High Resolution Radiography with Self-Modulated and Blowout Regime Laser Wakefield Acceleration generated X-ray sources

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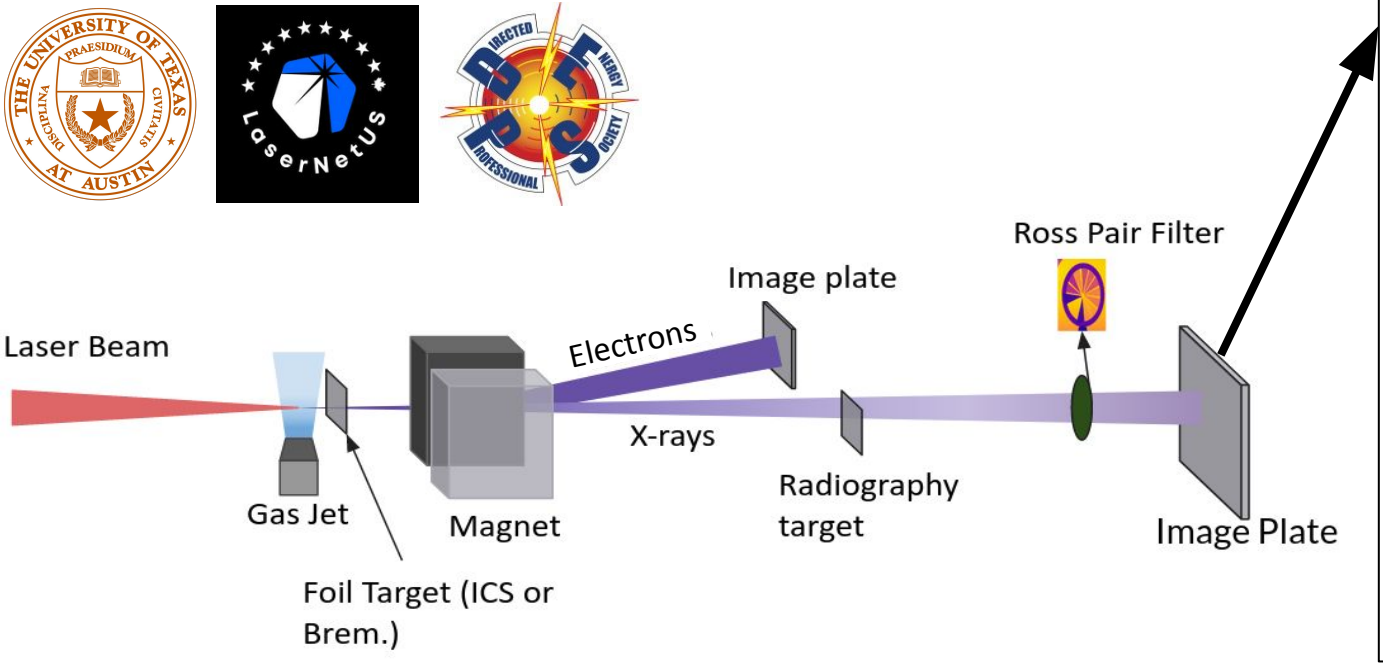
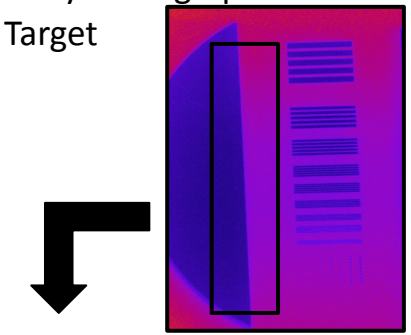
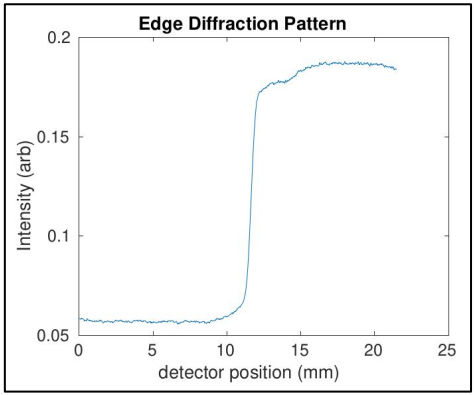
[1] The University of Texas at Austin, [2] LLNL [3]UCLA [4]FAMU



X-ray Radiograph of Resolution Target



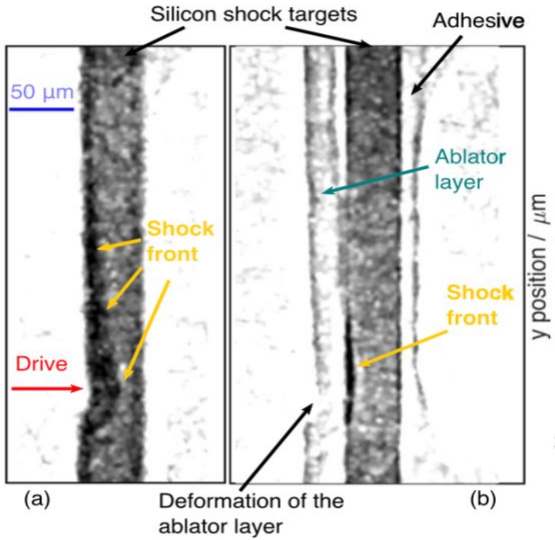


This work was performed under the auspices of the US Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC. Supported by the DOE Early Career Research Program SCW1575-1.

Lawrence Livermore National Laboratory

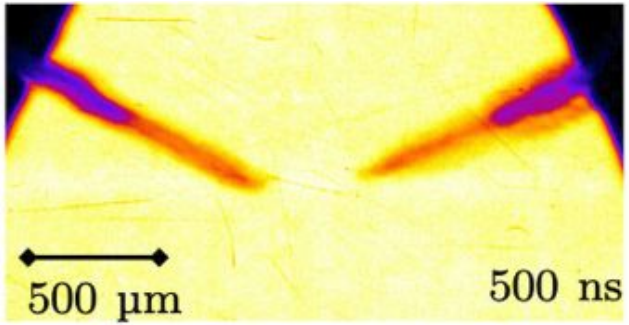
X-rays with a small source size can provide high resolution for various applications

Shockwave



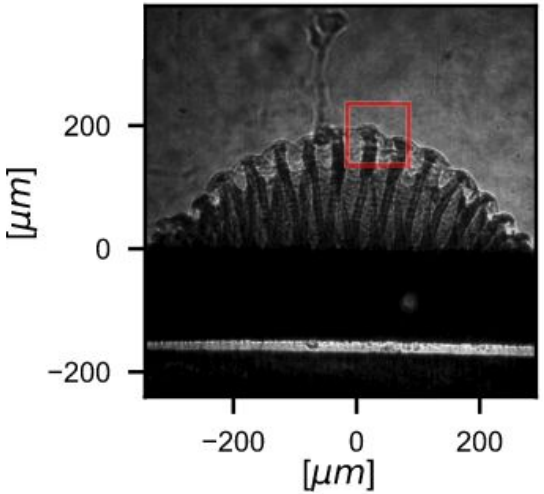
(Wood Nat. 2018)

Microjetting



(Saunders PRL 2021)

Rayleigh Taylor Instability

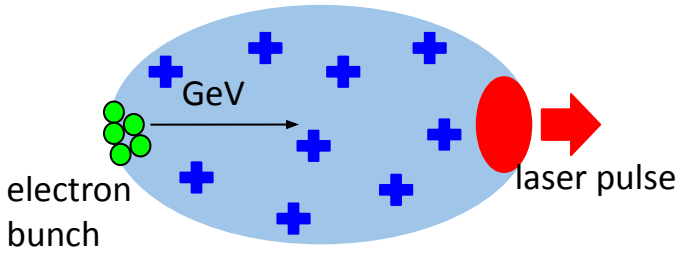


(Rigon Nat. Comm. 2021)

Laser Wakefield Acceleration (LWFA) generated X-rays can create a diagnostic capable of high spatio-temporal resolution

Electrons & X-rays generated by Self Modulated and Blowout Regime LWFA have distinct attributes

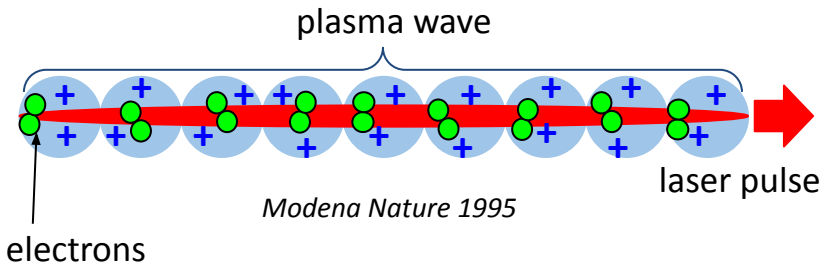
Blowout Regime



Lu PR STAB 2007

- $c\tau < \lambda_p$
- monoenergetic e- bunches
- GV/m e- acceleration
- smaller source size

Self Modulated Regime



Modena Nature 1995

- $c\tau >> \lambda_p$
- broad e- energy distribution
- high flux + charge
- larger source size

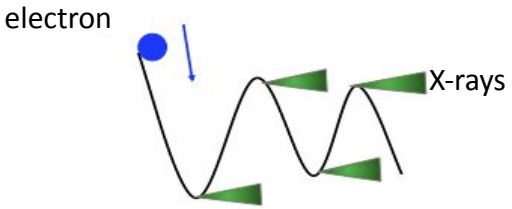
How are X-rays generated from SM/LWFA?

Type of Radiation

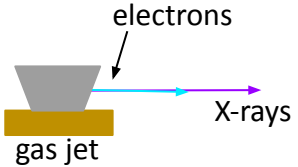
Betatron

$\sim 5 \times 10^{-21} \gamma^2 n_e r_0$

Diagram of Process



Experimental Set-up



How are X-rays generated from SM/LWFA?

Type of Radiation

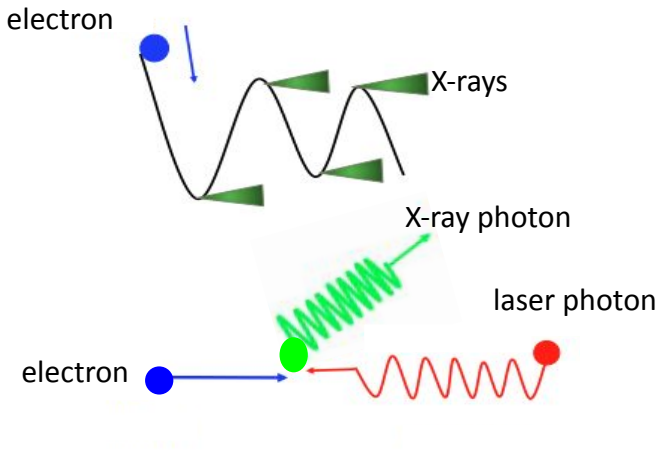
Betatron

$$\sim 5 \times 10^{-21} \gamma^2 n_e r_0$$

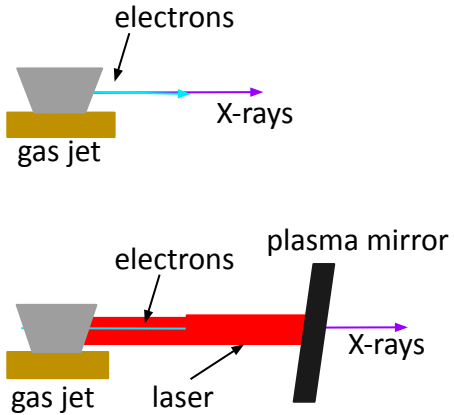
Inverse Compton Scattering

$$\sim 4\gamma^2 E_l$$

Diagram of Process



Experimental Set-up



How are X-rays generated from SM/LWFA?

Type of Radiation

Betatron

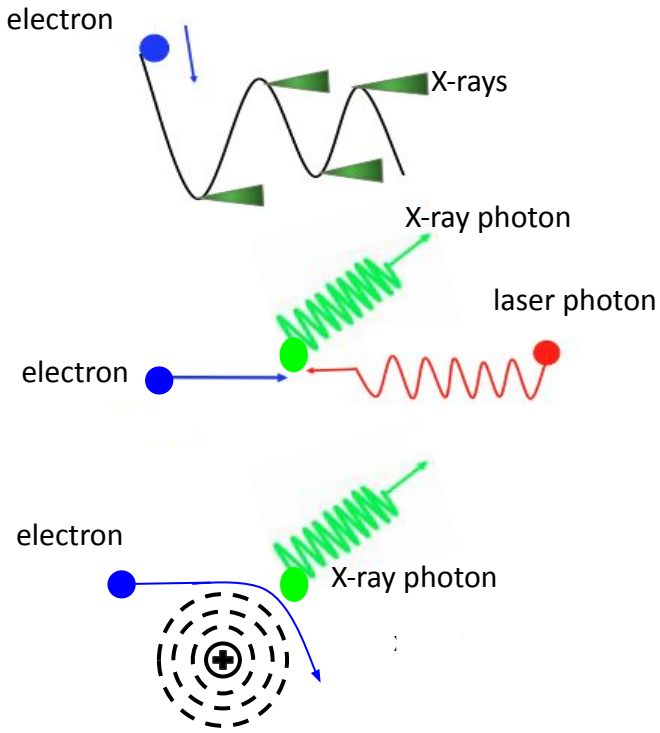
$\sim 5 \times 10^{-21} \gamma^2 n_e r_0$

Inverse Compton Scattering

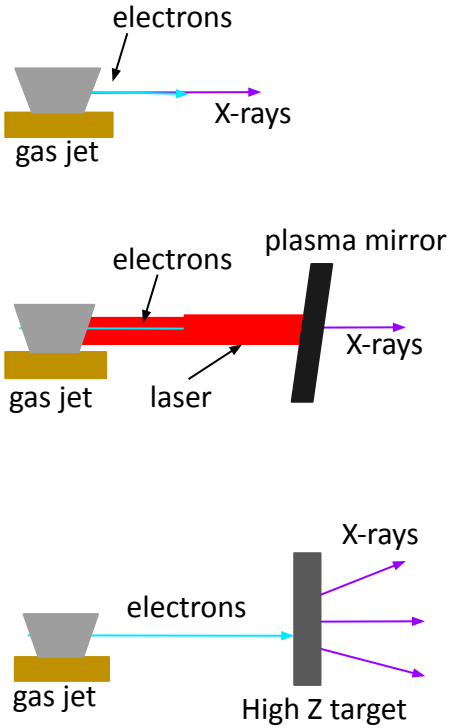
$\sim 4\gamma^2 E_l$

Bremsstrahlung

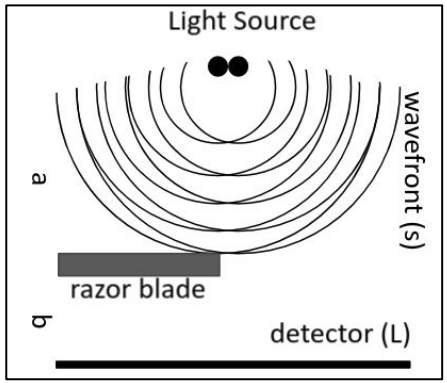
Diagram of Process



Experimental Set-up

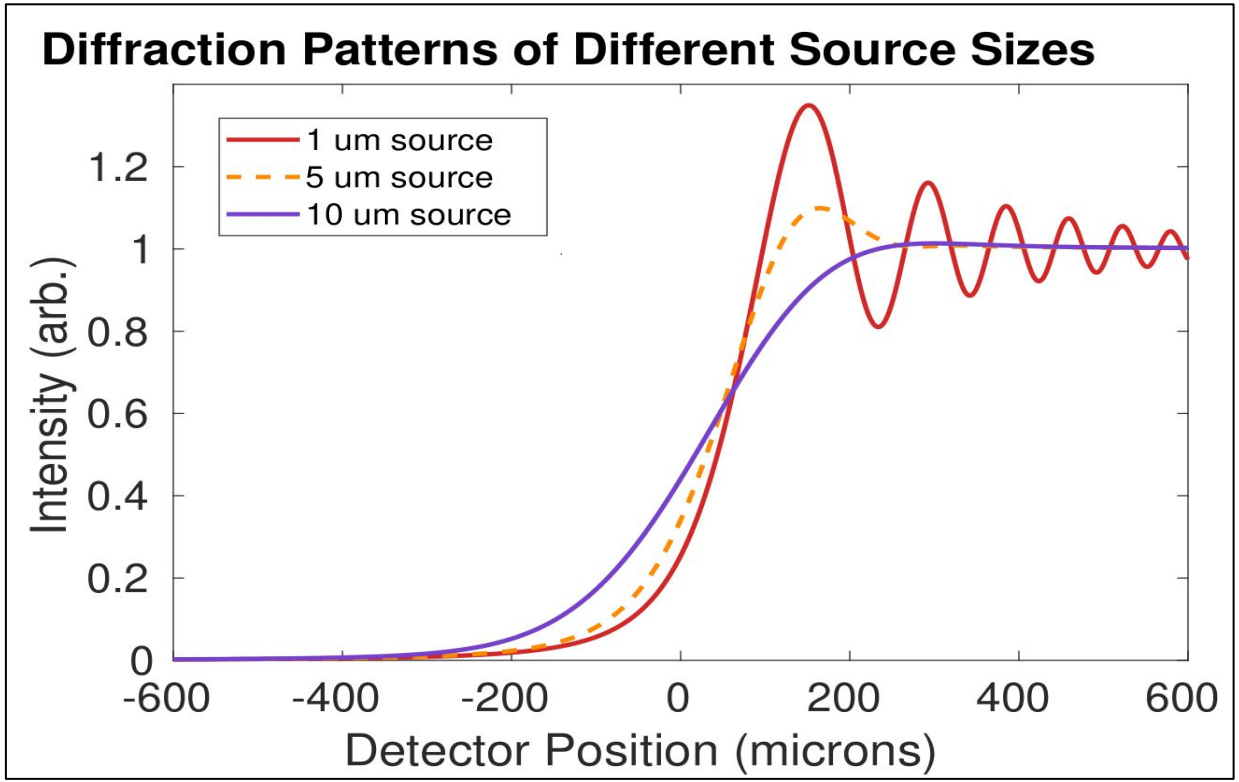


We use Fresnel Diffraction to determine the size of an x-ray source

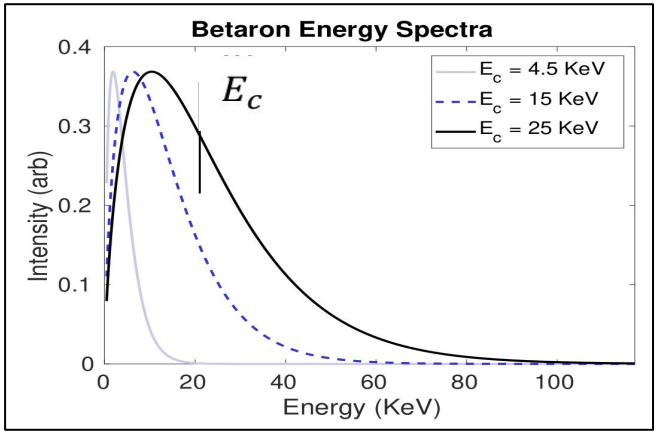


$$w = \sqrt{\frac{2(a+b)}{ab\lambda}} \qquad s = \frac{La}{a+b}$$

$$I = \tfrac{1}{2}\left[\left[\tfrac{1}{2} + C(w)\right]^2 + \left[\tfrac{1}{2} + S(w)\right]^2\right] I(0)$$

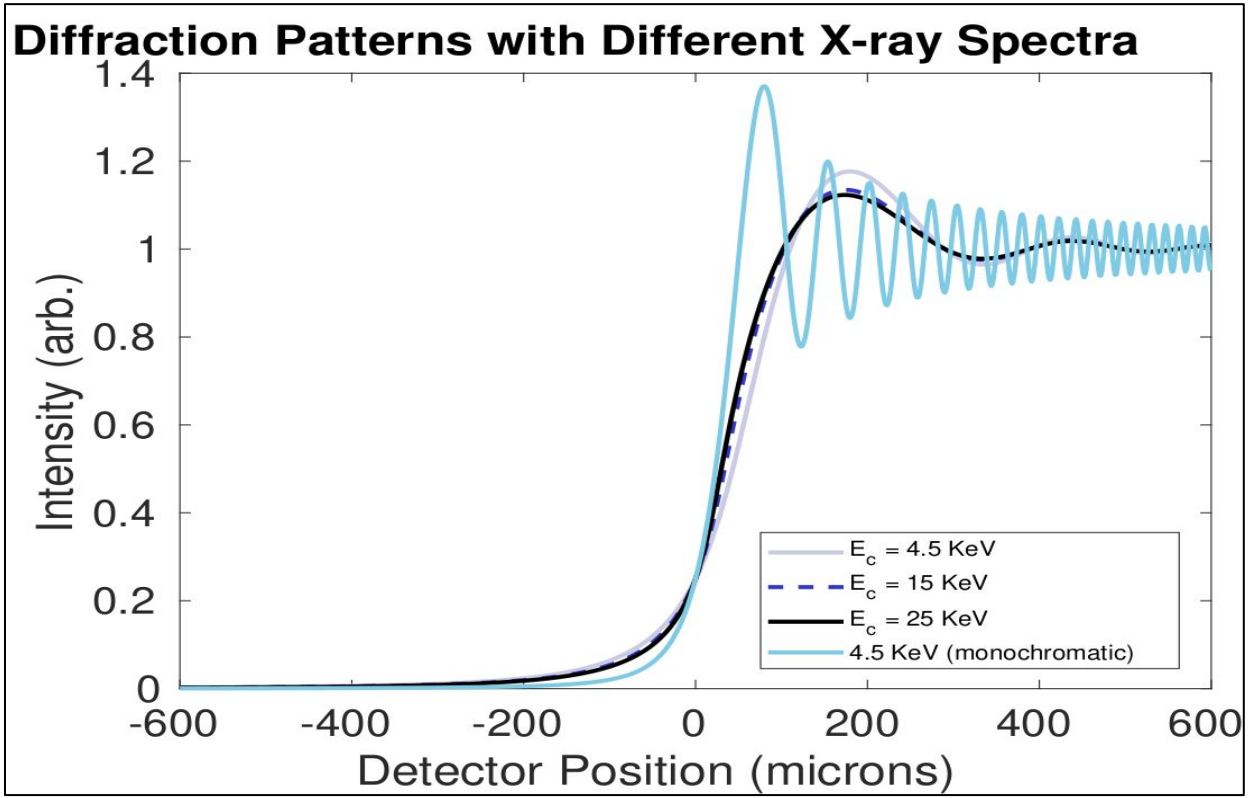


The Fresnel Diffraction pattern is dependent on the spectral distribution



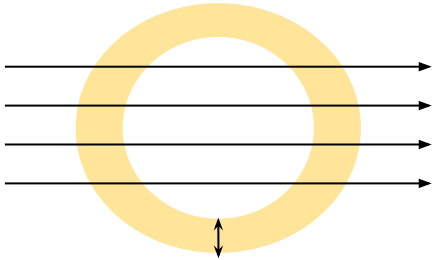
$$\frac{dI}{dE} \propto \left(\frac{E}{E_c}\right)^2 K_{2/3}^2 \left(\frac{E}{E_c}\right)$$

$$E_c \sim 5 \times 10^{-21} \gamma^2 n_e r_0$$



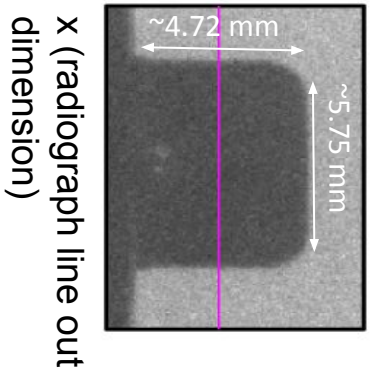
Using a modified X-ray ray tracing code we can detect the source size from a radiograph of a curved object

X-ray Ray tracing Model



top view

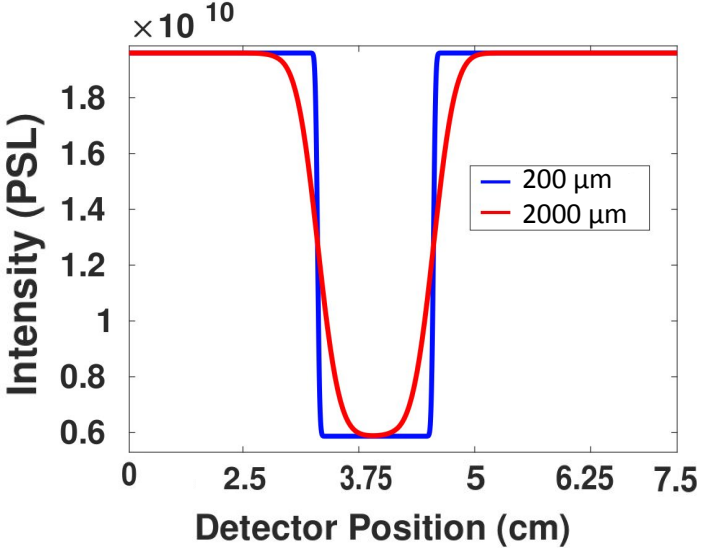
side view of hohlraum



$$dl(x) = 2\sqrt{R^2 - x^2}$$

$$\Delta(x) = I(0) \int \Lambda(E) e^{-\mu(E)\rho dl(x)} p(E) F(E) dE$$

X-ray Radiography Line out comparison from different source sizes



R. Tommasini et al. POP **24,** 053104 (2017)

X-ray source size is investigated at Titan, Jupiter Laser Facility (JLF)

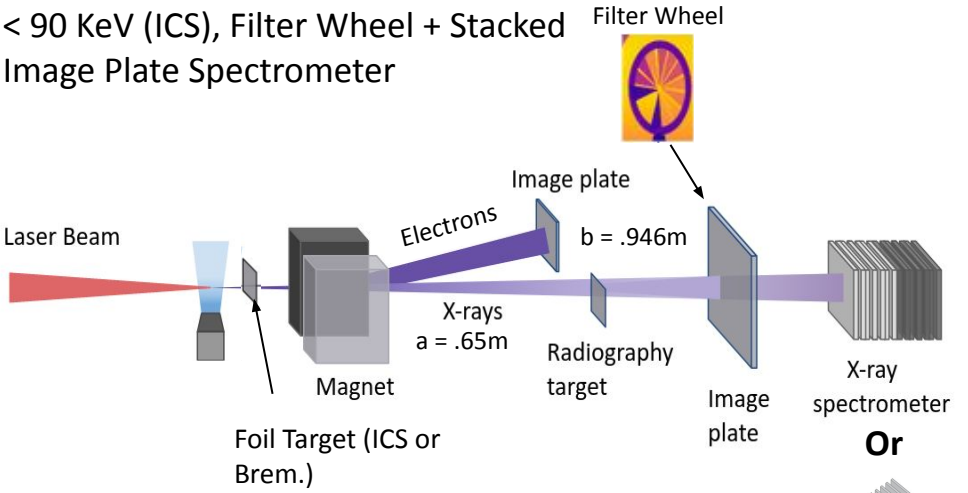
Titan, Jupiter Laser Facility (JLF)
Self-Modulated LWFA

Pulse width: 700±300,100 fs
Spot size (focal spot FWHM): 29µm
Energy: up to ~120J

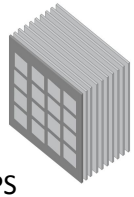
Spectral characterization of Titan, JLF SM-LWFA X-ray Source

Methodology

< 90 KeV (ICS), Filter Wheel + Stacked Image Plate Spectrometer



Or

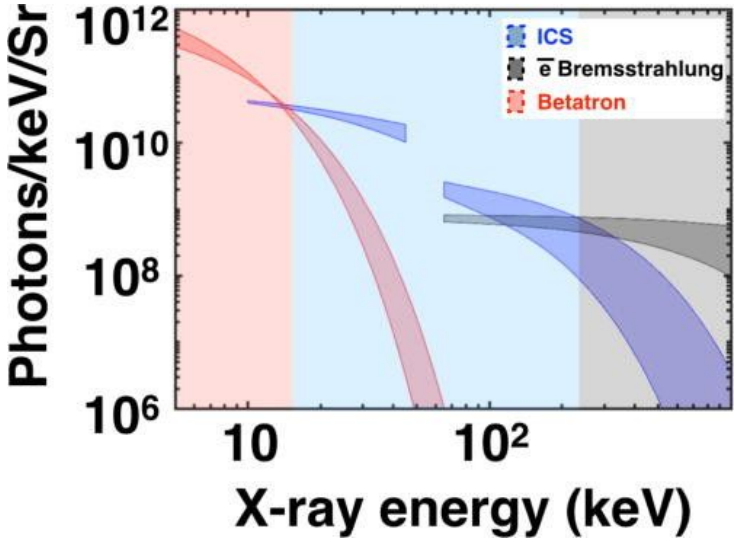


HEDFPS

> 90 KeV, High Energy Differential Filtering Photon Spectrometer (HEDFPS)

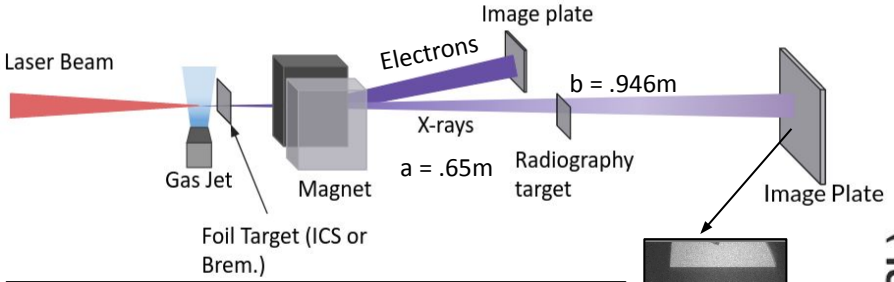
Lemos, PRL, in preparation.
King, Rev. Sci. Instrum. 90, 033503 (2019)

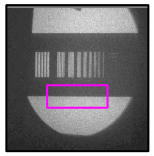
Plot of Betatron, ICS and Bremsstrahlung Spectra



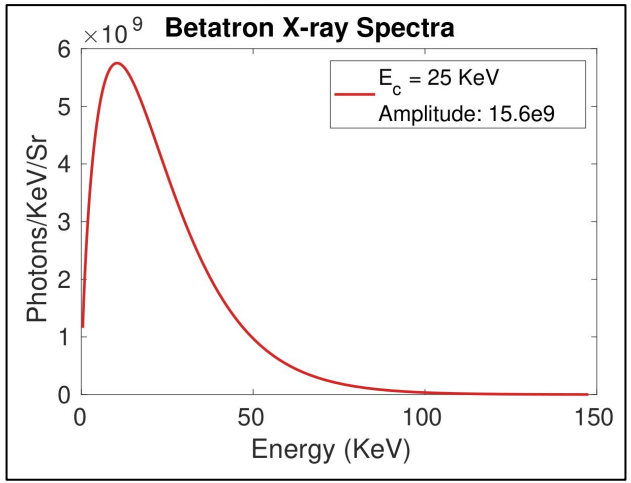
Lemos, POP, **26**, 083110 (2019).

Betatron X-rays with a source size of ~25 µm from SM-LWFA at Jupiter Laser Facility

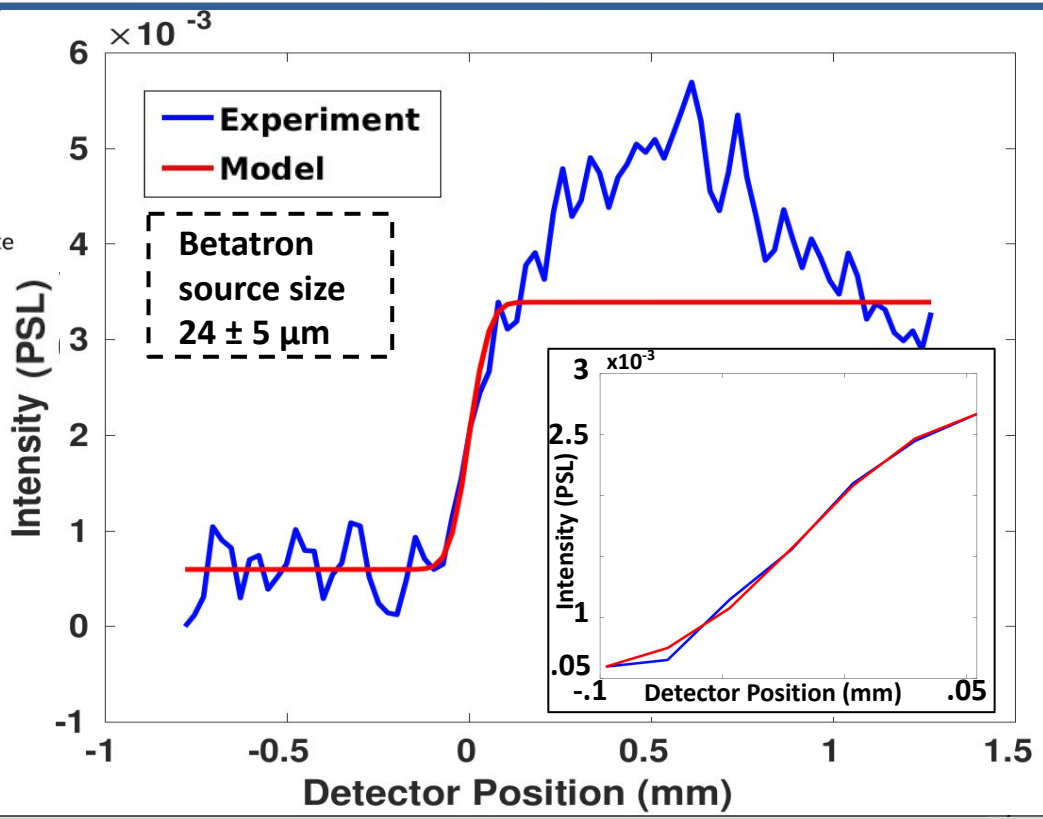




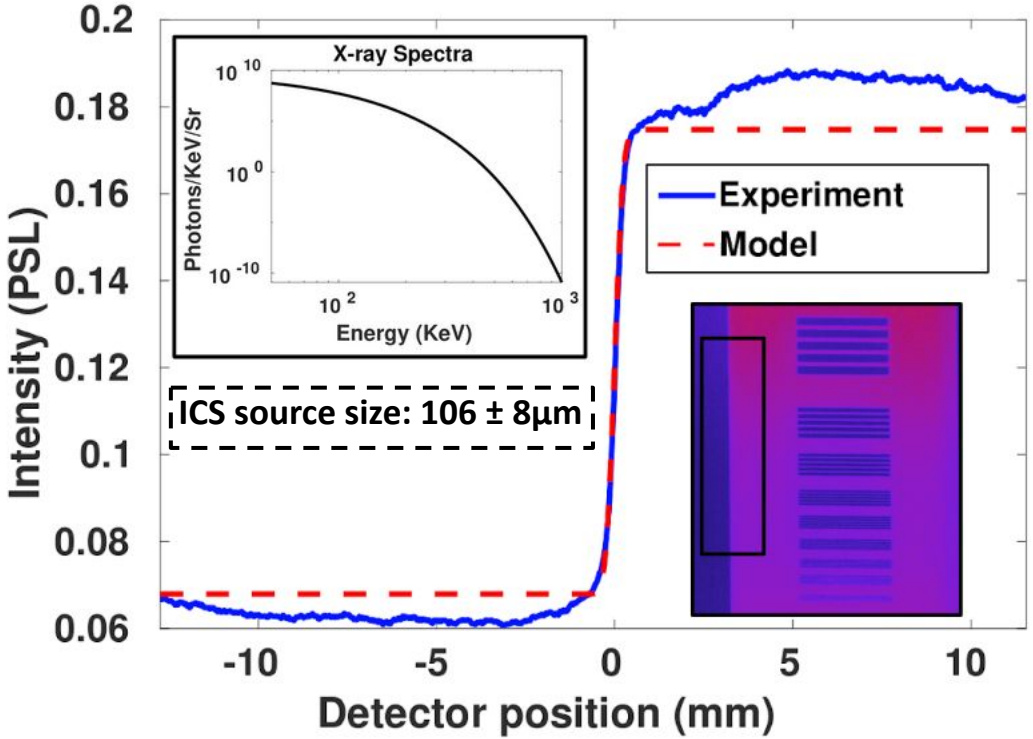
500 µm thick W RT

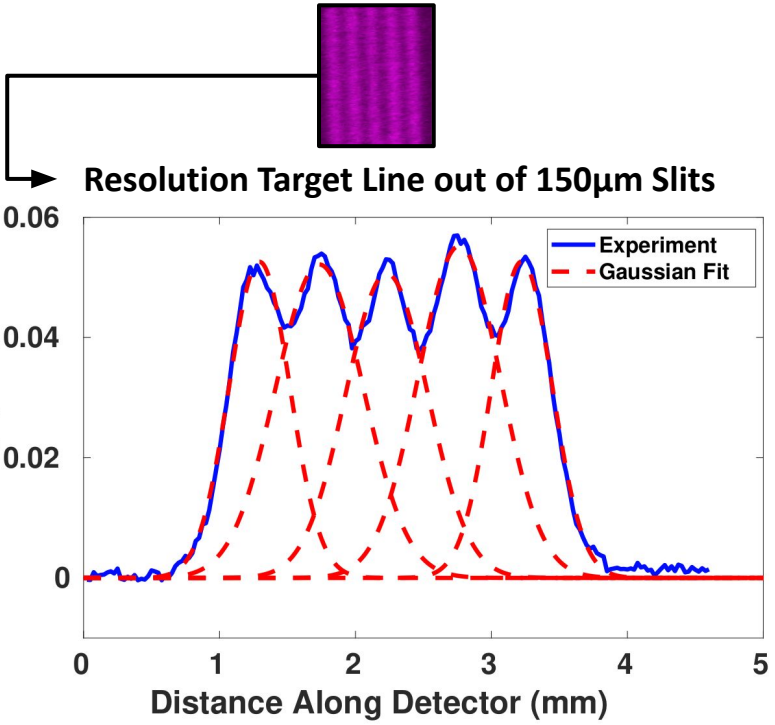


King RSI 2019



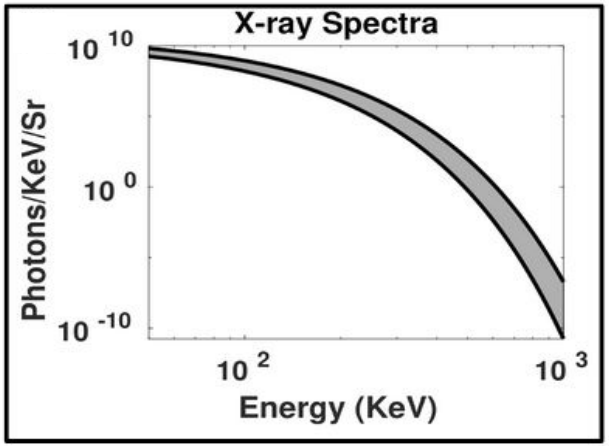
Inverse Compton Scattering X-rays with a source size of ~100 µm from SM-LWFA at Jupiter Laser Facility

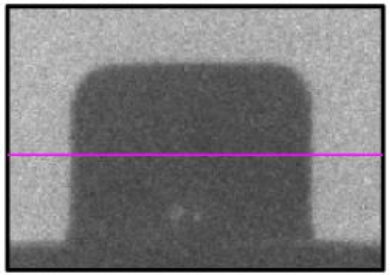


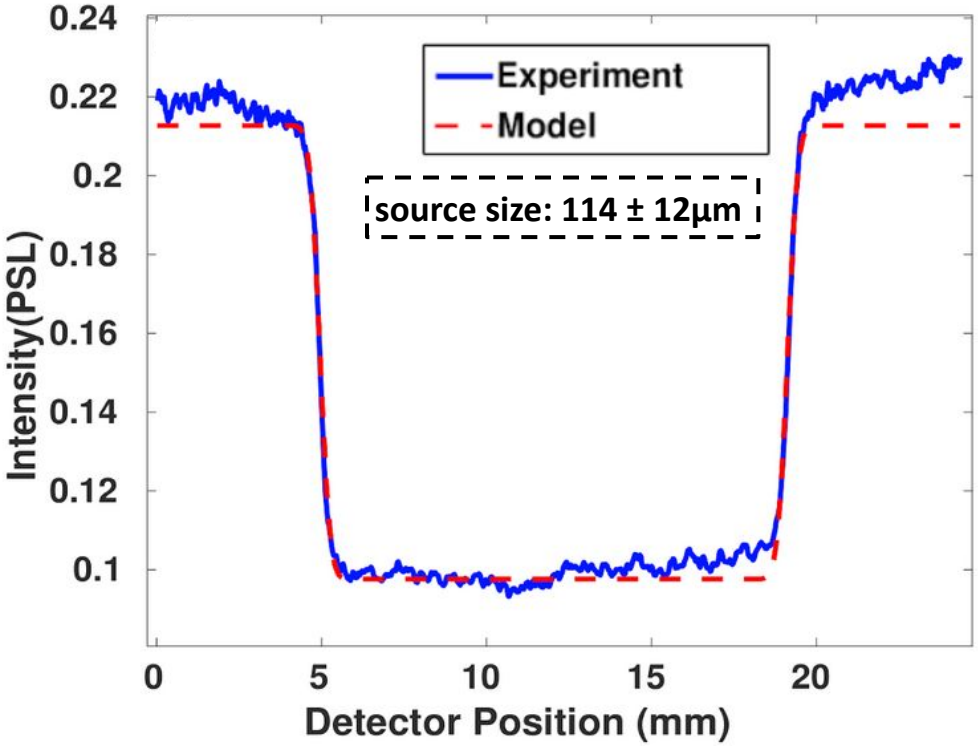


I.Pagano, Source Size Analysis of Self Modulated Laser Wakefield Acceleration generated X-rays, POP, In Preparation.

Hohlraum target radiograph of ICS X-rays confirms a source size of ~100 µm from SM-LWFA at Jupiter Laser Facility



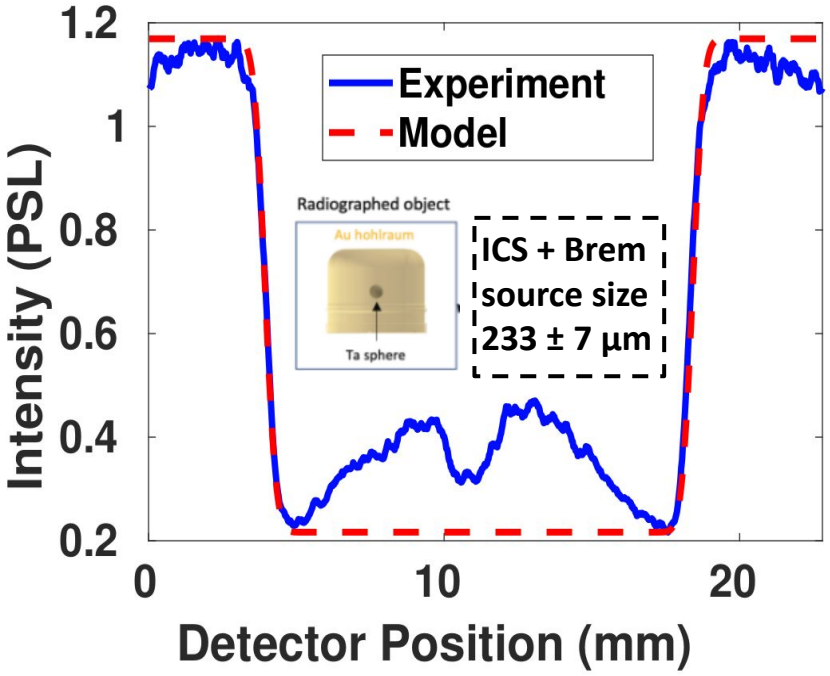




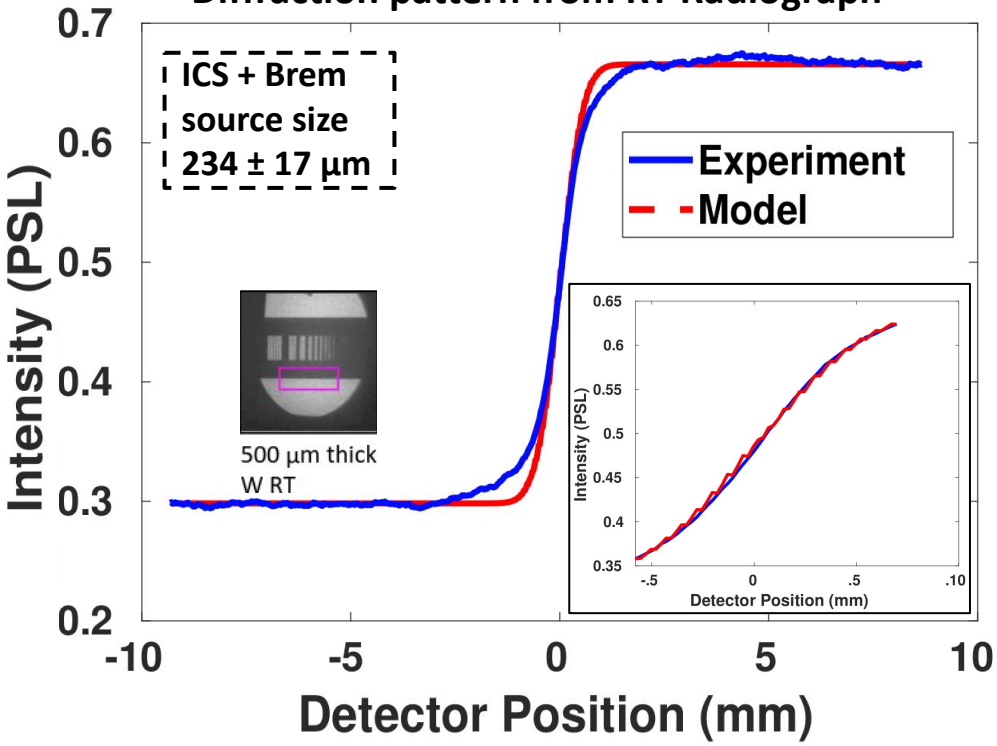
I.Pagano, Source Size Analysis of Self Modulated Laser Wakefield Acceleration generated X-rays, POP, In Preparation.

ICS + Brem. X-rays with a source size of ~200 µm from SM-LWFA at Jupiter Laser Facility

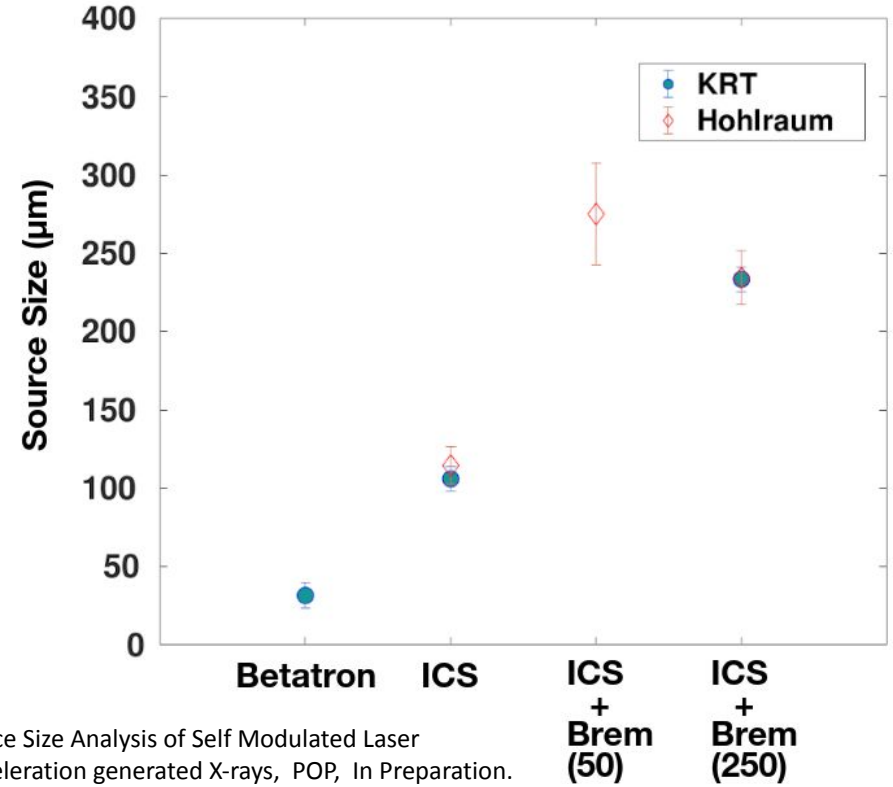
Lineout analysis from Hohlraum Radiograph



Diffraction pattern from RT Radiograph



How does the X-ray radiation generation mechanism impact source size?



I.Pagano, Source Size Analysis of Self Modulated Laser Wakefield Acceleration generated X-rays, POP, In Preparation.

Factors Impacting Resolution

- Laser spot size
- LWFA Regime & electron energy spectra
- X-ray generation mechanism

Conclusions & Future work

- Distinguishing between the differences in source size from various parameters enables further development of LWFA X-ray sources for specific purposes.

- Analytical tools developed for analysis of SM-LWFA at JLF, can be applied to the blowout regime at TPW, for further characterization and comparison.

- We will perform HEDS applications experiments to demonstrate radiography of dynamic processes.

This work was performed under the auspices of the Lawrence Livermore National Security, LLC, (LLNS) under Contract No. DE-AC52-07NA27344.
Supported by the DOE Early Career Research Program SCW1575-1, and LLNL-WCI ACT-UP subcontract B650922.

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