FUTURE
CIRCULAR
COLLIDER

FCC-ee Collimation Studies

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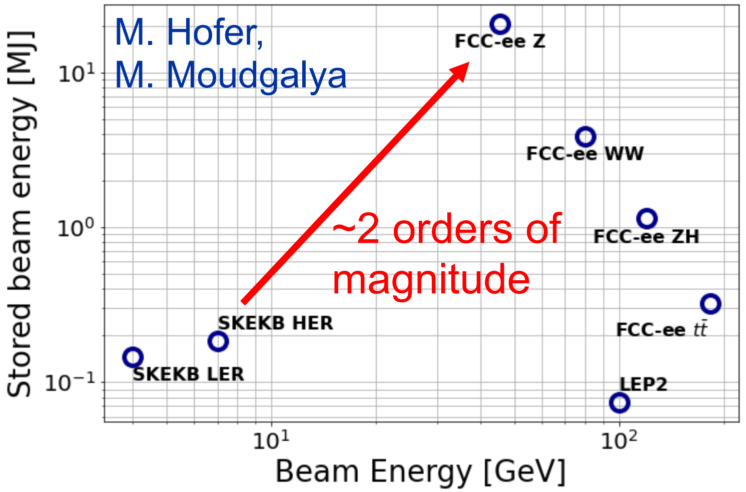
FCC-ee beam halo collimation

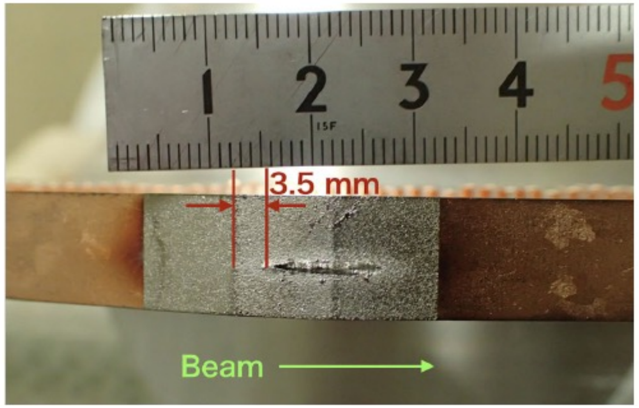
- **Studies are ongoing for a collimation system in the FCC-ee.**
  - The stored beam energy in the FCC-ee reaches **20.7 MJ**, which is comparable to heavy-ion operation at the LHC
  - Such beams are highly destructive
  - The main roles of the collimation system are:
    - Protect the equipment from unavoidable losses
    - Reduce the backgrounds in the experiment
  - The current focus is on the beam halo collimation
    - Betatron and off-momentum collimation in one insertion
    - Integrate with studies of synchrotron radiation collimators (MDI team)

see FCC week talk, K. Andre

- **In this talk:**
  - Development of collimation simulation tools for the FCC-ee
  - Status of the halo collimation system design



Comparison of lepton colliders



Collimator damage in SuperKEKB

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

Development of collimation simulations

- **Motivation:**
  - Simulation studies are an important aspect of collimation system design
  - For the FCC-ee collimation, need multi-turn tracking with synchrotron radiation (SR) and optics tapering, and particle-matter interactions in the collimators
  - No simulation frameworks available that fit all the requirements
  - Previously studied and selected promising particle tracking codes
  - EPFL-CERN collaboration to develop a beam dynamics simulation framework for the FCC-ee

CHART
Swiss Accelerator Research and Technology

see FCC week talk, T. Pieloni

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

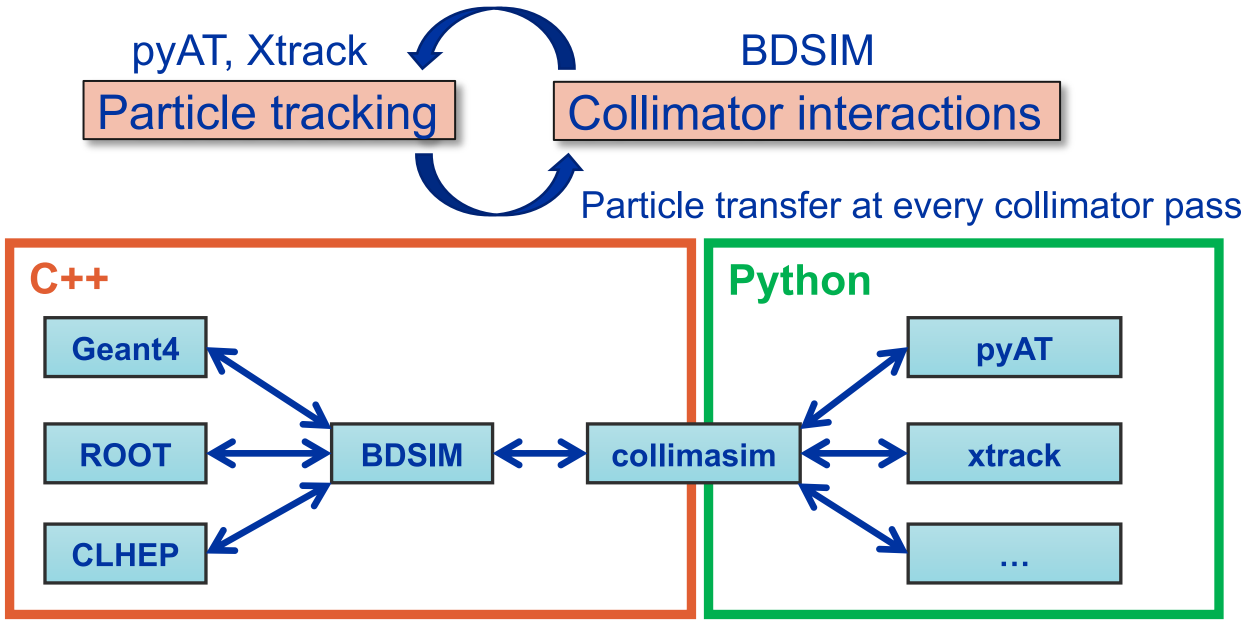
Quickly gaining popularity for studies at CERN and EPFL

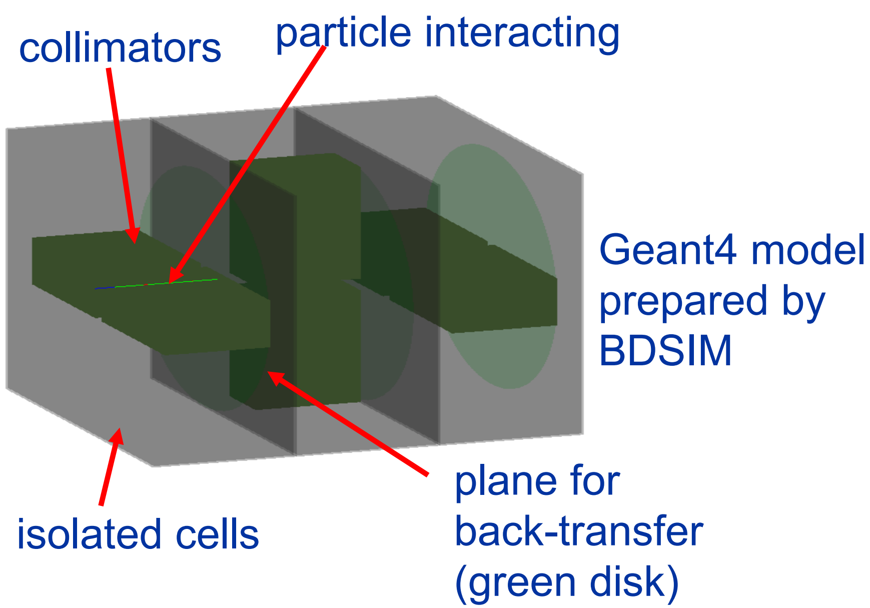
Developments for FCC-ee applications (G. Iadarola, P. Kicsiny, X. Buffat)

see FCC week talk, P. Kicsiny

Collimation simulation development

- **Software development strategy:**
  - Focussed on a coupling between a tracking code and a Monte Carlo physical interaction code
  - Adapted an existing interface (L. Nevay) to BDSIM (link), a simulation tool based on Geant4, 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)

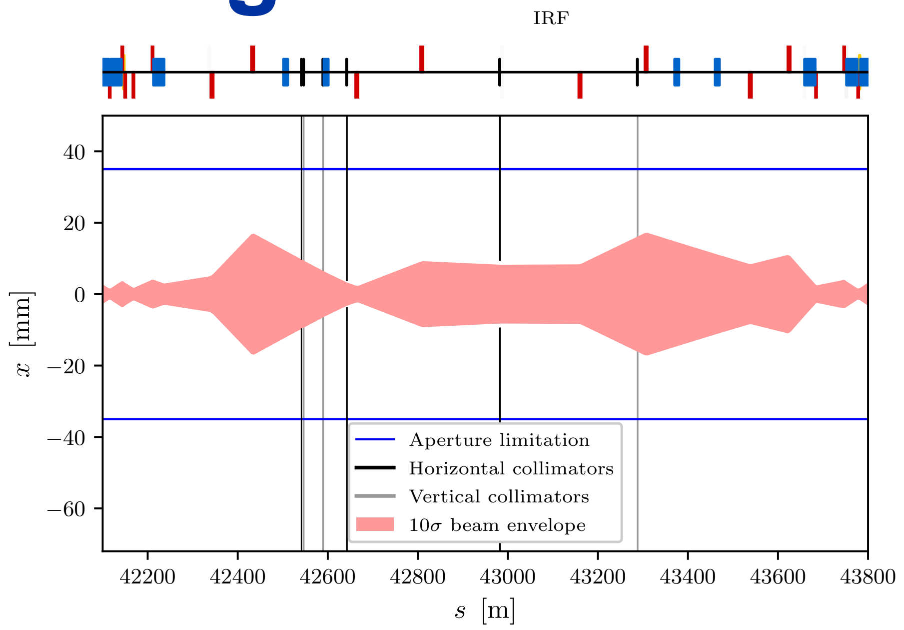




Collimation simulation benchmarking

- **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

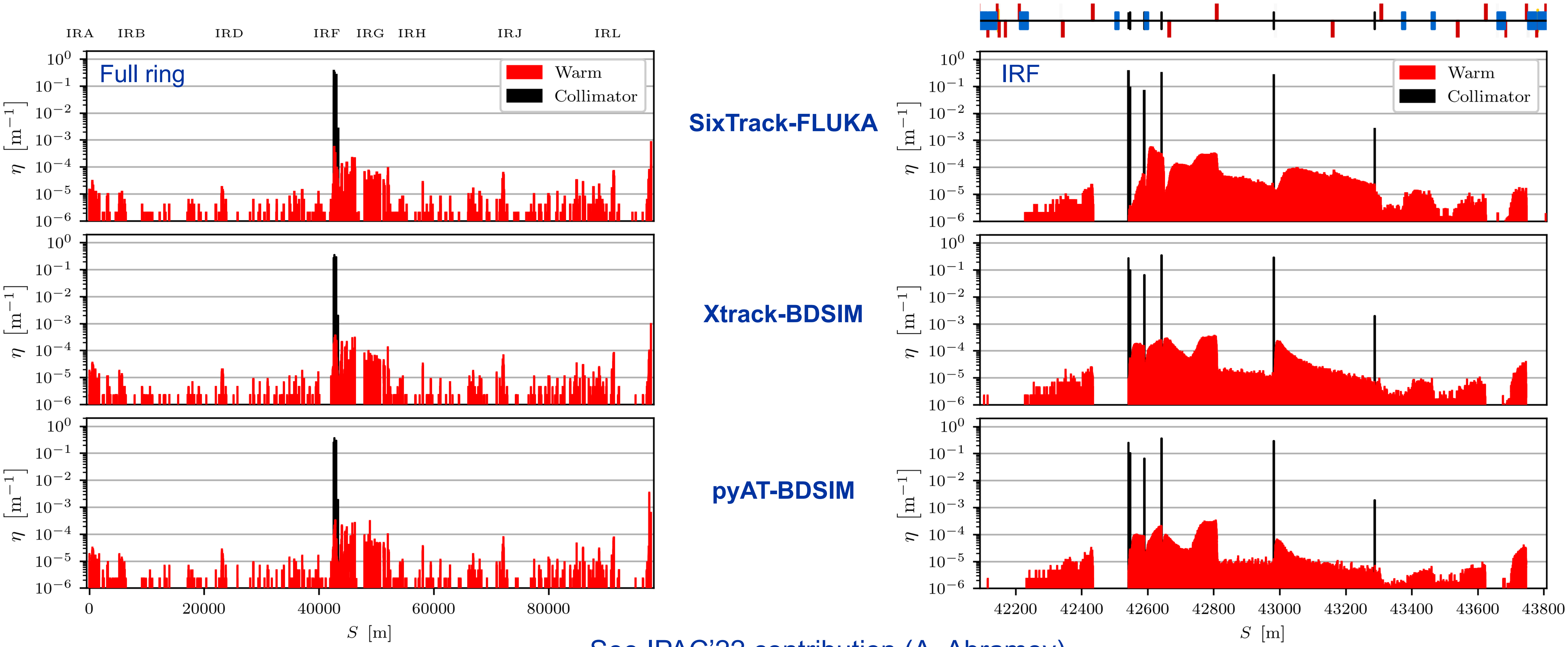
Collimator	Type	Plane	Opening [σ]
TCP.A.B1	Prim.	H	10
TCP.B.B1	Prim.	V	80
TCS.B1.B1	Sec.	V	89.5
TCS.A1.B1	Sec.	H	11.5
TCS.A2.B1	Sec.	H	11.5
TCS.B2.B1	Sec.	V	89.5

Collimator settings

CDR LAYOUT CONFIGURATION

Collimation simulation benchmarking

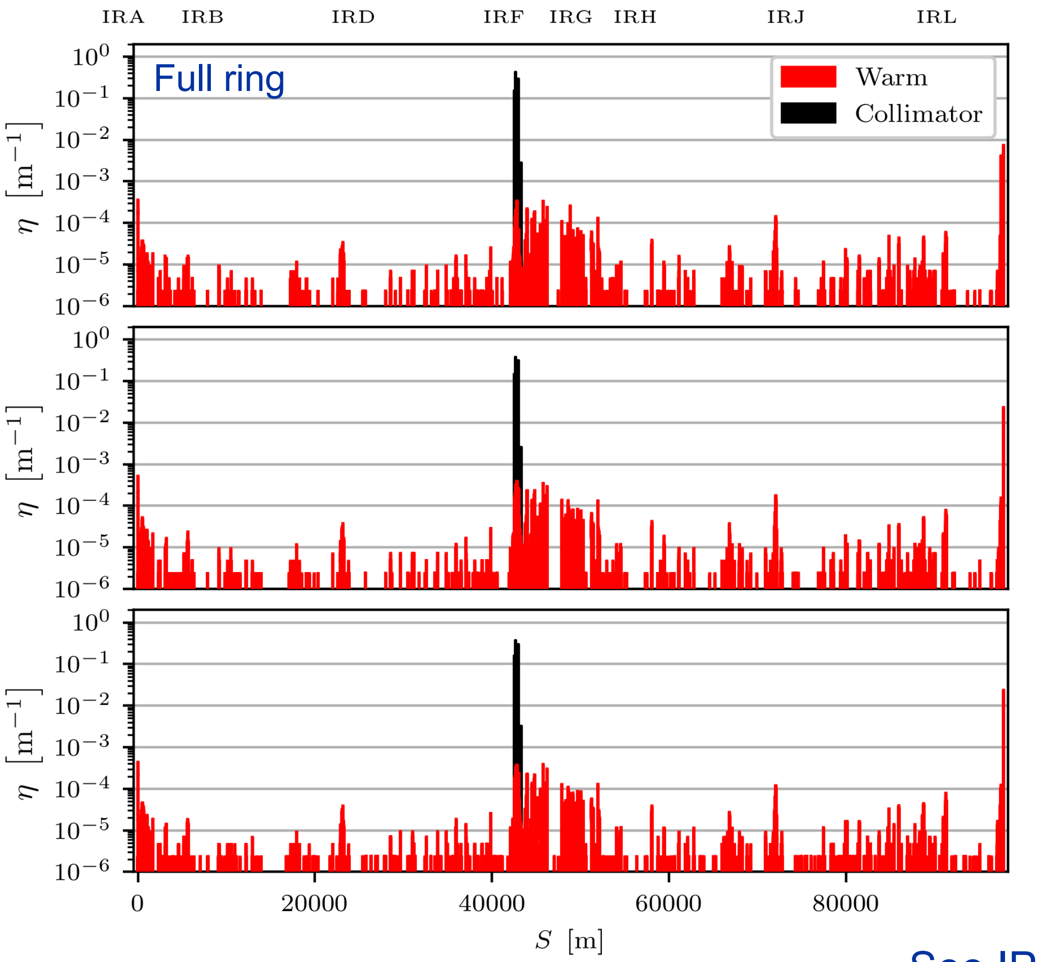
- **Loss maps without radiation and tapering** (CDR layout, parameters in FCC week 2021 talk)



See IPAC'22 contribution (A. Abramov)

Collimation simulation benchmarking

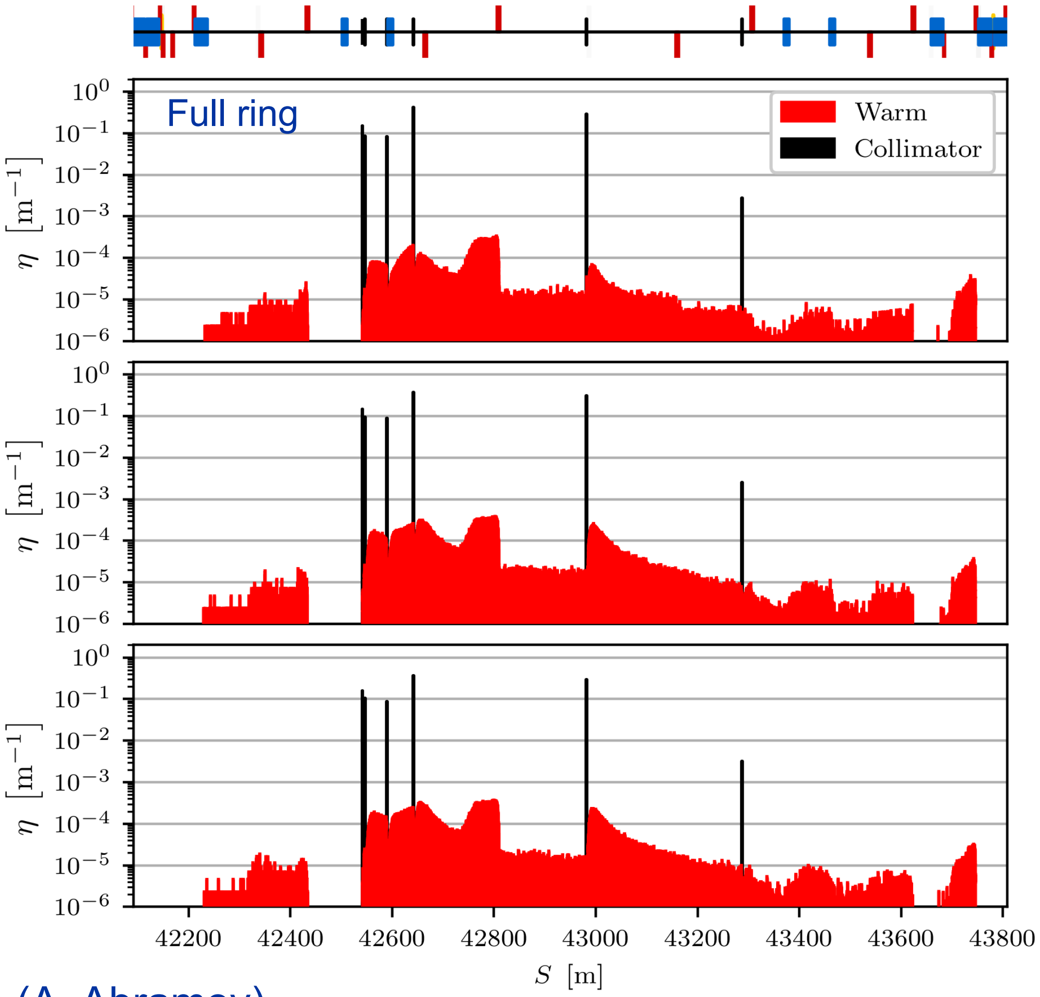
- **Loss maps** **with** **radiation and tapering** (CDR layout, parameters in FCC week 2021 talk)



pyAT-BDSIM (damping only)

Xtrack-BDSIM (damping only)

Xtrack-BDSIM (quantum fluct.)

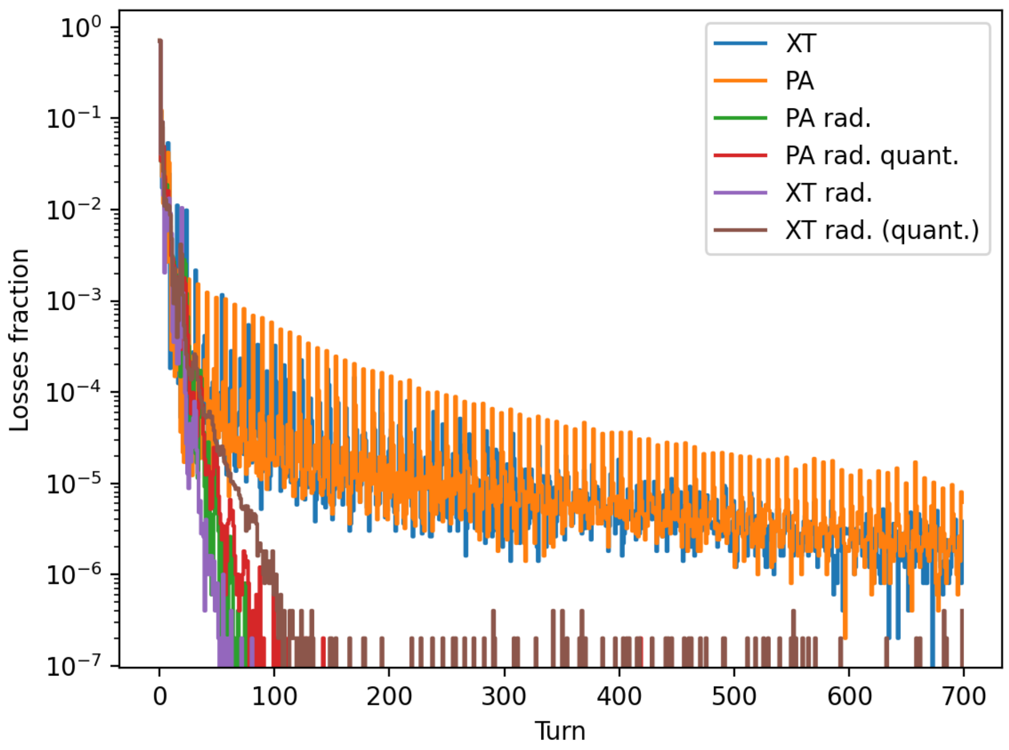


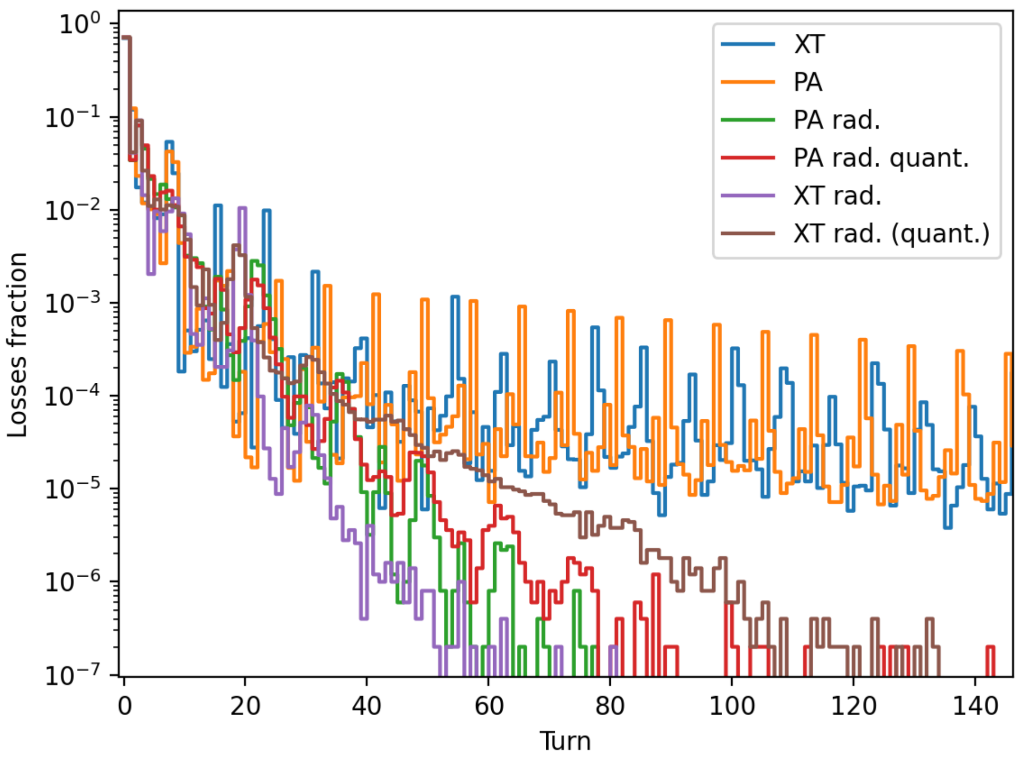
See IPAC'22 contribution (A. Abramov)

***pyAT results with quantum fluctuations not shown**

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

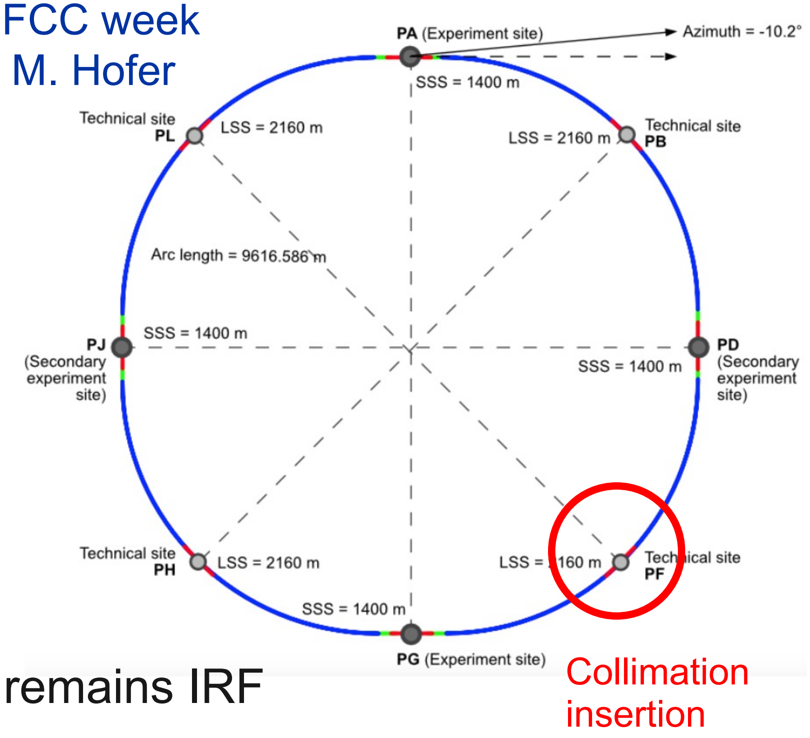




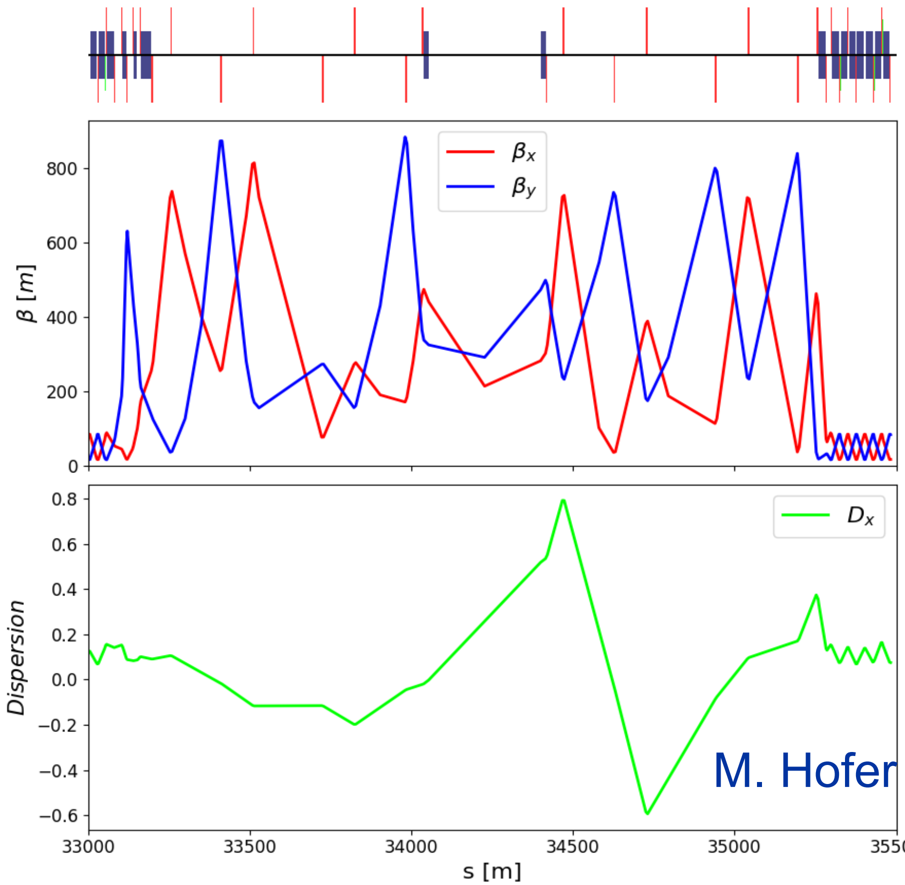
Collimation for the 4 IP layout

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

see FCC week talk, M. Hofer



Collimation insertion optics for the ttbar mode (182.5 GeV)



- **Optics for collimation**
  - The collimation insertion remains IRF
  - Optics for a split halo collimation system implemented (M. Hofer)
    - Betatron collimation upstream of crossing
    - Off-momentum collimation downstream of crossing
    - For details see IPAC'22 contribution (M. Hofer)

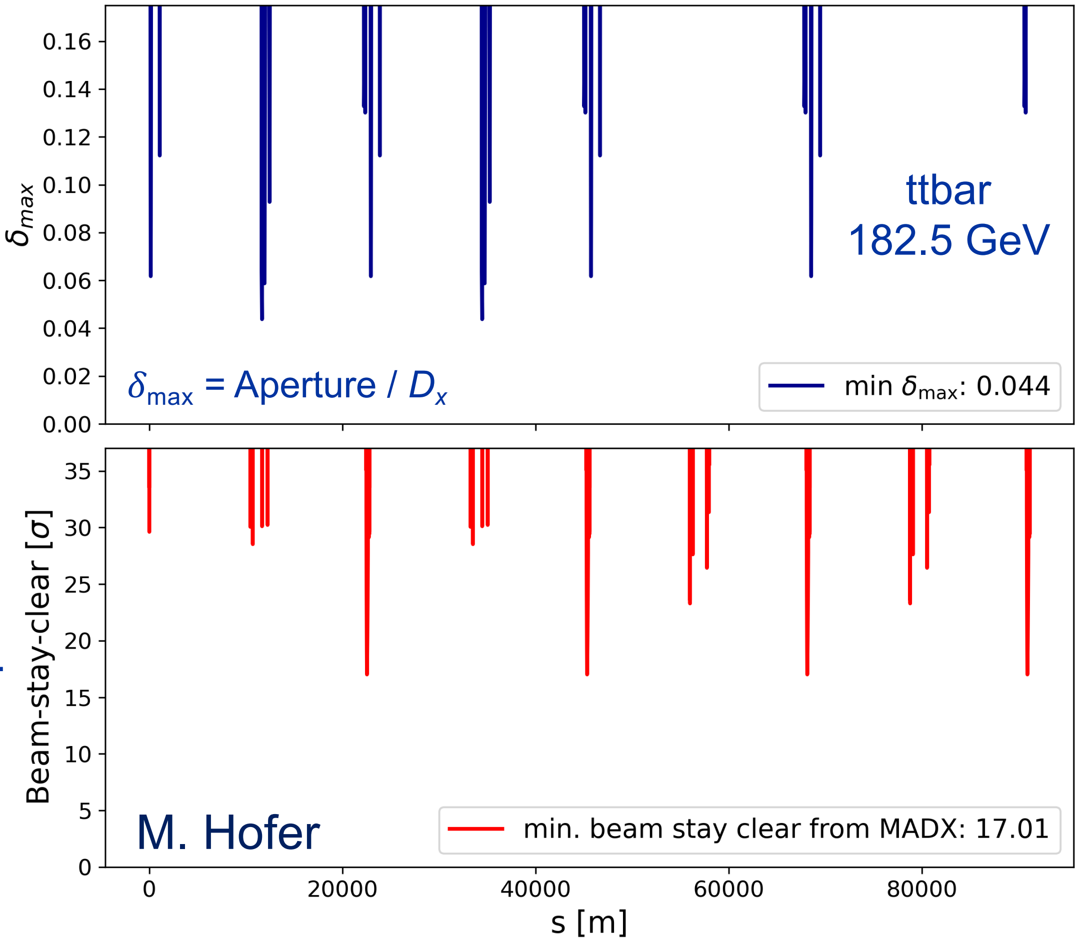
FCC-ee optics repository: link
FCC-ee collimation optics repository: link

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

WORK IN PROGRESS

Aperture with tolerances

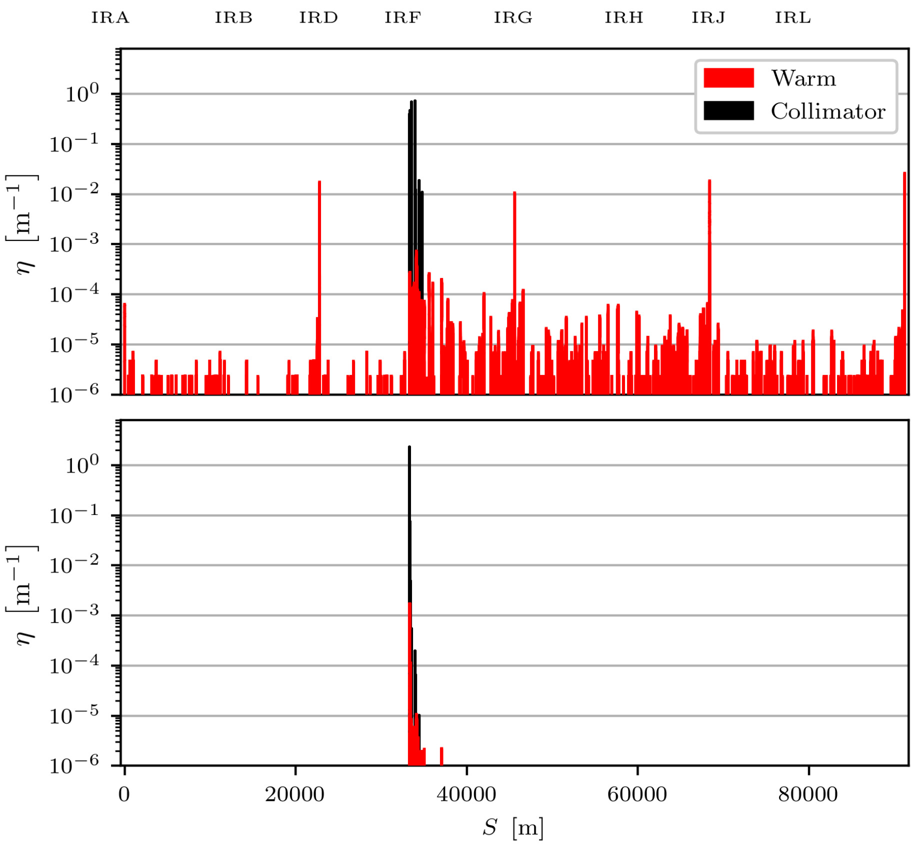


Collimators

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	Sec.	H	MoGr	0.4	23
TCS.HP1.B1	Sec.	H	Mo	0.3	26
TCS.HP2.B1	Sec.	H	Mo	0.3	26

Loss map studies

- **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, 5x10^6 primary positrons, 700 turns, 1 μm impact parameter

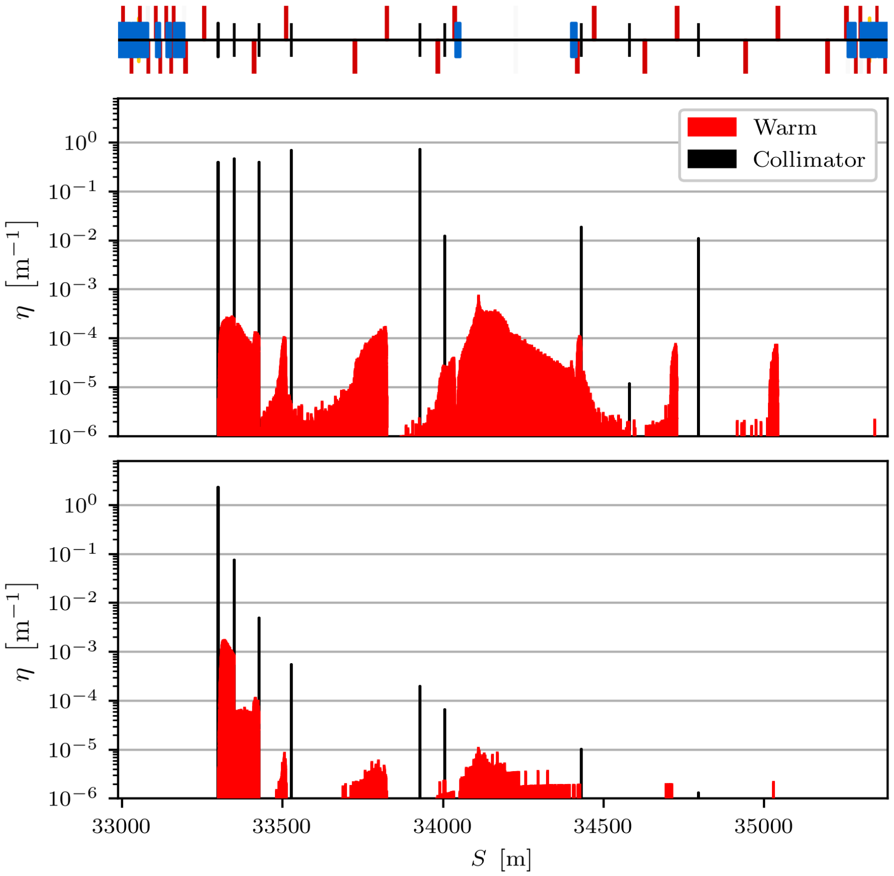


PRELIMINARY

Molybdenum-Graphite primary collimator

Tungsten primary collimator

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

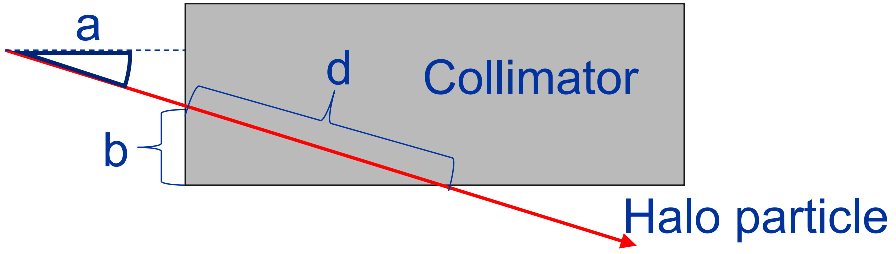


Loss map studies

- **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) talk, P. Kicsiny
  - Include synchrotron radiation collimators (in collaboration with the MDI team) talk, K. Andre
  - Evaluate the collimation performance with beam loss scenarios and equipment loss tolerances

Thank you!