国家重点研发计划

高能环形正负电子对撞机关键技术研发和验证

所属专项：　大科学装置前沿研究

项目负责人：　João Guimarães da Costa

项目承担单位：中国科学院 高能物理研究所

Task Final Review Meeting: June 19-20, 2023

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

国家重点研发计划

R&D and Verification of Key Technologies for a High Energy Circular Electron-Positron Collider

所属专项：大科学装置前沿研究

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中国科学院高能物理研究所
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任务分解和主要研究: Task Arrangement and Main Research

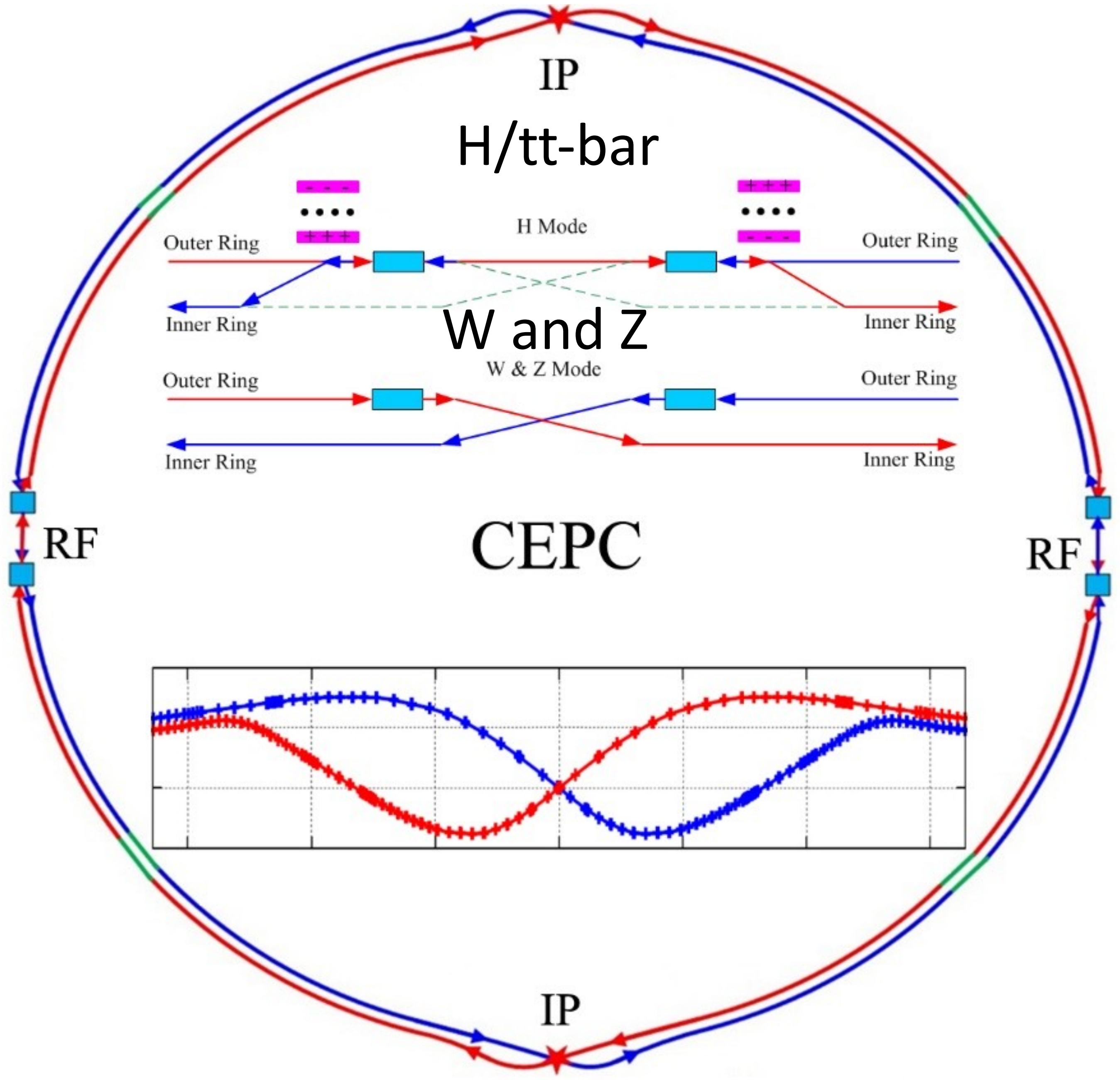
Task	Task Leader Institute	Research Content	Funds
Task 1: Accelerator	Yunlong Chi IHEP	Prototypes: low-field dipole magnet, vacuum pipe, RF shield bellows, HE separator. Beam polarization study	974万
Task 2: Silicon Detector	João Guimarães da Costa IHEP	Prototype: silicon tracker with high-resolution sensor, radiation resistant	1200万
Task 3: Hadronic Calorimeter	Jianbei Liu USTC	Prototype: imaging hadron calorimeter with scintillator + silicon photomultiplier tube (SiPM)	971万

Total funding: 3145 万

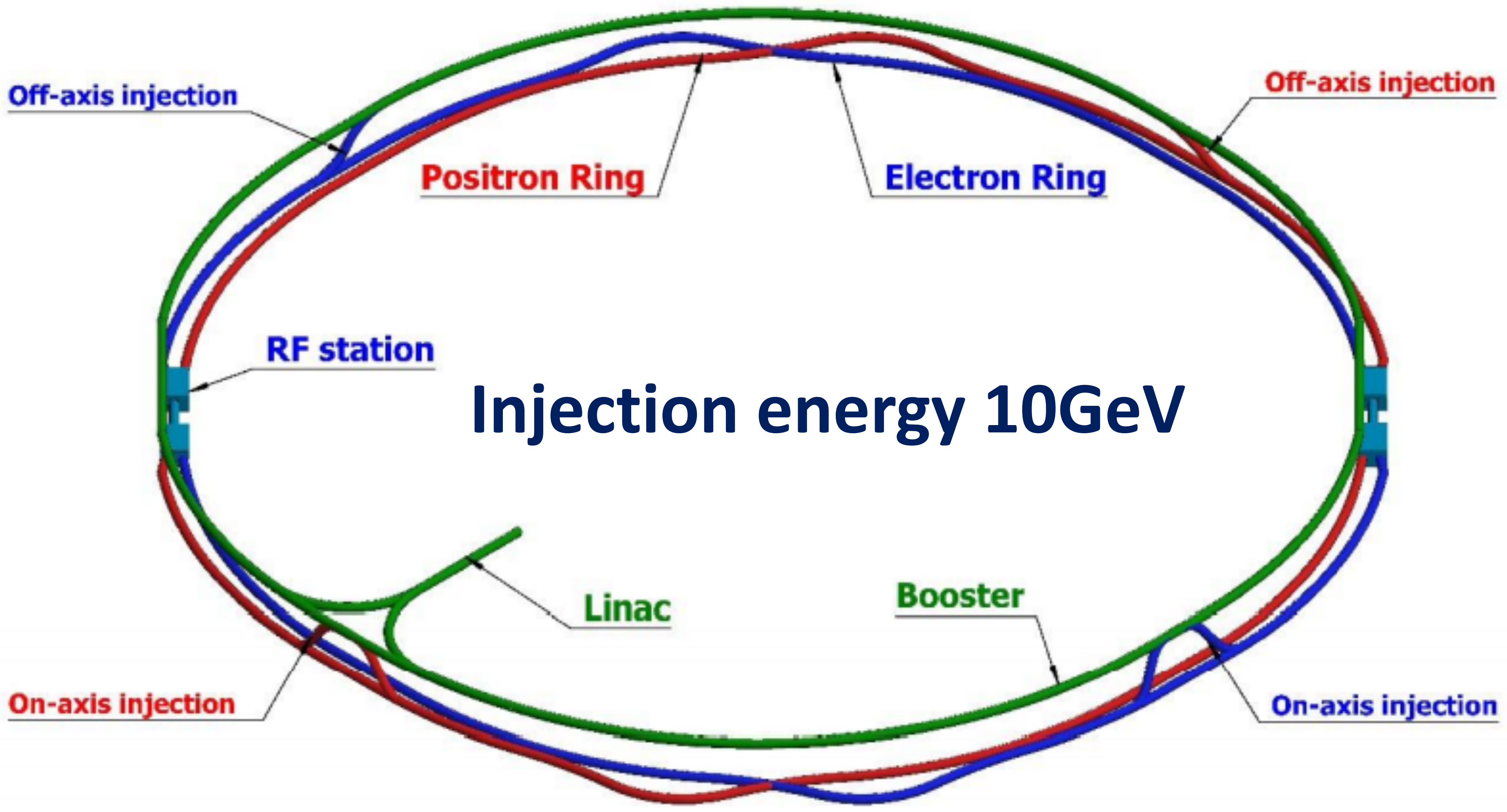
Circular Electron Position Collider (CEPC) - TDR Layout

CEPC as a Higgs Factory： H, W, Z, upgradable to tt-bar, followed by a SppC ~125TeV

30MW SR power per beam (upgradable to 50MW)



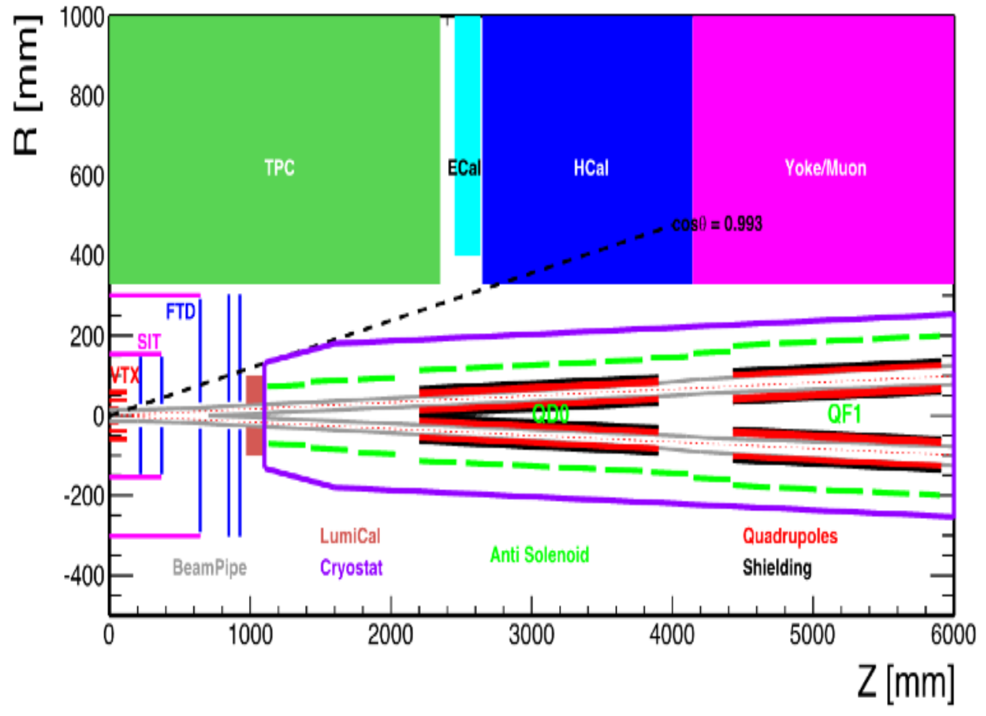
CEPC collider ring (100km)



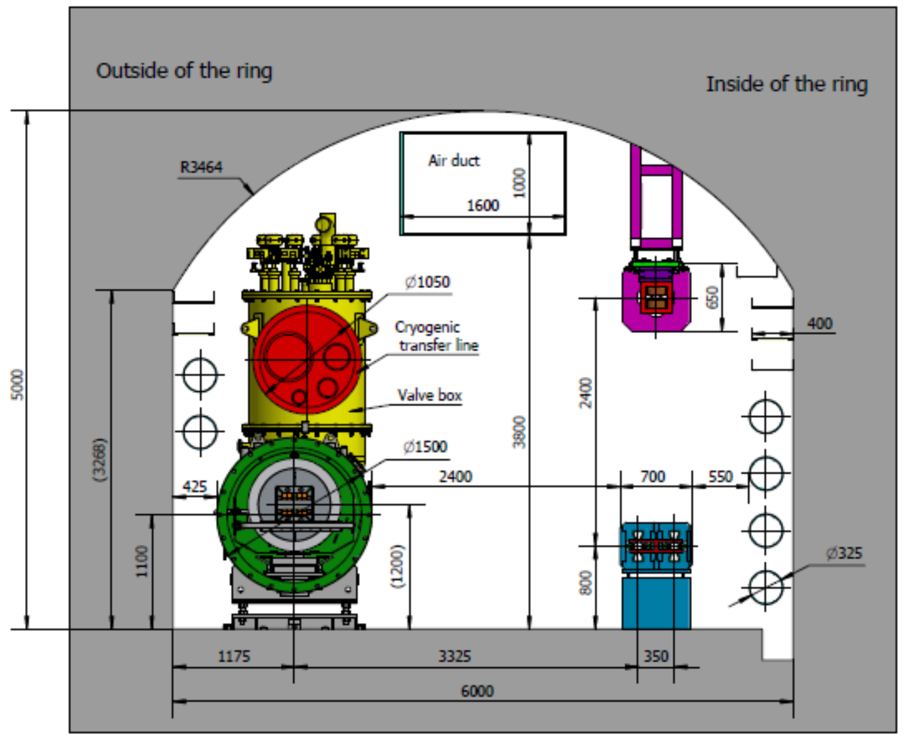
CEPC booster ring (100km)

Common tunnel for booster/collider & SppC

CEPC MDI



CEPC Civil Engineering



Critical aspects requiring prototyping: (this project)

- **Low-field dipole magnets for booster**
- **Electrostatic separator**
- **Vacuum system**

Circular Electron Position Collider (CEPC) - TDR Layout

CEPC as a Higgs Factory： H, W, Z, upgradable to tt-bar, followed by a SppC ~125TeV

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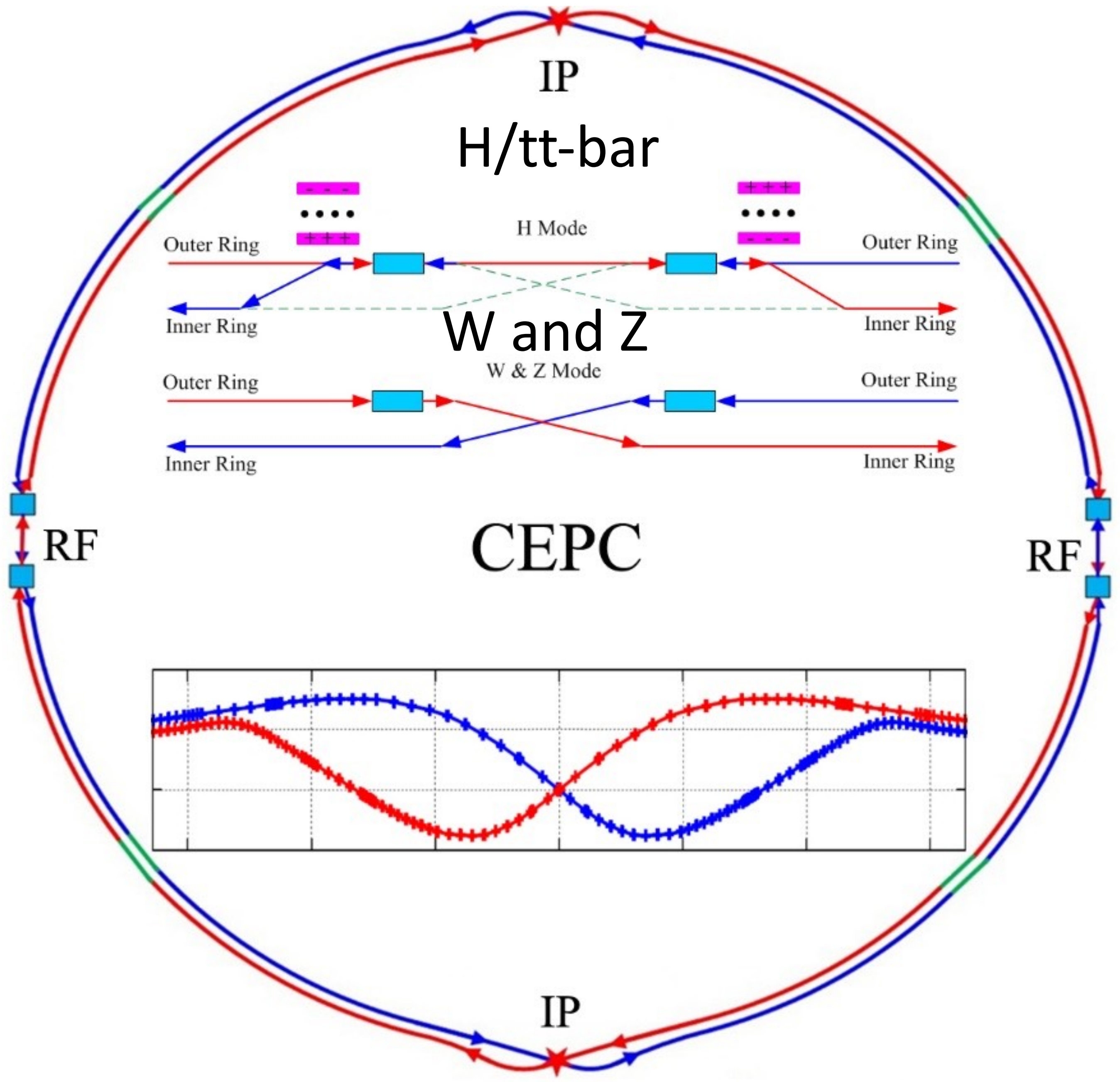
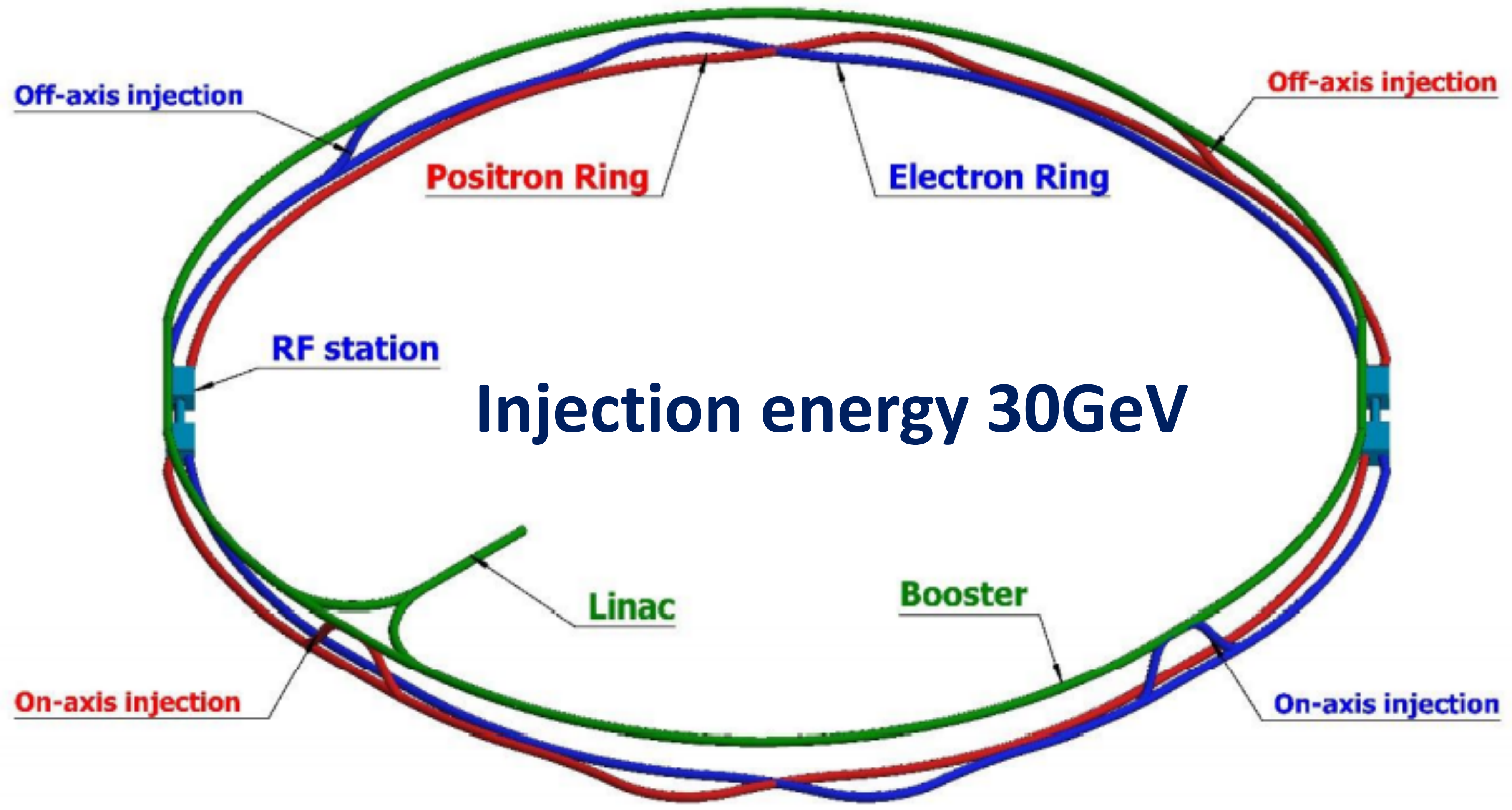


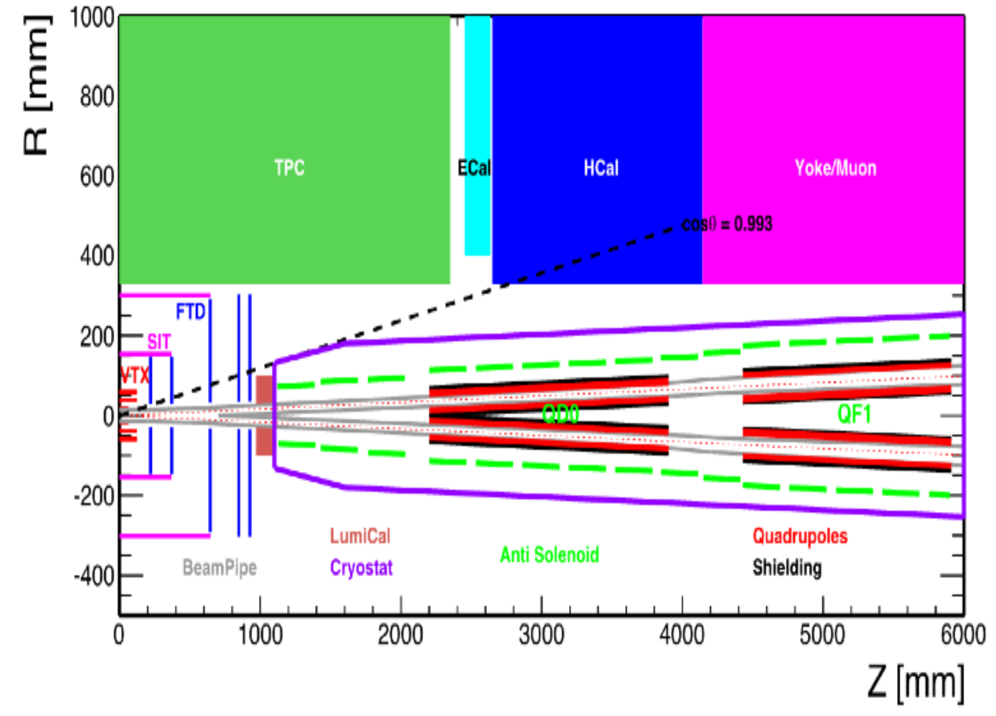
CEPC collider ring (100km)



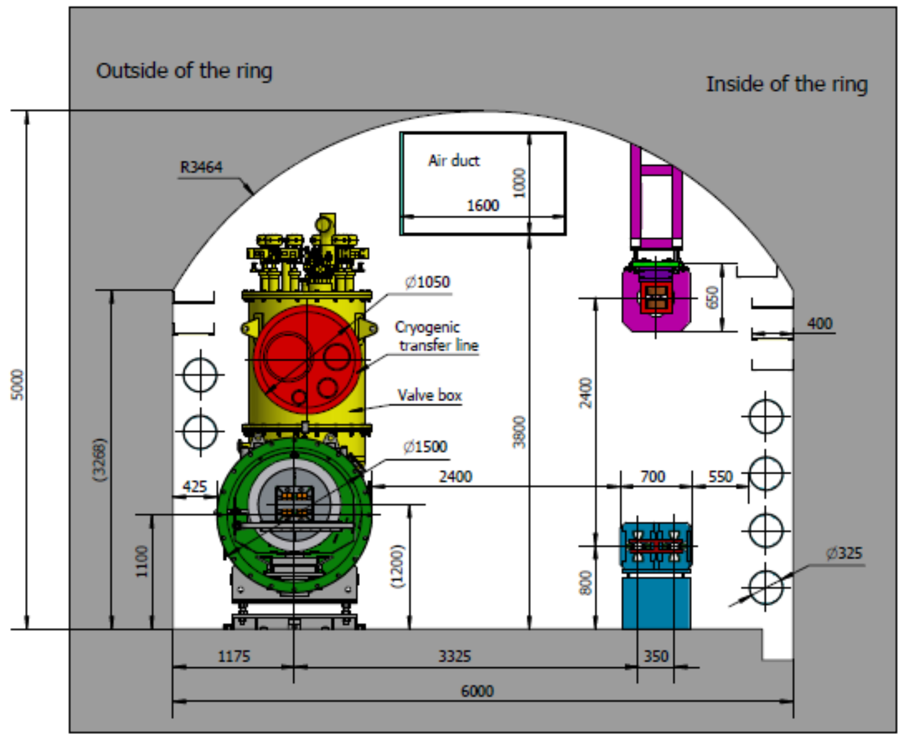
CEPC booster ring (100km)

Common tunnel for booster/collider & SppC

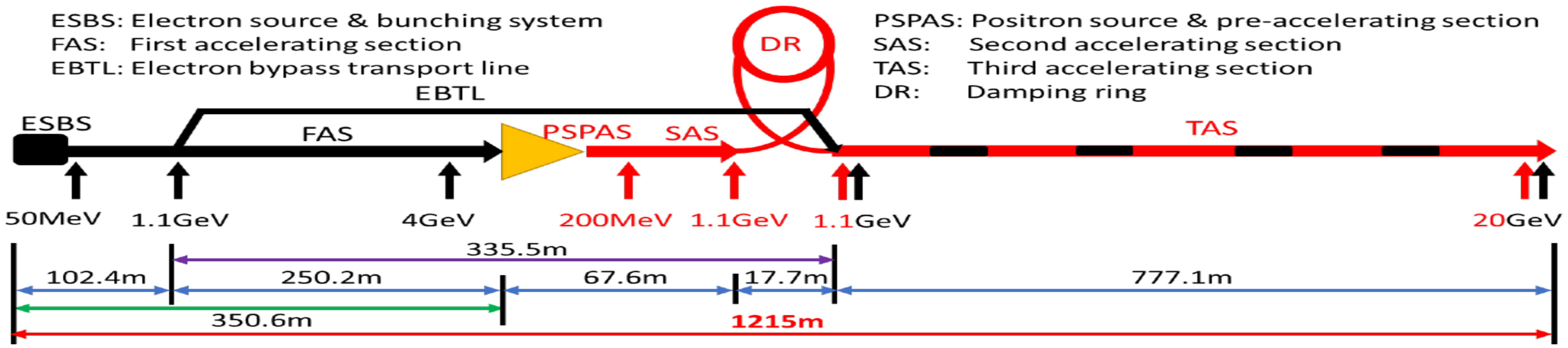
CEPC MDI



CEPC Civil Engineering



CEPC TDR S+C-band 30 GeV linac injector



Operation mode		ZH	Z	W+W-	tt
		~240	~91.2	158-172	~360
L / IP [×10³⁴ cm⁻²s⁻¹]	CDR (2018)	3	32	10	
	TDR (30MW)	5.0	115	16	0.5

Testing of full size prototypes allow us to face hidden challenges:

Knowledge acquire in these projects can be put to use to construct the final accelerator either using the same technology or similar technologies

All prototypes in this project are at least being built in China for the first time, some are worldwide achievements

Task 1: Accelerator

Task 1: Low-field dipole magnet for CEPC Booster

When the beam injection is at 10 GeV, the CEPC Booster requires dipole magnets with a minimum field of only 31 Gs, and extremely small field error (uniformity 5×10^{-4})

There would be about 16000 of such dipoles, 4.7m long, to cover the 100 km

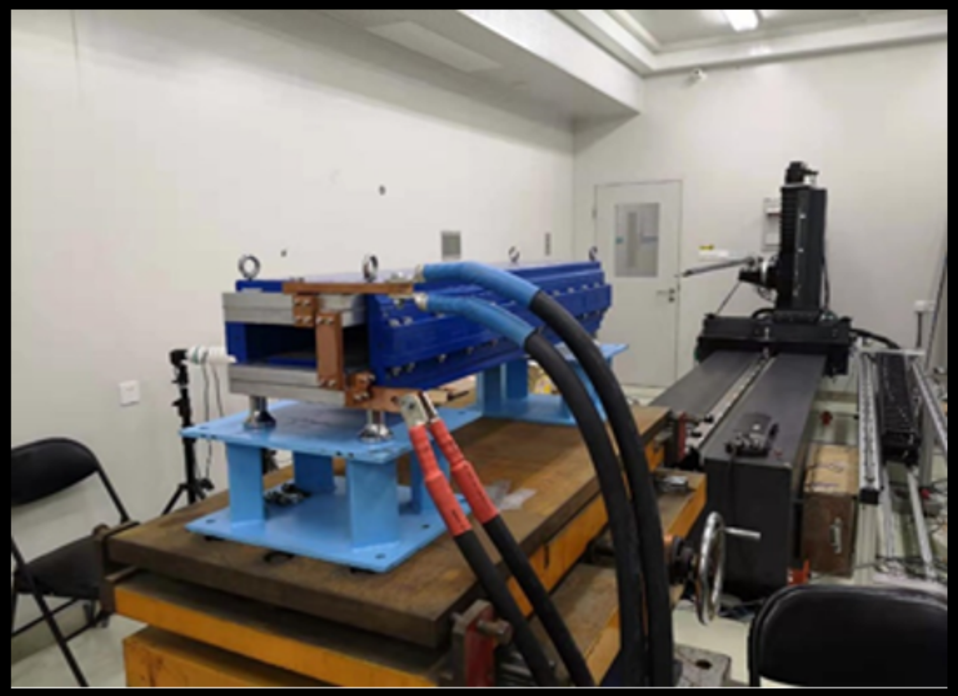
LEP: 170Gs → World class: 120Gs → This project: 31Gs

World leading

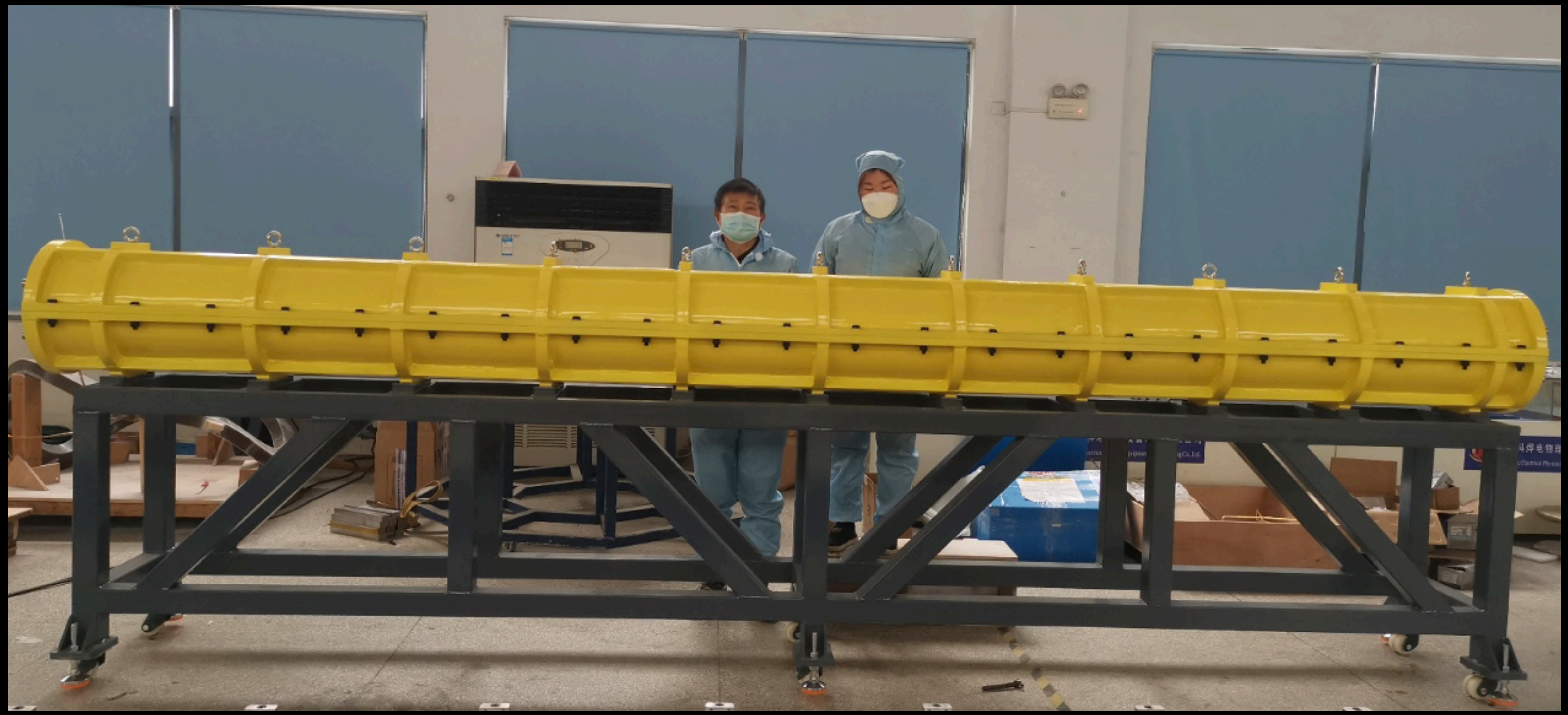
Two subscale prototypes were built

Cosine-Theta (CT) coil

iron-core dipole magnet



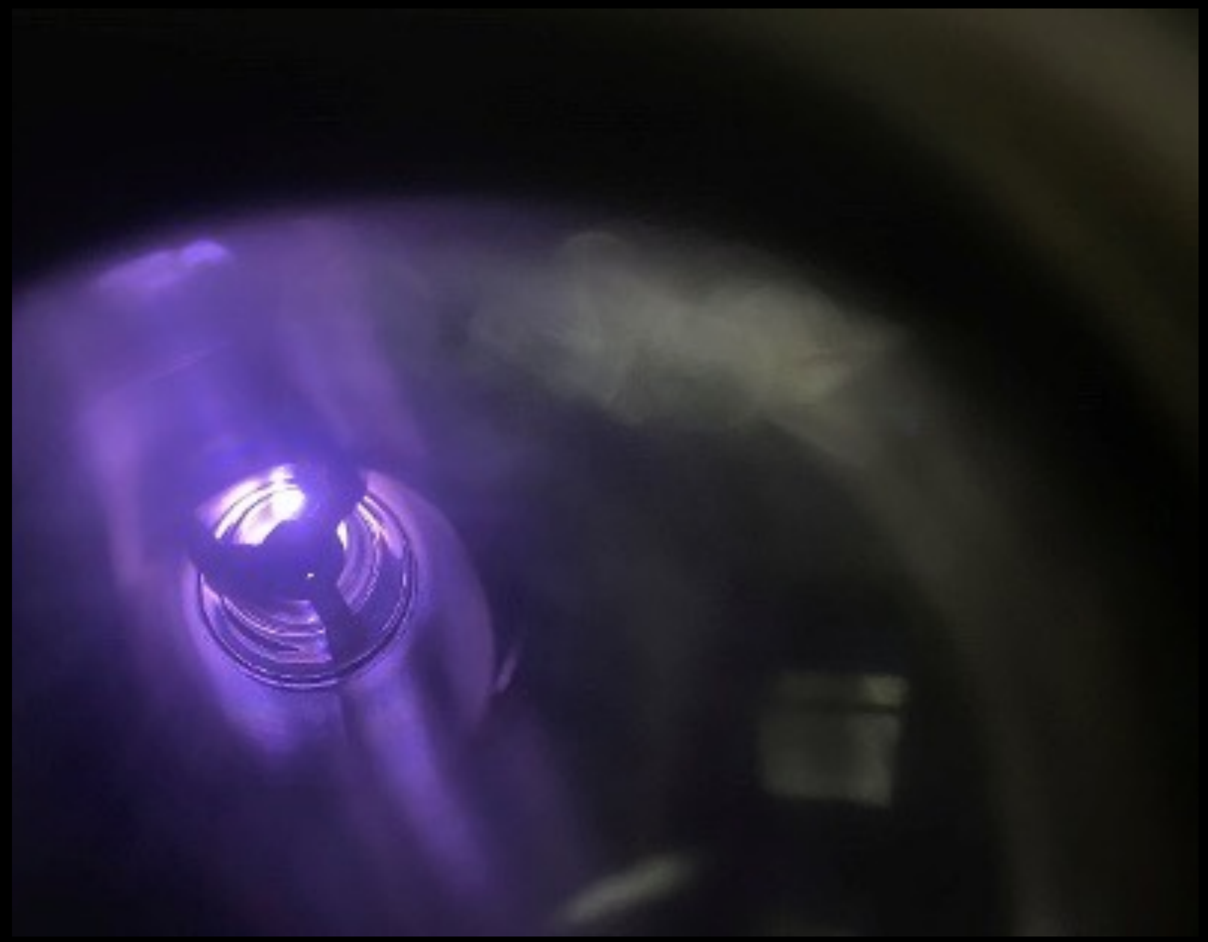
Built full-size CT coil magnet



Task 1: Vacuum system and RF shielding bellows prototypes

Prototype 6-m log vacuum chambers for beampipe

Develop technique for NEG coating of the inside of the beampipe (using sputtering technique)



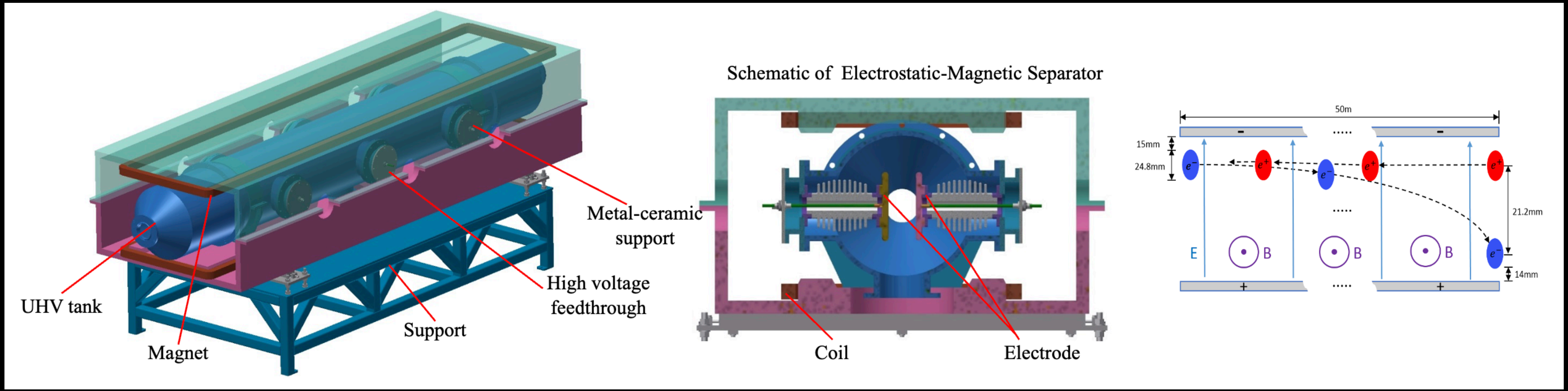
Coating done in sections for 6-m vacuum tube ultimately achieved good uniformity

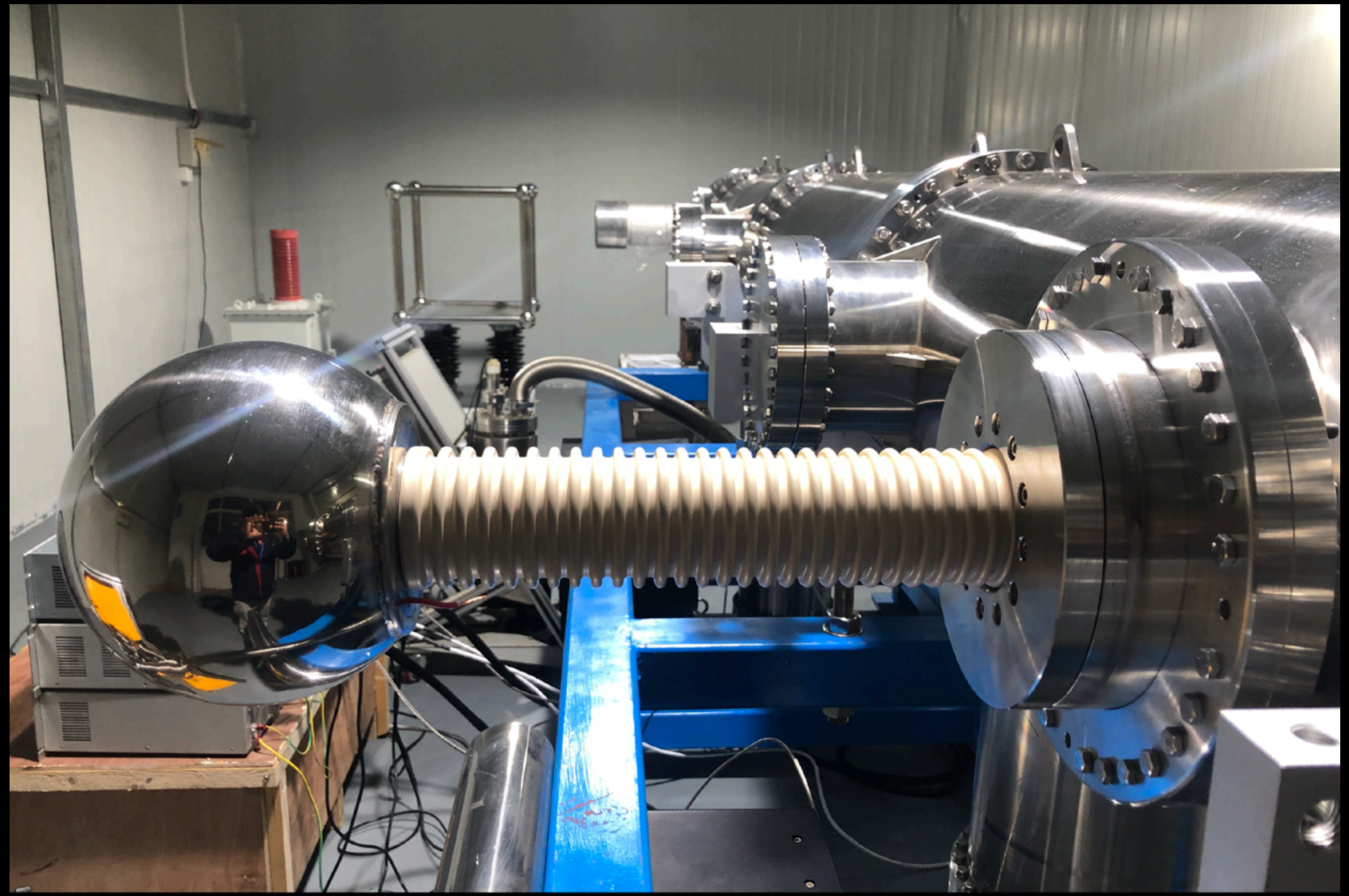
7 patents developed for this work

Task 1: Electrostatic separator prototype

The Electro-Magnetic Separator is a device consisting of perpendicular electric and magnetic fields.

One set of Electro-Magnetic Separators includes 8 units, total 32 units will be need for CEPC



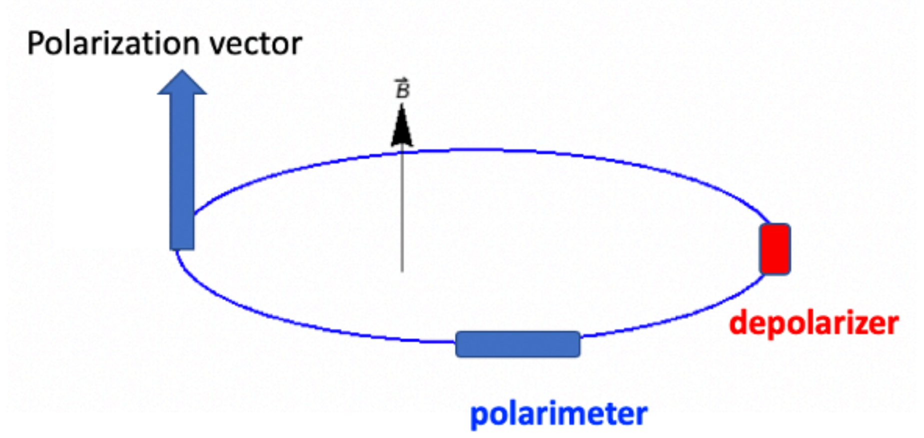


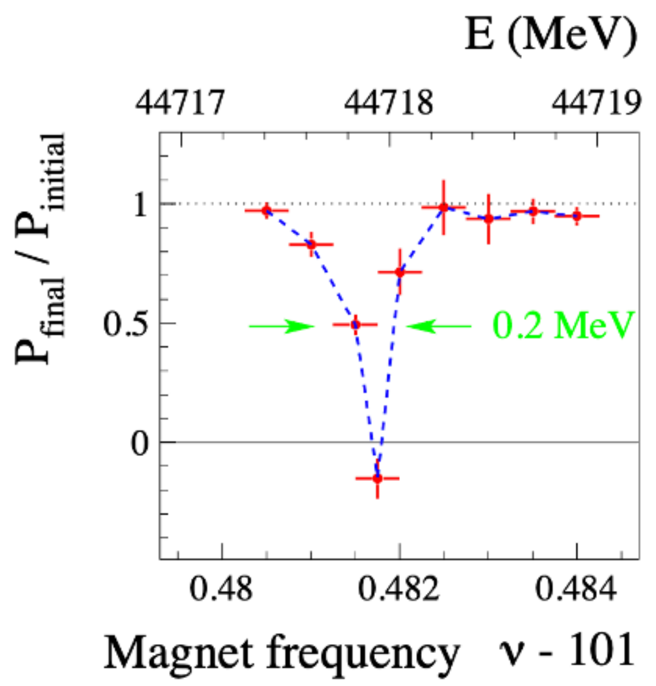
Task 1: Design of polarization at Z-pole

Considering both vertical and longitudinal polarization

Vertical polarization in the arc

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

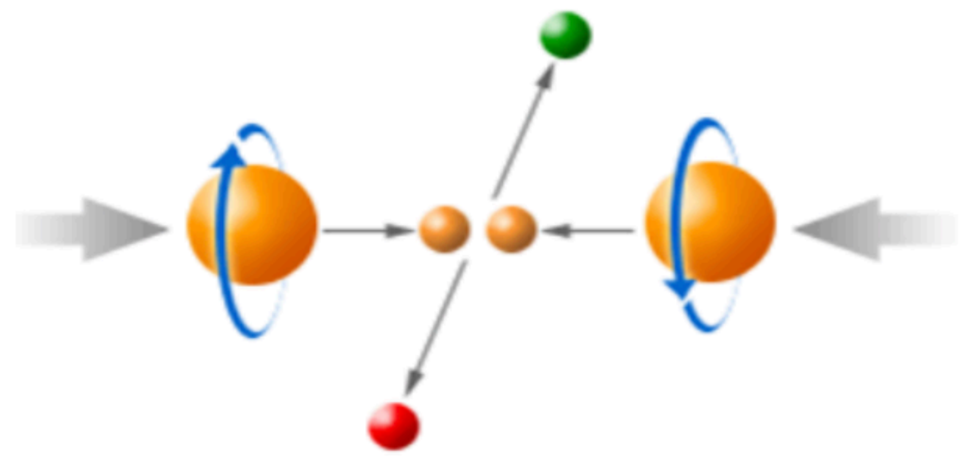




L. Arnaudon, et al., Z. Phys. C 66, 45-62 (1995).

Longitudinal polarization 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



- FCC-ee (CERN) focuses on vertical polarization for beam energy calibration.
- Both aspects are being pursued at the CEPC.

Subtask	Indicator	Requirement	Result	Conclusion	
High precision low-field dipole magnet prototype	Lowest field	<31 Gs	28.5 Gs	✓ Surpassed	**World leading**
	Field uniformity	$<5\times10^{-4}$	3×10^{-4}	✓ Surpassed	
Vacuum pipe and RF shielding bellow prototype	Vacuum degree	$< 2\times10^{-10}$ Torr	1.08 - 0.99 $\times10^{-10}$ Torr	✓ Surpassed	**First in China**
	Vacuum leakage	$< 2\times10^{-10}$ Torr.L/s	1×10^{-10} Torr.L/s	✓ Surpassed	
	RF shield bellows contact force	125±25 g/finger	123-135 g/finger	✓ Achieved	
High energy electrostatic separator prototype	Electric field	>2 MV/m @ ±110 kV	3.09 MV/m @ ±116 kV	✓ Surpassed	**First in China**
	Field uniformity	(1‰)10x10 mm^2	(0.5‰)46x30 mm^2	✓ Surpassed	
	Vacuum	$< 2.7\times10^{-8}$ Pa ($<2\times10^{-10}$ Torr)	$< 2.6\times10^{-8}$ Pa	✓ Achieved	
Polarization design	Beam polarization	> 50%	$P_{avg} > 70\%$	✓ Surpassed	**World leading**
	Beam lifetime	> 60 min	> 60 min	✓ Achieved	

Academic Achievements

	Accelerator	Vertex	Calorimeter	Total
Patents	8	3	1	12
Papers	11	5	8	24
Proceedings	2	1		3
Conferences	16	18	28	62
PhD Students	6	8	4	18
Master Students		23	3	26
Postdocs		2	1	3

小结

- All indicators have been achieved in the project
  - Some world-leading and china-first achievements were made
  - Long-lasting knowledge was acquired that will help us progress further in the future
- Details will follow in the next talks

谢谢

Agenda for the review

Tomorrow
Task 1: Accelerator

9:00 AM → 12:30 PM **Task1 课题一：高能环形正负电子对撞机加速器关键技术验证**

paperlist-acc.pdf | task1-self-assessm... | 评审意见草稿 Grou... | 课题1-专家个人评...

9:00 AM — **Brief overview** — 15m
Speaker: Joao Guimaraes da Costa

9:15 AM — **Sub-task 1：CEPC Booster Dipole Magnet Prototype (20'+5')** — 25m
子课题1：CEPC高精度二极磁铁原型机
Speaker: 文 康 (Accelerator Centor, IHEP)

9:40 AM — **Sub-task 2：Prototype of CEPC vacuum system（20'+5'）** — 25m
子课题2：CEPC真空系统关键设备样机
Speaker: Haiyi 董海义 (高能所)

10:05 AM — **Coffee break**

10:25 AM — **Sub-task3: Electron positron electronic separator （20'+5'）** — 25m
子课题3：正负电子束静电分离器样机
Speaker: 斌 陈 (高能所)

10:50 AM — **Sub-task 4: CEPC polirization study at Z-pole（20'+5）** — 25m
子课题4：CEPCZ能区极化束流的加速器物理研究与设计
Speaker: Zhe DUAN (高能所)

11:15 AM — **Discussion（Project group only)** — 45m
Main building A511

11:15 AM — **Discussion（Refrees only）评委内部讨论与撰写评审意见** — 45m

12:30 PM → 12:50 PM **Lunch box**

The end

Achievement Presentation and Assessment Methods

项目目标[1]	成果名称	成果类型	对应的课题（任务）[2]	考核指标[3]				考核方式（方法）及评价手段[5]
				指标名称	立项时已有指标值/状态	中期指标值/状态[4]	完成时指标值/状态	
1. 开展CEPC增强器关键设备高精度低场二极磁铁、弯转真空盒、RF屏蔽波纹管和真空盒内表面镀吸气剂膜、高能正负电子束静电分离器的研制；开展CEPC在Z能区极化束流的加速	Dipole Magnet 高精度低场二极磁铁	□新理论 □新原理 □新产品 □新技术 □新方法 ■关键部件 □数据库 □软件 □应用解决方案 □实验装置/系统 ■工程工艺 □标准 □专利 ■论文 □其他	课题1：加速器关键技术的研发和验证	高精度低场二极磁铁场强和均匀性	最低工作磁场127Gs，磁场均匀度5×10^{-4}	最低工作磁场60Gs，磁场均匀度5×10^{-4}	最低工作磁场31Gs，磁场均匀度5×10^{-4} ✓	同行专家组现场测试，测试报告将写入高能环型正负电子对撞机加速器关键技术设计和测试报告
	Vacuum pipe 研制弯转真空盒、RF屏蔽波纹管、真空盒内表面	□新理论 □新原理 □新产品 □新技术 □新方法 ■关键部件 □数据库 □软件 □应用解决方案 □实验装置/系统 ■工程工艺 □标准	课题1：加速器关键技术的研发和验证	真空盒极限真空	5×10^{-10}Torr	3×10^{-10}Torr	2×10^{-10}Torr ✓	同行专家组现场测试，测试报告将写入高能环型正负电子对撞机加速器关键技术设计和测试报告

Assessment method and means of evaluation:

Expert review in the visit to prototype

Test report will be included in "CEPC accelerator key technology design report and testing report”

Achievement Presentation and Assessment Methods

器物理研究与设计。 2. 研制出硅径迹探测器原型机，并验证其空间分辨率达到3-5微米；设计出抗电离辐射总剂量达到 1MRad的硅探测器。 3. 完成对采用闪烁体作为灵敏层的成像型强子量能器技术方案的验证	镀吸气剂膜 Vacuum pipe	☐专利 ■论文 ☐其他		真空盒总漏率	5×10^{-10} Torr•L/s	3×10^{-10} Torr•L/s	2×10^{-10} Torr•L/s ✓	同行专家组现场测试，测试报告将写入高能环型正负电子对撞机加速器关键技术设计和测试报告
	Bellows			RF屏蔽波纹管接触力	125±50g	125±30g	125±25g ✓	同行专家组现场测试，测试报告将写入高能环型正负电子对撞机加速器关键技术设计和测试报告
	高能正负电子静电分离器 Electrostatic separator	☐新理论 ☐新原理 ☐新产品 ☐新技术 ☐新方法 ☐关键部件 ☐数据库 ☐软件 ☐应用解决方案 ■实验装置/系统 ■工程工艺 ☐标准	课题 1：加速器关键技术的研发和验证	静电分离器电场强度	1.8MV/m@±60kV 工作电压	完成静电分离器的初步设计，以实现：2MV/m@±110kV 工作电压的电场强度要求	2MV/m@±110kV 工作电压 ✓	同行专家组现场测试，测试报告将写入高能环型正负电子对撞机加速器关键技术设计和测试报告

Assessment method and means of evaluation:

Expert review in the visit to prototype

Test report will be included in "CEPC accelerator key technology design and test report”

Achievement Presentation and Assessment Methods

Electrostatic separator	☐专利 ■论文 ☐其他		静电分离器电场均匀性	无	完成静电分离器初步设计，以实现(1‰)10×10 mm^{2}的场均匀性	(1‰)10×10 mm^2 ✓	同行专家评议，静电分离器设计报告将写入高能环型正负电子对撞机加速器关键技术设计和测试报告
			静电分离器腔体真空度	6×10^{-10}Torr	完成静电分离器初步设计，以实现2×10^{-10}Torr的腔体真空度要求	2×10^{-10}Torr ✓	同行专家组现场测试，测试报告将写入高能环型正负电子对撞机加速器关键技术设计和测试报告
Polarization CEPC在Z能区极化束流运行的整体物理设计	☐新理论 ☐新原理 ☐新产品 ☐新技术 ■新方法 ☐关键部件 ☐数据库 ☐软件 ☐应用解决方案 ☐实验装置/系统 ☐工程工艺 ☐标准 ☐专利 ■论文 ☐其他	课题1：加速器关键技术的研发和验证	在Z能区极化束流的加速器物理研究与设计	已有不含极化插入件的lattice 设计	明确极化插入件的基本参数选择和精确能量测量的工作模式；模拟研究束流极化度大于50%的实现条件	束流极化度大于 50%，束流 寿命大于 60 分钟 ✓	同行专家评审，束流极化物理设计报告报告将写入高能环型正负电子对撞机加速器关键技术设计和测试报告

Assessment method and means of evaluation:

- Expert review in the visit to prototype
- **Test** report will be included in final report (1)

- Peer expert review
- **Design** report will be included in final report (1)

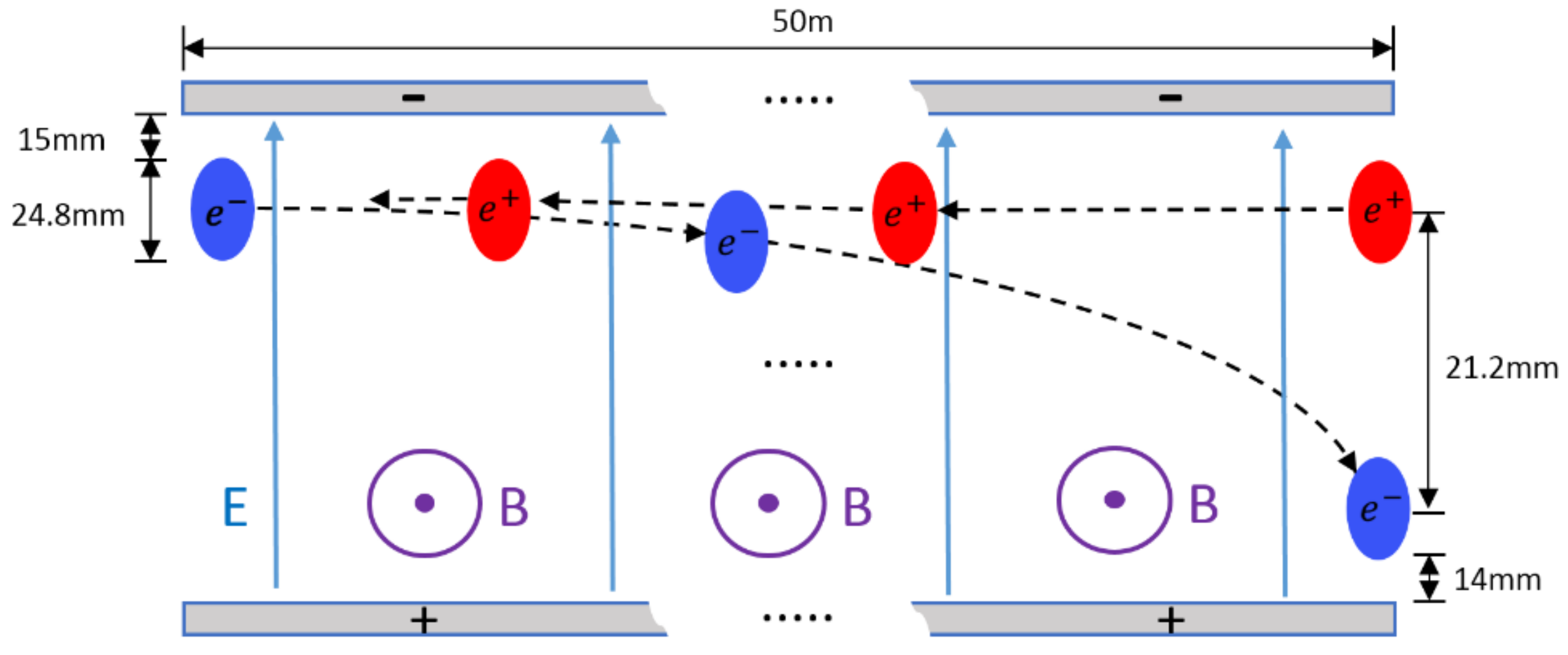
(1) Final report: ”CEPC accelerator key technology design and test report”

Electrostatic Separator R&D

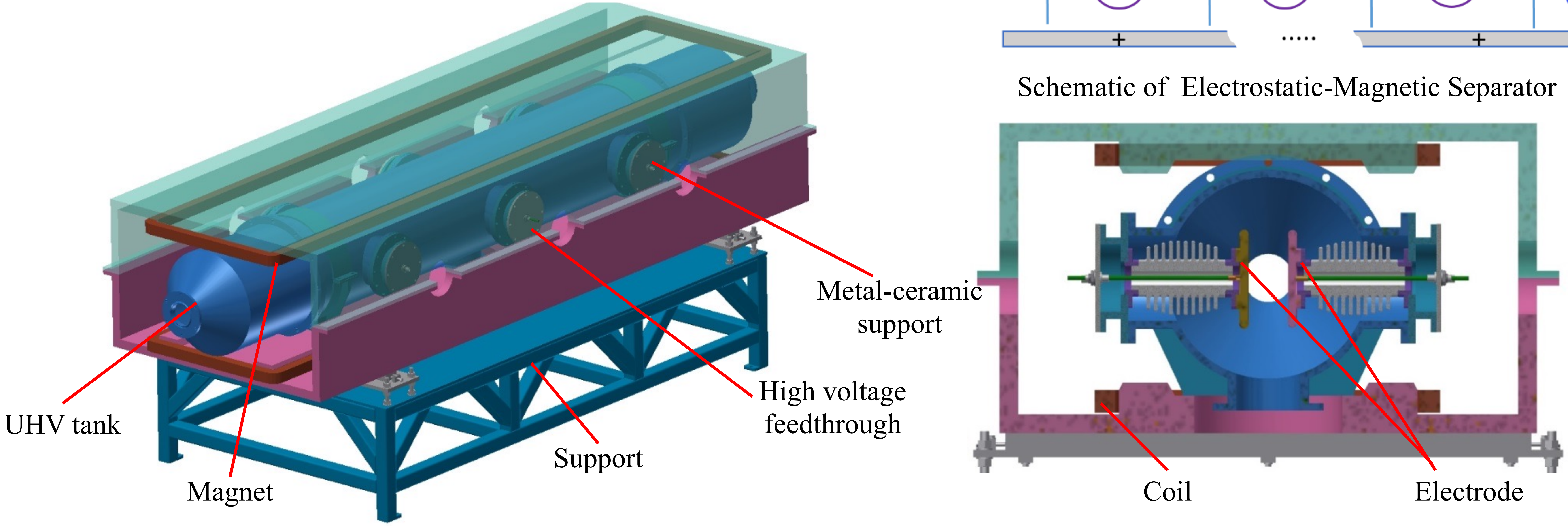
Introduction

- The Electro-Magnetic Separator is a device consisting of perpendicular electric and magnetic fields.
- One set of Electro-Magnetic Separators including 8 units, total 32 units will be need for CEPC.

	Filed	Effective Length	Good field region	Stability
Electrostatic separator	2.0MV/m	4m	46mm×11mm	5×10^{-4}
Dipole	66.7Gauss	4m	46mm×11mm	5×10^{-4}



Schematic of Electrostatic-Magnetic Separator



Structure drawing of Electrostatic-Magnetic Separator

Assessment Indicators of Science and Technology Report

序号	Report type	数量	提交时间	公开类别及时限
1	Annual technical progress report	1	2019 年 6 月	公开
2	Annual technical progress report	1	中期检查前	公开
3	Annual technical progress report	1	2021 年 6 月	公开
4	Annual technical progress report	1	2022 年 6 月	公开
5	Annual technical progress report - final report	1	结题验收前	公开
6	High Energy Circular Collider Detector Design Report	1	2021 年 4 月	公开
7	High Energy Circular Collider Detectors Test Report (task 2+3)	1	2023 年 4 月	公开
8	High Energy Circular Electron-Positron Collider Key Technology Design and Test Report	1	2023 年 4 月	公开