Towards real-time profiling of medical accelerator beams with gas jet system

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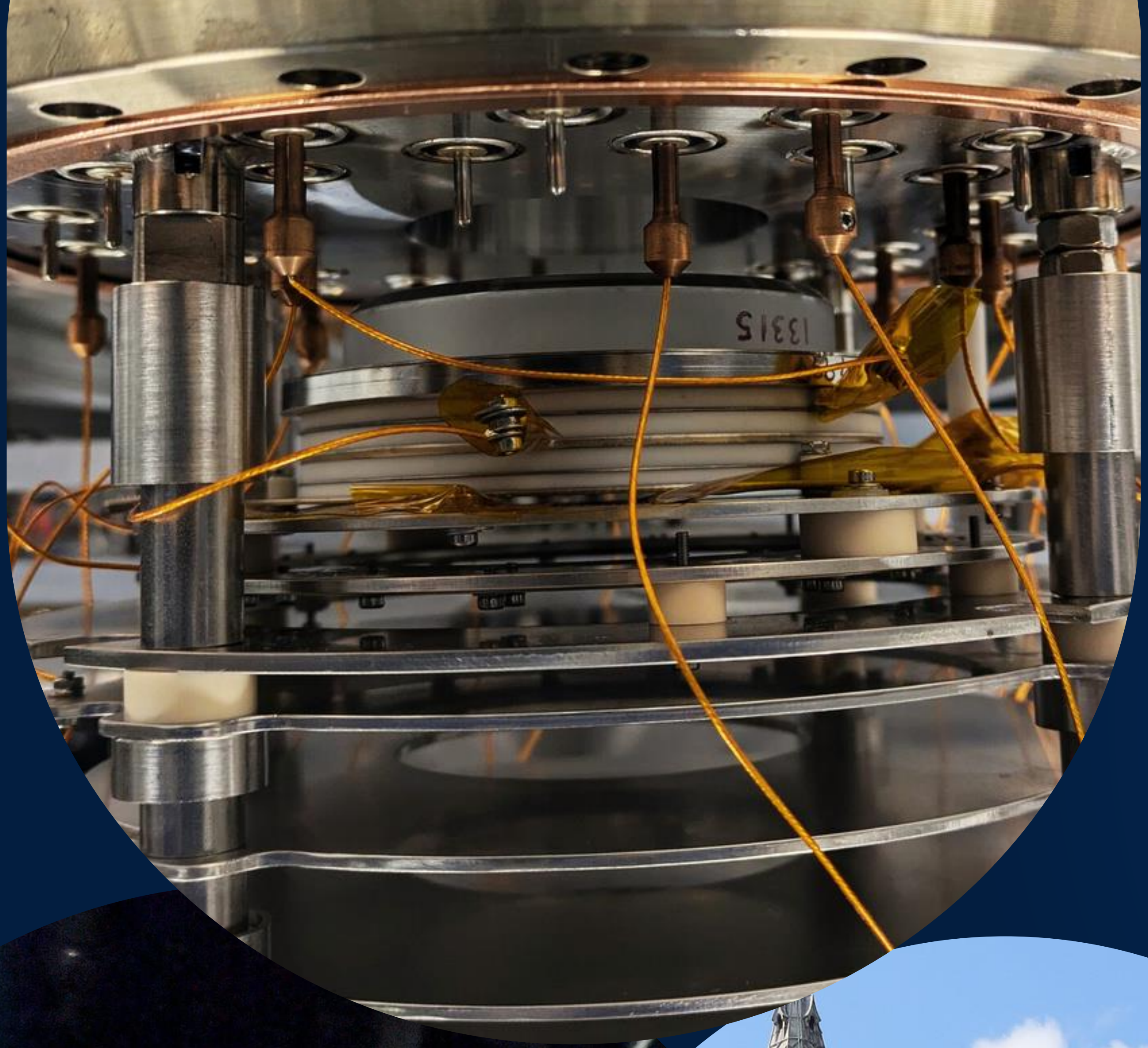


11th BGC Collaboration Meeting
2nd-3rd, Dec 2024

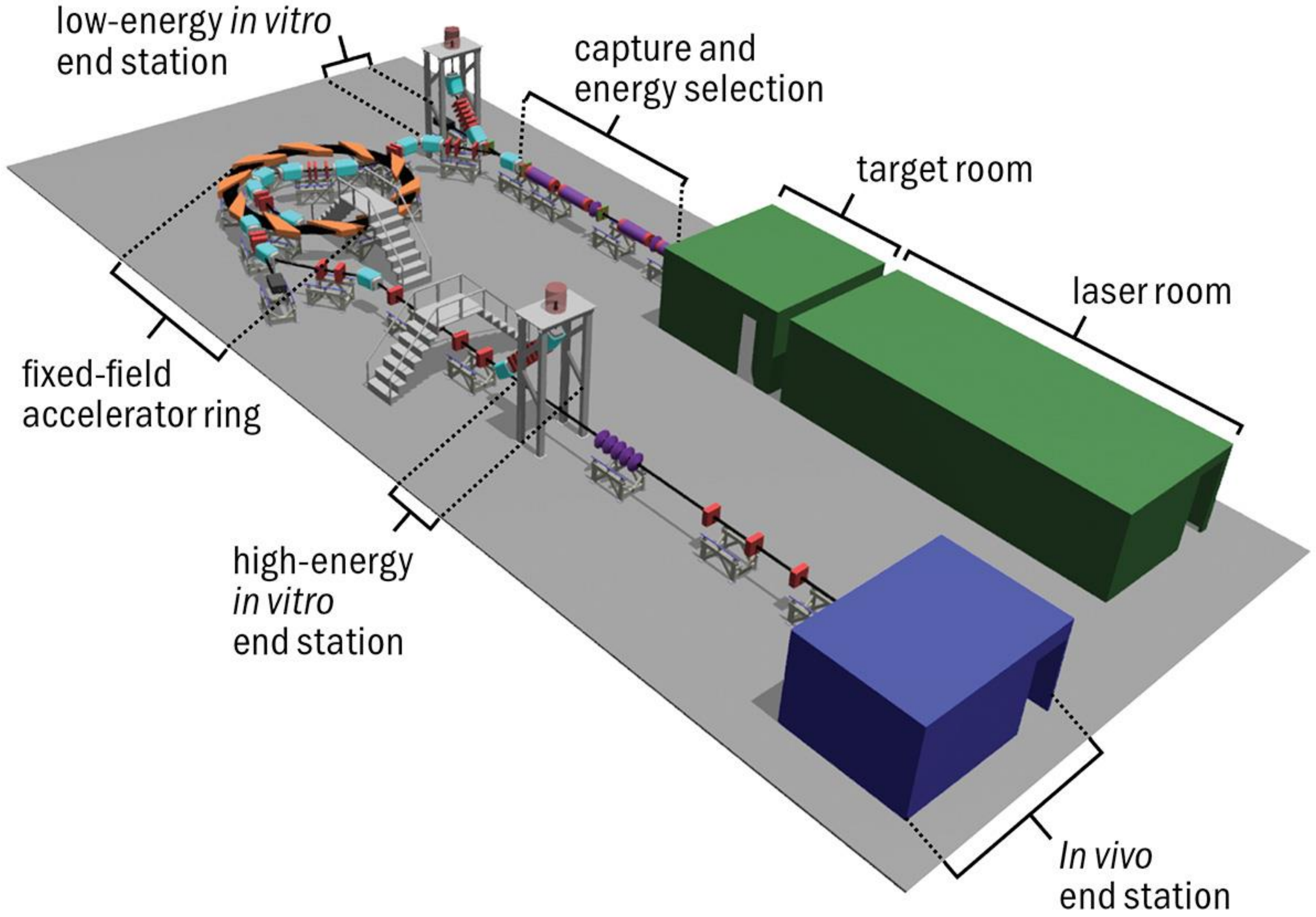
JetDose

LhARA
Laser-hybrid Accelerator for Radiobiological Applications

Medical applications

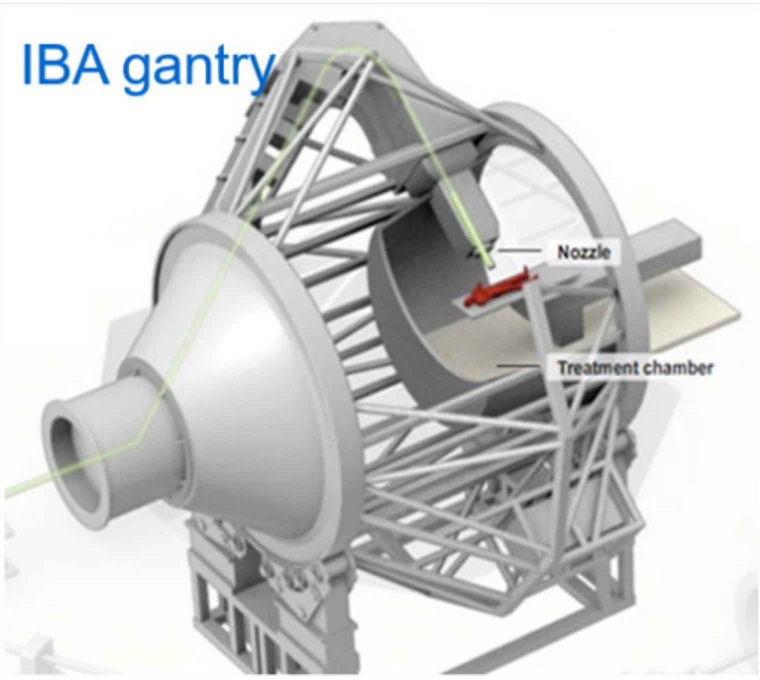
Future accelerators: LhARA[1] project (Laser Hybrid accelerator for radiobiological app.)

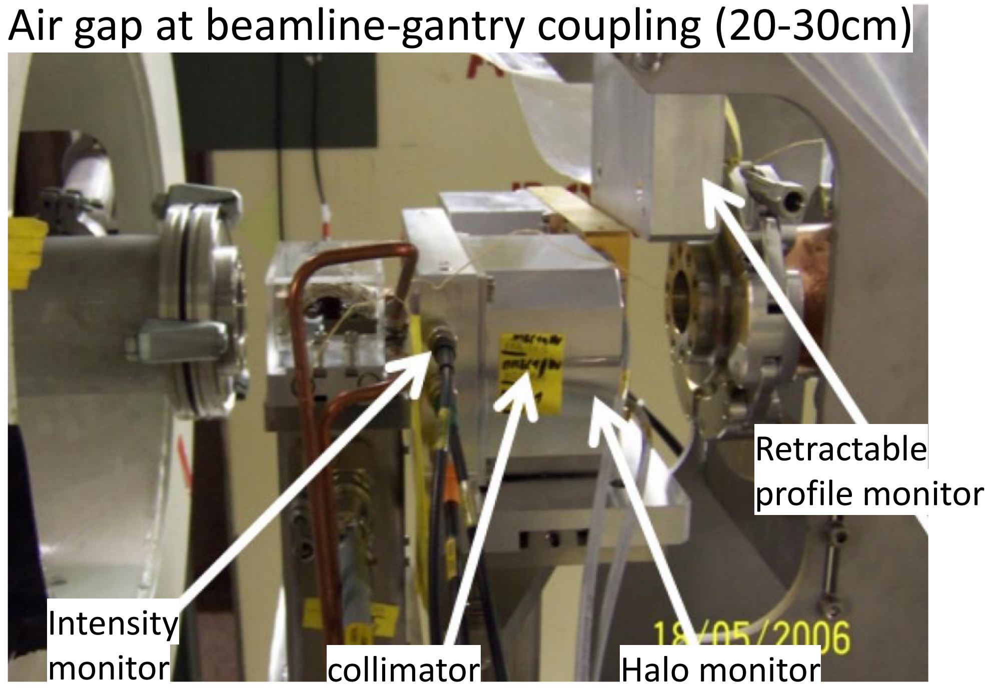
- **Accelerator**: Laser driven 10 Hz, ~10ns bunch of ~10^9 p^+ / C^{6+}.
- **Requirement:** beam profile monitor for in-vivo and in-vitro end-station.
- **Parameters to be monitored:** profile, current, energy and dose (if possible)



Operational accelerators: Jet Dose project

- **Accelerator:** Cyclotron (*IBA c230, Varian PROBEAM*), Synchrocyclotron (*IBA S2C2, Mevion S250*).
- **Proton beam Therapy:** 2 Gy (min) to 1 Liter ; **1.9 x 10^{11} p^+** ; delivered in **1 minute** (conventional dose rate) and **100 ms** (FLASH dose rate)[2]
- **Targets:** beam profile monitoring during treatment.

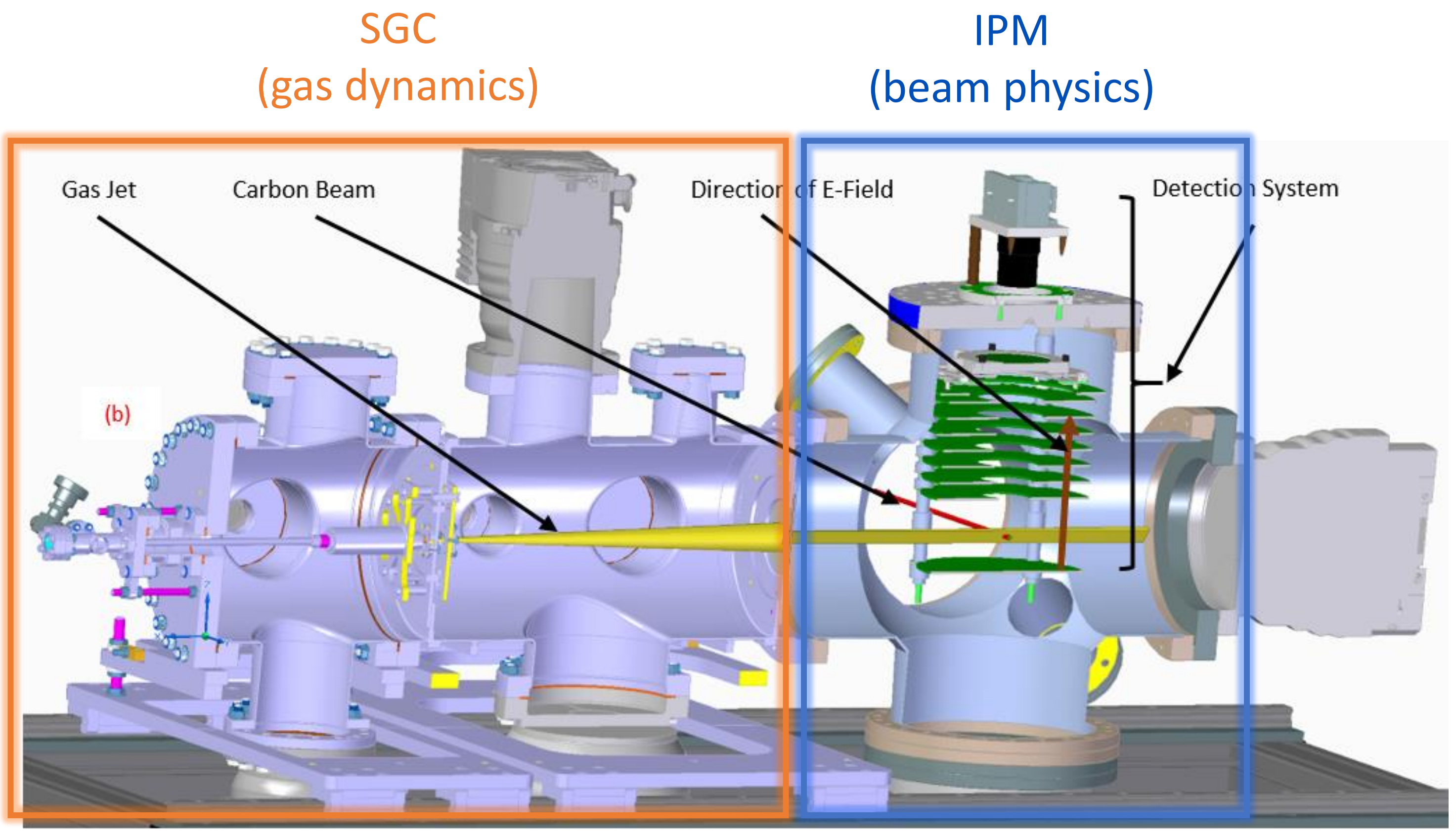


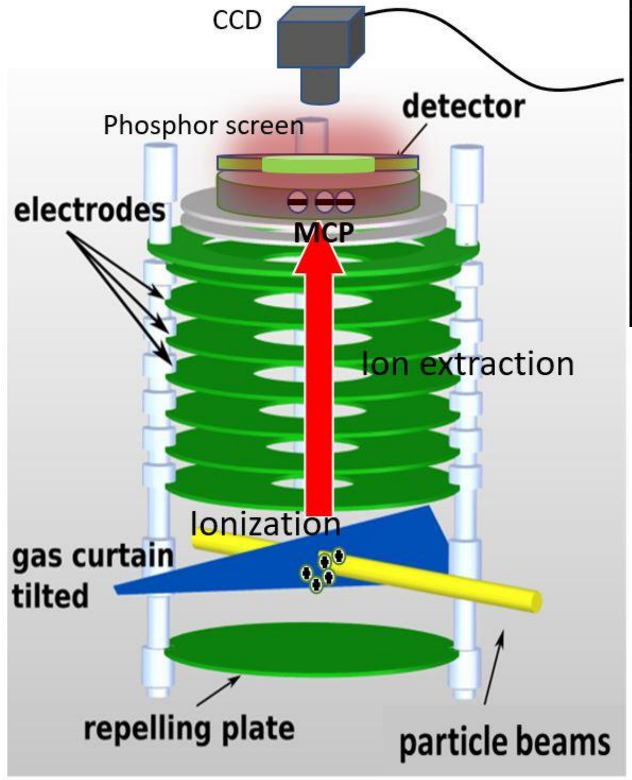


Typical beam transport system[3]

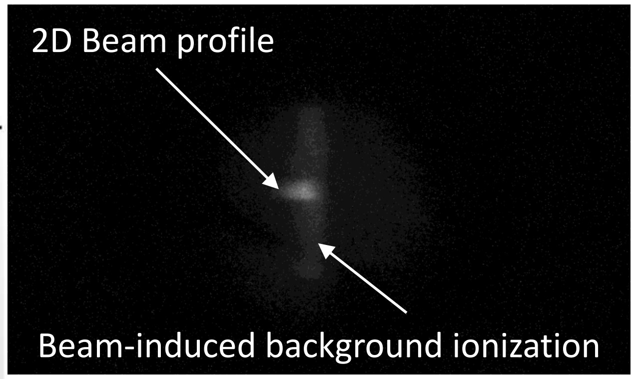
[1] Baseline for the LhARA design update. Technical Report CCAP-TN-11 Issue 1, The LhARA Collaboration (2022)
[2] S. Jolly, et al., "Technical challenges for FLASH proton therapy" Physics Medica 78(2020) 71-82
[3] J. M. Schippers, et al., "Beam Transport Systems for Particle Therapy." *arXiv: Medical Physics* (2017)

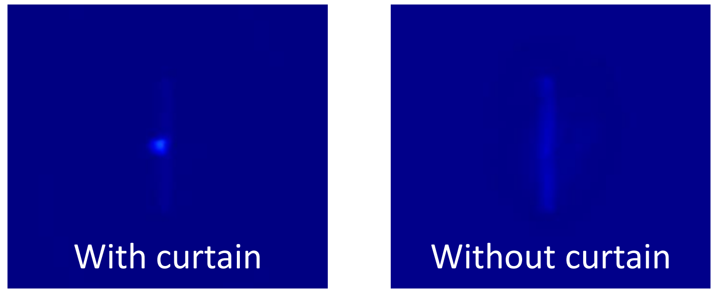
Supersonic gas curtain based Ionization profile monitor

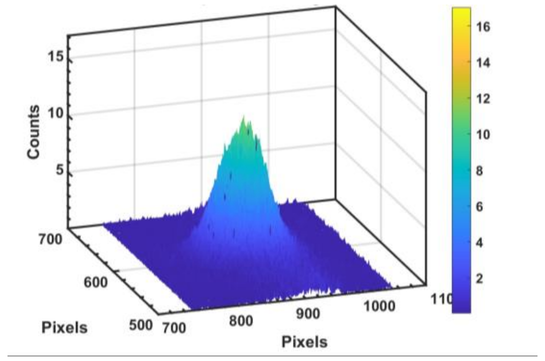




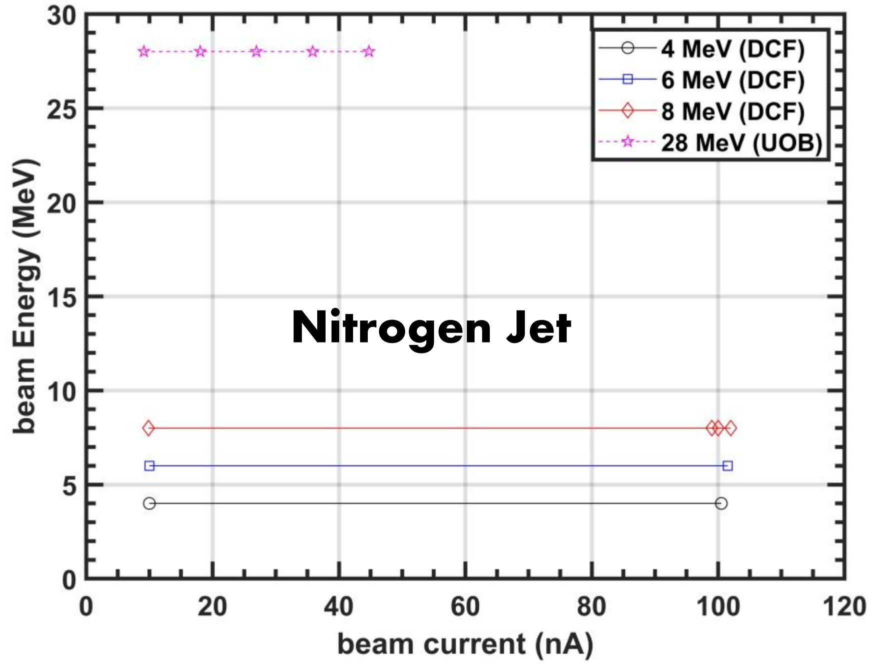
What camera sees

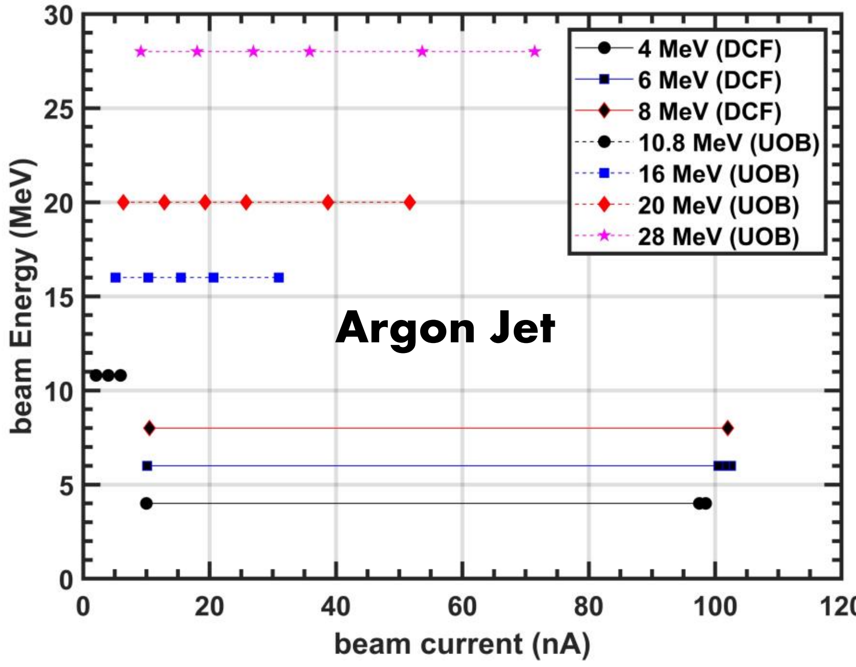






2D profile after subtracting background



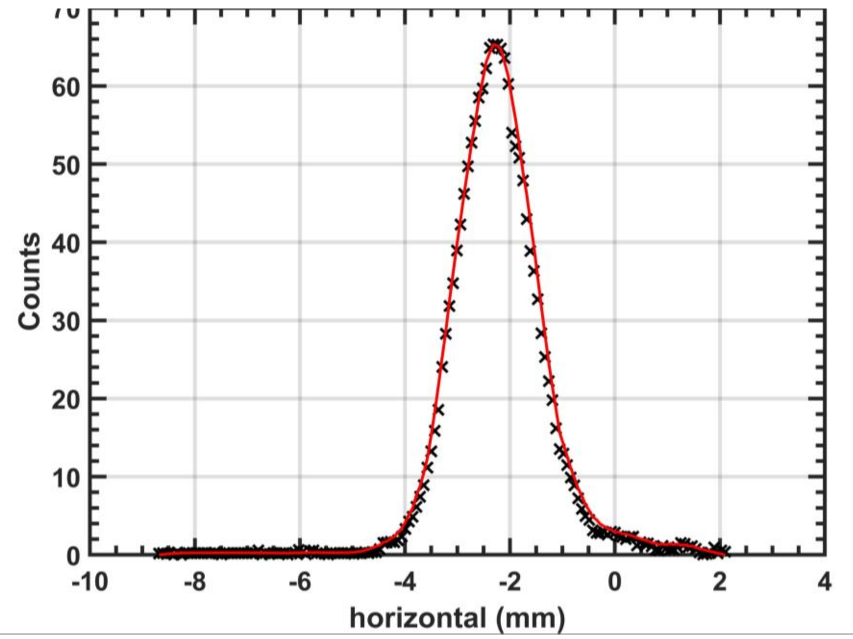


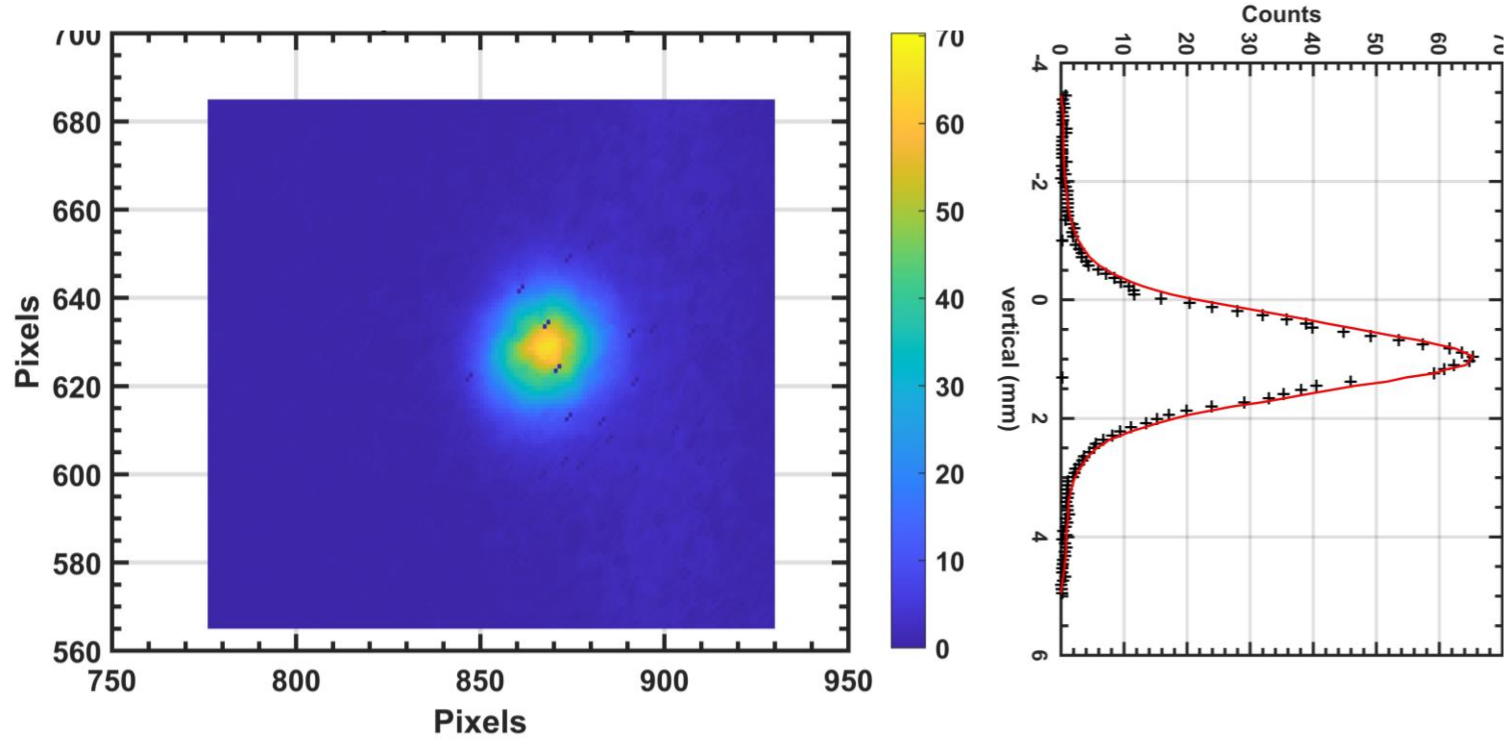
Proton beam profile measurements at Dalton Cumbria Facility, Whitehaven, UK and Uni. of Birmingham, UK

	Energy (MeV)	Current (nA)						
Argon	4	10	98	99				DCF
	6	10	103	102	101			
	8	11	102					
Nitrogen	4	10	101					
	6	10	102	102				
	8	10	99	100	102			
Argon	28	9.1	18.0	26.9	35.8	53.6	71.4	UoB
nitrogen	28	9.1	18.0	26.9	35.8	44.7		

Detection times

DCF: 4MeV, 100nA, 1s, FWHM 1.5mm

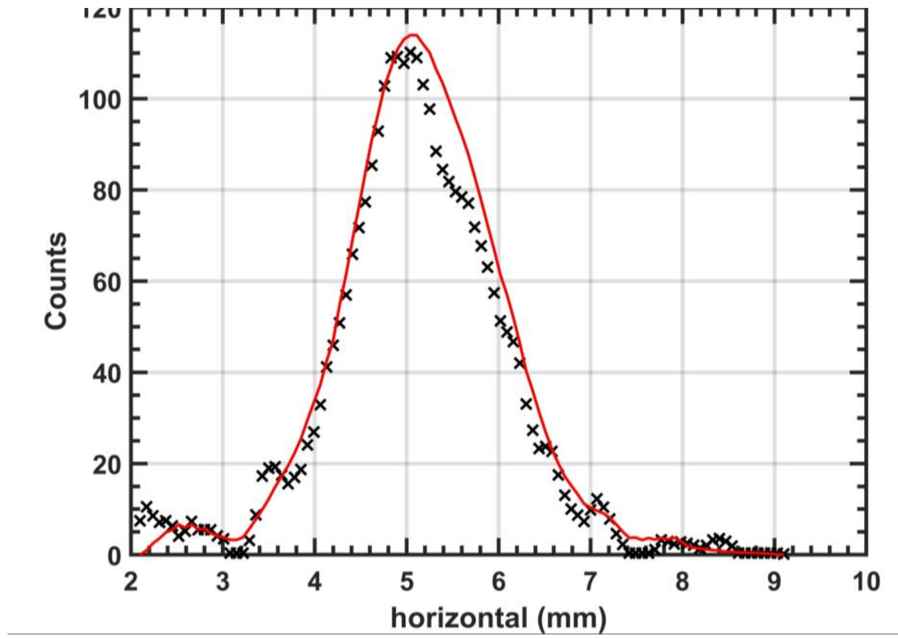


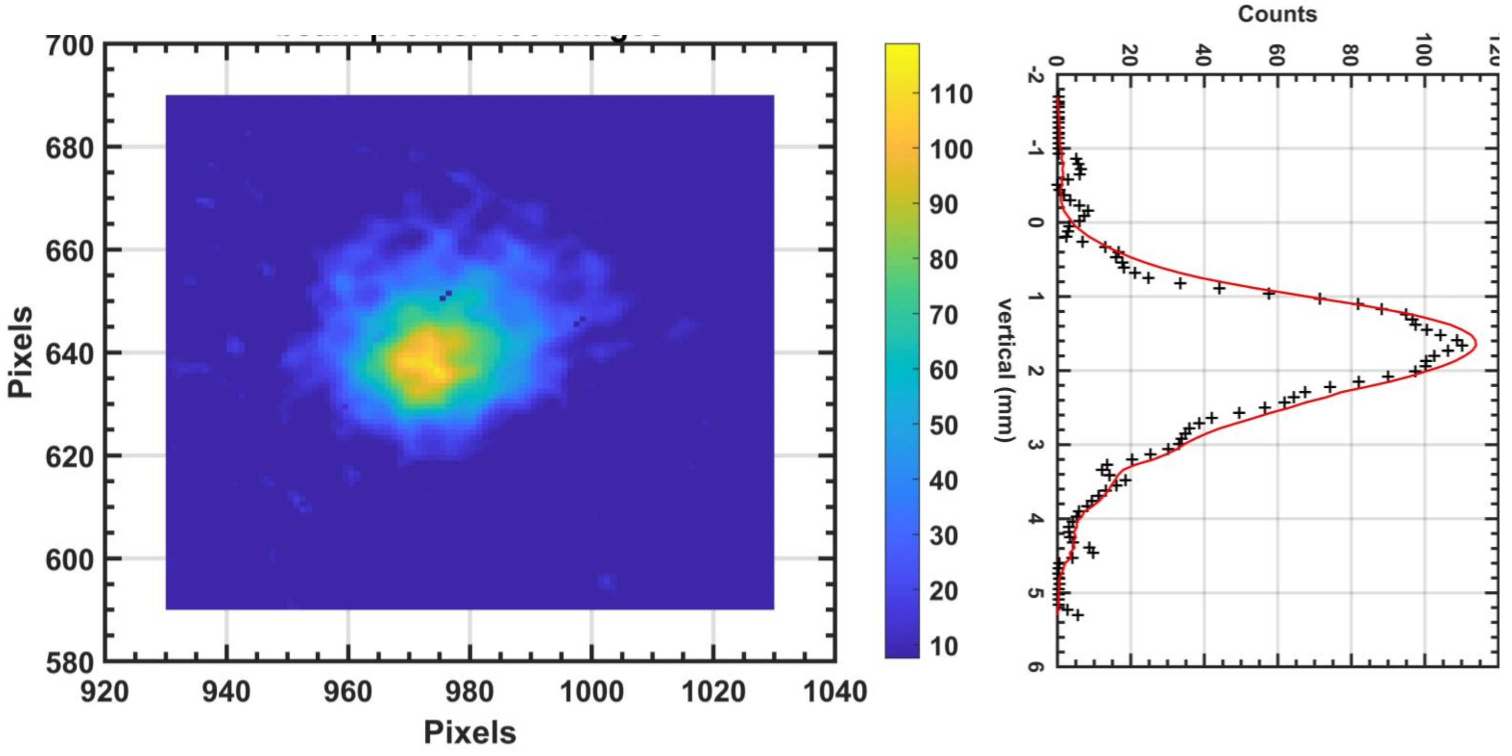


2x counts with ½ the integration, for 1/8th of beam current with ½ the current density

Sensitivity improvements factor of ~80

UOB: 28MeV, 12nA, 500ms, FWHM-2mm





Detector response with beam current and energy

$$D(beam\ fluence\ /no.) = \frac{1}{a}\left(\frac{I/qe \times t}{C}\right) = \frac{1}{\beta a}$$

Sensitivity scales with energy

$$C(no.) = \beta\left(\frac{I}{qe} \times t\right)$$

Const. E - Counts scales with current

where, D : Sensitivity (Fluence/count)
C : total integrated counts
q : charge of the beam
I : instantaneous beam current
t : integration time of the camera
β : Scaling factor

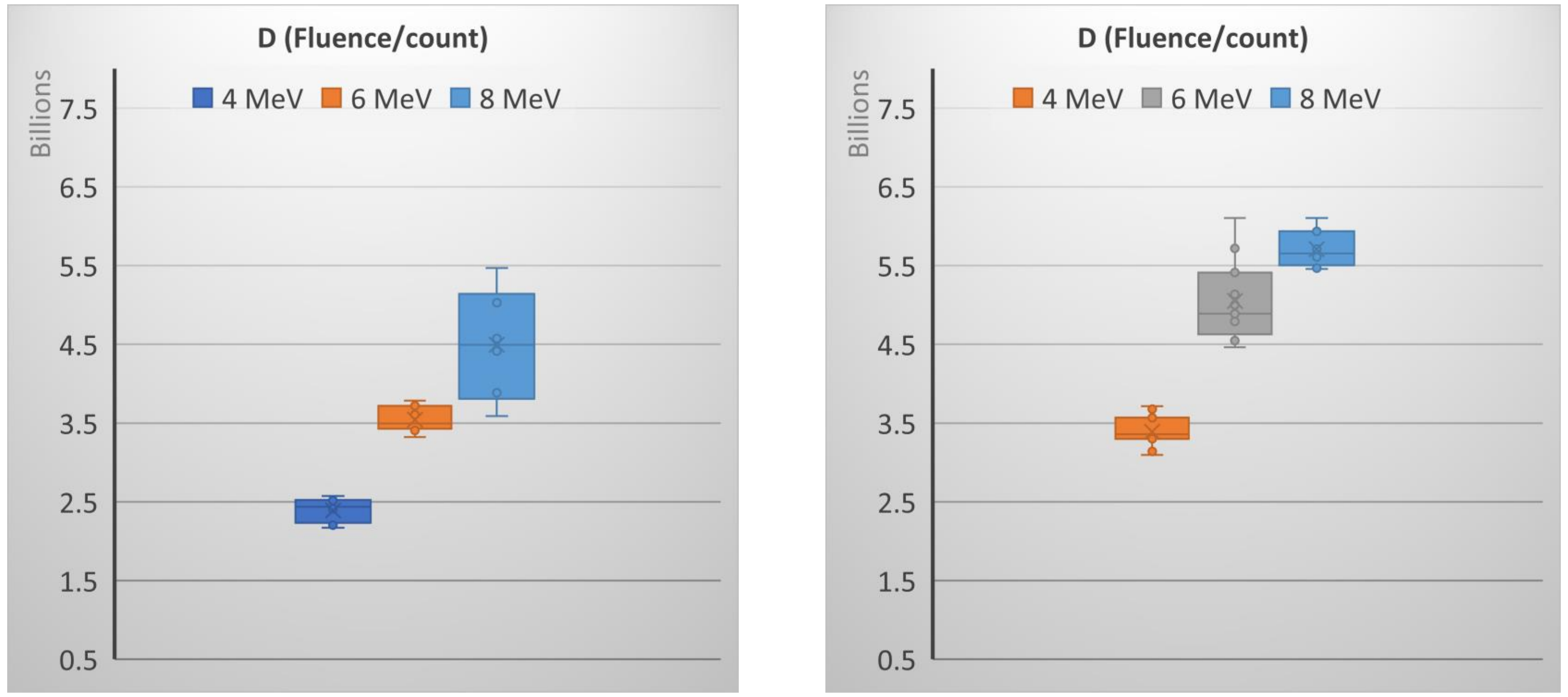
$$\beta = G_c \times E_L \times QE \times G_{MCP} \times E_{OAR} \times E_{IPM} \times P_{ion}(E)$$

Detector specific factors

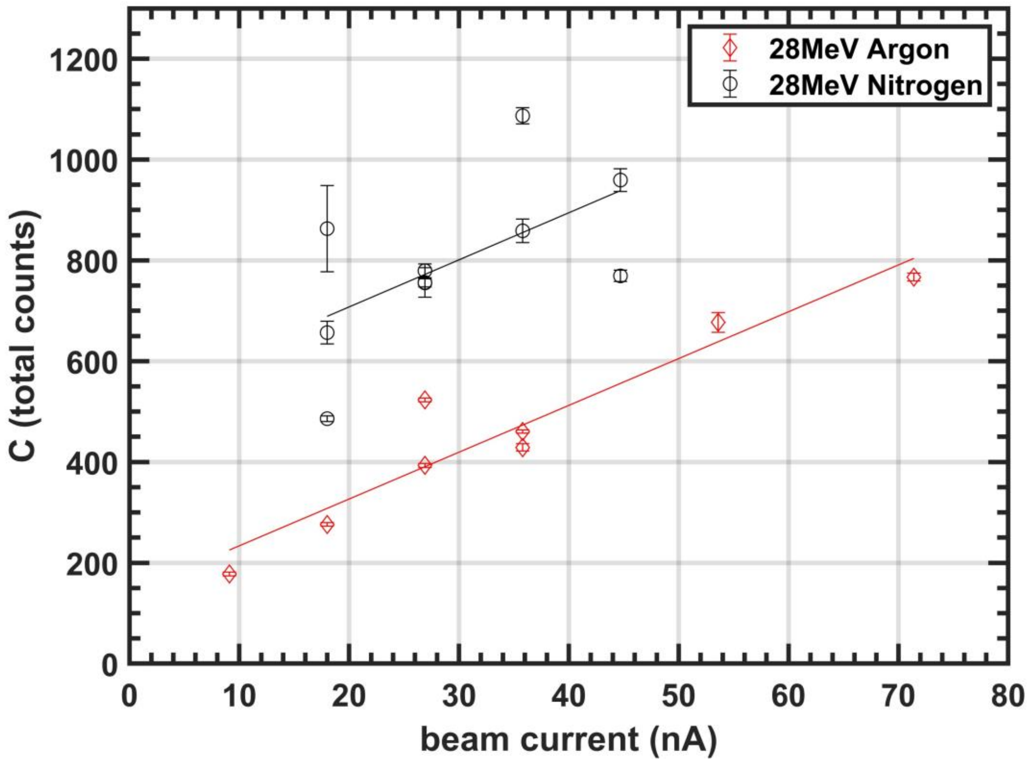
Ionization probability (function of energy)

$D_{28\ MeV}$ (fluence/count)	Argon	Nitrogen
DCF experiments	1.5×10^{10}	1.75×10^{10}
UoB experiments	3.8×10^{8}	2×10^{8}
Gain (noise normalized)	~40	~87.5

← higher value due to density improvement



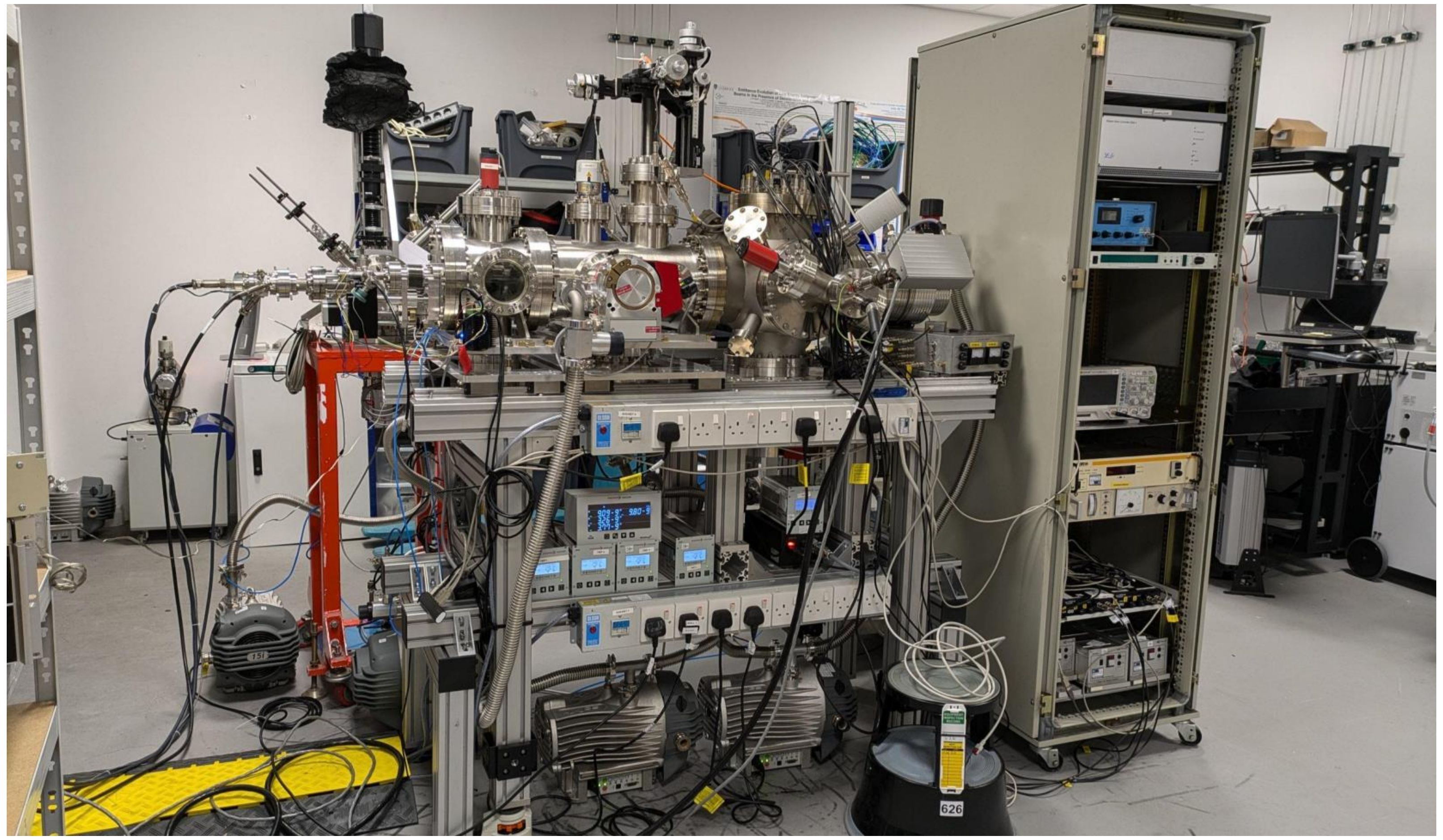
D (fluence/count) at different beam energies for 100 nA



C (counts) at different beam currents at 28 MeV

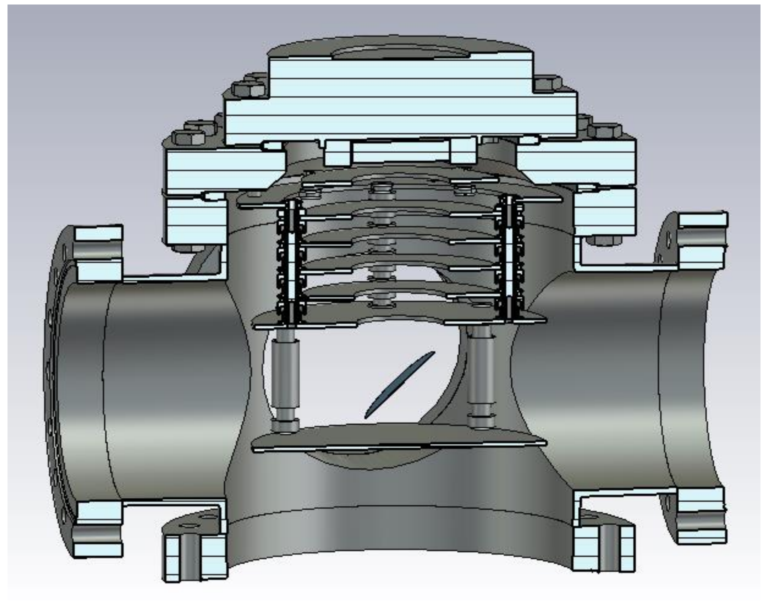
Ongoing and planned works

- Experiments with electron beam test stand to **estimate scaling laws** for
  - Count vs current
  - Fluence/count vs energy
- **Quantifying accuracy** of profile by comparison with redundant diagnostics to account for
  - Undesired focussing\defocussing effects.
  - Distortions at beam edges.
  - Contrast of the beam edge relative to the background.

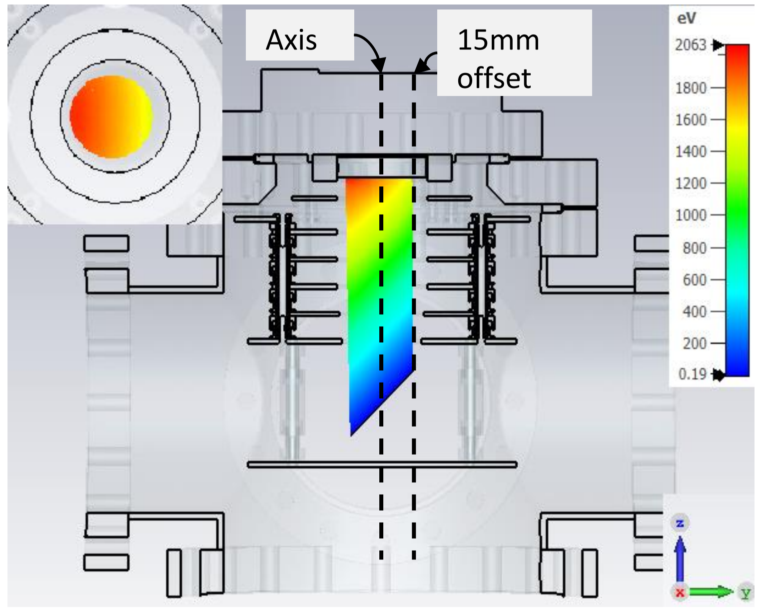


- IPM: **New design** for compactness and robustness
  - Field uniformity at the edges
  - Engineering study:

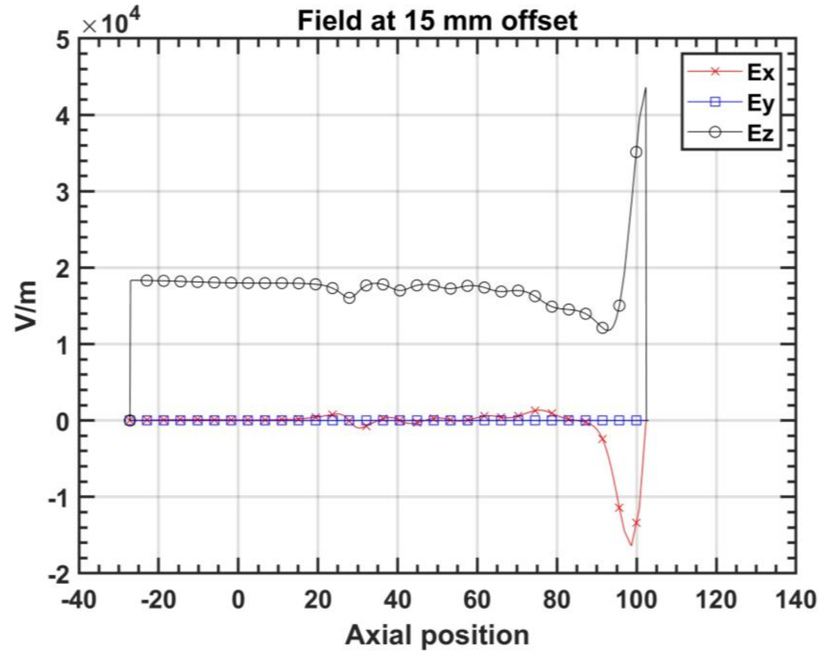
    DFM iterations, Structural analysis
  - Physics study: recoil energy and self-repulsion



New IPM Design
(75% of original)



Particle Trajectory and energy distribution



Electric field along the axis at edges

THANK YOU

<u>Project Team:</u>

- Carsten Welsch
- Narender Kumar
- Milaan Patel
- William Butcher (PhD student)
- Farhana Thesni (PhD student)