Introduction to CEPC/SppC R&D Issues

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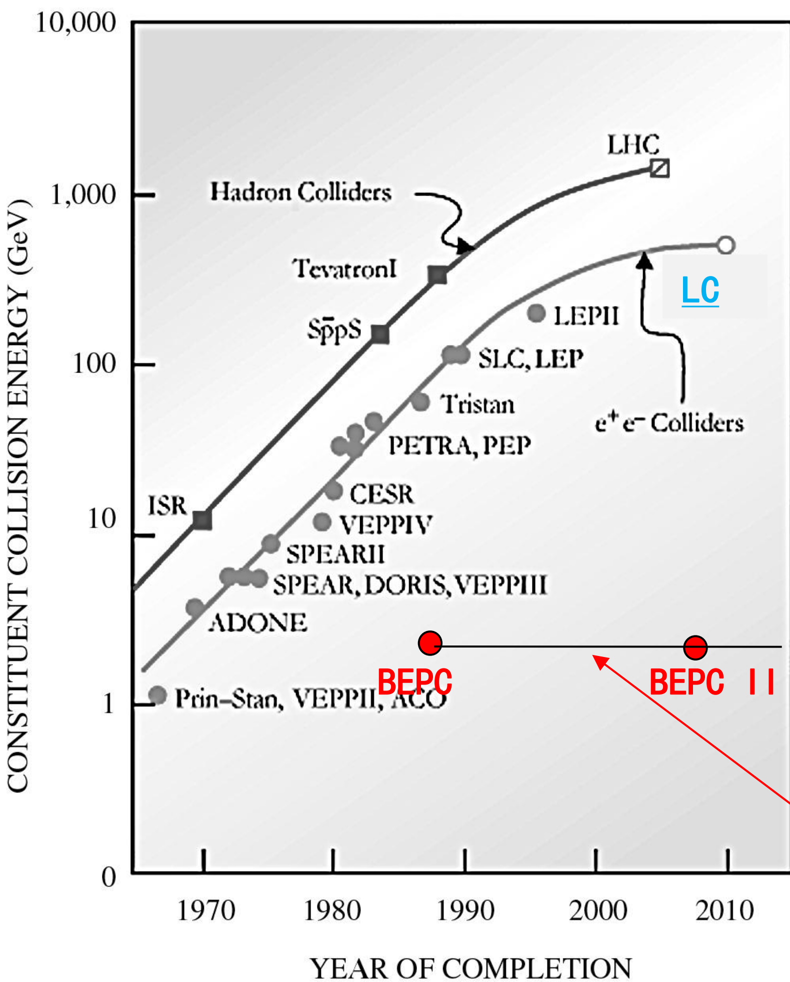
From BEPC to BEPCII

BEPC was completed in 1988 with luminosity $1\times10^{31}cm^{-2}s^{-1}$ @1.89GeV

BEPC II was completed in 2009 with Luminosity reached: $8.2\times10^{32}cm^{-2}s^{-1}$ @1.89GeV

After BEPCII what is the next high energy collider?

Lepton and Hadron Colliders' History and China Accelerator based High Energy Physics Development in the Future



Old picture!

CEPC+SppC

CEPC: Ecm=240GeV e+e- Circular Collider
SppC: Ecm=50-100TeV pp Collider

CEPC+SppC will be constructed with international collaboration and participation

HIEPAF: High Intensity Electron Positron Accelerator Facility

History of BEPC and BEPC II

Strategy on Future High Energy Colliders of China

1) On "The 464th Fragrant Hill Meeting， June 12-14， 2013", Chinese High Energy Physics Community arrived at the following consensus:

a) China supports ILC and will participate to ILC construction with in-kind contributions and requests R&D fund from government

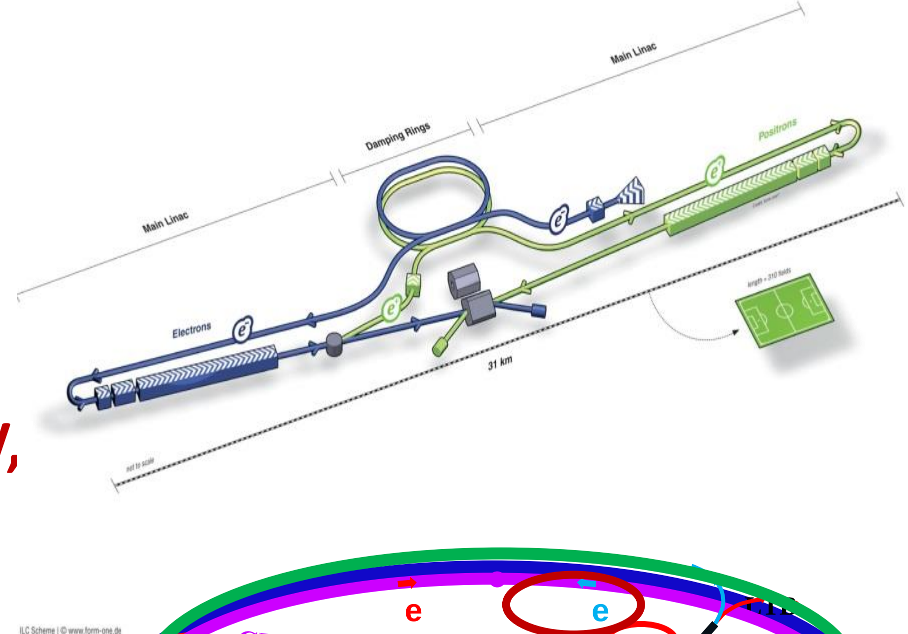
b) After the discovery of Higgs, as next collider after BEPCII in China, a circular e+e- Higgs factory（CEPC）and a Super proton-proton Collier (SppC) afterwards in the same tunnel is an important option and historical opportunity.

2) During the meeting of Chinese High Energy Physics Association on "China High Energy Physics based on Particle Accelerators", Feb. 28, 2014, it was concluded that: "Circular e+e- Circular Higgs Factory(CEPC) +Super pp Collider (SppC) is the first choice for China's future high energy physics accelerator.

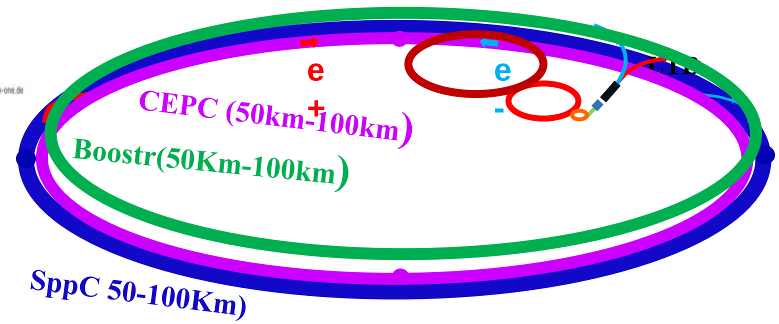
- **It is considered that CEPC (250GeV upper limit) is *supplementary to ILC in terms of its energy range down to W and Z boson and to the number of detectors from both machines***
- ***International collaboration and participation are necessary***

Ways to the future-Large accelerators：

- Higher energy
- Higher precision



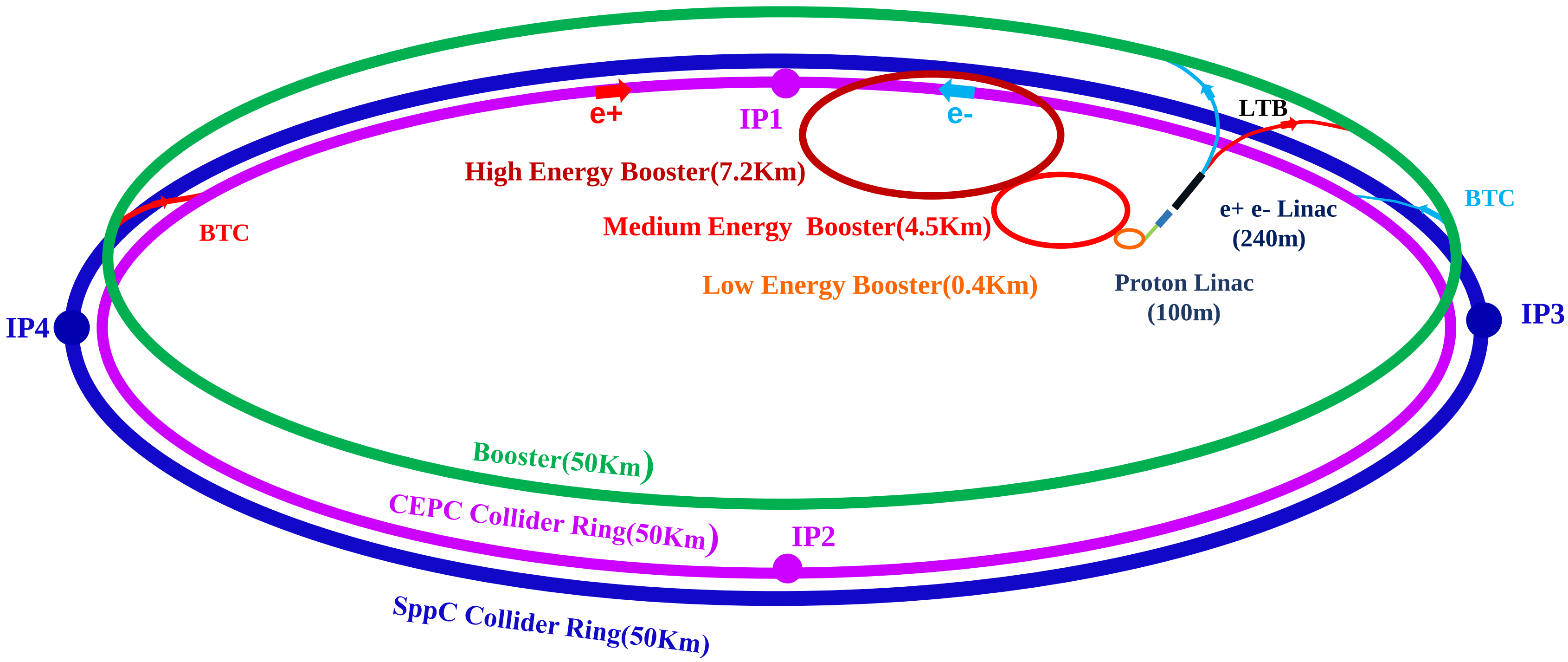
1） Linear colliders： ILC-CLIC （from Higgs energy to 5TeV, China participates)



2） Circular Colliders： CEPC-SppC e+e- Higgs factory-pp 50~100TeV (machine at home with international Participation)

Precision @ e+e- collider
Energy frontier @ pp collider

Introduction to CEPC+SppC



LTB : Linac to Booster

BTC : Booster to Collider Ring

Main parameters for CEPC

Parameter	Unit	Value	Parameter	Unit	Value
Beam energy [E]	GeV	120	**Circumference [C]**	m	54420
Number of IP[N_{IP}]		2	**SR loss/turn [U_0]**	GeV	3.11
Bunch number/beam[n_B]		50	**Bunch population [Ne]**		3.71E+11
SR power/beam [P]	MW	51.7	**Beam current [I]**	mA	16.6
Bending radius [ρ]	m	6094	**momentum compaction factor [α_p]**		3.39E-05
Revolution period [T_0]	s	1.82E-04	**Revolution frequency [f_0]**	Hz	5508.87
emittance (x/y)	nm	6.12/0.018	**β_{IP}(x/y)**	mm	800/1.2
Transverse size (x/y)	μm	69.97/0.15	**$\xi_{x,y}$/IP**		0.116/0.082
Beam length SR [$\sigma_{s.SR}$]	mm	2.17	**Beam length total [$\sigma_{s.tot}$]**	mm	2.53
Lifetime due to Beamstrahlung	min	80	**lifetime due to radiative Bhabha scattering [τ_L]**	min	52
RF voltage [V_{rf}]	GV	6.87	**RF frequency [f_{rf}]**	MHz	650
Harmonic number [h]		117900	**Synchrotron oscillation tune [ν_s]**		0.18
Energy acceptance RF [h]	%	5.98	**Damping partition number [Jε]**		2
Energy spread SR [$\sigma_{\delta.SR}$]	%	0.13	**Energy spread BS [$\sigma_{\delta.BS}$]**	%	0.08
Energy spread total [$\sigma_{\delta.tot}$]	%	0.16	**n_γ**		0.23
Transverse damping time [n_x]	turns	78	**Longitudinal damping time [n_ε]**	turns	39
Hourglass factor	Fh	0.692	**Luminosity /IP[L]**	$cm^{-2}s^{-1}$	2.01E+34

SppC main parameters

Parameter	Value	Unit
Circumference	52	km
Beam energy	35	TeV
Dipole field	20	T
Injection energy	2.1	TeV
Number of IPs	2 (4)	
Peak luminosity per IP	1.2E+35	$cm^{-2}s^{-1}$
Beta function at collision	0.75	m
Circulating beam current	1.0	A
Max beam-beam tune shift per IP	0.006	
Bunch separation	25	ns
Bunch population	2.0E+11	
SR heat load @arc dipole (per aperture)	56	W/m

Introduction to CEPC/SppC R&D Issues

1. CEPC SRF system
2. CEPC RF power system
3. CEPC Cryogenic system
4. CEPC Magnet system
5. CEPC Power supply system
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7. CEPC Instrumentation system
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11. CEPC Synchrotron shielding system
12. CEPC Linac injector system
13. SppC SC high field magnet system
14. ....

CEPC SRF System R&D

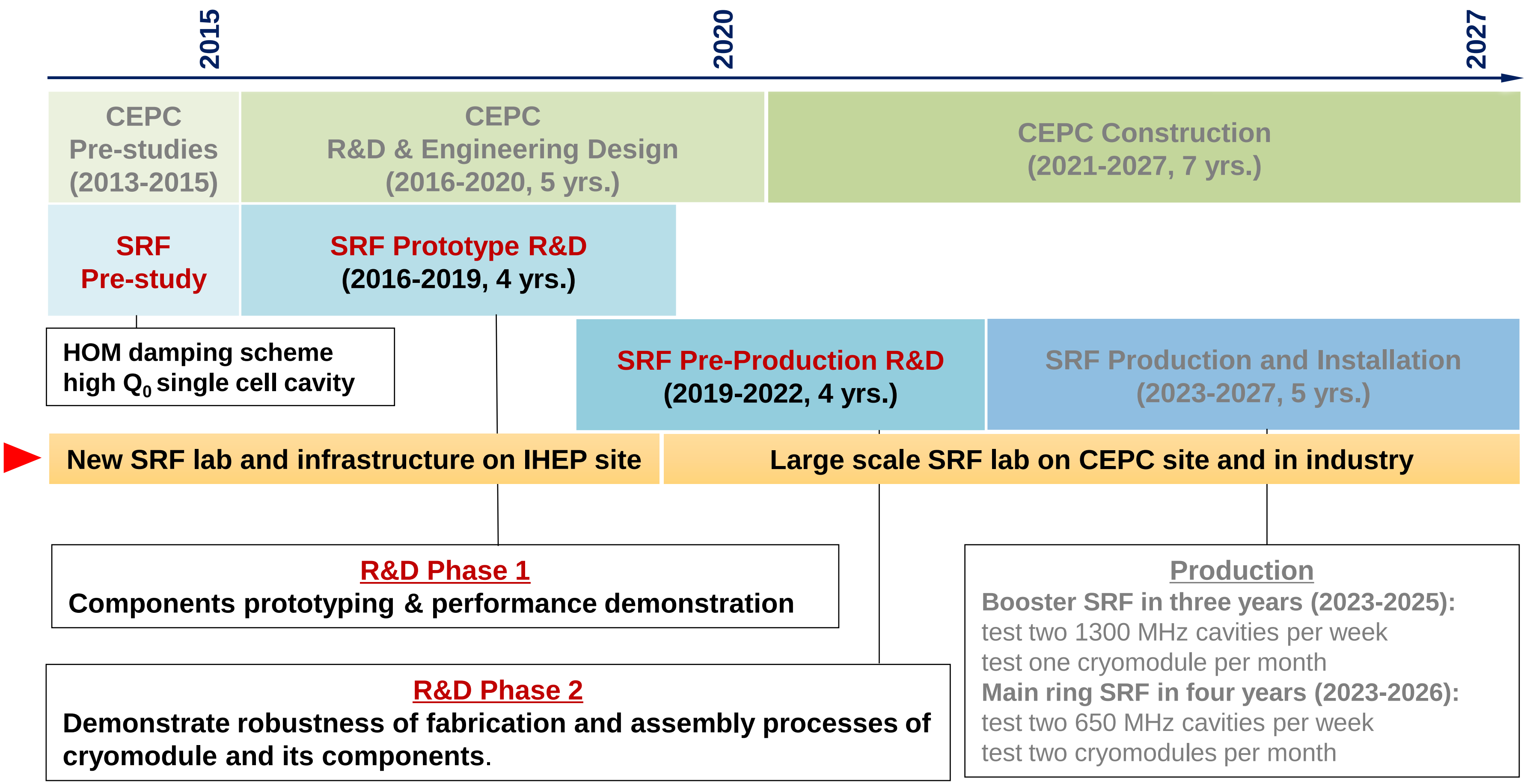
- CEPC will require two large SRF systems, which would be one of the largest SRF installations in the world.
  - 384 cavities operating at 650 MHz in 96 cryomodules for the main ring
  - 256 cavities operating at 1300 MHz in 32 cryomodules for the booster
  - to succeed with designing, fabricating, commissioning and installation of such a system, a very significant investment in R&D, infrastructure and personnel is absolutely necessary
- Three main challenges (push technology frontier)
  - huge HOM power extraction with low heat load
  - cavity with very high Q_0 at 15-20 MV/m
  - very high CW power coupler (robust, clean assembly and low heat load)

SRF Parameters and R&D Goals

Parameters	CEPC-Collider	CEPC-Booster
Cavity Type	650 MHz 5-cell Nitrogen-doped Nb	1.3 GHz 9-cell Nitrogen-doped Nb
Operating E_{acc}	15.5 MV/m	19.3 MV/m
Operating Q_0	4E10 @ 2K	2E10 @ 2K
Cavity vertical test qualification	20 MV/m @ 4E10	23 MV/m @ 2E10
Input coupler power (CW)	320 kW	20 kW (DF 20%)
HOM damper power (CW)	10 kW ferrite + 1 kW hook	50 W (hook + ceramic)
Cavity number	384	256
Cryomodule number	96 (4 cav. / module)	32 (8 cav. / module)

And cryomodule heat load …

SRF R&D Plan


2015
2020
2027
CEPC
Pre-studies
(2013-2015)
CEPC
R&D & Engineering Design
(2016-2020, 5 yrs.)
CEPC Construction
(2021-2027, 7 yrs.)
SRF
Pre-study
SRF Prototype R&D
(2016-2019, 4 yrs.)
HOM damping scheme
high Q_0 single cell cavity
SRF Pre-Production R&D
(2019-2022, 4 yrs.)
SRF Production and Installation
(2023-2027, 5 yrs.)
New SRF lab and infrastructure on IHEP site
Large scale SRF lab on CEPC site and in industry
R&D Phase 1
Components prototyping & performance demonstration
R&D Phase 2
Demonstrate robustness of fabrication and assembly processes of cryomodule and its components.
Production
Booster SRF in three years (2023-2025):
test two 1300 MHz cavities per week
test one cryomodule per month
Main ring SRF in four years (2023-2026):
test two 650 MHz cavities per week
test two cryomodules per month

Phase 1: Prototype R&D (2016-2019)

- Cavities
  - design and order 4 prototypes of each type from industry
  - perform tests to demonstrate the cavity performance goals
  - perform a series of tests to optimize the cavity surface treatment
  - weld helium jackets on the cavities, re-test and demonstrate the performance goals
- Input couplers, HOM dampers, Tuners and LLRF control system
  - design and order several prototypes from industry
  - build test stands
  - demonstrate that their performance meets the CEPC requirements
- Cryomodule design
- Horizontal Test Cryomodule
  - design and build a short (two-cavity) module for each cavity type
  - demonstrate performance of all components integrated into a cryomodule

Phase 2: Pre-Production R&D (2019-2022)

- Demonstrate 90 % cavity yield (2019-2020)

  Build and test 30 1.3 GHz booster cavities and 40 650 MHz main ring cavities (~ 10 % of mass production).
  - pre-qualify vendors for mass production of cavities
  - several cavities of each type should be chosen for horizontal testing
  - most of the cavities will be installed to the test cryomodules
- Demonstrate cryomodule performance (2020-2022)

  Build and test two booster cryomodules and three main ring cryomodules.
  - including 16 1.3 GHz booster cavities, couplers, tuners, etc.
  - including 12 650 MHz main ring cavities, couplers, tuners, etc.
  - beam test especially for the main ring HOM damping and heat load

SRF Infrastructures

- Facilities (IHEP site, CEPC site & industry; distributed)
  - cavity fabrication, welding, inspection and local repairing
  - RF lab and tuning machines
  - BCP and EP treatment facilities, ultrasonic cleaning device
  - annealing furnaces
  - 4 vertical test stands
  - clean rooms, HPR systems, baking system
  - input coupler preparation and conditioning facilities
  - cryomodule assembly lines
  - 4 cryomodule horizontal test stations
  - high power RF equipment and a cryogenic plant

A 5000 m^2 SRF lab on IHEP site should be available during 2016-2017.

A 10000 m^2 SRF (and Magnet) Lab on CEPC site is needed eventually

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13. SppC SC high field magnet system

Collider power source

Efficiency comparison and power demands

Klystron and Solid state amplifier (SSA)

Parameters mode	Klystron	SSA
Overall efficiency (%)	>50	<40
Beam power (MW)	100	100
DC input power (MW)	200	>250
RF overhead factor	1.3	1.3
Wall Plug power (MW)	**260**	**>325**

The klystron is more attractive because of its potential for higher efficiency than solid state amplifier.

Collider power source

CEPC collider SRF system parameters

Parameters mode	Value
Operation frequency	650MHz+/-5MHz
Cavity Type	650MHz 5-cell
Cavity number	384
RF input power (kW)	**260 CW**
RF source number	384

Klystron today:

Output Power: CW up to ~1.3MW (max.)

Collider power source

CEPC collider SRF system parameters

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RF input power (kW)	**260 CW**
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Considering klystron lifetime and power redundancy, the 2 cavities will be powered with one CW klystron capable to deliver more than 800 kW.

Collider power source

Klystron key design parameters

Parameters mode	Value
Centre frequency (MHz)	650+/-0.5
Output power (kW)	800
Beam voltage (kV)	90
Beam current (A)	18
Efficiency (%)	65
Gain (dB)	40

The klystrons are not available from main vendors. It will be development from existing 500 MHz or 700 MHz CW klystron.

R&D

1) 650MHz/800kW CW klystron

A minimum transmitter power of 260 kW is required to meet the sum of the radiated, HOM, and reflected power demands. The Collider power source output power is more than 800 kW.

There are no 650 MHz CW klystron in the major klystron vendor, CPI, THALES and TOSHIBA etc.

The klystron could be manufactured by industry after some initial R&D. It will be development from existing 500 MHz or 700 MHz CW klystron by IHEP and industrial company together with international cooperation.

R&D

2) 650MHz/400kW Solid state amplifier (SSA)

Because of less efficiency in solid state amplifier, the base line power source for CEPC collider is klystron.

The 650MHz/150kW SSA has been developed in different Chinese company for ADS Project.

On this basis, to promote 400kW SSA development in increasing efficiency, reducing cost, etc., to provide more options for the future CEPC collider power source.

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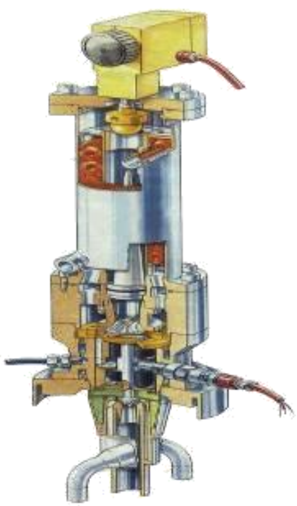
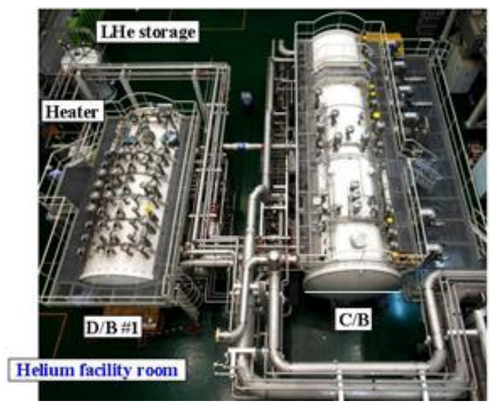
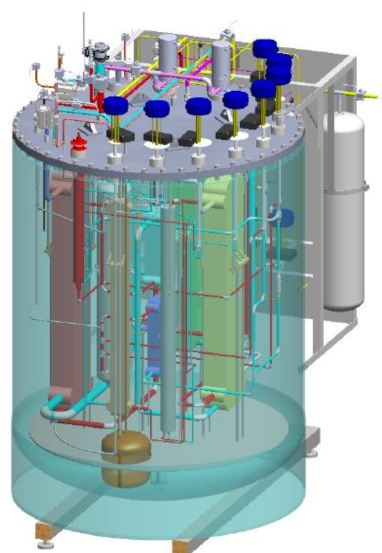
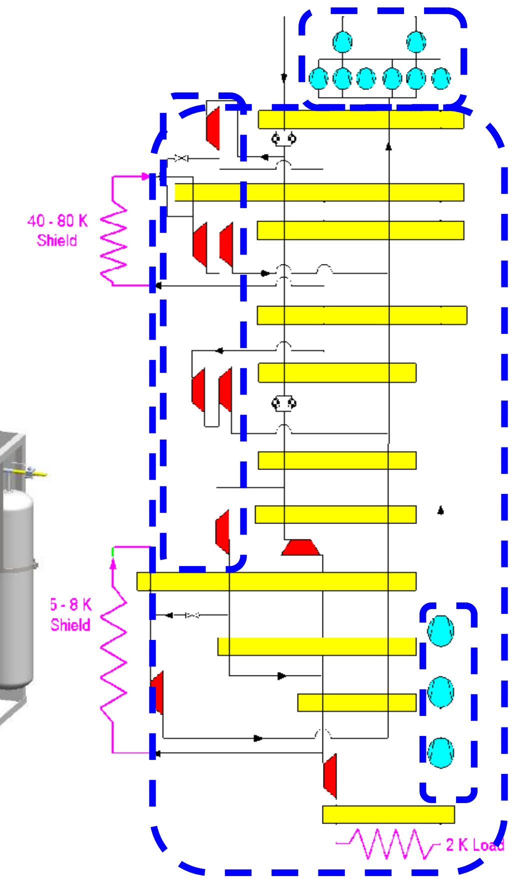
CEPC Helium cryogenic system R&D

- A 12KW@4.5K crygenic system and test stand









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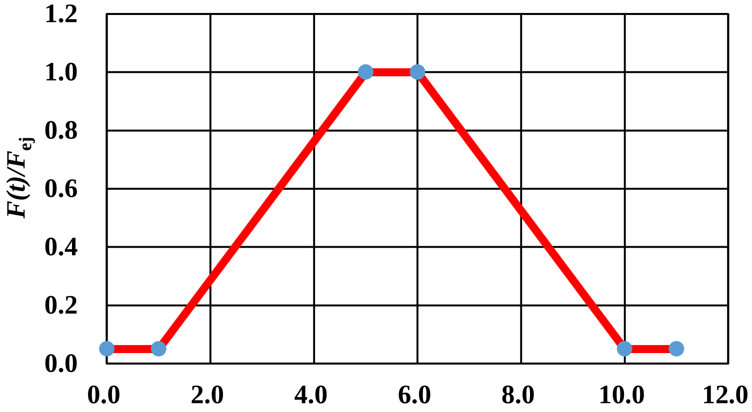
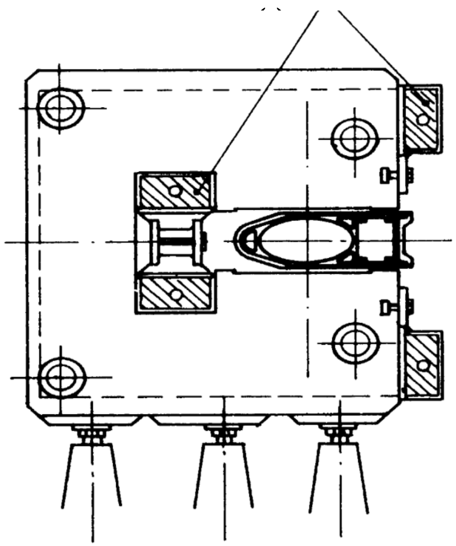
R & D plan of the magnet system

In the R & D stage of the CEPC project, three kinds of prototype magnets will be developed.

1 The prototype dipole magnet for the Booster

1) There are 5120 dipole magnets in the Booster, each long 8m, total length of the dipole magnets is 41km, covering 74% of the Booster;
2) The field changes from 30 Gs to 646 Gs, repetitive rate is 0.1Hz;
3) For economic reasons, the magnets will be made by C-shaped steel-concrete cores, the filling factor is about 20%. The coils will be made by hollow aluminium conductors instead of copper conductors.





R & D plan of the magnet system

The key technical issues of the prototype dipole magnet for the Booster.

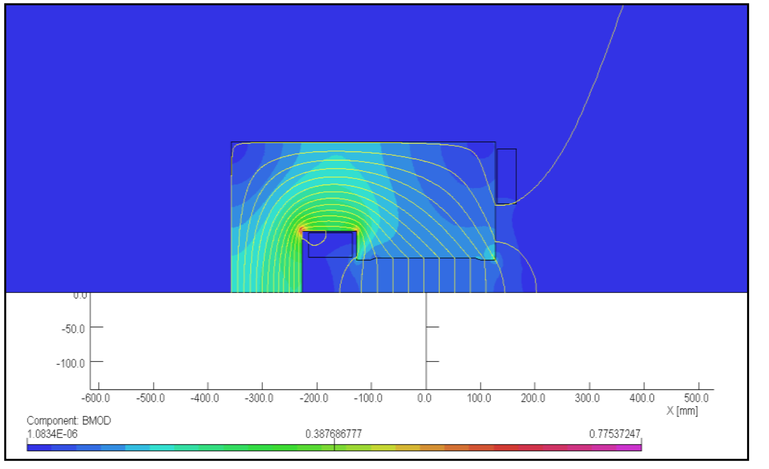
1) The magnetic and mechanical design of the dipole magnet with very low field.

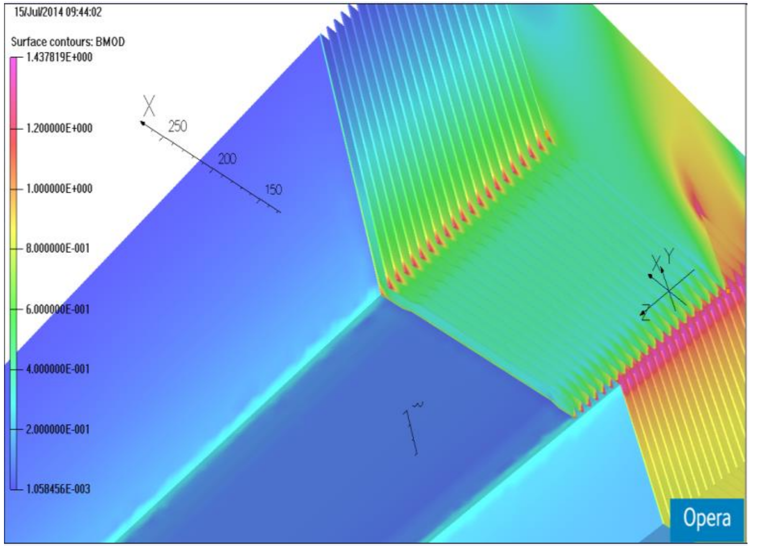
2) The effect of earth field.

3) The eddy current effect induced by the field ramping.

4) The fabrication procedures of steel-concrete cores with long length but small cross section.

5) The in situ. assembly of 8m long magnets and in situ. welding of hollow aluminum conductors

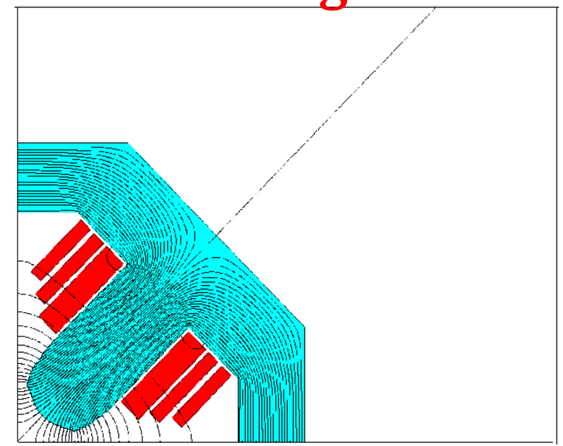


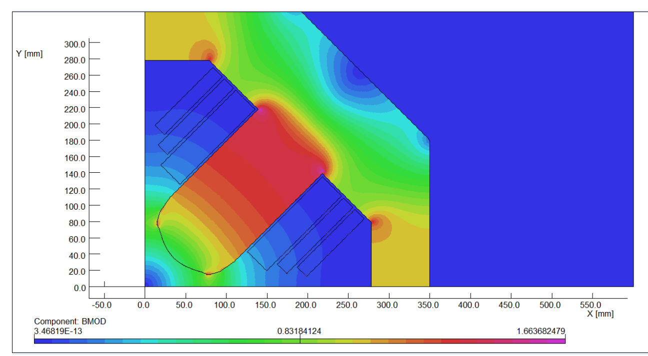


R & D plan of the magnet system

2 The prototype quadrupole magnet for the Main Ring

1) There are 1436 quadrupole magnets in the Main Ring, each long 1m;
2) The cores of the magnets are made by low carbon silicon laminations, but for economic reasons, the coils of the magnets will be made by aluminium conductors instead of copper conductors;
3) In order to reduce Joule loss, the cross section of the coils is designed as large as possible. And for coil installation, the cores of the quadrupole magnets must be divided into four parts.





R & D plan of the magnet system

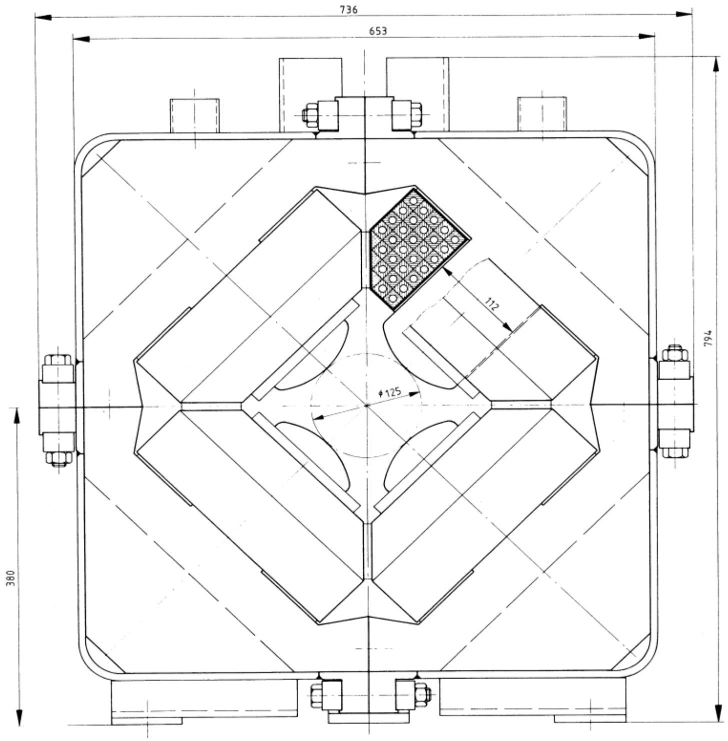
The key technical issues of the quadrupole magnet for the Main Ring

1) The magnetic and mechanical design of the quadrupole magnet with economical cross section and size.

2) Development and mass production of high quality hollow aluminum conductors.

3) The fabrication procedures of the coils wound by hollow aluminum conductors.

4) The magnetic field measurement of the 2m long quadrupole magnet with small aperture.



R & D plan of the magnet system

The main parameters of the prototype quadrupole magnet for the Main Ring

Bore diameter (mm)	100
Field gradient (T/m)	10
Magnetic length (m)	2.0
Ampere-turns per pole (AT)	10382
Coil turns per pole	29
Excitation current (A)	358
Conductor size (mm)	15×15, ∅9, r1(Hollow Al conductor)
Current density (A/mm^2)	2.2
Resistance (Ω) @35°	0.1
Inductance (H)	0.095
Voltage drop (V)	35.7
Joule loss (kW)	12.8
Water pressure (kg/cm^2)	6
Cooling circuits	4
Water flow velocity (m/s)	1.6
Total water flow (l/s)	0.41
Temperature increase of coolant (°C)	8.5
Core width and height (mm)	700×700
Core length (mm)	1960
Net core weight (t)	4.5
Net conductor weight (t)	0.24

R & D plan of the magnet system

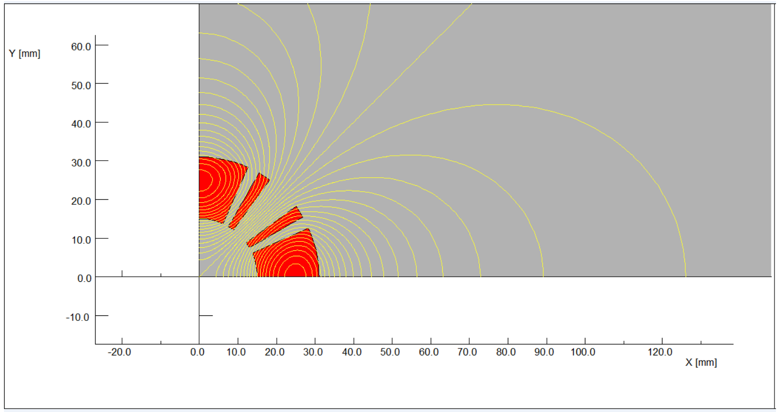
3 The prototype superconducting quadrupole magnet for the Main Ring

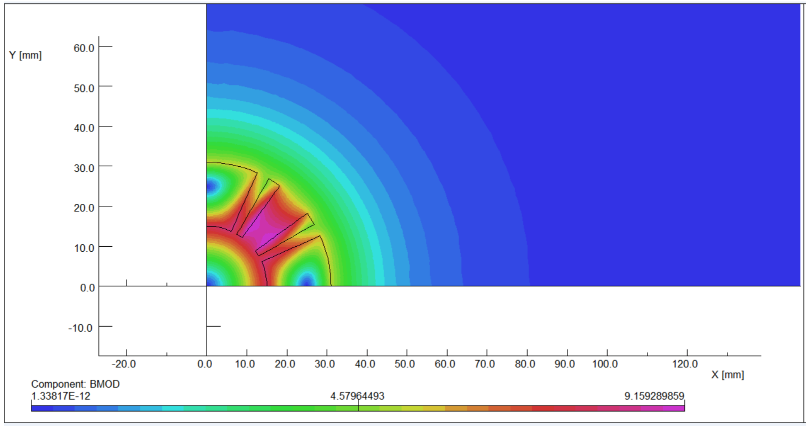
1） There are two types of strong field quadrupole magnets in the CEPC Interaction Region. The magnetic field at the pole region exceeds 7T. In addition, the magnets are inside the detector magnet with a field of 3.5T;

2） Rutherford Type Nb_3Sn Cables will be used to make the coils to meet the high field requirement;

3） Two type of magnets without iron yokes have the same cross section but different length.

4） The magnetic field calculation is performed by OPERA-2D.





R & D plan of the magnet system

The key technical issues of the prototype superconducting quadrupole magnet.

1) The magnetic and mechanical design of the superconducting quadrupole magnet with very high field.

2) Development of Ni3Sn Rutherford cable.

3) The fabrication procedures of the coils wound by Ni3Sn Rutherford cable.

4) The design and development of the cryomodule for the high field quadrupole magnet.

5) The assembly and the test of the magnet.

R & D plan of the magnet system

The main parameters of the superconducting quadrupole magnet.

Magnet name	QD	QF
Field gradient (T/m)	304	309
Magnetic length (m)	1.25	0.72
Cable Type	Rutherford Type Nb_3Sn Cable	
Coil turns per pole	24	24
Excitation current (kA)	8.15	8.25
Coil layers	2	2
Cable Width (mm)	8	8
Stored energy (KJ)	70.2	41.4
Inductance (mH)	2.1	1.2
Peak field in coil (T)	7.2	7.1
Coil inner diameter (mm)	40	40
Coil out diameter (mm)	74	74
Cable weight (kg)	26	17
Cold mass weight (kg)	190	125
Cryostat diameter (mm)*	400	400
Coil mechanical length (mm)	1500	950

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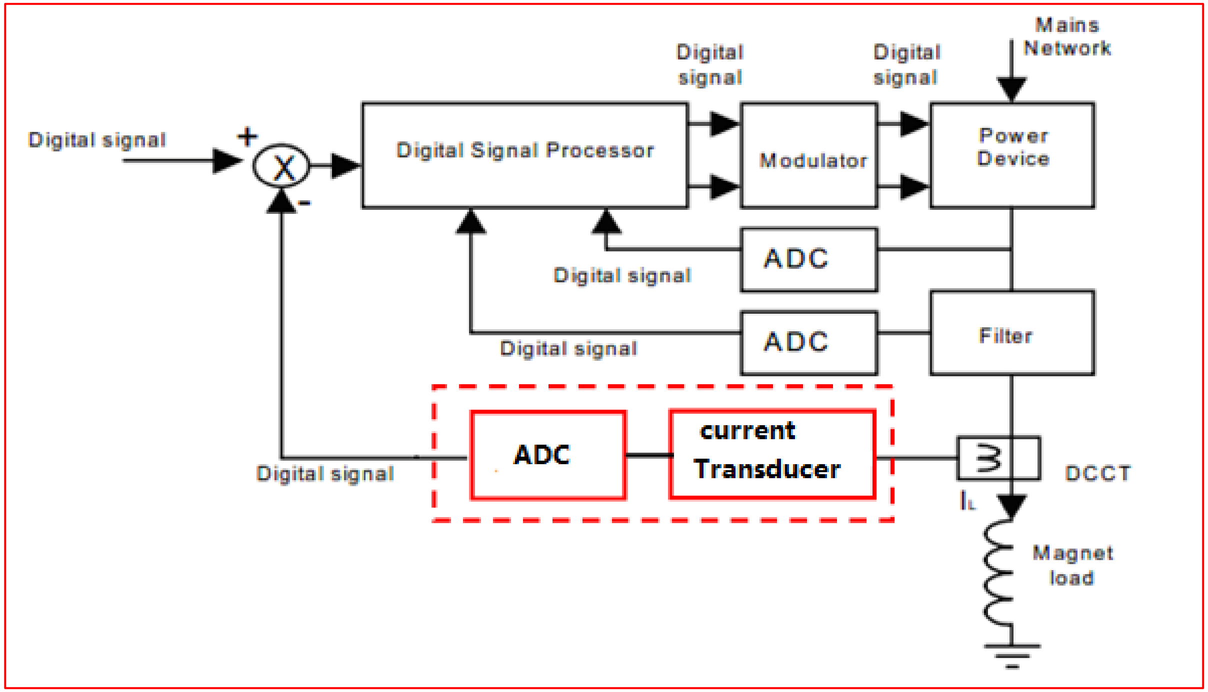
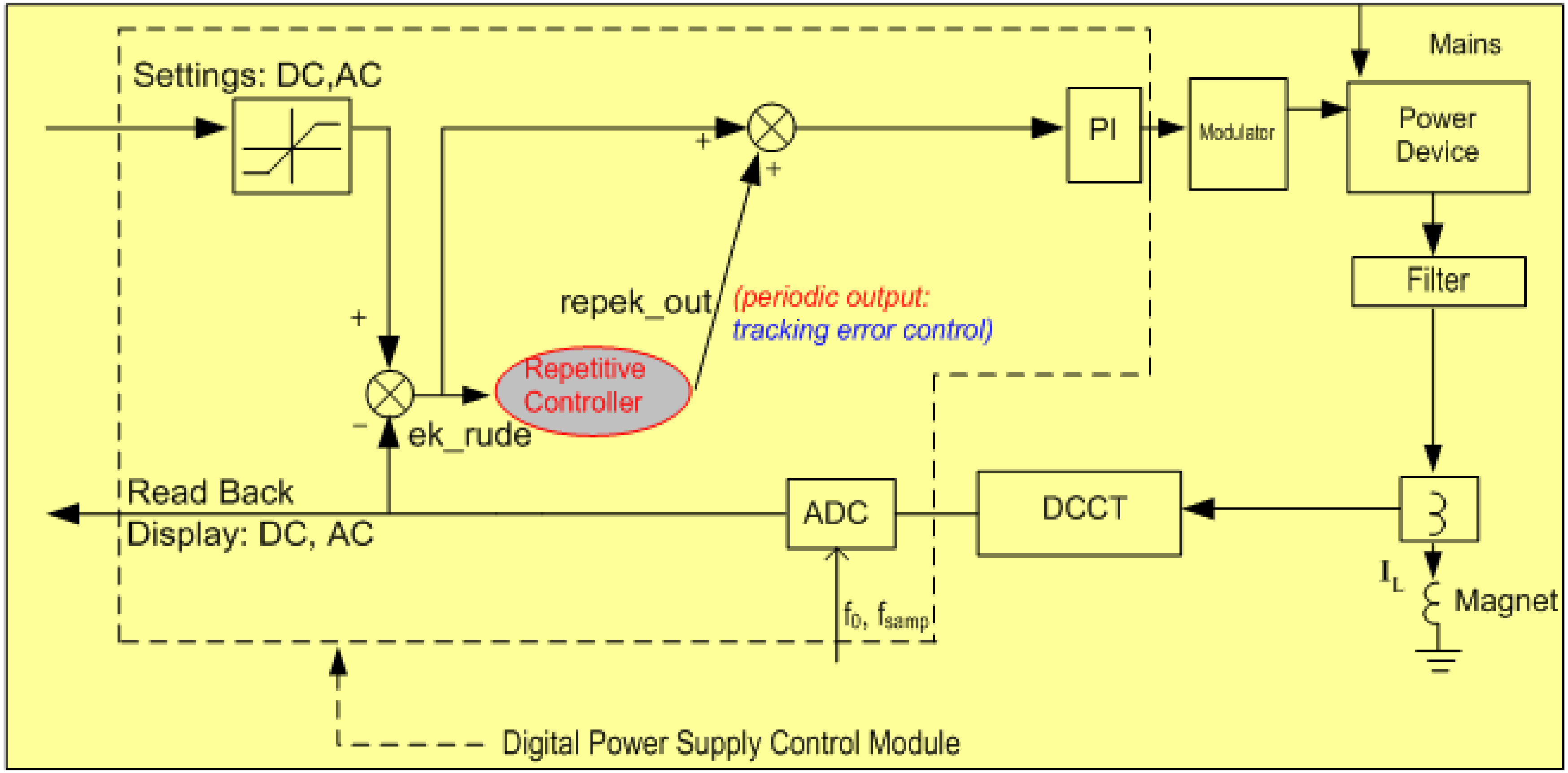
CEPC main ring magnets' power sources R&D

CEPC main ring magnets' power source will be all digital sources



Booster magnets' power supply R&D

0.1Hz dynamic digital power supply module for booster magnets



CEPC power supply R&D

1. CEPC main ring power supply

Power Supply	Number	Stability 8hours	Power (kW)/台
Dipole	8	100ppm	1600
Quad.	32	100ppm	985
Sext.D	32	300ppm	121
Sext.F	32	300ppm	79
Corrector	1500	500ppm	0.2
Total power for the storage ring power supply system			**55MW**

CEPC power supply R&D

2. Booster power supply（0.1Hz）

Power Supply	Number	Stability / tracking error	Power (kW)/台
Dipole	8	500ppm / 0.1%	411
Quad.F	16	500ppm / 0.1%	254
Quad.D	16	500ppm / 0.1%	133
Sext.D	32	1000ppm / 0.1%	1.1
Sext.F	32	1000ppm / 0.1%	1.3
Corrector	1436	1000ppm	0.3
Total power for the Booster power supply system			**12MW**

3. Power supply for injection linac

Power Supply	Number	Stability / tracking error	Power (kW)/台
Quad	200	500ppm	5.0
Corrector	120	1000ppm	1.6
Total power for the Booster power supply system			**1.2MW**

CEPC power supply（50km）

1. Power supply number：4000

2. Power supply：80MW

CEPC power supply（100km）

1. Power supply number：5000

2. Power supply：150MW

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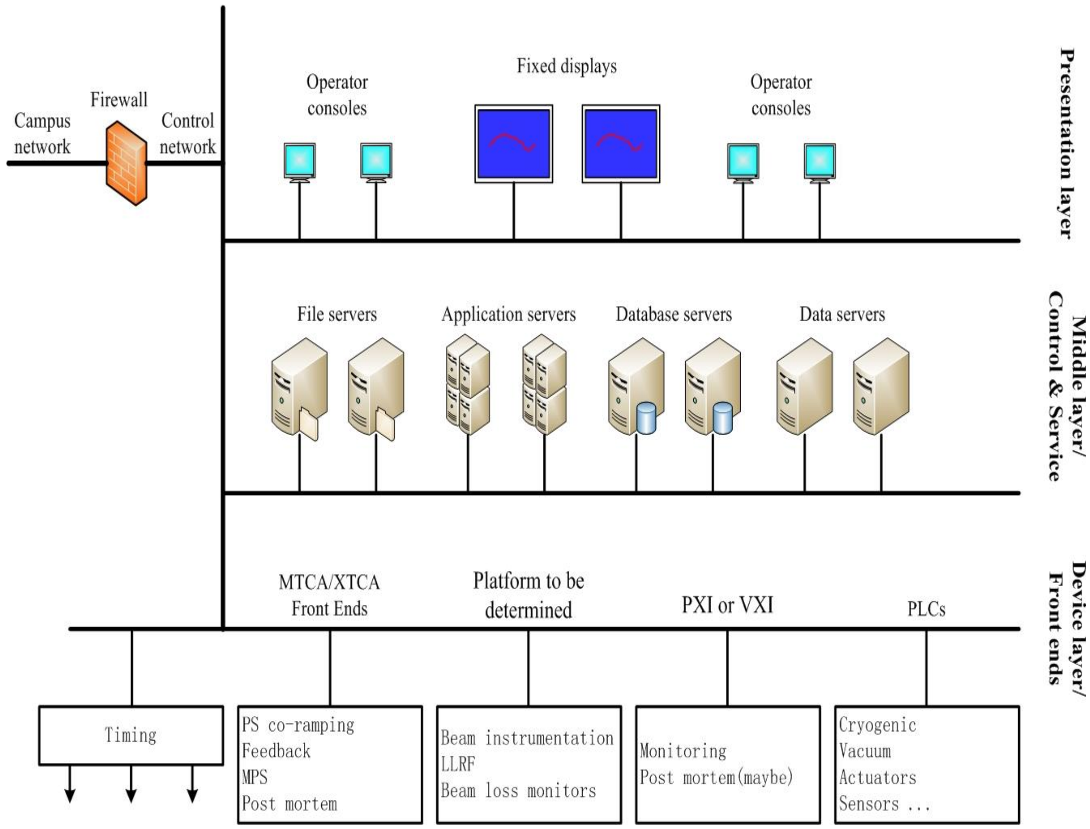
Main issues and design considerations

- Large scale control platform and applications, including software and hardware
- Large scale and high accuracy timing.
- Reliable machine protections.
- Post mortem recording and analysis.
- Others.

Main issues and design considerations
Large scale control platform

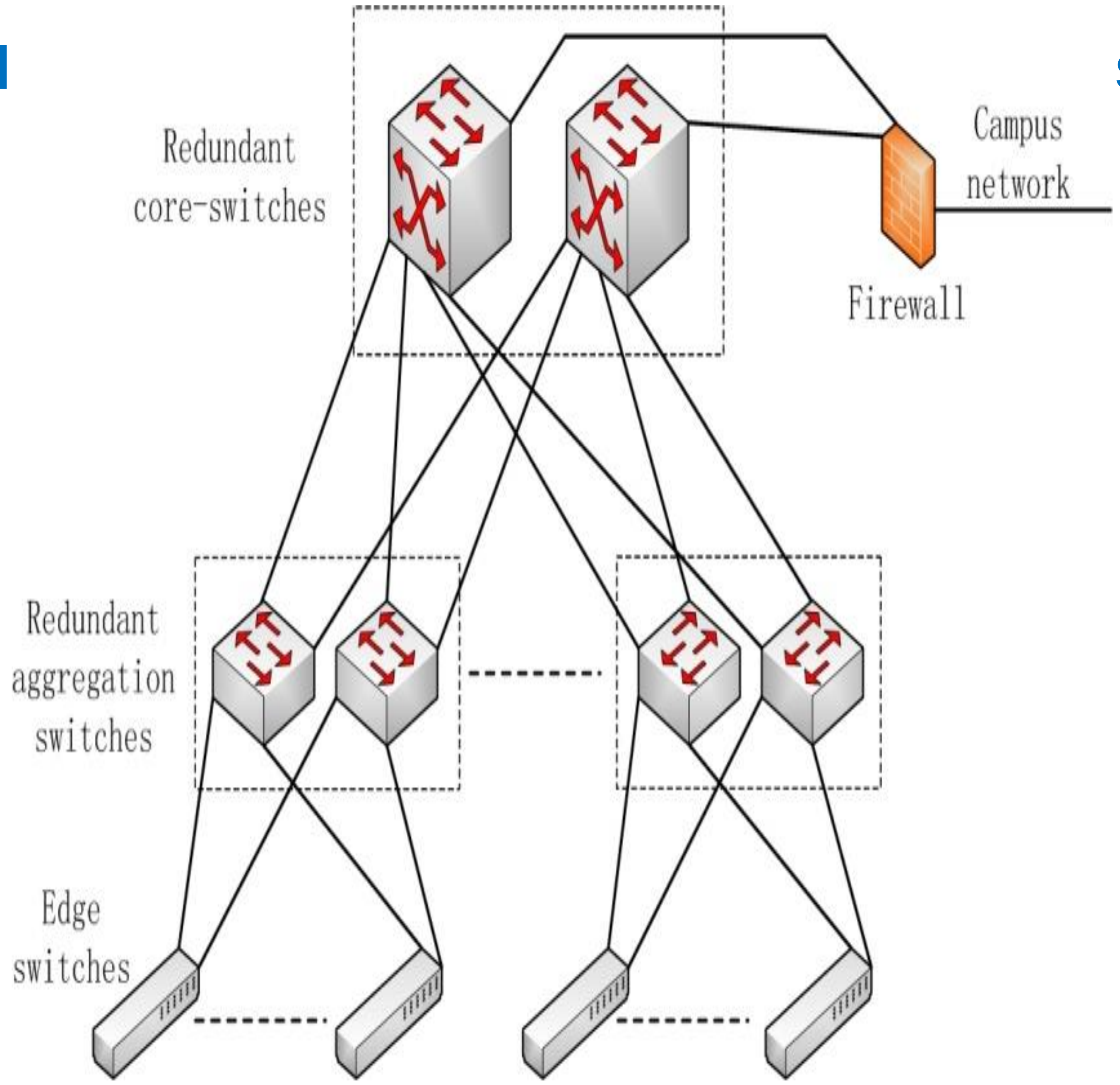
- Network based global connections.
- EPICS (Experimental Physics and Industrial Control System) based software platform.
- Data archiving and consultation, system alarms, event logging.
- Design database (Devices and their connections, design files …)
- Control software and hardware standardization.
- High reliability and high availability considerations (virtual machines, redundancy, fault-safe …)

Main issues and design considerations Large scale control platform



Overall architecture of the control system

M s


Redundant
core-switches
Campus
network
Firewall
Redundant
aggregation
switches
Edge
switches

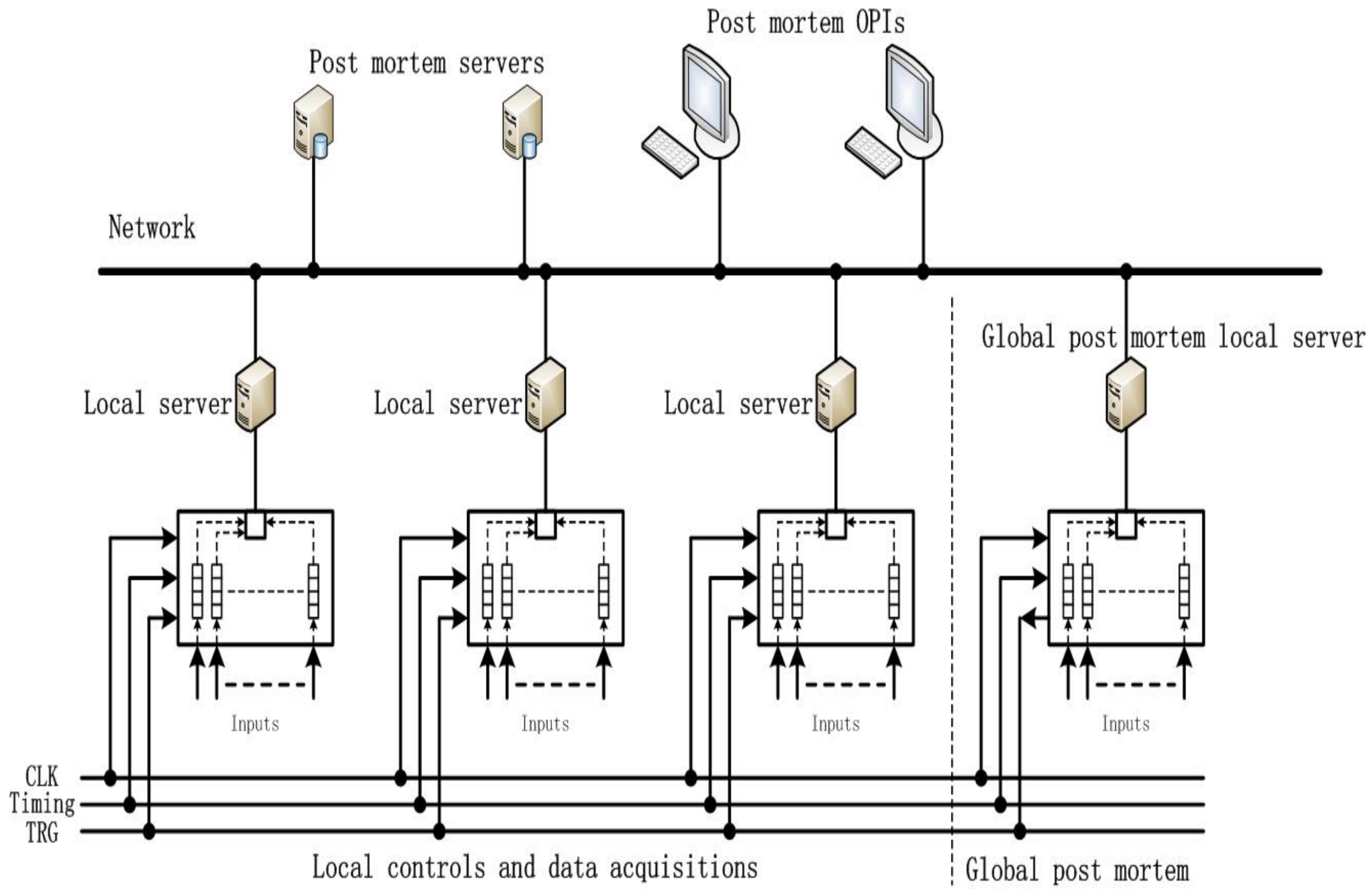
Main issues and design considerations
Large scale and high accuracy timing

- An maximum distance of about 30 km (A little larger than half a ring).
- Latency change due to temperature variations. Phase stabilized optical fiber and realtime compensation?
- Jitter of tens of ps?
- Event based digital timing system will be designed.
- Precise timestamp will be provided with an accuracy of ~100ns.

Main issues and design considerations
Post mortem recording and analysis

- For fast and accurate fault diagnostics.
- Both hardware and software works.
- Tightly related to the devices' controls.
- Accurate timestamp needed.
- Global trigger, global clocks, global timing, analysis software …

Main issues and design considerations
Post mortem recording and analysis



Preliminary design of post mortem recording and analysis

R&D

- High precise and high stable timing signals/clock fan out. Mainly for beam injection, extraction and acceleration.
- High reliable control and high precise diagnostics. For high reliability and high beam availability.
- Development of large scale control and application tools. Much larger data, different application layers, data exchange channels and control channels allocation, information system …

Introduction to CEPC/SppC R&D Issues

1. CEPC SRF system
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3. CEPC Cryogenic system
4. CEPC Magnet system
5. CEPC Power supply system
6. CEPC Control system
7. CEPC Instrumentation system
8. CEPC Vacuum system
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10. CEPC Survey and alignment system
11. CEPC Synchrotron shielding system
12. CEPC Linac injector system
13. SppC SC high field magnet system

Beam diagnostic system R&D

- Bunch by bunch digital beam position processor
- Vacuum feed-through (for BMP and kickers)
- Beam loss detector and electronics(电离室型BLM束流损失探头)

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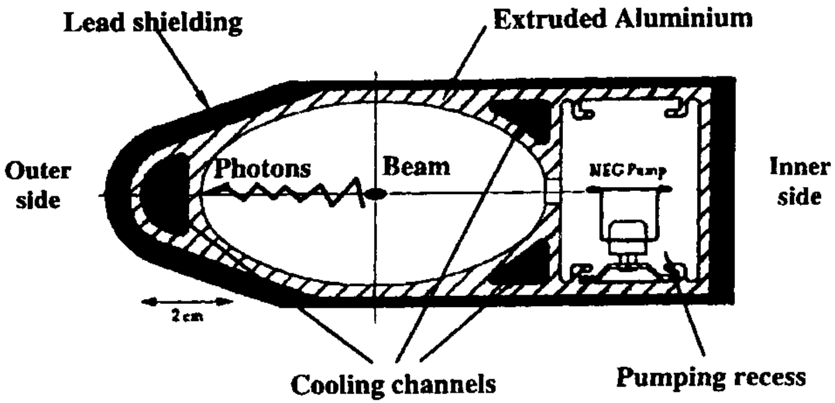
1. Vacuum chamber

Both types of dipole chambers can be chosen for the CEPC vacuum system. One is aluminum chamber of similar LEP with a beam channel, three cooling water channel, a pumping channel used to install NEG strips, and a lead shielding covered outside the dipole chamber with a thickness of 3 to 5 mm; another is copper chamber with a beam channel and a cooling water channel, which will be coated NEG films inside the dipole chamber. Two types of dipole chambers will be fabricated and tested. The final choice will be decided according to R & D results of the dipole chamber prototypes.



The aluminum chamber manufacturing procedure is:

- Extrusion of the chambers,
- Machining of the pumping slots,
- Machining of the components to be welded,
- Chemical cleaning,
- Welding of the side ports,
- Mounting of the NEG strips,
- Welding of the covers of the pumping channel, water connections and flanges,
- Leak detections,
- Lead coating of the outside chamber.

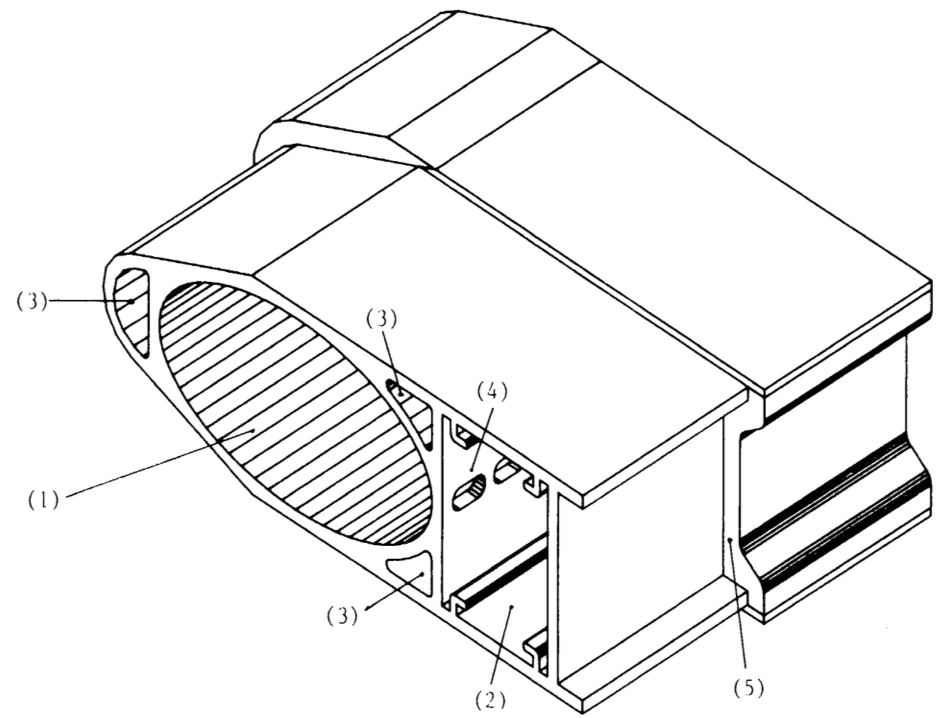
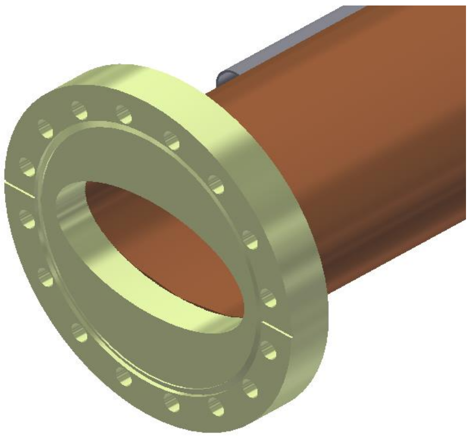
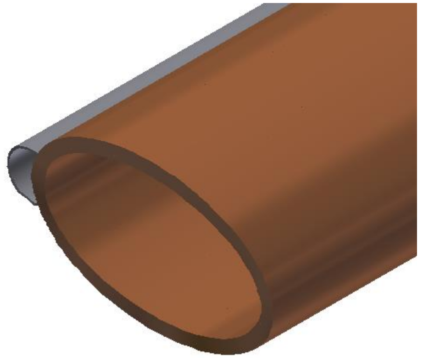


Fig. 8.4 LEP dipole vacuum chamber, with: 1) the elliptic beam channel (131 mm × 70 mm); 2) the rectangular pumping channel where the NEG strip is mounted; 3) three cooling channels; and 4) the pumping slots. The lead shielding (5) varies between 3 and 8 mm in thickness.

LEP aluminum vacuum chamber (11.7m long)





The copper chamber manufacturing procedure is:

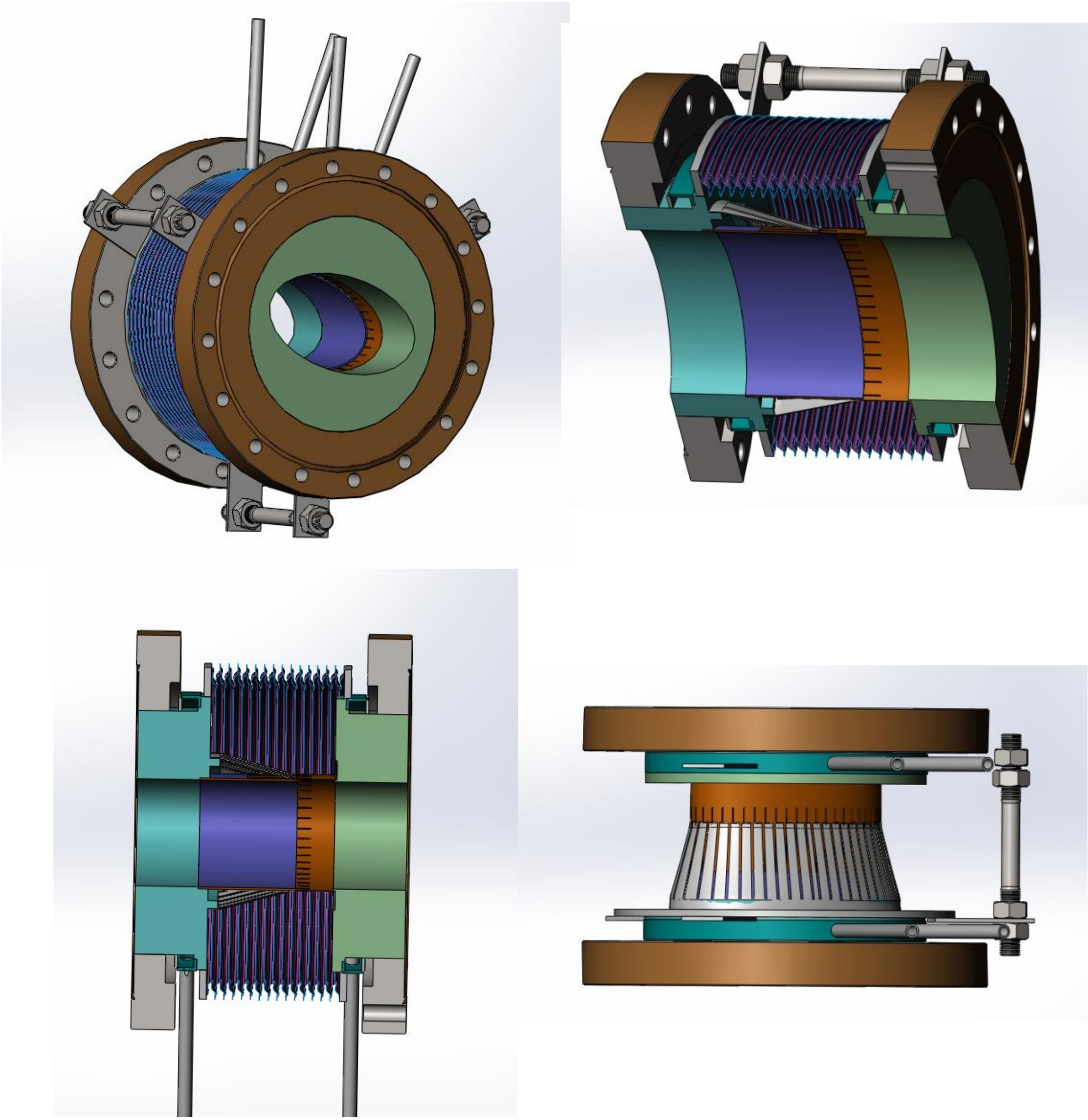
- Extrusion of the beam pipe and cooling channel,
- Machining of the components to be welded,
- Chemical cleaning,
- Electron-beam welding,
- Welding of the end flanges and water connections,
- Leak checks,
- NEG coating of the inside chamber.

CEPC copper vacuum chamber

(elliptical100×55, thickness 6, length 8000)

2. Bellows Module with RF Shielding

- The primary function of the bellows module is to allow for thermal expansion of the chambers and for lateral, longitudinal and angular offsets due to tolerances and alignment, while providing a uniform chamber cross section to reduce the impedance seen by beam.
- The usual RF-shield is done with many narrow Be-Cu fingers that slide along the inside of the beam passage as the bellows is being compressed.
- It is important to get a minimum contact force to avoid excess heating and abnormal arcing at the contact point. The leakage of higher order mode from the slits between contact fingers into the inside of bellows is another important problem.



RF shielding bellow module

For CEPC, the fingers are designed to maintain a relatively high contact pressure of 110±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.

3. NEG coating

- NEG coating has been used for several years in various accelerators. NEG coating suppresses electron multipacting and beam-induced pressure rises, as well as provides extra linear pumping.
- The NEG coating is a titanium, zirconium, vanadium alloy, deposited on the inner surface of the chamber through sputtering. Each dipole chamber will be fitted with three cathodes (made of twisting together Ti, Zr and V metal wires) mounted along the chamber axis to achieve uniform thickness distribution along the perimeter.
- NEG films can be fully activated at relatively low temperature, like 250°C×2 hrs. Even lower activation temperature for longer times (e.g. 180°C×24 hrs.) has been successfully applied in the case of aluminum chambers which cannot withstand high temperature bake-out.

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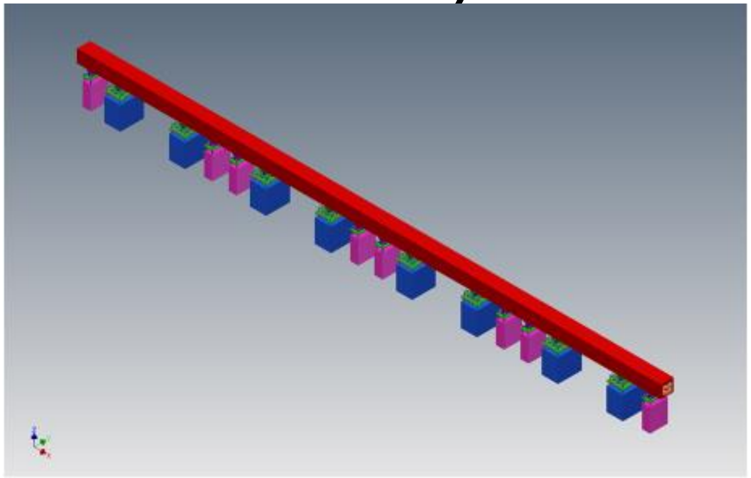
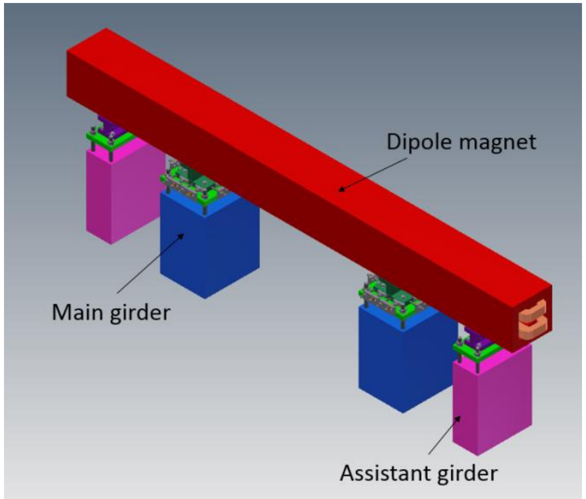
1.1 Collider girder system for dipole

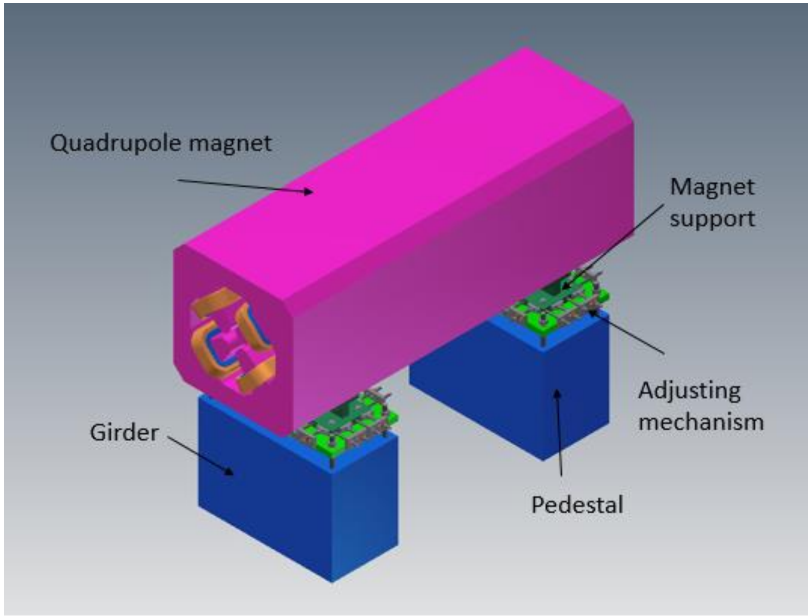
- Magnet length: 18 m（4×4.5m）. Width and height: 405×400 mm.
- 2 main girders and 2 assistant girders(reduce cost).
- Main girder: support and adjustment (6 DOFs).
- Assistant girder: support (avoid large deformation).





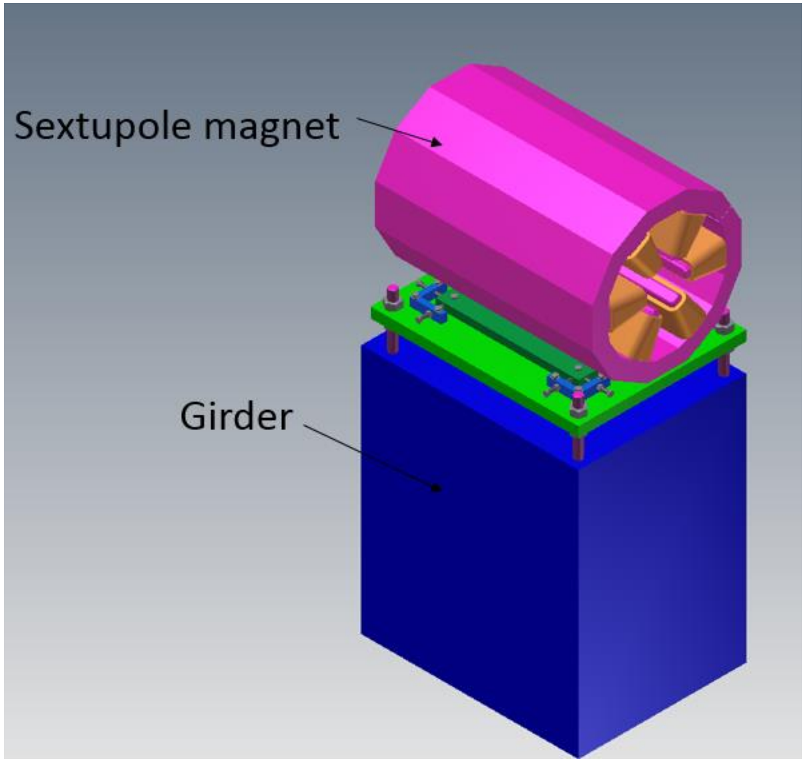
1.2 Collider girder system for quadrupole

- Magnet length: 2m. Width and height: 700×700mm.
- 2 girders: support and adjustment (6 DOFs), similar to the main girders of dipole girder's.

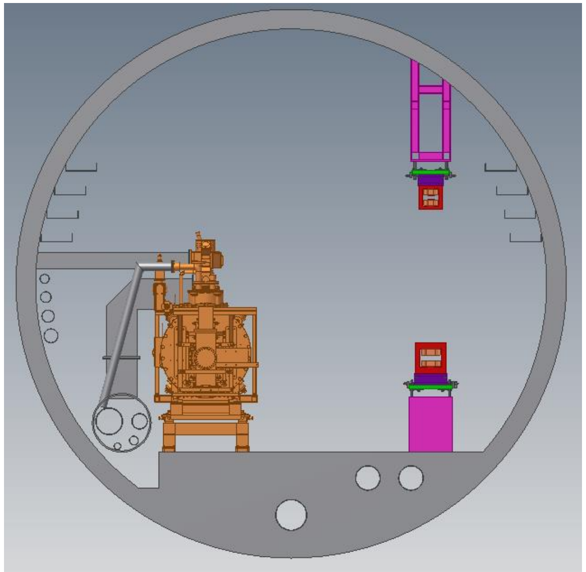


1.3 Collider girder system for sextupole

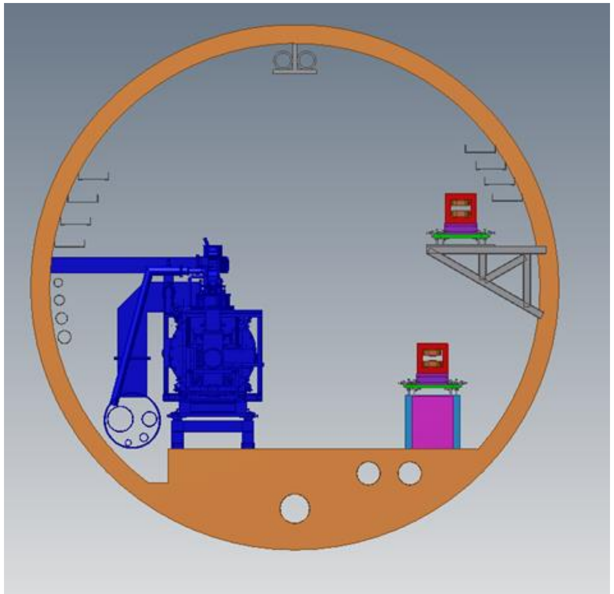
- Magnet length: 0.7mm. Width and height: 480×480mm.
- 1 girder: support and adjustment (6 DOFs).



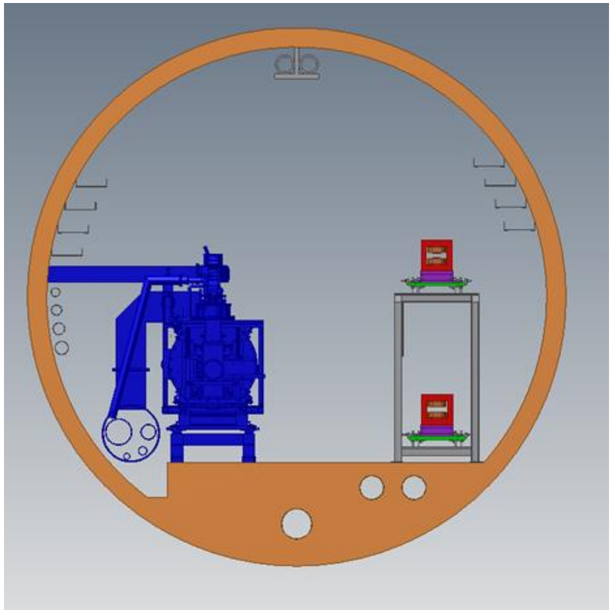
2 Booster girder system



Layout 1
(basic scheme)



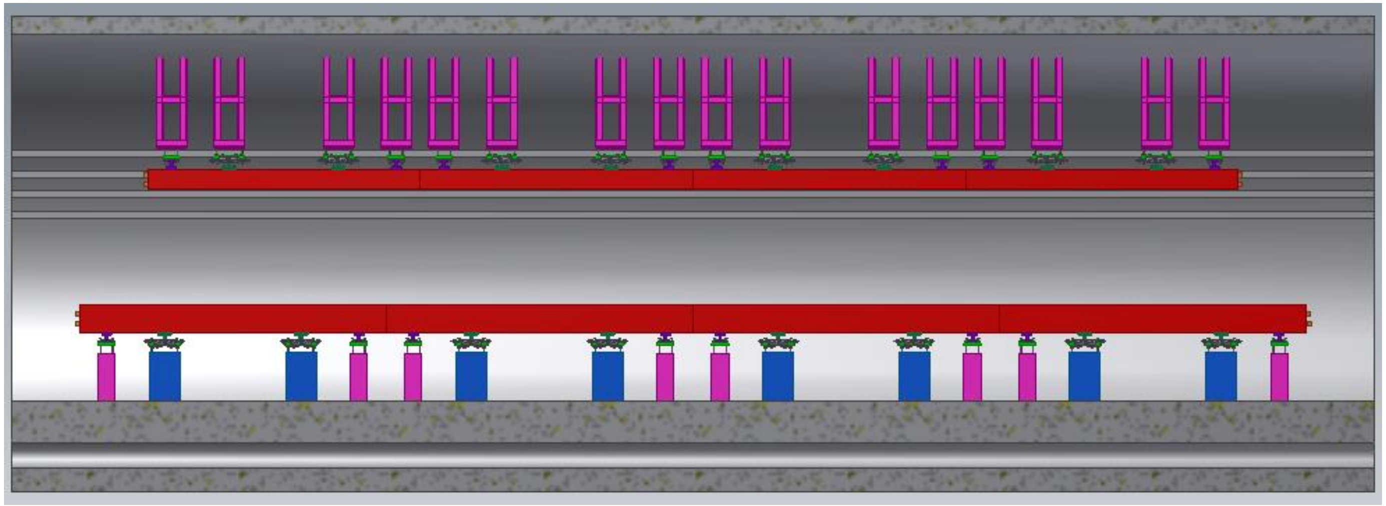
Layout 2



Layout 3

2 Booster girder system

- Dipole magnet length: 16m（4×4m）. Width and height: 265×280mm.
- 2 main girders and 2 assistant girders(reduce cost).
- One girder concludes pedestal, adjusting mechanism and magnet support.
  - Pedestal: concrete(steel frame).
  - Adjusting mechanism and magnet support: similar to dipole girder’s



3 Key technologies of R&D

- Contents of R&D
  - Girder system of 18m dipole magnet in MR.
  - Girder system of 16m dipole magnet in booster.
- Aims
  - hang and alignment 16m booster dipole
  - Alignment method of 18m (4×4.5m) MR dipole magnet and 16m (4×4m) booster dipole.
  - Simple and reliable mechanics for safe mounting and easy alignment.
  - Stability with large time constants (eg. creep, fatigue).
  - Kinematic support (6 DOFs).
  - Supporting devices such as magnets, vacuum chambers.
  - Low cost.

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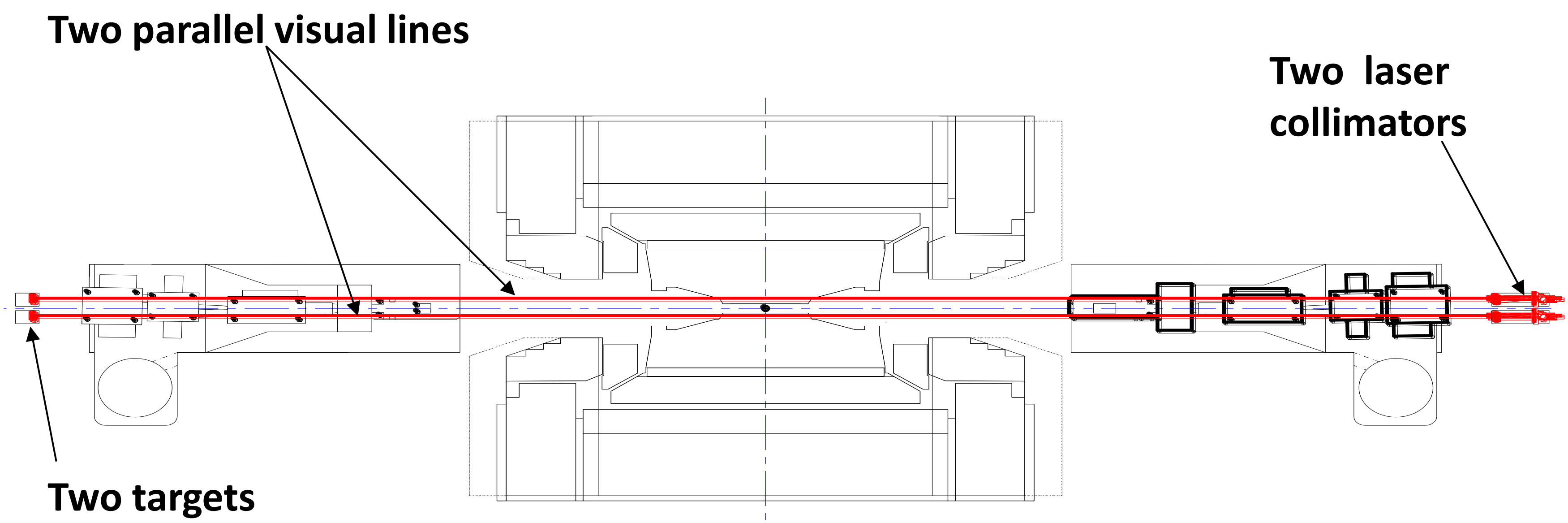
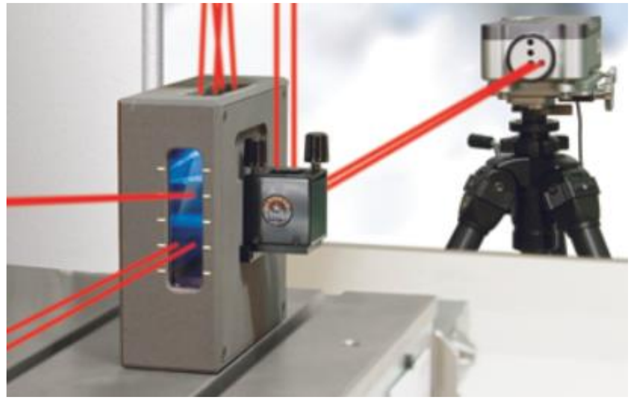
1、 Laser collimator system

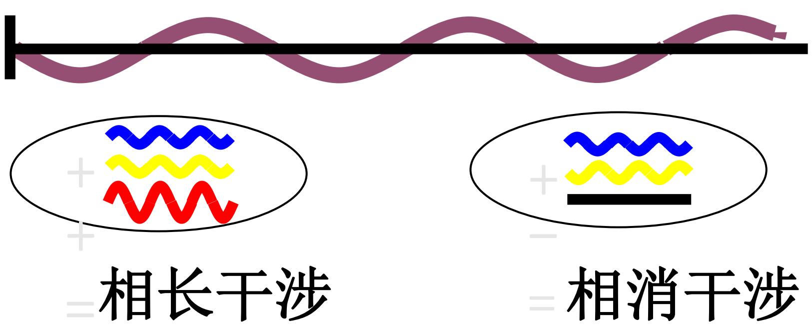
- Alignment in the interaction region will be much more demanding than in the Arcs due to the extremely low β-functions.
- The detector is too big to achieve the intervisiblity between both sides.
- We plan to use a laser collimator system to carry out the alignment in this region, which can reach high precision and suitable for linear alignment.
- We will install two laser collimators on one side of a IP and two targets on the other side. Using laser trackers and levels align the laser collimators and targets to the nominal position then we can use this system align all the components between them to the beam orbit. The accuracy we want to achieve is 0.1mm in 100m.

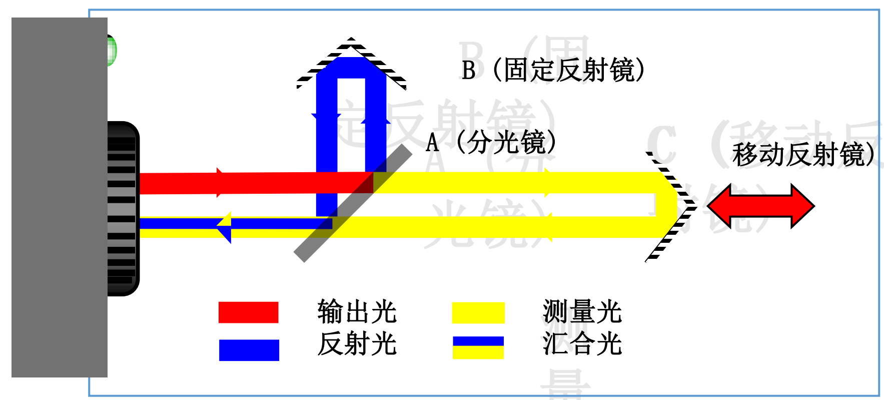


- The laser collimator system will consist of a laser system, a laser interferometer system, a data acquisition system and targets.



- The basic theory of laser meausrement.





- How to keep the laser stable in such a long distance will be a big problem we need to solve.

2、Photogrammetry R&D

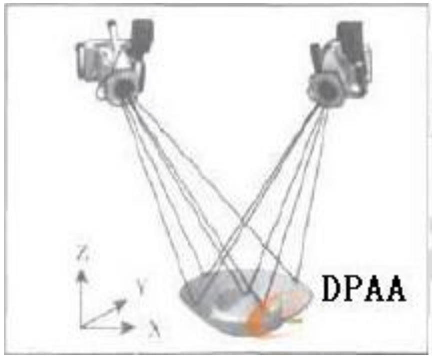
- How to carry out the alignment in serious radiation areas is always a big problem.
- Photogrammetry can make us survey the components from far away and efficiently.
- The basic formula of photogrammetry

$$x-\frac{L_1X+L_2Y+L_3Z+L_4}{L_9X+L_{10}Y+L_{11}Z+L_1}=0$$

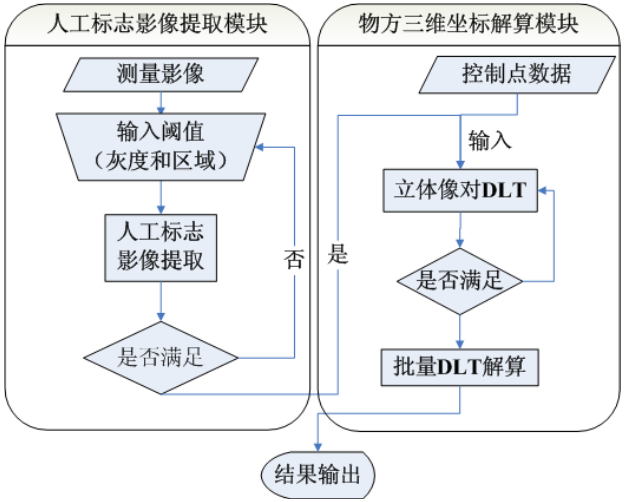
$$z-\frac{L_5X+L_6Y+L_7Z+L_8}{L_9X+L_{10}Y+L_{11}Z+L_1}=0$$

$$\Rightarrow$$

$$(x+K_1(x-x_0)r^2+V_x)(L_9X+L_{10}Y+L_{11}Z+L_1)$$
$$-(L_1X+L_2Y+L_3Z+L_4)=0$$
$$(z+K_1(z-z_0)r^2+V_z)(L_9X+L_{10}Y+L_{11}Z+L_1)$$
$$-(L_5X+L_6Y+L_7Z+L_8)=0$$



- Computer programs need to be developed

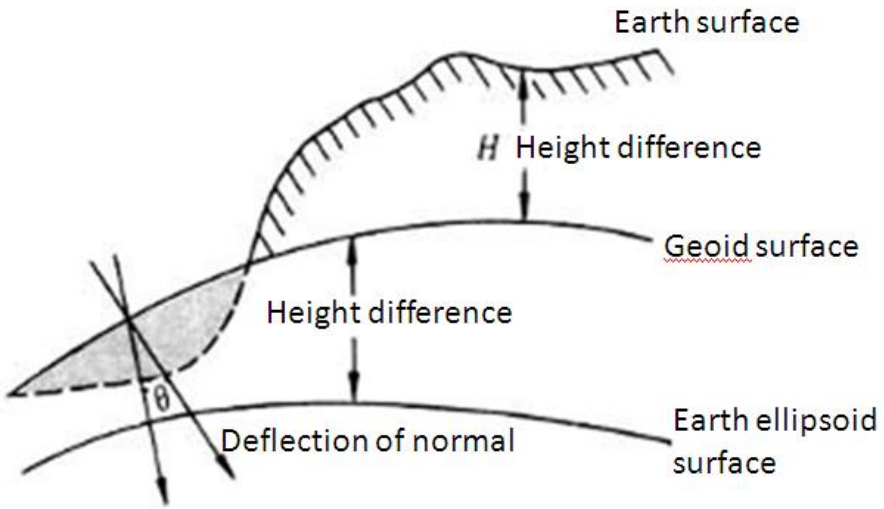


◆ Applying the photogrammetry technology to accelerator alignment still have some problems needs to be solved.

- For the complicated environment of the accelerator tunnel, it is very difficult for the program to identify the features from the image. We need to design some special targets and develop effective methods to enhance the identification rate.
- We need to do calibration calculation to decrease the camera lens distortion.
- We need to improve our program algorithm to increase the feature extraction accuracy.
- We need to develop the adjust algorithm used for photogrammetry which can process the joint survey result of several measurement stations.
- We should also build the hardware platform that can take enough high accuracy photos of the fiducial points.
- A lot of experiments need to be done to verify the effectiveness and accuracy.

3、Geoid refining

- Our traditional control network survey is within a small area (such as a 300m×300m area) and the survey is based on the local geoid surface. By measuring the geoid surface the survey is divided into the horizontal survey and the level survey.
- For a small area we can hypothesis the geoids we measured in every station are in the same plane, so we can do datum adjust in horizontal and in level separately. In this way we can avoid the error accumulation.
- But for CEPC the area is spacious and the geoid undulation must be taken into consideration.
- we need to do geoid refining survey, find out the change of gravity potential and the deflection of normal.



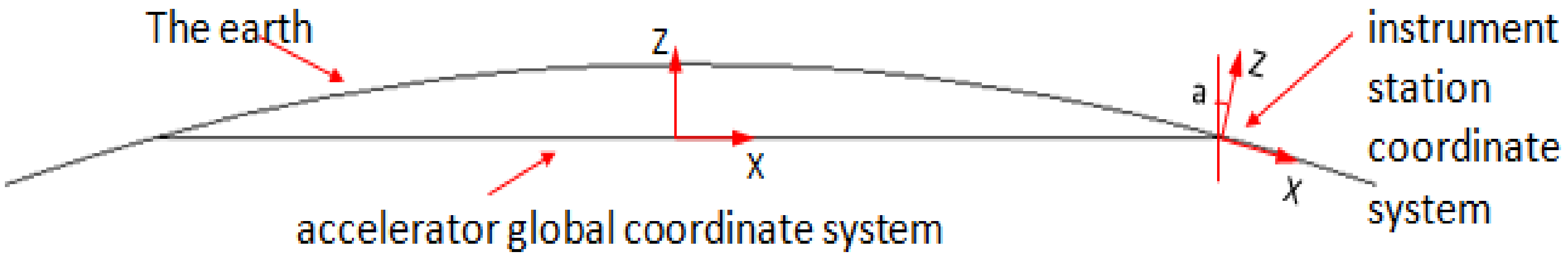
- We plan to carry out the geoid refining research, to do this research we need to measure a series of points along a 34km length area, the interval between adjacent points is 100m. By survey and research, we will calculate out the equipotent curve of the geoid.

gravimeter

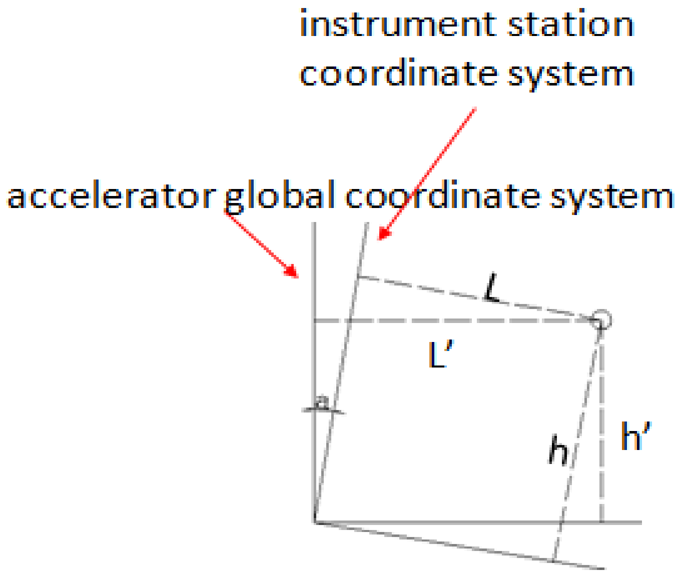
- Based on the geoid refining, we can correct all the control network monument coordinates to the earth ellipsoid and use the earth ellipsoid as a reference to do datum process.

4、Three-dimensional adjustment

- Another problem is the CEPC survey range is very large, the Z axis of each instrument station coordinate system is not parallel to the Z axis of accelerator global coordinate system .



- The angle ‘a’ will increase with the accelerator range extend, assume the earth radius R=6374km, the ring diameter D=17km, if the horizontal distance and the vertical distance L=h=5m, we can calculate the differences between L and L’, h and h’ are both 6.6mm.



- So the traditional 2D+1D network adjust method is not suitable, we must research a 3-D adjust method.
- The new method should use the earth ellipsoid as a reference and in order to avoid error accumulation, the Z axis of each instrument station should be held during adjust calculation .
- This research will include the adjust model establishment, software programming and survey test verification.

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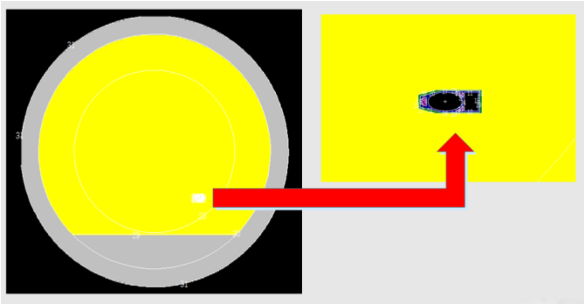
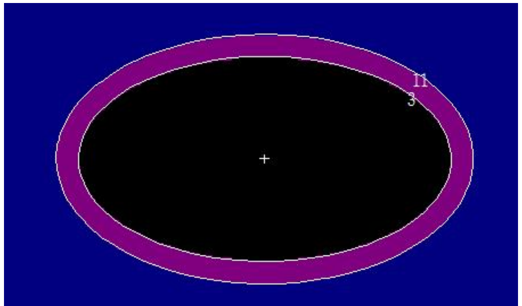
Radiation shielding simulation

- Radiation resistance material research used for cable and key equipment
- Propose a reliable and quick method used for estimate the production of O_3 and nitrogen oxides
- Shielding model and method should be verified independently
- Coordinate with relative systems to complete the actual shielding structure for vacuum chamber and hot spots
  - Limited radiation dose; ideal chamber structure; energy deposition; source analysis; heat load;





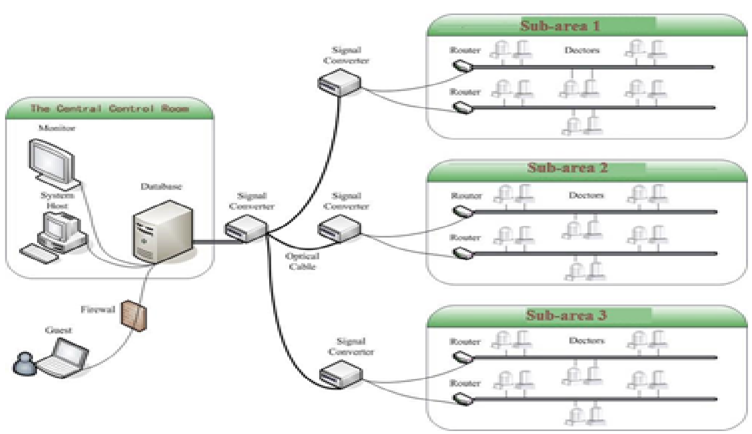
Radiation dosimeters in the tunnel

- Research on new dosimeters for machine protection (Active and Passive):
  - Polymer-alanine dosimeters (PADs)
  - Hydrogen-pressure dosimeters (HPDs)
  - Ethanol-chlorobenzene dosimeters (ECBs)
- Physical characteristic:
  - Range[Gy]
  - Uncertainty[%]
  - Energy dependence
  - Neutron sensitivity
  - Changing[time, temperature]

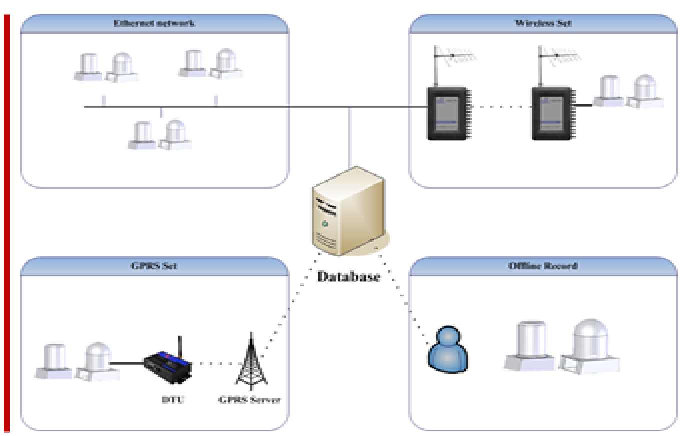
- In different areas, we should choose and develop different dosimeters according to demands and situations.

Radiation monitor for environment

- Research on a complex dose acquisition system, concluding: remote supervision, long term database storage , off-line data analysis
- Different communicating methods according to specific place
  - Ethernet network, wireless sets, GPRS sets, offline record.



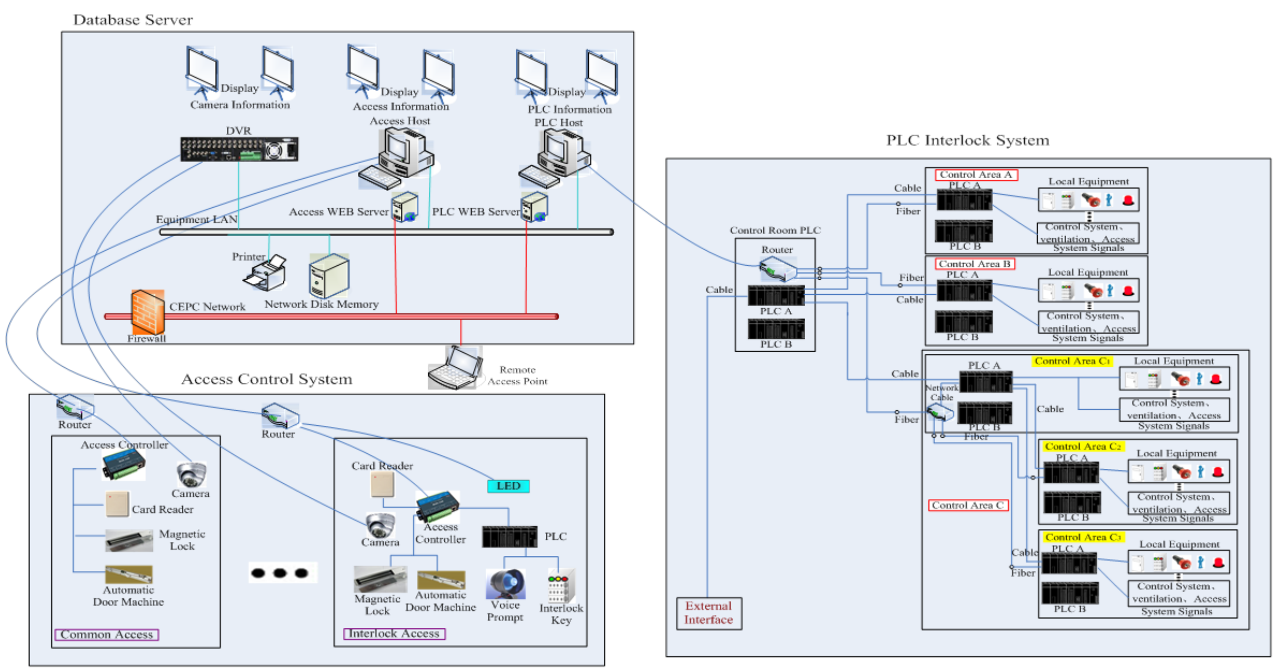
System framework



Date communication methods

Personal interlock system (PPS)

- Research on a large-scale, reliable interlock system
- Including PLC system, access control system, database server
  - Interlocking key, Door limit-switch, Emergency switch, Personal key



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Linac Overview

- **Main parameters**

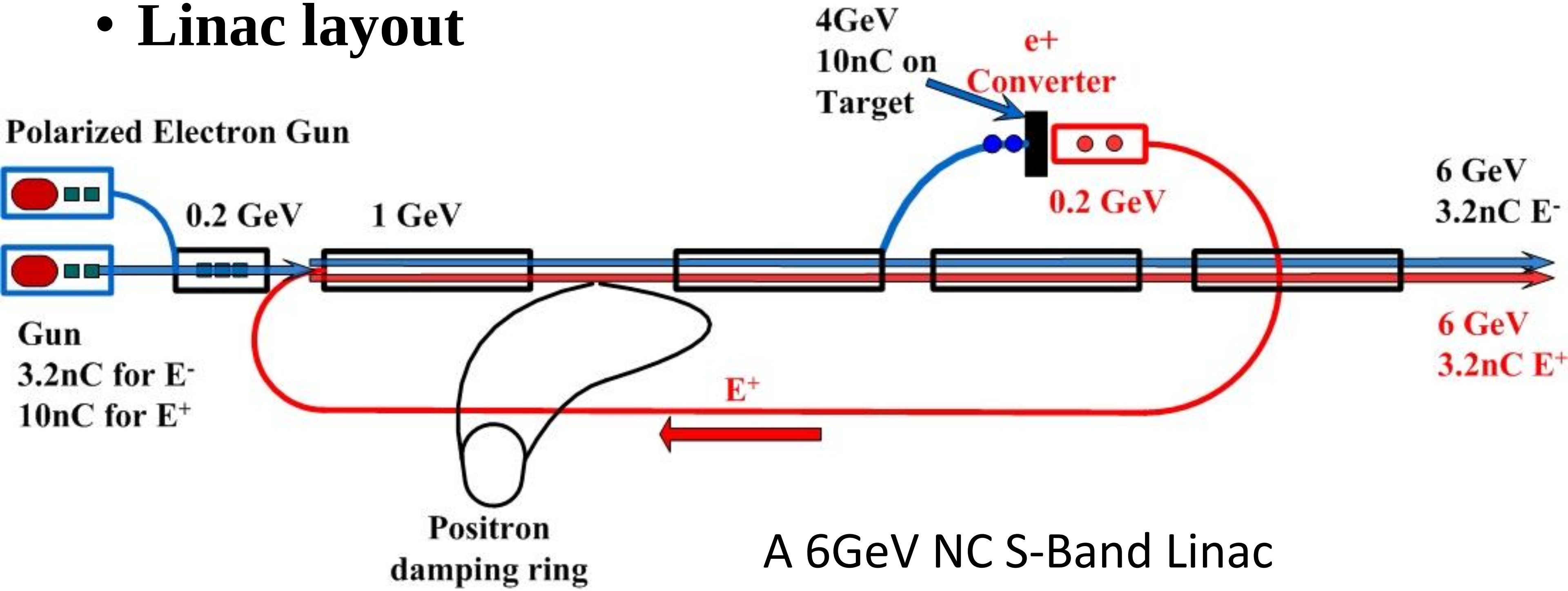
Parameter	Symbol	Unit	Value
E^- beam energy	E_{e-}	GeV	6
E^+ beam energy	E_{e+}	GeV	6
Repetition rate	f_{rep}	Hz	50
E^- bunch population	N_{e-}		2×10^{10}
E^+ bunch population	N_{e+}		2×10^{10}
Energy spread (E^+/E^-)	σ_E		$<1\times10^{-3}$
Emitance (E^-)			0.1 mm· mrad
Emitance (E^+)			**0.1 mm· mrad**

- **Polarization**

1. Unpolarized Linac for Baseline
2. Polarized electron beam as a R&D program

Linac Overview

- **Linac layout**



A 6GeV NC S-Band Linac

- A 150kV-200kV conventional thermionic gun
- A 100kV-150kV photocathode dc gun with a super-lattice structure GaAs cathode
- Bunching system
- S-Band SLAC type traveling wave accelerating structures
- positron converter and capture section
- A 200MeV positron beam return transport line+positron damping ring
- low-level RF controls, magnets and power supplies, vacuum system, beam diagnostics

Electron Source

The electron source consists of two electron guns:

- **Thermionic Triode Gun**

Electron Gun			
Gun type	Thermionic Triode Gun		
Cathode	Barium-impregnated tungsten cathode		
Beam Current (max.)		A	15
High Voltage of Anode		kV	150-200
Bias Voltage of Grid		V	0 ~ -200
Pulse duration （FWHM）		ns	1.0
Repetition Rate		Hz	50
Electron operation	Bunch charge	nC	3.2
Positron operation	Bunch charge	nC	>11nC

Typical bunch charge of electron and positron for injection to Booster both are 3.2nC

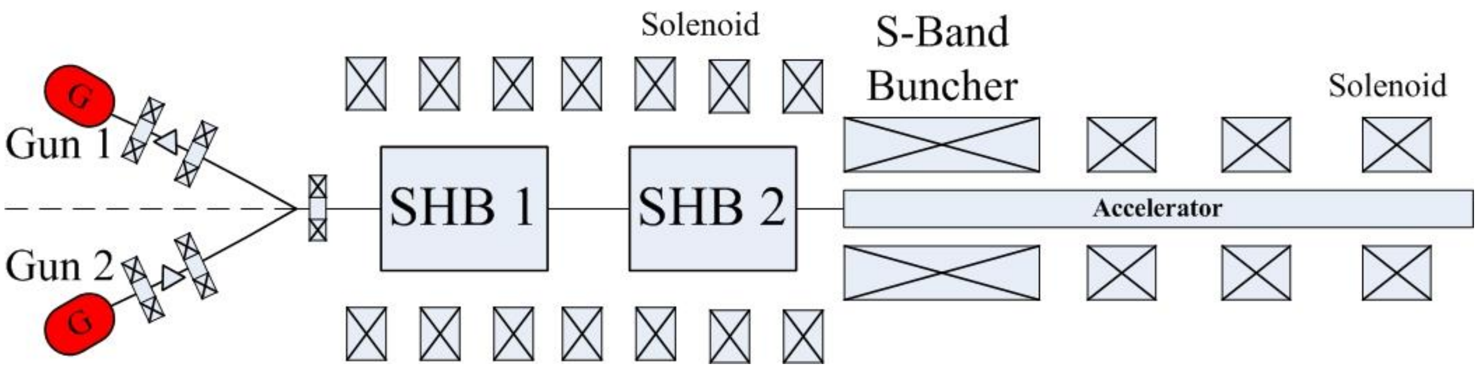
Electron Source (1)

- **Photocathode DC gun**
  - R&D program
  - Polarized electron beam generation
  - Polarized electron beam collide with unpolarized positron at CEPC

Electron Gun		
Gun type	Photocathode dc gun	
Cathode	Super-lattice GaAs photocathode	
High Voltage of Anode	kV	100~150
Maximum QE		~1%
Polarization		>80%

Bunching system

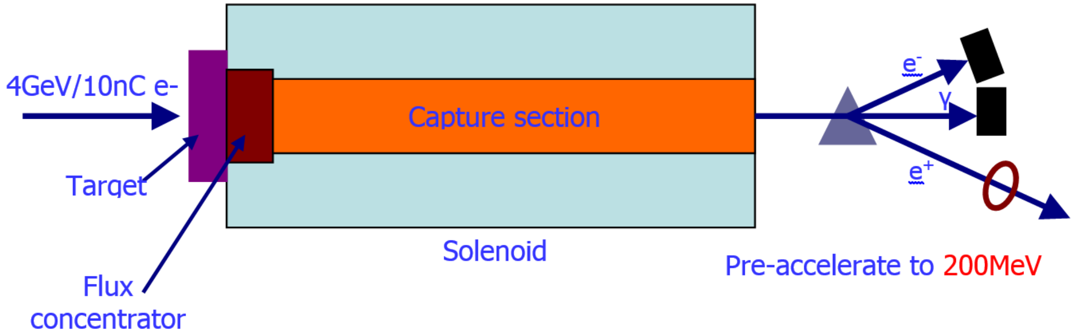
- **Sub-harmonic pre-bunchers + S-band buncher**



- First sub-harmonic buncher operating at 142.8375 MHz (20th subharmonic)
- Second sub-harmonic buncher operating at 571.35 MHz (5th subharmonic)
- A S-band buncher operating in $2\pi/3$ mode at 2856.75MHz

Positron source

- **Unpolarized positron source (Baseline)**

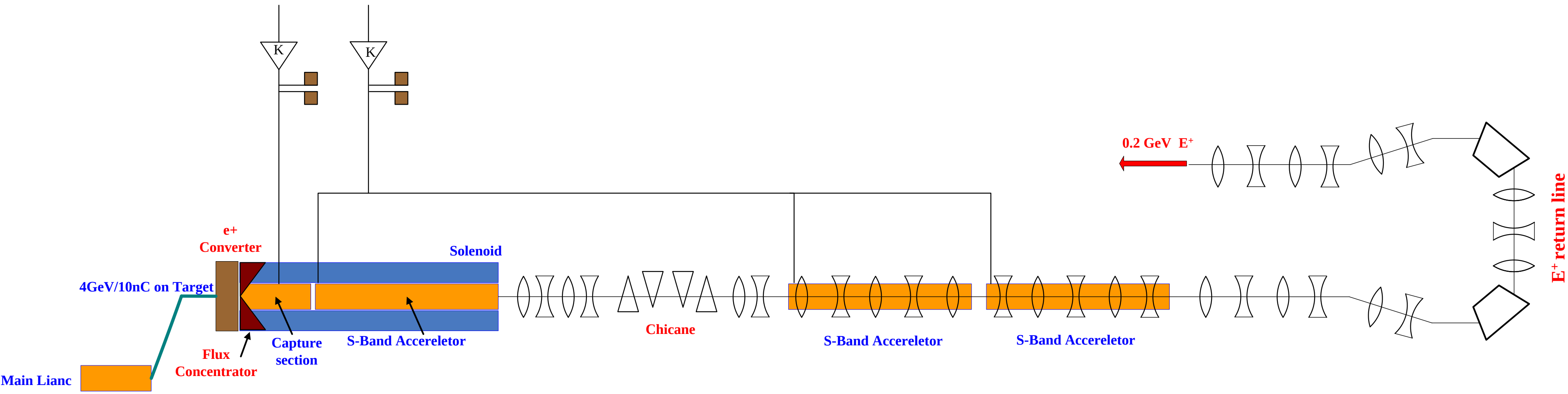


A conventional scheme

Positron source		
E^- beam energy on the target	GeV	4
E^- bunch charge on the target	nC	10
Target material	W-Re	
Target thickness	mm	14
Focus device	Flux Concentrator	6 Tesla
E+ bunch charge	nC	3.2
E+ Energy pre-accelerate	MeV	200

Positron source (1)

- **Unpolarized positron source + 200MeV returning line + damping ring**



➢ A flux concentrator with a 6-T peak pulsed field

➢ A high-gradient (>40 MeV/m) S-Band RF-capture section with a large aperture.

➢ A chicane to select positrons only in the desired energy range

➢ A 200MeV positron beam transport line with a quadrupole lattice

Main Linac

- **S-Band accelerating structures**

Parameters		Unit
Operation frequency	2856.75	MHz
Operation temperature	40.0 ± 0.1	^{o}C
Number of cells	84 +2 coupler cells	
Section length	3048	mm
Phase advance per cell	$2\pi/3$ - mode	
Cell length	35.0012	mm
Gradient	>20	MV/m

- **Power source: 65MW (80MW) klystrons**

R&D programs

- **Polarized Electron Source (R&D)**
  - R&D on a superlattice GaAs/GaAsP photocathode
  - R&D on a (100kV-150kV) DC gun.

- High intensity **Positron Source (R&D)**
  - R&D on the flux concentrator
  - Experimental collaboration research on high intensity positron production on Super-KEKB Linac
  - Polarized positron source R&D

R&D programs

CEPC Linac will also be considered to provide a high performance electron beam for FEL application. Some other R&D programs are also considered to improve the beam quality of Linac.

- **S-Band accelerating structure**
  - Adopting a dual-feed racetrack design instead of the single-feed couplers to minimize the multipole field effects and improve beam quality

- High stability pulse modulator

- High precision synchronization and timing system

Introduction to CEPC/SppC R&D Issues

1. CEPC SRF system
2. CEPC RF power system
3. CEPC Cryogenic system
4. CEPC Magnet system
5. CEPC Power supply system
6. CEPC Control system
7. CEPC Instrumentation system
8. CEPC Vacuum system
9. CEPC Mechanical system
10. CEPC Survey and alignment system
11. CEPC Synchrotron shielding system
12. CEPC Linac injector system
13. SppC SC high field magnet system

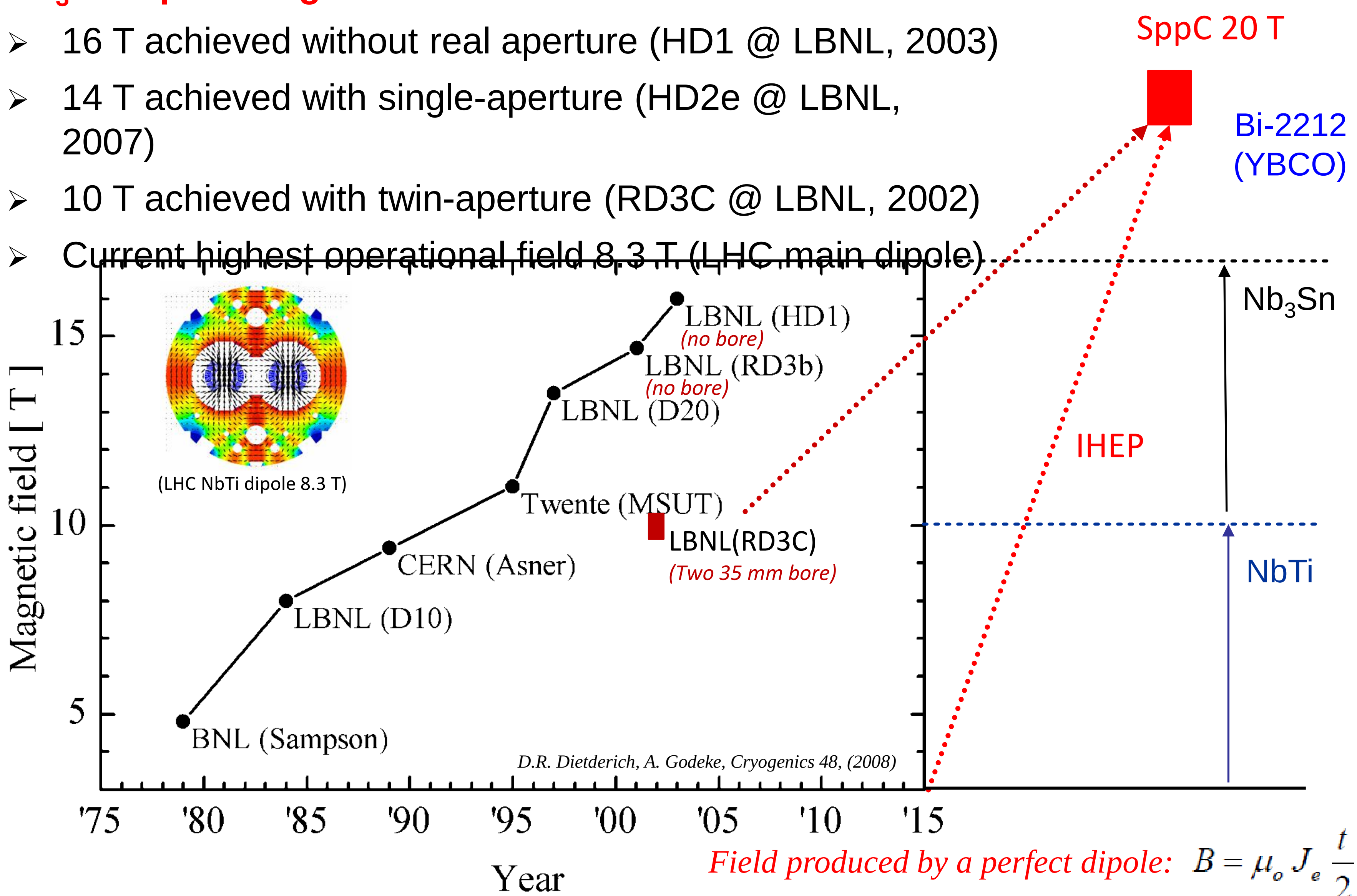
High field accelerator magnets for SppC

- Field strength of the main dipole: 20 Tesla
- Total magnetic length of the 20-T main dipole: ~ 33 km in a 50-km circumference
- SppC needs thousands of high field dipoles and quadrupoles installed along a tunnel 50-100 km in circumference
- Aperture diameter of the main dipole / quadrupole: 50 mm
- Field quality: 10^{-4} at the 2/3 aperture radius
- Distance between the two beam pipes: determined by the magnetic optimization of the main dipole (300 ~ 400 mm)
- Outer diameter of the magnet: 900 mm
- Outer diameter of the cryostat: 1500 mm (in a 6-m diameter tunnel)

Status of high field accelerator magnet R&D

Nb_3Sn dipole magnetic field records:

- 16 T achieved without real aperture (HD1 @ LBNL, 2003)
- 14 T achieved with single-aperture (HD2e @ LBNL, 2007)
- 10 T achieved with twin-aperture (RD3C @ LBNL, 2002)
- Current highest operational field 8.3 T (LHC main dipole)



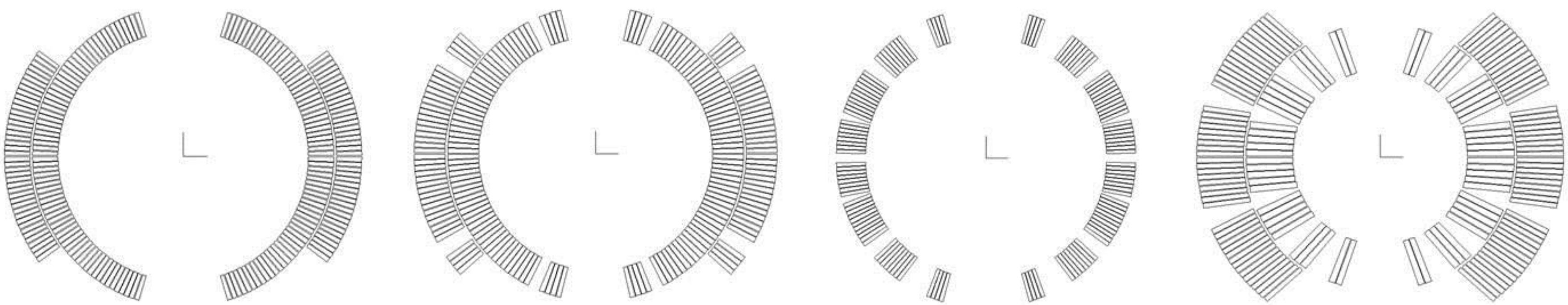
Field produced by a perfect dipole: $B = \mu_o J_e \frac{t}{2}$

Status of high field accelerator magnet R&D

Four Colliders using SC Magnets

	E (GeV)	B (T)	Length (m)	First beam
Tevatron	980	4.3	6280	7 1983
HERA	920	5.0	6336	4 1991
RHIC	100/n	3.5	3834	6 2000
LHC	7000	8.3	26659	9 2008

Tevatron **HERA** **RHIC** **LHC**



All cosine theta, all NbTi

Challenges and R&D focus of the 20-T accelerator magnets

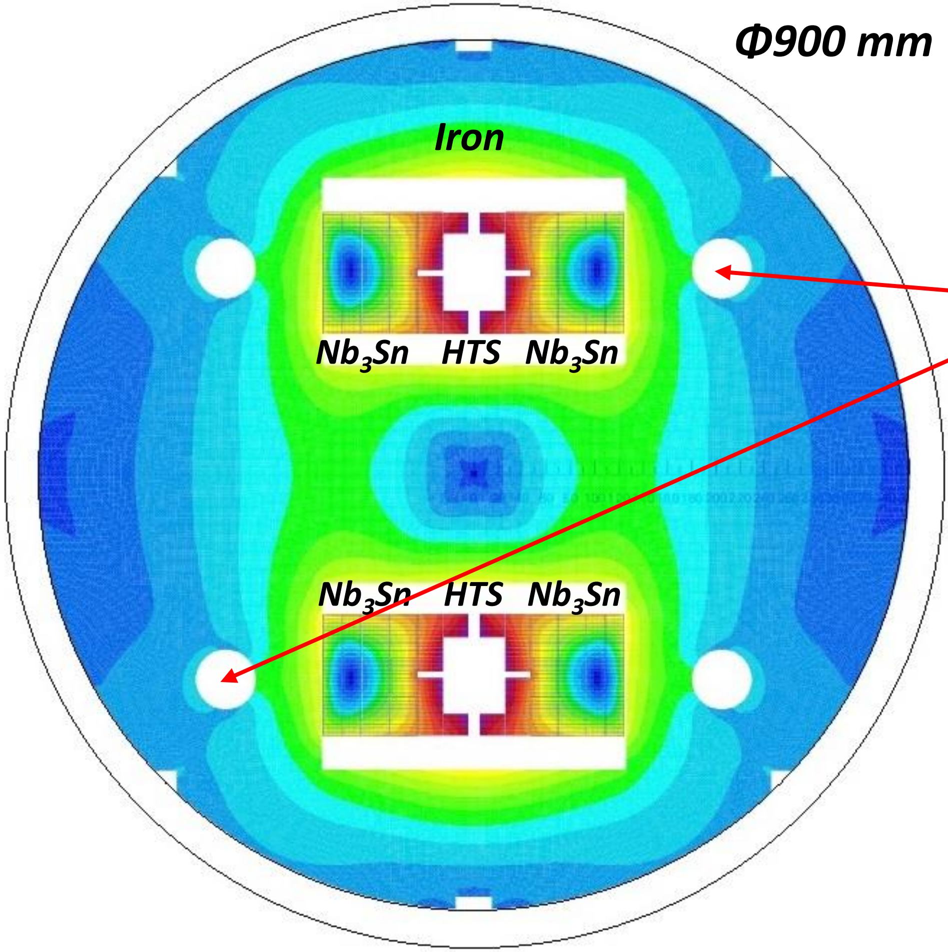
- J_c of Superconductors: Thousands of tons of Nb_3Sn and HTS is needed to fabricate the high field magnets for SppC. Further increase of J_c is expected to reduce the cost.
- HTS coils for accelerator magnets (especially tape conductors): field quality, quench protection and fabrication method.
- High level magnetic force in superconducting coils at 20 T: magnetic force proportional to the square of the field! And both Nb_3Sn and HTS superconductors are strain sensitive! Needs smart design of the mechanical support structure and strain management in coils.
- Twin aperture 20-T dipole/quadrupole with 10^{-4} field quality and 900 mm outer diameter: cross-talk between two apertures, iron saturation effect, magnetization effect… Needs smart magnetic design

Conceptual design study of the 20-T dipole

(Preliminary)

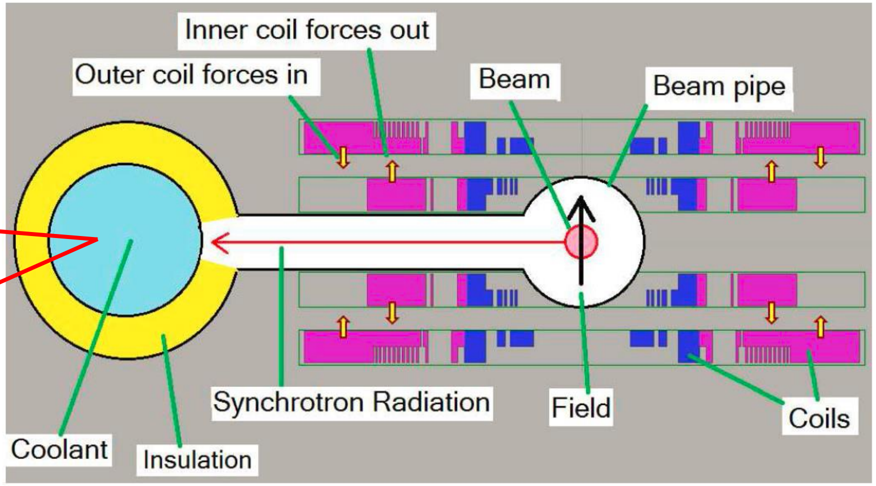
20-T Nb_3Sn + HTS common coil dipole for SppC

Maximum space for beam pipes: 2 * Φ50 mm, with the load line ratio of 85% @ 4.2K and the diameter of 900 mm



Open-plane design is under consideration

To remove the synchrotron radiation heat load at higher temperature



Ramesh Gupta, BNL

Decay particles will deposit energy in a warm absorber that is sufficiently away from the superconducting coils or support structure.

R&D plan of the 20-T accelerator magnets

(2015-2030)

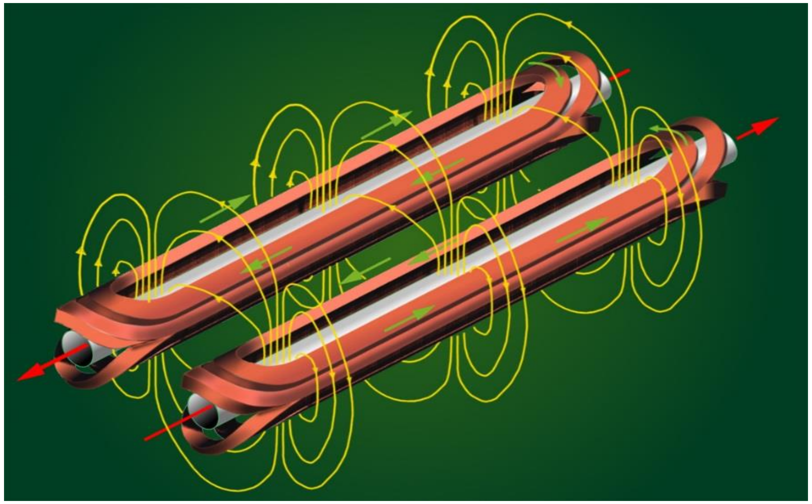
- **2015-2020**: Development of a 12-T operational field Nb_3Sn twin-aperture dipole with common coil configuration and 10^{-4} field quality; Fabrication and test of 2~3 T HTS (Bi-2212 or YBCO) coils in a 12-T background field and basic research on tape superconductors for accelerator magnets (field quality, fabrication method, quench protection).
- **2020-2025**: Development of 15-T Nb_3Sn twin-aperture dipole and quadrupole with 10^{-4} field uniformity; Fabrication and test of 4~5 T HTS (Bi-2212 or YBCO) coils in a 15-T background field.
- **2025-2030**: 15-T Nb_3Sn coils + HTS coils (or all-HTS) to realize the 20-T dipole and quadrupole with 10^{-4} field uniformity; Development of the prototype SppC dipoles and quadrupoles and infrastructure build-up.

R&D plan of the 20-T accelerator magnets

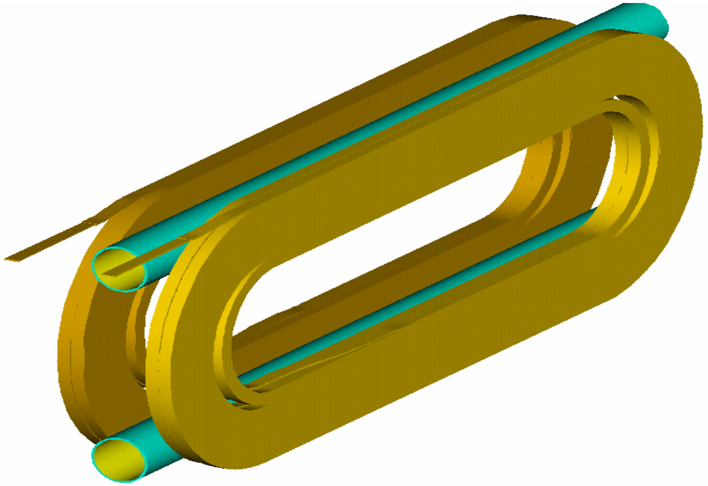
(2015-2020)

Magnet design study: Coil configuration; Field quality; Stress management;…

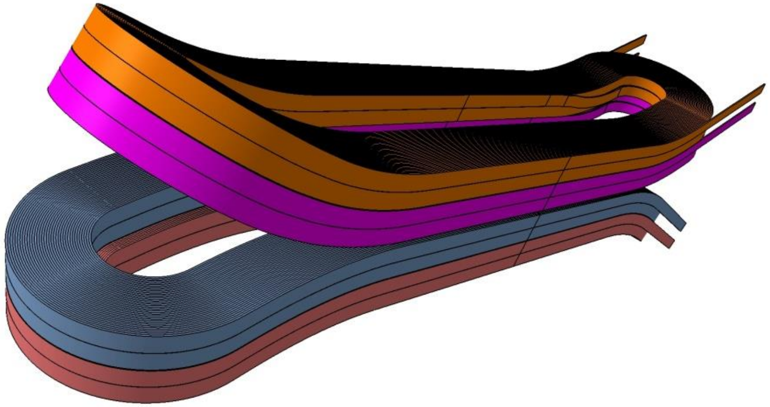
Cos-**th**eta dipole



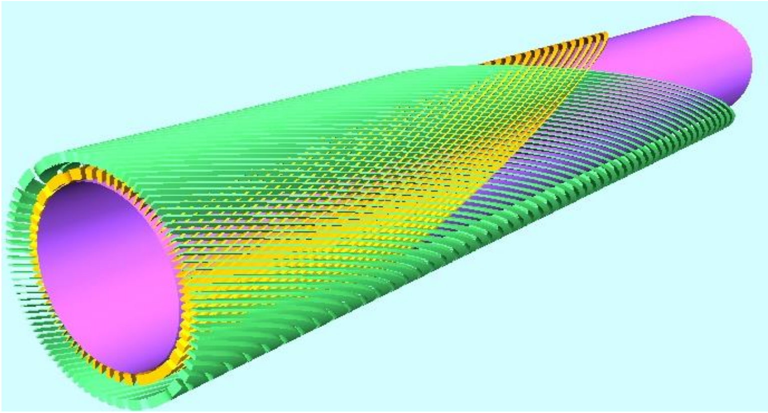
Common coil dipole



Block type dipole



Canted cos-theta dipole

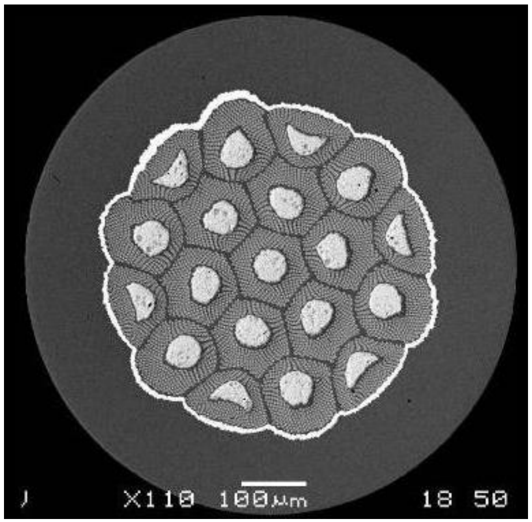


R&D plan of the 20-T accelerator magnets

(2015-2020)

Advanced high field superconductors R&D and fabrication

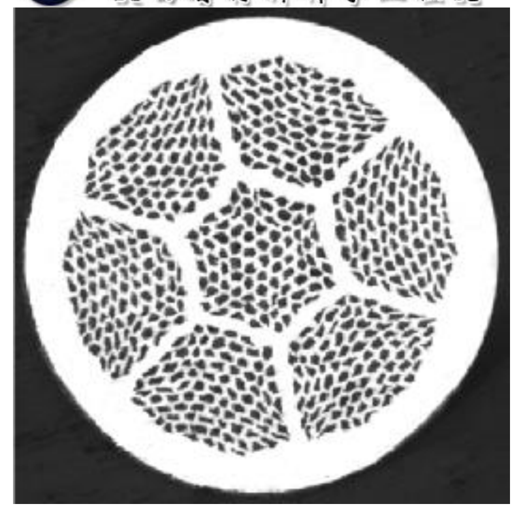
西部超导材料科技股份有限公司
Western Superconducting Technologies CO.,Ltd



Super High J_c
Nb_3Sn R&D

Over-pressure
Bi-2212 R&D

西北有色金属研究院
Northwest Institute For Non-ferrous Metal Research
陕西省材料科学工程院

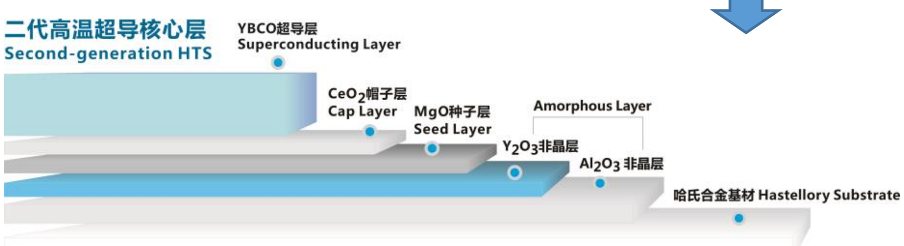


上海超导
Shanghai Superconductor

High field
YBCO R&D

Bi-2223
R&D

InnoST
英纳超导

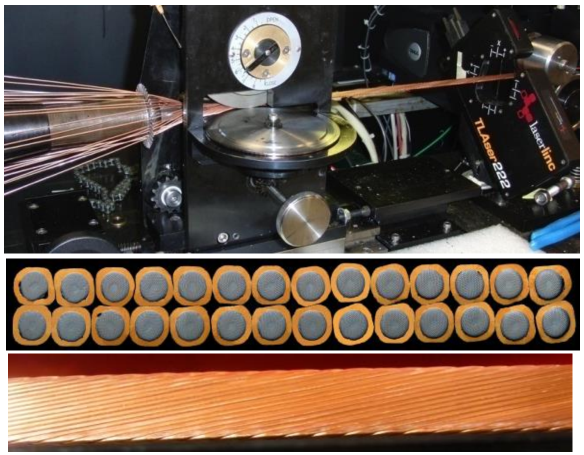


R&D plan of the 20-T accelerator magnets

(2015-2020)

High field magnet fabrication & Infrastructure build-up

Superconductor Cabling

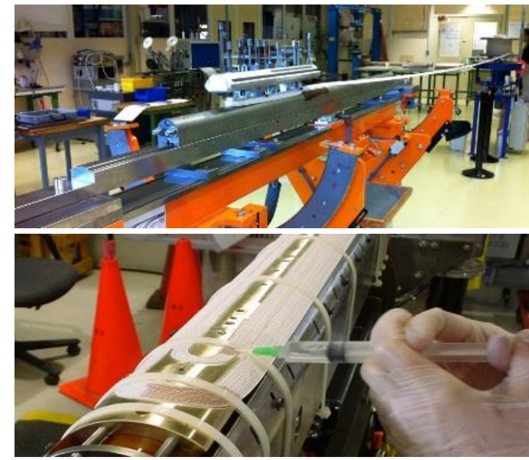


Rutherford Cabling @ Fermilab

Advanced insulation

AGY S2-glass fibers insulation

Coil fabrication

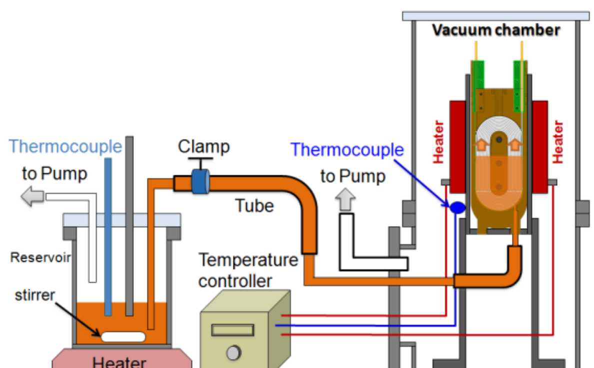


Nb3Sn coil winding @ CERN

Magnet assembly & test

Magnet test facility @ CERN

Coil impregnation



Epoxy impregnation system @ KEK

Coil heat reaction

Nb3Sn coil reaction @ CERN

Conclusions

- CEPC and SppC as advanced future circular colliders have many technical challenges which resulted from high luminosity and high energy compared with LEP-II and LHC

- Key technical R&D are necessary both for ensuring the machine to work and for reducing the construction cost

- The R&D schedule and tasks are very tight and heavy

- International collaboration are very necessary

Thank you for your attention!