First results from the E332 Experiment: Near-Field-CTR based Self-Focusing Effects and Target Damage Mechanism with High Intensity Beams at FACET-II

FACET-II

Facility for Advanced Accelerator Experimental Tests

20th Advanced Accelerator Concepts Workshop

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On behalf of the E332 Collaboration

November 6-11, 2022

Collaboration list

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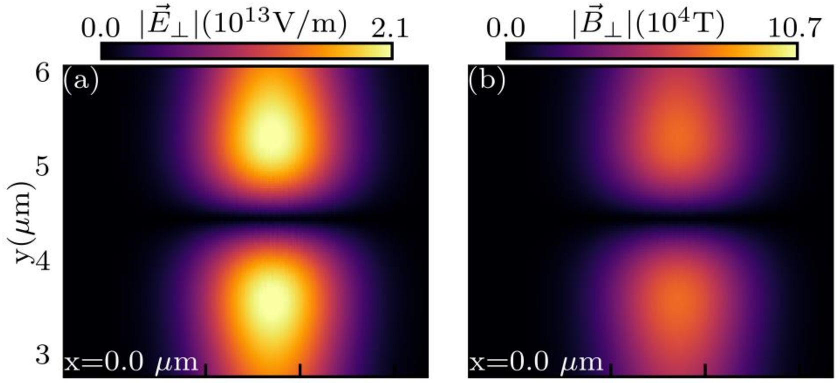
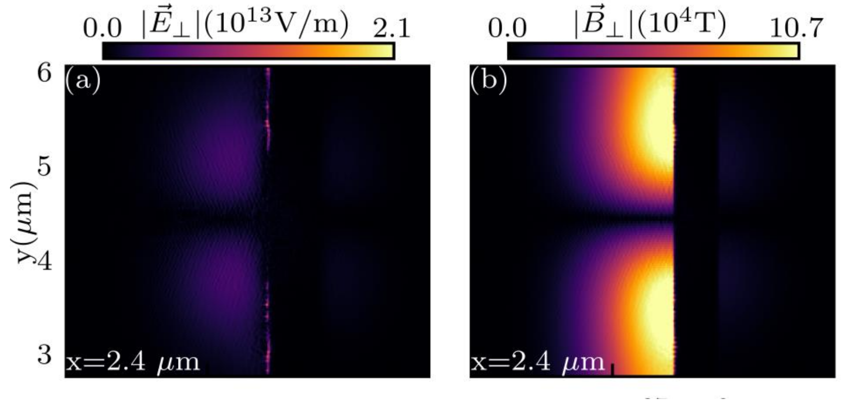
Near Field Coherent Transition Radiation Self Focusing

Initial beam fields – electric and magnetic:

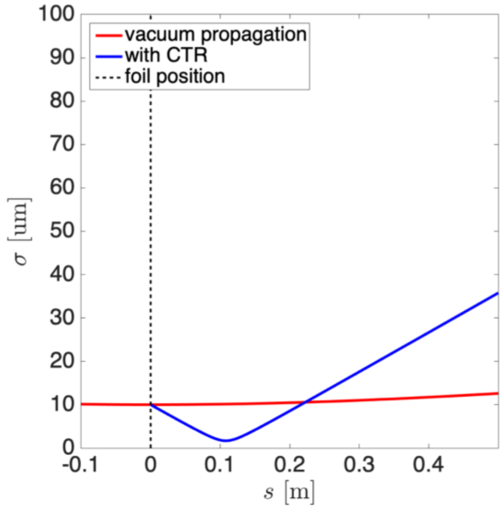


Fields at foil surface:



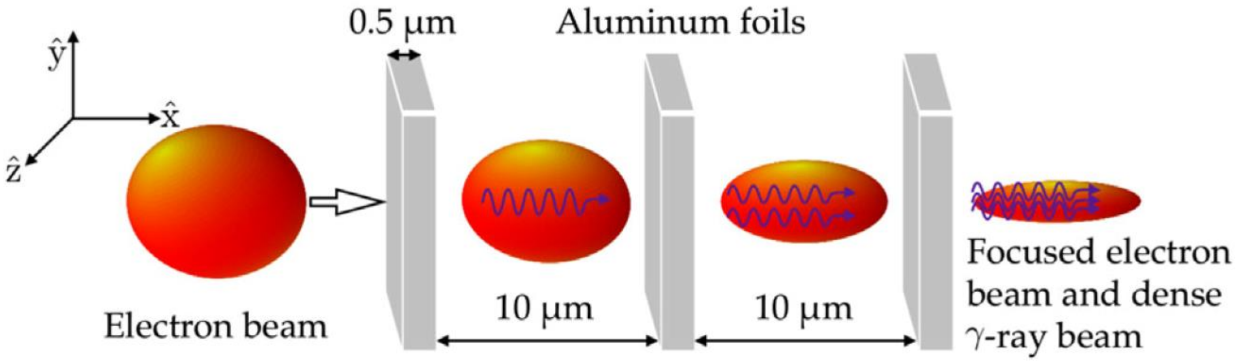
3D PIC simulations performed by A. Sampath

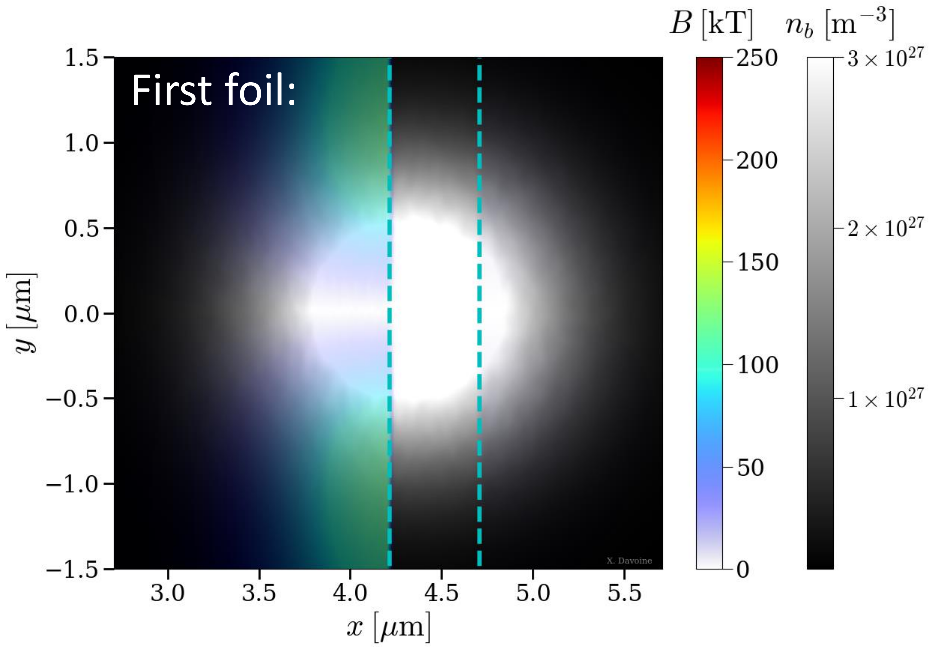
- A dense beam colliding with a conducting surface experiences strong CTR
  - E field at surface → 0
  - B field at surface → ~ x2
- CTR drives strong magnetic fields on the surface → strong Lorentz force self focusing
- Beam size propagation after a single foil:
  - FACET-II bunch parameters
    - $\epsilon_n = 3$ μm-rad
    - $\sigma_r = 10$ μm, $\sigma_z = 0.5$ μm
    - $Q_b = 2$ nC

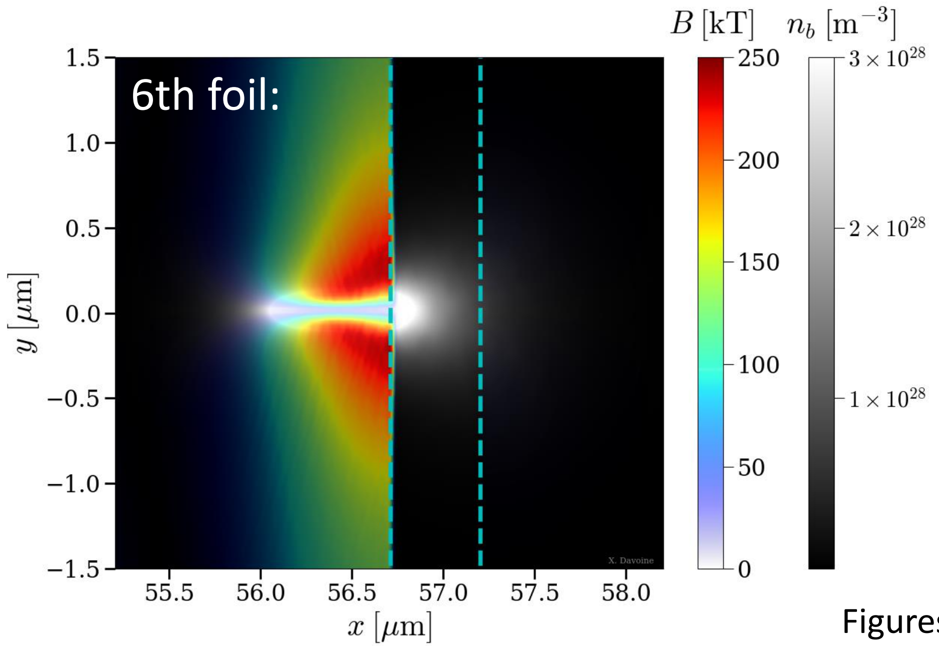


Near Field CTR Self Focusing through multiple foils

- Effect is enhanced by passing the beam through multiple foils
- Beam can be focused to radial density of order 10^{29} m^{-3}
- CALDER simulations showing beam distribution and magnetic field intensity







Figures by X. Davoine

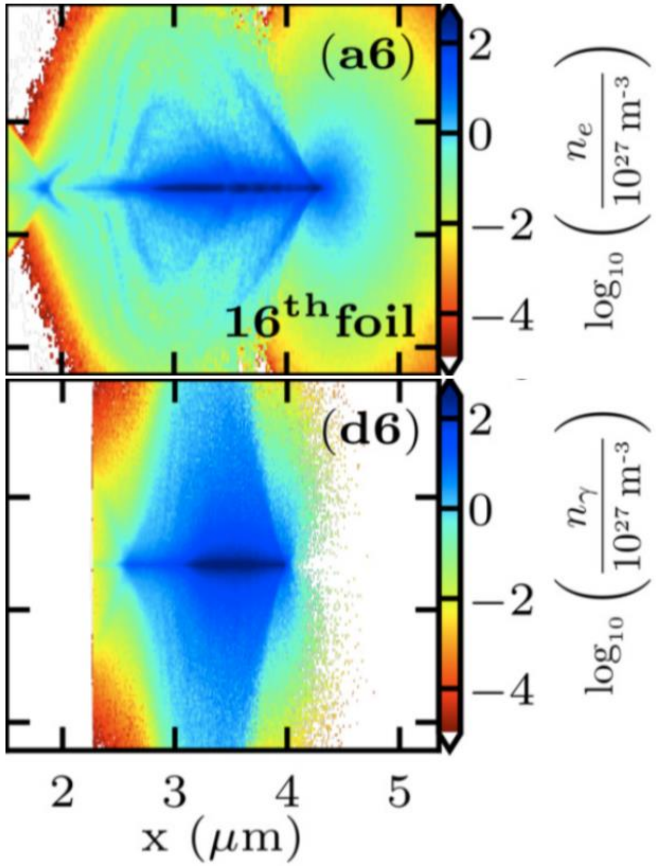
Sampath, A, PHYSICAL REVIEW LETTERS **126**, 064801 (2021)

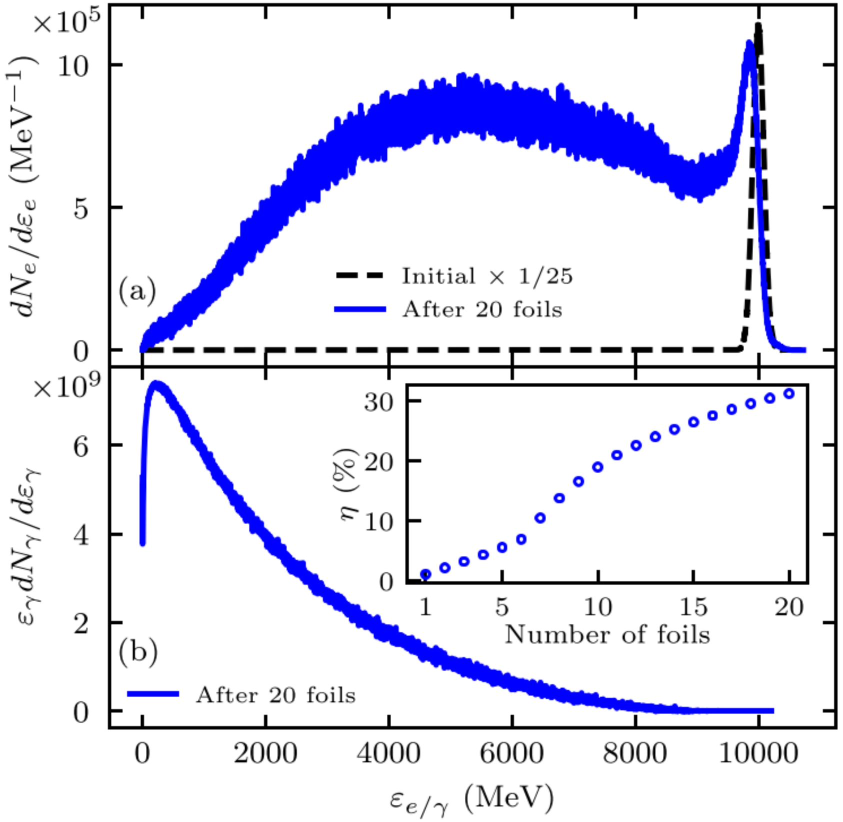
Generation of extremely intense Gamma-rays

- Focusing is accompanied by the emission of a short, collimated pulse of gamma photons
- Photons are generated with strong conversion efficiency and exceeding solid density

- Beam distribution after 16 foils:
  - 3.8×10^{29} m^{-3}

- Gamma distribution:
  - 2.8×10^{29} m^{-3}
  - 5 mrad aperture
  - 4 fs FWHM





Sampath, A, PHYSICAL REVIEW LETTERS **126**, 064801 (2021)

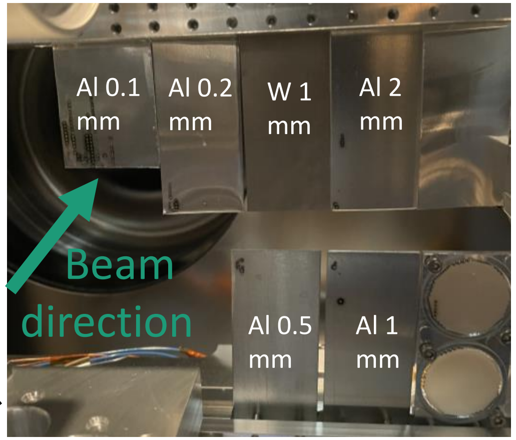
See talk by P. San Miguel on Tues. in WGs 2+7

E332 experimental setup a FACET-II

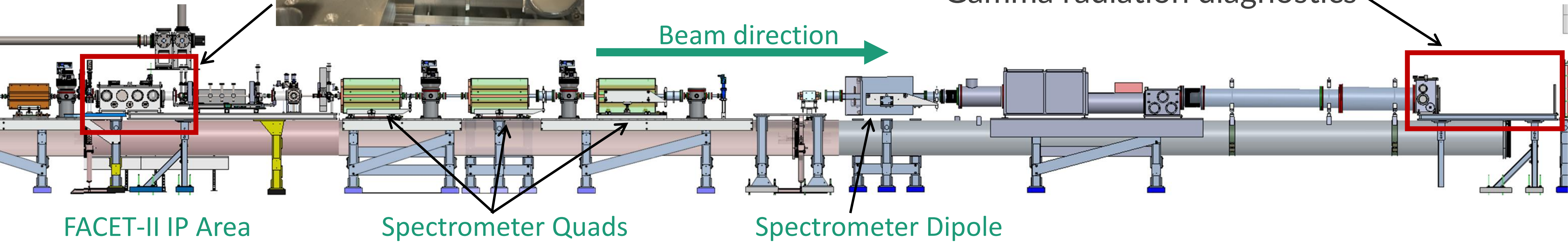
- Uses FACET-II beams with ultra-high intensity
- Aluminum foils at FACET-II IP
  - Currently 0.1-2mm thickness, single foils
- Spectrometer beamline to diagnose electron and gamma beams

Electron Beam Parameter		Current FACET-II Parameters	Operational Ranges
Final energy	[GeV]	10	4 – 13.5
Charge per pulse	[nC]	1.6	0.7 – 5
$\gamma\epsilon_{x,y}$ at S19	[µm]	~20	3 – 6
Min spot size	[µm]	~30-40	
Min bunch length	[µm]	~20	0.7 – 20
Max peak current	[kA]	--	10 - 200

Single foils at FACET-II IP:

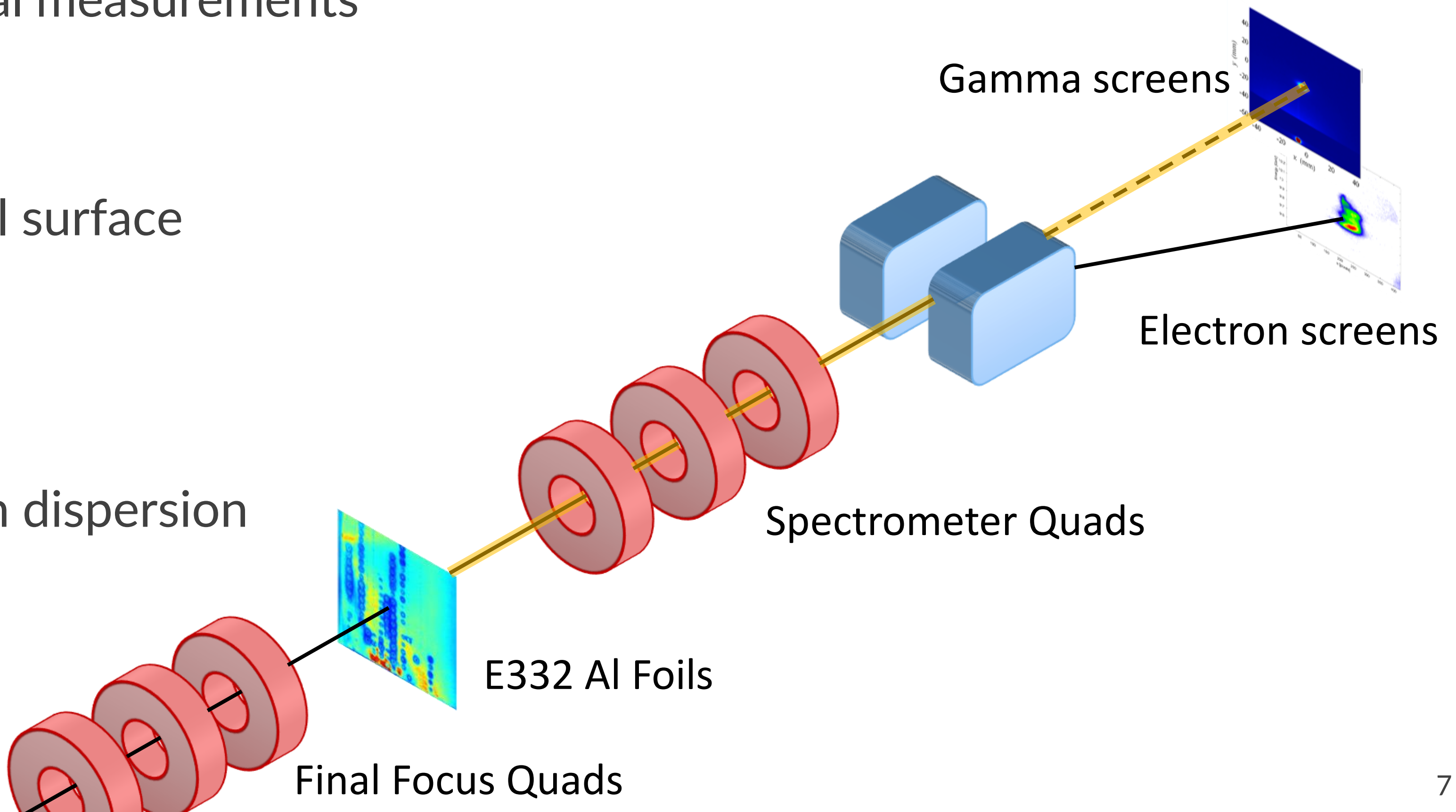


- Reimaging electron spectrometer
- Gamma radiation diagnostics



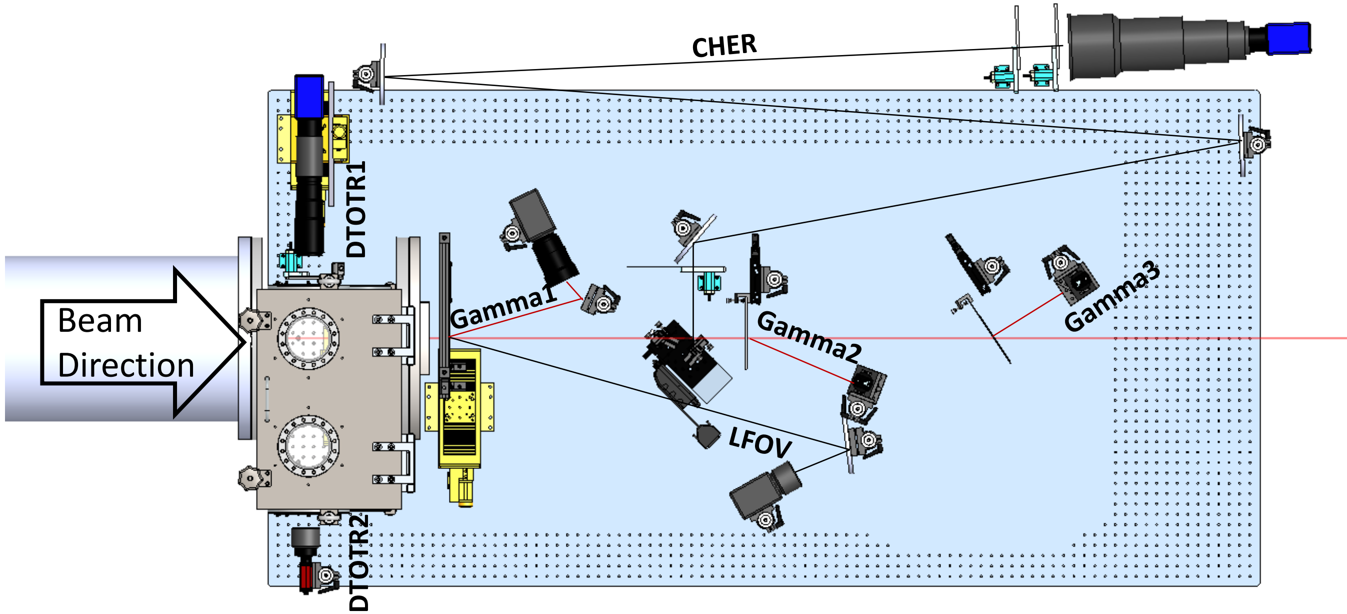
Diagnostics summary

- Observables:
  - Change to the vacuum propagation of e- beam
    - Increase in the beam divergence due to focusing, and change in focal plane of the beam
    - Energy spectrum after efficient energy loss to gamma beam
  - Gamma ray intensity and spectral measurements
- FACET IP diagnostics:
  - "Frontview" camera to image foil surface
- FACET-II spectrometer:
  - Reimaging triplet
  - Dipole bend with nominal 60mm dispersion
  - "Dump table" electron and gamma diagnostics



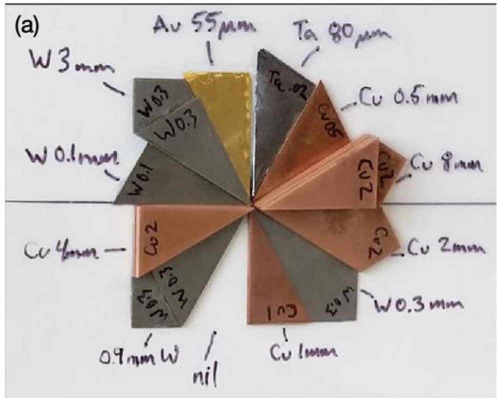
FACET-II Spectrometer diagnostics

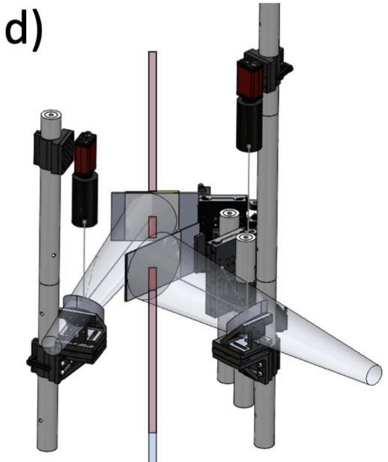
- Electron beam diagnostics
  - **DTOTR** – high resolution profile monitor:
    - ~4.5µm imaging resolution
    - ~fs longitudinal resolution w. XTCAV
  - **LFOV** and **CHER**– large field of view electron spectrometers
    - 0.4% energy resolution



- Photon diagnostics:
  - **Gamma1**: scintillator photon profile monitor
  - **Gamma2** and **3**: spectral info from <100keV to 10's of MeV
  - Upcoming: Compton and Pair spectrometers → 10 GeV spectrum

Gamma2 and 3 gamma screens:



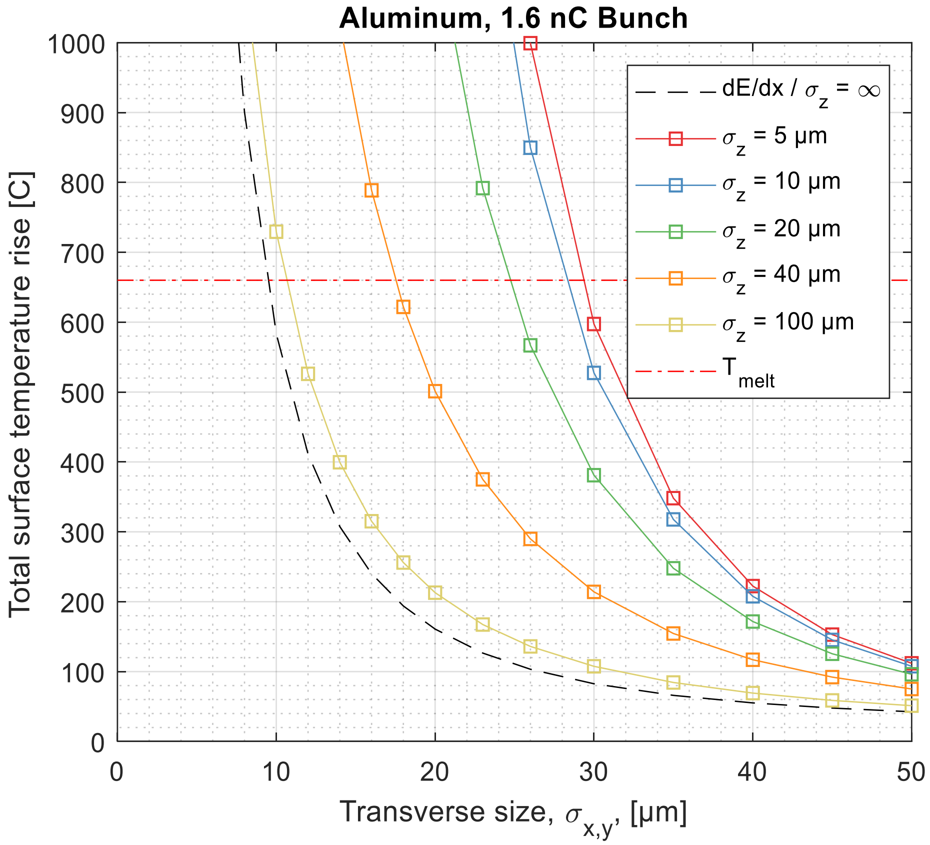


Target damage mechanism

- Two modes of heating:
  1. Bulk heating from collisional dE/dx
  2. Ohmic heating from image currents on surface

- Beam fields drive strong image currents in the foil surface
  - Currents penetrate within a skin depth of the surface
  - Result in Ohmic/resistive losses and surface heating
    - Stupakov, G., SLAC-PUB-15729 (2013)

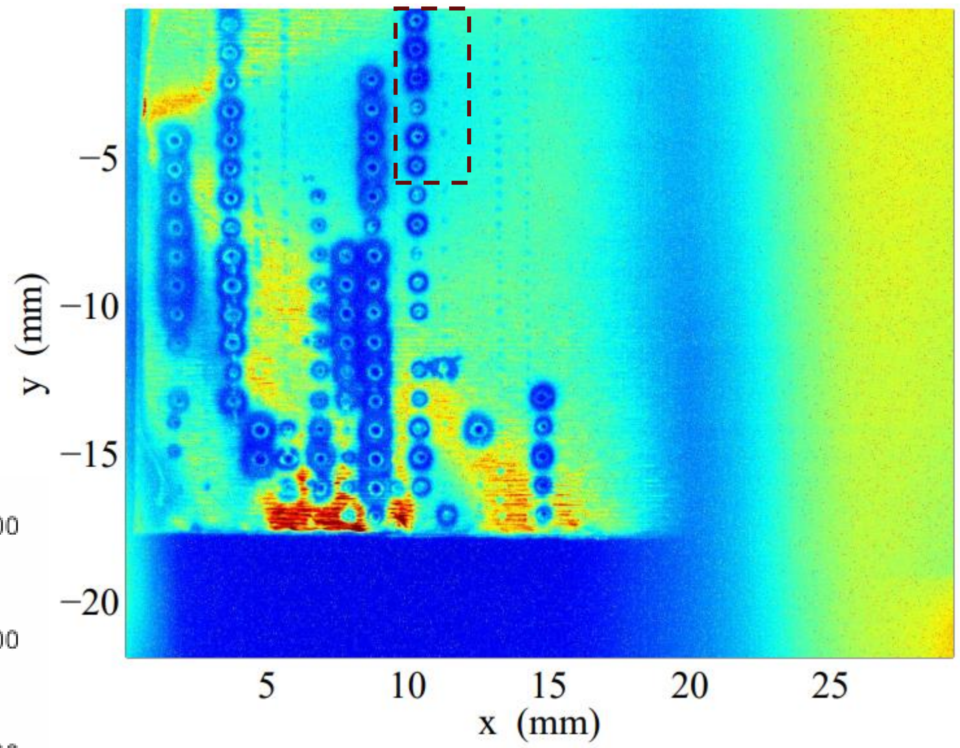
- For a typical FACET-II 2022 run:
  - Beam size: $\sigma_{x,y,z} \sim 20 \times 40 \times 20$ um^3
    - Collisional heating: $\Delta T_{dE/dx} \cong 100$℃
    - Ohmic heating: $\Delta T_{dE/dx} \cong 500$℃ at surface

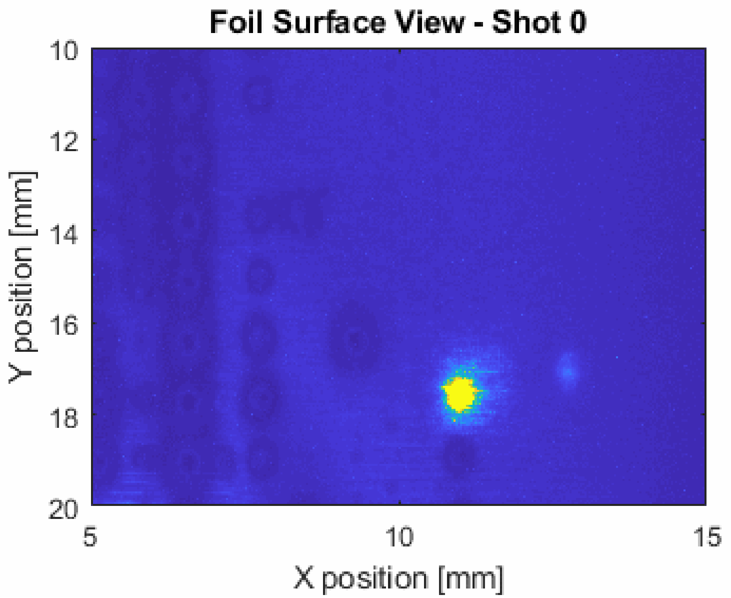


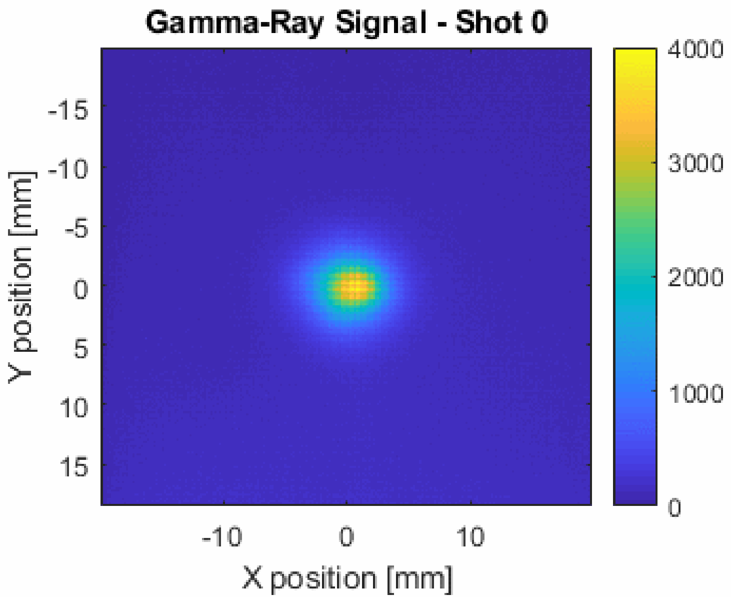
Diagnostics for target damage studies

- Camera to visualize damage in real time
- Gamma diagnostics to measure bremsstrahlung photon signal
- General radiation monitors

FrontView camera – 13-Aug-2022 01:57:33

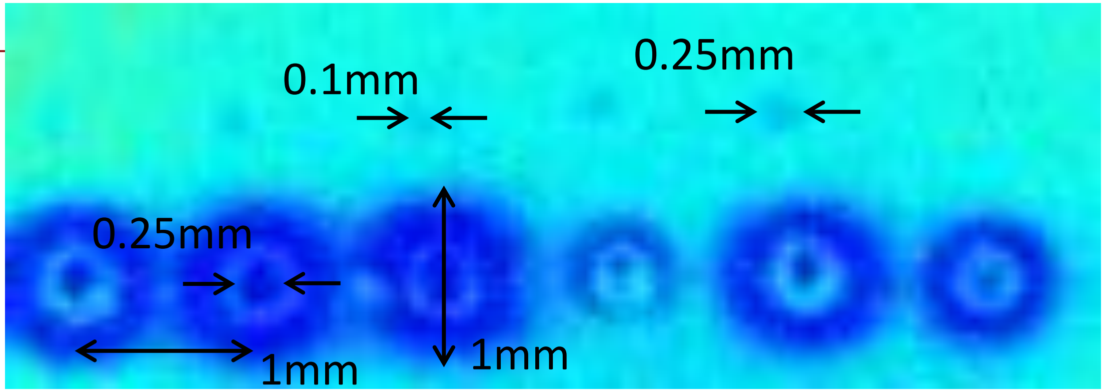


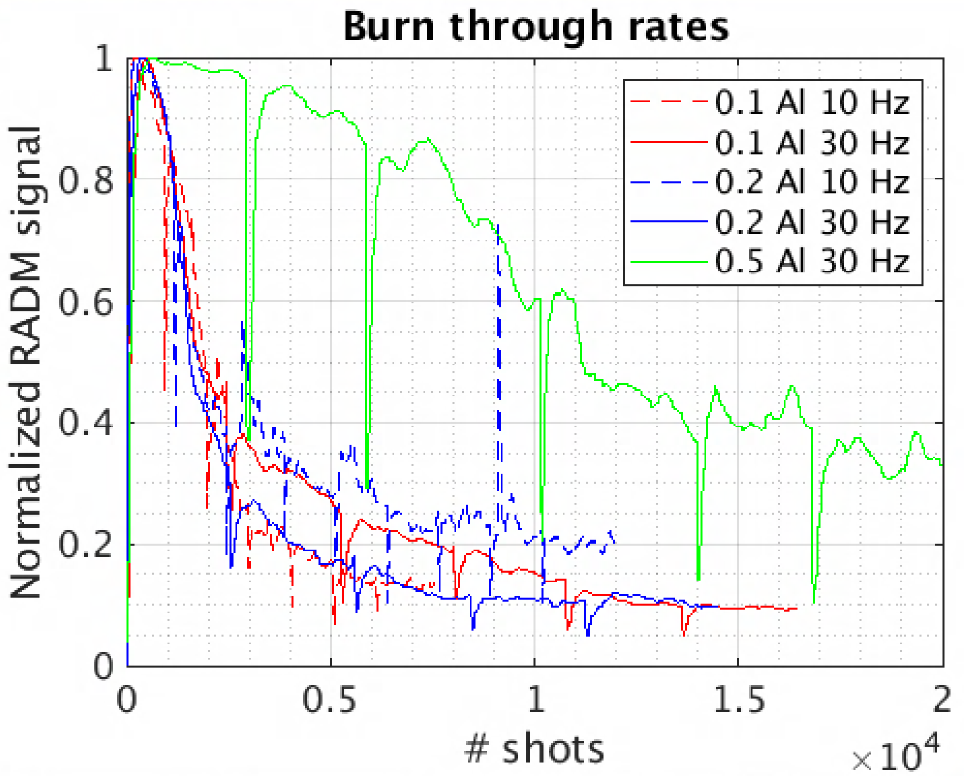




Single and multi-shot damage

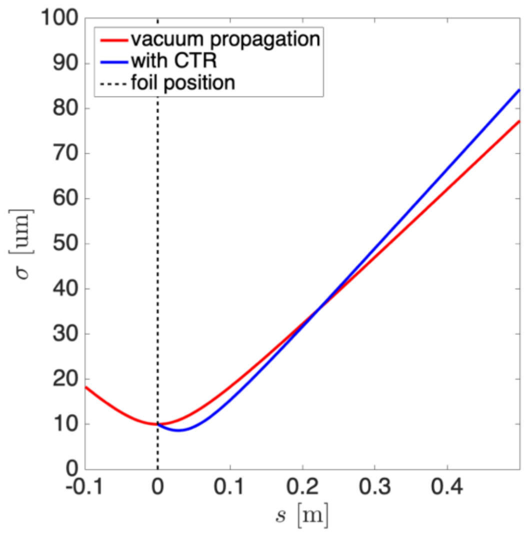
- Single shot damage – *top row*
  - Surface damage from single 1.6nC shot
  - Transverse size of 100-250 µm
- Multi-shot damages – *lower row*
  - 0.1mm Al melted through in 1000-2000 shots
    - ~50-100 nm of material removed/shot
  - Rate of etching through, and hole size depends on longitudinal compression
- Next steps
  - Parameter scans with reproducible parameters
  - Repeat with different materials
    - i.e. melting point, conductivity, etc





Initial search for NF-CTR focusing

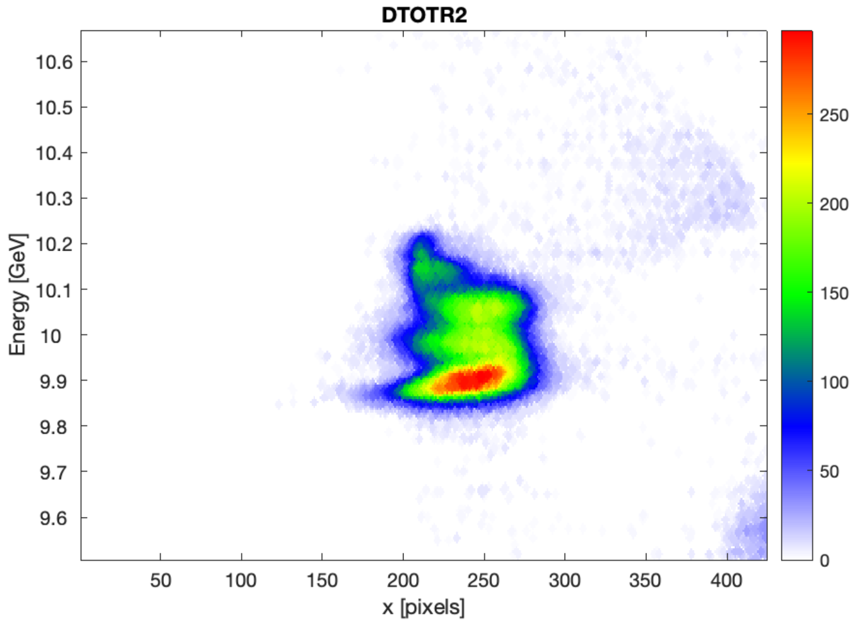
Beam size propagation - $\epsilon_n = 30$ μm

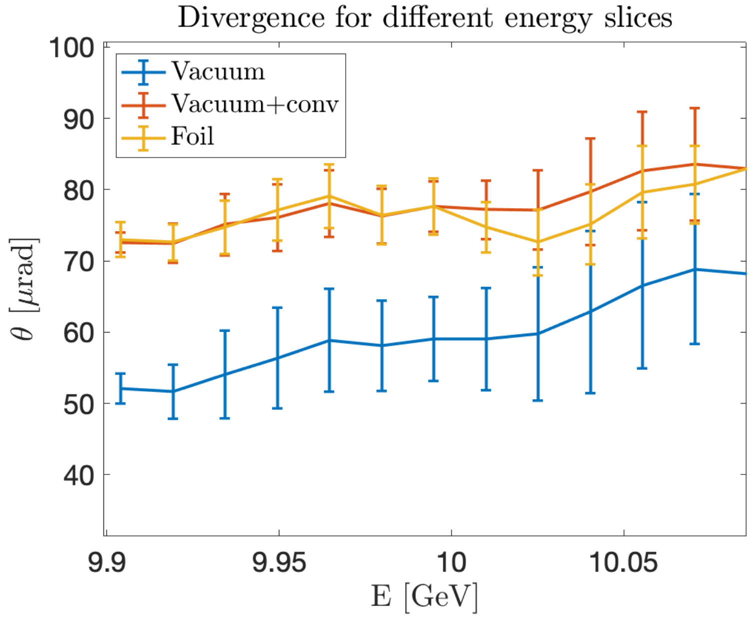


- Target foil rastered at the beam rate to provide "fresh" surface for each shot
- Spectrometer set for large M_{12} to enhance the divergence signal

- Change in divergence above the multiple scattering not visible with present beam parameters

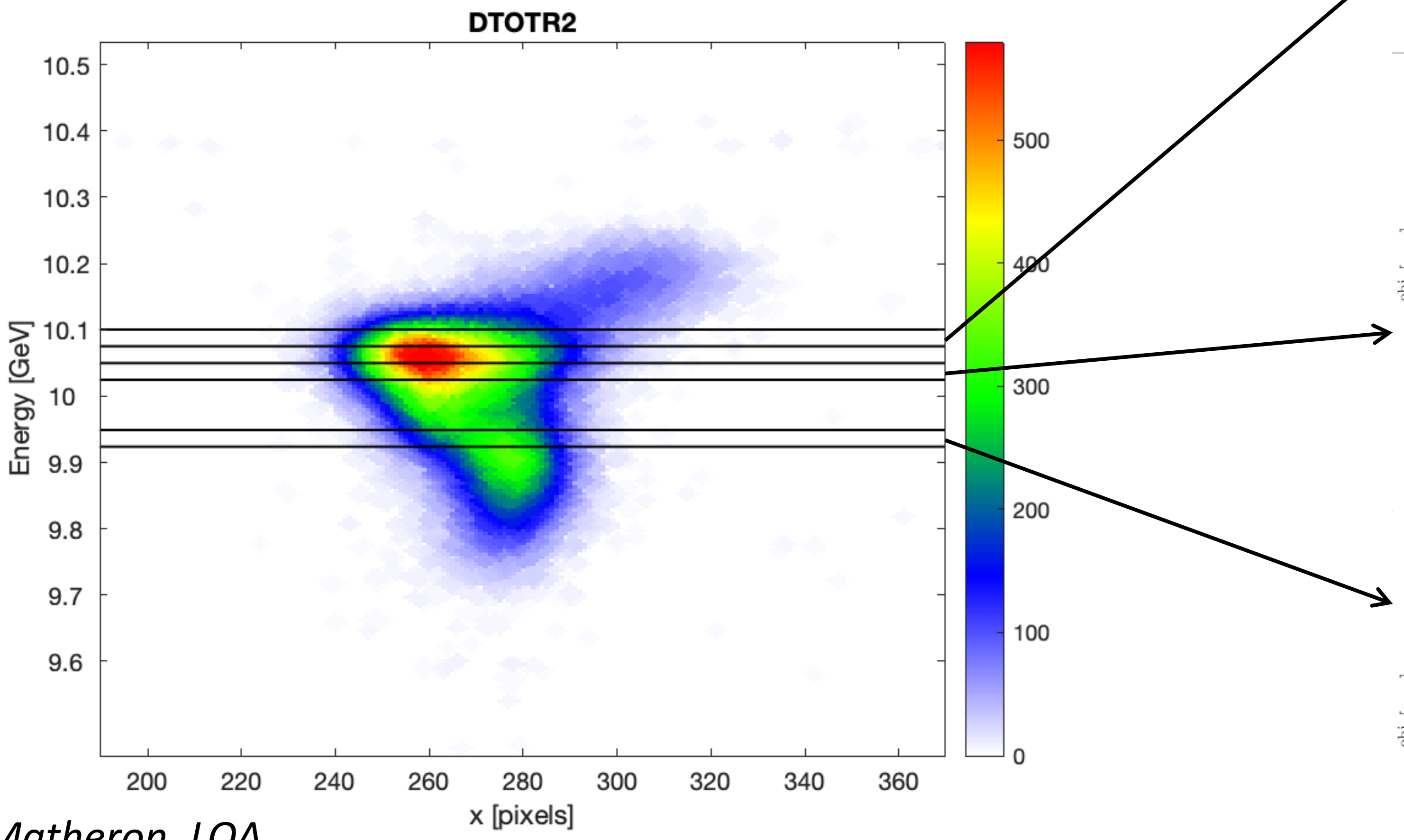
Analysis by A. Matheron, LOA

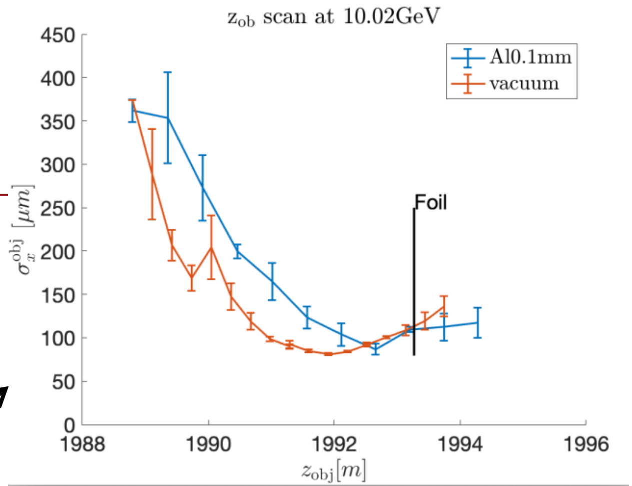


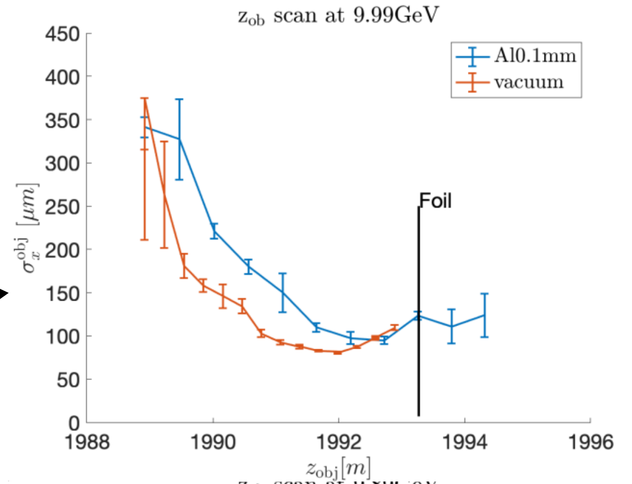


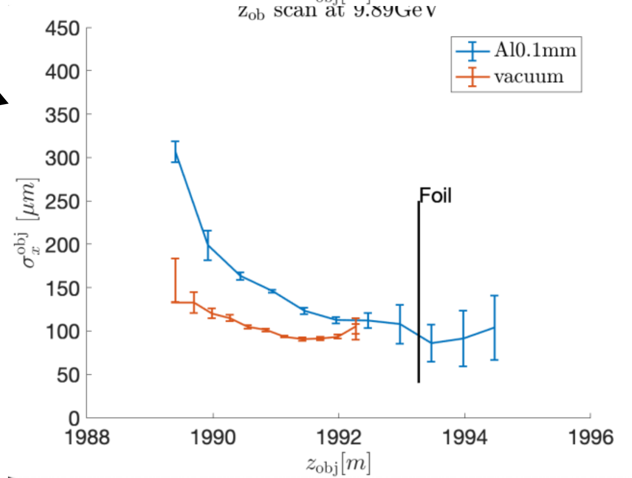
Object plane scans

- Scan of spectrometer quads, with single shot per foil position
- Higher divergence with foil, but no sign of change in focal position







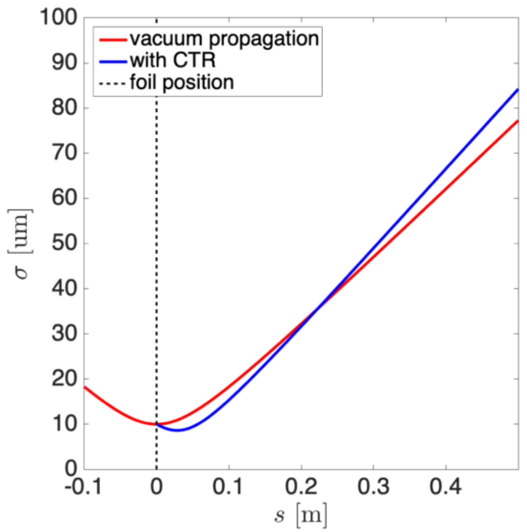


Analysis by A. Matheron, LOA

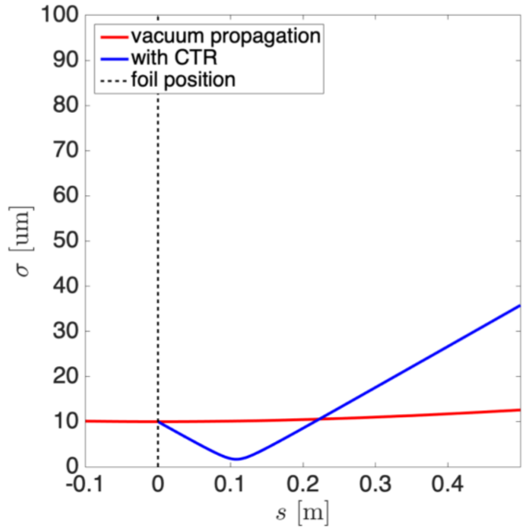
Next steps to demonstrate NF-CTR self focusing

- Focusing effect difficult to measure with present FACET-II beam parameters
  - Change to divergence is dominated by multiple scattering in foil
  - Change in waist position of cm’s difficult to resolve, for now
- Repeat these scans with:
  - Smaller emittance and spot size as FACET-II commissioning progresses
  - Replace 100 µm foils with ~1 µm foils
- Move on to multiple foils to enhance effect

Beam size propagation - $\epsilon_n = 30$ µm

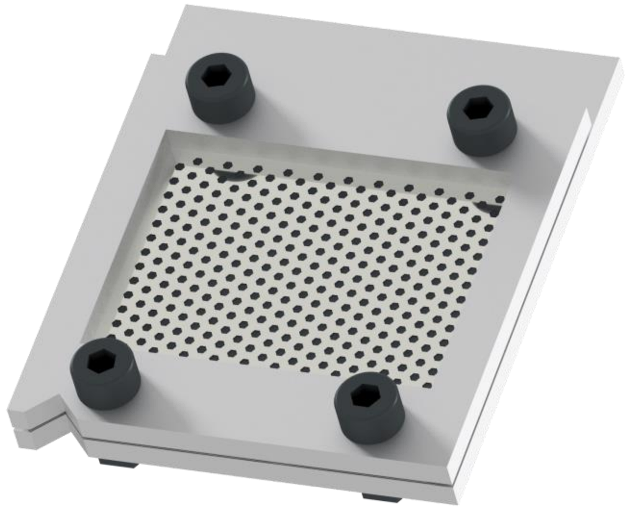


Beam size propagation - $\epsilon_n = 3$ µm

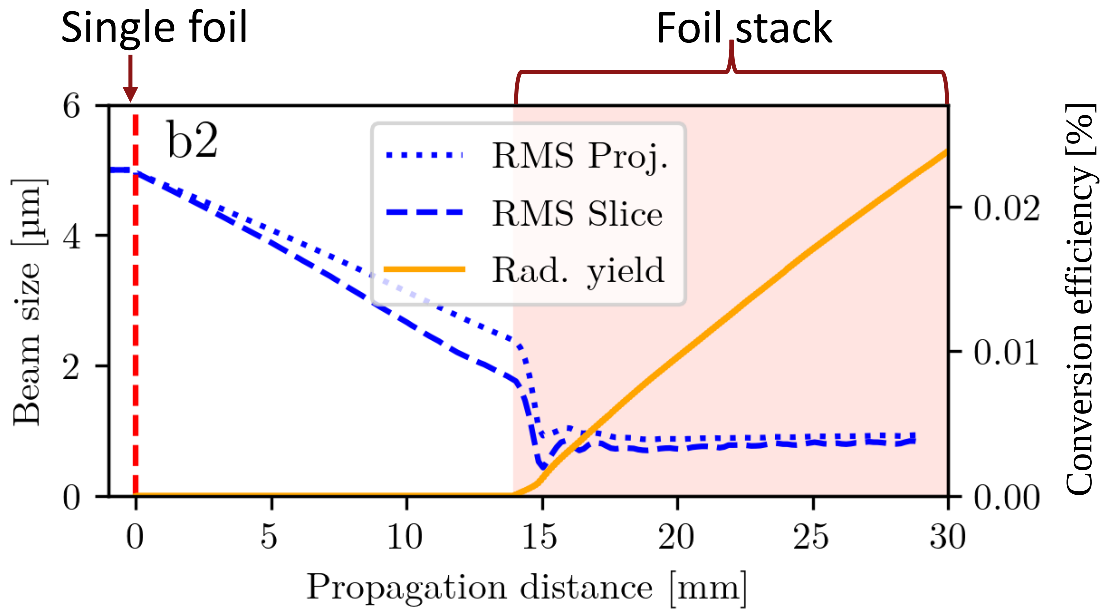


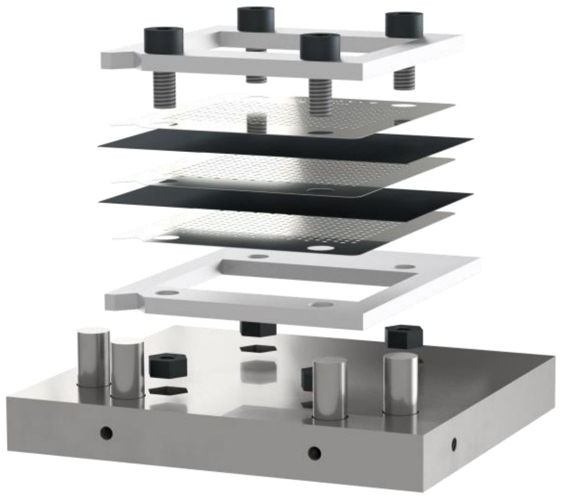
Upcoming: Multi-foil experiments

- Enhanced NF-CTR with multiple foil interactions
- Multi-foil stack with fixed foil spacing being designed
  - Interleaved stainless "screen" and Al foil
  - 1mm hole spacing, ~300 positions



- Simulations:
  - 2 nC, 10 GeV
  - $\sigma_z = 5$ µm
  - $\sigma_r = 5$ µm





Credit – M. Gilljohan

Summary

- Near Field CTR can result in strong transverse fields at a foil surface boundary that can have a strong impact on the beam:
  - Strong self focusing to achieve electron beams of solid-density
  - Intense emission of gamma-ray photons
- E332 aims to study this effect using single and multi-foil experiments with the high intensity beams at FACET-II
- Commissioning and first studies have been performed over the summer-2022 run
- As the beam parameters continue to improve we expect to be able to resolve the NF-CTR effect on our diagnostics

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Questions?

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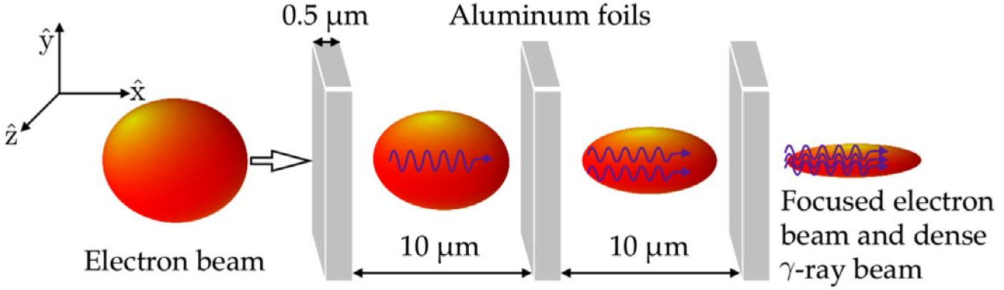
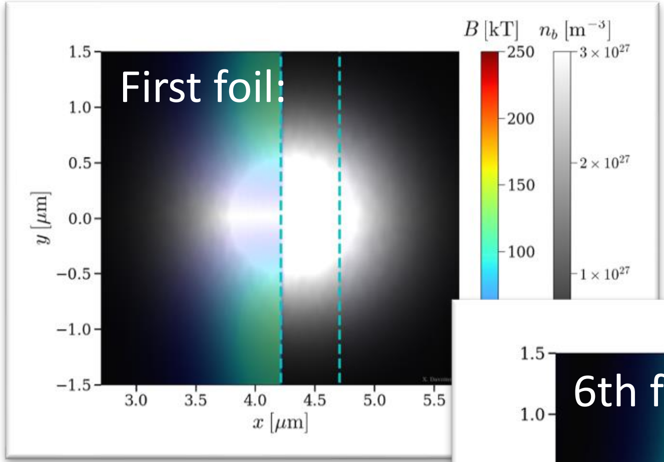
First results from the E332 Experiment: NF-CTR Self Focusing @ FACET-II

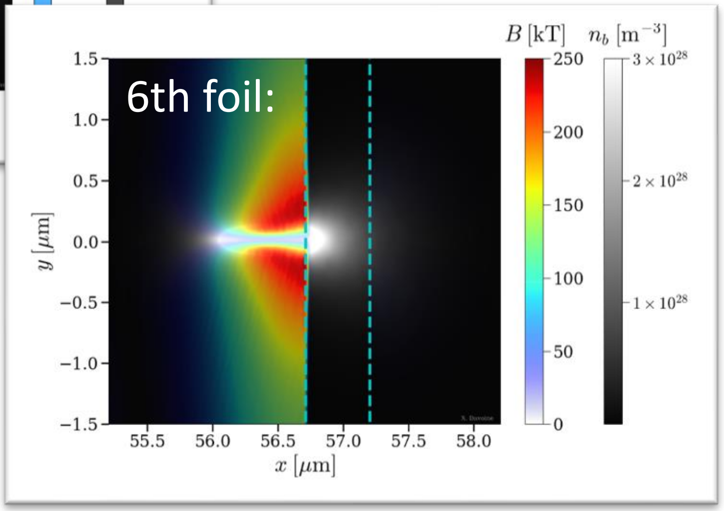
- Near Field Coherent Transition Radiation (NF-CTR) can result in strong transverse fields at a foil surface boundary that can have a strong impact on the beam:
  - Strong self focusing to achieve electron beams of solid-density
  - Drives the generation of an intense, collimated gamma beam



- E332 aims to demonstrate and probe these effects



- Progress and next steps:
  - Diagnostics and acquisition tools developed
  - Studies to understand target damage mechanism underway
  - NF-CTR self focusing not resolvable under current conditions



- Resolution of the NF-CTR effects are expected in upcoming run with smaller emittance beams and multi-foil targets