Overview of the CEPC Accelerator

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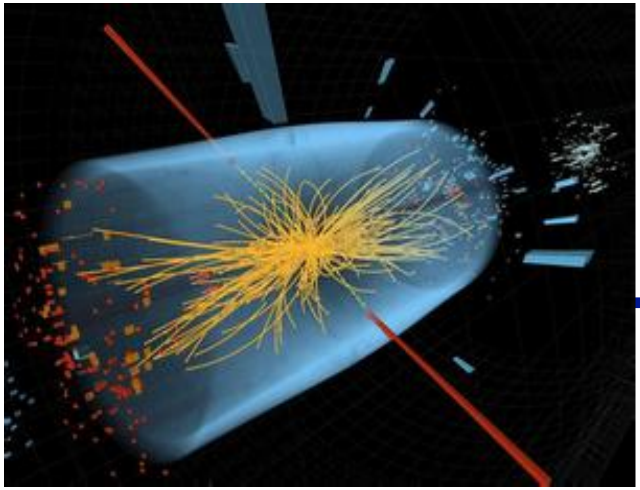
- ……

Outlines

- Introduction
- Main parameters and layout
- Accelerator physics issues
- Technical systems
- Plan in the near future
- Summary

1. Introduction

- **Motivations**
  - Higgs Boson was discovered two years ago, with a lower energy than expected.
  - Circular collider seems more mature and promising
  - More high energy physics hide in a possible pp collider converted by electron machine



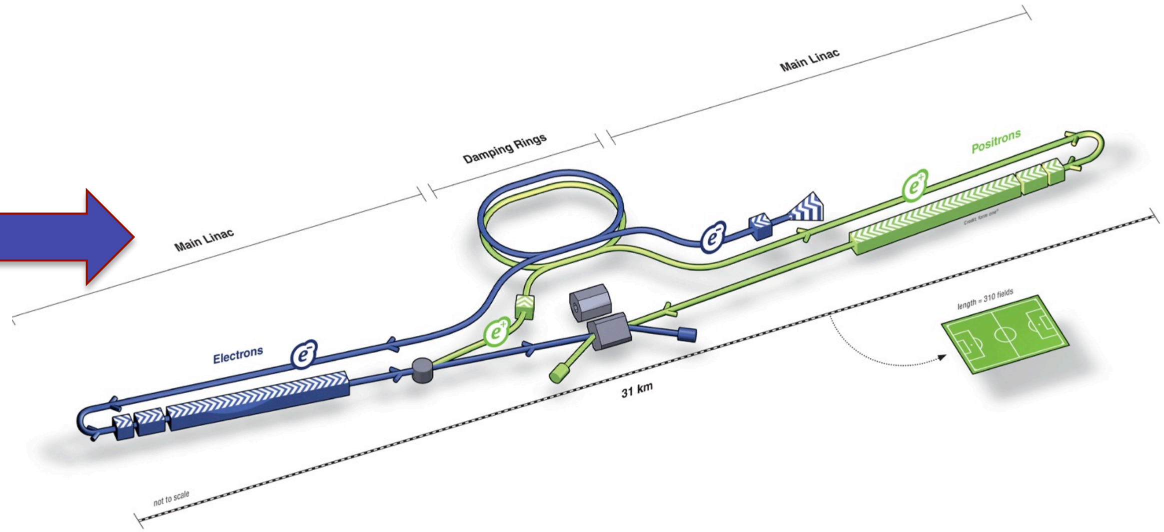
Forthcoming Discoveries in Particle Physics

Topic	Crucial measurement	Significance
WIMP	Existence	Dark Mater
Higgs boson	M ~125 GeV	Confirm spontaneous symmetry breaking in gauge theory
Super-symmetric particles	Existence, M > 1 TeV	Hope of understanding gravity
Technicolour particles	Existence, M > TeV?	Dynamic symmetry breaking, Composite Higgs
Gravitational waves (Gravitons)	Existence	Support general relativity
Magnetic monopole	Existence, mass, electric charge	Electric and magnetic charge symmetry predicted by Dirac. Structure of gauge field configuration
Free quarks	Existence, fractional charge	Would confuse all current prejudice
Neutrino mass and oscillation	M < 1 eV	Structure of GUTs. Eventual fate of the universe
Exotic hadron Glueball	M_g = 1-2 GeV, $M_{exotic,\ c}$~4 GeV Existence	Understand QCD

Possible Higgs Factories

- **Linear Collider**

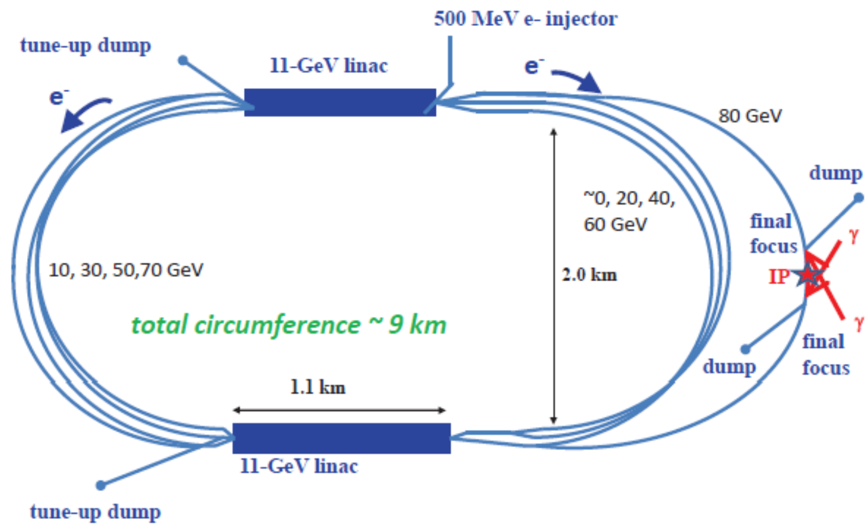
  - ◆ ILC
  - ◆ CLIC
  - ◆ SLC-type
  - ◆ Advanced concepts



$$L \propto \frac{\eta P_{RF}}{E_{CM}} \sqrt{\frac{\delta_{BS}}{\varepsilon_y}}$$

- γ- γ collider

  - SAPPHIRE – ERL based, γ-γ based on LHeC, …
  - CLICHÉ – CLIC Higgs Experiment



Need powerful laser…

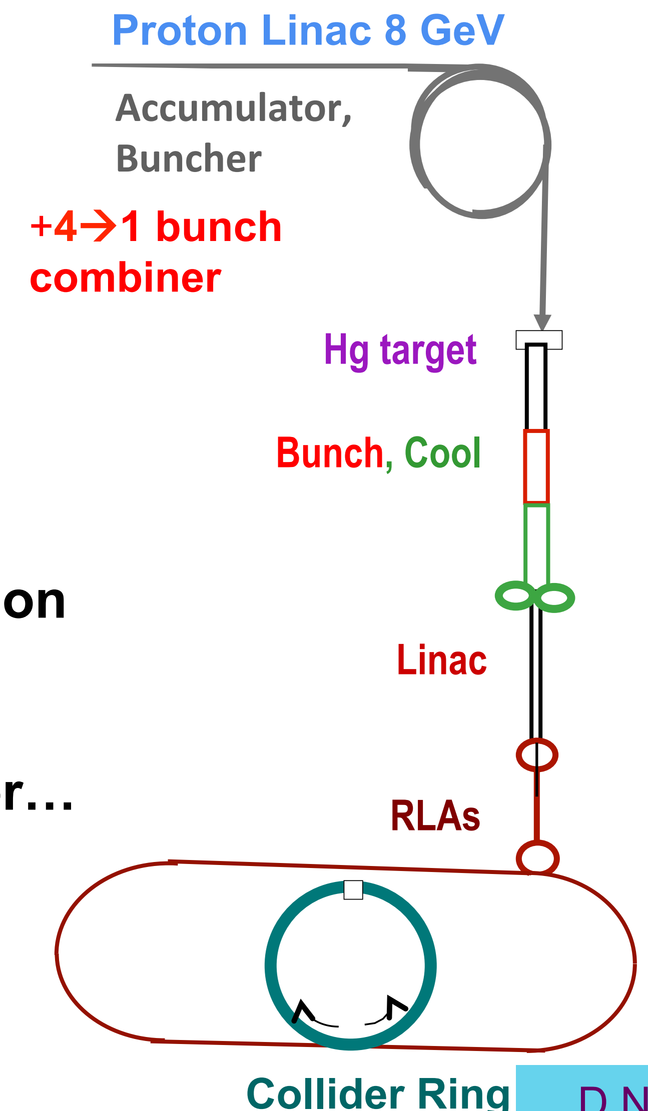
- **Muon collider**

◆ Driven by high power p accelerator

◆ MW level target，collect pion to muon

◆ Cooling of Muon

◆ Acceleration, collision ring, detector…



D.Neuffer
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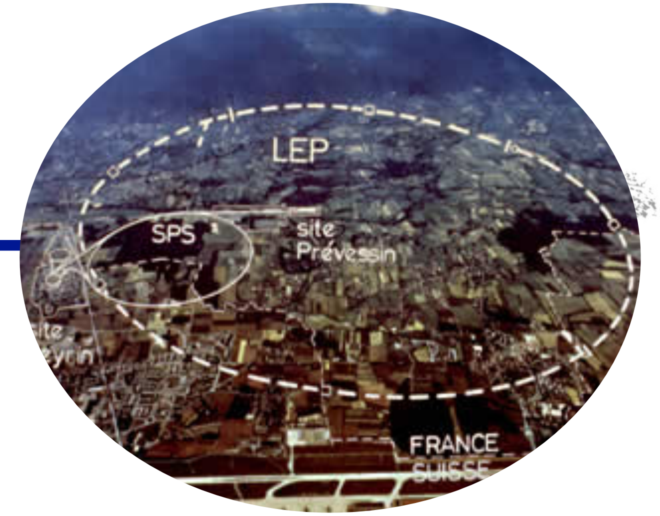
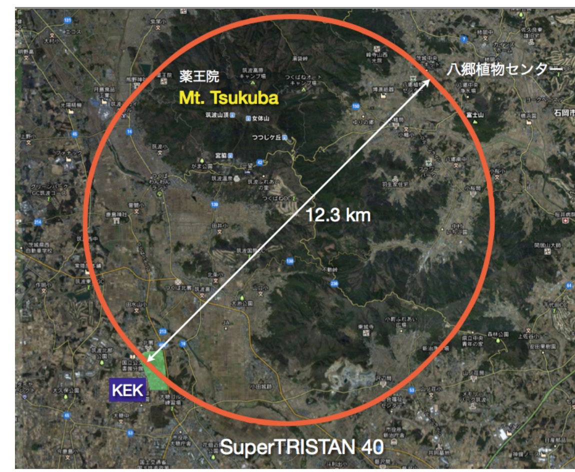
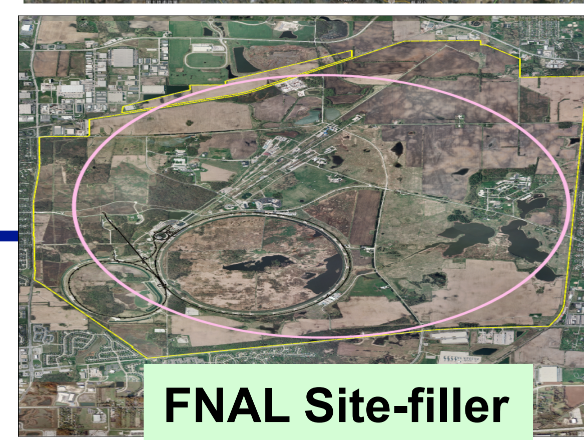
- **Circular e-e+ collider**

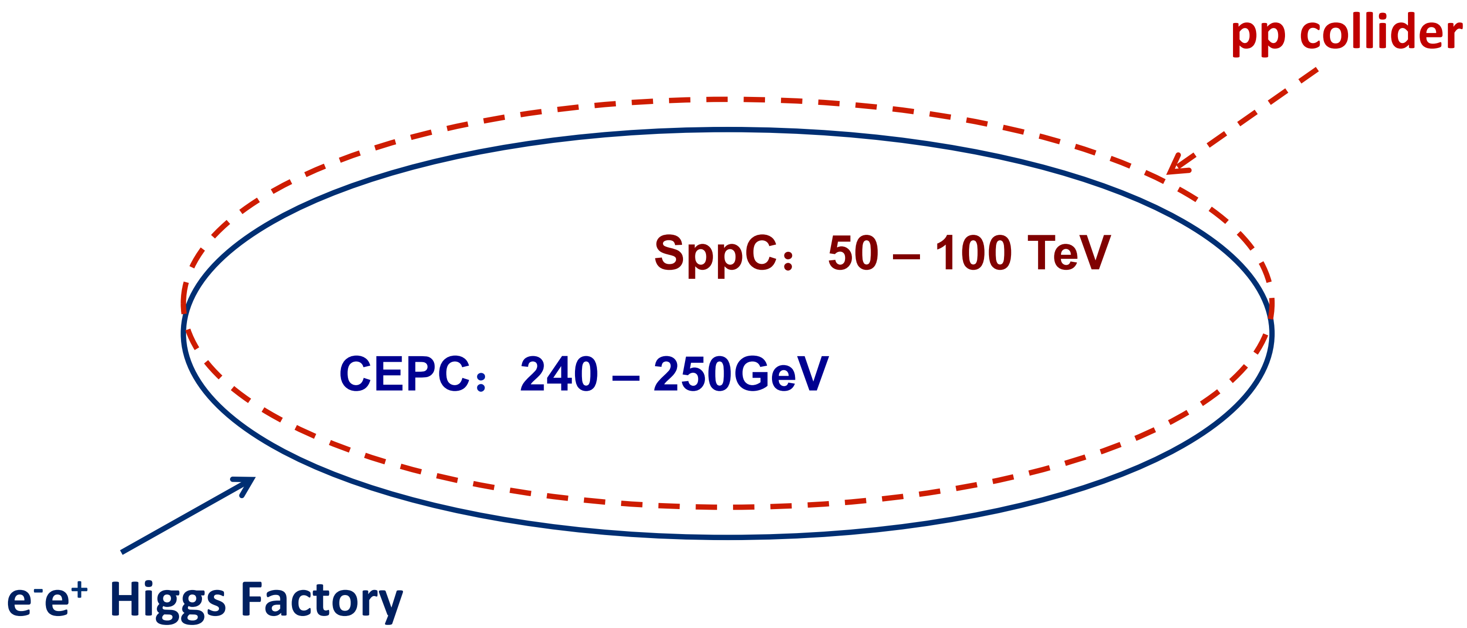
  - **LEP3**
  - **TLEP – FCC (hh, ee, …)**
  - **Super-Tristan**
  - **FNAL Site-filler**
  - **IHEP：CEPC+SppC**



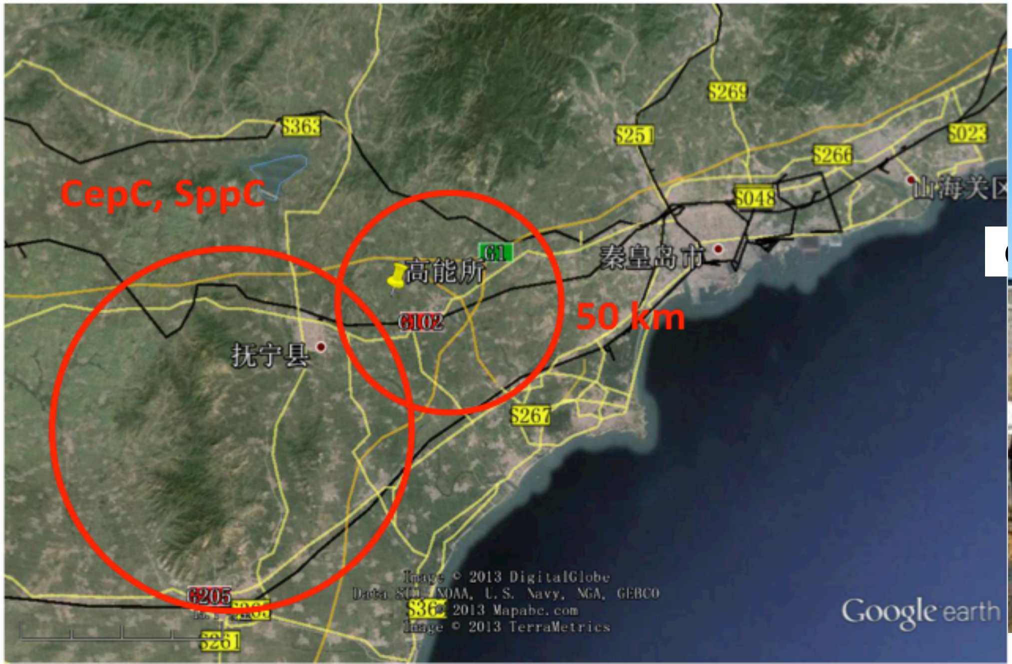




- **A CEPC (phase I) + SppC (phase II) was proposed in IHEP, Sept. 2012**



- **Possible site: Qinhuangdao, Hebei province**



Luminosity requirement

- $e^- - e^+$ collider :
  - Higgs produced above the ZH threshold
  - Collide at E_{cm}~240GeV， σ ~ 200 fb
  - Need 20000 events/yr/IP， i.e., 100 fb^{-1}/y —> $L = 10^{34} cm^{-2}s^{-1}$
- Muon collider
  - Higgs produced from s-channel
  - σ ~ 40 pb
  - 20000 Higgs/yr —> $L = 5*10^{31} cm^{-2}s^{-1}$

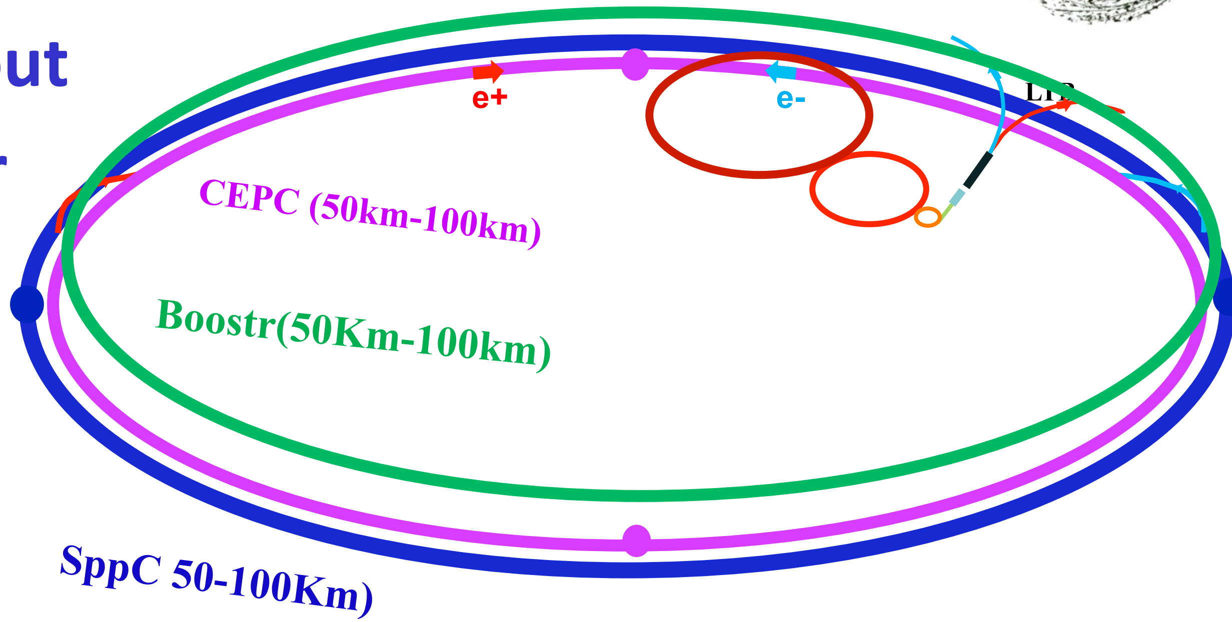
Design Goal

Possible circular collider

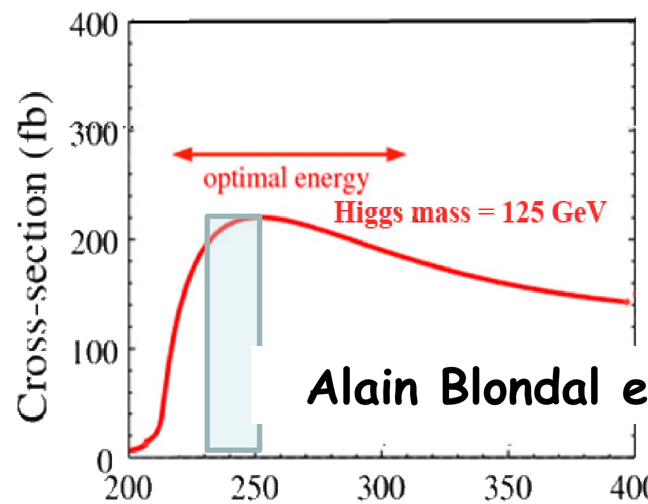
- In the existing tunnel:
  - LEP3, together w/LHC (27 km)
- Using lab field:
  - Fermilab Site Filler (16 km)
- Others：
  - DLEP (53 km), TLEP (80 km)
  - Super-Tristan (40, 60 km)
  - IHEP： CEPC+SppC (50, 70 km)
  - Very Large Lepton Collider (233 km in VLHC tunnel)
  - etc.

2. Main parameters and layout

- Schematic layout
- Linac + booster as injectors



- E_b=120GeV
  - Limited by beamstrahlung & SR (~125GeV)
- Cross-section = 200 fb



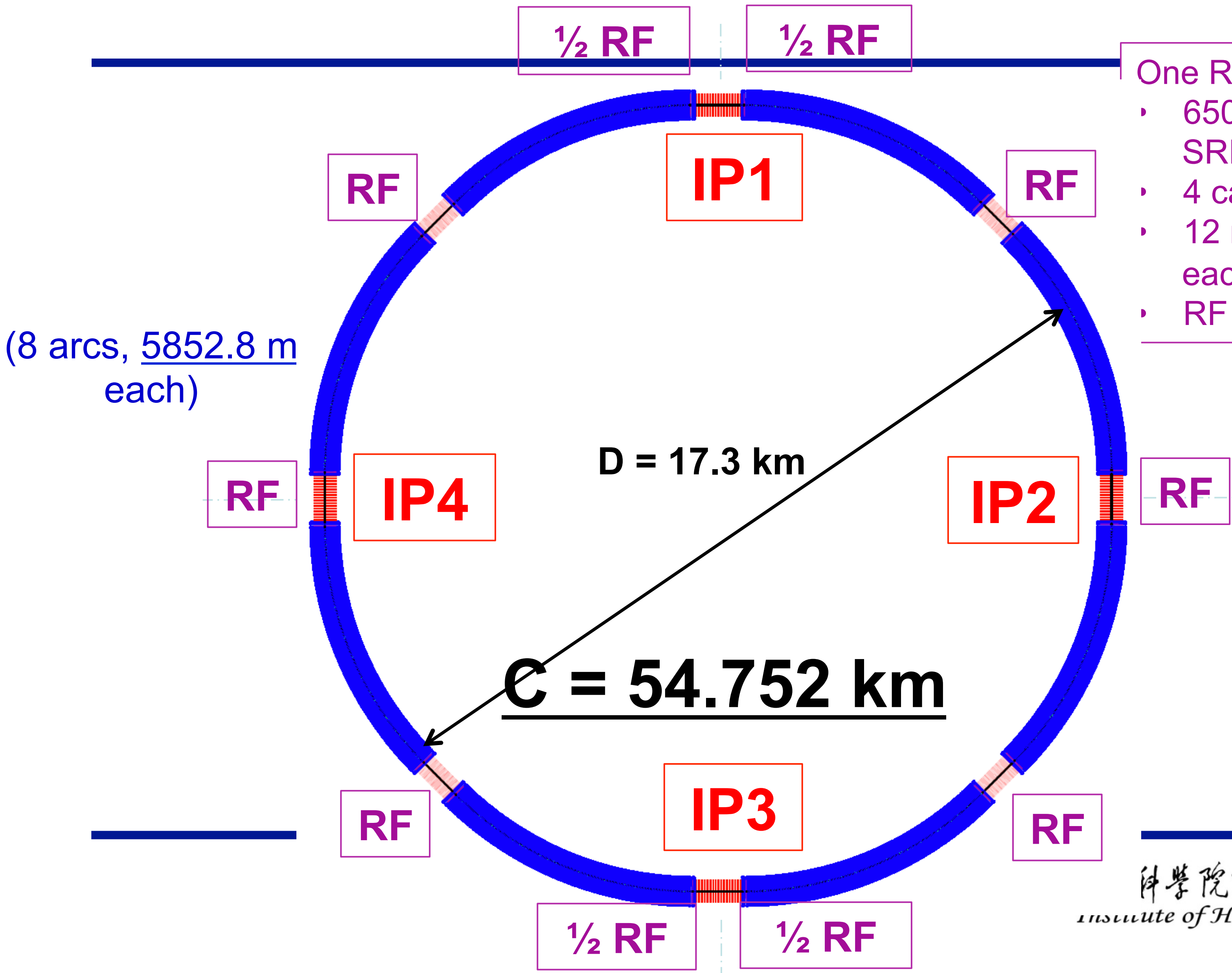
Alain Blondal et al

- Circumference
  - Determined by SppC beam energy
  - Assume Ecm=70-100TeV for new physics

Ec.m. (TeV)	B (T)	C (km)
70	12	~80
70	20	~50

- Beam power
  - 50 MW/beam, synchrotron radiation (51.7MW w/ FFS)
- Luminosity
  - $1\times10^{34}cm^{-2}s^{-1}$/IP

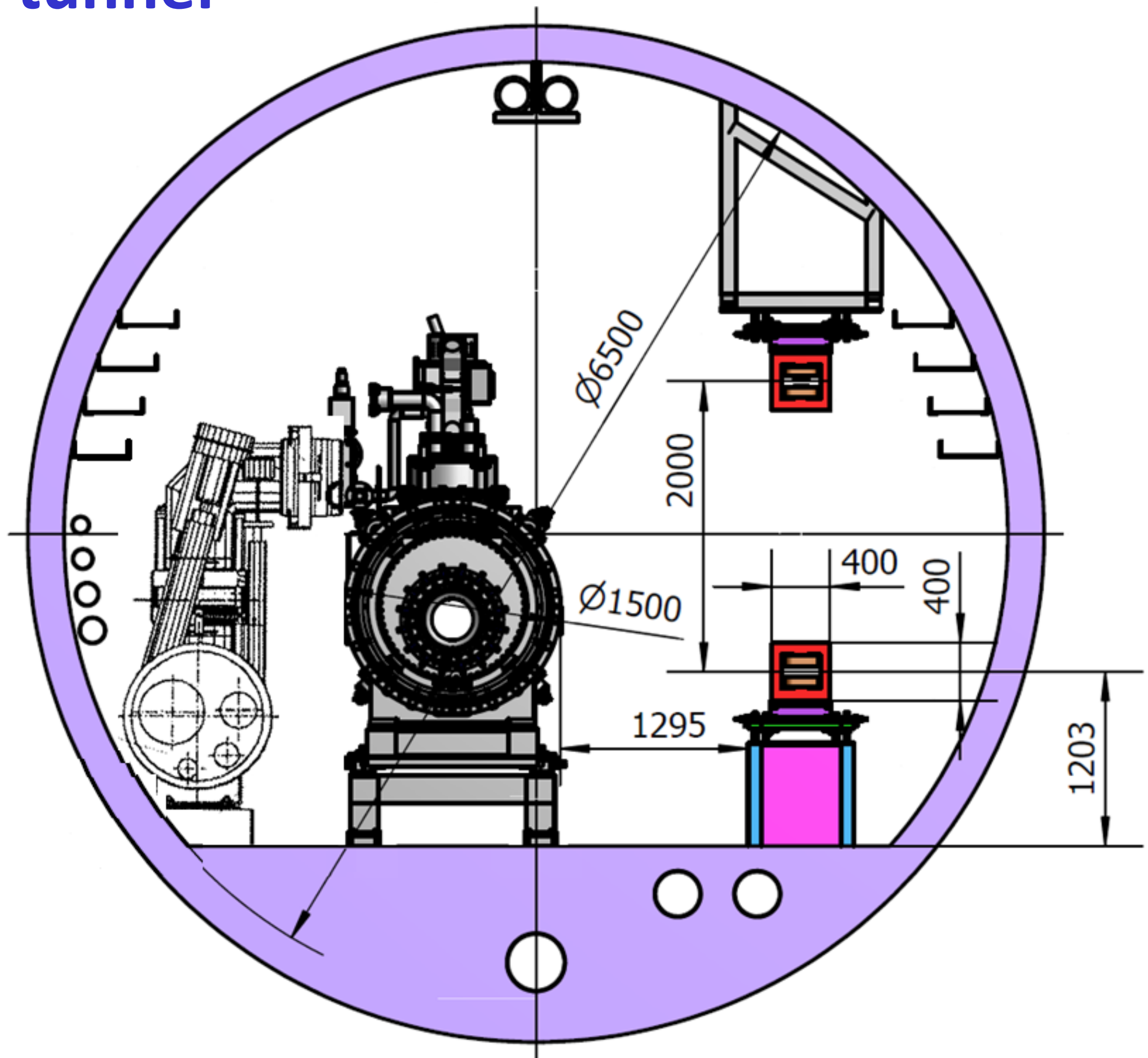
CEPC Lattice Layout (September 23, 2014)



One RF station:

- 650 MHz five-cell SRF cavities;
- 4 cavities/module
- 12 modules, 8 m each
- RF length 120 m

- 3 machines in one tunnel
  - CEPC & booster
  - SppC
- Crosstalk of CEPC straights & SppC's detector
- Layout of CEPC determined by SppC layout



- **Beam current:**

$$P[\mathrm{GW}] = C_\gamma \frac{E[\mathrm{GeV}]^4}{\rho[\mathrm{m}]} I[\mathrm{A}]$$

$$C_\gamma = 88.5\times10^{-6} \frac{\mathrm{m}}{\mathrm{GeV}^3}$$

$$P_{sr} = 51.7\mathrm{MW} \quad \Rightarrow \quad I = k_b I_b = 16.6\mathrm{mA}$$

- **Take filling factor of the ring = 0.7 ⇨ ρ = 6.1km**

Beamstrahlung[*]

- **Beamstrahlung fractional energy spread:**

$$\delta_{BS} = \frac{2r_e^3 N_e^2 \gamma F}{3\sigma_x \sigma_y \sigma_z} \qquad R = \frac{\sigma_x}{\sigma_y}, F(R=1) = 0.325, F(R>>1) \approx \frac{1.3}{R}$$

- **Beamstrahlung bending radius :** $\rho \approx \frac{\gamma \sigma_x \sigma_z}{2r_e}$

$$\frac{E_c}{E_0} = \frac{3\gamma r_e^2 N}{\alpha \sigma_x \sigma_z} \qquad u = \frac{\eta E_0}{E_c} \qquad n_{col} \approx 10 \frac{\sqrt{6\pi} r_e \gamma u^{3/2}}{\alpha^2 \eta l} e^u$$

the collision length $l \approx \sigma_z / 2$ **for head-on and** $l \approx \beta_y / 2$ **for crab waist collision**

[*] V.I. Telnov, PRL 110, 114801 (2013).

Luminosity & coupling coefficient

$$L_{\text{limit}} = 0.4565\times10^{34}\,\text{cm}^{-2}\text{s}^{-1}\,\frac{\rho(\text{km})P_{\text{SR}}(100\text{MW})\sqrt{\delta_{\text{BS}}(0.1\%)}}{(E/100\text{GeV})^{4.5}\sqrt{\varepsilon_y(\text{nm})}}$$

$$= 0.4565\times10^{34}\,\text{cm}^{-2}\text{s}^{-1}\,\frac{\rho(\text{km})P_{\text{SR}}(100\text{MW})}{(E/100\text{GeV})^{4.5}}\cdot\frac{\sqrt{\delta_{\text{BS}}(0.1\%)}}{\sqrt{r\varepsilon_x(\text{nm})}}$$

- **Take P_{SR} = 50MW, E = 120GeV, ε_x = 6.12nm,**
  r = 0.003 (empirical value)

Bunch number, particle number, emittance, etc., will be discussed in other talks in this workshop.

RF frequency and voltage

- Energy spread and acceptance due to SR $\sigma_e = \gamma\sqrt{\frac{C_q}{J_e \rho}}$ $\eta = \sqrt{\frac{U_0}{\pi \alpha_p h E} F_q}$
- Synchrotron tune and bunch length: $\nu_s = \sqrt{-\frac{\alpha_p h V_{rf} cos\varphi_s}{2\pi E}}$ $\sigma_z = \frac{\alpha_p R \sigma_{e0}}{\nu_s}$
- RF station distribute around the ring due to energy saw tooth
- Lifetime from beamstrahlung:

$$E_{cb} = \frac{3\gamma r_e^{\ 2} N_e E}{\alpha \sigma_x \sigma_z},\ u = \frac{\sigma_e E}{E_{cb}},\ n_{col} = \frac{20\sqrt{6\pi} r_e \gamma u^{3/2}}{\alpha^2 \sigma_e \sigma_z} \mathrm{e}^u$$

$$\tau = n_{col} T_0$$

Main parameters for CEPC

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 [r]	m	6094	momentum compaction [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)	mm	69.97/0.15	$\xi_{x,y}$/IP		0.118/0.083
Beam length SR [$\sigma_{S.SR}$]	mm	2.14	Beam length total [$s_{s.tot}$]	mm	2.88
Lifetime due to Beamstrahlung	min	47	Lifetime rad. Bhabha [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 [Je]		2
Energy spread SR [$\sigma_{d.SR}$]	%	0.132	Energy spread BS [$\sigma_{d.BS}$]	%	0.119
Energy spread total [$\sigma_{d.tot}$]	%	0.177	n_γ		0.23
Transverse damping time	turns	78	Longitudinal damping time [τ_e]	turns	39
Hourglass factor	F_h	0.658	Luminosity /IP[L]	$cm^{-2}s^{-1}$	1.98E+34

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3. Accelerator Physics Issues

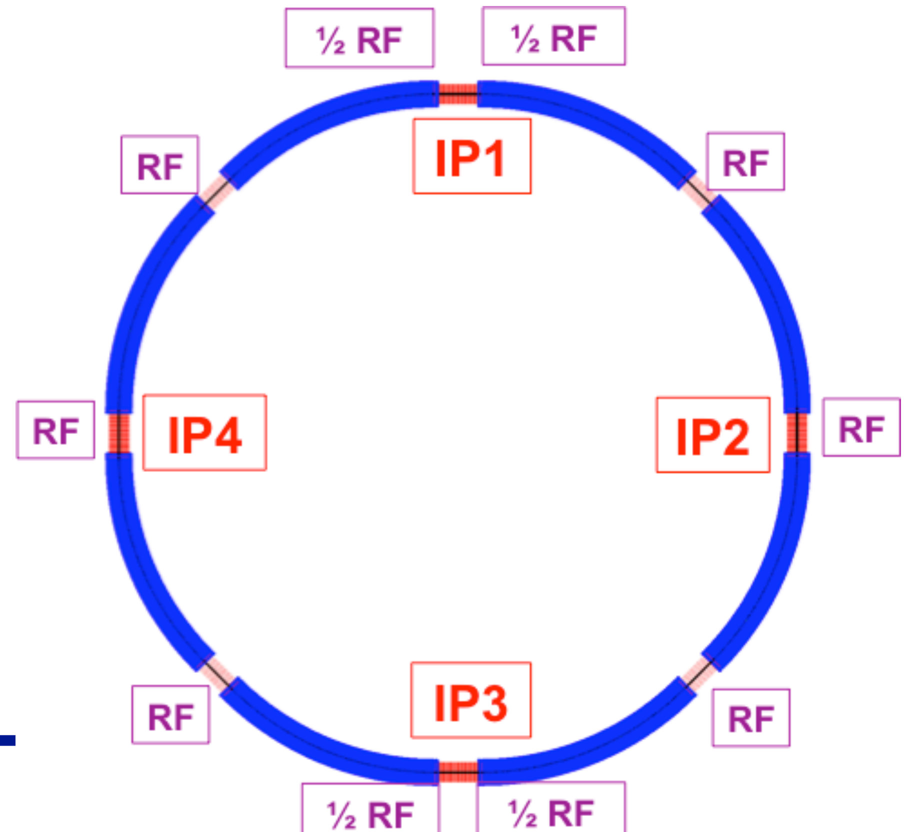
- **Lattice Design**

In current design:

- **Circumference: 54.7 km**
- **8 arcs**
- **8 straight sections**
- **2 IRs**
- **Filling factor: ~0.7**

➢ 8 RF sessions

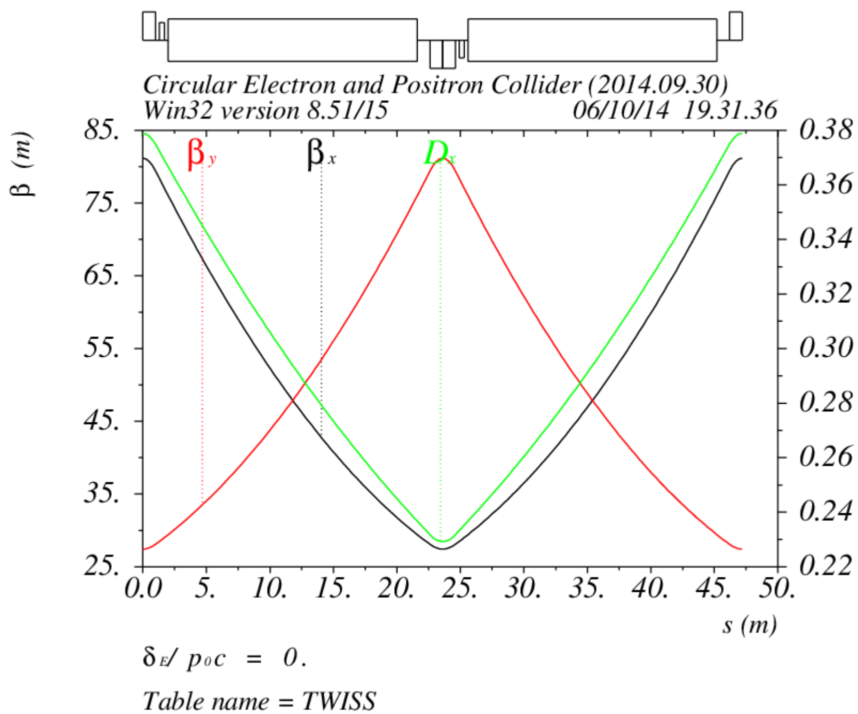
Not fixed yet !

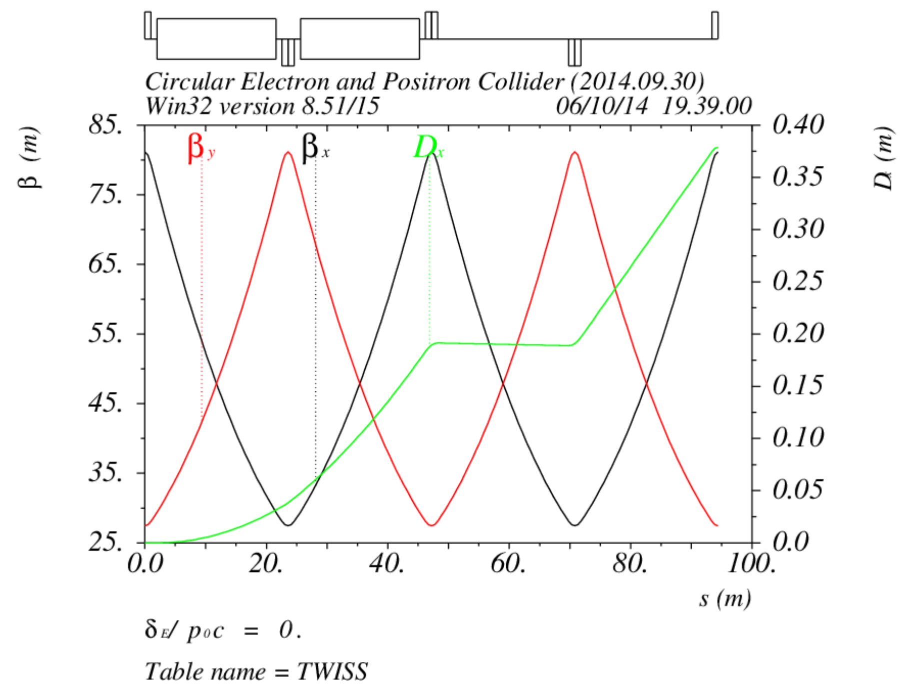


Lattice of arc sections

- **Length of FODO cell: 47.2m**
- **Phase advance of FODO cells: 60/60 degrees**

- Dispersion suppressor on each side of every arc
- Length: 92.4m





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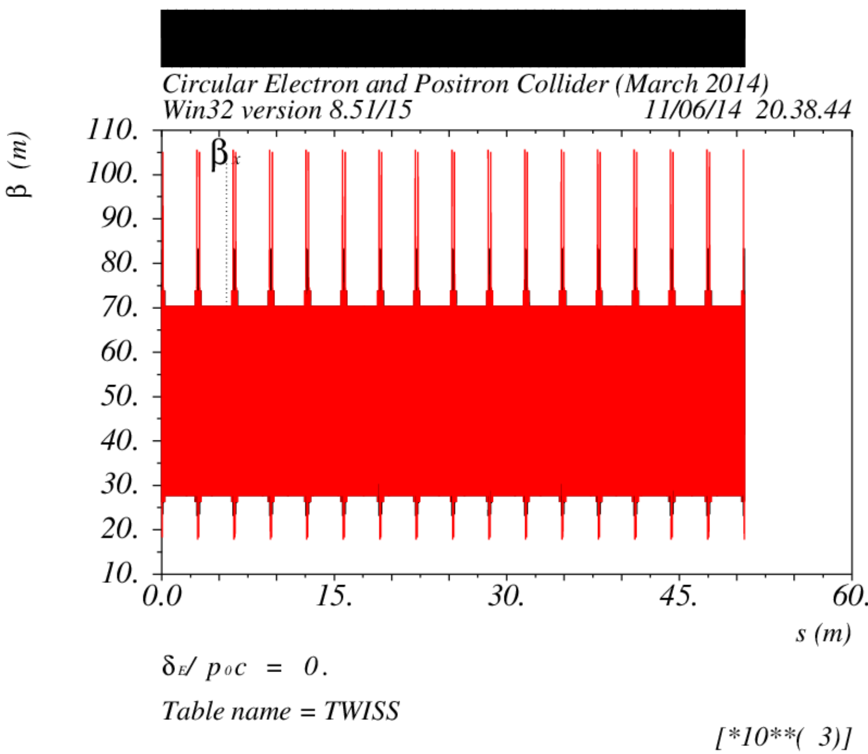
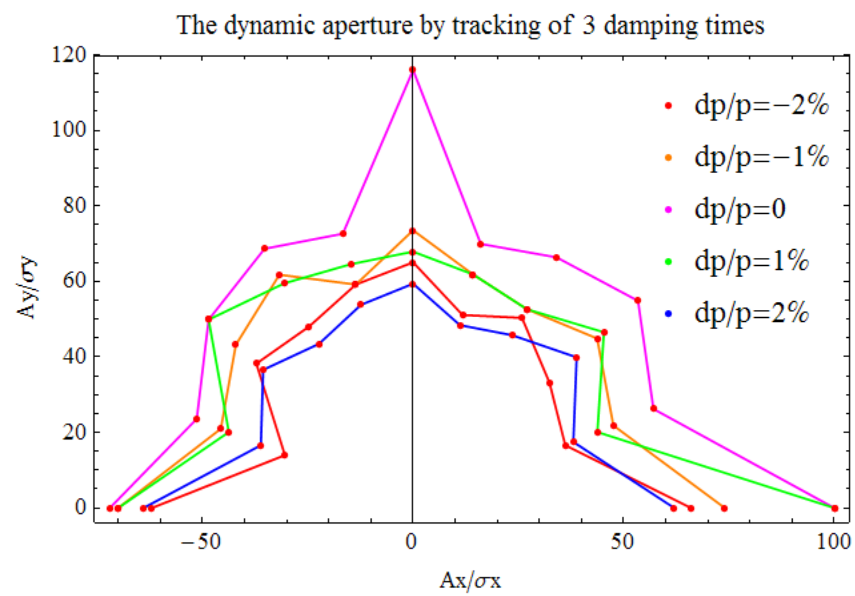
More details on lattice design, see Geng's talk.

Dynamic aperture (w/o FFS)

- 2 sextupole families are applied to correct chromaticity
- dynamic aperture: ~60σ_x in hori. ~60σ_y in vert.
- ±2% momentum deviation





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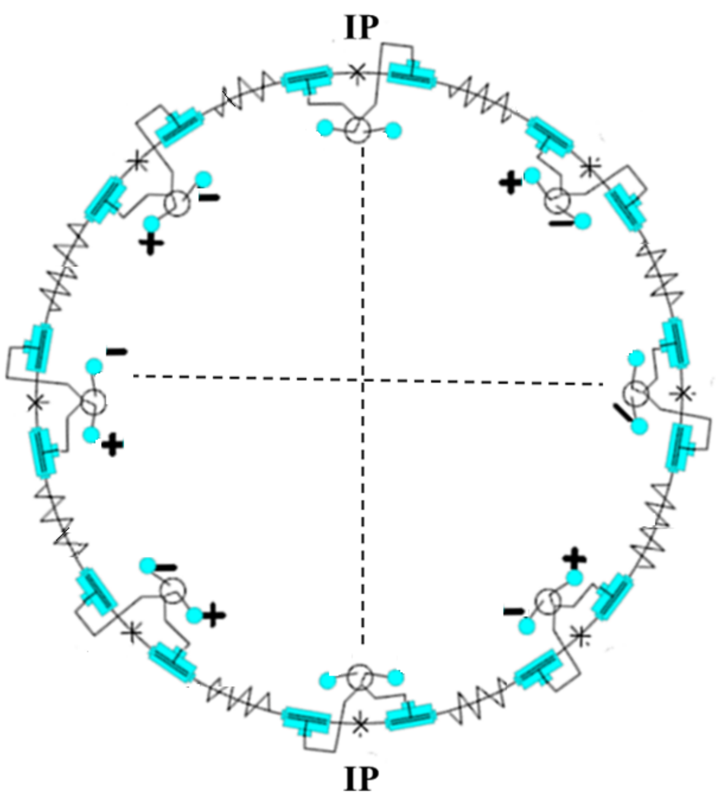
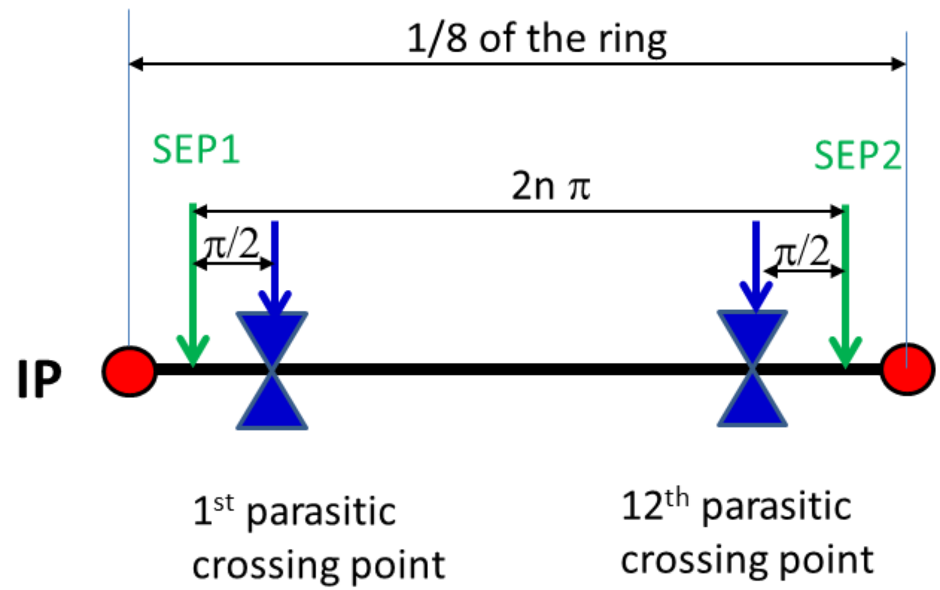
Pretzel scheme (1)

- No orbit in RF section to avoid beam instability and HOM in the cavity
- One pair of electrostatic separators for each arc





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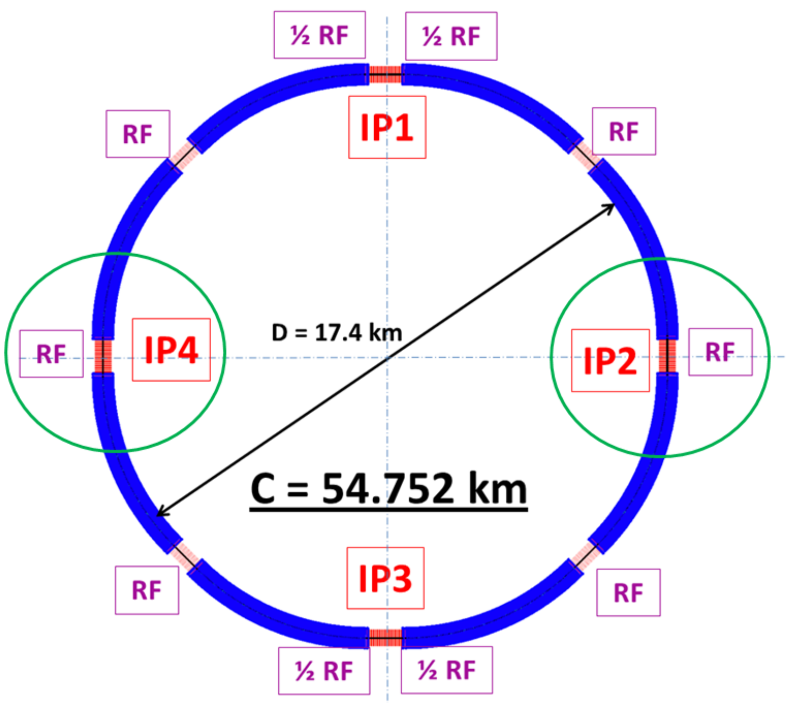
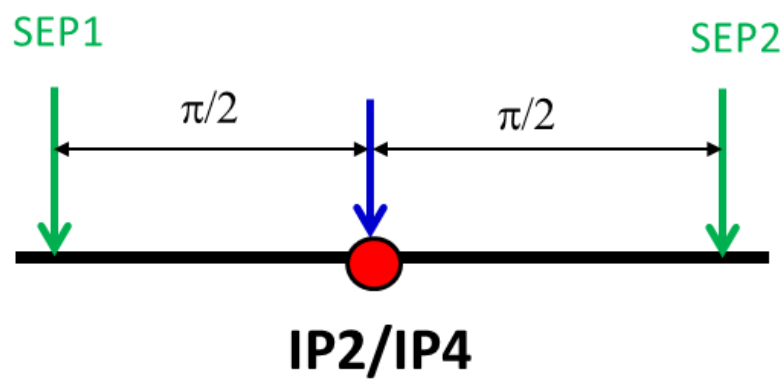
Pretzel scheme (2)

- IP2 and IP4 are parasitic crossing points, but have to avoid collision
- Two more pairs of electrostatic separators for IP2 and IP4





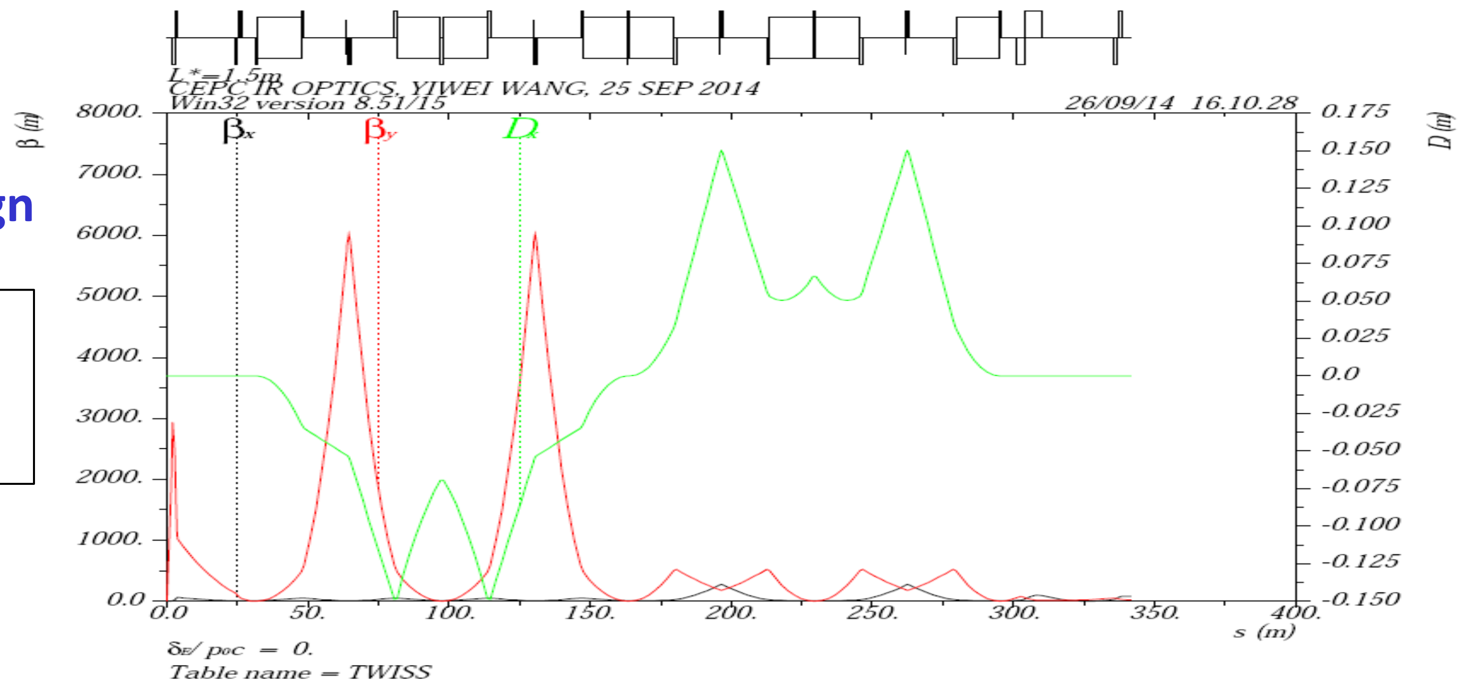
More details, see Geng's talk

FFS in CEPC

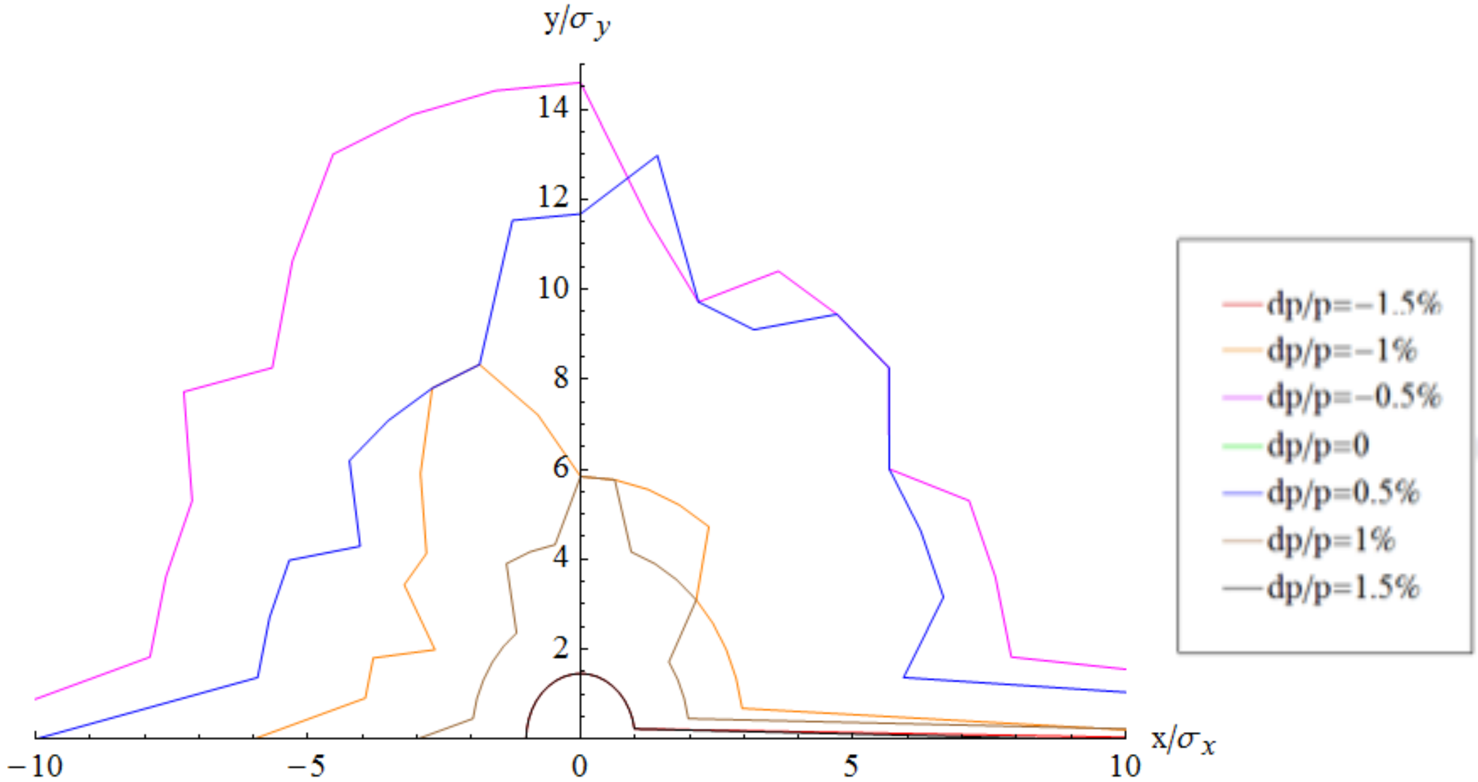
- Functions of Interaction Region (IR) optics
  - Provide very small beta function to achieve very small beam size: β_y*=1.2mm, σ_y*=0.16um, for CEPC
  - Correct large chromaticity due to small beta function: W~L*/ β_y*

Based on Yunhai's design

L*=1.5m
βx*=0.8m
βy*=1.2mm



Dynamic aperture with FFS

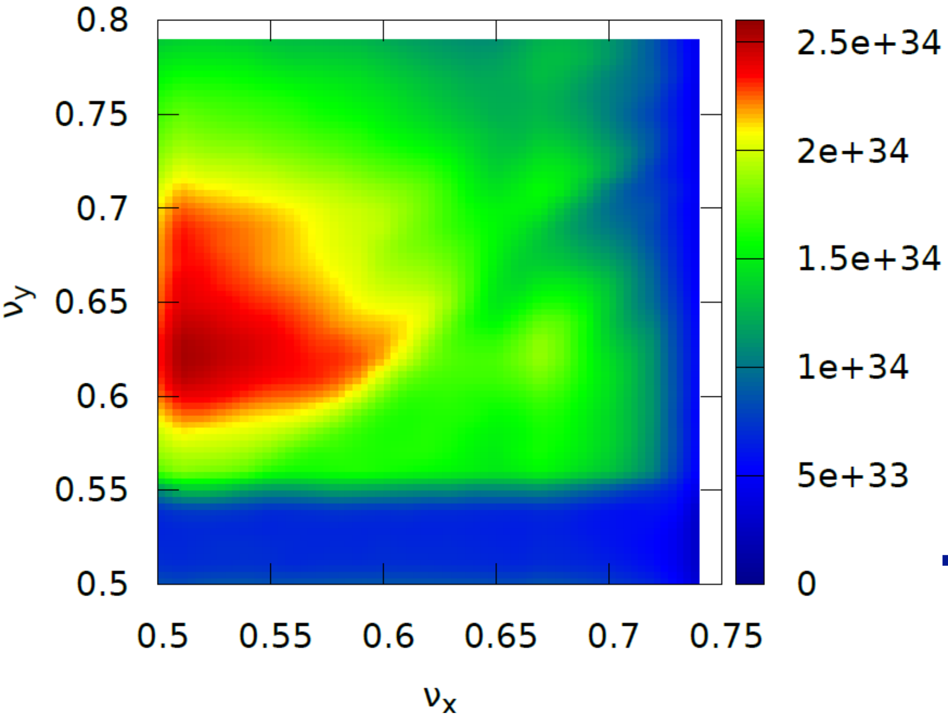


More details, ref to Y.W. Wang's talk

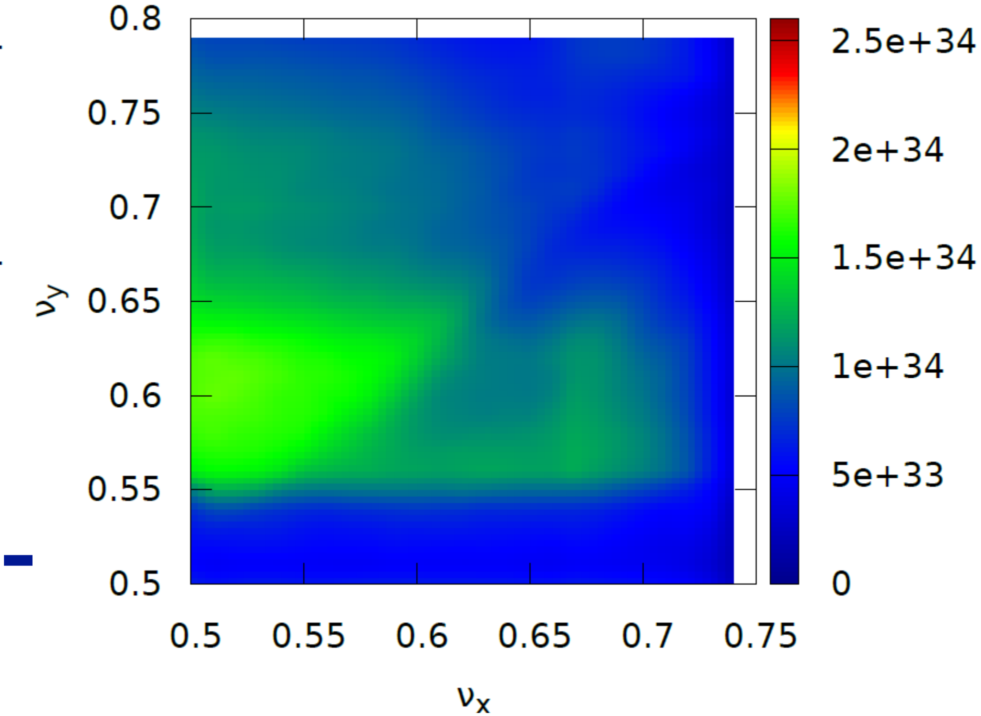
Beam-beam study

- **Tune scan (studied with Yuan Zhang's code)**

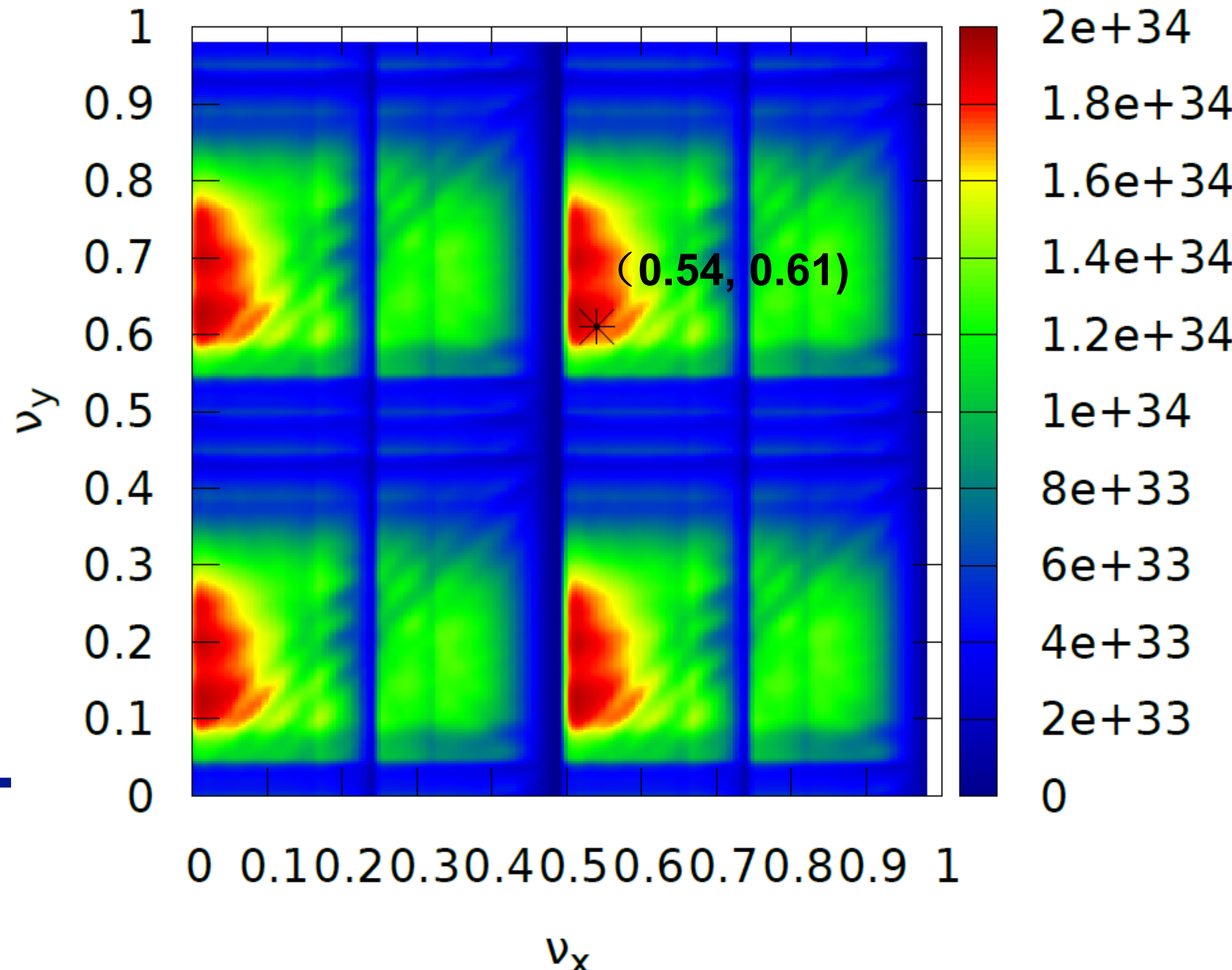
Beamstrahlung OFF



Beamstrahlung ON



- **Working point**



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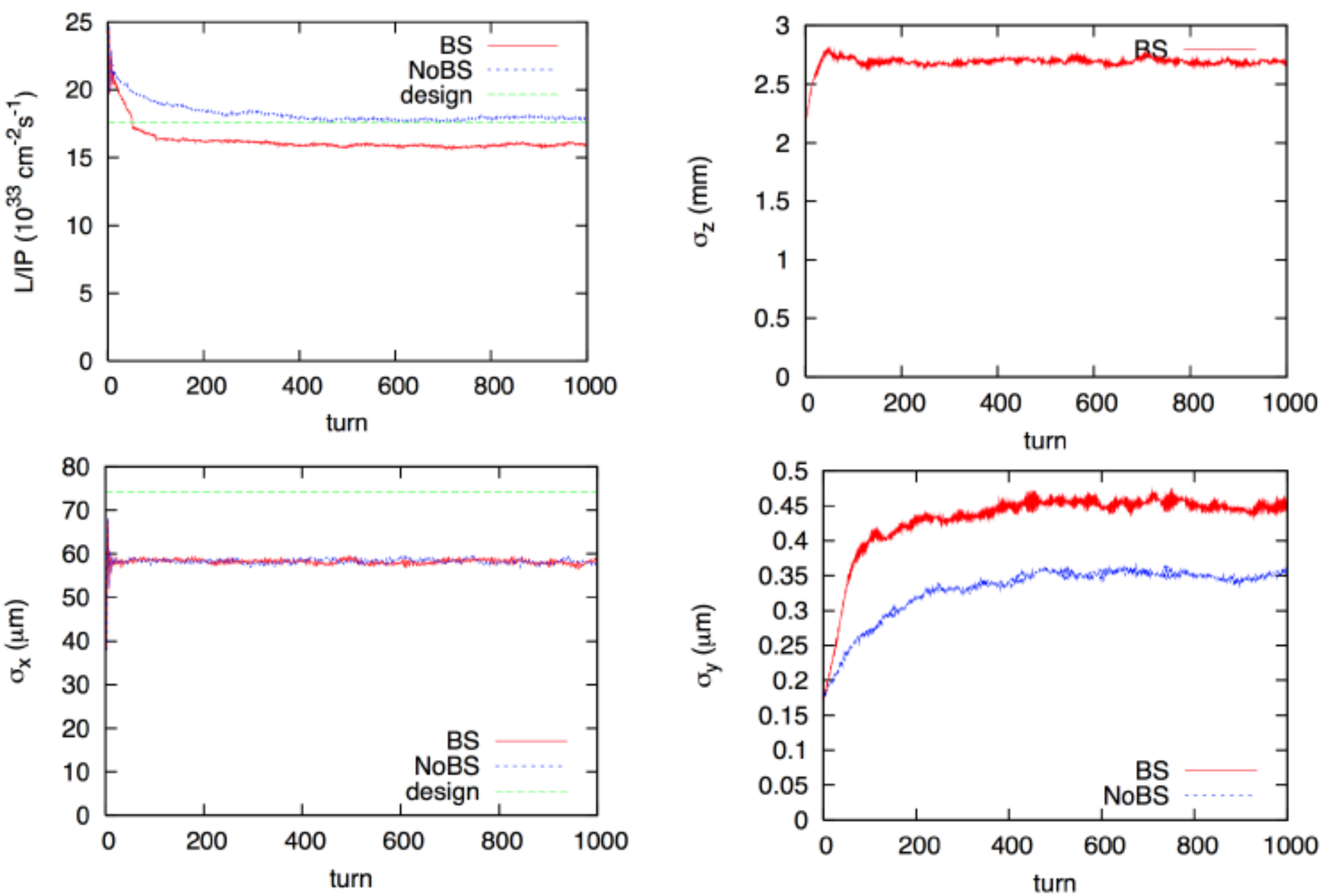
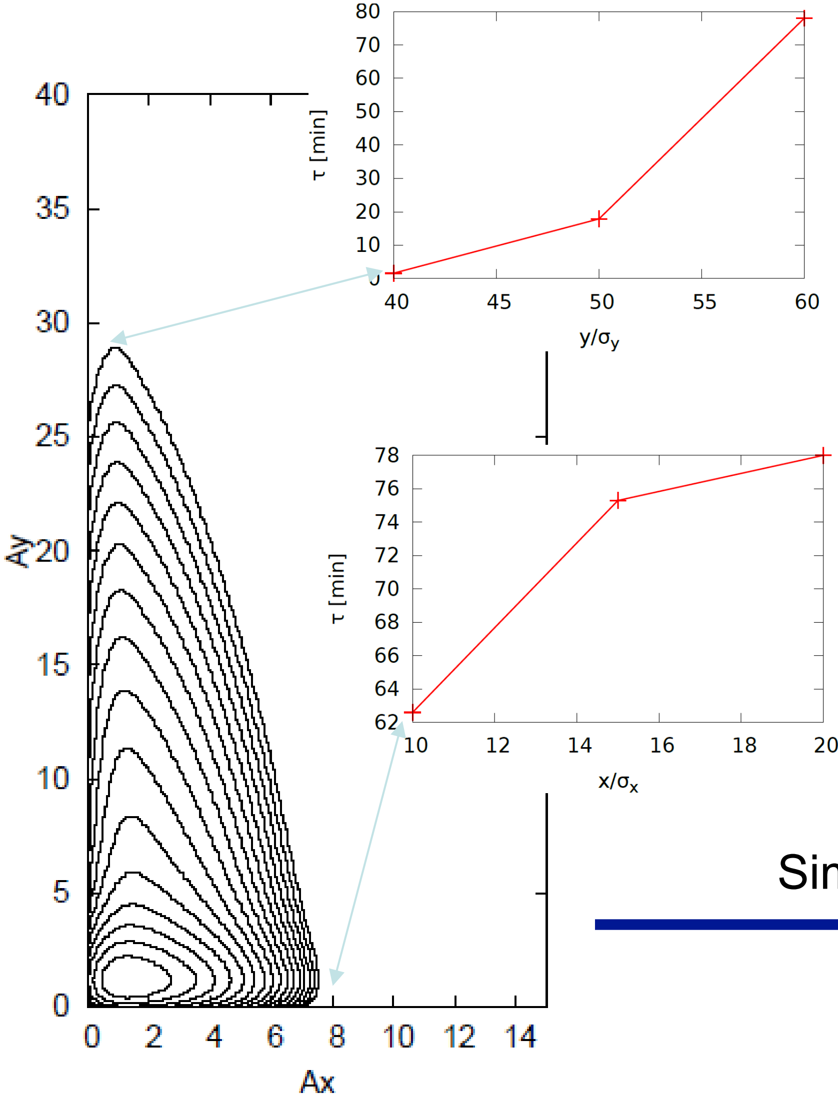
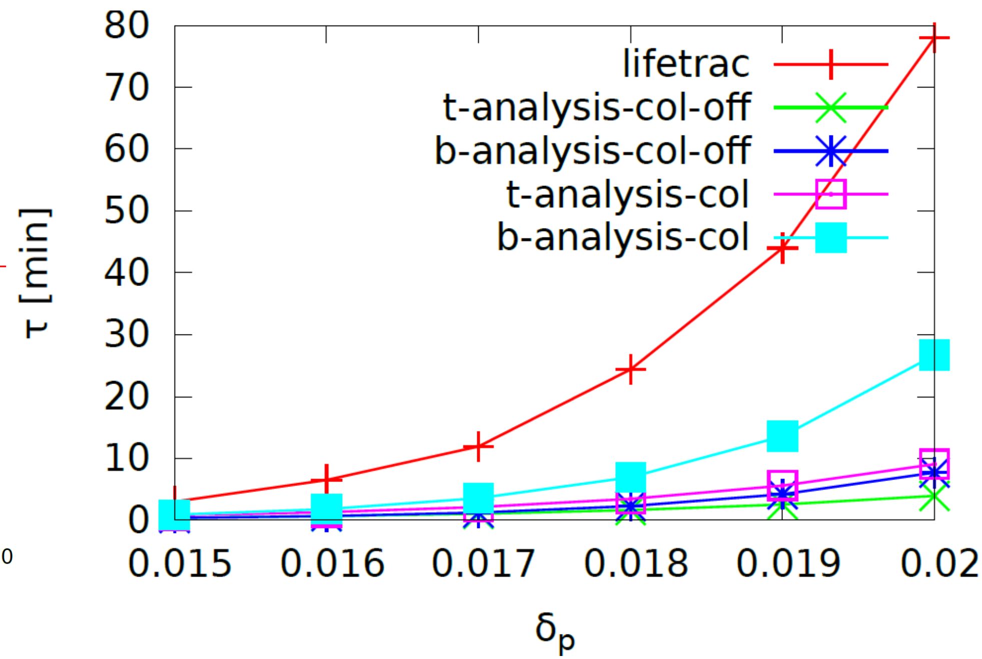
- **Working points from beam-beam simulation**

(.54， .61)



• Beam Lifetime vs dynamic aperture





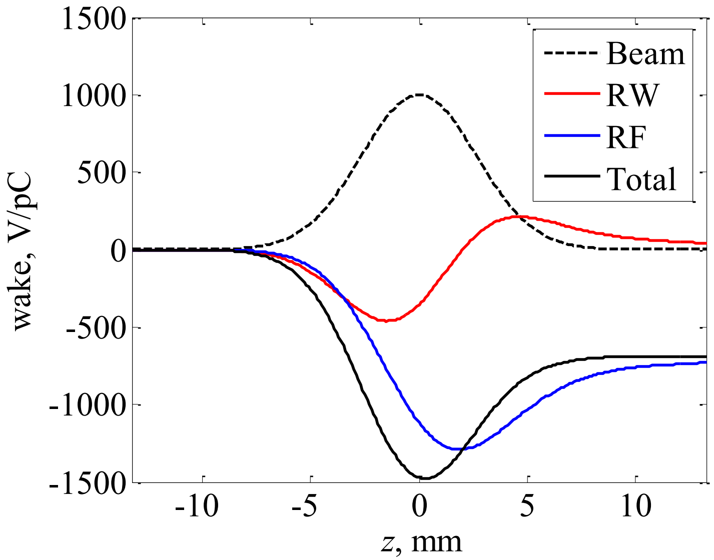
Simulation & analysis not so consistent

More details, ref. to Y. Zhang's talk

Collective effects

- CEPC ring wake and impedance budget

	R [kΩ]	L [nH]	k_{loss} [V/pC]	$\|Z_{//}/n\|_{eff}$ [Ω]
Resistive wall (Al)	9.5	124.4	301.3	0.0044
RF cavities (N=400)	28.1	--	893.9	---
Total	37.6	124.4	1195.2	0.0044



Longitudinal wake at nominal bunch length (σ_z=2.66mm)

- **The longitudinal wake is fitted with the analytical model**

$$W(s) = -Rc\lambda(s) - Lc^2\lambda'(s)$$

- **The loss is dominated by the RF cavities.**
- **The imaginary part of the RF cavities is capacitive.**

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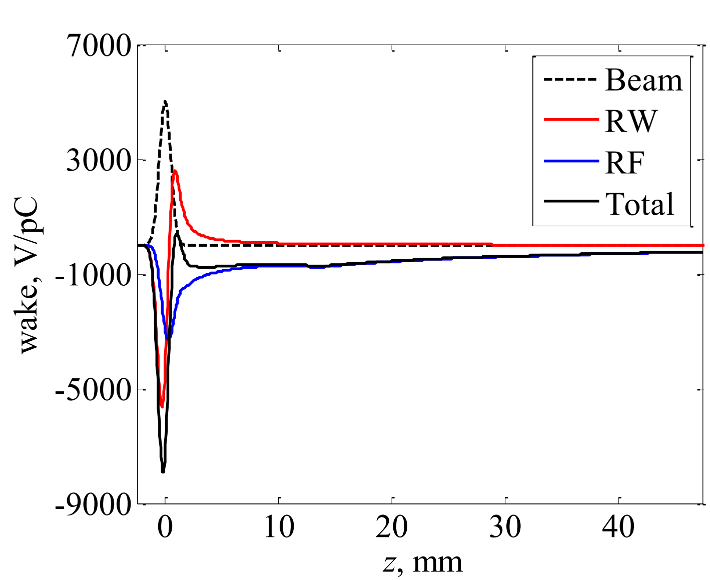
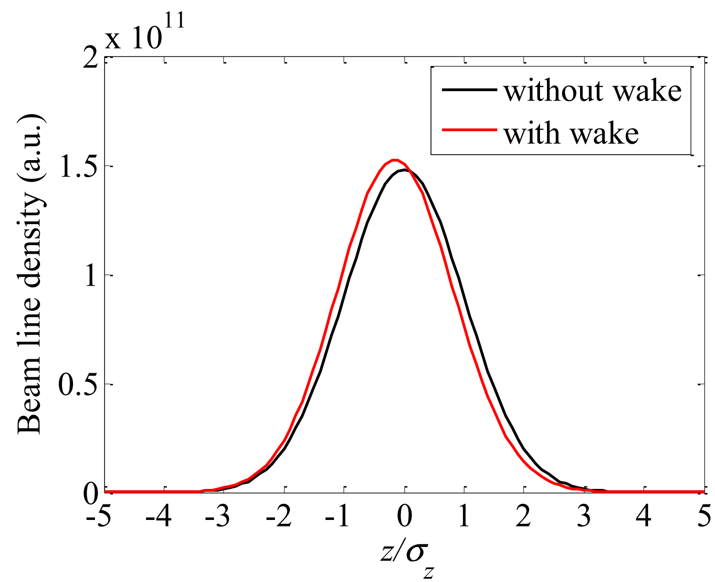
- **Bunch lengthening**
  - Steady-state bunch shape is obtained by Haissinski equation
  - Bunch is shortened due to the capacitive impedance of the RF cavity(only resistive wall and RF cavity considered)

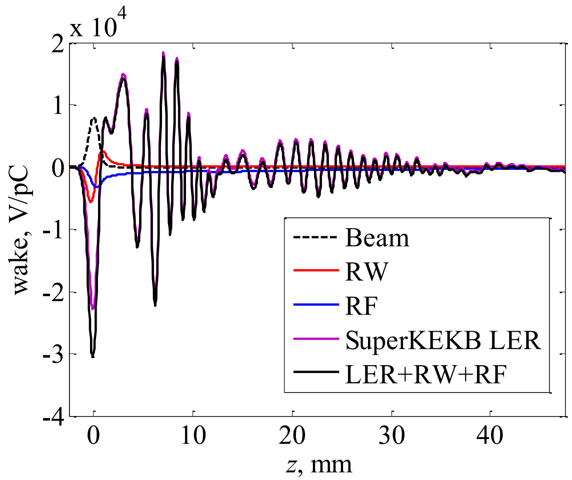


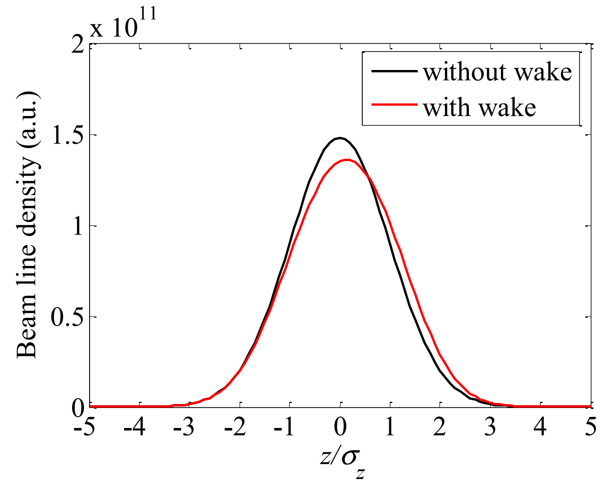
Pseudo-Green function wake (σ_z=0.5mm)



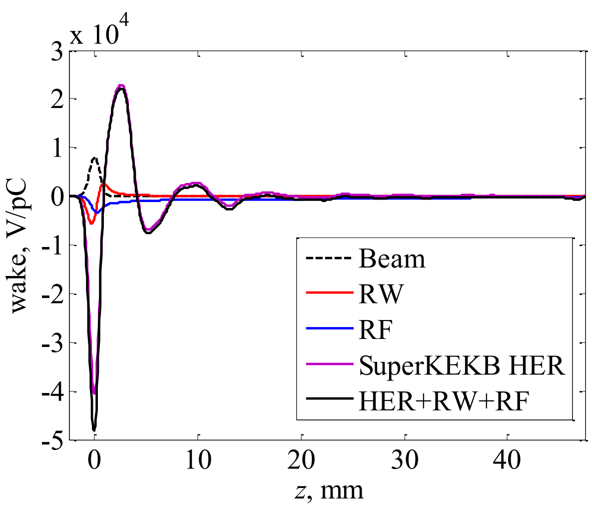
Steady-state bunch shape

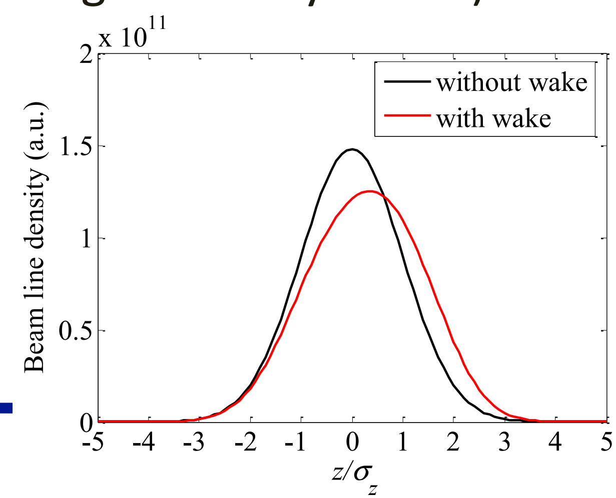
- Bunch lengthening with scaled SuperKEKB's geometry wake
  - Scaled LER wake+RW+RF (bunch is lengthened by 10-20%)





  - Scaled HER wake+RW+RF (bunch is lengthened by 18.5%)





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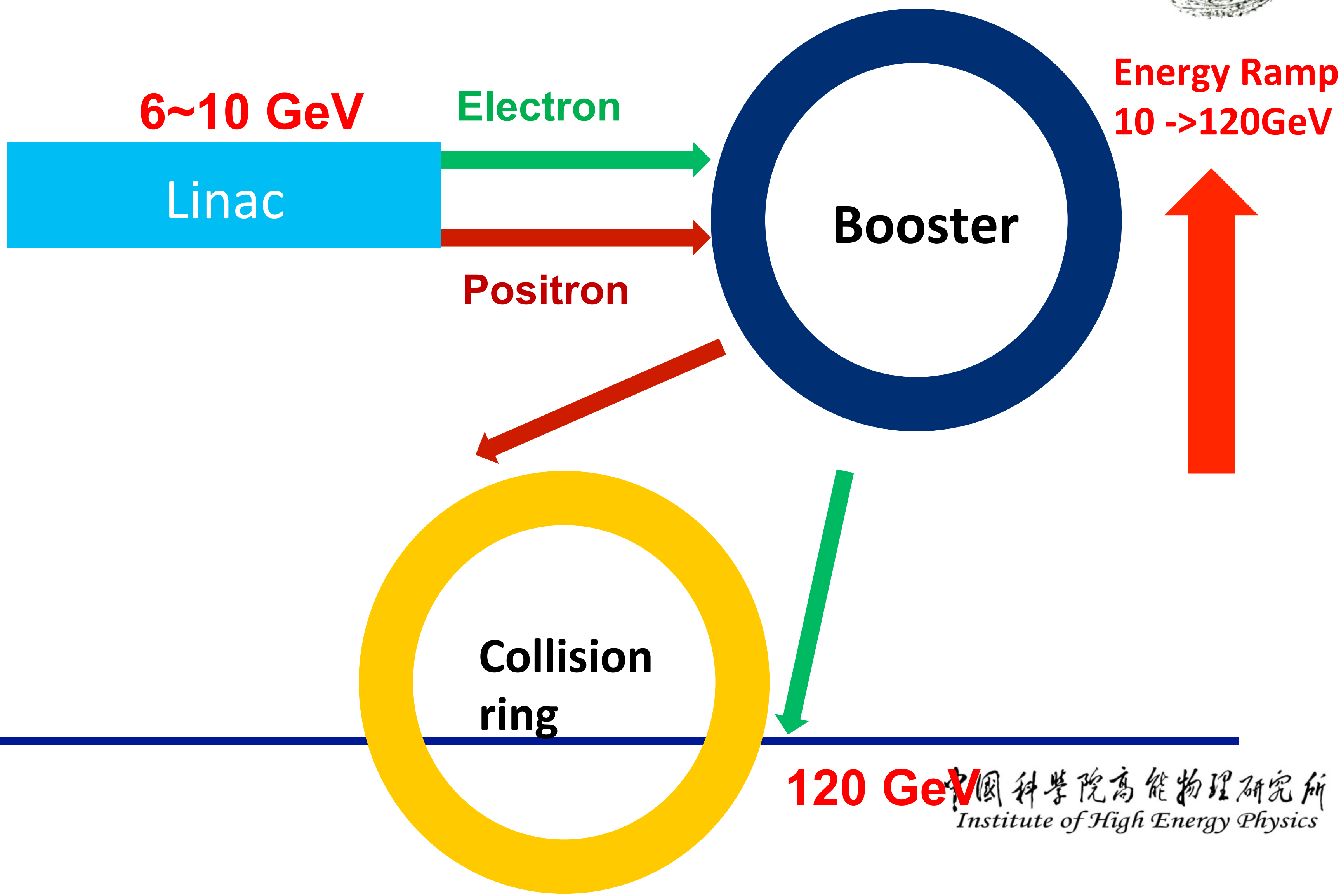
The scaling factor is Cir (CEPC)/Cir(SuperKEKB)=54.7e3/3016.315

- CSR, TMCI are not serious with very rough estimate
- Ion instability, ECI, will be less affected due to the other counter-rotating beam in the same vacuum chamber
- Due to pretzel scheme, when a beam cross a resonator (eg. RF cavity), the wake field excited by the beam will affect the other beam, i.e., the two beams will cross talk to each other.
- Some new phenomena: beam tilt effect

More details in Na Wang's talk

Injection



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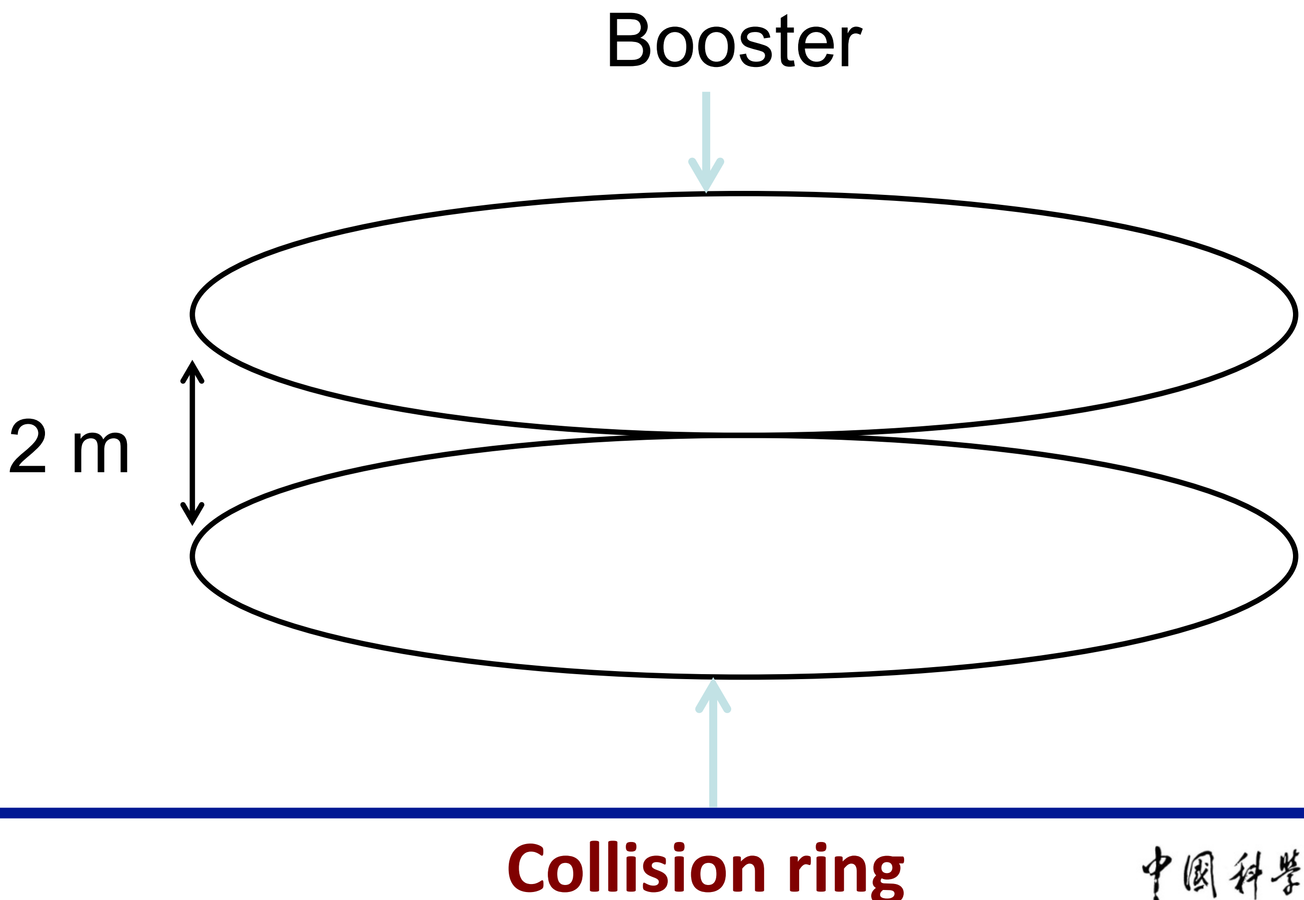
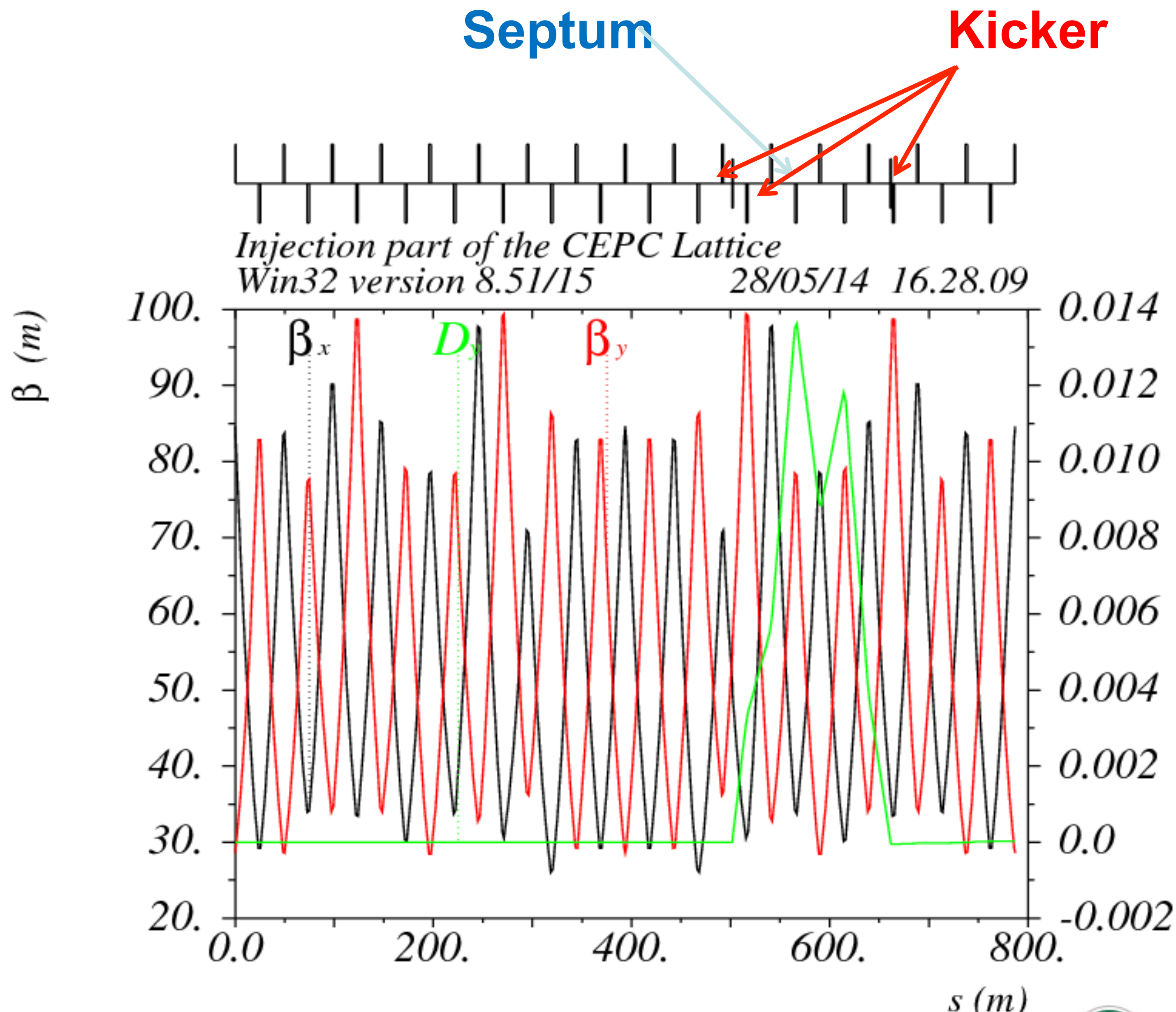
Geometrical Arrangement

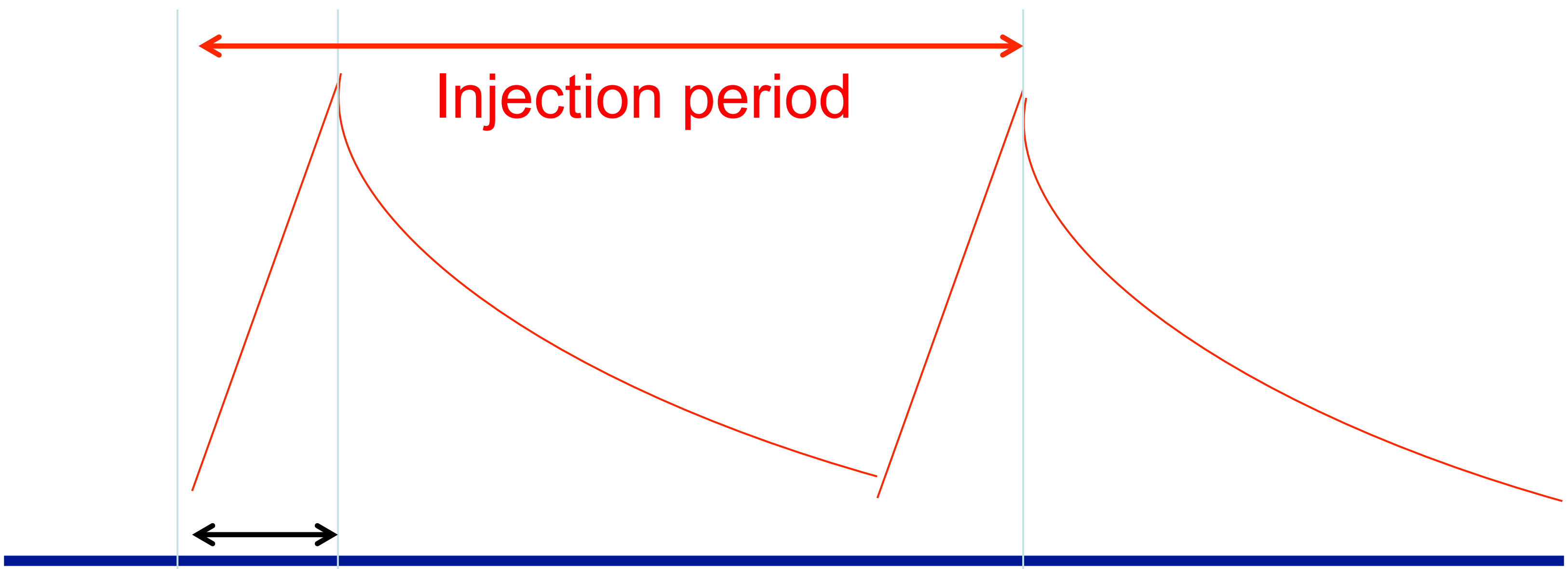




Twiss Parameters of the injection region

Injection time structure

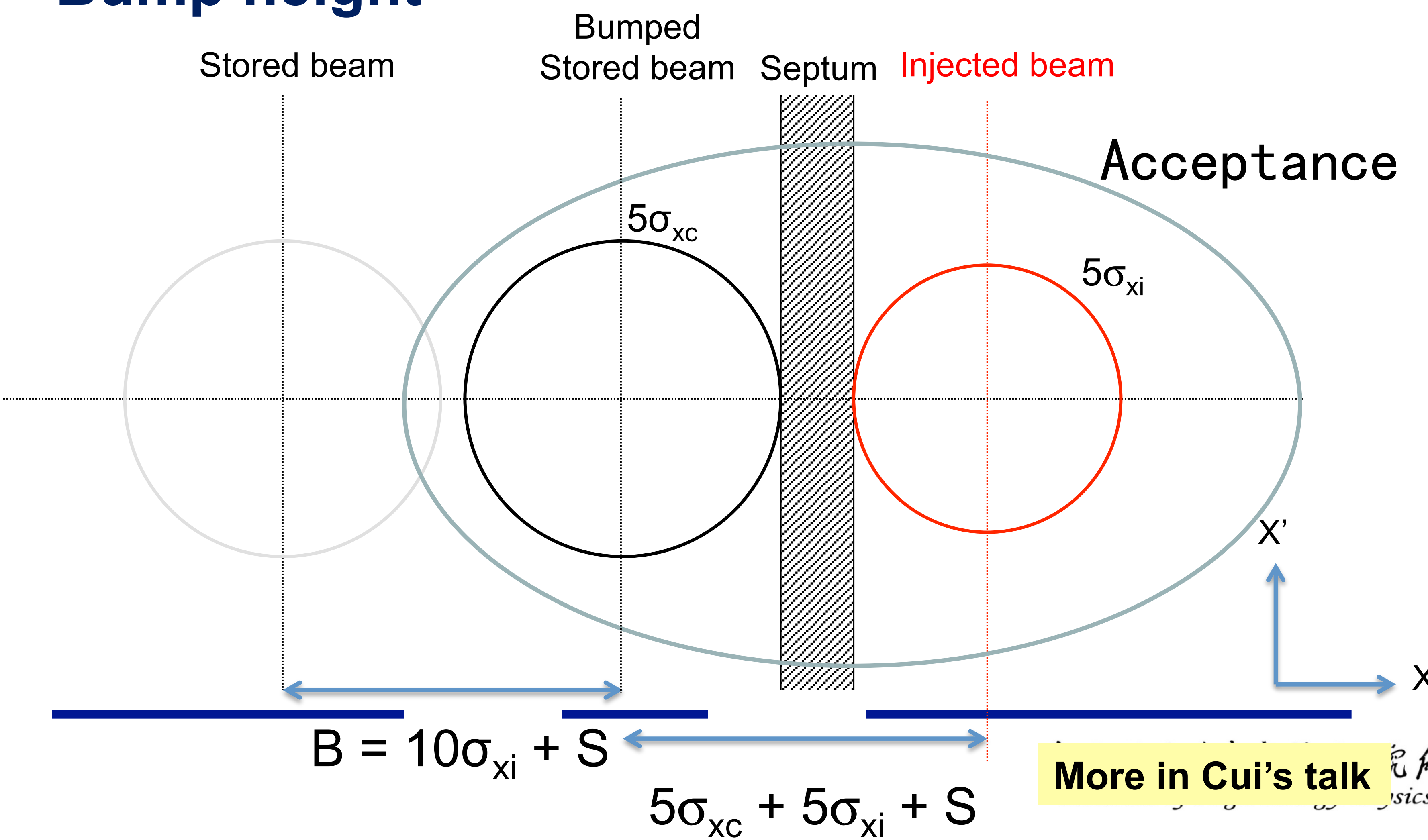
T_{life}(s)	Lum Drop	dN	$f_{injection}$(s)
1800	10%	9E11	90s



Injection time
~10s：

Injection Options

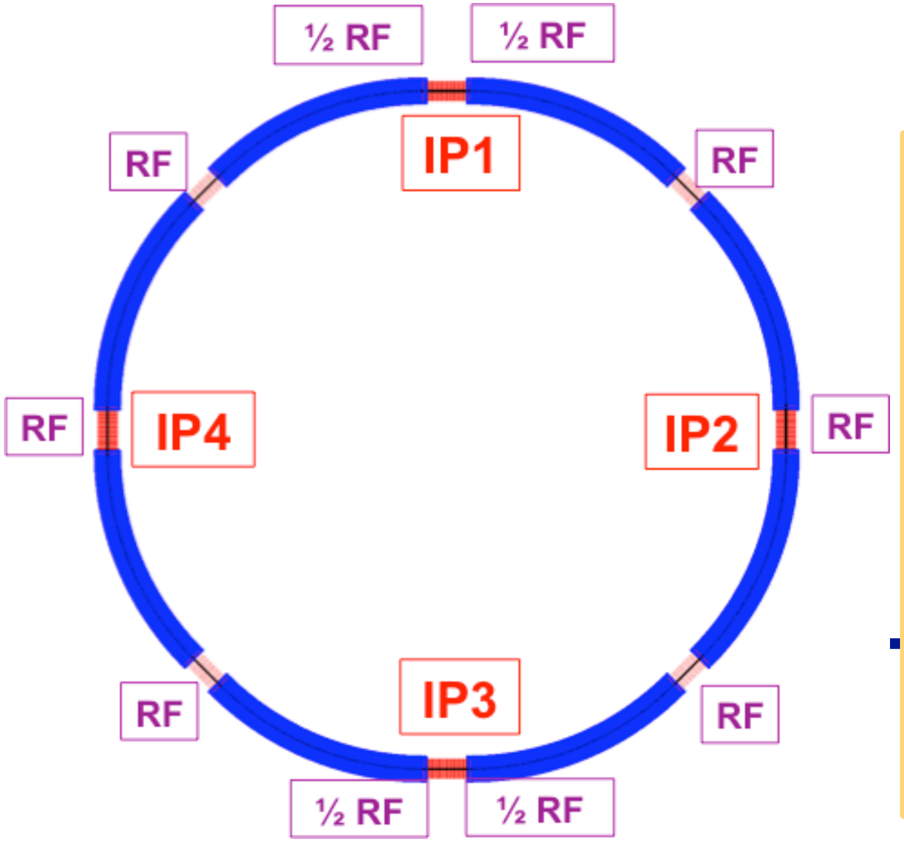
Bump height

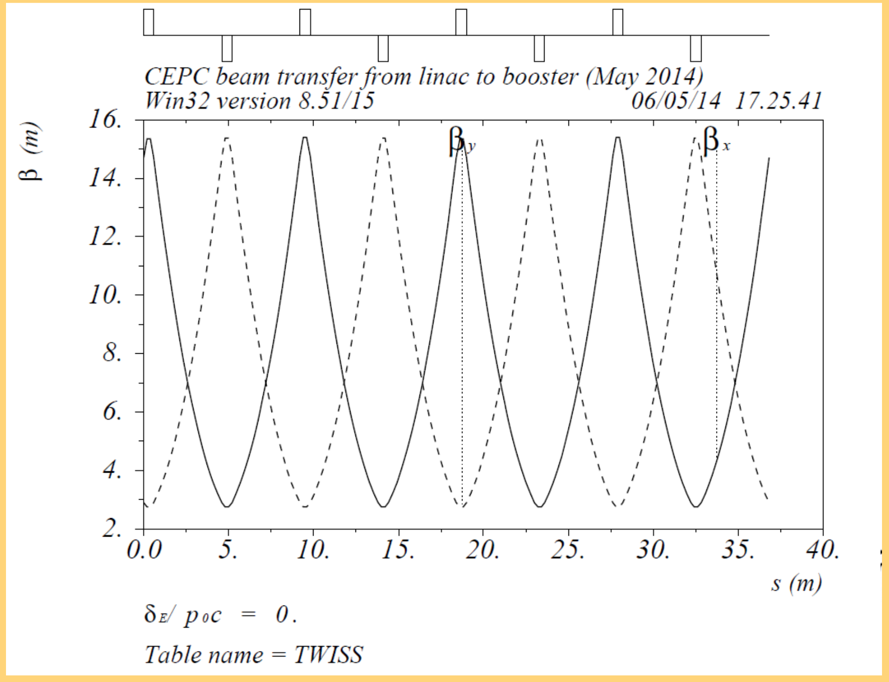


More in Cui's talk

Booster & linac

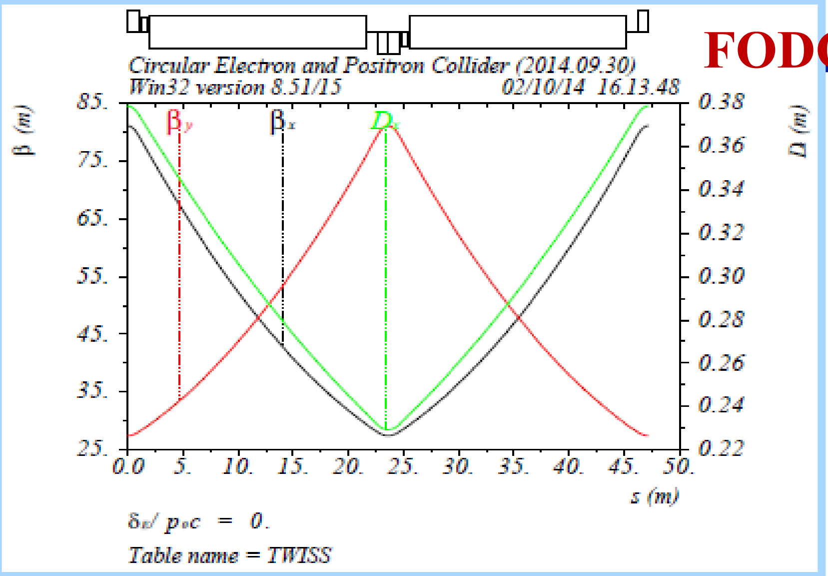
- Preliminary design for booster and transport lines
- Maybe a smaller booster with lower beam energy is necessary

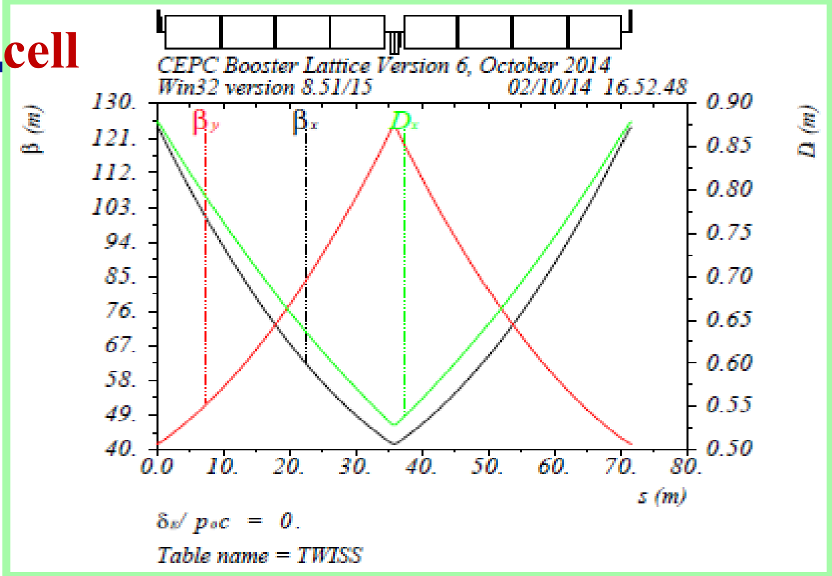




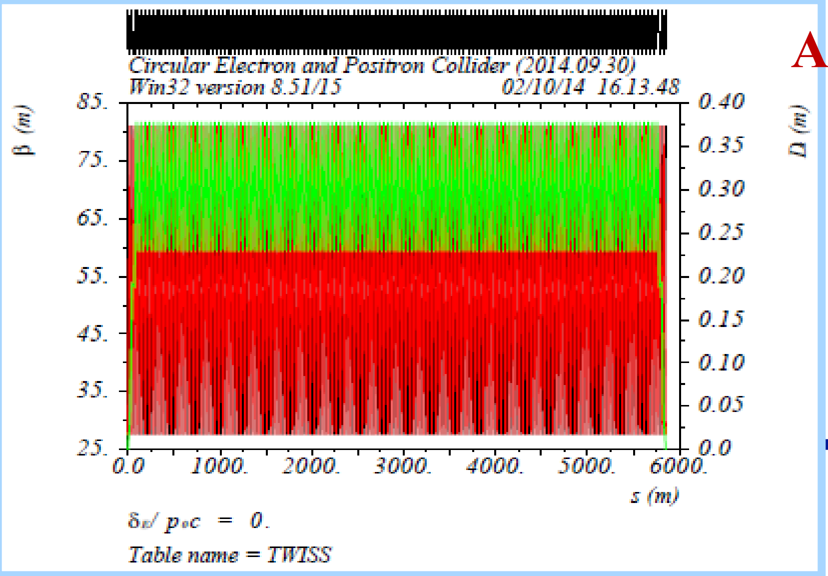
Lattice functions: booster vs. collider

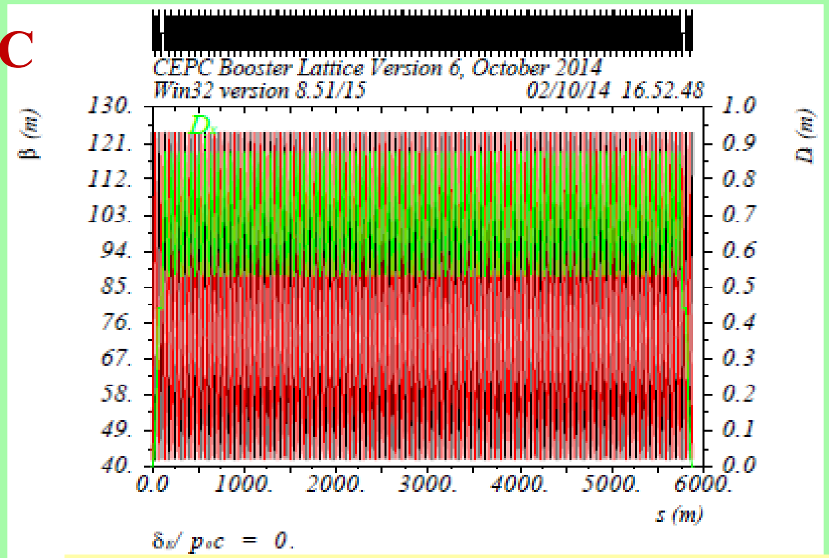
FODO cell





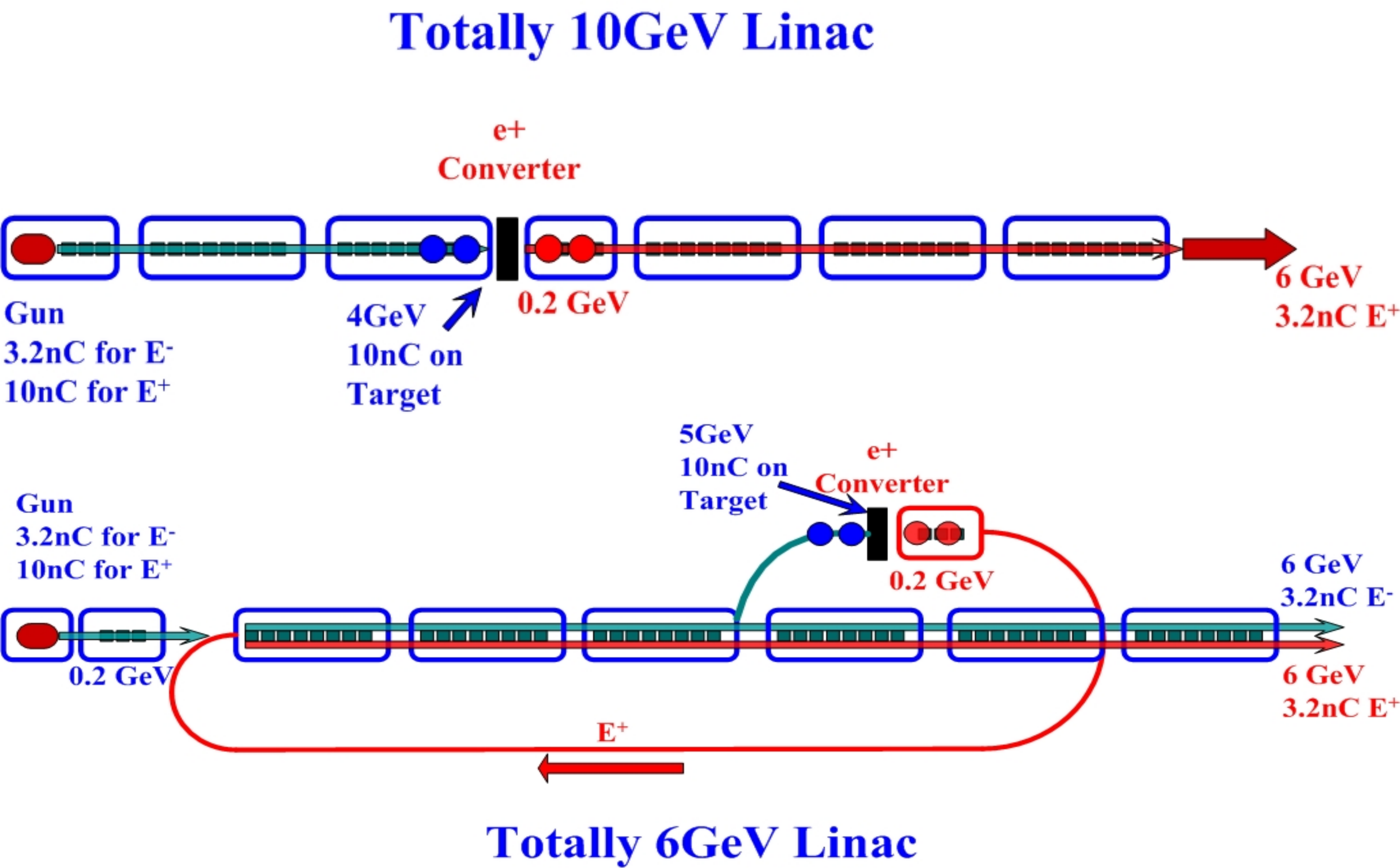
ARC





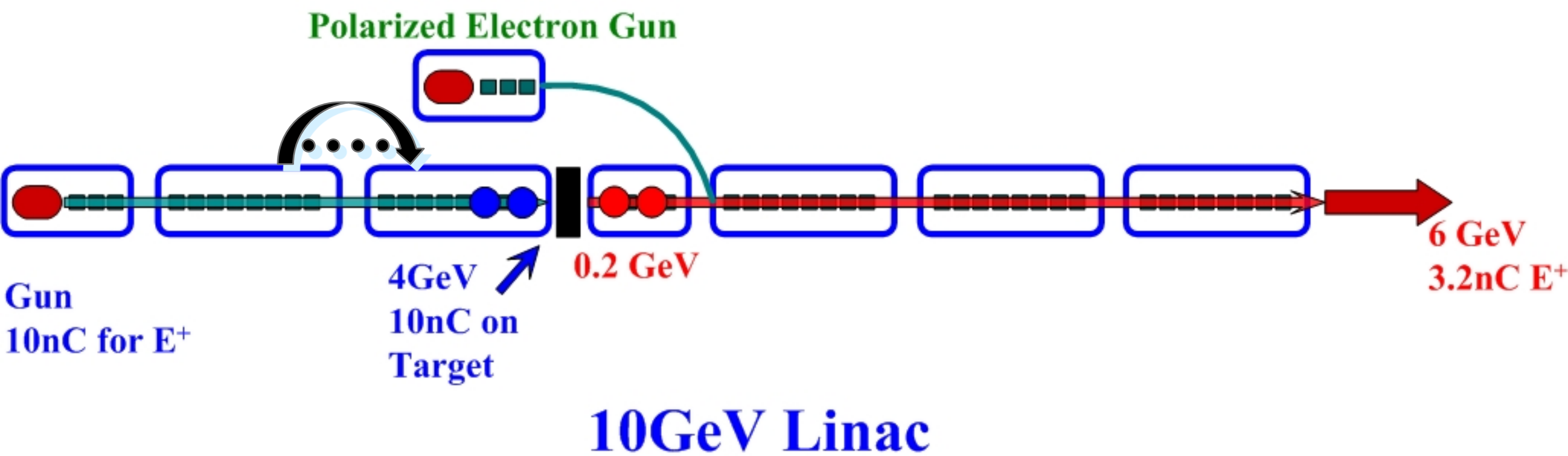
See more details in Zhang's talk

Unpolarized linac



Polarized linac

- Polarized Electron Source (R&D)



- Polarized electron gun for e-
- **Polarized electron beam collide with unpolarized positron**

4. Technical Systems

- All technical systems have been looked at
  - SRF, Cryo., power, magnet, vacuum, mechanics, instrumentation,…
- Conceptual designs of all systems have been done
- Each system has a request of R&D items

Magnets

Dipole magnet	type A	type B
Quantity	1984	
Beam energy (GeV)	120	
Bending angle (rad)	3.17E-03	
Bending radius (m)	5683.74	
Magnetic gap (mm)	100 (as LEP)	
Magnetic Length (m)	18	
Maximum field strength (T)	0.07	
Good field region, GFR (mm)		
Field uniformity across GFR		
Integral field deviation (magnet to magnet)		
Quadrupole magnet	**type A**	**type B**
Quantity	2304	
Beam energy (GeV)	120	
Aperture diameter(mm)	125	
Magnetic Length (m)	2	
Maximum field gradient (T/m)	10	
Good field region, GFR radius (mm)		
Harmonic field errors across GFR		
Integral field deviation (magnet to magnet)		
Sextupole magnet	**type A(SF)**	**type B(SD)**
Quantity	992	992
Beam energy (GeV)	120	120
Aperture diameter(mm)	150 (as LEP)	150
Magnetic Length (m)	0.4	0.7
Strength of sextupole field (T/m^2)	180	180
Good field region, GFR radius (mm)		
Harmonic field errors across GFR		

Superconducting RF System

- Accelerate e+ & e- beams, compensate synchrotron radiation losses, provide enough RF voltage for energy acceptance of the CEPC booster and main ring; dominates CEPC cost & efficiency.
- One of the world largest SRF installations
  - 12 GeV RF voltage, 640 cavities, total cryomodule length 1.4 km
  - 104.5 MW beam power, 2 MW HOM power, 124 MW installed RF power
  - 126 kW (4.2 K equiv.) installed cryogenic power (similar to LHC)
- Three main design and technical challenges
  - Cavity with very high Q_0 at 15-20 MV/m (use state-of-the-art technology)
  - Huge HOM power extraction and low heat load (key issue)
  - Very high power CW coupler (robust, clean assembly and low heat load)
- SRF R&D and pre-production planned for extensive development of key technology, personnel, infrastructure and industrialization

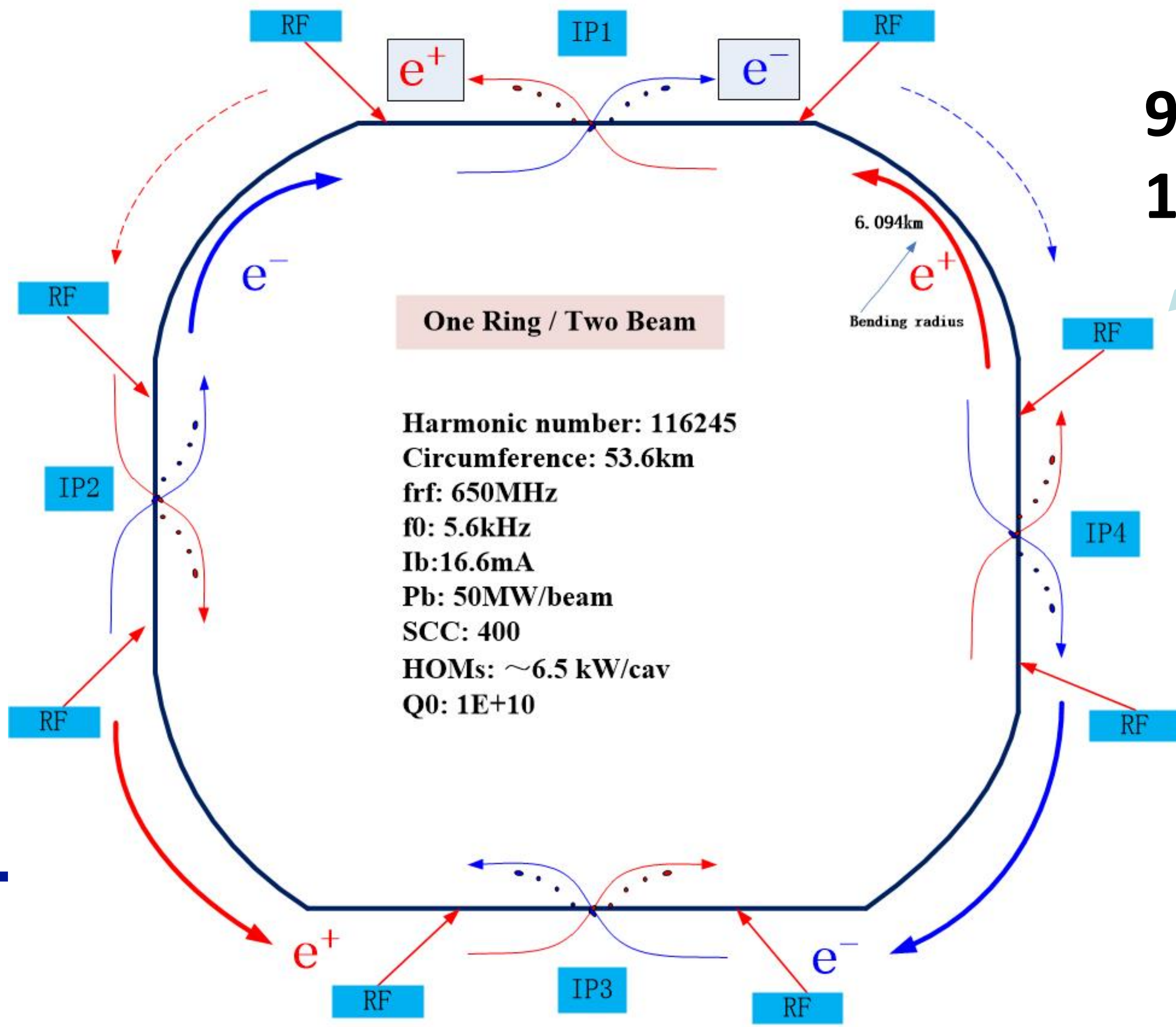
More details, ref. to Jiyuan Zhai, WG5, Oct 11

CEPC SRF System Parameters

Parameters	CEPC-Collider	CEPC-Booster	LEP2
Cavity Type	650 MHz 5-cell Nitrogen-doped Nb	1.3 GHz 9-cell Nitrogen-doped Nb	352 MHz 4-cell Nb/Cu sputtered
Cavity number	384	256	288
V_{cav} / V_{RF}	18 MV / 6.87 GeV	20 MV / 5.04 GeV	12 MV / 3.46 GeV
E_{acc} (MV/m)	15.5	19	6 ~ 7.5
Q_0	2E10 @ 2K	2E10 @ 2K	3.2E+9 @ 4.2K
Cryo AC power (MW)	25	2.5 (22% DF)	6.1
Cryomodule number	96 (4 cav. / module)	32 (8 cav. / module)	72 (4 cav)
RF input power / cav. (kW)	260	20	125
RF source number	384(300kW klystron)	256 (25 kW SSA)	36 (1.2 MW/8 cav)
RF AC power (MW)	200	2.4 (22% DF)	85
HOM damper power (W)	10k ferrite +1k hook	50 (hook+ceramic)	300 (hook)

384 cavities in 8 sections

CEPC SRF System location



90cavities
180m

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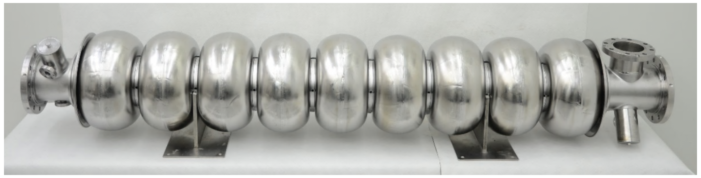
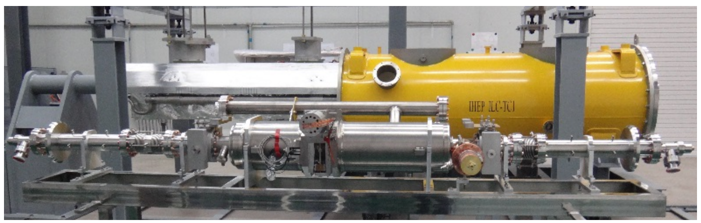
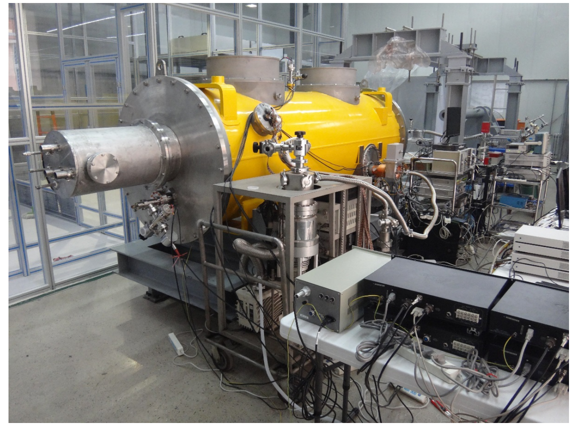
f High Energy Physics

IHEP SRF Key Technology Experience





1.3 GHz 9-cell cavity
vertical test 20 MV/m, Q_0=1.4E10

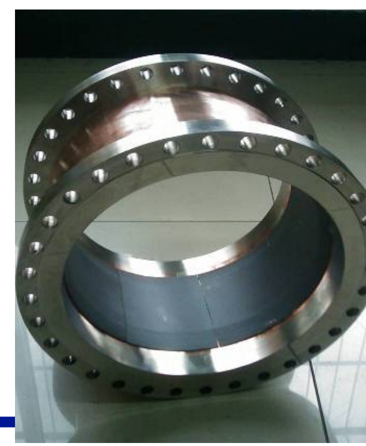


1.3 GHz test cryomodule
horizontal test soon

12 m 1.3 GHz cryomodule
for Euro-XFEL

650 MHz β=0.82 5-cell cavity
vertical test soon

500 MHz coupler
420 kW CW TW

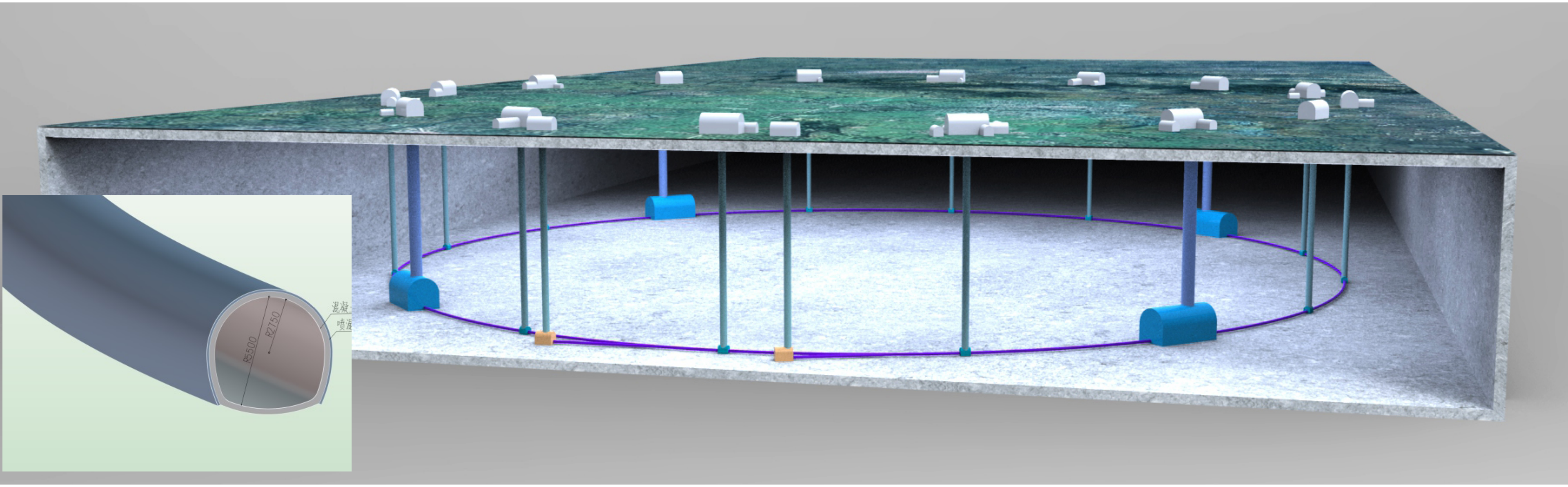


HOM absorber
ferrite 6kW

500 MHz cavity module
horizontal tested

Civil Design

- **Initial geological investigation and conceptual design of the tunnel has been started**
  - Underground tunnel
  - Surface facility
  - Utilities
  - Cost estimate and optimization



5. Plan in the near future

- CPEC
  - Pre-CDR study, R&D and preparation work
    - Pre-study: 2013-15 ➔ Pre-CDR by 2014
    - R&D: 2016-2020
    - Engineering Design: 2015-2020
  - Construction: 2021-2027
  - Data taking: 2030-2036
- SPPC
  - Pre-study, R&D and preparation work
    - Pre-study: 2013-2020
    - R&D: 2020-2030
    - Engineering Design: 2030-2035
  - Construction: 2036-2042
  - Data taking: 2042 -

Pre-CDR status

Table of Contents (Draft, February 10, 2014)

Finished the draft

Writing

Preparing

SppC Accelerator Design (preliminary)

- Proton-proton collider luminosity

$$L_0 = \frac{N_p^2 N_b f_{rep} \gamma}{4\pi \varepsilon_n \beta_{IP}} F \qquad \left(F = \sqrt{1 + \left(\frac{\theta_c \sigma_z}{2\sigma_{x,IP}}\right)^2}\right) \qquad \xi = \frac{N_p r_p}{4\pi \varepsilon_n} \leq 0.004$$

- Main constraint: high-field superconducting dipole magnets
  - **50 km**: B_{max} = 12 T, E = 50 TeV
  - **50 km**: B_{max} = 20 T, E = 70 TeV
  - **70 km**: B_{max} = 20 T, E = 90 TeV

$$B_{min} = \frac{2\pi(B\rho)}{C_0}$$

SppC Main Parameters (preliminary)

Parameter	Value	Unit
Circumference	52	km
Beam energy	35	TeV
Dipole field	20	T
Injection energy	2.1	TeV
Number of IPs	2 (4)	
Peak luminosity per IP	1.2E+35	$cm^{-2}s^{-1}$
Beta function at collision	0.75	m
Circulating beam current	1.0	A
Max 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	W/m

Summary

- "All" aspects of the machine design have been touched.
- Accelerator physics of CEPC ring, are being studied. But still a lot of important issues, background, MDI, error effect, etc., need further studies.
- Parameters of main ring, booster, linac, are still evolving, and major changes may still happen.
- Technical issues are also being considering, and some key technologies are proposed for R&D.
- The first stable version will be ready by the end of 2014.

Thanks for your attention!