SPPC Study Status

TANG Jingyu
for the SPPC study group

2019 CEPC Workshop, Nov.18-20, IHEP, Beijing

Outline

- Ongoing SPPC study
- Accelerator physics studies
- R&D efforts
- Summary

Ongoing SPPC Study

- Ongoing studies
  - Supported by two small-scale NSFC funds, a very limited resource working on the accelerator physics studies
  - Strong R&D efforts on high-field magnets which is integrated in the national effort for HT superconducting technology
  - International collaboration still plays a very important role in the SPPC study
  - Will follow the CEPC study in the TDR stage

SPPC main parameters

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	-

Collider Accelerator Physics

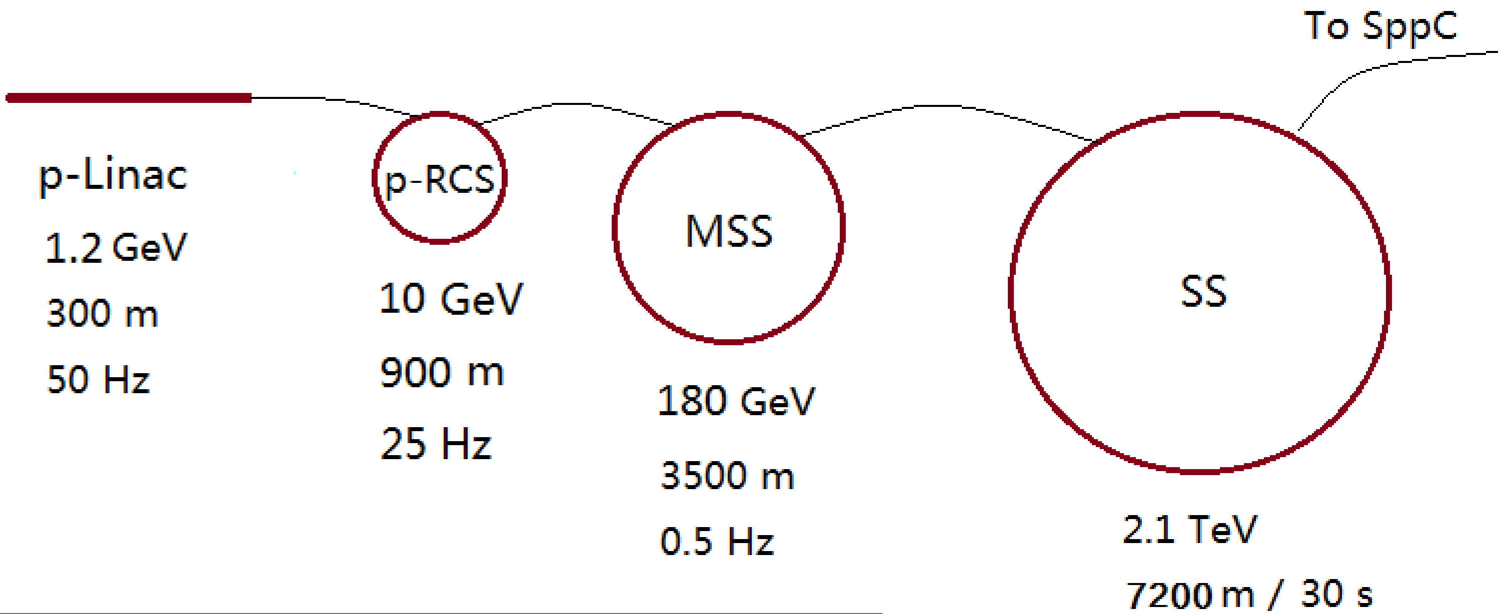
-Parameter list (no update since 2017.5)

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

Accelerator Physics

- Lattice, layout, dynamics aperture: Chen Yukai, Wang Yiwei
- Collimation: Yang Jianquan (left in July 2019), Zou Ye (Uppsala U.), Tang Jingyu, A. Faus-Golfe (LAL)
- Beam-beam, Luminosity leveling: Wang Lijiao, K. Ohmi (KEK), T. Sen (FNAL)
- Longitudinal dynamics (collider and injector chain): Zhang Linhao
- Instabilities: Zhang Linhao
- Injector chain AP: Hong Yang (MSS), Wang Xiangqi and Liu Tao (USTC, SS), Zhang Linhao (p-RCS)

Injector chain
(for proton beam)



p-Linac: proton superconducting linac

p-RCS: proton rapid cycling synchrotron

MSS: Medium-Stage Synchrotron

SS: Super Synchrotron

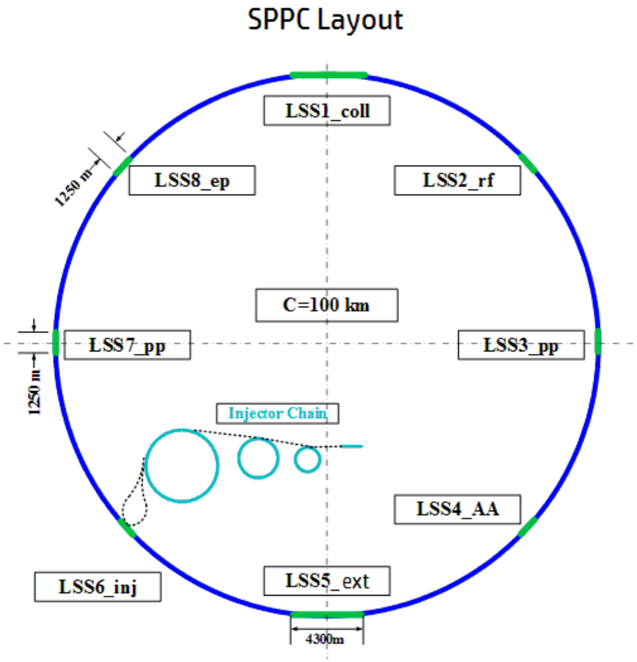
Ion beams have dedicated linac (I-Linac) and RCS (I-RCS)

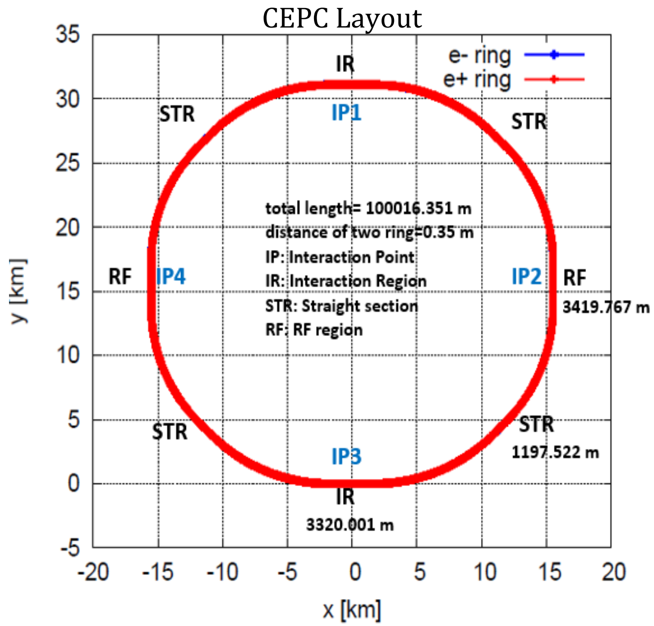
Lattice design

Chen Yukai
Wang Yiwei

- Recent study on
  - Bypass scheme study to be compatible with the CEPC, in order to accommodate CEPC and SPPC simultaneously in a same tunnel
  - Lattice optimization for IP and collimation sections
  - Dynamics tracking

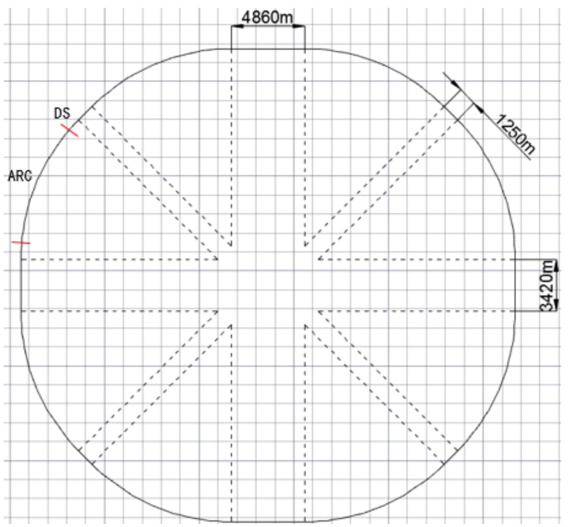
Talk:
Wang Yiwei



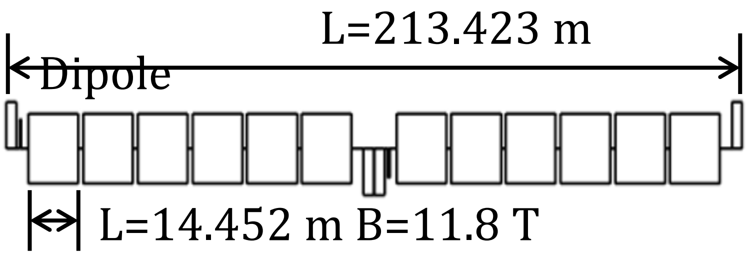


Lattice Update : arc FODO cells

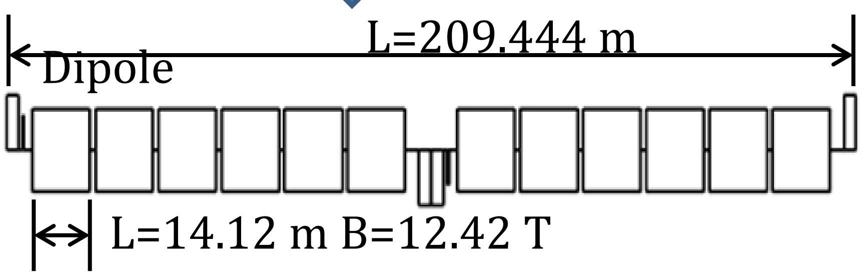
Layout needed considering compatibility with CEPC



- Length of each section considering compatibility with CEPC:
- 8 arcs, total length 78.44 km
- 2 IPs for pp, 3420 m each
- 2 IRs for inj. or RF, 1250 m each
- 2 IRs for ep or AA, 1250 m each
- 2 IRs for collimation(ee for CEPC) , 4860 m each

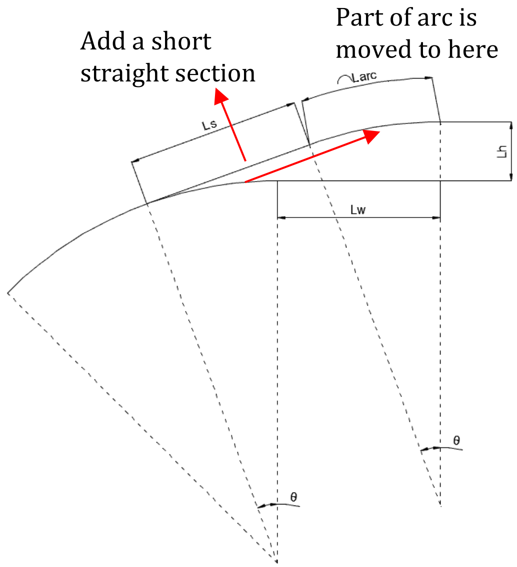


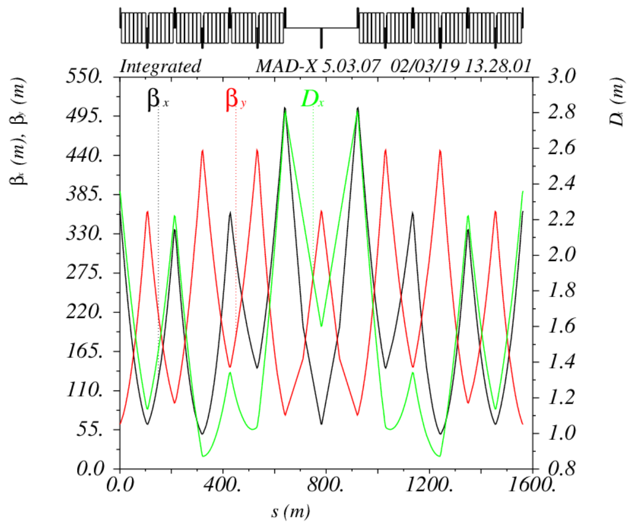
FODO cell : 13043.3 m
β_max= 361.9 m, β_min= 62.9 m
D_max= 2.36 m, D_min= 1.136 m
Phase of advance: 90 deg



FODO cell : 12445 m
β_max= 355.1 m, β_min= 61.7 m
D_max= 2.38 m, D_min= 1.147 m
Phase of advance: 90 deg

Bypass scheme at CEPC SCRF region





Optics function for bypass scheme

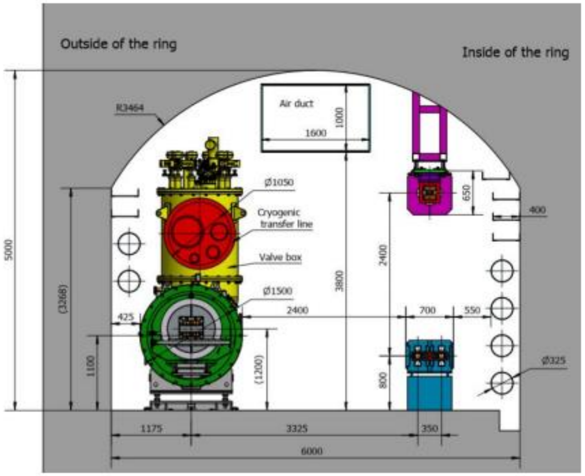
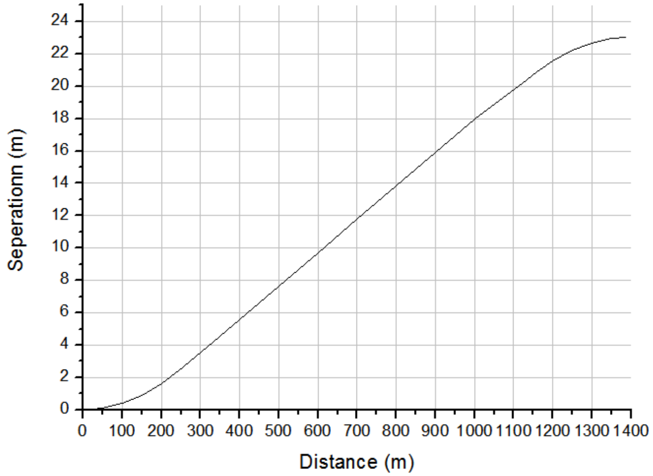


Figure 9.2.12: Inverted U-shape option in the Collider arc section

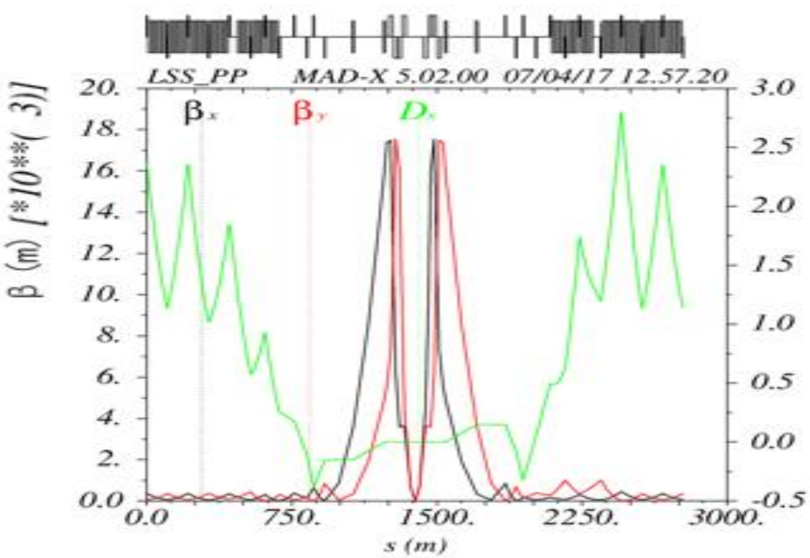


Orbits separation with distance

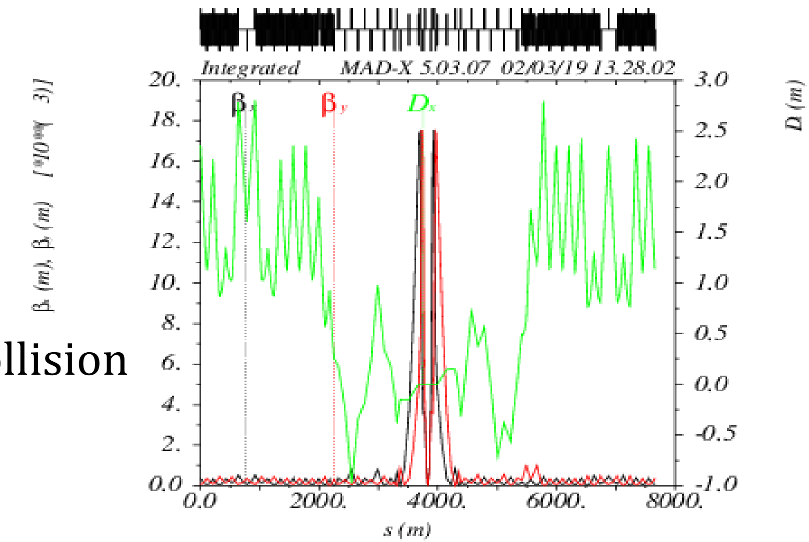
Bypass Scheme：

- Add a short straight section at the end of ARC
- Length of this short straight section can change the bypass distance
- Lw is the additional space for bypass, which will be 280 m when the bypass distance is 23 m

Lattice update: collision section



Update collision section



- Additional matching quadrupoles needed, more independent power supplies.
- Bump of beta function and dispersion function.(beta_max: 355 m -> 500 m; Dx_max: 2.38 m -> 2.8 m)
- Long straight section of SPPC collision increase from 1.5 km to 3.42 km, a 2-π phase advance extension section was designed.

Longitudinal beam dynamics

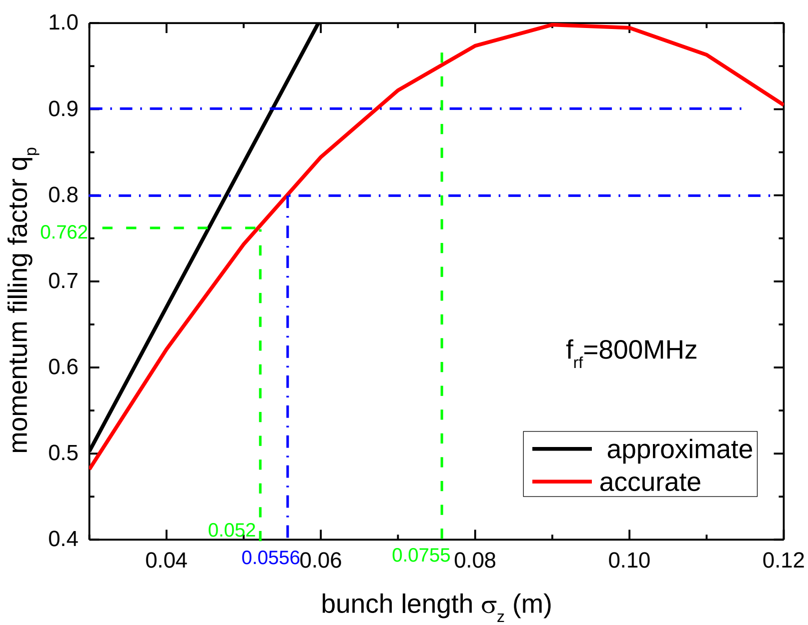
Zhang Linhao

- The work concerning long. Dynamics in both Collider and injector chain
- Concerns:
  - Bunch filling schemes
  - Luminosity leveling schemes
  - Instabilities
  - Requirement to the RF systems
  - Global study with the injector accelerators
- Recent study focusing on:
  - Instabilities suppression in the collider and longitudinal dynamics in the injector chain

RF schemes to mitigate longitudinal instability in SPPC

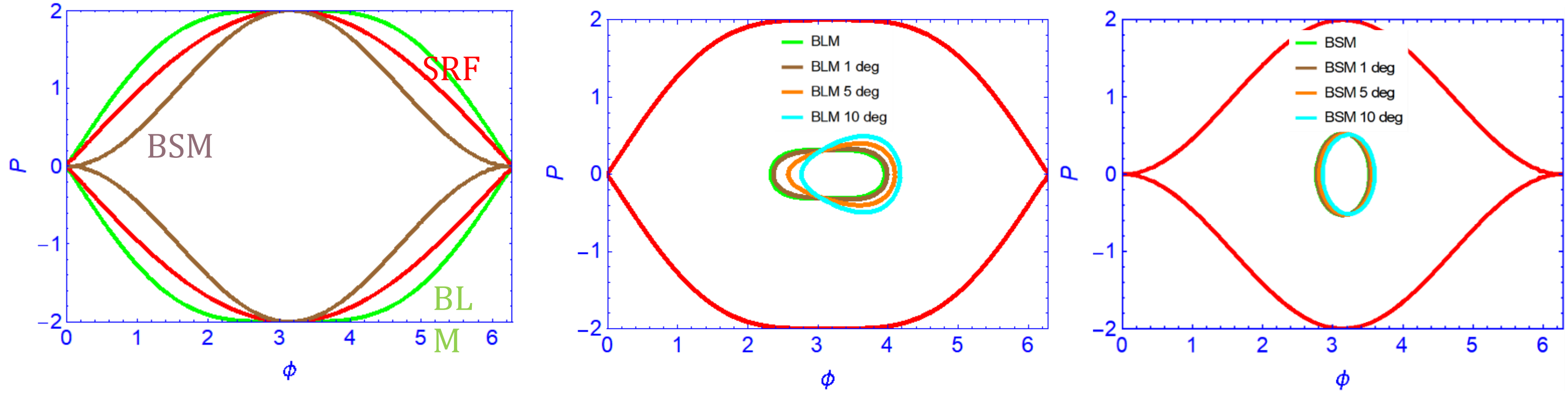
- In order to enhance Landau damping, a large spread in synchrotron frequency inside the bunch is required.
  - ① **Use a higher harmonic cavity (800MHz RF cavity)**
  - ② **Dual harmonic RF system**
  - ③ **Controlled emittance blow-up**

① 800 MHz RF system

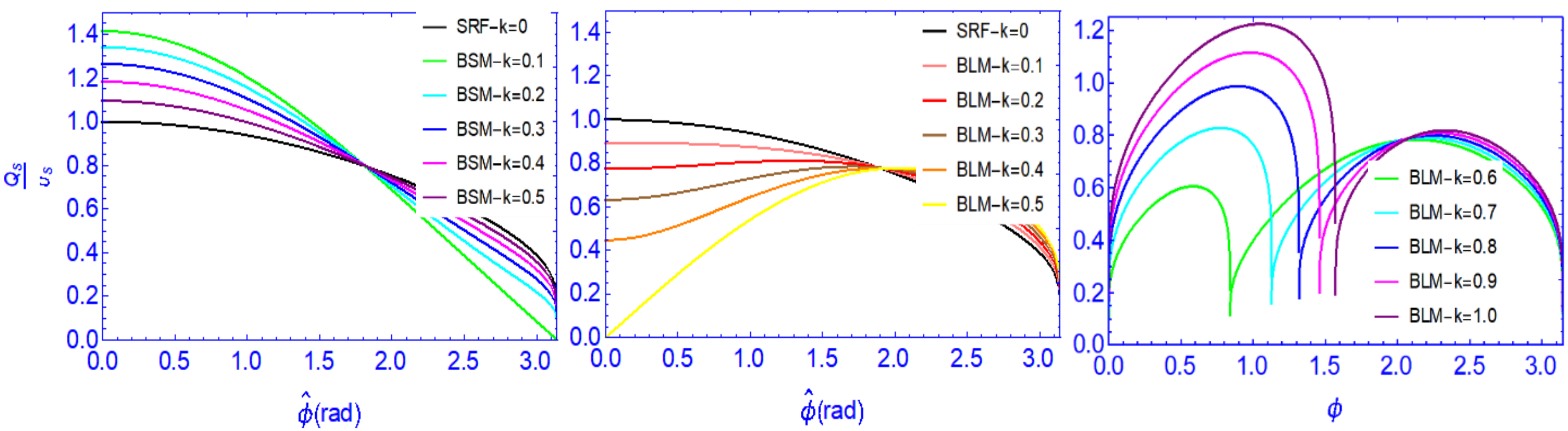


- σ_z =5.2 cm, q_p=76.2%;
- ε_s=6.4eVs, V_{RF}=52MV, σ_δ=0.79x10^{-4}
- the bucket area and bucket height are reduced
- RMS bunch length shorter, luminosity increased by 7%

② Dual harmonic RF system (400MHz+800MHz)



- Bunch lengthening mode(BLM): larger bucket area, smaller line density
- Bunch Shortening mode(BSM): less sensitive to phase error



- BLM: larger tune spread, but $Q_s'(\phi)=0$ exists → loss of Landau damping
- BSM: both average tune and tune spread increased (more promising)

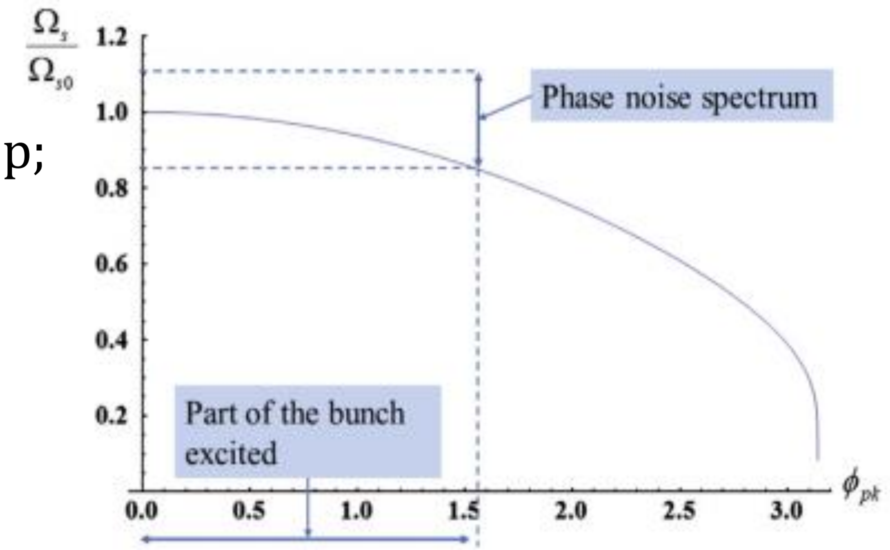
③ Controlled emittance blowup

(1) Band limited RF phase noise:

- In main RF system through phase Loop;
- Excitation noise spectrum:

$$0.85\Omega_{so} \leq \Omega \leq 1.1\Omega_{so}$$

- Steady state between resonance and diffusion
- Example: LHC, SPS, PSB



(2) Adding a phase-modulated high frequency RF to the main RF.

- Phase-modulated voltage :

$$V_H = \hat{V}_H \sin(h_H \omega_R t + \alpha sin\omega_M t + \theta_H)$$

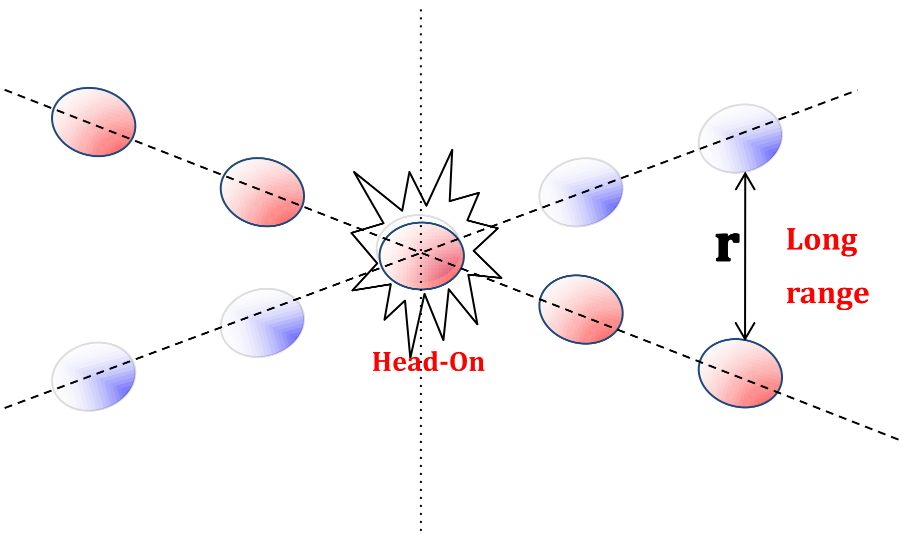
- RF phase-modulated higher harmonic rf system drive bunch near resonant island and cause the bunch density redistribution.
- Example: PS;

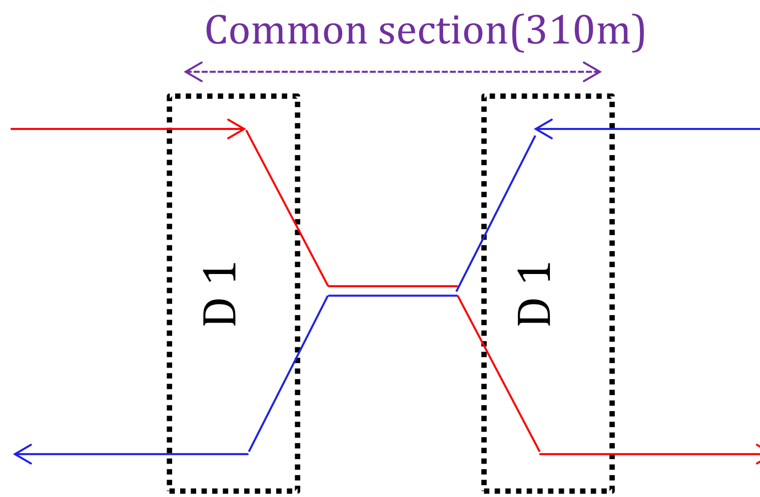
Both methods are under study for SPPC

Beam-beam effects

- Beam dynamics about beam-beam effects
  - Head-on interaction
  - Long-range interaction
  - Orbit effects
- Beam-beam compensation schemes

Wang Lijiao , collaborating with Tanaji Sen (FNAL) and K. Ohmi (KEK)



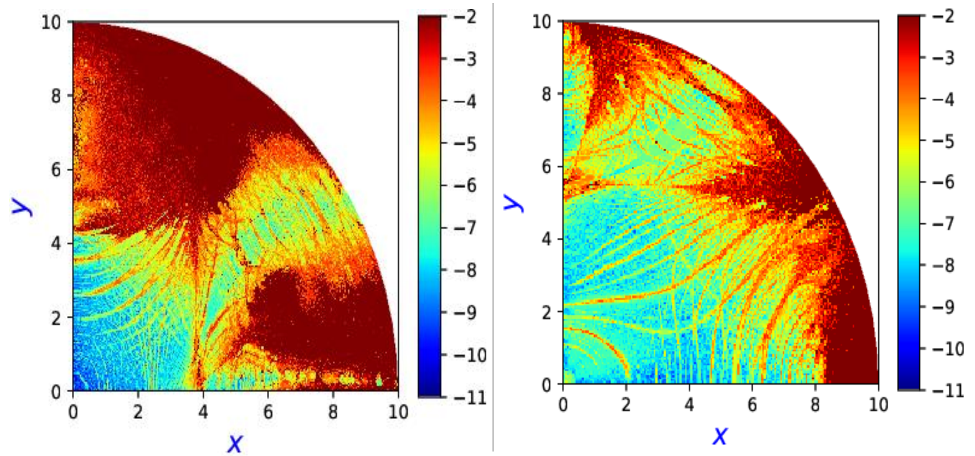


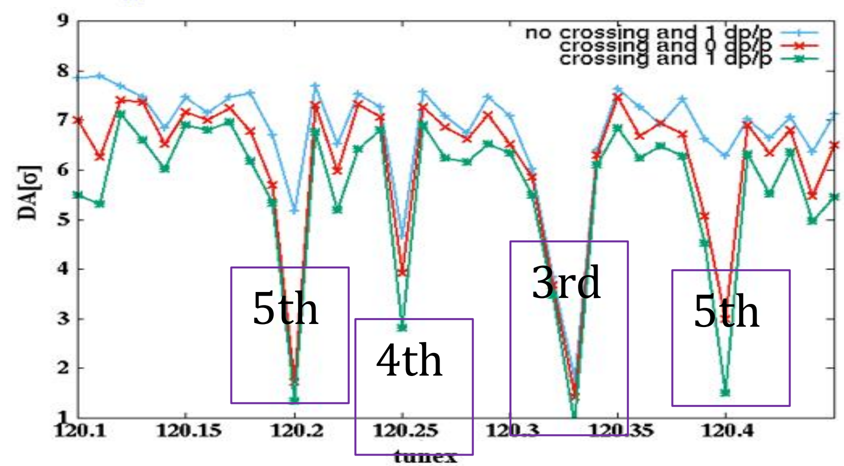
25ns spacing, 2 HO and 164 LR

Tune scan survey

	Smallest DA	Average DA
(0.31,0.32)	4.75	5.50
(0.19,0.17)	**5.75**	**6.57**
(0.37,0.35)	**5.75**	**6.70**
(0.38,0.37)	**6.25**	**6.50**
(0.12,0.13)	**6.25**	**7.13**
(0.27,0.26)	**6.00**	**7.02**
(0.17,0.19)	**6.25**	**7.12**

FMA plot: nominal (left), optimized (0.27, 0.26)

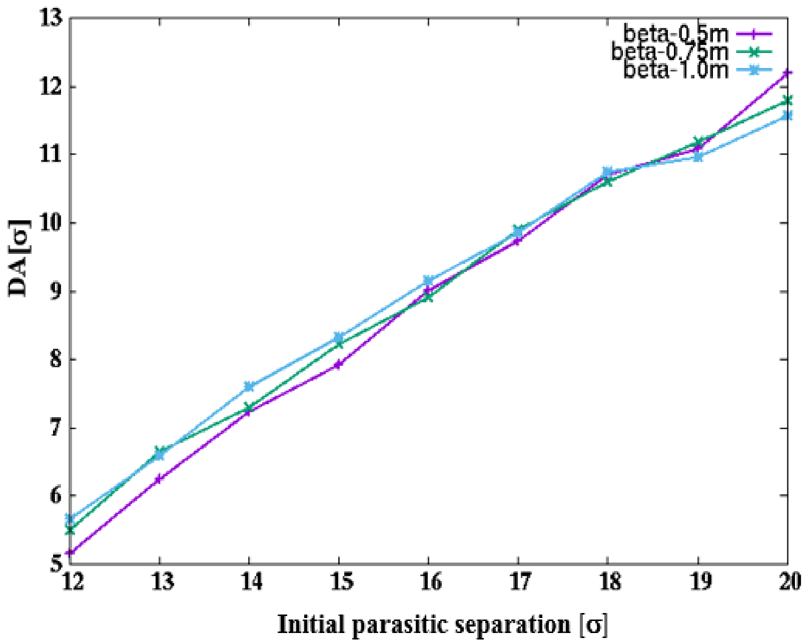




Average DA with different υx.
υy= υx ± 0.01

- ➢3rd, 4th, 5th order sum resonances dangerous even without the crossing angle; 9th and 10th orders with the crossing.
- ➢With the crossing, the synchro-betatron coupling further decreasing dynamic aperture
- ➢Tune spread also smaller at the better tune

Long-range interaction mitigation

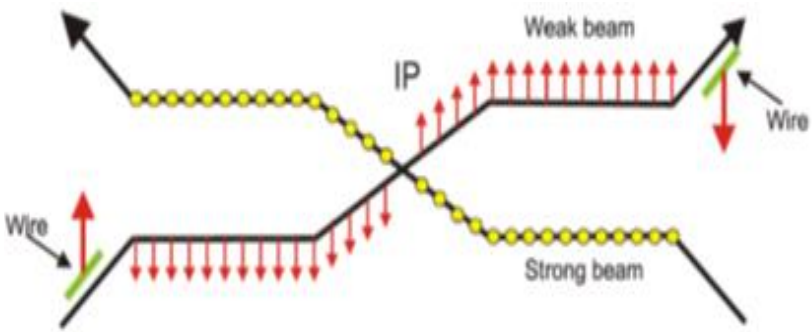


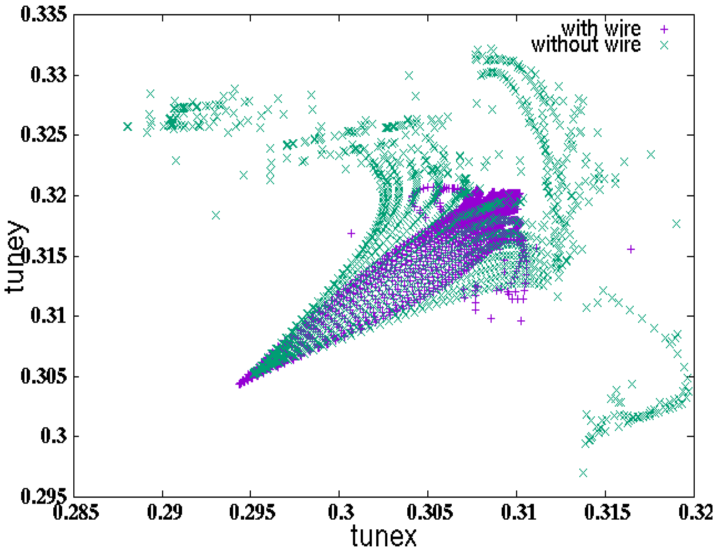
DA for different β* with increasing 1st parasitic separation

separation	Xangle [mrad]/ β*=1m	Xangle [mrad]/ β*=0.75m	Xangle [mrad]/ β*=0.5m
12σ′	96	110	132
13σ′	104	120	144
14σ′	112	128	155
15σ′	120	138	166
16σ′	128	146	177
17σ′	136	156	188
18σ′	144	164	199
19σ′	152	174	210
20σ′	**160**	**184**	**221**

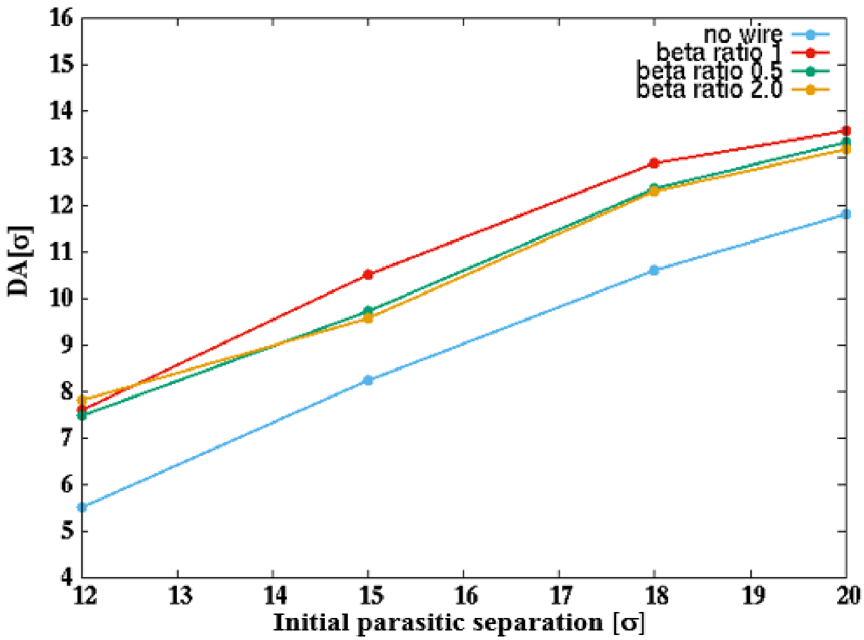
- For each β*, initial separations need to be 20 σ’ to reach the DA goal of 12 σ.
- For each β*, a 6 σ improvement in the DA from 12 σ’ separation to 20 σ’ separation.
- DA independent on β* provided the scaled separation is constant.
- Smallest physical aperture at 20σ’ drops from 14σ for β*= 0.75m to 9σ for β*= 0.5m.

Long-range interaction compensation with current wires





Tune footprint with wire compensation (violet points) and without compensation (green points)



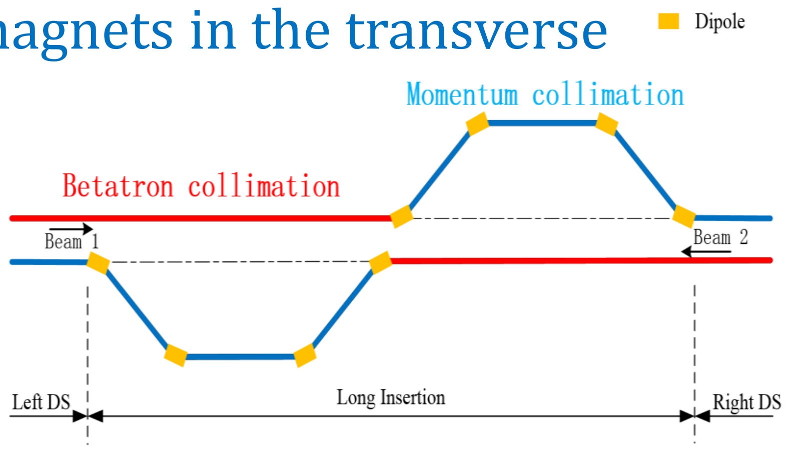
Dynamic aperture with increasing 1st parasitic separation

- 4 wires distributed along the SPPC ring with one wire on each side in each IR (118.1 A)
- $\beta x/\beta y = 1$ leads to the largest DA; with the antisymmetry of the optics, ratio either 2 or 0.5, the same DA.
- About 2σ increase in the DA with the wire compensation.

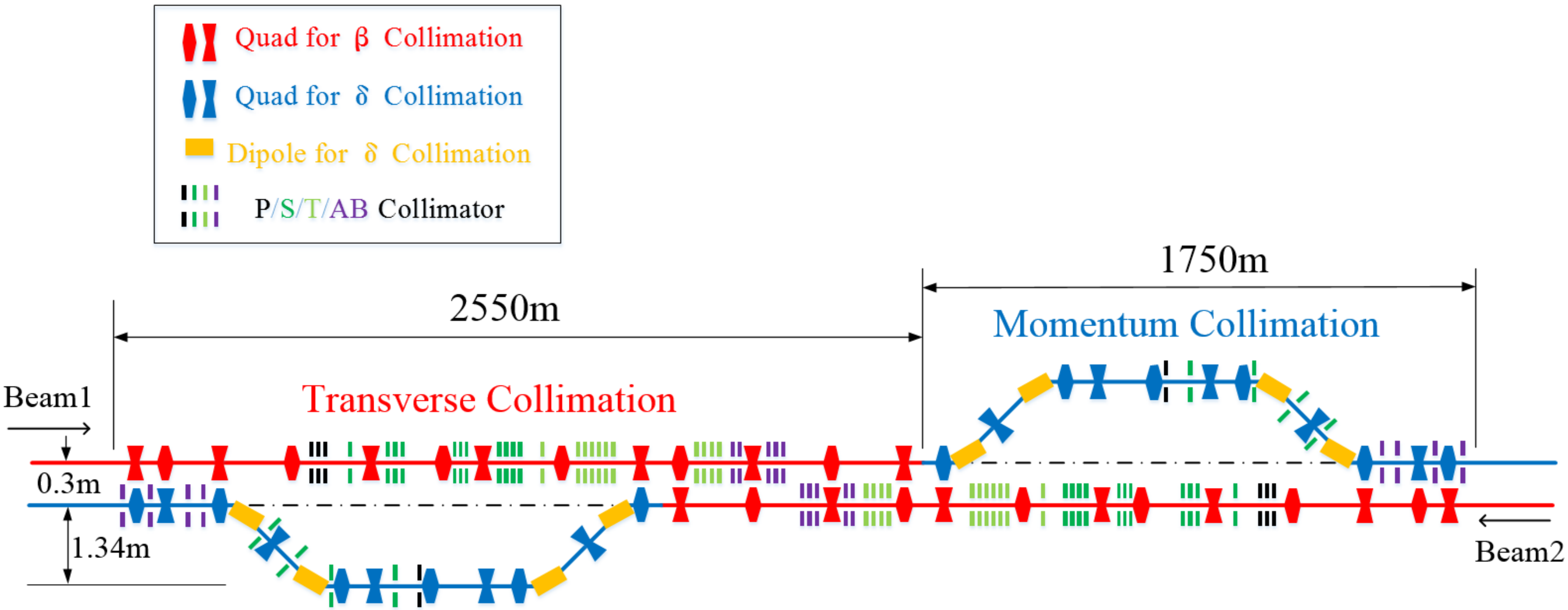
Beam Collimation

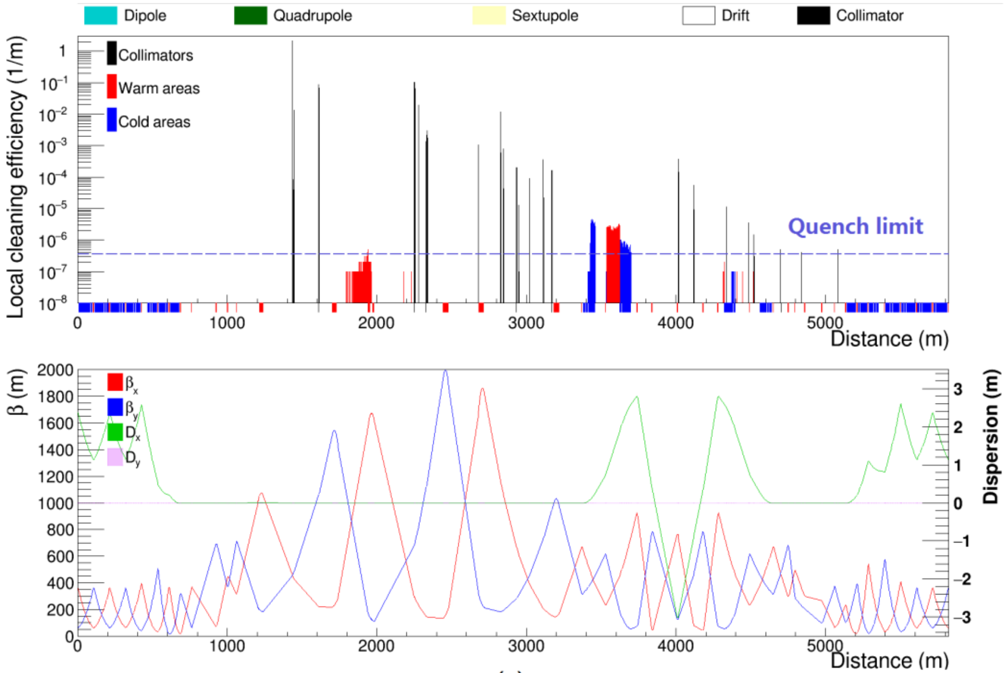
Yang Jianquan , Zou Ye (Uppsala U.), collaborating with LAL and LHC

- This work has been the main focus in the SPPC study: to tackle the huge stored energy, 9 GJ/beam
  - SPPC has adopted a combined collimation method by arranging the transverse and longitudinal collimation in one long straight section
- Yang Jianquan spent six months at LAL (A. Faus-Golfe)
- Recent progress
  - Overall simulations with two collimation schemes: one with RT magnets and the other with SC magnets in the transverse collimations
  - Simulations about the radiation protection of the SC magnets in the collimation section



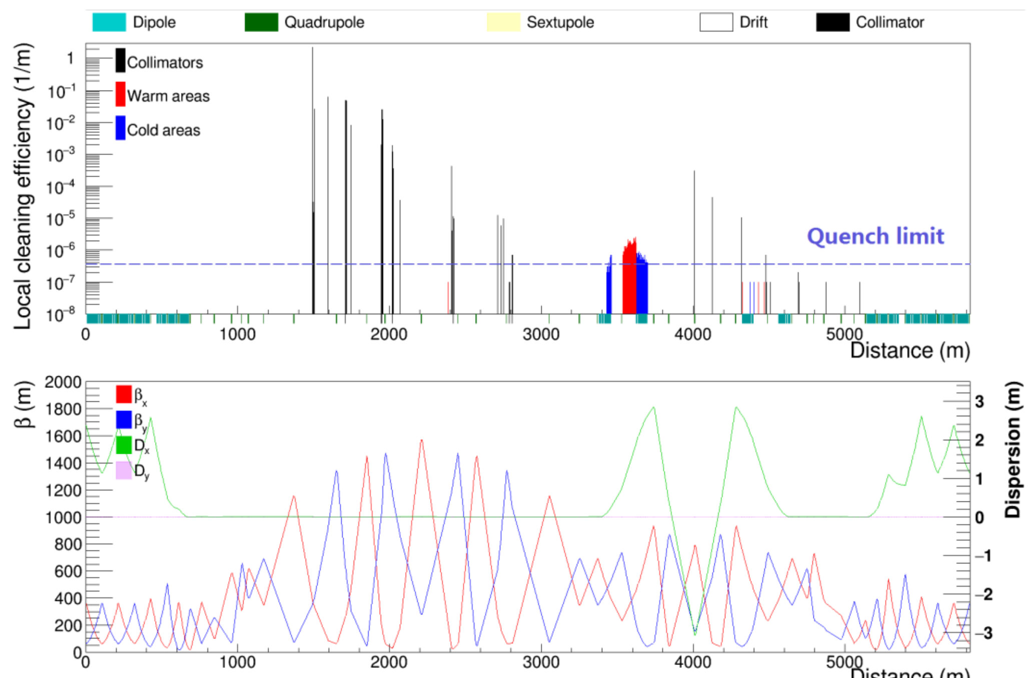
J.Q. Yang, PRAB 22, 023002 (2019)


Quad for β Collimation
Quad for δ Collimation
Dipole for δ Collimation
P/S/T/AB Collimator
1750m
2550m
Momentum Collimation
Beam1
Transverse Collimation
0.3m
1.34m
Beam2



(a)

With RT magnets in beta-collimation



(b)

With SC magnets in beta-collimation

Technical Challenges

- There are many technological challenges in building future p-p colliders, among them the most crucial is high-field SC magnets
  - Currently the only R&D effort for SPPC, supported by a CAS research program to promote high-temperature superconducting technology, which involves different CAS institutions and also some companies
  - Xu Qingjin will have a dedicated talk about this

Details in Qingjin Xu's talk

Fabrication and test of the 1st IBS solenoid coil at 24T

The 1st solenoid coil with IBS tape fabricated and tested with up to 24T background field. Performance is more than expected.

IOP Publishing Superconductor Science and Technology
Supercond. Sci. Technol. 32 (2019) 04LT01 (5pp) https://doi.org/10.1088/1361-6668/ab09a4

Letter

First performance test of a 30mm iron-based superconductor single pancake coil under a 24T background field

Dongliang Wang[1,2,5], Zhan Zhang[3,5], Xianping Zhang[1,2], Donghui Jiang[4], Chiheng Dong[1], He Huang[1,2], Wenge Chen[4], Qingjin Xu[3,6] and Yanwei Ma[1,2,6]

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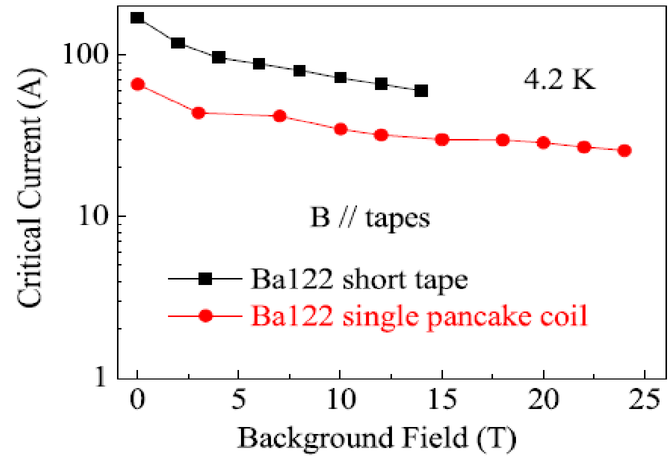
[2] University of Chinese Academy of Sciences, Beijing 100049, People's Republic of China
[3] Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, People's Republic of China
[4] High Magnetic Field Laboratory, Chinese Academy of Sciences, Hefei 230031, People's Republic of China



Viewpoint by NHMFL

'From a practical point of view, **IBS are ideal candidates for applications**. Indeed, some of them have quite a **high critical current density, even in strong magnetic fields**, and a low superconducting anisotropy.

Moreover, **the cost of IBS wire can be four to five times lower than that of Nb_3Sn**……

IOP Publishing Superconductor Science and Technology
Supercond. Sci. Technol. 32 (2019) 070501 (3pp) https://doi.org/10.1088/1361-6668/ab1fc9

CrossMark

Viewpoint

Constructing high field magnets is a real tour de force

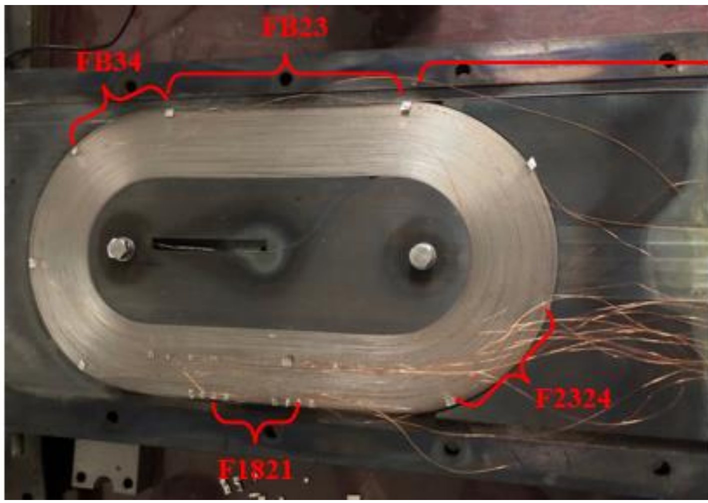
Jan Jaroszynski
National High Magnetic Field, Laboratory, Tallahassee, FL, 32310, United States of America
E-mail: jaroszy@magnet.fsu.edu

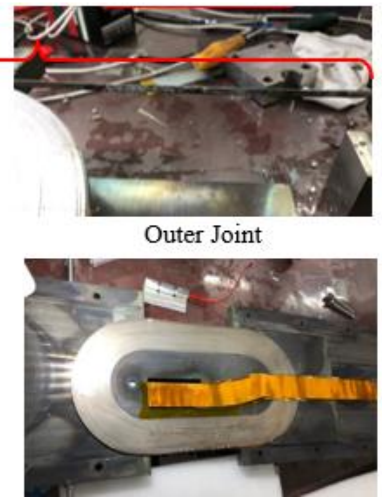
This is a viewpoint on the letter by Dongliang Wang *et al* (2019 *Supercond. Sci. Technol.* **32** 04LT01).

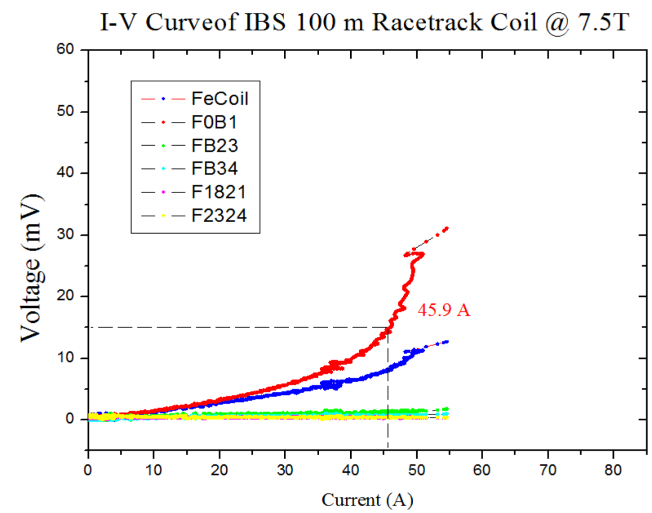
Following the discovery of superconductivity in 1911, Heike Kamerlingh Onnes foresaw the generation of strong magnetic fields as its possible application. He designed a 10 T electromagnet made of lead–tin wire, citing only the difficulty

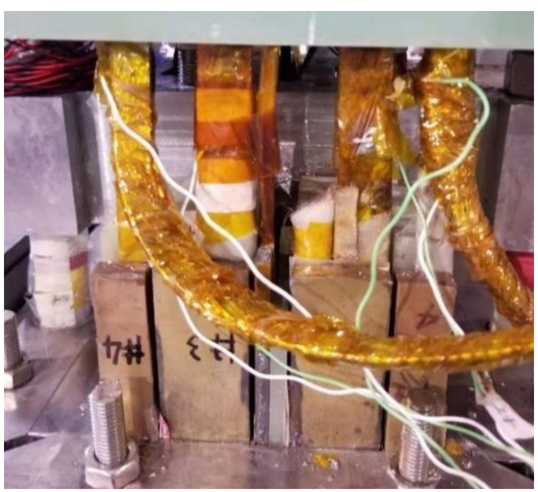
Fabrication and test of the 1st IBS racetrack coil at 8T

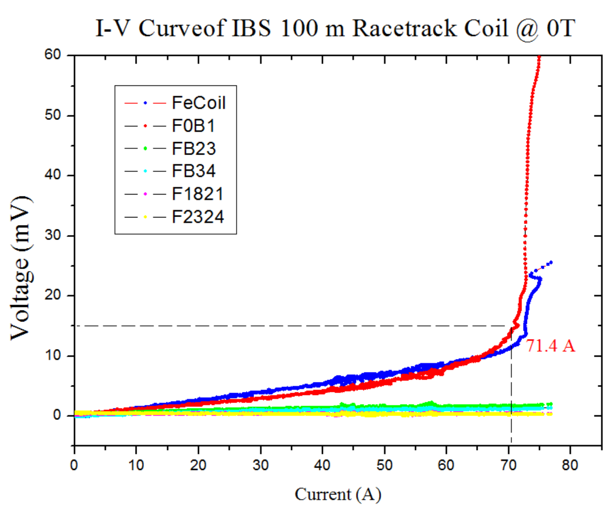
- The 1st racetrack coil with 100m long IBS tape fabricated and tested with up to 8T background field. Performance limited by unsatisfying joints.
- The 2nd IBS racerack coil has been fabricated and to be tested at 10-12T.

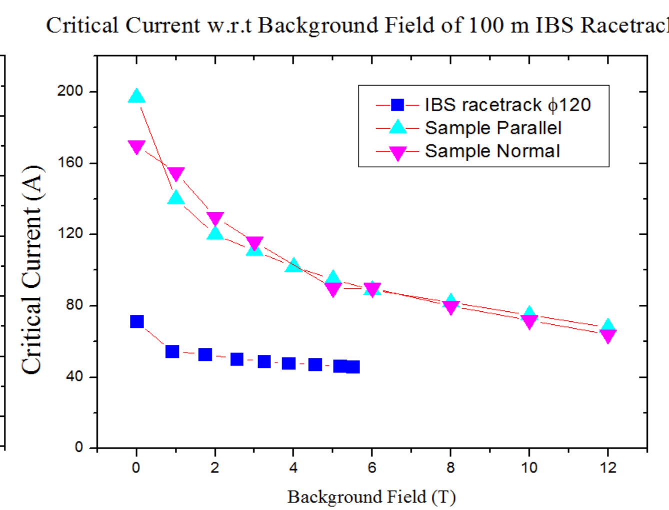










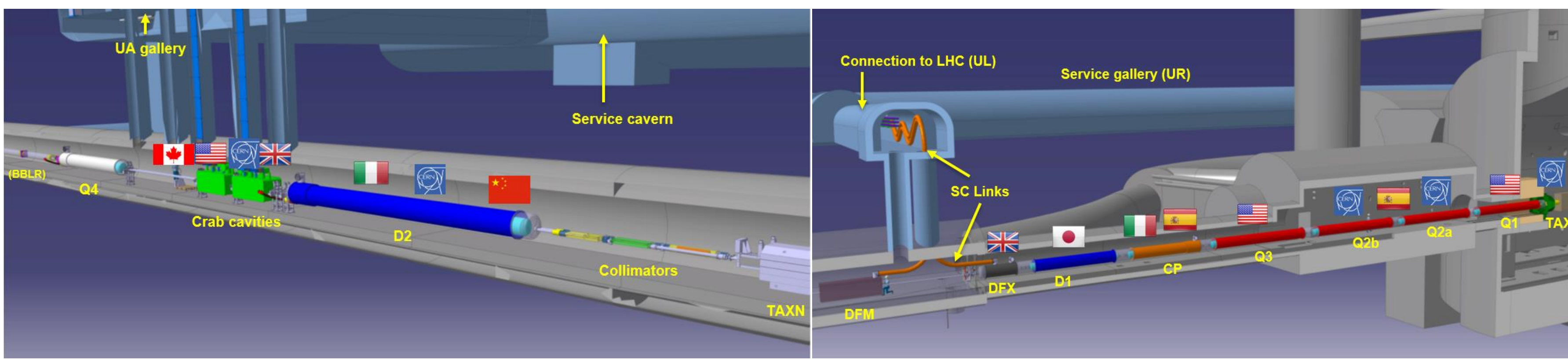


R&D of HL-LHC CCT Magnets

China provides 12+1 units CCT corrector magnets for HL-LHC before 2022

2*2.6T dipole field in the two apertures. 2.2m prototype being fabricated.

Agreement For HL-LHC CCT Magnets Signned in Sep 2018



Layout of the HL-LHC Magnets and Contributors

R&D of HL-LHC CCT Magnets

0.5m prototype completed. 2.2m prototype being fabricated and to be tested and delivered to CERN by Feb. 2020. Prodution to be started in spring 2020.

Fabrication of the 2.2m prototype CCT Magnet

Summary

- SPPC study continues but at a low profile to follow CEPC in the TDR stage
- Special emphasis on key accelerator physics problems and compatibility between CEPC and SPPC
- R&D efforts on high-field SC magnets is supported in a wider national effort to promote high-temperature superconducting technology

Thank you for your attention!