中国科学院高能物理研究所
Institute of High Energy Physics
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Optic design and performance evaluation for SPPC collimation systems

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Outline

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

Introduction

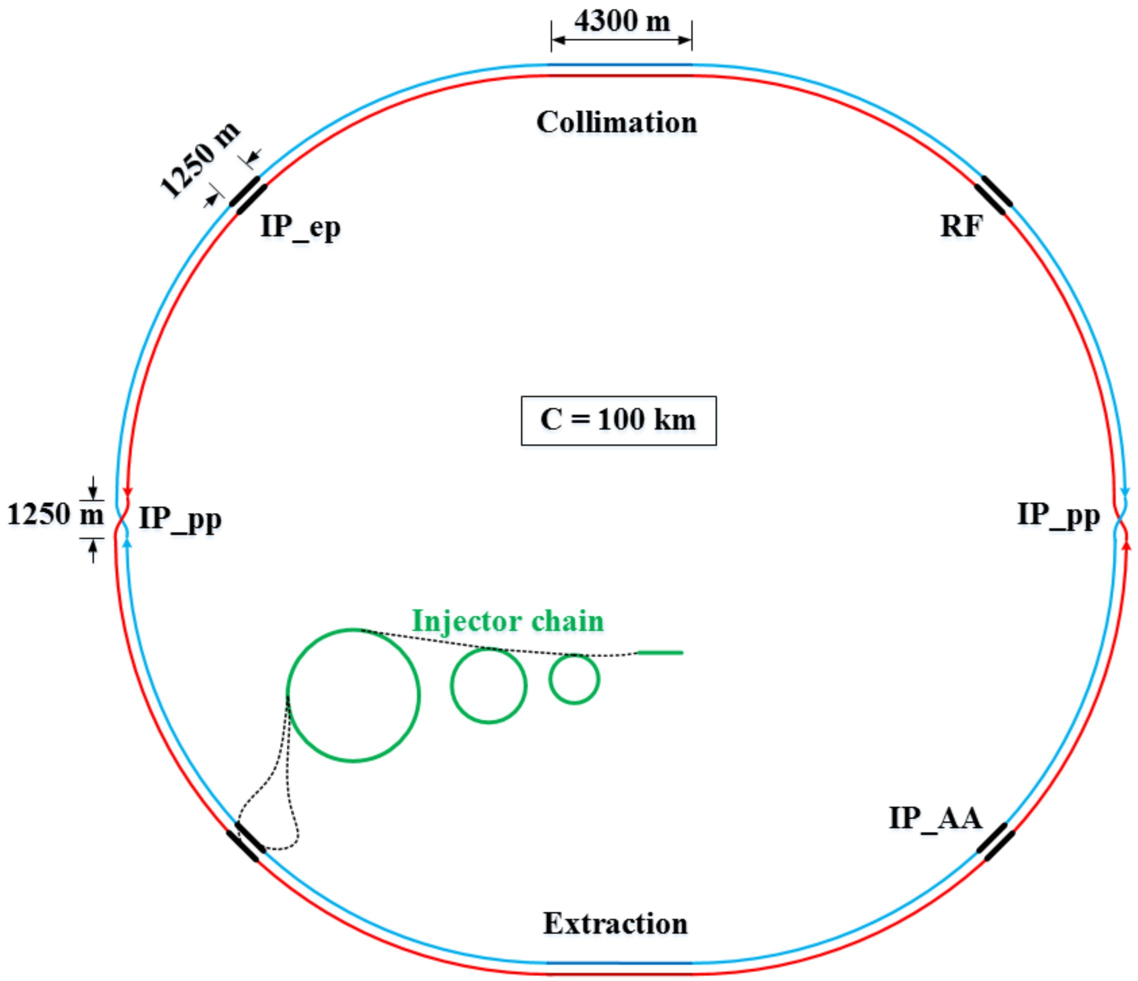
Main parameters of SPPC

- Baseline design
  - Tunnel circumference: 100 km
  - Dipole magnet field: 12 T, using full iron-based HTS technology
  - Center of Mass energy: 75 TeV
  - Injection energy: 2.1 TeV
  - Relatively lower luminosity for the first phase, higher for the second phase
- Energy upgrading phase
  - Dipole magnet field: 20 -24T, full iron-based HTS technology
  - Center of Mass energy: >125 TeV
  - Injector chain: 4.2 TeV

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

Introduction

Layout of SPPC



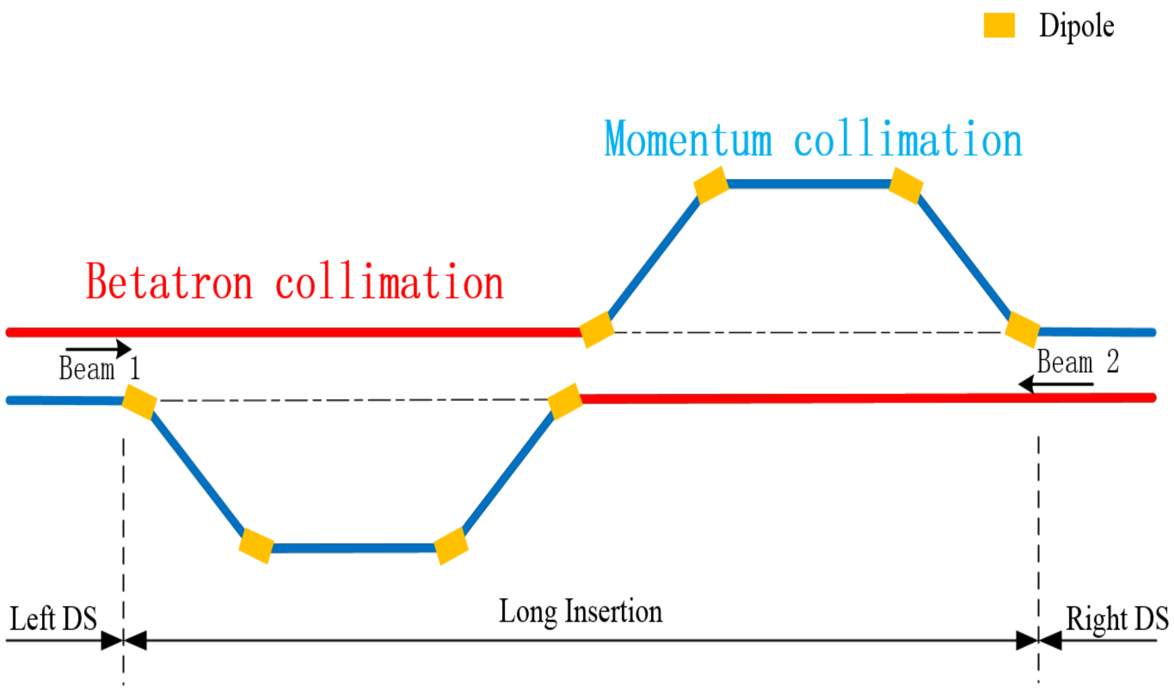
from Y. K. Chen

- Use the same tunnel to build CEPC and SPPC successively
- 8 ARCs, total length 83900m (including DS)
- 2 long straight insertion for collimation and extraction (ee for CEPC), 4300 m each
- Dipole length needed: 65.45 km
- Filling factor: 0.79
- ARC length： 65.45 km/0.79=82.9 km, Considering some reserved length, ARC length is chosen as 83.9 km, left 16.1 Km for long straight section

Introduction

Layout of collimation insertion

- 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
- Compatibility of two sets of collimation system for each beam needs to be considered
- Why choosing this layout will be explained later



Goals

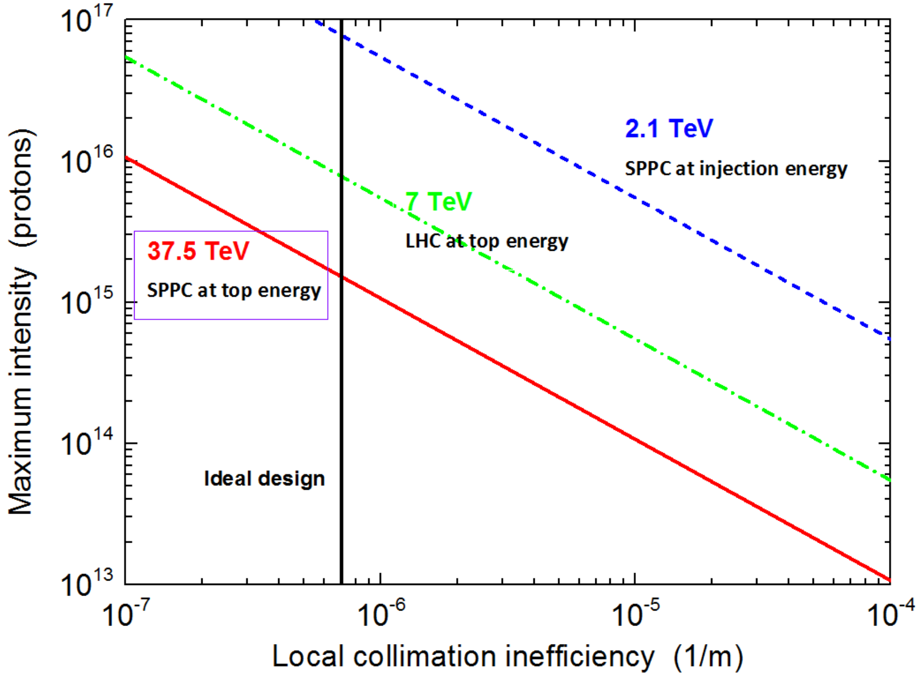
Collimation efficiency

Main functionality

- Quench prevention:

$$\tilde{\eta}_c = \frac{\tau_{\min} \cdot R_q}{N_{tot}^q}$$

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

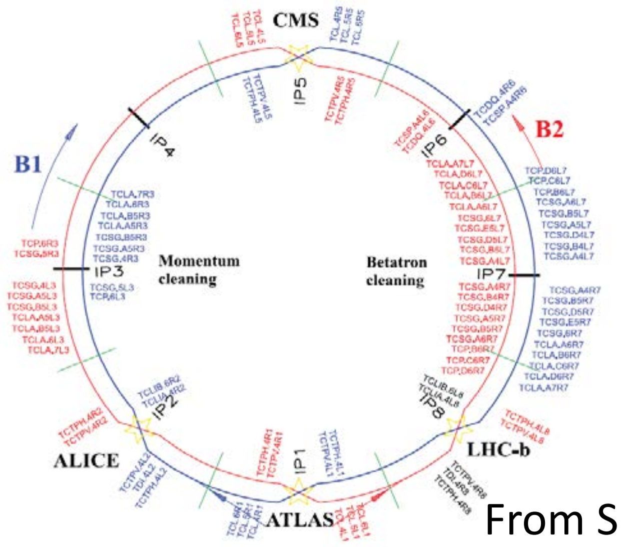


- Halo particles cleaning
- Machine protection: prevent damaging radiation-sensitive devices
- Radiation losses concentration: hands-on maintenance
- Cleaning physics debris: collision products
- Optimizing background: in the experiments
- halo diagnostics

motivations

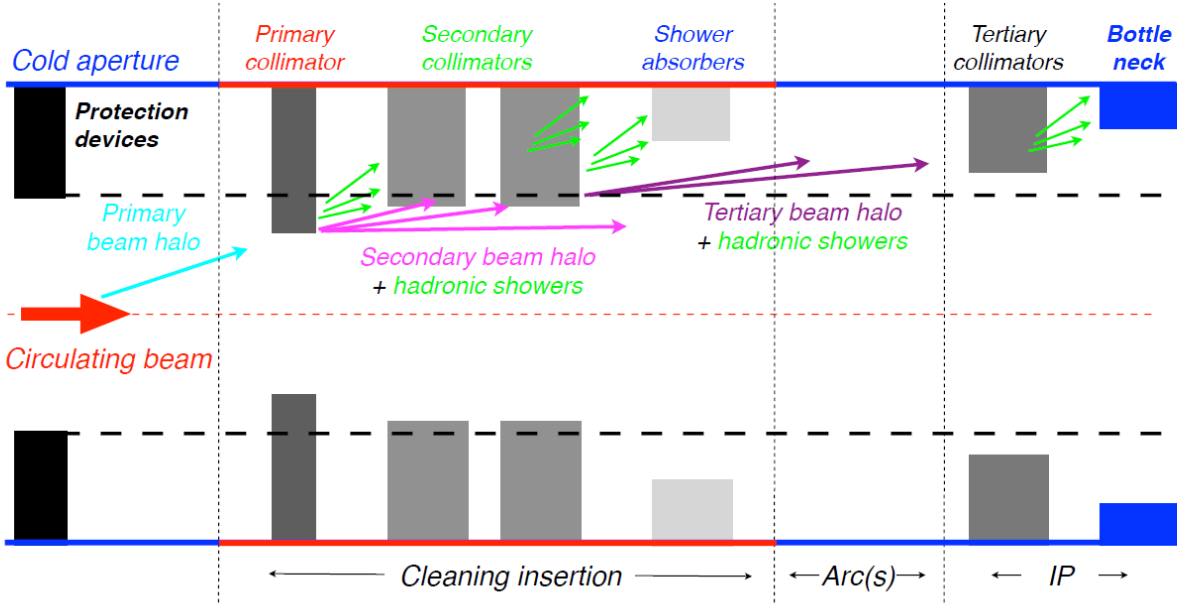
Multi-stage collimation in LHC

- 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**

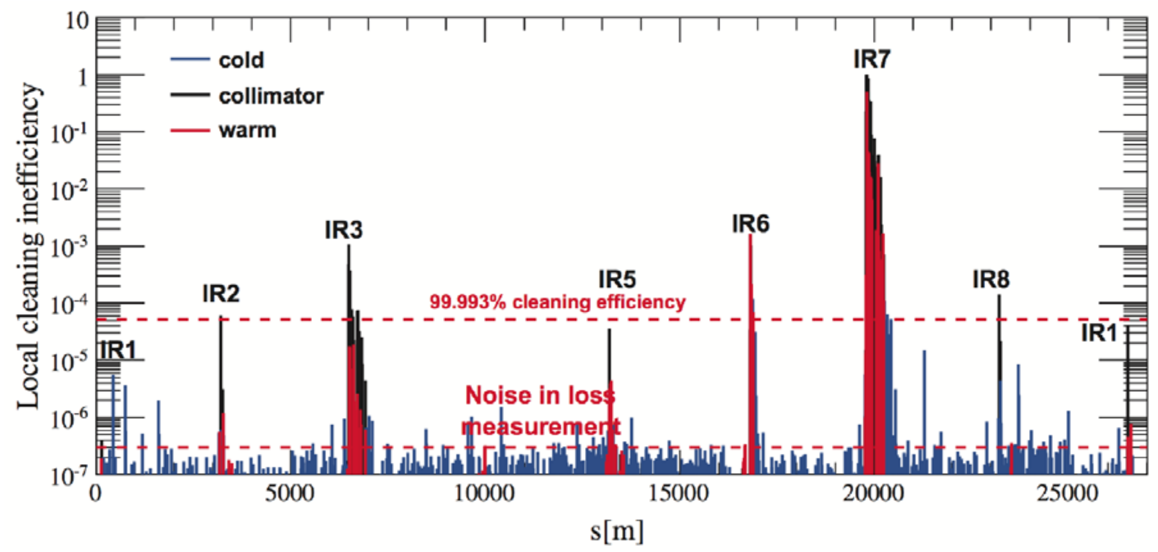


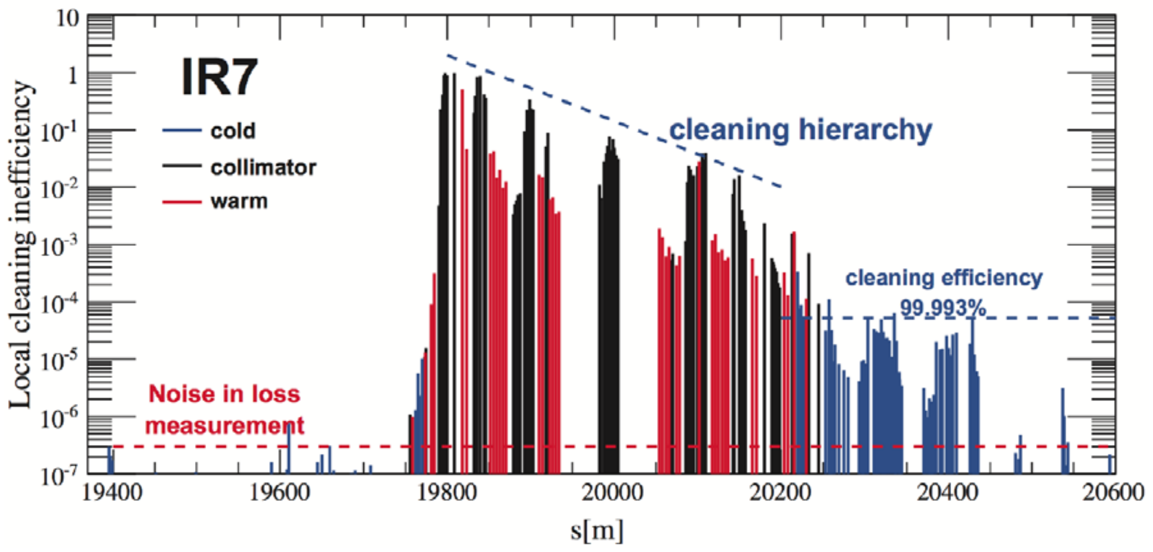
Motivations

challenges

- Particle losses in the DS are the highest cold losses around the ring, may pose a certain risk for inducing magnet quenches
- Single Diffractive scattering drives the secondary hole to dispersion suppressor: Such protons can emerge from the collimator jaw with their momentum modified only slightly in direction, but significantly in magnitude.

From B. Salvachua

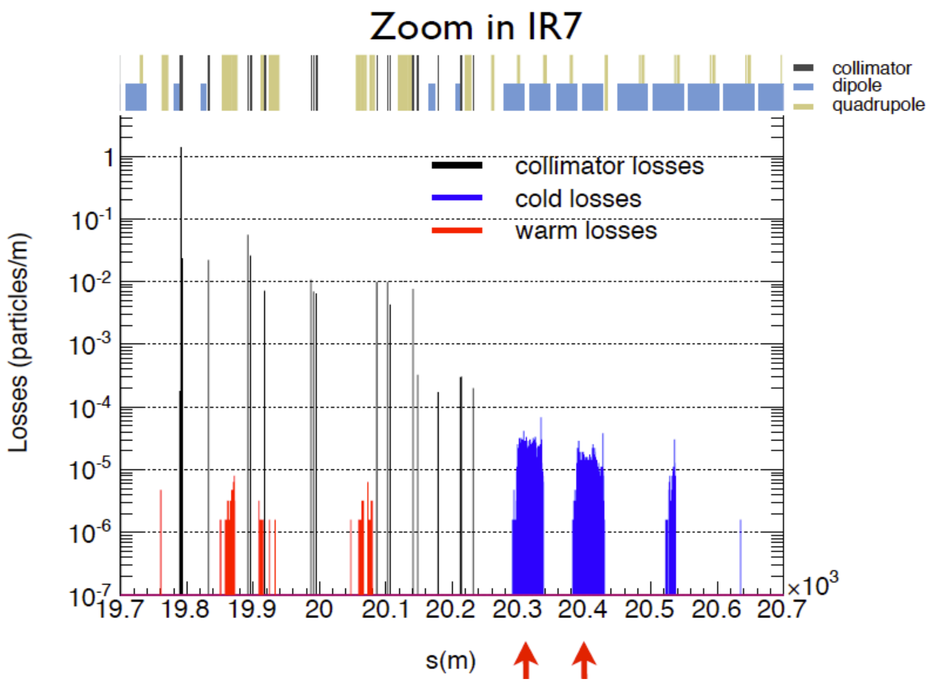




motivations

The novel collimation method

From M. Fiascaris

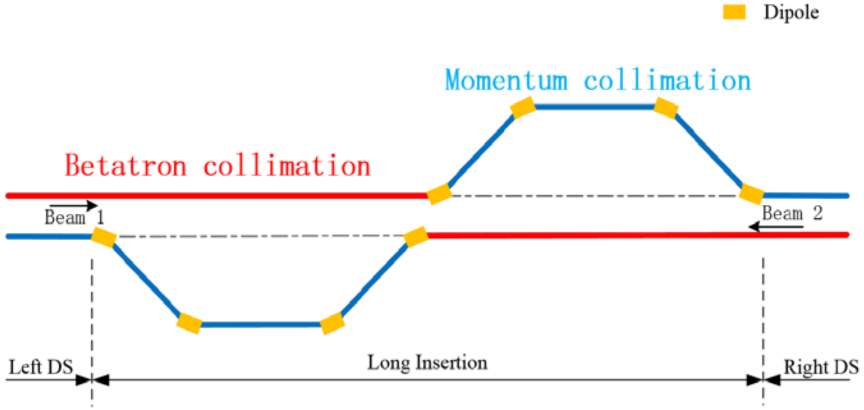


- Single diffractive scattering

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

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



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)

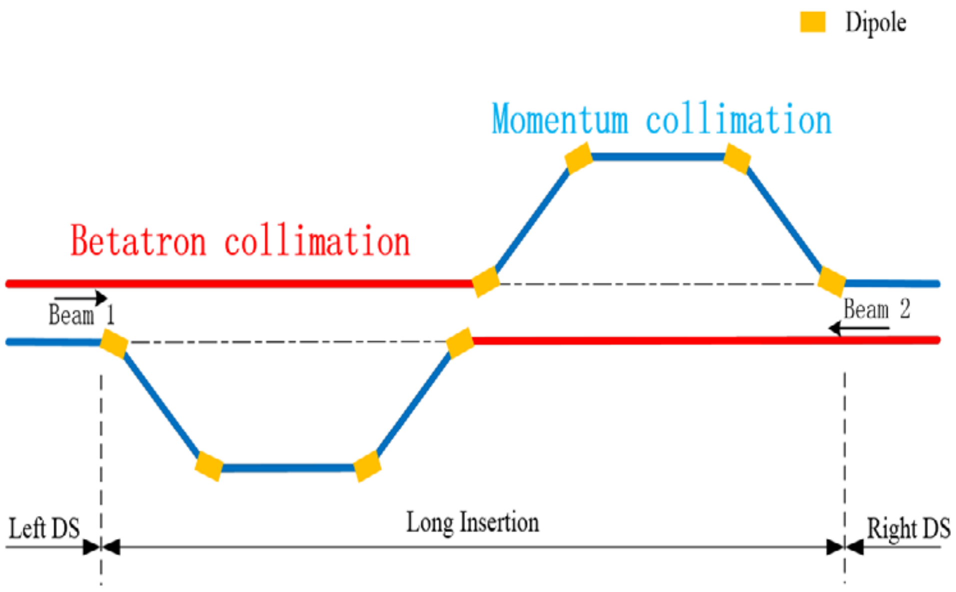
  - Normalized dispersion at primary momentum collimator satisfy:

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

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

Optics design

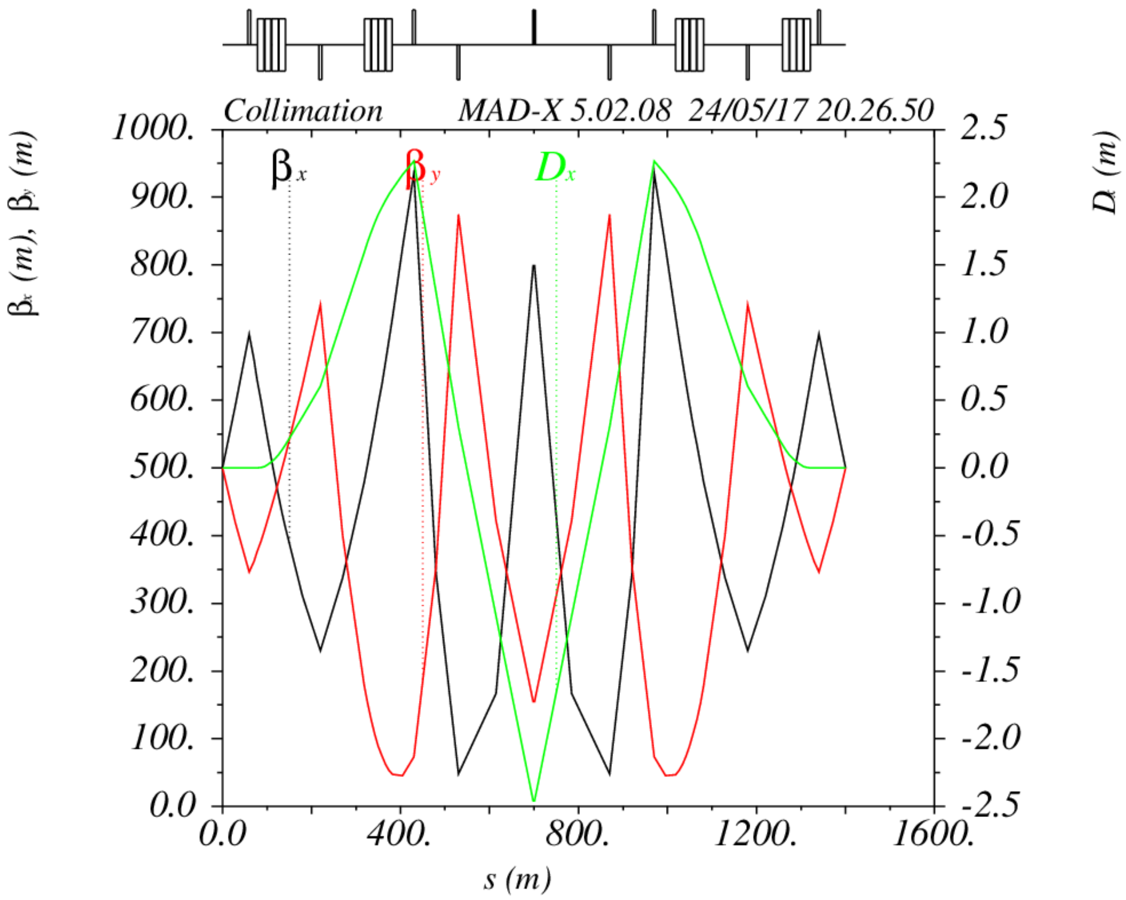
- Novel collimation method
  - Need some dipole magnets to produce the required dispersion for the momentum collimation and cancel the dispersion at the end
  - Betatron collimation requires significantly longer space for multi-stage collimation and the two proton beams
  - Compatibility with two sets of collimation system for each beam



Optics design

- Symmetric dispersion suppressor
  - 4 groups of superconducting dipoles, each group consists 5 dipoles,

    length 14 m, gap 1 m, same as in ARC
  - 9 quadrupoles are installed, the strength of pole is no more than 8 T
  - The primary momentum collimator is placed between the second and third groups of dipoles with almost maximum negative dispersion

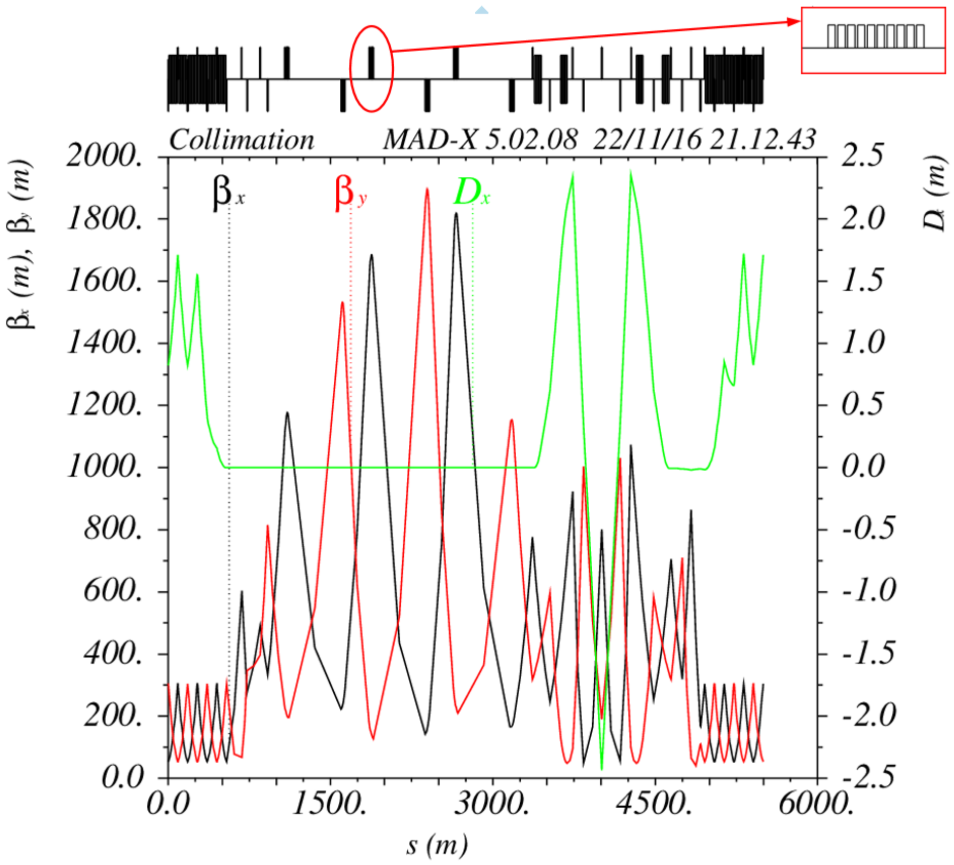


Optics design

Lattice scheme I

- warm quadrupoles are used in the transverse collimation because of their strong anti-radiation ability

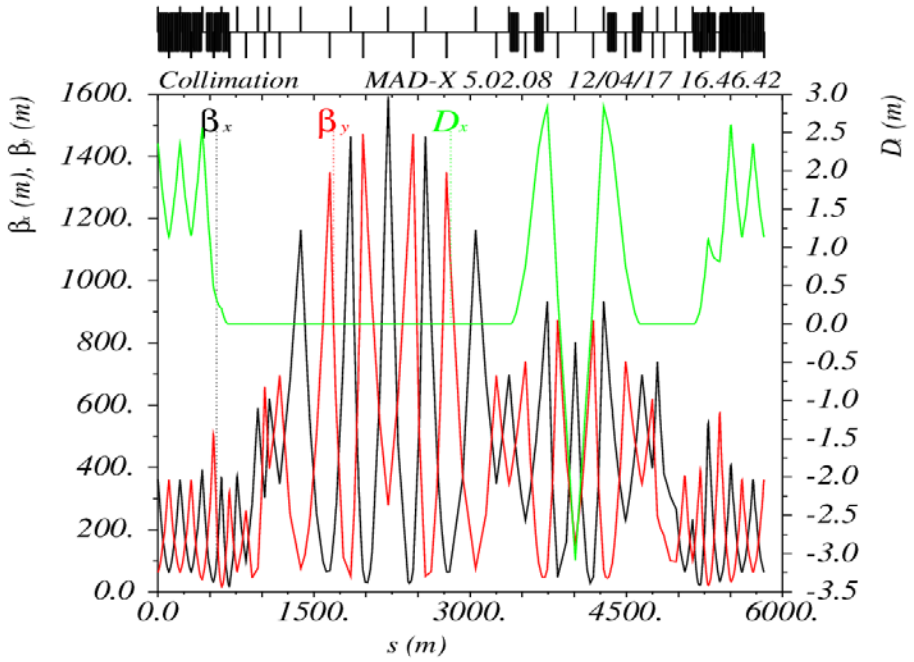
	Beta Coll.	Delta Coll.
μ_x	1.86 π	2.24 π
μ_y	1.88 π	2.11 π
β_x (max)	1810 m	1055 m
β_y (max)	1903 m	1010 m



Optics design

Lattice scheme II

- apply superconducting quadrupoles in the transverse collimation section
  - These quadrupoles are different from those in ARC, they will be designed with enlarged aperture and lower pole strength (no higher than 8 T)
- enhanced phase advance
  - Addition of the tertiary collimators in enhanced phase advance, following the secondary collimators, in order to clean the tertiary halo

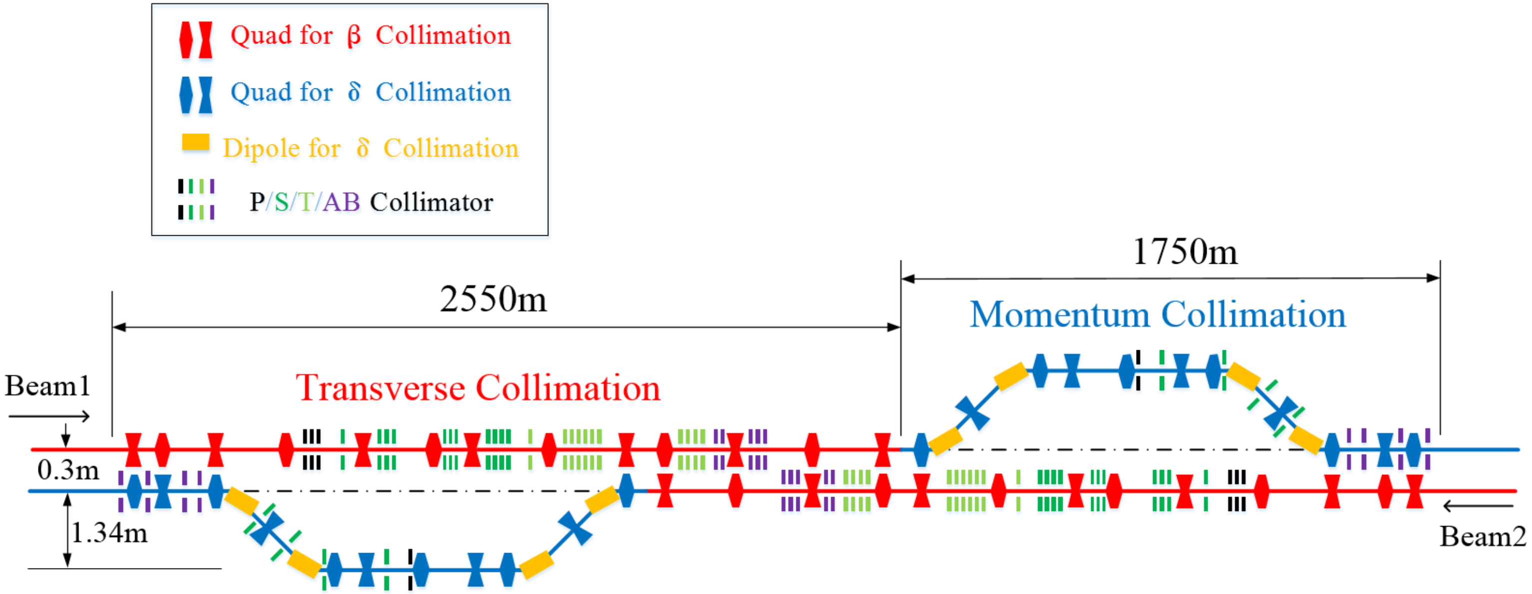


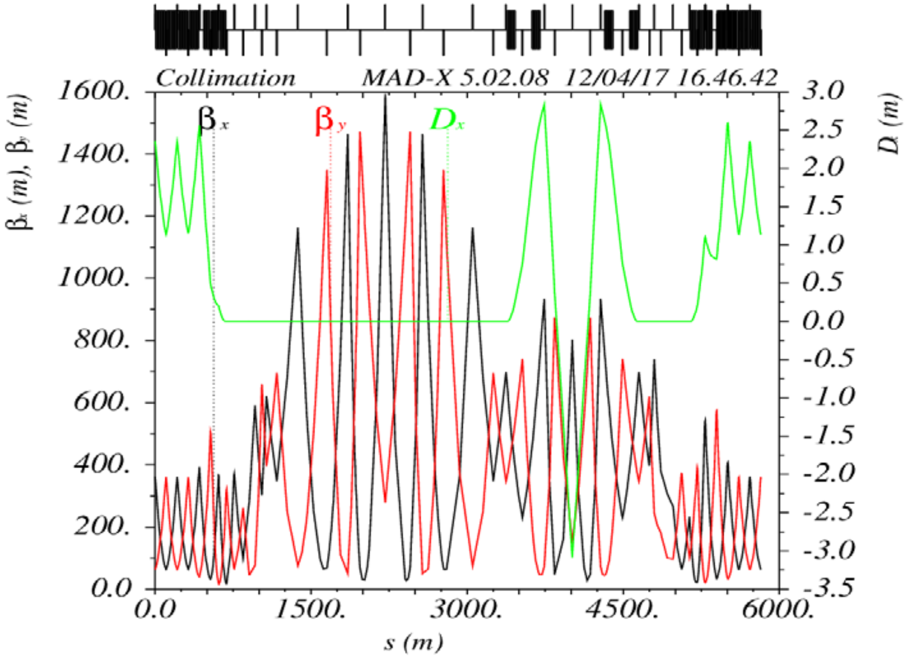
	Beta Coll.	Delta Coll.
μ_x	3.54 π	2.27 π
μ_y	3.31 π	2.14 π
β_x (max)	1600 m	905 m
β_y (max)	1470 m	885 m

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

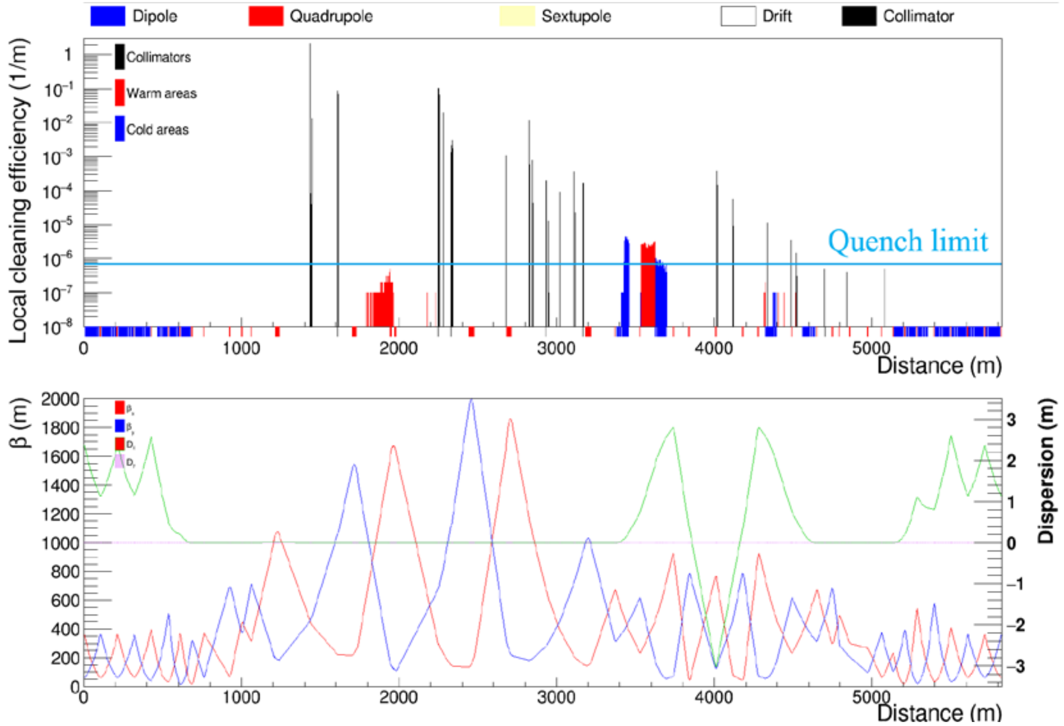




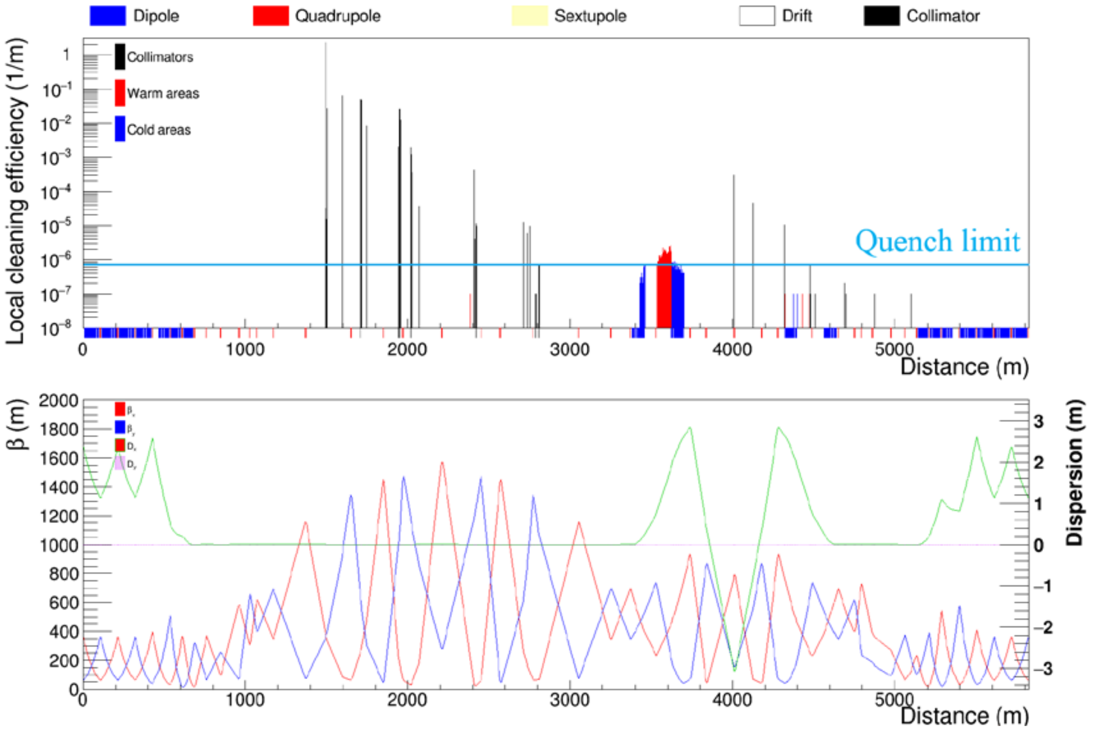
Simulation results

Vertical halo distribution

Lattice scheme I



Lattice scheme II



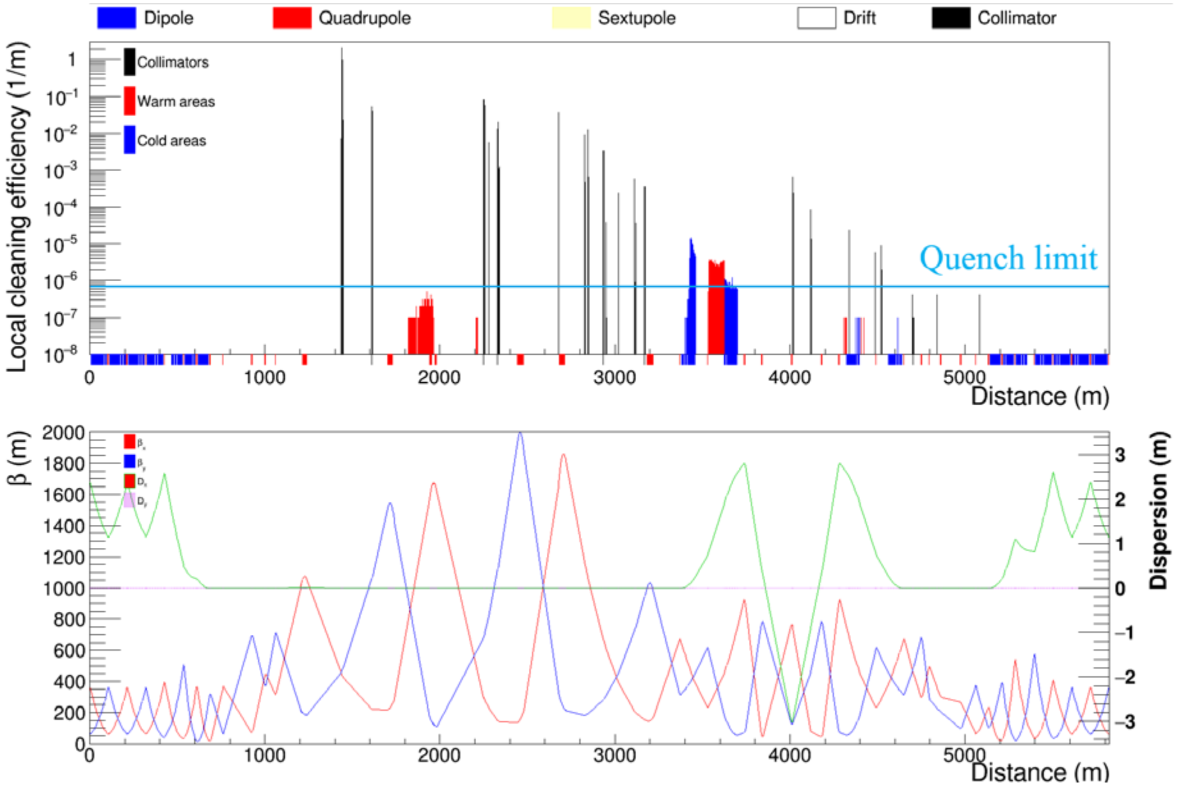
Collimator Acronym	Length (m)	Number	Aperture (σ)	Material	Lattice schemes
TPC	0.6	3	6	Carbon	I, II
TSC	1.0	11	7	Carbon	I, II
TTC	1.0	11	8.3	Copper	II
TAB	1.0	5	10	Tungsten	I, II
TQC	1.0	4	10	Tungsten	I, II
MPC	0.6	1	12	Carbon	I, II
MSC	1.0	4	15.6	Carbon	I, II
MAB	1.0	4	17.6	Tungsten	I, II

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

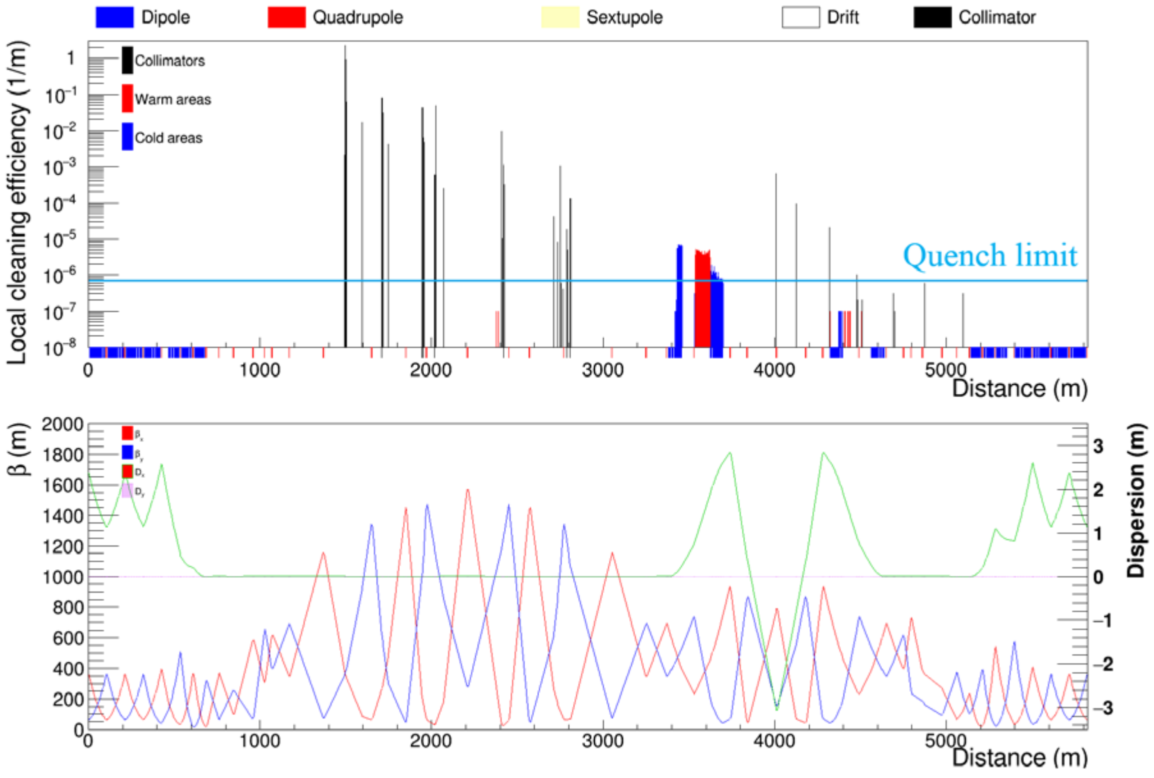
Simulation results

Horizontal halo distribution

Lattice scheme I



Lattice scheme II

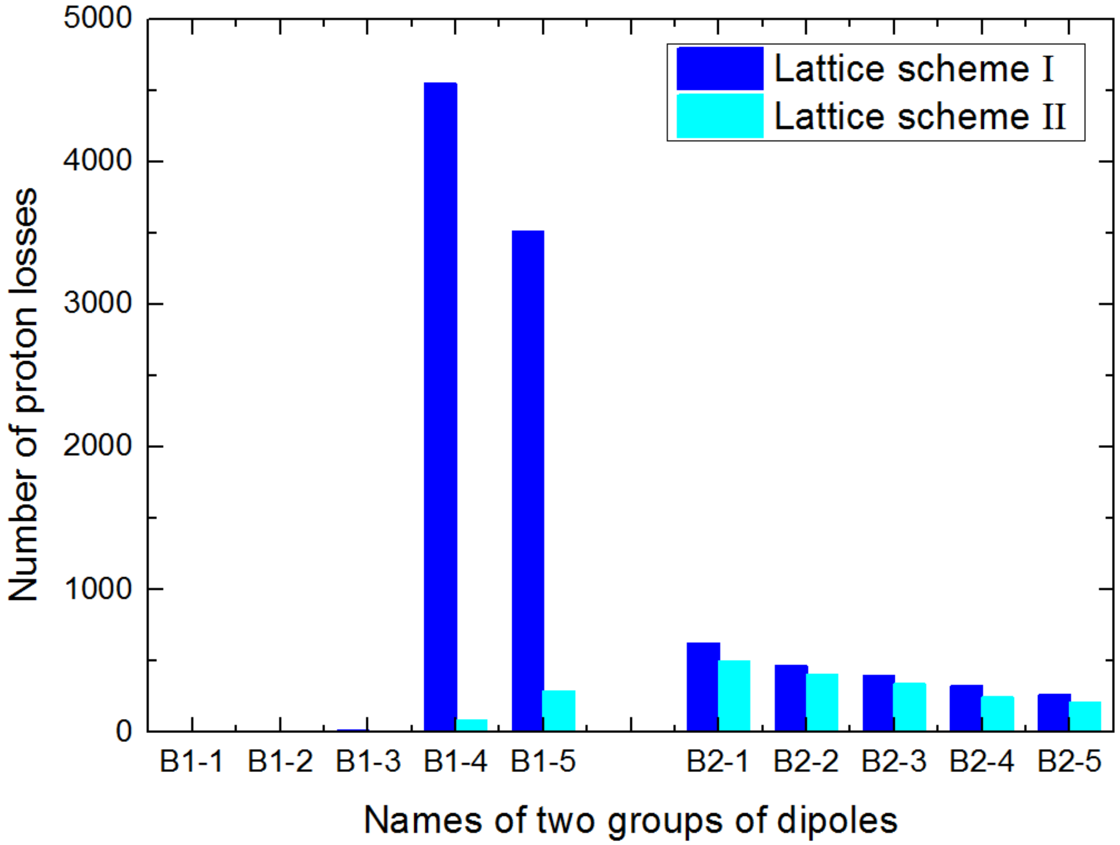


- For initial horizontal halo distribution, the spike proton losses can be reduced to half by introducing 11 tertiary collimators, but local protective collimators are still needed to dispose the proton losses related the single diffractive effect.

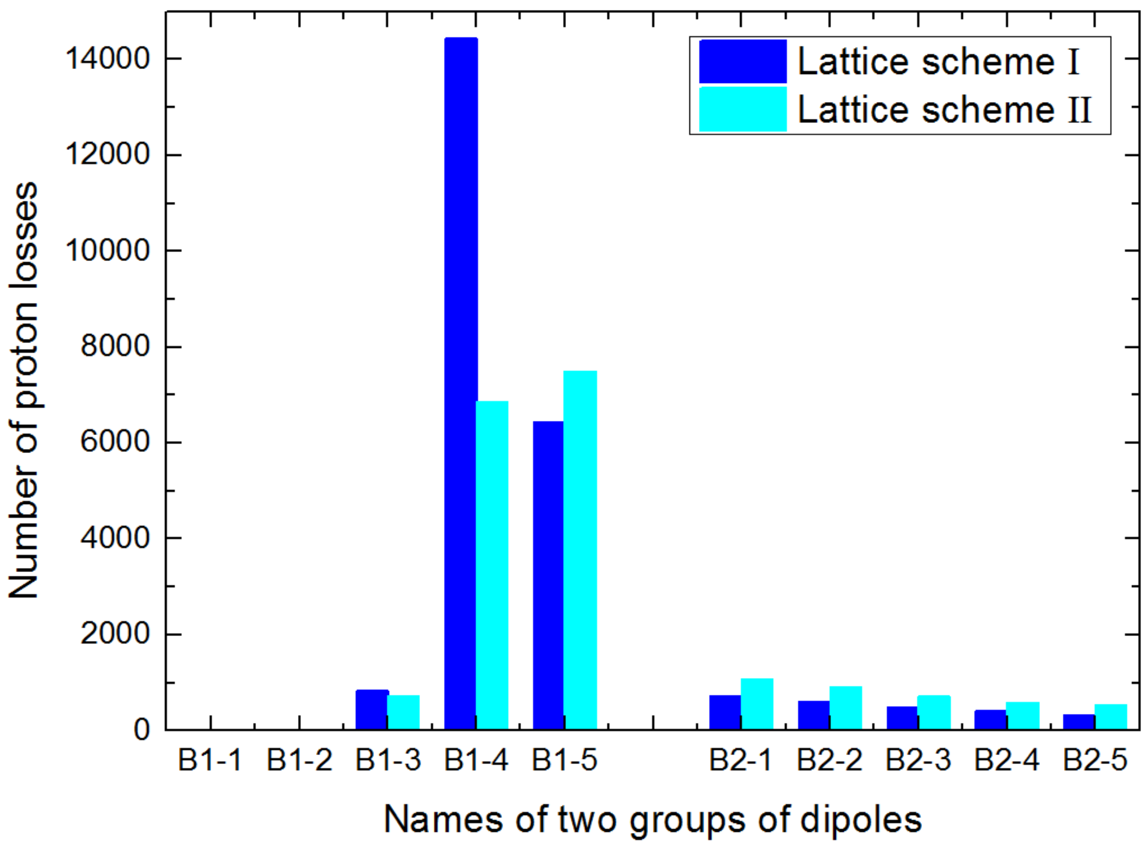
Simulation results

Comparation of two lattice schemes

Vertical halo



Horizontal halo

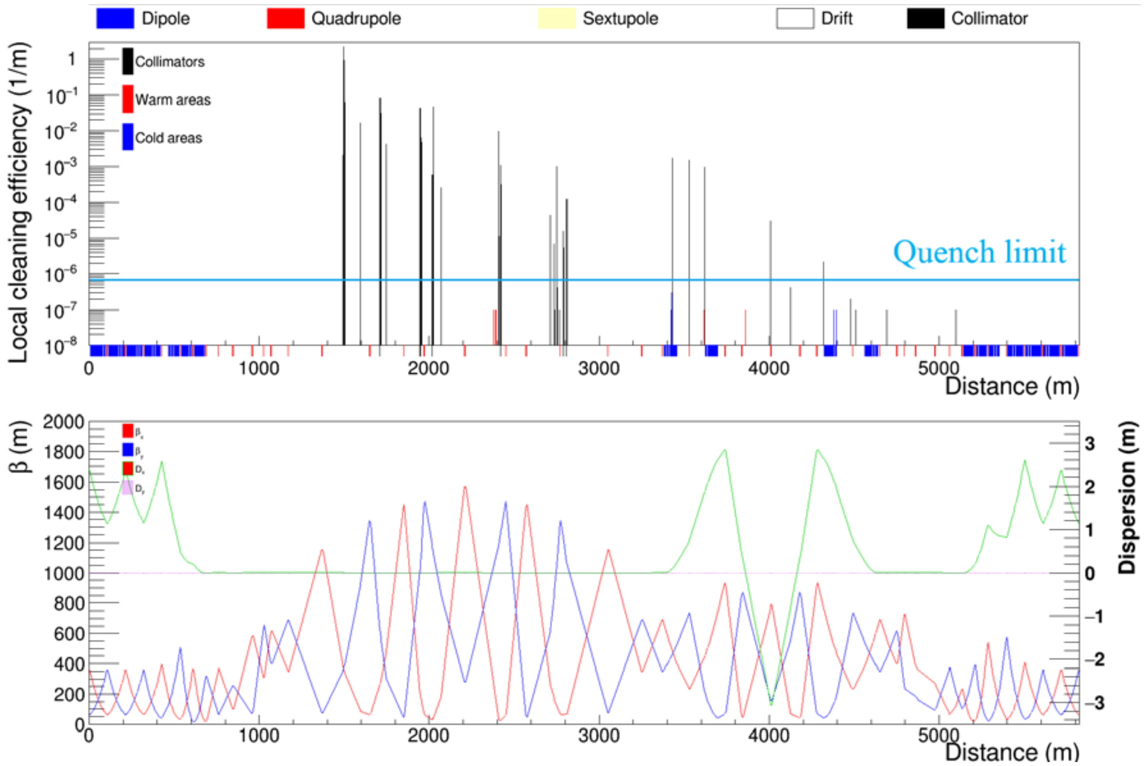


Simulation results

Local protection

- Installation of some protective collimators at the places where dispersion increases gradually: the particles with large momentum dispersion will impinge on the front momentum collimators firstly, and the particles with small momentum dispersion will impinge on the follow-up collimators.

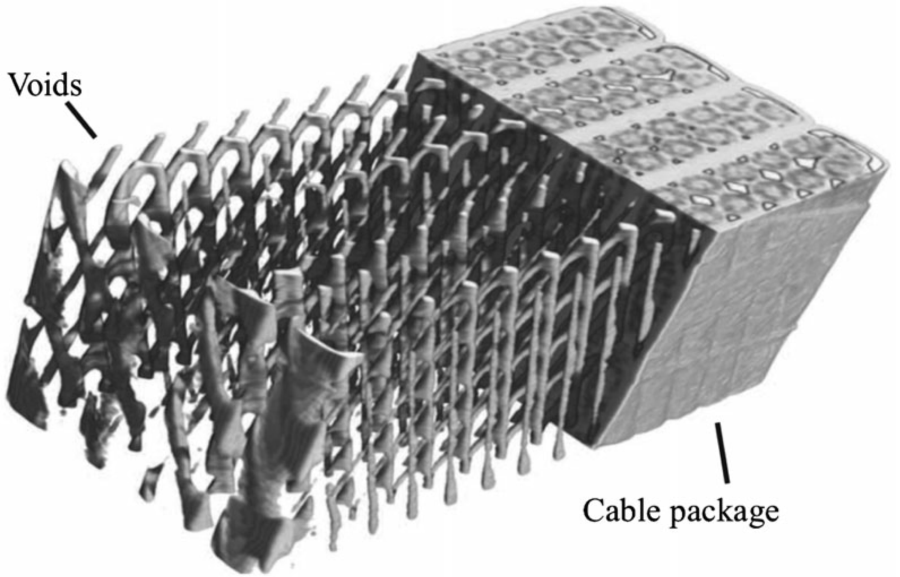
➢ There is no proton losses in the cold region exceed the quench limit along the full ring.



All simulations are carried out only with collision insertion and only considering the linear condition

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

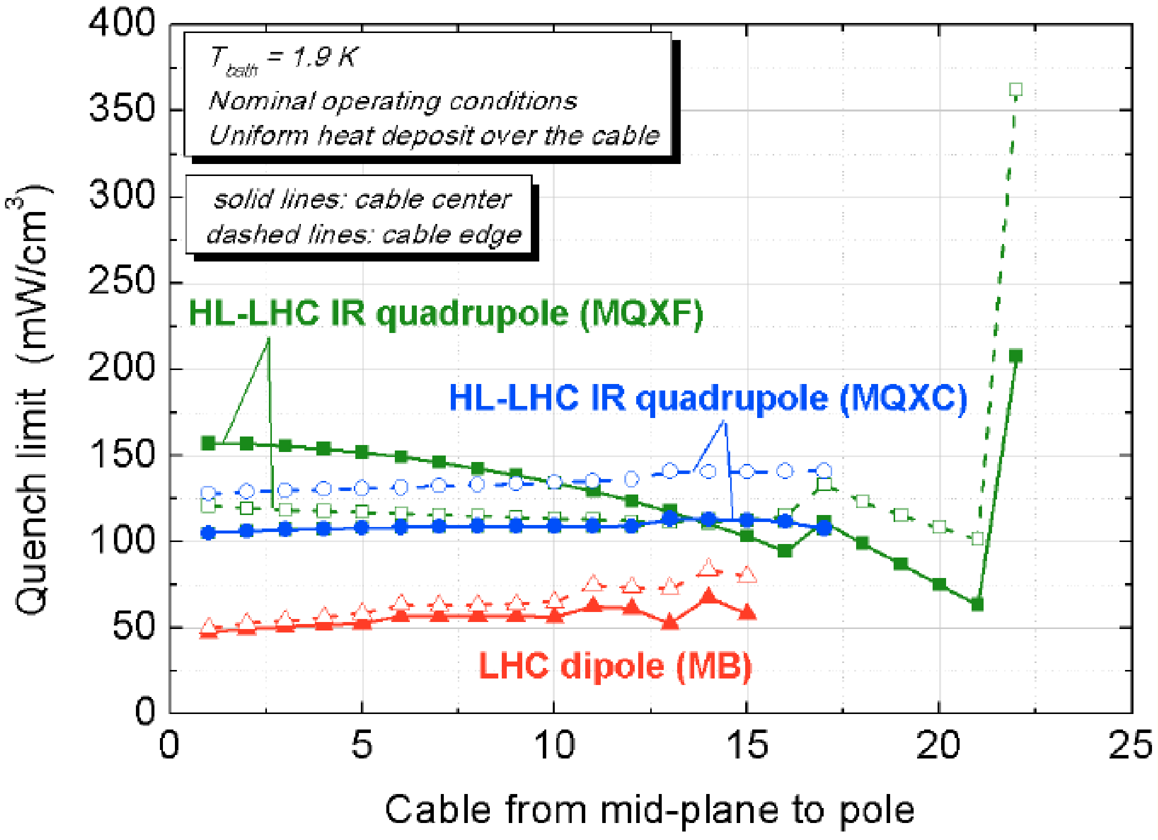
- SC quadrupoles in HL-LHC

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.

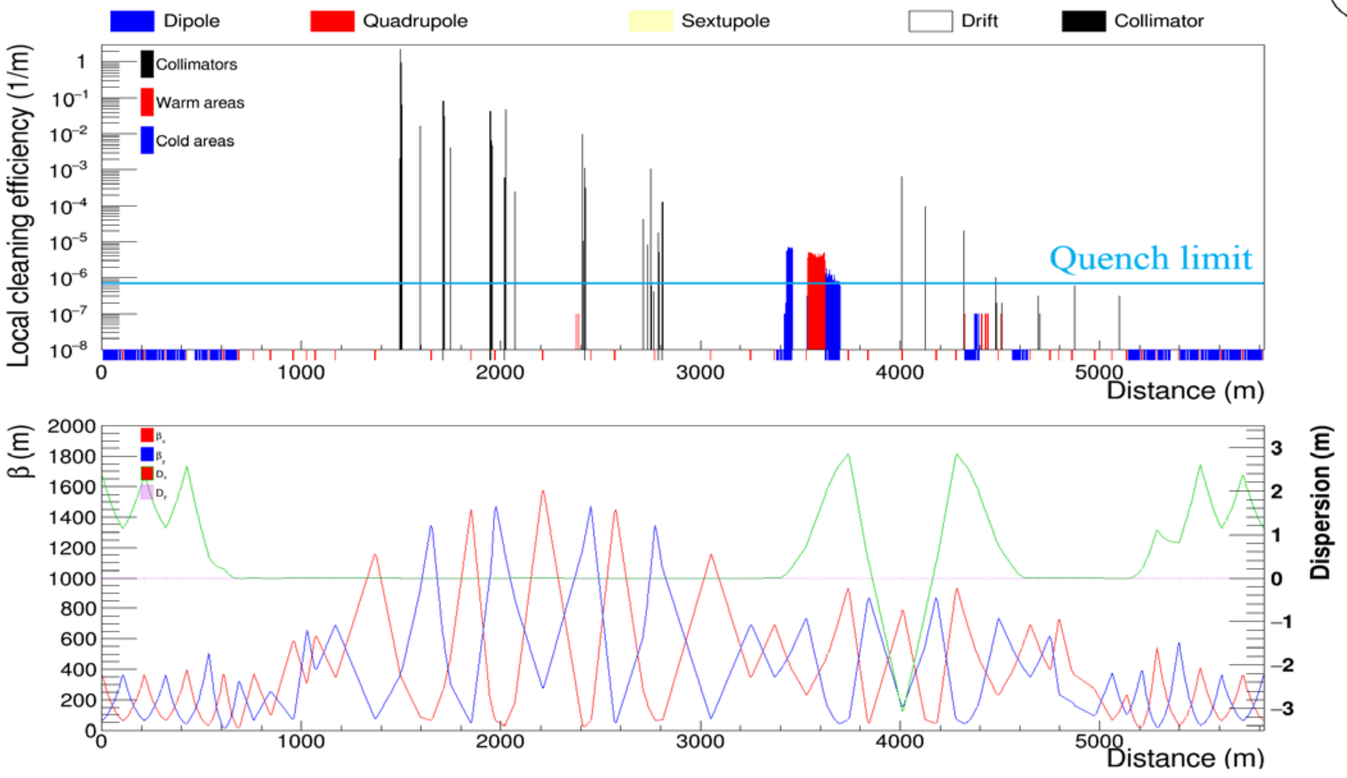


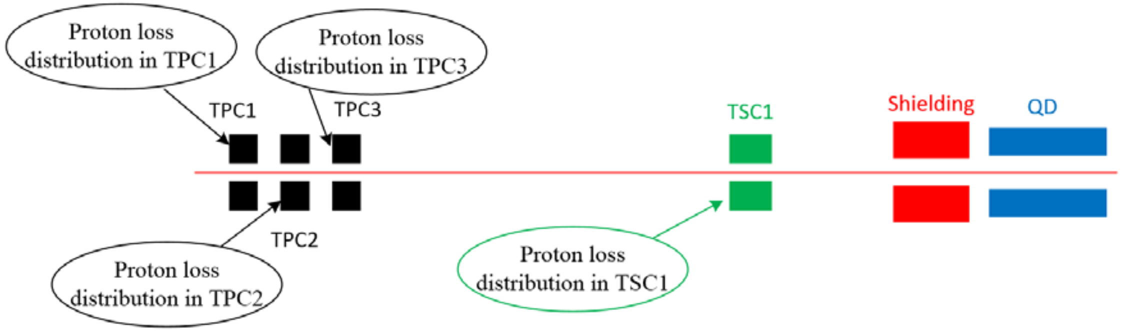
- In betatron collimation section, the highest quadrupole field is 8 T, which is lower than the IR quadrupole in LHC.
- Considering the He II and He boiling heat transfer mechanisms, which allow extracting more heat from the cable than the only solid conduction through the cable insulation, the quench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

Protection scheme

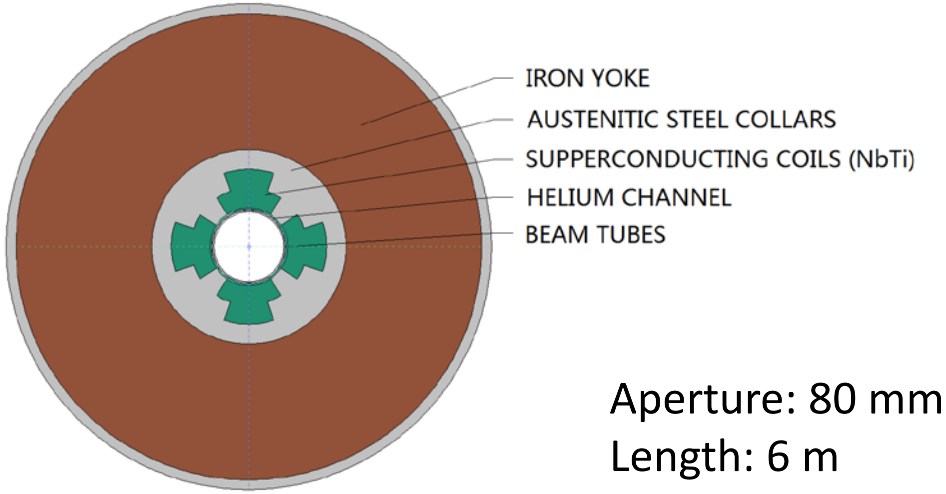
FLUKA simulation

- Which quadrupole will bear the greatest risk of quench?





Geometry model:

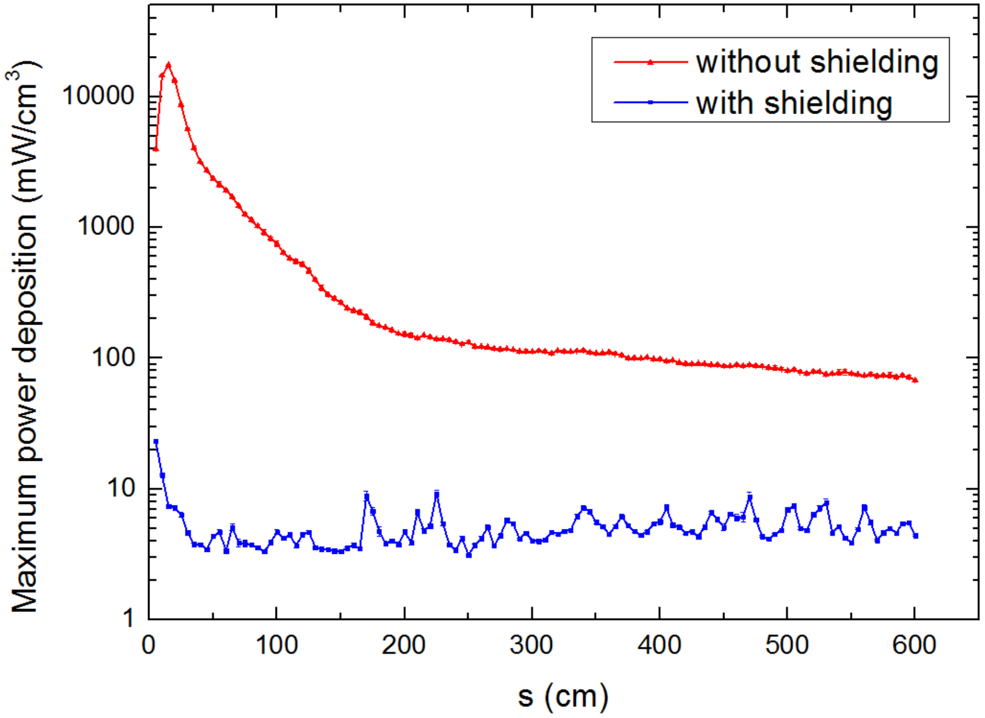


Aperture: 80 mm
Length: 6 m

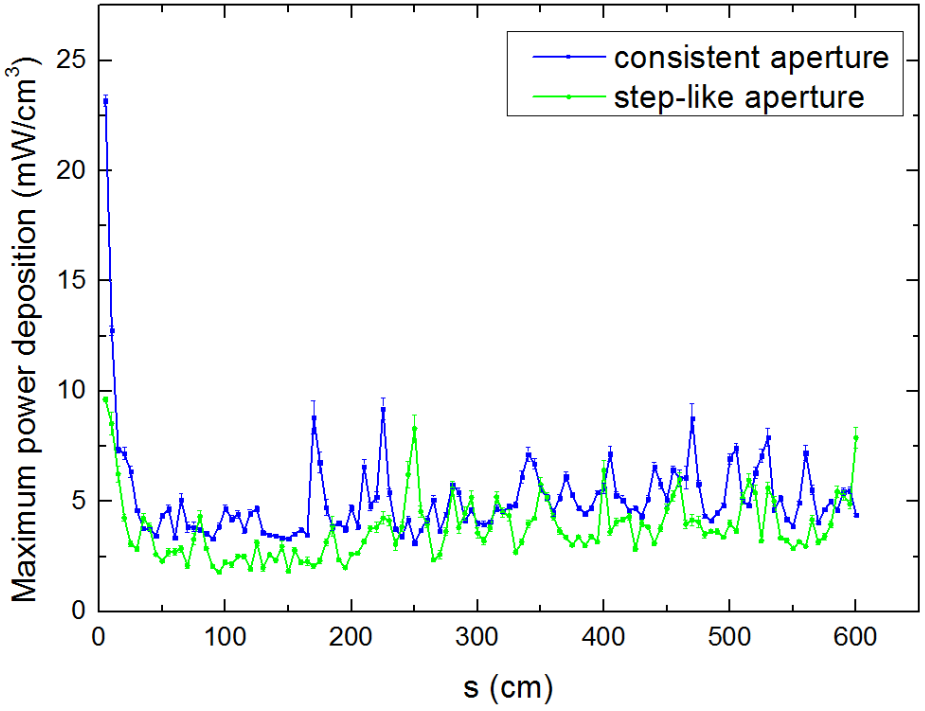
Protection scheme

Energy deposition in SC quadrupole

- 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 30% of all stored SPPC protons will be lost in the collimation section in one hour

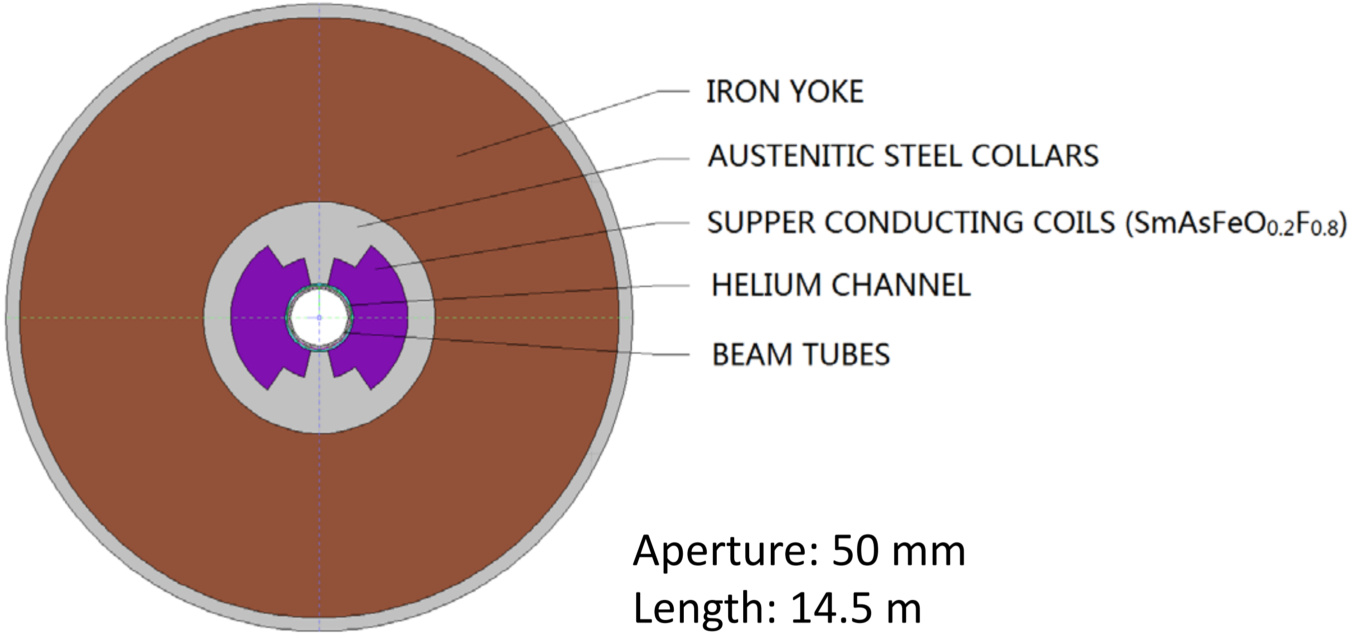


Step-like aperture: the aperture of the rear half is enlarged to 10.2 mm

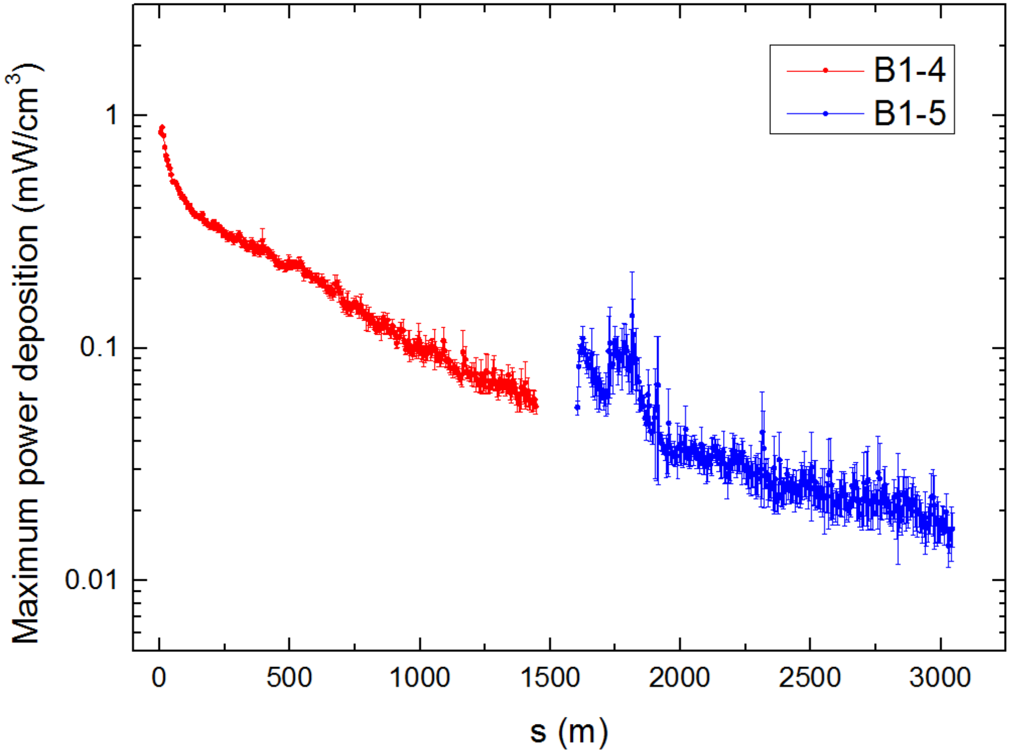


Protection scheme

- 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 combined 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 7×10^{-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 by a large factor from quenching.

Next to do

- Study the background sources from beam-beam interactions and the collimator themselves.
- Consider the effect of the layout on the machine impedance, beam energy deposition studies and power loads, as well as other safety and sustainability issues.

Thank you for your attention