中国科学院高能物理研究所
Institute of High Energy Physics, Chinese Academy of Sciences

Status of CEPC in China

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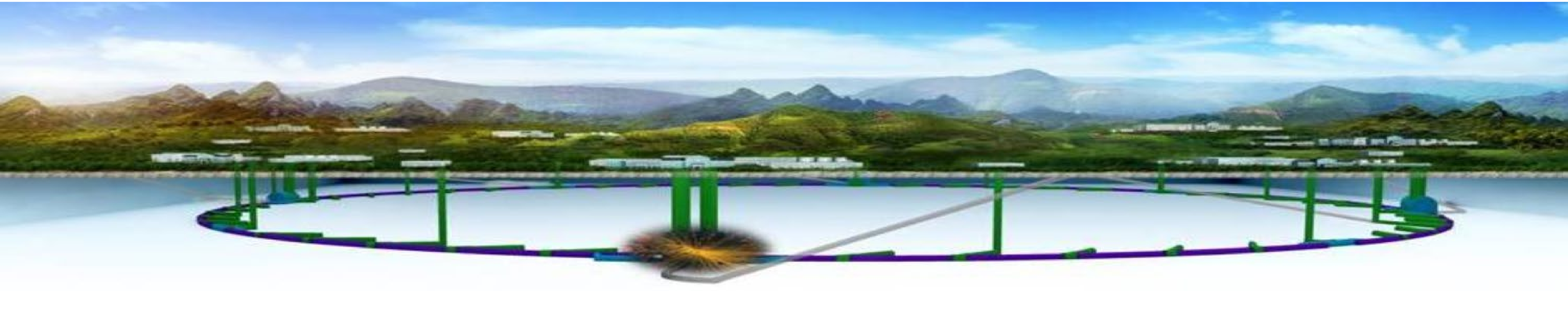
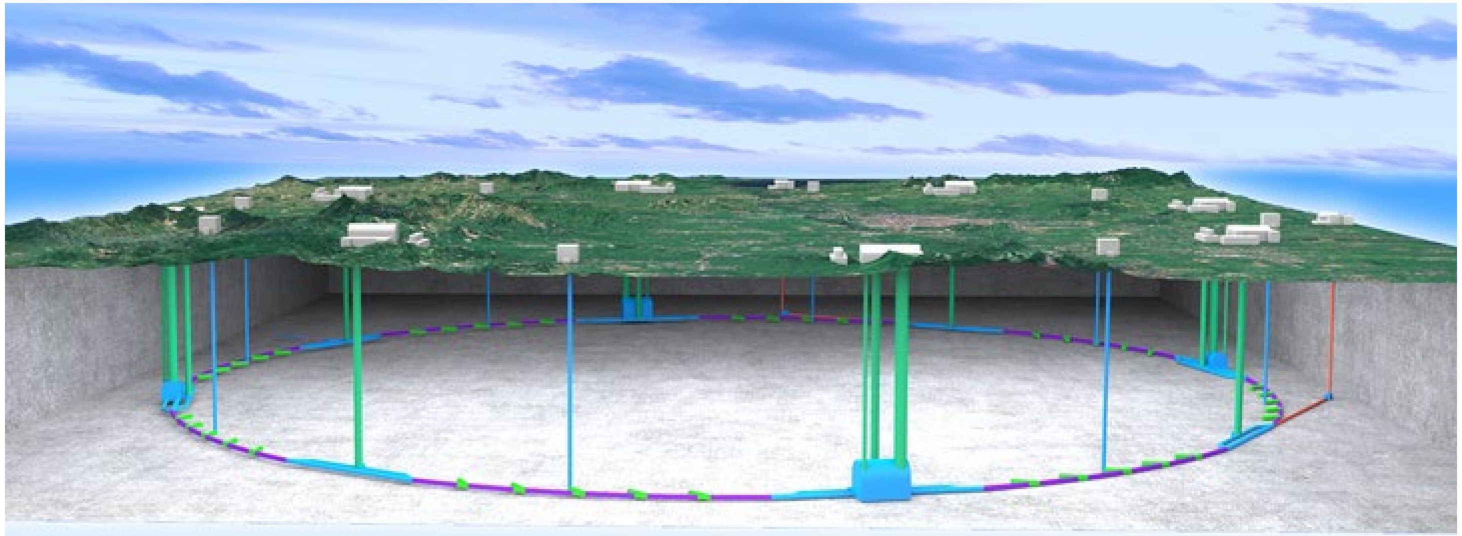
Institute of High Energy Physics, Beijing

Venice, June 24, 2025



CEPC: Introduction

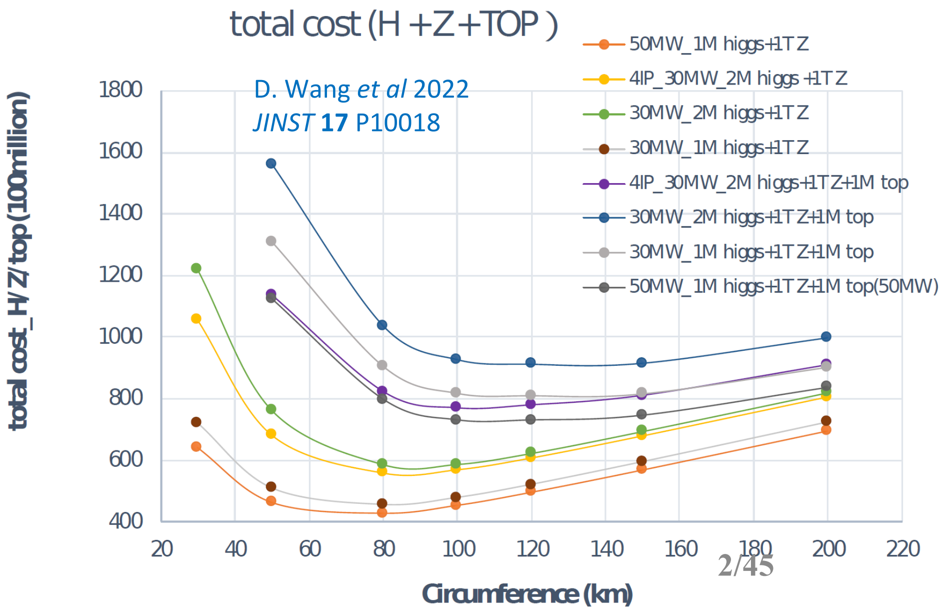
- Since 2005, we were thinking about the next machine after BEPCII/BESIII
- After its discovery, we realized that Higgs is the best portal for new physics and for the future of HEP
- The idea of a Circular e+e- Collider(CEPC) followed by a possible Super proton-proton collider(SPPC) was firstly proposed in Sep. 2012, and reported at Fermilab during the workshop: "Higgs Factories 2012" in Oct. 2012
- It quickly gained momentum in China and in the world



Fermilab-Conf-13-037-APC

arXiv:1302.3318[physics.acc-ph]

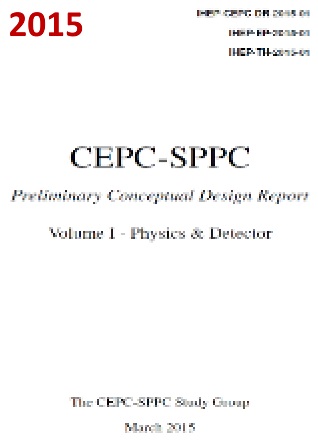
Optimum circumference for H/Z/Top

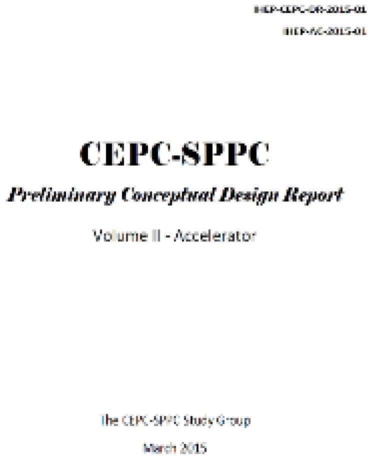


From Kick-off to TDR

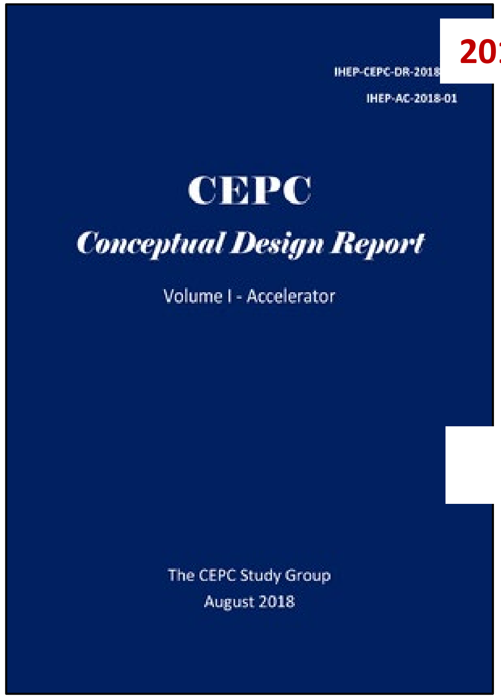
2013

2015





2018

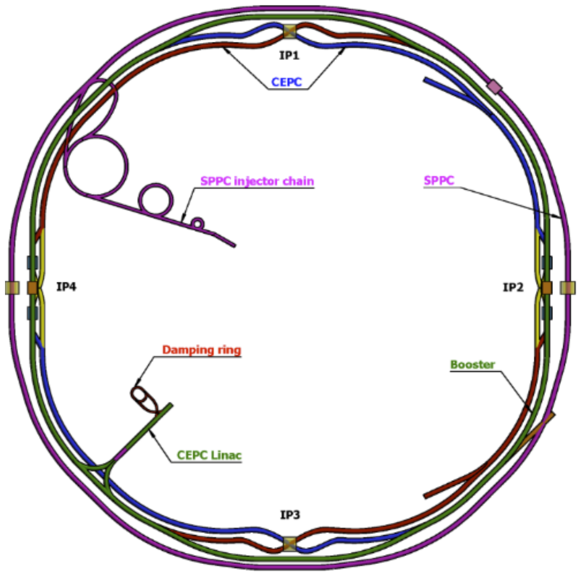


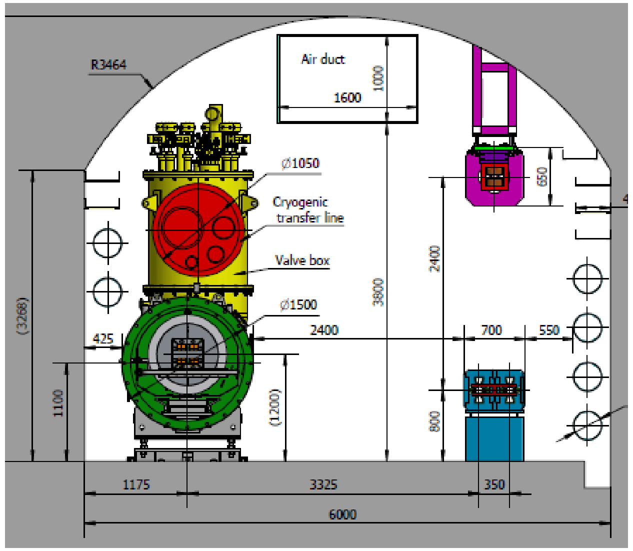
http://cepc.ihep.ac.cn

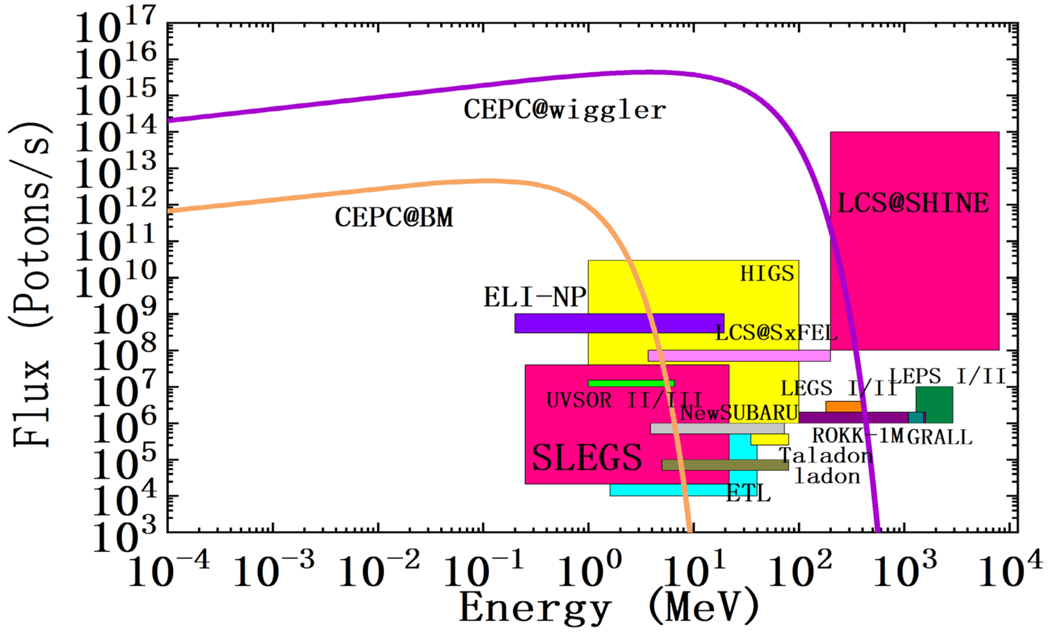
2023

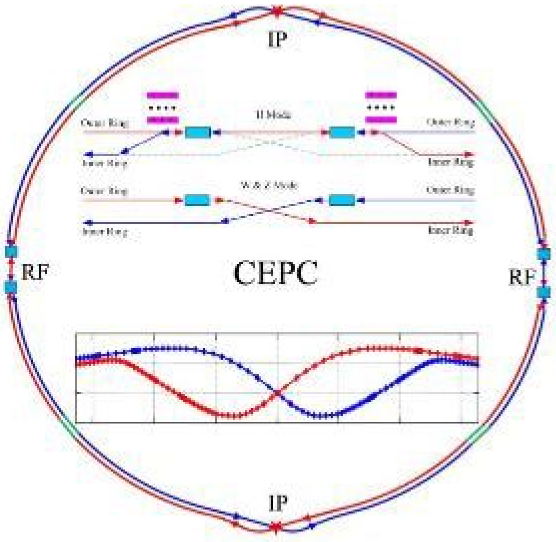
CEPC Layout and Design Essentials

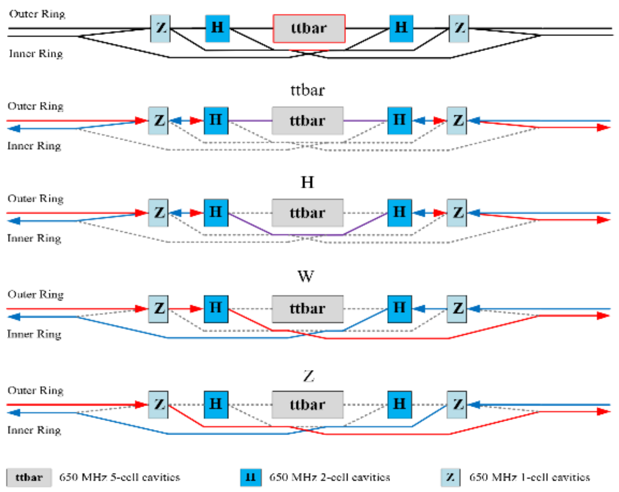
- 100km circumference
- Compatible tunnel for CEPC and SPPC
- Baseline: 100 km, 30 MW;
  Upgradeable to 50 MW, High Lumi Z, ttbar
- Switchable operation: Higgs, W/Z, top
- A very high energy Synchrotron radiation facility











H/W/Z/ttbar bypass scheme

CEPC Accelerator Baseline Parameters

Linac

Parameter	Symbol	Unit	Baseline
Energy	E_{e-}/E_{e+}	GeV	30
Repetition rate	f_{rep}	Hz	100
Bunch number per pulse			1 or 2
Bunch charge		nC	1.5 (3)
Energy spread	σ_E		1.5×10^{-3}
Emittance	ε_r	nm	6.5

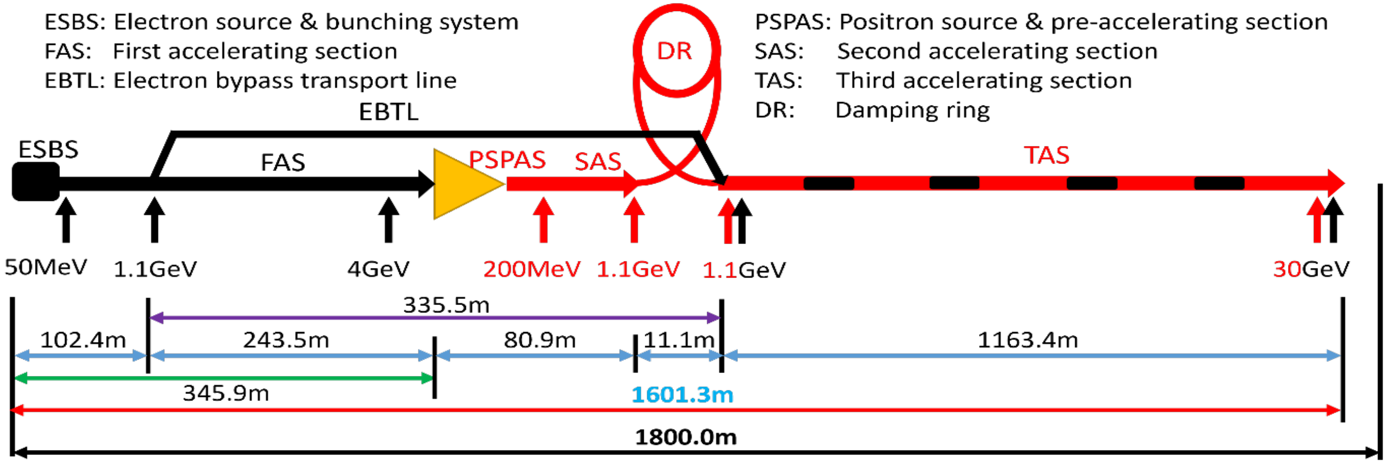
Booster

		tt	*H*		*W*	*Z*	
		Off axis injection	Off axis injection	On axis injection	Off axis injection	Off axis injection	
Circumfer.	km	100					
Injection energy	GeV	30					
Extraction energy	GeV	180	120		80	45.5	
Bunch number		35	268	261+7	1297	3978	5967
Maximum bunch charge	nC	0.99	0.7	20.3	0.73	0.8	0.81
Beam current	mA	0.11	0.94	0.98	2.85	9.5	14.4
SR power	MW	0.93	0.94	1.66	0.94	0.323	0.49
Emittance	nm	2.83	1.26		0.56	0.19	
RF frequency	GHz	1.3					
RF voltage	GV	9.7	2.17		0.87	0.46	
Full injection from empty	h	0.1	0.14	0.16	0.27	1.8	0.8

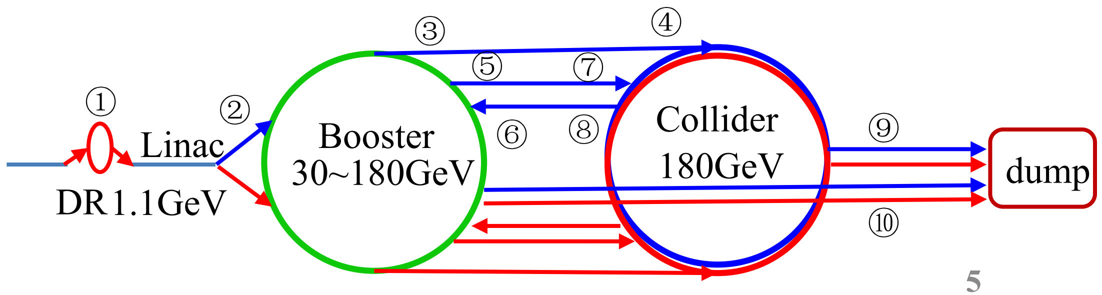
Collider

	Higgs	Z	W	$t\bar{t}$
Number of IPs	2			
Circumference (km)	**100.0**			
SR power per beam (MW)	**30**			
Energy (GeV)	**120**	**45.5**	**80**	**180**
Bunch number	268	11934	1297	35
Emittance $\varepsilon_x/\varepsilon_y$ (nm/pm)	0.64/1.3	0.27/1.4	0.87/1.7	1.4/4.7
Beam size at IP σ_x/σ_y (um/nm)	14/36	6/35	13/42	39/113
Bunch length (natural/total) (mm)	2.3/4.1	2.5/8.7	2.5/4.9	2.2/2.9
Beam-beam parameters ξ_x/ξ_y	0.015/0.11	0.004/0.127	0.012/0.113	0.071/0.1
RF frequency (MHz)	650			
Luminosity per IP (10^{34} cm^{-2} s^{-1})	**5.0**	**115**	**16**	**0.5**

Electron and Positron Injection Linac



Transport lines



Operation Plan

* Higgs is the top priority. The CEPC will commence its operation with a focus on Higgs

Particle	$E_{c.m.}$ (GeV)	Years	SR Power (MW)	Lumi. /IP ($10^{34}cm^{-2}s^{-1}$)	Integrated Lumi. /yr (ab^{-1}, 2 IPs)	Total Integrated L (ab^{-1}, 2 IPs)	Total no. of events
H*	240	10	50	8.3	2.2	21.6	4.3×10^6
			30****	5	1.3	13	2.6×10^6
Z	91	2	50	192**	50	100	4.1×10^{12}
			30****	115**	30	60	2.5×10^{12}
W	160	1	50	26.7	6.9	6.9	2.1×10^8
			30****	16	4.2	4.2	1.3×10^8
$t\bar{t}$	360	5	50	0.8	0.2	1.0	0.6×10^6
			30****	0.5	0.13	0.65	0.4×10^6

** Detector solenoid field is 2 Tesla during Z operation, 3Tesla for all other energies.

*** Calculated using 3,600 hours per year for data collection.

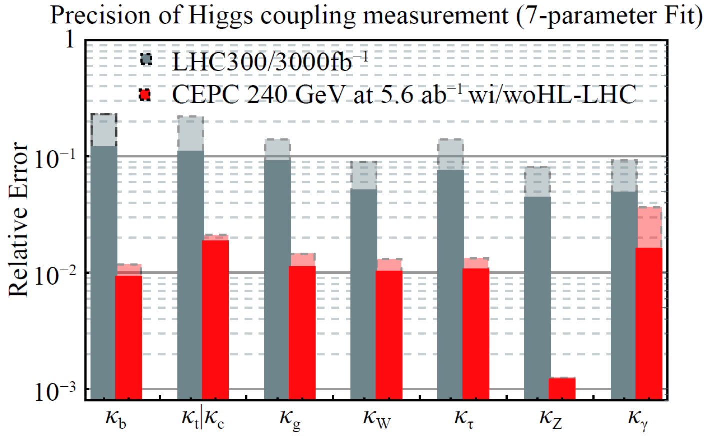
**** 30 MW leaves room for international in-kind contributions

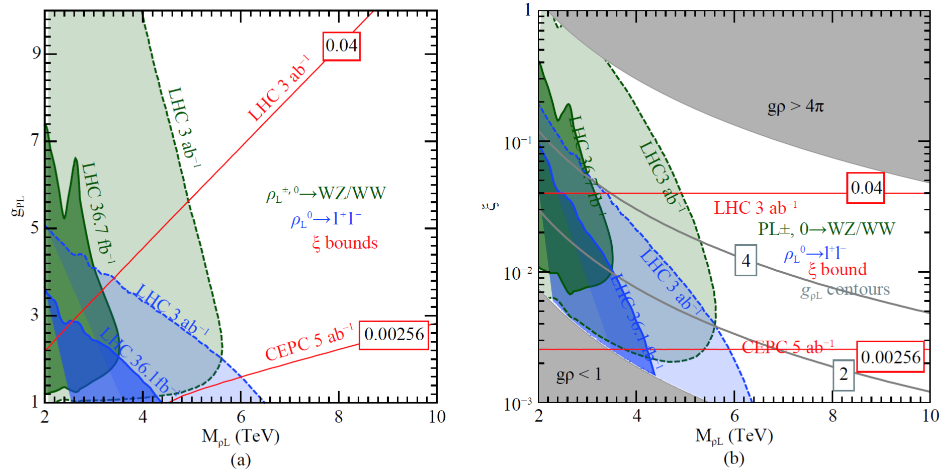
Scientific Objectives: “Discovery + Precision Measurement”

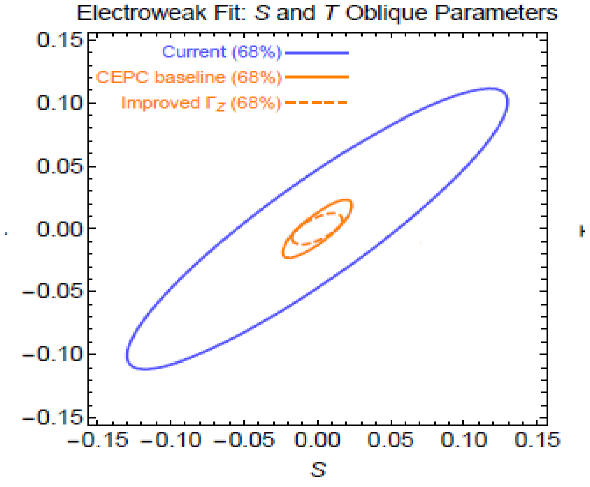
Higgs coupling measurement can be improved by orders magnititude

Direct and indirect proble to new physics up to 10 TeV, ×10 higher then HL-LHC

Electroweak measurement can be improved by a large factor

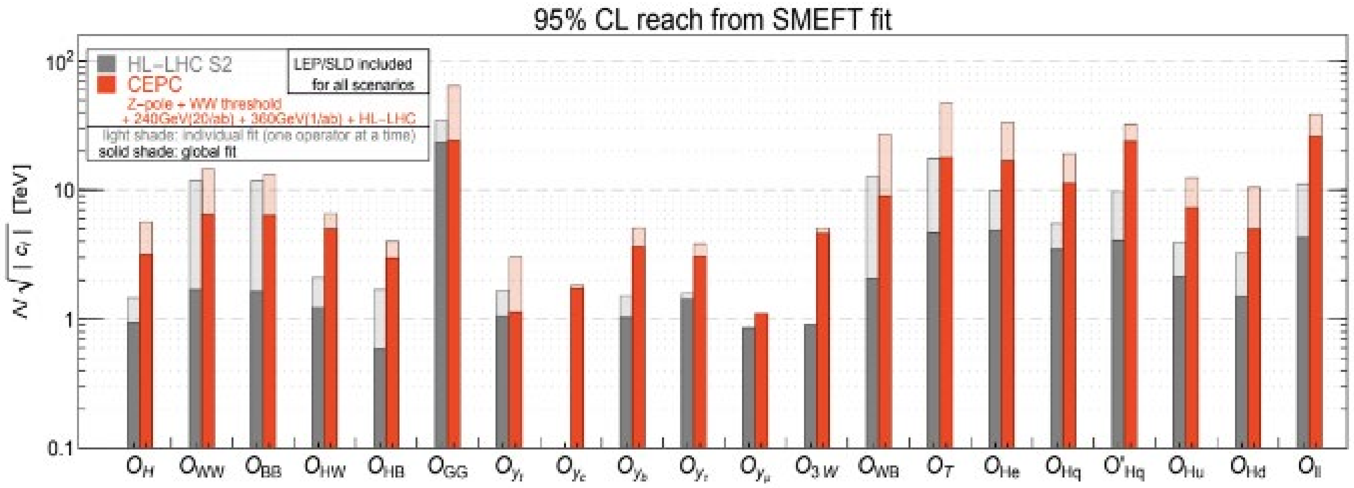






CEPC physics white papers:

1. **Higgs physics**, arxiv:1810.09037
   Chin. Phys. C 43(2019) 043002
2. **Flavor physics**, arxiv:2412.19743
3. **New Physics Search** at the CEPC: a General Perspective arXiv.2505.24810
4. **Electroweak physics**, to be published
5. **QCD**, to be published



High Energy Photon Source (HEPS)

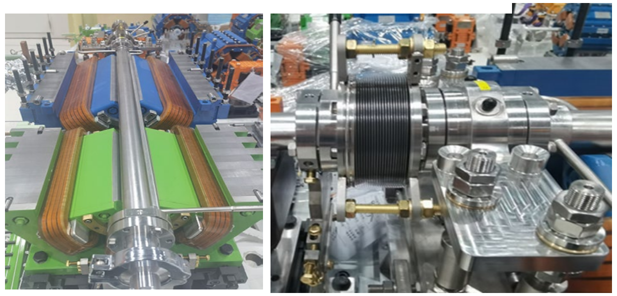
6 GeV, 36 nm·rad,
1.3 km circumference
Construction completed in 2025

Experience at HEPS/BEPCII

6 GeV, 36 nm·rad

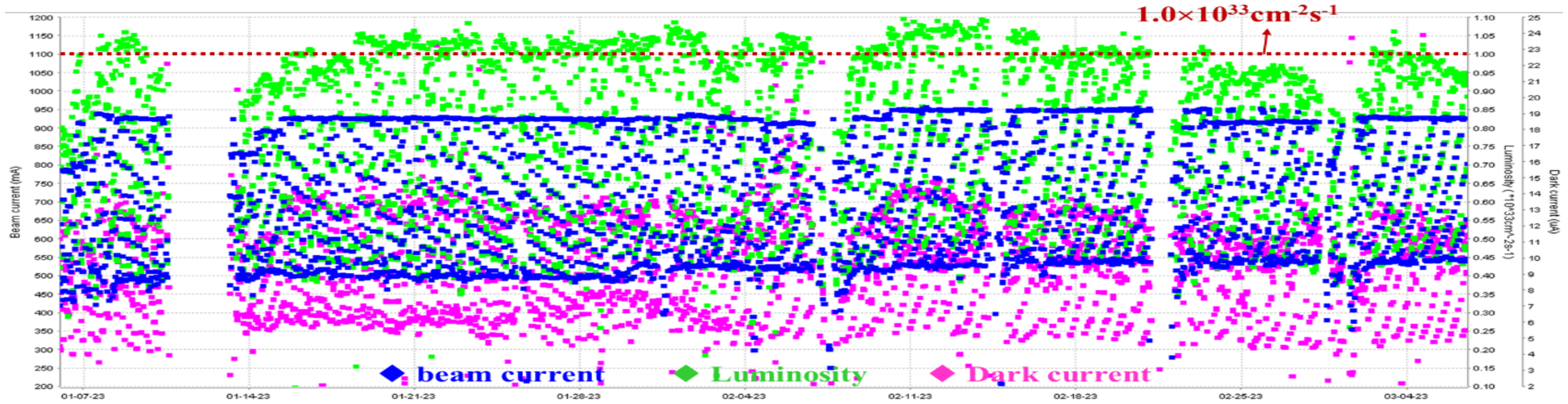
Magnets & alignment

Vacuum pipe and NEG coating



Electron gun

L. Feedback kicker



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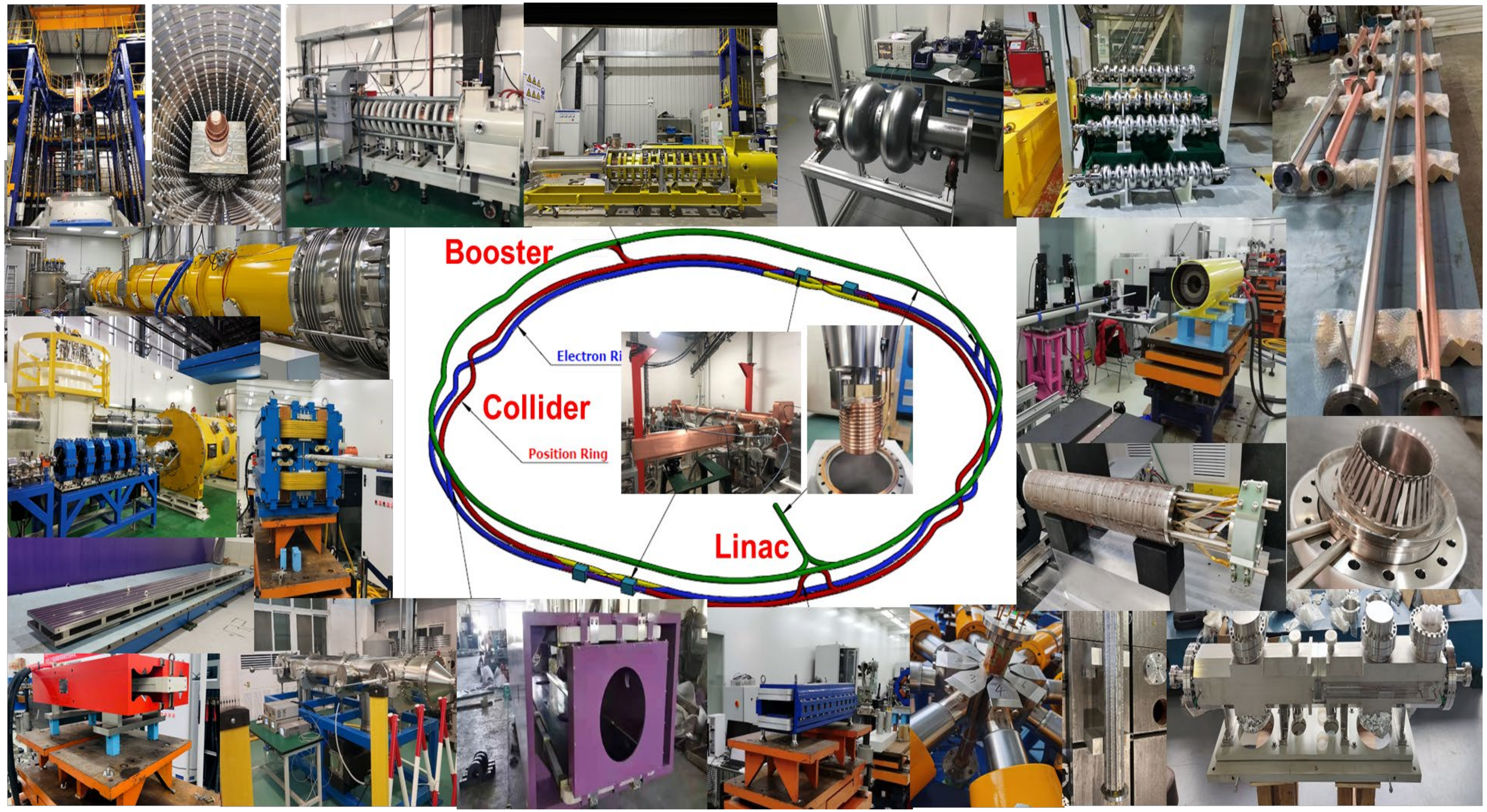
R&D: Key Technologies

- ➢ Key technologies R&D span over all components listed in CDR/TDR
- ➢ About 10% remaining (eg. RF power source, control, alignment, SC magnets, machine integration) to be completed by 2026.



✔ **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%

Accelerator TDR Published


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


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

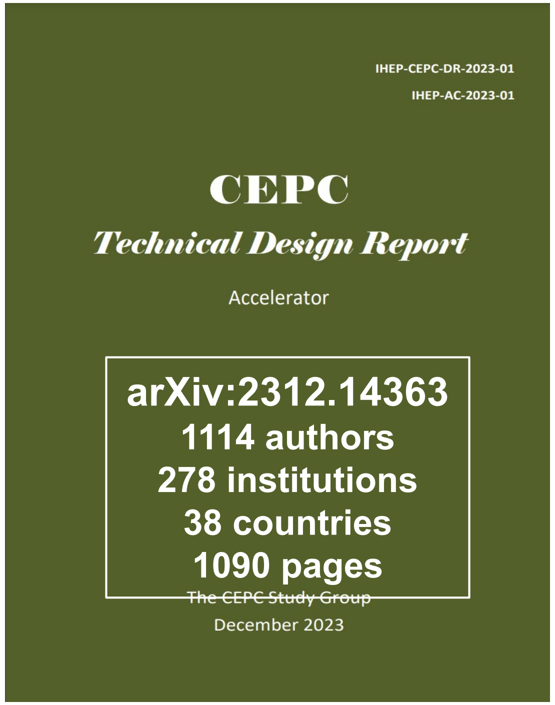
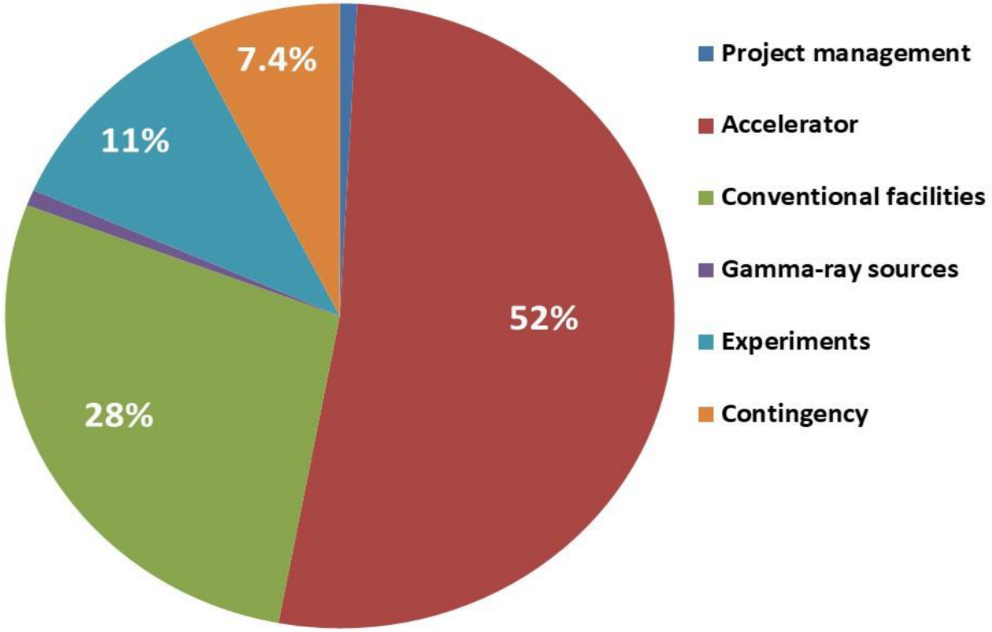


Table 12.1.2: CEPC project cost breakdown, (Unit: 100,000,000 yuan)

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%



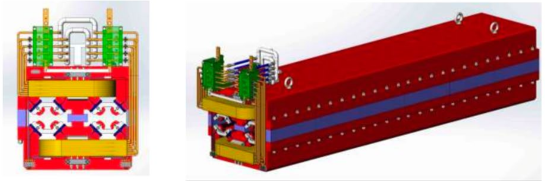
CEPC accelerator TDR link: （arXiv： 2312.14363）
CEPC accelerator TDR releasing news:
http://english.ihep.cas.cn/nw/han/y23/202312/t20231229_654555.html

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

Next Step for the Accelerator： EDR

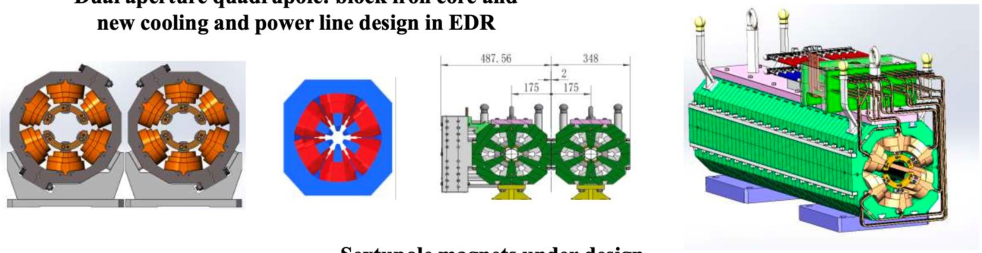
EDR tasks start with 35 WGs aiming for issues like further R&D of new technologies, mass production, mockup for installation, etc.

- A full cryomodule containing six 650 MHz 2-cell cavities
- Higher efficiency klystrons
- Automatic production for NEG coated vacuum chambers
- Automatic production for magnets
- More prototypes of magnets
- C-band LINAC test band
- CCT type SC quadrupole magnet for final focusing
- MDI design and background studies
- Control and timing
- Alignment and installation plan
- Mockup for installation
- PWFA test facility
- ….



Dual aperture quadrupole: block iron core and new cooling and power line design in EDR

Correctors: mechanical design completed

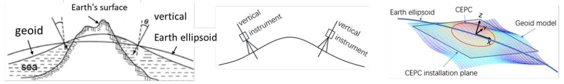


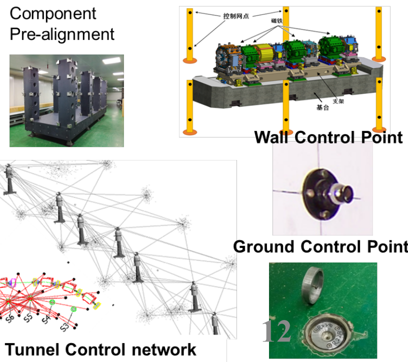
Sextupole magnets under design

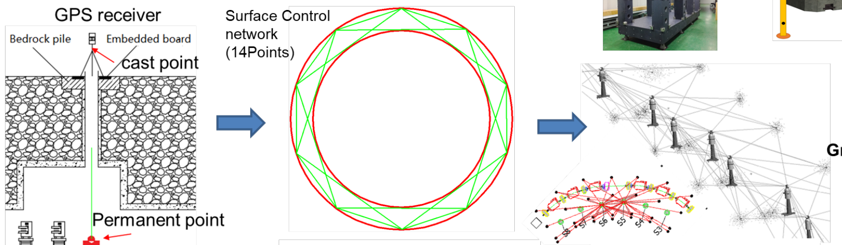
- Alignment accuracy requirement

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



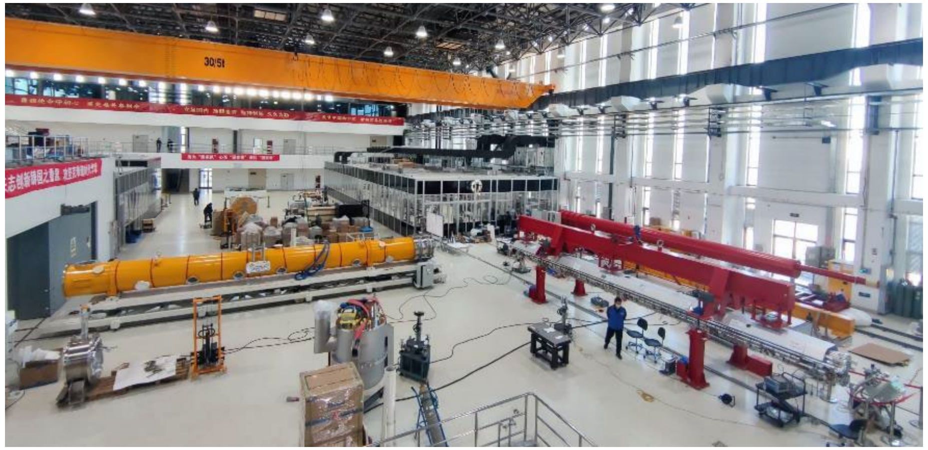


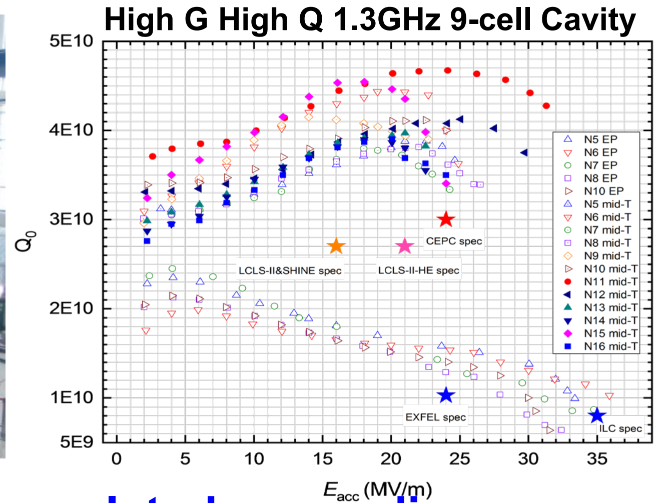


Backbone Control network (short line:300m; long line 600m)

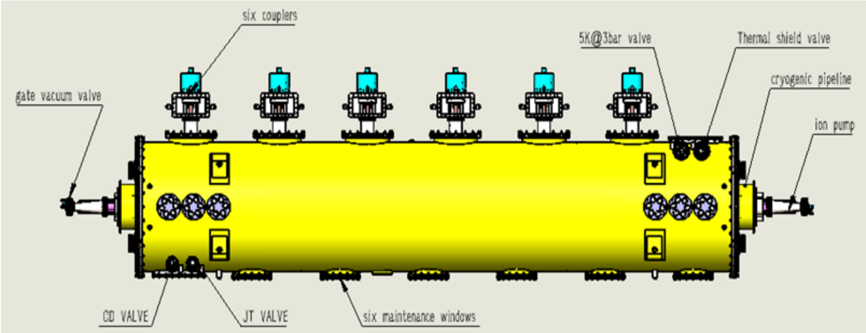
Tunnel Control network (interval of 6 meters)

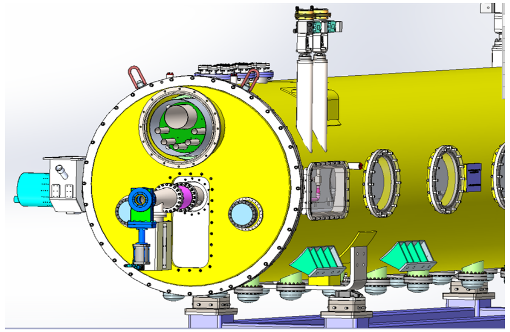
EDR Example 1: SRF Cavities and Modules

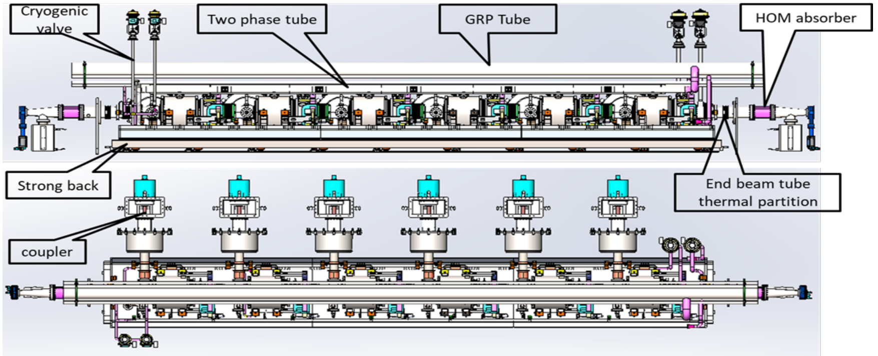




In TDR phase: 650MHz 2*cell short module and 1.3GHz full module has been completed, exceeding spec.



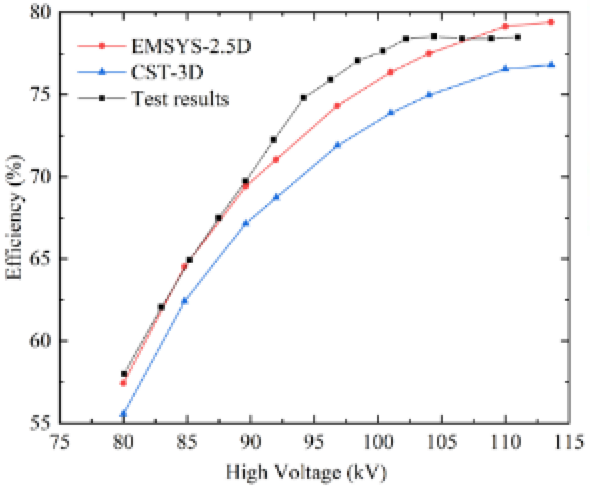


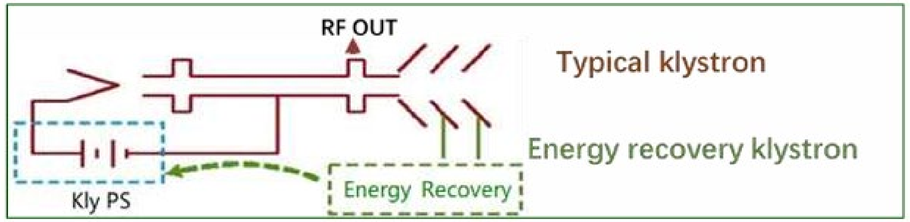


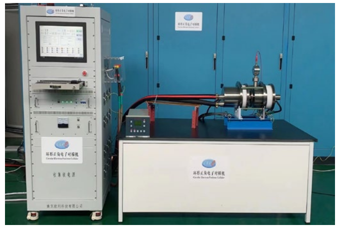
In EDR: a full 11 m-long cryomodule containing six 650 MHz 2-cell cavities will be built

Status： construction started

EDR Example 2: Higher Efficiency Klystrons

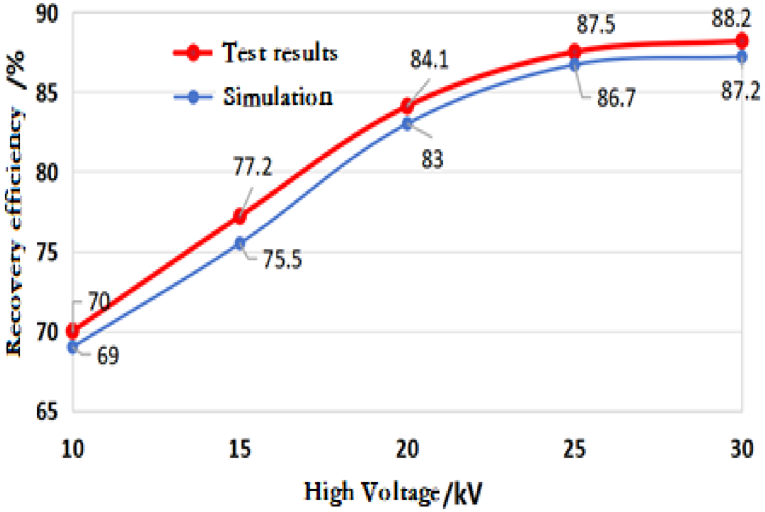


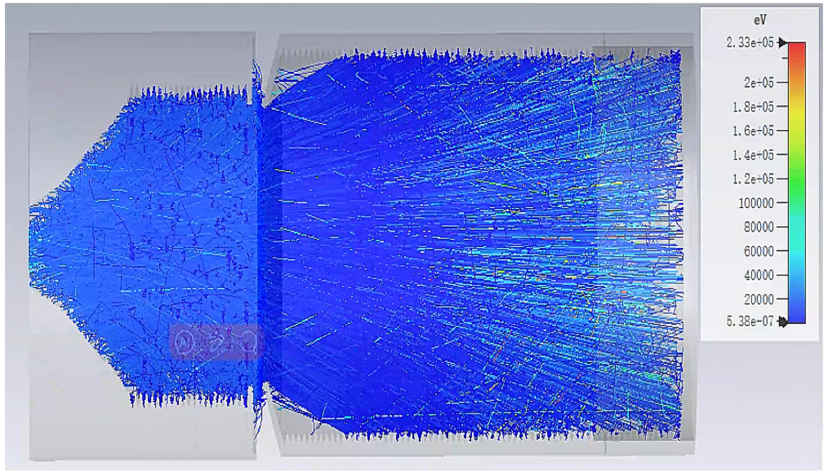


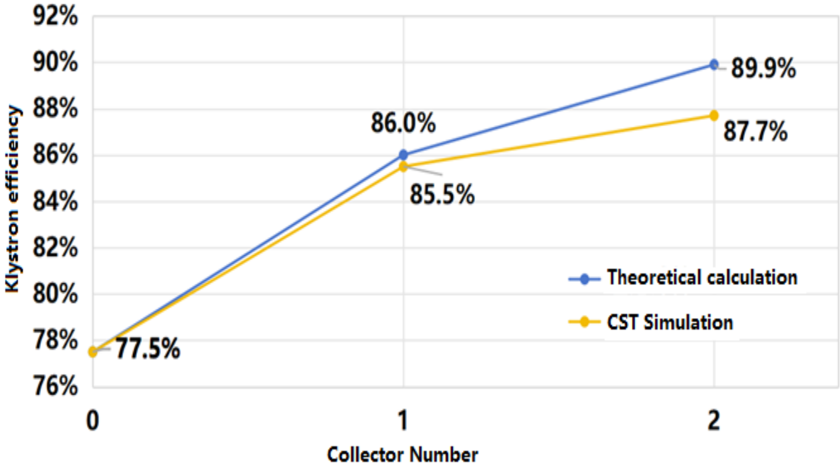


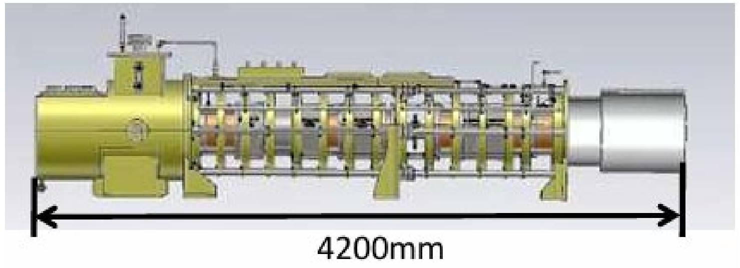
In TDR phase: CW 800 kW klystron reached effi. of ~78%

Energy recovery Klystron: a test stand reached eff. of ~88%





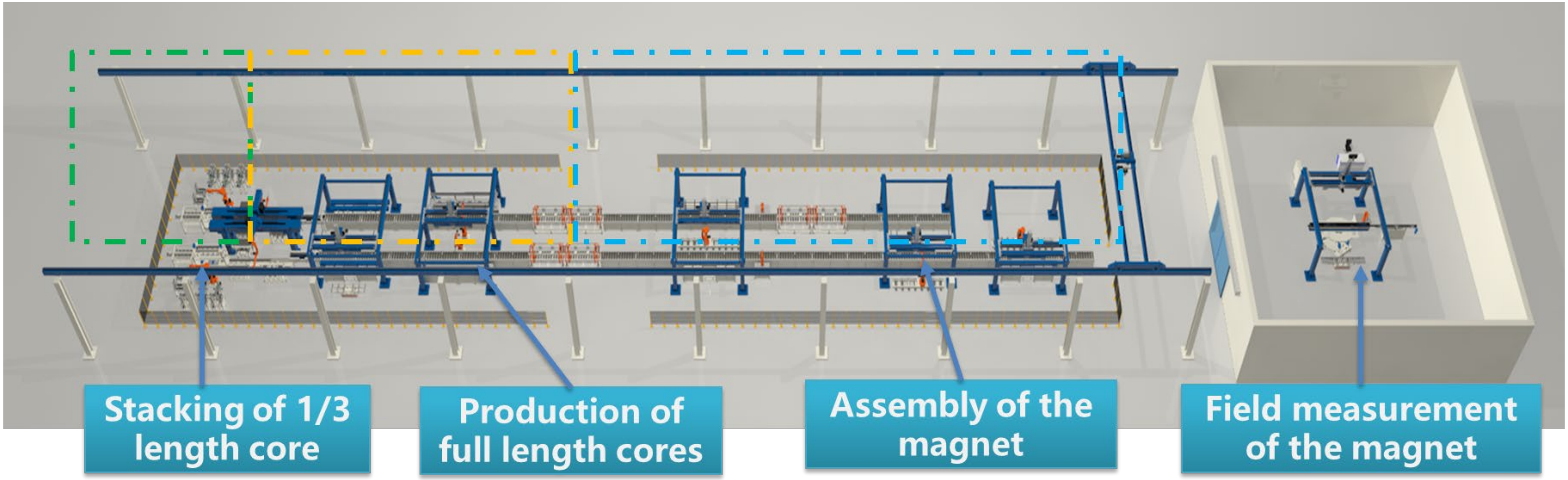


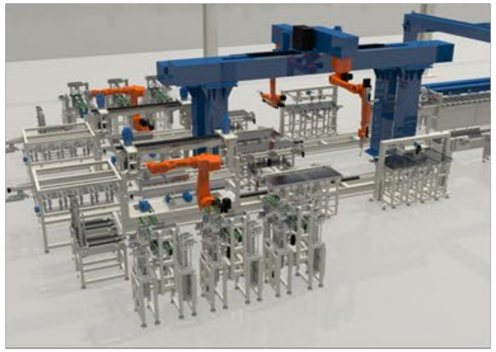


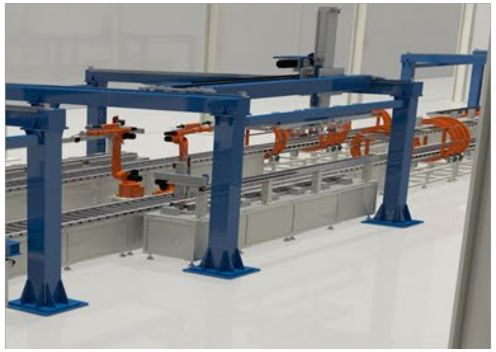
In EDR: A full Energy recovery Klystron aiming for an efficiency >85%, construction will start soon

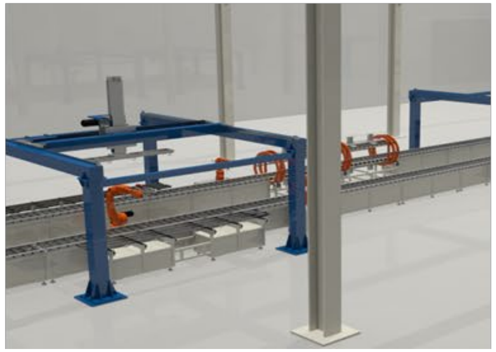
EDR Example 3: Automatic Production for Magnets

- Starting from booster dipole magnet: ~15000 magnets needed
- Can work 24h/day, 7days/week, may reduce the cost by ~30-50%





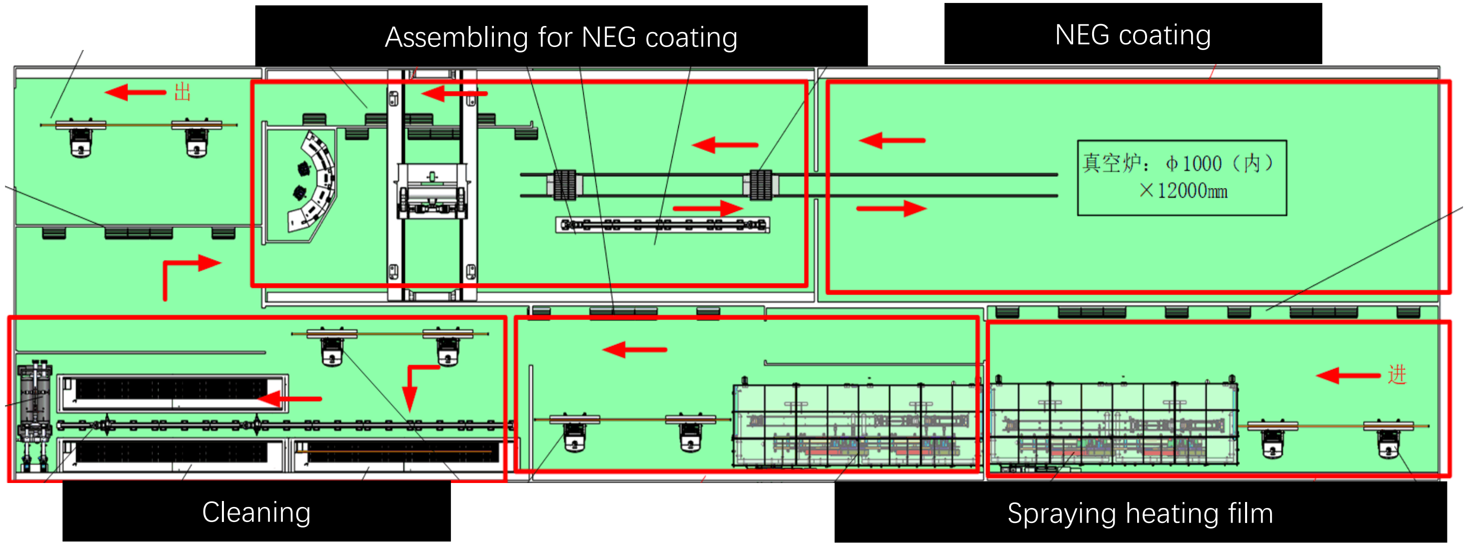




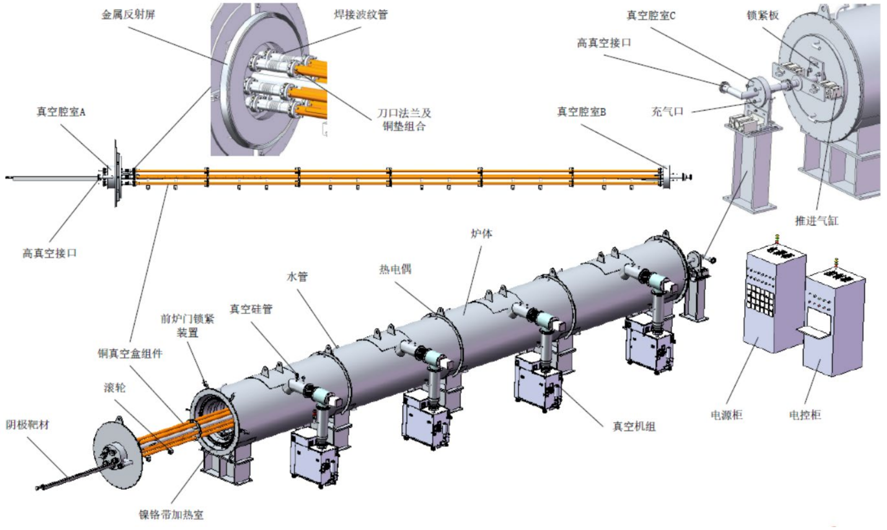
Status： design completed and construction started, commissioning test next year

EDR Example 4: Automatic Production for NEG Coated Vacuum Chamber

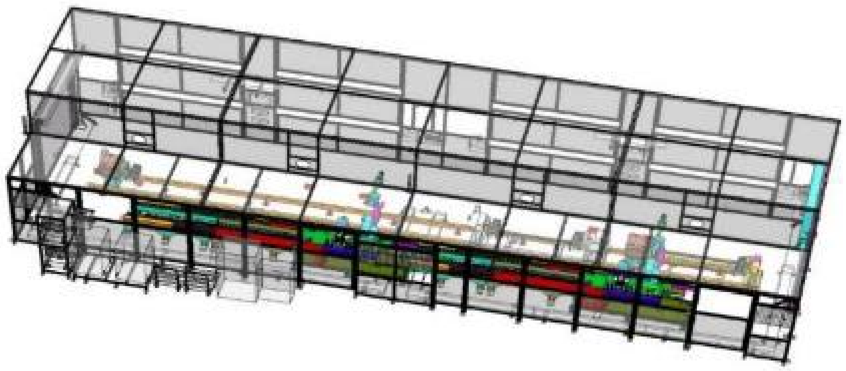
- **A total of 200 km needed**
- **Can work 24h/day, 7days/week, may reduce the cost by ~30-50%**



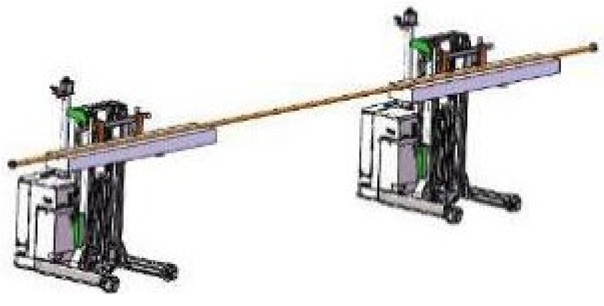
Layout of production line



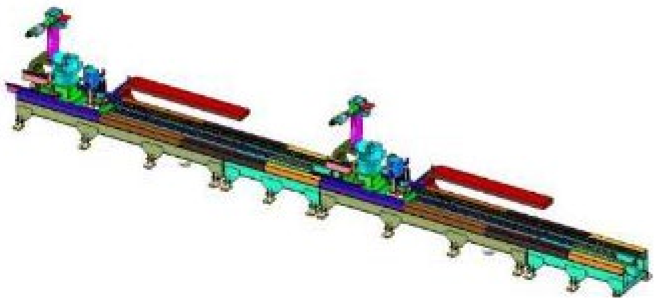
NEG coating facility by horizontal method



Production line of NEG coating, spraying



AGV(Automatic Guided Vehicle) transport

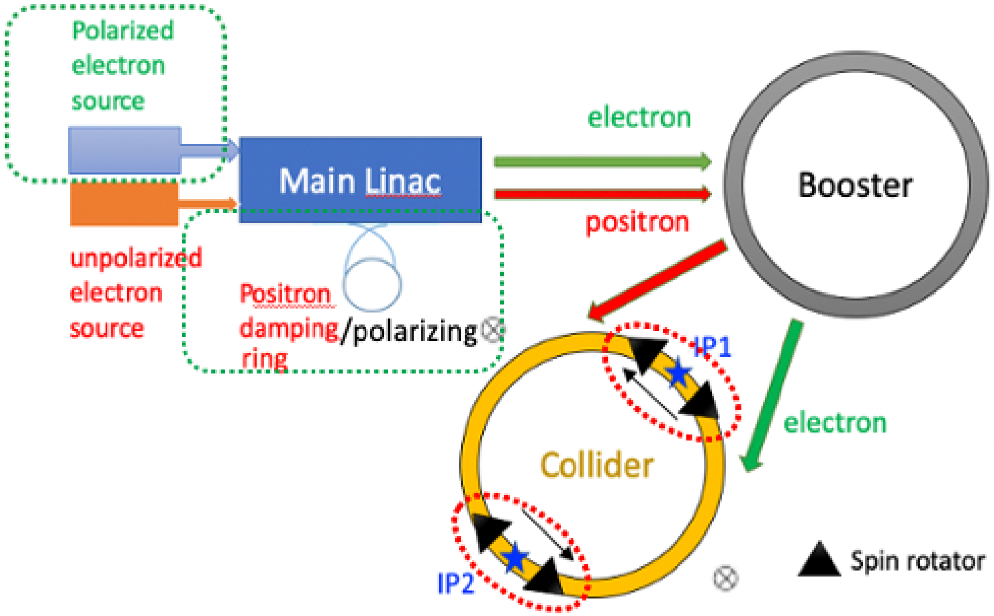


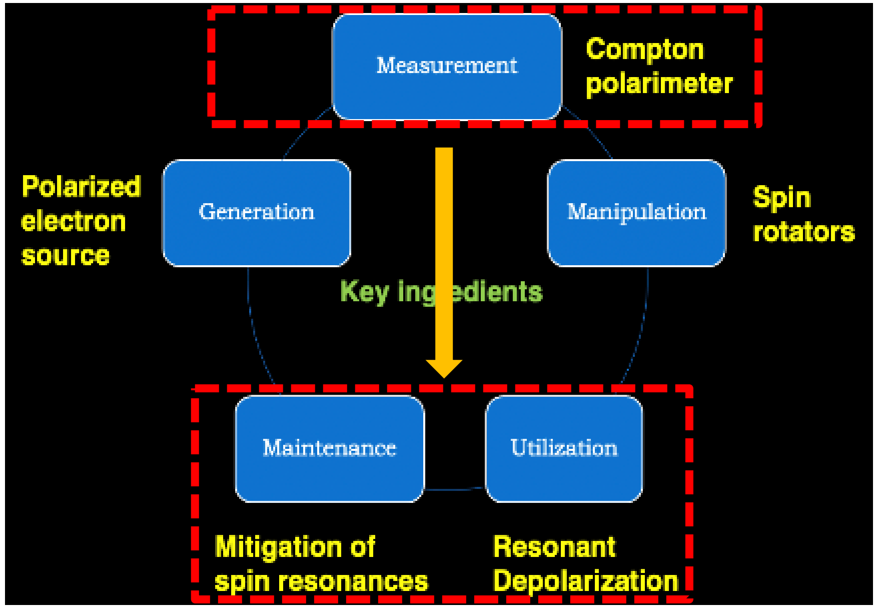
7-axis robot for assembling

Status：design completed and construction started, , commissioning test next year

EDR R&D for options: Polarization

Both the transverse and longitudinal polarization are feasible



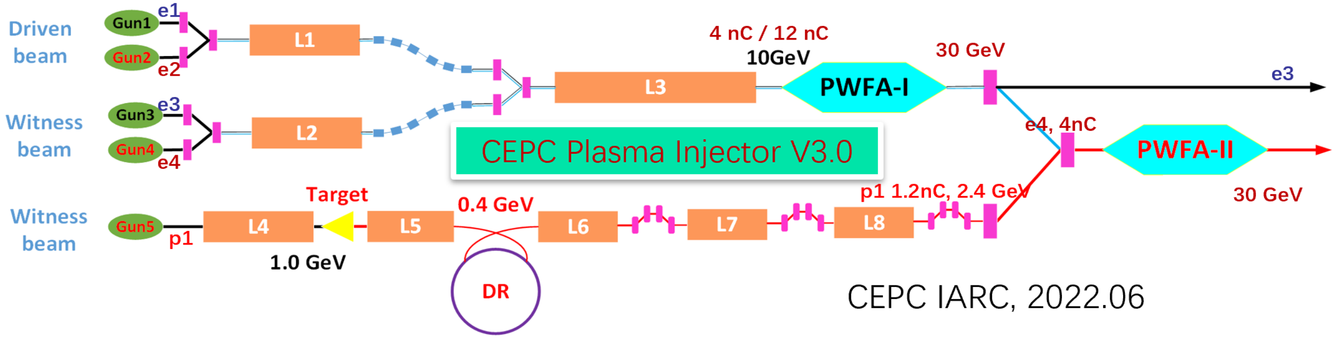


Future Plan

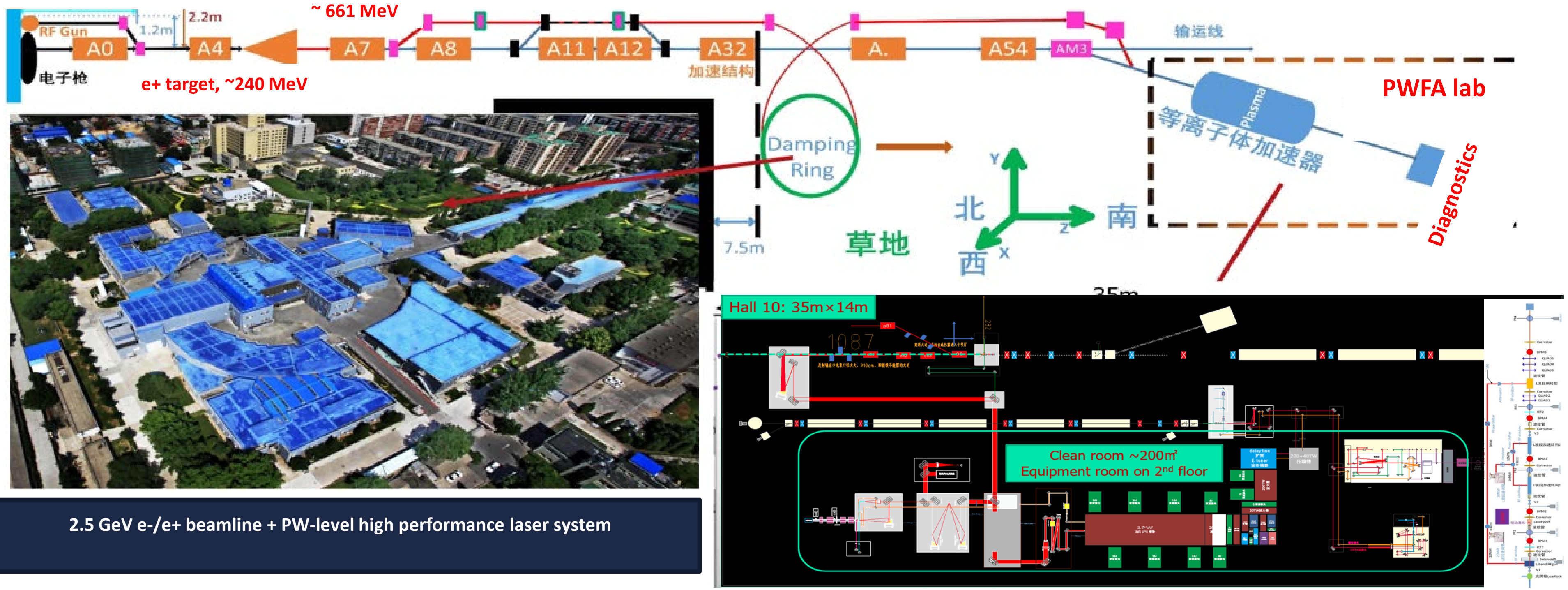
- Implement the lattice design to accommodate polarized beams: spin rotator, wiggler, Compton polarimeters, dumping ring and booster design, etc.
- R&D of equipment: Compton polarimeter, polarized electron sources, spin rotator, etc.
- Simulate the process and effects of errors
- Carry out experiments at BEPCII & HEPS booster

R&D for Future: Plasma accelerator as the CEPC Injector

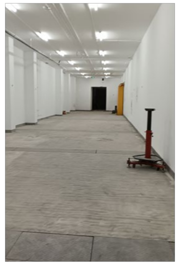
- Conceptual design based on simulation
- For experimental proof and prototyping, a test facility based on the BEPCII LINAC is under construction:
  - Cascading, positron acceleration,…
  - Technology: electron gun, laser, …



CEPC IARC, 2022.06

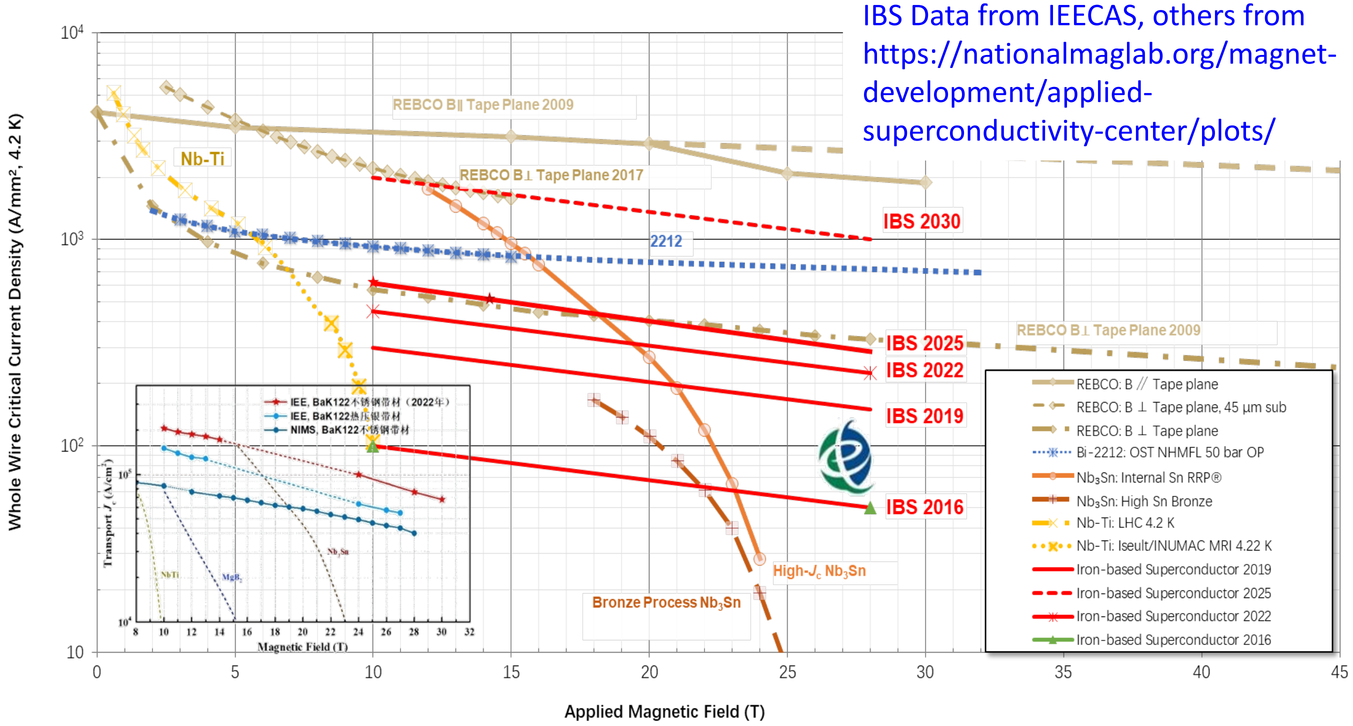


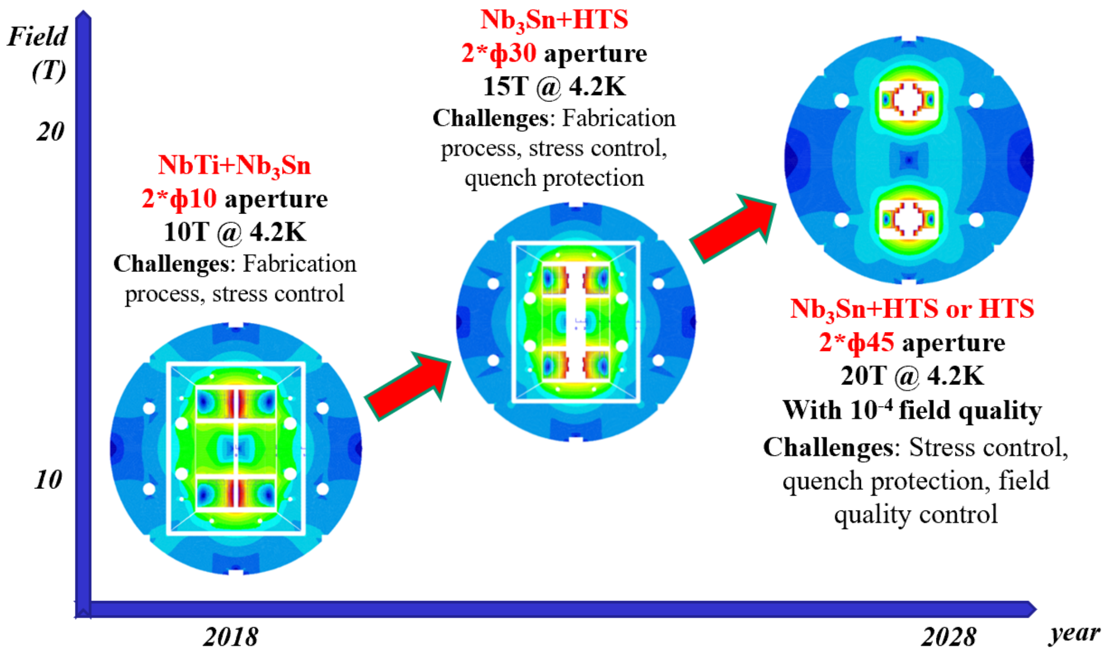
2.5 GeV e-/e+ beamline + PW-level high performance laser system



R&D for Future: Iron-Based HTS Magnet

IBS Data from IEECAS, others from https://nationalmaglab.org/magnet-development/applied-superconductivity-center/plots/





Why:

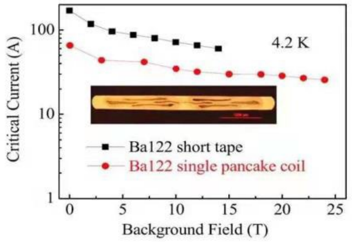
- “Metal”, isotropic, …
- Cheap: material($Ba_{0.6}K_{0.4}Fe_2As_2$) and production(PIT, steel tube)

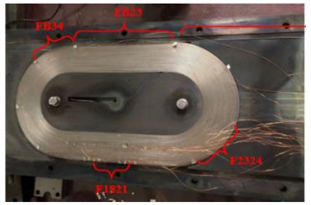
Status

- Cable length >1000m with good Jc
- Small-scale cable production techniques understood
- Test coil successful

Plan

- Continue to improve Jc by × 2-3
- Mid-scale cable production
- Test magnet



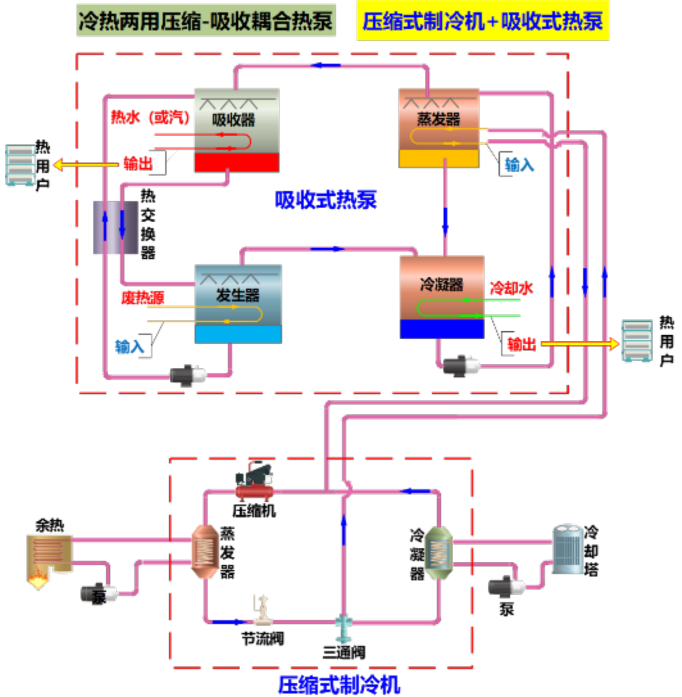


- First short coil with 40%Jc@24T
- First long coil with 80%Jc@10T

Efforts Towards a Green Accelerator

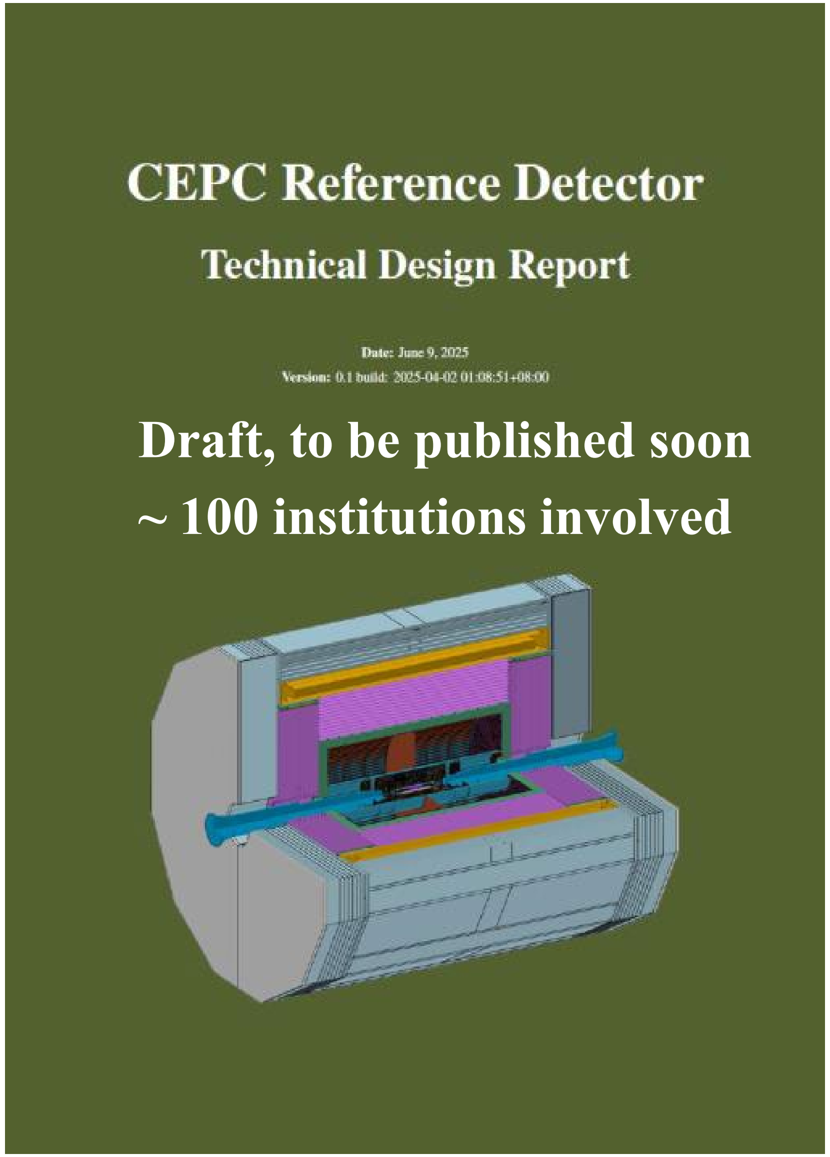
- Construct the underground tunnel in granite: minimum use of concrete and steel, re-use of granite, …
- Experience at HEPS
  - Solar panel: 10 MW ➔ 10% saving
  - Permanent magnet: 5.6 GWh saving/yr
  - Hot water(13 MW@42^{o}C) for heating
- R&D for CEPC
  - High eff. Klystron, energy recovery Klystron, Solid State Transformer, permanent magnet, …
  - Design and R&D of a "cooling-compressor + heating-pump system" to recover hot water in winter and cooling water in summer for use at HEPS
  - Continue to investigate power generator using low-T hot water

Solar panel on the roof of HEPS

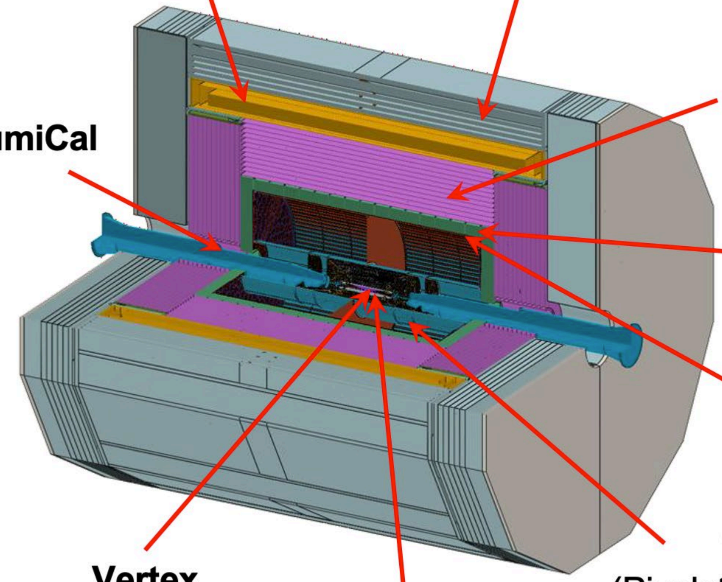


CEPC Detector： Reference Detector TDR

- International collaboration may only be established after the CEPC project is approved by the Chinese government
- For the approval, a design and budget is needed
- Solution: A reference TDR to demonstrate a working design, the feasibility, technologies, budget, etc.
  - CEPC international advisory committee suggested and approved this plan
- An international review of the Ref-TDR held in April 14-16
- TDR will be released in the mid of this year, after being reviewed by the International Detector Review Committee

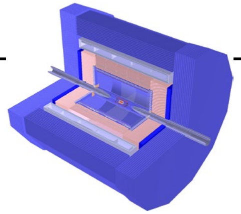
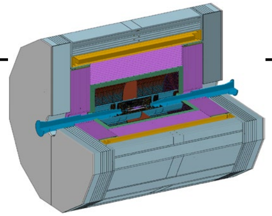


Reference Detector: Concept



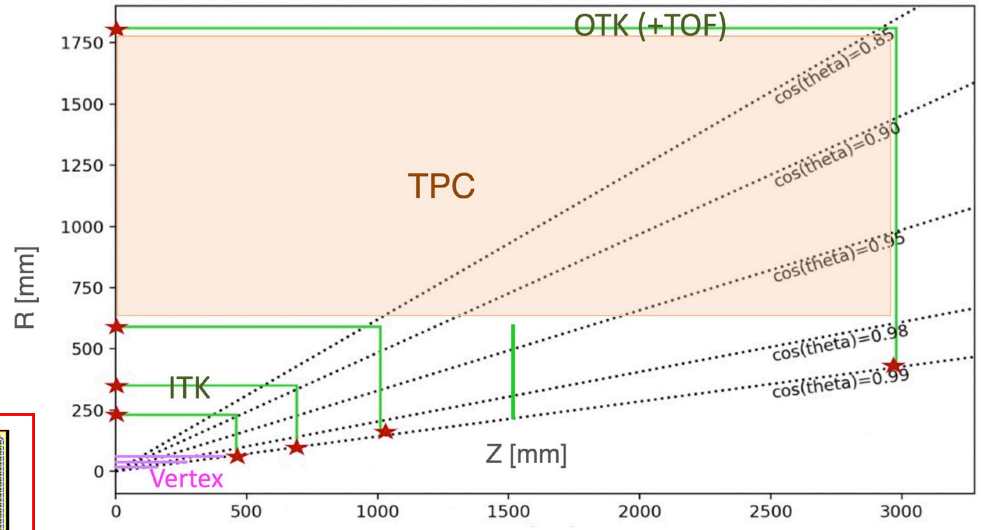
- **Silicon tracker+TPC:** precision tracking and PID
  - **Inner tracker**: three barrel layers and 2×4 endcap layers of MAPS HV-CMOS pixel sensors using 55nm tech.
  - **TPC for PID and tracking:** Pixelated readout ($500\times500\mu m^2$) of Micromegas for good tracking and PID
  - **Outer tracker for PID and tracking:** one barrel layer and two endcap disks based on AC-LGAD to measure timing and position simultaneously
- **PFA-oriented ECAL:** 18 layers of BGO crystal bars($1.5\times1.5\times40$ cm^3), arranged in the x-y direction alternatively, in perpendicular to the incident particle, to achieve fine 3D granularity, and good position and energy resolution
- **PFA-oriented HCAL:** 48 layers of glass scintillator tiles(4×4 cm^2) interspersed with steel plates for good 3D granularity and resolution

from CDR to Ref-detector TDR

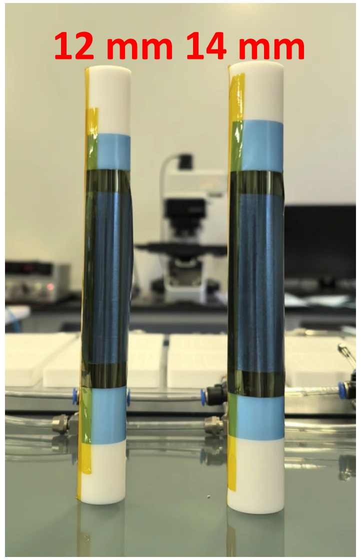
	CDR 	RefDet-TDR 
VTX	Inner radius of **16 mm**	Inner radius of **11 mm**
	Material Budget: 0.15%*6+0.14%(beampipe)= **1.05% X0**	Material Budget: 0.06%*4(inner)+0.165%*2(outer)+0.2%(beampipe)= **0.77% X0**
Gaseous Tracker	TPC with **1 mm* 6 mm** readout	TPC with **0.5 mm* 0.5 mm** readout **dN/dx resolution 3%**
ToF & Outer tracker	**-**	AC-LGAD, with **50 ps** per MIP, 10 um
ECAL	Si-W-ECAL: **17%**/√E ⊕ 1%	Crystal Bar-ECAL: **1.3%**/√E ⊕ 0.7%
HCAL	RPC-Iron: **60%**/√E ⊕ 2%	Glass-Steel: **30%**/√E ⊕ 6.5%

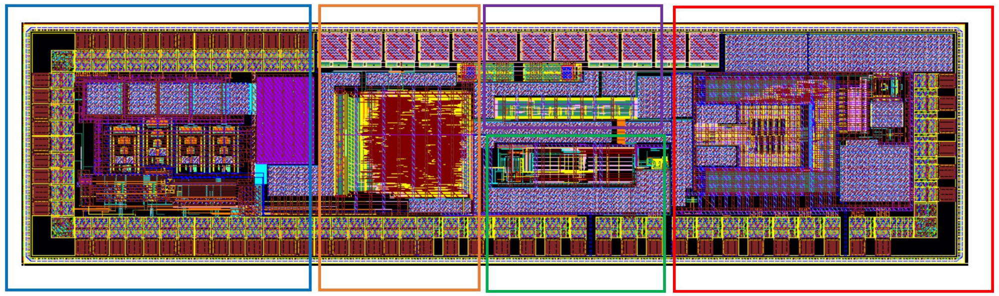
Vertex and Silicon Tracker

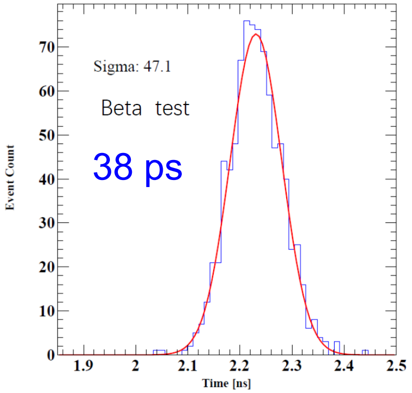
- Vertex: MAPS silicon sensors bend to a tube, for σ of 5 μm
- 20 m^2 Inner tracker using HV-CMOS pixel for σ <10 μm
- 80 m^2 outer tracker using AC-LGAD strips for σ<10 μm, σ_t<50 ps
- TPC for tracking and PID for σ<150 um, dN/dx ~ 3%

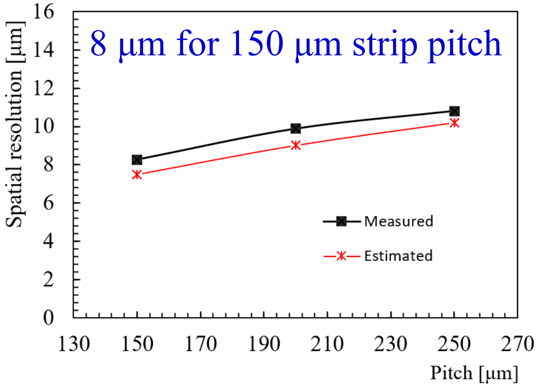


A dummy wafer, thinned to 40μm, can be curved to 12mm

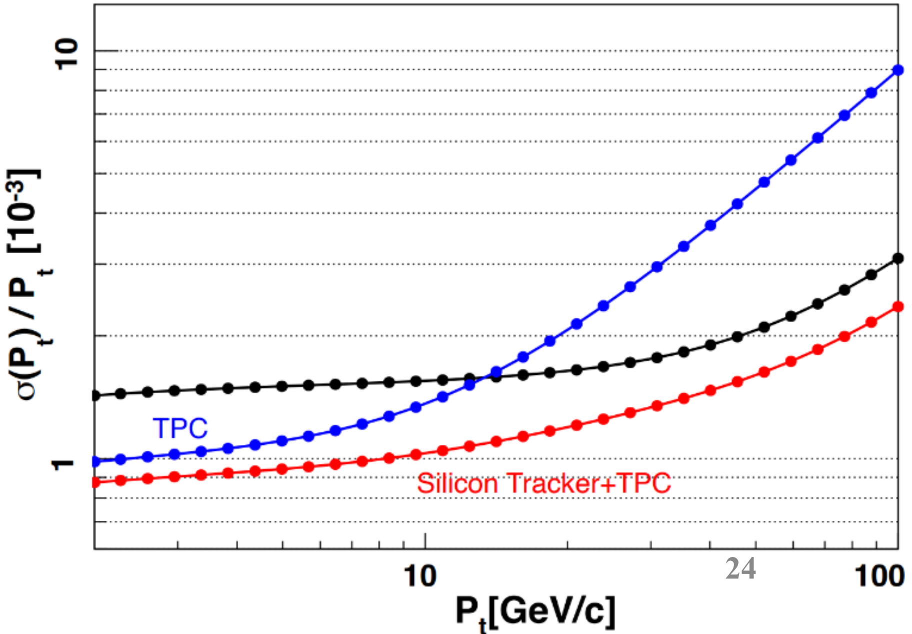






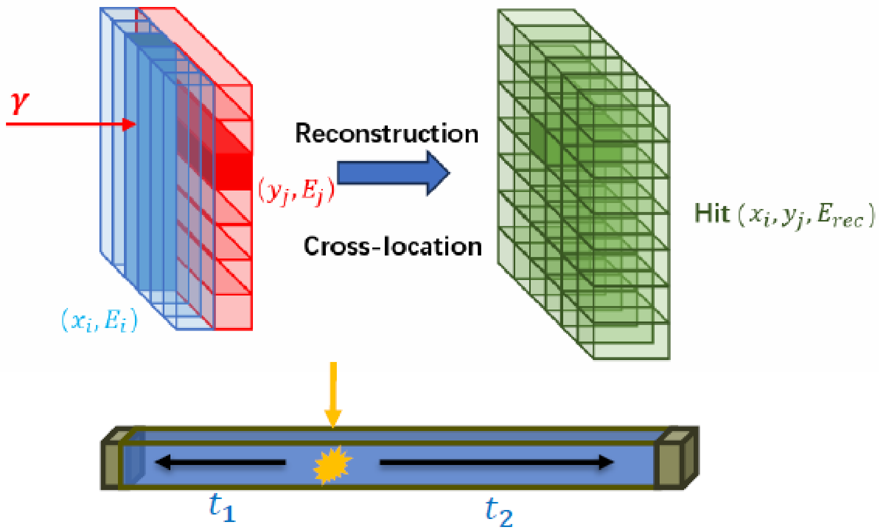


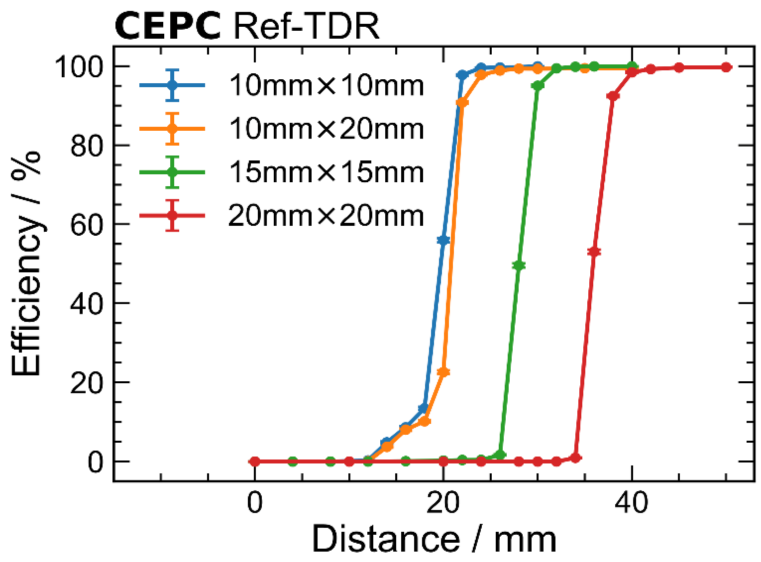
AC-LGAD test Performance

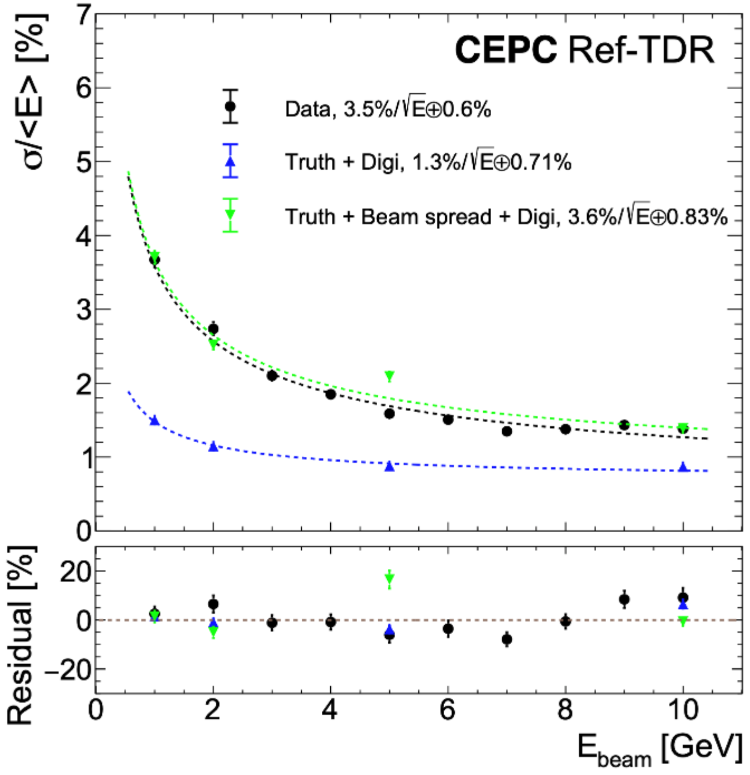


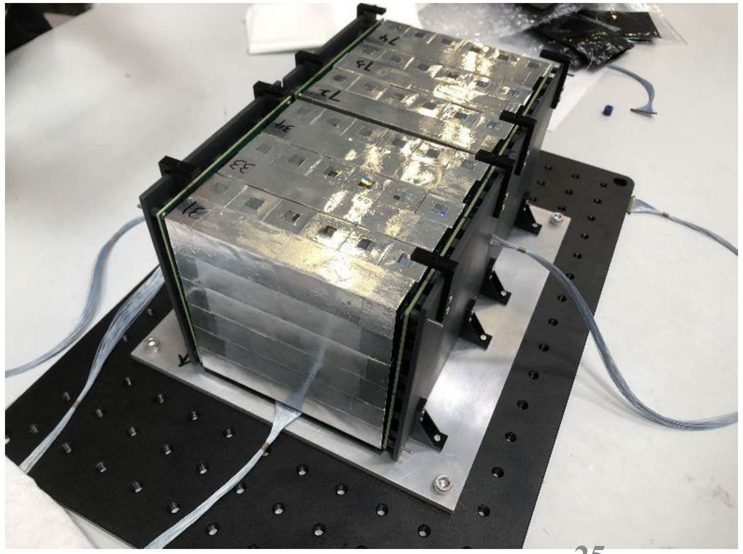
Electromagnetic Calorimeter

- Crystal bars are arranged in x-y direction alternatively, read by a 3×3 mm^2 SiPM at each end
- Good 3D shower reconstructed for PFA
- Shower separation ~ 2× crystal cross section
- Beam test at CERN with BGO bars: 1cm^2 cross section, 12cm long, Energy resolution: 1.3%/√E⊕0.7%





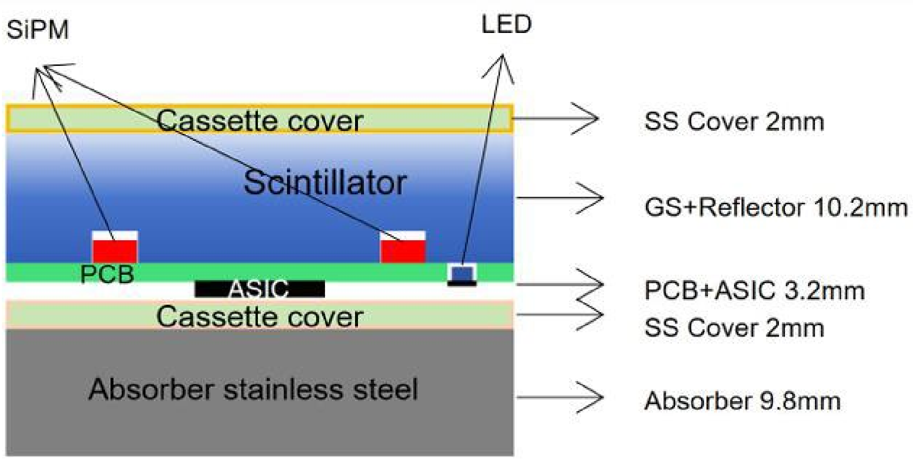




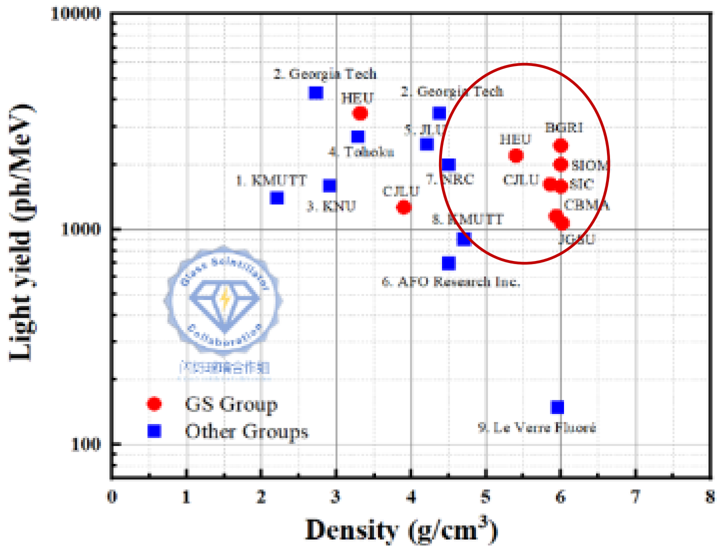
Crystal cross section of **15×15mm^2** selected

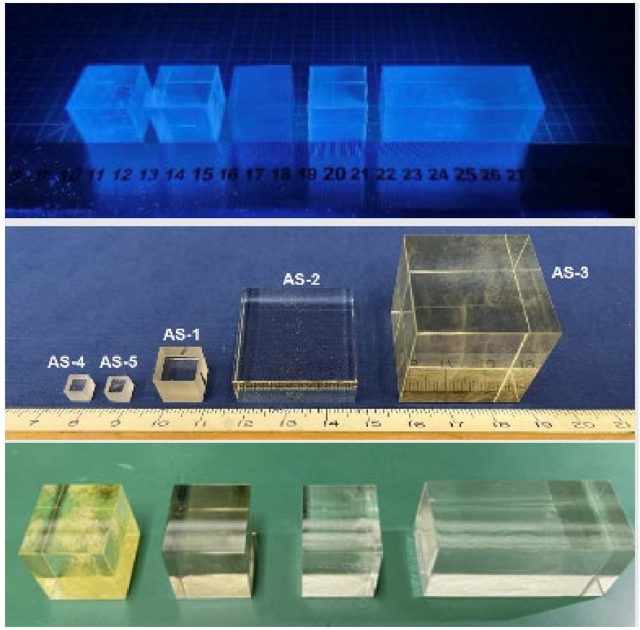
Hadron Calorimeter

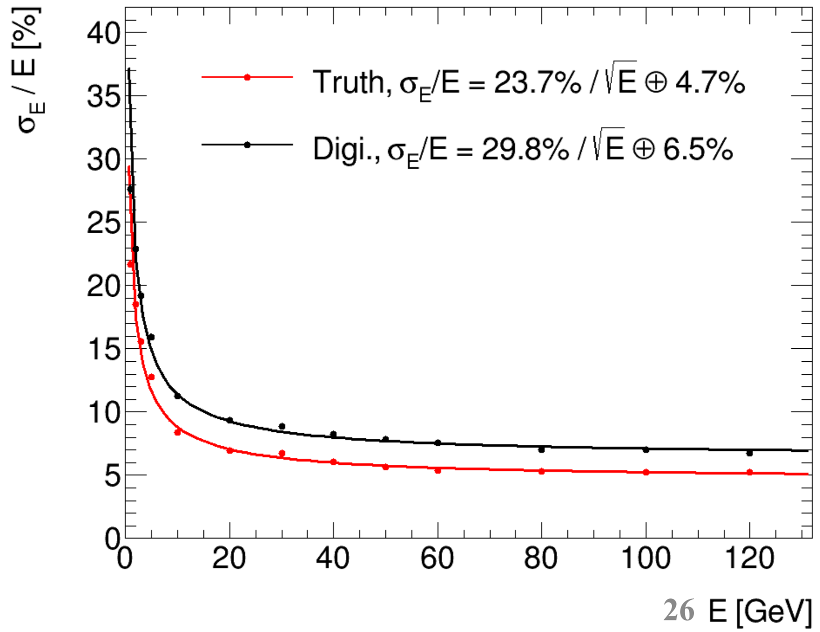
- High density glass scintillator for HCAL: much higher sampling ratio(~30%) and good energy resolution ~30%/√E
- Small size of glass tile: good for PFA
- Glass R&D for high density and high light yield:
  - ➢ Novel Gadolinium Fluoro-Oxide glass
  - ➢ Density: 6g/cm^3
  - ➢ Size: 40*40*10 mm^3
  - ➢ Light yield: ~1500 ph/MeV with a 3×3 mm^2 SiPM
  - ➢ Decay time: 600 ns



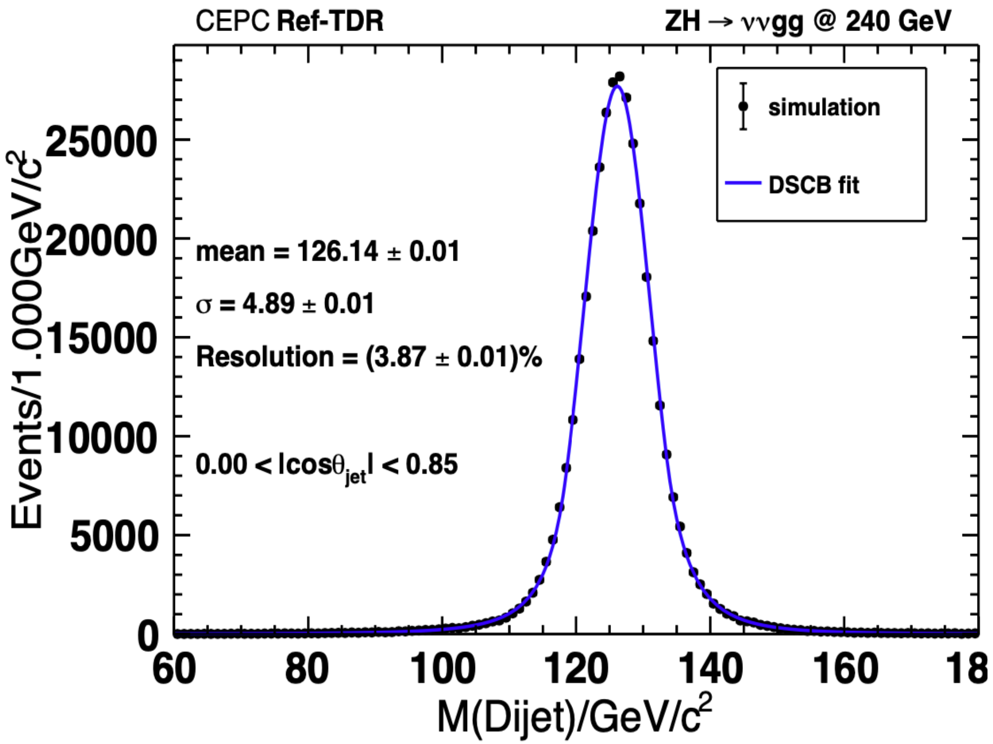
Light yield of Glass scintillators

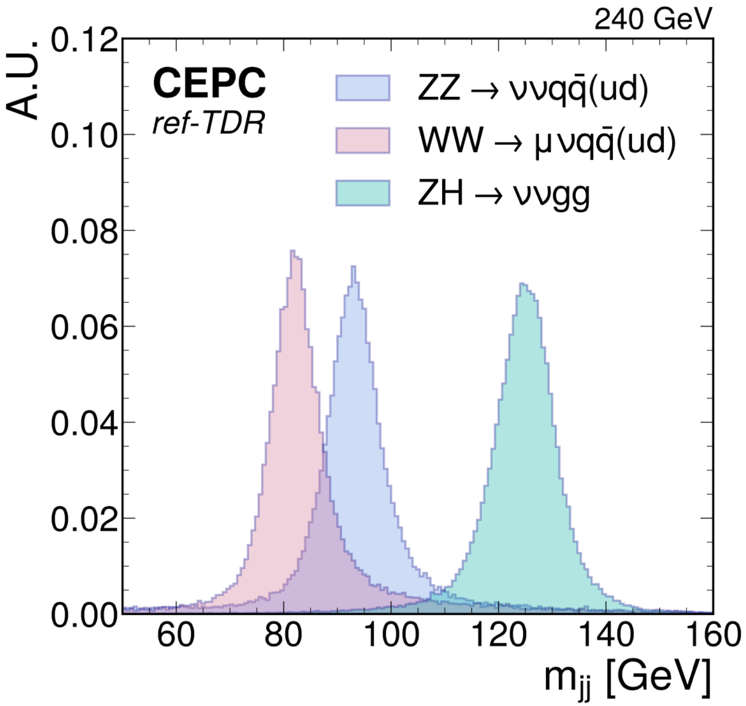


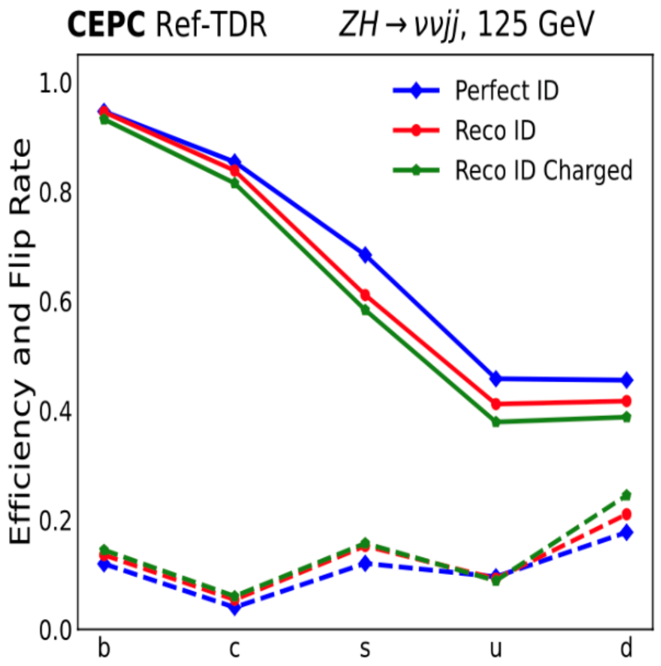




Jet Performance

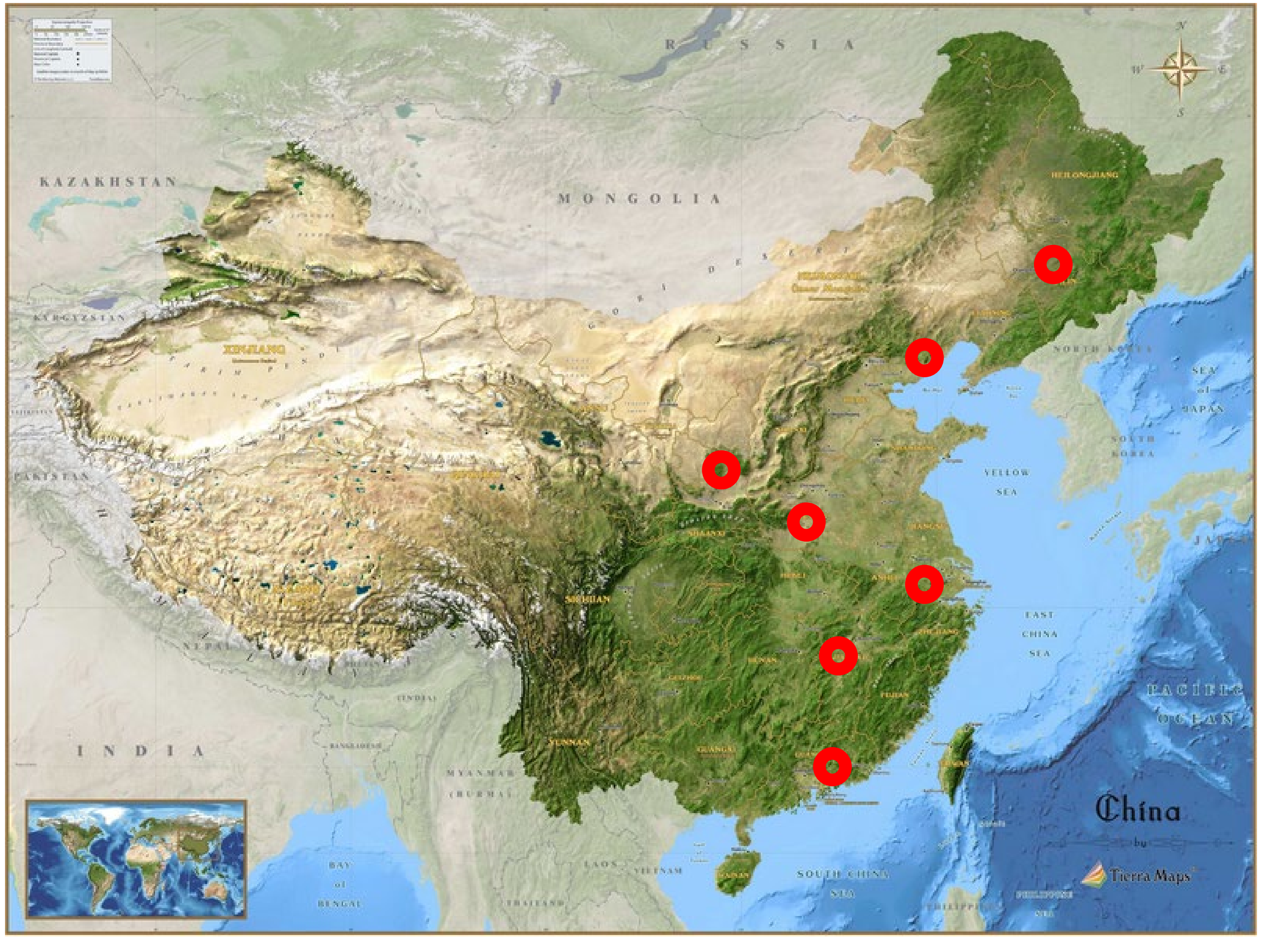






- Dijet Higgs well reconstructed, BMR in barrel reaches **3.87%,** design goal achieved (<4%)
- For the same BMR, crystal ECAL has a much better energy resolution
- Glass HCAL has a very good energy resolution, may be suitable for ECAL if light yield further improved ➔ A full absorption ECAL+HCAL

Site Selection

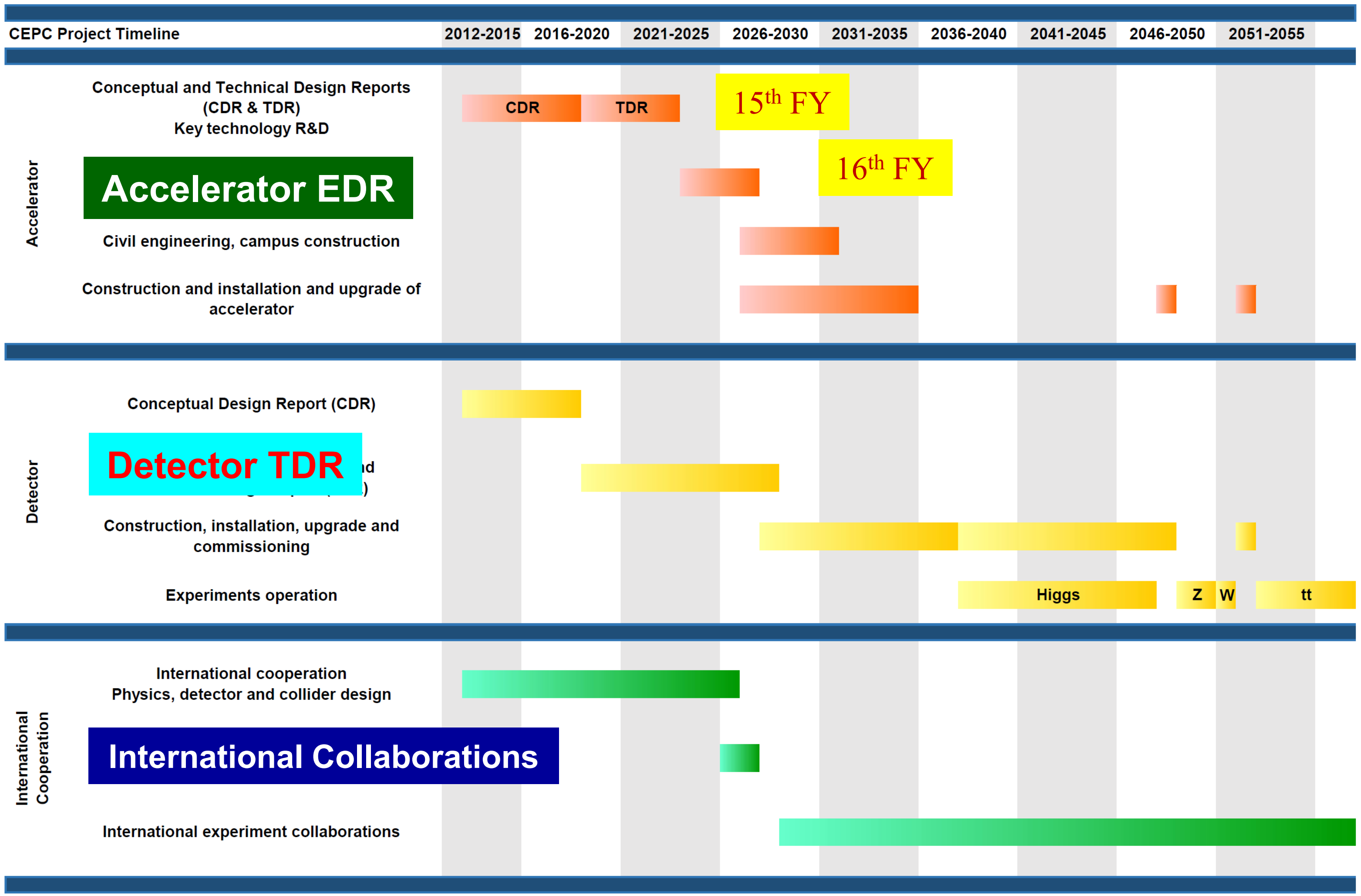


- All sites have been investigated: good geology, mostly granite
- Good living conditions, and local support

- Site selection will compare geology, electricity supply, transportation, environment for foreigners, local support & economy,…
- Final decision will depend on the negotiation between the central and local governments

CEPC Planning and Schedule

TDR (2023), EDR(2027), start of construction (~2027)



- CEPC plans to submit the proposal to the central government(NDRC) within the “15th five year plan”
- For this purpose, CAS organized studies and reviews
- CEPC was ranked by CAS as the No. 1 for HEP & NP, and No.2 for Basic Science
- We are waiting for the 2nd review by CAS later this year
- Waiting for the “call for proposals” by NDRC by the end of this year

NDRC: National Development and Reform commission

International Collaboration

- CEPC will be an international project, following the HEP tradition
- Internationalization will distinguish CEPC from other proposals to NDRC, enhance the successful chance
- IHEP successfully organized large projects such as BESIII, Daya Bay and JUNO with ~50% non-Chinese members and international in-kind contributions of ~5%, ~30%, and ~15% respectively
  - BESIII has >600 members from 84 institutions in 17 countries and regions
  - Daya Bay had >250 members from 40 institutions in 6 countries and regions
  - JUNO has >700 members from 72 institutions in 17 countries and regions
- Based on the experience from above experiments, our plan for CEPC is the following:
  - Goal: international contributions at the level of ~10-30%
  - Although the management system is yet to be settled, most likely IHEP will be the host lab
  - A concept of the management structure has been endorsed by IAC, further discussion needed
  - Once CEPC is approved in China(~ CD0 in DOE), international collaboration can be formally started
    - Discussion with partners about the management
    - Form various committees
    - Call for detector proposals, and select proposals
    - Form international collaborations, deliver TDRs, sign MoUs, build detectors,….
  - Civil construction and most of the accelerator construction can start after the CD3 approval by NDRC, internationalized construction of detectors and other accelerator equipment may come a few years later

Summary

- CEPC addresses most pressing & critical science problems in particle physics, provides early Higgs(W,Z) factories to the world HEP community
- Accelerator design and technology R&D are reaching maturity, TDR completed, ready for construction in ~2 years
- Reference detector TDR is under preparation now, to be completed by mid of this year for the proposal of the 15th 5-year plan
- Call for collaborations and proposals once CEPC is (preliminary) approved (~CD0)
- We will work with the community to maximize the internationalization of CEPC, and support other projects worldwide

Backup

Approving process of NDRC projects

• Pre-proposals organized and reviewed by ministries (e.g. CAS), and submitted to NDRC	1-10 years	Budget estimate	
• Proposals reviewed and selected by NDRC	~1 year	Budget proposal	CD0
• Review of the feasibility study by CAS	1-5 year	Budget & technical review	CD1+2
• Review of the Preliminary design by CAS & Budget review by NDRC	1-5 year	Technical design & Final budget	CD3+4

NDRC organize proposals every 5 years in "5-year plan"