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DFMA ASPECTS IN THE DESIGN OF A TRANSFER LINE FOR OFF-LINE ION SOURCES

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PREFACE

The work presented in this thesis has been carried out at the JYFL accelerator laboratory at the university of Jyväskylä.

I Would like to express my gratitude towards my supervisors, Prof., Ph.D Ari Jokinen for guidance, Harri Eskelinen for his humble, yet analytic, problem solving approach that I have tried to adapt. Special thanks are due to Veli Kolhinen for his patience towards my curiosity as well as for his never ending will to share his knowledge and support. Brother, you have been a great tutor and a valuable friend. The help and time my roommate Juho Rissanen contributed, was indispensable especially as I tried to get familiar with all the wonders of LaTeX.

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Finally I address my gratitude to my father, who during his lunch hour at home spent numerous times with a young boy interested in mathematics and to my mother; Äiti, vaikka en ole ollut se helpoin lapsi, sinun tukesi on ollut aina loputonta ja järkähtämätöntä, olet auttanut minua monien vaikeiden aikojen yli kuten nyt, kiitos siitä! Olet malttamattomana tiedustellut ja odottanut DI-työni valmistumista. Tässä se nyt sitten on. Vihdoin minä voin puolestani antaa Sinulle joitain mielestäsi tärkeää.

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Hakusanat: DFMA, siirtolinja, ioni-optinen simulointi, tyhjökammio, ionilähde.
Keywords: DFMA, transfer line, ion optical simulation, vacuum chamber, ion source.

Tässä työssä esitellään DFMA, jota käytetään siirtolinjan suunnittelussa yksinkertaistamaan osien valmistusta, helpottamaan kokoonpanoa ja asennusta sekä alentamaan kustannuksia. Siirtolinjan rakenne, pääkomponentit ja piirustukset esitellään tässä työssä. Asennuksen helppoutta sekä valmistuksen ja asennuksen kustannuksia verrataan teräksisen rakenteen ja alumiiniprofiilijärjestelmän välillä.

ALARA-periaatetta on noudatettu minimoimaan säteilyaltistusta sijoittamalla testi-ionilähteet pois radioaktiiviselta alueelta.

ABSTRACT

Lappenranta University of Technology
Faculty of Technology
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DFMA Aspects in the Design of a Transfer Line for Off-line Ion Sources

Master's Thesis

2013

145 pages, 30 figures, 8 tables, 44 appendices

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Keywords: DFMA, transfer line, ion optical simulations, vacuum chamber, ion source.
Hakusanat: design for manufacturing and assembly, siirtolinja, ioni-optinen simulointi, tyhjökammio, ionilähde.

In this thesis, the DFMA is presented and used for the purpose of having a design for a vertical transfer line that can be easily manufactured and assembled. The design of the transfer line, the major components and drawings are presented. The ease of assembly, the costs of manufacturing and differences between the use of steel structure and aluminum are compared.

The ALARA principle is followed to minimize the risk of radiation exposure by the means of locating the test ion sources outside the radioactive area.

Explanation of symbols

q	charge state
f_c	cyclotron frequency
f_{meas}	frequency of the ion of interest
f_{ref}	frequency of the reference ion
B	magnetic field
m_e	mass of an electron
m_{meas}	mass of the ion of interest
m	mass of the particle
T	measure for magnetic field strength

Explanation of acronyms

ALARA	As Low As Reasonably Achievable.
CERN	Conseil Européen pour la Recherche Nucléaire
CPT	Canadian Penning Trap
DC	Direct Current
DFA	Design for Assembly
DFD	Design for Disassembly
DFM	Design for Manufacturing
DFMA	Design for Manufacturing and Assembly
ECR	Electron Cyclotron Resonance
ECRIS	ECR Ion Source
FC	Faraday Cup
FURIOS	Fast Universal Resonant laser Ion Source
GSI	Gesellshaft für Schwerionenforschung
HV	High Voltage
ICRP	International Commission on Radiological Protection
IGISOL	Ion Guide Isotope Separator On-Line
ISOL	Isotope Separator on Line
ISOLDE	Isotope Separator on Line Detector
ISOLTRAP	Penning trap mass spectrometer at ISOLDE
JYFL	Jyväskyän Yliopiston Fysiikan Laitos
LASER	Light Amplification by Stimulated Emission of Radiation
LEBIT	Low Energy Beam and Ion Trap
LIISA	Light Ion Source Apparatus
MCP	Micro Channel Plate
MLLTRAP	Maier-Leibnitz Laboratory Penning TRAP mass spectrometer
MSU	Michigan State University
NSCL	National Superconducting Cyclotron Laboratory
PA	Potential Array
RFQ	Radio Frequency Quadrupole
SPIG	Sextupole Ion Guide
TITAN	TRIUMF's Ion Trap for Atomic and Nuclear science
TRIUMF	TRI-University Meson Facility

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1. INTRODUCTION

DFMA was used to find construction for a Vertical Transfer Line. VDI 2221, a guideline for product development, was used in the design process.

To connect the test ion sources to the main beam line of the accelerator, a Vertical Transfer Line is required. DFMA, a system to create a design that simplifies and thus lowers the costs of manufacturing and assembly, was to be utilized in the design process of the Vertical Transfer Line, the vacuum chamber for the ion sources and the necessary supporting structures as well as other various equipment needed. The scope of research included the design of the mechanical construction of the supports and the design of the equipment of the Vertical Transfer Line, as well as the ion optical simulations of the equipment. Ion-optical tuning and valve automation were not included in the scope of research.

The mass difference measurement is an essential part of the scientific research at the Accelerator Laboratory of the University of Jyväskylä. More than 250 atomic masses of ground states or isomeric states of nuclei have been measured using JYFLTRAP [1–7].

Two methods are used to execute the measurements, either on-line or off-line experiments.

The new Vertical Transfer Line enables the combination of measurements of the unknown isotope of interest produced using a nuclear reaction with an ideal, stable reference isotope. To follow the ALARA principle when working in a radioactive area, and to avoid exposure to the hazardous radioactivity during the change to an off-line ion-source after a radioactive on-line experiment, a safer and time saving technique is required.

A control sample produced using an additional ion source outside the radioactive area for calibration instead of a particle accelerator offers a safe, fast and less cumbersome method of producing test ions when changing from on-line beam to off-line beam or switching between optional off-line ion sources.

Ion-optical simulations were used for the dimensioning of the ion optical equipment.

2. MOTIVATION

To design a new vertical off-line DFMA was used in order to achive simple, light and economical solution. IGISOL IV is the latest generation facility, based on the Ion Guide Isotope Separator On-Line (IGISOL) technique developed in Jyväskylä in the 1980's [8–12]. A 3D-illustration of the separator and beam lines from the K-130 and the MCC30/15 particle accelerators in the new laboratory are presented in Fig. 2.1.

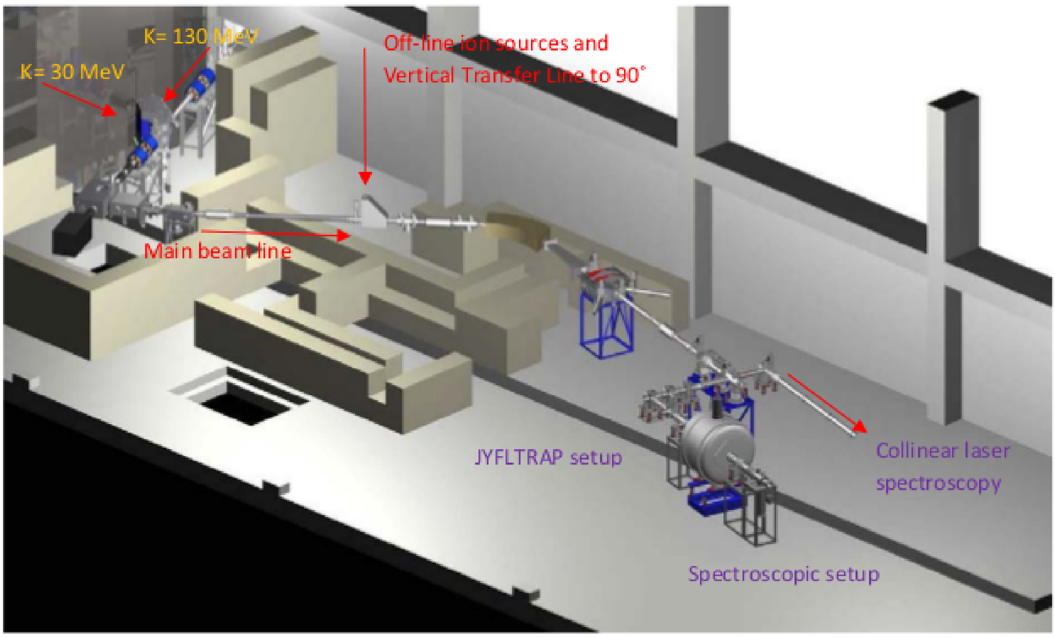

Figure 2.1.: *IGISOL IV Layout.*

In this technique, a thin target is placed inside a gas cell (ion guide) aligned with a primary beam coming either from the K-130 or the MCC30/15 cyclotron. As the beam hits the target, nuclear reaction products recoil from the target and are stopped and thermalized in a noble gas (helium). The charge state of the ions gradually decreases due to collisions with the helium atoms and impurities leading to singly-charged ions [13, 14].

Precision mass measurements are based on the repeated measuring sequence of unknown and reference isotopes produced in the present system either in nuclear reactions (on-line) or using the ion sources (off-line). On-line and off-line sources are located in the same target chamber and simultaneous use is not possible.

A new arrangement and location for the off-line ion sources serves the current needs and in addition, gives the possibility to combine on-line ion beam (main beam line) and off-line ion beam (Vertical Transfer Line).

Heavy primary ions results in low background radiation, however light-ion beams specially for use in fission runs with a uranium target will cause neutron background radiation. This radiation will activate the surroundings in the target cave as well as the metal in the structures and equipments. Because of the hazardous level of radioactivity, the laboratory area of the test ion source may be unaccessible for a period of one week. Even after this, the radiation level is higher than the surroundings [15].

The International Commission on Radiological Protection (ICRP) recommends a system for limiting the doses received by persons. The system has three features for dose limitation: justification, optimization, and dose limitation. Optimization, known as the ALARA-principle, is followed at the laboratory, meaning that even after the waiting period, the exposure for the higher level of radiation should be avoided [15]. This suggests that the test ion sources should be located away from the radioactive main beam line to a non-radioactive location.

ALARA is an acronym formed from the phrase 'As Low as Reasonably Achievable'. The phrase refers to a principle of keeping radiation doses and releases of radioactive materials to the environment as low as can be achieved, based on technological and economic considerations.

In this thesis, the aim is to provide a control sample for calibration without the need to access to the target area of either the K-130 or MCC30/15 cyclotrons. Equipment to be calibrated by using offline ion sources would be all the ion optics between the ion source and the Penning trap, as well as the extraction line of Penning trap.

In this thesis, an Electric Discharge Ion Source and Carbon Cluster Ion Source are considered to be used in the vertical transfer line. Availability of a third ion source is a future option.

A Carbon cluster ion source improves the accuracy of the measured masses. The atomic mass unit U is 1/12 of the mass of a carbon-12 atom, thus carbon clusters, that consists of several carbon-12 atoms, privides an absolute calibration for a relative comparison between the reference sample and the sample of interest. For this reason, carbon clusters are also ideal for examining the systematic effects of Penning traps, such as the Penning trap scetrometer JYFLTRAP, used for atomic mass measurements of exotic nuclei. Carbon clusters are available over a broad mass range in steps of 12 mass units. In addition, the mass of carbon clusters are almost equal to the mass of multiple carbon atoms, the only correction coming from the molecular binding energies of 7 eV per atom at most [16]

Main hypothesis:

Using DFMA a such a stucture can be designed that allows to calibrate the measuring sensors and measuring devices without a particle accelerator in operation can be designed.

Secondary hypothesis: Simultaneous calibration using a stable reference ion source with the main beam of the accelerator in operation. Ion source A is the primary ion source. Connectivity of alternative ion sources B and C to be studied.

A= Electric Discharge Ion Source

B = Carbon Cluster

C = Optional ion source

For the control sample, test ion sources and a Vertical Transfer Line to connect the equipment to the accelerator's main beam line are required.

A Vertical Transfer Line, including a layout of the ion source unit, vacuum chamber for the ion sources and its' supporting construction are to be designed, as well as other related equipment.

3. THEORETICAL BACKGROUND – ION SOURCES AND BEAM LINES

The purpose of the test ion source is to produce a reference ion beam of known stable material that functions as a control sample for the main ion beam of the material of interest for JYFLTRAP. These reference ions are used alternately with the ions extracted from the fission ion guide that functions as a target for the primary beam of the particle accelerator, either K-130 or MCC30/15 cyclotron. IGISOL IV and JYFLTRAP schematic presentation can be seen in Fig. 3.1.

3.1. Main Beam Line

In the JYFL accelerator laboratory there are three ion sources feeding the K130 cyclotron. Two of them are Electron Cyclotron Resonance Ion Sources (ECRIS) for heavy ions: JYFL 6.4 GHz ECRIS and JYFL 14 GHz ECRIS. The third is a filament-driven multi cusp type H–light ion source LIISA. The ECR ion sources are used for the production of highly-charged ion beams for nuclear and material physics experiments. LIISA is used for producing intensive proton beams for nuclear physics experiments and medical isotope production.

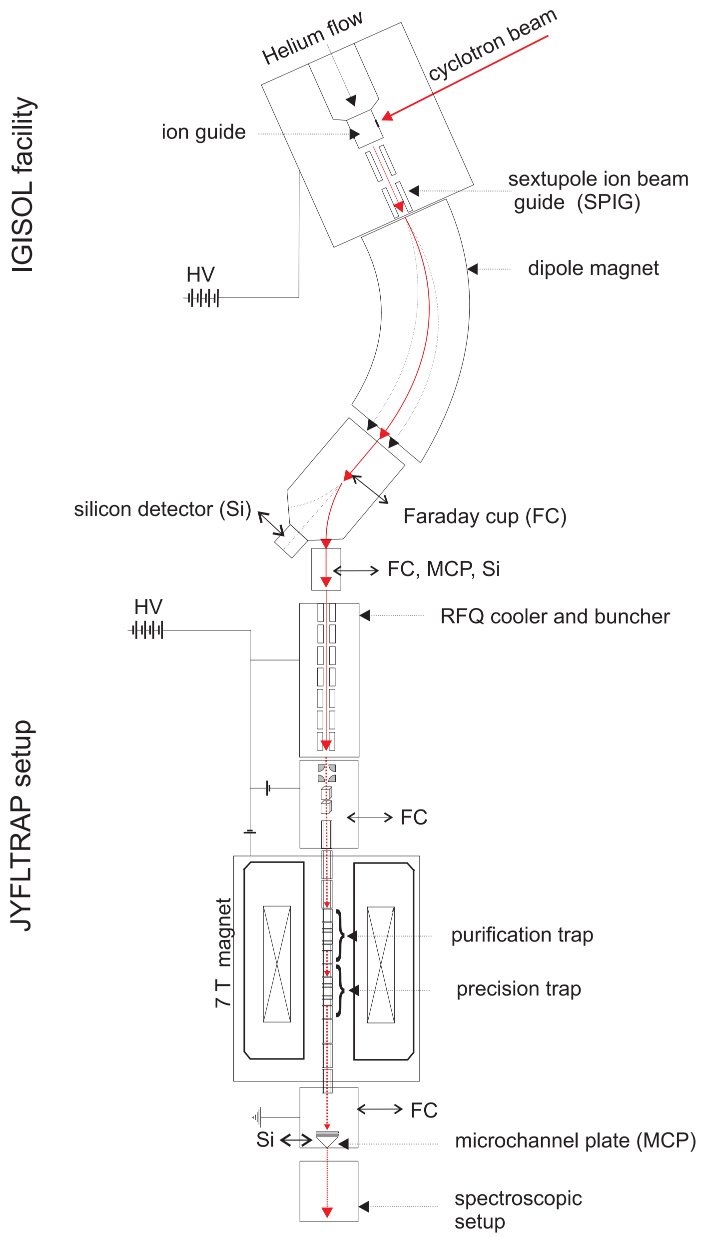

Figure 3.1.: *The old IGISOL-3 setup and JYFLTRAP. A schematic layout of the equipment, V.-V. Elomaa, 2009 [16]. IGISOL consists of a target chamber connected to a beam line of a cyclotron, he-buffer gas feed, Sextuple ion Guide, SPIG, followed by a dipole magnet, an electrostatic switchyard with a silicon (Si) detector, Faraday cup, and Micro Channel Plate, or MCP detector.*

3.1.1. The Front-end setup

The front-end setup on the main beam line from the K-130 and MCC 15/30 cyclotrons consists of a target chamber, an extractor chamber and a ground electrode. The target chamber includes a fission ion guide, a buffer gas inlet and SPIG. The extractor electrode is placed in the extractor chamber.

The primary ion source is positioned as the main equipment in the front-end setup. The primary beam from the cyclotron arrives to the target chamber that sitting at +30 kV potential, hitting the target in a fission ion guide. The resulting fission fragments are stopped and extrated towards a SPIG. From the SPIG, the fission fragments pass the extractor electrode that is at +20 kV potential, and proceed further to the ground electrode that is at 0 V potential. Karvonen, 2010 [17]. The front-end setup is presented in Fig. 3.2 and the primary ion source can be seen in Fig. 3.3.

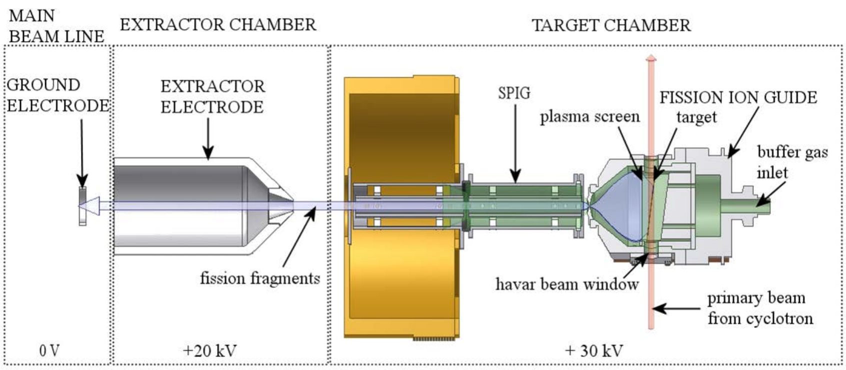

Figure 3.2.: *IGISOL IV front-end setup. In the target chamber, the primary beam from the cyclotron passes through an uranium target mounted in the Fission Ion Guide. The Sextupole Ion Guide, SPIG, guides the fission fragments to the extractor electrode in the extractor chamber. Karvonen, 2010 [17].*

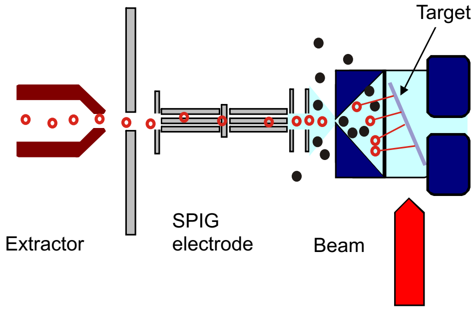

Figure 3.3.: *Operational principle of the Fission Ion Guide of IGISOL IV mounted on the primary beam line. The nuclear reaction products recoiling out of the target in a He-buffer gas filled chamber are transferred to SPIG electrode, that gets the ions to the mass seoarator with a final accelerating potential of +30 keV Elomaa, 2009 [16] Rissanen, 2011 [13].*

3.1.2. Dipole Magnet

Ions are accelerated to 30 keV and mass separated by a 55°dipole magnet [18]. The selectivity of a curve shaped dipole magnet is based on the masses of the particles. The centerline of the magnet has a certain radius. All the wanted particles having the correct mass will travel along the centerline,while heavier particles will depart off the centerline, with a larger radius at the exit. Particles will be forced by the magnet to have a tighter curve on the inner side of the magnet and thus be eliminated accordingly. The position of the 55°-dipole magnet can be seen in a schematic presentation Fig. 3.1.

3.1.3. Radio Frequency Quadrupole Ion Beam Cooler

The Radio Frequency Quadrupole or RFQ cooler is used for decelerating, stopping and cooling the ions coming from the mass separator. The principle of collecting and bunching the ions before re-acceleration is presented in Fig. 3.5. Ions are collected in a potential well, and then released by lowering the potential wall. The ions entering the RF–quadrupole are extracted and accelerated towards 1 keV the Penning trap. The ions can also be guided to the laser spectroscopy station, whereby they are accelerated to 30–40 keV. The mechanical construction of the RFQ–cooler is shown in Fig. 3.4.

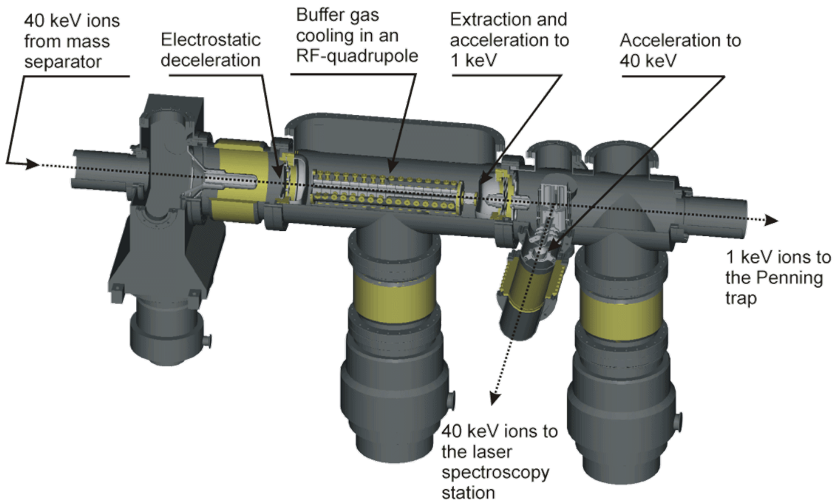

Figure 3.4.: *Construction of Radio Frequency Quadrupole, RFQ, used for cooling and bunching the ions.*

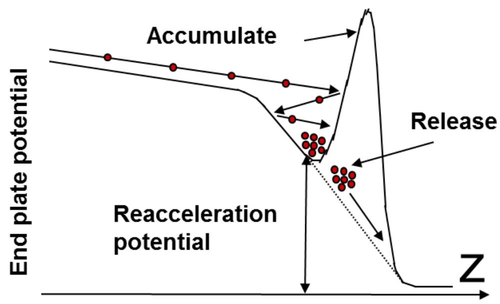

Figure 3.5.: *Ions are captured by creating a potential wall using segmental rods and DC fields. Potential wall is lowered and ions released.*

3.1.4. JYFLTRAP

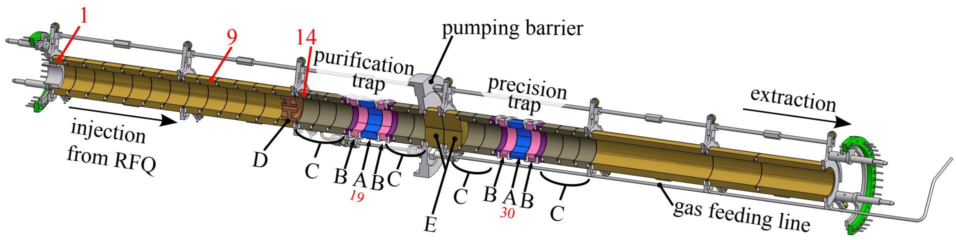

Figure 3.6.: *Trap electrodes of the purification- and precision traps within the 7–T superconducting magnet of JYFLTRAP. Electrodes are numbered from 1 to 38. A= ring electrodes (19th and 30th), B= correction electrode, C= end caps, D= ⌀3 mm diaphragm , E= ⌀1.5 mm diaphragm [19].*

The JYFLTRAP Penning trap mass spectrometer can be used for precise atomic mass determination of short-living radioactive atoms [20]. Penning trap experiments can be found also at the research facilities including ISOLTRAP at CERN, Switzerland, SHIPTRAP at GSI (Gesellschaft für Schwerionenforschung), Darmstadt, Germany, Low Energy Beam and Ion Trap (LEBIT) at the National Superconducting Cyclotron Laboratory (NSCL) in Michigan State University (MSU), U.S.A, Canadian Penning Trap (CPT) at Argonne National Laboratory, U.S.A, TITAN (TRIUMF's Ion Trap for Atomic and Nuclear science) at TRIUMF, run by a consortium of sixteen Canadian universities and located at Vancouver, BC, Canada.

The JYFLTRAP ion trap setup [21] consists of three traps, a linear Paul trap [22] and two Penning traps in a 7 Tesla superconducting magnet. The first trap is used to purify the ion sample from isobaric contaminants [23] which cannot be removed by the dipole magnet. The purified sample can be sent directly to a detector arrangement for nuclear spectroscopy located downstream form the magnet or can be injected into the second trap for precision atomic mass measurements.

A schematic of the two cylindrical traps is presented in Fig. 3.6. The magnet is used to create a homogenous magnetic field, [16, 19]

The physical dimensions of the magnet body includes a diameter D_{max}=1350 mm, and a measured length $L_{measured}$=1009 mm. A similar solution with a 7 T superconducting magnet and Penning trap mass spectrometer MLLTRAP is in use at the Maier-Leibnitz Laboratory Garching, Germany [24], SHIPTRAP at GSI and TRIGA-TRAP Johannes Gutenberg-Universität, Mainz, Germany.

The cyclotron frequencies are measured for both the control sample and for the sample of interest. For the ratio calculation, the control sample is from the test ion source and the material of interest is from the main beam line of the accelerator.

The cyclotron frequency f_c is

$$f_c = \frac{qB}{2\pi m} \tag{3.1}$$

The cyclotron frequency ratio is calculated by dividing the frequency value of material of interest with the frequecy of the control ion beam prior to and after each measurement of the ion beam of interest. This calculation helps to minimize the systematical uncertainity of the measured values. Several measurements are required to minimize the statistical error to the level where the systematic error will become dominant. The number of the control sample and test sample pairs during laboratory test run are numbered in the tens, if very accurate data is required. Relatively accurate information can, however, be achieved even with only few measurements.

The frequency of the reference ion f_{ref} and the frequency of the ion of interest f_{meas} are measured to calculate the mass of the ion m_{meas} of interest using equation (3.2). m_e is the mass of an electron.

$$m_{meas} = \frac{f_{ref}}{f_{meas}}(m_{ref} - m_e) + m_e \tag{3.2}$$

The mean frequency for the reference ion is interpolated from a linear least-square fit of two data points.

One of the systematic effects present in a Penning trap mass spectrometer depends on the mass difference between the ion of interest and reference ion. This effect can arise due to imperfections of the electrostatic field of the Penning trap or misalignment between the magnetic and electric field axis [16, 25–27].

3.2. Vertical Transfer Line

In an ideal transfer line, ion-optical corrections are not taken into consideration. For this reason, an ideal line can be compact. Limitations and errors existing in the real environment forces to add equipment to correct the imperfections of the beam and increasing the dimensions of the line. ion-optical simulations are used to find an optimal beam and construction.

3.2.1. Test Ion Sources

The purpose of the test ion source is to provide a reference beam to the main beam of the accelerator. The control sample from the ion source receives its' kinetic energy in the beginning of the process. High voltage, order of 30 kV is used to extract the ions from the chamber of the ion source.

However, if more than one ion source is to be used, a quadrupole deflector is required to bend the ion beams of optional ion sources on to the axis of transfer line. The bending capability of a quadrupole deflector is limited and therefore a voltage of <1 kV is used. In this case, the final acceleration must be done after the quadrupole deflector, see Fig. 3.8. The control ion beam does not receive any additional acceleration after this point.

After acceleration, the control beam requires shaping and guiding to reach the target area, that is in this case, the Penning trap. Guiding the control ion beam through the transfer line requires adjustments of the beam on transfer line, both vertical- and horizontal correction. Vertical line is from the test ion source(s) to the 90°bender, that turns the ion beam to the horizontal main beam line, originating from the accelerator.

The preliminary layout with some main components of the vertical transfer line of the IGISOL IV-isotope separator is presented in Fig. 3.7.

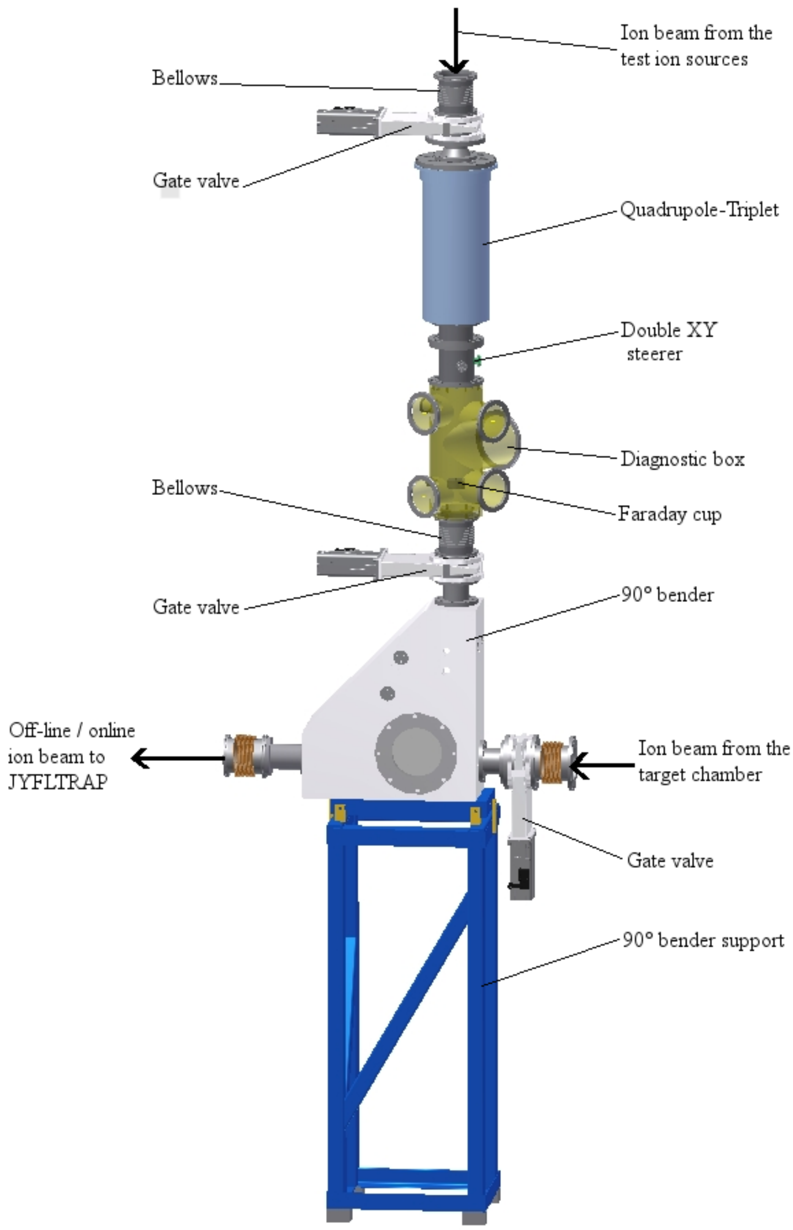

Figure 3.7.: *Preliminary layout of the Vertical Transfer Line assembly showing some of the main components. On top, bellows followed by a valve and double XY-deflector. Parts are supported by a quadrupole-triplet and diagnostic box that are attached to horizontally adjustable equipment racks and further to wall supports. A valve below isolates the vertical line of the 90° bender and the horizontal main beam line. A bellow is used to allow adjustment connecting the vertical line and the 90° bender together. Vacuum pumps are not shown.*

3.2.2. Quadrupole Deflector

A quadrupole deflector is used to bend the ion beam 90°, in Fig. 3.8 from the horizontal level, down to the vertical line. The beam is later to be manipulated by other ion-optical equipment. The quadrupole deflector consists of four metallic electrodes, where the voltage is applied.

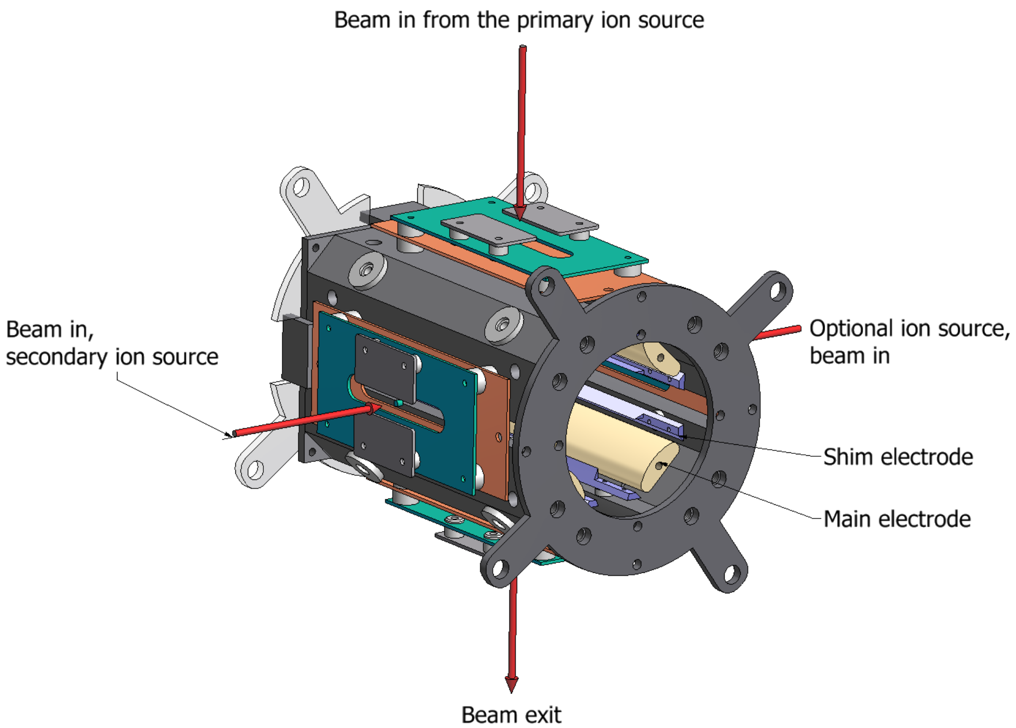

Figure 3.8.: *Quadrupole Deflector assembly, without a vacuum chamber. Main electrodes and shim electrodes are used to bend the beam.*

3.2.3. Quadrupole-Triplet

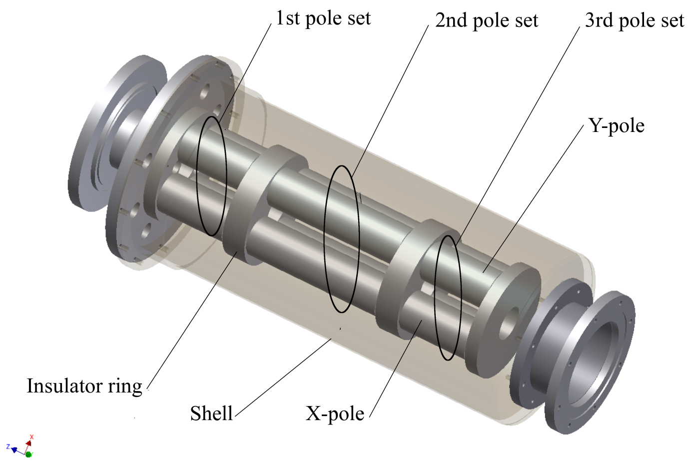

Figure 3.9.: *Quadrupole Triplet, transparent view, three sets of poles,each set consisting of a group of electrodes separated by insulating rings.*

A quadrupole-triplet consists of three sets of two positively and two negatively charged electrodes, see Fig. 3.9. The order of the sets may be either + - + or - + -, depending on the desired effect for the beam. One quadrupole consists of two circuits and electrode pairs; one is focusing and another defocussing.

3.2.4. Double XY-deflector

The double XY-deflector is to control the position of the beam. A double XY-deflector is formed by using two XY-deflectors back-to-back. Two XY-deflectors enables parallel transition for the beam. This function is useful if the beam is not on the centerline of the transfer line. A cross section of the double XY-deflector is presented in figure 3.11. A transparent view of the double XY-deflector is presented in Fig. 3.10.

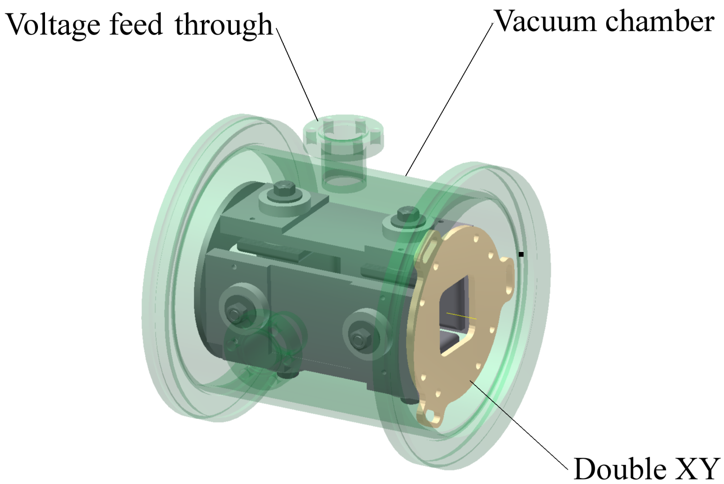

Figure 3.10.: *double XY deflector. Vacuum chamber is presented transparent.*

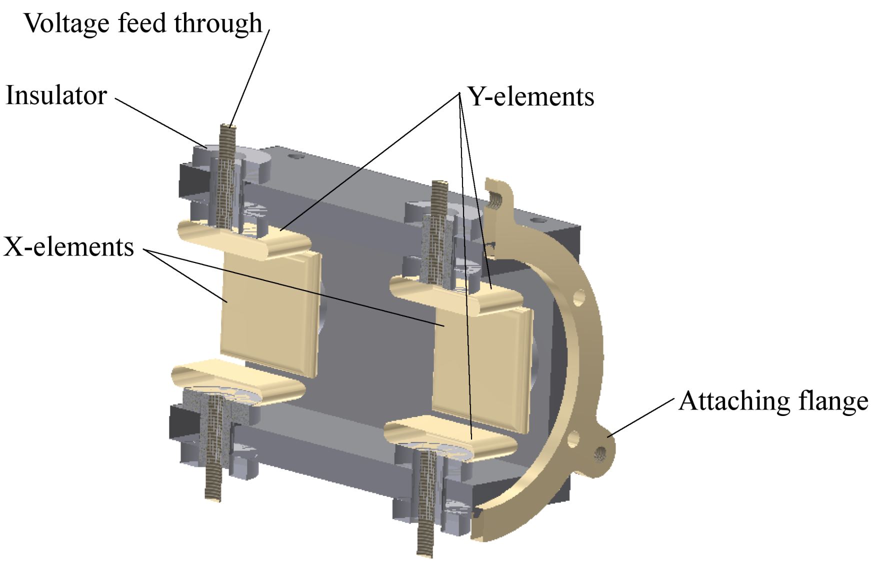

Figure 3.11.: *double XY cross section, the ion-optical elements shown in yellow.*

3.2.5. Diagnostic Box

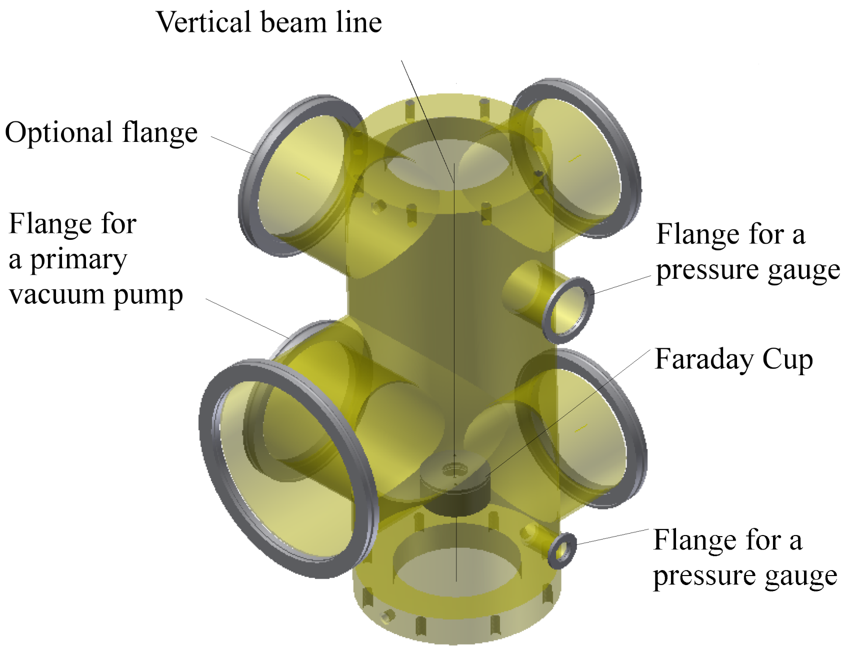

Figure 3.12.: *Diagnostic box, without the equipment to be installed to the flanges. Only the Faraday cup is illustrated, however the actuator for the Faraday cup is not shown. Optional flanges are closed with blank flanges.*

The diagnostic box is a cylindrical vacuum chamber with several variable sized flanges for the measuring equipment or devices. On the vertical transfer line, the diagnostic box is used as a platform for a vacuum pump and Faraday cup with an actuator. Other optional inlets are covered with blank flanges, giving the option for the installation of additional equipment. Currently, the new diagnostic boxes are ordered with standard dimensions. This means that due to the limited height between the ceiling and 90°bender, other equipment and layout options are to be studied in anticipation for designing a more compact diagnostic box. A 3D image of the diagnostic box showing the position of a Faraday cup inside the chamber can be seen in Fig. 3.12.

3.2.6. Vacuum pumps

Vacuum pumping is needed for the vertical line as the line needs to be isolated from the ion sources above and from the main line below. The first gate valve is placed just above the 90°bender and another one to be placed after the double XY, seen in Fig. 3.7. The primary pump is to be placed to the inlet flange of the diagnostic box.

For this position, a turbomolecular pump is considered to be ideal because of its size and relatively easy installation. A existing Edwards STP-301 turbomolecular pump has been considered to be used, as well as an Edwards XDS 10 scroll pump backing the turbomolecular pump.

3.2.7. Einzel lens

An Einzel lens provides a cylindrical-symmetric profile for the beam. It is constructed of three ring-shaped electrodes. Voltage is applied to the middle electrode, often longer than the electrodes at either end. This voltage causes a electric field that shapes the beam equally if the beam is on the centerline of the lens. If the beam is offset when arriving to the lens, it will be deflected aside from the intended beam axis after the Einzel lens.

3.3. Ion sources

3.3.1. Electric Discharge Ion Source

An electric discharge ion source will be the preliminary source for a control sample. A vertical placement of the source is ideal as there is no need for bending the beam. The electric discharge ion source is presented in Fig. 3.13. Other type of source need to be installed in a horizontal position, requiring a quadrupole deflector, presented in Fig. 3.8.

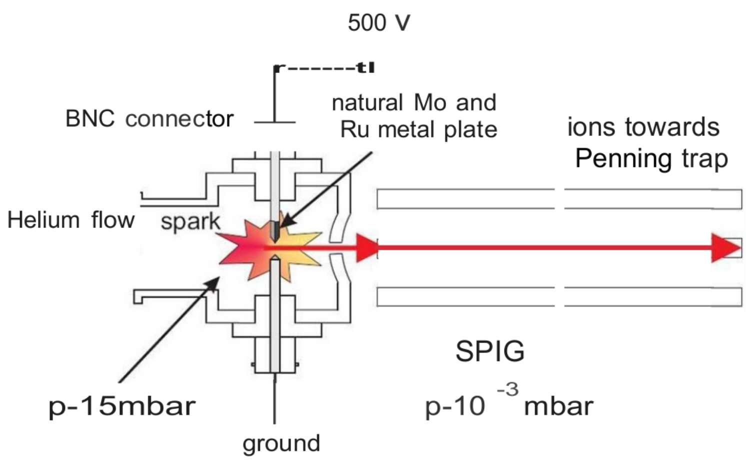

Figure 3.13.: *Discharge ion source with two different metals, Mo and Ru plates.*

3.3.2. Carbon Cluster Ion Source

The carbon cluster source, presented in Fig. 3.14 is under development. Carbon ion beam transport is presented in Fig.3.15.

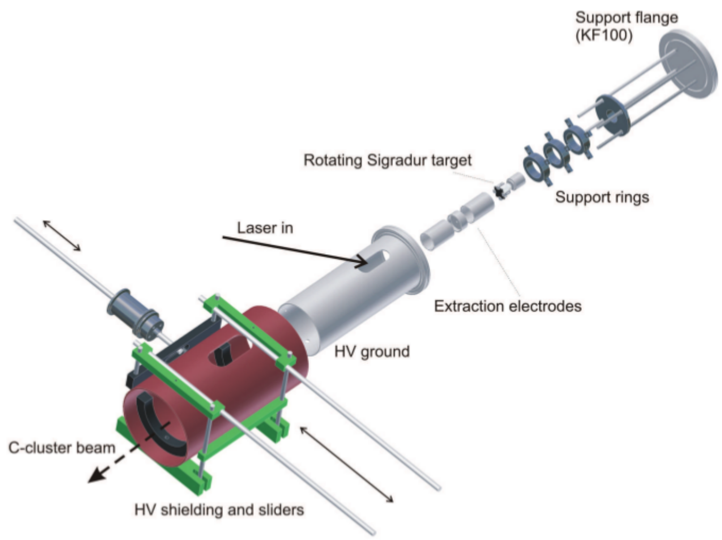

Figure 3.14.: *Detailed view showing the detailed structure and the main parts of the carbon cluster ion source. V.-V. Elomaa, [16]*

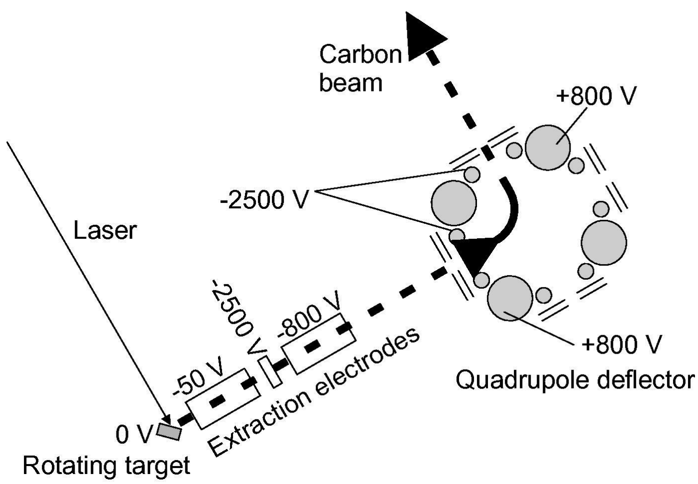

Figure 3.15.: *Presentation of the carbon ion beam transport from horizontal level to the vertical transfer line through a quadrupole deflector that bends the beam. V.-V. Elomaa [28].*

3.3.3. Optional ion source

An additional connection will be applied to maintain the possibility for an optional source to be developed in the future. Caesium and/or Rb ion sources could be considered as alternatives. Both metals liquidize and vaporize above room temperature, 30 °C . This property is utilized by heating the metal in a small volume tank. Vaporized metal gas is released through a valve into a heated metal wire, thus ionizing.

3.3.4. Ion-optical calculations

Ion-optical calculations does not include any valves nor diagnostic boxes. Such equipment, depending on their physical dimensions, affects the optical behavior of the beam. The starting point for the calculations is the ion source. The goal is to achieve the desired beam quality in a certain point. The ion-optical design of the vertical line as well as the IGISOL beam line is based on GIOS simulations. GIOS is an ion optics code used to determine optical properties of intense ion beams.

3.3.5. Control sampling methods for the calibration

The ion source defines the nature of the ion beam, i.e. density. The ion optics are used to focus the beam in such a way that it will form the desired shape. The quadrupole-triplet affects the phase space of the ion beam. The vacuum pipe defines the maximum size of the ion beam. For the current vacuum pipe used for the transfer line, the diameter being 110 mm, the diameter of the ion beam varies between 5 to 30 mm. The eventual size will be adjusted by double XY-deflector as well as the positioning of the beam on the pipeline.

In the future, a Carbon Cluster is considered to be an alternative ion source to a Discharge Ion Source on the IGISOL IV line. The additional sources also require a new vacuum chamber design to adapt the different versions of ion sources and other equipment. In production of the discharge, voltage and the vacuum chamber pressure are important factors used for adjustment.

4. METHODS

In this thesis, for the design of the Vertical Transer Line, a combination of different systematic engineering methodologies are utilized. DFMA principles are used for the evaluation of manufacturability and ergonomics. For the manufacturability of the parts and equipment, both existing and new, DFMA 1 forms are used. DFMA2 forms are used for the evaluation of the ergonomics in assembly. To support consistent engineering, the seven-stage VDI-2221 is used. The principle is to re-evaluate the ideas between the stages and if necessary, make improvements to the design due to the possible new information found during the iteration process. These methods are used for the engineering of the support system of the Vertical Transfer Line.

In addition to the mechanical engineering, the ion-optical properties of the equipment affect the design and layout of the Vertical Transfer Line. ion-optical simulation is used to confirm and define the functional dimensions for the engineering of the components as well as to find the theoretically optimal voltage values for the testing to be used as start-up values. The last, seventh stage of VDI-2221 – Final layout – is not studied until the final phase of this chapter, after ion-optical simulations.

DFMA is a combination of DFM - design for manufacture and DFA - design for assembly. DFMA can be utilized to achieve a balance between the benefits for both manufacturing and assembly. Eskelinen [29] sets several goals for DFMA; it aims to improve the integration between design and manufacturing, lowering costs, speeding up the product developement cycle, improve or increase quality, reliability and productivity and respond to customer requirements as well as shortening lead time.

Other methodologies like DFE = Design for Enviroment, DFD = Design for Disassembly, DFS=Design for Service or DFSS=Design for Six Sigma are not utilized on this study.

DFMA also has commercial applications, like a toolset combining Design for Manufacture and Assembly (DFMA) and software to customers product development process [30].

The motivation to use DFMA are varied, but the most common reasons are:

- Assembly costs

- Assembly time
- Reliability
- Total Time-to-Market

In this study, the total time-to-market has no remarkable significance due to the nature of the product, that is relatively unique research application as a part of a larger scale laboratory installation. Part of the product is also possible to install separately, so that it does not necessarily affect the use of other laboratory equipment and thus lowering the pressure to set a firm schedule for the installation.

Using DFMA is considered to have greater possibilities to lower assembly costs by using fewer parts, eliminating unique parts wherever possible, and decreasing the amount of labor required for assembly. DFMA is seen to shorten assembly time by utilizing standard assembly practices such as vertical assembly.

Increased reliability is achieved according to DFMA by lowering the number of parts, thus decreasing the chance of failure. Shorter total time-to-market for a product to go from conception to the consumer is considered to be shorter due to the quicker and smoother transition in the production phase when using DFMA in the development. This is achieved due to having a more complete and workable design the first time.

Benefits of DFMA:

- Reduced part number and part counts
- Reduced assembly operation
- Reduced product lead-time
- Reduced packaging costs
- Increased productivity and efficiency
- Reduced material cost
- Reduction in overall system/product cost
- Improved product quality and reliability

4.1. Review of wishes and requirements

The list of requirements was collected at a startup meeting of this thesis and later interviews [31–34].

Requirements:

- Control sample for calibration and ion-optical beam optimization without using the accelerator
- Valve automation
- HV-insulation between ion sources and the transfer line
- Vacuum compability of parts, equipment and HV-feed throughs
- Vacuum requirement order of 10^{-6} mbar
- General, HV- and radiation safety requirements
- Durable

Wishes:

- Compact design, the components of the transfer line must fit on a space height of 3450 mm
- Light weight
- Low cost
- Easy installation and adjustability
- Use of standard parts

The scope of research included the design of the mechanical construction of the supports, design of the equipment of the Vertical Transfer Line, as well as the ion-optical simulations of the equipment. Automation, electrical control, local and computer controlled ion-optical tuning were not included in the scope of this research, and the related items mentioned on the list of requirements for the Vertical Transfer Line were not studied.

List of requirements for the design and engineering of the Vertical Transfer Line can be seen in Table 4.1 [31–34].

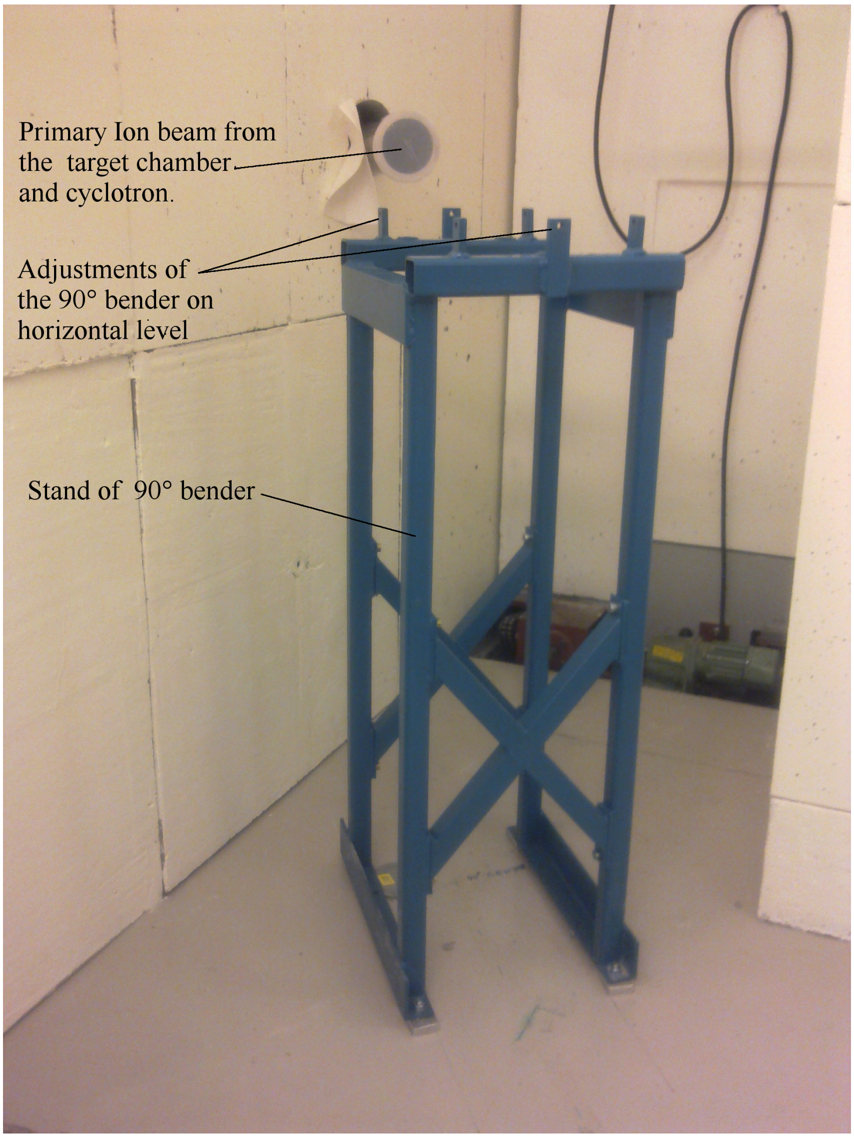

Figure 4.1.: *New Laboratory, the support structure of the original 90° bender installed. In the background, a hole and a vacuum pipe for the incoming accelerator line is shown. Similar hole is placed in the one meter thick radioactive protective concrete ceiling over the support. Room height is 3450 mm, so the concrete ceiling limits the layout of the mechanical components to be placed below it.*

List of Requirements for the Transfer Line	R= request W= wish
Control sample for calibration and for ion-optical beam optimization without using the accelerator.	R
Compact design, the components of the transfer line must fit on a space height of 3450 mm.	W
Durable	R
Light weight	W
Low cost	W
General, HV- and radiation safety requirements	R
Easy installation and adjustability	W
Use of standard parts	W
Valve automation	R
HV-insulation between ion sources and the transfer line	R
Vacuum compability of parts and equipment	R
Vacuum compability HV-feed through	R
Vacuum requirement order of 10^{-6} mbar	R
Remote ion-optical tuning	R
Computer controlled Ion-optical tuning, feedback of the set value.	W

Table 4.1.: *List of Requirements for the design and engineering of the vertical transfer line [31–34].*

4.2. Current Vertical Transfer Line design

There is an existing transfer line that has been dismantled from IGISOL-3 and parts are availlable for use. The original vertical transfer line can be seen in Fig. 4.2 on page 30. The simplest solution would be to reinstall these existing parts in the new laboratory. The problems however are the space limitations, the original setup was relatively high and the height of the building was not a limiting factor.

In the new laboratory, a concrete ceiling limits the installation of the equipment on the floor level to the height of +3450 mm. Ceiling is of 1 m thick concrete to reduce the radioactive radiation coming from the accelerator line, which may scatter and affect the future ion sources that are to be placed above it. The ceiling is thinner around the 160 mm hole for the transfer line, apparently half a meter thick on an area of approximately 1 m x 1,1 m. This opening is to be filled by tiles after the installation of the transfer line equipment to minimize the radiation outside the 'hot' radioactive area. Incoming accelerator line can be seen in Fig. 4.1.

4.2.1. Functional structure of the product

The functional structure of the product describes the relations between the main parts and/or functions to achieve the goal for the equipment. A flow diagram can bee seen in figure 4.2.

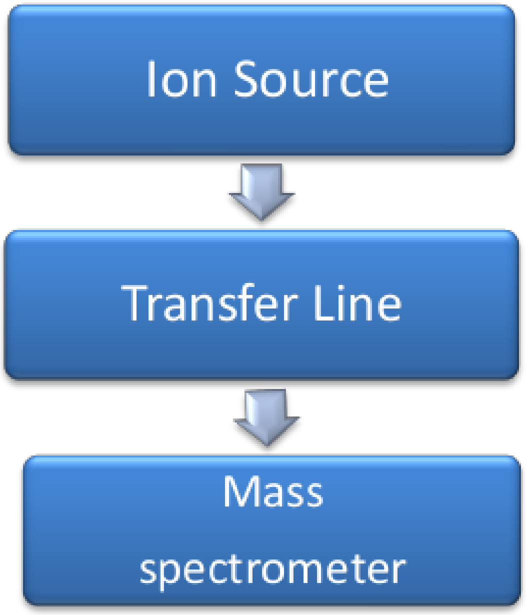

Table 4.2.: *Functional structure of the hot ion source, vertical transfer line and mass spectrometer*

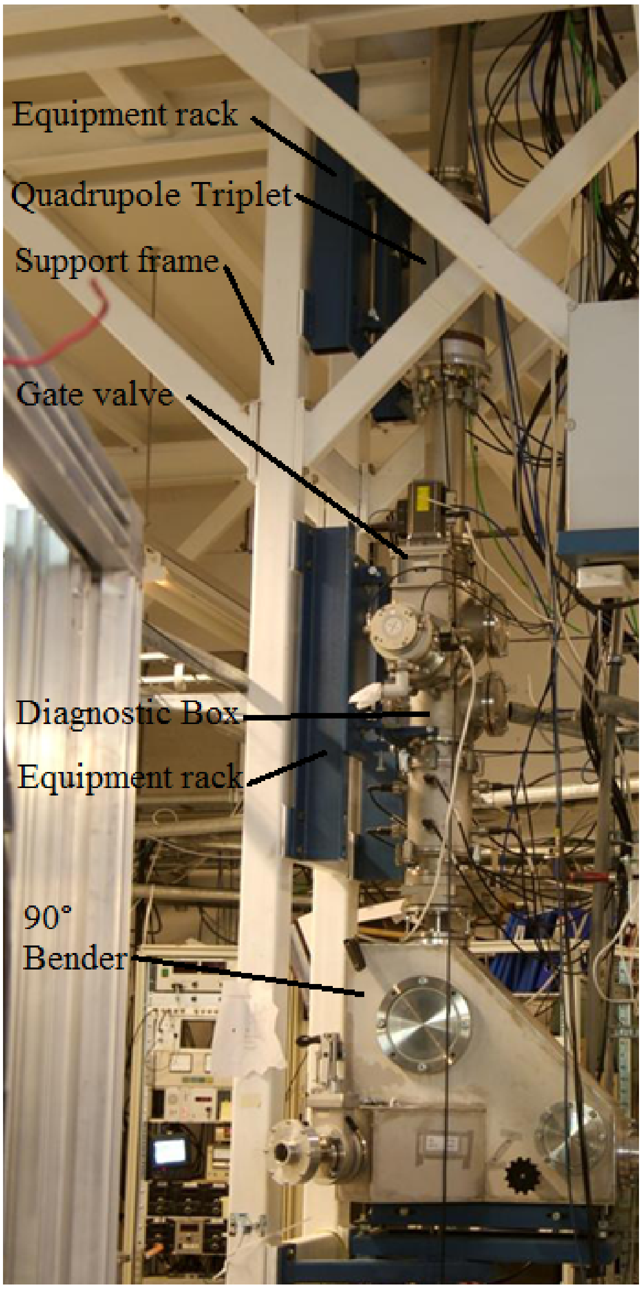

Figure 4.2.: *The original vertical transfer line at IGISOL-3 before dismantling. The blue metal frames bolted on the white, vertical roof support beams are equipment racks, welded of steel profile. There are no limitations for the mechanical construction above, unlike the new premises, where the concrete ceiling limits the mechanical components to be placed within a room height of 3450 mm.*

4.2.2. Evaluation of assembly and integration

Assembly of the existing structure in the new laboratory is considered to cause difficulties because of the heavy steel support for the equipment. As all the major components and related cabling, piping and their racks and supports are already installed to a limited space in the laboratory, the heavy steel structures are considered difficult to be installed using only manpower. No overhead cranes are available in this part of the laboratory.

In the original layout the blue painted equipment racks were made of steel, as well as the ceiling supporting white painted steel beam structure. Both can be seen on Fig. 4.2. Integration to the surrounding equipment is not ideal, but as it is mainly cabling along the already existing cabling tracks, integration can be done quite easily.

4.2.3. Evaluation of manufacturing processes and materials

The new laboratory has less room than the existing structure requires. This means, that to use the same construction, the materials would have to be either reused and/or purchased, welded, machined and assembled. The uppermost equipment rack, on Fig. 4.2 on page 30, reaches almost to the ceiling level of the building, meaning the current layout is too high to be used in the the new premises because the concrete ceiling limits the maximum height. Steel structure is also dimensionally big, so the integration to the other equipment on the limited space would meet challenges.

4.2.4. Identification of concerns and deficiencies

Moving the beams in limited space, as well as support and install them using only manpower is a concern. Also installation of lifting devices is difficult and time consuming. Even though the beams would be made smaller in length, the steel structure would still be difficult to handle. Required flanges to connect the shorter beams together would increase the total weight of the frame beams even further.

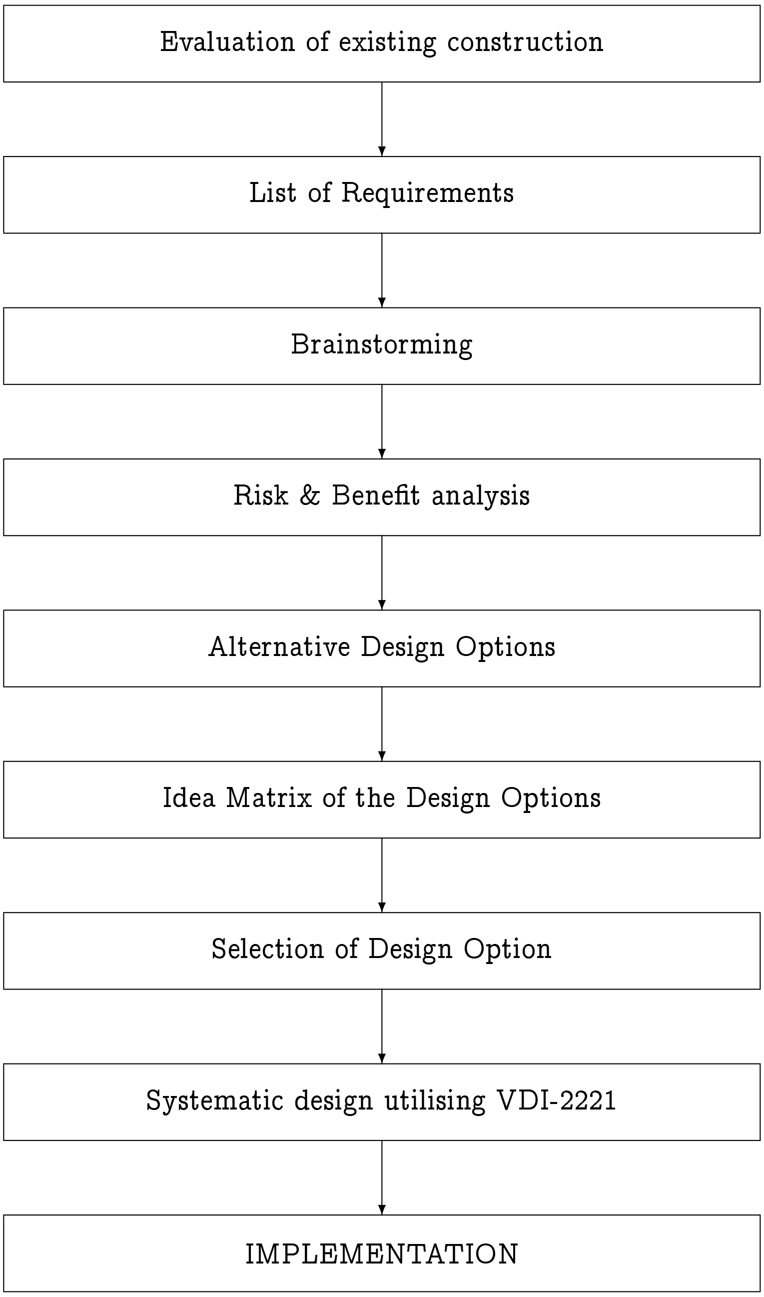

Table 4.3.: Progress steps on the DFMA evaluation

4.3. Idea Matrix for options

4.3.1. Option 1

Idea was the maximal utilization of the design of the existing steel structure of the building, that supported also the equipment racks to attach to the support structure as well as the related adjustments of the equipment. Benefits include savings in costs of materials. Basic construction was available, engineering and additional materials required to relocate existing parts. Idea was to avoid material and equipment costs. Downsides was seen the heavy weight and large dimensions of the equipment. This would lead to handling and assembly problems in a limited space, with no cranes.

4.3.2. Option 2

Next option was to build the vertical structure from a lighter material. Aluminium profiles were selected, as similar profiles with different dimensions were already in use at the laboratory for some applications.Existing equipment would be utilized as much as possible.

4.3.3. Option 3

In this scope, all the construction for the support of equipment will be new. Both the vertical support and equipment racks as well as the support for the new vacuum chamber of the ion sources to be designed from aluminium profiles. Heavier and stiffer profile 45x90 mm for the vertical support and vacuum chamber support and lighter 45x45 mm profile for the equipment racks.

Table 4.4.: *Idea Matrix*
Idea Matrix to compare
different manufacturing options. *DFMA Basic Principles, Edward C. Lai & Associates, [35].

IDEA MATRIX for – Vertical support – Vacuum Chamber Support** – Equipment racks **ITEM OF INTEREST**	**Option 1** Existing construction & materials	**Option** 2 Existing racks & new supports	**Option** 3 New construction & materials	N o t e
General:				
material of equipment racks	steel	steel	aluminium	
material of vertical supports	steel	aluminium	aluminium	
mass of equipment rack	–	–	+	
mass of vertical support	–	+	+	
need for additional supports	–	–	–	**
need for additional engineering	–	–	–	**
need for new racks	+	+	–	
costs for new racks	+	+	–	
Needs of manufacturing:		**existing/new**		
storing	–	–/+	+	
dismantling	–	–/+	+	
crane lifting & handling	–	–/+	+	
cutting	–	–/–	–	
welding	–	–/+	+	
grinding	–	–/+	+	
machining	–	–/+	+	
drilling	–	–/–	–	
finishing	–	–/+	+	
painting	–	–/+	+	
Assembly:		**existing/new**		
ease of assembly in difficult positions	–	–/+	+	
single hand held of part possible	–	–/+	+	
number & types of parts used	–	–/+	+	*
number and types of fasteners	–	–/+	+	*
standardized level of parts & finishes	–	–/+	+	*
simple components	–	–/+	+	*
need of site assy	+	+/–	–	
one tool assembly	–	–/+	+	
modular parts	–	–/+	+	
modular subassemblies	–	–/+	+	*
multifunctional parts	–	–/+	+	*
minimized assembler movements	–	–/+	+	*
self-locating features	–	–/+	+	*
accessibility for tests and rework	–	–/+	+	*
amount of operations & process steps	–	–/+	+	*
interchangable parts	–	–/+	+	
low cost post modifications	–	–/+	+	
Total number of positive factors	2	3+25/2=16	26	33

4.4. New construction

4.4.1. Brainstorming

A negative property of the original steel structure appeared to be the heavy weight. Laboratory room has plenty of equipment, electrical cabling and cabling racks, leaving only limited space for installation. As the supports were made of standard construction steel, mainly L-profile for heavily load applications, the supports became unnecessarily big in dimensions as well as heavy for the purpose in use.

Limited space handling of the big and heavy objects can cause problems during installation. Especially installation on a wall or on another vertical structure is challenging as the object needs to be supported over a period of time accurately to make the needed markings for holes or the actual attachment.

There is no crane in the room and building additional supports only for this installation would be difficult, time consuming and requiring special equipment for this purpose only. Manual installation on the other hand sets requirements to the size, weight and handling properties for the parts and equipment to be installed. It is an advantage, if the part can be held by only one hand, leaving another one for tools or for marking.Selecting a lighter material for the supporting construction would ease the installation process.

aluminium is well known for its lightweight properties, although the strength is not equal to steel. Selecting wall thickness and profile correctly, using aluminium it is possible to create constructions that can both stand remarkable loads and be easily manipulated due to the lightness. aluminium as a potential material lead to looking for the possibilities and advantages that an aluminium profile system already in use at the laboratory could offer for this application.

4.4.2. Design aspects

For the new construction, a profile system of aluminium was considered as a potential design. In manufacturability considerations the material is relatively flexible as it can be ordered as a bar stock or pre-machined according to manufacturing drawings. The delivery can include pre-drilled holes, special fasteners and all the other needed parts for wide range of applications. It is also possible to use stock bar and do the cut and machining in-house. The special fasteners of the aluminium system require holes of Ø17 mm which is a rare size on machining tools. It is available only as custom made and thus expensive. Ø17 mm drills are available in the workshop, but the slot on the aluminium profile causes the bare drill to yank, making drilling impossible without destroying the work piece. A drill guide tool that sets to the end of profile to the correct distance, utilizes the slot of the aluminium profile to lock by two bolts for drilling, was developed. This prevents the excess vibration of the drill, enabling use of the drilling machine instead of more complicated and expensive machinery.

Drawings of the special tool, see the List of Assembly Drawings, section D.

Compatibility of the manufacturing processes is negligible except machining, as there is only need to attach the profiles to other surfaces or the equipment using the special fasteners of the system. Material re-saler is a domestic company and considered reliable on their deliveries. As the material is available in several standardized profiles, the risk for losing the profile from the market should be low. Instead, new supplementary profiles have been presented to widen the selection for the heavier, or lighter load applications. This profile system is already used widely at the IGISOL-laboratory and even on other equipments close to the vertical transfer line. A uniform look for the construction could be achieved if the vertical line support structures would be made using this profile system.

4.4.3. Manufacturing and Assembly aspects

Advantages of the aluminium in general, and the profile system under consideration:

- aluminium profile as a light material ease the assembly.
- Assembly needs no welding, parts are connected using a connector system with pre-drilled holes.
- Flexible profile or dimensions of an assembly can be modified by changing the individual parts.
- Manufacturing easy and costs low, only cutting and drilled holes for the connectors needed.
- Additional parts available for adjusting purposes, no need for engineering of special parts.
- Possibility to utilize the slots on the profile for adjusting the equipment.

4.4.4. Preliminary Layout for iteration

The first preliminary layout of the transfer line was created in the kick-off meeting held at the University of Jyvaskylä, Department of Physics. Basic limitations, like the maximum height of 3450 mm for the equipment of the vertical transfer line was presented then and noted as one of the most important limitations for the engineering. Only some major components were noted, like the 90°bender, quadrupole-triplet, diagnostic-box, two valves and two bellows to the ends of the line, one set just below the concrete ceiling and another set just before the 90°bender. Preliminary layout, see Fig. 3.7.

4.5. DFMA Analyse Theory

Depending on the source, different number of guidelines are offered as DFA or DFMA principles for mechanical design. Boothroyd and Dewhurst [36] has eight guidelines and Edwards C. Lai & Associates has eleven basic principles [35]. Ham & Jeswiet [37] from the Queen's University are referring to Boothroyd & Dewhurst on their lecture, but yet has eleven guidelines for DFA.

DFA guidelines by Boothroyd & Dewhurst: [36]

1. Reduce part count and variations of parts
2. Attempt to eliminate adjustments
3. Design self-aligning and self-locating parts
4. Ensure easy access and unrestricted vision
5. Ensure ease of handling parts from bulk, tray etc.
6. Minimize the need for re-orientations during assembly
7. Design parts that cannot installed incorrectly
8. Maximize part symmetry if possible or make parts obviously asymmetrical

DFA guidelines by M. Ham & J. Jeswiet [37]

1. Reduce number of parts
2. Reduce number of different parts - Standardize parts
3. Simplification of assembly
4. Reduction number of processes
5. Less fasteners especially screws & bolts
6. Reduce tangling
7. Orientation
8. Critical orientation - obvious -see & fit
9. Non-critical orientation - fit in any direction
10. Ensure access & visibility
11. Easy part handling
12. Assemble from top

13. Reduce locating or alignment operations - manual or time consuming

DFMA Basic Principles by Edward C. Lai and Associates:

1. Minimize Part Count
2. Make Parts Multi-Functional
3. Reduce the Number of Screws and Screw Types
4. Facilitate Parts Handling
5. Use Standard Parts and Hardware
6. Encourage Modular Assembly
7. Use Stack Assemblies, Don't Fight Gravity
8. Design Parts with Self-Locating Features
9. Minimize Number of Surfaces
10. Assemble in the Open
11. Simplify and Optimize the Manufacturing Process
12. Eliminate Interfaces
13. Design for Part Interchangeability
14. Design Tolerances to Meet Process Capability

Principles of DFMA for electronics assembly were not followed in this study.

4.6. Systematic Iterative Design utilizing VDI-2221

Utilizing a systematic design tool, an engineering task is divided into seven separate stages. These seven stages are divided between four phases: clarification of the task, conceptual design, embodiment design and finally, detailed design. After reaching the next stage, iteration is done by going back to the previous stage with the information gained from the latter stage. The goals can be thus adjusted for better realization of the process through a learning curve.

Seven level iteration tasks and their expected results:

1. Defining the task - Specification
2. Determination of functions and their structure - Function structure
3. Search solution principles and their combinations - Principle solution

4. Divide into realizable modules - Module Structures
5. Develop layout of key modules - Preliminary layout
6. Complete overall layout - Definitive layouts
7. Prepare production and operation instructions - Product documents

In this study, the iteration tasks level 4: Dividing into realizable modules - Module Structures - and level 5: the Development of key modules - Preliminary layout - are combined to Modules of preliminary layout.

4.6.1. Transfer line for the test ion sources

The task is to design the transfer line to the laboratory for the test ion sources. This task is divided into two parts by the construction of the building: one meter thick concrete ceiling restricts the needed equipment in either the laboratory room, between main beam line level +1350 mm and ceiling +3450 mm or to the concrete roof above the room, that is +4450 mm from the floor level.

4.6.2. Determination of functions

Between the floor level and upper level is approximately 1 m long vacuum pipe, on a hole of 160 mm, drilled to the concrete ceiling and connecting the equipment on both 1st and 2nd floor. All the needed functions of the ion sources and vertical transfer line have to be placed over or below this vacuum pipe. This 1m thick concrete ceiling prevents placing the ion-optical components in the ideal positions. As a smallest possible feed through, the pipeline is considered to be the least problematic in prevention of radiation from the radioactive premises to the low radiation area and thus defines the design.

Needed functions of the ion sources and transfer line:

1. Vacuum chamber for the ion sources
2. Quadrupole deflector for ion beam optics; turning the ion beam 90°
3. Equipment rack for the vacuum chamber
4. Support frame for the equipment rack and vacuum chamber
5. High voltage (HV) insulation between the equipment rack/vacuum chamber and support frame
6. Vacuum pump
7. DN160 HV insulation between the vacuum chamber and the vacuum pump
8. Pre-vacuum pump to improve the efficiency of the vacuum pump
9. Extraction element for the ion beam
10. DN100 HV insulation between the vacuum chamber and an extraction element
11. DN100 Gate valve to separate the test ion sources from the main beam line
12. Double-XY-element for ion beam optics
13. Quadrupole-triplet for ion beam optics
14. Diagnostic box
15. Vacuum pump for the diagnostic box
16. Pre-vacuum pump to improve the efficiency of the vacuum pump
17. Faraday cup and actuator to the flange of diagnostic box
18. Pirani vacuum gauge for rough to medium vacuum range to the diagnostic box
19. Penning vacuum gauge for lower vacuum range of the diagnostic box
20. Double-XY-element for ion beam optics
21. Wall support for the equipment between +1350 mm to +3450 mm.
22. DN100 gate valve to separate the vertical transfer line from the main beam line
23. 90°bender to turn the test ion beam to the main beam line

4.6.3. Design options

The transfer line consists of several equipment with different requirements for their position in relation to the others.

1. All the equipment in one space: mechanically the most simple solution would be to place all the equipment on the floor level, between the levels +1350 and +3450 mm, leaving only the ion sources and other equipment that has to be close to the HV to the 2nd floor, above level +4450 mm. However, this solution has an ion-optical disadvantage.
2. Ideal solution: theoretically, due to the ion optics, the ideal solution is that the Quadrupole-triplet is positioned in the middle of the transfer line, i.e. between the quadrupole deflector and the inlet point of the 90°bender. However it is not possible to place the quadrupole-triplet in the ideal position, as it would be partly inside the concrete ceiling. Opening the 160 mm diameter hole is not considered because this would mean a bigger risk for radiation coming from the main beam line from the 1st floor when running the accelerator.
3. Equipment separation: the quadrupole deflector is possible to place just below the ceiling, but this means that the DN100 gate valve and the double-XY above it had to be moved to the 2nd floor, above level +4450 mm. For the efficient use of double-XY, best position would be immediately on the point where the ion beam leaves the ion sources. This way the corrective action can be done earlier, meaning lower energy needed for the transition.

4.6.4. Modules of preliminary layout: Ion Sources and Vertical Line

In this section, two iteration tasks levels of VDI-2221 on section 4.6, level 4 - Module Structures and level 5 - Preliminary layout - are combined to one.

Layout of the Ion source module consists of the functions 1-23 and additional parts like bellows to connect the module to the Vertical transfer line module. Layout can be seen on Fig. 4.3. Determination of functions, see 4.6.2.

- Ion source module consists of the functions 1-12 mentioned in Determination of functions.
- Vertical line module consists of the functions 13-21 mentioned in Determination of functions.

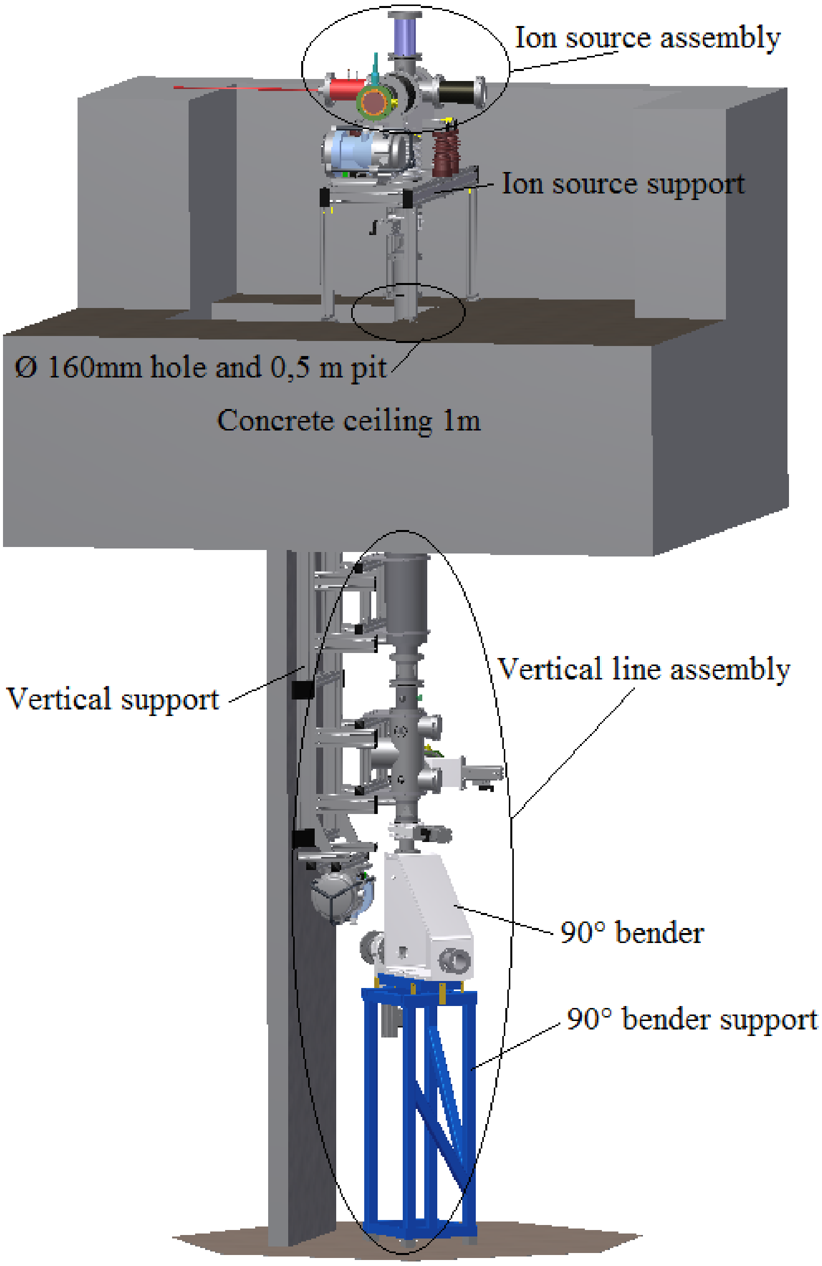

Figure 4.3.: *Layout of the new laboratory. The ion source assembly and support are over the 1 meter thick concrete ceiling. The hole through ceiling for the test ion beam transfer line is on a one by one meter and 0,5 meter deep pit. The Vertical Line assembly below is on the radioactive area, including the 90° bender and the related wall supports.*

Layout of the Ion source module consists of the functions 1-12 (see section 4.6.2) and additional parts like bellows to connect the module to the Vertical transfer line module. The layout can be seen in Fig. 4.4.

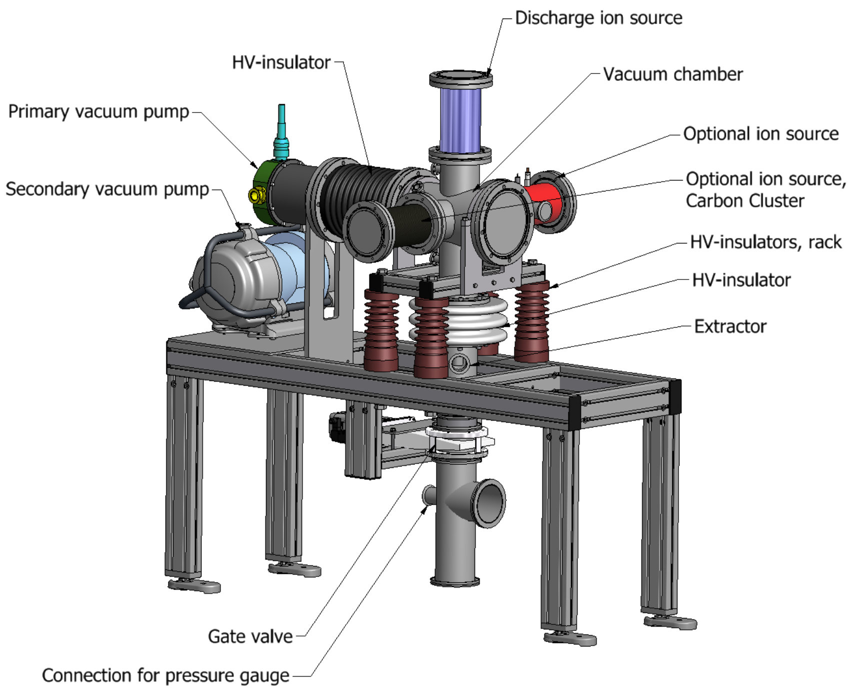

Figure 4.4.: *Assembly of the ion sources, pumps and a valve. HV insulators isolate the vacuum chamber from the pumps, extractor, valve and support frame that are grounded. The pipe with flanges for the pressure gages connects to the pipe below (not shown) coming through the concrete ceiling. Turbomolecular pump is the main pump, a scroll pump acts as a secondary pump. Ion sources shown are not actual, but only illustrate the relative positioning.*

Layout of the Vertical transfer line consists of the functions 13-21 (see section 4.6.2) and additional parts like bellows to connect the module to the Ion source module. The layout can bee seen on Fig. 4.5.

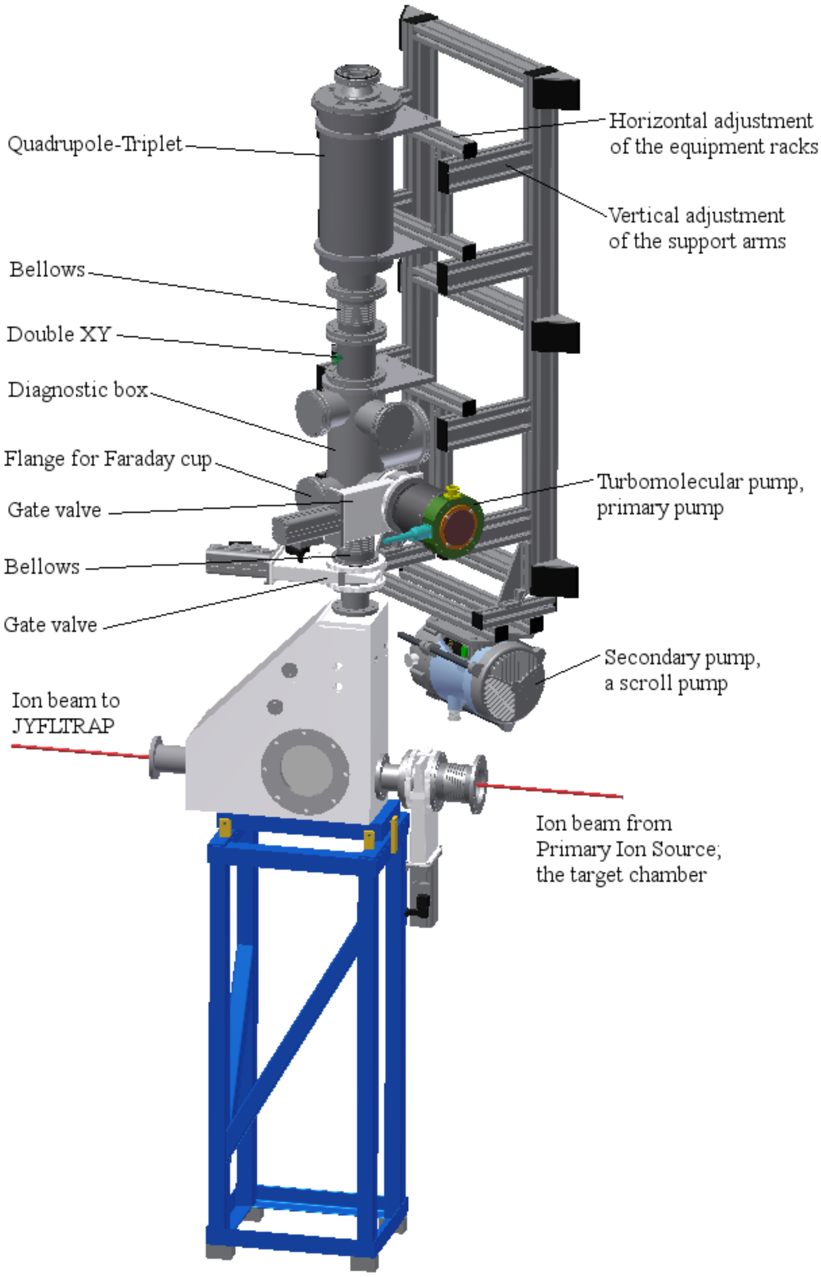

Figure 4.5.: *Assembly of the vertical line with the related equipment including quadrupole-triplet, diagnostic box, pumps, valves. Turbomolecular pump is the main pump, a scroll pump acts as a secondary pump. The pipe connecting the ion source to the transfer line is not shown.*

4.6.5. Instructions for production and operation

For the purchase and assembly of the aluminium support system, as well as for the production and assembly of the various equipment engineered for the test ion source transfer line, manufacturing drawings and assembly drawings were produced. List of Assembly Drawings, see D on page 90. List of Manufacturing Drawings, see E on page 108.

As the power supply system, electrical controls and definition of operations will be defined, delivered and built later, operation instructions are excluded the systematic iterative design principles in this work.

4.7. Cost estimation

Due to the heavy construction designed originally to support the roof of the building, and only secondary to serve as an attaching platform for the vertical transfer line, the material consumption and therefore also the costs can be considered to be higher than for the lighter construction, that is designed only for the support function of the vertical transfer line. Steel profile is purchased kg/m basis so the weight and costs will increase rapidly if the bigger profile is used.

The material costs of the aluminium vertical wall support and racks are calculated from the unit prices as the material was a part of a larger delivery. For this reason, the total sum was not available. The aluminium vacuum chamber support and rack support was ordered separately. The total sum of the invoice as well as the cost of vacuum chamber rack is presented.

The costs of in-house manufacturing of the steel structure was estimated by Research engineer Kimmo Ranttila [38] from the department of physics.

Table 4.5.: *Cost calculation of the Transfer line supports and equipment racks, aluminium system*

aluminium system **ITEMS**	**L** **[m]**	**pcs.**	**Unit price no VAT €**	**Total incl. VAT 22% €**
Vertical wall support and racks*				
45x90 L aluminium profile L=1500	1,5	2	21,47	79,22
45x90 L aluminium profile L=500	0,5	8	21,47	105,63
45x90 L aluminium profile L=290	0,29	3	21,47	22,98
45x45 L aluminium profile L= 590	0,59	2	10,23	14,85
45x45 L aluminium profile L= 500	0,5	4	10,23	25,17
45x45 L aluminium profile L=285	0,285	2	10,23	7,17
45x45 L aluminium profile L=250	0,25	4	10,23	12,58
Cutting of Al. profile series BSB-ISB		25	0,50	15,38
Drilling, hole Ø17 mm		48	1,20	70,85
Alu Connection Angle 90, 88 x 88 x 86		8	4,90	48,22
Cover Cap for Alu Connection Angle 90		8	1,14	10,96
Central Connector, hammer 0°		16	2,50	49,20
Central Connector, hammer 90°		8	2,48	24,40
Cover Cap 90x45 for BSB2796		12	1,30	19,19
Cover Cap 45x45 for BSB4569		12	0,56	8,27
Roll-In T-slot Nut M6 with spring leaf		26	-	-
aluminium die-cast angle, left, 175x86x43mm		2	7,17	17,64
Total Costs, support and rack				**531,70**
Vacuum chamber support and rack:				
45x45 L aluminium profile L=450	0,45	2	10,23	11,32
45x45 L aluminium profile L=130	0,13	2	10,23	3,27
Vacuum chamber support, aluminium				637,30
Vacuum chamber support, assembly		4	45	221,40
Total Costs, support and rack				**873,29**

Table 4.6.: *Cost estimation of the Transfer line supports and equipment racks, material:steel*

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Manufacturing in-house. Total sum includes VAT 23%, Ranttila [38].

ITEMS, steel structure Estimated costs Estimation of manpower and materials	hours	Unit price €	Total incl. VAT €
Vertical wall support and racks, steel**			
Engineering	14	45	774,90
Cutting	7	45	387,45
Welding	21	45	1 162,35
Machining	7	55	473,55
Painting	8	45	442,80
Installation	2	45	110,70
Materials			150,00
Total			**3 501,75**
Vacuum chamber support, steel**			
Cutting	2	45	110,70
Welding	8	45	442,80
Finishing and painting	4	45	221,40
Adjustment	4	45	221,40
Materials			150,00
Total			**1146,00**

4.8. Ion-optical simulations

Ion-optical simulations were used to study if an Einzel lens after the quadrupole deflector was required in order to transport the ion beam through the extractor before the beam scatters. First simulation was executed using the geometry of an existing Einzel lens construction and the reference simulation without it. Simulations showed a remarkable improvement was achieved when using the Einzel lens. For the vacuum chamber, the current construction appeared to be too long. A new, compact ion-optical equipment was designed and the geometry simulated. These simulations further showed the benefit of an Einzel lens in focusing of an ion beam.

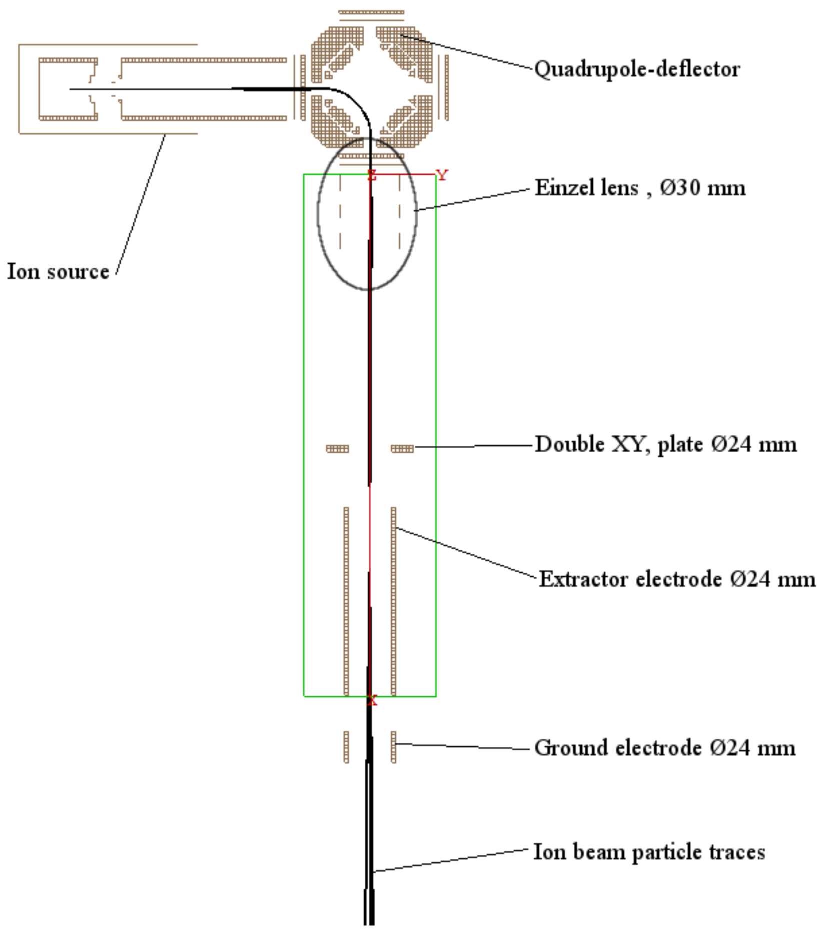


Figure 4.6.: *Ion beam and the positioning of the ion-optical elements in the simulation. Side view, X-Y direction*

Simulation was executed for the ion-optical equipment of the ion source unit, utilizing SIMION 8.1 Ion and Electron Optics Simulation software. The purpose of the simulation was to test the ion-optical properties of the intended dimensions and construction of the Einzel lens, extractor electrode and ground electrode with the existing Quadrupole deflector construction. Another aim was to find the start values for the voltage of the various ion-optical elements for the actual tuning of the Vertical Transfer Line.

Ion-optical simulation included an ion source, a Quadrupole deflector, an Einzel lens, an extractor and a ground electrode. A existing Quadrupole deflector simulation model along with different models of the Einzel lens and the extractor electrode, as well as different voltage values for the ion-optical elements were used. In each simulation, a group of ten particles were used to see the deviation of the particles in-flight. The effects of each change of the beam was followed by observing the behaviour of the XY- and 3D views of the simulation run, XY cut shown in Fig. 4.6 and a 3D cut in Fig. 4.7.

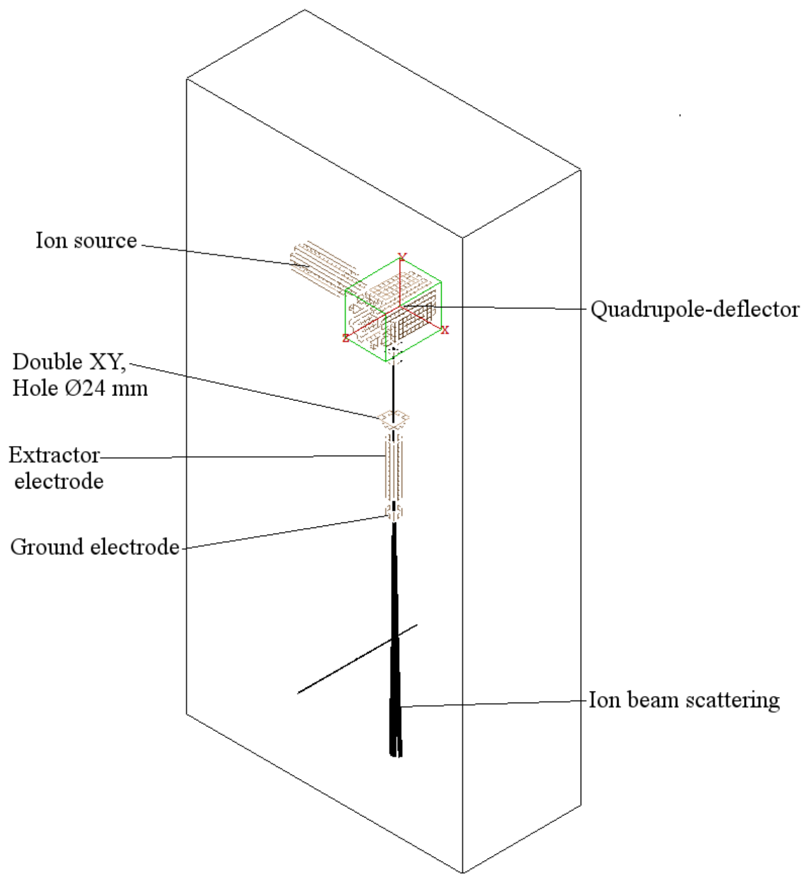


Figure 4.7.: *3D-view of the ion beam formation and positioning of the ion-optical elements in the simulation.*

The aim was to get all the particles of the simulated ion beam through the ion-optical elements. Voltage levels were adjusted to optimize the transport. Optimized voltages and levels can be seen in the chart of voltages in Table 4.7.

Table 4.7.: *Voltage values of the ion-optical elements, compared to the ion source voltage +30 kV.*

ION-OPTICAL ELEMENT	Voltage [V]
Ion source	
Ion extraction	-800
quadrupole deflector	
1	-800
2	-800
3 Main electrode	1 100
4 Main electrode	-1 800
5	-800
6	-800
7	-350
8	-850
9	-800
Einzel lens	
Electrode 1	-800
Electrode 2	-87
Electrode 3	-800
double XY	
Ø24 mm hole	-800
Extractor electrode	
Ø24 mm L=115	-20 000
Ground electrode	
Ø24 mm L=20	-30 000

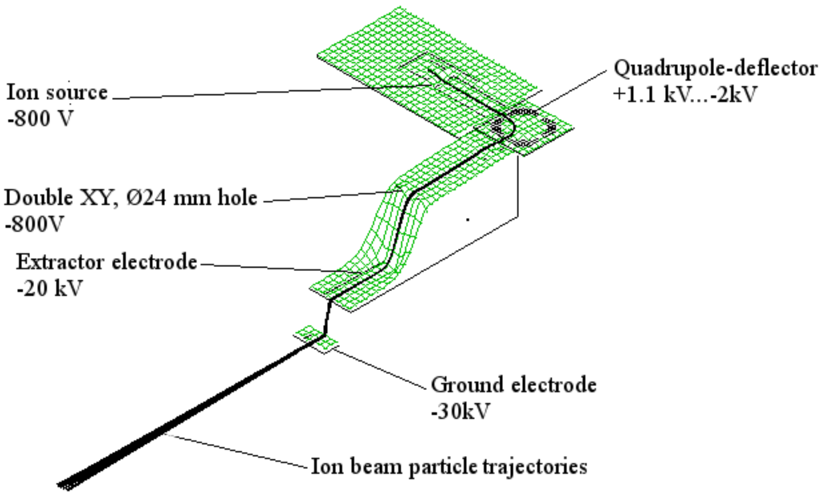


Figure 4.8.: *Potential energy level variation of the ion beam in simulation.*

The cross section of the ion beam simulation shows the deviation of the particles. An ideal situation would be a uniform, tightly focused circle spot. The deviation can be seen in figure 4.9.

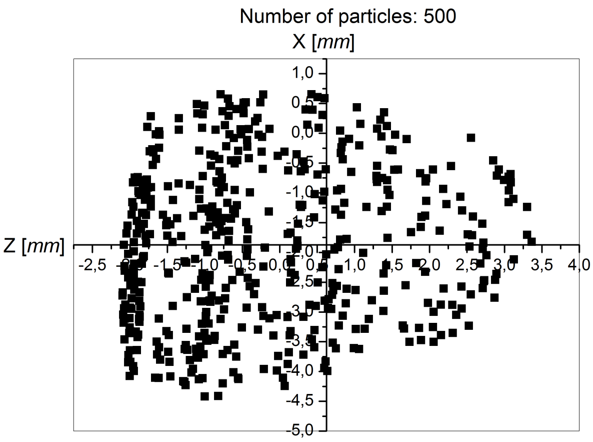


Figure 4.9.: *Particle deviation of the ion beam in the simulation.*

4.9. New ion-optical equipment

The preliminary layout of the Vertical Transfer Line did not include the Einzel lens, as it was considered that the ion beam optics could be adjusted adequately utilizing the previously used equipment. Using the focusing elements of the quadrupole deflector, both for the incoming beam and for the exiting beam, was not adequate to focus the beam sufficiently into the extractor in a tight bunch. Neither did the adjusting of the main electrodes and shim electrodes lead to an improvement in the beam direction, and to reflect the beam as a uniform group. In simulations, without an Einzel lens, the beam scattered before entering the extractor electrode.

In the first simulations with an Einzel lens, a geometry of an existing design (>100 mm) was used. With the Einzel lens positioned just after the quadrupole deflector, tighter grouping of ions during flight was noticed. Later, a new, compact design was simulated. The phenomenon existed, regardless of the length of the Einzel lens electrode rings. In the simulation, both the short and the long electrode rings of the Einzel lens improved the focus of the ion beam. Assembly of the compact Einzel lens can be seen in an assembly drawing in section D. Detailed drawings can be found from the List of Manufacturing Drawings in section E.

Simulation results supported placing the Einzel lens after the Quadrupole deflector. The limited space of the 6-way vacuum chamber lead to integrating a compact Einzel lens with the double XY electrode as seen in Fig. 4.10.

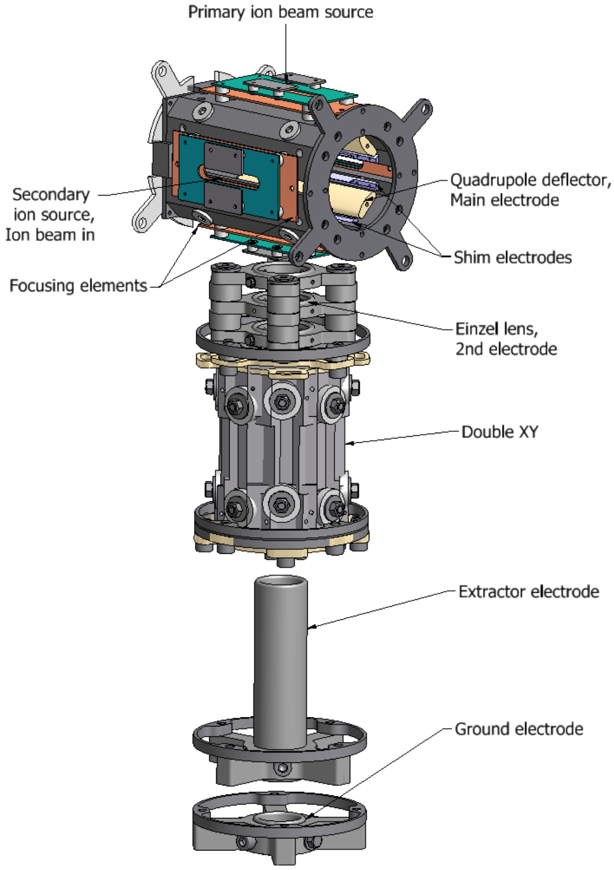


Figure 4.10.: *Assembly of the ion-optical equipment: quadrupole deflector, Einzel lens, double XY, extractor and ground electrode, positioned as in the ion-optical simulations. An Einzel lens and double XY are integrated to fit the equipment inside the 6-way vacuum chamber and to simplify the alignment of the various components. Extractor and ground electrode are placed into a common vacuum chamber with isolated power supplies.*

A short HV-isolator was designed to fit on the flange of the 6-way vacuum chamber to enable the connection of a new, small diameter extractor and a ground electrode construction. Due to the HV potential difference, the distance between the tip of the extractor and the double XY has to be approximately 30 mm. To reach this dimension, the extractor has to be installed partly inside the HV insulator, see cross section Fig. 4.11. The extractor and the ground electrode are also integrated into a common vacuum chamber with isolated power supplies. Short dimensions simplify the alignment of the optical elements. Alignment is important because it affects the beam trajectory in a similar way as adjustment of the voltage of the elements. Earlier, the alignment has been done using a laser and a cross hair on the vacuum pipelines and flanges. This is a time consuming process that requires accuracy. By integrating the Einzel lens and a double XY with the machined parts one alignment procedure can be eliminated. Using a special tool for the centering of the quadrupole deflector to the 6-way vacuum chamber pipes, the components can be aligned. Alignment does not require the installation of the 6-way vacuum chamber to the aluminium supports. After installing the HV insulator, the extractor electrode is considered to be aligned using a Ø24 mm diameter tool (Drawing on page 113), that is an exact fit with the electrode rings of the extractor electrode, ground electrode and with the end plates of the double XY.

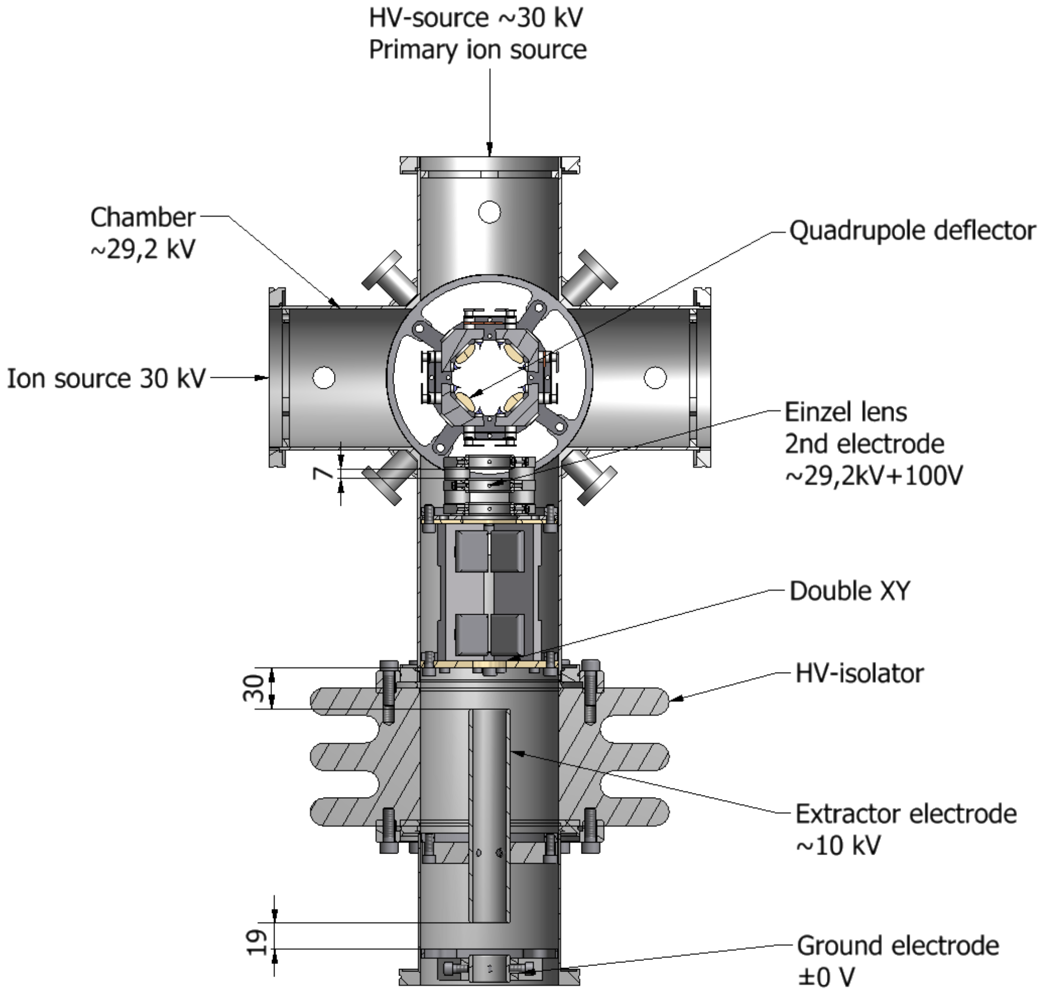


Figure 4.11.: *Cross section of the 6-way vacuum chamber with the ion-optical equipment installed, showing the ion-optical elements: a quadrupole deflector, an Einzel lens, double XY, extractor and ground electrode. The ion source has the same voltage as the HV source. The Einzel lens and double XY are integrated to fit inside the 6-way vacuum chamber and to ease the alignment of the various components.*

4.9.1. HV insulator's dielectric breakdown distance

Due to the high voltage of 30 kV between the double XY in the 6-way vacuum chamber and extractor electrode, a HV insulator is required. For a rigid construction, the length of the HV insulator should be as short as possible. HV sets limitations to this distance due to the risk for a dielectric breakdown. Dielectric breakdown causes permanent changes in appearance and properties on an insulation material.

For the new construction of the ion-optical components, an order of 100 mm long HV insulation was desirable. The existing HV insulator design available was 200 mm in length and was seen difficult to be installed because of its' length and to be used with the new equipment.

Another already proven HV insulator design is in use on the main beam line of the accelerator laboratory. The design is horizontally installed, 100 mm long and 300 mm in diameter, but was considered too big and heavy for the new vertical position. This Ø300 mm HV insulator was selected as the reference for the calculation to define the distance against the dielectric breakdown. This reference HV insulator was designed using criteria for both vacuum and atmospheric pressure. For a vacuum, 1 mm was used as equal to a voltage of 1 kV and in atmospheric pressure, 10 mm was used as equal to 1 kV in calculation of the minimum dielectric breakdown distance. Thus, the voltage of 30 kV requires a minimum dielectric breakdown distance of 300 mm in atmospheric pressure and in vacuum, 30 mm, respectively. [39].

The dielectric breakdown distance is calculated along the outer surface of the HV insulator. The surface of the HV insulator has a corrugated shape, having a certain number of ridges and furrows. A spreadsheet was created for the iteration process to select the design of the different combinations of length and number of ridges. Then optimization was continued selecting the outer- and inner diameters.

For the calculation, the maximum and minimum diameter of the insulating material, the length of the HV insulator and the number of the ridges were given as variables. The outer diameter of the metal flanges used for connecting the HV insulator to the vacuum system was also given, to deduct the impact of the stainless steel as a conductive material. As a result, the distance for dielectric breakdown between the metal flanges was calculated. This distance was then compared with the distance of the existing reference design, presented in Table 4.8.

Table 4.8.: *Dielectric breakdown distance calculation of the HV insulator. The dielectric breakdown distance for the new construction is required to exceed the 342 mm of the reference HV insulator. Dimensions of the new design can be seen in a manufacturing drawing KR3-A059 on page 110.*

DIMENSIONS OF THE ITEM	**Reference Ø300 Design** [mm]	**New Ø260 Design** [mm]
Required dielectric breakdown distance		**>342**
Calculated distance of diselectric breakdown	**342**	**352**
Measured thickness of the ridge	25	
Calculated thickness of the ridge		20
Measured length of the insulator	100	
Given length of the insulator		100
Maximum diameter of the insulator, ridge	Ø300	Ø260
Minimum diameter of the insulator, furrow	Ø200	Ø160
Flange diameter on HV-side	Ø165	Ø165
Flange diameter on grounded side	Ø165	Ø165
Inside diameter of the insulator	Ø100	Ø100
Number of ridges	[$pcs.$] 2	[$pcs.$] 3

The dielectric breakdown distance for the new construction is required to exceed the 342 mm of the reference HV insulator. The distance is measured between the edges of the connecting stainless steel flanges on the HV-side and grounded side. The dielectric breakdown distance of the new design is 352 mm, exceeding the reference dimension by 10 mm. Dimensions of the new design of the HV insulator can be seen in a manufacturing drawing KR3-A059 on page 110.

After engineering, the dielectric breakdown distance of the selected design was confirmed from the assembly drawing of the HV insulator, shown in Fig. 4.12.

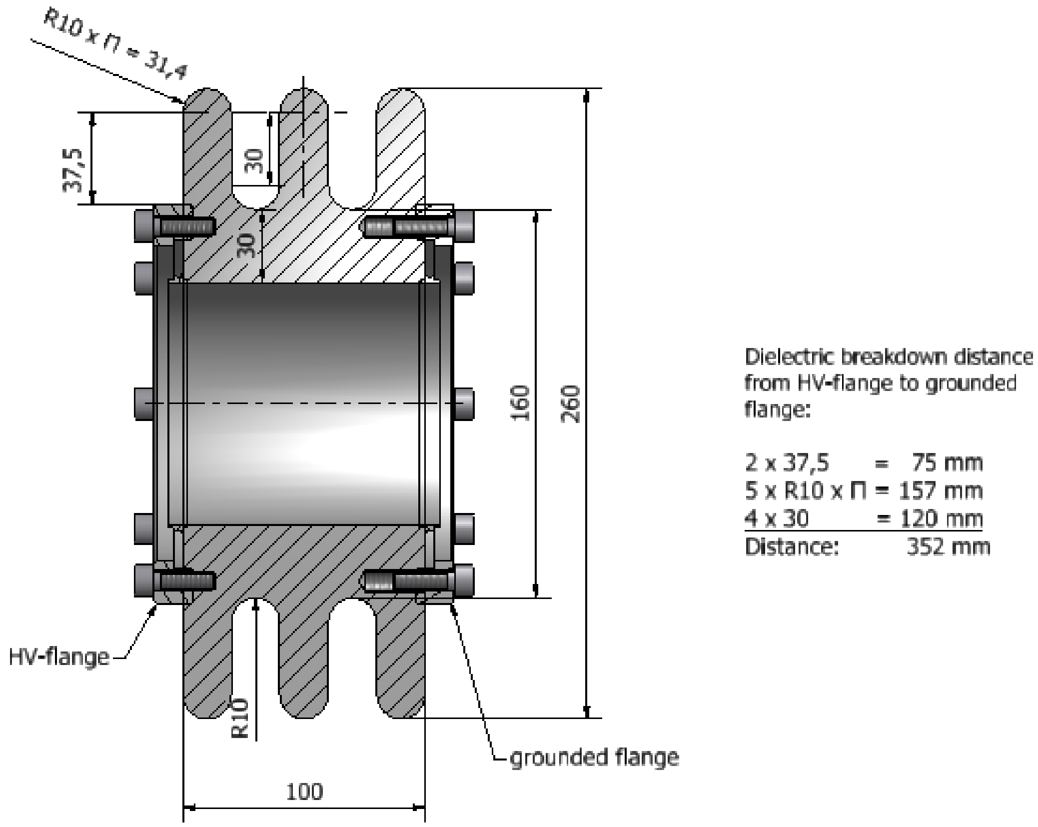


Figure 4.12.: *Dimensions of the HV insulator for the dielectric breakdown distance calculation. Calculation is done along the outer surface of the HV insulator between the edges of the connecting flanges on the HV side and grounded side.*

4.10. Final layout

The final layout contains both the new design of the aluminium support system utilizing the systematic design tools DFMA and VDI-2221 and the new ion-optical equipment, designed on the basis of ion-optical simulations. Test ion source assembly can be seen in section D and the manufacturing drawings section E. Master assembly of the Vertical Transfer Line, ion sources and their supports can be seen in Fig. 4.13.

Vertical wall support assembly on the 1st floor includes items 1-15:

1. 90°bender
2. Floor support for 90°bender
3. Two gate valves
4. Wall support
5. Equipment racks for quadrupole-triplet and diagnostic box
6. Quadrupole-triplet
7. Diagnostic box
8. Turbomolecular pump Edwards STP-301
9. Scroll pump Edwards XDS 10
10. Faraday cup and the actuator assembly, not presented
11. double XY
12. Bellows
13. Two intermediate pipes
14. Two pressure gauges for diagnostic box, not presented
15. Connecting pipe for 2nd floor

Ion source assembly on the 2nd floor includes items 16-32:

16. Ion source support
17. 6-way vacuum chamber for the test ion sources
18. Equipment rack for the 6-way vacuum chamber
19. HV insulator for Turbomolecular pump
20. HV insulators between 6-way chamber and the Ion source support
21. Turbomolecular pump Edwards STP-301
22. Support for the turbomolecular pump
23. Scroll pump Edwards XDS 10
24. Stand for the scroll pump
25. Quadrupole deflector
26. Double XY
27. Einzel lens
28. Extractor electrode
29. Ground electrode
30. HV insulator for extractor- and ground elecrode assembly
31. Gate valve, VAT
32. Support for VAT gate valve, not presented.
33. Intermediate pipe with connections for pressure gauges
34. Bellows
35. Blank flanges for optional connections

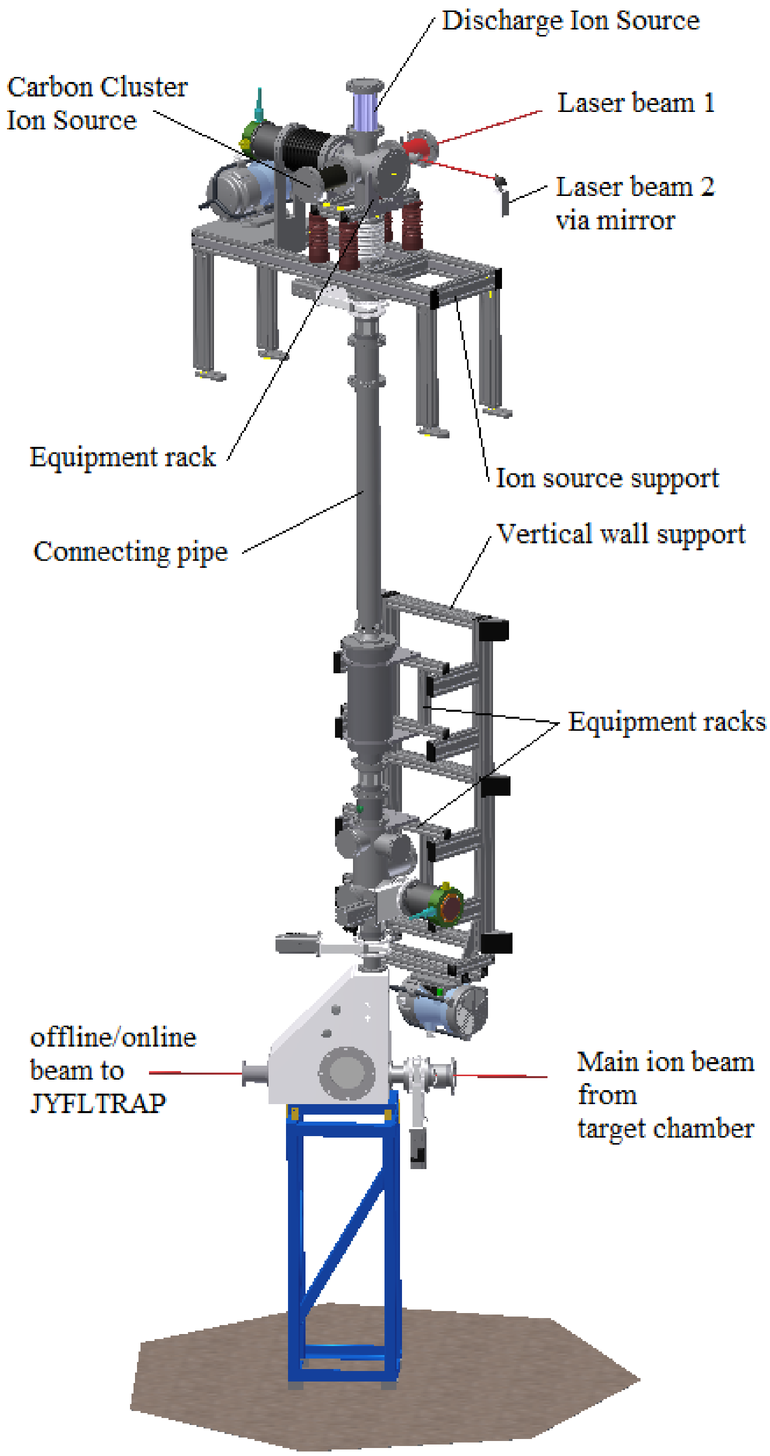


Figure 4.13.: *Layout of the ion sources, related HV isolators and the pipe connecting the Vertical transfer line through the concrete ceiling. Laser ion source is presented as an example of an optional future ion source only to illustrate different positions for the ion sources.*

5. RESULTS

A test ion beam can be produced without the use of an accelerator. Following the ALARA principle, improvement was achieved with respect to the radioactive exposure during the operation with the test ion sources.

The new construction enables:

- To switch between on-line and off-line ion beams without entering the radioactive area.
- Reduce the time between on-line and off-line ion beams by avoiding the cooling time of typically one week with light ion beams.
- Avoiding the dosage of radioactive background radiation after light ion beam runs by re-locating the manual off-line ion source out of the radioactive area to a non-active area.
- Mass separation of the test ions.
- Multiple stationary test ion sources available for test runs, not requiring any dismantling of previous ion source and installation of new one.
- Switch from one off-line ion source to another off-line ion source can be done without entering the radioactive area.

The construction of the Vertical Transfer Line is presented in the layout of the laboratory in Fig. 5.1.

5.1. Results of simulations

The ion-optical simulations showed that an Einzel lens after the quadrupole-deflector was required to transport the ion beam through the extractor electrode. New, compact ion-optical equipment was designed, based on the simulations.

- 50 mm long Einzel lens was designed to enable it to be placed after the quadrupole deflector. The Einzel lens was also designed to be integrated with the double XY deflector.

- A new, small diameter extractor electrode and holders were designed to fit into a DN100 vacuum line.
- Short extractor and the position of the compact double XY deflector required designing a short HV insulator. A 100 mm long HV-insulator was developed.

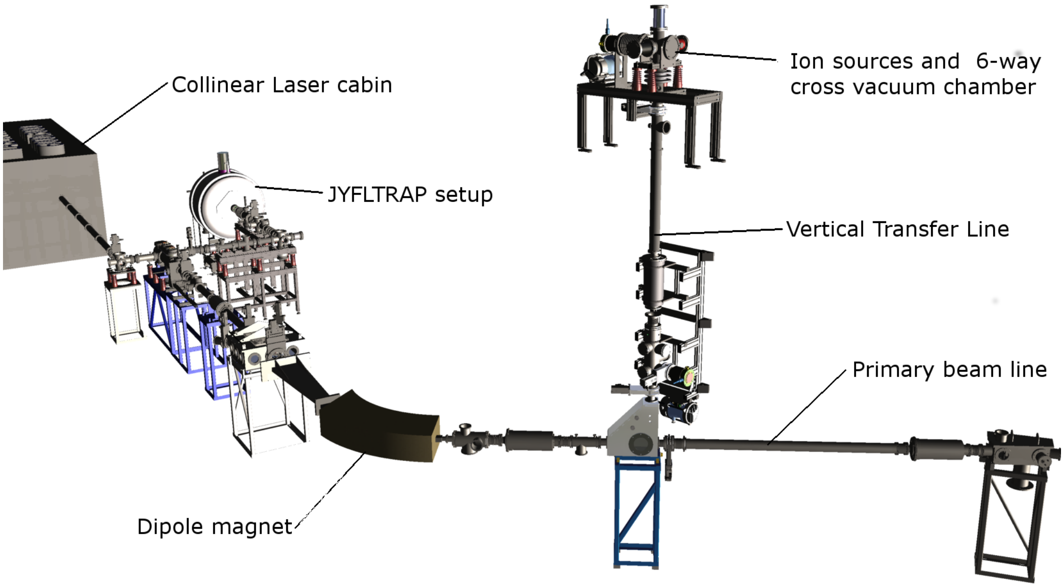


Figure 5.1.: *Layout of the IGISOL laboratory,including the Vertical Transfer Line.*

5.2. Results utilizing DFMA

- Aluminum beams for the supports and equipment racks can be assembled to each other using only one tool, a hex key.
- The heaviest individual aluminum system part weighs 4,6 kg. The weight of the frame of the wall support assembly to be installed manually to the concrete wall weighs 12,2 kg total.
- Assembly time for the vacuum chamber rack was 4 hours.
- Assembly time for the vertical support was 16 hours.
- Alignment of the equipment does not require any separate adjustment screws or other additional construction. The horizontal alignment is done by moving the equipment rack in relation to the support arms of the vertical rack. Vertical positioning of the equipment is done by moving and tightening the support arms to the specified position on the vertical wall support 45x90-profile beams.

- Modification of the dimensions of the assembly is flexible due to the interchangeable parts.
- Cost comparison of vertical wall support and racks: total costs of utilizing different materials: aluminum €468.18, versus steel €3 501.75, difference in advantage of aluminum system €3 033.57.
- Cost comparison of vacuum chamber support between two different materials: aluminum system €873.29 versus steel, €1 146.00. Difference in advantage of aluminum system €272.71.
- Total cost difference in advantage of the aluminum system €3 242.76, aluminum system, Table 4.5 and steel, Table 4.6.

6. DISCUSSION

The switch between on-line and off-line ion beams as well as between on-line to off-line ion sources has required an entry to the radioactive area. After the light ion source runs, the premises remain radioactive, requiring approximately cooling time of one week before entering the area and manually handling the ion sources.

Producing the test ion beam outside the radioactive area of the accelerator's main beam line lowers the exposure to radioactive radiation towards the personnel working on the test ion sources by eliminating the entry and working time in at the radioactive area. Avoiding the cooling time of the radioactive premises enables the start of new test ion runs earlier. The aim of ALARA principle is to lower the dosage of radioactive radiation. This can thus be followed.

Having multiple test ion sources, each installed to the 6-way cross vacuum chamber and positioned outside the radioactive area, speeds up the process switching the test ion source between the runs as there is no need for mechanical dismantling and/or assembly.The new layout makes possible mass separation of the test ions as the vertical line is placed before the dipole magnet.

Positioning the Einzel lens and double XY deflector immediately after the quadrupole deflector was seen as most economic way to control the beam. After the ion source and quadrupole deflector, the energy of the beam is relatively modest, meaning that the voltage required for control of the beam can be lower. To study this layout, simulations were performed.

Ion-optical simulations showed the need of an Einzel lens after the quadrupole deflector in order to transport the ion beam through the extractor. A new, compact ion-optical equipment was designed, based on these simulations. As the equipment is not yet installed, there are no test ion beam runs to confirm the results of the simulations. After the installation of the Vertical Transfer Line, the actual results can be compared to the simulations.

In addition, a new extractor for a smaller diameter vacuum pipe was designed. The existing extractors were designed solely for the bigger diameter vacuum line and would have limited the vacuum pumping capacity in a smaller diameter line. The layout of the equipment; quadrupole deflector. followed by the einzel lens integrated with the double XY deflector, and assembly of extractor electrode and ground electrode was a result of the aim towards a compact design, according to the ideal situation. Since there is a 1 meter-thick concrete ceiling limiting the positioning of the equipment of the Vertical Transfer Line, the long transfer to the next ion-optical equipments below the ceiling may prove to be problematic due to the scattering of the ion beam. The beam may scatter before entering the quadrupole-triplet, causing reduction in transport efficiency. In the line, however, there are intermediate parts that can be re-positioned. If needed, the extractor- and ground electrodes, either both or the ground electrode only, can be placed lower, even under the 1 meter ceiling and replaced with a bellows or pipe of the same length of 120 mm. This way, the extraction length can be extended thus diminishing the scattering effect before the next ion-optical element in the vacuum line.

Mass separation of the test ions is possible due to the location of the test ion sources. As the ion source is before the bending magnet, the test ions will be mass separated.

Ion-optical simulations gave the impression of a functional ion-optical layout. In reality, the equipment seldom performs as good as in the simulations. The unknown factors may lower the performance.

Vacuum level is a concern when producing an ion beam as the uniformity of the beam depends on the vacuum. In this case, the vacuum pumps, their positioning and the design of the ion-optical equipment is essential. In the vacuum line, there should be sufficient pumping capacity.

In this study, the aim is to gain a control sample for calibration without the use of a cyclotron. Equipment to be calibrated by using the off-line ion source would be all the ion optics between the ion source and the Penning trap, as well as the extraction of Penning trap.

In this thesis, an electric discharge ion source is considered as a main test ion source. An optional secondary ion source was Carbon Clusters. The third position in the 6-way vacuum chamber is for any other future option.

If DFMA would not have been used, a remarkable number of advantages and disadvantages of the different options of the construction might have been unnoticed. DFMA analysis led to a systematic comparison of the problem and to concentrate on a more detailed level thus enabling a widening of the range of issues related to improvement of the current construction.

In this study, the DFMA forms DFMA1 and DFMA2 may not have been utilized in their full potential. DFMA1 was used to evaluate the existing complete dismantled steel construction. The aluminium construction and equipment was placed to a new location, so the surroundings were not equal. The difficulty with DFMA1 is to define which of the violations against the manufacturability are characteristic only for the supports and which are for the equipment or is it a combination of both.

DFMA1 forms, see section A on page 72.

DFMA2 forms were used to evaluate the ergonomics on assembly of the new aluminum system. Under evaluation was the separate parts including wall support, support frame of the ion sources, equipment racks of diagnostic box, quadrupole triplet, vacuum chamber and the assemblies of the above mentioned; vertical section 1st floor and ion source assembly 2nd floor. DFMA2 forms, see section B. DFMA2 forms may give an over optimistic impression of the assembly as there is only one or two violations against 21 DFMA principles in total. If the place of assembly is clean, level and there is room to unpack the parts in good order, the assembly of the separate beam elements is easy. Especially, any perpendicular feature in addition to a level surface will make the assemby quicker. In this case, it is easy to pre-tighten the hexagon-screws, position the profiles and make the final tightening. Assemblies of order 0.5 m by 1 m can be handled manually. If the working place is not even, it makes the assembly more demanding in the early phase, as then it may require to both hands for the alignment of two different profiles at the same time, preventing simultaneous holding and tightening of the connector's screw. Also dirt may cause difficulties in this application, possibly turning the connector head wrong way in the slot, preventing the locking and slowing down the assembly. Durability against dirt, however, was not mentioned as a violation against the DFMA principles.

In this thesis, some of the DFMA main principles were utilized including:

- Minimize number of parts.
- Minimize manufacturing phases
- Minimize tools used

This led to construction that requires only two different aluminum profiles, cutting, drilling and one tool for the assembly. Attaching the equipment such as the diagnostic box required three holes per profile, six altogether for the M8 bolts and an additional M13 wrench. It can be considered relatively simple in terms of construction manufacturability and assembly.

- Requires only two different aluminum profiles
- Only cutting is needed to manufacture a part
- Drilling holes for the connectors, for 45 x 45 one hole/joint and for 45 x 90 profile two holes/joint
- One tool for the assembly
- Light parts to install

  The mass of the bigger profile, 45 x 90 is 3.1 kg/m. The heaviest separate aluminum part was the beam of the vertical wall support; 4.6 kg. The weight of the wall support assembly consist of two of these beams and three connection beams weighs a total of 12.2 kg. This is well below the recommendation of ILO, International Labour Organization, the Maximum Permissible Weight to Be Carried by One Worker Recommendation R128; temporary lifts 55 kg, continuous lifts 35 kg for men and for women 30 kg and 20 kg accordingly [40, 41].

7. CONCLUSIONS

DFMA was used to design the Vertical Transfer Line. ALARA principle was followed and the resulting risk to exposure of radioactivity is reduced. This has been achieved by relocating the reference ion sources to a non-hazardous area.

Current design allows the flexible modifications or addition of new equipment, especially the area around the ion sources. Also modifications of the supporting structure are simple, dismantling is easy and material costs are low. Use of DFMA eased to evaluate the different technical solutions and lead to a low cost structure. Method, however, would be more beneficiary for serial production.

Emphasis for the future research projects could be re-engineering of the current 90°bender. The existing design currently has no capacity to bend the HV beams. Secondly, the installation of the existing discharge ion source, as well as the design of a carbon cluster ion source is required. Utilizing laser technology for this ion source unit is not currently planned, but could be included in a long term development program at the Department of Physics. The unit has been designed so that a laser beam can be relatively easily directed into the ion source.

A. DFMA1 manufacturability forms

DFMA1 forms are used to evaluate how user friendly the construction is to manufacture. The ease of manufacturing was measured by the number of different stages and parts required for finished product.

List of DFMA1 manufacturability forms:

DFMA 1

Ergonomics in Design for Manufacture and Asssembly

Product name: Vertical Transfer Line

Author: Kari Rytkönen

Instructions:
1. List the parts in design order they are assembled.
2.Note the design rules that are violated for each step.
3. Mark each of the violating boxes with "1" and the score will be automatically calculated to "SCORE/ITEM" and "OVERALL SCORE" sells.

Color tells the level of coplexity of assembly:
RED= complex,
YELLOW= average
GREEN= easy

Item no.	MAIN ASSEMBLY / PART / SUBASSEMBLY	Separate fastener	Spring or washer	Separate label	Further integration	Needs leads, guides, chamfers	Needs pilot holes	Flexible, slippery or sharp	Can nest or tangle	Slightly assymetrical	Low friction grasping surface	Uncommon fastener	More than one "right" way	Multi-step assembly	Assemled from side	Can´t see mating surface	Reorient product	Insufficient clearance	Precision / Adjustment	High joining forces	Reach below 0,6-1,3 m	Reach beyond 0,4 m	Tool required	Separate subassembly	SCORE / ITEM
1	Wall Rack	1	1		1	1	1		1	1		1	1	1	1	1	1		1			1	1	1	17
2	90-degree bender	1	1		1				1	1			1	1					1				1	1	10
3	Adaptor	1	1		1									1			1						1		6
4	Gate Valve	1	1		1				1	1				1			1		1			1	1	1	11
5	[Double XY]	1	1		1									1									1	1	6
6	Bellows DN100	1	1	1	1			1									1		1			1	1		9
7	Diagnostic Box	1	1	1	1	1			1	1		1	1	1	1		1	1	1			1	1	1	17
8	Adaptor	1	1		1									1			1						1		6
9	Quadrupole Triplet	1	1		1	1				1				1			1		1			1	1		10
10	Double XY	1			1																	1	1	1	5
11	Gate Valve	1	1		1				1	1							1		1			1	1	1	10
12	Bellows DN100	1	1	1	1			1														1	1		7
13	Tube DN100	1		1	1			1	1			1		1					1			1	1		10
14	Extraction Electrode	1			1					1												1	1		5
15	Insulator	1			1					1												1	1		5
16	Adaptor	1			1																	1	1		4
17	Test Ion Source Unit	1			1	1				1			1	1	1				1			1	1	1	11
18																									0
19	Product Maintenance	Access ports and test points not labeled																							0
20		Difficult access to key maintenance areas																							0
21		Cannot see display while adjusting																							0
																								OVERALL SCORE	149

DFMA 1

Ergonomics in Design for Manufacture and Asssembly

Product name: Vertical Transfer Line

Author: Kari Rytkönen

Instructions:
1. List the parts in design order they are assembled.
2.Note the design rules that are violated for each step.
3. Mark each of the violating boxes with "1" and the score will be automatically calculated to "SCORE/ITEM" and "OVERALL SCORE" sells.

Color tells the level of coplexity of assembly:
RED= complex,
YELLOW= average
GREEN= easy

Item no.	SUBASSEMBLY 2, TEST ION SOURCE UNIT Part / Assembly	Separate fastener	Spring or washer	Separate label	Further integration	Needs leads, guides, chamfers	Needs pilot holes	Flexible, slippery or sharp	Can nest or tangle	Slightly assymetrical	Low friction grasping surface	Uncommon fastener	More than one "right" way	Multi-step assembly	Assemled from side	Can´t see mating surface	Reorient product	Insufficient clearance	Precision / Adjustment	High joining forces	Reach below 0,6-1,3 m	Reach beyond 0,4 m	Tool required	Separate subassembly	**SCORE / ITEM**
1	Vacuum Chamber	1	1		1	1			1	1			1	1			1		1				1		11
2	Quadrupole Deflector	1	1			1			1	1			1	1			1		1				1	1	11
3	Diffusion Pump	1	1			1			1	1			1	1			1		1				1	1	11
4	Adaptor A	1	1			1			1	1			1	1			1		1				1		10
5	Adaptor B	1	1			1			1	1			1	1			1		1				1		10
6	Adaptor C	1	1			1			1	1			1	1			1		1				1		10
7	Test Ion Source A	1	1		1	1			1	1			1	1			1		1				1		11
8	Test Ion Source B	1	1		1	1			1	1			1	1			1		1				1	1	12
9	Test Ion Source C	1	1		1	1			1	1			1	1			1		1				1	1	12
10																									0
11																									0
12																									0
13																									0
14																									
15																									0
16																									0
17																									0
18	**Product**	Access ports and test points not labeled																							0
19	**Maintenance**	Difficult access to key maintenance areas																							0
20		Cannot see display while adjusting																							0
																								OVERALL SCORE	98

DFMA 1

Ergonomics in Design for Manufacture and Asssembly

Product name: Vertical Transfer Line

Author: Kari Rytkönen

Instructions:
1. List the parts in design order they are assembled.
2.Note the design rules that are violated for each step.
3. Mark each of the violating boxes with "1" and the score will be automatically calculated to "SCORE/ITEM" and "OVERALL SCORE" sells.

Color tells the level of coplexity of assembly:
RED= complex,
YELLOW= average
GREEN= easy

Item no.	MAIN ASSEMBLY / PART / SUBASSEMBLY	Separate fastener	Spring or washer	Separate label	Further integration	Needs leads, guides, chamfers	Needs pilot holes	Flexible, slippery or sharp	Can nest or tangle	Slightly assymetrical	Low friction grasping surface	Uncommon fastener	More than one "right" way	Multi-step assembly	Assemled from side	Can´t see mating surface	Reorient product	Insufficient clearance	Precision / Adjustment	High joining forces	Reach below 0,6-1,3 m	Reach beyond 0,4 m	Tool required	Separate subassembly	SCORE / ITEM
1	Wall Rack	1	1		1	1	1		1	1		1	1	1	1	1	1		1			1	1	1	17
2	90-degree bender	1	1		1				1	1			1	1					1				1	1	10
3	Adaptor	1	1		1									1			1						1		6
4	Gate Valve	1	1		1				1	1				1			1		1			1	1	1	11
5	[Double XY]	1	1		1									1									1	1	6
6	Bellows DN100	1	1	1	1			1									1		1			1	1		9
7	Diagnostic Box	1	1	1	1	1			1	1		1	1	1	1		1	1	1			1	1	1	17
8	Adaptor	1	1		1									1			1						1		6
9	Quadrupole Triplet	1	1		1	1				1				1			1		1			1	1		10
10	Double XY	1			1																	1	1	1	5
11	Gate Valve	1	1		1				1	1							1		1			1	1	1	10
12	Bellows DN100	1	1	1	1			1														1	1		7
13	Tube DN100	1		1	1			1	1			1		1					1			1	1		10
14	Extraction Electrode	1			1					1												1	1		5
15	Insulator	1			1					1												1	1		5
16	Adaptor	1			1																	1	1		4
17	Test Ion Source Unit	1			1	1				1			1	1	1				1			1	1	1	11
18																									0
19	Product Maintenance	Access ports and test points not labeled																							0
20		Difficult access to key maintenance areas																							0
21		Cannot see display while adjusting																							0
																								OVERALL SCORE	149

DFMA 1

Ergonomics in Design for Manufacture and Asssembly

Product name:		**Author:**
Vertical Transfer Line		**Kari Rytkönen**

Instructions:
1. List the parts in design order they are assembled.
2.Note the design rules that are violated for each step.
3. Mark each of the violating boxes with "1" and the score will be automatically calculated to "SCORE/ITEM" and "OVERALL SCORE" sells.

Color tells the level of coplexity of assembly:
RED= complex,
YELLOW= average
GREEN= easy

Item no.	SUBASSEMBLY 3, DIAGNOSTIC BOX – Part / Assembly	Separate fastener	Spring or washer	Separate label	Further integration	Needs leads, guides, chamfers	Needs pilot holes	Flexible, slippery or sharp	Can nest or tangle	Slightly assymetrical	Low friction grasping surface	Uncommon fastener	More than one "right" way	Multi-step assembly	Assemled from side	Can't see mating surface	Reorient product	Insufficient clearance	Precision / Adjustment	High joining forces	Reach below 0,6-1,3 m	Reach beyond 0,4 m	Tool required	Separate subassembly	**SCORE / ITEM**
1	Vacuum Chamber	1	1	1	1					1			1	1	1		1		1				1	1	12
2	FC-Cup assembly	1	1		1					1			1	1	1		1		1				1	1	11
3	Bellow tube	1		1	1					1		1	1						1				1		8
4	Prepump Edwards XDS-10	1	1	1	1					1			1	1			1		1				1	1	11
5	Turbomolecular pump Edwards	1	1	1	1					1			1	1			1		1				1	1	11
6	Connector	1										1					1		1				1		5
7																									0
8																									0
9																									0
10																									0
11																									0
12																									0
13																									0
14																									0
15																									0
16																									0
17																									0
18	**Product Maintenance**	Access ports and test points not labeled																							0
19		Difficult access to key maintenance areas																							0
20		Cannot see display while adjusting																							0
																								OVERALL SCORE	58

B. DFMA2 ergonomics forms

DFMA2 forms are used to find solution to the problematic issues found on assembly and manufacturing.

List of DFMA2 ergonomics forms:

Ergonomics in DFMA Problem Solving Form

Use this form to identify opportunities for improvement in the product design process

1) Check the design principle is violated
2) Note the specific part that could be improved
3) Briefly note the anticipated improvement
4) Use the form on the reverse side / following page to more develop the recommendations.

Product name: Vertical transfer line Name: Wall support Date: 15.8.2012

DFMA Principle	Violation	Part	Anticipated improvement
Design for stable base			
Minimize reorientation			
Insertion point easy to see and reach			
Decrease need for specialized fixtures			
Insertion of parts			
Decrease ambiguity in part/subassembly orientation			
Design parts with self locking features	V		
Fail-safe Assembly	V		
Minimize part count/levels of assembly			
Minimize levels of assembly			
Minimize number/types of fasteners, cables, etc.			
Modular, interchangeable assemblies			
Self-fastening features			.
Use unique characteristics of the material			
Built-in springs			
Pressed or molded parts			
Injection-molded buttons or signs			
Ergonomics Applications			
Ease of Handling			
Correct tool			
Eliminate special tools			
Avoid "washrag" postures			
Eliminate mechanical pressure			
Comfort zone			
Reach and see access			

Ergonomics in DFMA Problem Solving Form

Use this form to identify opportunities for improvement in the product design process

1) Check the design principle is violated
2) Note the specific part that could be improved
3) Briefly note the anticipated improvement
4) Use the form on the reverse side / following page to more develop the recommendations.

Product name: Vertical transfer line Name: Support frame / Ion Sources Date: 15.8.2012

DFMA Principle	Violation	Part	Anticipated improvement
Design for stable base			
Minimize reorientation			
Insertion point easy to see and reach			
Decrease need for specialized fixtures			
Insertion of parts			
Decrease ambiguity in part/subassembly orientation			
Design parts with self locking features			
Fail-safe Assembly	V		
Minimize part count/levels of assembly			
Minimize levels of assembly			
Minimize number/types of fasteners, cables, etc.			
Modular, interchangeable assemblies			
Self-fastening features			.
Use unique characteristics of the material			
Built-in springs			
Pressed or molded parts			
Injection-molded buttons or signs			
Ergonomics Applications			
Ease of Handling			
Correct tool			
Eliminate special tools			
Avoid "washrag" postures			
Eliminate mechanical pressure			
Comfort zone			
Reach and see access			

Ergonomics in DFMA Problem Solving Form

Use this form to identify opportunities for improvement in the product design process

1) Check the design principle is violated
2) Note the specific part that could be improved
3) Briefly note the anticipated improvement
4) Use the form on the reverse side / following page to more develop the recommendations.

Product name: Vertical transfer line Name: Vertical section, 1st floor Date: 15.8.2012

DFMA Principle	Violation	Part	Anticipated improvement
Design for stable base			
Minimize reorientation			
Insertion point easy to see and reach			
Decrease need for specialized fixtures			
Insertion of parts			
Decrease ambiguity in part/subassembly orientation			
Design parts with self locking features	V		
Fail-safe Assembly	V		
Minimize part count/levels of assembly			
Minimize levels of assembly			
Minimize number/types of fasteners, cables, etc.			
Modular, interchangeable assemblies			
Self-fastening features			.
Use unique characteristics of the material			
Built-in springs			
Pressed or molded parts			
Injection-molded buttons or signs			
Ergonomics Applications			
Ease of Handling			
Correct tool			
Eliminate special tools			
Avoid "washrag" postures			
Eliminate mechanical pressure			
Comfort zone			
Reach and see access			

Ergonomics in DFMA Problem Solving Form

Use this form to identify opportunities for improvement in the product design process

1) Check the design principle is violated
2) Note the specific part that could be improved
3) Briefly note the anticipated improvement
4) Use the form on the reverse side / following page to more develop the recommendations.

Product name: Vertical transfer line Name: Ion source assy, 2nd floor Date: 15.8.2012

DFMA Principle	Violation	Part	Anticipated improvement
Design for stable base			
Minimize reorientation			
Insertion point easy to see and reach			
Decrease need for specialized fixtures			
Insertion of parts			
Decrease ambiguity in part/subassembly orientation			
Design parts with self locking features	V		
Fail-safe Assembly	V		
Minimize part count/levels of assembly			
Minimize levels of assembly			
Minimize number/types of fasteners, cables, etc.			
Modular, interchangeable assemblies			
Self-fastening features			·
Use unique characteristics of the material			
Built-in springs			
Pressed or molded parts			
Injection-molded buttons or signs			
Ergonomics Applications			
Ease of Handling			
Correct tool			
Eliminate special tools			
Avoid "washrag" postures			
Eliminate mechanical pressure			
Comfort zone			
Reach and see access			

Ergonomics in DFMA Problem Solving Form

Use this form to identify opportunities for improvement in the product design process

1) Check the design principle is violated
2) Note the specific part that could be improved
3) Briefly note the anticipated improvement
4) Use the form on the reverse side / following page to more develop the recommendations.

Product name: Vertical transfer line Name: Rack / Diagnostic box Date: 15.8.2012

DFMA Principle	Violation	Part	Anticipated improvement
Design for stable base			
Minimize reorientation			
Insertion point easy to see and reach			
Decrease need for specialized fixtures			
Insertion of parts			
Decrease ambiguity in part/subassembly orientation			
Design parts with self locking features			
Fail-safe Assembly	V		
Minimize part count/levels of assembly			
Minimize levels of assembly			
Minimize number/types of fasteners, cables, etc.			
Modular, interchangeable assemblies			
Self-fastening features			.
Use unique characteristics of the material			
Built-in springs			
Pressed or molded parts			
Injection-molded buttons or signs			
Ergonomics Applications			
Ease of Handling			
Correct tool			
Eliminate special tools			
Avoid "washrag" postures			
Eliminate mechanical pressure			
Comfort zone			
Reach and see access			

Ergonomics in DFMA Problem Solving Form

Use this form to identify opportunities for improvement in the product design process

1) Check the design principle is violated
2) Note the specific part that could be improved
3) Briefly note the anticipated improvement
4) Use the form on the reverse side / following page to more develop the recommendations.

Product name: Vertical transfer line Name: Rack / Vacuum chamber Date: 15.8.2012

DFMA Principle	Violation	Part	Anticipated improvement
Design for stable base			
Minimize reorientation			
Insertion point easy to see and reach			
Decrease need for specialized fixtures			
Insertion of parts			
Decrease ambiguity in part/subassembly orientation			
Design parts with self locking features			
Fail-safe Assembly	V		
Minimize part count/levels of assembly			
Minimize levels of assembly			
Minimize number/types of fasteners, cables, etc.			
Modular, interchangeable assemblies			
Self-fastening features			.
Use unique characteristics of the material			
Built-in springs			
Pressed or molded parts			
Injection-molded buttons or signs			
Ergonomics Applications			
Ease of Handling			
Correct tool			
Eliminate special tools			
Avoid "washrag" postures			
Eliminate mechanical pressure			
Comfort zone			
Reach and see access			

Ergonomics in DFMA Problem Solving Form

Use this form to identify opportunities for improvement in the product design process

1) Check the design principle is violated
2) Note the specific part that could be improved
3) Briefly note the anticipated improvement
4) Use the form on the reverse side / following page to more develop the recommendations.

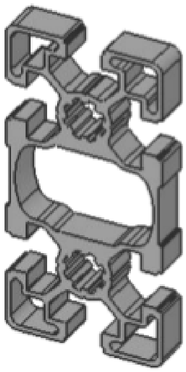
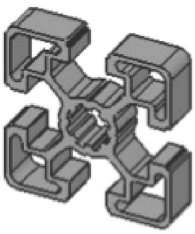
Product name: Vertical transfer line Name: Rack / Quardrupole Triplet Date: 15.8.2012

DFMA Principle	Violation	Part	Anticipated improvement
Design for stable base			
Minimize reorientation			
Insertion point easy to see and reach			
Decrease need for specialized fixtures			
Insertion of parts			
Decrease ambiguity in part/subassembly orientation			
Design parts with self locking features	V		
Fail-safe Assembly			
Minimize part count/levels of assembly			
Minimize levels of assembly			
Minimize number/types of fasteners, cables, etc.			
Modular, interchangeable assemblies			
Self-fastening features			.
Use unique characteristics of the material			
Built-in springs			
Pressed or molded parts			
Injection-molded buttons or signs			
Ergonomics Applications			
Ease of Handling			
Correct tool			
Eliminate special tools			
Avoid "washrag" postures			
Eliminate mechanical pressure			
Comfort zone			
Reach and see access			

C. List of commercial parts

On this list are described all the major components but attaching elements like screws and anchor bolts are not included.

List of commercial small parts for the support system of the vertical transfer line

Product	Article number	Order quantity for vertical support for Ion Source support	Additional information
1. 45 x 90L 	BSB 2796	L=1500 mm 2 pcs. L=1400 mm 2 pcs. L=520 mm 8 pcs. L=500 mm 3 pcs. L_1=360mm 3 pcs. L_2=360 mm 1 pc. L=290 mm 8 pcs.	
2. 45 x 45L 	BSB 4569	L= 590 mm 4 pcs. L=450 mm 2 pcs. L= 285 mm 2 pcs. L= 250 mm 2 pcs. L=130 mm 2 pcs.	
3. 90x90 Connection Angle 45 	WMH 321 120	16 pcs	

4. Cover Cap 90x90 Connection Angle 45 	WMH 321 180	16 pcs.	
5. Central Connector 0˚ 	099B10171000	20 pcs. 16 pcs.	d = 17 mm b = 22.5 mm
6. Central Connector 90˚ 	099B10171090	16 pcs. 16 pcs.	
7. Profile nut PMK-2 		-	
8. Cover Cap 45x90 	WMH 401 060	12 pcs.	

9. Cover Cap 45x45 	WMH 401 020	8 pcs. 4 pcs.	
10. Floor Bracket 175 x 86 x 43 	093W1751RN10		
11. Levelling Feet 	098D080KBZG	8 pcs.	
12. Threaded Rod M10x150 for Swivel Feet 	098DM10150M	8 pcs	

13. Transport and Base Plate 45 x 90 	093T45901008R	8 pcs	
14. Self Tapping Bush M8 	340ME111	8 pcs	

D. Assembly drawings

List of assembly drawings:

1. KR3-A007.01 Vacuum Chamber
2. KR3-A025 6-Cross Chamber Rack
3. KR3-A027 Vacuum Chamber Support Frame
4. KR3-A033 Wall Support Assembly
5. KR3-A034 Vacuum Pump Rack Assembly
6. KR3-A040 Equipment Rack, Quadrupole Triplet
7. KR3-A041 Equipment Rack, Diagnostic Box
8. KR3-A048 Lining tool, assembly
9. KR3-A052 Quide D17 mm, assembly
10. KR3-A061 Ground electrode D30 asssembly
11. KR3-A062 Extractor D30 assembly
12. KR3-A067 Einzel lens assembly
13. KR3-A071 Extractor chamber assembly
14. KR3-A075 6-cross chamber equipment assembly
15. KR3-A078 Dielectric breakdown distance
16. KR3-A080 Support, VAT-valve
17. KR3-A083 Test ion source assembly

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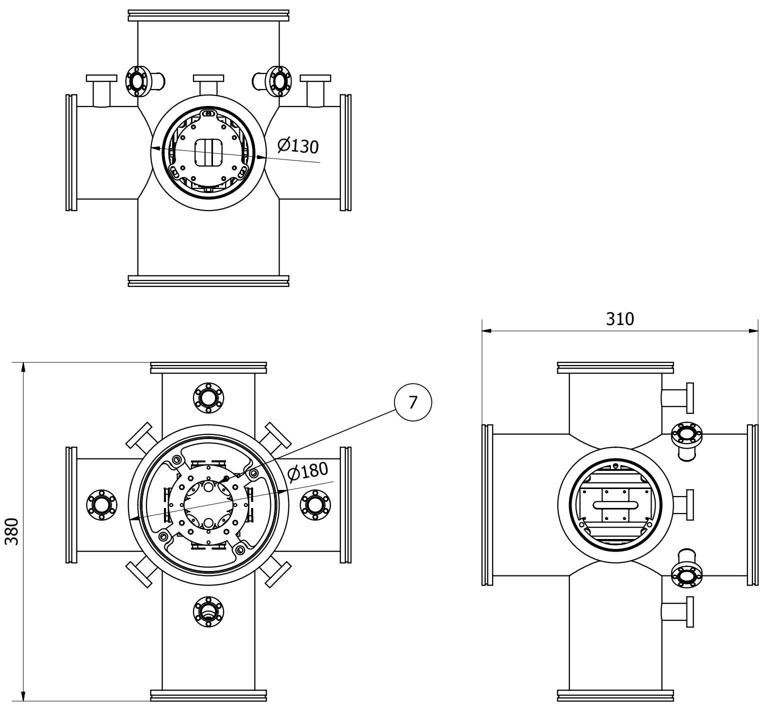
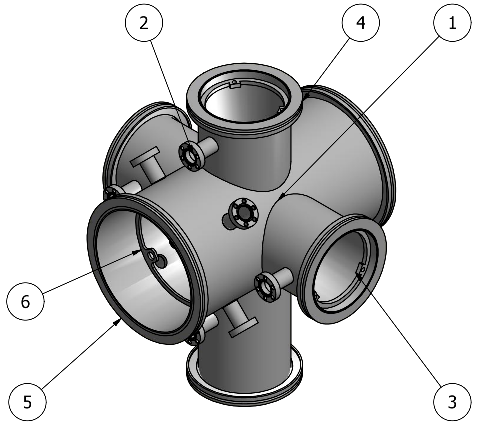
PARTS LIST

ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	Main Chamber	
2	8	CF16 nipple	
3	4	Electrode holder ring	
4	4	DN100ISO-F	DN100ISO-F flange
5	2	DN160ISO-F	DN160ISO-F flange
6	2	Chamber holder, 4 holes x 90 deg.	4-haarakiinnike
7	1	Quadrupole Deflector	Kvadrupolikäännin





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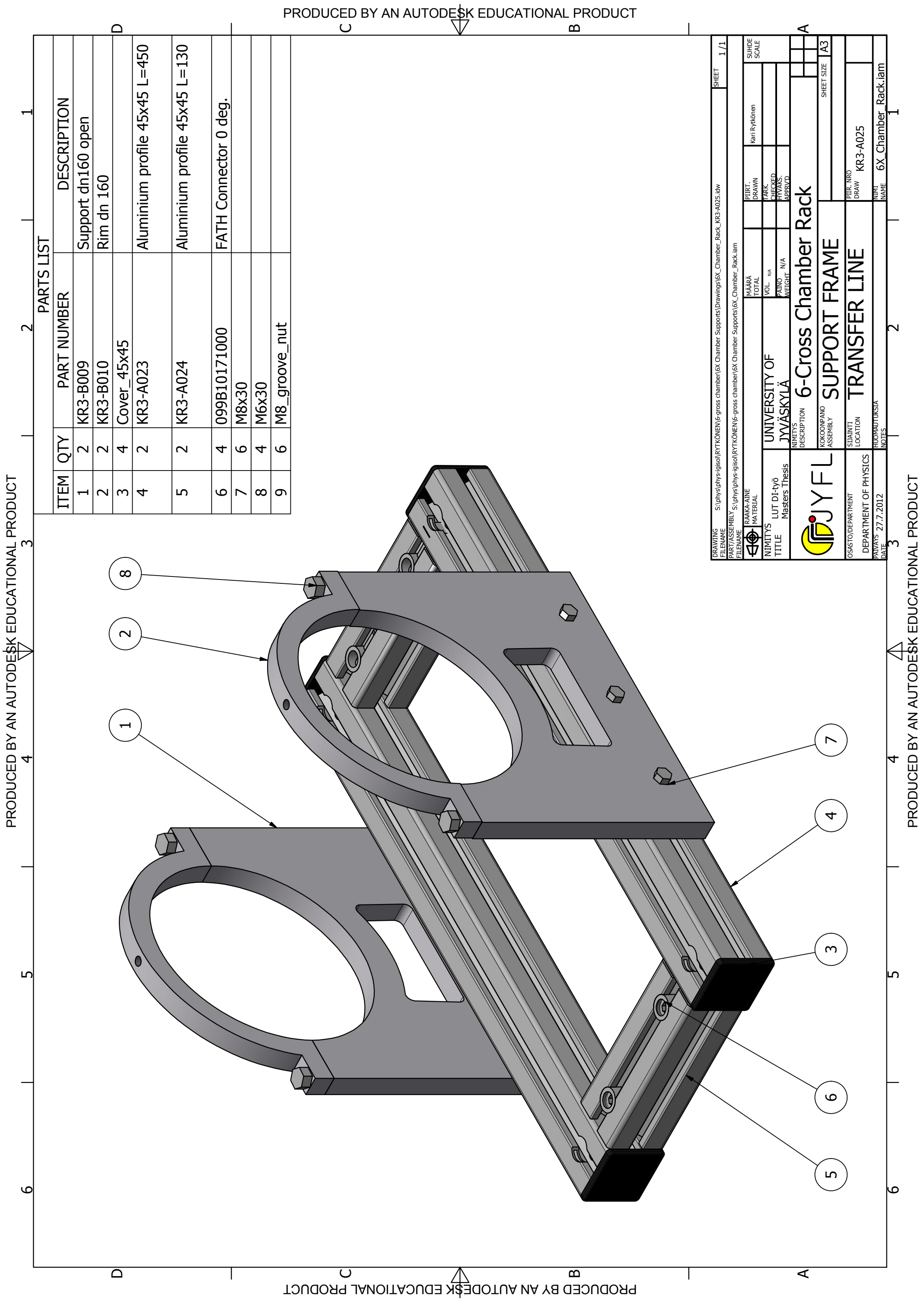
SHEET 1 / 1
PART/ASSEMBLY FILENAME S:\phys\phys-igisol\RYTKÖNEN\6-gross chamber\6-X Chamber Full Assembly.iam
RAAKA-AINE MATERIAL
MÄÄRÄ TOTAL
PIIRT. DRAWN Kari Rytkönen
SUHDE SCALE
NIMITYS TITLE LUT DI-työ Masters Thesis
UNIVERSITY OF JYVÄSKYLÄ
VOL. N/A
PAINO WEIGHT N/A
TARK. CHECKED
HYVÄKS. APPRV'D
JYFL
NIMITYS DESCRIPTION Vacuum Chamber
KOKOONPANO ASSEMBLY TEST ION SOURCES
SHEET SIZE A3
OSASTO/DEPARTMENT DEPARTMENT OF PHYSICS
SIJAINTI LOCATION TRANSFER LINE
PIIR. NRO DRAW KR3-A007
01
PÄIVÄYS DATE 30.7.2012
HUOMAUTUKSIA NOTES
NIMI NAME 6-X Chamber Full Assembly.iam

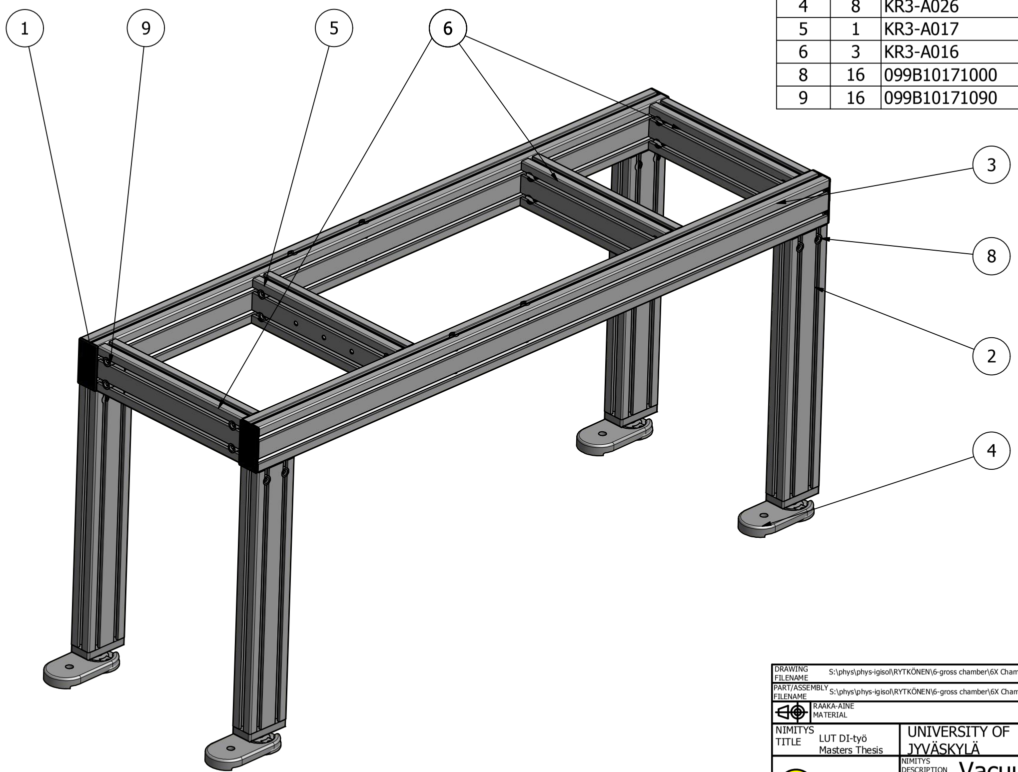


PARTS LIST

ITEM	QTY	PART NUMBER	DESCRIPTION
1	2	KR3-B009	Support dn160 open
2	2	KR3-B010	Rim dn 160
3	4	Cover_45x45	
4	2	KR3-A023	Aluminium profile 45x45 L=450
5	2	KR3-A024	Aluminium profile 45x45 L=130
6	4	099B10171000	FATH Connector 0 deg.
7	6	M8x30	
8	4	M6x30	
9	6	M8_groove_nut	

PARTS LIST

ITEM	QTY	PART NUMBER	DESCRIPTION
1	4	Cover cap 45 x 90	091064
2	8	KR3-A015	Aluminum profile BSB 45 x 90 L
3	2	KR3-A014	Aluminum profile BSB 45 x 90 L
4	8	KR3-A026	Levelling Feet M10 x 150 Assy
5	1	KR3-A017	Aluminium Profile 45 x 90, L=360
6	3	KR3-A016	Aluminium Profile 45 x 90, L=360
8	16	099B10171000	FATH Connector 0 deg.
9	16	099B10171090	FATH Connector 90 deg.



DRAWING FILENAME	S:\phys\phys-igisol\RYTKÖNEN\6-gross chamber\6X Chamber Supports\Drawings\Support _Frame_KR3-A027.idw
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PART/ASSEMBLY FILENAME	S:\phys\phys-igisol\RYTKÖNEN\6-gross chamber\6X Chamber Supports\6X-Chamber_Support.iam
RAAKA-AINE MATERIAL	
MÄÄRÄ TOTAL	
VOL.	N/A
PAINO WEIGHT	N/A
PIIRT. DRAWN	Kari Rytkönen
TARK. CHECKED	
HYVÄKS. APPRV'D	
SUHDE SCALE	
NIMITYS TITLE	LUT DI-työ Masters Thesis
	UNIVERSITY OF JYVÄSKYLÄ
NIMITYS DESCRIPTION	Vacuum Chamber Support Frame
KOKOONPANO ASSEMBLY	TEST ION SOURCES
SHEET SIZE	A3
SIJAINTI LOCATION	TRANSFER LINE
OSASTO/DEPARTMENT	DEPARTMENT OF PHYSICS
PIIR. NRO DRAW	KR3-A027
PÄIVÄYS DATE	31.7.2012
HUOMAUTUKSIA NOTES	
NIMI NAME	6X-Chamber_Support.iam

JYFL

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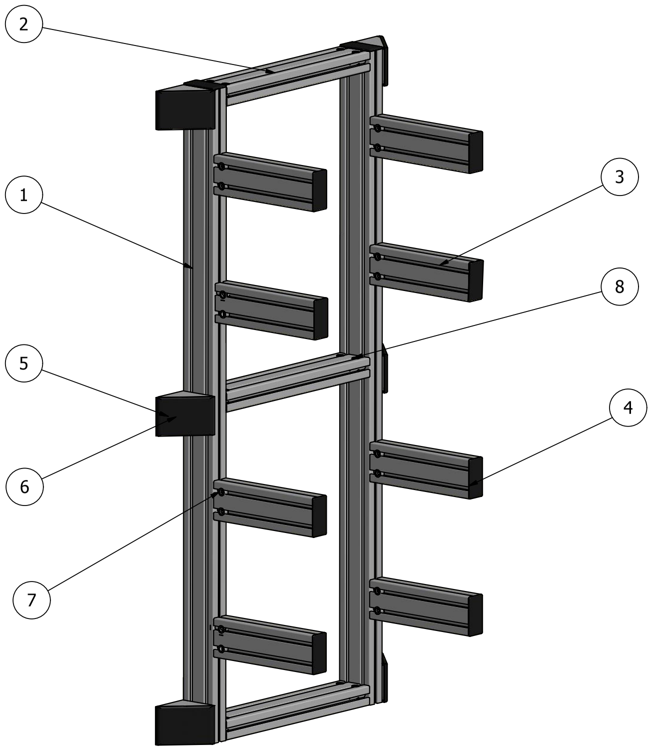
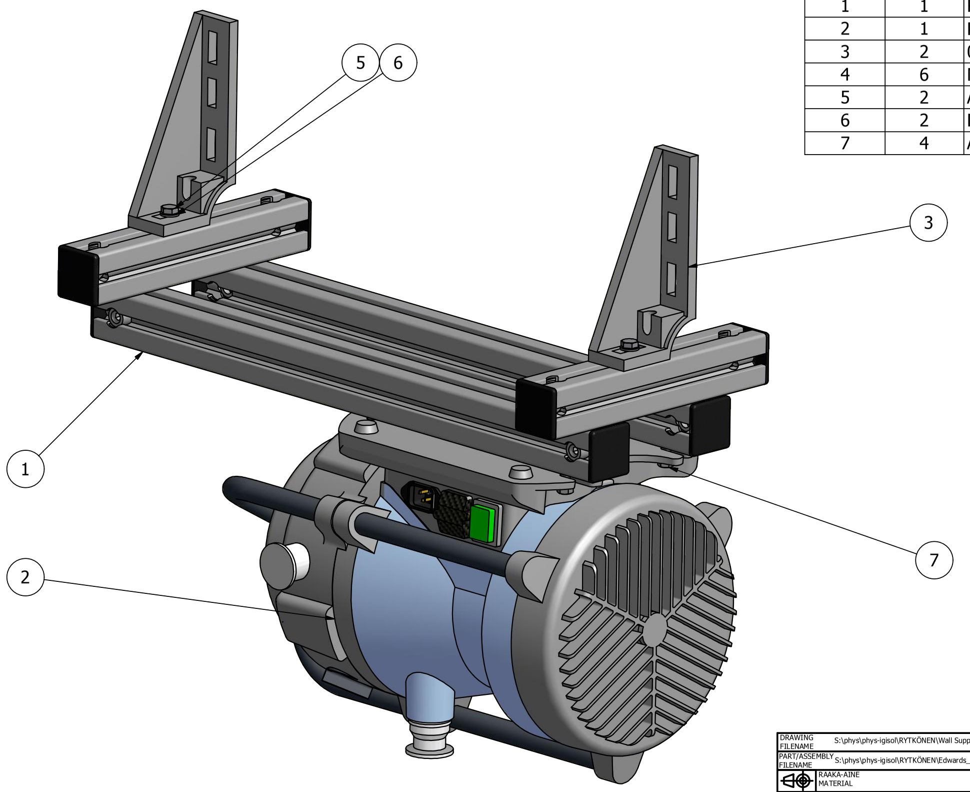


PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	2	KR3-A030	90x45 Al.profile L=1500
2	3	KR3-A031	90x45 Al.profile L=500
3	8	KR3-A032	90x45 Al.profile L=520
4	10	091064	Cover 90x45
5	6	WHM 321 120	Angle Bracket 90x90
6	6	WMH 321 180	Cover for 90x90 Angle Bracket
7	16	099B10171000	FATH Connector 0 deg
8	12	099B10171090	FATH Connector 90 deg

DRAWING FILENAME S:\phys\phys-igisol\RYTKÖNEN\Wall Support parts\Drawings\Wall support assembly KR3-A033.idw
SHEET 1 / 1
PART/ASSEMBLY FILENAME S:\phys\phys-igisol\RYTKÖNEN\Support_vertical_1550x90x45.iam
RAAKA-AINE MATERIAL
MÄÄRÄ TOTAL
PIIRT. DRAWN Kari Rytkönen
SUHDE SCALE
NIMITYS TITLE LUT DI-työ Master's Thesis
UNIVERSITY OF JYVÄSKYLÄ
VOL. N/A
PAINO WEIGHT N/A
TARK. CHECKED
HYVÄKS. APPRV'D
NIMITYS DESCRIPTION Wall support assembly
JYFL
KOKOONPANO ASSEMBLY VERTICAL SUPPORT
SHEET SIZE A3
OSASTO/DEPARTMENT DEPARTMENT OF PHYSICS
SIJAINTI LOCATION TRANSFER LINE
PIIR. NRO DRAW KR3-A033
PÄIVAYS DATE 11.9.2012
HUOMAUTUKSIA NOTES
NIMI NAME Support_vertical_1550x90x45.iam

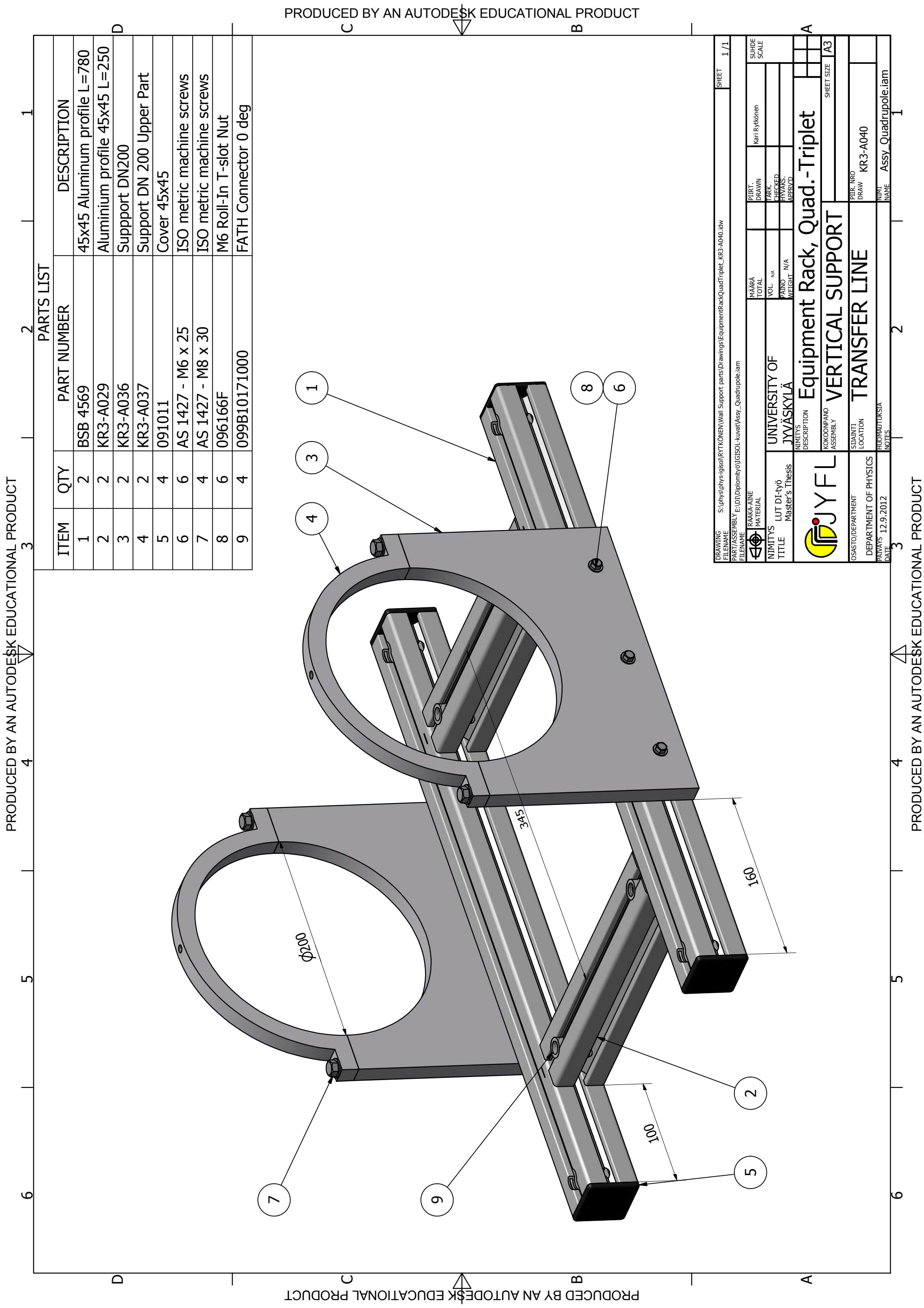
PRODUCED BY AN AUTODESK EDUCATIONAL PRODUCT



PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	KR3-A035	Equipment Rack Assembly
2	1	Pump Edwards XDS 10	Vacuum Scroll Pump
3	2	093W1751RN10	Floor Bracket
4	6	M8_groove_nut	
5	2	AS 1110 - M8 x 25	Bolt
6	2	DIN 125 - A 8,4	Washer
7	4	AS 1427 - M8 x 25	Bolt

DRAWING FILENAME S:\phys\phys-igisol\RYTKÖNEN\Wall Support parts\Drawings\VacPumpRackAssy_KR3-A034.idw
SHEET 1 / 1
PART/ASSEMBLY FILENAME S:\phys\phys-igisol\RYTKÖNEN\Edwards_XDS-10_rack_assy.iam
RAAKA-AINE MATERIAL
MÄÄRÄ TOTAL
PIIRT. DRAWN Kari Rytkönen
SUHDE SCALE
NIMITYS TITLE LUT DI-työ Master's Thesis
UNIVERSITY OF JYVÄSKYLÄ
VOL. N/A
PAINO WEIGHT N/A
TARK. CHECKED
HYVÄKS. APPR'D
JYFL
NIMITYS DESCRIPTION Vacuum Pump Rack Assembly
KOKOONPANO ASSEMBLY VERTICAL SUPPORT
SHEET SIZE A3
OSASTO/DEPARTMENT DEPARTMENT OF PHYSICS
SIJAINTI LOCATION TRANSFER LINE
PIIR. NRO DRAW KR3-A034
PÄIVÄYS DATE 18.7.2012
HUOMAUTUKSIA NOTES
NIMI NAME Edwards_XDS-10_rack_assy.iam

PRODUCED BY AN AUTODESK EDUCATIONAL PRODUCT

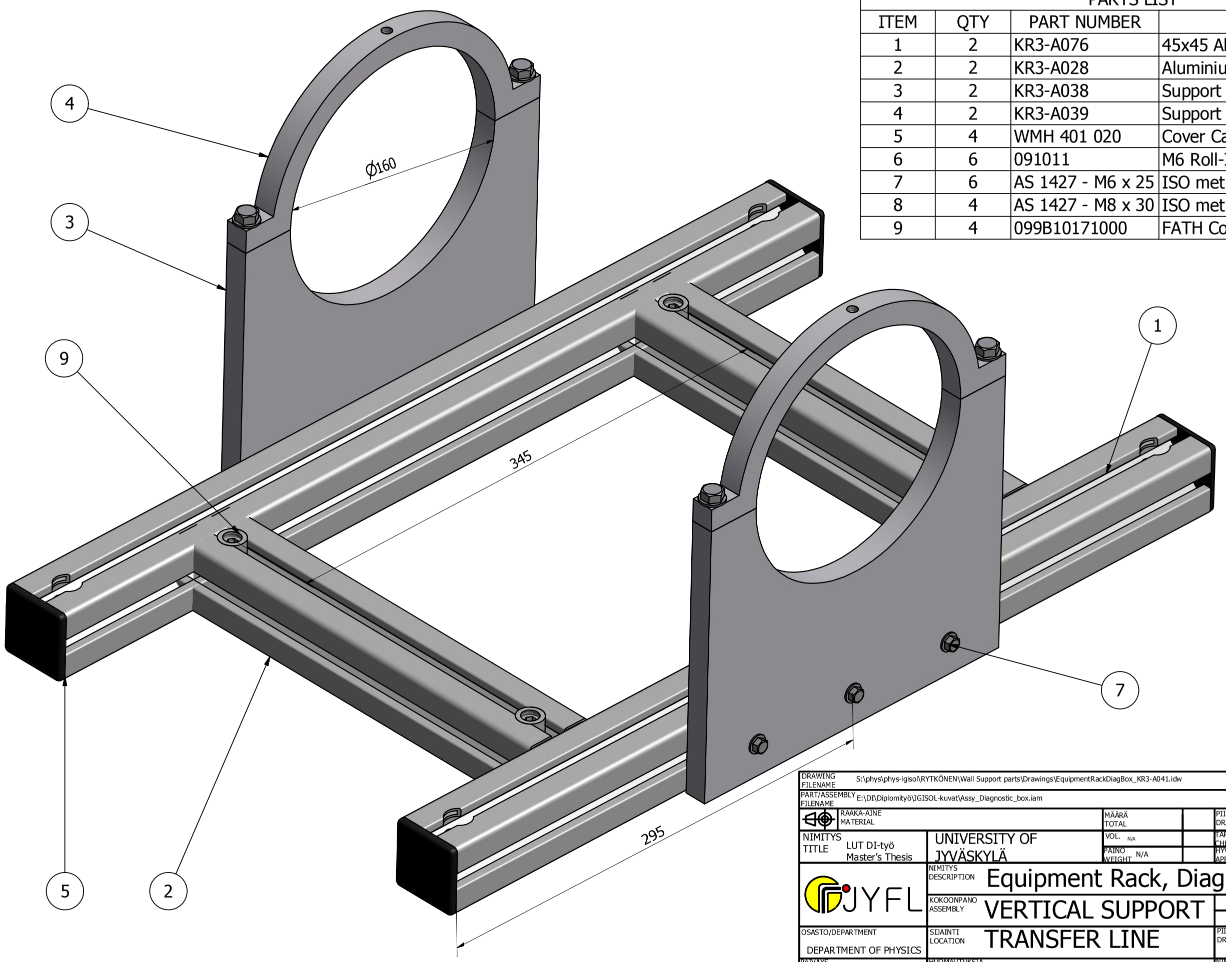


PARTS LIST

ITEM	QTY	PART NUMBER	DESCRIPTION
1	2	BSB 4569	45x45 Aluminum profile L=780
2	2	KR3-A029	Aluminium profile 45x45 L=250
3	2	KR3-A036	Support DN200
4	2	KR3-A037	Support DN 200 Upper Part
5	4	091011	Cover 45x45
6	6	AS 1427 - M6 x 25	ISO metric machine screws
7	4	AS 1427 - M8 x 30	ISO metric machine screws
8	6	096166F	M6 Roll-In T-slot Nut
9	4	099B10171000	FATH Connector 0 deg

PARTS LIST

ITEM	QTY	PART NUMBER	DESCRIPTION
1	2	KR3-A076	45x45 Aluminim profile L=590
2	2	KR3-A028	Aluminium profile 45x45 L=285
3	2	KR3-A038	Support DN160
4	2	KR3-A039	Support DN160, Rim
5	4	WMH 401 020	Cover Cap 45x45
6	6	091011	M6 Roll-In T-slot Nut
7	6	AS 1427 - M6 x 25	ISO metric machine screws
8	4	AS 1427 - M8 x 30	ISO metric machine screws
9	4	099B10171000	FATH Connector 0 deg.



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SHEET 1/1

PART/ASSEMBLY FILENAME E:\DI\Diplomityö\IGISOL-kuvat\Assy_Diagnostic_box.iam

RAAKA-AINE MATERIAL

MÄÄRÄ TOTAL

PIIRT. DRAWN Kari Rytkönen

SUHDE SCALE

NIMITYS TITLE LUT DI-työ Master's Thesis

UNIVERSITY OF JYVÄSKYLÄ

VOL. N/A

PAINO WEIGHT N/A

TARK. CHECKED

HYVÄKS. APPRV'D

JYFL

NIMITYS DESCRIPTION Equipment Rack, Diag.Box

KOKOONPANO ASSEMBLY VERTICAL SUPPORT

SHEET SIZE A3

OSASTO/DEPARTMENT DEPARTMENT OF PHYSICS

SIJAINTI LOCATION TRANSFER LINE

PIIR. NRO DRAW KR3-A041

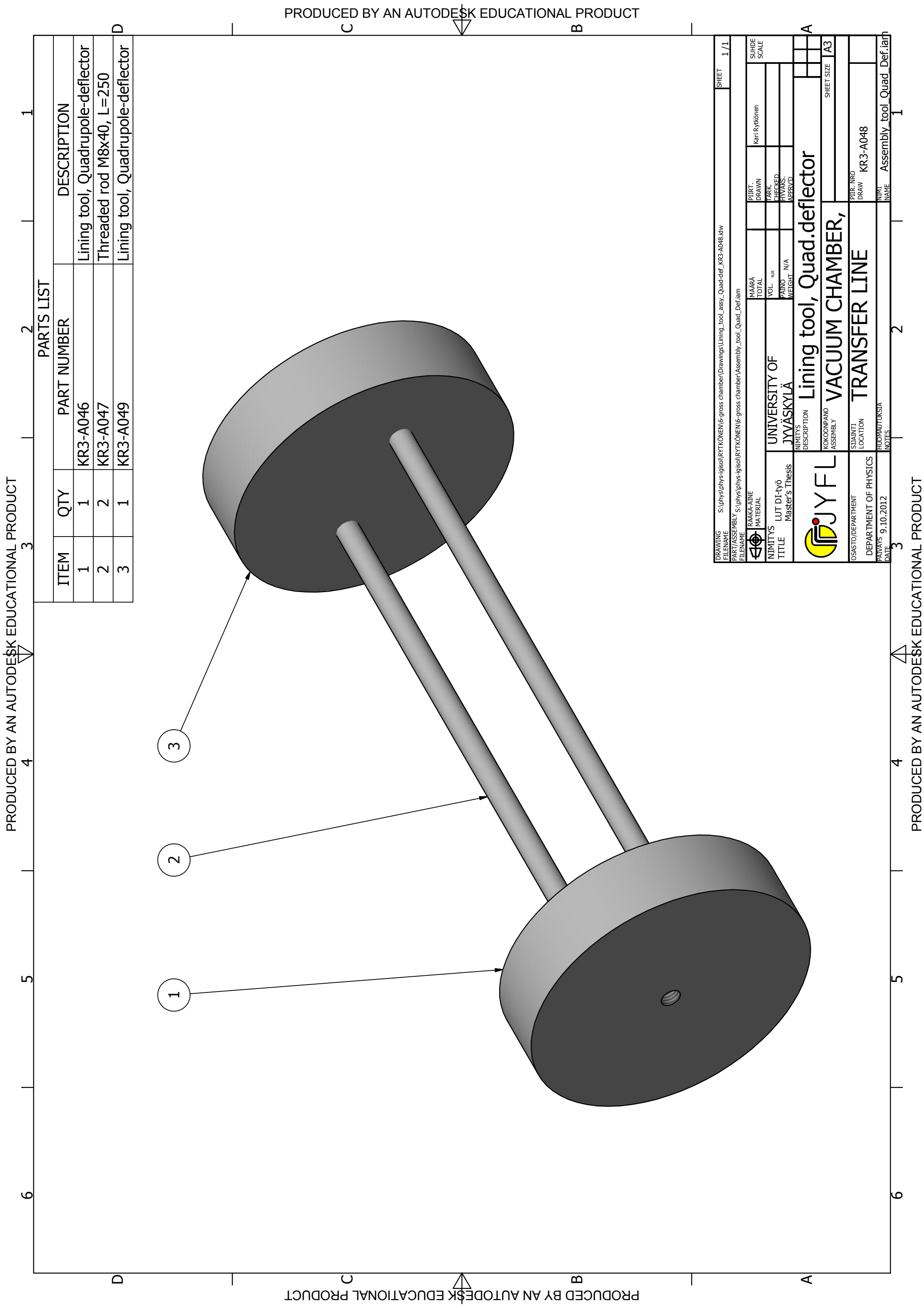
01

PAIVAYS DATE 12.9.2012

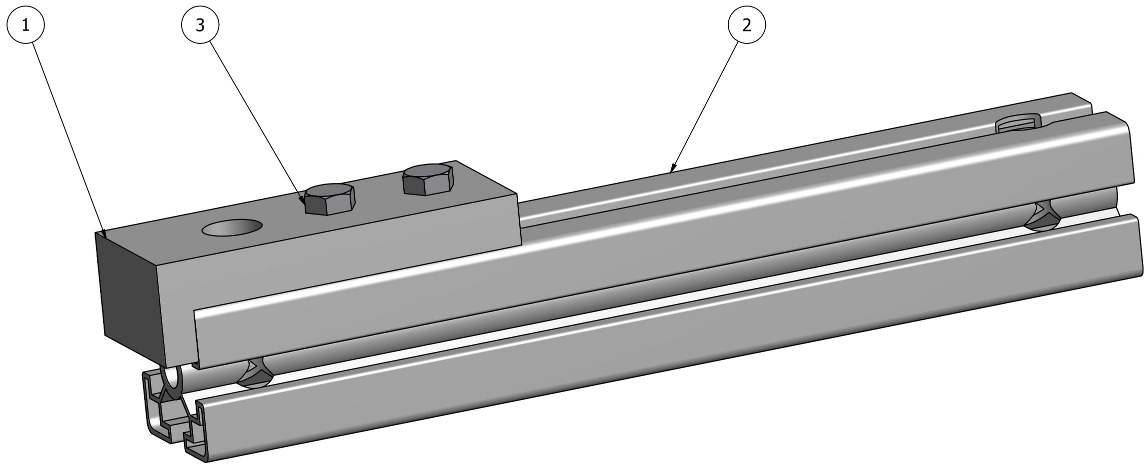
HUOMAUTUKSIA NOTES

NIMI NAME Assy_Diagnostic_box.iam

PRODUCED BY AN AUTODESK EDUCATIONAL PRODUCT


PRODUCED BY AN AUTODESK EDUCATIONAL PRODUCT
PARTS LIST
ITEM | QTY | PART NUMBER | DESCRIPTION
1 | 1 | KR3-A046 | Lining tool, Quadrupole-deflector
2 | 2 | KR3-A047 | Threaded rod M8x40, L=250
3 | 1 | KR3-A049 | Lining tool, Quadrupole-deflector
1
2
3
UNIVERSITY OF JYVÄSKYLÄ
JYFL
LUT DI-työ
Master's Thesis
Lining tool, Quad.deflector
VACUUM CHAMBER,
TRANSFER LINE
DEPARTMENT OF PHYSICS
9.10.2012
KR3-A048
Assembly_tool_Quad_Def.iam
Kari Rytkönen
A3
1/1

PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	KR3-A051	Drilling guide
2	1	KR3-A028	Aluminium profile 45x45 L=285
3	2	DIN 609 - M8 x 28-13	Hexagon Fit Screw
4	2	M8_groove_nut	



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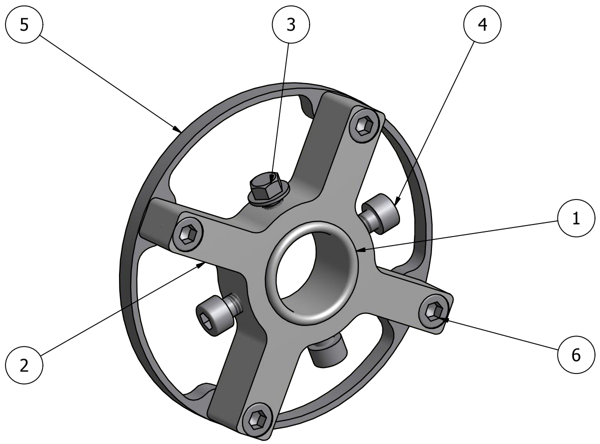
SHEET 1 / 1
PART/ASSEMBLY FILENAME S:\phys\phys-igisol\RYTKÖNEN\generic_parts\FATH-articles\Guide_dia17mm_assembly.iam
RAAKA-AINE MATERIAL
MÄÄRÄ TOTAL
PIIRT. DRAWN Kari Rytkönen
SUHDE SCALE
NIMITYS TITLE LUT DI-työ Master's Thesis
UNIVERSITY OF JYVÄSKYLÄ
VOL. N/A
TARK. CHECKED
PAINO WEIGHT N/A
HYVÄKS. APPRV'D
JYFL
NIMITYS DESCRIPTION Guide Ø17 mm assembly
KOKOONPANO ASSEMBLY DRILLING GUIDE
SHEET SIZE A3
OSASTO/DEPARTMENT DEPARTMENT OF PHYSICS
SIJAINTI LOCATION AL. PROFILE
PIIR. NRO DRAW KR3-A052
PÄIVÄYS DATE 10.10.2012
HUOMAUTUKSIA NOTES
NIMI NAME Guide_dia17mm_assembly.iam

PARTS LIST

ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	KR3-A060	Ground electrode D30, L=20
2	1	Extrator_holder_D30	
3	1	AS 1427 - M6 x 12	Groud connetion
4	3	AS 1420 - 1973 - M6 x 12	Electrode locking screws
5	1	KR3-A044	Ring_dia99_4x90-M6
6	4	AS 1420 - 1973 - M6 x 16	Hexagon socket head cap screws



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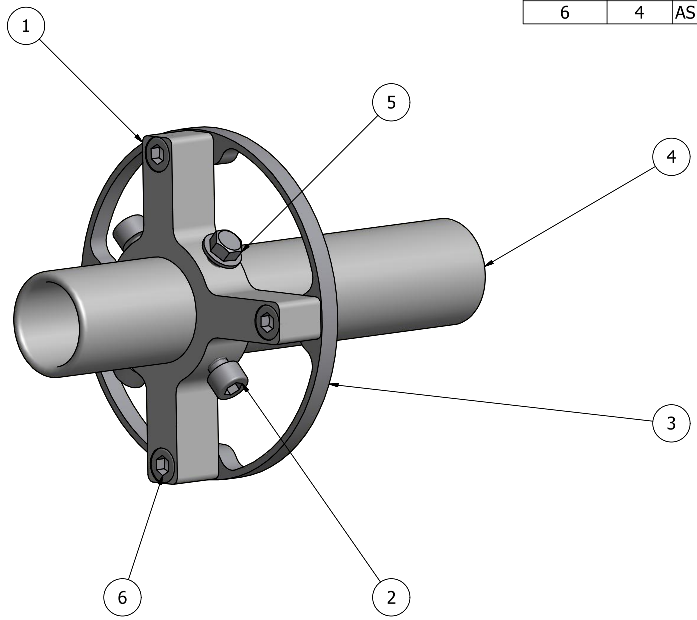
PART/ASSEMBLY FILENAME	S:\phys\phys-igisol\RYTKÖNEN\Extractor\Ground elctrode\Ground_Electrode.iam	
RAAKA-AINE MATERIAL	MÄÄRÄ TOTAL	PIIRT. DRAWN Kari Rytkönen
NIMITYS TITLE LUT DI-työ Master's Thesis	UNIVERSITY OF JYVÄSKYLÄ	VOL. N/A; PAINO WEIGHT N/A; TARK. CHECKED; HYVÄKS. APPRV'D; SUHDE SCALE
JYFL	NIMITYS DESCRIPTION Ground electrode D30 assembly	
	KOKOONPANO ASSEMBLY Vacuum chamber,	SHEET SIZE A3
OSASTO/DEPARTMENT DEPARTMENT OF PHYSICS	SIJAINTI LOCATION Transfer line	PIIR. NRO DRAW KR3-A061
PÄIVAYS DATE 2.11.2012	HUOMAUTUKSIA NOTES	NIMI NAME Ground_Electrode.iam

PARTS LIST

ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	KR3-A056	Extractor holder
2	3	AS 1420 - 1973 - M6 x 12	socket head cap screws
3	1	KR3-A044	Ring_dia99_4x90-M6
4	1	KR3-A055	Extractor D30
5	1	AS 1427 - M6 x 12	screws
6	4	AS 1420 - 1973 - M6 x 16	Hexagon socket head cap screws



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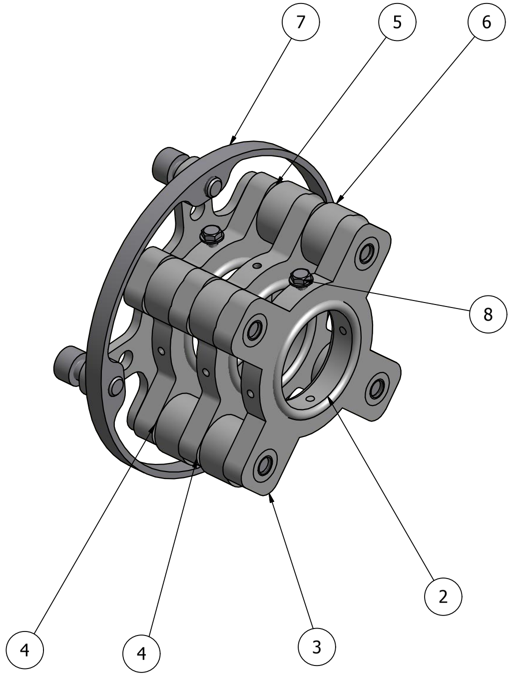
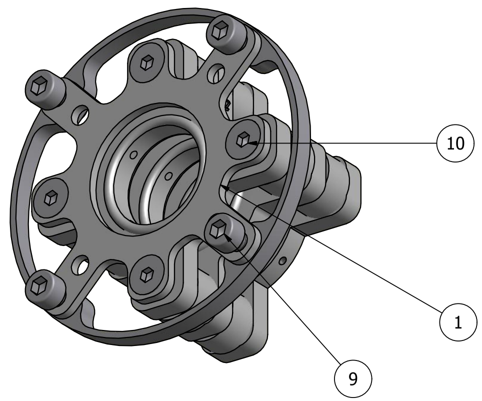
SHEET 1 / 1
PART/ASSEMBLY FILENAME S:\phys\phys-igisol\RYTKÖNEN\Extractor\Extractor_D30_Assy_KR3-A062.iam
RAAKA-AINE MATERIAL
MÄÄRÄ TOTAL
PIIRT. DRAWN Kari Rytkönen
SUHDE SCALE
NIMITYS TITLE LUT DI-työ Master's Thesis
UNIVERSITY OF JYVÄSKYLÄ
VOL. N/A
PAINO WEIGHT N/A
TARK. CHECKED
HYVÄKS. APPRV'D
JYFL
NIMITYS DESCRIPTION Extractor D30_Assembly
KOKOONPANO ASSEMBLY Vacuum chamber,
SHEET SIZE A3
OSASTO/DEPARTMENT DEPARTMENT OF PHYSICS
SIJAINTI LOCATION Transfer line
PIIR. NRO DRAW KR3-A062
PÄIVÄYS DATE 2.11.2012
HUOMAUTUKSIA NOTES
NIMI NAME Extractor_D30_Assy_KR3-A062.iam

PRODUCED BY AN AUTODESK EDUCATIONAL PRODUCT

PARTS LIST

ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	KR3-A066	Chamber holder 4 x 90 deg.
2	3	KR3-A063	Electrode 10 mm
3	1	KR3-A064	Electrode holder D36/M6
4	2	KR3-A065	Electrode Holder D36/D10
5	4	KR3-A053	Insulator Pin 1
6	4	KR3-A054	Insulator Pin 2
7	1	KR3-A044	Ring_dia99_4x90-M6
8	4	AS 1427 - M3 x 8	machine screws
9	4	AS 1420 - 1973 - M6 x 14	Electrode locking screws
10	4	BS 4168 - M6 x 45	Hexagon socket countersunk screws





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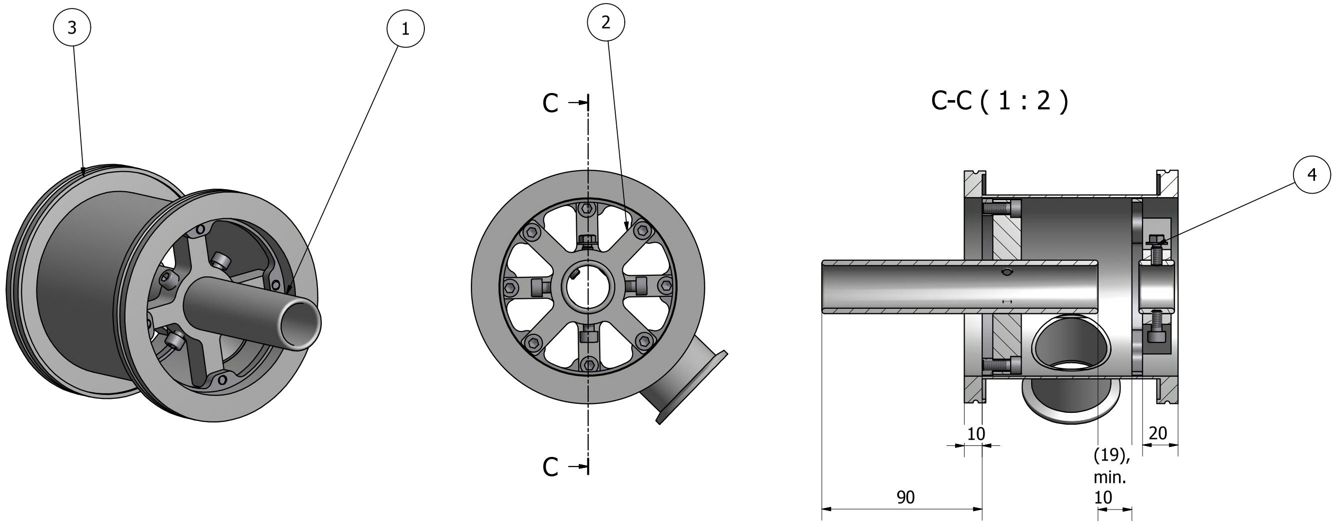
SHEET 1/1
PART/ASSEMBLY FILENAME S:\phys\phys-igisol\RYTKÖNEN\Einzel\Einzel_Assembly.iam
RAAKA-AINE MATERIAL
MÄÄRÄ TOTAL
PIIRT. DRAWN Kari Rytkönen
SUHDE SCALE
NIMITYS TITLE LUT DI-työ Master's Thesis
UNIVERSITY OF JYVÄSKYLÄ
VOL. N/A
PAINO WEIGHT N/A
TARK. CHECKED
HYVÄKS. APPRV'D
JYFL
NIMITYS DESCRIPTION Einzel lens assembly
KOKOONPANO ASSEMBLY Vacuum chamber,
SHEET SIZE A3
OSASTO/DEPARTMENT DEPARTMENT OF PHYSICS
SIJAINTI LOCATION Transfer line
PIIR. NRO DRAW KR3-A067
PÄIVÄYS DATE 6.11.2012
HUOMAUTUKSIA NOTES
NIMI NAME Einzel_Assembly.iam

PARTS LIST

ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	KR3-A062	Extractor D30 assembly
2	1	KR3-A061	Ground electrode D30 assembly
3	1	KR3-A070	Extractor chamber
4			Ground cable connection



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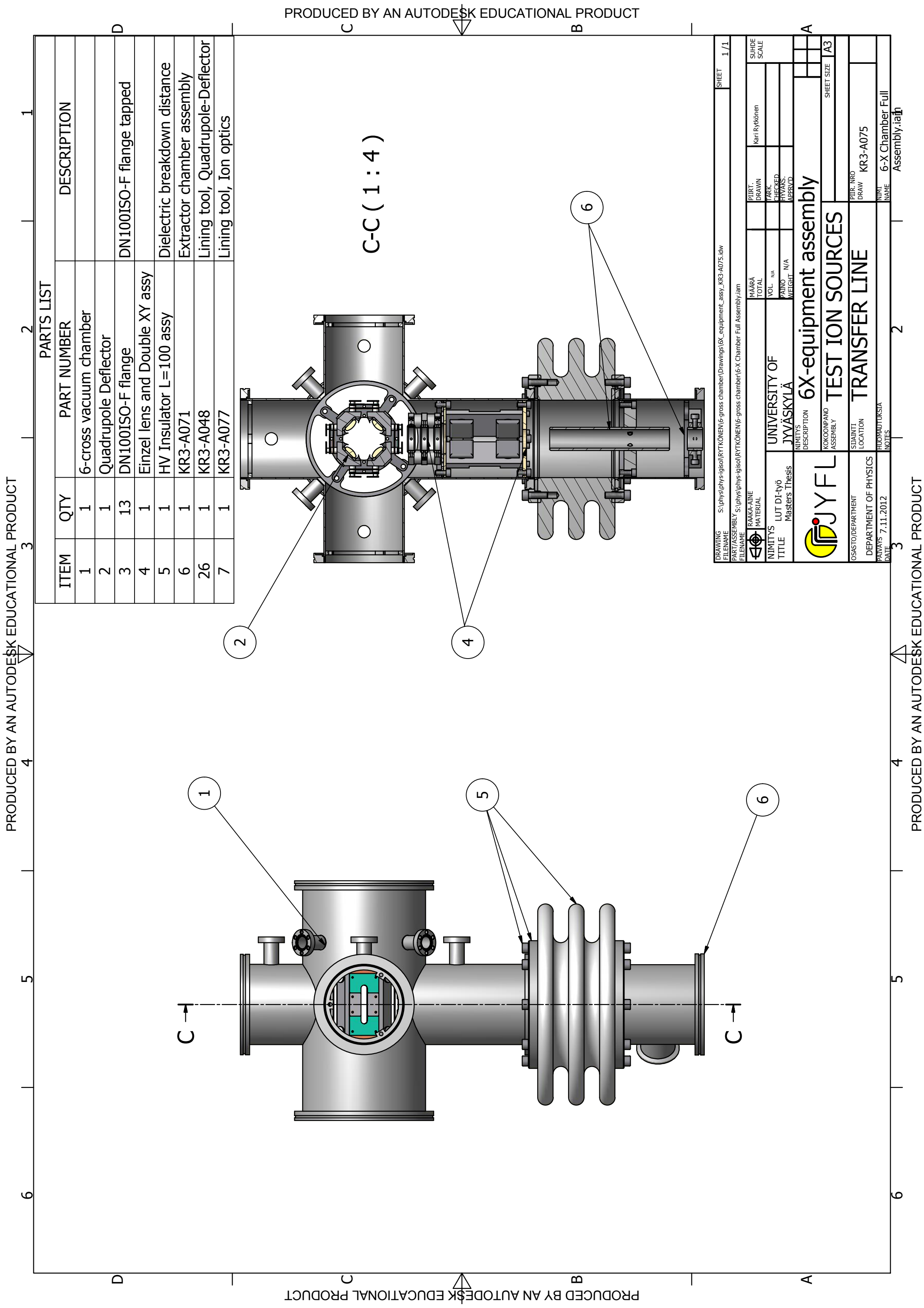
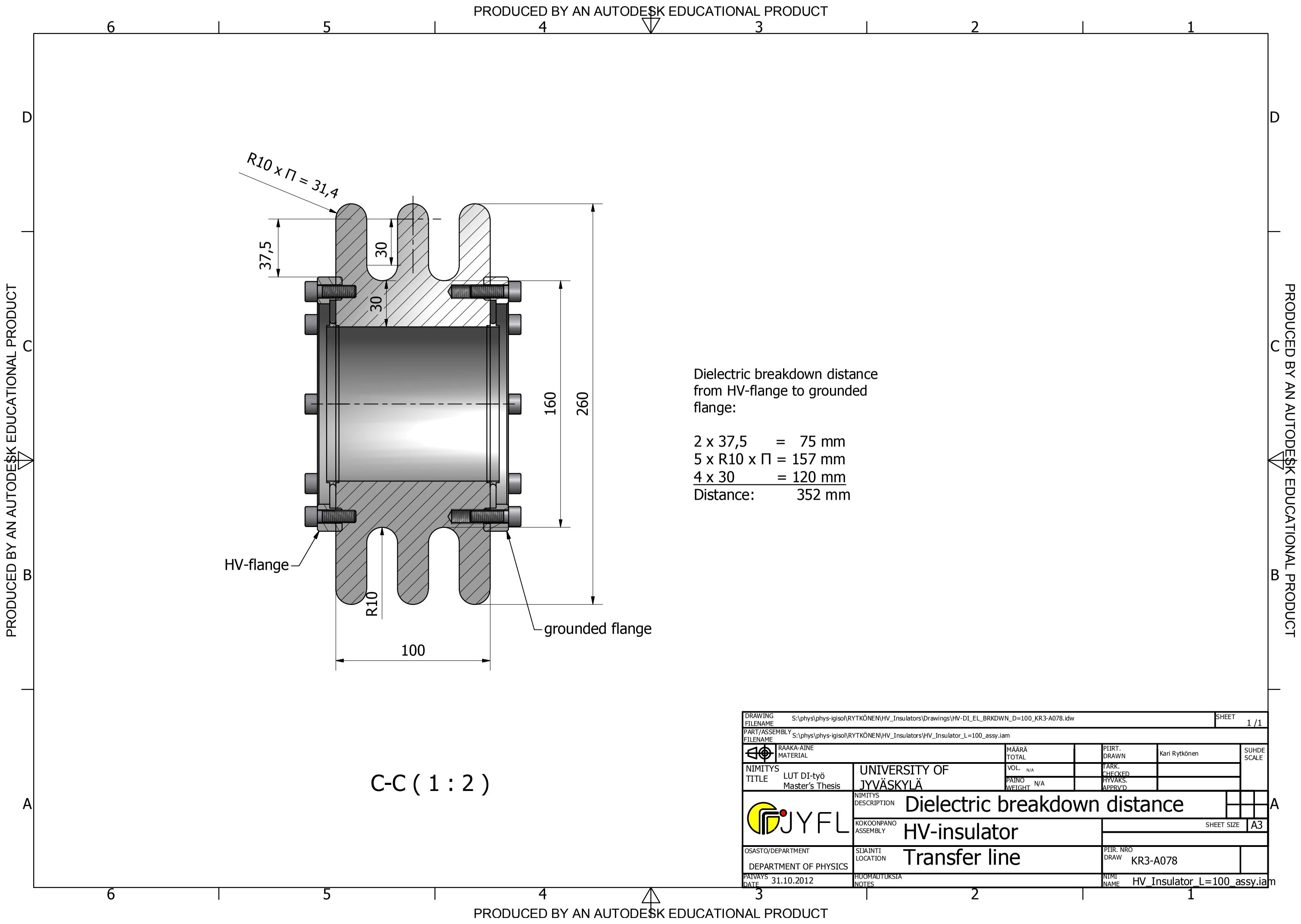
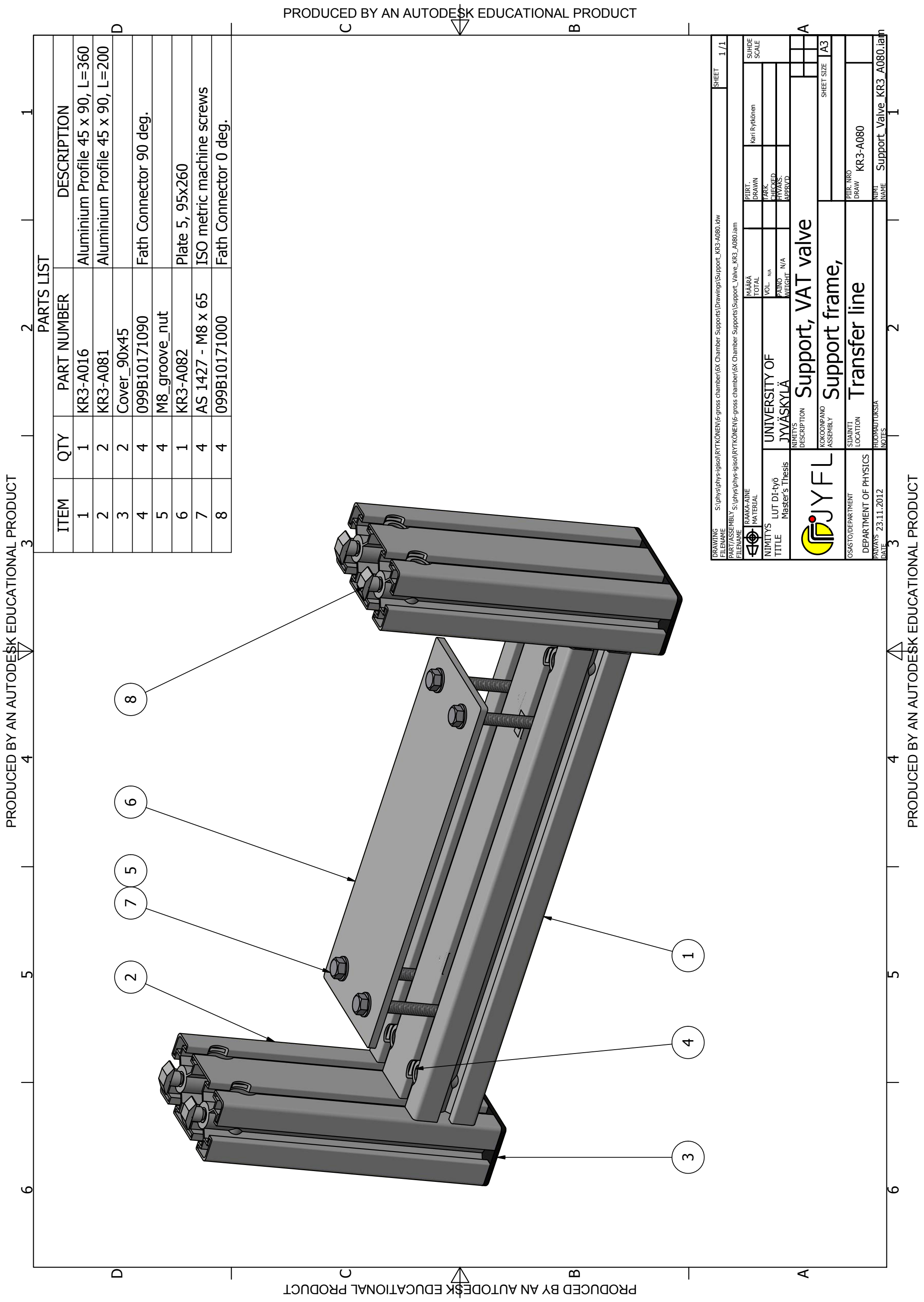
SHEET 1 / 1
PART/ASSEMBLY FILENAME S:\phys\phys-igisol\RYTKÖNEN\Extractor\Extractor_D30_Ground_El_Assy.iam
RAAKA-AINE MATERIAL
MÄÄRÄ TOTAL
PIIRT. DRAWN Kari Rytkönen
SUHDE SCALE
NIMITYS TITLE LUT DI-työ Master's Thesis
UNIVERSITY OF JYVÄSKYLÄ
VOL. N/A
PAINO WEIGHT N/A
TARK. CHECKED
HYVÄKS. APPRV'D
JYFL
NIMITYS DESCRIPTION Extractor chamber assembly
KOKOONPANO ASSEMBLY Vacuum piping,
SHEET SIZE A3
OSASTO/DEPARTMENT DEPARTMENT OF PHYSICS
SIJAINTI LOCATION Transfer line
PIIR. NRO DRAW KR3-A071
PÄIVÄYS DATE 2.11.2012
HUOMAUTUKSIA NOTES
NIMI NAME Extractor_D30_Ground_El_Assy.iam

PRODUCED BY AN AUTODESK EDUCATIONAL PRODUCT



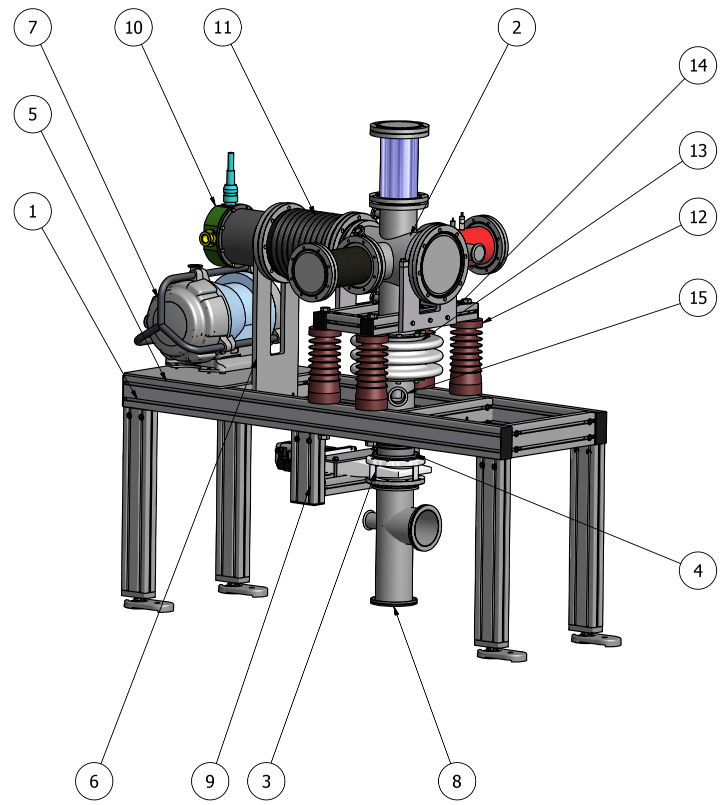
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	6-cross vacuum chamber	
2	1	Quadrupole Deflector	
3	13	DN100ISO-F flange	DN100ISO-F flange tapped
4	1	Einzel lens and Double XY assy	
5	1	HV Insulator L=100 assy	Dielectric breakdown distance
6	1	KR3-A071	Extractor chamber assembly
26	1	KR3-A048	Lining tool, Quadrupole-Deflector
7	1	KR3-A077	Lining tool, Ion optics


PRODUCED BY AN AUTODESK EDUCATIONAL PRODUCT
R10 x Π = 31,4
37,5
30
30
160
260
HV-flange
R10
grounded flange
100
Dielectric breakdown distance from HV-flange to grounded flange:
2 x 37,5 = 75 mm
5 x R10 x Π = 157 mm
4 x 30 = 120 mm
Distance: 352 mm
C-C (1 : 2)
DRAWING FILENAME S:\phys\phys-igisol\RYTKÖNEN\HV_Insulators\Drawings\HV-DI_EL_BRKDWN_D=100_KR3-A078.idw
PART/ASSEMBLY FILENAME S:\phys\phys-igisol\RYTKÖNEN\HV_Insulators\HV_Insulator_L=100_assy.iam
SHEET 1 /1
RAAKA-AINE MATERIAL
MÄÄRÄ TOTAL
PIIRT. DRAWN Kari Rytkönen
SUHDE SCALE
NIMITYS TITLE LUT DI-työ Master's Thesis
UNIVERSITY OF JYVÄSKYLÄ
VOL. N/A
PAINO WEIGHT N/A
TARK. CHECKED
HYVÄKS. APPRV'D
JYFL
NIMITYS DESCRIPTION Dielectric breakdown distance
KOKOONPANO ASSEMBLY HV-insulator
SHEET SIZE A3
OSASTO/DEPARTMENT DEPARTMENT OF PHYSICS
SIJAINTI LOCATION Transfer line
PIIR. NRO DRAW KR3-A078
PÄIVAYS DATE 31.10.2012
HUOMAUTUKSIA NOTES
NIMI NAME HV_Insulator_L=100_assy.iam



PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	KR3-A016	Aluminium Profile 45 x 90, L=360
2	2	KR3-A081	Aluminium Profile 45 x 90, L=200
3	2	Cover_90x45	
4	4	099B10171090	Fath Connector 90 deg.
5	4	M8_groove_nut	
6	1	KR3-A082	Plate 5, 95x260
7	4	AS 1427 - M8 x 65	ISO metric machine screws
8	4	099B10171000	Fath Connector 0 deg.

PRODUCED BY AN AUTODESK EDUCATIONAL PRODUCT



PARTS LIST

ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	KR3-A027	Vacuum Chamber Support Frame
2	1	KR3-A007	Vacuum chamber
3	1	ISOF-100 HV gate valve	
4	1	Bellows DN100	
5	1	KR3-A018	Plate 6mm 360x450
6	1	KR3-B021	Support DN 100
7	1	Pump Edwards XDS 10	Scroll pump
8	1	KR3-A069	Pipe DN100/DN40 L=380
9	1	KR3-A080	Support, VAT valve
10	1	Pump Edwars STP-301	Turbomolecular pump
11	1	KR3-A005	HV-insulator, pump STP-301
12	4	HV-insulator	HV, vacuum chamber rack
13	1	KR3-A059	HV, vacuum chamber
14	1	KR3-A025	Vacuum chamber rack
15	1	KR3-A071	Extractor chamber assembly

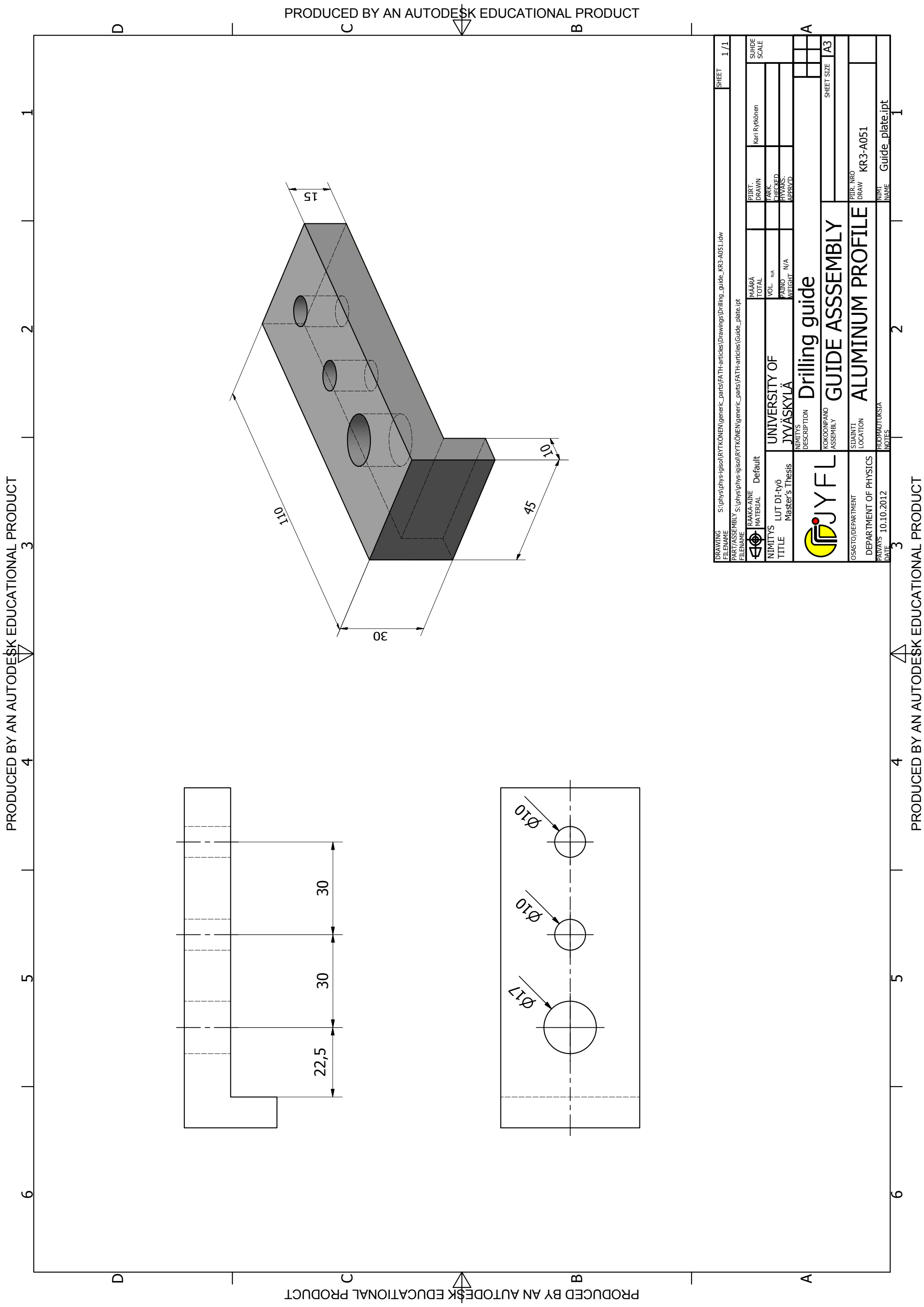
DRAWING FILENAME S:\phys\phys-igisol\RYTKÖNEN\Drawings\Test_ion_source_assy_KR3-A083.idw — SHEET 1/1
PART/ASSEMBLY FILENAME S:\phys\phys-igisol\RYTKÖNEN\2nd_Floor_assy.iam
RAAKA-AINE MATERIAL — MÄÄRÄ TOTAL — PIIRT. DRAWN Katarytk — SUHDE SCALE
NIMITYS TITLE LUT DI-työ Masters Thesis — UNIVERSITY OF JYVÄSKYLÄ — VOL. N/A — PAINO WEIGHT N/A — TARK. CHECKED — HYVÄKS. APPR'D
JYFL — NIMITYS DESCRIPTION Test Ion Source Assembly
KOKOONPANO ASSEMBLY TEST ION SOURCES — SHEET SIZE A3
OSASTO/DEPARTMENT DEPARTMENT OF PHYSICS — SIJAINTI LOCATION 2nd FLOOR — PIIR. NRO DRAW KR3-A083
PÄIVÄYS DATE 3.12.2012 — HUOMAUTUKSIA NOTES — NIMI NAME 2nd_Floor_assy.iam

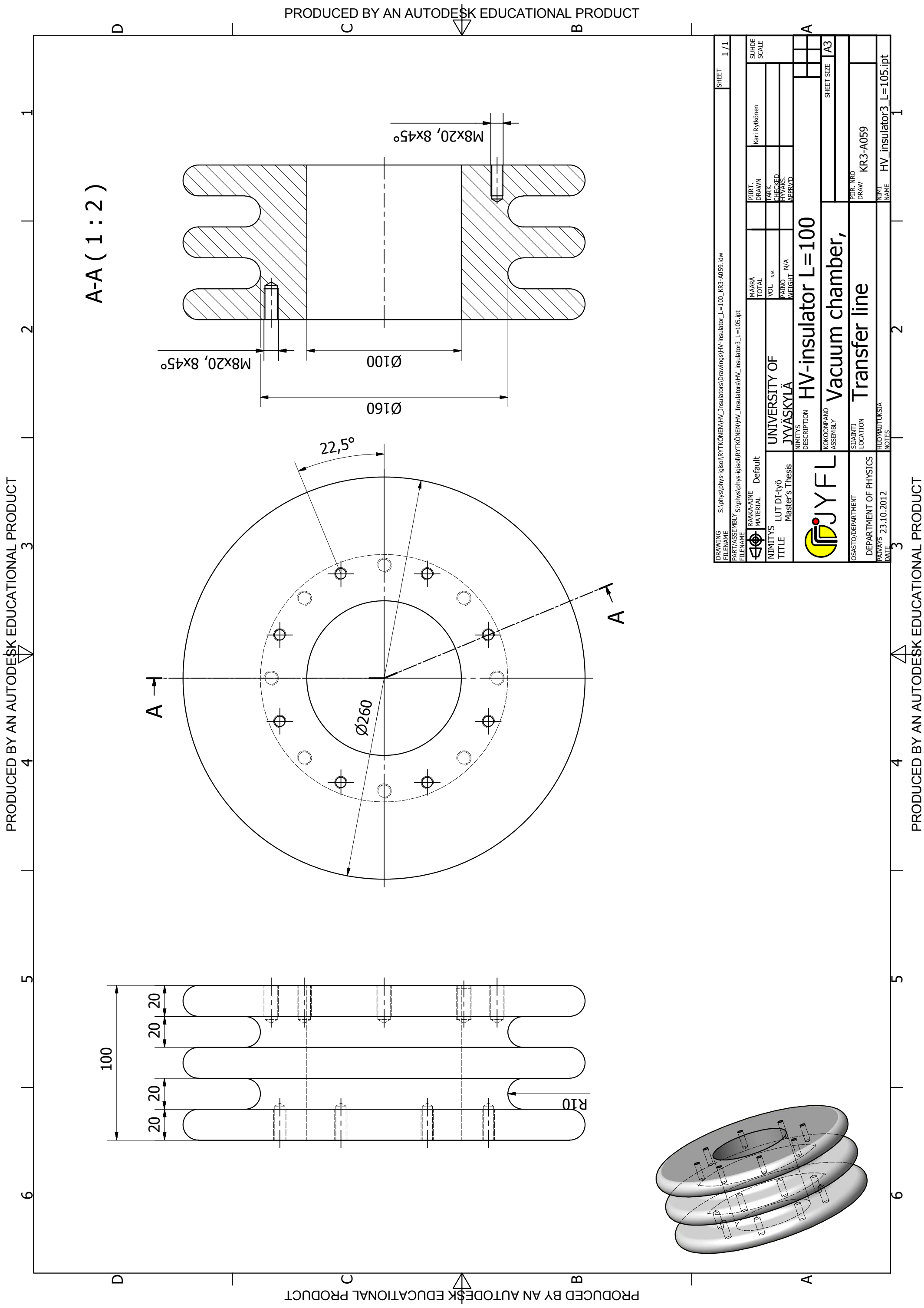
PRODUCED BY AN AUTODESK EDUCATIONAL PRODUCT

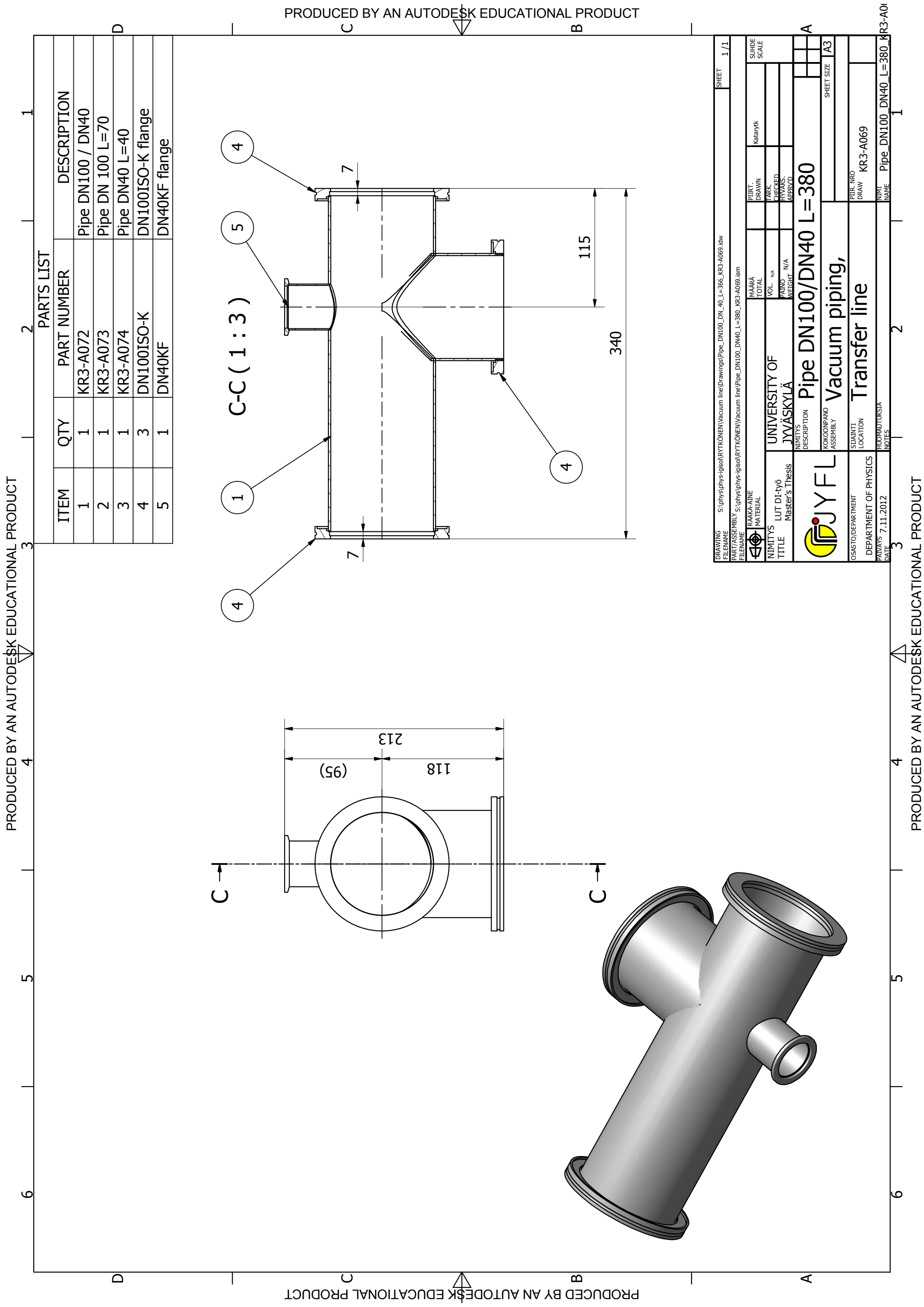
E. Manufacturing drawings

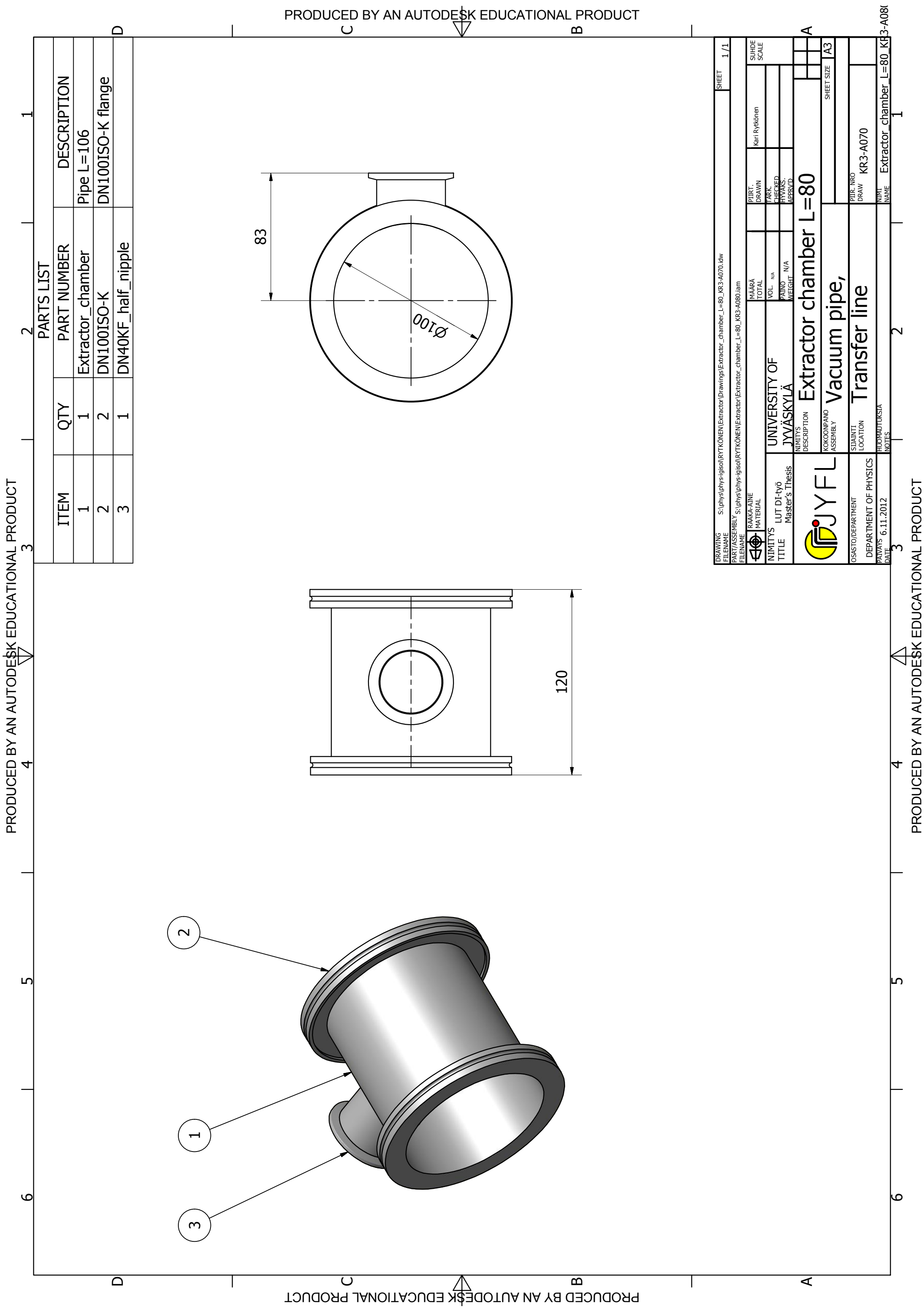
List of manufacturing drawings:

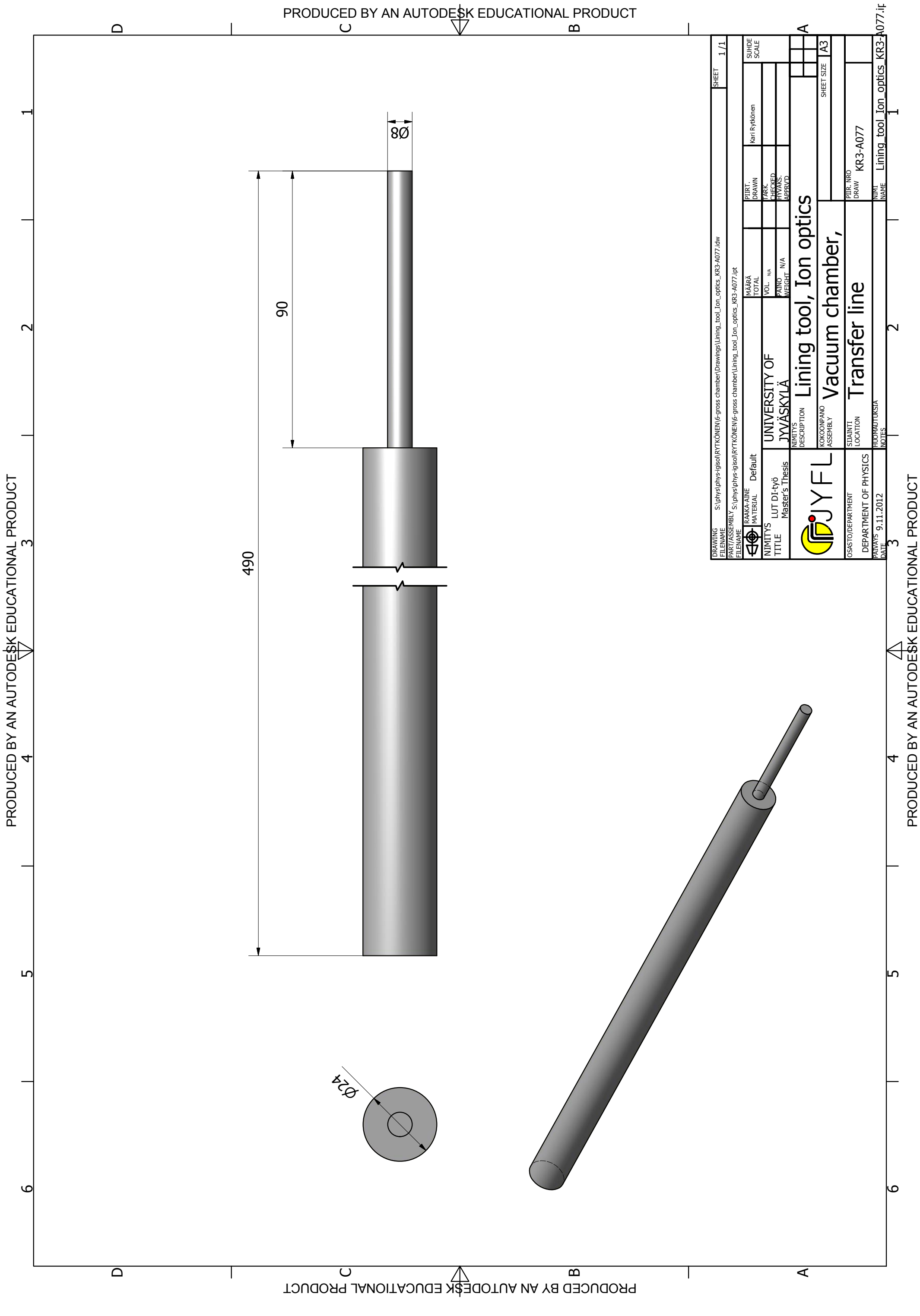
1. KR3-A051 Drilling guide
2. KR3-A059 HV-insulator, L=100
3. KR3-A069 Pipe DN100 L=380
4. KR3-A070 Extractor chamber L=80
5. KR3-A077 Lining tool, ion optics


PRODUCED BY AN AUTODESK EDUCATIONAL PRODUCT
Drilling guide
GUIDE ASSSEMBLY
ALUMINUM PROFILE
UNIVERSITY OF JYVÄSKYLÄ
LUT DI-työ
Master's Thesis
Default
DEPARTMENT OF PHYSICS
10.10.2012
KR3-A051
Guide_plate.ipt
A3
1/1
110
45
30
15
10
30
30
22,5
Ø10
Ø10
Ø17


PRODUCED BY AN AUTODESK EDUCATIONAL PRODUCT
A-A (1 : 2)
M8x20, 8x45°
Ø100
Ø160
22,5°
Ø260
A
100
20
R10
UNIVERSITY OF JYVÄSKYLÄ
HV-insulator L=100
Vacuum chamber,
Transfer line
JYFL
DEPARTMENT OF PHYSICS
23.10.2012
LUT DI-työ
Master's Thesis
Default
Kari Rytkönen
KR3-A059
HV_insulator3_L=105.ipt
A3
1/1


PRODUCED BY AN AUTODESK EDUCATIONAL PRODUCT
PARTS LIST
ITEM | QTY | PART NUMBER | DESCRIPTION
1 | 1 | KR3-A072 | Pipe DN100 / DN40
2 | 1 | KR3-A073 | Pipe DN 100 L=70
3 | 1 | KR3-A074 | Pipe DN40 L=40
4 | 3 | DN100ISO-K | DN100ISO-K flange
5 | 1 | DN40KF | DN40KF flange
C-C (1 : 3)
7
115
340
213
(95)
118
C
UNIVERSITY OF JYVÄSKYLÄ
LUT DI-työ Master's Thesis
Pipe DN100/DN40 L=380
Vacuum piping, Transfer line
DEPARTMENT OF PHYSICS
7.11.2012
Katarzyk
KR3-A069
A3
1 / 1


PRODUCED BY AN AUTODESK EDUCATIONAL PRODUCT
PARTS LIST
ITEM | QTY | PART NUMBER | DESCRIPTION
1 | 1 | Extractor_chamber | Pipe L=106
2 | 2 | DN100ISO-K | DN100ISO-K flange
3 | 1 | DN40KF_half_nipple
83
Ø100
120
UNIVERSITY OF JYVÄSKYLÄ
LUT DI-työ Master's Thesis
Extractor chamber L=80
Vacuum pipe,
Transfer line
DEPARTMENT OF PHYSICS
6.11.2012
Kari Rytkönen
KR3-A070
A3
1/1
Extractor_chamber_L=80_KR3-A080


PRODUCED BY AN AUTODESK EDUCATIONAL PRODUCT
Ø8
90
490
Ø24
Lining tool, Ion optics
Vacuum chamber,
Transfer line
UNIVERSITY OF
JYVÄSKYLÄ
LUT DI-työ
Master's Thesis
Default
JYFL
DEPARTMENT OF PHYSICS
9.11.2012
Kari Rytkönen
KR3-A077
Lining_tool_Ion_optics_KR3-A077.ip
A3
1/1

F. Ion optical simulation

Datasheets 1-8 includes the coordinates of the distripution of 500 particles of the ion beam simulation, perpendicular to the ion beam of flight.

Data sheet 1: Particles 1-64

Data sheet 2: Particles 65-128

Data sheet 3: Particles 196-192

Data sheet 4: Particles 193-256

Data sheet 5: Particles 257-320

Data sheet 6: Particles 321-384

Data sheet 7: Particles 385-448

Data sheet 8: Particles 449-500

Particle	X	Hit Y=	Z	X - 50	Z - 25
1	52,1502	-384	22,1211	2,1502	-2,8789
2	48,1186	-384	23,9962	-1,8814	-1,0038
3	49,192	-384	24,0051	-0,808	-0,9949
4	48,9286	-384	24,0501	-1,0714	-0,9499
5	50,616	-384	24,3949	0,616	-0,6051
6	51,3583	-384	24,9461	1,3583	-0,0539
7	49,7583	-384	24,6916	-0,2417	-0,3084
8	49,4418	-384	20,8943	-0,5582	-4,1057
9	49,0201	-384	21,9975	-0,9799	-3,0025
10	48,8214	-384	20,982	-1,1786	-4,018
11	51,6448	-384	21,7704	1,6448	-3,2296
12	50,1441	-384	23,3313	0,1441	-1,6687
13	49,963	-384	21,0146	-0,037	-3,9854
14	49,0752	-384	23,5855	-0,9248	-1,4145
15	48,5399	-384	23,469	-1,4601	-1,531
16	49,3188	-384	23,204	-0,6812	-1,796
17	47,9396	-384	22,1227	-2,0604	-2,8773
18	50,5727	-384	25,3074	0,5727	0,3074
19	47,978	-384	22,9728	-2,022	-2,0272
20	52,3106	-384	21,6488	2,3106	-3,3512
21	48,9691	-384	20,8892	-1,0309	-4,1108
22	50,2252	-384	24,6467	0,2252	-0,3533
23	49,1522	-384	23,2859	-0,8478	-1,7141
24	52,0454	-384	24,391	2,0454	-0,609
25	49,2545	-384	23,5761	-0,7455	-1,4239
26	48,215	-384	23,6288	-1,785	-1,3712
27	48,1744	-384	24,0879	-1,8256	-0,9121
28	51,9493	-384	24,189	1,9493	-0,811
29	48,2829	-384	24,0953	-1,7171	-0,9047
30	52,4348	-384	23,7039	2,4348	-1,2961
31	49,7815	-384	21,931	-0,2185	-3,069
32	50,7004	-384	22,2879	0,7004	-2,7121
33	49,4465	-384	24,706	-0,5535	-0,294
34	52,68	-384	22,8124	2,68	-2,1876
35	48,0569	-384	22,8058	-1,9431	-2,1942
36	48,1045	-384	24,2627	-1,8955	-0,7373
37	49,218	-384	23,3481	-0,782	-1,6519
38	50,3676	-384	25,1436	0,3676	0,1436
39	51,4408	-384	24,0513	1,4408	-0,9487
40	49,554	-384	23,5055	-0,446	-1,4945
41	49,0637	-384	22,5299	-0,9363	-2,4701
42	48,1823	-384	23,6642	-1,8177	-1,3358
43	50,7304	-384	23,0476	0,7304	-1,9524
44	48,9636	-384	25,0931	-1,0364	0,0931
45	48,1758	-384	22,9132	-1,8242	-2,0868
46	48,8891	-384	21,3066	-1,1109	-3,6934
47	50,9892	-384	21,3905	0,9892	-3,6095
48	52,9947	-384	24,2137	2,9947	-0,7863
49	49,125	-384	21,5319	-0,875	-3,4681
50	50,5971	-384	25,5879	0,5971	0,5879
51	48,1482	-384	23,4154	-1,8518	-1,5846
52	49,5801	-384	23,3863	-0,4199	-1,6137
53	49,5153	-384	25,4283	-0,4847	0,4283
54	47,9192	-384	23,1251	-2,0808	-1,8749
55	51,0134	-384	22,3678	1,0134	-2,6322
56	50,7439	-384	23,7182	0,7439	-1,2818
57	48,0817	-384	24,1796	-1,9183	-0,8204
58	49,4783	-384	25,0643	-0,5217	0,0643
59	52,7203	-384	23,1638	2,7203	-1,8362
60	49,3034	-384	21,3597	-0,6966	-3,6403
61	51,3922	-384	22,3556	1,3922	-2,6444
62	49,8533	-384	23,6856	-0,1467	-1,3144
63	48,0641	-384	24,2549	-1,9359	-0,7451
64	49,5683	-384	23,2163	-0,4317	-1,7837

Particle	X	Hit Y=	Z	X - 50	Z - 25
65	50,6017	-384	22,1885	0,6017	-2,8115
66	49,3984	-384	24,0472	-0,6016	-0,9528
67	48,5215	-384	22,644	-1,4785	-2,356
68	51,0178	-384	21,7137	1,0178	-3,2863
69	48,1223	-384	21,8798	-1,8777	-3,1202
70	48,9228	-384	21,5903	-1,0772	-3,4097
71	48,2674	-384	23,3055	-1,7326	-1,6945
72	51,6964	-384	24,902	1,6964	-0,098
73	51,4327	-384	25,1214	1,4327	0,1214
74	53,0577	-384	24,2683	3,0577	-0,7317
75	48,8011	-384	21,191	-1,1989	-3,809
76	49,1549	-384	24,1932	-0,8451	-0,8068
77	52,4277	-384	22,4258	2,4277	-2,5742
78	49,2193	-384	24,166	-0,7807	-0,834
79	51,4727	-384	24,7273	1,4727	-0,2727
80	48,0242	-384	23,6339	-1,9758	-1,3661
81	48,226	-384	24,2228	-1,774	-0,7772
82	51,4229	-384	22,7843	1,4229	-2,2157
83	48,0483	-384	23,7671	-1,9517	-1,2329
84	52,9008	-384	24,2863	2,9008	-0,7137
85	50,4283	-384	21,5386	0,4283	-3,4614
86	50,6879	-384	22,049	0,6879	-2,951
87	48,2319	-384	25,1059	-1,7681	0,1059
88	47,9951	-384	21,8957	-2,0049	-3,1043
89	48,7511	-384	22,8263	-1,2489	-2,1737
90	49,2223	-384	23,5259	-0,7777	-1,4741
91	52,3567	-384	21,9503	2,3567	-3,0497
92	48,4857	-384	23,4566	-1,5143	-1,5434
93	50,2441	-384	23,4801	0,2441	-1,5199
94	48,1736	-384	24,0365	-1,8264	-0,9635
95	51,6799	-384	22,4483	1,6799	-2,5517
96	49,5605	-384	22,9395	-0,4395	-2,0605
97	48,9931	-384	25,4637	-1,0069	0,4637
98	50,2816	-384	24,3626	0,2816	-0,6374
99	49,2287	-384	24,2547	-0,7713	-0,7453
100	50,107	-384	23,3091	0,107	-1,6909
101	50,8174	-384	24,6692	0,8174	-0,3308
102	52,138	-384	23,3635	2,138	-1,6365
103	47,905	-384	22,3258	-2,095	-2,6742
104	50,8846	-384	22,1433	0,8846	-2,8567
105	50,462	-384	21,4079	0,462	-3,5921
106	49,5598	-384	22,0718	-0,4402	-2,9282
107	48,0942	-384	21,359	-1,9058	-3,641
108	49,1946	-384	24,565	-0,8054	-0,435
109	49,3803	-384	23,7227	-0,6197	-1,2773
110	49,2381	-384	25,3702	-0,7619	0,3702
111	48,895	-384	25,4908	-1,105	0,4908
112	49,3066	-384	22,9549	-0,6934	-2,0451
113	50,3462	-384	25,3969	0,3462	0,3969
114	48,1608	-384	22,8073	-1,8392	-2,1927
115	50,2343	-384	23,1994	0,2343	-1,8006
116	49,0195	-384	21,5475	-0,9805	-3,4525
117	48,129	-384	22,3314	-1,871	-2,6686
118	48,653	-384	25,2525	-1,347	0,2525
119	51,3009	-384	24,4506	1,3009	-0,5494
120	49,3983	-384	24,4936	-0,6017	-0,5064
121	49,5469	-384	25,5182	-0,4531	0,5182
122	48,2175	-384	23,1509	-1,7825	-1,8491
123	51,8919	-384	23,5949	1,8919	-1,4051
124	50,9565	-384	24,351	0,9565	-0,649
125	52,711	-384	22,4001	2,711	-2,5999
126	48,1645	-384	23,6635	-1,8355	-1,3365
127	50,044	-384	20,8973	0,044	-4,1027
128	48,3459	-384	24,9834	-1,6541	-0,0166

Particle	X	Hit Y=	Z	X - 50	Z - 25
129	48,3041	-384	24,4681	-1,6959	-0,5319
130	49,5998	-384	22,4289	-0,4002	-2,5711
131	51,0323	-384	25,4331	1,0323	0,4331
132	51,2959	-384	24,228	1,2959	-0,772
133	48,0221	-384	22,054	-1,9779	-2,946
134	48,4945	-384	23,5259	-1,5055	-1,4741
135	51,5808	-384	24,3897	1,5808	-0,6103
136	50,1056	-384	21,9141	0,1056	-3,0859
137	50,1333	-384	21,6089	0,1333	-3,3911
138	49,2219	-384	24,1393	-0,7781	-0,8607
139	49,5649	-384	24,8859	-0,4351	-0,1141
140	52,5248	-384	21,7682	2,5248	-3,2318
141	50,6214	-384	22,9644	0,6214	-2,0356
142	49,1983	-384	23,4786	-0,8017	-1,5214
143	49,153	-384	23,5308	-0,847	-1,4692
144	49,4019	-384	23,6523	-0,5981	-1,3477
145	49,7811	-384	22,7602	-0,2189	-2,2398
146	49,0997	-384	23,7693	-0,9003	-1,2307
147	48,9492	-384	23,7336	-1,0508	-1,2664
148	50,1211	-384	21,3222	0,1211	-3,6778
149	49,2861	-384	24,7795	-0,7139	-0,2205
150	49,0734	-384	24,6423	-0,9266	-0,3577
151	48,5758	-384	23,8774	-1,4242	-1,1226
152	48,7429	-384	20,7727	-1,2571	-4,2273
153	49,1732	-384	23,6717	-0,8268	-1,3283
154	49,0819	-384	24,4578	-0,9181	-0,5422
155	48,4994	-384	23,2792	-1,5006	-1,7208
156	49,2715	-384	22,2294	-0,7285	-2,7706
157	53,1206	-384	23,8985	3,1206	-1,1015
158	52,7615	-384	22,9507	2,7615	-2,0493
159	49,0124	-384	21,9288	-0,9876	-3,0712
160	48,1398	-384	22,0939	-1,8602	-2,9061
161	48,8989	-384	25,3312	-1,1011	0,3312
162	51,9563	-384	24,2447	1,9563	-0,7553
163	48,7294	-384	20,8278	-1,2706	-4,1722
164	48,487	-384	21,6759	-1,513	-3,3241
165	48,044	-384	21,0889	-1,956	-3,9111
166	51,733	-384	21,4986	1,733	-3,5014
167	49,2583	-384	22,0439	-0,7417	-2,9561
168	47,9308	-384	22,693	-2,0692	-2,307
169	49,4493	-384	20,875	-0,5507	-4,125
170	50,5682	-384	22,7509	0,5682	-2,2491
171	49,2305	-384	22,9443	-0,7695	-2,0557
172	51,5407	-384	24,9752	1,5407	-0,0248
173	53,3633	-384	23,1775	3,3633	-1,8225
174	51,5056	-384	24,7171	1,5056	-0,2829
175	47,9781	-384	22,5777	-2,0219	-2,4223
176	49,7879	-384	21,0434	-0,2121	-3,9566
177	48,3632	-384	21,2857	-1,6368	-3,7143
178	48,0439	-384	22,5915	-1,9561	-2,4085
179	49,5699	-384	23,0506	-0,4301	-1,9494
180	50,5074	-384	22,4959	0,5074	-2,5041
181	48,1633	-384	24,1874	-1,8367	-0,8126
182	48,2273	-384	23,8936	-1,7727	-1,1064
183	51,3858	-384	22,0176	1,3858	-2,9824
184	50,7036	-384	22,4834	0,7036	-2,5166
185	48,0223	-384	22,4786	-1,9777	-2,5214
186	48,9856	-384	21,2899	-1,0144	-3,7101
187	51,5314	-384	24,3874	1,5314	-0,6126
188	48,0515	-384	21,0073	-1,9485	-3,9927
189	51,8872	-384	21,5287	1,8872	-3,4713
190	49,4331	-384	24,5486	-0,5669	-0,4514
191	49,3237	-384	23,3599	-0,6763	-1,6401
192	50,3028	-384	23,7934	0,3028	-1,2066

Particle	X	Hit Y=	Z	X - 50	Z - 25
193	49,1325	-384	23,6384	-0,8675	-1,3616
194	48,1077	-384	22,5059	-1,8923	-2,4941
195	50,7162	-384	22,3622	0,7162	-2,6378
196	49,3096	-384	25,5826	-0,6904	0,5826
197	49,3405	-384	23,5773	-0,6595	-1,4227
198	51,1349	-384	21,7174	1,1349	-3,2826
199	49,0527	-384	23,6872	-0,9473	-1,3128
200	48,1248	-384	22,1899	-1,8752	-2,8101
201	51,9429	-384	23,6166	1,9429	-1,3834
202	52,8937	-384	22,6361	2,8937	-2,3639
203	48,5691	-384	23,173	-1,4309	-1,827
204	48,2415	-384	24,0878	-1,7585	-0,9122
205	48,2108	-384	23,2832	-1,7892	-1,7168
206	48,0577	-384	22,3731	-1,9423	-2,6269
207	50,2379	-384	23,1092	0,2379	-1,8908
208	49,6706	-384	25,1984	-0,3294	0,1984
209	50,6519	-384	22,2152	0,6519	-2,7848
210	48,3825	-384	20,8912	-1,6175	-4,1088
211	48,9519	-384	22,5375	-1,0481	-2,4625
212	48,3882	-384	25,0192	-1,6118	0,0192
213	48,96	-384	21,8004	-1,04	-3,1996
214	48,0542	-384	23,1716	-1,9458	-1,8284
215	48,9258	-384	23,8927	-1,0742	-1,1073
216	49,3932	-384	21,4493	-0,6068	-3,5507
217	52,1835	-384	24,0664	2,1835	-0,9336
218	50,4587	-384	23,5882	0,4587	-1,4118
219	51,4659	-384	23,9613	1,4659	-1,0387
220	50,6108	-384	21,1711	0,6108	-3,8289
221	48,278	-384	23,8951	-1,722	-1,1049
222	49,5671	-384	24,7741	-0,4329	-0,2259
223	51,2926	-384	24,2844	1,2926	-0,7156
224	48,1099	-384	21,6189	-1,8901	-3,3811
225	49,4208	-384	21,2488	-0,5792	-3,7512
226	50,767	-384	24,0385	0,767	-0,9615
227	48,9473	-384	22,1764	-1,0527	-2,8236
228	51,1576	-384	23,7632	1,1576	-1,2368
229	48,0416	-384	24,1767	-1,9584	-0,8233
230	49,0526	-384	22,1828	-0,9474	-2,8172
231	49,0076	-384	23,1219	-0,9924	-1,8781
232	50,5733	-384	23,8718	0,5733	-1,1282
233	49,487	-384	24,9826	-0,513	-0,0174
234	51,9581	-384	23,8628	1,9581	-1,1372
235	49,7098	-384	21,7021	-0,2902	-3,2979
236	47,9778	-384	21,1544	-2,0222	-3,8456
237	52,1902	-384	22,3946	2,1902	-2,6054
238	48,0544	-384	23,018	-1,9456	-1,982
239	49,6585	-384	22,2994	-0,3415	-2,7006
240	47,9883	-384	22,6312	-2,0117	-2,3688
241	49,3659	-384	22,5341	-0,6341	-2,4659
242	51,8246	-384	22,8185	1,8246	-2,1815
243	47,9968	-384	21,7382	-2,0032	-3,2618
244	48,1443	-384	23,9646	-1,8557	-1,0354
245	51,8837	-384	23,4265	1,8837	-1,5735
246	50,0666	-384	20,758	0,0666	-4,242
247	49,7792	-384	25,6508	-0,2208	0,6508
248	48,2276	-384	24,1982	-1,7724	-0,8018
249	48,5107	-384	22,6606	-1,4893	-2,3394
250	48,9395	-384	21,4166	-1,0605	-3,5834
251	48,168	-384	23,6619	-1,832	-1,3381
252	48,278	-384	23,7704	-1,722	-1,2296
253	49,8648	-384	25,0719	-0,1352	0,0719
254	49,2388	-384	21,2919	-0,7612	-3,7081
255	47,9676	-384	23,448	-2,0324	-1,552
256	52,7304	-384	22,5305	2,7304	-2,4695

Particle	X	Hit Y=	Z	X - 50	Z - 25
257	49,2815	-384	22,4041	-0,7185	-2,5959
258	53,0594	-384	24,0408	3,0594	-0,9592
259	48,6525	-384	25,0594	-1,3475	0,0594
260	50,5946	-384	21,0614	0,5946	-3,9386
261	52,0479	-384	21,7478	2,0479	-3,2522
262	50,0633	-384	24,6882	0,0633	-0,3118
263	48,0558	-384	22,8075	-1,9442	-2,1925
264	50,4236	-384	25,6522	0,4236	0,6522
265	49,3308	-384	24,9822	-0,6692	-0,0178
266	49,1282	-384	24,6209	-0,8718	-0,3791
267	50,1515	-384	22,8307	0,1515	-2,1693
268	48,3137	-384	24,6795	-1,6863	-0,3205
269	48,65	-384	24,1561	-1,35	-0,8439
270	52,3035	-384	22,1177	2,3035	-2,8823
271	49,8631	-384	21,8933	-0,1369	-3,1067
272	51,3871	-384	22,6441	1,3871	-2,3559
273	50,8962	-384	22,3893	0,8962	-2,6107
274	48,0008	-384	21,3556	-1,9992	-3,6444
275	47,9021	-384	22,2745	-2,0979	-2,7255
276	48,9215	-384	20,8708	-1,0785	-4,1292
277	49,1779	-384	20,59	-0,8221	-4,41
278	49,1969	-384	24,3628	-0,8031	-0,6372
279	50,5037	-384	24,3054	0,5037	-0,6946
280	51,1142	-384	22,9902	1,1142	-2,0098
281	48,8669	-384	22,3907	-1,1331	-2,6093
282	48,8819	-384	21,3816	-1,1181	-3,6184
283	50,8076	-384	23,2132	0,8076	-1,7868
284	48,529	-384	21,1638	-1,471	-3,8362
285	48,9276	-384	24,7085	-1,0724	-0,2915
286	48,443	-384	23,6297	-1,557	-1,3703
287	50,1987	-384	22,619	0,1987	-2,381
288	48,1472	-384	23,4225	-1,8528	-1,5775
289	50,3983	-384	22,1178	0,3983	-2,8822
290	49,131	-384	21,5951	-0,869	-3,4049
291	48,8028	-384	24,1328	-1,1972	-0,8672
292	48,6845	-384	23,2743	-1,3155	-1,7257
293	50,751	-384	21,3874	0,751	-3,6126
294	49,9745	-384	24,6197	-0,0255	-0,3803
295	48,9734	-384	24,2795	-1,0266	-0,7205
296	51,8606	-384	21,7301	1,8606	-3,2699
297	52,8771	-384	22,5372	2,8771	-2,4628
298	49,8017	-384	23,0799	-0,1983	-1,9201
299	48,7677	-384	21,3624	-1,2323	-3,6376
300	49,4654	-384	22,6734	-0,5346	-2,3266
301	51,3685	-384	24,2491	1,3685	-0,7509
302	49,0669	-384	22,1921	-0,9331	-2,8079
303	48,0057	-384	22,444	-1,9943	-2,556
304	50,8957	-384	23,2267	0,8957	-1,7733
305	51,9426	-384	22,6733	1,9426	-2,3267
306	52,5338	-384	23,0961	2,5338	-1,9039
307	49,2405	-384	20,8004	-0,7595	-4,1996
308	50,2834	-384	23,7631	0,2834	-1,2369
309	48,1901	-384	24,2108	-1,8099	-0,7892
310	49,4235	-384	25,404	-0,5765	0,404
311	49,0347	-384	21,5177	-0,9653	-3,4823
312	49,2689	-384	25,1362	-0,7311	0,1362
313	48,572	-384	22,1009	-1,428	-2,8991
314	48,1274	-384	21,8327	-1,8726	-3,1673
315	50,8183	-384	23,6317	0,8183	-1,3683
316	49,351	-384	23,566	-0,649	-1,434
317	49,4943	-384	21,7399	-0,5057	-3,2601
318	48,2633	-384	24,6972	-1,7367	-0,3028
319	49,6032	-384	24,0082	-0,3968	-0,9918
320	48,5071	-384	24,1077	-1,4929	-0,8923

Particle	X	Hit Y=	Z	X - 50	Z - 25
321	49,0439	-384	23,0696	-0,9561	-1,9304
322	50,4675	-384	23,9764	0,4675	-1,0236
323	50,6347	-384	21,0095	0,6347	-3,9905
324	47,996	-384	22,6243	-2,004	-2,3757
325	48,9981	-384	20,5826	-1,0019	-4,4174
326	53,3034	-384	23,2962	3,3034	-1,7038
327	49,2105	-384	21,8807	-0,7895	-3,1193
328	48,5215	-384	21,6106	-1,4785	-3,3894
329	50,7779	-384	23,0857	0,7779	-1,9143
330	48,0932	-384	23,3164	-1,9068	-1,6836
331	48,3366	-384	20,8955	-1,6634	-4,1045
332	50,3156	-384	21,2816	0,3156	-3,7184
333	50,1137	-384	24,3764	0,1137	-0,6236
334	50,6447	-384	22,0665	0,6447	-2,9335
335	48,39	-384	25,0346	-1,61	0,0346
336	51,6599	-384	21,7223	1,6599	-3,2777
337	51,1895	-384	21,883	1,1895	-3,117
338	50,4386	-384	25,3948	0,4386	0,3948
339	49,0144	-384	22,5493	-0,9856	-2,4507
340	50,1511	-384	22,6579	0,1511	-2,3421
341	48,7281	-384	22,8493	-1,2719	-2,1507
342	48,1232	-384	23,3917	-1,8768	-1,6083
343	48,7598	-384	22,2462	-1,2402	-2,7538
344	47,9281	-384	21,5377	-2,0719	-3,4623
345	47,9171	-384	21,8211	-2,0829	-3,1789
346	51,4329	-384	23,7647	1,4329	-1,2353
347	49,3291	-384	25,4514	-0,6709	0,4514
348	51,0624	-384	24,796	1,0624	-0,204
349	52,8664	-384	22,2403	2,8664	-2,7597
350	52,4114	-384	23,9339	2,4114	-1,0661
351	51,0593	-384	21,377	1,0593	-3,623
352	52,7259	-384	22,5181	2,7259	-2,4819
353	51,3937	-384	25,3511	1,3937	0,3511
354	52,71	-384	23,0589	2,71	-1,9411
355	49,5869	-384	24,579	-0,4131	-0,421
356	49,3128	-384	22,8782	-0,6872	-2,1218
357	49,1512	-384	23,5043	-0,8488	-1,4957
358	48,3883	-384	24,7541	-1,6117	-0,2459
359	47,98	-384	21,2745	-2,02	-3,7255
360	53,0572	-384	23,8414	3,0572	-1,1586
361	51,7532	-384	23,3402	1,7532	-1,6598
362	50,7868	-384	22,7191	0,7868	-2,2809
363	47,9336	-384	21,89	-2,0664	-3,11
364	49,02	-384	22,5326	-0,98	-2,4674
365	48,1248	-384	21,8559	-1,8752	-3,1441
366	51,4394	-384	23,2448	1,4394	-1,7552
367	48,7549	-384	21,7157	-1,2451	-3,2843
368	50,1073	-384	21,125	0,1073	-3,875
369	50,4632	-384	21,6954	0,4632	-3,3046
370	51,4332	-384	24,2108	1,4332	-0,7892
371	48,6302	-384	23,5734	-1,3698	-1,4266
372	50,3177	-384	24,5237	0,3177	-0,4763
373	49,5188	-384	25,3378	-0,4812	0,3378
374	49,2099	-384	25,6544	-0,7901	0,6544
375	49,0508	-384	21,806	-0,9492	-3,194
376	49,4279	-384	23,7927	-0,5721	-1,2073
377	49,5724	-384	22,5721	-0,4276	-2,4279
378	50,8384	-384	24,8574	0,8384	-0,1426
379	48,9706	-384	22,6486	-1,0294	-2,3514
380	51,8742	-384	24,3266	1,8742	-0,6734
381	50,5056	-384	25,6053	0,5056	0,6053
382	49,7421	-384	25,5186	-0,2579	0,5186
383	49,9163	-384	21,6041	-0,0837	-3,3959
384	52,154	-384	21,6117	2,154	-3,3883

Particle	X	Hit Y=	Z	X - 50	Z - 25
385	48,3069	-384	24,7082	-1,6931	-0,2918
386	48,7326	-384	21,3774	-1,2674	-3,6226
387	48,0323	-384	23,8429	-1,9677	-1,1571
388	49,1695	-384	24,1707	-0,8305	-0,8293
389	48,1028	-384	21,5792	-1,8972	-3,4208
390	48,8709	-384	22,888	-1,1291	-2,112
391	48,2797	-384	25,2847	-1,7203	0,2847
392	52,849	-384	24,542	2,849	-0,458
393	48,0947	-384	23,5287	-1,9053	-1,4713
394	50,1445	-384	21,6774	0,1445	-3,3226
395	48,0782	-384	21,6684	-1,9218	-3,3316
396	48,3955	-384	24,9748	-1,6045	-0,0252
397	53,0817	-384	24,3121	3,0817	-0,6879
398	49,0342	-384	23,0038	-0,9658	-1,9962
399	53,127	-384	22,8834	3,127	-2,1166
400	47,9538	-384	23,3177	-2,0462	-1,6823
401	52,512	-384	23,3033	2,512	-1,6967
402	51,2322	-384	22,195	1,2322	-2,805
403	52,055	-384	22,0025	2,055	-2,9975
404	50,763	-384	22,4368	0,763	-2,5632
405	49,0921	-384	22,2706	-0,9079	-2,7294
406	49,0666	-384	22,6202	-0,9334	-2,3798
407	48,0447	-384	22,7255	-1,9553	-2,2745
408	49,0216	-384	23,7382	-0,9784	-1,2618
409	48,9736	-384	25,3175	-1,0264	0,3175
410	51,3018	-384	24,1837	1,3018	-0,8163
411	51,3012	-384	25,0783	1,3012	0,0783
412	49,3493	-384	24,5455	-0,6507	-0,4545
413	48,8491	-384	23,6128	-1,1509	-1,3872
414	48,3887	-384	21,4072	-1,6113	-3,5928
415	49,061	-384	23,4328	-0,939	-1,5672
416	52,2277	-384	23,8101	2,2277	-1,1899
417	47,9918	-384	21,6457	-2,0082	-3,3543
418	52,5524	-384	22,2941	2,5524	-2,7059
419	51,0785	-384	25,1568	1,0785	0,1568
420	50,8434	-384	21,936	0,8434	-3,064
421	50,8253	-384	24,7643	0,8253	-0,2357
422	48,2226	-384	23,9623	-1,7774	-1,0377
423	49,3865	-384	24,9185	-0,6135	-0,0815
424	51,9791	-384	22,1504	1,9791	-2,8496
425	50,5182	-384	25,092	0,5182	0,092
426	49,7746	-384	24,4005	-0,2254	-0,5995
427	49,0126	-384	22,4226	-0,9874	-2,5774
428	48,2988	-384	24,7311	-1,7012	-0,2689
429	49,6768	-384	22,4826	-0,3232	-2,5174
430	47,9219	-384	22,0612	-2,0781	-2,9388
431	48,3858	-384	21,8884	-1,6142	-3,1116
432	48,9074	-384	21,2333	-1,0926	-3,7667
433	49,1964	-384	23,4808	-0,8036	-1,5192
434	49,0736	-384	22,1715	-0,9264	-2,8285
435	48,0522	-384	22,6403	-1,9478	-2,3597
436	52,5557	-384	24,9251	2,5557	-0,0749
437	48,1539	-384	22,5002	-1,8461	-2,4998
438	52,2874	-384	24,4484	2,2874	-0,5516
439	50,218	-384	23,0607	0,218	-1,9393
440	53,084	-384	24,1751	3,084	-0,8249
441	50,5934	-384	24,019	0,5934	-0,981
442	48,1868	-384	22,9373	-1,8132	-2,0627
443	49,3012	-384	23,8308	-0,6988	-1,1692
444	50,8633	-384	23,8321	0,8633	-1,1679
445	50,1447	-384	22,8859	0,1447	-2,1141
446	51,3609	-384	23,694	1,3609	-1,306
447	48,3571	-384	21,5009	-1,6429	-3,4991
448	48,0065	-384	21,6716	-1,9935	-3,3284

Particle	X	Hit Y=	Z	X - 50	Z - 25
449	48,9974	-384	23,3798	-1,0026	-1,6202
450	48,1281	-384	21,9492	-1,8719	-3,0508
451	48,0076	-384	21,163	-1,9924	-3,837
452	50,4812	-384	22,0992	0,4812	-2,9008
453	52,9272	-384	24,3914	2,9272	-0,6086
454	50,708	-384	21,485	0,708	-3,515
455	51,3458	-384	25,2267	1,3458	0,2267
456	49,7651	-384	24,9394	-0,2349	-0,0606
457	50,8082	-384	25,0425	0,8082	0,0425
458	49,254	-384	24,0952	-0,746	-0,9048
459	50,3156	-384	21,9172	0,3156	-3,0828
460	48,8415	-384	21,0456	-1,1585	-3,9544
461	47,9983	-384	20,9247	-2,0017	-4,0753
462	48,4051	-384	21,1969	-1,5949	-3,8031
463	48,7119	-384	20,8366	-1,2881	-4,1634
464	50,8429	-384	24,5637	0,8429	-0,4363
465	49,3806	-384	20,9881	-0,6194	-4,0119
466	49,1428	-384	25,0597	-0,8572	0,0597
467	48,5113	-384	21,3288	-1,4887	-3,6712
468	47,9096	-384	21,9529	-2,0904	-3,0471
469	50,2671	-384	23,7988	0,2671	-1,2012
470	48,1314	-384	21,9218	-1,8686	-3,0782
471	49,3181	-384	25,294	-0,6819	0,294
472	49,5864	-384	25,0688	-0,4136	0,0688
473	49,764	-384	22,0777	-0,236	-2,9223
474	48,5392	-384	20,9174	-1,4608	-4,0826
475	48,3494	-384	24,5698	-1,6506	-0,4302
476	47,9999	-384	22,0705	-2,0001	-2,9295
477	49,187	-384	22,1908	-0,813	-2,8092
478	49,9791	-384	21,2614	-0,0209	-3,7386
479	50,334	-384	24,3956	0,334	-0,6044
480	50,8207	-384	24,0651	0,8207	-0,9349
481	52,0546	-384	21,4972	2,0546	-3,5028
482	49,7191	-384	24,976	-0,2809	-0,024
483	48,9947	-384	21,6461	-1,0053	-3,3539
484	48,7458	-384	21,4433	-1,2542	-3,5567
485	48,0233	-384	22,2303	-1,9767	-2,7697
486	47,9276	-384	22,7697	-2,0724	-2,2303
487	49,7032	-384	25,2545	-0,2968	0,2545
488	49,9602	-384	21,9464	-0,0398	-3,0536
489	49,5192	-384	25,5119	-0,4808	0,5119
490	48,1875	-384	23,4758	-1,8125	-1,5242
491	53,3021	-384	23,7638	3,3021	-1,2362
492	50,9265	-384	24,9041	0,9265	-0,0959
493	52,5693	-384	23,2867	2,5693	-1,7133
494	52,7048	-384	23,4802	2,7048	-1,5198
495	50,789	-384	21,772	0,789	-3,228
496	52,4305	-384	22,0575	2,4305	-2,9425
497	48,1127	-384	24,0296	-1,8873	-0,9704
498	48,2	-384	23,8832	-1,8	-1,1168
499	50,1384	-384	22,4949	0,1384	-2,5051
500	52,5817	-384	23,6031	2,5817	-1,3969

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