SPPC Study Progress

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for the SPPC study group

FCC Week 2017, May 29-June 2, 2017, Berlin, Germany

Main topics

- New design scope for SPPC
- Collider accelerator physics
- Design concepts on the injector chain
- Technical issues
- Project status
- Summary

SPPC New Design Scope

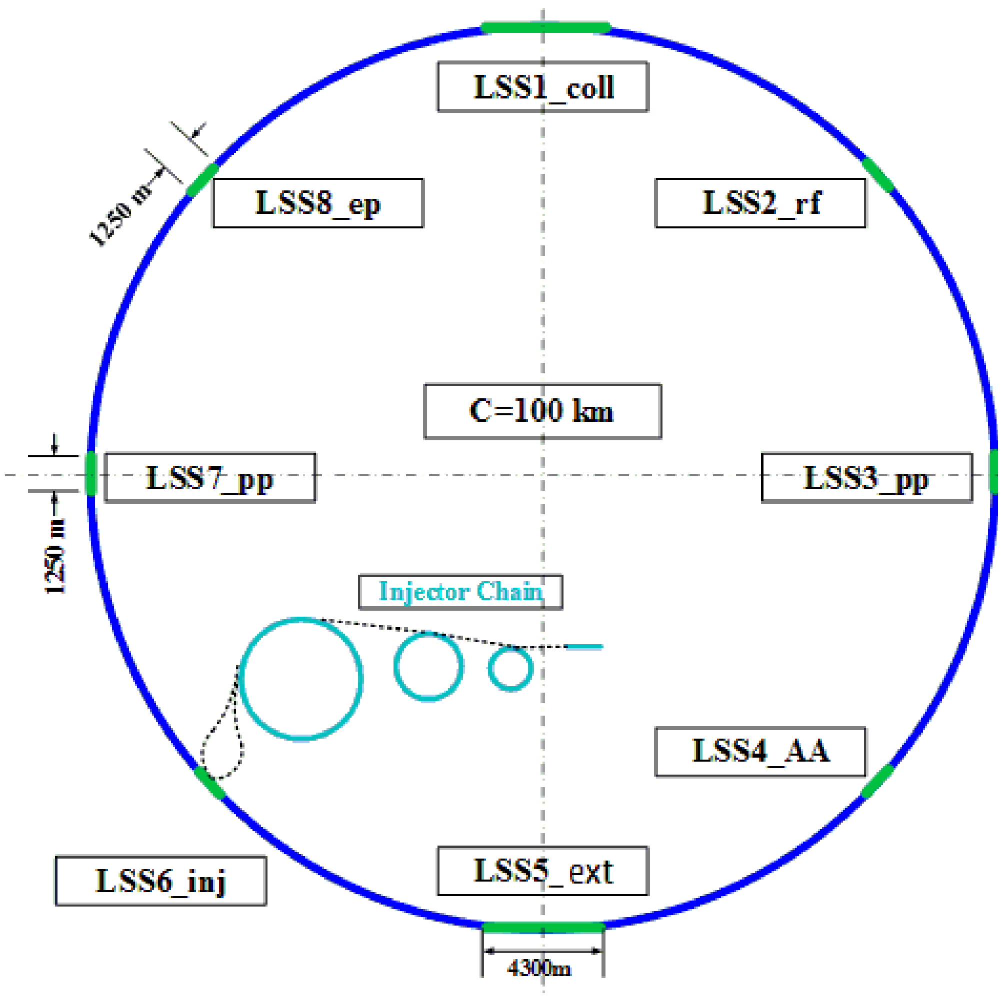
From Jan. 2017

- Baseline design
  - Tunnel circumference: 100 km
  - Dipole magnet field: 12 T, using full iron-based HTS technology
  - Center of Mass energy: >70 TeV
  - Injector chain: 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 (e.g., adding a high-energy booster ring in the main tunnel in the place of the electron ring and booster)
- Development of high-field superconducting magnet technology
  - Starting to develop required HTS magnet technology; before applicable iron-based HTS wire are available, models by YBCO and LTS wires can be used for specific studies (magnet structure, coil winding, stress, quench protection method etc.)

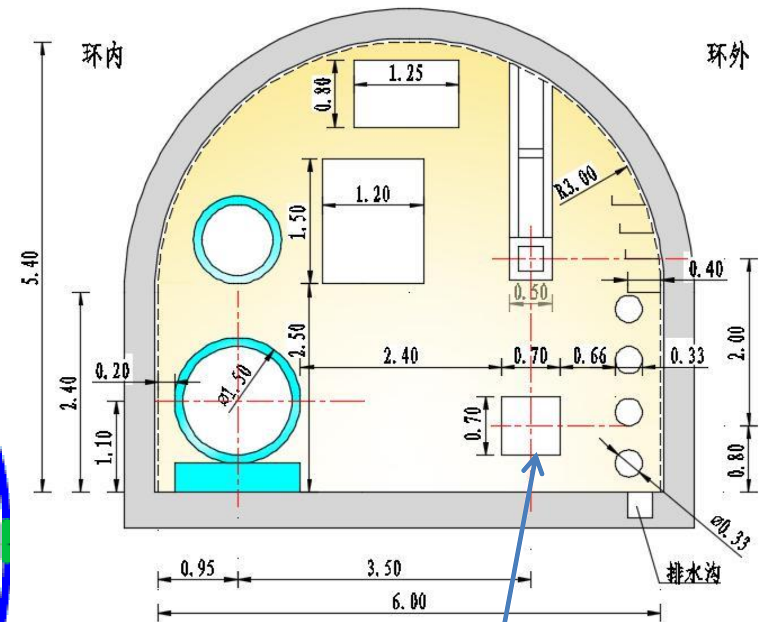
SPPC main parameters (updated)

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

Collider Accelerator Physics

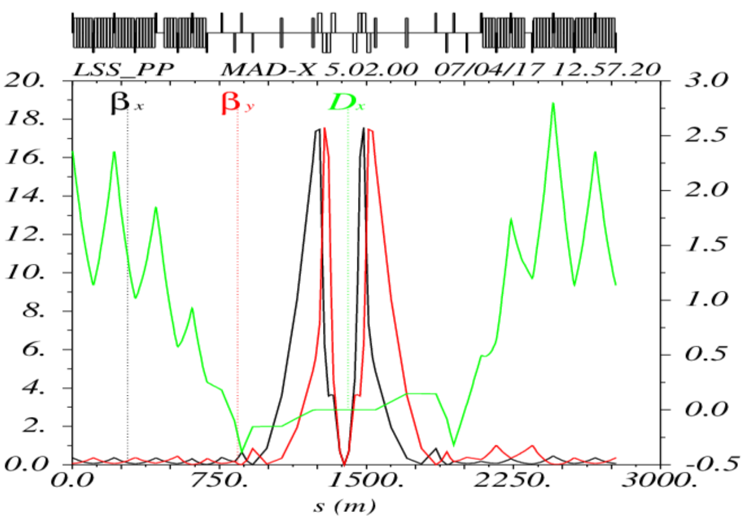
-Parameter list updating

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

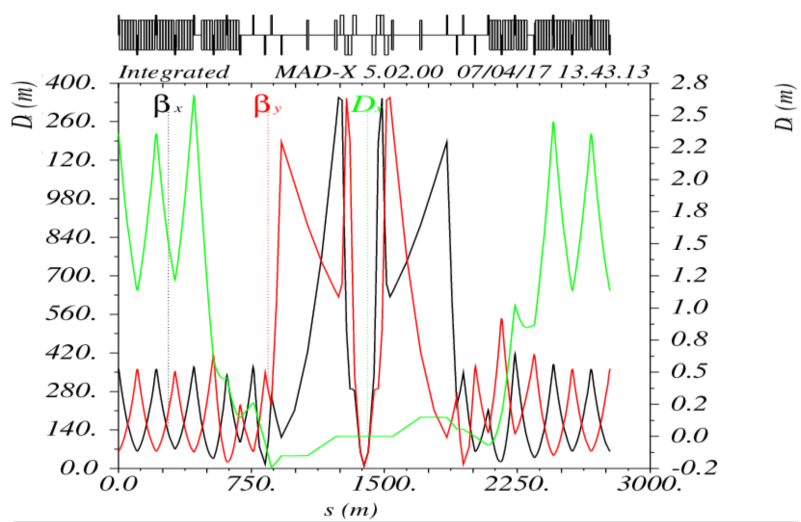
Total / inelastic cross section	147	mbarn
Reduction factor in luminosity	0.85	
Full crossing angle	110	µrad
rms bunch length	75.5	mm
rms IP spot size	6.8	µm
Beta at the 1st parasitic encounter	19.5	m
rms spot size at the 1st parasitic encoun	34.5	µm
Stored energy per beam	9.1	GJ
SR power per ring	1.1	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

- Different lattice designs
  - Different schemes (100 TeV and 75 TeV @100 km)
  - Lattice at injection
  - Compatibility between CEPC and SPPC
  - Arc cells, Dispersion suppressors, insertions



IP: at collision

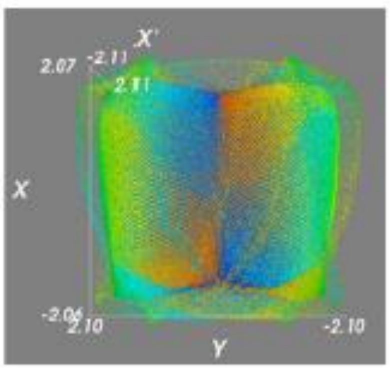


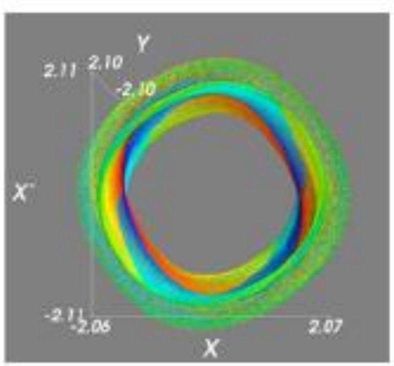
IP: at injection

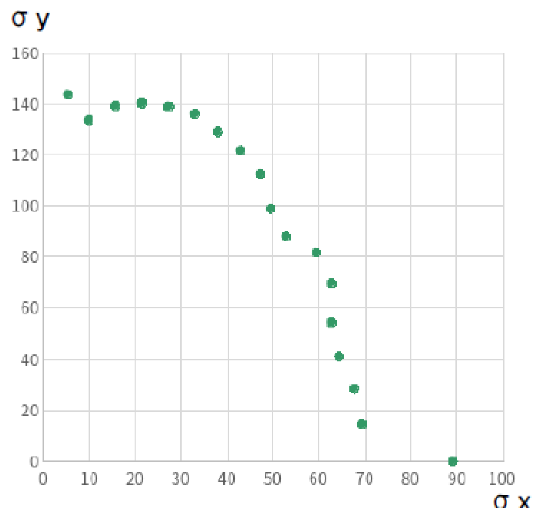
Dynamic aperture study

- At collision energy
- At injection energy

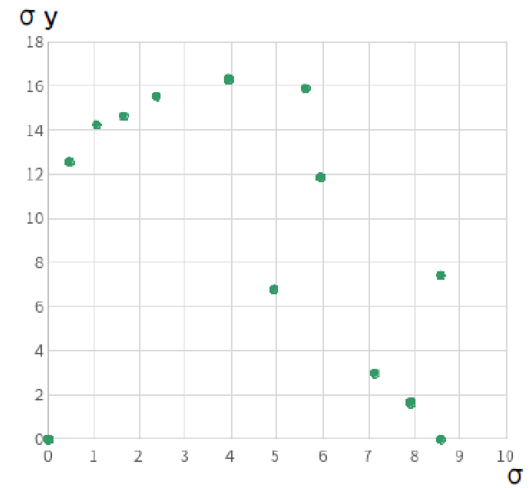
  (Sixtrack code)



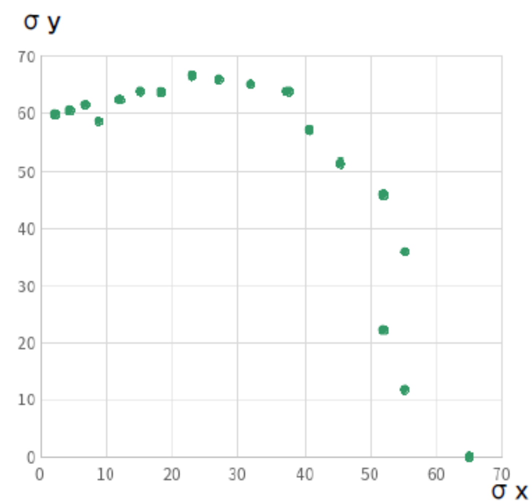




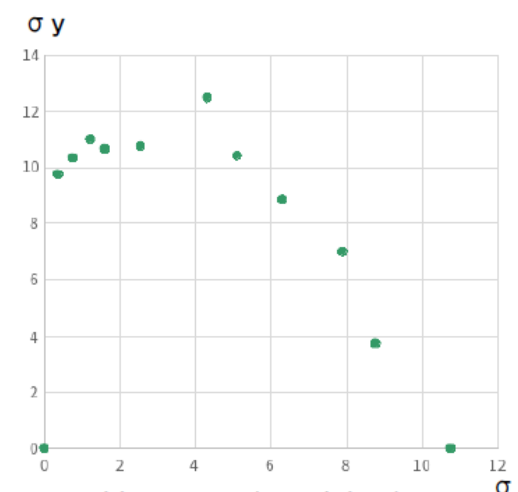
Adding sextuple without dipole error (chromaticity corrected)



Adding sextuple and dipole error (chromaticity corrected)



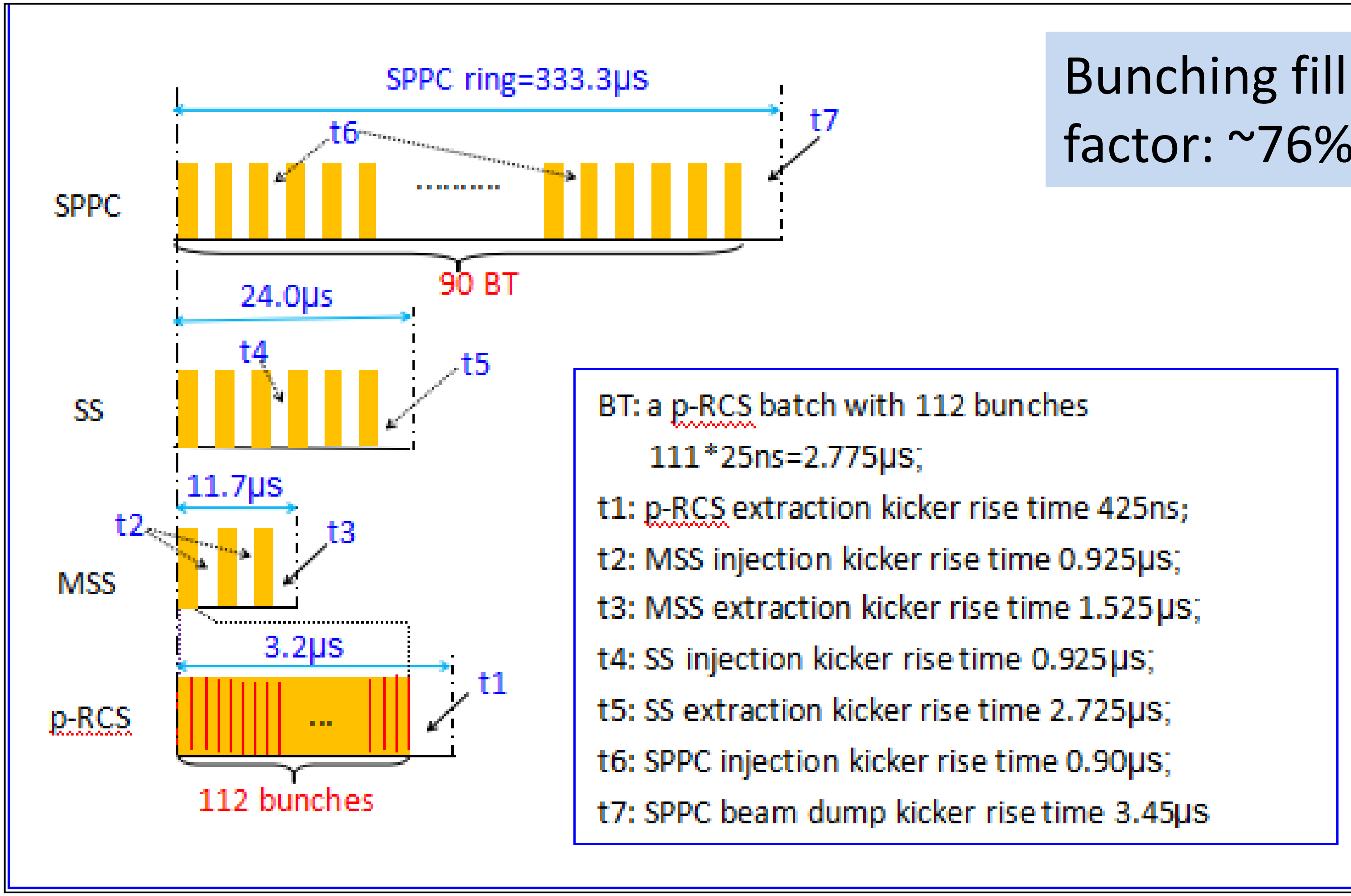
Adding sextuple without dipole error (chromaticity corrected)



Adding sextuple and dipole error (chromaticity corrected)

Bunch filling schemes

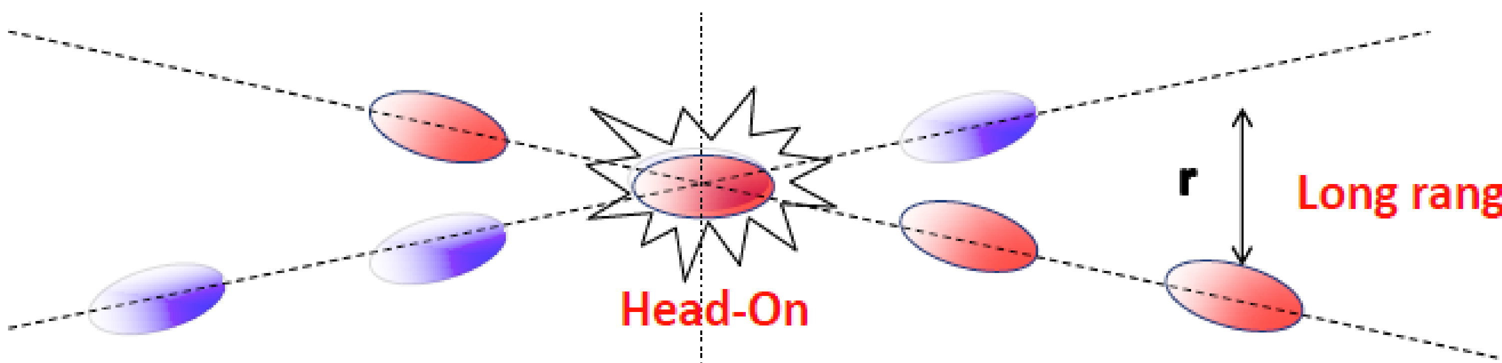
- 100 km - 75 TeV -25 ns (also for different SPPC designs)



Bunching filling factor: ~76%

Beam-beam effects

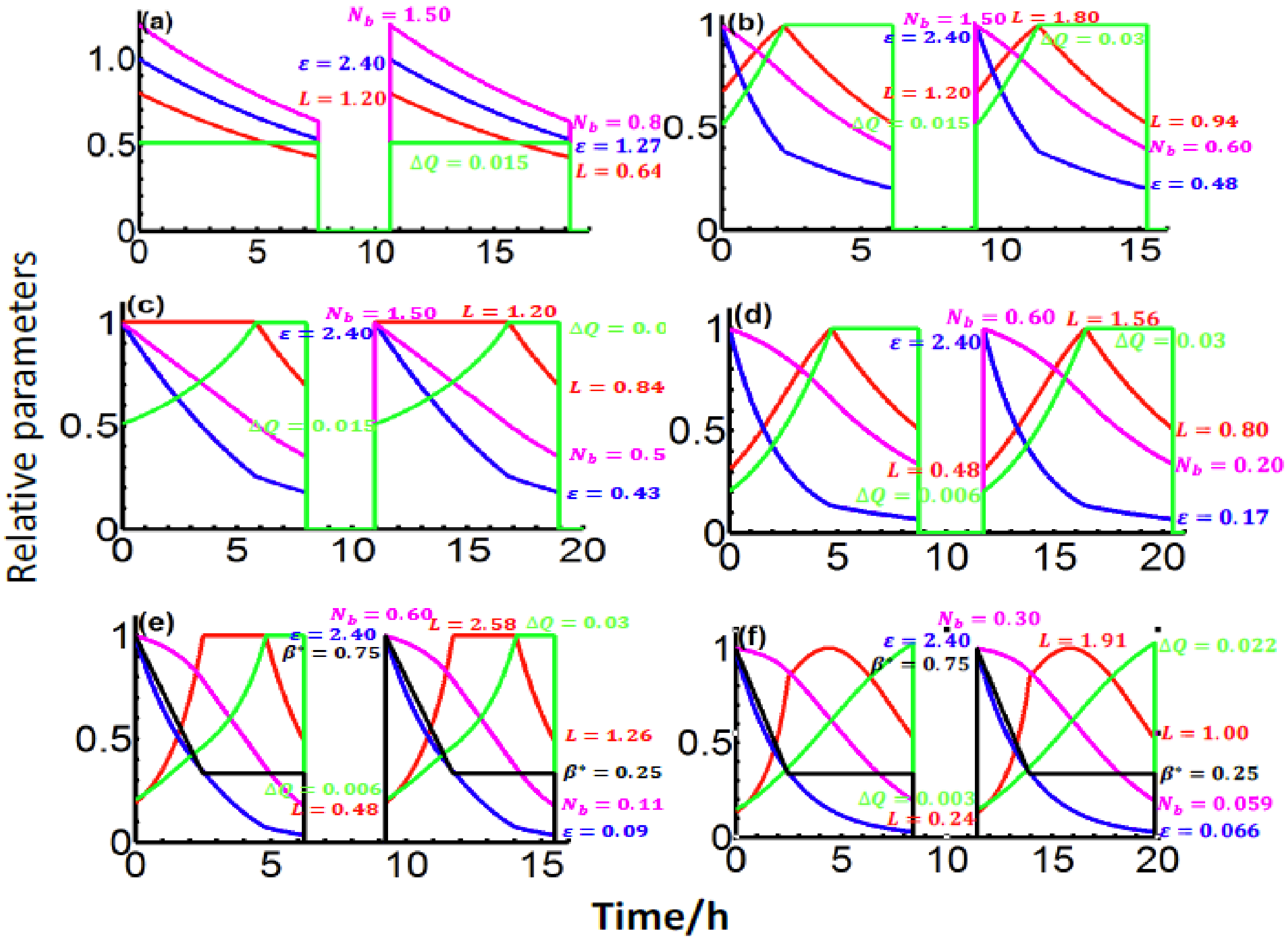
- Studying different effects (just started)
  - Head-on interaction
  - Long-range interaction
  - Pacman effects
  - Orbit effects
  - Coherent beam effects
  - BB compensation methods (Electron lens, Compensation wires)



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)

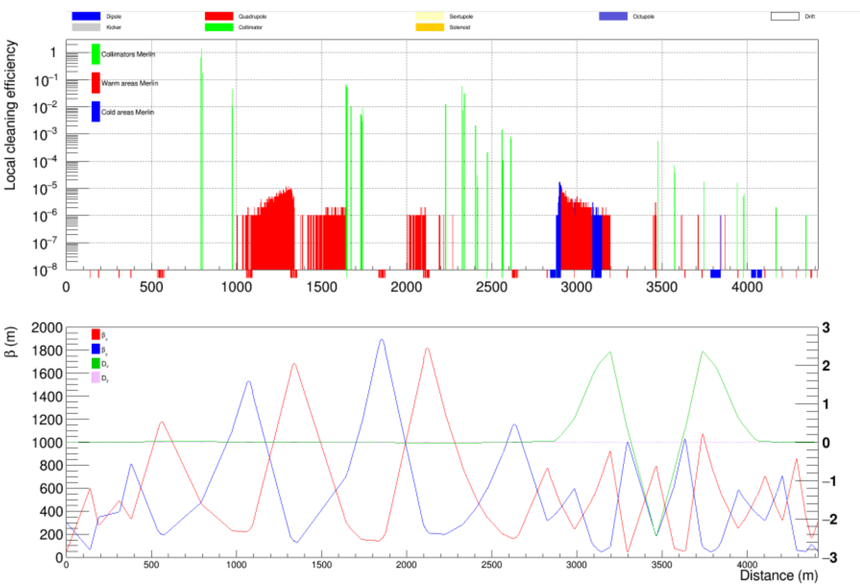


- Turnaround:
  0.8 hrs (min),
  2.4 hrs (ave)
- ΔQ: 0.03 (max)
- Spacing:
  25, 10, 5 ns
- Beta*:
  0.75 m
  0.75->0.25m

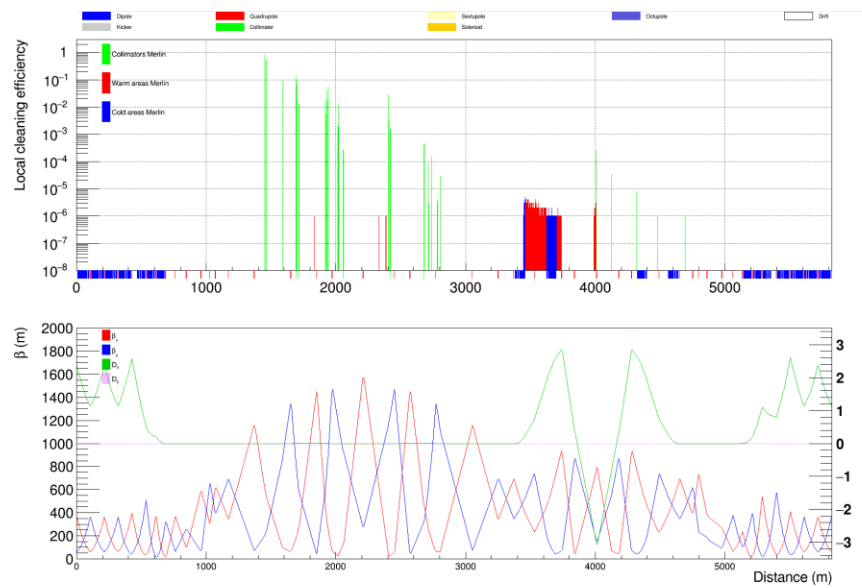
Collimation study

See J.Q. Yang's talk (next)

- We further develop the concept of combining betatron and momentum collimations in a same long straight section
- Recently we make 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



With RT magnets in beta-collimation



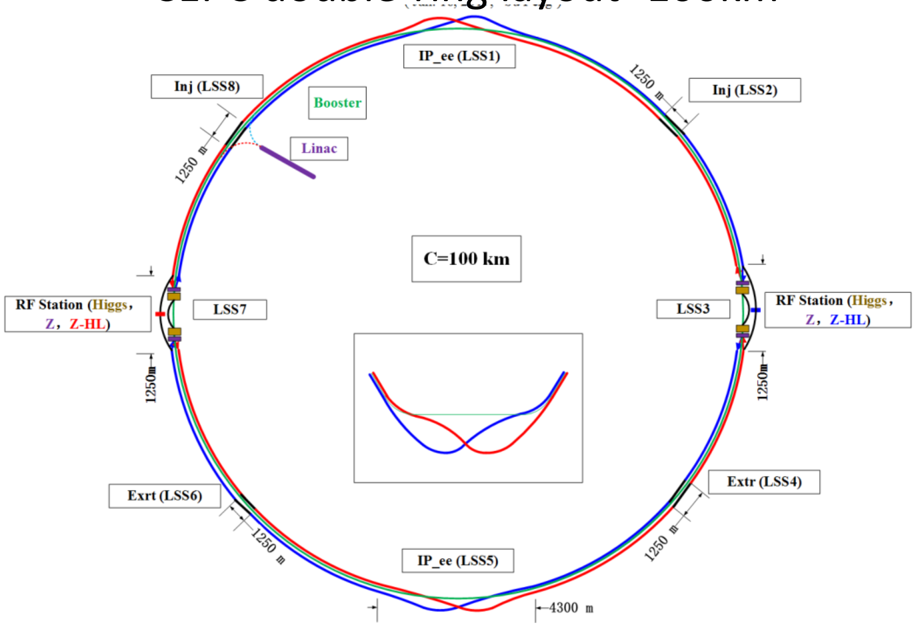
With SC magnets in beta-collimation

- Other studies on accelerator physics
  - Instabilities: mainly on electron cloud effect and impedance from beam screen and collimators
  - Injection/extraction: concepts and hardware requirements
  - Longitudinal dynamics: including the injector chain

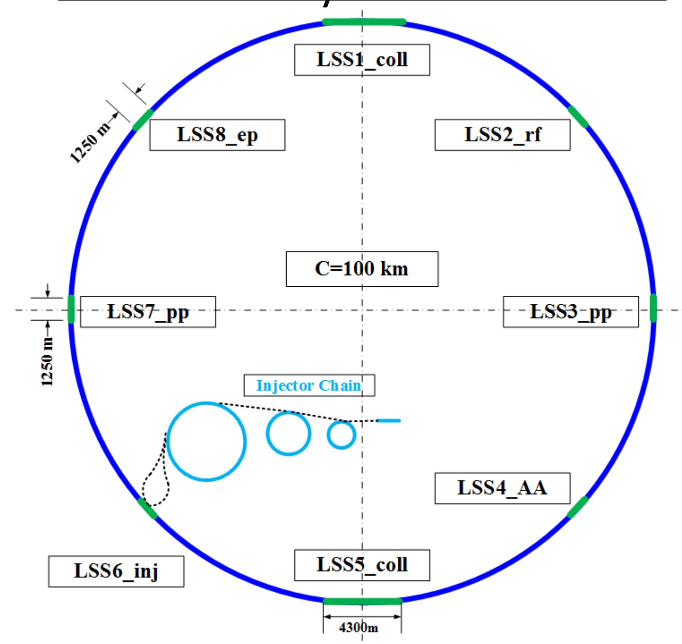
Compatibility between CEPC and SPPC

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

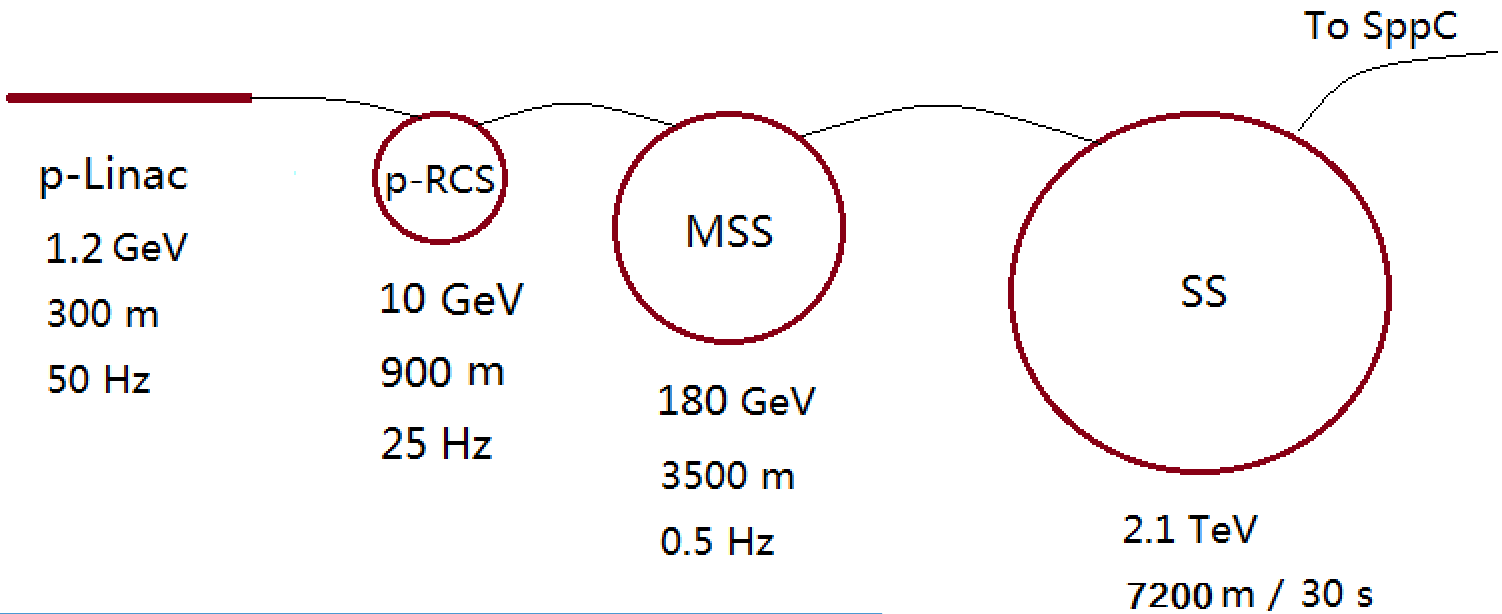
CEPC double-ring layout- 100km



SPPC layout- 100km



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)

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
- Design work started: schemes, lattices, …
- Key technical challenges should be identified, so needed R&D program can be pursued (e.g. high-Q ferrite-loaded RF cavities)

Technical challenges and R&D requirements

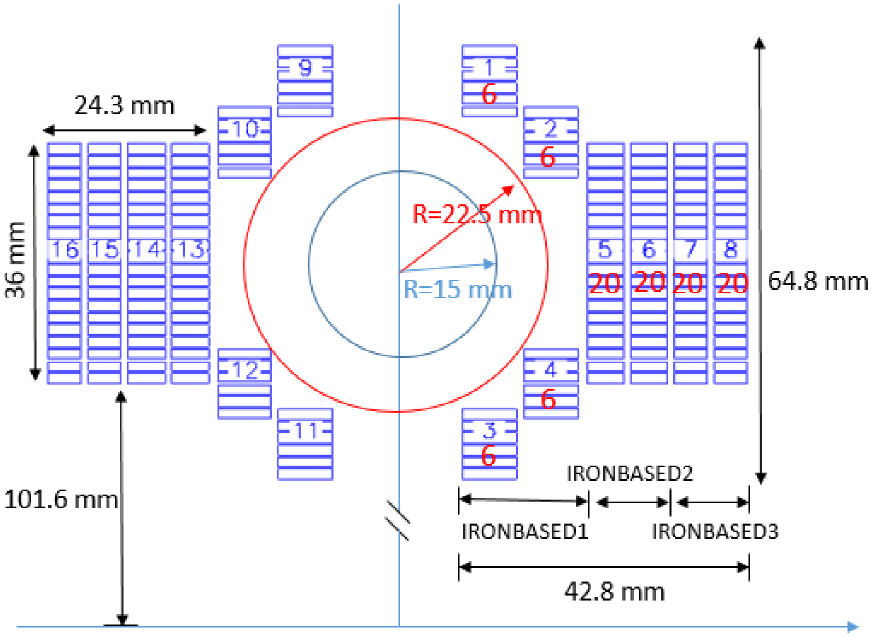
-High field SC magnets

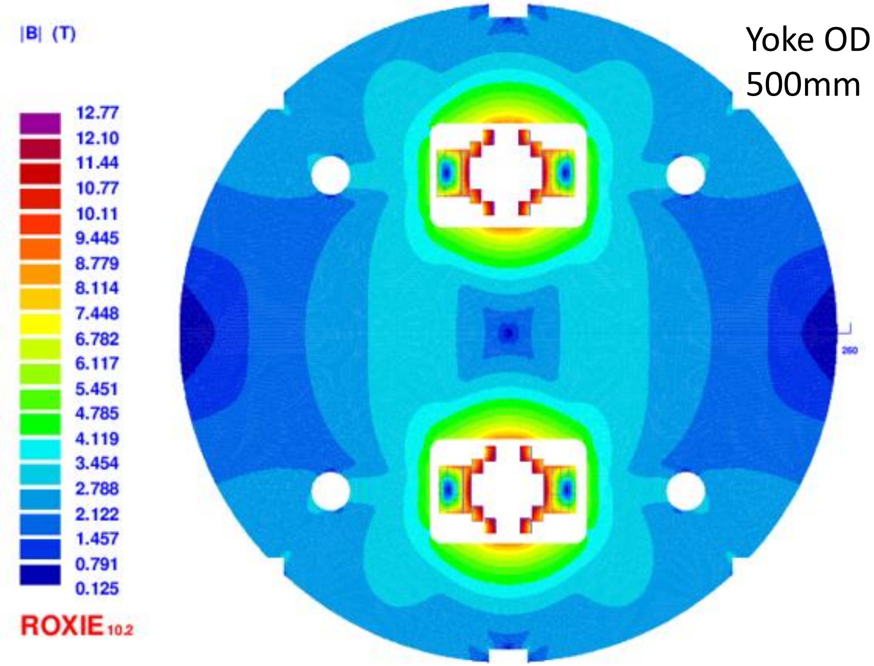
- Following the new SPPC design scope
  - Phase I: 12 T, all-HTS (iron-based conductors)
  - Phase II: 20-24 T, all-HTS
- New magnet design for 12-T dipoles
- R&D effort in 2016-2018
  - Cables, infrastructure
  - Development of a 12-T Nb3Sn-based twin-aperture magnets (alone, with NbTi, with HTS)
-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

Q.J. Xu's talk on Wed. afternoon

Design of 12-T Fe-based Dipole Magnet

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





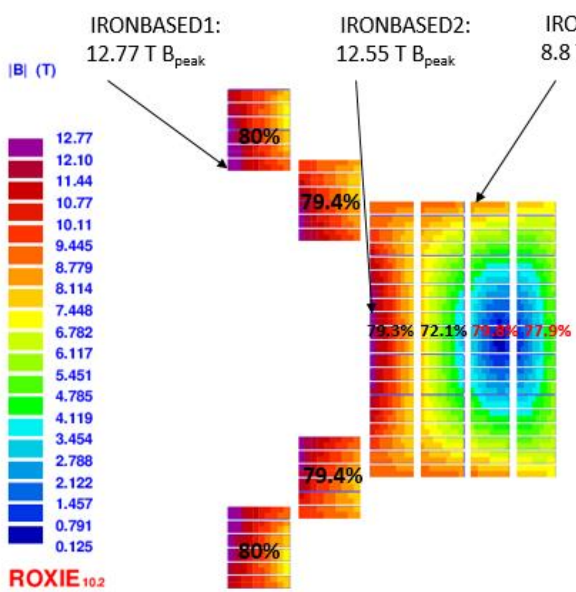


Table 1: Main parameters of the cables

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

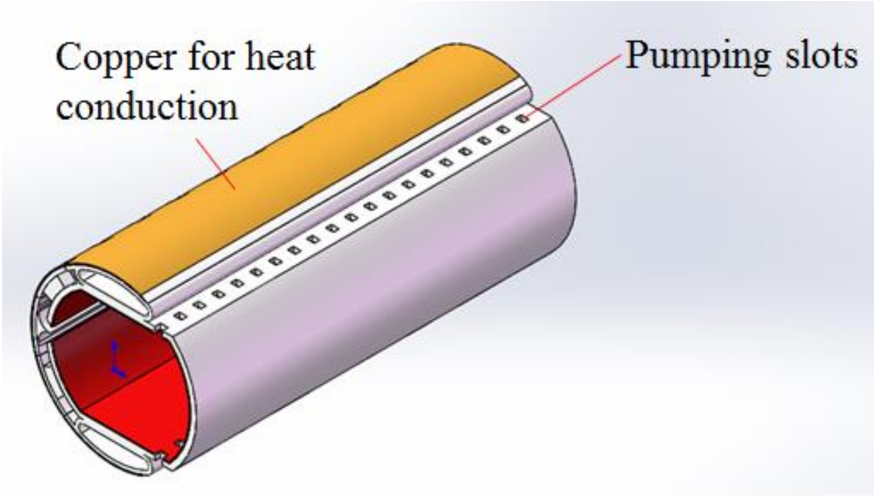
Domestic Collaboration on HTS

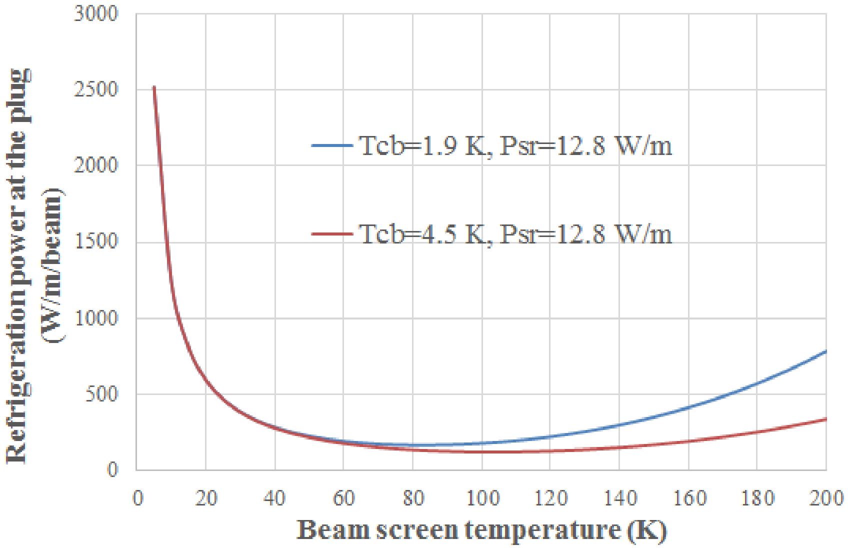
In October 2016, A consortium for High-temperature superconducting materials and applications was formed in China, with participation of major research and production institutions on HTS.

China is actually leading the development of Fe-HTS technology in the world; world-first 100-m Fe-HTS wire was made by CAS-Institute of Electrical Engineering in the last year .

Beam screen study

- 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: HTS coating and working temperature



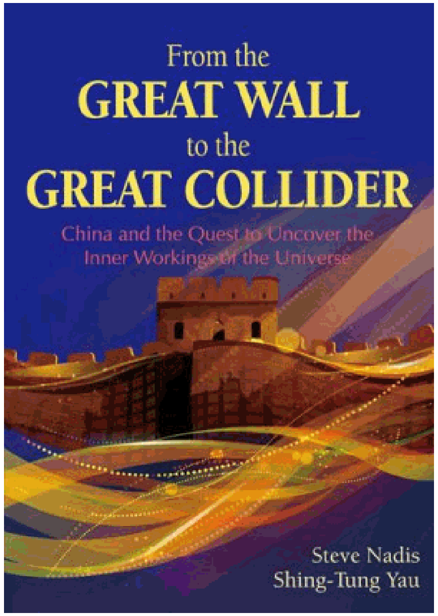


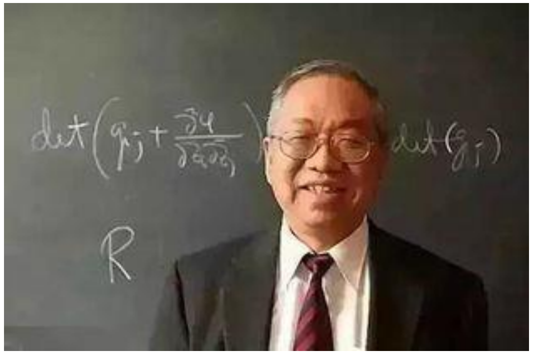
Other important technical challenges

- 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

Project status

- CEPC is now the key project at IHEP
  - SPPC modestly behind CEPC, as a long-term plan
- Modest budget is coming from: MOST (2016, 2018, national key research program) , Beijing Municipal Government (advanced accelerator technology development platform, shared with HEPS), CAS (pioneering projects) and NSFC (research centers, may need to wait for longer time)
- Study team steadily building-up
- International workshop on CEPC on November 6-8
- Very interesting: national debate (also with international players) on if China should build super colliders since last year, triggered by Nobel Laureate C.N. Yang's opposition on CEPC-SPPC





S.T. Yau
C.N. Yang
Y.F. Wang

Summary

- SPPC - the second phase of CEPC-SPPC, a schematic design for a 75-125 TeV pp collider is being studied, to explore new physics in energy frontier
- SPPC will provide wide physics programs, including the collider and the beams from the injector accelerators
- Technical challenges to be solved in the next two decades, in particular, high-field HTS magnets and beam screen
- Some progresses have been made, with a goal of pre-conceptual design integrated in the CEPC-SPPC CDR by early 2018
- It is very important to have wide collaboration with international labs, and unification of domestic resources
- Suggestions and participation in study are much welcome

Thanks for your attention!