Betatron radiation from a hybrid self-modulated wakefield and direct laser accelerator

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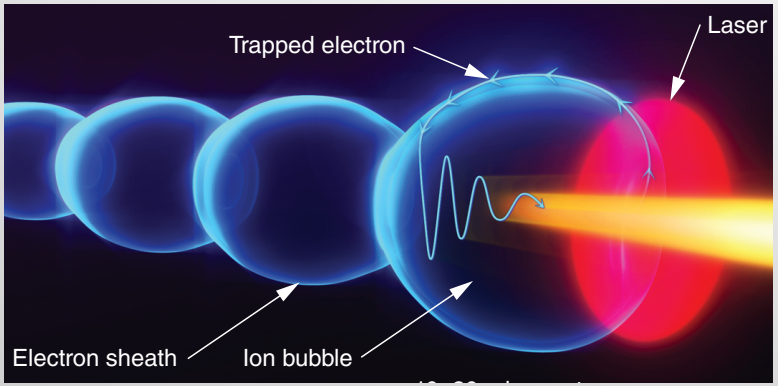
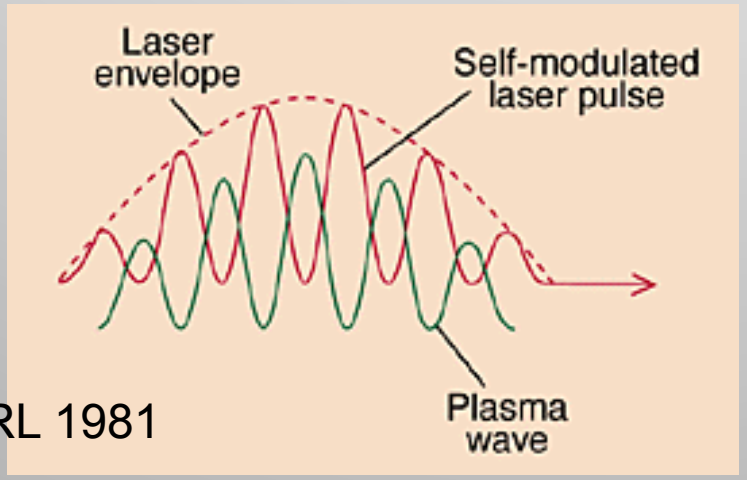
Work supported by

DOE- OFES SCW1476

LLNL LDRD program 13-LW-076

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

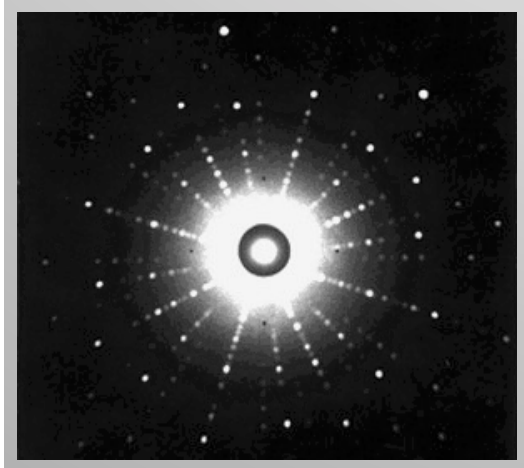
We are developing betatron radiation platform based on the self-modulated LWFA regime

Regime of laser-plasma acceleration	Laser/plasma parameters	Facilities
Blowout 	1-12 J 25-60 fs $n_e=10^{19}$ cm^{-3} $T_{laser} \sim T_{plasma}$	Callisto (LLNL) LCLS-MEC (SLAC)
Self modulated Or Direct laser Acceleration  C. Joshi PRL 1981	50-1000 J 1 ps $n_e=10^{19}$ cm^{-3} $T_{laser} >> T_{plasma}$	Titan (LLNL) NIF-ARC (LLNL) OMEGA EP (LLE) LMJ-PETAL (CEA) Vulcan (RAL)* **S. Kneip et al, PRL (2008)*

Developing directional, hard X-ray sources on large HED drivers will enable new capabilities

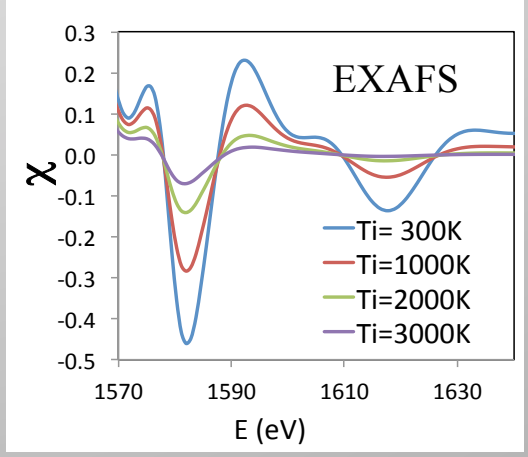
NIF - ARC	JLF - Titan	LMJ - PETAL	OMEGA-EP
• 400 J • 2 ps • 2 beamlets	• 150 J • 1 ps	• 2 kJ • 500 fs	• 400 J • 1 ps • 2 beams

Laue diffraction



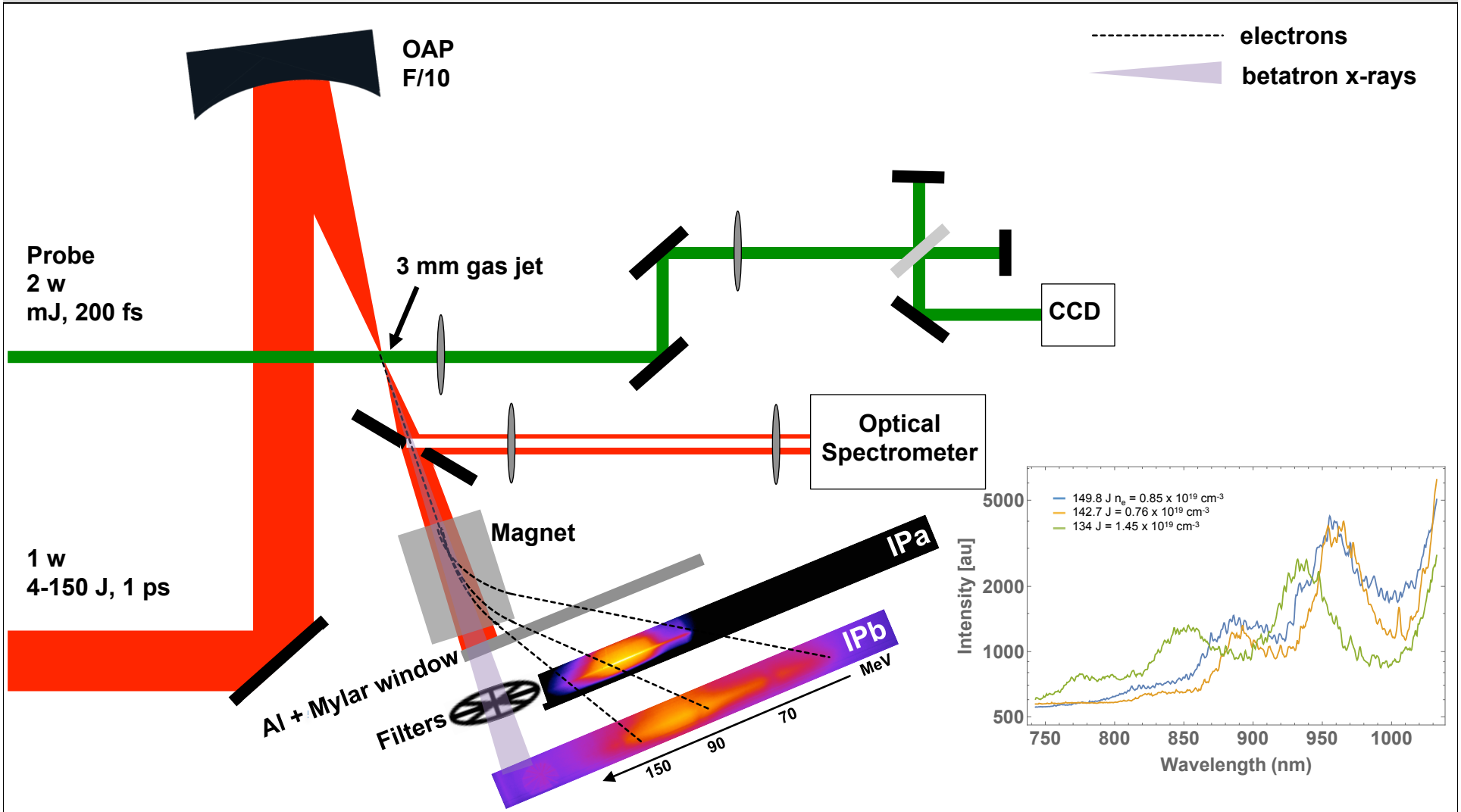
X-ray phase contrast imaging of laser-driven shocks

High energy x-ray absorption

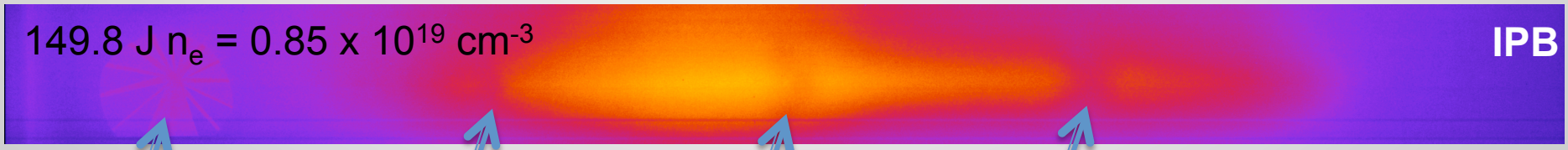


Installation of a new F/10 optics in Titan for LWFA experiments.

Recent demonstration of betatron radiation at Using ps-class laser - Titan



Electrons up to >200 MeV with self modulation



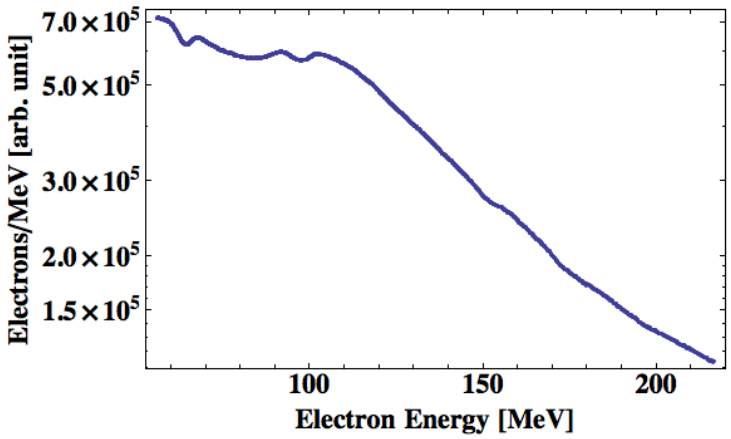
X-rays

Fiducial #1
154 MeV, - 8 mrad

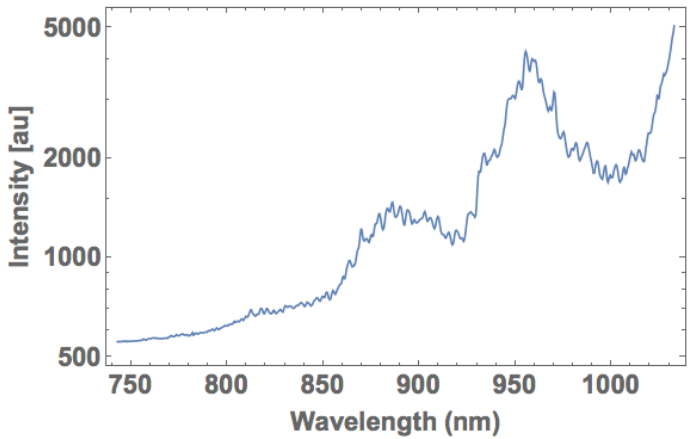
Fiducial #2
90 MeV, - 5 mrad

Fiducial #3
68.7, - 0.9 mrad

Electron spectrum



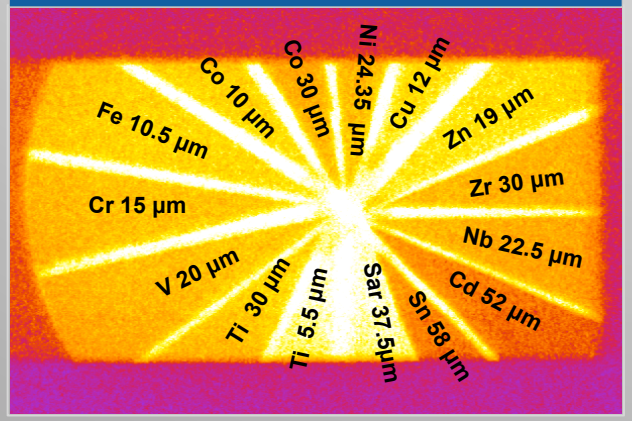
Transmitted laser spectrum



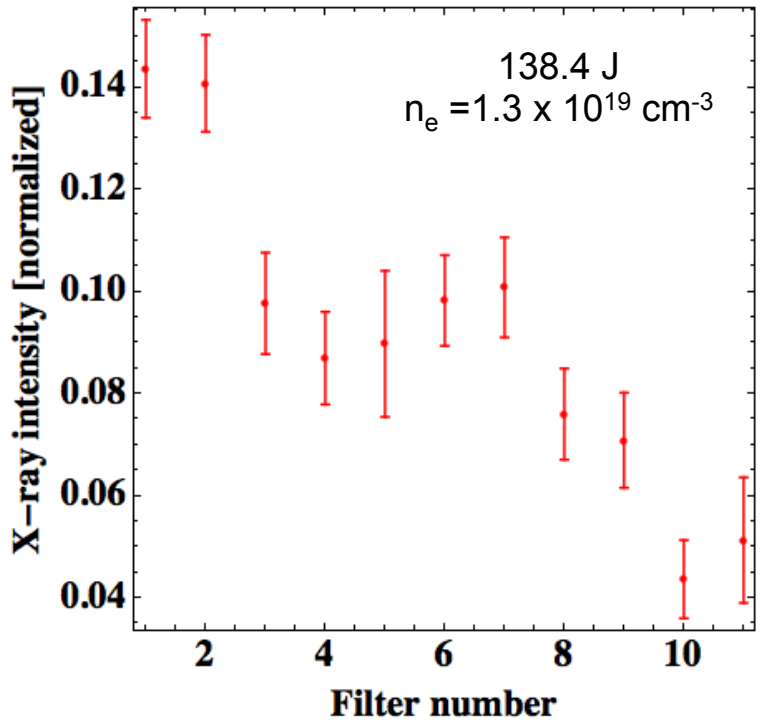
X-ray yield measured through thin filter wheel

Filter wheel

X-rays through filters on IP

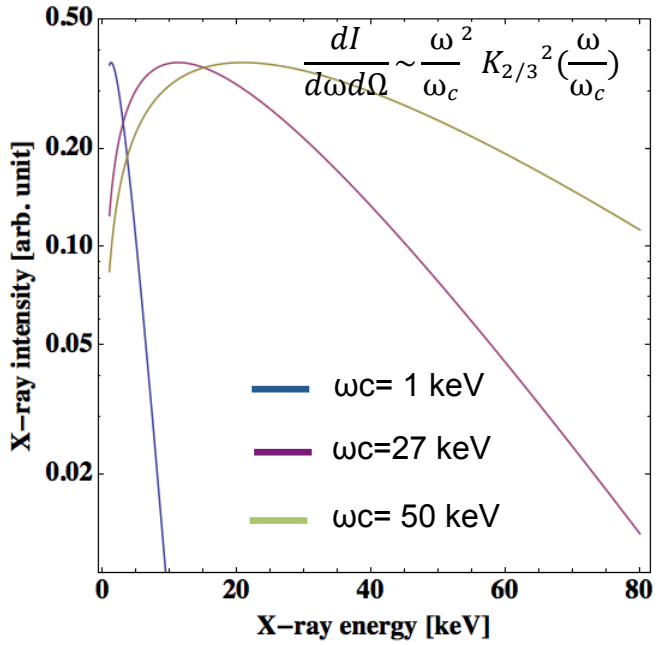


X-ray intensity on IP (normalized)



X-ray signal through filters fitted with theoretical synchrotron spectra gives a reasonable fit with ω_c= 27keV

Theoretical spectra



X

Transmission through window

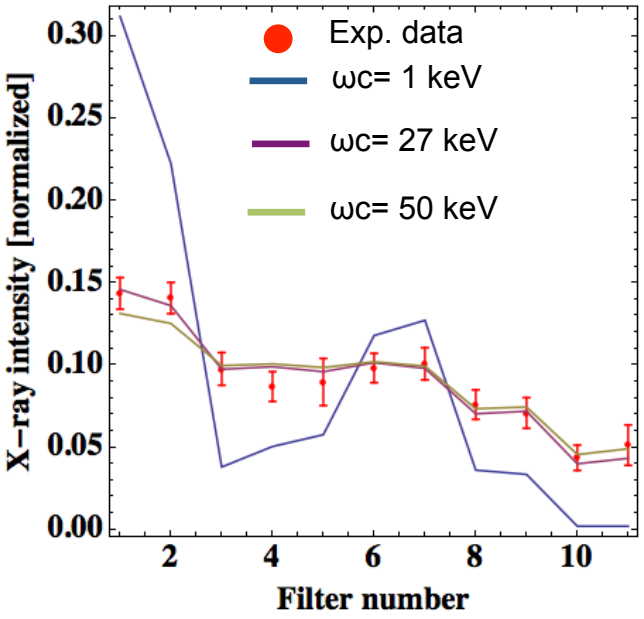
X

X

Image plate QE

=

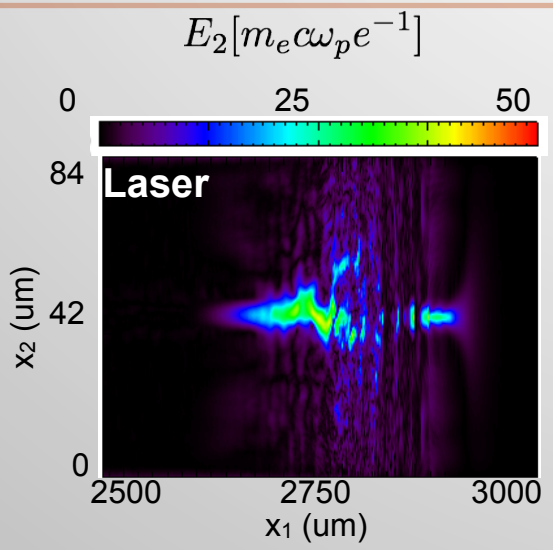
Signal in each filer

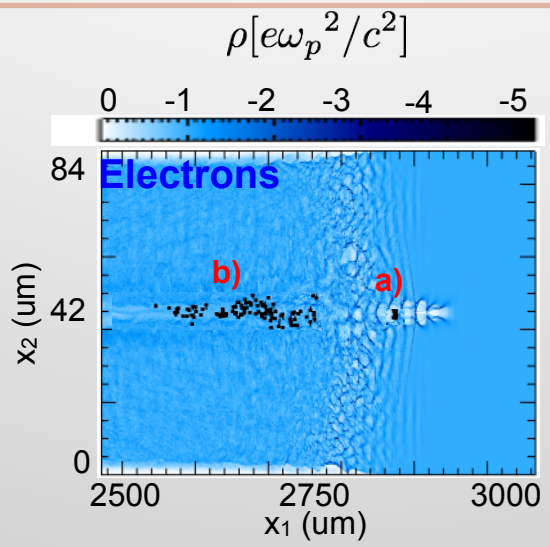


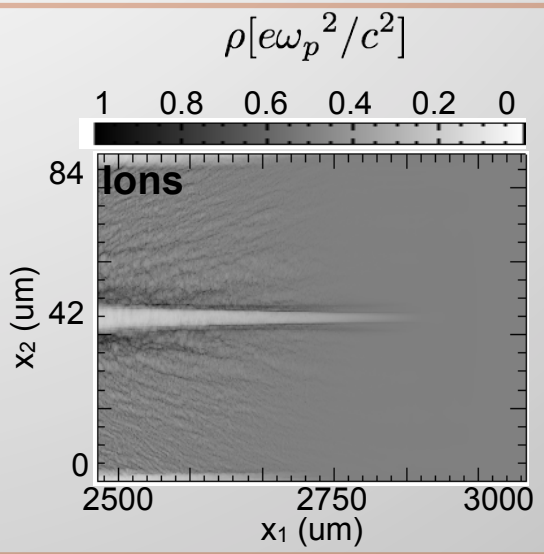
Best fit for ω_c = 27 keV +/- 5 keV (least squares fit)

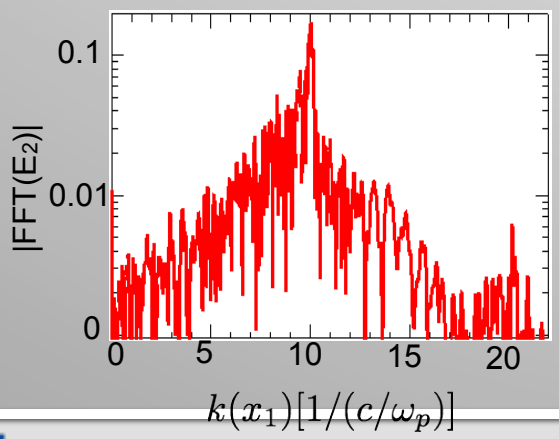
2D Simulations

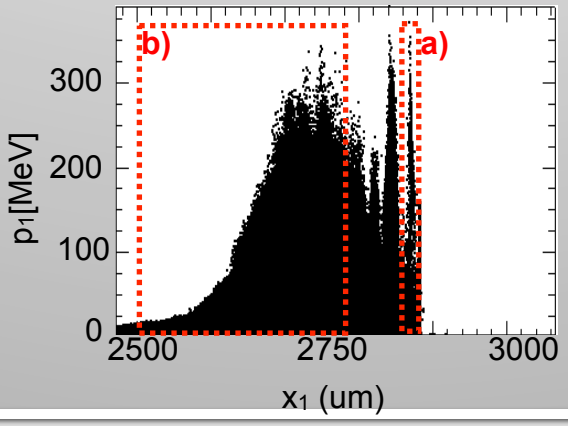
Electron acceleration

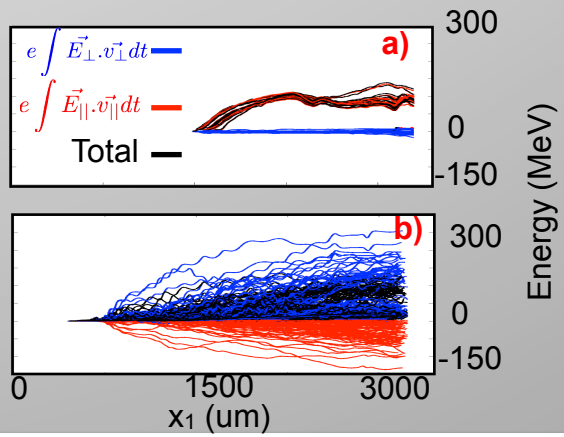




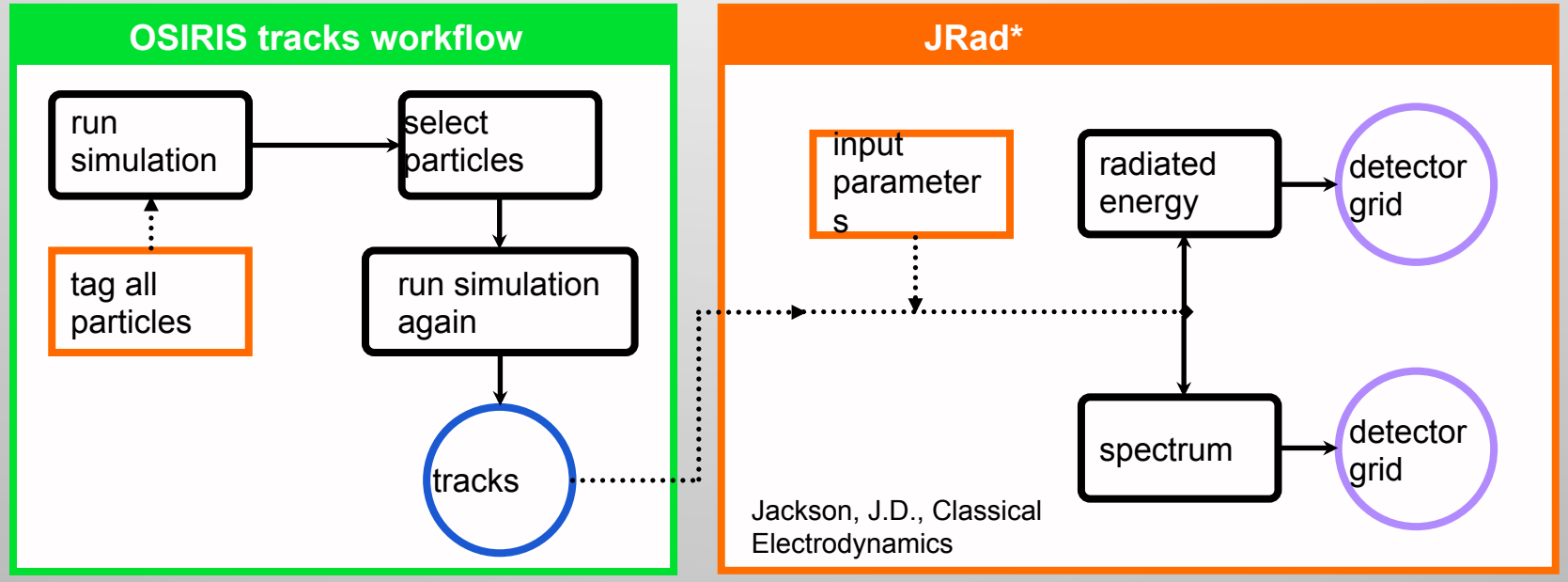








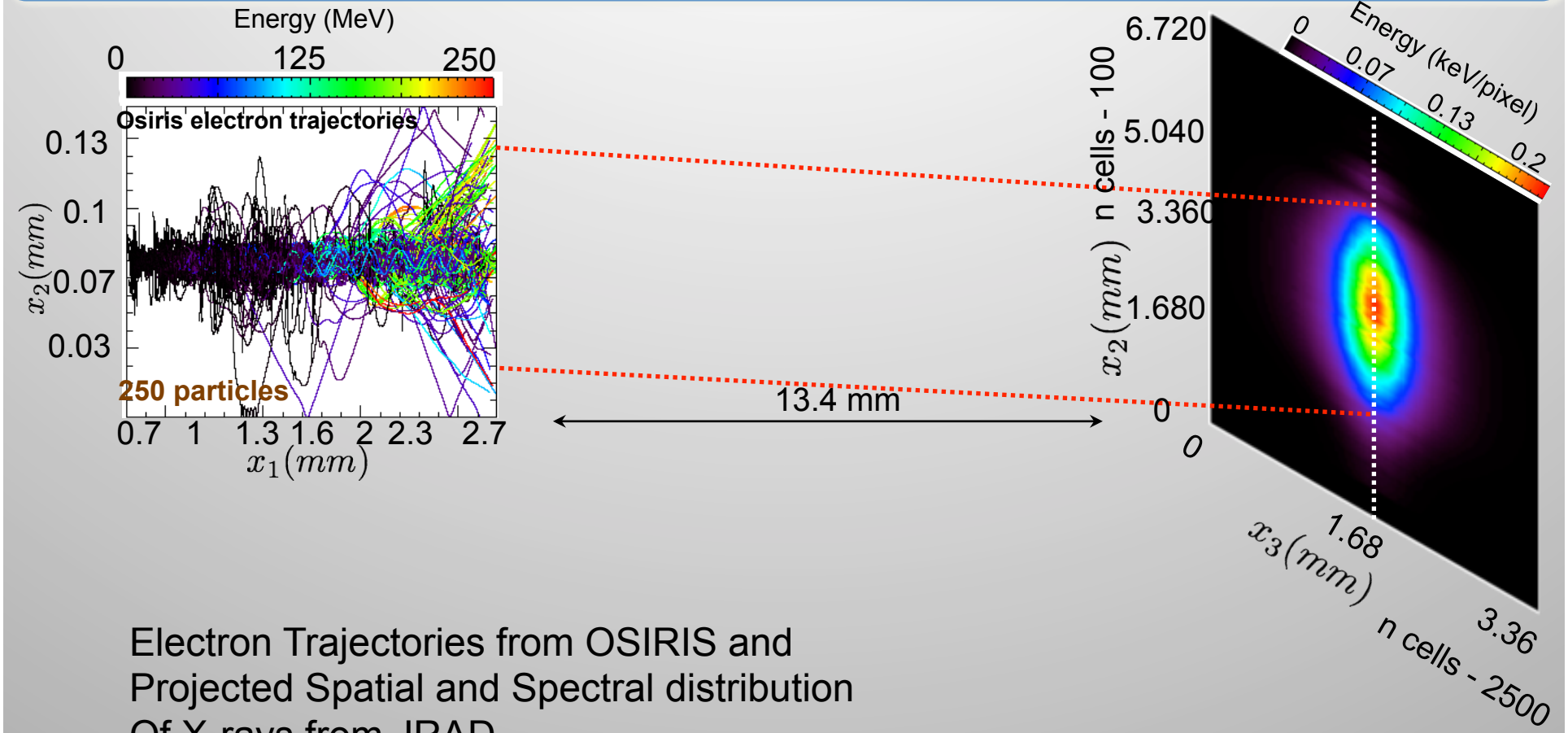
Capturing the radiation: post-processing modeling



*Courtesy of Joana Martins

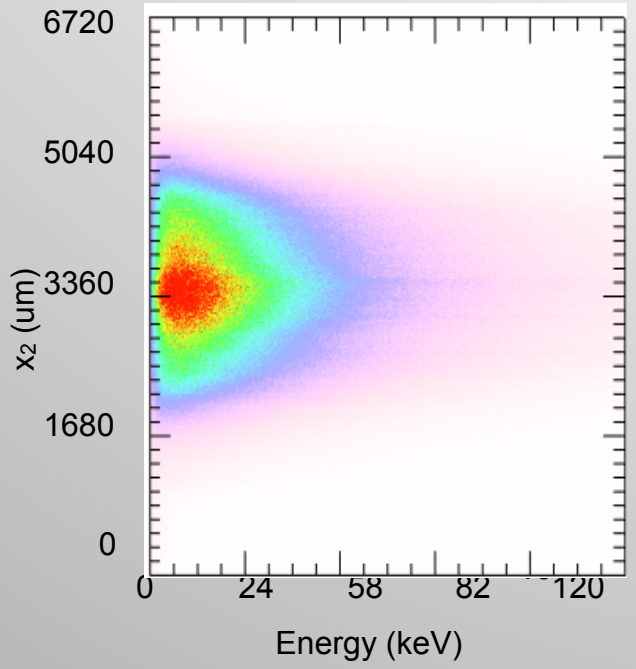
2D Simulations

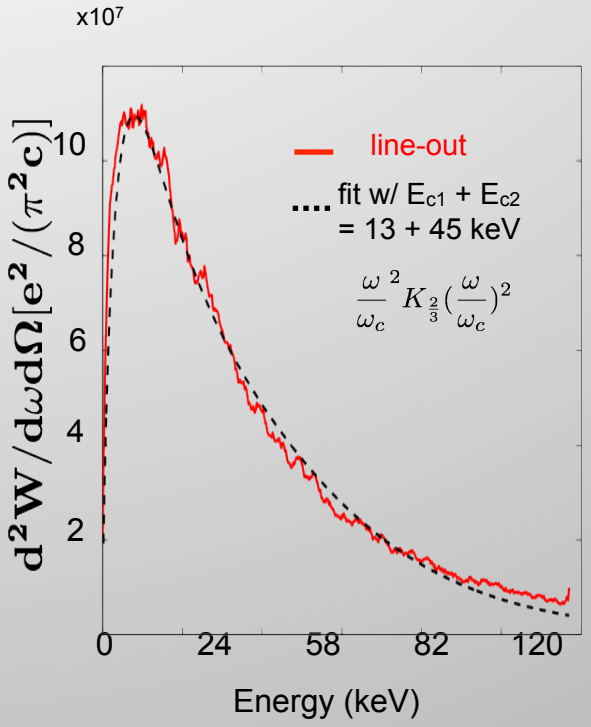
Radiation spectrum



Electron Trajectories from OSIRIS and
Projected Spatial and Spectral distribution
Of X-rays from JRAD

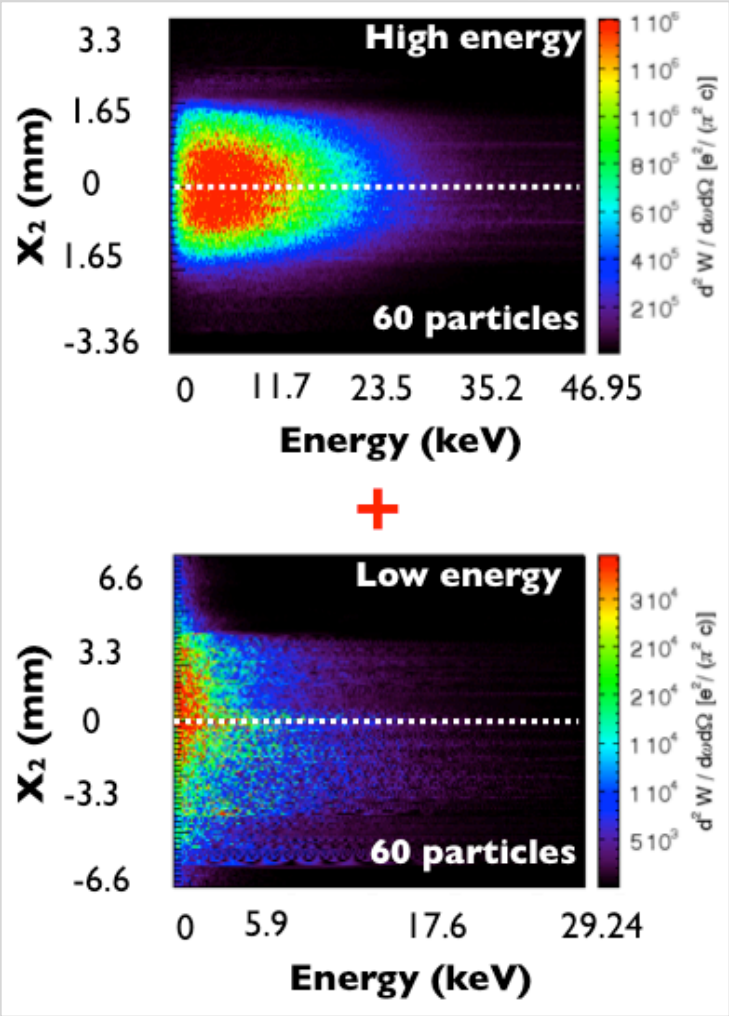
Radiation spectrum



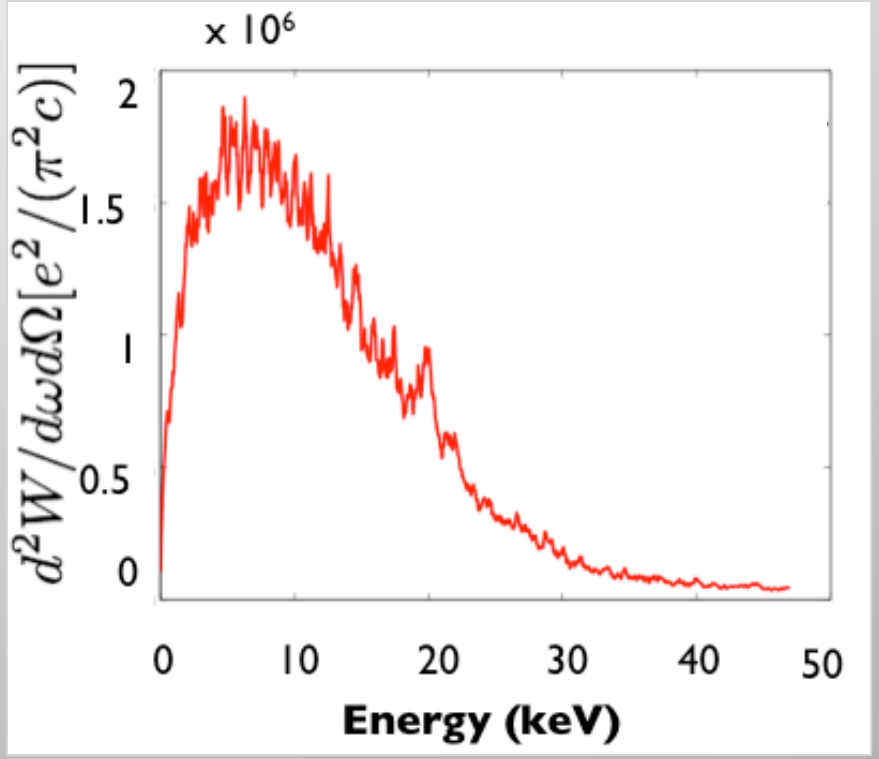


Spectrum fitted with synchrotron spectrum with critical photon energies of 13 and 45 KV respectively, emitted by two groups of electrons with similar energies but very different initial radii.

Total spectrum of tracked particles consistent with experimental observation of ~ 20 keV critical energy



X-ray spectrum



Conclusion

- **We have characterized betatron x-ray radiation in the self-modulated regime of laser-wakefield acceleration**
- **In SMLWFA electrons with energies > 200 MeV and betatron x-rays with ~ 27 keV critical energies are measured**
- **2-D PIC PIC simulations with mobile ions, show a similar electron spectrum with contribution from both SMLWFA and DLA***
- **The X-ray spectrum calculated using JRAD code can be fitted with a synchrotron spectrum with critical photon energies of 13 and 45 KV respectively, emitted by two groups of electrons with similar energies but very different initial radii.**
- **Promising applications on large-scale HED science facilities**

** Nuno Lemos et al, LPAW proceedings (to be published)*

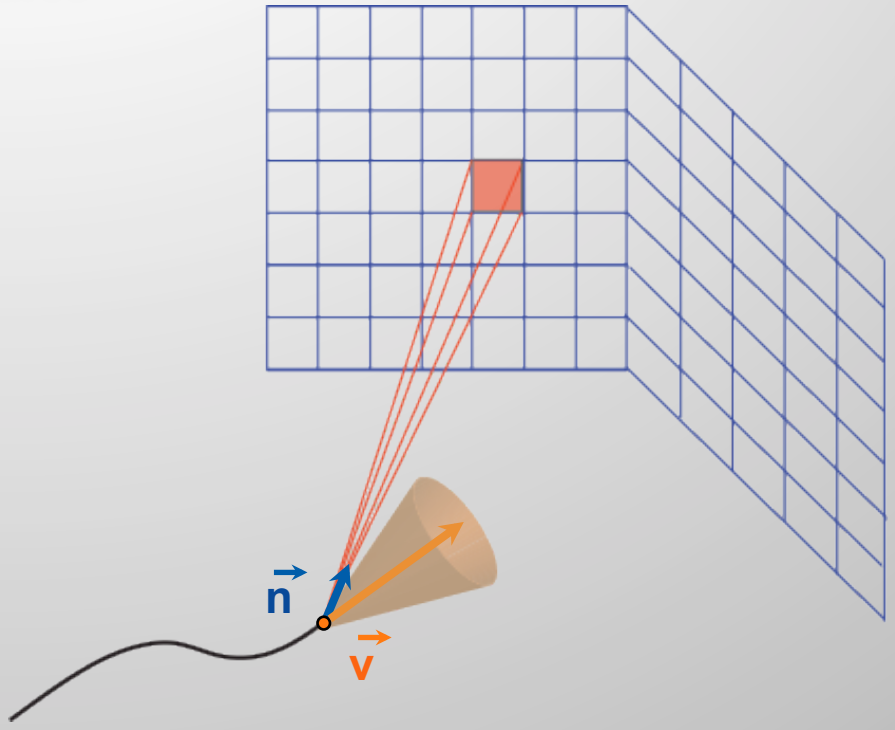
Detecting radiation in a "virtual detector"

Energy deposition pattern and spectral features

Power

$$\frac{dP}{dS} = \frac{e^2}{4\pi c} \frac{|\vec{n} \times [(\vec{n} - \vec{\beta}) \times \dot{\vec{\beta}}]|^2}{(1 - \vec{\beta}.\vec{n})^5 R(t')^2}$$

Jackson, J.D., Classical Electrodynamics



Spectrum

$$\frac{d^2 I}{d\omega dS} = \frac{e^2}{4\pi c} \left| \int_{-\infty}^{-\infty} \frac{\vec{n} \times [(\vec{n} - \vec{\beta}) \times \dot{\vec{\beta}}]}{(1 - \vec{n} \cdot \vec{\beta})^2 R(t')^2} e^{i\omega(t' + R(t')/c)} dt \right|^2$$

Jackson, J.D., Classical Electrodynamics