First results of the E302 experiment at the FACET-II facility

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Abstract

Plasma-wakefield accelerators are capable of sustaining accelerating fields on the GV/m scale, making them well-suited for shrinking the size and cost of future linear colliders. The recently proposed efficiency–instability relation sets an upper limit on the achievable power transfer efficiency from the driver to the trailing bunch if the stability of the transverse phase space of the trailing bunch is to be preserved. Examining the relation between efficiency and strength of transverse instabilities is a main objective in the E302 experiment which aims to identify, measure, and mitigate the beam-breakup (BBU) instability in beam-driven plasma-wakefield acceleration. We will discuss data taken during the first experimental shifts at the FACET-II facility at SLAC, Menlo Park, CA in April 2025. The shifts focused on (1) measuring the instability using the dipole spectrometer at FACET-II with parallel-to-point imaging, and (2) seeding a transverse offset between the trailing and driving bunches using a transverse deflecting cavity.

Measurement setup: FACET-II imaging spectrometer

- Dispersive dipole magnet is used to determine the energy spectrum of the beam.
- Focusing quadrupole triplet used for emittance measurements.
- In-vacuum OTR screen, scintillator screen, Cherenkov light spectrometer.

Observing instability through angular kicks

- m_{12} is the transport matrix element that converts angle at the object plane to position on the spectrometer screen.
- We set up the spectrometer to have a high energy resolution and a large m_{12}.
- We convert x-E spectrometer image to a x'-E distribution at the plasma exit by dividing position on the screen with m_{12}.
- We look at the x'-E distribution to look for indications of transverse instabilities (i.e., angular kicks increasing in amplitude along the energy axis).

Converting spectrometer images to energy–angle space

- We set up the spectrometer to have high energy and angular resolution at 12 GeV ($m_{34} = 0, m_{12} = 10$).
- The high-intensity beam is sent through lithium vapour, where it ionizes the gas and interacts with the plasma, accelerating electrons up to around 13 GeV.

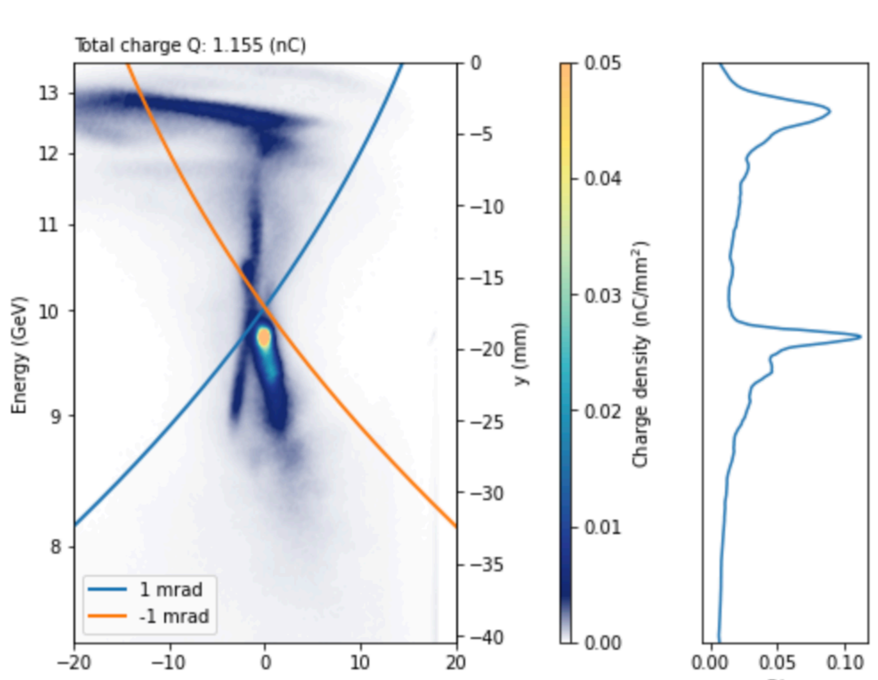

Fig. 1a: A picture of the Cherenkov spectrometer screen taken at FACET-II. The orange/blue lines represent a divergence of ± 1 mrad.

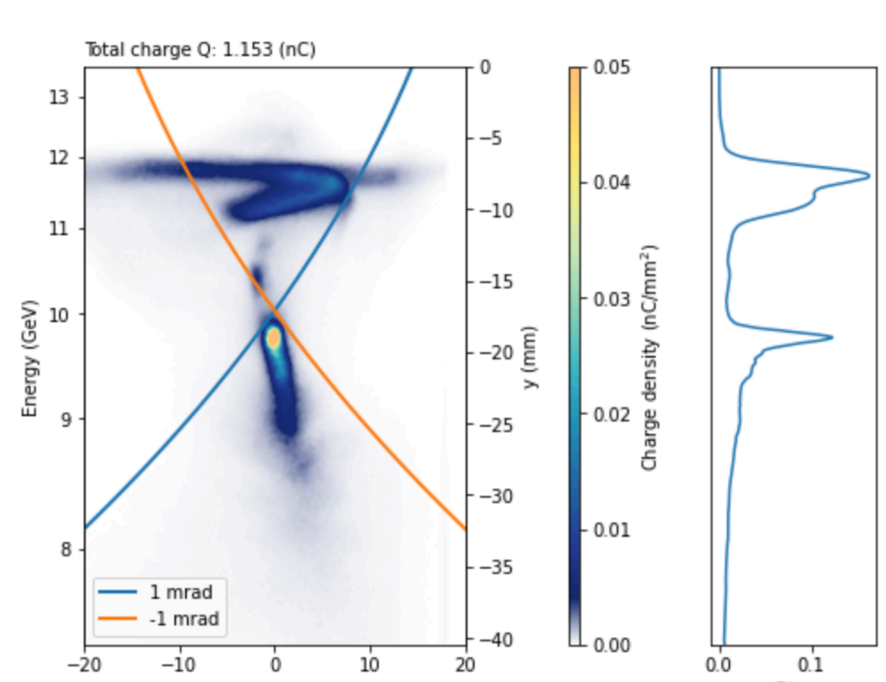

Fig. 1b: A picture of the Cherenkov spectrometer screen taken at FACET-II. The orange/blue lines represent a divergence of ± 1 mrad.

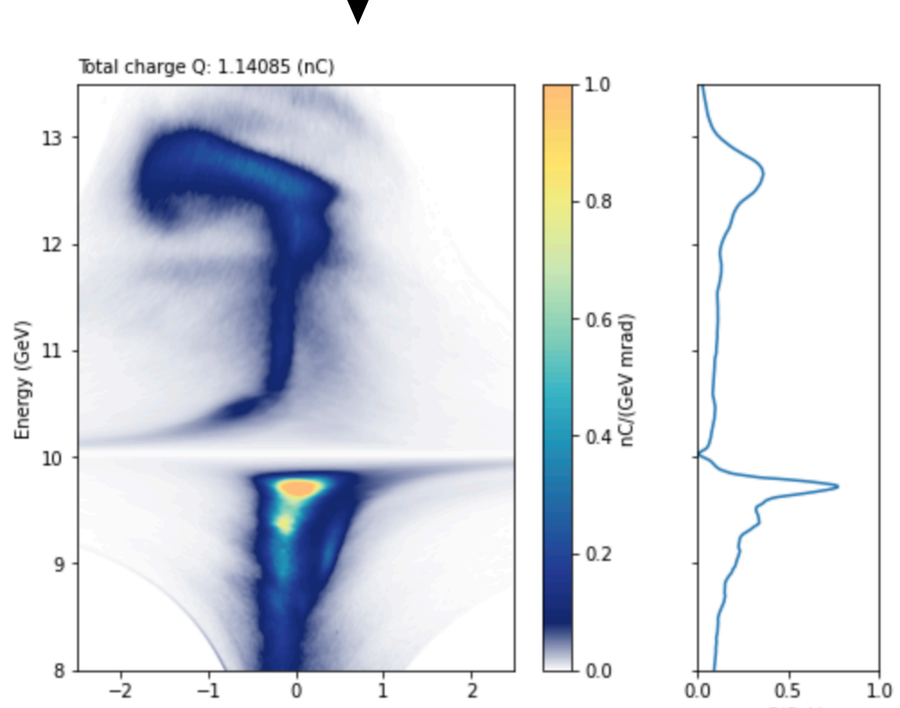

Fig. 2a: The converted x'-E distribution of the driver and trailing bunch.

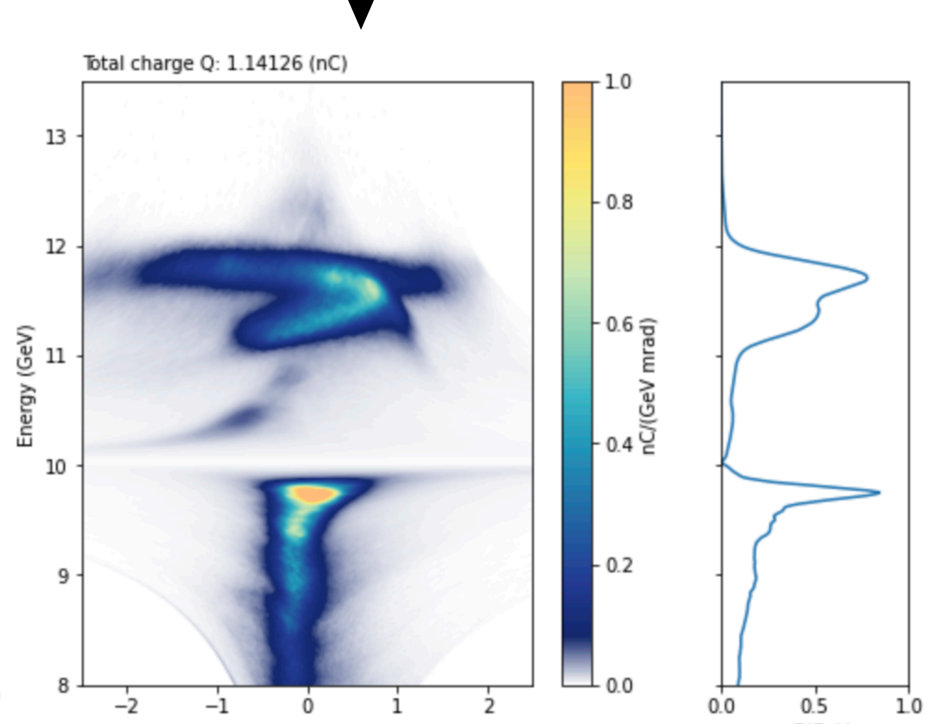

Fig. 2b: The converted x'-E distribution of the driver and trailing bunch.

Is there more instability at higher energy efficiency?

- We scan the phase of one of the klystrons.
- This probes the distance between the driver and trailing bunch.
- In the plasma this ensures a scan over the accelerating phase of the wakefield.
- We use a threshold to estimate the left and right edge of the beam on the Cherenkov screen.
- BC14 is the feedback value for the phase.
- We don't have a similar scan with the spectrometer set up to image deacceleration.
  - We roughly scale up the efficiency for now to compensate for charge loss due to imaging conditions.
  - We are still working on accurately estimating the efficiency.

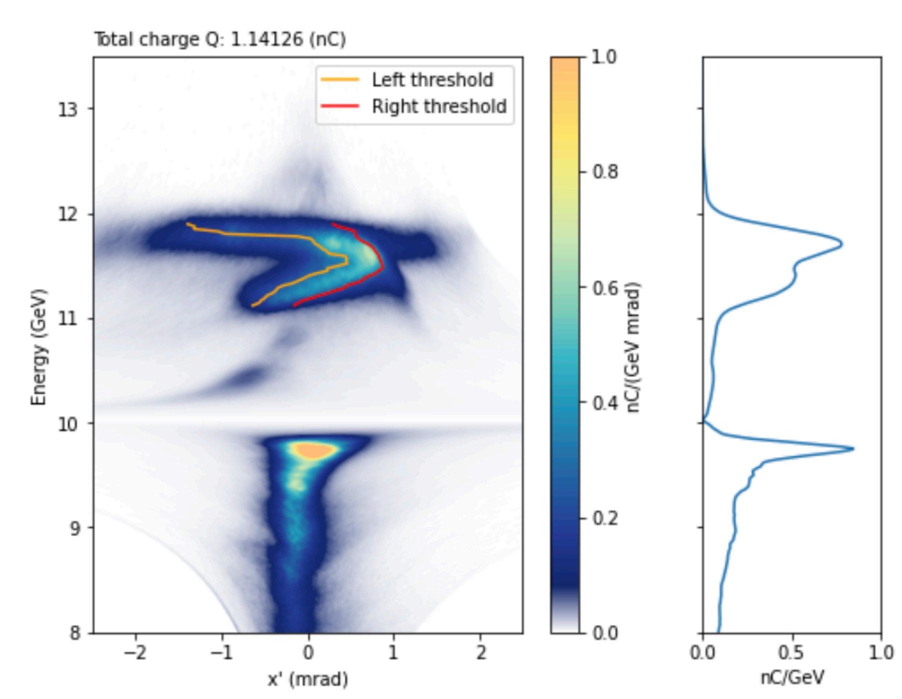

Fig. 3a: The converted x'-E distribution of the driver and trailing bunch. Lines are drawn on the distribution to determine the locations on either side of the trailing bunch where the signal drops to a threshold value.

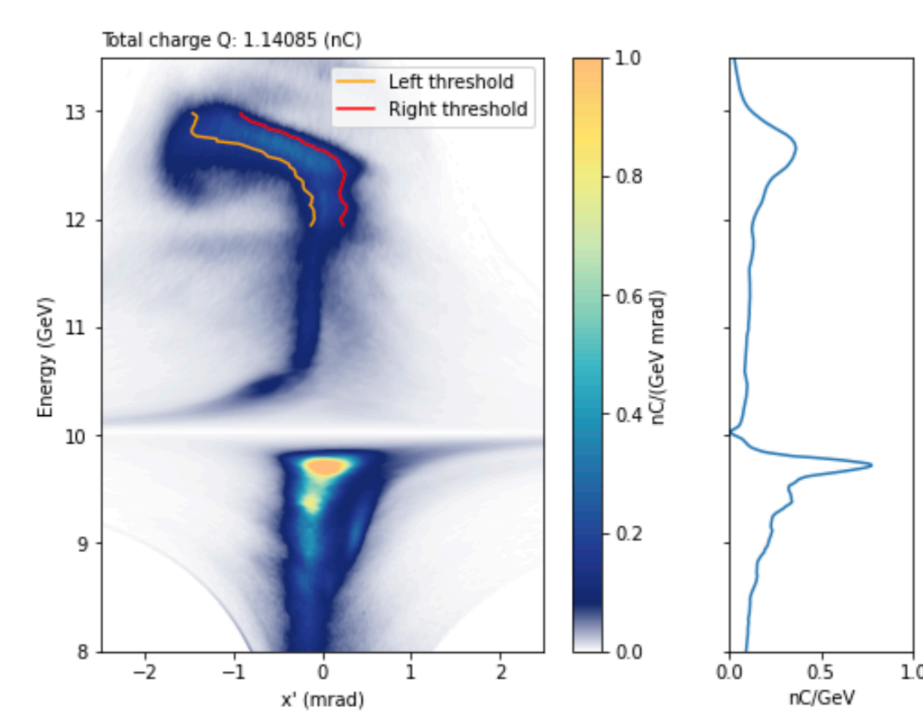

Fig. 3b: The converted x'-E distribution of the driver and trailing bunch. Lines are drawn on the distribution to determine the locations on either side of the trailing bunch where the signal drops to a threshold value.

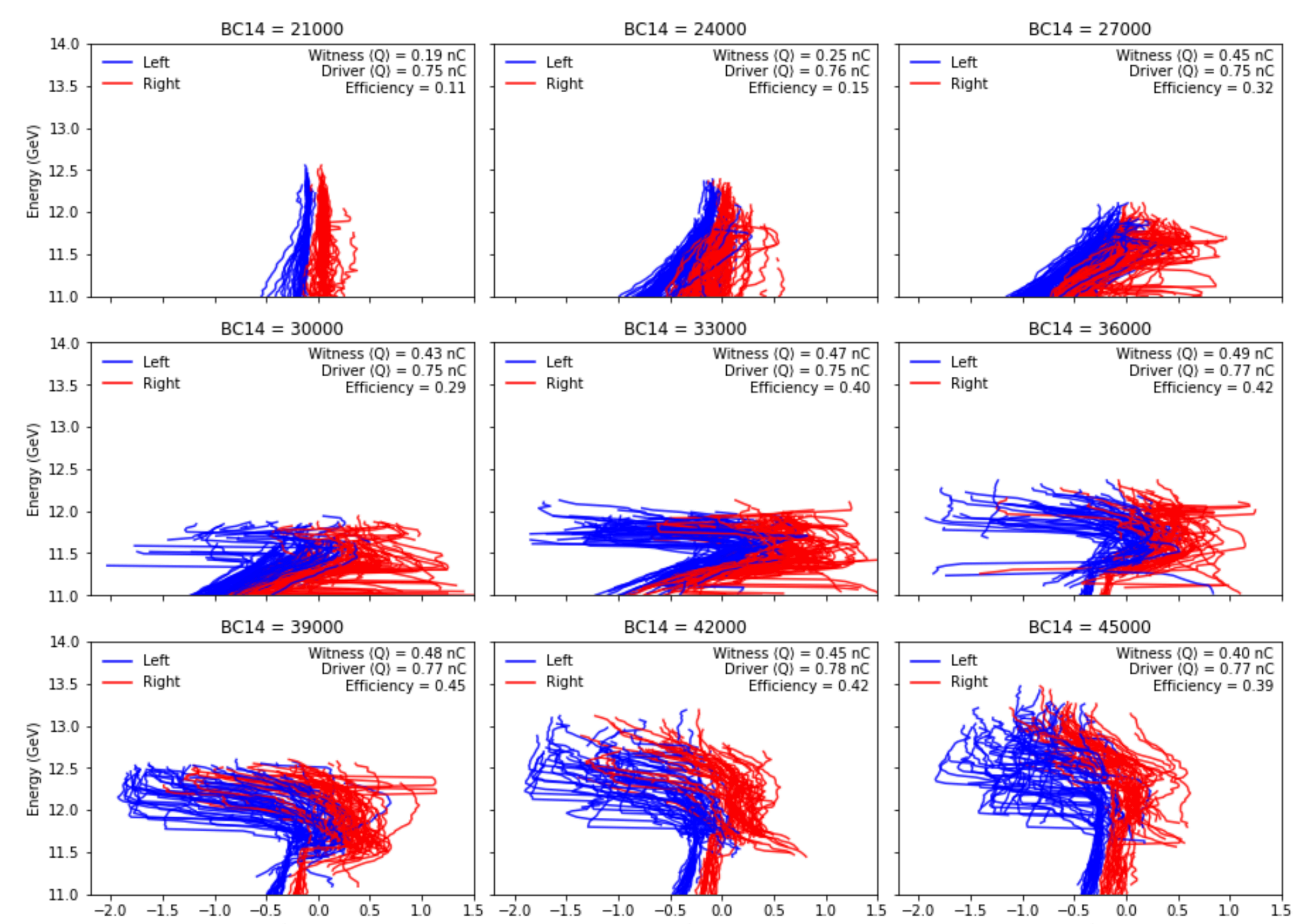

Fig. 4: The left and right threshold x'-E lines extracted from each shot in the scan. Efficiency is calculated for each step using the mean energy gain of the witness and mean energy loss of the driver for a single step in the scan.

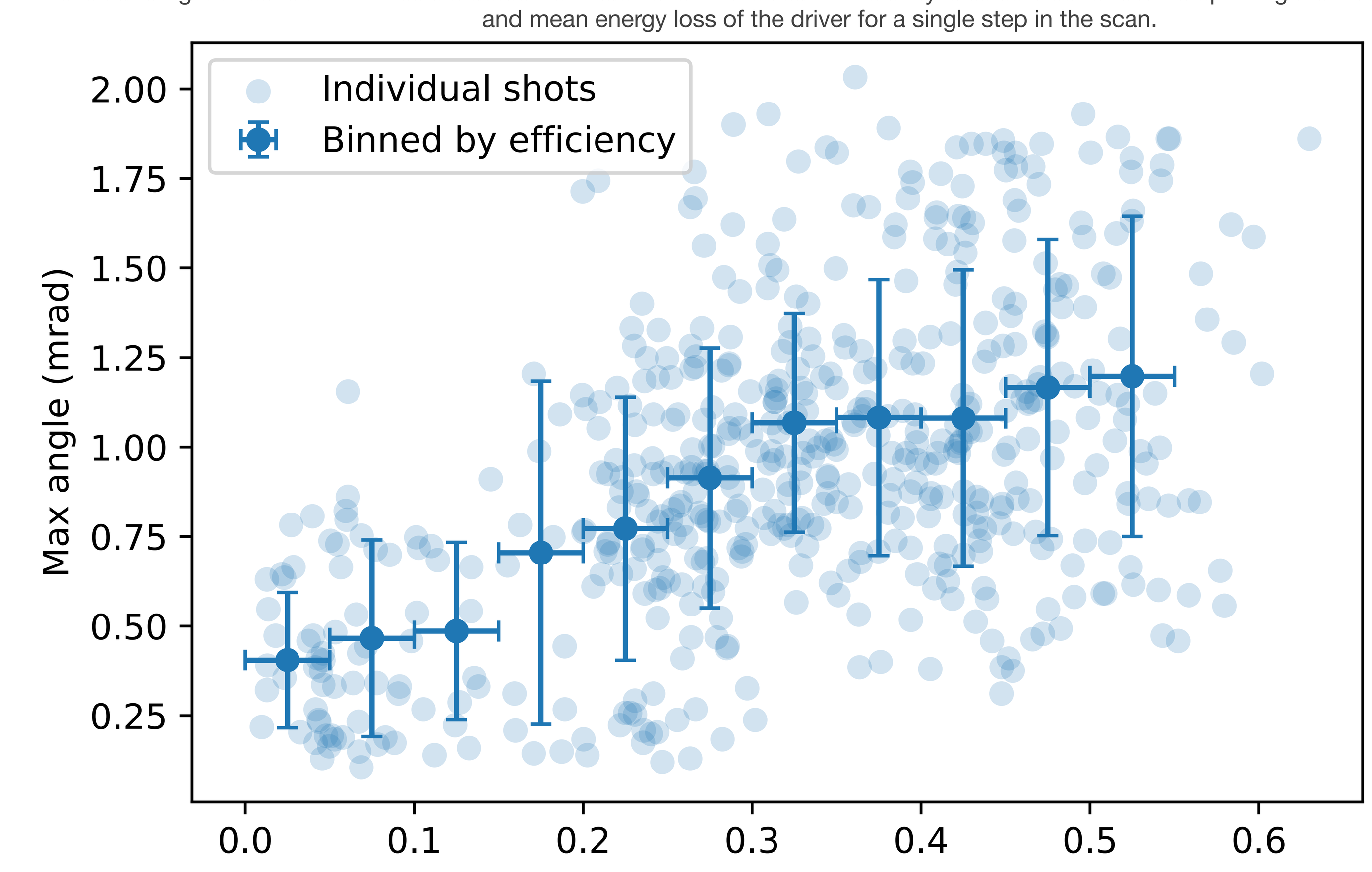

Fig.5: The max angle across energies at each step in the scan against efficiency. The dots are each individual shots, whereas the error bars are the points binned by efficiency.

Conclusions

- Analysis of single shots indicate development of the beam-breakup instability.
- We see a correlation between transverse kicks and driver-to-trailing efficiency from a scan of the bunch seperation.
- We are currently working on improving the efficiency estimation and characterising the bunches.

ACKNOWLEDGEMENTS
This work was supported by the Research Council of Norway (NFR Grant No. 313770).