Laser-Based Collimation of Beam Halo Electrons via Compton Scattering

FACET-II
Facility for Advanced Accelerator Experimental Tests

AAC26

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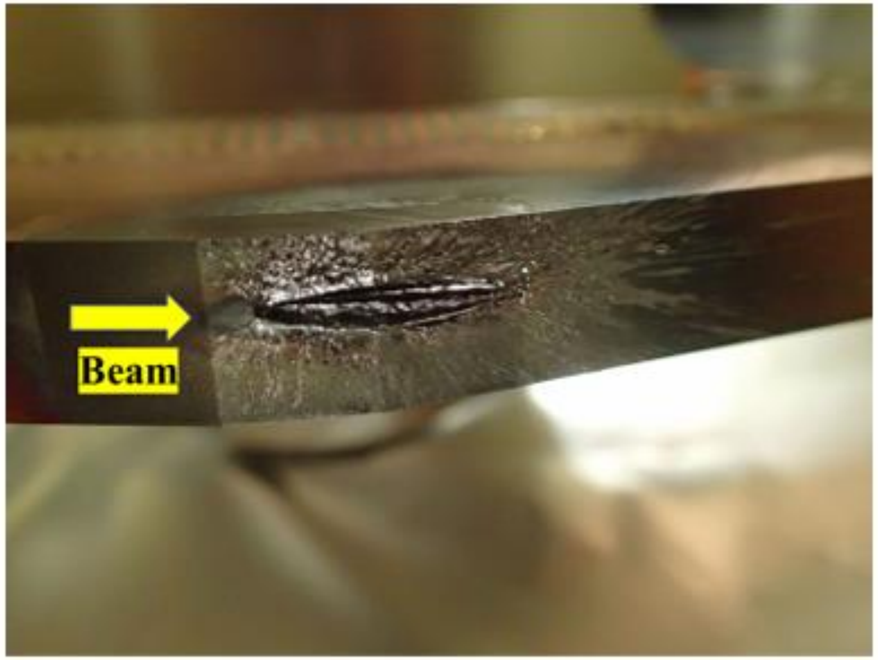
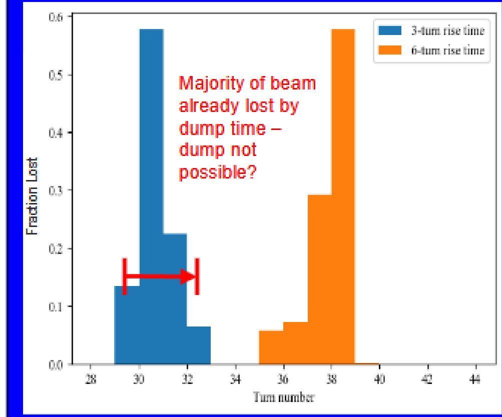
Motivation: Collimation Challenges



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

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



Fast Instability study (full failure of damping system) in GHC – initial particle tracking by Giulia Nigrelli

Very fast loss (3 turns ~1ms), no time to detect losses and dump

Primary particles could have hit secondary collimators!

Vaporisation of jaw implies catastrophic downstream effects.

Failures like these must be protected against upstream, through machine protection systems or early detection.

Temperatures for τ = 3 turns, Horizontal hit	TCP_H	TCP_V	TCS_H2	TCS_V1	TCS_H1	Failed Colls
0.01% beam hit (~1 bunch)	33	28	441	107	52	0
0.1% beam hit (~11 bunches)	148	28	melts	107	109	1
1% beam hit (~112 bunches)	1104	33	vaporises	122	977	1
10% beam hit (~1120 bunches)	vaporises	84	vaporises	342	vaporises	3
100% beam hit (11200 bunches)	vaporises	481	vaporises	vaporises	vaporises	4

Richard Cowan, FCC Week 2026

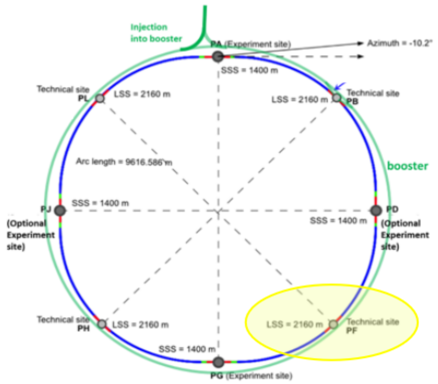
Fast instabilities cause catastrophic collimator damage.

Laser Collimation as a Defense-in-Depth Layer

LCC Collimation System Design

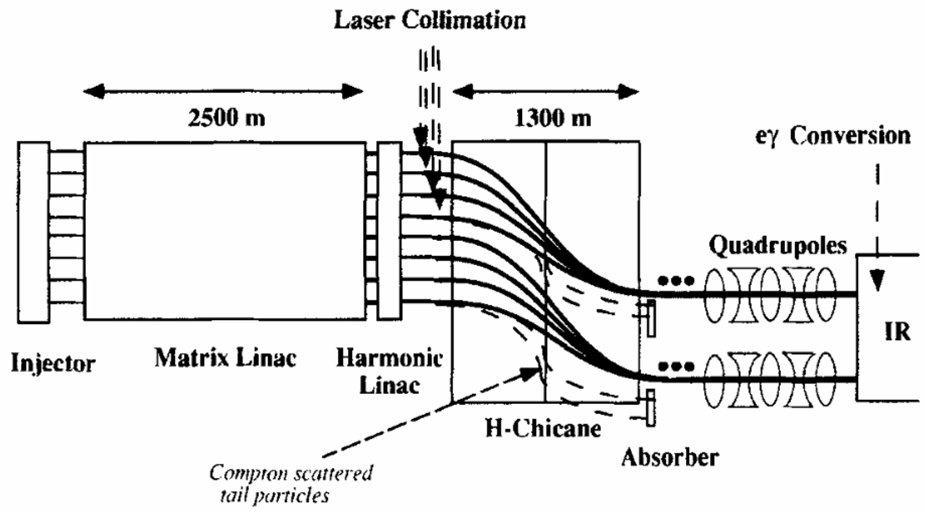
Major changes for LCC optics:
Two phase (2x primary collimators) betatron collimation at Point F
Momentum collimation primary at Points D & G
Primary collimators reduced to 10cm

Device	Requirements	Material	Location
Primary	Initial halo interaction	Carbon based	Point F
Secondary	Absorb scattered particles after Primaries	TZM (Mo alloy)	Point F
Shower Absorbers	Absorb main shower energy after Primaries	TZM (Mo alloy)	Point F & where necessary
Momentum Primaries	Initial off-momentum interaction	Carbon based	Points D and G, downstream of Ex
Tertiary	Protects ex. and final focus from beam losses	Carbon based	Upstream of experiment
SR Collimators	Background reduction from SR for ex.	Tungsten	Upstream of experiment



See Giacomo Broggi's talk for more info on collimation system layout changes and loss studies – current design shows best ever betatron cleaning performance

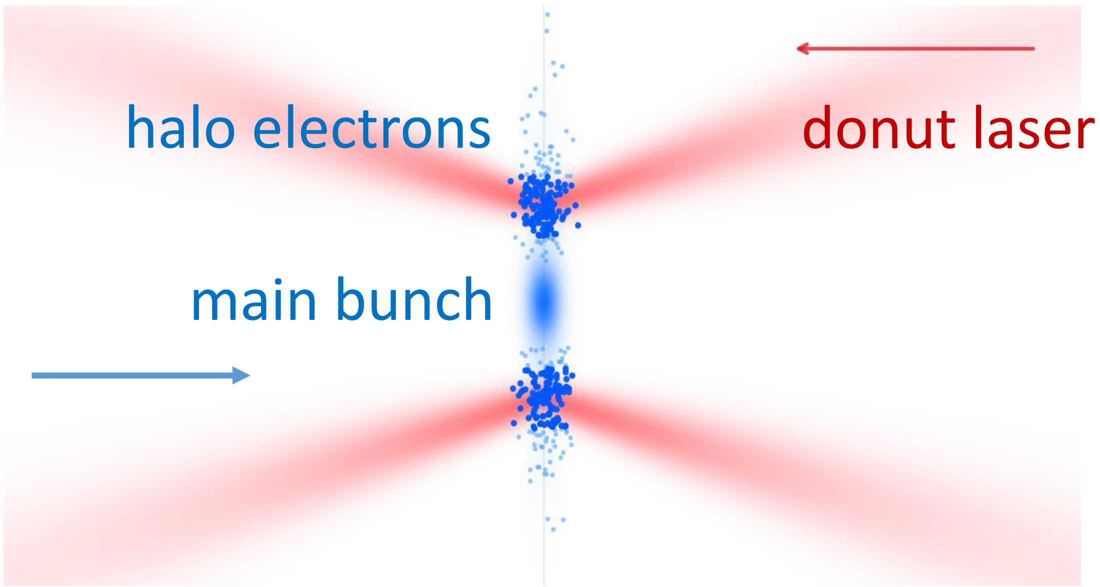
Richard Cowan, FCC Week 2026

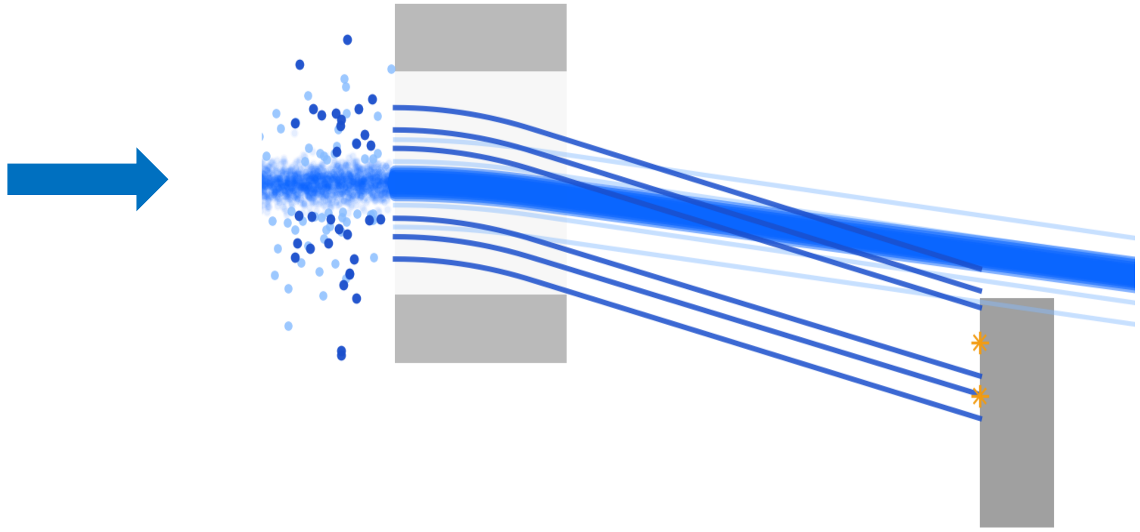


F. Zimmermann, AIP Conf. Proc. 472, 103–117 (1999).

An additional, non-material layer to reduce the load on conventional collimators.

Laser Collimation Concept





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

Laser Requirements: FCC-ee vs FACET-II

Common Requirements

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

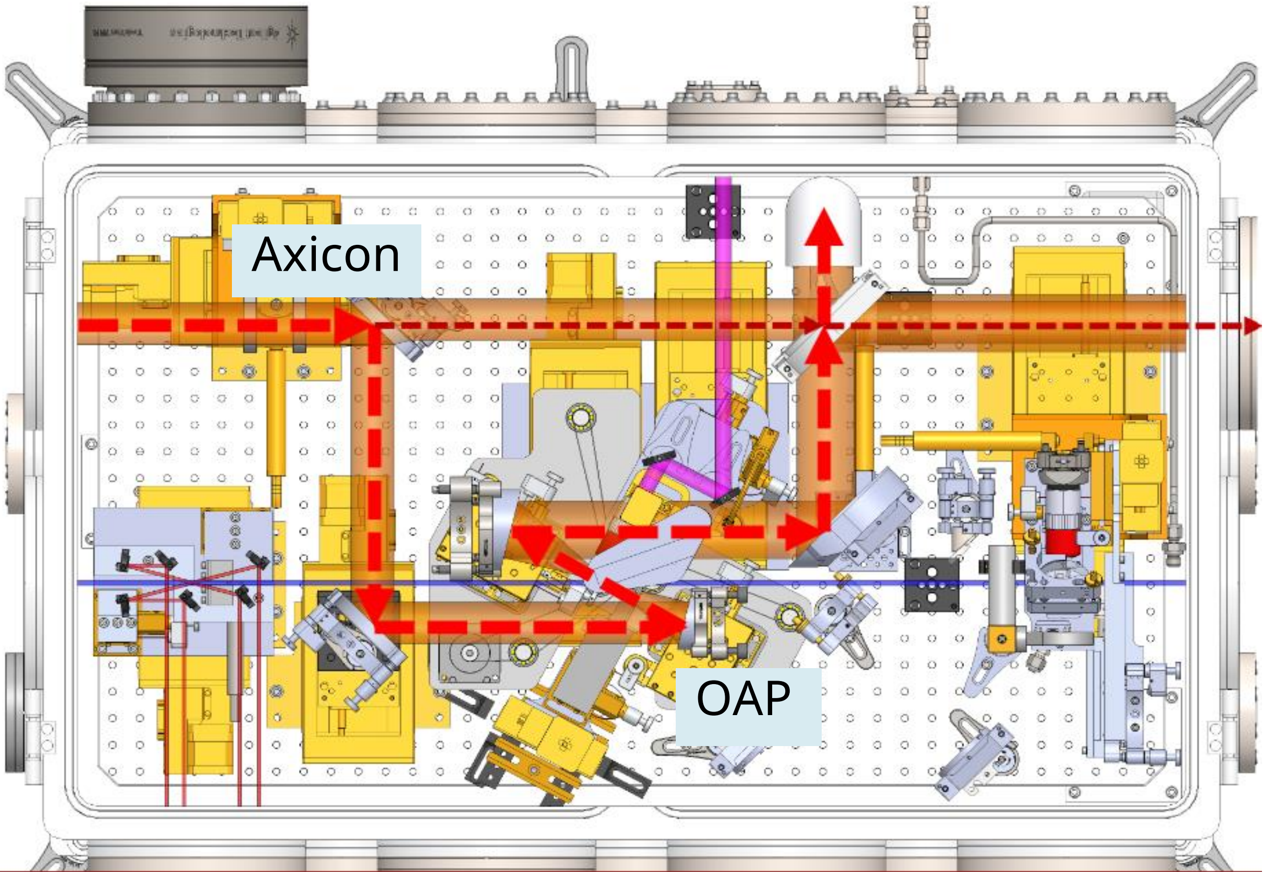
Laser transverse scale: ~ 10–$100\ \mu$m

FCC-ee Application	FACET-II Demonstration
Tailored laser profile matched to a flat beam	**Circular donut profile** matched to a more symmetric beam
Shaped beam or multiple beams	
$\sim 2.3\ \mathrm{mJ}/\mu\mathrm{m}^2$	High contrast for a clear signal

E344: Laser-Collimation Test at FACET-II

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	$0.8\ \mu$m
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	$1.69\ \mu$m FWHM

Built on the established E320 platform



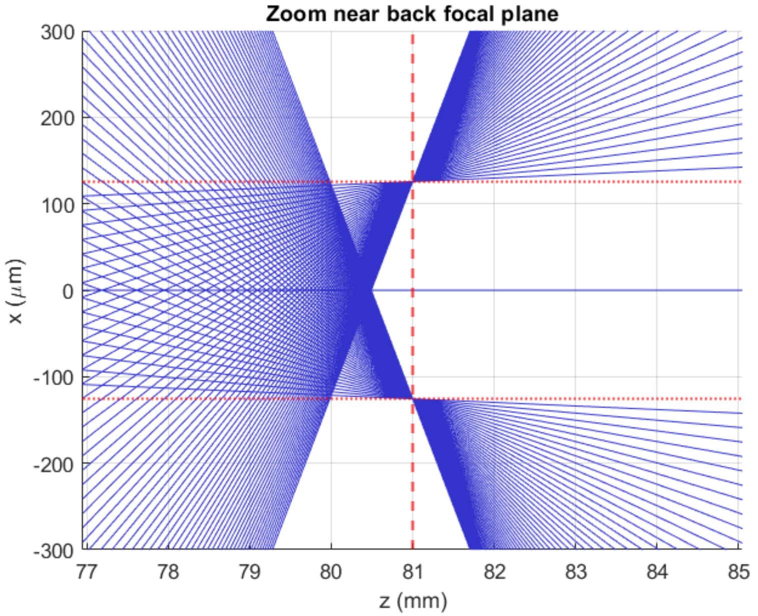
FACET-II enables a near-term test of laser collimation.

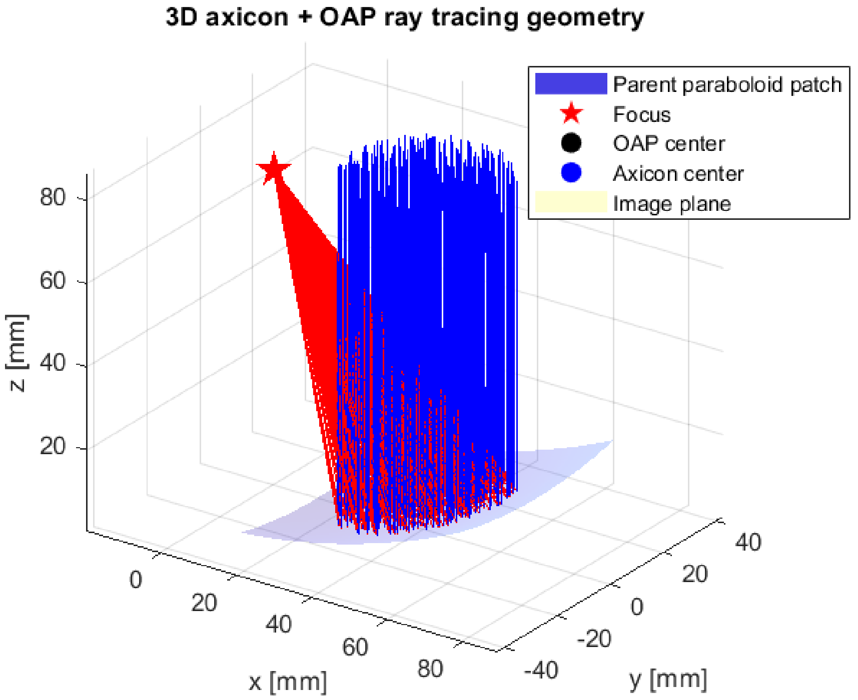
Comparison of Optical Schemes

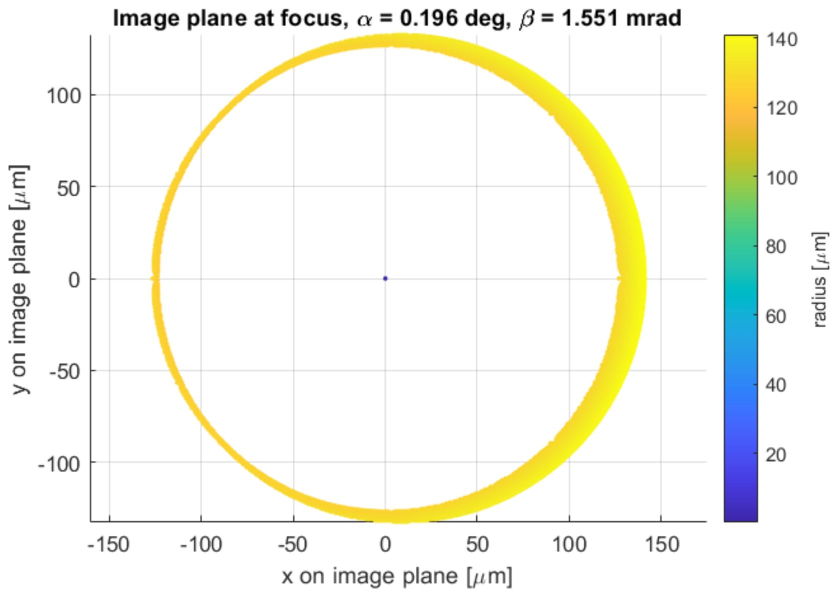
Property	High-NA axicon + OAP	Low-NA axicon + focusing optic	Spiral phase plate + high-NA OAP
Ring radius	broadly tunable	broadly tunable	tied to diffraction scale
Ring thickness	thin	thick	moderate
Radius/thickness independent control	good	good	limited
Peak intensity	high	low	high
Main-ring energy concentration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

Ray-Tracing Simulation

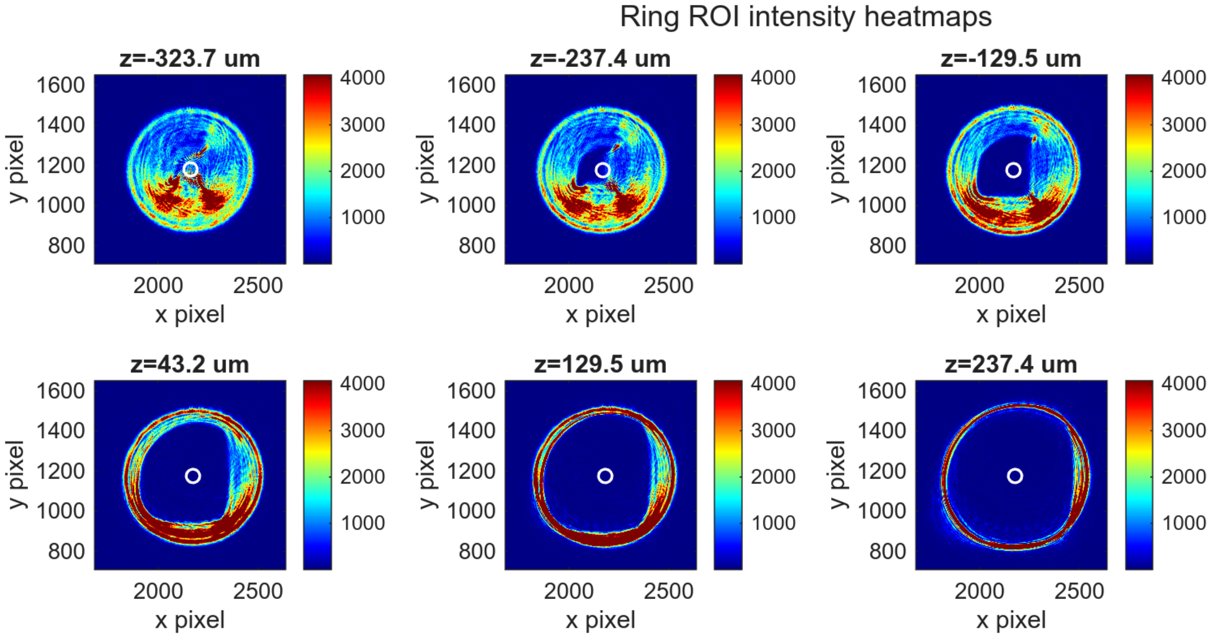
- 1+1D simplified ray tracing
- 3D ray-tracing

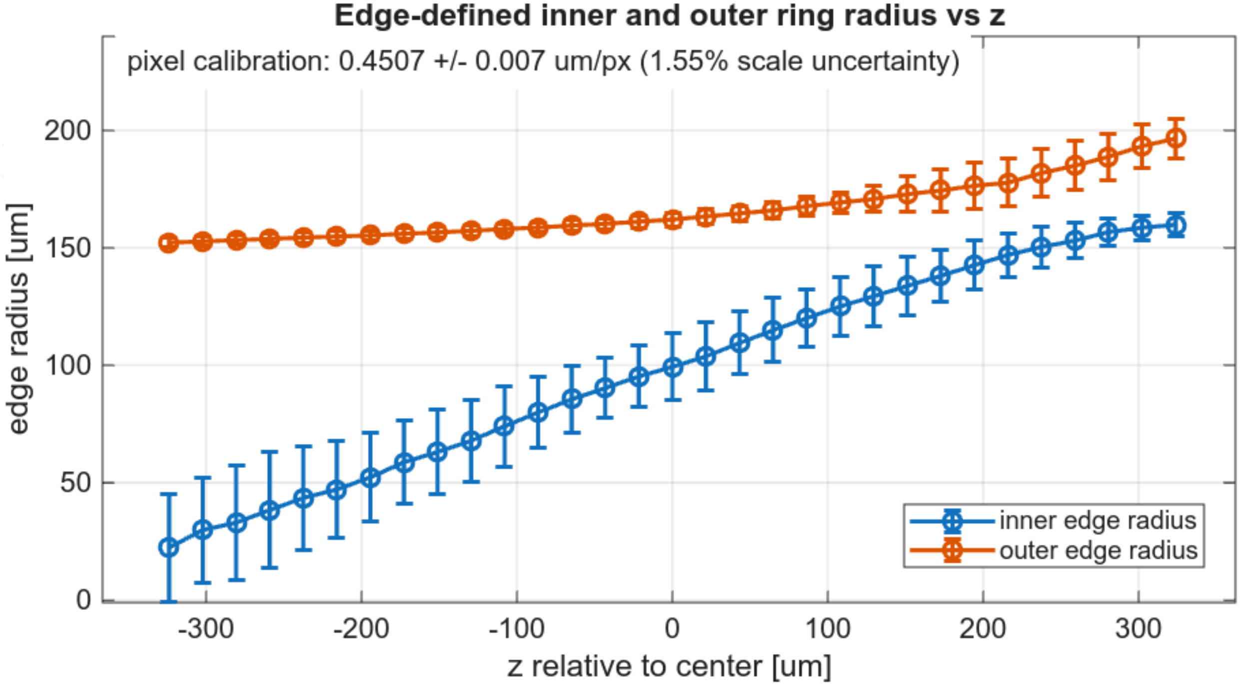






Donut-Beam Profile Measurement



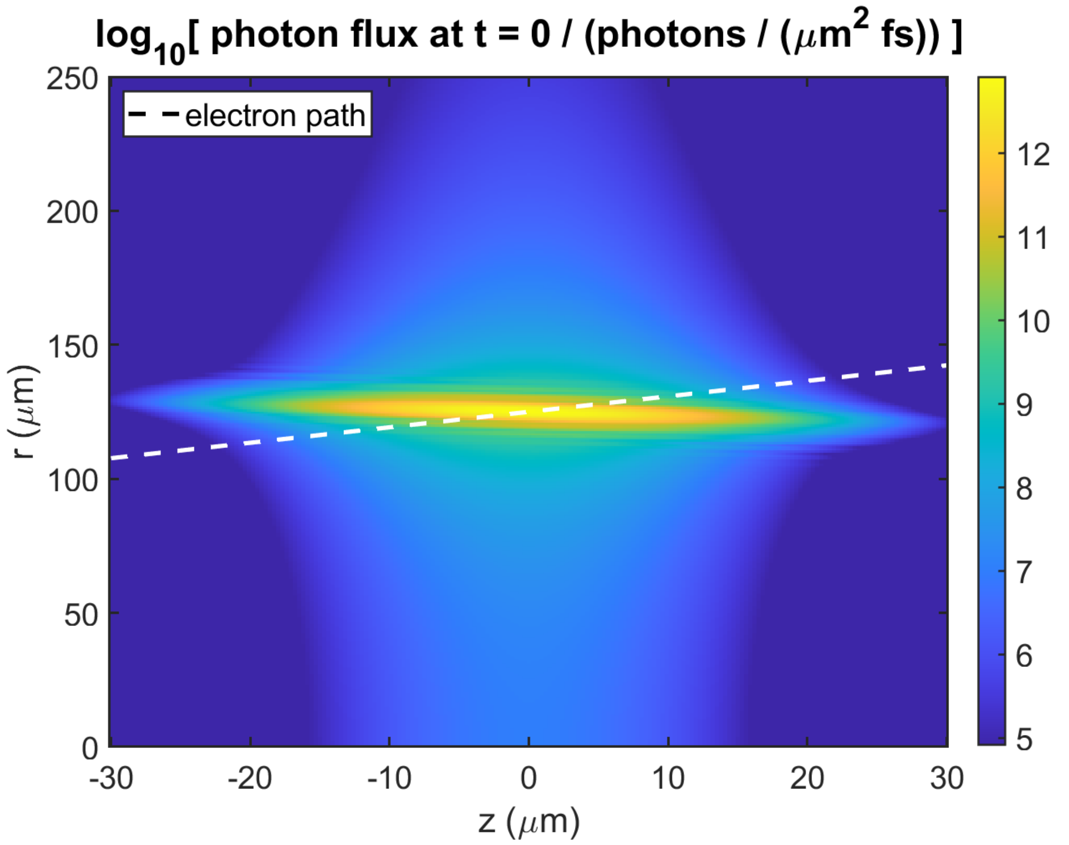


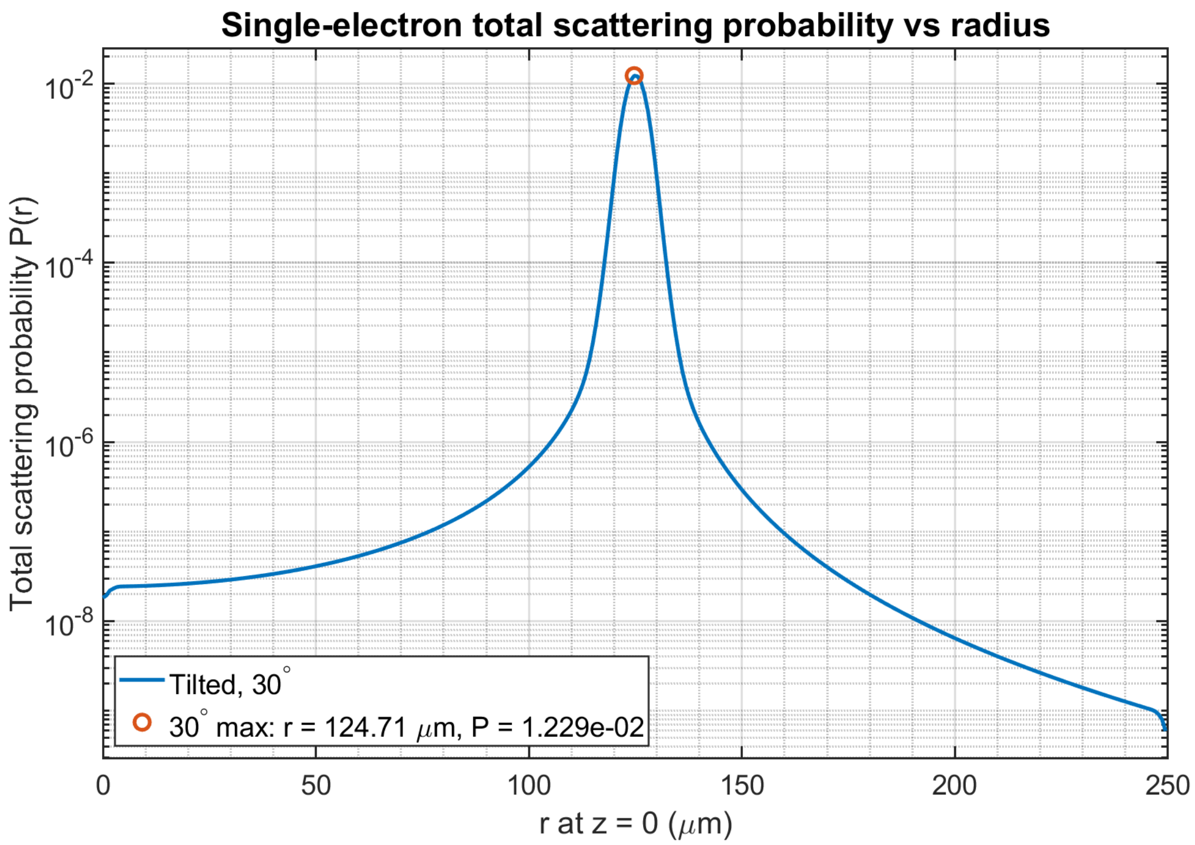
Target radius: 125 µm

Measured radius: 131 µm

Difference likely from residual alignment error

Scattering Probability

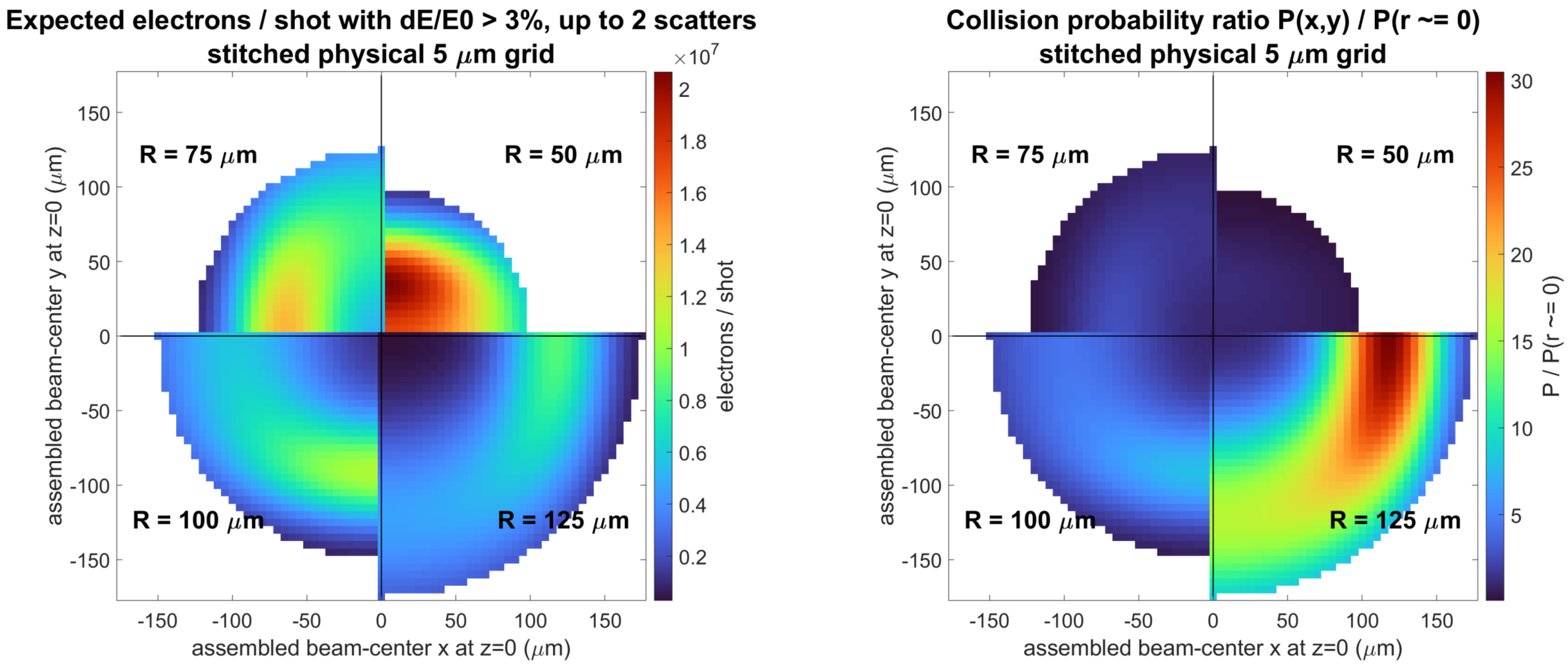




~1% Scattering Probability for Single Electron

SLAC

Choosing the Ring Radius



An Axicon w. $R = 125\mu m$ Maximizes a Clear Proof-of-Concept Signal.

Toward Collider-Scale Laser Collimation

High-Repetition-Rate Operation

Cavity-enhanced laser system

$\sim$30 MHz interaction rate

Efficient pulse recycling

(30W pump laser?)

Flexible Laser Profiles

Light sheet · LG modes · Multiple beams ·

Target intensity profiles via phase masks

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 $21.3\ \mathrm{mJ}/\mu\mathrm{m}^2$ over the region to be collimated in order to reach a 99% interaction probability, assuming an electron energy of $45\ \mathrm{GeV}$ and a laser wavelength of $1064\ \mathrm{nm}$.

References

- [1] S. Terui et al., “Collimator challenges at SuperKEKB and their countermeasures using nonlinear collimator,” Phys. Rev. Accel. Beams 27, 081001 (2024). https://doi.org/10.1103/PhysRevAccelBeams.27.081001
- [2] R. Cowan et al., “Mechanical Design of FCC-ee Collimators,” presented at FCC Week 2026, Helsinki, Finland (2026). https://indico.cern.ch/event/1552126/
- [3] F. Zimmermann, “New final focus concepts at 5 TeV and beyond,” AIP Conf. Proc. 472, 103–117 (1999). https://doi.org/10.1063/1.58898
- [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). https://doi.org/10.18429/JACoW-IPAC2022-WEPOST010
- [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). https://arxiv.org/abs/2601.19865