CEPC R&D highlights – status and plan

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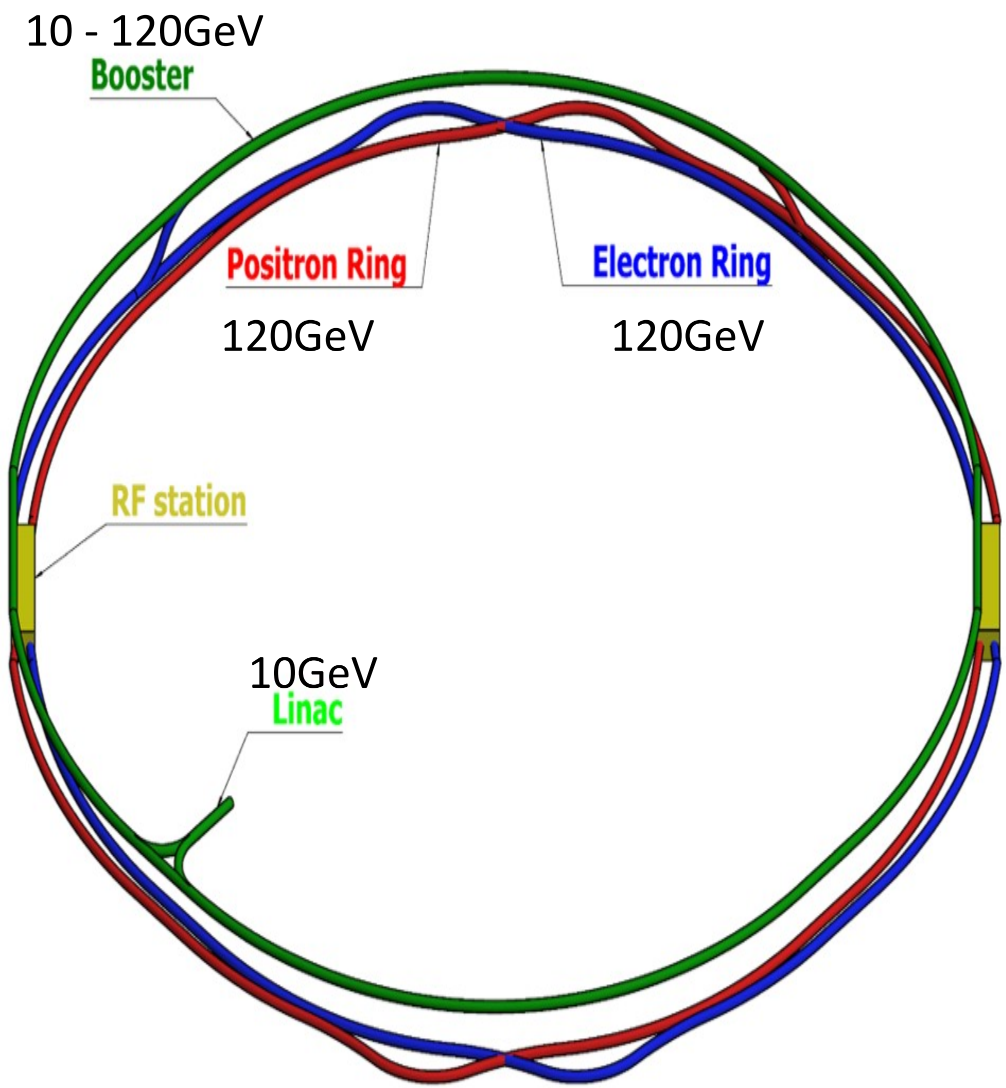
Contents

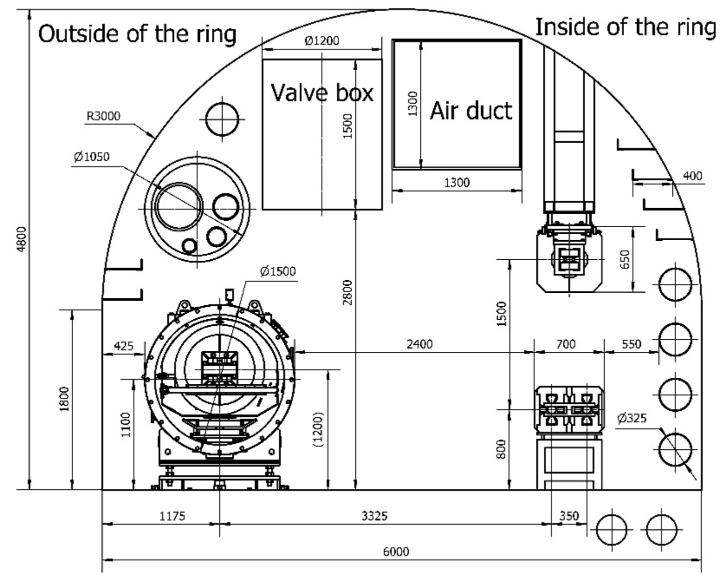
Physics goals of CEPC

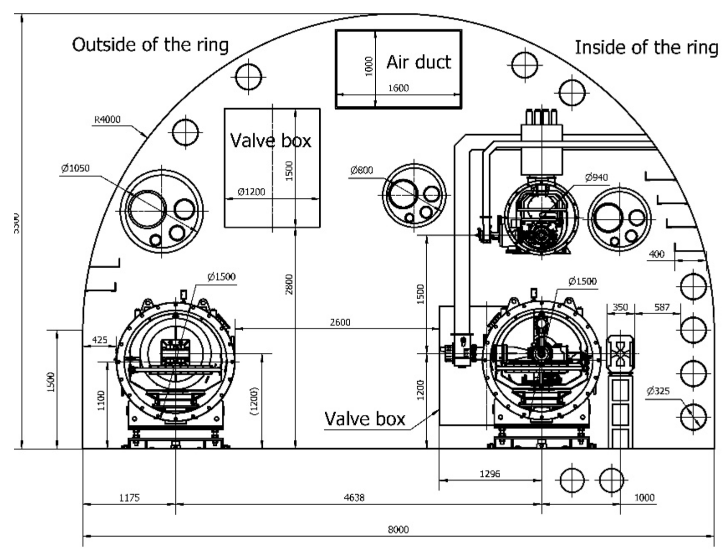
Electron-positron collider (45.5, 80, 120 GeV)

- **Higgs Factory**
  - **Precision study of Higgs (m_H, J^{PC}, couplings)**
  - **Looking for hints of new physics**
  - **Luminosity > $2.0\times10^{34}cm^{-2}s^{-1}$**
- **Z & W factory**
  - **Precision test of standard model**
  - **Rare decays**
  - **Luminosity > $1.0\times10^{34}cm^{-2}s^{-1}$**

Accelerator: Linac → Booster → Collider ring

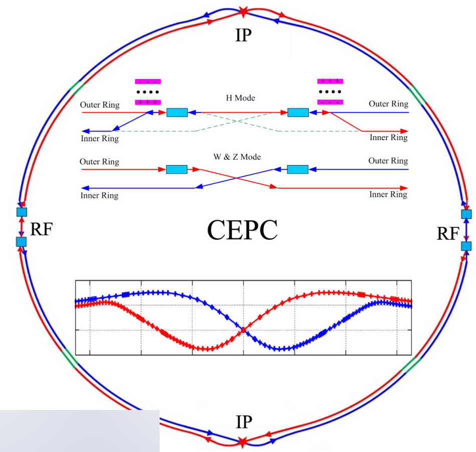


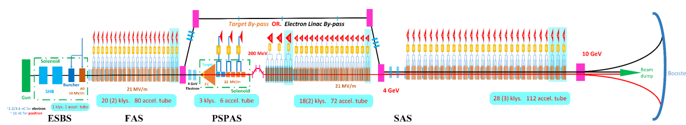


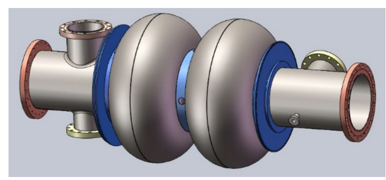


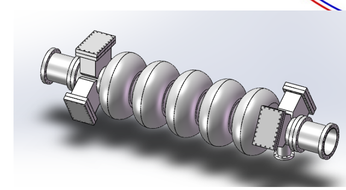
Accelerator design and R&D

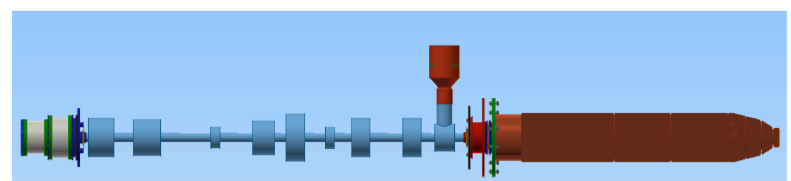
- Design & R&D works of Accelerator systems moving forward well
  - Accelerator physics
  - Linac
  - SRF
  - RF power source
  - Cryogenics
  - Magnet
  - SC magnet
  - Power supply & E- seperator
  - Vacuum
  - Instrumentation
  - Control
  - Radiation Shielding
  - Survey & Alignment
  - Mechanics
  - Conventional facilities
  - Etc.

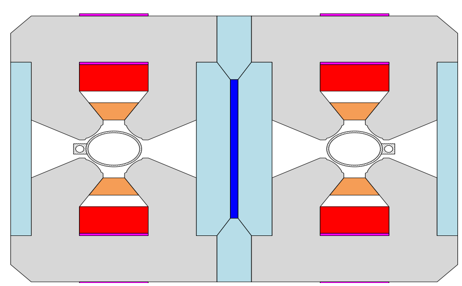






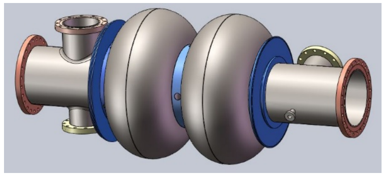
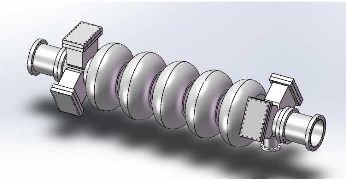
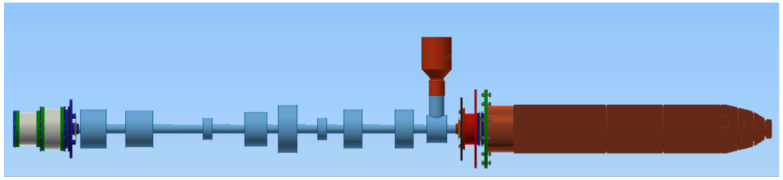
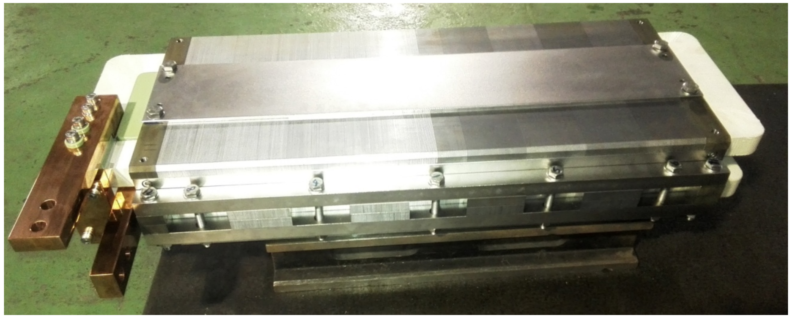


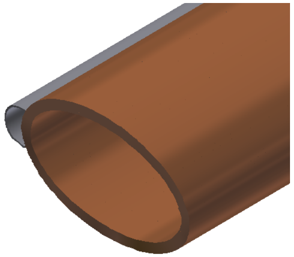
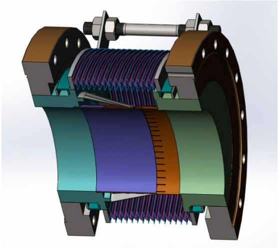
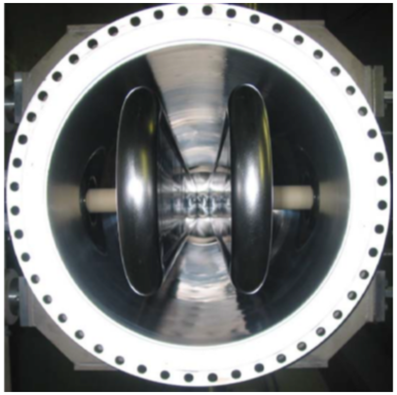




Key Tech. R&D prototype items

- SC Cavities
- High efficiency klystron
- Low field dipole magnet
- BPM electronics
- Copper vacuum chamber & Bellows
- Electro static separator
- …

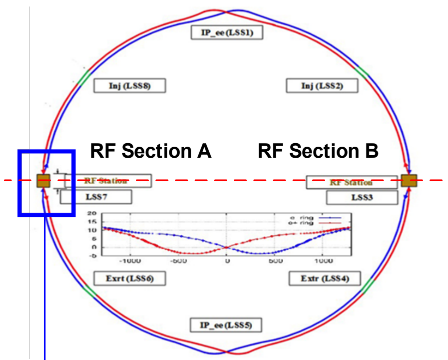




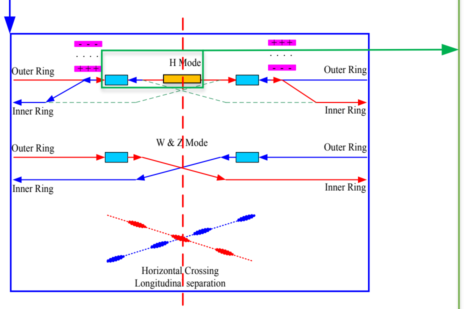
R&D Funding (~285 M RMB)

- IHEP fund: 6.83 M RMB
  - Accelerator physics
  - Research of High Q cavity
  - 650MH/ 300kW klystron development
  - Digital BPM
- Most fund 2016 (phase I): 15.48 M RMB
  - Accelerator physics
  - SRF Technology R&D
  - Injector key technology R&D
- PAPS fund: 210 M RMB
  - SRF infrastructure construction
  - SC Cavity R&D
  - Cavity & klystron high power test
- Beijing fund: 5 M RMB
  - EP etc.
- Yifang Wang's Scientist studio fund: 35 M RMB
  - 650MHz/800kW CW high efficiency klystron
  - QD0 power supply
  - Survey & alignment
  - Control system
  - Radiation shielding
  - Key tech. of cryogenics
  - Permanent diple magnet
  - IR quodrupole
  - Vacuum
- Most fund 2018 (phase II): ~15 M RMB
  - Low field dipole magnet
  - Copper chamber & chamber
  - Electro static separator

SRF System Layout

Two RF sections. Two Collider 650 MHz RF stations and one Booster 1.3 GHz RF station in each RF section.





RF Section A

- Two Collider Ring RF Stations CRFA1 (84 cavities in 14 cryomodules) and CRFA2 (84 cavities in 14 cryomodules) (blue)
- One Booster RF Station BRFA (48 cavities in 6 cryomodules) (orange)
- Straight section length between CRFA1 and CRFA2: 368.6 m

Outside | **Inside**

650 MHz

Collider Ring RF Station CRFA1 (224 m) on floor

- 14 Collider Ring cryomodules in seven FODO cells.
- One cryomodule in a half FODO cell.
- Six cavities per module.
- Half FODO cell length 16 m.
- Cryomodule length 10 m.

RF Power Source for CRFA1 (84 cavities, 42 klystrons)

Cryogenics for CRFA1 and half BRFA

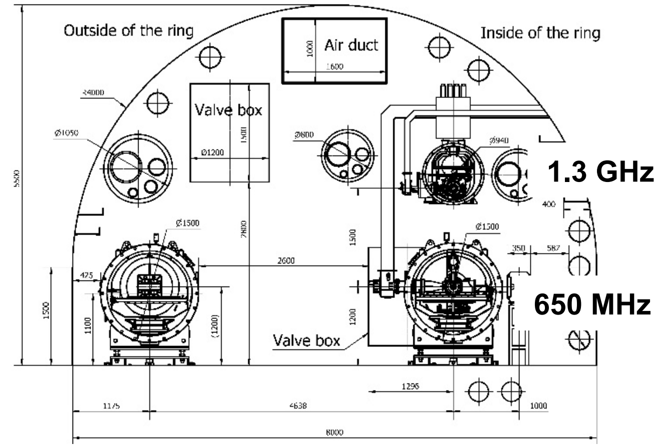
1.3 GHz

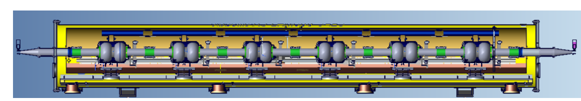
Booster RF Station BRFA (116 m) on ceiling

- Six Booster cryomodules in one FODO cells.
- Three cryomodules in a half FODO cell.
- Eight cavities per module.
- Half FODO cell length 58 m.
- Cryomodule length 13 m.

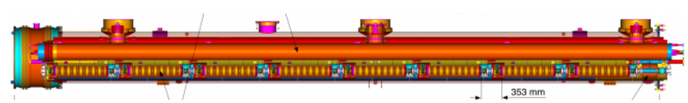
RF Power Source for BRFA (48 cavities, 48 SSA)

Not to scale

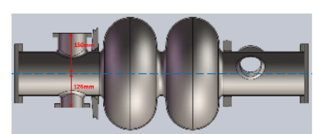




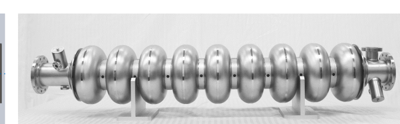
Collider Ring 650 MHz cryomodule (56)



Booster Ring 1.3 GHz cryomodule (16)



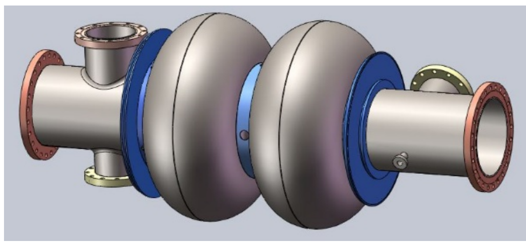
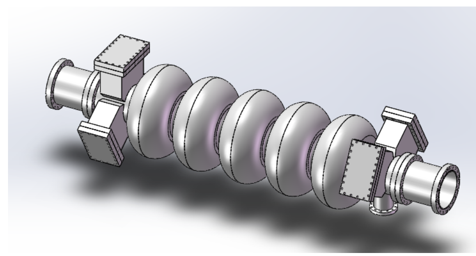
650 MHz 2-cell cavity (336)

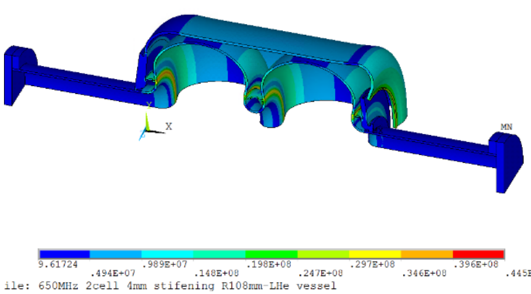


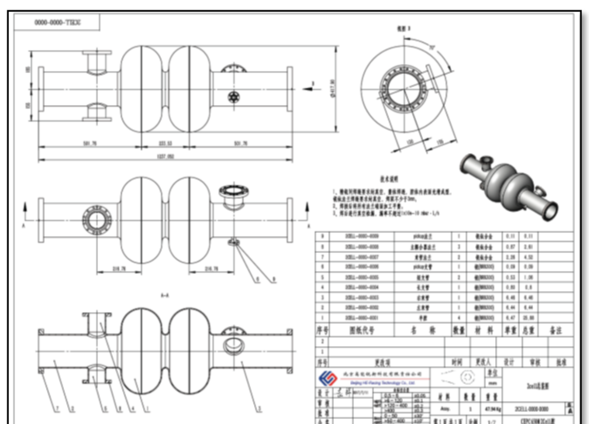
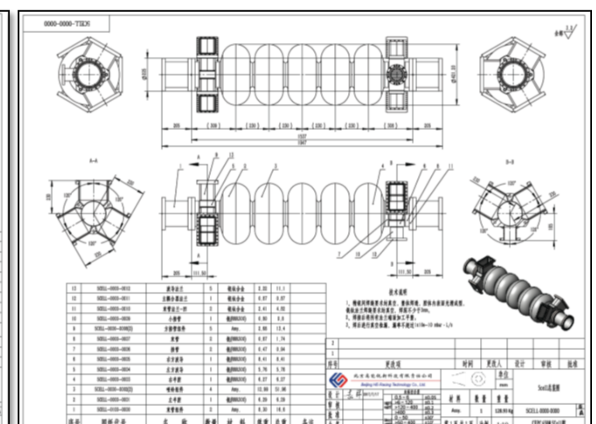
1.3 GHz 9-cell cavity (96)

SRF Technology R&D

Three 2-cell cavities with coaxial HOM coupler, one 5-cell cavity with waveguide HOM coupler will complete fabrication at the end of 2017.

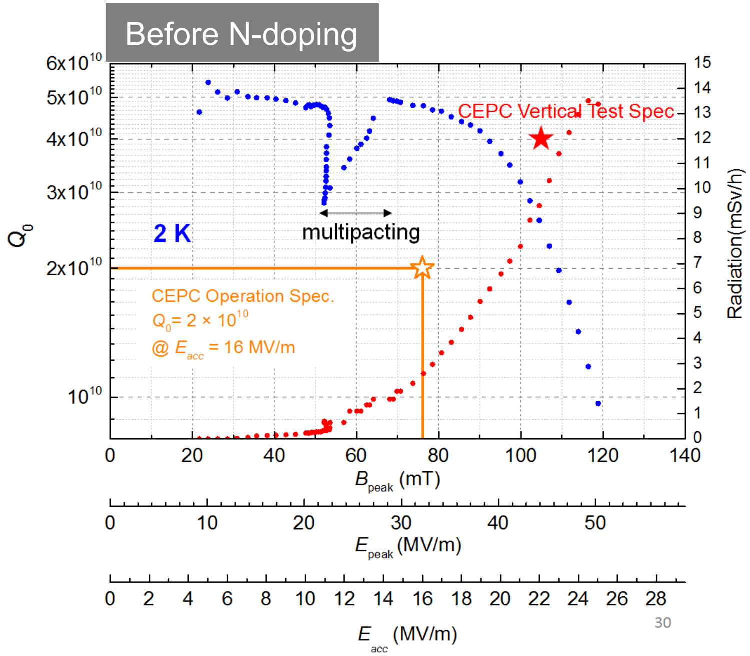



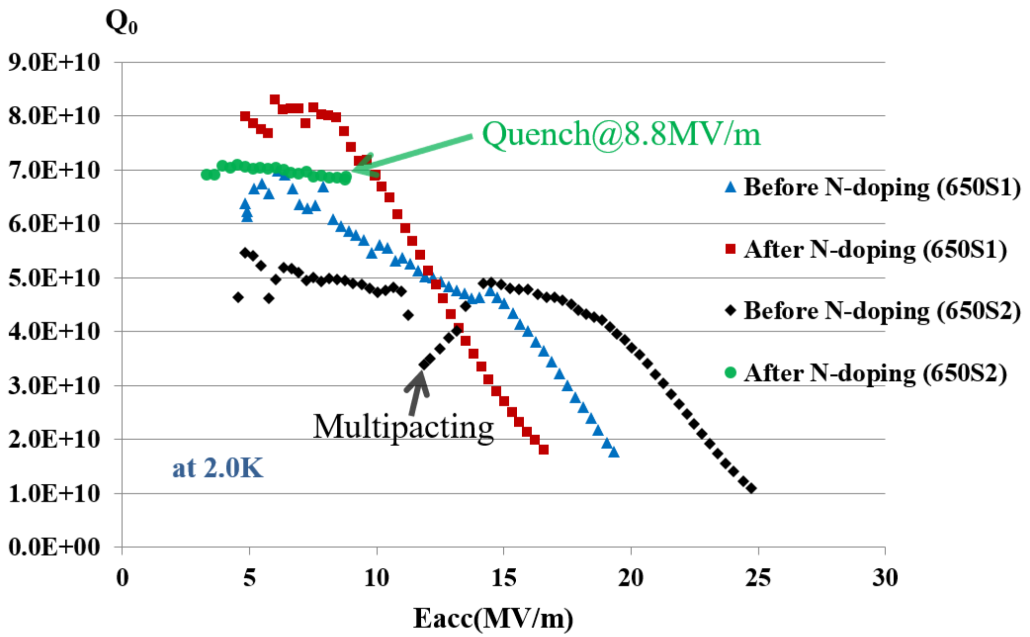
SRF Technology R&D – N-doping

After N-doping of two 650 MHz single cell cavities (BCP treated), Q_0 increased obviously at low field for both cavities, which is first observed in China.

- 650S1: Q_0=7e10 @ Eacc=10 MV/m. But Q_0 decreased quickly at high field (>10 MV/m).
- 650S2: Quench at Q_0=6.9e10 @ Eacc=8.8 MV/m.

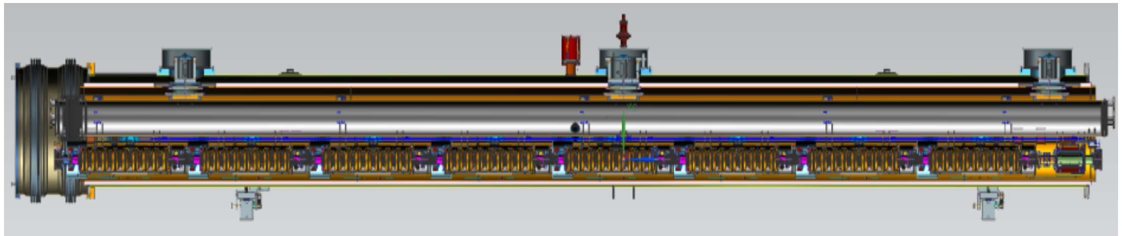
EP facility will be ready to use in mid 2018.

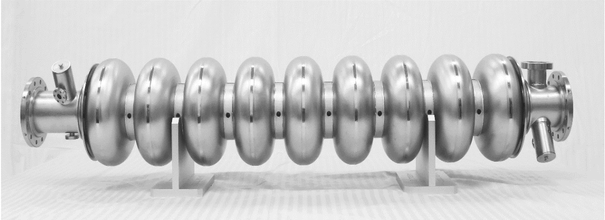




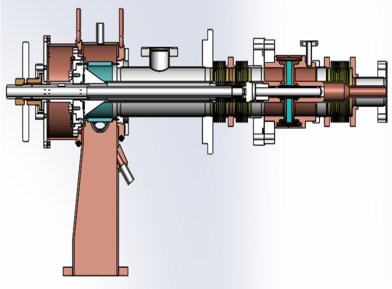
1.3 GHz SRF Technology for Booster

XFEL and LCLS-II type cryomodule, without SCQ. Technology R&D in synergy with Shanghai XFEL (SCLF). No big challenge.

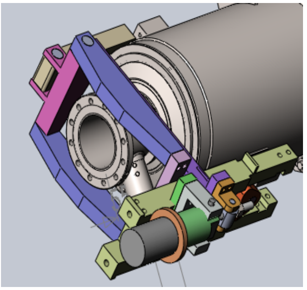




TESLA cavity. Nitrogen-doped bulk niobium and operates at 2 K. $Q_0 > 3 \times 10^{10}$ at 24 MV/m for the vertical acceptance test. $Q_0 > 1{\times}10^{10}$ up to 20 MV/m for long term operation.



XFEL/ILC/LCLS-II or other type **variable power coupler**. Peak power 30 kW, average 4 kW, Q_{ext} 1E7-5E7, two windows.



XFEL/LCLS-II type **end lever tuner**. Reliability. Large stiffness. Piezos abundance, radiation, overheating. Access ports for easy maintenance.

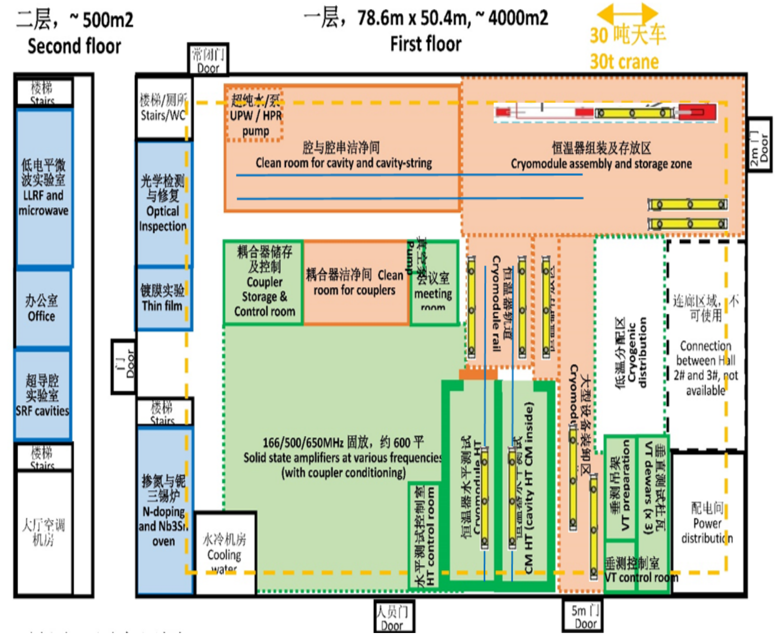
PAPS SRF Facility

4500 m^2 SRF lab in the *Platform of Advanced Photon Source Technology R&D* (PAPS), Huairou Science Park, Beijing.

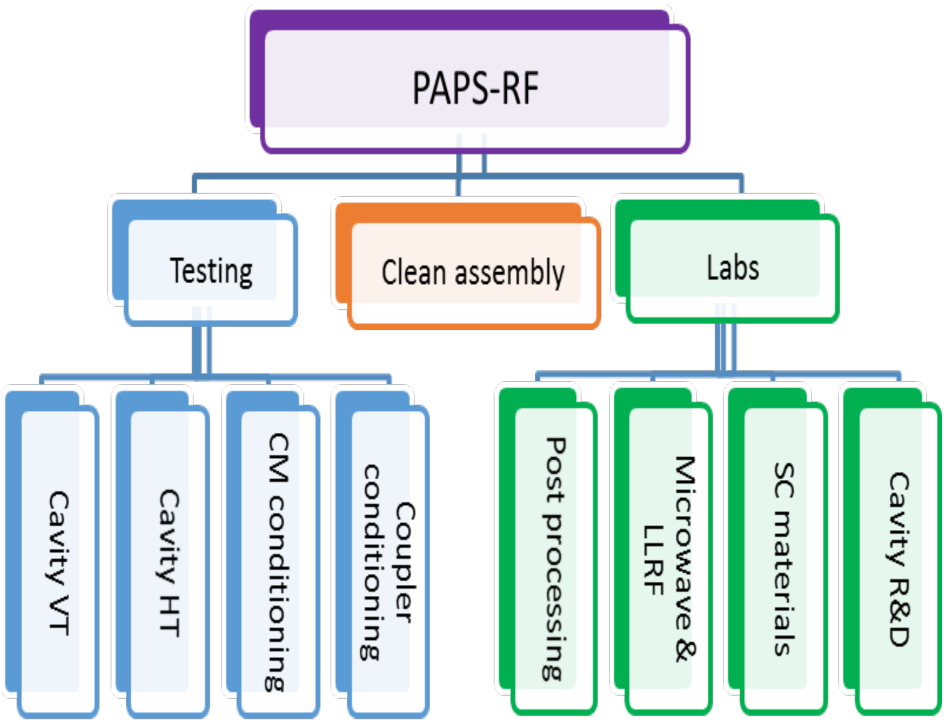
Mission: World-leading SRF Lab for Superconducting Accelerator Projects and SRF Frontier R&D.

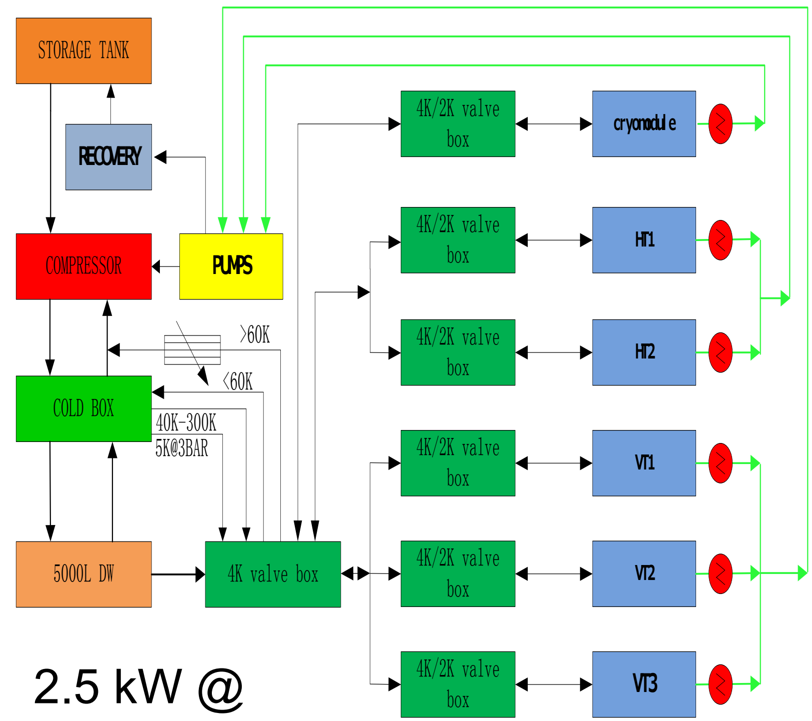
Mass Production: 200 ~ 400 cavities (couplers) test per year, 20 cryomodules assembly and horizontal test per year.

Construction and facility commissioning: 2017 - 2020



PAPS SRF Lab and Cryogenics

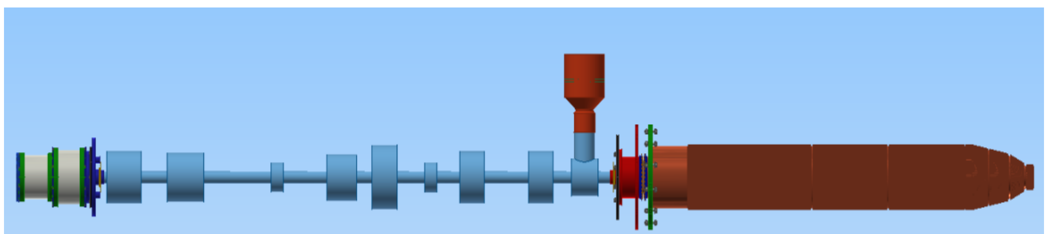


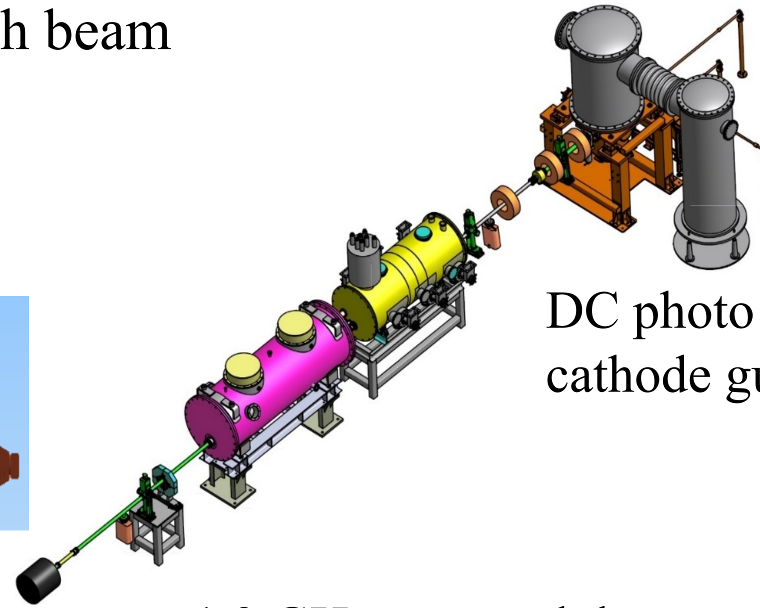


2.5 kW @ 4.5 K

PAPS Test Stand with Beam

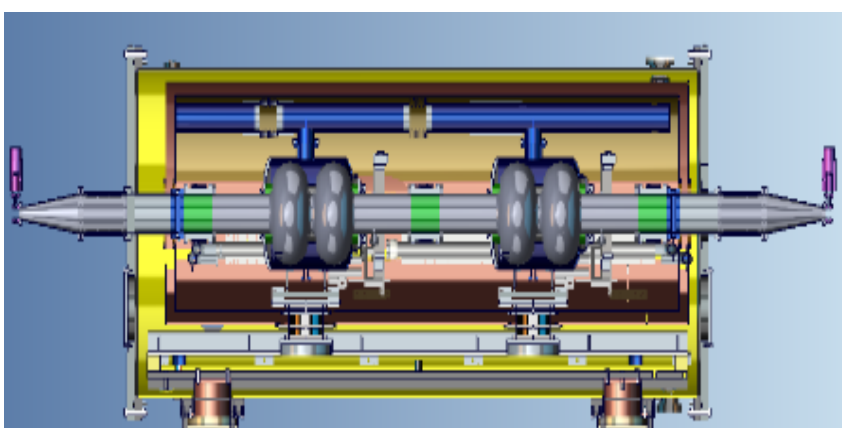
- Test 650MHz & 1.3Ghz cavities with beam
- Test High Efficiency klystron
- Test CW beam10 mA, 50 MeV



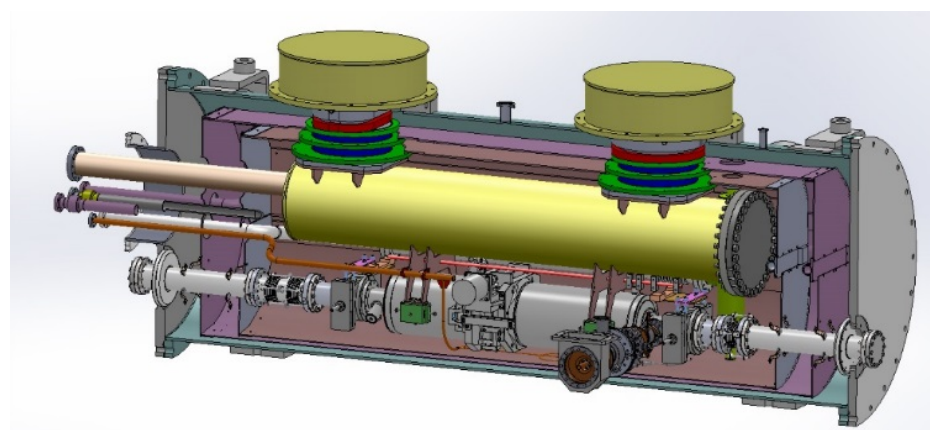


DC photo cathode gun

650 MHz test module



1.3 GHz test module

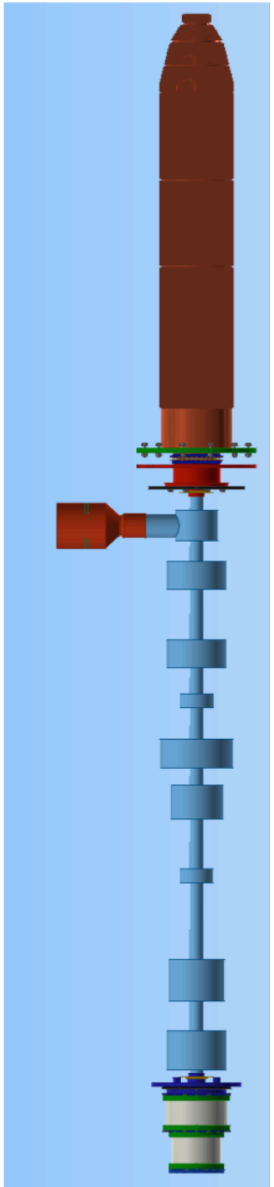


SRF R&D Plan (2017-2022)

- **Two small Test Cryomodules** (650 MHz 2 x 2-cell, 1.3 GHz 2 x 9-cell)
- **Two full scale Prototype Cryomodules** (650 MHz 6 x 2-cell, 1.3 GHz 8 x 9-cell)
- **Schedule**
  - 2017-2018 (key components, IHEP Campus)
    - high Q 650 MHz and 1.3 GHz cavities, N-doping + EP
    - 650 MHz variable couplers (300 kW)， 1.3 GHz variable couplers (10 kW)
    - high power HOM coupler and damper, fast-cool-down and low magnetic module, reliable tuner
  - 2019-2020 (test modules integration, Huairou PAPS)
    - Horizontal test 16 MV/m, $Q_0 > 2E10$
    - beam test 1~10 mA
  - 2021-2022 (prototype modules assembly and test, Huairou PAPS)

High efficiency klystron R&D

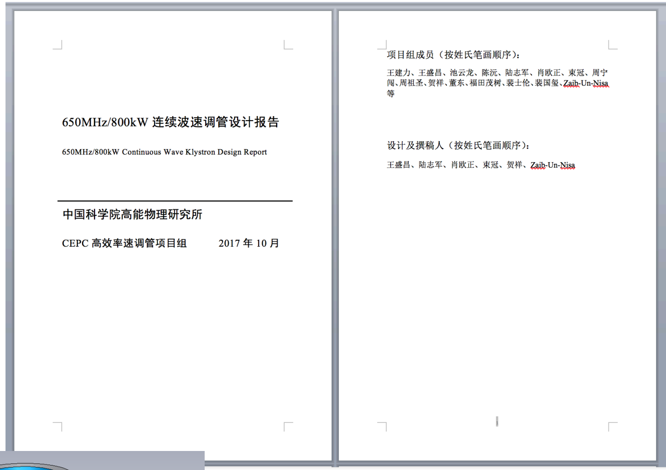
Parameters	Conventional	High efficiency
Centre frequency (MHz)	650+/-0.5	650+/-0.5
Output power (kW)	800	800
Beam voltage (kV)	80	-
Beam current (A)	16	-
Efficiency (%)	65	80



- Schedule
  - 2016 - 2018 Design conventional & high efficiency klystron
  - 2017 - 2018 Fabricate conventional klystron & test
  - 2018 - 2019 Fabricate 1st high efficiency klystron & test
  - 2019 - 2020 Fabricate 2nd high efficiency klystron & test
  - 2020 - 2021 Fabricate 3rd high efficiency klystron & test

High efficiency klystron R&D

- The design of the electron gun and collector has been completed;
- RF Section for classical design klystron is completed;
- RF Section for high efficiency design klystron is almost completed.
- Fabrication for high efficiency klystron will be started.


650MHz/800kW 连续波速调管设计报告

650MHz/800kW Continuous Wave Klystron Design Report

中国科学院高能物理研究所

CEPC 高效率速调管项目组 2017 年 10 月

项目组成员（按姓氏笔画顺序）：

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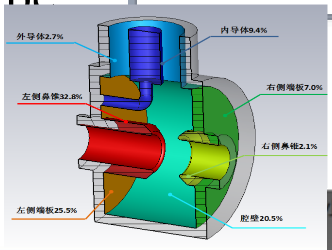
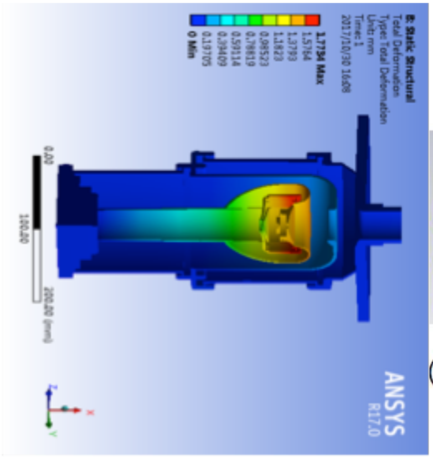
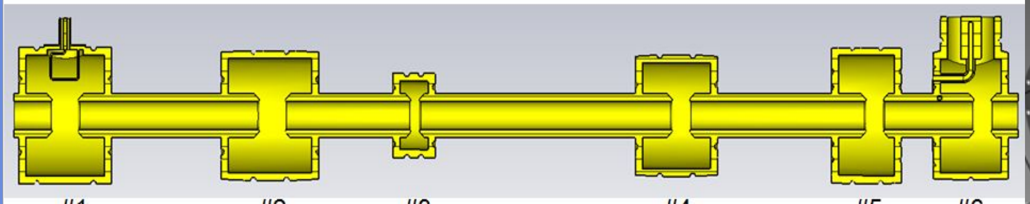
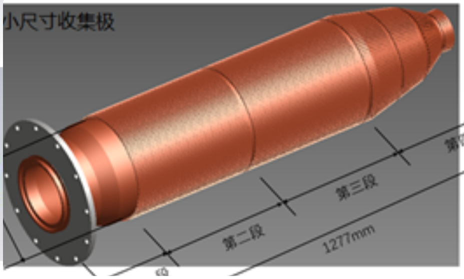
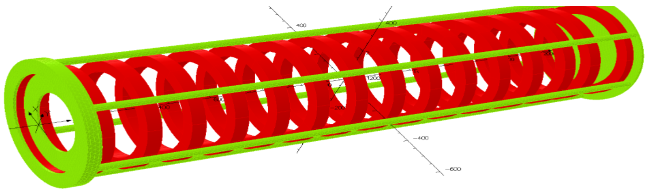






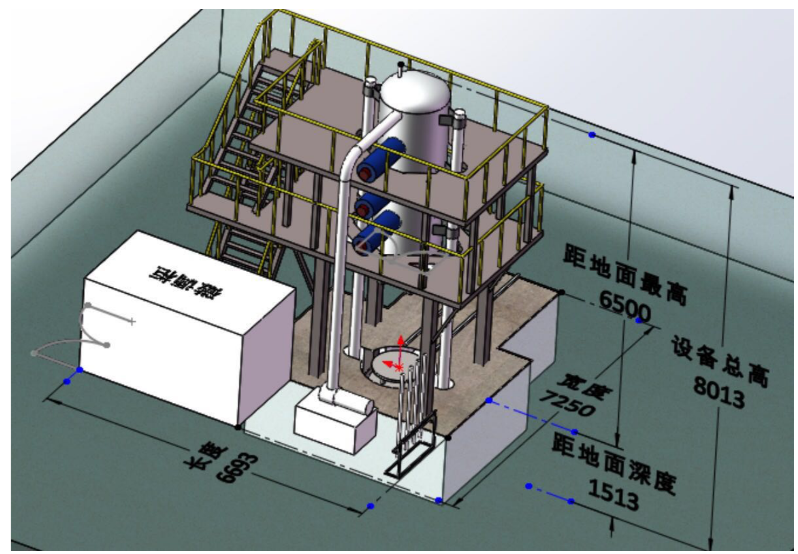
#1 (input cavity) #2 #3 #4 #5 #6 (output cavity)





High efficiency klystron R&D

- Collaboration with industries:
  - Established High efficiency klystron collaboration consotium, including IHEP, IE, THU and GLVAC et al.
  - Established GLVAC Industrial Technology Research Institute for High Power Devices supported by local government
    - Build large Hydrogen furnace & baking furnace
    - High power klystron manufacture



Booster low field dipole magnet R&D

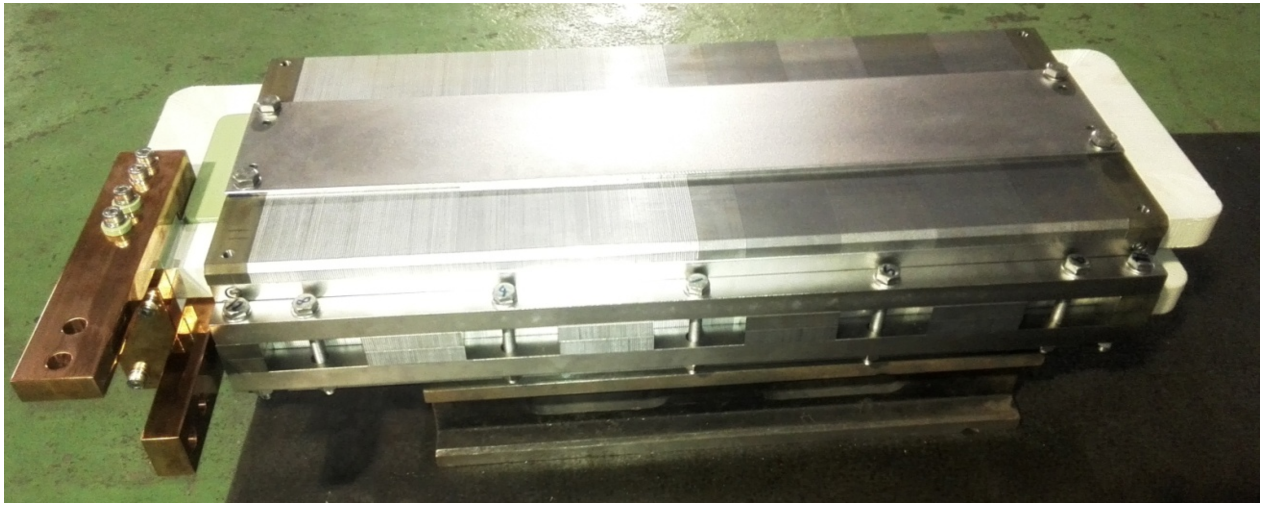
Quantity	13312
Minimum field (Gs)	29
Maximum field (Gs)	352
Gap (mm)	63
Magnetic Length (mm)	5500
Good field region (mm)	55
Field uniformity	0.1%
Field reproducibility	0.05%

Challenges

- Total length of the dipoles ~70km → how to reduce cost
- Field error <29Gs*0.1%=0.029Gs → how to design
- Field reproducibility<29Gs*0.05%=0.015Gs → how to measure
- Magnet length ~5500mm → how to fabricate

Booster low field dipole magnet R&D

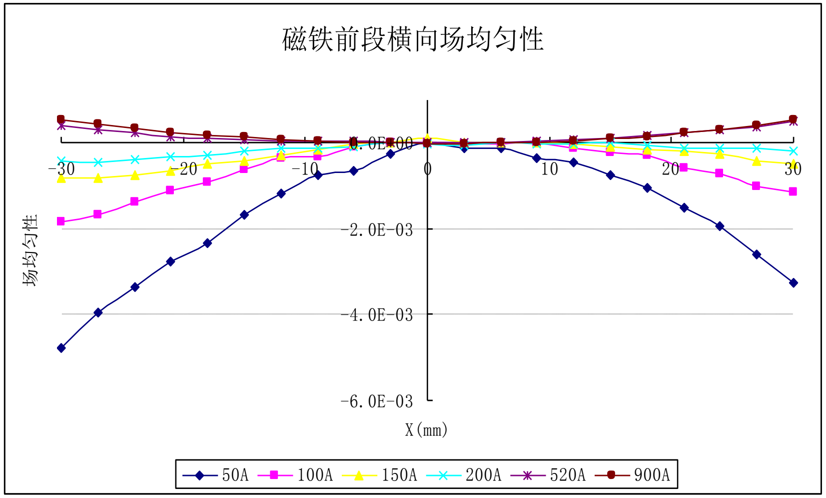
In order to verify the design of the CEPC low field dipole magnet, a subscale prototype dipole magnet was produced.

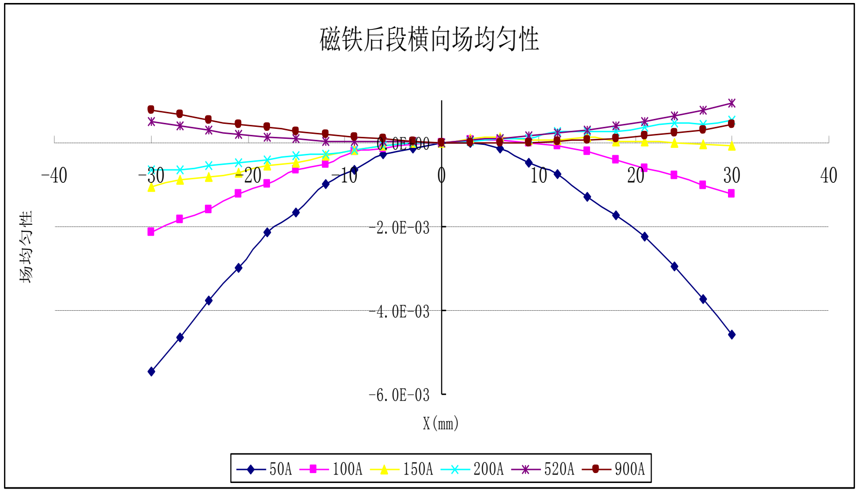


- The core of the magnet is about 1m long. One half is stacked by the steel laminations, another half is stacked by the steel laminations interleaved with the aluminum laminations.
- The coils of the magnet have only one turn per pole, which is made by solid aluminum bars without water cooling.

Booster low field dipole magnet R&D

- Due to remnant field, the field errors at low field becomes 10 time larger than that at high field.
- To meet the field uniformity of 5E-4, the minimum field of the magnet should be higher than 100Gs.
- The measured remnant field in the magnet gap is about 4-6Gs, which is 13%-20% of the low field of 30Gs.

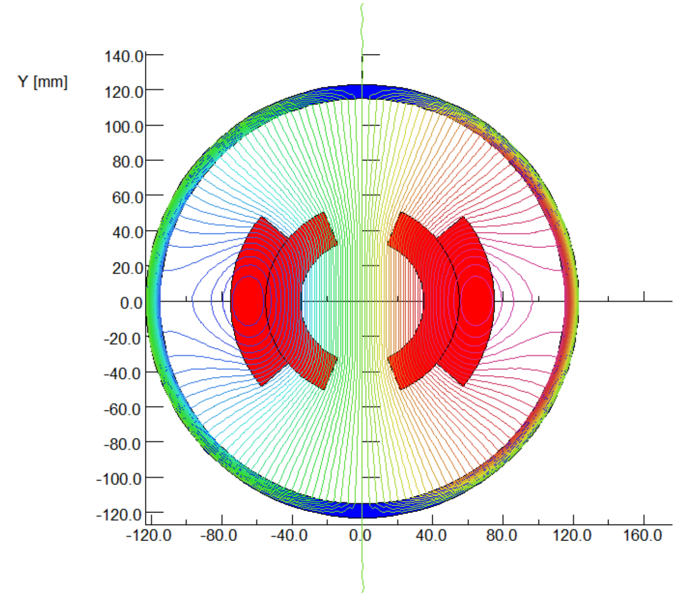




Booster low field dipole magnet R&D

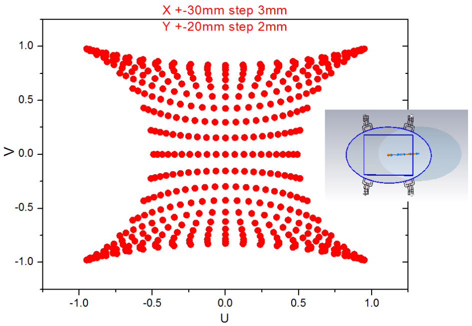
The ways to improve the field qualities of the low field magnets

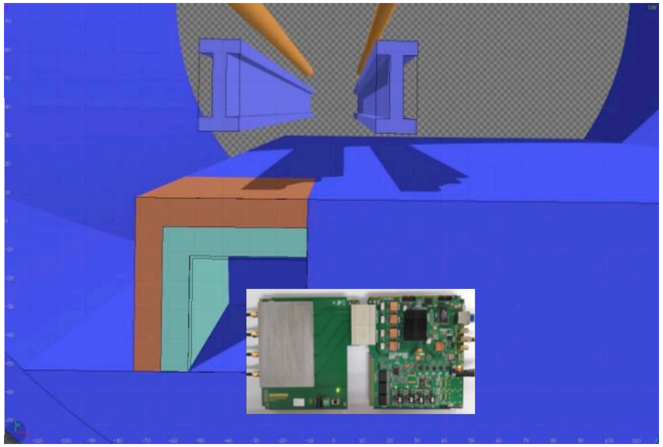
- To increase the injection energy of the Booster so that the minimum field of the magnet is increased from 30Gs to 100Gs.
- To develop high quality silicon steel laminations with very low remnant field.
- To design and develop the low field magnet without magnetic core like superconductor dipole magnets.



Beam Position Monitor R&D

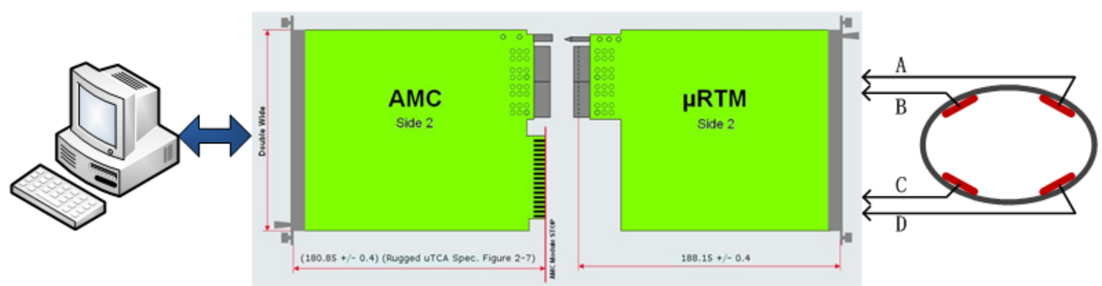
- There are 4708 BPMs in booster and collider ring
- Button type electrode will be adopted, for its good high frequency response and small beam impedance
- The resolution of BPM will be ~2um level

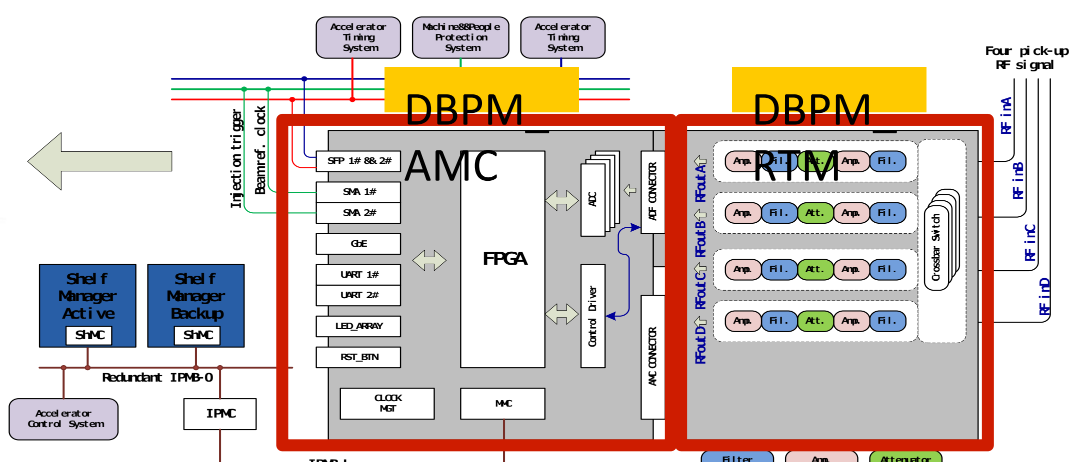




BPM electronics

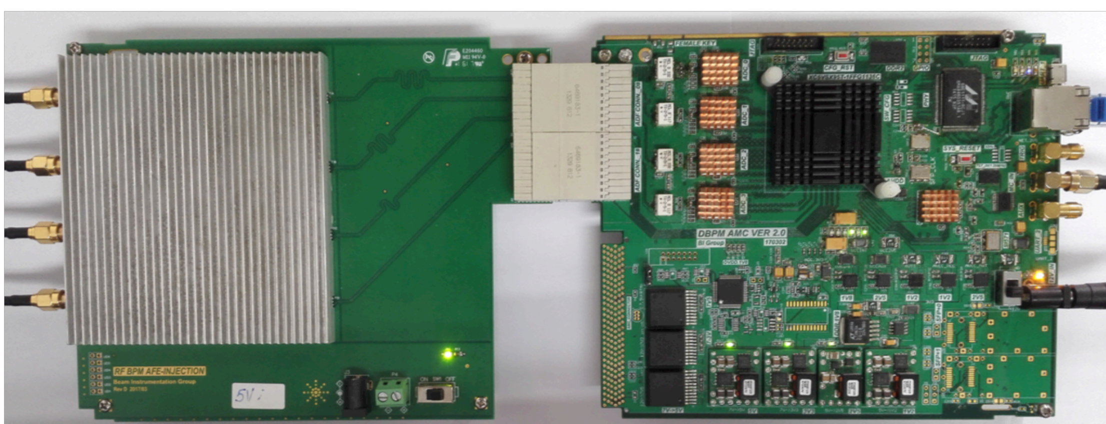
- Adopt MicroTCA.4 standard
- Electronics including three parts: RF Frontend board, Digit board, Timing module
- The timing trigger can be adjusted to make ADCs peak sampling

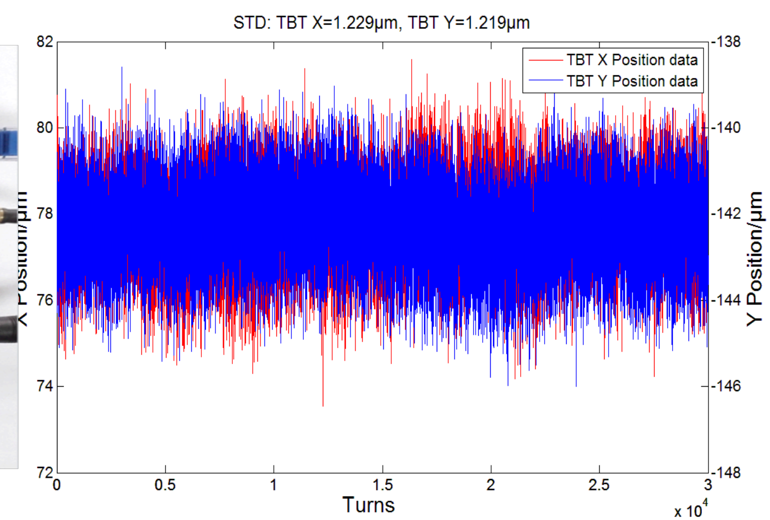




BPM electronics

- The first version of BPM electronics prototype has been finished
- The resolution (RMS) is 1.229 μm for turn by turn data, 0.4 μm (3 s) for FA data, and 0.19 μm (10 s) for SA data.
- New version based MicroTCA is under developing.
- Beam test will be done in BEPCII.

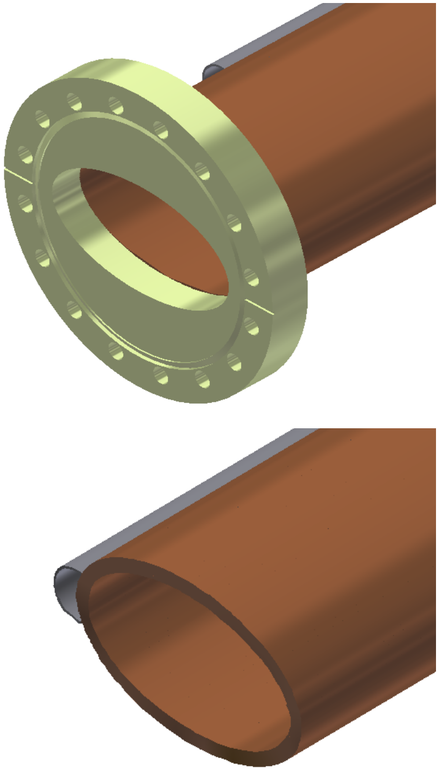




Vacuum system R&D

The materials and shapes of the vacuum chambers are analyzed and compared, final choice will be done by R & D results of vacuum chambers prototypes.

CEPC copper vacuum chamber (elliptical100×55, thickness 6, length 8000)

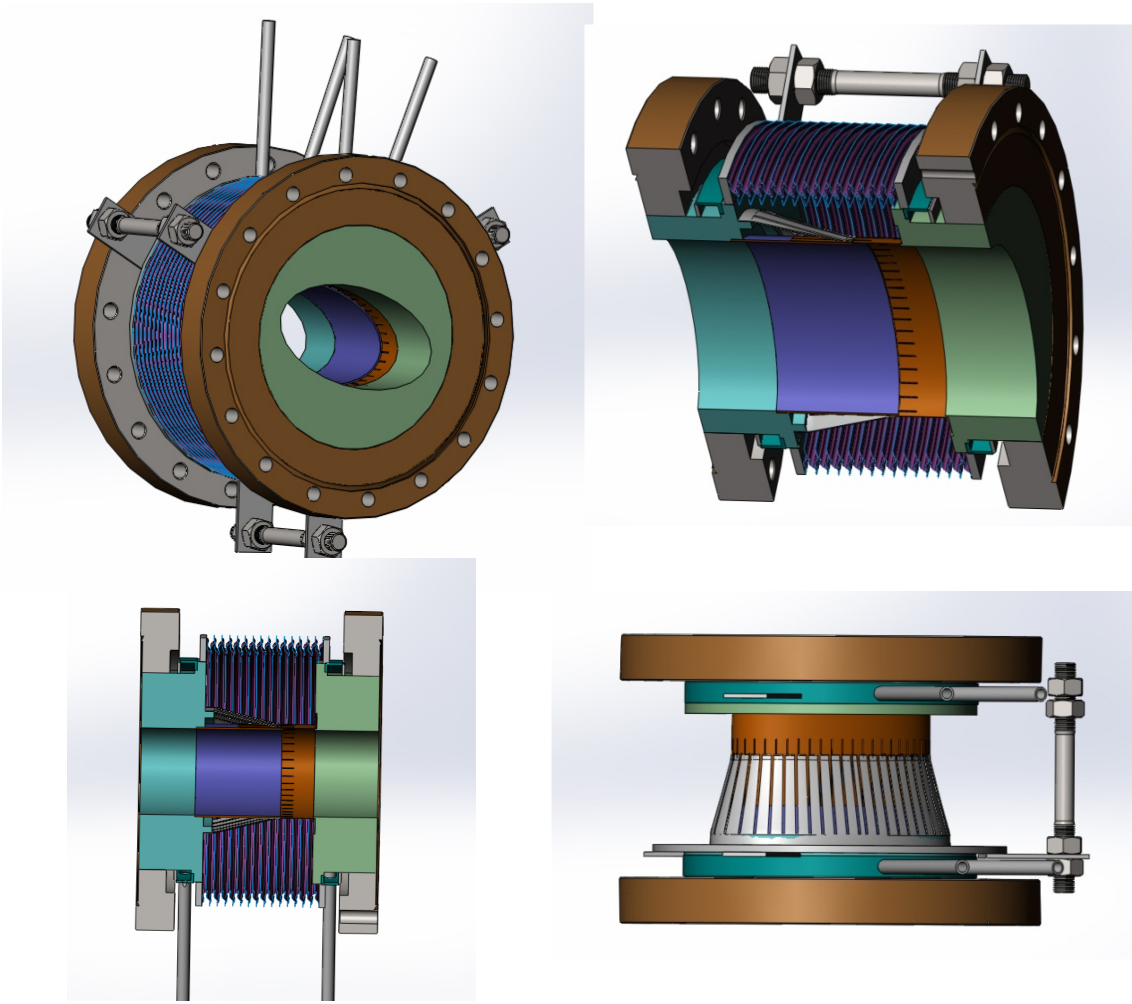


The copper chamber manufacturing procedure:

- Extrusion of the beam pipe and cooling channel,
- Machining of the components to be welded,
- Chemical cleaning,
- Electron-beam welding,
- Welding of the end flanges and water connections,
- Leak checks,
- NEG coating of the inside chamber.

Vacuum system R&D

A three-dimensional drawings of RF bellows are designed.



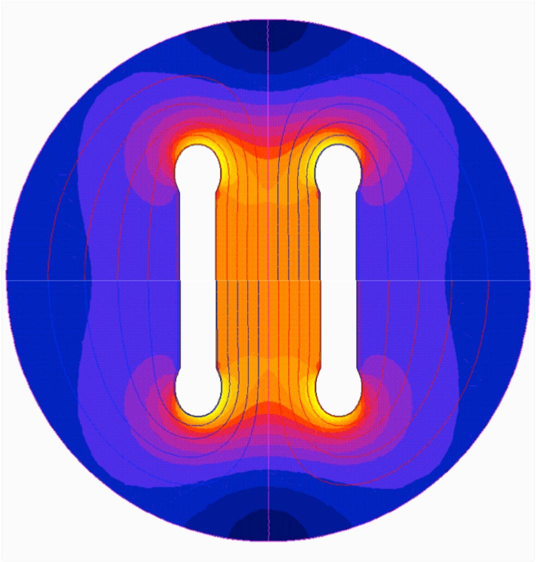
RF shielding bellow module

For CEPC, the fingers are designed to maintain a relatively high contact pressure of 150±10 g/finger, and the slit length between fingers is set to be 20mm. The RF-shield should absorb the maximum expansion of 10 mm and contraction of 20 mm, allowing for the offset of 2 mm. The step at the contact point is limited to less than 1mm. The cooling water channel is attached considering the reflecting power of the synchrotron radiation, Joule loss and HOM heat load on the inner surface, and the leaked HOM power inside the bellows.

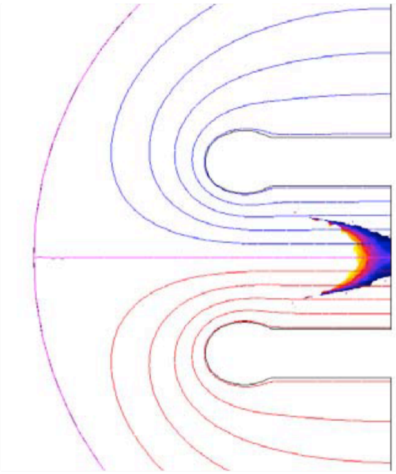
Electrostatic Separator R&D

Beam energy	120 GeV
Separator length	4.5m
Inner diameter of separator tank	540mm
Electrode length	4.0m
Electrode width	260mm
Nominal gap	110mm
Maximum operating field strength	2MV/m
Maximum operating voltage	±110kV
Maximum conditioning voltage	±160kV
Maximum deflection	62.5urad
Horizontal good field region (1% limit)	±80mm
Nominal vacuum pressure	2.7e-8 Pa

- **Electrode**
- Field homogeneity : 1‰ in 10 x 10 mm^2
  - Electrode shape


Field distribution

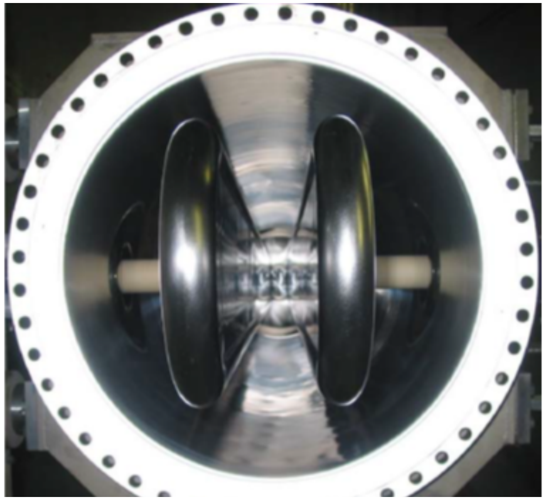
ZL: 1‰ for 25 x 13 mm

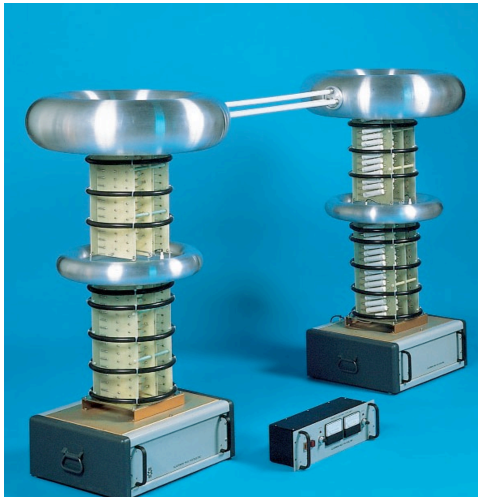

Field homogeneity

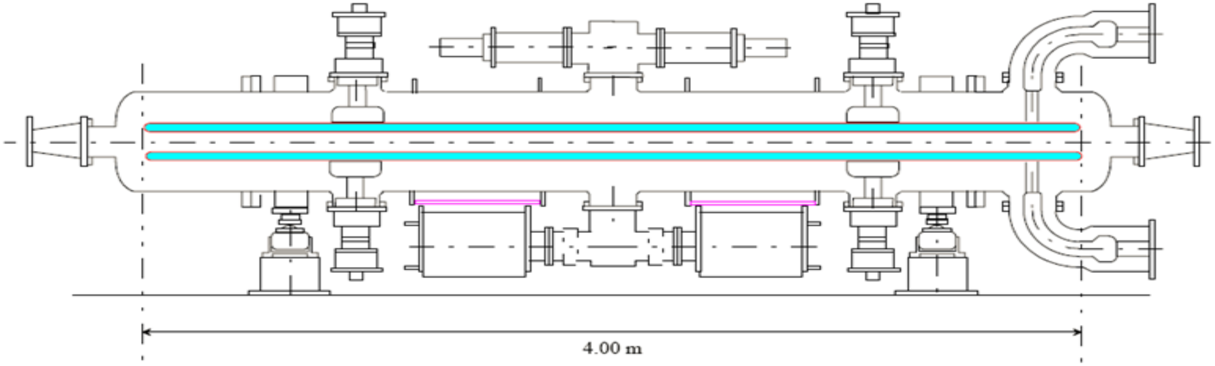
Electrostatic Separator R&D

- A separator unit including: a pair of electrodes, UHV tank, metal-ceramic supports, high voltage feedthrough, High voltage circuit, vacuum system.

- **Electrode** (a pair of hollow metal flat plate)
- Dimension : 4m long and 260mm wide
- Material : Titanium
- Separated direction : Horizontal
- Field strength : 2MV/m
  - Electrode material
  - Surface preparation







CEPC accelerator CDR mini-review

4-5 November 2017, IHEP

- About 27 talks for accelerator physics and systems
  - Accelerator physics
  - Linac
  - SRF
  - RF power source
  - Cryogenics
  - Magnet
  - SC magnet
  - Power supply & E- separator
  - Vacuum
  - Instrumentation
  - Control
  - Radiation Shielding
  - Survey & Alignment
  - Mechanics
  - Conventional facilities
  - Siting

  Etc.

CEPC-SPPC CDR Mini-review members (15)

Name (alphabetical order)	**Institute**	**Country**
Anton Bogomyakov	BINP	Russia
Brian Foster	Oxford U.	U.K.
Eugene Levichev	BINP	Russia
Kexin Liu（刘克新）	Peking U.	China
Ernie Malamud	Fermilab	USA
Kazuhito Ohmi	KEK	Japan
Katsunobu Oide	CERN / KEK	Switzerland
Carlo Pagani	U. of Milan / INFN	Italy
John Seeman	SLAC	USA
Sergey Sinyatkin	BINP	Russia
Mike Sullivan	SLAC	USA
Chuanxiang Tang（唐传祥）	Tsinghua U.	China
Lin Wang（王林）	USTC	China
Xiangqi Wang（王相綦）	USTC	China
Akira Yamamoto	KEK	Japan

Conclusion

- Designing of all accelerator systems moving forward well including accelerator physics, SRF system, high efficiency klystron etc.
- CEPC accelerator CDR mini-review, 4-5 Nov. 2017
- About 285M RMB Funding from variable sources for accelerator key technology R&D for recent 5 years.
- Hope complete development of all necessary key technologies and prototyping in the 5 years before 2022.

Thanks for your attention!