Laser-Based Collimation of Beam Halo Electrons via Compton Scattering

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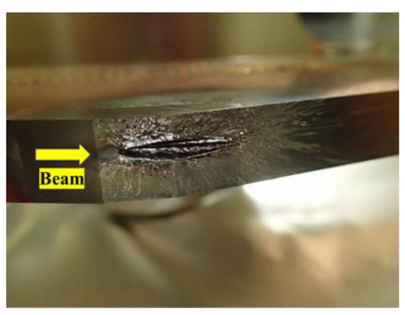
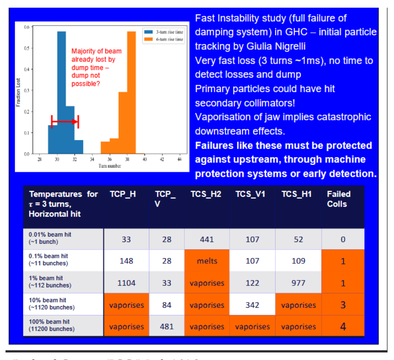
MOTIVATION: COLLIMATION CHALLENGES



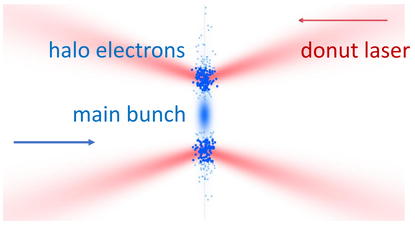
S. Terui *et al.*, Phys. Rev. Accel. Beams **27**, 081001 (2024).

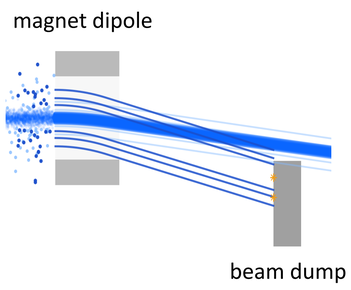


Richard Cowan, FCC Week 2026

- Impedance limits narrow-aperture collimation
- Sudden beam losses can damage collimators

LASER COLLIMATION CONCEPT





$$P_{\text{scatter}}(x_0, y_0) = \sigma_{\text{KN}} \frac{1+\cos\alpha}{\cos\alpha} \int n_\gamma(r(z), z)\, dz$$

Donut-laser scattering separates halo electrons from the main beam.

COMPARISON OF OPTICAL SCHEMES

Low intensity at the beam core • High intensity at the halo

Laser transverse scale: $\sim$ 10–100 μm

FCC-ee Application

Tailored laser profile
matched to a flat beam

Shaped beam or multiple beams

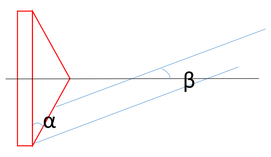
$\sim 2.3\ \text{mJ}/\mu\text{m}^2$

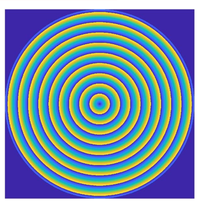
FACET-II Demonstration

Circular donut profile
matched to a more symmetric beam

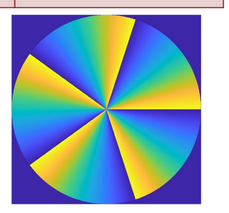
High contrast for a clear signal

Property	High-NA axicon + OAP	Low-NA axicon + focusing optic	Spiral phase plate + high-NA OAP
Ring radius	broadly tunable	broadly tunable	tied to diffraction scale
Ring thickness	thin	thick	moderate
Radius/thickness independent control	good	good	limited
Peak intensity	high	low	high
Main-ring energy concentration	high	moderate-high	moderate
On-axis suppression	good	moderate	excellent
Input beam size sensitivity	low for radius	low for radius	high



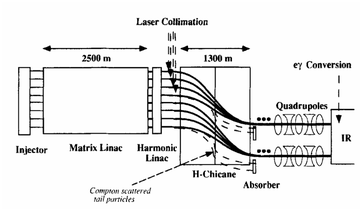


phase of axicon



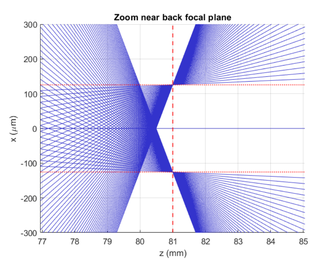
phase of spiral phase plate

RAY-TRACING SIMULATION

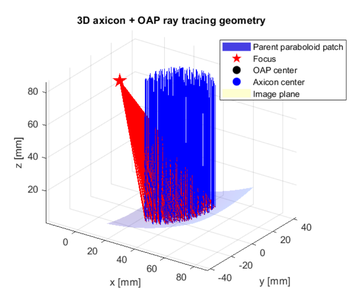


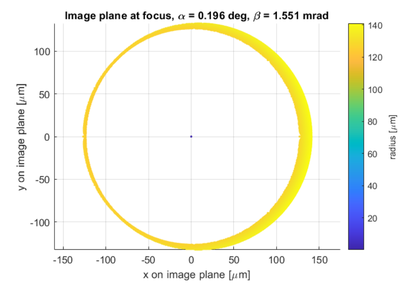
F. Zimmermann, AIP Conf. Proc. 472, 103–117 (1999).

- 1+1D simplified ray tracing



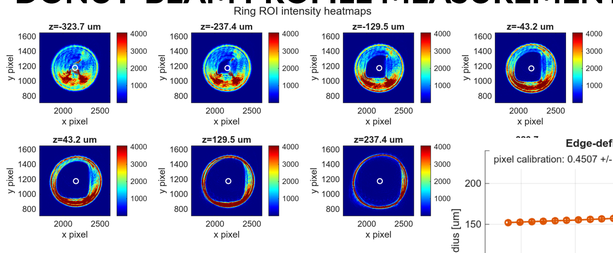
- 3D ray-tracing

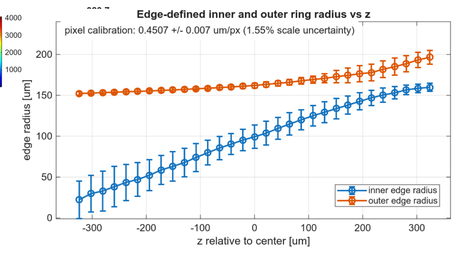




- The thickness of the ring at focus is determined by two main factors: (1) the diffraction limit and (2) astigmatism.
- If one wants a thicker ring or other beam structures, phase-retrieval methods such as the Gerchberg–Saxton (GS) algorithm can be used.

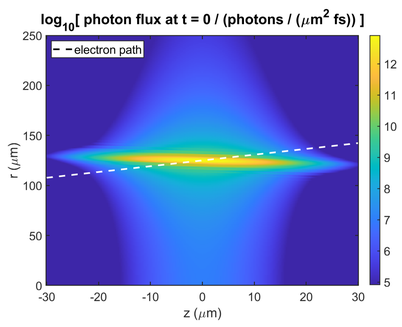
DONUT-BEAM PROFILE MEASUREMENT

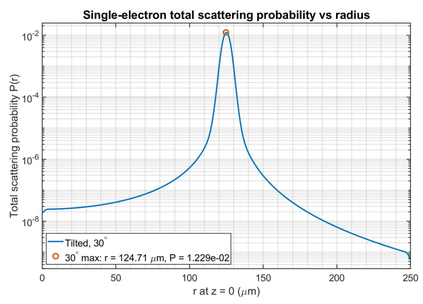




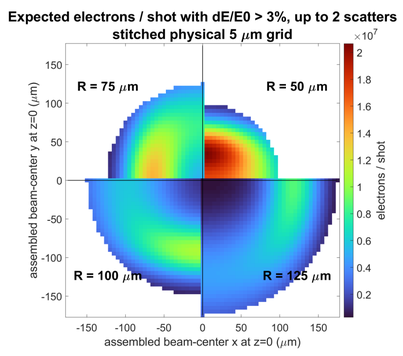
Target radius: 125 µm
Measured radius: 131 µm
Difference likely from residual alignment error

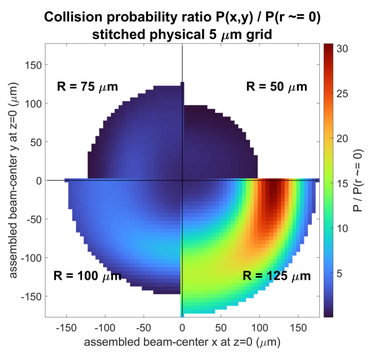
SCATTERING PROBABILITY





~1% Scattering Probability for Single Electron

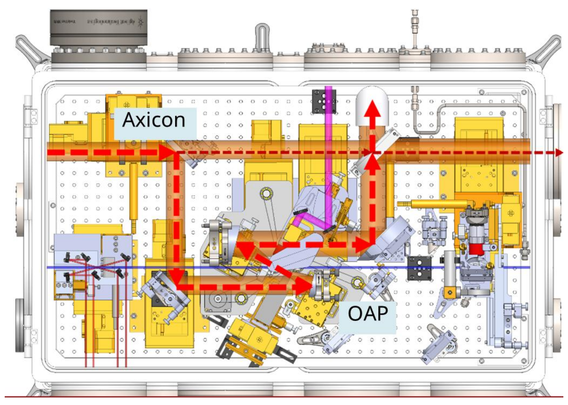




An Axicon w. R=125µm Maximizes a Clear Proof-of-Concept Signal.

PROOF-OF-CONCEPT EXPERIMENT: E344

Parameter	Value
Cross section	5.49×10^{-29} m^2
Electron beam	
Electron energy	10 GeV
Electrons per bunch	1.0×10^{10}
RMS beam size	$\sigma_x = 46\ \mu$m, $\sigma_y = 23\ \mu$m
RMS bunch length	$\sigma_z = 20\ \mu$m
Laser and focusing	
Wavelength	0.8 μm
Pulse energy	240 mJ
Photons per pulse	9.67×10^{17}
Pulse duration	40 fs FWHM
Input beam	$A(R) = \exp[-(R/20\ \text{mm})^8]$
OAP focal length	81 mm
Numerical aperture	0.240
Diffraction-limited spot size	1.69 μm FWHM



CONCLUSION

- In the proof-of-concept experiment, we will generate a donut-shaped laser beam and demonstrate controlled Compton scattering with an electron beam.
- For an FCC-ee implementation, the required laser energy density is estimated to be 21.3 mJ/μm^2 over the region to be collimated in order to reach a 99% interaction probability, assuming an electron energy of 45 GeV and a laser wavelength of 1064 nm.

ACKNOWLEDGEMENTS

This work is supported by the SLAC LDRD Program and by U.S. Department of Energy under contract DE–AC02–76SF00515.

REFERENCES

[1] S. Terui et al., "Collimator challenges at SuperKEKB and their countermeasures using nonlinear collimator," Phys. Rev. Accel. Beams 27, 081001 (2024).
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[3] F. Zimmermann, "New final focus concepts at 5 TeV and beyond," AIP Conf. Proc. 472, 103–117 (1999).
[4] F. Zimmermann and T. O. Raubenheimer, "Controlling e+/e− circular collider bunch intensity by laser Compton scattering," in Proc. IPAC'22, Bangkok, Thailand, pp. 1695–1698 (2022).
[5] C. Munting, P. Kicsiny, E. Barbi, N. Gonzalez, S. Gessner, and I. Drebot, "Laboratory Tests of Laser Control of Electron Beams for Future Colliders," arXiv:2601.19865 [physics.acc-ph] (2026).