Los Alamos NATIONAL LABORATORY

Flash particle radiography with p^{+} / $4He^{2+}$ -- an overview

3rd ion imaging workshop

Martin Schanz
P-1 Dynamic Imaging & Radiography

10/14/2022

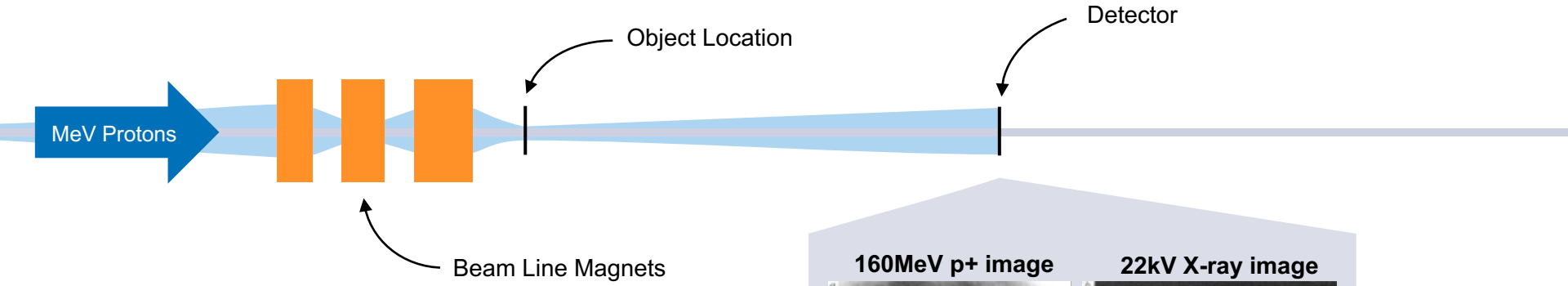
LA-UR-22-30636

Outline

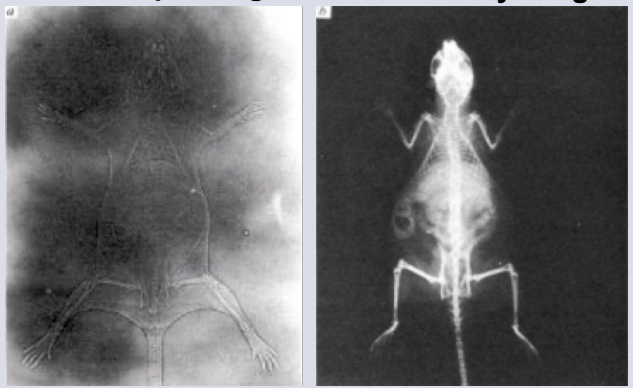
- Lens-based Particle (p^+) Radiography
  - History & Concept
  - Setup & Common Applications @ LANL
- Previous Medical Experiments
  - Phantom / Small Animal Imaging
  - Proton aided xCT Calibration
- Dual-lens Imaging and Treatment with p^+ or $^{12}C^{6+}/^{4}He^{2+}$
  - Concept
  - Geant4/BDSIM/TOPAS/PROSIT Simulations

Lens-Based Particle Radiography

History



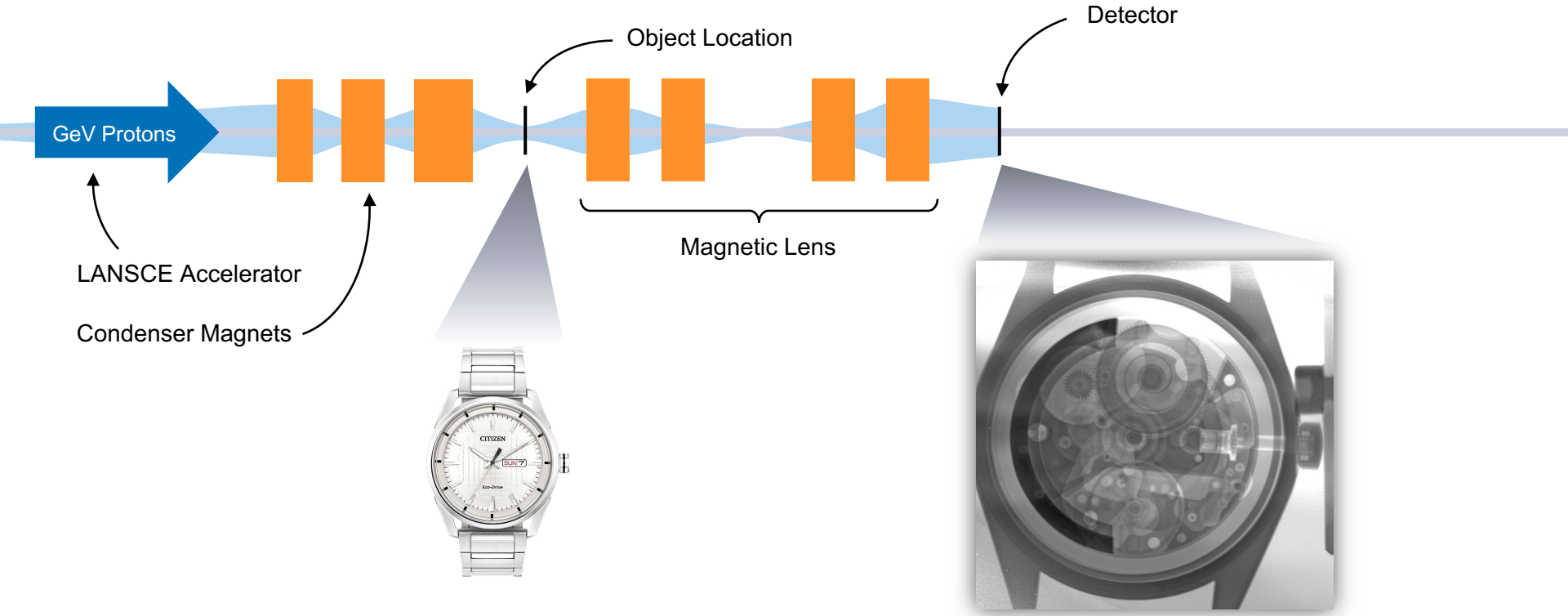
160MeV p+ image **22kV X-ray image**



D. West, A.C. Sherwood, Nature **239**, 1972

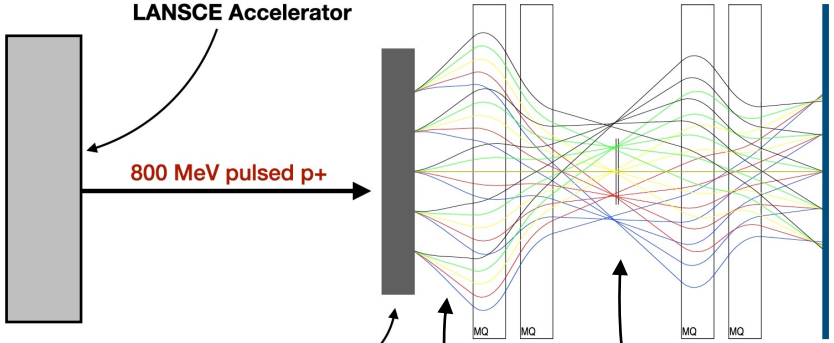
Lens-Based Particle Radiography

Concept



Lens-Based Particle Radiography

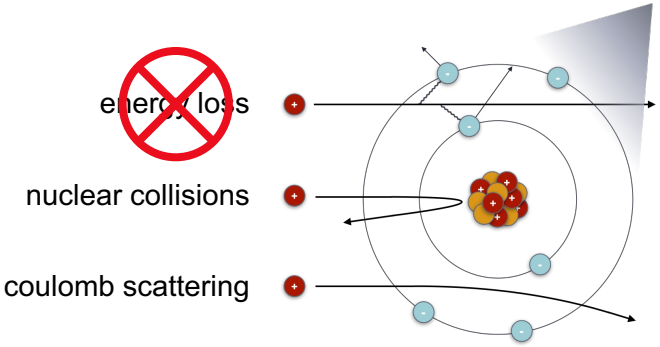
Concept

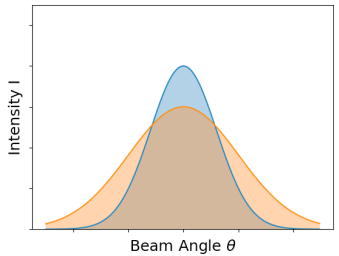


Target

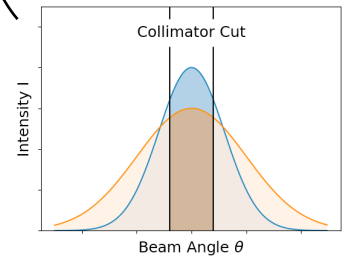
Detector

Transmission ∝ Density





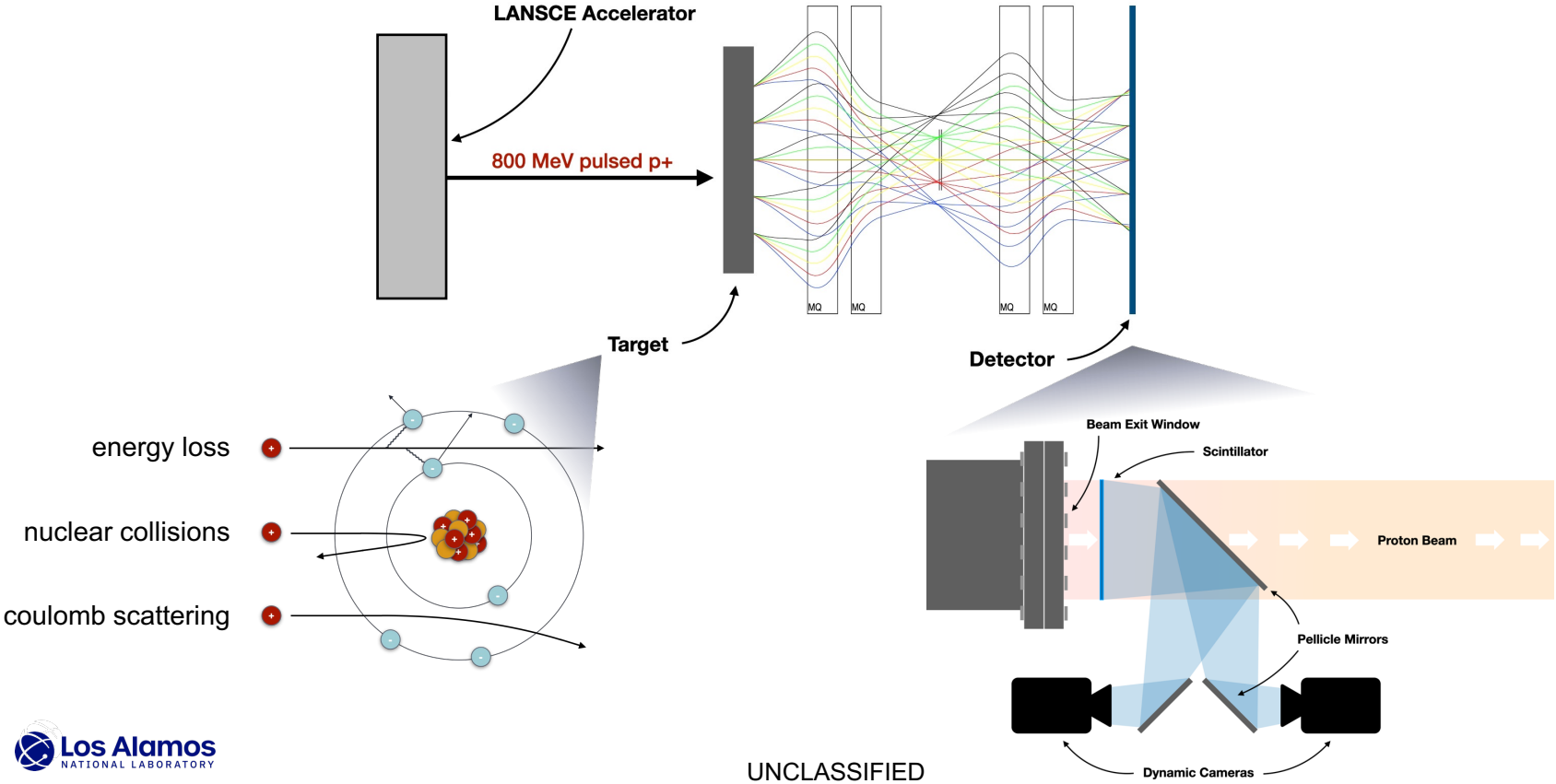
Angular distribution after object interaction



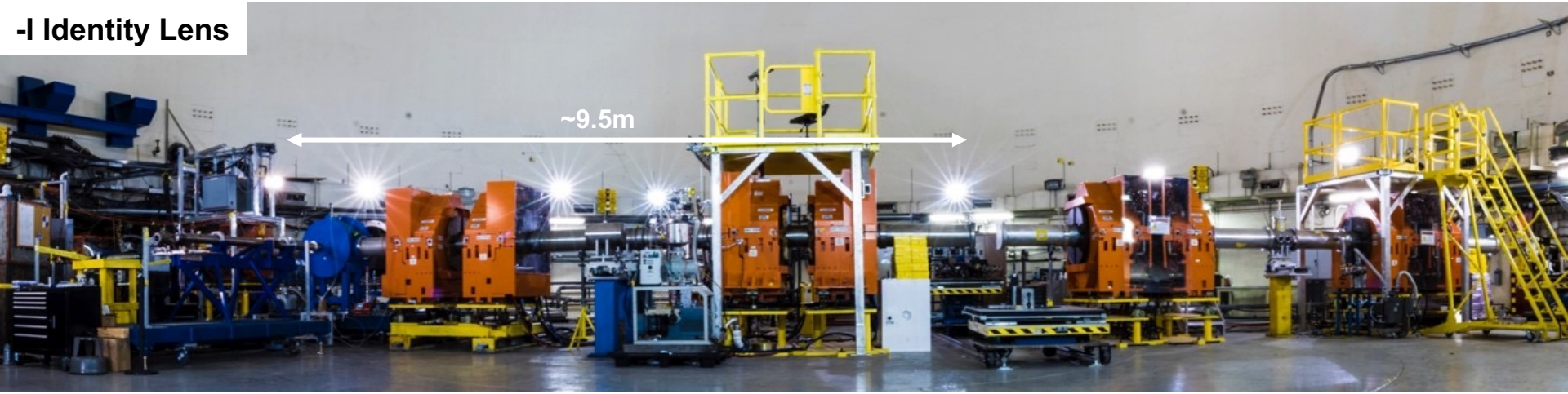
Angular distribution at collimator plane

Lens-Based Particle Radiography

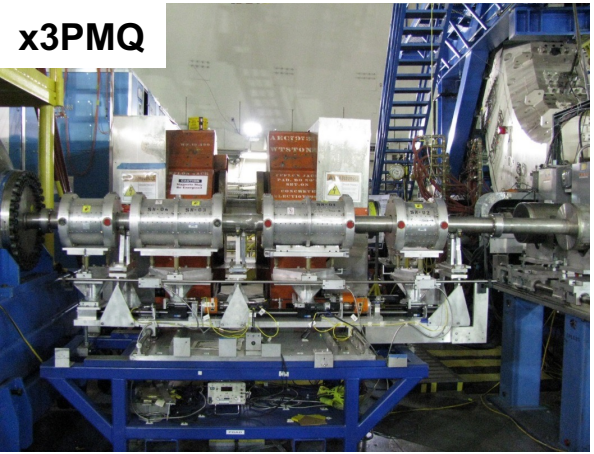
Concept



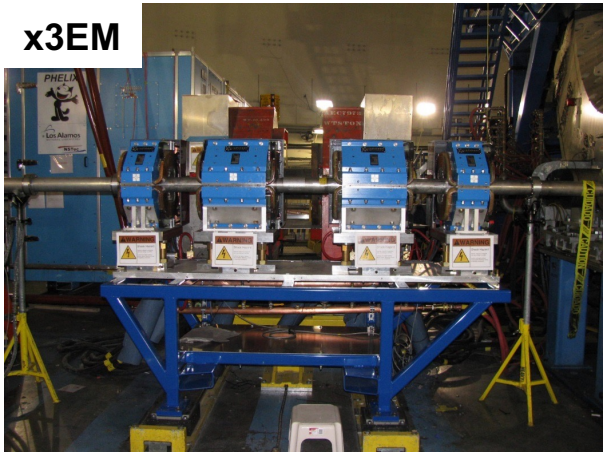
-I Identity Lens



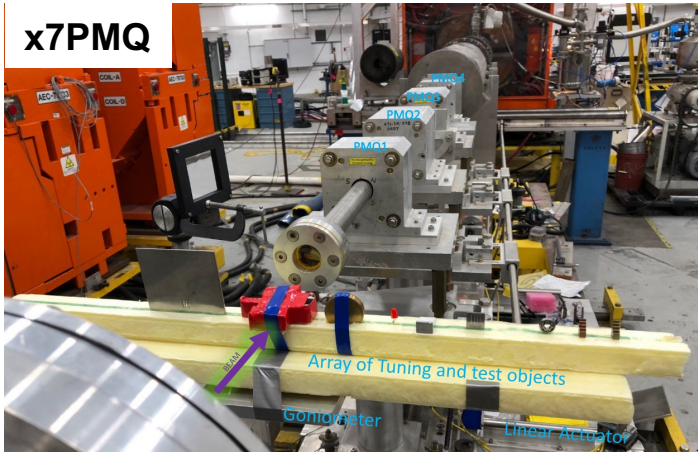
x3PMQ



x3EM



x7PMQ

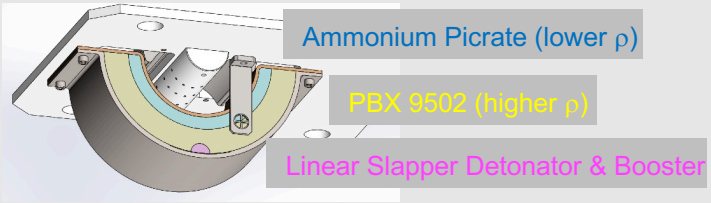


Lens-Based Particle Radiography

Typical pRad Applications

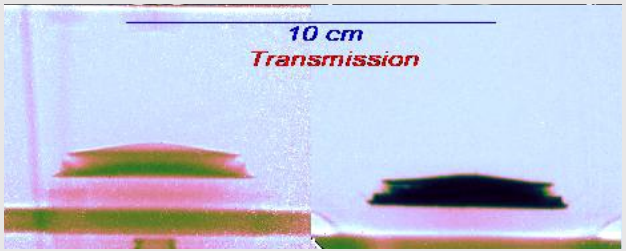
Halfpipe

- Interactions of two different types of explosives
- Initiation
- Detonation front propagation



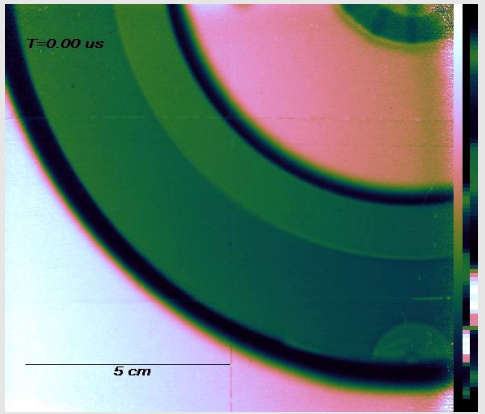
Dynamic material strength

- Stress induced material failure in various metals



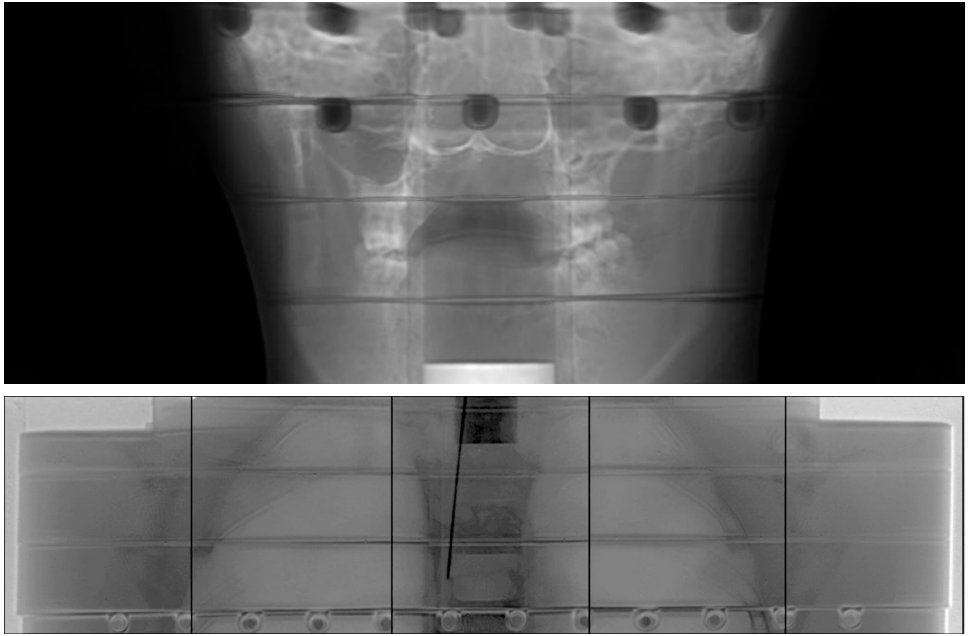
High explosive induced material failure in:

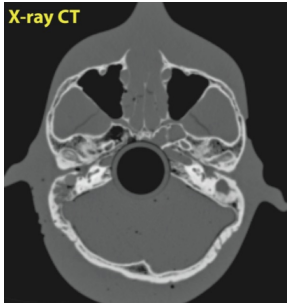
Aluminum **Tantalum**

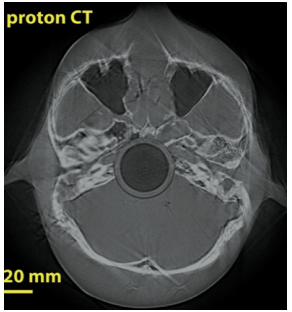


Medical Proton Imaging

Matroshka Phantom / Projections & Tomography







Prall, M., *et al.* High-energy proton imaging for biomedical applications. *Sci Rep* **6**, 27651 (2016)

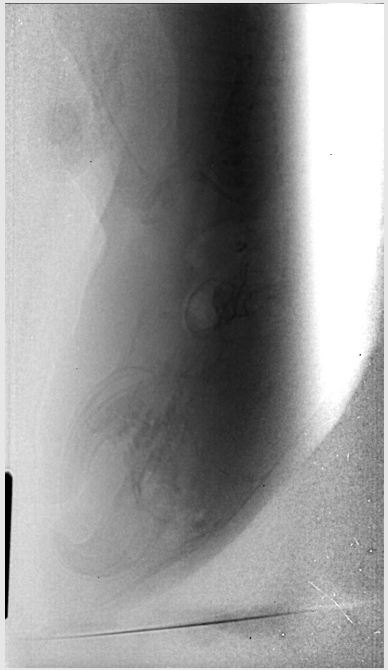
Medical Proton Imaging

Various Biological Samples

Mouse Tomography (2015 & 2022)

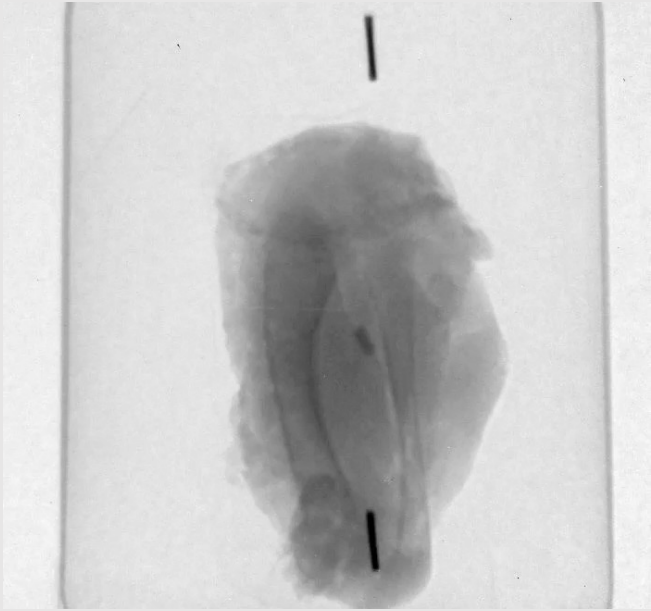
800MeV LANL

2.5 GeV GSI



Chicken Wing Tomography (2016)

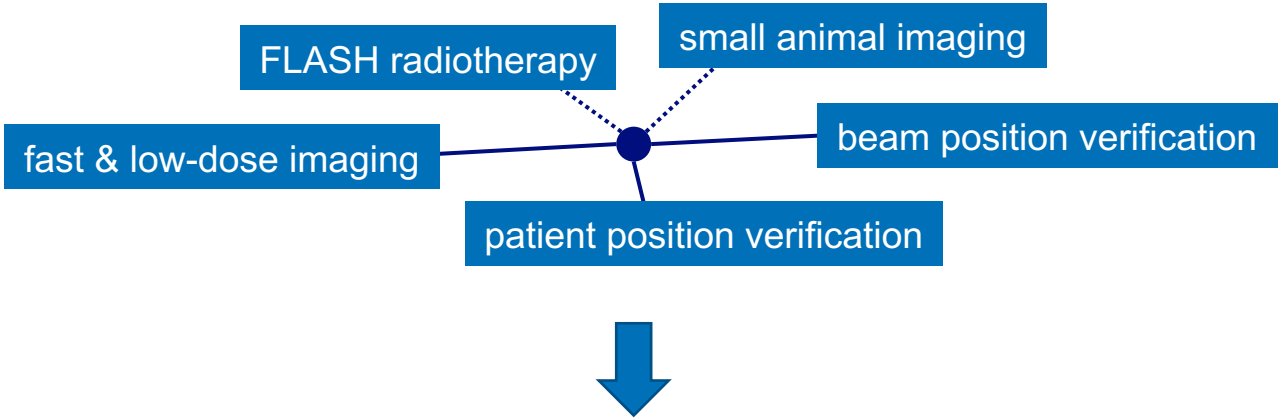
800MeV LANL



Prall, M., *et al.* High-energy proton imaging for biomedical applications. *Sci Rep* **6**, 27651 (2016)

Medical Particle Imaging

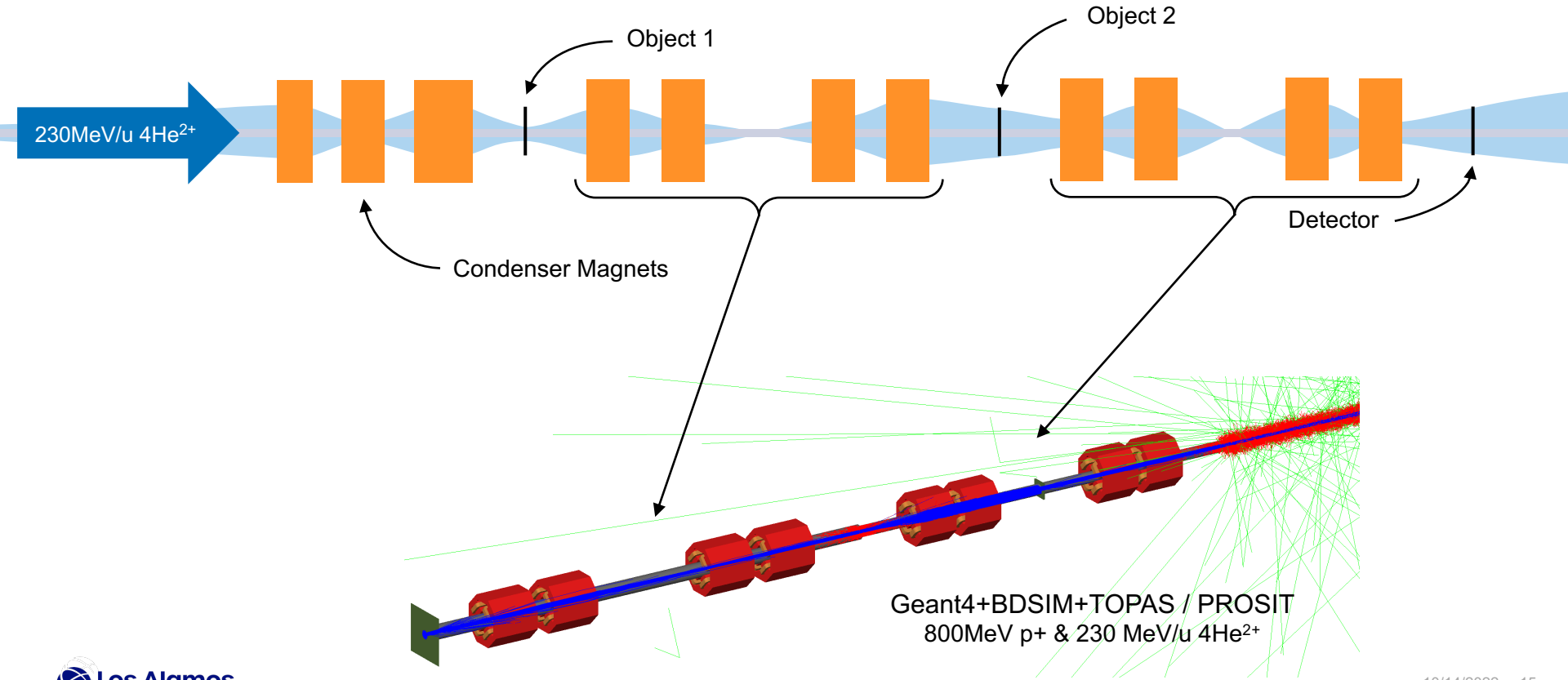
Towards Online Imaging/Treatment Verification



Carbon treatment & full-scale imaging with parasitic Helium ions?

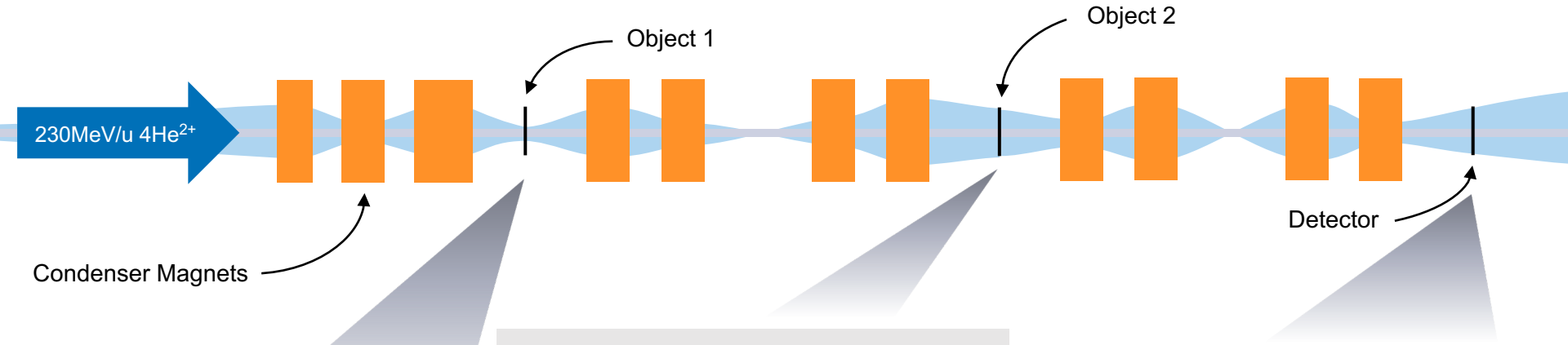
Medical Particle Imaging

Dual-Lens Treatment & Imaging (p+ or 12C/4He mixed beam)



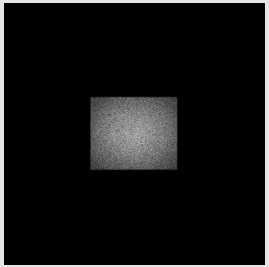
Medical Particle Imaging

Dual-Lens Treatment & Imaging (p+ or 12C/4He mixed beam)



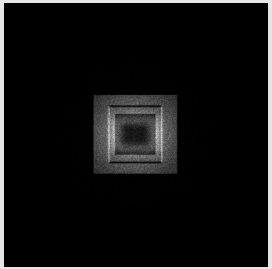
MLC Collimator

Patient



- MLC distribution is mapped 1:1 on patient
- Scattered particles exiting the MLC are stopped inside the first quadrupole

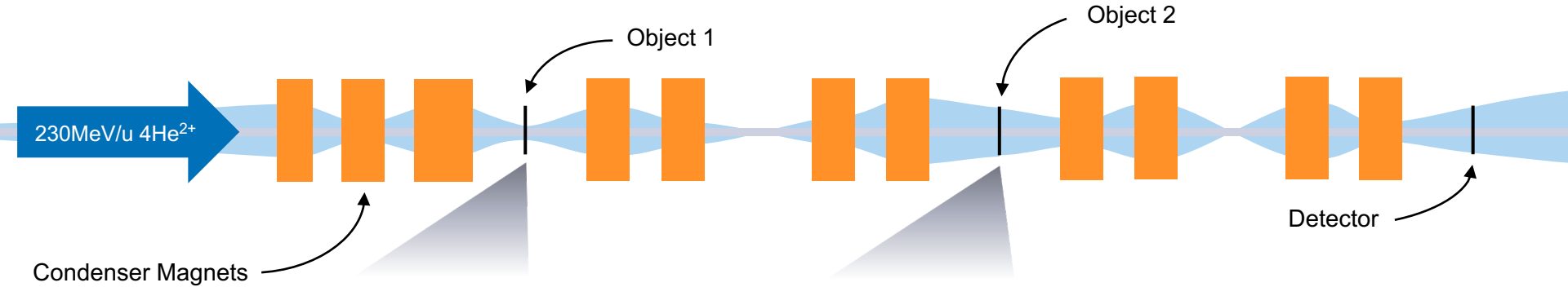
Image Location

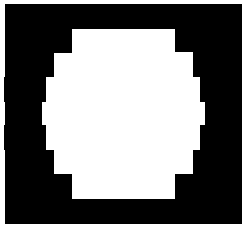


- Instant picture of treated volume
- Instant density map of treated volume

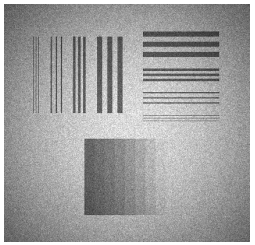
Medical Particle Imaging

Dual-Lens Treatment & Imaging (p+ or 12C/4He mixed beam)





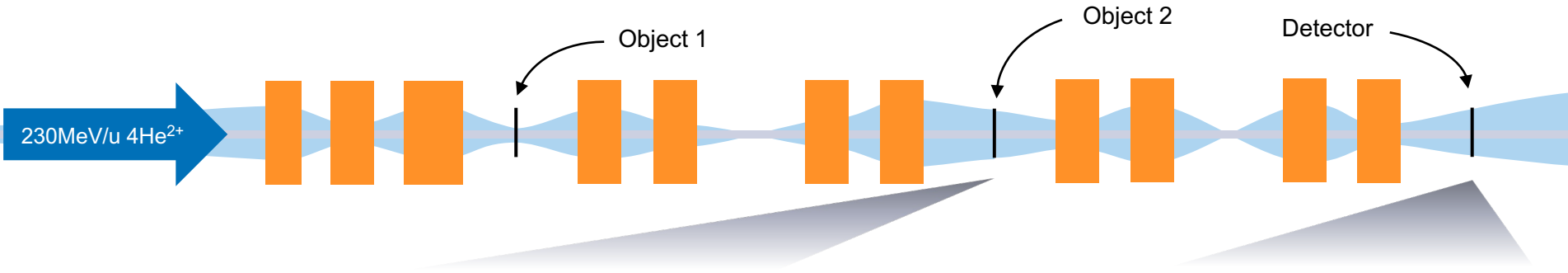
2cm W MLC collimator
~390 MeV energy loss
~50 mrad scattering



W test pattern
spatial resolution pattern
density wedge
embedded in 2-20cm of H_2O

Medical Particle Imaging

Dual-Lens Treatment & Imaging - 800MeV p^+ & $4He^{2+}$ 230MeV/u imaging results



Treatment distribution

- Precise mapping of MLC shape on patient (edge resolution <30μm)
- Remaining transmission <0.1% due to system acceptance

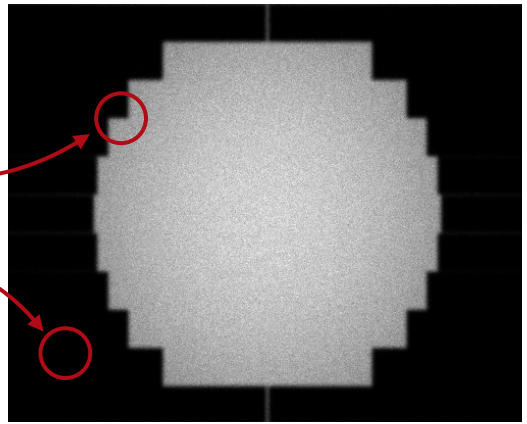
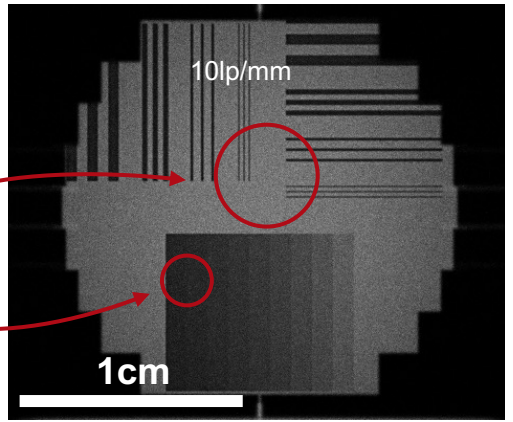


Image of treated area

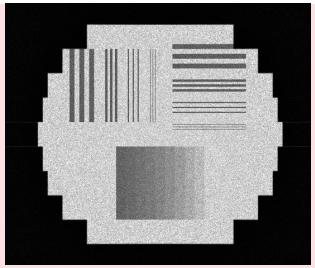
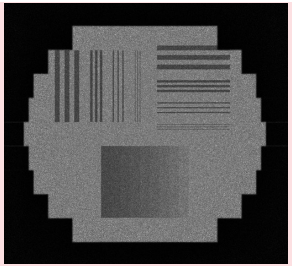
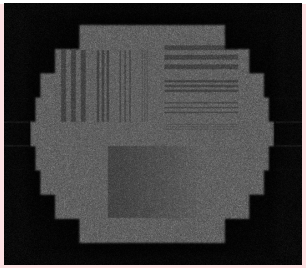
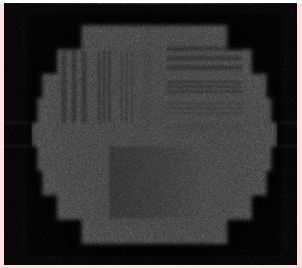
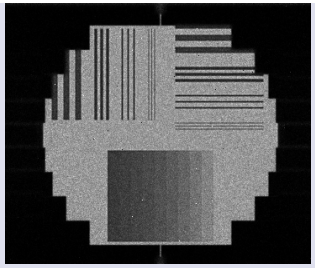
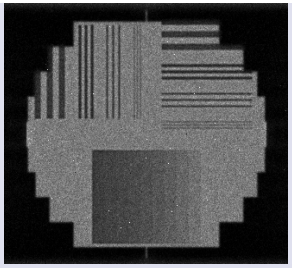
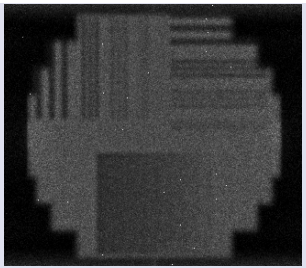
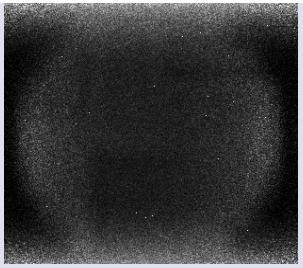
- Spatial resolution between 50μm and 800μm depending on target geometry
- Density resolution of <1%



Medical Particle Imaging

Dual-Lens Treatment & Imaging – 800MeV p^+ & $4He^{2+}$ 230MeV/u imaging results

Pattern embedded in:

	2cm of H_2O	4cm of H_2O	10cm of H_2O	20cm of H_2O
Protons	 Rx/Ry = 46μm	 Rx/Ry = 63μm	 Rx/Ry = 70μm	 Rx/Ry = 121μm
Helium	 Rx/Ry = 98μm	 Rx/Ry = 122μm	 Rx/Ry = 229μm	 Rx/Ry ≈ 800μm

Medical Particle Imaging

Dual-Lens Treatment & Imaging – 800MeV p^+ & $4He^{2+}$ 230MeV/u imaging results

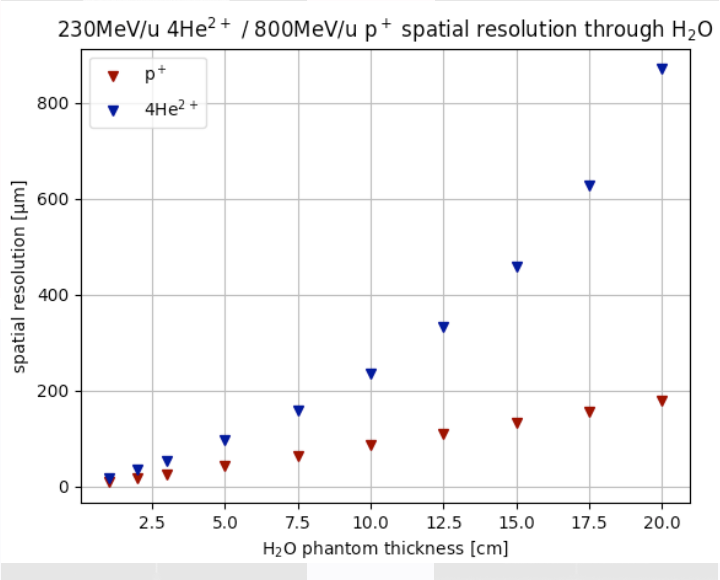
Pattern embedded in:

2cm of H_2O 4cm of H_2O 10cm of H_2O 20cm of H_2O

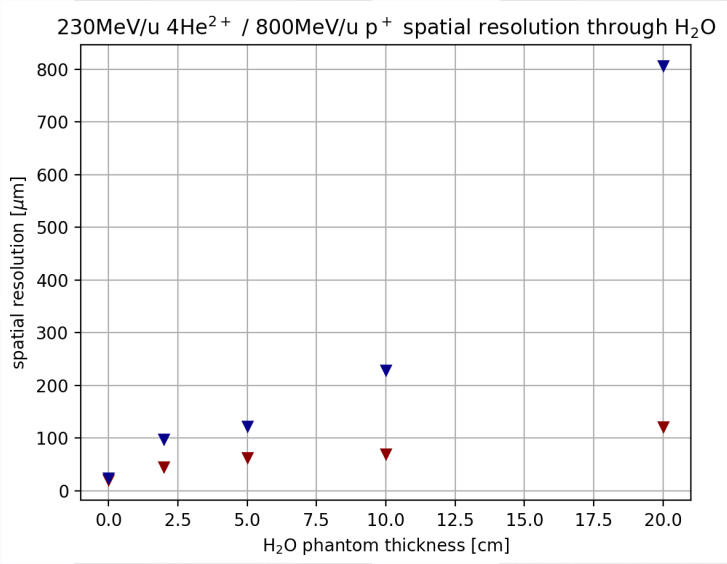
Protons

Helium

Model



MC Simulation



Rx/Ry = 98μm Rx/Ry = 122μm Rx/Ry = 229μm Rx/Ry = ---

Outlook

Dual-lens p^+ imaging

LANL pRad proposal for 2023

$4He^{2+}$ flash radiography

GSI PRIOR-II proposal for 2023/2024

Combining dual-lens and $4He^{2+}$ flash radiography

202X?