中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

SPPC Collimation Design

CEPC international workshop

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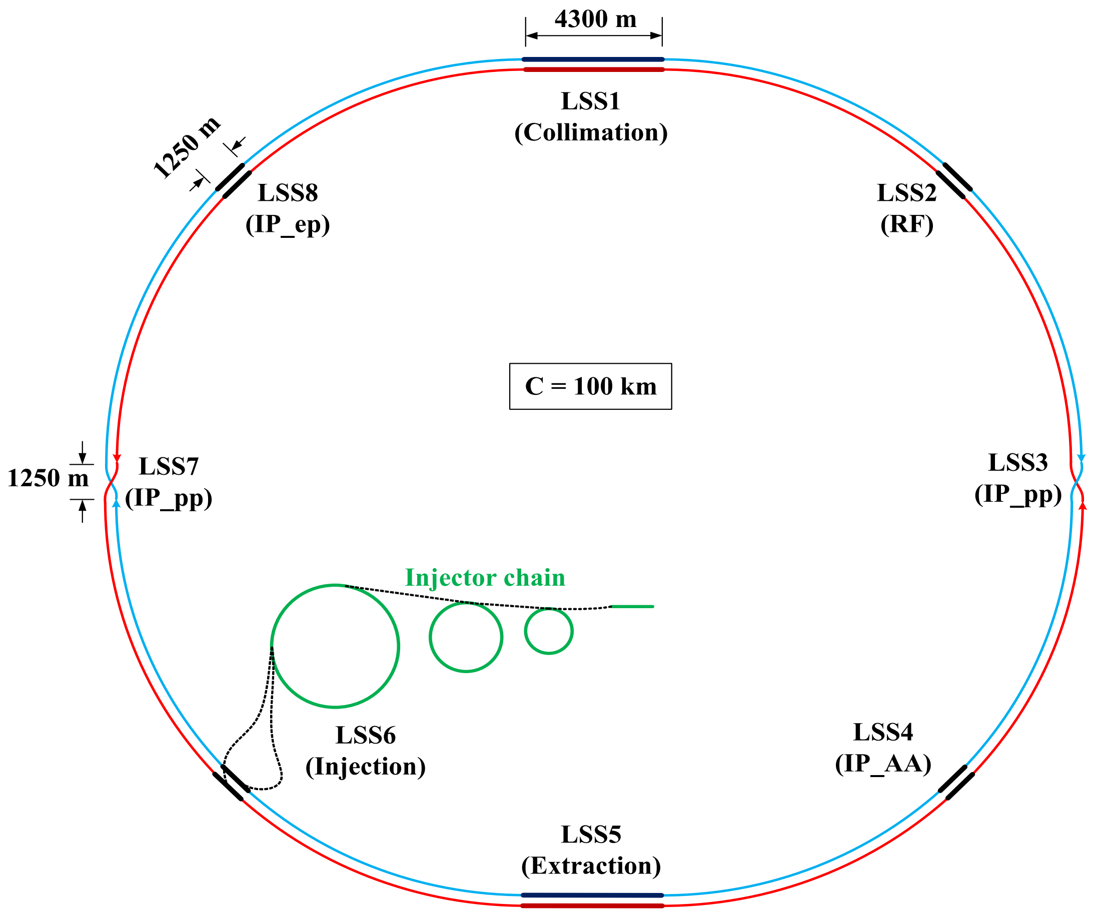
Outline

- Introduction
- Motivations and goals
- Optics design
- Multi-particle simulation results
- Protection scheme of the SC magnets
- Conclusions
- Next to do

Introduction

Layout of SPPC

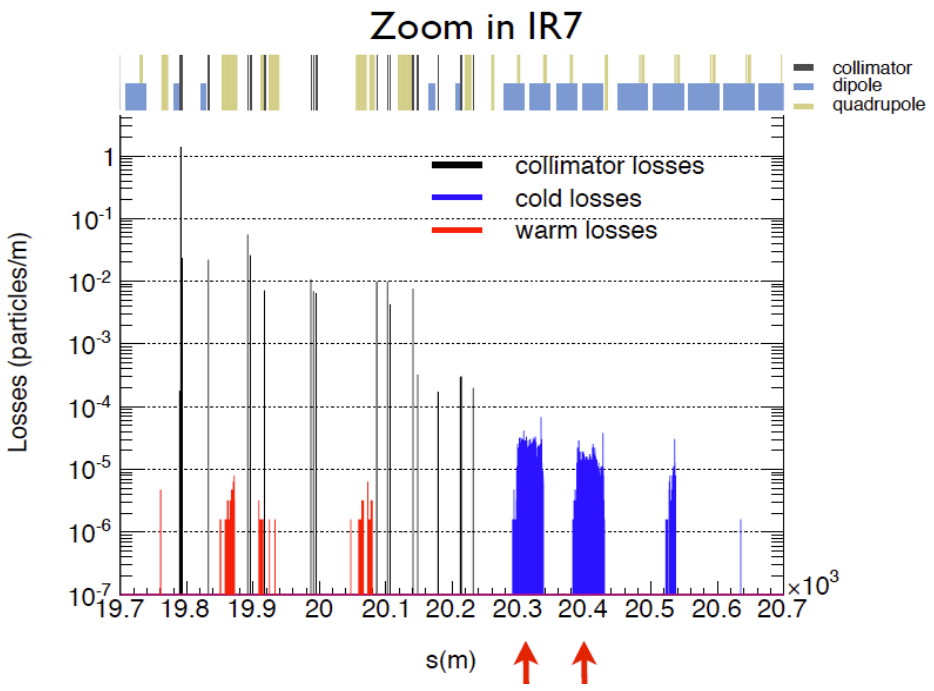


Parameter	Unit	Value
Proton energy	TeV	37.5
Nominal luminosity	$cm^{-2}s^{-1}$	1.01×10^{35}
Number of IPs	-	2
Bunch separation	ns	25
Bunch filling factor	-	0.756
Number of bunches	-	10080
Bunch population	$\times\ 10^{11}$	1.5
Normalized rms transverse emittance	μm	2.4
rms bunch length	mm	75.5
Stored beam energy per beam	GJ	9.1

Introductions

The novel collimation method

From M. Fiascaris

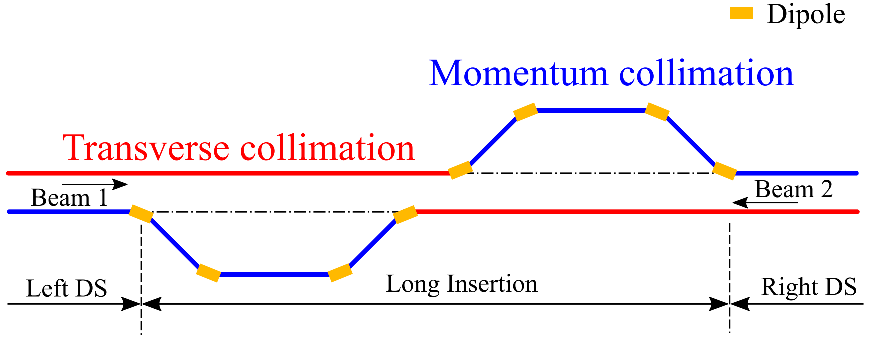


- Single diffractive scattering

$$P_1 = P_0 \cdot \frac{\sqrt{E_1} \cdot \ln(0.3 \cdot E_1)}{\sqrt{E_0} \cdot \ln(0.3 \cdot E_0)} \quad \text{With } E_1 > E_0$$

Loss from 7 TeV to 37.5 TeV factor 7

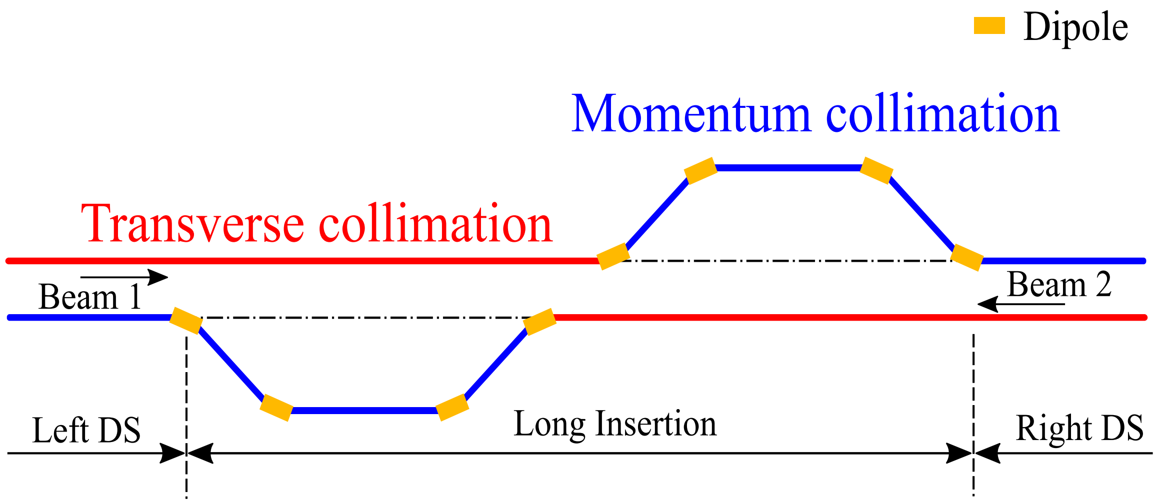
- The particles experiencing single diffractive interactions in the primary collimators will loss in the cold magnets of DS
- In order to deal with these particle losses, we can arrange the transverse and momentum collimation in the same cleaning insertion



Introduction

Novel collimation method

- Length 4300 m
- Arrange the transverse and momentum collimation in the same long straight insertion
- Four groups of SC dipoles are used to produce required dispersion for momentum collimation cancel the dispersion at the section end
- Betatron collimation requires significantly longer space for multi-stage collimation and the two proton beams
- Compatibility of two sets of collimation system for each beam needs to be considered



Motivations

Beam loss mechanism

- Regular proton losses

Blt: beam lifetime
Egt: emittance growth time

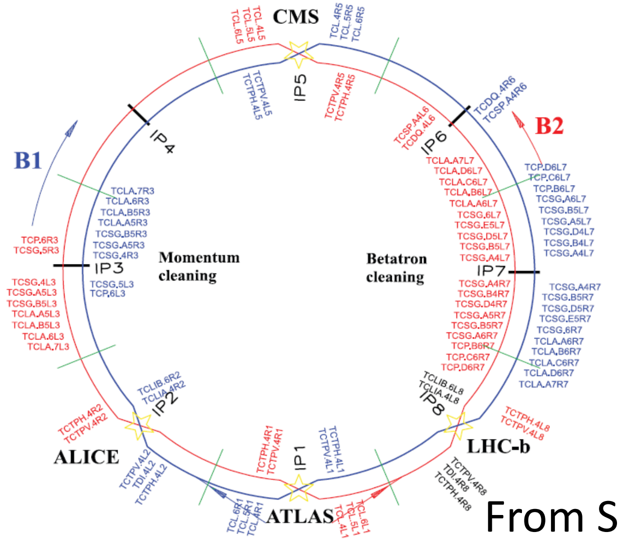
	Injection energy	Collision energy
IBS: blt	~40 h	~ 170 h
Touschek: blt	~8000 h	~ 30000h
Beam-gas: egt	~35 h	~ 800 h
Beam-Beam collision: egt		~120 h

- Irregular proton losses
  - Operational errors
  - Equipment failures

Motivations

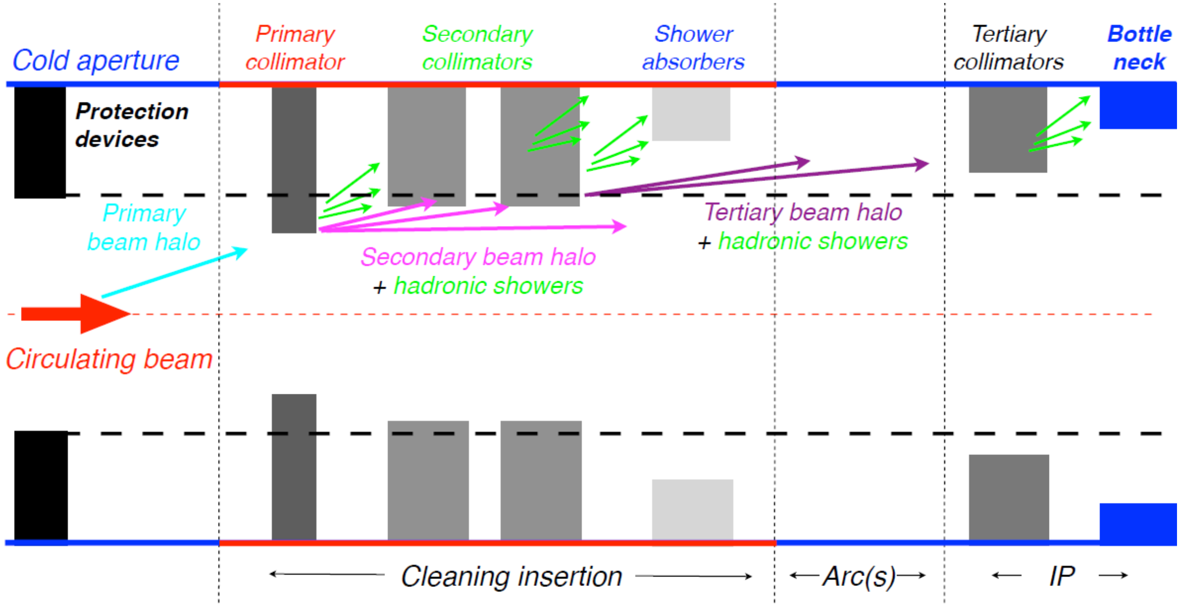
Multi-stage collimation method

- 98 two-sided and 2 one-sided movable collimators;
  396 degrees of freedom
- Two warm interaction regions are used to provide betatron and momentum collimation



From S. Redaelli

- Primary collimators scatter the primary halo
- Secondary collimators intercept and stop part of the scattered particles
- Absorbers stop the showers
- Tertiary collimators protect the SC dipoles or Quadrupole triplets in IP
- TCLs absorb physics debris



Goals

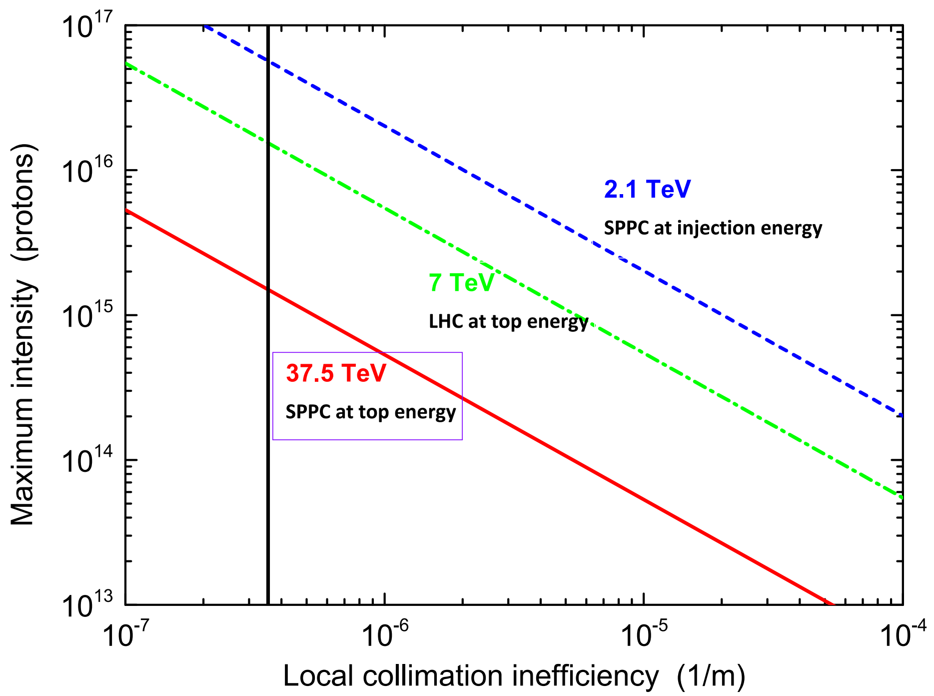
Collimation efficiency

Main functionality

- Quench prevention:

$$\tilde{\eta}_c = \frac{\tau_{\min} \cdot R_q}{N_{tot}^q} \qquad R_q = 1.7 \cdot 10^8 E^{-\frac{3}{2}}$$

for SPPC: $\tilde{\eta}_c < 3.55 \times 10^{-7}\ \mathrm{m}^{-1}$



- Halo particles cleaning
- Machine protection: prevent damaging radiation-sensitive devices
- Radiation losses concentration: hands-on maintenance
- Cleaning physics debris: collision products
- Optimizing background: in the experiments
- halo diagnostics

Optics design

- Betatron Collimation
  - Large beta function

  >> maximize the impact parameters and reduce the possibility of collision between the beam halo and the collimator surface

  >> reduce the impedance induced by collimators
  - Phase advances greater than 2π
- Momentum Collimation
  - βx lower than in betatron collimation

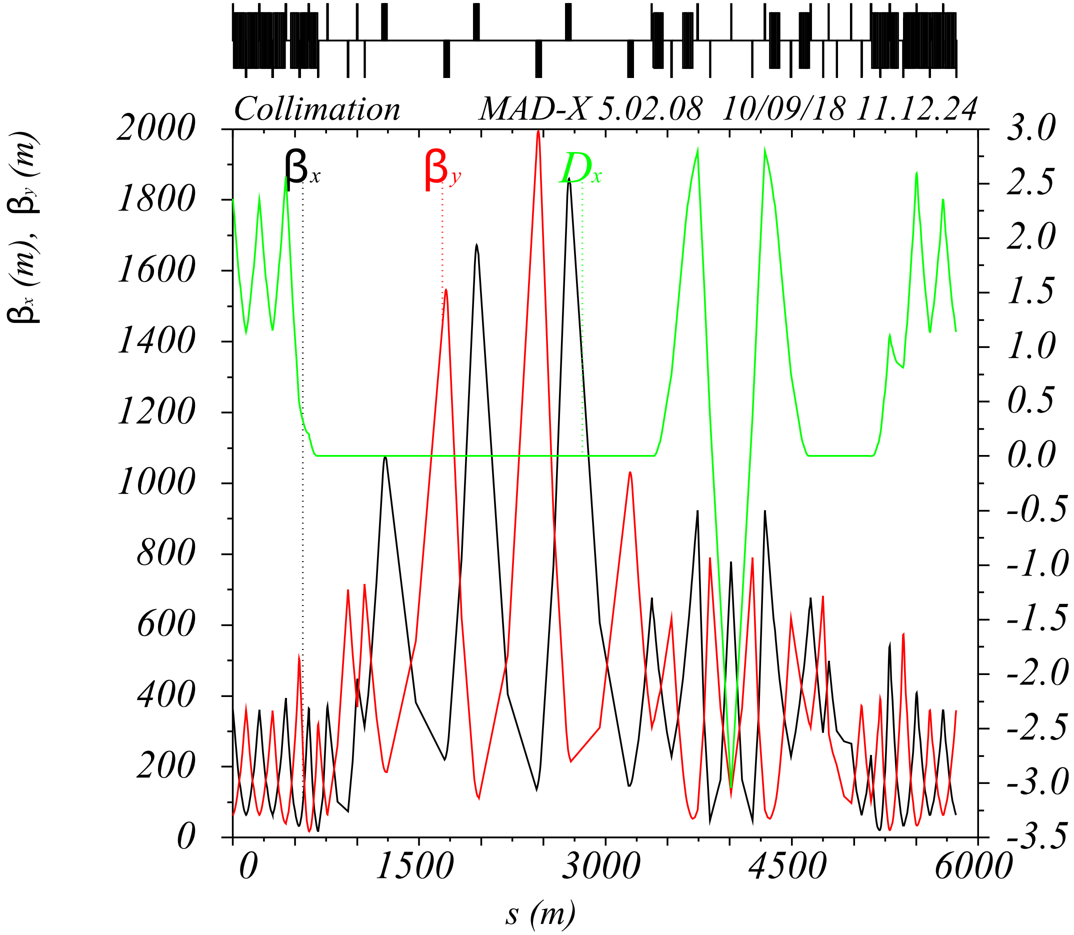
  >> maximize the momentum dispersion resolution (normalized dispersion)
  - Normalized dispersion at primary momentum collimator satisfy:

$$\left|\chi_{D,\mathrm{prim}}(n_1)\right| \geq \frac{n_1 \chi_{D,\mathrm{arc}}}{A_{\mathrm{arc,inj}}(\delta_p=0)-(n_2^2-n_1^2)^{1/2}} \quad \& \quad \frac{D_x'}{D_x} = -\frac{\alpha_x}{\beta_x}$$

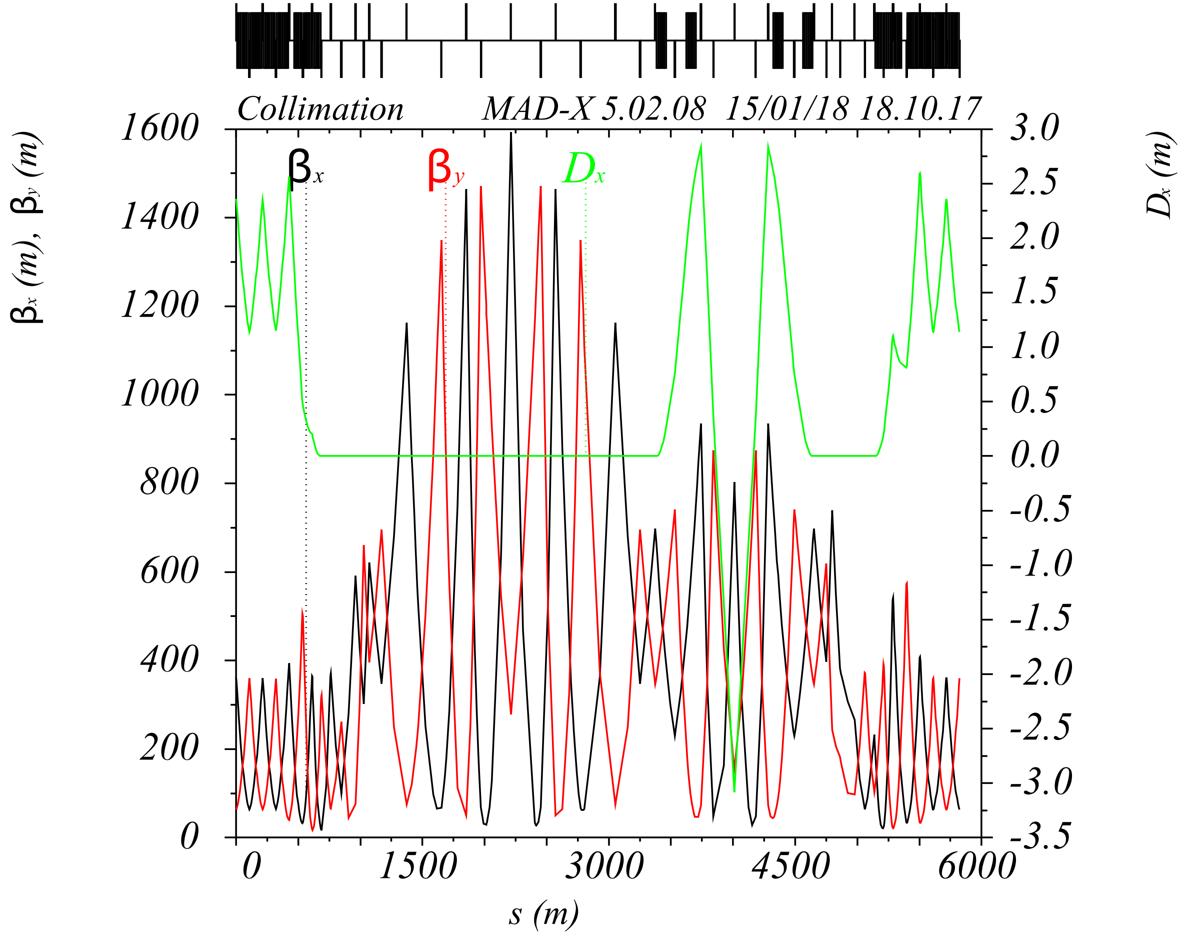
  >> make sure the cut of the secondary halo is independent of the particle momentum

Optics design

Lattice scheme I



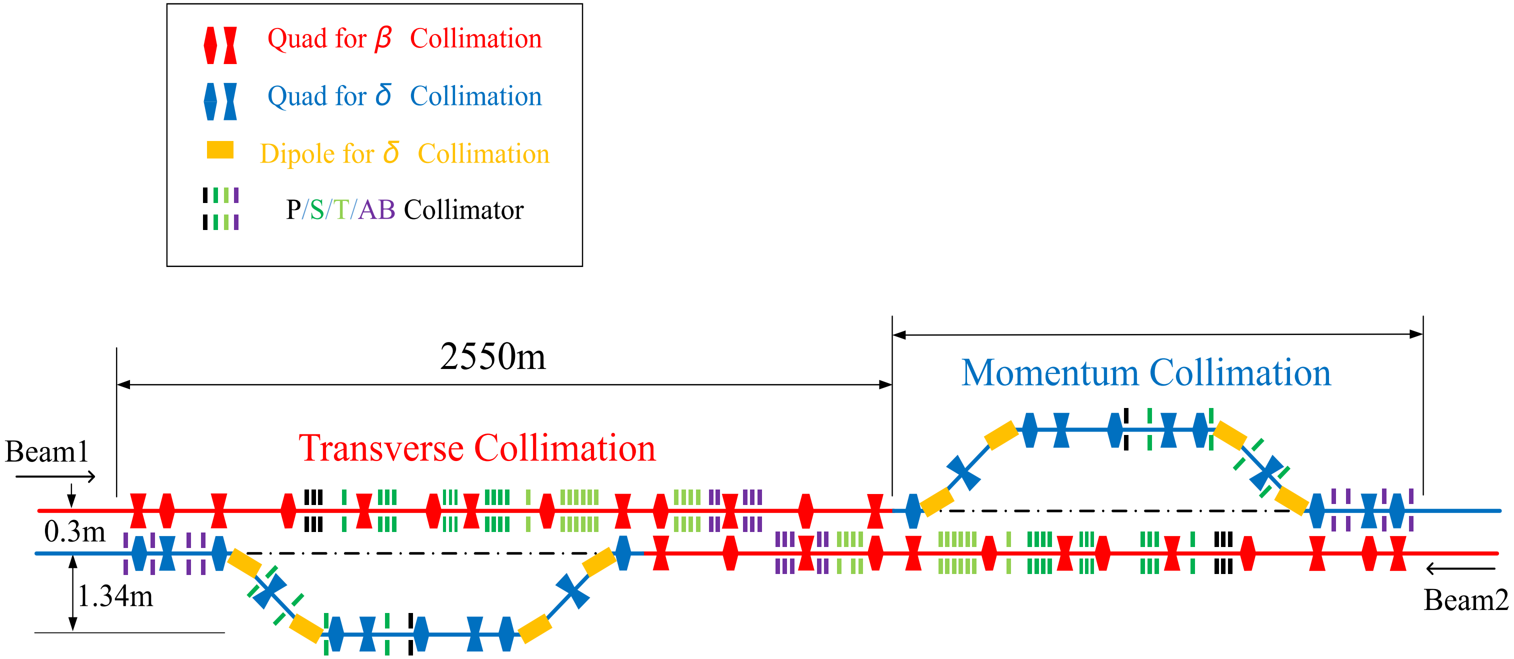
Lattice scheme II

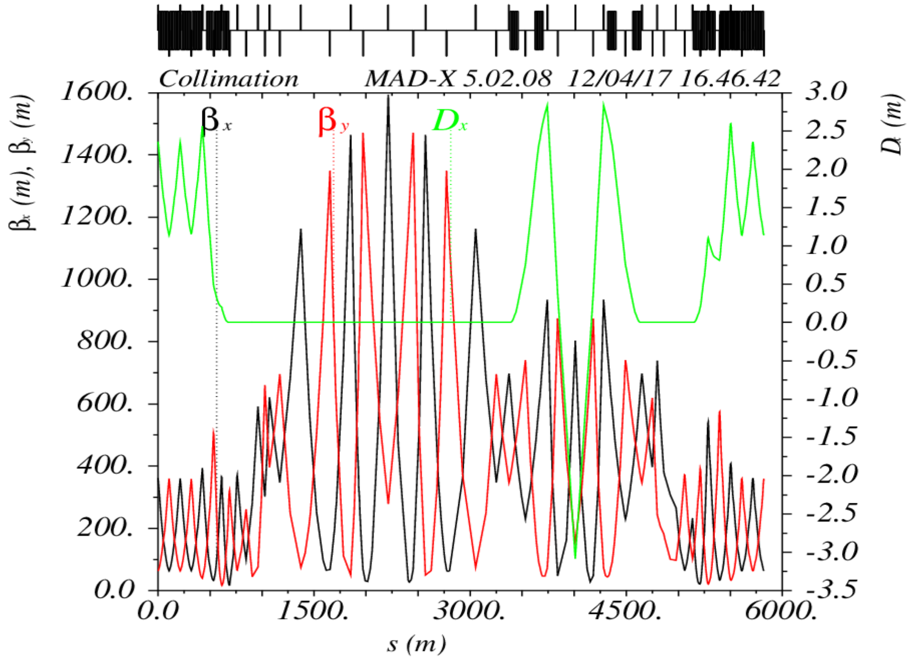


Optics design

Lattice scheme II

- Compatibility with two sets of collimation system for each beam
  - Quadrupoles with twin apertures are installed in the overlapping region between the two beam
  - Quadrupoles with single aperture are installed in the position with horizontal offset

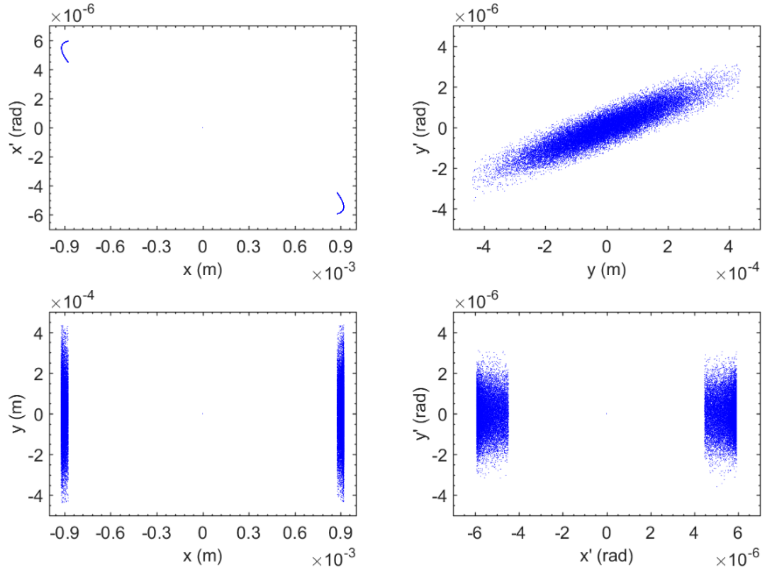




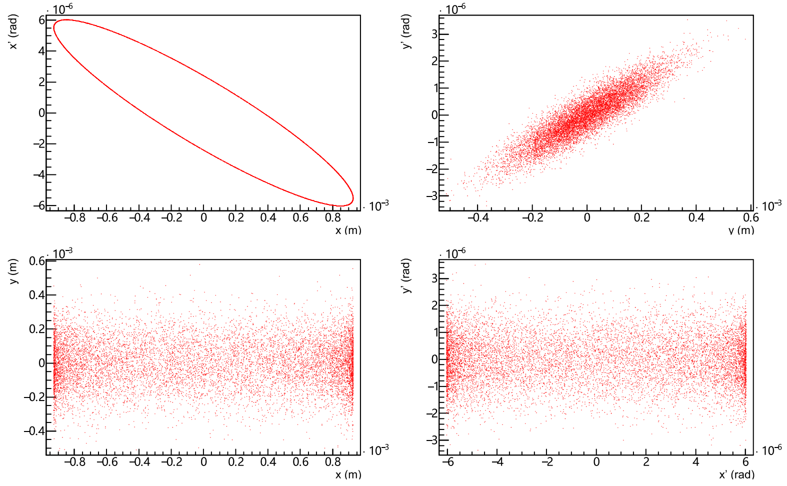
Multi-particle simulation

- LHC-phase 1 like, the same aperture in σ, same phase advances, same material
- Simulation code: Merlin, SixTrack
- Energy: 37.5 TeV
- 10^8 particles
- 2.4 μm rad emittance
- Beam distribution: ring in x, x' with 6.05 σ and Gaussian in y, y' with 3 σ
- 1 μm impact parameter
- 300 turns

MerLin



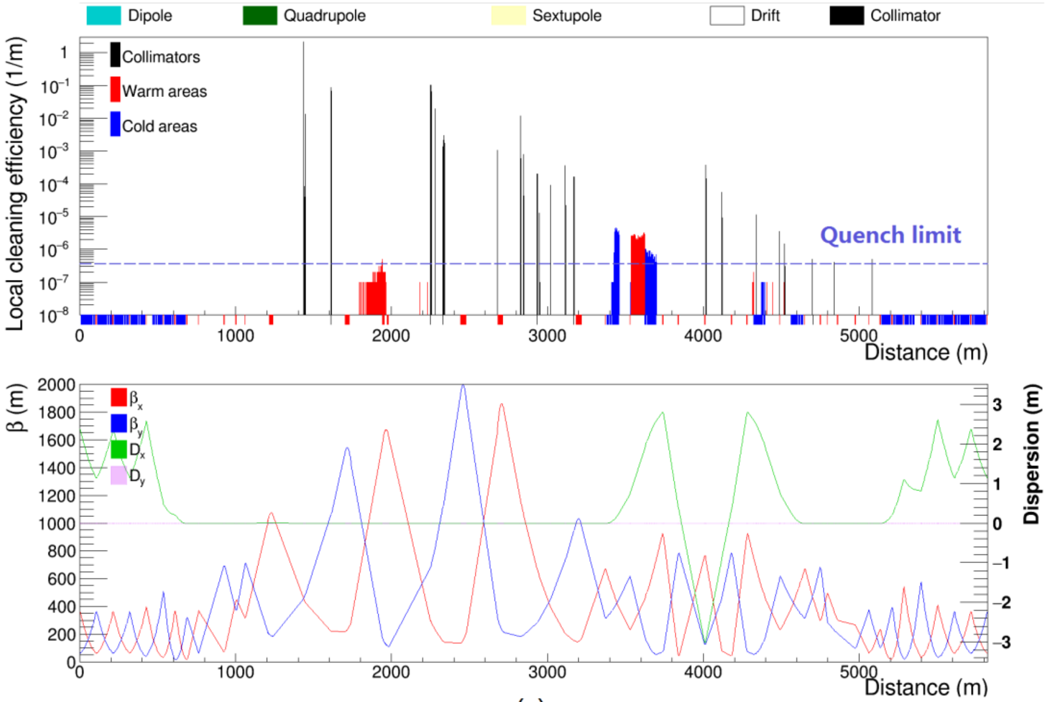
SixTrack



Merlin results

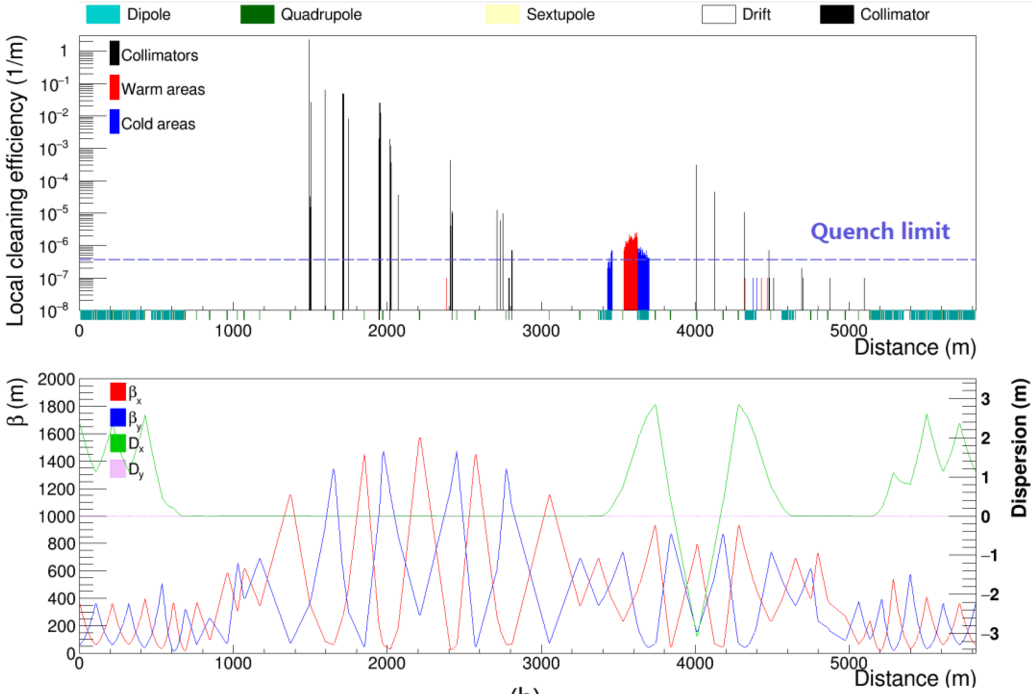
Vertical halo distribution

Lattice scheme I



(a)

Lattice scheme II



(b)

Collimator Acronym	Length (m)	Number	Aperture (σ)	Material	Lattice schemes
TPC	0.6	3	6	Carbon	I, II
TSC	1.0	11	7	Carbon	I, II
TTC	1.0	11	8.3	Copper	II
TAB	1.0	5	10	Tungsten	I, II
TQC	1.0	4	10	Tungsten	I, II
MPC	0.6	1	12	Carbon	I, II
MSC	1.0	4	15.6	Carbon	I, II
MAB	1.0	4	17.6	Tungsten	I, II

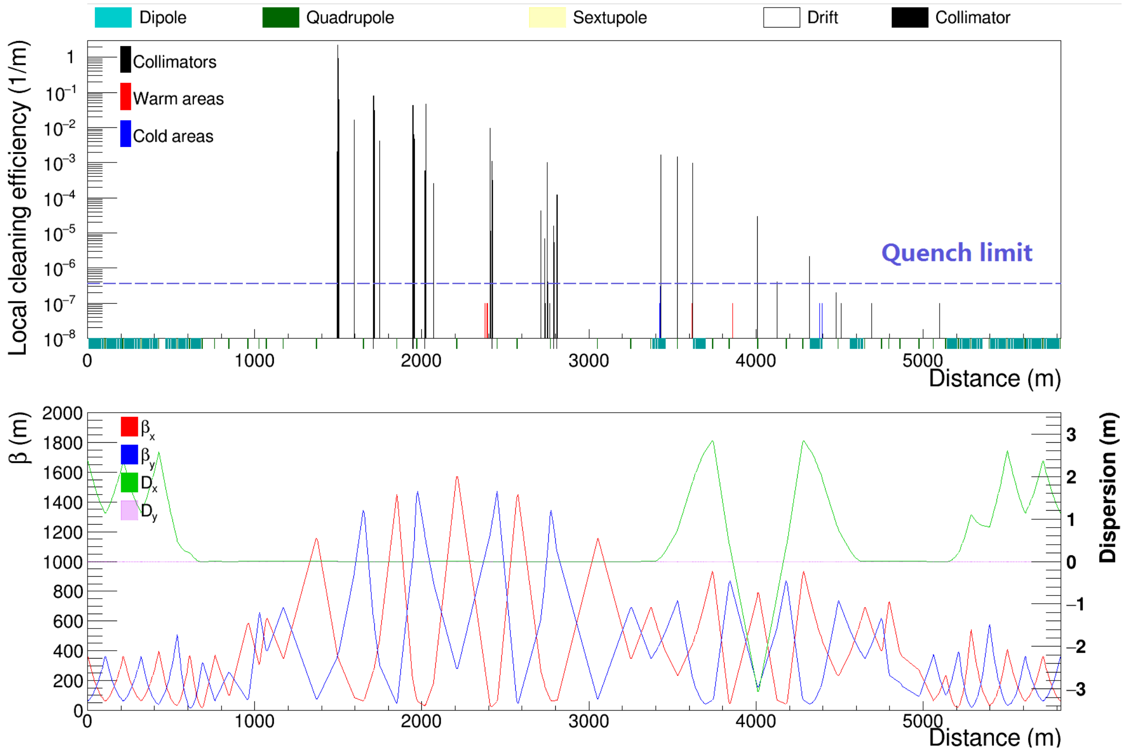
- the four-stage collimation system can make the local cleaning inefficiency in the cold region below the quench limit of SC magnets.

Simulation results

Local protection

- Installation of some protective collimators at the places where dispersion increases gradually.

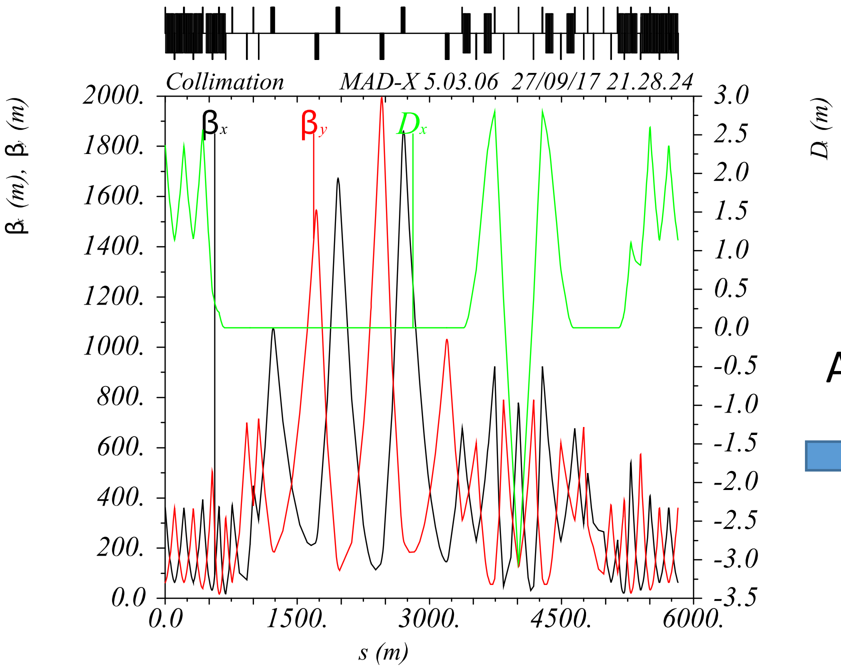
➢ There is no proton losses in the cold region exceed the quench limit along the full ring.



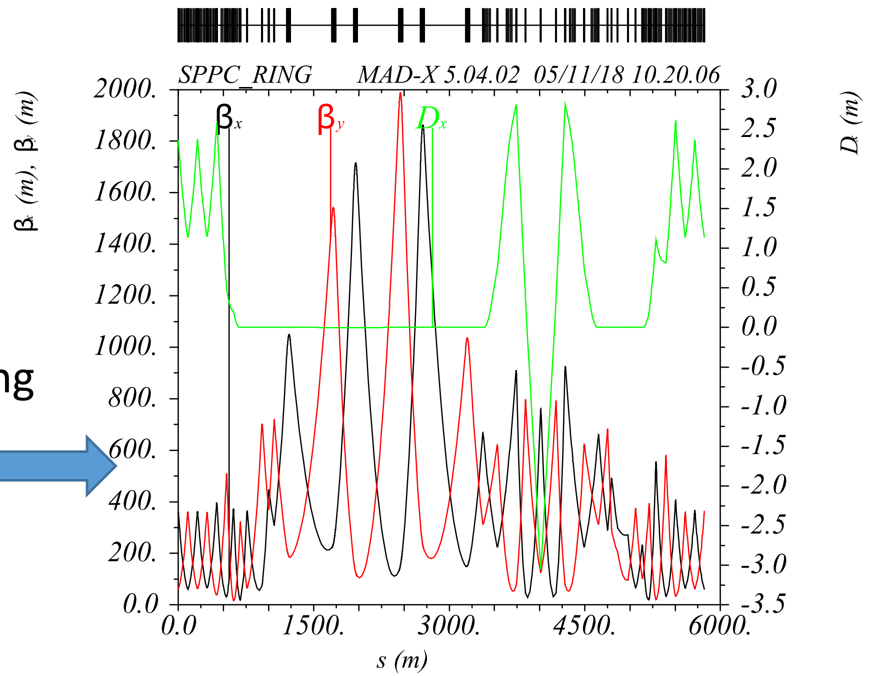
All simulations are carried only considering the linear condition!

SixTrack results

- Use the lattice scheme of SPPC
- Slicing： slice the triplets in IP to 20 slices
- Beta beating < 1%
- μx: 119.5192→119.5181
- μy: 116.3463→116.3454



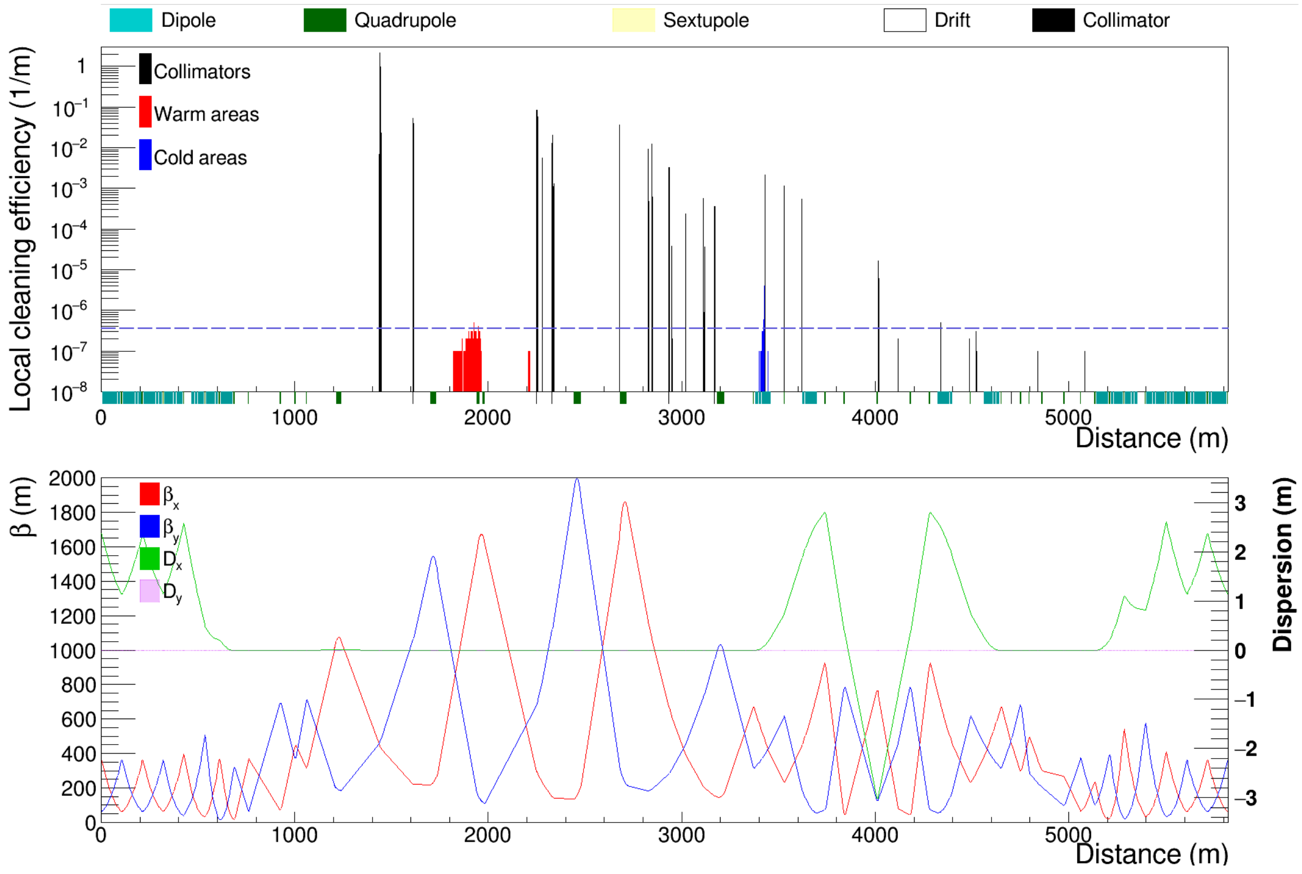
After slicing



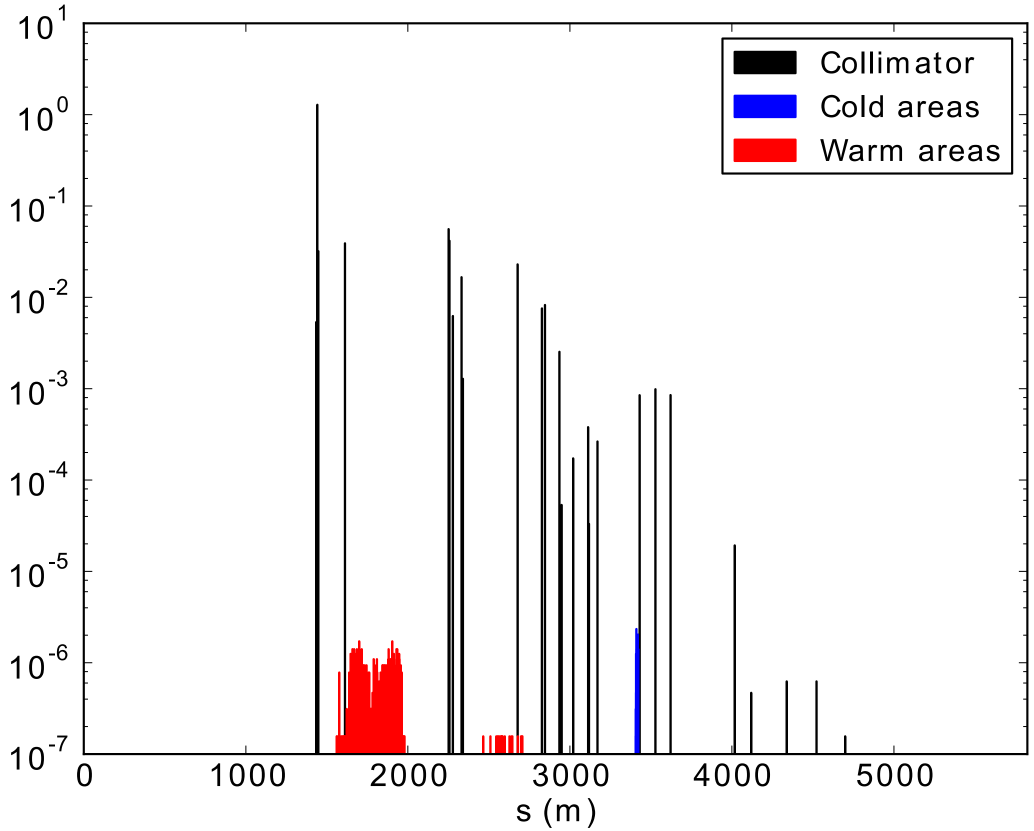
Benchmarking

Lattice scheme I

MerLin



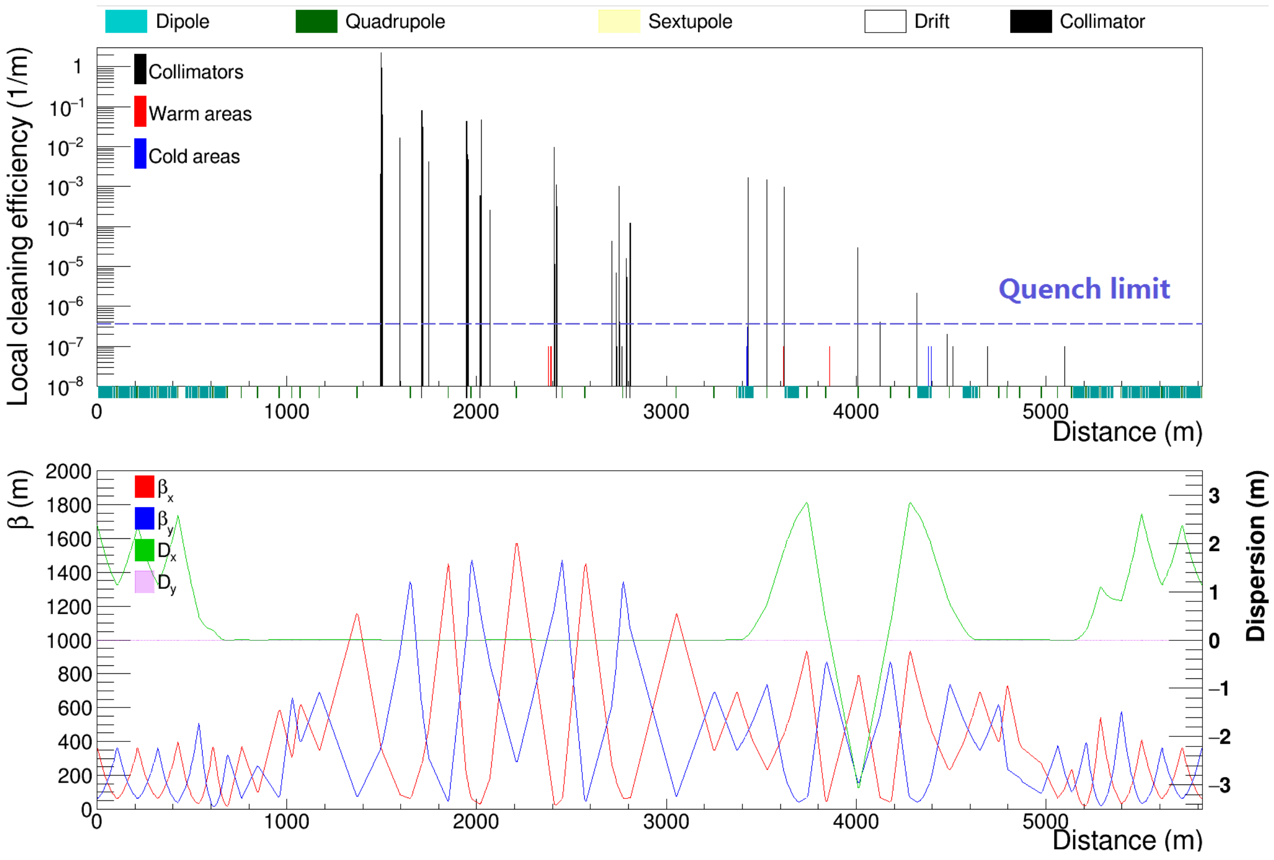
SixTrack



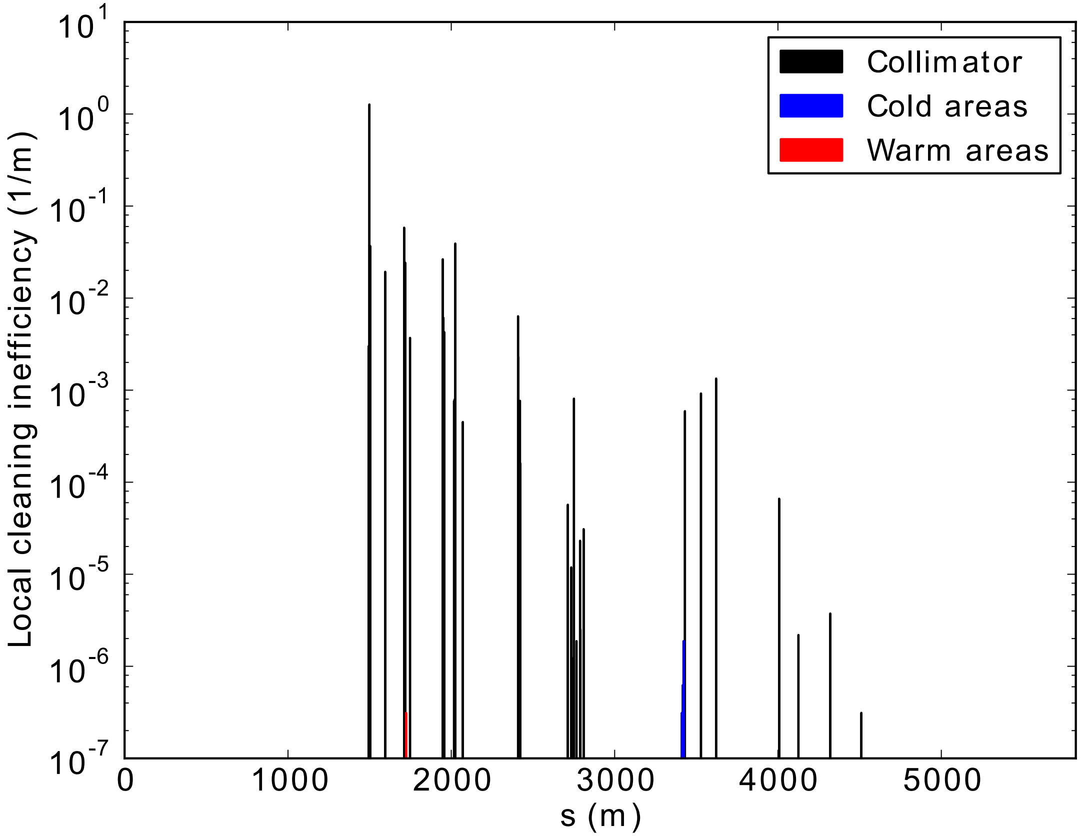
Benchmarking

Lattice scheme II

MerLin



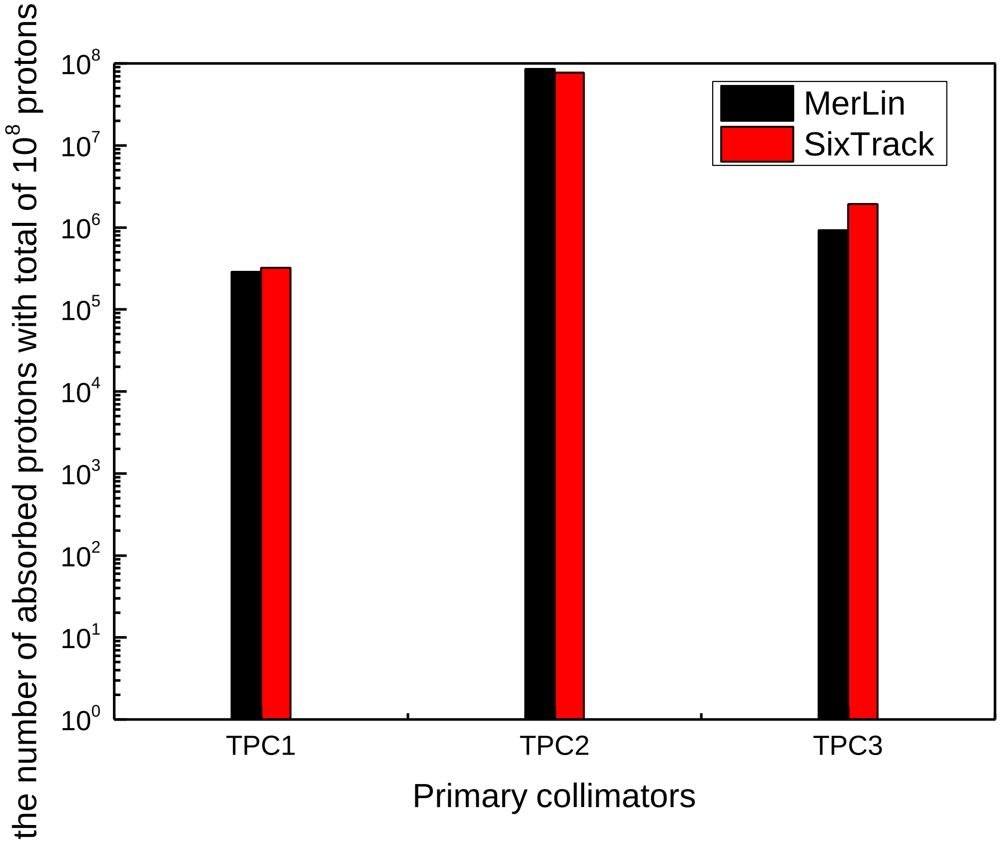
SixTrack

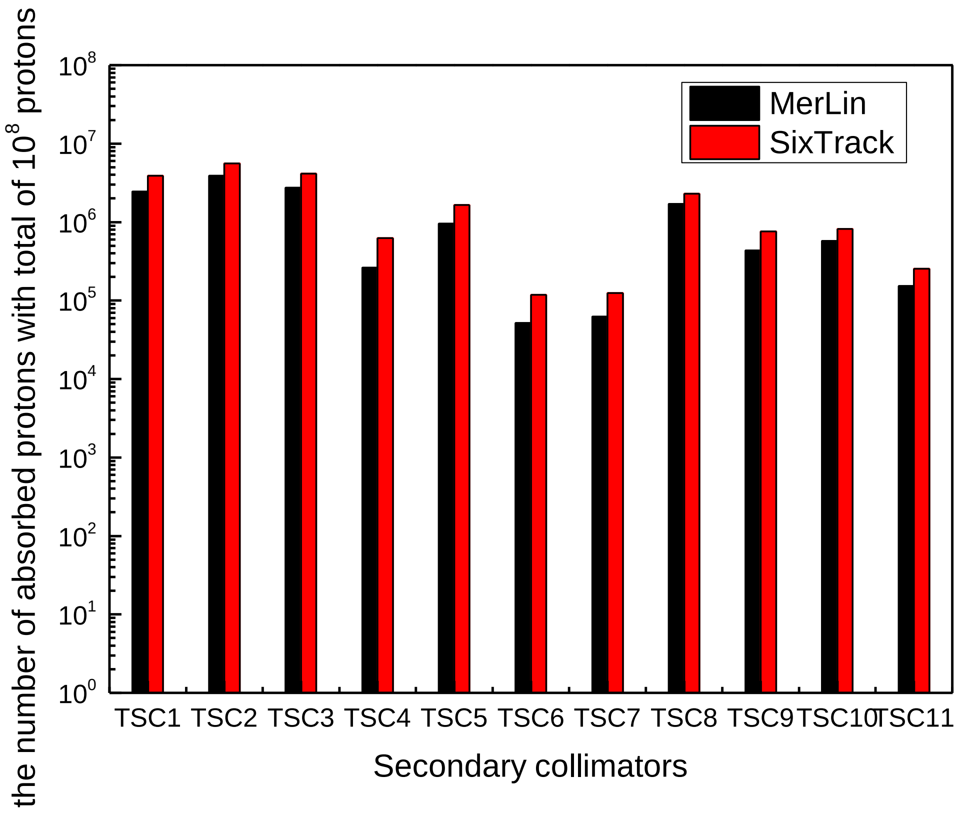


- **Good benchmark between SixTrack and Merlin**

Benchmarking

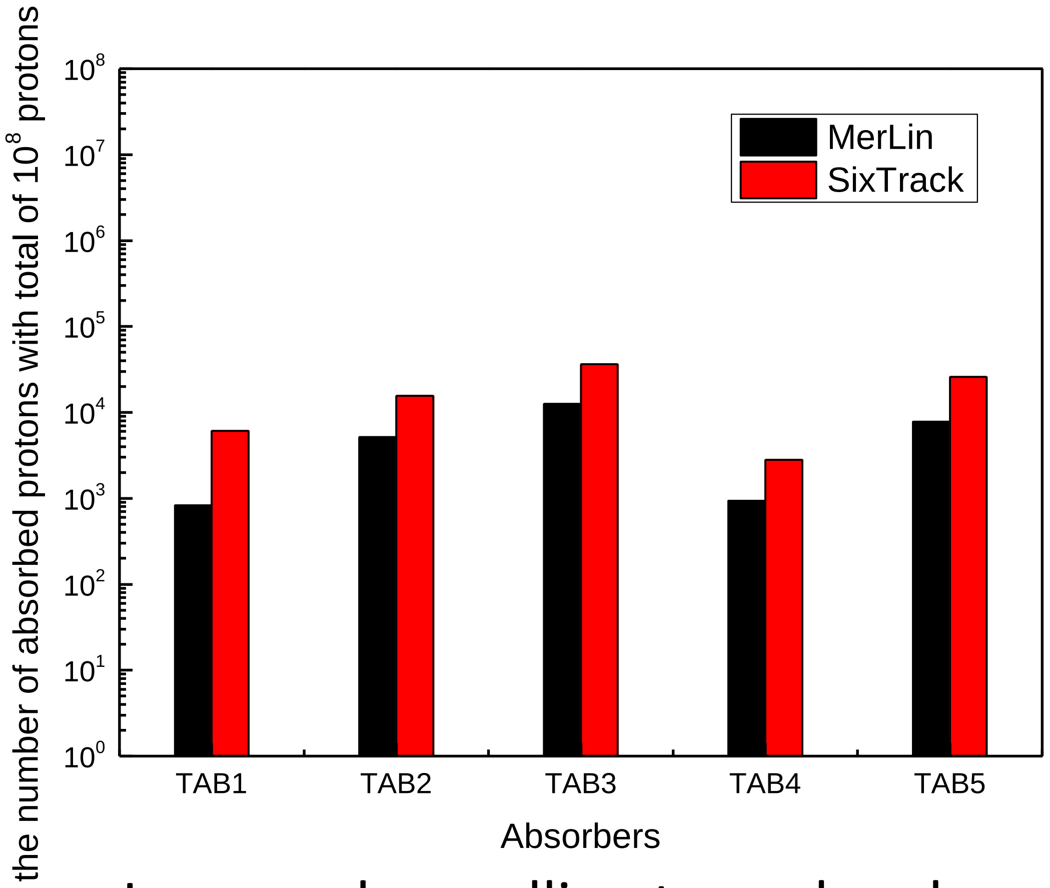
Lattice scheme I

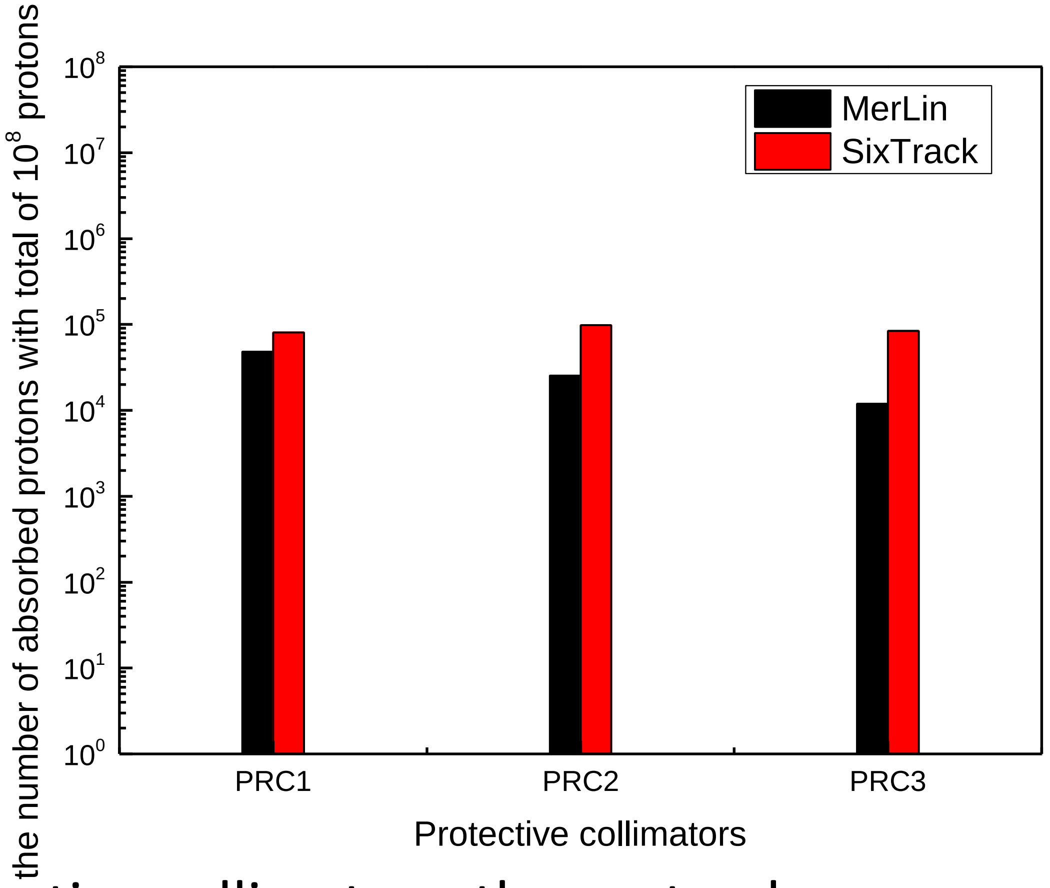




Benchmarking

Lattice scheme I

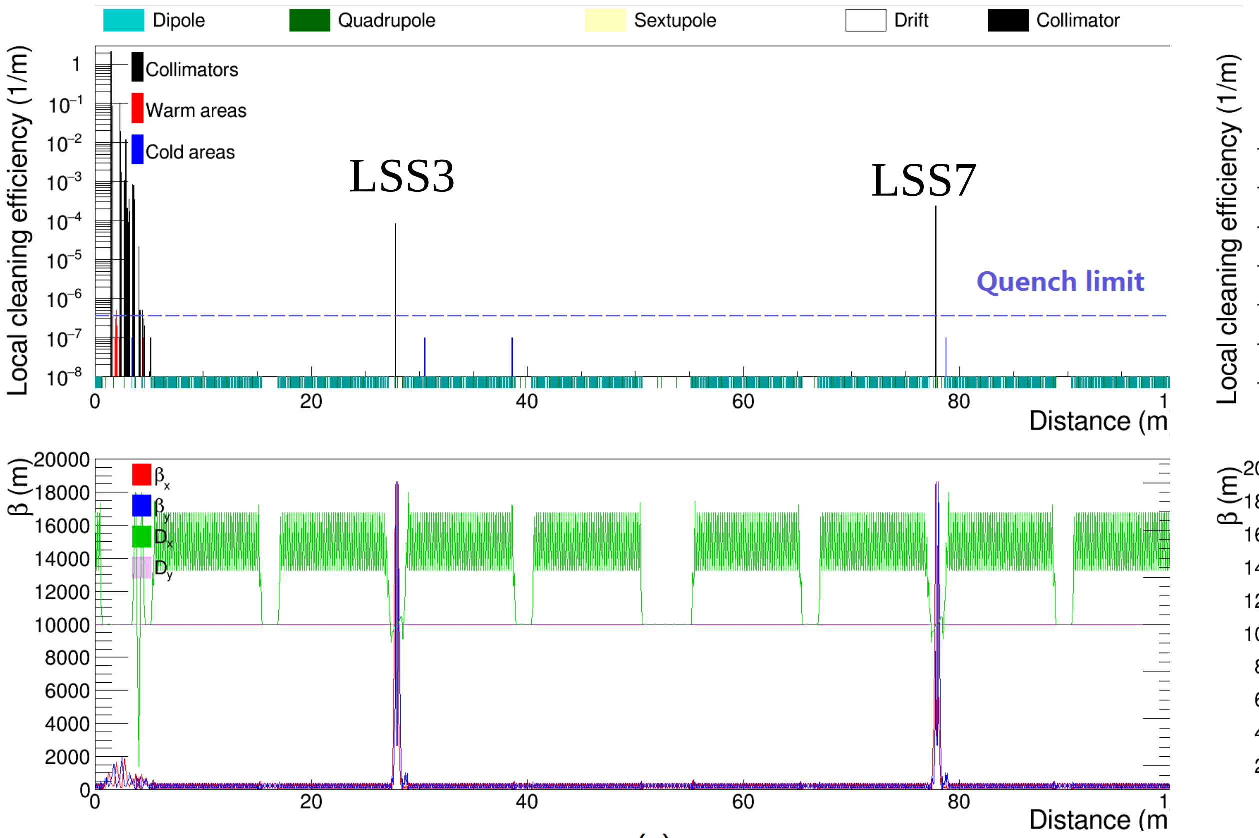




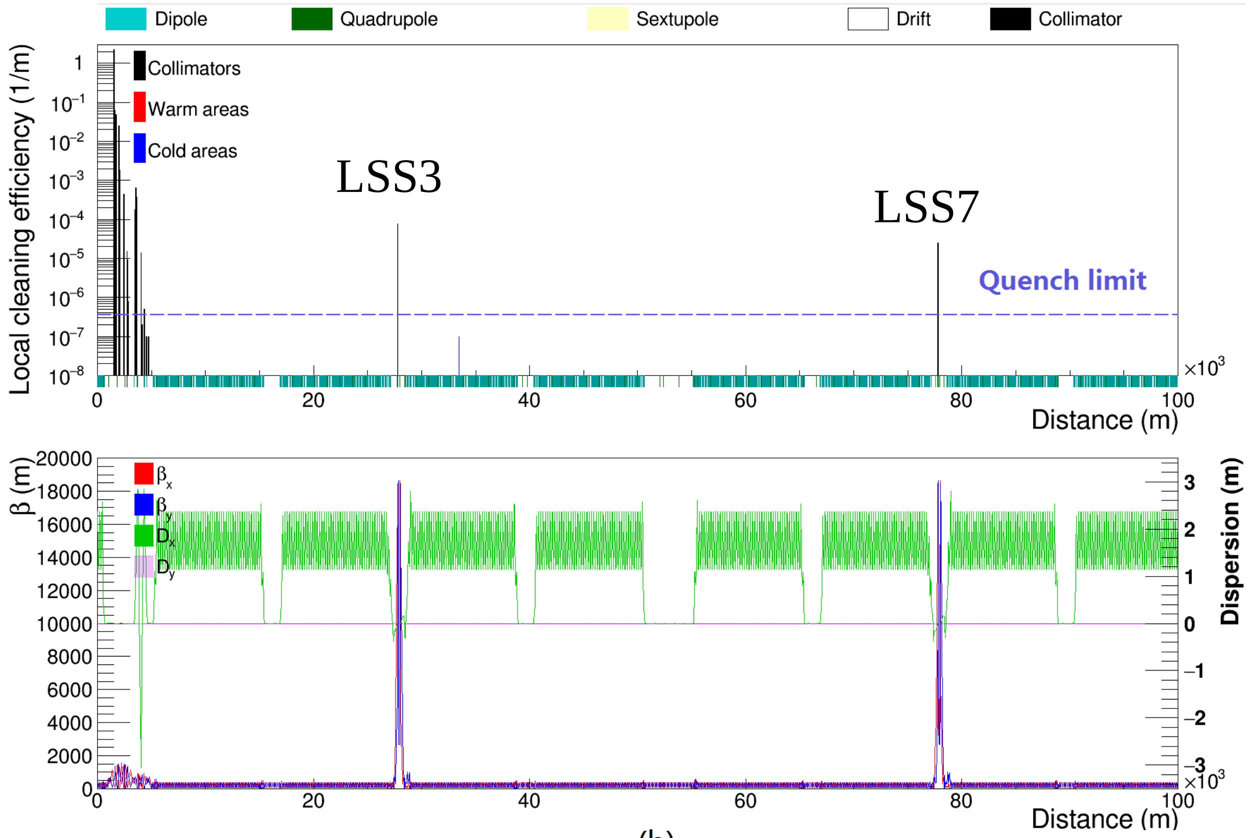
In secondary collimators, absorbers, protective collimators, the proton losses with Sixtrack are large than MerLin, the reason is the differences between the initial halo distribution. For MerLin, More protons are stoped by the TPC2.

Simulation results

Whole ring， vertical halo



(a)



(b)

Lattice Scheme I

lattice Scheme II

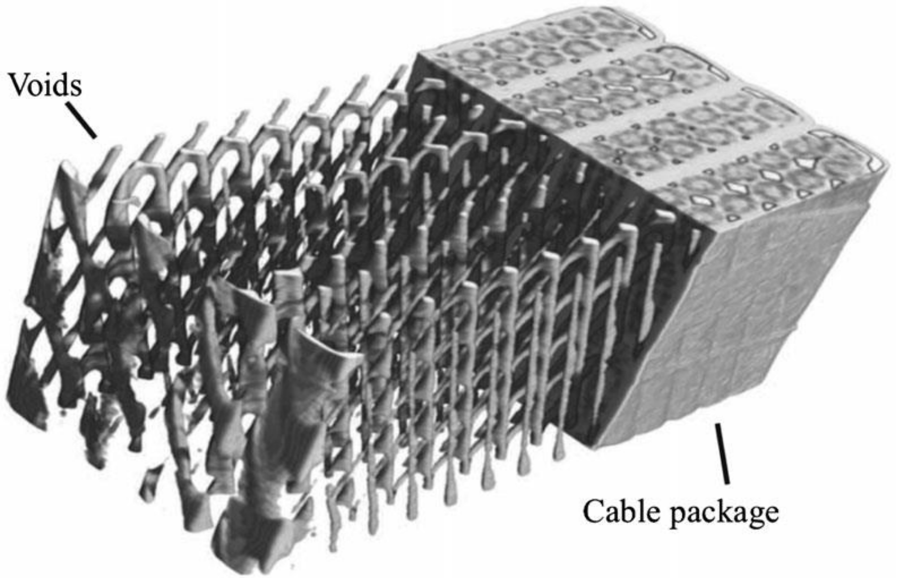
- the proton losses at the quaternary collimators are reduced by more than one order in the experiment region LSS7, and by four times in the experiment region LSS3, compared to the Lattice Scheme I

Protection scheme

➢The quench level is defined as the minimum local energy or power deposition that, for a given beam-loss scenario, will result in a transition from superconducting to normal conducting state.

➢Factors:

- local magnetic field
- operating temperature
- cooling conditions
- geometrical loss pattern
- time distribution of beam losses
  - ➢Short-duration ($t < 50$ μs)
  - ➢Intermediate duration (50 μs $\lesssim t \lesssim$ 5 s)
  - ➢Steady state ($t > 5$ s)



Protection scheme

Quench limits

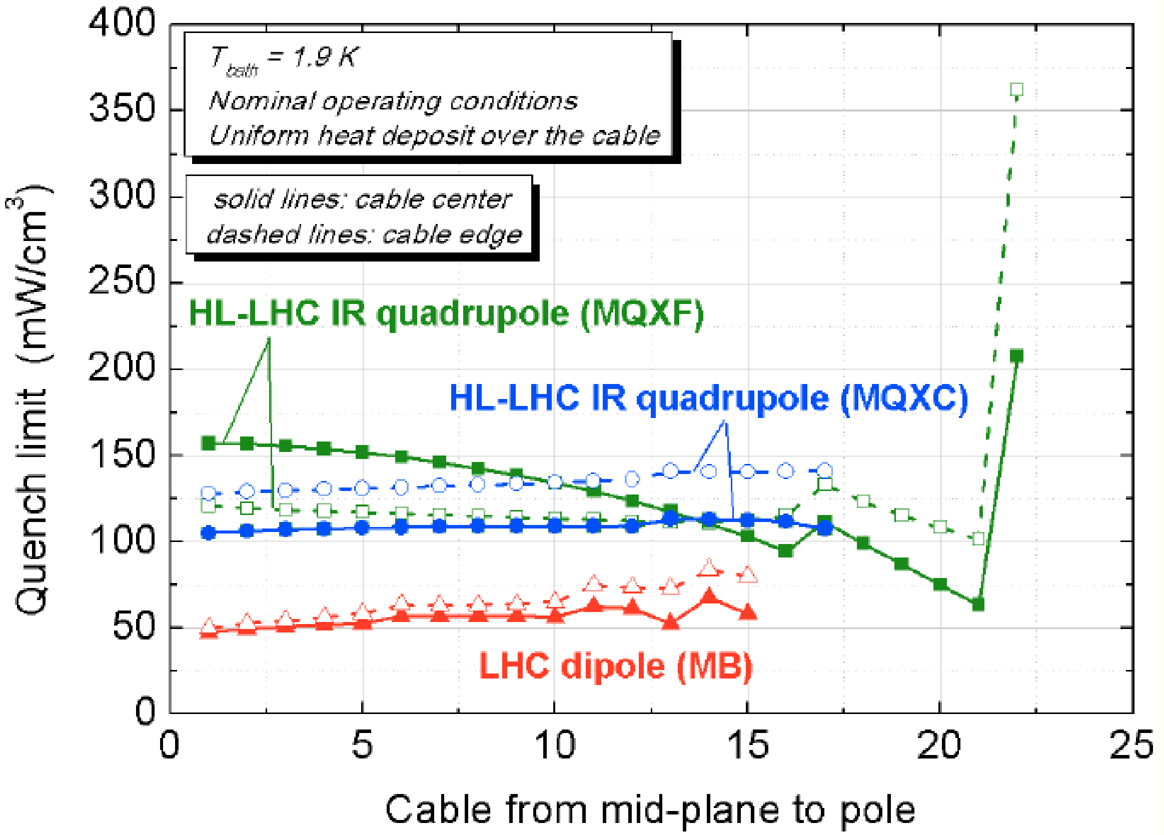
- SC quadrupoles in HL-LHC

From P. P. Granieri

TABLE I
CABLE QUENCH LIMITS OF LHC AND HL-LHC MAGNETS

Magnet	SC	Operating current (kA)	Quench limit in the cable center – edge (mW/cm^3)
MB	Nb-Ti	6.8 (4 TeV)	58 - 80
		11 (6.5 TeV)	49 - 57
		11.8 (7 TeV)	47 - 49
MQXF	Nb_3Sn	17.3	63 - 99

The values provided refer to the most critical cable determined above for each magnet. The bath temperature is 1.9 K.

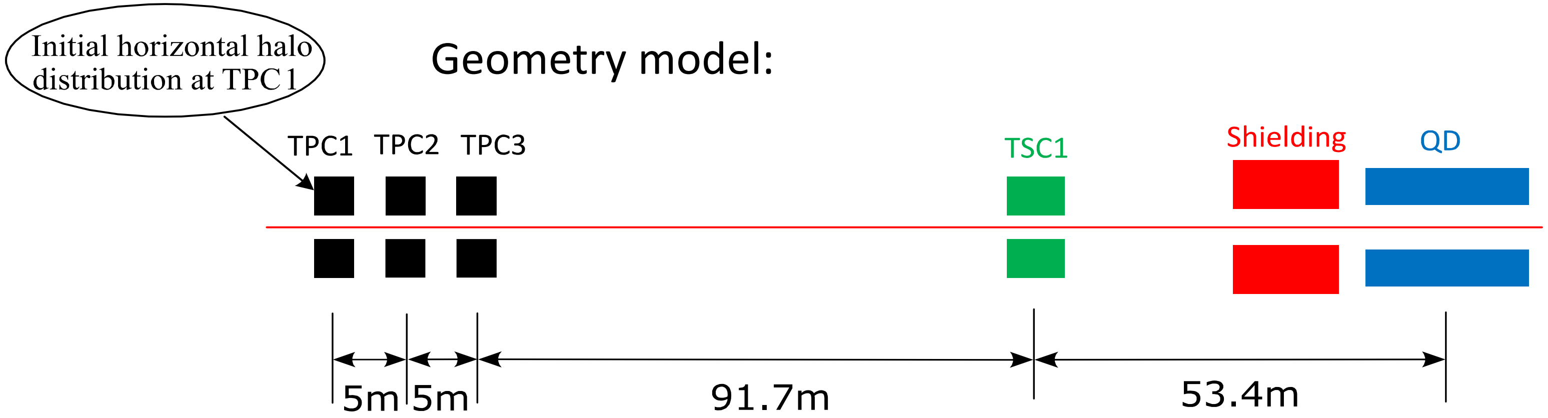


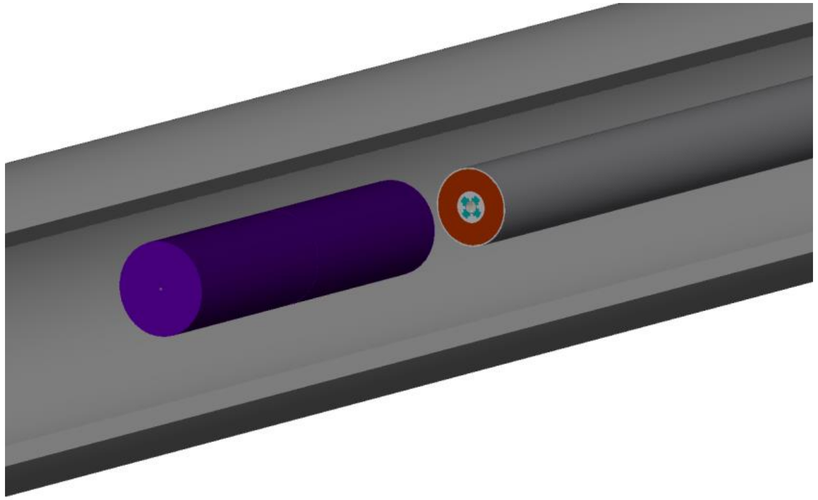
- In betatron collimation section, the highest quadrupole field is 8 T, which is lower than the IR quadrupole in LHC.
- Considering the He II and He boiling heat transfer mechanisms, which allow extracting more heat from the cable than the only solid conduction through the cable insulation, the quench limit value is estimated as 50~100 mW/cm^3.

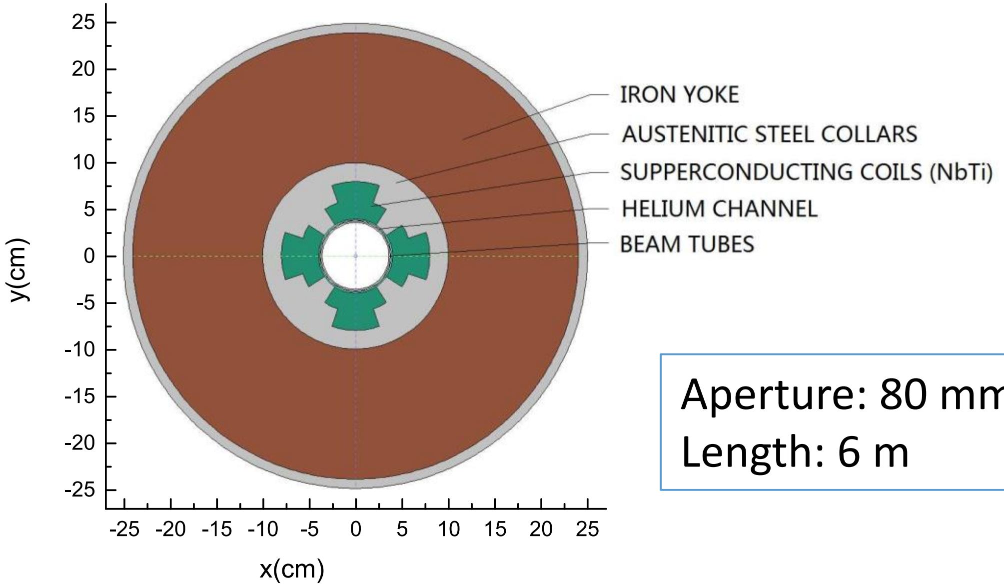
Protection scheme

- Which quadrupole will bear the greatest risk of quench?

Geometry model:





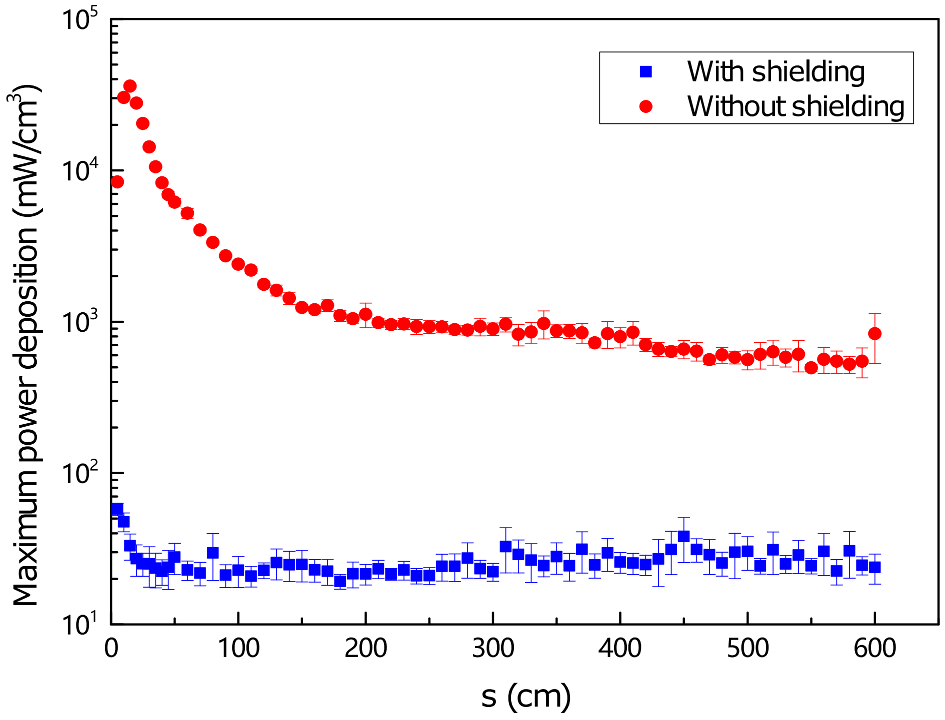


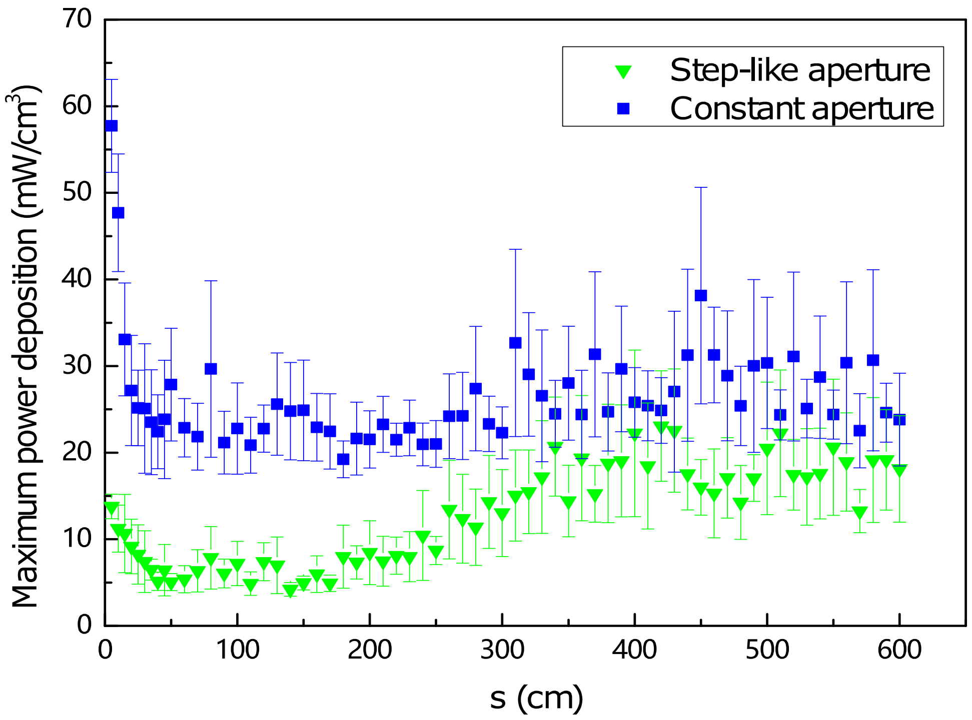
Aperture: 80 mm
Length: 6 m

Protection scheme

- Shielding: placed in front of the QD for one meter, which is a hollow cylinder, with length 3m and inner half-aperture 10 mm, about 37 σ.
- Assume that all stored SPPC protons will be lost in the collimation section in one hour

Step-like aperture: the aperture of the rear half is enlarged to 10.5 mm

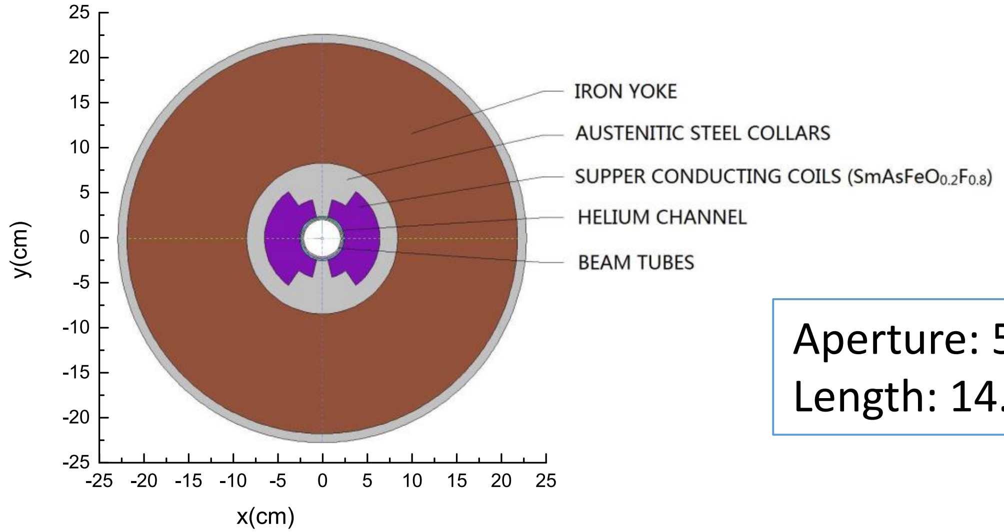




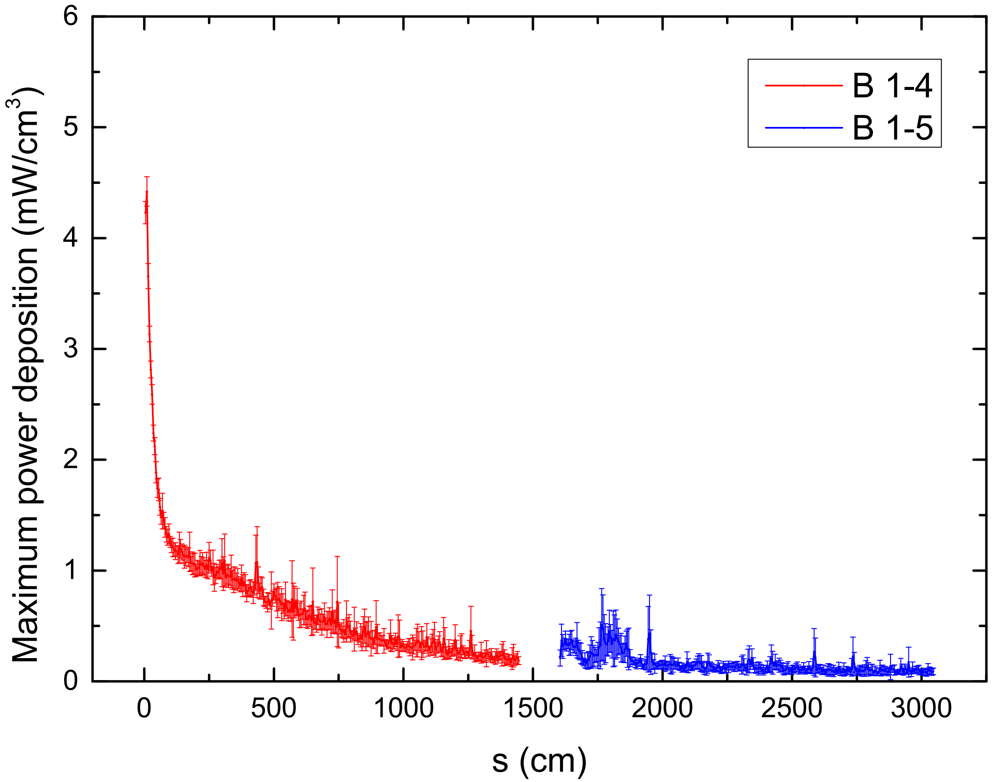
Protection scheme

Energy deposition in SC dipole

- Quest limit estimation: 5~10mW/cm^3
- one protective collimator is placed between the third and fourth dipole magnets of the first dipole group to intercept particles with very large momentum deviation.



Aperture: 50 mm
Length: 14.5 m



conclusions

- The consecutive collimation method by arranging both transverse and momentum collimation systems in the same cleaning insertion and employs superconducting quadrupoles has a good performace. The goal of collimation inefficiency 3.55×10^{-7} m^{-1} can be accomplished.
- With protective shieldings, the power deposition in the superconducting coils in the collimation section can be reduced to below 10 mW/cm^3, which is safe from quenching.

Next to do

- Consider the effect of the imperfections of collimators, like offset errors, tilt errors, flatness errors and so on.
- In LAL, study a combined collimation method used in LHC, HE-LHC, even FCC-hh and SPPC
- Study the background sources from beam-beam interactions and the collimator themselves.

Acknowledgements

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Thank you for your attention