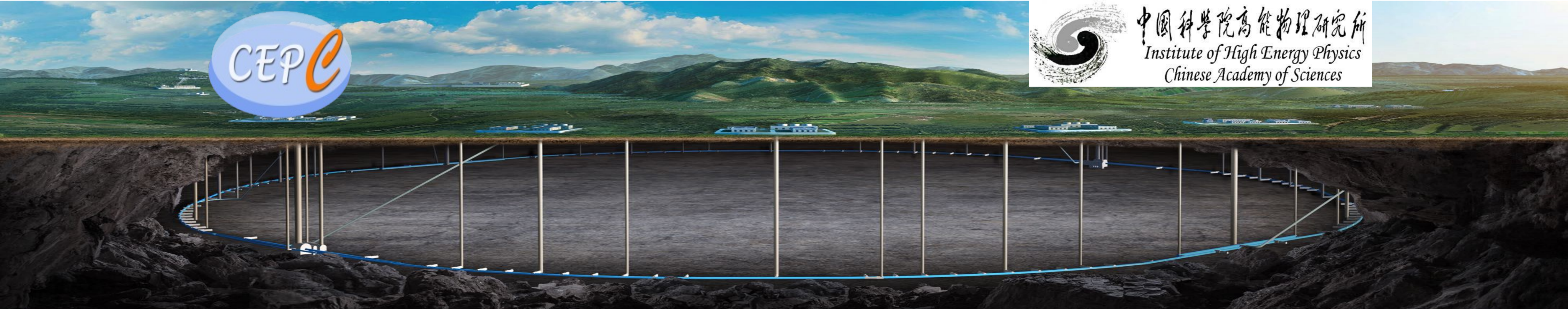

CEPC beam loss and machine protection considerations

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Supervisor: Yuhui Li

Dec 8 , 2023

Content

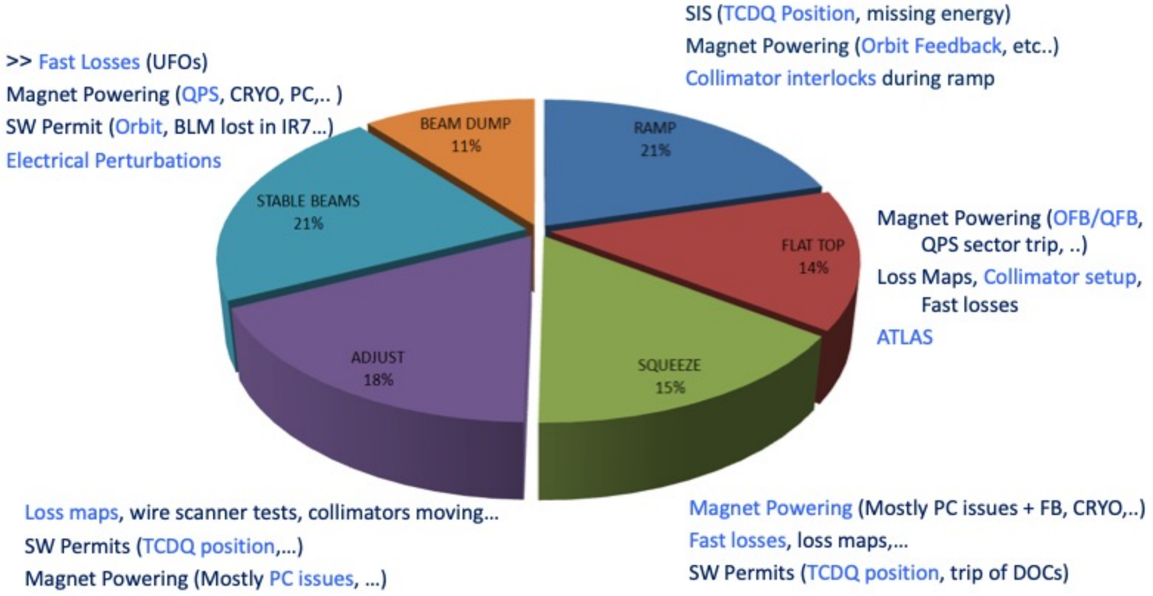
- **Motivation—Collimation for CEPC**
- **Current arrangement of collimators**
- **Beam dynamic simulation**
- **SAD-FLUKA coupling**
- **Impedance**
- **Summary**

Motivation—Collimation for CEPC

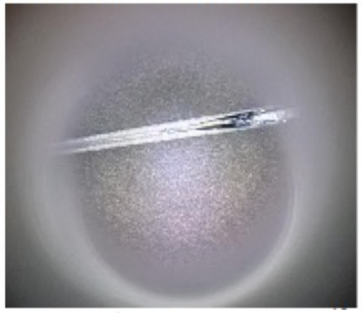
- CEPC is e^+e^- collider designed for 4 beam operation modes
  - The energy stored in the machine is very high, compared to other lepton colliders
  - Such beam is highly destructive
- Machine Protection
  - ➢ Global equipment protection
  - ➢ Reduce the background near IP
  - ✓ Active protection (beam dump)
    - ✓ CEPC active machine protection system can only work for the beam failure of time scale larger than 1ms
  - ✓ passive protection(collimators, shielding…)
    - ✓ Very fast beam loss, synchrotron radiation (SR)…

Table 1: Parameters for the CEPC machine protection

	Higgs	*Z*	*WW*	$t\bar{t}$
Beam Energy (GeV)	120	45.5	80	180
Bunch Population/10^{10}	13	21.4	13.5	20
Number of Bunches	446	13104	2162	58
Total Energy (MJ)	1.1	20	3.7	0.33



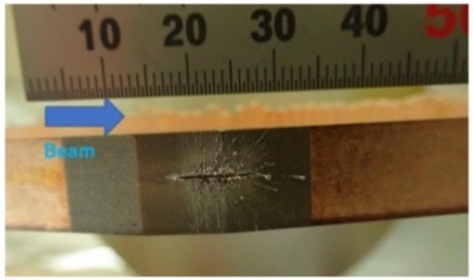
Damaged tip of D09V1 (KEKB type) in HER due to the sudden beam loss



[1]T. Ishibashi and S. Terui, SuperKEKB collimator design, FCC-EIC Joint & MDI Workshop 2022

Damaged jaw of D06H3 in LER due to the accidental-firings

Damaged jaw of D02V1 in LER due to the sudden beam loss



[2] M. Zerlauth, Do we understand everything about MP system response, LHC beam operation workshop, 2010

Fig.2 Damage to collimator jaw due to accident beam loss in the SuperKEKB

- **Motivation—Collimation for CEPC**
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Arrangement of the collimators

- **Consideration of collimation installation(where is the better position to install collimator):**

  Safeguarding IR region, cleaning efficiency, Impedance, different operation modes, beam lifetime

  ----Larger beta function

  ----Drift

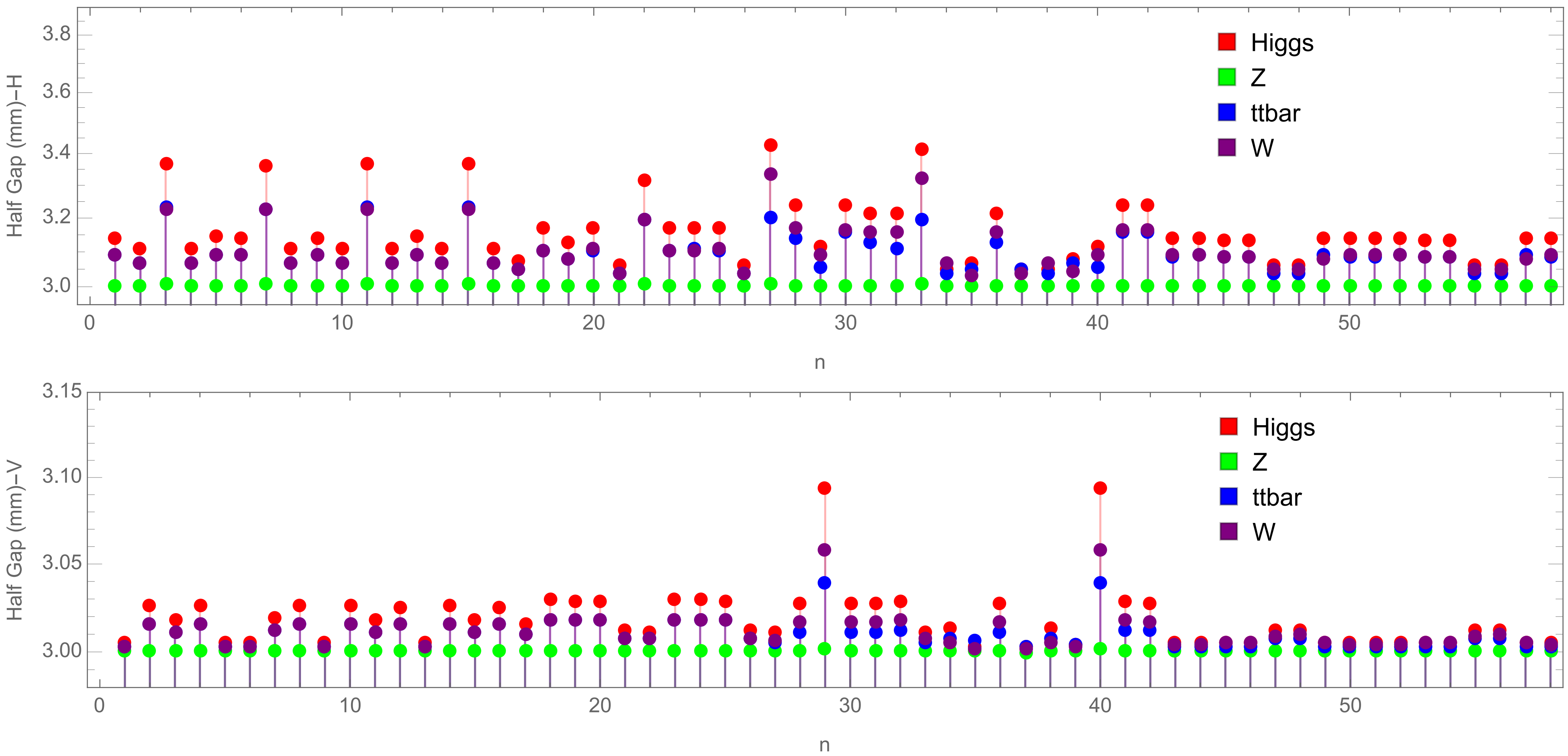
  ----Gaps of collimators > beam-stay-clear region

  ----Moveable collimator

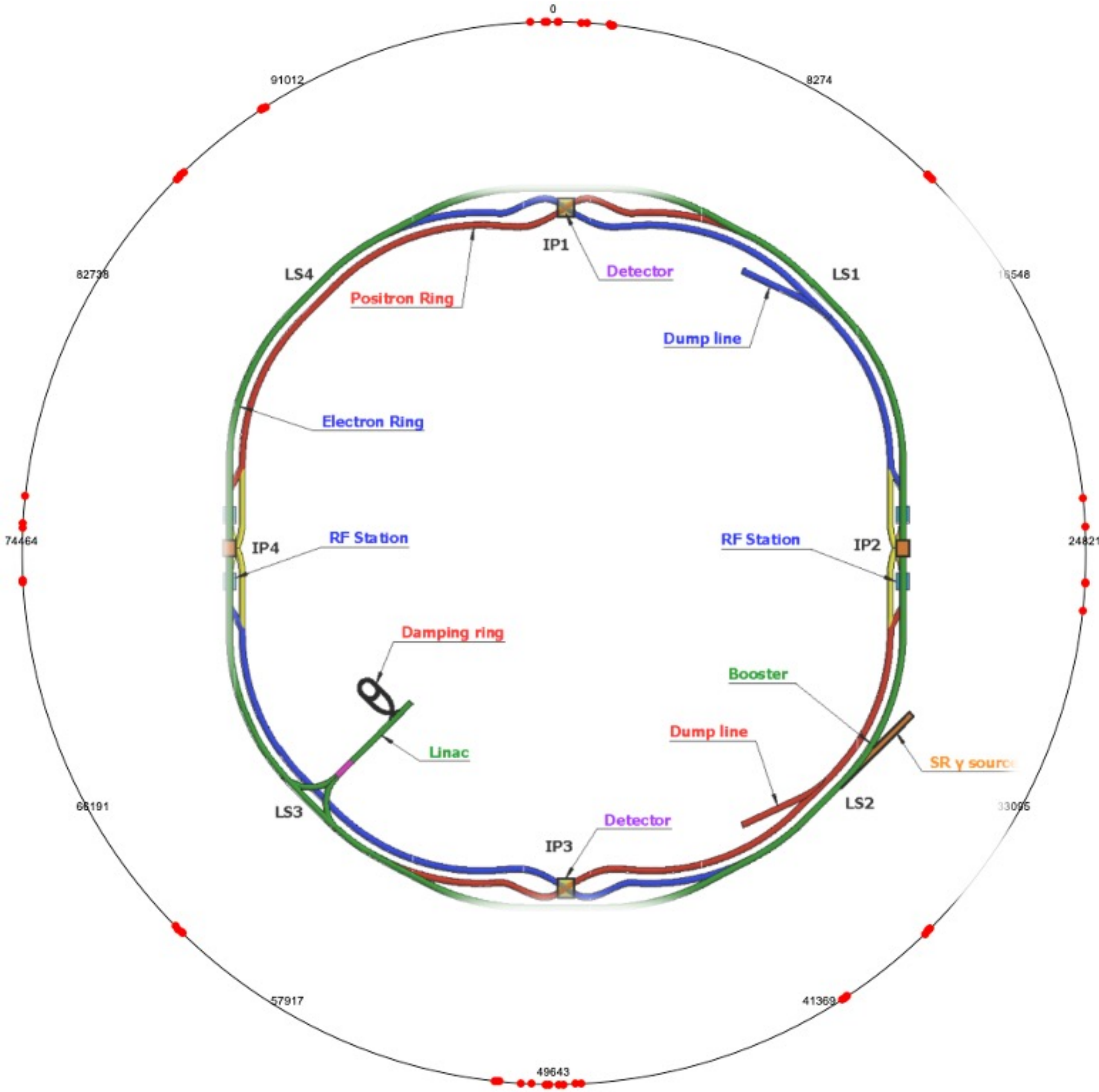
- **Current arrangement (58 collimators (14 moveable collimators) in the single ring)**

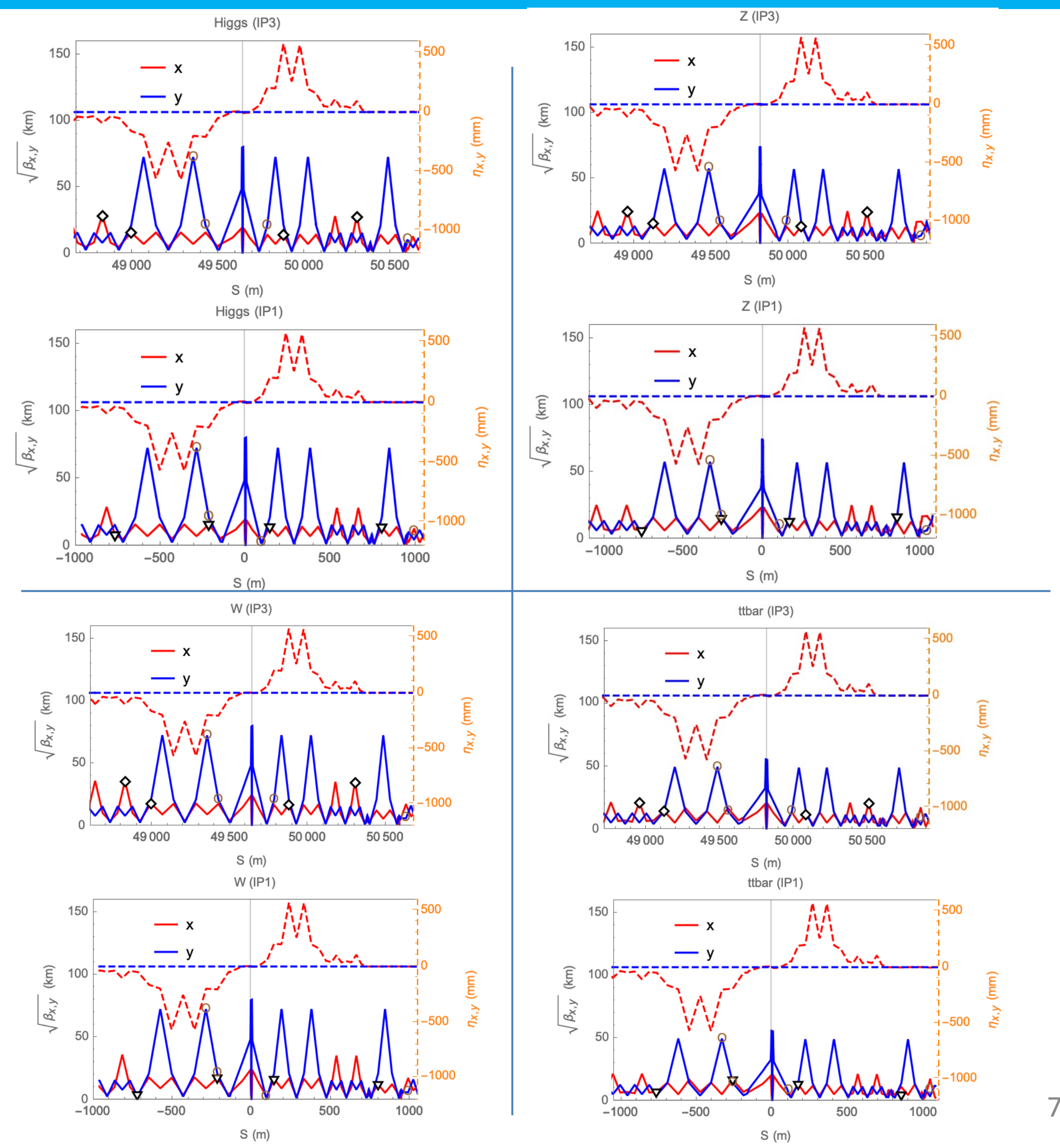
  - Three horizontal and two vertical collimators are installed upstream and downstream of RF stations, totaling 10 collimators. In each region, the first horizontal and vertical collimators are moveable.
  - Two horizontal and vertical collimators are installed for both LS1, LS2, LS3, and LS4, totaling 16 collimators. In each region, the first horizontal and vertical collimators are moveable.
  - Four horizontal and vertical collimators are installed upstream and downstream of IPs for the MDI purpose, which has already been studied. This amounts to 16 collimators for MDI purpose.
  - Four horizontal and four circular collimators are installed upstream and downstream of IPs for machine protection, totaling 16 collimators.

Beam-stay-clear region



Arrangement of the collimators





- **Motivation—Collimation for CEPC**
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SAD simulation—aperture model

- Aperture model around the collider ring is required in the simulation.
- Pipe radius in MDI can be found in the following figure. Except for MDI, pipe radius is 28 mm.

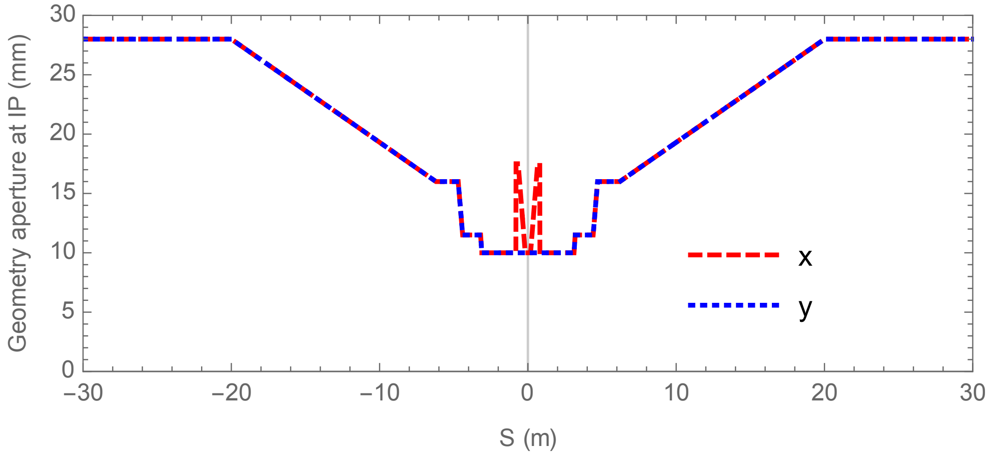


Figure 1. Aperture model at IPs

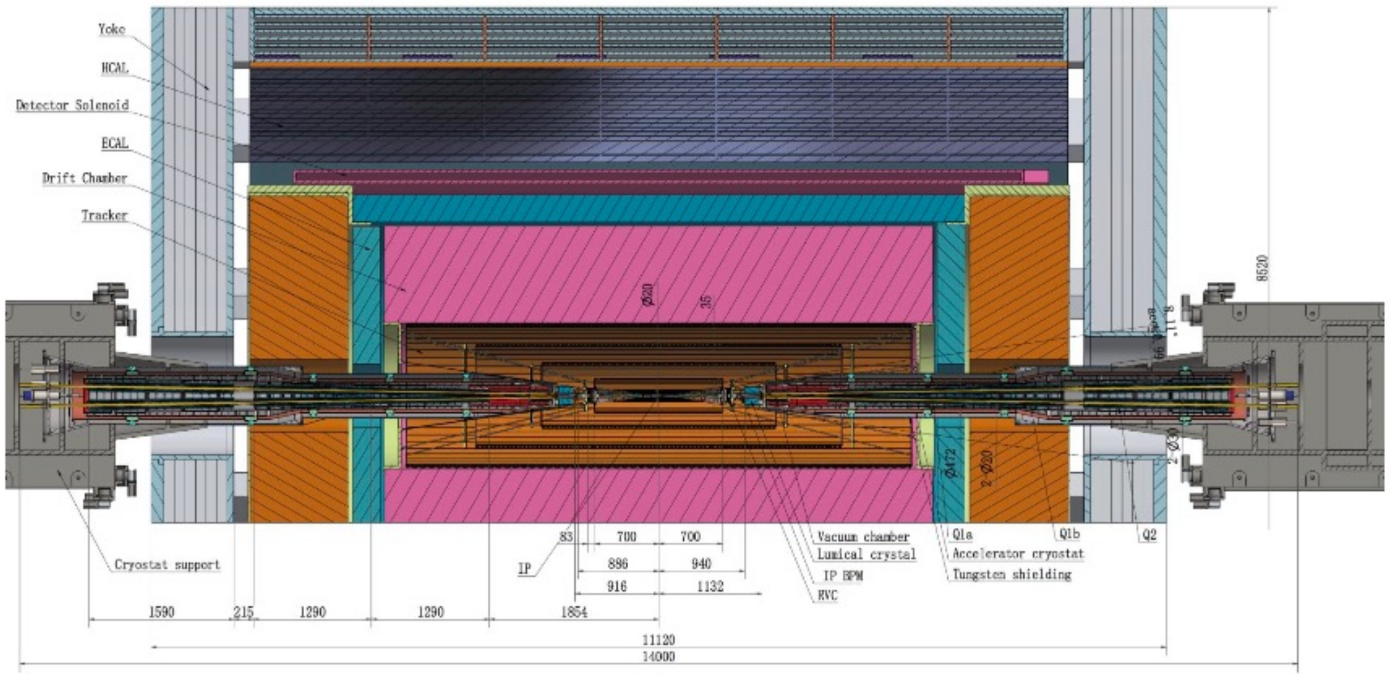
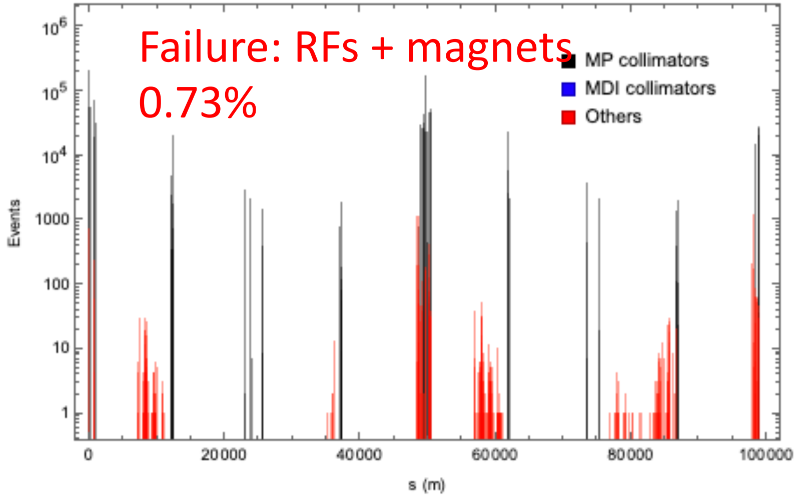


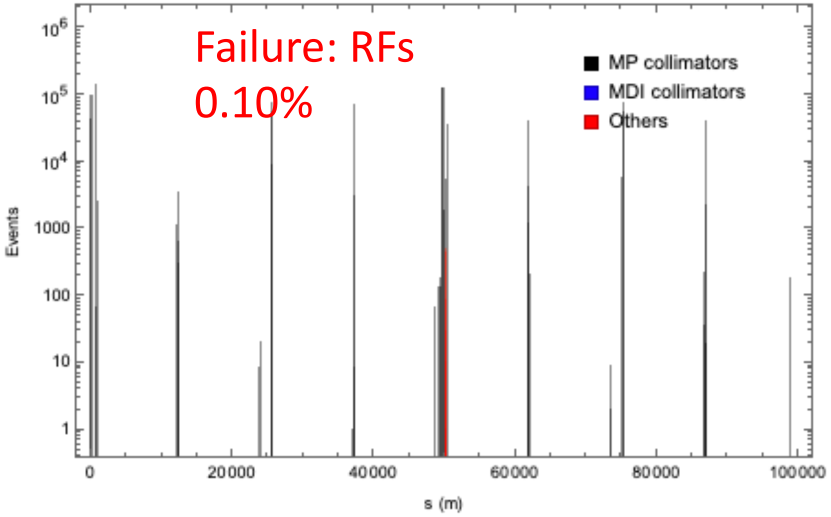
Figure 2. CEPC MDI layout

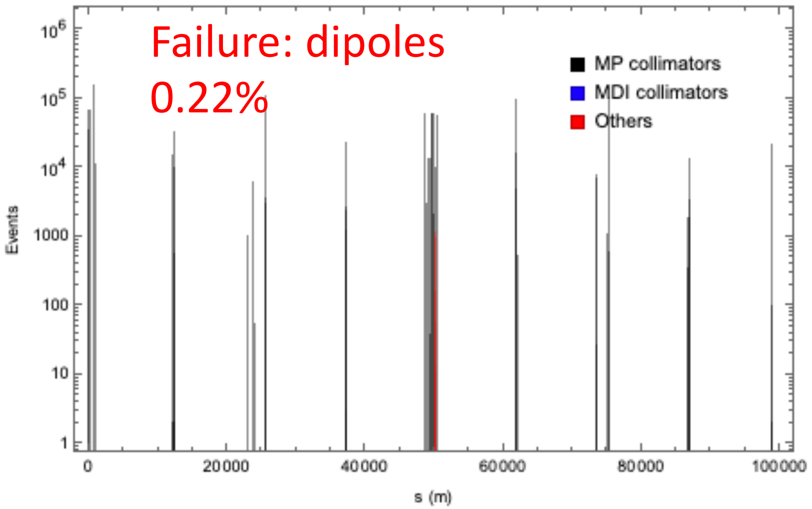
SAD simulation--failure case

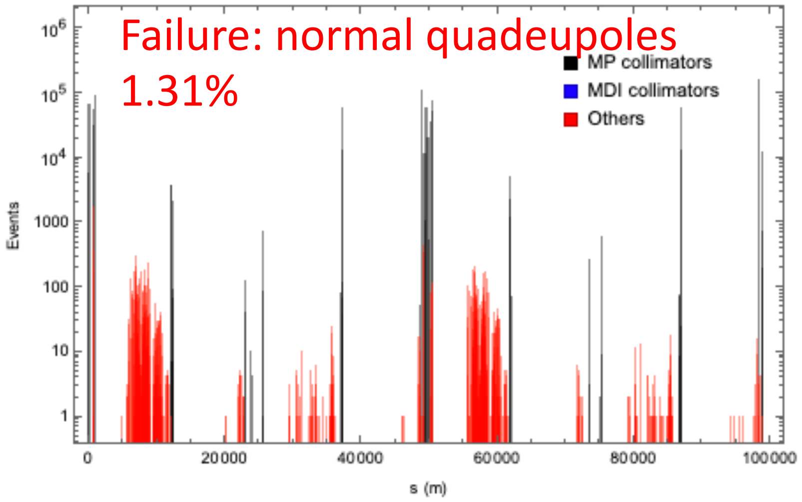
- **Scenarios of the fast equipment failures (Four modes)**
- **In current simulation, different starting points (LS1,LS2,LS3,LS4 and arc regions) are considered to provide a comprehensive analysis**
  - Critical RF failures — $\tau \approx 773\ \mu s$ — J.Y Zhai
  - Quenches of superconducting quadrupole magnets — τ: $10 \sim 100\ ms$ — Y.S Zhu
  - Powering failure of normal magnets — τ: $10 \sim 100\ ms$ — B. Chen
    - bending magnets
    - quadrupole magnets
    - sextupole magnets
- **Failure model:** $Q = Q_0 e^{-t/\tau}$
- **Single passage for CEPC ~ 331 μs**
- **$\tau = 10\ ms$ for the magnet failures**

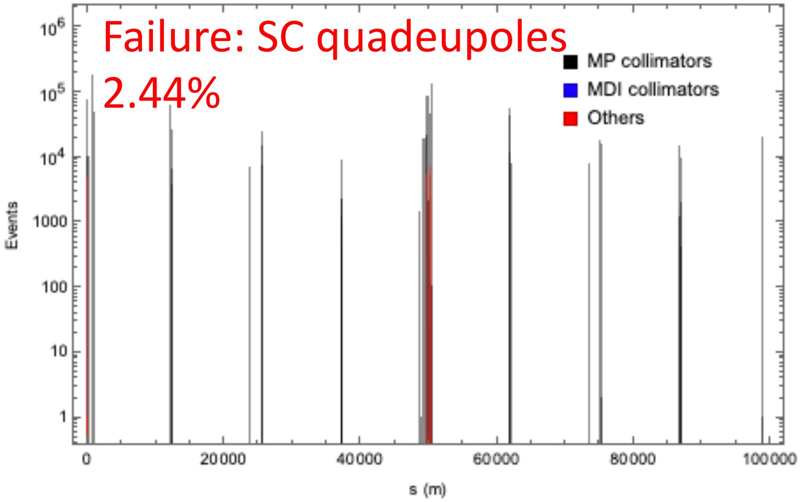
Higgs modes

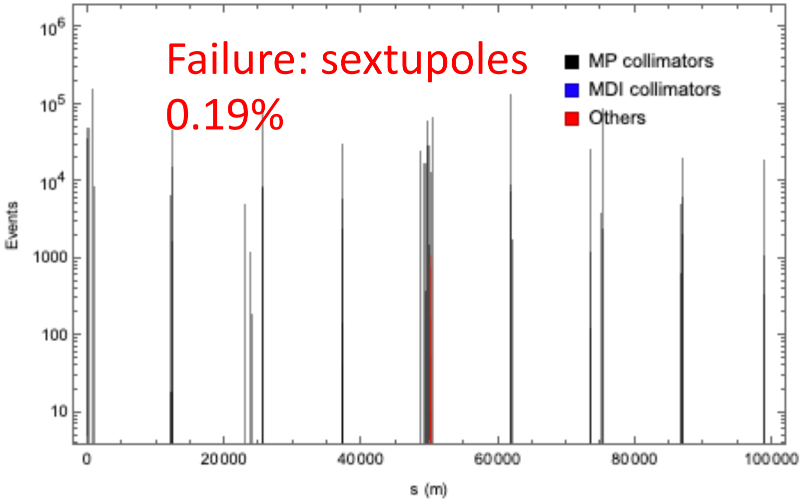

Failure: RFs + magnets
0.73%
MP collimators
MDI collimators
Others
Events
s (m)


Failure: RFs
0.10%
MP collimators
MDI collimators
Others
Events
s (m)

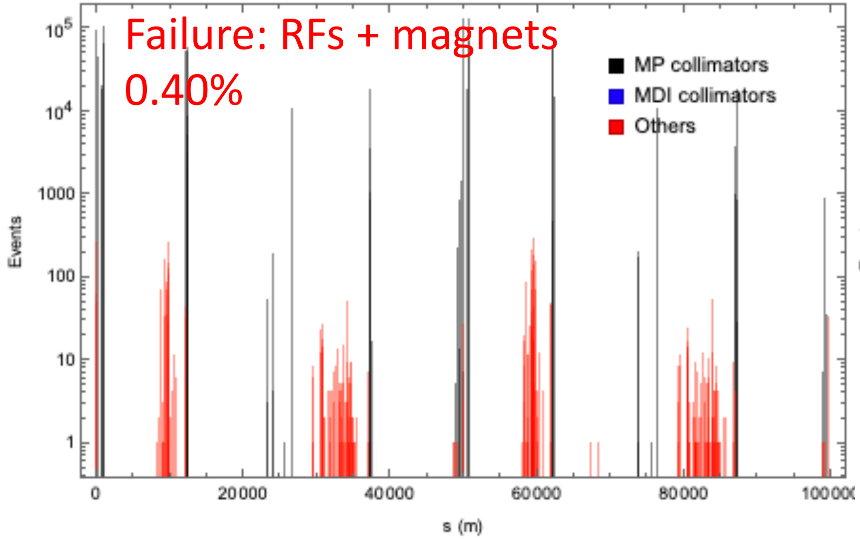

Failure: dipoles
0.22%
MP collimators
MDI collimators
Others
Events
s (m)

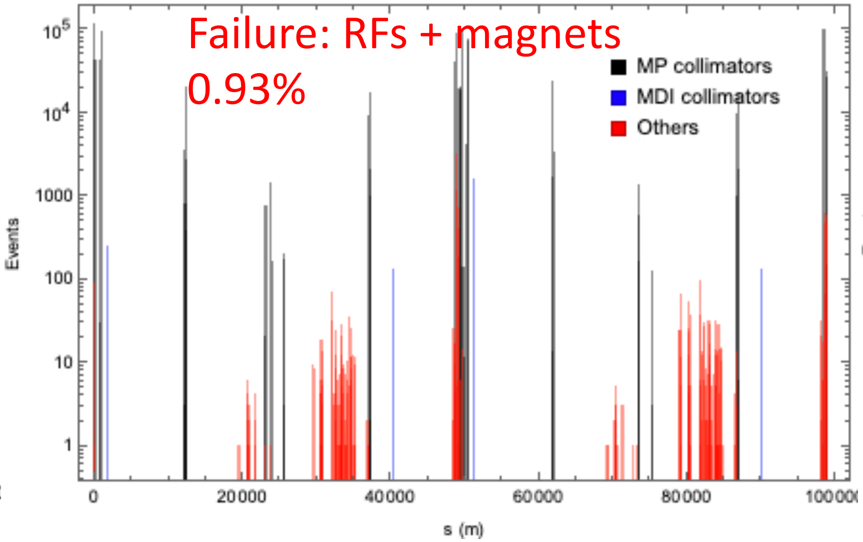

Failure: normal quadeupoles
1.31%
MP collimators
MDI collimators
Others
Events
s (m)

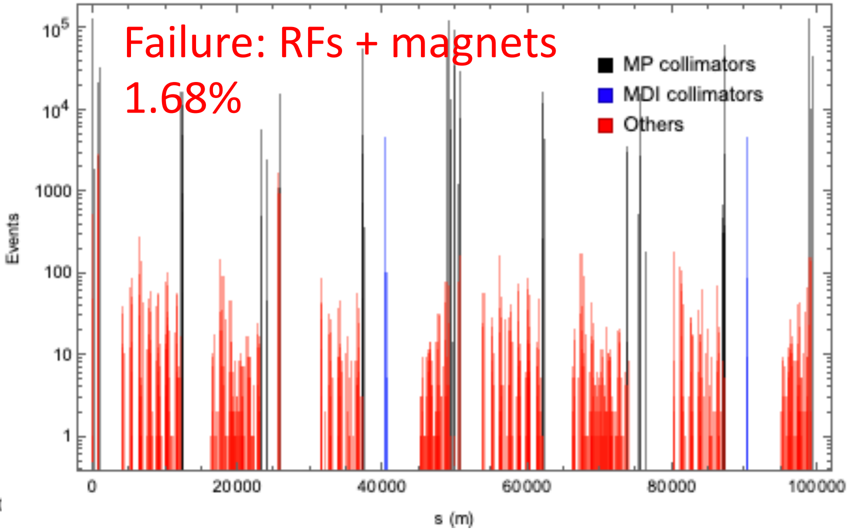

Failure: SC quadeupoles
2.44%
MP collimators
MDI collimators
Others
Events
s (m)

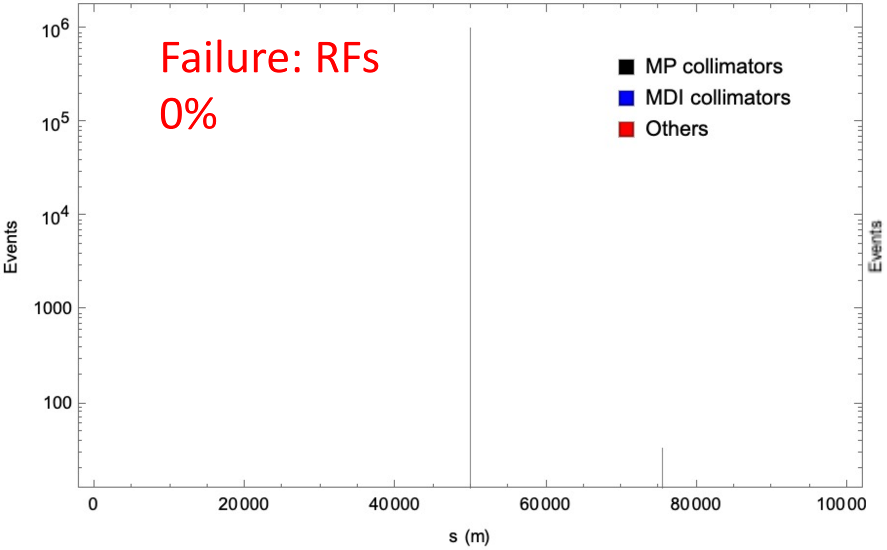

Failure: sextupoles
0.19%
MP collimators
MDI collimators
Others
Events
s (m)

Z   W   ttbar

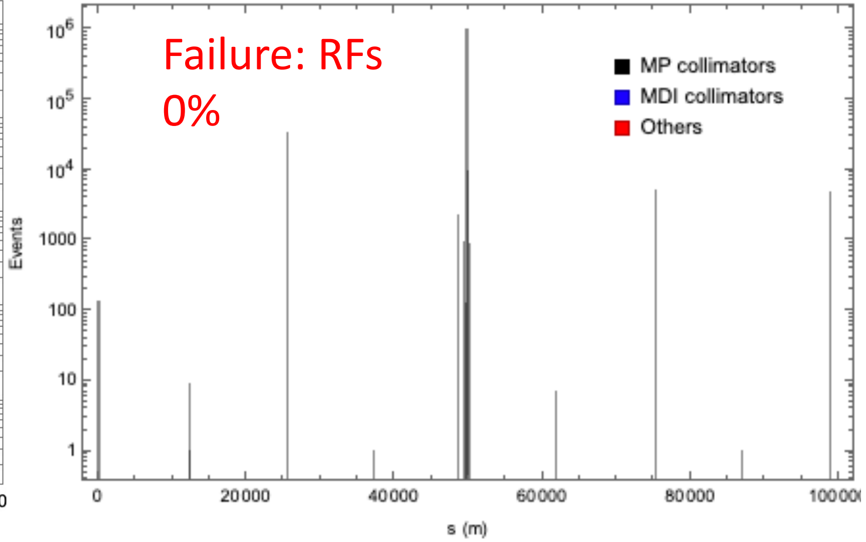


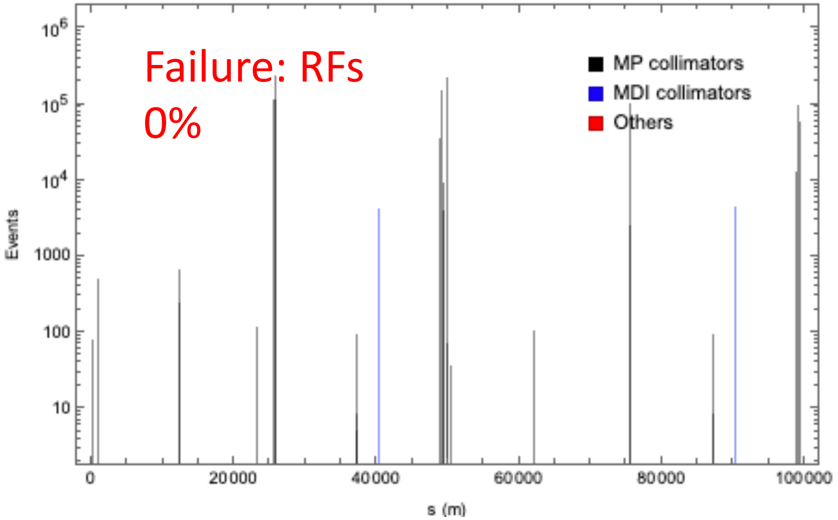






>8 turns





- **Motivation—Collimation for CEPC**
- **Current arrangement of collimators**
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- **SAD-FLUKA coupling**
- **Impedance**
- **Summary**

SAD-FLUKA coupling

- SAD is responsible for tracking the electron throughout the full lattice, while FLUKA simulates the electron-matter interactions within the collimators.

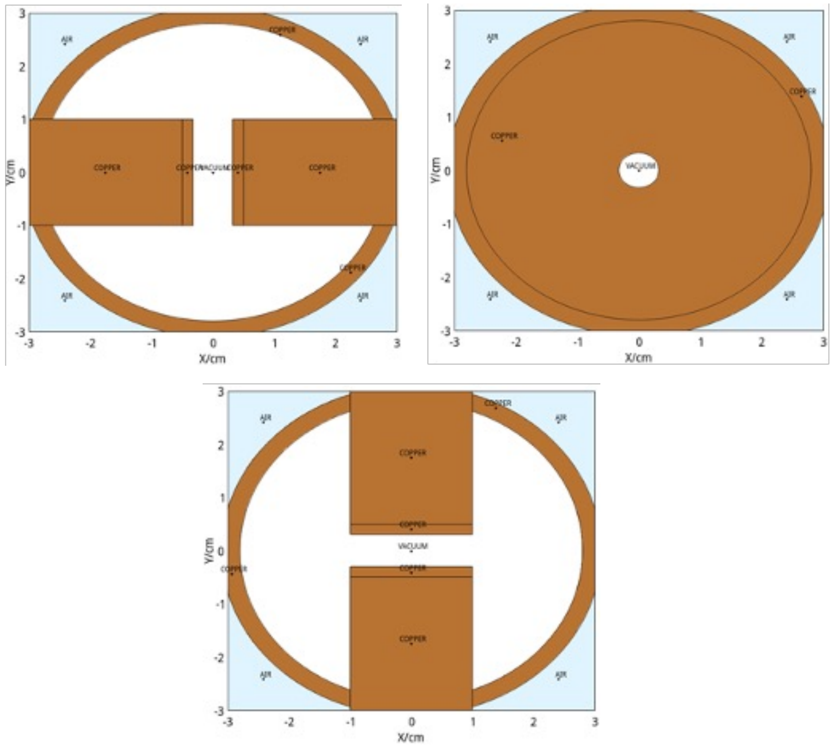


Fig 1. Three types of collimator models

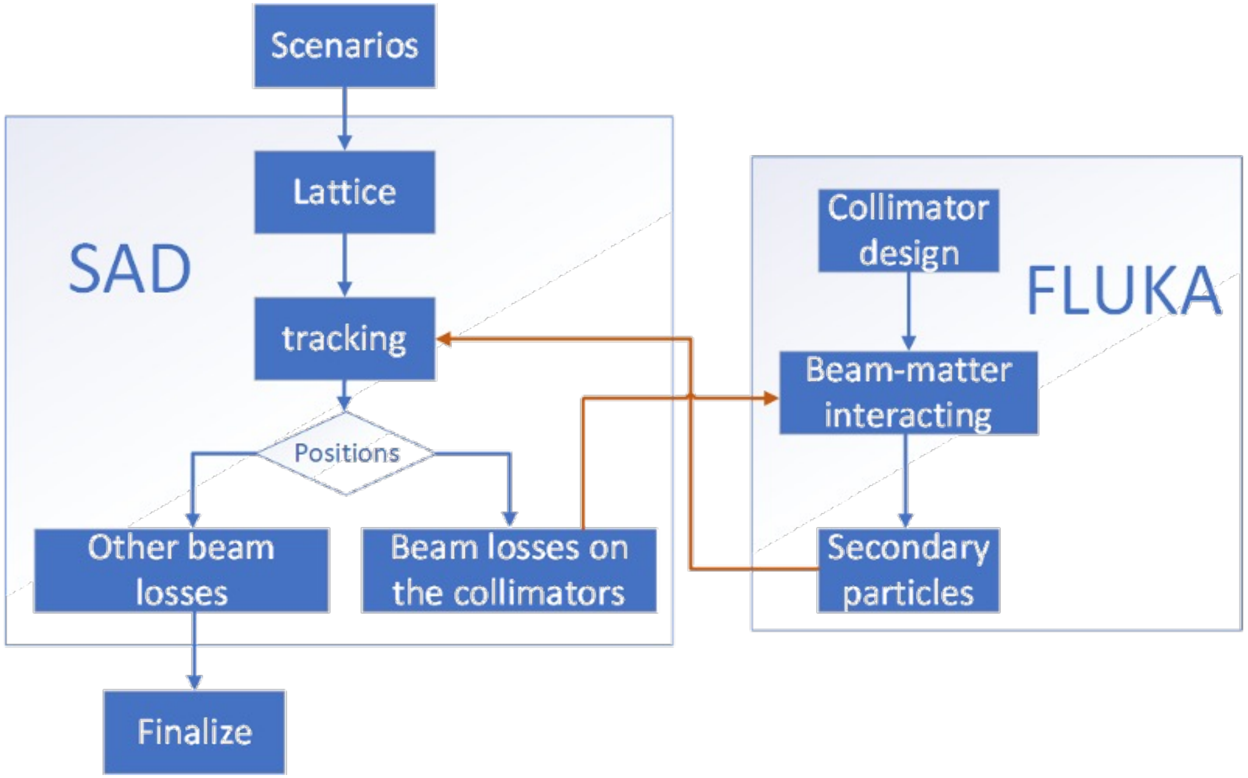
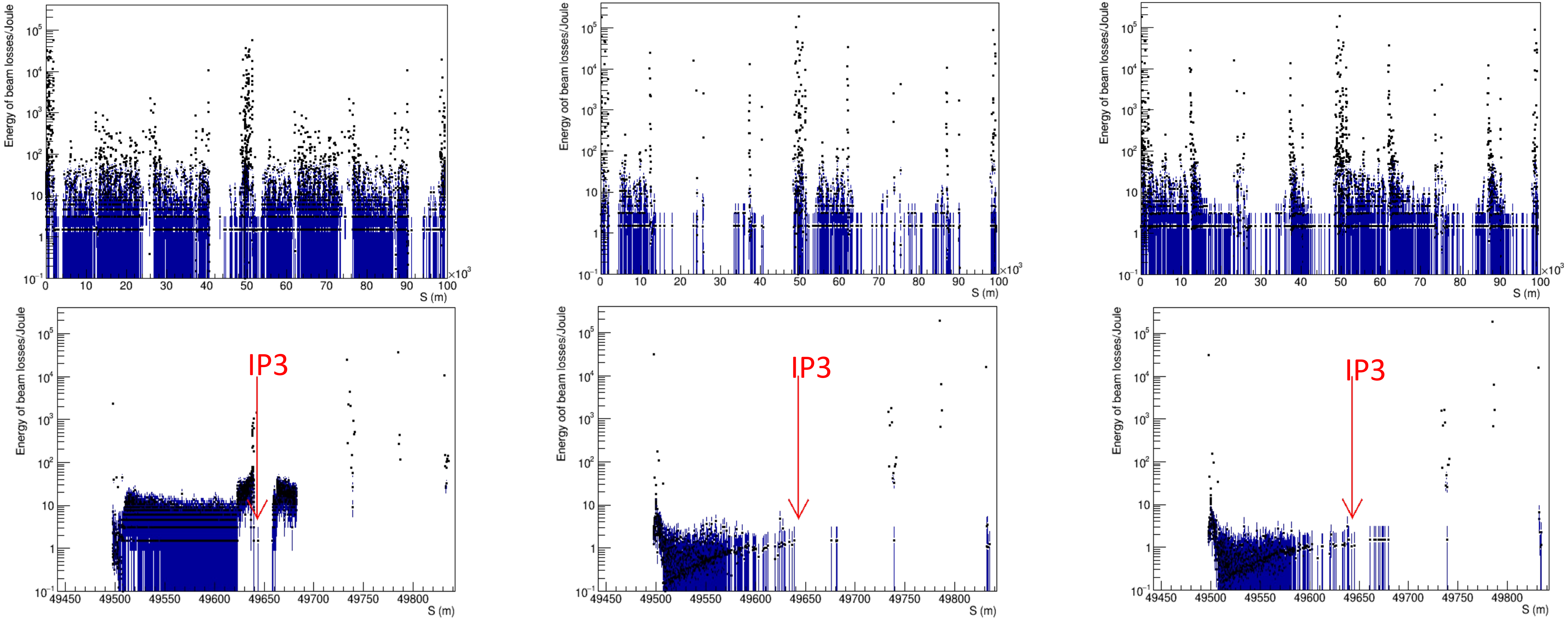


Fig 2. Workflow for SAD-FLUKA coupling

Heat deposition @Higgs: failure of all components

16 MDI collimators (Copper) | 58 collimators (Copper) | 58 collimators (MoGr)



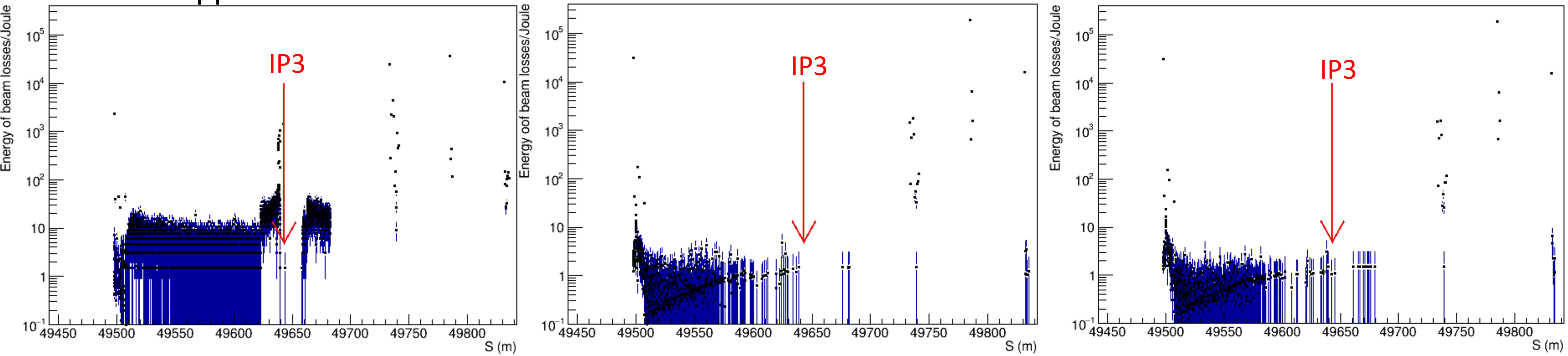
The peak energy in the 58-collimator case decrease by 3 orders, compared with the 16-collimator case

Need more check, such as

- Energy depositions in the collimators, beam-pipes, etc.
- More scenarios.

@Higgs: around IP3

- 16 MDI collimators made of copper.
- 58 collimator made of copper.
- 58 MDI collimators made of MoGr.

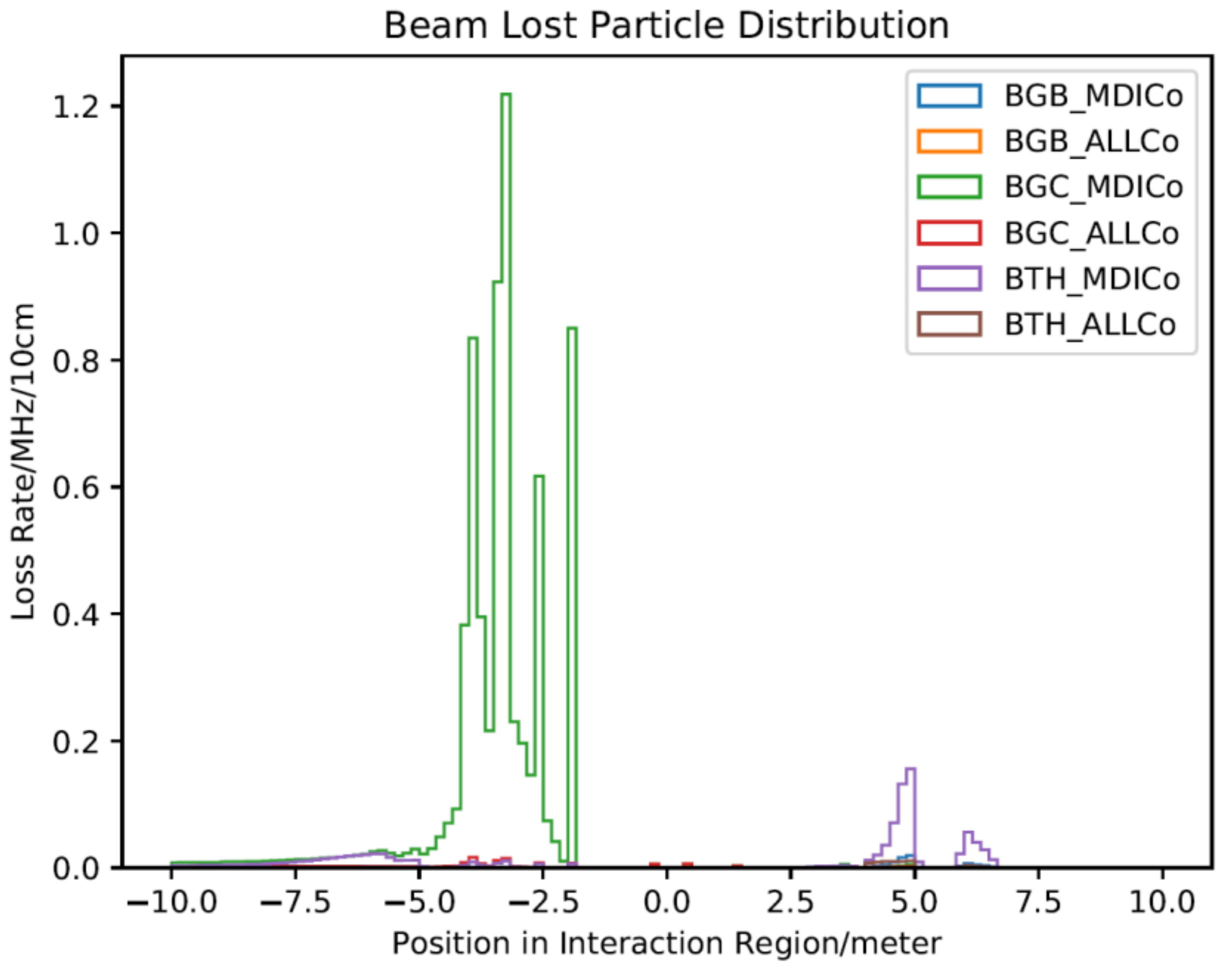


- The peak energy in the 58-collimator case decrease by 3 orders, compared with the 16-collimator case
- Need more check, such as
  - Energy depositions in the collimators, beam-pipes, etc.
  - More scenarios.
- Will optimize the collimator parameters.

Background @Higgs

- Beam induced background
  - Beam-gas bremsstrahlung
  - Beam-gas coulomb
  - Beam thermal photon

H.Y Shi



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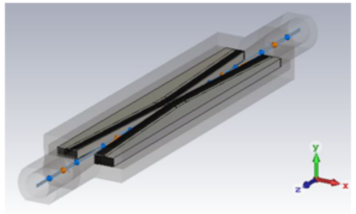
Impedance

- Impedances of collimators have been preliminarily optimized compared with the impedances shown in CEPE2023 [1].

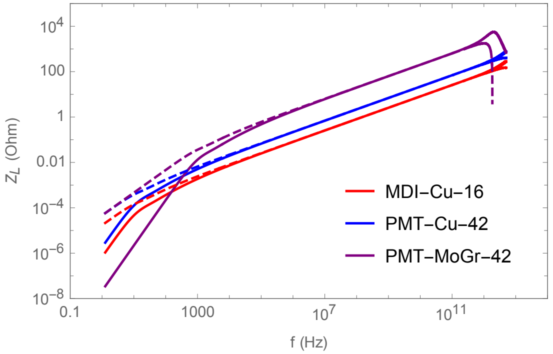
- Impedance evaluation of the preliminary design of the collimators for the machine protection
  - 18 horizontal+12 vertical extra collimators
  - Rough estimation take the same impedance model as for the IR region (with collimator jaw gap of 4.4mm)

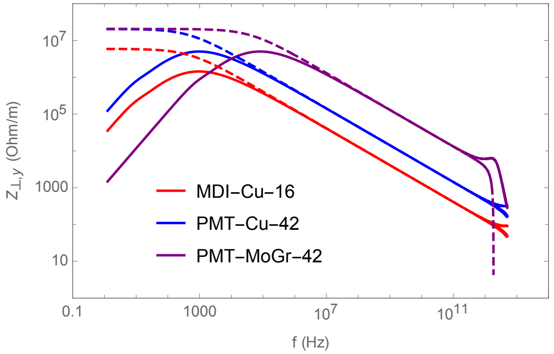


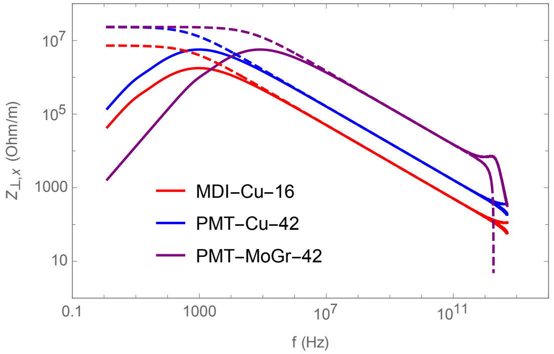
- ☐ Their contributions to the transverse broadband impedance is the main concern → Comparable to the total TDR transverse impedance budget ⇒ further optimizations are required.
- ☐ Their contributions to the longitudinal impedance budget are trivial.

Vertical dipolar impedance [2,3]

Conductivity	
Cu	MoGr
58 MS/m	0.96 MS/m







- The resistive wall impedance is calculated with IW2D
- The form factor of taper is considered.
- Considering that the transverse impedance scales with the cubic power of the half gap, the current contribution is substantially lower.

[1] https://indico.ihep.ac.cn/event/19316/sessions/11549/#20231023
[2] DOI: 10.1016/j.nima.2022.166928
[3] *https://github.com/amorimd/CloneIW2D*

Summary

- In the current collimator design, 58 collimators are installed in a single collider ring.
- SAD-FLUKA coupling is achieved.
- More scenarios should be taken into consideration. In addition, simulation of beam halo is required.
- Need more check, such as

  --Energy depositions in the collimators, beam-pipes, etc.
- Will optimize the collimator parameters.

Your comments and suggestions are highly appreciated!

Thanks

Backup

Methods for Simulation studies

- **Designing the collimation system requires:**
  - **The particle tracking studies**
  - **Beam-mater interaction studies**

Collider	Method (tracking)	Beam-matter interaction
SuperKEKB [1]	SAD	FLUKA
LHC [2]	SixTrack	FLUKA
FCC-hh [3]	SixTrack	FLUKA
FCC-ee [4,5]	SixTrack	FLUKA
	Xsuit [7]	BDSIM(Geant4) [6]
	pyAT/ MAD-X	
CEPC	SAD	FLUKA

[1] doi:10.18429/JACoW-IPAC2021-WEPAB358
[2] Chiara Bracco , Commissioning scenarios and tests for the LHC collimation system, CERN-THESIS-2009-031, 2009
[3] doi: 10.18429/JACoW-IPAC2019-MOPRB048
[4] https://indico.ihep.ac.cn/event/19316/contributions/143168
[5] doi: 10.18429/JACoW-IPAC2022-WEPOST016
[6] https://www.pp.rhul.ac.uk/bdsim/manual/
[7] https://xsuite.readthedocs.io/en/latest/index.html

- BDSIM is a code to make 3D models of particle accelerators using Geant4.
- Xsuite is a collection python packages for the simulation of the beam dynamics in particle

Simulation studies

- **SAD simulations – beam loss map**
  - Different scenarios
    - Optimum/acceptable/particular operating conditions:
      - Beam halo/tails, Top-up injection
      - Change of optics, tuning, collimator aperture setting, etc
    - Fast beam loss
      - Standard equipment failure, fast equipment, other accident beam loss, etc
      - Injection failure, SuperKEK fast beam loss (should be understand if possible)
    - Different operation modes
      - Higgs, Z, W, ttbar
- **FLUKA simulations**
  - Beam-matter interaction1
- **Workflow**