FCC-ee collimation

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Outline

- **Introduction**
  - Collimation for the FCC-ee
  - FCC-ee collimation system
- **FCC-ee beam losses and collimation simulations**
- **Updates on current studies**
  - Beam halo losses
  - Collimation studies including beam-beam effects: first results
  - Collimation studies including beam-gas interactions: first results
- **An alternative collimation layout to reduce impedance contribution from collimators**
- **FCC-ee collimation summary**

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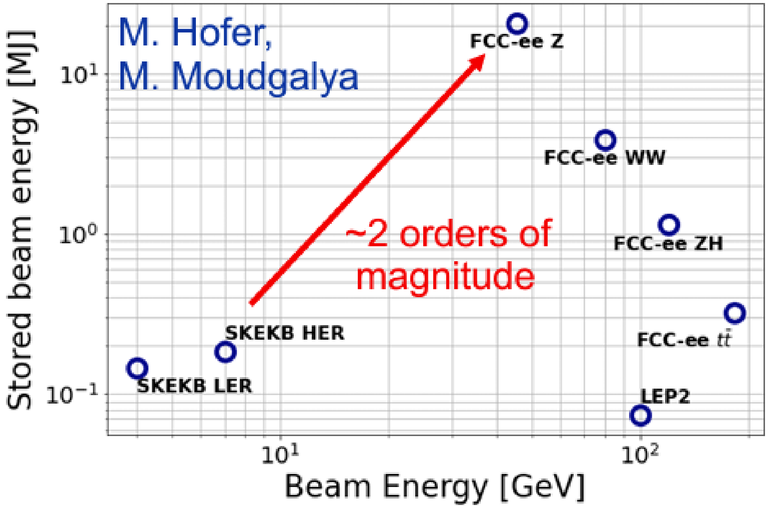
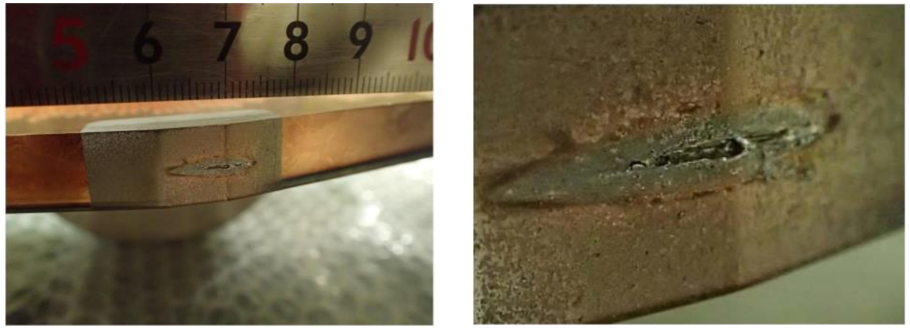
Collimation for the FCC-ee

Comparison of lepton colliders



- **FCC-ee is the FCC first stage e^+e^- collider**
  - ➢ 90.7 km circumference, tunnel compatible with FCC-hh
  - ➢ 4 beam operation modes, optimized for production of different particles: ***Z*** (45.6 GeV), ***W*** (80 GeV), ***H*** (120 GeV), ***ttbar*** (182.5 GeV)

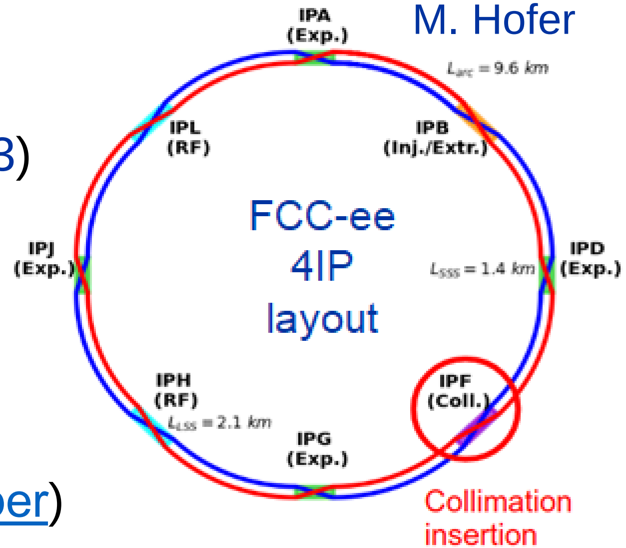
- **FCC-ee presents unique challenges**
  - ➢ Unprecedented stored beam energy for a lepton collider: up to **17.5 MJ** in the ***Z*** operation mode (45.6 GeV)
  - ➢ Highly destructive beams: **collimation system indispensable**
  - ➢ The main roles of the collimation system are:
    - Reduce background in the experiments
    - Protect the machine from unavoidable losses
  - ➢ Two types of collimation foreseen for the FCC-ee:
    - Beam halo (global) collimation
    - Synchrotron Radiation (SR) collimation – around the IPs
    - Need of further local protection (e.g., experimental IRs) – to be assessed



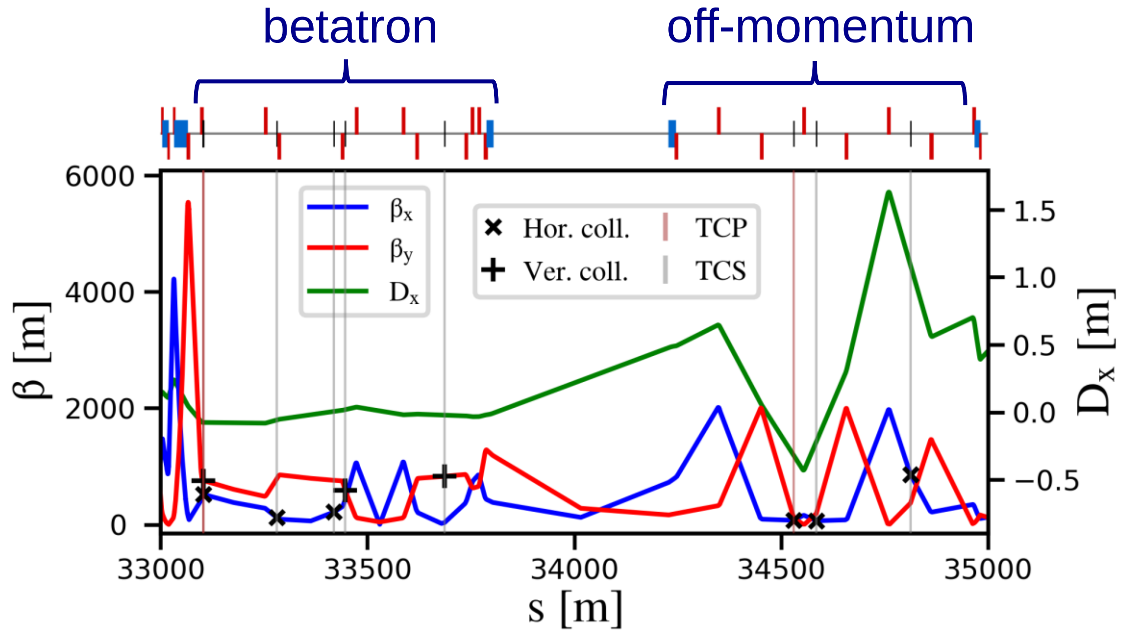
Damage to coated collimator jaw due to accidental beam loss in the SuperKEKB – T. Ishibashi (talk)

FCC-ee halo collimation system

M. Hofer



- **Dedicated halo collimation system in PF** (new version compared to FCC week 2023)
  - ➢ Dedicated collimation optics (M. Hofer)
  - ➢ Two-stage betatron and off-momentum collimation system in one insertion
  - ➢ Ensure protection of the aperture bottlenecks in different conditions
    - ➢ **Aperture bottleneck at *Z***: 14.6σ (H plane), 85σ (V plane)
  - ➢ First collimator design for cleaning performance
    - ➢ Ongoing studies for optimizing the collimator design (G. Broggi – IPAC'24 paper)



V23, tridodo_572 collimation optics,
https://gitlab.cern.ch/mihofer/fcc-ee-collimation-lattice

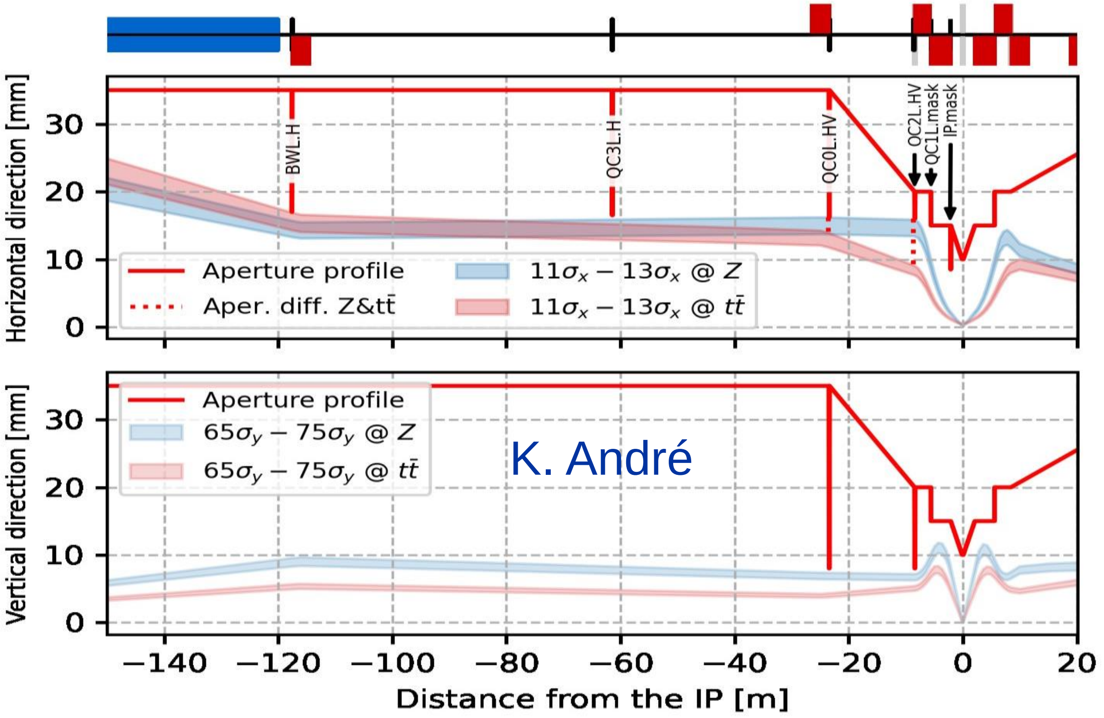
FCC-ee beam halo collimator parameters and settings

Name	Plane	Material	Length [cm]	Gap [σ]	Gap [mm]	δ_{cut} [%]
TCP.H.B1	H	MoGr	25	11	6.7	8.9
TCP.V.B1	V	MoGr	25	65	2.4	-
TCS.H1.B1	H	Mo	30	13	3.8	6.7
TCS.V1.B1	V	Mo	30	75	2.5	-
TCS.H2.B1	H	Mo	30	13	5.1	90.6
TCS.V2.B1	V	Mo	30	75	3.0	-
TCP.HP.B1	H	MoGr	25	18.5	4.2	1.3
TCS.HP1.B1	H	Mo	30	21.5	4.6	2.1
TCS.HP2.B1	H	Mo	30	21.5	16.8	1.6

Further materials will be studied in the future

FCC-ee SR collimation system

- **Synchrotron radiation collimators around the IPs**
  - 6 collimators and 2 masks upstream of the IPs
  - Designed to reduce detector backgrounds and power loads in the inner beampipe due to photon losses



FCC-ee SR collimators parameters and settings

Name	Plane	Material	Length [cm]	Gap [σ]	Gap [mm]
TCR.H.WL.B1	H	W	10	14.1	17.0
TCR.H.C3.B1	V	W	10	13.5	16.5
TCR.V.C0.B1	V	W	10	80.1	8.0
TCR.H.C0.B1	H	W	10	13.0	16.2
TCR.V.C2.B1	V	W	10	82.0	8.0
TCR.H.C2.B1	H	W	10	13.1	16.0

- More details in K. André, Synchrotron Radiation background studies, FCC week 2024 (Thu 13/06)

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FCC-ee beam losses

- **Important to study beam loss processes and define the ones to protect against** (H. Burkhardt, talk)
  - ➢ Must study equipment loss tolerances, for both regular and accidental losses

- **Important loss scenarios for particle tracking studies**:
  - ➢ **Generic beam halo** ⬅ current studies

New compared to FCC week 2023

  - ➢ **Spent beam due to collision processes** (Beamstrahlung, Bhabha scattering)
  - ➢ **Beam tails from beam-gas interactions**

} ⬅ First results

  - ➢ Beam tails from Touschek scattering (likely negligible at the FCC-ee energies)

  - ➢ Top-up injection
  - ➢ Scattering on thermal photons
  - ➢ Failure modes (injection failures, asynchronous dump, others)

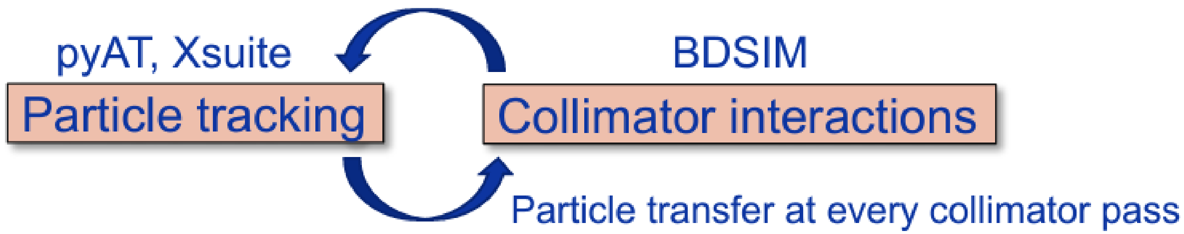
} ⬅ Inputs required to set up models

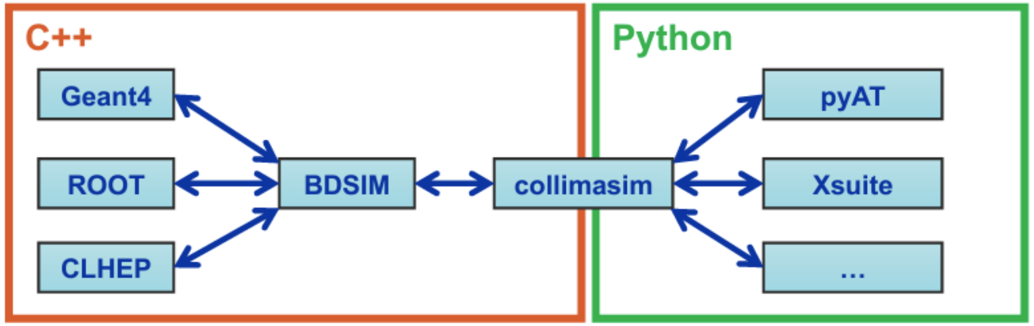
FCC-ee collimation simulations

- **FCC-ee presents unique challenges for collimation simulations**
  - Synchrotron radiation and magnet strength adjustment (tapering) to compensate it
  - Complex beam dynamics – strong sextupoles in the lattice, strong beam-beam effects (beamstrahlung)
  - Detailed aperture and collimator geometry modelling
  - Electron/positron beam particle-matter interactions
  - Large accelerator system – 90+ km beamline

Ongoing effort for benchmarking Xsuite-BDSIM with data from lepton machines (SuperKEKB, DAΦNE)

- **Xsuite + BDSIM (Geant4) coupling**
  - Developed for FCC collimation simulations (A. Abramov, IPAC’22 paper, JINST paper)
  - Benchmarked against
    - other simulation codes: MAD-X, pyAT, Sixtrack-FLUKA (A. Abramov)
    - measured data from proton machines: SPS (T. Pugnat), LHC (G. Broggi)
  - Xsuite-FLUKA coupling being set up (F. Van der Veken, HB’23 paper, K. Skoufaris, FLUKA team)





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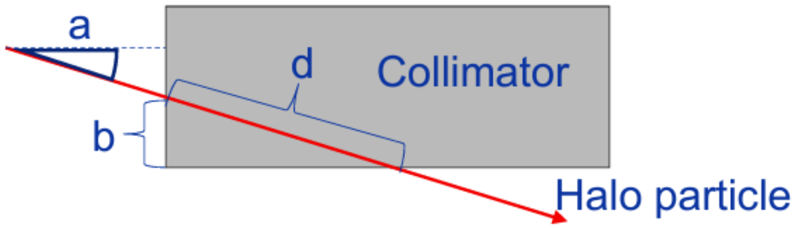
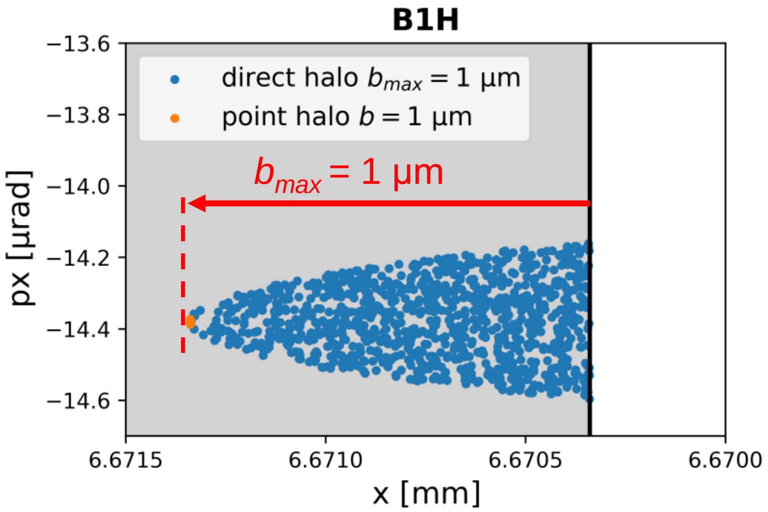
Generic beam halo losses

- **«Generic beam halo» beam loss scenario**
  - Specify a minimum beam lifetime that must be sustained during normal operation - preliminary specification of a **5 min** lifetime
  - Assume a slow loss process – halo particles always intercepted by the primary collimators
  - **Loss process not simulated**: all particles start impacting a collimator from the collimator edge to a maximum impact parameter b_{max} (R. Bruce - PRSTAB paper)
  - Currently assuming $b_{max} = 1$ µm
  - Studies needed to asses the most realistic b_{max} value
    - Impact parameter scans showed monotonically worsening collimation performance with decreasing impact parameters (G. Broggi, FCC-ee MDI workshop 2023 talk)
  - Particles scattered out from the collimator tracked for a given number of turns (~700), and losses on the aperture are recorded → **loss maps**



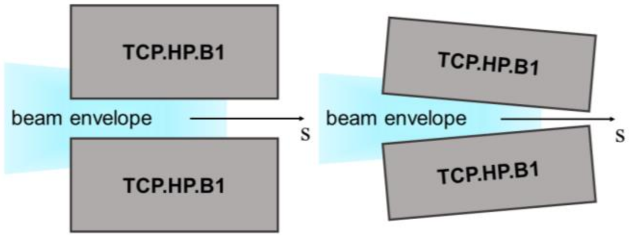
a = angle of incidence
b = impact parameter
d = distance traversed



Generic halo losses for the Z mode

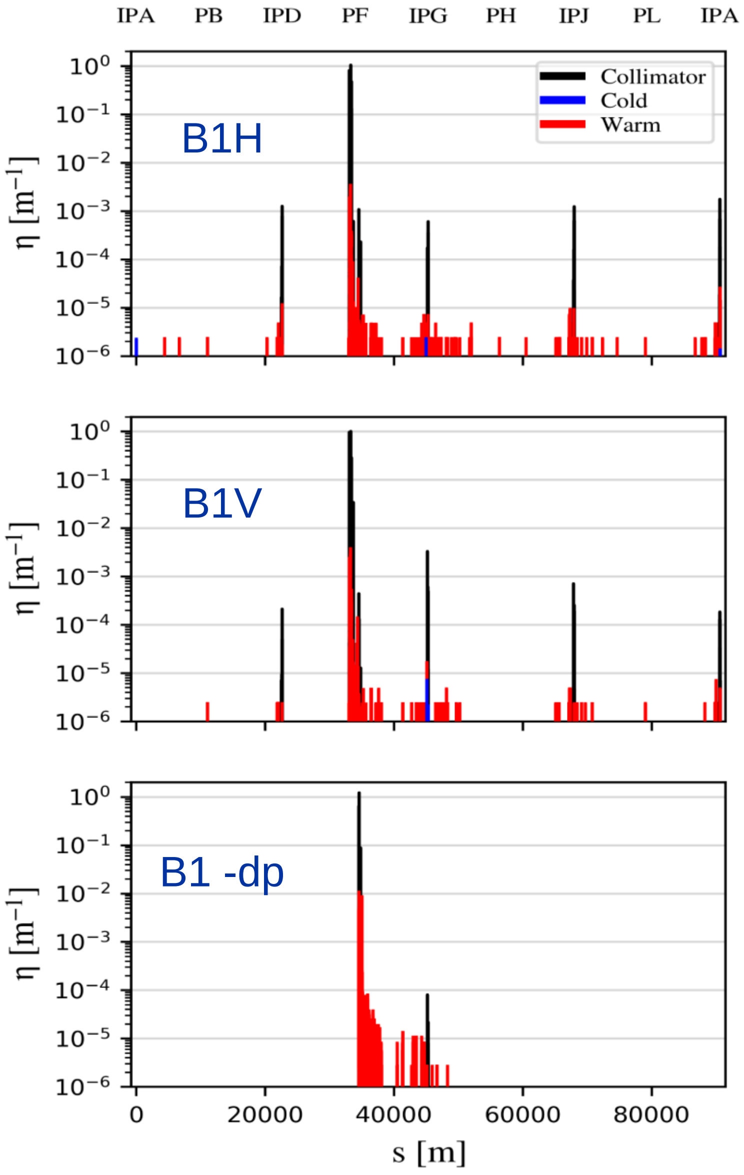
- The ***Z* mode** is the **current focus** (Beam 1, 45.6 GeV e+)
  - ➢ **17.5 MJ** stored beam energy
- **5 min** beam lifetime assumed → **58.3 kW** total loss power
- Radiation and tapering included
- 3 cases considered:
  - Horizontal and vertical betatron losses (B1H, B1V)
  - Off-momentum losses (B1 -dp)

- For the off-momentum case only, the primary collimator TCP.HP.B1 is aligned to the beam envelope by applying a tilt of 63 urad



TCP.HP.B1 parallel to the closed orbit and aligned to the beam envelope

- **Good halo cleaning performance overall**
  - ➢ Losses well contained (>99%) within the collimation insertion PF
  - ➢ Loss suppressed by ~4 orders of magnitude on SR collimators and by ~5-6 orders of magnitude on all the other elements outside PF

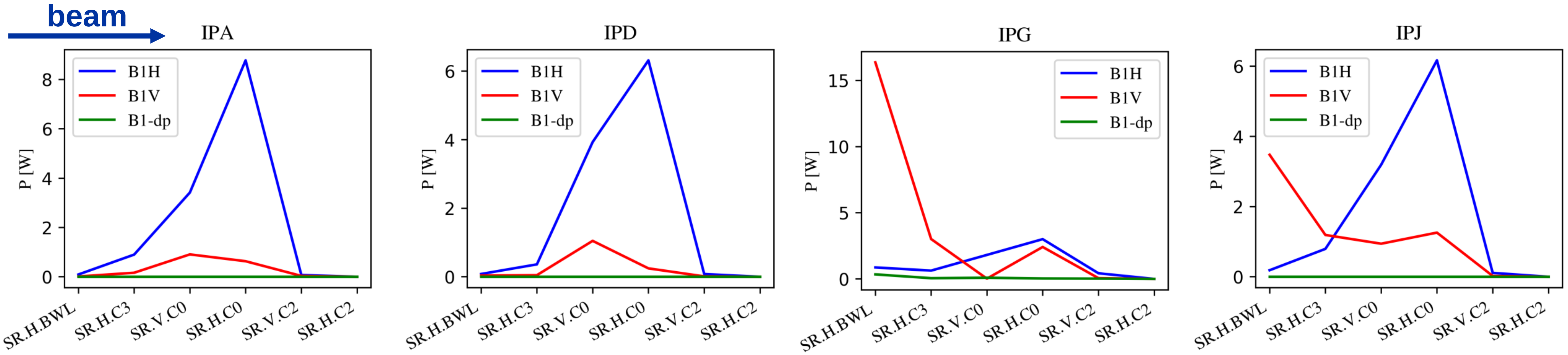


Z mode betatron and off-momentum halo loss maps

Generic halo losses for the Z mode

Total loss power: **58.3 kW**

- The **SR collimators intercept beam losses in all cases:**



  - ➢ Highest load on C0 and BWL horizontal SR collimators, **up to 16.4 W** (but increases at smaller b_{max})
  - ➢ Lowest load on C2 horizontal and vertical SR collimators

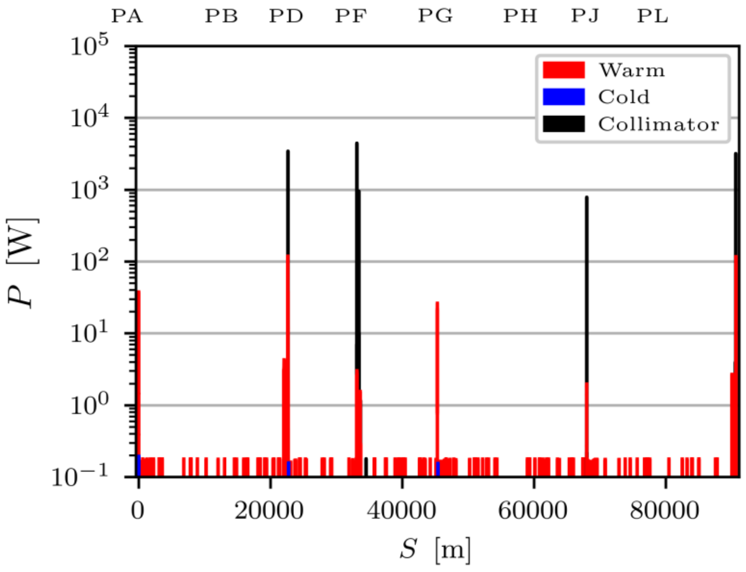
- Max. power load from generic halo losses much lower than the **max. recorded power from SR** about **200 W** (K. André – IPAC'24 paper)

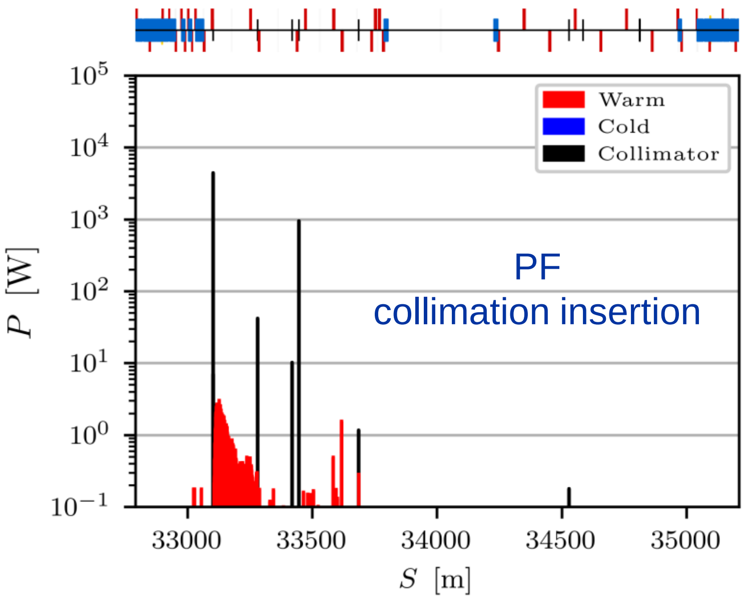
- **Energy deposition** and **thermo-mechanical studies** required for collimators and most exposed magnets
  - The need of shower absorbers in the collimation insertion needs to be assessed

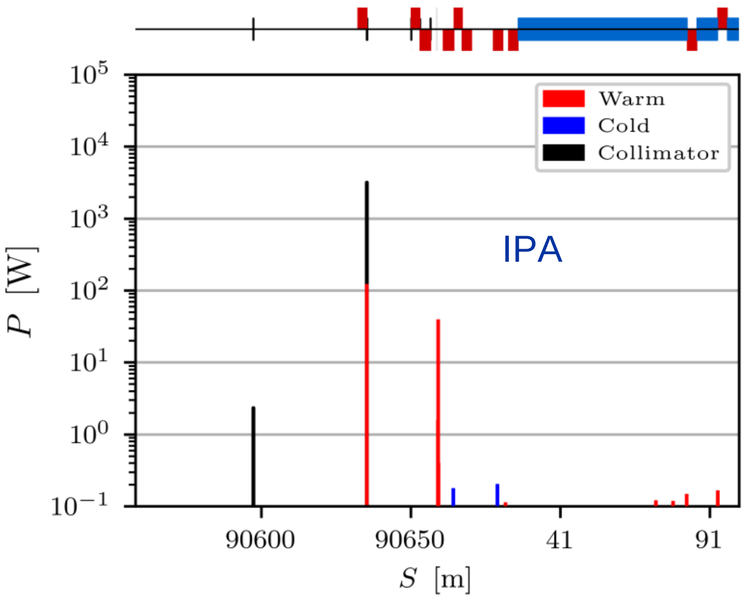
Collimation studies including beam-beam effects

PRELIMINARY: detailed checks ongoing

- **Interactions at the IPs have a crucial role in FCC-ee beam dynamics**
  - ➢ Main contribution to the beam lifetime in nominal operation
  - ➢ Produce distinct beam loss distributions around the ring
- **Large effort to model these effects in Xsuite** (P. Kicsiny, X. Buffat, T. Pieloni – FCC week 2024 talk)
- **First integration of beam-beam effects** (beamstrahlung, radiative Bhabha) **in collimation tracking studies** (A. Abramov – FCCIS23 talk)



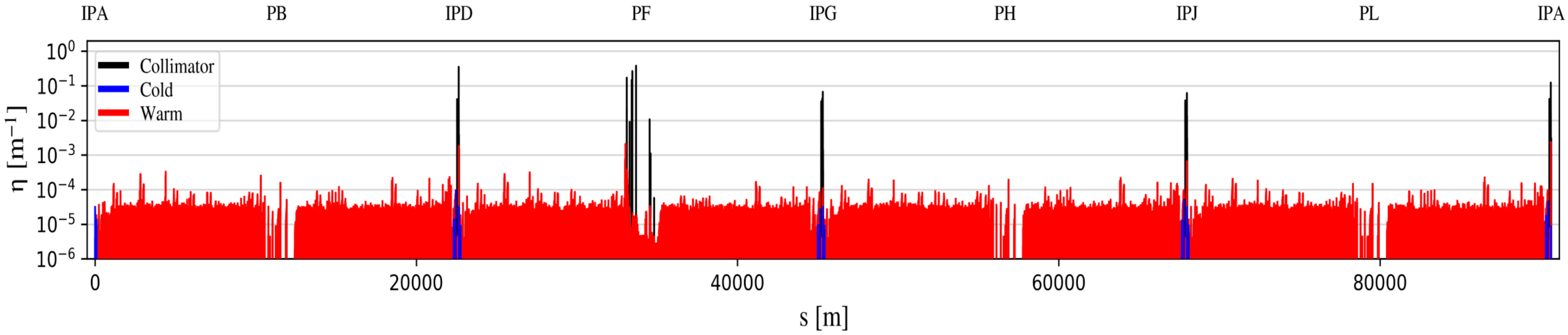




Collimation studies including beam-gas interactions

- **Pressure profile in the FCC-ee** (*Z*) provided by the vacuum team (R. Kersevan)
- **Implementation of beam-gas scattering centers in Xsuite-BDSIM** to model the interaction with residual gas in the vacuum pipe
- **First integration of beam-gas interactions in FCC-ee collimation tracking studies**

PRELIMINARY: detailed checks ongoing



- More details in G. Broggi, [Beam-gas beam losses and MDI collimators, FCC week 2024](#) (Thu 13/06)

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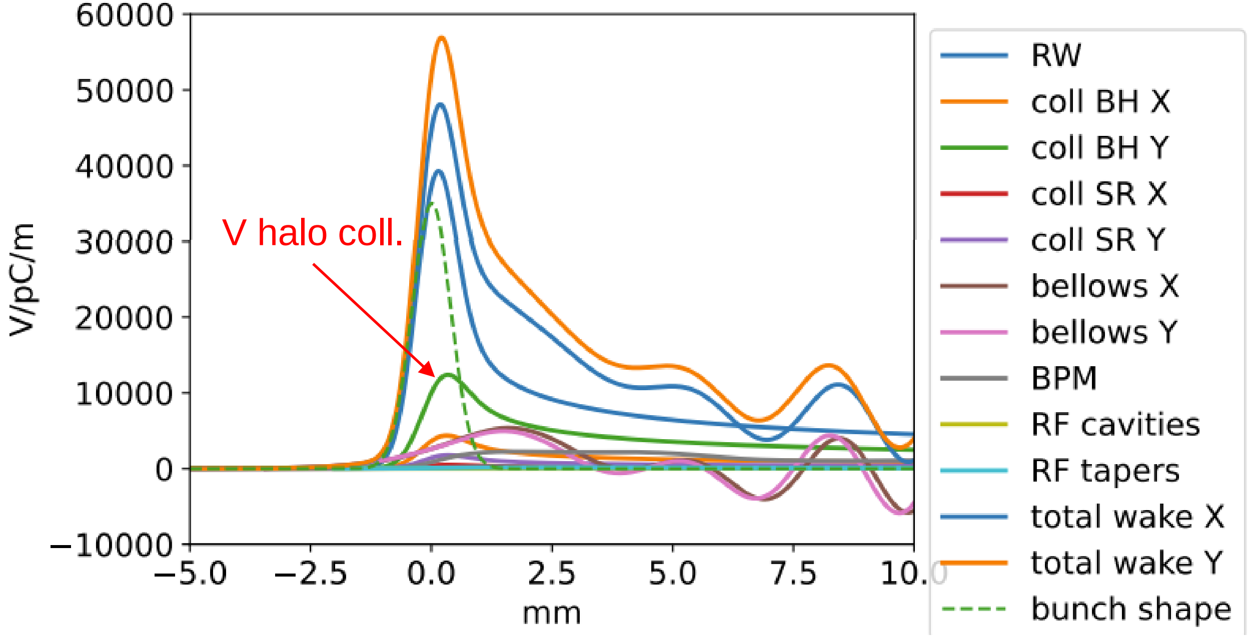
Alternative collimation layout: motivation

- Impedance team found that **halo collimators significantly contribute to impedance**
- The primary vertical collimator tcp.v.b1 gives the highest contribution



tcp.v.b1 has the smallest half-gap: 2.4 mm

Transverse dipolar wake potential for a 0.4 mm Gaussian bunch.
M.Migliorati et al., IPAC'24 paper

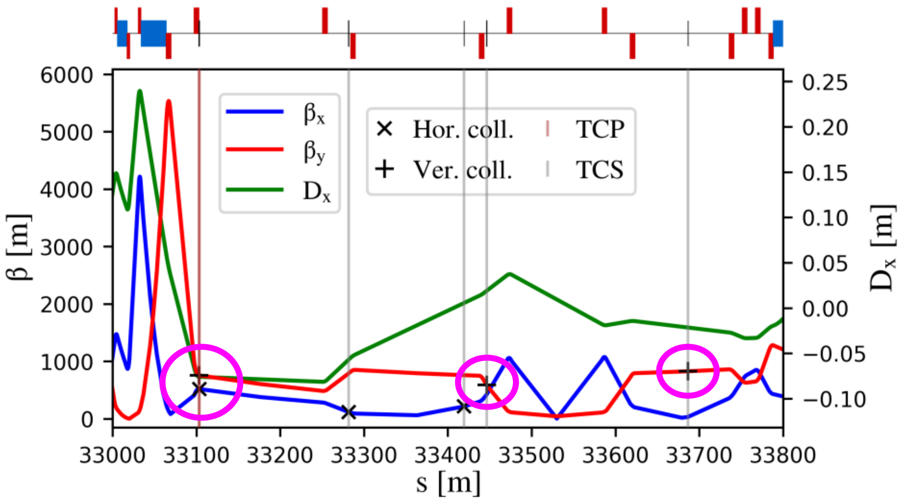
- More details in M. Migliorati, FCC-ee single beam collective effects, FCC week 2024 (Wed 12/06)

- **Alternative collimation layout** studied to **increase tcp.v.b1 half-gap**

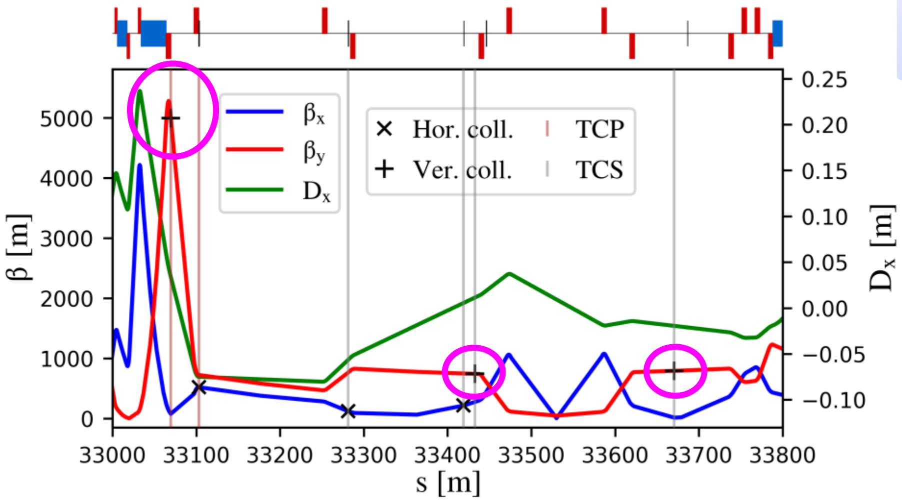
Alternative collimation layout

- The current (betatron) **primary collimator positions** have been selected with **two constraints**:
  1) **Large β-functions**: to set collimator at acceptable half-gap for impedance constraints
  2) **Small Twiss α**: to minimize the angle of incidence of halo particles onto the collimator jaw

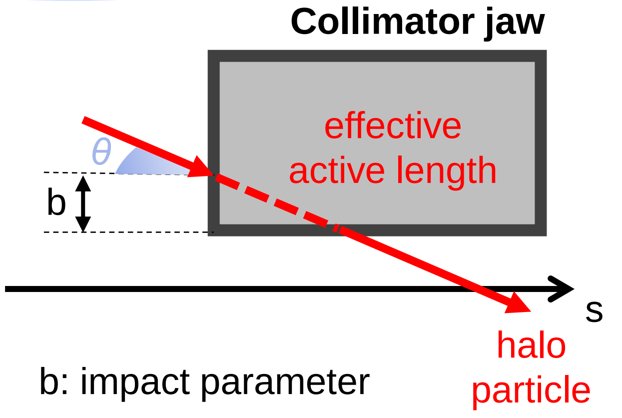
current betatron collimation layout



alternative betatron collimation layout



$$\theta \propto -\alpha\sqrt{\epsilon/\beta} \propto -\beta'\beta^{-\frac{1}{2}}$$

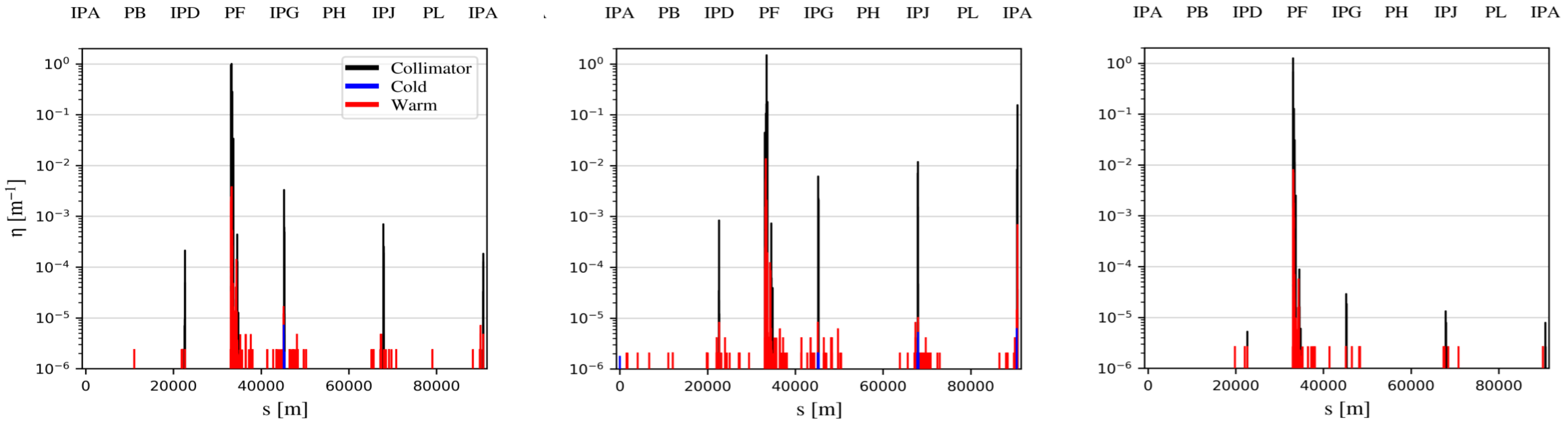


- The studied **alternative collimation layout** relaxes the **constraint 2)** and allows tcp.v.b1 to be close to the βy peak at the start of the collimation insertion
  - ➢ Allows to gain a factor of ~3 on tcp.v.b1 half gap: 2.4 mm → 6.3 mm !
  - ➢ ~20-30% gain also for vertical secondary collimators half-gap

Alternative layout: collimation performance

- **Significant gain in half-gap** but **collimation performance significantly worsen**
- However, by applying a **130 urad angular tilt** to **tcp.v.b1** to align it to the divergence of the beam envelope the **collimation perfomance is well recovered**:

current collimation layout | **alternative collimation layout** | **alternative collimation layout** (tcp.v.b1 with 130 urad angular tilt)



- **Strong indication that it is important to allow angular position control of beam halo collimators**
- Studies will be performed to asses collimation perfomance vs. deviation from ideal angular position

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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**
    - ➢ First **integrated beam-beam and collimation studies**
    - ➢ First **integrated beam-gas and collimation studies**
    - ➢ Collaboration with the MDI, impedance, engineering, FLUKA studies team
  - **Possibility to increase the halo collimators half-gap if angular control of the collimator jaws is allowed**

- **Next steps**
  - Study other beam loss scenarios – failure scenarios, top-up injection, …
  - Obtain input for the **equipment tolerances** – superconducting magnets, collimators, others…
    - ➢ Energy deposition studies required for magnets, collimators, and masks
    - ➢ Impact of beam losses on experimental background as well as detector tolerances to be studied
  - Study all beam modes
  - Sensitivity study of collimation performance vs. angular position of halo collimators

Thank you!

FCC-ee aperture

- Closed orbit tolerance: 250 µm
- Maximum beta-beating: 10%

Aperture bottleneck for Z operation mode