SPPC Study and R&D Planning

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IAS Program for High Energy Physics
January 18-21, 2016, HKUST

Main topics

- Pre-conceptual design study
- Studies on key technical issues
- R&D planning on key technologies
- About team and collaboration
- Summary

CEPC-SPPC Project Timeline (dream, personal view)

CEPC

1st Milestone: pre-CDR (by the end of 2014) → R&D funding request to Chinese government in 2015 (China's 13th Five-Year Plan 2016-2020)

SPPC

Overlapping probably necessary for time to construct and commission the complex SPPC injector chain

(original from Chou Weiren)

ABOUT PRE-CONCEPTUAL DESIGN

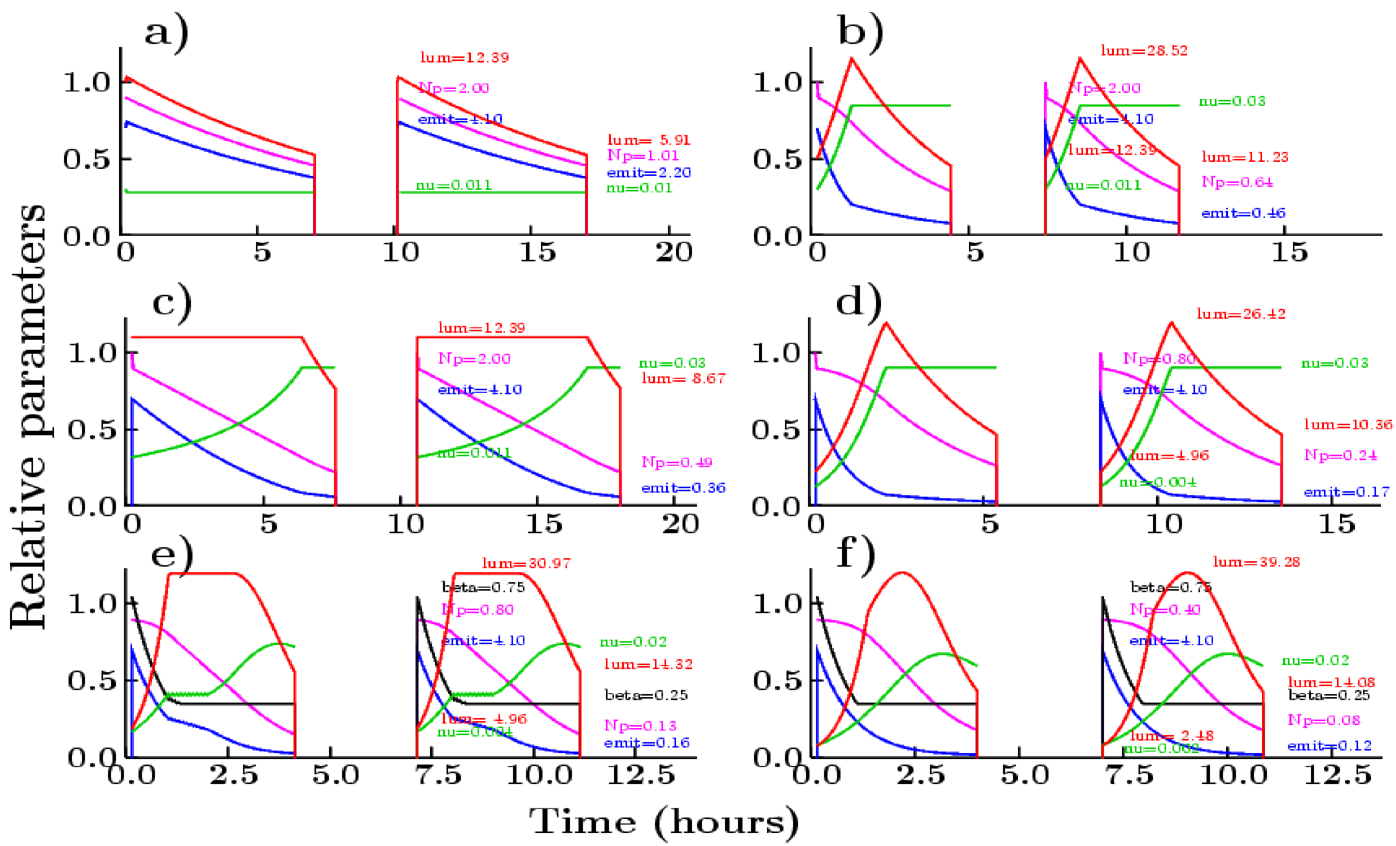
SPPC main parameters

Parameter	Value	Unit
Circumference	54.36	km
C.M. energy	70.6	TeV
Dipole field	20	T
Injection energy	2.1	TeV
Number of IPs	2 (4)	
Peak luminosity per IP	1.1E+35	$cm^{-2}s^{-1}$
Beta function at collision	0.75	m
Circulating beam current	1.0	A
Nominal beam-beam tune shift per IP	0.006	
Bunch separation	25	ns
Bunch population	2.0E+11	
SR heat load @arc dipole (per aperture)	56.9	W/m

- As this is a long-term study, we are focusing on
  - Identification of key challenges on Accelerator Physics and Technologies in designing and building the accelerator
  - Coping with the CEPC design in consistence and compatibility: layout, tunnel cross-section etc.
- Main working topics
  - General parameterization design
  - Collider accelerator physics
    - Layout and lattice design
    - Collimation
    - Beam-beam effects
    - Injection/extraction
    - Instabilities
    - Longitudinal dynamics
  - Identifying technical challenges
  - Schematic design for the injector chain

Collider Accelerator Physics

- General parameters
  - We maintain a parameter list
- Luminosity performance
  - Some studies on luminosity leveling (mainly by R. Palmer)

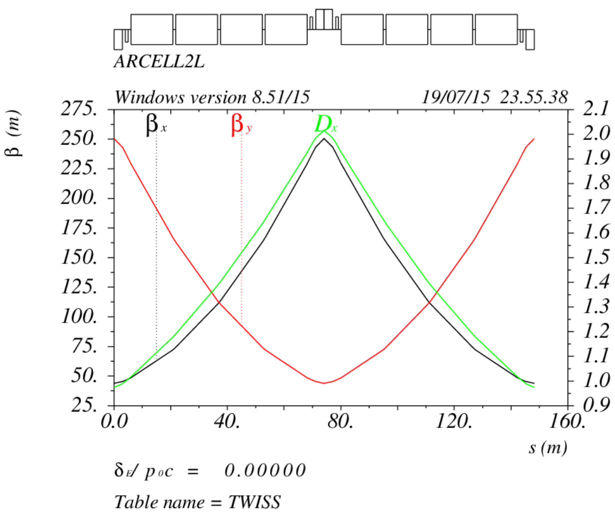


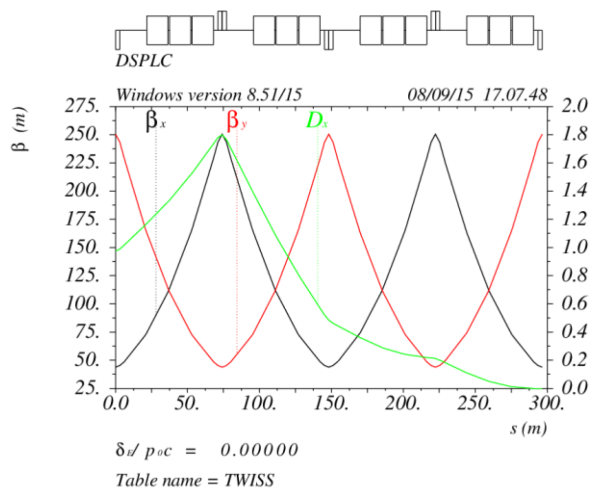
Different luminosity leveling schemes

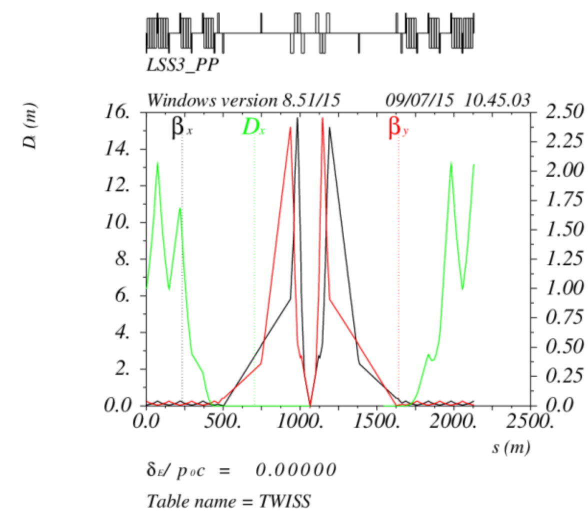
Lattice design

- Two persons working in parallel on the SPPC lattice design
  - Arc-DS lattice, IP lattice, detouring lattice

More in Su Feng's talk



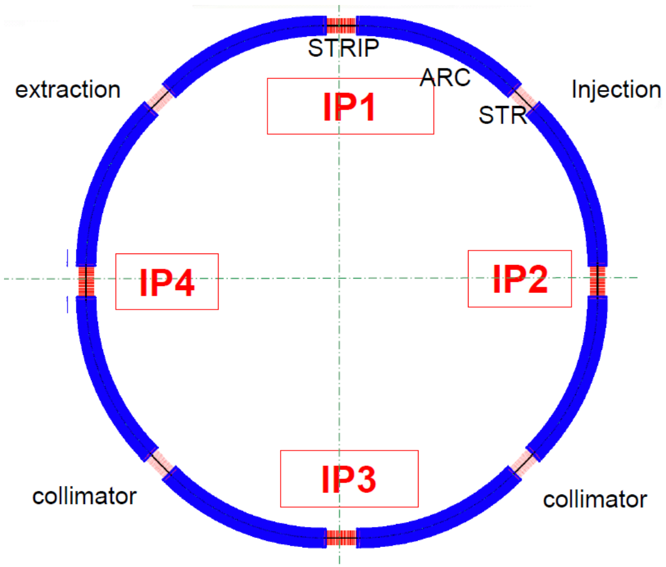




L: arc standard; M: dispersion suppressor; R: IP (very preliminary)

Beam Collimation

- A very important topic, concerning the CEPC-SPPC layout to some extent. Three persons working on the study.
  - Mechanism quite different from lower energy collimation
  - Good progress has been made.



- Extremely efficient collimation system is key to SPPC operation (6.3 GJ beam energy):

  Cleaning inefficiency: < 10^{-6}
- Multi-stage collimation: very long space (two long straight sections, betatron and momentum)
- More challenging than LHC

Some key points for SPPC Collimation

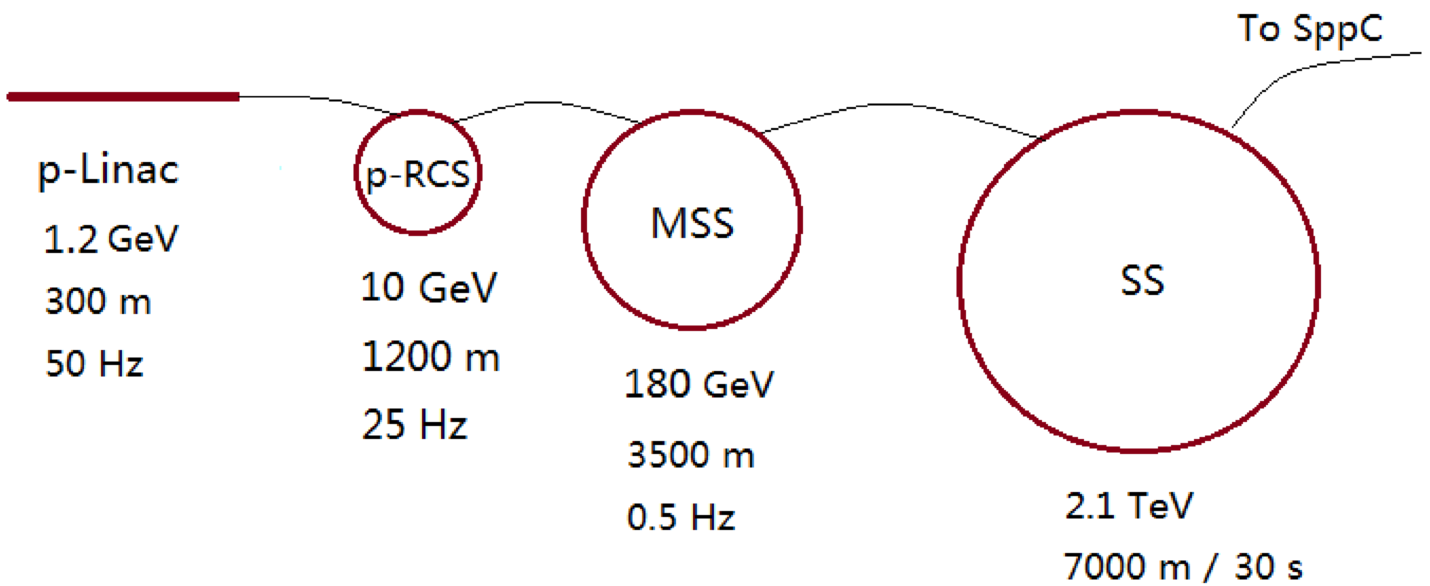
- Understanding the beam-material interaction at the TeV level (tracking tool still lacked)
- Necessity to introduce low-field superconducting quads in the warm section with precaution or protection
- Concept to arrange transverse and longitudinal collimations in the same long straight section, avoiding collimators in the Dispersion-Suppression region
- Taking advantage of race-track lattice having two very long straight sections (as also required by CEPC partial double ring scheme)

- Other AP studies:
  - Instabilities: survey on possible instabilities, impedance sources, especially electron cloud effect and impedance from the beam screen
  - Beam-beam effects: bunch pattern, simulations, feedbacks, coping with luminosity leveling.
  - Injection and extraction: layout, physics and technical issues.
  - Longitudinal dynamics: injection and ramping, collision and beam heating (vs. emittance damping)

Injector chain

- A very powerful injector chain is needed to feed the pp collider. and should be built earlier than SPPC by a few years to allow relatively long-time commissioning stage by stage
- Each stage of the injector chain can have its own physics program (spare time not to fill next-stage accelerator), 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
  - SS: hadron physics and else, or start e-p collision with it before SPPC is to be built

Injector chain scheme (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	1.63	MW	Beam power	3.67	MW
p-RCS			SS		
Energy	10	GeV	Energy	2.1	TeV
Average current	0.19	mA	Accum. protons	2.55E14	
Circumference	900	m	Circumference	7000	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	2.0E11	
			Dipole field	8	T

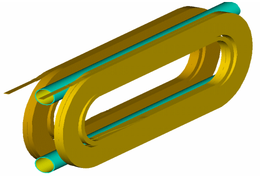
KEY TECHNICAL ISSUES

High-field superconducting magnets

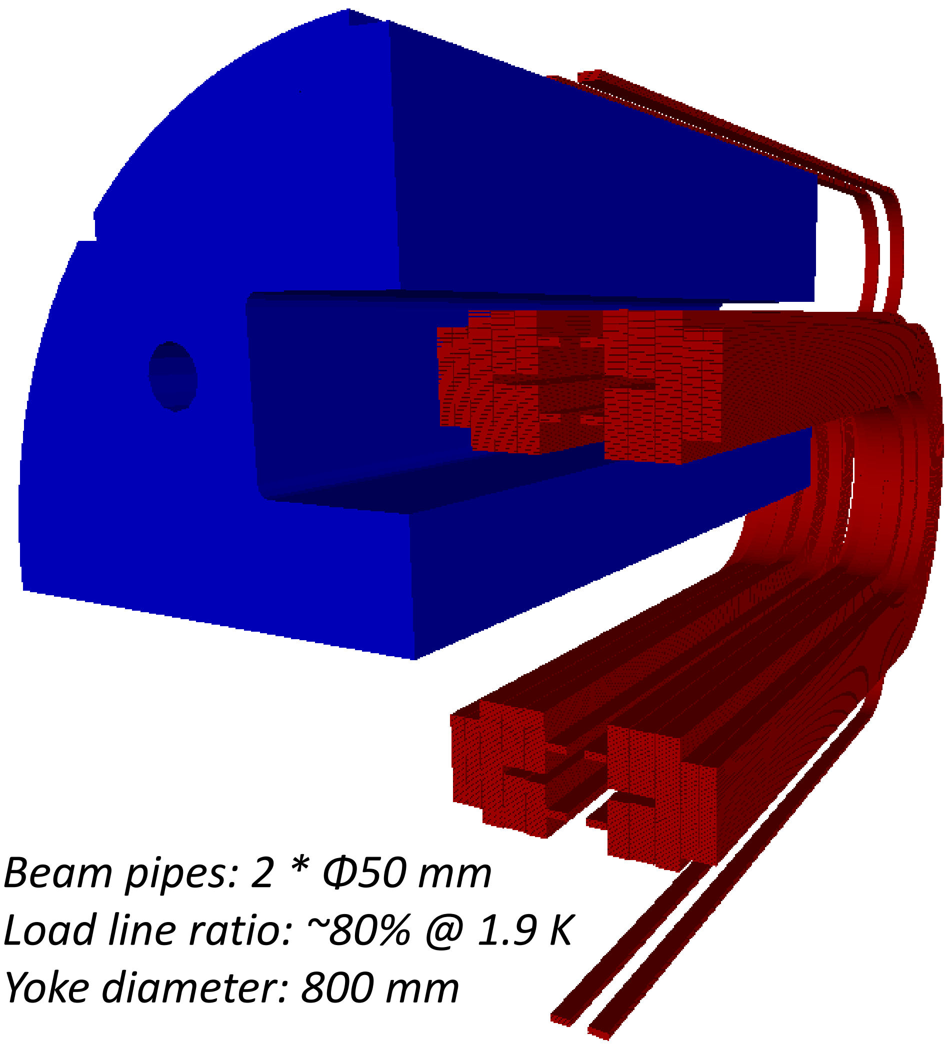
- The most challenging technology for SPPC to be overtaken in next 15 years (raising magnetic field from 8.3 T at LHC to 20 T at SPPC)
- It will be a long-term study and R&D efforts, requiring strong support from both domestic and international collaborators, and also industrial partners.
- Currently, main work is on magnet design, building small-scale prototypes, infrastructure building-up

More details see
XU Qingjin's talk

Magnetic design study of a 20-T dipole



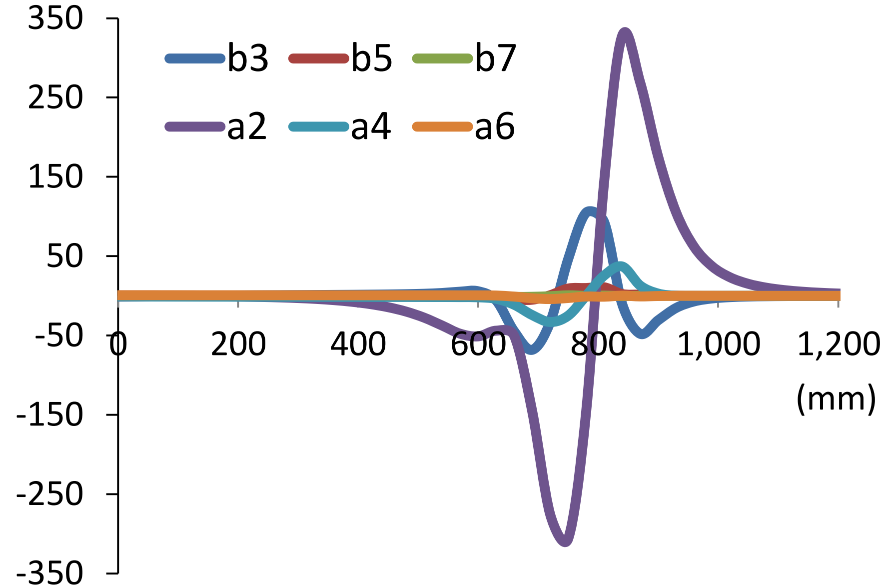
20-T coil end design with common coil configuration



*Beam pipes: 2 * Φ50 mm*
Load line ratio: ~80% @ 1.9 K
Yoke diameter: 800 mm

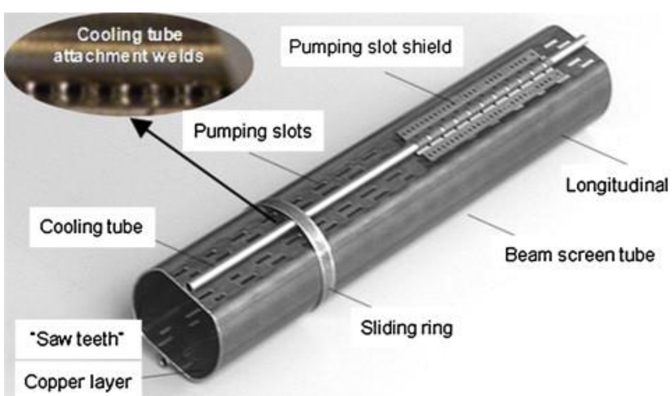
Integrated multiples with optimized coil ends

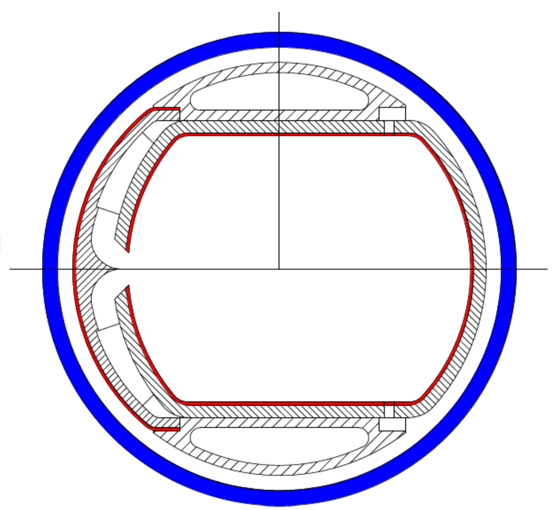
Integrated bn/an	Value (10^{-4})
b3	0.14
b5	1.42
b7	-0.40
a2	-0.29
a4	-1.81
a6	0.03

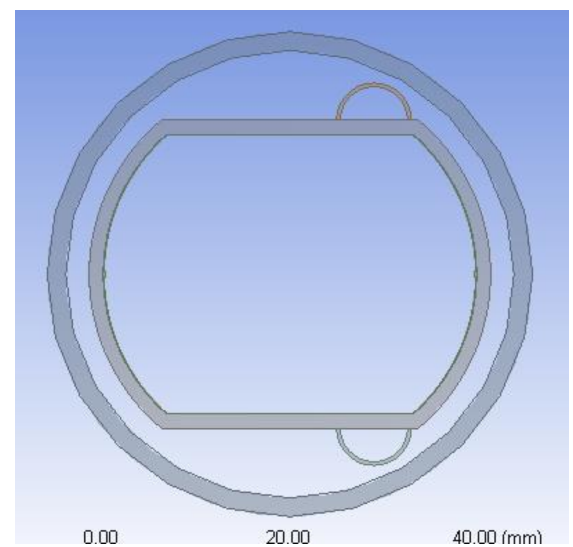


Beam screen and vacuum

- Synchrotron radiation poses critical challenges to the cryogenic vacuum in next-generation pp colliders. Beam screen (shielding the light) is seen as a potential stopper of the colliders.
- Generic ideas are coming out to tackle the problem, we are also investigating possible solutions.







Other technical challenges under inspection

- Beam instrumentation and controls
  - Very fast and reliable beam instrumentation and controls for both machine protection and sophisticated beam manipulations (emittance blow-up, luminosity leveling etc.)
- Machine protection
  - It is tough to deal with 6.3 GJ energy at max in beam, and also huge energy stored in magnets. A workable and reliable machined protection system is critical for operating the machines
- RF systems
  - RF systems for both the collider and injector rings (more challenging)
- Cryogenics
  - For three large sub-systems: SC magnet, SRF, vacuum

R&D PLANNING ON KEY TECHNOLOGIES

- Although there are many technical challenges in building the SPPC and its injector chain, most of them can be waited to be solved a few years before construction. Actually we have identified two key technologies for long-term and early R&D:
  - High-field SC magnets: extremely challenging, needing very heavy R&D efforts with global collaboration
  - Beam screen: potential show-stopper, very complicated (vacuum, beam instability, mechanical support, cryogenics, magnet aperture), needing to develop special structure and material coating

R&D plan of the 20-T magnet technology

- **2015-2020**

Development of a 12-T operational field Nb_3Sn twin-aperture dipole; Fabrication and test of 2~3 T HTS (Bi-2212 or YBCO) coils in a 12-T background field, and basic study on tape superconductors for accelerator magnets (field quality, fabrication method, quench protection).

Assume with enough funding!

- **2020-2025**

Development of 15-T Nb_3Sn twin-aperture dipole and quadrupole with 10^{-4} field uniformity; Fabrication and test of 4~5 T HTS (Bi-2212 or YBCO) coils in a 15-T background field.

- **2025-2030**

Nb_3Sn coils + HTS coils (*or only one of them*) to realize the 20-T dipole and quadrupole with 10^{-4} field uniformity; Development of the prototype SPPC dipole/quadrupole and infrastructure build-up.

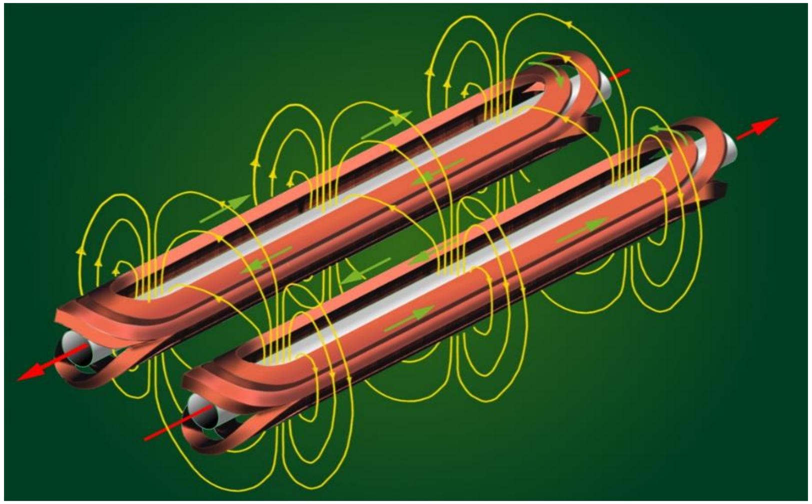
R&D plan of the 20-T magnet technology

(2015-2020)

***Magnetic & mechanical design study:** coil configuration, field quality, stress management, …*

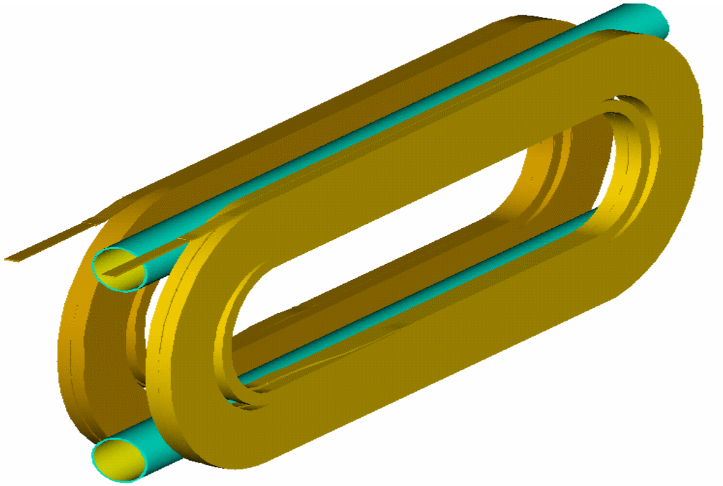
Cos-**th**eta dipole

High efficiency, complicated ends with hard-way bending



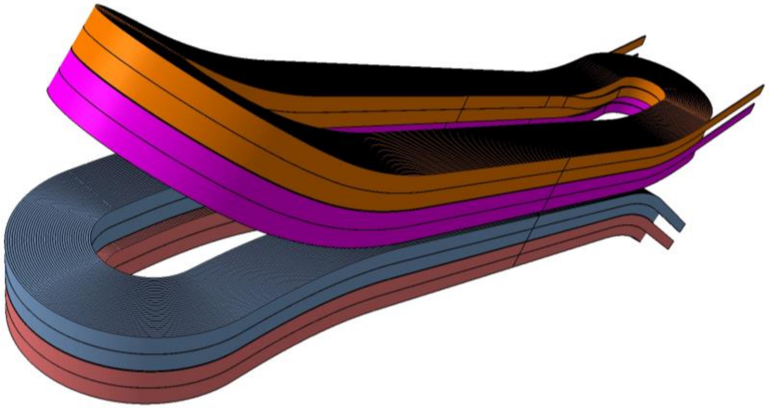
Common coil dipole

Simplest structure with large bending radius, low efficiency



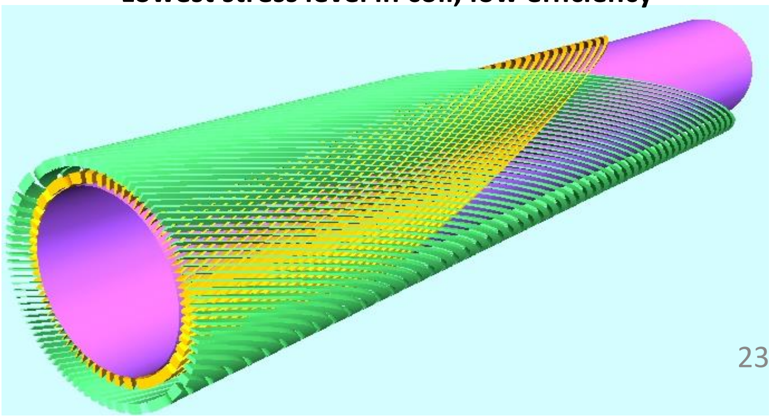
Block type dipole

Simpler structure with hard-way bending, low efficiency



Canted cos-theta dipole

Lowest stress level in coil, low efficiency

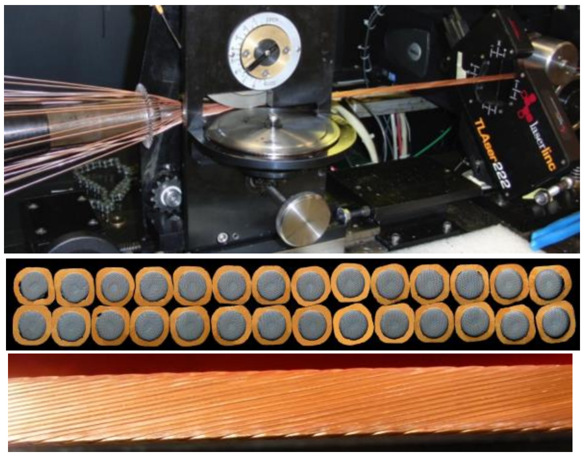


R&D plan of the 20-T magnet technology

(2015-2020)

Fabrication of high field magnet & Infrastructure build-up

Superconductor cabling

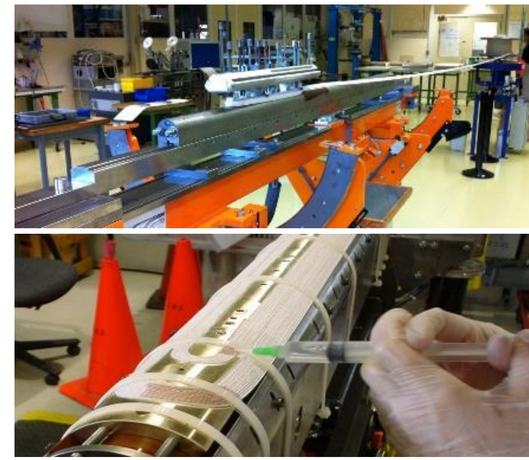


Rutherford Cabling @ Fermilab

Advanced insulation

AGY S2-glass fibers insulation

Coil fabrication

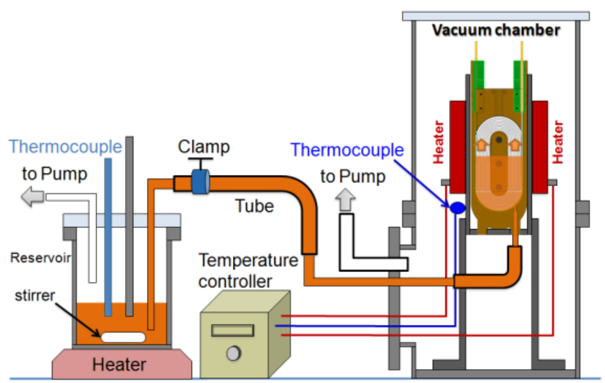


Nb3Sn coil winding @ CERN

Magnet assembly & test

Magnet test facility @ CERN

Coil impregnation



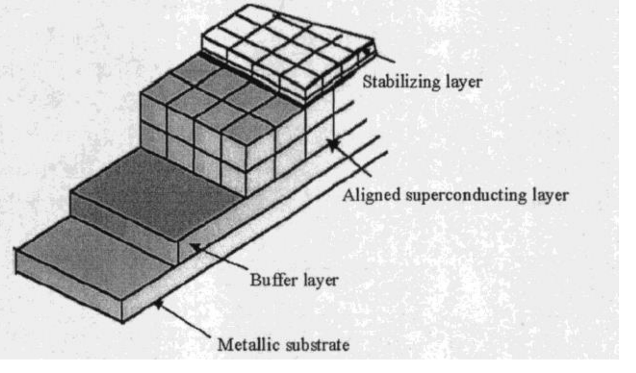
Epoxy impregnation system @ KEK

Coil heat reaction

Nb3Sn coil reaction @ CERN

R&D planning for beam screen

- Study different structures and material compositions for the beam screen (joint effort: PKU and USTC)
- Set up small-scale experimental teststand for coating special materials (such as HTS, amorphous carbon and NEG) on the structure of stainless steel, and measuring properties such as conductivity and SEY under low temperature and high-field environment.



ABOUT TEAM AND COLLABORATION

- SPPC study team is gradually growing up, with more young people joined recently, mainly from IHEP and USTC. Subgroups will be gradually formed to work more efficiently.
- Collaboration between IHEP and USTC is strengthened via an NSFC fund. Hope the MoST fund will help the strengthening of the collaboration among all member institutions
- Collaboration with BNL has made good output, hopeful to be continued
- Collaboration with oversea Chinese physicists continues
- Collaboration with international HFM experts continues
- It is imperative to establish good collaboration with FCC

Summary

- We have been making progress on SPPC study steadily.
- We will align with the CEPC study for the CEPC-SPPC CDR report by end 2016.
- Study team gradually building up, and more people are welcome.
- Based on the available funds, some R&D efforts will be pursued, with particular stress on HFM.
- Collaboration within domestic institutions and with international labs or experts will be strengthened.

Thanks for your attention and welcome collaboration!