Electro-Optic Sampling Beam Positioning Monitor for Relativistic Electron Beams

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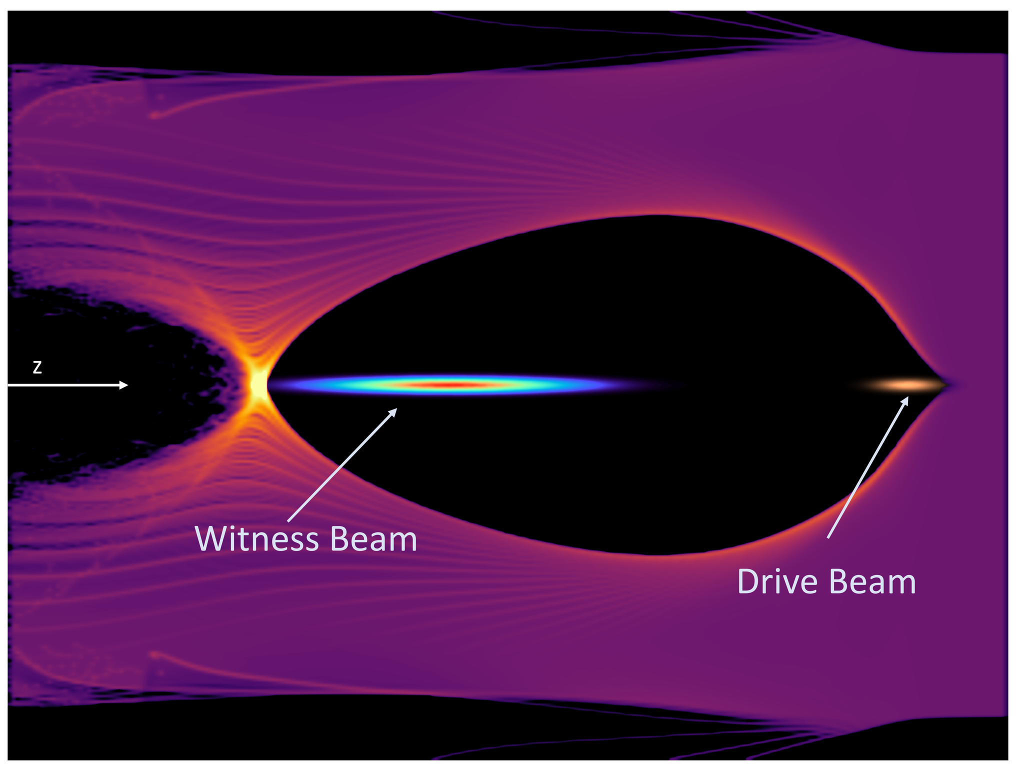
Motivation

Non-destructive diagnostics able to resolve transverse offsets and longitudinal separation of ultra-relativistic, two-bunch electron beams are necessary for a variety of applications including ion channel laser (ICL) and plasma wakefield acceleration (PWFA) experiments. PWFA requires precise longitudinal separation for optimal beam loading, minimizing energy spread and maximizing efficiency. Additionally, they require precise transverse alignment to preserve emittance. An offset witness bunch will experience chromatic phase spreading which leads to emittance growth. Traditional electronic BPMs are unable to resolve lower than ns time scales which inhibits the resolution of the bunches separately. Transverse Deflecting Cavities (TCAVs) are able to resolve long separations but are also destructive. We leverage ultra-fast optics to encode fs/µm scale information into a laser pulse with electro-optic sampling to create a non-destructive diagnostic able to resolve transverse offsets and longitudinal separation on order of 10 fs and 100 µm respectively.

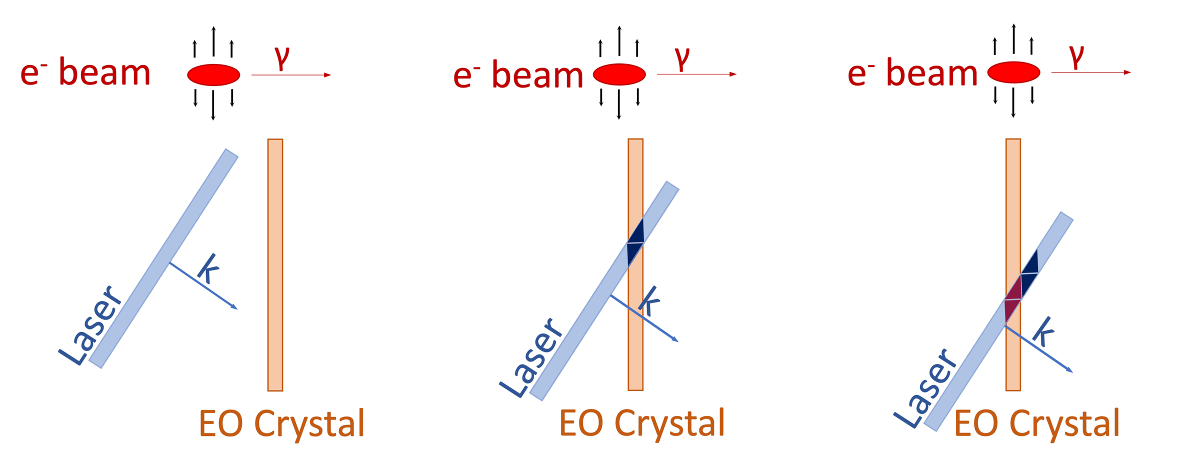
PWFA Simulation



Parameters (FACET-II)

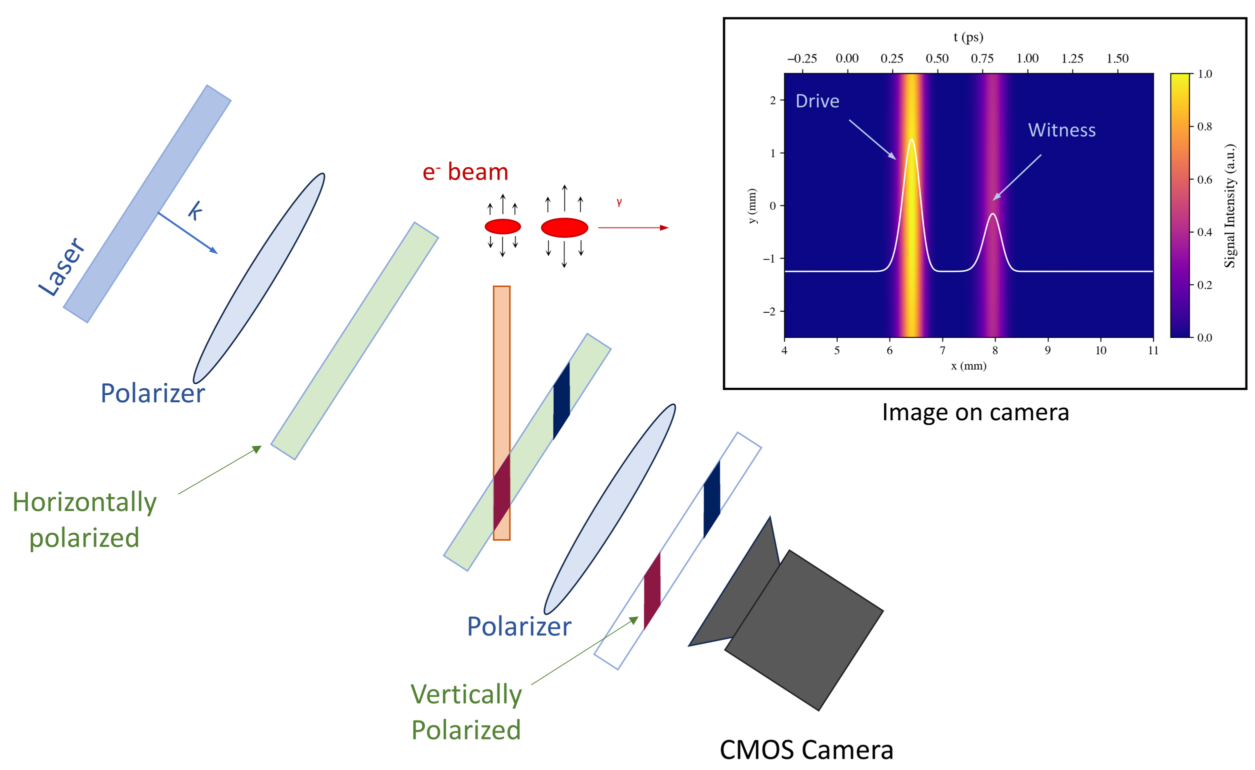
Parameter	Value	Unit
Laser Wavelength	800	nm
Laser Angle	5	degree
Drive Beam Charge	1000	pC
Witness Beam Charge	800	pC
Time Delay btw. Beams	450/135	fs/µm
Transverse Beam Offset Drive	~10	µm
Transverse Beam Offset Witness	~10	µm
Bunch Length (Both)	50/15	fs/µm
GaP Crystal Thickness	100	µm

EO Spatial Encoding Scheme

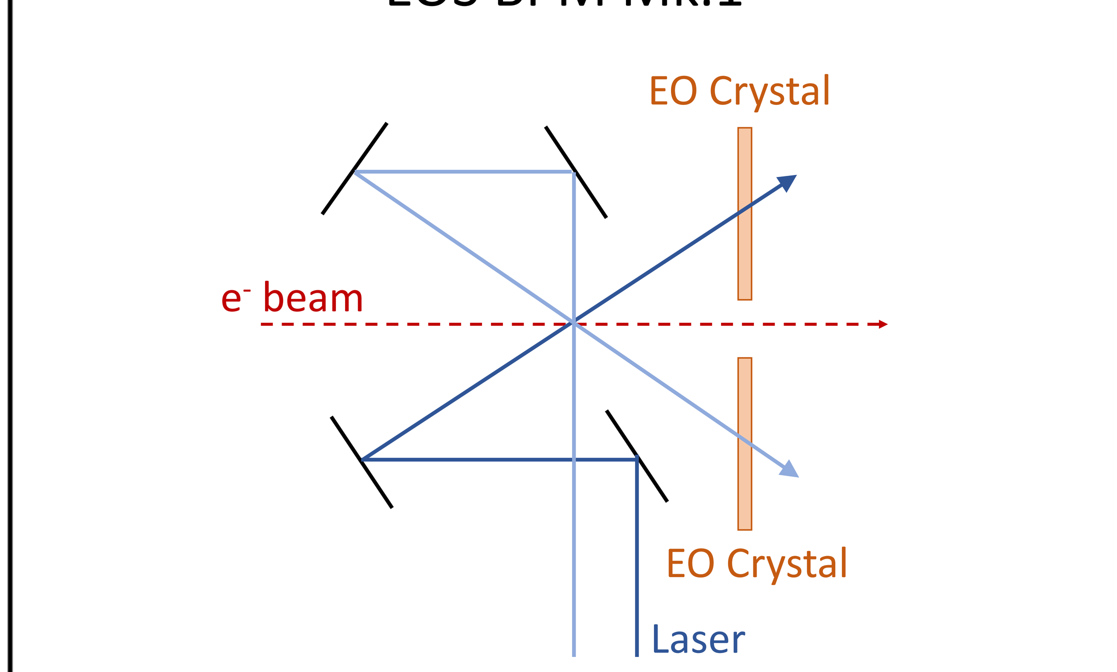


The E-field from a passing electron beam modifies the birefringence of the crystal which rotates the polarization of the part of the laser intersecting the crystal at that time.[1]

Cross Polarization Scheme

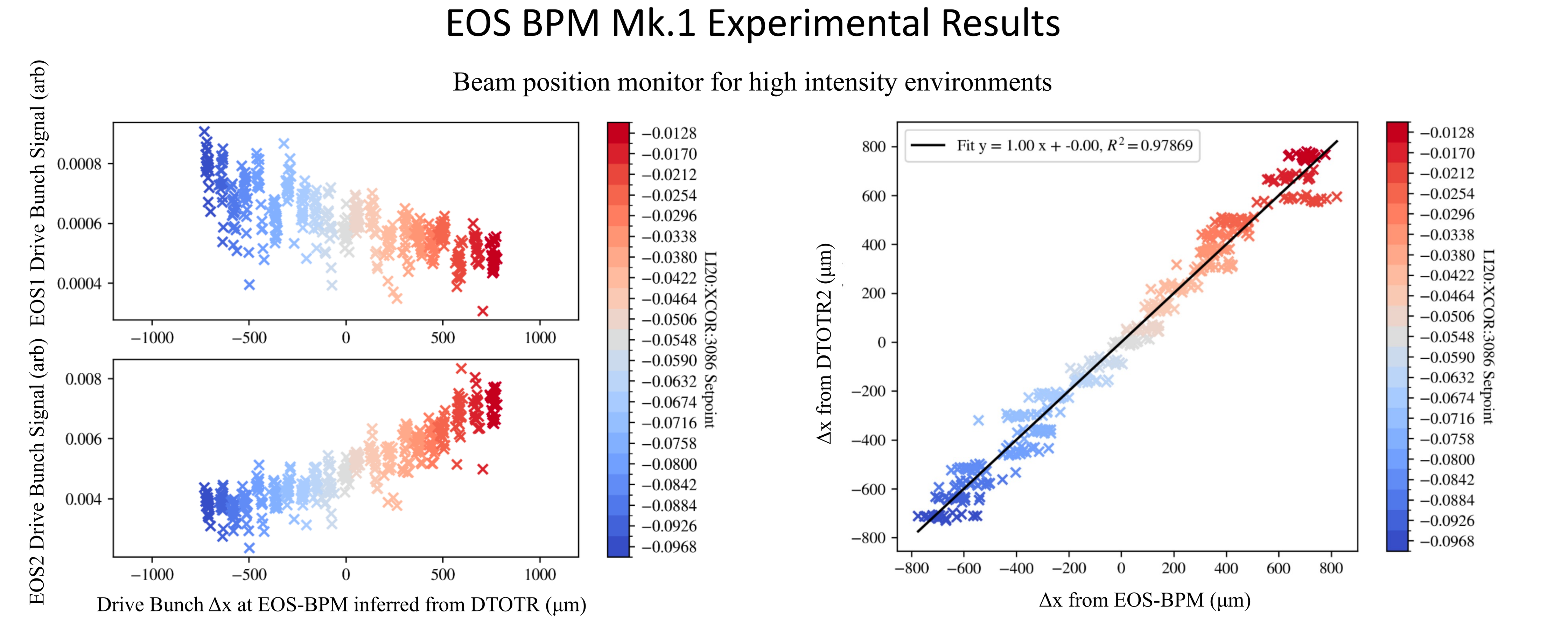


EOS BPM Mk.1

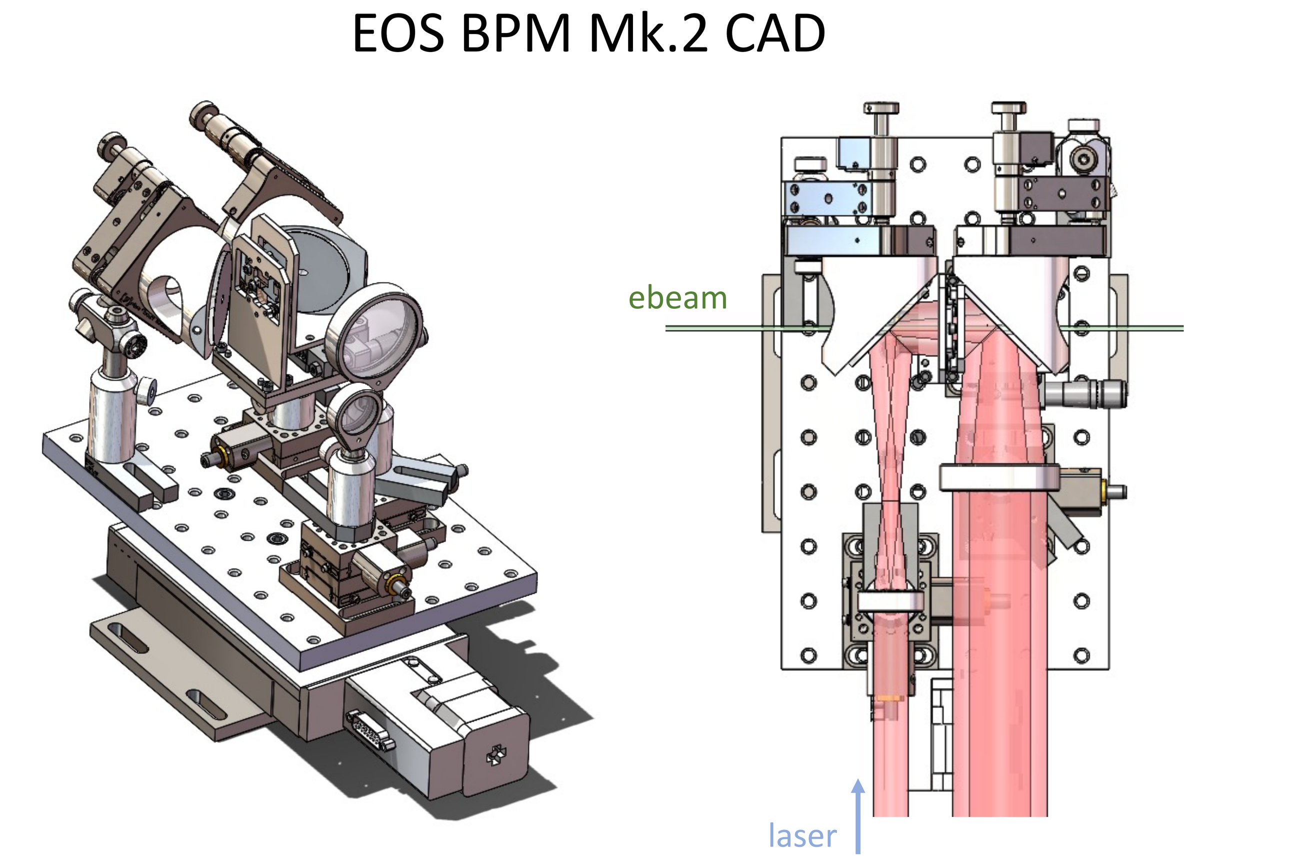


This 2 crystal design leverages the correlation between strength of phase retardation and e- beam location to find the position of the drive and witness beams. [2]

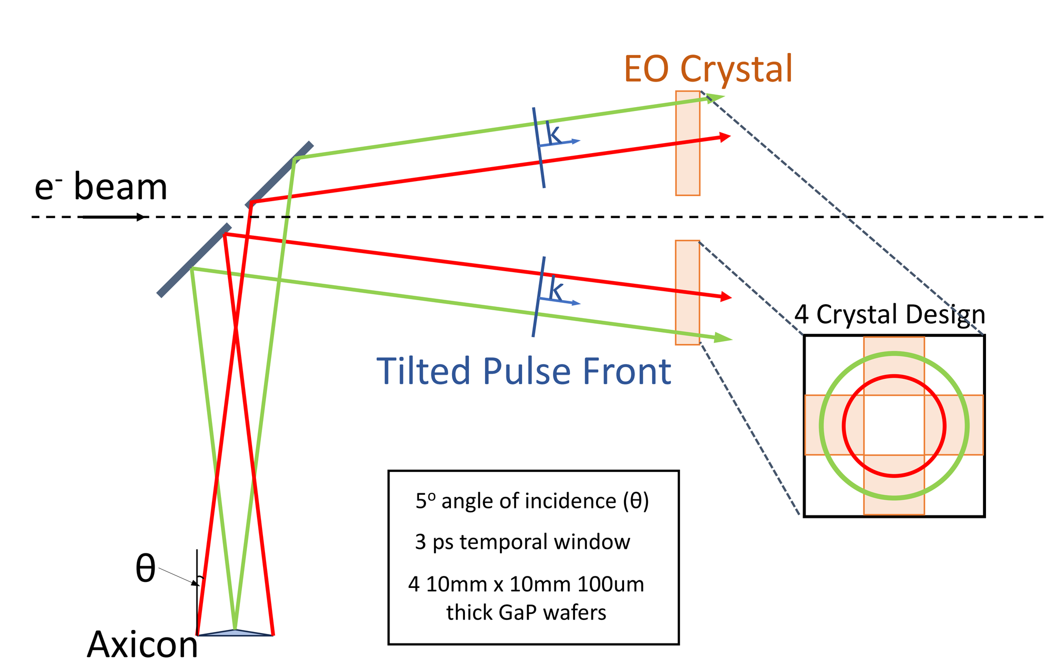
EOS BPM Mk.1 Experimental Results



EOS BPM Mk.2 CAD

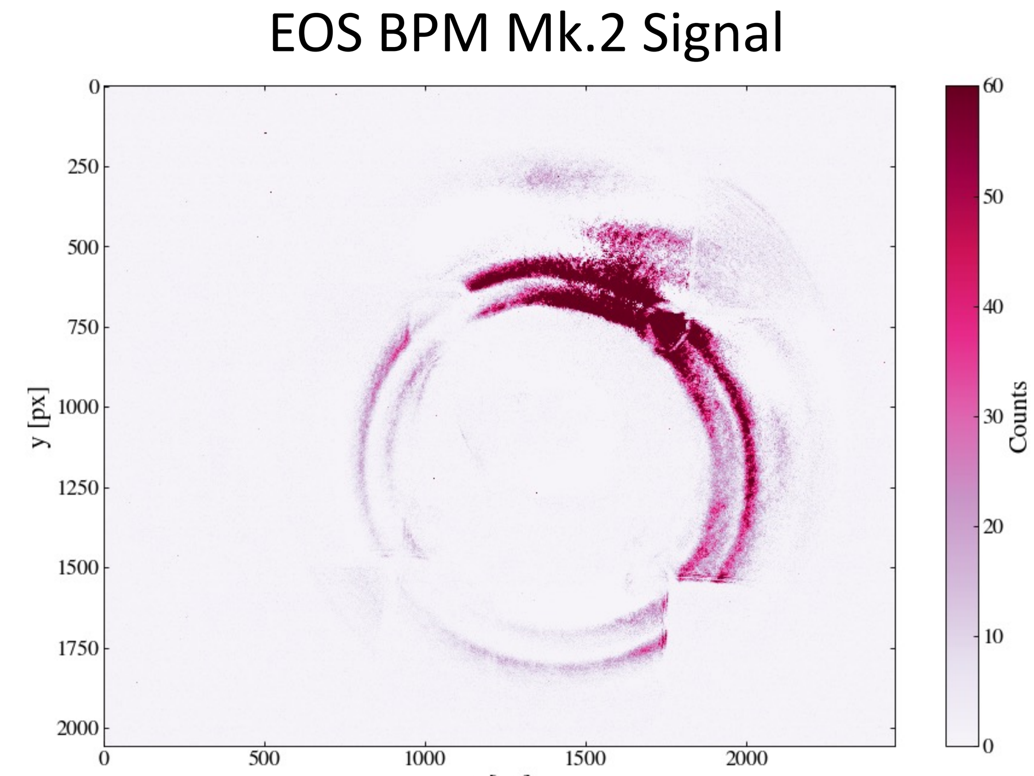


EOS BPM Mk.2 Design



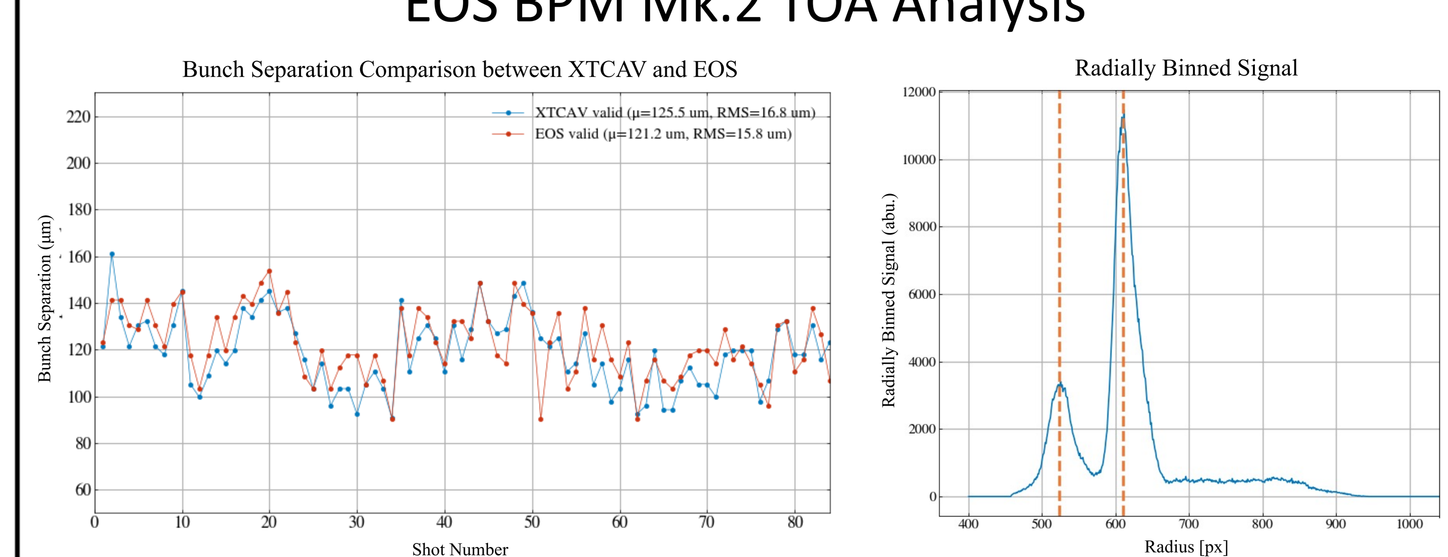
This 4 crystal design with a donut probe beam allows for a full 3D reconstruction of the relative centroid bunch positions as well as better temporal and transverse resolution.

EOS BPM Mk.2 Signal



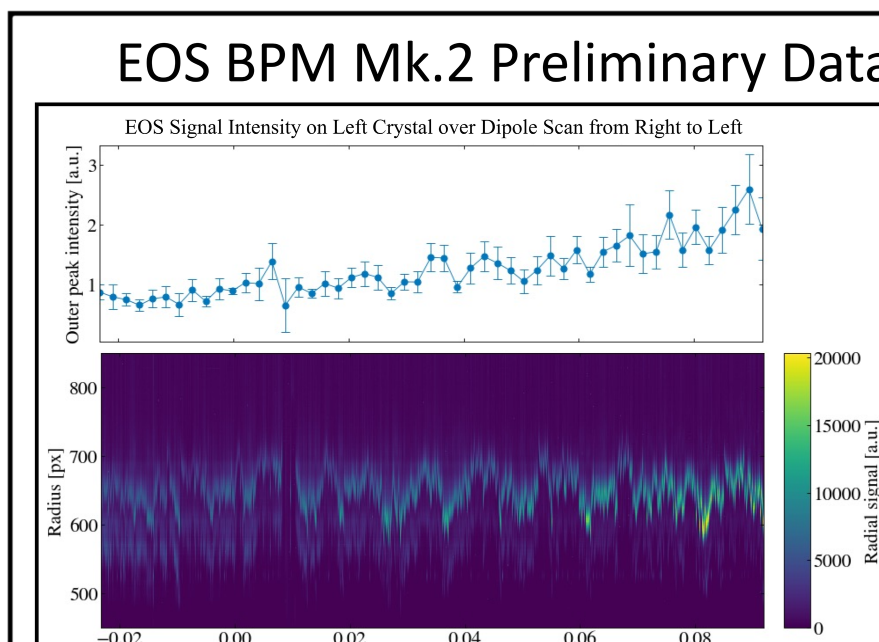
Two bunch signal 1000/500 pC charge ratio with ~ 10 um FWHM bunch length from FACET-II with background subtraction.

EOS BPM Mk.2 TOA Analysis



4 µm mean offset between EOS and TCAV with 13 µm RMS difference

EOS BPM Mk.2 Preliminary Data/ TOA Performance



Total Temporal Window: ~2.5 ps

Temporal resolution: 6 fs/pixel

Good agreement between EOS and TCAV.

Clear BPM response in areas on the donut without wavefront distortion.

Summary/Next Steps

1) Novel ultra-fast optical device for measuring beam centroid location with fs/µm level precision.
   - Required for emittance preservation of PWFA.
   - Required to minimize energy spread and maximize efficiency.
2) Improvements:
   - Install Spatial Light Modulator to flatten wavefront
3) Future Work:
   - BPM and TOA measurements with flattened wavefront.
   - Explore the utility of EOS BPM to diagnose tilted beams.

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