SPPC Study Status

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for the SPPC study group

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Outline

- Summary of ongoing SPPC study
- Considerations about SPPC using 20-T magnets

Ongoing SPPC Study

- Ongoing studies
  - 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
  - Following the CEPC study in the TDR stage

SPPC main parameters (as for 2017)

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)

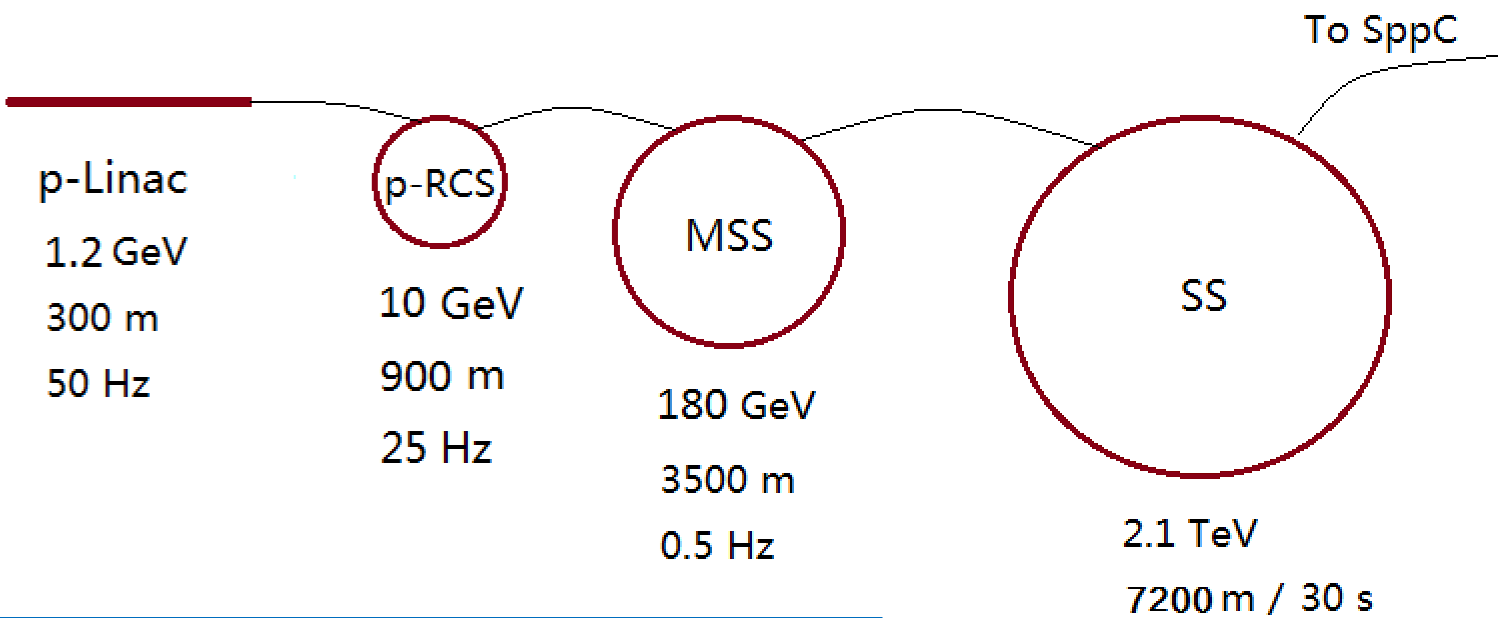
Parameter	Value	Unit
Main parameters		
Circumference	100	km
Beam energy	37.5	TeV
Lorentz gamma	39979	
Dipole field	12.00	T
Dipole curvature radius	10415.4	m
Arc filling factor	0.780	
Total dipole magnet length	65442.0	m
Arc length	83900	m
Total straight section length	16100	m
Energy gain factor in collider 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

- Still active:
  - Longitudinal dynamics (collider and injector chain): Zhang Linhao, Tang Jingyu
  - Instabilities: Zhang Linhao, Wang Lijiao, Tang Jingyu
  - Beam-beam and Luminosity leveling: Wang Lijiao, Tang Jingyu
  - Lattice, layout, dynamics aperture: Xu Haocheng, Chen Yukai, Wang Yiwei
  - Injector chain AP - MSS: Zhang Linhao
- Several papers under preparation

Injector chain
(for proton beam)



p-Linac: proton superconducting linac

p-RCS: proton rapid cycling synchrotron

MSS: Medium-Stage Synchrotron

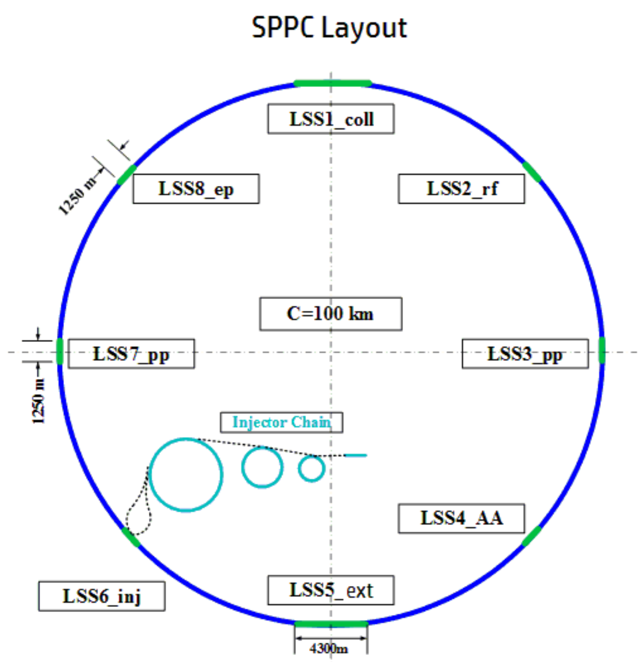
SS: Super Synchrotron

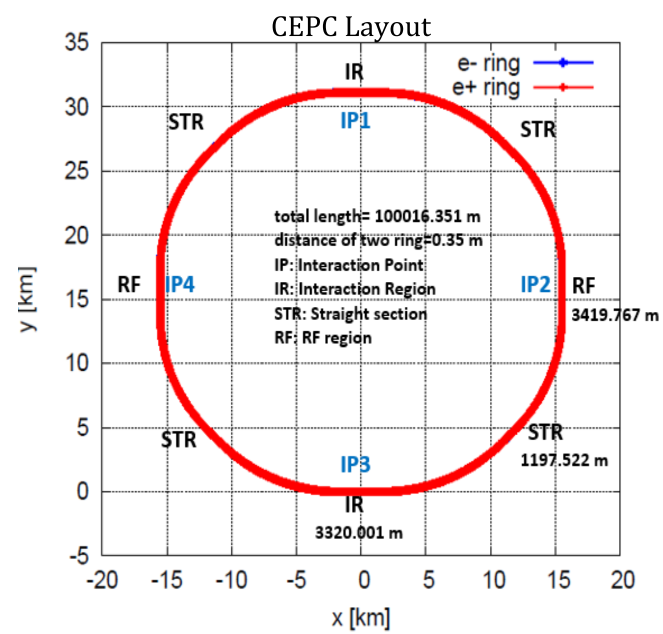
Ion beams have dedicated linac (I-Linac) and RCS (I-RCS)

Lattice design

Wang Yiwei,
Chen Yukai

- Bypass issue with CEPC
  - Bypass scheme study to be compatible with the CEPC, in order to accommodate CEPC and SPPC simultaneously in a same tunnel
  - Very challenging, following the CEPC study evolution





Longitudinal beam dynamics

Zhang Linhao, Tang Jingyu

- The work concerning long. Dynamics in both collider and injector chain (five accelerators in series)
- Concerns:
  - Bunch filling schemes
  - Luminosity leveling schemes
  - Instabilities
  - Requirement to the RF systems
  - Global study with the injector accelerators
- Study focusing on:
  - Instabilities suppression in the collider
  - Longitudinal dynamics in the injector chain, especially bunch splitting in the MSS

JINST 16, P03035 (2021)

Bunch splitting in MSS

- Motivation
  - Mitigate the pileup effects and collective instabilities of a single bunch in the SPPC
  - Bunch spacing: 25 ns → 5 ns (five-splitting of single bunch)
- Bunch splitting methods in proton synchrotrons

(1) Debunching and rebunching

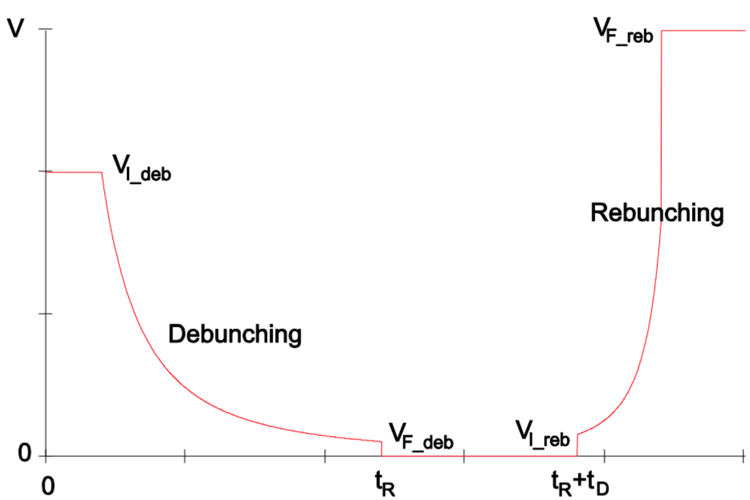
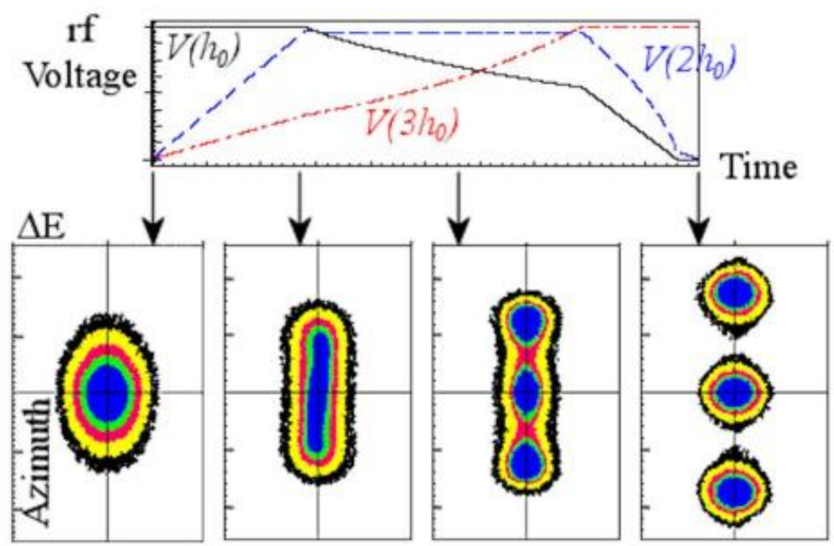


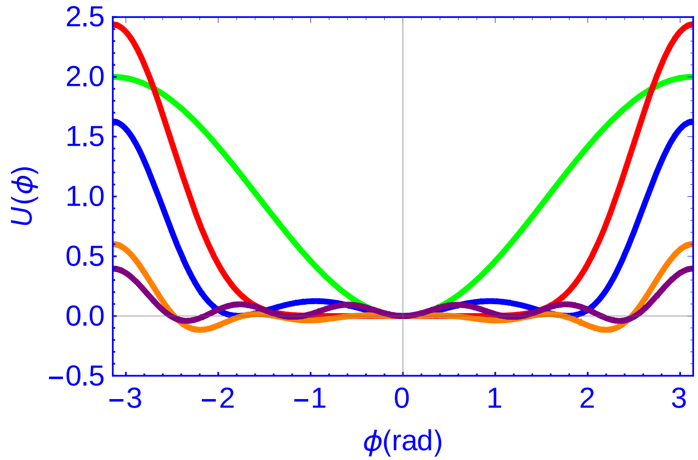
Fig. 7: Voltages for iso-adiabatic debunching–rebunching

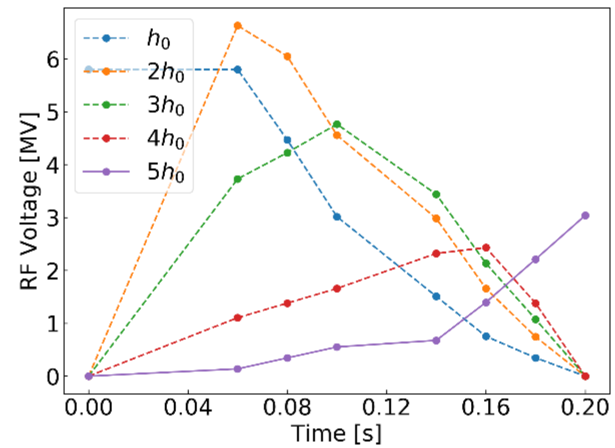
(2) Multi-harmonic RF bunch splitting

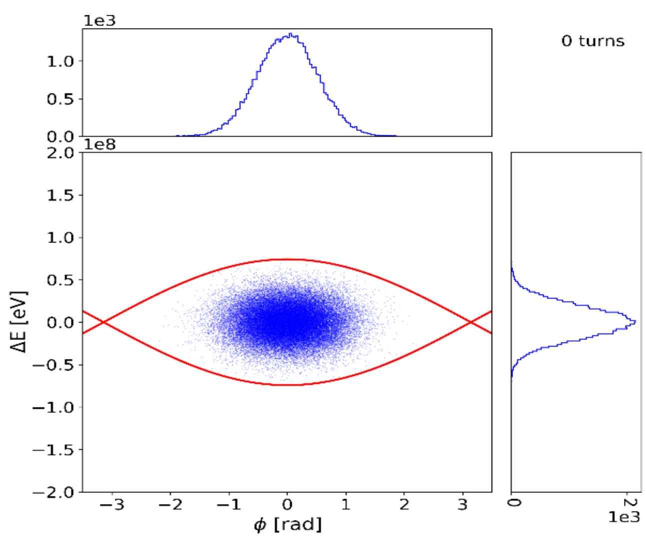


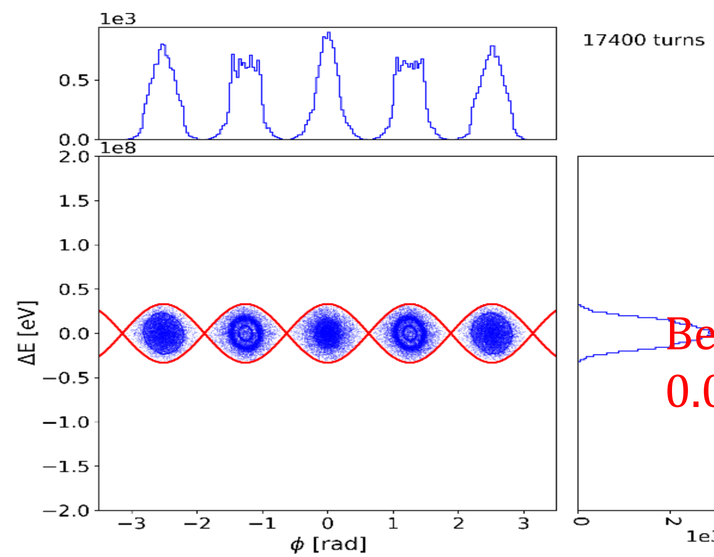
Triple-splitting in LHC/PS

Bunch splitting at the MSS injection energy









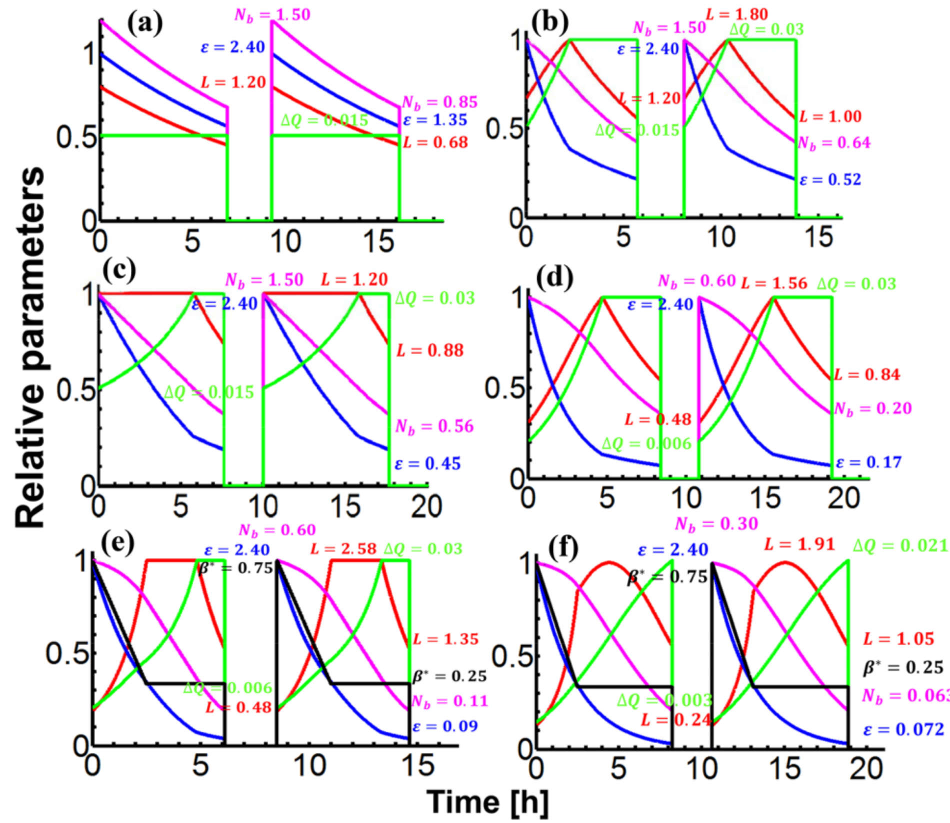
Beam loss rat
0.094%

Paper in review

Luminosity optimization

Wang Lijiao , Tang Jingyu,
R.Palmer (BNL)

- Luminosity optimization and leveling schemes
  - Goal: 30 ab^{-1} in 10–15 years
  - Increasing integrated lumi: adopting dynamic β*, emittance damping, crab cavities
  - Flat beam optics instead of round ones when no crab cavities



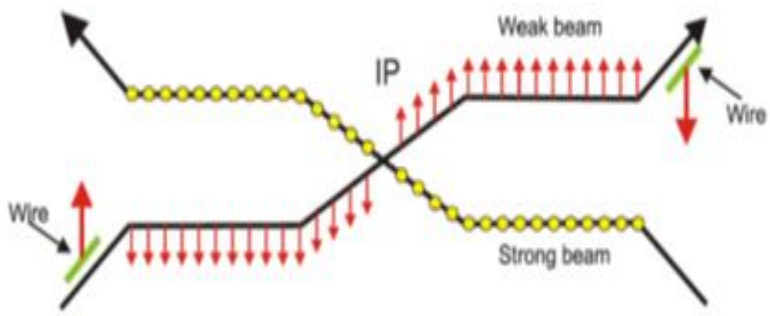
RDTM 5, 245–254 (2021)

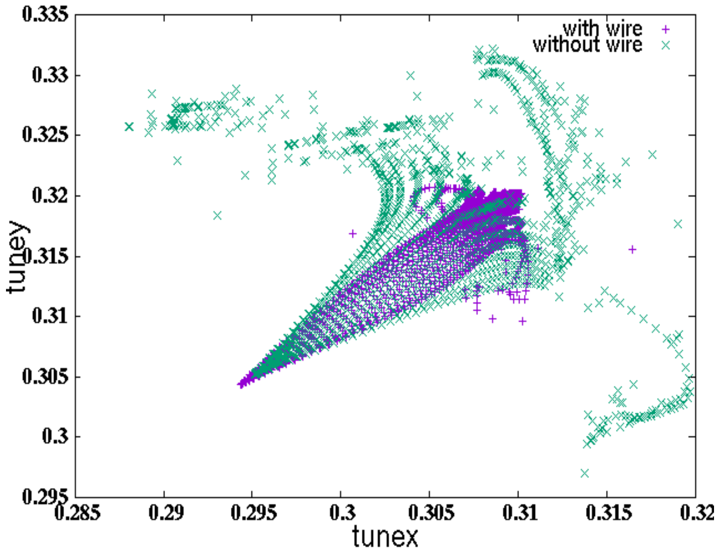
Beam-beam effects and compensations

Wang Lijiao , Tang Jingyu,
collab. with Tanaji Sen (FNAL)

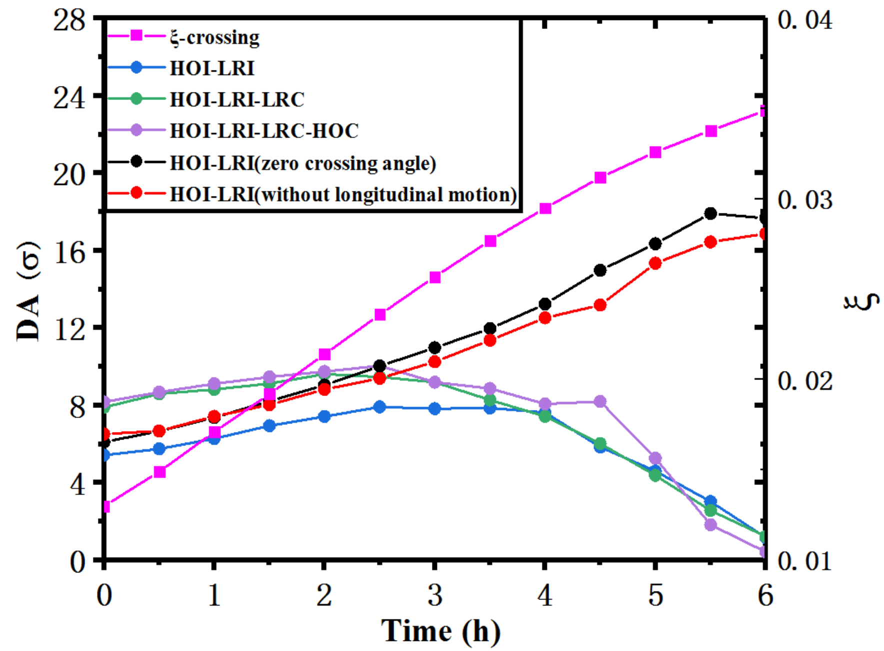
- Effects and compensation of head-on interactions
  - Reduction on dynamic aperture
  - Large tune shift causing resonances
  - Compensation by electric lens
- Effects and mitigation of long range interactions
  - Dynamic aperture limited mainly by the long-range B-B effects
  - Balance between the B-B effect and luminosity loss with a large crossing angle
  - Compensation method: current wires
- B-B effects with a realistic operation scenario
  - Emittance damping and bunch particles burning-off
  - Combined influence on the B-B effects and luminosity leveling

To be submitted to NIM-A





Tune footprint with wire compens. (violet points) and without compens. (green points)



DA evolution with time for natural emittance damping and particle burning-off

Considerations about SPPC using 20-T magnets

- SPPC plans to use Iron-based HTS magnets, till-now progress very encouraging
  - We have been investigating the possibility to go to 20-24 T directly (formerly as ultimate stage), to reach C.o.M. energy of 125-150 TeV
  - A compromise is to have 20T-125TeV design
- Compatibility problem with CEPC
  - Currently taking the full CEPC tunnel, but a bypass scheme is always possible in the future in order to keep the whole CEPC (including detectors) when building SPPC
- Synchrotron radiation problem
  - Radiation power per particle increased by 7.7 times ($\propto \gamma^4$)
  - Keeping bunch population unchanged and reducing bunch numbers: circulating current and bunch filling factor largely reduced
  - SR power per aperture at arcs: 16.4 W/m (12.8 W/m CDR)

- Luminosity problem： significant reduction in luminosity due to small bunch number, recovery measures needed
  - Keep higher possible bunch population
  - Nominal B-B parameter increased from 0.015 to 0.03 (two IPs)
  - Initial lumi 4*10^34 (40% of that in CDR)
  - Peak lumi. 8*10^34 (with emittance damping), leveling schemes to increase integrated lumi (dynamic β^*, emittance shrinking, crab waist etc)
- Injector chain problem
  - Maintain original structure (four stages)
  - SS energy increased from 2.1 TeV to 3.2 TeV, others unchanged (p-Linac: 1.2 GeV, p-RCS: 10 GeV, MSS: 180 GeV)
- Ring layout:
  - IR layout as before; arcs cells modestly changed
  - Collimation section length ~4.2 km, five-stage, superconducting magnets
  - Energy stored in beam: 2.5 GJ (9.1 GJ in CDR)

SPPC updated parameters (preliminary)

Parameter	Unit	Value		
		PreCDR	CDR	TDR
Circumference	km	54.4	100	100
C.M. energy	TeV	70.6	75	125
Dipole field	T	20	12	20
Injection energy	TeV	2.1	2.1	3.2
Number of IPs		2	2	2
Nominal luminosity per IP	$cm^{-2}s^{-1}$	1.2e35	1.0e35	8.0e34
Beta function at collision	m	0.75	0.75	0.5
Circulating beam current	A	1.0	0.7	0.12
Bunch separation	ns	25	25	25
Bunch population		2.0e11	1.5e11	1.5e11
SR power per beam	MW	2.1	1.1	1.4
SR heat load per aperture @arc	W/m	45	13	16

- Under study
  - Lattice update with higher energy
  - How to raise initial and integrated luminosity (based on B-B effects)
  - Possibility to increase SR limits (total power consumption and beam screen)
  - Previous collimation scheme still work?
  - Laser-driven accelerating possibility for the injector chain

Summary

- SPPC study continues but at a low profile to follow CEPC in the TDR stage
- For SPPC to jump directly to the ultimate stage, 125 TeV with 20-T magnets
  - Basically no show stopper
  - More design study is needed

Thank you for your attention!