FUTURE
CIRCULAR
COLLIDER

FCC-ee Collimation Studies

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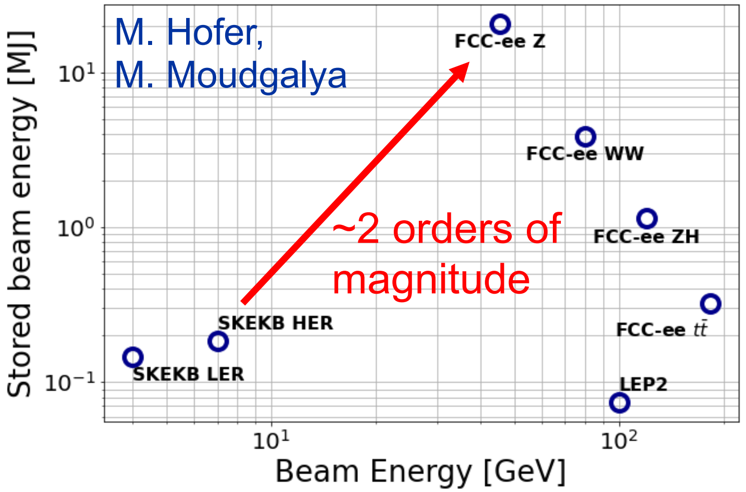
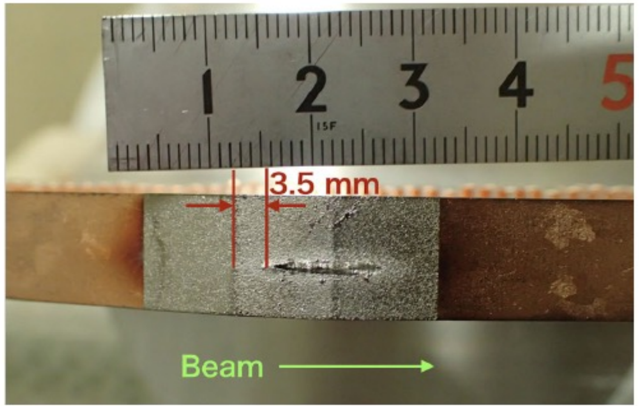
FCC-ee beam halo collimation

- **Studies are ongoing for a collimation system in the FCC-ee.**
  - The stored beam energy in the FCC-ee reaches **20.7 MJ**, which is comparable to heavy-ion operation at the LHC
  - Such beams are highly destructive: a collimation system is required
  - The main roles of the collimation system are:
    - Protect the equipment from unavoidable losses
    - Reduce the backgrounds in the experiment
  - Two types of collimation foreseen for the FCC-ee:
    - The beam halo (global) collimation
    - Synchrotron Radiation (SR) collimation
  - The current focus is the beam halo collimation system

"You cannot collimate electrons, you can only make them angry"
- Bob Jacobsen



Comparison of lepton colliders

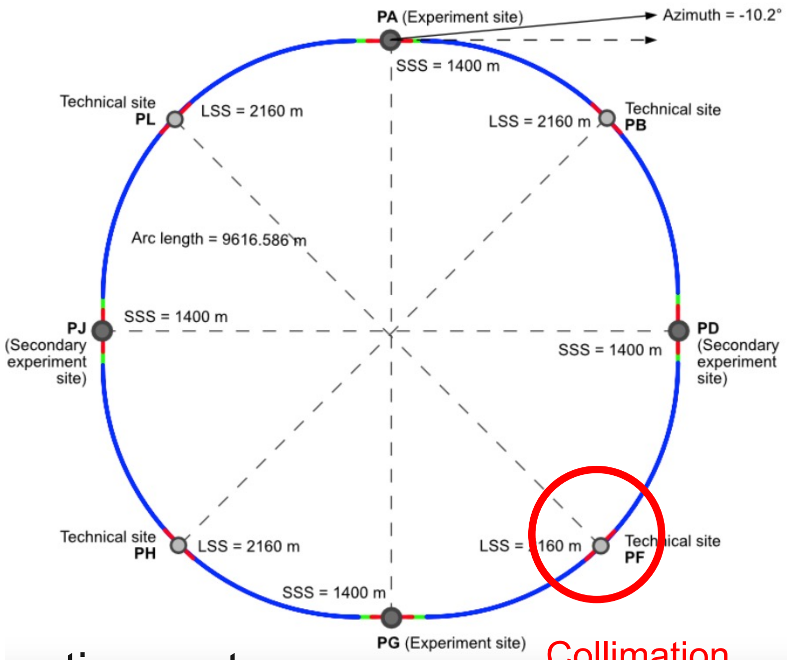


Collimator damage in SuperKEKB

T. Ishibashi et. al. https://doi.org/10.1103/PhysRevAccelBeams.23.053501

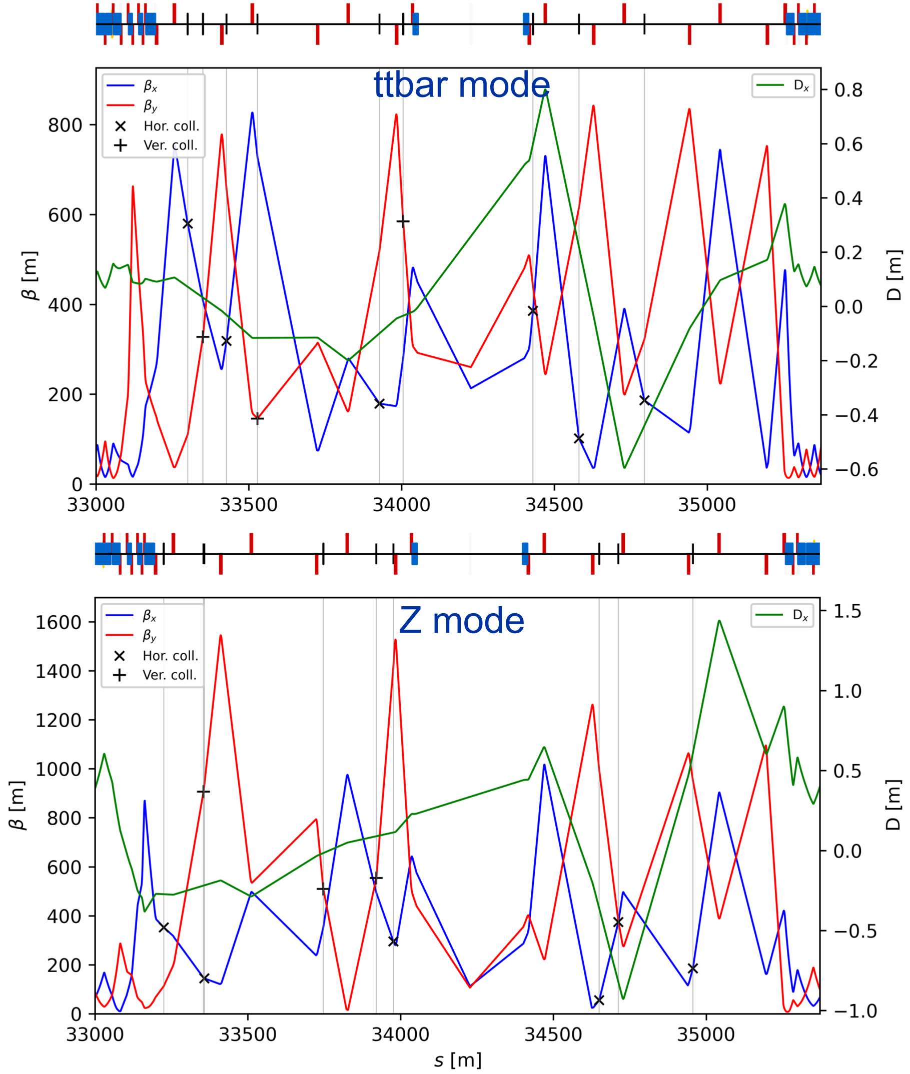
Collimation for the FCC-ee 4 IP layout

- **Latest ring layout**
  - 4 interaction points
  - Reduced circumference
  - All auxiliary insertions have the same length
  - Beam crossings in all auxiliary insertions



- **Optics for collimation**
  - Optics for a split halo collimation system implemented (M. Hofer)
    - Betatron collimation upstream of crossing
    - Off-momentum collimation downstream of crossing
  - Two-stage collimation system in all planes
  - Collimator layout based on optimal phase advance

Collimation insertion optics

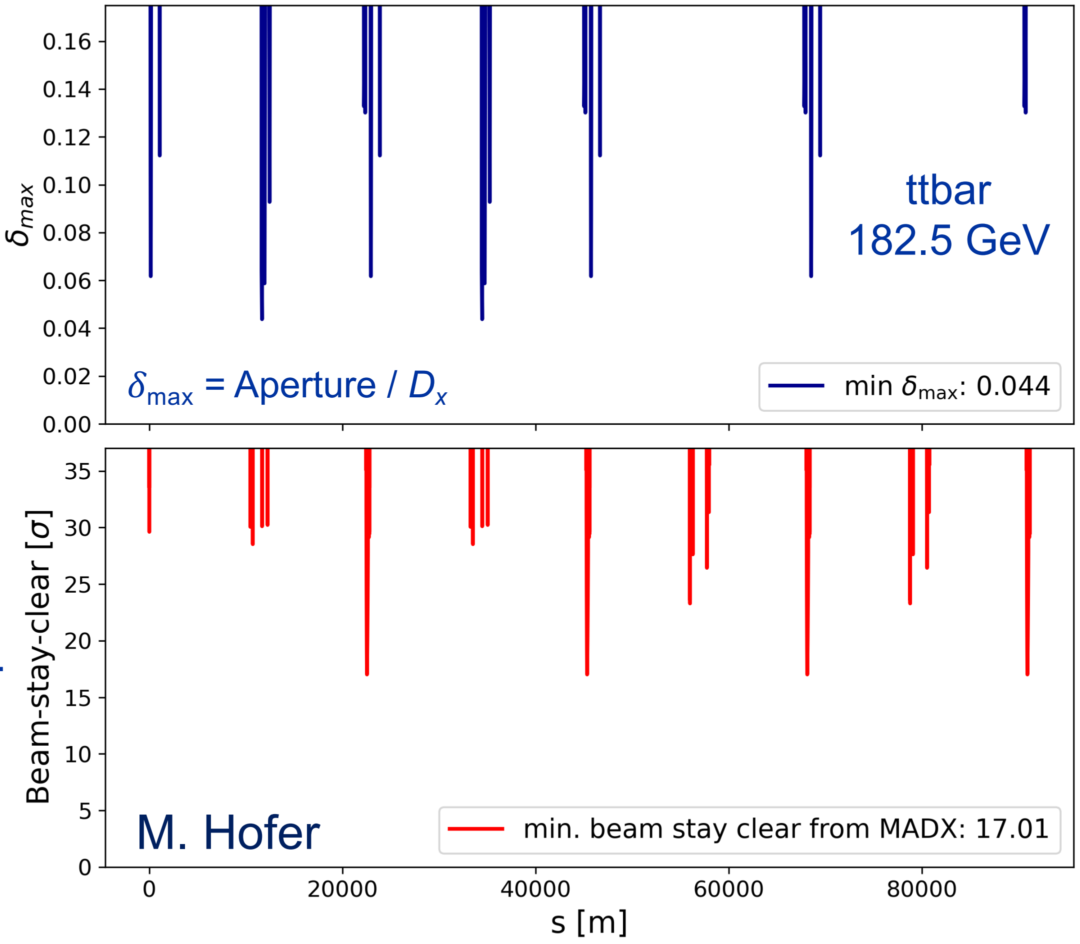


FCC-ee optics repository: link
FCC-ee collimation optics repository: link

Aperture and collimators

- **Aperture model** (M. Hofer, M. Moudgalya)
  - 35 mm circular beam pipe around the ring
  - 10 mm inner beampipe and SR mask in the MDI
  - First guess for tolerances and imperfections included
- **Collimators**
  - Two-stage betatron and off-momentum collimation systems in IRF
  - Settings selected to protect aperture bottlenecks, while meeting min. aperture requirement by injection and momentum acceptance (M. Hofer)
  - **Preliminary** FCC-ee collimator design parameters (G. Broggi)
    - First guess on robustness, absorption, and impedance (to be studied in detail)
    - Molybdenum (Mo) and Molybdenum-Graphite (MoGr) materials tentatively selected
    - Active length from analytical considerations

Aperture with tolerances



Collimators

Collimator	Type	Plane	Material	Length [m]	Opening [σ]
TCP.H.B1	Prim.	H	MoGr	0.4	15
TCP.V.B1	Prim.	V	MoGr	0.4	80
TCS.H1.B1	Sec.	H	Mo	0.3	17
TCS.V1.B1	Sec.	V	Mo	0.3	89.5
TCS.H2.B1	Sec.	H	Mo	0.3	17
TCS.V2.B1	Sec.	V	Mo	0.3	89.5
TCP.HP.B1	Prim.	H	MoGr	0.4	23
TCS.HP1.B1	Sec.	H	Mo	0.3	26
TCS.HP2.B1	Sec.	H	Mo	0.3	26

Beam collimation simulation tools

- Tracking studies are essential for designing a collimation system
- Effects such as synchrotron radiation and optics tapering make the tracking studies more challenging for the FCC-ee

*Optics tapering: modulating the magnetic strengths around the ring to account for SR energy loss

- The requirements for collimation simulation tools are:
  - **Tracking of beam electrons (and positrons) in the magnetic lattice**
  - **Particle-matter interactions inside the collimators**
  - **Synchrotron radiation and optics tapering**
  - **Aperture modelling and loss recording**
  - **Accurate and efficient tracking over many turns**
  - **Beam-beam effects**
- Studied several different simulation tools:
  - MAD-X, SixTrack-FLUKA coupling, BDSIM, Merlin++, pyAT, Xtrack
  - No established frameworks fit all the requirements
  - Develop specialized tools for FCC-ee collimation simulations

Development of collimation simulations

- **Outline:**
  - Develop a coupling between a tracking code and a Monte Carlo physical interaction code
  - Previously studied and selected promising particle tracking codes: **pyAT** and **XSuite**
  - EPFL-CERN collaboration to develop a beam dynamics simulation framework for the FCC-ee
  - Selected **BDSIM** (link), a simulation tool based on Geant4, as the particle-matter engine for collimator interactions

pyAT (link)

Python interface to the tracking library Accelerator Toolbox (AT)

Actively used for studies for light sources, such as ESRF

Developments for FCC-ee applications (F. Carlier, M. Rakic, T.Pieloni, S. White)

Xtrack (link)

New tracking particle tracking tool, part of the Xsuite project

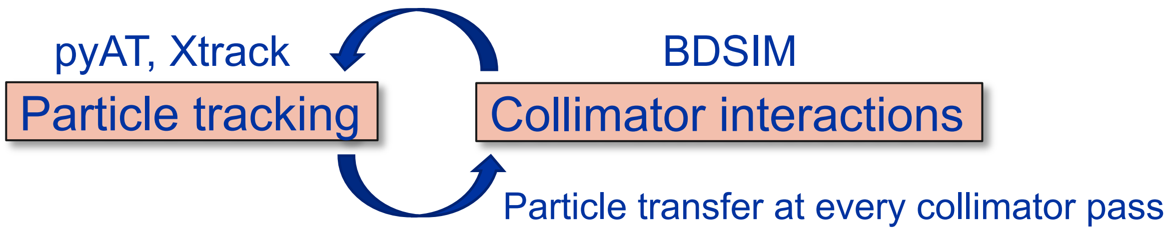
Quickly gaining popularity for studies at CERN and EPFL

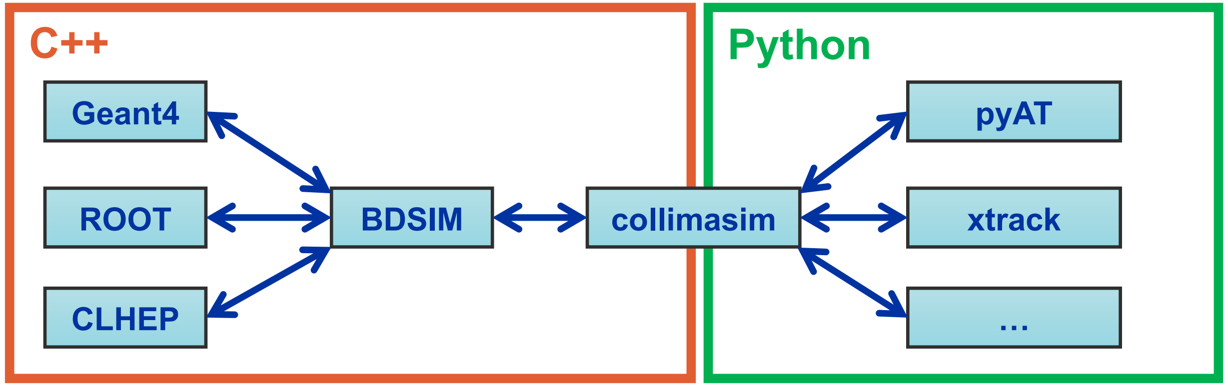
Developments for FCC-ee applications (G. Iadarola, P. Kicsiny, X. Buffat)

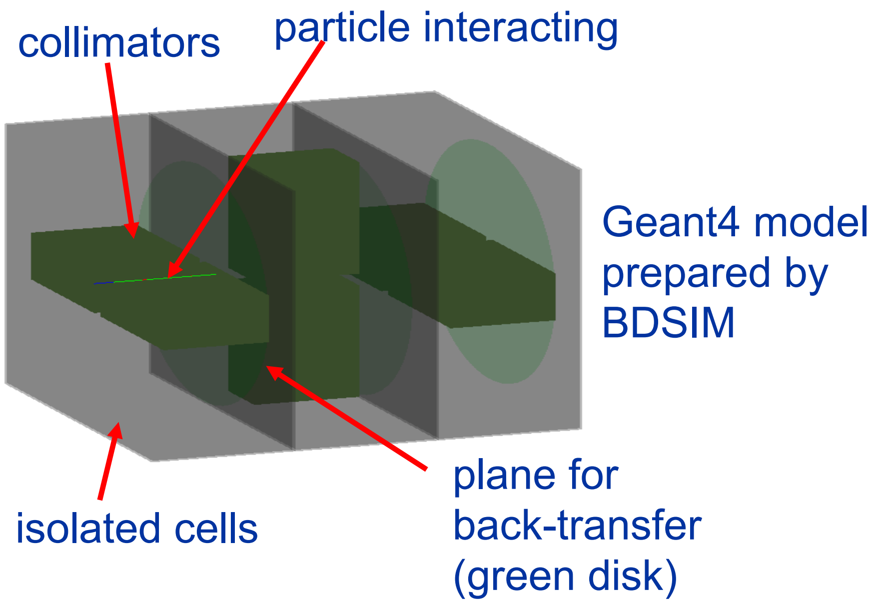
Swiss Accelerator Research and Technology

Collimation simulation development

- **Software development strategy:**
  - Adapted an existing interface (L. Nevay) to **BDSIM**, originally developed for LHC studies.
  - Implemented a connection to **pyAT** and **Xtrack** for multi-turn collimation simulations (collimasim).
  - Benchmark against the **SixTrack-FLUKA coupling**, without radiation and tapering:
    - SixTrack-FLUKA coupling is a standard tool for collimation studies at CERN, benchmarked with the LHC
    - No SR implementation in SixTrack, coupling to FLUKA foreseen for Xtrack and pyAT (CERN FLUKA team)



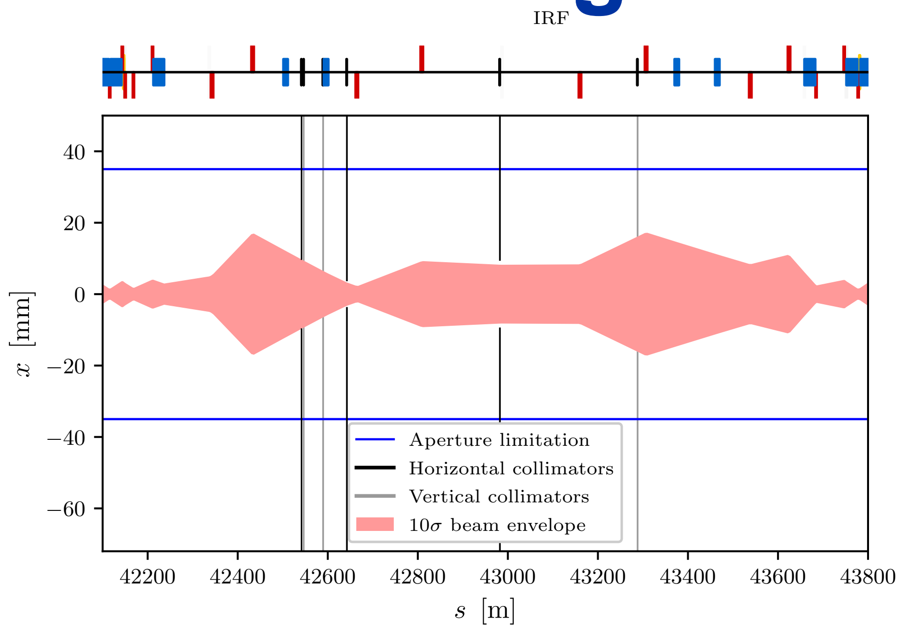




FCC-ee collimation simulation benchmarking

- **Collimation setup from FCC week 2021:**
  - Two-stage betatron collimation system in IRF
  - Aperture model from 2021 (M. Moudgalya)
  - LHC collimator parameters
    - 0.6 m carbon-fibre-composite (CFC) primary collimators
    - 1 m CFC secondary collimators
  - ttbar mode (182.5 GeV), beam 1 horizontal (positron)
    1 µm impact parameter, 700 turns

- **Synchrotron radiation and optics tapering**
  1. Compare pyAT-BDSIM and Xtrack-BDSIM to SixTrack-FLUKA without radiation and tapering
  2. Compare pyAT-BDSIM and Xtrack-BDSIM with:
     - SR damping modelled as an average effect
     - Excitation by SR quantum fluctuations
       - Modelled as random photon emission in Xtrack
       - Modelled using an effective diffusion matrix in pyAT



Halo collimation system in IRF

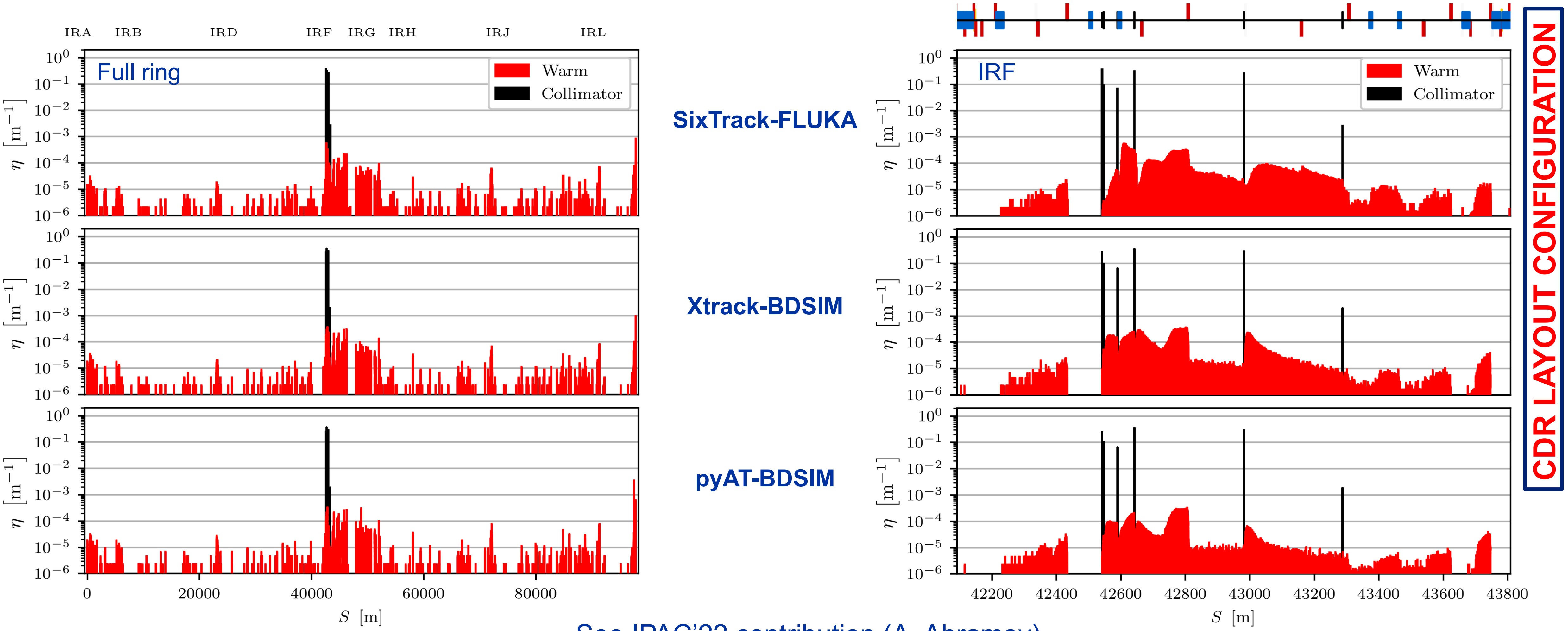
Collimator	Type	Plane	Opening [σ]
TCP.A.B1	Prim.	H	10
TCP.B.B1	Prim.	V	80
TCS.B1.B1	Sec.	V	89.5
TCS.A1.B1	Sec.	H	11.5
TCS.A2.B1	Sec.	H	11.5
TCS.B2.B1	Sec.	V	89.5

Collimator settings

CDR LAYOUT CONFIGURATION

Collimation simulation benchmarking

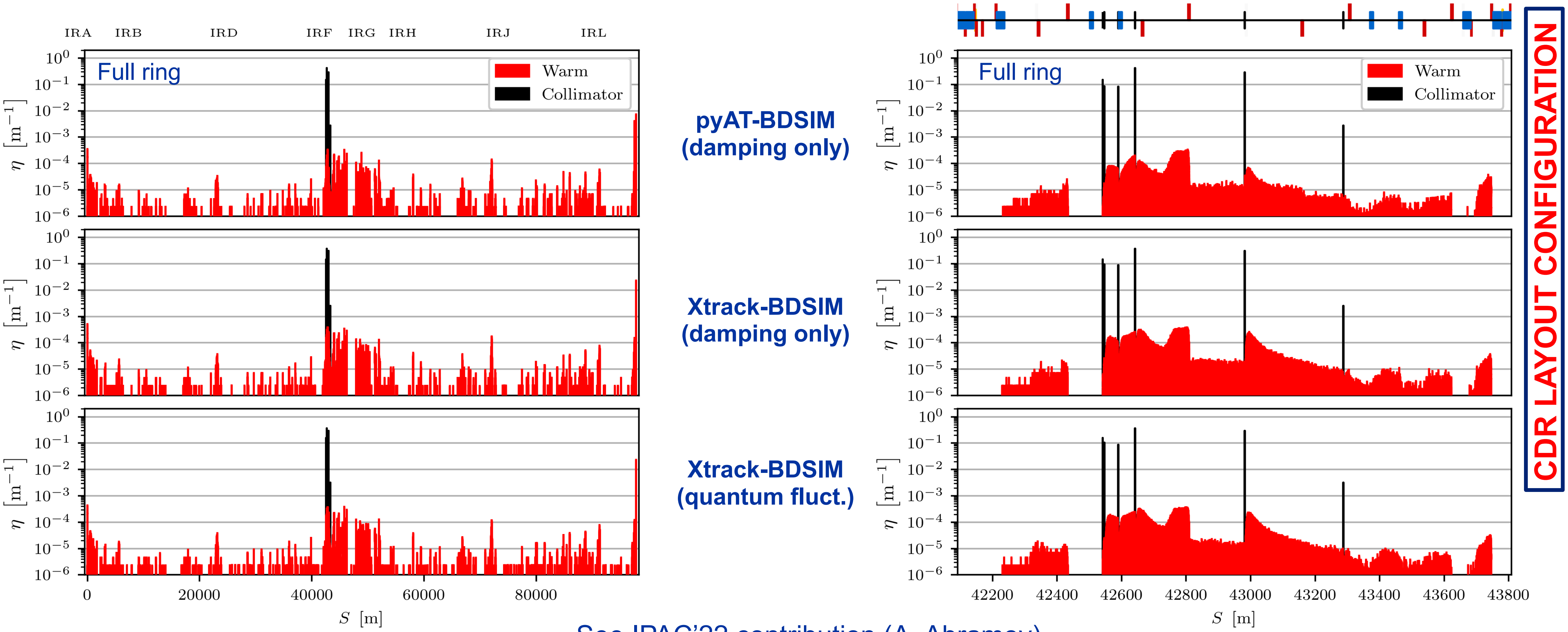
- **Loss maps without radiation and tapering** (CDR layout, parameters in FCC week 2021 talk)



See IPAC'22 contribution (A. Abramov)

Collimation simulation benchmarking

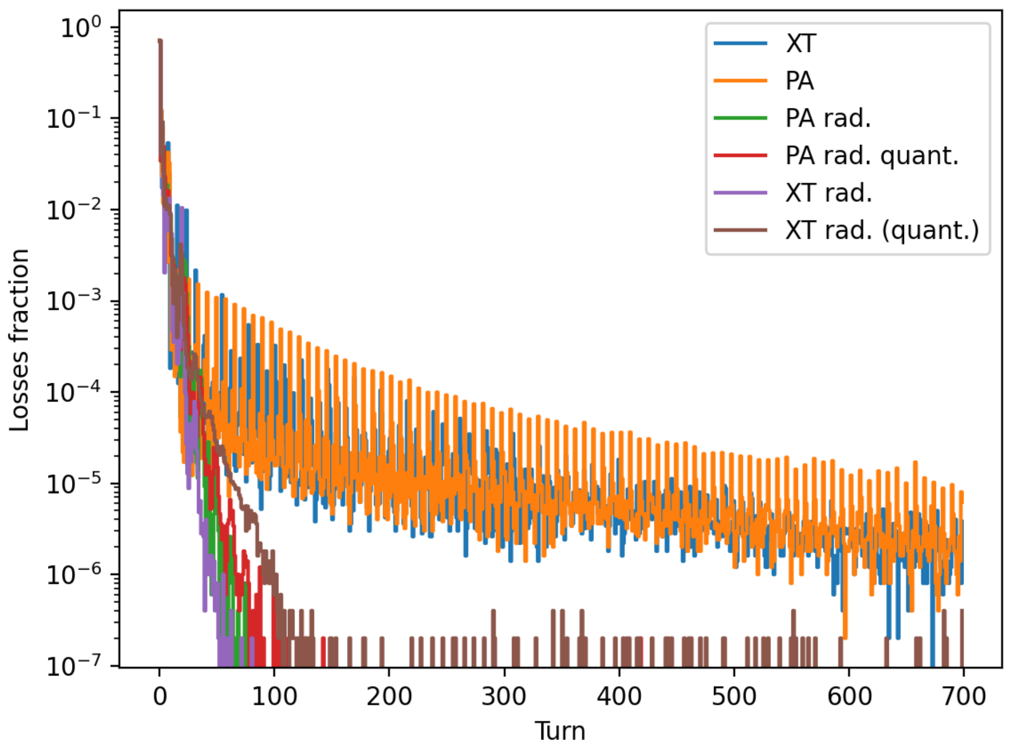
- **Loss maps with radiation and tapering** (CDR layout, parameters in FCC week 2021 talk)

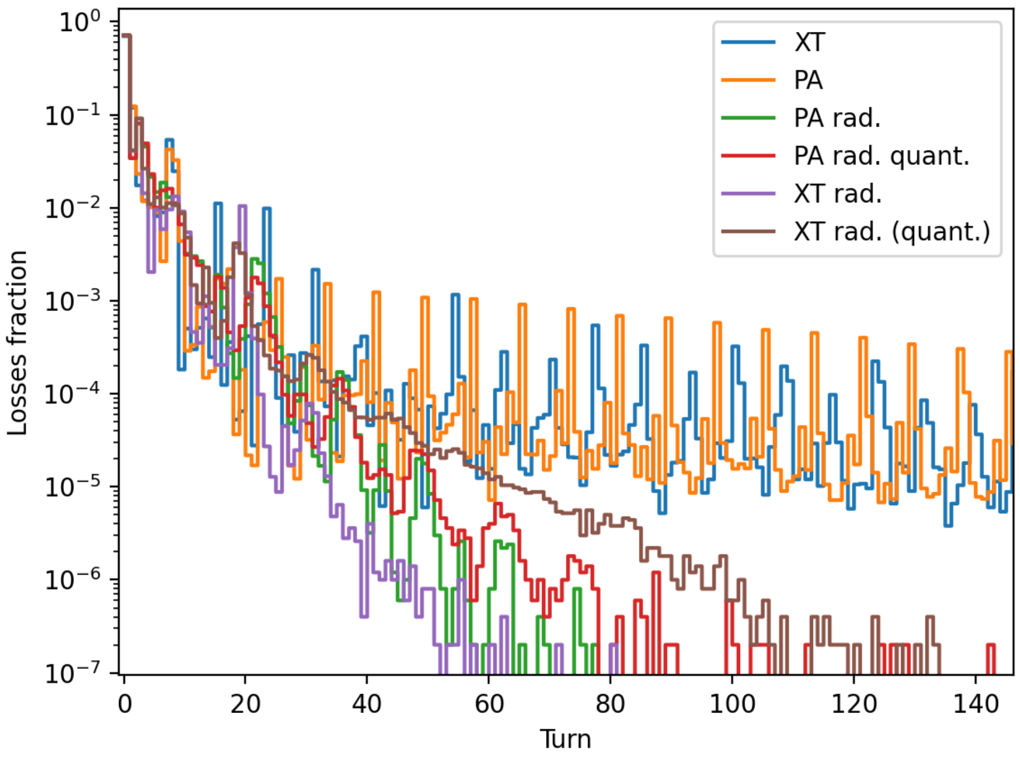


See IPAC'22 contribution (A. Abramov)

Collimation simulation benchmarking

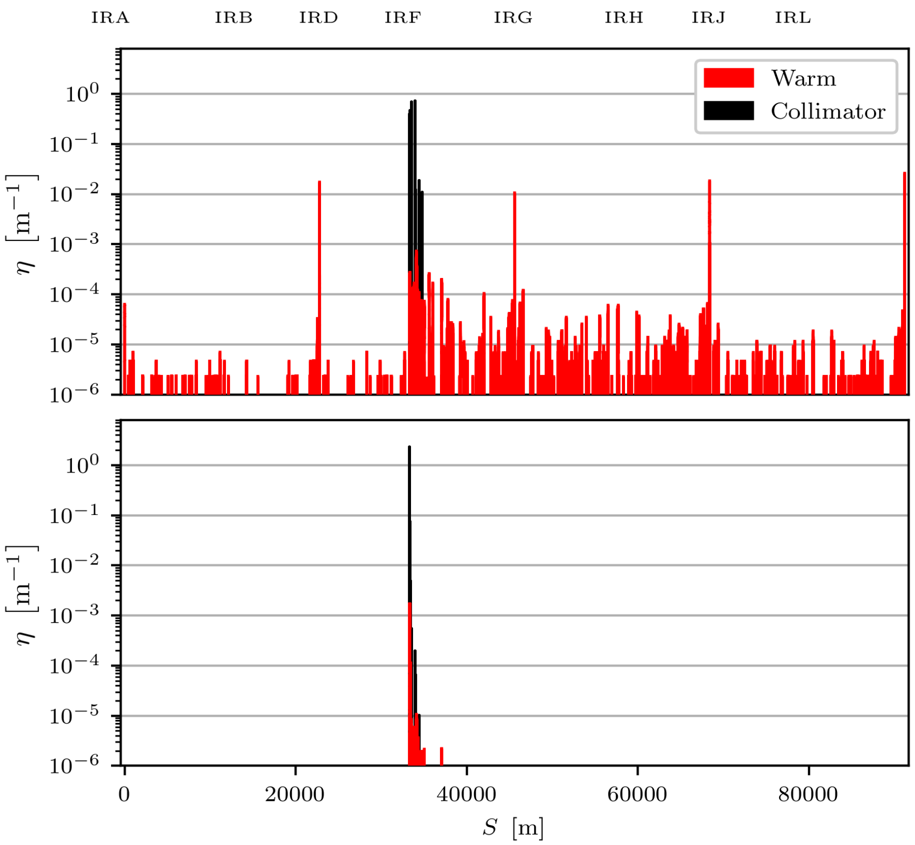
- **Multi-turn loss comparison between Xtrack-BDSIM (XT) and pyAT-BDSIM (PA)**
  - The largest fraction of the losses occurs in the first few turns for all simulated cases
  - With SR on, the simulated losses stop around turn 80-100 due to particles damping towards the core
  - Must investigate in detail the multi-turn losses in the simulations





Loss map studies for ttbar 4 IP lattice

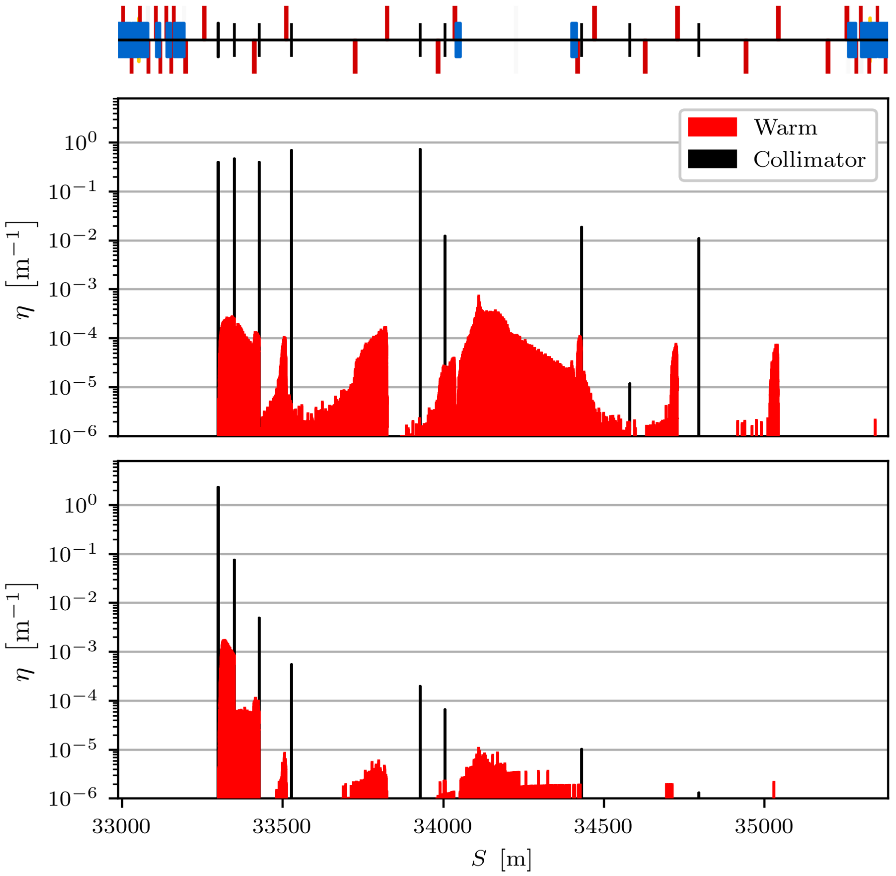
- **First loss map study for the 4 IP configuration**
  - Betatron collimation, ttbar (182.5 GeV) mode, Beam 1 horizontal
  - Xtrack-BDSIM, no radiation and tapering, 5×10^6 primary positrons, 700 turns, 1 μm impact parameter



Molybdenum-Graphite primary collimator

Tungsten primary collimator

for comparison only, likely not feasible with with multi-MJ beams

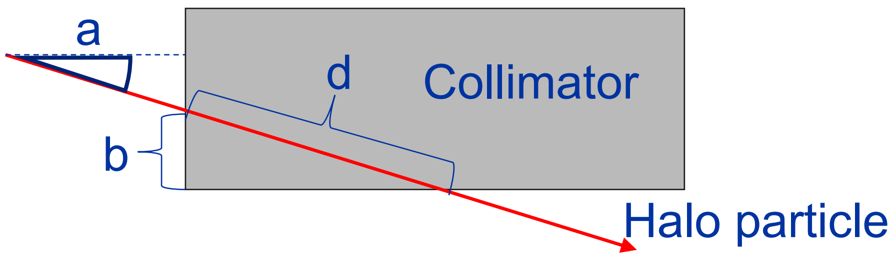


Loss map studies for ttbar 4 IP lattice

- **Loss map results**
  - Significant losses observed near all 4 IPs with the nominal configuration
  - Using a tungsten primary collimator alleviates the losses

    tungsten likely not robust enough for the multi-MJ stored beam energy in the FCC-ee

- **Discussion**
  - The effective collimator length is shorter for particles with large angles and small impact parameters
  - The angle is determined by the optics - possible to adjust
  - Optimise the secondary collimator settings
  - Consider using angularly aligned jaws instead of parallel ones
  - Study collimator design parameters in detail:
    - Absorption vs. robustness vs. impedance
    - Other considerations – thermal stability, outgassing, etc.
    - First studies ongoing
    - Collaborate with the engineering and impedance teams



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

Summary

- **FCC-ee has a factor 100 higher stored beam energy than present highest (Super-KEKB)**
  - Beam halo collimation system is required for safe operation
  - The FCC-ee collimation studies are making good progress
- **Developed collimation simulation tools for the FCC-ee**
  - Xtrack-BDSIM and pyAT-BDSIM
  - Benchmarked with and without radiation and optics tapering
- **Status of collimation for the new 4 IP layout:**
  - New collimation insertion optics and layout
  - Off-momentum collimation system included
  - Revised aperture model, collimator settings, and collimator design
  - Preliminary loss map studies performed
- **Next steps:**
  - Study all beam operation modes
  - Include of beam-beam effects (e.g. Beamstrahlung) on the single-particle dynamics in the simulation (in collaboration with the beam-beam team)
  - Include synchrotron radiation collimators (in collaboration with the MDI team)
  - Evaluate the collimation performance with beam loss scenarios and equipment loss tolerances

Thank you!