CEPC Accelerator study

**H.P. Geng, Y.Y. Guo, Q. Qin, D. Wang, N. Wang,
G. Xu, C. Zhang, J. Gao, M. Xiao, T. Yue**

Institute of High Energy Physics, CAS

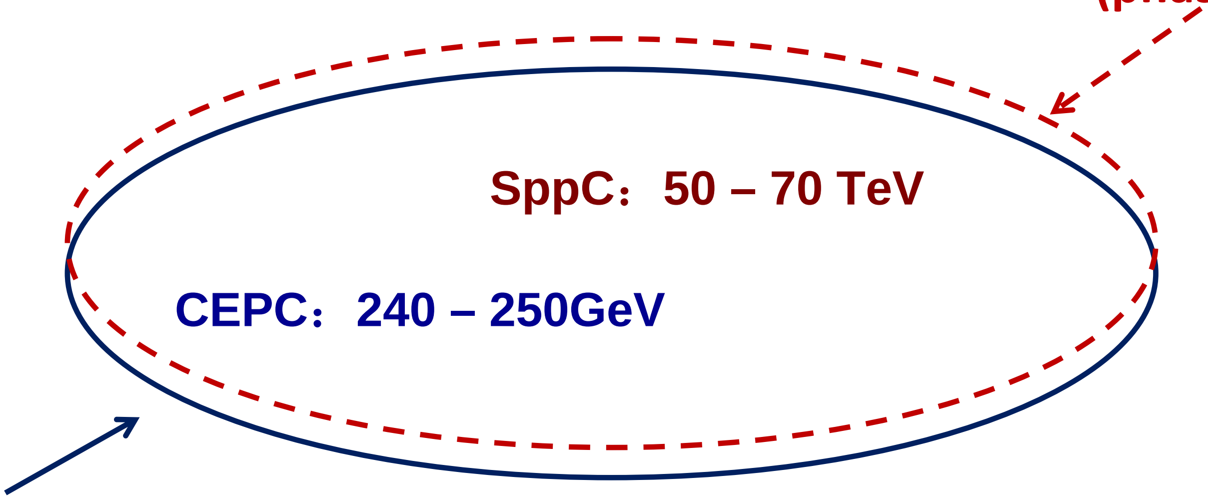
Outline

- Overview of CEPC
- Parameters determination
- Preliminary design results of accelerator
- Design study on CEPC detector
- Summary

1. Overview of CEPC

CEPC is

- an **C**ircular **E**lectron **P**ositron **C**ollider
- proposed to carry out high precision study on Higgs bosons
- to be upgraded to a super proton-proton collider



pp collider
(phase II)

SppC：50 – 70 TeV

CEPC：240 – 250GeV

e^-e^+ Higgs Factory (phase I)

CEPC basic parameter:

- Beam energy ~120 GeV.
- Synchrotron radiation power ~50 MW.
- 50/70 km in circumference.

SppC basic parameter:

- Beam energy ~50-70 TeV.
- 50/70 km in circumference.
- Needs B_{max} ~20T.

The circumference of CEPC is determined by that of the SppC, which is determined by the final energy of proton beam and the achievable dipole field strength.

Circumference

- Currently the design effort are mostly focused on the C = 50km scenario and the CEPC machine

Empirical parameters taken

- Ring filling factor
  - ✓ $\kappa = 0.78$ (C=50km)
- Beam-beam tune shifts and β_y
  - ✓ $\xi_y = 0.1$ (e machine) & $\beta_y = 1$ mm

2. Parameters determination and limits

CEPC 50km scenario

- **Circumference C =50 km**
- **Ring filling factor κ = 0.78 (C=50km)**

$$\Longrightarrow \quad \rho = 6.2\text{km}$$

- **SR power of beam = 50 MW**

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

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

$$\Longrightarrow \quad I = k_b I_b = 16.9\mathrm{mA}$$

CEPC luminosity

$$L[\mathrm{cm^{-2}s^{-1}}] = 2.17\times10^{34}(1+r)\xi_y \frac{E[\mathrm{GeV}]I[\mathrm{A}]}{\beta_y[\mathrm{cm}]}$$

- **Empirically choose**

$$\xi_y = 0.1, \quad \beta_y = 1\mathrm{mm}$$

⇨

$$L = 4.42\times10^{34}[\mathrm{cm^{-2}s^{-1}}]$$

(Hour glass effect excluded)

k_b, N_e and ε_x

Beam-beam tune shift

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

And $$\beta_y = 1\mathrm{mm}$$

Flat beam

$$\Rightarrow$$

r=0.005

$$N_e = 5.26\times10^{19}\,\varepsilon_x$$

Beamstrahlung fractional energy spread

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

r is the aspect ratio, empirically taken to be 0.005.

k_b, N_e and ε_x (cont.)

In combination with:

$$I = k_b I_b = 16.9\text{mA}$$

A small N_e means

- ➢ **decrease ε_x to keep luminosity (or beam-beam tune shift)**
- ➢ **reduce δ_{BS} , but increase k_b to keep luminosity (or beam current) and increase the difficulty of pretzel scheme**

- **$k_b \leq 50$** ⇨ $N_e = 3.52\times10^{11}, \quad \varepsilon_x = 6.69\text{nm}$

Beamstrahlung

Beamstrahlung fractional energy spread

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

Beamstrahlung limited luminosity:

$$L_{\mathrm{limit}} = 0.4565 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1} \frac{\rho(\mathrm{km}) P_{\mathrm{SR}}(100\mathrm{MW}) \sqrt{\delta_{\mathrm{BS}}(0.1\%)}}{(E/100\mathrm{GeV})^{4.5} \sqrt{\varepsilon_y(\mathrm{nm})}}$$

$$= 0.4565 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1} \frac{\rho(\mathrm{km}) P_{\mathrm{SR}}(100\mathrm{MW})}{(E/100\mathrm{GeV})^{4.5}} \cdot \frac{\sqrt{\underline{\delta_{\mathrm{BS}}}(0.1\%)}}{\sqrt{r\varepsilon_x(\mathrm{nm})}}$$

Life time due to beamstrahlung:

$$E_{cb} = \frac{3\gamma r_e^2 N_e E}{\alpha \sigma_x \sigma_z}, \quad u = \frac{\sigma_e E}{E_{cb}}, \quad n_{col} = \frac{20\sqrt{6\pi} r_e \gamma u^{3/2}}{\alpha^2 \underline{\sigma_e \sigma_z}} \mathrm{e}^u \qquad \tau = n_{col} T_0$$

RF frequency and voltage

- **Energy spread and acceptance due to SR**

$$\underline{\sigma_e} = \gamma\sqrt{\frac{C_q}{J_e\rho}} \qquad \eta = \sqrt{\frac{U_0}{\pi\alpha_p hE}F_q}$$

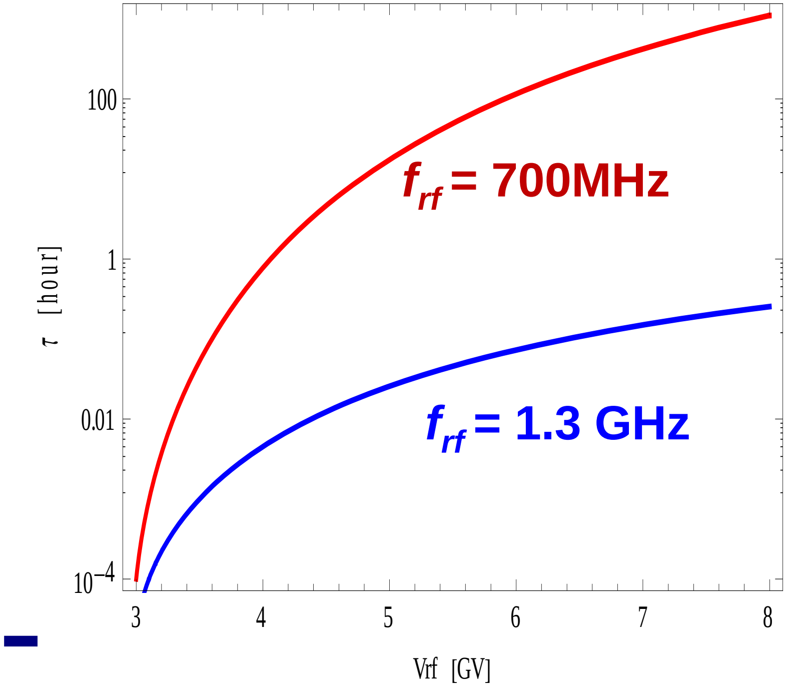
- **Synchrotron tune and bunch length:**

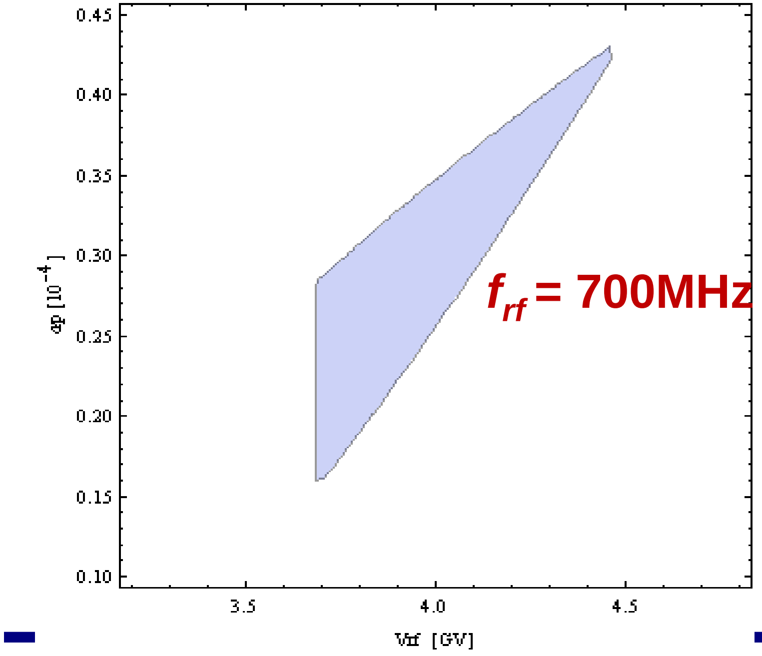
$$\nu_s = \sqrt{-\frac{\underline{\alpha_p hV_{rf}}cos\varphi_s}{2\pi E}} \qquad \underline{\sigma_z} = \frac{\underline{\alpha_p}R\underline{\sigma_{e0}}}{\nu_s}$$

- **Beamstrahlung effects are determined by f_{rf}, V_{rf} and α_p *(at given transverse parameters)*!**

RF frequency and voltage

- **For chosen transverse bunch size and N_e, beam lifetime due to beamstrahlung is 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 at given f_{rf}.**





FODO cells

- **A FODO cell is adopted in arcs, and 60 degree is chosen as the phase advance, then ε_x and α_p can be got roughly from**

$$\varepsilon_x = \frac{1-\frac{3}{4}sin^2\frac{\mu}{2}}{sin^3\frac{\mu}{2}cos\frac{\mu}{2}}C_q\gamma^2(\frac{\varphi}{2})^3 \qquad \alpha_p = (\frac{\varphi}{2})^2(\frac{1}{sin^2\frac{\mu}{2}}-\frac{1}{12})$$

$\varepsilon_x = 6.69\text{nm}$ → $\alpha_p = 0.4\times10^{-4}$ → **V_{rf} = 4.2 GV**

•5-cell RF cavity can be a candidate for RF system:

E_{acc}=20MV/m, V_c=2MV, L_{acc}=1m, N_{cav}=210

Main beam parameters for CEPC at 50km

Parameter	Unit	Value	Parameter	Unit	Value
Energy	GeV	120	Circumference	km	50
Number of IP		1	SR loss	(GeV/turn)	2.96
N_e/bunch	1E11	3.52	N_b/beam		50
Beam current	mA	16.9	SR power/beam	MW	50
Partition Je		2	Long. damp. time	ms	6.7
Dipole field	Tesla	0.065	Bending radius	km	6.2
Dipole length	m	9.978	Bending angle	mrad	1.609
Emittance (x/y)	nm	6.69/0.033	β_{IP} (x/y)	mm	200/1
Trans. size (x/y)	μm	36.6/0.18	Mom. compaction	1E-4	0.4
$\xi_{x,y}$ /IP		0.1/0.1	Bunch length	mm	3

Parameters (cont.)

Parameter	Unit	Value	Parameter	Unit	Value
RF voltage V_{rf}	GV	4.2	RF frequency f_{rf}	GHz	0.7
Long. tune ν_s		0.13	Harmonic number		116747
Hourglass factor		0.6	n_γ		0.42
Energy spread SR		0.0013	Energy spread BS		0.00014
Energy acceptance	%	2.7	Lifetime BS	hr	1.6
L_0 /IP (10^{34})	$cm^{-2}s^{-1}$	2.65	L_{limit} /IP (10^{34})	$cm^{-2}s^{-1}$	1.26

3. Preliminary design results of accelerator

CEPC main ring:

- A FODO lattice in arcs with 60 degree phase advances
- 16-folder symmetry
- RF sections distribute around the ring
- Pretzel scheme will be adopted for multi-bunch collision

Booster:

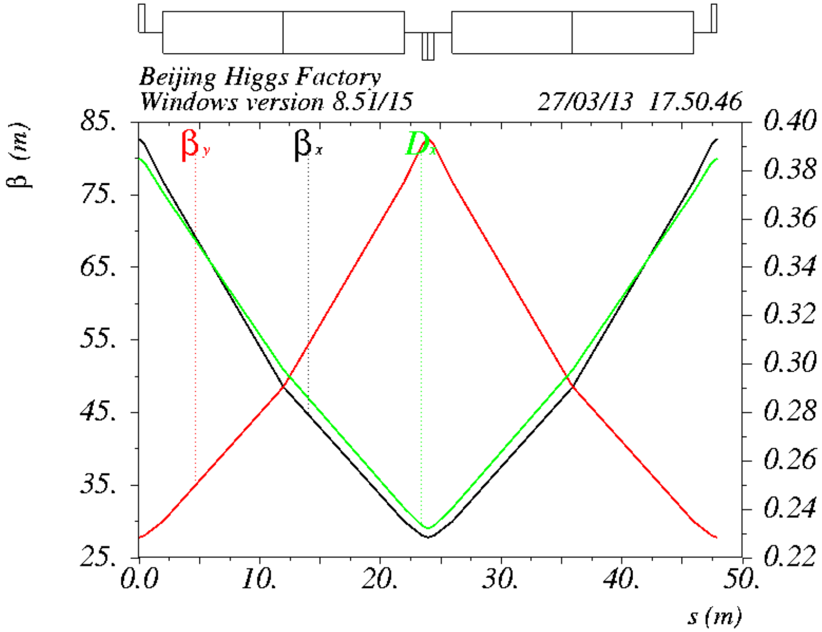
- In the same tunnel of the collider (6 – 120 GeV)

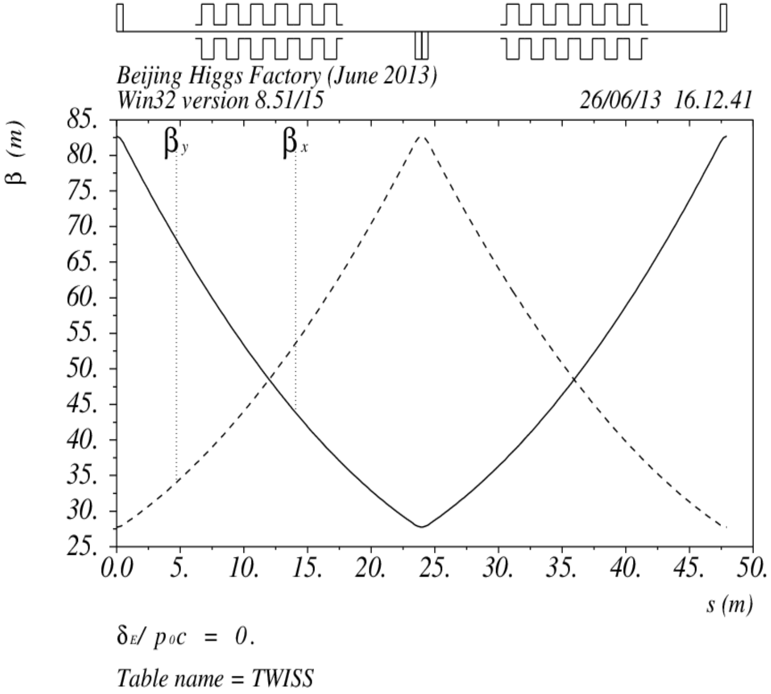
Linac:

- 6GeV–Linac will be adopted.

Linear lattice of CEPC main ring

- **Standard FODO lattice in arcs and RF sections**

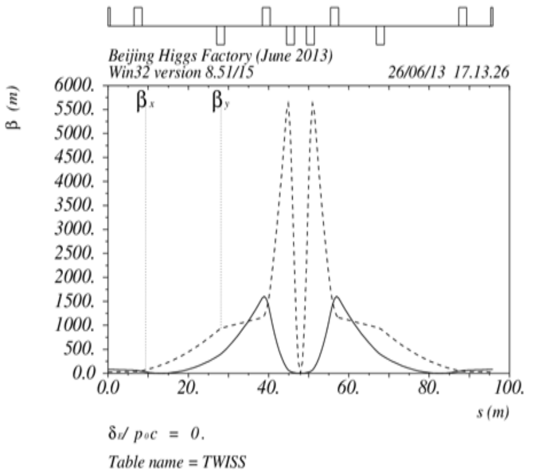


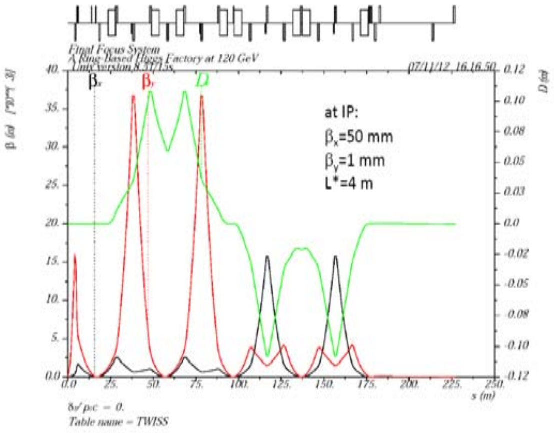


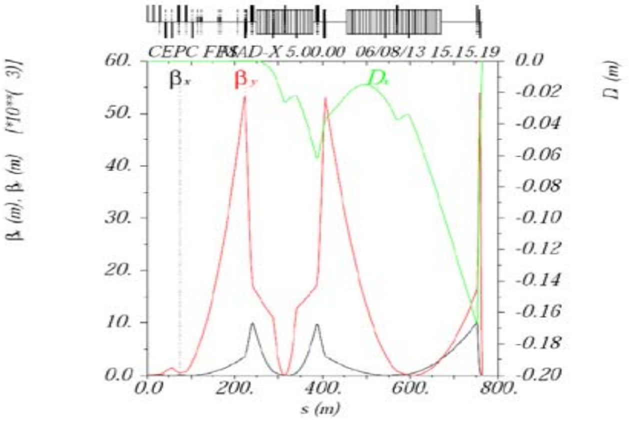
Final focus system

- **Simple FFS design had been tried, but the beam dynamic aperture is too small**
- **SLAC type and ILC type FFS designs are currently under study in parallel to achieve a reasonable dynamic aperture**

Please see Wang Dou’s talk for details.







Possibility to lower the wall-plug power

- High beam power due to SR will cause huge power consumption of the whole machine
  - Arising heating of vacuum chamber
  - Increasing the cost of construction and operation
- How can we save the power (beam, total)
  - Reducing beam current → luminosity decreased dramatically.
  - Reducing beam current, and lower the β_y@IP – keep luminosity decreased not so much.
  - etc.

Low-beta parameters for 50km CEPC

	β_{IP}(y) 1mm	β_{IP}(y) 0.48mm	β_{IP}(y) 0.35mm
SR power /beam (MW)	50	25	15
Beam current (mA)	16.9	8.45	5.07
N_e/bunch (10^{12})	0.79	0.38	0.28
Bunch number	22	23	19
$\beta_{IP\ x}$ (m)	0.2	0.071	0.041
Emittance x/y (nm)	14.6/0.073	9.5/0.035	8.9/0.026
σ_{IP} (um)	54/0.27	25.9/0.13	19.2/0.096
ξ_x	0.1	0.076	0.06
F (hour glass)	0.68	0.48	0.41
L_{max}/IP ($10^{34}cm^{-2}s^{-1}$)	3.1	2.31	1.58
L_{limit}/IP ($10^{34}cm^{-2}s^{-1}$)	1.5	0.9	0.8
Lifetime Bhabha (min)	35	17	12
Total AC power* (MW)	288	186	145

* including main ring, booster, injectors and detector etc.

Long. and tran. microwave instabilities

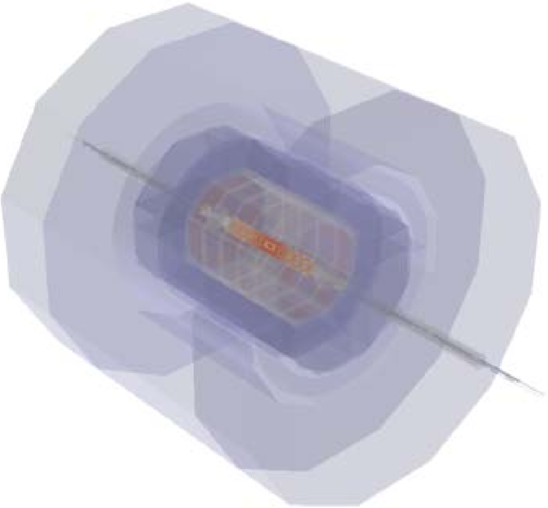
SR Power/beam(MW)	50	25	20	15	LEP3/50
Energy (GeV)	120	120	120	120	120
Circumference (km)	50	50	50	50	26.7
Beam current (mA)	16.9	8.45	6.76	5.07	7.2
Bunch number	50	23	21	19	3
Bunch current (μA)	338.0	367.4	321.9	266.8	2400
α_p (10^{-4})	0.4	0.38	0.38	0.38	0.81
σ_δ (10^{-3})	1.3	1.3	1.3	1.3	2.32
σz (mm)	3	2.2	2.2	2.2	3
νx/νy	172.3/171.3				70/100
ZL/nthreshold (Ω)	0.022	0.015	0.017	0.020	0.052
TMCI threshold I_{th} (μA)	656.5				1796.5
MWI threshold I_{th} (μA)	1045.2				4168.5

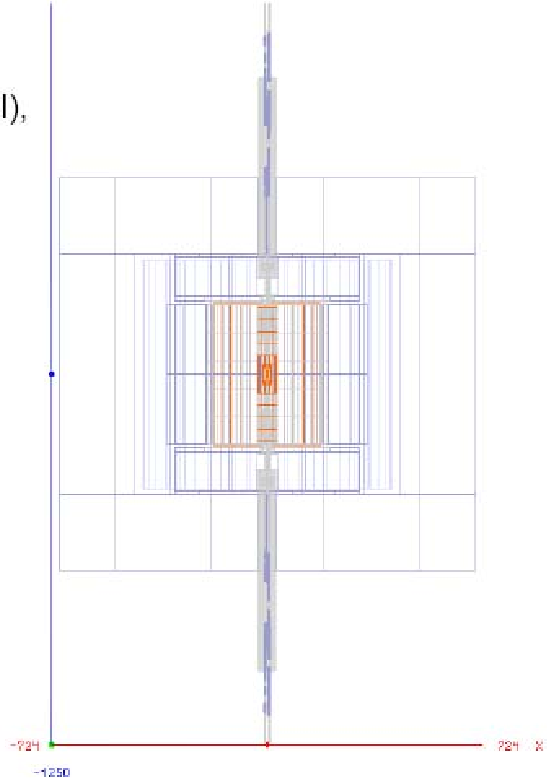
4. Design study on CEPC detector

Reference detector for CEPC: ILD

Scale: half_Z: 12.5/6.62 meter, radius 7.24 meter

Sub detectors: VTX, SIT, FTD, TPC, SET/ETD(optional),
Ecal, Hcal, Coil, Muon





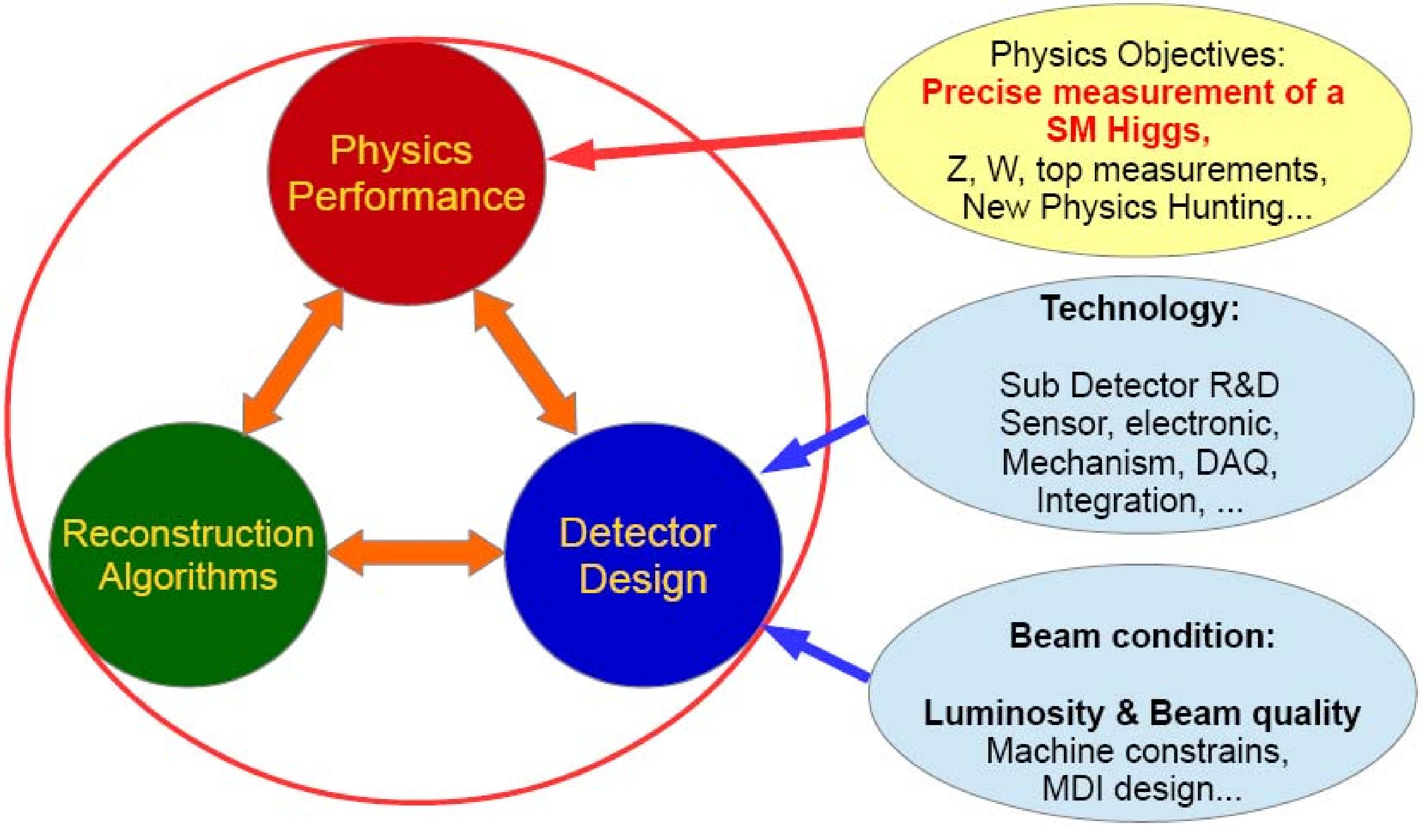
ILD

- Massive usage of silicon pixel/strips in the tracking system & VTX: ensures good accuracy in Impact parameter & momentum measurement
- TPC as its main tracker
- PFA Oriented Calorimeter: Identify and measure each incident particles with sufficient energy
- Calorimeter R&D for ILD: Ultra high granularity: ~ 1 channel cm^{-3}. 3d, 4d or 5d image...

From ILD to CEPC detector

- **Many new designs**
  - **Changed granularity (no power pulsing)**
  - **Changed L***
  - **Changed VTX inner radius and TPC outer Radius**
  - **Changed Detector Half Z**
  - **Changed Yoke/Muon thickness**
  - **Changed Sub detector design**
  - **…**
- **All Changes need to be implemented into simulation, iterate with physics analysis and cost estimation**

Detector optimization: Basic ingredients



Physics Objectives:
Precise measurement of a SM Higgs,
Z, W, top measurements,
New Physics Hunting...

Technology:

Sub Detector R&D
Sensor, electronic,
Mechanism, DAQ,
Integration, ...

Beam condition:

Luminosity & Beam quality
Machine constrains,
MDI design...

More than 10 national institutes have joined this efforts

Summary

- A CEPC + SppC was proposed in IHEP for high precise probe of Higgs, and new discovery of physics as well.
- Main parameters and basic lattices are being studied and further iterations are required.
- Detector design are being investigated, optimization work is underway.
- CEPC+SPPC design work formally launched, more institutions are involved, man power and computing resources are being allocated to different topics.

Thank you for your attention !