

Highlights of the accelerator R & D in CEPC2021 Workshop

Eiji KAKO
(CASA, Accelerator Lab., KEK, Japan)



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)



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

- 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)

Beam Dynamics

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

- 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)
- 15:00 “CEPC linac injector status and R&D” 20’
Speaker: Ms. Jingru Zhang (IHEP)

Beam Instability

RF Technology

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. Ji yuan 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)
- 11:50 “CEPC Low Level RF R&D” 20’
Speaker: Xinpeng MA (IHEP)

SRF Technology

RF Technology

CEPC Accelerator R & D Session (2)



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

- 14:00 "Progress of photocathode 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 alignment 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)

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
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5. Summary

RF Technologies (1)

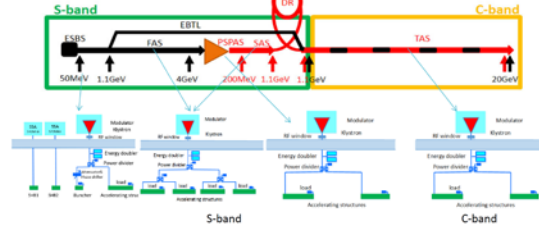
Normal-conducting Structures for Injector LINAC

Findings;

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

RF distribution of the linac

- RF distribution of the linac
 - S-band accelerating structures, 80 MW klystron
 - C-band accelerating structures, 50 MW klystron
 - S-band Acc. Structure: 109
 - C-band structures: 292



S-band accelerating structure

- High power test result (with SLED)
 - The modulator voltage is 37.5 kV
 - the SLED energy multiplication factor: 1.8
 - The tested gradient has reached 33 MV/m

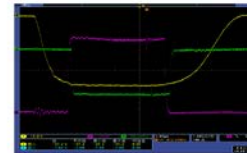
$$P_{in} = \frac{(V * L)^2}{RL(1 - e^{-2\alpha L})M^2}$$



Modulator and klystron



High power test bench



The waveform without SLED

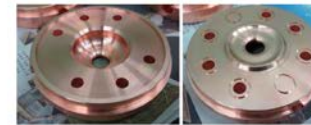


The input power with SLED



C band RF system

- The preliminary design of the C-band accelerating structure
 - No klystron and high power test facility of C-band in IHEP
 - In the lab



Cavity



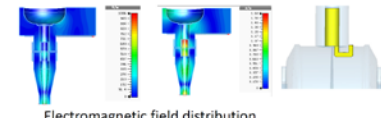
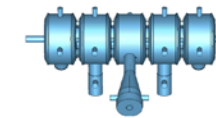
C-band accelerating structure



Damping Ring RF cavity

- RF design of the 5 cell cavity
 - RF cavity design
 - Input coupler and doorknob design
 - Coupling factor simulation
 - ◆ The coupling ring is perpendicular to the direction of the magnetic field, and the coupling degree is 6.4
 - ◆ Coupling degree ~ 5 at rotation angle ~ 28 degrees

	Unit	Value
Beam tube aperture	mm	45
Total length	mm	1383.66
Cell length	mm	5*230.61
Outside diameter	mm	945
Resonance frequency	MHz	649.993
Q0		31665
β/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)



Electromagnetic field distribution

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%

The critical factor is klystron efficiency

Much higher efficiency, less energy consumption.



Klystron baking out



Klystron final assembly

Klystron final assembly



Target efficiency: ~ 80%

by Zusheng ZHOU (IHEP)

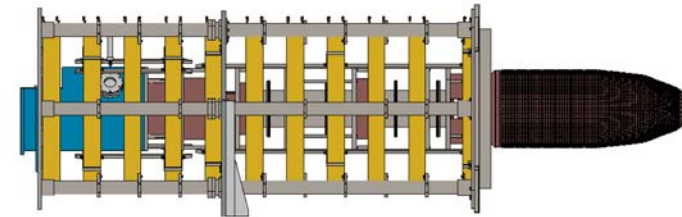
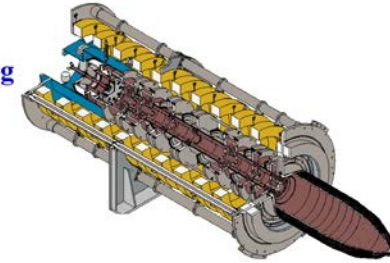


② Multi-beam klystron



2) 3d mechanical drawing

- ◆ The preliminary 3d mechanical drawing is finished.

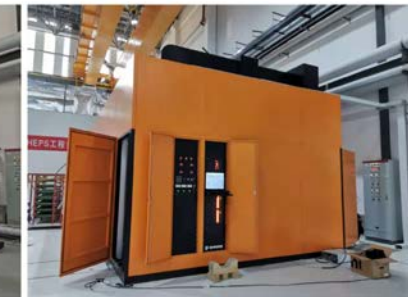
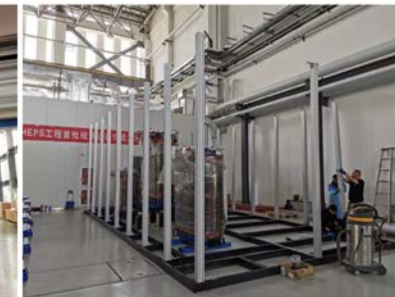


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③ High power test stand

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

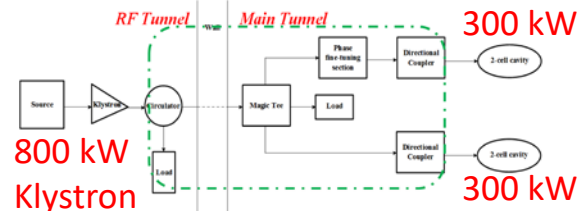
Collider Design consideration

Superconducting Cavity power demands

Parameters	Value
Freq.(MHz)	650+/-0.5
Cavity No.	240
Coupler input power(kW)	300

- Considering klystron lifetime, power redundancy and cost, the 2 cavities will be powered with one CW klystron capable to deliver more than 800 kW.
- Distribution of RF power (800kW) to the cavities (300kW), including waveguide, power divider, phase shifter, circulator and load.
- Other Auxiliary PS, Interlock and Controls, LLRF, Pre-amplifier.

Schematic of the RF Transmission System (RFTS)



Booster Design consideration

- The Booster RF system consists of 1.3 GHz superconducting RF cavities. There are 12 cryo-modules for Higgs operation, each containing eight 9-cell superconducting cavities.
- These cavities need 96 set 1300 MHz power sources.

Power source choice-SSA

- Their capabilities extend from a few kW to several hundred kW, reasonable efficiency (~50%), high gain, and modular design provide high reliability.

Damping ring

Introduction

- There are 2 RF station, RF power is 650MHz/100kW per station.

100 kW, SSA

650MHz/100kW SSA Specifications

Parameters	Values
Frequency	650MHz
Power	100 kW
Gain	≥65 dB
Bandwidth (1dB)	≥ 1 MHz
Amplitude stability	≤0.1% RMS
Phase stability	≤0.1° RMS
Phase Variation	≤10°
Harmonic	< -30 dBc
Spurious	< -60 dBc

Linac injector

Introduction

- The main high power RF components are 35 units of 80 MW S-band klystrons, 146 units of 50MW C-band klystrons and conventional solid state modulators.
- A waveguide system is used for power transmission from the klystrons to the accelerating structures, 181 klystrons are used to provide power for 401 accelerating structures.

Power distribution



Type	Numbers	Value	Accelerator structure
Repetition rate [Hz]	/	100	
S-band KLY	35	2860MHz 80 MW 4us	1-set 1-to-1 14-set 1-to-2 20 set 1-to-4
C-band KLY	146	5720MHz 50 MW 3us	1-to-2

Development of Low-Level RF

Findings;

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

LLRF Control System @ PAPS for 650MHz CEPC SC Cavities

LLRF system includes:

- MicroTCA.4 based hardware, very high stability and reliability, maintenance, remote manageable, 10Gb data bandwidth;
- sampling all signals(>18) of powers source and couplers and cavities and HOMs;
- control of piezo/motor for frequency stability;



Power Meter

Timing Module

Master Oscillator

LLRF Front-end

LLRF Controller
(MicroTCA.4 Crate)

10MHz Rb Clock

LLRF Rack



LLRF development for Linac

2019.10

Signal Fanout

Power Meter

MicroTCA
LLRF Crate

Front-end

SSA

UPS



- Y20-Y21, 6 new S-band LLRF system installed on BEPCII Linac and in operation stable

- 8ADC ; 2DAC ;
- vector modulator ;
- Ref: 2856MHz ;
- 8 microwave monitor ;
- 2 HV/I monitor ;
- Trigger ;
- digital PSK for SLED ;
- fully digital ;



by Xinpeng MA (IHEP)

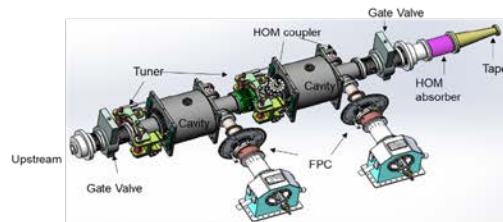
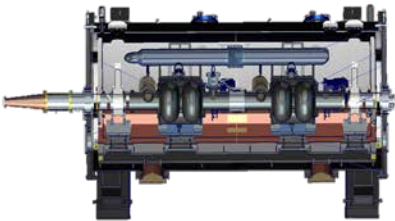
SRF Technologies (1)

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



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)



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.



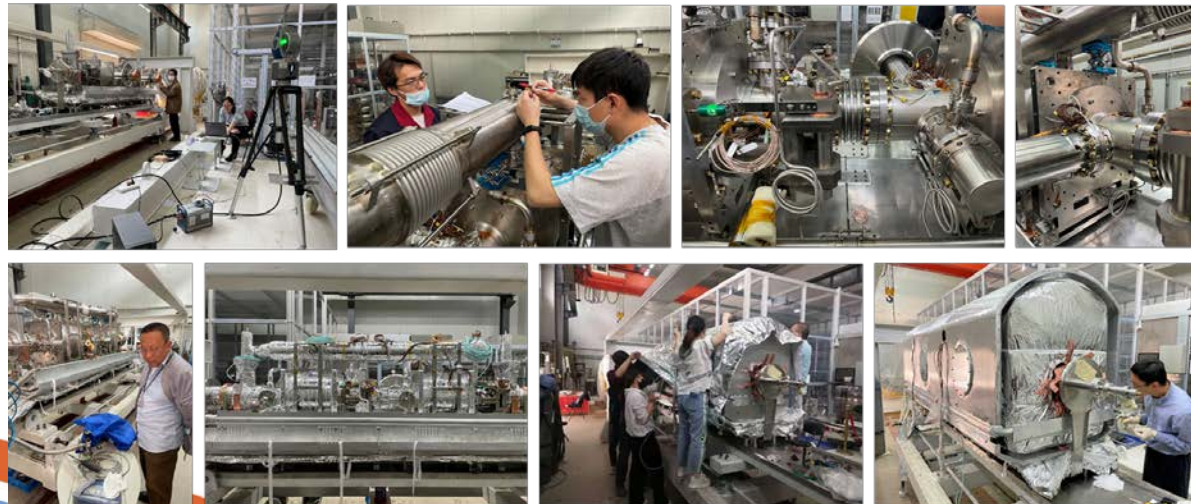
SRF Technologies (2)

Cryomodules and Infrastructures

Findings;

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

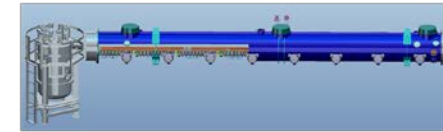
650 MHz Test Cryomodule Assembly



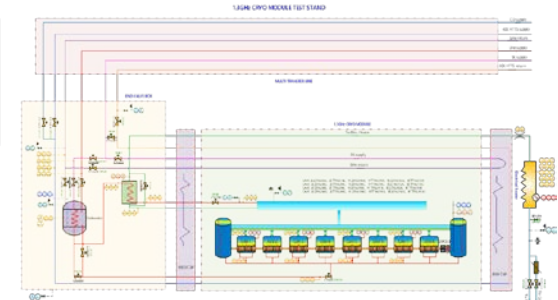
by Jiyuan ZHAI
(IHEP)

1.3 GHz High Q Cryomodule (8x9-cell)

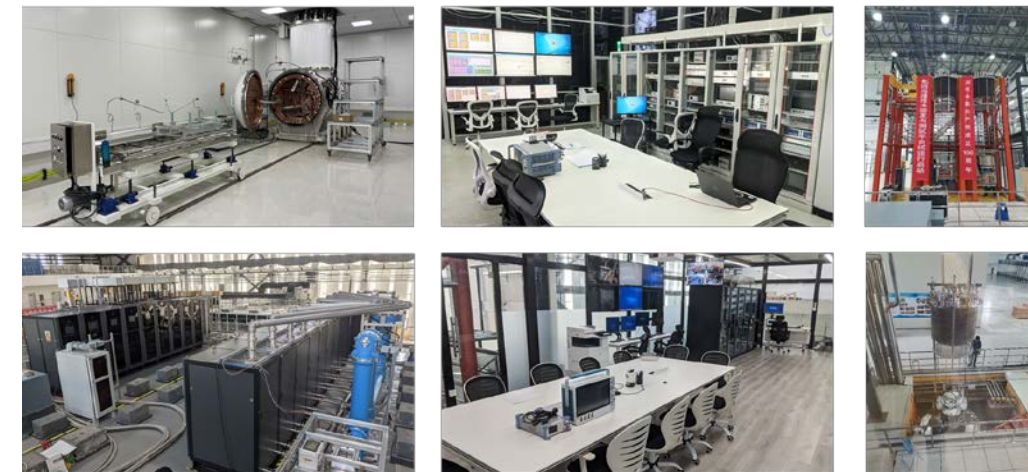
CEPC booster 1.3 GHz SRF technology R&D and industrialization in synergy with domestic CW FEL projects.



- 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



PAPS SRF Lab in Full Operation



SRF Technologies (3)

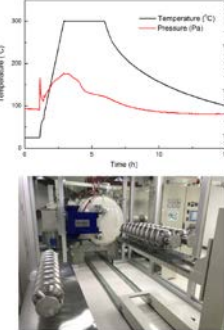
Cavity Performance

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

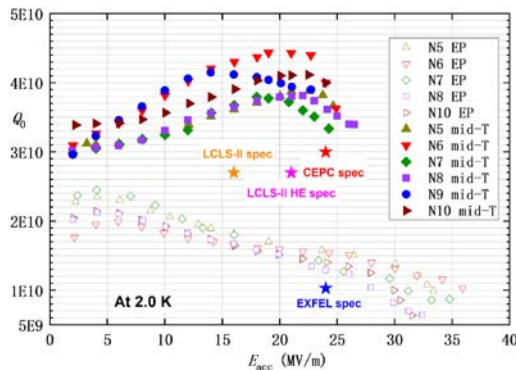
- Six 1.3 GHz 9-cell cavities (N5~N10) received mid-T furnace baking (300 °C 3h).
- One 9-cell cavity (N9) adopted the simplified recipe, which cancelled light Electro-polishing.



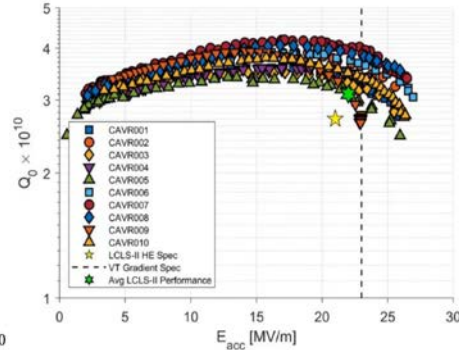
Treatments for 1.3 GHz 9-cell cavities mid-T furnace baked

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

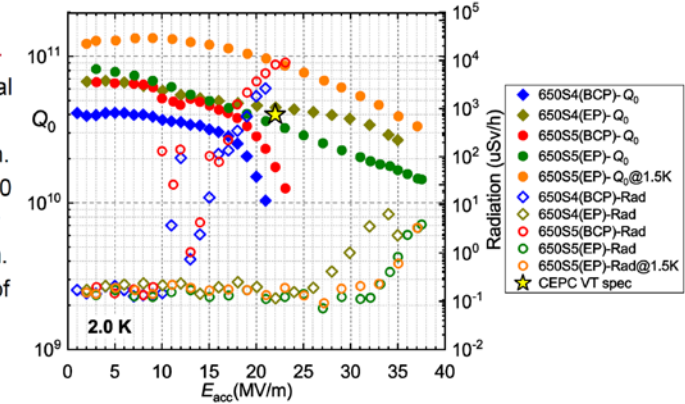


1.3 GHz 9-cell cavities N-doped for LCLS-II HE

by Peng SHA (IHEP)

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.
- Q₀ 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 Q₀ 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



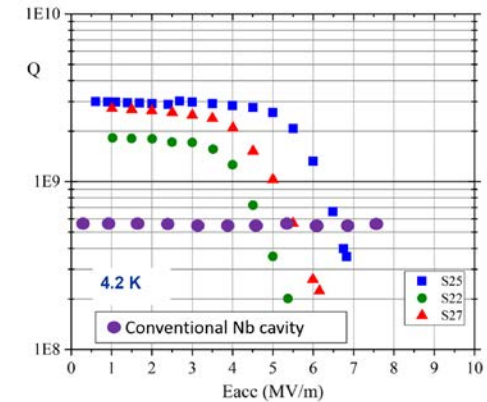
Cell after coating



Equator before coating



Equator after coating



Vertical test results of Nb₃Sn cavities

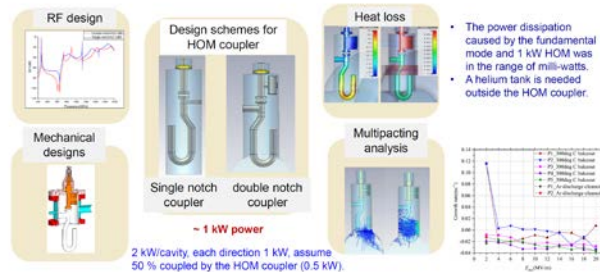
SRF Technologies (4)

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

HOM coupler design contents



2021-11-09

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650 MHz HOM Coupler Fabrication

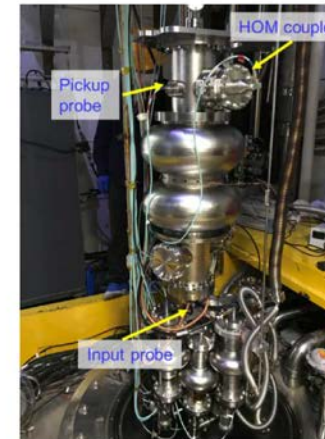
- Four HOM couplers have been finished fabrication, post-processing, which have been assembled in the test cryomodule in the Platform of Advanced Photon Source Technology R&D (PAPS).
- Compact structure design, control machining accuracy



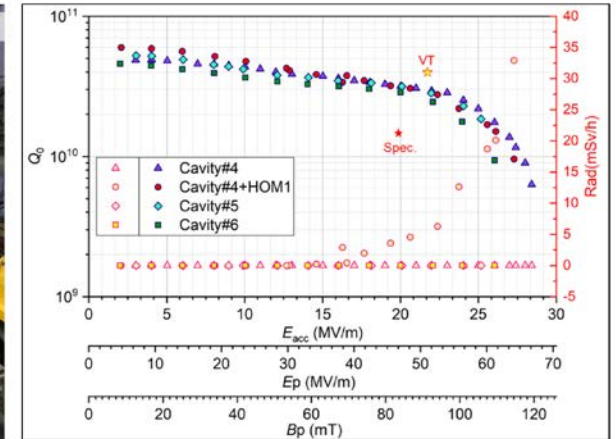
by Hongjuan ZHENG (IHEP)

Eiji Kako (KEK, Japan)

Cavity vertical test with HOM coupler



2021-11-09



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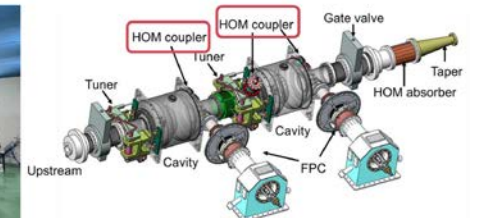
CEPC 650 MHz Test Cryomodule



- Modul installation in beamline, 2 K cool down test in May to July.
- Three HOM coupler installed on the cavity string.
- Q_e for TM010 measured at 2K: 6.8E13, 1.9E13, 2.1E12
- No vacuum leakage occurred.

2021-11-09

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CEPC2021 workshop in November 11, 2021'

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Magnet Technologies (1)

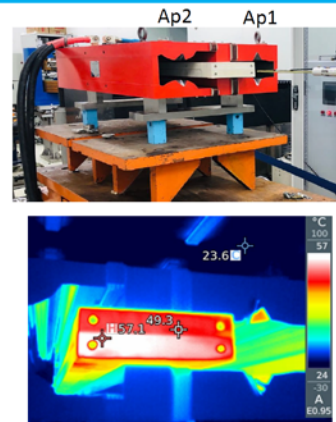
Collider Ring Magnet

Findings;

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

Coil Modification of short dipole magnet prototype

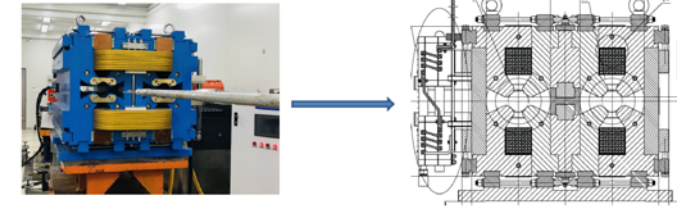
- Old coils:
 - 4 turns of aluminum busbars without cooling holes.
 - Material : non pure aluminum.
 - Insulated with Kapton and glass ribbon.
 - Temperature rise at the end of the coil.
 - Aluminum end faces are easy to oxidize and become insulated.
- Modification
 - Add a cooling hole in the busbars.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



by Mei YANG (IHEP)

Modification of short DAQ prototype

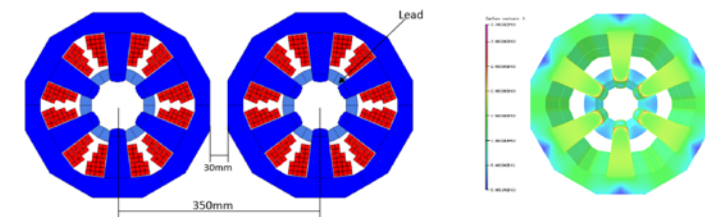
- Modification of the dual aperture quadrupole magnet (short model: 1m)
 - The new simulation of the 1m magnet is been checked. Mechanical design is done and the DT4 block will be modified.
 - Machining is in progress.
 - Field measurement methods: RCS and SSW.
 - A new rotating coil is planned for the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



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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.



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Magnet Technologies (2)

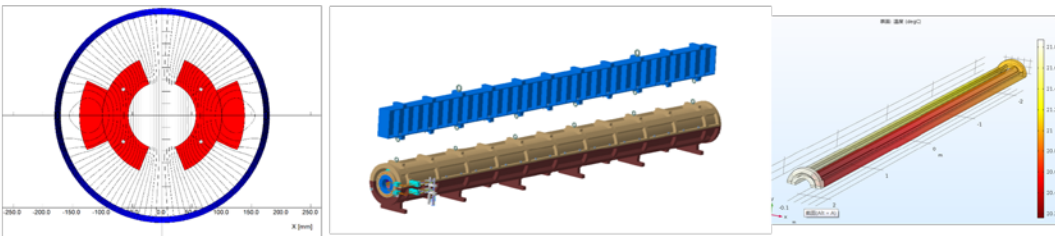
Booster Ring Magnet

Findings;

- Manufacturing of full-scale dipole magnet
- Construction of field 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.

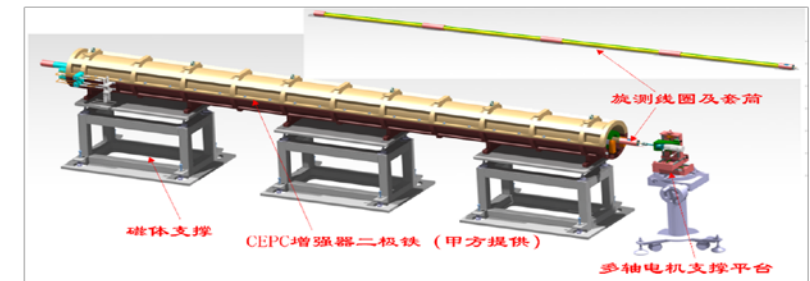


- ✓ The total length of the magnet including the shielding tube is 5.1m.
- ✓ The coil conductors will be made from pure aluminum, the size tolerance less than 0.05mm, the position tolerance less than 0.1mm.

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

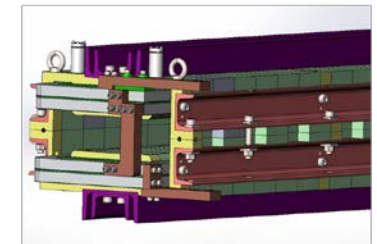
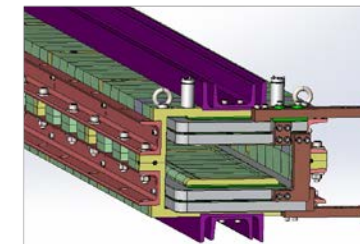


Design of the full-scale iron-core dipole magnet

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)

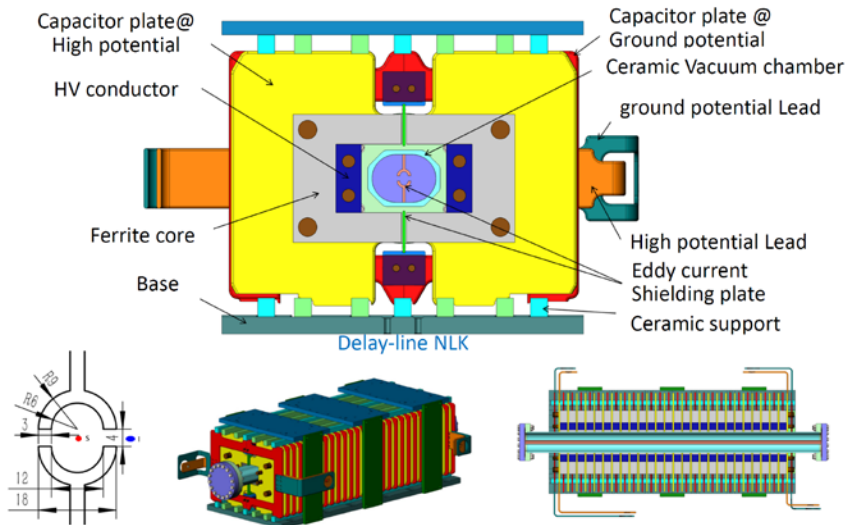
Magnet Technologies (3)

Kicker Magnet

Findings;

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

Structure mechanical design



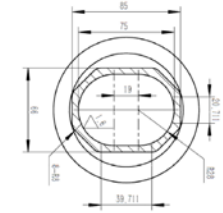
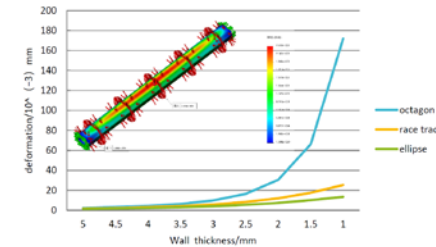
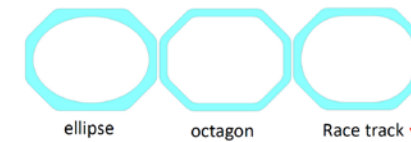
17

by Jinhui CHEN (IHEP)

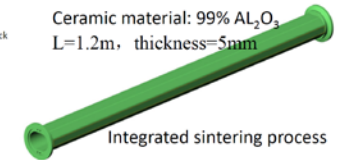


Ceramic vacuum chamber fabrication

- Ceramic vacuum chamber with special pattern metallic coating is key component for in-air kicker magnet.

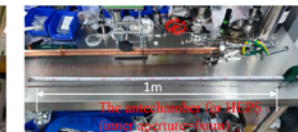


Ceramic material: 99% Al_2O_3
L=1.2m, thickness=5mm

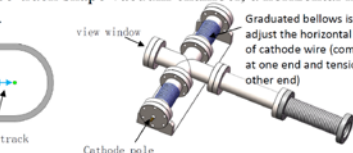


Magnetron sputtering coating prepare

- According to the experience of coating, the cathode target discharge is unstable for long vacuum chamber more than 600mm and it is easy to cause ignition or local film formation failure.
- So, sectional coating method by a movable solenoid is proposed for our ceramic vacuum chamber of 1.2m. The coating experiment shows uniform coating can be achieved in one antechamber of 1m for HEPS.



- In order to obtain uniform coating on race-track shape vacuum chamber, a horizontal movable cathode wire target solution is proposed.



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Magnet Technologies (4)

Superconducting Magnet for SppC

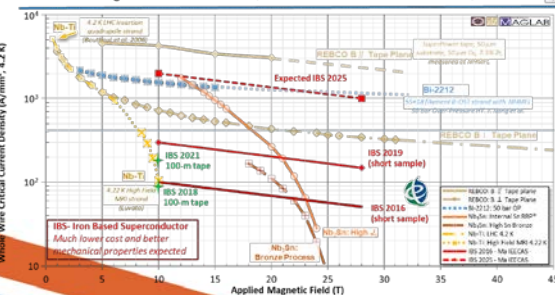
Findings;

- 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

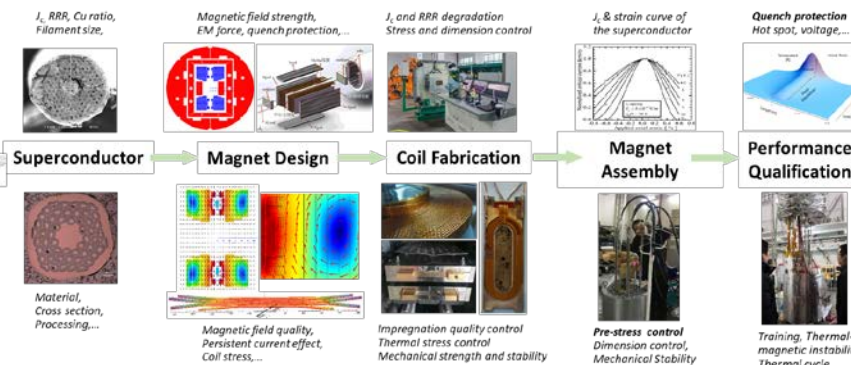
Magnet Design Scope for SPPC

	$E[\text{GeV}] = 0.3 \times B[\text{T}] \times \rho[\text{m}]$	
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 ₃ Sn etc as options	Nb ₃ Sn 16 T to reach 100 TeV
Timeline	Construction at 2040s	Construction at 2050-60s
Cost	*	**

J_c of Practical Superconductors Presently



R&D Route for High-field Accelerator Magnets

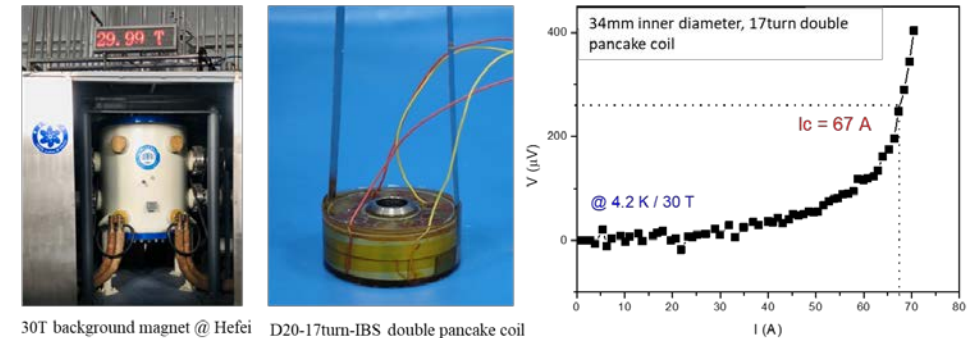


The 2021 International Workshop on CEPC, Nov. 8-12 2021

by Qingjin XU (IHEP)

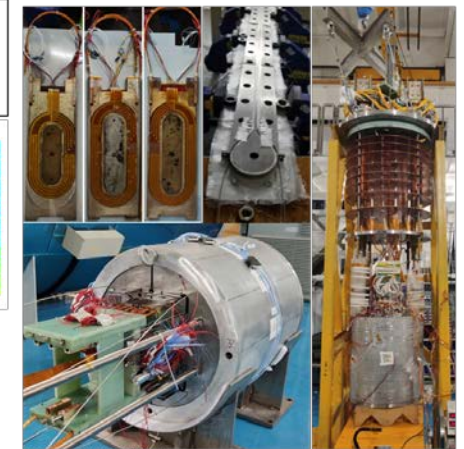
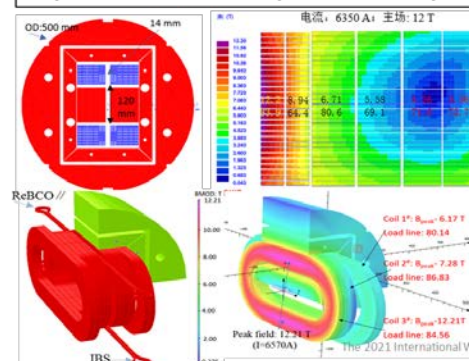
High Field IBS Insert Solenoids

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



I_c of the IBS solenoid reached **67 A at 30 T. New world record!**
R&D of the 1st NbTi+Nb₃Sn Model Dipole Magnet

Development of the LPF1 **NbTi+Nb₃Sn 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)

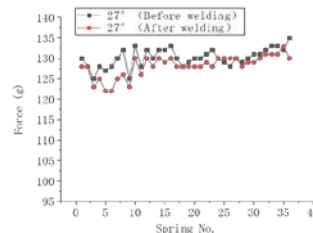
Vacuum System

Findings;

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

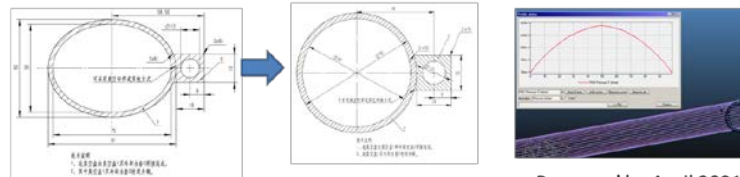
R&D of RF shielding bellows

- ◆ 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 ± 25 g. 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 diameter 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 $Q_{LS} = 1.5 \times 10^{-9} \text{ Torr} \cdot \text{l} \cdot \text{s}^{-1} \cdot \text{m}^{-1}$ ($\eta = 2 \times 10^{-5}$)
- Thermal load gas $q = 1.0 \times 10^{-11} \text{ Torr} \cdot \text{l} \cdot \text{s}^{-1} \cdot \text{cm}^{-2}$
- 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.

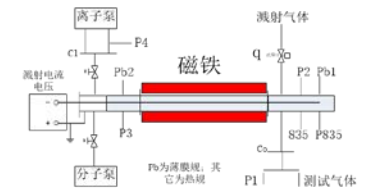
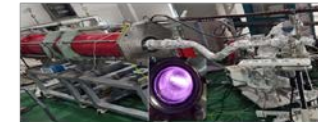
by Youngsheng MA (IHEP)

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 (°C)	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, $\phi 22$ 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 than 22/4000.



Accelerator Key System (2)

Electromagnetic Separator

Findings;

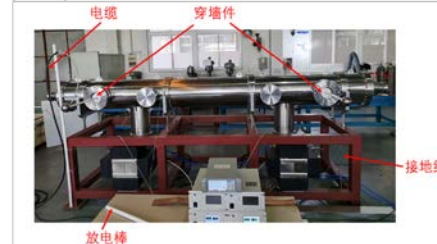
- Prototype development
- Factory tests
- High voltage feedthrough
- Fabrication of Dipole magnet

by Bin CHEN (IHEP)

Prototype development of electrostatic separator

■ Factory test

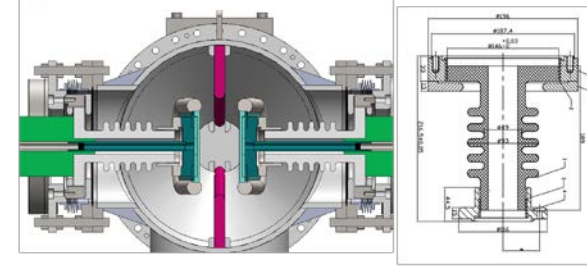
■ High voltage test



1. The output high voltage of the power supply is connected to the feedthrough through the cable, and the cavity is connected to the ground column end of the power supply through the copper wire, which connected to the earth.
2. Open the switch of high voltage power supply, gradually increase the voltage.
3. Observe the change of vacuum degree during the process of increasing the voltage.

Prototype development of electrostatic separator

■ High voltage feedthrough



- The feedthrough of each electrode plate, both feed HV and cooling liquid.
- The insulating part is made of alumina ceramic, both ends are metallized, and the sleeve is sealed with pure titanium flange.
- The coolant loop is machined on the main electrode for adequate cooling.
- Bellows are soft connections for easy installation and position adjustment.

Prototype development of dipole magnet

■ The magnet is being manufactured in the factory



- Since the length of the magnet is 4 meters, the number of turns of the coil is 12×17 ($H \times V$), and the size of the wire is 3×3 ($H \times V$, mm), the middle part of the coil is deformed during winding

Mechanical and supporting Structure

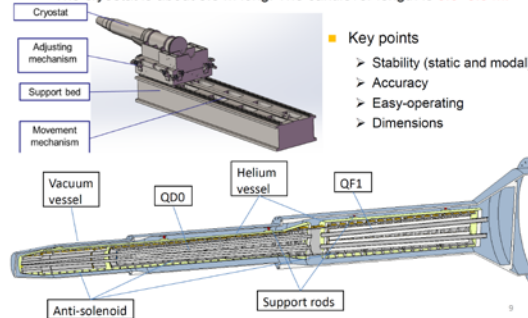
Findings;

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

by Haijing WANG (IHEP)

SC magnet support system

- The cryostat is about 5.5 m long. The cantilever length is 3.6~5.5 m.



- Key points
 - Stability (static and modal)
 - Accuracy
 - Easy-operating
 - Dimensions

Collimators for background decreasing

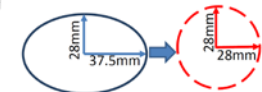
- 4 collimators per IP per ring

■ Horizontal aperture

- 4.4 mm~20 mm

■ Chamber aperture

- CDR: Elliptical, 75~56 mm
- Now: circle, $\phi 56\text{mm}^*$
- The design is based on the CDR chamber, and will be updated to circle one.

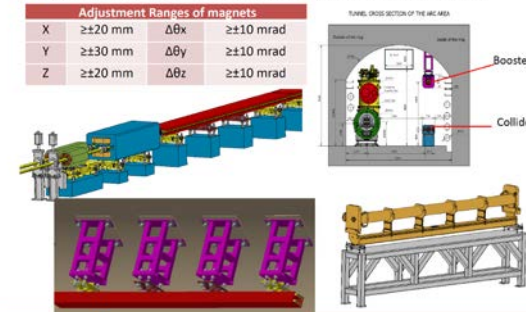


* From Y. Liu, report on CEPC DAY, March 25th, 2021

name	Position	Distance to IP/m	Beta function/m	Horizontal Dispersion/ μm
APT1X1	D11.1897	2139.06	113.83	0.24
APT1X2	D11.1894	2207.63	113.83	0.24
APT1X3	D10.10	1832.52	113.83	0.24
APT1X4	D10.14	1901.09	113.83	0.24

Supports for regular magnets

- Over 80% of the length is covered by magnets of about 138 types.



Accelerator Key System (3)

Beam Instrumentation

Findings;

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

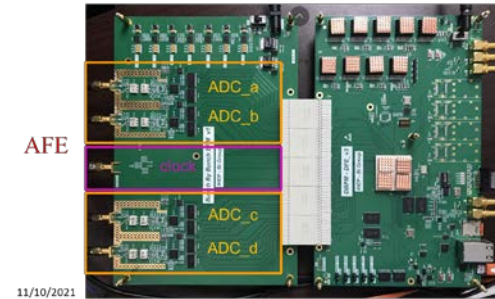
by Yanfeng SUI (IHEP)

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: 10nA/ per bunch Relatively precision: 1/4095	2
	Average current	DCCT	Dynamic measurement range: 0.0-4.5A 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 DDD	Resolution: 0.001 Resolution: 0.001	2
	Beam loss monitor	PIN-diode	Dynamic range: 120 dB Maximum counting rate: 210 MHz	5800
	Feedback system	TFB	Damping time: ~47ms	2
		IFB	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

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 CIPIC 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
- 5bilty and real time
- Control plat home

by Gang LI (IHEP)

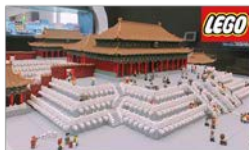
Scope of the Control System

- 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

- 5bilty+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.



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

Novel Accelerator Concept (1)



Cryogenic System

Findings;

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

Novel Accelerator Concept (2)



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



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)

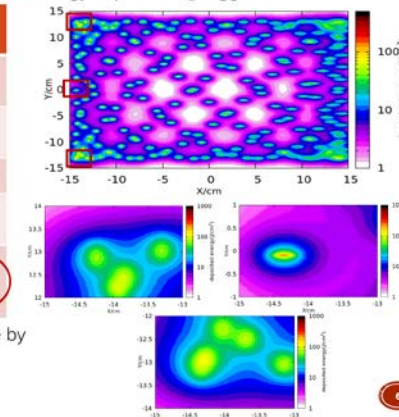
MAX. TEMPERATURE RISE

• 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 $\pm 3^\circ\text{C}$	154 $\pm 5^\circ\text{C}$	103 $\pm 1^\circ\text{C}$	714 $\pm 12^\circ\text{C}$

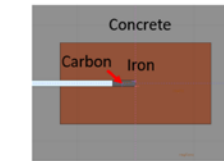
• Max. temperature rise @Z mode can decrease by increasing the bunch distance on the dump surface.

• Energy deposition @Higgs mode

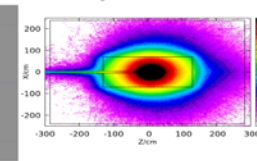


LOCAL SHIELD DESIGN FOR HOT SPOTS

- 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.



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 (11 GeV dump as example):
2D map of dose distribution was simulated by FLUKA, the dose rate along Z or X axis was averaged by $10 \times 10 \text{ cm}^2$ area, the shielding size can be selected by the setting dose rate limit.

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

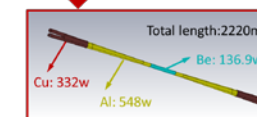
Preliminary design results for different beam energy analysis station:
Radiation level nearby each energy analysis station was figured out, also specify a roughly space for the future local shielding.

- 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.

Power density in different region of IR

	CDR beam parameters		High Luminosity beam parameters	
Power	HOM power(w)	power density (w/cm ²)	HOM power(w)	power density(w/cm ²)
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%

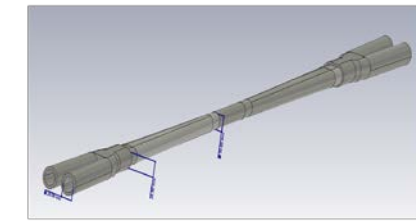
Most Critical component!

Total impedance budget @3mm

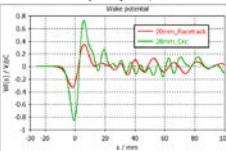
Components	Number	$Z_{ }/n$, mΩ	k_{loss} , V/pC	k_y , kV/pC/m
Resistive wall	-	6.2	363.7	11.3
RF cavities	60	0.5	101.2	0.5
Flanges	37714	5.2	37.3	5.2
BPMs	1808	0.04	9.5	0.2
Bellows	15949	2.9	87.4	3.9
Gate Valves	500	0.2	14.5	0.4
Pumping ports	5316	0.3	2.3	0.2
Collimators	8	0.02	11.7	0.3
IP chambers	2	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

by Dong YU (IHEP)

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;

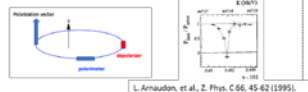
- Polarized beam program
- Solenoid based spin rotators
- New design of spin rotators

by Duan ZHE (IHEP)

Motivation of CEPC Z-pole polarized beam program

Vertically polarized beams in the arc

- Beam energy calibration via the resonant depolarization technique
- Essential for precision measurements of Z and W properties
- At least 5% ~ 10% vertical polarization, for both e+ and e- beams

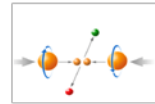


L. Amundson, et al., Z. Phys. C66, 45-62 (1995).

Final deliverable: a detailed design report of polarized beam operation @ Z-pole

Longitudinally polarized beams at IPs

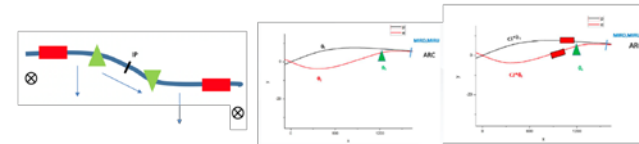
- Beneficial to colliding beam physics programs at Z, W and Higgs
- Figure of merit: Luminosity * f(Pe+, Pe-)
- ~50% or more longitudinal polarization is desired, for one beam, or both beams



Spin rotators in the CEPC CDR lattice

First attempt to implement spin rotators into the collider ring lattice

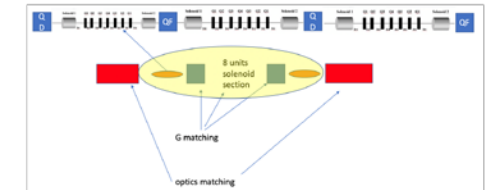
- Solenoid spin rotators is implemented at the first short straight sections next to IR
- Modified the ring layout -> $\theta_{\text{bend}} = 15\text{mrad}$
 - Keep the IR geometry
 - Keep the transverse distance between e+ and e- rings $D=0.35\text{m}$
 - Scale the bending angle before and after the short straight section



New design of spin rotators

Redesign of the spin rotators and implementation into lattice

- A new version of CEPC lattice is under design
 - The geometric requirement is built-in
 - A space of ~300m is reserved for each spin rotator, in a long straight section near IR
- A new modular design of spin rotator is also under way



Synchrotron Radiation Application

Findings;

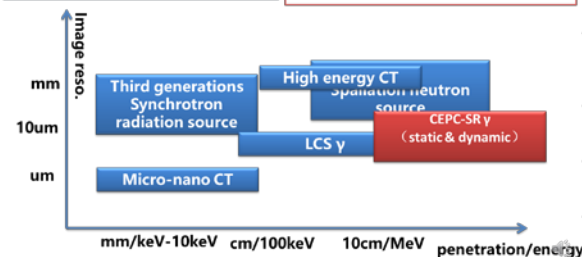
- High-flux γ -ray beamlines
- Industrial applications
- Medical isotope production
- MeV γ -ray beam

by Youngsheng HUANG (IHEP)

CEPC high-flux γ beamlines

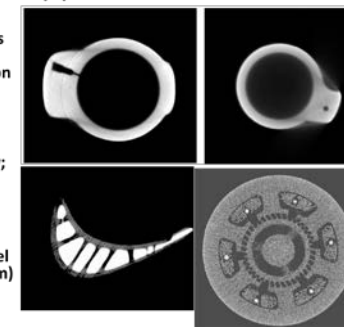
Complementary with the third generations synchrotron sources, spallation neutron sources, industrial CT, and LCS gamma sources:
7.5cm steel penetration, several micron resolution, high flux fast imagination

Static imaging - engine blade inspection:
6cm thick steel, 1-5 micron resolution
Dynamic imaging---metal phase change process-droplet solidification/seawater corrosion mechanism: us, 6cm thick steel, 1-5 micron resolution

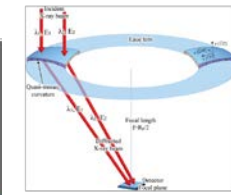


CEPC-SR: Applications—Industrial, material applications

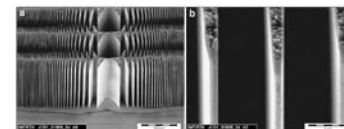
1. Measurement of the internal structure of precision workpieces in the aerospace, aerospace and other industries and the detection of defects;
2. Inspection of ammunition packing density and quality inspection of key components of weapons in the weapon industry;
3. Non-destructive testing of key components in the automotive industry
4. Online monitoring and quality inspection of products in the steel industry: Engine blade ($\sim 1\mu\text{m}/1\text{cm}$)
5. Evaluation of samples in geology and archaeology;



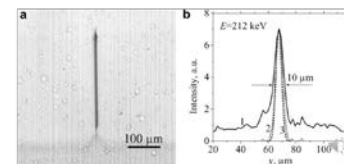
The focalization of hard x-ray And soft gamma-ray 100keV-1MeV, 1MeV still problem?



Schematic representation of a Laue lens based on QM crystals. J. Appl. Cryst. (2015). 48, 977-989



LIGA fabrication of X-ray Nickel lenses 100keV-1MeV : Microsystem Technologies 11 (2005) 292-297



1. Progress on accelerator technologies for CEPC
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Beam Dynamics

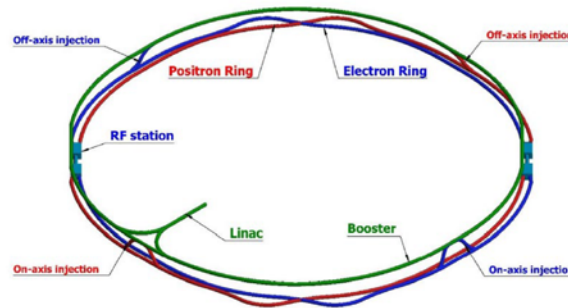
Findings;

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

Design requirement of the CEPC collider ring

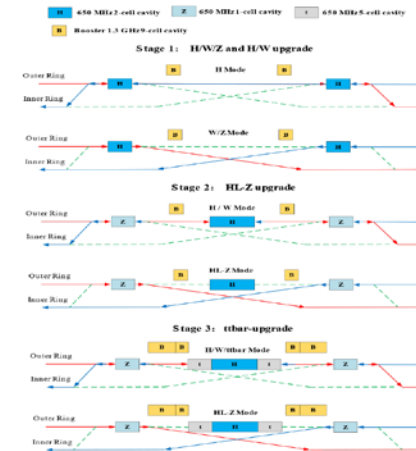
- SR power 30MW (50 MW upgradable), 100km, 2 IPs
- Crab waist collision
- Local chromaticity correction for the interaction region
- Non-interleaved sextupoles
- Correction of sawtooth orbit
- Shared cavities for two beam @ tt, Higgs
- Dual aperture dipole and quadrupole magnets
- Spin polarized beam @ 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.

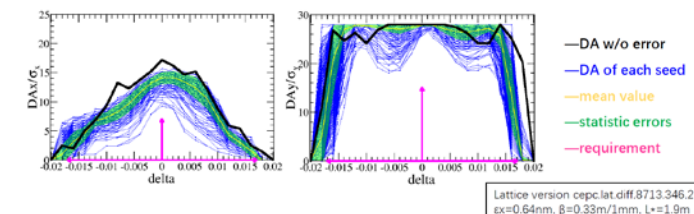
Stage 3 (ttbar upgrade):

- 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

- Error correction started with 50 μm 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 μm misalignment in IR quadrupoles is undergoing.

Component	Δx (mm)	Δy (mm)	$\Delta \theta_z$ (mrad)	Field error
Dipole	0.10	0.10	0.1	0.01%
Are Quadrupole	0.10	0.10	0.1	0.02%
IR Quadrupole	0.05	0.05	0.05	
Sextupole	0.10	0.10	0.1	



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

Beam Instabilities

Findings;

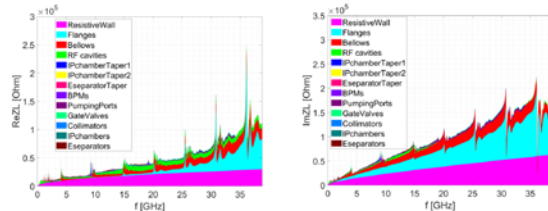
- Collective instabilities in collider ring
- Collective instabilities in booster ring
- Collective instabilities in damping ring

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

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.

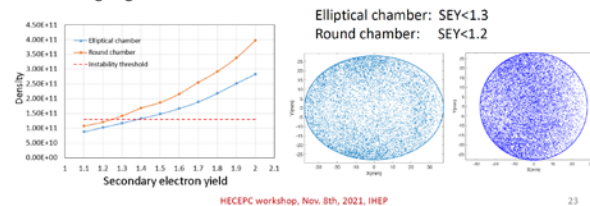


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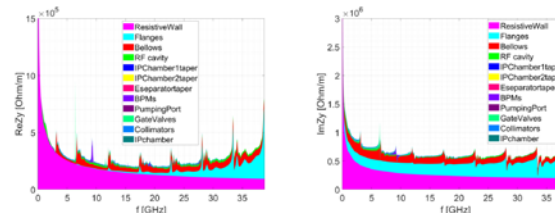
Electron cloud

- 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.



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!

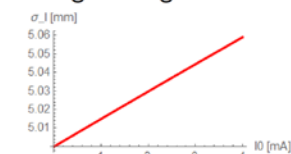
Parameter [unit]	Injection	Extraction
Calculated $ Z_L/n _{eff}$ [mΩ]	2.7	
Calculated k_y [kV/pC/m]	19.3	
Threshold on broadband $ Z_L/n _{eff}$ [mΩ]	0.3	3.9
Threshold on broadband k_y [kV/pC/m]	89.3	224.6

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

Parameter [unit]	Z-High Lumi	Injection	Extraction
Threshold on narrowband $\frac{f}{\text{GHz}} \frac{\text{Re}Z_L}{\text{MΩ}} e^{-(2\pi f a_1)^2}$	0.6	4.1	122.5
Threshold of narrowband $\frac{\text{Re}Z_L}{\text{MΩ/m}} e^{-(2\pi f a_1)^2}$	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 $\frac{f}{\text{GHz}} \frac{\text{Re}Z_L}{\text{MΩ}} e^{-(2\pi f a_1)^2}$	0.07	0.09
Threshold of narrowband $\frac{\text{Re}Z_L}{\text{MΩ/m}} e^{-(2\pi f a_1)^2}$	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

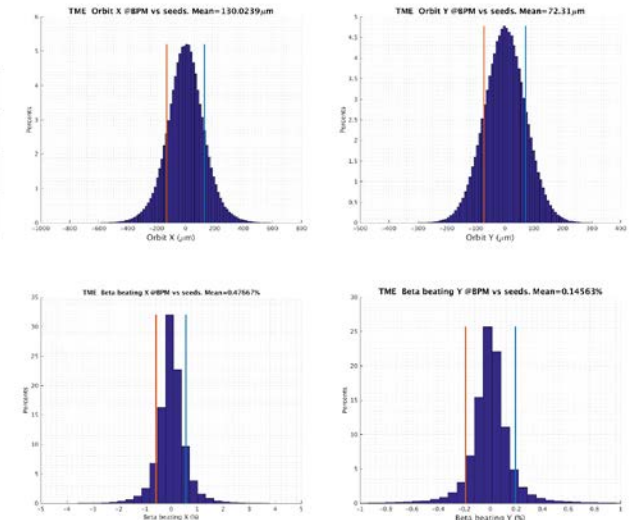
- Orbit Correction + Horizontal dispersion
 - RM + SVD
 - 1218H+1220V Corrector
 - Iteration from small singular value (max 80%)
 - Corrector strength limited
- Optics correction
 - RM + LOCO
 - All quadrupole independent
 - Coupling and vertical dispersion also corrected by skew field of some quadrupoles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

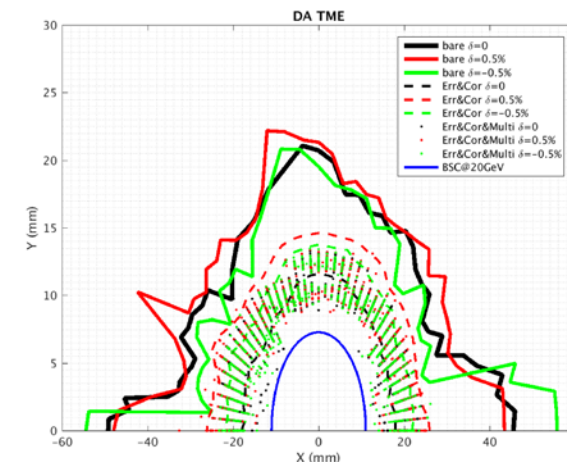
Correction Result

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.

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CEPC Site Choice

1. Qinhaungdao
(秦天島市)

2. Huzhou
(湖州市)

3. Changsha
(長沙市)

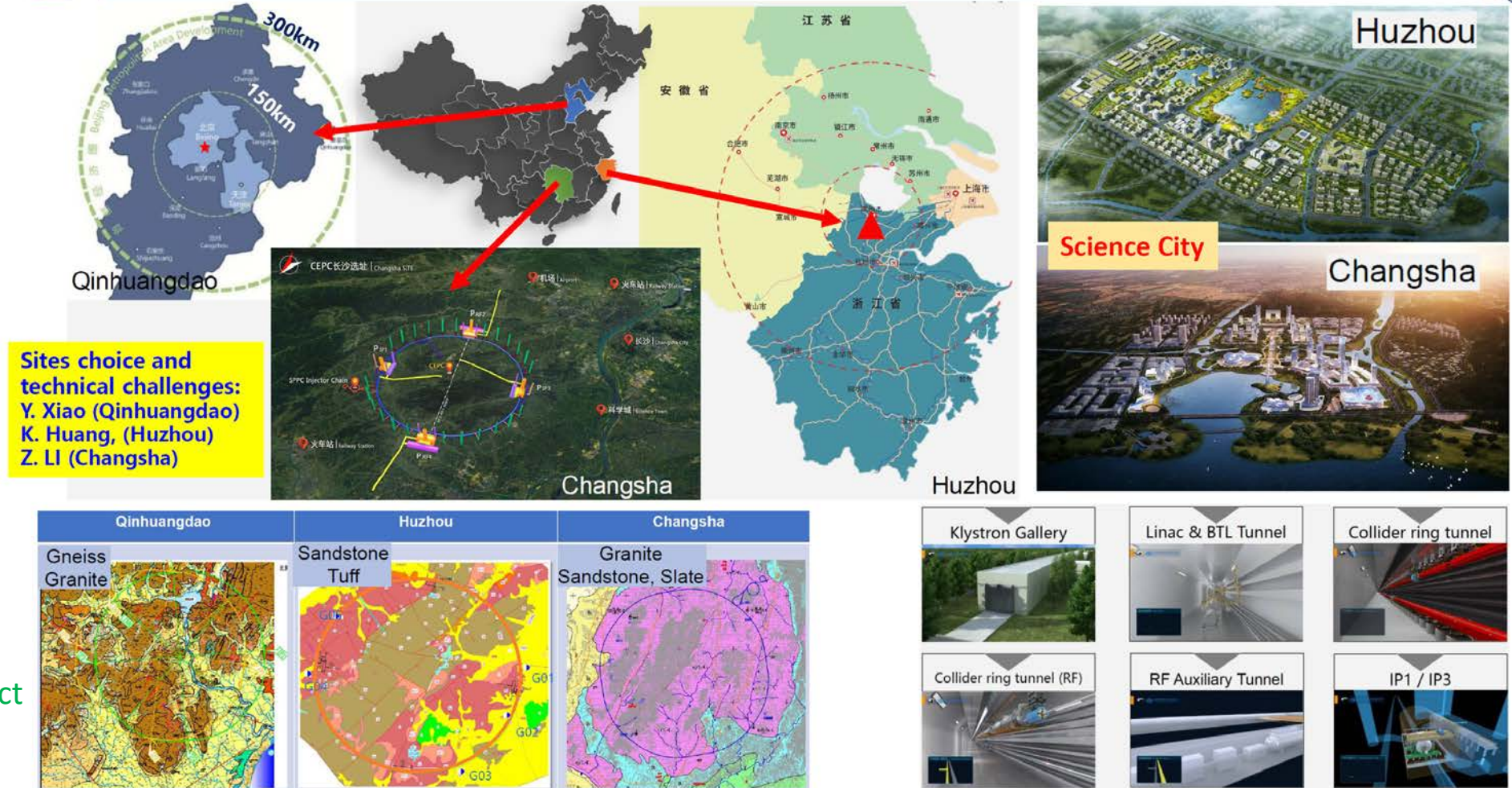
Findings;

- 3 candidates for CEPC site

Overview of the CEPC Project
by Haijun Yang (SJTU)



CEPC Sites, Geology and Science Cities



Installation and Alignment

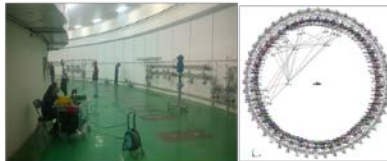
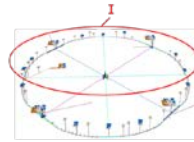
Findings;

- 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



4

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

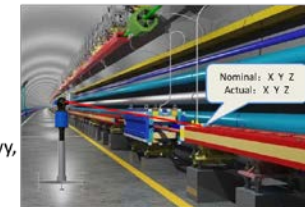
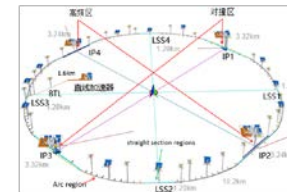
1. Alignment control network error
2. Component fiducialization pre-alignment error
3. Measurement error
4. Installation adjustment error

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Vision instrument introduction

- Workload of CEPC alignment

- Tunnel length 109.55km : 100.034km main ring + 6.64km IR 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.



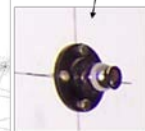
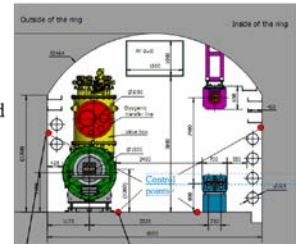
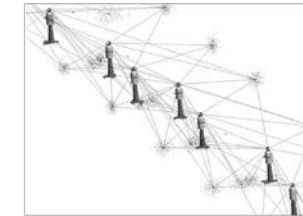
Ring tunnel

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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

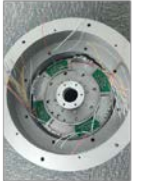


地面控制点

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Vision instrument 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

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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