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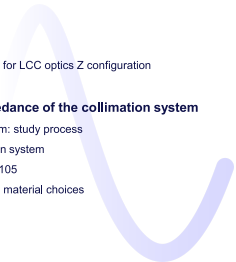
Update on FCC-ee Collimators Impedance Studies

FCC-ee Collimation Meeting, 4th December 2025

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Overview

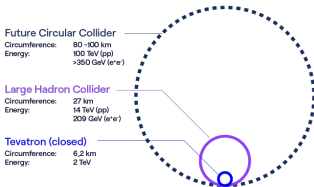
- **Introduction**
 - FCC-ee main parameters for LCC optics Z configuration
 - **FCC-ee beam coupling impedance of the collimation system**
 - FCC-ee collimation system: study process
 - Criticality of the collimation system
 - Collimation optics: LCC v105
 - Guidelines for design and material choices
 - **Conclusion and next steps**
- 

○ Introduction

FCC-ee main parameters for Z configuration

Optics	LCC (Z mode)
Beam energy E (GeV)	45.6
Circumference C (m)	90644.816
Arc-cell setup	52/45
Momentum compaction factor α_c (1e-6)	9.5
Energy Loss per turn W_0 (GeV)	0.035
Beam Intensity N (1e12particles)	2424
Bunch Intensity N_b (1e11particles)	2.02
Number of Bunches	12000
Horizontal β -function at IP β_x^* (cm)	9
Vertical β -function at IP β_y^* (mm)	0.7
Horizontal emittance ε_x (nm)	0.71
Vertical emittance ε_y (non.coll./coll.) (pm)	1.77 / 2.37
Transverse tune Q_x/Q_y	194.14 / 170.22
Chromaticity Q'_x/Q'_y	12 / 5
Harmonic number h at 400MHz	121200
Total RF voltage of 400 / 800 MHz (GV)	0.09
Synchrotron tune Q_s	0.031
Bunch length σ_z (non.coll./coll.) (mm)	5.1 / 16.7
Rel. mom. spread σ_p (non.coll./coll.) (1e-3)	0.39 / 1.34
Longitudinal damping time τ_z (turns)	1297
Crab-waist ratio (%)	55
Beam-beam parameter $\xi_{x,y}$ (1e-3)	1.4, 80
Luminosity \mathcal{L} (1e34 ⁻¹²)	150

Table 1: Parameter table for the LCC lattice v105 at Z mode.



Future Circular Collider

Circumference: 80 -100 km
Energy: 100 TeV (pp)
>350 GeV (e⁺e⁻)

Large Hadron Collider

Circumference: 27 km
Energy: 14 TeV (pp)
209 GeV (e⁺e⁻)

Tevatron (closed)

Circumference: 6,2 km
Energy: 2 TeV

Necessity of a **highly flexible** model to account for changes during this development phase

○ FCC-ee beam coupling impedance
of the collimation system

FCC-ee collimation system: study process

Schematic design



Winglets design



Non-winglets design

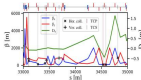


Step-taper design



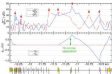
The collimator design is still evolving → All studied versions are currently stored and available for further comparison and analysis

GHC v23



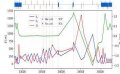
K. Oide: [FCCWeek_Optics_Oide_230606](#)

GHC v24.4



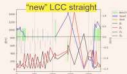
K. Oide: [Optics_Oide_241106](#)

GHC v25.2



K. Oide: [Optics_Oide_box_tech1_250424](#)

LCC v105

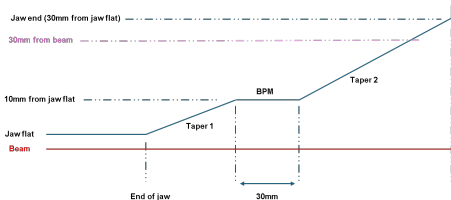


P. Raimondi: [LCC optics developments.pdf](#)

GHC: Global Hybrid Chromaticity Correction
LCC: Local Chromaticity Correction

Collimators with step taper

Proposed taper section design for the FCC-ee collimators



Features:

- Small flats at ± 10 mm from jaws for BPMs

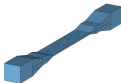
Advantages:

- Simplified mechanical design: flexibility needed in only one direction
- More robust RF fingers
- Enhanced mechanical reliability

Status:

- Lengths adjustable; taper angle is not a limiting factor

The design allows the use of flexible elements in only 1 direction, offering improved conductance and more robust shielding around the edge of the jaw and simplifying mechanical design



Criticality of the collimation system

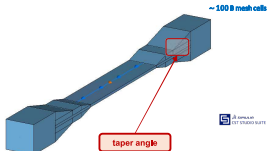
Criticality of the collimation system → identified as one of the primary impedance sources in FCC-ee.

Challenging simulation regime:

- Combination of **large beam** pipe dimension (30 mm radius) and **short bunch lengths** (5÷15 mm)
→ computationally demanding simulations.
- Very high number of mesh cells (~billions) in electromagnetic solvers → CST.

Beam coupling impedance contributions of the collimation system:

- Geometrical impedance
→ Optimizing taper transitions
→ $Z_{\perp}(f)$ increases with taper angle
- Resistive wall impedance
→ Optimizing material selection
→ $Z_{\perp}(f) \propto 1/\sqrt{\sigma}$
- Impact of optics
→ $Z_{\perp}(f) \propto 1/\text{gap}^3$
→ $Z_{\perp}(f) \propto \beta$
→ $Z_{\perp}(f) \propto L$



Collimation optics: LCC v105

Collimator parameters from [version 105](#) of the LCC collimation layout optics. It is important to highlight the contribution of the vertical primary collimator **tcp.v.b1**, which plays a critical role in the overall impedance of the collimation system.

Table below summarizes the main parameters of the primary and secondary collimators for the LCC optics v105:

Name	Length (m)	gap/2 (mm)	Material	nsigma	β_x (m)	β_y (m)
tcp.h.b1	0.25	5.7	MoGr	8	727.20	74.25
tcp.v.b1	0.25	1.9	MoGr	50	252.20	727.45
tcs.h1.b1	0.3	5.0	Mo	9.5	395.33	517.07
tcs.v1.b1	0.3	2.5	Mo	65	169.49	724.37
tcs.h2.b1	0.3	5.0	Mo	9.5	399.86	79.56
tcs.v2.b1	0.3	2.5	Mo	65	252.11	723.00
tcp.hp.b1	0.25	8.6	MoGr	15	469.73	741.47
tcs.hp1.b1	0.3	8.5	Mo	18	321.52	976.55
tcs.hp2.b1	0.3	7.7	Mo	18	263.31	79.68

tcp: primary, tcs: secondary, h: horizontal, v: vertical, $\sigma_{\text{MoGr}} = 10^6 \text{ S/m}$, $\sigma_{\text{Mo}} = 1.8 \cdot 10^7 \text{ S/m}$.

$$Z_{\perp}(f) = \sum_{i=1}^N Z_{\perp}^i(f) \frac{\beta_{\perp}^i}{\langle \beta_{\perp} \rangle}$$

$$Z_{\perp}(f) \propto 1/\text{gap}^3$$

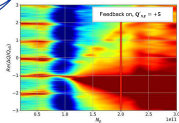
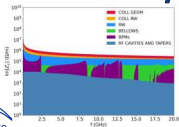
$$Z_{\perp}(f) \propto \beta$$

Collimation optics: LCC v105 with non-optimized collimators geometry

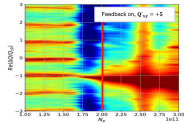
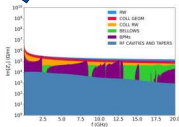
TCP.V.B1 with higher electrical conductivity ($\sigma_{TCP.V.B1} = 4 \cdot 10^7 \text{ S/m}$)

Only primaries (TCP) and secondaries (TCS) collimators

Single-bunch simulations



Unstable



Unstable

Single-bunch simulations



Bunch intensity:

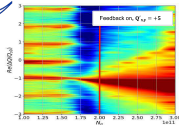
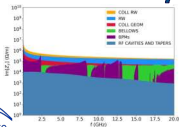
$$N_p = 2.02 \times 10^{11} \text{ ppb}$$

Collimation optics: LCC v105 with optimized collimators geometry

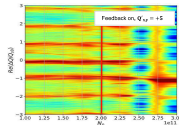
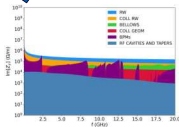
TCP.V.B1 with higher electrical conductivity ($\sigma_{TCP.V.B1} = 4 \cdot 10^7 \text{ S/m}$)

Only primaries (TCP) and secondaries (TCS) collimators

Single-bunch simulations



Unstable



Stable

Single-bunch simulations

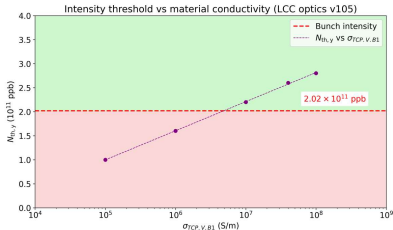


Bunch intensity:
 $N_p = 2.02 \times 10^{11} \text{ ppb}$

Guidelines for design and material choices

Summary plots illustrating the intensity thresholds at which instability arises for the **LCC optics version 105**, considering nominal materials and varying **only** the electrical conductivity of the primary vertical collimator **TCP.V.B1**.

The *optimized geometry* - reducing the taper angles for all vertical collimators and adopting a step-taper design - was used throughout the analysis.



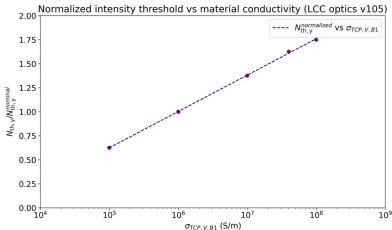
Nominal materials: materials with electrical conductivity of $\sigma_{TCP} = 10^6$ S/m for all primary and $\sigma_{TCS} = 1.8 \cdot 10^7$ S/m for all secondary collimators

Nominal intensity threshold:
 $N_{Th,y}^{nominal} = 1.6 \times 10^{11}$ ppb

Guidelines for design and material choices

Summary plots illustrating the normalized intensity thresholds at which instability arises for the **LCC optics version 105**, considering nominal materials and varying **only** the electrical conductivity of the primary vertical collimator **TCP.V.B1**.

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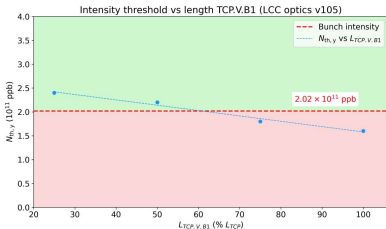
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Nominal intensity threshold:
 $N_{Th,y}^{nominal} = 1.6 \times 10^{11} ppb$

Guidelines for design and material choices

Summary plots illustrating the intensity thresholds at which instability arises for the **LCC optics version 105**, considering nominal collimator lengths and varying **only** the length of the primary vertical collimator **TCP.V.B1**.

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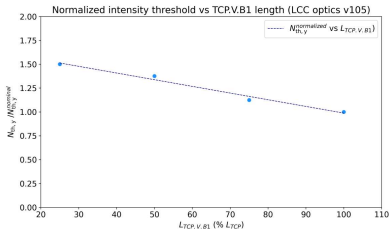
Nominal lengths: $L_{TCP} = 250$ mm for all primary and $L_{TCS} = 300$ mm for all secondary collimators

Nominal intensity threshold:
 $N_{Thy}^{nominal} = 1.6 \times 10^{11}$ ppb

Guidelines for design and material choices

Summary plots illustrating the normalized intensity thresholds at which instability arises for the **LCC optics version 105**, considering nominal collimators lengths and varying **only** the length of the primary vertical collimator **TCP.V.B1**.

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○ **Conclusion and next steps**

Conclusion and next steps

- ◆ **Impedance/Wake model development for critical design decisions**
 - The extremely **short bunch length** makes impedance and wakefield simulations particularly **challenging**.
 - A **flexible and modular** model has been developed to accommodate updates in optics, material choices, coating thicknesses, geometries, and new machine elements.
 - The model enables impedance evaluations across different scenarios.
 - Available on GitHub: [ImpedanCE/fcc_ee_IW_model: Impedance/Wake model of the Future Circular Collider \(FCC\)](#)

- ◆ **Optimization of the impedance of the collimation system is crucial for FCC-ee beam stability**
 - Impedance optimization strategies are currently under development in collaboration with the collimation team:
 - **Taper transition design.**
 - **Material choice**
 - ➔ Favor materials with **higher electrical conductivity**.
 - **Collimators length**
 - ➔ Keep collimators **lengths as small as possible**.



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A large, light blue sine wave graphic that spans across the middle of the slide, partially overlapping the text.

Thank you for your attention

FCC-ee Collimation Meeting, 4th December 2025