Development of a Self-Modulated Laser Wakefield Accelerator Platform with a 10 keV to 1 MeV Hyper Spectral Photon Source for HEDS

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in collaboration with LLNL (JLF, NIF) and LLE

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Department of Energy, NNSA

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UCLA Samueli
Electrical & Computer Engineering

Lawrence Livermore National Laboratory

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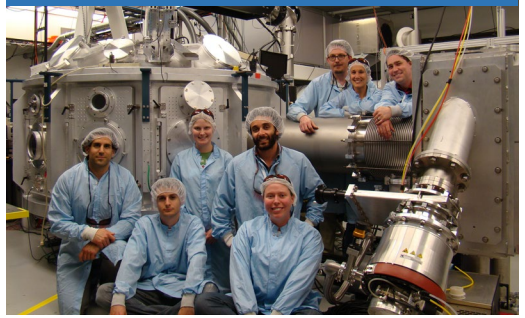
Our project is developing LWFA-driven sources on large kJ-class picosecond lasers: Two 3 year NNSA awards

Titan, LLNL	OMEGA-EP, LLE	NIF – ARC, LLNL	LMJ – PETAL, CEA
			

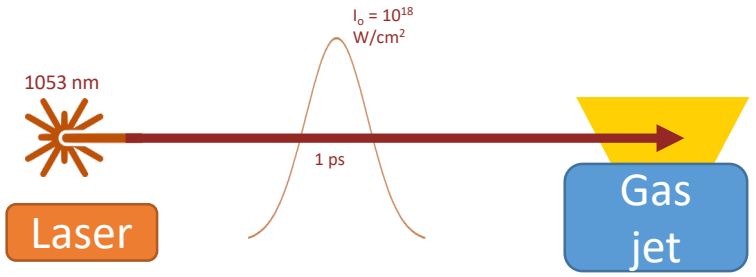
2015 → 2016 → 2017 → 2018 → 2019 → 2020 → 2021

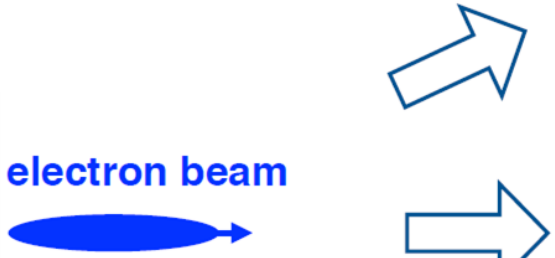
2015	2016	2017	2018	2019	2020	2021
Titan SMLWFA electrons Betatron radiation		**Titan** Compton scattering/Bremsstahlung		**Titan** Prliminary Radiography	**Titan** Shock Compression	
			OMEGA-EP SMLWFA electrons	**OMEGA-EP** X-ray sources	**OMEGA-EP** Radiography + shocks	
				NIF - ARC SMLWFA electrons	**NIF - ARC** X-ray sources	
					LMJ – PETAL SMLWFA electrons	

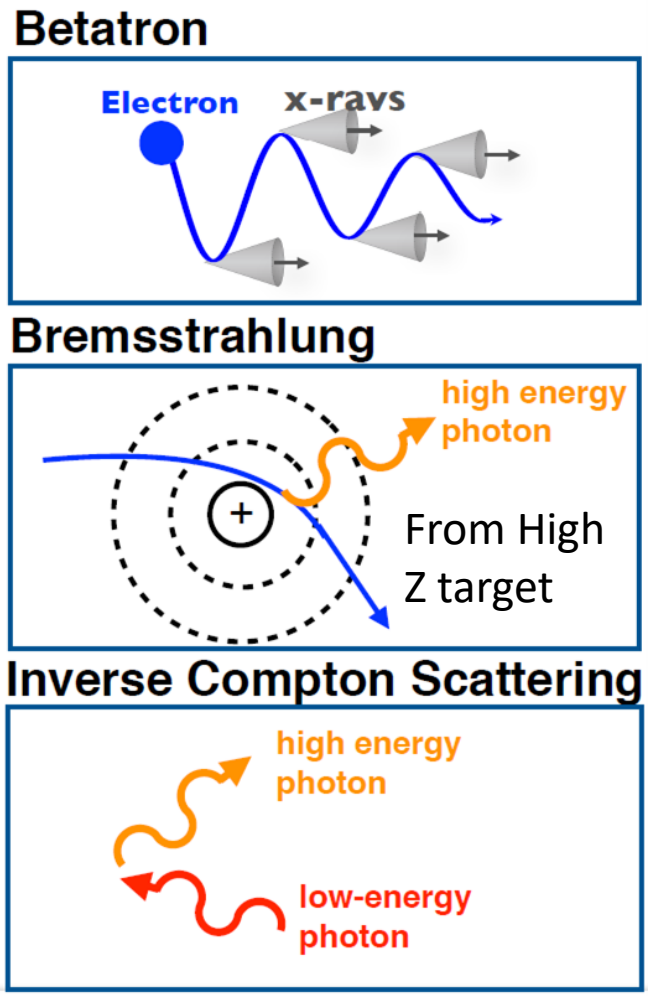
COVID19 and Titan Upgrade Impact:

The overall schedule has been delayed by about 12 months. We have an approved shot on ARC but no plans for radiography on LMJ or Omega-EP

We are developing a usable broadband, keV-MeV, x-ray platform for High Energy Density Science (HEDS)







- PM King *et al* (2020) APS **24** (1), 011302
- N Lemos et al (2019) Phys. of Plas. **26** (8), 083110
- PM King *et al* (2019) Rev. of Sci. Inst. **90** (3), 033503
- GJ Williams et al (2018) Rev. of Sci. Inst. **89**, 10F116
- F Albert *et al* (2018) Nuc. Fus.
- F Albert *et al* (2018) Phys. of Plas. **25**, 056706
- N Lemos *et al* (2018) *Plasma. Phys. Control. Fusion* **60** 054008
- F Albert *et al* (2017) *Phys. Rev. Lett.* **118** 134801
- N Lemos *et al* (2016) *Plas. Phys. Control. Fusion* **58** 034018

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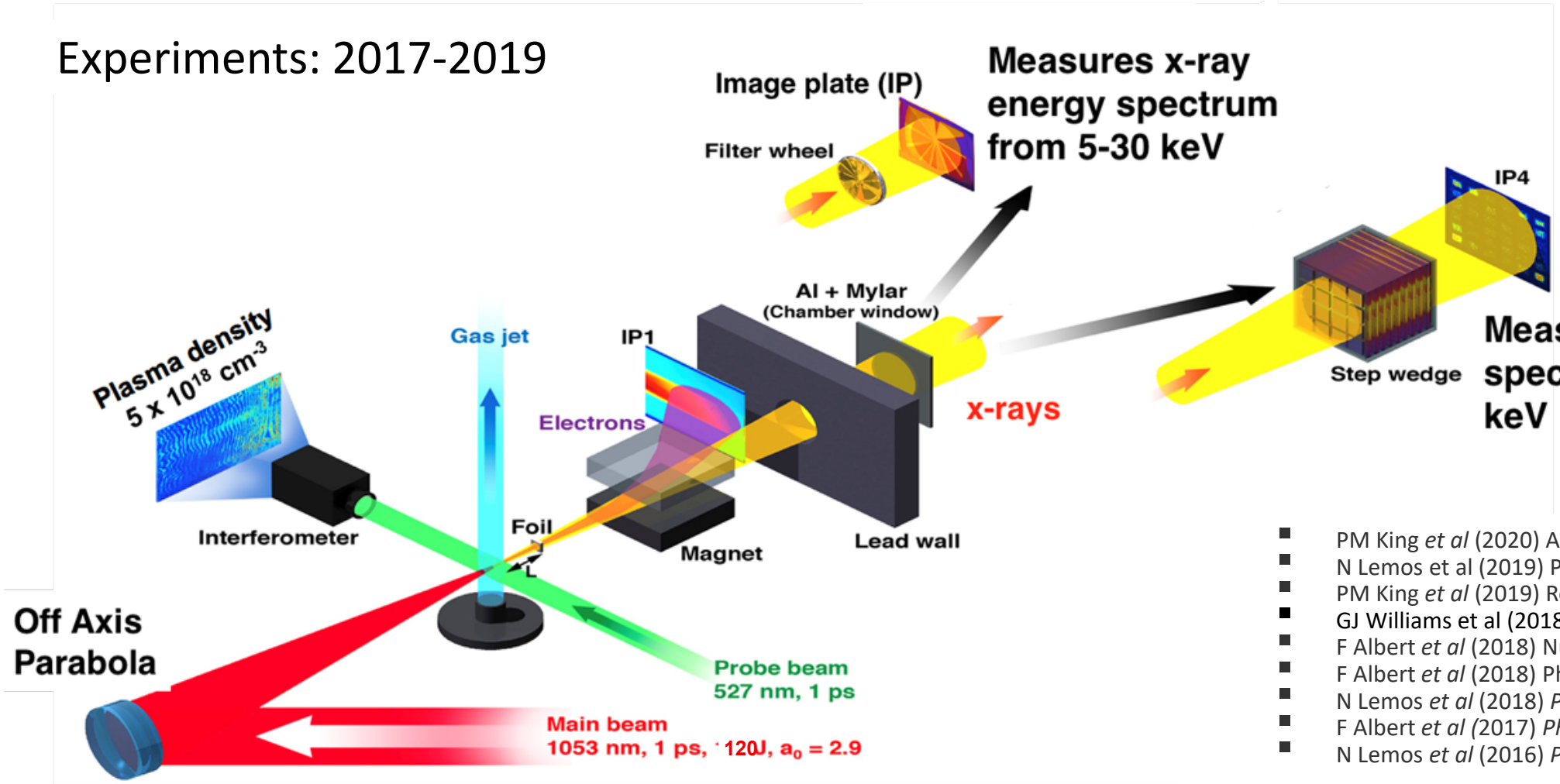
To optimize the X-ray source we need to optimize the spectrum and charge of high energy electrons from intense ps pulse LPI.

- 1) Experiments on Titan using 1ps, $a_0 \sim 2$, 500 J laser pulses
- Goal: Optimize the electron yield above 100 MeV by optimizing DLA process over wakefield acceleration process.
- Understand the electron acceleration mechanism
- 2) Experiments on Omega EP
- Goal: Optimize the charge

Experimental set up at the Titan laser

Experiments: 2017-2019



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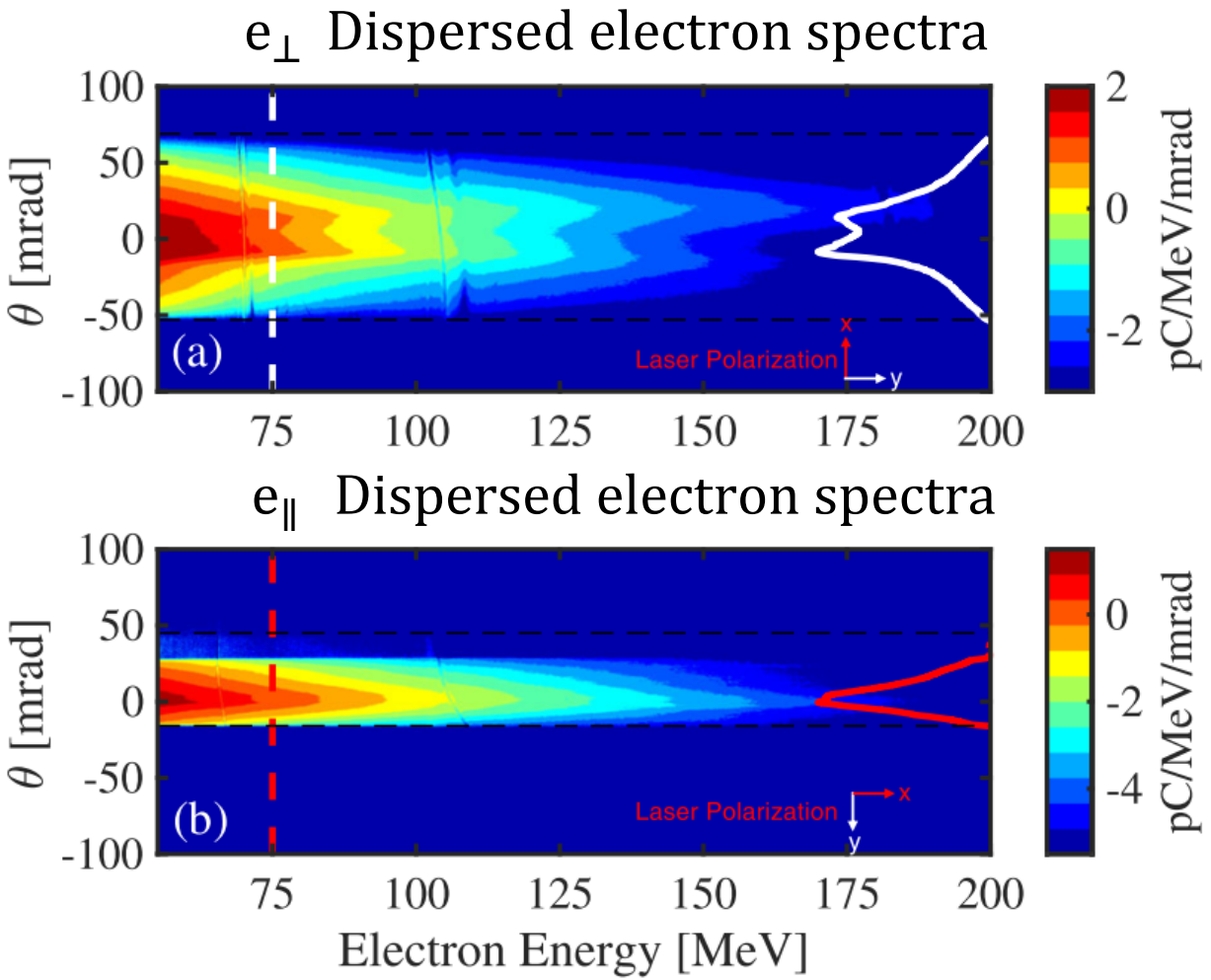
Dispersed electrons provide Experimental Evidence of DLA

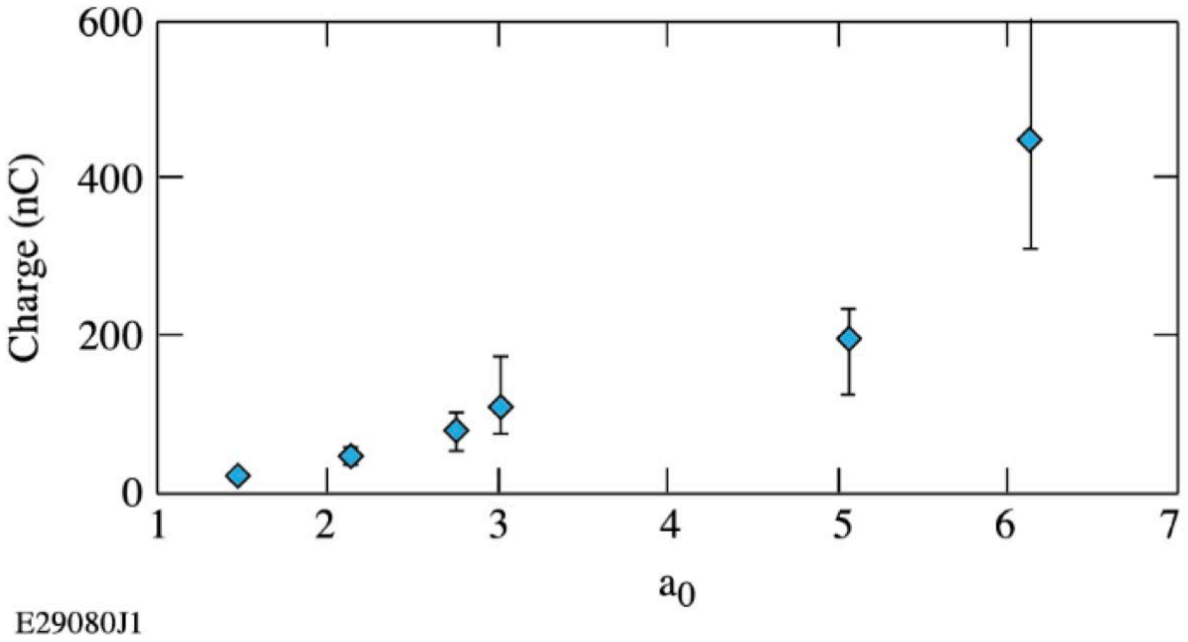
- Evidence of DLA at $n_e = 3x10^{17}$ cm^{-3}
- Forking structure characteristic of DLA revealed when electrons were dispersed perpendicular to laser polarization but not when polarization was in the direction of dispersion.
- Careful analysis of PIC results using a new 3D code showed that the role of the longitudinal field of laser pulse can be significant in DLA
- **Ref: J. Shaw PRL 118, no. 6 (2017): 0648012**

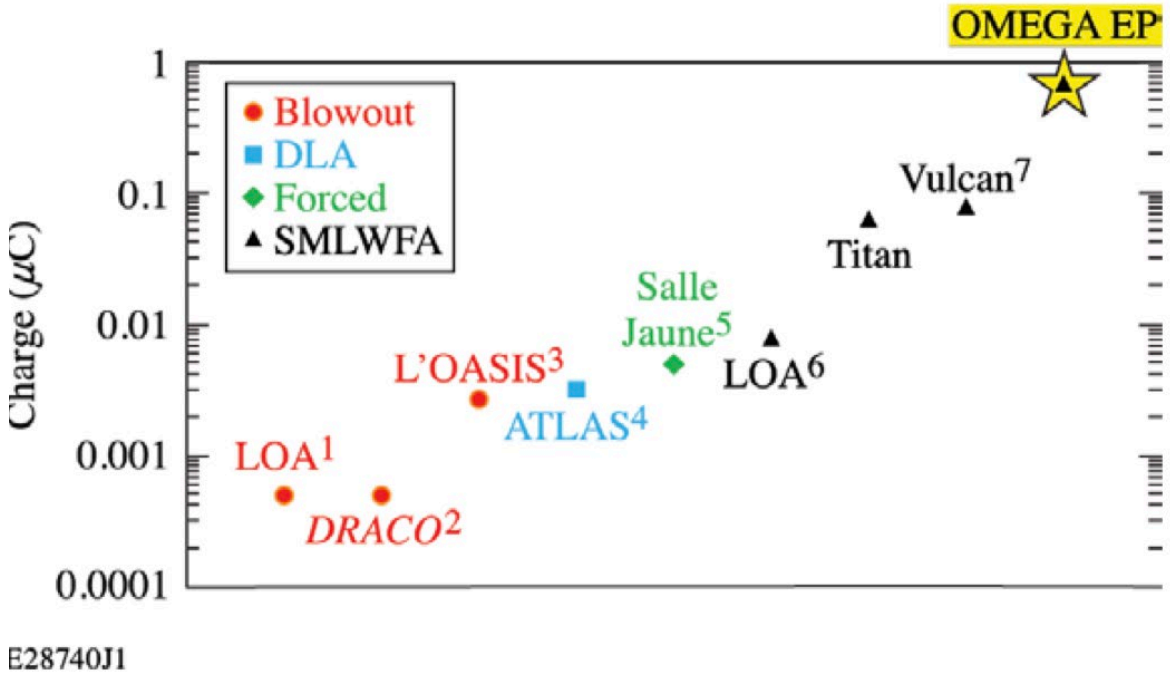


King et. al., Predominant Contribution of Direct Laser Acceleration to High-Energy Electron Spectra in a Low-Density Self-Modulated Laser Wakefield Accelerator. *PRA&B, 24*(1), 11302. http://doi.org/10.1103/PhysRevAccelBeams.24.011302

Optimizing the charge using Omega EP laser

(electron charge increases rapidly with a_0)



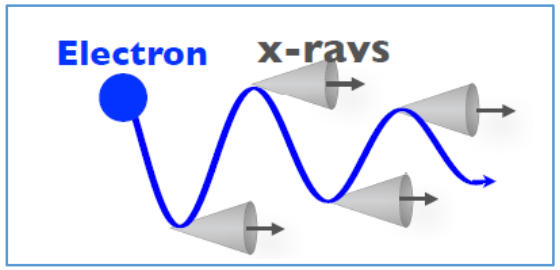


Parameters: ne 5x1018 cm-3, 6 mm gas jet, w0~15 um , 700 fs (FWHM)

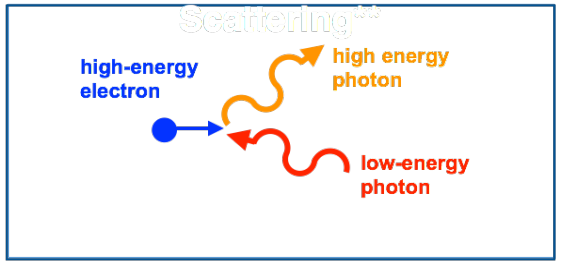
Ref: J. Shaw et al : Accepted for publication in Scientific Reports

Relativistic electrons are used to created x-rays through Inverse Compton Scattering and bremsstrahlung radiation

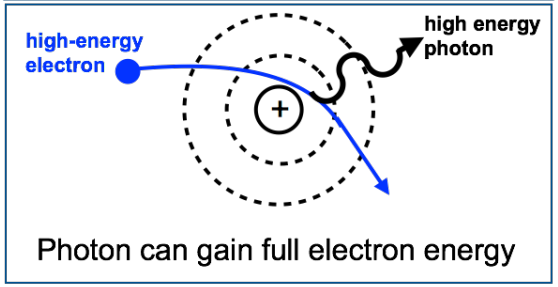
Betatron

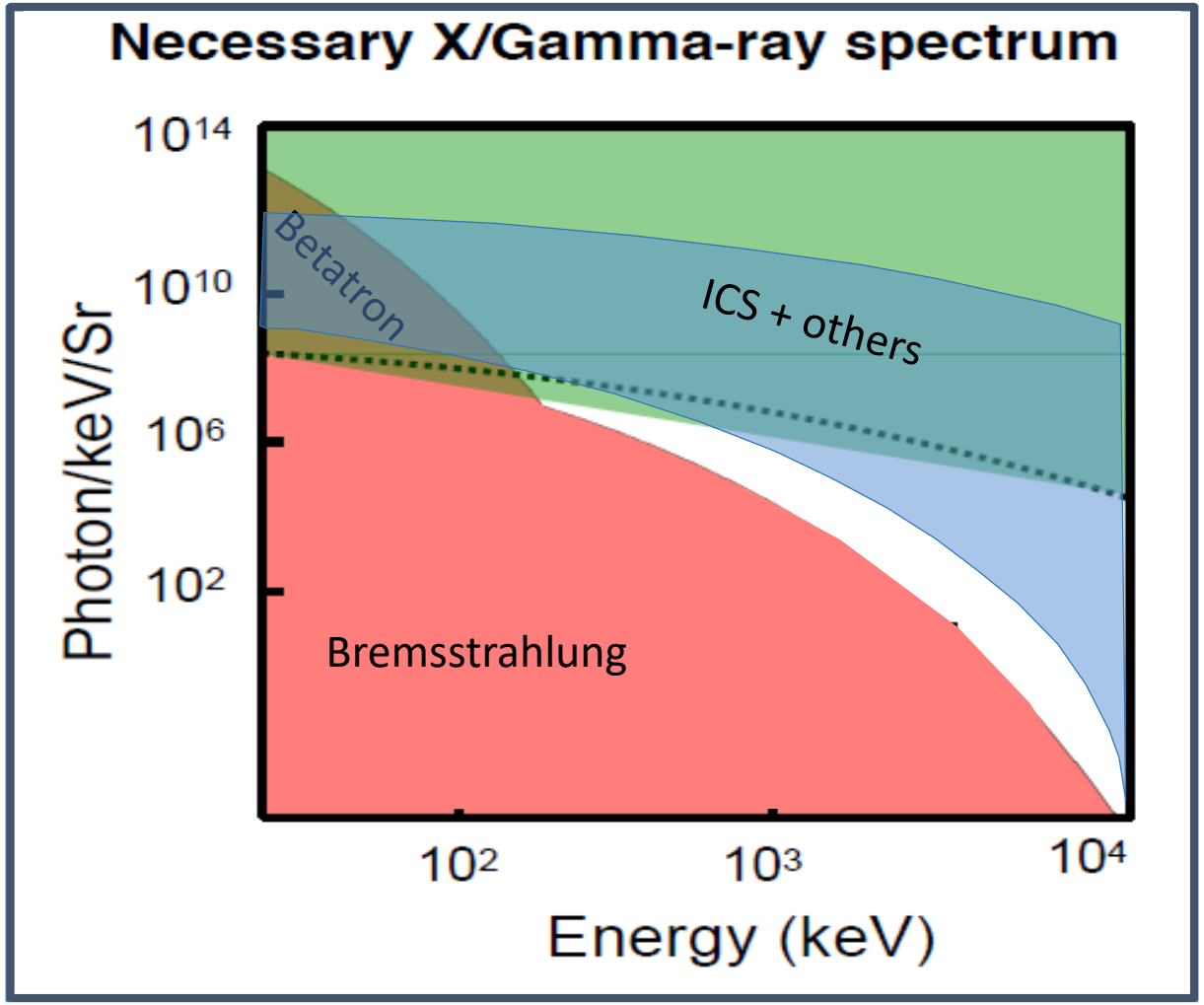


Inverse Compton

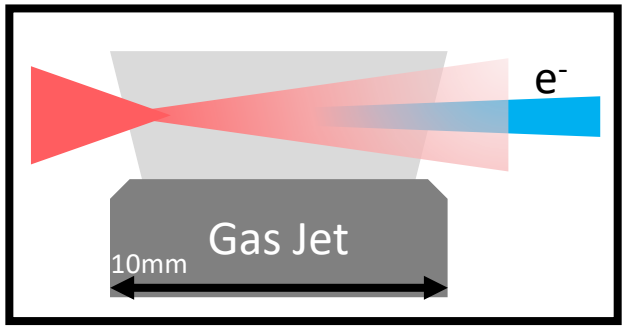


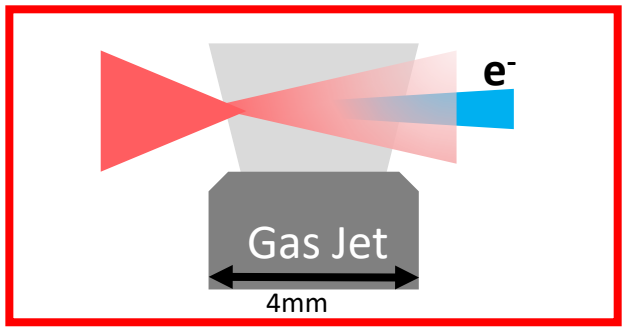
Bremsstrahlung



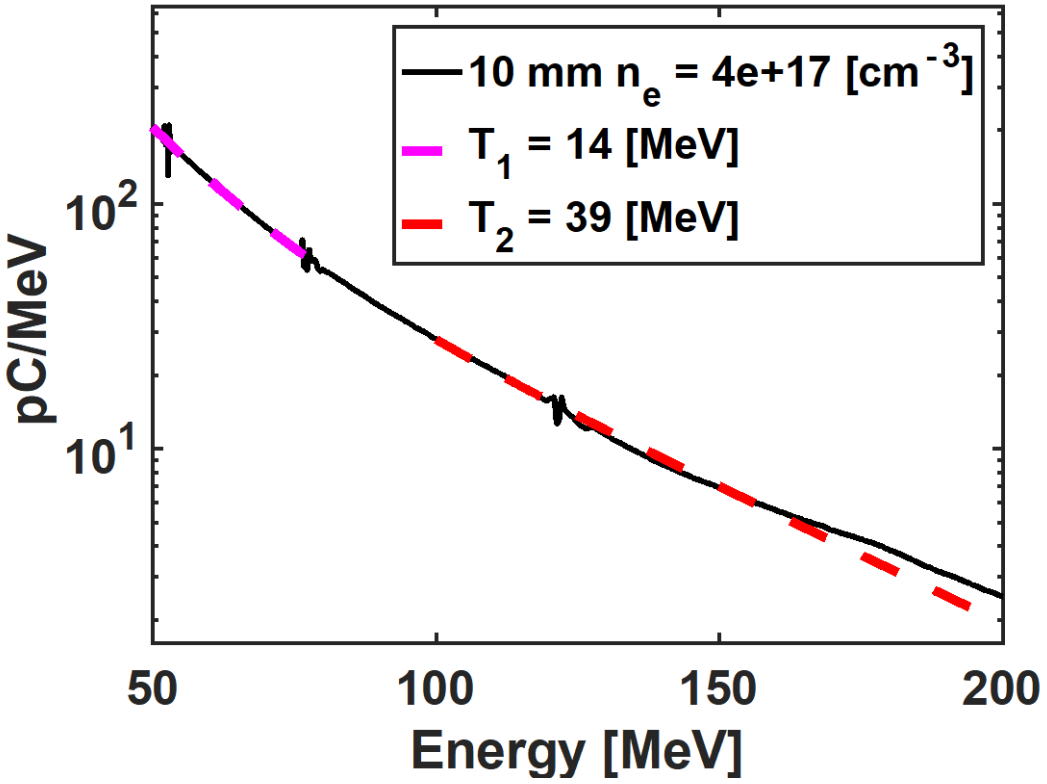


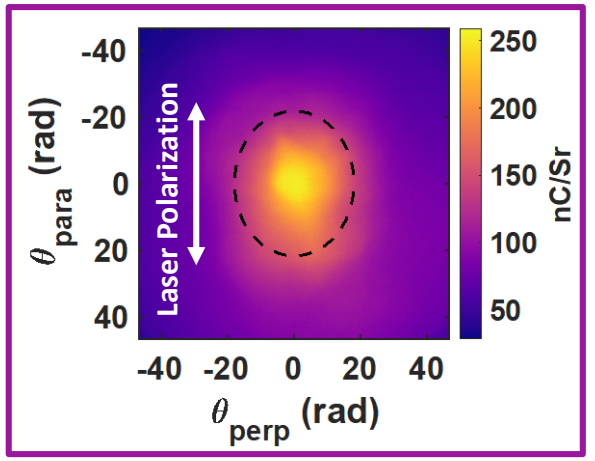
Electron energy spectrum follows a two-temperature distribution





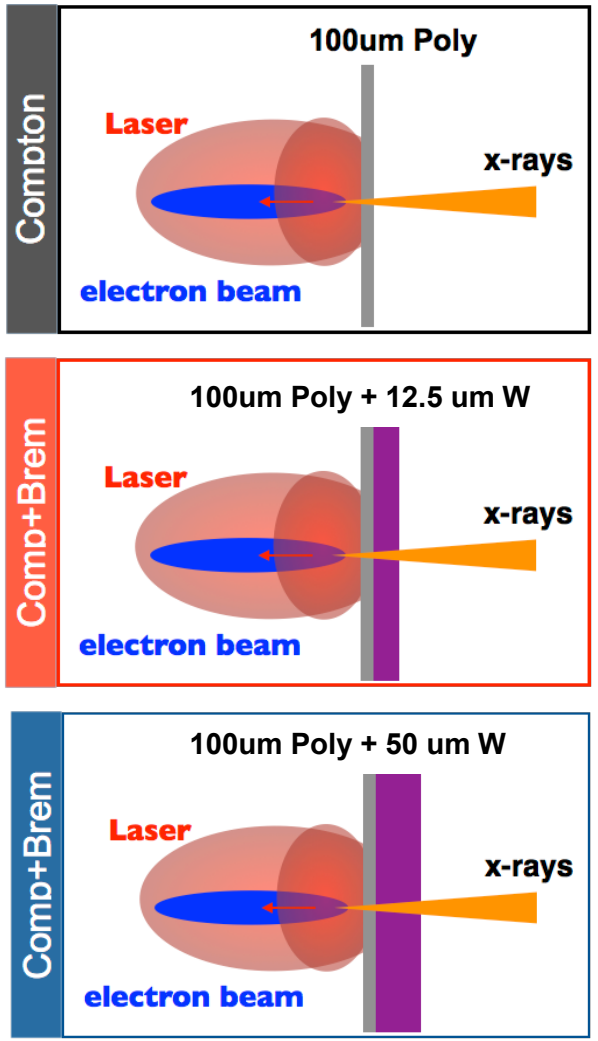
$$\frac{dN}{dE_e} = A\, e^{\frac{E_e}{T_1}} + B\, e^{\frac{E_e}{T_2}}$$





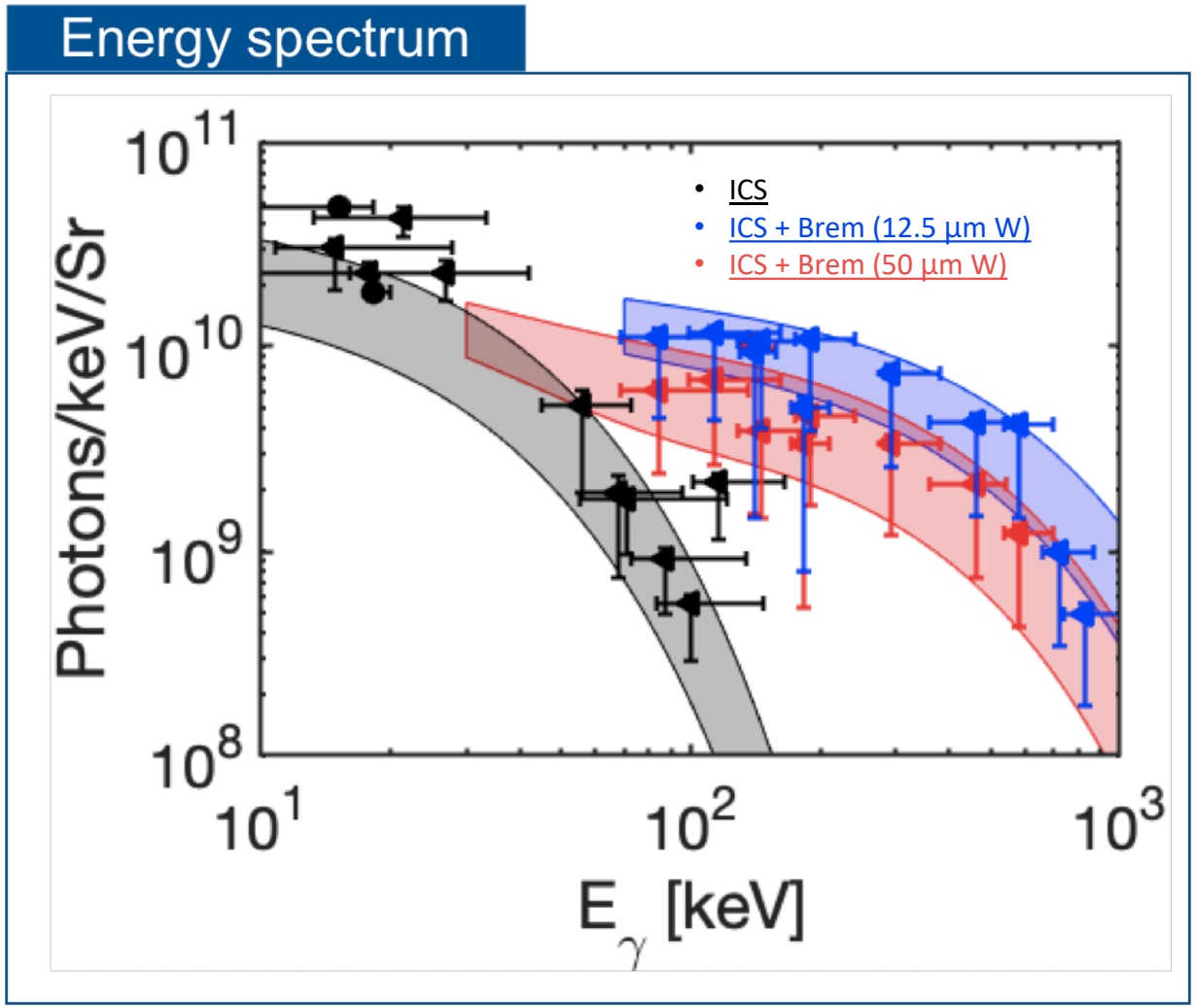
~ 40 mrad beam divergence

The electrons can then be used to generate a tunable x-ray source by varying the method in which the x-rays are generated

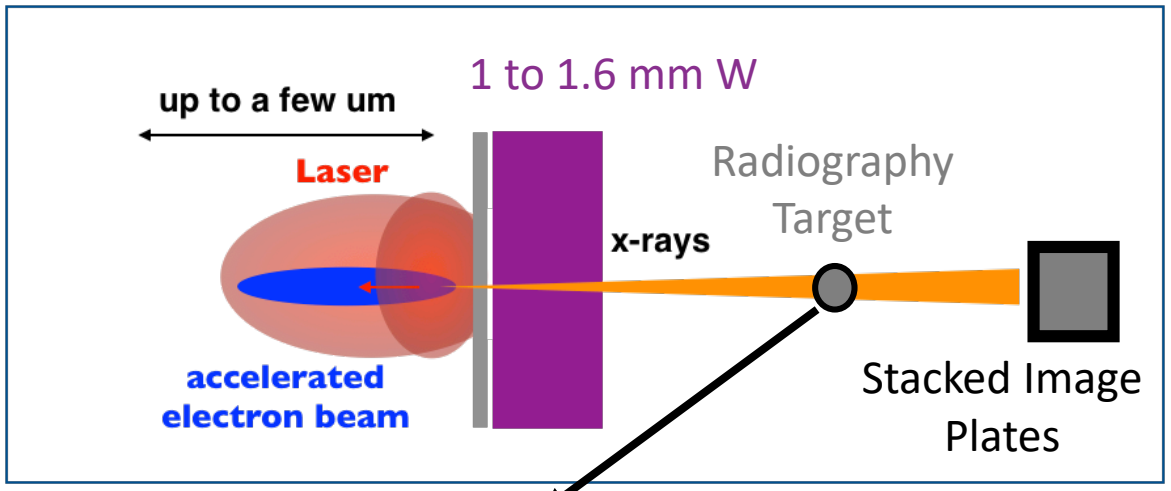


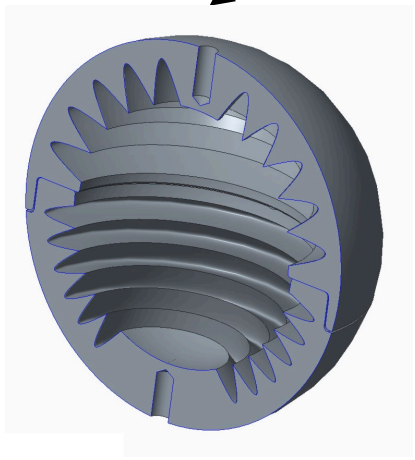
- P. M. King, et al, Rev. Sci. Inst. 90, 033503 (2019)
- P. M. King, et. al., In Preparation

Energy spectrum

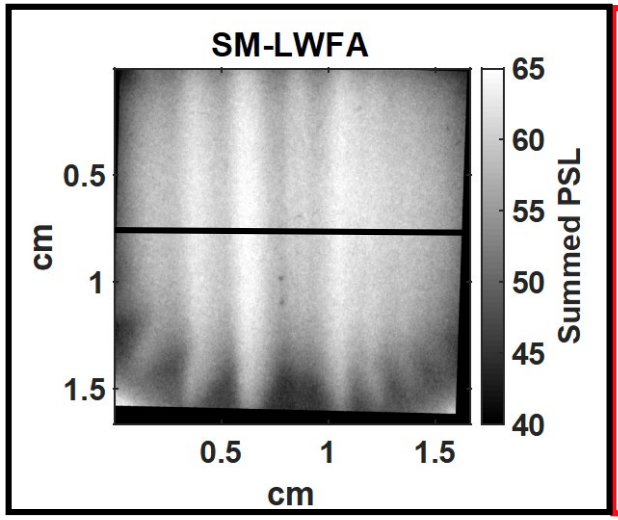


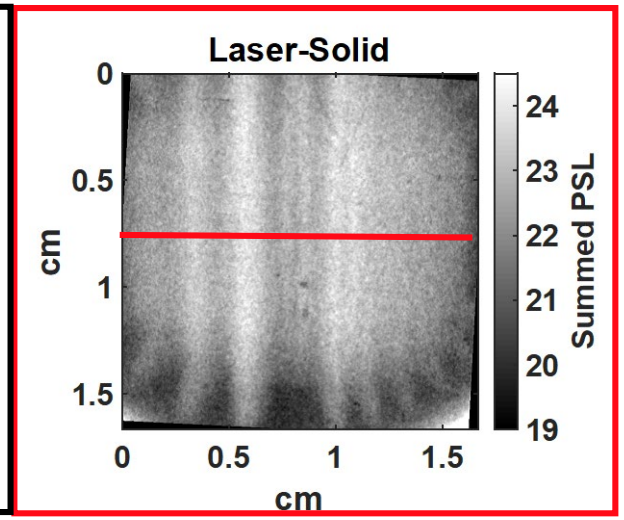
LPA shows better signal to noise compared to MeV radiography for the same laser conditions and target

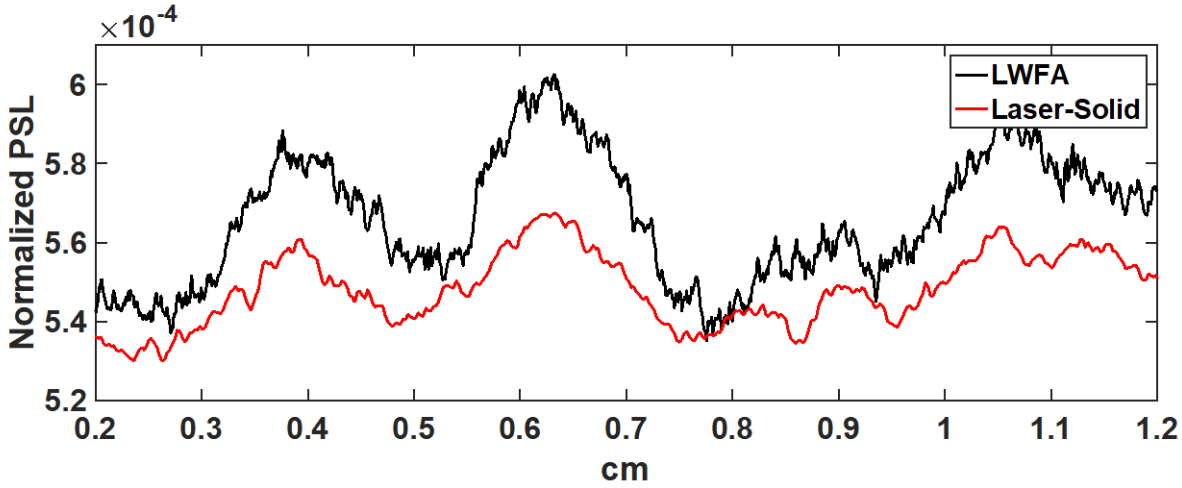




Areal Density = 7.6 g/cm^2 [Lead]







NIF-ARC Shot results

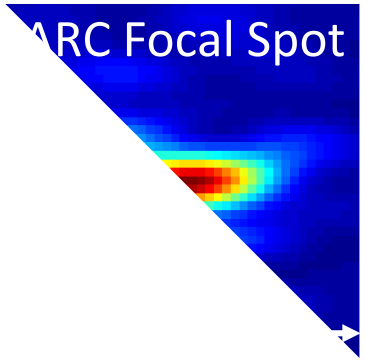
Lawrence Livermore National Laboratory

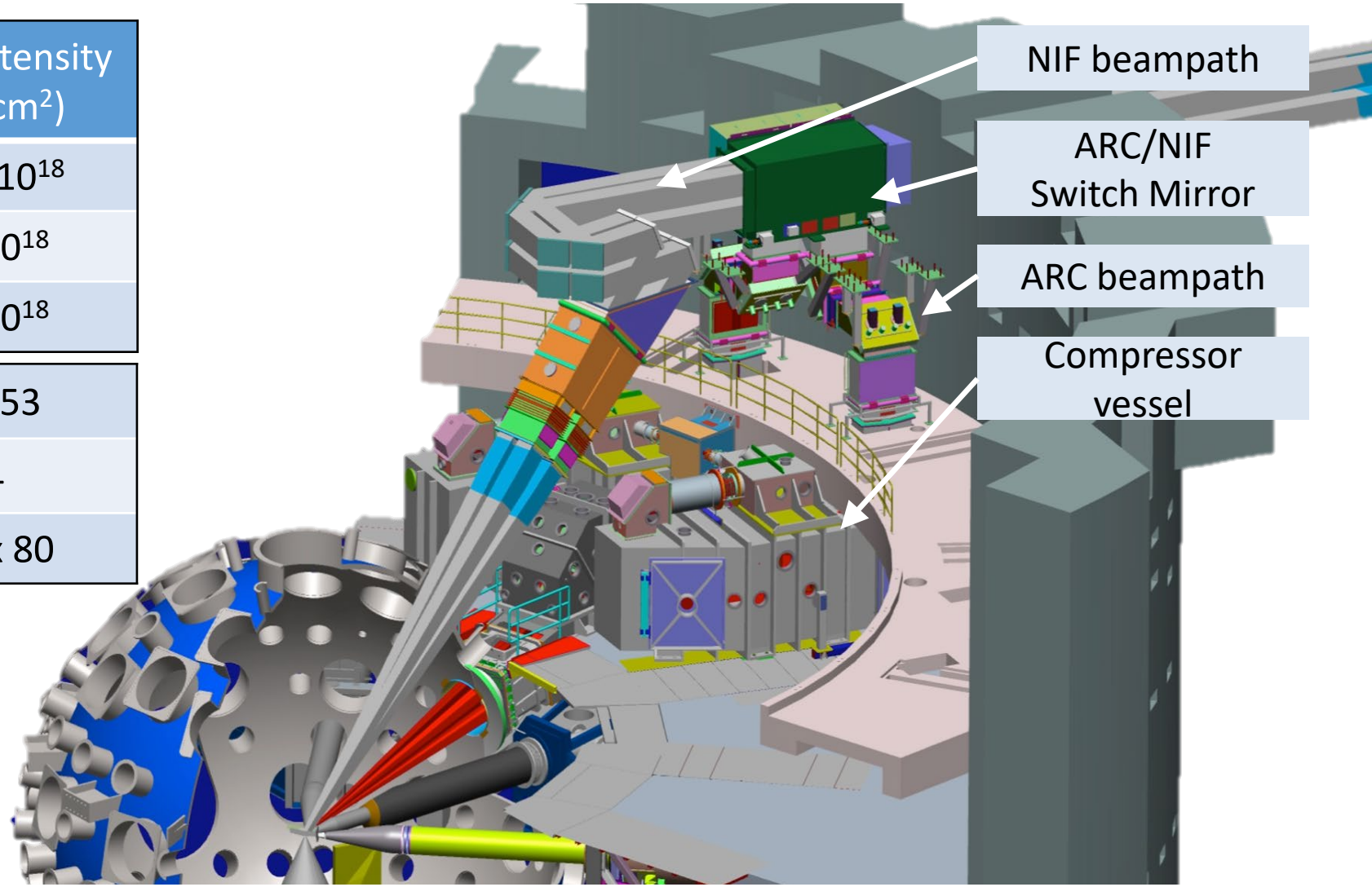
UCLA Samueli Electrical & Computer Engineering

We used NIF's short pulse laser, the advanced radiographic capability (ARC)

Energy/ beamlet (kJ)	Pulse Duration (ps)	Peak Intensity (W/cm^2)
1.0	30	$0.3x10^{18}$
0.6	10	$1x10^{18}$
0.25	1	$2x10^{18}$

Wavelength (um)	1.053
Number of beams	4
Spot Size Radius (um^2)	40 x 80

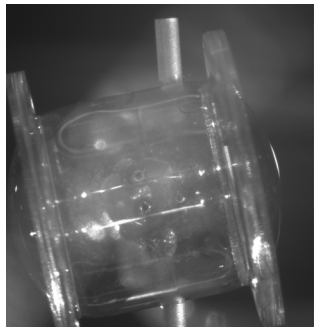


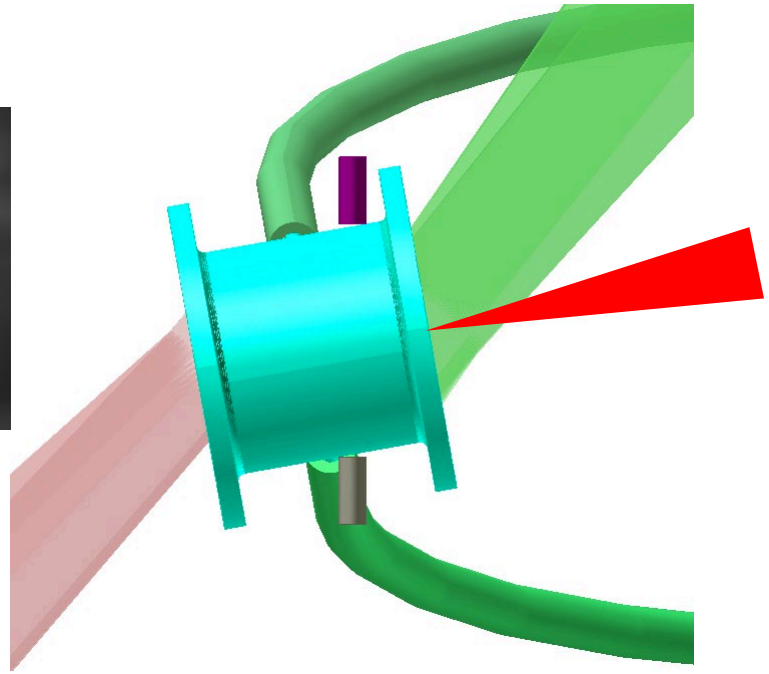


NIF-ARC shot P.I. Felicie Albert

ARC shot into a gas tube filled with He at 10^{19} cm^{-3}

Gas tube
Filled with He
0.75 µm polyamide windows
Oriented along ARC Axis



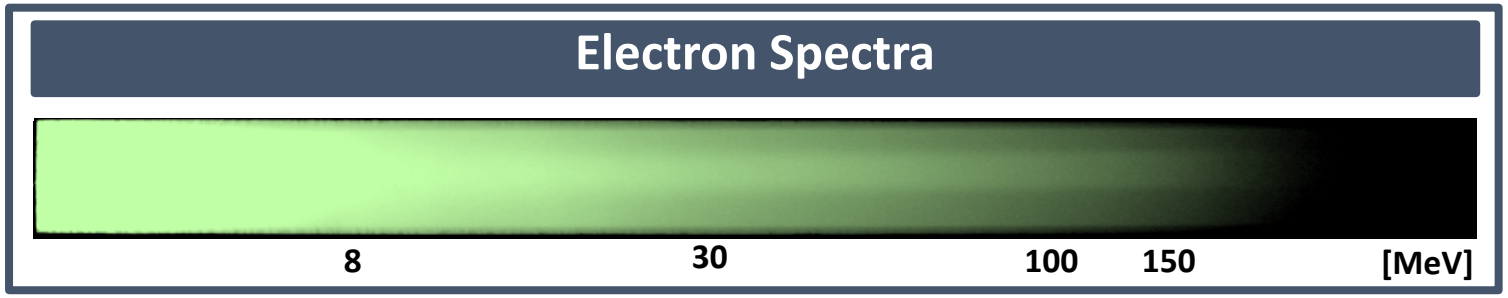


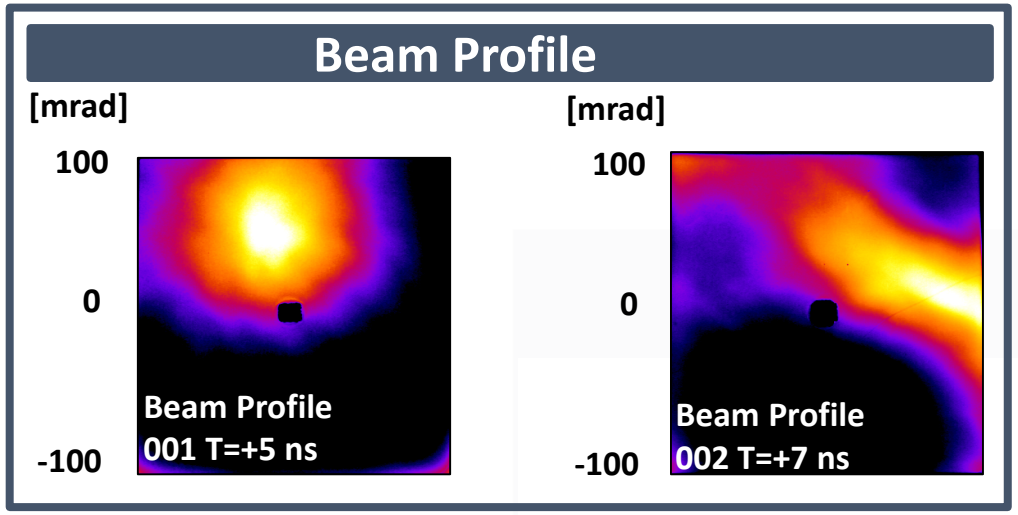
NIF Beams
2 x 88 ps, 56 J, 3ω
Focused 100 µm upstream
of tube entrance

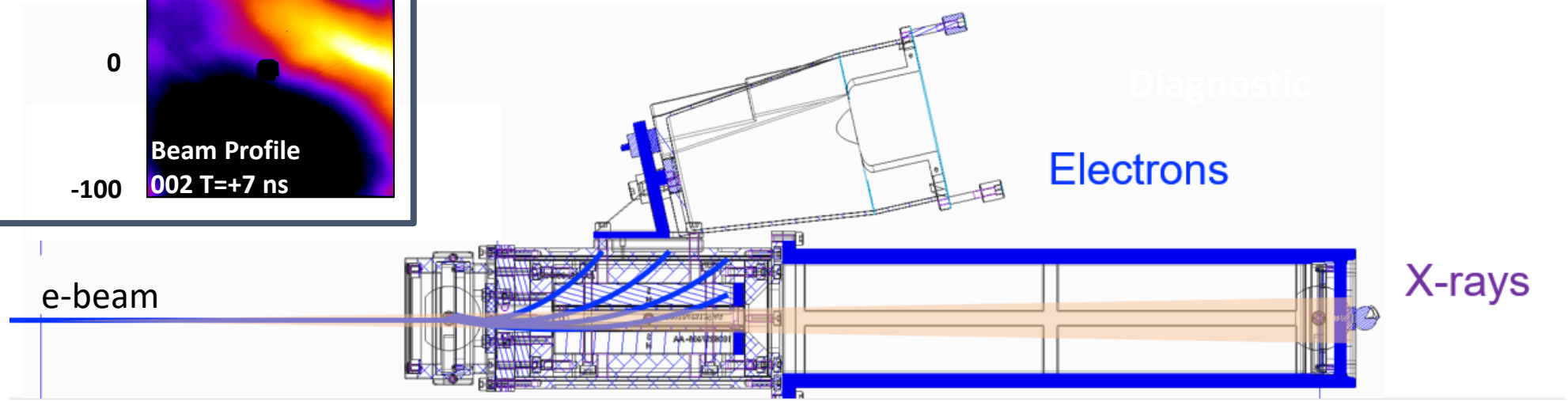
ARC
1 ps, 250 J, 1ω (1053 nm)
Focused at the entrance of the tube

NIF Beams
4 x 88 ps, 56 J, 3ω
Focused 100 µm
downstream of tube exit

We recorded electron beam profiles and spectra with a newly commissioned electron spectrometer







Summary

Development of a SM-LWFA Platform for an X-Ray probing applications:

- HEDS
- Astrophysics
- Security
- NDE material testing

Milestones for platform development

1. Electron production
2. X-Ray generation
3. Radiography

Proved Relativistic Electron

- Titan
- OMEGA-EP
- NIF

Proved X-Rays and Radiography

- Titan

Next steps

- Prove X-rays & Radiographic Capabilities on OMEGA-EP & NIF-ARC