Status of CEPC accelerator physics study

Yiwei WANG (王毅偉)
CPEC AP study group
H. Geng, Y. Guo, N. Wang, Y. Peng, X. Cui, Y. Zhang, T. Yue, Z. Duan, Y. Wang, D. Wang, S. Bai, Q. Qin, F. Su, M. Xiao, C. Zhang, G. Xu, J. Gao, W. Chou, Q. Qin et al.
Institute of High Energy Physics (IHEP, Beijing)

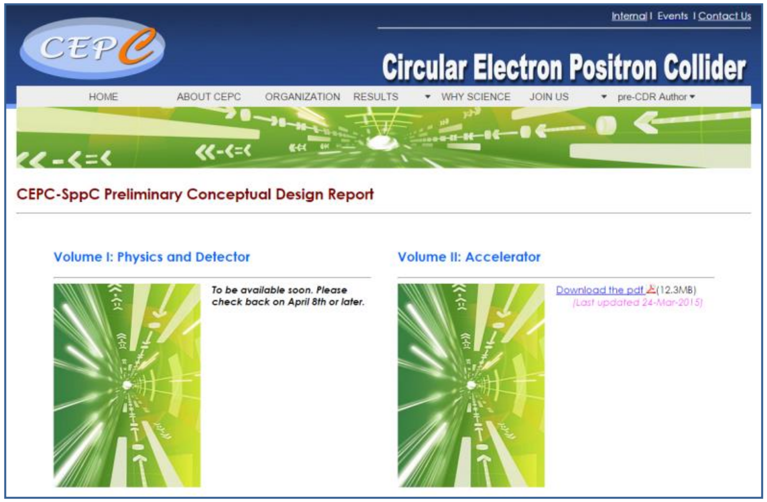
KEK Seminar, 27 Oct. 2015

Outline

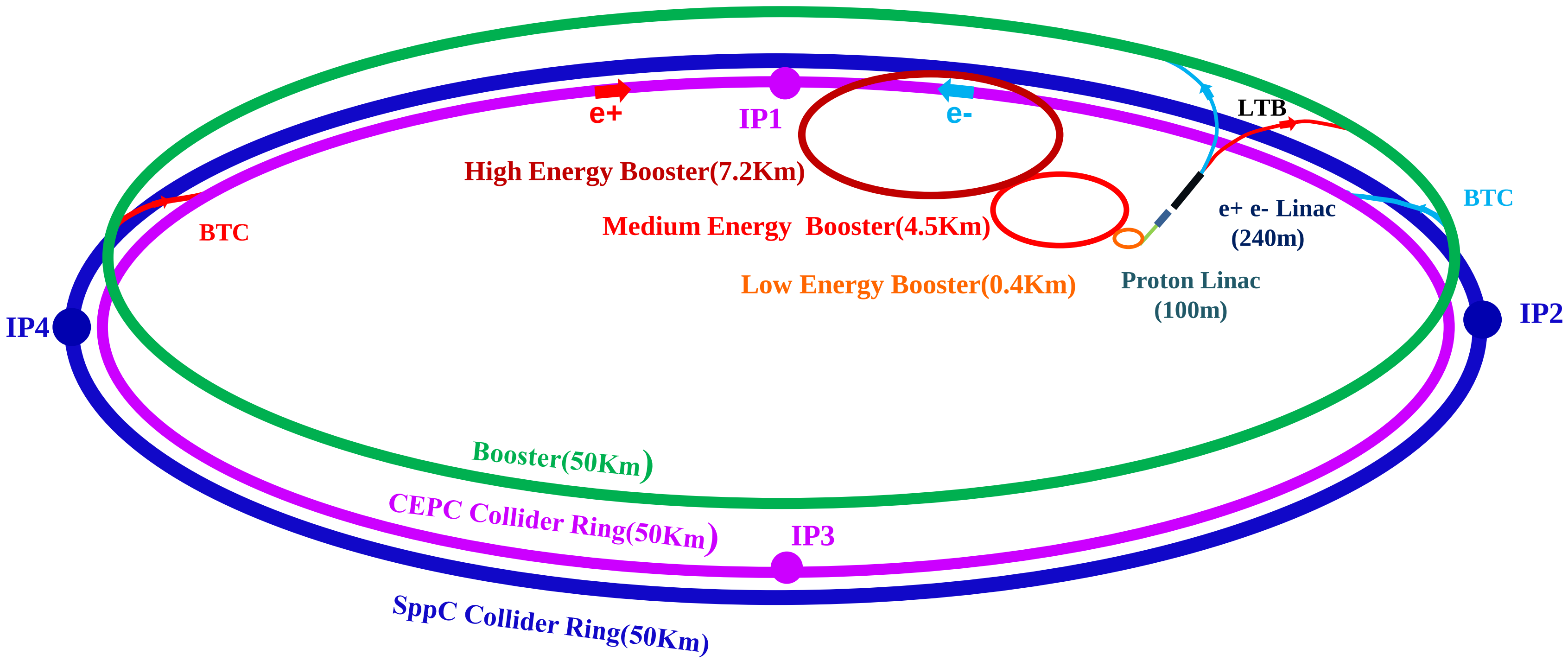
- Introduction
- CEPC layout and parameters
- Key issues of CEPC accelerator physics
- lattice, interaction region, booster, partial double ring…
- Summary

Introduction

- CEPC (a Circular Electron Positron Collider) has been proposed to study the Higgs boson
- CEPC has temporarily chosen the single ring as the baseline design and a partial double-ring as the alternative design
- A circumference of around 54km as baseline is chosen to have a reasonable cost
- The facility would then be upgraded by adding a 70-100 TeV Super Proton-Proton Collider (SPPC) in the same tunnel.
- Quite a lot of work has been done during the past two years
- Pre-CDR of CEPC/SPPC finished in March 2015 http://cepc.ihep.ac.cn/preCDR/volume.html
- CDR will be finished by the end of 2016



CEPC-SppC Layout

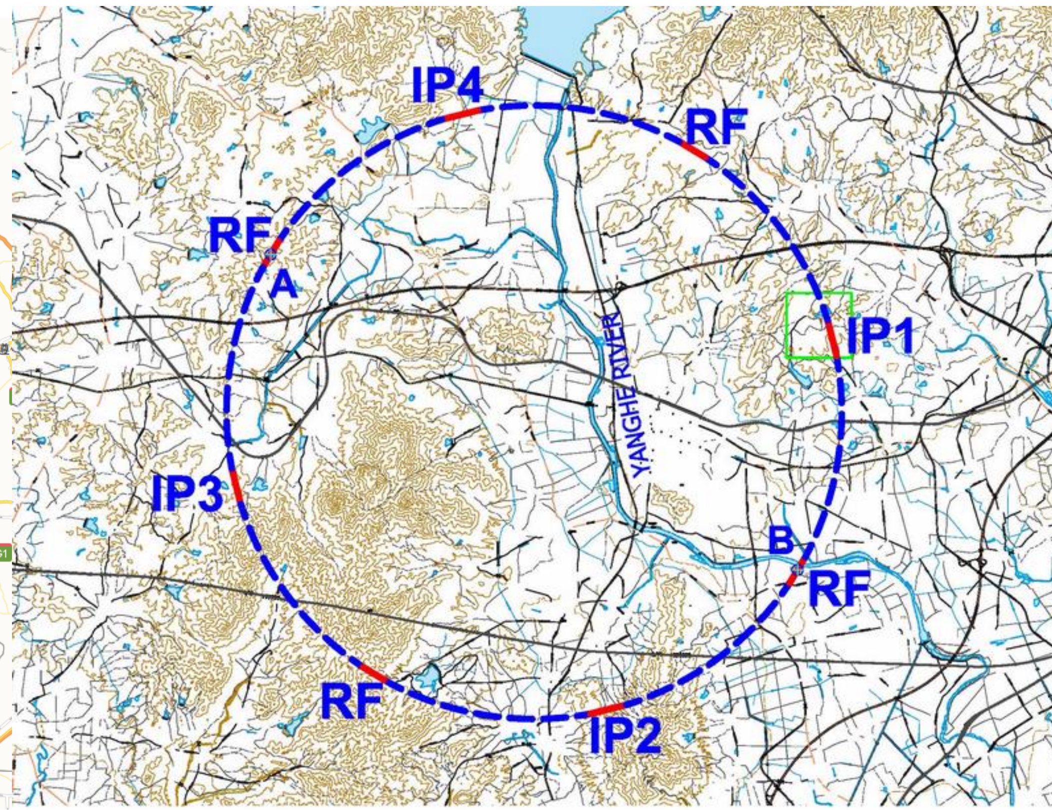


LTB : Linac to Booster

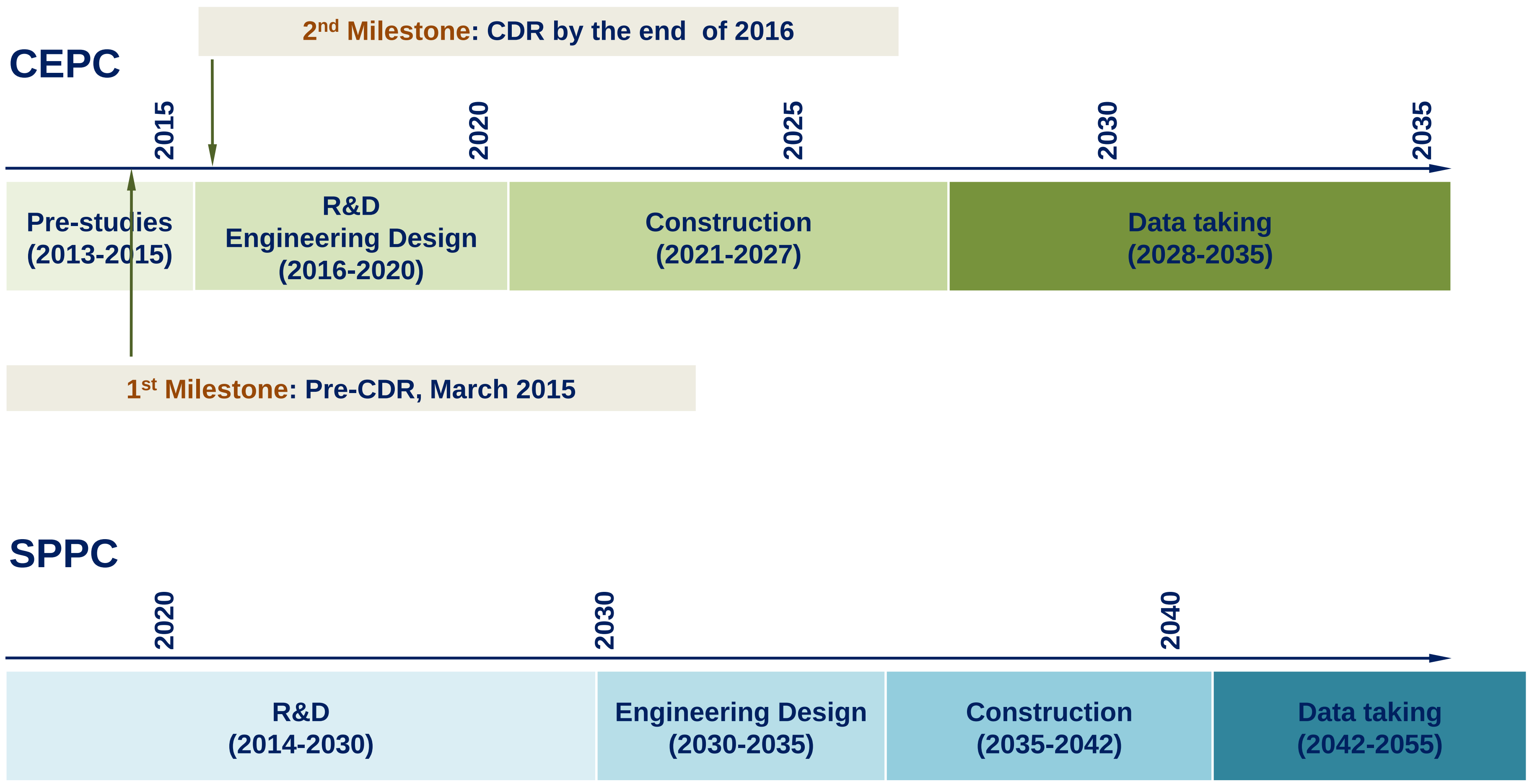
BTC : Booster to Collider Ring

Candidate location

- One of the candidate location
  - QinHuangDao, east of Beijing, 300km, 3h30m drive



CEPC-SPPC Timeline (preliminary)



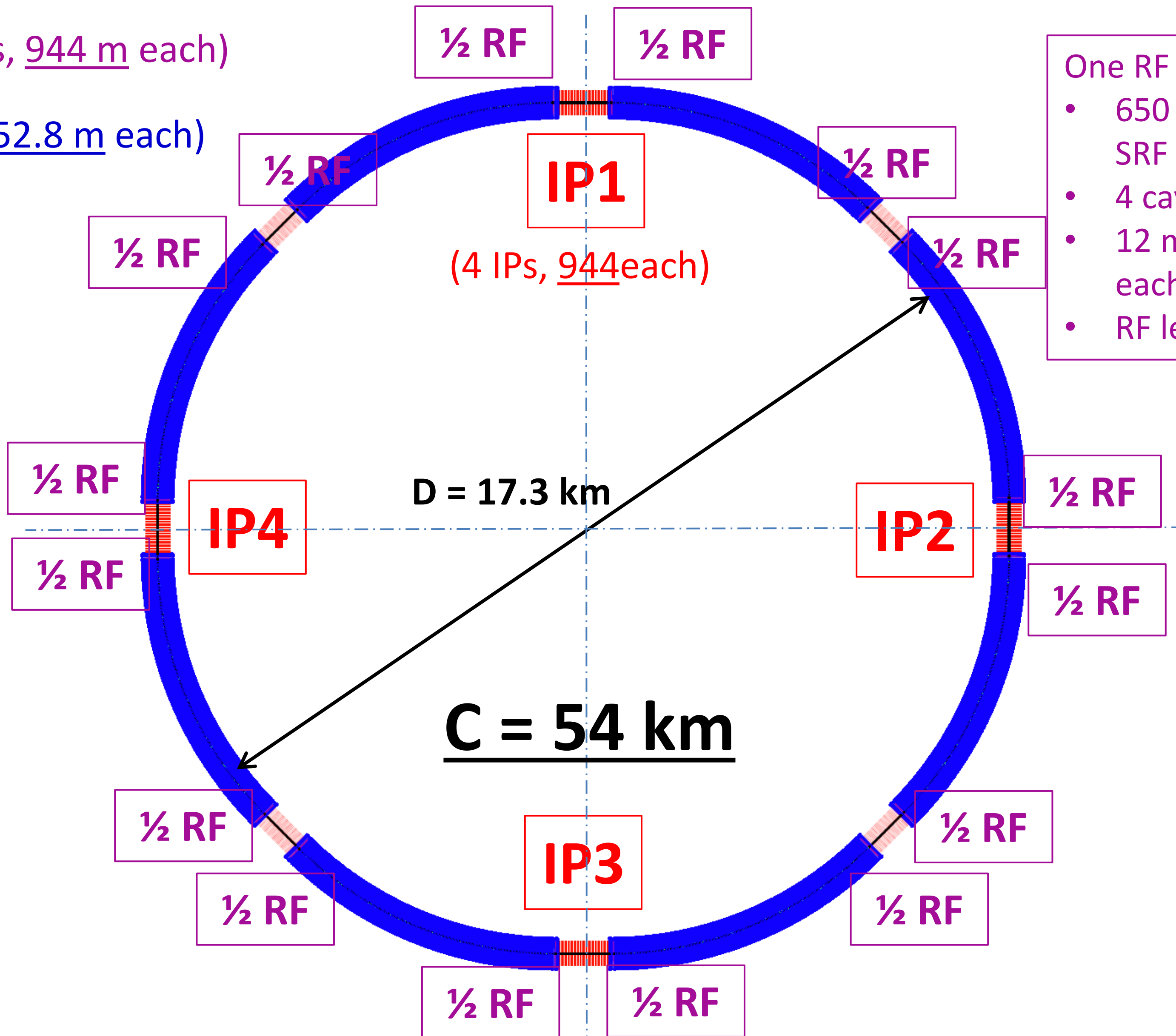
CEPC main ring Layout

(4 straights, 944 m each)

(8 arcs, 5852.8 m each)

One RF station:

- 650 MHz five-cell SRF cavities;
- 4 cavities/module
- 12 modules, 10 m each
- RF length 120 m



CEPC parameters

Parameter	Unit	Value	Parameter	Unit	Value
Beam energy [E]	GeV	120	Circumference [C]	m	54752
Number of IP[N_{IP}]		2	SR loss/turn [U_0]	GeV	3.11
Bunch number/beam[n_B]		50	Bunch population [Ne]		3.79E+11
SR power/beam [P]	MW	51.7	Beam current [I]	mA	16.6
Bending radius [ρ]	m	6094	momentum compaction factor [α_p]		3.36E-05
Revolution period [T_0]	s	1.83E-04	Revolution frequency [f_0]	Hz	5475.46
emittance (x/y)	nm	6.12/0.018	β_{IP}(x/y)	mm	800/1.2
Transverse size (x/y)	μm	69.97/0.15	$\xi_{x,y}$/IP		0.118/0.083
Beam length SR [$\sigma_{s.SR}$]	mm	2.14	Beam length total [$\sigma_{s.tot}$]	mm	2.88
Lifetime due to Beamstrahlung	min	47	lifetime due to radiative Bhabha scattering [τ_L]	min	52
RF voltage [V_{rf}]	GV	6.87	RF frequency [f_{rf}]	MHz	650
Harmonic number [h]		118800	Synchrotron oscillation tune [ν_s]		0.18
Energy acceptance RF [h]	%	5.99	Damping partition number [$J\varepsilon$]		2
Energy spread SR [$\sigma_{\delta.SR}$]	%	0.132	Energy spread BS [$\sigma_{\delta.BS}$]	%	0.119
Energy spread total [$\sigma_{\delta.tot}$]	%	0.177	n_γ		0.23
Transverse damping time [n_x]	turns	78	Longitudinal damping time [n_ε]	turns	39
Hourglass factor	Fh	0.658	Luminosity /IP[L]	$cm^{-2}s^{-1}$	2.04E+34

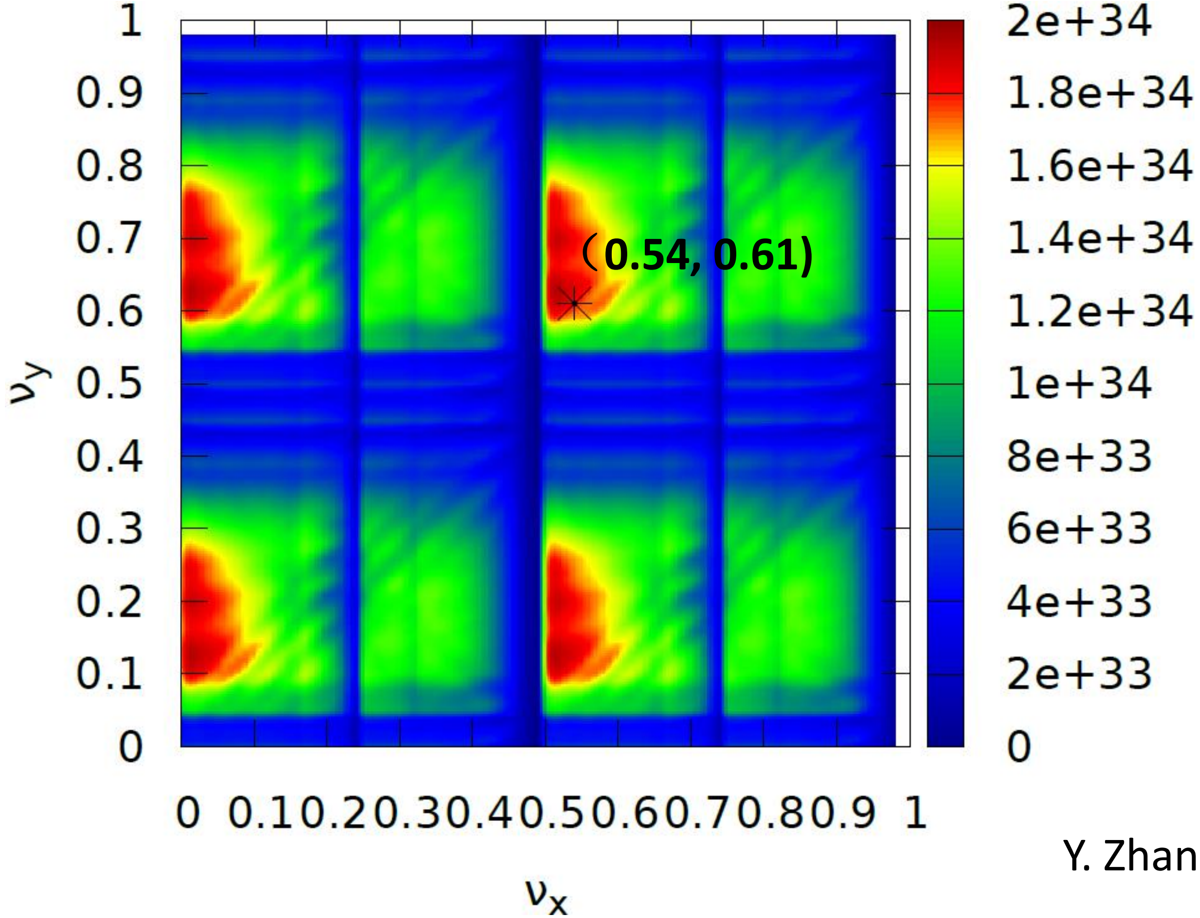
Key issues of CEPC accelerator physics

- Dynamic aperture: large enough DA for dp/p=$\pm$2% to get a reasonable beam lifetime
- Pretzel orbit: stability
- Partial double ring: crossing angle, crab waist
- Machine detector interface: background simulation, shielding of the SR, FD, solenoid compensation scheme…
- Booster ring: low bending field @ 6GeV

Beam-beam simulation

Choice of Working Point

With 2 IP
Vx=0.08
Vy=0.22

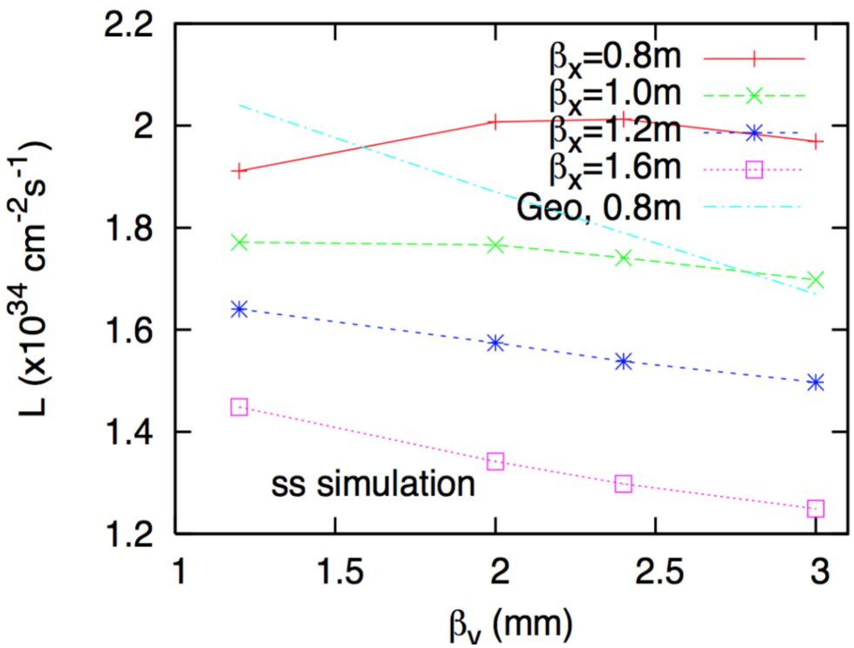


BBWS

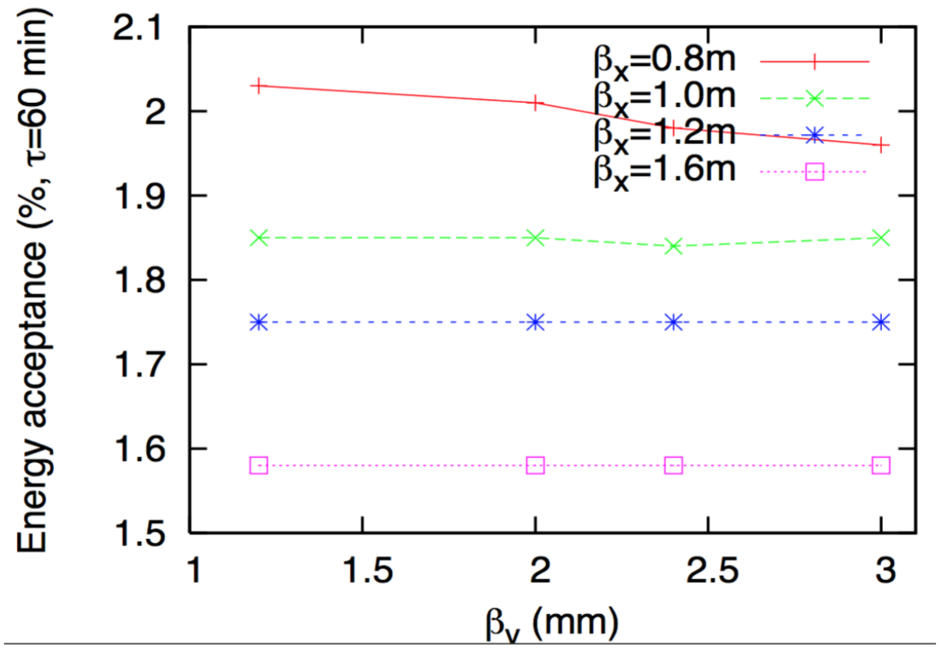
Y. Zhang, K. Ohmi

Luminosity and lifetime for various β*

BBSS



BBWS

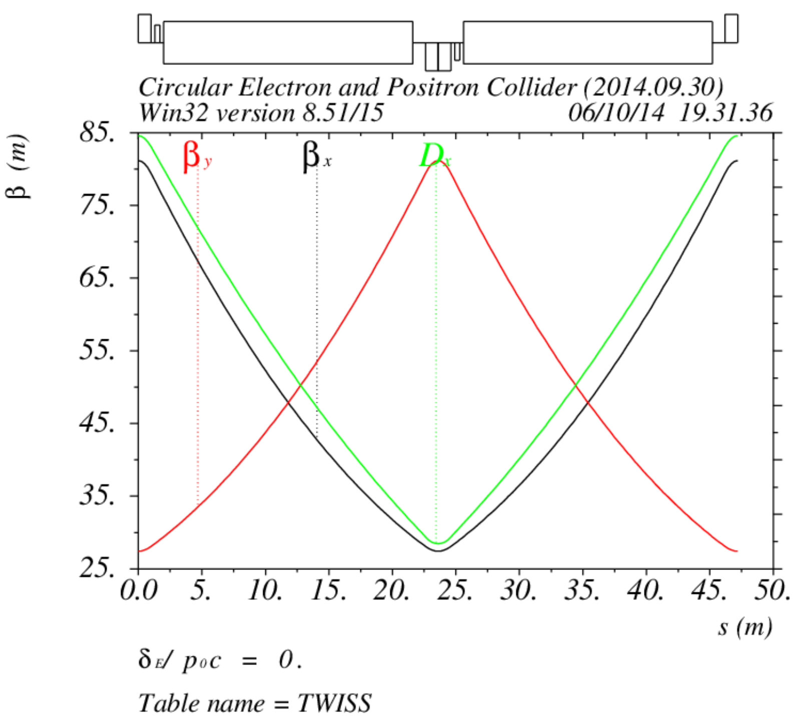


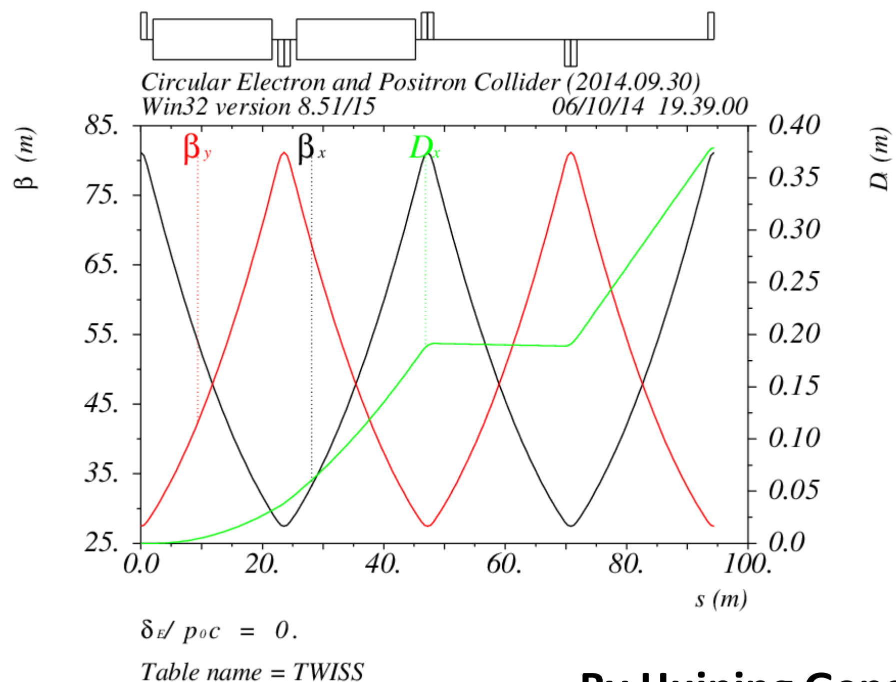
Y. Zhang, K. Ohmi

- Luminosity is higher for lower β_x* and β_y*
- Lifetime depends on β_x* but little depend on β_y*.

Lattice of arc sections

- Length of FODO cell: 47.2m
- Phase advance of FODO cells: 60/60 degrees
- One sextupole next to each quadrupole in the arc section
- Dispersion suppressor on each side of every arc
- Length: 94.4m

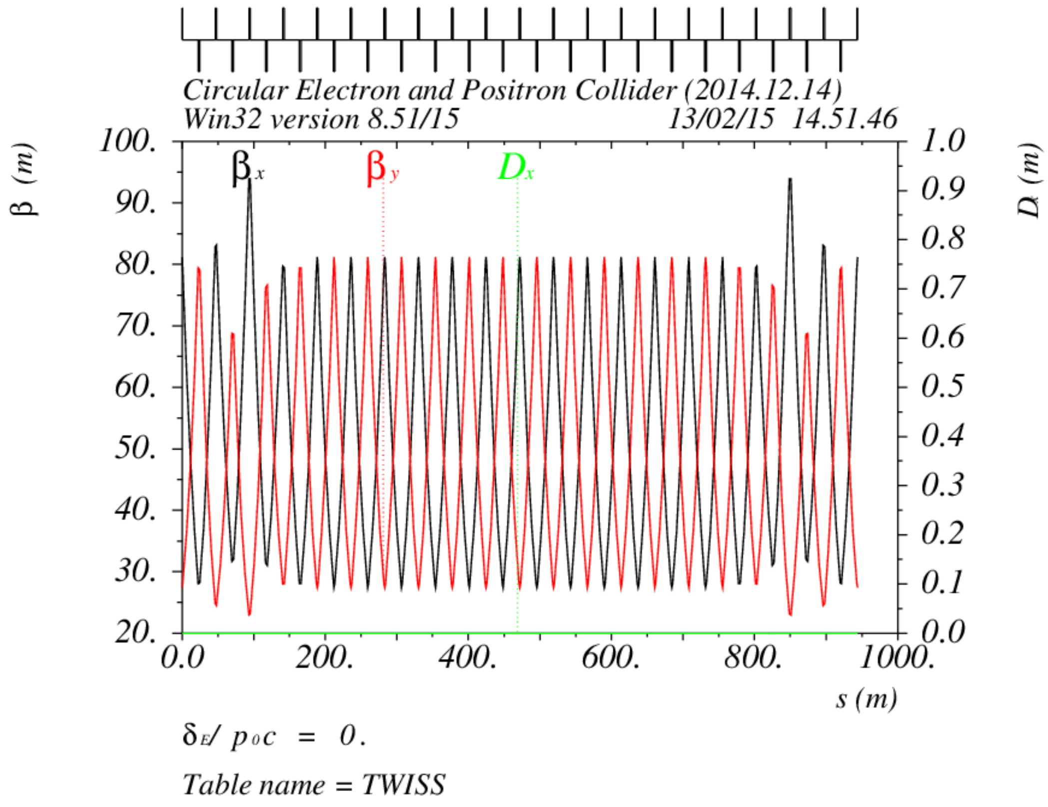




By Huiping Geng

Lattice of straight sections

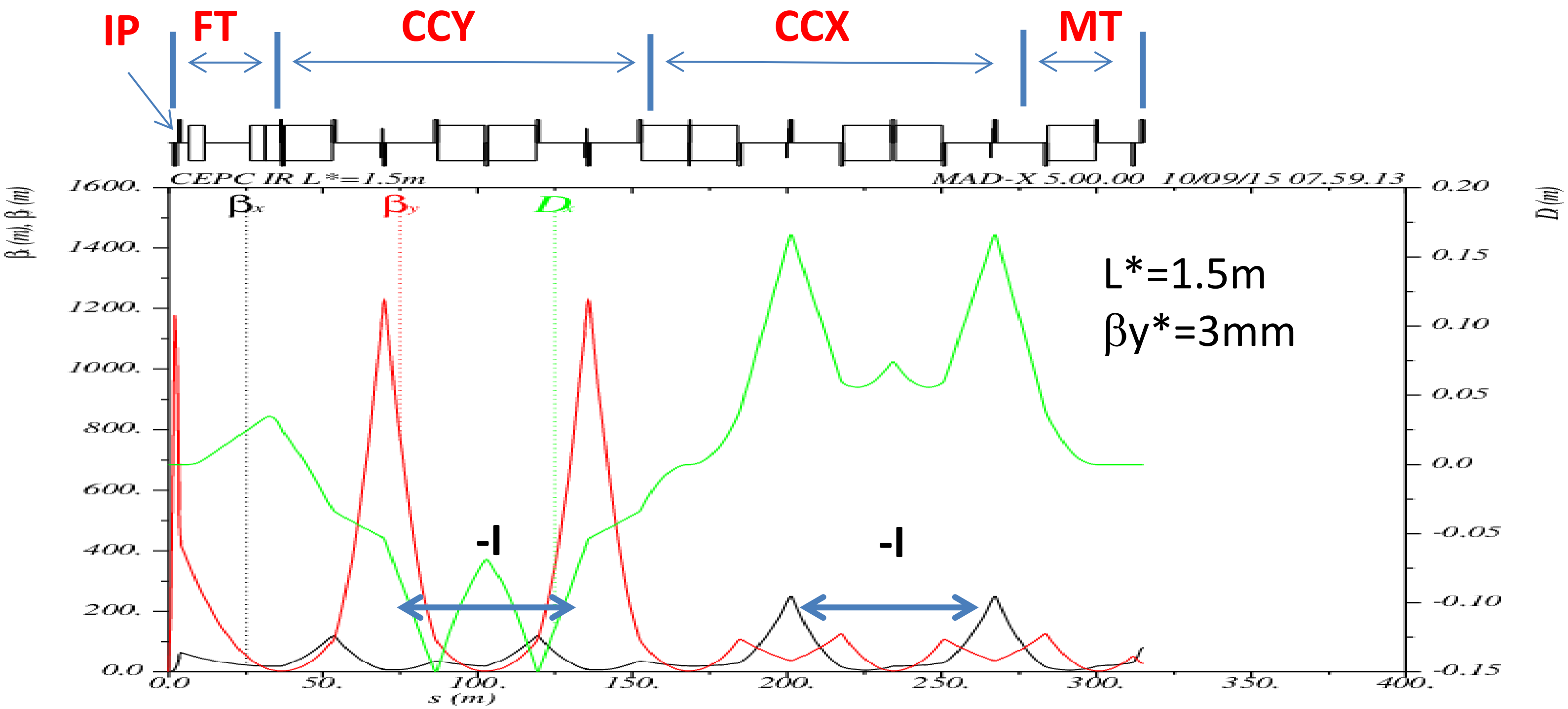
- All straights: 20 FODO cells
- Length: 944m
- Used for adjusting working point and matching
- Can be used for RF, injection and beam dump, etc.



By Huiping Geng

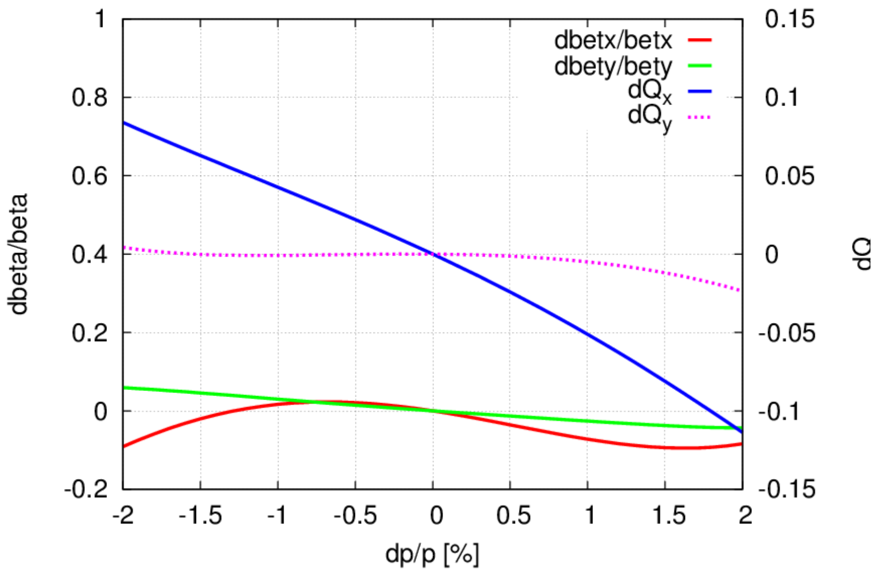
Lattice of interaction region

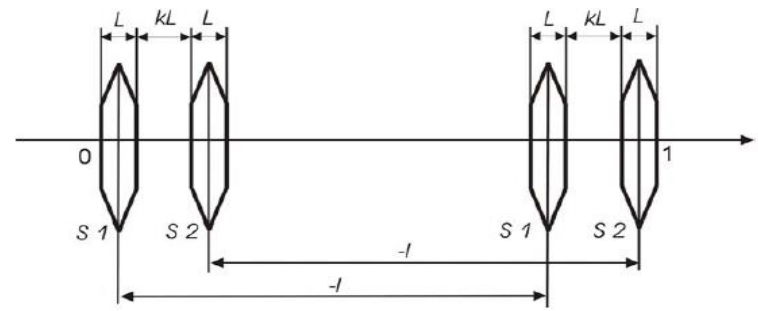
- Beam-beam simulation show that the luminosities of CEPC are almost the same when βy* increased from 1.2 mm to 3 mm.
- IR design with local chromaticity correction



Local chromaticity correction

- To reduce the high order chromaticity
  - only 2 quads in final transformer
  - additional sextupole at 1st image point
  - phases of sextupoles carefully tuned
- To compensate the the finite length effect*
  - additional weak sextupoles next to the main ones



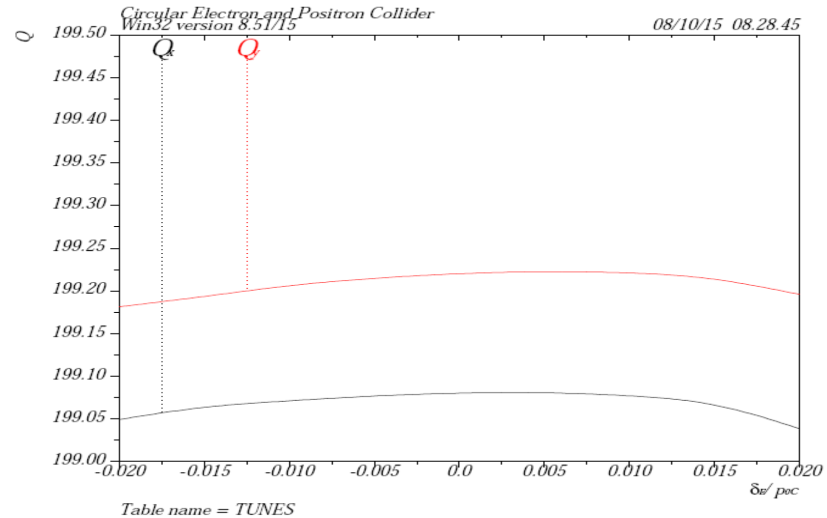


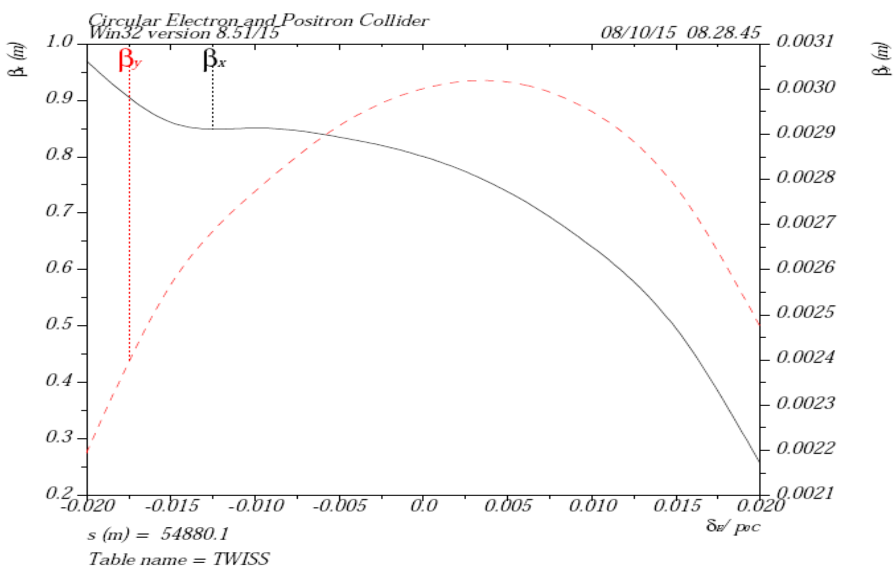
k=1, S1/S2=-0.1

*A.Bogomyagkov et al.
http://arxiv.org/abs/0909.4872

Chromaticity of the ring

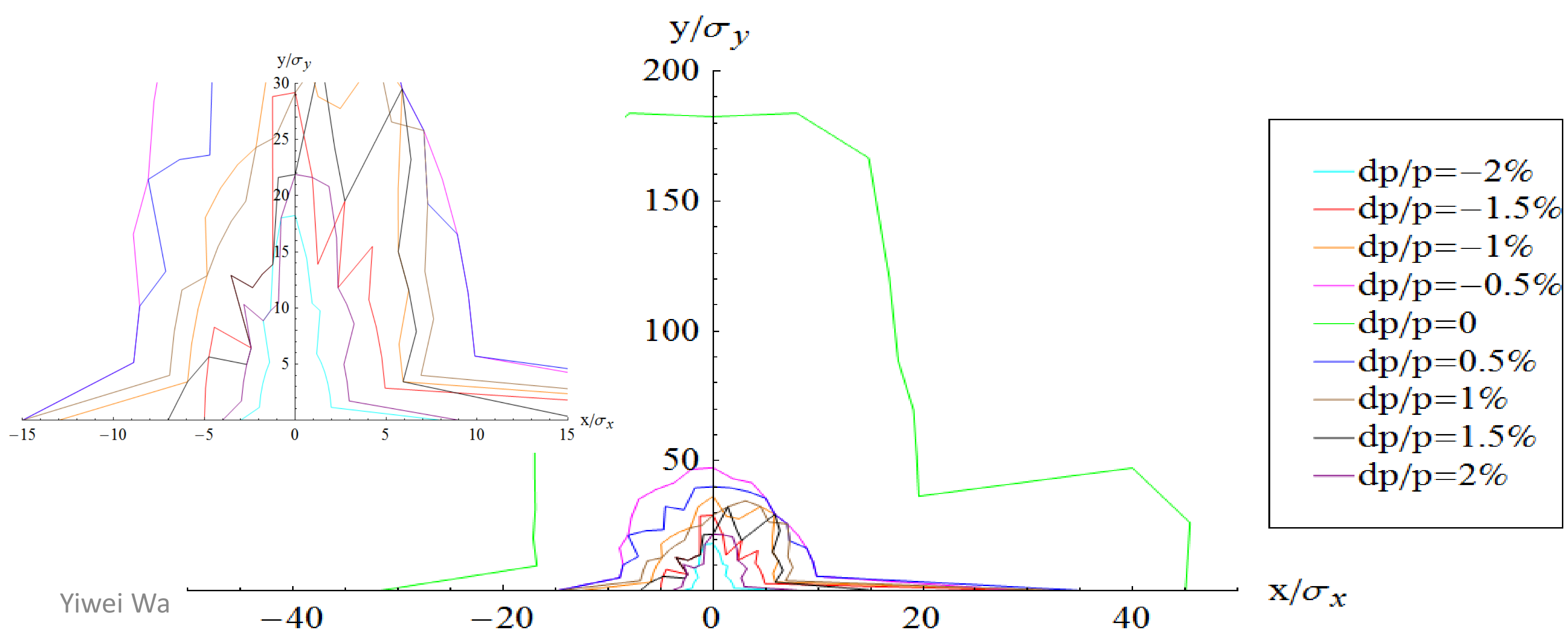
- Adjust the tune to be .08/.22 ($\nu x/\nu y$)
  - determined by beam-beam study
- match Q' to be ~0.5 with the sextupoles in the ARC
  - 5 families in IR + 2 families in ARC





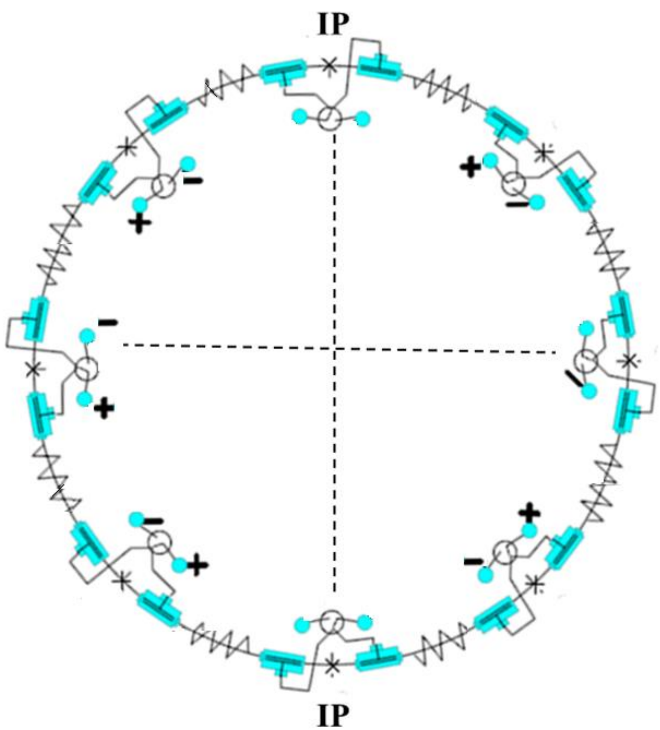
Dynamic aperture

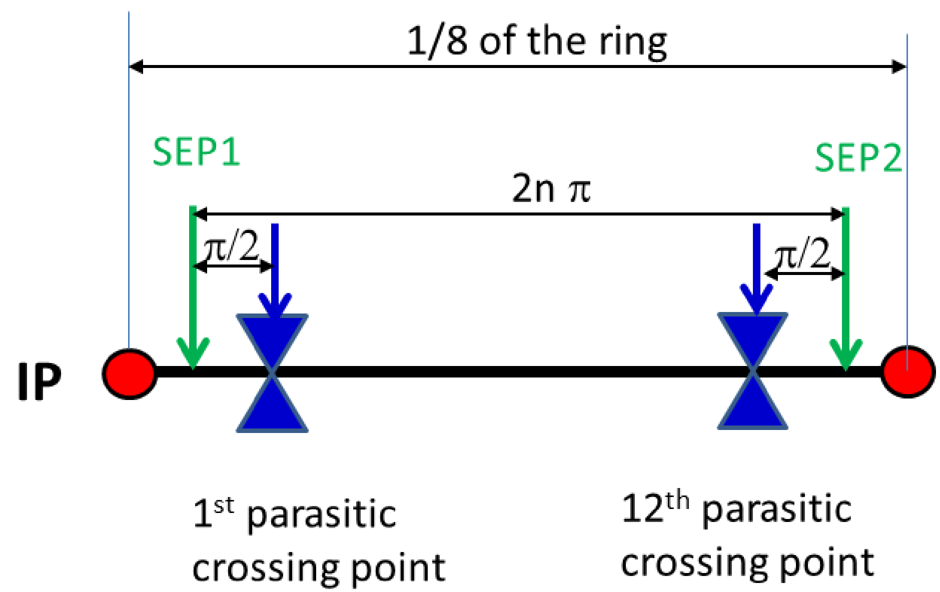
- without radiation damping, error of the magnets
- Synchrotron motion included
- Tracking with 3 times of damping time
- Coupling factor κ=0.003 for emitty
- For vertical plane, 20 sigma for dp/p=±2% achieved(green line)
- For horizontal plane, ~3.5 sigma dp/p=±2%
  - the horizontal plane need further optimization



Pretzel scheme (only ARC)

- Designed for 48 bunches/beam, every 4pi phase advance has one collision point
- Horizontal separation is adopted to avoid big coupling
- No off-center orbit in RF section to avoid beam instability and HOM in the cavity
- One pair of electrostatic separators for each arc

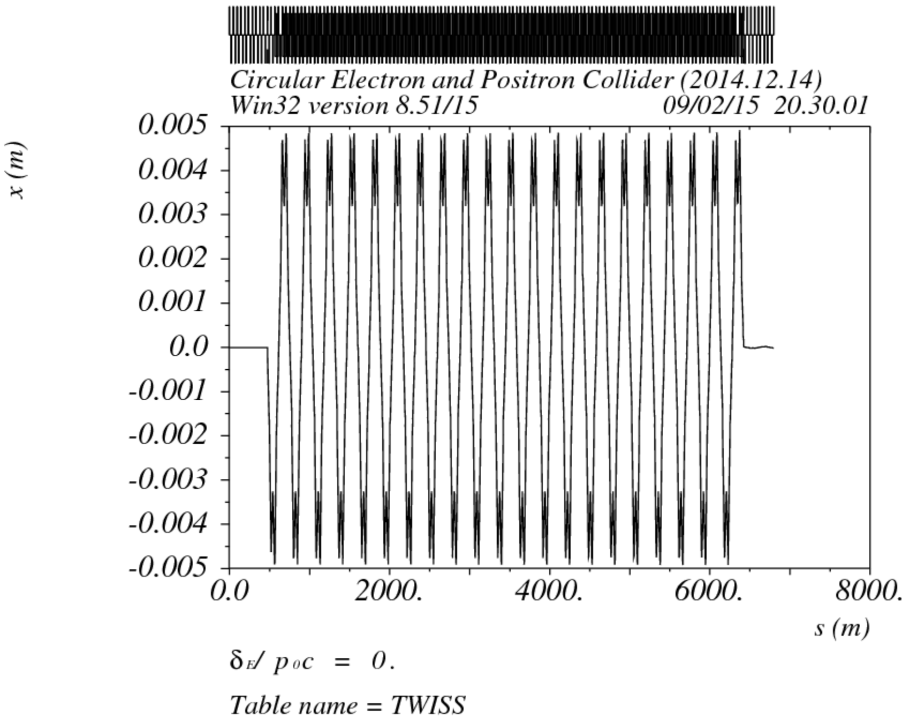




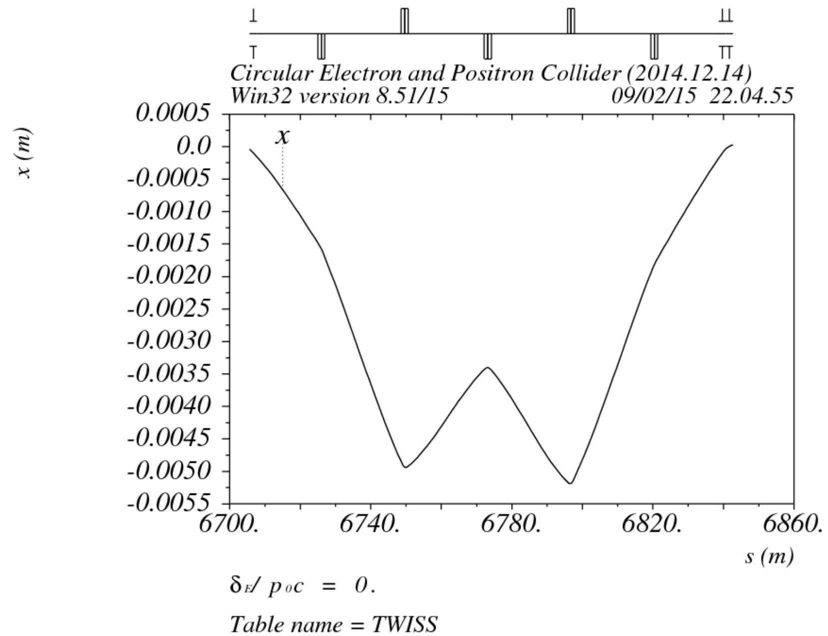
Huipng Geng, FCC week 2015

Pretzel scheme (only ARC)

- Separation distance: ~5 σx for each beam (10 σx distance between two beam)
- Maximum separation distance between two beams is : ~10 mm



Orbit for the first 1/8 ring

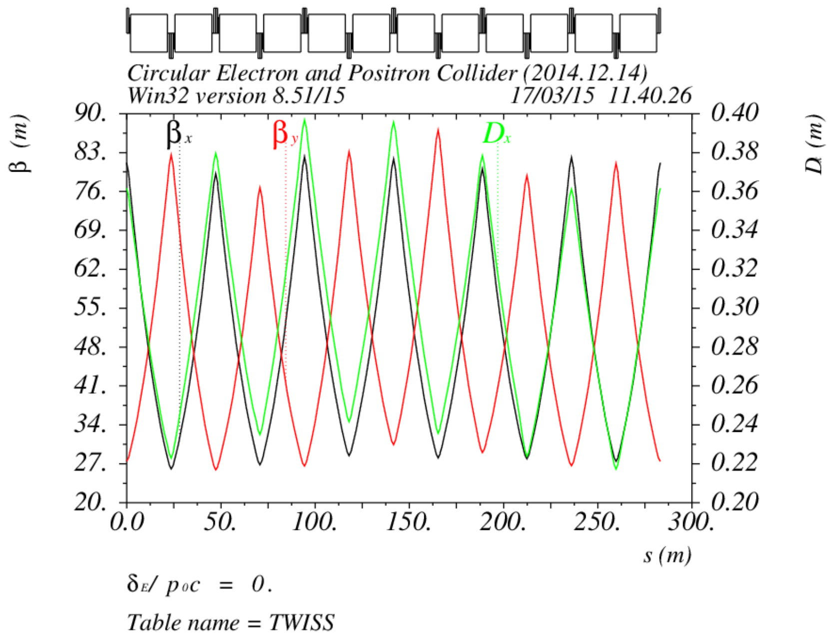


Orbit for IP2/IP4 and the other four symmetric points

Huipng Geng, FCC week 2015

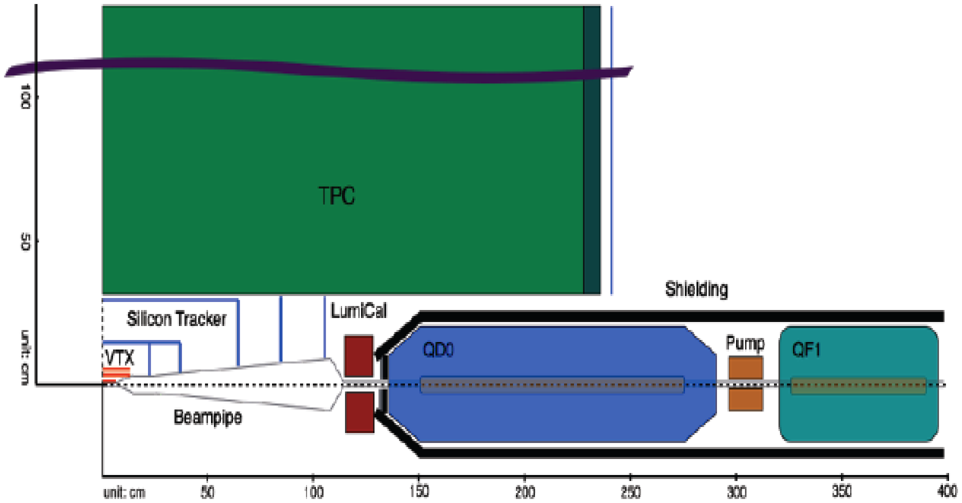
Correction of pretzel orbit effects

- The distortion of pretzel orbit effects on beta functions and dispersions can be corrected by making quadrupoles individually adjustable, which can be done by adding shunts on each quadrupoles
- A new periodic solution can be found by grouping 6 FODO cells together as one new period
- The maximum adjustment of quadrupole strength is ~2%



Machine detector interface

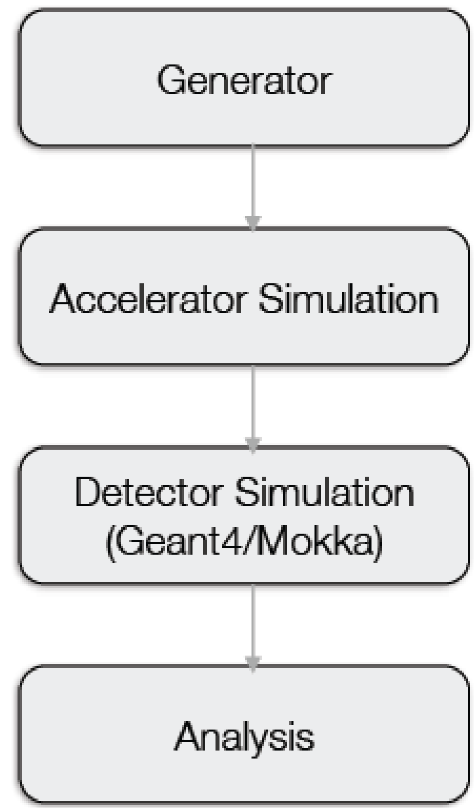
- Mandatory to cover topics that are common to the machine and the detector:
  - Interaction region layout
  - Final focusing magnets
  - Beam pipe
  - Luminosity calorimeter
  - Background estimation
  - Detector shielding
  - Mechanics and integration
- Regular group meetings
  - Indico: http://indico.ihep.ac.cn/category/323/
  - Twiki: cepc.ihep.ac.cn/~cepc/cepc_twiki/index.php/Machine_Detector_Interface



IR layout in pre-CDR

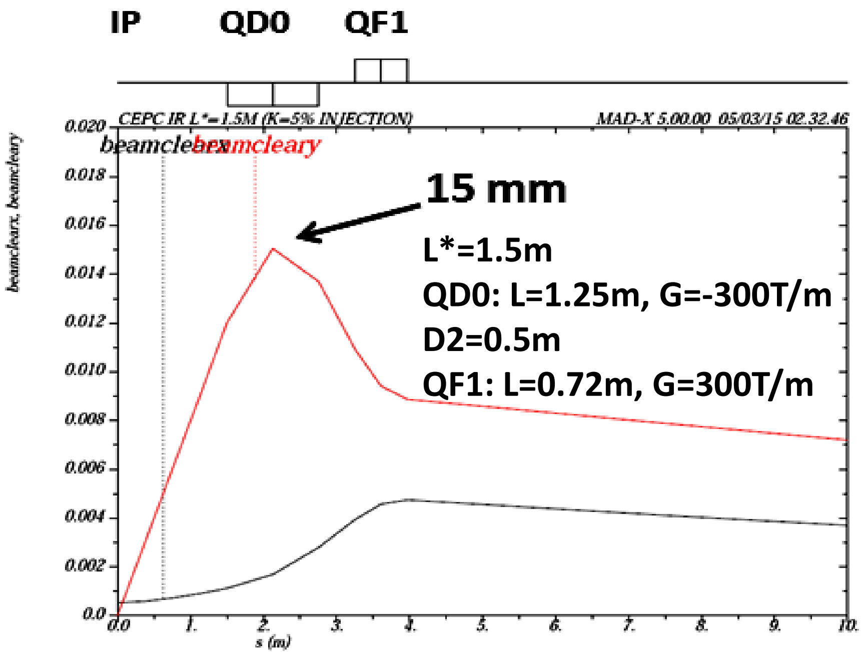
Background Estimation

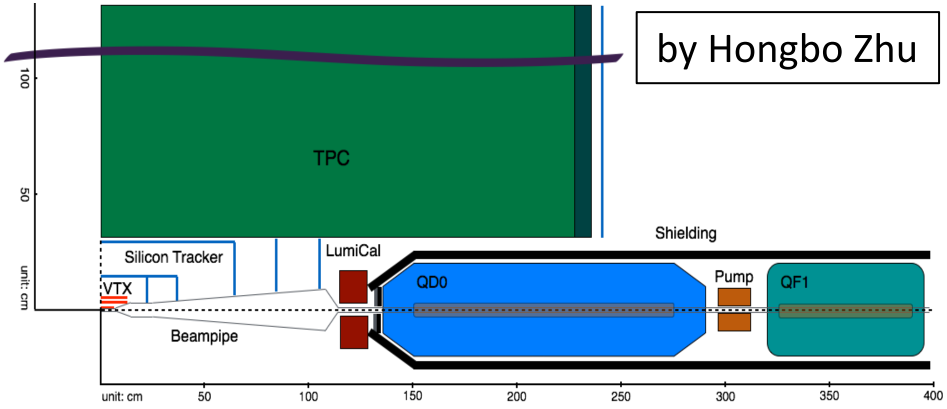
- Collision induced
  - Beamstrahlung
    - Pair production
    - Hadronic background
  - Radiative Bhabha
- Machine induced
  - Synchrotron Radiation
  - Beam-Gas Scattering
  - Compton scattering on thermal photons
  - Beam halo
  - …



Size of QD0 and QF1

- coil inner radius = 21 mm
  - beam pipe inner radius = 17 mm (2mm for safety)
  - pipe wall thickness = 2 mm
  - gap between pipe and coil = 2 mm
- gradient = 300 T/m
- estimated cryostat diameter = 400 mm
  - Including anti-solenoid
  - acceptable for detector

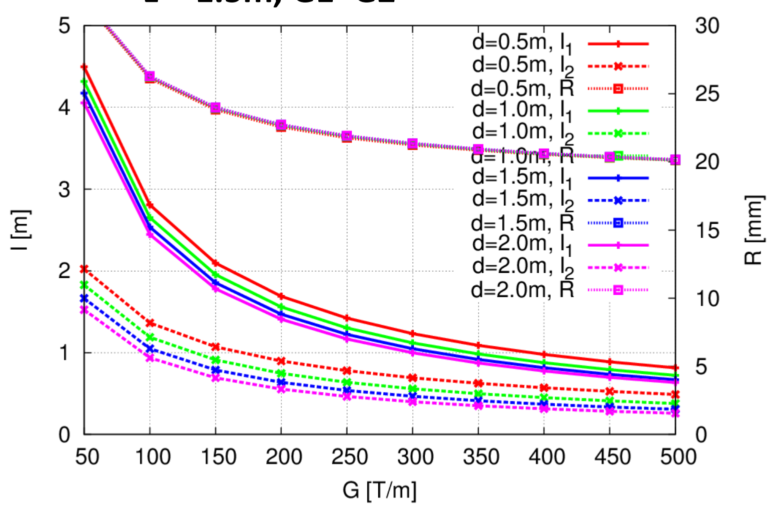




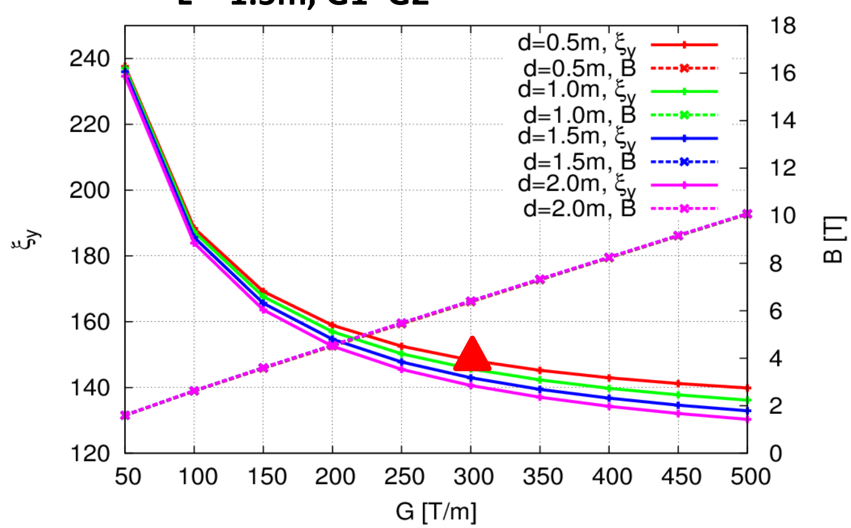
Optimization of final doublet

- When G>200T/m
  - **ξy decrease slowly with the increase of G**
  - B increase almost linearly with G and independent of the space between QD0 and QF1
- Seems possible to reduce the gradient from 300T/m to 200T/m
  - ξy slightly increased from -148 to -149 and B significantly decreased from 6.4 to 4.5 T with ay (7.88*10^-8 m·rad) used in the pre-CDR
  - With a more optimistic ay (5.33*10^-8 m·rad), B could be further reduce to be 3.9 T
  - **need to check with a full IR lattice. At present we still work with G=300T/m**

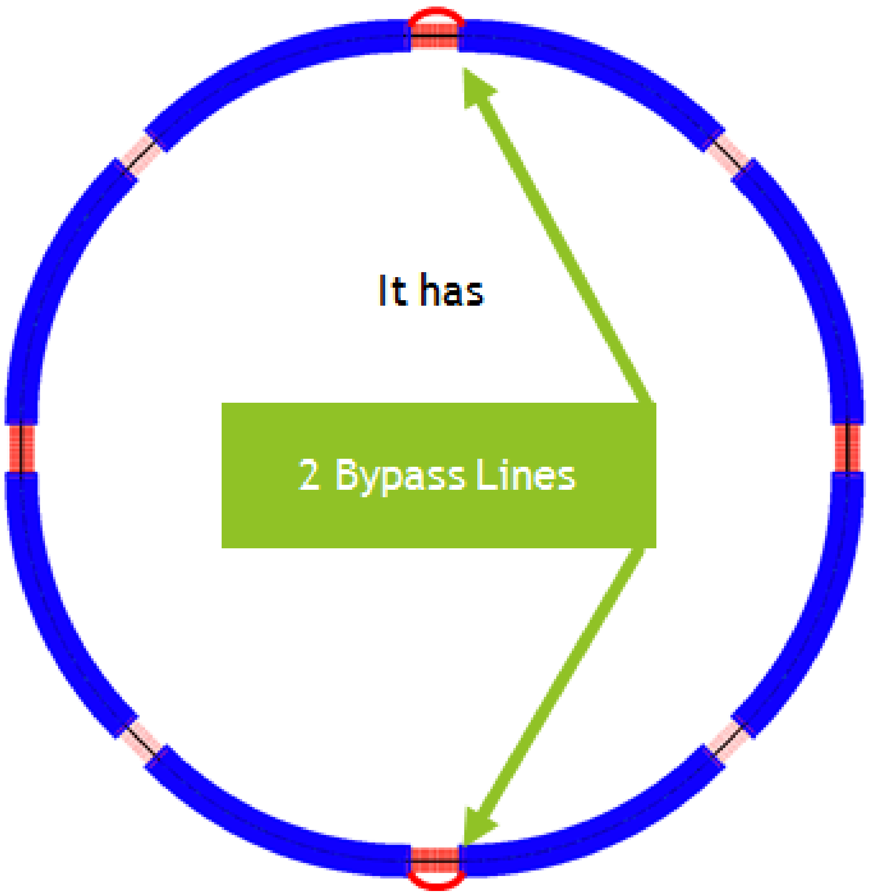
L*=1.5m, G1=G2



L*=1.5m, G1=G2



Booster ring



- Provides beams for the collider with top-up frequency of 0.1 Hz.
- Using 1.3 GHz RF system;
- The injection energy of the booster is 6 GeV;
- Magnetic Field is as low as 31 Gauss at injection.

C. Zhang, X. Cui

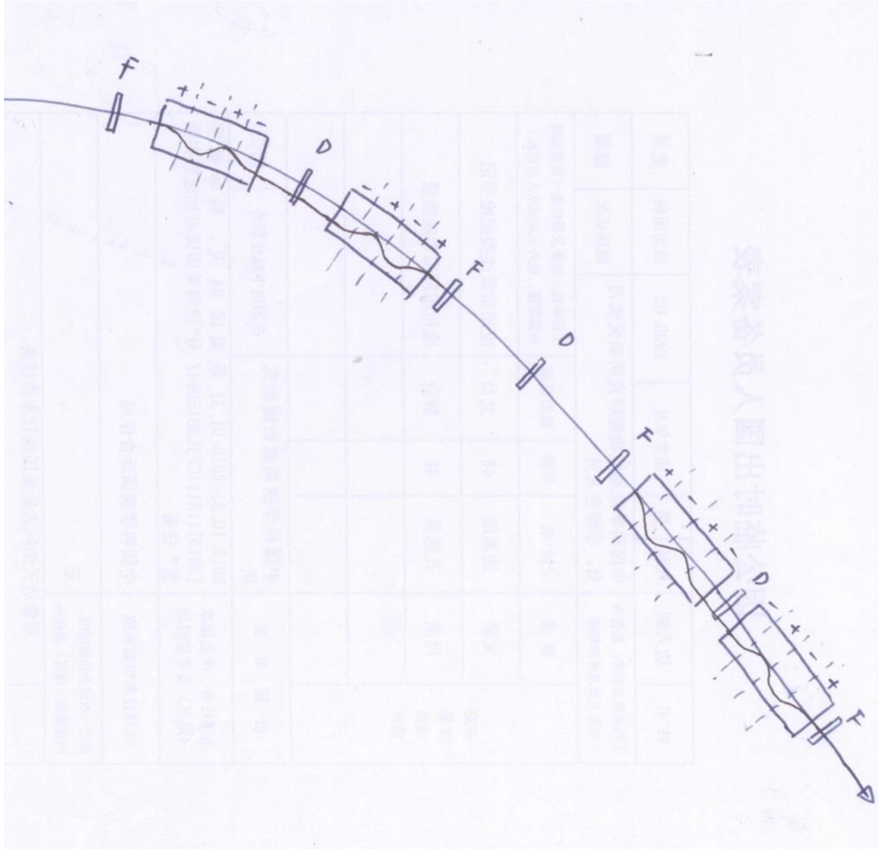
Main Parameters

Parameter	Symbol	Unit	Value
Injection Energy	*E*inj	GeV	6
Ejection Energy	*E*ej	GeV	120
Bending Radius	ρ	m	6089
Bending Field	*B*ej/*B*inj	T	0.0657/0.00329
Bunch Number	Nb		48
Bunch Population	*N*b	10^{10}	2.1
Beam Current	*I*beam	mA	0.83
SR power@120 GeV	*P*SR	MW	2.5
Emittance@120 GeV	εej	nm.rad	6.3
Emittance@6 GeV	εinj	nm.rad	0.0157
Transverse DampingTime@ 6GeV	Tdamp	s	115.5967s

C. Zhang, X. Cui

Alternative booster design

- Wiggling Bend Scheme
- Originally proposed by Gang XU
  - The inject energy is 6GeV.
  - If all the dipoles have same sign, 33Gs@6GeV may cause problem.
  - In wiggling bend scheme, adjoining dipoles have different sign.
  - This scheme will avoid the low field problem.
  - Shorten the Damping times greatly.



By T. Bian, J. Gao, G. Xu et al

Alternative booster design

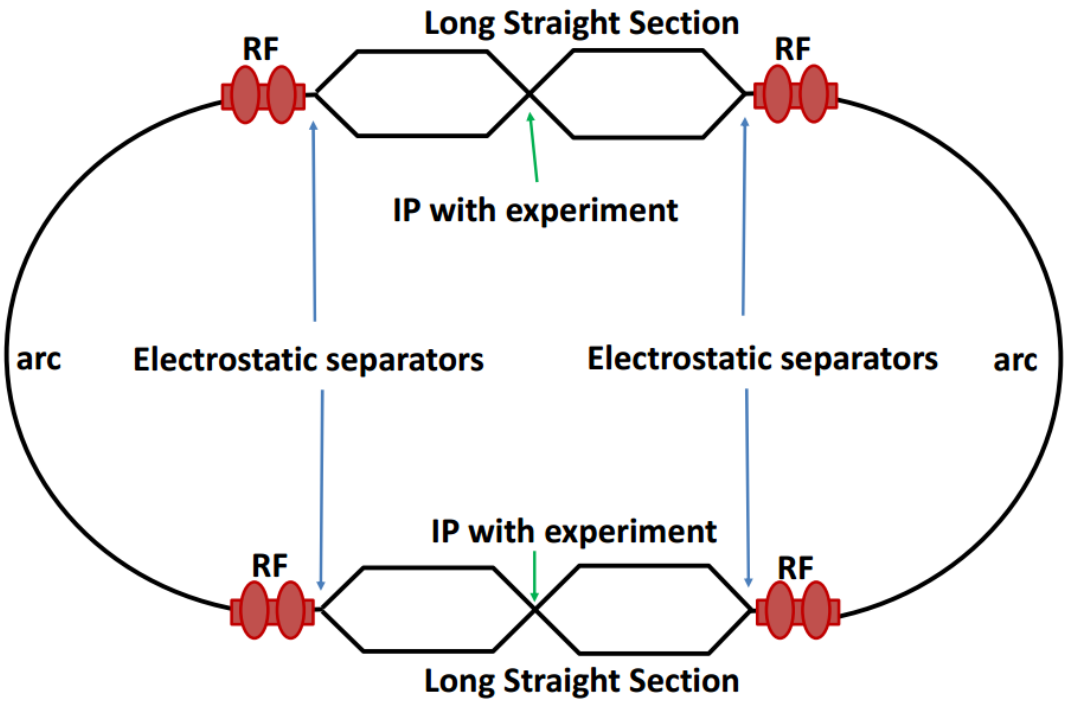
- **Compare with the baseline design**

Main Parameter			
	Baseline@6GeV	New@6GeV	@120GeV
U0 [MeV/turn]	0.019	0.71	3013
Damping times(x/y) [s]	115.6/115.6	2.4/3.1	14.43E-3/14.43E-3
Emittances(x) [pi nm]	0.0157	0.15	6.29
Strength of dipole [Gs]	33	-170/+227	657
Length of dipole [m]	19.6*1	4.9*4	\
Length of FODO [m]	47.2	47.2	\

By T. Bian, J. Gao, G. Xu et al

Partial double ring

- **Advantages**
  - No pretzel
  - More bunches
  - Cover Z
- **Challenges**
  - Crossing angle & crab waist design.
  - Electron cloud issues.
  - Bunch train operation introduces an uneven load to the RF system.



Ming XIAO, CEPC MDI meeting, June 26,2015

Summary

- Quite a lot of work has been done during the past two years
  - Pre-CDR of CEPC/SPPC finished in March 2015
- We are working for the CDR which will be finished by the end of 2016.
  - A lot of work need to be done
  - Dynamic aperture, pretzel stability, MDI, partial double ring…

Acknowledge

- Thanks to many colleges who provide me the slides!

Thank you!