Institute of High Energy Physics
Chinese Academy of Sciences

# CEPC Accelerator TDR Review Processes and Some Experiences


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**IHEP**


**On behalf of the CEPC-SppC accelerator team**

**May 21, 2024, IHEP**

# CEPC Accelerator TDR Review and Cost Review Scopes and Processes



1) CEPC accelerator TDR review contains complete and consistent accelerator complex TDR designs (reaching the design goals, such as energies, luminosities…) and full spectrum TDR technology demonstration (with prototypes and measurement results reaching the design goals)
2) CEPC accelerator TDR cost review contains all accelerator systems and subsystems
3) CEPC civil engineering cost review was done domestically with serval site candidates, and report to TDR cost review committee
4) Each review has its own review report (TDR review and cost review are two different committees)
5) IAC will receive TDR reports from TDR review and TDR cost review committees, and IAC will provide a final top level review comments and recommendations agreeing that CEPC accelerator TDR be completed, could be released and ready to enter EDR phase

# CEPC Accelerator TDR Review and Cost Review Preparation Guidelines-1



1) Well define CEPC accelerator TDR Report structure (chapters) and contains, according to main key system, its subsystem, global system, etc. to facilitate whole accelerator cost evaluation, including system cost, subsystem cost, global system cost and total machine cost, etc.
2) CEPC accelerator TDR system and subsystem authors are responsible for the costing of corresponding systems and subsystems
3) The contains of the TDR report and costing should reflect the newest status of the TDR design and hardware R&D, including text, figures and pictures, references
4) The total number of chapters is 12 and 11 appendixes, the total page number around 1000, plus more than 1000 author name list (including international ones) . The relevant review committee member lists are included in TDR.
5) The TDR is firstly published in arXiv and then on RDTM

# CEPC Accelerator TDR Review and Cost Review Preparation Guidelines-2



1) Since CEPC accelerator TDR review and cost review have different focuses, TDR review materials mainly focus on system and subsystem design and prototype R&D with measurement results, etc.
2) And cost review materials are mainly focusing on system and subsystem costs based on the design parameters, quantities, manufactured prototype prices, relevant project costs such as HEPS, market materials prices variations and average prices in the last five years used in the TDR costing
3) The cost estimation should take some key factors into consideration:
   a) large amount of quantities of components;
   b) corresponding technology development aiming to reduce the price in EDR phase before mass production and construction
   c) having a TDR cost target goal as a hard boundary constraints
   d) Automatic mass production methods to be developed during EDR phase should be considered during the TDR costing process

# CEPC Accelerator TDR Review and Cost Review Work Quality Control-1



1) The responsible authors for systems and subsystems be well chosen
2) The TDR Report documentation and ppt presentation templates should be well prepared and distributed to all the authors and presenters.
3) The length (page numbers) of the each chapter and sections should be assigned to each author to guarantee the most important details and information be included in the TDR document, and total page number of 1000 pages is acceptable for this goal.
4) Once the TDR writing starts, each week a half day meeting is needed to scan each system and subsystem contains, and accelerator conveners should be presented to guided and to guarantee the completeness and the quality of the contains (text and figures and photos) . Many rounds are needed.
5) The costing materials should be presented in CEPC day to scan several rounds of all the systems and subsystems, in order that the same standard and assumptions applies to all systems and subsystem during costing

# CEPC Accelerator TDR Review and Cost Review Work Quality Control-2



1) The assignment of a dedicated TDR editor is necessary
2) The time starting from TDR writing up of each chapter till the TDR review is at least six months, and to the cost review about 9 months.
3) Before final TDR release, there should be a process of IAC permission process.
4) From the final TDR and TDR cost review to the TDR formal delivery it takes two months.
5) Taking all this time duration taking into account, the starting date of the writing up of TDR should be well calculated (about one year)

# CEPC Accelerator System Parameters in TDR

## 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 | $\sigma_E$ | | $1.5\times10^{-3}$ |
| Emittance | $\varepsilon_r$ | nm | 6.5 |

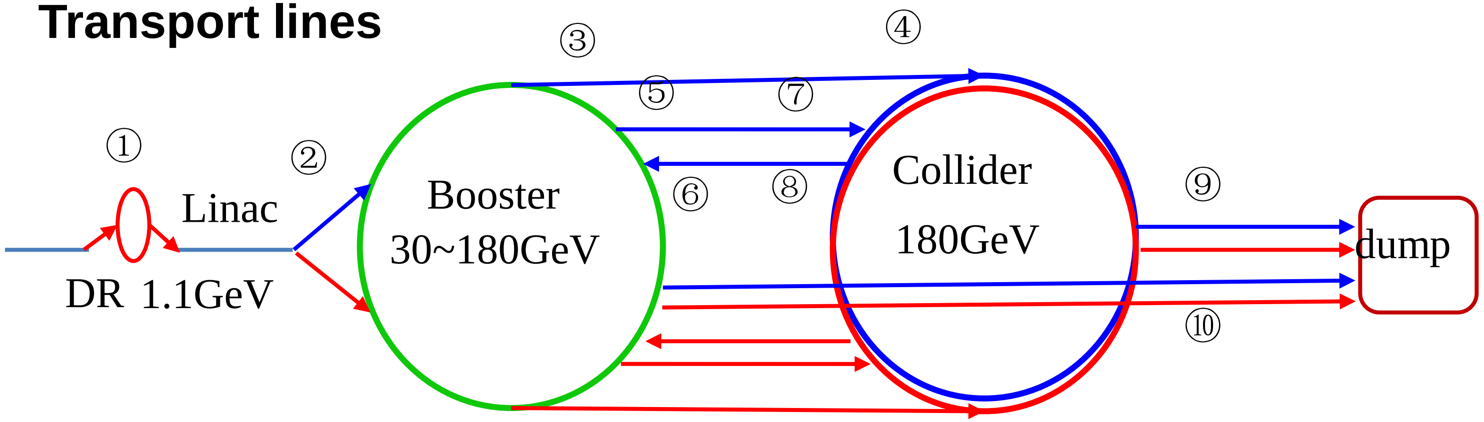
## Booster

| | | *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 $\sigma_x/\sigma_y$ (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 $\xi_x/\xi_y$** | 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** |

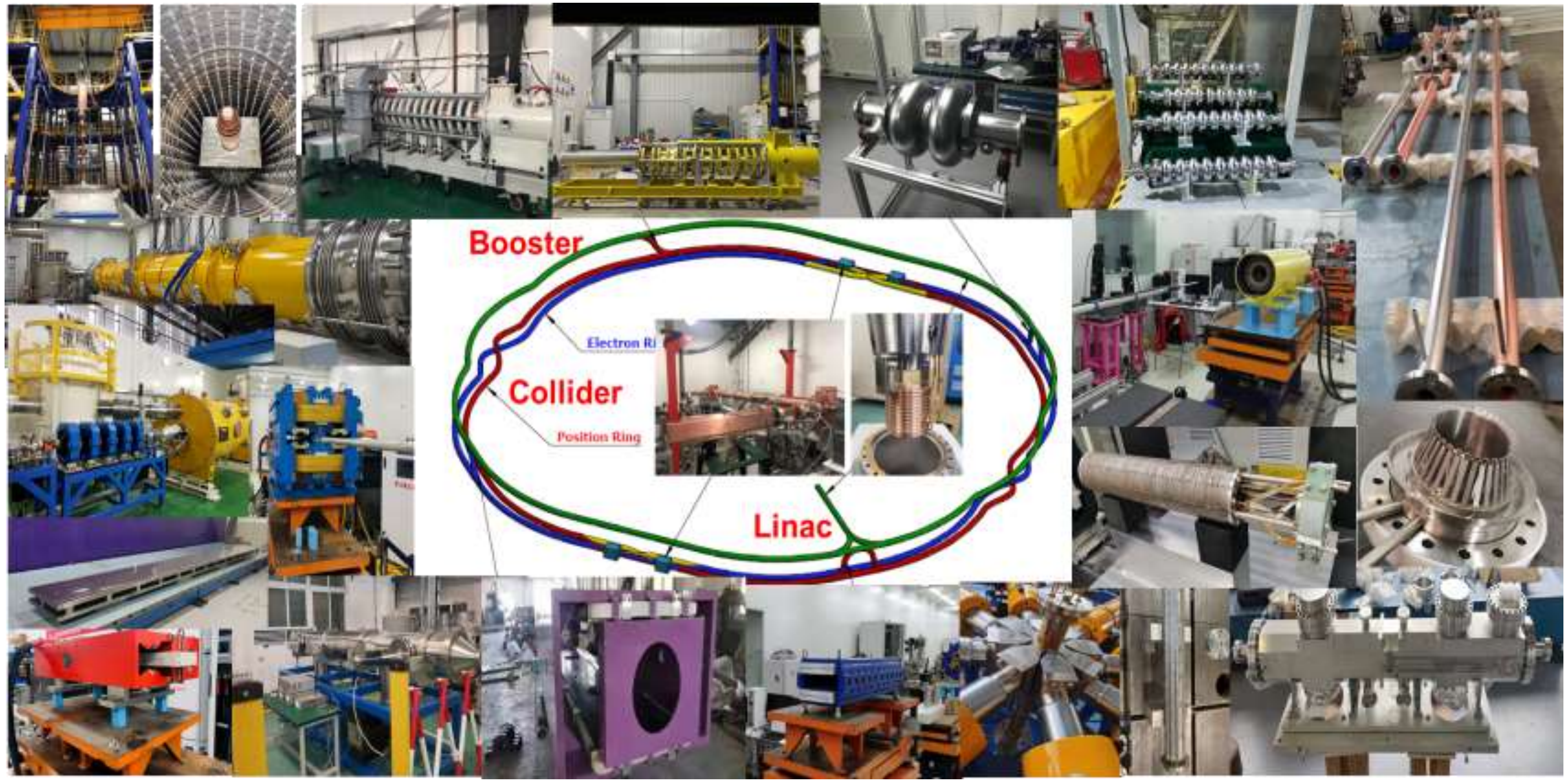
## Transport lines




CEPC Technical Design Report (TDR) includes:
1) CEPC Accelerator TDR
2) CEPC Detector TDRrd (rd=reference design)
will be released by June 2025

# CEPC Key Technology R&D Status in TDR

Specification Met ✓ Prototype Manufactured ✓




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

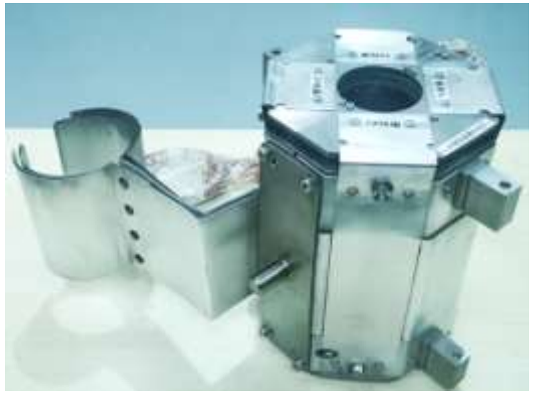
Key technology R&D in TDR spans all component lists in CEPC CDR

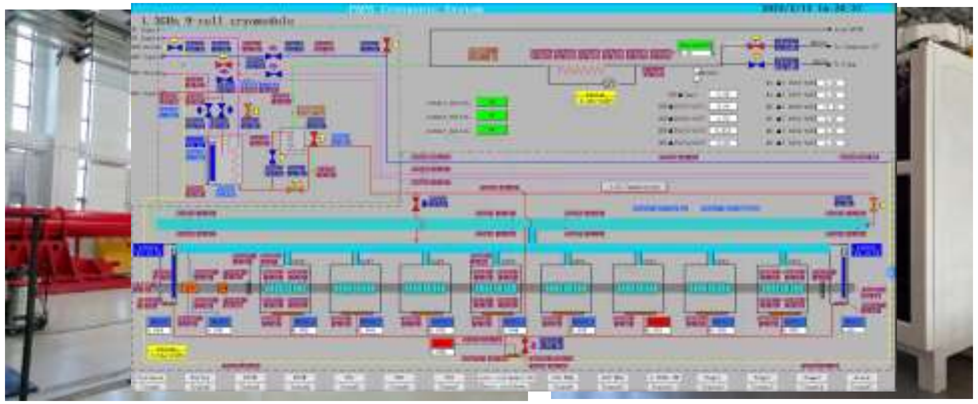
# CEPC Booster 1.3 GHz 8 x 9-cell High Q Cryomodule

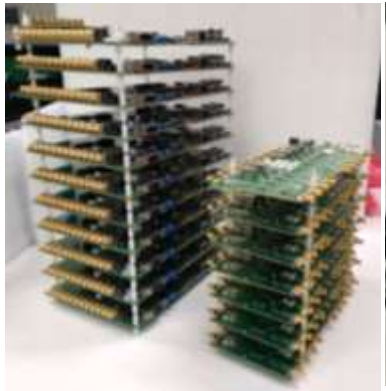
CEPC booster 1.3 GHz SRF R&D and industrialization in synergy with CW FEL projects.

| 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 | $3.0\times10^{10}$ @ 21.8 MV/m | $2.7\times10^{10}$ @ 16 MV/m | $2.7\times10^{10}$ @ 20.8 MV/m |
| Average $Q_0$ @ 21.8 MV/m | $3.4\times10^{10}$ | | | |



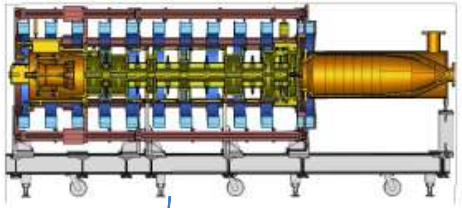



# CEPC High Efficiency High Power Klystron Development and RF Power Distribution System

CEPC klystron R&D

Klystron No. 1
Efficiency 65%
(2020)

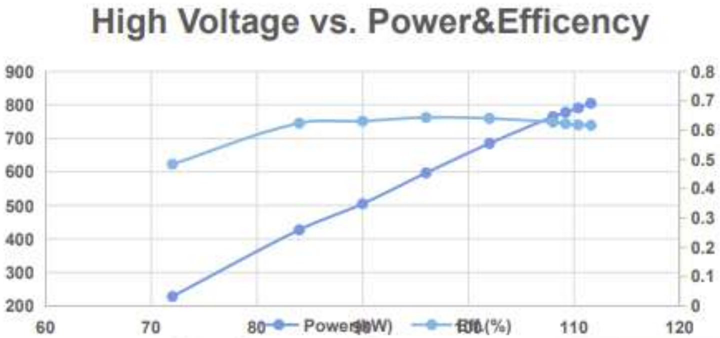
Klystron No. 2
Efficiency 77%
(2021)

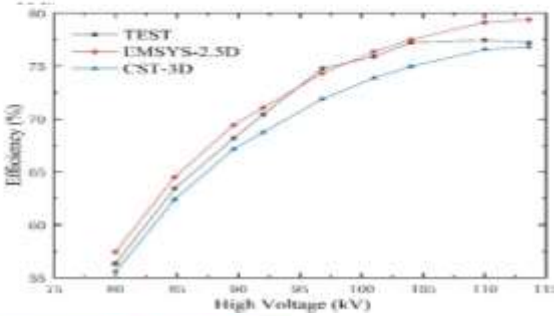


Klystron No. 3 （MBK
Efficiency 80.5%
(under fabrication)

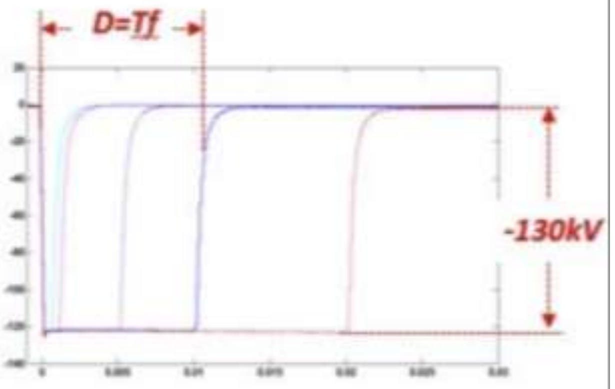
Power Supply Modulator

Pulsed RF Mode (30% duty factor, 60ms/5Hz) 77.2%@849kW pulsed in 2024

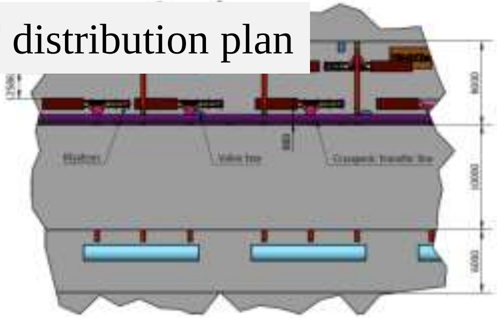


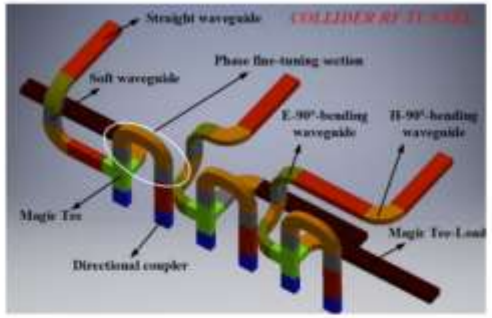




To be tested in 2024




RF distribution plan






- Three prototypes of the **650MHz 800KW CW** klystrons are developed. The efficiency reaches 70%
- PSM is developed with the industrial collaboration
- RF tunnel distribution was planed

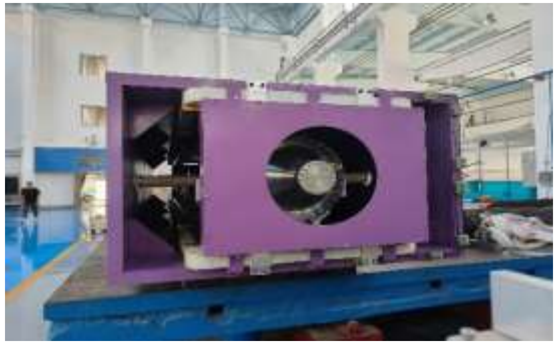
# R&D: Other Prototypes



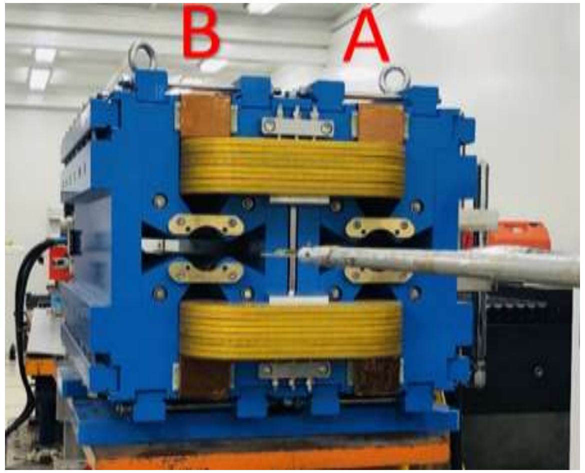
**Collider dipole magnet**

**booster dipole magnet**


**EM deflector**



**Collider quad magnet**



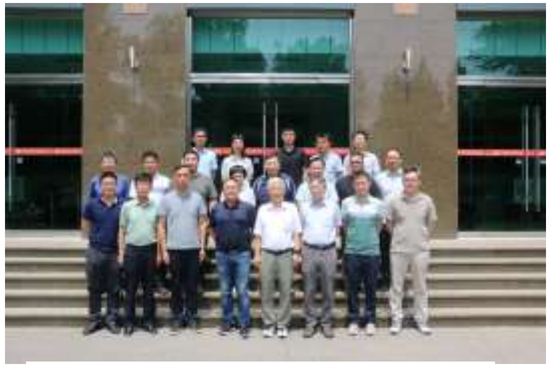

Vacuum pipes and RF shielding bellows

**Lambertson magnets**

# CEPC Accelerator International TDR Review and Cost Review June 12-16, and Sept. 11-15, 2023, in HKUST-IAS, Hong Kong

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

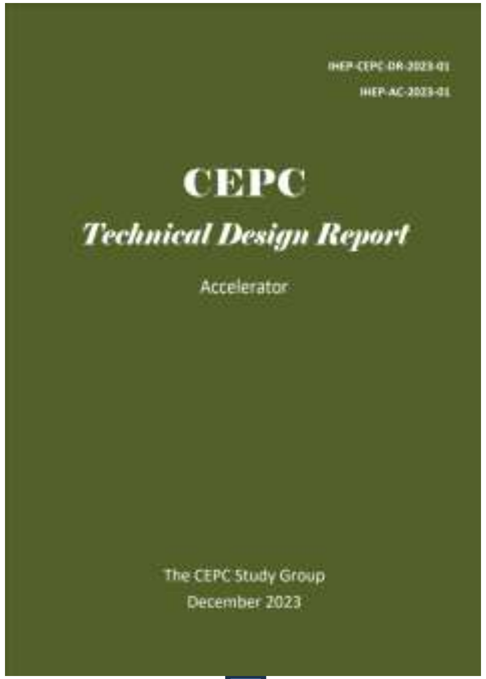
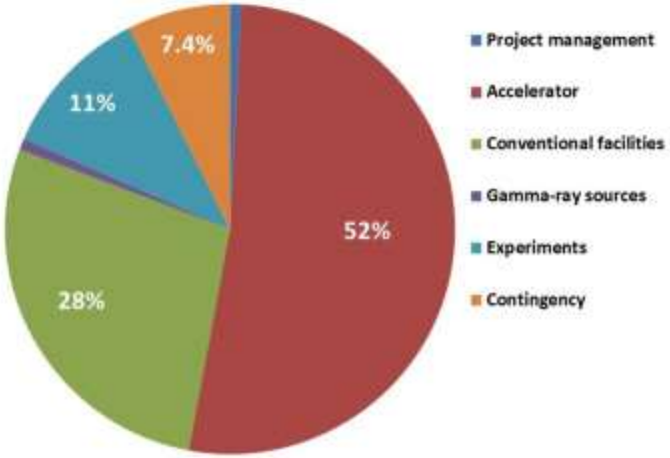



**Table 12.1.2:** CEPC project cost breakdown, (Unit: 100,000,000 yuan)

| 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**

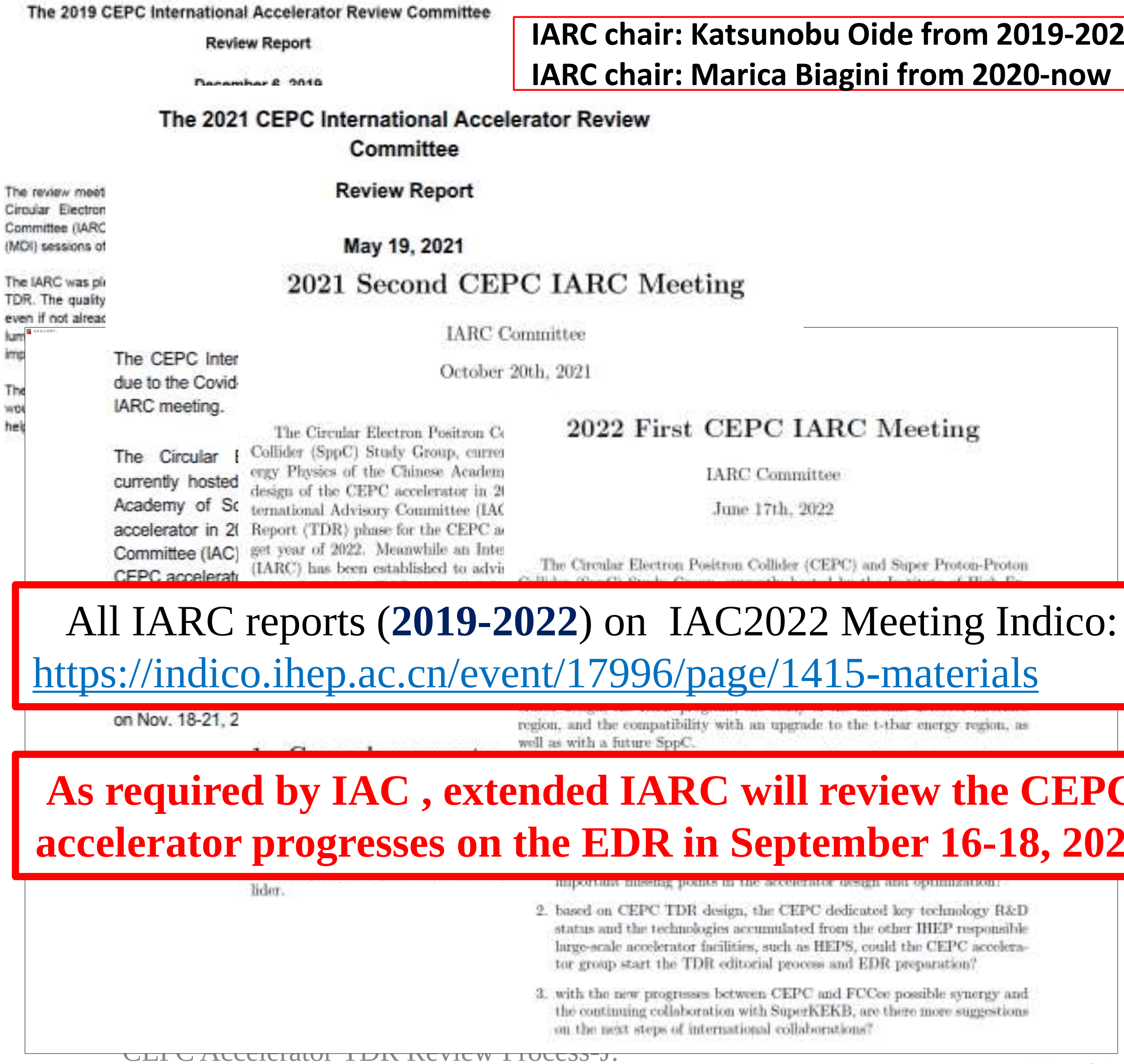
**CEPC accelerator TDR has been completed and formally released on December 25, 2023**

**CEPC accelerator TDR link:** (arXiv: 2312.14363)

**CEPC accelerator TDR releasing news:**
http://english.ihep.cas.cn/nw/han/y23/202312/t20231229_654555.html

# CEPC Accelerator IARC Meetings in TDR and EDR

## International Accelerator Review Committee (IARC) under IAC


The 2019 CEPC International Accelerator Review Committee

Review Report

The 2021 CEPC International Accelerator Review Committee

Review Report

May 19, 2021

2021 Second CEPC IARC Meeting

IARC Committee

October 20th, 2021

2022 First CEPC IARC Meeting

IARC Committee

June 17th, 2022

IARC chair: Katsunobu Oide from 2019-2020
IARC chair: Marica Biagini from 2020-now


Nov. 2019: https://indico.ihep.ac.cn/event/9960/
May, 2021: https://indico.ihep.ac.cn/event/14295
October, 2021: https://indico.ihep.ac.cn/event/15177
June, 2022: https://indico.ihep.ac.cn/event/16801/

Jan. 2024: preparation zoom meeting
Sept. 2024: first extended IARC meeting in EDR phase

All IARC reports (**2019-2022**) on IAC2022 Meeting Indico:
https://indico.ihep.ac.cn/event/17996/page/1415-materials

**As required by IAC , extended IARC will review the CEPC accelerator progresses on the EDR in September 16-18, 2024**

After the completion of CEPC CDR in Nov. 2018, since the first CEPC IARC meeting in **2019**, there has been **totally 4 IARC meetings till 2022**, with each meeting a carefully written IARC report, which are very helpful for CEPC accelerator in TDR phase and beyond.

# CEPC Accelerator TDR International Reviews and CEPC IAC Meeting Endorsement



June 12-16, 2023, in HKUST-IAS, Hong Kong

Chaired by Frank Zimmermann

## Phase 1 CEPC TDR Review Report

CEPC TDR Technical Review Committee

15 July 2023

The CEPC Study Group, hosted by the Institute of High Energy Physics (IHEP), has been working on the design and development of a forefront $e^+e^-$ collider as a Higgs factory that can extend to energies corresponding to the Z, WW and the top-quark pairs, with the upgrade potential to a high-energy pp collider. The CEPC represents a "grand plan" proposed, studied, and to be constructed by Chinese scientists in close collaboration with international partners. Since the release of the CEPC Conceptual Design Report in 2018, the CEPC Study Group has devoted significant effort to the design optimisation, the R&D of key technologies and the study of the technical systems of the CEPC.

The CEPC Study Group has produced a draft Technical Design Report (TDR). The International Review Committee, chaired by Dr. Frank Zimmermann (CERN), was asked to conduct a first phase review of this TDR draft. This first phase review shall cover all but the cost and site aspects of the CEPC.

The Phase 1 CEPC TDR Review Committee meeting was held in person at HKUST from 12 to 16 June 2023.

https://indico.ihep.ac.cn/event/19262/timetable/

Sept. 11-15, 2023, in HKUST-IAS, Hong Kong

Chaired by Loinid Rivkin

## CEPC Accelerator TDR Cost Review

The CEPC Accelerator TDR Cost Review committee examined the cost estimate of the TDR of accelerator systems for the first stage of the CEPC project operated as a Higgs factory with synchrotron radiation power up to 30 MW per beam (including all infrastructure that is not easily upgradeable and is already designed to operate up to the ttbar energy and at 50 MW). The cost estimate under review does not include the civil engineering, the detectors at the IPs with their technical services, and the central computing services.

In the opinion of the committee the cost estimate presented is sufficiently complete to form a proper basis for the next iteration that will be done during the EDR stage.

https://indico.ihep.ac.cn/event/19262/timetable/

Oct. 30-31, 2023, in IHEP

Chaired by Brian Foster

## The Ninth Meeting of the CEPC-SppC International Advisory Committee

IAC Committee
M. E. Biagini, Y.-H. Chang, A. Cohen,
M. Davier, M. Demarteau, B. Foster (Chair),
B. Heinemann, K. Jakobs, L. Linssen,
L. Maiani, M.L. Mangano, T. Nakada, S. Stapnes,
G. N. Taylor, A. Yamamoto, H. Zhao

November 14th, 2023

https://indico.ihep.ac.cn/event/20107

The IAC also supports another key conclusion in the TDR Review Report, that the accelerator team is well prepared to enter the EDR phase.

-The IAC also support another conclusion in the TDR Review Report that the accelerator team is well prepared to **enter the EDR phase**

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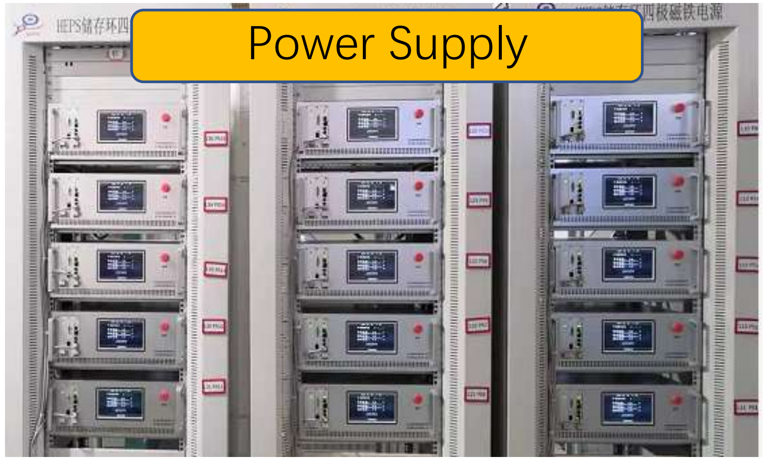
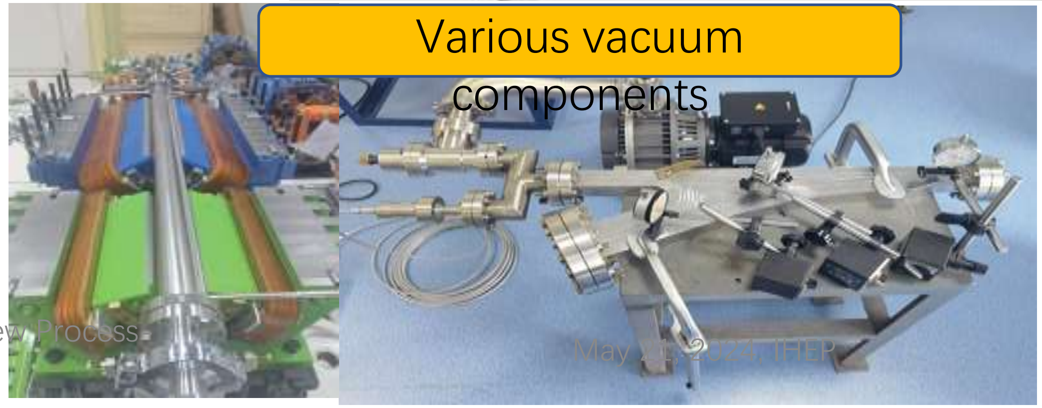
# BEPCII/HEPS mass production and price

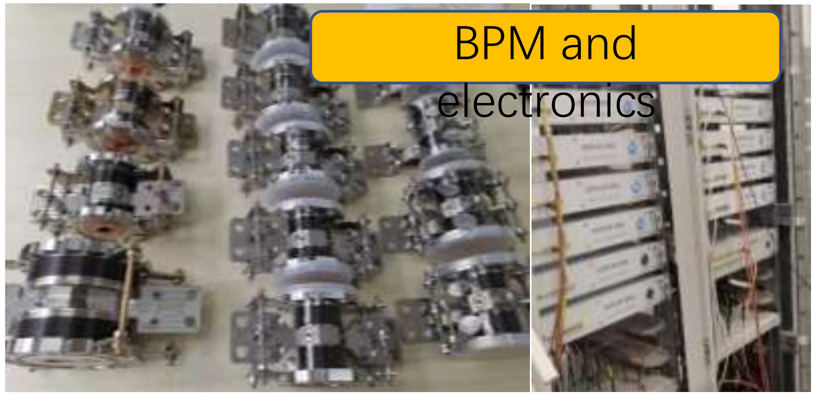
- Many of the CEPC needed key technologies were developed and verified in projects such as BEPCII and HEPS, which was conducted by IHEP. These technologies include conventional magnets, vacuum system, magnet power supply, mechanical system, alignment, etc.
- The relevant system cost for CEPC can be accordingly evaluated precisely.





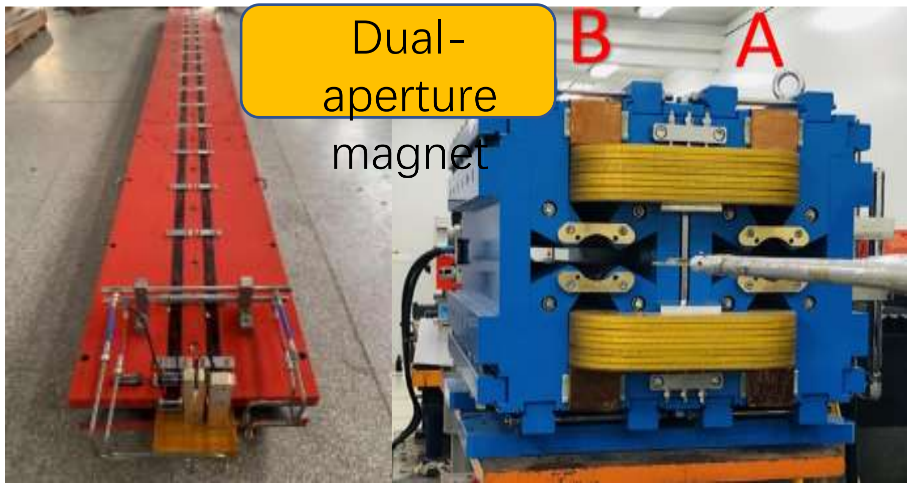


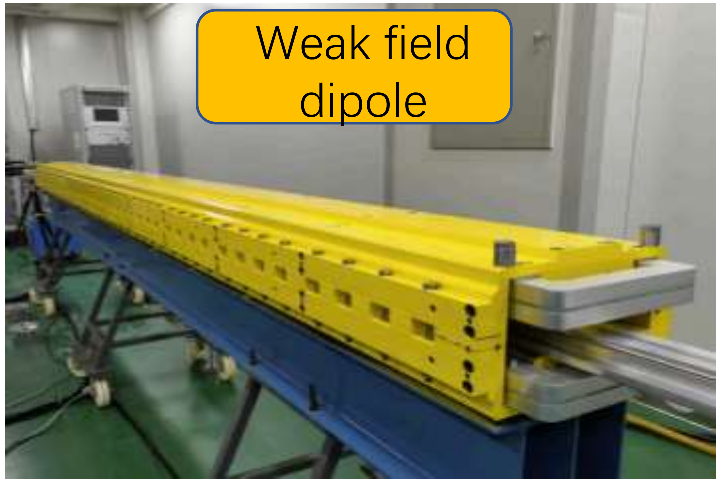


# Prototype R&D and price

- With the CEPC dedicative funding, prototypes for the CEPC high cost fraction systems, including magnet, vacuum, SRF, klystron, Linac key components etc.








- The prototype R&D provides insight into price information. Based on experience with the price ratio between the prototype and mass production, the CEPC budget can be evaluated accurately.

# Good Records on Schedule & Budget


Construction years: 1984-1988
Budget: 0.24 Billion CNY
No delay, in budget


Construction years: 2004-2008
Budget: 0.64 Billion CNY
No delay, in budget


Construction years: 2011-2016
Budget: 0.40 Billion CNY
No delay, in budget

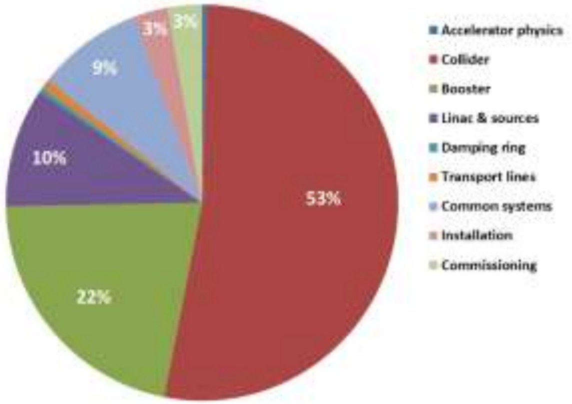

Construction years: 1984-1988
Budget: 1.87 Billion CNY
No delay, in budget


Construction years: 2019-2025
Budget: 4.8 Billion CNY
In construction, on schedule, in budget

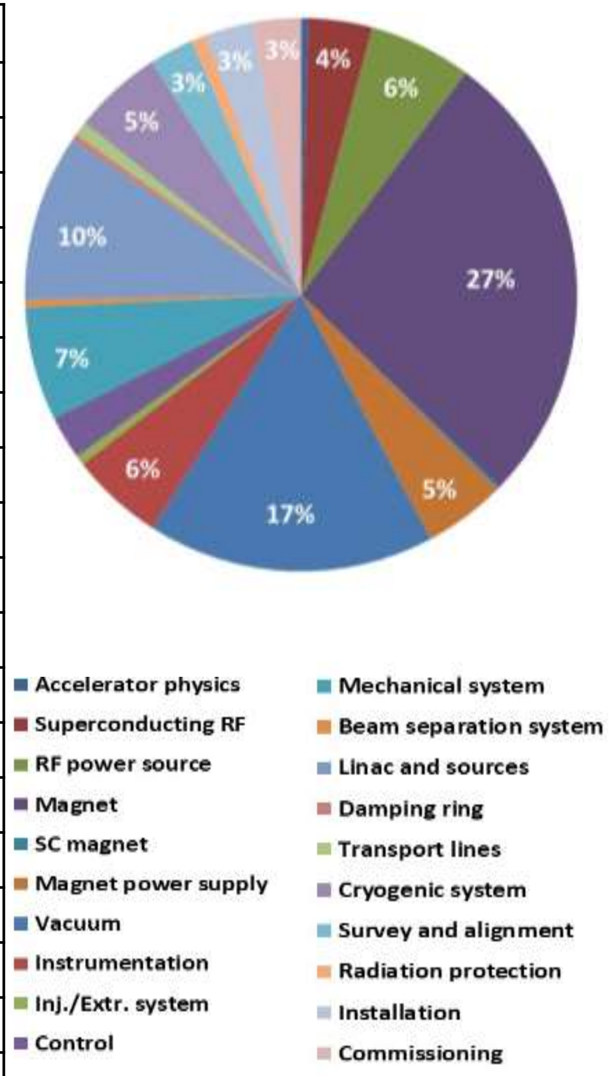
IHEP has constructed large-scale accelerator facilities since 1980’s, including circular collider, proton superconducting linac, splashing neutron source, synchrotron radiation source. All these high-budget accelerators have been built on schedule and in budget

# Accelerator Cost Summary

| Accelerator Total | 189.8 | 100% |
|---|---|---|
| Accelerator physics | 0.8 | 0.42% |
| Collider | 99.99 | 52.70% |
| Booster | 41.13 | 21.68% |
| Linac and sources | 18.3 | 9.64% |
| Damping ring | 0.59 | 0.31% |
| Transport lines | 1.57 | 0.83% |
| Common systems (cryogenic+protection+alignment) | 16.63 | 8.76% |
| Installation (3%) | 5.37 | 2.83% |
| Commissioning (3%) | 5.37 | 2.83% |

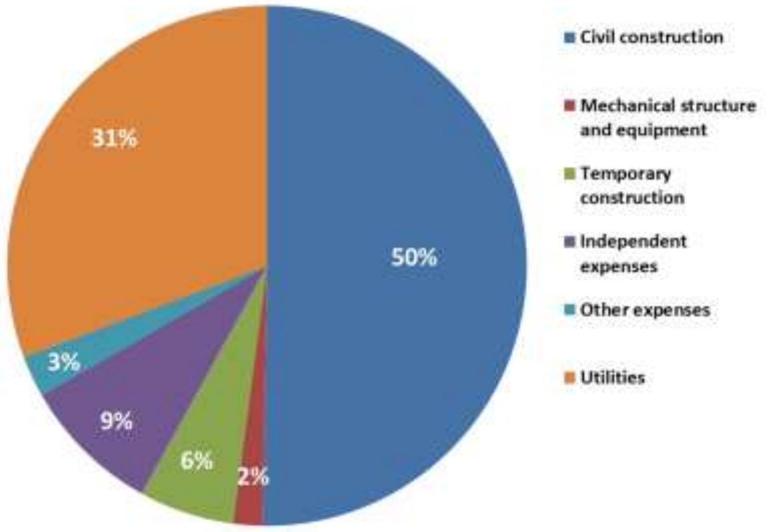



| Accelerator Total | 189.8 | 100% |
|---|---|---|
| Magnets | 50.9 | 26.82% |
| Vacuum | 31.7 | 16.70% |
| Linac and sources | 18.3 | 9.64% |
| Mechanics | 12.5 | 6.59% |
| RF power source | 11.3 | 5.95% |
| Instrumentation | 10.3 | 5.43% |
| Cryogenics | 9.87 | 5.20% |
| Magnet power supplies | 9.0 | 4.74% |
| SRF | 7.02 | 3.70% |
| Installation (3%) | 5.37 | 2.83% |
| Commissioning (3%) | 5.37 | 2.83% |
| Survey and alignment | 5.13 | 2.70% |
| Control | 5.73 | 3.02% |
| Radiation protection | 1.63 | 0.86% |
| Transport lines | 1.57 | 0.83% |
| Inj. / Extr. | 1.02 | 0.54% |
| Beam separation system | 0.80 | 0.42% |
| Accelerator physics | 0.80 | 0.42% |
| Damping ring | 0.59 | 0.31% |
| SC magnets | 0.88 | 0.46% |



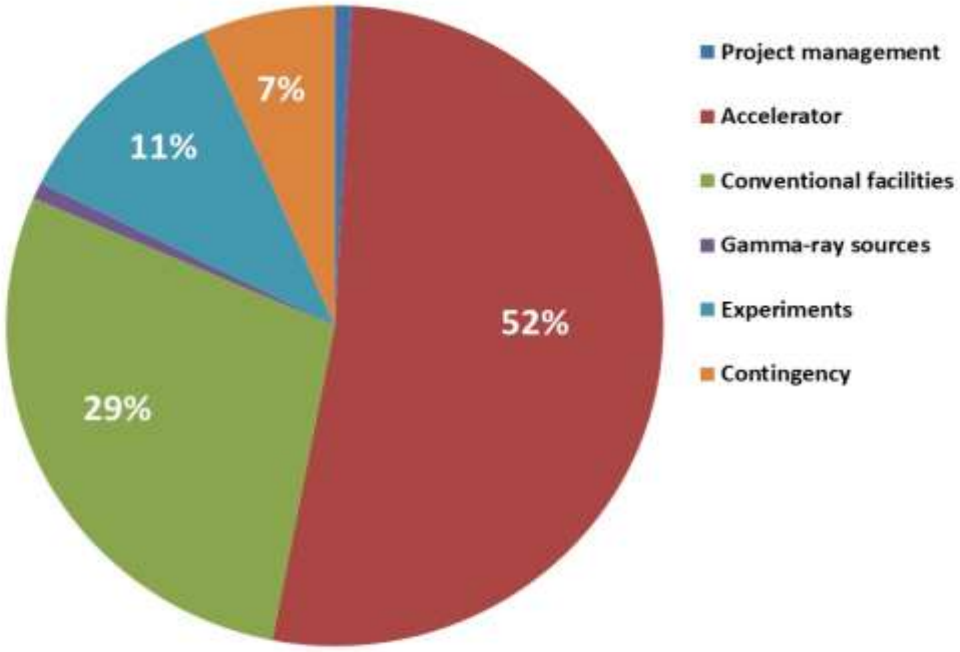
# Cost Summary on Conventional Facility

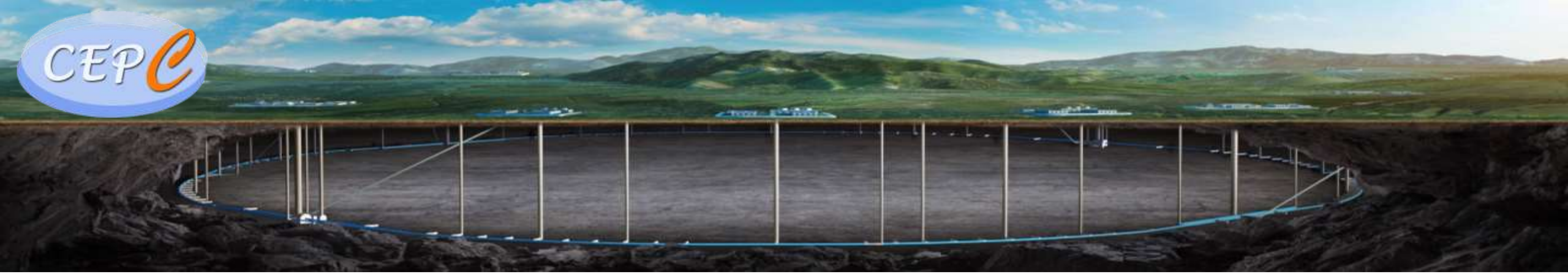
| | | |
|---|---|---|
| **Conventional Facilities Total** | 103 | **100%** |
| Civil construction | 51.6 | 50.02% |
| Mechanical structure and equipment | 1.86 | 1.80% |
| Temporary construction | 6.06 | 5.87% |
| Independent expenses | 8.93 | 8.66% |
| Other expenses | 2.64 | 2.56% |
| General Utilities | 32.06 | 31.08% |



# Project Cost Summary

| | | |
|---|---|---|
| **Total** | **368** | **100%** |
| Project management (1%) | 3 | 0.82% |
| Accelerator | **190** | 51.63% |
| Conventional facilities (Civil + General Utility) | 103 | 27.99% |
| Gamma-ray beam lines | 3 | 0.82% |
| Experiments | 40 | 10.87% |
| Contingency (8%) | 29 | 7.88% |






# Cost Evaluation for the Magnets of CEPC Injector

As an example
Simplified ppt

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- **Introduction**
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  - Research team
- **Basic consideration**
  - Material, fabrication, principles for cost evaluation, measures for cost reduction…
- **Cost analysis of the magnets for CEPC Booster**
- **Cost conclusions**
- **Summary**

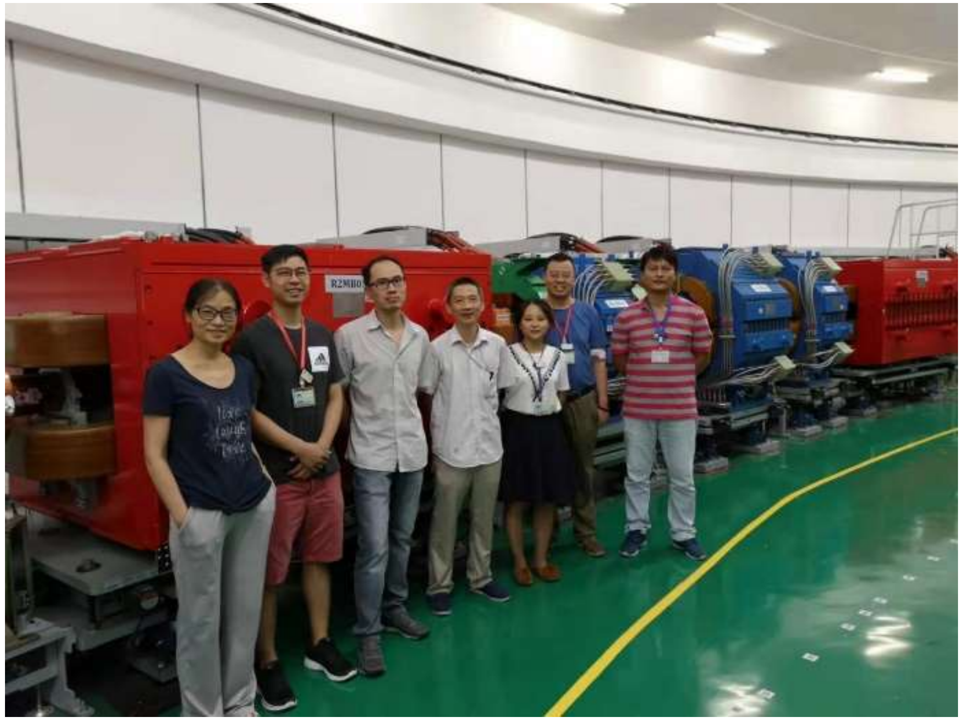
# Introduction

- This is a cost evaluation about the magnet systems for CEPC injector, including Linac, Damping Ring(DR), Booster and Transport Lines (TL).
- The magnet numbers and cost for TDR and CDR design are summarized:

| | TDR | | CDR | |
|---|---|---|---|---|
| | Number | Cost (M Yuan) | Number | Cost (M Yuan) |
| Magnets for Linac | 703 | 43.4 | 294 | 26.0 |
| Magnets for DR | 316 | 15.3 | 140 | 8.0 |
| Magnets for Booster | 19624 | 1541 | 19154 | 1408 |
| Magnets for TL | 296 | 48.3 | 251 | 40.0 |
| Total | 20939 | 1648 | 19839 | 1482 |

# Introduction

- **The speaker is from the magnet group of IHEP.**
- **The research team has accomplished the design, cost evaluation, mass production and test of the magnet systems for BEPCII, CSNS and HEPS (on time, within budget, good quality) as well as R & D of the magnets for CEPC.**



**The CSNS magnets in tunnel**

**The HEPS Booster magnets in tunnel**

# Basic Consideration

- **The primary cost constituents of the magnets:**

  - **Cost of material:**
    - **The core material: steel laminations, aluminum laminations and solid iron.**
    - **The coil material: hollow aluminum conductor, solid aluminum conductor and copper conductor**
    - **For all these material, the average price from 2018 to 2023 is used to evaluate cost of the magnets for the CEPC injector.**
  - **Cost of fabrication:**
    - **Includes labor, machinery, delivery etc.**
    - **According to the cost analysis of magnets for IHEP's other projects, such as BEPCII, CSNS and HEPS, the fabrication cost is usually twice of the material cost.**

# Basic Consideration

**Since the total length of all magnets for the CEPC injector is 74.4km, the cost of the magnets is a significant concern in the design and production.**

- **To search a reasonable scheme for magnet design, so that the magnets could be easily produced by the material easily achieved.**
- **To get an optimized magnetic and mechanical design for the magnets, so that the magnet should have a cross section as small as possible and a mechanical structure as simple as possible**
- **To investigate an economical technical route for the magnet production, so that the fabrication time could be shortened and the production efficiency could be improved.**
- **To verify the magnet design and finalize fabrication procedure by R & D of the prototype magnets as well as the first batch production of magnets.**

# Basic Consideration

- To develop automatic or semi-automatic production lines for large mass production, so that the magnets could be efficiently produced almost 24 hours everyday.
- To construct the magnet production lines near the CEPC construction site for reduction of magnet delivery expense.

# Cost analysis of the magnets for CEPC Booster

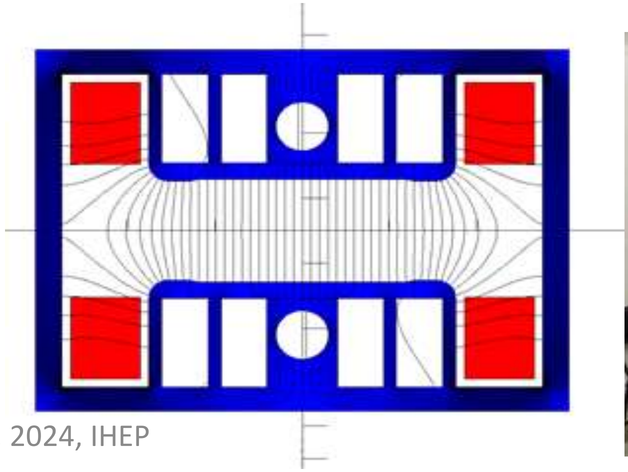
**Because the magnets of the Booster is 98.5% of the magnets for The CEPC injector, the cost analysis is focused on the magnets for the Booster. The main specifications of the magnets are listed in the table.**

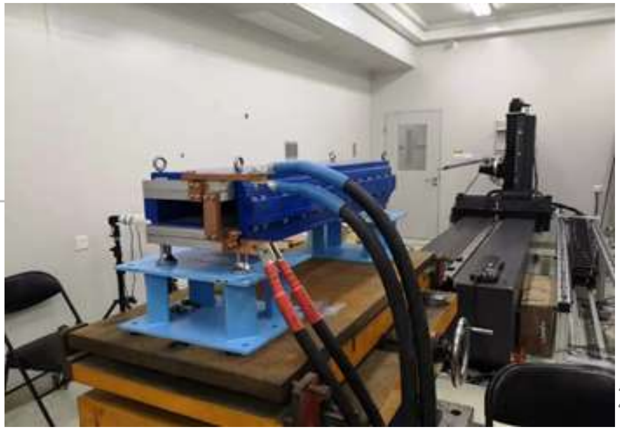
| | Number | Length | Min. field | Max. field |
|---|---|---|---|---|
| Dipoles | 14866 | 4.7m | 95Gs | 564Gs |
| Quadrupoles | 3458 | 2m/1m/0.7m | 2.0T/m | 15.86T/m |
| Sextupoles | 100 | 0.4m | $18T/m^2$ | $217T/m^2$ |
| Correctors | 1200 | 0.58m | 20Gs | 200Gs |

# Cost analysis of the magnets for CEPC Booster-Dipoles

**In TDR stage, two kinds of prototype dipole magnets are developed and studied. One is Cosine Theta(CT) coil dipole magnet, the other is iron-core dipole magnet.**

- ✓ **The CT coil dipole magnet could work at 10GeV injection energy of the Booster but have high cost and high power loss.**
- ✓ **The cost and power loss of the iron core dipole magnet are much lower than that of CT coil magnet but only work until the injection energy increases to 30GeV.**
- ✓ **In order to make the cheap iron-core dipole magnet as baseline design for the Booster, its injection energy was finally increased from 10GeV to 30GeV.**

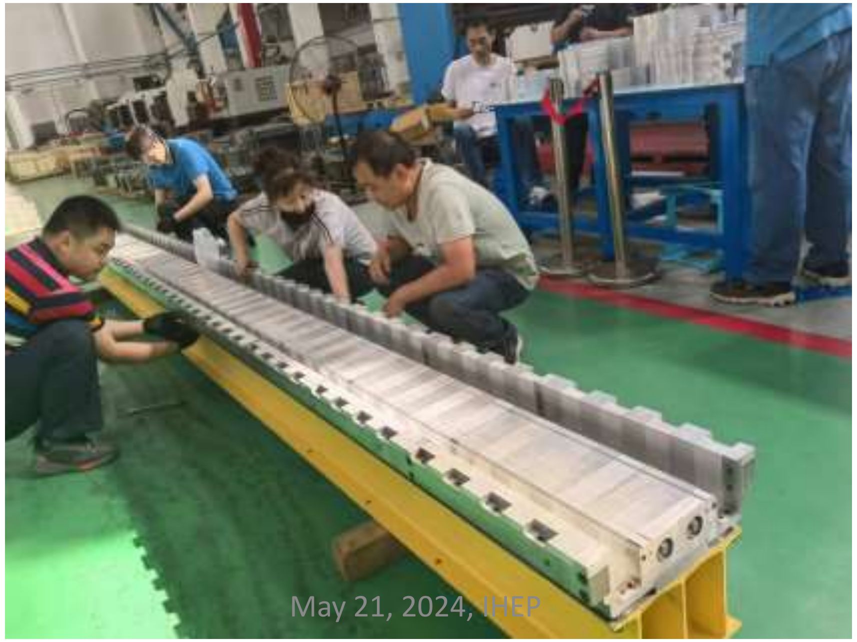


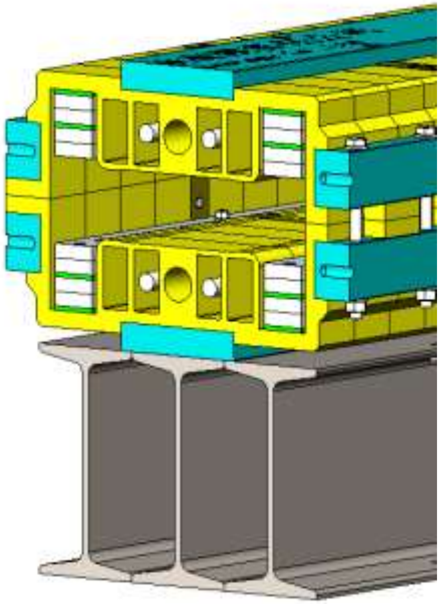


# Cost analysis of the magnets for CEPC Booster-Dipoles

**The design of the iron core dipole magnet,**

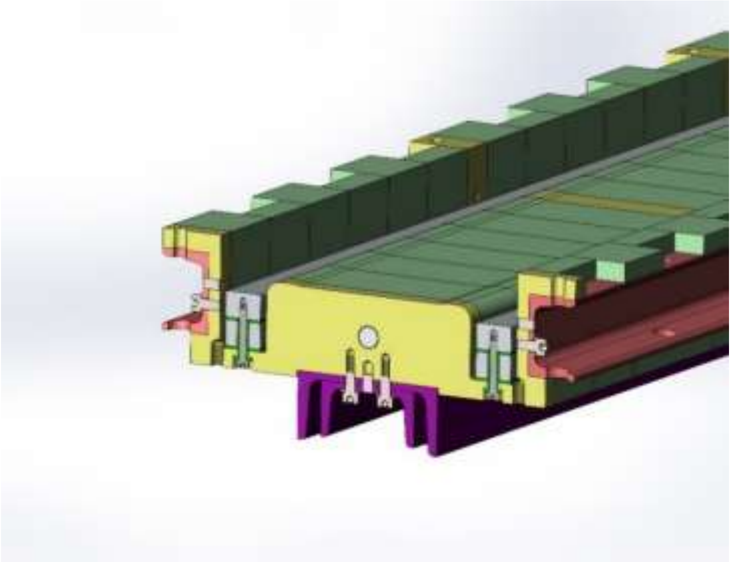
- ✓ The dipole magnets have a **H-type structure**, which could be split into **two halves**.
- ✓ Due to **very low working field**, the **core dilution technologies can be used**, the yokes are made of **non-oriented steel laminations** interleaved with **cheap aluminum laminations**.
- ✓ The return yokes of the cores are made **as thin as possible** and **some holes are punched** in the pole areas of the laminations.





# Cost analysis of the magnets for CEPC Booster-Dipoles

- ✓ The coils of the magnet are simply formed with several pieces of the aluminum bars without water cooling.
- ✓ Unlike the conventional vacuum epoxy casting, the insulation of the coils are simply made by G10 plates.
- ✓ By using some kind of special structure, the coils can be simply fixed on the iron cores.



# Cost analysis of the magnets for CEPC booster-Dipoles

## The main parameters related to the cost of the magnets are listed

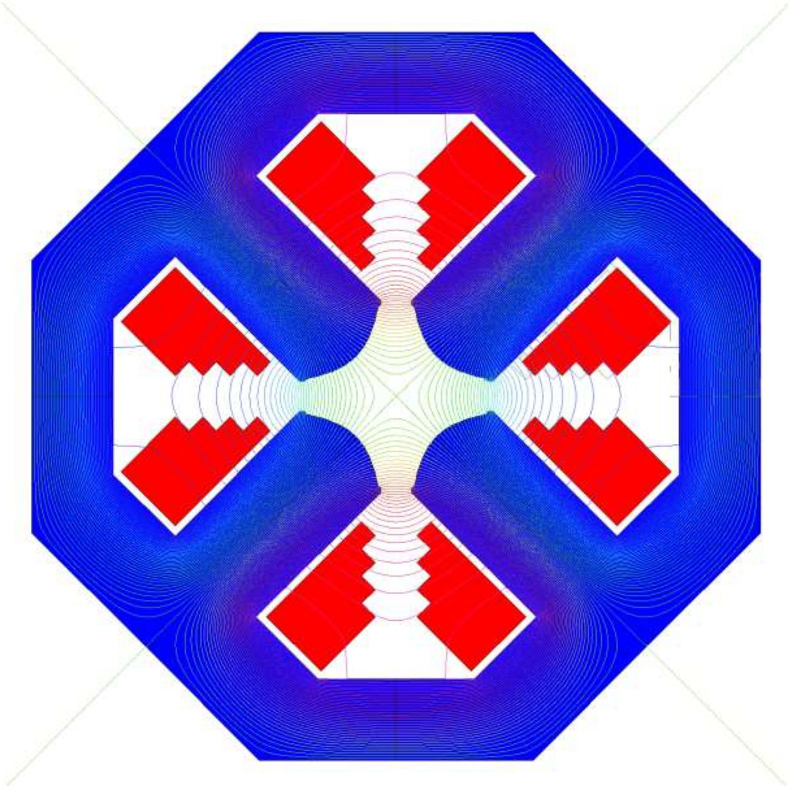
| Magnet name | BST-63B | BST-63B-SF | BST-63B-SD |
|---|---|---|---|
| Quantity | 10832 | 2017 | 2017 |
| Aperture [mm] | 63 | 63 | 63 |
| Max. Field [Gs\|T/m$^2$] | 564\|0 | 564\|16.04 | 564\|-19.14 |
| Min. Field [Gs\|T/m$^2$] | 95\|0 | 95\|2.67 | 95\|-3.19 |
| Turns per pole | 2 | 2 | 2 |
| Max. current[A] | 714 | 791 | 764 |
| Size of conductor [mm*mm] | 25*40-Al | 25*40-Al | 25*40-Al |
| Core height [mm] | 280 | 280 | 280 |
| Core width [mm] | 400 | 400 | 400 |
| Core Length [mm] | 4700 | 4700 | 4700 |
| Weight of steel laminations [ton] | 2.80 | 2.80 | 2.80 |
| Weight of Al laminations [ton] | 0.70 | 0.70 | 0.70 |
| Weight of coil conductor [ton] | 0.27 | 0.27 | 0.27 |

**Three kinds of the dipole magnets have the same size and weight, so the same cost.**

# Cost analysis of the magnets for CEPC Booster-Quadrupoles

**The quadrupole magnets for the booster are group into three families according to their effective length, which have a same cross-sectional shape.**

- ✓ **The quadrupole magnets will be assembled from four identical quadrants for coil installation.**
- ✓ **The cores are stacked by the cheap non-oriented silicon steel laminations.**
- ✓ **In order to reduce the cost, the coils are wound by the cheaper hollow aluminium conductors instead of the hollow copper conductors.**
- ✓ **Thanks to the relatively low gradient, the pole root of the quadrupole magnets is rectangular rather than tapered. This allows for a cheaper core with small simple cross-sectional shape, and a cheaper coil with simple racetrack structure.**



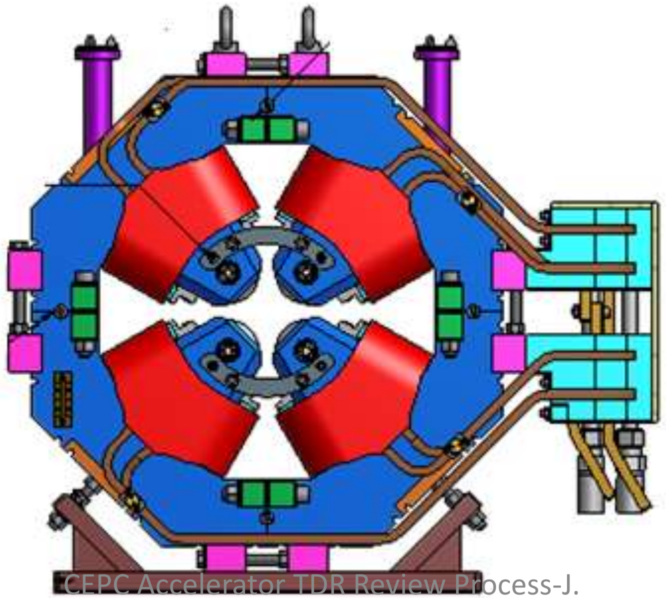
# Cost analysis of the magnets for CEPC Booster-Quadrupoles

## The main parameters related to the cost of the quadrupole magnets

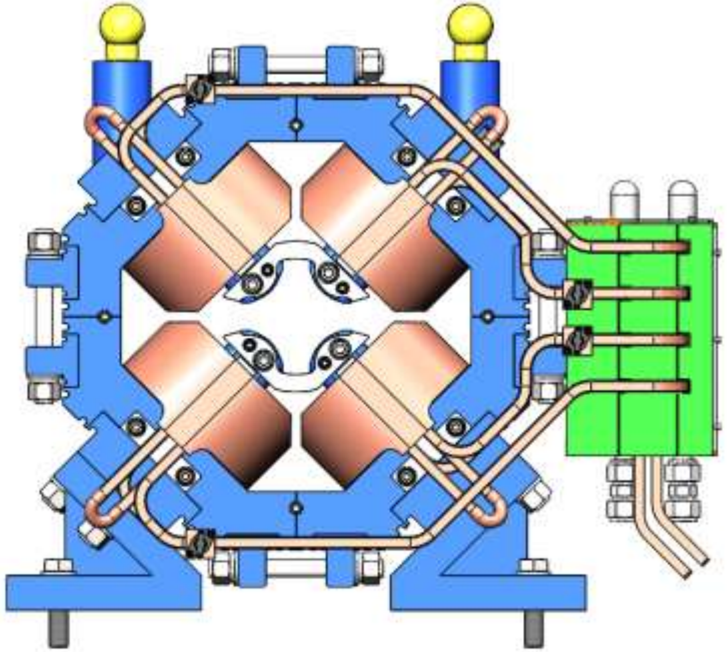
| Magnet name | BS-63Q-2000L | BS-63Q-1000L | BS-63Q-700L |
|---|---|---|---|
| Quantity | 1144 | 296 | 2018 |
| Aperture [mm] | 63 | 63 | 63 |
| Max. Field [T/m] | 12.88 | 15.86 | 12.03 |
| Min. Field [T/m] | 2.15 | 2.64 | 2.01 |
| Turns per pole | 20 | 20 | 20 |
| Max. current[A] | 257 | 316 | 240 |
| Min. current[A] | 42.8 | 52.7 | 40.0 |
| Size of conductor [mm*mm] | 10×10D6-Al | 10×10D6-Al | 10×10D6-Al |
| Core height [mm] | 450 | 450 | 450 |
| Core width [mm] | 450 | 450 | 450 |
| Core Length [mm] | 2000 | 1000 | 700 |
| Weight of steel laminations [ton] | 5.91 | 2.95 | 2.07 |
| Weight of coil conductor [ton] | 0.1 | 0.05 | 0.04 |

# Cost analysis of the magnets for CEPC Booster-Quadrupoles

- ✓ **Because the production procedures of the quadrupole magnet produced for the HEPS booster is nearly similar to that of the magnet for the CEPC Booster, the prototype quadrupole magnet for the CEPC Booster has not been developed in TDR stage.**



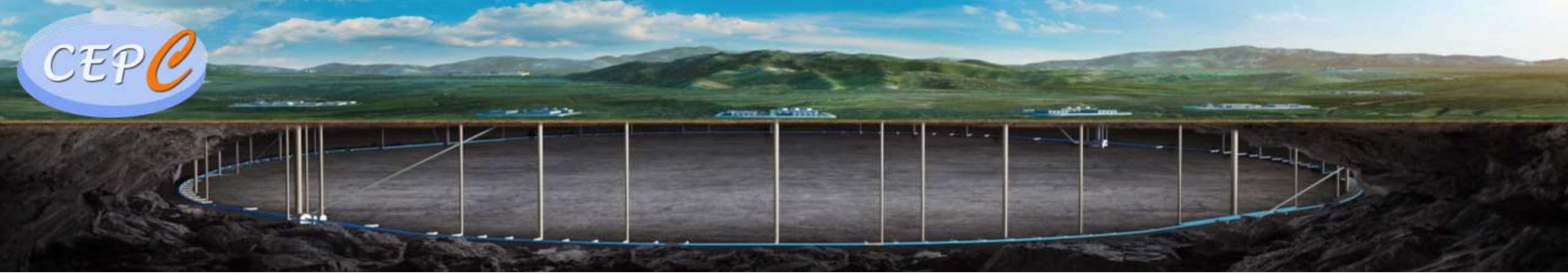
HEPS quadrupole magnet



CEPC quadrupole magnet

# Summary

- ✓ There are nearly 21000 magnets in the CEPC injector, most of them are equipped with the Booster. The total cost of the magnets for injector is 1646M Yuan, of which the magnets for the Booster is 1541M Yuan.
- ✓ Since the dipole magnets of the Booster work at very low field, their cost could be reduced dramatically by using the technologies of core dilution, cheaper material as well as the automatic production lines.
- ✓ To reduce the cost, the quadrupole magnets of the Booster are optimized to have a simple and cheap structure due to its relatively low gradient, the coils of the magnets are wound by the cheaper hollow aluminium conductors.
- ✓ The other magnets for the CEPC injector are conventional magnets, so their cost is evaluated by consulting the similar magnets produced for other accelerator projects, such as HEPS and BEPCII.




# Backup slides

As an example

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

# Introduction-components

## Specifications of the magnets for the DR

| Type | Name | Number | Length[m] | Gap[mm] | Field[T\|T/m\|T/m$^2$] |
|---|---|---|---|---|---|
| Dipoles-I | B0 | 40 | 0.70 | 38 | 1.300 |
| Dipoles-II | Br | 40 | 0.25 | 38 | 1.300 |
| Quadrupole-01 | Qarc | 96 | 0.20 | 44 | 17.00 |
| Quadrupole-02 | QRF | 8 | 0.20 | 38 | 30.00 |
| Sextupole-01 | SF | 36 | 0.10 | 38 | 94.00 |
| Sextupole-02 | SD | 36 | 0.10 | 38 | 140.00 |
| Corrector | CORR | 60 | 0.07 | 40 | 0.01 |

# Introduction-components

## Specifications of the magnets for the Transport Lines (10)

| Transport Lines | Name | Number | Length[m] | Gap[mm] | Field[T\|T/m] |
|---|---|---|---|---|---|
| LA to DR (2) | Dipole | 28 | 2.00 | 44 | 0.75 |
| | Quadrupole | 28 | 0.30 | 54 | 5.00 |
| LA to BS (2) | Diople-BT0&BT1 | 36 | 5.00 | 37 | 1.50 |
| | Dipole-BTv | 4 | 28.00 | 37 | 1.50 |
| | Quadrupole-33Q | 80 | 0.90 | 33 | 14.70 |
| | Corrector-37C | 24 | 0.20 | 37 | 0.17 |
| BS to CLD (6) | Dipole-BT0&BT1 | 12 | 5.00 | 37 | 1.50 |
| | Dipole-BT2 | 8 | 35.00 | 24 | 0.46 |
| | Dipole-BT3 | 4 | 15.00 | 24 | 0.81 |
| | Quadrupole-24Q | 40 | 2.00 | 24 | 27.00 |
| | Corrector-24C | 30 | 0.30 | 24 | 0.30 |

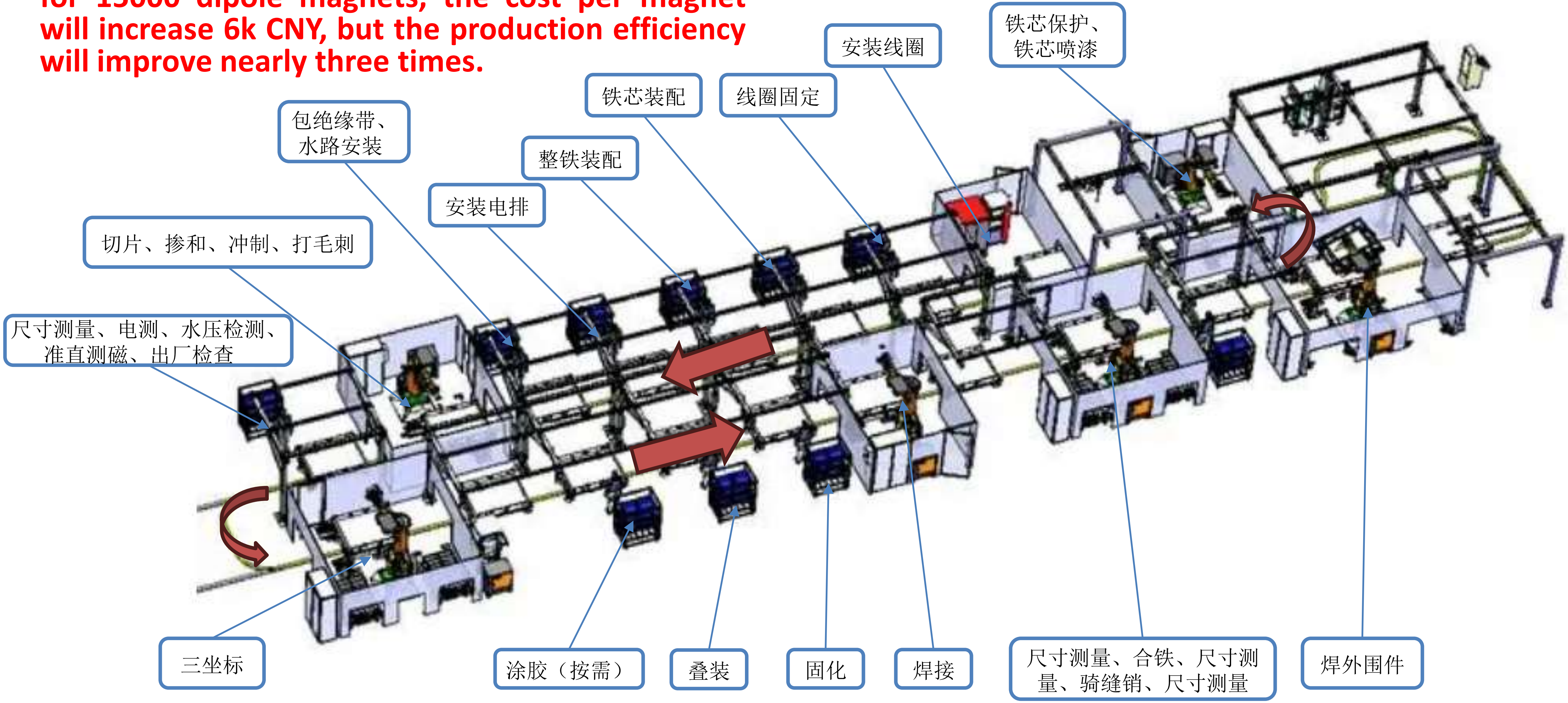
# Introduction-components

## Specifications of the magnets for the CEPC Booster

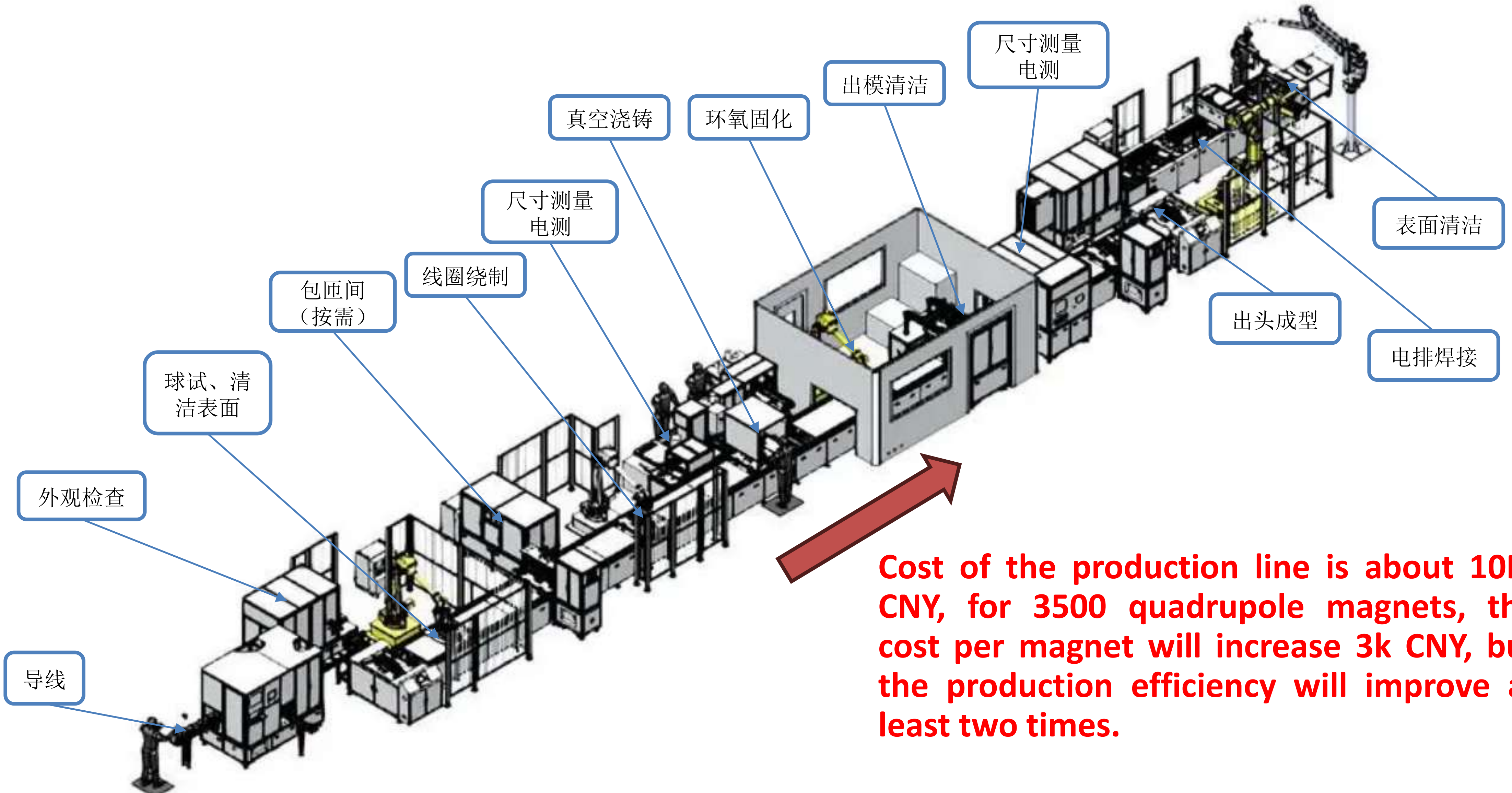
| Type | Name | Number | Length[m] | Gap[mm] | Max. Field [Gs\|T/m\|T/m$^2$] | Min. Field [Gs\|T/m\|T/m$^2$] |
|---|---|---|---|---|---|---|
| Dipoles-I | BS-63B | 10732 | 4.70 | 63 | 564\|0 | 95\|0 |
| Dipoles-II | BS-63B-SF | 2017 | 4.70 | 63 | 564\|16.04 | 95\|2.67 |
| Dipoles-III | BS-63B-SD | 2017 | 4.70 | 63 | 564\|-19.14 | 95\|-3.19 |
| Quadrupole-I | BS-63Q-700L | 2018 | 0.70 | 63 | 12.03 | 2.01 |
| Quadrupole-II | BS-63Q-1000L | 296 | 1.00 | 63 | 15.86 | 2.64 |
| Quadrupole-II | BS-63Q-2000L | 1144 | 2.00 | 63 | 12.88 | 2.15 |
| Sextupole | BS-63S | 100 | 0.40 | 63 | 216.90 | 18.10 |
| Corrector | BS-63C | 1200 | 0.58 | 63 | 200.00 | 30.00 |

# Automatic production line of the magnet yoke

**Cost of four production lines is about 120M CNY, for 15000 dipole magnets, the cost per magnet will increase 6k CNY, but the production efficiency will improve nearly three times.**



# Automatic production line of the magnet coil




**Cost of the production line is about 10M CNY, for 3500 quadrupole magnets, the cost per magnet will increase 3k CNY, but the production efficiency will improve at least two times.**

# Summary

- The TDR review and cost review should be complete, clear, logic, convincing, etc. based on the R&D prototype design, measurement results and cost, also based on the other relevant components costs
- The writing up should start as early as possible to go through several rounds of correction during meetings and CEPC day, etc.
- Before international review, internal reviews are necessary
- A clear and logic TDR structure and presentation templates are important
- A dedicated editor working on TDR text editing is essential
- A systematic dedicated meetings are necessary
- ...