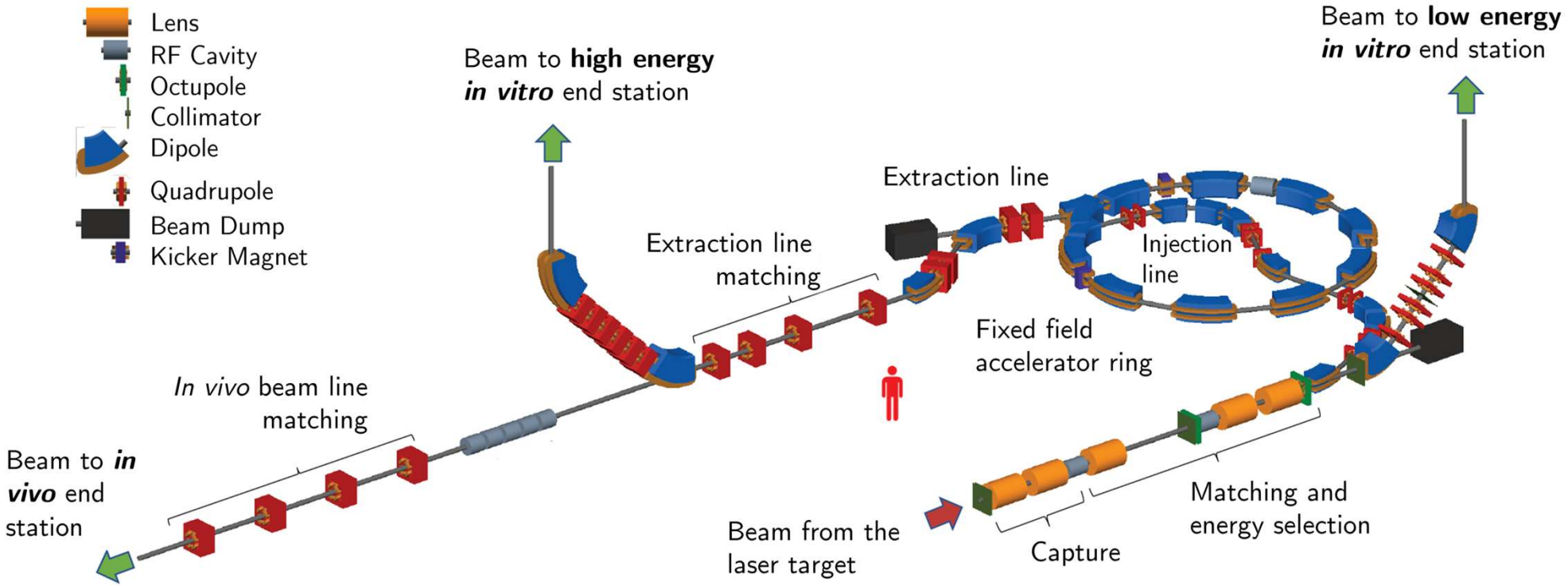
Capture Work Package

LhARA Collaboration Meeting
&
ITRF 12 month review overview

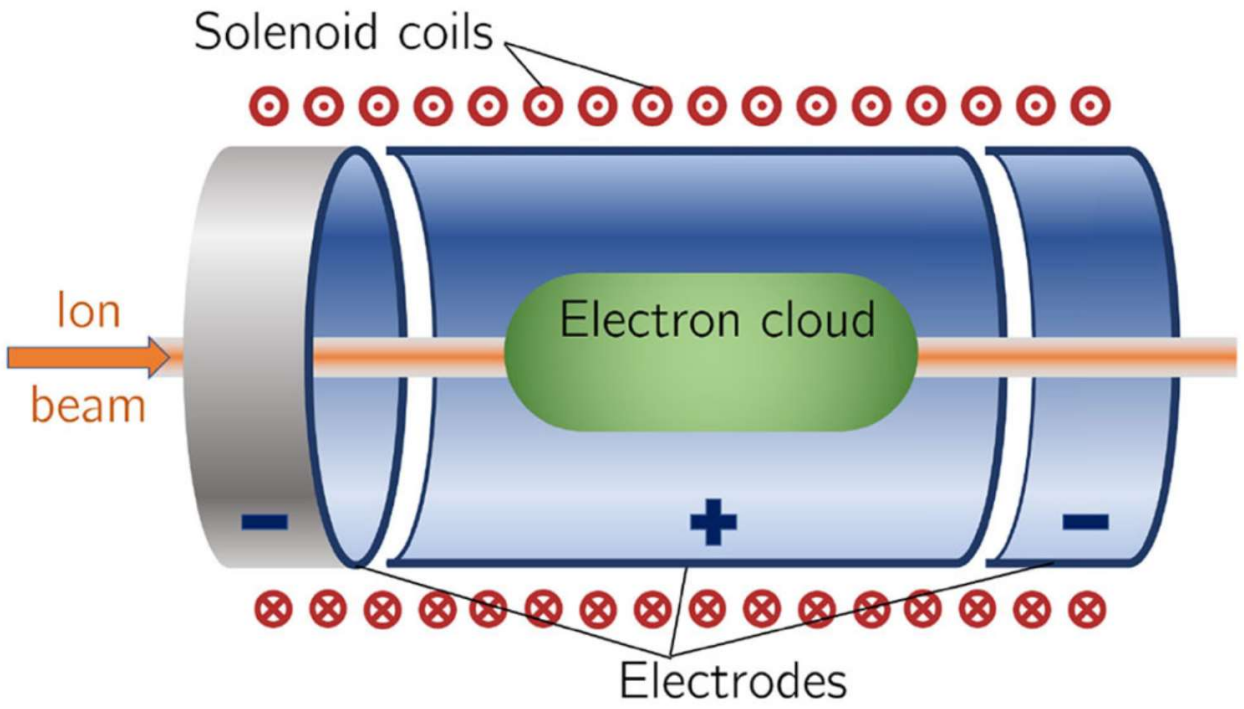
Christopher Baker

20th September 2023

Beamline sketch



Basic Gabor Lens



Recall Focusing alternatives

- Pulsed normal conducting solenoids
- Superconducting solenoids
- Quadrupole
- Synchronised discharge plasmas
- Self-sustaining discharge plasmas
- …

- All have benefits & drawbacks
- Chosen to initially focus on thermalised, long-time stable, non-neutral plasmas

See KL 1st Aug 2023 Fortnightly slides

Recall specification & work elsewhere

- Aymar *et al.*:

  Frontiers in Physics **08** 567738 (2020)

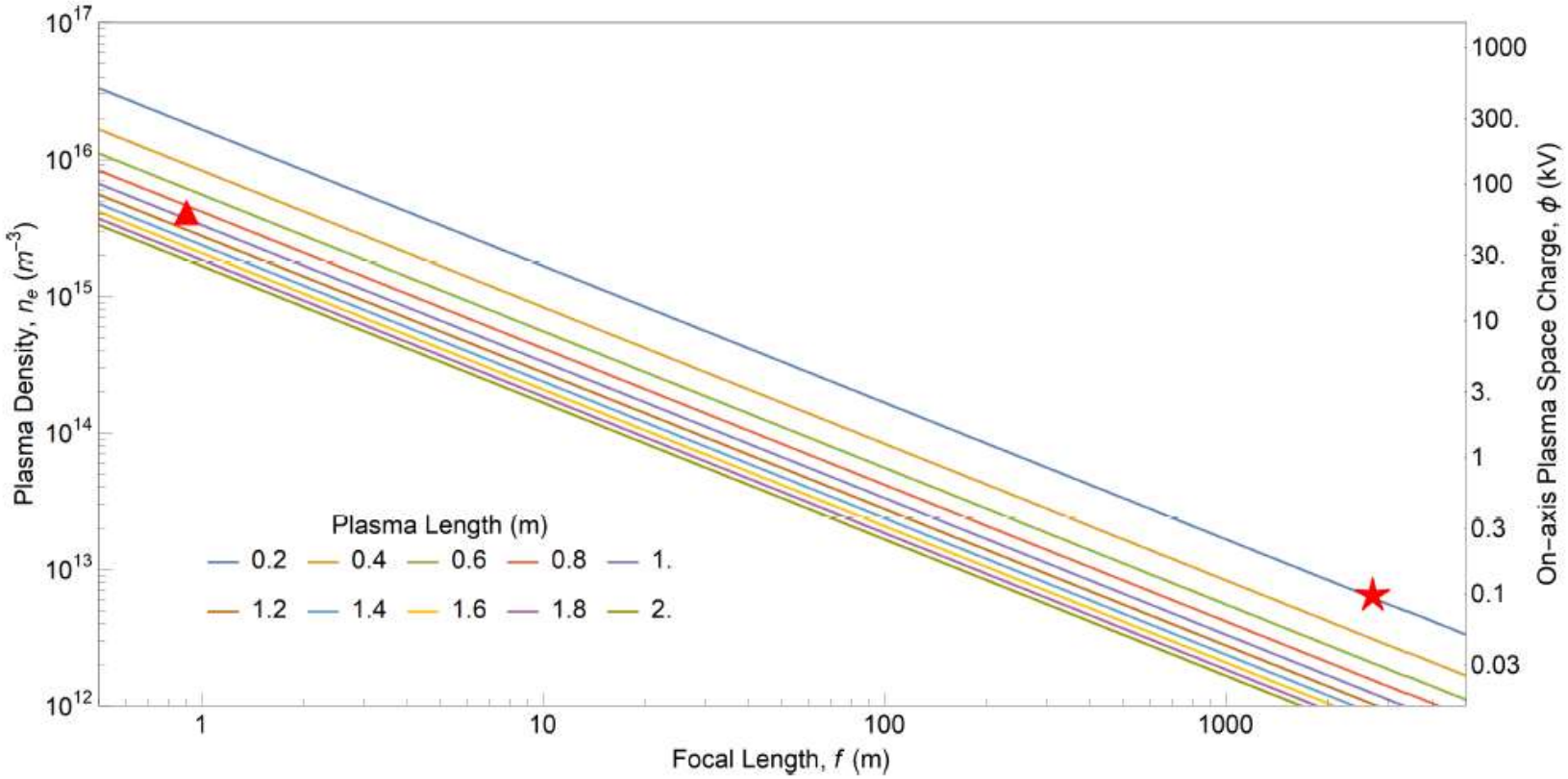
Proton and ion capture		
Beam divergence to be captured	50	mrad
Gabor lens effective length	0.857	m
Gabor lens length (end-flange to end-flange)	1.157	m
Gabor lens cathode radius	0.0365	m
Gabor lens maximum voltage	65	kV
Number of Gabor lenses	2	
Alternative technology: solenoid length	1.157	m
Alternative technology: solenoid max field strength	1.3	T

- Each parameter largely achieved elsewhere

  (See previous presentations)

  - Lengths >1 m
  - Radii >3 cm
  - Density >10^{15} m^{-3}
  - Lifetime >days
  - Space Charge >kV
  - Low B-fields <1 T

Recall requirement



Recall original Phase-I plan

- Use Swansea-based apparatus to generate & study ‘small’ plasma
  - Significant upgrades dropped in ITRF/PA1 reprofiling
- Continue & extend previous VSim simulations
  - Efforts began by TSD
- Design ‘intermediate’ plasma testbench

Recall plan Objectives, & milestones

O3.1: Use existing apparatus at Swansea University to make measurements of electron-plasma dynamics that will be used to evaluate and bench-mark numerical simulations. The measurement, simulation and analysis will be used to gain insights and understanding as part of the Gabor-lens risk-management programme; and

O3.2: Develop a detailed design of the next generation Gabor-lens prototype based upon state-of-the art plasma techniques and including the guidance gained from the associated simulations.

M3.1 (month 6): Report on the modification of the existing apparatus to accommodate the study of electron-plasma dynamics and to validate numerical codes;

M3.2 (month 12): Report describing the performance of the modified apparatus in initial electron-plasma experiments. The report will record the observations and compare them with the results of numerical simulation; and

M3.3 (month 18): Report on the study of electron plasmas documenting progress towards understanding their behaviours under the conditions expected in the next generation Gabor-lens prototype.

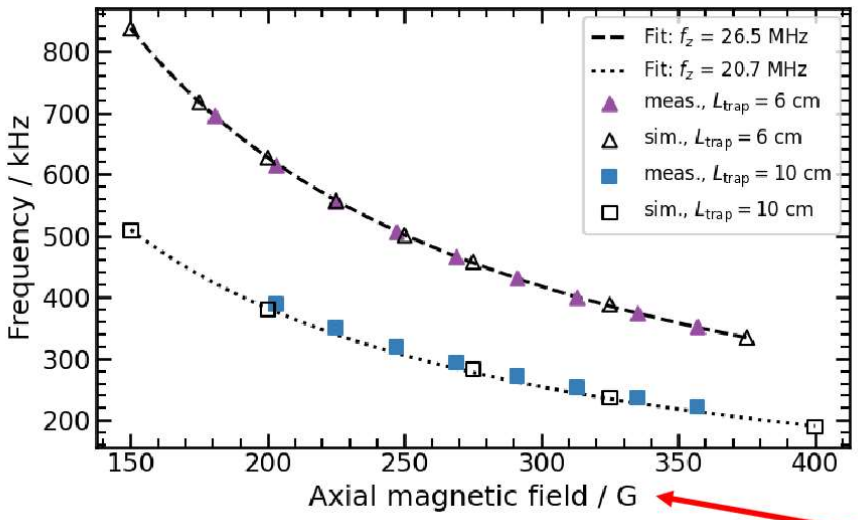
Issues

- Recruitment
  - PDRA is yet to start
    - Several administrative hurdles appear to be overcome, but some remain outstanding
    - Aiming for late Summer (September 2023) start
  - Mitigation
    - Two additional Swansea-based colleagues have joined the effort
      - Simulation
      - Experimentation
    - WPM/PI efforts extending beyond ‘administration’
    - Upcoming experimental effort will benefit from dedicated beamtime

Progress – Simulation VSim

- Recall preliminary VSim findings
  - Experimental and Computational agreement of simulation (& theory)
- Recall, VSim is a commercial package
  - Licence yet to be obtained
- Can operate VSim at Swansea, on Swansea-based HPC (CPU) resources

Magnetron freq. vs. B-field



Research/GaborLens/Meetings/2022/01/27 : 2022_01_27_LhARA_Capture_TSD.pdf

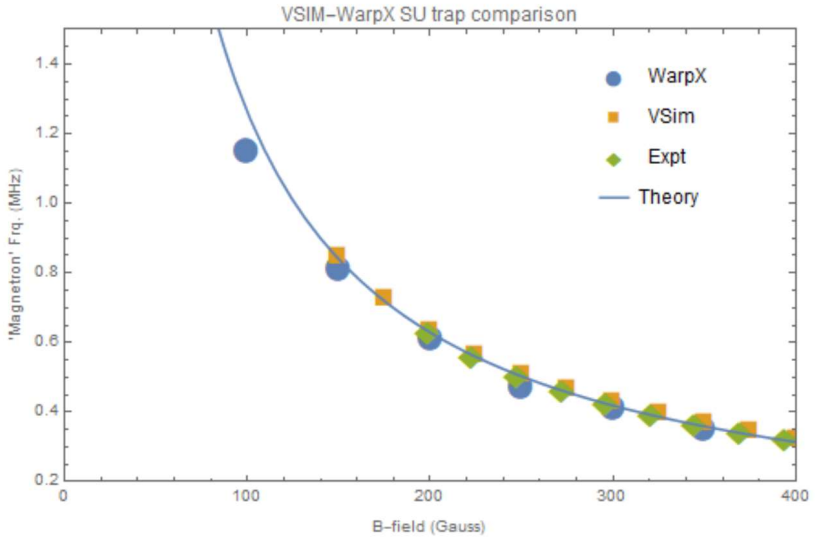
Progress – Simulation WarpX

- Recall alternative simulation package(s) identified

- Focus on WarpX
  - ‘Access’ to authors for support
  - Publications report techniques implemented to ensure accurate ‘speed-up’
  - Open Source
  - Licence fee free
  - Included physics is modifiable
  - …

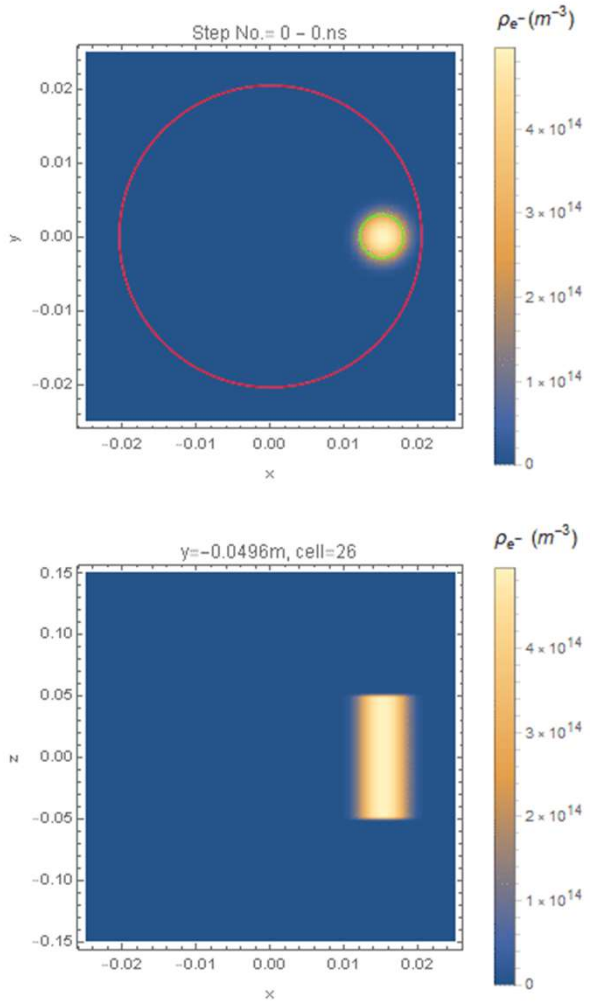
Progress – Simulation WarpX I

- Progress
  - Successfully duplicated VSim magnetron results



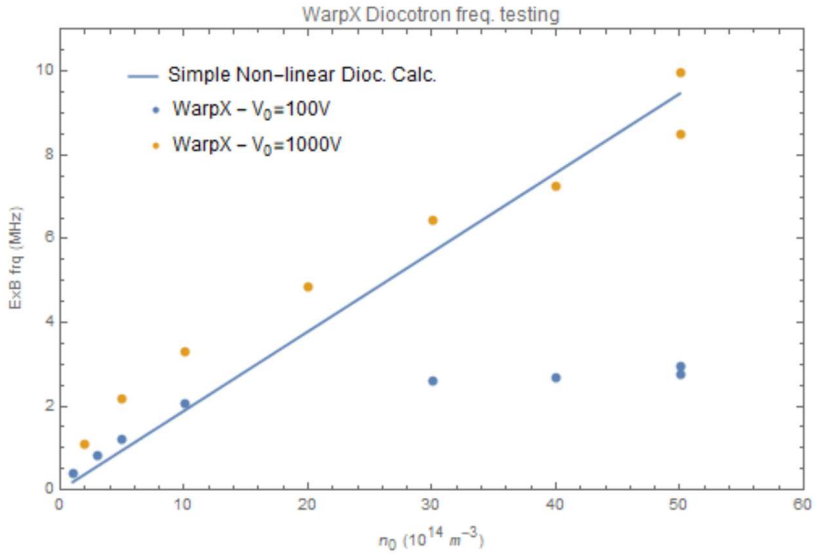
Progress – Simulation WarpX II

- Progress
  - Successfully duplicated VSim magnetron results
  - Successfully generated and studied plasmas



Progress – Simulation WarpX III

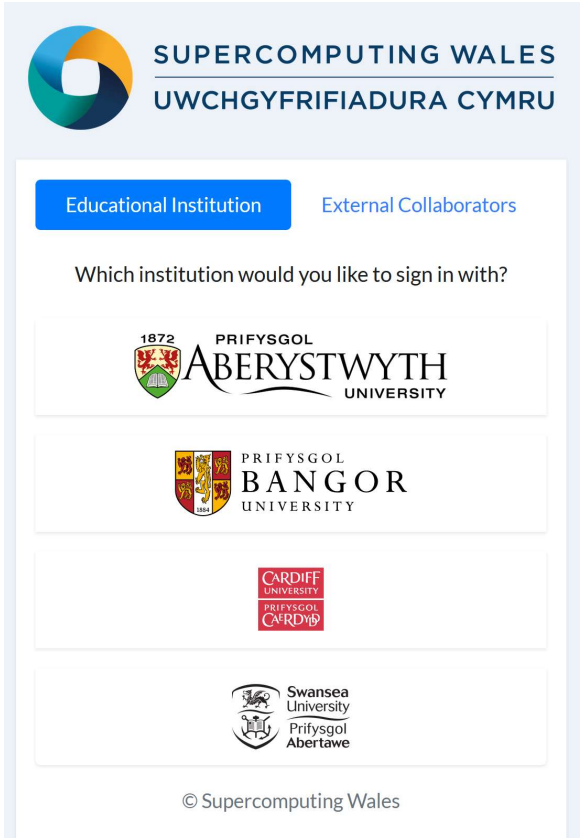
- Progress
  - Successfully duplicated VSim magnetron results
  - Successfully generated and studied plasmas
  - Successfully investigated theoretical Diocotron expectations
    - Deviations from ‘simple theory’ understood
    - Poor simulation initialisation



$$f_{Dnl} = \frac{e\,\rho_0 {r_p}^2}{4\,\pi\varepsilon_0 B {r_w}^2}\left(\frac{1}{1-\frac{r^2}{{r_w}^2}}\right)$$

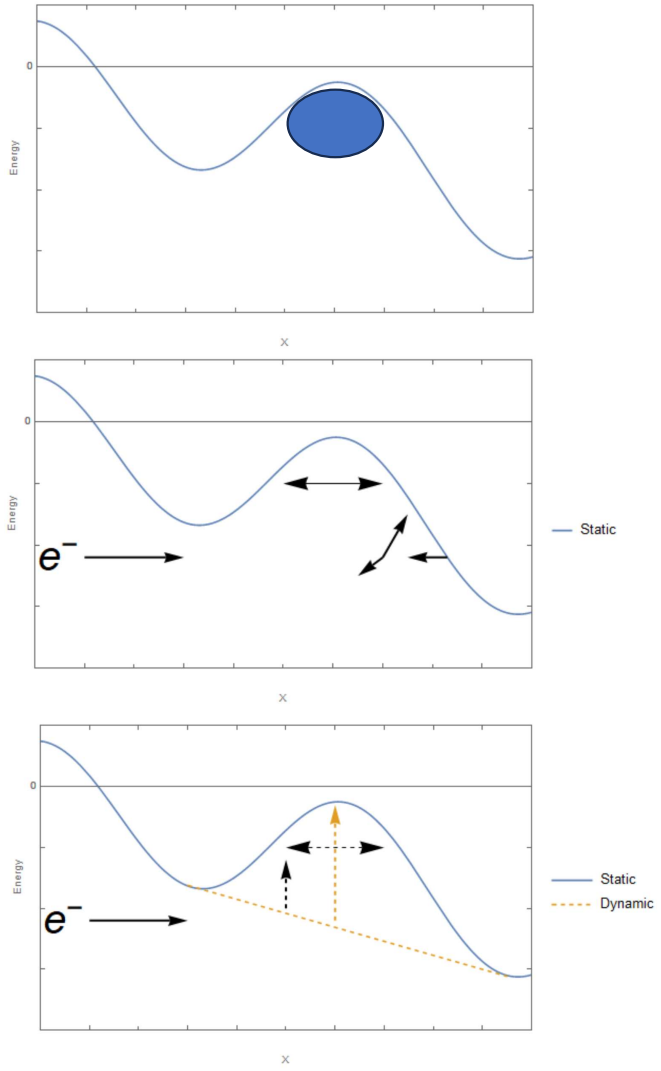
Progress – Simulation WarpX III

- Progress
  - Successfully duplicated VSim magnetron results
  - Successfully generated and studied plasmas
  - Successfully ‘investigated’ theoretical Diocotron expectations
    - Deviations from ‘simple theory’ understood
    - Poor simulation initialisation
  - Implemented on Swansea-based Supercomputing Wales HPC (CPU & GPU) resources

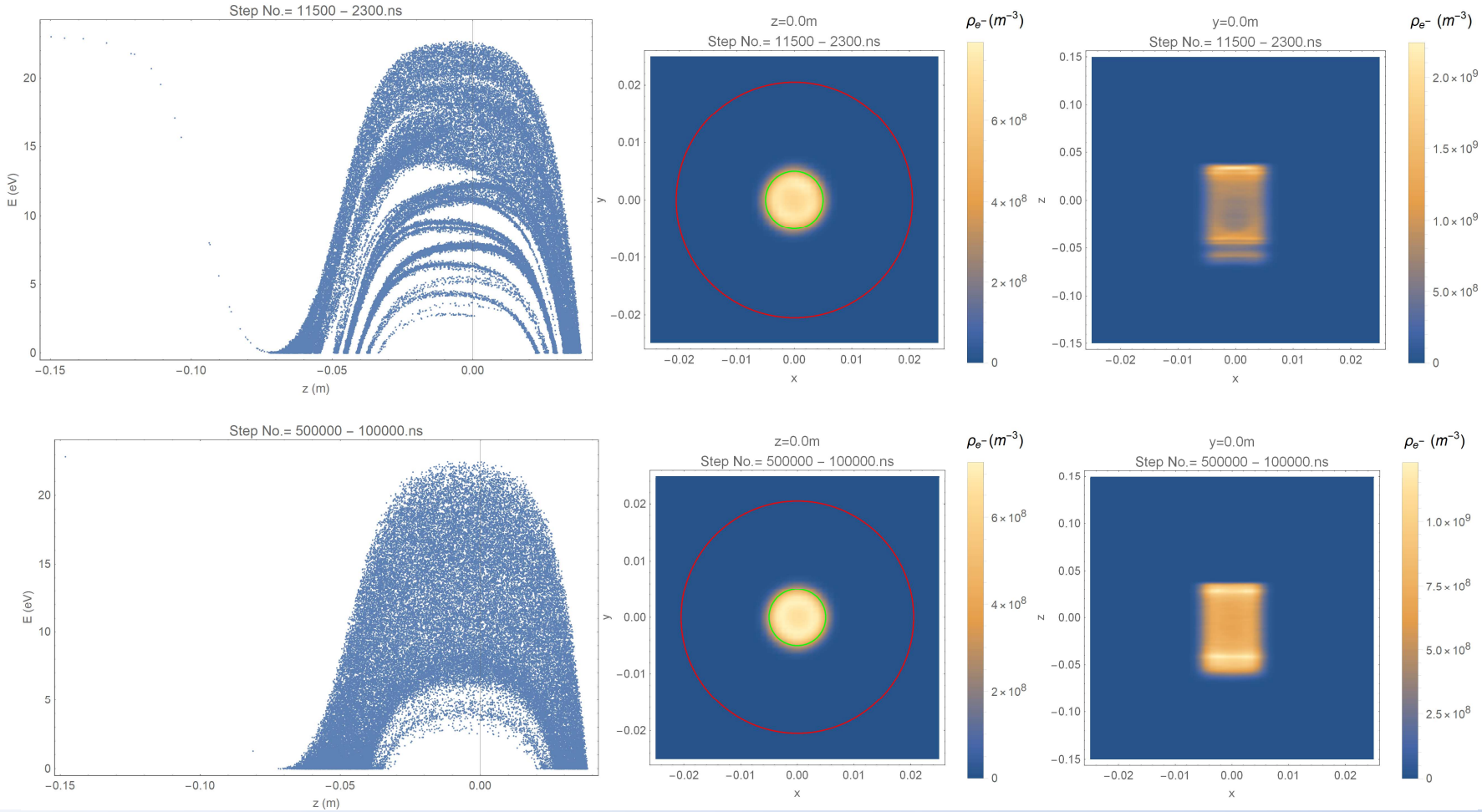


Simulation next steps

- Continue Diocotron/Magnetron simulations
- Accumulate plasma from electron beam
  - Static trap
  - Dynamic trap

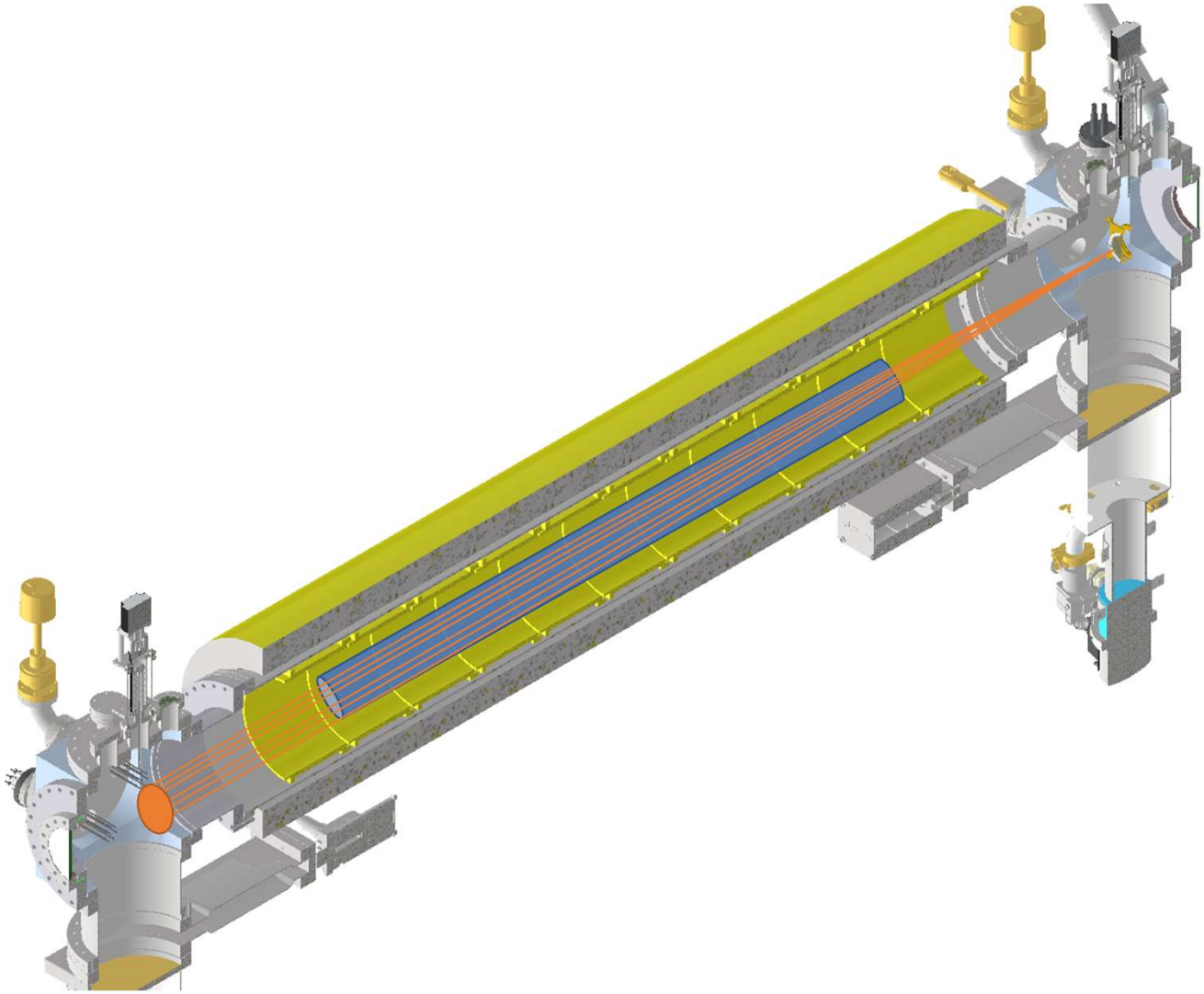


Dynamic accumulation simulation



Objective(s)

- PA1
  - Design testbench
- PA2
  - Construct testbench
  - Use testbench
  - PoP experiment
  - Upgrade testbench
  - Use testbench
  - Design Gabor Lens



Summary

- Issues have continued but mitigations have limited the impact
- WarpX has been successfully ran in various configurations at Swansea
- WarpX simulations have provided qualitative observations of many expected phenomena
- Experimental campaign at Swansea to start very soon