FCC-ee IR Beam Losses and MDI collimation

G. Broggi [1,2,3], A. Abramov [2] , M. Boscolo [3], R. Bruce [2]

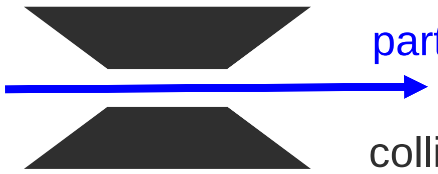
[1] Sapienza University of Rome, Rome, Italy
[2] CERN, Meyrin, Switzerland
[3] INFN-LNF, Frascati, Italy

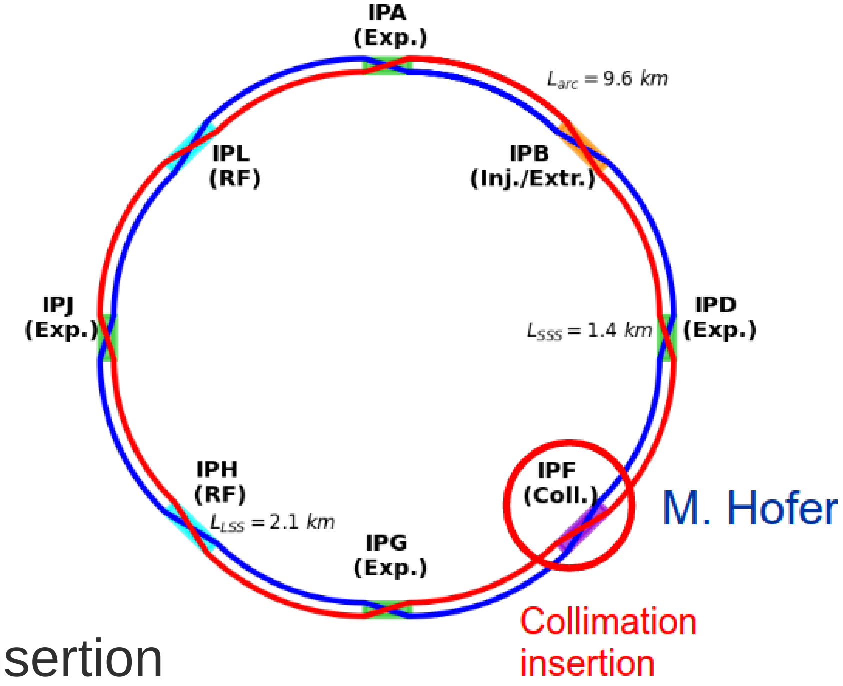
2nd FCC@LNF meeting – 23/05/2023

Many thanks for discussions and input to:
A. Lechner, M. Hofer, M. Migliorati, K. Oide, A. Perillo-Marcone, S. Redaelli, F. Zimmerman

FCC-ee: collimation system requirements

- **FCC-ee** will have an **unprecedented stored beam energy for a lepton collider**
  - Up to **17.8 MJ** (Z mode) → highly destructive beams!
- **Collimation system** indispensable
  - **Reduce the background in the experiments**
  - **Protect the machine from unavoidable losses**





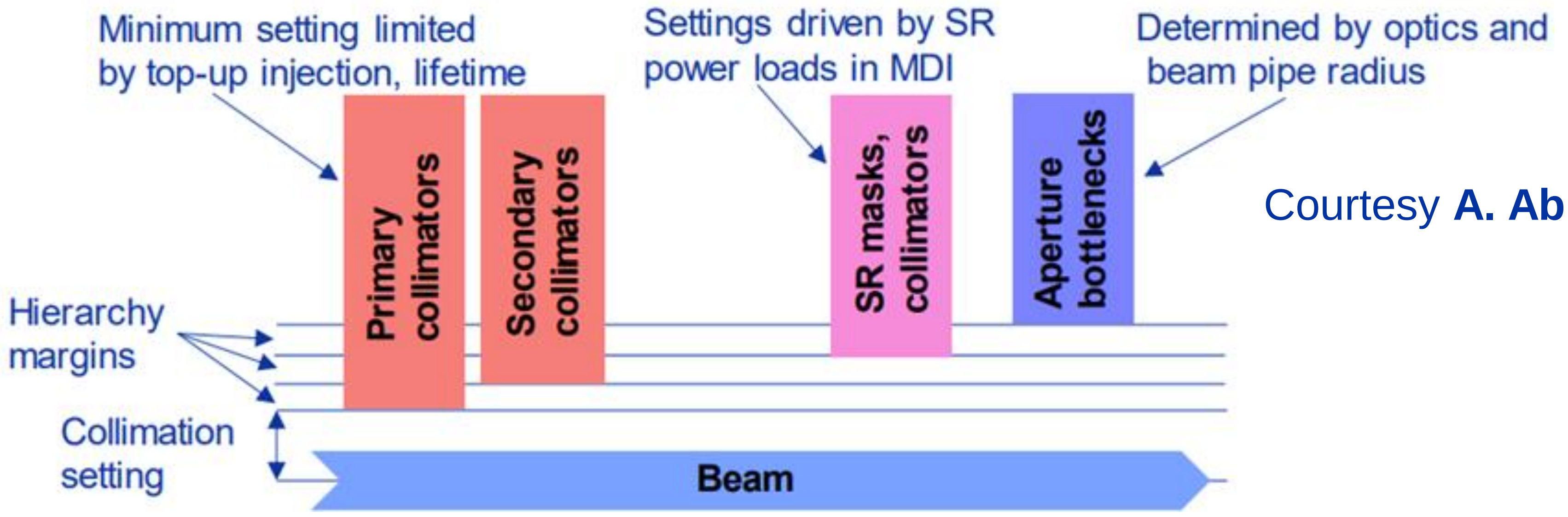
- **Dedicated halo collimation system in PF** (A. Abramov - talk)
  - ➢ Two-stage betatron and off-momentum collimation in one insertion
  - ➢ First collimator design for beam cleaning performance
    - ▪ Primary collimators (TCPs): MoGr – 33 cm
    - ▪ Secondary collimators (TCSs): Mo – 30 cm

Further optimization studies ongoing!

- **Synchrotron radiation collimators around the IPs** (K. André - talk)

FCC-ee aperture bottlenecks

- The **aperture bottlenecks** are in the **experimental interaction regions (IRs)**
- The **bottlenecks must be protected** → **collimation system**
  - ➢ The **final focusing quadrupoles** are **superconducting**: **risk of quenches!**
  - ➢ The **detectors** are **sensitive to backgrounds from beam losses**
  - ➢ The **SR collimators and masks** are **not robust to large direct beam impacts** and they can also produce **backgrounds**



Courtesy **A. Abramov**

FCC-ee halo collimation system optimization

Goals

- **Evaluate the halo collimation system performance for beam loss cleaning**
- **Study beam dynamics aspects for beam cleaning performance**
- **Optimization of the collimator design parameters**
- **Study possible loss mitigation strategies**

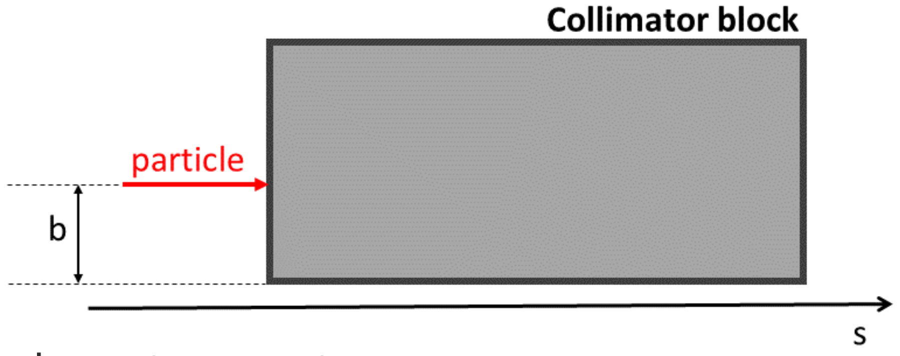
In this talk

- **Evaluation of the halo collimation system performance for beam loss cleaning**
  - ➢ FCC-ee 4IP layout, generic beam halo loss scenario
- **Impact parameter scan for different scenarios**
  - ➢ Without and with radiation and tapering
  - ➢ Without and with collimators aligned to the beam envelope (loss mitigation strategy)
- **Suppression of power loads in the IRs by aligning the primary collimators to the beam envelope**
- Possible **collimator design optimization** through a **parametric scan of the primary collimator length (tt mode)** – **PRELIMINARY!**

SIMULATION SETUP

Case study: beam halo losses

- **Tracking simulations (Xtrack-BDSIM)** to evaluate the collimation system cleaning performance
- **Generic halo beam loss scenario**
  - ➢ Simulation starts with halo particles impacting a primary collimator at a given impact parameter
  - ➢ The **impact parameter** affects the **collimator active length**
  - ➢ To get a **conservative performance estimate**: the particles impact the collimator at the **critical impact parameter**



b: impact parameter

critical impact parameter

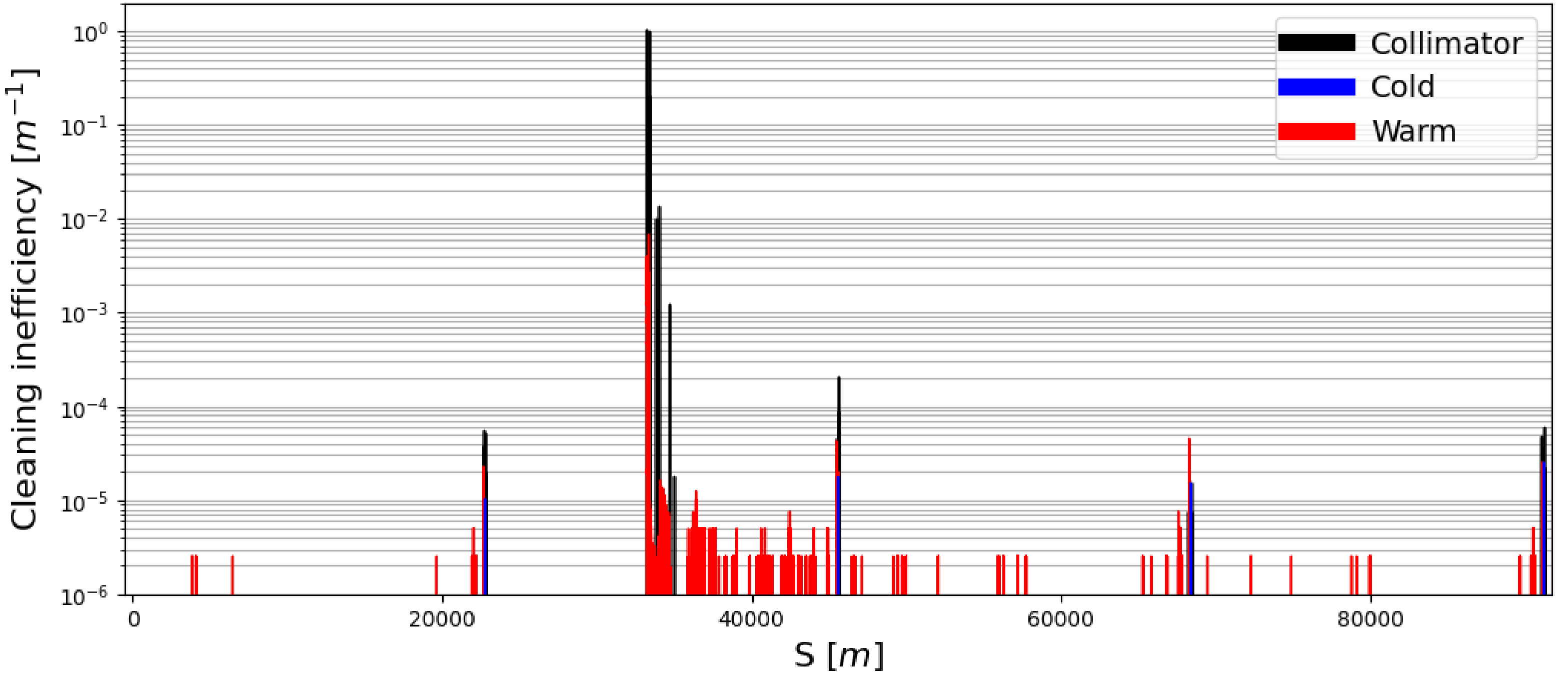
↕

impact parameter scan

  - ➢ The particles scattered out from the collimator are tracked, and the losses on the aperture are recorded (**loss maps**)

Example: Z mode betatron halo loss map

- FCC-ee 4IP layout, Z operation mode (B1, **45.6 GeV** positrons), **17.8 MJ** stored beam energy
- Halo particles (5x10^6) impacting the horizontal primary collimator TCP.H.B1, **1 µm impact parameter**
- Particles scattered out from TCP.H.B1 tracked for **700 turns**
- Synchrotron radiation emission and lattice tapering



IMPACT PARAMETER SCAN

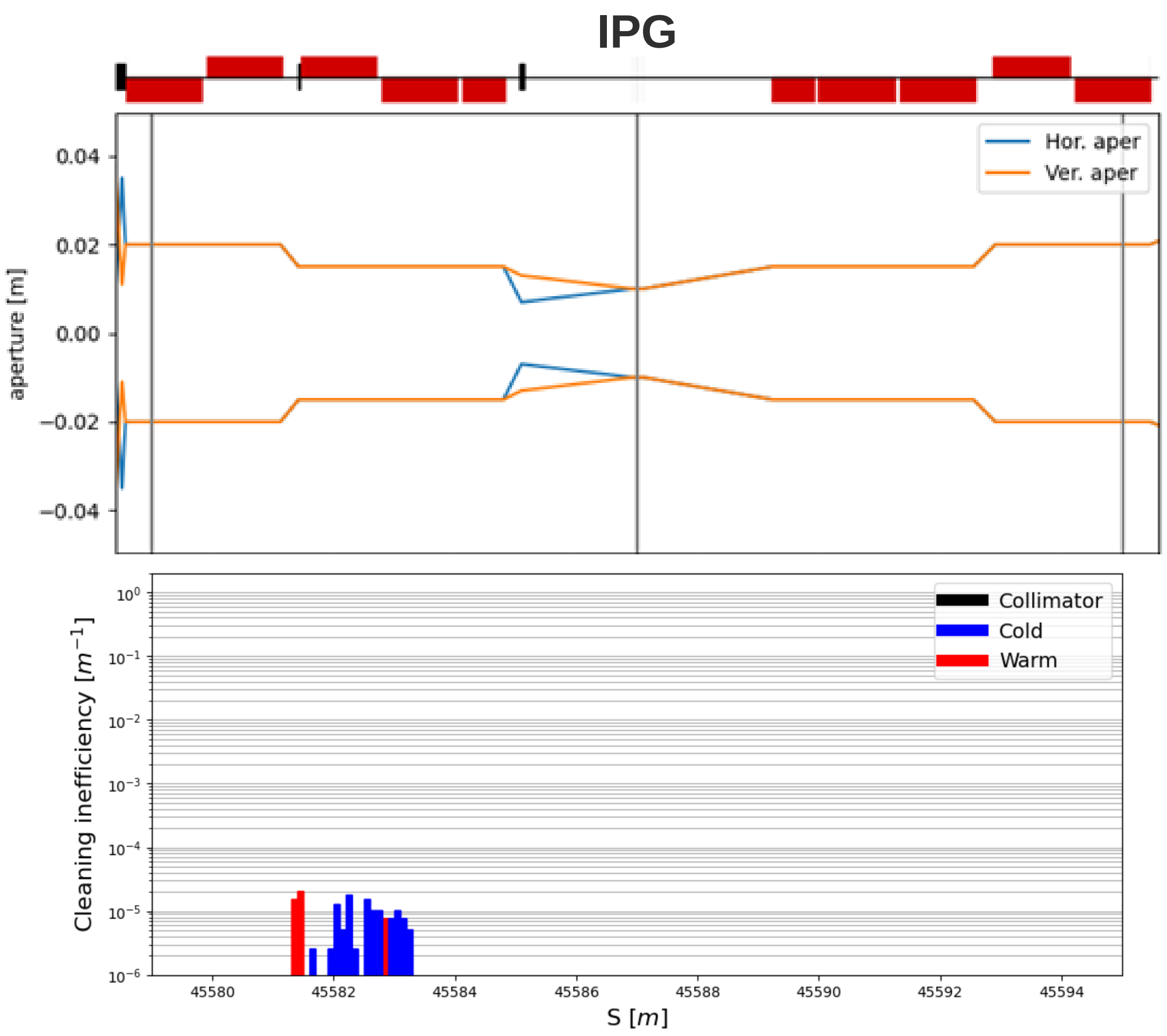
Impact parameter scan

- Scan to determine the **loss cleaning performance as a function of the impact parameter**
- FCC-ee 4IP layout
  - **Z operation mode** (B1, **182.5 GeV** positrons, **0.3 MJ** stored beam energy)
  - **tt operation mode** (B1, **45 GeV** positrons, **17.8 MJ** stored beam energy**)**
- Different scenarios examined:

	SR emission	lattice tapering	tilted TCP.H.B1
NO R&T	✗	✗	✗
R&T	✓	✓	✗
R&T + tilted TCP.H.B1 *	✓	✓	✓

* Aligning the collimators to the beam divergence significantly increases the loss cleaning performance

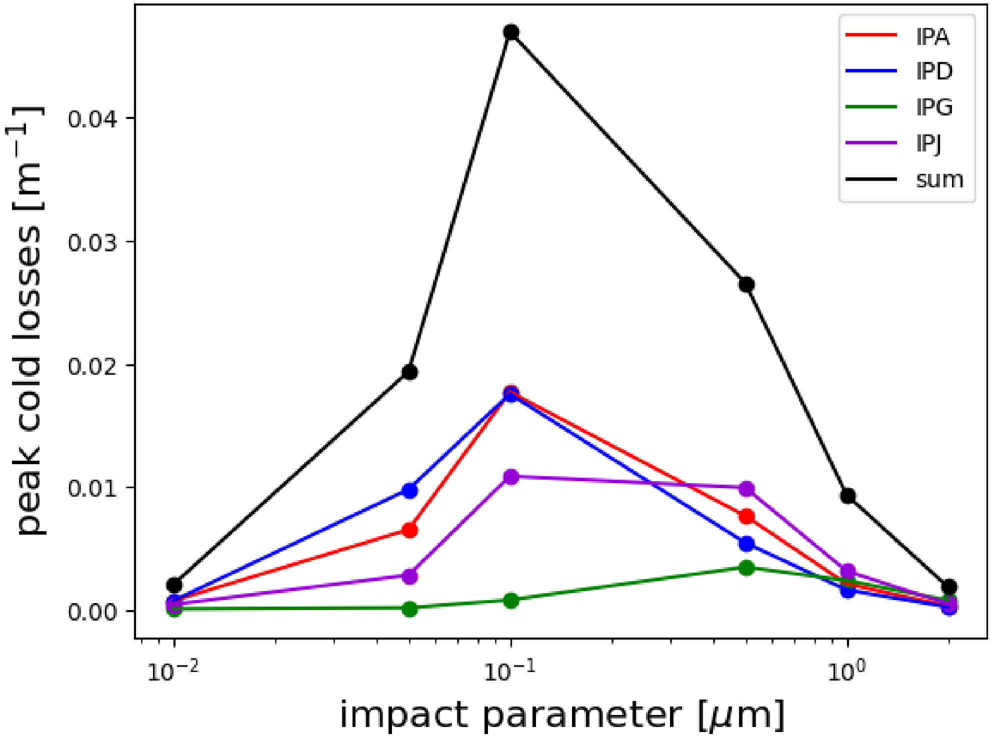
Impact parameter scan: figures of merit

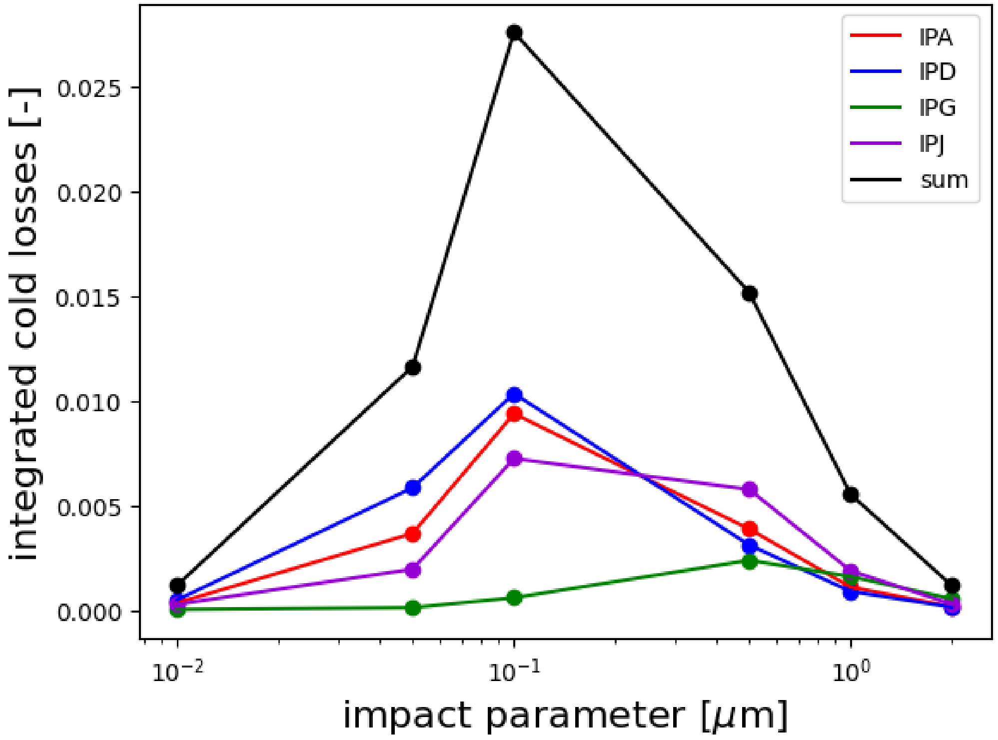


Peak and integrated (along s) **cold losses ± 8 m from the IPs** chosen as representative quantities for the overall cleaning performance
(i.e., **losses in the final focusing quads**)

from the example
on slide 4

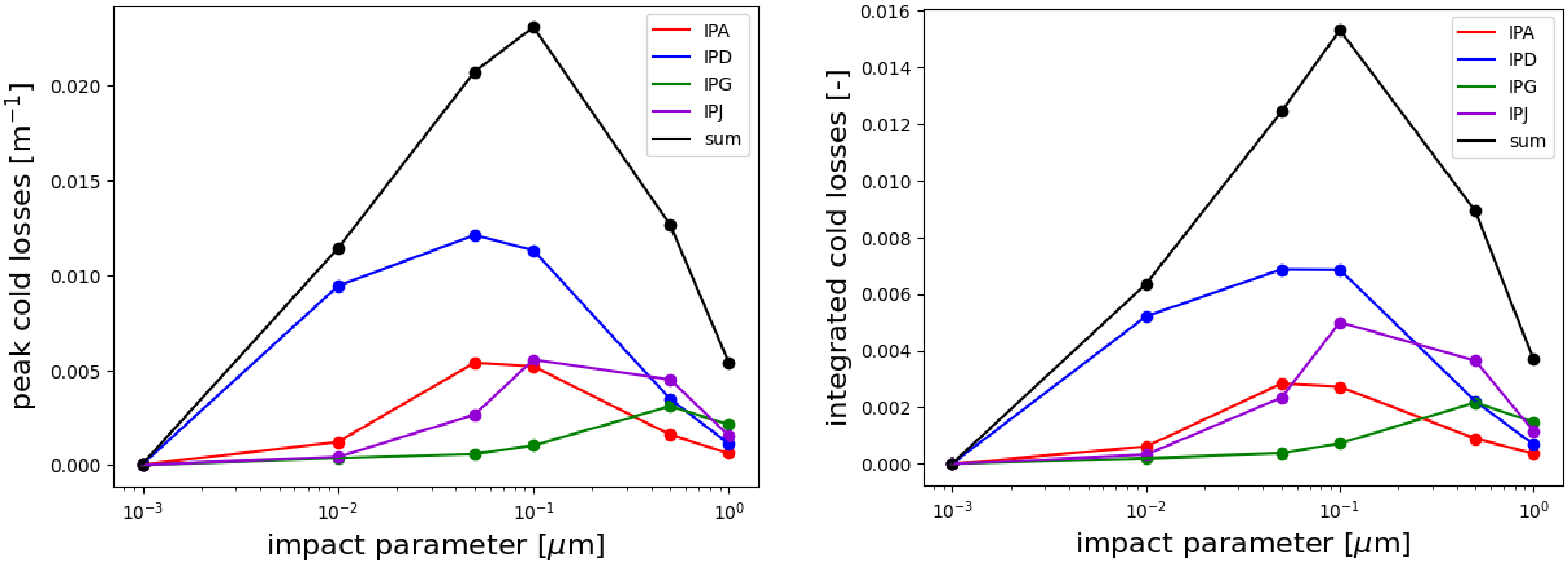
tt mode – NO radiation and tapering





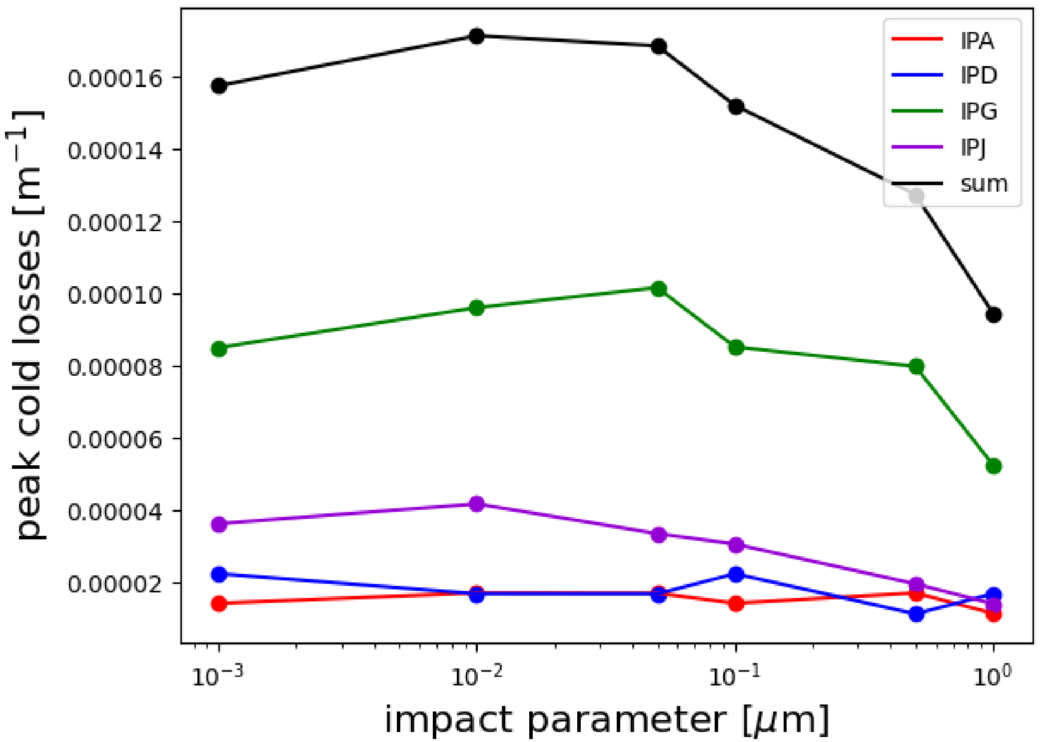
- The critical impact parameter is **b_{crit} = 0.1 μm**
- The **most critical IPs** are **IPA** and **IPD** (the farther from the collimation insertion)
- **Second-turn effects** likely determine the decrease for the smallest impact parameters

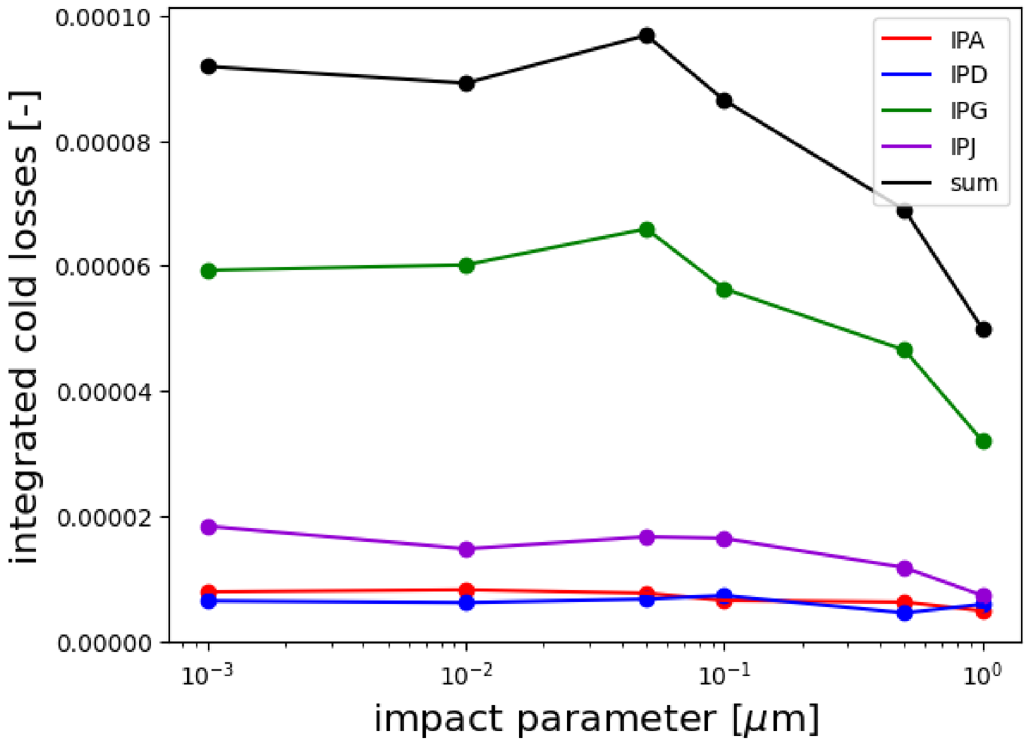
tt mode – radiation and tapering



- The critical impact parameter is **b_{crit} = 0.1 µm** (as without radiation and tapering)
- With **radiation and tapering losses** are **lower**
- The **most critical IP** is **IPD** (the farther from the collimation insertion)
- **Second turn effects/radiation damping** likely determine the decrease for the smallest impact parameters

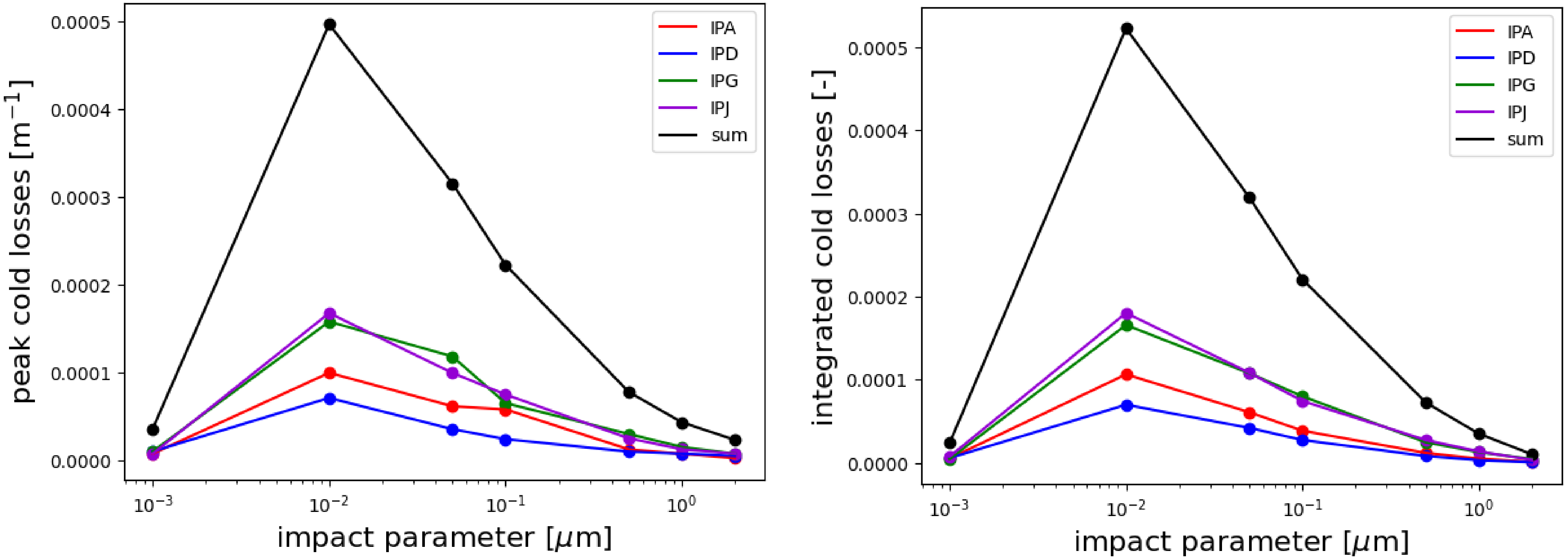
tt mode – radiation and tapering + tilted TCP.H.B1





- The critical impact parameter becomes **b_{crit} = 50 nm**
- **Aligning TCP.H.B1 to the beam divergence** leads to **significantly better cleaning performance** (2 orders of magnitude) for the same impact parameter
- The **most critical IP** is **IPG** (the one downstream of the collimation insertion, located in PF)

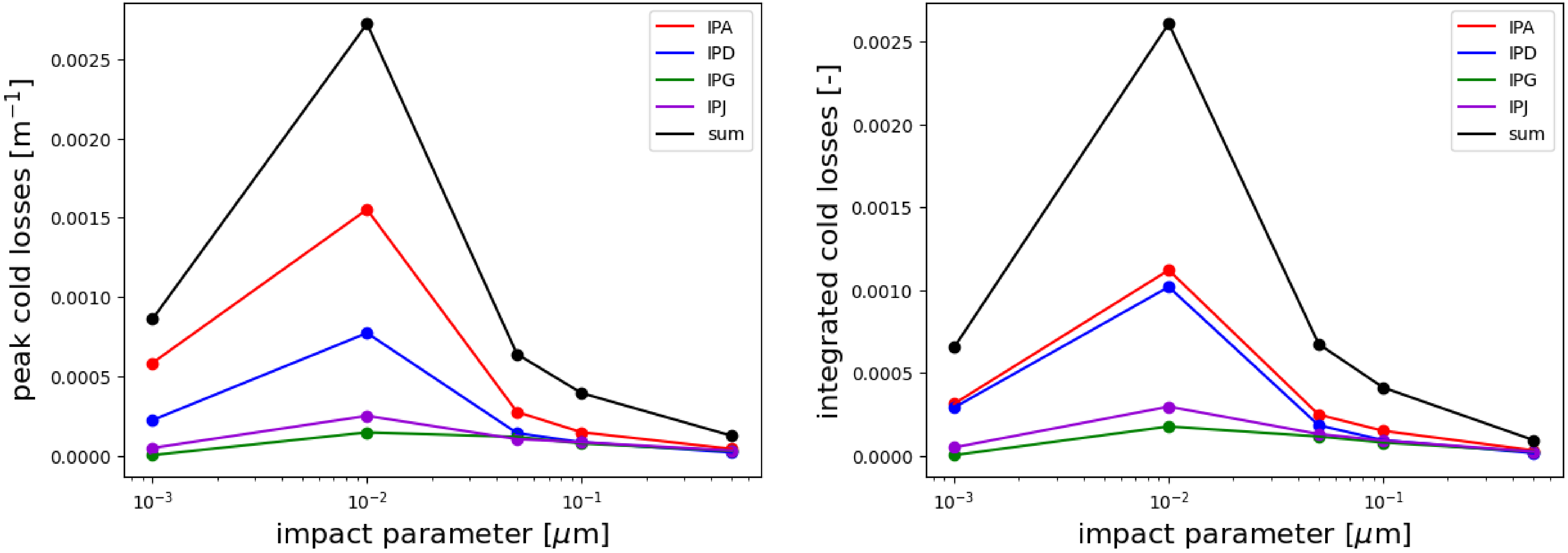
Z mode – NO radiation and tapering



- The critical impact parameter is **b_{crit} = 10 nm ***
- The **most critical IPs** are **IPG** and **IPJ** (the one downstream of the collimation insertion, located in PF)
- **Second-turn effects** likely determine the decrease for the smallest impact parameter

*** 10 nm is at the level of a grain size: surface roughness should be taken into account!**

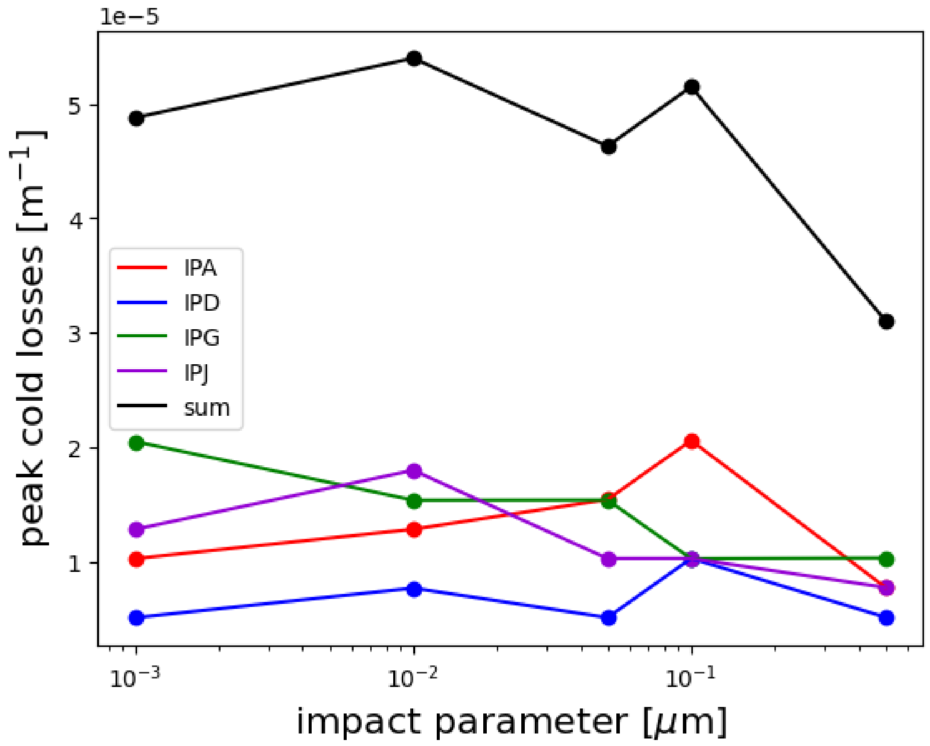
Z mode – radiation and tapering

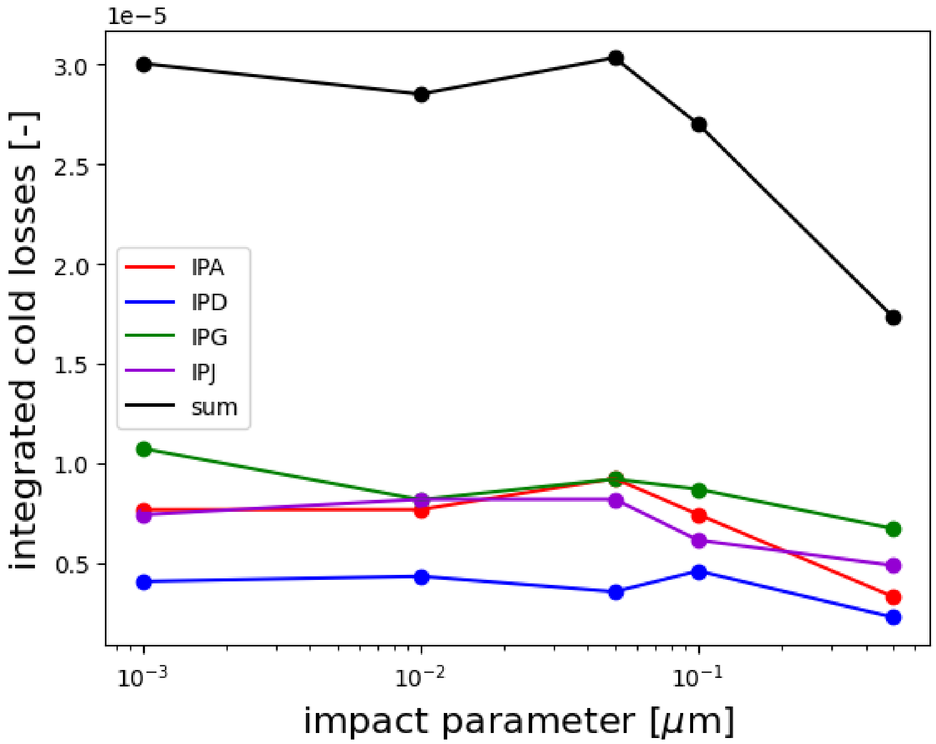


- The critical impact parameter is **b_{crit} = 10 nm *** (as without radiation and tapering)
- With **radiation and tapering losses** are **higher** (opposite to tt)
- The **most critical IPs are IPA** and **IPD** (the farther from the collimation insertion, located in PF)
- The effects of radiation and tapering on this scenario must be studied

*** 10 nm is at the level of a grain size: surface roughness should be taken into account!**

Z mode – radiation and tapering + tilted TCP.H.B1

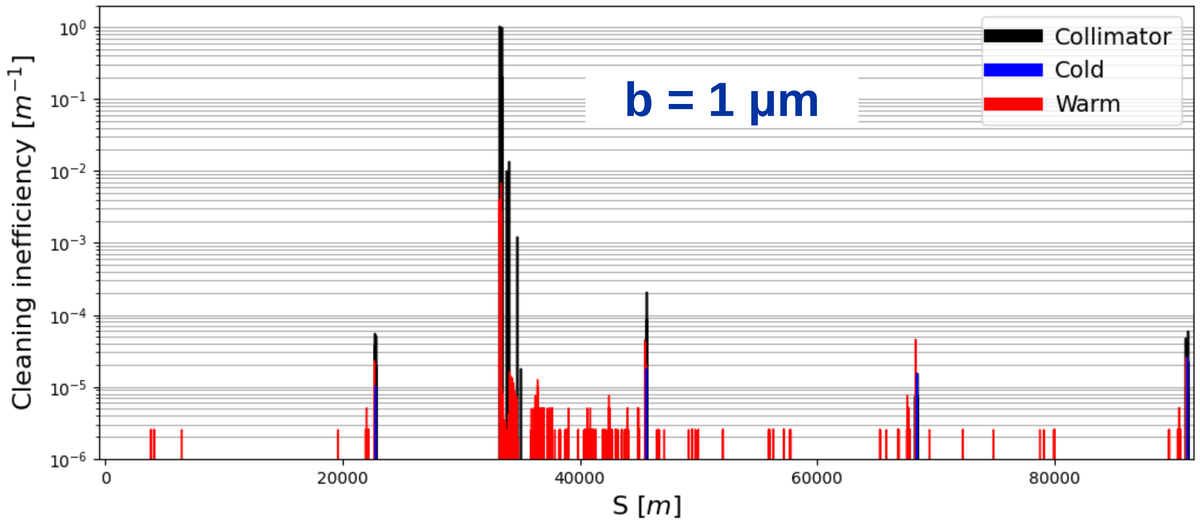


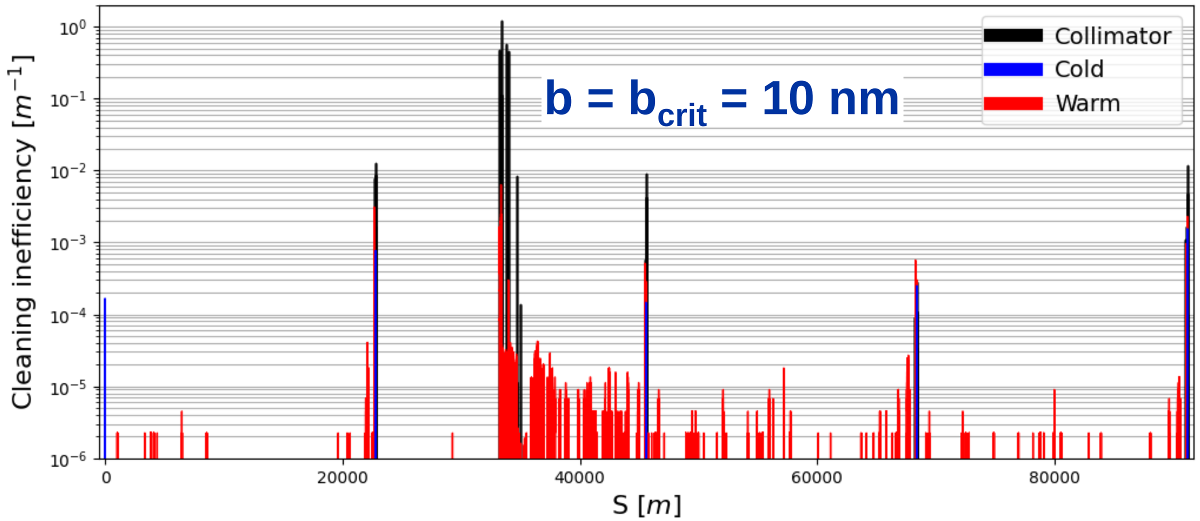


- The critical impact parameter is b_{crit} **= 10 nm *** (not very sharp, statistical fluctuations can play a role)
- **Aligning TCP.H.B1 to the beam divergence** leads to **significantly better cleaning performance** (more than 2 orders of magnitude) for the same impact parameter
- **NO most critical IPs**

*** 10 nm is at the level of a grain size: surface roughness should be taken into account!**

Example: Z mode betatron halo loss map





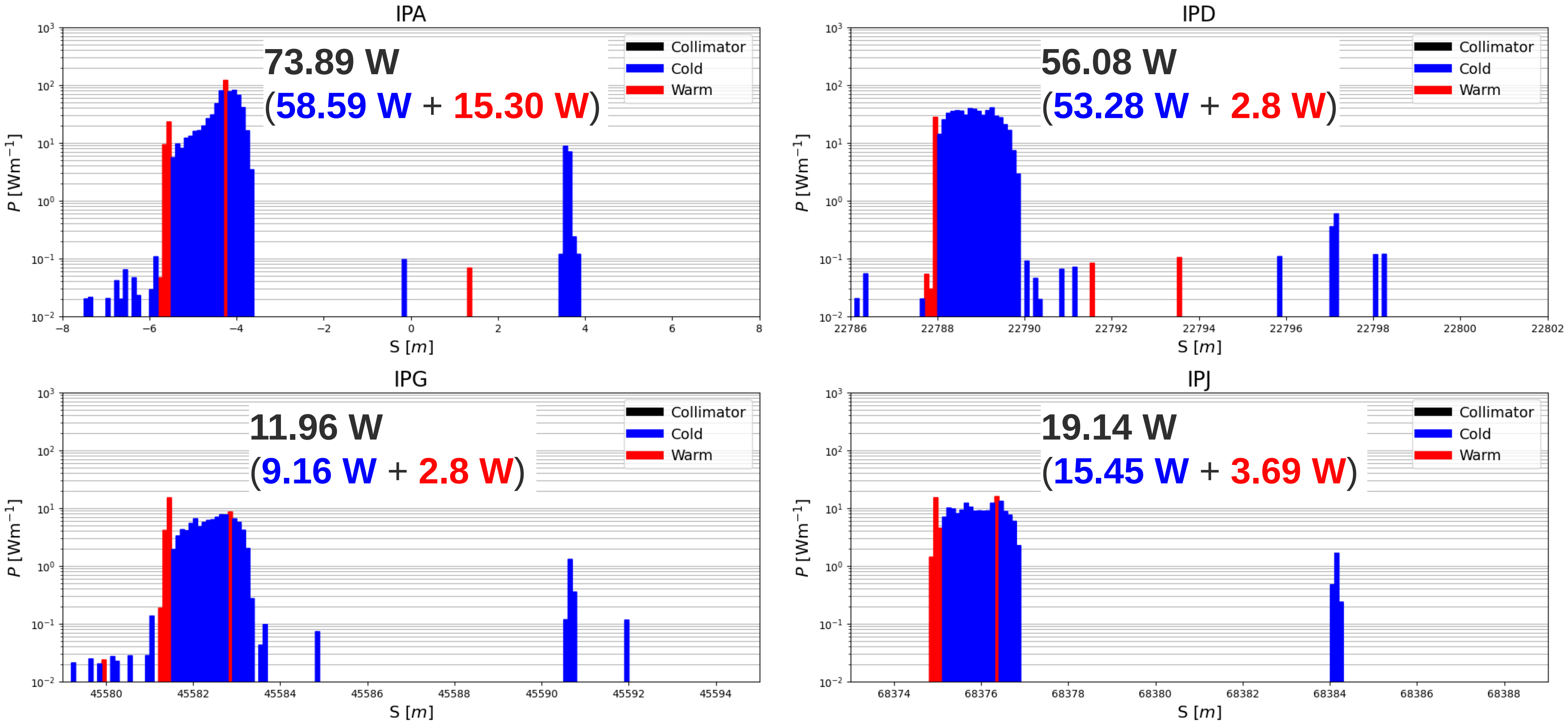
- FCC-ee 4IP layout, Z mode (B1, **45.6 GeV** positrons), **17.8 MJ** stored beam energy
- Untilted TCP.H.B1
- **b = 1 µm** has been used as **standard in the studies so far**
- **Significant increase in the losses at the critical impact parameter!**

Note: Further checks of the beam dynamics and modelling techniques should be carried out before selecting a new impact parameter for future studies.

SUPPRESSION OF POWER LOADS IN THE IRs

Z mode – radiation and tapering

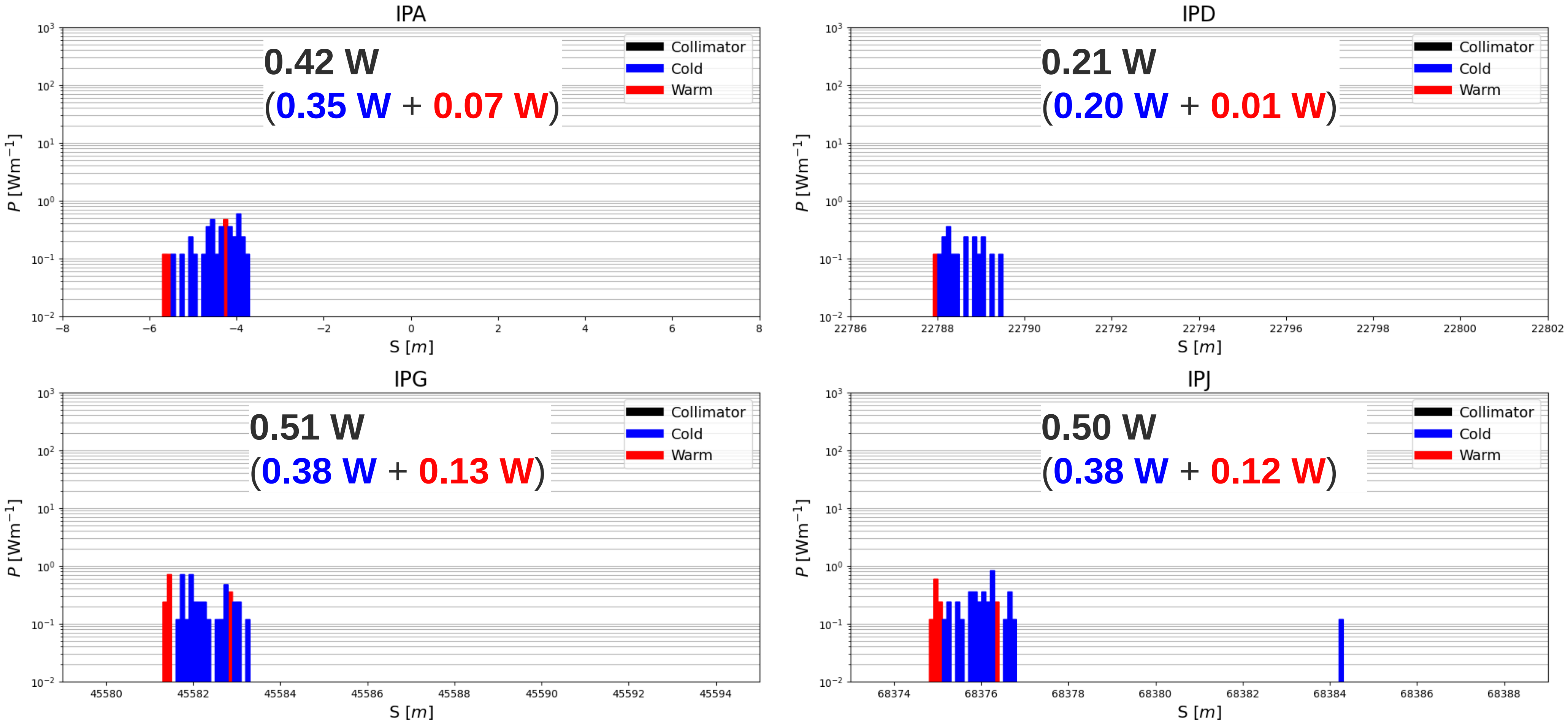
- Impact parameter **b_{crit} = 10 nm**, **5 min lifetime** assumed



- **161.06 W power load** in the IRs (**136.47 W** + **24.59 W**)

Z mode – radiation and tapering + tilted TCP.H.B1

- Impact parameter $\mathbf{b_{crit}}$ **= 10 nm**, **5 min lifetime** assumed



- **1.64 W power load** in the IRs (1.31 W + 0.33 W)

PARAMETRIC SCAN OF THE PRIMARY COLLIMATOR LENGTH (tt mode)

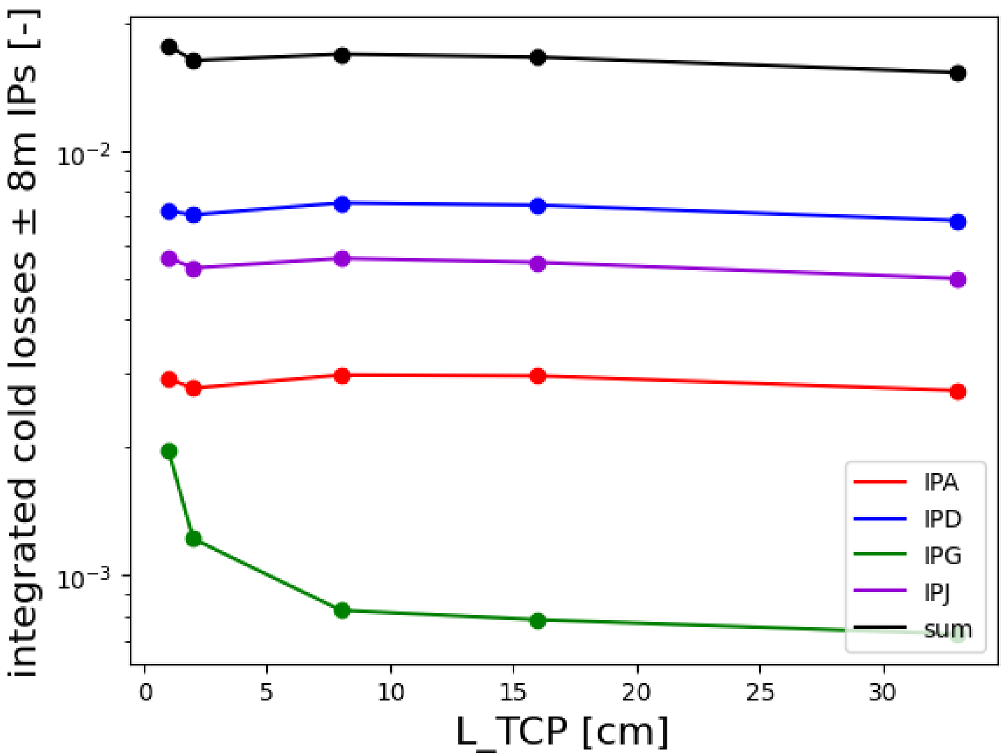
PRELIMINARY!

Parametric scan of the TCP length (tt mode)

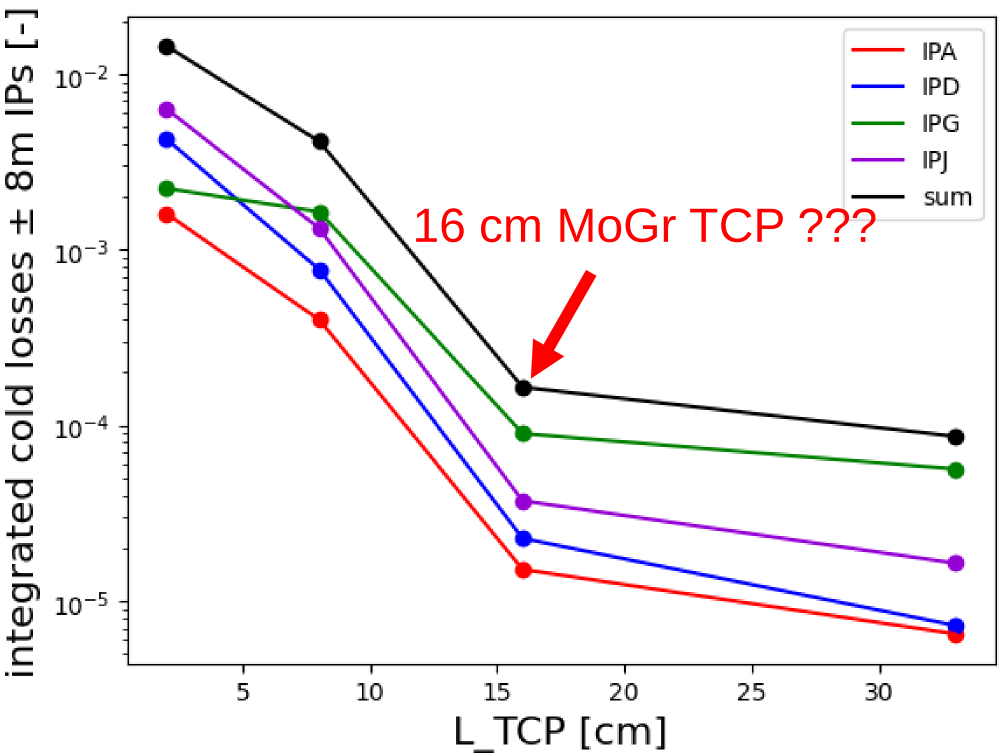
- **Current TCP length** relies on the **LEP collimation experience** (2 rad. length primary collimators)
- **Primary collimators** give a **significant contribution to the global RF impedance**
  - They are the collimators **closest to the circulating beam** ✖
  - Because of **robustness requirements**, they are typically made of **low-density** and **low electrical conductivity materials** (e.g., MoGr) ✖
  - **Low-density** translates into **high radiation length**; therefore, if the design criterion requires that a certain number of radiation lengths is needed, this could lead to **long collimators** ✖
- **Parametric scan of the TCP length** performed with the aim of observing the **behaviour of the halo collimation system performance as a function of the primary collimator length**
- **Xtrack-BDSIM simulation setup** used to perform this study
- **Goal:** reduce as much as possible the TCP length without significantly worsening the halo collimation system cleaning performance

Parametric scan of the TCP length (tt mode)

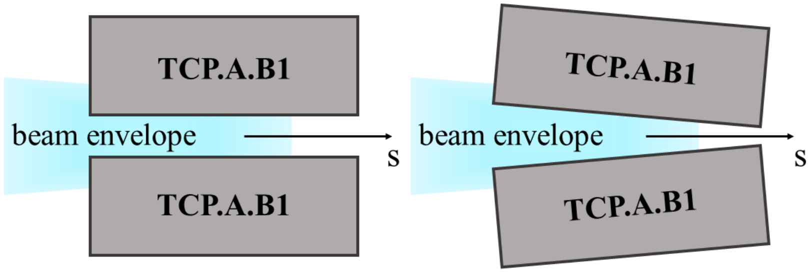
TCP.H.B1 parallel to the closed orbit



TCP.H.B1 aligned to the beam envelope



- **To check**: behaviour with the **Z lattice**



SUMMARY AND NEXT STEPS

Summary

- The **halo collimation system performance** has been **evaluated** for **FCC-ee 4IP** lattice (**Z** and **tt**)
- An **impact parameter scan** identified the **most critical impact parameter in different scenarios**
- The **collimator jaws need to be aligned to the beam envelope** to **significantly suppress** (**two orders of magnitude**) the **power loads in the IRs**
- **PRELIMINARY:** a parametric study of the primary collimator length suggests that **shorter TCP can give comparable cleaning performance**

Next steps

- Determine whether the **cleaning performance** offered by the halo collimation system are **adequate or not** (beam loss tolerances needed)
- **Sensitivity study** of the **collimator tilt angle**
- Investigate further the **beam dynamics determining the critical impact parameter** (including the effects of **radiation and tapering** and **dynamic aperture**)
- **Further optimize the collimator design** (alternative materials, parametric scan of secondary collimator length…)
- **Iterate the collimator design** with the engineering, impedance and FLUKA teams

Thank you!