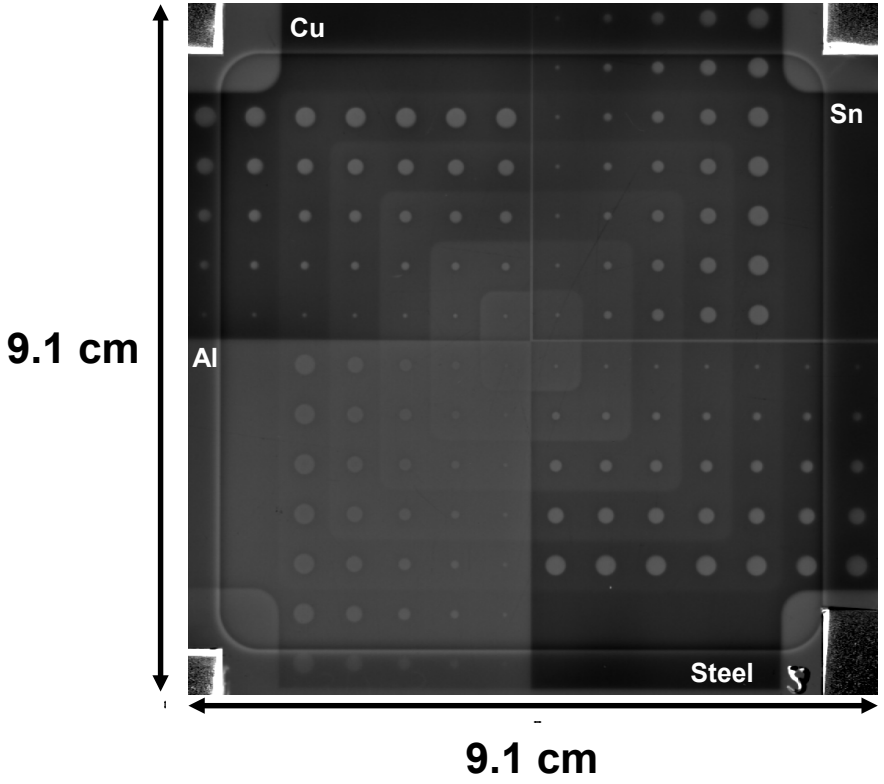
Electron Radiography based on the Electron Beams from Laser-Plasma Accelerators



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Summary

Electron radiography based on the electron beams from a LPA could enable a flexible, portable, powerful diagnostic for the visualization of ultra-fast, ultra-thin dynamic processes

- **Prior electron radiography (eRad) experiments using linac-produced electron beams have demonstrated that eRad could fill the existing gap in radiographic capabilities**

- **Experiments on OMEGA EP demonstrated point-source eRad using the electron beam from a laser-plasma accelerator (LPA) with resolutions as low as 100 μm**

- **Upcoming experiments will seek to demonstrate projected eRad and eRad of a dynamic system using the same electron beam**

Collaborators

G. Bruhaug
University of Rochester, Laboratory for Laser Energetics

M. Freeman, F. Merrill, V. Geppert-Kleinrath, and C. Wilde
Los Alamos National Laboratory

Motivation

eRad is a potential path to fill the gap in visualizing fast, dynamic processes in the meso-scale range of materials from mg/cm^2 to several mg/cm^{2*}

- Today's workhorse radiographic probes can evaluate the following scales of areal density
  - The very thick (180 g/cm^2 using LANL's DARHT)
  - The intermediate (1-50 g/cm^2 using LANL's pRad)
  - The very thin (< 0.001 g/cm^2 using Washington State's DCS)

Gap

- Prior eRad experiments using linac-produced electrons demonstrated the ability of eRad to visualize materials in the 0.01 g/cm^{2**} to several g/cm^{2†} range
  - These experiments showed that the gap between very thin and intermediate areal density capabilities is the one that eRad can potentially fill

Can LPA-based eRad driven by the lasers already associated with HED facilities also fill that gap?

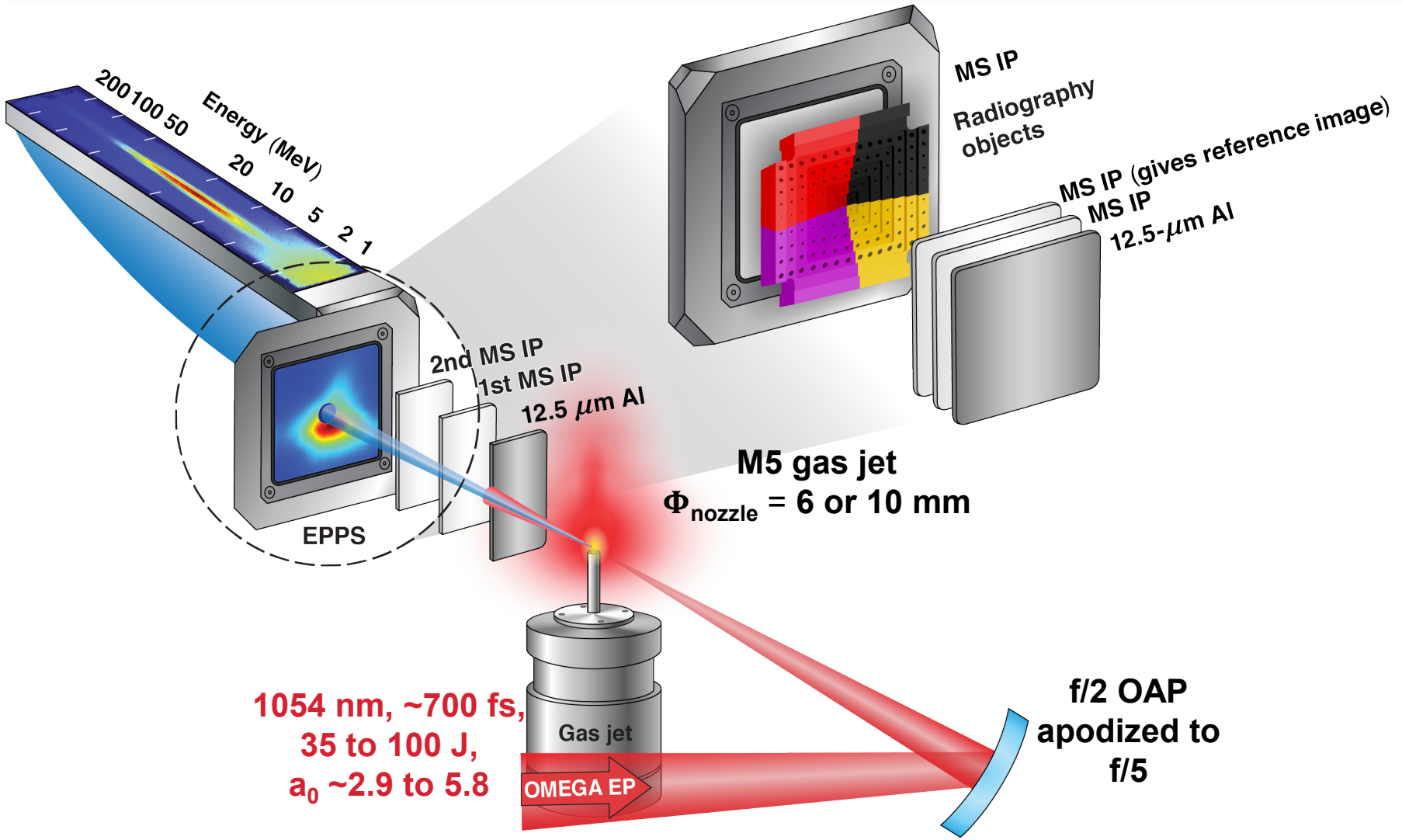
* Merrill, F.E., "imaging with penetrating radiation for the study of small dynamic physical processes", Laser and Particle Beams, 2015
DARHT: Dual-Axis Radiographic Hydrodynamic Test Facility
DCS: Dynamic Compression Sector at Washington State
** F. Merrill *et al.*, Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms 261 (1-2), 382 (2007).
† F. E. Merrill *et al.*, Applied Physics Letters 112 (14), 144103 (2018).

In additional to filling the gap, charged particle (electron & proton) radiography has several advantages compared to classic radiography (neutrons & x/gamma rays)

- **Generation:**
  - **Typically cheap and efficient compared to neutrons and x/gamma rays**
  - **Control over pulse length, depending on generation mechanism (fs to s)**

- **Utilization:**
  - **Extremely penetrative compared to x-rays**
    - **Able to penetrate high Z material and a wide variety of areal densities**
  - **Sensitive to magnetic and electric fields**
  - **Magnetic optics can be used to enhance the resolution and utilize distant focal planes**

eRad experiments were performed on OMEGA EP using the LPA platform, which can produce electron beams with charges as high as 0.7 μC*



Materials:

- Cu
- Al
- Ti
- W
- Sn
- S. Steel

*J.L. Shaw *et al.* Sci. Rep. 11, 7498 (2021).

EPPS: electron–positron–proton spectrometer

OAP: off-axis parabola

$a_0 = \frac{eE_0}{mc\omega_0} \propto \sqrt{I_0[W/cm^2]}$, I_0 = Peak laser intensity

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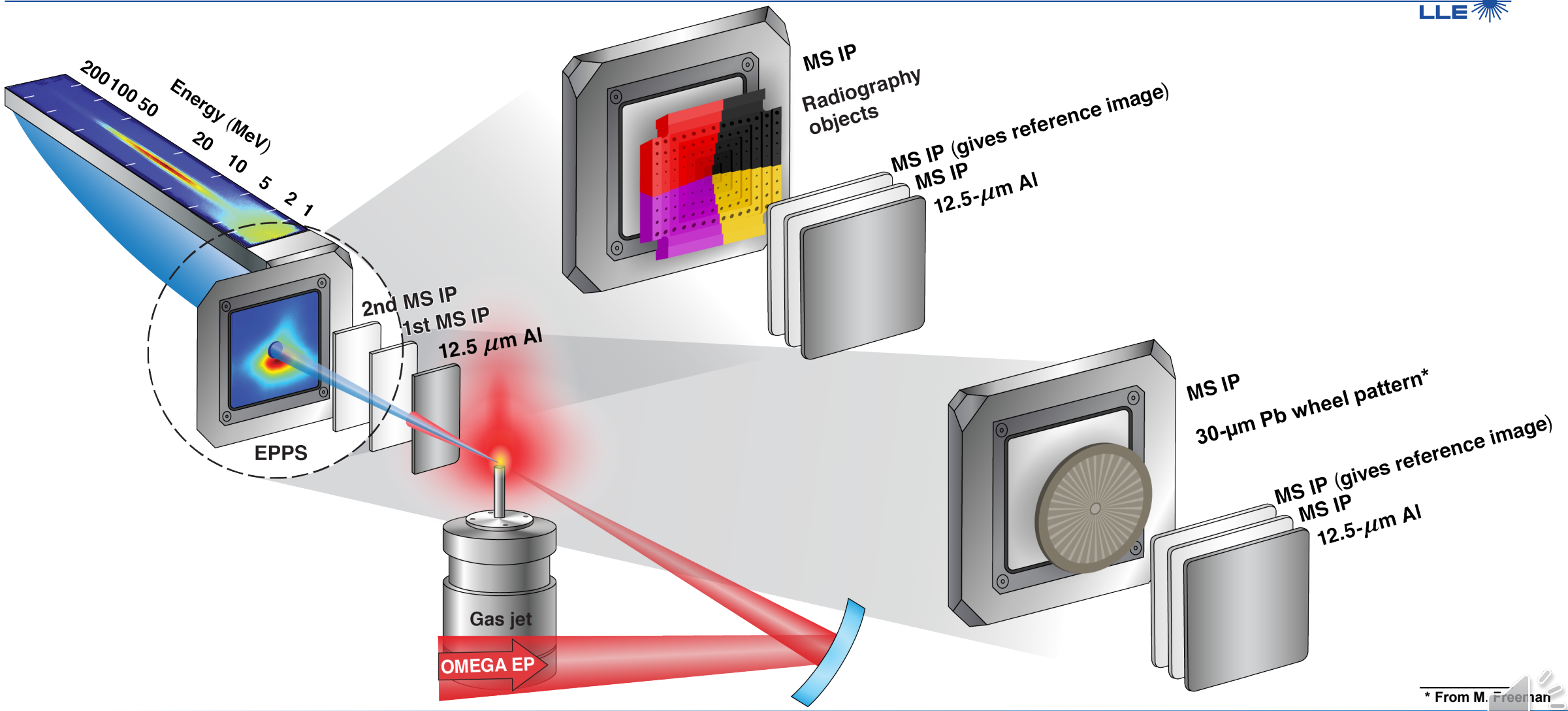
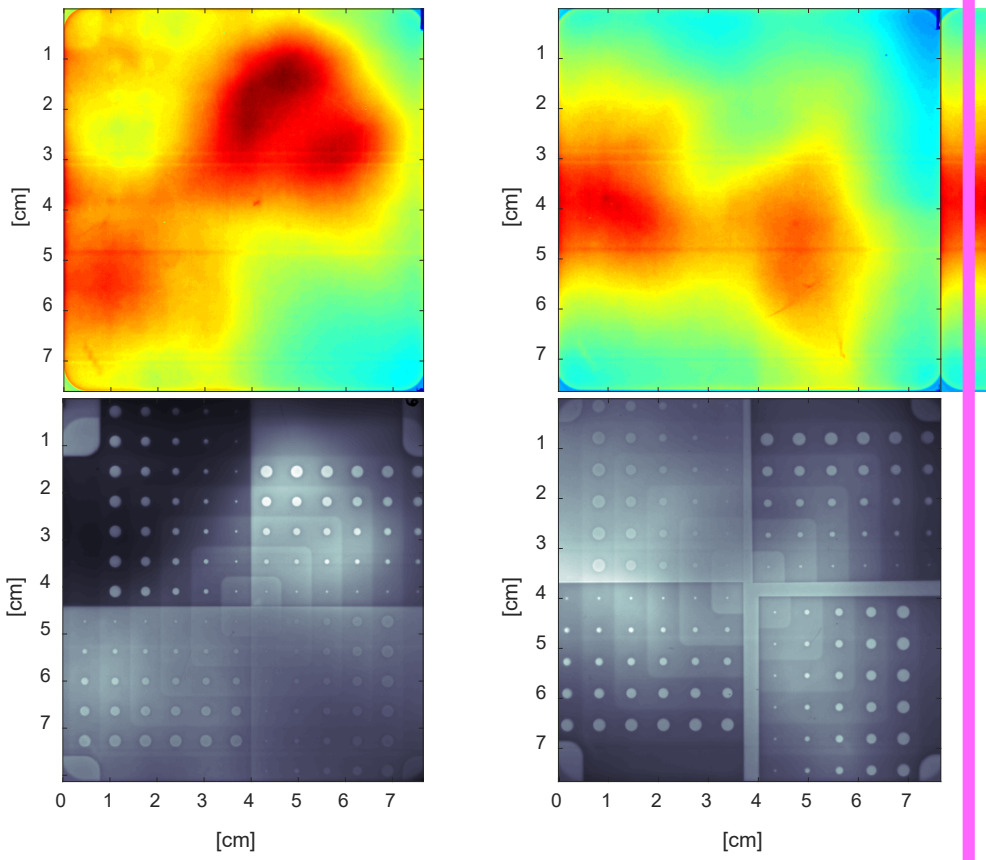


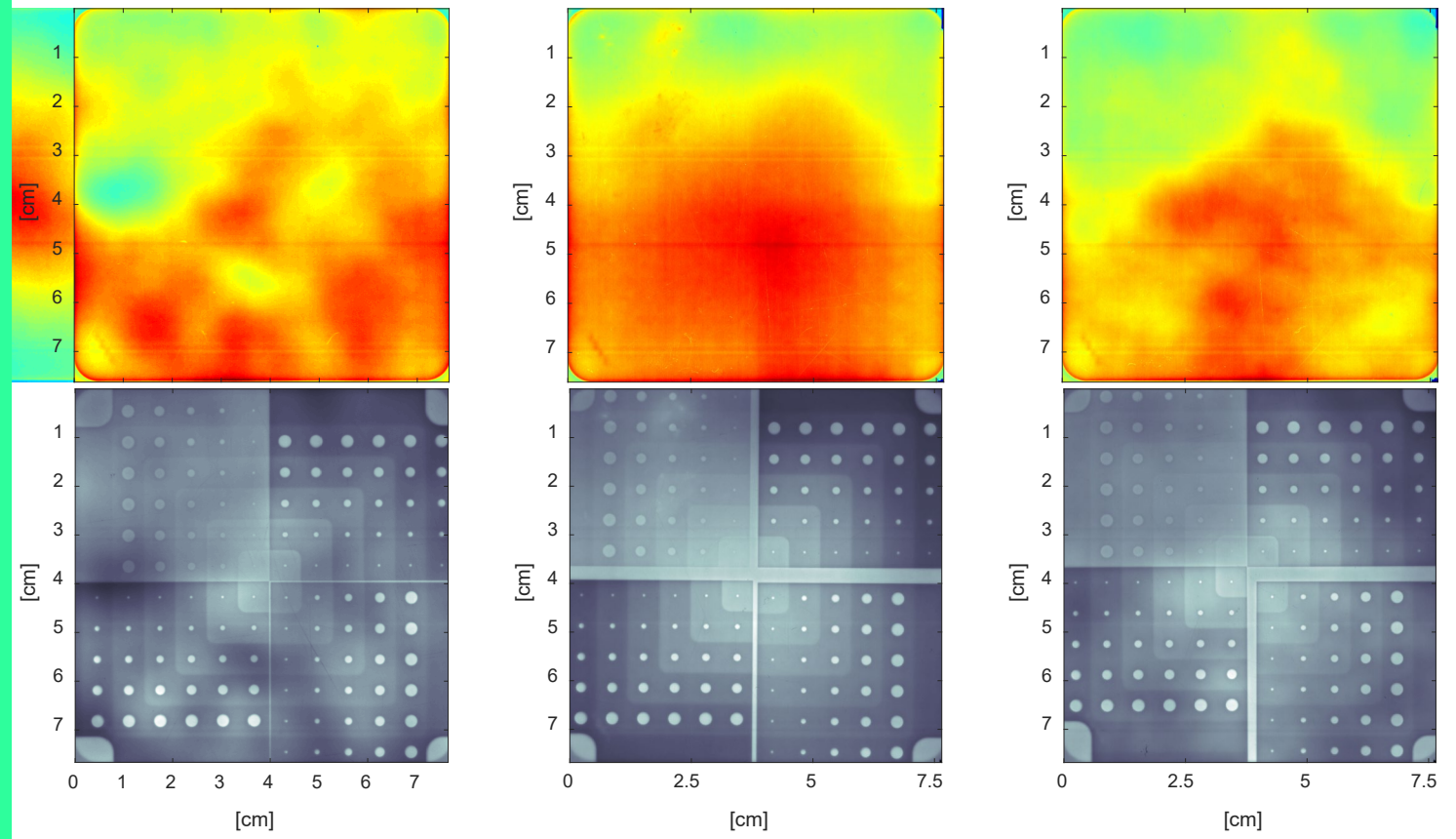
* From M. Freeman

We held the LPA parameters fixed to two configurations and looked at the reproducibility of eRad with varying transverse electron beam profiles

High-Charge Configuration*

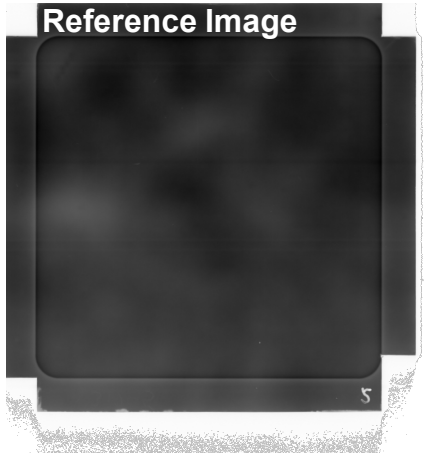


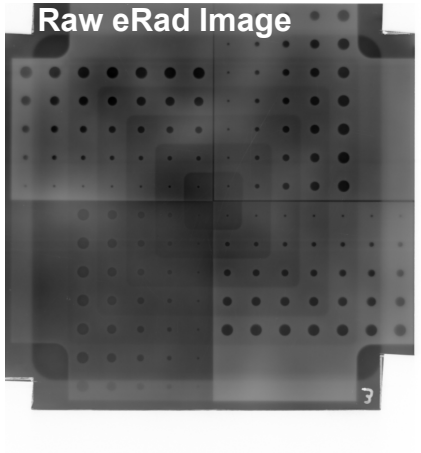
Large-Divergence Configuration**



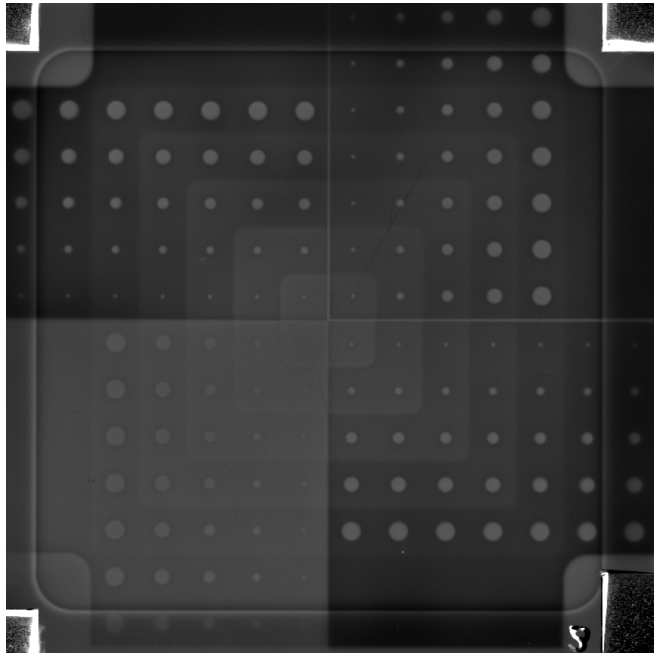
* 6 mm dia. nozzle @ 7.5 x 10^{18} cm^{-3}
** 10 mm dia. nozzle @ 3.5 x 10^{19} cm^{-3}

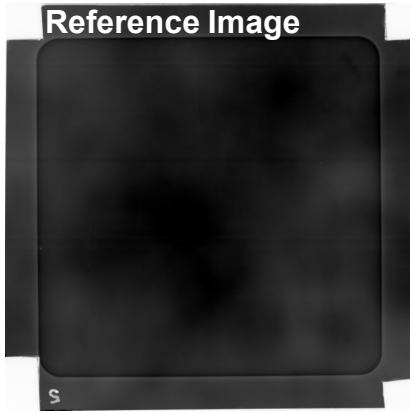
The structure from the electron beam can be flattened with the reference image

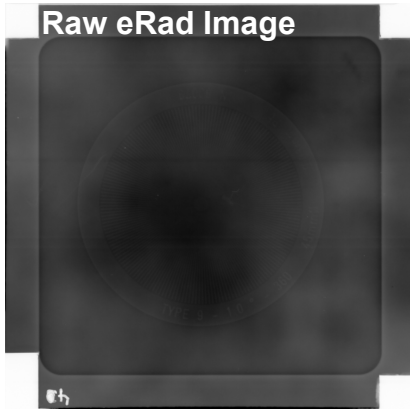




Final eRad Image







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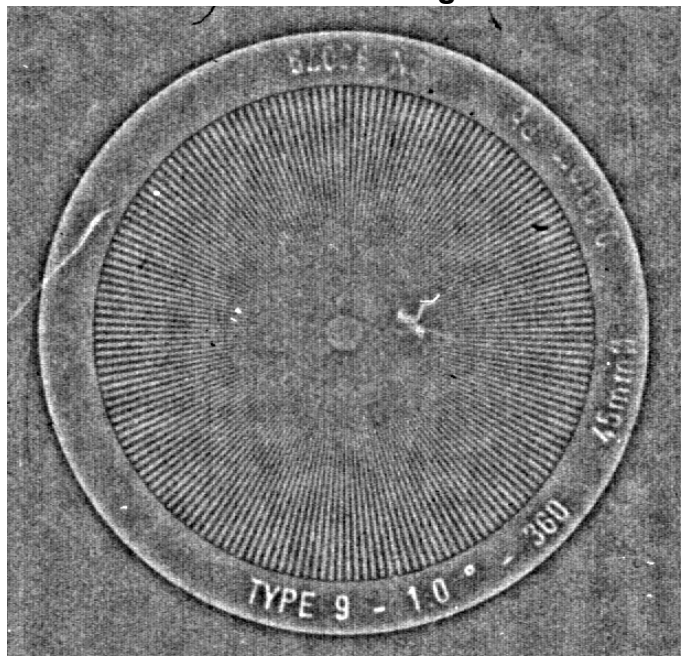
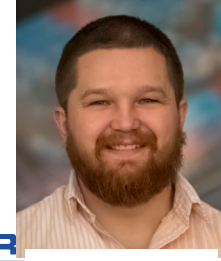
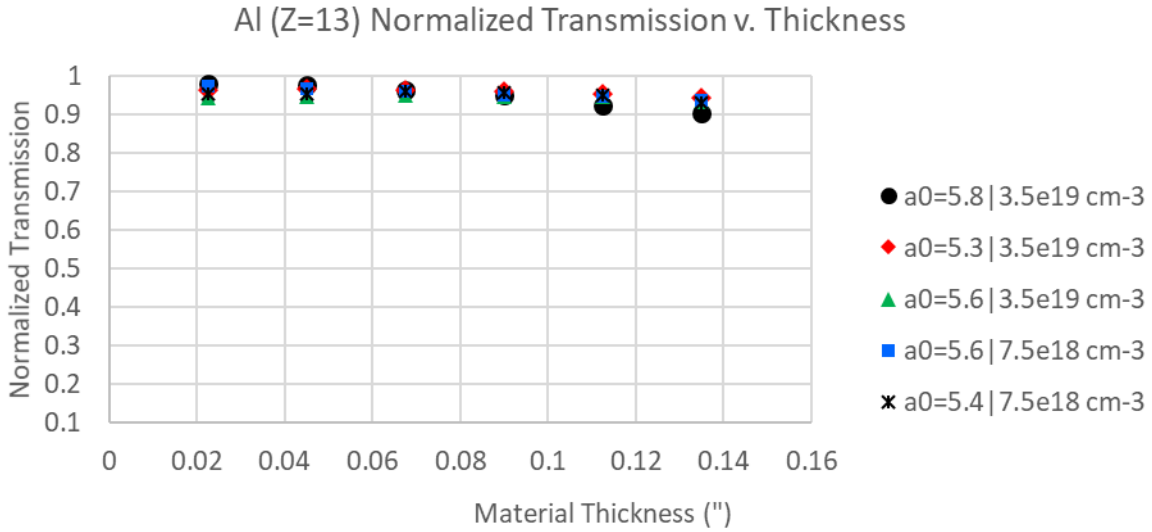


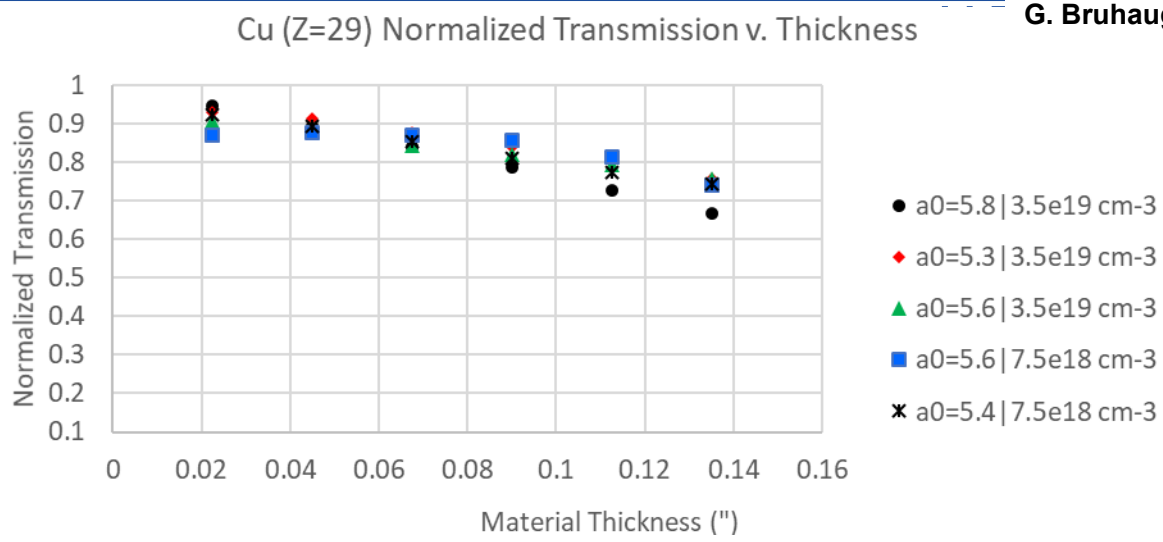
* Images measure 9.1 x 9.1 cm

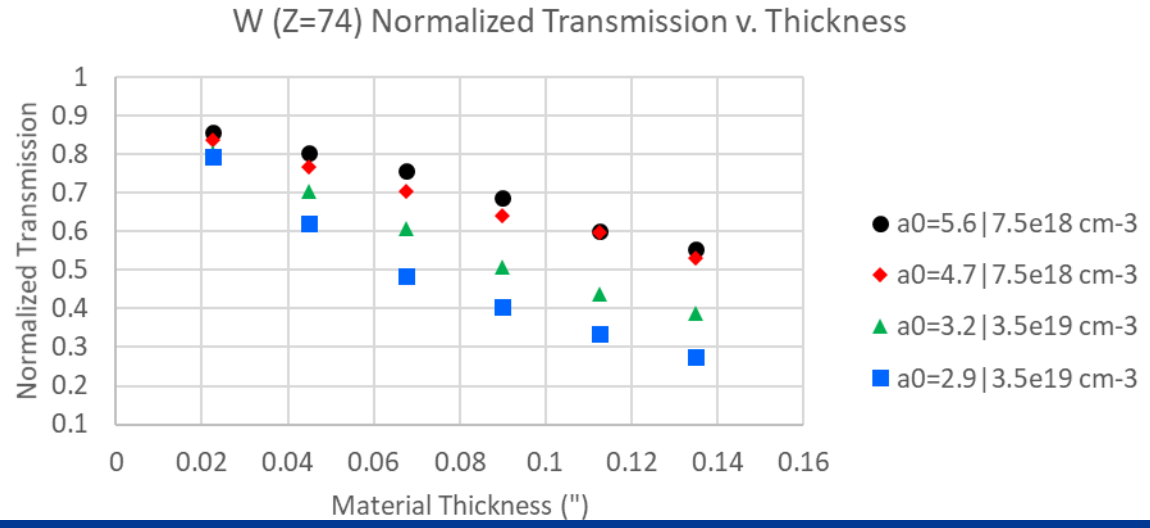
Despite variability in electron beam, transmission is remarkably stable shot-to-shot for similar a_0 lasers driving the LPA



G. Bruhaug



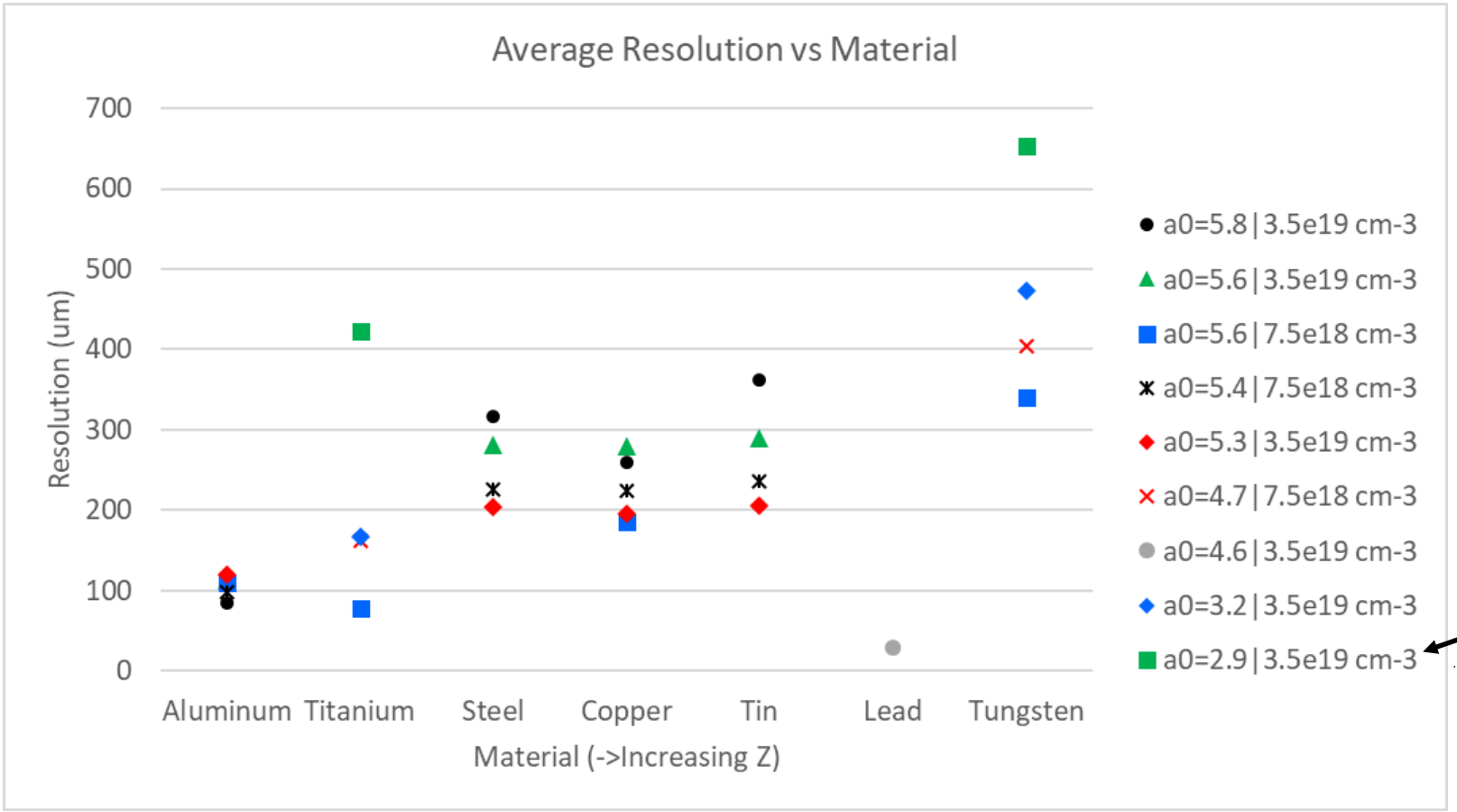




Reproducibility in transmission enables eRad with LPA beams to be used to discern areal densities of unknown or dynamic samples

Average resolutions as low as 100 um were measured

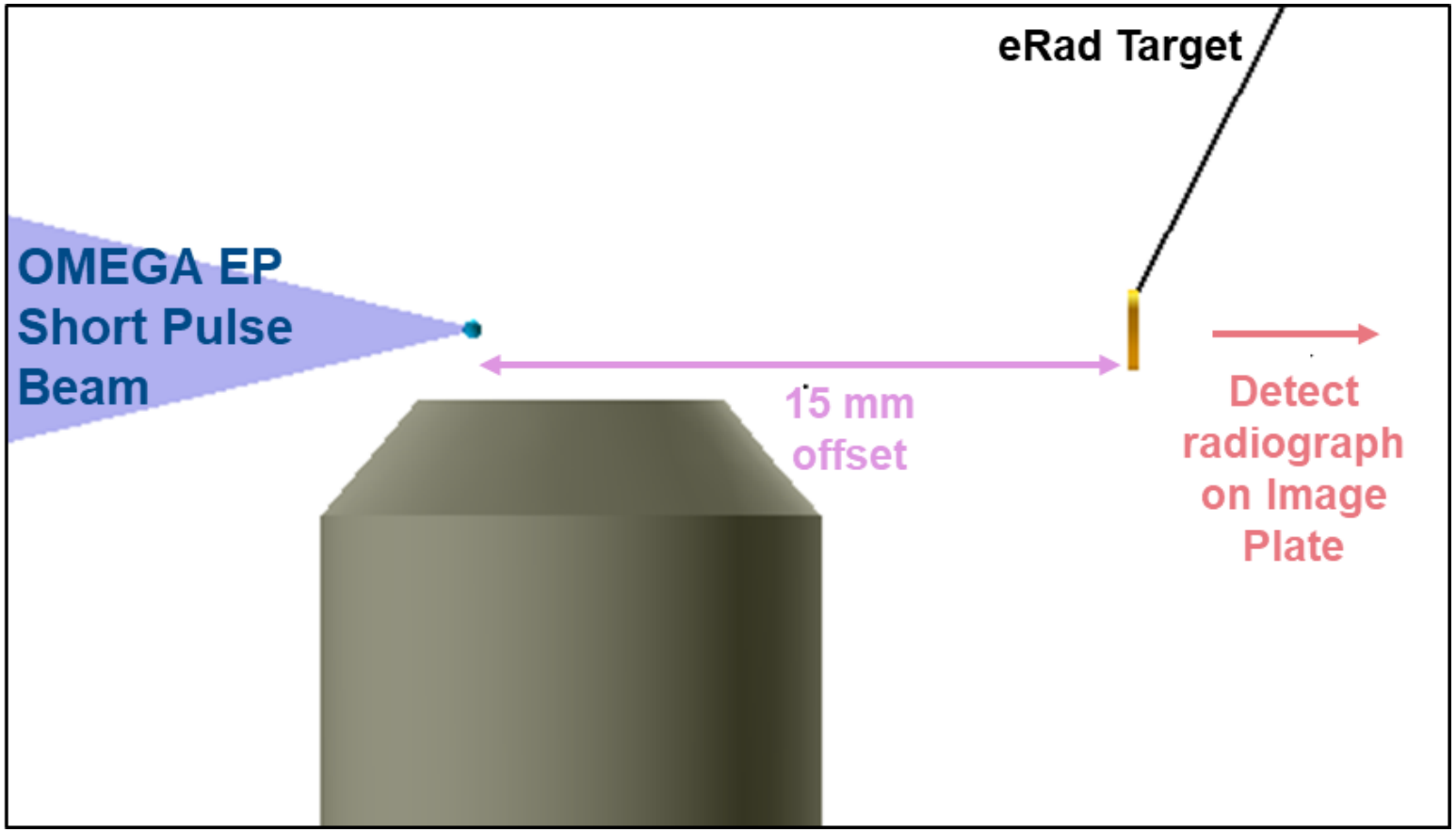
G. Bruhaug



Lowest a_0 shot

Average resolution increases for higher Z materials and lower a_0 shots

Upcoming shot day on OMEGA EP will seek to demonstrate projected eRad with the electron beam from a LPA using target-based test objects



Future experiments will investigate the eRad of a dynamic system and the use of magnetic optics towards the goal of 10 μm resolution

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National Nuclear Security Administration