Development of an Electro-Optic Sampling Beam-Position Monitor (EOS-BPM) at FACET-II

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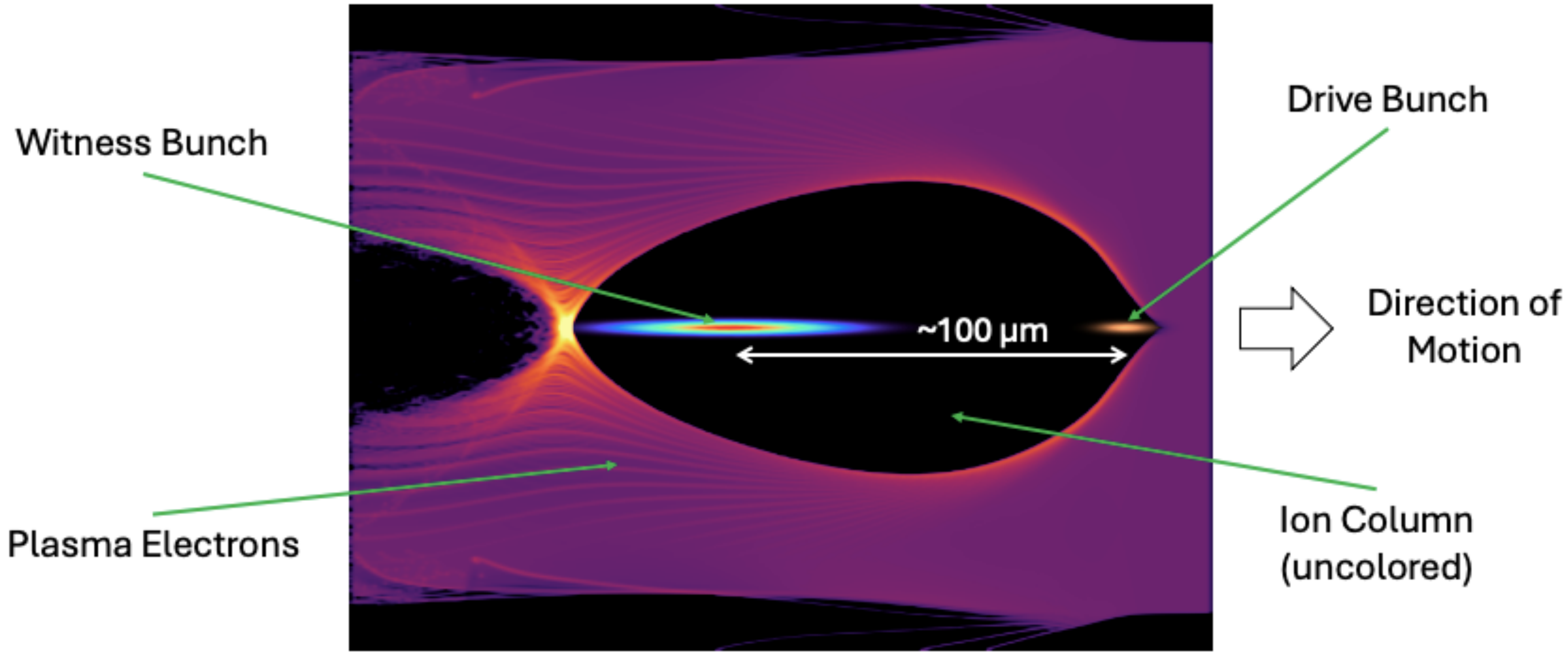
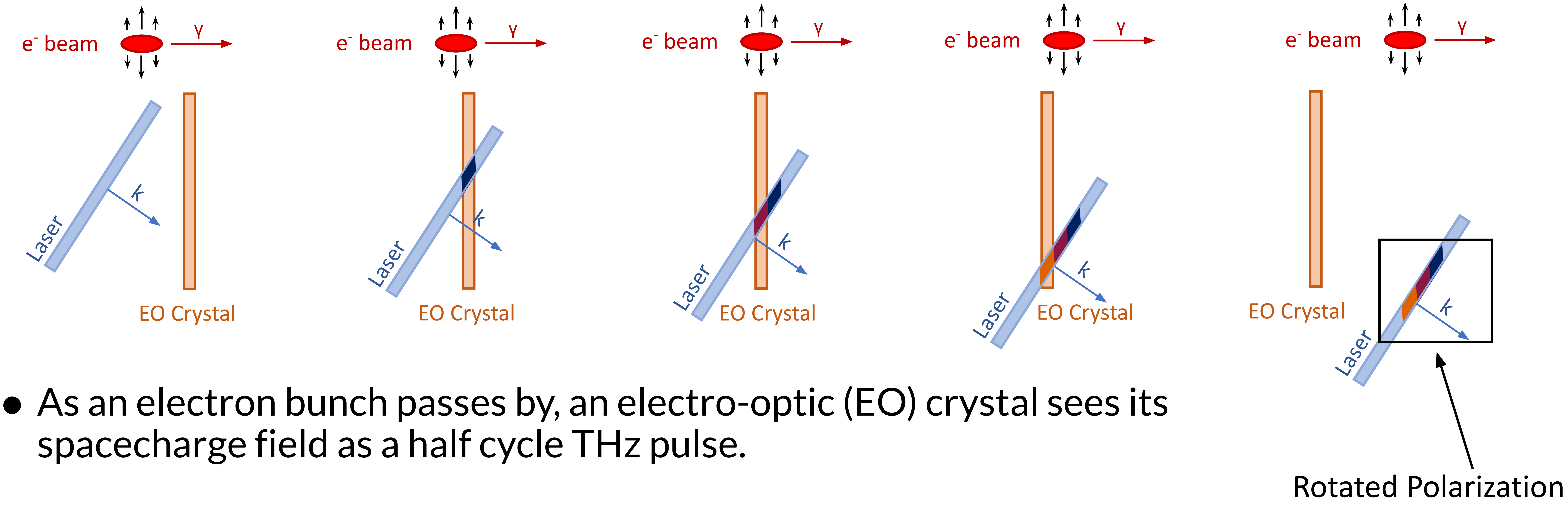
Motivation

- **Advanced accelerators need advanced diagnostics!**
- Emittance preservation and energy spread minimization in PWFAs requires measurement and control of transverse offsets and longitudinal separation between bunches.
- There is a particular need for a **high resolution**, **non-destructive** and **single shot** diagnostic that can measure where (x, y, ζ) and when (t) the drive and witness bunches are.



Spacially Encoded EOS

Figure: Elena Ros



- As an electron bunch passes by, an electro-optic (EO) crystal sees its spacecharge field as a half cycle THz pulse.
- This electric field induces a birefringence in the EO crystal.
- An ultrafast laser pulse passing through the crystal at the same time picks up a spacially encoded polarization rotation.

Spacially Encoded EOS

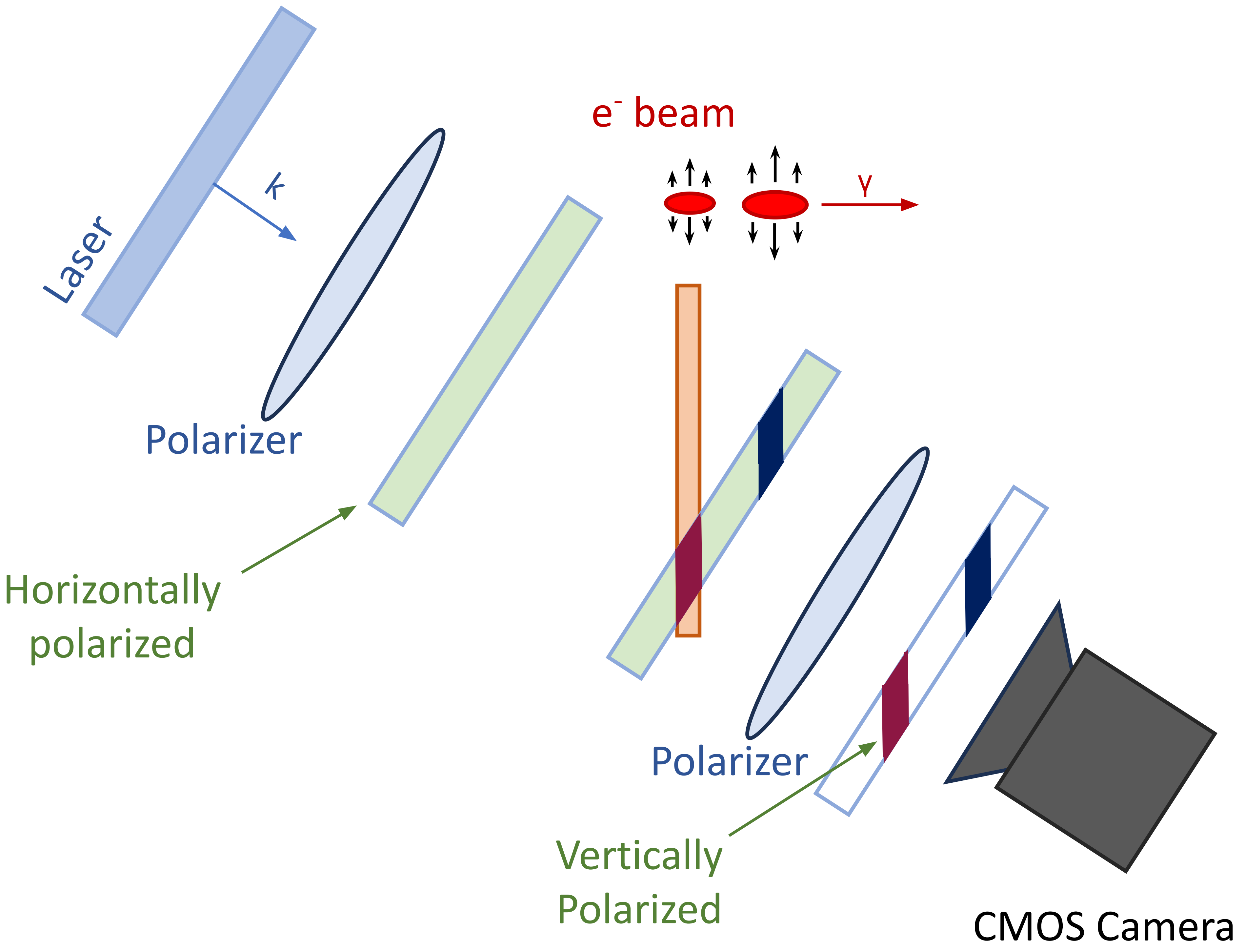


Image on camera

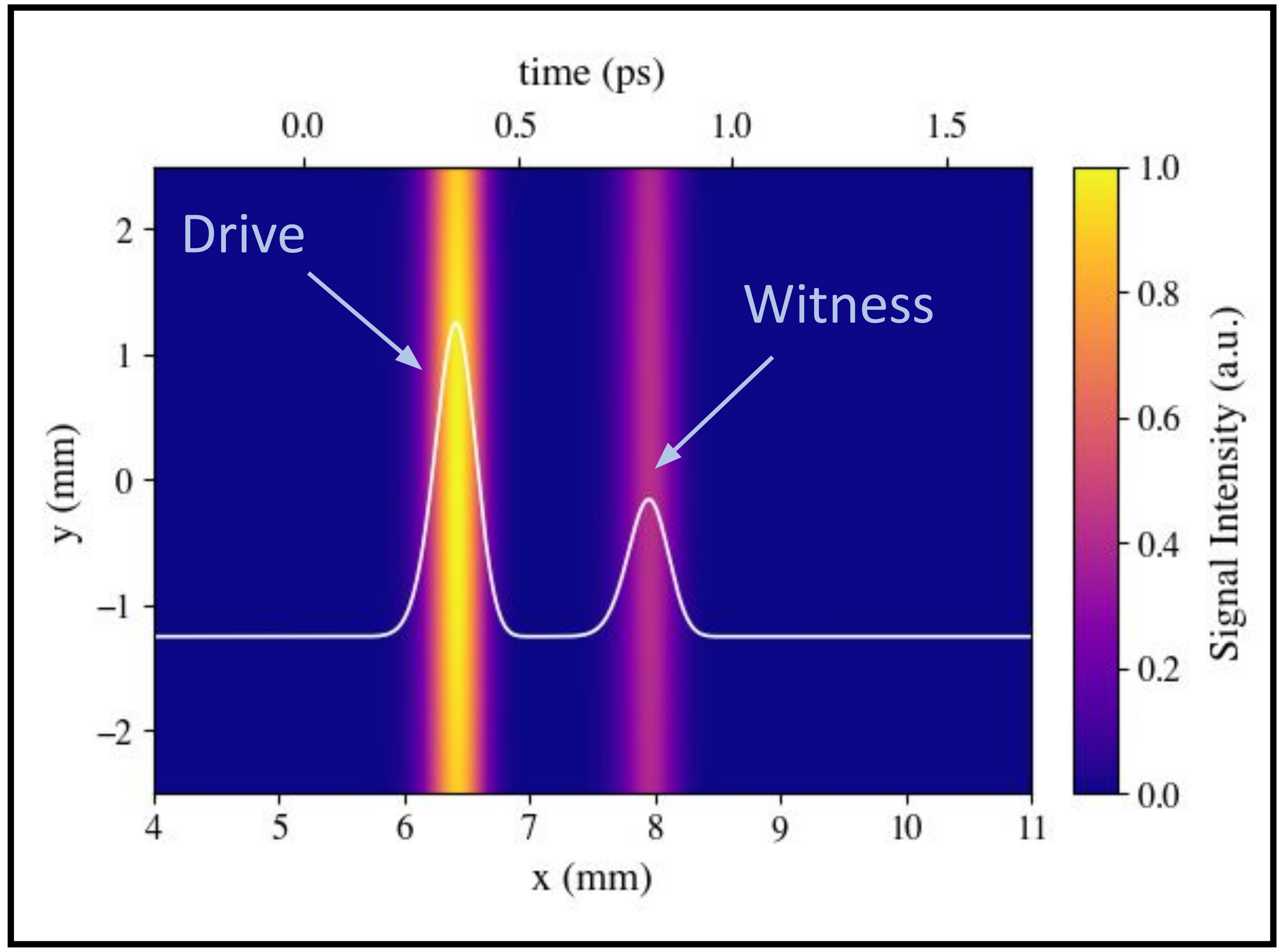
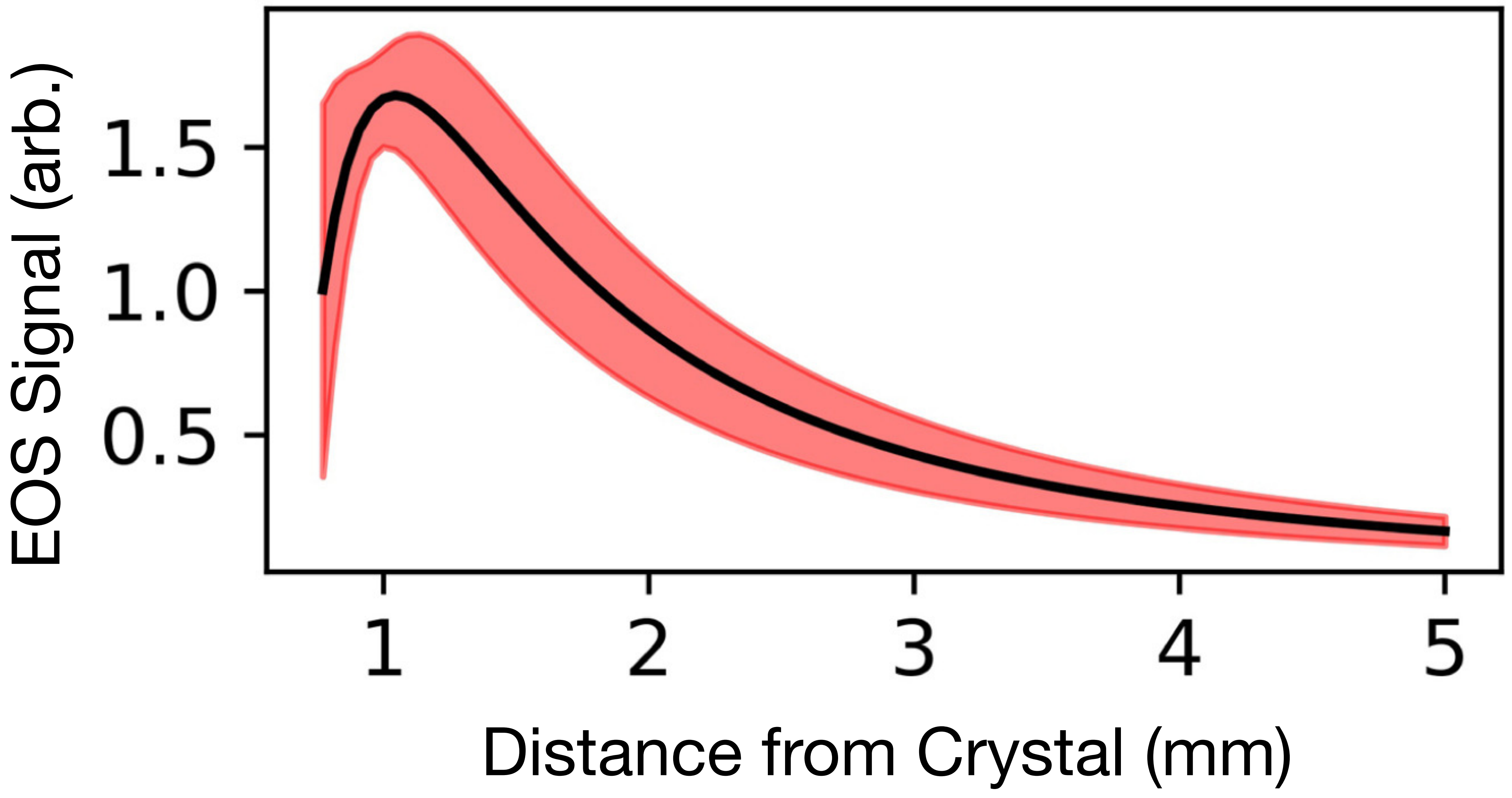


Figure: Elena Ros

- Polarizer converts spacially varying polarization to spacially varying intensity which is imaged.
- Projecting 2D image onto the x (time) axis gives the time resolved EOS signal.
- EOS signal depends on bunch current and distance from the crystal.
- Crystal acts as a low pass filter for the current density, doesn't capture longitudinal variation in the current on lengthscales less than a few 10s of μm.

Spacial Dependence

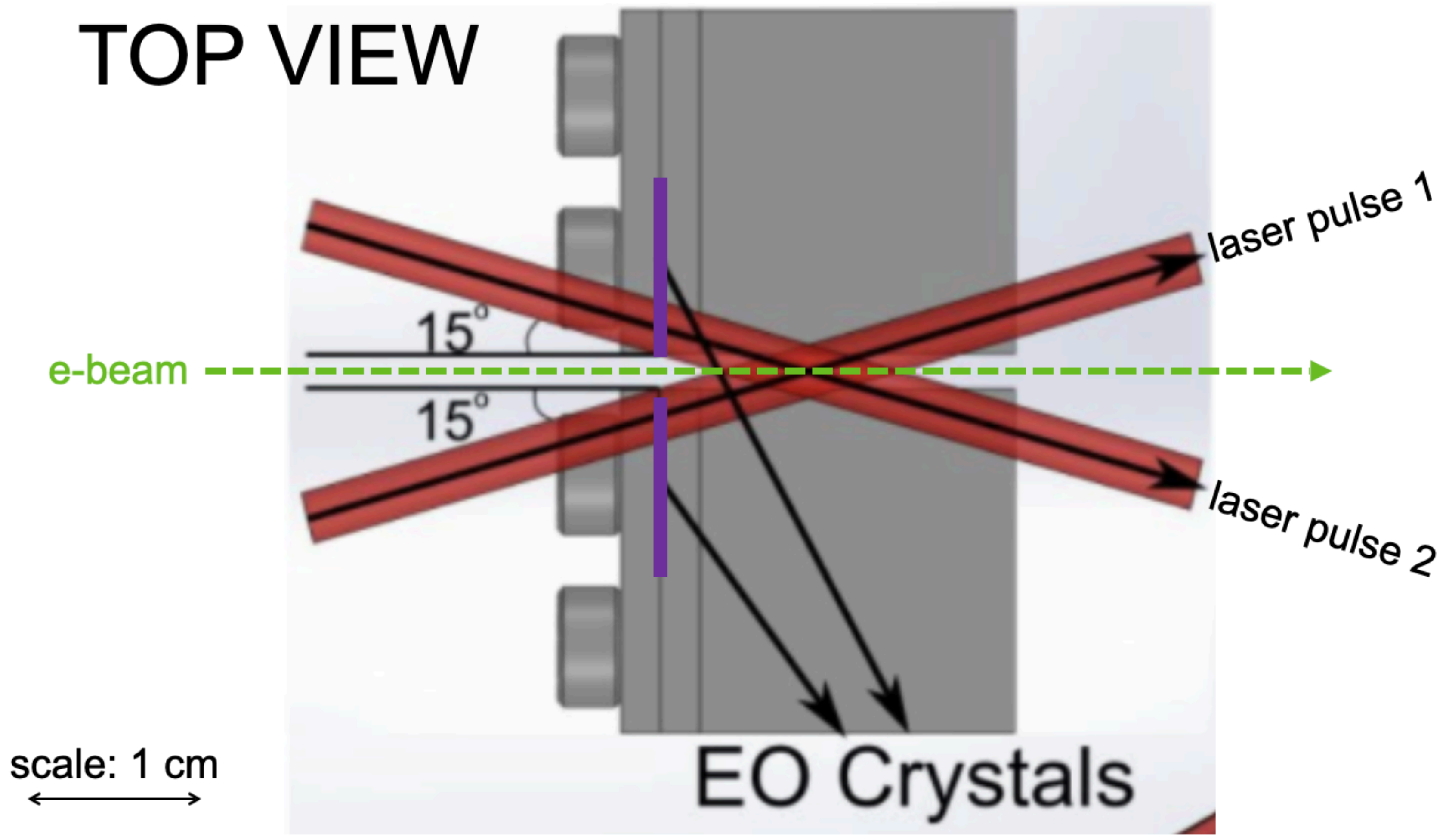
- Comparing the strength of the EOS signal on two crystals on either side of the electron bunch allows the effects of current and distance to be separated



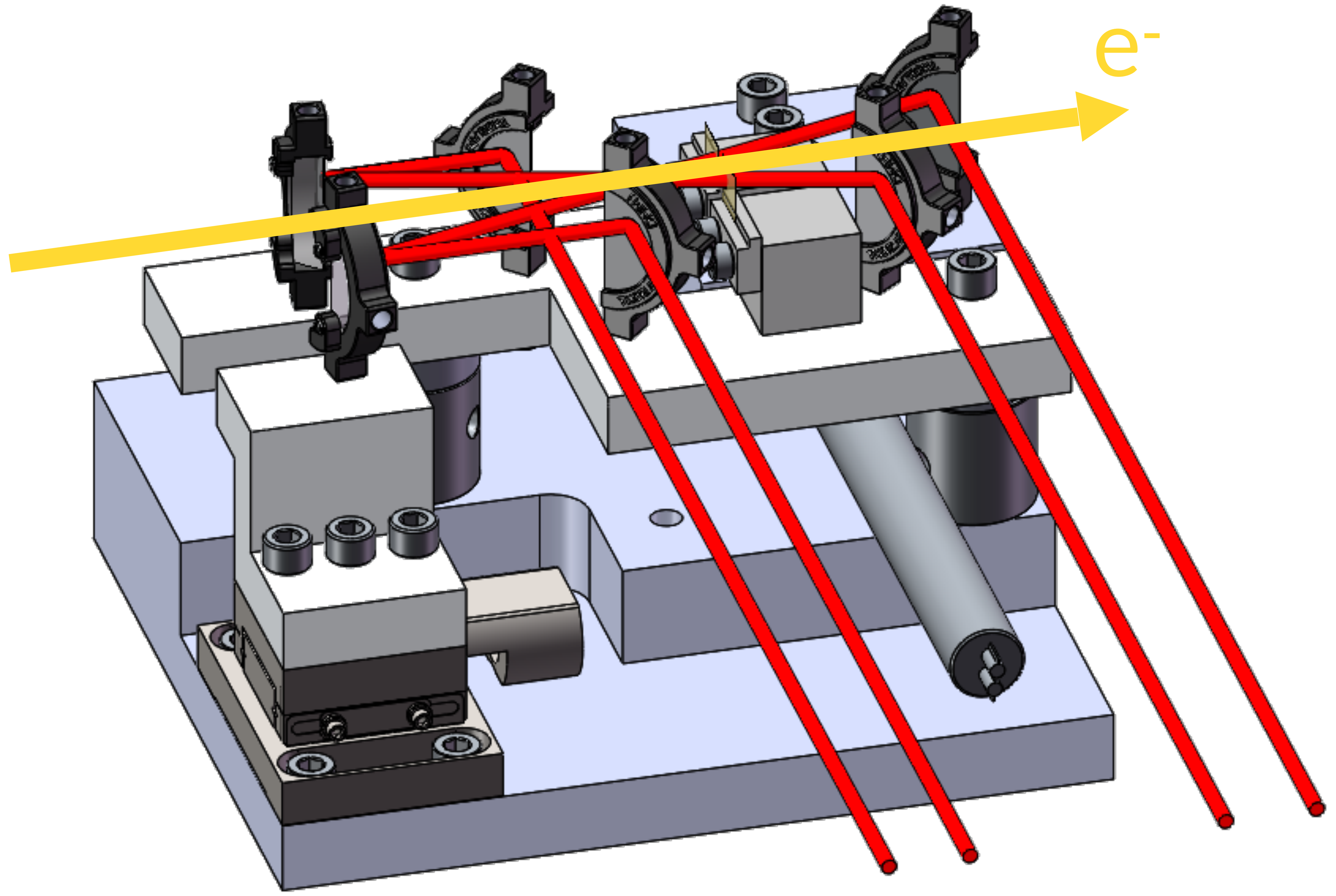
$$x \propto \frac{S_1 - S_2}{S_1 + S_2}$$

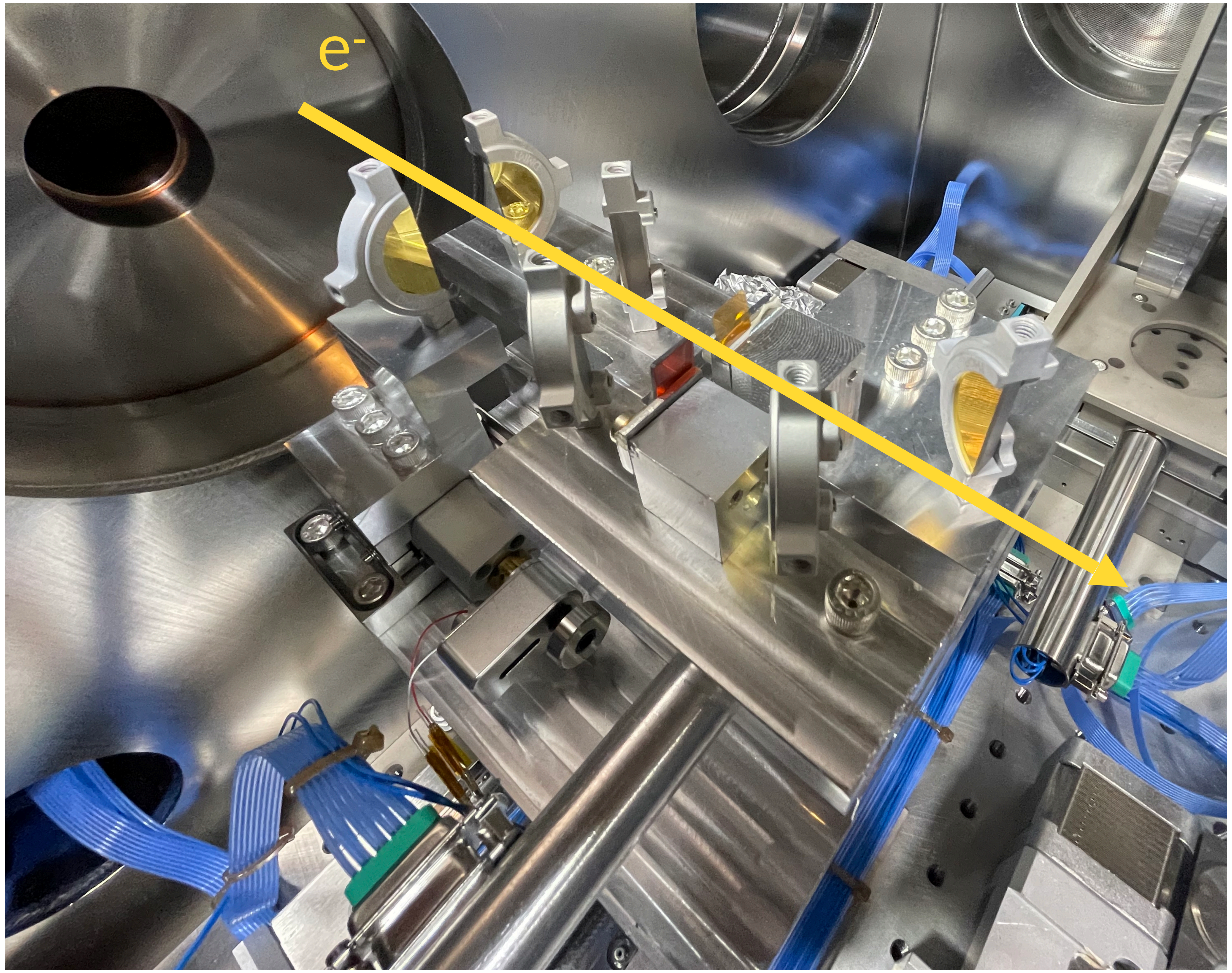
S_1 :EOS1 Signal Strength

S_2 :EOS2 Signal Strength



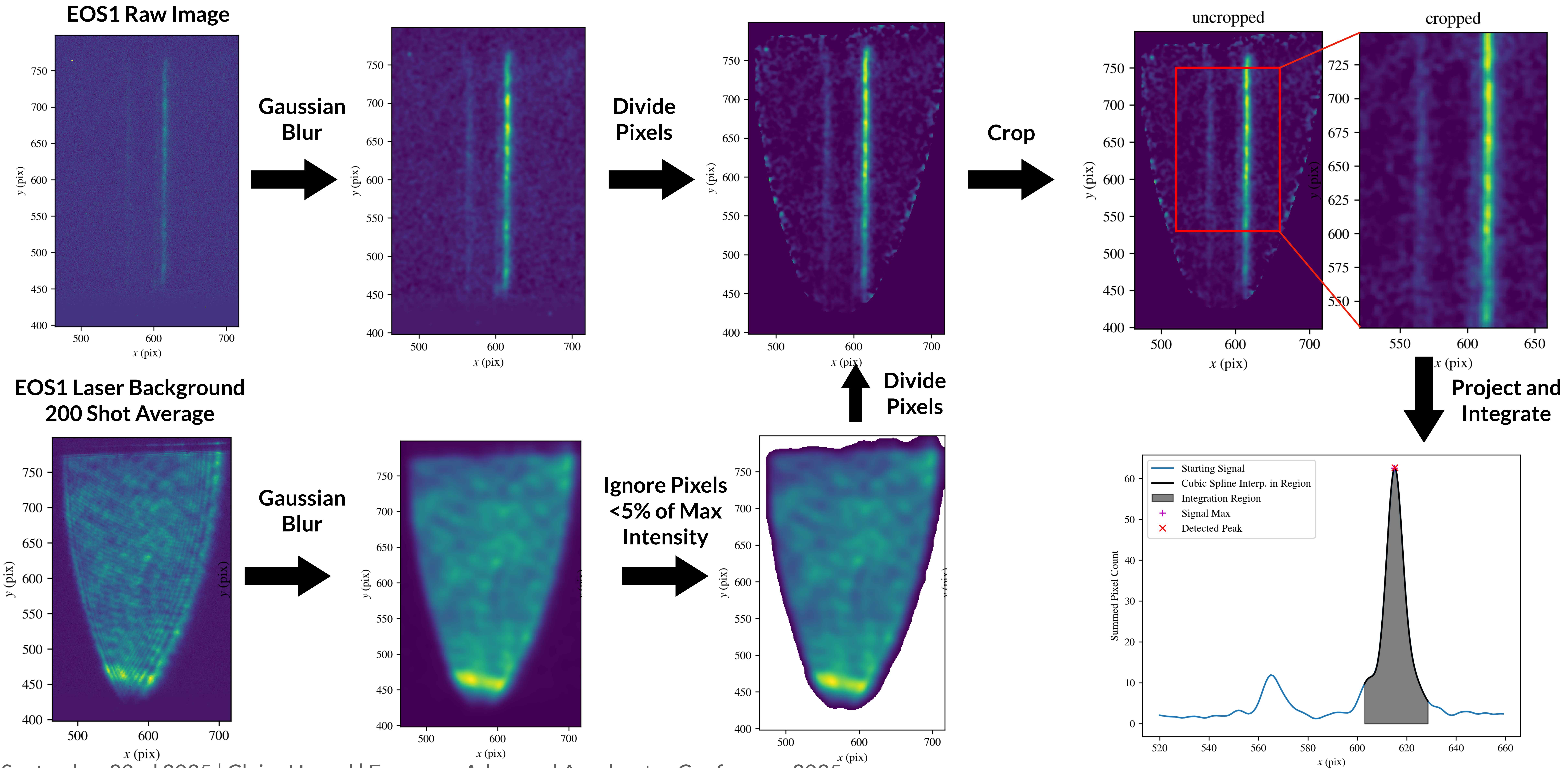
EOS-BPM Mk. 1



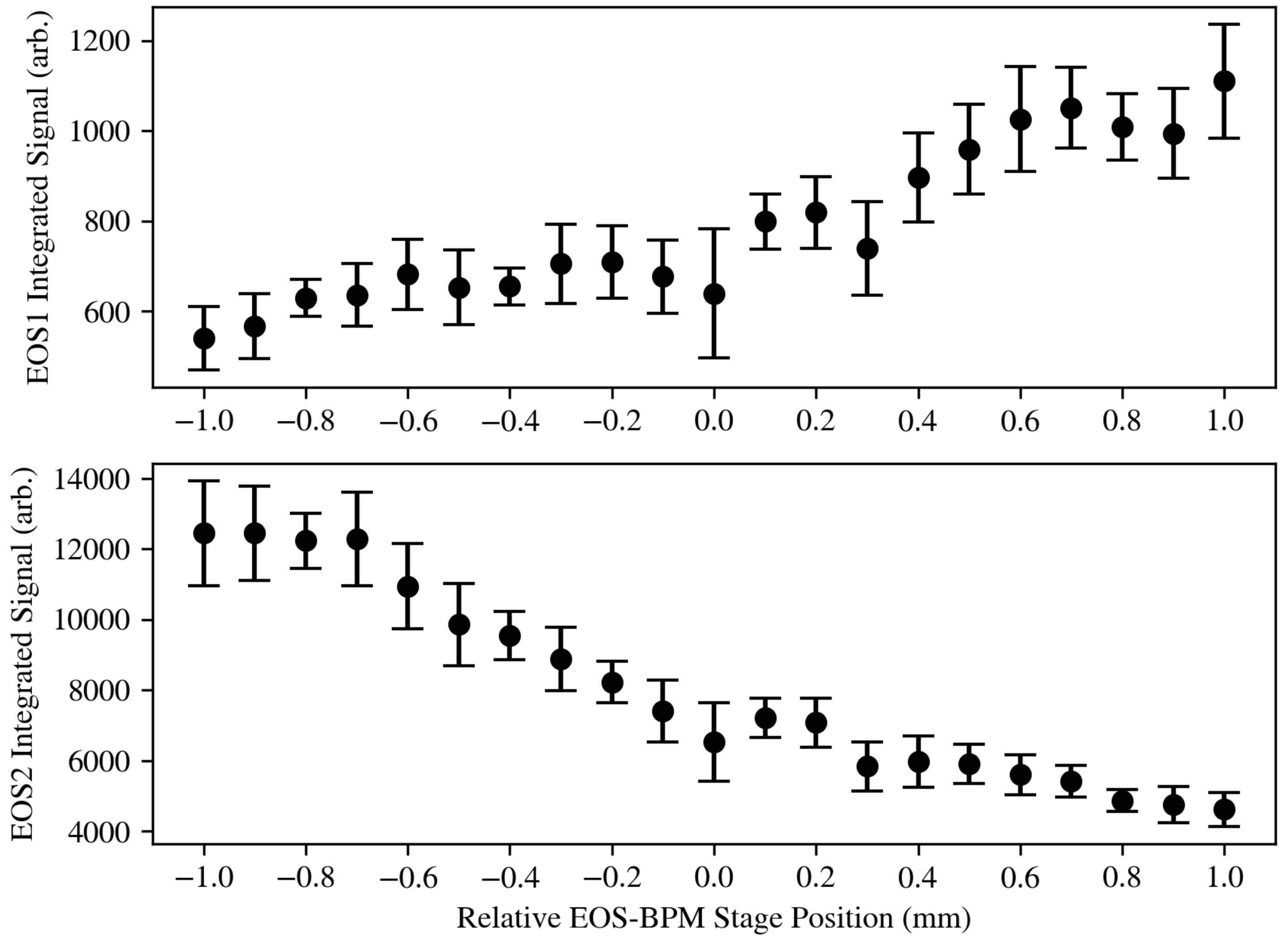


- Prototype installed at FACET-II.
- Two 100μm Gallium Phosphide (GaP) Crystals
- Can only act as a BPM in one transverse dimension.
- PID feedback was implemented to adjust the laser digital delay and keep the signal in the middle of the crystal despite long term machine drifts.

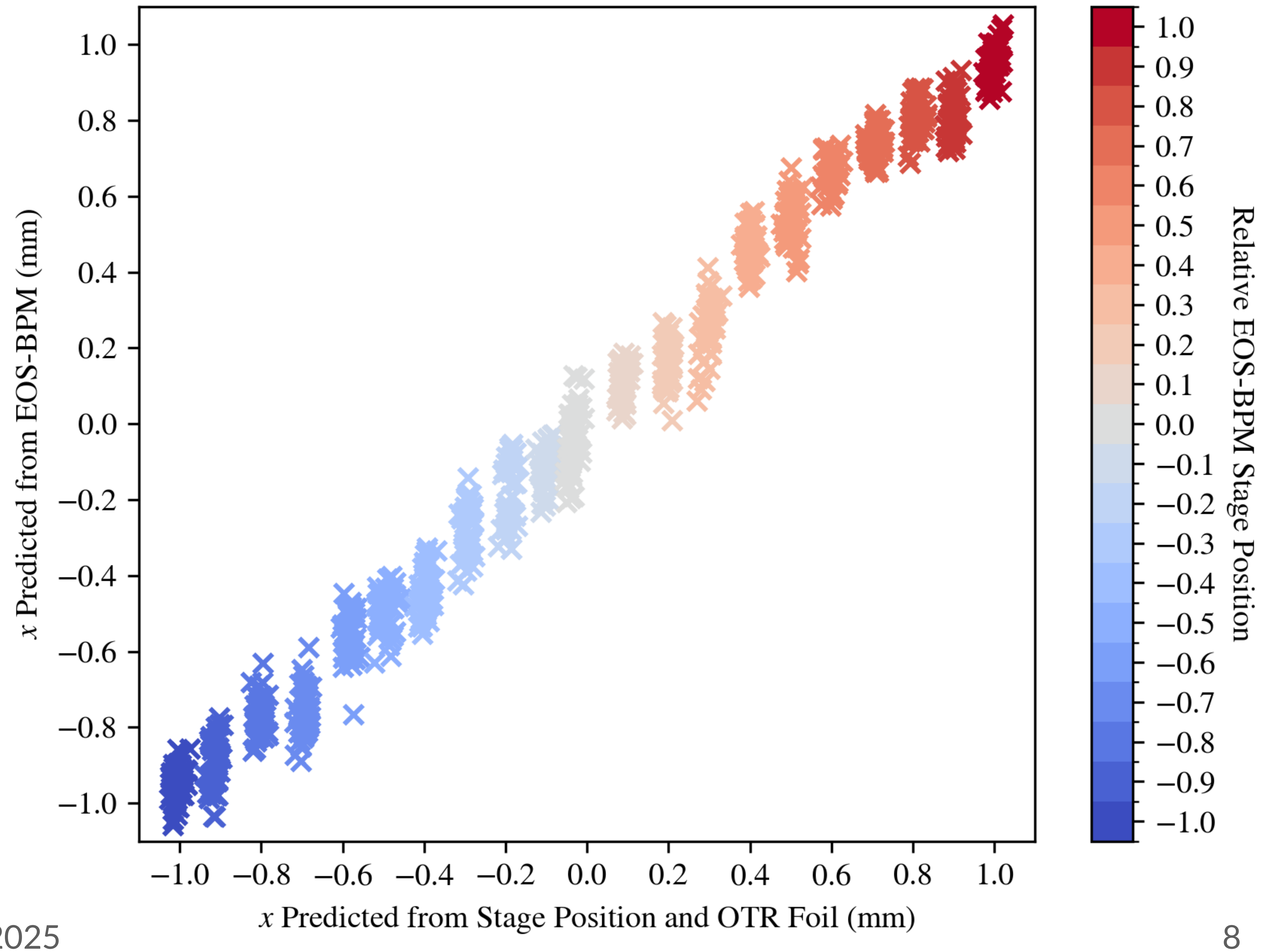
Data Analysis



Results — Stage Position



$$\sigma(x_{\mathrm{EOS-BPM}} - x_{\mathrm{Stage,OTR}}) = 73.1\mu\mathrm{m}\ \text{(No Laser Intensity Correction)}$$
$$= 69.0\mu\mathrm{m}\ \text{(Laser Intensity Correction)}$$

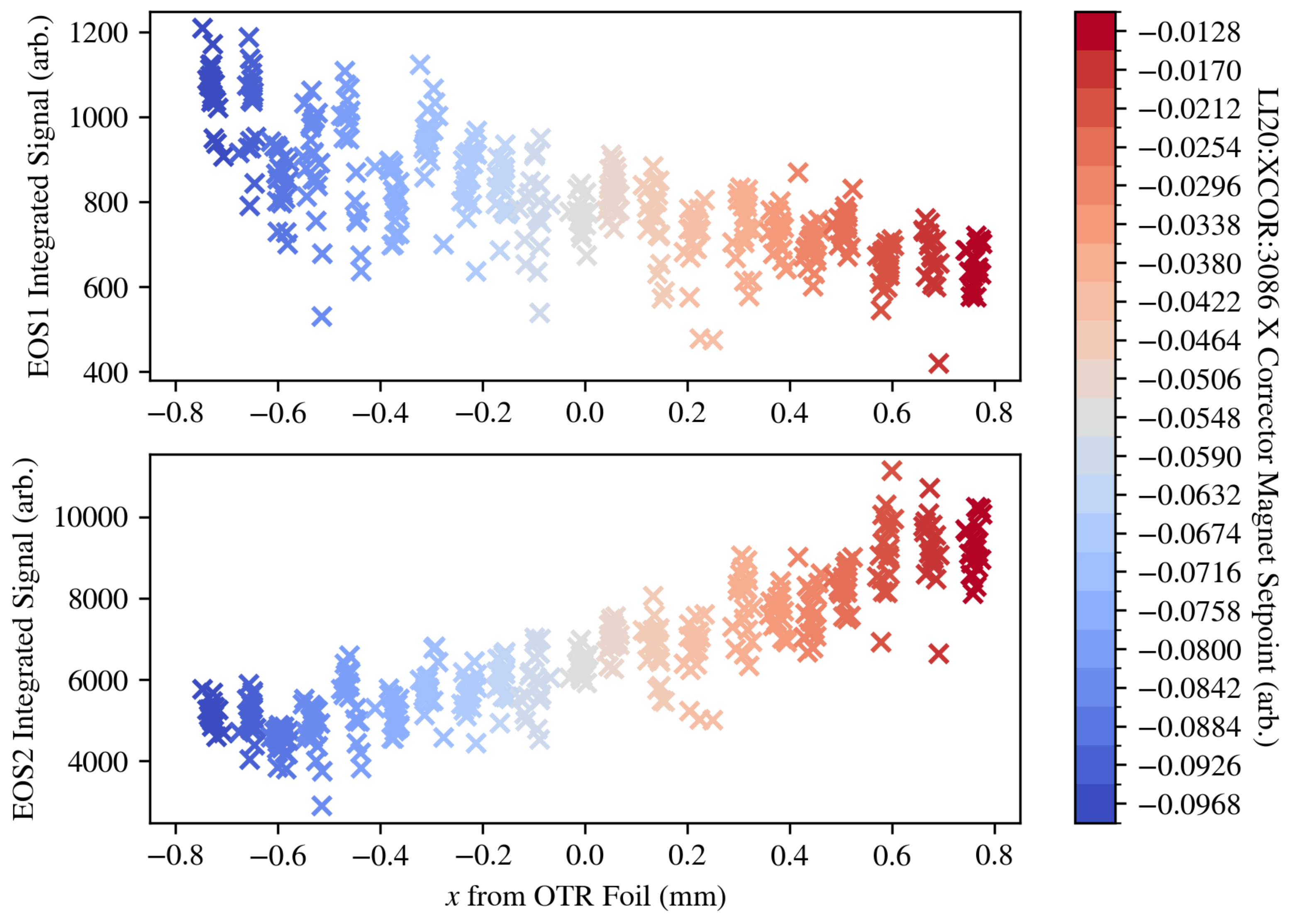


- Entire EOS-BPM assembly rests on a translation stage which we scanned the transverse position of.
- Accelerator optics were configured to image beam at EOS-BPM to a downstream OTR foil. Stage position and beam x position on OTR foil were used to get the 'true' x position at the EOS-BPM instrument.
- x position predicted from EOS-BPM was determined using the equation

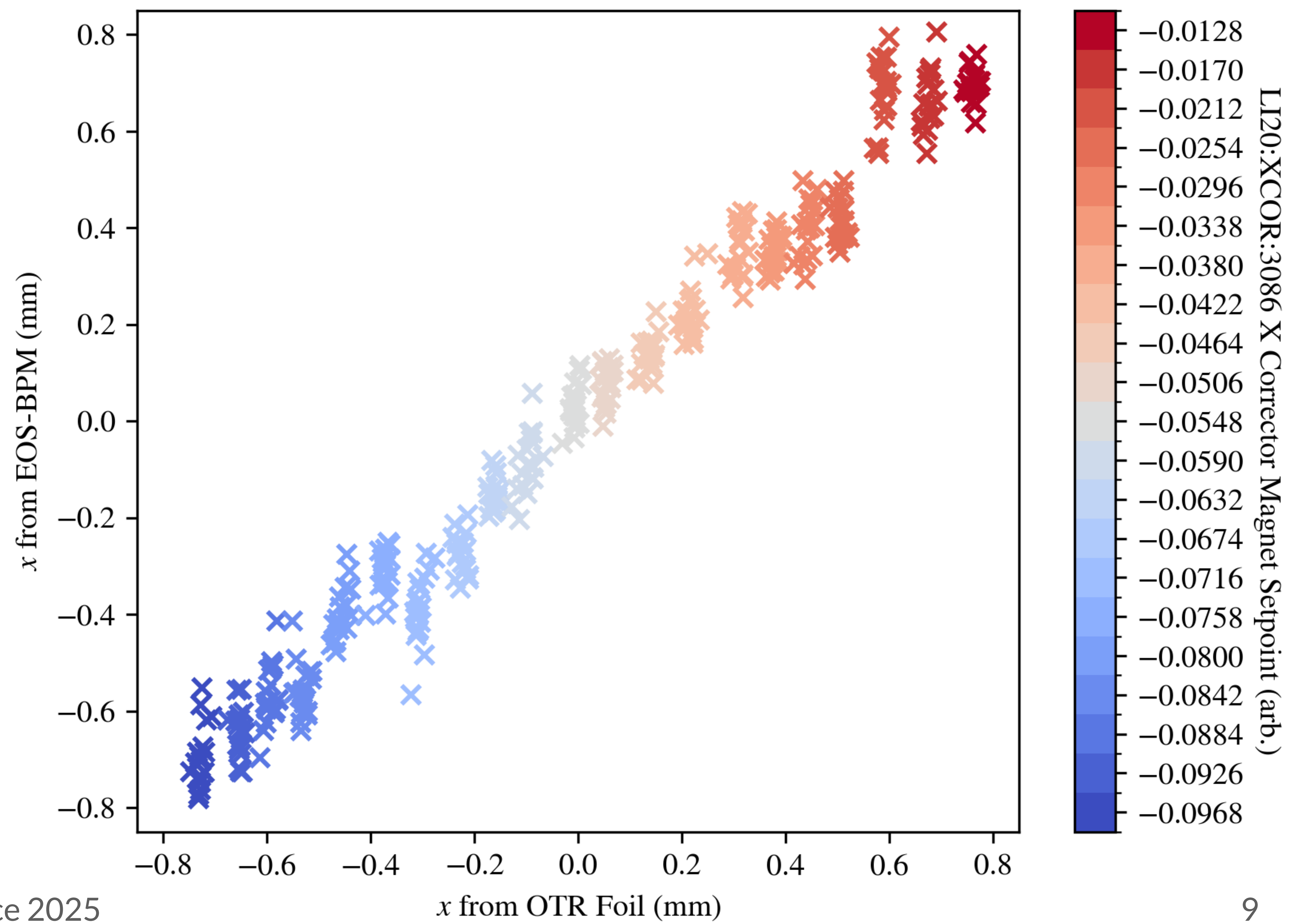
$$x_{\mathrm{EOS-BPM}} = c_1 \frac{S_1 - c_2 S_2}{S_1 + c_2 S_2} + c_3$$

- Constants c_1, c_2, c_3 were chosen via a Nelder-Mead optimization to minimize the difference between the 'true' x position and the EOS-BPM prediction.

Results — Corrector Dipole



$$\sigma(x_{\text{EOS-BPM}} - x_{\text{Stage,OTR}}) = 84.0\mu m \text{ (No Laser Intensity Correction)}$$
$$= 66.6\mu m \text{ (Laser Intensity Correction)}$$



- Field of a corrector dipole upstream of EOS-BPM was scanned
- Similar results when using OTR foil and conventional BPMs to determine 'true' position

Summary of Mk. 1 Results

1. **First demonstration of transverse beam position measurement by an EOS-BPM**

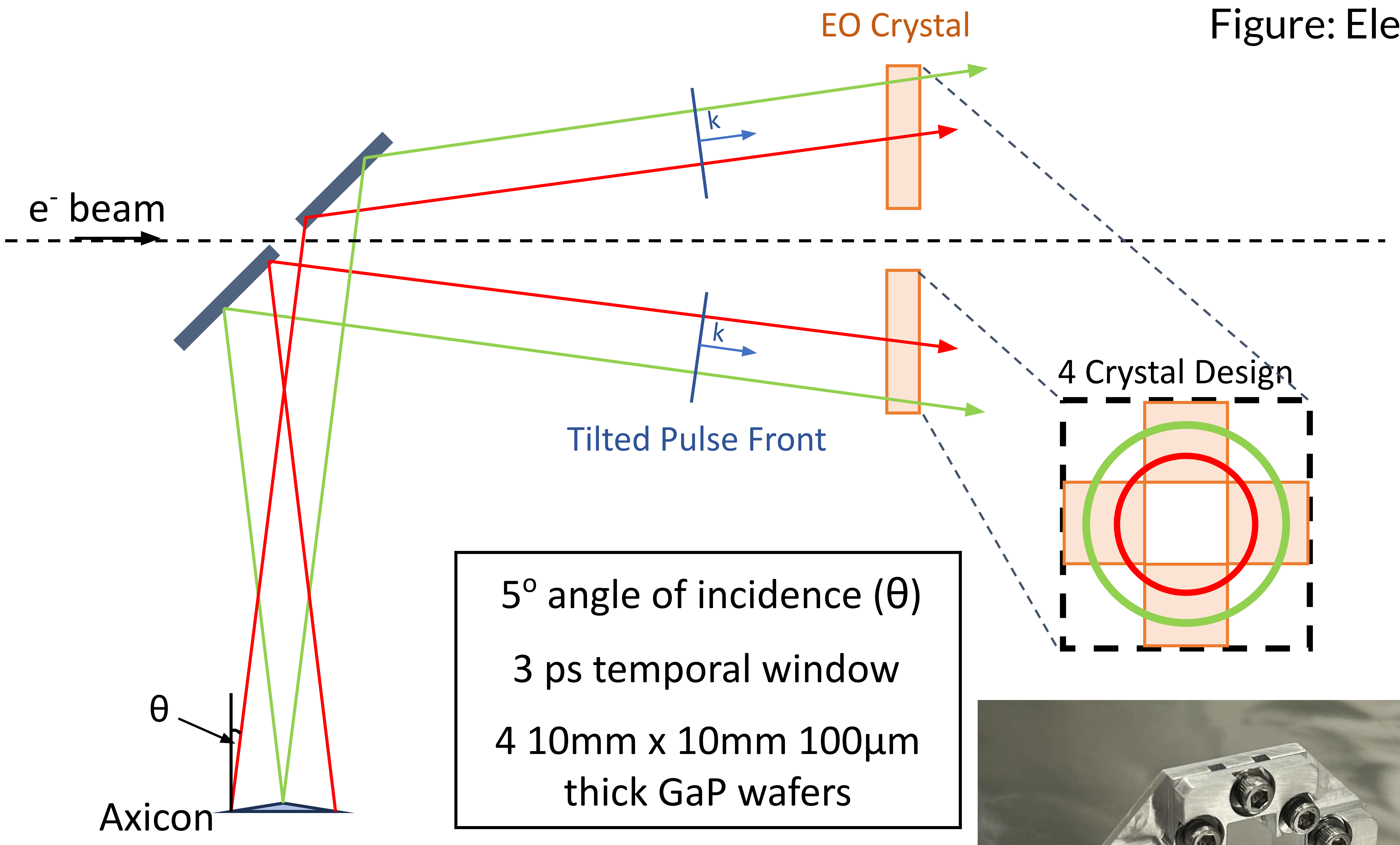
2. **Relatively poor resolution of 70μm (before focusing into a plasma)**

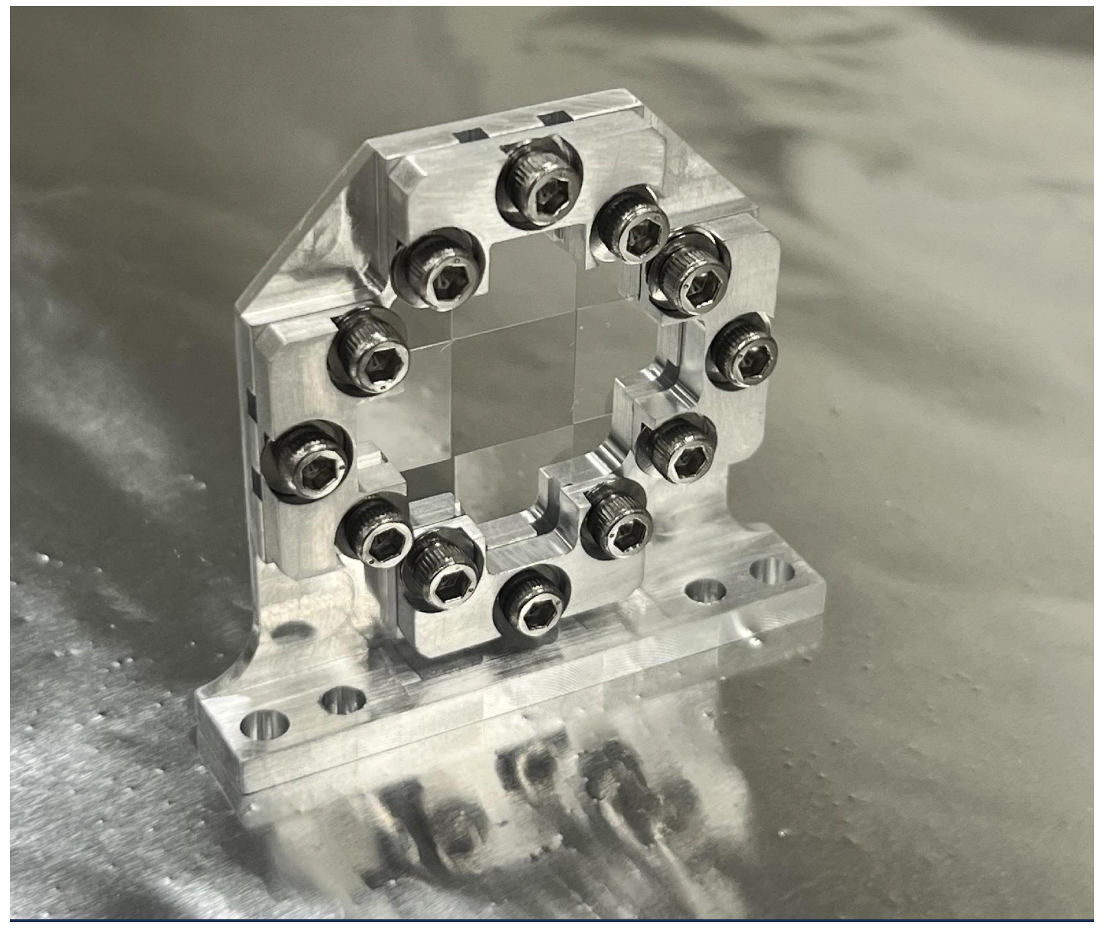
3. **What is the leading cause this error?**

EOS-BPM Mk. 2 Design

- Four crystals allow BPM functionality in both transverse dimensions.
- Axion creates circular ‘donut’ laser profile.
- Improved signal to noise over Mk. 1 Prototype leads to higher resolution

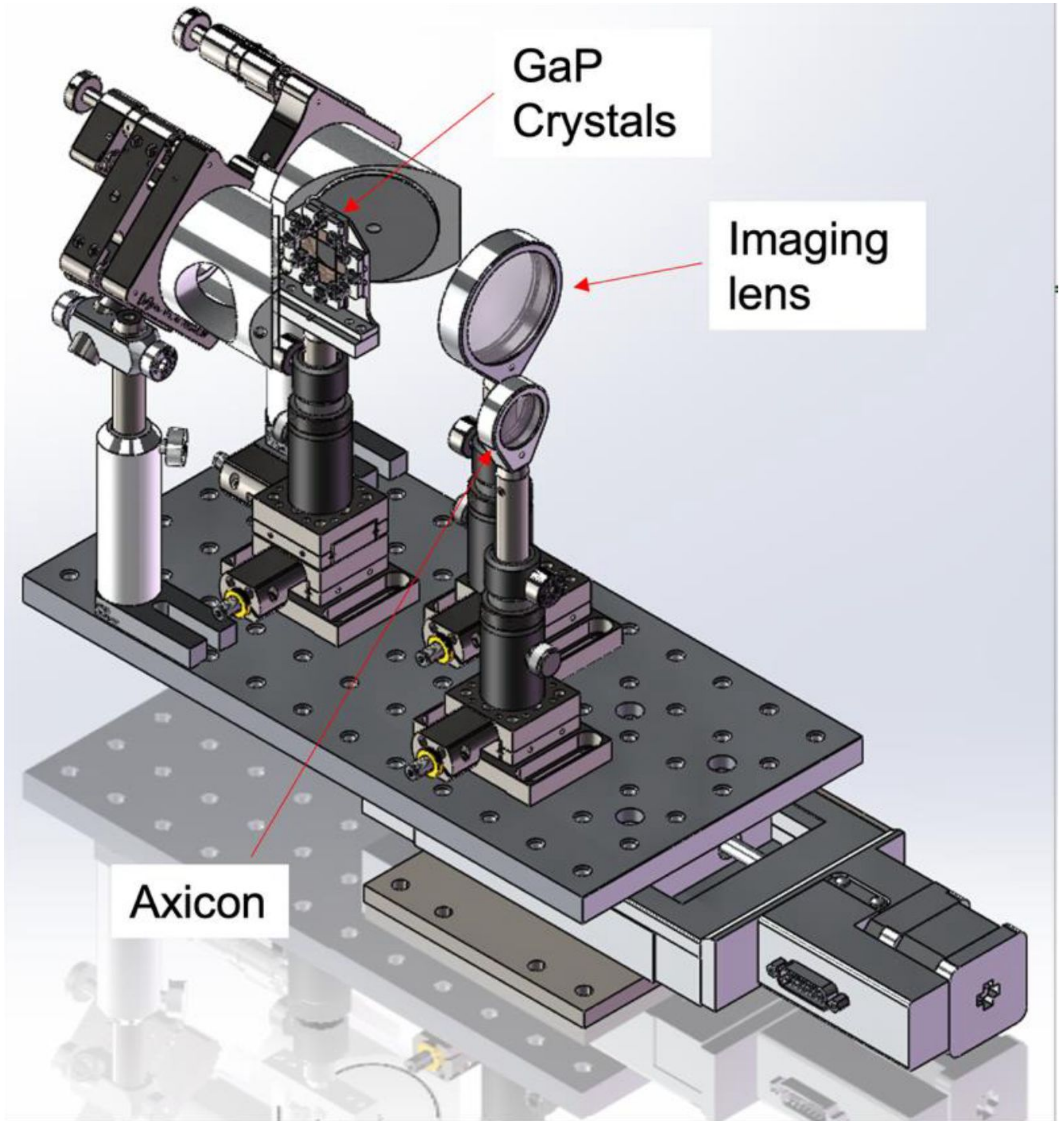
Figure: Elena Ros

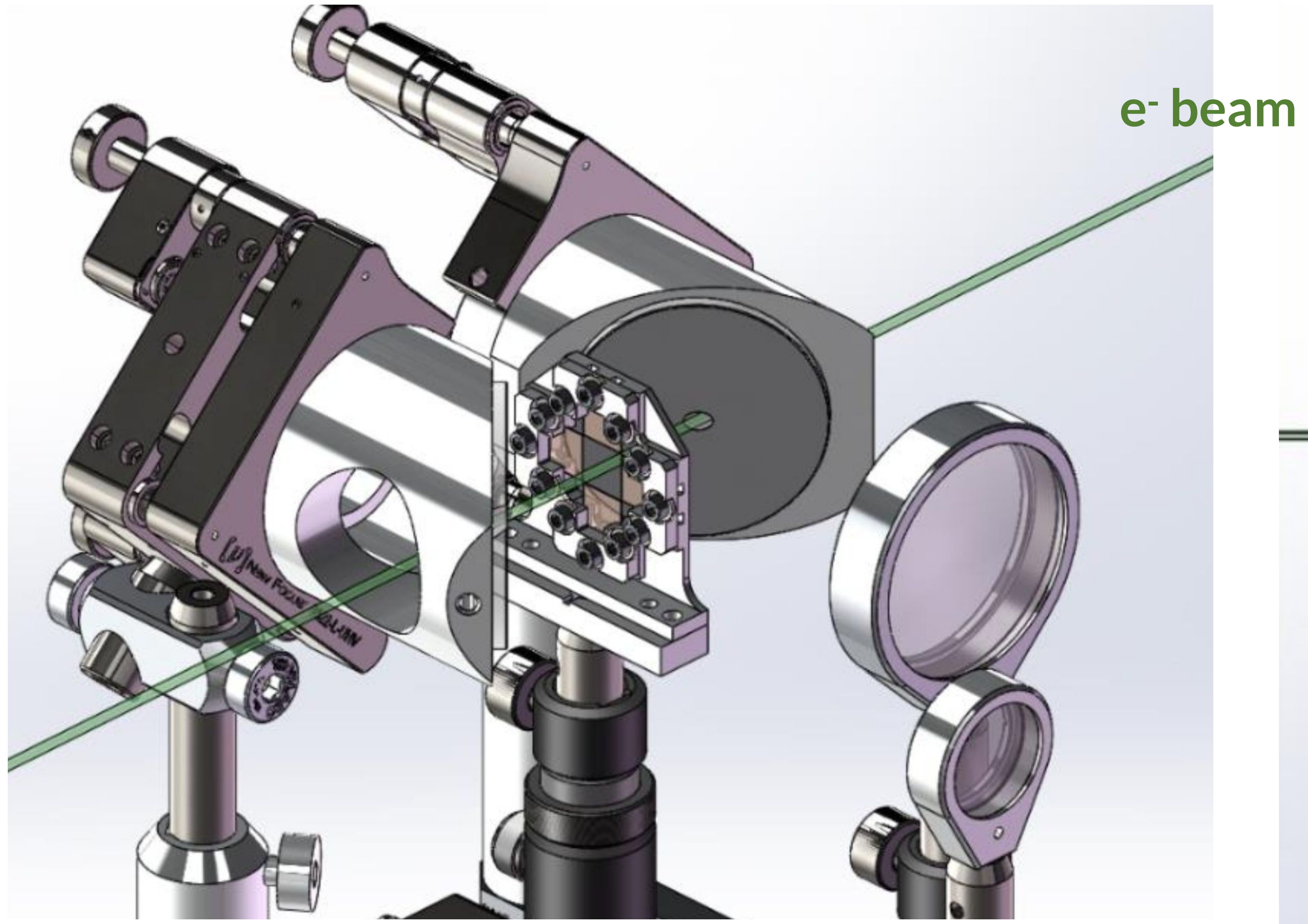


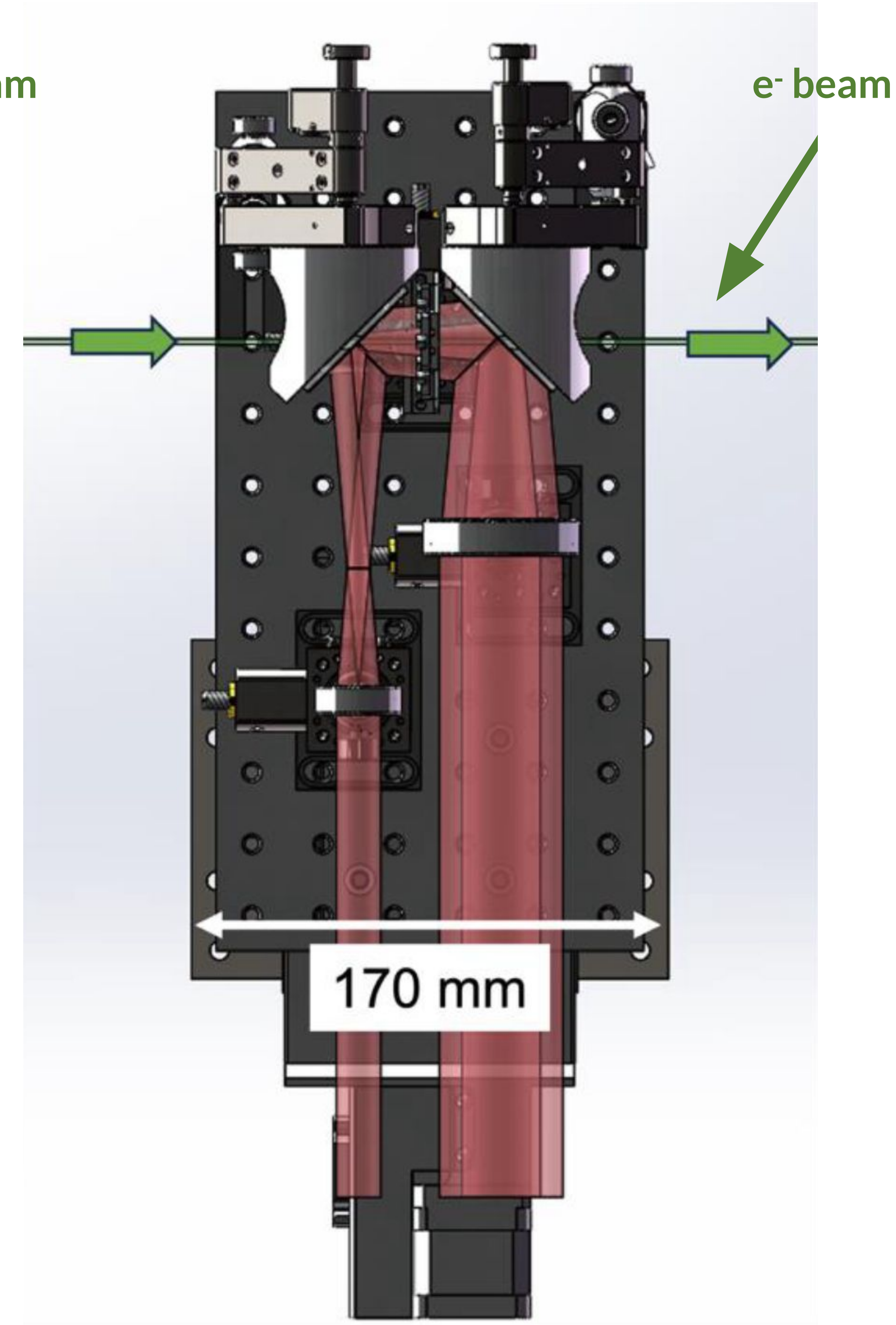


Crystal Holder

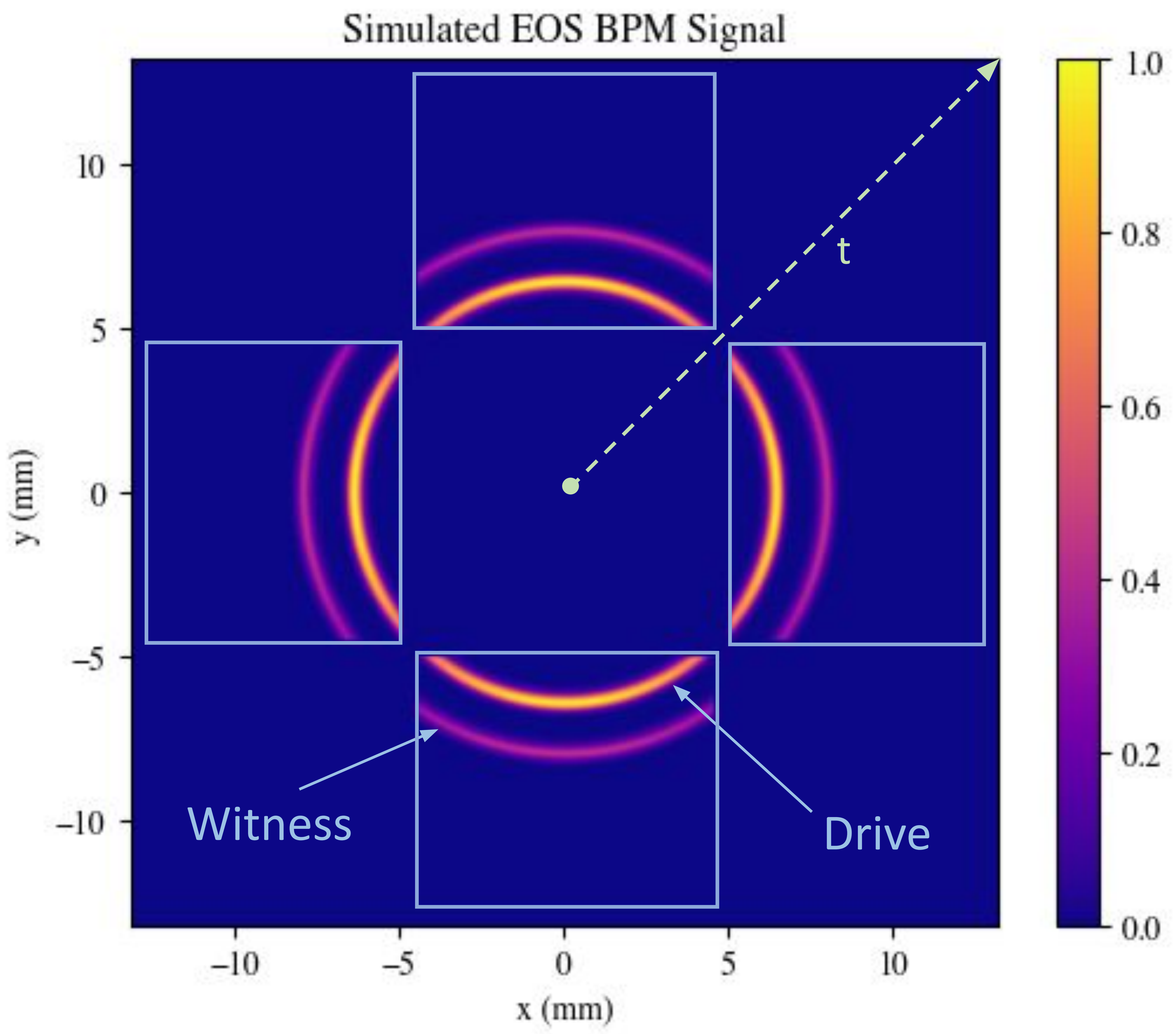
EOS-BPM Mk. 2 CAD Models







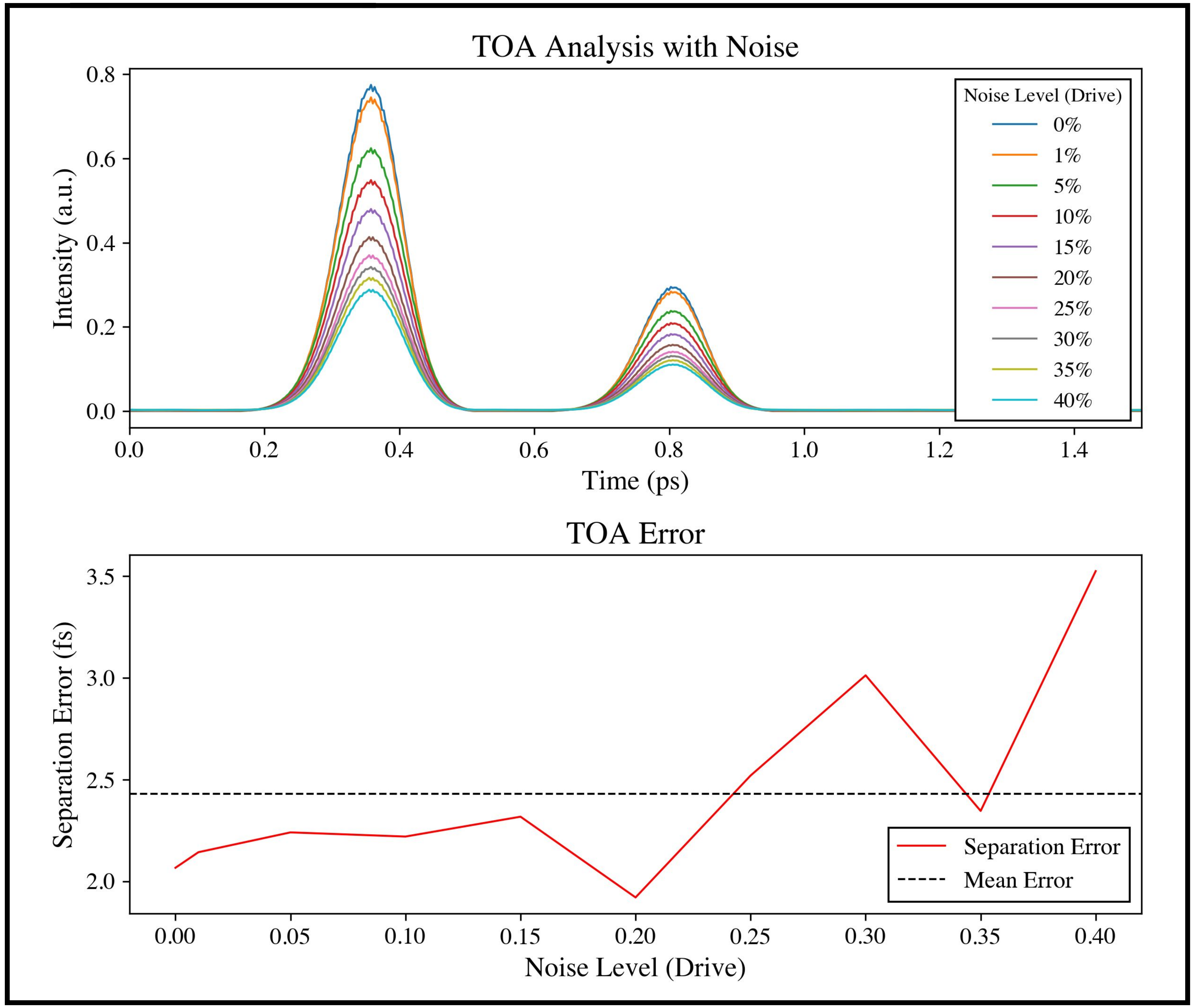
EOS-BPM Mk. 2 Simulations



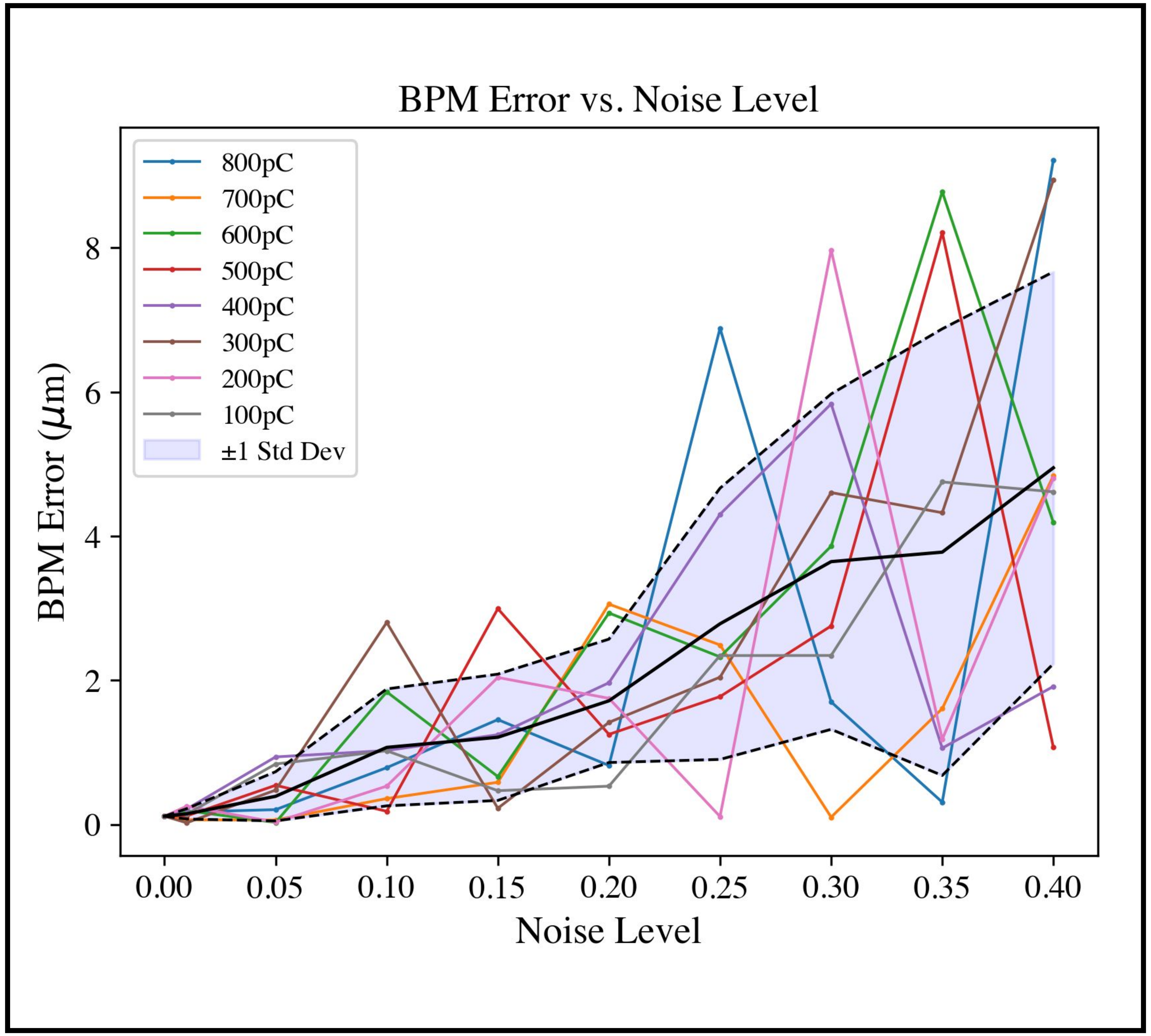
Parameter	Value	Unit
Laser Wavelength	800	nm
Laser Angle	5	degree
GaP Wafer Thickness	100	µm
Drive Beam Charge	1000	pC
Witness Beam Charge	800	pC
Time Delay btw. Beams	450/135	fs/µm
Transverse Beam Offset Drive	~10	µm
Transverse Beam Offset Witness	~10	µm
Bunch Length (Both)	50/15	fs/µm

Slide: Elena Ros

EOS-BPM Mk. 2 Simulations

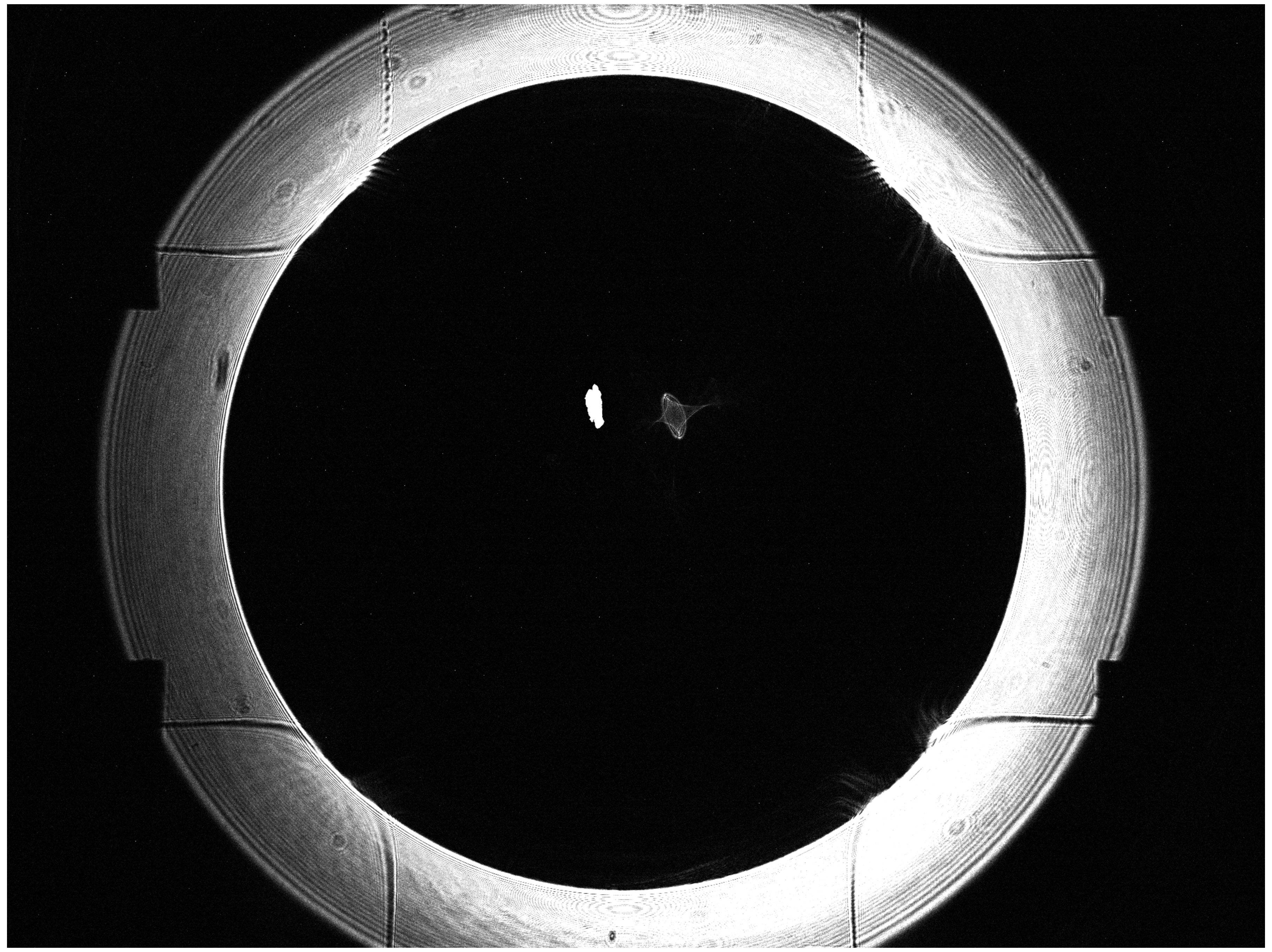


3 fs relative TOA resolution



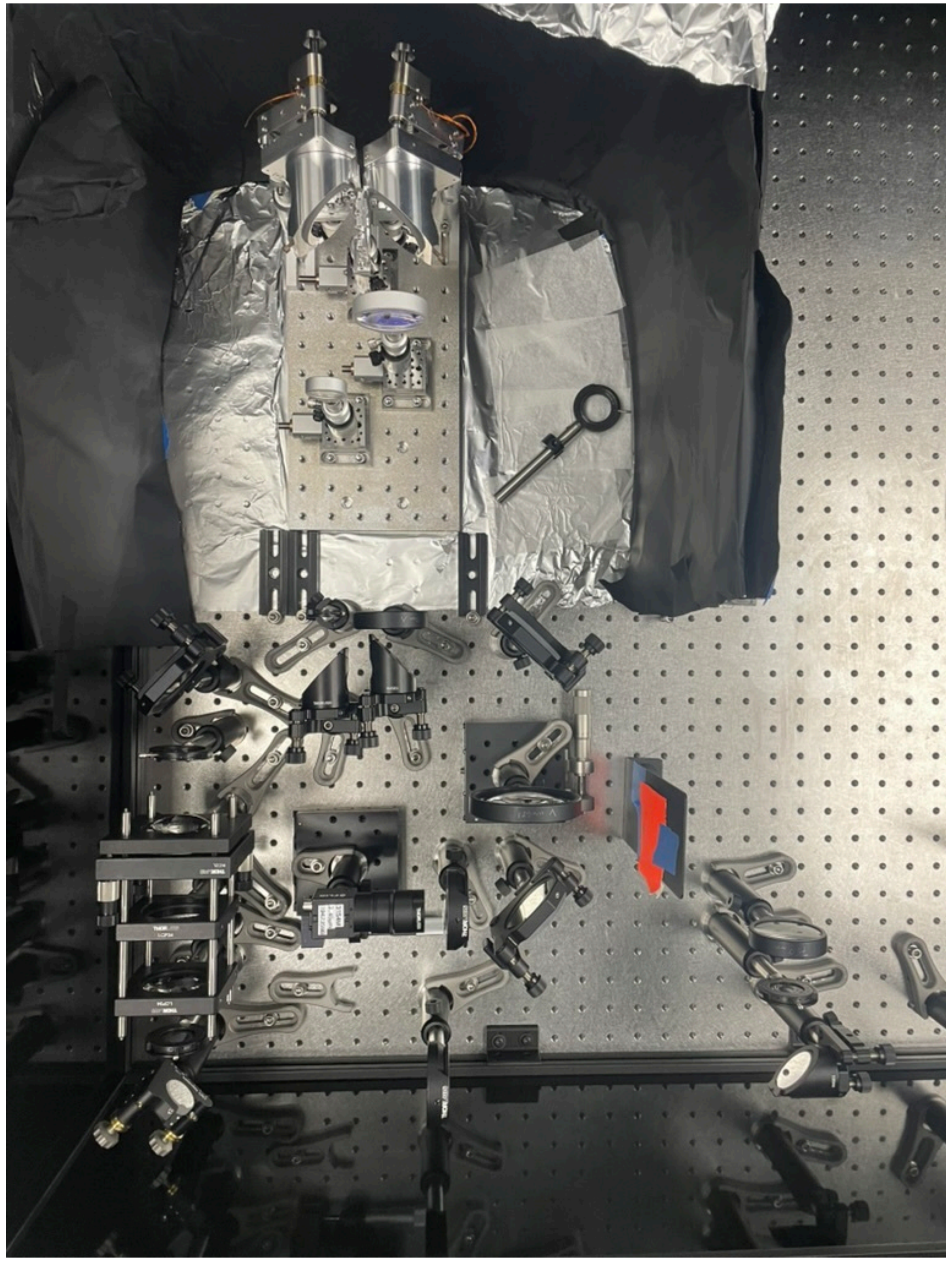
<5 µm transverse resolution

EOS-BPM Mk. 2 Status



Donut laser profile from EOS-BPM Mk. 2

- Prototype assembled and tested at CU
- Will be installed and commissioned at FACET-II this fall



EOS-BPM Mk.2 assembled at CU

Questions?

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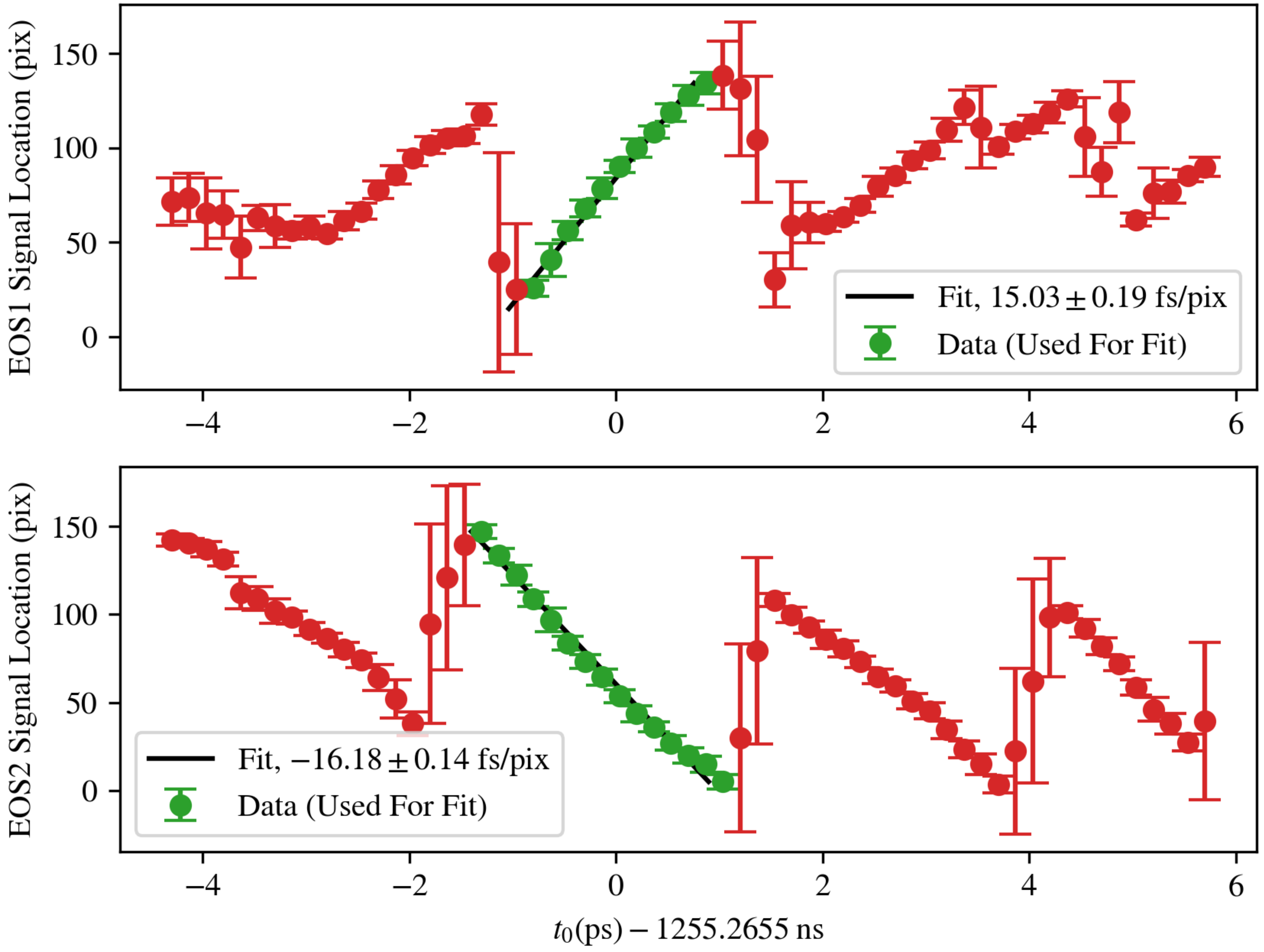
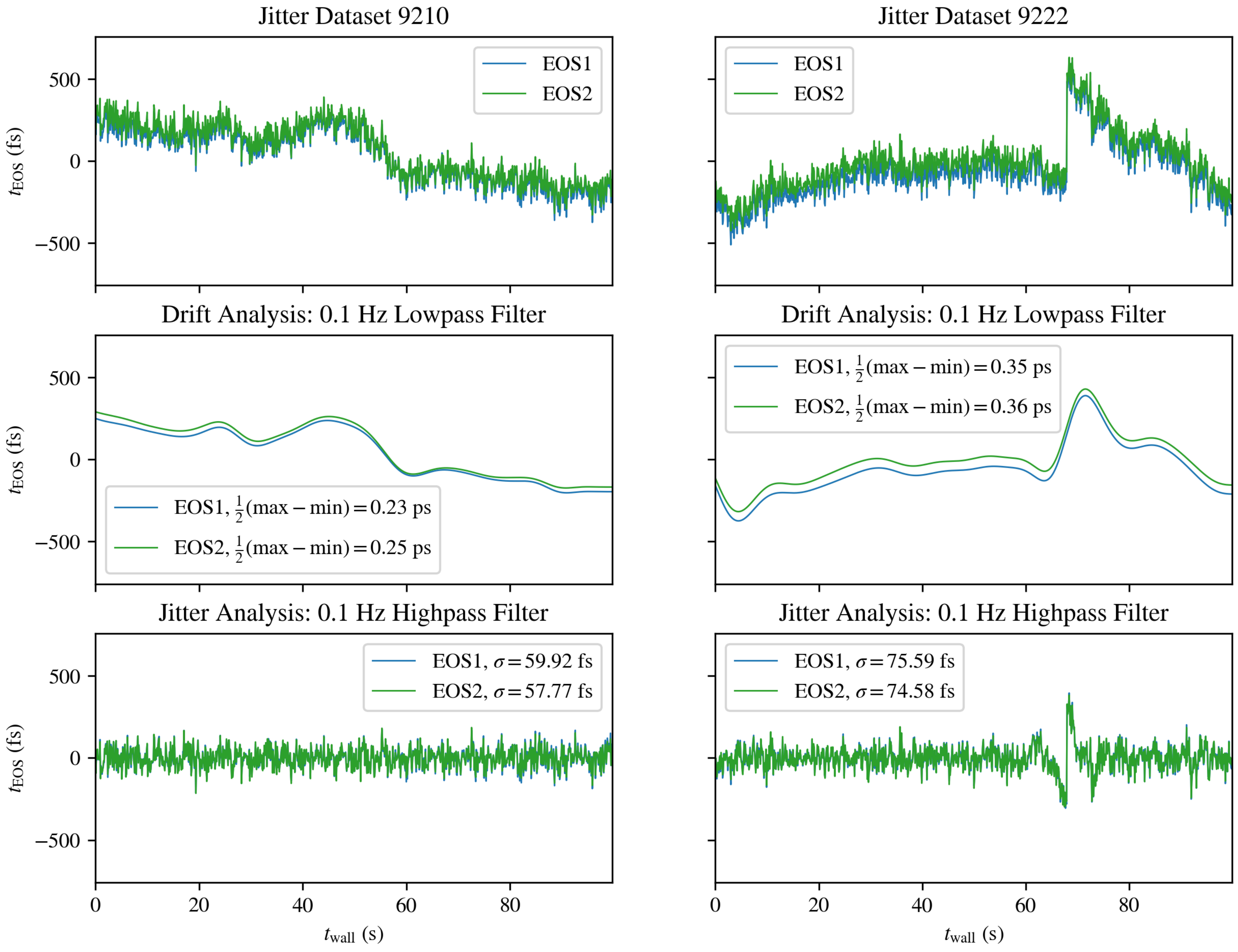
Calibration

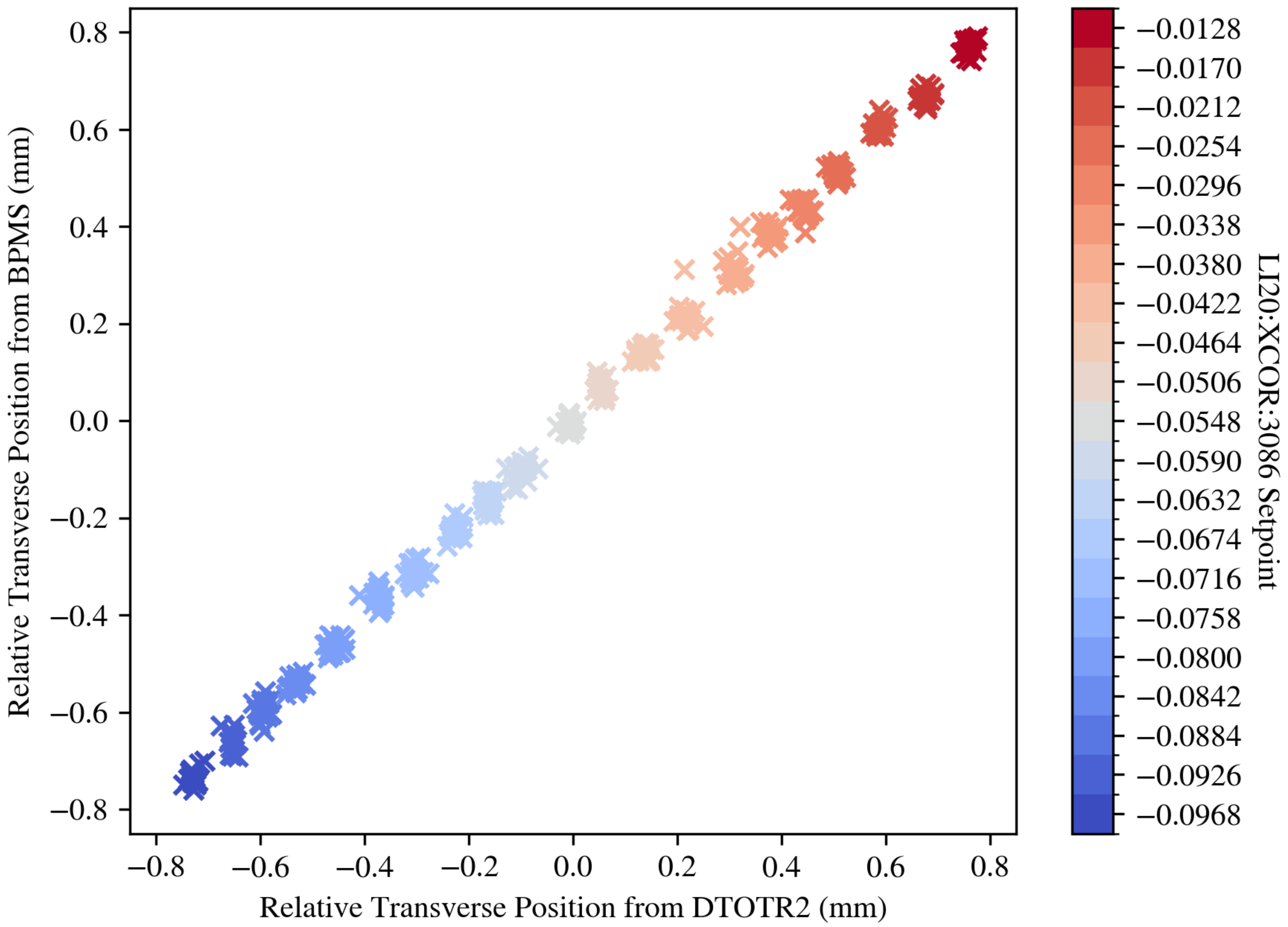


Jitter

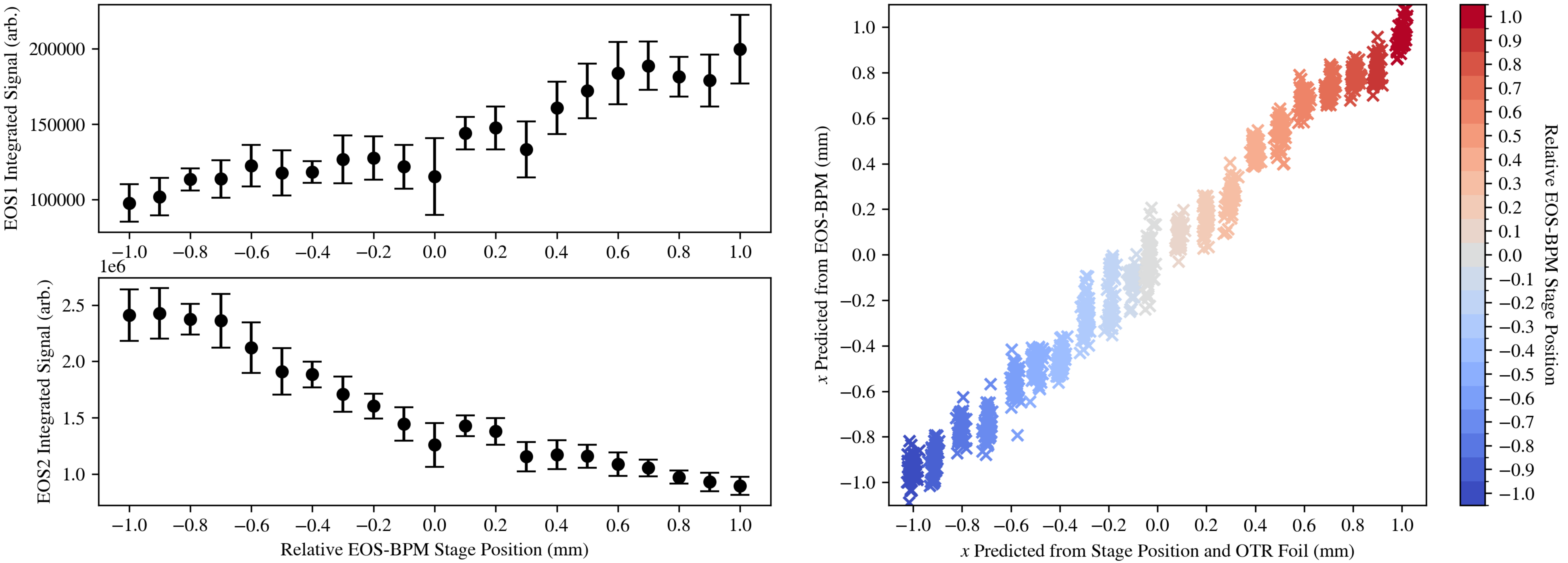

Jitter Dataset 9210
Jitter Dataset 9222
EOS1
EOS2
Drift Analysis: 0.1 Hz Lowpass Filter
EOS1, $\frac{1}{2}$(max − min) = 0.23 ps
EOS2, $\frac{1}{2}$(max − min) = 0.25 ps
EOS1, $\frac{1}{2}$(max − min) = 0.35 ps
EOS2, $\frac{1}{2}$(max − min) = 0.36 ps
Jitter Analysis: 0.1 Hz Highpass Filter
EOS1, σ = 59.92 fs
EOS2, σ = 57.77 fs
EOS1, σ = 75.59 fs
EOS2, σ = 74.58 fs
t_{EOS} (fs)
t_{wall} (s)
500
0
−500
0
20
40
60
80

DTOTR2-BPM Correlation

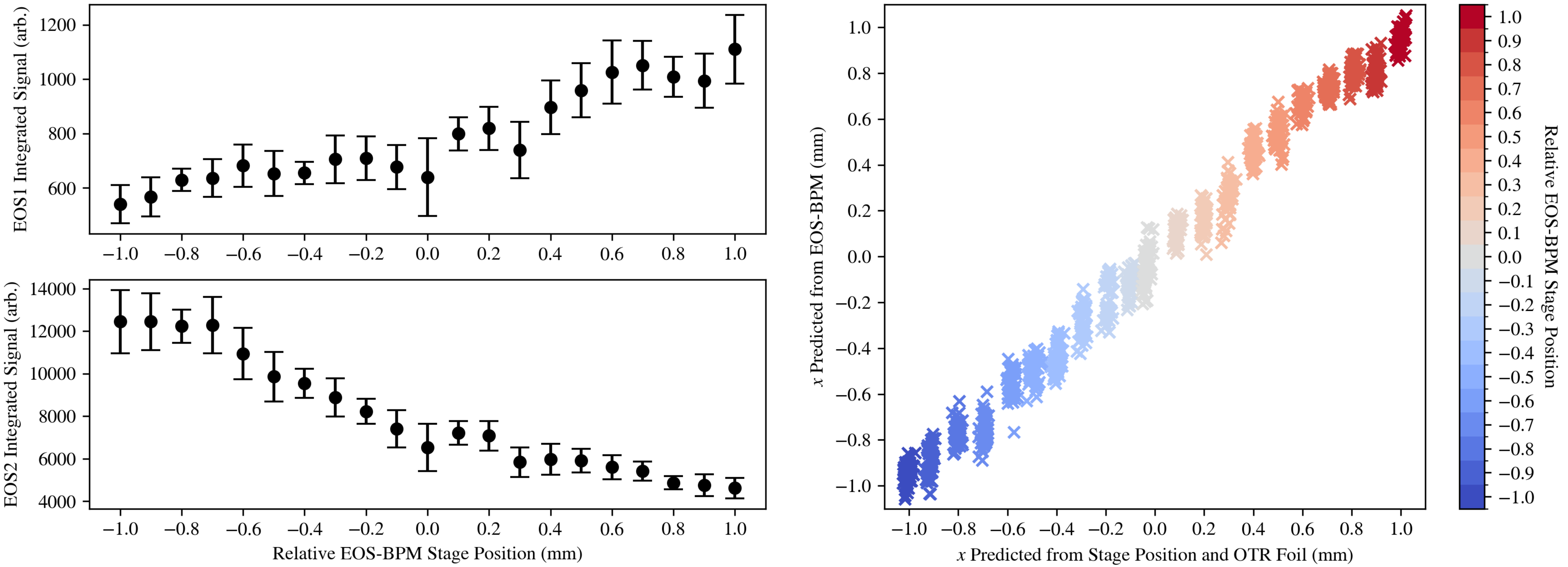
$$\sigma(x_{\mathrm{DTOTR2}} - x_{\mathrm{BPM}}) = 20.0\mu\mathrm{m}$$



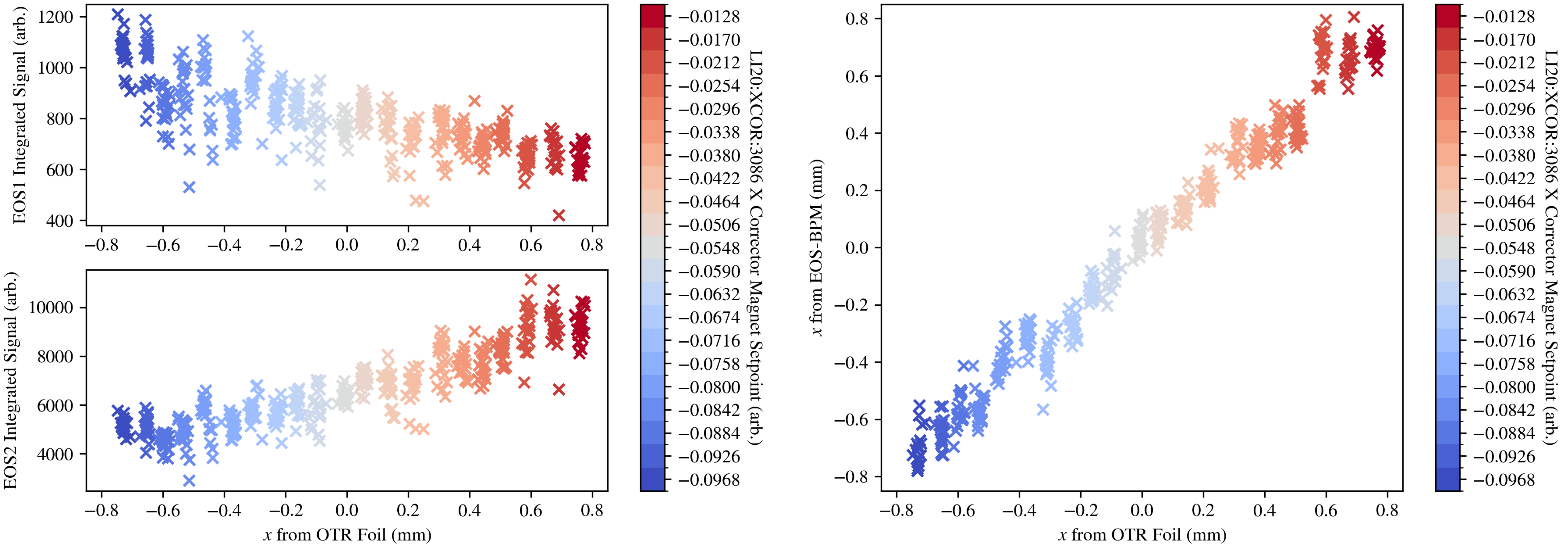
Stage Scan—Intensity Correction Off



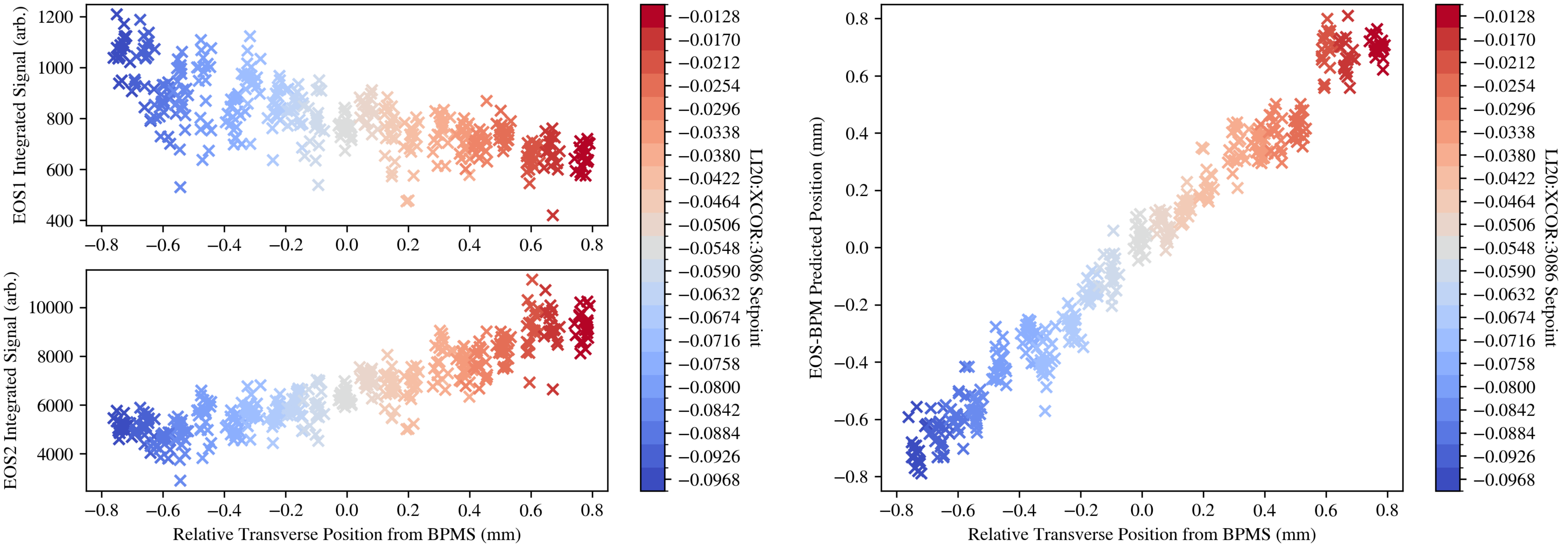
Stage Scan—Intensity Correction On



XCORR Scan—Intensity Correction On DTOTR2



XCORR Scan—Intensity Correction On BPMs



XCORR Scan—Intensity Correction On BPMs

	Intensity Correction Off	Intensity Correction On
Stage	73.1 um	69.0 um
XCORR BPM	86.2 um	69.8 um
XCORR DTOTR2	84 um	66.6 um