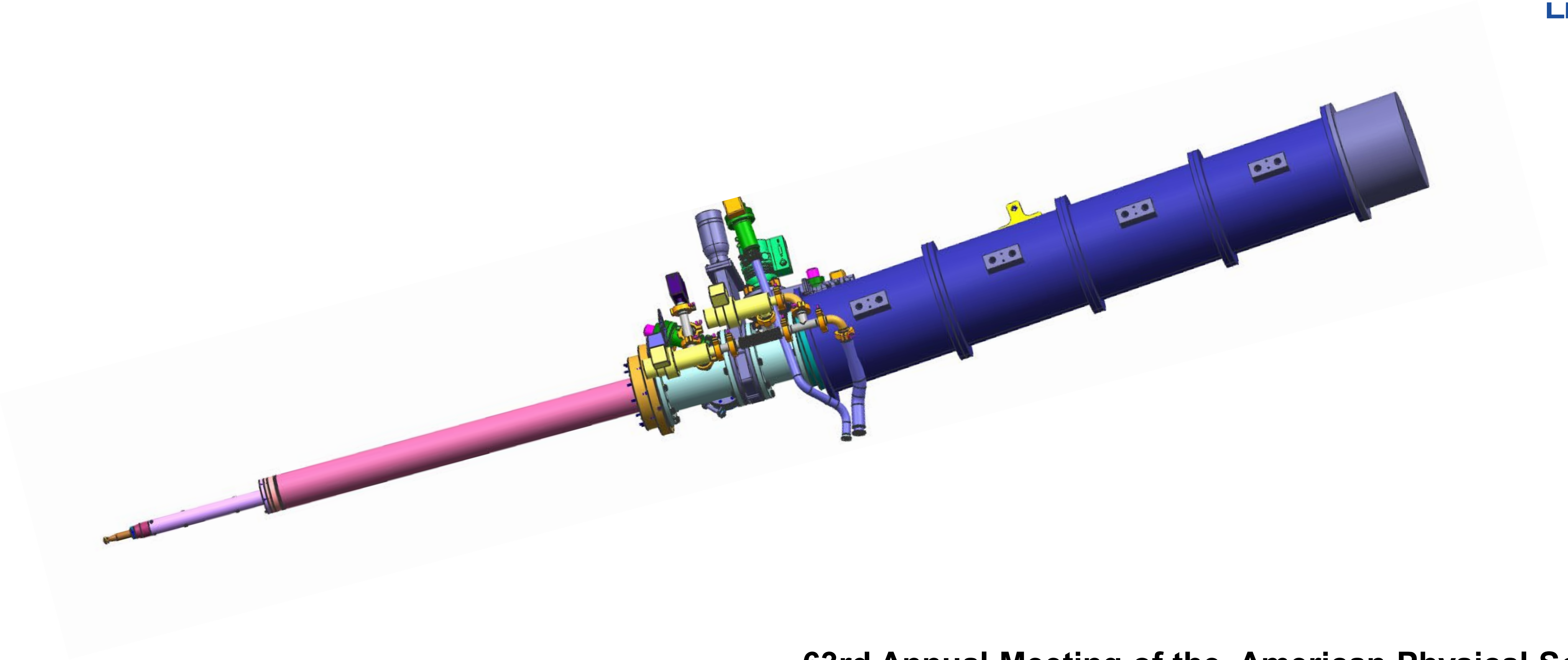
Design of the Third X-Ray Line of Sight for OMEGA



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ICF: inertial confinement fusion
hCMOS: hybrid complementary metal-oxide semiconductor

Collaborators

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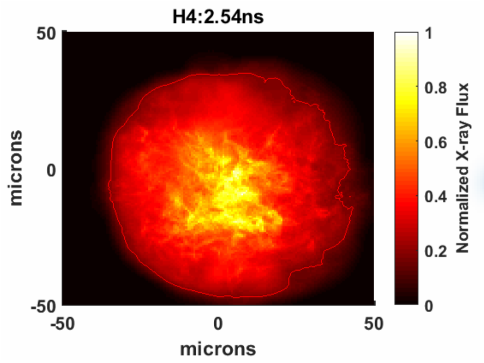
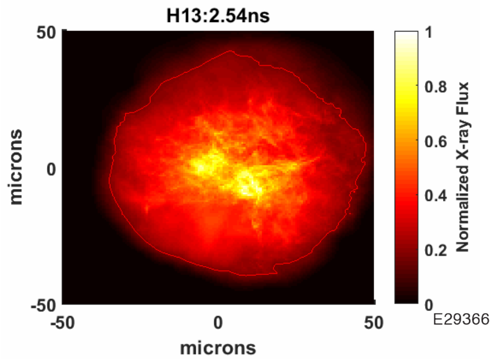
D. Garand
Sydor Technologies

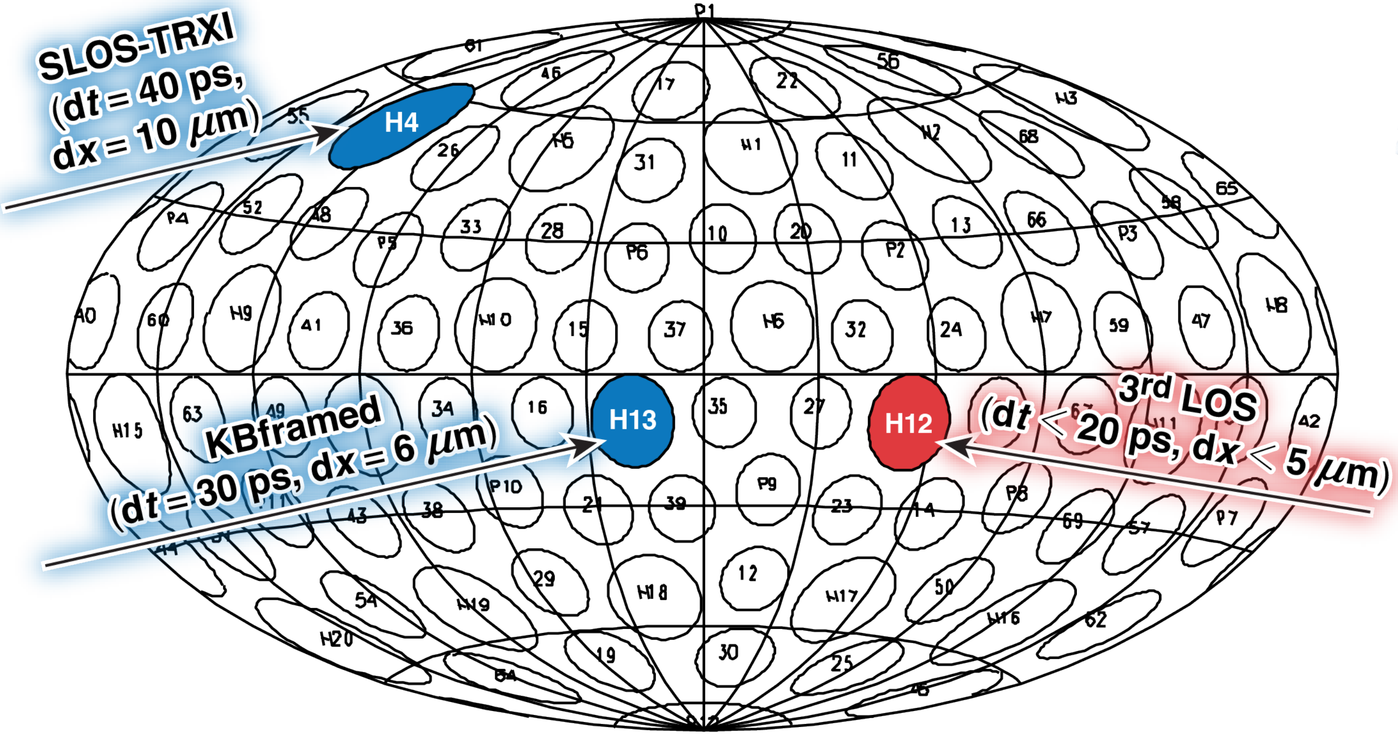
Multidimensional effects on hot-spot formation will be diagnosed with 3-D-gated x-ray imaging of the hot-spot plasma

*ASTER** 3-D simulation x-ray image

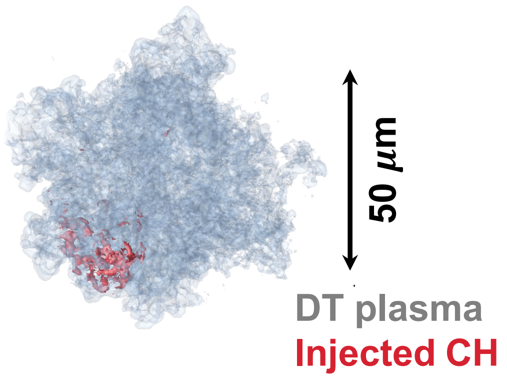


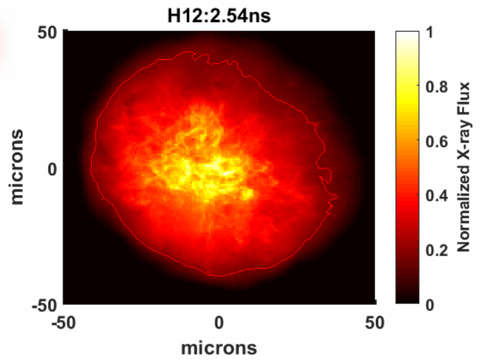


OMEGA Target Chamber



*ASTER** 3-D simulation (T_e ~ 1-keV surface)





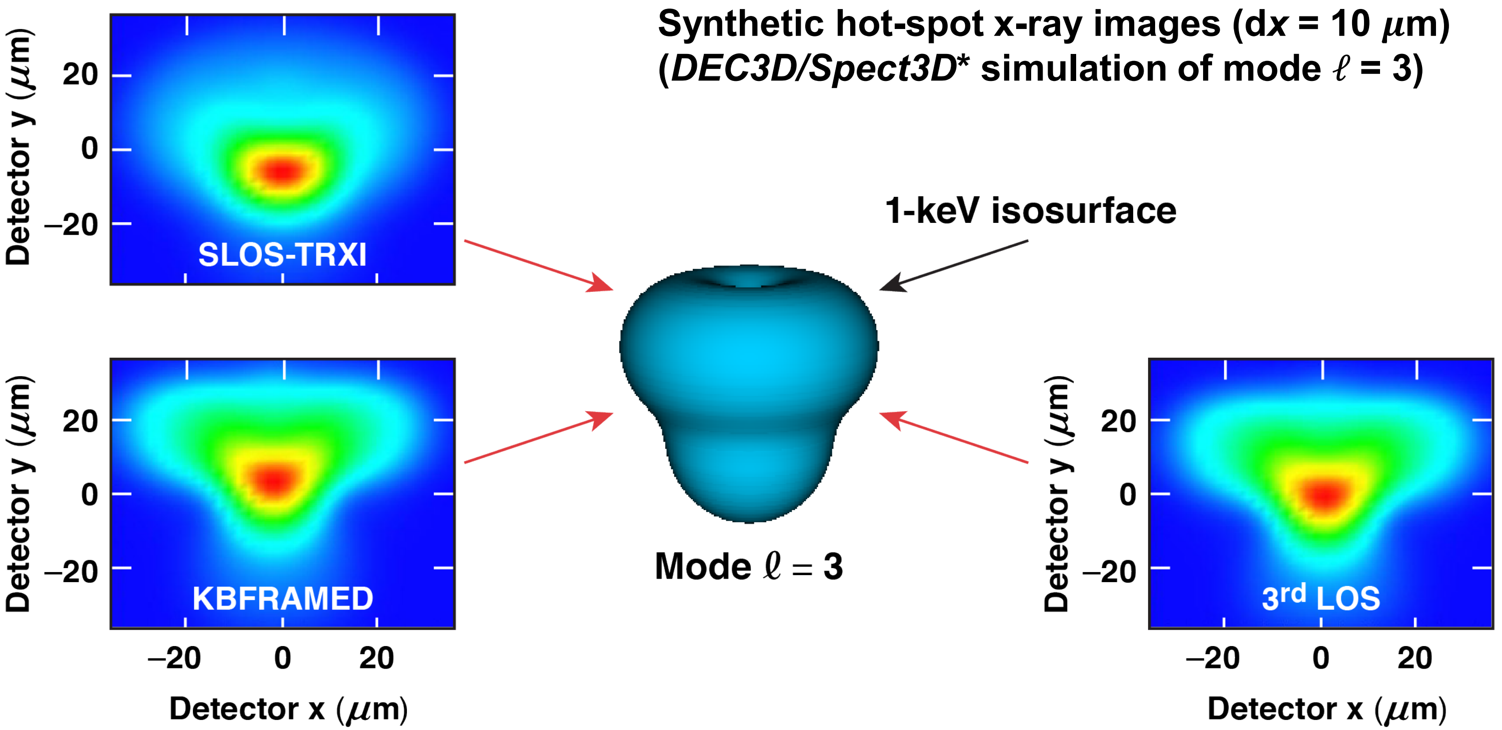
Three-dimensional gated x-ray imaging of the hot spot will use three quasi-orthogonal lines of sight.

LOS: line of sight

SLOS-TRXI: single line-of-sight time-resolved x-ray imager

* I. V. Igumenshchev *et al.*, Phys. Plasmas 23, 052702 (2016).

The 3-D hot-spot x-ray imaging requirements are being developed based on 3-D radiation-hydrodynamic simulations



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Preliminary requirements to resolve modes ℓ = 1 to 3 with 3-D view:

- **Spatial resolution of 5 to 10 μm (hot-spot diameter ~50 μm)**
- **Temporal resolution of 20 to 30 ps (burnwidth ~80 ps)**
- **≥3 diagnostic lines of sight with absolute reference frames**

Machine-learning techniques will be applied in the 3-D data analysis.**

* K. M. Woo *et al.*, Phys. Plasmas 25, 052704 (2018);
Spect3D, Prism Computational Sciences Inc., Madison, WI 53711;
VisIt, Lawrence Livermore National Laboratory, Livermore, CA 94550;
J. Delettrez *et al.*, Phys. Rev. A 36, 3926 (1987).

** B. Zirps *et al.*, "A Platform to Infer the Dominant Mode from Experimental X-Ray Images Using the Deep-Learning Convolution Neural Network," to be submitted.

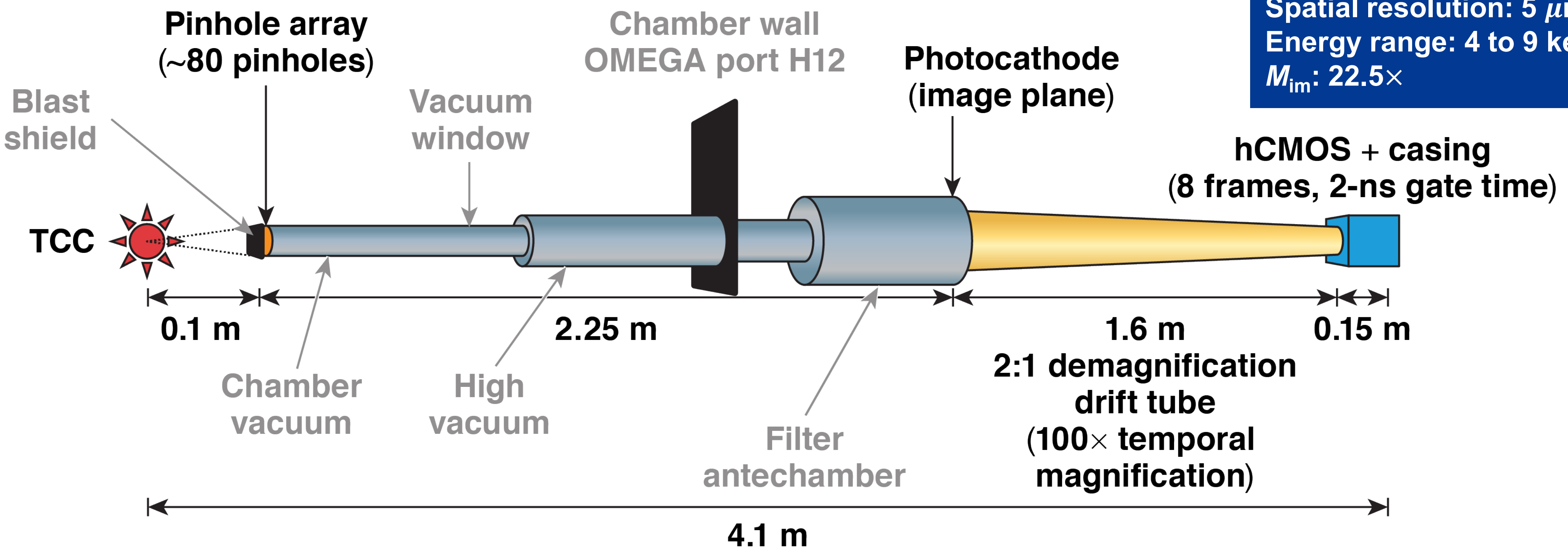
The basis for technical requirements for the third line of sight flow from the need for 3-D reconstruction

Requirement item	Requirement value	Requirement basis/rationale/justification
X-ray energy range	2 keV to 10 keV	Record the hot-spot x-ray emission; actual range might be narrower with additional filtration, e.g., 4 keV to 9 keV
Signal-to-noise ratio	≥20:1	Required to discriminate the signal of interest above noise; limited by drift tube current
Field of view	≥120 × 120 μm^2 at TCC	The field of view is required to be at least ~2× the diameter of a typical hot spot
Spatial resolution	Best achievable	A spatial resolution of 5 μm or better is required to resolve mode ℓ = 10 in the shape of the hot spot with a typical diameter of 50 μm
Temporal resolution	<20 ps	The burn duration of a high-performing cryo implosion is ~80 ps; four or more independent images at different times of evolution
Record length	≥160 ps	Twice the burn duration (~80 ps) to allow for timing jitter error and full record of hot-spot evolution
Neutron background resilience	>2 × 10^8 n cm^{-2}	High neutron yield of up to 2 × 10^{14} might pose background issues
Electronic readout	N/A	Provides data right after shot to inform PI for shot decisions—3-D hot-spot reconstruction

TCC: target chamber center PI: principal investigator

The design is based on a robust x-ray imaging platform and will have improved spatial ($\leq$5-μm) and temporal (20-ps) resolutions

Gate width: ~20 ps
Image to image: 20 ps
Spatial resolution: 5 μm
Energy range: 4 to 9 keV
M_{im}: 22.5×



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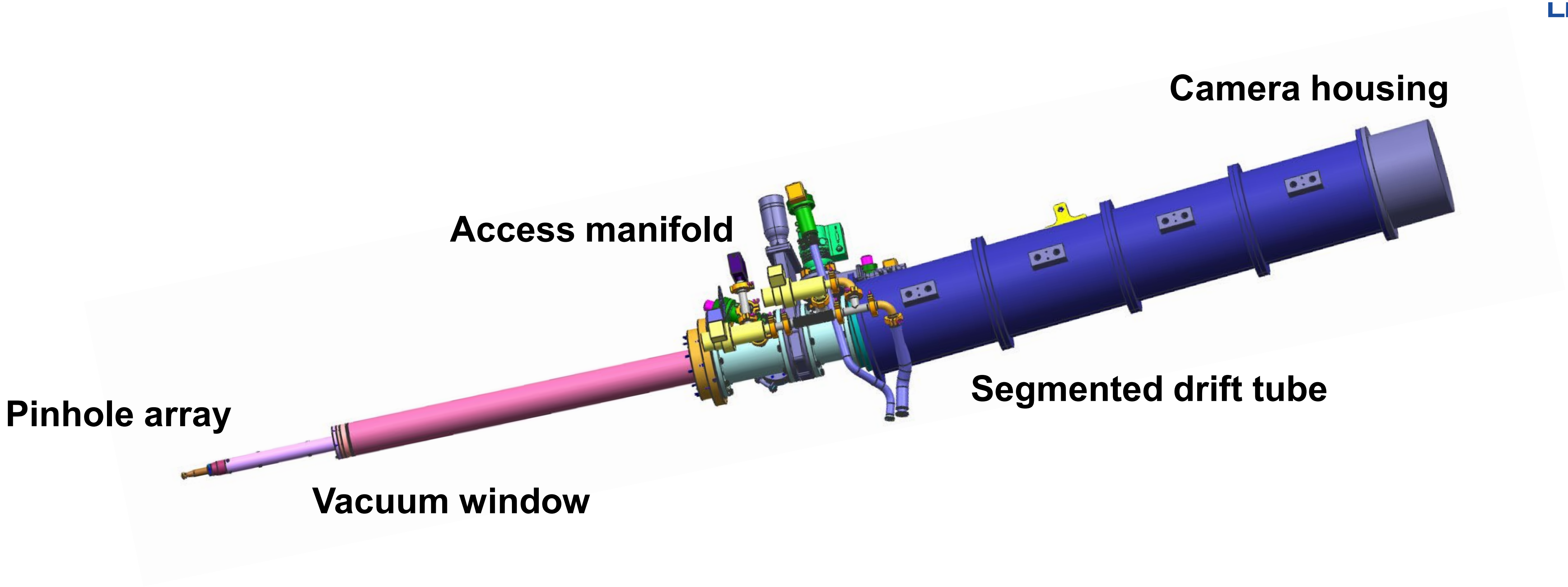
The initial drift tube imager project, SLOS-TRXI, has provided the foundation for designing and implementing this next-generation imager

TCC: target chamber center

Preliminary mechanical layout of the imager is underway



The segmented geometry allows for flexible shaping of the drift field to achieve 2:1 demagnification.

A photometric estimate for the third LOS gated x-ray imager indicates a similar signal level per pixel as with the current drift tube imager

Average transmission through filter

Drift tube demagnification

Solid angle

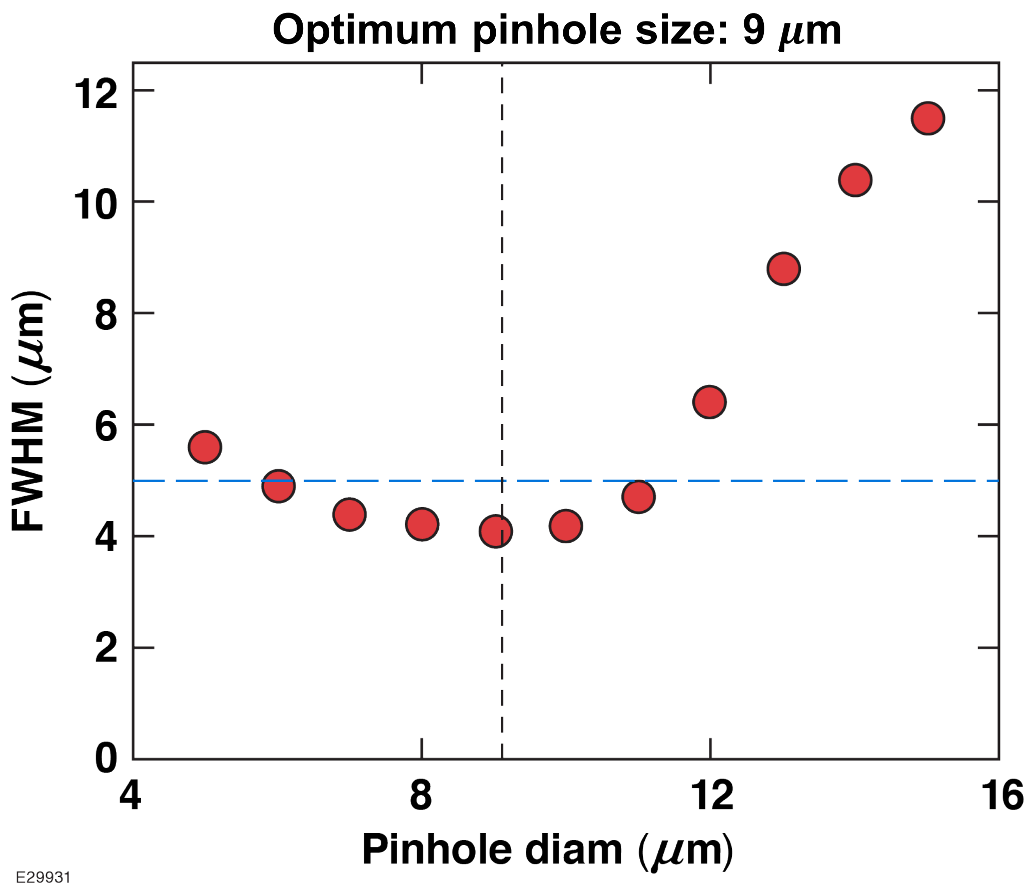
$$\mathrm{Signal}_{\mathrm{hCMOS,pixel}} \quad \frac{\Delta\Omega * T_{\mathrm{filter}} * D^2_{\mathrm{demag}}}{M^2_{\mathrm{imager}}}$$

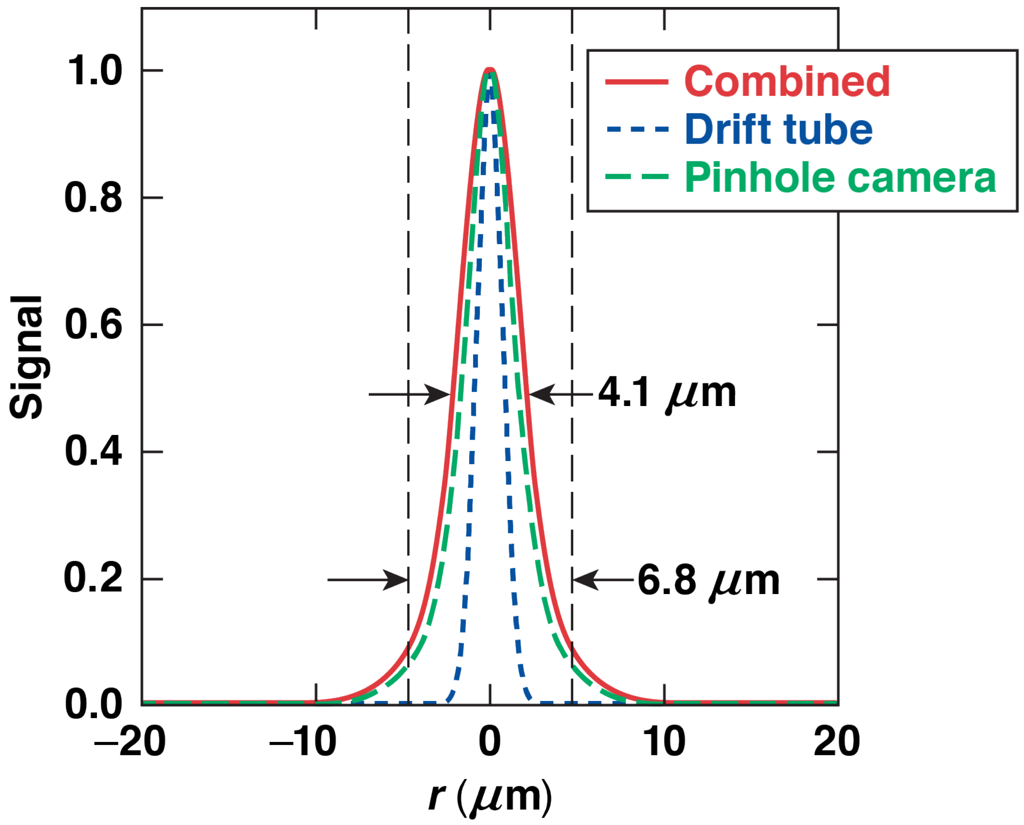
Imager magnification

	SLOS-TRXI (second LOS)	Third LOS
PH-object (a) (cm)	16.7	10
PH-image plane (cm)	207.2	225
Pinhole diam (μm)	10	8.5
$\Delta\Omega$ PH (ster)	2.8×10^{-9}	5.1×10^{-9}
T_{filter}	0.07	0.07
M_{imager}	12.4	22.5
D_{demag}	1×	2×
Signal (ADU) (40-ps gate)	100	220
Signal (ADU) (20-ps gate)	50	110

A demagnifying drift tube increases the signal level at the detector plane and allows shorter time gating of sub-10-μm features.

The point-spread function of the third LOS x-ray imager was calculated with the Fresnel approximation using the anticipated spectral sensitivity





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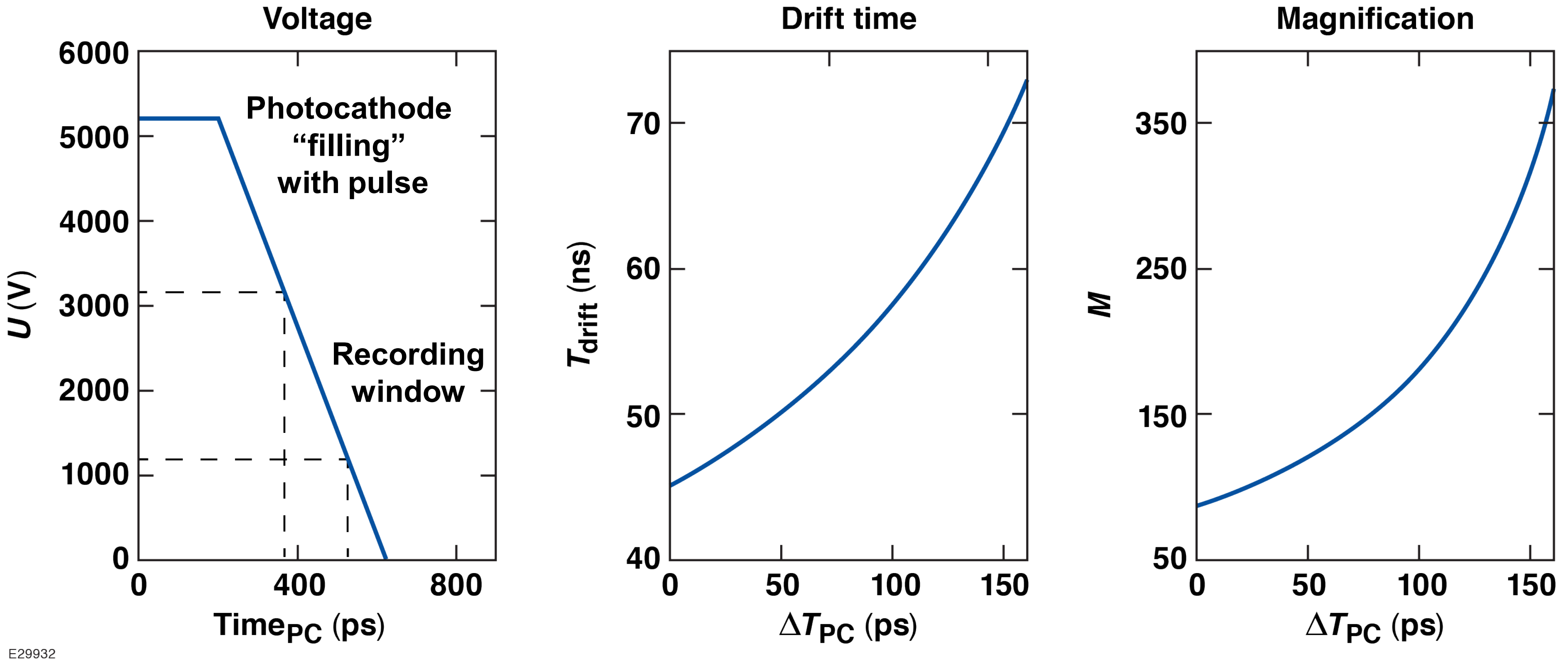
This calculation assumes a 40-μm Larmor orbit radius of electrons in the drift tube.

A voltage pulse ramped at –12 V/ps provides a recording window of 160 ps with a nonlinear mapping between the input and output time



A 20-ps event is dilated to 2 ns at the start of the ramp and nearly 7 ns at the end of the ramp.

Summary/Conclusions

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