LhARA - Beam Capture

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Gabor Lenses

- Why use Gabor lenses?
- History
- Program
  - – Challenges
  - – Progress to date
    - Interface with Laser target
    - Vacuum pressure
  - – Plans
    - Numerical simulations
    - Experimental program
  - – Mitigation

Gabor Lenses

Advantages

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

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

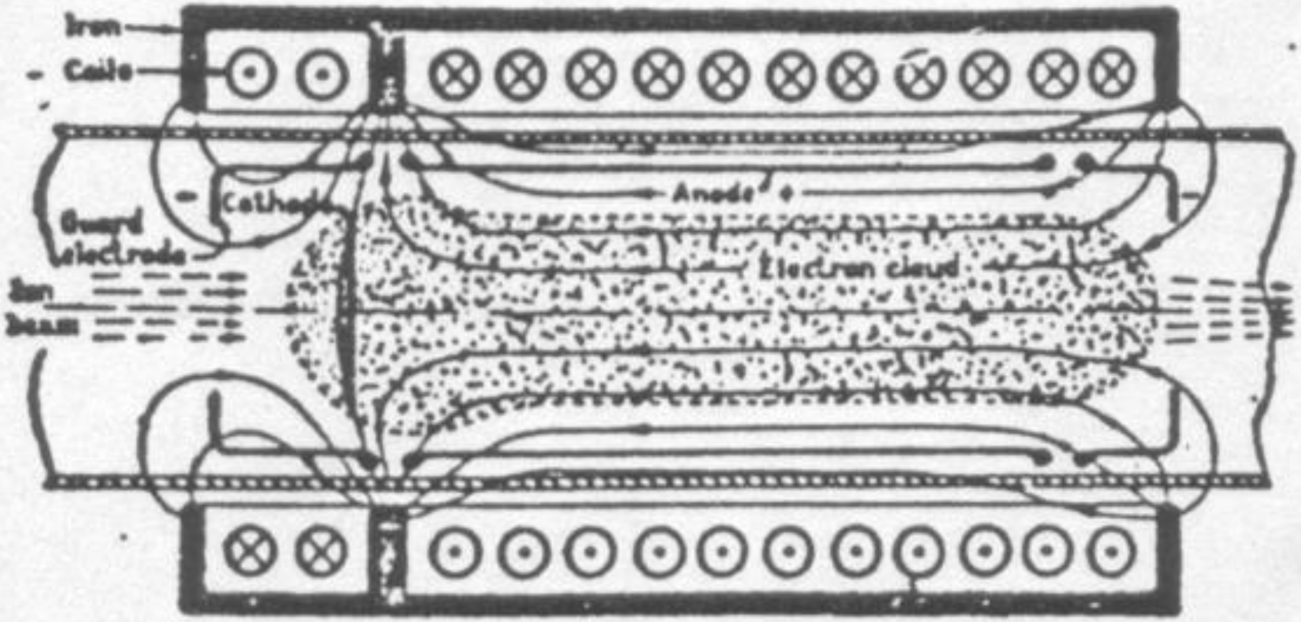
For protons

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

- 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

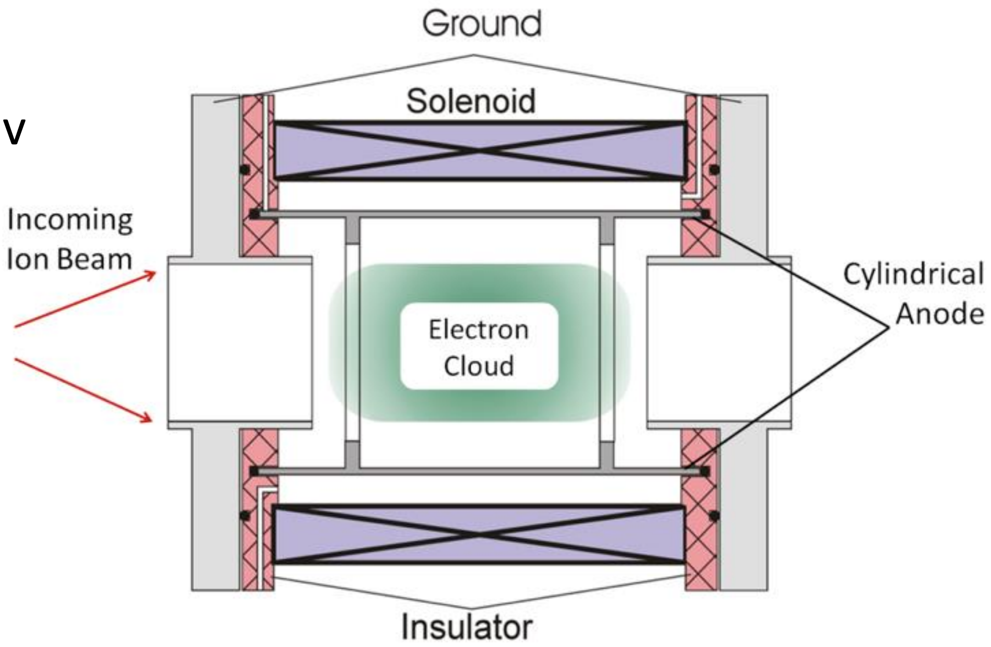
Gabor Lenses - History

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

But… lens performance was below prediction in terms of both focal length and aberration.

Re-emergence – heavy ion beam focussing.

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

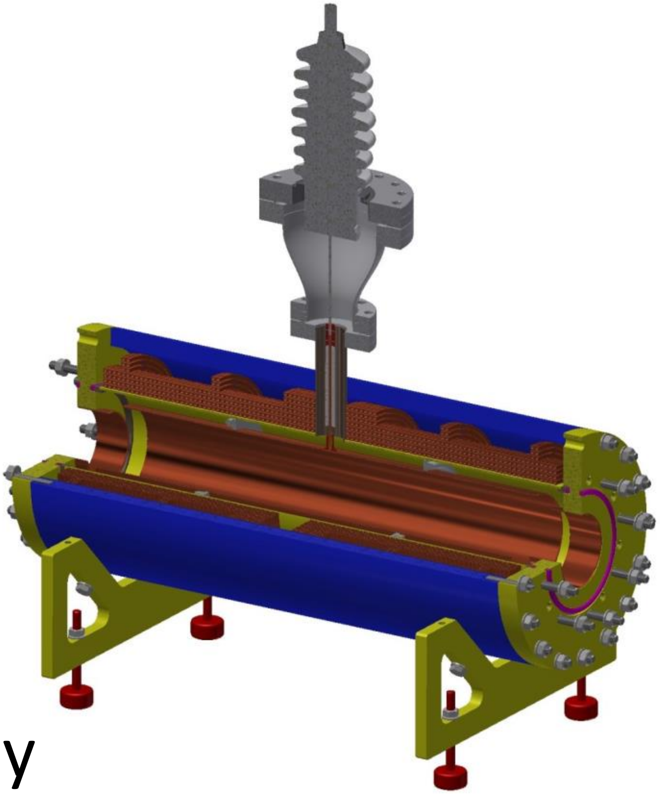


Gabor Lens – more recent

Frankfurt/ICL Pozimski, Schulte, Meusel

- Experiment

  n_e ~1 x 10^{15}
- Numerical simulation
- Diagnostics
  - – Electron density – ion beam
  - – Electron temp – spectroscopic
  - – $n_e < 1 \times 10^{15}$ dicotron instability
    - Seen in numerical simulation



Gabor Lens - Theory

Radial confinement

$$n_e = \varepsilon_0 B^2/2m_e e = 5\mathrm{x}10^{18}\,\mathrm{B}^2 <= 1\mathrm{x}10^{15}$$

Axial confinement

$$n_e = 4\varepsilon_0 V_A/eR^2$$

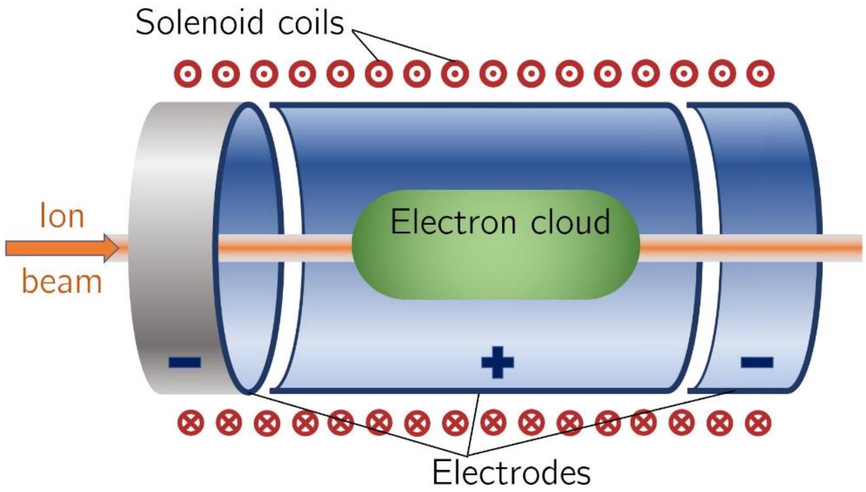
Focal length

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

B field reduction

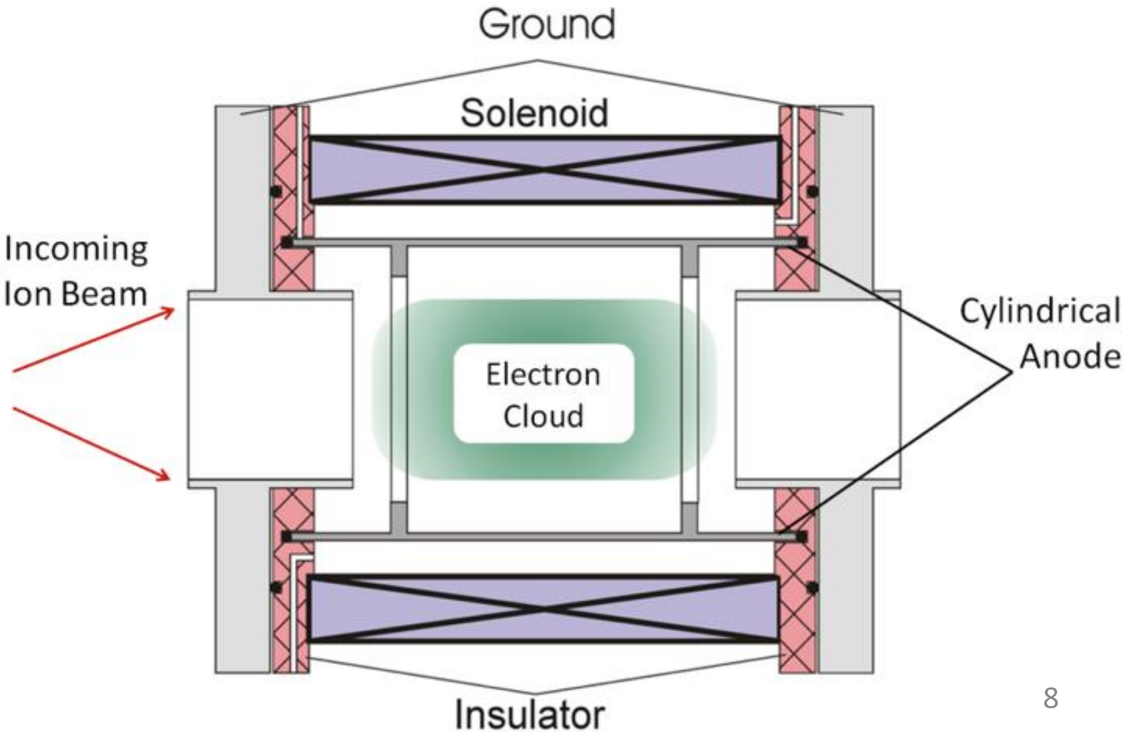
$$B_g/B_{sol} = (\mathrm{m_e}/\mathrm{m_{ion}})^{0.5} \;\sim= 44$$

Penning – Malmberg trap



Excellent beam aperture

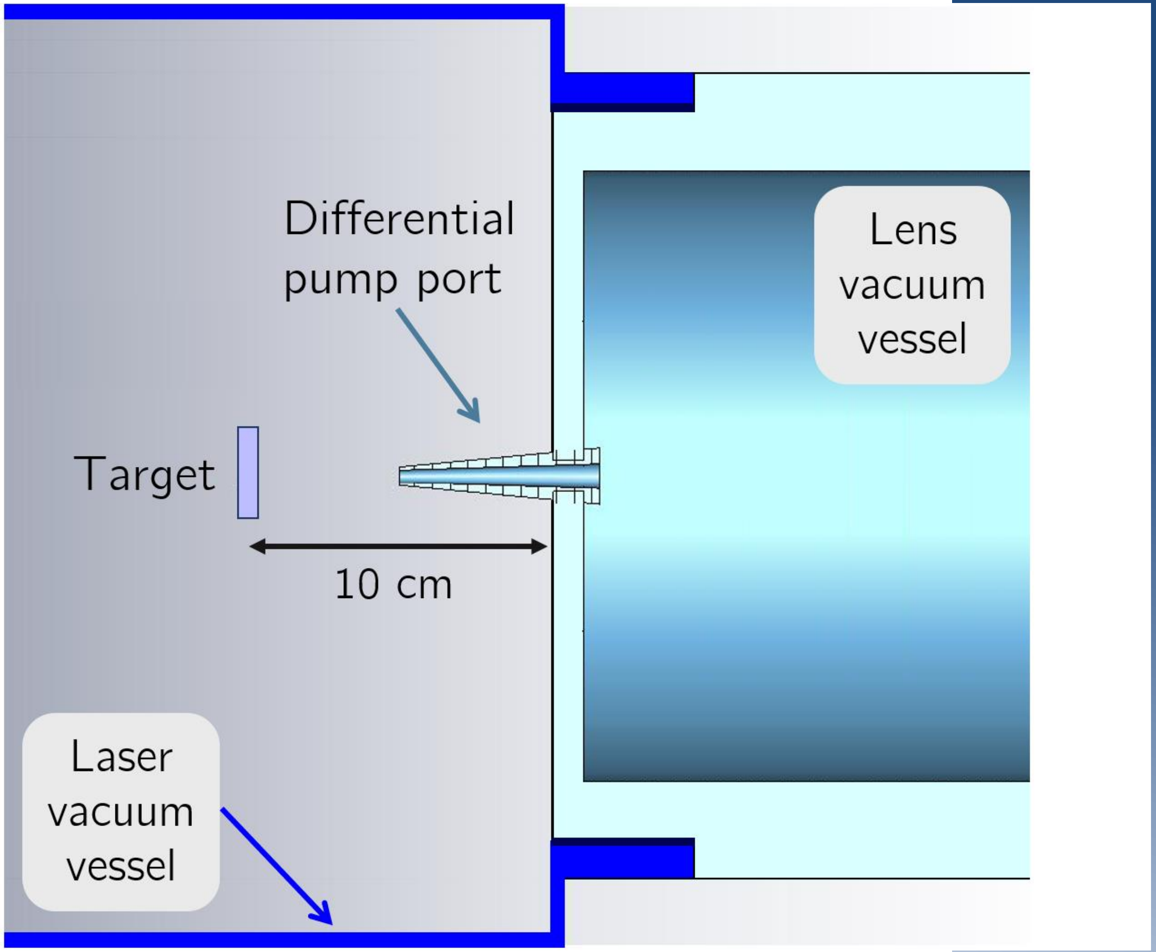
Design for High voltage



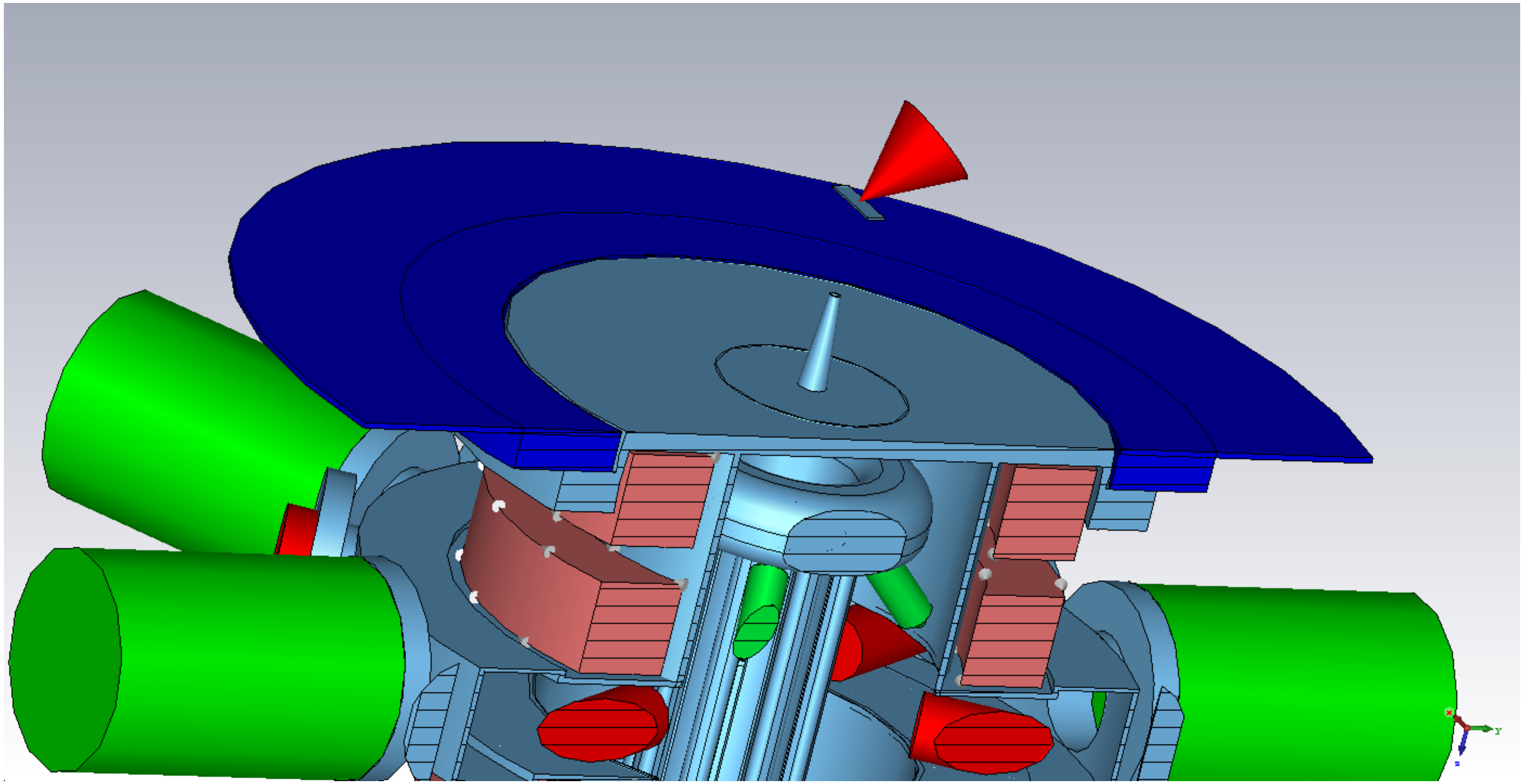
Target Capture Interface

Vacuum vessel division line 100mm upstream of target foil

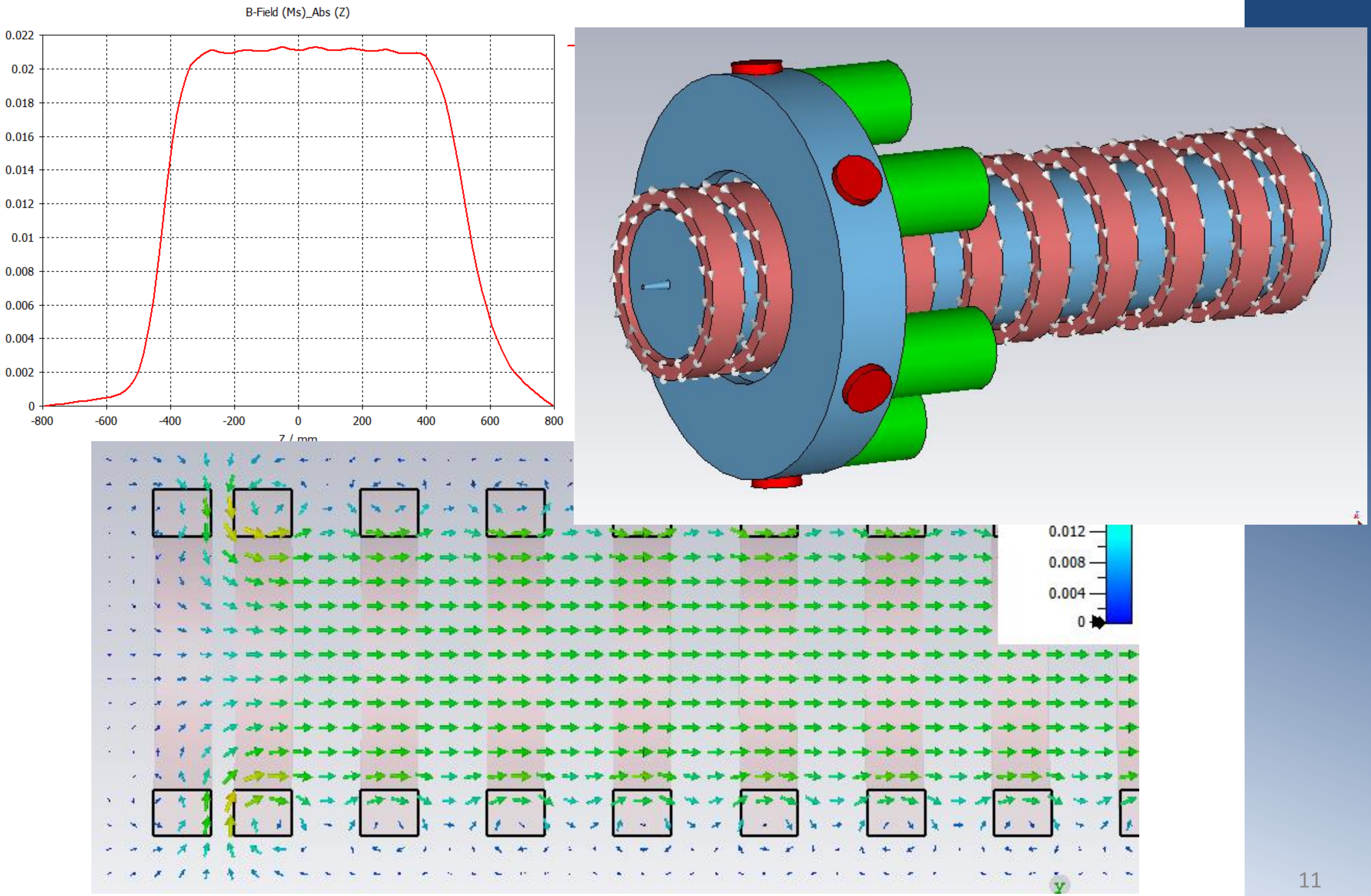
- Target vacuum 1x10^{-6} mBar at best, possibly considerably poorer - ablation of target
- Gabor lens 1x10^{-8} mBar desirable
- No physical barrier – differential pumping.
- Re-entrant ‘cone’ penetrating 50mm into Target-side vacuum
- 3 orders of magnitude pressure differential



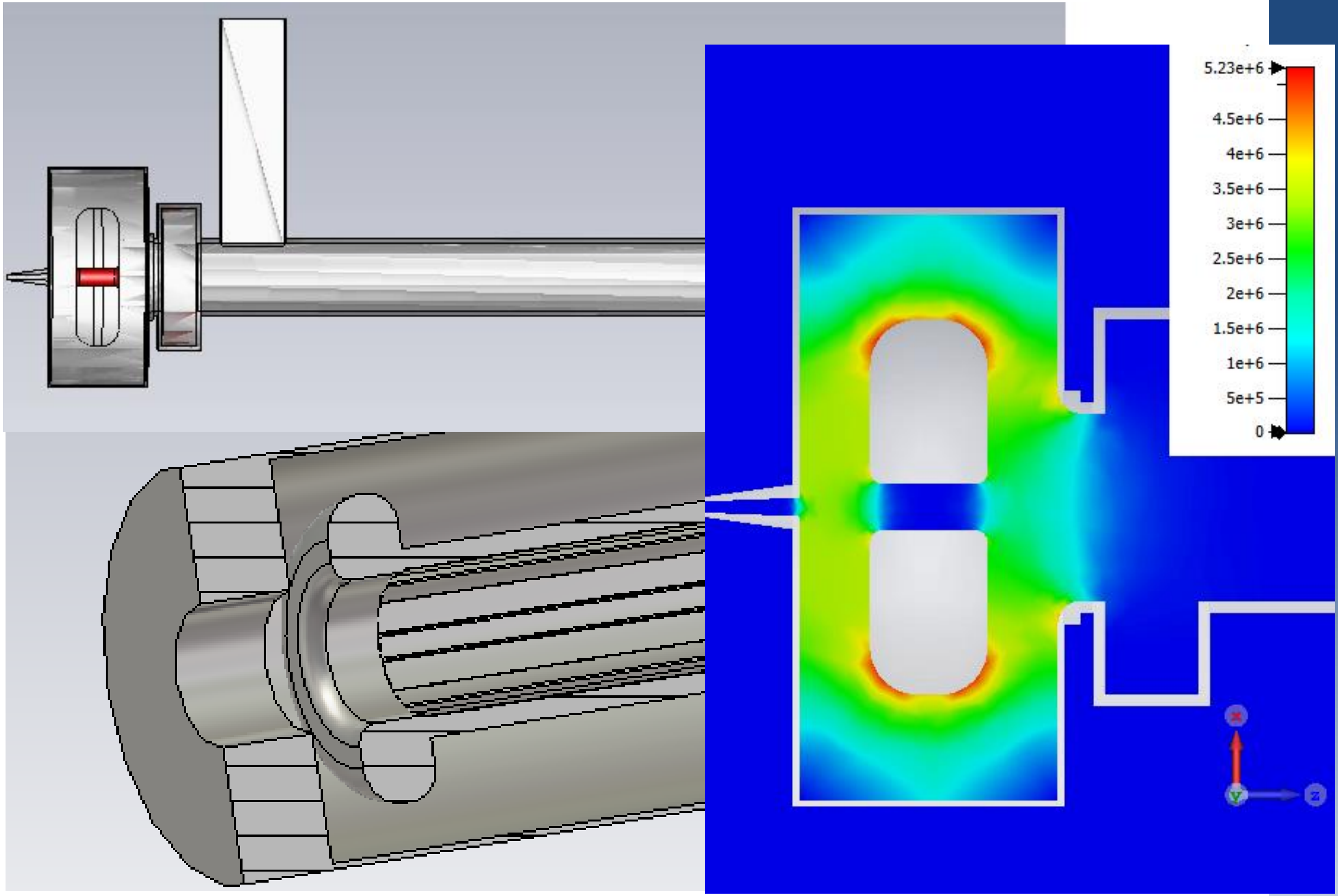
Target-Capture Interface



Magnetic Field



High Voltage design



Vacuum

- All dry system
- Turbo drag pump backed by scroll pump.
- Permanently pumped system.
- Requires excellent conductance paths to remove debris from target chamber
- Possible
  - ion pump
  - NEG pumping

Experimental Investigation

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

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

Where

λ=wavelength of probe radiation
l=length of probe path through plasma column

Phase shift = n_e*l*λ*constant

Maximise λ and l to maximise phase shift

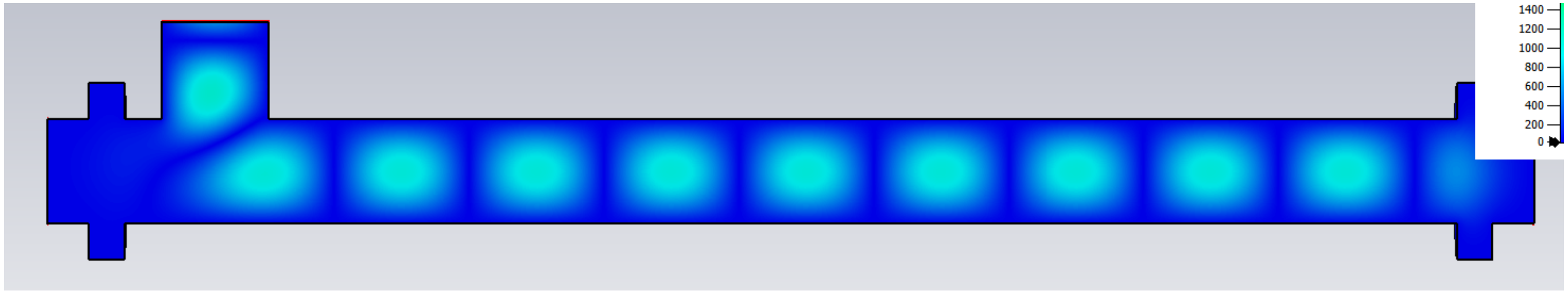
For λ = 100mm, l =2m

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

No spatial resolution – limited bandwidth

Spatially resolved data via light emission from plasma

Electron Density



- Low frequency, long wavelength, 2 pass design.
- Input and output from rectangular port to top
- Directional couplers – Vector network analyser
- Less than 1 degree phase shift at n_e=1x 10^{14}
  - Measureable via VNA
  - Can increase number of passes but will reduce bandwidth

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

Experimental Investigation

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.

1.3T 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.