FUTURE CIRCULAR COLLIDER

FCC-ee collimation studies

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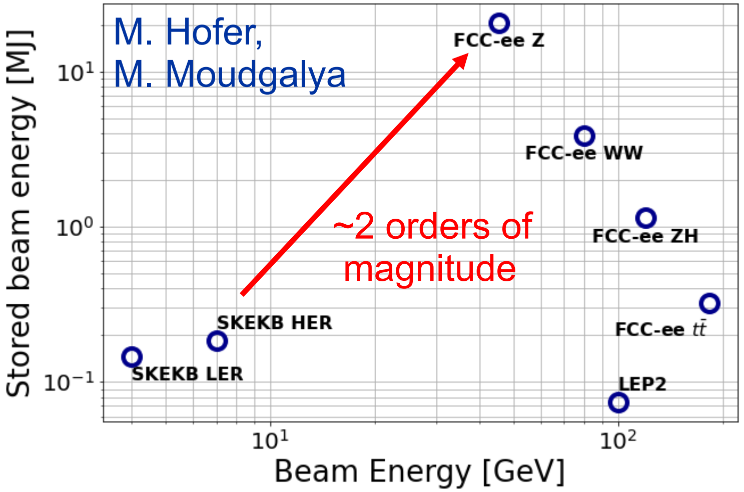
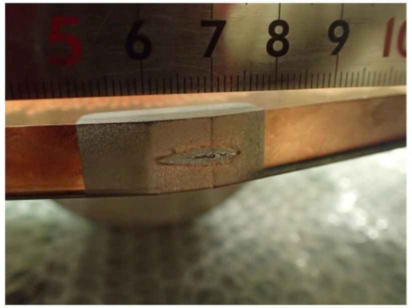
Collimation for the FCC-ee

- **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)



Comparison of lepton colliders

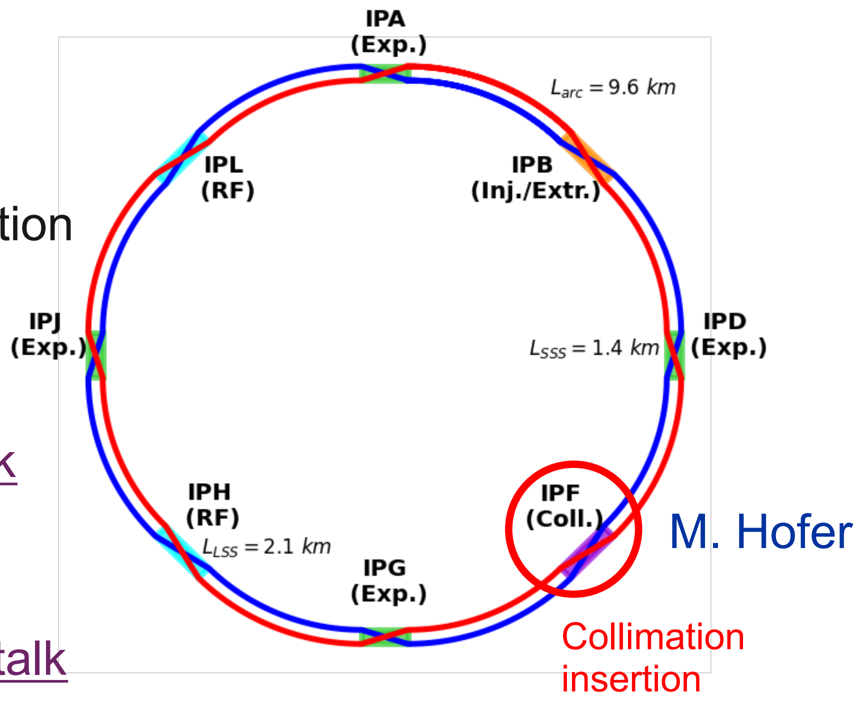
- **The FCC-ee presents unique challenges**
  - The stored beam energy reaches **17.8 MJ** for the **45.6 GeV (*Z*)** mode, which is comparable to heavy-ion operation at the LHC
  - Such beams are highly destructive: a collimation system is required
  - The main roles of the collimation system are:
    - Protect the equipment from unavoidable losses
    - Reduce the backgrounds in the experiments
  - Two types of collimation foreseen for the FCC-ee:
    - The beam halo (global) collimation
    - Synchrotron Radiation (SR) collimation – near the IPs



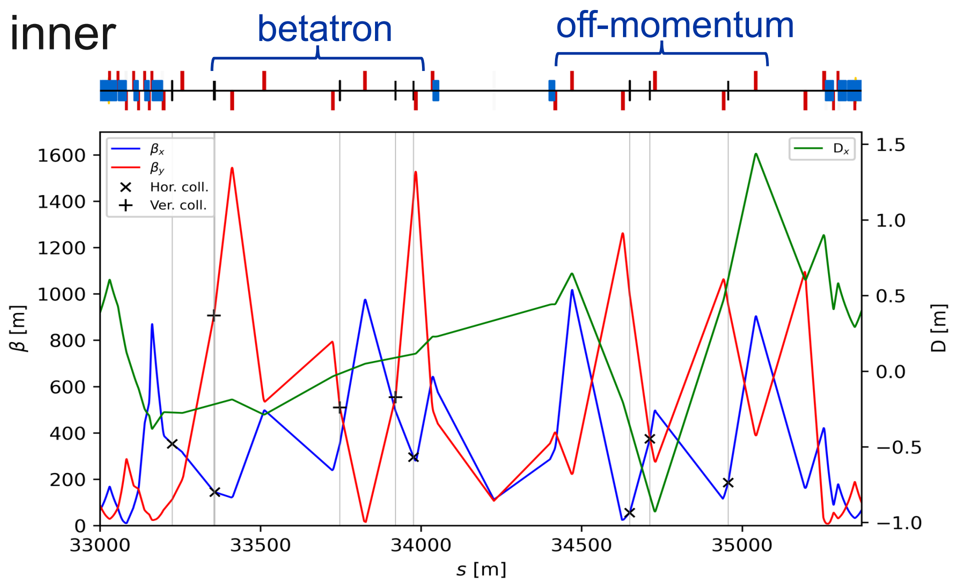

Damage to coated collimator jaw due to accidental beam loss in the SuperKEKB – T. Ishibashi (talk)

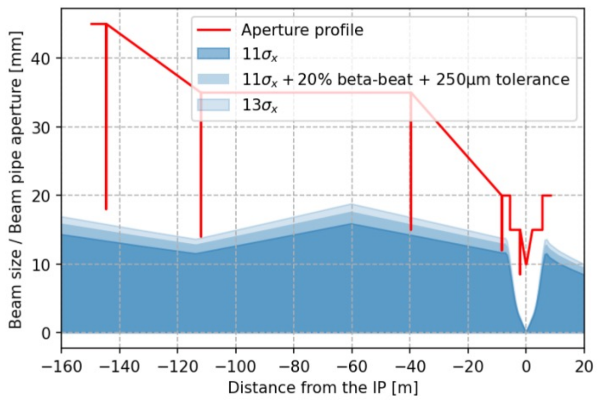
FCC-ee collimation system

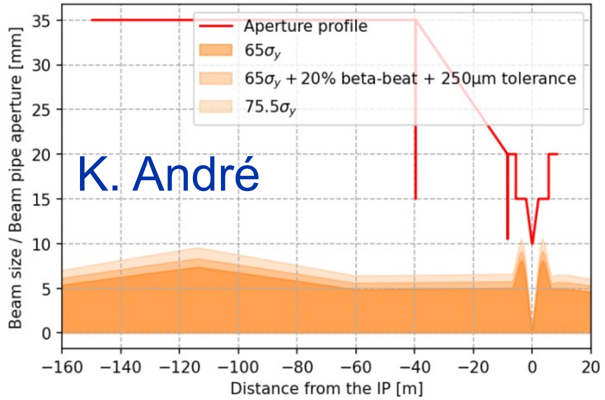
- **Dedicated halo collimation system in PF**
  - Two-stage betatron and off-momentum collimation systems in one insertion
  - Ensure protection of the aperture bottlenecks in different conditions
  - Dedicated collimation optics (M. Hofer)
  - Collimator design for cleaning performance G. Broggi, FCC week 23 talk



- **Synchrotron radiation collimators around the IPs**
  - 6 collimators and 2 masks upstream of the IPs K. André, FCC week 23 talk
  - Designed to reduce detector backgrounds and power loads in the inner beampipe due to photon losses

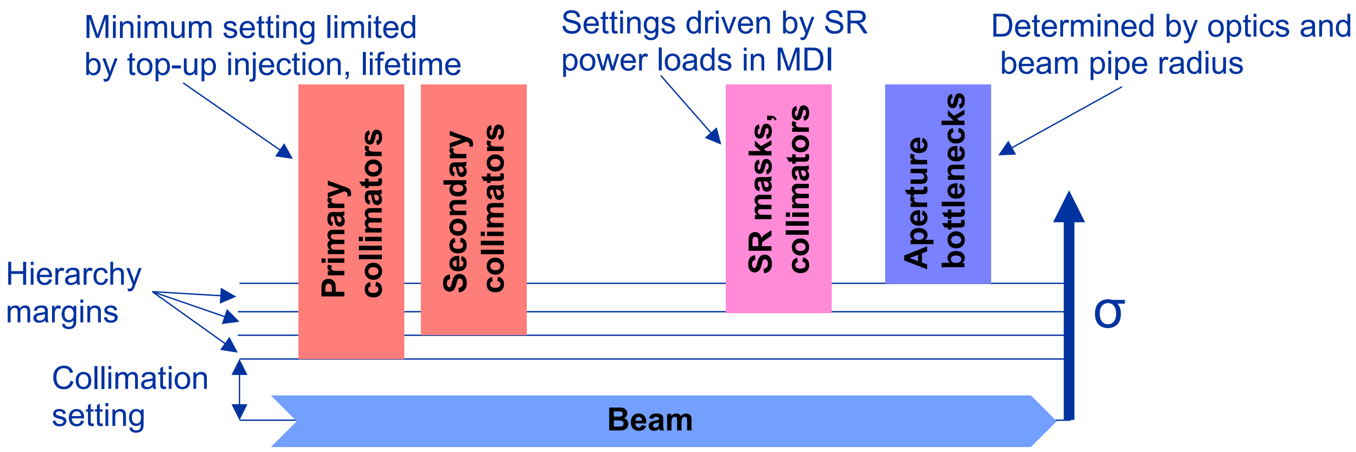






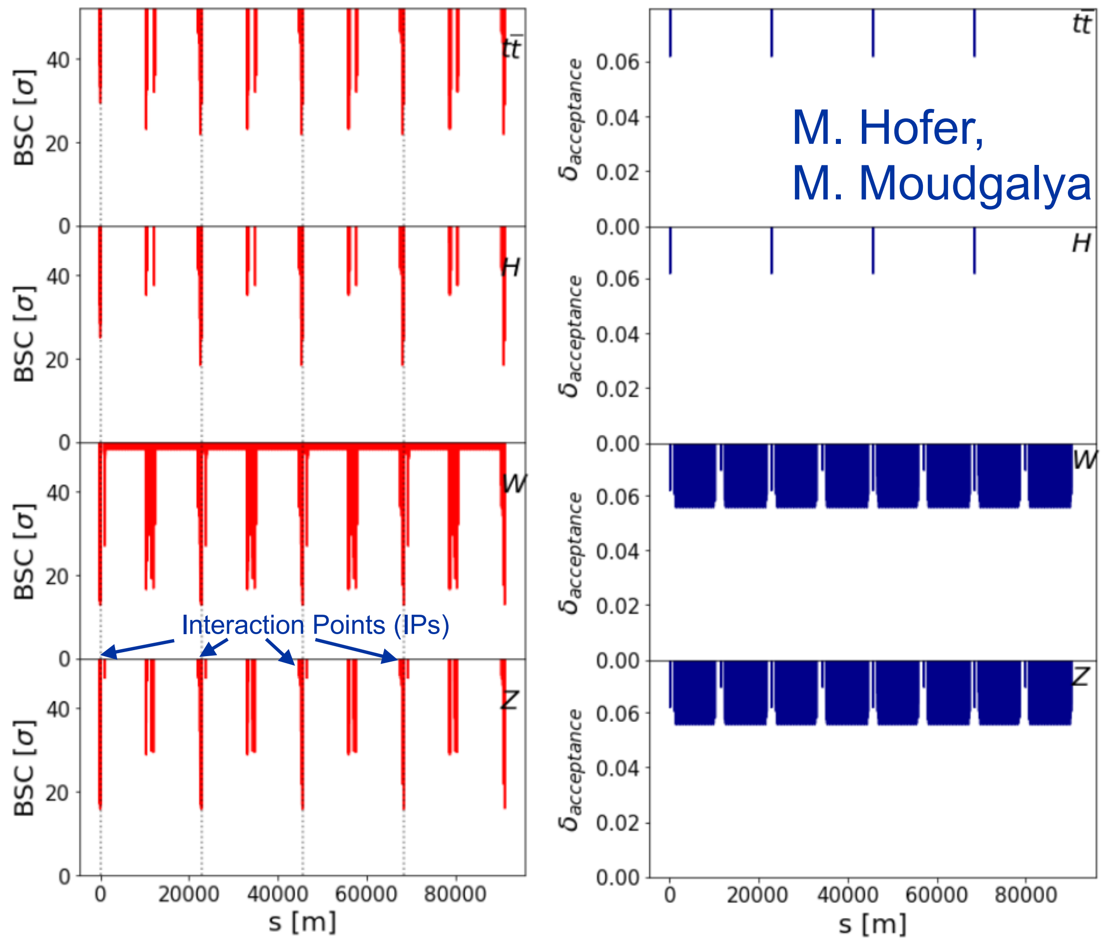
FCC-ee aperture

- **The aperture bottlenecks are in the experimental interaction regions (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
  - The collimation margins are tight



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 beam losses

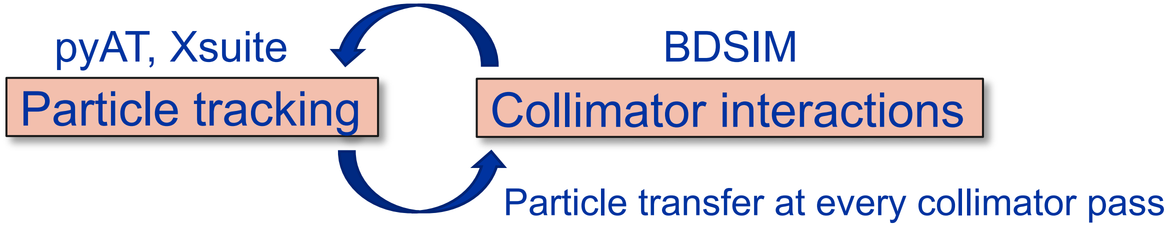
- **The FCC-ee will operate in a unique regime**
  - Electron / positron beam dynamics and beam-matter interactions
  - Stored beam energy exceeding material damage limits
  - Superconducting final focus quadrupoles, crab sextupoles, and RF cavities
  - Must study the beam loss processes and define the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

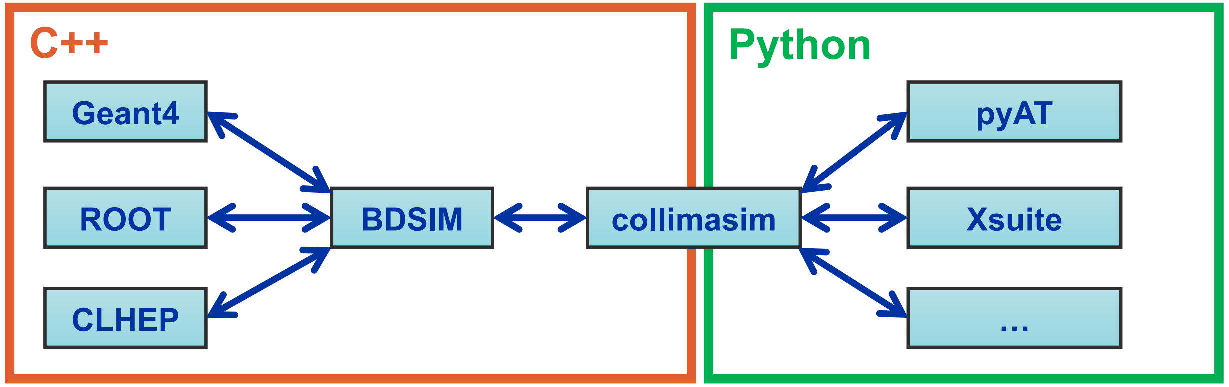
- **Important loss scenarios for particle tracking studies:**
  - **Beam halo** ⟵ Current studies
  - Top-up injection
  - Spent beam due to collision processes (Beamstrahlung, Bhabha scattering)
  - Beam tails from Touschek scattering and beam-gas interactions
  - Failure modes (injection failures, asynchronous dump, others)
    - The SuperKEKB fast beam losses should, if possible, be understood and modelled

Input required to set up models

FCC-ee collimation simulations

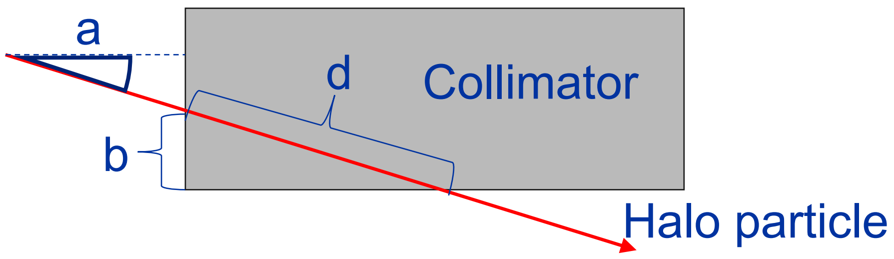
- **The FCC-ee presents unique challenges for collimation simulations:**
  - Synchrotron radiation and magnet strength adjustment (tapering) to compensate it
  - Complex beam dynamics – strong sextupoles in lattice, strong beam-beam effects (Beamstrahlung)
  - Detailed aperture and collimator geometry modelling
  - Electron/positron beam particle-matter interactions
  - Large accelerator – 90+ km beamline
- **Xsuite + BDSIM (Geant4) coupling**
  - Developed for the collimation simulations in the FCC IPAC'22 paper
  - Benchmarked against other codes for FCC-ee – MAD-X, pyAT, SixTrack-FLUKA coupling
  - Xsuite-FLUKA coupling will be available soon (LHC collimation and FLUKA teams)
  - New features continuously added





Current study: beam halo losses

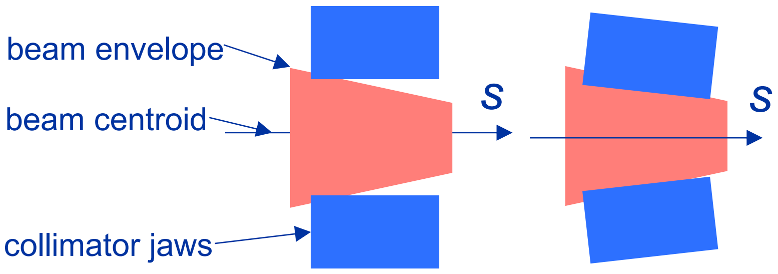
- **"Generic beam halo" beam loss scenario:**
  - Specify a minimum beam lifetime that must be sustained during normal operation
    - Preliminary specification of a **5 minute** lifetime
  - Assume a slow loss process – halo particles always intercepted by the primary collimators
  - The loss process 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 G. Broggi, FCC week 23 talk



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 consiered:
  - **Horizontal betatron losses (B1H)**
  - **Vertical betatron losses (B1V)**
  - **Off-momentum losses δ < 0 (B1-dp)**
- For the off-momentum case, using a tilted collimator, aligned to the beam divergence

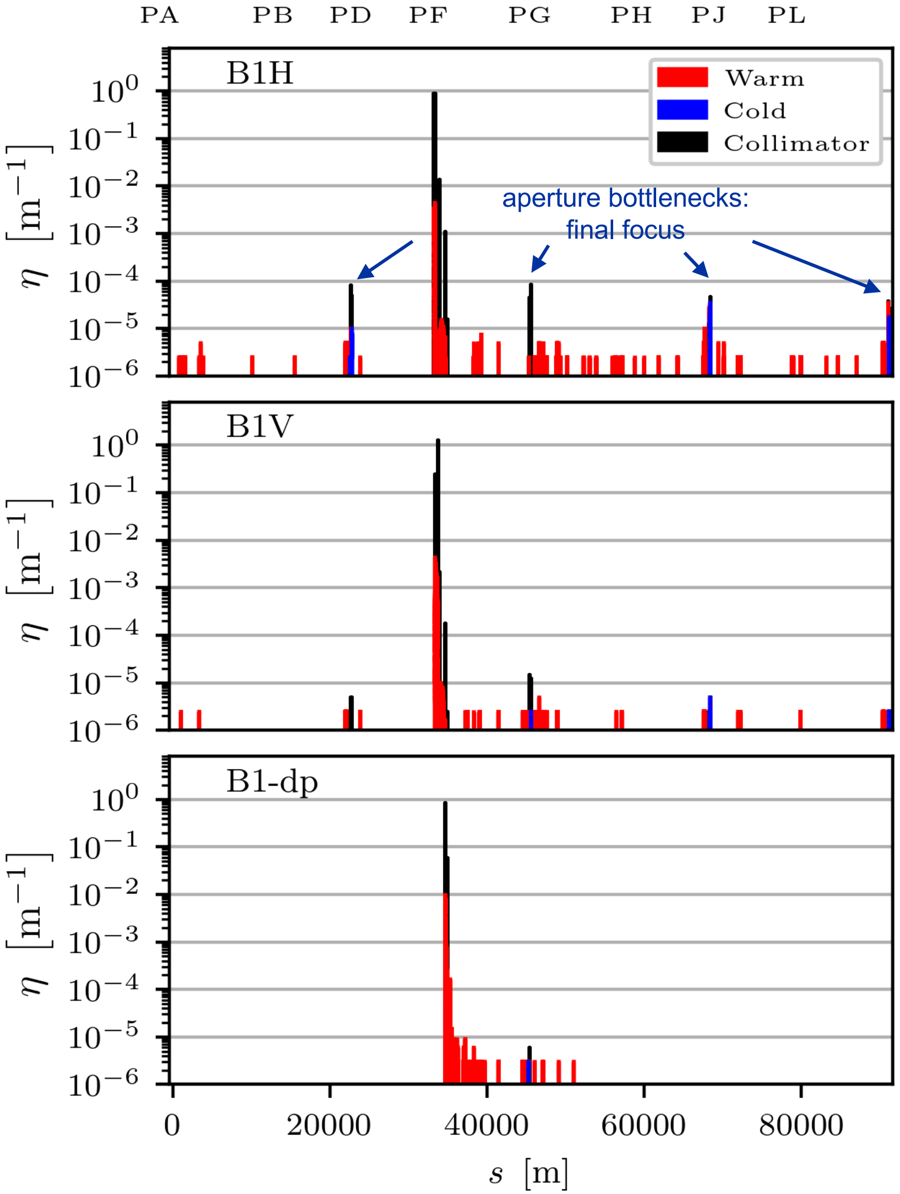


Parallel jaw and tilted collimator schematic

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

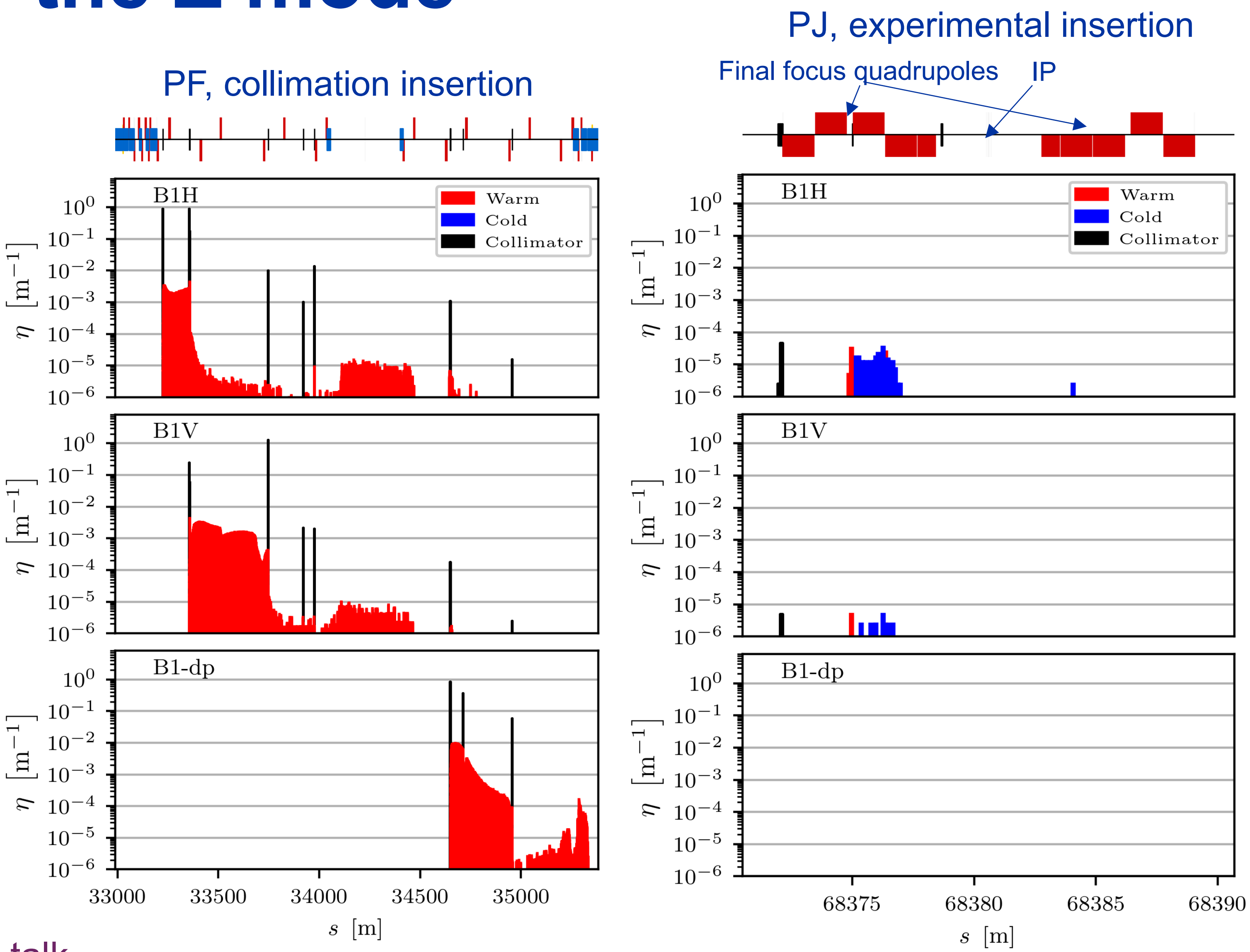
Total loss power: **59.2 kW**



Z-mode betatron halo loss maps

Beam halo losses for the Z mode

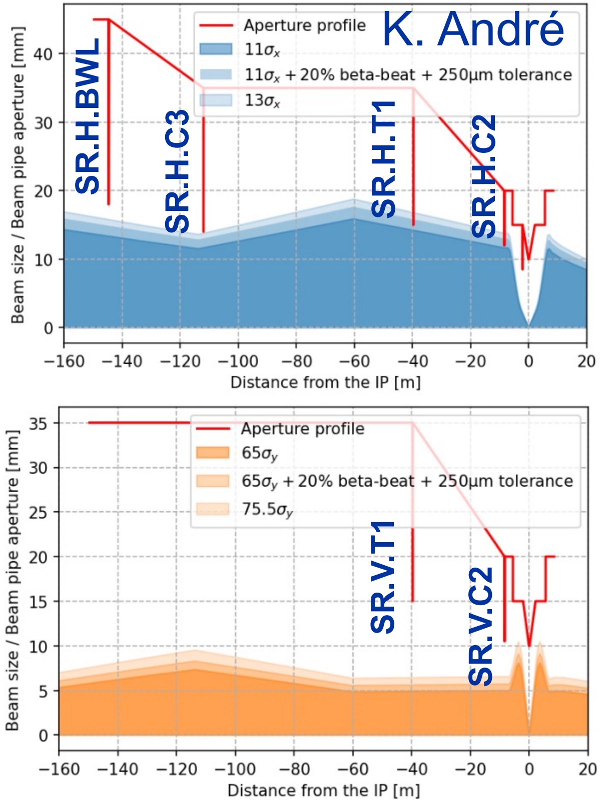
- The beam collimation system shows significant loss suppression
  - More than 99.96% of losses contained within the collimation insertion PF, only up to 1.7 W reaching any IR
  - Tilted primary collimators are essential for the performance at the Z mode
  - Energy deposition studies and thermo-mechanical studies are required for the collimators and most exposed magnets
- Collaborative studies ongoing
  - Impedance and collective effects M. Migliorati, FCC week 23 talk
  - IR losses and collimator parameter optimization G. Broggi, FCC week 23 talk
  - Tracking of the collimation losses in the detector A. Ciarma, FCC week 23 talk
  - First collimator energy deposition G. Lerner, talk and thermomechanical studies R. Andrade, talk



Z-mode betatron halo loss maps for selected regions

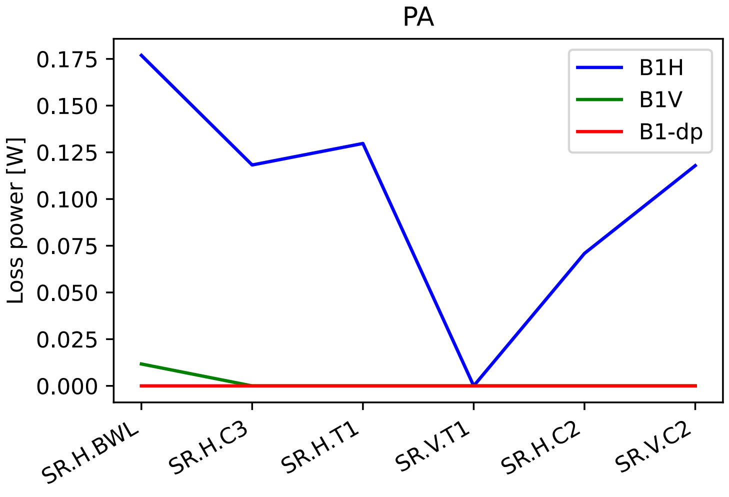
Z mode losses on SR collimators

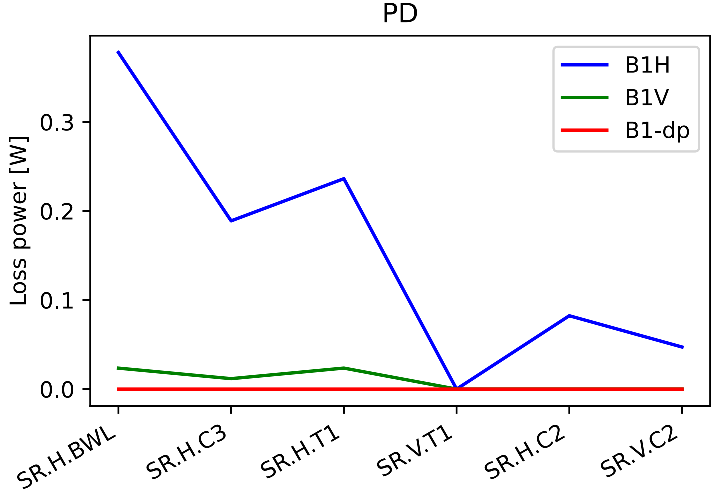
- **The SR collimators intercept losses for all cases**
  - Highest load on BWL and C3 horizontal collimators, up to 0.4 W
  - Lowest load on the vertical T1 collimator

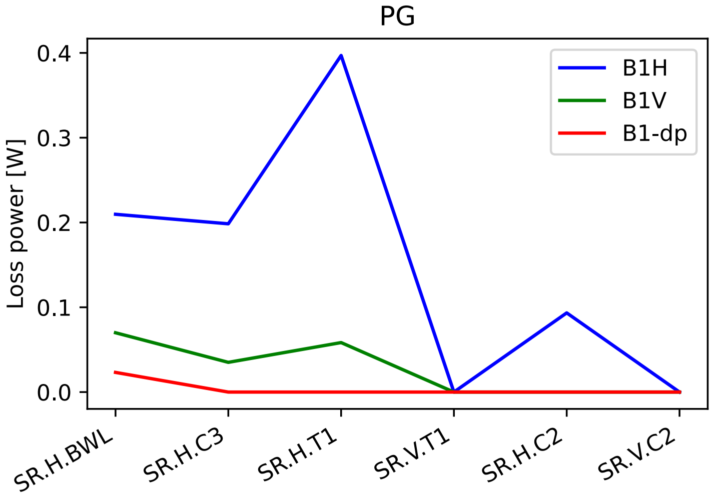


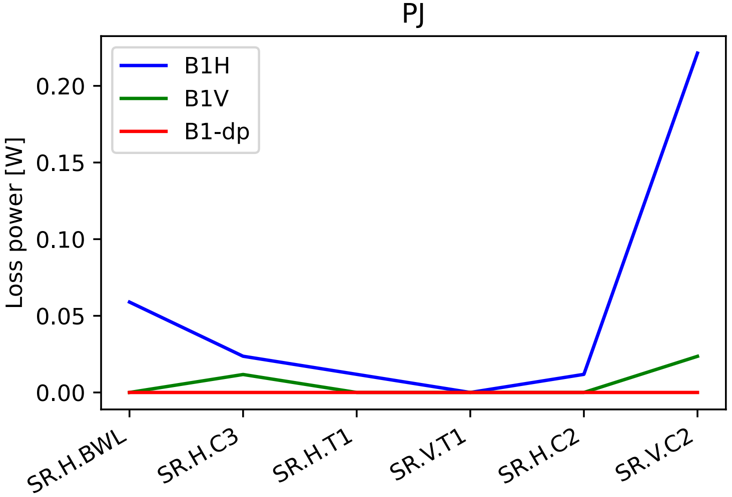
beam →

Total loss power: 59.2 kW



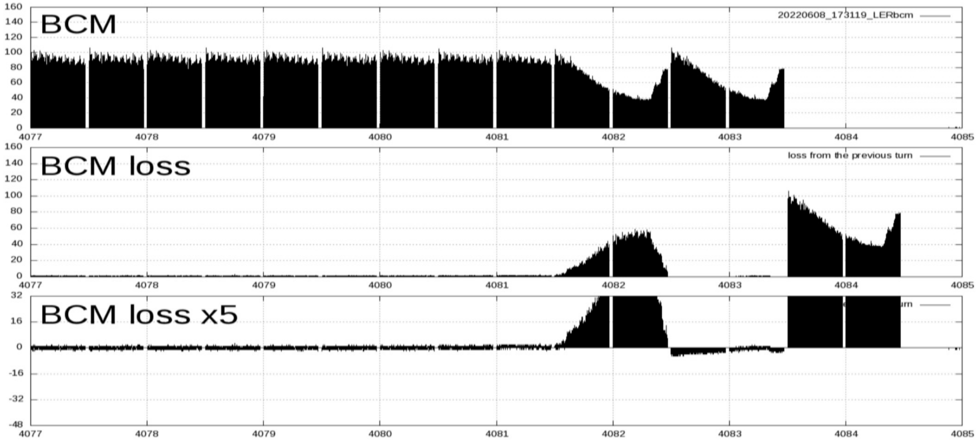




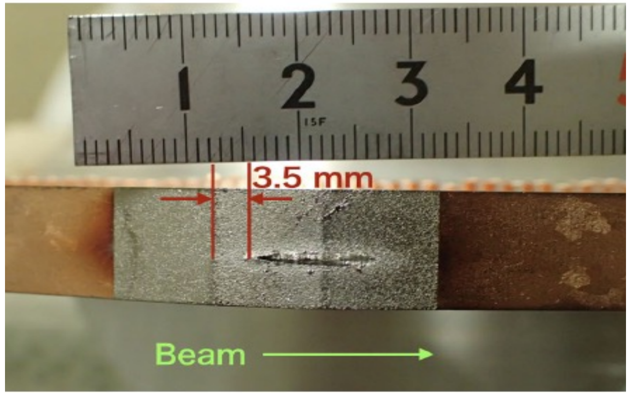


Failure beam loss scenarios

- **Fast beam losses due to failures are important for the design of the collimation system**
  - SuperKEKB has experiences sudden beam loss, up to 80% intensity loss over 2 turns (T. Ishibashi, talk)
  - Such events have damaged collimators, and the cause is not well understood
- **Fast beam losses in the FCC-ee:**
  - Accidental beam loss scenarios and their likelihood must be studied in detail to devise a protection strategy
    - Injection failures and asynchronous beam dumps are likely failures that must be modelled in detail
  - The set of failure modes to protect against could drive significant changes in the collimation design
    - Special solutions may be required to handle such losses
    - As a worst-case, sacrificial collimators can be considered



Beam current during a sudden beam loss in the SuperKEKB – T. Ishibashi (talk)



Collimator damage in SuperKEKB
https://doi.org/10.1103/PhysRevAccelBeams.23.053501

Moving forward: a new FCC-ee baseline

- **There have been several major changes in the FCC-ee design recently**
  - Details in K. Oide, FCC week 23 talk
  - Updated ring layout (**PA31-3**), reduced circumference (**90.7 km**)
  - A single RF insertion used for all the operating modes
  - Beam pipe aperture reduction in the arcs (**35 → 30 mm**)
  - Altered IR geometry and optics
  - New beam parameter set

- **Ongoing effort to set up collimation for the new baseline**
  - Integrating the collimation insertion into the new ring optics
  - Running aperture checks and preparing halo collimation settings
  - Updating the SR collimator configuration

New collimation insertion optics

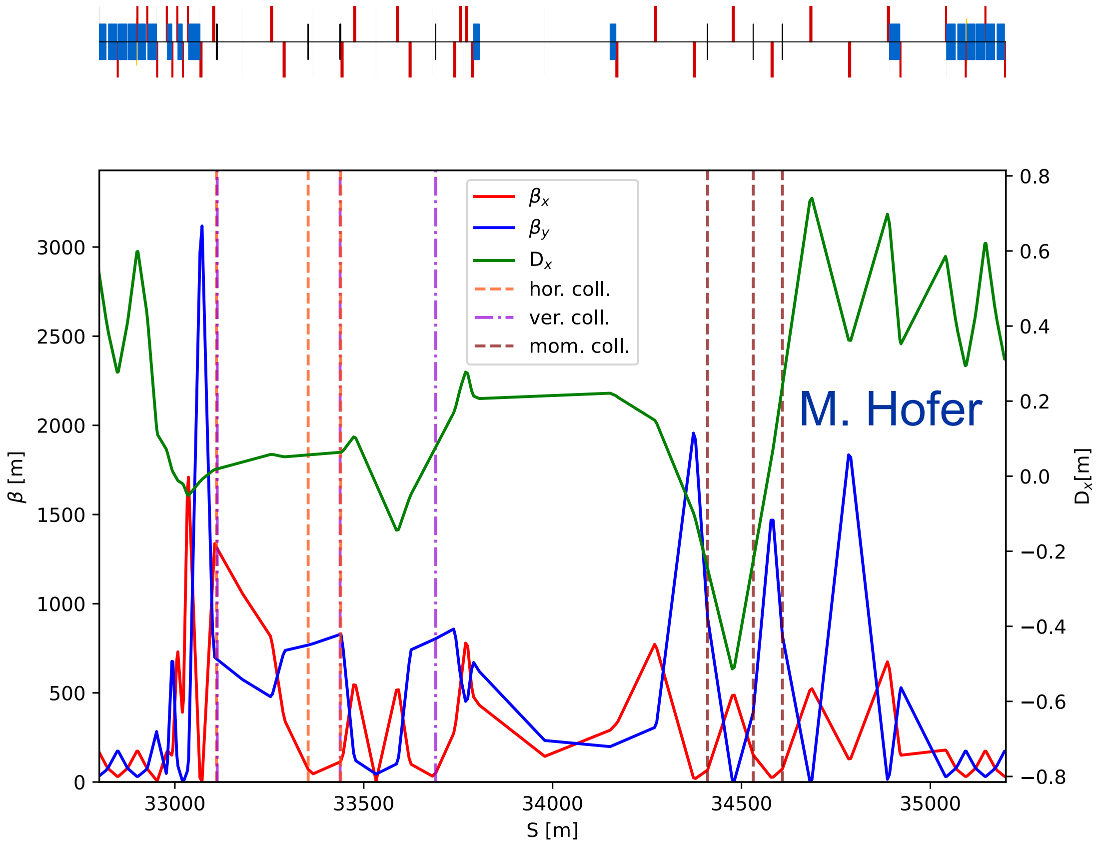
- **Preliminary collimation optics for the new baseline:**
  - Developed by M. Hofer
  - Split-function betatron and off-momentum collimation
  - Based on a triple double doublet scheme
  - Designed to maintain optimal collimator phase advance at acceptable mechanical gaps

preliminary

	TCP [σ]	TCS [σ]
Hor.	9	11
Ver.	70	80
Mom.	16	19

Name	Gap [mm]	δ_{cut} [%]
TCP.H.B1	8.7	46.1
TCP.V.B1	2.2	-
TCS.H1.B1	2.5	4.4
TCS.V1.B1	2.7	-
TCS.H2.B1	3.2	5.0
TCS.V2.B1	2.7	-
TCP.HP.B1	3.6	1.5
TCS.HP1.B1	6.2	2.8
TCS.HP2.B1	4.3	1.8

Beam halo collimator settings



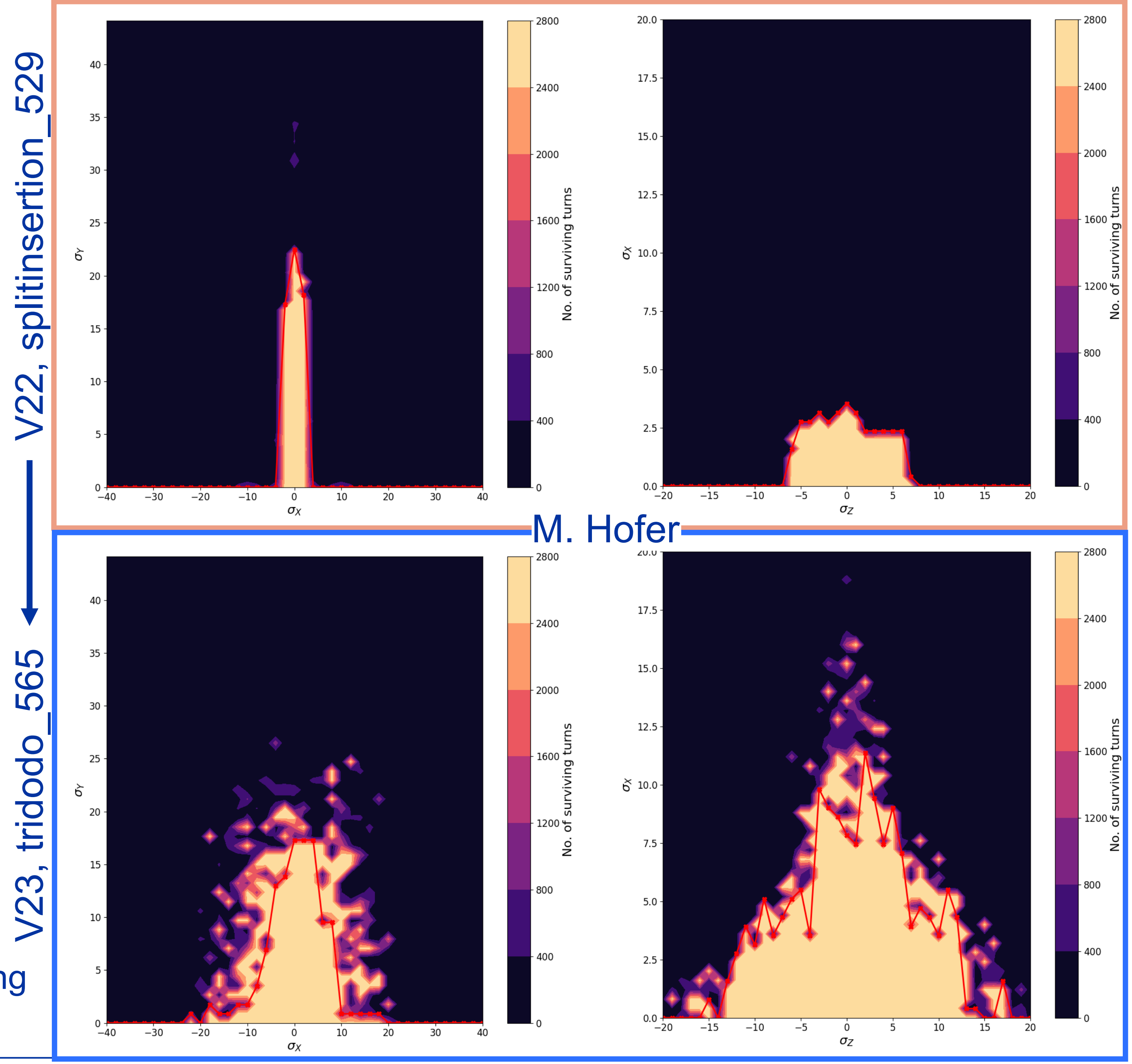
V23, tridodo_565 collimation optics

https://gitlab.cern.ch/mihofer/fcc-ee-collimation-lattice

New collimation optics

- **The new optics is integrated with the ring optics**

- **The DA and momentum acceptance are improved relative the current collimation optics**
  - The dynamic aperture and the momentum acceptance are improved
  - Further tuning and optimization are possible
  - This will help in performing studies with effects like beam-beam, where the beam tails need to be tracked long-term

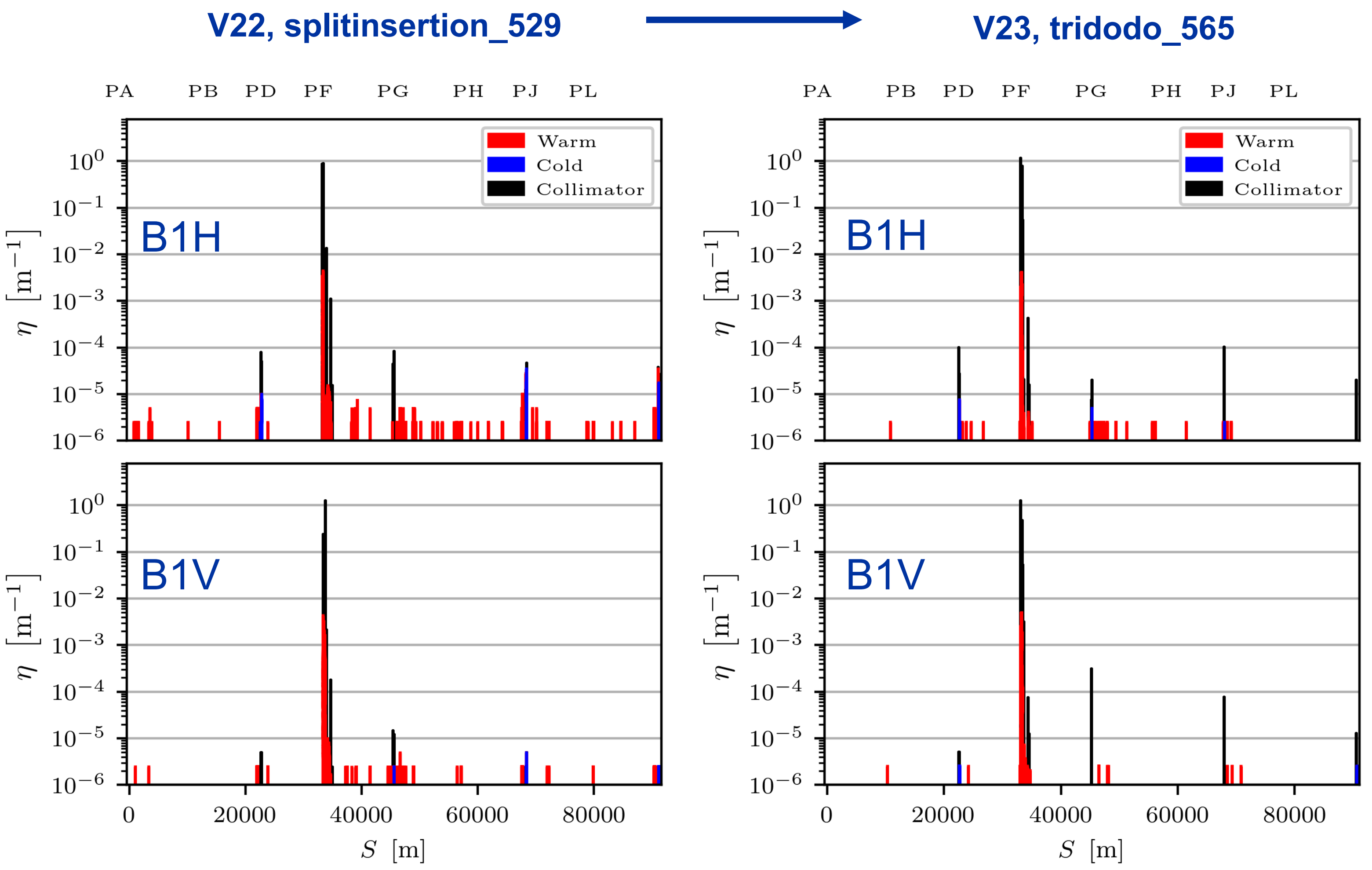


DA and momentum acceptance with radiation and tapering

https://gitlab.cern.ch/mihofer/fcc-ee-collimation-lattice

Collimation performance

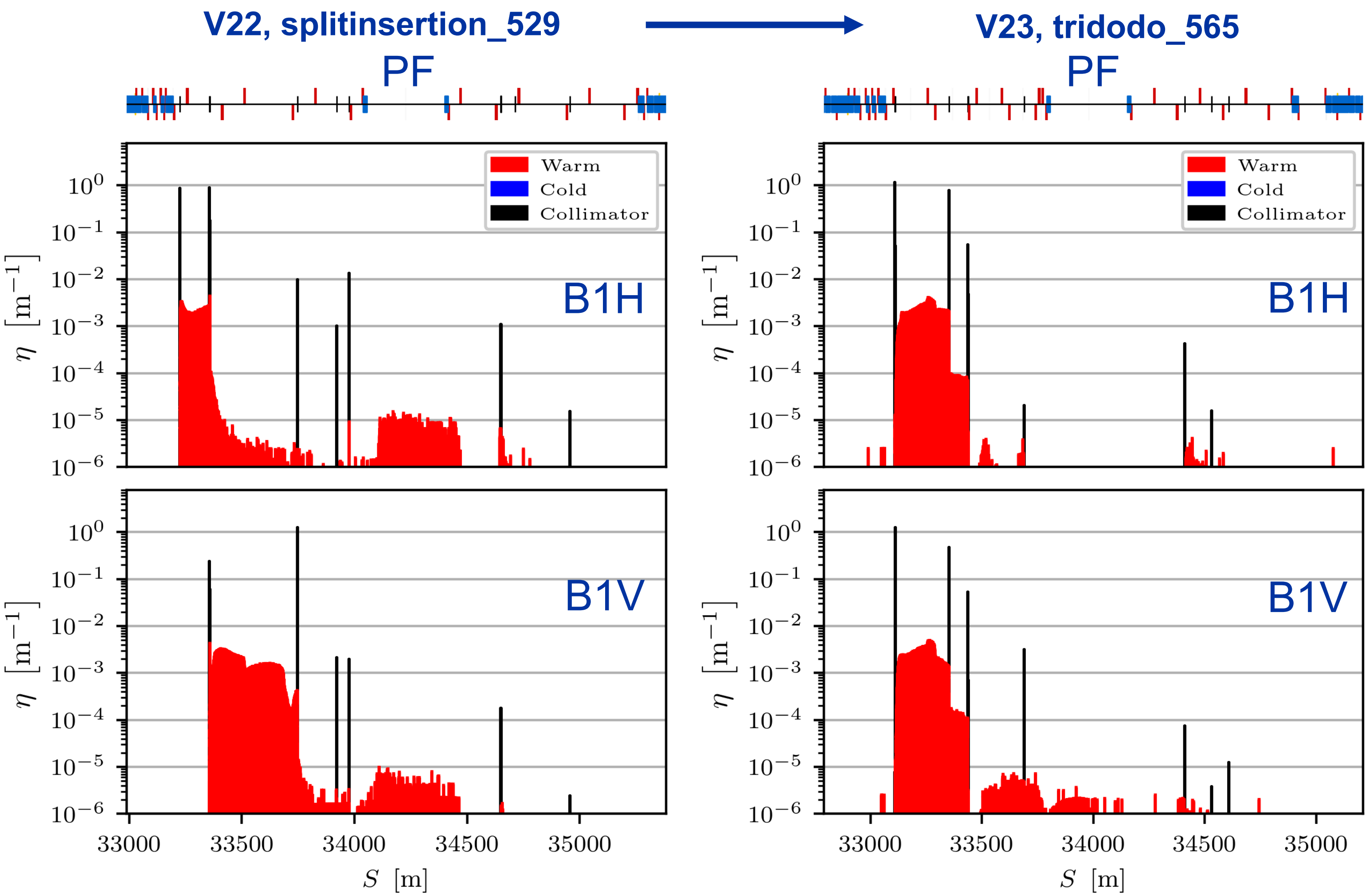
- **Running simulations with the new configuration**
  - **Shorter primary collimators used**
    0.4 m → 0.25 m MoGr
    see G. Broggi, FCC Week 23 talk
  - Radiation and tapering enabled, no tilt applied
  - Studied the horizontal and vertical betatron cases (B1H, B1V)
- **Similar performance to the current baseline**
  - Losses on the final focus quadrupoles are overall lower
  - Higher SR collimator losses for B1V



Collimation performance

- **Losses in the collimation insertion PF**
  - The loss pattern is different due to the new layout
  - Smoother collimator hierarchy
  - Lower losses over the auxiliary beam crossing
  - Lower losses on the off-momentum collimation

- **Promising results so far**
  - Further checks ongoing
  - The impedance must be evaluated



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 on an updated collimation system design
    - The goal is a refined set of specifications before the autumn

- **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!