IR beam losses and collimation status

G. Broggi [1,2,3], A. Abramov [2], K. André [2], M. Boscolo [3], R. Bruce [2], M. Hofer [2], S. Redaelli [2]

[1] Sapienza University of Rome, Italy
[2] CERN, Meyrin, Switzerland
[3] INFN-LNF, Frascati, Italy

FCC-ee MDI & IR mockup Workshop – INFN-LNF, Frascati, Italy, 17/11/2023

Many thanks to:

H. Burkhardt, F. Carlier, A. Ciarma, Y. Dutheil, P. Hunchak, G. Iadarola, A. Lechner, G. Lerner, L. Nevay, M. Migliorati, M. Moudgalya, K. Oide, A. Perillo Marcone, R. Ramjiawan, T. Raubenheimer, L. van Riesen-Haupt, S. White, F. Zimmermann

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
  - IR beam halo losses
  - Impact parameter scan

- **IR beam losses and FCC-ee collimation summary**

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
  - IR beam halo losses
  - Impact parameter scan

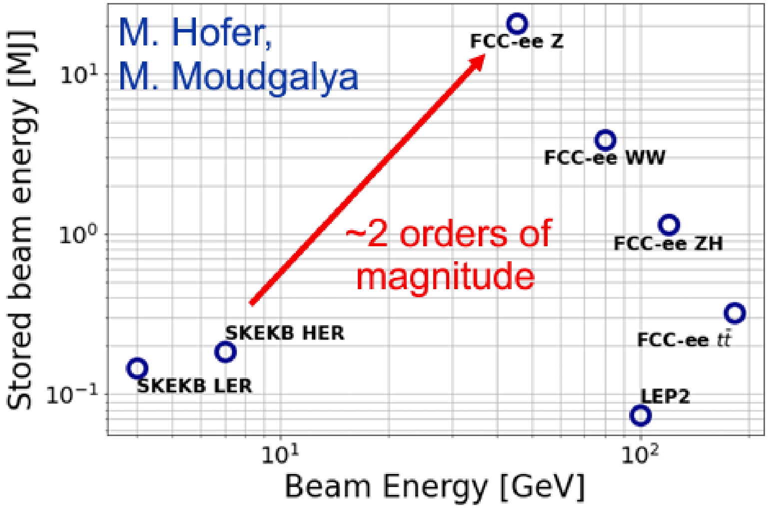
- **IR beam losses and FCC-ee collimation summary**

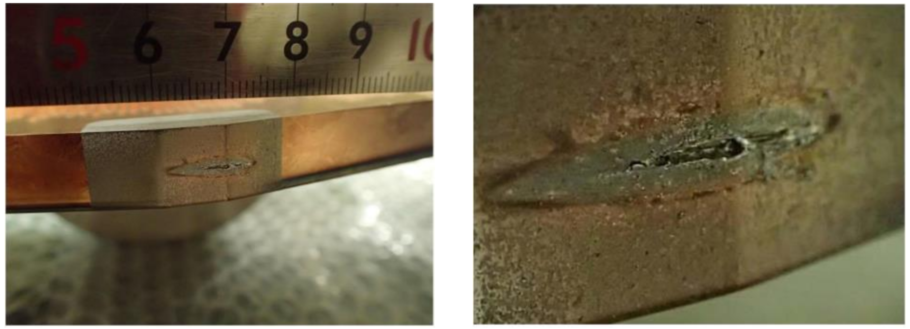
Collimation for the FCC-ee

- **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

Comparison of lepton colliders

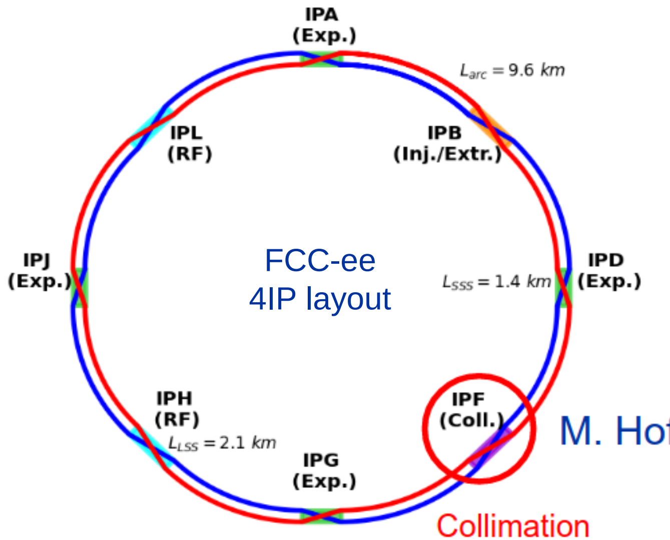




Damage to coated collimator jaw due to accidental beam loss in the SuperKEKB – T. Ishibashi (talk)

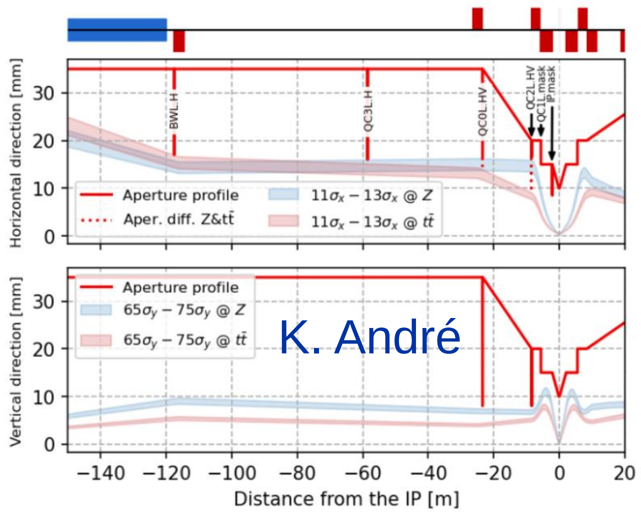
FCC-ee collimation system

- **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
  - New dedicated collimation optics (M. Hofer)
  - Collimator design for cleaning performance (FCC week 23 talk)
- **Synchrotron radiation collimators around the IPs**
  - 6 collimators and 2 masks upstream of the IPs (K. André, talk this workshop)
  - Designed to reduce detector backgrounds and power loads in the inner beampipe due to photon losses



M. Hofer

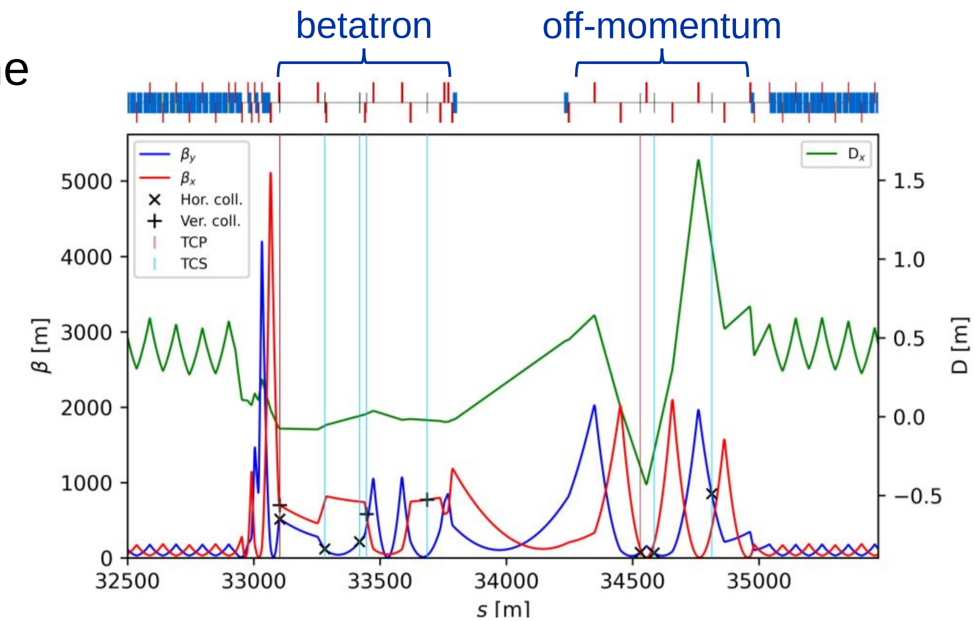
Collimation insertion



K. André

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	2.1	-
TCS.H1.B1	H	Mo	30	13	3.7	6.7
TCS.V1.B1	V	Mo	30	75	2.2	-
TCS.H2.B1	H	Mo	30	13	5.1	90.6
TCS.V2.B1	V	Mo	30	75	2.5	-
TCP.HP.B1	H	MoGr	25	18.5	4.2	1.3
TCS.HP1.B1	H	Mo	30	21.5	4.7	2.1
TCS.HP2.B1	H	Mo	30	21.5	26.7	1.6

Beam halo collimator parameters and settings



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

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
  - IR beam halo losses
  - Impact parameter scan
- **IR beam losses and FCC-ee collimation summary**

FCC-ee beam losses

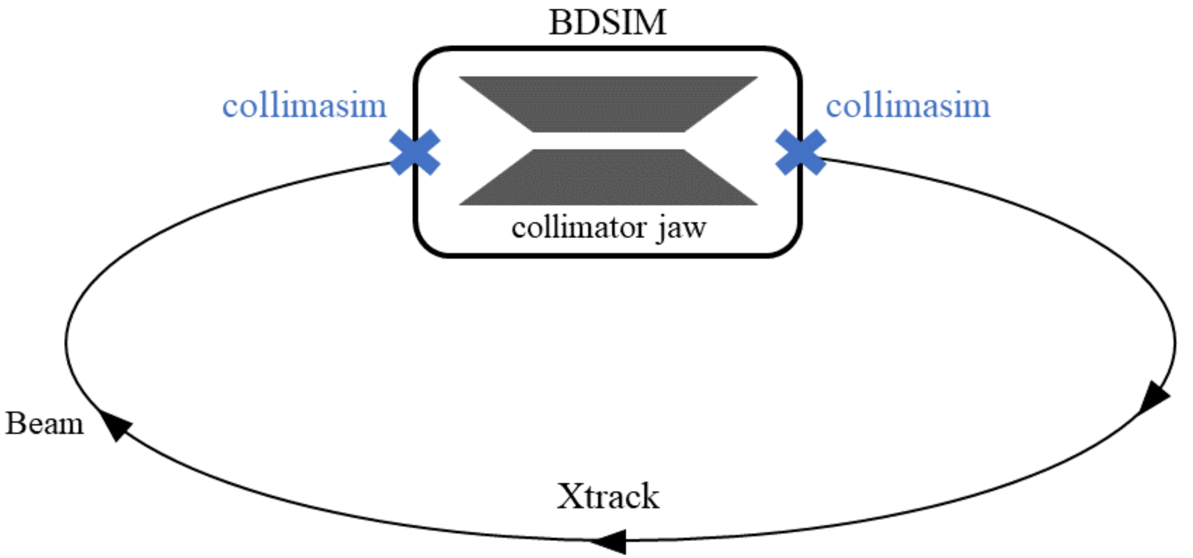
- **FCC-ee will operate in a unique regime**
  - Electron/positron beam dynamics and beam matter interactions
  - Stored beam energy exceeding material damage limits
  - Superconducting final focus quadrupoles, crab sextupoles, and RF cavities
  - Must study beam loss processes and define the ones to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

- **Important loss scenarios for particle tracking studies**:
  - **Beam halo** ⟵ **current studies**
  - **Spent beam due to collision processes** (Beamstrahlung, Bhabha scattering) – preliminary considerations (FCCIS 23 talk)
  - Top-up injection
  - Beam tails from Touschek scattering and beam-gas interactions
  - Failure modes (injection failures, asynchronous dump, others)

  } Inputs required to set up models

Simulation tool

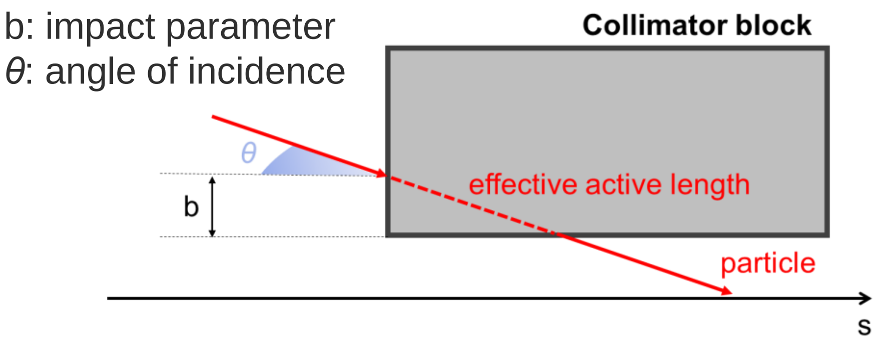
- **Xsuite-BDSIM simulation tool** used to evaluate beam losses along the accelerator ring
- **Xsuite**: collection of Python packages for beam dynamics simulations in particle accelerators
- **BDSIM**: C++ software package based on the Geant4 toolkit to simulate radiation transport in accelerators and beam lines
  - ➢ Can be used together for studies including particle tracking and particle-matter interaction



➢ Benchmarked against
- other simulation codes: **MAD-X**, **pyAT**, **Sixtrack-FLUKA** (A. Abramov)
- measured data from proton machines: **SPS** (T. Pugnat), **LHC** (G. Broggi)

Current study: beam halo losses

- **Xsuite-BDSIM simulation tool** used to evaluate beam losses in the FCC-ee
- **«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 primary collimator at a given impact parameter
  - To get a conservative performance estimate, particles impact the collimator at the **critical impact parameter**



critical impact parameter

↕

impact parameter scan

- Currently using 1 μm impact parameter as standard

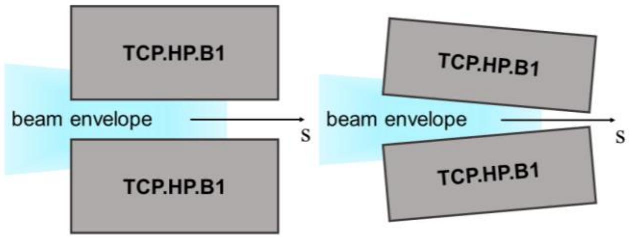
  - Particles scattered out from the collimator tracked for a given number of turns, and losses on the aperture are recorded (**loss maps**)

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
  - IR beam halo losses
  - Impact parameter scan
- **IR beam losses and FCC-ee collimation summary**

Beam halo losses for the Z mode

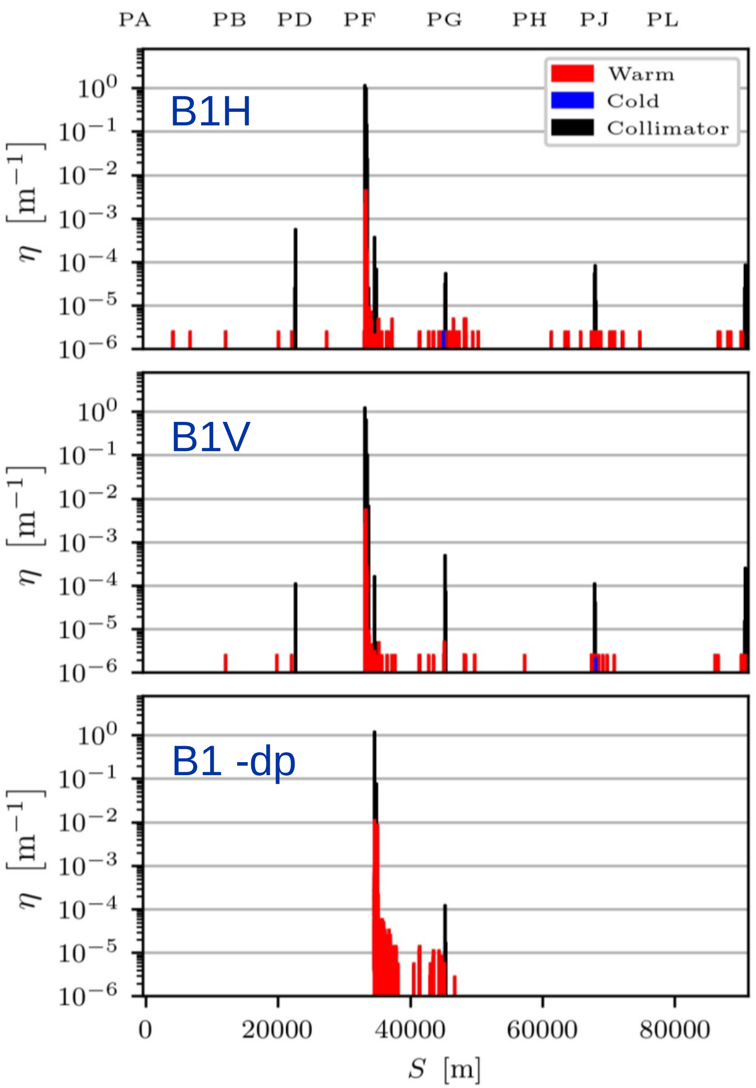
- The ***Z* mode** is the **current focus** (Beam 1, 45.6 GeV e+)
  - ➢ **17.5 MJ** stored beam energy
- **5 min** beam lifetime assumed → **58.3 kW** total loss power
- Radiation and tapering included
- 3 cases considered:
  - **Horizontal betatron losses** (B1H)
  - **Vertical betatron losses** (B1V)
  - **Off-momentum losses** (B1 -dp)
- For the off-momentum case, the primary collimator TCP.HP.B1 is aligned to the beam envelope



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

- **The beam collimation system shows significant loss suppression**
  - ➢ More than 99.98% of losses contained within the collimation insertion PF
  - ➢ Minimal cold losses on final focusing quadrupoles in all scenarios
  - ➢ Residual cold losses on crab sextupoles

1 µm impact parameter

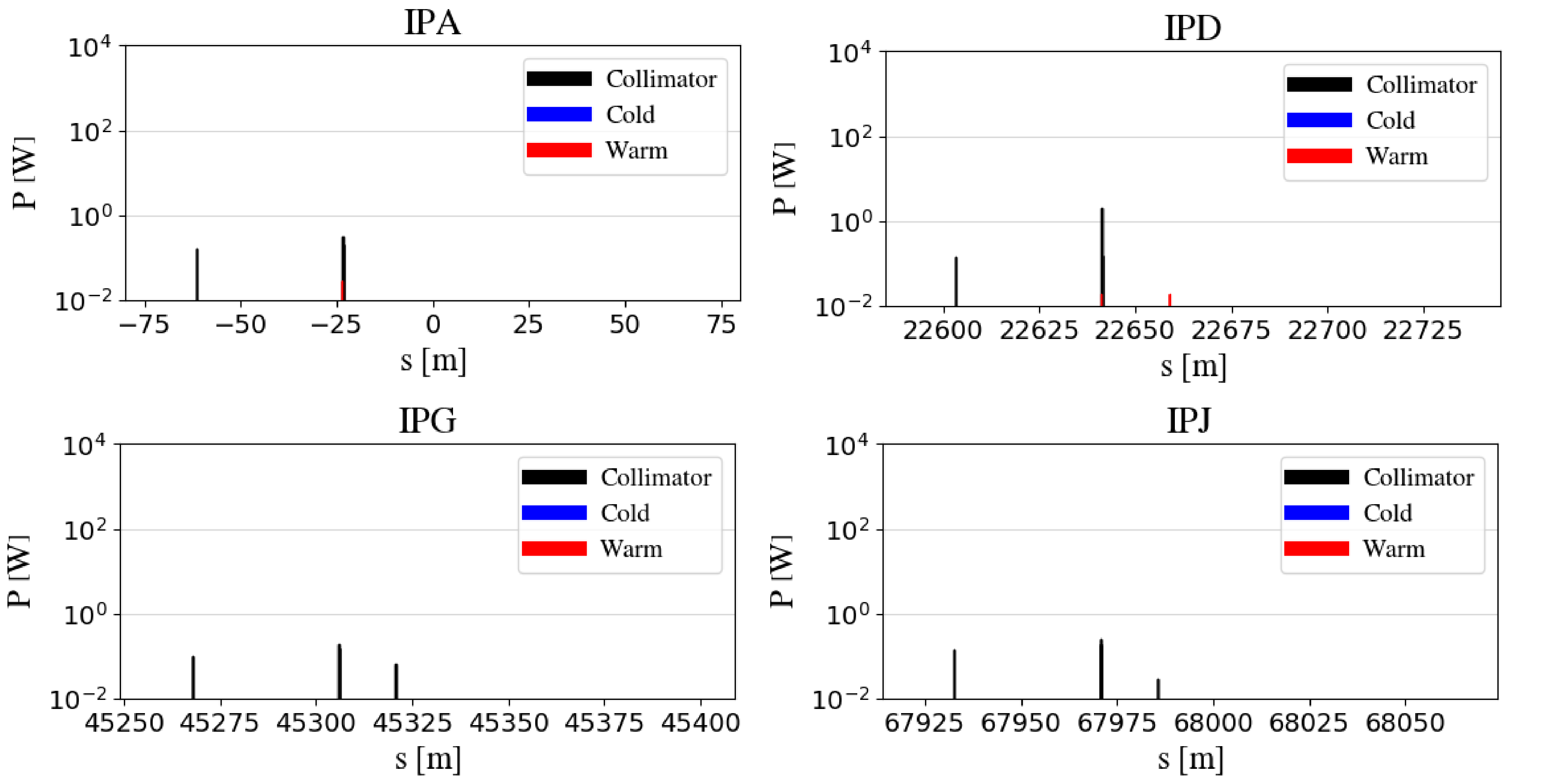


Z mode betatron and off-momentum halo loss maps

IR beam halo losses for the Z mode

- **Horizontal betatron** (**B1H**) **IR losses**, **5 min** beam lifetime assumed

1 μm impact parameter

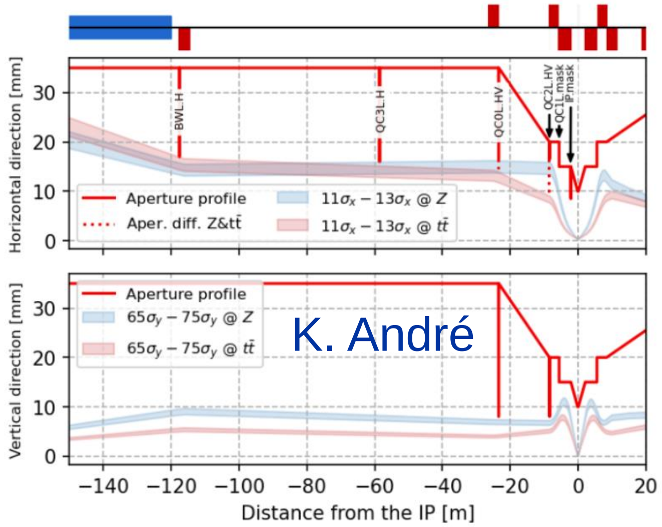


- Absence of cold power loads on final focusing quadrupoles (FFQs)
- Most of IR beam losses end up on SR collimators

Z mode beam losses on SR collimators

1 μm impact parameter

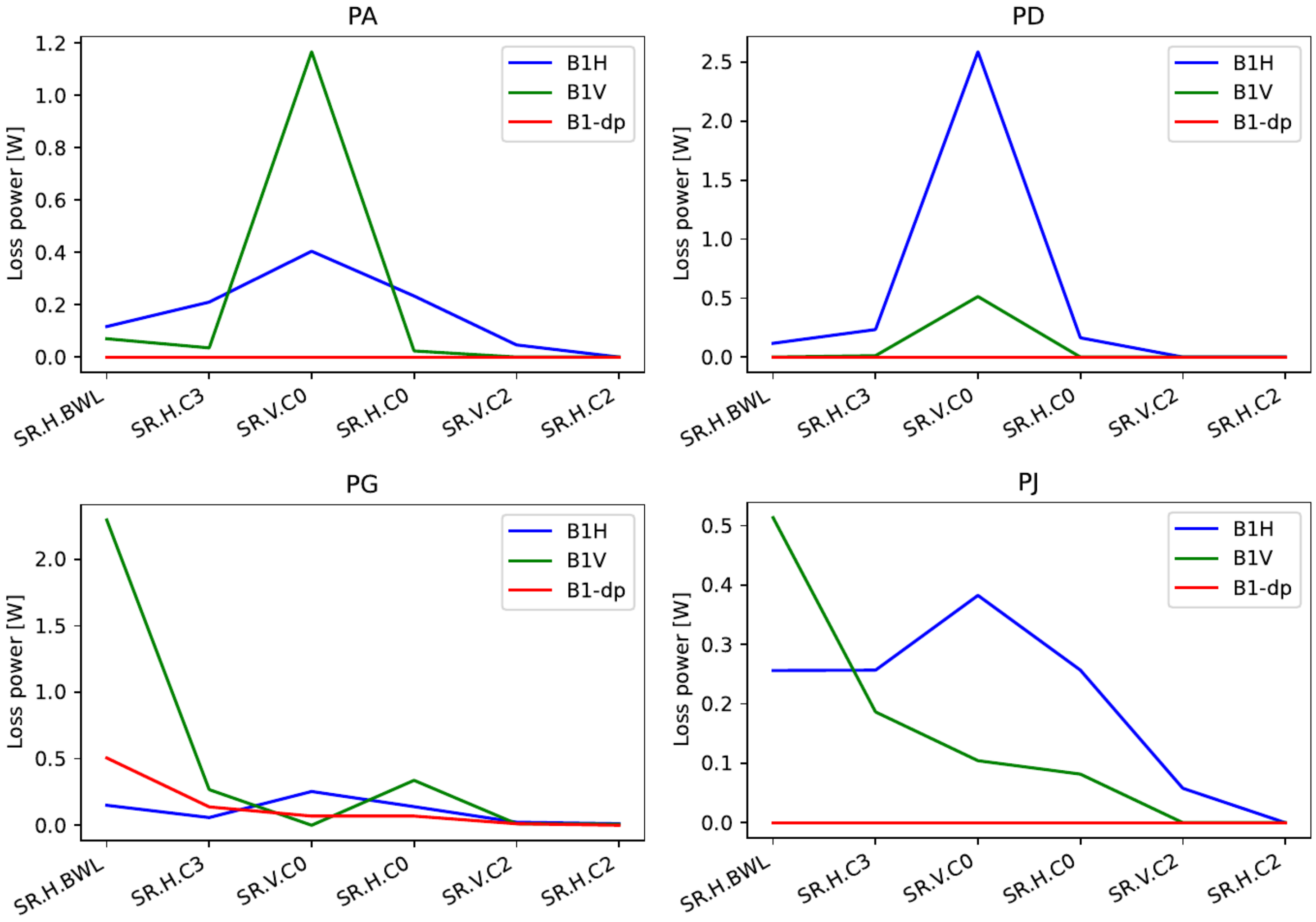
- **The SR collimators intercept losses for all cases**
  - ➢ **Highest load** on C0 vertical and BWL horizontal SR collimators, up to 2.6 W
  - ➢ Lowest load on C2 horizontal and vertical SR collimators



- At different impact parameters on halo collimators the picture might change
  - ➢ **Impact parameter scan**

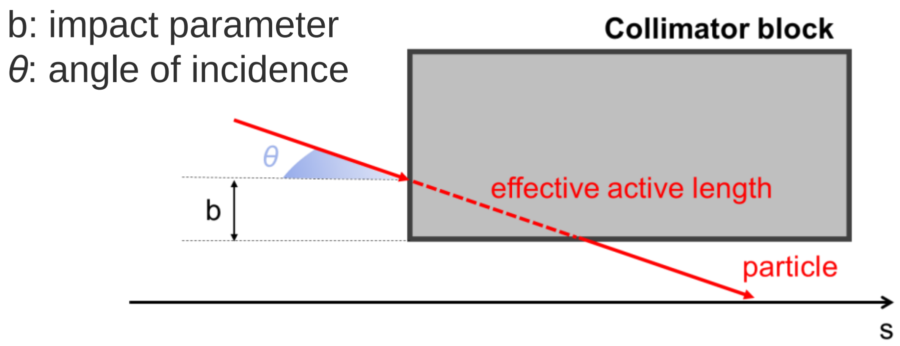
beam →

Total loss power: **58.3 kW**



Impact parameter scan

- Scan to determine the **halo cleaning performance as a function of the impact parameter** ↔ **IR beam losses as a function of the impact parameter**



- FCC-ee ***Z* operation mode**: B1, **45.6 GeV** positrons, **17.5 MJ** stored beam energy

- **Horizontal betatron collimation** (B1H)
  - ➢ Expected to be the case with the highest sensitivity on the impact parameter
  - ➢ Comparison with previous studies

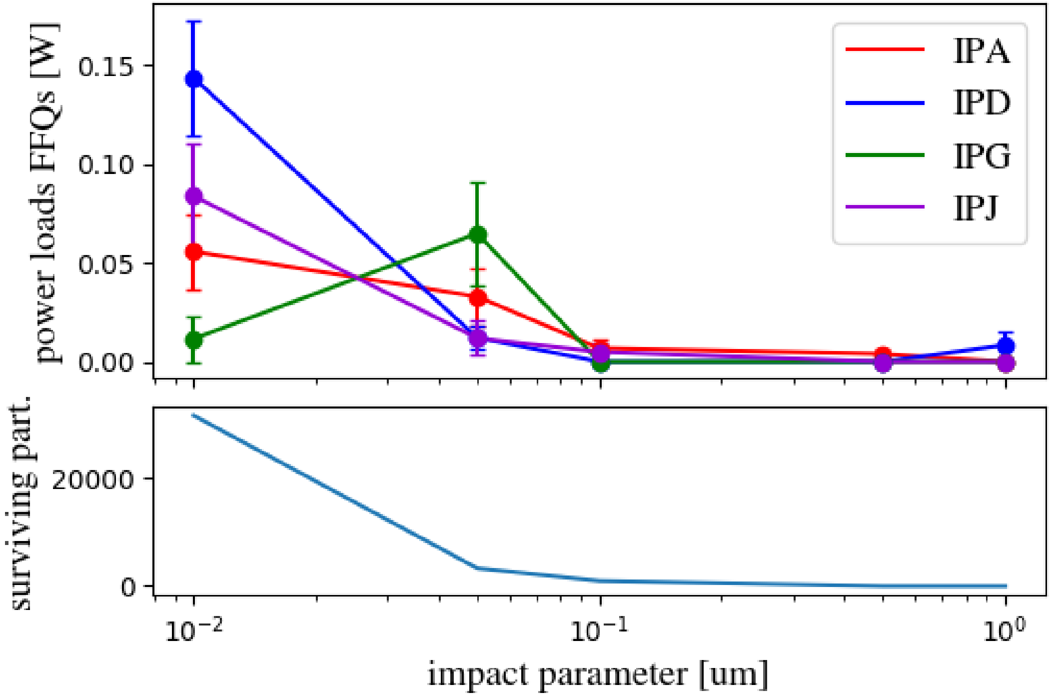
- Radiation and tapering included

- **Figure of merit for halo cleaning performance**: **cold power loads in the FFQs**
  - ➢ FFQs: Final Focusing Quadrupoles

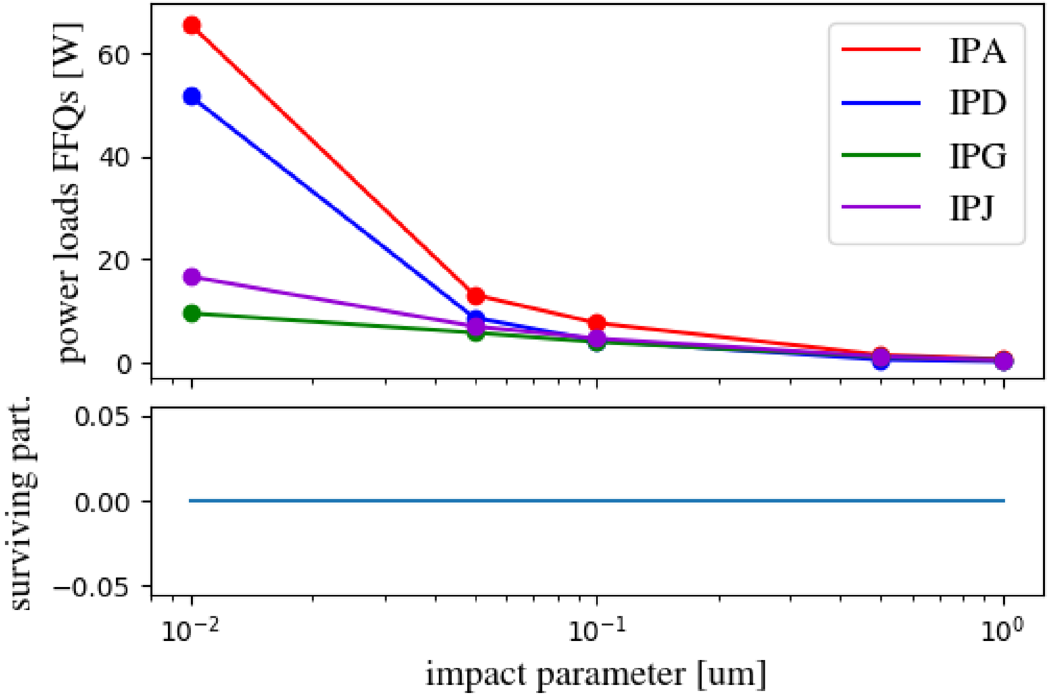
Impact parameter scan

Presented at FCC week 23, [talk]

V23, tridodo_572 collimation optics



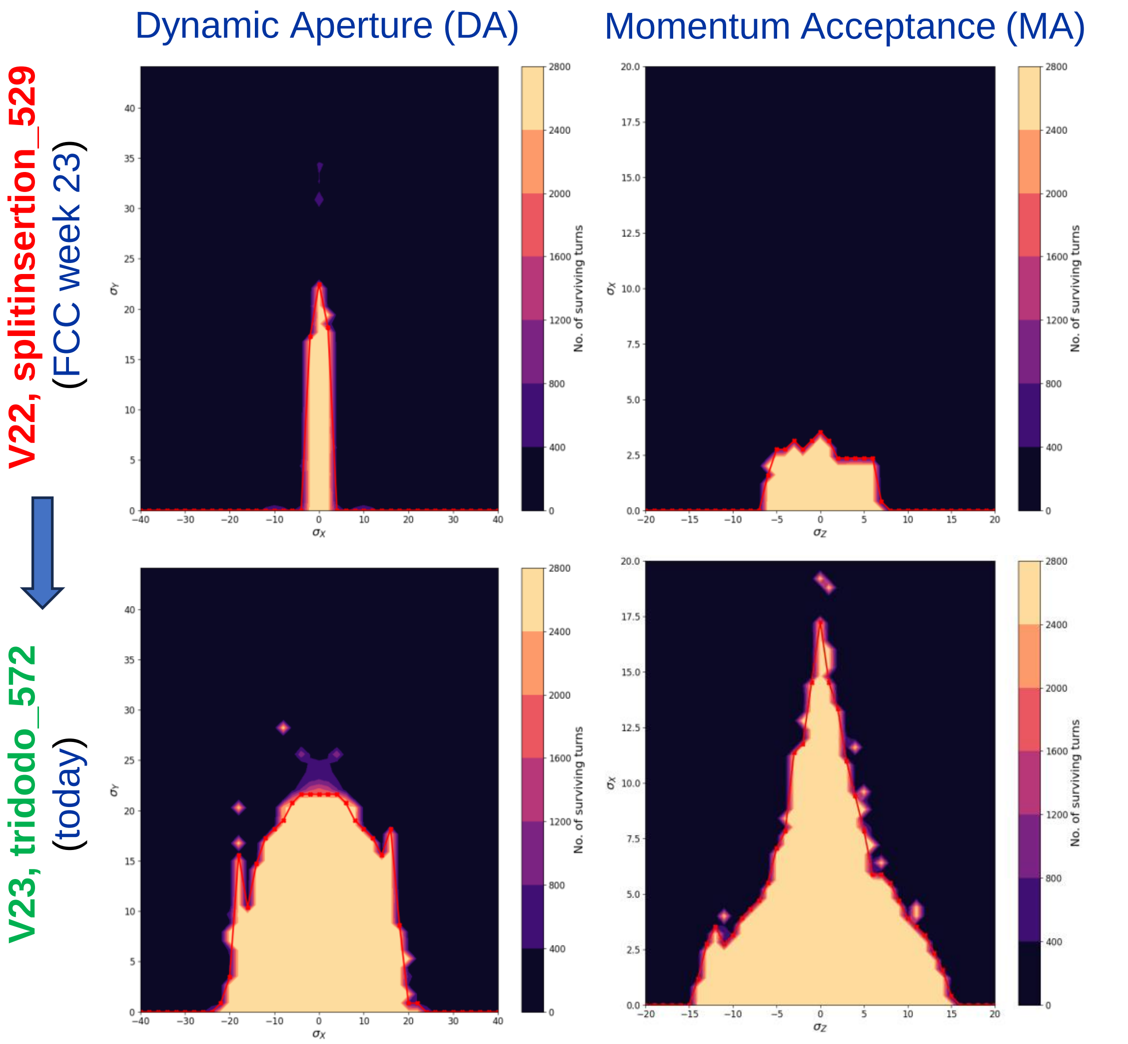
V22, splitinsertion_529 collimation optics



- Absence of a clear pattern - critical impact parameter cannot be identified
- Surface roughness effects not considered – can play a role for b $\lesssim$ 0.1 um
- Minimal power loads in the FFQs for all cases
- Significantly lower power loads compared to previous studies
  - ➢ Most likely due to improved DA thanks to the new collimation insertion optics (M. Hofer)

DA with the new collimation optics

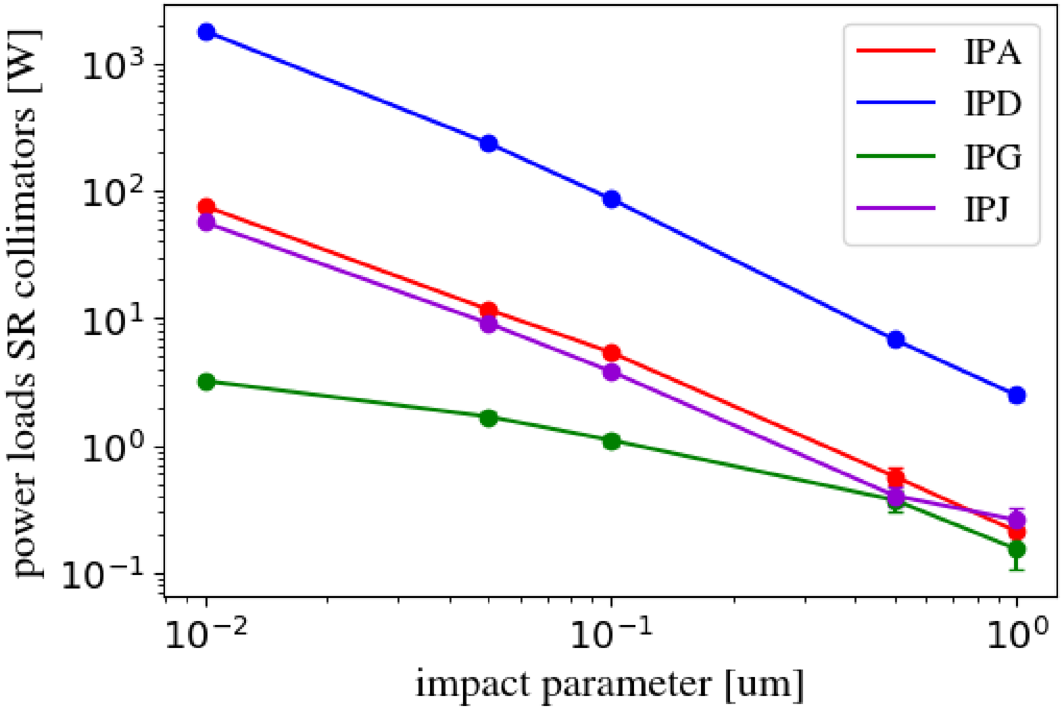
- **New collimation optics is integrated with the ring optics**
- **The DA and momentum acceptance are satisfactory**
  - ➢ Improved compared to previous optics
  - ➢ Further tuning and optimization are possible
  - ➢ This will also help in performing collimation studies with effects like beam-beam, where beam tails need to be tracked long-term
  - ➢ **First collimation studies including beam-beam effects have started** (A. Abramov, details in FCCIS 23 talk) thanks to the recent implementation of beam-beam effects in Xsuite (P. Kicsiny, X. Buffat, T. Pieloni, FCCIS 23 talk)



DA and MA with radiation and tapering (M. Hofer)
https://gitlab.cern.ch/mihofer/fcc-ee-collimation-lattice

Impact parameter scan: losses on SR collimators

- Near absence of cold power loads on FFQs
- Beam halo losses, and the consequent power loads, on SR collimators is another aspect that might be critical
  - ➢ SR collimators are likely not robust enough to sustain large beam losses
  - ➢ SR collimators can be source of background in the detectors

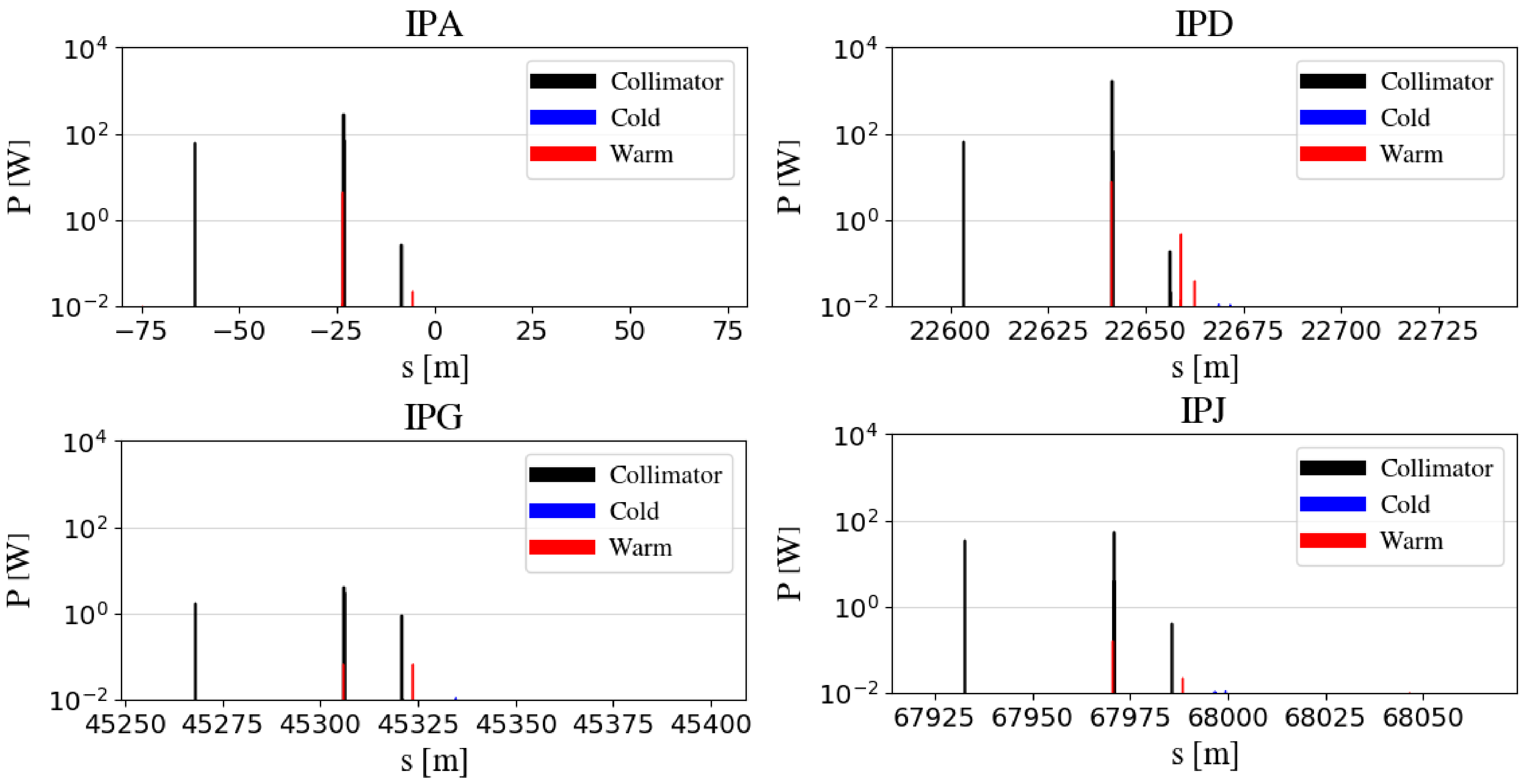


- **SR collimators upstream of IPD are the ones most exposed to beam halo losses**
  - ➢ Up to 1.8 kW on a single SR collimator with beam halo impacting with 10 nm impact parameter on the horizontal betatron collimator

IR beam halo losses for the Z mode

- **Horizontal betatron** (**B1H**) **IR losses**, **5 min** beam lifetime assumed

10 nm impact parameter

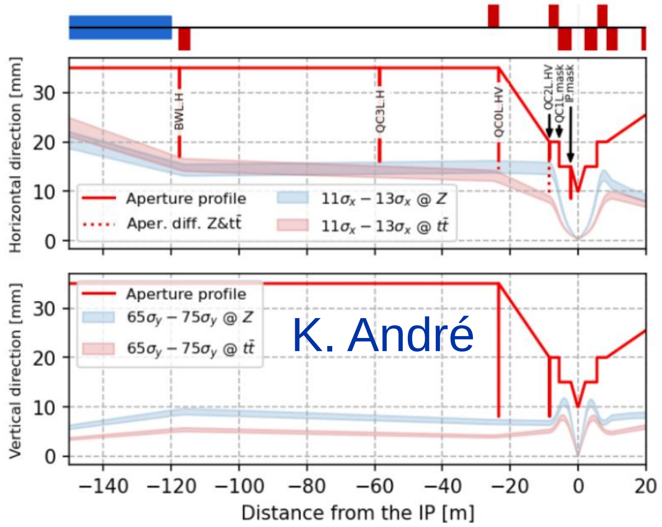


- Minimal cold power loads on final focusing quadrupoles (FFQs)
- Most of IR beam losses end up on SR collimators

Z mode beam losses on SR collimators

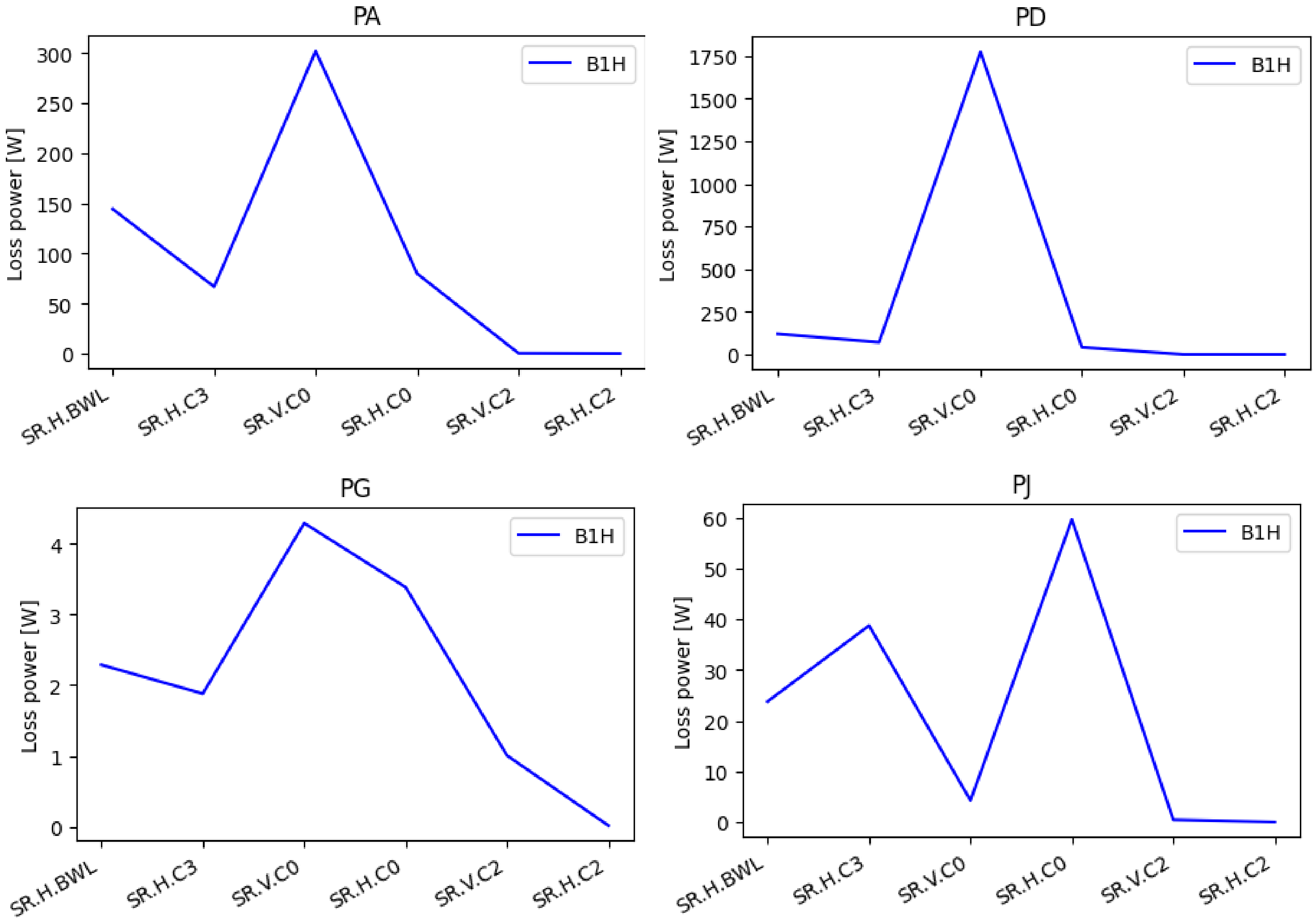
10 nm impact parameter

- **At smaller impact parameters SR collimators intercept a significant fraction of beam losses**
  - ➢ Highest load on C0 vertical SR collimators, up to 1.8 kW
  - ➢ Lowest load on C2 horizontal and vertical SR collimators



beam →

Total loss power: 58.3 kW



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
  - IR beam halo losses
  - Impact parameter scan
- **IR beam losses and FCC-ee collimation summary**

Summary

- **Studies of beam losses and collimation for the FCC-ee**
  - First collimation system design available, including beam halo and SR collimators
    - ➢ Newly developed collimation optics enhance betatron halo cleaning performance
  - Simulation of beam loss scenarios ongoing
    - ➢ Beam halo losses studied for the most critical Z mode – no show-stoppers identifies
    - ➢ Impact parameter scans ongoins – power loads on SR collimators up to ~kW for very small impact parameters
    - ➢ First integrated beam-beam and collimation studies (FCCIS 23 talk)
    - ➢ Collaboration with the MDI, impedance, engineering, FLUKA studies team

- **Next steps**
  - Study other beam loss scenarios – failure scenarios, top-up injection, …
  - Obtain input for the **equipment tolerances** – superconducting magnets, collimators, others …
  - Study all beam modes
  - Investigate further the effects determining high power loads on SR collimators at small impact parameters
  - Optimize further the collimator design with the help of engineering, impedance and FLUKA teams
  - Would be beneficial to benchmark simulation tools with operating lepton colliders

Thank you!