Circular Electron-Positron Collider
Status and Prospects

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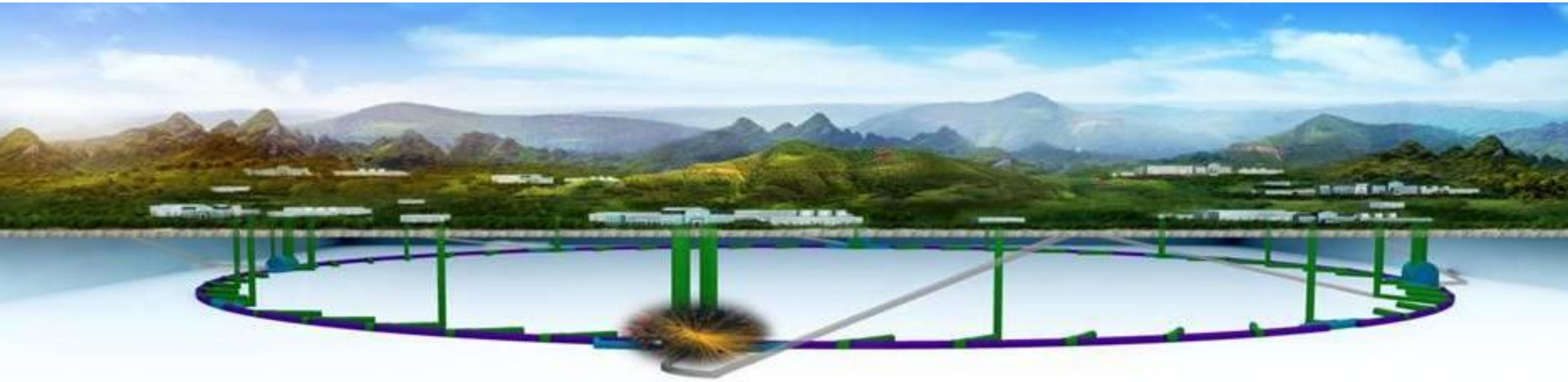


Outline

- Reminder & introduction
- CEPC accelerator design improvement
- Detector, software and simulation study
- Site investigation
- Prospects

CEPC accelerator TDR and details will not be covered here

Reminder about the CEPC-SppC

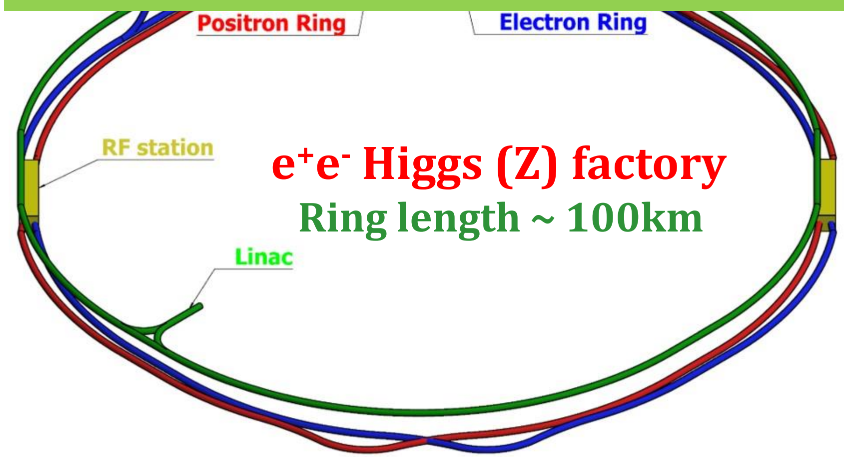
e^+e^- Higgs (Z) factory Initially team set up the minimum goals

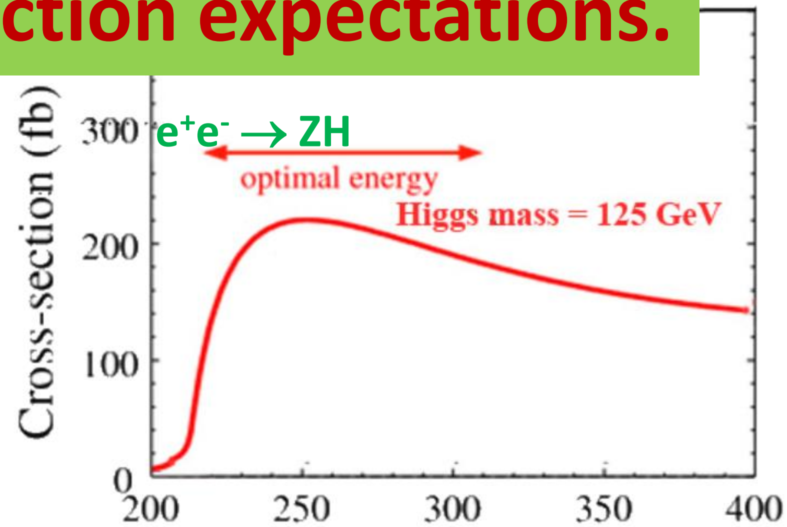
$E_{cm}\approx 240$GeV, luminosity $\sim 2\times 10^{34}\ cm^{-2}s^{-1}$, 2IP， 1M H in 10 years
at the Z-pole 10^{10}Z bosons/yr

Higgs precision
1% or better

Upg

CDR and post CDR design improvement exceeds these minimum requirement on the Higgs and Z in production expectations.



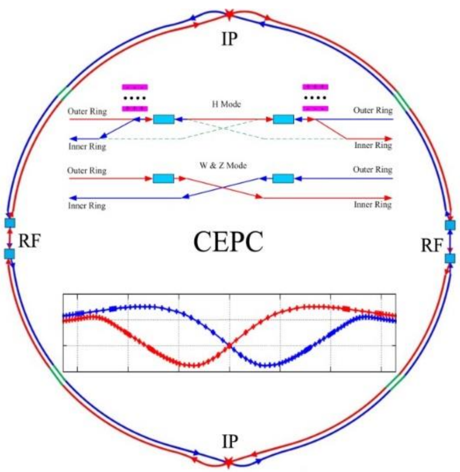


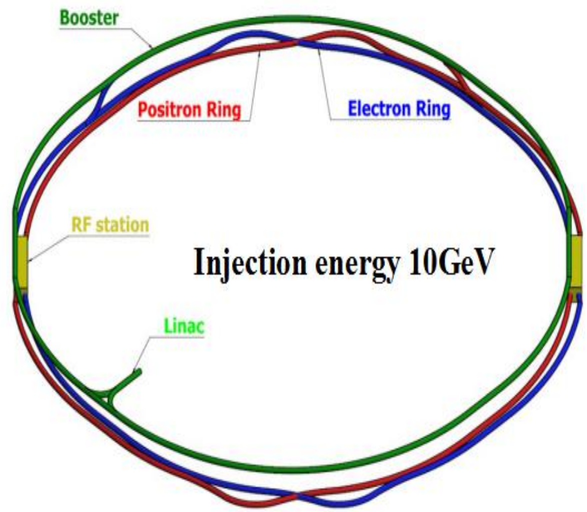
BEPCII improvement – will likely complete its mission ~2029;
CEPC – possible accelerator based particle physics program in China after BIII

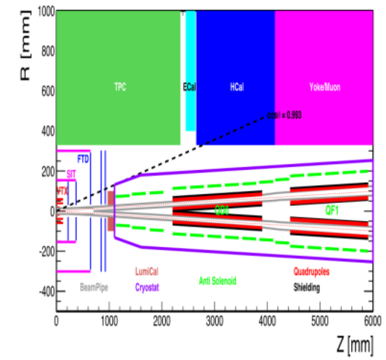
CEPC CDR – Accelerator (2018)

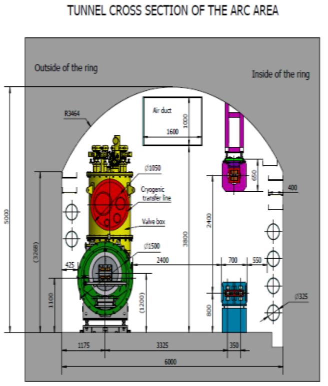
Lumi.	Higgs	W	Z	Z(2T)
$\times 10^{34}$	2.93	11.5	16.6	32.1

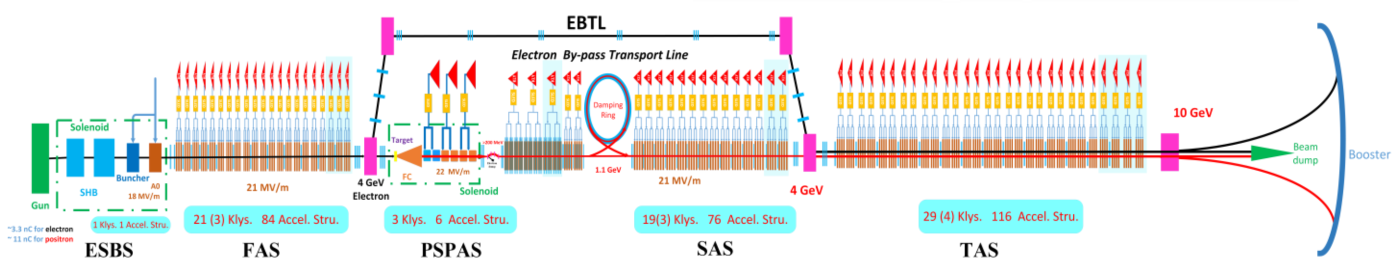
http://cepc.ihep.ac.cn/CEPC_CDR_Vol1_Accelerator.pdf







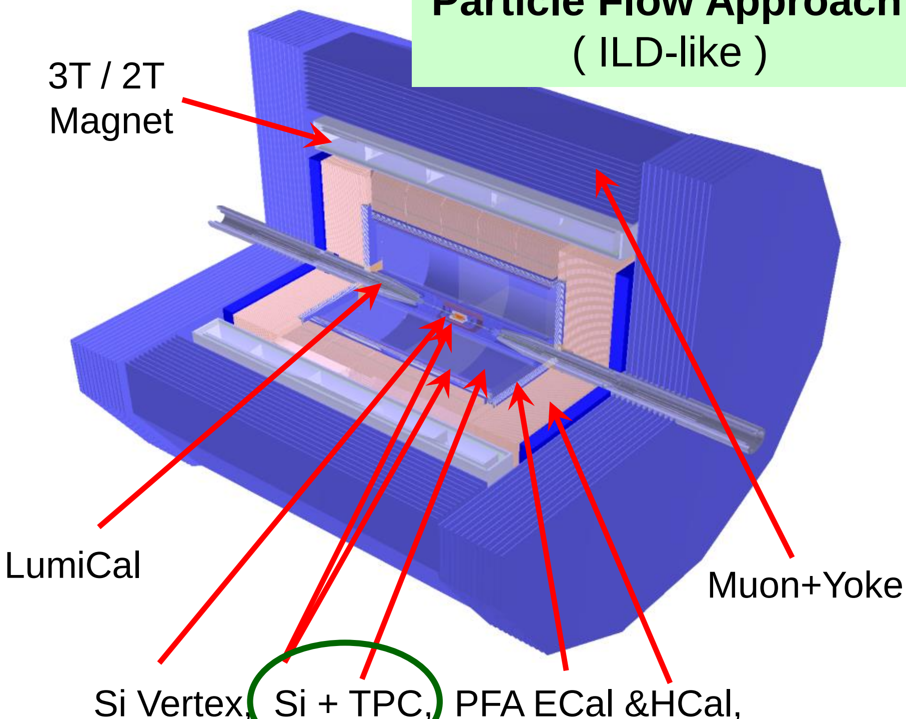




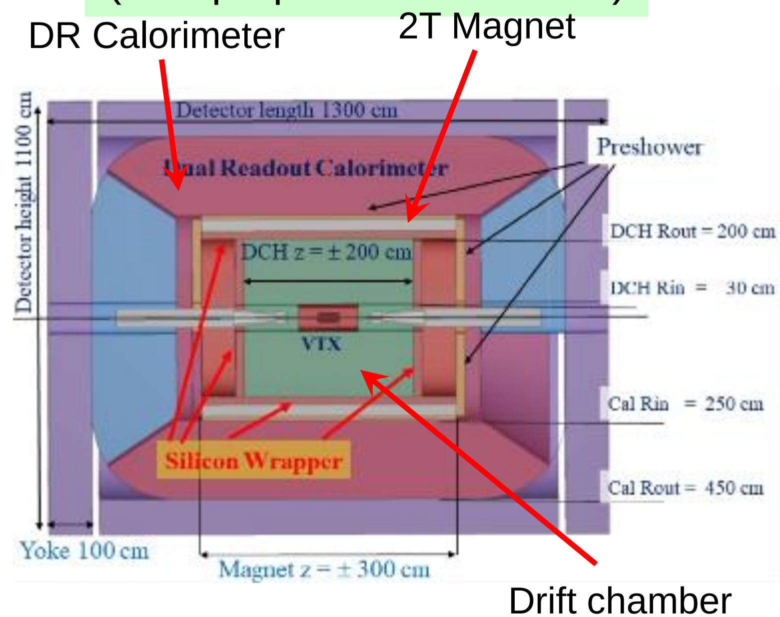
Baseline: 100 km, 30 MW; Upgradable to 50 MW, High Lumi Z, ttbar; Compatible to pp collider

CDR - Detector-Physics (2018)

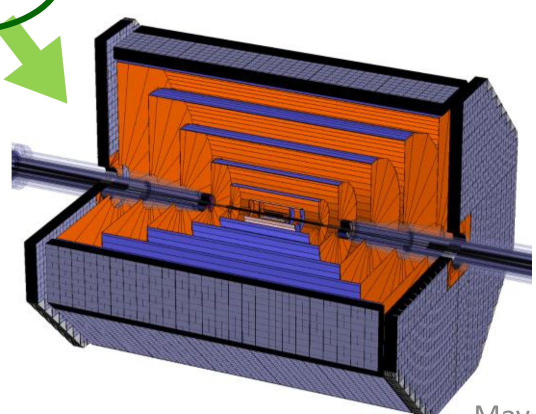
Particle Flow Approach
(ILD-like)



IDEA concept
(also proposed for FCC-ee)

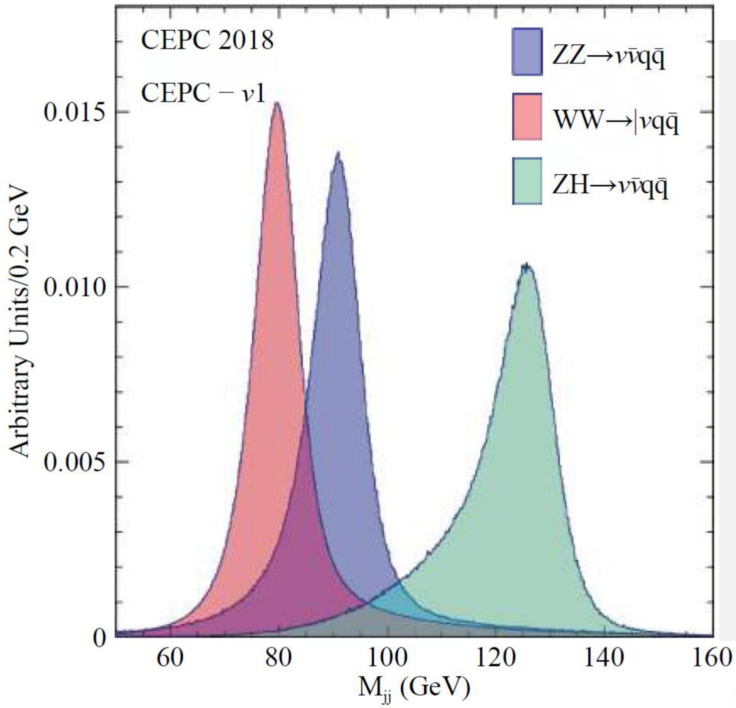


Full Silicon
Tracker
(FST) concept



- Official international collaborations are to be formed, and to decide the detector design.
- The working group is doing R&D of all sub-systems in the CDR design, and exploring various other technologies.
- The final two detectors likely are mixtures of different options.

CEPC CDR – Physics Performance (2018-19)



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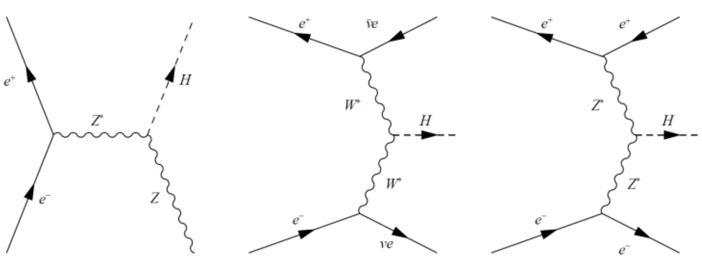
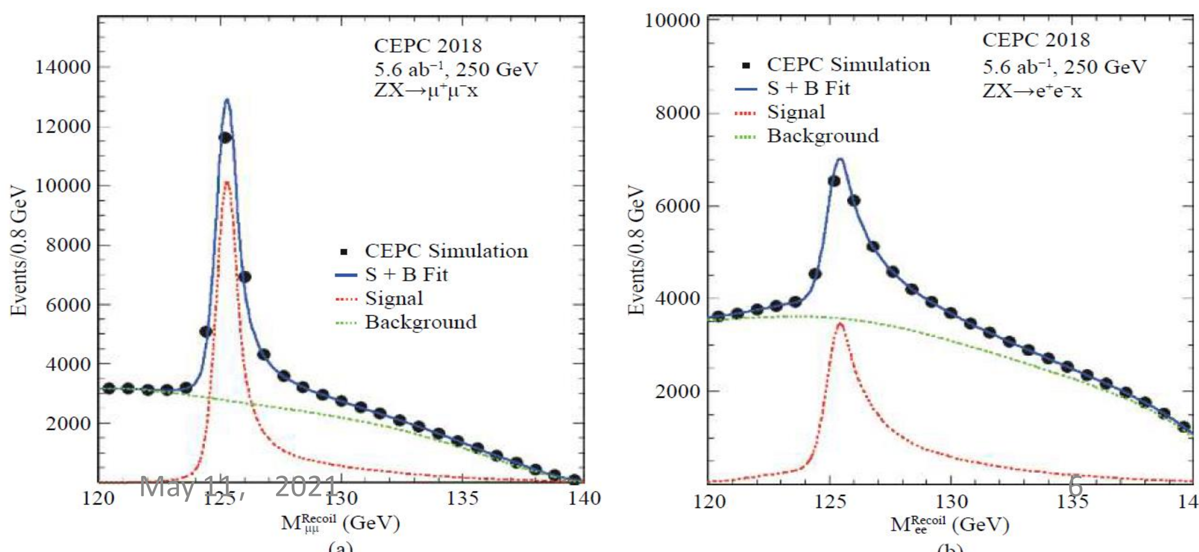
- CEPC experiments can detect well various physics processes
- Very challenging events with missing neutrinos and q-jets are well reconstructed and identified (left)
- Untouched Higgs are detected via recoil mass of the reconstructed Z, allowing for model independent & full investigation of the Higgs and any new physics the Higgs may reveal (below)

e^+e^- annihilations at CEPC





CEPC CDR – Physics Performance (2018-19)

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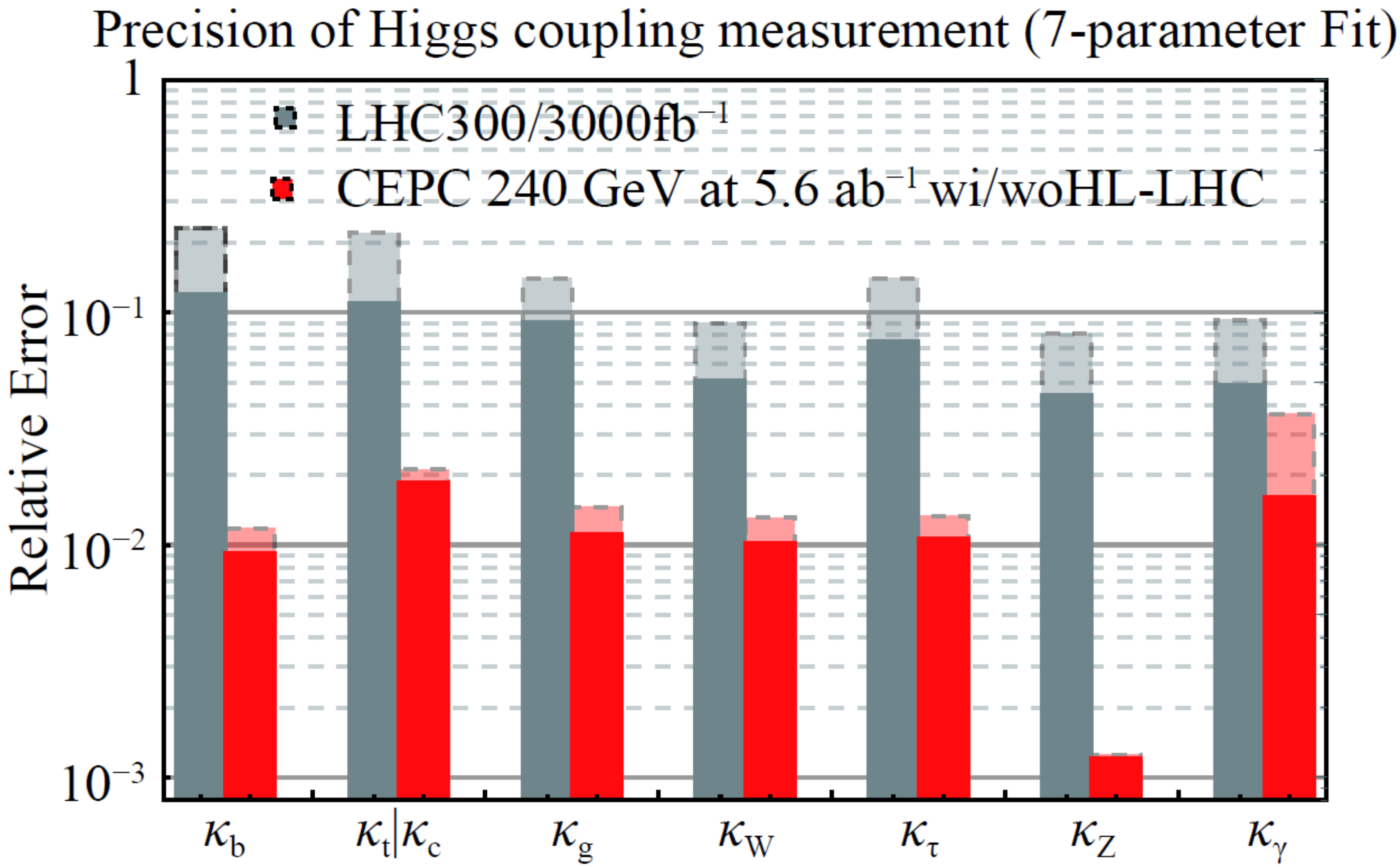

Order(s) of magnitude enhancement in precision ⇒ many unknown/discoveries

CEPC CDR – Physics Performance (2018-19)

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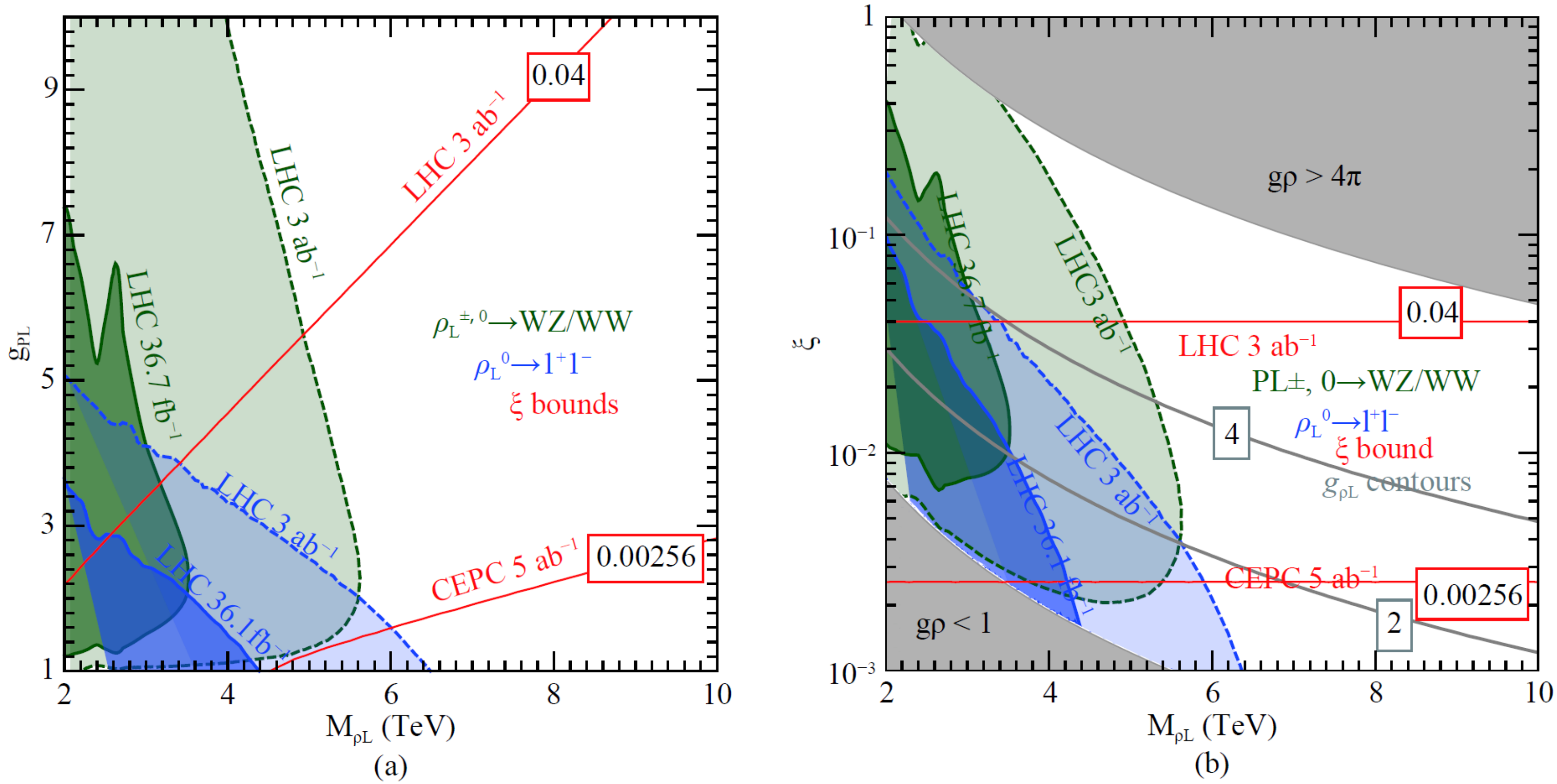
CEPC can probe multi-TeV space for new physics



(color online) Limits on the composite Higgs boson model from both direct searches at the LHC and precision measurement at the CEPC. The figures are updated versions of the ones presented in Ref. [138].

CEPC CDR – Physics Performance (2019)

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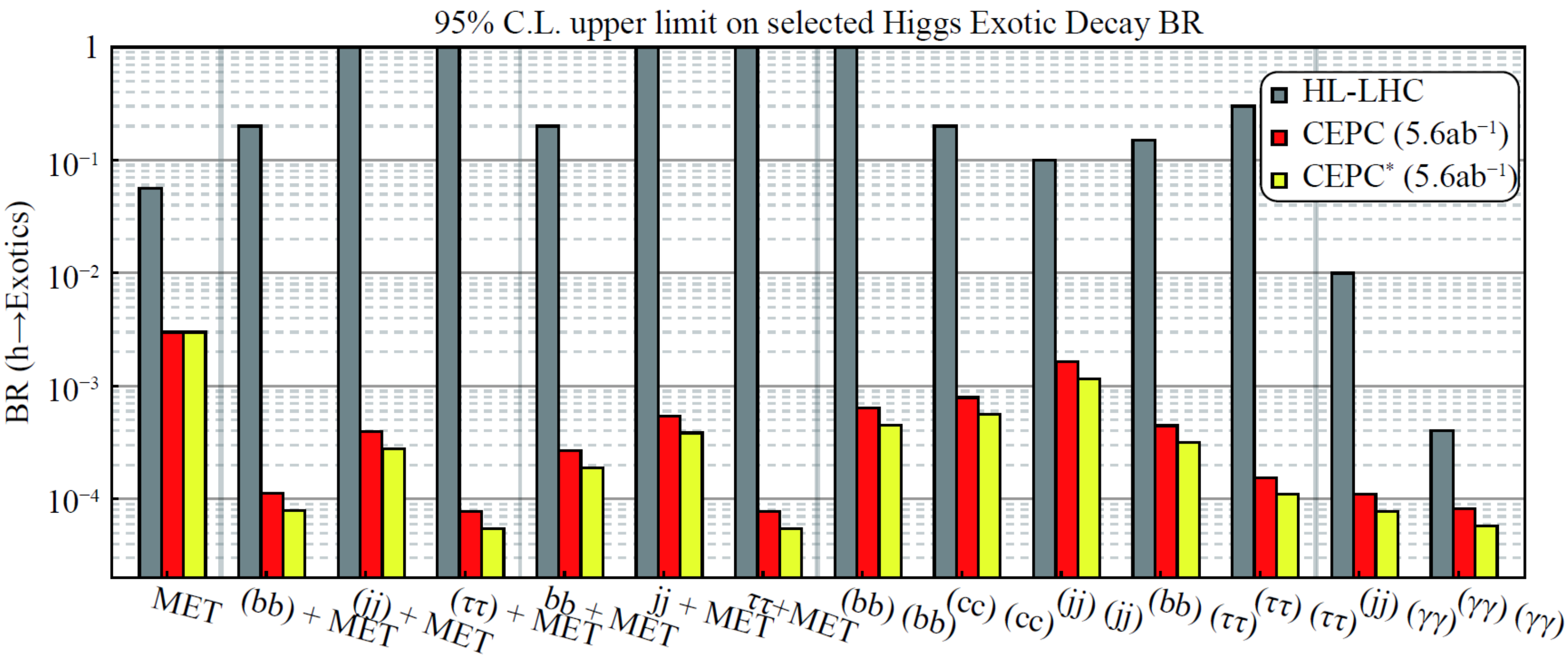
CEPC can detect far better new & exotic behavior of the Higgs



Beyond CDR

design enhancement, R&D, detector-simulation, and infrastructure

CEPC accelerator design improvement

- **High luminosities at Z and H**
  - Optimization of parameters, improving the dynamic aperture(DA) to include errors and more effects, …
  - New lattice for high luminosity at Higgs
  - New RF section layout
  - More detailed study of MDI
  - Optimization of the booster design and its magnets
  - A new alternative design of the LINAC injector
  - A new plasma injector design
  - Injection design
  - ……

- **Accelerator Review Committee** – recommended by the IAC, established and met in November, 2019

CEPC accelerator design improvement

CDR scheme (Higgs)

- ✓ **L*=2.2m, θc=33mrad, βx*=0.36m, βy*=1.5mm, Emittance=1.2nm**
  - Strength requirements of anti-solenoids (peak field B_z~7.2T)
  - Two-in-one type SC quadrupole coils (Peak field 3.8T & 136T/m)

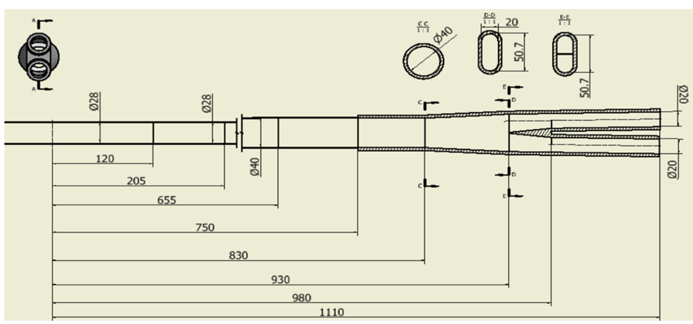
High luminosity scheme (Higgs)

- ✓ **L*=1.9m, θc=33mrad, βx*=0.33m, βy*=1.0mm, Emittance=0.68nm**
  - Strength requirements of anti-solenoids (peak field B_z~7.2T)
  - Two-in-one type SC quadrupole coils (Peak field 3.8T & 141T/m) with room temperature vacuum chamber & Iron yoke

Change of IP chamber

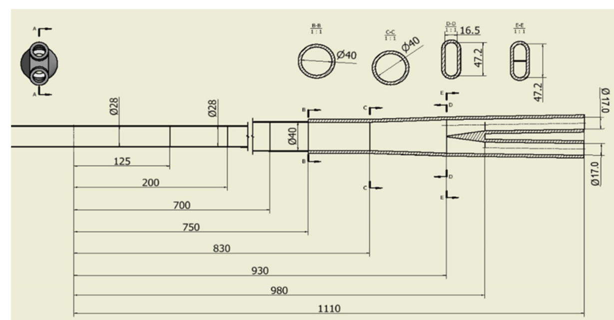
CDR

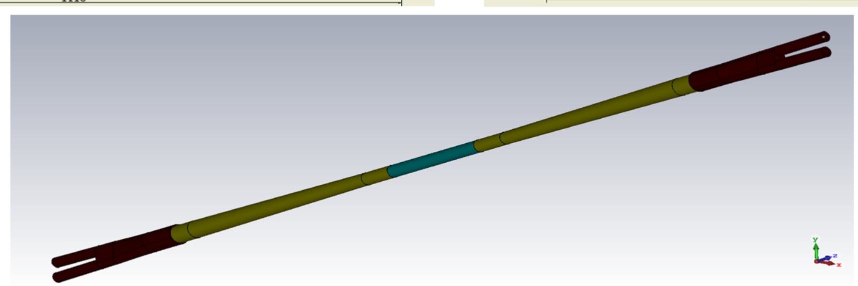
Be pipe: 28mm, SCQ Beam pipe:20mm



High luminosity

Be pipe: 28mm, Beam pipe:17mm





CEPC High Luminosity Parameters beyond CDR

	tt	*Higgs*	*W*	*Z*	
Number of IPs	2	2	2	2	
Energy (GeV)	**180**	**120**	**80**	**45.5**	
Circumference (km)	100	100	100	100	
SR loss/turn (GeV)	8.53	1.73	0.33	0.036	
Half crossing angle (mrad)	16.5	16.5	16.5	16.5	
Piwinski angle	1.16	4.87	9.12	24.9	
N_e/bunch (10^{10})	20.1	16.3	11.6	15.2	
Bunch number (bunch spacing)	37 (4.45μs)	214 (0.7us)	1588 (0.2μs)	3816 (86ns)	11498 (26ns)
Beam current (mA)	3.5	16.8	88.5	278.8	839.9
SR power /beam (MW)	**30**	**30**	**30**	**10**	**30**
Bending radius (km)	10.7	10.7	10.7	10.7	
Phase advance of arc cell	90°/90°	90°/90°	90°/90°	60°/60°	
Momentum compaction (10^{-5})	0.73	0.73	0.73	1.48	
β_{IP} x/y (m)	1.0/0.0027	0.33/0.001	0.33/0.001	0.15/0.001	
Emittance x/y (nm)	1.45/0.0047	0.68/0.0014	0.28/0.00084	0.27/0.00135	
Transverse σ_{IP} (um)	37.9/0.11	15.0/0.037	9.6/0.029	6.36/0.037	
ξ_x/ξ_y/IP	0.076/0.106	0.018/0.115	0.014/0.13	0.0046/0.131	
V_{RF} (GV)	9.52	2.27	0.47	0.1	
f_{RF} (MHz) (harmonic)	650 (216816)	650 (216816)	650 (216816)	650 (216816)	
Nature bunch length σ_z (mm)	2.23	2.25	2.4	2.75	
Bunch length σ_z (mm)	2.66	4.42	5.3	9.6	
HOM power/cavity (kw)	**0.45 (5cell)**	**0.48 (2cell)**	**0.79 (2cell)**	**2.0 (2cell)**	**3.02 (1cell)**
Energy spread (%)	0.17	0.19	0.11	0.12	
Energy acceptance requirement (DA) (%)	2.0	1.7	1.2	1.3	
Energy acceptance by RF (%)	2.61	2.5	1.83	1.48	
Lifetime (hour)	0.59	0.35	1.3	1.7	1.4
L_{max}/IP ($10^{34}cm^{-2}s^{-1}$)	**0.5**	**5.0**	**18.7**	**35.0**	**105.5**

67%⇑

329%⇑

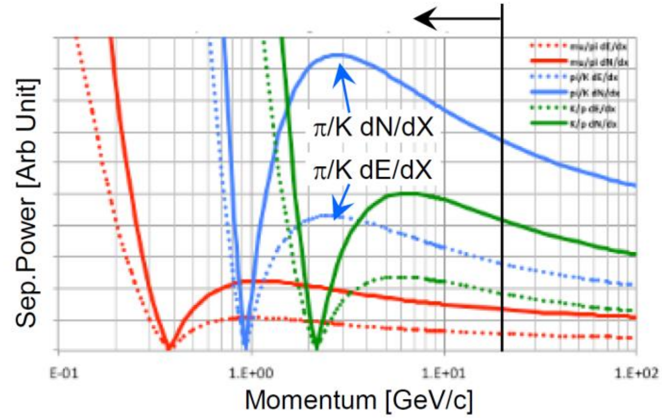
* High luminosity Z has a lattice same as that of CDR for Higgs. but high luminosity Higgs has a new lattice

Detector, software and simulation study

- **Detector R&D, software development**
  - Silicon pixel vertex detector: σ(IP)~5μm, 2 lines of ASICs developed, plans to build a full size prototype ladder …
  - Large area silicon tracker: 70-140m^2, investigating HV-CMOS option, aims at a short stave demonstrator based on ATLASPix3
  - TPC: prototype + a laser calibration system built, to correct for ion backflow; exploring pixel TPC with double mesh or micromegas
  - IDEA drift chamber study: mechanical, wire selection, cluster counting electronics, …
  - Built PFA ECAL and HCAL prototypes, …
  - New ideas with crystal ECAL;
  - ……
- **A 4th detector concept – new design based on crystal calorimeter + silicon tracker + ionization PID + thin magnet**
- **Detector R&D Review Committee** – recommended by the IAC, a large committee (~16 members) has been established

Particle Identifications - Choices

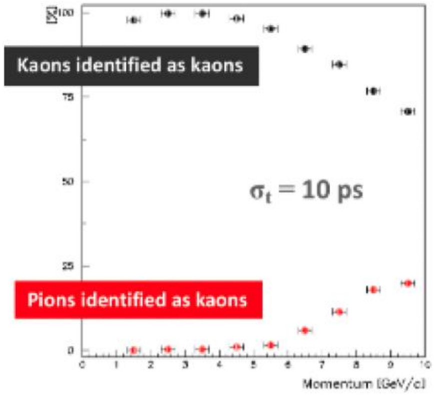
- Charge particle ID is crucial for the flavor physics. Aiming at P < ~ 20 GeV/c.
- Both TPC & DC provide good PID, with dE/dX or dN/dX cluster counting.
- For the FST solution, a supplement PID detector is needed. Combination of different PID detectors is also viable.



① **Drift chamber** between the outer layers of FST. It is promising in a simple simulation. More work in design optimization, and the physics impact.

② **Time of flight** detectors, e.g. LGAD. The resolution ~20-30 ps today (ATLAS/CMS). Sensor by IHEP & NDL reaches 25ps. By the time of CEPC, 10 ps might be possible.

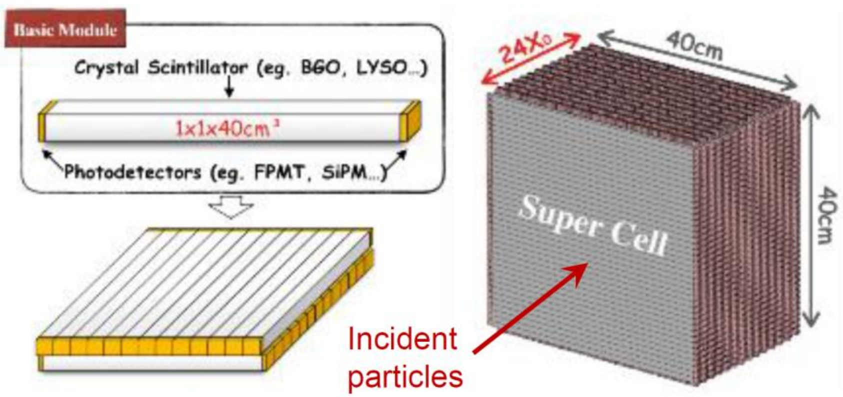
IHEP-NDL LGAD-V2
Pixel size 1.3×1.3 mm^2

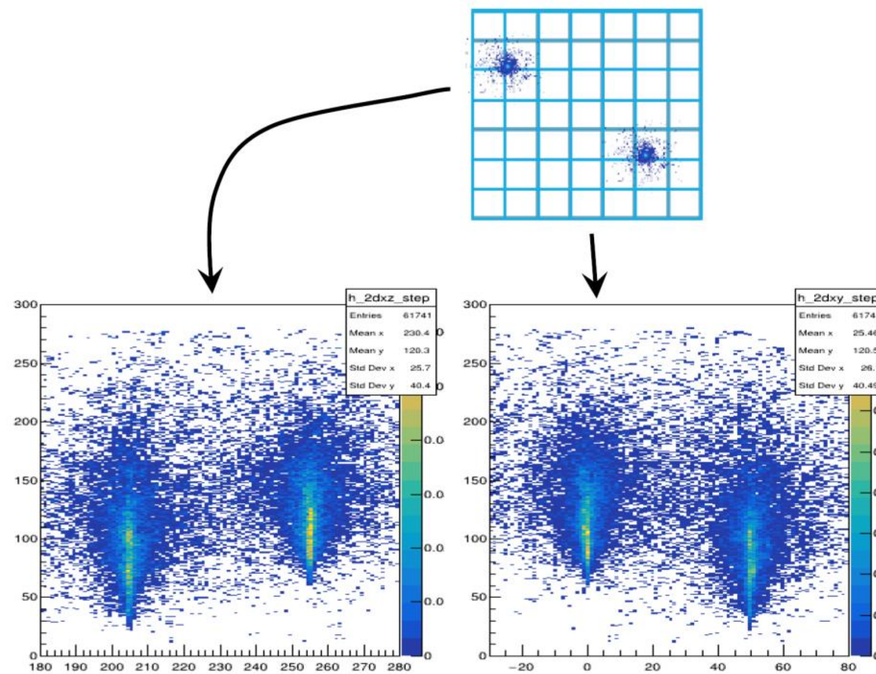


③ A **RICH** of aerogel or gaseous radiators. Space constraint needs to be studied.

- More options and studies are needed.

New Crystal Calorimeter Design





- Crystal bar perpendicular to particles. Significant reduction of number of channels.
- Energy & time matching provide a solution of ambiguity / ghost hits.

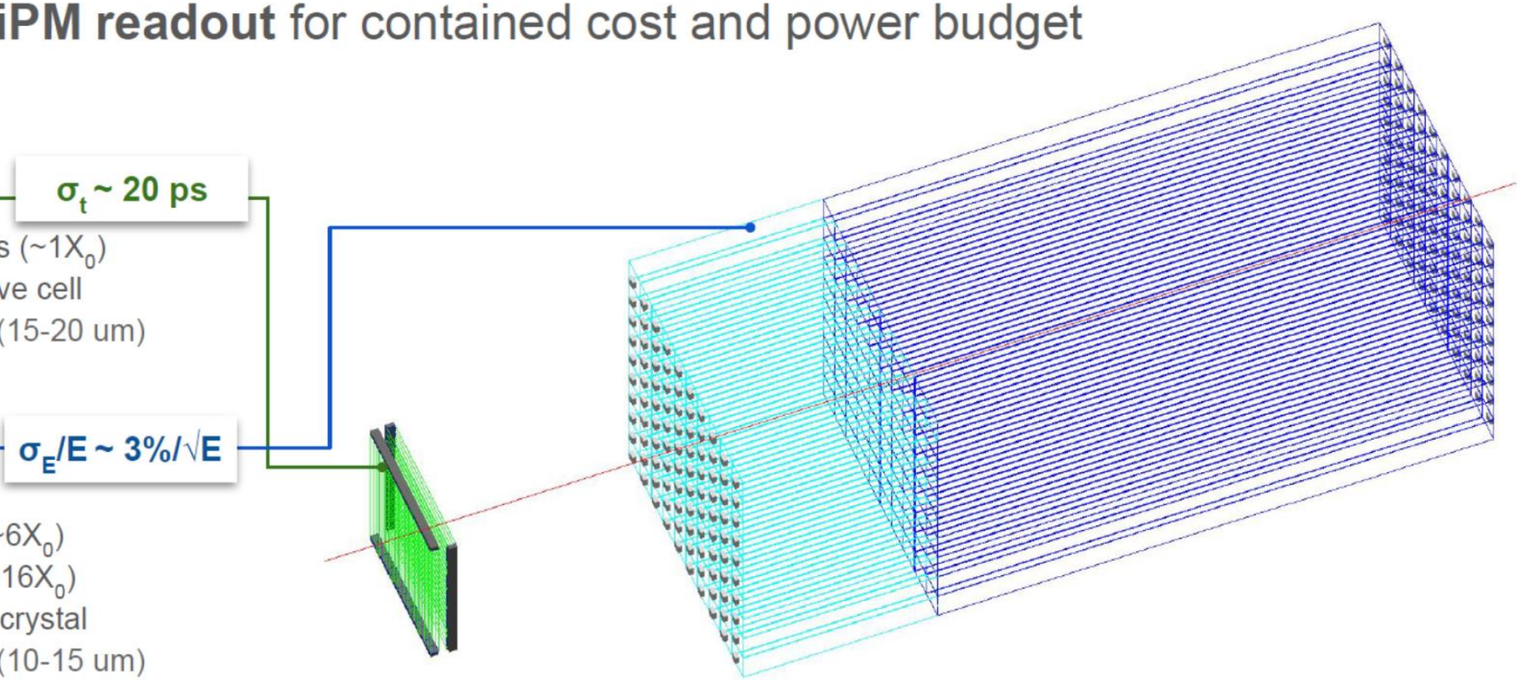
New Crystal Calorimeter Design

Also exploring a design of adding a time layer to the longitudinal solution.

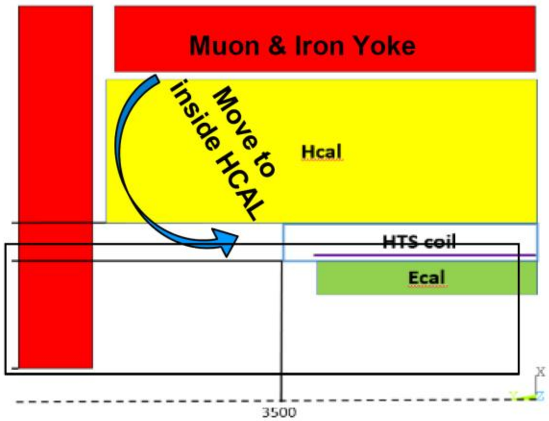
- ***SCEPCAL:*** a **S**egmented **C**rystal **E**lectromagnetic **P**recision **C**alorimeter
- **Transverse and longitudinal segmentations** optimized for particle identification, shower separation and performance/cost
- Exploiting **SiPM readout** for contained cost and power budget

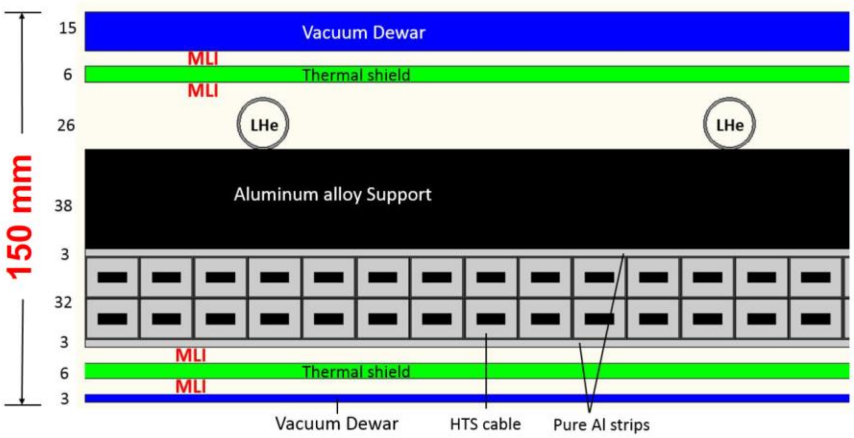
Timing layer
- LYSO:Ce crystals (~1X_0)
- 3x3x54 mm³ active cell
- 3x3 mm² SiPMs (15-20 um)

ECAL layer
- PbWO crystals
- Front segment (~6X_0)
- Rear segment (~16X_0)
- 10x10x200 mm³ crystal
- 5x5 mm² SiPMs (10-15 um)



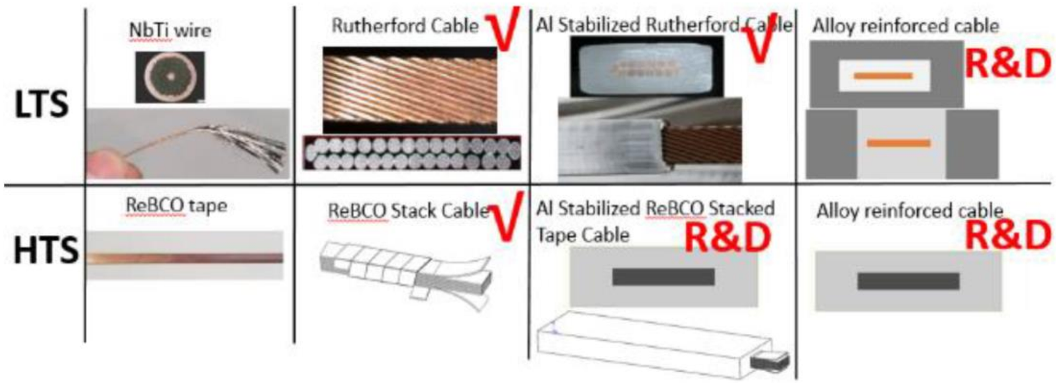
Detector Solenoid Design





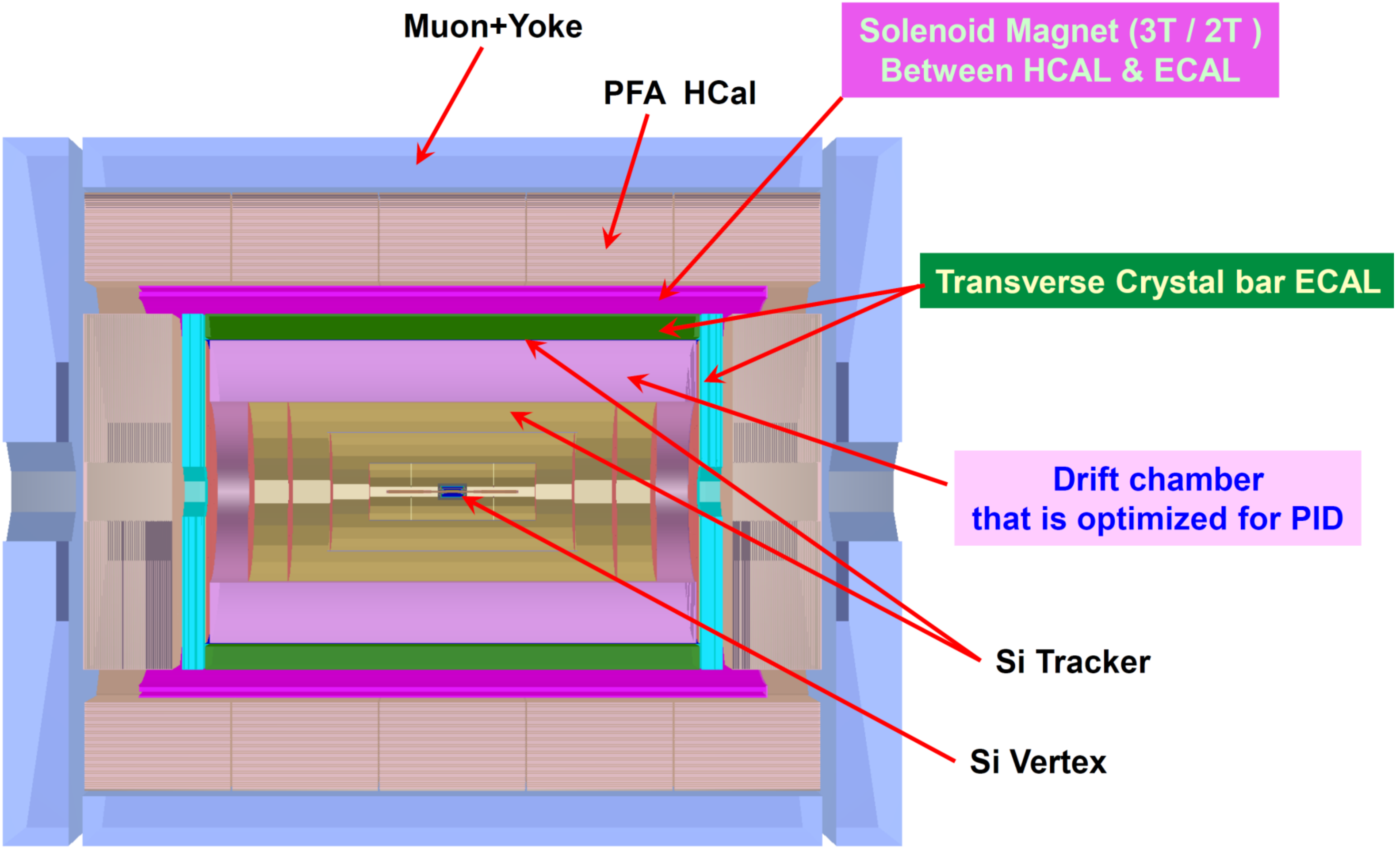
Challenges

Low mass, ultra-thin, high strength cable



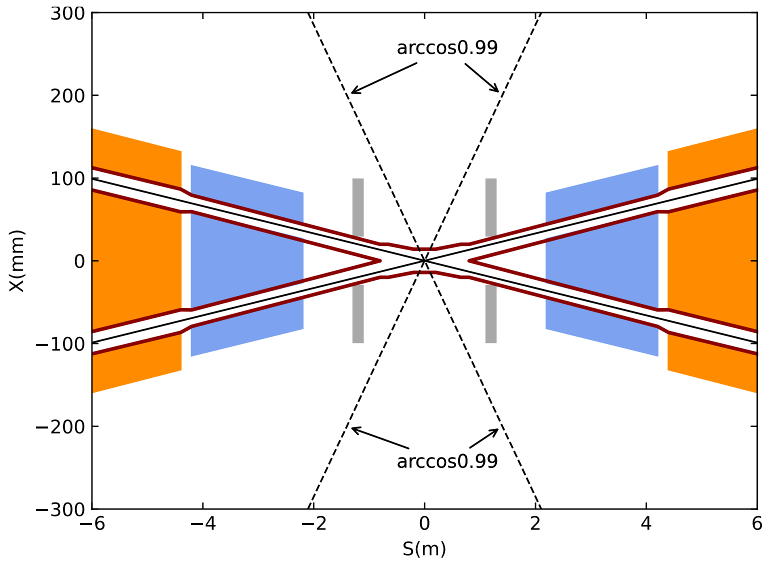
LTS solution also possible, but can not be placed inside HCAL

4th Detector Conceptual Design

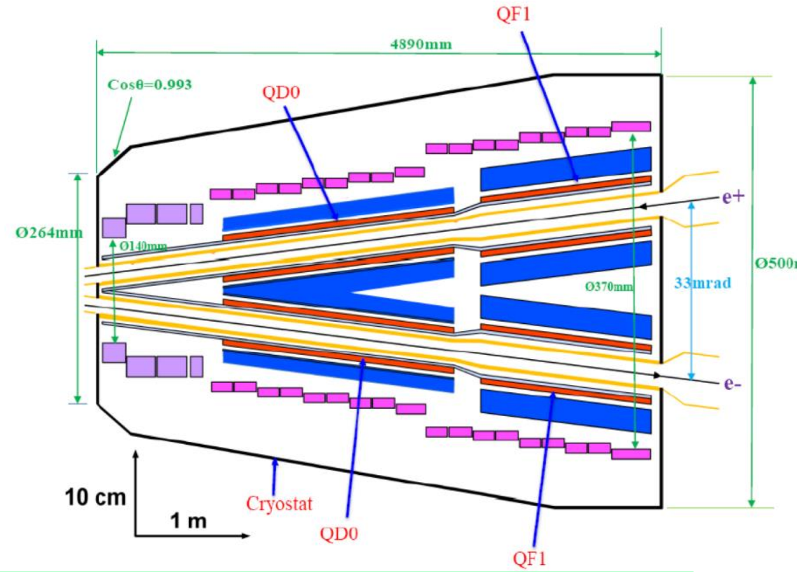


Machine-Detector Interface (MDI)

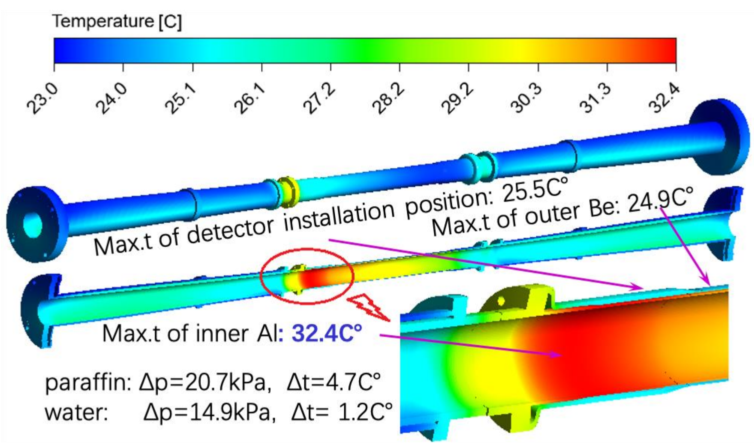
Crossing angle of 33 mrad, focal length of 2.2 m



Final focusing magnets (QD0, QF1) with Segmented Anti-Solenoidal Magnets



Beam pipe design



Temperature distribution under **High Order Mode (HOM) heat**

Central beampipe made with **Beryllium** and located at **r = 14 mm**, beampipe opened up in the forward region and made with aluminum

Structure: Double thin beryllium layers with paraffin (coolant) in the middle, forward beampipe with water cooling

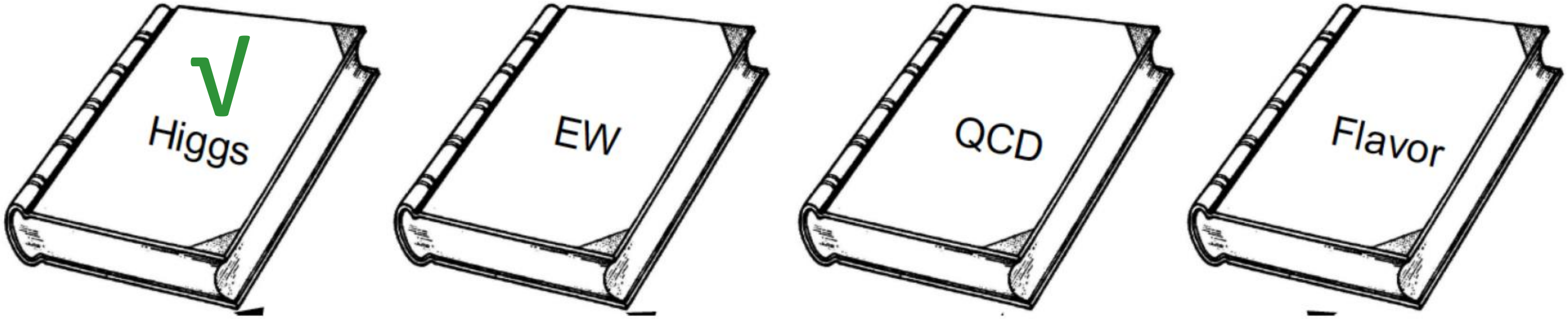
Work in progress with MDI

CEPC Software

- The CEPC software development first started with the iLCSoft
  - Reused most software modules: Marlin, LCIO, MokkaC, Gear
  - Developed its own software components for simulation and reconstruction
  - Massive M.C. data produced for detector and physics potential studies
  - CDR was released in Nov, 2018, based on results from the iLCSoft
- **A new CEPC software, CEPCSW, prototype was proposed at the Oxford workshop in April 2019**
- **The consensus among CEPC, CLIC, FCC, ILC and other future experiments was reached at the Bologna workshop in June 2019**
  - Develop a Common Turnkey Software Stack (Key4hep) for future collider experiments
  - Maximize the sharing of software components among different experiments
- Now CEPCSW, fully integrated with Key4hep, is being developed to facilitate further R&D activities of the experiment

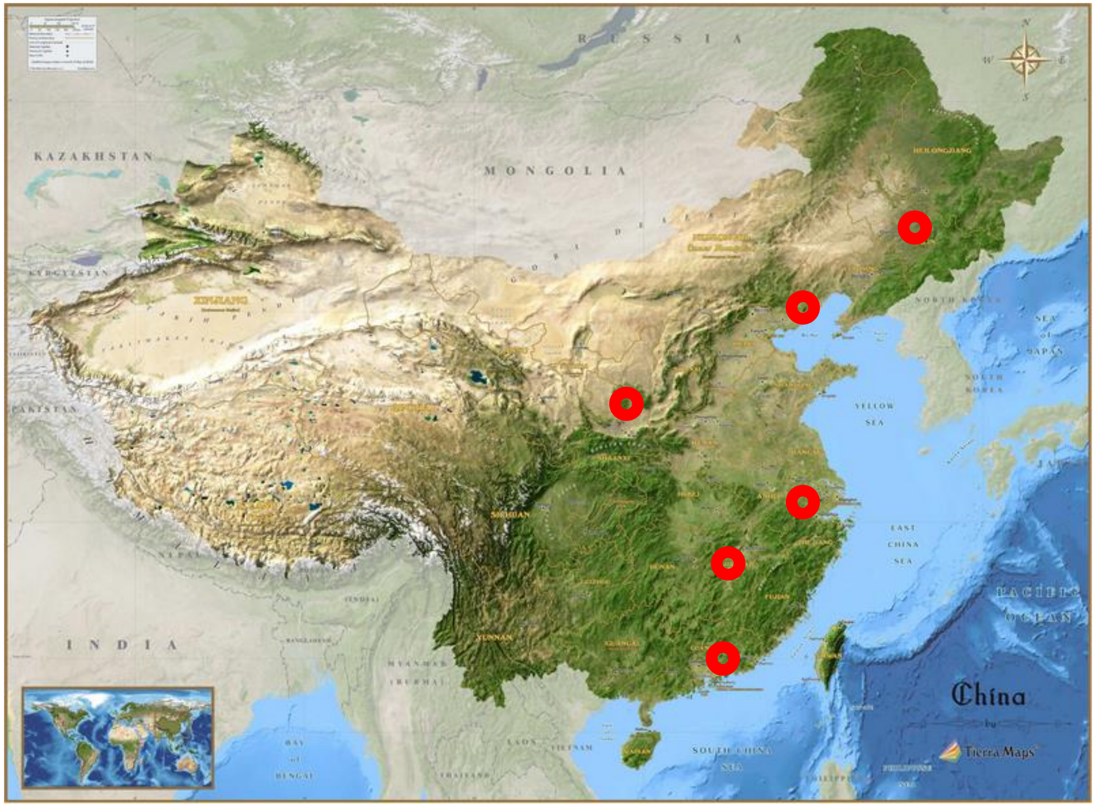
CEPC Simulation Study

White papers



- To promote the physics study at TDR & to converge to the Physics White Papers
- Physics white papers:
  - Physics handbooks for new comers: PostDoc/Student
  - Official references for the physics potential
  - Guideline for future detector design/optimization
- Higgs white paper published in 2019

Site Investigation and Civil Design



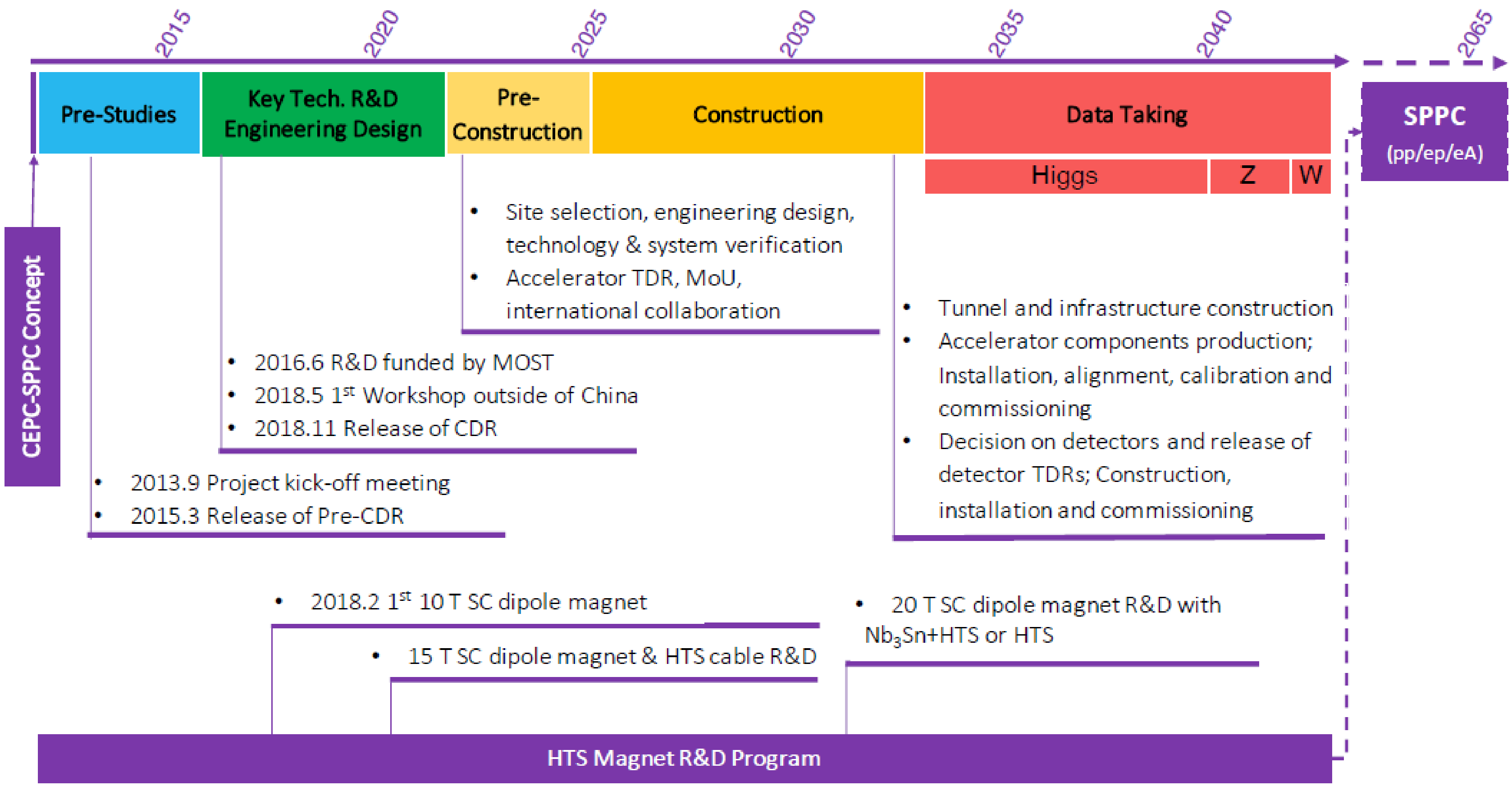
- Site selection is based on geology, electricity supply, transportation, environment for foreigners, local support & economy,…
- North are better for running cost
- CDR study is based on Qing-Huang-Dao, which is 300 km from Beijing

- More invitations from local governments: Changsha, Changchun, …
- Recent visit to Shangsha and Changchun: good geology & transportation(~20 km from large city & international airport)

CEPC Prospects

Roadmap and Schedule proposed

CEPC Project Timeline



CEPC Prospects

Continuing DRD and deep understanding of physics potentials

- Suggestions submitted to Ministry of Sci. & Technology to seek support for R&D and validations of key technologies and innovations
- Planning **next round design improvement, R&D**, site investigations-study
- CEPC accelerator TDR
- **CEPC physics whitepaper**; physics potentials in Snowmass 2021 arena

……

International Collaboration and Engagement

- Regular-formal annual meetings with major international labs and partners
- Actively participating in Snowmass2021 activities
- Engaging actively in ILC, FCC as well as HL-LHC upgrade activities
- R&D and make major progress + breakthroughs in common technologies
- Finding and sharing solutions to common issues (design, E_{beam}, components, …)

……

Backup Slides

CEPC Accelerator TDR, R&D Priority

test facilities are available for many of the tasks

- CEPC 650MHz 800kW klystron: high efficiency (80%), **fabrication will be completed by year end, tests in 2022**
- High precision booster dipole magnets: which are critical for booster operation, **to complete full-size magnet model in 2021**
- CEPC 650MHz SC accelerator system, including SC cavities and cryomodules, **to complete test cryomodule in 2022**
- Collider dual aperture dipole magnets, dual aperture quadrupoles and sextupole magntes: **to complete full-size model in 2022**
- Vacuum chamber system: **to complete fabrication and costing test in 2022**
- SC magnets including cryostats: **to complete short test model in 2022**

CEPC Accelerator TDR, R&D Priority,

test facilities are available for many of the tasks

- MDI mechanic system: **vacuum connection removal to be tested in 2022**
- Collimator: **to complete model test in 2022**
- Linac components: **to complete key components test in 2022**
- Civil engineering design: **to complete reference implementation design in 2022**
- Plasma wakefield injector: **to complete the electron accelerator test in 2022**
- 18KW@4.5K cryoplant: **industrial partner**
- ...

SppC technology R&D

- Ion based supercondcuting materials and high field magnets

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