Tracking Studies for FCC-ee Collimator Design

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Many thanks for discussions and input to:

A. Abramov, R. Bruce, F. Carra, S. Gilardoni, A. Lechner, M. Migliorati, A. Perillo-Marcone, S. Redaelli, F. Van der Veken, F. Zimmerman

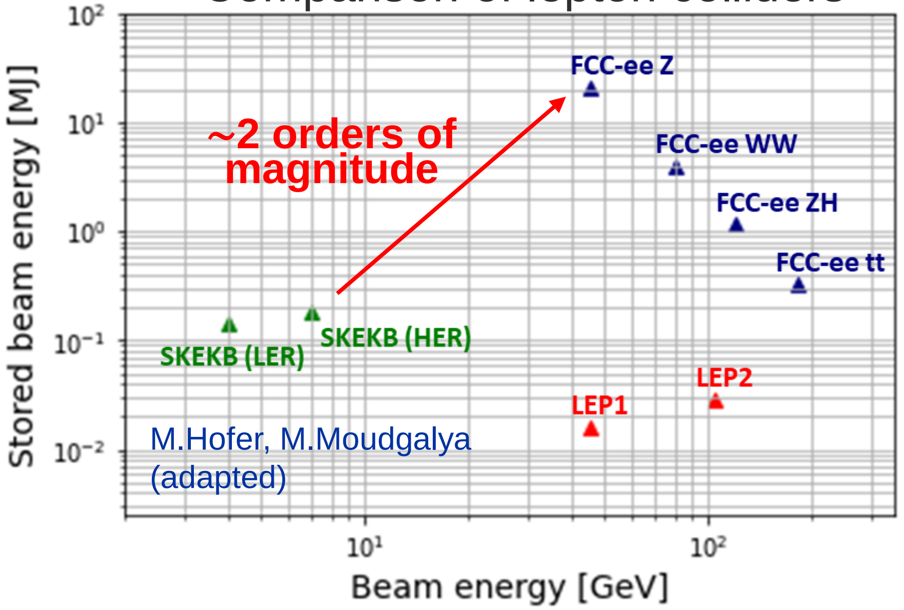
FCC-ee: collimation system requirements

- **FCC-ee** will have an **unprecedented amount of stored beam energy for a lepton collider**
  - The stored beam energy in the FCC-ee reaches **20.7 MJ**, which is comparable to the heavy-ion operation at the LHC
  - Such beams are **highly destructive**

⇨ A suitable **collimation system is indispensable!**

- The **main requirements** for the collimation systems are:
  - **Protect the machine from unavoidable losses**
  - **Reduce the background in the experiments**
- The current focus is on the **beam halo collimation**
- **Collimator design** and **tracking studies** are **key aspects**

Comparison of lepton colliders



- The **starting assumption** is given by the **LHC collimator geometry**
  - Two-stage betatron collimation insertion in IRF
  - #2 60cm Carbon Fiber Composite (CFC) primary collimators (TCPs)
  - #4 100cm Carbon Fiber Composite (CFC) secondary collimators (TCSs)

… but FCC-ee is a quite different machine compared to the LHC!

FCC-ee: first guess on collimator design

- Relying on:
  - **LEP experience**
  - **(approximated) analytical considerations** (see [158th FCC-ee Optics Design Meeting talk])

⇨ **first guess*** for **FCC-ee collimator design parameters** identified

Collimator	Type	Plane	Material	Length [m]	Opening [σ]
TCP.A.B1	Prim.	H	MoGr	0.33	10
TCP.B.B1	Prim.	V	MoGr	0.33	80
TCS.B1.B1	Sec.	V	Mo	0.30	89.5
TCS.A1.B1	Sec.	H	Mo	0.30	11.5
TCS.A2.B1	Sec.	H	Mo	0.30	11.5
TCS.B2.B1	Sec.	V	Mo	0.30	89.5

TCPs: MoGr - 2.8 r.l. (33cm)
TCSs: Mo - 30 r.l. (30cm)

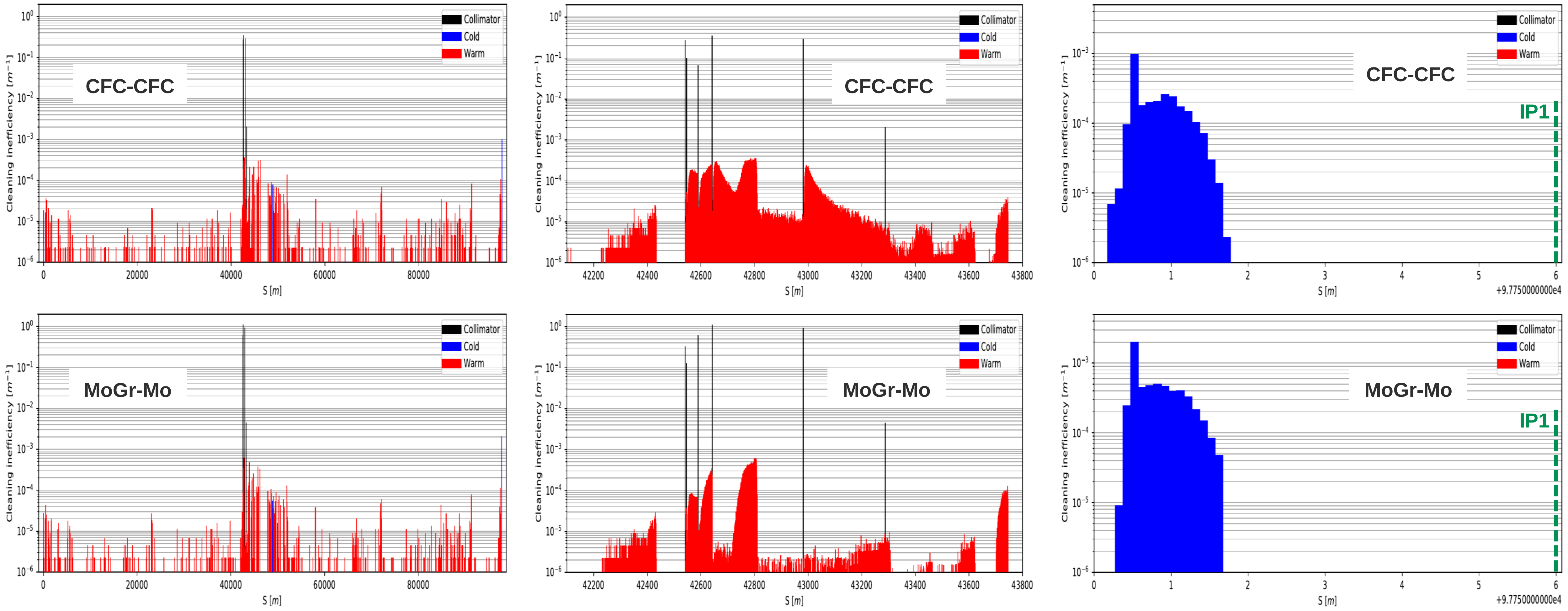
- First **tracking simulations** to evaluate the collimation system cleaning performance (and compare them to the starting assumption design ones) carried out with **Xtrack-BDSIM**
- **FCC-ee 2IP optics and layout without radiation and tapering**, **tt operation mode**
- Betatron collimation only
- $5x10^6$ primary positrons, 700 turns, 1μm impact parameter

***preliminary**, expect further iterations on collimator material and length! R&D ongoing, e.g., **high conductivity CFC!**

SIMULATION RESULTS

Starting assumption vs. proposed configuration

full ring | collimation insertion | IP1



Loss maps comparison

- **Significant losses** are observed in **IP1** in both cases
- The **cleaning efficiency** for the **MoGr-Mo configuration** is **overall very similar to the starting assumption one**, however, the overall **«impedance cost» has been reduced**

	CFC	MoGr	Mo
RFI	0.38	1	4.4

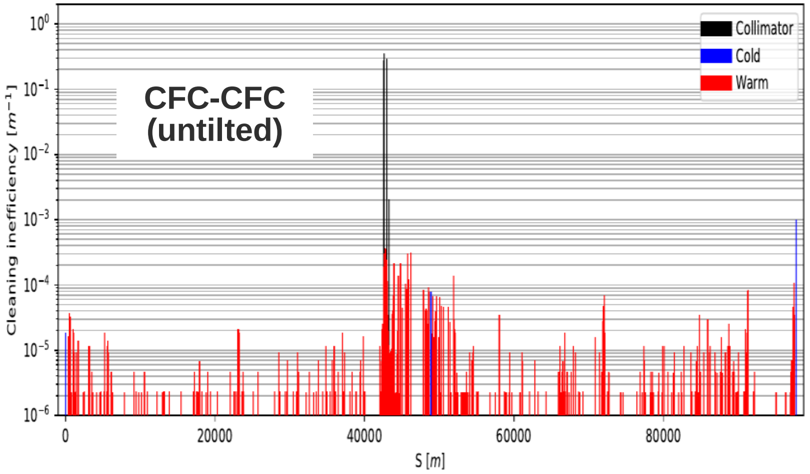
Note: The higher the RFI is the lower is the contribution of the material to the RF impedance

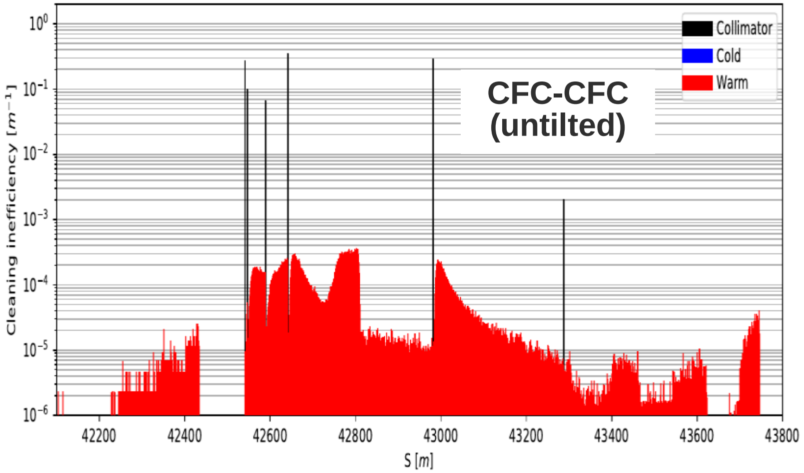
- The effective collimator active length is shorter for particles with large angles and small impact parameters (see FCC week 2022 talk, A. Abramov)
- **Solutions**: adjust the optics, **tilted jaws** (recently implemented in BDSIM, see talk by A. Abramov)

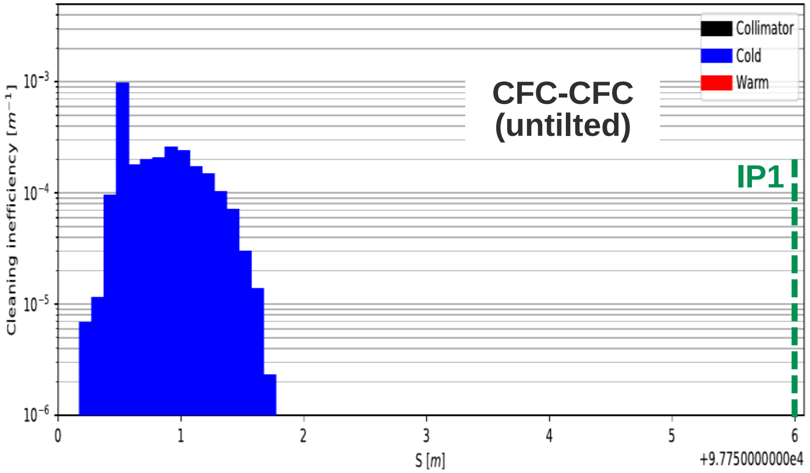
- **Losses in collimators** are very similar for the two configurations
- **Losses within the collimation insertion** are **lower** for the **MoGr-Mo configuration**
- Including **radiation & tapering** same considerations hold but losses are higher along the whole ring (see impact parameter scan, next slides)

Tilted jaws: starting assumption vs. proposed config.

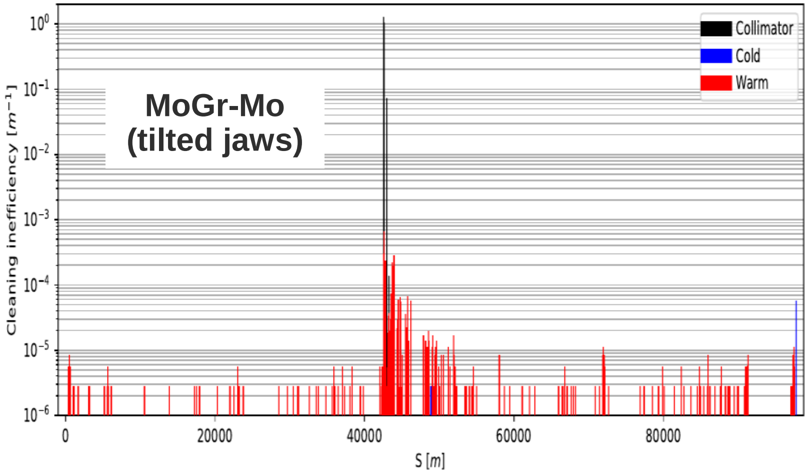
full ring | collimation insertion | IP1

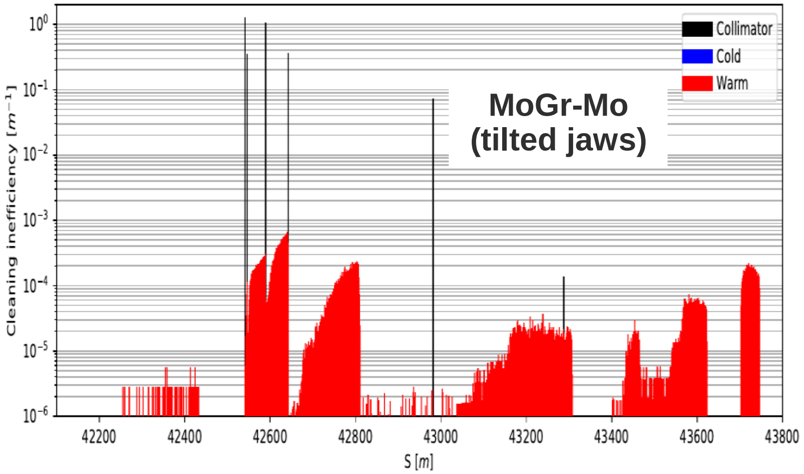


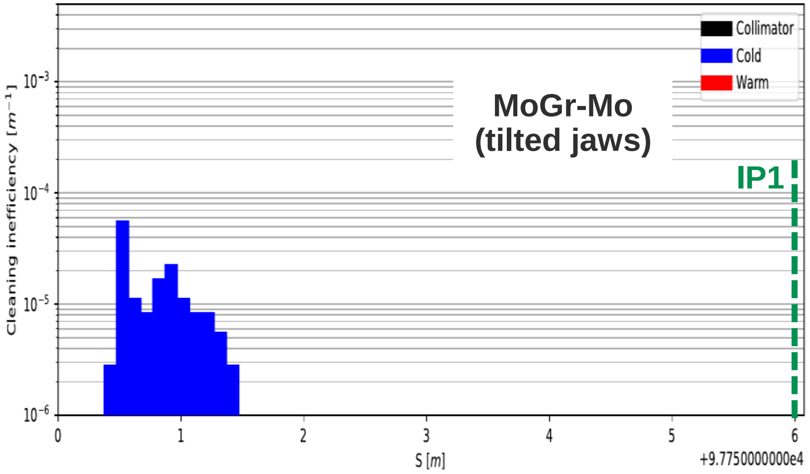




horizontal TCP (TCP.A.B1) tilted by 66.7 urad to match the beam divergence:







Tilted jaws: loss maps comparison

- As expected, by tilting the horizontal TCP (TCP.A.B1) to match the beam divergence **losses decrease along the whole ring**

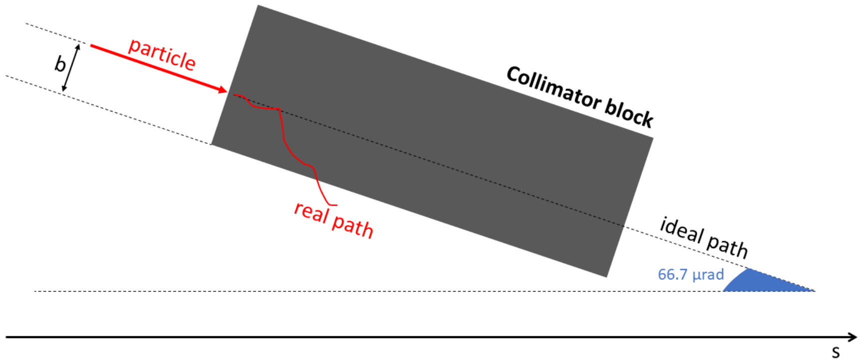
- The **peak loss upstream IP1** is **reduced by a factor of ≈20** with respect to the starting assumption configuration

- The **integrated losses upstream IP1** are **reduced by a factor of ≈20** with respect to the starting assumption configuration

⇨ **including tilt**, strong decrease in losses with the MoGr-Mo configuration compared to CFC-CFC!

- Residual losses likely due to particles escaping TCP.A.B1 before having traversed the full length of the collimator block and not intercepted by TCSs

b: impact parameter



- **To check**: sensitivity and mechanical tolerances on jaw tilt

IMPACT PARAMETER SCAN

Impact parameter scan

- A scan is performed to determine the **loss cleaning performance as a function of the impact parameter**
- **FCC-ee 2IP optics and layout without radiation and tapering, tt operation mode**
- Collimation system layout:

Collimator	Type	Plane	Material	Length [m]	Opening [σ]
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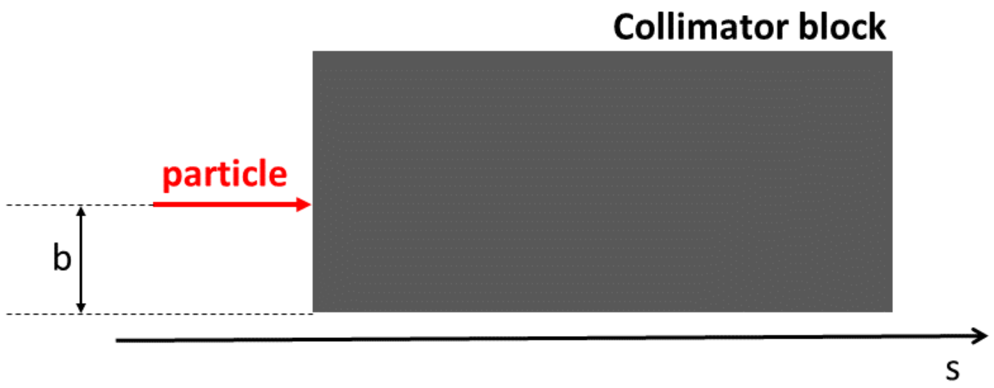
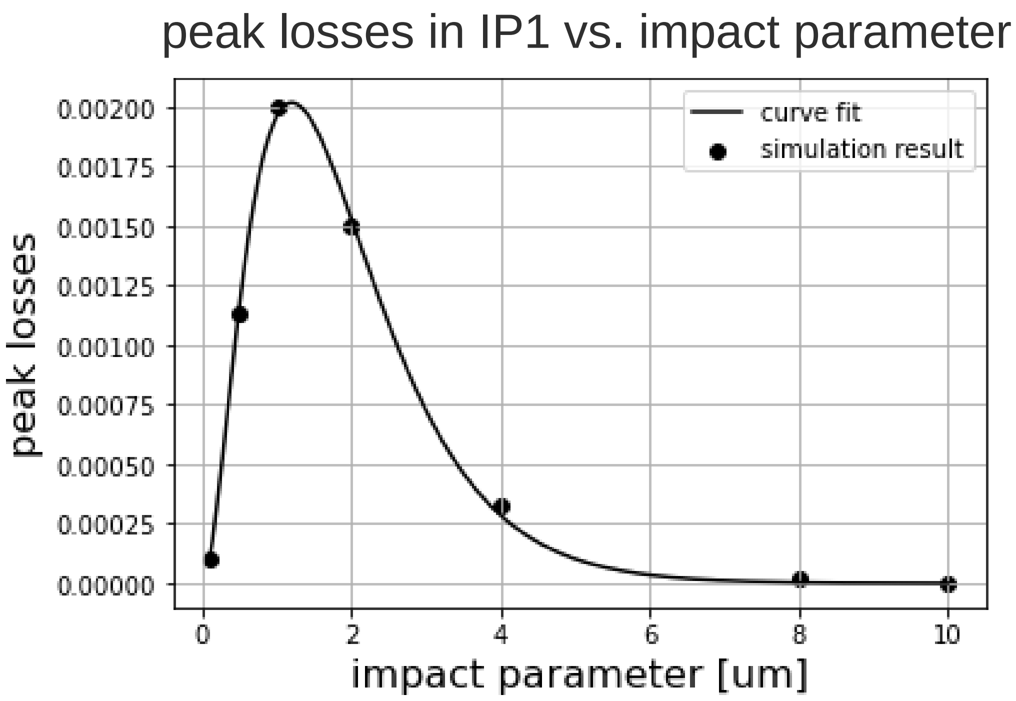
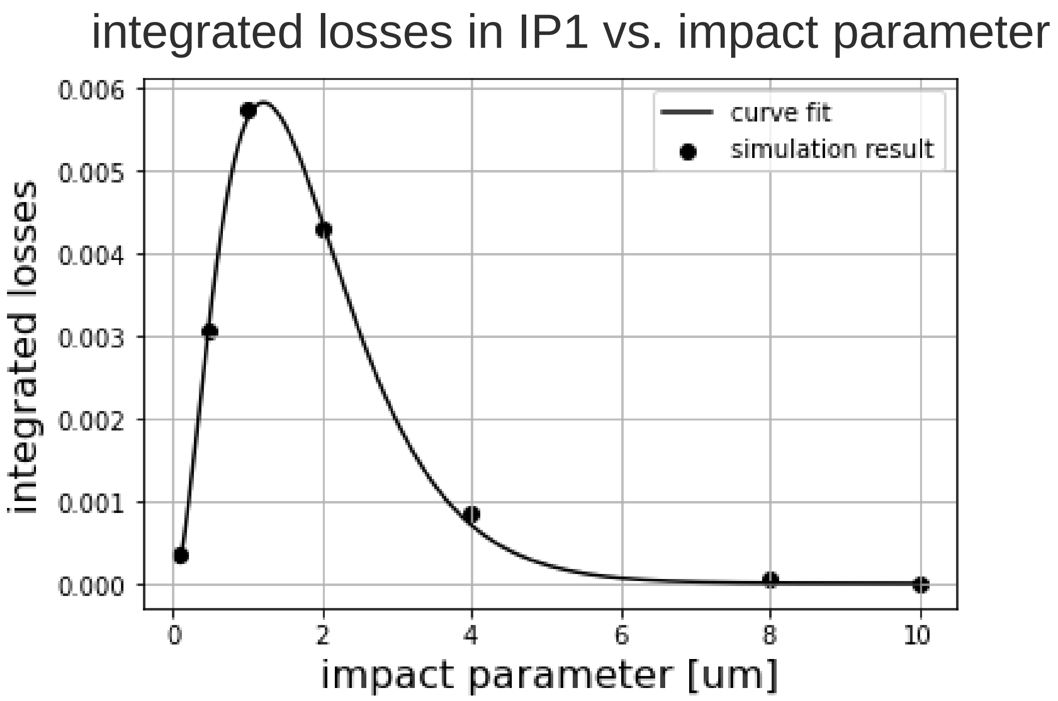


b: impact parameter

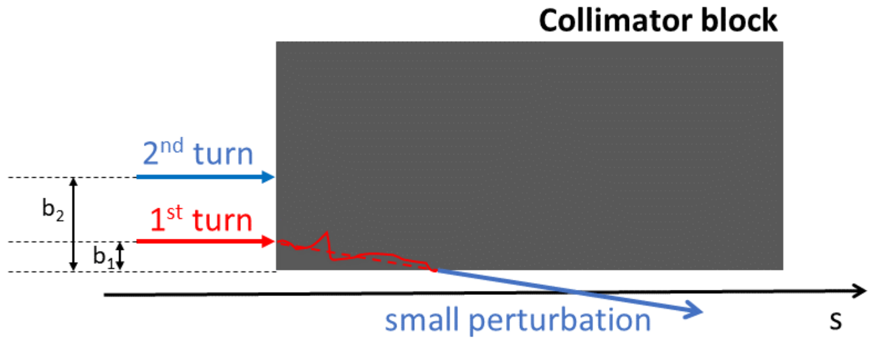
- **NO collimator tilt**
- Impact parameters: 0.1µm, 0.5 µm, 1µm, 2µm, 4µm, 8µm, 10µm
- 5×10^6 primary positrons, 700 turns

Impact parameter scan: NO radiation & tapering



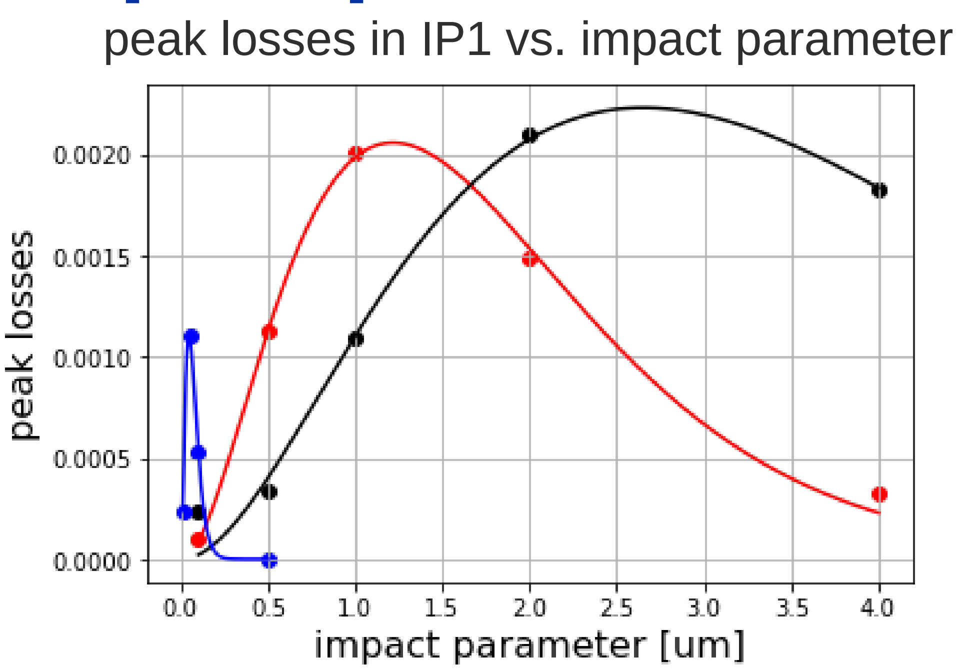


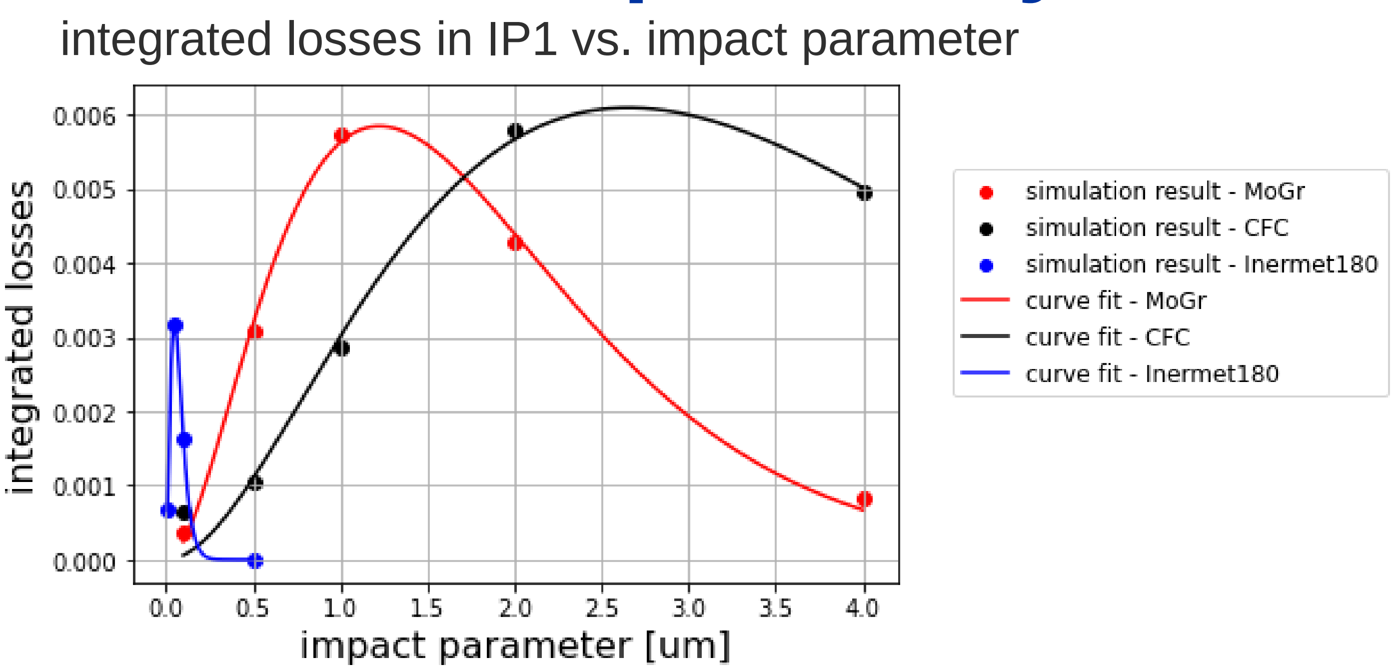
- Fitting curve: ax^2e^{-bx}
- **The critical impact parameter is 1µm**



Note: losses normalized over the total energy of lost particles

Impact parameter scan: material dependency



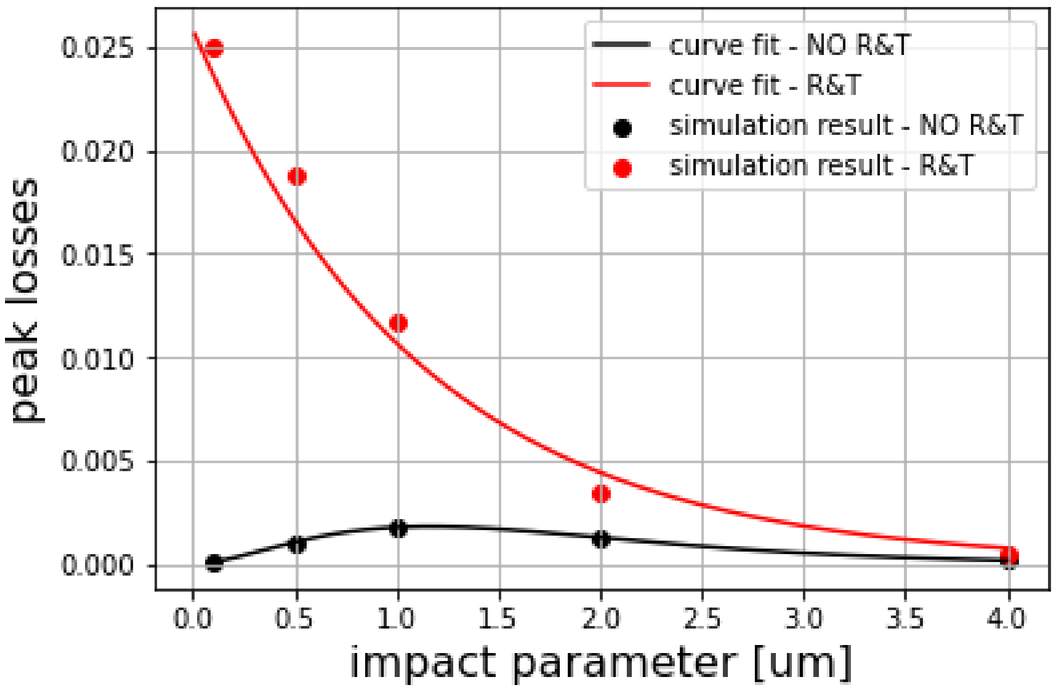


- Fitting curve: ax^2e^{-bx}
- The critical impact parameter is shifted towards smaller impact parameters for higher-Z (lower-radiation length) materials
- The critical impact parameter is shifted towards larger impact parameters for lower-Z (larger-radiation length) materials
- Losses are higher for lower-Z (larger-radiation length) materials

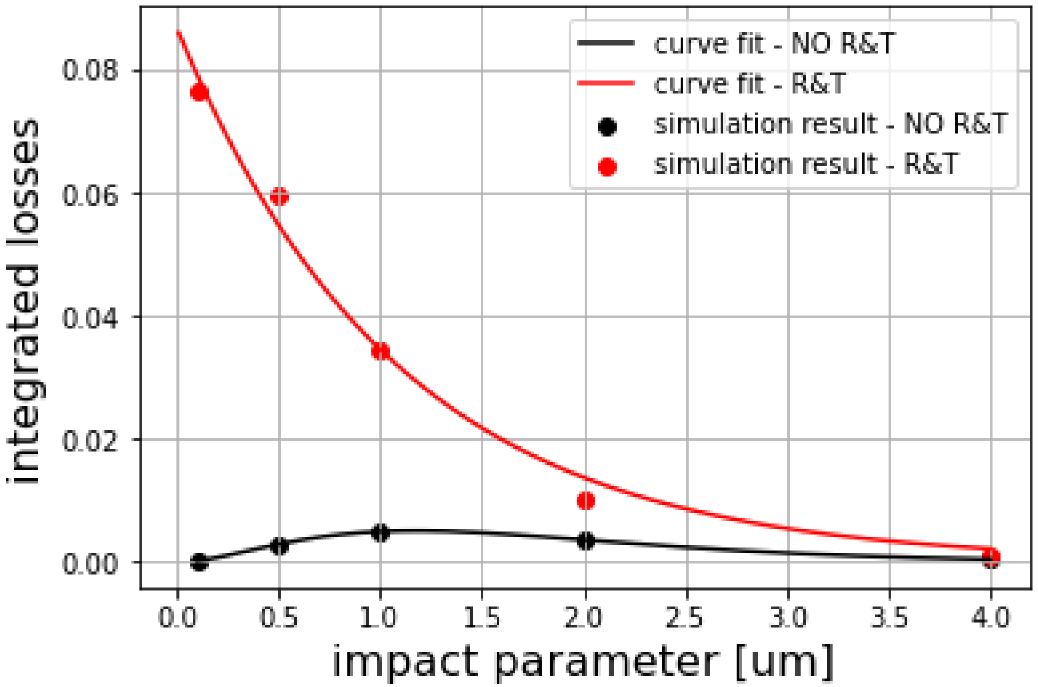
Note: losses normalized over the total energy of lost particles

Impact parameter scan: radiation & tapering

peak losses in IP1 vs. impact parameter



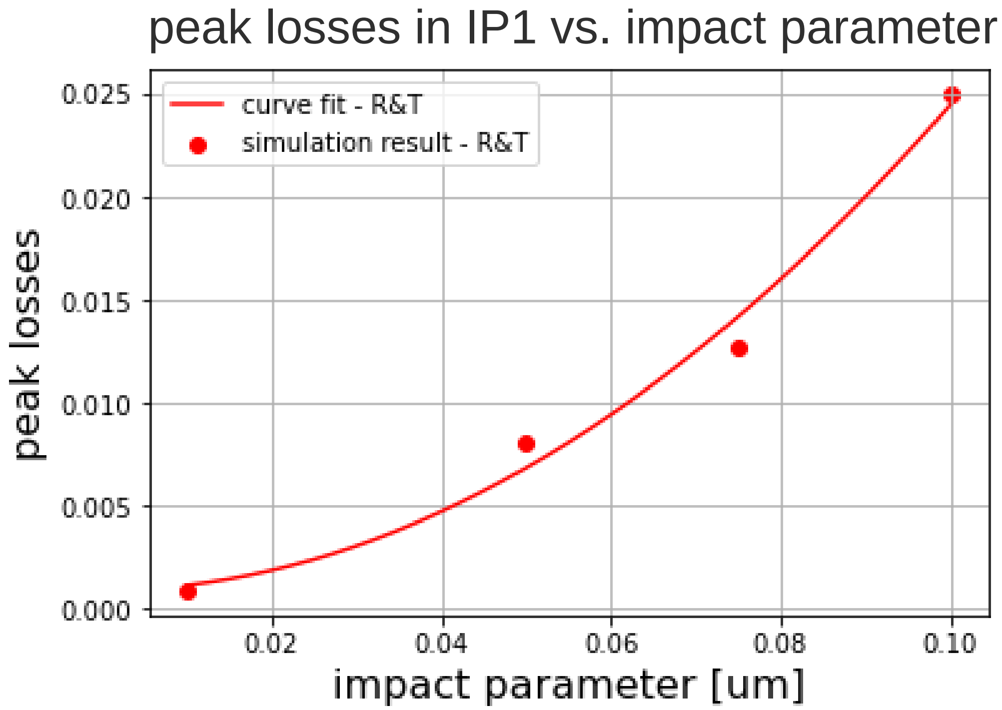
integrated losses in IP1 vs. impact parameter

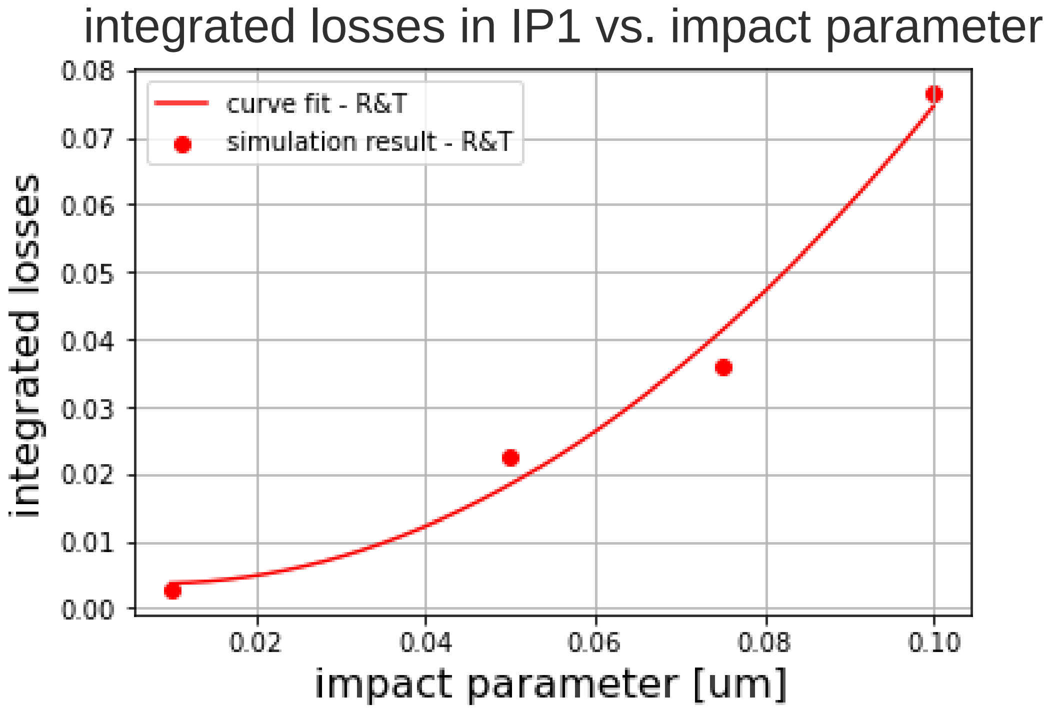


- Fitting curve (R&T): ae^{-bx}
- With radiation & tapering on losses increase going towards smaller impact parameters
  → likely due to **reduced second-turn effects because of radiation damping**
- …Further investigation of smaller impact parameters (0.01μm, 0.05μm, 0.075μm)

Note: losses normalized over the total energy of particles impacting TCP.A.B1 on the first turn (i.e., total energy)

Impact parameter scan: radiation & tapering (b<0.1μm)



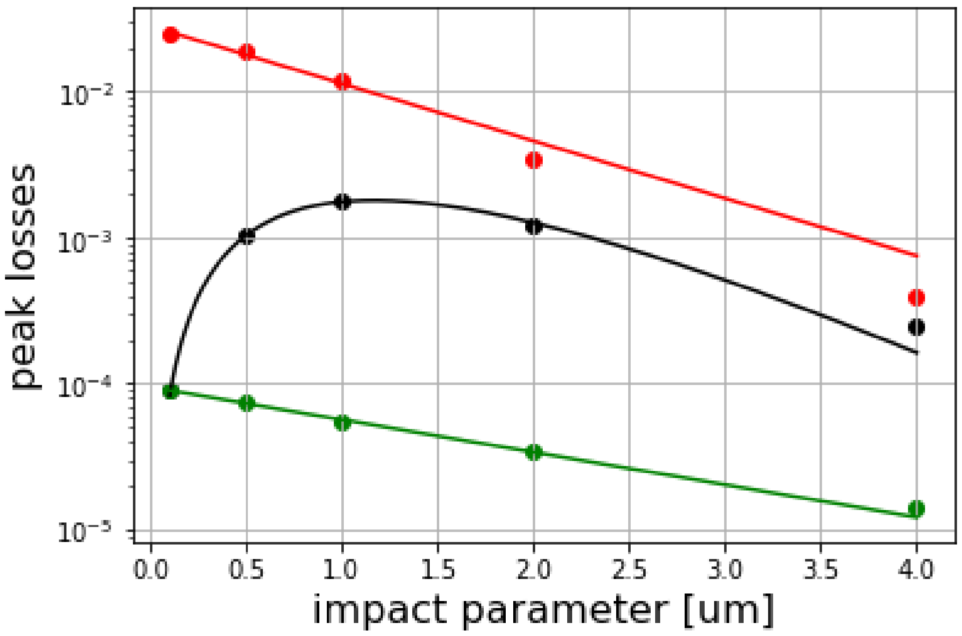


- Going towards smaller impact parameters losses start to decrease
  → the impact with the TCP is so shallow that particles are not lost in the aperture but go back into the beam
- With radiation & tapering on **the critical impact parameter is very small: ≈0.1μm**

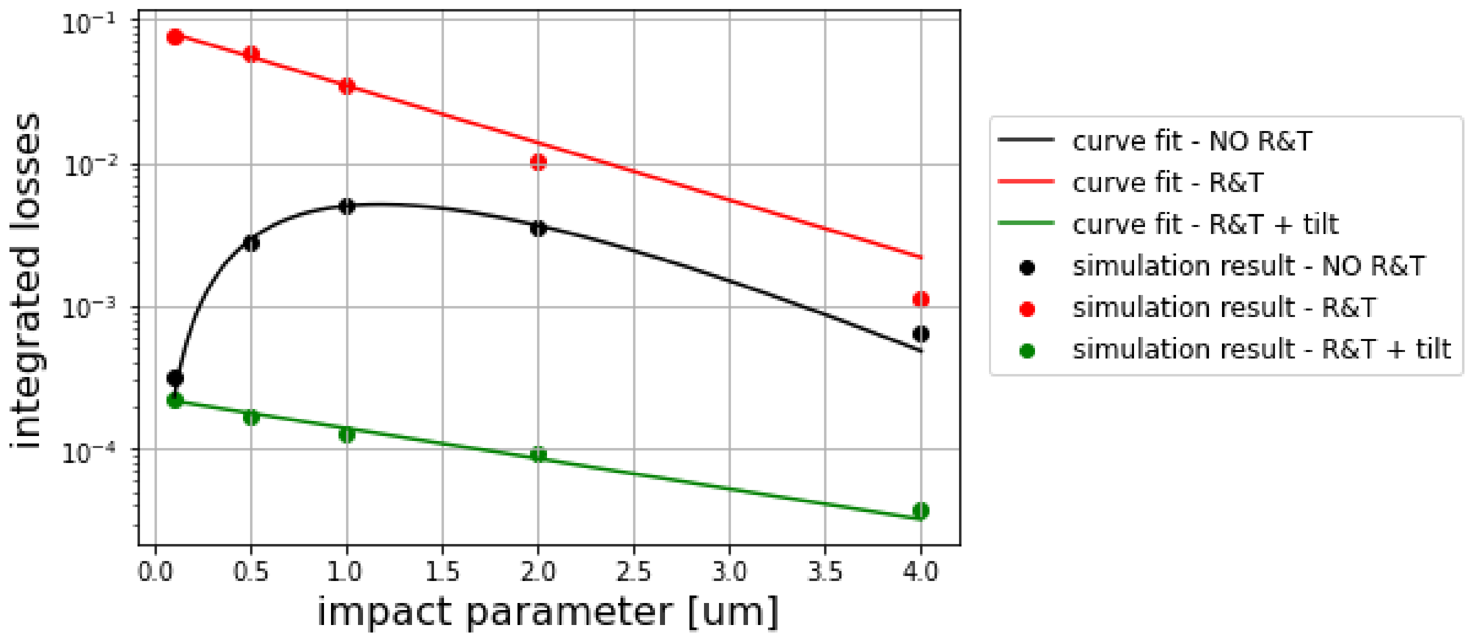
<u>Note</u>: losses normalized over the total energy of particles impacting TCP.A.B1 on the first turn (i.e., total energy)

Impact parameter scan: R&T + tilted jaws

peak losses in IP1 vs. impact parameter



integrated losses in IP1 vs. impact parameter



- By tilting the horizontal TCP (TCP.A.B1) to match the beam divergence **losses decrease a significantly** → **R&T + tilted jaws vs. R&T only**: **losses are ≈2 orders of magnitude lower for all impact parameters!**
- Losses with **tilted jaws + R&T** are even lower than in the **NO-R&T** case

Note: losses normalized over the total energy of particles impacting TCP.A.B1 on the first turn (i.e., total energy)

SUMMARY AND NEXT STEPS

Summary

- A **first guess** for the **FCC-ee collimator design parameters (2IP-layout)** has been **identified**
  → used to perform **first tracking simulations**
  → can be used for **further performance studies**
  (e.g., detailed beam loss scenarios, energy deposition, impedance, …)
- The collimation system **performance increase by using tilted jaws**
- An **impact parameter scan** for the first guess configuration has been performed

Next steps

- Determine whether the cleaning performance and robustness are adequate or not with the help of first **energy deposition and thermo-mechanical studies**
- Check the **feasibility of employing tilted jaws**
- Iterate the collimation system design with the **impedance** team
- Update to the **4IP layout** of FCC-ee
- Study **other beam operation modes** (starting from the Z)
- Study **other possible design** both in terms of materials and length

Work is still in progress, expect further iterations on collimator material and length. Any input on this front is welcome!

Thank you!