Development of deuterium-deuterium compact neutron source

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Outline

1. Deuterium-deuterium (D-D) neutron source fundamentals
2. D-D Source
3. RF System
4. Plasma Chamber:
    1. Magnetic simulations
    2. EM simulations
5. Particle extractor
    1. Lens System design with SIMION
6. Ion Beam Transport & Target
7. Actual state & future works

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1. D-D neutron source fundamentals

- D-D **fusion** reaction:
  - **2.45 MeV** neutrons
  - He-3

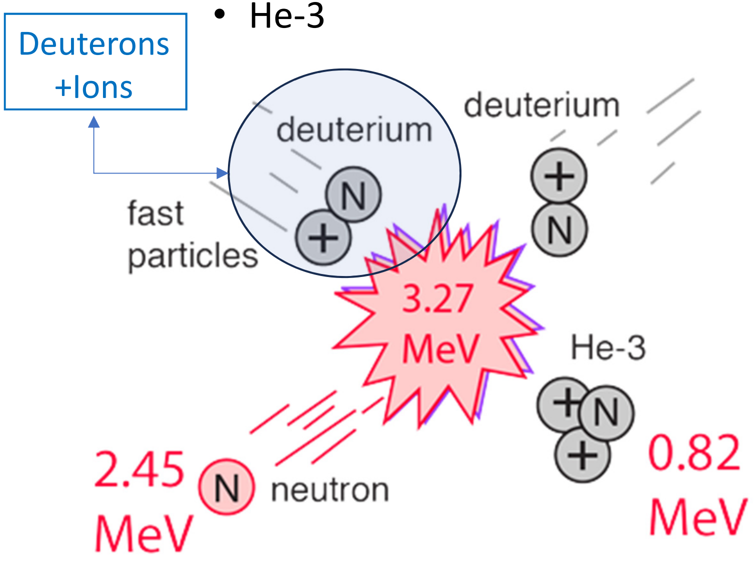


Fig 1. D-D nuclear reaction

- Applications:
  - *Nuclear medicine:*
    - Radioisotopes production
  - *Safety:*
    - Nuclear material detection in explosive devices
  - *Materials research:*
    - Non-destructive imaging technique
    - Determination of the cross-sections of relevant isotopes
    - STUMM-PROTO (IFMIF-DONES)
- Neutron flux: $\mathbf{10^7 \frac{neutrons}{cm^2\,s}}$
- **LOW-COST → D-D sources the cheapest to build**
- **Goals: Gain scientific and engineering know-how**

2. D-D source

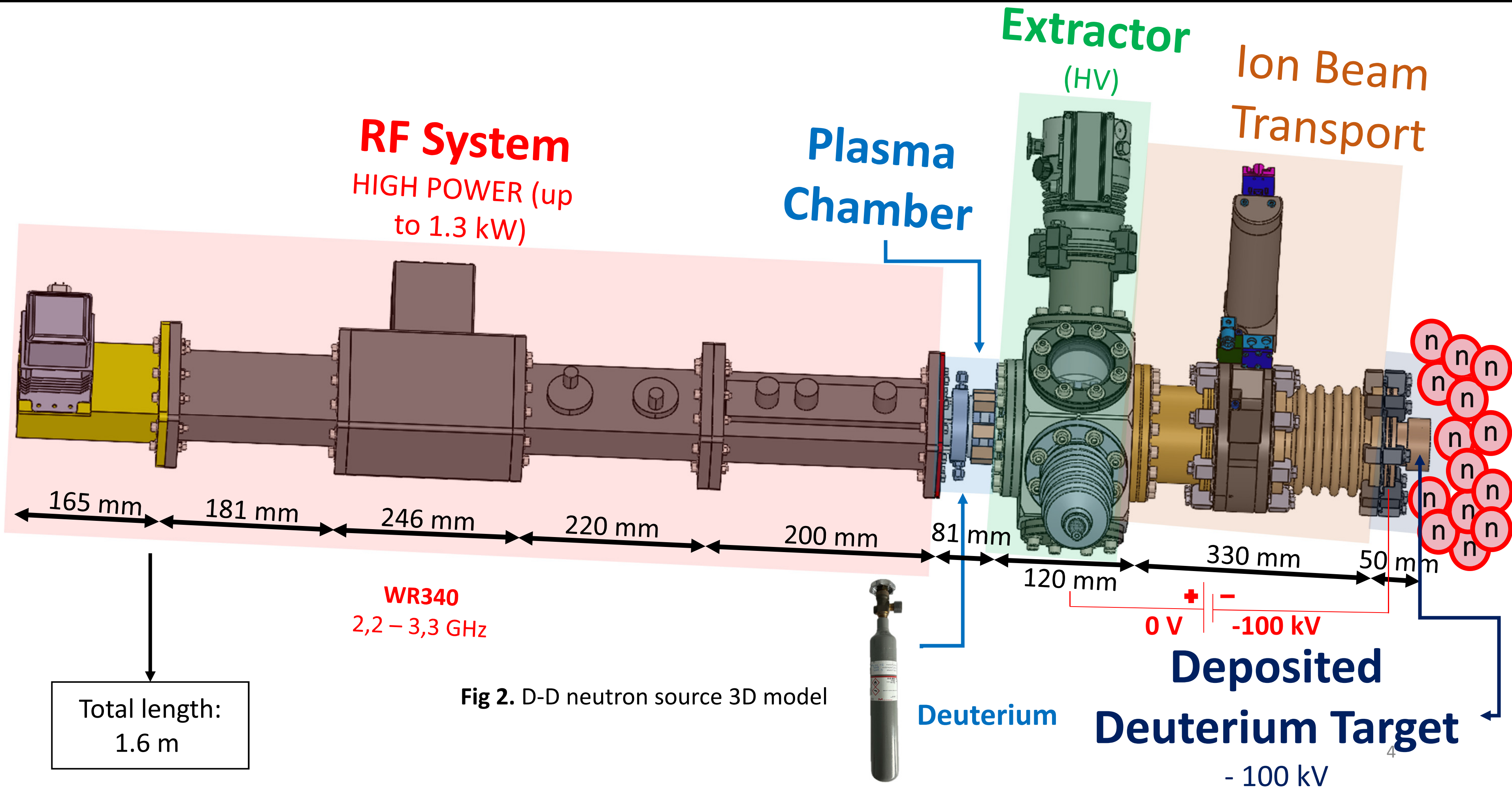


Fig 2. D-D neutron source 3D model

3. RF system

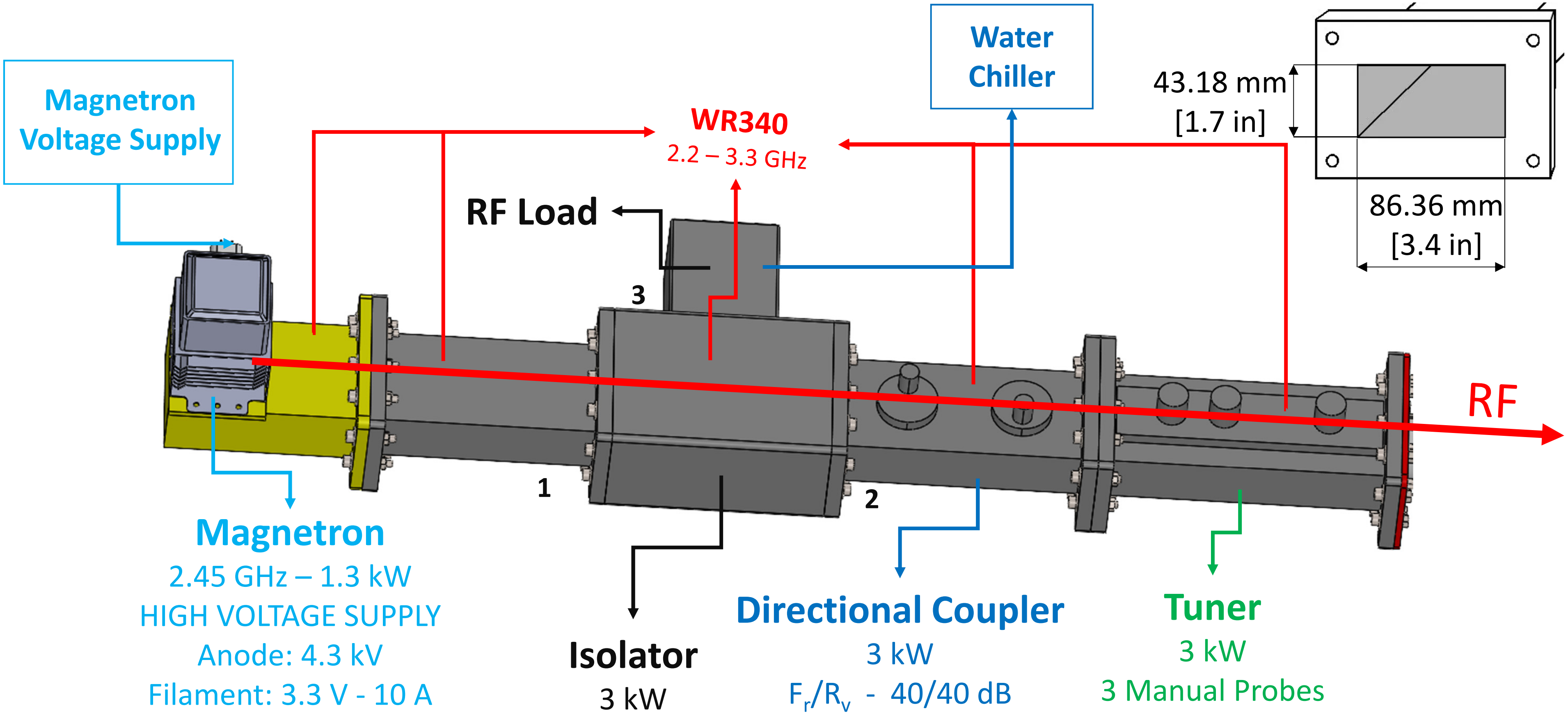


Fig 3. RF System 3D model

3. RF system

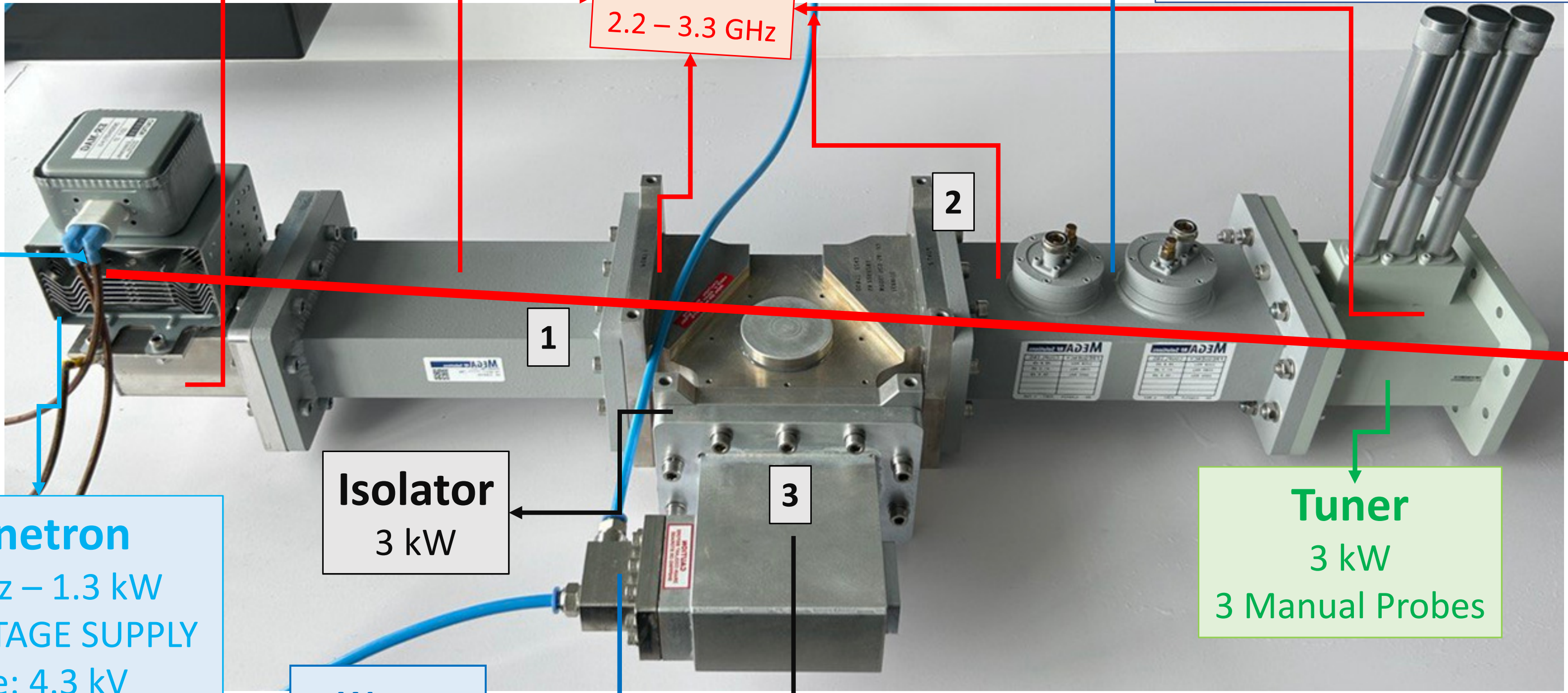


Fig 4. RF System

4. Plasma chamber

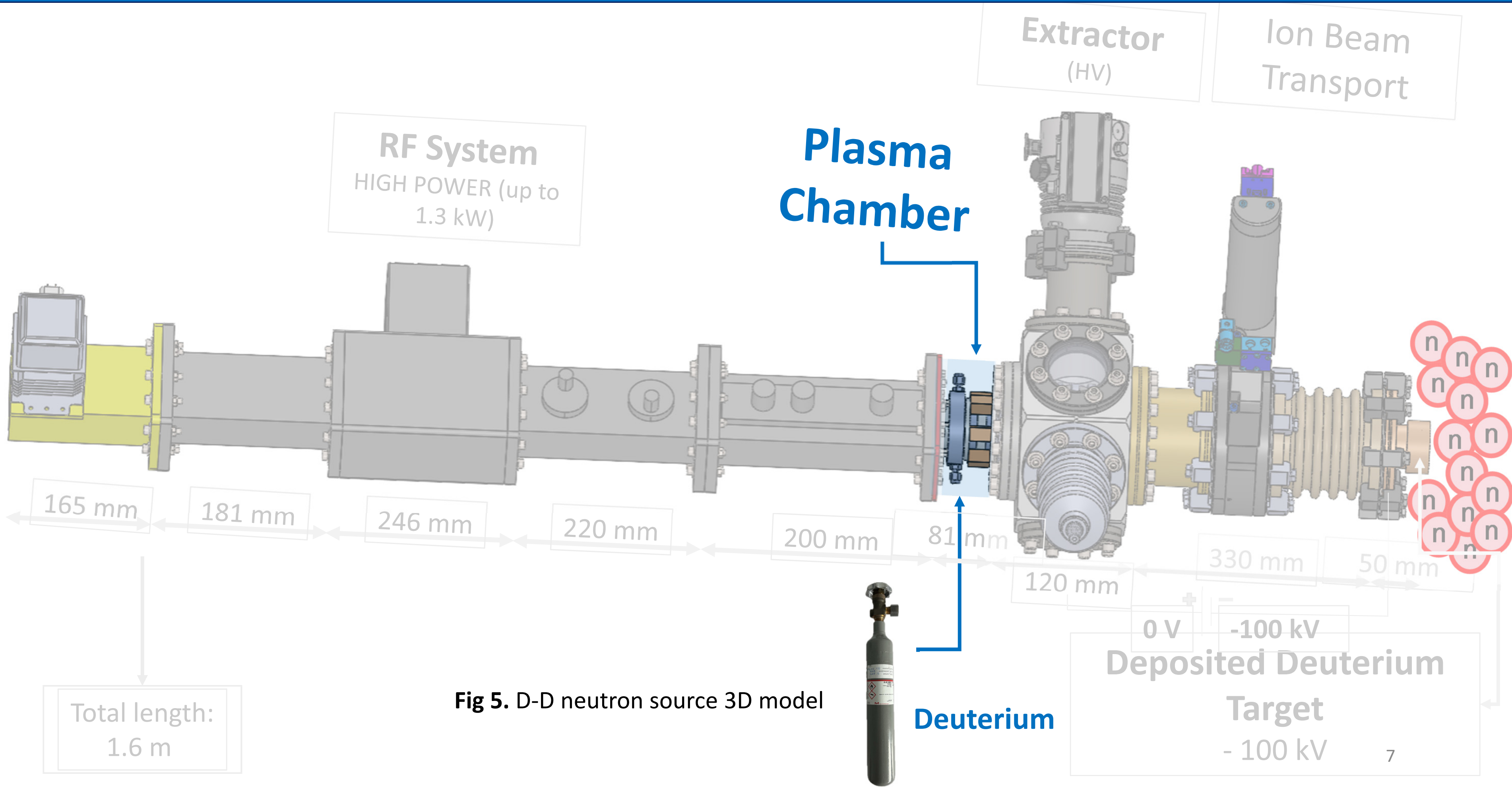


Fig 5. D-D neutron source 3D model

4. Plasma chamber

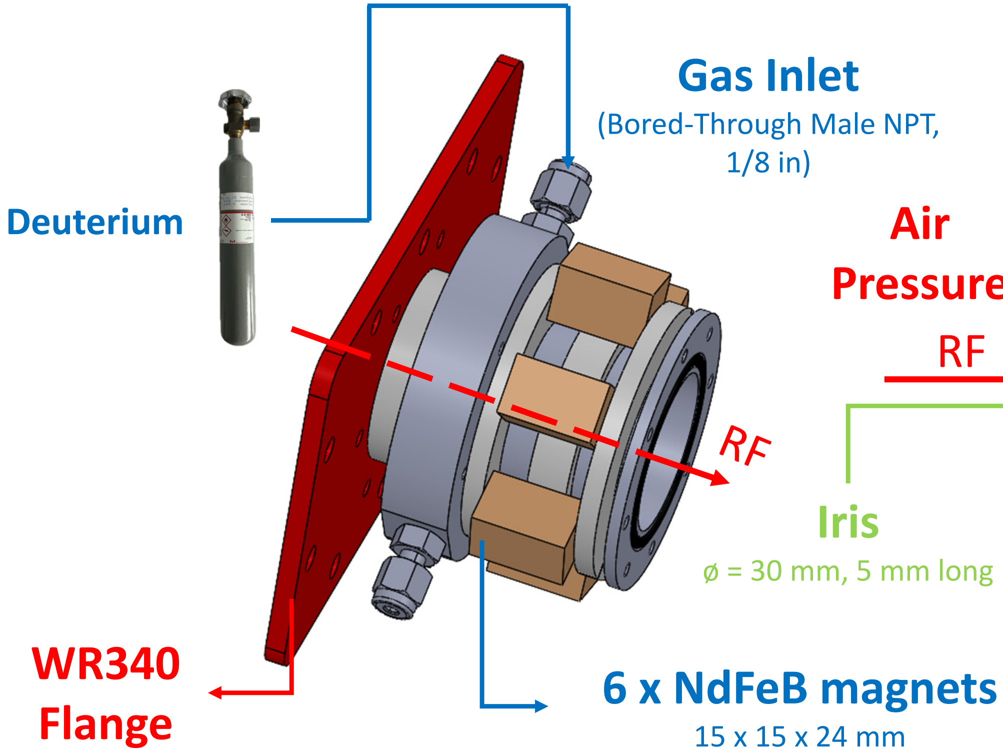


Fig 6.1. Plasma chamber 3D model

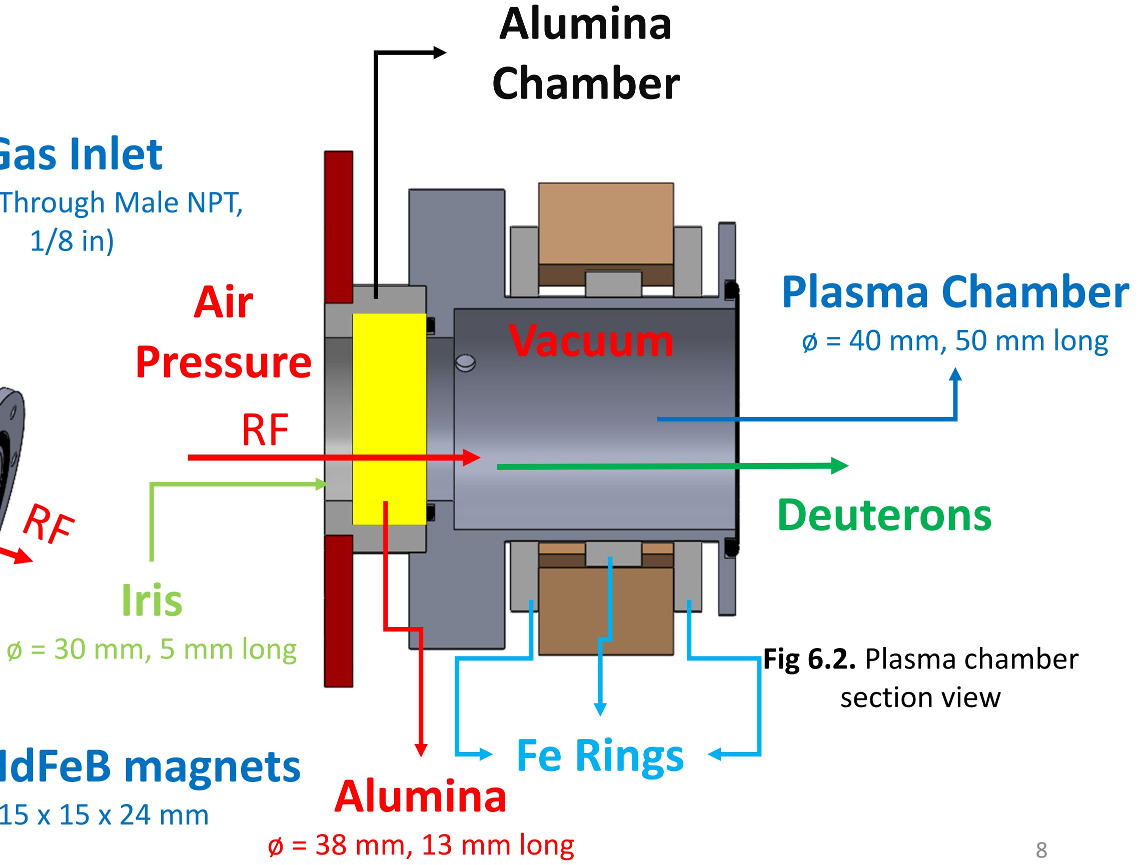


Fig 6.2. Plasma chamber section view

1. RF window
2. Help plasma ignition (first excited electrons)

4.1 Plasma chamber – Magnetic simulations

- **E**lectron **C**yclotron **R**esonance (ECR) Plasmas

$$f = \frac{q \cdot B}{2\pi \cdot m_e} \text{ (Hz)}$$

- q = Electron charge (C)
- B = Magnetic field (T)
- m_e = Electron mass (kg)

- For a **2.45 GHz** RF signal, the value of the desired magnetic field is of **87.5 mT (875 G)**.

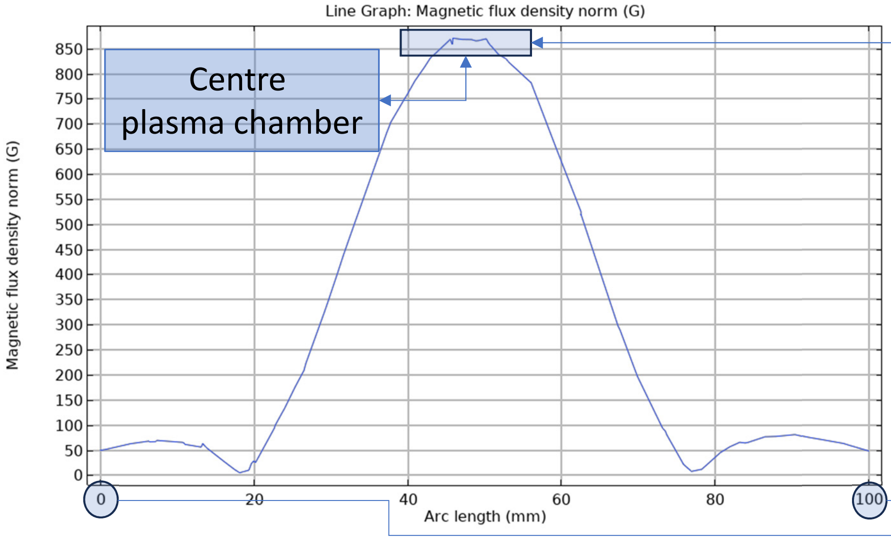


Fig 10. Magnetic field along the magnets

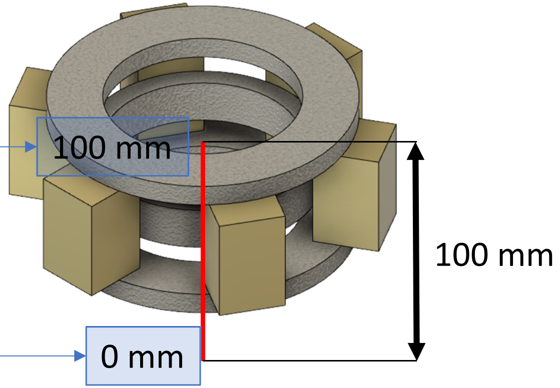


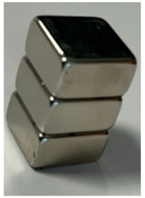
Fig 11. Magnets 3D model

4.1 Plasma chamber – Temporal magnet geometry

Vid 2. Magnet geometry assembly

6 x NdFeB magnets

15 x 15 x 24 mm



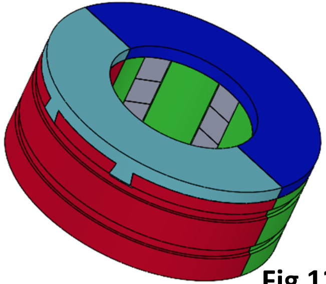


Fig 12. Magnet support

Fig 13. Gaussmeter measurement

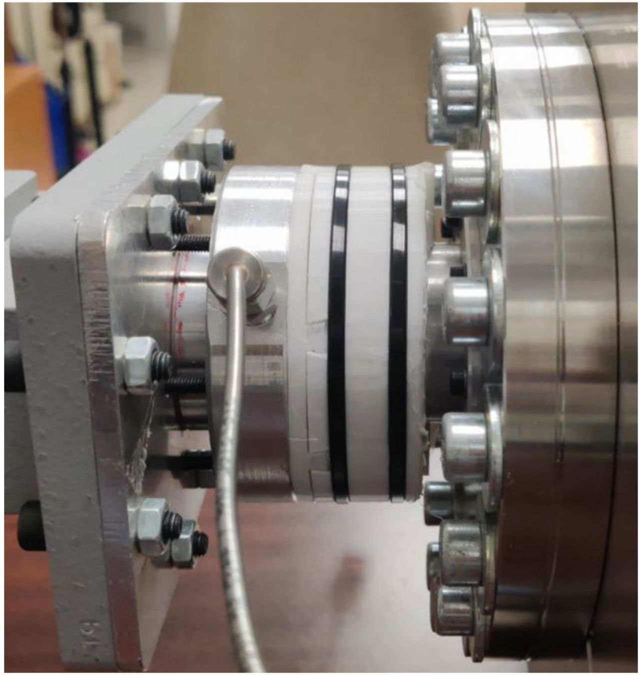


Fig 14. Implementation

4.2 Plasma chamber – EM simulations

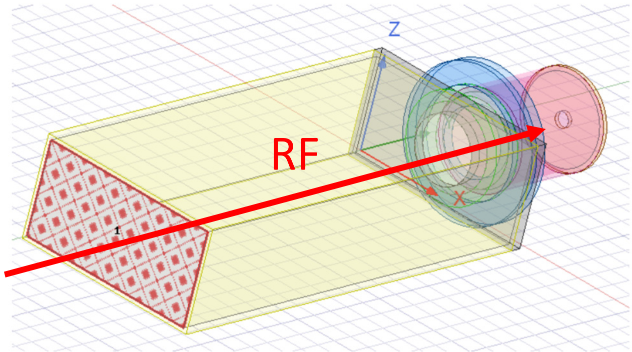


Fig 15. WR340 + Plasma chamber HFSS model

- Iris to adapt the WR340 to plasma chamber geometry
- $P_{\text{in}} = P_{\text{Forward}} = 330\text{ W}$
- NO PLASMA
- $|S_{11}| = -10.19\text{ dB}\ at\ 2.4556\text{ GHz} \rightarrow P_{\text{Reverse}} = 31\ \%$

Low-cost MW Magnetron

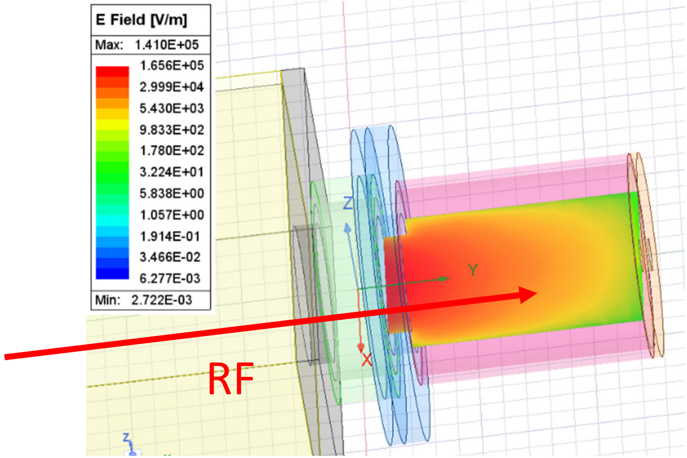


Fig 16. Electric field $\left(\frac{\text{V}}{\text{m}}\right)$ inside the plasma chamber

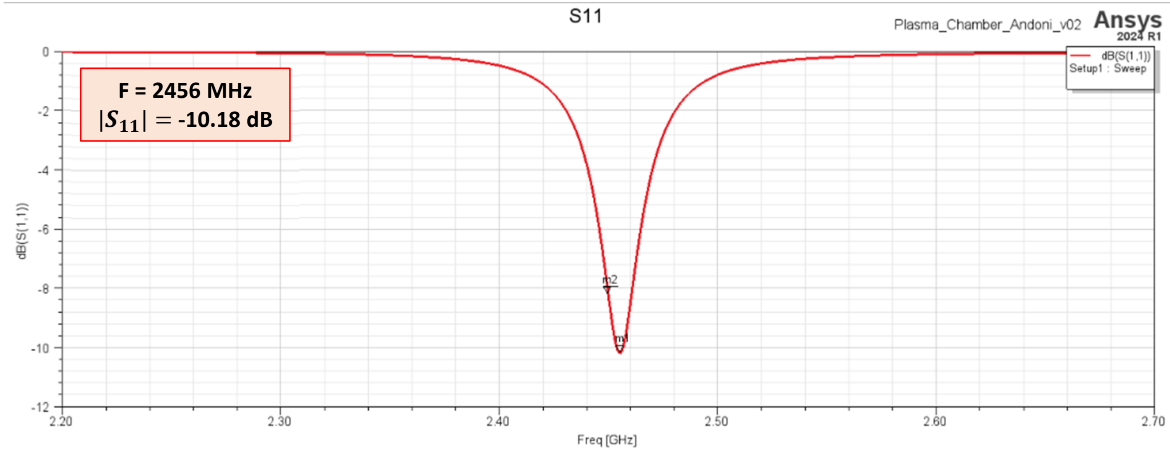


Fig 17. $|S_{11}|$

4.2 Plasma chamber – RF results

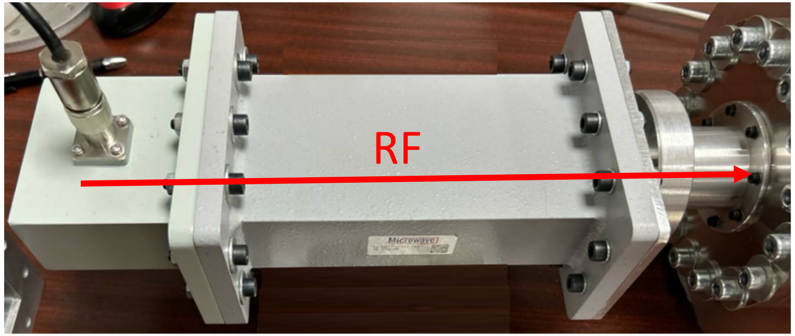


Fig 18. VNA characterization geometry

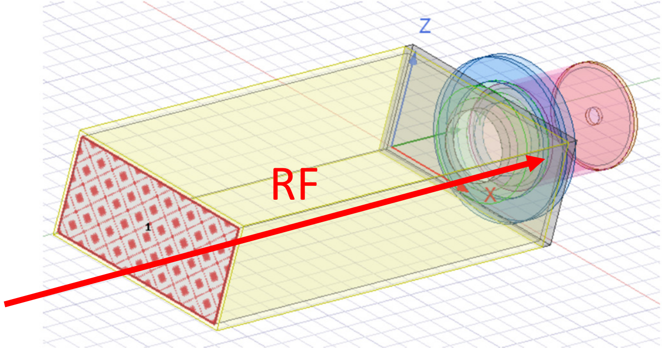


Fig 19. Simulated geometry

VNA characterization

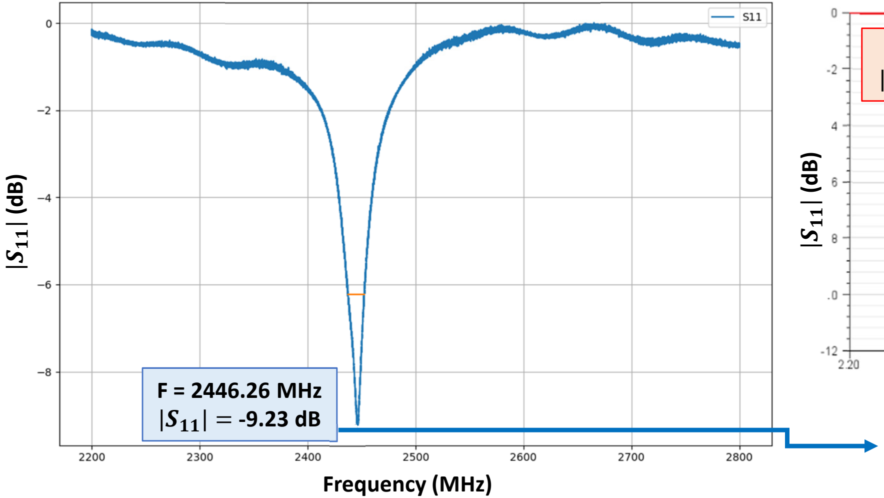


Fig 20. VNA results

SIM results

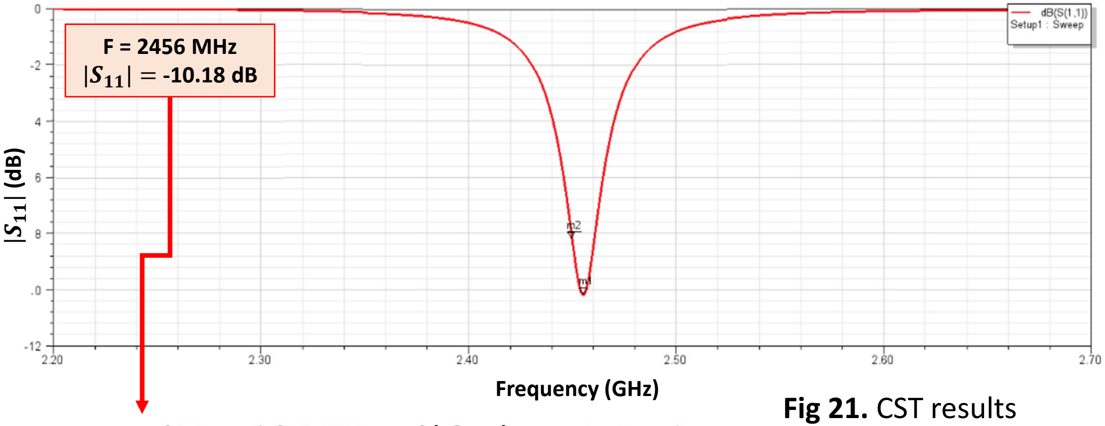


Fig 21. CST results

- $\Delta F = 10$ MHz, $\Delta|S_{11}|$ = - 0.95 dB

4.2 Plasma chamber – Plasma ignition test

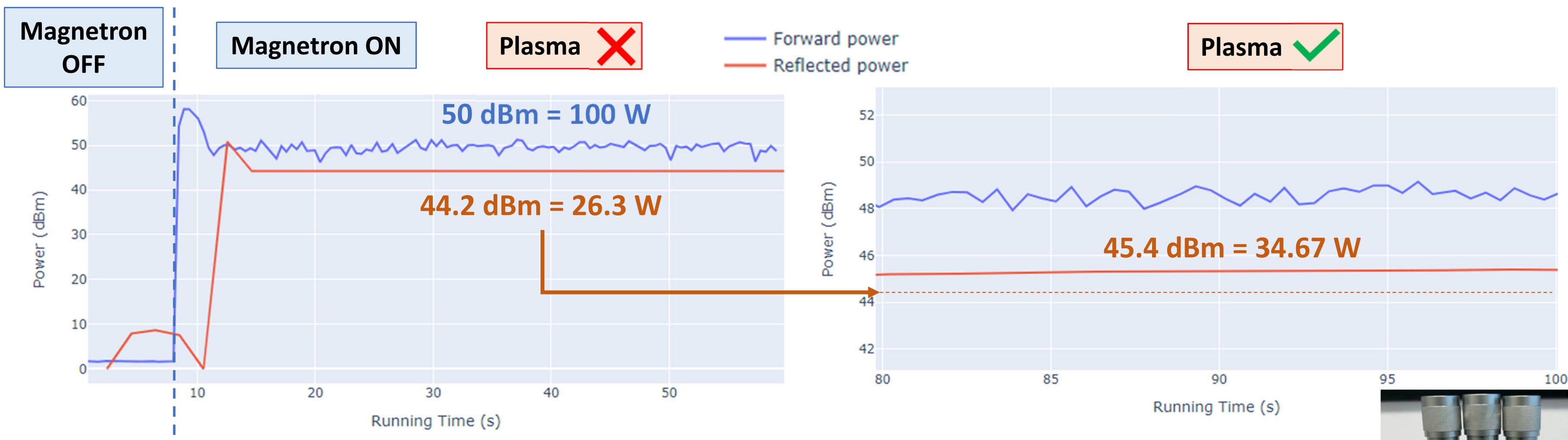


Fig 22. Test results

How to optimise the RF coupling?

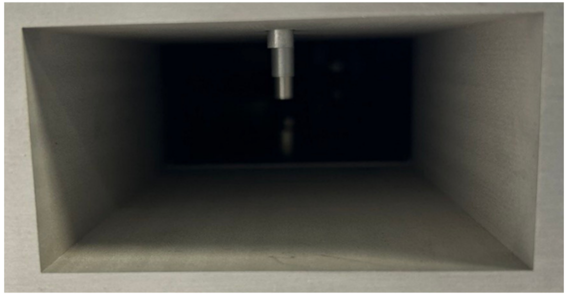
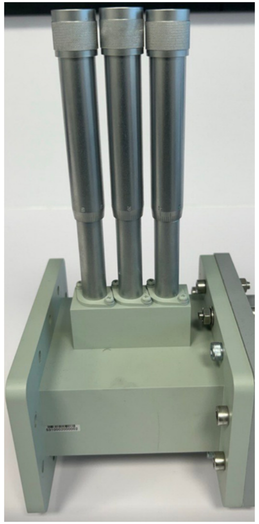


Fig 23. Tuner inside view

Fig 24. Tuner



5. Positive particle extractor

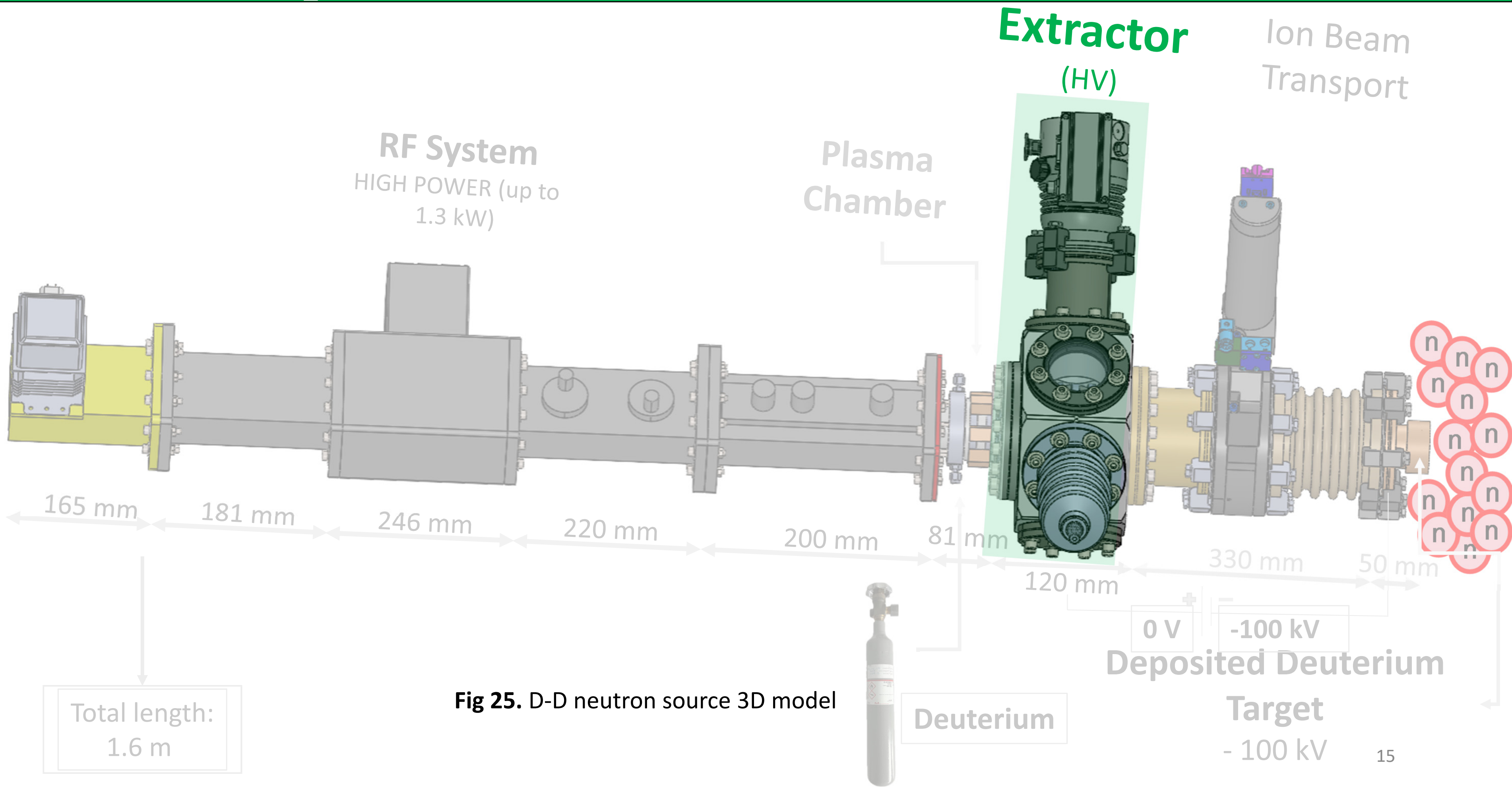


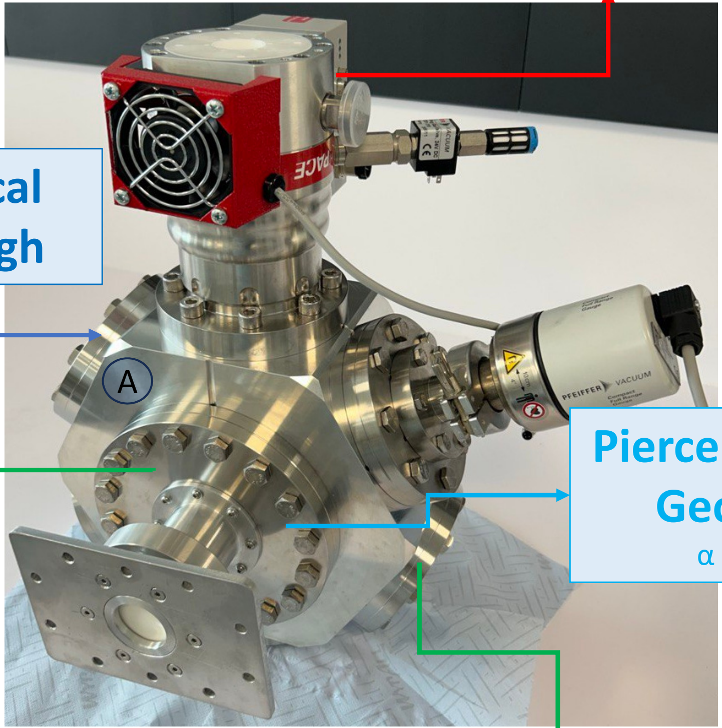
Fig 25. D-D neutron source 3D model

5. Positive particle extractor

Turbopump HiPace 80

Min. Pressure $< 5 \cdot 10^{-10}$ mbar

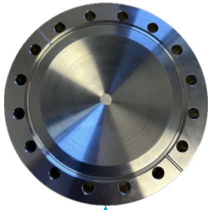
HV Electrical Feedthrough



2 x DN 100 CF Ports

Fig 26. Extractor

6 x DN 63 CF Ports



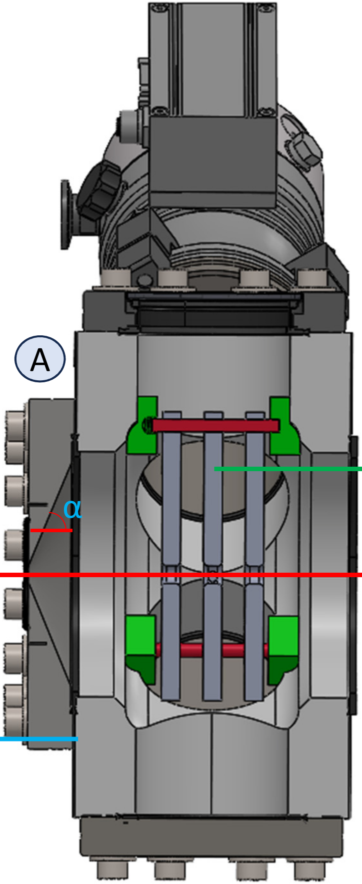
Pierce Electrode Geometry

$\alpha = 67.5$ º

Lens system

Fixed at [-60 kV, 0 V]

Design phase

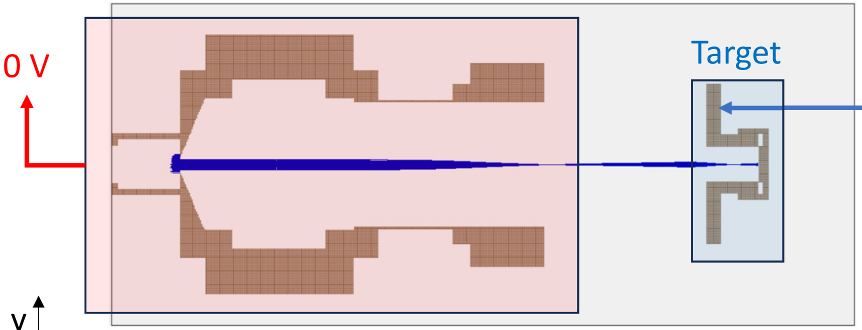


+Ion Beam

Fig 27. Extractor 3D model section view

5. Extractor – Lens system design SIMION

No lense acceleration 2D geometry:



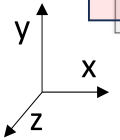


Fig 28. SIMION 2D geometry

Target voltage (kV)	% ion transport	% ion splats	% splat area
-10	64.95	100	0.36
-30	63.99	100	0.28
-60	64.59	100	0.19
-100	64.93	100	0.13

Tab 1. SIMION results

Nparticles = 10000

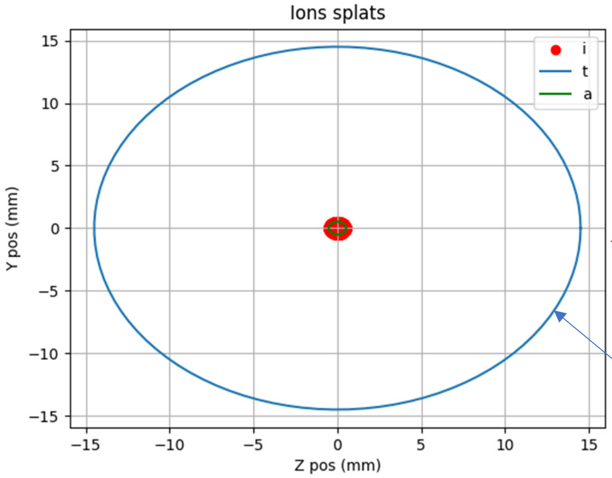


Fig 29. Ions splat

Target

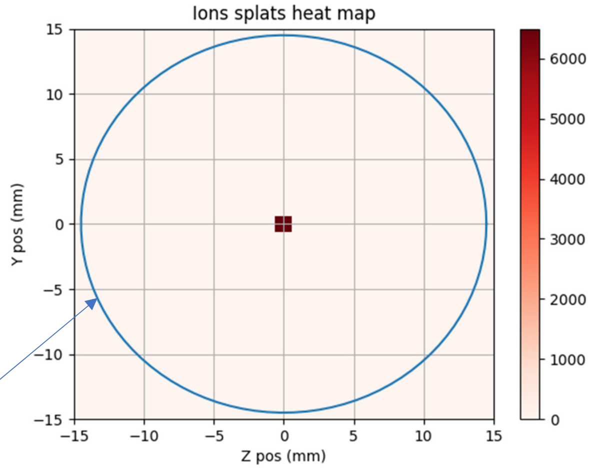


Fig 30. Ions splat heat map

5. Extractor – Lens system design SIMION

1 lense acceleration 2D geometry:

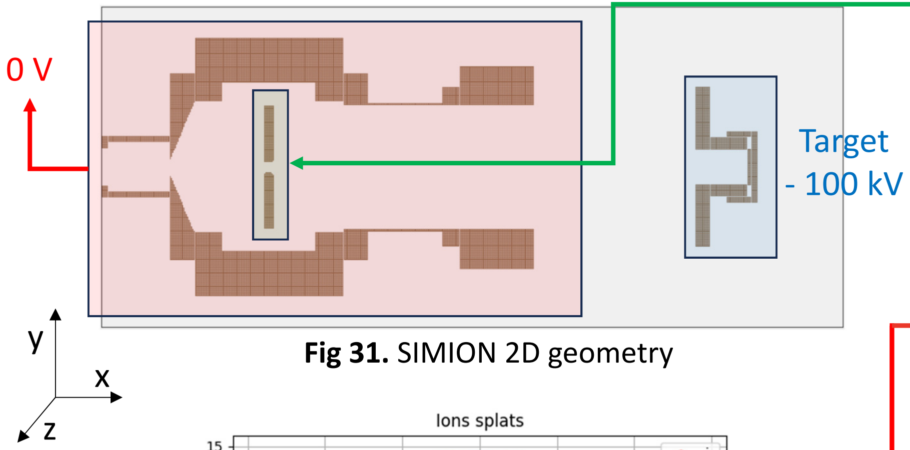


Fig 31. SIMION 2D geometry

Lens voltage (kV)	Target voltage (kV)	% ion transport	% ion splats	% splat area
0	-100	64.97	92.21	0.11
-10	-100	97.43	53.51	3.3
-30	-100	99.89	64.03	8.72
-60	-100	99.99	76.15	14.23

Nparticles = 10000

Tab 2. SIMION results

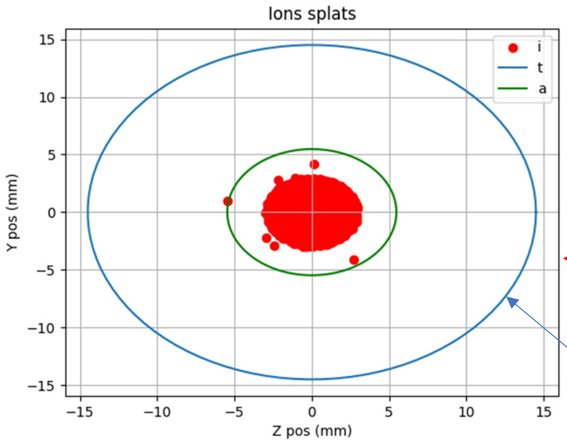


Fig 32. Ions splat

Target

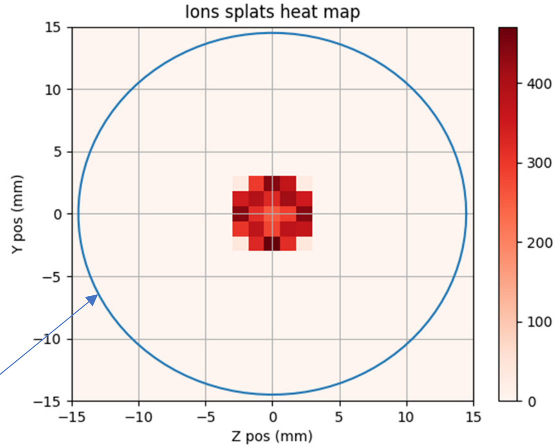


Fig 33. Ions splat heat map

6. Ion beam transport & target

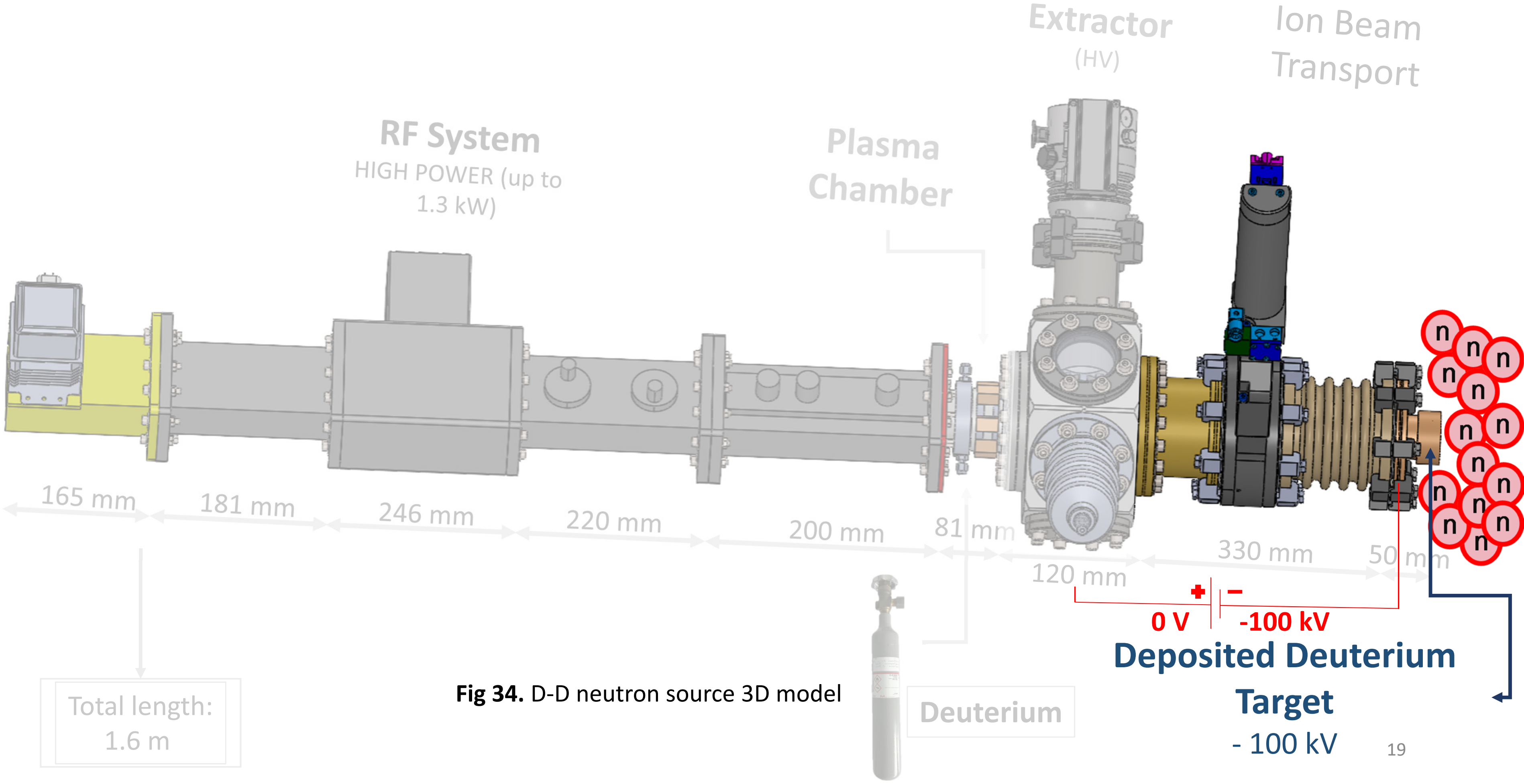


Fig 34. D-D neutron source 3D model

6. Ion beam transport & target

1. Keep vacuum state while changing the target
2. Stop the ion beam in unsafe conditions

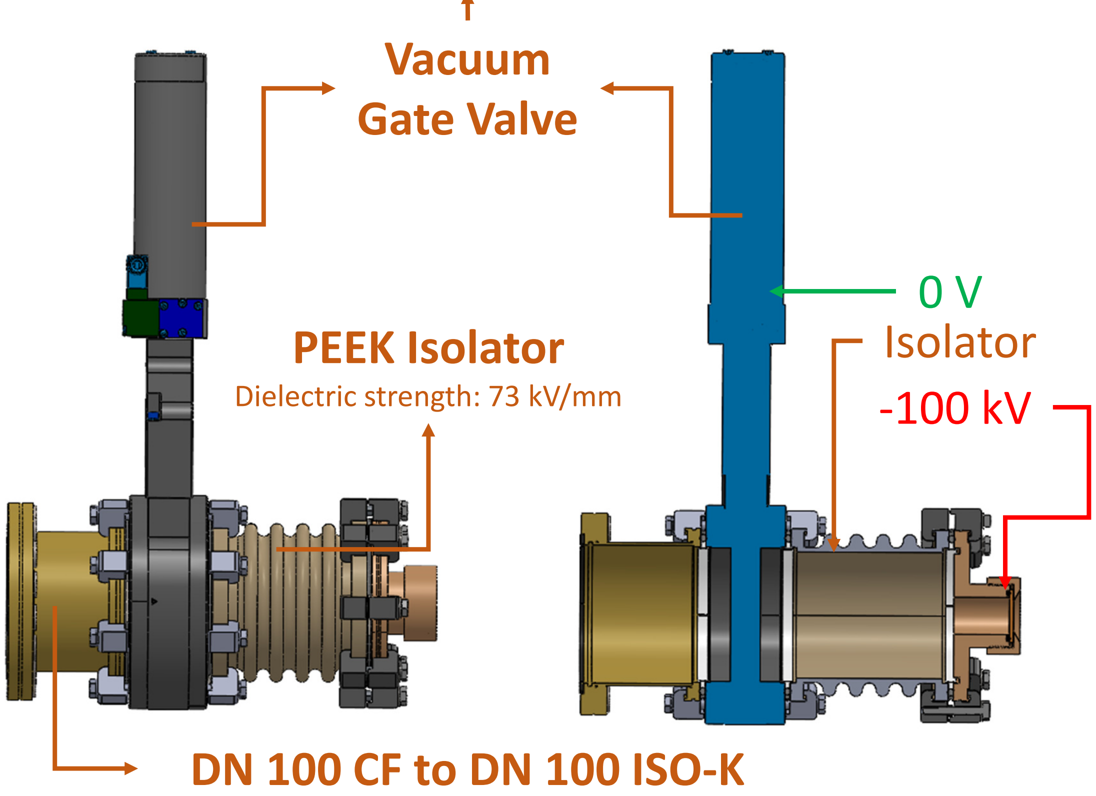


Fig 35. Beam tranport & target

Fig 36. Ceramic isolator

6. Ion beam transport & target

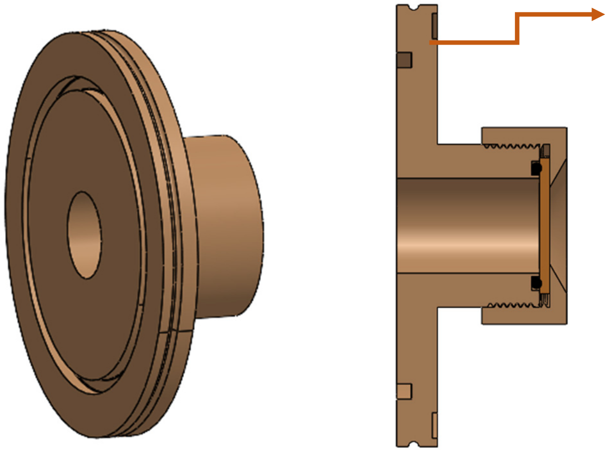


Fig 37. Target geometry

Vid 3. Target assembly

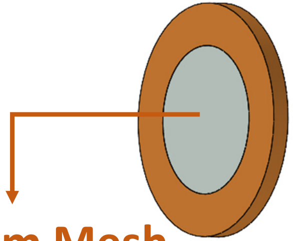
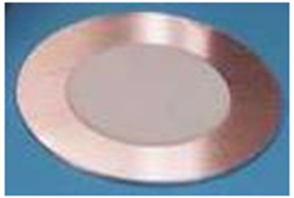


Fig 38. Target 3D model

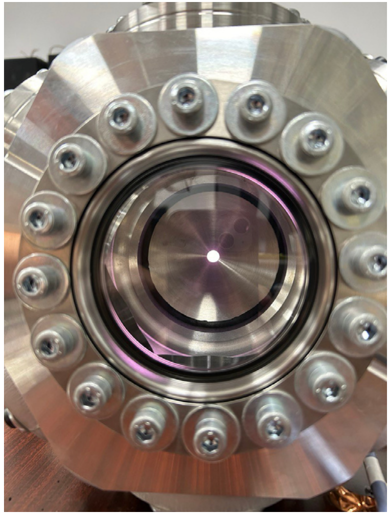
Standard targets (OFHC copper disks)

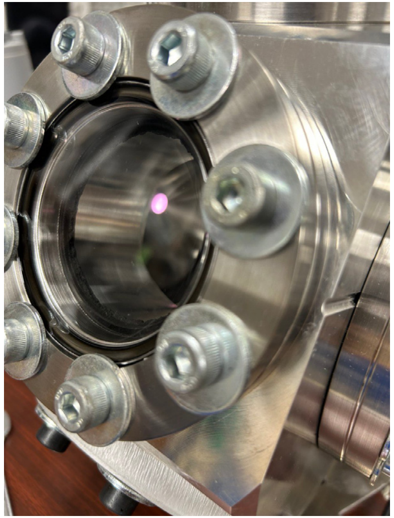


7. Actual state & future works

Actual state:

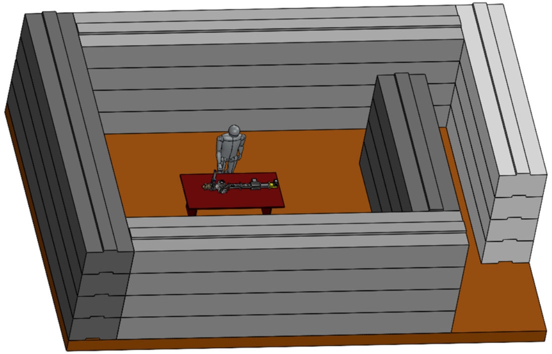
- Most of the design completed
- First deuterium plasma ignited





Future works:

- Measure the min RF level to ignite plasma
- Study behaviour different gases
- Langmuir probe measurements
- Accelerator’s HV end construction
- Extraction and ion beam current study
- Radioprotection bunker design and construction



Thank you for your attention