Matter in Extreme Conditions at LCLS: Diagnosing High Energy Density plasmas for high pressure science

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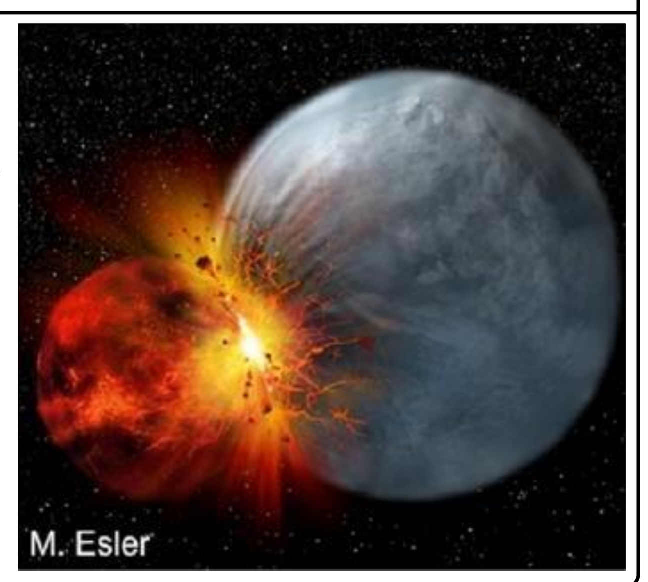
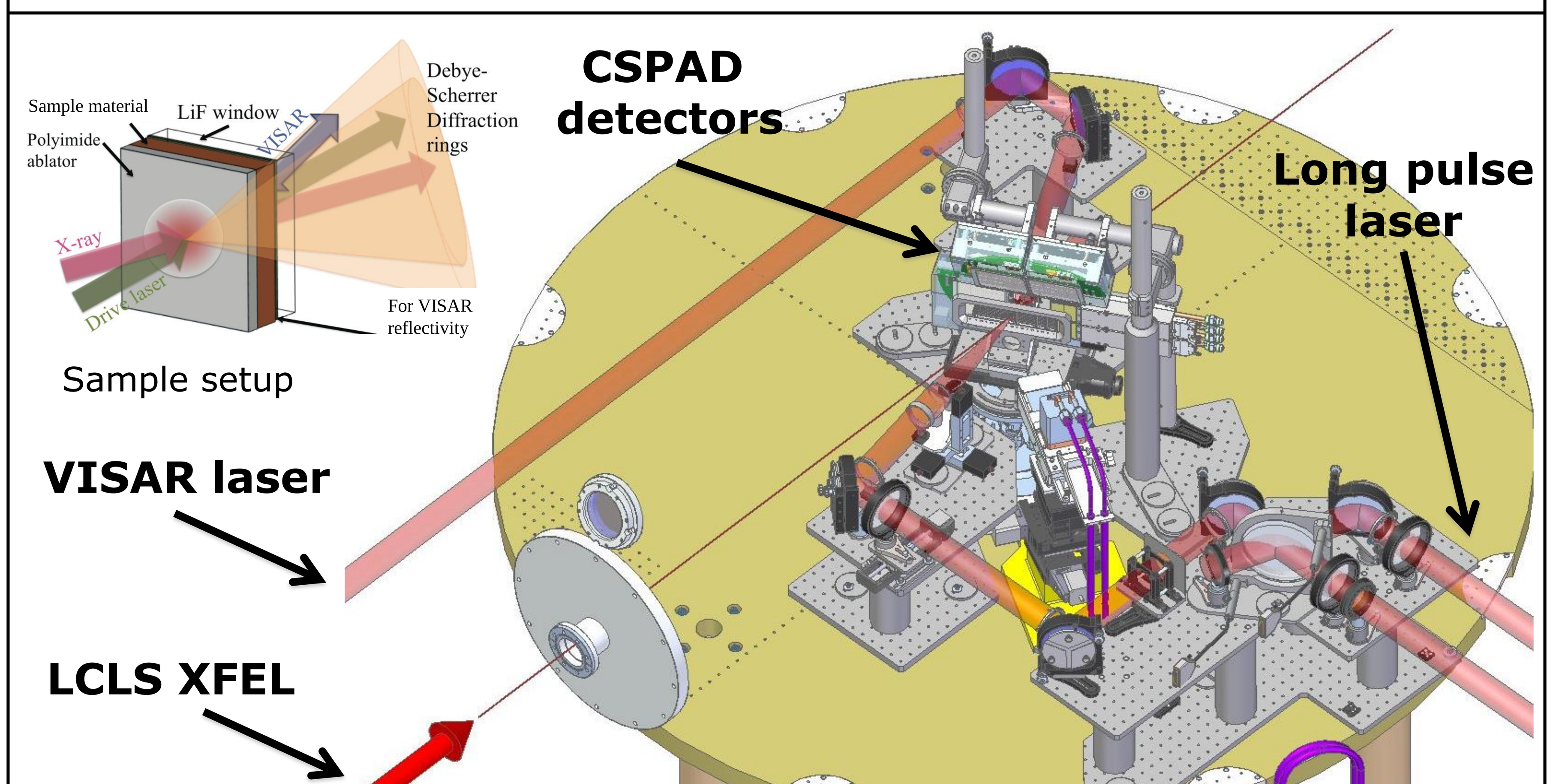
Introduction

The Linac Coherent Light Source (LCLS) Matter in Extreme Conditions (MEC) laboratory at SLAC provides a unique opportunity to study high energy density (HED) physics and laboratory astrophysics. The combination of high power optical lasers and the LCLS X-ray Free Election Laser (XFEL) makes it possible to study the transient behavior of extreme states of matter. XFELs provide the ability to make lattice-level measurements of phase transitions and deformation[1]. MEC has a suite of diagnostics tailored to this field of science, such as X-ray Diffraction (XRD) and Velocity Interferometer System for Any Reflector (VISAR).

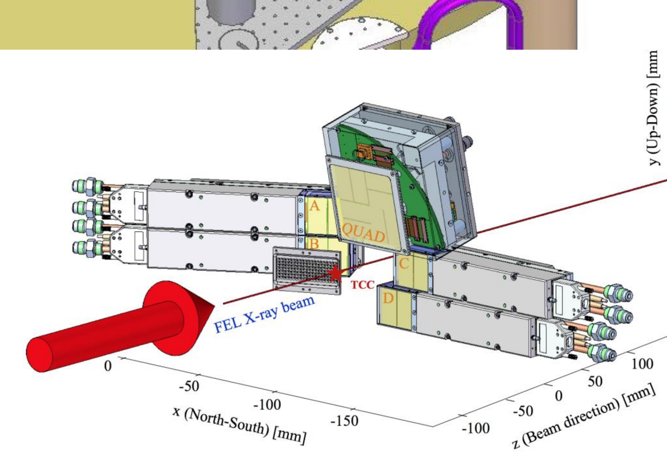


Standard Configuration Experimental Setup



X-ray parameters:
- Photon energy: 4 – 12 keV
- Pulse duration: 60 – 300 fs
- Pulse energy: 1 – 3 mJ
- PRF: 120 Hz

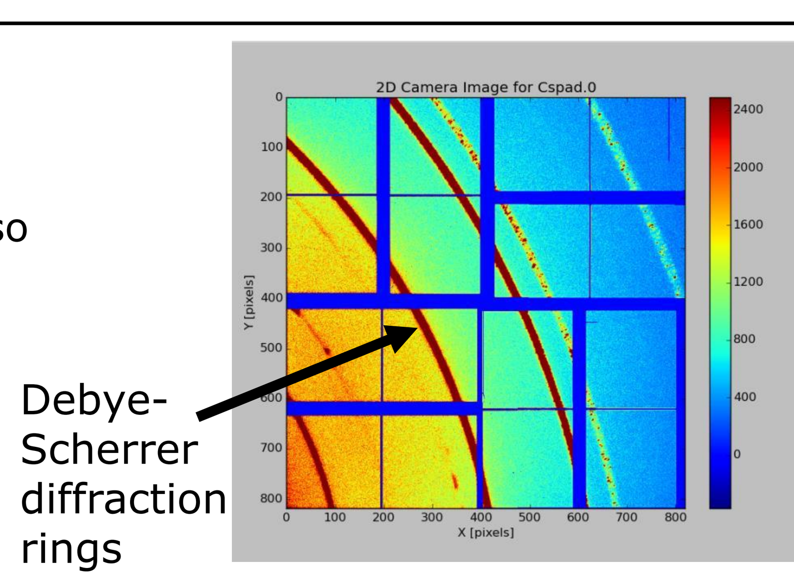
Long Pulse Laser:
- Nd:Glass laser
- Wavelength: 527 nm
- Pulse duration: 2 – 200 ns
- Pulse energy: ~1 J/ns per arm, max. 40 J in 20 ns
- Pulse shape: Square or ramp for steady drive shock
- Beam diameter: 100, 150, 250, and 500 μm

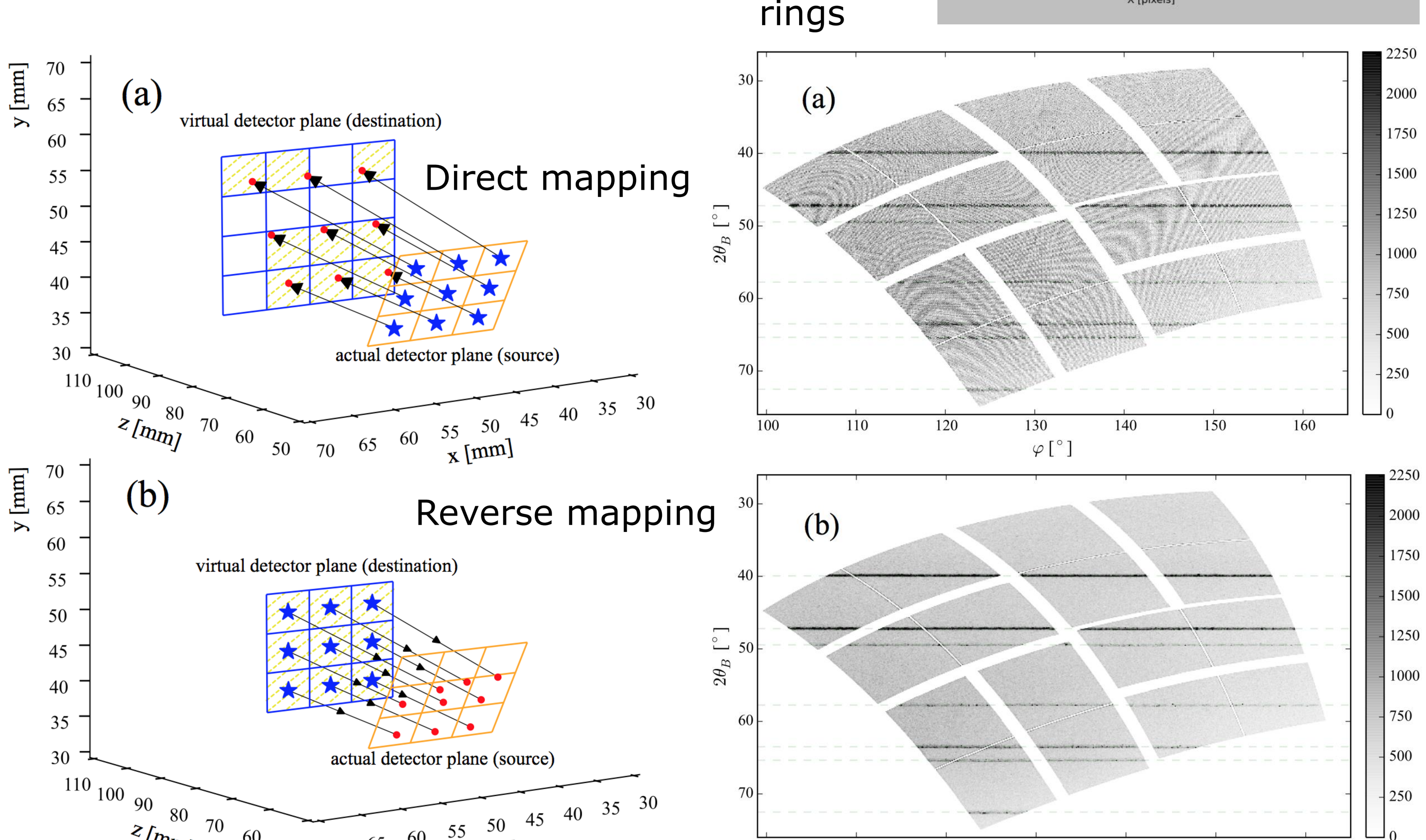


CSPADs for measuring XRD

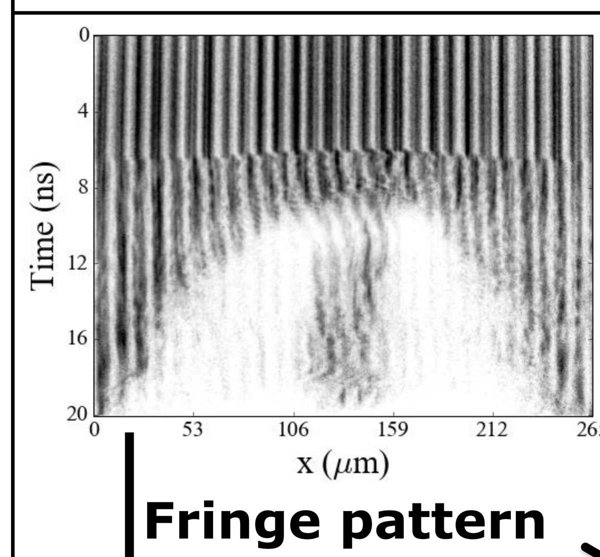
XRD Analysis

- Crystallographic states can be determined with the X-ray snapshots of the samples taken at different times[2].
- The growth of nanocrystalline grains can also be characterized on the nanosecond timescale after the shock compression[3].
- A perspective transformation (mapping 3D points to a 2D plane) is necessary to reconstruct the XRD data.



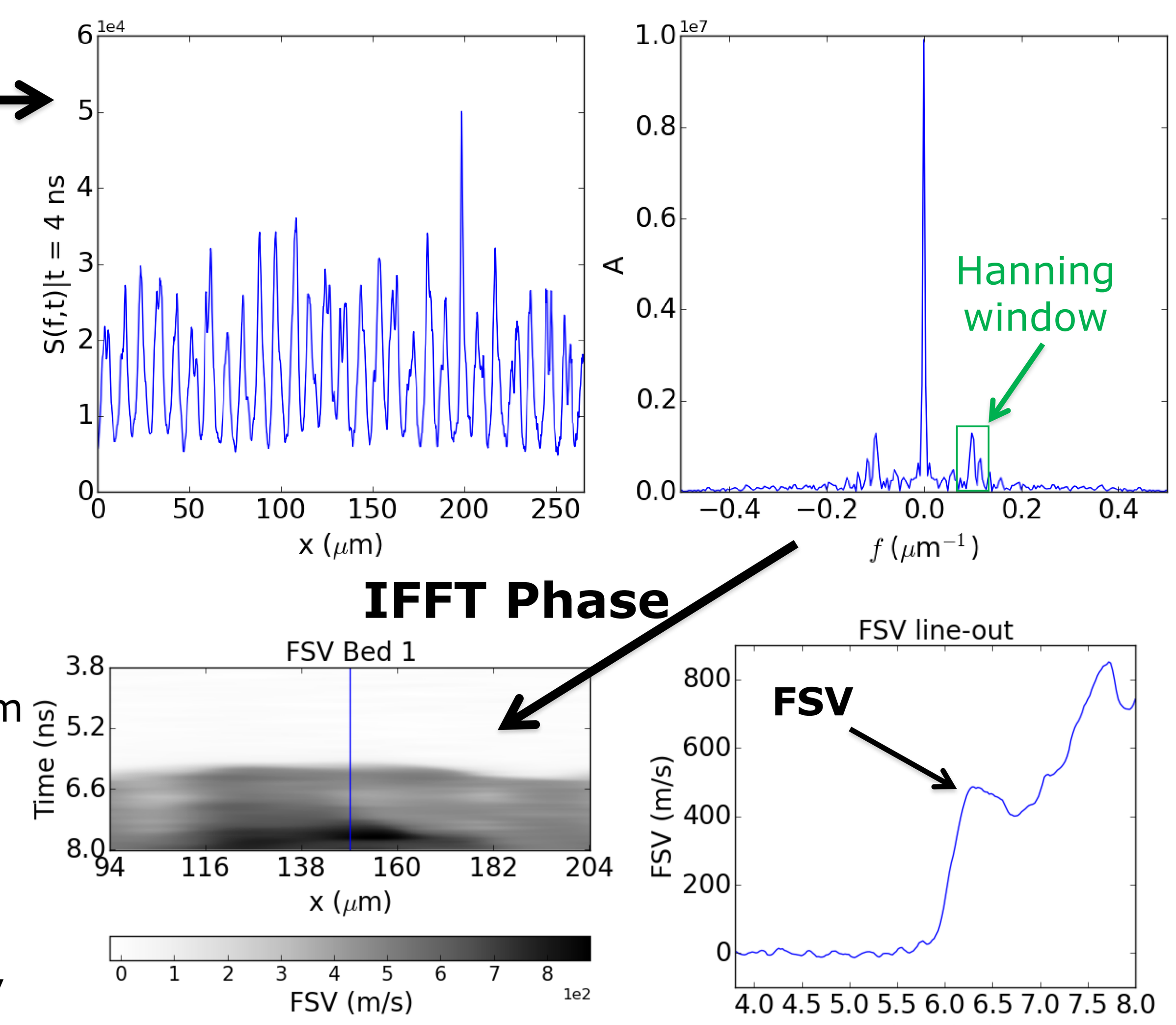


VISAR Analysis

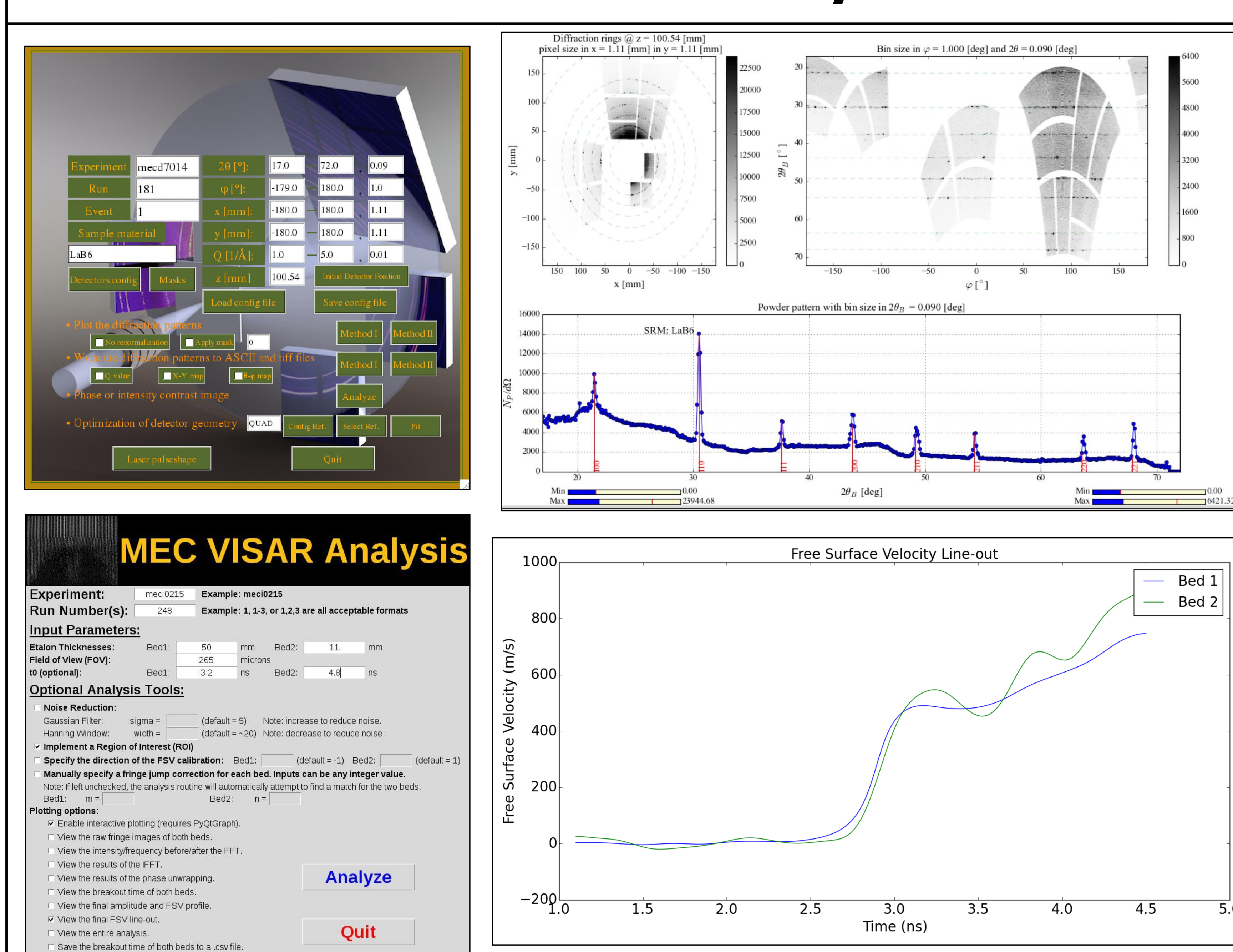


The FSV helps determine the internal pressure produced within the sample as a result of the induced shock. While there are no simple analytical formulas for calculating the pressure, there are databases of empirical data that can be used to equate FSVs to pressures for a given material and density, such as the LASL Shock Hugoniot Data book by Los Alamos[5].

1. Fourier Transformer (FFT) is taken of the raw fringe pattern.
2. Hanning window is applied around the positive frequency peak.
3. Inverse Fourier Transform (IFFT)
4. Phase is extracted from the complex valued function[4].
5. Unwrapped phase (Φ)
6. FSV = Φ*VPF (velocity per fringe)



In-situ XRD & VISAR Analysis at MEC



Conclusions

MEC's data analysis framework give users a quick and efficient method for determining lattice structure (XRD) and calculating shock-induced breakout velocities and internal pressures (VISAR). This makes MEC a unique platform for studying HED physics and laboratory astrophysics, allowing users to look at the transient behavior of materials under high pressures and determine the internal conditions generated by these extreme conditions. Researchers hope to recreate scenarios that allow them to study material properties under conditions similar to those existing in fusion plasmas, planetary interiors, and astronomical objects. For more information, please visit:
https://portal.slac.stanford.edu/sites/lcls_public/instruments/mec/Pages/default.aspx

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