

# **Outcome of MOST Project: R&D** and Verification of Key Technologies for a High **Energy Circular Electron-Positron Collider**

## **CEPC** Day, June 21, 2023





Institute of High Energy Physics Chinese Academy of Sciences



## 国家重点研发计划



# 任务分解和主要研究: Task Arrangement and Main Research

Task	Task Leader Institute	
Task 1: Accelerator	Yunlong Chi IHEP	Prototyp pipe
Task 2: Silicon Detector	João Guimarães da Costa IHEP	Prototyp
Task 3:HadronicCalorimeter	Jianbei Liu USTC	Prototy scinti



Total funding: 3145 万





## Task final review: June 19-20

## Monday, June 19

#### **Task 3: Calorimeter**

9:00 AM → 9:10 AM	Leader welcon	ne speech 承担单位领导致辞	🕲 10m	<b>1:20 PM</b> → 5:25 PM	Task2 课题	二:硅径迹探测器关键技术验证	
9:10 AM → 9:40 AM	Overview of pr Speaker: Joao (	<b>oject 项目总结汇报</b> Guimaraes da Costa	(30m)		papers a 1:20 PM	and confere w Task2 self-assess w 课题2-专家个人评 w 课题2评审意见草稿 Lab visit 参观样机和实验室	<b>(</b> ) 40m
9:40 AM → 12:00 PM	Task3 课题三 ₩ papers and 9:40 AM	: 成像型强子量能器技术验证 d confere  w task3-self assess r  w 评审意见草稿-Grou  w 课题3-专家个人评 Overview 课题三整体汇报 (20'+5') Speaker: Jianbei Liu (University of Science and Technology of China)	© 20m		2:00 PM 2:25 PM	Overview 课题二整体汇报 (20'+5') Speaker: 梁志均 LIANG Zhijun Sensor chip design and testing 传感器芯片设计与测试 (20'+5') Speaker: Ying ZHANG (IHEP)	© 25m
	10:00 AM 10:20 AM	Group photo and Coffee break 合影+茶歇 Highlight of HCAL R&D 量能器技术研究亮点 (20'+5') Speaker: Yunlong Zhang (University of Science and Technology of China)	© 25m		2:50 PM	Structure and assembly of detector prototype 探测器样机的结构与组装(20'+5') Speaker: Jinyu Fu (高能所)	© 25m
	10:45 AM	Analysis of beam test result 束流测试数据分析 (20'+5') Speaker: 禹坤 石 (中国科学技术大学) 区 AHCAL Calibration	<b>③</b> 25m		3:35 PM	Analysis of beam test result 束流测试 (20'+5') Speaker: Shuqi Li	© 25m
	11:10 AM	Discussion (Project group only) Main building A511	350m		4:00 PM	Discussion (Project group only) Main building A511	(§ 1h
	11:10 AM	Discussion (Refrees only) 评委内部讨论与撰写评审意见	🕲 50m		4:00 PM	Discussion (Refrees only) 评委内部讨论与撰写评审意见	(§ 1h
<b>12:00 PM</b> → 2:00 PM		Lunch box 午餐		6:00 PM → 7:00 PM		Dinner	

#### All three tasks passed the review



## Tuesday, June 20

#### **Task 1: Accelerator**

:00 AM → 12:30 PM	Task1 课题一	:高能	环形	正负电子对	<b>甘撞机加速</b>	器关	键技术验证			
	Paperlist-a	acc.pdf	W	task1-self-a	ssessm	Ŵ	评审意见草稿 Grou	Ŵ	课题1-专家个人评	
	9:00 AM	Brief o Speake	verv er: Jo	<b>riew</b> bao Guimara	aes da Cos	ta				
	9:15 AM	Sub-ta 子课题1 Speake	<b>sk 1</b> : Cl r: 文	: CEPC Bo	<b>Doster Dip</b> 极磁铁原型 or Centor, IHE	ole N 机 P)	Aagnet Prototype	(20'+5	Ŋ	
	9:40 AM	Sub-ta 子课题2 Speake	sk 2 :: Cl r: Ha	2: <b>Prototyp</b> EPC真空系统 aiyi 董海义 (7	be of CEP( 关键设备样 高能所)	C vac 机	uum system (20'	+5′)		
	10:05 AM						Coffe	e bre	ak	
	10:25 AM	Sub-t 子课题 Speak	ask  3: j :er: )	<b>3: Electron</b> 正负电子束静 武 陈 (高能所)	<b>positron</b> ( 电分离器样	e <b>lect</b>	ronic separator (	20'+5'	)	
	10:50 AM	Sub-t 子课题 Speak	<b>ask</b> 4: ( ( <b>er</b> : 2	4: CEPC pc CEPCZ能区极 Zhe DUAN (高	blirization 化束流的加 <sup>5能所)</sup>	<b>stud</b> i速器	<b>y at Z-pole (20'+</b> 物理研究与设计	5)		
	11:15 AM	<b>Discu</b> Main b	<b>ssic</b> ouildi	on (Project	t group or	ly)				
	11:15 AM	Discu	ssic	on (Refree	s only)អ៊	委内	部讨论与撰写评审	意见		
<b>2:30 PM</b> → 12:50 PM							Lunch box			



(§ 15m	
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<b>③</b> 25m	
© 25m	
<b>③</b> 45m	
<b>③</b> 45m	

## Task 1: Accelerator



#### Subtask

#### Indicator

#### Lowest field

**High precision low-field** dipole magnet prototype

Field uniformity

## Very challenging magnet built and measurement done



World leading



Requirement	Result	Conclusion
<31 Gs	28.5 Gs	Surpassed
<5×10-4	3×10-4	Surpassed

Permanent magnets added at the end to help keep the beam uniformity within the **MOST2 requirements** 







# 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 enough uniformity

7 patents developed for this work







#### Subtask

#### Indicator

**High precision low-field** dipole magnet prototype Lowest field

Field uniformity

Vacuum degree

#### Vacuum pipe and RF shielding bellow prototype

Vacuum leakage

RF shield bellows contact fo









	Requirement	Result	Conclusion
	<31 Gs	28.5 Gs 🗸	Surpassed
	<5×10-4	3×10-4	Surpassed
	< 2×10 <sup>-10</sup> Torr	1.08 - 0.99 x10 <sup>-10</sup> Torr 💙	Surpassed
	< 2×10 <sup>-10</sup> Torr.L/s	1×10-10 Torr.L/s	Surpassed
orce	125±25 g/finger	123-135 g/finger	Achieved





## all requirements achieved well within project timescale







# Task 1: Electrostatic separator prototype

#### Most challenging subtask to pass review







Ultra-High-Vacuum tank and electrostatic components finished — Magnet to be finished









Subtask	Indicator	Requirement	Result	Conclusion
High precision low-field	Lowest field	<31 Gs	28.5 Gs 💊	Surpassed
dipole magnet prototype	Field uniformity	<5×10-4	3×10-4	Surpassed
Vacuum ning and PE	Vacuum degree	< 2×10 <sup>-10</sup> Torr	1.08 - 0.99 x10 <sup>-10</sup> Torr	Surpassed
shielding bellow	Vacuum leakage	< 2×10 <sup>-10</sup> Torr.L/s	1×10 <sup>-10</sup> Torr.L/s	Surpassed
prototype	RF shield bellows contact force	125±25 g/finger	123-135 g/finge	Achieved
	Electric field	>2 MV/m @ ±110 kV	3.09 MV/m @ ±116 kV	Surpassed
High energy electrostatic separator prototype	Field uniformity	(1‰)10x10 mm <sup>2</sup>	(0.5‰)46x30 mn	n <sup>2</sup> Surpassed
	Vacuum	< 2.7×10 <sup>-8</sup> Pa (<2×10 <sup>-10</sup> Torr)	< 2.6×10 <sup>-8</sup> Pa	Achieved
		31 9 36	9	









## **Referee Report:**

课题组完成了120GeV 高能正负电子束静电分离器原型样机的研制,其各项指标均达到或优于任务 书要求技术指标。样机的研制完成,攻克了主环高频区正、负电子束团分离关键技术,进一步降低 了CEPC工程制造成本。

The research group has completed the development of the prototype of the 120GeV highenergy positron-negative electron beam electrostatic separator, and its various indicators have reached or exceeded the technical indicators required in the mission statement. The development of the prototype machine was completed, and the key technology of positive and negative electron bunch separation in the high frequency area of the main ring was overcome, which further reduced the CEPC engineering manufacturing cost



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









## **Referee Report on Polarization**

在CEPC Z能区极化束研究方面,课题组提出并研究了极化束流的产生、逐级加速和传输、并实现 极化束对撞和共振退极化束流能量测量的初步可行方案。基于CEPC概念设计报告的磁聚焦结构和 关键参数,完成了Z能区纵向极化束对撞的完整设计。模拟研究显示,对撞束流时间平均极化度可 达到50%以上,在对撞环中加入非对称扭摆磁铁和自旋旋转器对束流寿命没有显著影响,束流寿命 大于60分钟,符合考核指标要求。针对高能电子环形加速器,拓展了自旋共振结构的理论模型,首 次解释了自旋共振强度增强和削弱的物理机理;模拟验证了辐射退极化效应存在非相干共振穿越区 域,首次揭示了现有理论在处理相关问题时存在缺陷。这些研究加深了对自旋退极化物理机理的认 识,为在未来对撞机中开展极化束应用提供了重要参考



## Task 2: Vertex Detector Prototype





## Task 2: Vertex Detector Prototype Research Goal

- **Produce a world class vertex detector prototype** 
  - Spatial resolution 3~5 µm (pixel detector)
  - Radiation hard (>1 MRad) •

**Typical vertex tracker** 



#### **Typical cost of such detectors:** 350-700 MRB

#### ATLAS/CMS upgrade (10-20 µm)

Alice upgrade (5~10 µm)

This project (3~5 µm)

Key ingredient:

**Full size sensor/ASIC**  $(2-4 \text{ cm}^2)$ 

Major goal: develop the know-how in China to build such advanced detectors

#### Resolution









## Task 2: Vertex Detector Prototype Development

production of this vertex detector and other silicon-based devices





- Resolution of  $< 5 \mu m$  demonstrated with:
  - laser tests on bench
  - test beam telescope ullet
  - test beam with full size CEPC vertex prototype ullet

# Developed first full-size CMOS monolith imaging sensor in China, adequate for the

- Full size 1024×512 Pixel array, Chip Size: 15.9 × 25.7 mm<sup>2</sup>
- 25×25µm<sup>2</sup> pixel size allowing high spatial resolution
- Process: Towerjazz 180 nm
- Fast Periphery digital readout, high-speed data interface







## Task 2: Vertex Detector Prototype Development

## **Full scale ladder**





**FPGA** board

#### Vertex detector configuration for test beam



First in-depth full scale silicon vertex prototype developed in China allowing for the studies of mechanical structures, low-mass materials, and cooling procedures

Ladder readout system

Three double sided ladders in two sets, for a total of 12 layers

Twice the layers that a particle would transverse in a real detector



## Task 2: Vertex Detector Prototype Test Beam

## Two test beam events at DESY, Germany:

- December 2022
- April 2023



Prototype connected with readout electronics 12 layers of sensors visible



#### **Resolution with full-size mechanical prototype**









## Indicators and review report

Indicator	Requirement	Result	Conclusion
Spatial resolution	3-5 µm	Laser test: x: 4.0 µm; y: 4.1 µm Beam test: x/y: 4.8-4.9 µm	Achieved
Total ionization dose (TID)	> 1 MRad	> 3 MRad	Surpassed

该课题在高性能硅像素传感器芯片研究方面攻克了高空间分辨、低物质量和抗辐照等一系列关 键技术难题,达到了国际先进水平, …… 建议加强束流实验数据的分析处理,为探测器的进一 步优化设计提供参考。同时,建议持续开展该技术的研发,以促进国内先进传感器芯片技术的 发展







## Task 3: Calorimeter Prototype





## Task 3: HCAL Prototype Research Goals

- **R&D of SiPM based HCAL prototype** 
  - High energy resolution ( $60\%\sqrt{E/GeV}$ )
  - High linearity (non-linearity <3%) •
- Initial prototype design
  - $0.5 \times 0.5 \text{ m}^2$ ,  $35 \text{ layer (4}\lambda)$ ,  $3 \times 3 \text{ cm}^2$  module •
  - SiPM and scintillator coupling



Automatic system developed to cope with the large number of channels





- Actual prototype built
  - $0.72 \times 0.72 \text{ m}^2$ , 40 layer (4 $\lambda$ ), 4×4cm<sup>2</sup> module
  - Number of total channels: 12,960

#### Assembled HCAL Basic Units

#### Mechanics design









# Task 3: HCAL Prototype TestingThree test beam campaigns at CERN: Oct 2022, April 2023 and May 2023HCAL prototypePion event displayTeam at CERN





#### 65 million events collected in total

- Achieved requirement with second test beam data
- ECAL tested in front of HCAL











## **Achievements and Assessment Methods**

Indicator	Requirement	Result	Conclusion	
Energy resolution	60%/√(E/GeV) ⊕ 3% (10 GeV < E < 80 GeV)	(57.6%)/√E⊕2.3%	Surpassed	F
Energy linearity	3% (10 GeV < E < 80 GeV)	<2%	Surpassed	F

This project has made a series of innovative achievements in key technologies including mass production, packaging and testing of plastic flash units, large area, high integration, fully embedded readout electronics, large-scale and fast SIPM performance monitoring and calibration based on LED, which plays an important role in the research and development of key technologies of cepc.



## Academic Achievements

	Accelerator	Vertex	Calorimeter	Total
Patents	8	12		21
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		3





## International Collaboration



# collaboration with UK and US institutes within the vertex detector project

The pandemic made international collaboration much complicated, and prevented



## 小结

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





## The end

