SPPC General Progress

Jingyu Tang
for the SPPC study group

Informal mini-review on CEPC CDR, Nov. 4-5, 2017, IHEP

Outline

- Ongoing SPPC study
- Collider accelerator physics
- Technical issues
- Injector chain
- Plan for CDR writing
- Summary

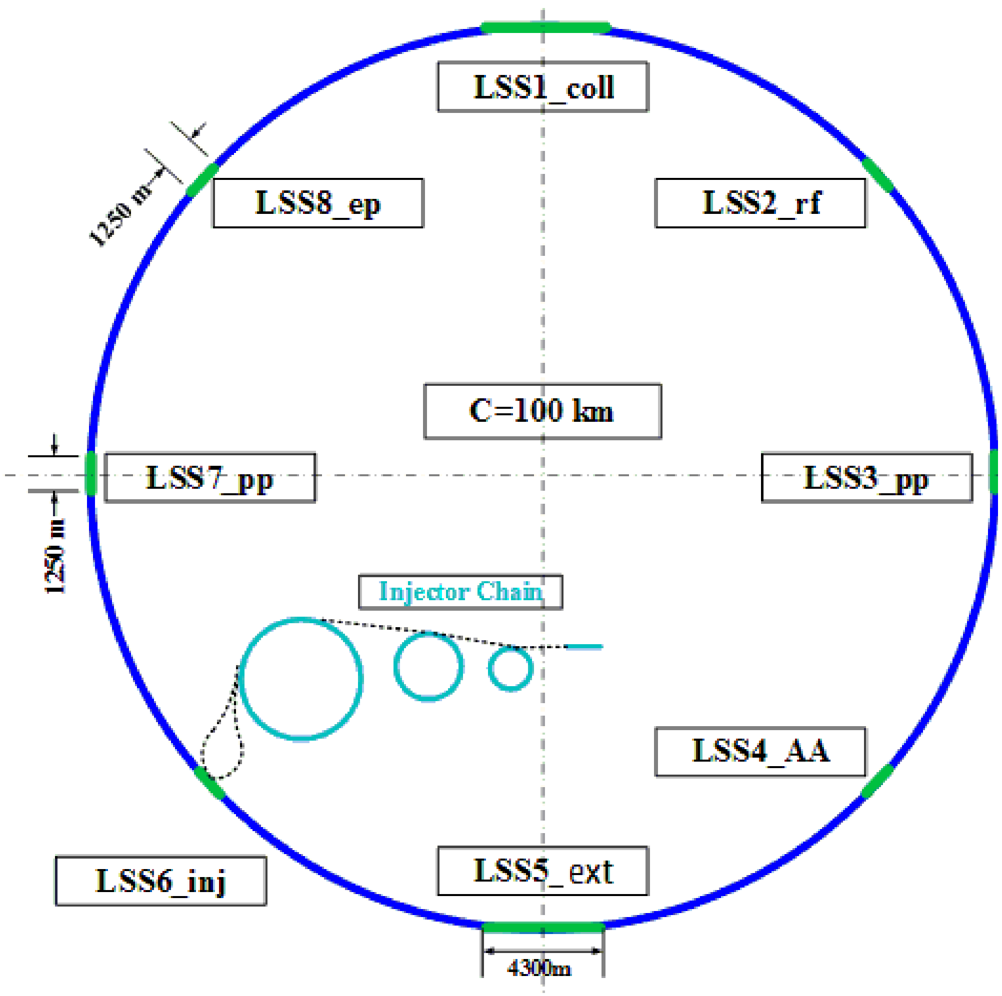
Ongoing SPPC Study

- Accelerator physics
  - Describing what a future proton-proton collider looks like, physics performance
  - Layout design with compatibility to CEPC
  - Key accelerator physics: lattice, collimation, beam-beam effects, longitudinal dynamics, injection/extraction, instabilities, machine protection strategy
- Technological developments
  - Identifying key technical challenges, for some of them needing long-term R&D efforts
  - Strong R&D program on high-field superconducting magnets
  - Beam screen issues
  - High-Q ferrite-loaded RF cavities

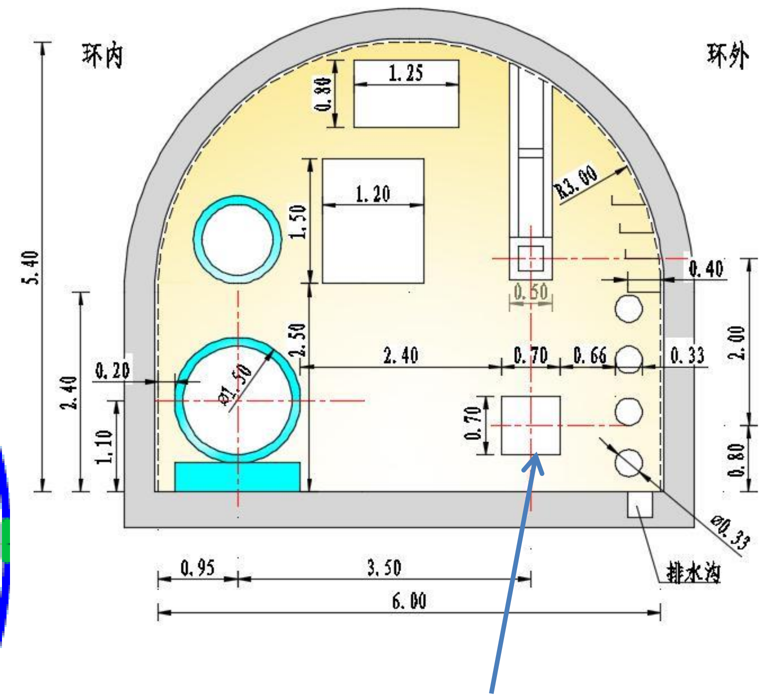
SPPC main parameters (updated)

Parameter	Unit	Value		
		PreCDR	CDR	Ultimate
Circumference	km	54.4	100	100
C.M. energy	TeV	70.6	75	125-150
Dipole field	T	20	12	20-24
Injection energy	TeV	2.1	2.1	4.2
Number of IPs		2	2	2
Nominal luminosity per IP	$cm^{-2}s^{-1}$	1.2e35	1.0e35	-
Beta function at collision	m	0.75	0.75	-
Circulating beam current	A	1.0	0.7	-
Bunch separation	ns	25	25	-
Bunch population		2.0e11	1.5e11	-
SR power per beam	MW	2.1	1.1	-
SR heat load per aperture @arc	W/m	45	13	-

SPPC Layout



Tunnel cross-section



More space required for CEPC double-ring scheme

Considerations on layout

- Layout consideration
  - 8 arcs and long straight sections (accepted by CEPC)
  - Arcs will be traditional FODO based, 6-8 long SC dipoles per half cell, missing dipoles for dispersion suppression
  - Long straight sections (LSS) are important for pp colliders, here, two IPs, injection, extraction, collimation and RF stations

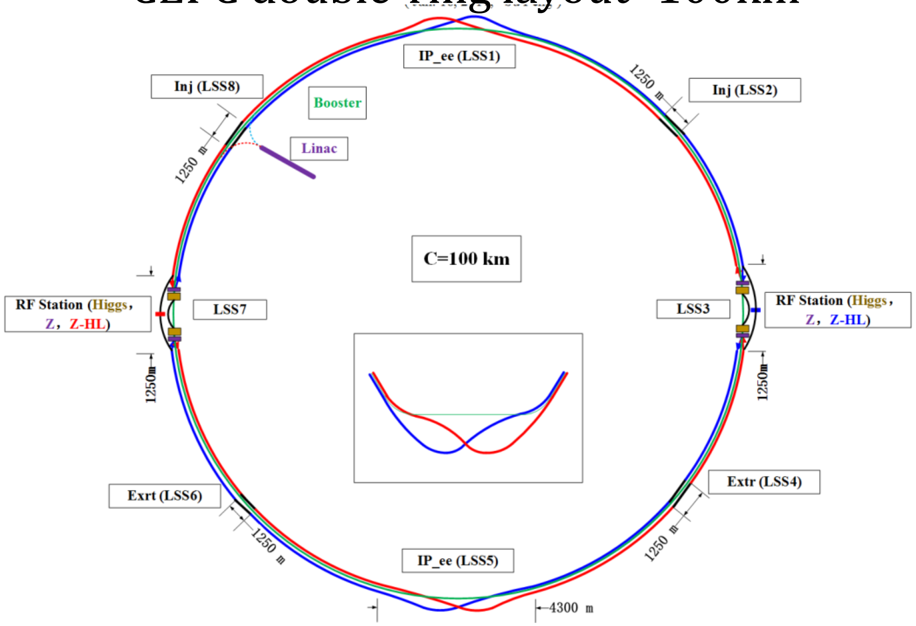
    [Two very long LSSs for collimation and extraction

    Perhaps one IP more for A-A and one for e-p]
- Detouring detectors: quite challenging, CEPC rings and ee detectors to bypass the SPPC rings and pp detectors, how about AA and ep detectors

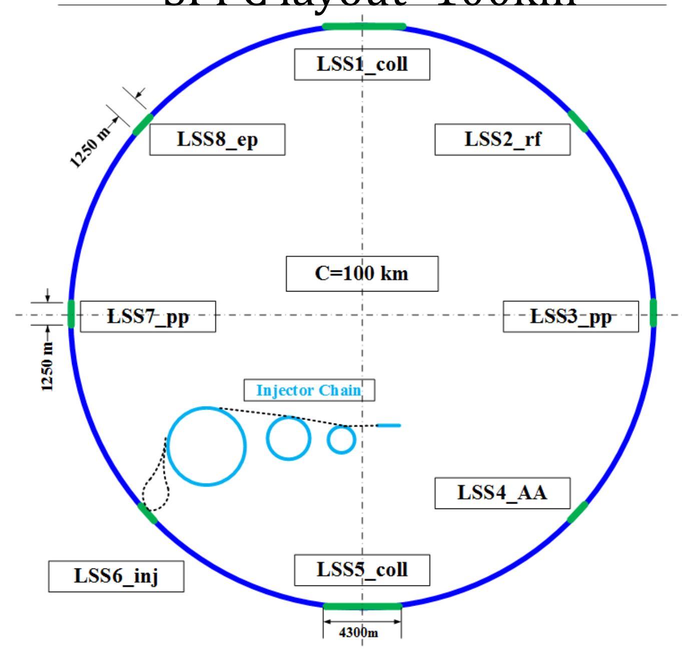
Compatibility between CEPC and SPPC

- CEPC first to be built, with potential to add SPPC later
- Three machines in one tunnel: e booster, ee double-ring collider, pp double-ring collider
- Allow ep collision in the future, to solve the problem in circumference difference (CEPC outside of SPPC)
- Layout: 8 long straights and arcs, LHC-like DS lattice, lengths for LSSs
- Several rounds of interactions between CEPC and SPPC design teams, tbc

CEPC double-ring layout- 100km



SPPC layout- 100km



Collider Accelerator Physics

-Parameter list updating

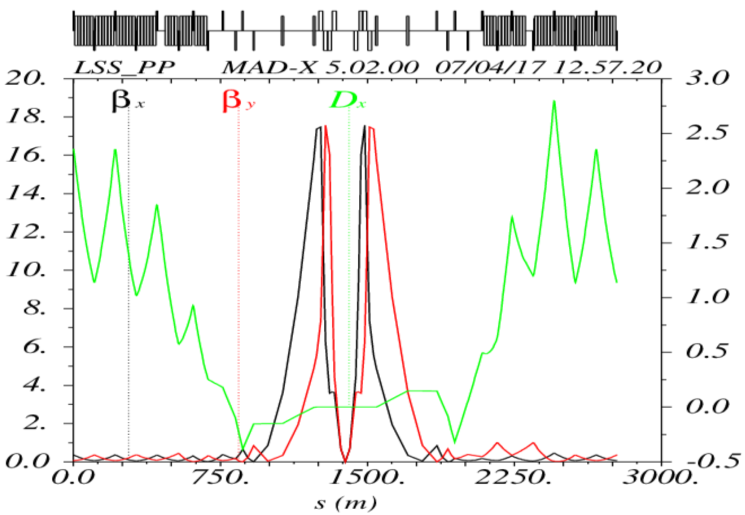
Parameter	Value	Unit
Main parameters		
Circumference	100	km
Beam energy	37.5	TeV
Lorentz gamma	39979	
Dipole field	12.00	T
Dipole curvature radius	10415.4	m
Arc filling factor	0.780	
Total dipole magnet length	65442.0	m
Arc length	83900	m
Total straight section length	16100	m
Energy gain factor in collider rings	17.86	
Injection energy	2.10	TeV
Number of IPs	2	
Revolution frequency	3.00	kHz
Revolution period	333.3	μs
Physics performance and beam parameters		
Nominal luminosity per IP	1.01E+35	$cm^{-2}s^{-1}$
Beta function at initial collision	0.75	m
Circulating beam current	0.73	A
Nominal beam-beam tune shift limit per	0.0075	
Bunch separation	25	ns
Bunch filling factor	0.756	
Number of bunches	10080	
Bunch population	1.5E+11	
Accumulated particles per beam	1.5E+15	
Normalized rms transverse emittance	2.4	μm
Beam life time due to burn-off	14.2	hour
Turnaround time	3.0	hour
Total cycle time	17.2	hour

Total / inelastic cross section	147	mbarn
Reduction factor in luminosity	0.85	
Full crossing angle	110	μrad
rms bunch length	75.5	mm
rms IP spot size	6.8	μm
Beta at the 1st parasitic encounter	19.5	m
rms spot size at the 1st parasitic encoun	34.5	μm
Stored energy per beam	9.1	GJ
SR power per ring	1.1	MW
SR heat load at arc per aperture	12.8	W/m
Critical photon energy	1.8	keV
Energy loss per turn	1.48	MeV
Damping partition number	1	
Damping partition number	1	
Damping partition number	2	
Transverse emittance damping time	2.35	hour
Longitudinal emittance damping time	1.17	hour

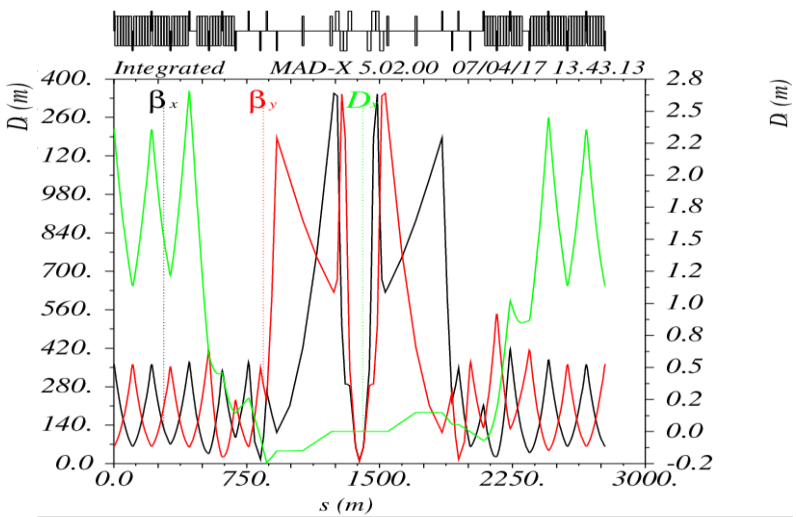
Lattice design

Yukai Chen, Feng Su, Linhao Zhang

- Different lattice designs
  - Different schemes (100 TeV and 75 TeV @100 km)
  - Lattice at injection and collision
  - Compatibility between CEPC and SPPC
  - Arc cells, Dispersion suppressors, insertions
- For supporting other studies, e.g. magnets, collimation, dynamic aperture, …



IP: at collision



IP: at injection

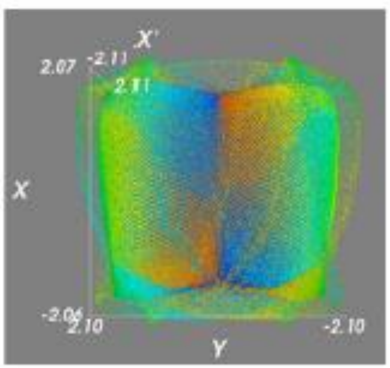
Dynamic aperture study

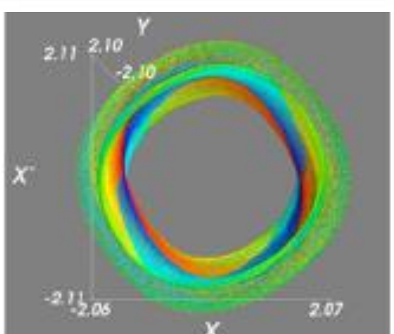
Yukai Chen, Feng Su, collaborating with F. Schmidt

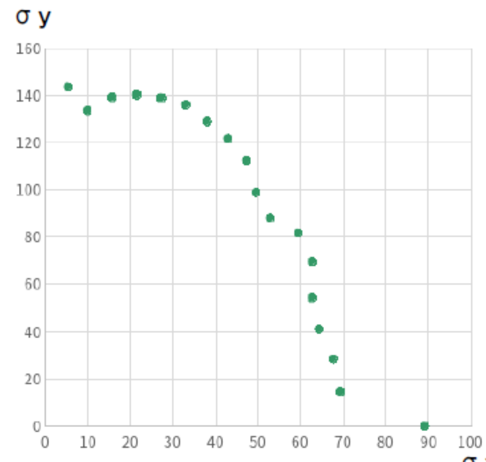
- At collision energy
- At injection energy

(Sixtrack code)

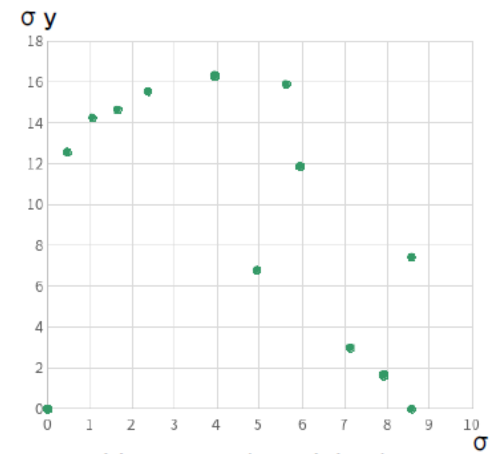
For the moment, it is ok, with iterations with magnet design



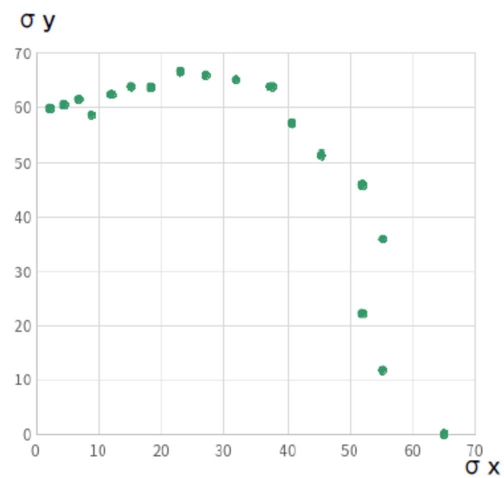




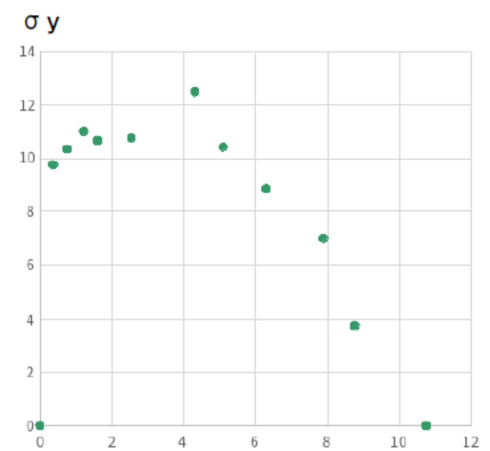
Adding sextuple without dipole error (chromaticity corrected)



Adding sextuple and dipole error (chromaticity corrected)



Adding sextuple without dipole error (chromaticity corrected)

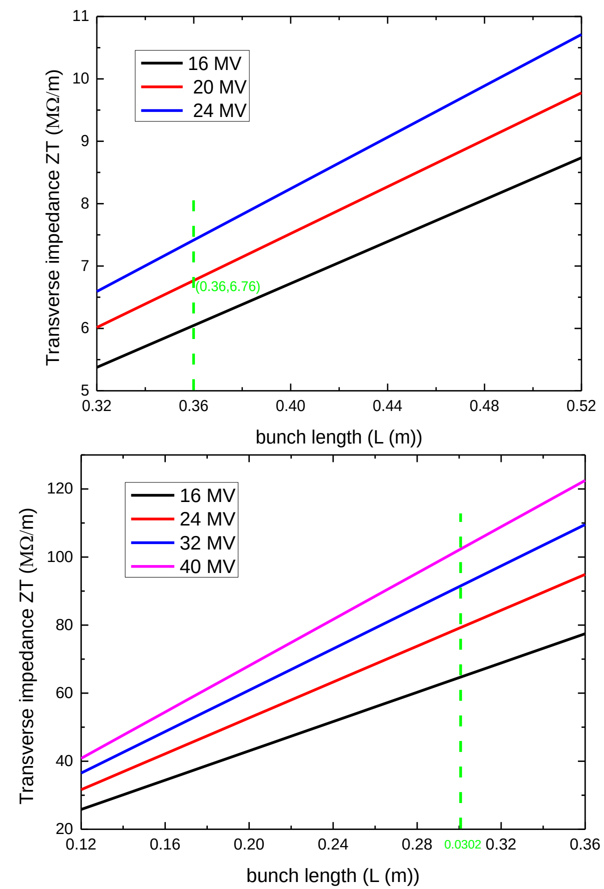


Adding sextuple and dipole error (chromaticity corrected)

Longitudinal beam dynamics

Linhao Zhang

- Concerns:
  - Bunch filling schemes
  - Luminosity leveling schemes
  - Instabilities
  - Requirement to the RF systems
  - Global study with the injector accelerators
- Different factors:
  - IBS effect
  - Emittance control (shrinking and blow-up)
  - Bunch preparation in the injector chain

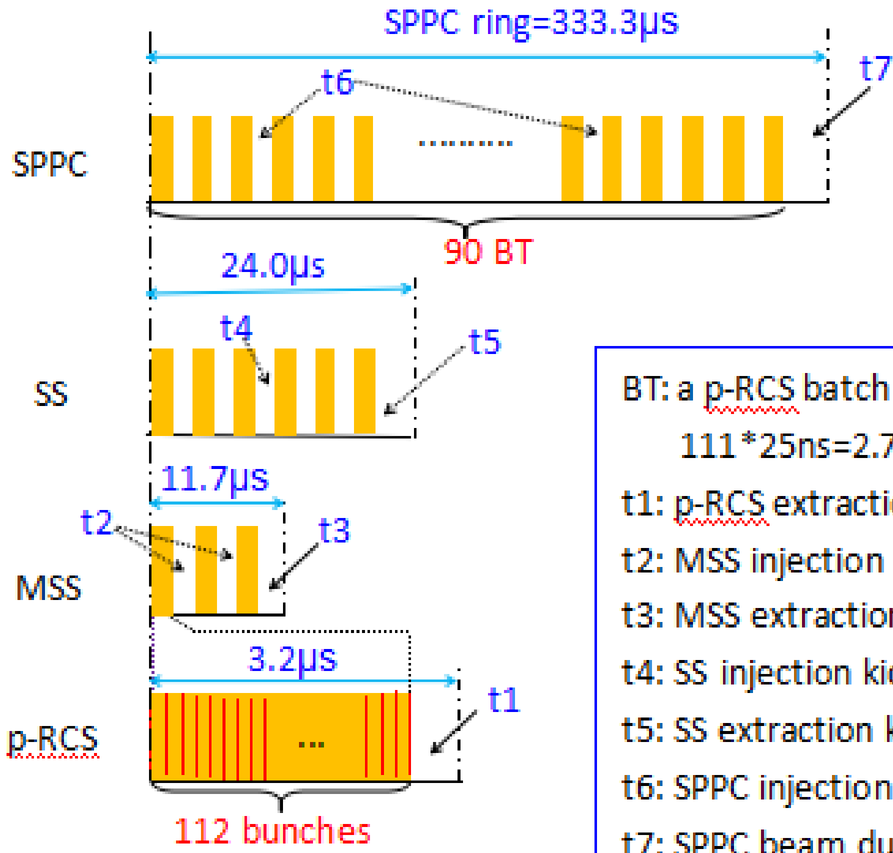


Limitation by Transverse Mode Coupling Instability

Bunch filling schemes

- 100 km - 75 TeV -25 ns (also for different SPPC designs)

Bunching filling factor: ~76%



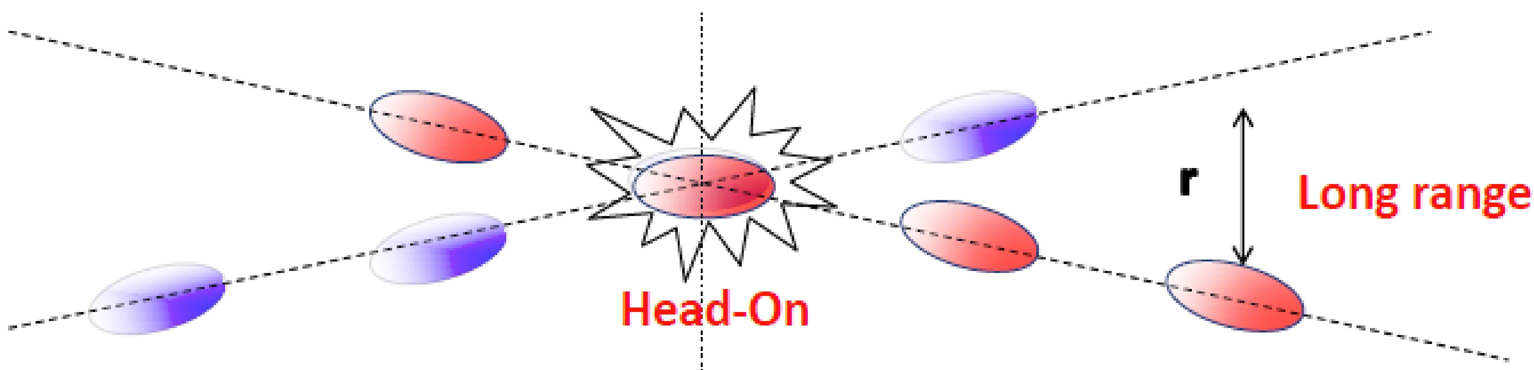
BT: a p-RCS batch with 112 bunches
111*25ns=2.775μs;
t1: p-RCS extraction kicker rise time 425ns;
t2: MSS injection kicker rise time 0.925μs;
t3: MSS extraction kicker rise time 1.525μs;
t4: SS injection kicker rise time 0.925μs;
t5: SS extraction kicker rise time 2.725μs;
t6: SPPC injection kicker rise time 0.90μs;
t7: SPPC beam dump kicker rise time 3.45μs

Beam-beam effects

Lijiao Wang,
collaborating with
K. Ohmi and T. Sen

- Beam-beam effect has direct impact to the luminosity
- Studying different effects (ongoing)
  - Head-on interaction
  - Long-range interaction
  - Pacman effects
  - Orbit effects
  - Coherent beam effects
  - BB compensation methods (Electron lens, Compensation wires)

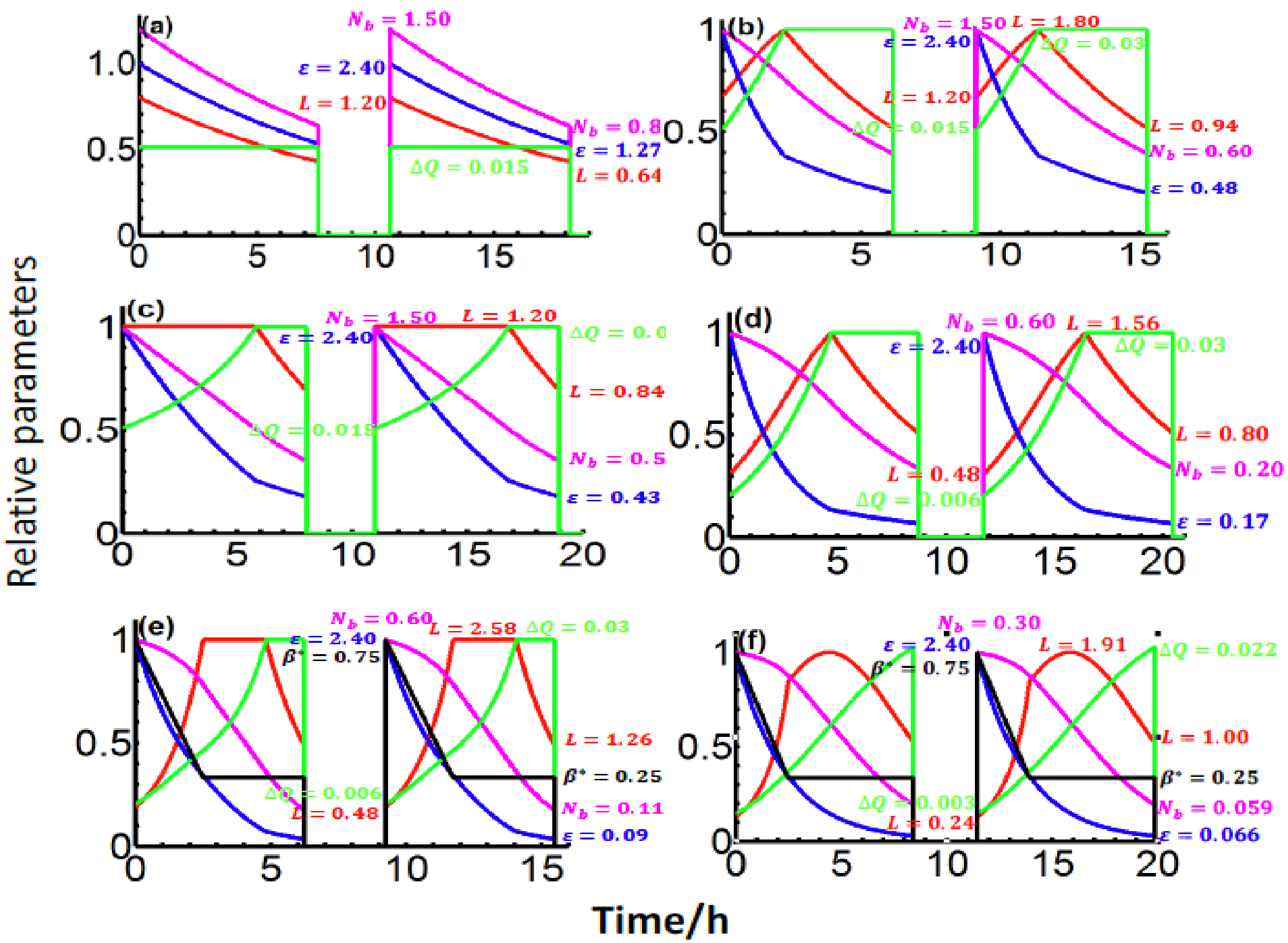
$$\mathcal{L} \propto \xi \frac{1}{\beta_y} N n_b f_r$$



SPPC: normal bunch (164 LRBBI) Pacman bunch (82~164 LRBBI)

Luminosity Leveling

Increasing the average luminosity by programing the beam collision scenario (controlled emittance shrinking, turnaround time, beta*, B-B parameter, bunch spacing)



- Turnaround: 0.8 hrs (min), 2.4 hrs (ave)
- ΔQ: 0.03 (max)
- Spacing: 25, 10, 5 ns
- Beta*: 0.75 m 0.75->0.25m

Collimation study

Ye Zou, Jianquan Yang, collaborating with LAL and LHC

- *Requirements*
  - SC magnet quench prevention:

Huge stored energy: 9.1 GJ/beam

$$\tilde{\eta}_c = \frac{\tau_{\min} \cdot R_q}{N^q_{tot}}$$

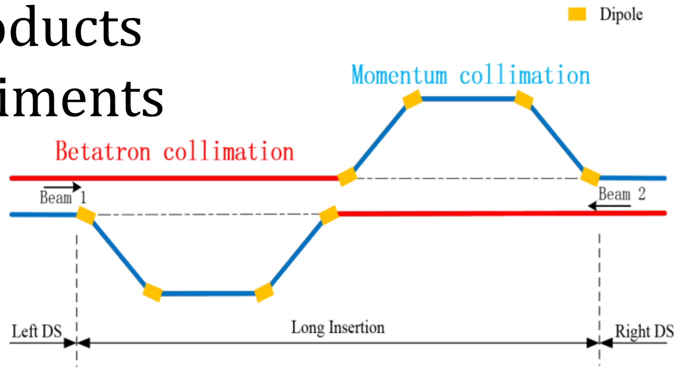
Rq: ~10^6 protons/m/s

N^q_{tot} : 1.5×10^{15}

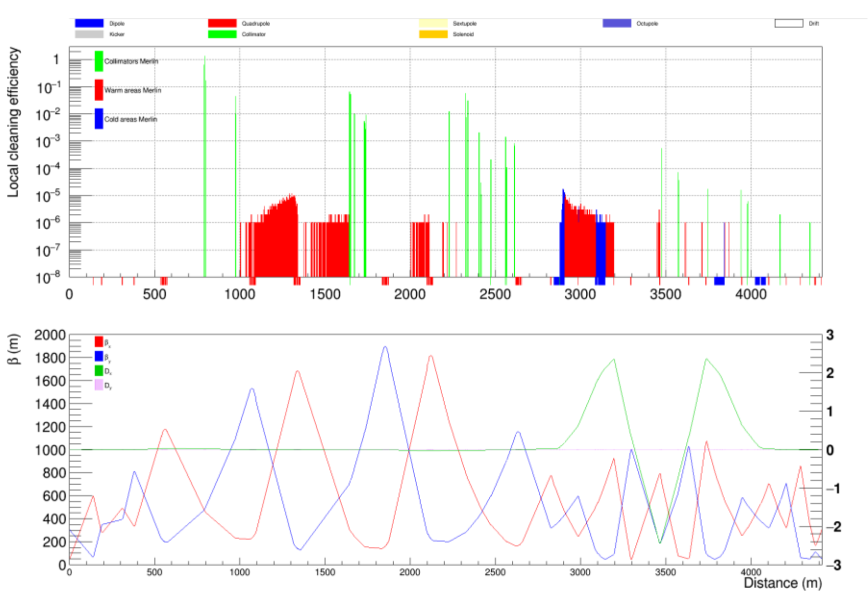
$\tau_{\min}$: 0.2 h (10s) /5 h

$\tilde{\eta}_c < 4.5\times10^{-7}\,\mathrm{m}^{-1}$

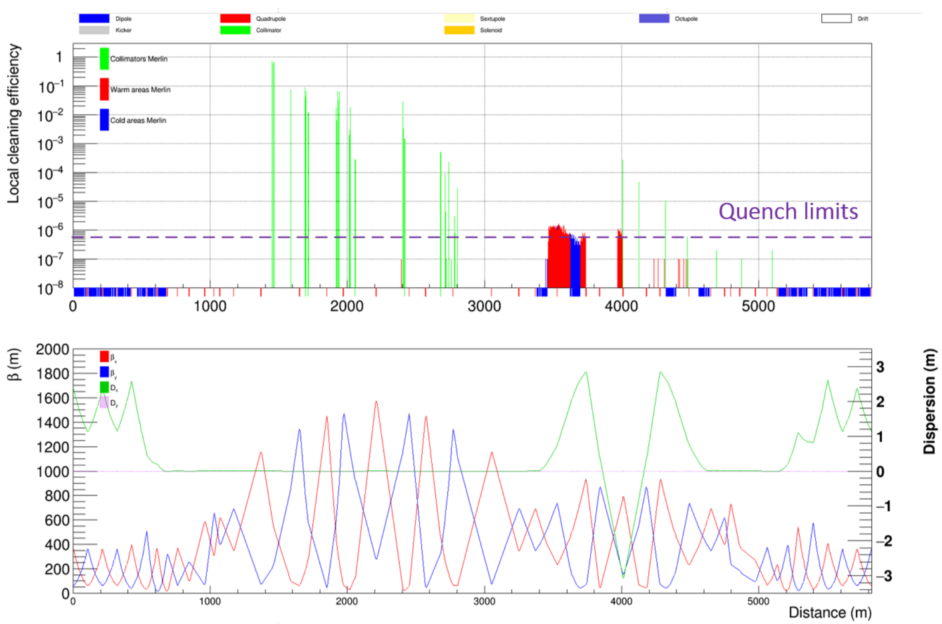
  - Halo particles cleaning
  - Machine protection: prevent damaging radiation-sensitive devices
  - Radiation losses concentration: hands-on maintenance
  - Cleaning physics debris: collision products
  - Optimizing background: in the experiments
  - halo diagnostics



- Further developing the concept of combining betatron and momentum collimations in a same long straight section (4.3km)
- Recently a new design for the transverse collimation section, by introducing protected large-aperture superconducting magnets and add an additional collimation stage
  - Simulations show good effect in collimation efficiency
  - Protection-aid low-field SC quadrupoles workable



With RT magnets in beta-collimation

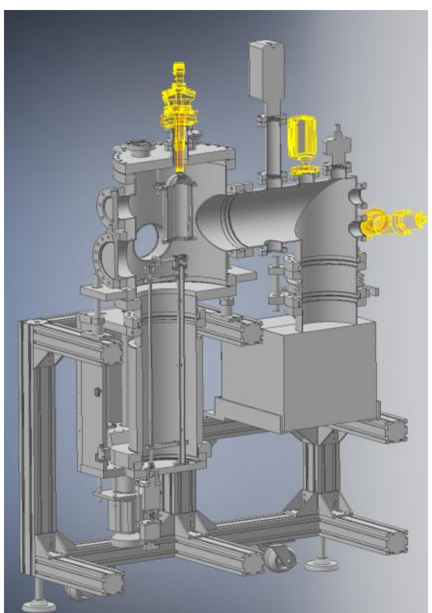


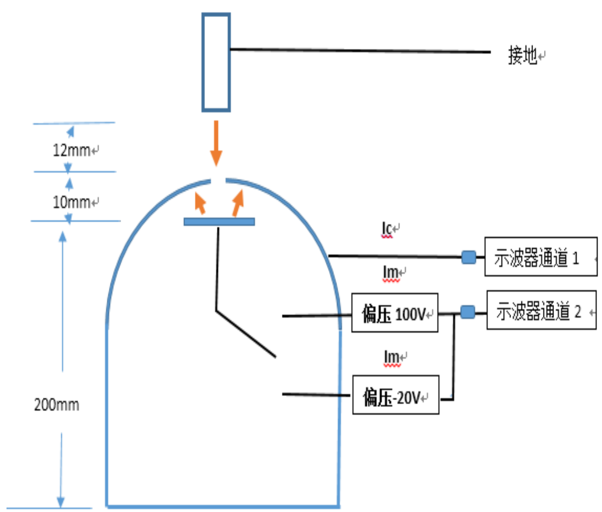
With SC magnets in beta-collimation

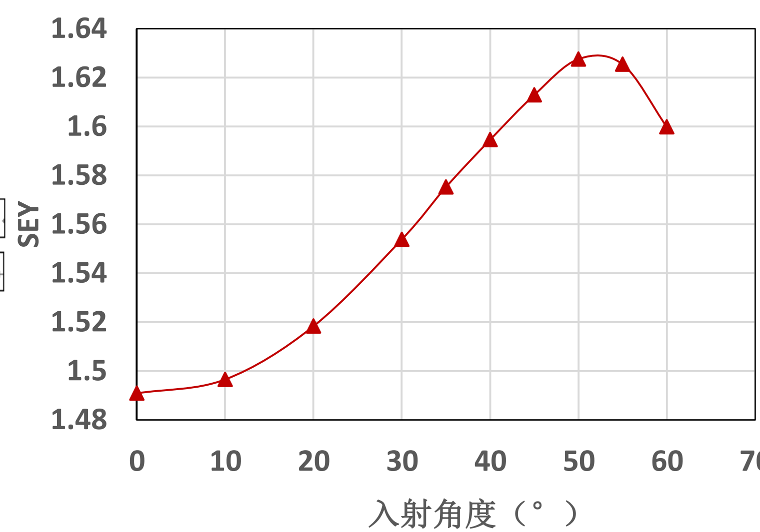
Impedance and instabilities

Yudong Liu

- General consideration about the instabilities and impedance budget
- Emphasizing the study on electron cloud effects
- Wall impedance from beam screen: coated YBCO
- Efforts to reduce SEY (<1.2); experimental study of secondary electrons (supported by NSFC fund)



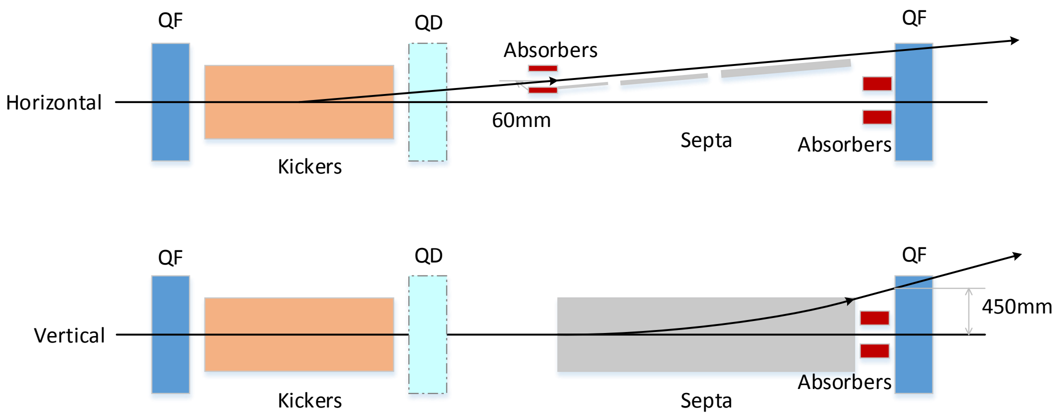


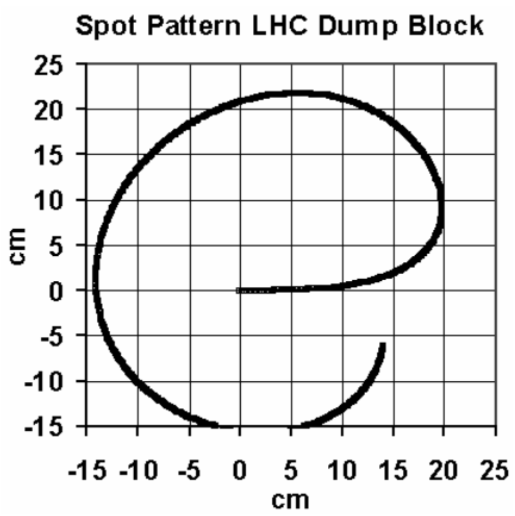


Injection and extraction

Ye Yang, Guangrui Li

- Injection:
  - Beam transfer from SS to SPPC (two beams)
  - Multiple injections
  - Injection scenario
- Extraction/abort:
  - MPS safety concerns
  - Optics
  - Energy dilution methods
- Identifying technical challenges
  - SC septum magnets
  - Kicker risetimes
  - Dump materials





Machine Protection

Hongliang Xu,
Zhiliang Ren

- Work on
  - Safety operation strategy of the machine
  - Analysis of different safety issues related to beams and magnets
  - Injection and extraction issues
  - Beam transfer from SS to SPPC
  - Safety issues in the high-power injector accelerators

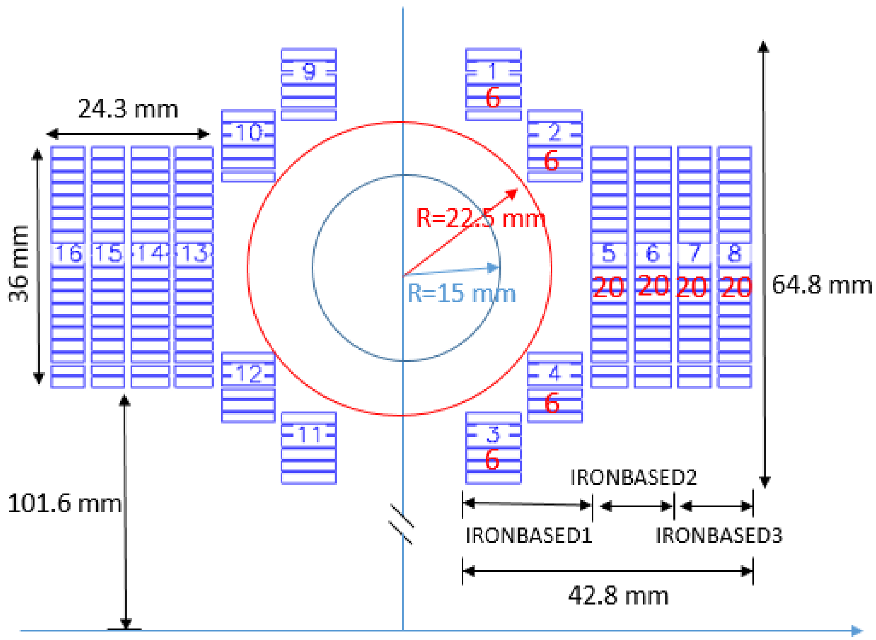
Technical challenges and R&D requirements
-High field SC magnets

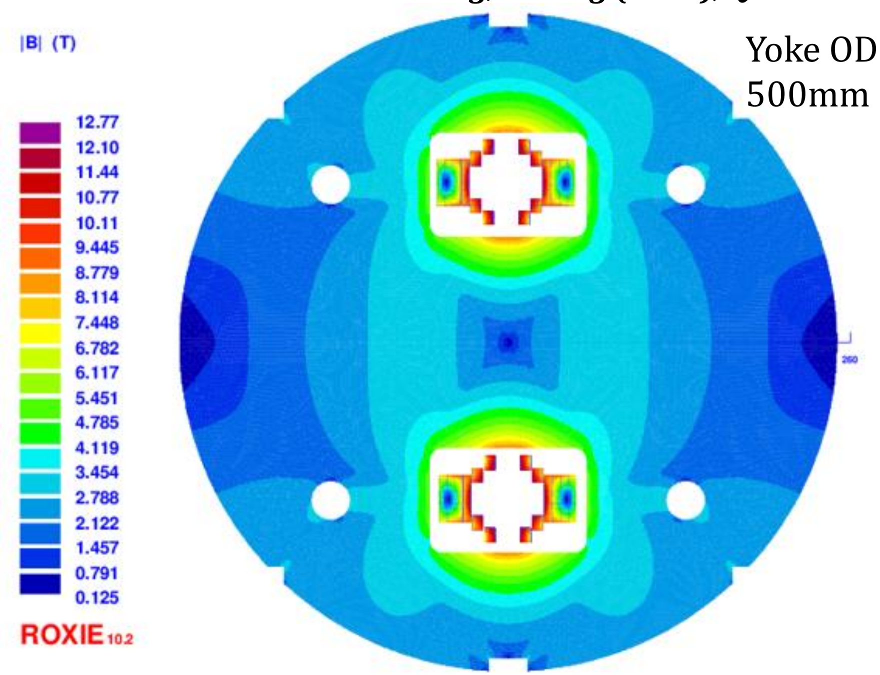
- Following the new SPPC design scope
  - Phase I: 12 T, all-HTS (iron-based conductors)
  - Phase II: 20-24 T, all-HTS
- New magnet design for 12-T dipoles
- R&D effort in 2016-2018
  - Cables, infrastructure
  - Development of a 12-T Nb3Sn-based twin-aperture magnets (alone, with NbTi, with HTS)
- Collaboration
  - Domestic collaboration frame on HTS (material and applications) formed in October 2016
  - CERN-IHEP collaboration on HiLumi LHC magnets

Details: next talk by Q.J. Xu

Design of 12-T Fe-based Dipole Magnet

C. Wang, E. Kong (USTC), Q. Xu et al.





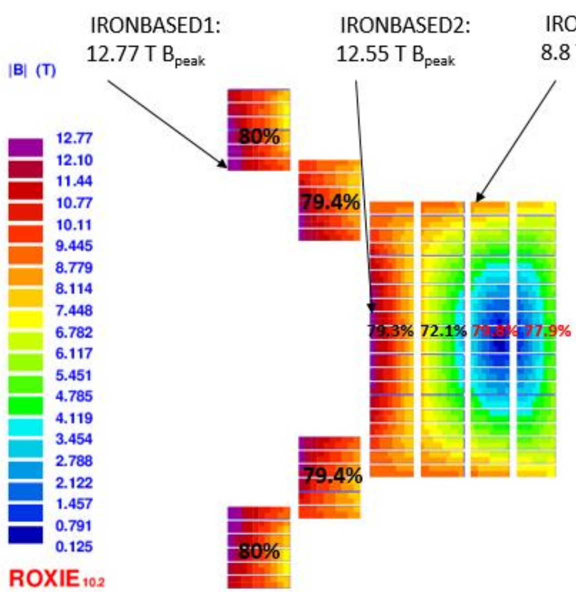


Table 1: Main parameters of the cables

Cable	Hight	Width-i	Width-o	Ns	Strand	Filament	Insulation
IRONBASED1	8	1.5	1.5	20	IRON-BASED	FE-BASED	0.15
IRONBASED2	5.6	1.5	1.5	14	IRON-BASED	FE-BASED	0.15
IRONBASED3	5	1.5	1.5	12	IRON-BASED	FE-BASED	0.15

Table 2: Main parameters of the strand

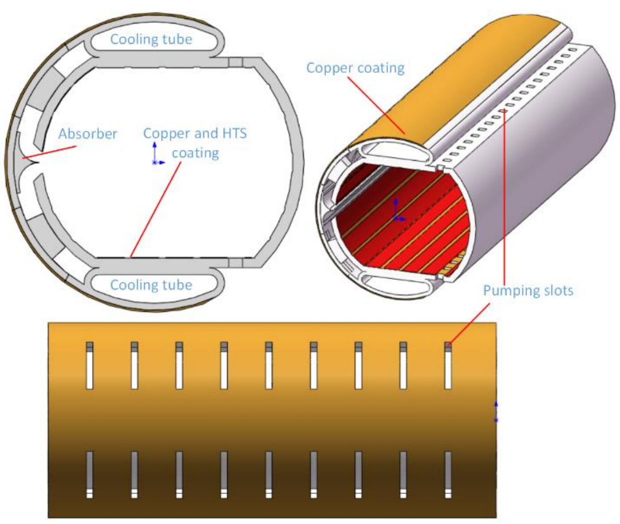
Strand	diam.	cu/sc	RRR	Tref	Bref	Jc@ BrTr	dJc/dB
IRON-BASED	0. 802	1	200	4. 2	10	4000	111

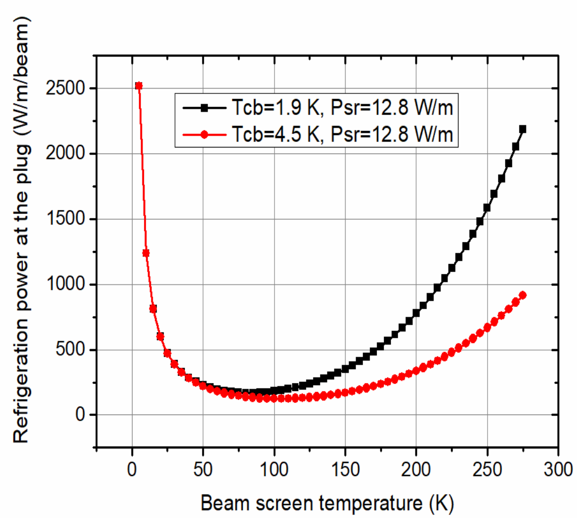
For per meter of such magnet, the required length of the iron-based strand: 6.08 Km

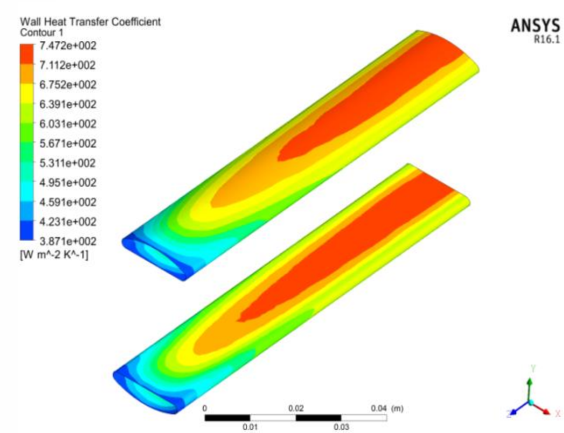
Beam screen study

Kun Zhu,
Pingping Gan

- With the new design scope, SR power decreases from 45 W/m to 12.8 W/m, but still very important, and beam screen still a critical issue
- Different effects combined: impedance, electron cloud, vacuum, magnet quenches, cooling etc.
- Recent work focused on: structure, HTS coating, working temperature, impedance, cooling method



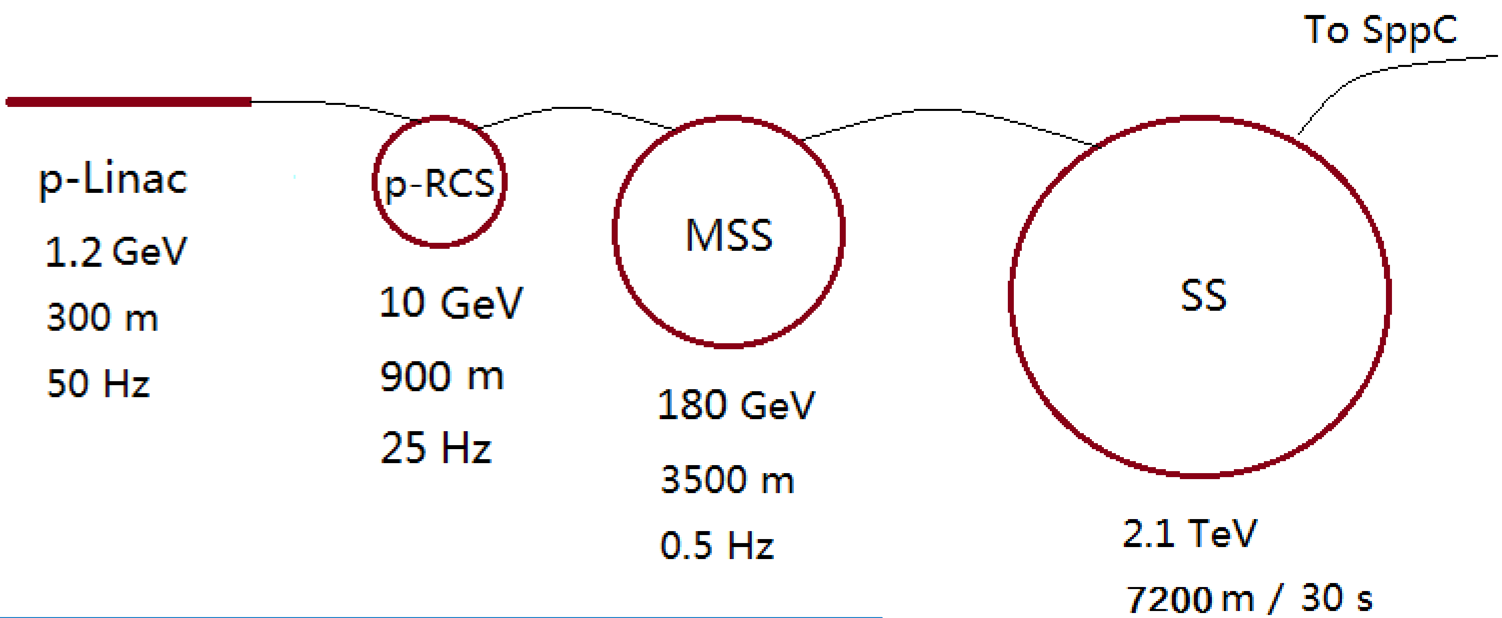




Other important technical challenges

- Collimation system: new materials to reduce impedance and tolerate more heat deposit
- Very large scale cryogenics system: SC magnets, SRF, beam screens
- Sophisticated beam feedback system: to control the emittance heat-up and suppress beam instabilities
- Machine protection system: fast detection of abnormal function, reliable beam abort (kickers and septa)
- There are also many technical challenges in building high-power injector chain: e.g. RF systems for p-RCS and MSS, fast ramping for SS

Injector chain
(for proton beam)



p-Linac: proton superconducting linac

p-RCS: proton rapid cycling synchrotron

MSS: Medium-Stage Synchrotron

SS: Super Synchrotron

Ion beams have dedicated linac (I-Linac) and RCS (I-RCS)

Preliminary design of the injector chain

- Accelerator schemes and parameter lists
- Preparation of the beam for injection into SPPC: energy, intensity, emittance, bunch pattern, turnaround time
- Maximize the performance with modest cost for each accelerator (different settings from service to SPPC)
- Pre-conceptual design on each stage:
  - p-Linac/i-Linac: Yuanrong Lu, Haifeng Li (RFQ, DTL, SC cavities)
  - p-RCS/i-RCS: Linhao Zhang, Jingyu Tang (parameter design)
  - MSS: Yang Hong (parameter design, lattice)
  - SS: Xiangqi Wang, Tao Liu (parameters, lattice, injection/extraction, acceleration)

Major parameters for the injector chain

	Value	Unit		Value	Unit
p-Linac			MSS		
Energy	1.2	GeV	Energy	180	GeV
Average current	1.4	mA	Average current	20	uA
Length	~300	m	Circumference	3500	m
RF frequency	325/650	MHz	RF frequency	40	MHz
Repetition rate	50	Hz	Repetition rate	0.5	Hz
Beam power	1.6	MW	Beam power	3.7	MW
p-RCS			SS		
Energy	10	GeV	Energy	2.1	TeV
Average current	0.34	mA	Accum. protons	1.0E14	
Circumference	970	m	Circumference	7200	m
RF frequency	36-40	MHz	RF frequency	200	MHz
Repetition rate	25	Hz	Repetition period	30	s
Beam power	3.4	MW	Protons per bunch	1.5E11	
			Dipole field	8.3	T

More about the Injector Chain

- Injector chain by itself is a very complicated and powerful accelerator system, large enough by a single stage
  - Totally new, different from LHC or Tevatron (building-up by steps)
  - No close reference accelerators (scaled up by large factors)
  - Should be built earlier than SPPC by a few years to allow relatively long-time commissioning stage by stage
- Rich physics programs for each stage, e.g.:
  - p-Linac: producing intense neutrons and muons and rare isotopes for wide research areas
  - p-RCS and MSS: producing very powerful neutrino beams for neutrino oscillation experiments
- Key technical challenges should be identified, so needed R&D program can be pursued (e.g. high-Q ferrite-loaded RF cavities)

Plan on the SPPC chapter in the CDR

- Subsection material preparation assignment: November 2017
- Material collection will be finished by December 2017 (Jingyu Tang)
- First version to the editor: mid-January 2018
- Second version to the editor : end-January 2018
- Final version to the editor: mid-February

- If needed, we can accelerate the process

Contents in CDR

Ch.7 Upgrade to SPPC

7.1 Introduction (Tang Jingyu and theorists, some changes from Pre-CDR)

7.1.1 Science reach at the SPPC

7.1.2 The SPPC complex

7.1.3 Design goals

7.1.4 Overview of the SPPC design

7.2 Key accelerator physics issues

7.2.1 Main parameters (Update, Tang Jingyu)

7.2.2 Synchrotron radiation (no change)

7.2.3 Beam-beam effects (Wang Lijiao, K. Ohmi and Tanaji Sen)

7.2.4 Electron cloud effects (Liu Yudong)

7.2.5 Beam loss and collimation (Zou Ye)

7.2.6 Injection and extraction (Yang Ye/ Li Guangrui)

7.3 Preliminary accelerator physics design

7.3.1 Lattice design (Su Feng/ Chen Yukai)

7.3.2 Collimation design (Zou Ye)

7.3.2 Longitudinal dynamics (Zhang Linhao)

7.4 Key technical systems

7.4.1 High-field superconducting magnets (Xu Qingjin)

7.4.2 Cryogenic vacuum and beam screen (Zhu Kun/ Wang Yong)

7.4.3 Other technical challenges (Tang Jingyu)

7.5 Injector chain

7.5.1 General considerations (Tang Jingyu)

7.5.2 Proton and ion linacs (Lu Yuanrong)

7.5.3 Rapid Cycling Synchrotrons (Tang Jingyu)

7.5.4 Medium-Stage Synchrotron (Hong Yang/ Tang Jingyu)

7.5.5 Super Synchrotron (Wang Xiangqi)

7.6 Reconfiguration of the accelerator complex from CEPC to SPPC (Zhang Yuhong, almost no change)

Summary

- SPPC - the second phase of CEPC-SPPC, a pre-conceptual design for a 75-TeV pp collider is ongoing, to explore new physics in energy frontier
- SPPC will provide wide physics programs, including the collider and the beams from the injector accelerators
- Study focusing on a few key accelerator physics issues: lattice, collimation, b-b effects, longitudinal dynamics, instabilities, injection/extraction
- Identifying technical challenges to be solved in the next two decades, besides high-field SC magnets and beam screen
- Pre-conceptual study on the injector chain is also under way

THANK YOU!