Beam Losses in the MDI

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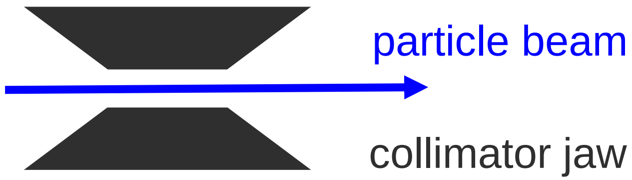
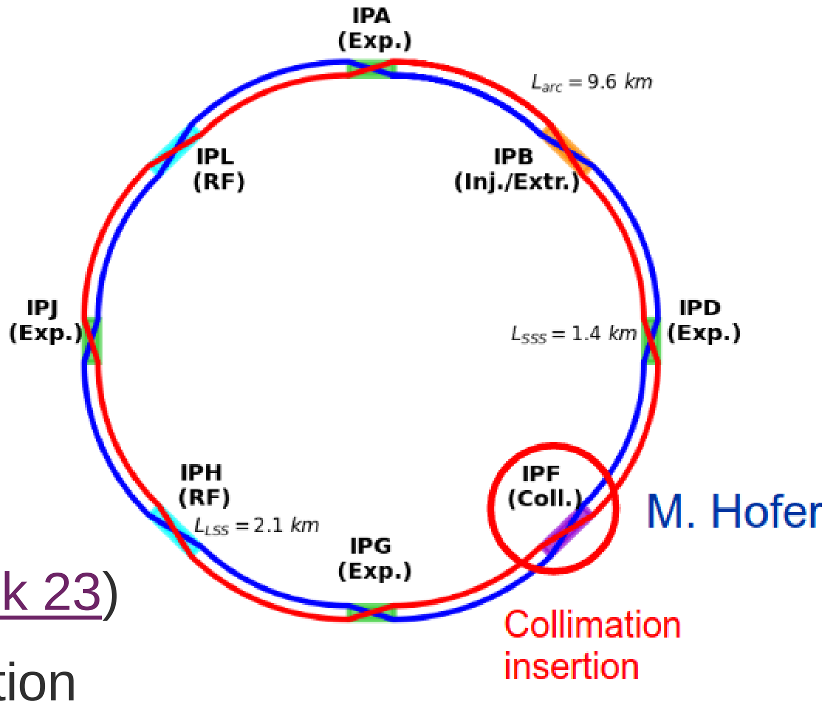
FCC-ee: collimation system requirements

- **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**





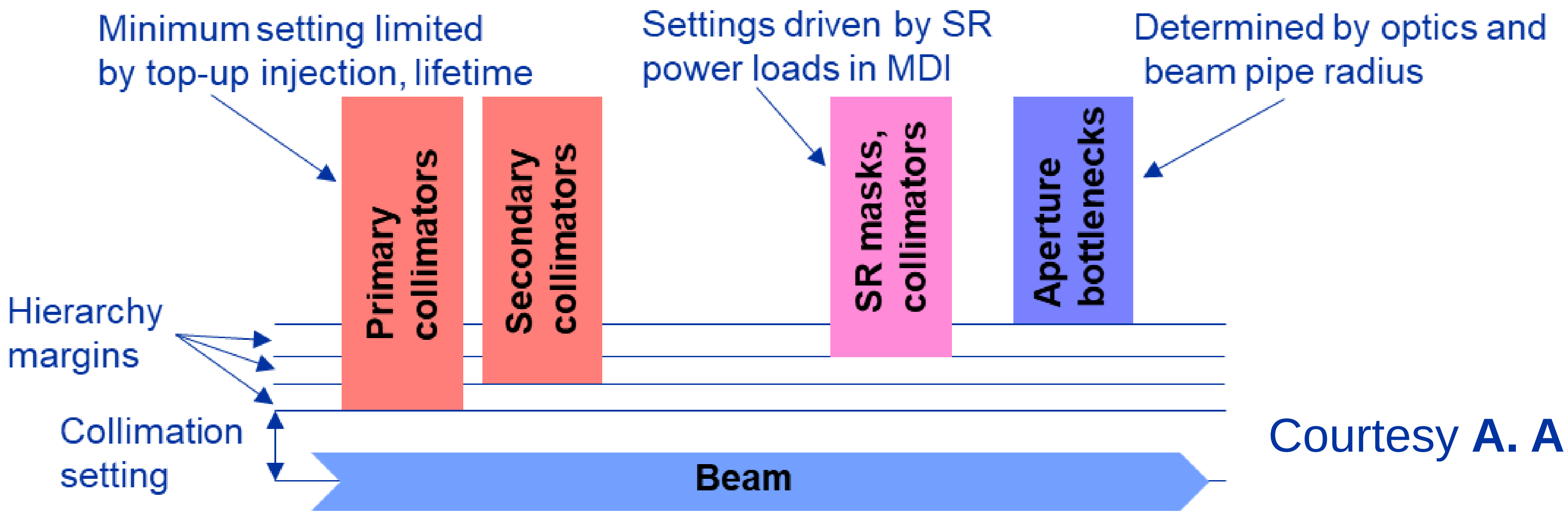
- **Dedicated halo collimation system in PF** (A. Abramov – FCC week 23)
  - ➢ Two-stage betatron and off-momentum collimation in one insertion
  - ➢ **First collimator design for beam cleaning performance** (G.Broggi – Master's thesis)
    - ▪ Primary collimators (TCPs): MoGr – 33 cm
    - ▪ Secondary collimators (TCSs): Mo – 30 cm

Further optimization studies ongoing (materials, length)

- **Synchrotron radiation collimators around the Interaction Points (IPs)** (K. André – FCC week 23)

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**

Goals

- **Evaluate the halo collimation system performance for beam loss cleaning**
  ↔ evaluate beam losses in the Machine Detector Interface (MDI)
- **Study beam dynamics aspects affecting beam losses in the MDI**
- **Optimization of the halo collimator design parameters**
- **Study possible loss mitigation strategies**

In this talk

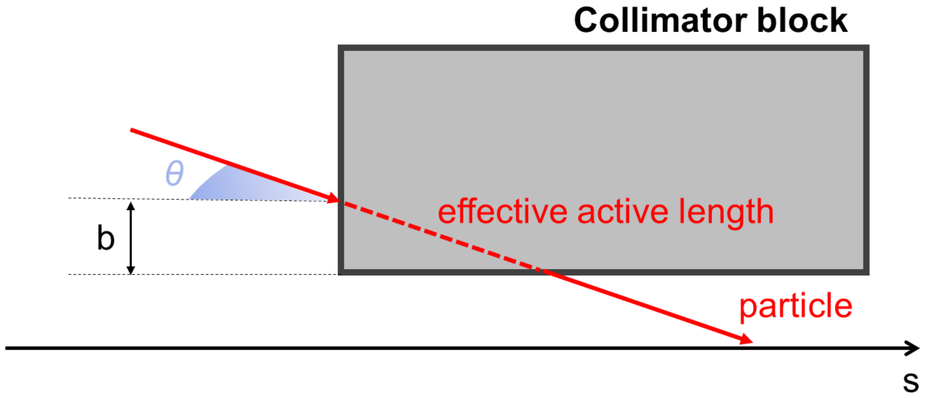
- **Evaluation of the halo collimation system performance ↔ evaluation of beam losses in the MDI**
  - FCC-ee 4IP layout (Z and ttbar) generic beam halo loss scenario
- **Collimator design optimization** through a **parametric scan of the primary collimator length**
  - FCC-ee 4IP layout (Z and ttbar)
- **Impact parameter scan for different scenarios**
  - FCC-ee 4IP layout (Z and ttbar)
  - Without and with radiation and tapering
  - Without and with collimators aligned to the beam envelope (loss mitigation strategy)

SIMULATION SETUP

Case study: beam halo losses

- **Tracking simulations** (**Xtrack-BDSIM**) to evaluate beam losses in the MDI
- **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
θ: angle of incidence



critical impact parameter

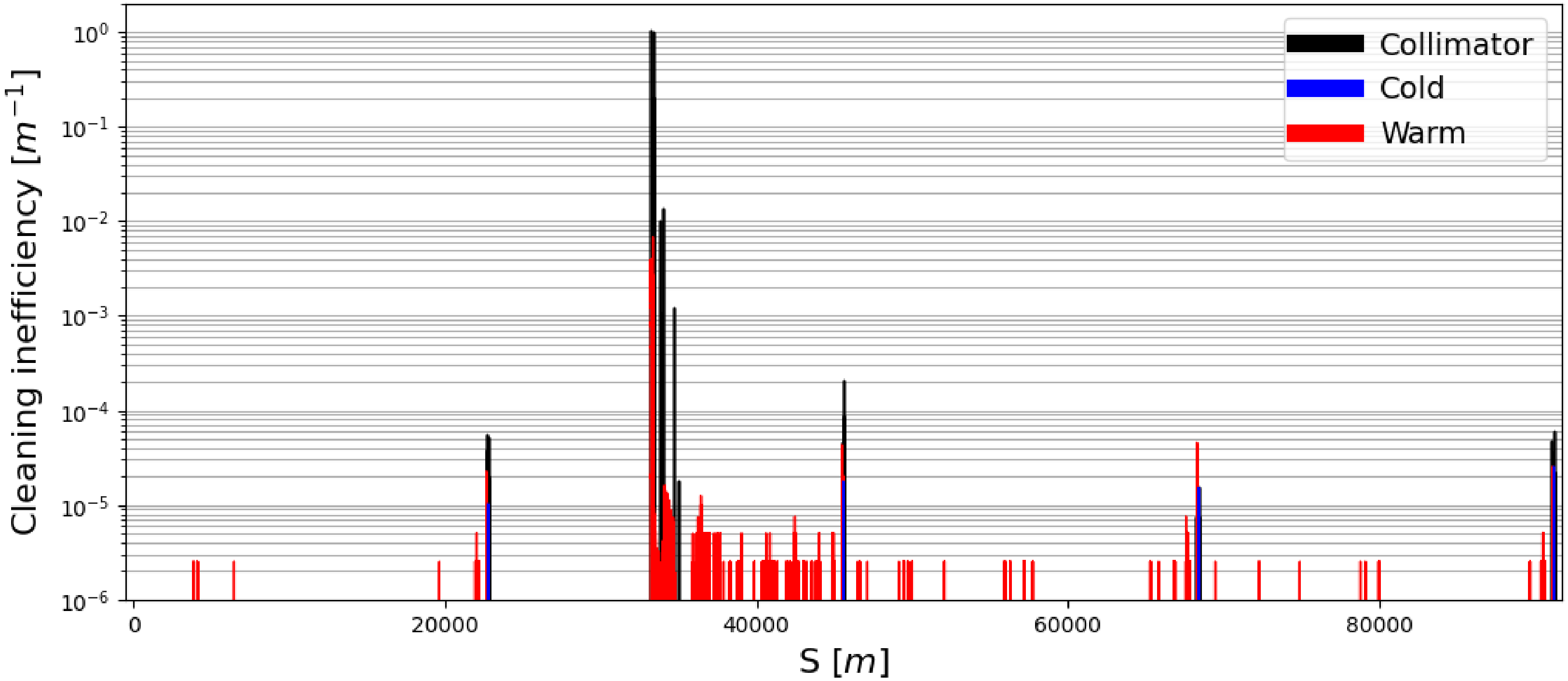
↕

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
- **Impact parameter b = 1 μm** (standard used in the studies so far)
- Particles scattered out from TCP.H.B1 tracked for **700 turns**
- Synchrotron radiation emission and lattice tapering



PARAMETRIC SCAN OF THE PRIMARY COLLIMATOR LENGTH

Parametric scan of the TCP length: motivation

- **Current TCP length** relies on **LEP collimation experience** (G. von Holtey - article)
  - Two radiation-length primary collimators (TCP)

- **Primary collimators** give a **significant contribution to the global RF impedance**

  - They are the collimators **closest to the circulating beam**

  - Because of **robustness requirements** for the FCC-ee, need to consider **low-Z materials** with a **lower electrical conductivity** (e.g., MoGr)

  - **Low-Z** 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**

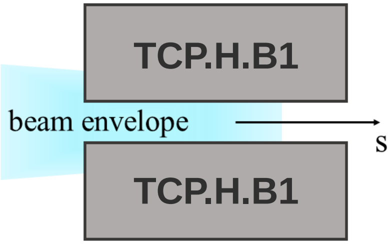
Goal

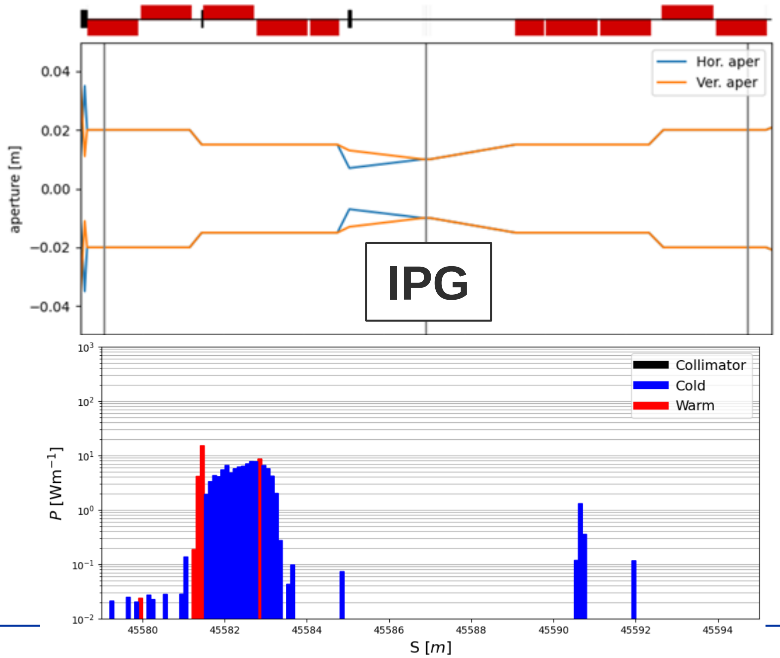
- reduce as much as possible the TCP length without significantly worsening the cleaning performance ↔ without significantly increasing beam losses in the MDI

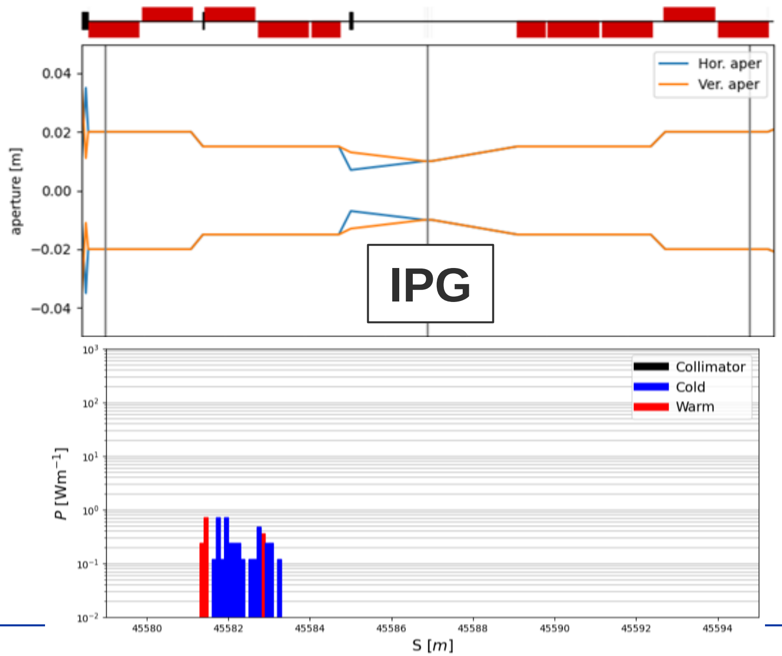
Parametric scan of the TCP length

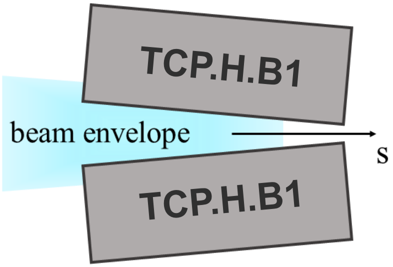
- **Xtrack-BDSIM simulation setup** used to perform this study
- **FCC-ee 4IP** layout (**Z** and **ttbar** operation modes)
- **Figure of merit**: **cold power loads ± 8 m from the IPs** (i.e., power loads in the final focusing quads)
- Two scenarios
  - **TCP.H.B1 parallel to the closed orbit**
  - **TCP.H.B1 aligned to the beam envelope** (loss mitigation strategy) - "**tilted TCP.H.B1**"

s range considered most critical for MDI losses (region in between the SR collimators closest to the IPs)







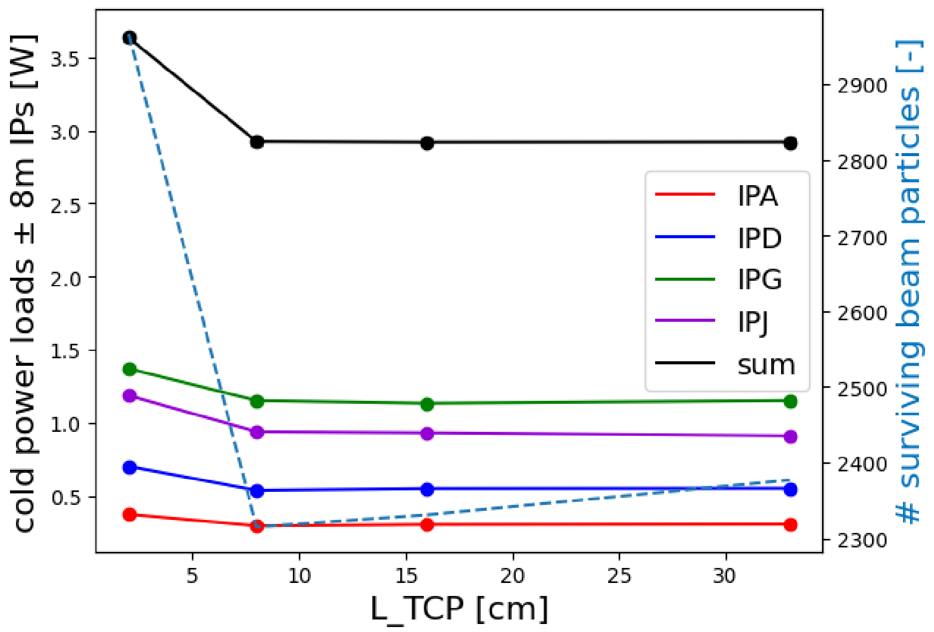


Parametric scan of the TCP length (ttbar mode)

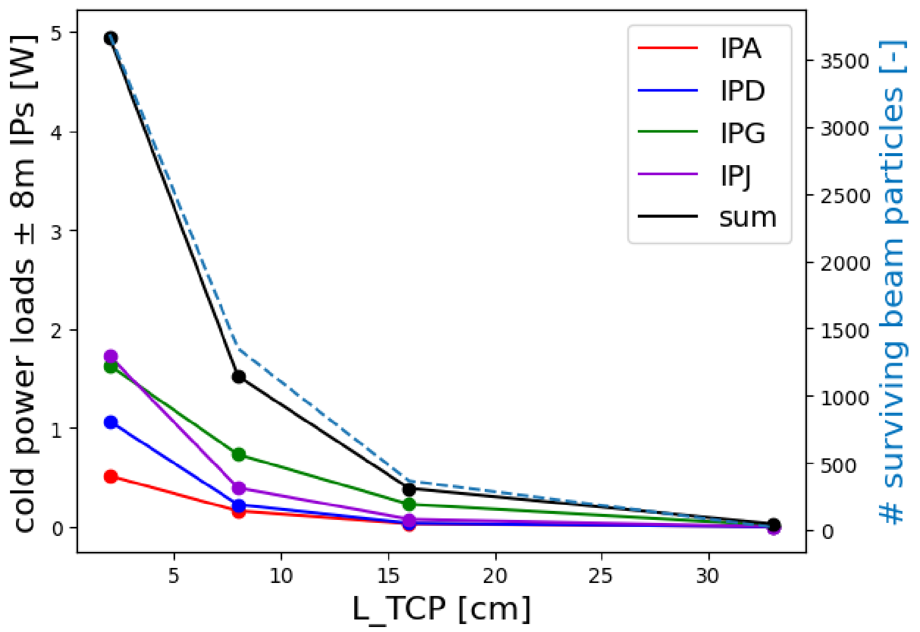
To compute the **cold power loads in the MDI**, **5 min beam lifetime** assumed.

Impact parameter
b=1 μm

TCP.H.B1 parallel to the closed orbit



TCP.H.B1 aligned to the beam envelope



- **Untilted TCP.H.B1**: **NO power loads increase till $L_{TCP} \approx 2$ cm**
- **Tilting TCP.H.B1**: **lower power loads** (tilt angle = 45.68 μrad)
  - ➢ **Power loads in the MDI increase exponentially as L_{TCP} is decreased**

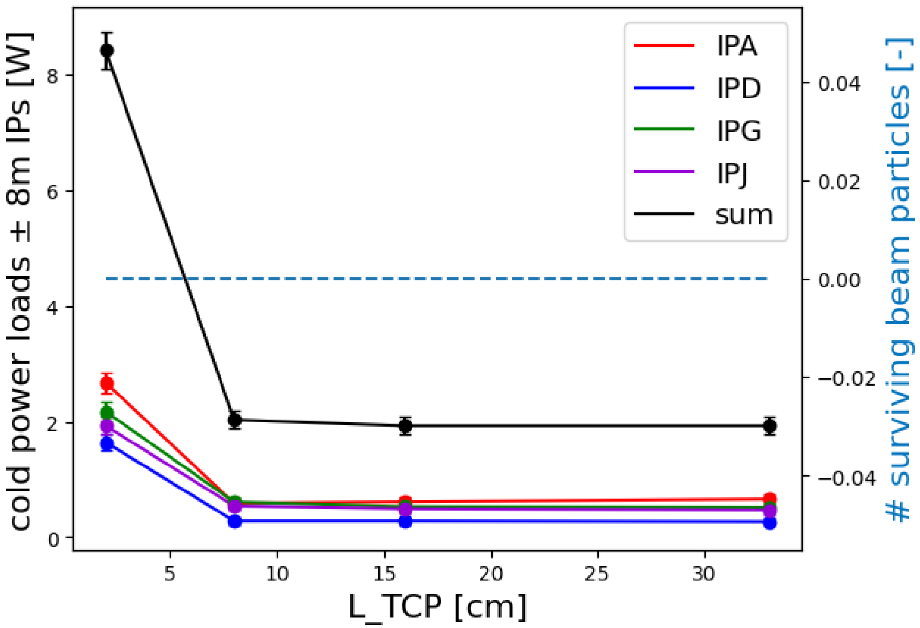
* 2 cm is roughly the distance traversed by primary particles through an untilted collimator jaw (ttbar mode)

Parametric scan of the TCP length (Z mode)

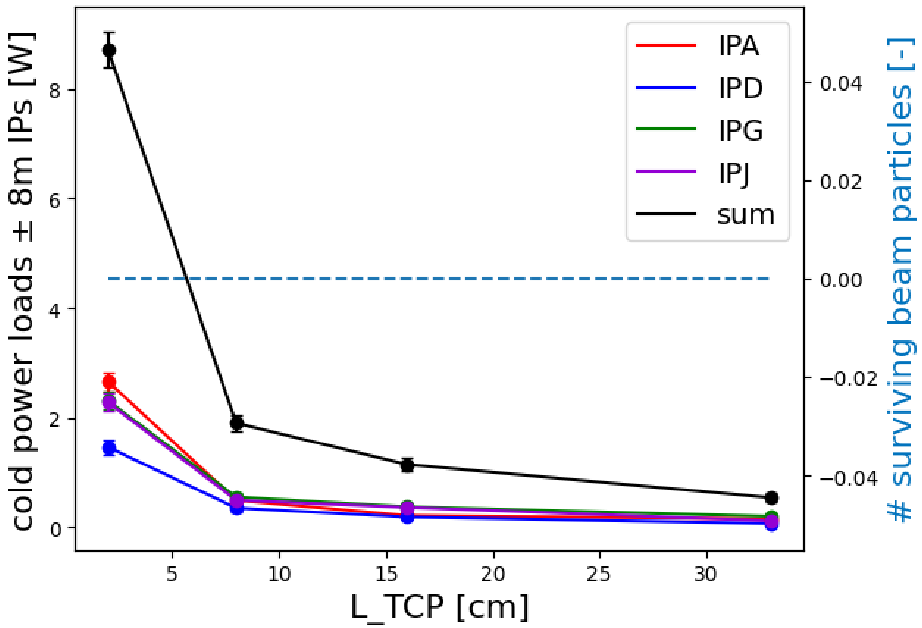
To compute the **cold power loads in the MDI**, **5 min beam lifetime** assumed.

Impact parameter
b=1 μm

TCP.H.B1 parallel to the closed orbit



TCP.H.B1 aligned to the beam envelope



- **Untilted TCP.H.B1**: **NO power loads increase till L_{TCP} = 8 cm**
- **Tilting TCP.H.B1**: **NO significant reduction of the power loads** (tilt angle = 9.69 μrad)
  - **Power loads in the MDI increase exponentially as L_{TCP} is decreased**

* 8 cm is roughly the distance traversed by primary particles through an untilted collimator jaw (Z mode)

IMPACT PARAMETER SCAN

Impact parameter scan

- Scan to determine the **loss cleaning performance as a function of the impact parameter**
- FCC-ee 4IP layout
  - **ttbar operation mode**(B1, **182.5 GeV** positrons, **0.3 MJ** stored beam energy)
  - **Z operation mode** (B1, **45 GeV** positrons, **17.8 MJ** stored beam energy**)**
- **Nominal primary collimator length** (33 cm)
- Different scenarios examined:

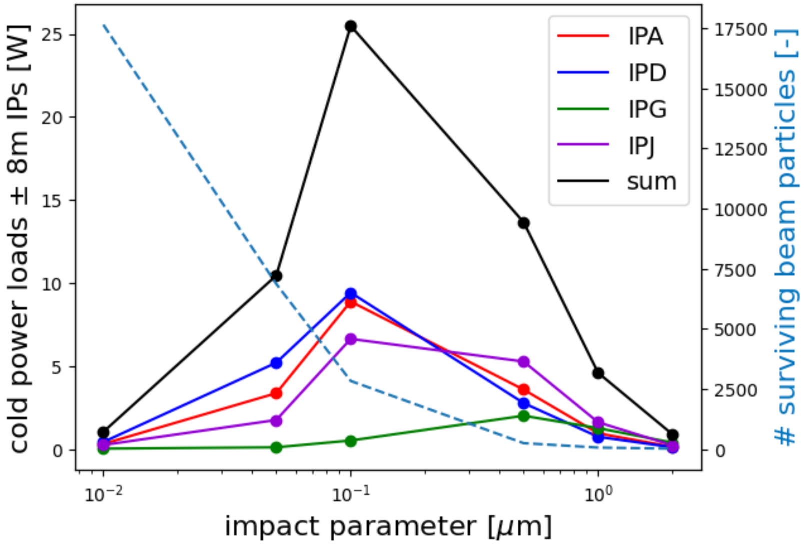
	SR emission	lattice tapering	tilted TCP.H.B1
NO R&T	✘	✘	✘
R&T	✔	✔	✘
R&T + tilted TCP.H.B1	✔	✔	✔

- **Figure of merit**: **cold power loads ± 8 m from the IPs** (i.e., power loads in the final focusing quads)

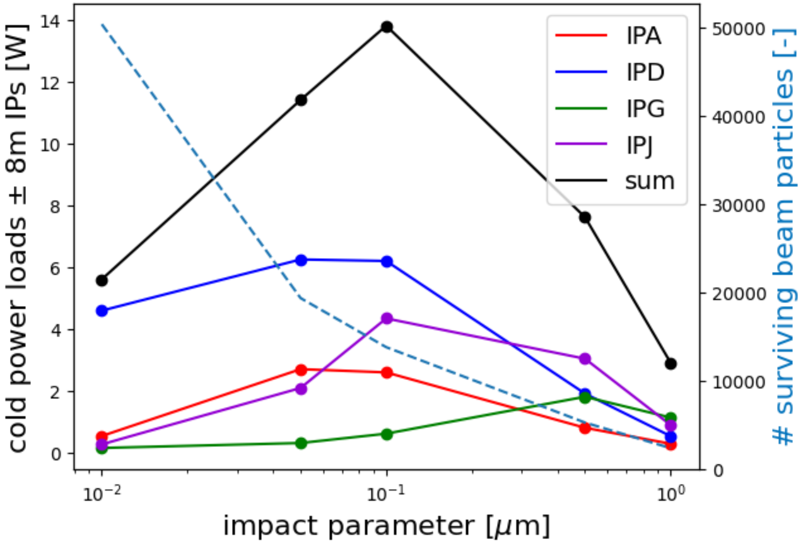
Impact parameter scan (ttbar mode)

Nominal TCP length
L_{TCP}=33 cm

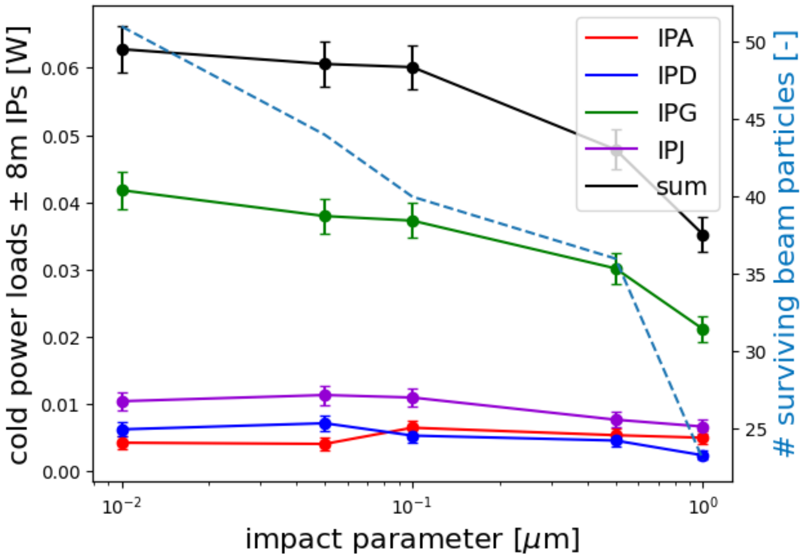
NO radiation and tapering



radiation and tapering



radiation and tapering + tilted TCP.H.B1

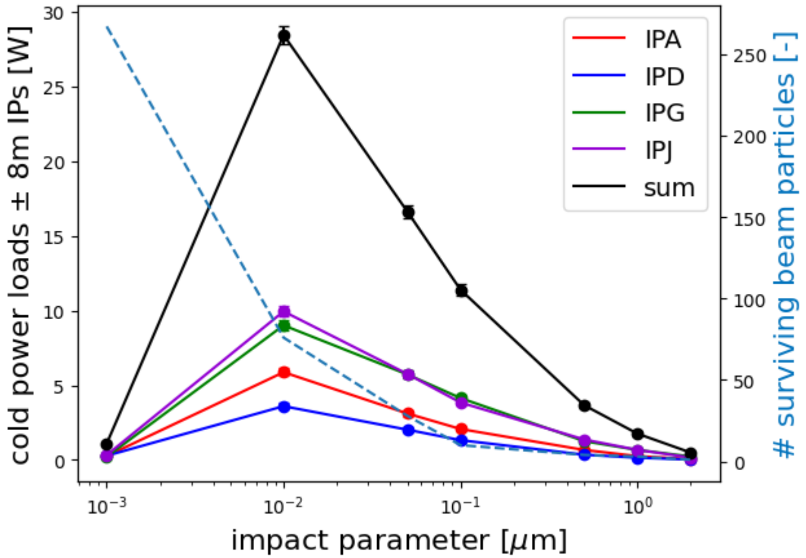


- Critical impact parameter **b_{crit} = 0.1 μm**
  - ➢ With this impact parameter, **power loads in the MDI are a factor of ≈5 higher**
- **Tilting TCP.H.B1: power loads suppression** (**≈2 orders of magnitude**) for all impact parameters
  - ➢ NO clear critical impact parameter b_{crit}
- With **radiation and tapering, lower power loads in the MDI**
  - ➢ Likely due to a **reduction of aperture losses** because of **radiation damping**

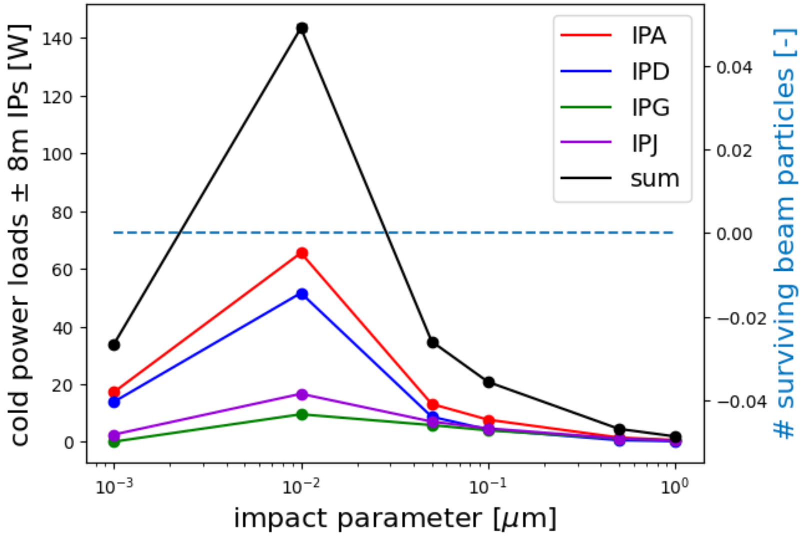
Impact parameter scan (Z mode)

Nominal TCP length
L_{TCP}=33 cm

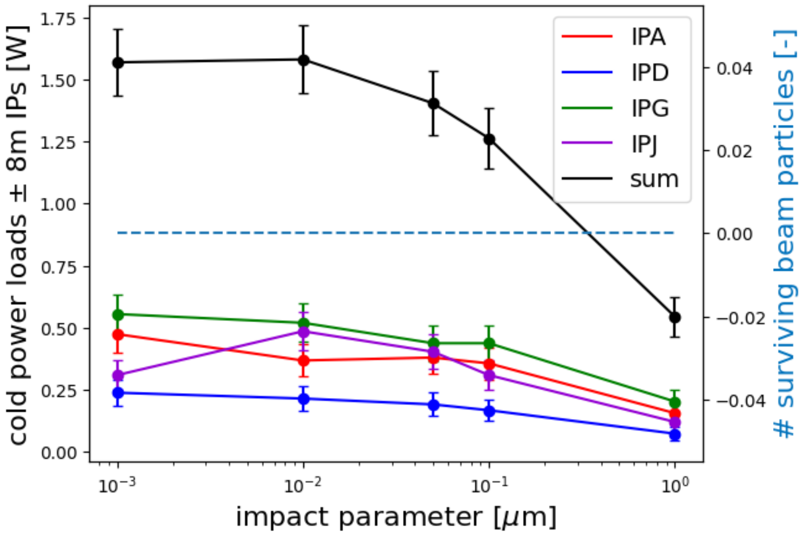
NO radiation and tapering



radiation and tapering



radiation and tapering + tilted TCP.H.B1



- Critical impact parameter **b_{crit} = 10 nm** (surface roughness should be considered **!**)
  - ➢ With this impact parameter, **power loads in the MDI are 2 orders of magnitude higher**
- **Tilting TCP.H.B1**: **power loads suppression** (**2 orders of magnitude**) at **b=b_{crit}**
  - ➢ However, no significant improvements are observed for higher impact parameters
  - ➢ NO clear critical impact parameter b_{crit}
- With **radiation and tapering** → **higher power loads in the MDI** (and **no surviving particles**)
  - ➢ Likely due to an **increase of aperture losses** because of **insufficient dynamic aperture** (**DA**)

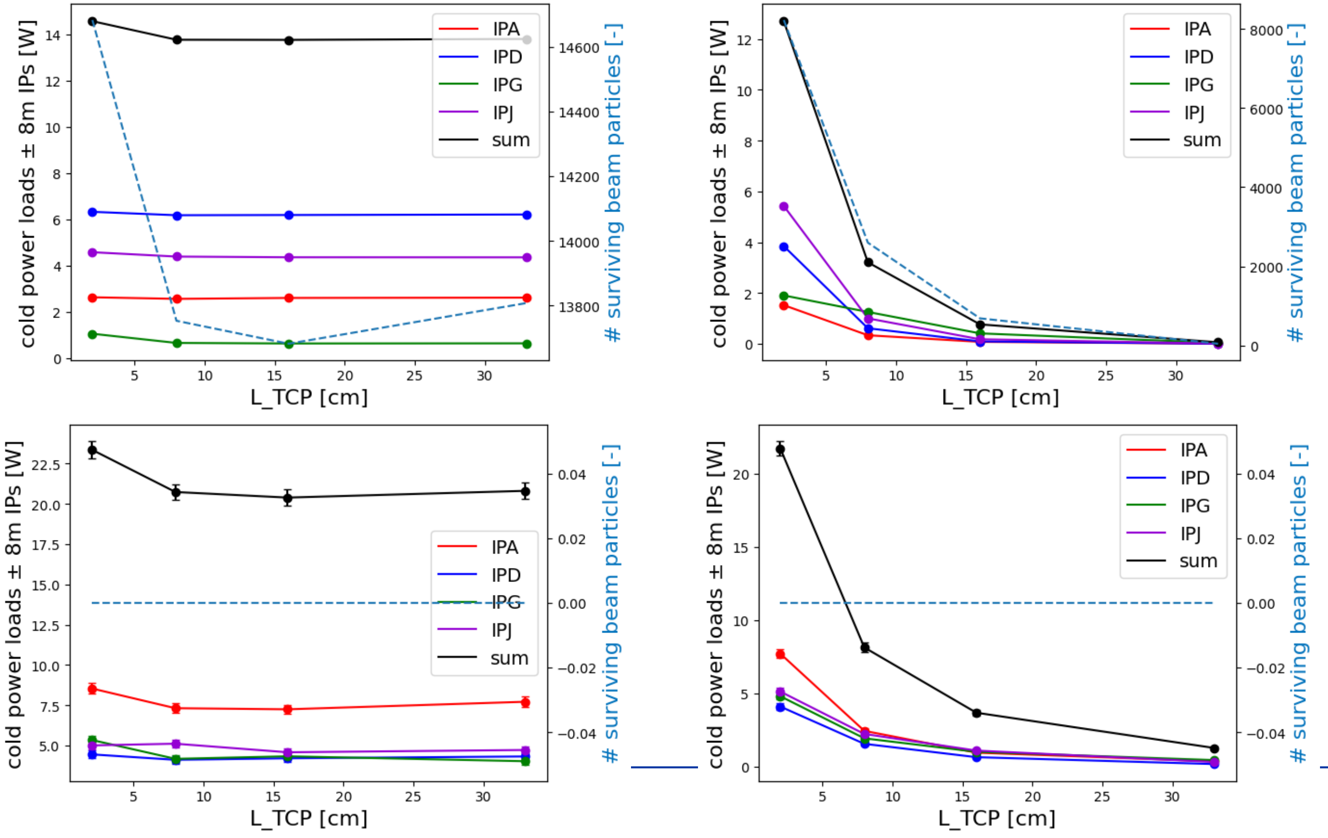
Parametric scan of the TCP length at $b=b_{crit}$

- To get **conservative power load estimates**, **$b=b_{crit}$** should be considered
  - ➢ However, **further checks** on beam dynamics and modelling techniques should be carried out **before selecting a new standard impact parameter for future studies**
- Tentatively repeated the **studies for shorter TCP** considering a smaller impact parameter **b=0.1 μm**

TCP.H.B1 parallel to the closed orbit | TCP.H.B1 aligned to the beam envelope

ttbar mode

Z mode



… Same considerations done for b=1 μm hold, but higher power load suppression observed when tilting TCP.H.B1

FUTURE CIRCULAR COLLIDER

SUMMARY AND NEXT STEPS

Summary

- **Beam losses in the MDI** been **evaluated** for **FCC-ee 4IP** lattice (**Z** and **tt**)
- A **parametric study of the primary collimator length** suggests that we can **tentatively shorten the TCP** (25-30 cm) **without significantly increasing power loads in the MDI**
- An **impact parameter scan** identified the **critical impact parameters in different scenarios** (but further studies needed before selecting a new standard impact parameter for future studies)
- The **collimator jaws need to be aligned to the beam envelope** to **significantly suppress** (**two orders of magnitude**) the **power loads in the MDI**

Next steps

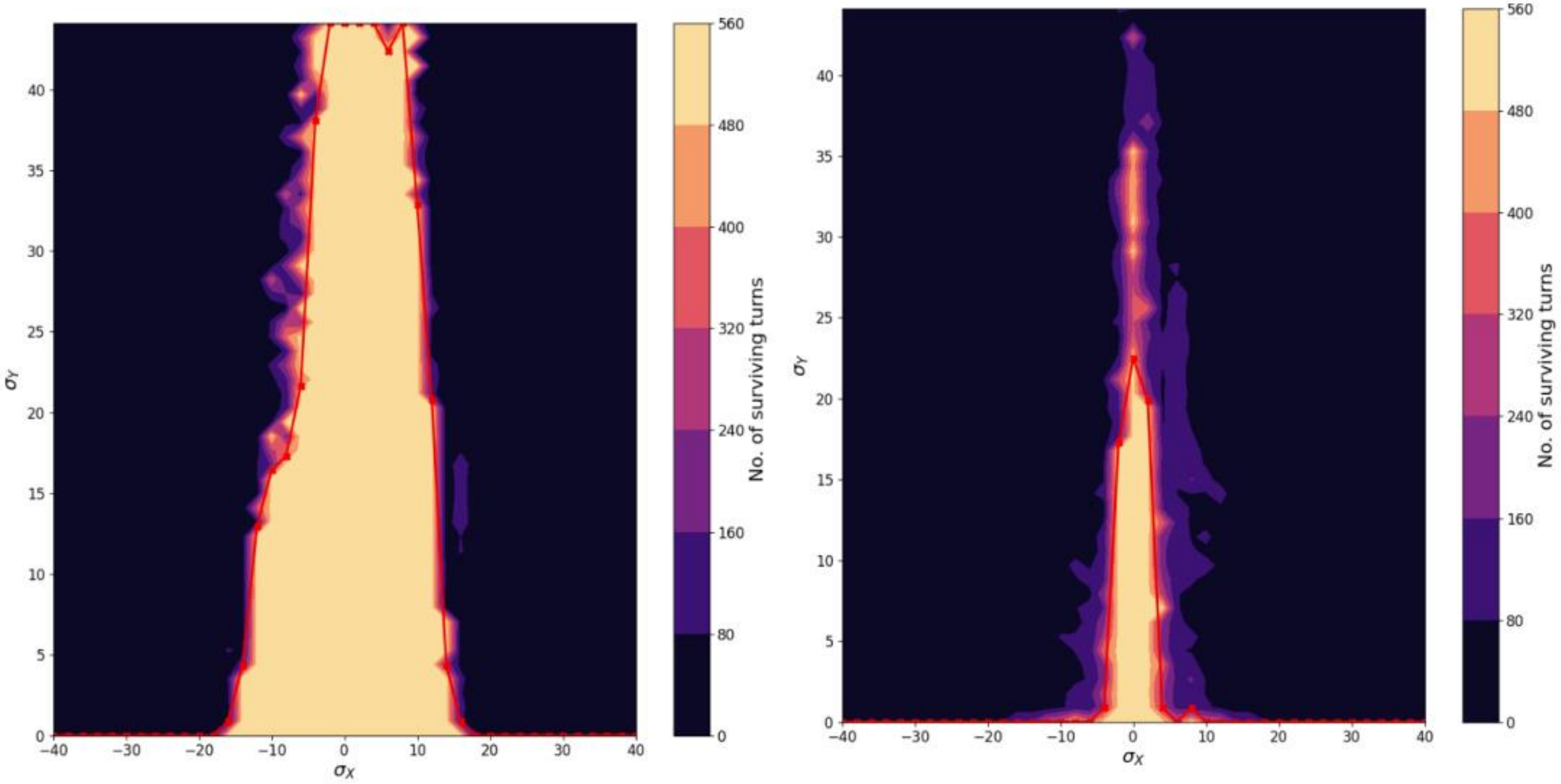
- Update the studies to the **latest available lattice** (with improved DA)
- Check if we can **further shorten the TCP – power load limits needed**
- **Further optimize the collimator design** (alternative materials, parametric scan of secondary collimator length, local TCT-like collimators? …)
- **Sensitivity study** of the **collimator tilt angle**
- **Iterate the collimator design** with the engineering, impedance and FLUKA teams

Thank you!

Backup: dynamic aperture at Z

- Full FCC-ee 4IP lattice (Z mode) - collimation insertion optics included

DA@Z – NO radiation and tapering   DA@Z – radiation and tapering



Courtesy **M.Hofer**

- Inclusion of **collimation insertion optics** has a **detrimental effect on DA** (Z, radiation and tapering)