LhARA - Beam Capture

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Gabor Lenses – Why?

- Focal length scales with the kinetic energy of the incoming beam
- Solenoid like, but requires much lower B field for equivalent focal length

$$B_{GPL} = B_{SOL} * (m_e/m_{ion})^{0.5}$$

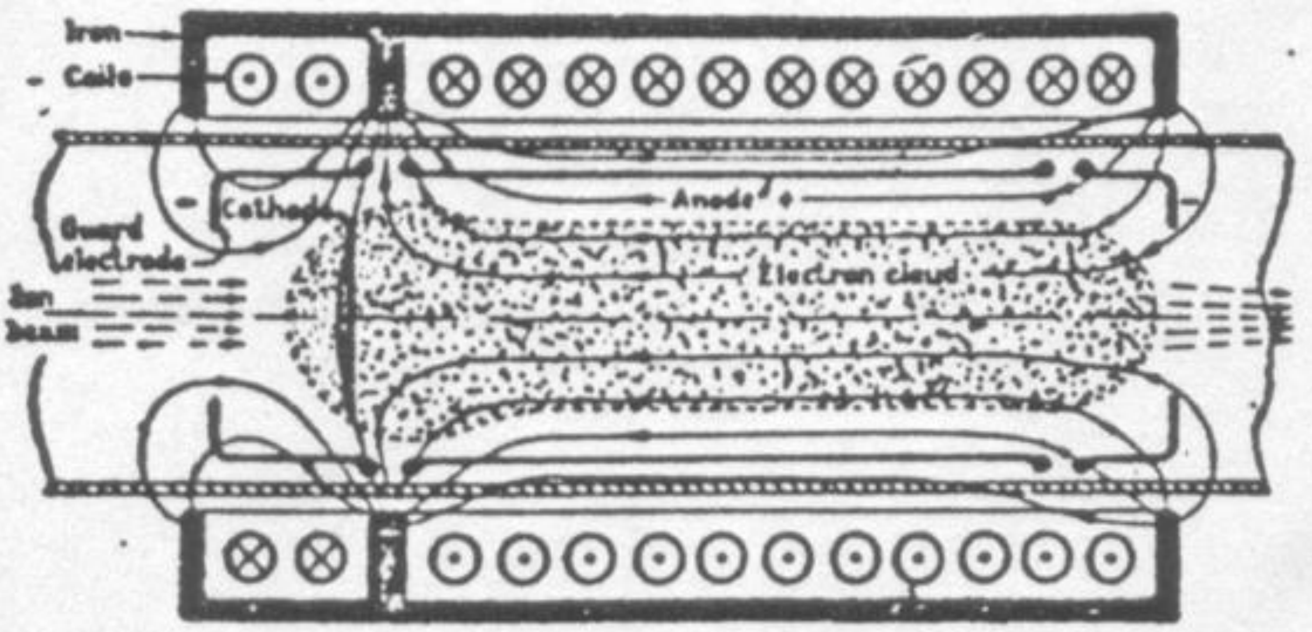
For protons

$$B_{GPL} = B_{SOL}/44$$

- Quadrupole scales with momentum, longer focal length at high beam energy.

Gabor Lenses

- Gabor – 'A space-charge lens for the focussing of ion beams' Nature July 19, 1947.
- A uniform static electron 'cloud' produces an ideal focusing electric field.

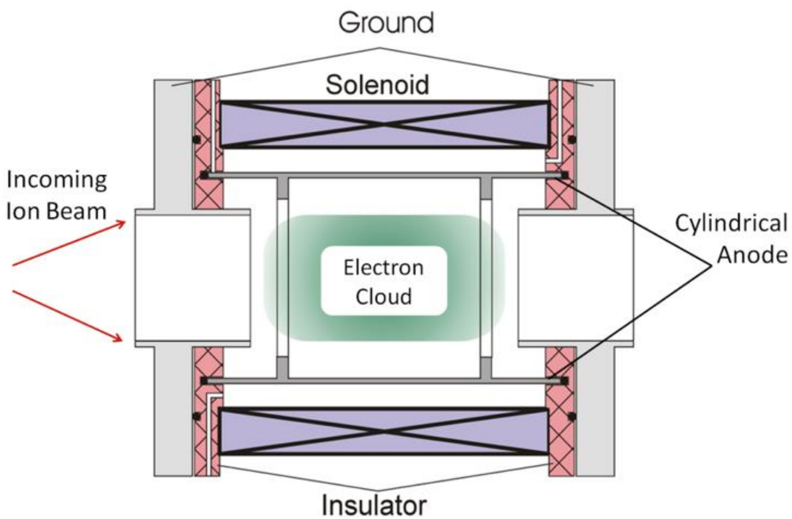


MAGNETRON LENS FOR ION BEAMS

Gabor Lenses - History

- Brookhaven. Mobley, Gammel, Maschke
- Russia Morozov, Goncharov
- Livermore NL Booth & Lefevre
- Fermi NL Palkovic
- Maryland Reiser

But… lens performance was poor



Re-emergence – heavy ion beam.

- Devices with background plasma for beam space charge neutralisation. Goncharov, Tauschwitz, Ivanov, Neuner.

Frankfurt/ICL Pozimski, Schulte, Meusel

Experiment

n_e ~1 x 10^{15}

Numerical simulation

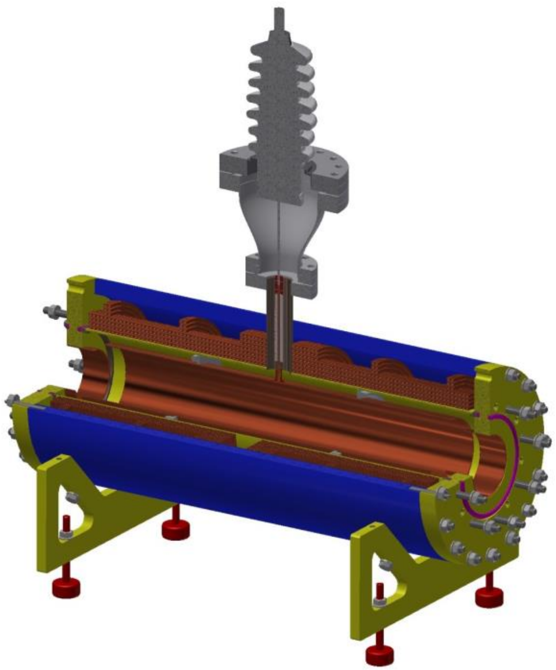
Diagnostics

Electron density – ion beam

Electron temp – spectroscopic

n_e < 1 x 10^{15} dicotron instability

Seen in numerical simulation



Gabor Lens - Theory

Radial confinement

$$n_e = e_0 B^2/2m_e e = 5x10^{18} B^2$$

Axial confinement

$$n_e = 4e_0 V_A/eR^2$$

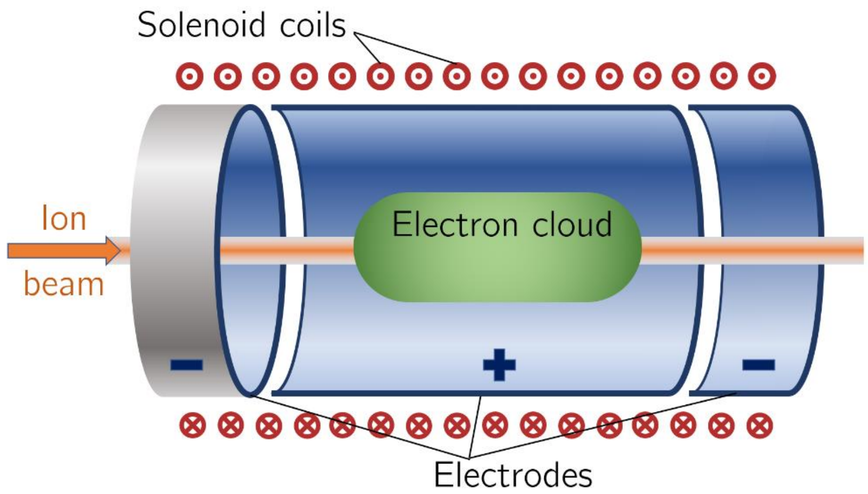
Focal length

$$f = 4m_e m_p v_p{}^2/e^2 B^2 l$$

B field reduction

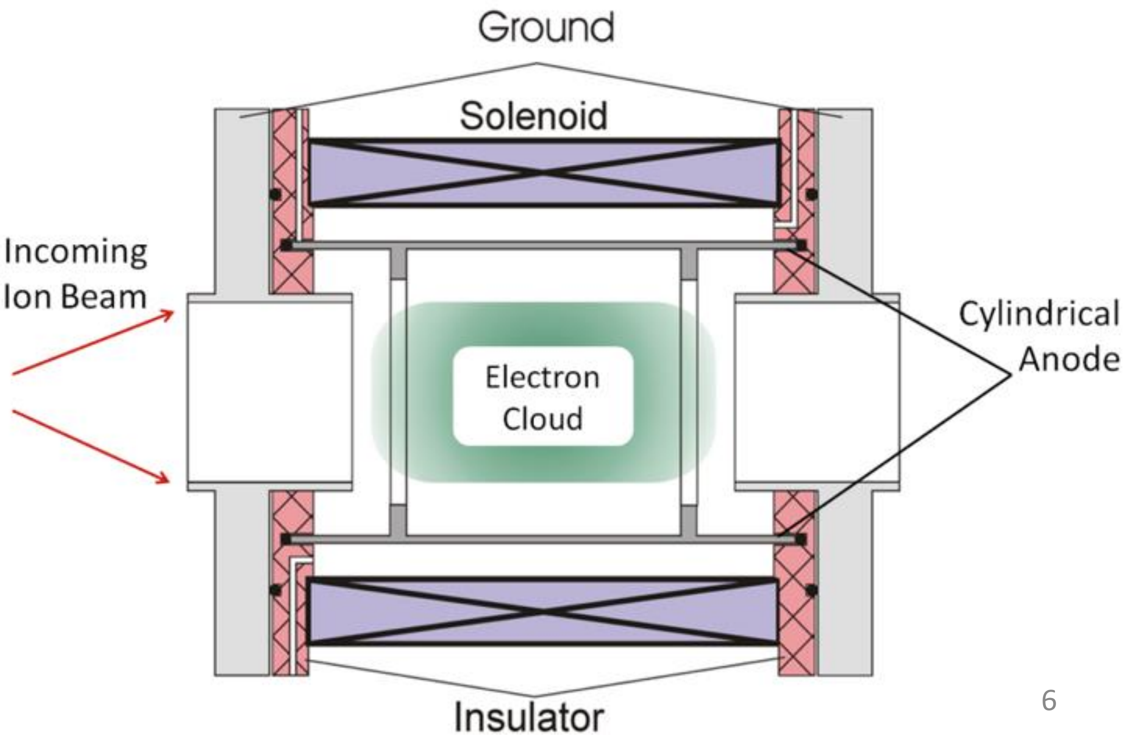
$$B_{gpl}/B_{sol} = (m_e/m_{ion})^{0\cdot 5} \sim = 44$$

Penning – Malmberg trap

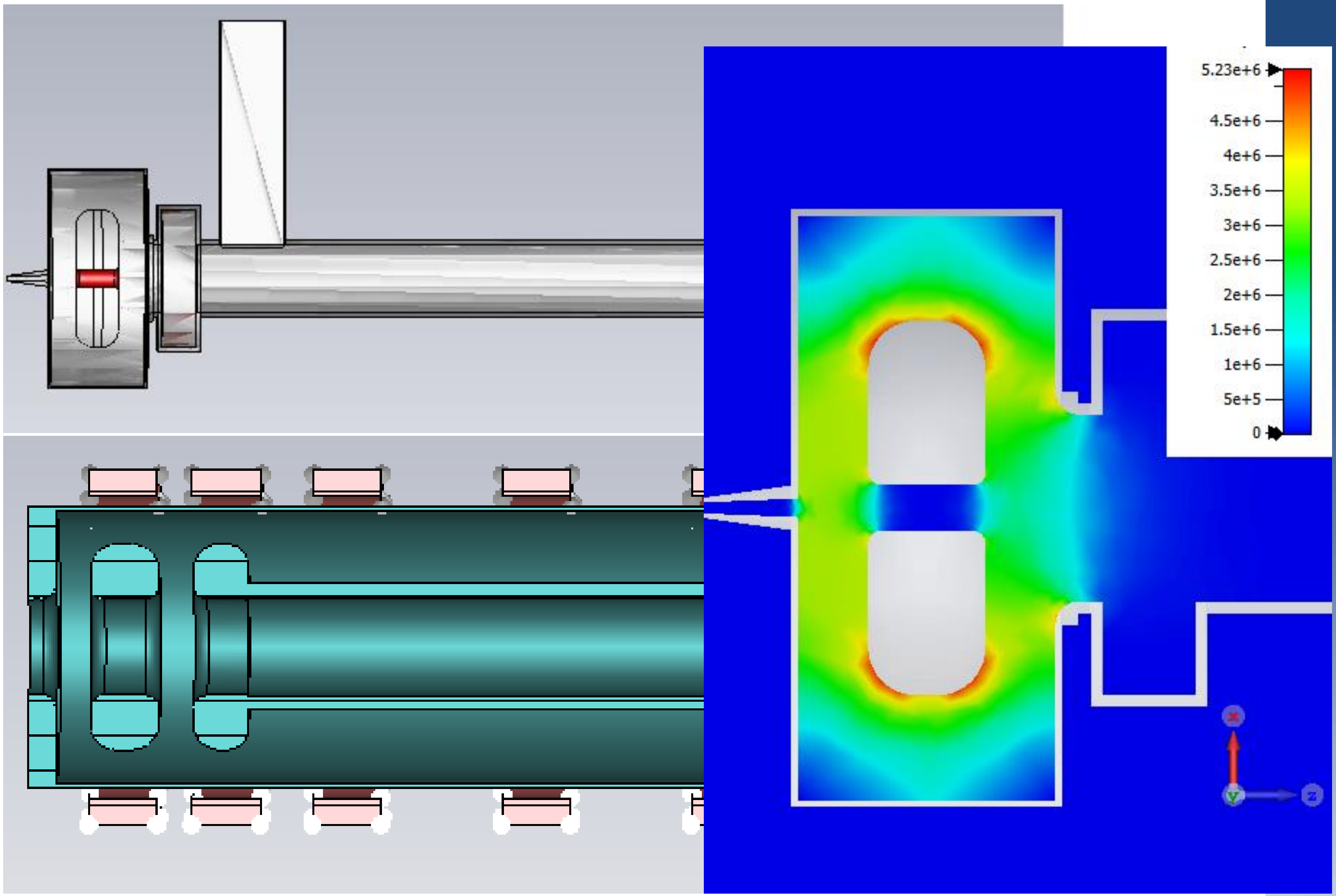


Excellent beam aperture

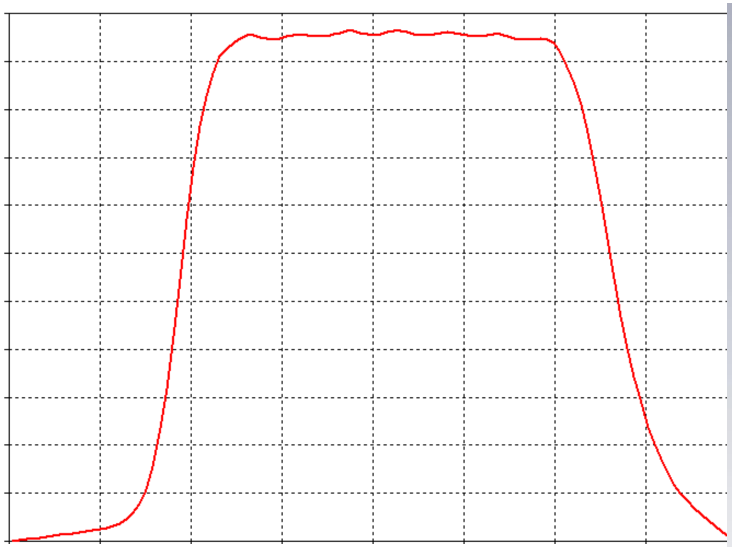
Design for High voltage

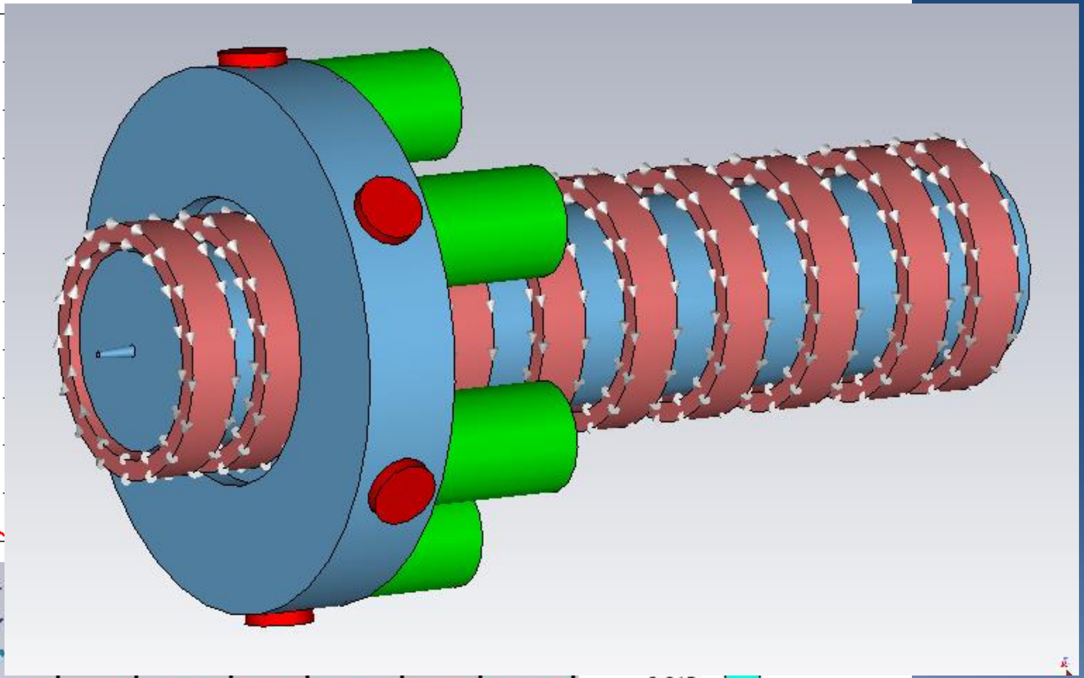


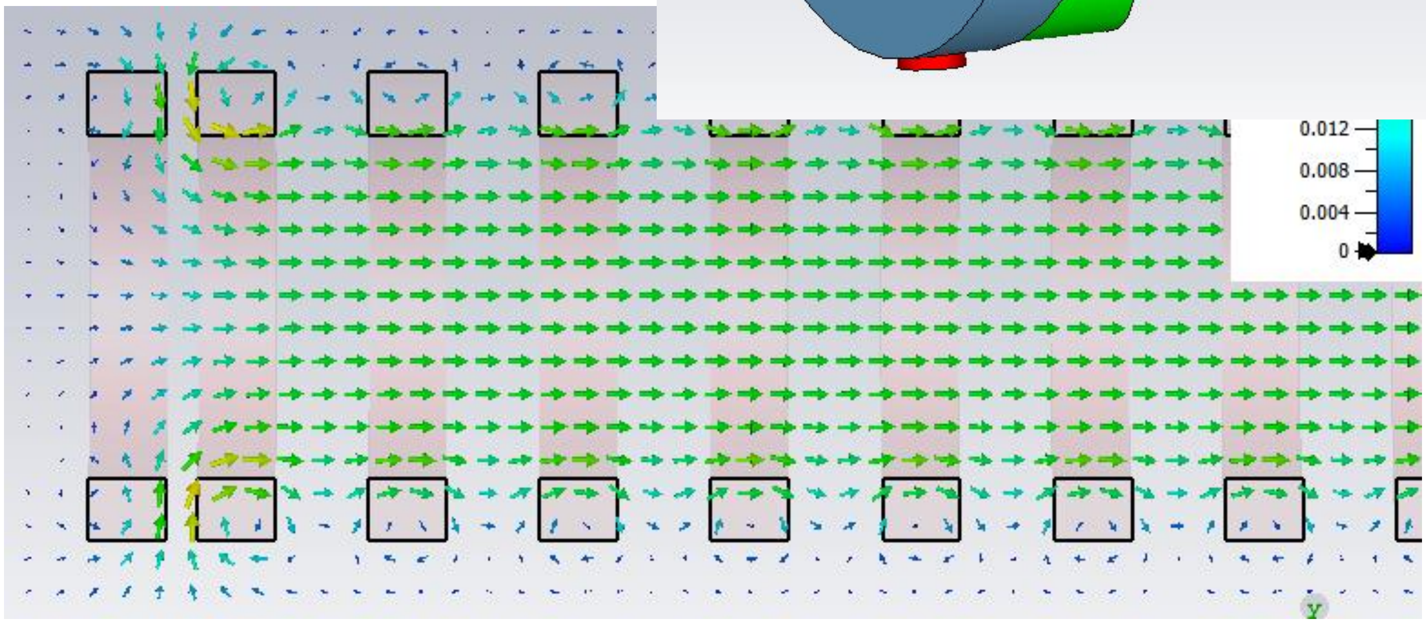
High Voltage design



Magnetic Field



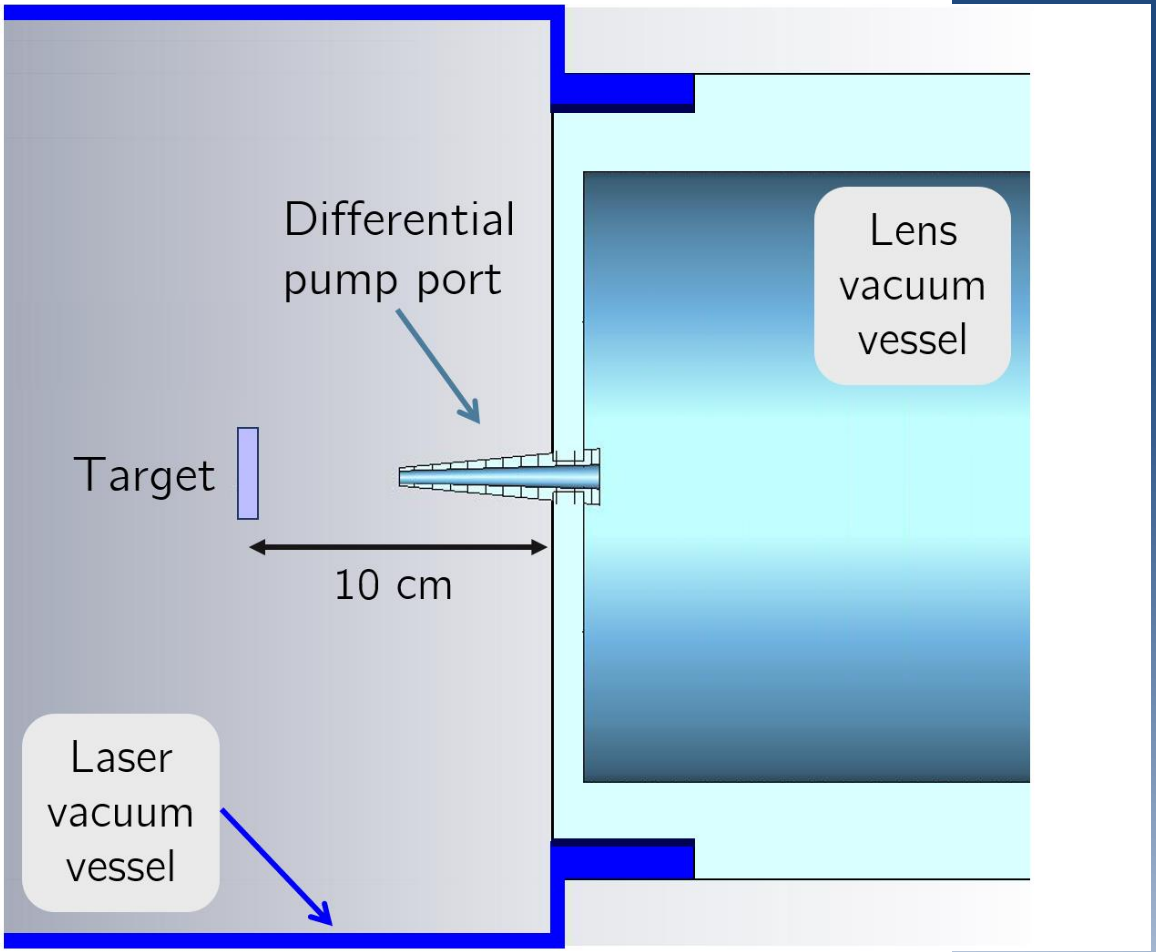




Target Capture Interface

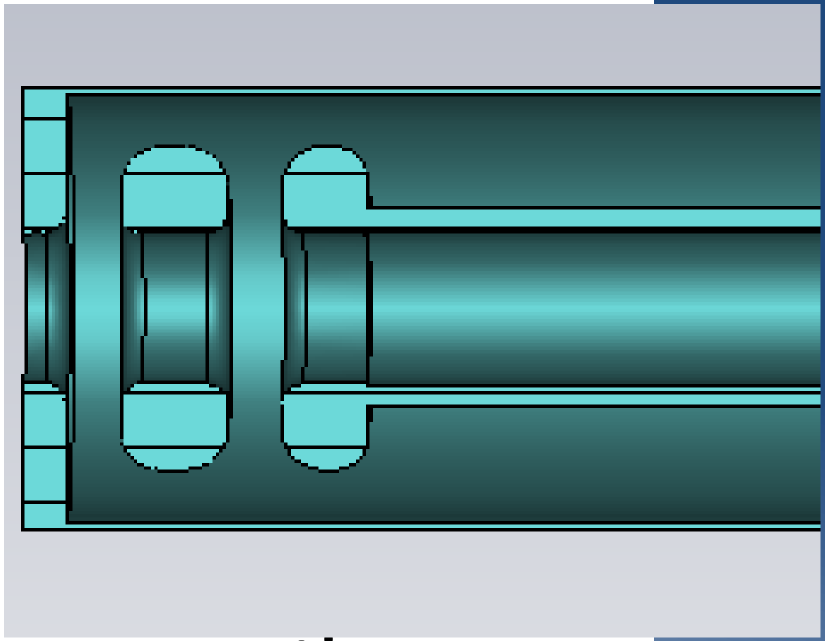
Vacuum vessel division line 100mm upstream of target foil

- Target vacuum $1x10^{-6}$ mBar at best, possibly considerably poorer - ablation of target
- Gabor lens $1x10^{-8}$ mBar desirable
- No physical barrier – differential pumping.
- Re-entrant 'cone' penetrating 50mm into Target-side vacuum
- 3 orders of magnitude pressure differential



R & D Experiment Phase 1

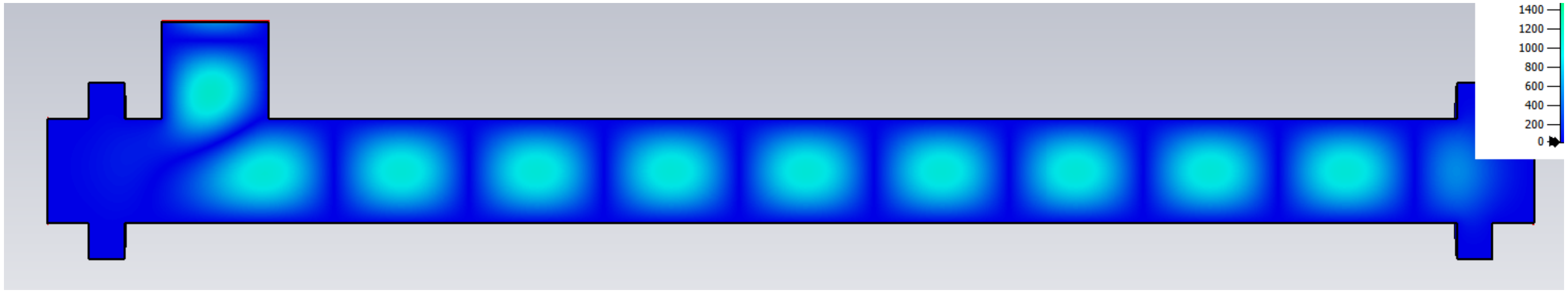
1st Pass plasma lens



- Penning-Malmberg Trap
  - 3 ‘floating’ electrodes
  - Options to operate
    - grounded anode
    - grounded cathode
- Processed for high vacuum operation
- DC high voltage
- Characterisation of properties using alpha source and thin film detector in vacuum.

Diagnostics

Electron density measurement



Phase shift = $n_e * l * \lambda * [e^2/4\pi c^2 m_e \varepsilon_0]$

Maximise λ and l to maximise phase shift

For λ = 100mm, l =2m

phase shift ~<1 degree at n_e=1 x10^{14}

No spatial resolution – limited bandwidth

Spatially resolved data via light emission from plasma

Numerical simulation

Plasma Stability

Full 3D pic code simulation

- Well established group
  - Prof. Bingham RAL/Strathclyde
  - Mini-cluster or larger
- Diocotron instability.

OSIRIS, VSIM, Vorpal, EPOCH, Magic

Electron beam simulation

Original proposal by Gabor

- ‘hot wire’ electron source.
- modern cathode ~2-10A/cm^2 <10^{5}A/m^2
- required electron density, n_e=1x 10^{14}
- required current density is easily achievable with modern cathodes – an order of magnitude uplift in electron density may be possible

CST Microwave Studio to simulate electron gun – Strathclyde expertise in high alpha electron guns

R & D Experiment Phase 2

2nd generation plasma lens

- Input from PIC code modelling for stability
- Electron source inside lens
- RF system for measurement of e density
- Processed for high vacuum operation
- Pulsed HV ~10s of ns pulse length.
- Characterisation of properties using alpha source and thin film detector in vacuum.

Parallel – Solenoid design

Recognise possibility Gabor lens design may not converge in time.

Parallel investigation of alternate solenoid design.

1.4T magnet ~1m long 35mm aperture.

Warm magnet design possible, superconducting possibly too expensive.

Pulsed at 10Hz also possible.

Break point in program to allow switch to alternate solution.