ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-TUPAK018

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2018). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

STUDY ON THE COLLIMATION METHOD FOR A FUTURE PROTON-PROTON COLLIDER*

J. Yang†, J. Tang, Y. Bao, IHEP, Chinese Academy of Sciences, Beijing, China
Y. Zou, Uppsala University, Uppsala, Sweden

Abstract

As the second phase of CEPC-SPPC project, SPPC (Super Proton-Proton Collider) is to explore new physics beyond the standard model in the energy frontier with a center-of-mass energy of 75 TeV. In order to handle extremely-high stored energy in beam, the collimation system of extremely high efficiency is required for safe operation. SPPC has been studying a collimation method which arranges both the transverse and momentum collimations in one long straight section. In this way, the downstream momentum collimation section can clean those particles related to the single diffractive effect in the transverse collimation section thus eliminate beam losses in the arc section. In addition, one more collimation stage is obtained with use of special superconducting quadrupoles in the transverse collimation section. Multiple particle simulations have proven the effectiveness of the methods. This paper presents the study results on the collimation scheme.

INTRODUCTION

As a future proton-proton collider, SPPC aims for energy-frontier physics, especially for beyond-Standard Model research [1], which will collide protons at a center of mass energy of 75 TeV, with circumference of 100 km, a nominal luminosity of 1.01×10^{35} $cm^{-2}s^{-1}$ per IP. In the baseline design, full iron-based HTS technology will be used in the superconducting magnets, the field strength of the main dipoles is 12 T. Figure 1 shows the layout of the SPPC.

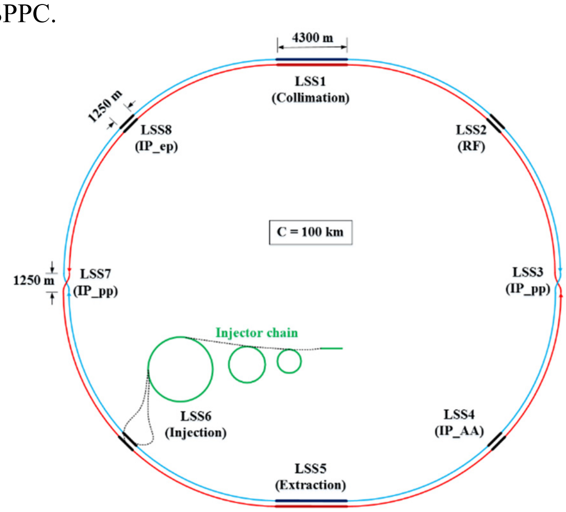

Figure1: The layout of SPPC in current baseline

* Work supported by the National Natural Science Foundation of China (Projects: 11527811, 11575214).
† yangjq@ihep.ac.cn

It is foreseeable that SPPC parameter largely exceeds the current LHC in every aspect; especially, the stored energy in beam is as high as 9.1 GJ per beam, about 25 times of that of the LHC at the design energy. In order to protect the superconducting magnets from quenching, a more robust and extremely-efficient collimation system is necessary to safely dispose beam losses. The designed intensity of 1.5×10^{15} protons per beam requires a cleaning inefficiency of 7×10^{-7} m^{-1}, which is more stringent than the LHC with about an order of magnitude. Thus, a sophisticated collimation system including multiple-stage betatron and momentum collimations is being studies at SPPC.

LATTICE FOR COLLIMATION SYSTEM

Combined Betatron and Momentum Collimation

At LHC, the major limiting locations in terms of particle losses on the superconducting magnets are the dispersion suppressors downstream of the betatron collimation insertion. These losses are due to the protons experiencing single diffractive interactions in the primary collimators [2]. Such protons can survive the interaction and emerge from the collimator jaws with momentum modified only slightly in direction, but significantly in magnitude. For the design of the SPPC collimation system, considering the increasing probability of the single diffractive interaction which increases with beam energy [3], in order to solve the problem more thoroughly, a novel collimation method has been studying, which arranges both the transverse and momentum collimations in the same cleaning insertion [4]. In this way, the downstream momentum collimation system will clean off the particles with large momentum deviation including those which experience single diffractive interactions with the primary transverse collimators. Figure 2 shows the layout of this collimation method, where some cold dipole magnets are used to produce the required dispersion for the momentum collimation and cancel the dispersion at the section end.

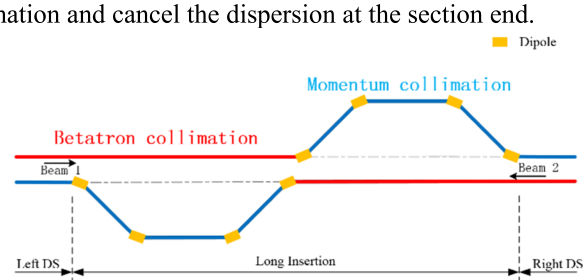

Figure 2: Layout of the novel collimation method.

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-TUPAK018

Lattice Scheme with Superconducting Magnets

At SPPC, we plan to install one more stage of collimators in the betatron collimation section, which will be helpful to clean off the tertiary beam halo that emerges from the secondary collimators and improve the collimation efficiency. In order to provide the required phase advance in the limited insertion space, superconducting quadrupoles are used instead of warm quadrupoles. These SC quadrupoles are very different from those in the arcs, they will be designed with enlarged apertures and lower pole strength (no higher than 8 T), and are comparable to the triplet quadrupoles used in the experiment insertions in LHC. With higher betatron collimation efficiency, the probability of particle losses in the downstream momentum collimation section will be reduced largely. In this way we can arrange tertiary collimators in the added cells, just following the secondary collimators. Figure 3 shows the lattice functions.

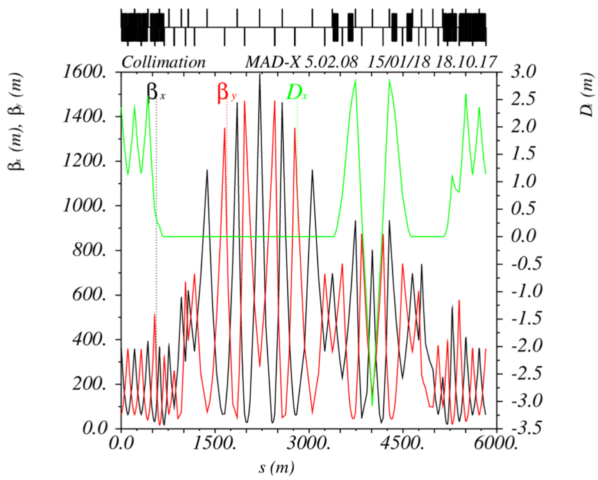

Figure 3: Lattice functions in the collimation insertion.

SIMULATION RESULTS OF THE BEAM LOSS DISTRIBUTIONS

Multi-particle simulations using the above collimation lattice have been carried out with the code MERLIN [5]. The local cleaning inefficiency $\tilde{\eta}_c$ is defined as the ratio of number N_i of protons lost at any location of the ring in a given bin of length L_i (set to 10 cm in general) over the total number N_{tot} of protons lost:

$$\tilde{\eta}_c = \frac{N_i}{N_{tot} \cdot L_i},$$

which is the measure of the performance for collimation simulations.

Considering the main factors that affect the collimation performance, we only add the collimation and experiment insertions to the SPPC ring lattice, other insertions, such like RF, injection and extraction insertions, are replaced by periodic FODO structure. Collimator parameters used in the simulations are shown in Table 1. In order to increase the accuracy of local cleaning inefficiency, 10^8 protons are tracked for 300 turns, in which the initial bunch distribution is chosen as a so-called halo-ring distribution, the impact parameter is chosen as 1 μm, and the normalized emittance is 2.4 μm.

From Fig. 4, we can see a good performance of the collimation system with initial vertical halo distribution, the four-stage collimation system can make the local cleaning inefficiency in the cold region below the quench limit of superconducting magnets. However, for initial horizontal halo distribution, the proton losses in the cold dipoles of the momentum collimation section is still evident, thus some protective collimators in Tungsten with the aperture 10σ are added there. Observing the beam loss distributions along the full SPPC ring, there is no proton losses in the cold region exceed the quench limit.

Table 1: Collimator Parameters for SPPC

Collimator	Aperture (σ)	Material	Location
TPC	6	Carbon	Transverse
TSC	7	Carbon	collimation
TTC	8.3	Copper	section
TAB	10	Tungsten	
TQC	10	Tungsten	IR
MPC	12	Carbon	Momentum
MSC	15.6	Carbon	collimation
MAB	17.6	Tungsten	section

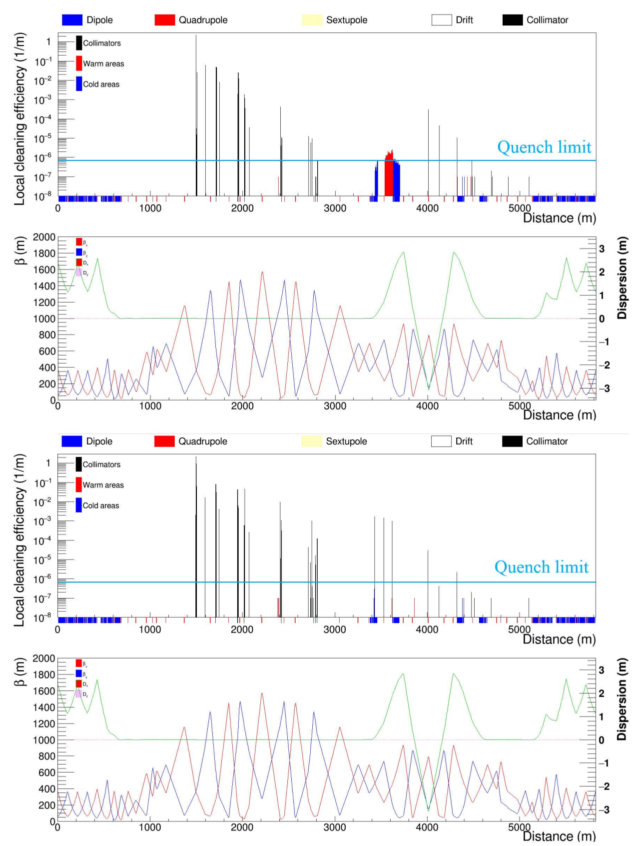

Figure 4: Proton loss map in the collimation insertion with initial vertical (top) and horizontal (down) halo distribution.

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2018). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-TUPAK018

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2018). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

ENERGY DEPOSITION IN THE SC MAGNETS OF THE COLLIMATION SECTION

If particles impact on the vacuum chamber or collimators and their secondary showers depose energy in the SC magnet coils, the magnet may experience a quench. In order to ensure the superconducting magnets in the collimation section from quenches, it is very important to take some shielding measures to move away the particle showers and reduce the energy or power deposition in the magnet coils. In this section, we provide the protection schemes for the superconducting quadrupoles and dipoles used in the section. Assuming steady state beam-loss scenario, the heat in coils is constantly removed with a rate that is mainly determined by the heat transfer to the helium bath through the cable insulation [6].

The cold quadrupoles in the section are designed with enlarged aperture to intercept as possible few particles and with lower magnet field as the quench limits increase as the magnet field decreases [7]. The highest quadrupole field is set 8 T, which is lower than the IR quadrupoles in LHC. Considering the Helium II boiling heat transfer mechanisms, the estimations of quench limits in the cable of cold quadrupoles are ranging from 50-100 mW/cm^3 [8].

Following the proton loss distribution in Fig. 4, the first quadrupole downstream of the primary collimators is one which bears the greatest risk of quench. The layout of a geometry model is shown in Fig. 5. The input distribution is provided by MERLIN code with the initial horizontal halo distribution.

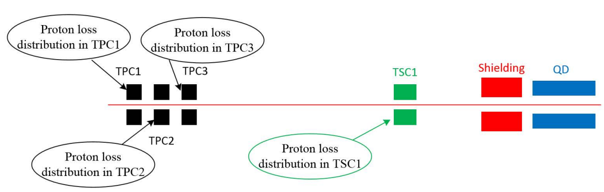

Figure 5: the layout of geometry model for analysis of energy deposition in SC quadrupole in FLUKA.

The aperture of defocusing quadrupole QD is 80 mm, and the material of coils is a mixture of 50% Nb-Ti and 50% copper. As high Z material, tungsten has been chosen as the shielding material, which can absorb the particle shower more effectively. The shielding block of a hollow cylinder with a length of 3 m and inner half-aperture of 10 mm or about 37σ is placed at one meter before the QD. In the simulations, 30% of all stored SPPC protons is assumed to get lost in the collimation section in one hour. Figure 6 show the results of maximum power deposition density in 5 cm bins along QD. It is found that the shielding with a step-like aperture (the aperture of the rear half is enlarged to 10.2 mm) can reduce the power deposition to below 10 mW/cm^3, which means a safety factor 5 from the quench limit 50-100 mW/cm^3

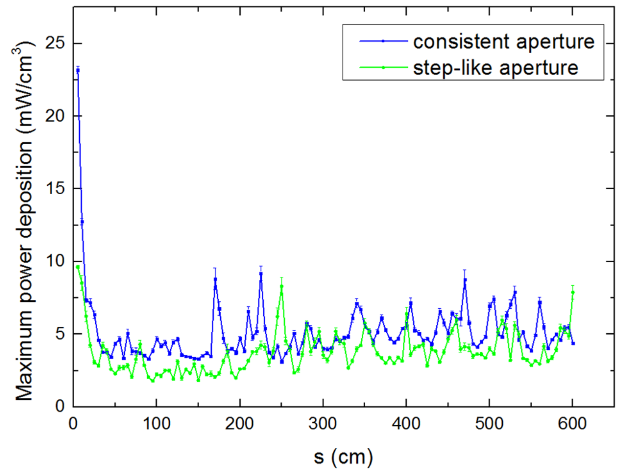

Figure 6: Maximum power deposition density along the QD before and after aperture optimization of the shielding.

CONCLUSION

The combined collimation method by arranging both transverse and momentum collimation systems in the same cleaning insertion and employs superconducting quadrupoles has been studied. According to the simulation results by MERLIN, the momentum collimation section following the betatron collimation section can effectively remove beam losses in the arc sections. The goal of collimation inefficiency 7×10^{-7} m^{-1} can be accomplished. In addition, the larger phase advance and one more collimation stage thanks to the superconducting magnets have a good effect in increasing the collimation efficiency, thus the beam loss in the collimation section. 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.

ACKNOWLEGEMENT

The authors thank James Molson of CERN and Jianshu Hong of IHEP for supporting the MERLIN code at IHEP, and also SPPC leagues for discussions.

REFERENCES

[1] The CEPC-SPPC Study Group, "CEPC-SPPC Preliminary Conceptual Design Report, Volume II: Accelerator", 2015.

[2] S. Redaelli, Collimation Upgrades for HL-LHC LHC Performance Workshop, Chamonix, France, 2014.

[3] K. Goulianos, "Diffractive Interactions of Hadrons at High Energies", *Physics Reports,* 101(3): 169-219, 1983.

[4] Y. Zou, J. Yang, J. Tang, "A Novel Collimation Method for Large Hadron Colliders", arXiv preprint, arXiv: 1611.05492, 2016.

[5] R. B. Appleby *et al.*, "The Practical Pomeron for High Energy Proton Collimation", *The European Physical Journal C*, 2016, 76(10): 520.

[6] B. Auchmann, T. Baer, M. Bednarek, *et al.*, "Testing Beam-induced Quench Levels of LHC Superconducting Magnets", *Phys. Rev. ST Accel. Beams* 18 (2015) 061002.

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-TUPAK018

[7] D. Bocian, B. Dehning, and A. Siemko, “Modeling of Quench Limit for Steady State Heat Deposits in LHC Magnets”, *IEEE Trans. Appl. Supercond*. 18, 112 (2008).

[8] P. P. Granieri and R. van Weelderen, “Deduction of Steadystate Cable Quench Limits for Various Electrical Insulation Schemes with Application to LHC and HL-LHC Magnets”, *IEEE Trans. Appl. Supercond*. 24, 4802806 (2014).

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2018). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.