FUTURE CIRCULAR COLLIDER

FCC-ee collimation scheme

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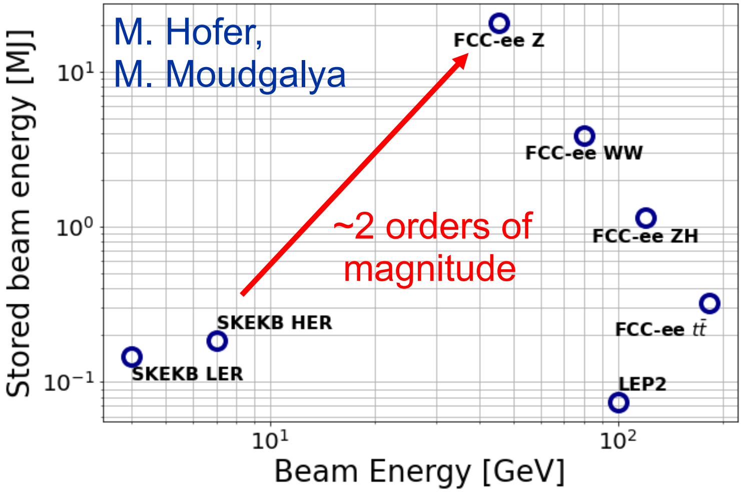
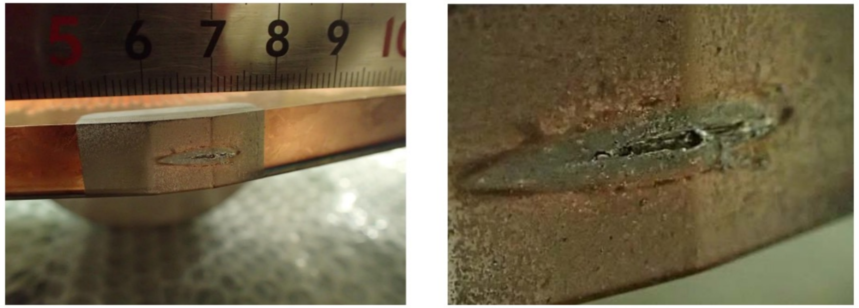
Collimation for the FCC-ee

- **The FCC-ee is the FCC first stage e+e- collider**
  - 90.7 km circumference, tunnel compatible with the FCC-hh
  - 4 beam operation modes, optimized for production of different particles: ***Z*** (45.6 GeV), ***W*** (80 GeV), ***H*** (120 GeV), $t\bar{t}$ (182.5 GeV)
  - The stored beam energy reaches **17.8 MJ** for the 45.6 GeV ***Z*** mode, which is comparable to heavy-ion operation at the LHC



Comparison of lepton colliders

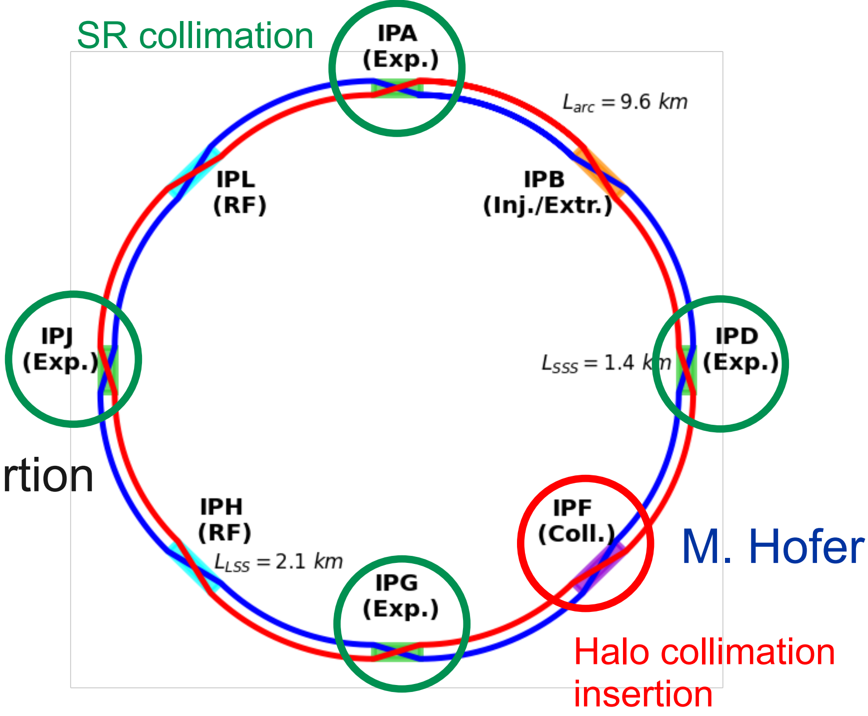
- **The FCC-ee presents unique challenges**
  - Such beams are highly destructive: a collimation system is required
  - The main roles of the collimation system are:
    - Protect the equipment from unavoidable losses
    - Reduce the backgrounds in the experiments
  - The beam halo collimation system was studied, and a first baseline design was developed

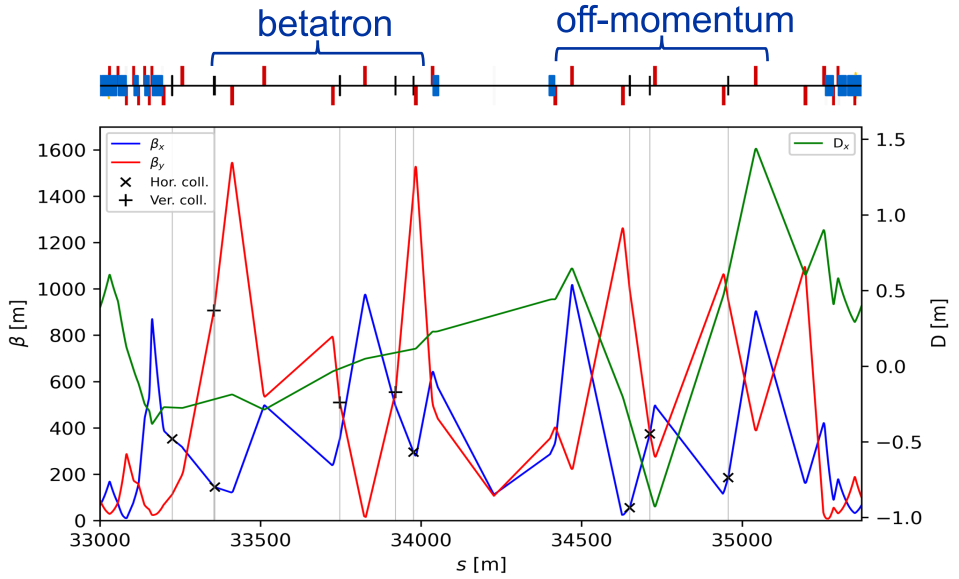


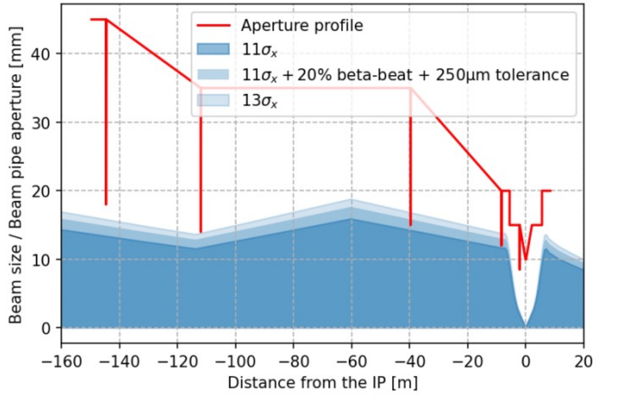
Damage to coated collimator jaw due to accidental beam loss in the SuperKEKB – T. Ishibashi (talk)

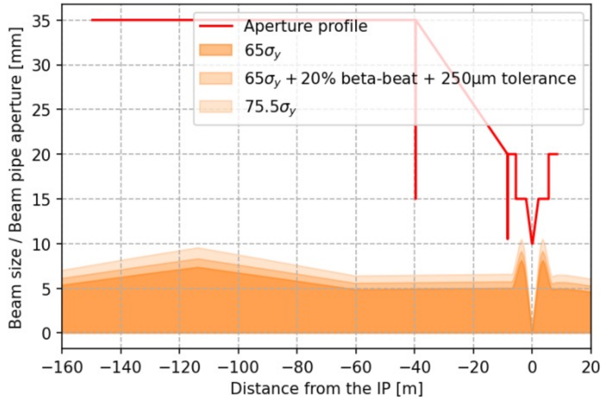
FCC-ee collimation system

- **Two types of collimation foreseen for the FCC-ee:**
  - The beam halo (global) collimation
  - Synchrotron Radiation (SR) collimation – near the IPs
- **Halo collimation in a dedicated insertion**
  - Two-stage betatron and off-momentum collimation systems in one insertion
  - Ensure protection of the aperture bottlenecks in different conditions
  - Collimation optics (M. Hofer) and collimator parameters (G. Broggi)
- **Synchrotron radiation collimators around the IPs**
  - 6 collimators and 2 masks upstream of the IPs (K. André)
  - Designed to absorb SR photons









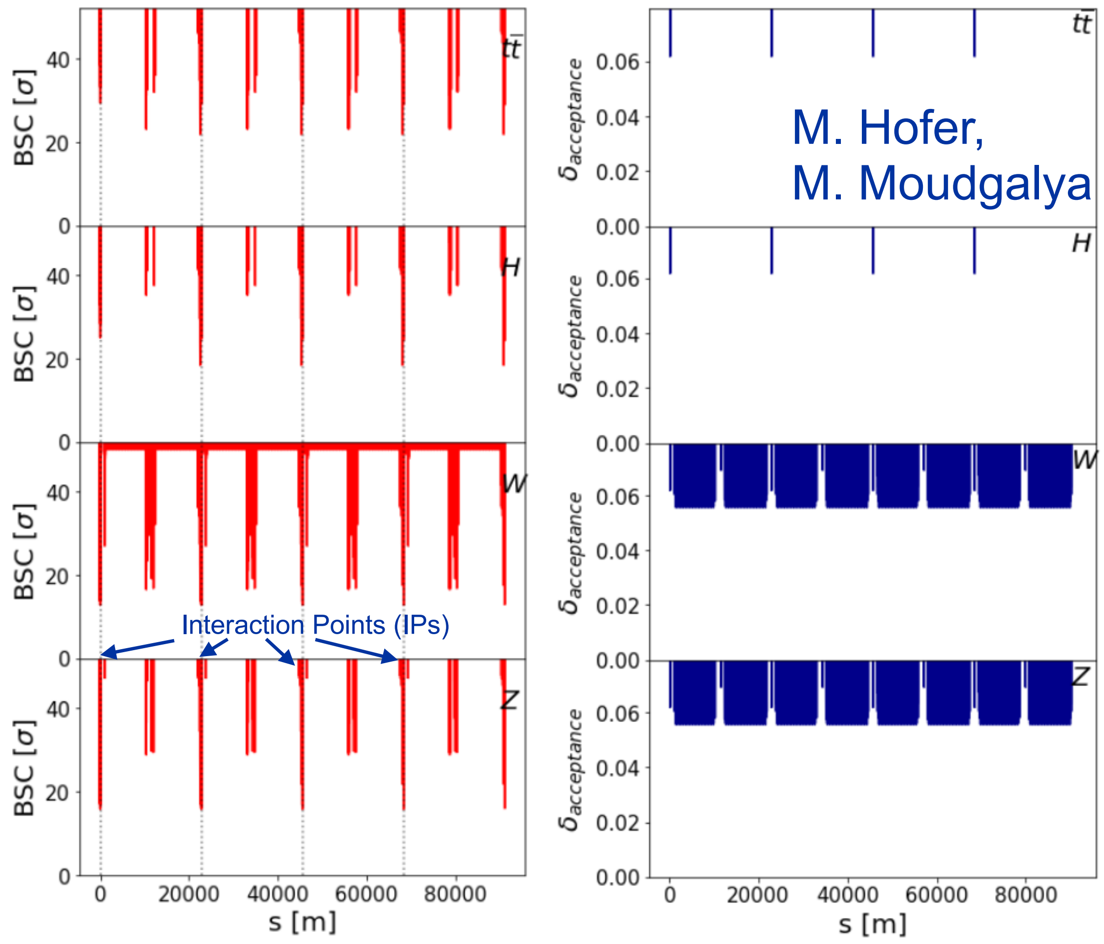
FCC-ee aperture

- **The aperture bottlenecks are in the experimental interaction regions (IRs)**
  - Depend on the optics, layout, and mechanical aperture in the IRs

- **The bottlenecks must be protected**
  - The final focus quadrupoles are superconducting and there is a risk of quenches
  - The detector is sensitive to backgrounds from beam losses
  - The SR collimators and masks are not robust to large direct beam impacts, can also produce backgrounds

Beam stay-clear (**BSC**) is the distance from the beam to the aperture in units of beam size

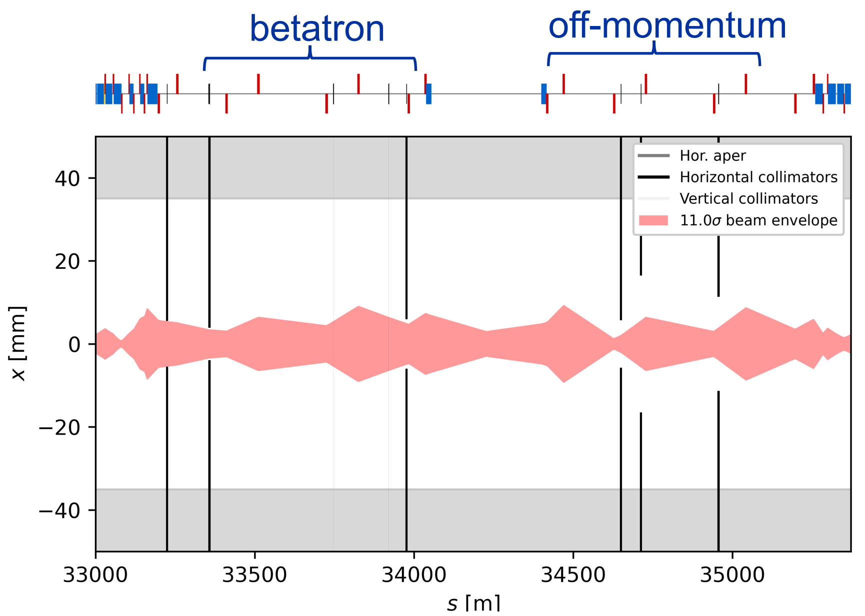
The momentum acceptance is the δ **= A / D**, where **A** is mechanical aperture and **D** is dispersion



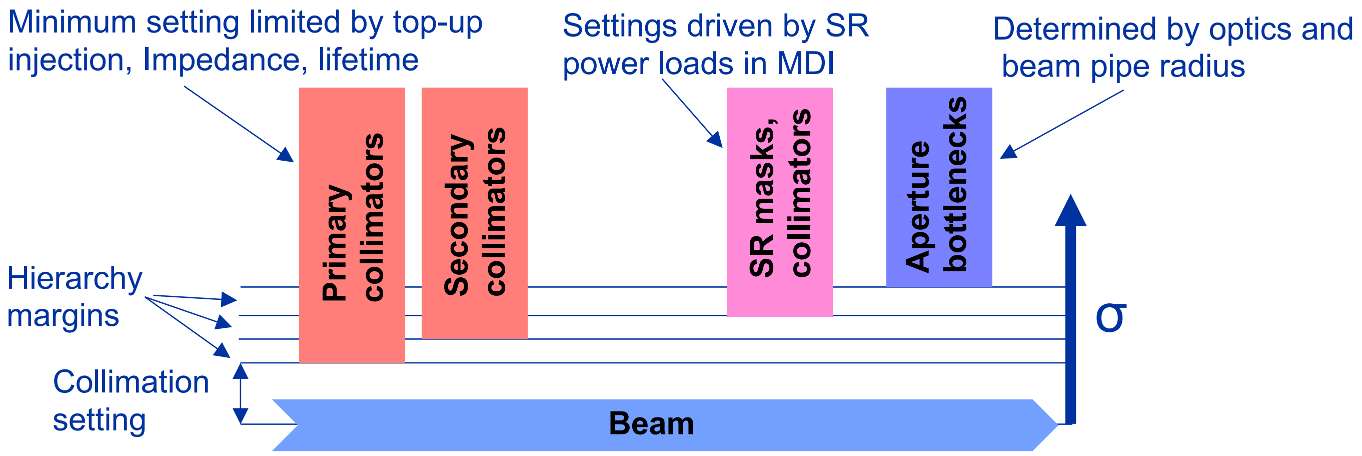
Aperture bottlenecks for the different operating modes

FCC-ee halo collimation

- **Collimator parameters and settings**
  - Preliminary collimator parameters selected to optimize the collimation cleaning performance (G. Broggi)
  - Settings selected to protect aperture bottlenecks
  - The settings of the SR collimators are driven by MDI power loads, but are constrained by the halo collimation settings
  - The collimation hierarchy margins are tight



Aperture and collimators in PF for the Z mode



Type	Plane	Material	Length [m]	Gap [σ]
β prim.	H	MoGr	0.4	11.0
β sec.	H	Mo	0.3	13.0
β prim.	V	MoGr	0.4	65.0
β sec.	V	Mo	0.3	75.5
δ prim.	H	MoGr	0.4	29.0
δ sec.	H	Mo	0.3	32.0
SR BWL	H	W	0.1	18.6
SR QC3	H	W	0.1	16.7
SR QT1	H	W	0.1	14.6
SR QT1	V	W	0.1	196.4
SR QC2	H	W	0.1	14.2
SR QC2	V	W	0.1	154.2

Collimator parameter and settings for the Z mode

FCC-ee beam loss scenarios

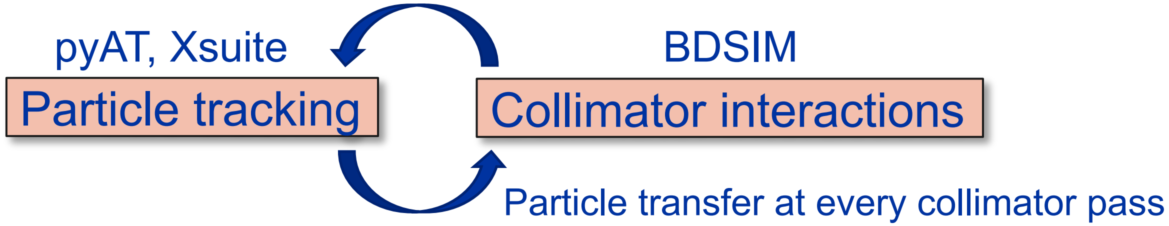
- **The FCC-ee will operate in a unique regime**
  - Electron / positron beam dynamics and beam-matter interactions
  - Stored beam energy exceeding material damage limits
  - Superconducting final focus quadrupoles, crab sextupoles, and RF cavities
  - Must study the beam loss processes and define the ones to protect against
  - Must study the equipment loss tolerances, for both regular and accidental losses

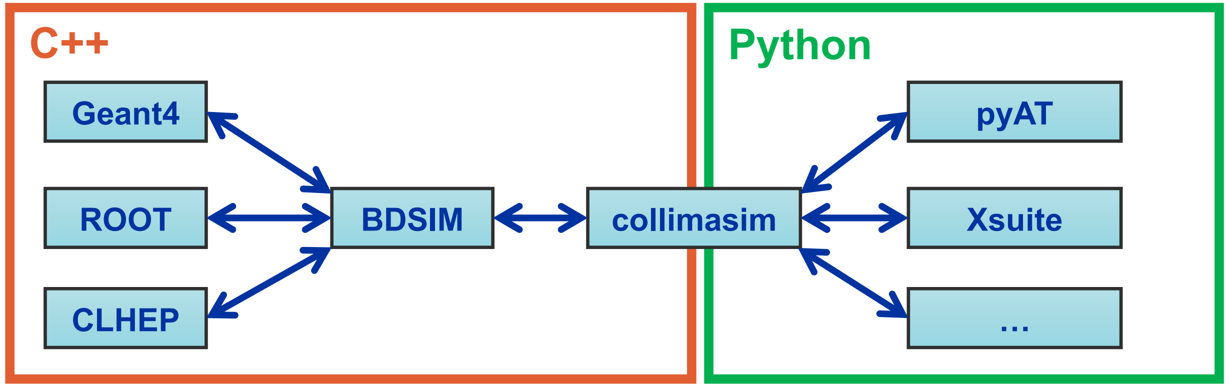
- **Important loss scenarios for particle tracking studies:**
  - **Beam halo** ← Current studies
  - Top-up injection
  - Spent beam due to collision processes (Beamstrahlung, Bhabha scattering)
  - Failure modes (injection failures, asynchronous dump, others
  - Beam tails from Touschek scattering and beam-gas interactions

Setting up studies

FCC-ee collimation simulations

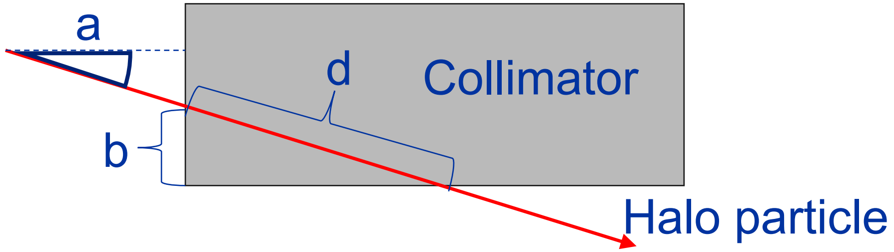
- **The FCC-ee presents unique challenges for collimation simulations:**
  - Synchrotron radiation and magnet strength adjustment (tapering) to compensate it
  - Complex beam dynamics – strong sextupoles in lattice, strong beam-beam effects (Beamstrahlung)
  - Detailed aperture and collimator geometry modelling
  - Electron/positron beam particle-matter interactions
  - Large accelerator – 90+ km beamline
- **Xsuite + BDSIM (Geant4) coupling**
  - Developed for the collimation simulations in the FCC
  - Benchmarked against other codes for FCC-ee – MAD-X, pyAT, SixTrack-FLUKA coupling
  - Xsuite-FLUKA coupling first release is available (LHC collimation and FLUKA teams)





Current study: beam halo losses

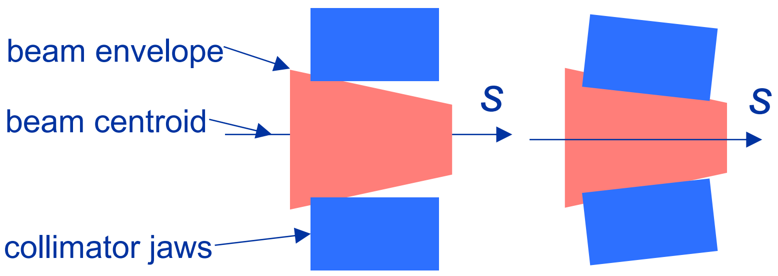
- **"Generic beam halo" beam loss scenario:**
  - Specify a minimum beam lifetime that must be sustained during normal operation
    - Preliminary specification of a **5 minute** lifetime
  - Assume a slow loss process – halo particles always intercepted by the primary collimators
  - The loss process is not simulated, all particles start impacting a collimator
    - Track the particles scattered out from the collimator and record losses on the aperture
  - Currently using 1 μm impact parameter as standard
    - Selected to give a conservative performance estimate
    - Impact parameter scans ongoing



a = angle of incidence
b = impact parameter
d = distance traversed

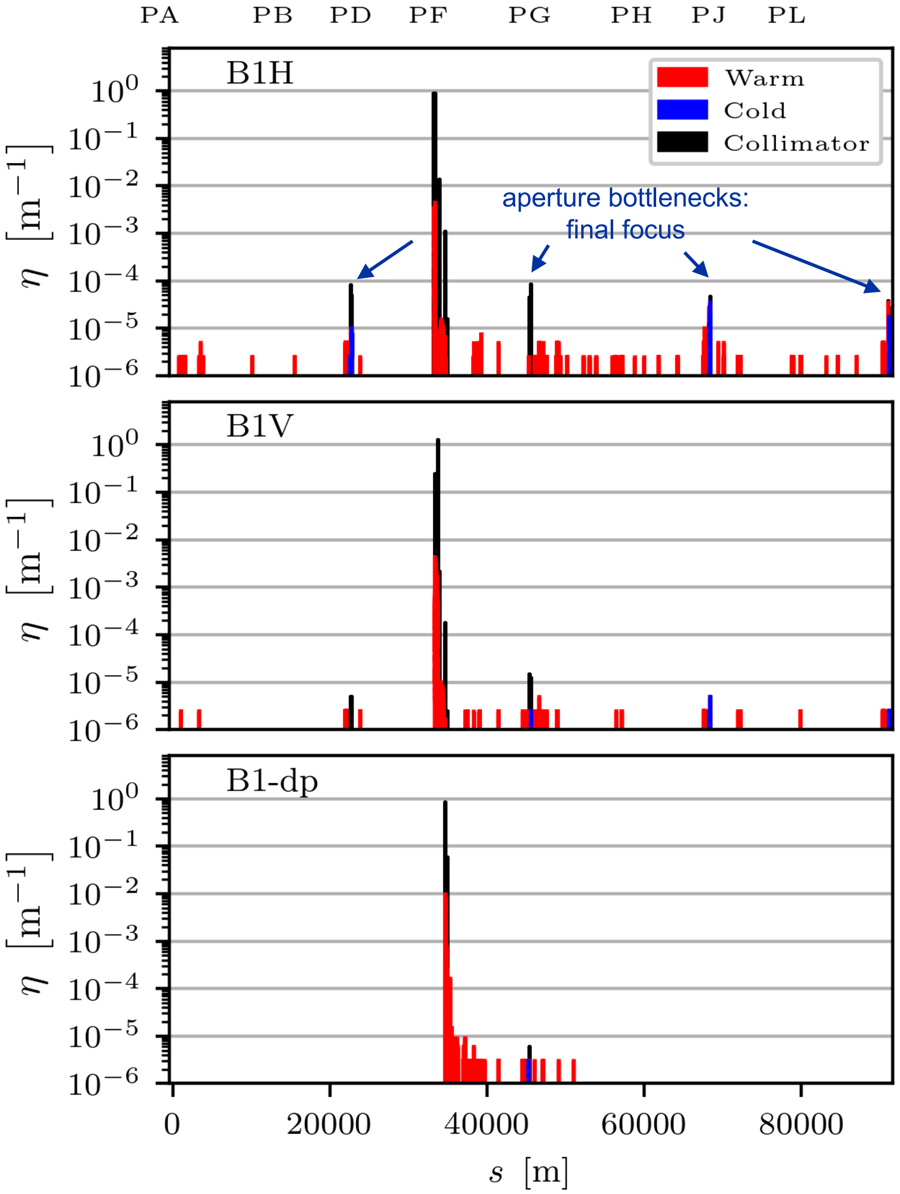
Beam halo losses for the Z mode

- The *Z* mode is the current focus (Beam 1, 45.6 GeV, e^+), **17.8 MJ** stored beam energy
- The **5 minute** beam lifetime → total loss power **59.2 kW**
- Radiation and tapering included
- 3 cases considered:
  - **Horizontal betatron losses (B1H)**
  - **Vertical betatron losses (B1V)**
  - **Off-momentum losses $\delta < 0$ (B1-dp)**
- For the off-momentum case, using a tilted collimator, aligned to the beam divergence



Parallel jaw and tilted collimator schematic

Total loss power: **59.2 kW**

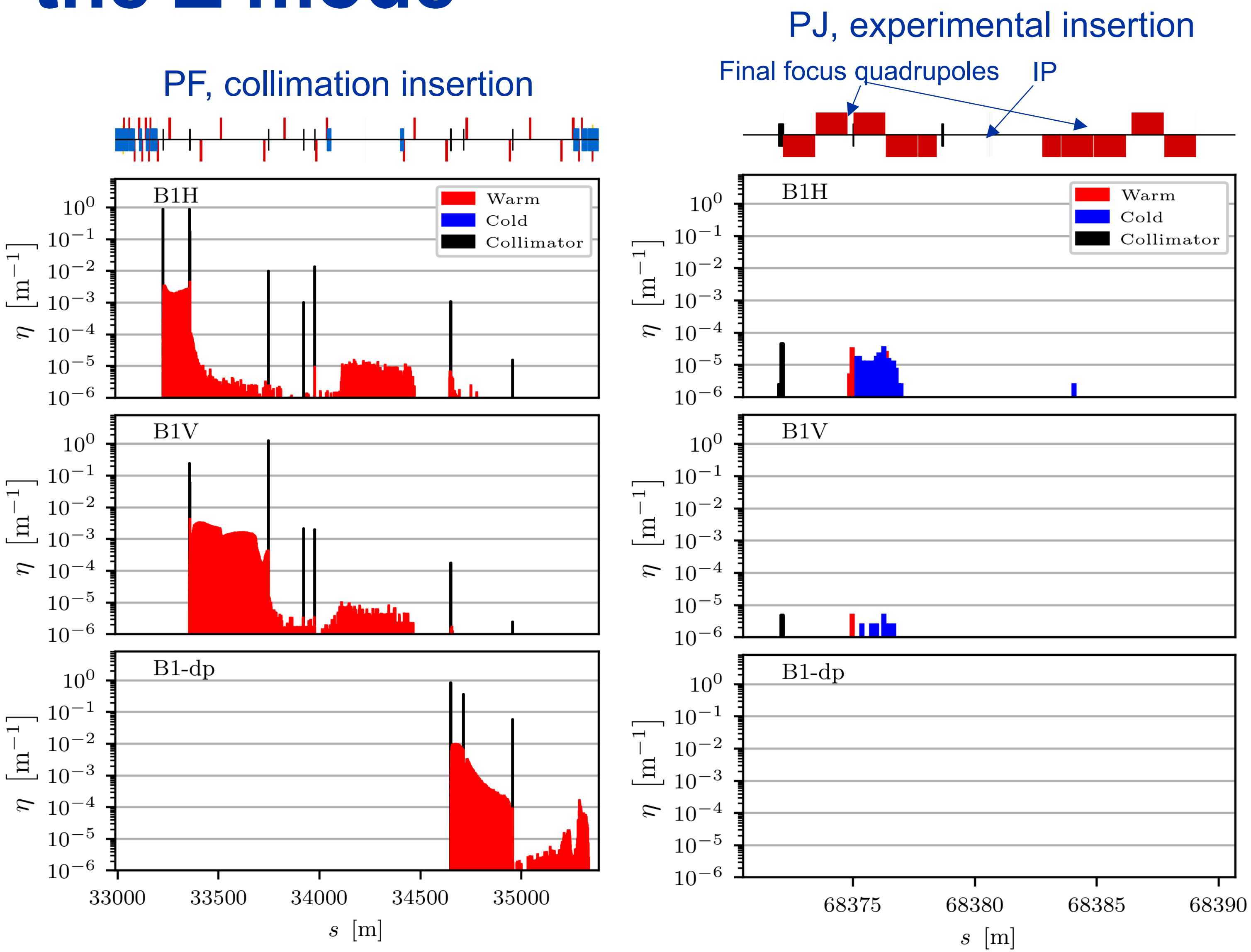


Z-mode betatron halo loss maps

Beam halo losses for the Z mode

- The beam collimation system shows significant loss suppression
  - More than 99.96% of losses contained within the collimation insertion PF, only up to 1.7 W reaching any IR
  - Tilted primary collimators are essential for the performance at the Z mode
  - Energy deposition studies and thermo-mechanical studies are required for the collimators and most exposed magnets

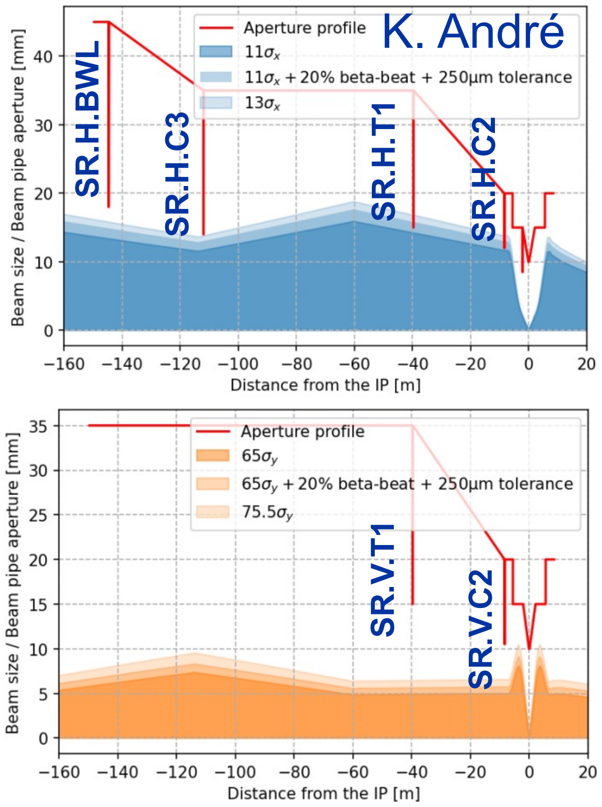
- Collaborative studies ongoing:
  - IR loss optimization (G. Broggi)
  - Detector backgrounds (A. Ciarma)
  - Impedance (M. Migliorati)
  - Energy deposition & thermomechanical studies (G. Lerner, R. Andrade)
  - Detector backgrounds (A. Ciarma)



Z-mode betatron halo loss maps for selected regions

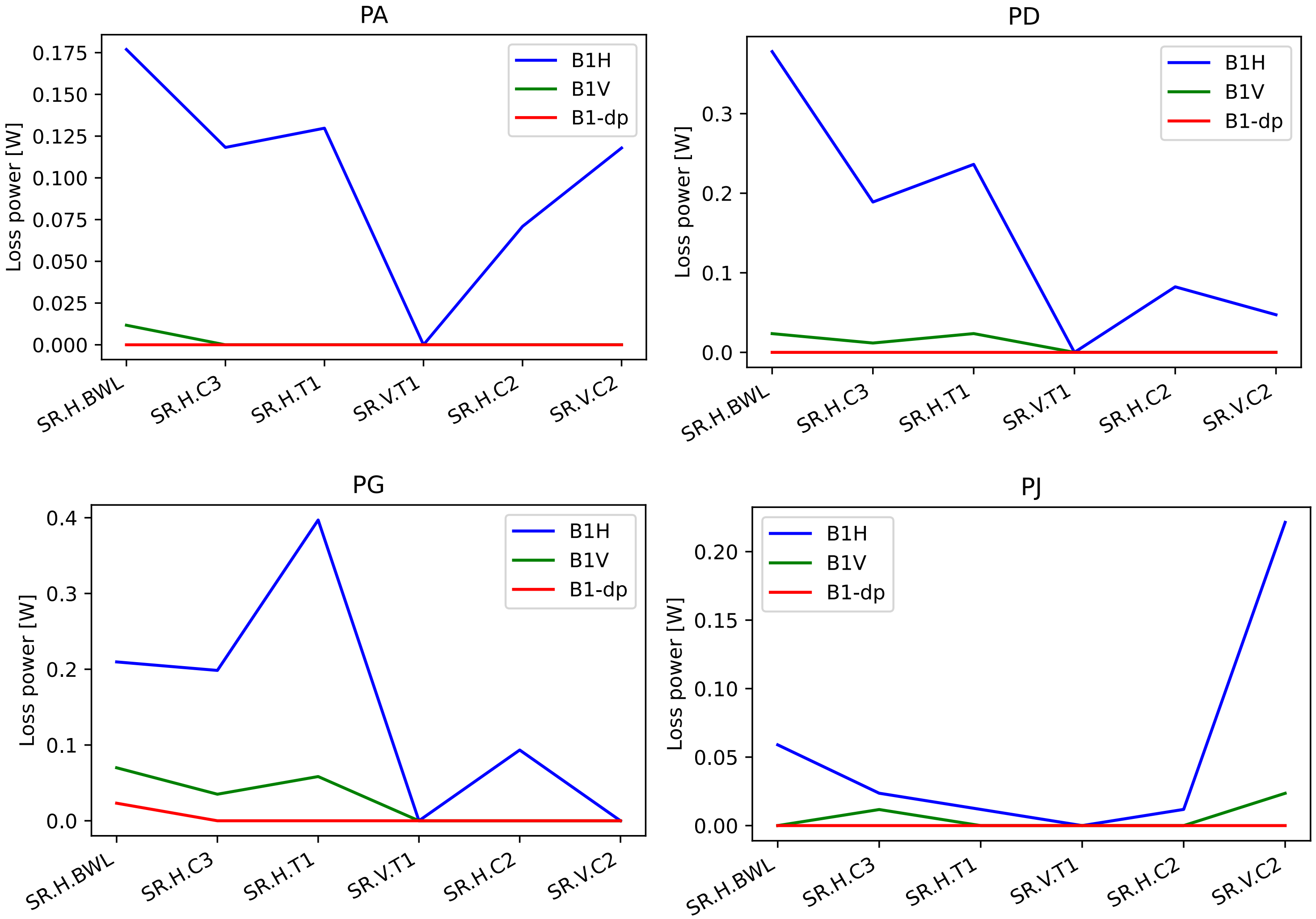
Z mode losses on SR collimators

- **The SR collimators intercept losses for all cases**
  - Highest load on BWL and C3 horizontal collimators, up to 0.4 W
  - Lowest load on the vertical T1 collimator



beam →

Total loss power: **59.2 kW**



FCC-ee collimation summary

- **Studies of beam losses and collimation for the FCC-ee**
  - First collimation system design available, including beam halo and SR collimators
  - Simulations of beam loss scenarios ongoing
    - Beam halo losses studied for the most critical *Z* mode, no show-stoppers identified
    - Collaboration with the MDI, impedance, engineering, FLUKA studies team
    - Input on equipment loss tolerances needed to optimize performance
  - Studies ongoing of an updated collimation system design

- **Next steps**
  - Study other beam loss scenarios – failure scenarios, spent beam, top-up injection
  - Obtain input for the equipment loss tolerances – superconducting magnets, collimators, other
    - Energy deposition studies required for magnets, collimators, and masks
    - Tolerance of the detectors to backgrounds required
  - Study all beam modes

Thank you!