Highlights of the accelerator R & D in CEPC2021 Workshop

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(CASA, Accelerator Lab., KEK, Japan)

Highlights of the accelerator R & D

Total 54 invited talks in 12 Accelerator sessions for 18 hours

1. Global Accelerator Design
2. Beam Physics Issues
3. Accelerator Technologies
4. Novel Accelerator Concepts

Acknowledge to all speakers and conveners.

CEPC Accelerator R & D Session (1)

Center for Applied Superconducting Accelerator
応用超伝導加速器センター

Accelerator-I : convener (J. Gao/IHEP)

Beam Dynamics

10:30 "CEPC accelerator beam dynamics key issues" 20'
Speaker: Mr. Chenghui (IHEP)

10:50 "CEPC collider ring optimization design" 20'
Speaker: Dr. Yiwei WANG (IHEP)

11:10 "Luminosity tuning at SuperKEKB" 20'
Speaker: Dr. Hiroshi Sugimoto (KEK)

11:30 "Beam-beam simulations and measurements at SuperKEKB" 20'
Speaker: Dr. Demin Zhou (KEK)

11:50 "Analysis of CEPC coherent beam-beam instability with longitudinal impedance" 20'
Speaker: Chuntao LIN (IHEP)

Accelerator-II : convener (M. Tobiyama/KEK)

Beam Instability

14:00 "TMCI instability influence on SuperKEKB luminosity" 20'
Speaker: Dr. Ohmi Kazuhito (KEK)

14:20 "CEPC booster and damping ring" 20'
Speaker: Dr. Dou WANG (IHEP)

14:40 "CEPC Impedance and collective instabilities" 20'
Speaker: Ms. Na WANG (IHEP)

RF Technology

15:00 "CEPC linac injector status and R&D" 20'
Speaker: Ms. Jingru Zhang (IHEP)

Accelerator-III : convener (C. Pagani/INFN)

16:00 "Status and challenges of Super Tau-charm factory in Novosibirsk" 20'
Speaker: Dr. Anton Bogomyagkov (BINP)

16:20 "FCC-ee machine error correction" 20'
Speaker: Dr. Tessa Charles

16:40 "CEPC collider ring orbit corrections" 20'
Speaker: Bin Wang (IHEP)

17:00 "Error corrections studies in CEPC booster"20'
Speaker: Dr. Daheng JI (IHEP)

Error Correction

Accelerator-IV : convener (E. Kako/KEK)

10:30 "ILC SRF technology development at KEK" 20'
Speaker: Kensei Umemori (KEK)

10:50 "Progress on CEPC SCRF system design and validation plans" 20'
Speaker: Mr. Jiyuan Zhai (IHEP)

11:10 "Status of the high Q R&D for CEPC SCRF cavities" 20'
Speaker: Dr. Peng SHA (IHEP)

11:30 "Status of the CEPC HOM coupler development" 20'
Speaker: Dr. Hongjuan ZHENG (IHEP)

SRF Technology

11:50 "CEPC Low Level RF R&D" 20'
Speaker: Xinpeng MA (IHEP)

RF Technology

CEPC Accelerator R & D Session (2)

Center for Applied Superconducting Accelerator
応用超伝導加速器センター

Accelerator-V : convener (A. Sidorin/JINR)

14:00 "CEPC Injection/Extraction including kicker technology" 20'
Speaker: Dr. Jinhui Chen (IHEP)
14:20 "CEPC collider ring magnets R&D" 20'
Speaker: Mei YANG(IHEP)
14:40 "CEPC booster magnets R&D" 20'
Speaker: Dr. Wen KANG (IHEP)
15:00 "CEPC injection/extract line and timing" 20'
Speaker: Mr. Xiaohao (IHEP)

Magnet Technology

Accelerator-VI : convener (A.V. Bogomyagkov/BINP)

16:00 "Korea accelerator projects and technology R&D" 20'
Speaker: Seunghwan Shin
16:20 "CEPC 650MHz High-Efficiency Klystrons and MBKs" 20'
Speaker: Dr. Zusheng Zhou (IHEP)
16:40 "FCC-ee MDI IP quads" 20'
Speaker: Mike Korazinos
~~17:00 "NICA status" 20'~~
~~Speaker: Anatoly Sidorin (JINR)~~

RF Technology

Accelerator-VII : convener (Y. Sohn/POSTEC)

10:30 "CEPC collider ring vacuum system R&D" 20'
Speaker: Y.S. Ma
10:50 "CEPC electromagnet separators and power sources R&D" 20'
Speaker: Mr. Bin CHEN (IHEP)
11:10 "CEPC instrumentation R&D" 20'
Speaker: Dr. Yanfeng Sui (IHEP)
11:30 "CEPC Control system status and challenges" 20'
Speaker: Mr. Gang LI (IHEP)
11:50 "CEPC mechanical systems and supporting structures", 20'
Speaker: Haijing WHAG (IHEP)

Accelerator System

Accelerator-VIII : convener (J. Gao/IHEP)

14:00 "Progress of photocathde RF gun development at Tsinghua University" 20'
Speaker: 应超 杜 (Tsinghua University)
14:20 "CEPC linac beam dynamics" 20'
Speaker: Mr. Cai Meng (IHEP)
14:40 "Status of CEPC RF power delivery systems
(solid state sources for the CEPC booster)" 20'
Speaker: Dr. Zusheng Zhou (IHEP)
15:00 "Laser plasma accelerator for proton" 20'
Speaker: Xuexing (PKU)

RF Technology

Beam Dynamics

CEPC Accelerator R & D Session (3)

Accelerator-IX : convener (F. Zimmermann/CERN)

16:00 "Storage rings to detect gravitational waves" 20'
Speaker: Giuliano Franchetti (GSI)

~~16:20 "IJCLab accelerator activities" 20'~~
~~Speaker: Iryna Chaikovska (IJCL)~~

16:40 "SppC status" 20'
Speaker: Prof. Jingyu Tang (IHEP)

17:00 "SppC high field SC magnet" 20'
Speaker: Dr. Qingjin Xu (IHEP)

R&D for SppC

Accelerator-X : convener (X.Q. Yan/PKU)

10:30 "CEPC Z-pole polarization" 20'
Speaker: Dr. Zhe Duan (IHEP)

10:50 "CEPC cryogenic system design in view of energy saving" 20'
Speaker: Mr. Rui GE (IHEP)

11:10 "CEPC IP region HOM mode and wake-fields" 20'
Speaker: Dr. Yudong LIU(IHEP)

11:30 "CEPC synchrotron radiation applications" 20'
Speaker: HUANG Yongsheng (SYSU)

11:50 "CEPC dump systems and radiation safety issues" 20'
Speaker: Mr. Guangyi Tang (IHEP)

Novel Concept

Accelerator-XI : convener (J. Gao/IHEP)

14:00 "CEPC Installation and allignment strategies and technologies" 20'
Speaker: Mr. Xiaolong Wang (IHEP)

14:20 "CEPC site choice and related technical challenges (1 Qinhuangdao)" 20'
Speaker: Y. Xiao

14:40 "CEPC site choice and related technical challenges (2 Huzhou)" 20'
Speaker: K. Huang

15:00 "CEPC site choice and related technical challenges (3 Changsha)" 20'
Speaker: Zhiji Li

15:20 "Recent progress in assess of CEPC site at Changsha" 20'
Speaker: Ling-yun Dai (Hunan University)

Site Choice

Accelerator-XII : convener (A. Faus/IJCL)

16:00 "Recent progress on CEPC plasma injector" 20'
Speaker: Dr. Dazhang LI (IHEP)

16:20 "On PWFA with FLASH Forward" 20'
Speaker: Richard D'Arcy

16:40 "Positron Acceleration in a Hollow Channel Plasma Wakefield Accelerator" 20'
Speaker: Shiyu Zhou

17:00 "Recent Developments in Quick PIC Open Source" 20'
Speaker: Weiming An (Beijing Normal University)

Novel Concept

Highlights of Accelerator R & D for CEPC

Highlights of the accelerator R & D for CEPC

1. Progress on accelerator technologies for CEPC
   - RF Technologies: Normal-conducting structures, Klystron, RF delivery system, LLRF
   - SRF Technologies: SRF cavities, Cryomodules, Cavity performances, HOM couplers
   - Magnet Technologies: Collider ring, Booster ring, Kicker magnet, SC magnet
   - Accelerator Key Systems: Vacuum, Separator, Instrumentation, Control, Support
2. Novel accelerator concepts for CEPC
   - Cryogenic system, Dump system, Radiation shielding, HOM, Polarization, SR application
3. Global accelerator design issues for CEPC
   - Beam dynamics, Beam instabilities, Error correction
4. CEPC site choice: 1. Qinhuangdao, 2. Huzhou, 3. Changsha, Installation and Alignment
5. Summary

(Sorry, for omitting Worldwide Contributions from SuperKEKB, ILC-SRF, FCC-ee, Novosibirsk, JINR, Korea, GSI)

Highlights of the accelerator R & D for CEPC

Center for Applied Superconducting Accelerator
応用超伝導加速器センター

1. Progress on accelerator technologies for CEPC
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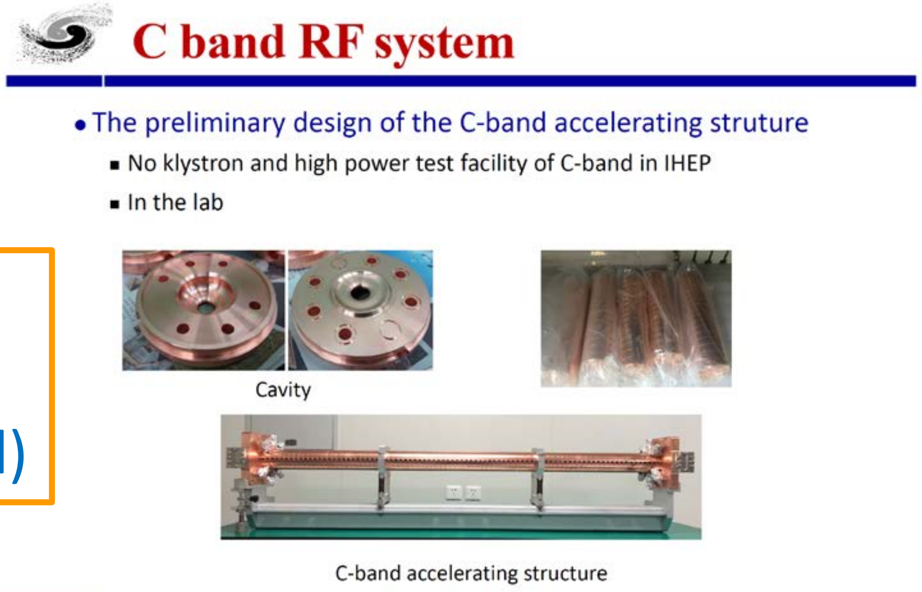
5. Summary

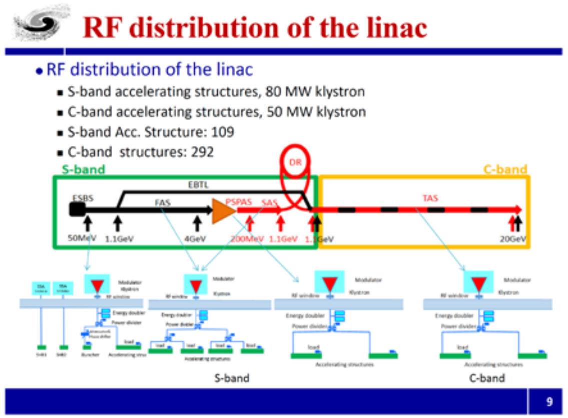
RF Technologies (1)

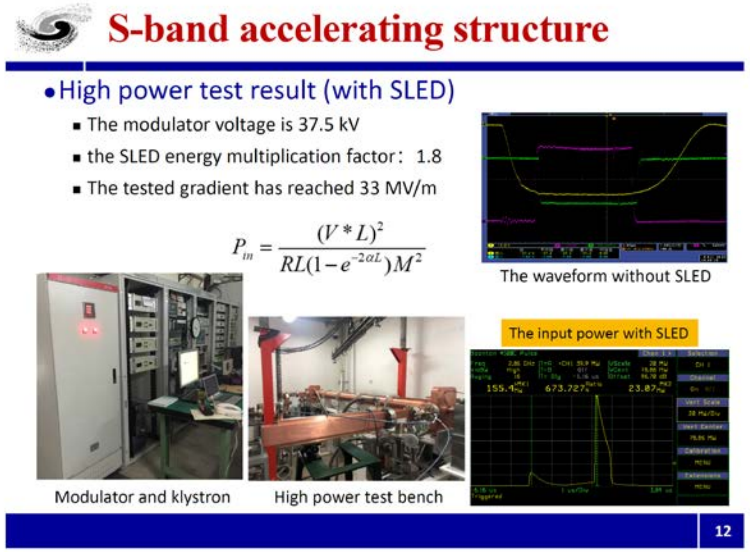
Normal-conducting Structures for Injector LINAC

Findings;

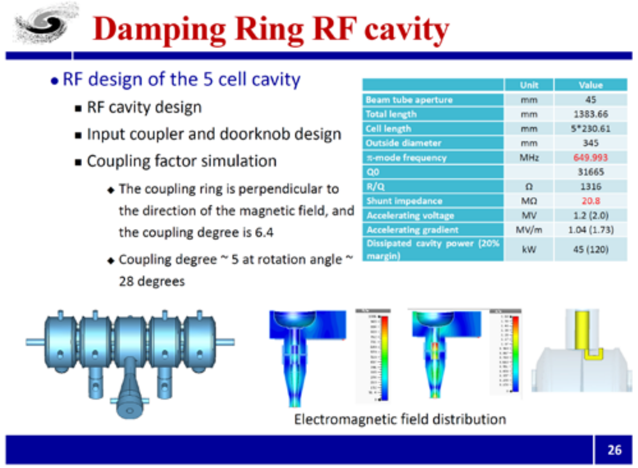
- High power tests of S-band structures (109)
- Fabrication of C-band structures (292)
- Design of 650 MHz damping ring cavity (5-cell)







$$P_{in} = \frac{(V*L)^2}{RL(1-e^{-2\alpha L})M^2}$$



	Unit	Value
Beam tube aperture	mm	45
Total length	mm	1383.66
Cell length	mm	5*230.61
Outside diameter	mm	345
π-mode frequency	MHz	649.993
Q0		31665
R/Q	Ω	1316
Shunt impedance	MΩ	20.8
Accelerating voltage	MV	1.2 (2.0)
Accelerating gradient	MV/m	1.04 (1.73)
Dissipated cavity power (20% margin)	kW	45 (120)

by Jingru Zhang (IHEP)

RF Technologies (2)

650 MHz High Efficiency Klystron

Findings;

- Manufacturing of high efficiency klystron
- Design of 650 MHz multi-beam Klystron
- Construction of high-power test stand

System overall efficiency

CEPC Collider SRF Wall Plug Efficiency

Wall to PSM power supply/modulator	95%
Modulator to klystron	96%
Klystron to waveguide	70%
Waveguide to coupler	95%
Coupler to cavity	~100%
Cavity to beam	~100%
Overall efficiency	**~60.6%**

Saturation: 80%
Linear region: 70%

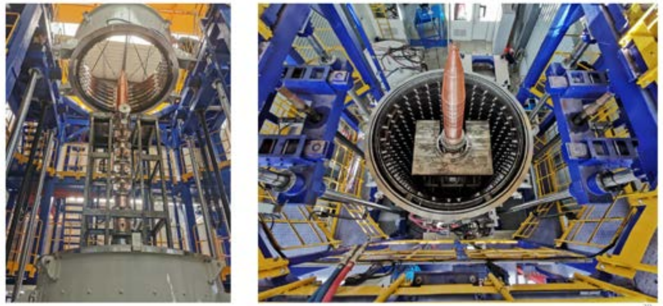
The critical factor is klystron efficiency

Much higher efficiency, less energy consumption.

Klystron final assembly

Klystron final assembly

Klystron baking out



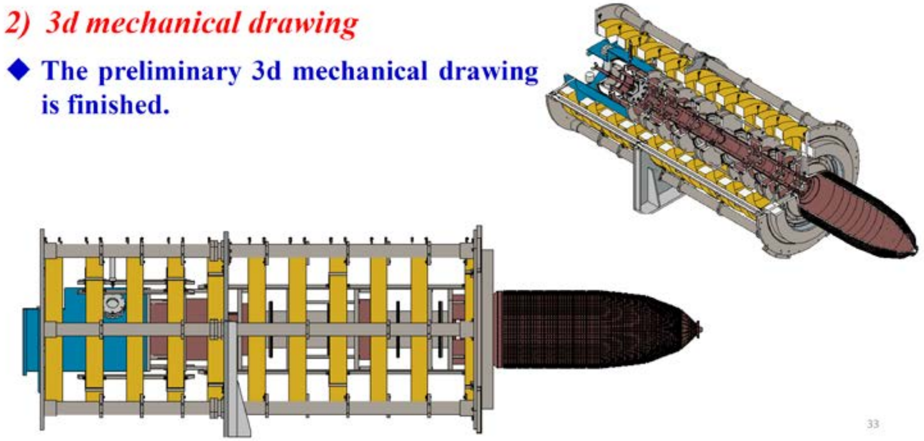
Target efficiency: ~ 80%

by Zusheng ZHOU (IHEP)

② Multi-beam klystron

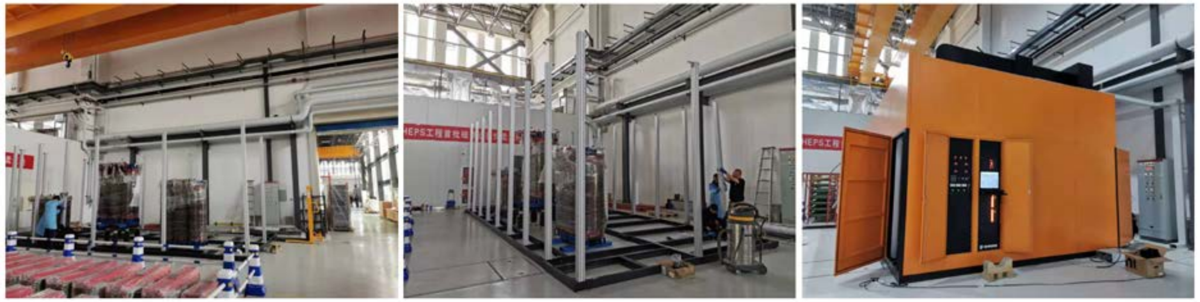
2) 3d mechanical drawing

◆ **The preliminary 3d mechanical drawing is finished.**



③ High power test stand

Site installation and test

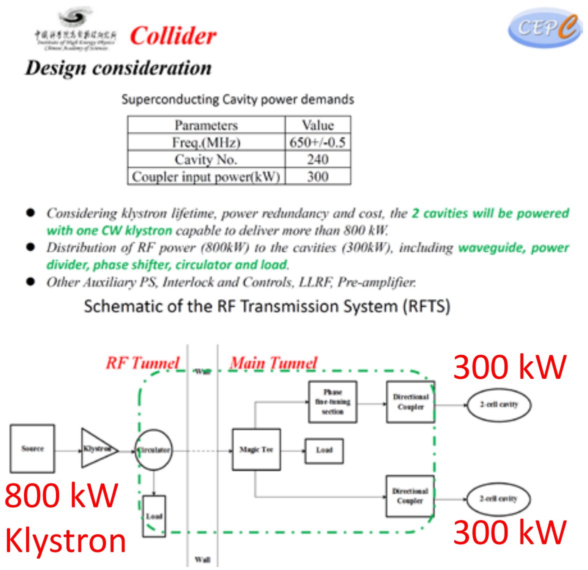


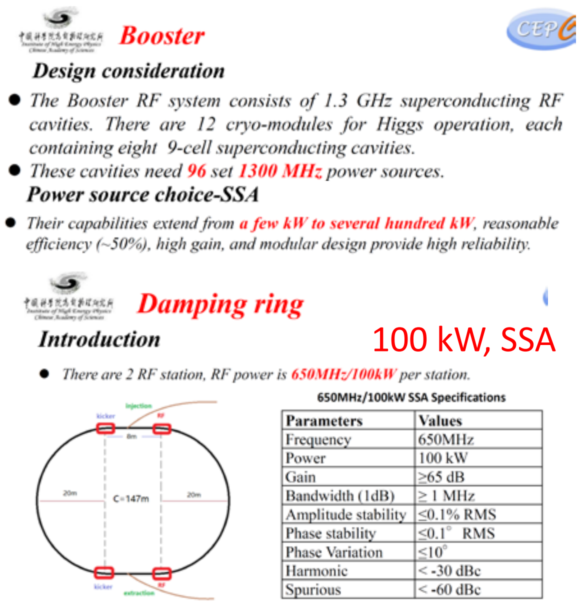
RF Technologies (3)

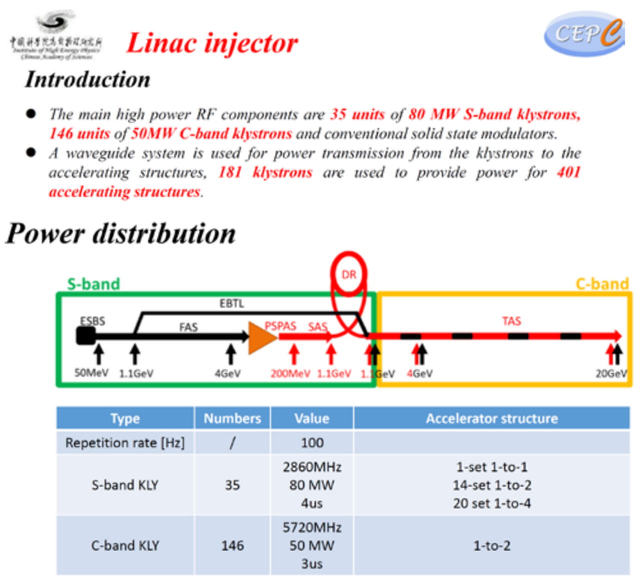
RF Delivery System

Findings;

- For collider ring RF
- For booster ring RF
- For damping ring RF
- For LINAC RF



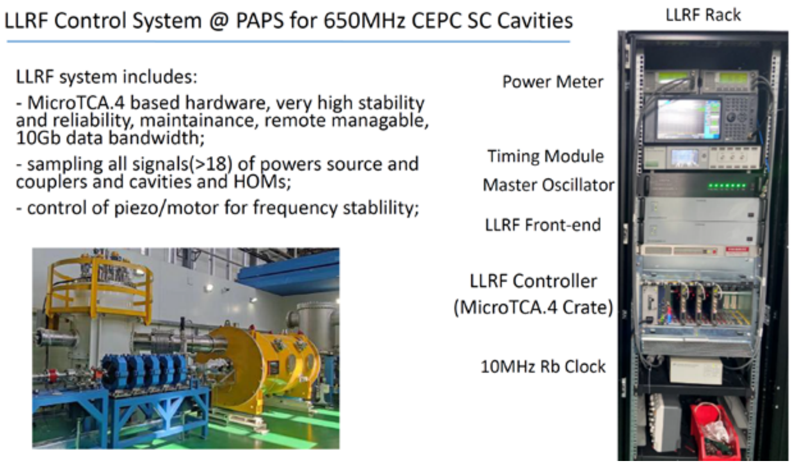


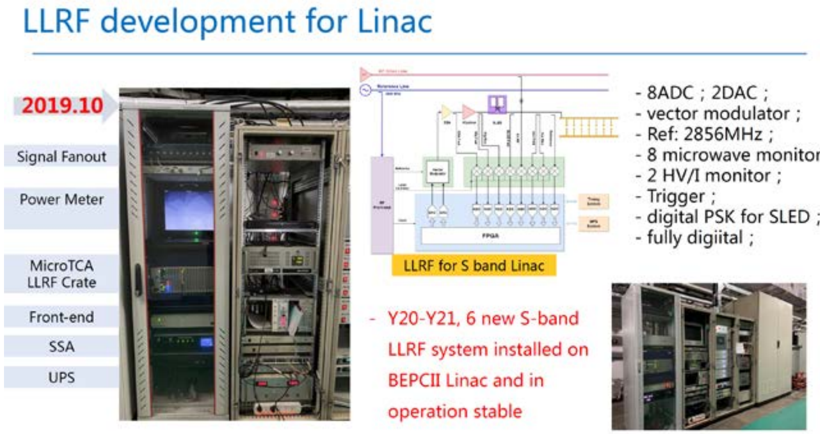


Development of Low-Level RF

Findings;

- LLRF for 650 MHz cryomodule
- Beam experiment at PAPS
- LLRF for LINAC RF system
- LLRF for Booster cavities





by Xinpeng MA (IHEP)

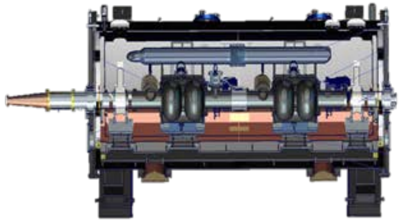
SRF Technologies (1)

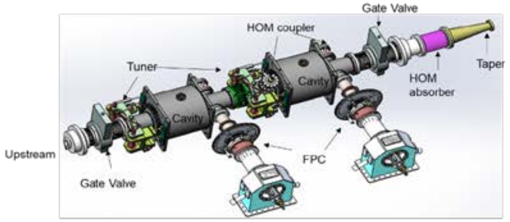
SRF Cavities and Input Couplers

Findings;

- Fabrication of 650 MHz components
- Development of mass-production tools
- Production of 1.3 GHz cavity, coupler, tuner

CEPC 650 MHz Test Cryomodule





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by Jiyuan ZHAI (IHEP)

RF Measurement and Tuning Machine for Mass Production

- New automatic half-cell/dumbbell frequency measurement machine
- Improvement of the pre-tuning machine (ongoing)

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1.3 GHz Cavity, Input Coupler and Tuner Production

- Eight 1.3 GHz 9-cell cavities production (test at PAPS in late 2021 to early 2022).
- Eight 1.3 GHz input couplers production (conditioning at PAPS in early 2022).
- 1.3 GHz tuner prototyping.

北京高能锐新科技有限责任公司
Beijing HE-Racing Technology Co., Ltd.

SRF Technologies (2)

Cryomodules and Infrastructures

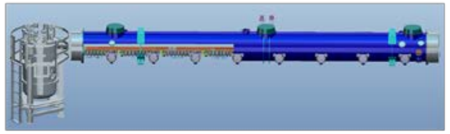
Findings;

- Assembly of 650 MHz test cryomodule at PAPS
- 1.3 GHz High-Q prototype cryomodule for DALS
- Completion of PAPS SRF infrastructures

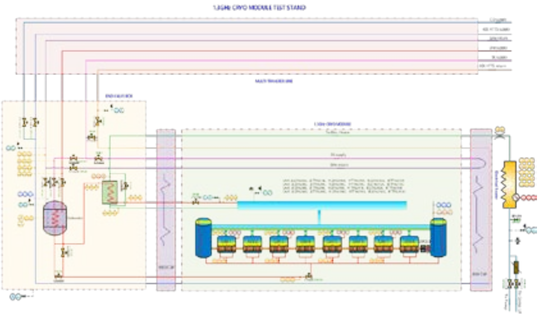
650 MHz Test Cryomodule Assembly

1.3 GHz High Q Cryomodule (8x9-cell)

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



- 1.3 GHz 8x9-cell high Q cryomodule prototype
- Component fabrication in 2021 to mid 2022
- Assemble and horizontal test in 2022
- Ship to Dalian in 2023



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PAPS SRF Lab in Full Operation

by Jiyuan ZHAI (IHEP)

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SRF Technologies (3)

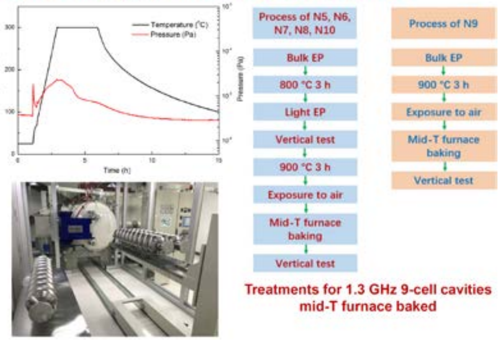
Cavity Performance

Findings;

- Mid-T furnace baking
- 650 MHz 1-cell cavities
- Nb3Sn cavity at 4.2 K

Mid-T furnace baking of 1.3 GHz 9-cell cavities

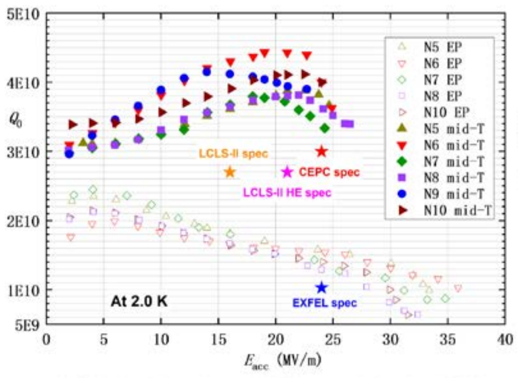
- Six 1.3 GHz 9-cell cavities (N5~N10) received mid-T furnace baking (300 C 3h).
- One 9-cell cavity (N9) adopted the simplified recipe, which cancelled light Electro-polishing.



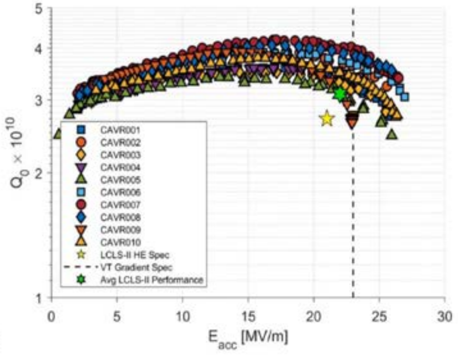
Treatments for 1.3 GHz 9-cell cavities mid-T furnace baked

Vertical test results of 9-cell cavities

- After mid-T furnace baking, all the six 9-cell cavities demonstrated high Q (3.5–4.4E10 @ 16–24 MV/m), which is as good as LCLS-II HE.



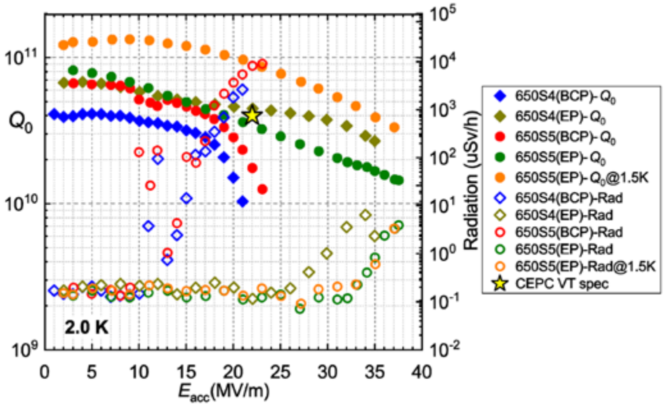
1.3 GHz 9-cell cavities mid-T furnace baked at IHEP



1.3 GHz 9-cell cavities N-doped for LCLS-II HE

650 MHz 1-cell cavities EP processed (2)

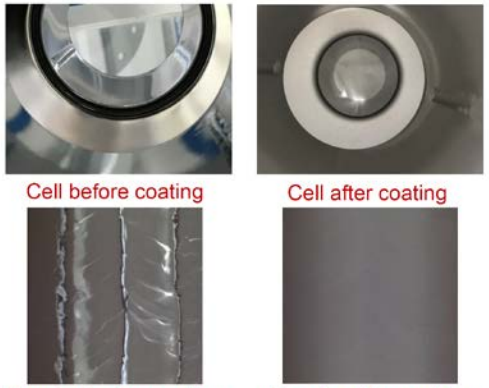
- Both cavities exceeded 35 MV/m, which is state-of-the-art gradient for large elliptical cavities (< 1 GHz).
- 650S4: 4.5E10@22.0 MV/m.
- Q_0 of 650S5 is 3.4E10@22.0 MV/m, which is a little lower than 650S4 above 20 MV/m. The Q-slope phenomenon of 650S5 at 1.5 K is similar as that at 2.0 K. The relatively low Q_0 of 650S5 may be resulted from the cancellation of annealing.



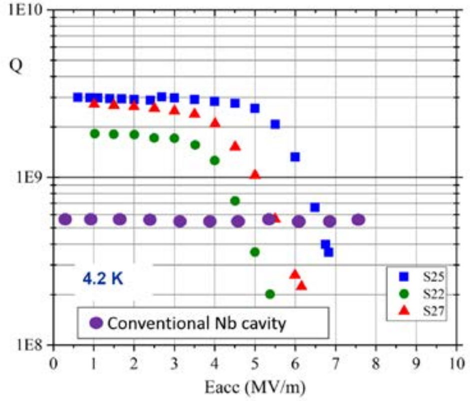
Comparison of 650 MHz 1-cell cavities processed with BCP and EP.

Results of Nb3Sn coating (4.2 K)

- Max gradient: 5~7 MV/m; Max Q: ~3E9.
- The coating process still needs optimization.



Cell before coating · Cell after coating · Equator before coating · Equator after coating



Vertical test results of Nb3Sn cavities

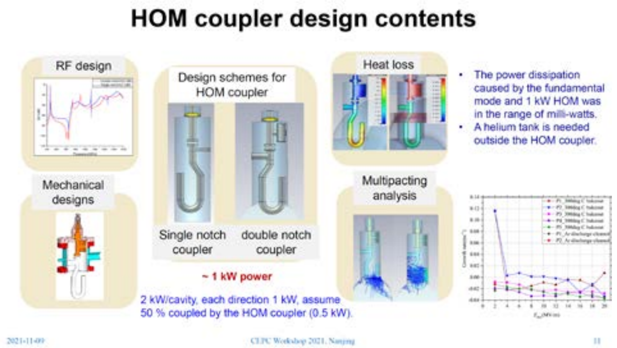
by Peng SHA (IHEP)

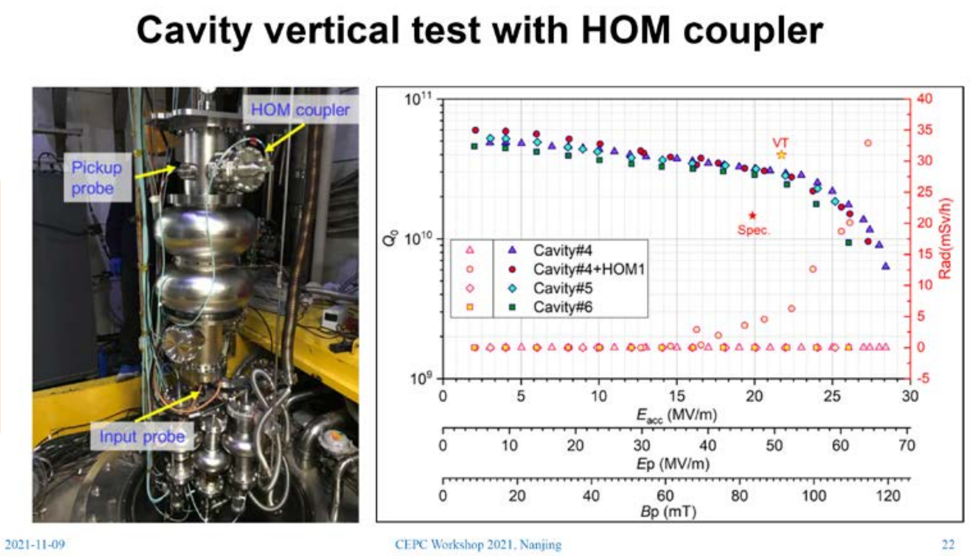
SRF Technologies (4)

HOM Couplers

Findings;

- Design, fabrication, processing, RF measurement
- Vertical tests of 2-cell cavity with HOM couplers
- High power tests and beam operation in cryomodule





by Hongjuan ZHENG (IHEP)

Magnet Technologies (1)

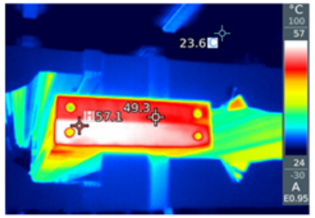
Collider Ring Magnet

Findings;

- Modification of dual aperture dipole magnets
- Modification of dual aperture quadrupole magnets
- Design of sextupole magnets

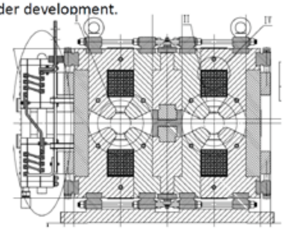
Coil Modification of short dipole magnet prototype

- Old coils:
  - 4 turns of aluminum busbars without cooling holes.
  - Material : non pure aluminum.
  - Insulated with Kapton and glass ribbon.
  - Temperature rise at the end of the coil.
    - Aluminum end faces are easy to oxidize and become insulated.
- Modification
  - Add a cooling hole in the busbars.
  - Contact resistance: Silver plated surface.
  - Radiation resistance: special surface treatment.
  - No epoxy and organic materials.



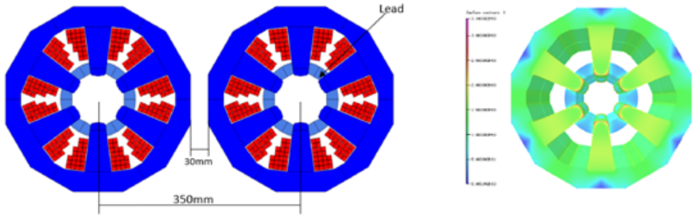
Modification of short DAQ prototype

- Modification of the dual aperture quadrupole magnet (short model: 1m)
  - The new simulation of the 1m magnet is been checked. Mechanical design is done and the DT4 block will be modified.
  - Machining is in progress.
  - Field measurement methods: RCS and SSW.
    - A new rotating coil is planned for the DAQ.
    - Also a stretched wire measurement system is under development.



Design of sextupole magnet

- Basic design
  - Wedge-shaped magnetic poles are used to reduce magnetic pole saturation and improve excitation efficiency
  - Further optimization to the position of the lead block and the arrangement of coil wires to reserve space for magnet assembly.
  - Mechanical design is in progress.



by Mei YANG (IHEP)

Magnet Technologies (2)

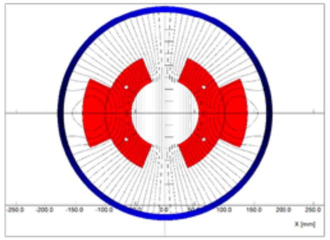
Booster Ring Magnet

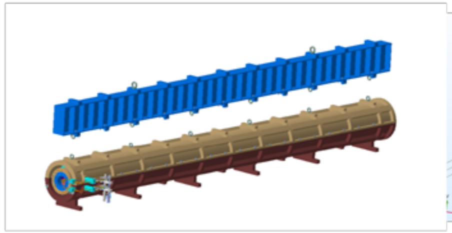
Findings;

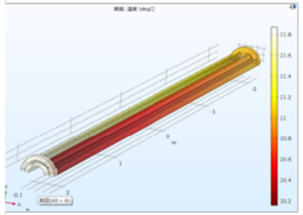
- Manufacturing of full-scale dipole magnet
- Construction of filed measurement system
- Design of full-scale iron-core dipole magnet

Status of the full-scale prototype CT coil dipole magnet

On the base of the subscale prototype CT dipole magnet, the mechanical design of a full scale prototype CT dipole magnet was finished. The production of the magnet on the way.





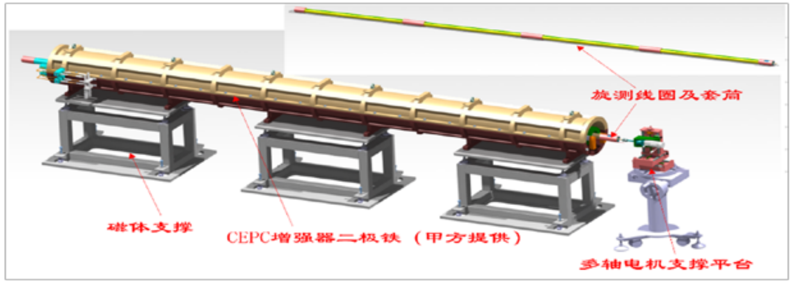


- ✓ The total length of the magnet including the shielding tube is 5.1m.
- ✓ The coil conductors will be made from pure aluminum, the size tolerance less than 0.05mm, the position tolerance less than 0.1mm.

Status of the field measurement system

A 5.6m long rotating coil field measurement system will be used to measure the field of the full-scale CT magnet, it is composed of

1、Long coil
2、Motor and Driver
3、Encoder
4、Motor control
5、Signal acquisition device

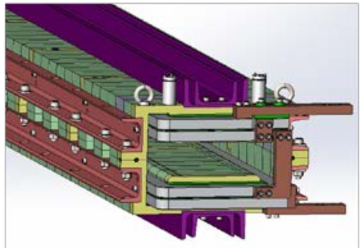


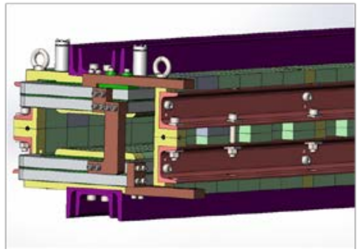
Design of the full-scale iron-core dipole magnet

The main design considerations of the full-scale iron-core dipole magnet

- ➢ To increase the strength of the iron-core as high as possible.
- ➢ To decrease the production cost as low as possible.

So all the metal bars around the iron-cores that pull the laminations together will be made by U-steel which has high strength and low cost.





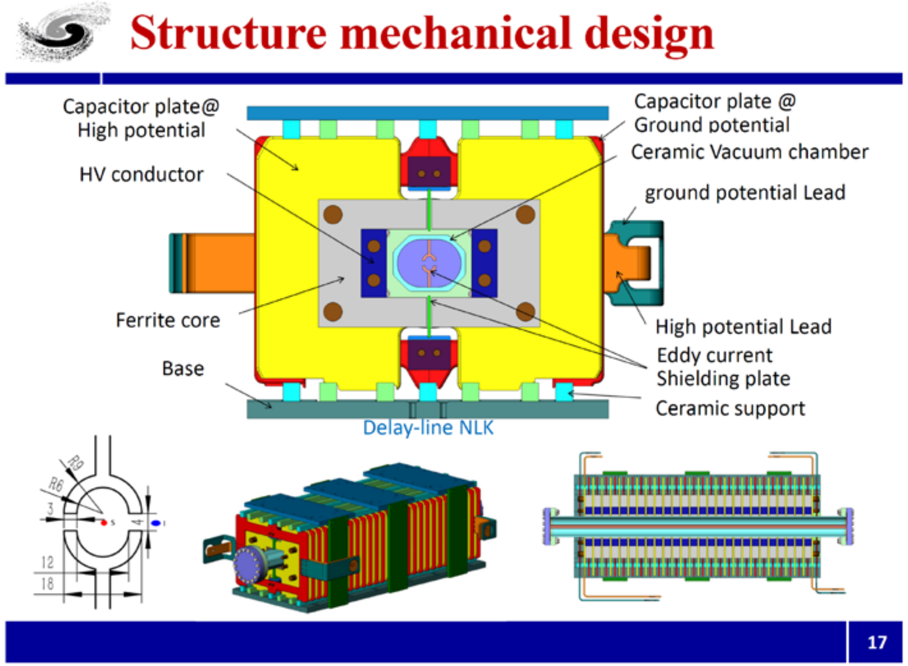
by Wen KANG (IHEP)

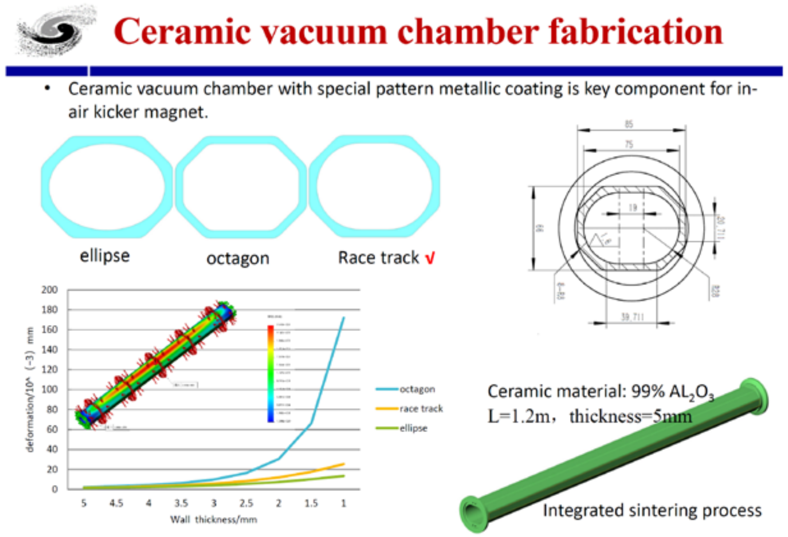
Magnet Technologies (3)

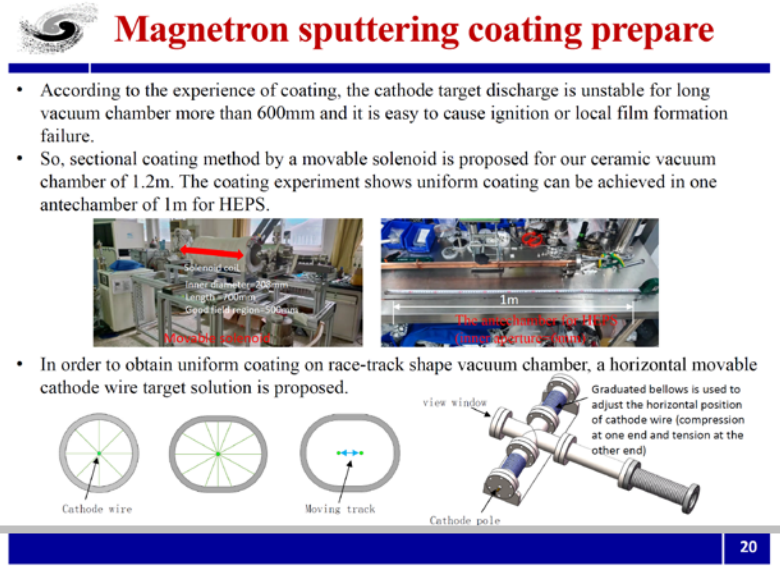
Kicker Magnet

Findings;

- Ferrite core kicker magnet system
- Kicker ceramic vacuum chamber with coating
- Coating system by magnetron sputtering







by Jinhui CHEN (IHEP)

Magnet Technologies (4)

Superconducting Magnet for SppC

Findings;

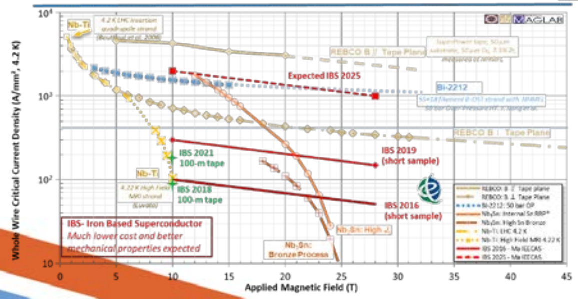
- New IBS; Iron-based superconductor for SC-magnet
- Double pancake IBS solenoid coil reached 67A at 30T
- NbTi+Nb3Sn model dipole magnet reached 12.47T

Magnet Design Scope for SPPC

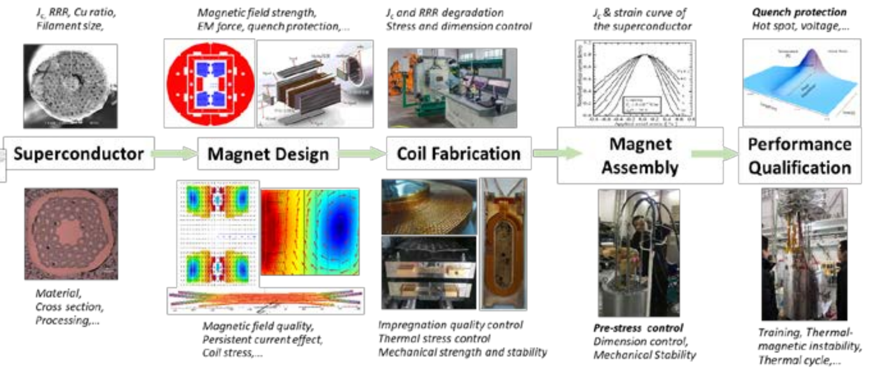
$E[GeV] = 0.3 \times B[T] \times \rho[m]$

High Energy Circular Colliders for next decades	SPPC	FCC
Proposed institution	IHEP-CAS, China	CERN, Europe
Proposed dates	2012	2014
Site of the project	China	Europe
Baseline technology	IBS 12~24 T to reach 75-150 TeV, Nb_3Sn etc as options	Nb_3Sn 16 T to reach 100 TeV
Timeline	Construction at 2040s	Construction at 2050-60s
Cost	*	**

J_e of Practical Superconductors Presently



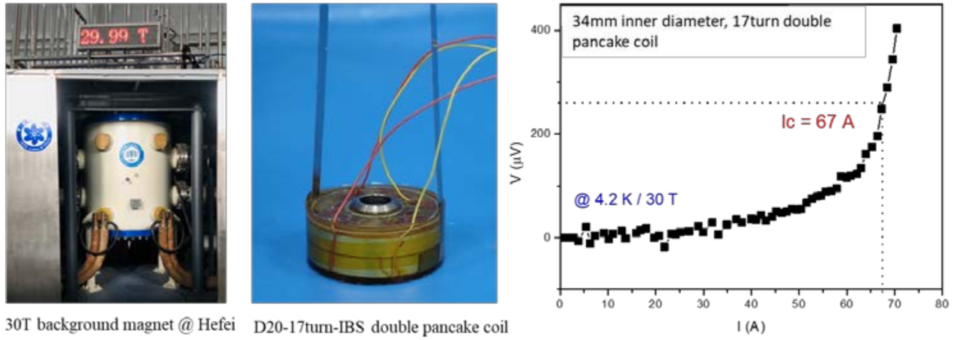
R&D Route for High-field Accelerator Magnets



by Qingjin XU (IHEP)

High Field IBS Insert Solenoids

Performance test of the double pancake IBS solenoid at **30 T background field**

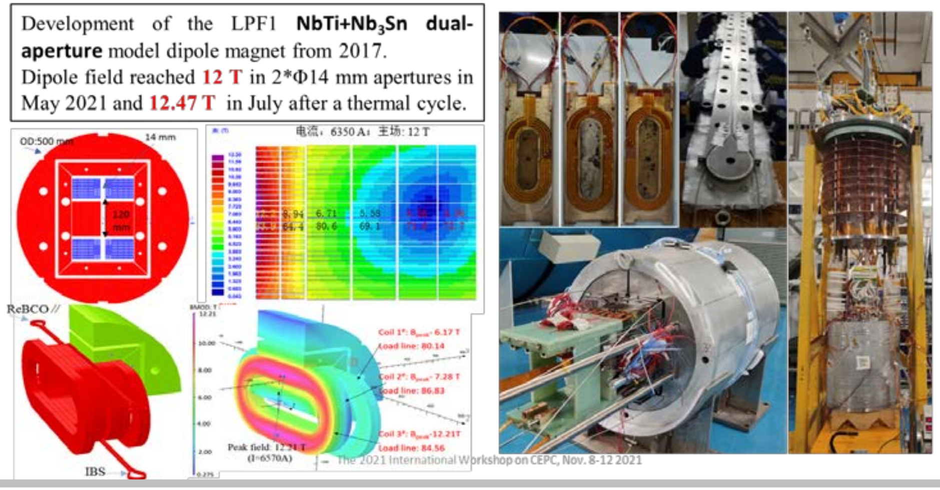


30T background magnet @ Hefei   D20-17turn-IBS double pancake coil

I_c of the IBS solenoid reached 67 A at 30 T. ***New world record!***

R&D of the 1st $NbTi+Nb_3Sn$ Model Dipole Magnet

Development of the LPF1 **$NbTi+Nb_3Sn$ dual-aperture** model dipole magnet from 2017. Dipole field reached **12 T** in 2*Φ14 mm apertures in May 2021 and **12.47 T** in July after a thermal cycle.



Accelerator Key System (1)

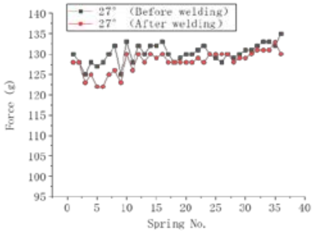
Vacuum System

Findings;

- RF shielding bellows
- Storage ring vacuum chamber
- Cu and Al vacuum chamber
- NEG coating parameters
- NEG coating facility at PAPS

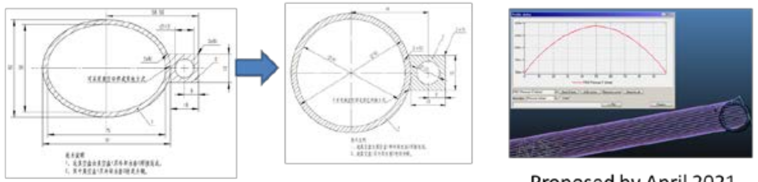
R&D of RF shielding bellows

◆The key components experiments such as spring fingers and contact fingers have been carried out. Contact force is uniformly from different fingers and meets the target of 125±25g. The prototypes of RF shielding bellows have been fabricated.



Structure of storage ring vacuum chamber

- To eliminate the quadrupolar wakes, elliptical vacuum chamber in the collider ring will be replaced by circular chambers with dimeter of 56 mm, meanwhile, the magnet costs and power supply will be reduced about 80M CNY. With other conditions unchanged, the vacuum pressure is increased by about 28% and the cost will reduce about 7.61 million CNY.



Proposed by April 2021.

- Synchrotron radiation gas load $Q_{LS} = 1.5\times10^{-9}\ Torr\cdot l\cdot s^{-1}\cdot m^{-1}$ ($\eta=2\times10^{-6}$)
- Thermal load gas $q= 1.0\times10^{-11}\ Torr\cdot l\cdot s^{-1}\cdot cm^{-2}$
- Suppose there is an ion pump of 100L/s in a spacing of 6 m; (electron ring without NEG coating)

Round chamber is easier to be fabricated.

Cu and Al vacuum chamber prototypes

- A 6 m long simple vacuum furnace is fabricated, which is used to weld the water cooling channels of Cu chambers through low temperature brazing solder.
- The welding seams are checked by wire-electrode cutting. The welding joints are smooth and have good contacting.
- The prototypes of copper & aluminum vacuum chambers with a length of 6 m have been fabricated and tested, which meet the engineering requirements.

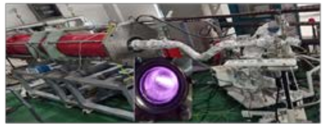
Round chamber is easier to be fabricated.

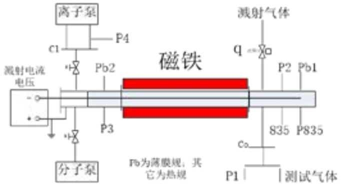
Geometrical shape of 56×75 NEG coating

- 1.5m long vacuum pipe have been coated to explore the coating parameter at geometrical shape of 56×75.

Coating parameter	value
Magnetic(G)	300
Substrate Temperature (℃)	120
Vacuum of coating (Pa)	1
Discharge current (A)	0.4
Discharge voltage (V)	300
Deposition time (h)	10
Geometric diameter (mm)	56×75×1500

NEG No. CF100-1500-0001





NEG coating facility @ PAPS

☐ NEG coating of vacuum pipe

A setup of NEG coating which has ability to coat 4 meters long pipe has been built for vacuum pipes of HEPS at location of PAPS. And one test vacuum pipe of 4 meters long, φ22 mm of inner diameter have been coated, which shows that NEG film has good adhesion and thickness distribution. Theoretically, It is easier to be coated of CEPC vacuum pipe, because of the ratio of diameter to length is 56/6000 which is bigger then 22/4000.

by Youngsheng MA (IHEP)

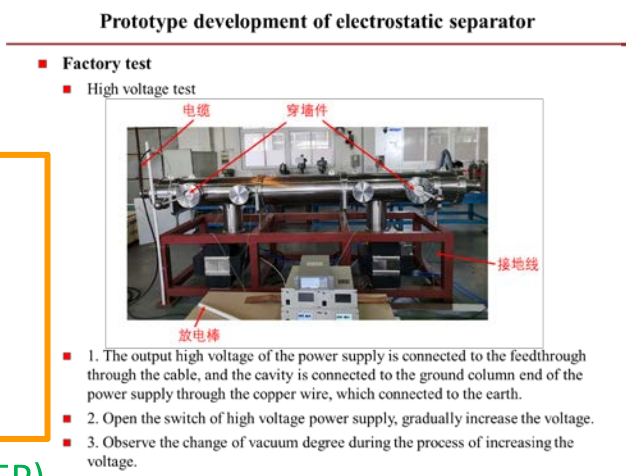
Accelerator Key System (2)

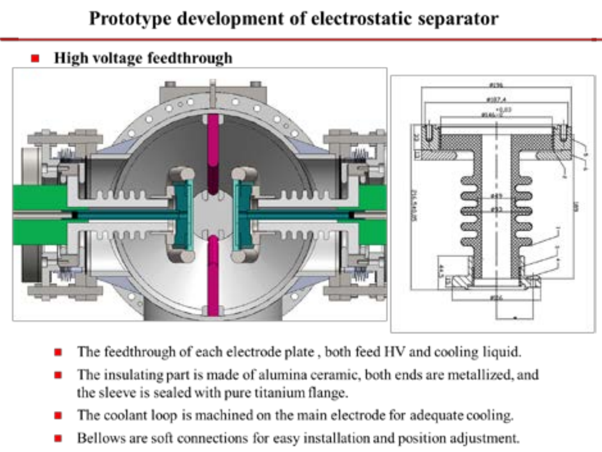
Electromagnetic Separator

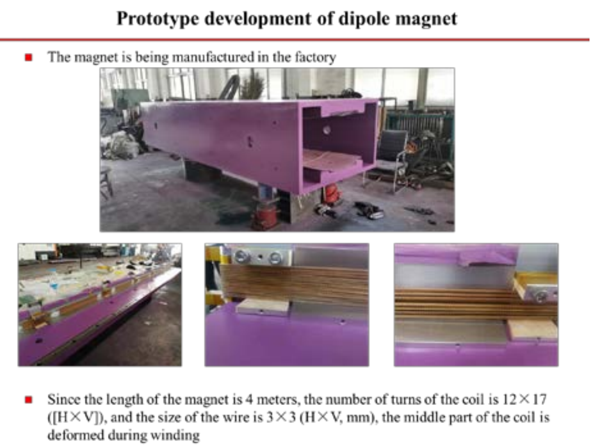
Findings;

- Prototype development
- Factory tests
- High voltage feedthrough
- Fabrication of Diploe magnet

by Bin CHEN (IHEP)





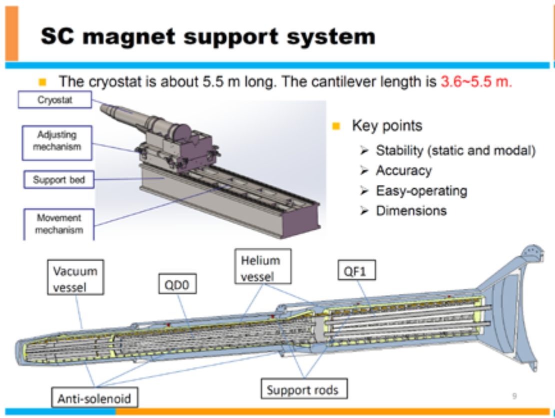


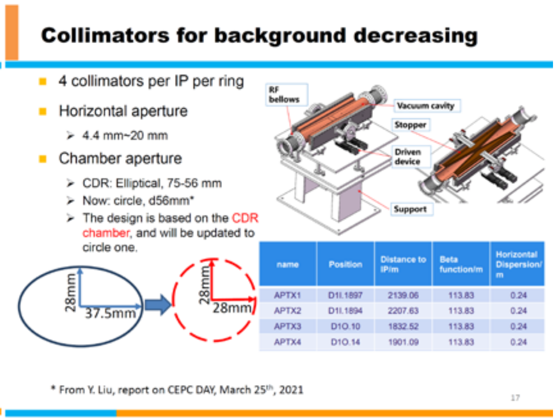
Mechanical and supporting Structure

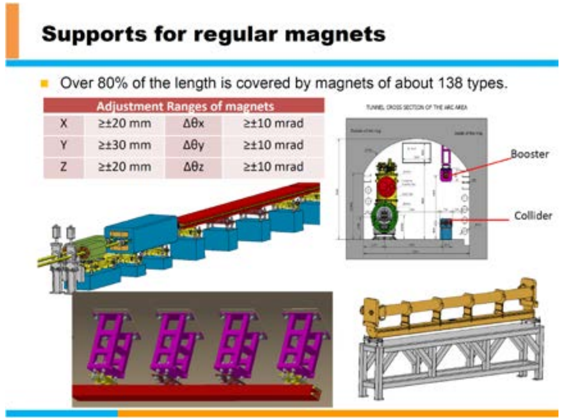
Findings;

- SC magnet support system
- Design of collimators
- Support for regular magnets

by Haijing WANG (IHEP)







Accelerator Key System (3)

Bean Instrumentation

Findings;

- Beam monitor system
- Bunch by bunch BPM
- Feedthrough R&D

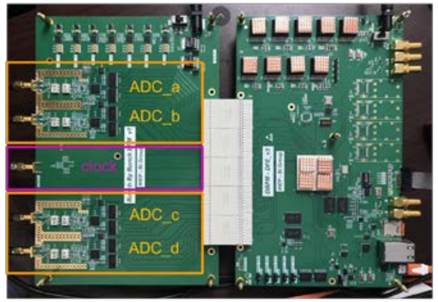
by Yanfeng SUI (IHEP)

The beam instrumentation in CEPC ring

	Item		Method	Parameter	Amounts
Storage ring	Beam position monitor	Closed orbit	Button electrode BPM	Measurement area (x × y) : ±20mm × ±10mm Resolution: <0.6um Measurement time of COD: < 4 s	2900
		Bunch by bunch	Button electrode BPM	Measurement area (x × y) : ±40mm × ±20mm Resolution: 0.1mm	
	Bunch current		BCM	Measurement range: 10mA / per bunch Relatively precision: 1/4095	2
	Average current		DCCT	Dynamic measurement range: 0.0~1.5A Linearity: 0.1 % Zero drift: <0.05mA	2
	Beam size		Double slit interferometer x ray pin hole	Resolution:0.2 μm	4
	Bunch length		Streak camera Two photon intensity interferometer	Resolution:1ps@10ps	2
	Tune measurement		Frequency sweeping method	Resolution:0.001	2
			DDD	Resolution:0.001	
	Beam loss monitor		PIN-diode	Dynamic range:120 dB Maximum counting rates≥10 MHz	5800
	Feedback system		TFB	Damping time<=47ms	2
			LFB	Damping time<=100ms	2

Bunch by bunch BPM electronics

Sampling clock: 500MHz,free running clock or externally clock locked with beam signal



11/10/2021 20

Feed-through R&D

- Finished the study of feed-through in beam instrumentation.
- Independent research and development of feed-through was kicked off
- Two versions of feed-through have been made with the help of CIPC Member Company in the last year.

BPM feed-through V1.0

BPM feed-through V2.0

Kicker feed-through

Control System

Findings;

- Scope of control system
- 5bility and real time
- Control plat home

by Gang LI (IHEP)

Scope of the Control System

- Global control
  - Control Platform
  - Center Control System: computers, servers, database, etc
  - Network System
  - Timing System
  - Post Mortem System
  - Machine Protection System
  - Video system
- Local control
  - Power Supply Control System
  - Vacuum Control System
  - Temperature Monitoring System
  - Linac Control System
- Integration of subsystems
  - LLRF, Cryogenic system, Injection/Extraction system etc.
- Interface to other system
  - Detector(Experimental physics), beamline and conventional facility

- 5bility+RT
  - ➢Stability
  - ➢Availability
  - ➢Flexibility
  - ➢Scalability
  - ➢Reliability
  - ➢Real Time

Control Platform

- ●Software Platform: EPICS
  - ➢Open source, free SCADA/DCS, toolkits

- ●Hardware Platform
  - ➢Standardization, Modularity and Commercial products
  - ➢Workstation and servers
  - ➢ATCA/uTCA (High Availability)
  - ➢PLC
  - ➢Fieldbus: Serial device servers and so on
  - ➢Motion controller/Driver
  - ➢etc.

Highlights of the accelerator R & D for CEPC

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    - RF Technologies: Normal-conducting structures, Klystron, RF delivery system, LLRF
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    - Magnet Technologies: Collider ring, Booster ring, Kicker magnet, SC magnet
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3. Global accelerator design issues for CEPC
    - Beam dynamics, Beam instabilities, Error correction
4. CEPC site choice: 1. Qinhuangdao, 2. Huzhou, 3. Changsha, Installation and Alignment
5. Summary

Novel Accelerator Concept (1)

Center for Applied Superconducting Accelerator
応用超伝導加速器センター

Cryogenic System

Findings;

- Very interesting presentation
- Challenging huge cryogenic plants
- Unfortunately, no uploaded file
- ………. by Rui GE (IHEP)

Novel Accelerator Concept (2)

Dump and Shielding System

Findings;

- Dump design and optimization
- SR shielding for collider and booster
- Dose distribution for collider and LINAC

by Guangyi TAN (IHEP)

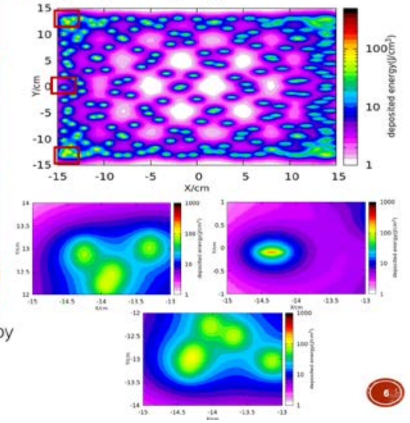
MAX. TEMPERATURE RISE

- Example: aluminum core

	ttbar	Higgs	WW	Z
Beam energy/GeV	175	120	80	45.5
Ne/bunch/ 10^{10}	24	17	12	15
Bunch number	34	218	1569	15000
Total energy/MJ	0.2	0.7	2.4	16.4
Maximum temperature rise	234 ±3℃	154 ±5℃	103 ±1℃	714 ±12℃

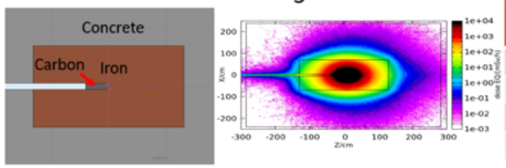
- Max. temperature rise @Z mode can decrease by increasing the bunch distance on the dump surface.

- Energy deposition @Higgs mode



LOCAL SHIELD DESIGN FOR HOT SPOTS

- Carbon and iron is selected as the absorber material, surrounded by the concrete as local shielding.
- 5.5mSv/h dose-equivalent is set as upper limit to decide the thickness of local shielding .



Beam energy	Trans. Area /m^2	Length/m
60MeV	0.75*0.75	1.36
1.2GeV	1.56*1.56	3.05
250MeV	0.98*0.98	1.56
11GeV	2.10*2.10	3.36

Absorber geometry and local shielding: Size for carbon and iron for different beam energy, adopt from other projects, is suitable but haven't been optimized.

Local size selection (11GeV dump as example): 2D map of dose distribution was simulated by FLUKA, the dose rate alone Z or X axis was averaged by 10*10cm^2 area, the shielding size can be selected by the setting dose rate limit.

Preliminary design results for different beam energy analysis station: Radiation level nearby each energy analysis station was figured out, also specify a roughly space for the future local shielding.

- The thickness of shielding will be optimized so that the dose-eq out of dumps is on the order of dose-eq by beam loss in linac tunnel.

HOM and Wake-fields

Findings;

- Impedance budget at IR
- Power density around IR
- Shrink central aperture

by Dong YU (IHEP)

Total impedance budget @3mm

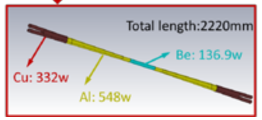
Components	Number	$Z_{||}/n$, mΩ	k_{loss}, V/pC	ky, kV/pC/m
Resistive wall	-	6.2	363.7	11.3
RF cavities	60	0.5	101.2	0.5
Flanges	37714	5.2	37.3	5.2
BPMs	1808	0.04	9.5	0.2
Bellows	15949	2.9	87.4	3.9
Gate Valves	500	0.2	14.5	0.4
Pumping ports	5316	0.3	2.3	0.2
Collimators	8	0.02	11.7	0.3
IP chambers	2	0.004	0.3	0.05
Electro-separators	20	-0.1	34.5	0.1
Taper transitions	48	0.04	2.5	0.09
Total		15.3	664.9	22.2

Power density in different region of IR

	CDR beam parameters		High Luminosity beam parameters	
Power	HOM power(w)	power density（w/cm²）	HOM power(w)	power density(w/cm²）
Be pipe (w)	25	0.227	68.45	0.622
Al: Transition pipe (w)	171	0.316	548.5	1.012
Cu: Y-shape crotch (w)	103.5	0.158	332	0.507
Total power in IR pipe (w)	296	0.234	949	0.714

IP chamber length: 22ppm of ring circumference

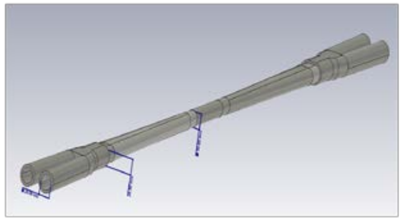
This structure seems feasible !



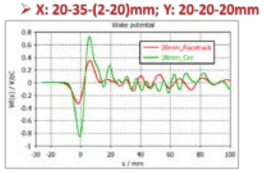
IP chamber power loss: 0.45%

Most Critical component!

Another solution:
shrink the central aperture to 20mm



- Inner diameter at IP: 20 mm
- X: 20-35-(2-20)mm; Y: 20-20-20mm



Primary studies show that the loss factor is reduced by a factor of 3. More detailed studies are under going.

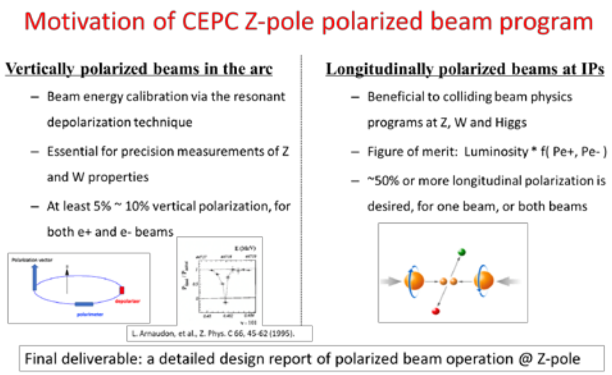
Novel Accelerator Concept (3)

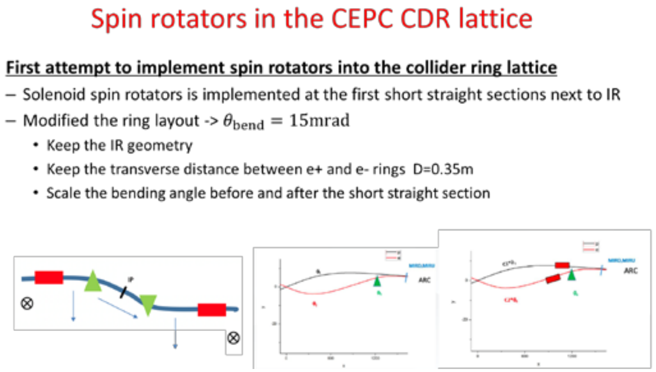
Z-pole Polarization

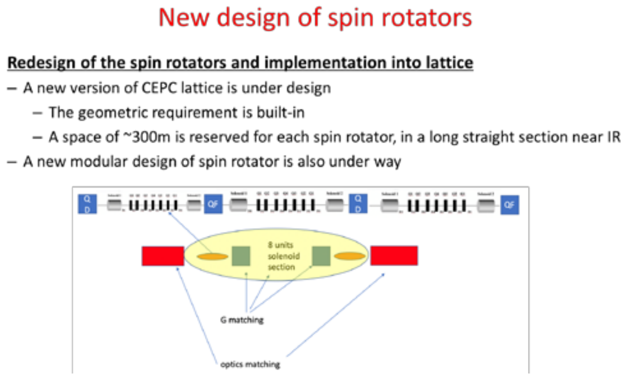
Findings;

- Polarized beam program
- Solenoid based spin rotators
- New design of spin rotators

by Duan ZHE (IHEP)





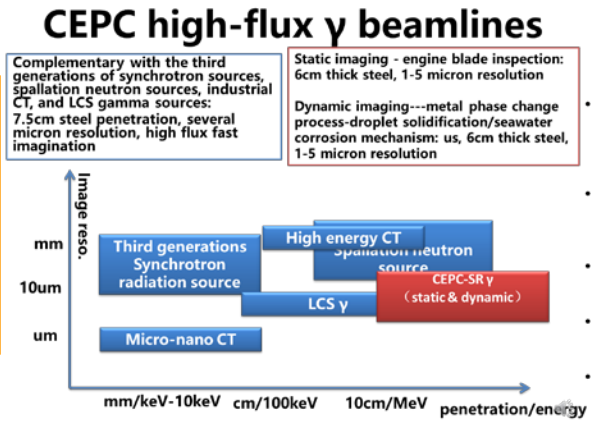


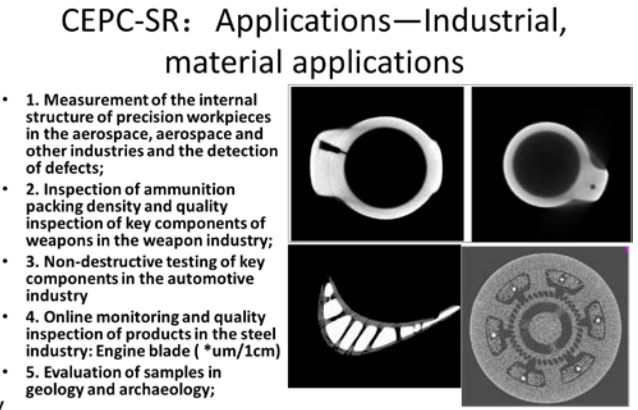
Synchrotron Radiation Application

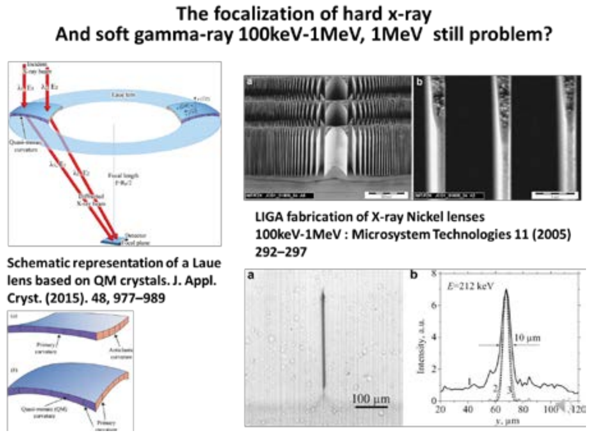
Findings;

- High-flux γ-ray beamlines
- Industrial applications
- Medical isotope production
- MeV γ-ray beam

by Youngsheng HUANG (IHEP)







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Beam Dynamics

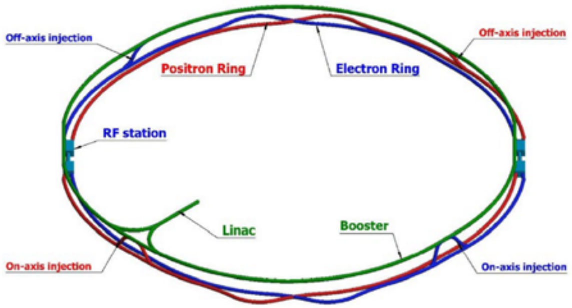
Findings;

- Design requirement of collider ring
- RF staging for compatible modes
- Dynamic aperture with error at Higgs

Design requirement of the CEPC collider ring

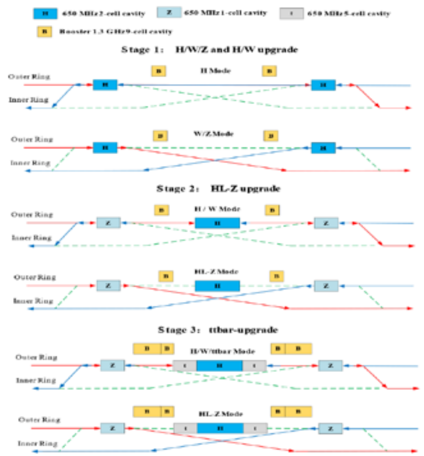
- SR power 30MW (50 MW upgradable), 100km, 2 IPs
- Crab waist collision
- Local chromaticity correction for the interaction region
- Non-interleaved sextupoles
- Correction of sawtooth orbit
- Shared cavities for two beam @ tt, Higgs
- Dual aperture dipole and quadrupole magnets
- Spin polarized beam @ Z
- Asymmetric interaction region
- Compatible of $t\bar{t}$/H/W/Z modes
- Compatible with SPPC

*ref: K. Oide, arXiv:1610.07170; M. Zobov et al, Phys. Rev. Lett. 104, 174801(2010); A. Milanese, PRAB 19, 112401 (2016); CEPC pre-CDR; CEPC-CDR



By Yiwei WANG (IHEP)

RF staging for compatible modes



- 1st priority of the Higgs running and flexible switching
- Low cost at early stage
- Get high luminosity for all modes

Stage 1 (H/W run)
- Layout and parameters are same with CDR except longer central part
- Medium or low luminosity at Z

Stage 2 (HL-Z upgrade)
- **Move Higgs cavities to center and add high current Z cavities.**
- **By-pass low current H cavities.**

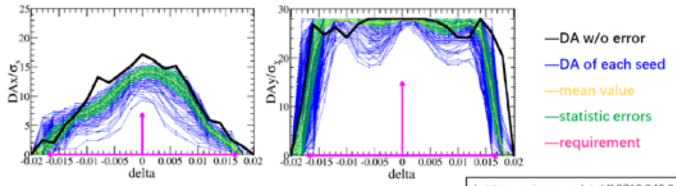
Stage 3(ttbar upgrade):
- Add ttbar cavities (low current, high gradient, high Q)
- Nb3Sn@4.2 K or others to significant reducing the cost of cryo-system and AC power.

Dynamic aperture with error @ Higgs

Bin Wang, Yuanyuan Wei, Yiwei Wang

- Error correction started with 50 um misalignment in IR quadrupoles
  - closed orbit distortion (COD) and dispersion free steering (DFS) correction has been done
  - DA with 418 (out of 1000) error seeds satisfy the on-axis injection requirements
- Further optimization with 100 um misalignment in IR quadrupoles is undergoing.

Component	Δx (mm)	Δy (mm)	Δθ$_z$ (mrad)	Field error
Dipole	0.10	0.10	0.1	0.01%
Arc Quadrupole	0.10	0.10	0.1	0.02%
IR Quadrupole	**0.05**	**0.05**	**0.05**	
Sextupole	0.10	0.10	0.1	



Lattice version cepc.lat.diff.8713.346.2p used
εx=0.64nm, β=0.33m/1mm, L*=1.9m

- Dynamic aperture w/o error @ Higgs energy fulfills the requirements.

Beam Instabilities

Findings;

- Collective instabilities in collider ring
- Collective instabilities in booster ring
- Collective instabilities in damping ring

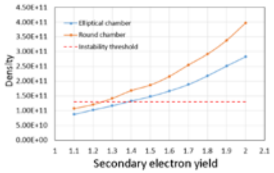
Collective instabilities in the Collider

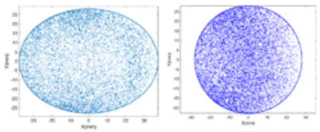
- ☐ Impedance model is updated regarding the change of the chamber cross section (elliptical → circular), more impedance contributions included.
- ☐ Instability issues for high luminosity Z are investigated
  - Single bunch instabilities
  - Coupled bunch instabilities
  - Influence of impedance on beam-beam interaction
  - Electron cloud
  - Beam ion instability

Electron cloud

- ☐ The electron density is increased due to the change of the chamber cross section. The SEY needs to be reduced to <1.2 by introducing NEG coating.
- ☐ More detailed simulations as well as evaluation of its induced heating are under going.

Elliptical chamber: SEY<1.3
Round chamber: SEY<1.2





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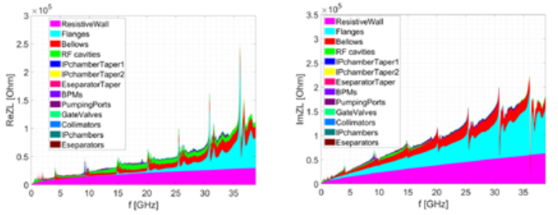
Ring longitudinal impedance

- ☐ Broadband impedances are mainly contributed by: resistive wall, flanges, bellows, RF cavities.
- ☐ Only broadband impedances are included for: RFs, IP chambers
- ☐ Narrowband impedances need to be further checked.



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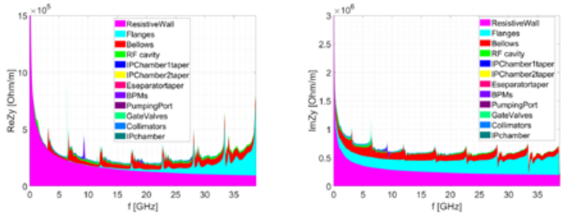
Ring transverse impedance

- ☐ Broadband impedances are mainly contributed by: resistive wall, flanges, bellows.
- ☐ Only broadband impedances are included for: RFs, IP chambers
- ☐ Narrowband impedances need to be further checked.



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Collective instabilities in the Booster

- ☐ Single bunch instabilities
  - ☐ Safety margin reserved!

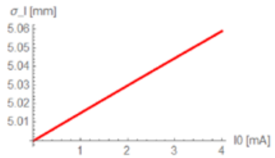
Parameter [unit]	Injection	Extraction
Calculated $\|Z_L/n\|_{eff}$ [mΩ]	2.7	
Calculated k_y [kV/pC/m]	19.3	
Threshold on broadband $\|Z_L/n\|_{eff}$ [mΩ]	0.3	3.9
Threshold on broadband k_y [kV/pC/m]	89.3	224.6

- ☐ Coupled bunch instability threshold
  - ☐ Much more relaxed compare to the collider ring

Parameter [unit]	Z-High Lumi	Injection	Extraction
Threshold on narrowband $\frac{f}{GHz}\frac{ReZ_L}{M\Omega}e^{-(2\pi f\sigma_l)^2}$	0.6	4.1	122.5
Threshold of narrowband $\frac{ReZ_\perp}{M\Omega/m}e^{-(2\pi f\sigma_l)^2}$	0.8	0.8	24.4

Collective instabilities in the damping ring

- ☐ Enough safety margin for the single bunch instabilities
- ☐ Bunch lengthening due to the longitudinal resistive wall impedance



The increase of bunch length is ~1% with only resistive wall impedance.

- ☐ Growth time for the transverse resistive wall instability is ~100 ms ⇒ can be damped by the synchrotron radiation
- ☐ Requirements on the shunt impedance of the HOMs

Parameter [unit]	Design1	Design2
Threshold on narrowband $\frac{f}{GHz}\frac{ReZ_L}{M\Omega}e^{-(2\pi f\sigma_l)^2}$	0.07	0.09
Threshold of narrowband $\frac{ReZ_\perp}{M\Omega/m}e^{-(2\pi f\sigma_l)^2}$	2.8	3.3

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by Na WANG (IHEP)

Error Correction

Findings;

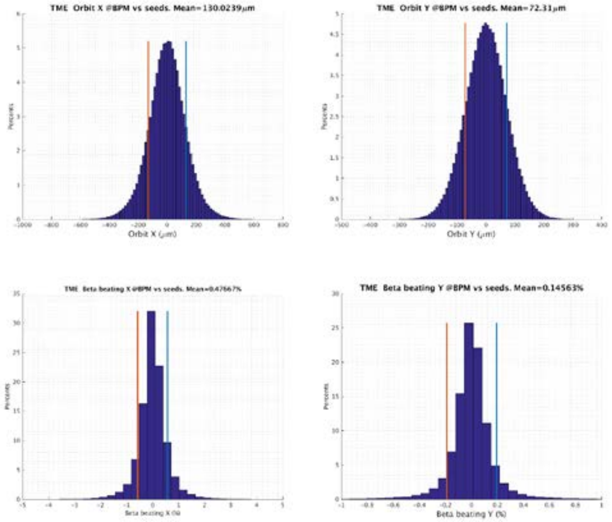
- Orbit correction
- Error simulation analysis
- Dynamic aperture reduction

Correction simulation

- Orbit Correction + Horizontal dispersion
  - RM + SVD
  - 1218H+1220V Corrector
  - Iteration from small singular value (max 80%)
  - Corrector strength limited
- Optics correction
  - RM + LOCO
  - All quadrupole independent
  - Coupling and vertical dispersion also corrected by skew field of some quadrupoles in this step
- Orbit correction and optics correction iterate twice
- 91 of 100 seeds succeeded in auto cycle

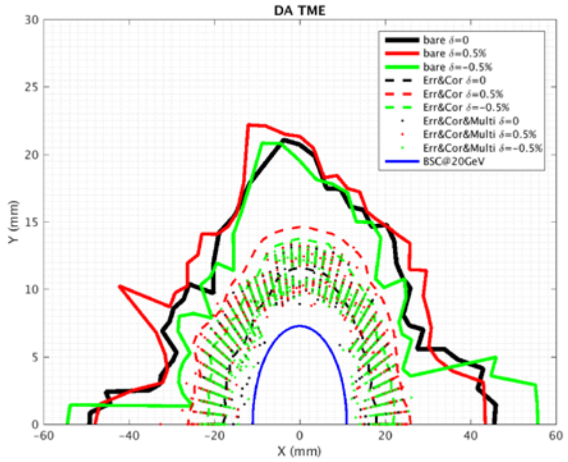
Correction Result

RMS	TME 91Seeds
Orbit (mm)	0.130/0.072
Beta Beating(%)	0.48/0.14
Δ Dispersion(mm)	1.82/3.5



- ➢ All quads used in correction independent
- ➢ Linear parameter and DA is recovered well after correction
- ➢ The results show that TME has advantages in error sensitivity, which is consistent with the previous estimates

DA result



- ➢ After correction, the DA reduction caused by error effect is reasonable
- ➢ The multipole field effect has little effect on DA
- ➢ The effect of off momentum on the aperture is acceptable
- ➢ Error simulation analysis shows that the corrected booster design can basically meet the aperture requirements.

- Error simulation analysis shows that the corrected booster design can basically meet the aperture requirements.
- In the design process, taking into account the sensitivity of errors can effectively improve the performance.
- Hardware can now meet the needs of large-scale computing simulation.
- The process of linear correction has been improved, and the next step will turn to the study of specific effects such as multipole field, dynamic error, etc

by Daheng JI (IHEP)

Highlights of the accelerator R & D for CEPC

1. Progress on accelerator technologies for CEPC
    - RF Technologies: Normal-conducting structures, Klystron, RF delivery system, LLRF
    - SRF Technologies: SRF cavities, Cryomodules, Cavity performances, HOM couplers
    - Magnet Technologies: Collider ring, Booster ring, Kicker magnet, SC magnet
    - Accelerator Key Systems: Vacuum, Separator, Instrumentation, Control, Support
2. Novel accelerator concepts for CEPC
    - Cryogenic system, Dump system, Radiation shielding, HOM, Polarization, SR application
3. Global accelerator design issues for CEPC
    - Beam dynamics, Beam instabilities, Error correction
4. **CEPC site choice:** 1. Qinhuangdao, 2. Huzhou, 3. Changsha, Installation and Alignment
5. Summary

CEPC Site Choice

1. Qinhaungdao
（秦天島市）

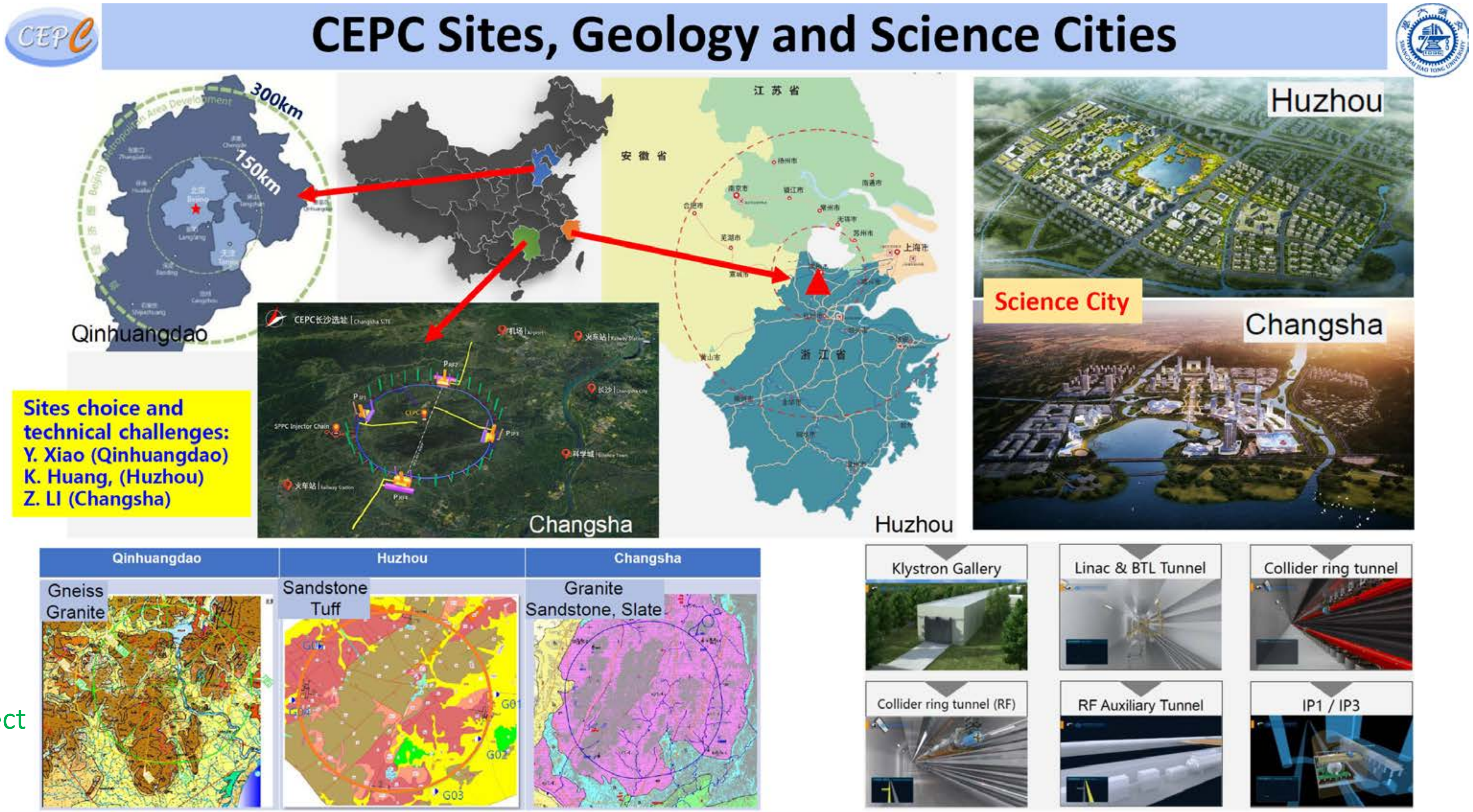
2. Huzhou
（湖州市）

3. Changsha
（長沙市）

Findings;

- 3 candidates for CEPC site

Overview of the CEPC Project
by Haijun Yang (SJTU)



CEPC Site Choice

Installation and Alignment

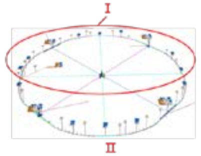
Findings;

- Installation strategies
- Alignment strategies
- Vision instrument R&D

by Xialong WANG (IHEP)

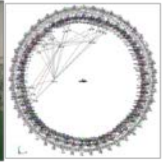
一、CEPC installation strategy

- HDEC CPM, Civil construction will be divided into two phases.
- Installation and alignment scheme is made based on the civil construction schedule, includes two phases.
- project period is :3 years and 9 months



- Tasks:

1. Control network construction.
2. Control network measurement
3. Support setting out and installation
4. Component fiducialization
5. Ring installation and alignment.
6. Linac and BT installation and alignment
7. Smooth alignment



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Component alignment precision requirement

Provide by physics group

Component	Transversal /mm	Vertical /mm	Longitudinal /mm	Pitch /mrad	Yaw /mrad	Roll /mrad
Arc Dipole	0.1	0.1	0.1	0.1	0.1	0.1
Arc Quadrupole	0.1	0.1	0.1	0.1	0.1	0.1
Arc Sextupole	0.1	0.1	0.1	0.1	0.1	0.1
IR Quadrupole	0.05	0.05	0.05	0.05	0.05	0.05
IR SCQ	0.05	0.05	0.05	0.05	0.05	0.05
IR Sextupole	0.05	0.05	0.05	0.05	0.05	0.05

RF、injection、Linac alignment requirement reference to the arc region components

Error sources

1. Alignment control network error
2. Component fiducialization pre-alignment error
3. Measurement error
4. Installation adjustment error

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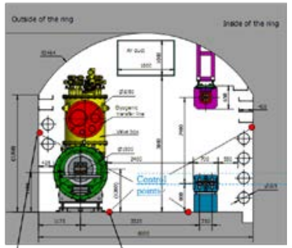
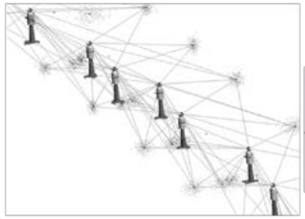
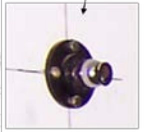
二、CEPC alignment strategy

Tunnel control network

- Providing position reference for component installation and alignment
- Along CEPC tunnel, will be evenly distributed with an interval of 6 meters
- 4 control points each section
- Using laser trackers and levels carry out tunnel network survey







墙面控制点

地面控制点

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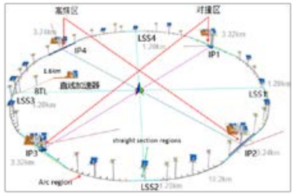
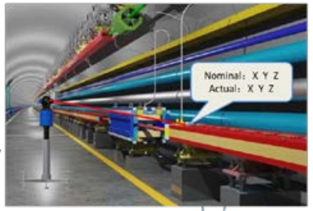
Vision instrument introduction

- Workload of CEPC alignment
  - Tunnel length 109.55km ：100.034km main ring + 6.64kmIR booster tunnel + 1.21km Linac + 0.06km DR+ 1.07km BT + 2X0.268km BT
  - Component quantities：41563～52155
  - Use laser tracker 18259 X2=36518 stations.
  - 1 group 10 stations / day. 12 groups, 1 year
  - Measurement workload is very heavy, need to improve measurement efficiency.





Ring tunnel

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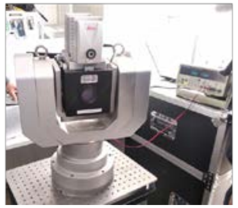
Vision instrument R&D status

- Completed the components assembly

- Completed the motion test after installing the camera and rangefinder



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Summary of Accelerator R & D in CEPC'2021-WS

Summary of Accelerator R &D for CEPC

1. A number of staffs with expertized knowledges and experiences have presented their excellent works and studies in this WS.

2. Remarkable progress in accelerator R&D for CEPC project has been made between CEPC2020 in Shanghai and this CEPC2021-WS.

3. Many challenging R&D efforts in key accelerator technologies have been certainly going advance and will conduct the realization for constructing the CEPC accelerator.

Thank you for your attention.

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