



Swansea University
Prifysgol Abertawe



LhARA IAB Review

Accelerators and Technology

WP3: Proton and ion capture

Christopher Baker

Capture work package

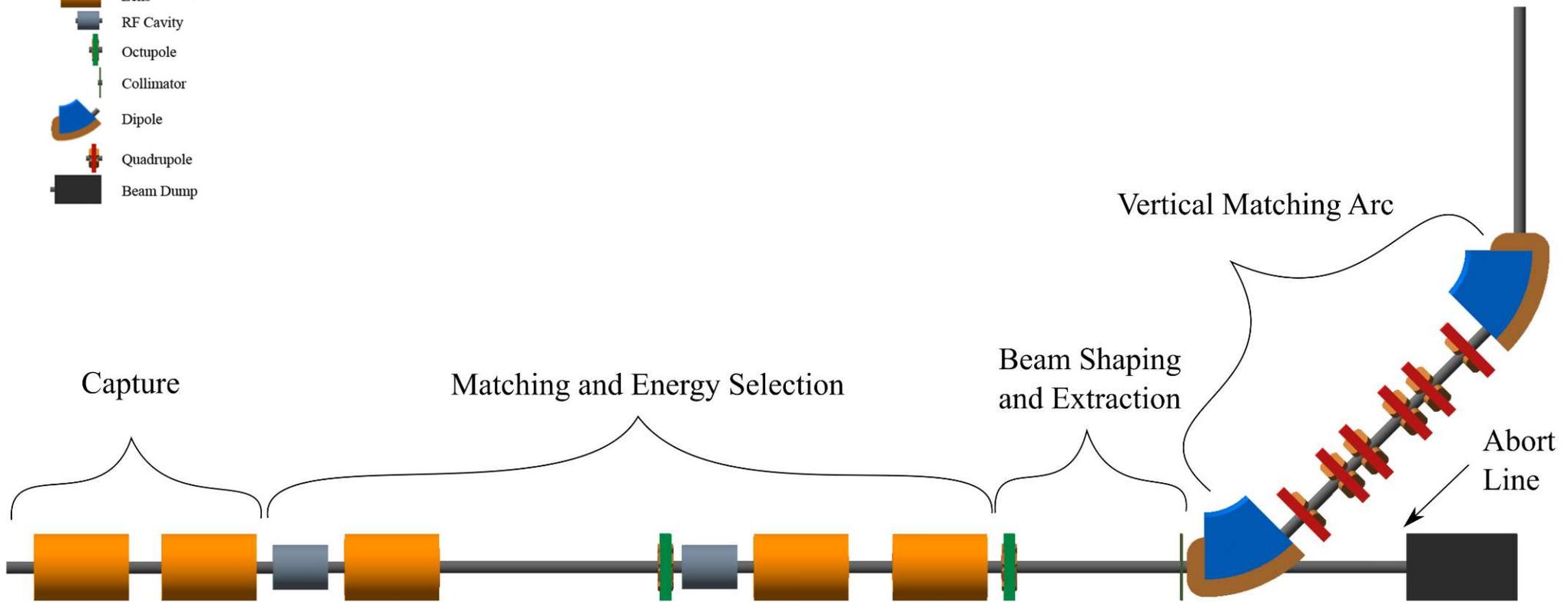
- Holistic approach to project, with feedback and synergy
 1. Take output from upstream components, laser source (see WP2), as input
 2. Tailor beam as required for transfer line capabilities (see WP6) and end-station requirements (WP4, WP5)

Beam parameters for Capture section

	Input		Output	
Stage:	preliminary	final	preliminary	final
Energy range				
Divergence				
Flux				

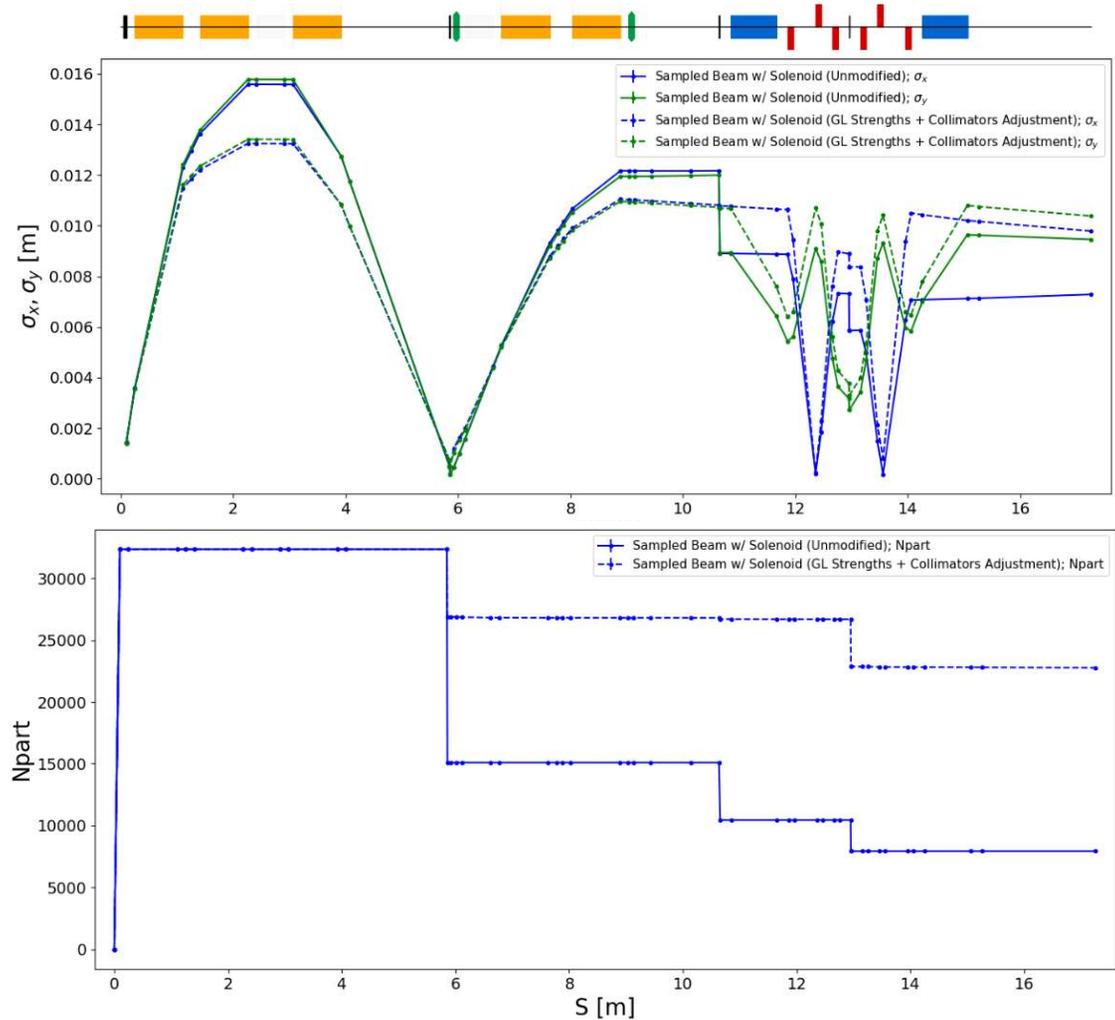
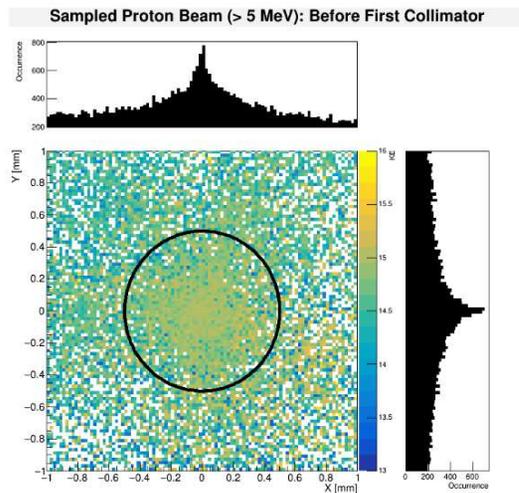
Capture system overview (see WP6)

- Lens
- RF Cavity
- Octupole
- Collimator
- Dipole
- Quadrupole
- Beam Dump

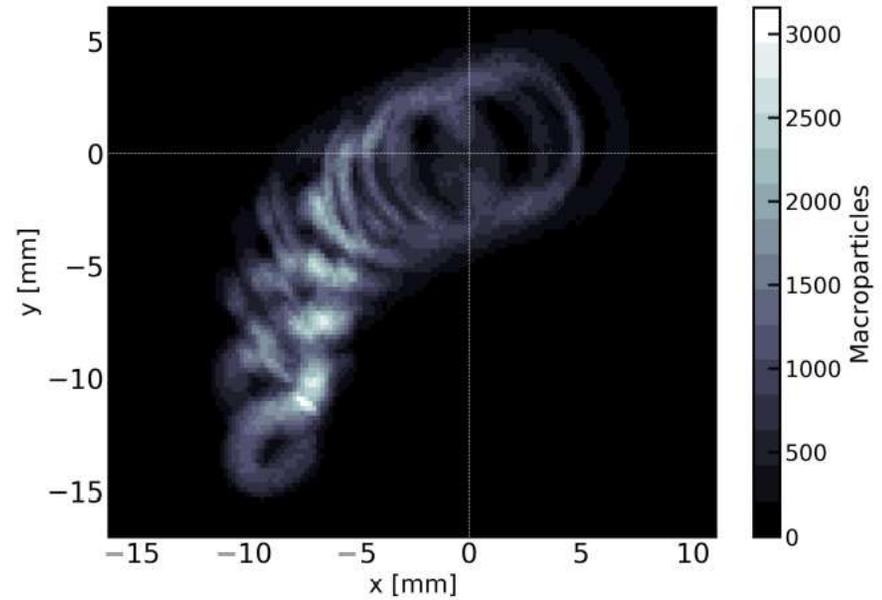
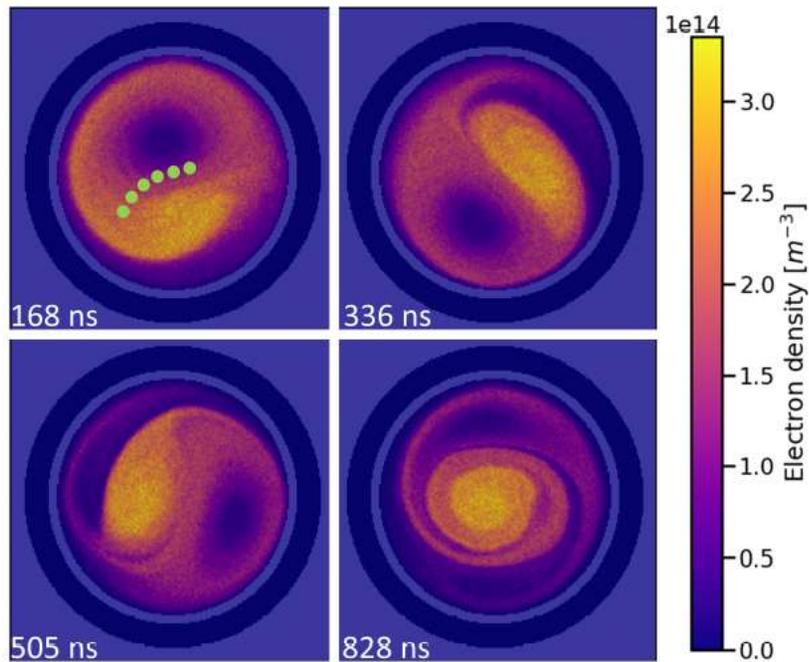


Simulations - Beam

- Particle tracking
 - BDSIM, GPT, VSIM
 - Ideal behaviour, approximated, & simulated fields



Simulations – Plasma



Lenses - Magnetic field (solenoid)

- Focussing strength proportional to magnetic field strength (current density)
- Normal conducting or Superconducting options
 - Non-trivial design – Windings, thermal, jackets, etc.
 - Financially expensive – Materials, specialists
 - Power intensive – Electrical and cooling
 - Limited flexibility
 - Well known technology
 - Commercially available
- Risk mitigation programme includes preliminary solenoid design efforts

Lenses - Electric field (plasma), Gabor Lens

- Focussing strength proportional to plasma density
 - V. high E -fields (& hence focussing strengths) possible
 - Dictated predominantly by applied voltages
- Existing Gabor lens attempts use discharge plasma
 - Shot-by-shot synchronised with ion source
 - Each plasma is quasi-stable
 - Plasma established by limited control of initial conditions
 - No known successful implementation despite many decades of effort
- Proposed Gabor lens will build upon equilibrated non-neutral plasmas
 - Experimental effort!

Efforts elsewhere

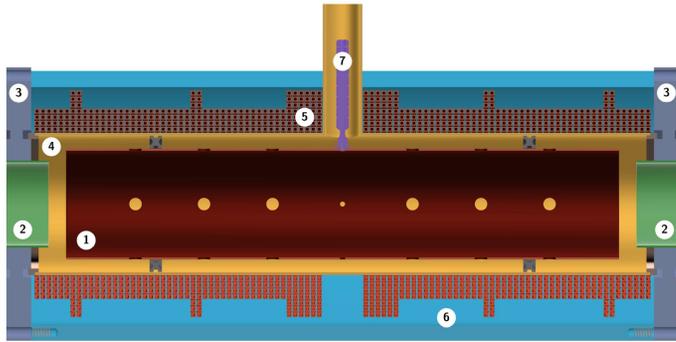
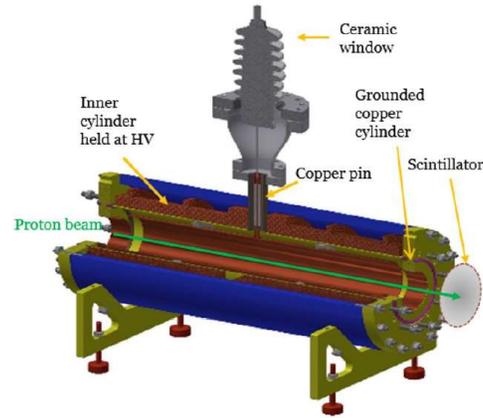
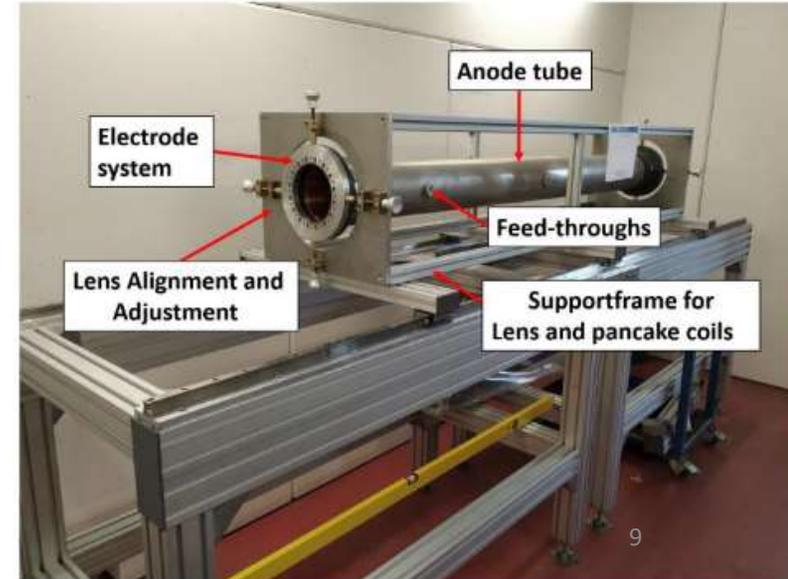
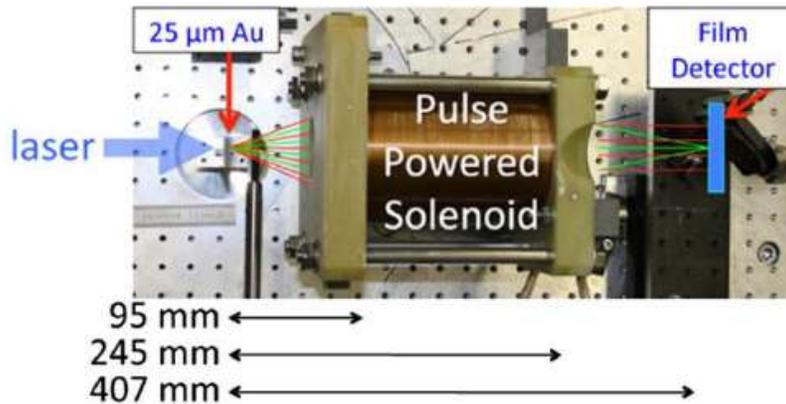
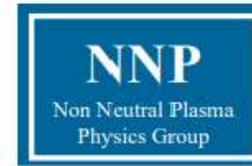


Figure 1. Internal structure of the IC Gabor lens viewed in longitudinal cross-section. The main components are: 1-central anode, 2-end electrodes, 3-end flanges, 4-vacuum tube, 5-pancake coils, 6-outer tube, 7-high-voltage feed-through.



Appl. Sci. **11** 4357 (2021)
 Proc. IPAC2016 TUPMY024
 Ecloud '18 Proc. 143 (2020)
 Phys Rev STAB **14** 121301 (2011)



Existing non-neutral plasma

PHYSICS OF PLASMAS 13, 022101 (2006)

Finding the radial parallel temperature profile in a non-neutral plasma using equilibrium calculations on experimental data

Grant W. Hart and Bryan G. Peterson

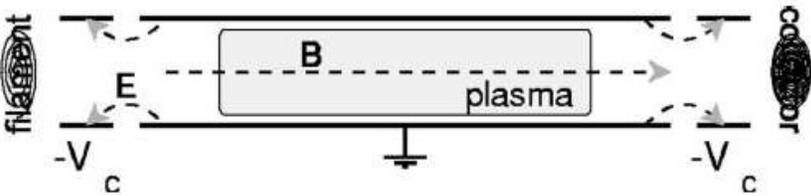


FIG. 1. Electric and magnetic fields in a Malmberg-Penning trap.

Our experiment is a fairly typical Malmberg-Penning trap with a nominal plasma length of 60 cm and a ring radius

of 4 cm. Typically our plasmas had a radius of about 2.5 cm. The central density in these data is near $7 \times 10^{12} \text{ m}^{-3}$. Our neutral gas pressure is normally near 8×10^{-9} Torr. While we have not made the measurement for these specific data sets, a typical particle confinement time in this machine is 5–6 s.

Phys. Plasmas, Vol. 7, No. 7, July 2000 2776

Confinement and manipulation of non-neutral plasmas using rotating wall electric fields

E. M. Hollmann, F. Anderegg, and C. F. Driscoll

A “rotating wall” perturbation technique enables confinement of up to 3×10^9 electrons or 10^9 ions in Penning–Malmberg traps for periods of weeks. These rotating wall electric fields transfer torque

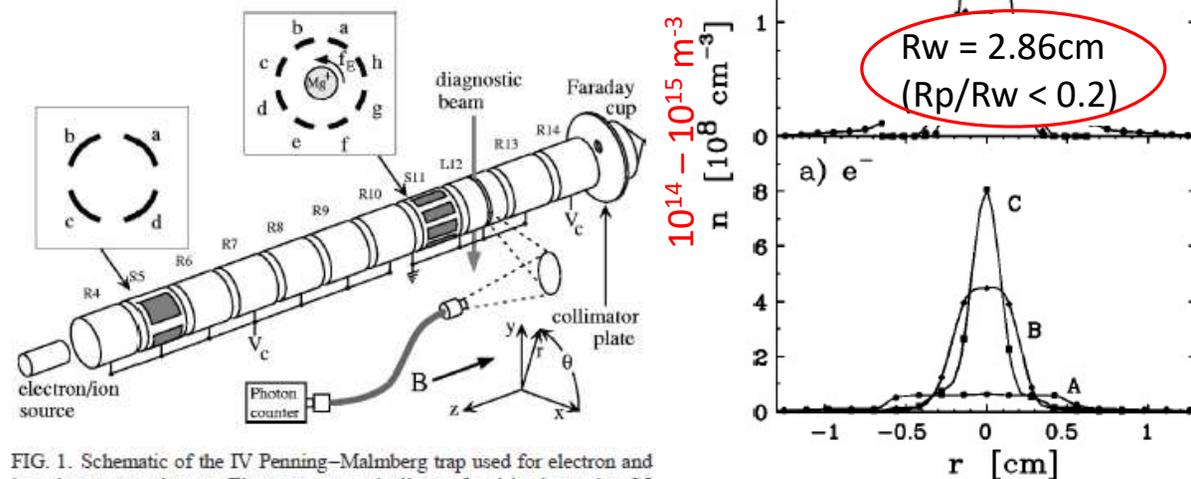
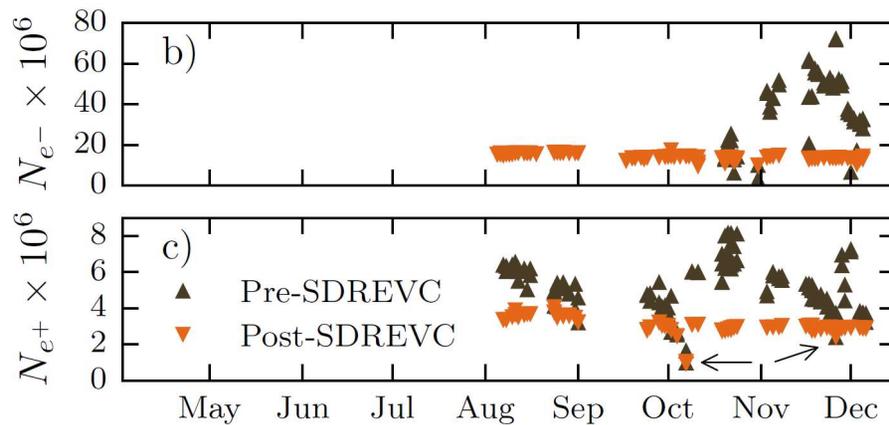
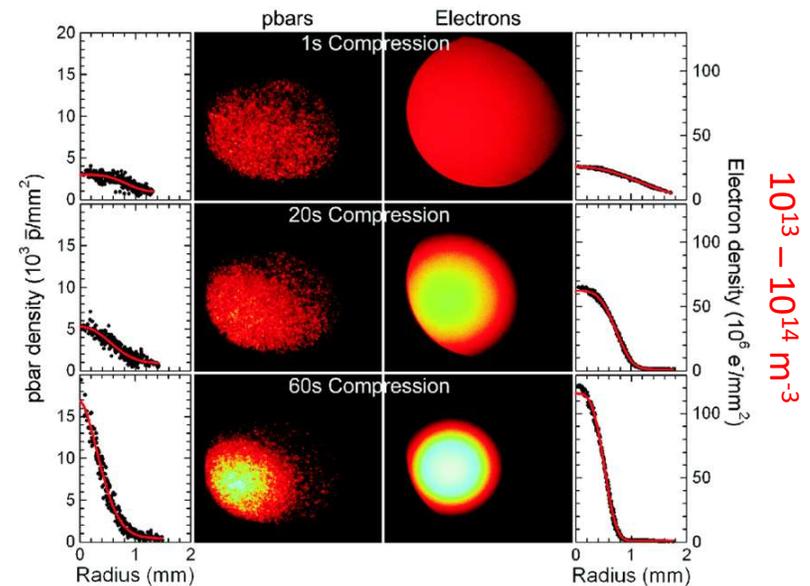


FIG. 1. Schematic of the IV Penning–Malmberg trap used for electron and ion plasma experiments. Electrons are typically confined in the region S5 → S11; Mg^+ ions (shown) are typically confined in the region S11 → R13. A laser diagnostic is used for ion plasmas; a collimator plate and Faraday cup diagnostic is used for electron plasmas. Azimuthally-dependent modes are driven and detected with sectored rings (S5 and S11).

Existing non-neutral plasma manipulation in ALPHA at CERN



- Length ~ 10 cm
- Radius ~ 0.5 mm (at 1T)
- Density $10^{12} - 10^{14} \text{ m}^{-3}$

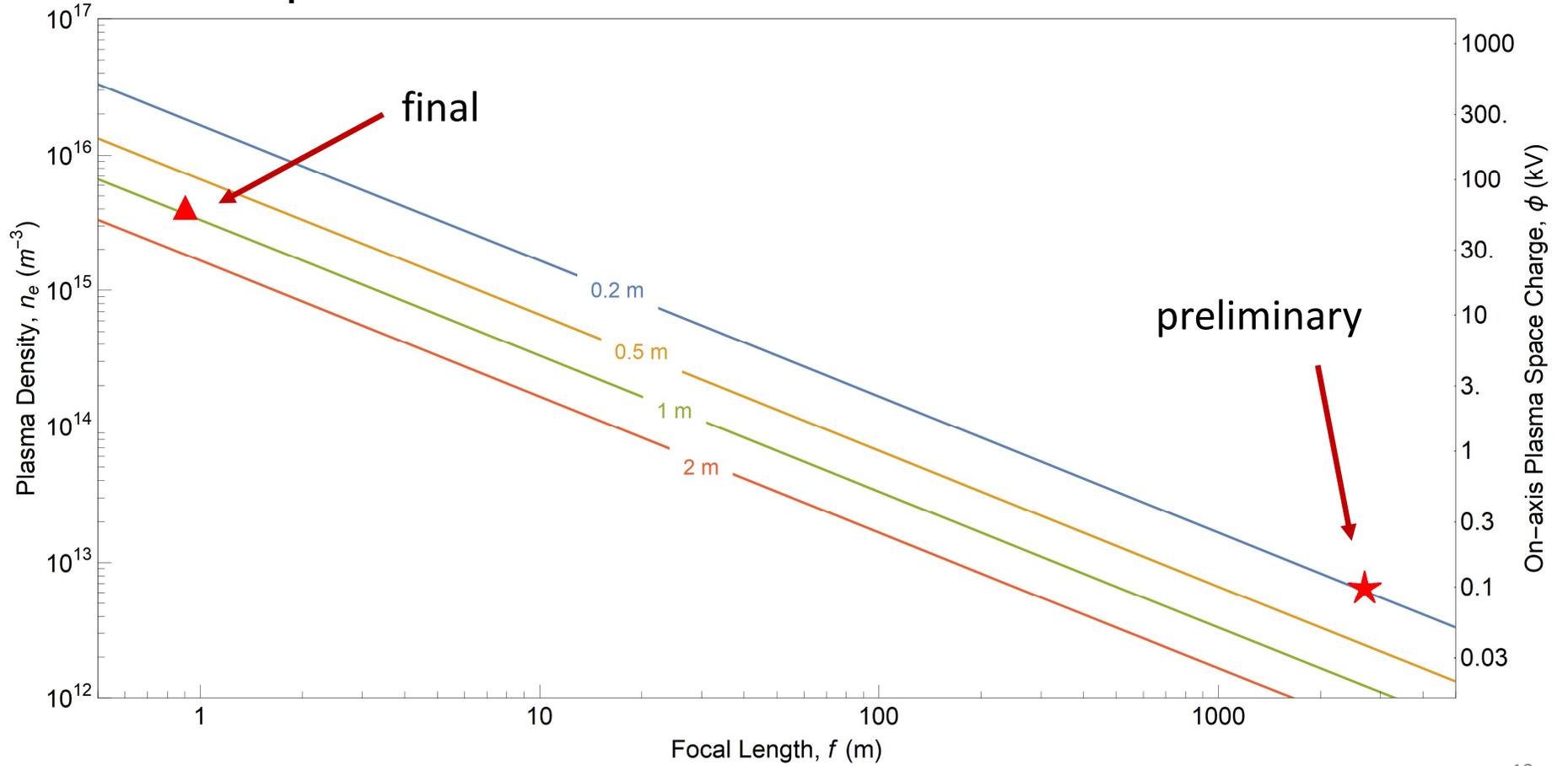


Plasma parameters

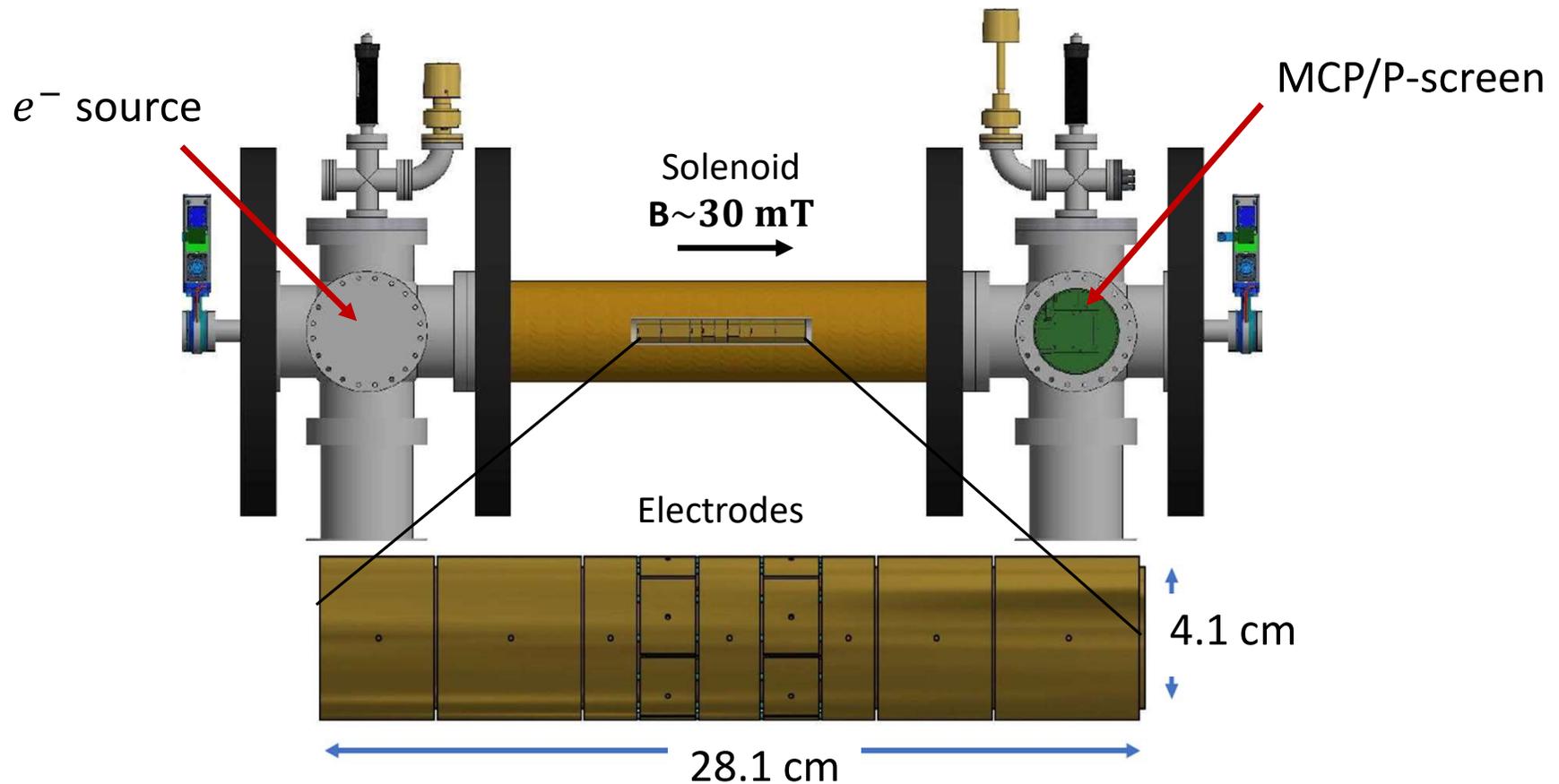
	Preliminary	Pre-construction	Final
Diameter	1 cm	3 cm	3.5 cm
Plasma Length	10 cm	1 m	1.2 m
Density	$\sim 10^{13} \text{ m}^{-3}$	$5 \times 10^{14} \text{ m}^{-3}$	$5 \times 10^{15} \text{ m}^{-3}$
Space-charge potential	20 V	2 kV	50 kV
Focal length	1000's m	10's m	1 m
B -field	0.03 T	0.1 T	0.15 T

Iterative & parameterised approach in preliminary & pre-construction phases

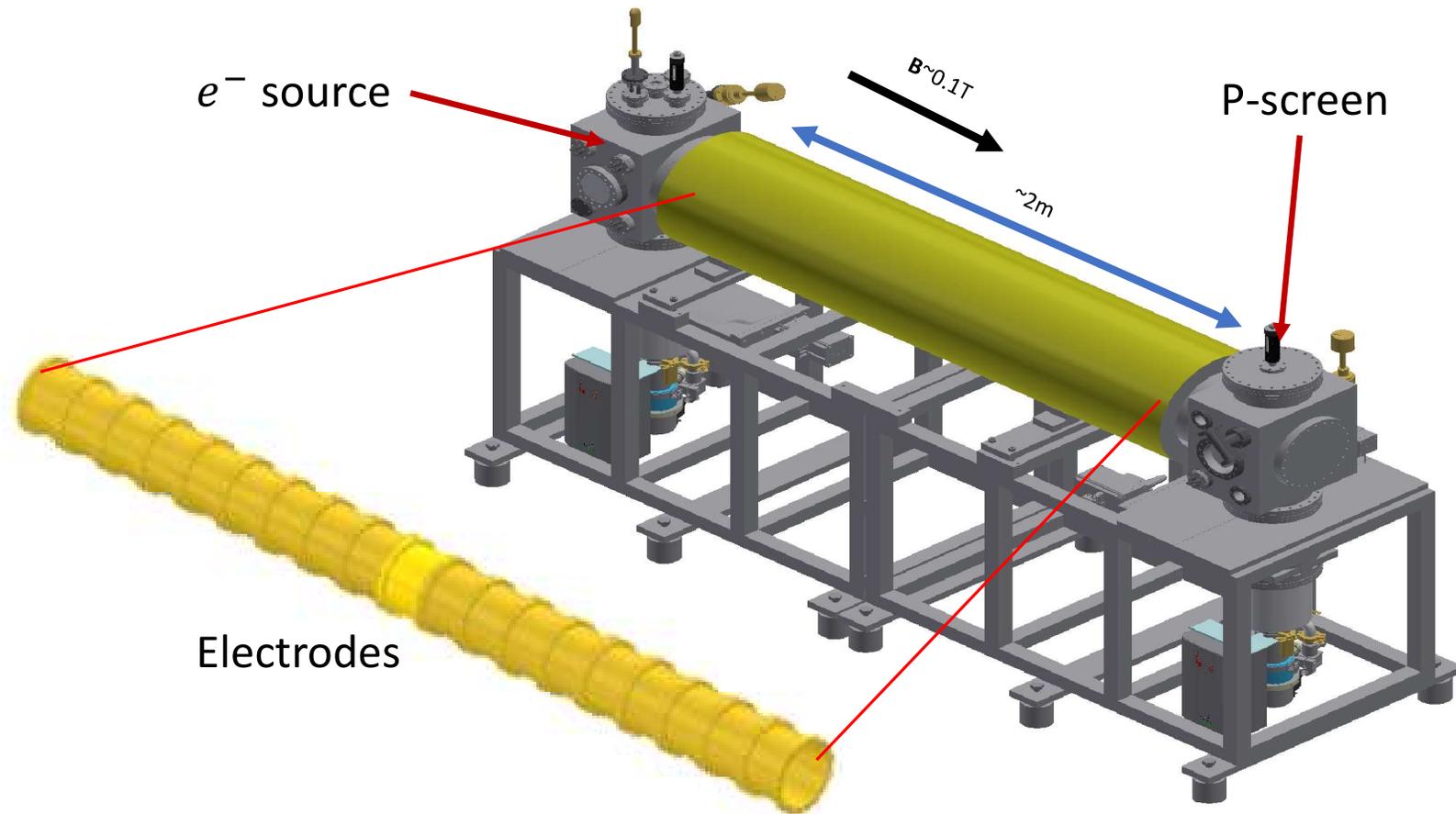
Plasma parameters



Current Apparatus (preliminary activity)



Proposed Apparatus (preconstruction phase)



R&D Philosophy

- Cautious approach
 - Built upon decades long experiences at CERN
- Iterative approach
 - Confirm simulation methods & feedback into multiple designs & apparatus upgrades
 - Vary single parameter (as far as possible)
 - Analyse using Machine Learning due to correlations
 - Confirm 'known physics' (scaling laws) in new apparatus

Risks / mitigations

Being unable to create a suitable plasma:

- Density
- Size (radius, length)
- Timescales

- Possible technical/engineering solutions
 - Utilise inbuilt redundancy – e.g. Increase confining fields, compartmentalise plasma
 - Modify designs – e.g. Increase apparatus size
- Should be identified in simulations!

Lens options

- End of preconstruction phase report to provide recommendation
- Why not implement magnetic from outset?
 - Magnetic lens implementation as challenging as electric lens
 - Electric lens lay some groundwork (magnet design)
 - Limited magnetic vs. significant electric flexibility
 - Significant lifetime cost savings using electric
 - Significant technology transfer opportunities for electric

Resources

- ITRF Scoping project provides limited preliminary activity resources
 - Enables profitable studies for preconstruction phase apparatus design
 - Limited by one junior postdoctoral researcher
 - Ideally 4 fulltime personnel!
- Existing apparatus at Swansea (& internationally) employed for studies
- Existing international expertise employed for efficiency
- Timeline identifies years 2, 5 (& 7) as critical
 - Resource shortfall early can be recovered at later stage (at non-linear cost)

Questions?