Summer Student Report

Commissioning of the Apparatus for Surface Physics and Interfaces at CERN's Ion Implantation Chamber (ASCII)

LOI248

CERN Summer Student Programme

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01.06.- 27.09.2024

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This report is submitted as part of the CERN Summer Student Programme.

Abstract

This report outlines my contributions to the commissioning of the Apparatus for Surface Physics and Interfaces at CERN's Ion Implantation Chamber (ASCII), part of the ISOLDE facility. My work is focused on the design and construction of a Faraday cage to ensure high-voltage safety, performing mechanical modifications to improve the vacuum system, and assisting in the commissioning of the high-voltage systems. Additionally, I ran SIMION and SRIM simulations to model ion beam behaviour and implantation depth. These contributions are essential steps toward the safe and efficient operation of the ASCII chamber, enabling future research at CERN.

Contents

1. Introduction

The Apparatus for Surface Physics and Interfaces at CERN's Ion Implantation chamber (ASCII) is designed for ultra-low ion implantation of radioactive isotopes on the surface of a target material, such as 2D-materials or multiferroics, to study the underlying solid state physics like the electric and magnetic properties of those materials. Designed for the use at the ISOLDE facility at CERN [CAB+17] [JSC+17] [B+00], ASCII was delivered in March 2023 and needs a lot of preparation to finalize the setup and meet the CERN safety requirements before commissioning. The main developments include the conceptualization and partial construction of a Faraday cage to insure safe high-voltage (HV) operations within the ASCII-chamber. In addition, the load lock system got changed and was successfully tested in the vacuum environment. The Faraday cage that contains the devices and power supplies to run the HV operations needed to get modified, including proper grounding and new plates to meet CERN safety requirements.
Next to these tasks, a simulation for the ion beam in the deceleration stage is done to adjust applied voltages for different isotopes and beam energies.
These efforts are necessary steps to complete the ASCII setup and ensure safety when commissioning ASCII for future research at the ISOLDE facility at CERN.

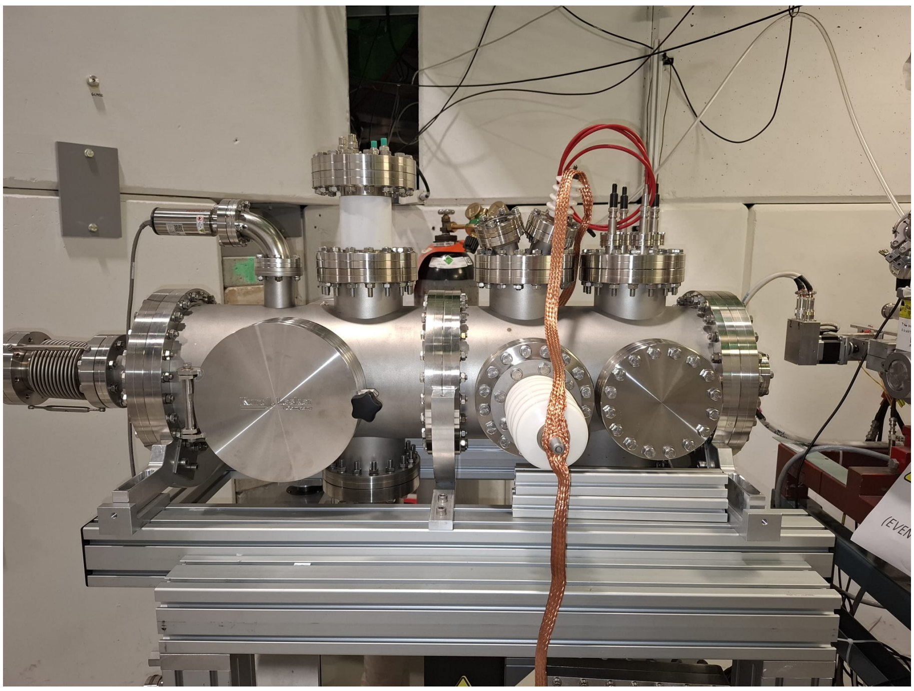

Figure 1.1.: The ASCII chamber

2. The ASCII Chamber

ASCII, which stands for the Apparatus for Surface Physics and Interfaces at CERN's Ion Implantation Chamber, is a device designed to implant radioactive isotopes into the surface of materials at ultra-low energies (down to 20 eV)[SHHS+23][HS20][SLAH22]. The chamber's primary function is to conduct surface-level implantation to study surface physics and material interfaces, particularly on 2D materials like graphene and multiferroic materials like bismuth ferrite.
The ASCII vacuum chamber operates under ultra-high vacuum (UHV) conditions, maintaining pressures as low as 10^{-9} to 10^{-10} mbar to ensure clean ion implantation processes. Achieving such low pressures requires a combination of pre-vacuum, turbo molecular, and ion pump. The chamber can also undergo a baking process where it is heated up, further lowering contamination levels and enhancing vacuum conditions.

2.1. Main Components of the ASCII Chamber

- **Deflector Plates /Beam Sweep**:
  - Positioned near the ion beam inlet.
  - These plates steer the ion beam toward the deceleration stage and sweep it over small angles (up to 1.5°), ensuring uniform ion distribution over the sample surface using a Fermat's spiral pattern.
- **Deceleration Stage**:
  - Capable of decelerating ions to very low energies by adjusting the voltage of various electrodes before hitting the sample.
  - The ions' final energy is proportional to the bias voltage applied to the sample, allowing fine control over ion energy (from 0 eV to 60 keV).
  - The primary focus is on ultra-low energy ion implantation, typically $\leq$ 100 eV, suitable for studying nanostructures and controlling ion implantation depth within several nanometers.
- **Sample Manipulator**:
  - Features a bayonet locking system for easy sample exchange.
  - Moves the sample into position for implantation or backward for exchange.
  - Contains a heating element. This temperature control reduces implantation-induced defects and enhances the diffusion of atoms into substitutional positions within the crystal lattice.

A schematic of the main components, a CAD and a picture of the ASCII chamber is shown in figure 2.1.

The ASCII chamber's ability to precisely control both the vacuum conditions and the implantation energy ensures high precision in ion implantation to study surface physics. The information above and further information can be found in the article "Introducing Ultra-Low Energy Ion Implantation of Radioactive Isotopes at ISOLDE, CERN for (Near-)Surface Characterization: The ASPIC and ASCII Vacuum Chambers" [SLAH22] and the master thesis "Upgrading a Surface Analysis Chamber for Ultra Low-Energy Ion Implantation / Weiterentwicklung einer Oberflächenanalysekammer für Niederenergieionenimplantation" by L. Lieske [Lie21].

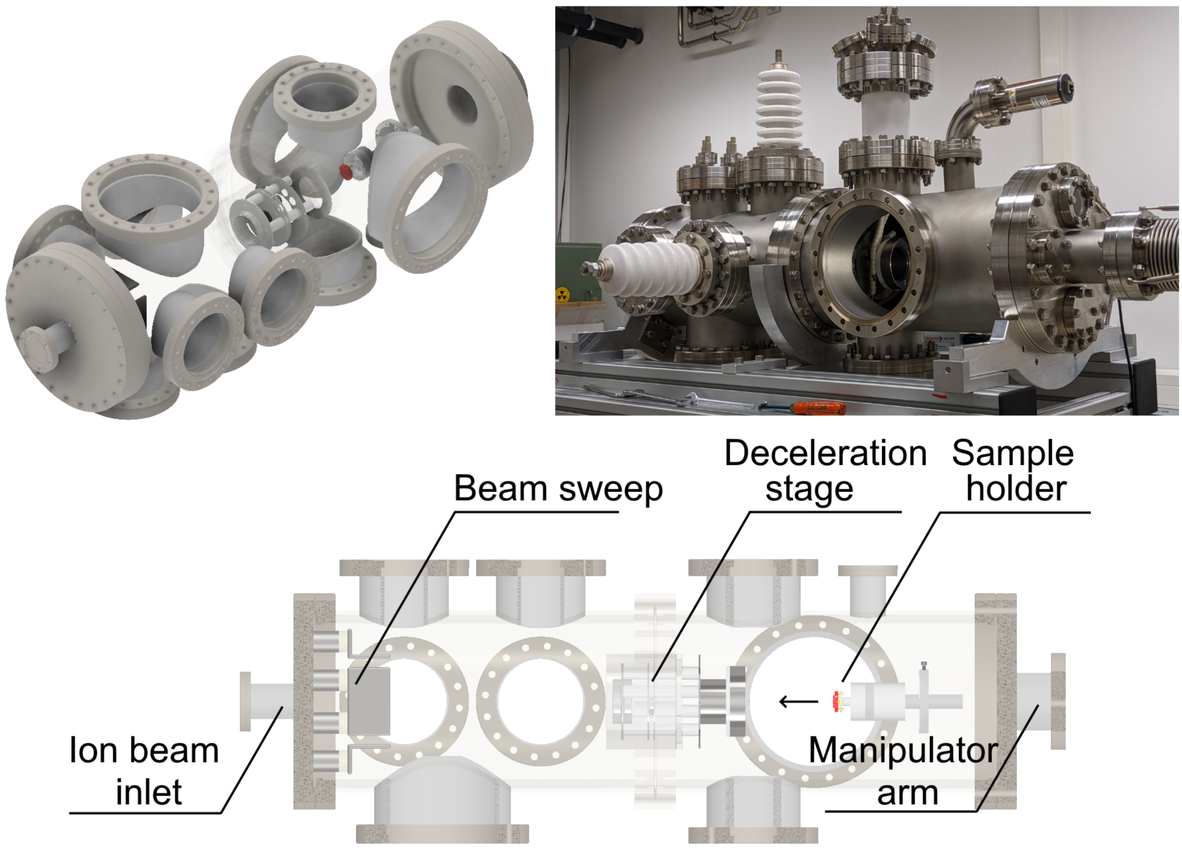

Figure 2.1.: The ASCII chamber [SLAH22]

2.2. The ASCII setup

The ASCII setup includes a Faraday cage with high-voltage devices next to the vacuum chamber, as well as a rack with various power supplies that power the components of the implantation chamber. Between the Faraday cage, the implantation chamber and the rack for the power supplies, various cable connections have to made, as shown in the current high-voltage system schematic shown in figure 2.5.

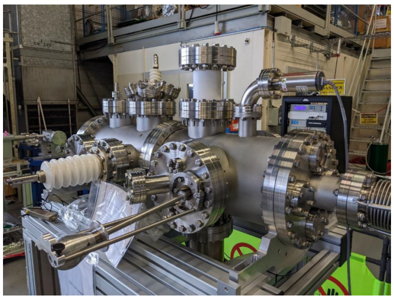

Figure 2.2.: Caption for image 1

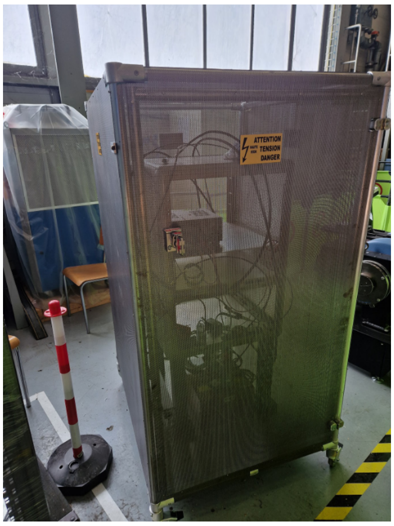

Figure 2.3.: Caption for image 2

Figure 2.4.: Caption for image 3

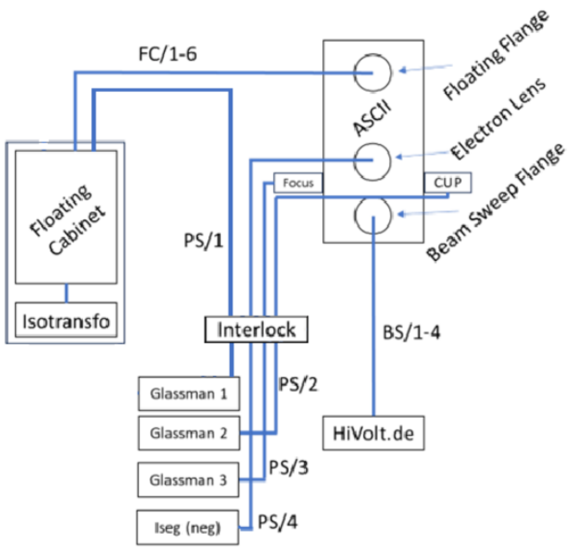

Figure 2.5.: Schematic for the high-voltage system

3. My Contributions to the ASCII Project

3.1. Design and Construction of the Faraday Cage

One of my key tasks during this project was to conceptualize and design a Faraday cage to ensure safe operation when using ASCII. The Faraday cage covers the chamber and the main high-voltage connection, that power the electrodes inside. The cage is primarily used to ensure safety by preventing accidental contact with high-voltage components. Since the high-voltage connections can run up to 60 keV, the cage helps to prevent electrical sparking and protects personnel from electric shock. Additionally, it prevents stray electric fields from affecting other electrical components in the ISOLDE hall.
I began by learning 3D modelling and CAD software to create precise designs for the cage. This required detailed measurements of ASCII's cylindrical structure, which posed challenges due to its round geometry and alignments. For high voltage operation, the Faraday cage must be located at a minimum distance of 10 cm from high voltage connections and comply with IP3X standards for safety.
The concept was changed and refined many times and discussed in weekly meetings with the electrical safety personnel. Therefore, also the measurements had to be redone and fine-tuned. The final concept exists out of five metal sheets (four side plates and one plate for the top) and two cups mounted on the sides to cover the insulators. Each plate has to be cut to fit on the ASCII chamber, giving access to the load lock and bayonet system. Additionally, the top plate has a hole for the pipe that will carry and isolate the high-voltage cables. The exact technical drawings can be seen in the appendix A.4. An overview is shown in figure 3.1

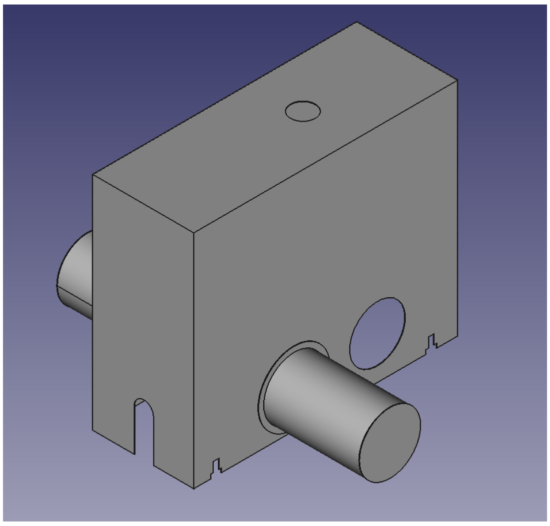

Figure 3.1.: Designed Faraday-cage for the ASCII chamber in FreeCAD

All Faraday cage and the technical drawings were done by using the Linux based FreeCAD software. Because I have a Linux system on my personal Laptop and the software being beginner-friendly, FreeCAD was suitable for designing the Faraday cage. On the other hand, I also used the more professional Autodesk Inventor CAD software to try and measure the ASCII by measuring an existing CAD file of the chamber itself. However, it turned out that not every measurement of the ASCII chamber in the CAD file was the same as the real chamber, so I continued with my own measurements of the chamber.

For the Faraday cage different materials, that are suitable for building it, have to be tested. One of the insulator covers was build using stainless steel with a thickness of 2 mm. This turned out to be too heavy, because the covers mounted on the side plates would create a torque. To be stable enough also the side plates would have to be done using stainless steel plates. So, building the whole Faraday cage out of stainless steel would weight about 50 kg and is considered to be too heavy for the mounting of the ASCII chamber.

After discussing with the safety personnel, it would be best to try to build the Faraday cage using the same IP3X steel plates, like those, that are currently mounted on the Faraday cage that secures the electrical equipment. The holes inside those plates have a diameter less than 2.5 mm, making it IP3X conform and reducing the mass of the Faraday cage, but still assuring a stable structure. Another possibility would is using IP3X aluminium plates. However, the CERN store has no perforated aluminium plates, that are IP3X conform. In addition, steel is cheaper and more stable than aluminium, but on the other hand heavier. The Faraday cage will be built by the CERN workshop together with a metal structure made out of angled profiles to connect the plates.

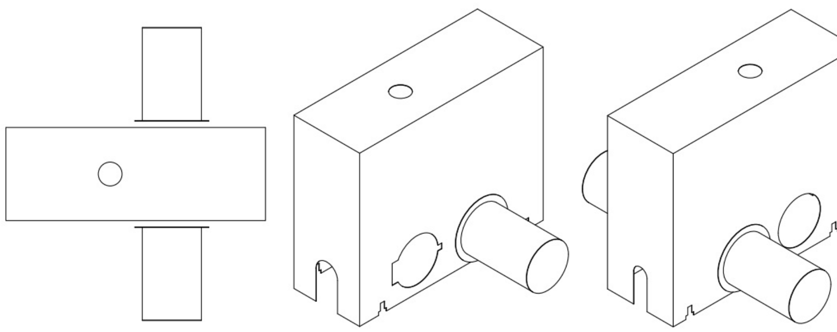

Figure 3.2.: Overview of the Faraday cage for the ASCII chamber

3.2. Commissioning of the High Voltage Systems

I also worked on the Faraday cage containing the floating cabinet that houses the high-voltage devices supplying the various power supplies for the electrodes of the deceleration stage. The electrodes of the apparatus are crucial for manipulating the ion beam's energy and focus. The high-voltage system has to be carefully shielded to comply with CERN's safety restrictions, ensuring that no operator could be exposed to potential electrocution hazards during operation. For that, we dismounted the installed Makrolon polycarbonate plates and aluminium plates of the Faraday cage and replaced them by mounting IP3X steel plates. The holes for cable inlet and outlet are secured with rubber gasket. In addition, the grounding of the floating cabinet inside the Faraday cage was installed using resistors, as shown in figure 3.3. This work was in cooperation with Julie Lund, who worked together with the group for a month and wrote a detailed report about her work on the HV system [Lun24]. For the high voltage procedure, an insulation rod was ordered and a grounding hook acquired (3.4). Last but not least, due to different standards between Germany and Switzerland, a plug in the electrical system inside the Faraday cage was changed to be compatible with the rest of the electrical equipment.

Figure 3.3.: Grounding of the floating cabinet

Figure 3.4.: Grounding hook for the insulator rod

Figure 3.5.: Faraday cage with new IP3X plates, safety signs and proper grounding

3.3. Mechanical Modifications on ASCII and Vacuum Testing

The load lock door on ASCII got replaced, and the vacuum tested to ensure no leaks occurred. This was essential for achieving the ultra-high vacuum required for ion implantation. The new fast entry access load lock door, shown in figure 3.6, enables quicker access and easier access to the sample holder with the increased aperture. We achieved a vacuum of 9.7×10^{-8} mbar.

Additionally, the ceramic screw of the sample holder was broken. It was taken to the workshop to be redone, then mounted back on the sample holder and the connection with the ASCII chamber was checked.

Figure 3.6.: New load lock door [Pre24]

Figure 3.7.: Vacuum pressure panel

4. Simulations

4.1. Motivation

Bismuth ferrite ($BiFeO_3$) is a rare multiferroic material at room temperature with both ferroelectric and antiferromagnetic properties [K+06]. Therefore, it is a highly promising candidate for applications like for example as a catalyst for water dissociation [ESG21]. It has strong polarization and coupling, when used in thin layers or nanoparticles, making it interesting of materials science and nanotechnology. Understanding the local electric and magnetic environments of bismuth ferrite is crucial to understand its properties and possible applications.
Studying the local properties of bismuth ferrite needs experimental techniques such as Time-Differential Perturbed Angular Correlation (TDPAC) [M+20] [S+22] [D+22] and Mössbauer spectroscopy [WC00] [HS+23]. Both methods can be employed to study local phenomena using radioactive isotopes implanted directly into the surface of the material [FS65] [SSL17] [J+17]. These radioactive isotopes are used to gather information about the local electric field gradients and magnetic environments, providing data on the material's properties at the atomic level. Nevertheless, the isotope implantation procedure and the interactions between the ion beam and the surface can change the structure of the material and have an impact on the results of the experiments.
To better understand and optimize the ion implantation process, simulation tools such as SRIM (Stopping and Range of Ions in Matter) and SIMION are used. These software programs allow for simulated data on ion interactions with materials and the behaviour of ions within electromagnetic fields. Simulating the implantation of isotopes into bismuth ferrite provides crucial information on the depth distribution, energy distribution, and potential damage caused by the ion beams, that need to be optimized by fine-tuning the experimental setup.

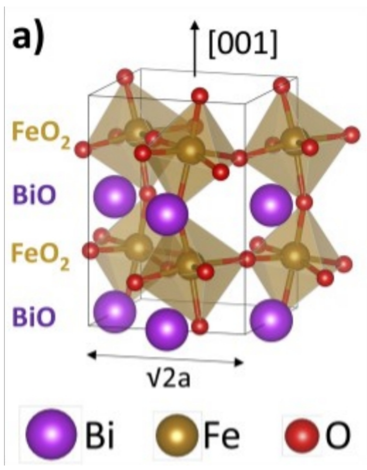

Figure 4.1.: Atomic structure of $BiFeO_3$ [ESG21]

4.2. SIMION Simulations

To better understand the beam dynamics inside ASCII, I used the SIMION software to simulate the implantation process of Cadmium-111 ions on a bismuth ferrite sample. The goal was to decelerate a 30 keV ion beam to 20 eV by applying voltages to the deceleration unit's lenses and electrodes. The full version of the SIMION software was generously provided by the ISOLDE group, enabling precise ion optics simulations. To simulate the beam onto the sample holder, different steps are required:

1. Implement the deceleration Unit into the SIMION software:

To implement the deceleration unit, I used the already existing .stl files. SIMION has an **SL Tools** function, for converting STL into PA files. The PA-file (or .pa) is the required format used by SIMION to simulate the so-called **potential arrays** to calculate the electrostatic field that manipulates the beam. Therefore, all STL files can be converted into PA by choosing the input file. Here I used *ASCII_Chamber_20220303_again_%.stl* in the folder where all STL files are saved. By using %, you can implement all files simultaneously, where the %-symbol is a placeholder for the numeration of the files (in this case number *1* to *7*). This has the advantage, that the lenses are already in the right arrangement. To have a more precise result, I adjusted the grid cell size from *1* to *0.3* in all coordinates. The resulting PA is shown in figure 4.2. After converting, the PA files should be loaded in the main window of SIMION and solved using the *Refine* function. Then the simulation can be configured and run in the workbench.

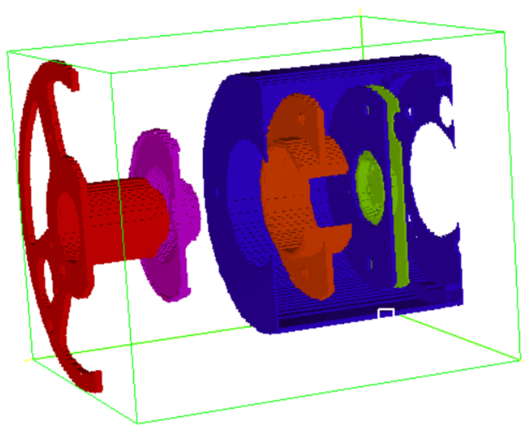

Figure 4.2.: Implemented potential array for the deceleration unit

2. Run the simulation:

Before starting the simulation, the voltages of the electrodes and the beam have to be configured. To configure the beam, the function *Define Particles* in the tab Particles is used. To come close to the ^{111m}Cd beam at ISOLDE, I used the following configuration:

Num particles	1000000
Mass	single value, 111
Charge	single value, 2
Source position:	gaussian3d distribution, Mean: {x:70, y:70, z:173}, Stdev: {x:0.849, y:0.849, z:0}
Velocity format	direction+KE
Direction:	single vector {x:0, y:0, z:-1}
KE	gaussian distribution, Mean: 30000, FWHM: 2 eV

Table 4.1.: Beam configuration

Using the *Fast Adjust Voltages* function in the **PAs** tab, the different voltages of the electrodes can be configured. For this simulation, there is no specific sample or implantation area, the voltages of the lenses, that are used to focus the beam are not used and therefore zero. The voltage of the electrode that is connected with the sample holder and the sample holder itself should have the voltage equal to the beam energy minus the desired implantation energy divided by the charge of the beam isotope. In this case, the 30 kev beam gets decelerated down to 20 eV, with a cadmium charge of +2 . In comparison, the other electrodes try to decelerate the beam down to a kinetic energy of 0 eV, by only deviding the beam energy by the electrical charge of the isotope. The resulting potential is shown in figure 4.4.

$$V_{elect} = \frac{30000\,\text{eV} - 20\,\text{eV}}{2 \cdot e} = 14990\,V \tag{4.1}$$

PA number	Voltage (in V)
1	14990
2	14990
3	15000
4	0
5	0
6	0
7	15000

Table 4.2.: Electrode (PA / number of the STL file) and it's applied voltage

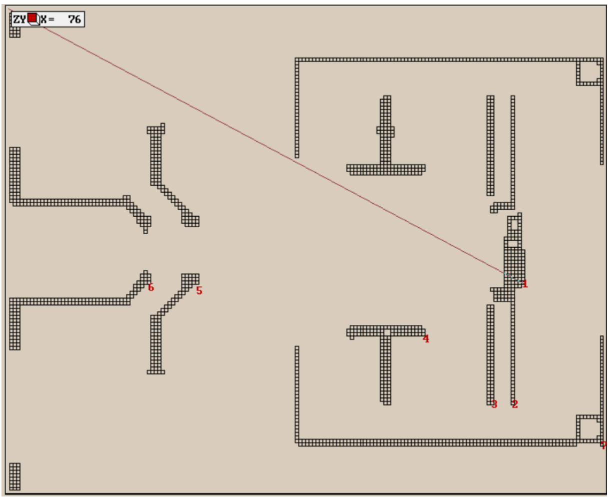

Figure 4.3.: Profile of the deceleration unit and the electrode numeration

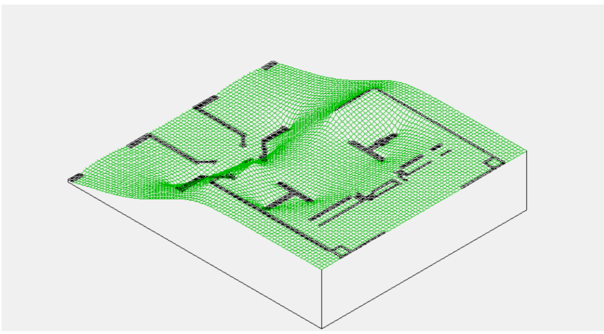

Figure 4.4.: Resulting potential in the profile of the deceleration

Before running the simulation using the *Fly'm*, the data export needs to be configured and activated. Simply by checking the box *Record Data:*, the data gets saved in the workbench. For further output files in the same folder as the workbench, the data export can be configured. In my case, I want to read the x-, y-, and z-position and kinetic energy as well as the kinetic energy error in a CSV file, so I can analyze the data using python. Therefore, I open the *Data Recording* option in the Particles tab and set the Format for Recorded Data as *Delimited* with the delimiter "," and enter a name for the output file.

3. Analyzing the Data:

I analyzed the data using a python environment with Jupyter Lab. The energy distribution could be fitted as a nice Gaussian distribution, as expected. Also, by not simulating the beam sweep and the lens system, the ion distribution gives us back the 2d Gaussian distribution we simulated as our beam. Important here is that we have no additional effects appearing in the deceleration unit, that deviates the result from our expected outcome, and that the desired implantation energy is met. As visualized in 4.5 we get an energy distributed around 20 eV. Here the mean value is actually a little lower with 19.76 eV and a standard deviation of $\sigma = 0.91$. The code for analyzing the data and plotting is shown in the appendix A.2.

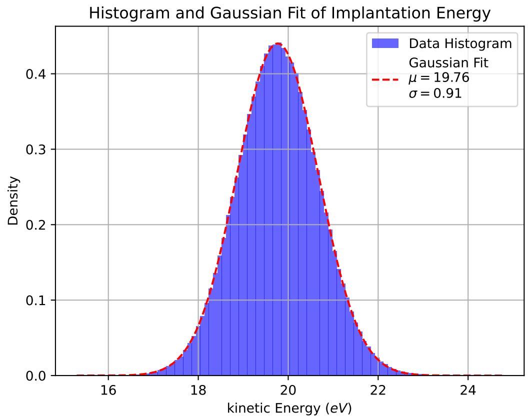

Figure 4.5.: Energy distribution of the isotopes, when hitting the sample

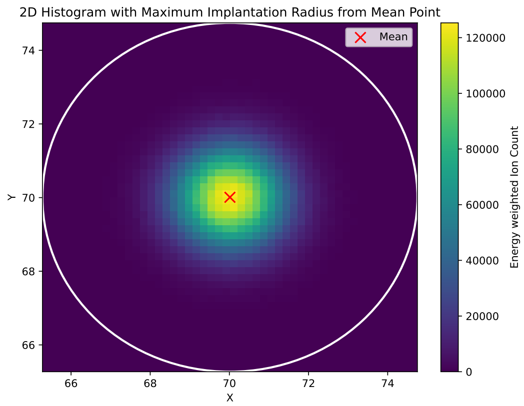

Figure 4.6.: Energy weighted Ion distribution on the sample

4.3. SRIM Simulations

Only doing the SIMION simulation is not sufficient. To know how deep the Isotopes get implanted in the sample, SRIM (Stopping and Range of Ions in Matter) [ZZB10] [ZB85] simulations are necessary. In this simulation, I used SRIM to model the implantation depth of Cadmium ions in bismuth ferrite at different implantation energies. The TRIM calculations of the SRIM software is configured as following:

Table 4.3.: Ion/ Beam data:

Symbol	Cd
Name of Element	Cadmium
Atomic Number	48
Mass (amu)	111

Table 4.4.: Target Layers

Layer Name	Layer 1
Width	200 Å- 20 Å (depending on implantation energy)
Density g/cm^3	8.24

Table 4.5.: Input Elements to Layer

Symbol	Name	Atomic Number	Atom Stoich
Bi	Bismuth	83	1
Fe	Iron	26	1
O	Oxygen	8	3

Although the beam ISOLDE is only at 30 keV, I do the simulation for high energy implantation using a range from 60 keV (maximum beam energy of single charged ion, that could possibly be decelerated by ASCII down to 20 eV) down to 1 keV and for low energy implantation a range from 900 eV down to 100 eV. To export the data, the *Ion Ranges* box has to be checked in the *Output Disk Files* section. After running the simulation, the files can then be extracted from the *SRIM Outputs* folder, that can be found in the directory, where the software is installed. One line in the output file has characters that are not UTF-8 conform and might cause problems. An easy fix is to open the data file with a text editor and replace the characters with UTF-8 conform characters, for example "=". Deleting the line is sufficient, but the Python code in A.3 is designed to replace the characters. The resulting Gaussian distributions are fitted in figure 4.7 and 4.9. To compare implantation energy, implantation depth (mean of the Gaussian) and implantation spread (standard deviation of the Gaussian), the relationship between those values are visualized in figures 4.8 and 4.10.
At higher energies, such as 60 keV, the simulation predicted much deeper implantation, with a wider spread of ion penetration depths. The results showed that as the implantation energy decreases, the depth and spread of the ions are significantly reduced, making ultra-low energy implantation ideal for precise surface studies. At 100 eV, the simulation showed a mean implantation depth of approximately 10 Å with a standard deviation of 3.4 Å, indicating that the ions would embed themselves into the third unit cell of the bismuth ferrite crystal structure.

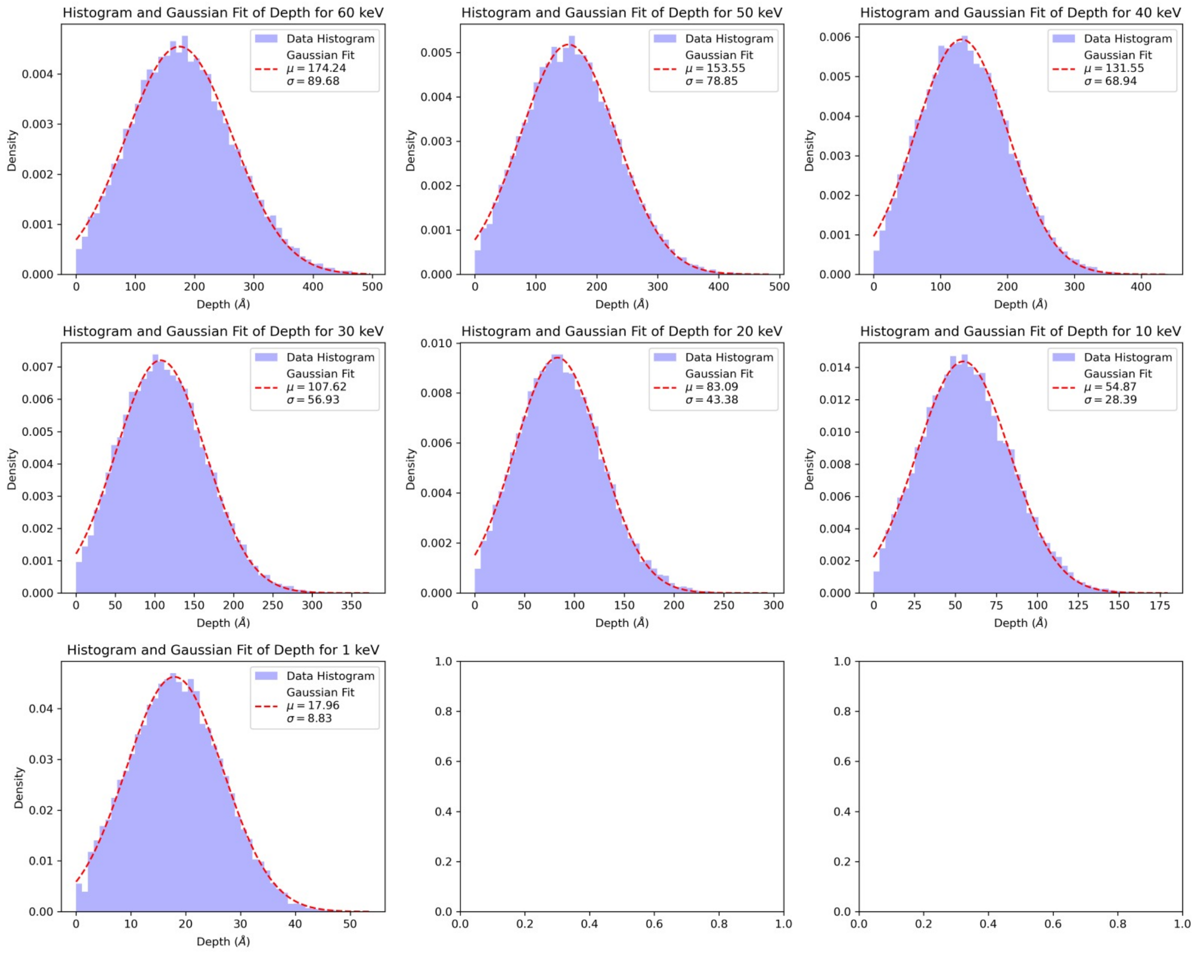

Figure 4.7.: Distribution of implantation depth for high energies

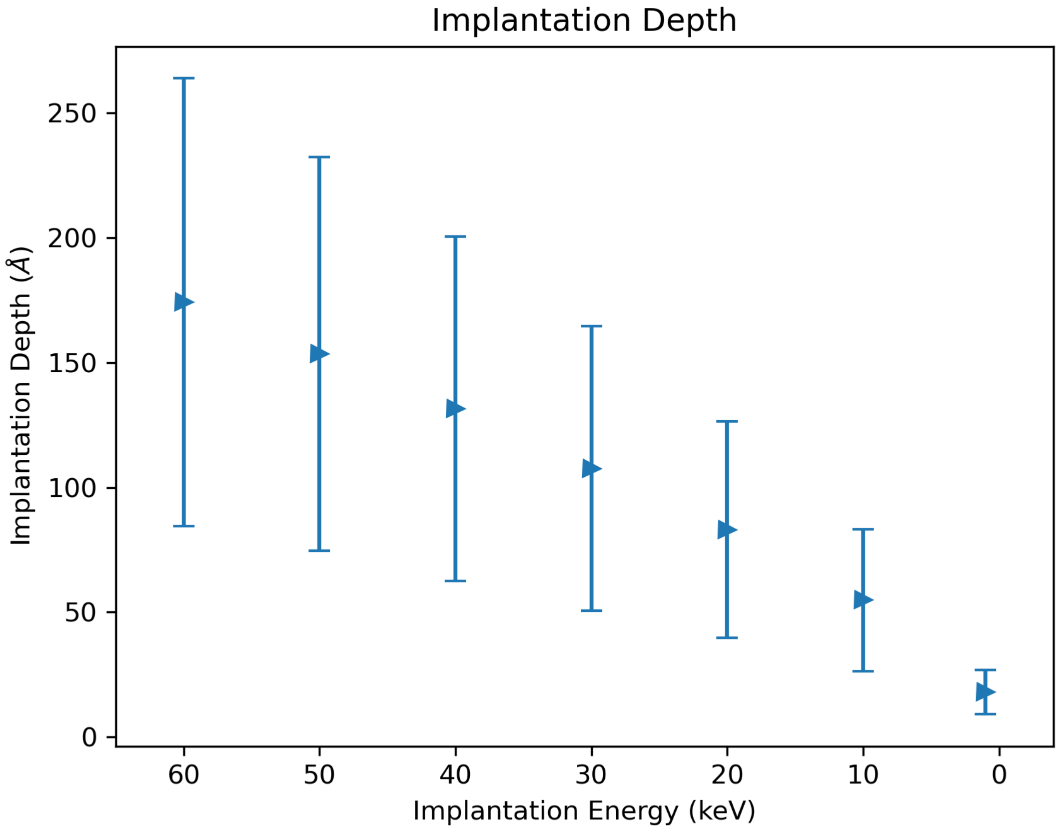

Figure 4.8.: Implantation depth and spread vs. high implantation energy

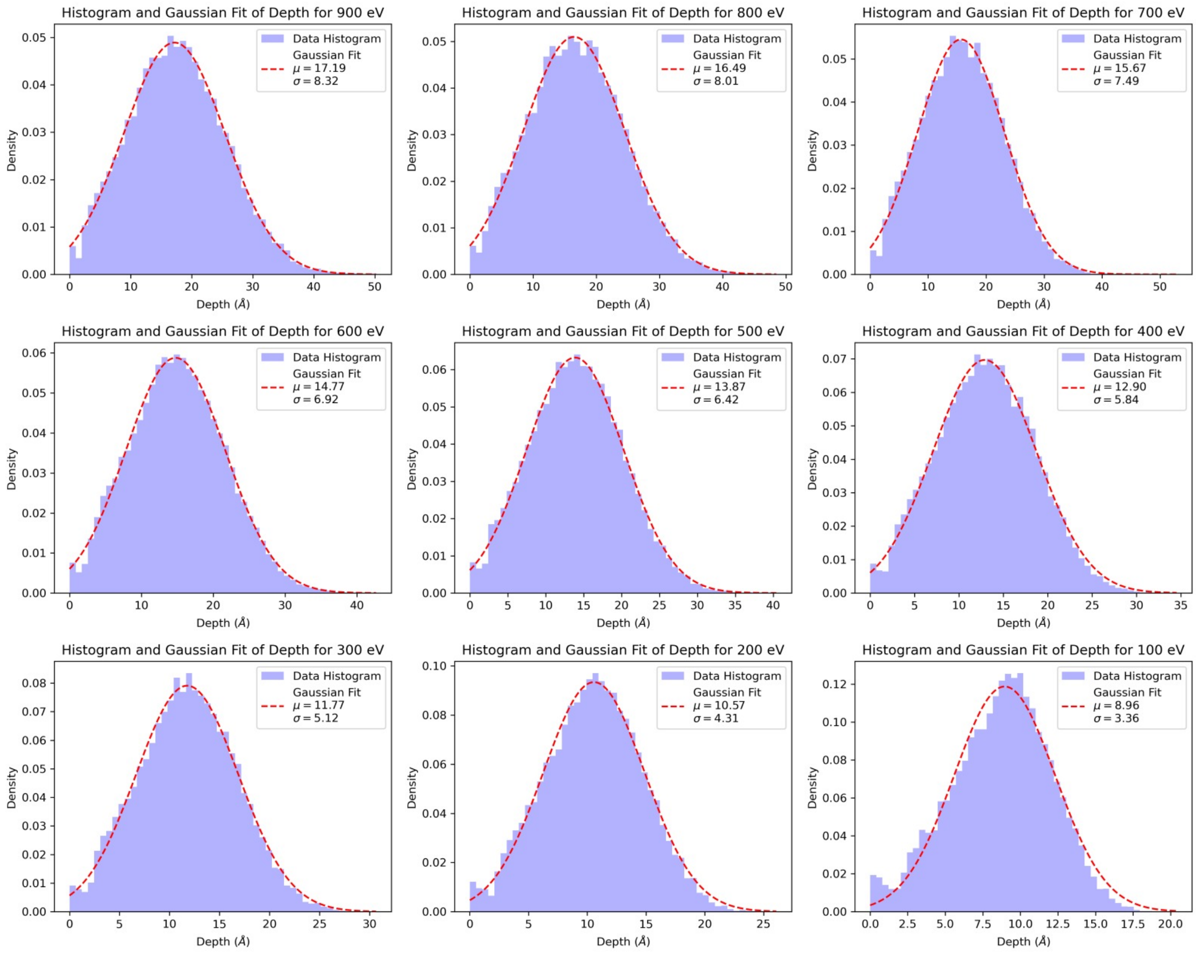

Figure 4.9.: Distribution of implantation depth for low energies

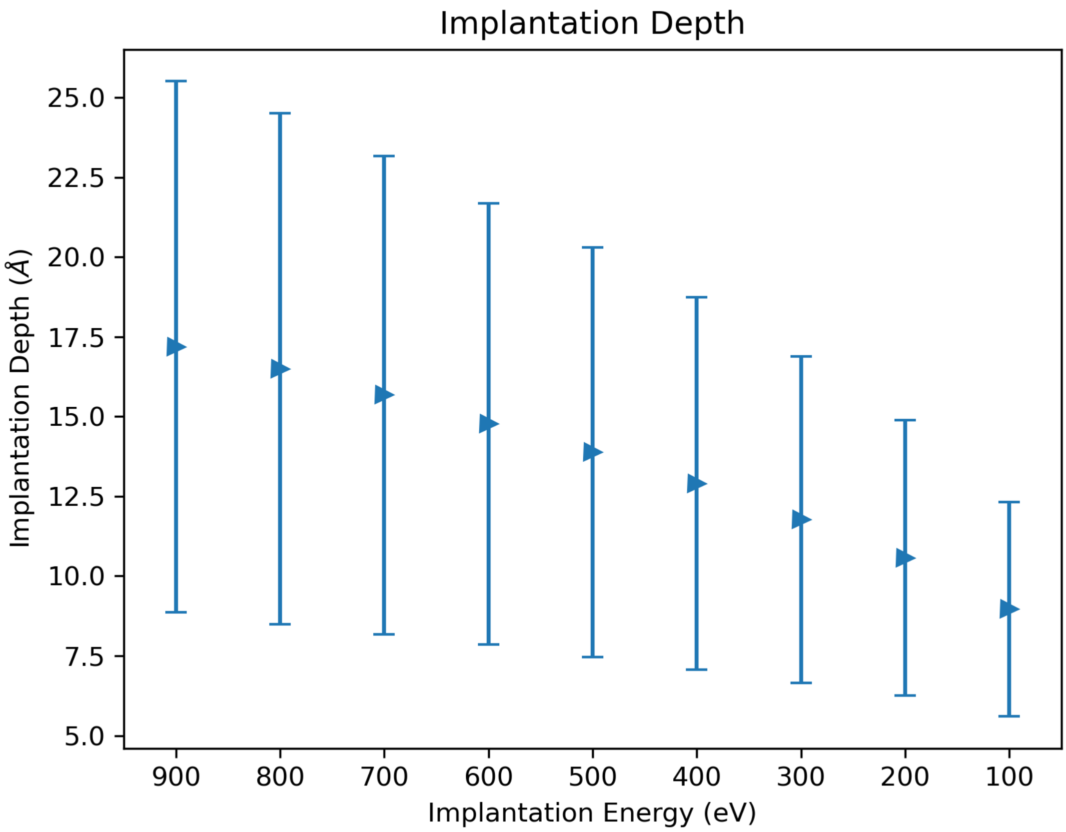

Figure 4.10.: Implantation depth and spread vs. low implantation energy

5. Challenges and Future Work

One major challenge is completing the cabling and electrical setup of ASCII, ensuring all systems are correctly grounded and compliant with CERN's safety standards. This includes finalizing the interlock system and ensuring the high-voltage connections are shielded and operational. Therefore, some connections still have to be made by the electrical workshop. To ensure that the load lock door isn't open while performing high-voltage procedures, the interlock system should be expanded by interlocking the vacuum. This would make it impossible to start high voltage procedure while a vacuum of for example 1×10^{-4} mbar is not met, making it impossible to open the load lock door because of the inner pressure. Additionally, the workshop has to finish building the designed Faraday cage for the ASCII chamber. If needed, the Faraday cage has to be adjusted and gasket added to the holes for the flanges. Another task is measuring the length of the Makrolon tubes that are isolating the high-voltage cables coming from the Faraday cage with the electrical equipment to the chamber and cutting them to mount them with clamps as mechanical support.

Then the chamber would be ready for safety inspection, a test for high-voltage operation and a stable beam test.

6. Conclusion

To conclude my summer student project at CERN, I have gained various knowledge and hands-on experience in different fields, including CAD software for 3D modelling, safety measures for high-voltage systems, solid-state physics, radiation area procedures and simulation software. This work has been both challenging and rewarding, as we made significant progress toward commissioning the ASCII project.
I am incredibly grateful for the opportunity to take part in such a wide array of activities, from attending the summer student lectures to meeting people from around the globe, and especially working closely with my supervisors and the ISOLDE group. So my special thanks go out to my supervisors Juliana Schell and Nicole Pereira De Lima for giving me this great opportunity, and together with Ian Yap and Julie Lund, for creating a nice and friendly working environment. And last but not least, the ISOLDE group for making this possible.

Additionally, we acknowledge the financial support provided by the German Federal Ministry of Education and Research (BMBF) through Grants No. 05K22PGA and 05K22PGB, and the support of the European Union's Horizon Europe Framework research and innovation programme under grant agreement No. 101057511 (EURO-LABS).

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A. Appendix

A.1. Orders in the CERN system

Number	Type	Short Description	Date
10533747	MAG	(QUAL10533747) ASCII Faraday Cage plug	11.09.2024
10516318	DAI	ASCII PVC corners	04.09.2024
10468657	DAI	ASCII LOADLOCK DOOR 8”	12.08.2024
10456863	DAI	ASCII tubes for electrical instalation	05.08.2024
10453515	MAG	(QUAL10453515) ASCII turbo pump cable	02.08.2024
10449537	MAG	(LN__10449537) SCII Faraday Cage IP3X	31.07.2024
10444207	MAG	(QUAL10444207) ASCII grounding resistor	29.07.2024
10444201	MAG	(QUAL10444201) ASCII insulate rod	29.07.2024

Table A.1.: Orders done in the CERN system during my stay

A.2. SIMION - python data analysis code

Listing A.1: Imports

```
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
from scipy.optimize import curve_fit
```

Listing A.2: Data read from CSV

```
# Define the path to your file
file_path = 'run_1.txt'

# Load the data, skipping the header lines and replacing commas with
    periods
data = np.genfromtxt(file_path, delimiter=',', skip_header=9)
# Define the column names
columns = ["Ion-N","TOF","X","Y","Z","KE","KE-Error"]
# Create the DataFrame
df = pd.DataFrame(data, columns=columns)
display(df)
```

Listing A.3: Analysis for the Implantation Energy

```python
# Let's use the 'Depth (Angstrom)' column for the histogram and fit
n_bins=100
data = df['KE'][:1000000]

# Define the Gaussian function
def gaussian(x, A, mu, sigma):
    return A * np.exp(-(x - mu)**2 / (2 * sigma**2))

# Compute the histogram
counts, bin_edges = np.histogram(data, bins=n_bins, density=True)

# Use the center of the bins for the x values
bin_centers = (bin_edges[:-1] + bin_edges[1:]) / 2

# Fit the Gaussian function to the histogram data
popt, _ = curve_fit(gaussian, bin_centers, counts, p0=[1, np.mean(
    data), np.std(data)])

# Extract the fit parameters
A_fit, mu_fit, sigma_fit = popt

# Generate x values for plotting the fitted Gaussian curve
x_fit = np.linspace(bin_edges[0], bin_edges[-1], 1000)
y_fit = gaussian(x_fit, *popt)

# Plot the histogram
plt.hist(data, bins=n_bins, density=True, alpha=0.6, color='blue',
    label='Data Histogram')

# Plot the fitted Gaussian curve
plt.plot(x_fit, y_fit, 'r--', label=f'Gaussian Fit\n$\mu={mu_fit:.2f}
    $\n$\sigma={sigma_fit:.2f}$')

# Add labels and title
plt.xlabel(r'kinetic Energy ($eV$)')
plt.ylabel('Density')
plt.title('Histogram and Gaussian Fit of Implantation Energy')
plt.legend()
plt.grid(True)

plt.savefig('Energy_distribution.pdf')
# Show the plot
plt.show()
```

Listing A.4: Analysis for the implantation area

```
x = df['X'][:1000000]  # x data
y = df['Y'][:1000000]  # y data
energy = df['KE'][:1000000]  # energy data

# Calculate the mean of x and y
mean_x = np.mean(x)
mean_y = np.mean(y)

# Calculate the distance of each point from the mean
distances = np.sqrt((x - mean_x)**2 + (y - mean_y)**2)

# Find the maximum distance
max_radius = np.max(distances)

# Create a 2D histogram
plt.figure(figsize=(8, 6))
#counts, xedges, yedges, im = plt.hist2d(x, y, bins=50, cmap='viridis
    ',range=[[mean_x-max_radius, mean_x+max_radius], [mean_y-
    max_radius, mean_y+max_radius]])
counts, xedges, yedges, im = plt.hist2d(x, y, bins=50, weights=energy
    ,cmap='viridis',range=[[mean_x-max_radius, mean_x+max_radius], [
    mean_y-max_radius, mean_y+max_radius]])

# Add a colorbar to indicate energy levels
plt.colorbar(im, label='Energy weighted Ion Count')



# Draw a circle around the mean point with the calculated radius
circle = plt.Circle((mean_x, mean_y), max_radius, color='white', fill
    =False, linewidth=2)
plt.gca().add_patch(circle)

# Mark the mean point
plt.scatter(mean_x, mean_y, color='red', marker='x', s=100, label='
    Mean')

# Set labels and title
plt.xlabel('X')
plt.ylabel('Y')
plt.title('2D Histogram with Maximum Implantation Radius from Mean
    Point')
plt.legend()

plt.savefig('Ion_distribution.pdf')

# Show plot
plt.show()
```

A.3. SRIM - python analysis code

Listing A.5: Package imports and Gaussian function

```
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
from scipy.optimize import curve_fit

# Define the Gaussian function
def gaussian(x, A, mu, sigma):
    return A * np.exp(-(x - mu)**2 / (2 * sigma**2))
```

Listing A.6: Function for reading data, fitting and visualizing

```
def fit_gaussian(energies,N,nmax,unit='keV',n_rows=3,n_cols=3,
    mean_pos=[-1,-1],fig_name='figure.png'):
    mu, sigma = [], []

    # Set up the grid layout
    fig, axes = plt.subplots(n_rows, n_cols, figsize=(15, 12))

    for i, eng in enumerate(energies):
        # Load the data
        data = np.genfromtxt('RANGE_3D_' + str(eng) + unit+'.txt',
            delimiter=None, skip_header=19,
                                converters={1: lambda s: float(s.replace
                                    (b',', b'.')),
                                            2: lambda s: float(s.replace
                                                (b',', b'.')),
                                            3: lambda s: float(s.replace
                                                (b',', b'.'))}).T[1]
        data=data[:nmax]
        # Compute the histogram
        counts, bin_edges = np.histogram(data, bins=N, density=True)
        bin_centers = (bin_edges[:-1] + bin_edges[1:]) / 2

        # Fit the Gaussian
        popt, _ = curve_fit(gaussian, bin_centers, counts, p0=[1, np.
            mean(data), np.std(data)])
        A_fit, mu_fit, sigma_fit = popt
        mu.append(mu_fit)
        sigma.append(sigma_fit)

        # Generate x values for plotting the fitted Gaussian curve
        x_fit = np.linspace(bin_edges[0], bin_edges[-1], 1000)
        y_fit = gaussian(x_fit, *popt)

        # Determine the subplot
        ax = axes[i // n_cols, i % n_cols]
```

```
        # Plot the histogram
        ax.hist(data, bins=N, density=True, alpha=0.3, color='blue',
            label='Data Histogram')

        # Plot the fitted Gaussian curve
        ax.plot(x_fit, y_fit, 'r--', label=f'Gaussian Fit\n$\mu={
            mu_fit:.2f}$\n$\sigma={sigma_fit:.2f}$')

        # Add labels and title
        ax.set_xlabel(r'Depth ($\AA$)')
        ax.set_ylabel('Density')
        ax.set_title(f'Histogram and Gaussian Fit of Depth for {eng} '+unit)
        ax.legend()

    # Adjust layout to avoid overlap
    plt.tight_layout()

    # Save the figure
    plt.savefig(fig_name, dpi=300)

    # Close the plot
    plt.show()
    plt.close()

    delta_e_lim=(energies[0]-energies[1])/2
    plt.errorbar(energies,mu,sigma,fmt='>',label='Mean and Std',
        capsize=4)
    plt.xlabel('Implantation Energy ('+unit+')')
    plt.ylabel(r'Implantation Depth $(\AA)$')
    plt.title('Implantation Depth')
    plt.xlim(max(energies)+delta_e_lim,min(energies)-delta_e_lim)
    plt.savefig('res_'+fig_name, dpi=300)
    plt.grid(True)
    plt.legend()
    plt.show()

    return mu,sigma
```

Listing A.7: Run high energy analysis

```
energies = [60, 50, 40, 30, 20, 10, 1]
N = 50
nmax=25000

fit_gaussian(energies,N,nmax,unit='keV',fig_name='
    hv_gaussian_fits_grid.png')
```

Listing A.8: Run low energy analysis

```
energies = [900, 800,700,600,500,400,300,200,100]
N = 50
nmax=25000

fit_gaussian(energies,N,nmax, unit='eV',n_rows=3,n_cols=3,mean_pos
    =[-1,-2],fig_name='lv_gaussian_fits_grid.png')
```

A.4. ASCII chamber Faraday cage - Technical drawings

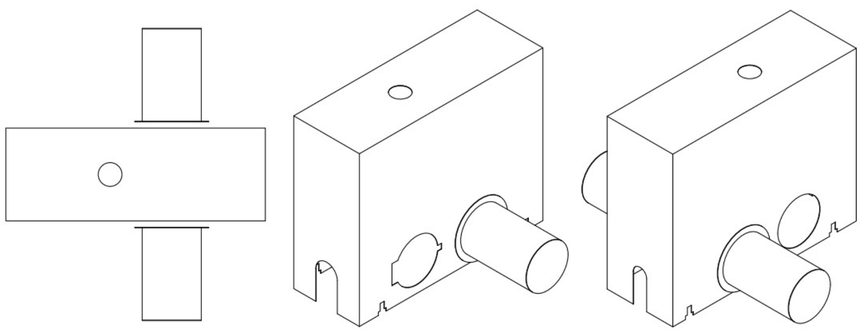
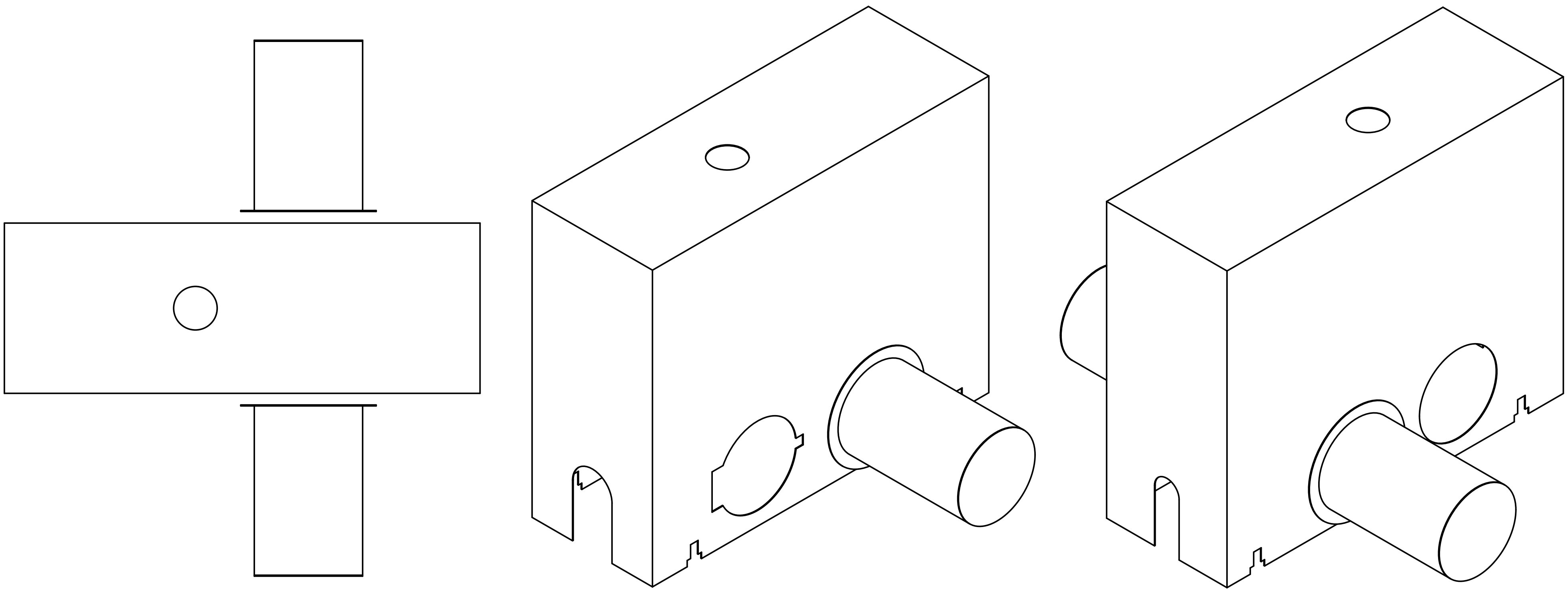
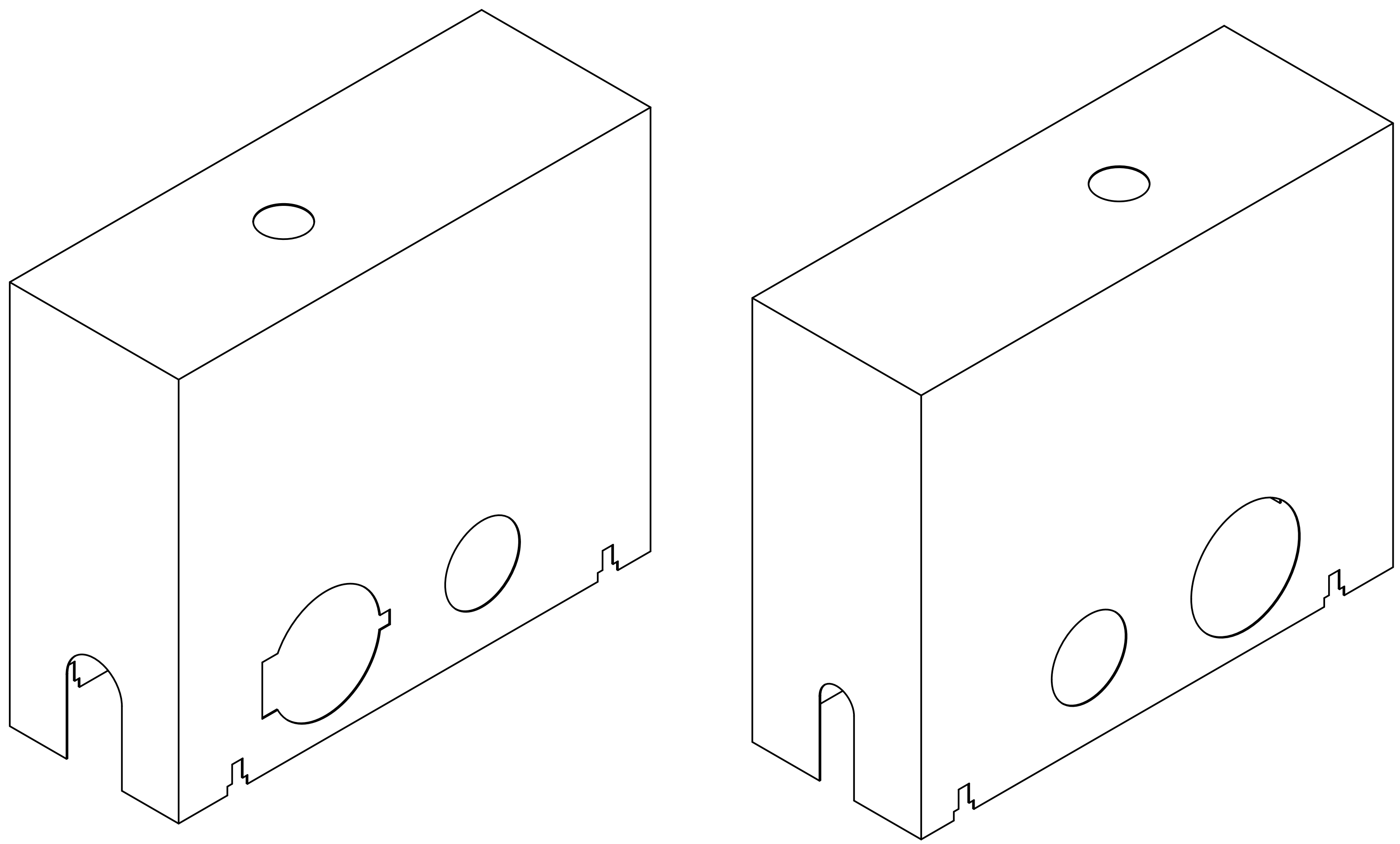


Figure A.1.: Overview of the designed ASCII Faraday cage

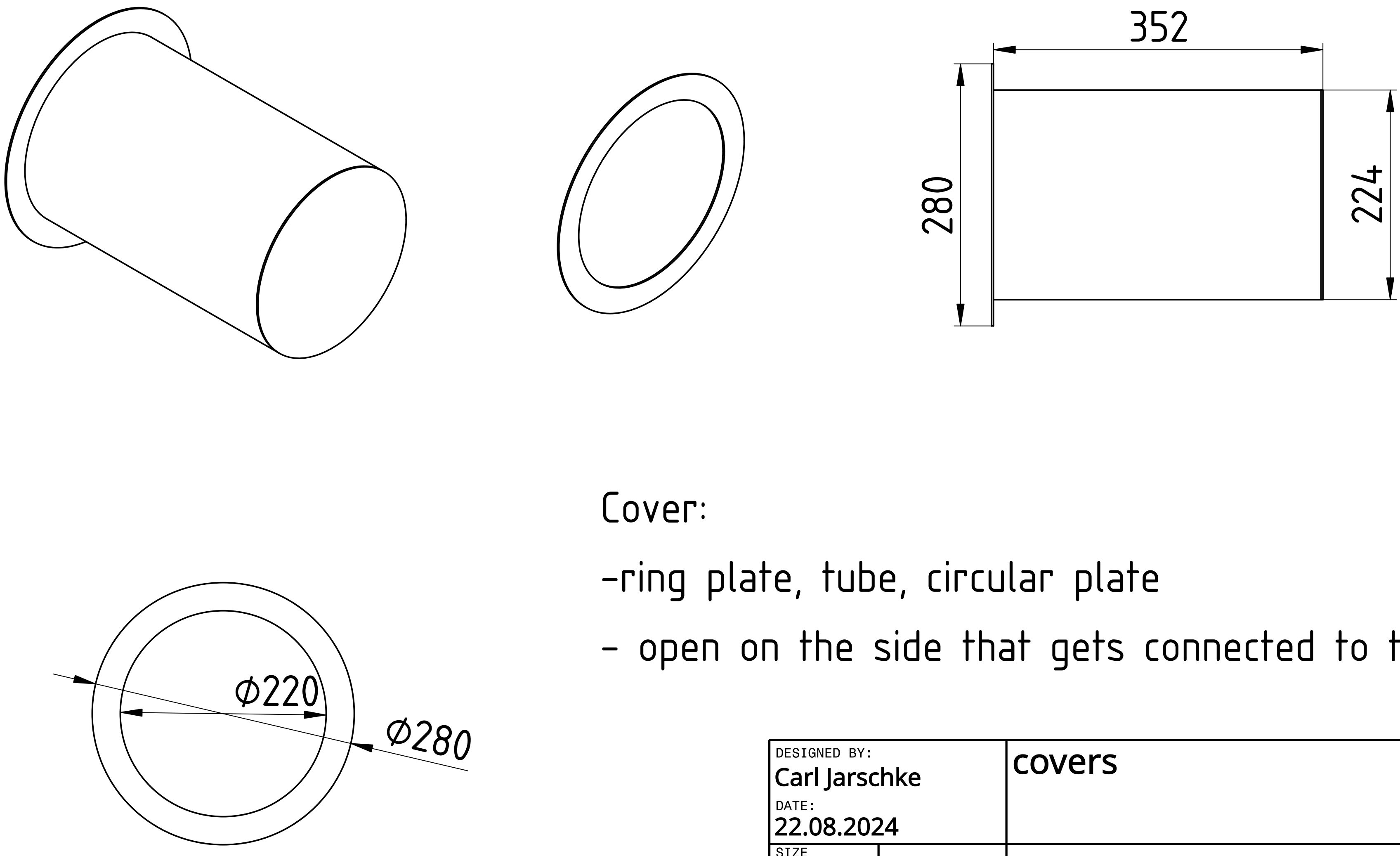


DESIGNED BY: Carl Jarschke DATE: 22.08.2024		Overview		G _
				F _
SIZE A4				E _
				D _
SCALE 0,08	WEIGHT (kg)	DRAWING NUMBER	SHEET	C _
				B _
This drawing is our property; it can't be reproduced or communicated without our written consent.				A _



DESIGNED BY: Carl Jarschke DATE: 22.08.2024	Without covers
SIZE: A4	
SCALE: 0,1	WEIGHT (kg):	DRAWING NUMBER:	SHEET:

Revision	
G	_
F	_
E	_
D	_
C	_
B	_
A	_



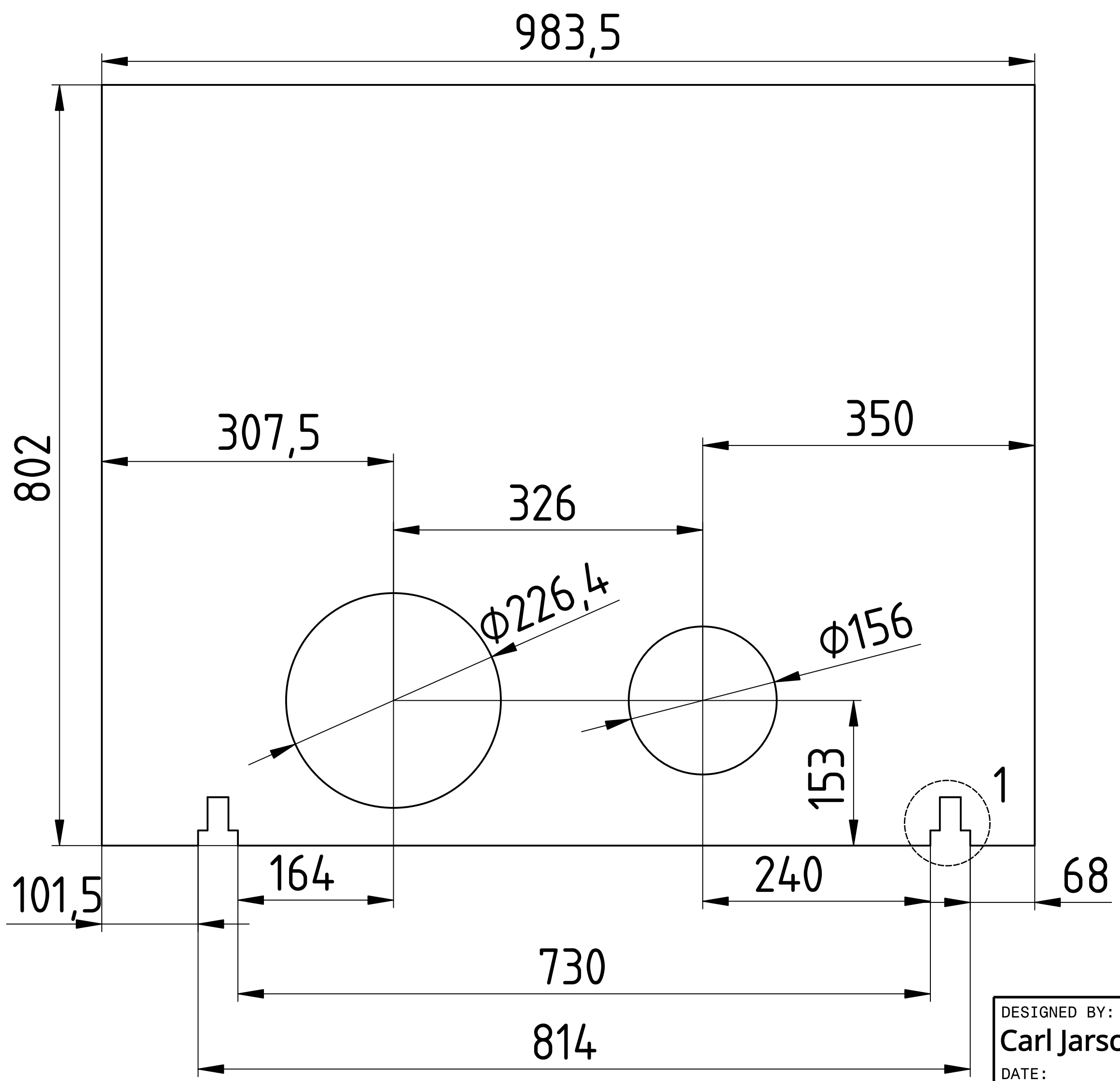
Cover:

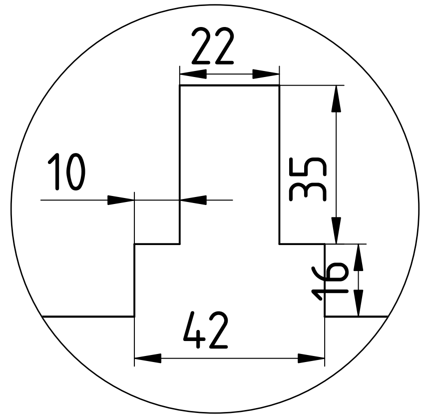
-ring plate, tube, circular plate

- open on the side that gets connected to the plate

DESIGNED BY: Carl Jarschke	DATE: 22.08.2024	covers	
SIZE A4			
SCALE 0,15	WEIGHT (kg)	DRAWING NUMBER	SHEET

G	_
F	_
E	_
D	_
C	_
B	_
A	_





DESIGNED BY:
Carl Jarschke
DATE:
22.08.2024

side plates

SIZE
A4

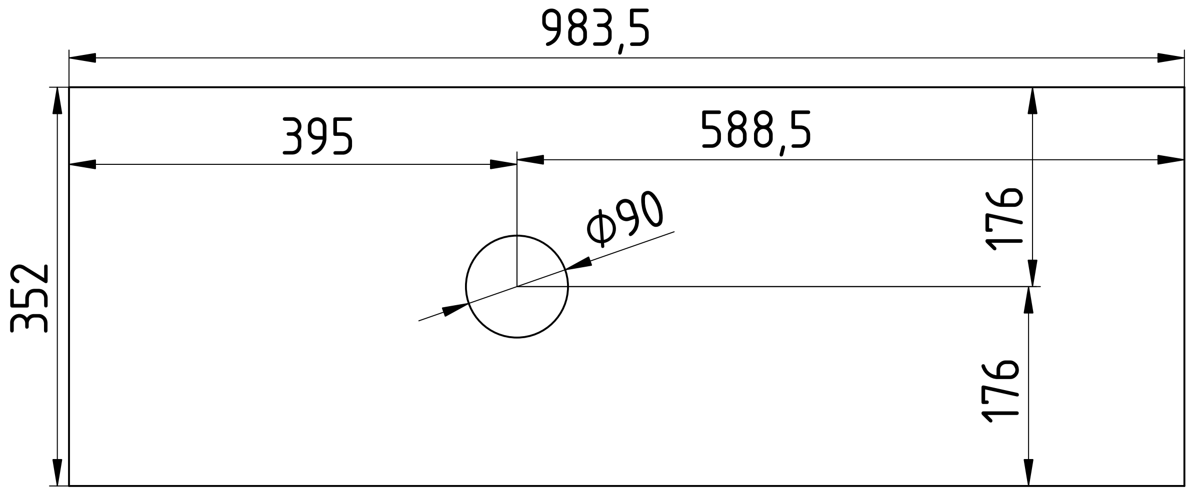
SCALE
0,13

WEIGHT (kg)

DRAWING NUMBER

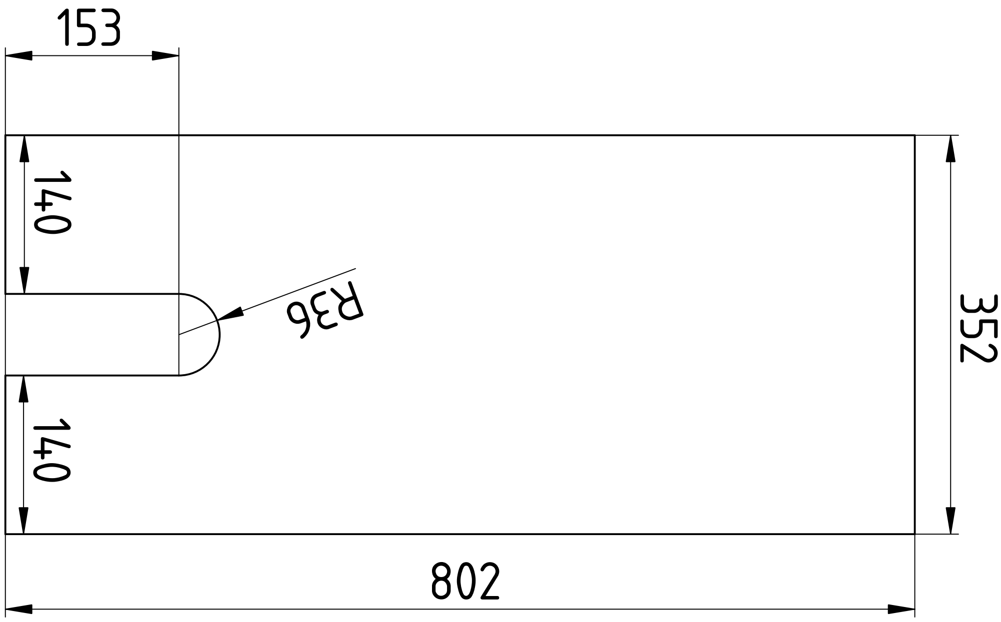
SHEET

G	_
F	_
E	_
D	_
C	_
B	_
A	_



DESIGNED BY: Carl Jarschke DATE: 22.08.2024		top plate	
SIZE A4			
SCALE 0,15	WEIGHT (kg)	DRAWING NUMBER	SHEET

G	_
F	_
E	_
D	_
C	_
B	_
A	_



back plate

DESIGNED BY: Carl Jarschke

DATE: 22.08.2024

SIZE: A4

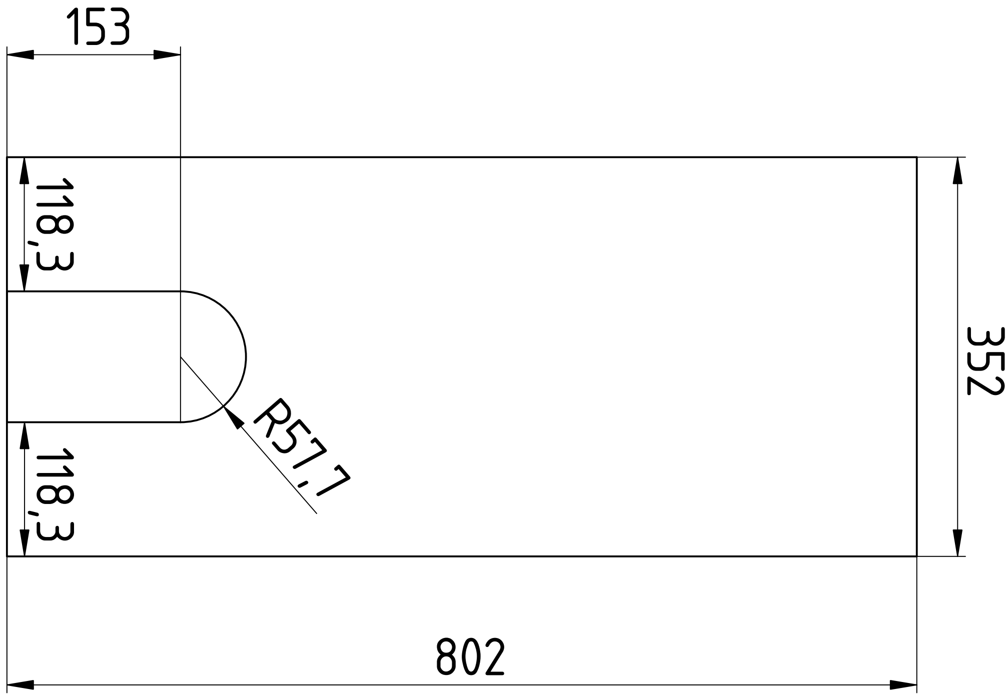
SCALE: 1,5

WEIGHT (kg):

DRAWING NUMBER:

SHEET:

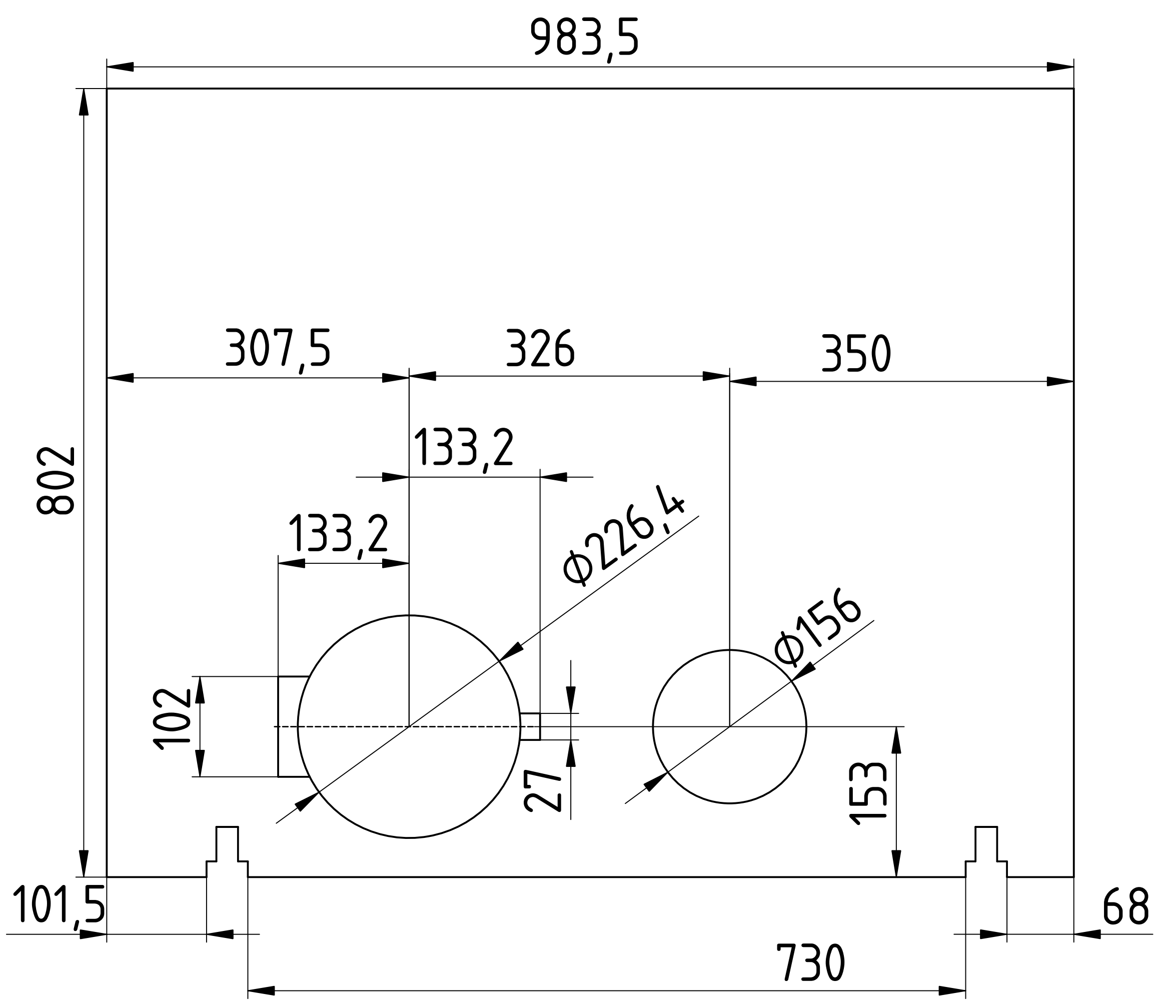
A	B	C	D	E	F	G
_	_	_	_	_	_	_



front plate

DESIGNED BY:	Carl Jarschke
DATE:	22.08.2024
SIZE	A4
SCALE	0,15
WEIGHT (kg)	
DRAWING NUMBER	
SHEET	

A	B	C	D	E	F	G
–	–	–	–	–	–	–



DESIGNED BY: Carl Jarschke DATE: 23.08.2024		right side plate	
SIZE A4			
SCALE 0,13	WEIGHT (kg)	DRAWING NUMBER	SHEET

G	_
F	_
E	_
D	_
C	_
B	_
A	_