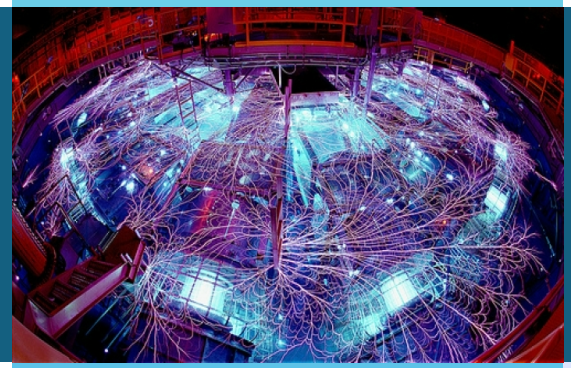
SAND2020-13319C

A Time-Resolved, In-Chamber X-Ray Pinhole Imager for Z



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High Temperature Plasma Diagnostics Conference, 2020

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Abstract

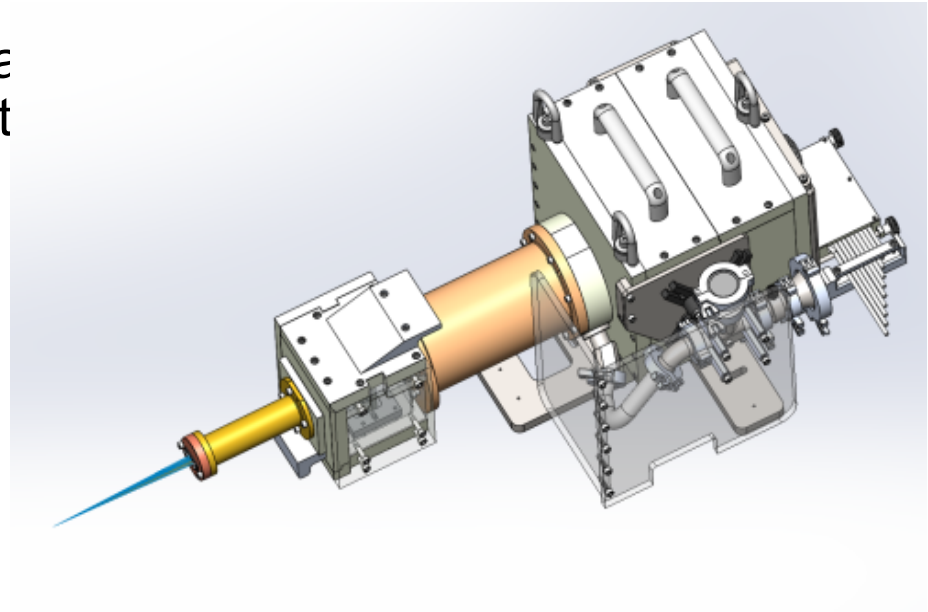
We have commissioned a new time-resolved, x-ray imaging diagnostic for the Z facility. The primary intended application is diagnosing the stagnation behavior of MagLIF and similar targets. We have a variety of imaging systems at Z, both time-integrated and time-resolved, such as TIPC, HRCXI, MLM, and others that provide valuable x-ray imaging information, but no system at Z up to this time provides a combined high-resolution imaging with multi-frame time resolution; this new diagnostic, called TRICXI for Time Resolved In-Chamber X-ray Imager, is meant to provide an integrated capability for resolution in the spatial and time domain. The multi-frame camera consists of a Gen II MCP camera. A key component to achieving the design goals is to place the instrument inside the Z vacuum chamber within one meter of the load which necessitates a considerable amount of x-ray shielding as well as a specially designed, independent vacuum system. A demonstration of the imaging capability for a series of MagLIF shots are presented.

Introduction

The main goal is to have multi-time-frame, two-dimensional, high-sensitivity x-ray imaging diagnostics. This was to be accomplished with:

- A multi-pin hole camera
- MCP camera for time resolution
- Located in-chamber to maximize signal flux.

The primary “customer” was MagLIF but other loa
may be applicable. Hence a number of configurat
were included to make the diagnostic flexible.



Science and Other Requirements

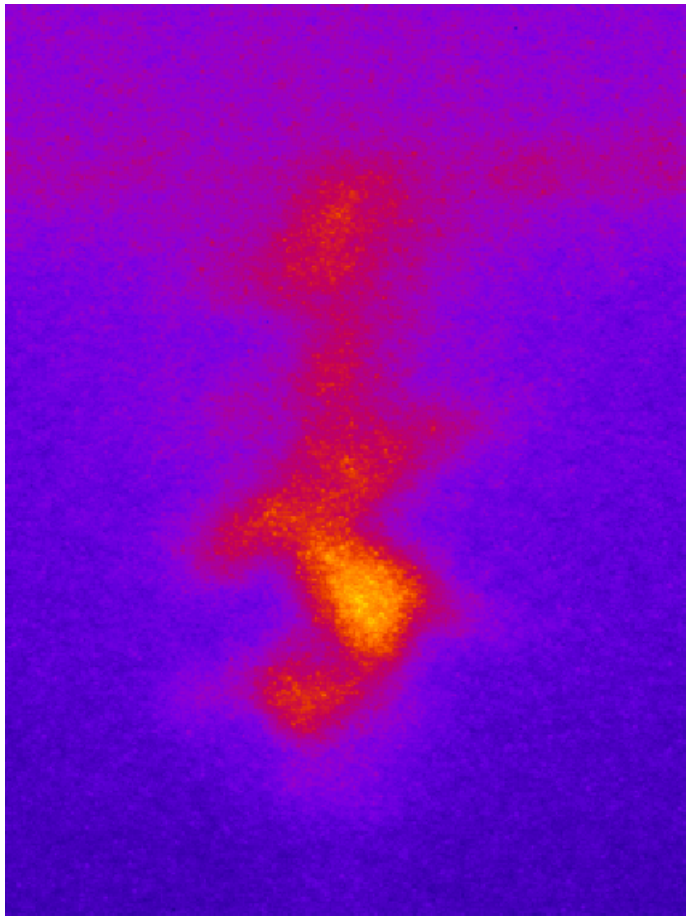
Science requirements (MagLIF-centric): What do they want to measure?

- Resolution < 50 μm
- Desire: Eight frames of 0.25 ns gate and 0.5 ns interframe.
- Signal strength on par with MLMc

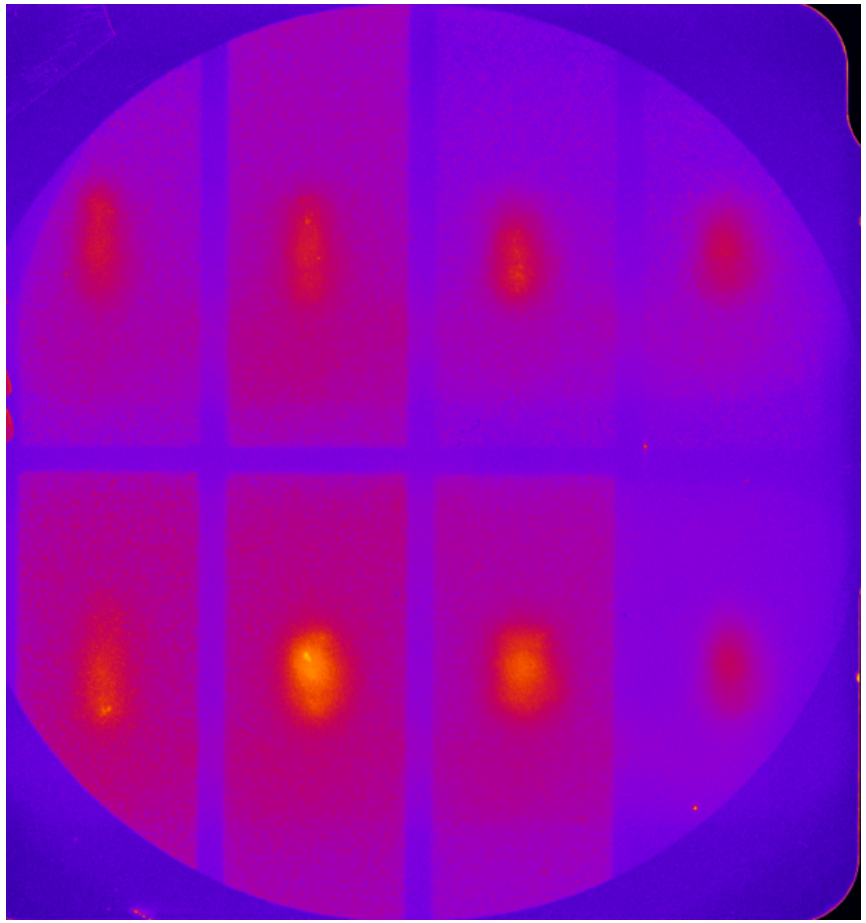
- At least one inch thick tungsten shielding to the MCP from general Z x-ray environment
- Internal pump down > 3 hours for MCP with operating vacuum in the low E-5 Torr.
- Alignment: 0.5 mm at the target.

Compare to other imaging diagnostics

Low Resolution,
Time-Integrated: TIPC

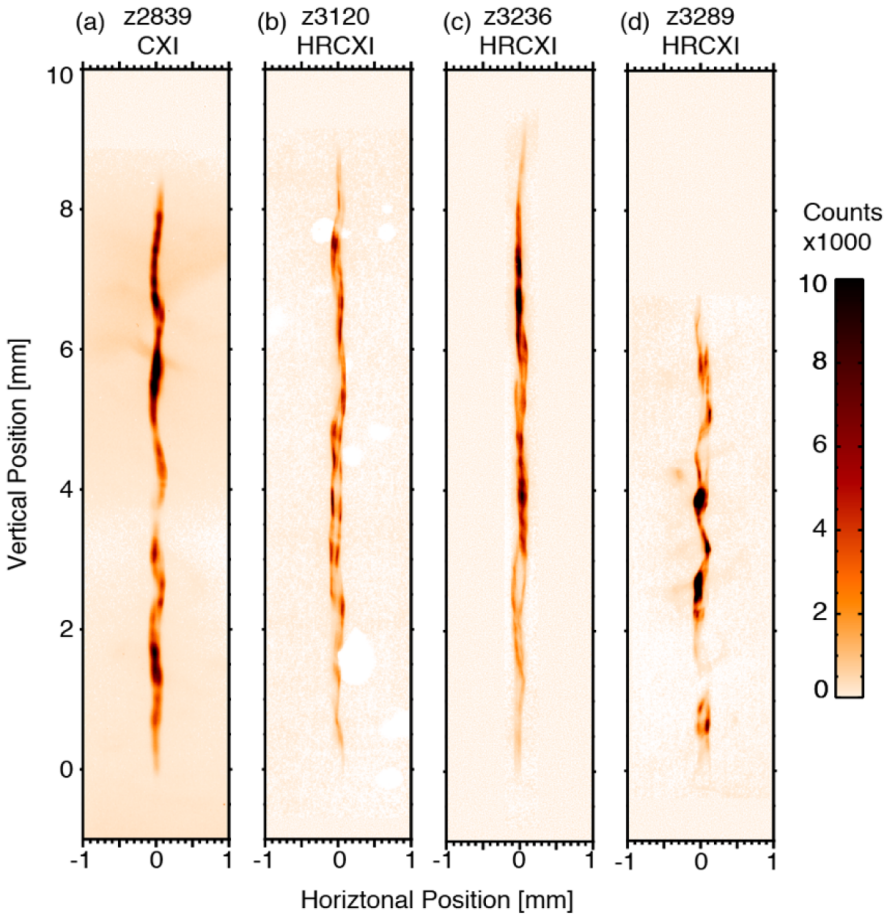


Low Resolution,
Time-Resolved: MLM



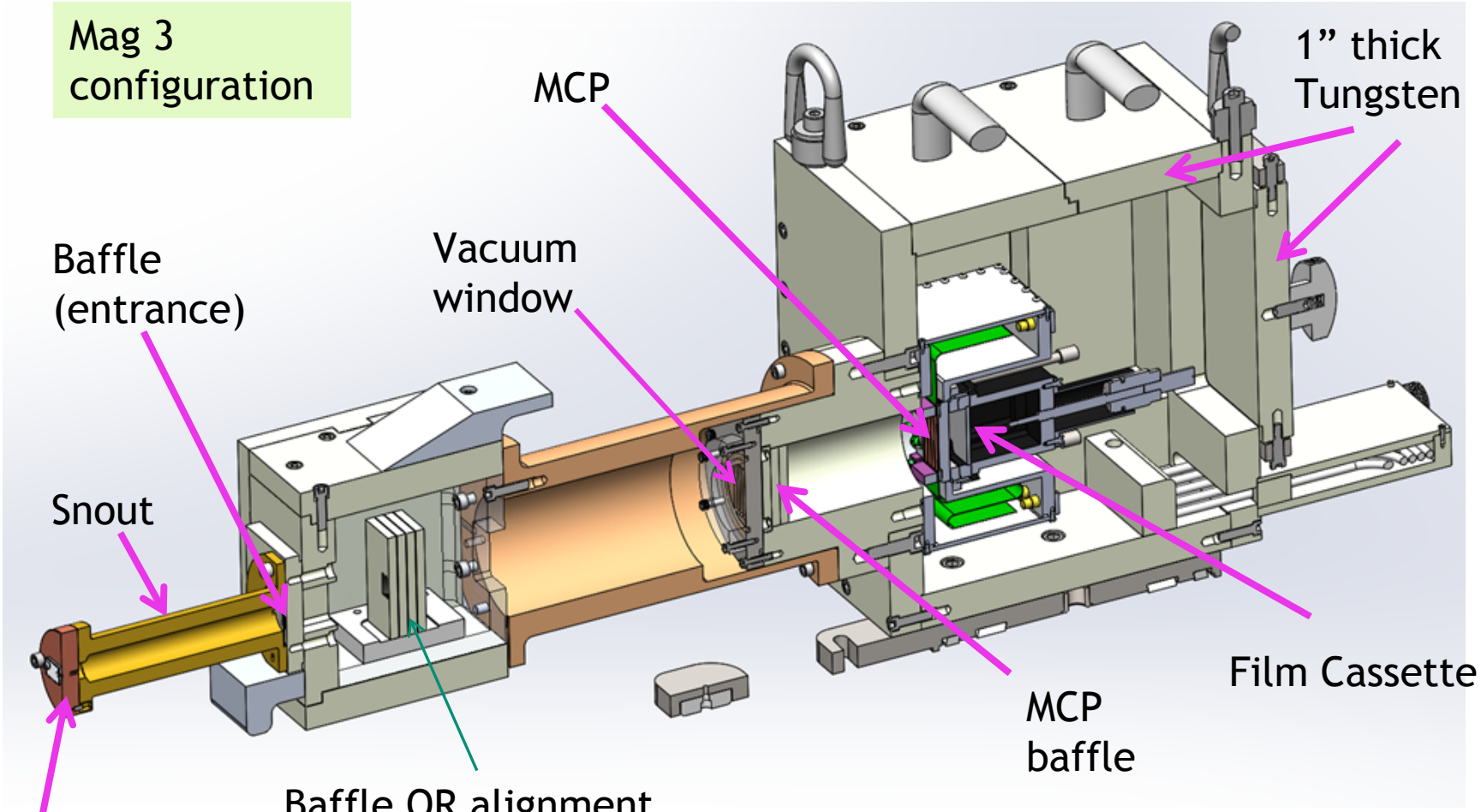
Z3293

High Resolution,
Time-Integrated: Crystal Imagers



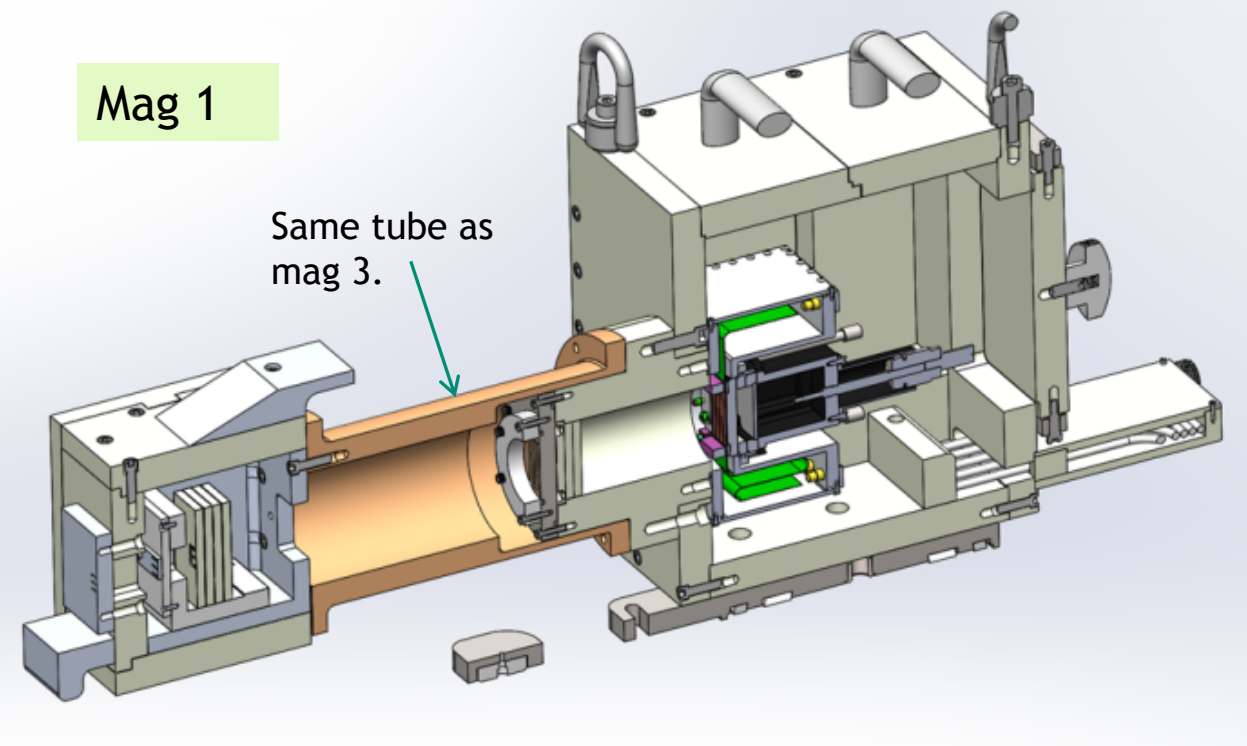
Primary Components

Mag 3 configuration



* The MCP requires an independent vacuum system.

TRICXI PHC Configurations



Fielding Options

Magnifications:
3X, 1X, 0.5X

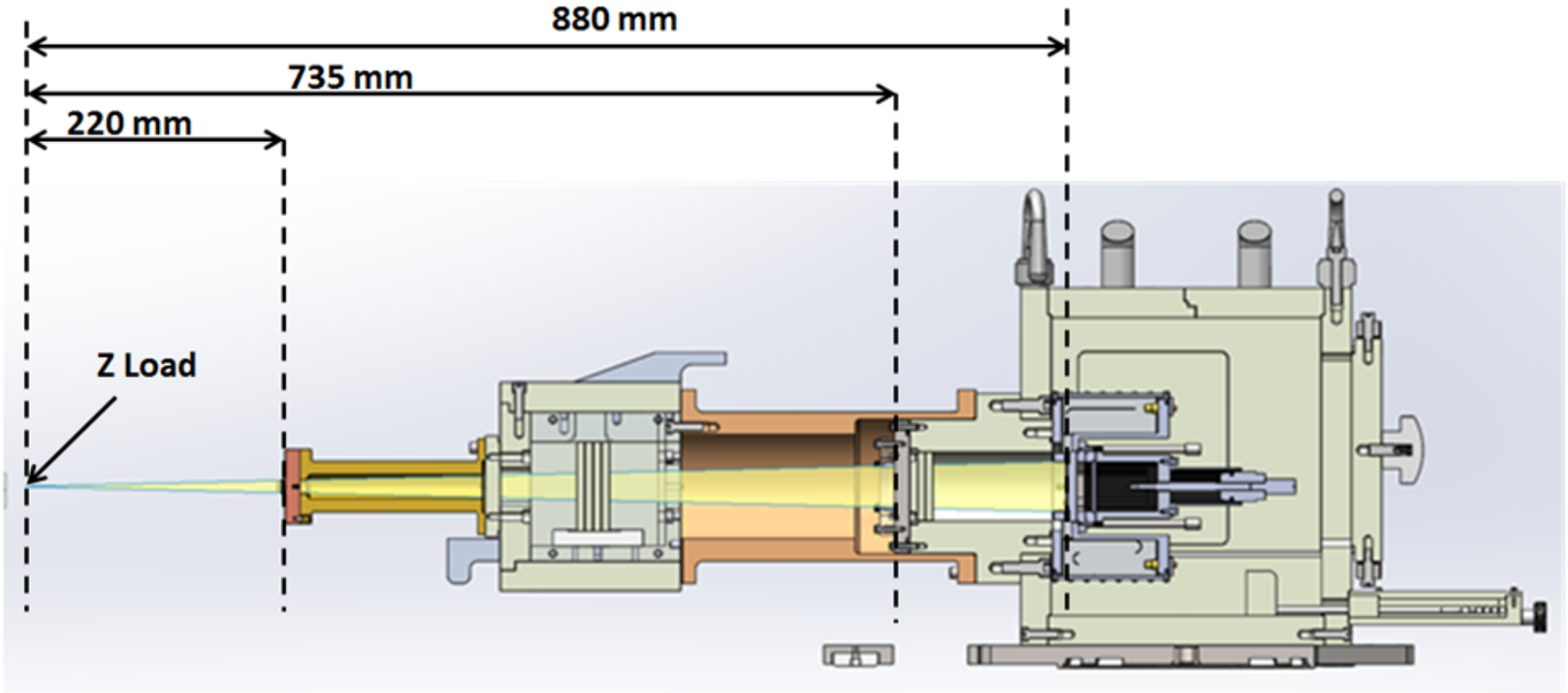
Pin Holes, MLM-style (μm):
15, 20, 30, 50, 75, 100, 150, 200, 250, 500

Number of optical paths (see Fig. 2):
Mag 3X: eight pin holes, one per MCP strip
Mag 1X, 0.5X: 24 pin holes, three per MCP strip

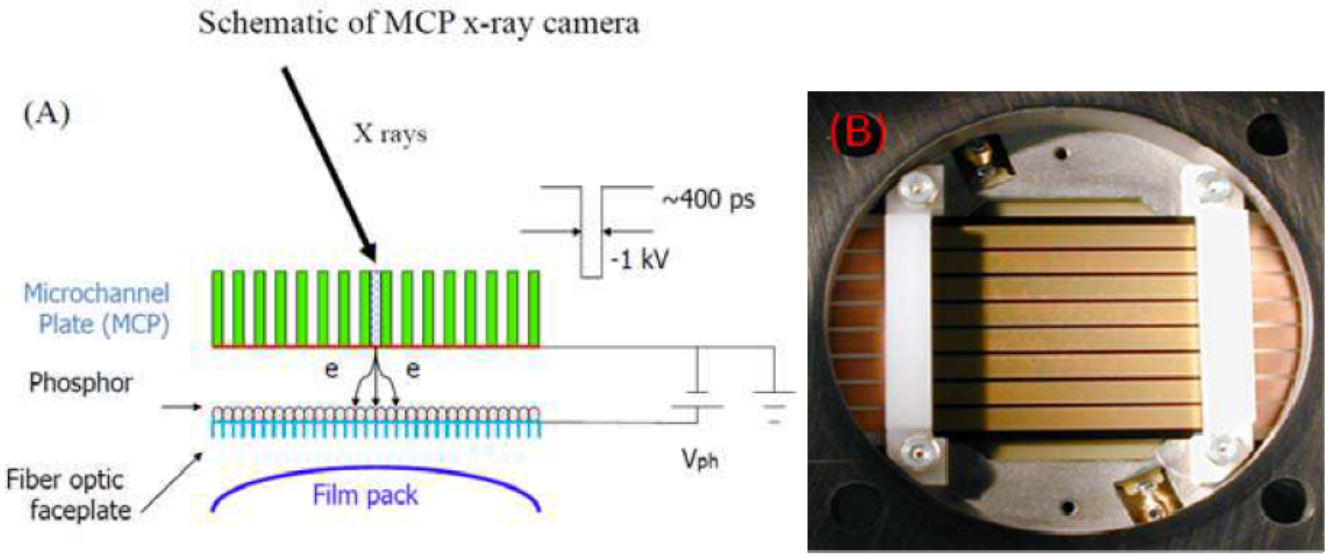
MCP gating, Gen II:
0.15, 0.25, 0.8 ns gates, independent gating in four sets of two.

For all magnifications, detector remains at the same distance from the source, the pin hole positions are changed. Mag 0.5 is achieved with a shorter tube.

Side-View Geometry



MCP Summary



Gain: $G \propto V^n$, n ≈ 11 for E ≤ 3 keV, n ≈ 9 for E ≥ 20 keV
adjustable ±100 V relative to nominal -900 V

Resolution: < 50 µm @ 15 keV, normal incidence, 2.5 kV phosphor voltage

Gen II MCPs:
8 Frames, 4 mm x 40 mm

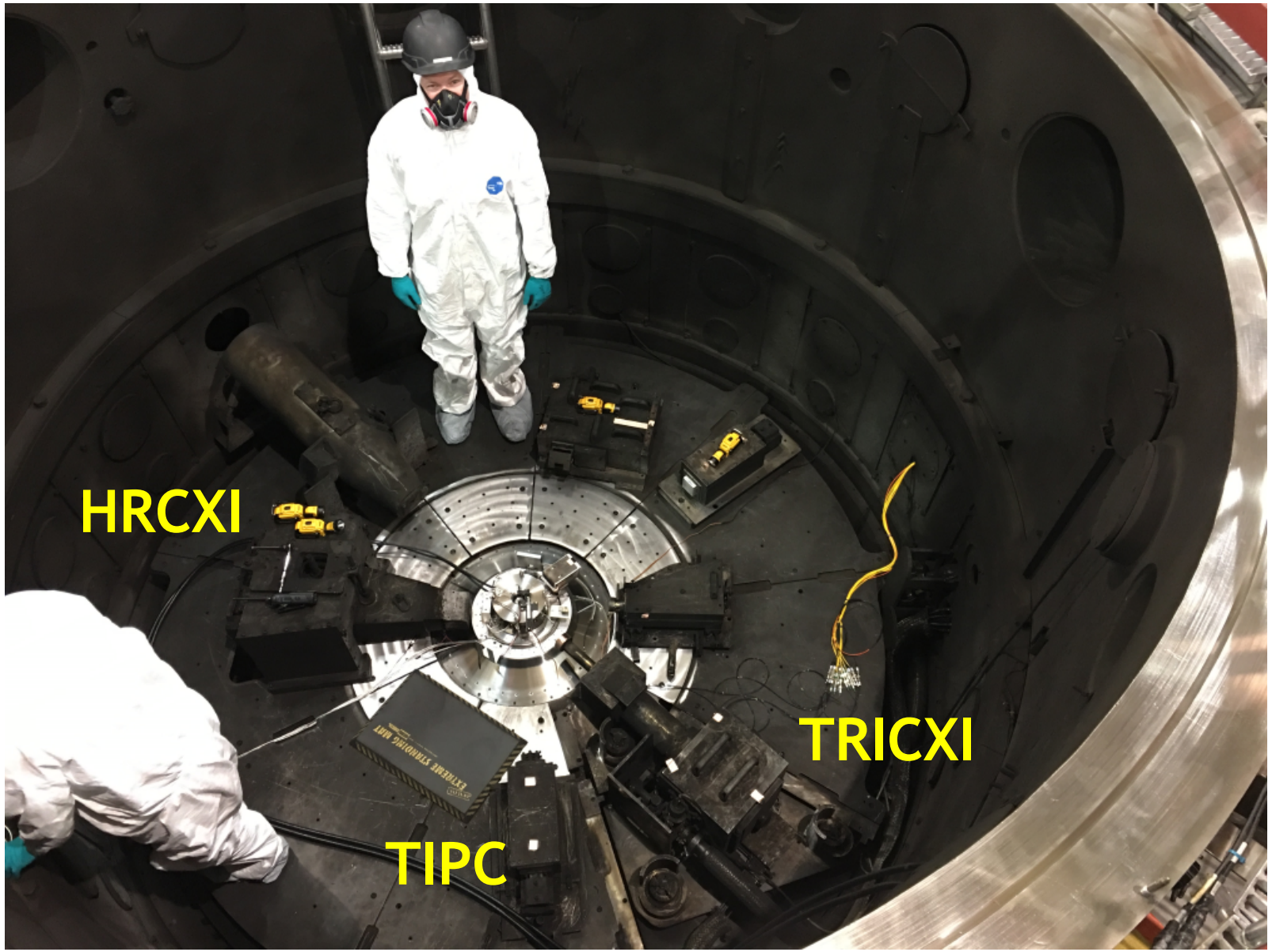
Gate widths:
250 ps, 800 ps,

Interframe time: 1, 2, 3, ns
(custom values available)

X-ray sensitivity:
< 0.25 kV to ≈ 25 kV

Schematic from: C.A. Kruschwitz and M. Wu. "Monte Carlo Simulations of Microchannel Plate-Based, Time-Gated Imagers." http://www.intechopen.com/books/applications-of-montecarlo-method-in-science-and-engineering/monte-carlo-simulations-of-microchannel-plate-based-time-gated-xray-imagers . (2011)

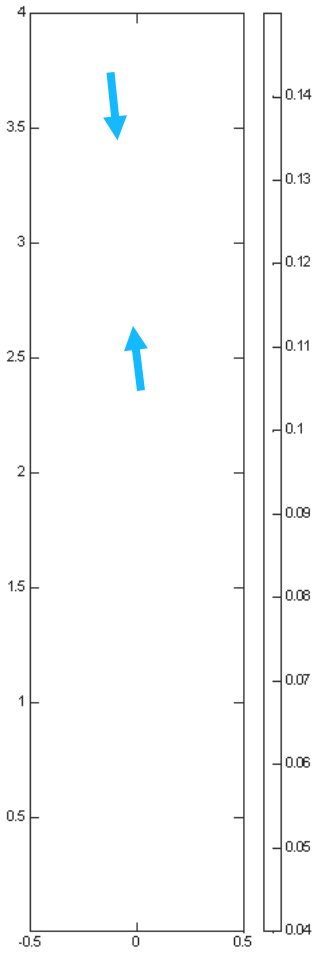
In-Chamber Installation



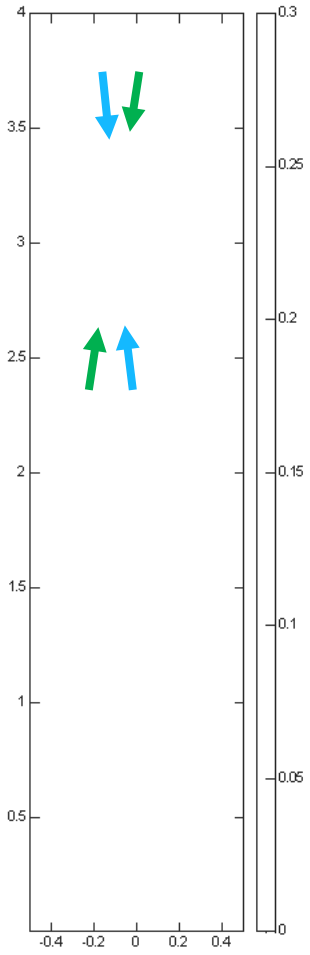
Some things that are special about TRICXI that often includes additional installation steps compared to other diagnostics.

- Special MITL deck plate with custom alignment legs.
- Vacuum pipe connection (the pumps are located outside the chamber)
- MCP cables must be connected at the chamber wall one-by-one in coordination with MCP team.
- One of the heaviest diagnostics

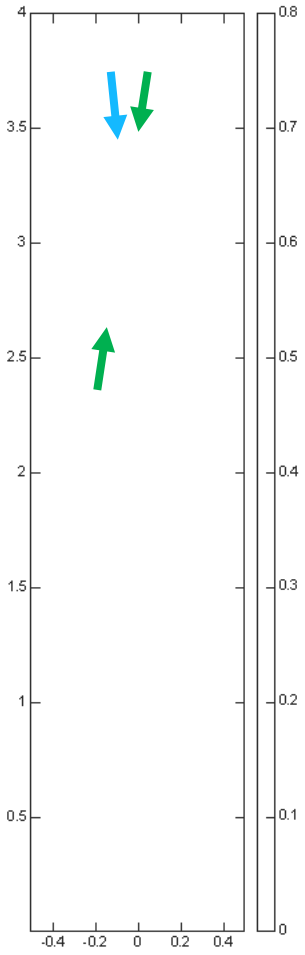
Processed Data on Z3292



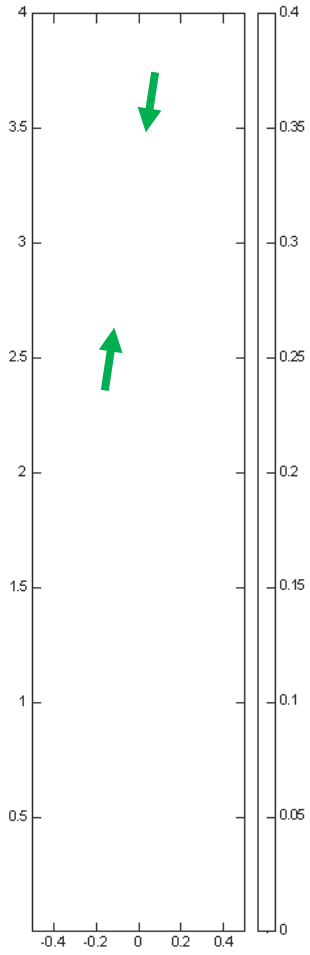
Frame 3



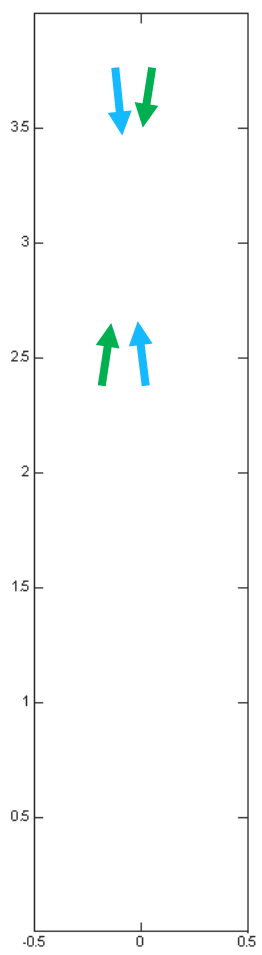
Frame 4



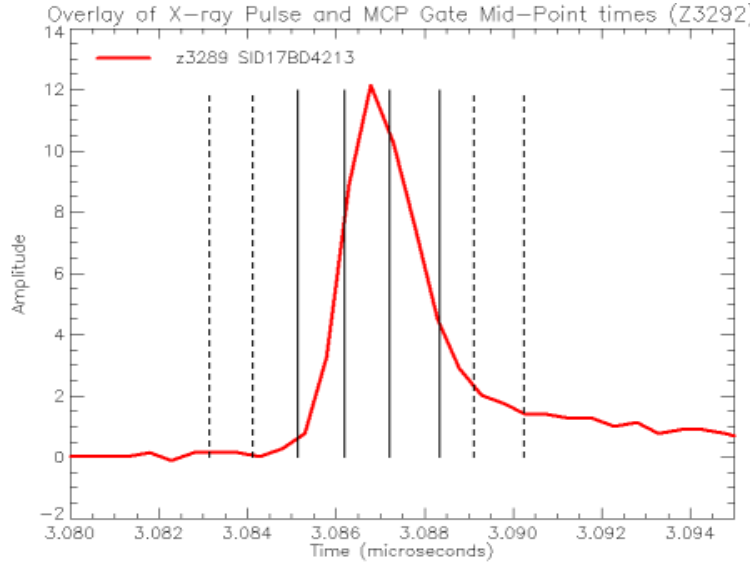
Frame 5



Frame 6

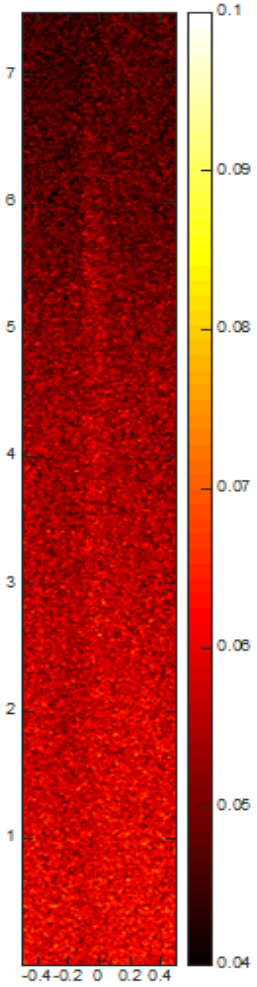


HRCXI

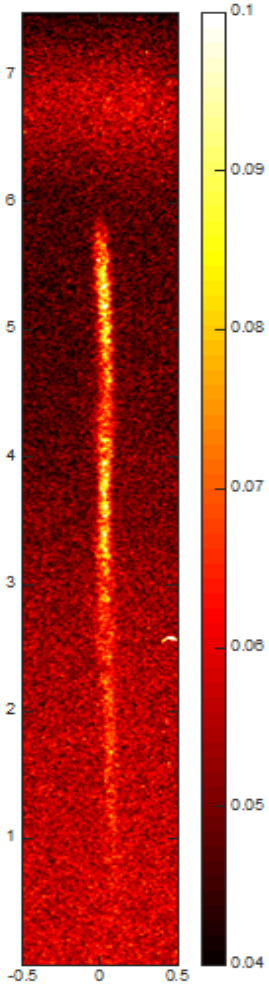


Note: X-ray pulse data from a different shot where timing appeared to be similar.

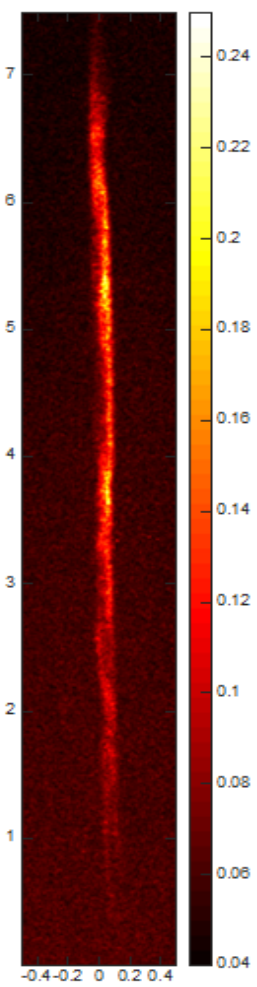
Another shot, Z3296, with lower yield and different images.



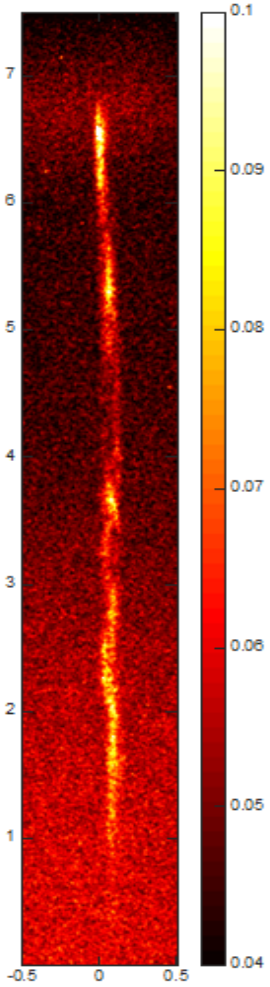
Frame 4



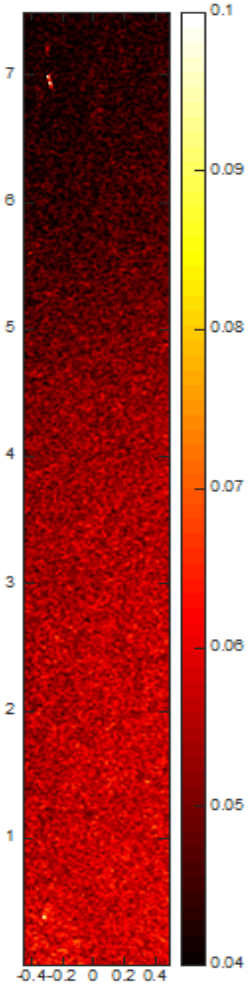
Frame 5



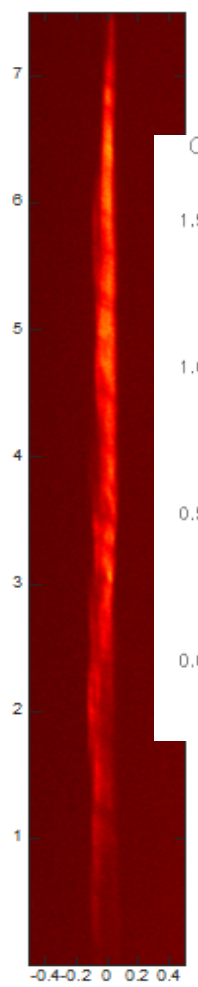
Frame 6



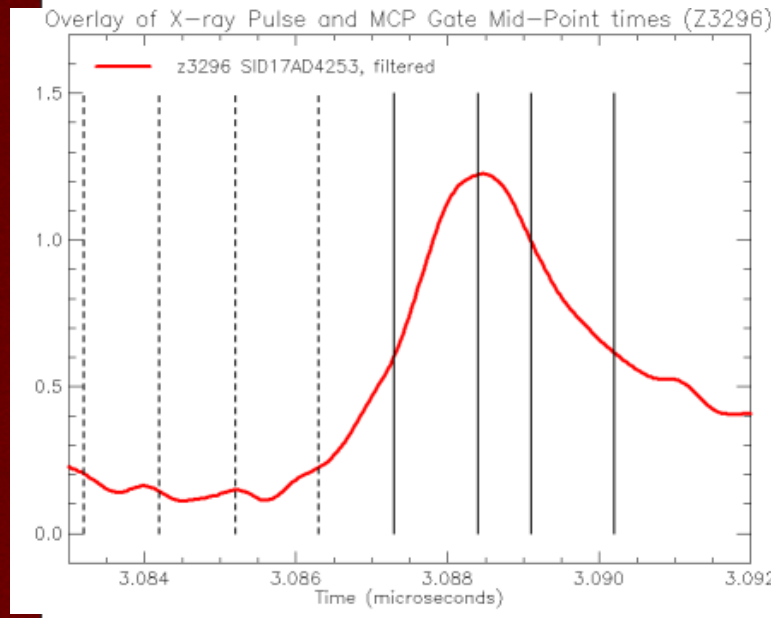
Frame 7



Frame 8



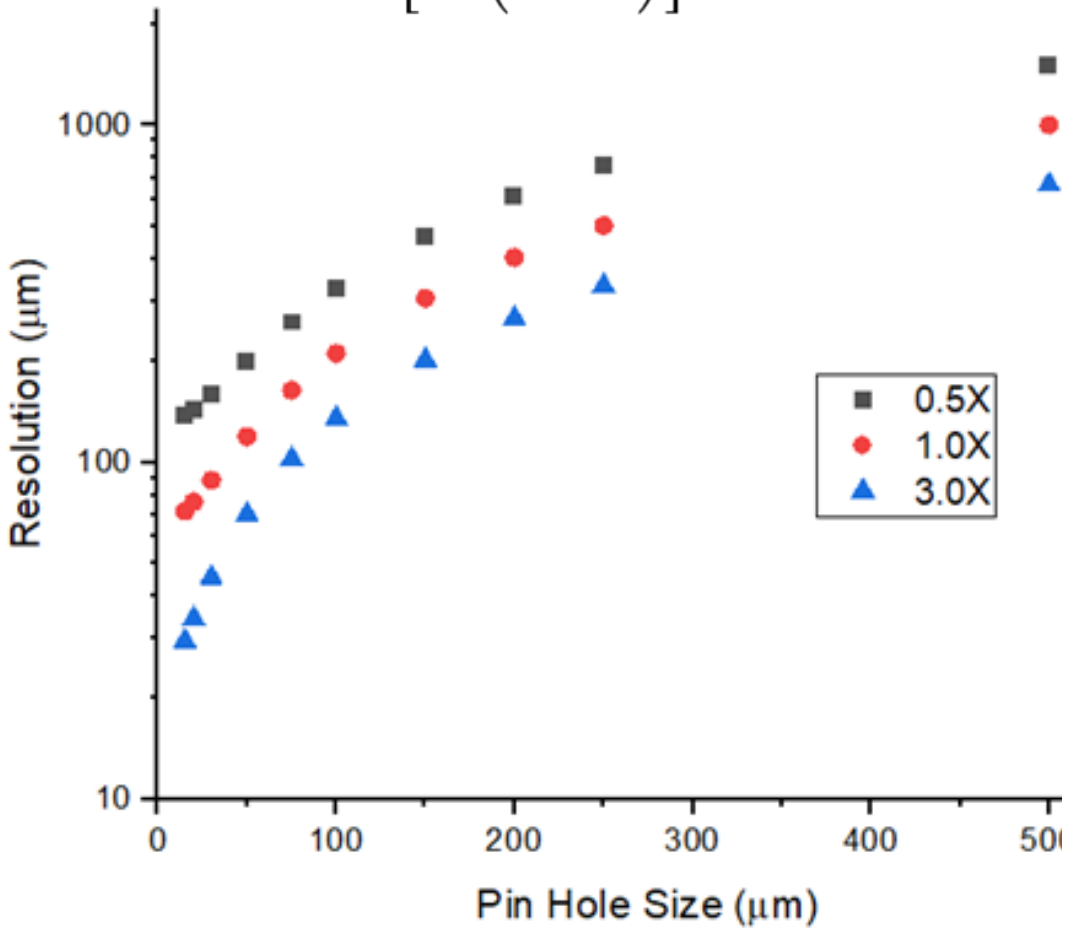
HRCXI

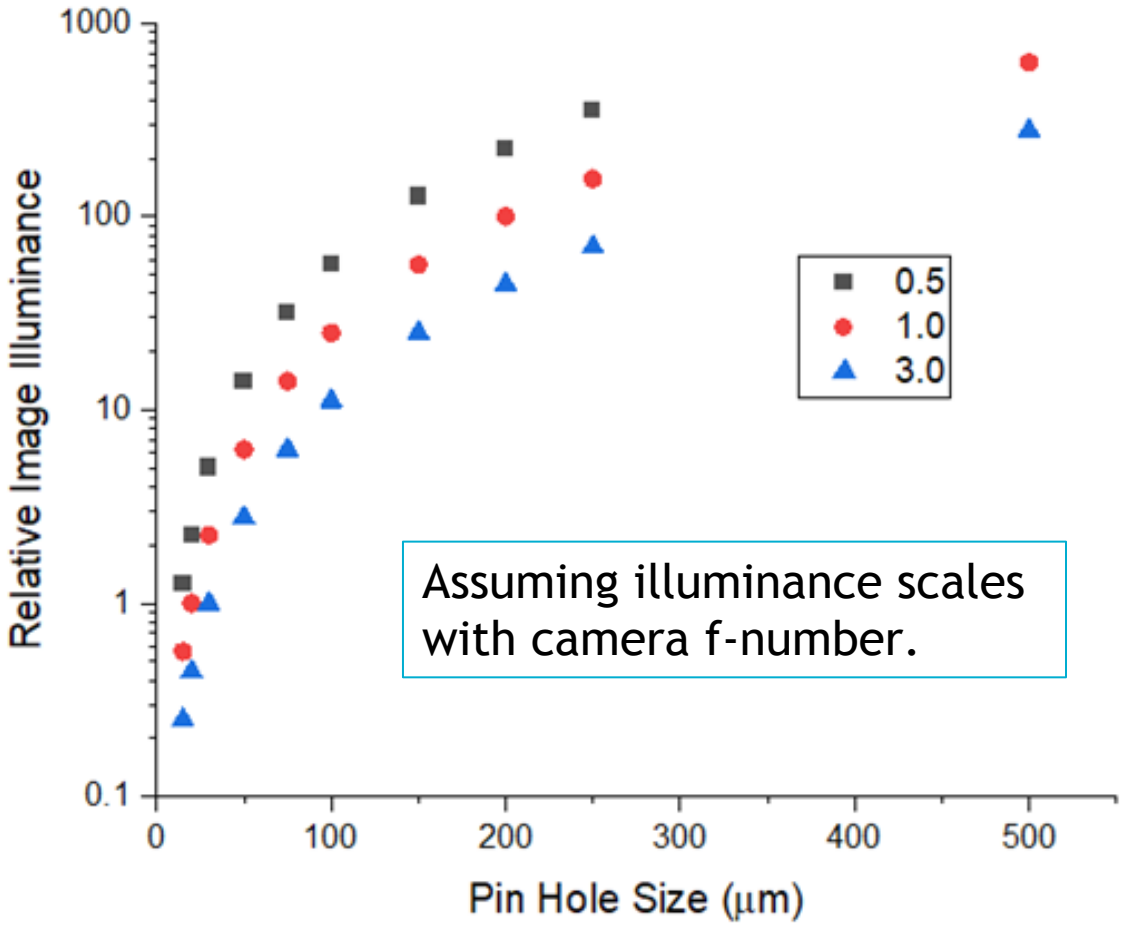


Note: this *is* the x-ray pulse from this shot.

Predications of resolution and sensitivity

$$Res^2 = \left[ph\left(\frac{M+1}{M}\right)\right]^2 + \left[\frac{mcp}{M}\right]^2$$





Assuming illuminance scales with camera f-number.

Conclusions and Future Work

We have demonstrated a new capability for time-resolved pin hole imaging at the Z facility at Sandia National Laboratories. Achieving high magnification requires the diagnostic to reside inside the Z vacuum chamber which is a demanding environment with high x-ray backgrounds, heavy shot debris, and large g-forces in the Z shot. The MCP detector must be placed in an independent vacuum system. A shock-absorbing support system was designed. Time-resolved imaging was demonstrated on some MagLIF style targets in support of characterizing the pinch morphology.

Future improvements to gain increased time and space resolution are already available including:

- Increased MCP sensitivity with available increased gain.
- Improved MCP resolution in time and space.
- Use smaller diameter pin holes

Other improvements are straightforward to implement in the future:

- Increased vacuum throughput for improved MCP reliability
- Improved alignment tools.