Circular Higgs Factory Design in China

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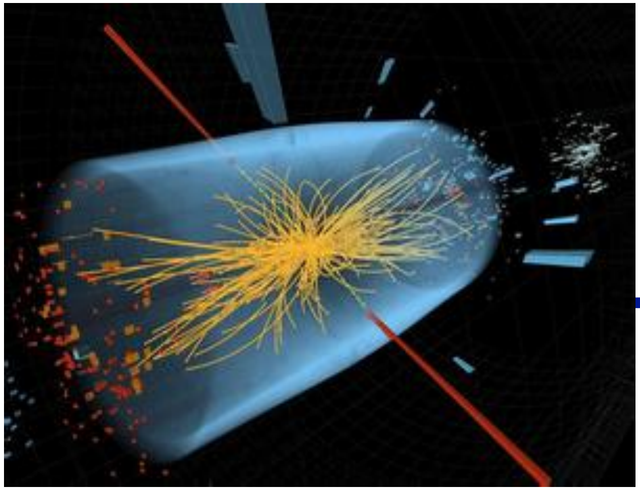
Outlines

- Introduction
- Parameter determination of CEPC
- Main AP issues
- 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

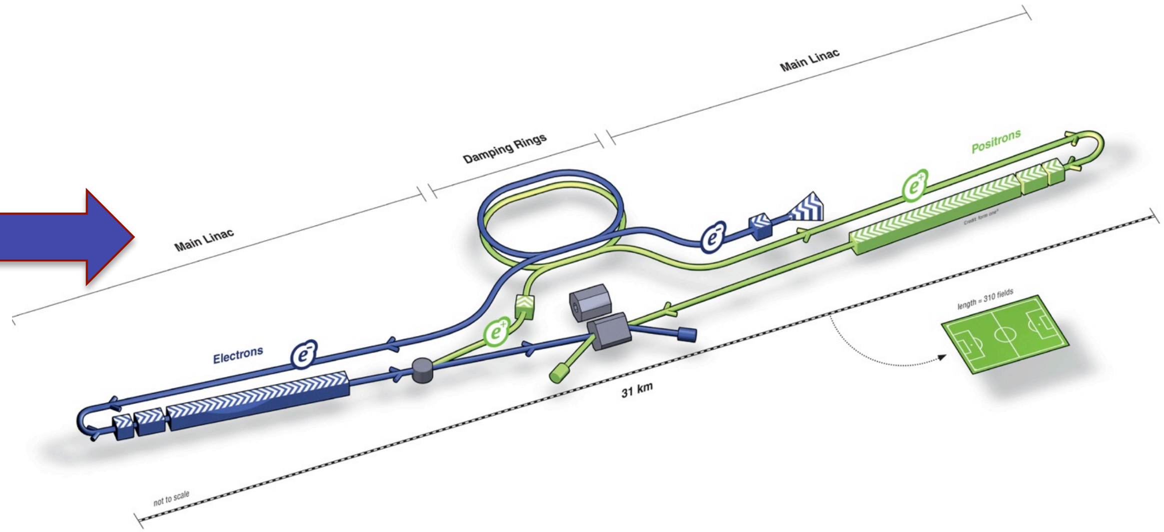


Forthcoming Discoveries in Particle Physics

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

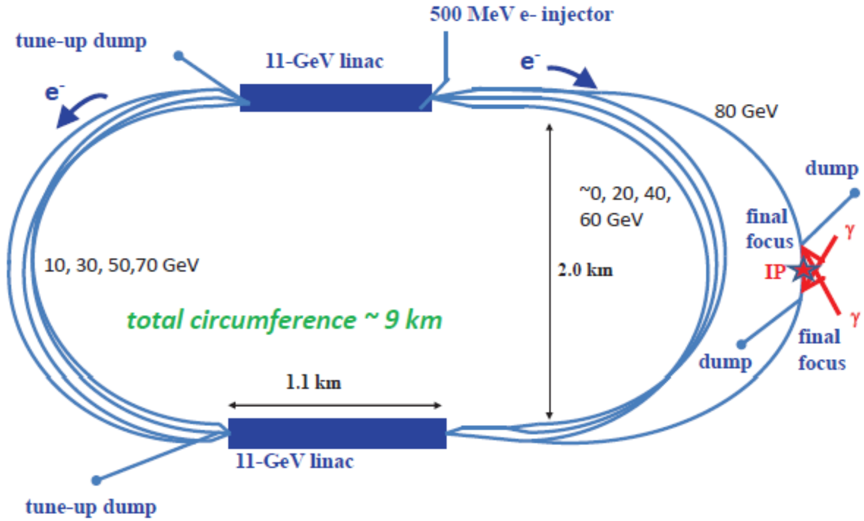
Possible Higgs Factories

- **Linear Collider**
  - ◆ ILC
  - ◆ CLIC
  - ◆ SLC-type
  - ◆ Advanced concepts



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

- **Higgs工厂之二：**
  - γ- γ collider

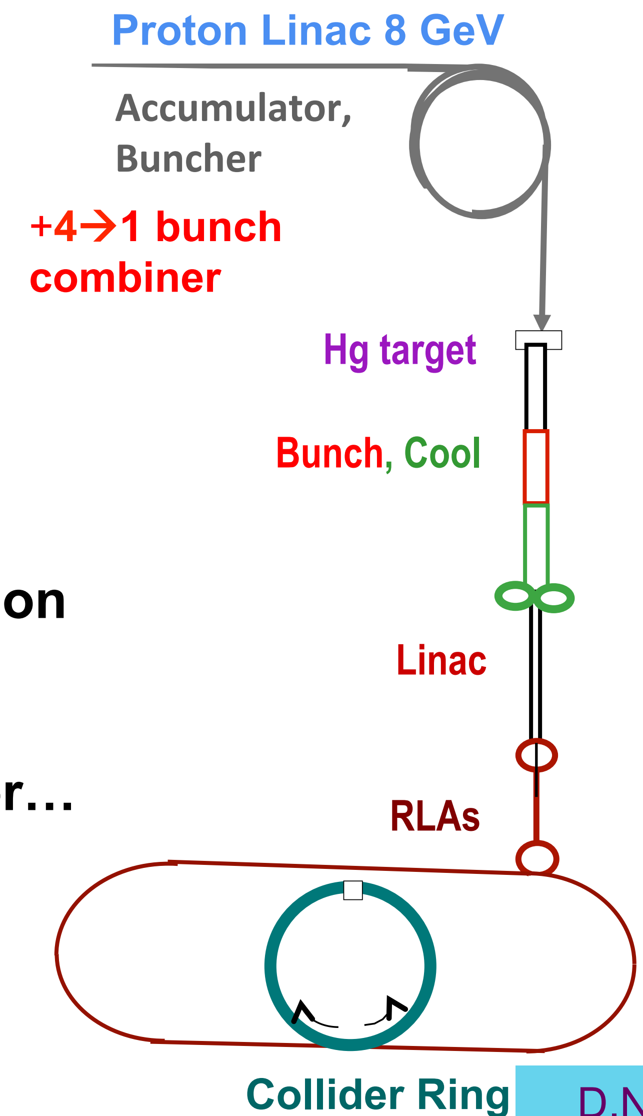


- ◆ **SAPPHIRE – ERL based, γ-γ based on LHeC, …**
- ◆ **CLICHÉ – CLIC Higgs Experiment**

Need powerful laser…

- **Muon collider**

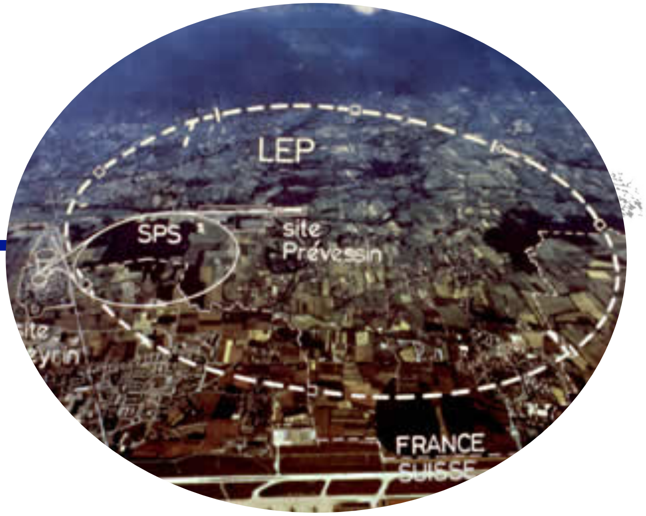
- ◆ Driven by high power p accelerator
- ◆ MW level target，collect pion to muon
- ◆ Cooling of Muon
- ◆ Acceleration, collision ring, detector…

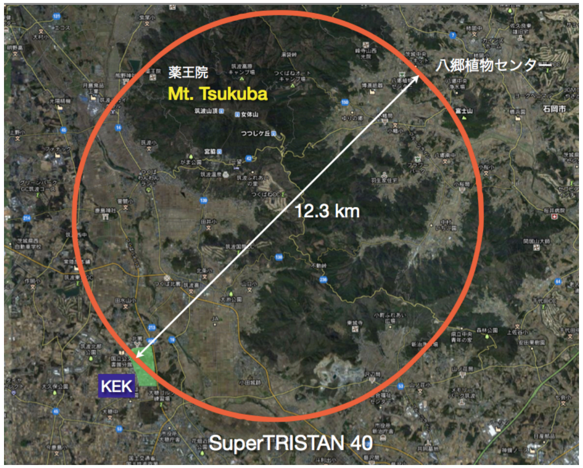


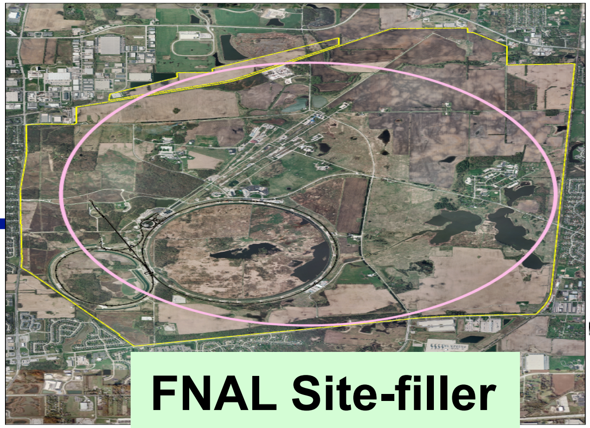
D.Neuffer
AAC12
NuFACT12

- **Circular e-e+ collider**

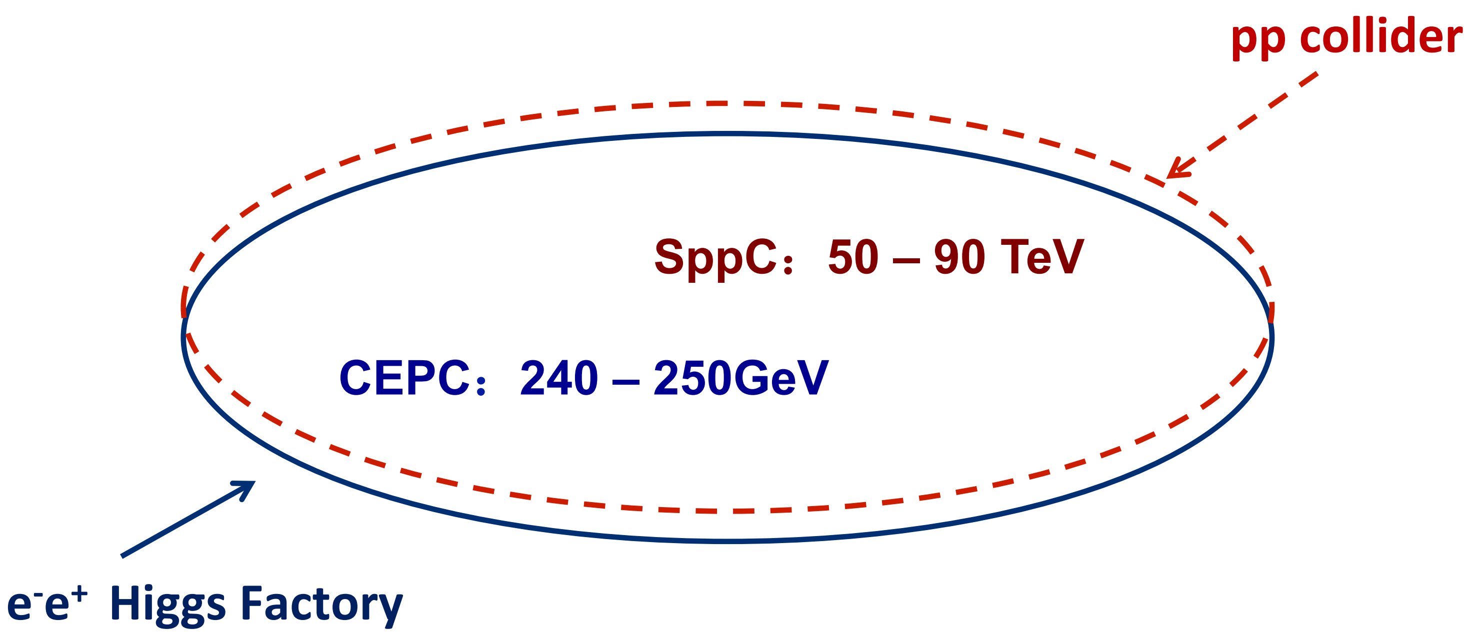
  - ◆ **LEP3**
  - ◆ **TLEP**
  - ◆ **Super-Tristan**
  - ◆ **FNAL Site-filler**
  - ◆ **IHEP：CEPC+SppC**







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



Higgs Factory Accelerator Pros and Cons (S. Henderson)

	Linear Collider	Circular Collider	Muon Collider	γ-γ Collider
Technical Maturity	☺	☺☺	☹	☹
Size	☹	☹	☺	☺
Cost	☹	😐	😐	☺
Power Consumption	😐	☹	😐	😐
Energy Resolution	☹	☹	☺	☹
MDI	😐	😐	☹	☹
TeV Upgradability (Energy)	☺	☹☹	☺☺	☺
TeV Upgradability (Cost, Size, Power)	😐	☹☹	☺	😐
pp collider convertible	☹	☺	☹	☹

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 = $5*10^{31}cm^{-2}s^{-1}$

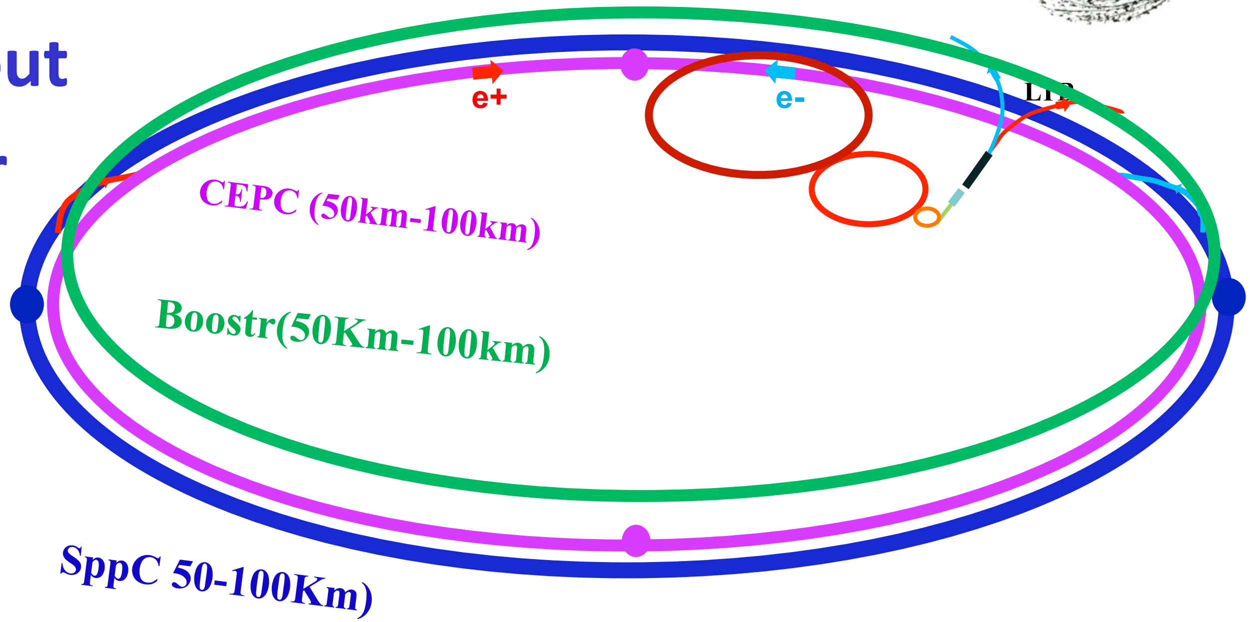
Design Goal

Possible circular collider

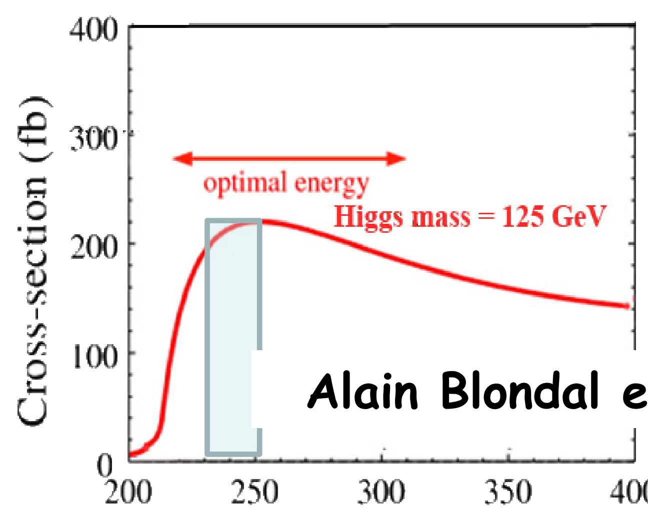
- In the existing tunnel:
  - LEP3, together w/LHC (27 km)
- Using lab field:
  - Fermilab Site Filler (16 km)
- Others：
  - DLEP (53 km), TLEP (80 km)
  - Super-Tristan (40, 60 km)
  - IHEP： CEPC+SppC (50, 70 km)
  - Very Large Lepton Collider (233 km in VLHC tunnel)
  - etc.

2. Parameter determination of CEPC

- Schematic layout
- Linac + booster as injectors



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



Alain Blondal et al

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

Ec.m. (TeV)	B (T)	C (km)
100	12	~80
100	20	~50

- **Beam power**
  - 50 MW/beam, synchrotron radiation
- **Luminosity**
  - $1\times10^{34} cm^{-2}s^{-1}$/IP

- **Beam current:**

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

$$C_\gamma = 88.5 \times 10^{-6} \frac{\text{m}}{\text{GeV}^3}$$

$$P_{sr} = 50\text{MW} \quad \Rightarrow \quad I = k_b I_b = 16.9\text{mA}$$

- **Take filling factor of the ring = 0.78 ⇨ ρ = 6.2km**

Beamstrahlung

- **Beamstrahlung fractional energy spread[1]:**

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

- **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**

[1] H. Wiedemann, SLAC-PUB-2849, 1981.

Bunch number, particle number, emittance

$$\delta_{\mathrm{BS}} \equiv \frac{\langle \Delta E_{\mathrm{BS}} \rangle}{E} = 0.864 r_e^3 \gamma \left(\frac{N_e}{\sigma_z (\sigma_x + \sigma_y)} \right)^2 \beta_y \approx 0.864 r_e^3 \gamma \frac{r}{\sigma_z^2} \frac{2\pi\gamma}{r_e} \xi_y N_e$$

$$\xi_y = \frac{r_e N_e \beta_y}{2\pi\sigma_y (\sigma_x + \sigma_y)} = 0.1$$

$$N_e = 5.26 \times 10^{19} \varepsilon_x$$

- **Small N_e will reduce δ_{BS}, but increase N_b and decrease ξ_x to keep luminosity**
- **N_b = 50** ⇨ $N_e = 3.52 \times 10^{11}, \quad \varepsilon_x = 6.69\mathrm{nm}$

Luminosity & coupling coefficient

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

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

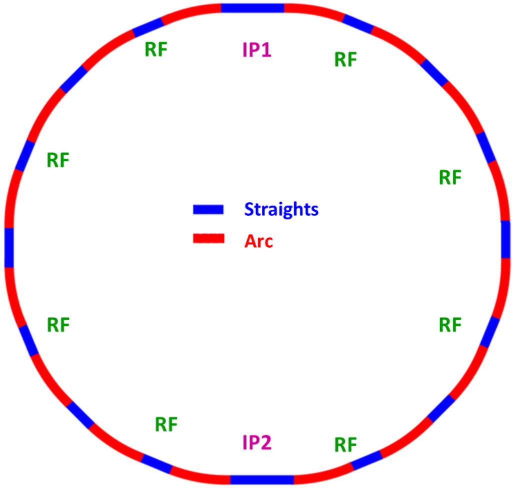
- **Take P_{SR} = 50MW, E = 120GeV, ε_x = 6.69nm,**
  r = 0.005 (empirical value)

RF frequency and voltage

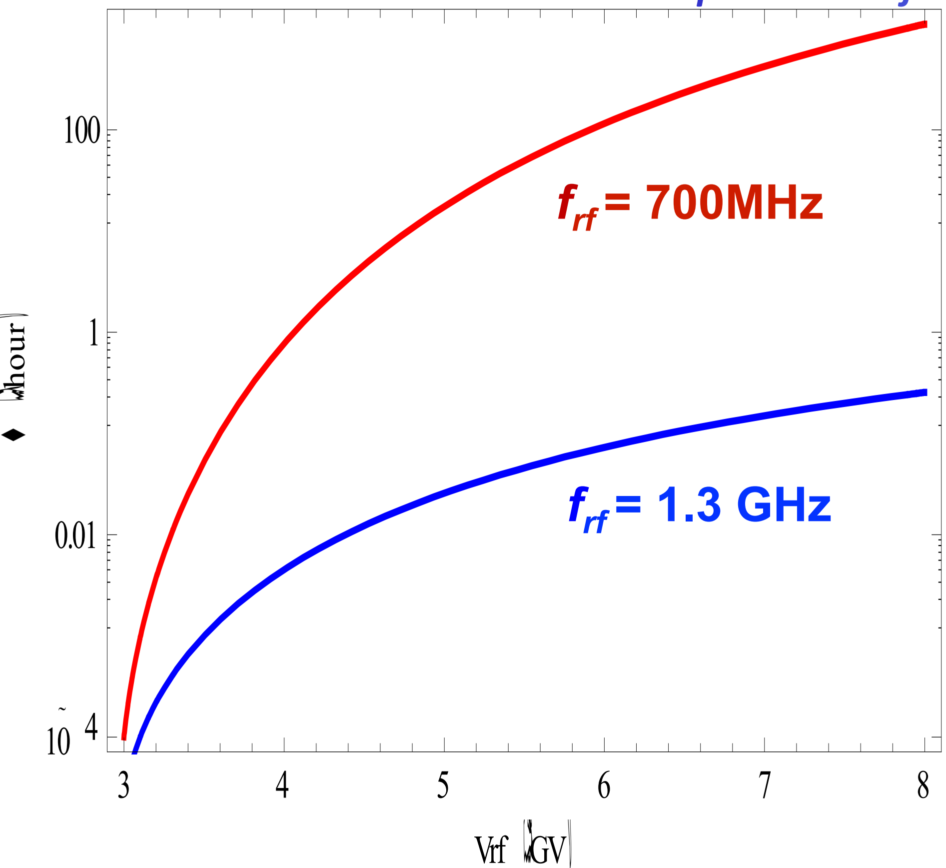
- **Energy spread and acceptance due to SR** $\sigma_e = \gamma\sqrt{\frac{C_q}{J_e\rho}}$ $\eta = \sqrt{\frac{U_0}{\pi\alpha_p hE}F_q}$
- **Synchrotron tune and bunch length:** $\nu_s = \sqrt{-\frac{\alpha_p h V_{rf} cos\varphi_s}{2\pi E}}$ $\sigma_z = \frac{\alpha_p R\sigma_{e0}}{\nu_s}$
- **RF station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

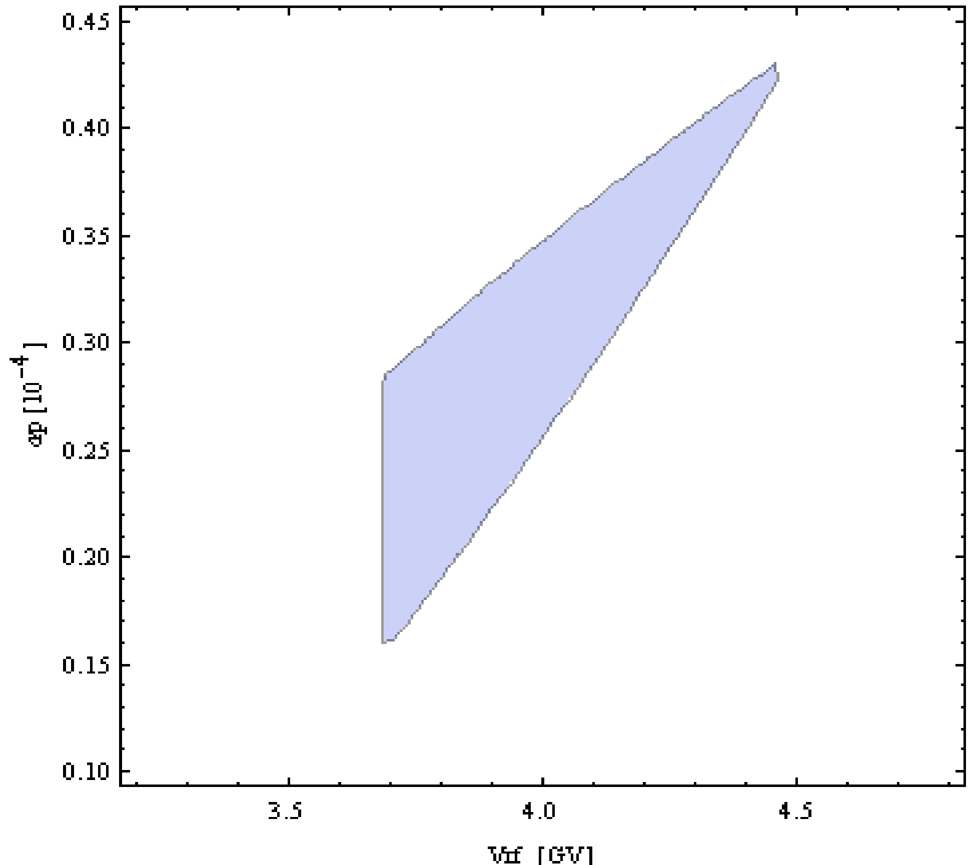
$$E_{cb} = \frac{3\gamma r_e{}^2 N_e E}{\alpha\sigma_x\sigma_z},\ u = \frac{\sigma_e E}{E_{cb}},\ n_{col} = \frac{20\sqrt{6\pi} r_e \gamma u^{3/2}}{\alpha^2\sigma_e\sigma_z}\mathrm{e}^u$$

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



- **For chosen transvers bunch size and *N_e* , beam lifetime due to beamstrahlung as a function of *V_{rf}* at different *f_{rf}* .**
- **For σ_z<3mm, ν_s<0.3, δ_{BS} <σ_e/3, η <0.05 & τ >10min, the co-relation between α_p and V_{rf} can be got:**





Main parameters of CEPC ring

Number of IPs	2
Beam Energy (GeV)	120
Circumference (km)	53.6
SR loss/turn (GeV)	3
N_e/bunch (10^{11})	3.5
Bunch number	50
Beam current (mA)	16.9
SR power /beam (MW)	50
B_0 (T)	0.065
Bending radius (km)	6.2
Momentum compaction (10^{-4})	0.4
β_{IP} x/y (mm)	800/1.2

Emittance x/y (nm)	6.9/0.021
Transverse σ_{IP} (um)	74.3/0.16
ξx/IP	0.097
ξy/IP	0.068
V_{RF} (GV)	6.87
Nature bunch length σ_z (mm)	2.12
Bunch length include BS (mm)	2.42
Nature Energy spread (%)	0.13
Energy acceptance RF(%)	5.4
n_γ	0.22
δ_{BS} (%)	0.07
Lmax/IP ($10^{34}cm^{-2}s^{-1}$)	1.76

3. Main Accelerator Physics Issues

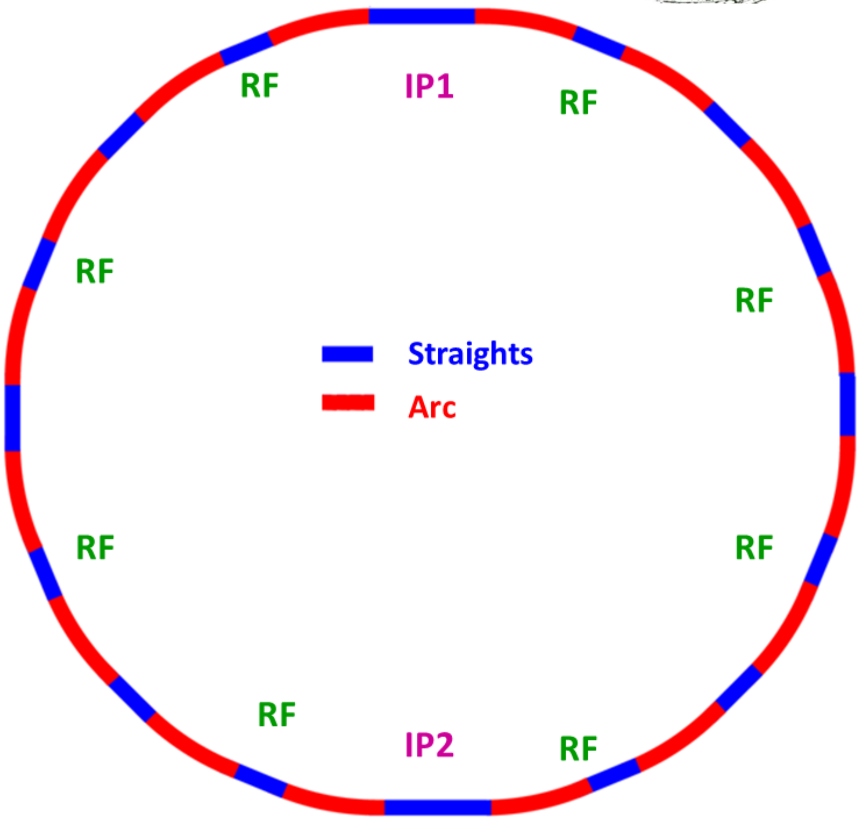
- **Lattice Design**

In current design:

- •Circumference: 53.6 km
- •16*arcs: 48.4km
- •14*short straight: 14*144m=2.0km
- •2*IPs: 2*576m=1.2km

➢ 8 RF cavities are uniformly distributed in every other straights.

➢ The other 6 straights can be used for injection and dump.

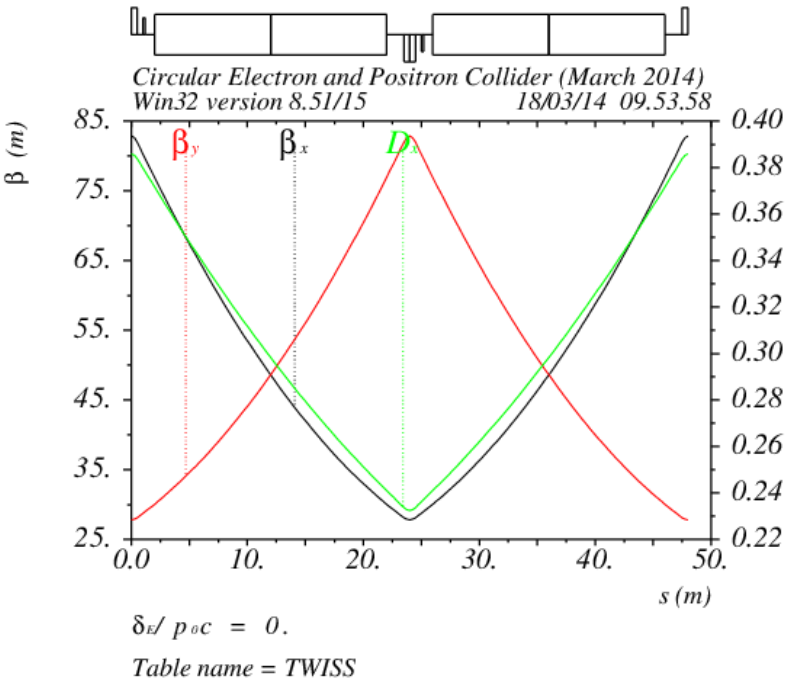


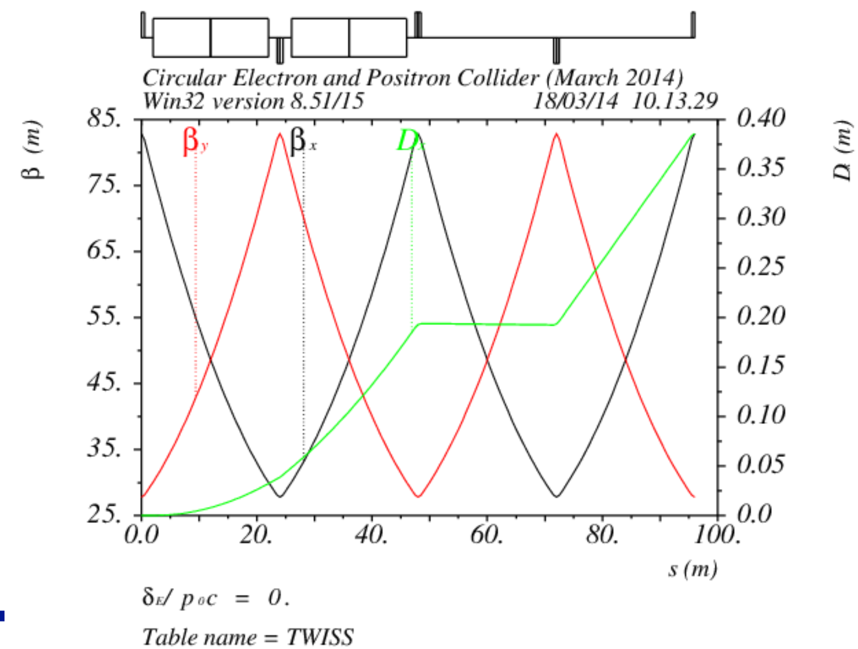
Not fixed yet !

Lattice of arc sections

- **Length of FODO cell: 48m**
- **Phase advance of FODO cells: 60/60 degrees**

- Dispersion suppressor on each side of every arc
- Length: 96m





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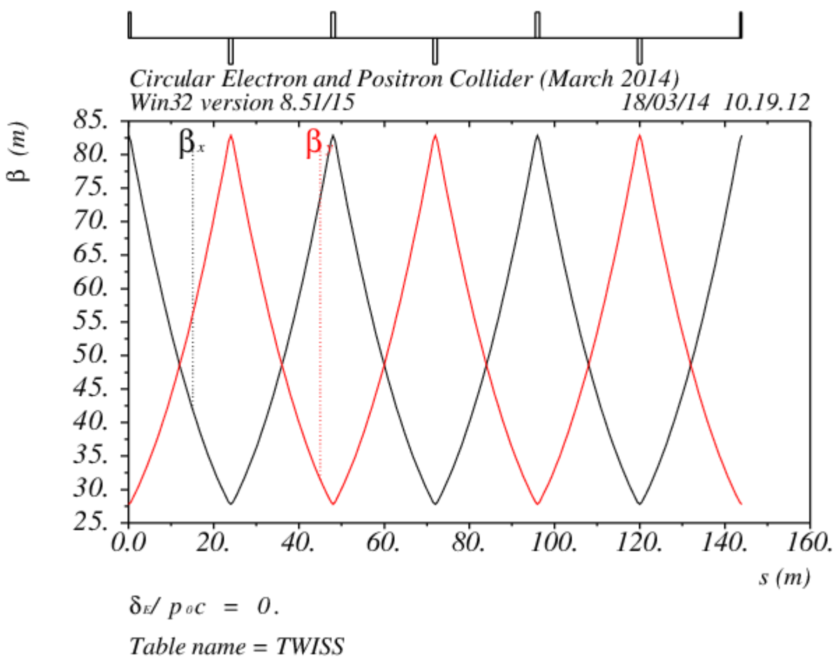
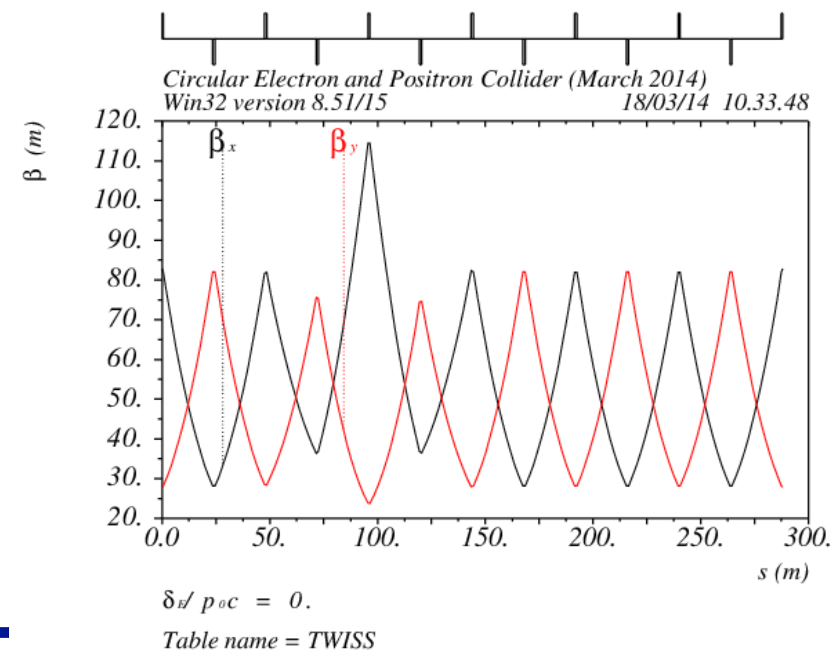
Lattice of straight sections

- **Length straight: 144m**
- **Phase advance of FODO cells: 60/60 degrees**

- FFS is temporarily replaced by FODO cells
- Length of each IP section: 576m
- Used for workpoint adjustment





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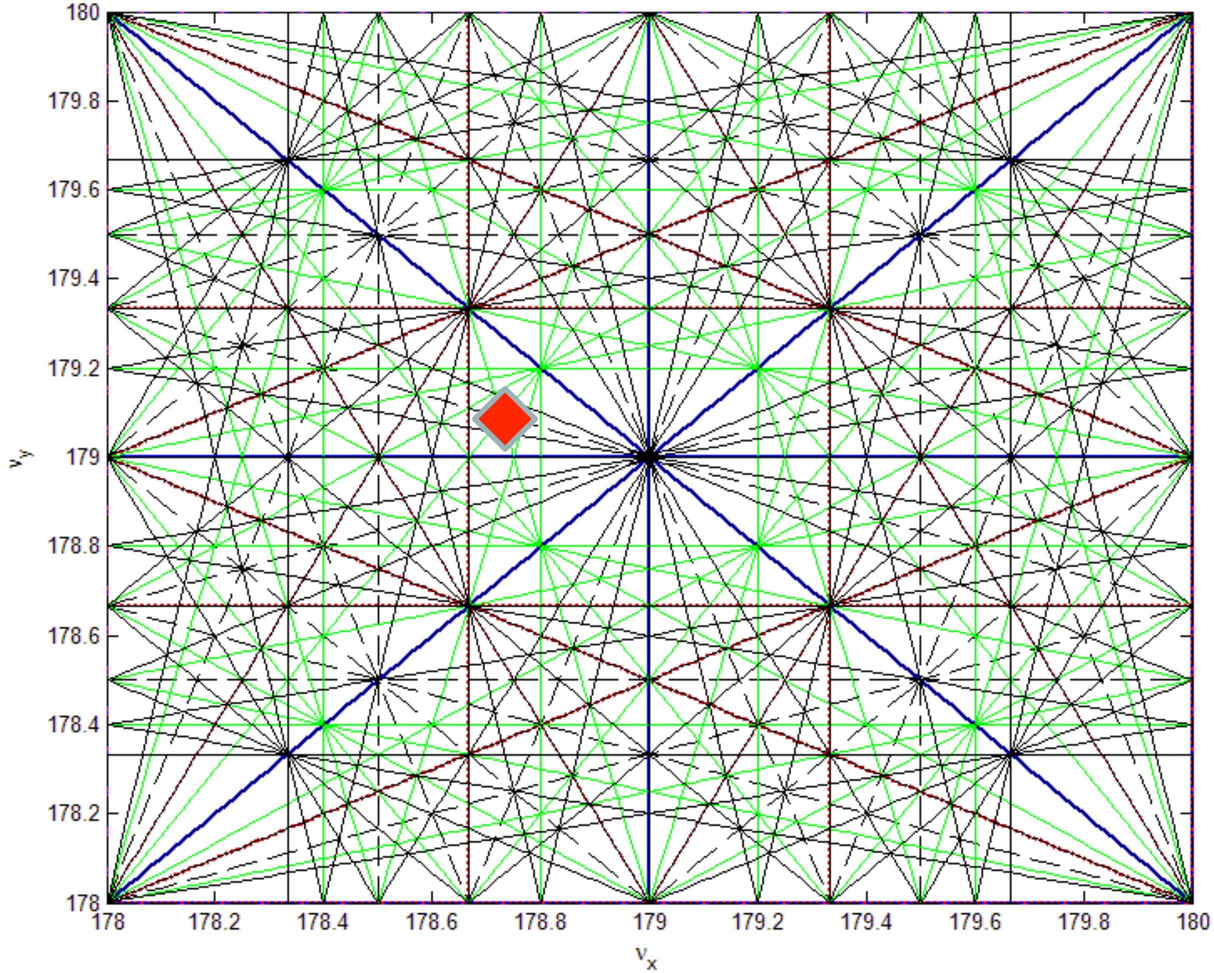
Tune diagram of CEPC lattice



Work point: (178.73, 179.12)

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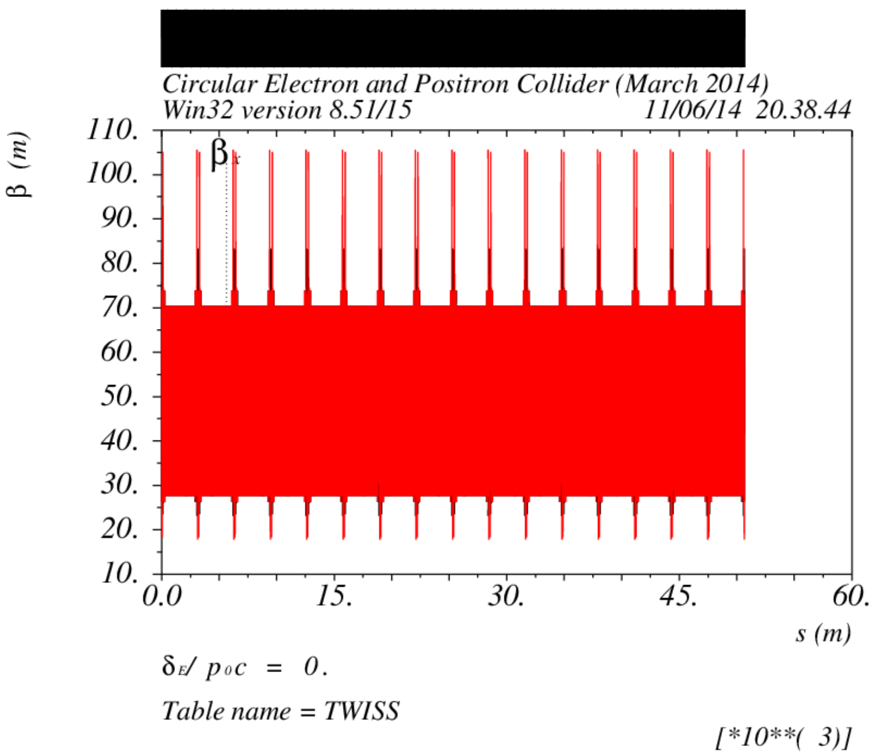
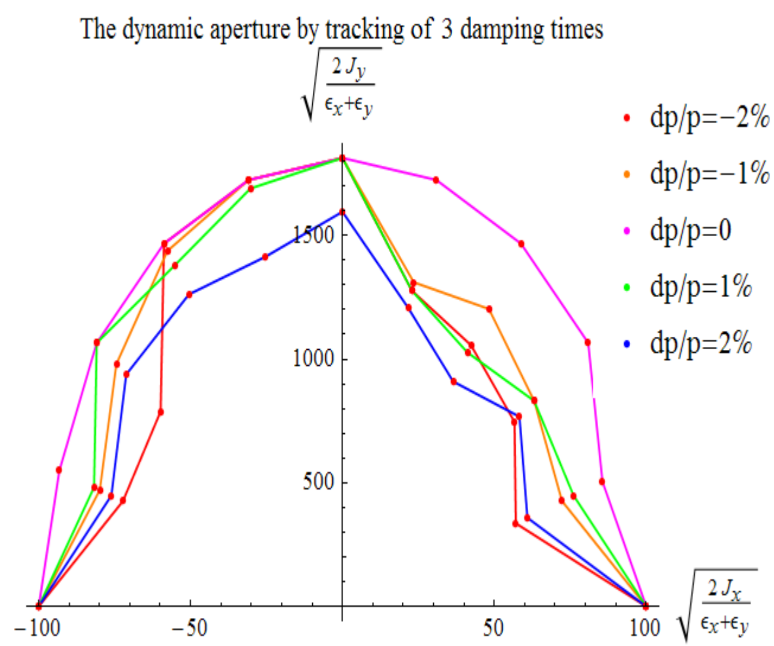
Dynamic aperture (w/o FFS)

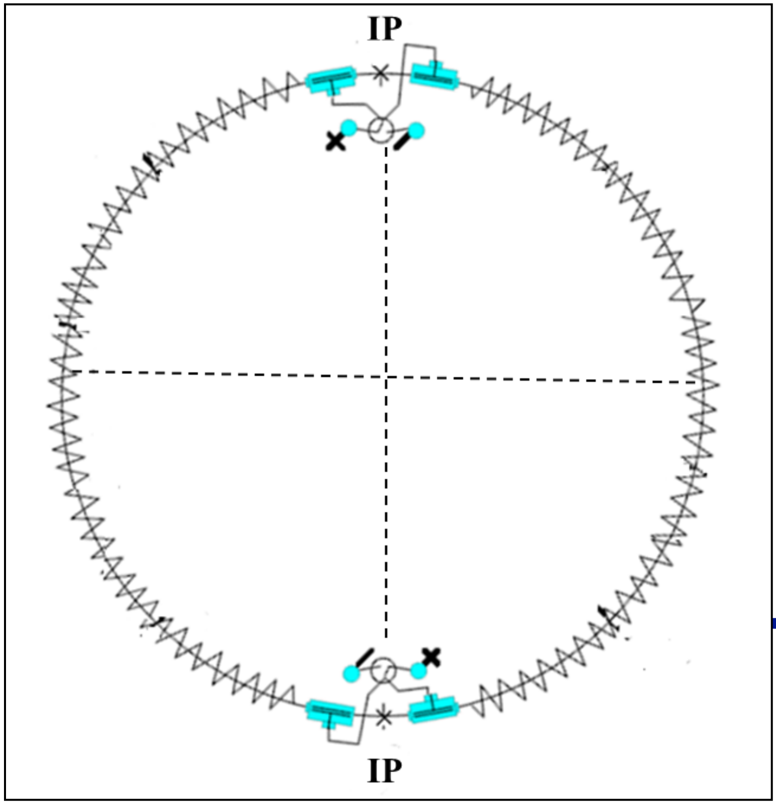
- 2 sextupole families are applied to correct chromaticity
- dynamic aperture: ~$100\sigma_x$ in hori. ~$150\sigma_y$ in vert.

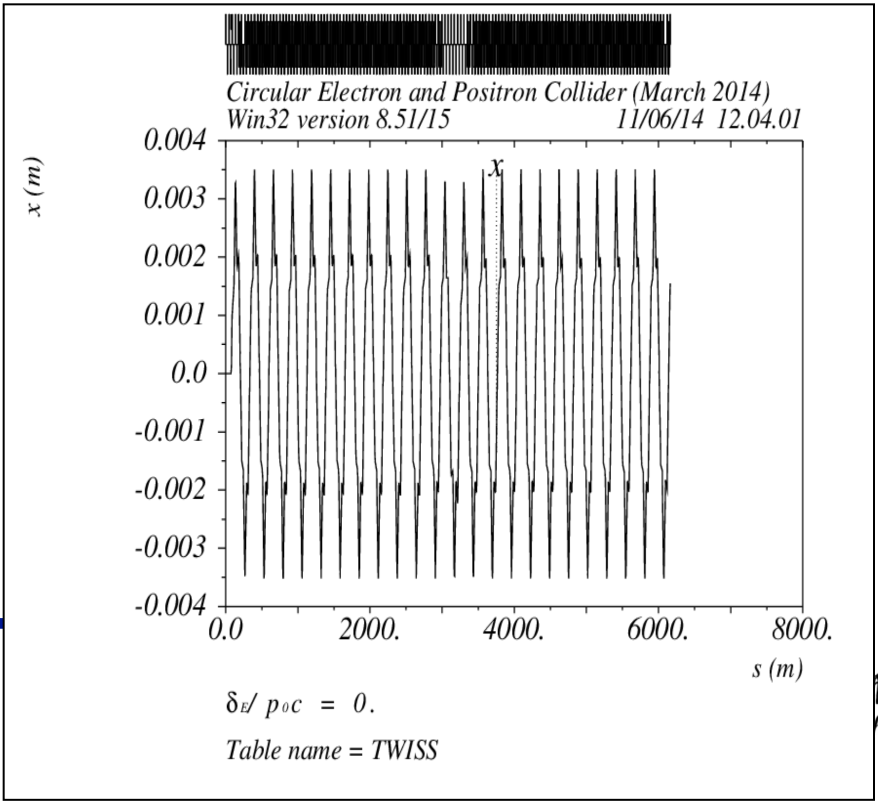




Pretzel scheme

- 2 sets of electrostatic separators
- horizontal separation，5 × (rms bunch size)
- maximum bunch number = 96



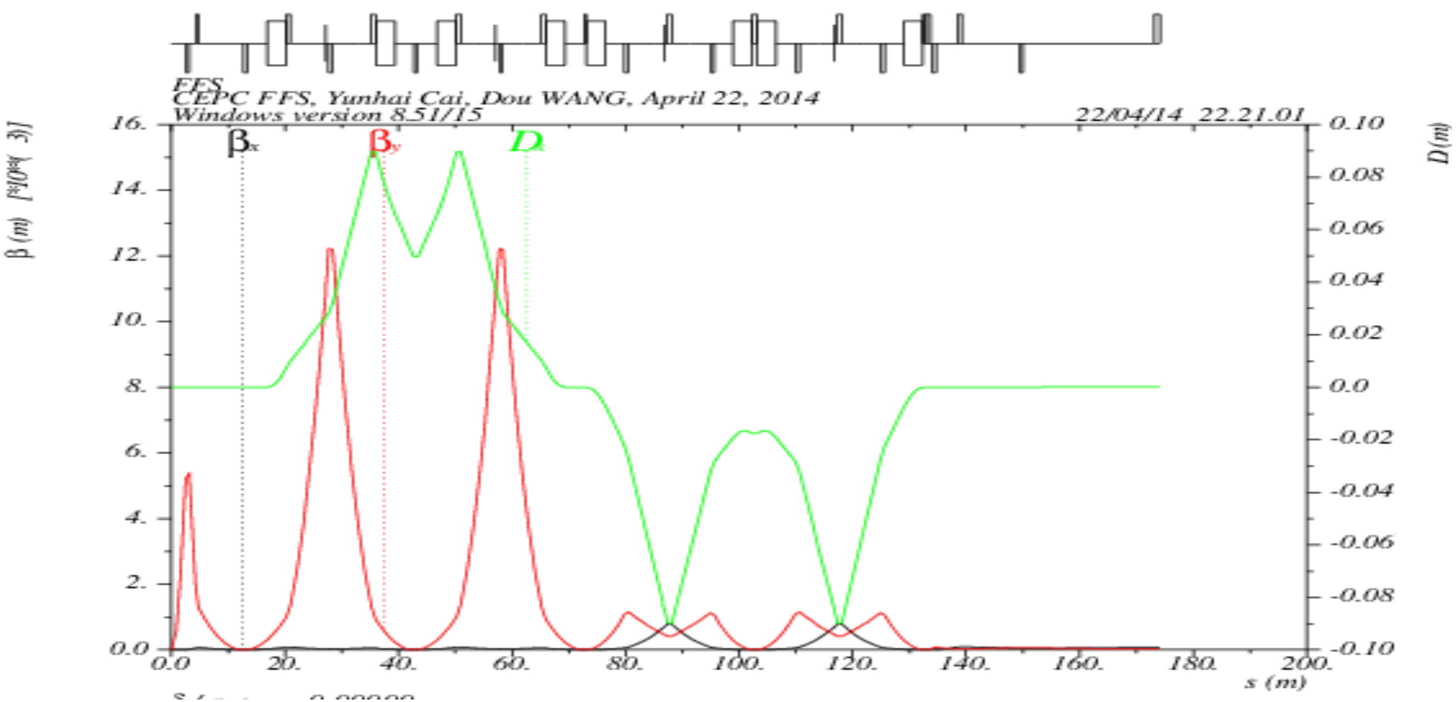


FFS in CEPC

- 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*

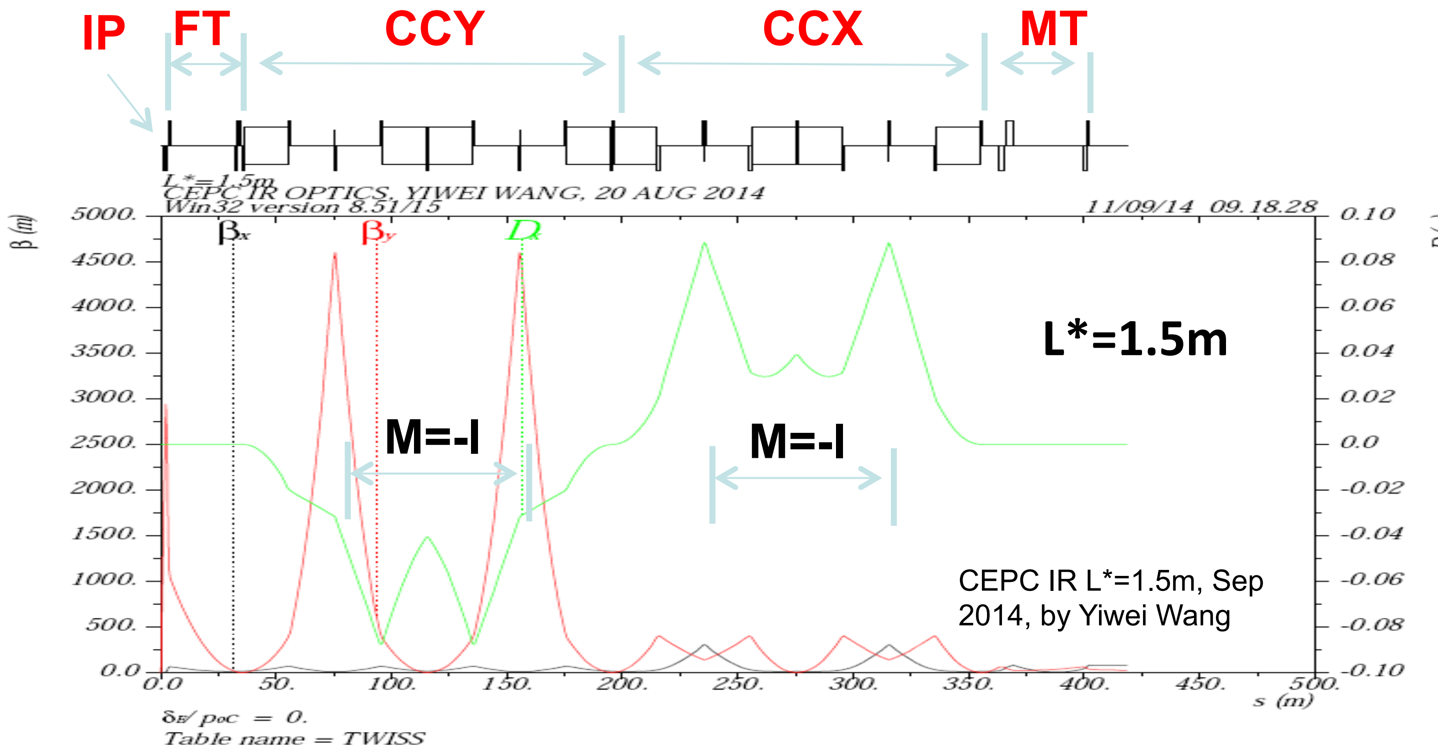
Based on Yunhai's design

L*=2.5m
βx*=0.8m
βy*=1.2mm



FFS in CEPC

- Dynamic aperture is small due to large chromaticity at final doublet which is difficult to well correct
- Reduce chromaticity at final doublet by reducing L* from 2.5m to 1.5m (still in progress)



FT: final telescopic transformer

CCY: chromatic correction section Y

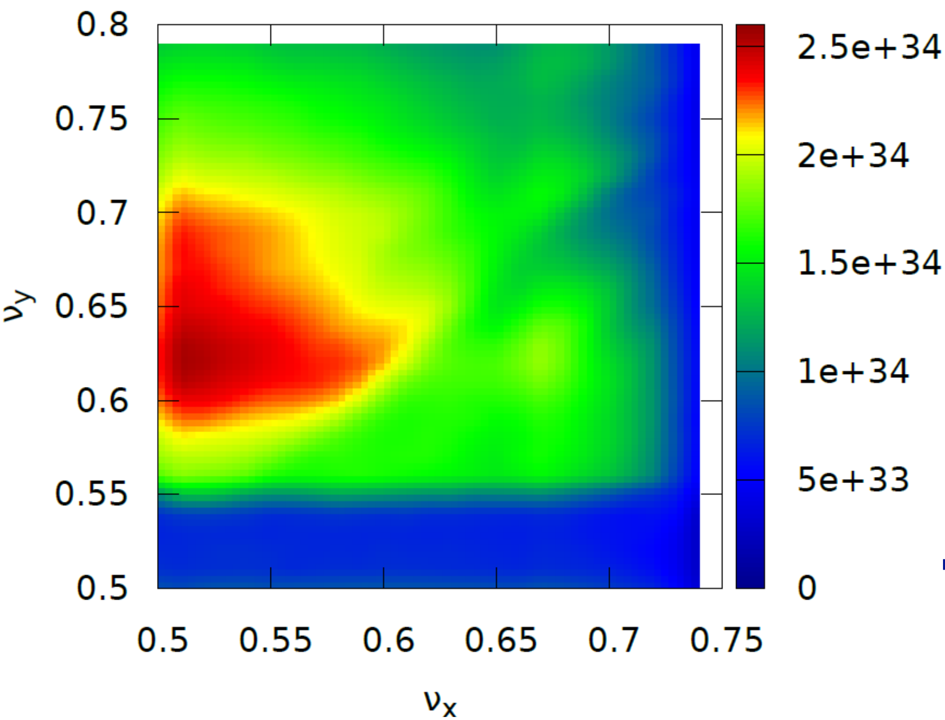
CCX: chromatic correction section X

MT: matching telescopic transformer

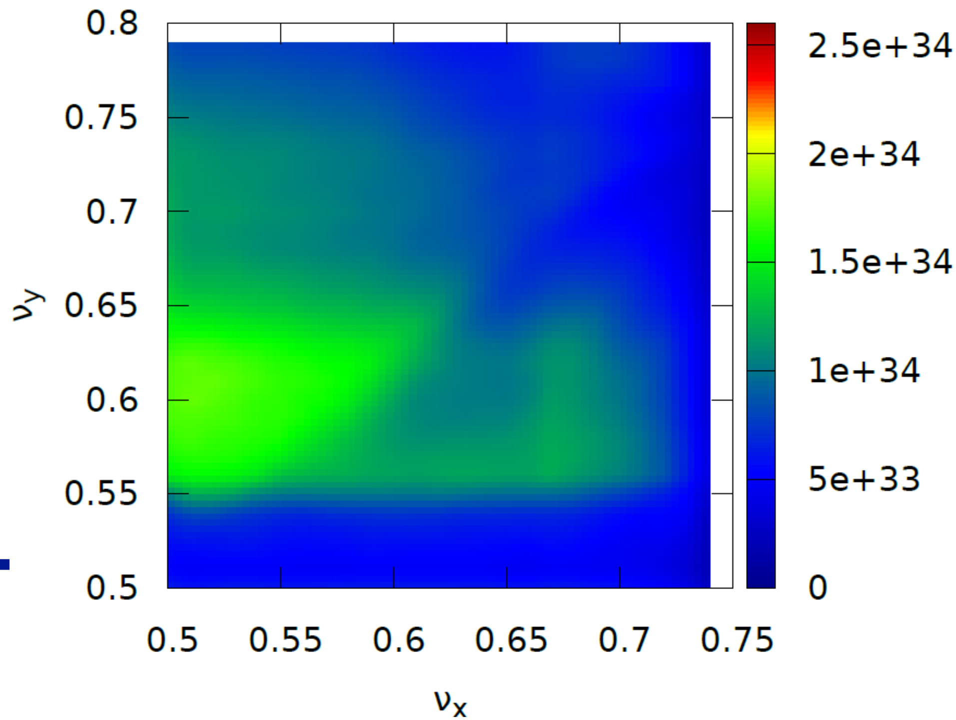
Beam-beam study

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

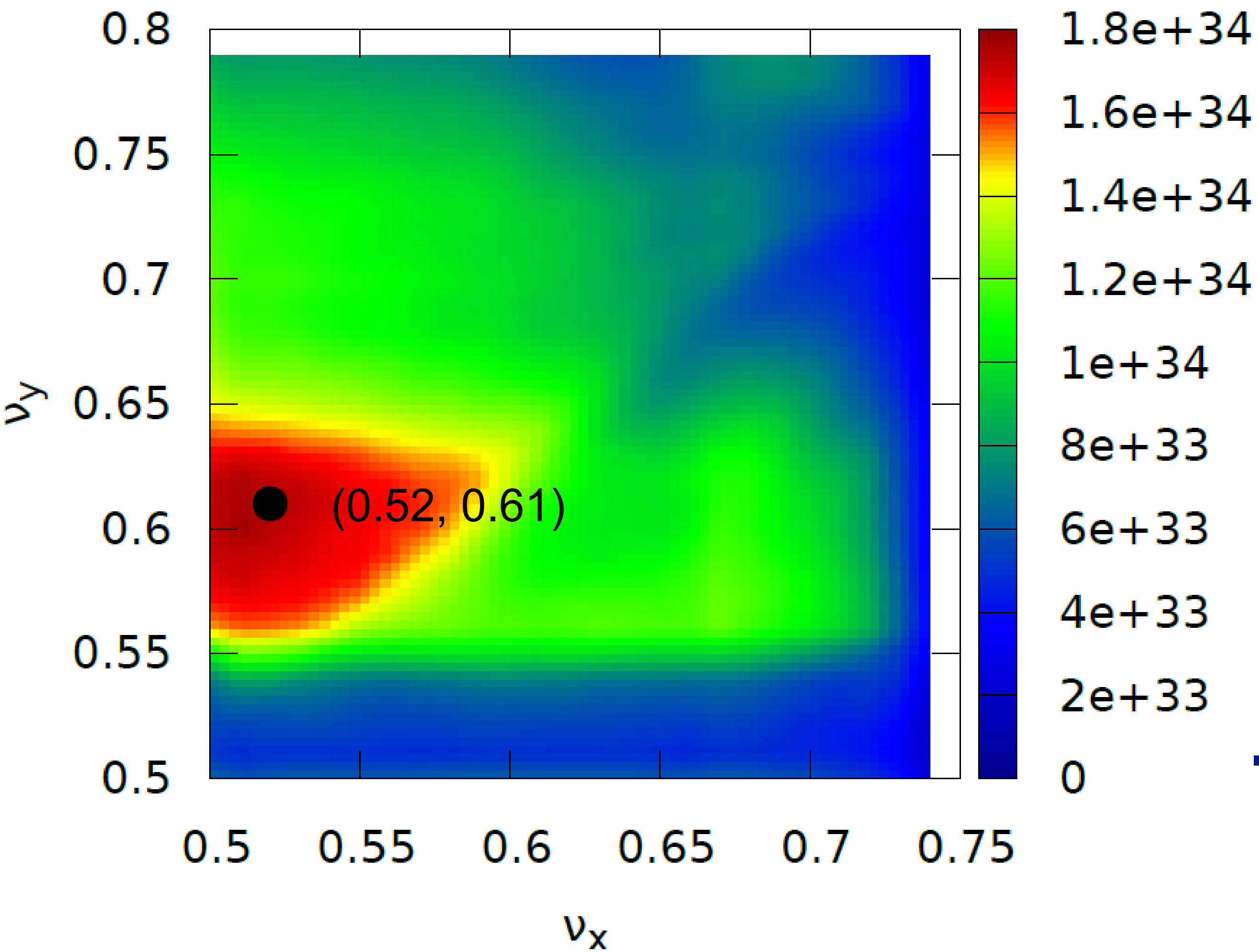
Beamstrahlung OFF



Beamstrahlung ON



- # Tune Scan w/ Beamstrahlung

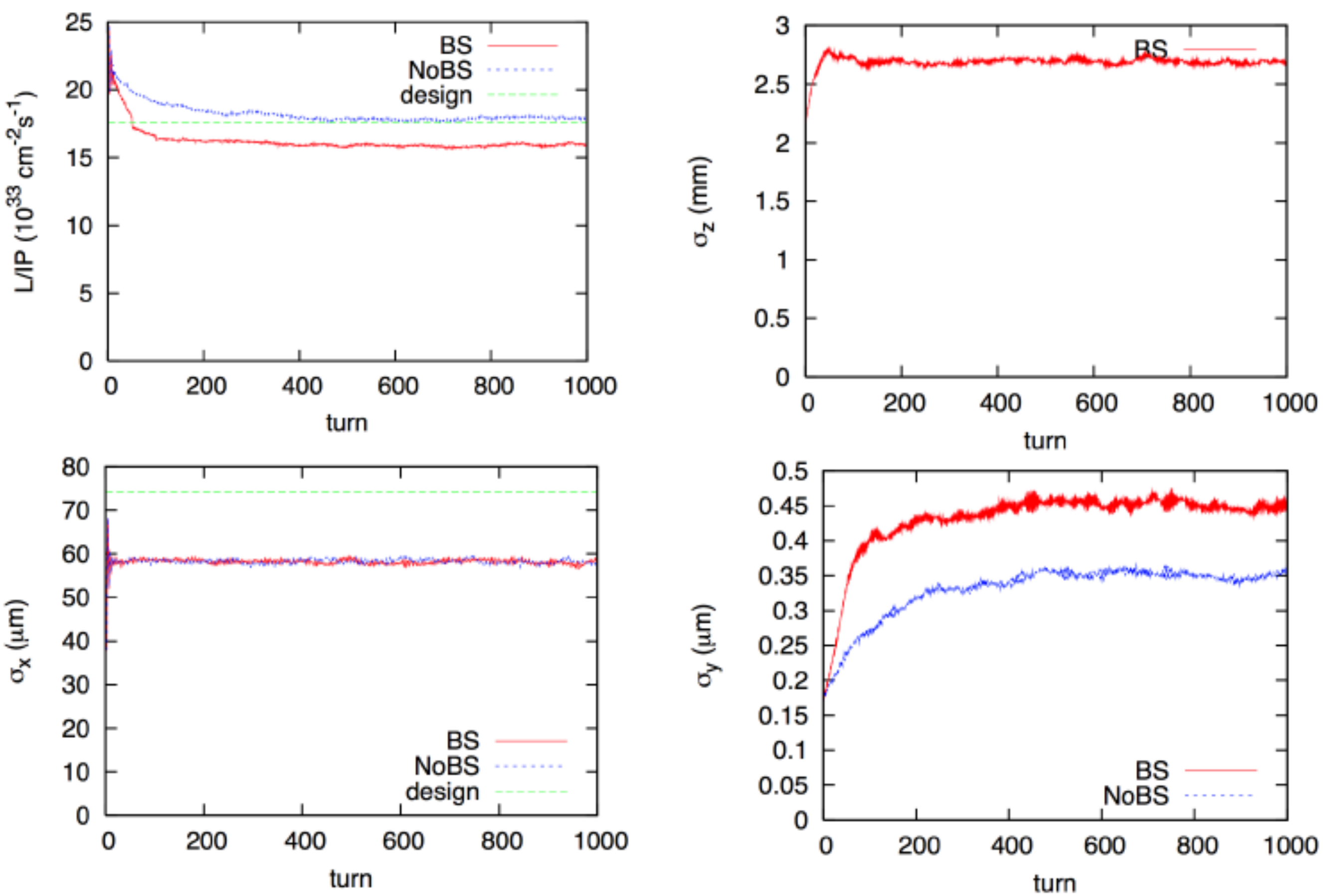


16.9mA*16.9mA,
50bunches,
BBWS,
Luminosity ~ 1.6e34

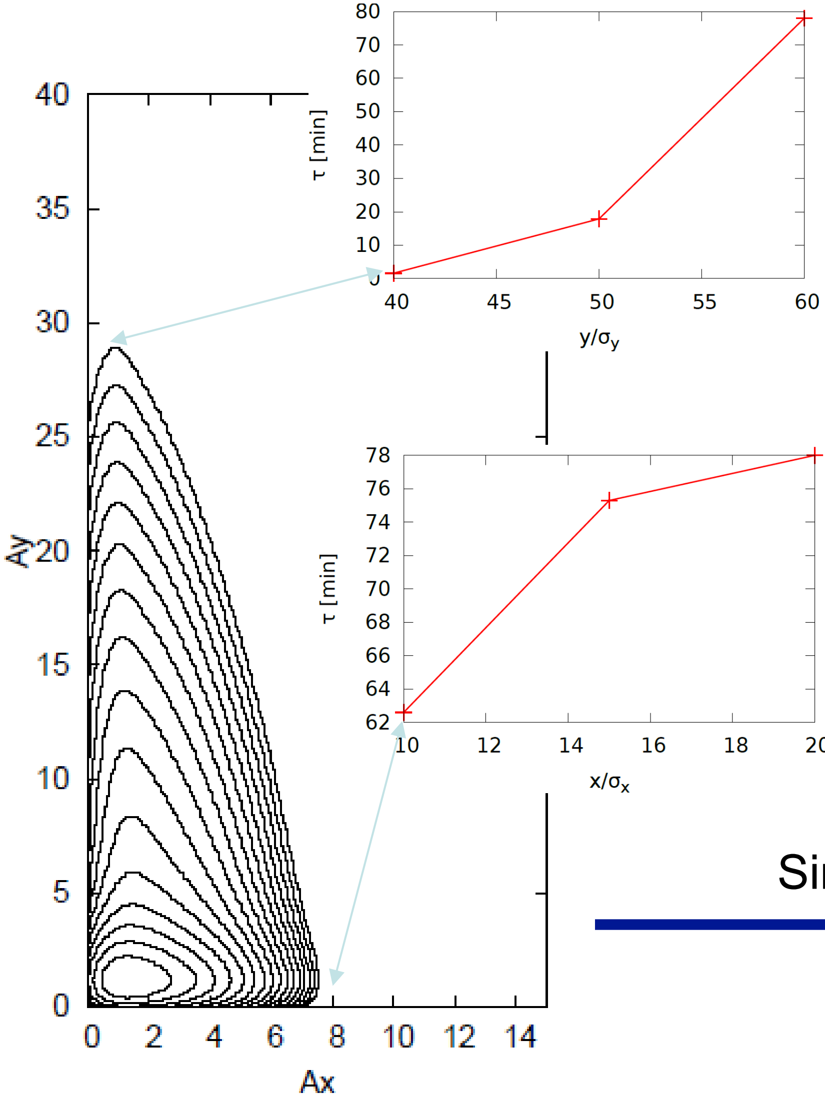
Quasi-Strong-Strong simulation shows Luminosity ~ 1.1e34

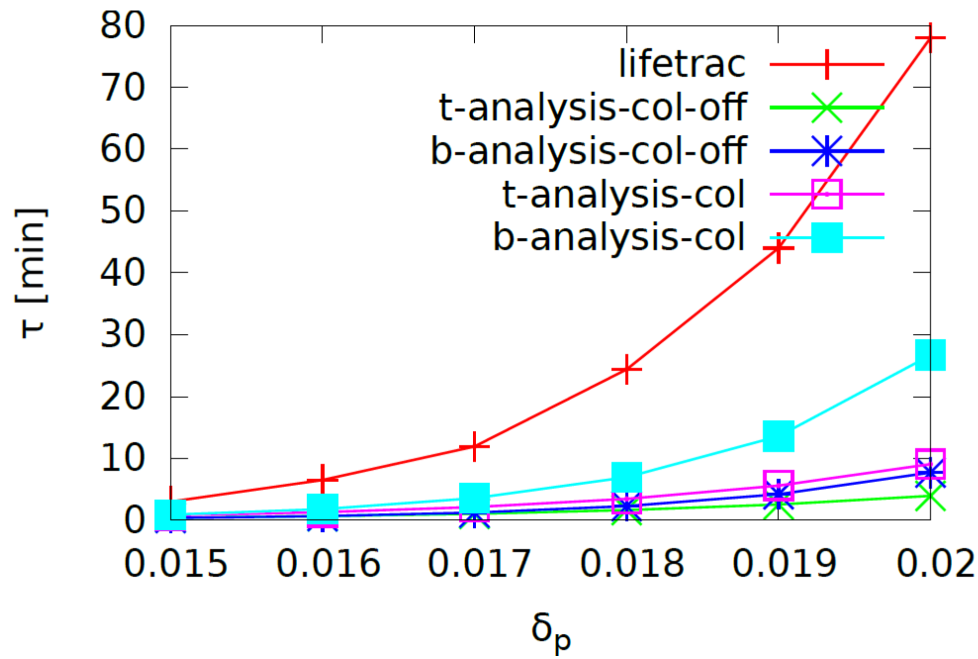
- **New working points from beam-beam simulation**

(.54， .62)



- # Beam Lifetime vs dynamic aperture



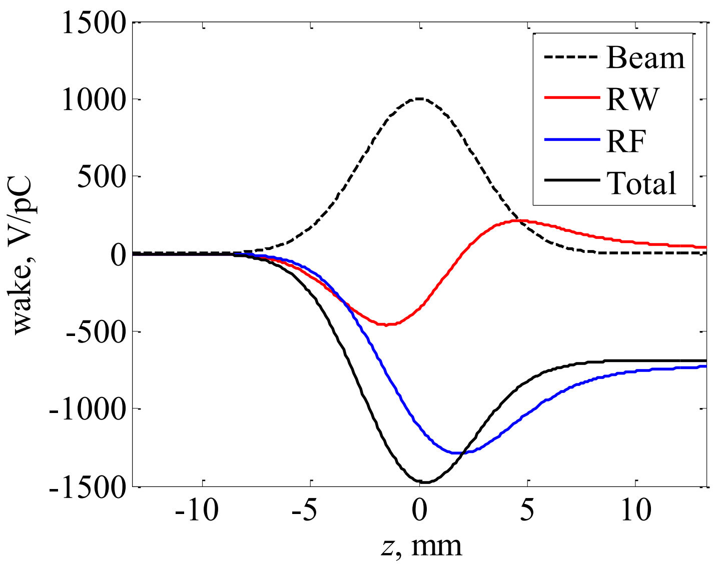


Simulation & analysis not so consistent

Collective effects

- CEPC ring wake and impedance budget

	R [kΩ]	L [nH]	k_{loss} [V/pC]	$\|Z_{//}/n\|_{eff}$ [Ω]
Resistive wall (Al)	6.6	87.1	210.9	0.0031
RF cavities (N=400)	29.3	--	931.2	---
Total	35.9	87.1	1142.1	0.0031



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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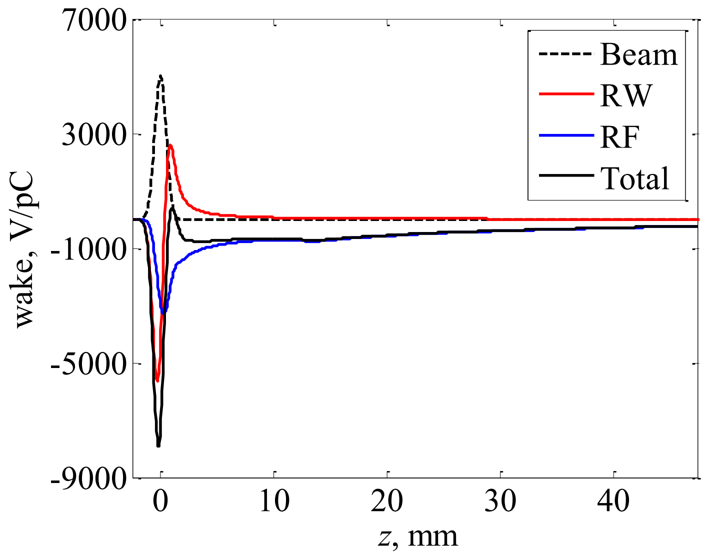
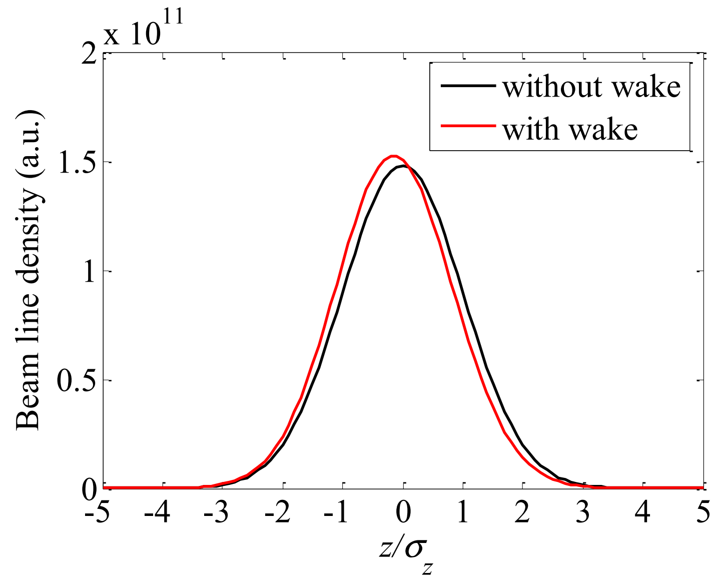
• Bunch lengthening

- 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)

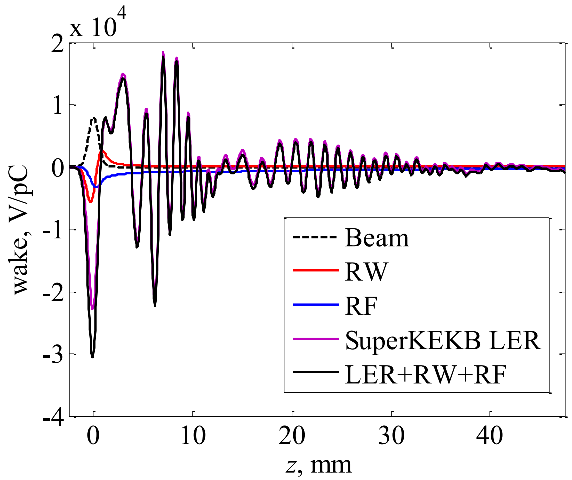


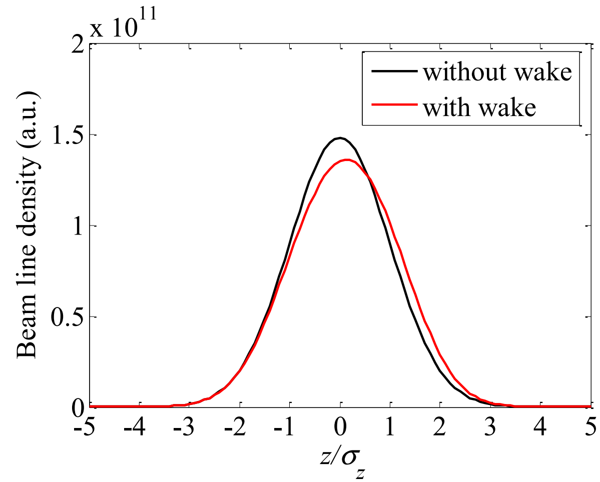
Pseudo-Green function wake (σ_z=0.5mm)



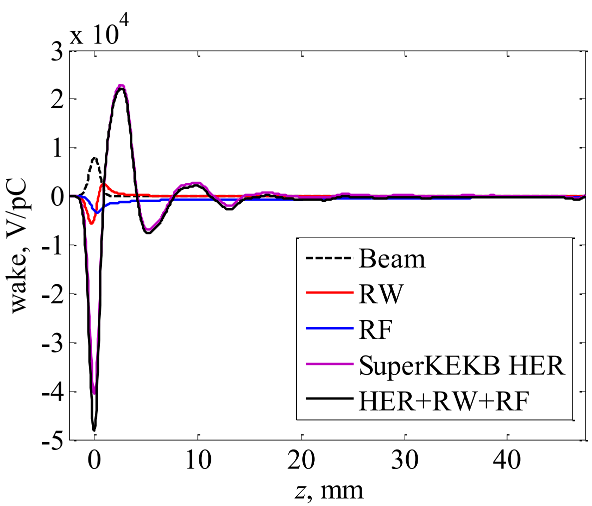
Steady-state bunch shape

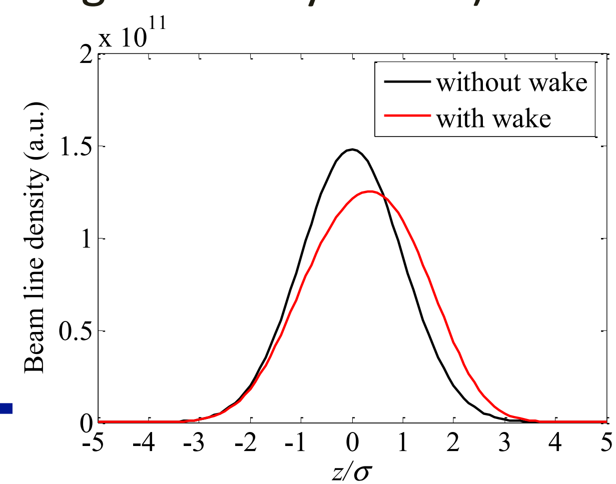
- Bunch lengthening with scaled SuperKEKB's geometry wake
  - Scaled LER wake+RW+RF (bunch is lengthened by 9.0%)





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



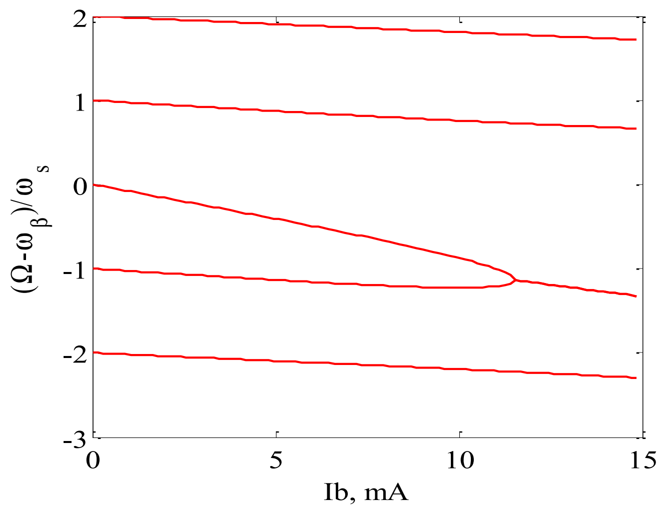


The scaling factor is Cir (CEPC)/Cir(SuperKEKB)=53.6e3/3016.315

- **CSR is not a problem in CEPC, with preliminary analyses**
- **TMCI**

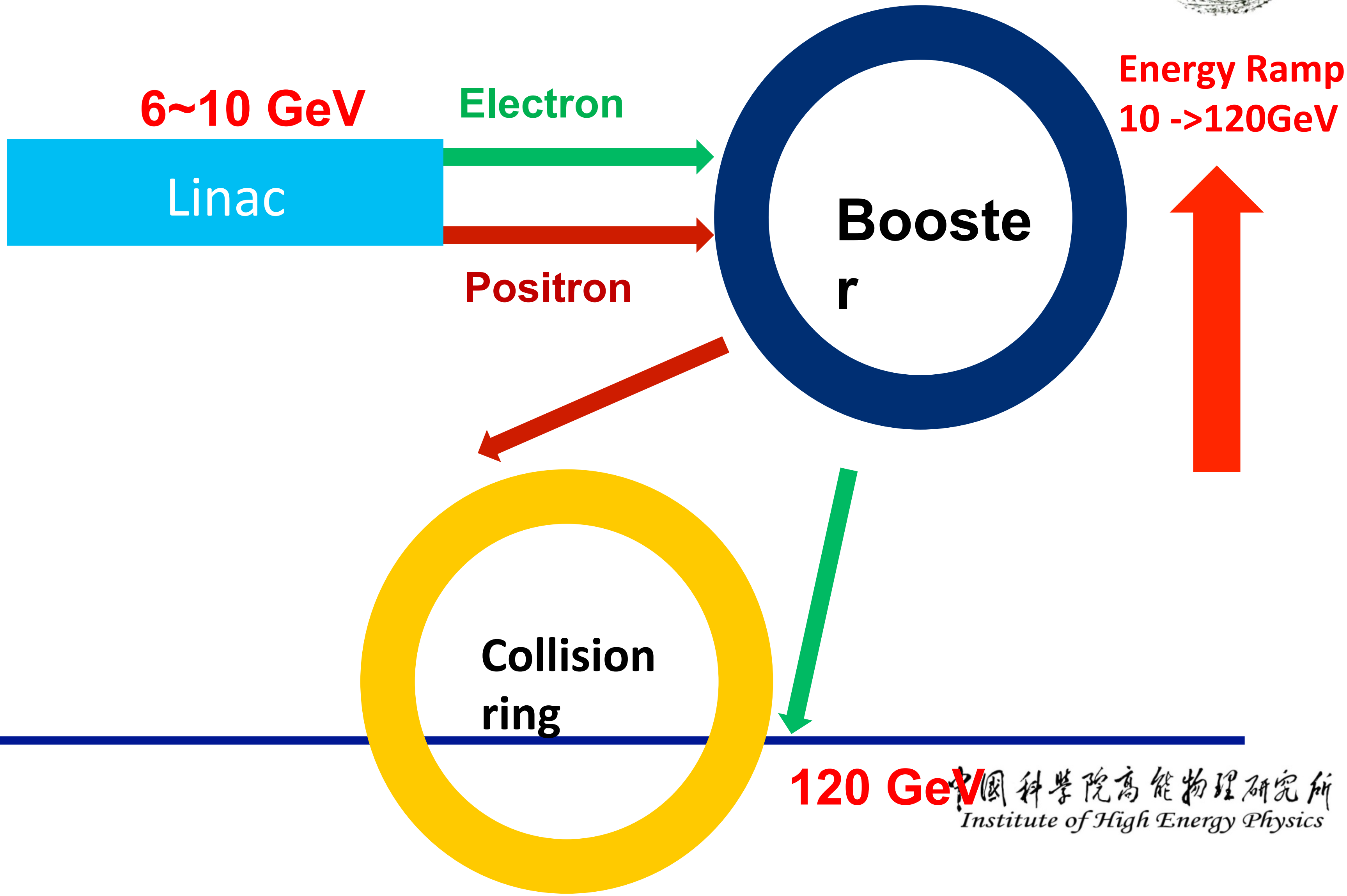
$$|Z_\perp| \le \frac{4\nu_s E b}{e I_b R < \beta_\perp >}$$

  - **The threshold of transverse impedance is $|Z| < 28.3\ M\Omega/m$.**
  - **The equivalent longitudinal impedance is 2.66 Ω, which is much larger than that of the longitudinal instability.**
- **Eigen mode analysis**
  - **Considering only resistive wall impedance**
  - **Beam current threshold:**
  - I_b^{th}=11.6mA (I_0^{th}=578mA)
  - **Safe for CEPC ring**



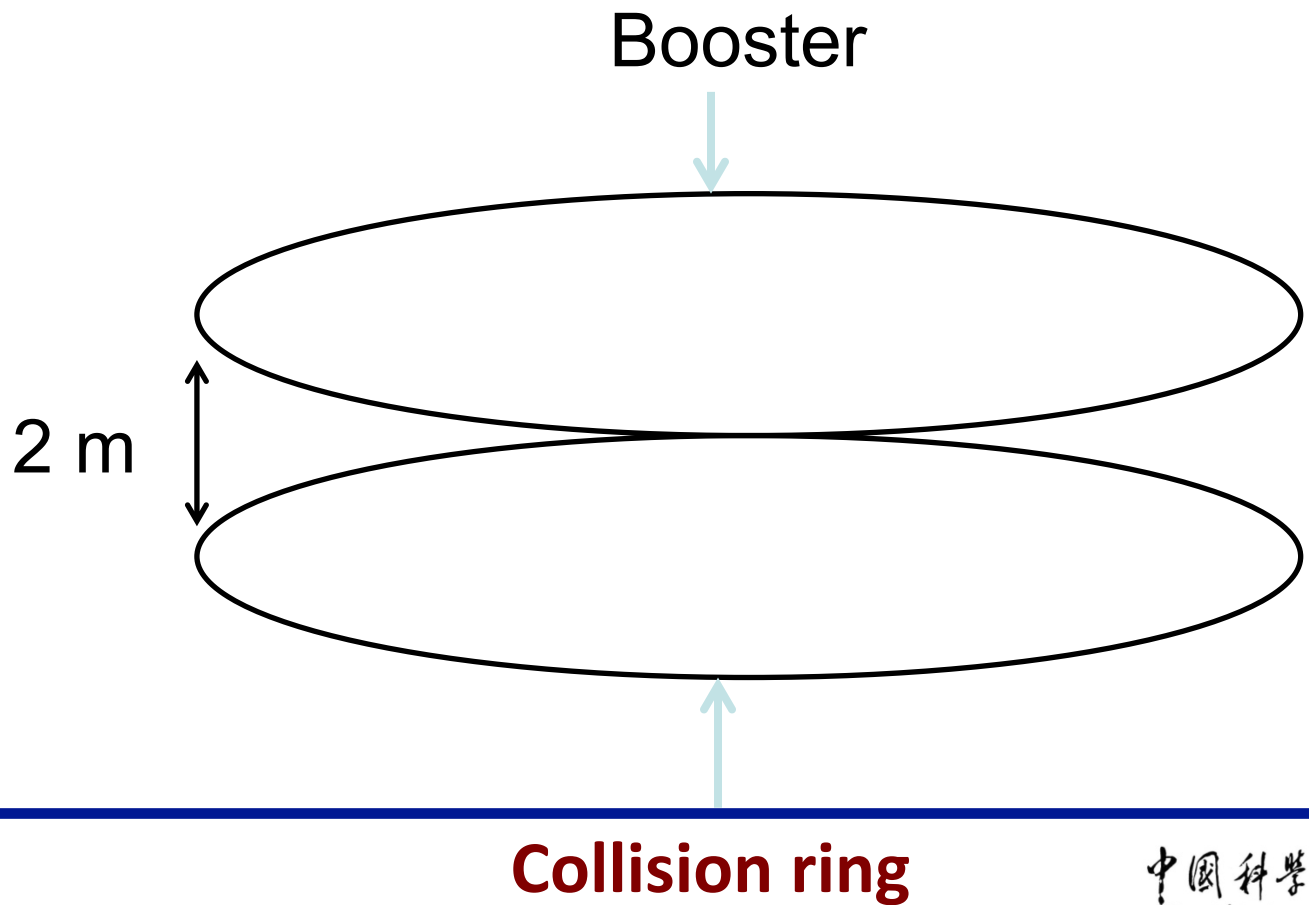
- Ion instability, ECI, will be less affected due to the other counter-rotating beam in the same vacuum chamber
- Due to pretzel scheme, when a beam cross a resonator (eg. RF cavity), the wake field excited by the beam will affect the other beam, i.e. the two beams will cross talk to each other.
- Some new physics…

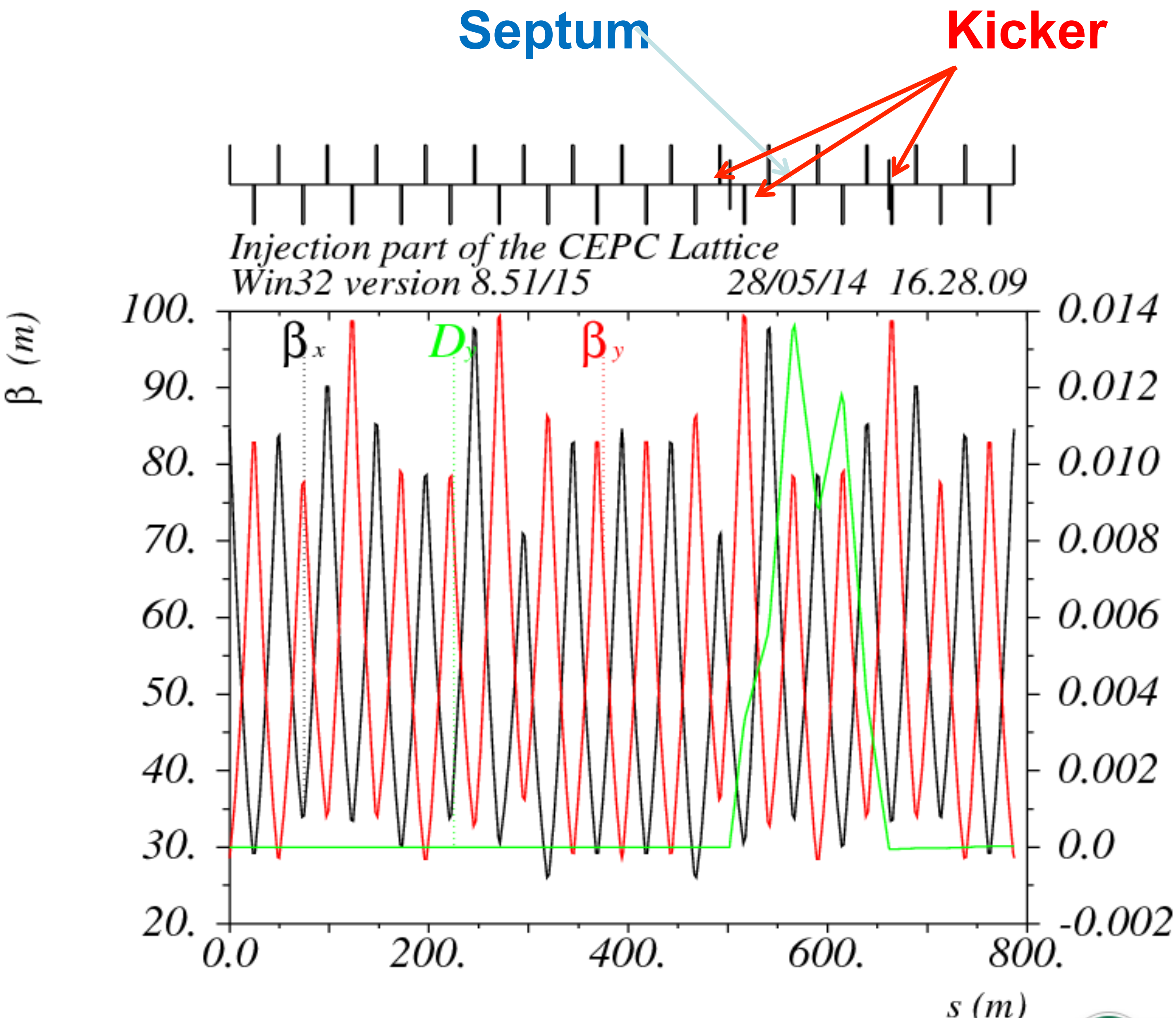
Injection



6~10 GeV
Linac
Electron
Positron
Booster
Energy Ramp
10 ->120GeV
Collision ring
120 GeV

Geometrical Arrangement





Twiss Parameters of the injection region

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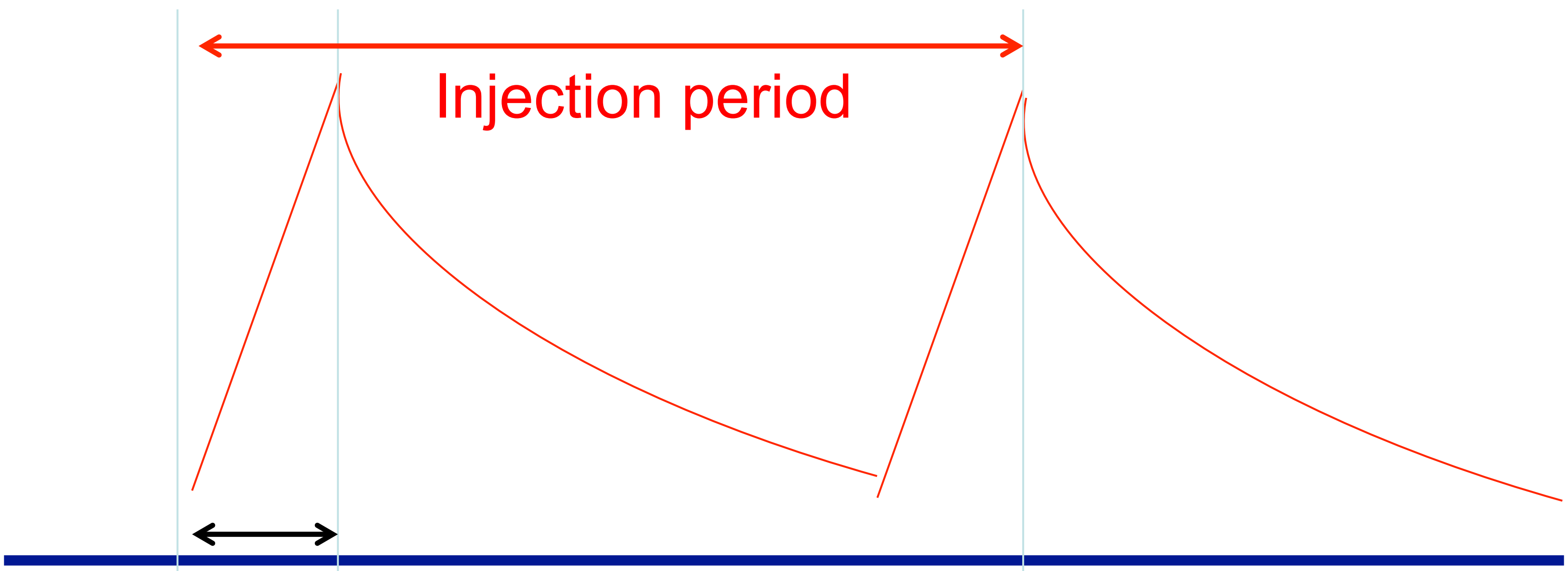
Injection time structure

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



Injection time
~10s:

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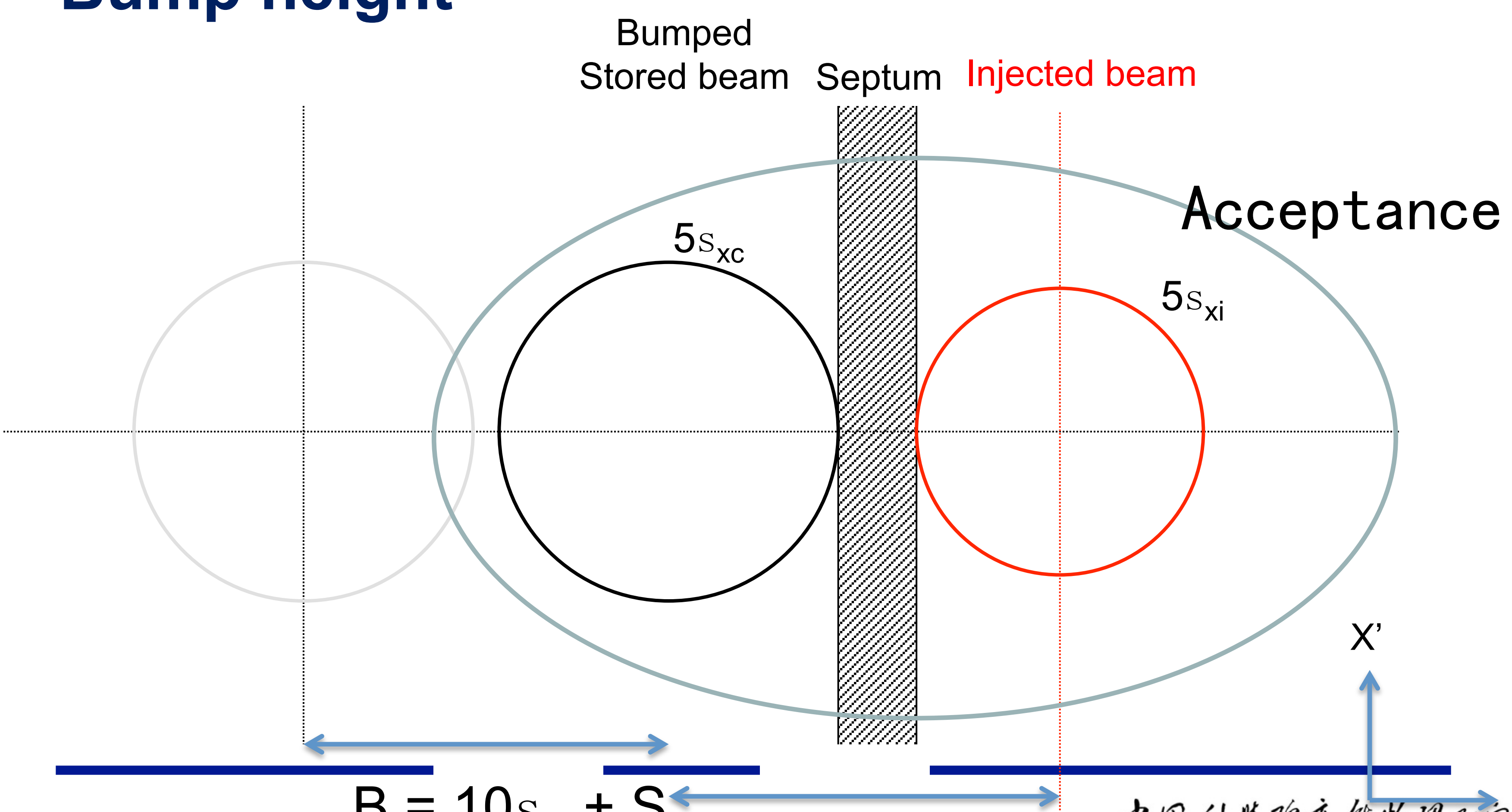
Injection Options

Bump height



$B = 10s_{xi} + S$

$5s_{xc} + 5s_{xi} + S$

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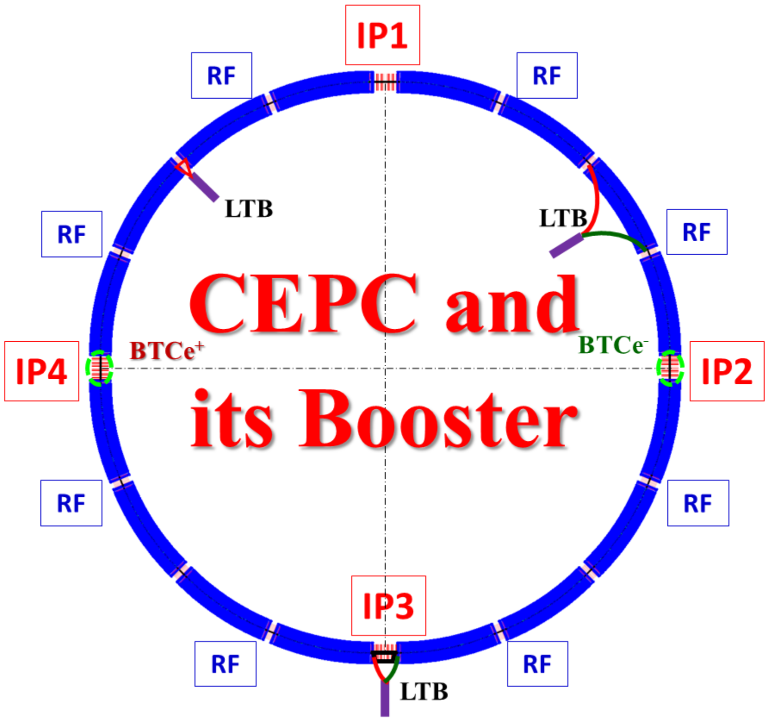
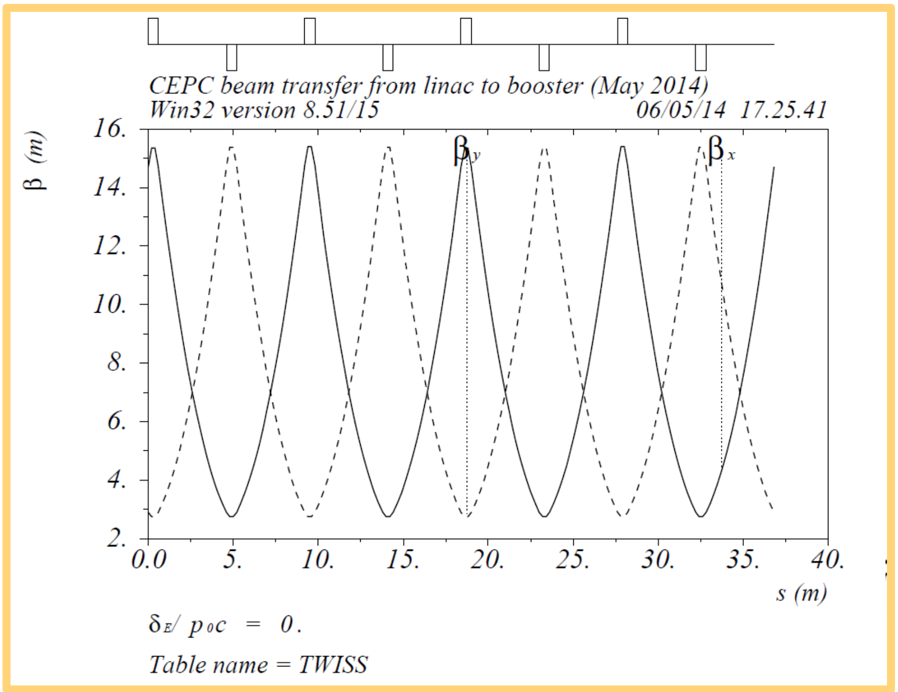
Booster & linac

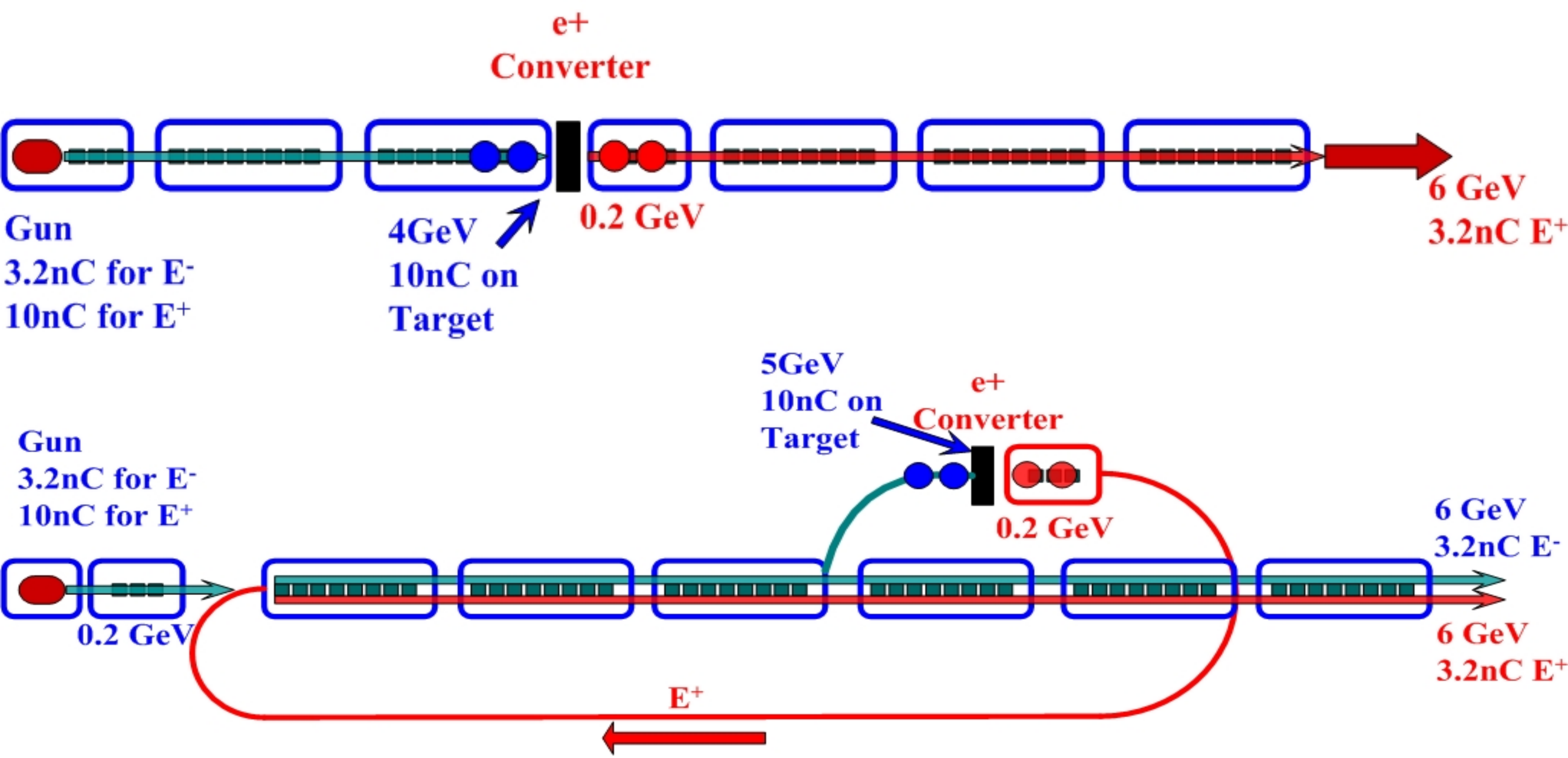
- Preliminary design for booster and transport lines
- Maybe a smaller booster with lower beam energy is necessary





Unpolarized linac

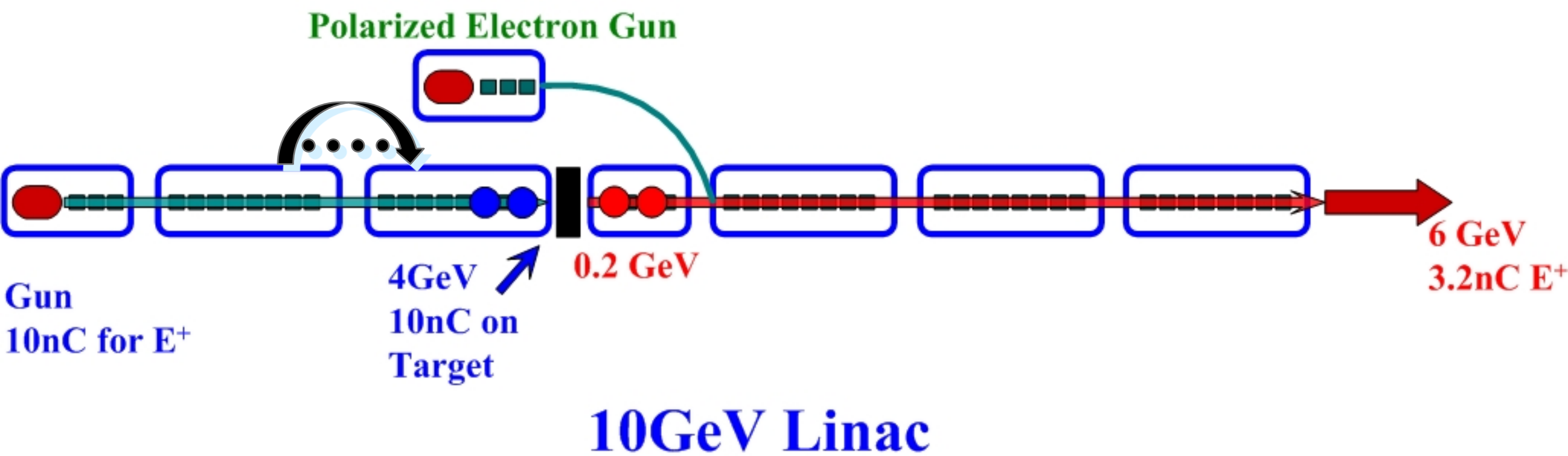
Totally 10GeV Linac



Totally 6GeV Linac

Polarized linac

- **Polarized Electron Source (R&D)**

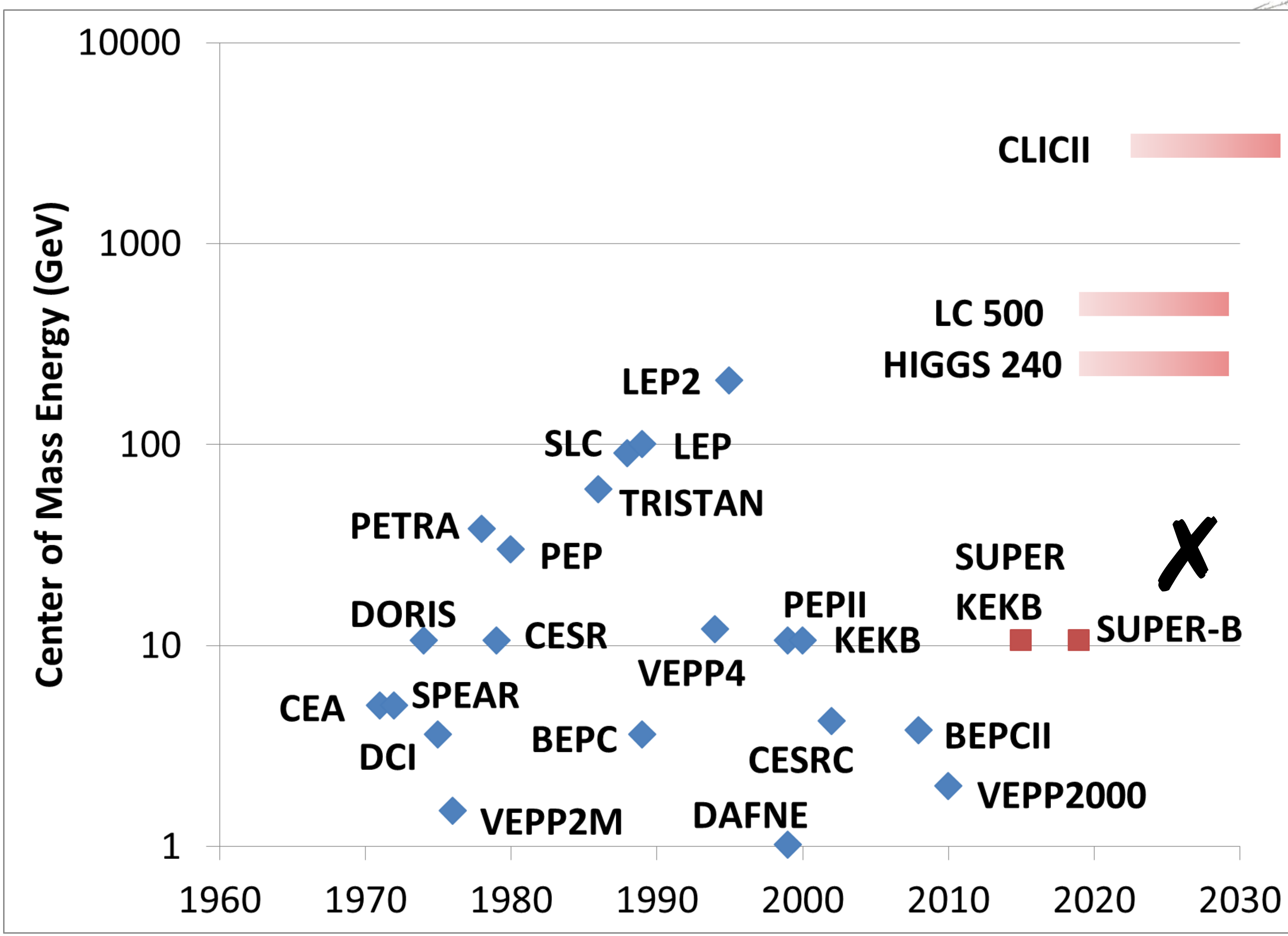


- Polarized electron gun for E-
- **Polarized electron beam collide with unpolarized positron**

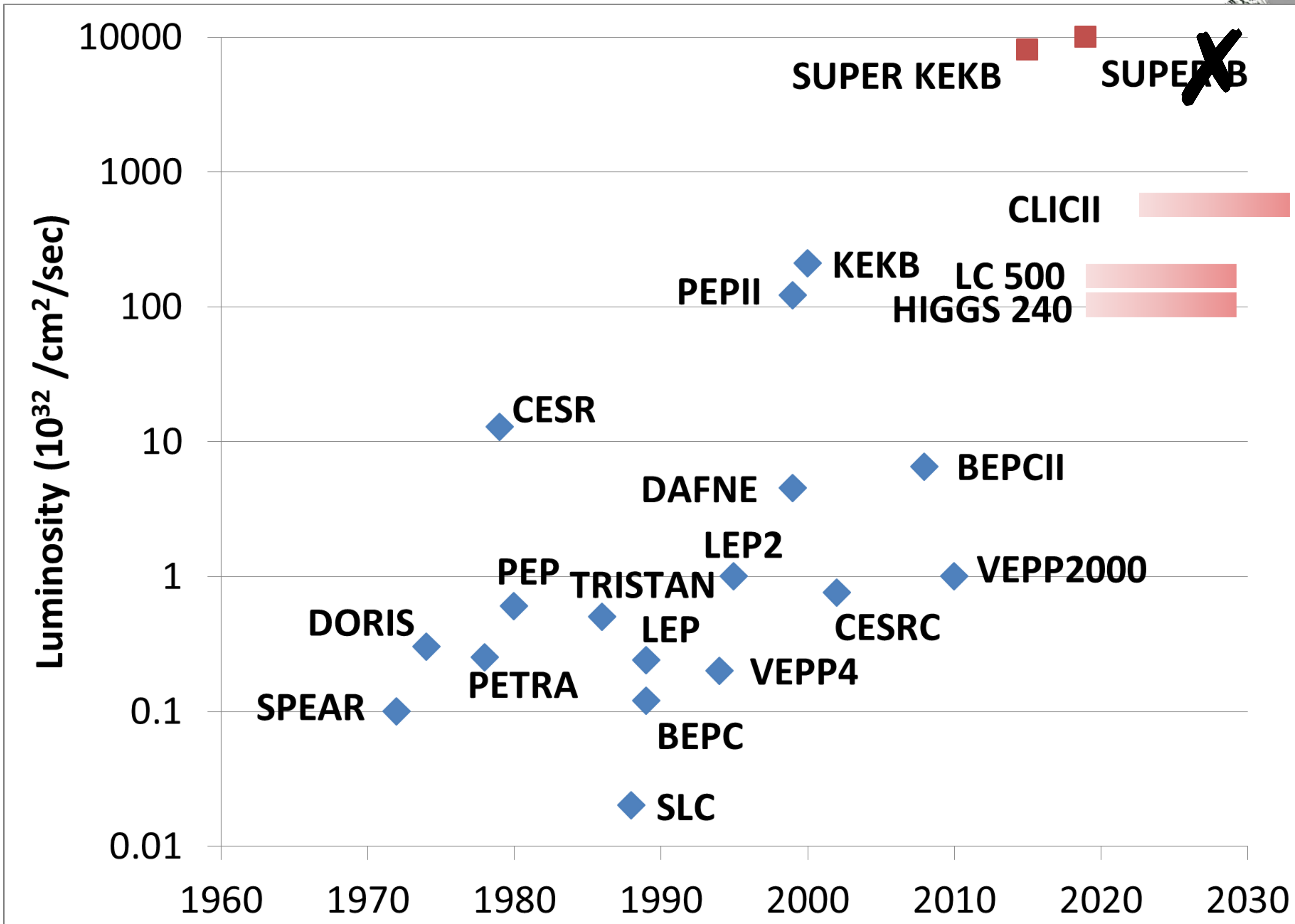
4. Plan in the near future

- CPEC
  - Pre-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 -

Livingston Chart (energy)



Livingston Chart (luminosity)



Summary

- A possible ring-based Higgs factory, CEPC is being studied and its R&D will be proposed in the near future.
- Accelerator physics of CEPC ring, are discussed. But still a lot of important issues, background, MDI, error effect, etc., need further studies.
- Hardware is also being considering, and some key tech are proposed.
- International collaborations are necessary.

Acknowledgement

- IHEP: H.P. Geng, Y. Zhang, Y.Y. Guo, N. Wang, Y.W. Wang, J. Gao, D. Wang, X.H. Cui, G. Xu, C. Zhang, G.X. Pei, X.P. Li, etc.
- FNAL: W. Chou
- SLAC: Y.H. Cai
- KEK: K. Ohmi, Y. Funakoshi, K. Oide, etc.
- CERN: F. Zimmermann, etc.
- Jlab: Y.H. Zhang
- ……

Thanks for your attention!