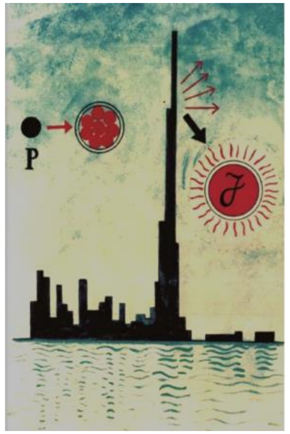
Symposium on 50th Anniversary – the Discovery of the J Particle

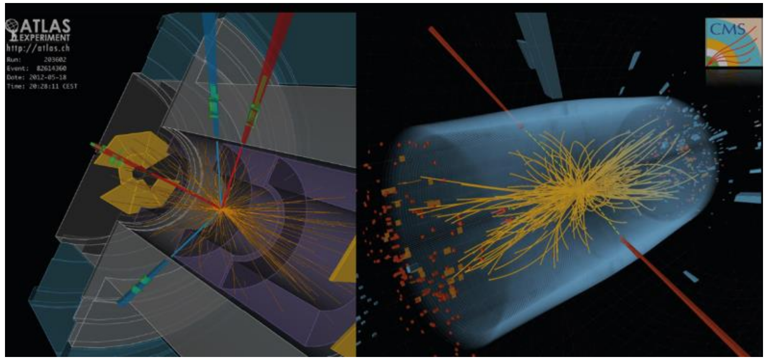
The Circular Electron Positron Collider

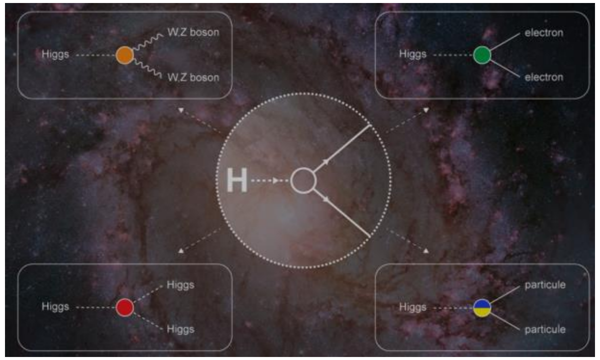
A factory of Higgs, Z, W, hadrons, QCD and "new physics"

XinChou LOU

IHEP, Beijing







Outline

CEPC

PART I
From J to the Higgs

PART II
What is CEPC?

PART III
Can We Do It?

PART IV
Going Forward

From J to the Higgs

from BEPC to CEPC

From J to the Higgs

- The discovery of the J particle in 1974 has inspired many of us for half of a century
- Through the J/ψ great advances have been made in particle physics
  - establishing the quark and lepton family, QCD,
  - XYZ family of new forms of hadrons discovered through the J/ψ
  - discovery of the CP violation in B through B→J/ψK_s
  - probing QCD via J/ψ production in e+e- and pp collisions
  - ……

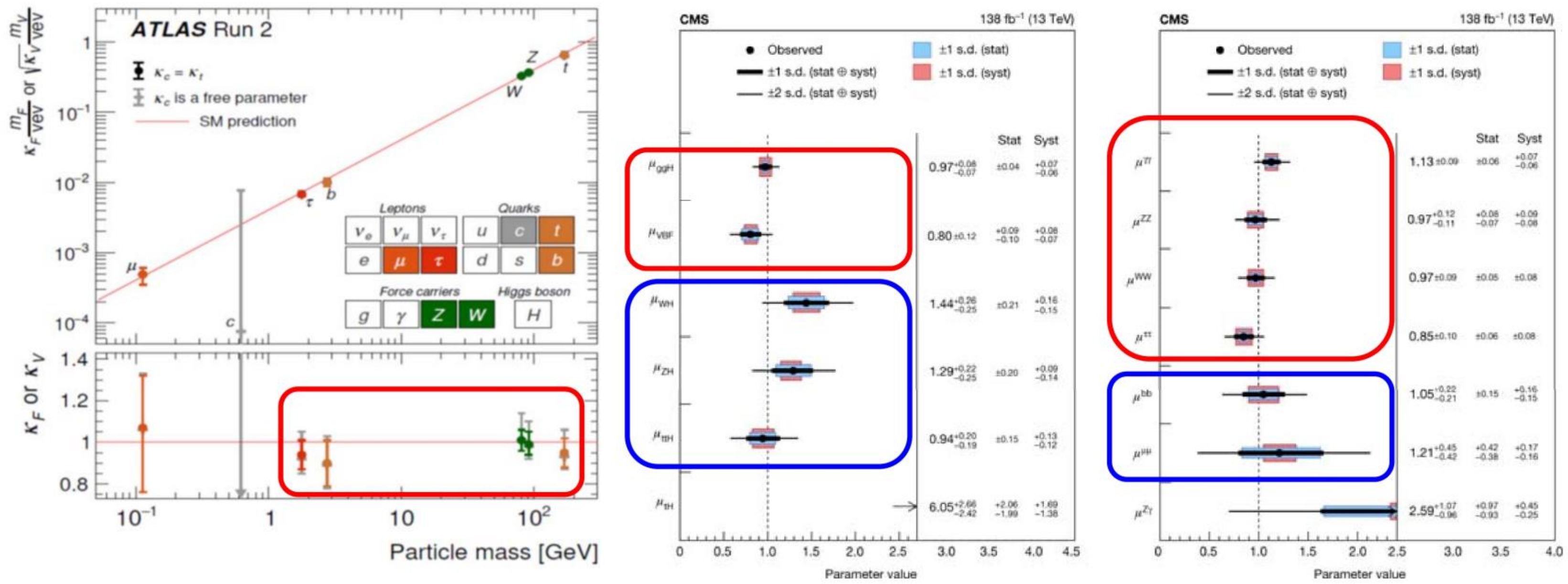
- The BES(-II,III) experiments at the BEPC(-II) (J/ψ data is one of the center pieces)
  - carried out successful physics programs
  - trained generations of scientists
  - benefited Chinese light source projects; many applications derived
  - brought large scale international collaboration on science to China
  - continues to yield critical insights into nature
  - ……

Where do we go from here (BEPC) in China?

From J to the Higgs

Observed Higgs boson consistent with SM → masses of fermions ~ Higgs

Much higher precisions will rely on future e^+e^- Higgs factory



Nature 607 (2022) 52-59

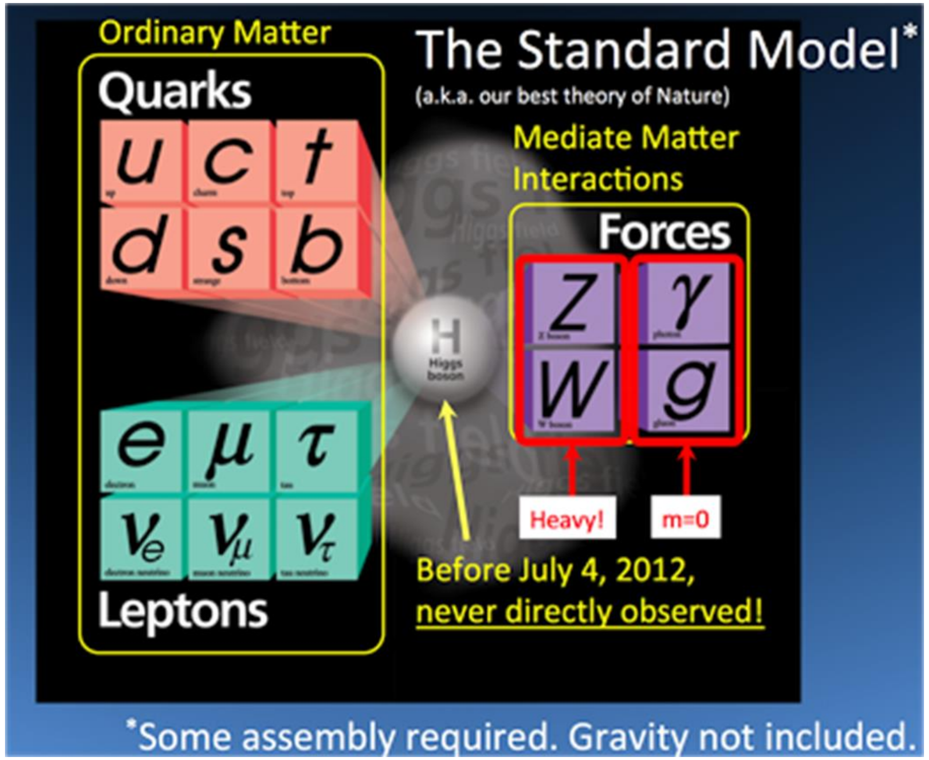
Nature 607 (2022) 60-68

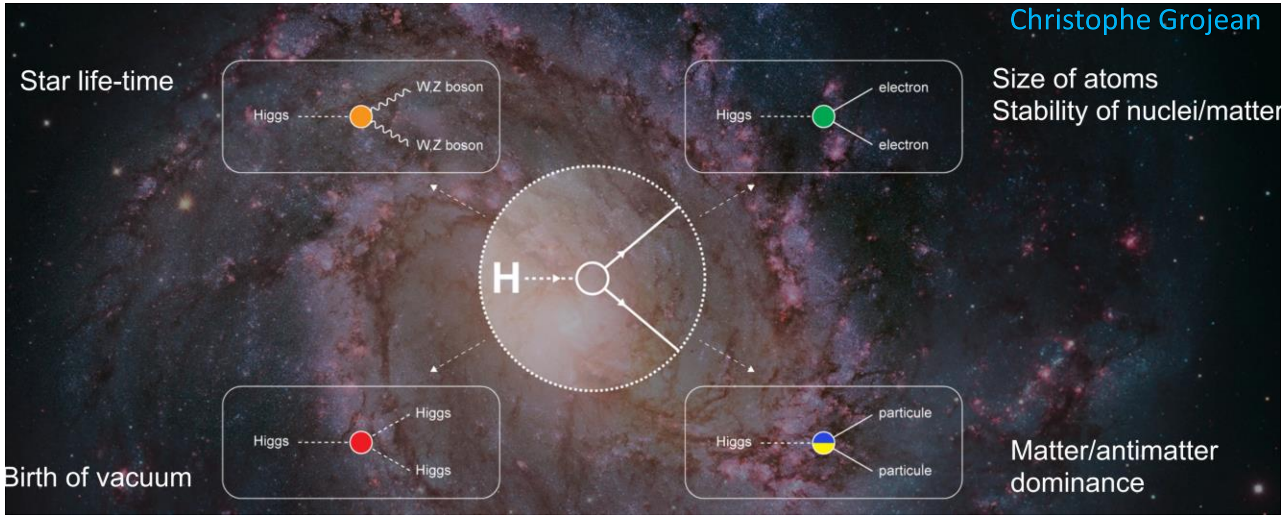
5-10%

20-40%

From J to the Higgs

The Higgs boson (mass ~125 GeV) presents us an outstanding opportunity





The Higgs

is related to many important issues in the Universe

The Higgs

may be a portal to new physics

may connect us to dark matter

……

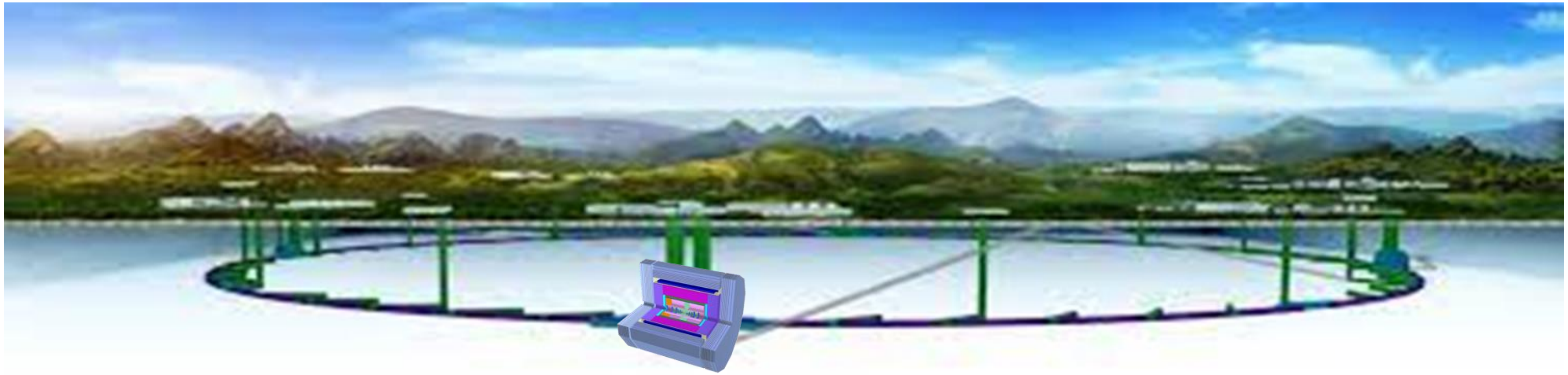
Circular e^+e^- Collider Higgs Factory (CEPC)

What is CEPC?

Where do we stand?

What is CEPC?

A large electron-positron collider at 91–360GeV, with detectors, for discovering new physics

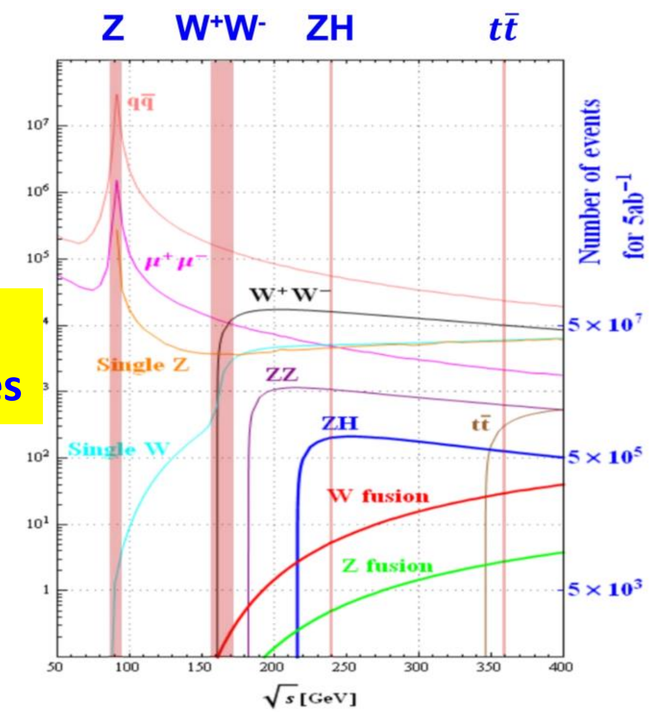


- The idea of CEPC was proposed in Sep. 2012, and quickly gained the momentum in IHEP and in the world.
- A Higgs factory - to run at $\sqrt{s}$ ~ 240 GeV, above the **ZH** production threshold for ≥1 M Higgs; at the **Z** pole for ~Tera Z; at the **W^+W^-** pair and then $t\bar{t}$ pair production thresholds.
  To probe new physics beyond SM
- The CEPC aims to start operation in 2030's, in China.

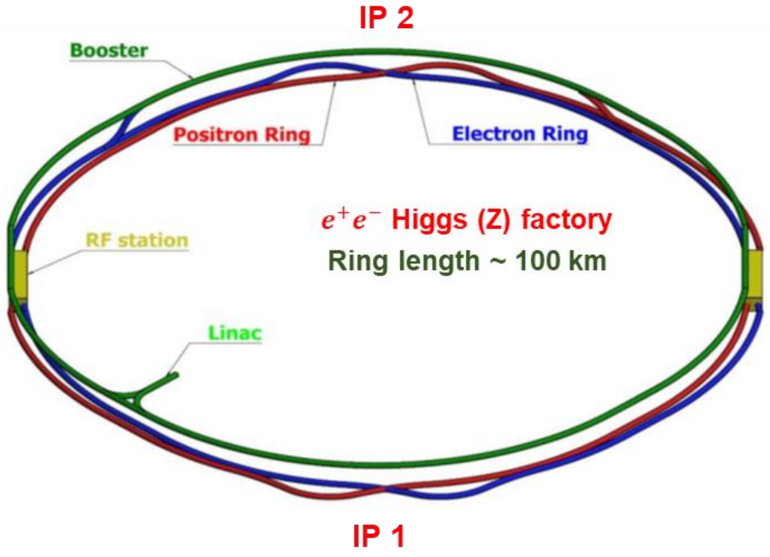
Factory of
4 Million Higgs
4 Trillion Z bosons
200 Million W^+W^- pairs
600K $t\bar{t}$ pairs

What is CEPC?

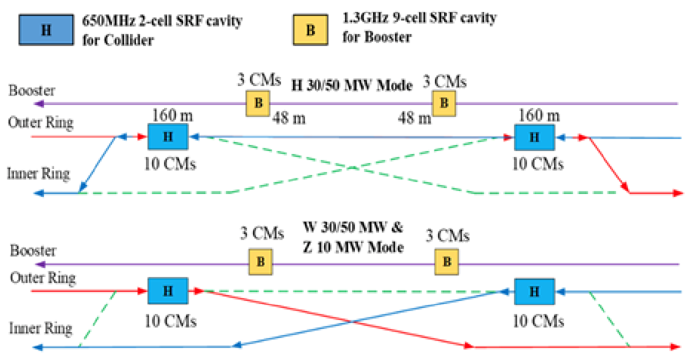
An advanced, versatile and upgradable accelerator for enabling discoveries



e+e-→ final states



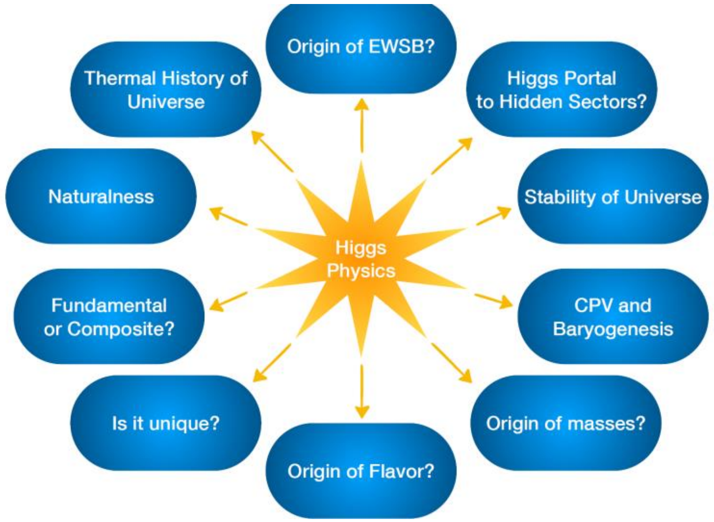
Switchable operation for Higgs W and Z

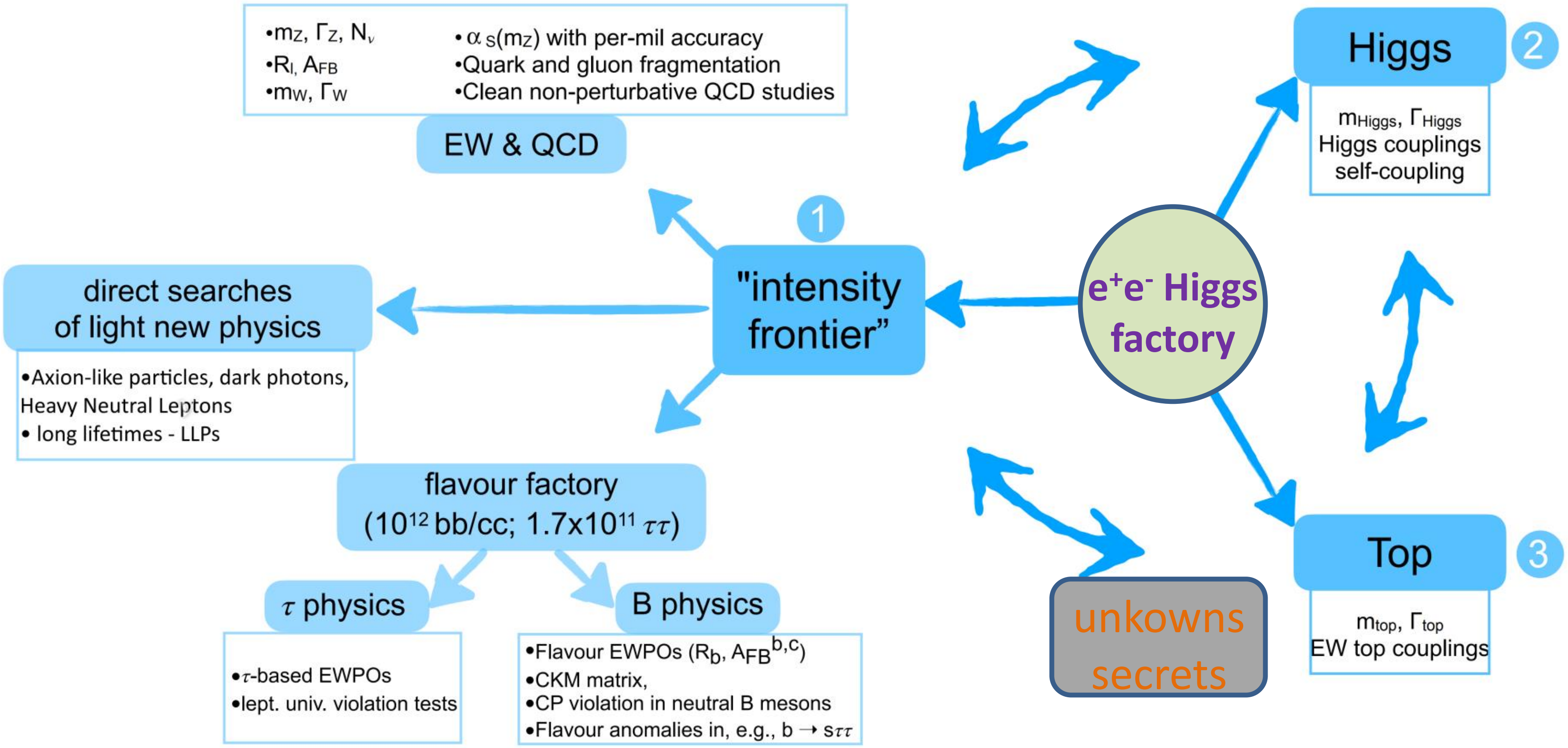


- CEPC complex comprises of a Linac, a 100 km booster and a collider ring
- **Circular collider**: Higher luminosity>linear collider
- **100km circumference**: Optimal total cost
- **Switchable operation**: Higgs, W/Z, top

What is CEPC?

A factory of clean Higgs, Z, W, hadrons, QCD and "new physics"





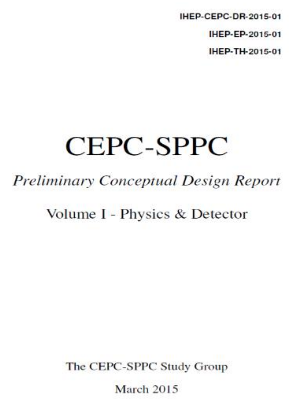
Christophe Grojean

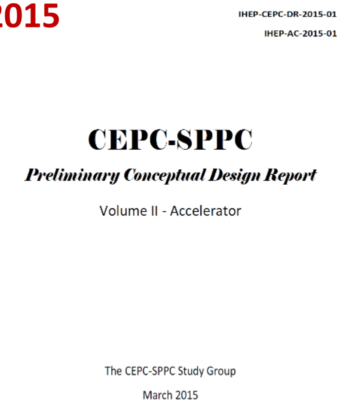
What is CEPC?

CEPC team took steps to advance

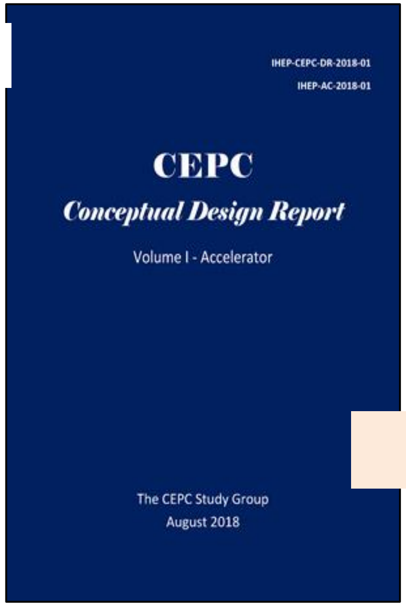
2013

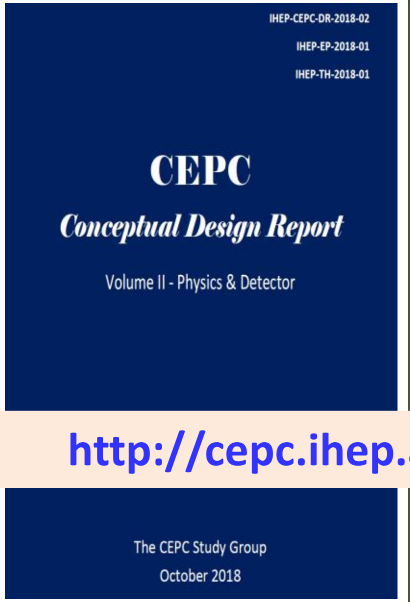
2015





2018





2023

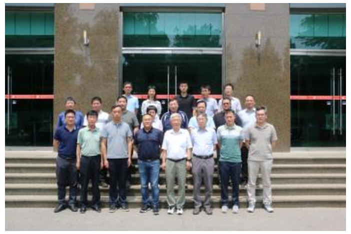
2024

http://cepc.ihep.ac.cn

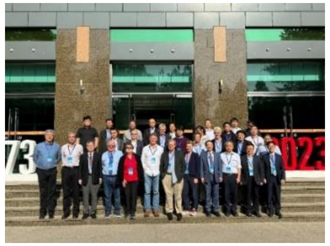
CEPC Accelerator TDR Published

CEPC Accelerator TDR Review
June 12-16, 2023, Hong Kong

CEPC Accelerator TDR Cost Review
Sept. 11-15, 2023, Hong Kong



Domestic Civil Engineering
Cost Review, June 26, 2023, IHEP



9th CEPC IAC 2023 Meeting
Oct. 30-31, 2023, IHEP

Table 12.1.2: CEPC project cost breakdown, (Unit: 100,000,000 yuan)

Total	**364**	**100%**
Project management	3	0.8%
Accelerator	190	52%
Conventional facilities	101	28%
Gamma-ray beam lines	3	0.8%
Experiments	40	11%
Contingency (8%)	27	7.4%

Distribution of CEPC Project total TDR cost of **36.4B RMB (~ 5B €)**

CEPC accelerator TDR was completed and formally released on December 25, 2023

CEPC accelerator TDR link: （arXiv： 2312.14363）

published in
RDTM Vol.8
June 2024

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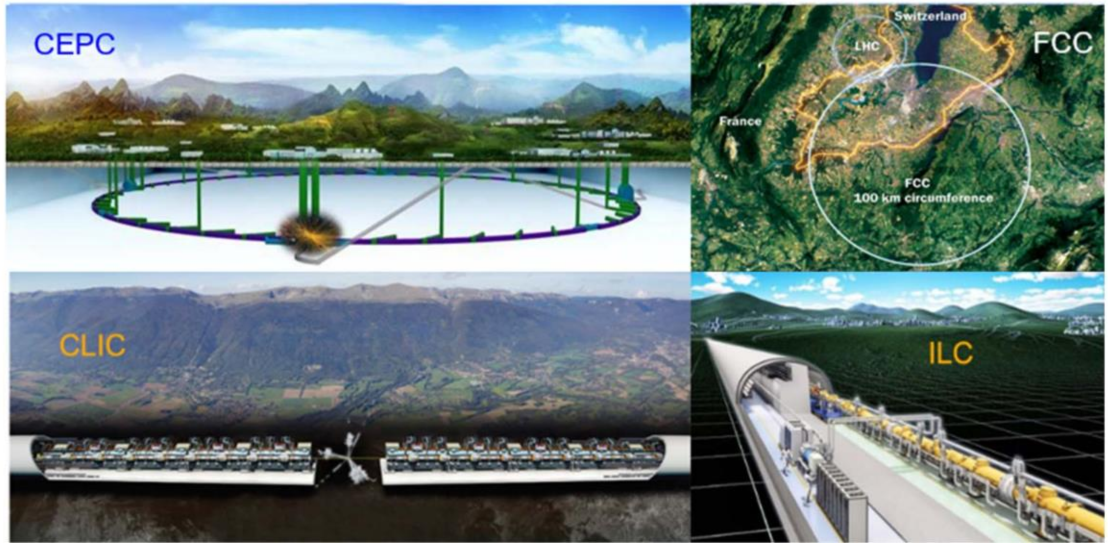
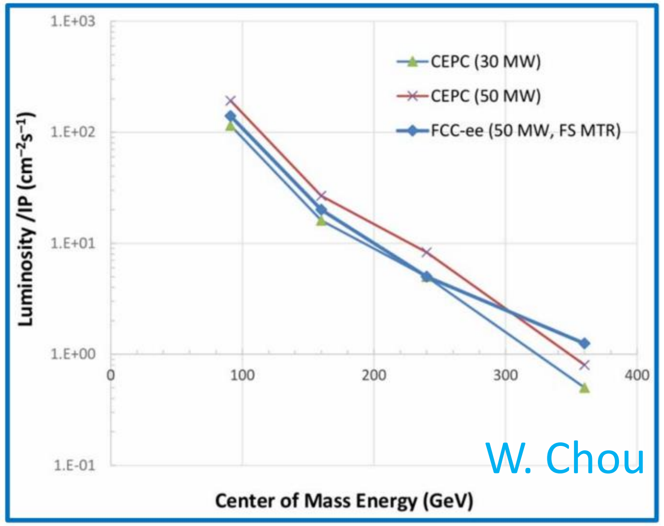
What is CEPC?

Advantages of CEPC compared to other Higgs factories

Mature e+e- Higgs factory options world wide



Luminosity/IP (CEPC vs. FCC-ee)



W. Chou

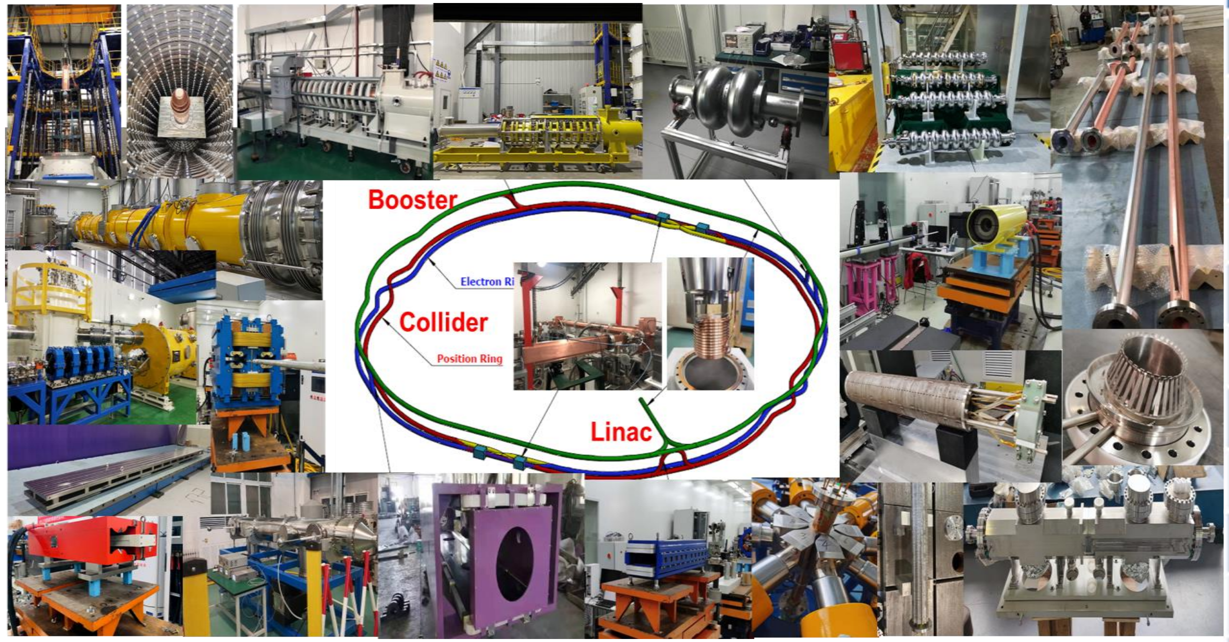
CEPC compared with ILC
higher Luminosity (Z-H-W)
upgradable to pp to reach 100 TeV

CEPC compared with FCC
early start (2030s vs 2040s)
larger ring size
lower cost

What is CEPC?

Accelerator R&D and validations of technologies since 2013

Key Technologies for the CEPC



Specification Met ✓ Prototype Manufactured ✓

Accelerator	Fraction
Magnets	27.3%
Vacuum	18.3%
RF power source	9.1%
Mechanics	7.6%
Magnet power supplies	7.0%
SC RF	7.1%
Cryogenics	6.5%
Linac and sources	5.5%
Instrumentation	5.3%
Control	2.4%
Survey and alignment	2.4%
Radiation protection	1.0%
SC magnets	0.4%
Damping ring	0.2%

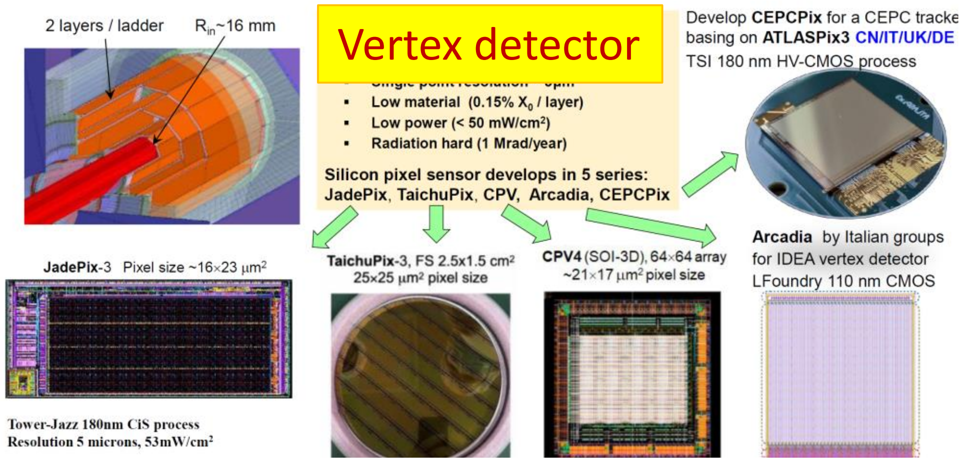
R&D and Validation key technology R&D spans all component for CEPCready for construction by 2027-8

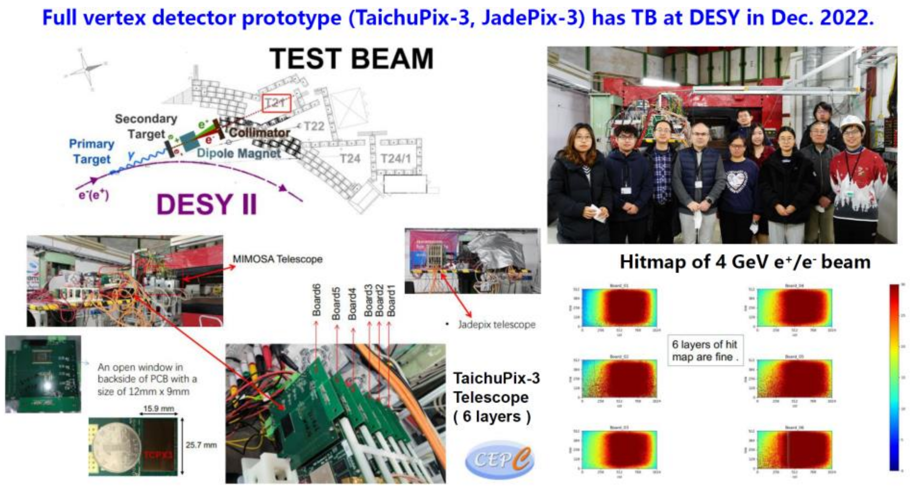
HEPS just completed by IHEP

What is CEPC?

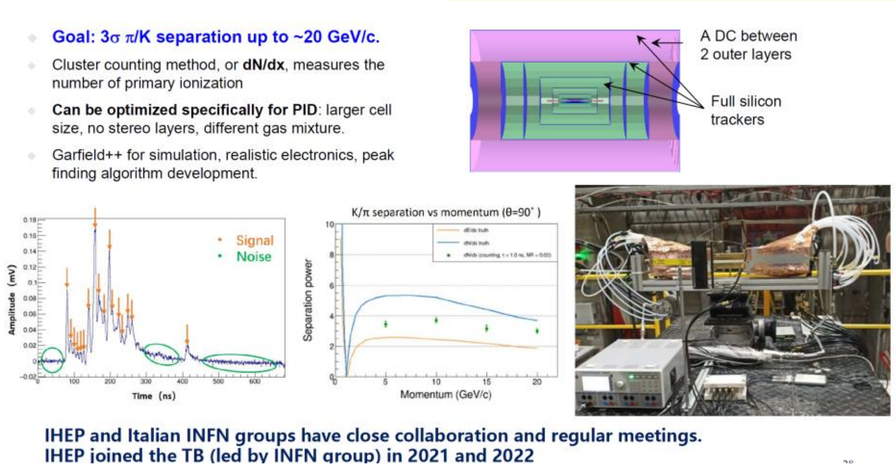
Detector R&D and validations of technologies since 2013

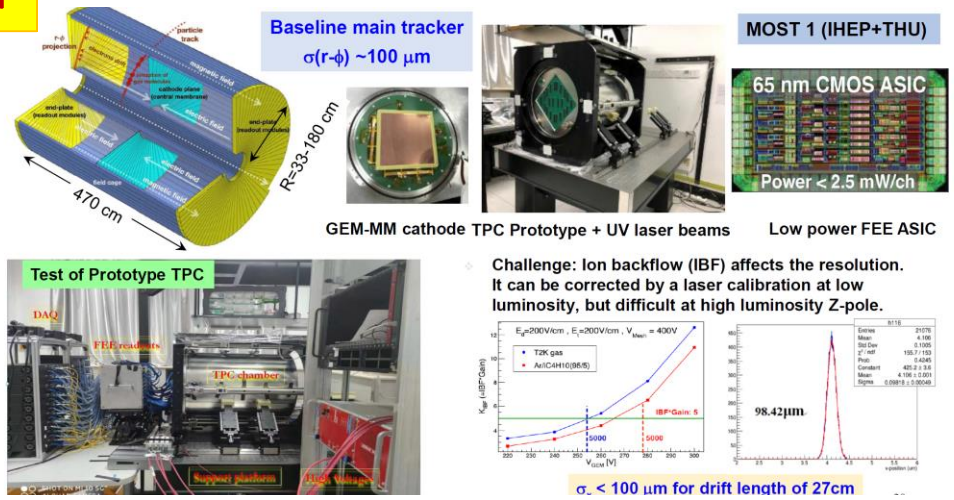
Vertex detector





particle ID +main tracker



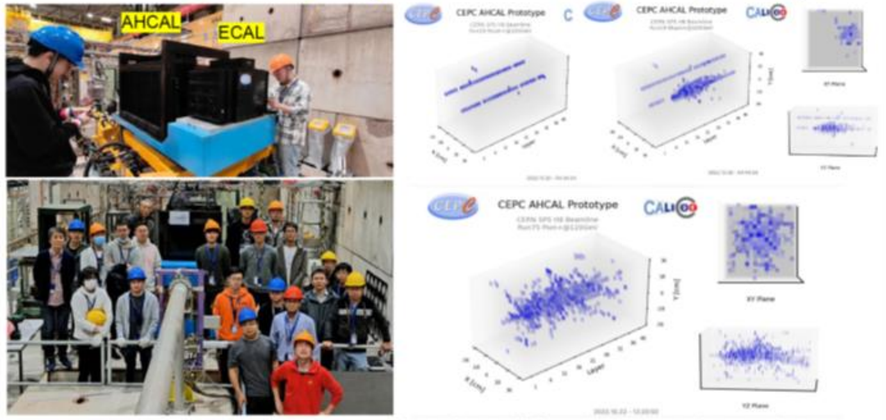


What is CEPC?

Detector R&D and validations of technologies since 2013

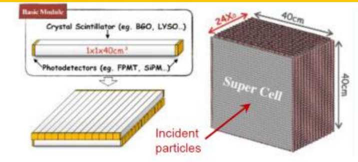
EM + hadron colarimeters： prototypes

➤ PFA ScW-ECAL & AHCAL prototypes: Test Beam at CERN SPS H8 (Oct. 2022)



USTC, IHEP, SJTU, Japanese & Israel groups have close collaboration and regular meetings

new crystal EM calorimeter for better resolution

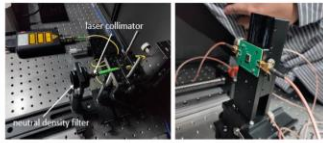


- Long bars: 1 x 40 cm, super-cell: 40x40 cm²
- Timing at both ends for positioning along bar.
- Significant reduction of number of channels.

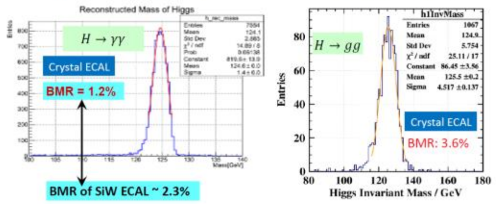
Goal

- Boson Mass Resolution < 4%
- Better BMR than ScW-ECAL
- Much better sensitivity to γ/e, especially at low energy.

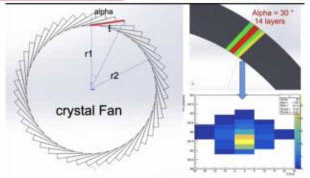
Bench Test



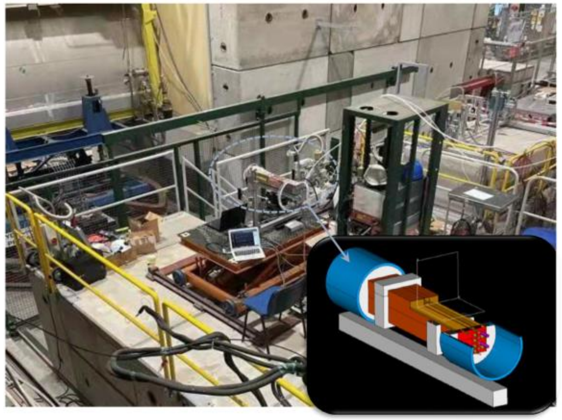
Full Simulation Studies + Optimizing PFA for crystals

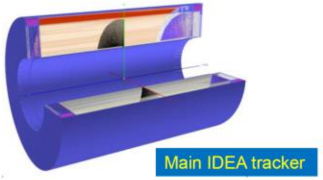


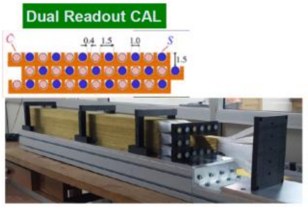
Crystal Fan Design Fine segmentation in Z, ϕ, r



Dual readout crystal calorimeter also being considered by USA and Italian colleagues







Italian groups and IHEP colleagues participated the test beam at CERN.

software

Key4hep: an international collaboration with CEPC participation
CEPCSW: a first application of Kep4hep – Tracking software
CEPCSW is already included in Key4hep software stack

https://github.com/cepc/CEPCSW

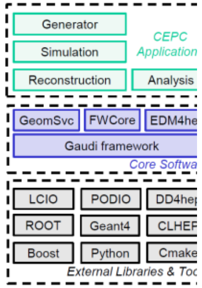
Architecture of CEPCSW

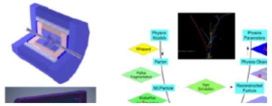
- External libraries
- Core software
- CEPC applications for simulation, reconstruction and analysis

Core Software

- Gaudi framework: defines interfaces of all software components and controls the event loop
- EDM4hep: generic event data model
- FWCore: manages the event data
- GeomSvc: DD4hep-based geometry management service

CEPCSW Structure

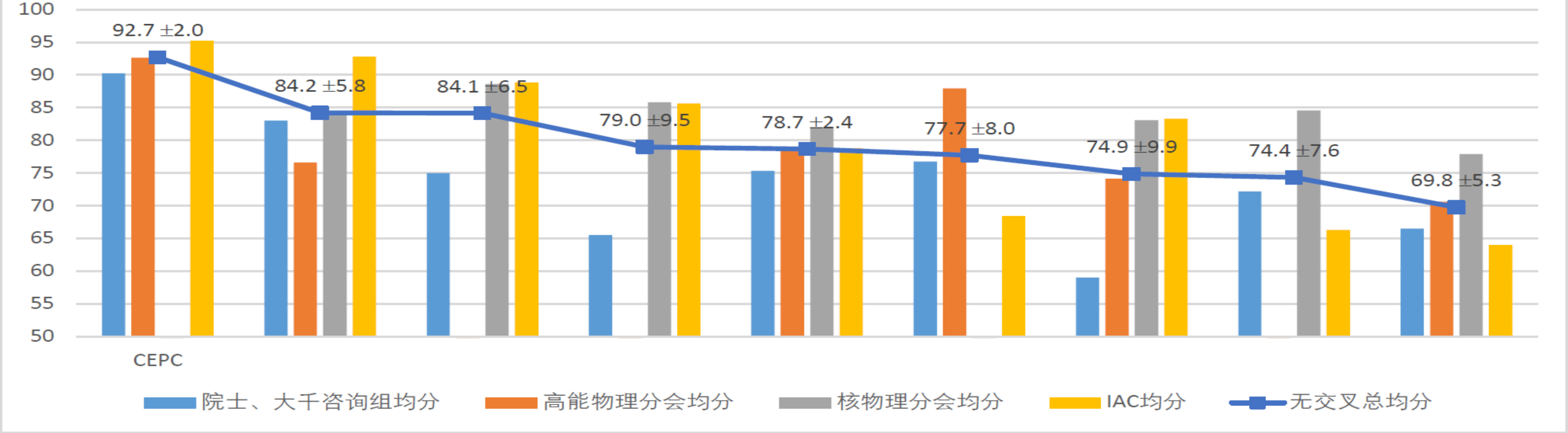




What is CEPC?

Future development

- CAS is planning for the 15th 5-years plan for large science projects, and a steering committee has been established, chaired by the president of CAS
- **High energy physics**, as one of the 8 groups, accomplished the following:
  - Set up rules and the standard (based on scientific and technological merits, strategic value and feasibility, R&D status, team and capabilities, cost-benefit, etc.), established domestic and international advisory committees
  - Collected 15 proposals and selected 9, based on the above-mentioned standard
  - Evaluations and ranking done by committees after oral presentations by all projects
- **CEPC is ranked No. 1, with the smallest uncertainties, by every committee**



Can We do it?

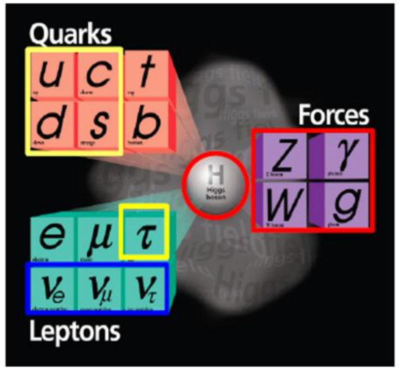
Can we build the CEPC and carry through the scientific program?

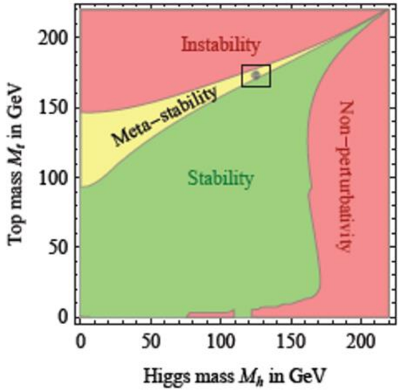
- ✓ The science
- ✓ The technology and capability
- ✓ The cost

Can We Do It? The science

Understanding the science and identifying the opportunities

- We have a very successful Standard Model
- But we still have a lot of issues and questions:
  - Anything fundamentals behind the flavor symmetry ?
  - Mass hierarchy of elementary particles normal ?
  - Fine tuning of Higgs mass natural ?
  - Why a meta-stable vacuum ?
  - What are dark matter particles ?
  - No CP in the SM to explain Matter-antimatter asymmetry
  - Dirac or Majorana Neutrino mass ?
  - Unification of interactions at a high energy ?
- We are at a turning point:
  - a new, much deeper theory ?
  - Choices of experimental approaches ?
    - e^+e^-, pp, ep, $\mu^+\mu^-$ or no machine ?





- "Small cost" to look for hints. If yes, go for direct searches

$$\mathcal{L} = \mathcal{L}_{SM} + \sum_i \frac{c_i}{M^2} \mathcal{O}_{6,i} \qquad \delta \sim c_i \frac{v^2}{M^2}$$

No signal at LHC:

Direct searches: M ~ 1 TeV

10% precision: M ~ 1 TeV

Look for signals at CEPC/FCC-ee:

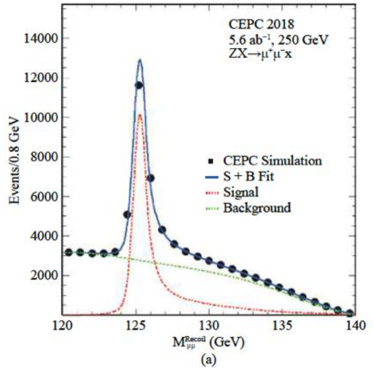
Precisions exceed HL-LHC ~ 1 order of magnitude (1% precision) ➔ M ~10 TeV

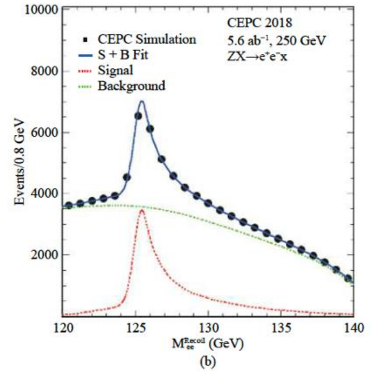
Naturalness will be at ~10^{-4} up to 10 TeV
If no New Physics up to 10 TeV, there will be no naturalness ➔ even bigger discovery ?

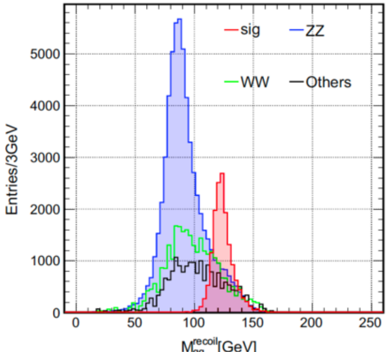
Pressing science questions, best addressed by an e^+e^- Higgs factory (~1% precision)

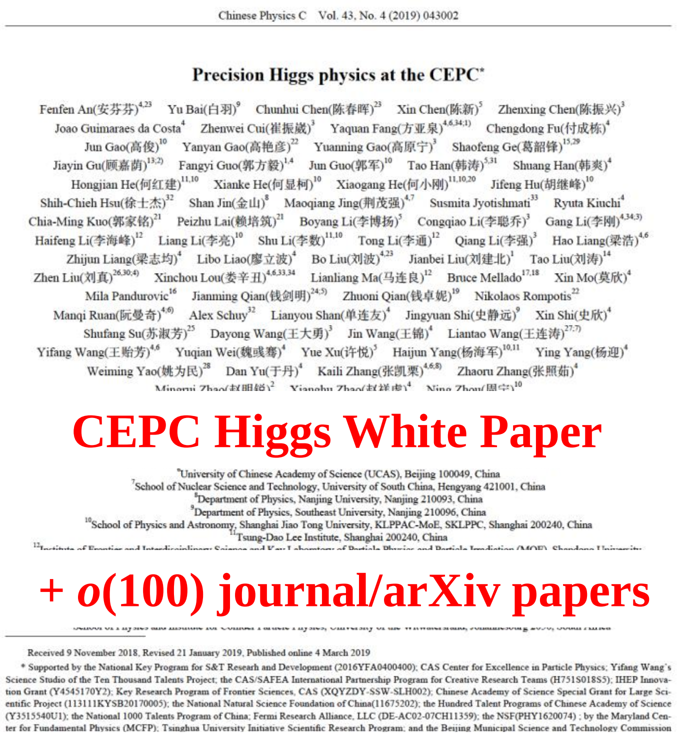
Can We Do It? The science

Understanding the science and identifying the opportunities








Chinese Physics C Vol. 43, No. 4 (2019) 043002

Precision Higgs physics at the CEPC*

Received 9 November 2018, Revised 21 January 2019, Published online 4 March 2019

CEPC Higgs White Paper

+ o(100) journal/arXiv papers

Table 2.1: Precision of the main parameters of interests and observables at the CEPC, from Ref. [1] and the references therein, where the results of Higgs are estimated with a data sample of 20 ab^{-1}. The HL-LHC projections of 3000 fb^{-1} data are used for comparison. [2] CEPC CDR

Higgs			W, Z and top		
Observable	HL-LHC projections	CEPC precision	Observable	Current precision	CEPC precision
M_H	20 MeV	3 MeV	M_W	9 MeV	0.5 MeV
Γ_H	20%	1.7%	Γ_W	49 MeV	2 MeV
$\sigma(ZH)$	4.2%	0.26%	M_{top}	760 MeV	$\mathcal{O}(10)$ MeV
$B(H \to bb)$	4.4%	0.14%	M_Z	2.1 MeV	0.1 MeV
$B(H \to cc)$	-	2.0%	Γ_Z	2.3 MeV	0.025 MeV
$B(H \to gg)$	-	0.81%	R_b	3×10^{-3}	2×10^{-4}
$B(H \to WW^*)$	2.8%	0.53%	R_c	1.7×10^{-2}	1×10^{-3}
$B(H \to ZZ^*)$	2.9%	4.2%	R_μ	2×10^{-3}	1×10^{-4}
$B(H \to \tau^+\tau^-)$	2.9%	0.42%	R_τ	1.7×10^{-2}	1×10^{-4}
$B(H \to \gamma\gamma)$	2.6%	3.0%	A_μ	1.5×10^{-2}	3.5×10^{-5}
$B(H \to \mu^+\mu^-)$	8.2%	6.4%	A_τ	4.3×10^{-3}	7×10^{-5}
$B(H \to Z\gamma)$	20%	8.5%	A_b	2×10^{-2}	2×10^{-4}
Bupper$(H \to \text{inv.})$	2.5%	0.07%	N_ν	2.5×10^{-3}	2×10^{-4}

Scientific Significance quantified by **CEPC physics** studies, via full simulation/phenomenology studies:

- Higgs: Precisions exceed HL-LHC ~ 1 order of magnitude.
- EW: Precision improved from current limit by 1-2 orders.
- Flavor Physics, sensitive to NP of 10 TeV or even higher.
- Sensitive to varies of NP signal.
- ……

Can We Do It? The science

Understanding the science and identifying the opportunities

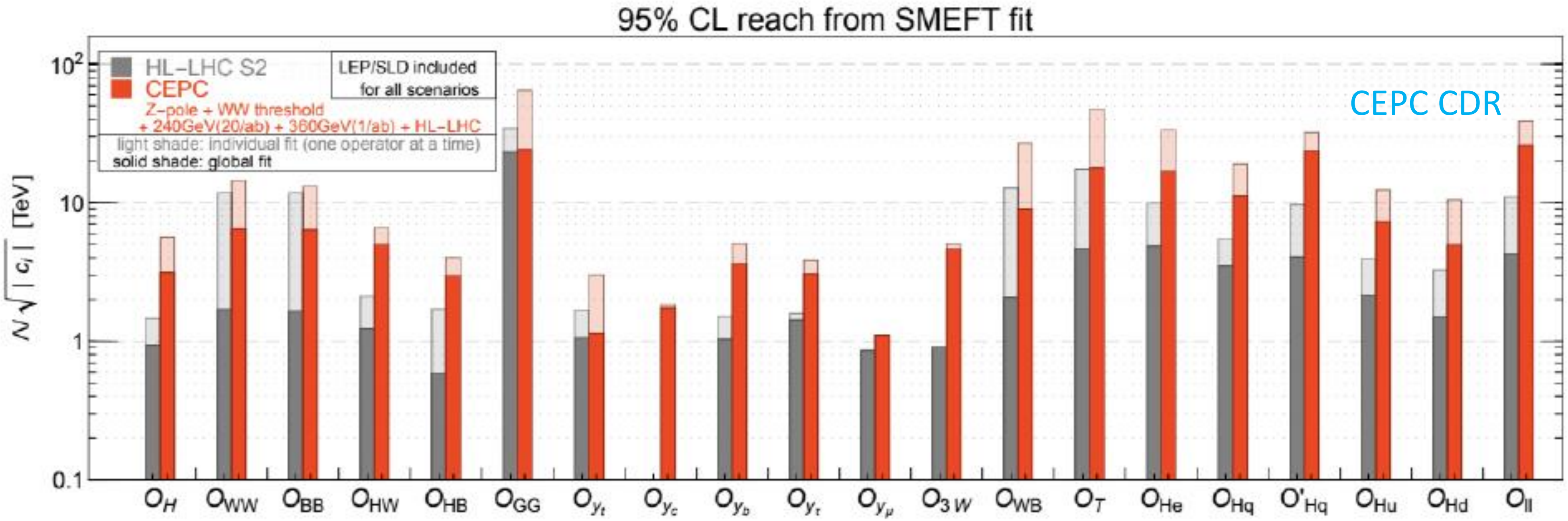


Figure 2.1: Covered energy scales of new physics from CPEC and HL-LHC, based on measurements of operators in the framework of the Standard Model Effective Field Theory (SMEFT). [1]

- **CEPC team and collaborators evaluated physics performance**
- **More Higgs/Z data as result of optimized TDR, phys. performance being updated, and will be better**

Can We Do It?

The technology and capability

BEPCII/HEPS prepared CEPC; CEPC R&D outcomes used in BEPCII and HEPS

Yuhui LI

500MHz SRF system for BEPCII and HEPS

Jiyuan Zhai

- In 2006, all the 3 sub-systems of BEPCII SRF system (500 MHz cavity, RF power source, LLRF control) were imported from Japan and France.
- In 2011-2023, they were replaced with in-house-made ones with more advanced technology and better performance.
- In 2024, three new 500 MHz SRF systems were in-house built for BEPCII upgrade and HEPS.
- In 2025, a new system with even higher performance will be built for Hefei Advanced Light Facility.

Imported SRF cavity for BEPCII (2006)

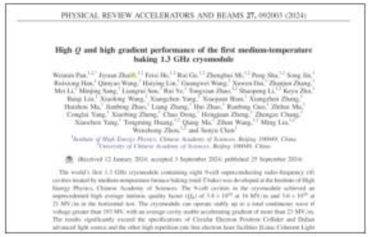
Home-made SRF cavity for HEPS and BEPCII upgrade (2024)

CEPC SRF R&D: Pushing Superconducting Technology Frontier

Jiyuan Zhai

- World's best 650 MHz and 1.3 GHz superconducting RF cavity and high performance cryomodule with new medium-temperature baking recipe, major technology choice for future SRF accelerator.
- CEPC technology used in China's FEL project SHINE, producing a dreaming 1.3 GHz cryomodule with unprecedented performance, leading the frontier of superconducting accelerator technology.

CEPC 1.3 GHz Superconducting Cryomodule (12 m long)
(> 100 units needed in China in 5 yrs; CEPC needs 44 units)

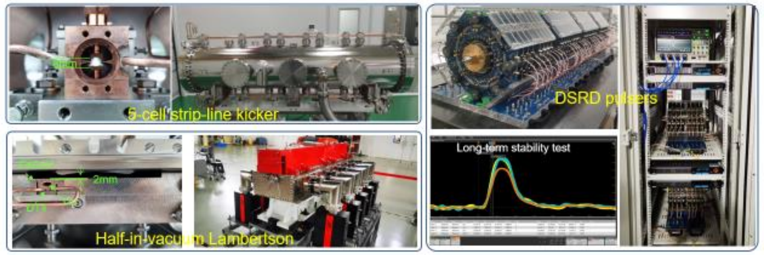

PHYSICAL REVIEW ACCELERATORS AND BEAMS 27, 092003 (2024)

High Q and high gradient performance of the first medium-temperature baking 1.3 GHz cryomodule

Injection & Extraction system for HEPS

Jinghui Chen

- HEPS features the on-axis swap-out top-up injection with beam accumulation function booster, which resolves the challenge of high current in small dynamic aperture. The CEPC Higgs operation takes this novel scheme.
  - Septum magnet: Half-in-vacuum Lambertson magnets with 2mm septum board.
  - Kicker: 5-cell strip-line kickers with 8mm blade distance.
  - Fast pulser: DSRD pusler with 10ns bottom width and ±18kV peak.



BPM electronics

Yanfeng Sui

- IHEP provided funding for BPM electronics R&D. The first development stage was completed in 2018. The prototype was tested at BEPCII, and a modified version with enhanced performance was developed in 2019.
- The BPM electronics were implemented in the BEPCII in 2019 and have been operating steadily since then. There are now 120 sets of BPM electronics implemented at BEPCII.
- 700 sets of BPM electronics have been applied in the HEPS, playing a crucial role in the beam commissioning process.
- The performance of the BPM electronics meets the requirements of the CEPC, demonstrating their effectiveness and reliability in BEPCII and HEPS.

In-house BPM electronics

BPM electronics are installed in local station of BEPCII

BPM electronics for HEPS

S-band accelerator sturcture

Jingru Zhang

- The S-band inner water cooled accelerating structure developed for CEPC has been successfully applied in the HEPS linac
- The S-band accelerator structure has been optimized for the CEPC. The design parameters have been applied to the HEPS linac, and the accelerating gradient of 26 MV/m was measured

Frequency: (MHz)	2860
No. of Cells	84+2*0.5
Phase advance	2π/3
Total length(m)	3.1
Length of cell : d (mm)	34.988
Disk thickness: t (mm)	5.5
Shunt impedance : Rs (MΩ/m)	60.3~67.8
Quality factor	15465~15373
Group velocity: Vg/c (%)	2% ~ 0.94%
Filling time : t_f (ns)	784
Attenuation factor : τ (Np)	0.46

High power test bench

Modulator and klystron

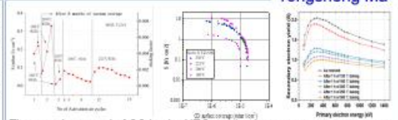
S-band accelerating structure for CEPC

HEPS 500 MeV linac tunnel

NEG coating for collider vacuum chambers

Yongsheng Ma

- The NEG coatings of TiZrV has been developed and applied to the vacuum chambers of HEPS, for the low activation temperature with high pumping speed and surface pumping capacity.
- The NEG coating helps to suppress the e-cloud in the positron ring, which results in beam instabilities and increasing heat loads.
- Prototypes have been successfully developed. Facilities for the mass production was established.



The pumping speed of CO by the NEG coating is approximately 6-8 times higher than that of H_2, while the capacity of CO is much smaller than that of H_2. NEG coating has a Secondary Electron Yield (SEY) of approximately 1.1.

There are a total of 641 circular chambers with lengths ranging from 280mm to 2475mm, 98 antechambers with lengths between 705mm to 1024mm, and 201 racetrack chambers with lengths ranging from 1042mm to 2167mm have been NEG coated for HPES.

Can We Do It?

The technology and capability

Accelerator R&D and validations of technologies since 2013

CEPC Booster 1.3 GHz 8 x 9-cell High Q Cryomodule

CEPC booster 1.3 GHz SRF R&D and industrialization in synergy with CW FEL projects.

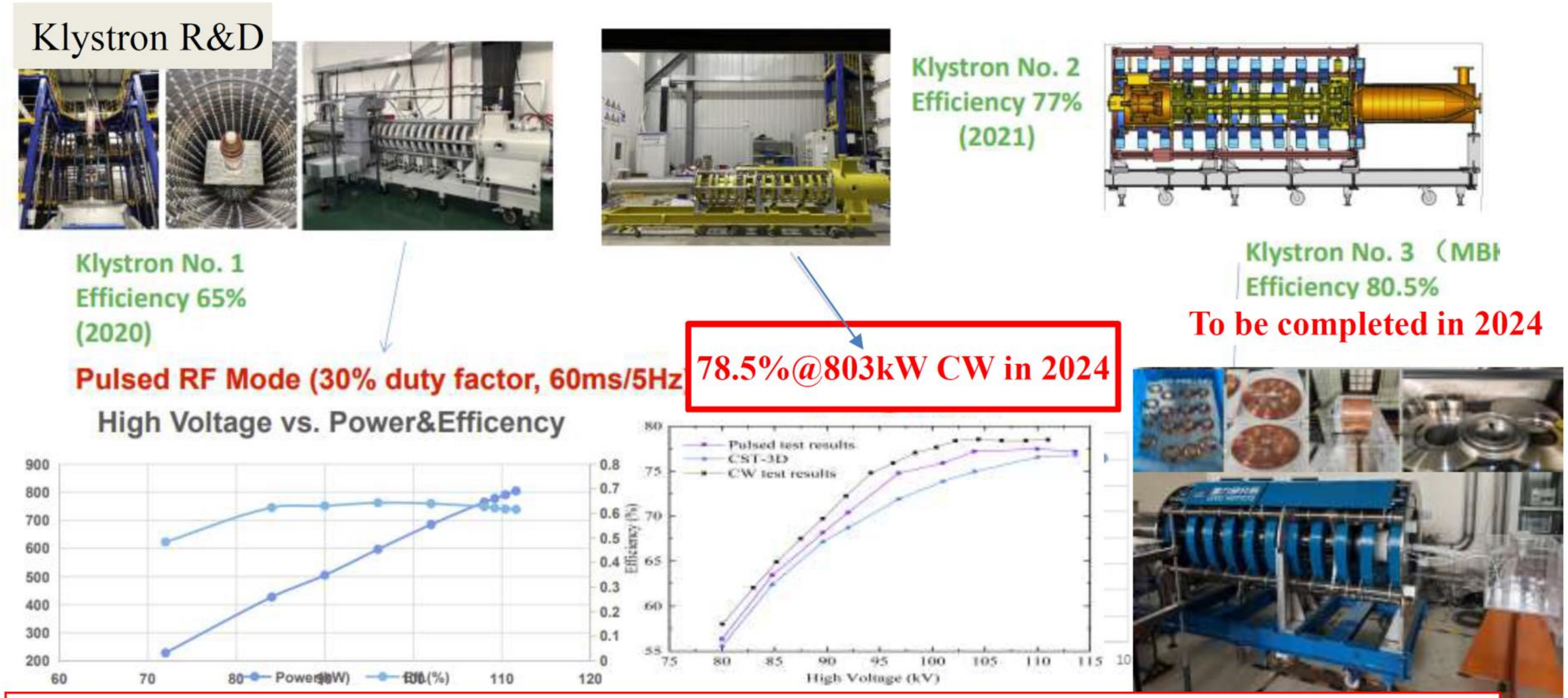
Parameters	Horizontal test results	CEPC Booster Higgs Spec	LCLS-II, SHINE Spec	LCLS-II-HE Spec
Average usable CW E_{acc} (MV/m)	23.1	3.0×10^{10} @ 21.8 MV/m	2.7×10^{10} @ 16 MV/m	2.7×10^{10} @ 20.8 MV/m
Average Q_0 @ 21.8 MV/m	3.4×10^{10}			

Exceeds the CEPC specifications

Can We Do It?

The technology and capability

Accelerator R&D and validations of technologies since 2013



CEPC collider ring 650MHz klystron development in TDR phase

Can We Do It?

Rising HEP scientists in China

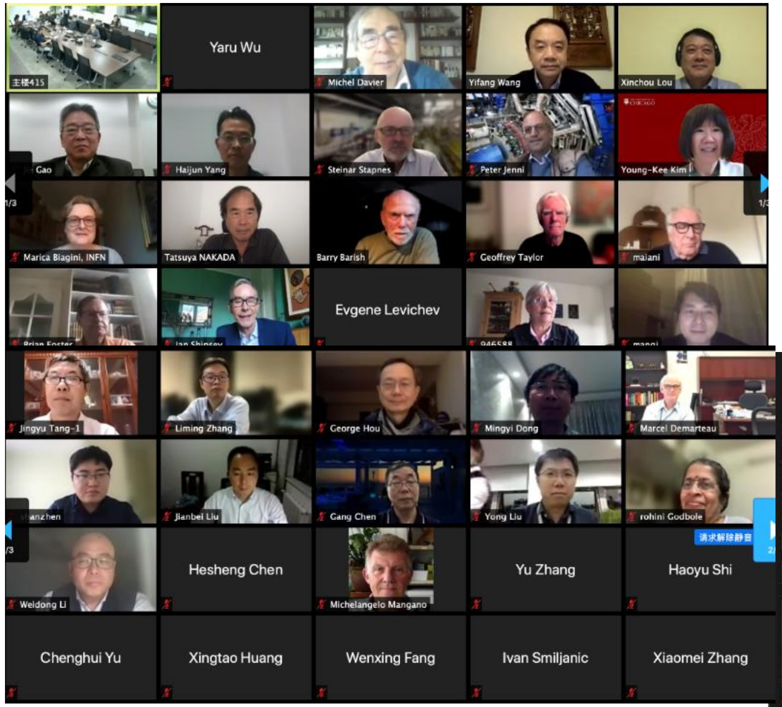
Photo credits: CEPC

Can We Do It?

Global collaboration

international experts reviewing TDR study (June 2023)

IAC meeting (Nov. 2021)



Accelerator Review (October 2021)

photo credits： Yaru Wu

Can We Do It?

Industrial Partners and Suppliers

	System
1	Magnet
2	Power supplier
3	Vacuum
4	Mechanics
5	RF Power
6	SRF/ RF
7	Cryogenics
8	Instrumentation
9	Control
10	Survey and alignment
11	Radiation protection
12	e-e+Sources

CEPC Industrial Promotion Consortium (CIPC, established in Nov. 2017)

Potential international collaborating suppliers and partners worldwide

Can We Do It?

The technology and capability

Report by the CEPC accelerator TDR review committee

International Technical Review Committee

Philip Bambade	LAL, Center Scientifique d'Orsay, Orsay
Maria Enrica Biagini	LNF-INFN, Frascati
Manuela Boscolo	LNF-INFN, Frascati
Brian Foster	U. of Oxford & DESY, Hamburg (Observer)
Yoshihiro Funakoshi	KEK, Tsukuba
Kazuro Furukawa	KEK, Tsukuba
Roberto Kersevan	CERN, Geneva
Hélène Mainaud Durand	CERN, Geneva
Norihito Ohuchi	KEK, Tsukuba
Carlo Pagani	U. of Milano & INFN Milano, Segrate
Anatoly Sidorin	JINR, Dubna
Makoto Tobiyama	KEK, Tsukuba
Kay Wittenburg	DESY, Hamburg
Akira Yamamoto	KEK, Tsukuba
Zhentang Zhao	SINAP, CAS, Shanghai
Frank Zimmermann	CERN, Geneva (Chair)

"The key technologies for CEPC have been developed. Prototypes meeting or exceeding the specifications are available. The CEPC team is on track to launch an engineering-design effort. After a site has been selected, the construction of the CEPC could start in 2027 or 2028. The Committee endorses this plan."

"The Committee wishes to congratulate the CEPC team on the excellent progress. The Committee is impressed by the amount and quality of the work performed and presented."

Can We Do It?

The technology and capability

nature

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nature > news > article

NEWS | 17 June 2024 | Correction 18 June 2024

China could start building world's biggest particle collider in 2027

The US$5 billion facility would be cheaper, bigger and faster to build than a similar one proposed by European scientists.

"We are now confident this is a real machine that we can build," says Wang, "We are trying to make sure we are fully ready for such a project,"

says Zimmermann, who chaired the review committee for the CEPC's technical-design report and is also involved in the FCC. **"They made big progress"**

. **"If they want to build the accelerator and move forward, they can."** Cohen, a member of the CEPC International Advisory Committee

Can We Do It?

The Cost

CEPC is in good synergy with other accelerator projects in China

Project name	Machine type	Location	Cost (B RMB)	Completion time
CEPC	Higgs factory Upto ttar energy	Led by IHEP, China	**36.4 (where accelerator 19)**	Around 2035 (starting time around 2027)
BEPCII-U	e+e-collider 2.8GeV/beam	IHEP (Beijing)	**0.15**	2025
HEPS	4th generation light source of 6GeV	IHEP (Huanrou)	**5**	2025
SAPS	4th generation light source of 3.5GeV	IHEP (Dongguan)	**3**	2031 (in R&D, to be approved)
HALF	4th generation light source of 2.2GeV	USTC (Hefei)	**2.8**	2028
SHINE	Hard XFEL of 8GeV	Shanghai-Tech Univ., SARI and SIOM of CAS (Shanghai)	**10**	2027
S3XFEL	S3XFEL of 2.5GeV	Shenzhen IASF	**11.4**	2031
DALS	FEL of 1GeV	Dalian DICP	**-**	(in R&D, to be approved,)
HIAF	High Intensity heavy ion Accelerator Facility	IMP, Huizhou	**2.8**	2025
CIADS	Nuclear waste transmutation	IMP, Huizhou	**4**	2027
CSNS-II	Spallation Neutron source proton injector of 300MeV	IHEP, Dongguan	**2.9**	2029

Total other accelerators under construction/planned in China ~39B RMB

more than the cost of CEPC
mostly completed/near completion when CEPC starts
technologies & industrial infrastructures well prepared for future projects

Can We Do It?

The Cost

“少建300公里高速公路就可以建设CEPC了”

I overheard a person of importance recently

According to Baidu Ai智能回答（Ai chat):

the cost of building highway (高速公路) in China is 100-300M RMB/km，
so the cost of CEPC is ~ a few hundred km of highway.

The total length of highway (高速公路) in China as of Feb-2024 is 184,000km,
the longest among all the countries in the world.

His words make real sense, plus we can not build highway forever

Let’s build a CEPC

Going Forward

Technical design of the detector
Engineering Design Study
Global collaboration
Realizing CEPC - a flagship facility in China; an early Higgs factory for the world

Going Forward

CEPC Accelerator Engineering Design Study has begun

CEPC Accelerator EDR Phase goals, scope and the working plan (preliminary) of 35 WGs summarized in a documents of 20 pages to be reviewed by IARC in 2024

CEPC International Accelerator Review Committee (IARC) Meeting was held from Sept. 18-20, 2024 at IHEP

The CEPC International Accelerator Review Committee (IARC) members visited IHEP 4th Generation 6GeV HEPS light source in Huairou campus of IHEP on Sept. 20, 2024 at IHEP

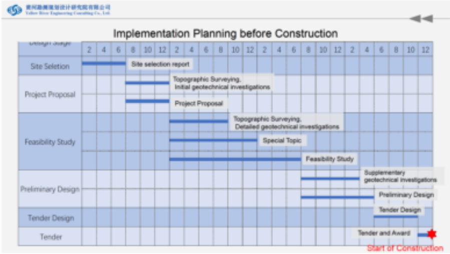
The CEPC International Accelerator Review Committee (IARC) members in the control room Of HEPS, and 30mA stored beam current have been reached during storage ring commissioning in Sept. 2024

Going Forward

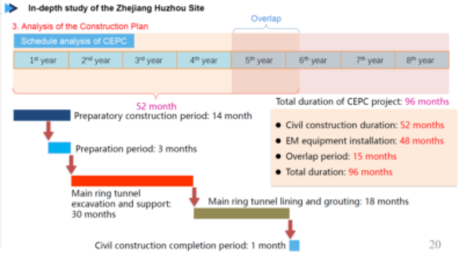
CEPC Accelerator EDR

CEPC Site Implementation and Construction Plans

CEPC site implementation plan in EDR



CEPC construction plan



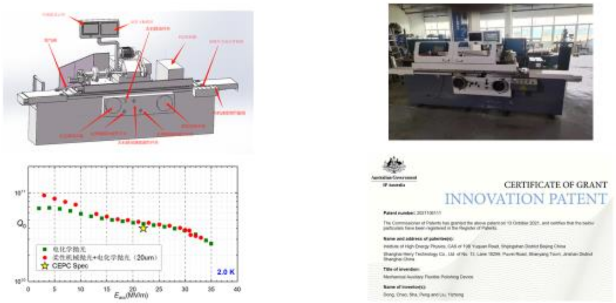
CEPC Accelerator EDR Plan-J. Gao HKUST-IAS HEP Conference, Jan. 22, 2024, Hong Kong 23

Future Plan for CEPC SRF

	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034-2035	2036-2045	2046-2047	2048	2049-2053
EDR																
Civil construction																
Acc. construction & installation																
Commission & operation													H	Z	W	ttbar
SRF system engineering design	Layout, cost, module, beam-cavity, LLRF, interfaces ...															
650 MHz test module (2x2-cell)	Beam operation, replace with high Q cav & variable coupler															
650 MHz H module (6x2-cell)	Design	pCM fabrication		pCM test	Prepare	Production of 32 CM / 192 2-cell CAV for 30 MW H				Installation, Commissioning			Op & +24 CM	Operation		
1.3 GHz H module	High Q module	Mass production of modules with SCM and BPM			pCM fab	pCM test	Production of 12 CM / 96 9-cell CAV			Installation, Commissioning			Operation			
1.3 GHz Z module (high current)		Design and R&D			pCM fabrication		pCM test		Production of 4 CM / 32 9-cell CAV	Installation, Commissioning			Operation			
650 MHz HL-Z module	Conceptual design. 500 MHz high current module production.				Design and R&D							Produce and Install 60+40 1-cell CM		Op		
ttbar cavity and module	Design and R&D of high gradient high Q and new material (Nb3Sn etc.) 650 MHz and 1.3 GHz cavities and module for ttbar								pCM fabrication and test				Production and Installation of 48 CM / 192 650 MHz 5-cell CAV 32 CM / 256 1.3 GHz 9-cell CAV			Op

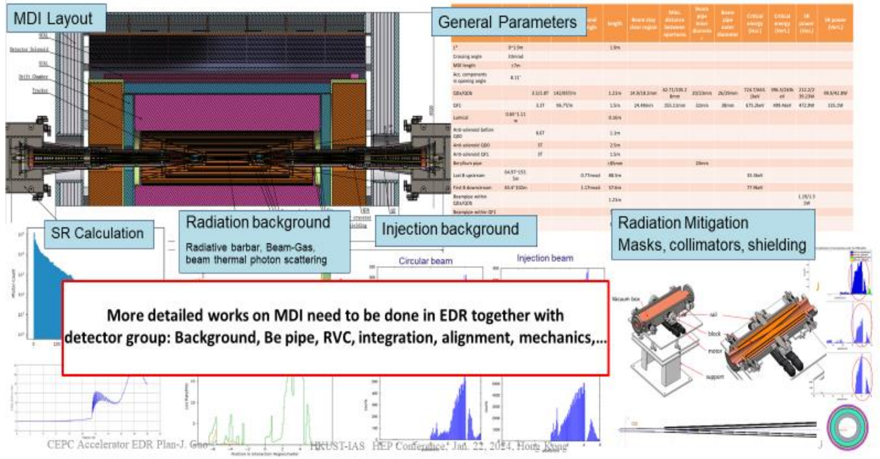
CEPC SRF Industrial Production Technology

- In 2023, IHEP invented soft SRF cavity polishing equipment has been completed and it will be installed at IHEP soon, and it reached the same surface roughness as EP. CEPC 650 MHz cavity treated by the soft polishing equipment reached the CEPC specification



650 MHz SC measurement result with soft polishing technology

CEPC MDI in EDR

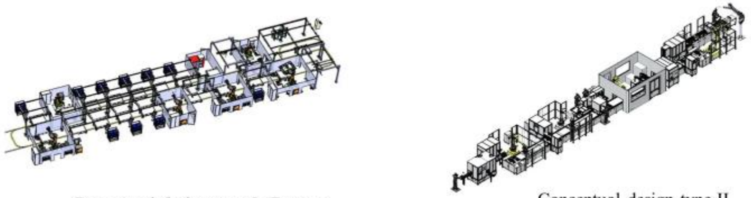


Going Forward

CEPC Accelerator EDR

CEPC Magnets' Automatic Production Lines in EDR

To reduce the fabrication cost of the magnets of CEPC, automatic magnet production lines will be demonstrated in EDR and used during construction

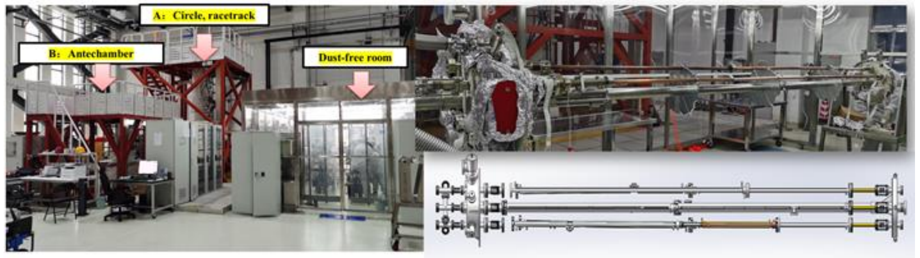


Conceptual design type-I (Booster magnet)

Conceptual design type-II (Collider ring magnet)

Massive Production Line of NEG Coating Vacuum Chambers in EDR

- The coating device A: Vacuum chambers are connected in parallel to 6 groups, each group of vacuum chambers length should be lower than 3.5m, outer diameter is about 0.47m;
- The coating device B: Antechamber are connected in parallel to 4 groups, each group of vacuum chambers length should be lower than 1.5m, due to its discharge difficulty.
- Two setups of NEG coating have been built for vacuum pipes of HEPS at IHEP Lab. And a lot of test vacuum pipes have been coated, which shows that NEG film has good adhesion and thickness distribution.
- **In EDR phase a dedicated CEPC NEG coated vacuum chamber production line is planned**



CEPC Accelerator Control and Timing in EDR

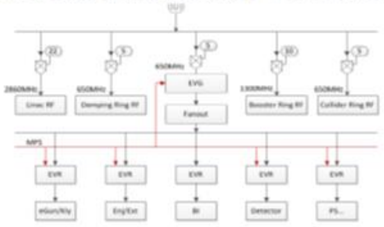
The basic structure of Timing System

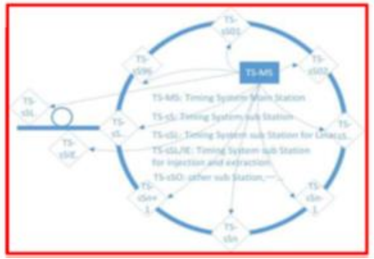
- Event system and RF transmission system
- Event system: Trigger signal and Low frequency clock signal
- RF transmission system: Transmit high stability RF signal

Temperature variation induced drift compensation

0.7ns for 10km optical fiber with 1 ℃ change normally

In EDR phase CEPC high precision timing and control technology will be developed



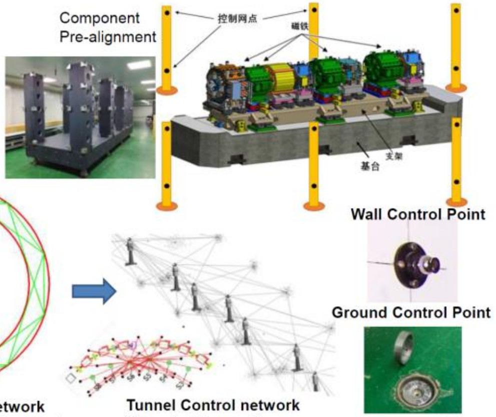


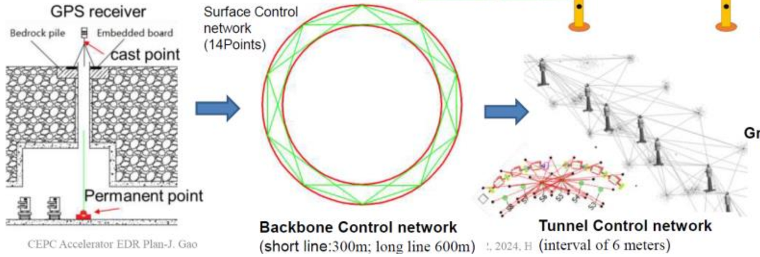
CEPC Alignment and Installation Plan in EDR

- Alignment accuracy requirement

Component	Δx (mm)	Δy (mm)	$\Delta\theta_z$ (mrad)
Dipole	0.10	0.10	0.10
Arc Quadrupole	0.10	0.10	0.10
IR Quadrupole	0.10	0.10	0.10
Sextupole	0.10*	0.10*	0.10

*implement beam-based alignment



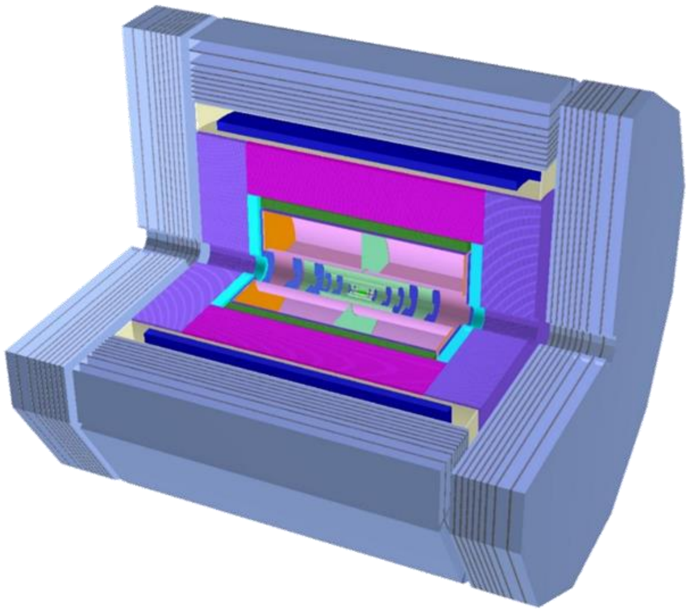


Going Forward

CEPC is integrating the instrumentation technologies into a new detector system

- The CEPC group will produce the TDR of a reference detector (ref-TDR) by June 2025.
- An international review committee has been formed to guide and review the design.
- CEPC will continue to adopt better technologies; final detectors will be determined by international detector collaborations

System	Technologies	
	Baseline	For comparison
Beam pipe	Φ20 mm	
LumiCal	SiTrk+Crystal	
Vertex	CMOS+Stitching	CMOS Pixel
Tracker	CMOS SiDet ITrk	
	Pixelated TPC	PID Drift Chamber
	AC-LGAD OTrk	SSD / SPD OTrk
		LGAD ToF
ECAL	4D Crystal Bar	PS+SiPM+W, GS+SiPM, etc
HCAL	GS+SiPM+Fe	PS+SiPM+Fe, etc
Magnet	LTS	HTS
Muon	PS bar+SiPM	RPC
TDAQ	Conventional	Software Trigger
BE electr.	Common	Independent



Foundations:
- CEPC Instrumentation R&D
- LHC detector upgrade projects
- other HEP experiments
- progress in HEP worldwide R&D
- development in industry

Summary

CEPC

- is on the path to converge into a complete package
- detector Ref. TDR will be a crucial part of the overall readiness
- is committed to strive to maximize international collaboration
- has received great help from international scientists and labs
- is making strong effort to complete a proposal to the government for approval
- will offer the HEP community an early Higgs factory if successful

Acknowledgements

- CEPC team's hard work, very fruitful international and CIPC collaborations have been critical to the CEPC program
- Special thanks to CEPC IB, SC, IAC, IARC, IDRC, TDR review (+cost) Committees for their critical advices, suggestions and supports
- Funding agencies, governments, CAS and IHEP for their financial supports