中国科学院高能物理研究所
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SPPC Collimation study

FCC-Week

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Outline

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- Conclusions
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Introduction

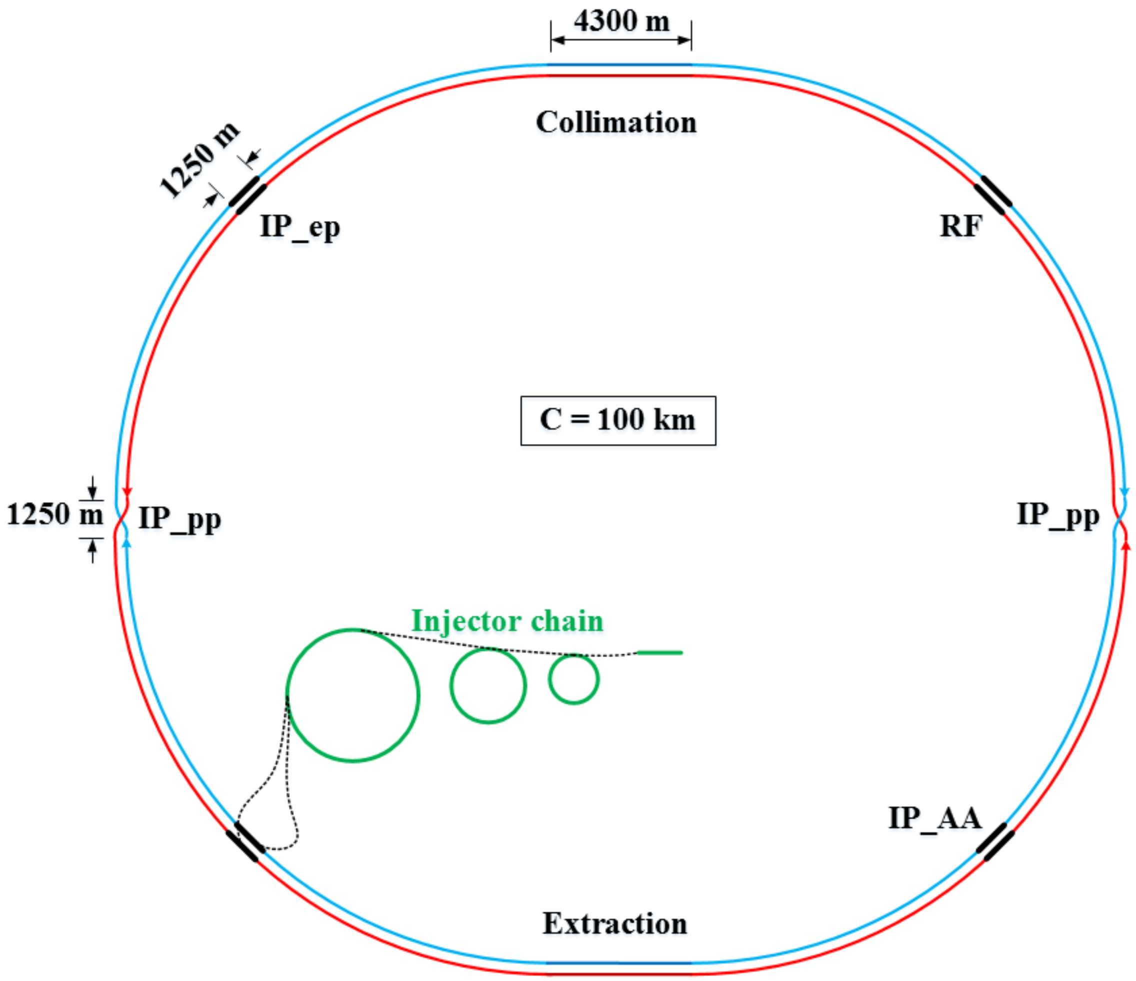
Main parameters of SPPC

- 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



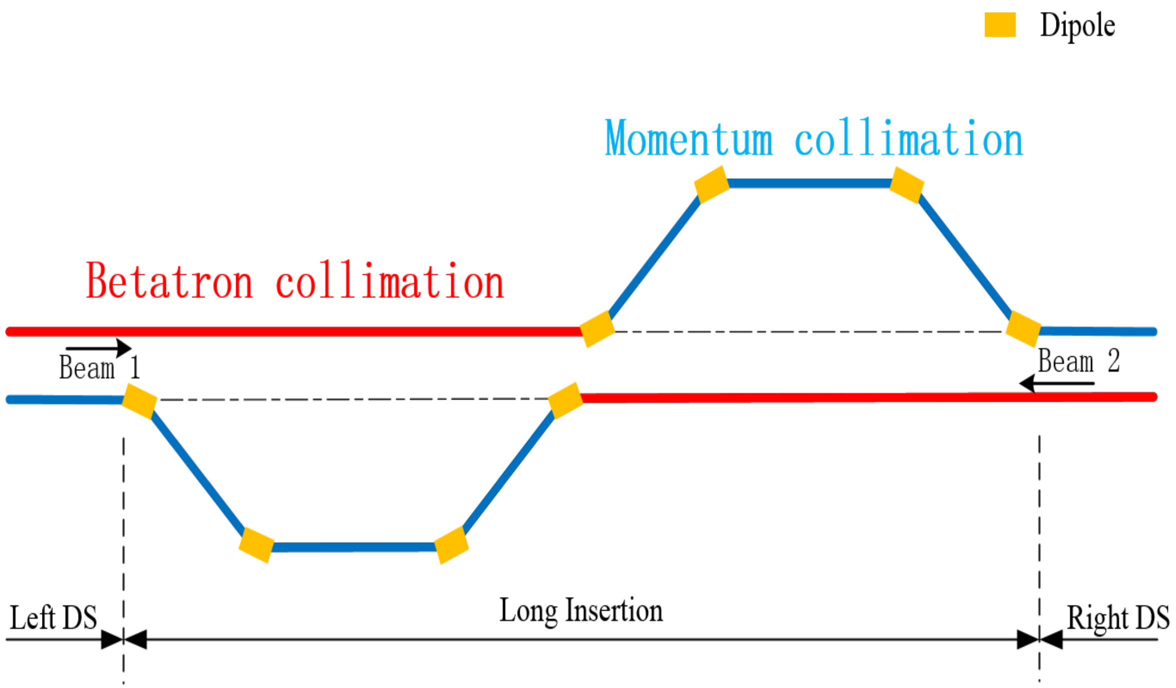
from Y. K. Chen

- 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
- Two groups of SC dipoles are used to produce required dispersion for momentum collimation
- 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:

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

SPPC

Rq: ~10^6 protons/m/s

N_{tot}^q : 1.5×10^{15}

$\tau_{\min}$: 0.2 h

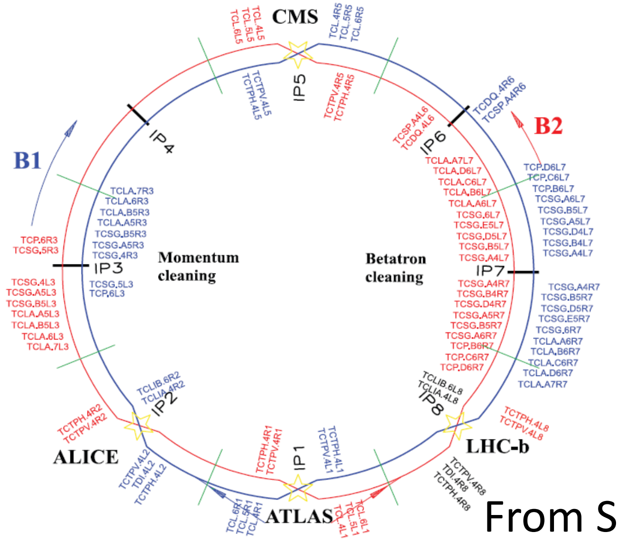
$$\tilde{\eta}_c < 4.5 \times 10^{-7}\ \mathrm{m}^{-1}$$

- 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

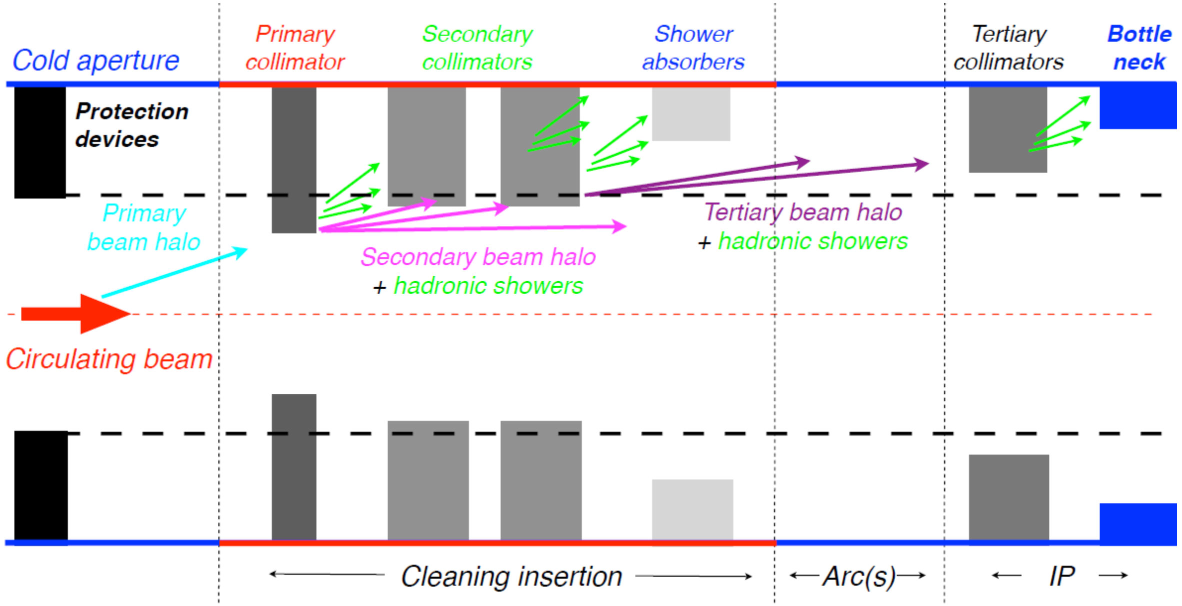
Multi-stage collimation in LHC

- 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**
- **TCLs absorb physics debris**

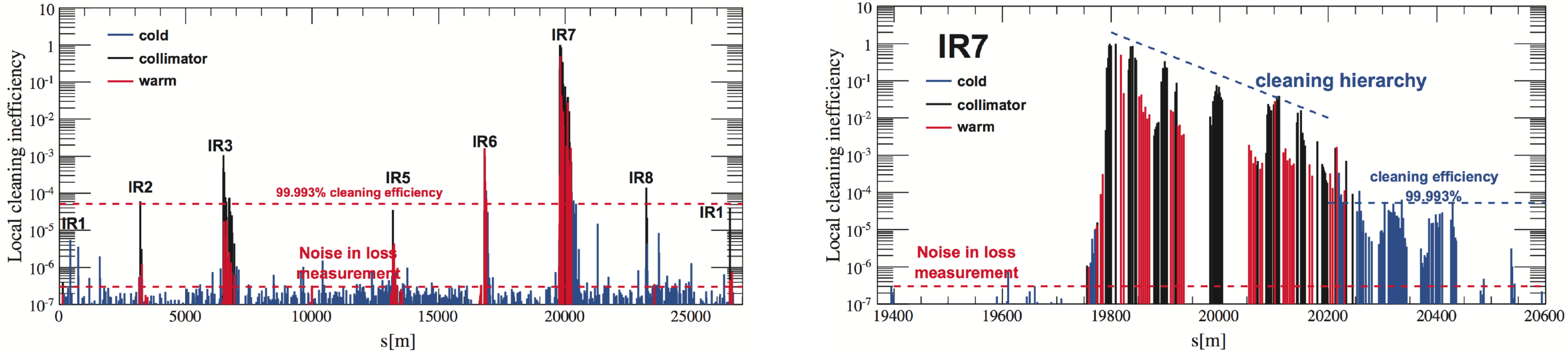


Motivations

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

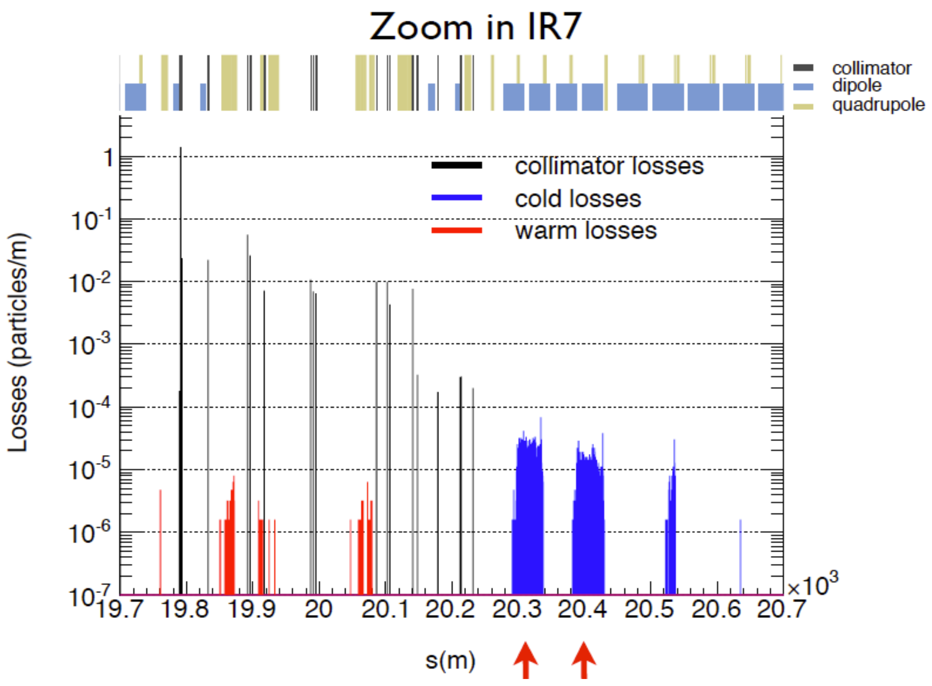
- Single diffractive scattering

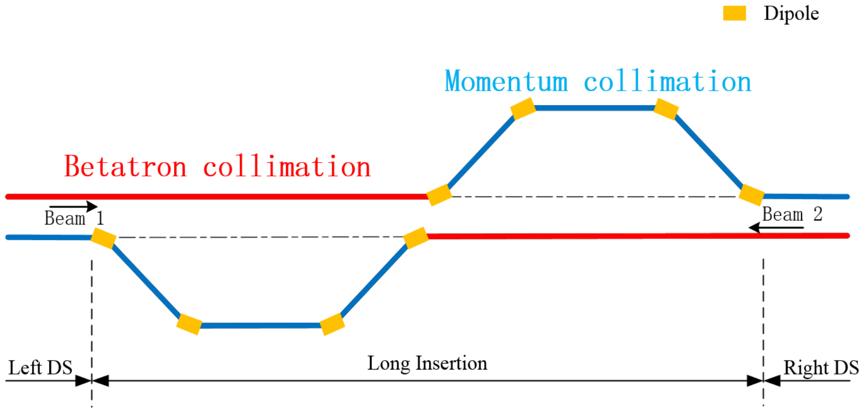
$$P_1 = P_0 \cdot \frac{\sqrt{E_1} \cdot \ln(0.3 \cdot E_1)}{\sqrt{E_0} \cdot \ln(0.3 \cdot E_0)} \qquad \text{With } E_1 > E_0$$

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

From M. Fiascaris





Optics design

Requirements I

- 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:

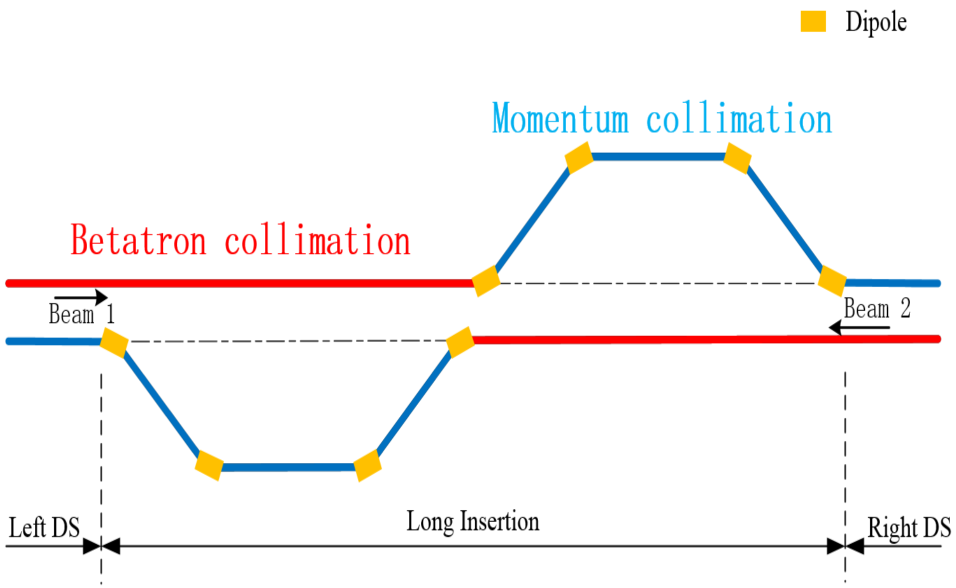
$$\left|\chi_{D,\mathrm{prim}}(n_1)\right| \geq \frac{n_1 \chi_{D,\mathrm{arc}}}{A_{\mathrm{arc,inj}}(\delta_p=0) - (n_2^2 - n_1^2)^{1/2}} \quad \& \quad \frac{D_x'}{D_x} = -\frac{\alpha_x}{\beta_x}$$

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

Optics design

Requirements II

- 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

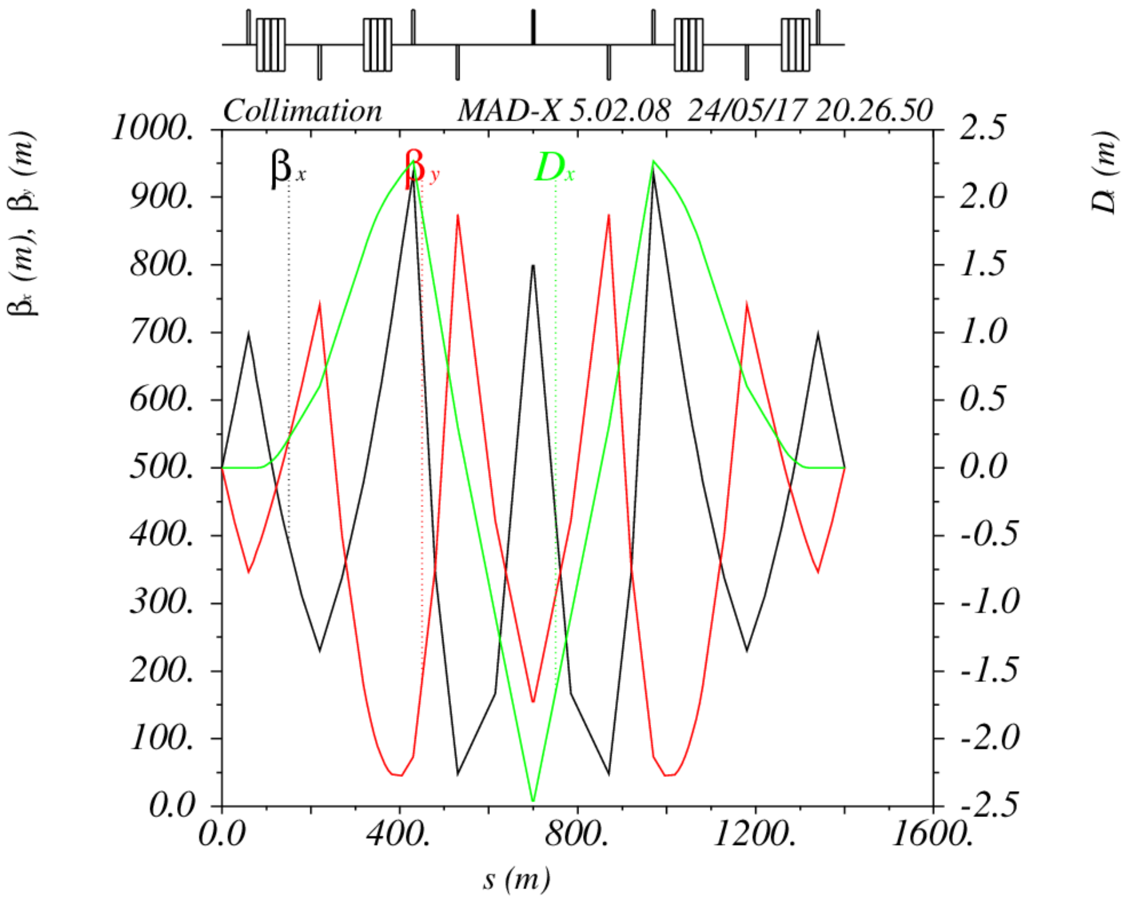


Optics design

Momentum collimation

- 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

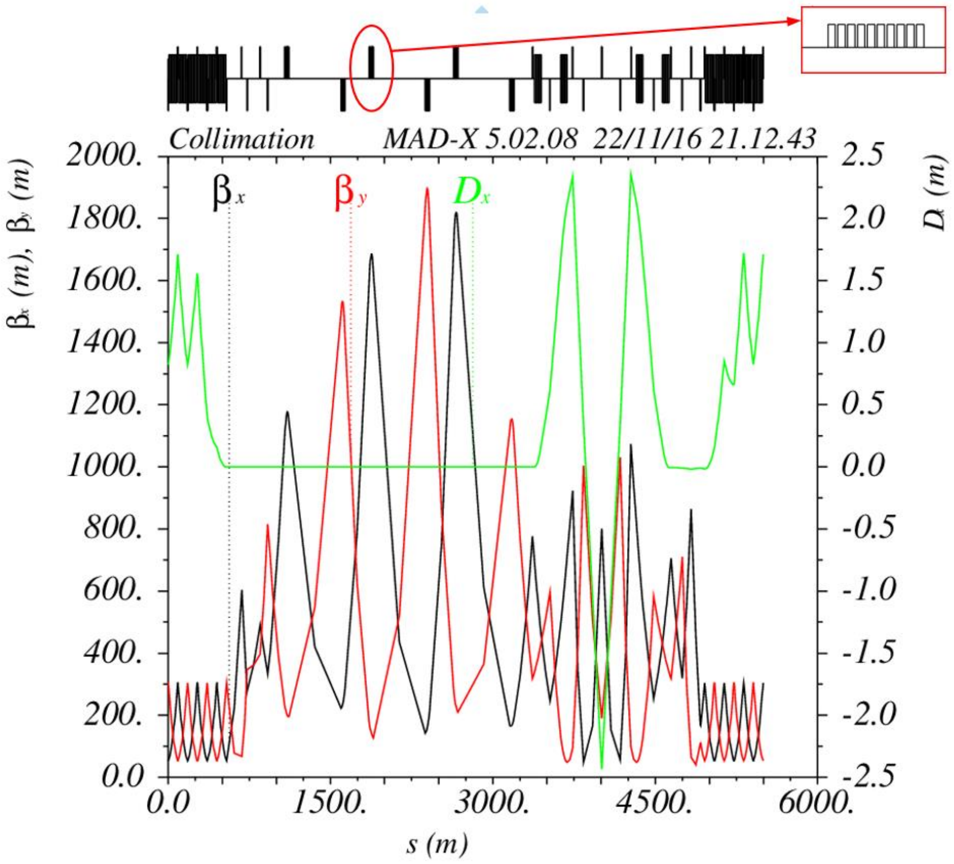


Optics design

Version I

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

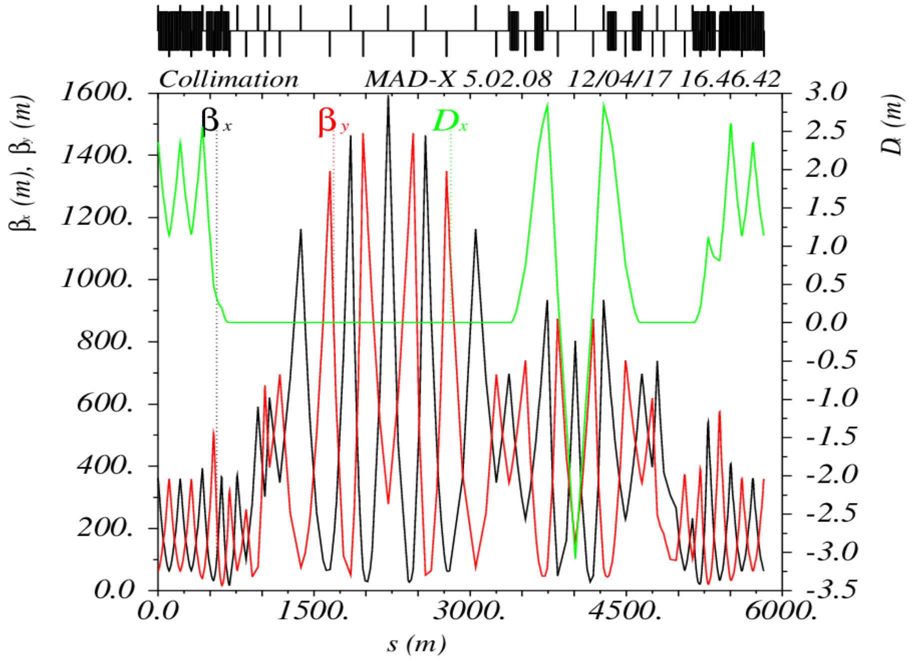
	Beta Coll.	Delta Coll.
μ_x	1.86 π	2.24 π
μ_y	1.88 π	2.11 π
β_x (max)	1810 m	1055 m
β_y (max)	1903 m	1010 m



Optics design

Version 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

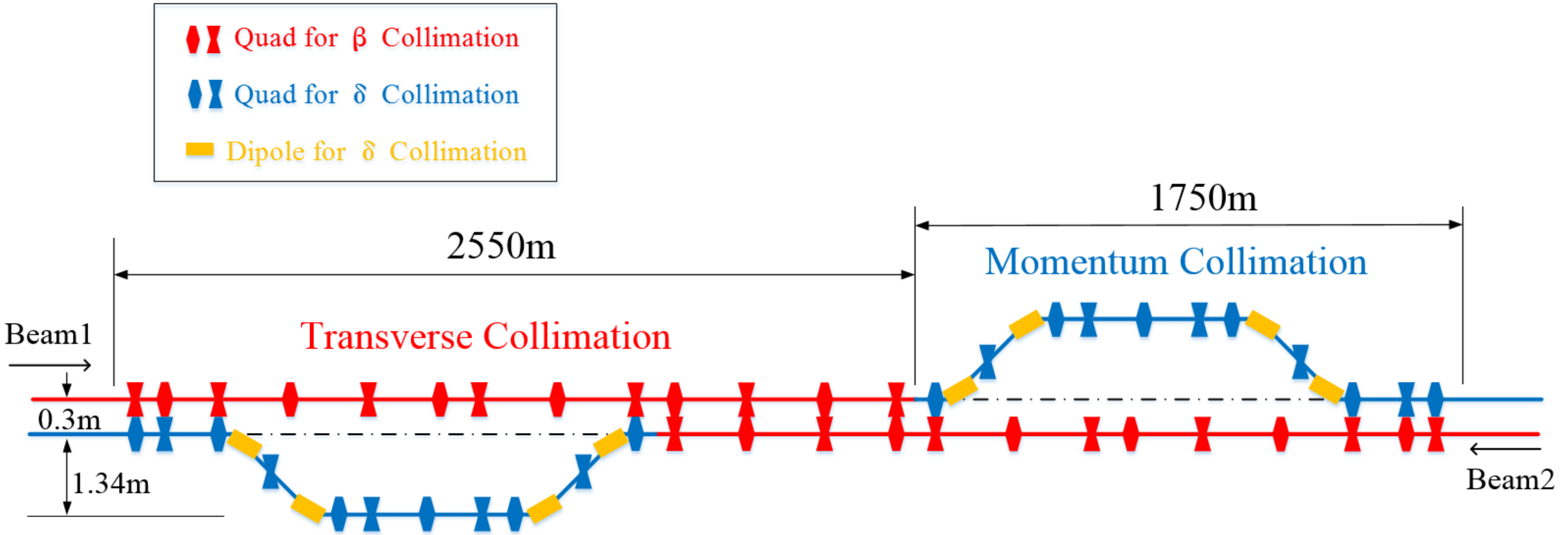


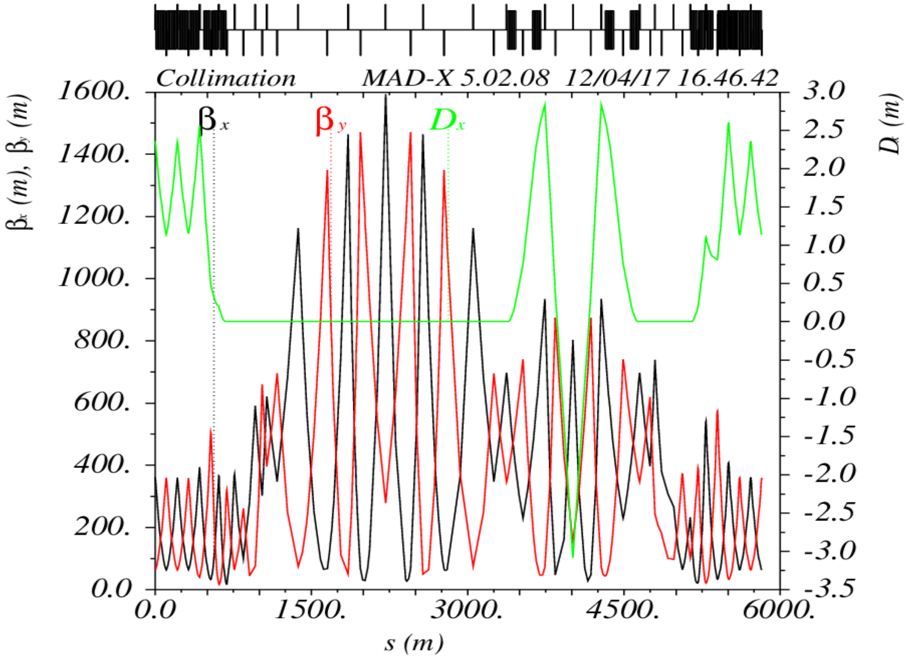
	Beta Coll.	Delta Coll.
μ_x	3.54 π	2.27 π
μ_y	3.31 π	2.14 π
β_x (max)	1600 m	905 m
β_y (max)	1470 m	885 m

Optics design

Version II

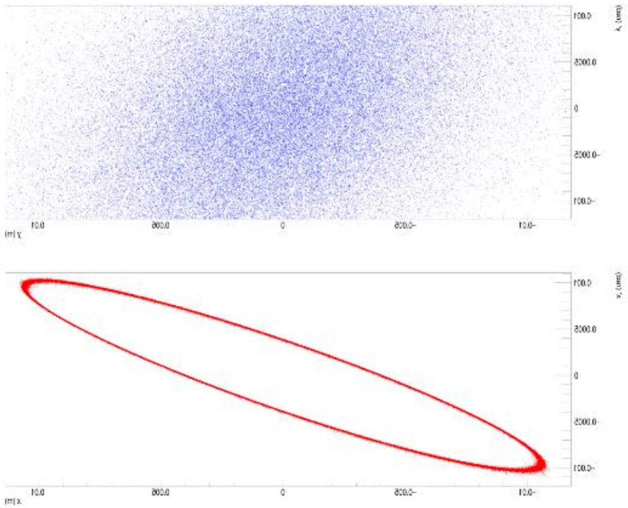
- Compatibility with two sets of collimation system for each beam
  - Quadrupoles with twin apertures are installed in the overlapping region between the two beam
  - Quadrupoles with single aperture are installed in the position with horizontal offset





Simulation results

- Bunch distribution (Model horizontalHaloDistribution2)
  - Vertical: gaussian distribution
  - Horizontal: halo distribution
  - Particle number: 3×10^7
- Code: Merlin
  - Shared by James Molson at LAL

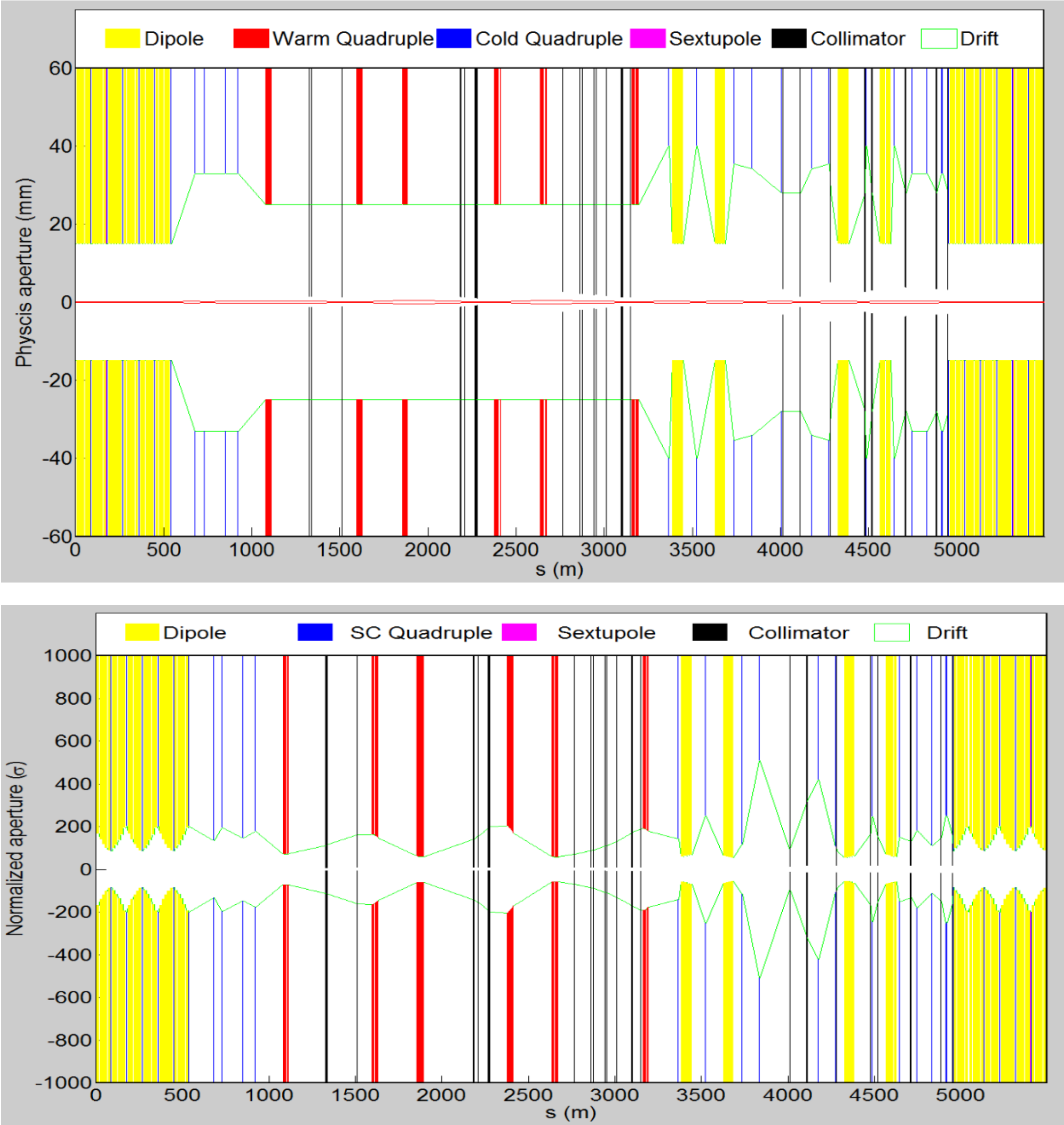


Acronym	Length	Number	Aperture	Material	Versions
TPC	0.6 m	3	6 σ	C	I, II
TSC	1 m	11	7 σ	C	I, II
TTC	1 m	11	8.3 σ	Cu	II
TAB	1 m	5	10 σ	W	I, II
LPC	0.6 m	1	12 σ	C	I, II
LSC	1m	4	15.6 σ	C	I, II
LAB	1m	4	17.6 σ	W	I, II

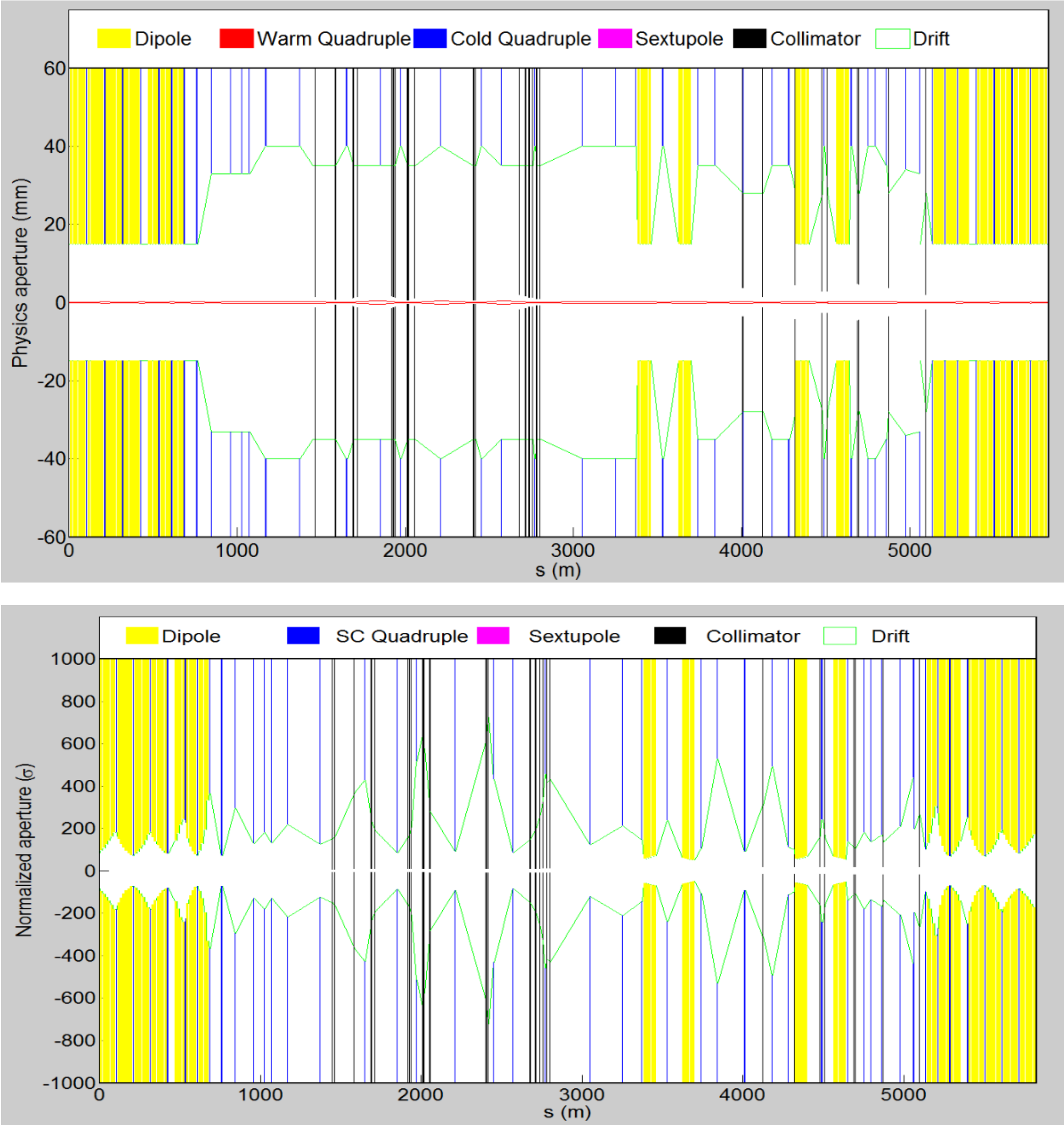
Simulation results

Aperture setting

Version I

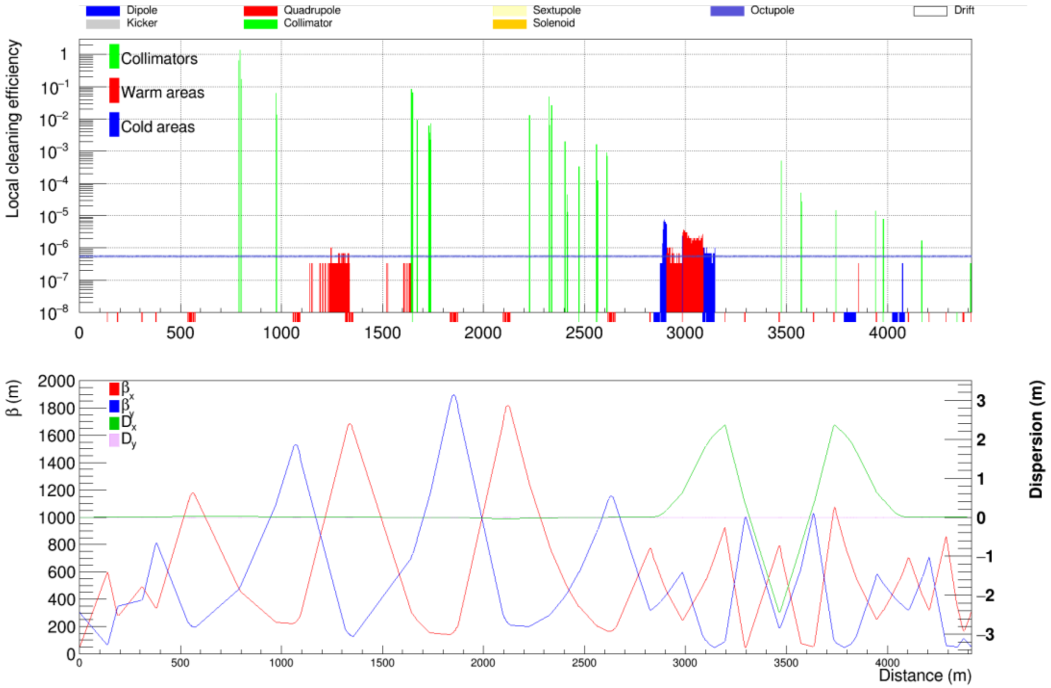


Version II

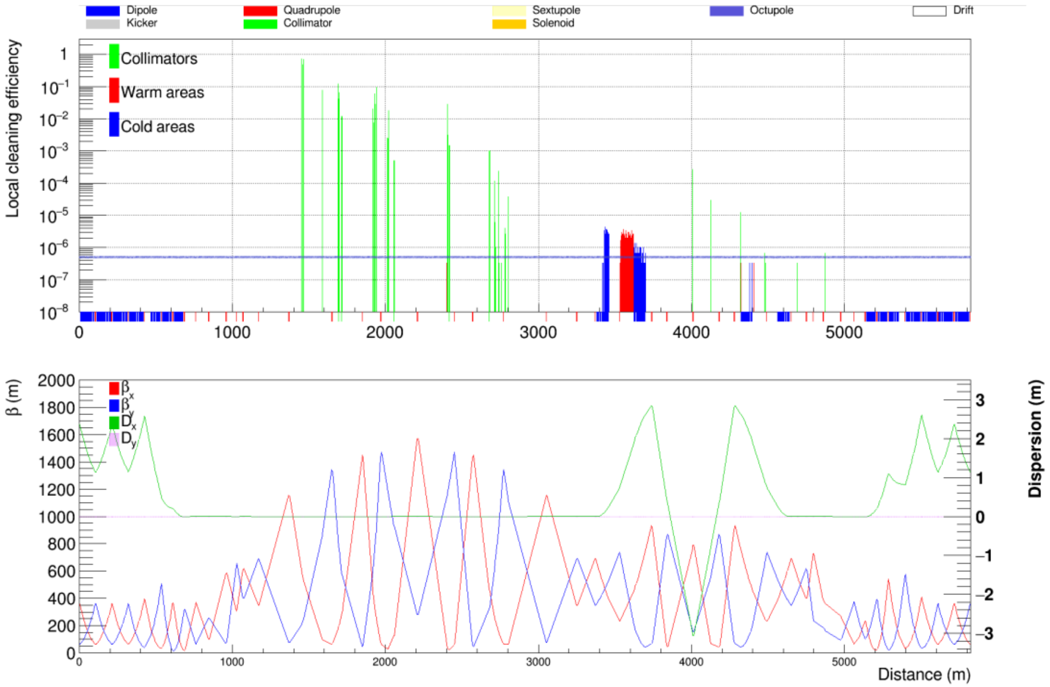


Simulation results

Version I



Version II

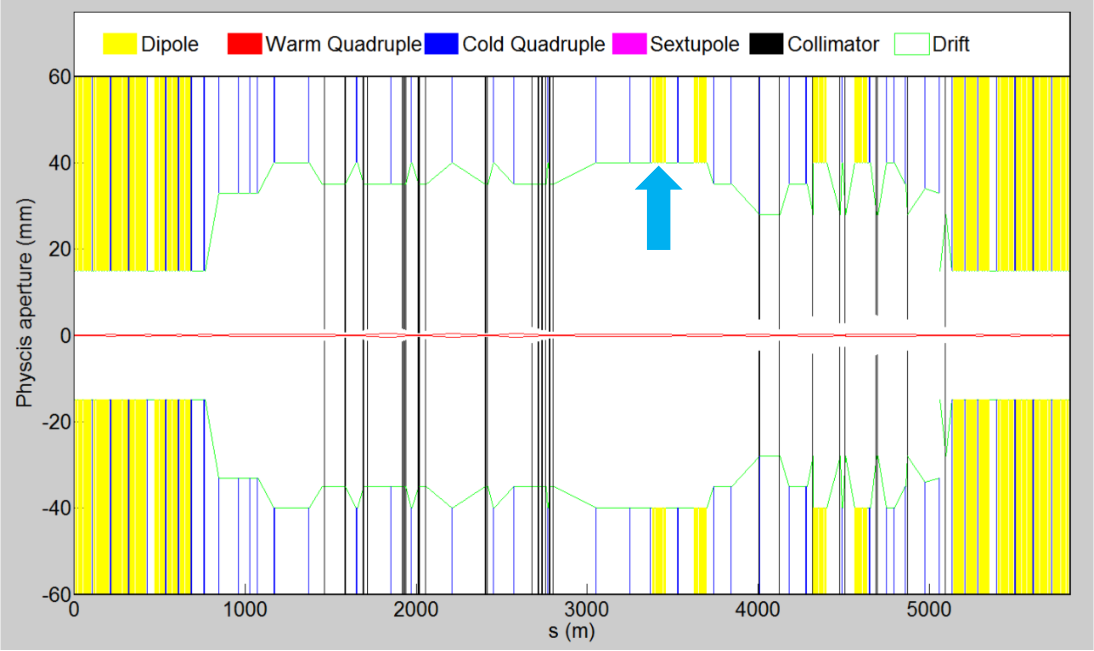


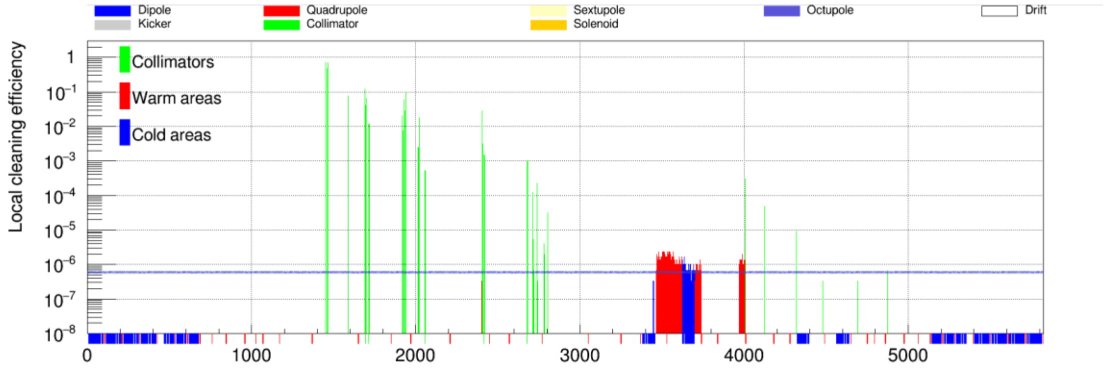
- **Conclusion**
  - Cleaner in the warm region;
  - Less particle losses at the beginning of dispersion, but still can lead to quench

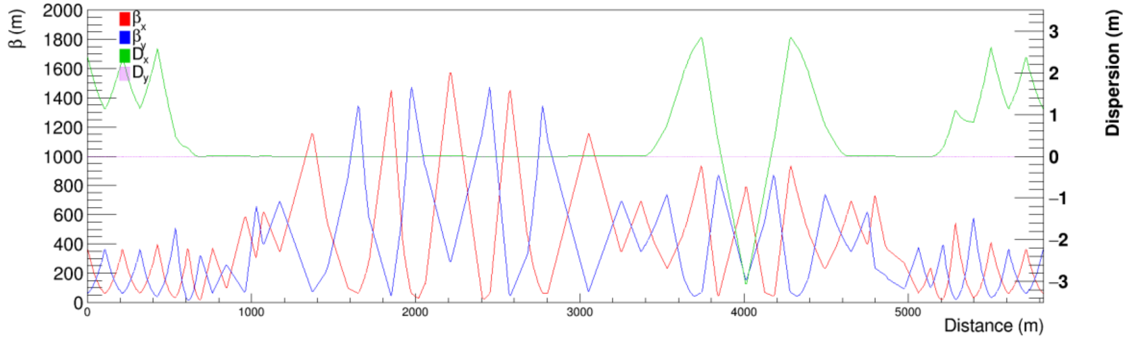
Simulation results

Solution I

- enlarge the aperture of cold dipoles in the momentum collimation, making beam halo through this cold region to impinge on the primary momentum collimators
- Less particle losses in cold dipoles





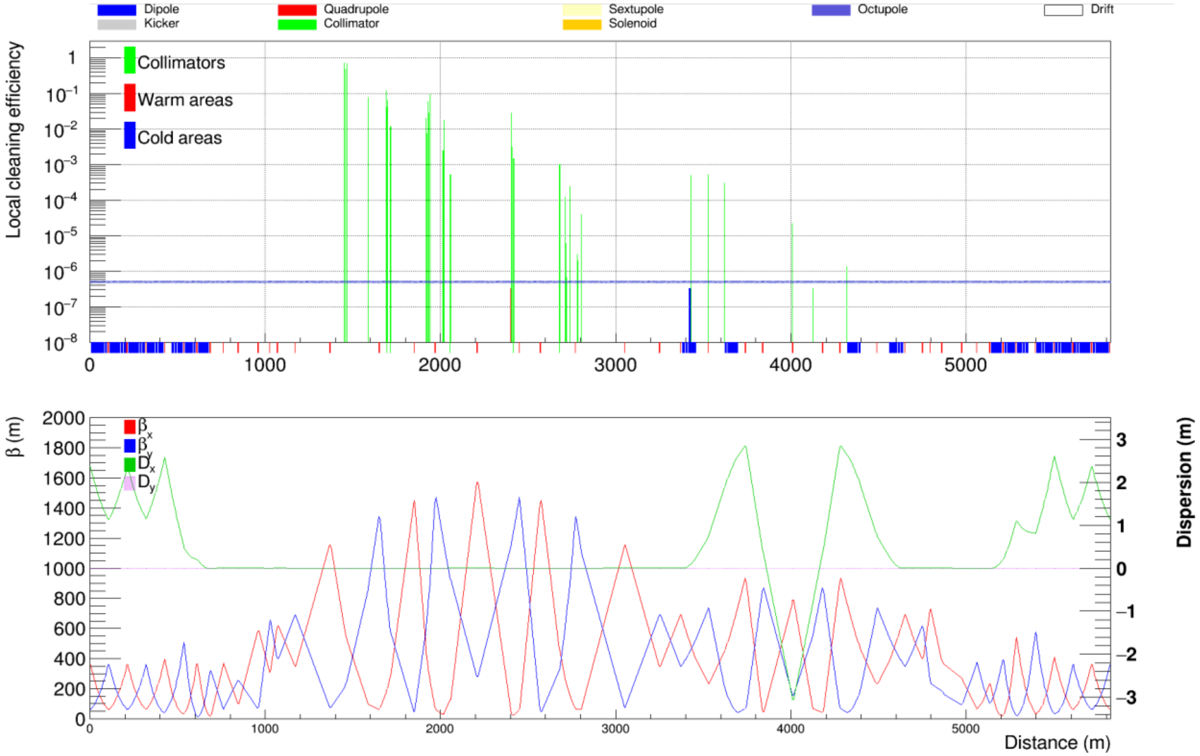


Simulation results

Solution II

- 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.

No losses!



All simulations are carried out without other insertion, only considering the linear condition

conclusions

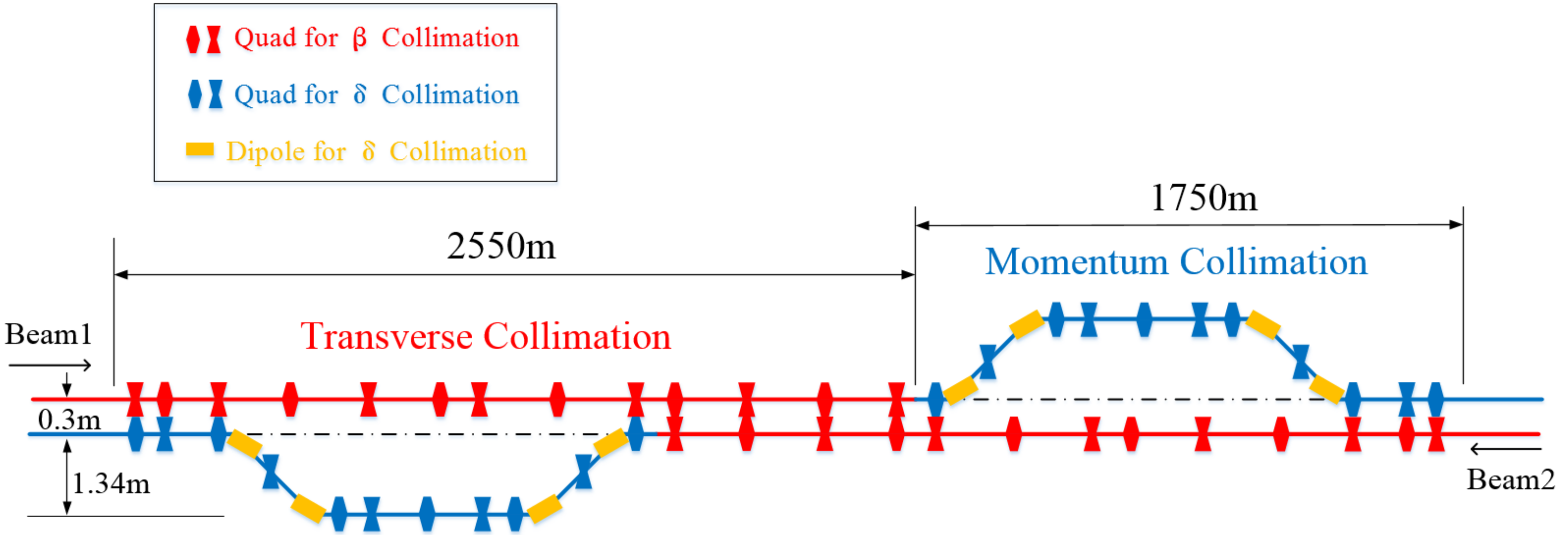
- The collimation system with superconducting magnets have a better performance than with warm magnets, By introducing tertiary collimators and protective collimators, the particle losses in the cold region can be cleaned off effectively.
- The collimation efficiency can be improved one order of magnitude at least.

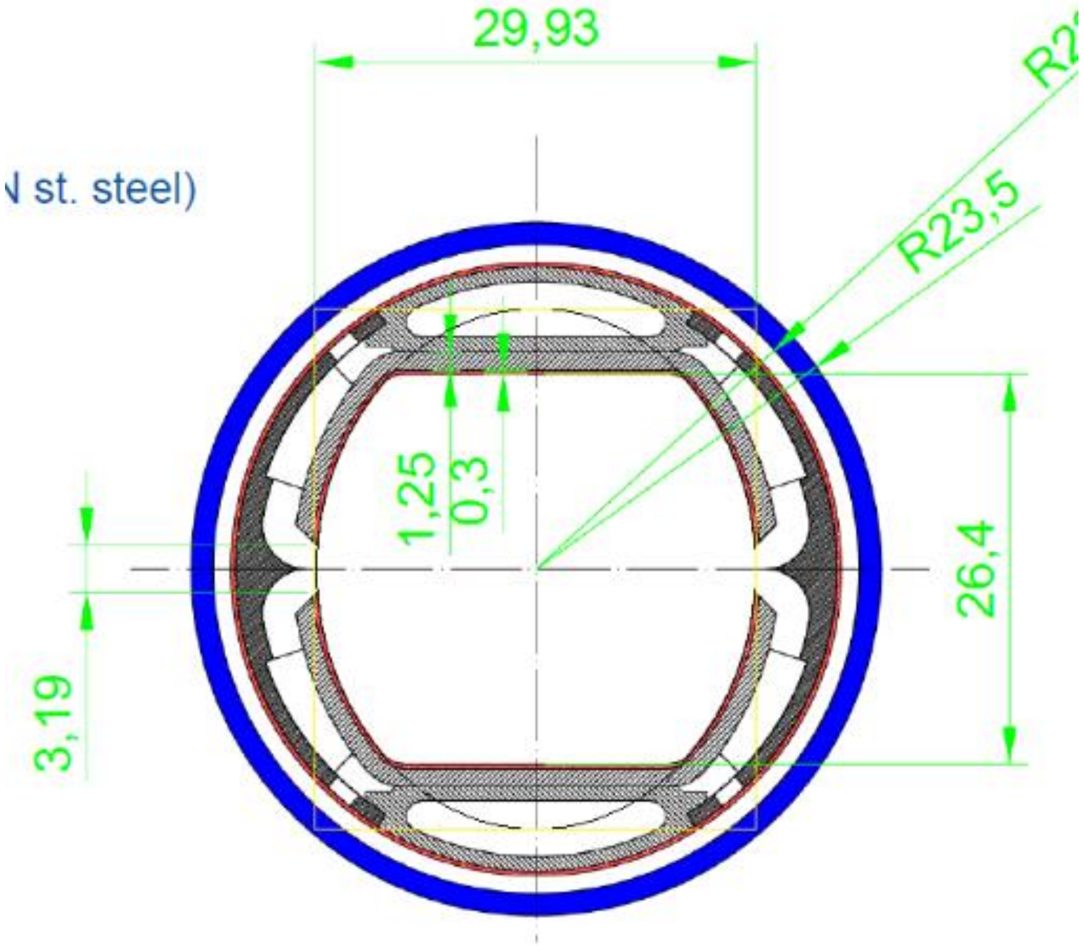
Next to do

- Add the collision insertion and carry out the simulation results.
- Consider the collimation system at injection energy.
- Consider the impedance induced by collimators.

Thank you for your attention

- Because of the lower electromagnetic forces, the two apertures are not combined but are assembled in separate annular collaring systems. This is in contrast to the case of the main dipoles. Computations, since confirmed by measurements, have shown that the magnetic coupling between the two apertures is negligible. This remains true even when the two apertures are excited with very different currents.




st. steel)
29,93
R2
R23,5
1,25
0,3
26,4
3,19