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Submicropulse Energy-Time Correlations of 40-MeV Electron Beams at FAST*

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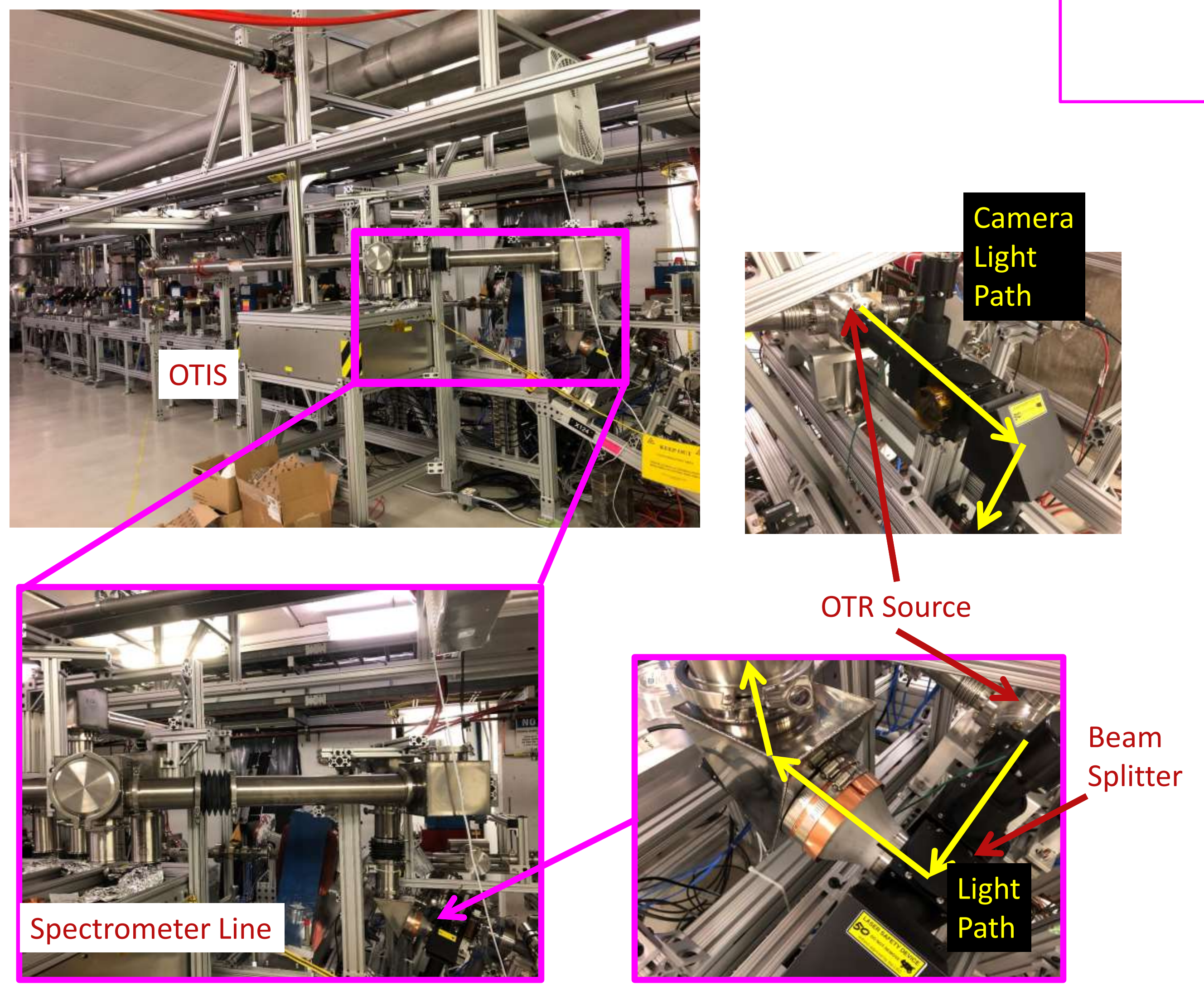
Abstract

We have recently extended our ability to explore submicropulse effects in relativistic electron beams to energy-time (E-t) correlations. The Fermilab Accelerator Science and Technology (FAST) facility consists of a photoinjector, two superconducting TESLA-type capture cavities, one superconducting ILC-style cryomodule, and a small ring for studying non-linear, integrable beam optics called IOTA. The linac contains, as part of its instrumentation, an optical transport system that directs optical transition radiation (OTR) from an Al-coated Si surface to an externally located streak camera for bunch length measurements. For the first time, an OTR screen after the spectrometer magnet was used for measurements of submicropulse E-t correlations. The projected, micropulse time profile was fit to a single Gaussian peak with σ = 11.5 ± 0.5 ps for 500 pC/micropulse and with a 200-micropulse synchronous sum, in agreement with the upstream bunch-length measurement at a non-energy-dispersive location. The submicropulse E-t images were explored for four rf phases of CC1, and the E vs. t effects will be presented.

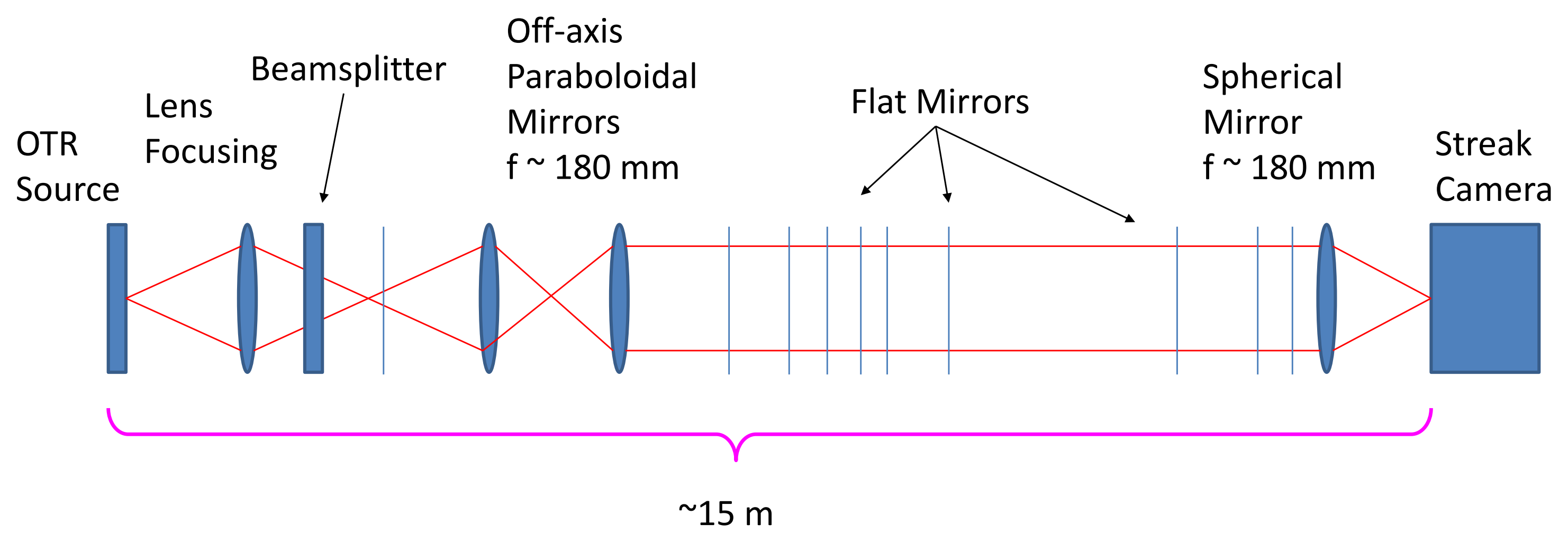
Experimental Apparatus

The measurements utilize a new addition to the existing Optical and Terahertz Instrumentation System (OTIS) [3]. An optical transport line was added from the spectrometer camera OTR source to the streak camera outside the beam enclosure. A pellicle beam splitter was added to the camera optical transport and directs light through the OTIS box and to the streak camera. The streak camera is a Hamamatsu C5680 mainframe with S20 PC streak tube that can accommodate a vertical sweep plugin unit and a horizontal sweep unit or blanking unit. It is also equipped with the M5675 synchroscan unit which allows the accumulation many micropulses with no significant phase jitter.

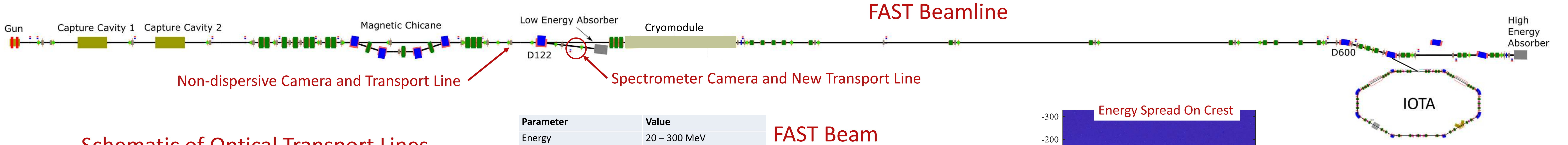


Optical Path

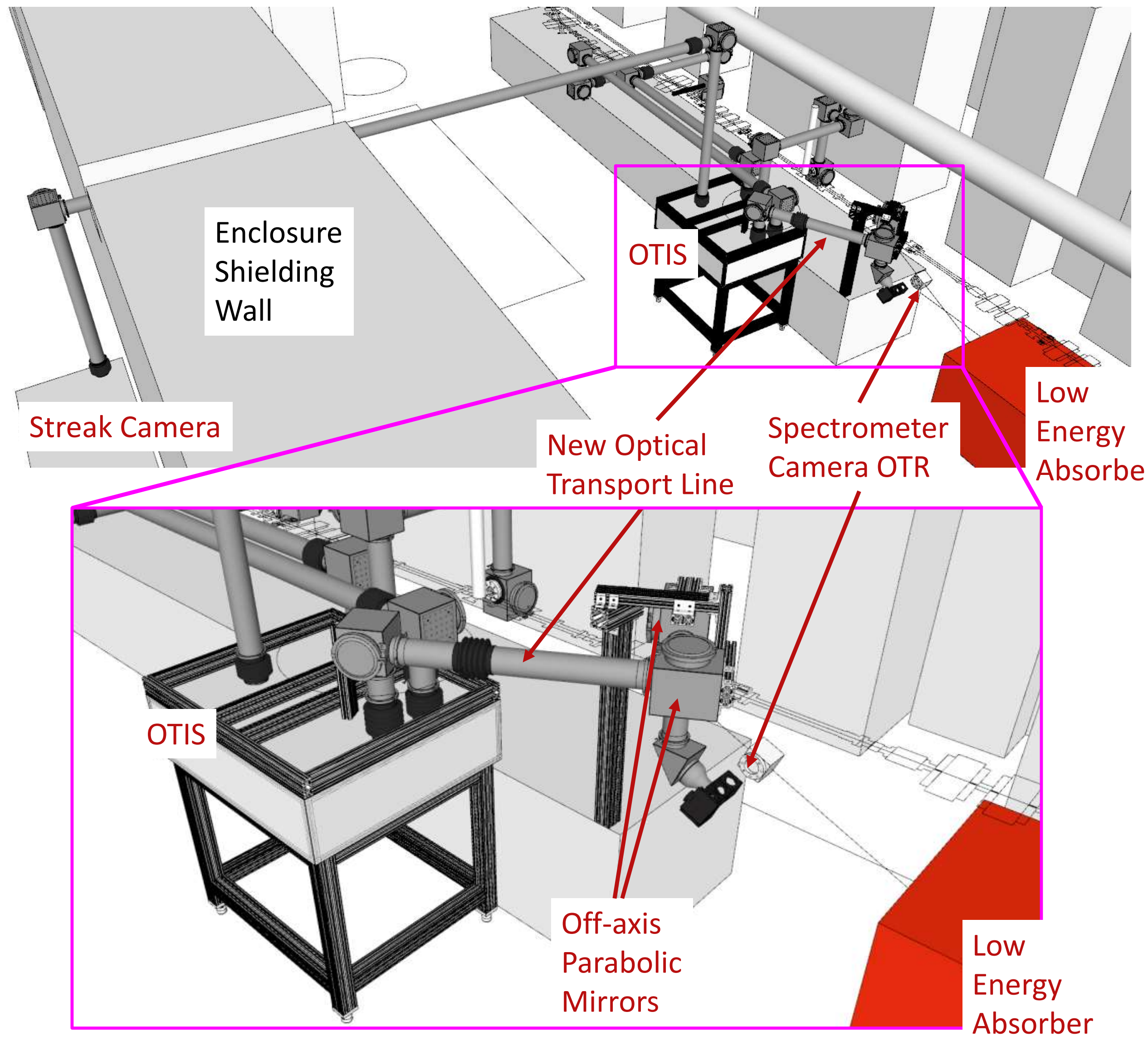
Effective optical path of the new transport line from OTR source to streak camera (not to scale). There are 10 flat mirrors (indicated by the thin lines) in addition to the labeled optical components.



FAST Beamline

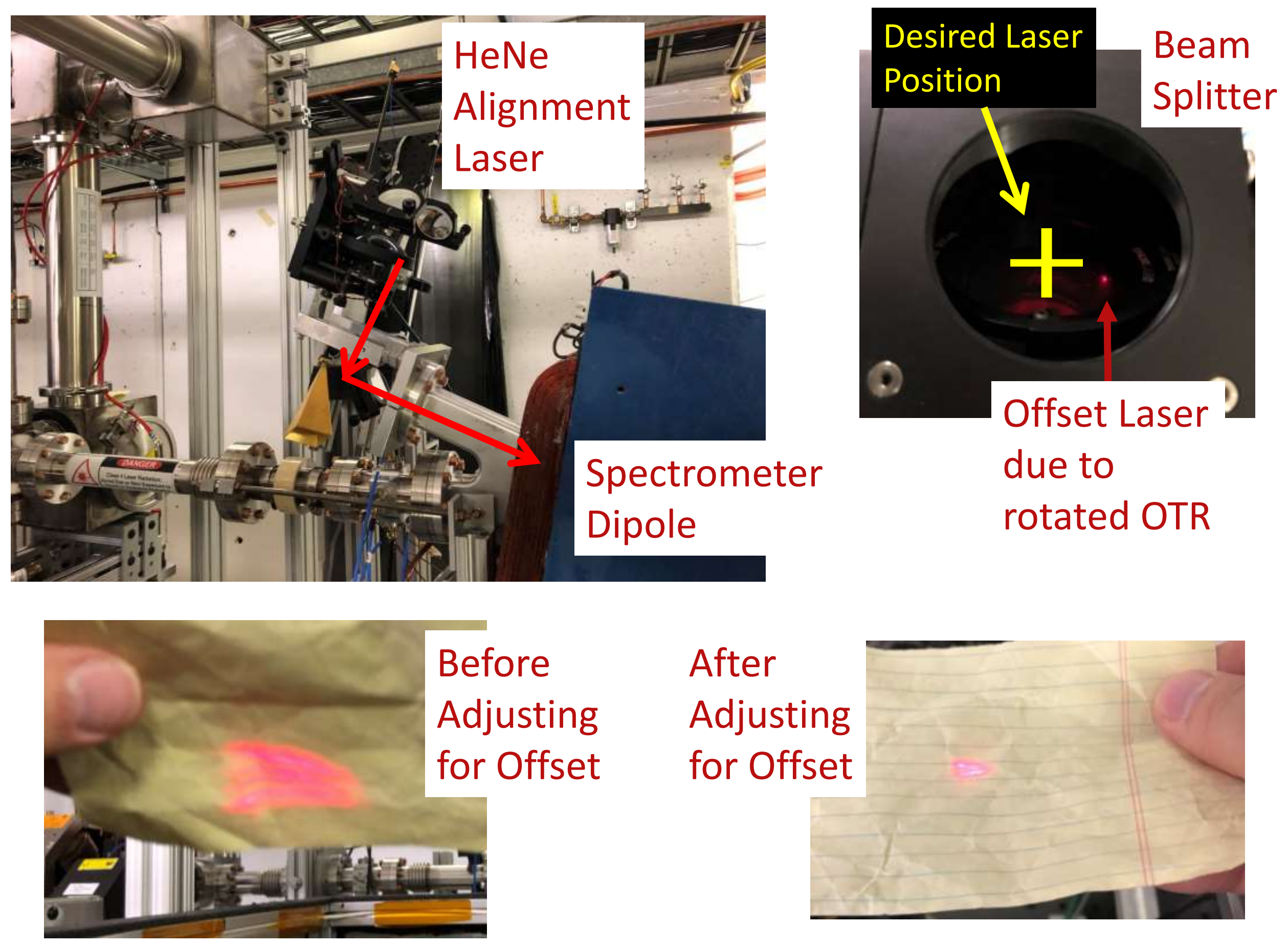


Schematic of Optical Transport Lines



Alignment

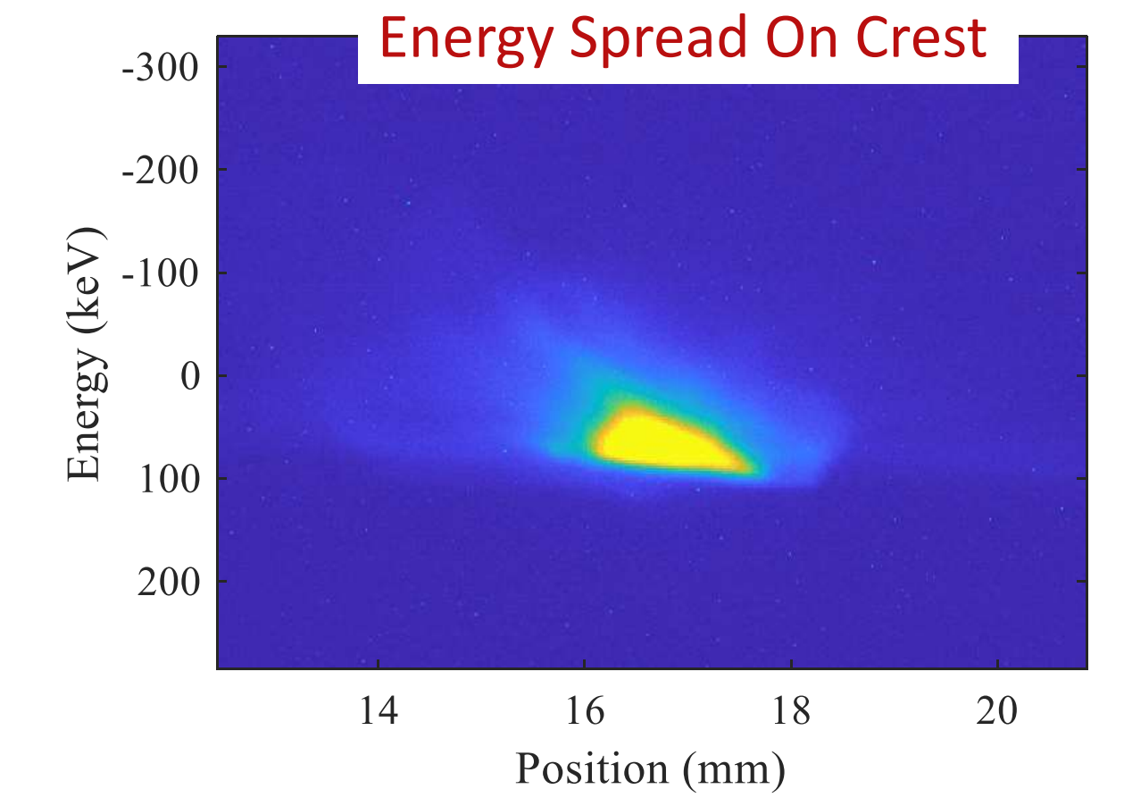
The alignment of the transport line was accomplished via a laser injected through a viewport on the input side of the spectrometer magnet. It was focused at the location of the OTR screen and allowed to exit by reflection off the screen which allowed us to both align and adjust the collimation of the transport line. In attempting to align the transport line it was discovered that the OTR screen is not positioned at 45 degrees to the beam. It appears to be off by about 5 degrees which complicated the alignment slightly as the focusing properties of off-axis parabolic mirrors are sensitive to the position and direction of the light. Below, the misalignment can be seen at the beam splitter. This caused the light to follow a zig-zag path inducing distortion from the paraboloidal mirrors.



FAST Beam Parameters

Parameter	Value
Energy	20 – 300 MeV
Bunch Charge	< 10 fC – 3.2 nC
Bunch Frequency	0.5 – 9 MHz
Macropulse Duration	≤ 1 ms
Macropulse Frequency	1 – 5 Hz
Transverse Emittance	> 1 μm
Bunch Length	0.9 – 70 ps

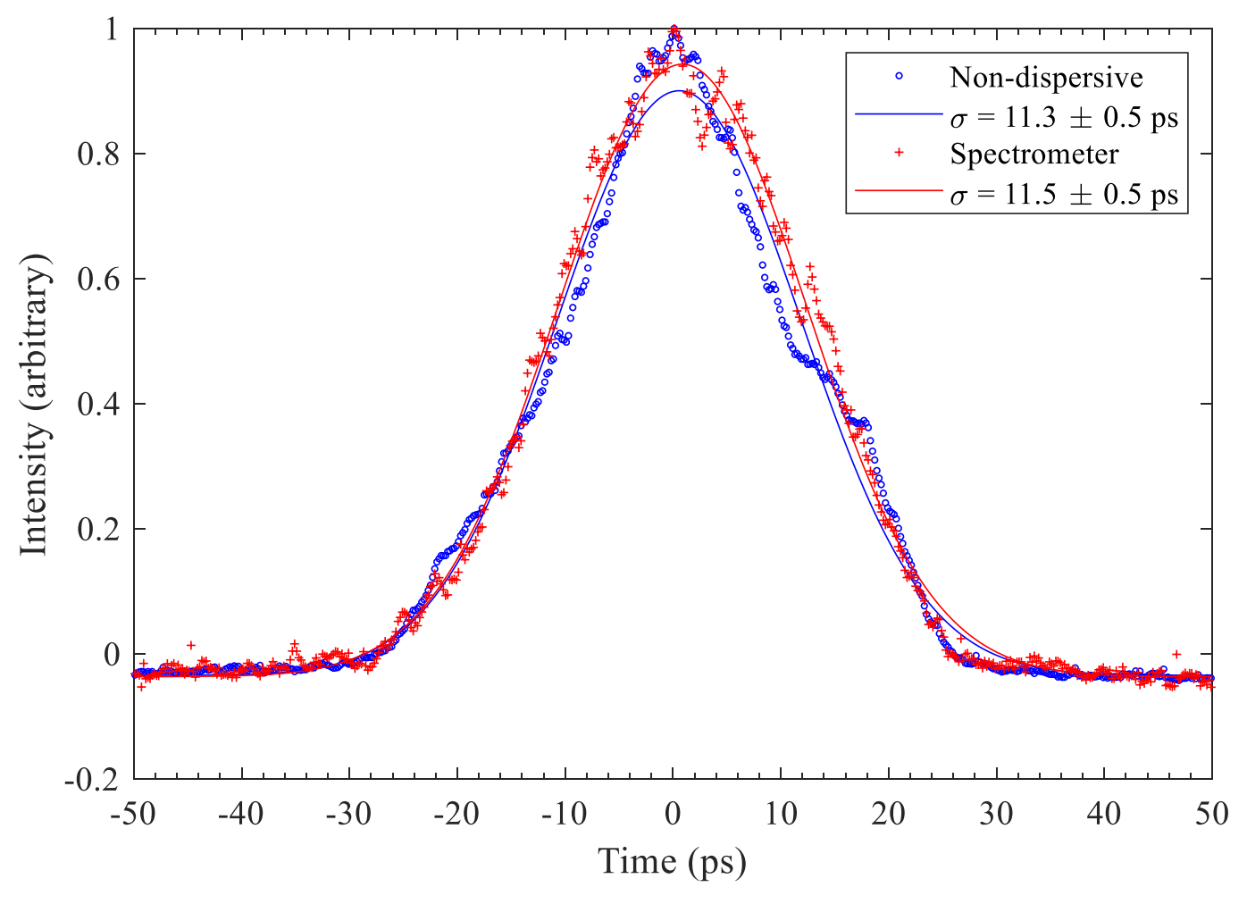
Energy Spread On Crest



Measurement

Our measurement of the E-t phase space utilizes changes in the rf phase of the first capture cavity, CC1. The beamline was setup with the gun providing ~4.5 MeV, CC1 providing ~23 MeV, CC2 providing ~13 MeV, and 500 pC per micropulse. Initially, beam images from the YAG:Ce screen in the spectrometer were taken to get a measure of the intrinsic energy spread with the beam on crest. Measurements using the OTR screen in the spectrometer were then taken at various degrees off-crest. . Images taken from the spectrometer are an accumulation of 10 camera images, each an accumulation of 200 micropulses. A comparison of bunch length between that measured from the spectrometer line, and that measured from an upstream non-dispersive region were found to be in good agreement. The images from the non-dispersive line were 10 camera images of 150 micropulses.

Bunch Length
Spectrometer vs. Non-dispersive

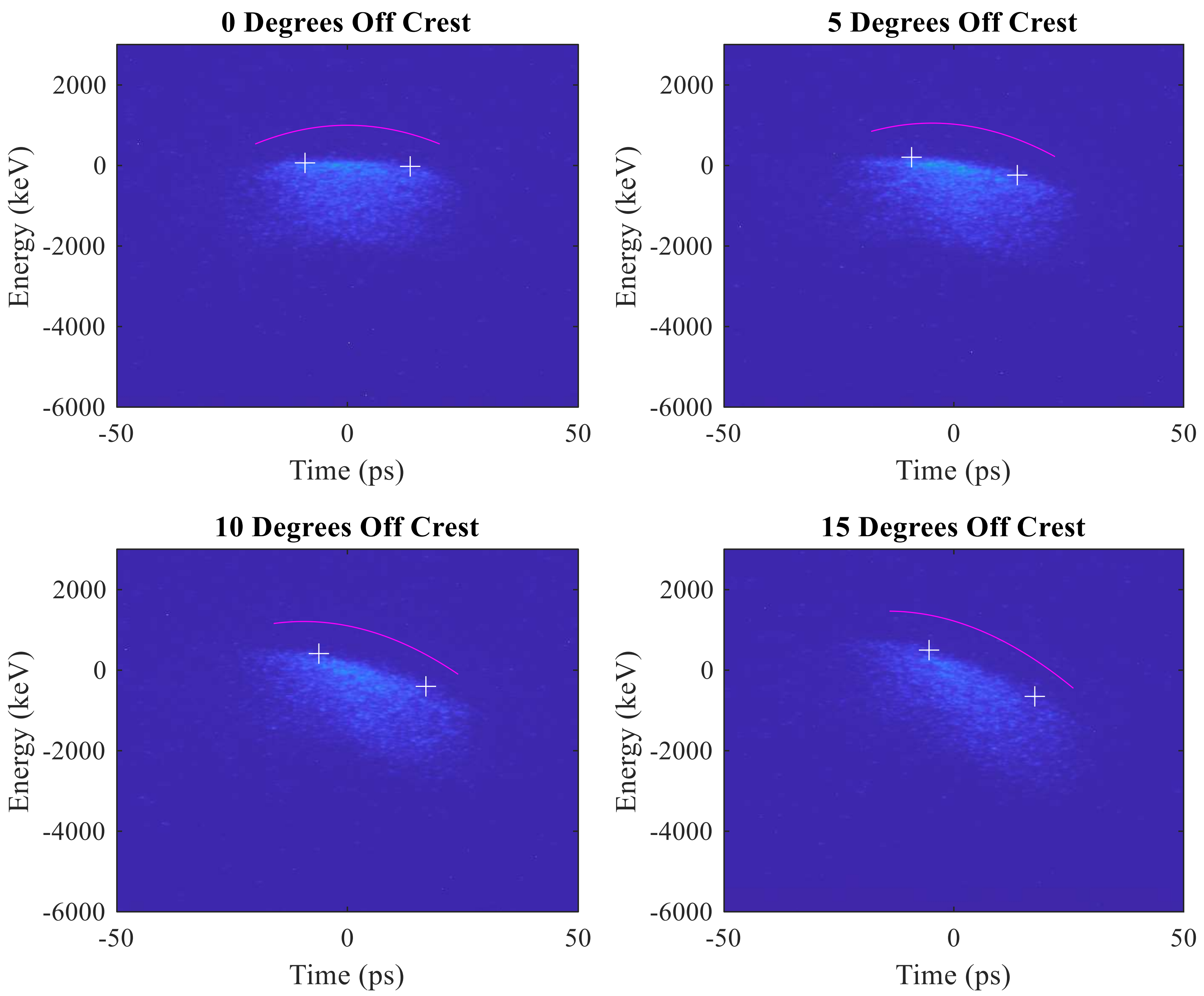


To determine the sensitivity of the setup to changes in the E-t phase space, the phase and amplitude of CC1 were changed to move the beam off the rf crest and induce a slope in the phase space. Four phase values were used: 0, 5, 10, and 15 degrees off crest.

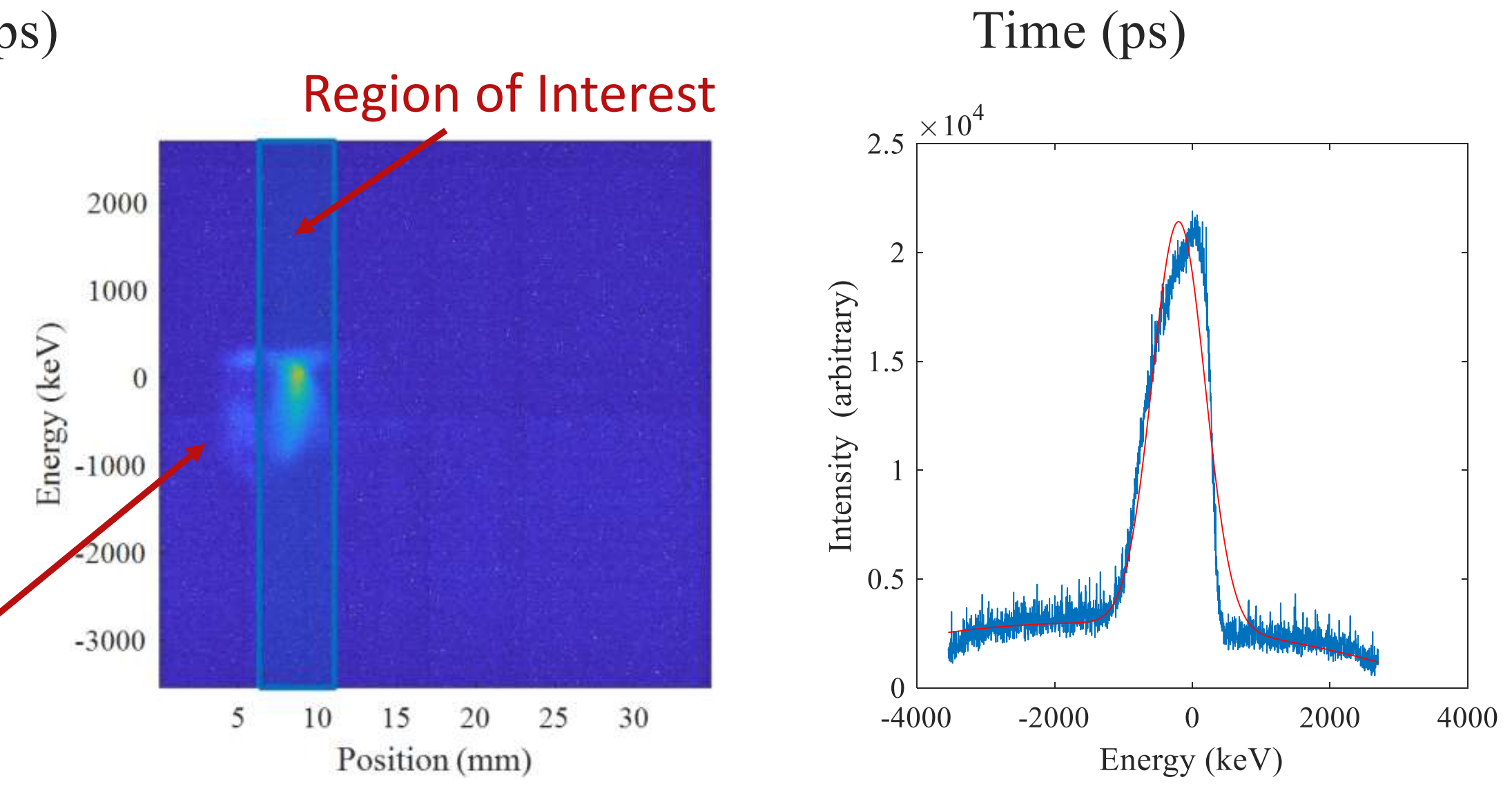
The crosses in the images are the points which were used to obtain the slope induced by the rf. Using those points together with the slope of the rf sinusoid we obtain a calibration constant for the 5, 10, and 15 degrees off crest cases of 10.9, 10.7, and 10.9 KeV/pixel respectively. The consistency builds confidence in the technique.

The red curves are the predicted energy curvature from the sinusoidal shape of the rf from CC1 and CC2 and the previously measured calibration constants.

The upper shape of the beam images seem to fit well with the expectation, however, the vertical size does not correspond well at all with the expected energy spread. From our initial energy spread, we would expect something on the order of 50 to 100 KeV, but from the 0-degree image, the spread is more like 2 MeV. One possible explanation for this is poor focusing resulting from the rotated OTR screen.



Additional cross-check of the expected energy spread from the rf phase offset. This is the spectrometer camera image of the OTR screen for 15 degrees off crest. For a micropulse with rms length of 11.5 ps, the expected rms energy spread from the slope of the rf is ~500 KeV. Accounting for the actual sinusoidal shape of the rf results in a rms energy spread of 580 KeV. The gaussian fit in the far-right plot has a sigma of 383 KeV. Some of this discrepancy may be due to poor positioning of the beam on the OTR screen, since it appears that part of the beam may be off the screen.



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