SPPC PARAMETER CHOICE AND LATTICE DESIGN*

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Abstract

In this paper we showed a systematic method of appropriate parameter choice for a circular pp collider by using analytical expression of beam-beam tune shift limit started from given design goal and technical limitations. Based on parameters scan, we obtain a set of parameters for SPPC with different circumferences like 54km, 78 km or 100 km and different energies like 70TeV or 100TeV. We also showed the first version of SPPC lattice although it needs lots of work to do and to be optimized.

INTRODUCTION

With the discovery of the Higgs boson at the LHC, the world high-energy physics community is investigating the feasibility of a Higgs Factory as a complement to the LHC for studying the Higgs and pushing the high energy frontier. CERN physicists are busy planning the LHC upgrade program, including HL-LHC and HE-LHC. They also plan a more inspiring program called FCC, including FCC-ee and FCC-hh. Both the HE-LHC and the FCC-hh are proton-proton (pp) colliders aiming to explore the high energy frontier and expecting to find new physics [1–3]. Chinese accelerator physicists also plan to design an ambitious machine called CEPC-SPPC (Circular Electron Positron Collider-Super Proton Proton Collider). The CEPC-SPPC program contains two stages. The first stage is an electron-positron collider with center-of-mass energy 240 GeV to study the Higgs properties carefully. The second stage is a proton-proton collider at center-of-mass energy of more than 70 TeV [4]. The SPPC design is just starting, and first we developed a systematic method of how to make an appropriate parameter choice for a circular pp collider by using an analytical expression of beam-beam tune shift, starting from the required luminosity goal, beam energy, physical constraints at the interaction point (IP) and some technical limitations [5, 6]. Then we start the lattice design according to the parameter list and have the first version SPPC lattice.

SPPC PARAMETER CHOICE

The energy design goal of the SPPC is about 70-100 TeV, using the same tunnel as the CEPC, which is about 54 km in circumference [7, 8]. A larger circumference for the SPPC, like 100 km, is also being considered. It is planned to use superconducting magnets of about 20 T [4]. We obtain a set of parameters for the 54.7 km SPPC. In this set of parameters, the full crossing angle θ_c keeps the separation of 12 RMS beam sizes for the parasitic crossings. The luminosity reduction factor due to the crossing angle is larger than 0.9 and the ratio of β^* and σ_z is about 15. We also give a set of parameters for the larger circumference SPPC, considering both 78 km and 100 km. Table 1 is the parameter list for the SPPC. We choose the dipole field as 20 T and get a center-of-mass energy of 70 TeV. If we want to explore the higher energy, we should make the circumference larger. To explore a center-of-mass energy of 100 TeV while keeping the dipole field at 20 T, the circumference should be 78 km at least. With this condition, there is hardly any space to upgrade, so a 100 km SPPC is much better because the dipole field is then only 14.7 T. If the dipole field is kept at 20 T in a 100 km SPPC, we can get a center-of-mass energy as high as 136 TeV.

SPPC LATTICE CONSIDERATION

According to the Pre-CDR, in the future, SPPC is in the same tunnel with CEPC and will be running at the same time. So the layout of SPPC should consider the CEPC layout. Fig. 1 shows the layout of SPPC according the layout of CEPC partial double ring scheme.

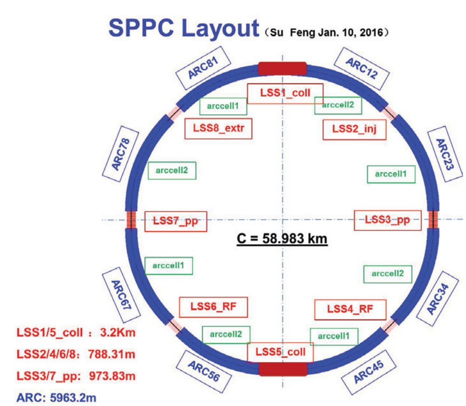

Figure 1: SPPC lattice layout.

SPPC LATTICE DESIGN

ARC and FODO Cell

In this part, we introduced the preliminary lattice design of SPPC. There are 8 arcs and 8 long straight sections. We use FODO in the ARC, and Fig. 2 shows the parameters of FODO cell in ARC. Each cell has 8 dipoles whose length is $14.8m$ and strength is $20T$. The total cell length is $144.4m$, maximum beta function is $244.8m$, minimum beta function is $42.6m$ and phase advance is 90 degree in both horizontal and vertical. The quadrupole gradient and dipole parameter is reasonable according to the Pre-CDR choice. And the aperture of quadrupole is also reasonable for both injection

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Table 1: SPPC Parameter List

	SPPC(Pre-CDR)	SPPC-54.7Km	SPPC-100Km	SPPC-100Km	SPPC-78Km
Main parameters and geometrical aspects					
Beam energy[E_0]/TeV	35.6	35.0	50.0	68.0	50.0
Circumference[C_0]/km	54.7	54.7	100.0	100.0	78.0
Dipole field[B]/T	20	19.69	14.73	20.03	19.49
Dipole curvature radius[ρ]/m	5928	5922.6	11315.9	11315.9	8549.8
Bunch filling factor[f_2]	0.8	0.8	0.8	0.8	0.8
Arc filling factor[f_1]	0.79	0.79	0.79	0.79	0.79
Total dipole length [L_{Dipole}]/m	37246	37213	71100	71100	53720
Arc length[L_{ARC}]/m	47146	47105	90000	90000	68000
Straight section length[L_{ss}]/m	7554	7595	10000	10000	10000
Physics performance and beam parameters					
Peak luminosity per IP[L]/ $cm^{-2}s^{-1}$	1.1×10^{35}	1.2×10^{35}	1.52×10^{35}	1.02×10^{36}	1.52×10^{35}
Beta function at collision[β^*]/m	0.75	0.85	0.97	0.24	1.06
Max beam-beam tune shift per IP[ξ_y]	0.006	0.0065	0.0067	0.008	0.0073
Number of IPs contribut to ΔQ	2	2	2	2	2
Max total beam-beam tune shift	0.012	0.013	0.0134	0.016	0.0146
Circulating beam current[I_b]/A	1.0	1.024	1.024	1.024	1.024
Bunch separation[Δt]/ns	25	25	25	25	25
Number of bunches[n_b]	5835	5835	10667	10667	8320
Bunch population[N_p] (10^{11})	2.0	2.0	2.0	2.0	2.0
Normalized RMS transverse emittance[ε]/μm	4.10	3.72	3.65	3.05	3.36
RMS IP spot size[σ^*]/μm	9.0	8.85	7.85	3.04	7.86
Beta at the 1st parasitic encounter[$\beta 1$]/m	19.5	18.70	16.51	64.1	15.36
RMS spot size at the 1st parasitic encounter[σ_1]/μm	45.9	43.2	33.6	51.9	31.14
RMS bunch length[σ_z]/mm	75.5	56.5	65	15.8	70.6
Full crossing angle[θ_c]/μrad	146	138	108	166	99
Reduction factor according to cross angle[F_{ca}]	0.8514	0.9257	0.9248	0.9283	0.9248
Reduction factor according to hour glass effect[F_h]	0.9975	0.9989	0.9989	0.9989	0.9989
Energy loss per turn[U_0]/MeV	2.10	1.97	4.30	14.7	5.69
Critical photon energy[E_c]/keV	2.73	2.60	3.97	9.96	5.25
SR power per ring[P_0]/MW	2.1	2.0	4.4	15.1	5.82
Transverse damping time [τ_x]/h	1.71	1.80	2.15	0.86	1.27
Longitudinal damping time [τ_ε]/h	0.85	0.90	1.08	0.43	0.635

and collision energy. Fig. 3 and Fig. 4 is the optics of FODO cell and ARC.

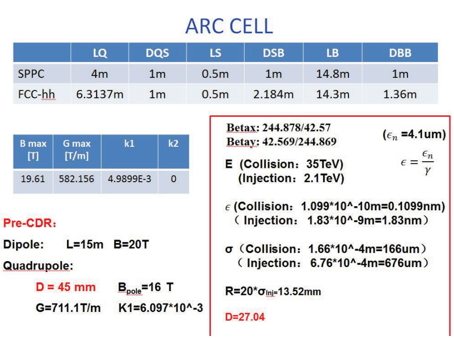

Figure 2: SPPC FODO cell parameter choice.

Dispersion Suppressor Section

For 90 degree phase advance FODO cell, the dispersion suppressor section has three schemes, called full-bend scheme, half-bend scheme and missing-dipole scheme. Fig. 5 shows these three schemes for SPPC. And in our design we choose the missing-dipole scheme as the space can be used for collimation in the future.

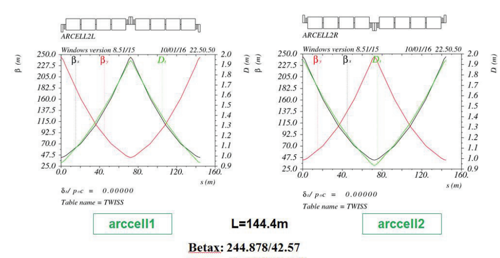

Figure 3: SPPC FODO cell optics.

Long Straight Section and Interaction Region

There are 8 long straight sections in SPPC lattice which are named as $LSS1\_coll$, $LSS2\_inj$, $LSS3\_pp$, $LSS4\_RF$, $LSS5\_coll$, $LSS6\_RF$, $LSS7\_pp$ and $LSS8\_extr$. Long straight section 3 and 7 are for low β pp collision, long straight section 1 and 5 are for collimation using the long space as $3.2km$, long straight section 4 and 6 are for RF system and long straight section 2 and 8 are for injection and extraction. Fig. 6, 7, 8, 9 show the optics of these long straight sections. Fig. 10 shows the quadrupole strength of $LSS3\_pp$ and $LSS7\_pp$, and the gradient and aperture are reasonable according to the Pre-CDR parameter choice for quadrupoles.

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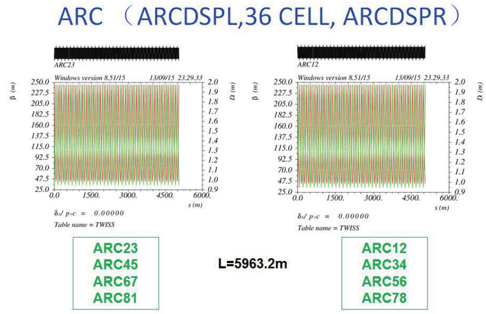
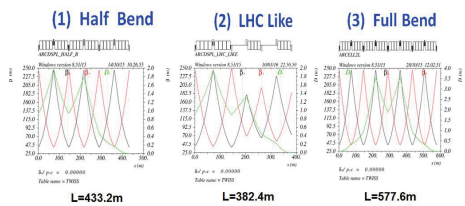


Figure 4: SPPC ARC optics.



	BDSP1L	BDSP2L	BDSP1R	BDSP2R	B0	
(1)	9.805	9.805	9.805	9.805	19.61	(T)
(2)	18.93	18.93	18.93	18.93	19.61	(T)
(3)	19.61	19.61	19.61	19.61	19.61	(T)

Figure 5: Dispersion suppressor section for SPPC.

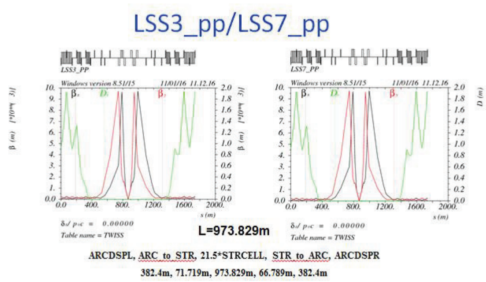


Figure 6: Long straight section for low β pp collision.

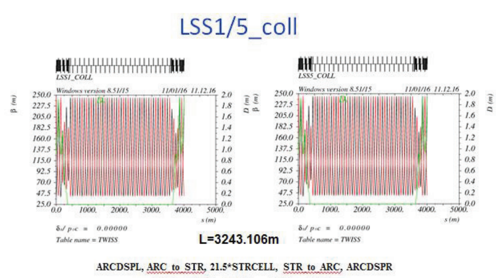


Figure 7: Long straight section for collimation.

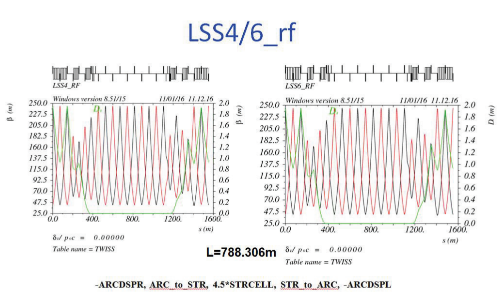


Figure 8: Long straight section for RF system.

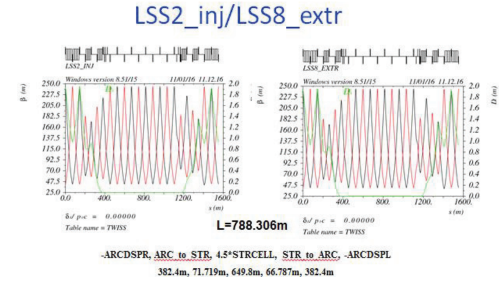


Figure 9: Long straight section for injection and extraction.

R	K1(m^-2)	G（T/M）	L(M)	βmax	L	K1(m^-2)	G（T/M）	L(M)	βmax
K1.QT.1R	4.9751e-03	580.428	6	3543.69	K1.QT.1L	-4.9751e-03	-580.428	6	3543.69
K1.QT.A2R	-5.2595e-03	-613.668	9	9601.686	K1.QT.A2L	5.2595e-03	613.668	9	9601.686
K1.QT.B2R	-5.2595e-03	-613.668	9	9601.686	K1.QT.B2L	5.2595e-03	613.668	9	9601.686
K1.QT.3R	5.3434e-03	623.369	8	9731.53	K1.QT.3L	-5.3434e-03	-623.369	8	9731.53
K1.QM.4R	-2.2804E-04	-266.04	4	3798.29	K1.QM.4L	2.2804E-04	266.04	4	3798.29
K1.QM.5R	8.8592E-04	103.36	4	1506.53	K1.QM.5L	-8.8592E-04	-103.36	4	1506.53
K1.QM.6R	-1.2144E-03	-141.68	4	587.87	K1.QM.6L	1.2144E-03	141.68	4	587.87
K1.QM.7R	1.0640E-04	124.133	4	531.25	K1.QM.7L	-1.0640E-04	-124.133	4	531.25
K1.QM.8R	-4.2431E-03	-495.028	4	162.20	K1.QM.8L	4.2431E-03	495.028	4	162.20

Figure 10: Quadrupole gradient and aperture in $LSS3\_pp$ and $LSS7\_pp$.

SUMMARY

In this paper, we showed a set of parameters for SPPC with different circumferences like 54km, 78 km or 100 km and different energies like 70TeV or 100TeV. We also showed the first version of SPPC lattice although it needs lots of work to do and to be optimized.

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