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

Internal Review — Overview: June 7, 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

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

Internal Review — Overview: June 7, 2023

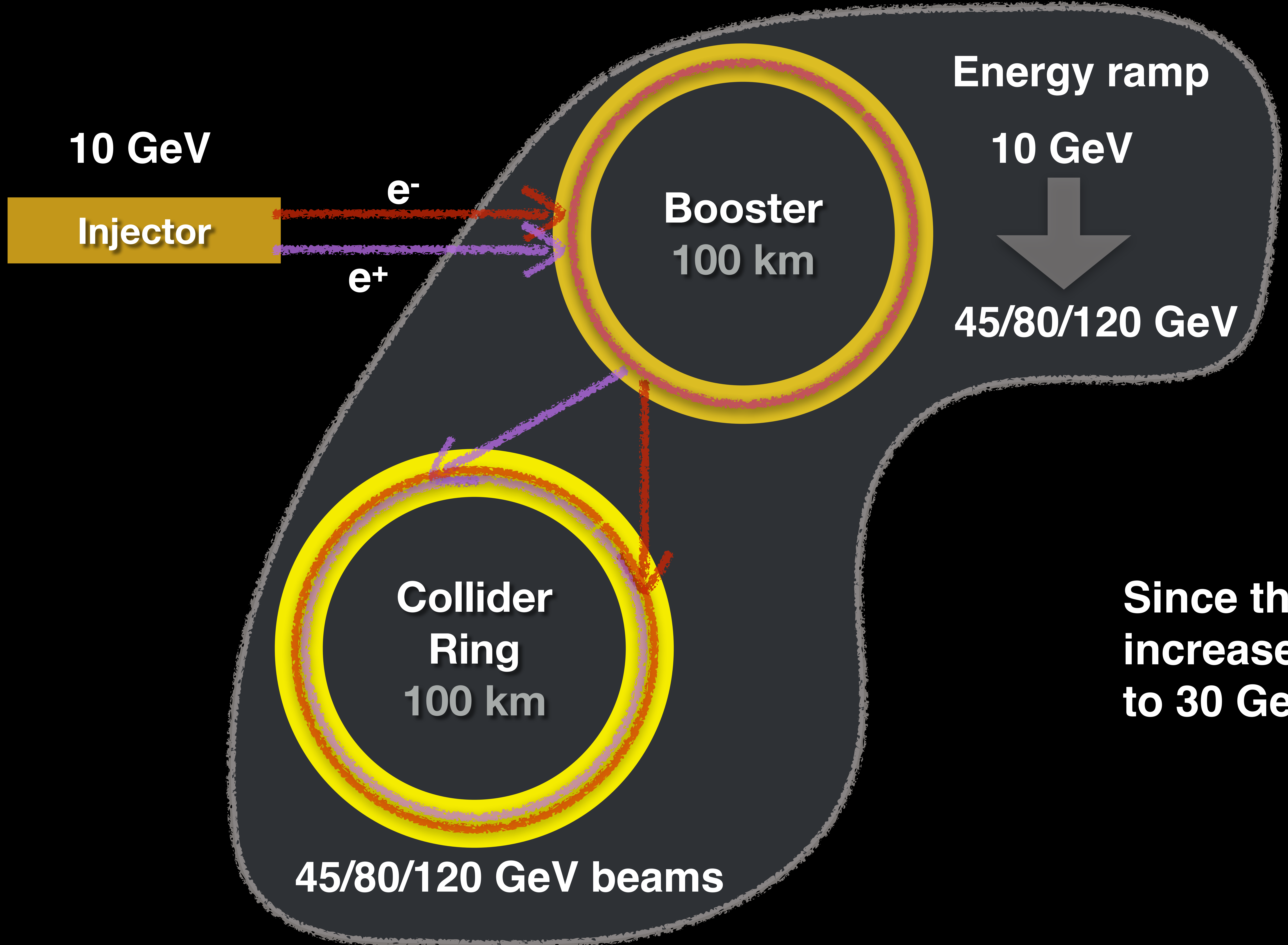
中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

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	974万
Task 2: Silicon Detector	João Guimarães da Costa IHEP	Prototype: silicon tracker with low-material budget, 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

Task 1: Requirements and goals: Accelerator Chain and Systems



Since then, CEPC project increased injection energy to 30 GeV

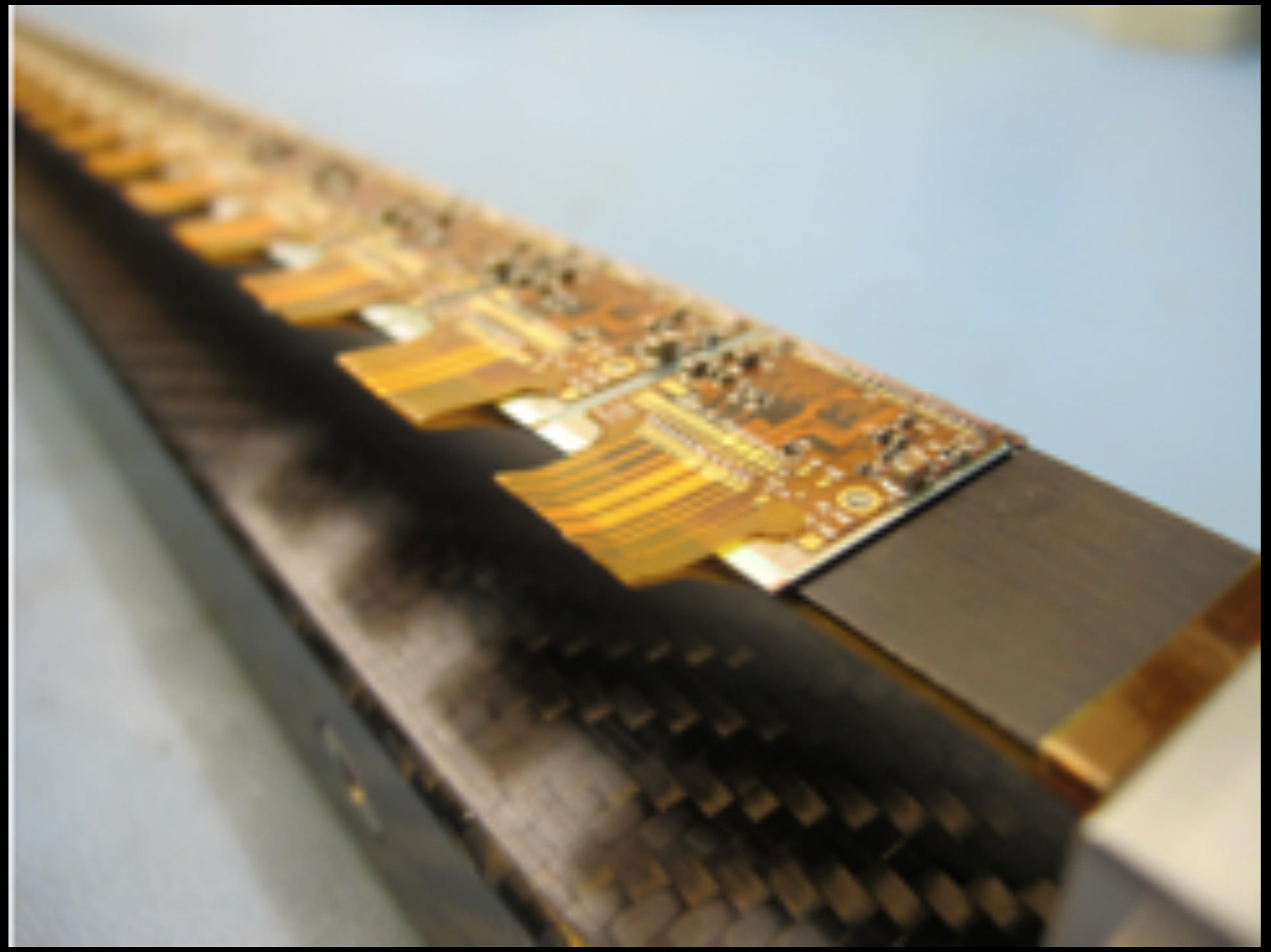
Task 1: Research target

		Assessment
• **High precision low-field dipole magnet prototype** • Lowest field 31 Gs， uniformity 5×10^{-4} LEP: 170Gs → World class: 120Gs → This project: 31Gs	World leading	Provide prototype design and test reports for peer review
• **Bending vacuum pipe and RF shielding bellow prototype** • Vacuum degree better than 2×10^{-10} Torr • Leakage $<2\times10^{-10}$ Torr.L/s • RF shield bellows contact force is 125±25 g/finger	First in China	
• **High energy electrostatic separator prototype** • High field >2 MV/m	First in China	
• **Z pole beam polarization** • High Polarization >50%， lifetime>60 min	World leading	Provide design report for peer review

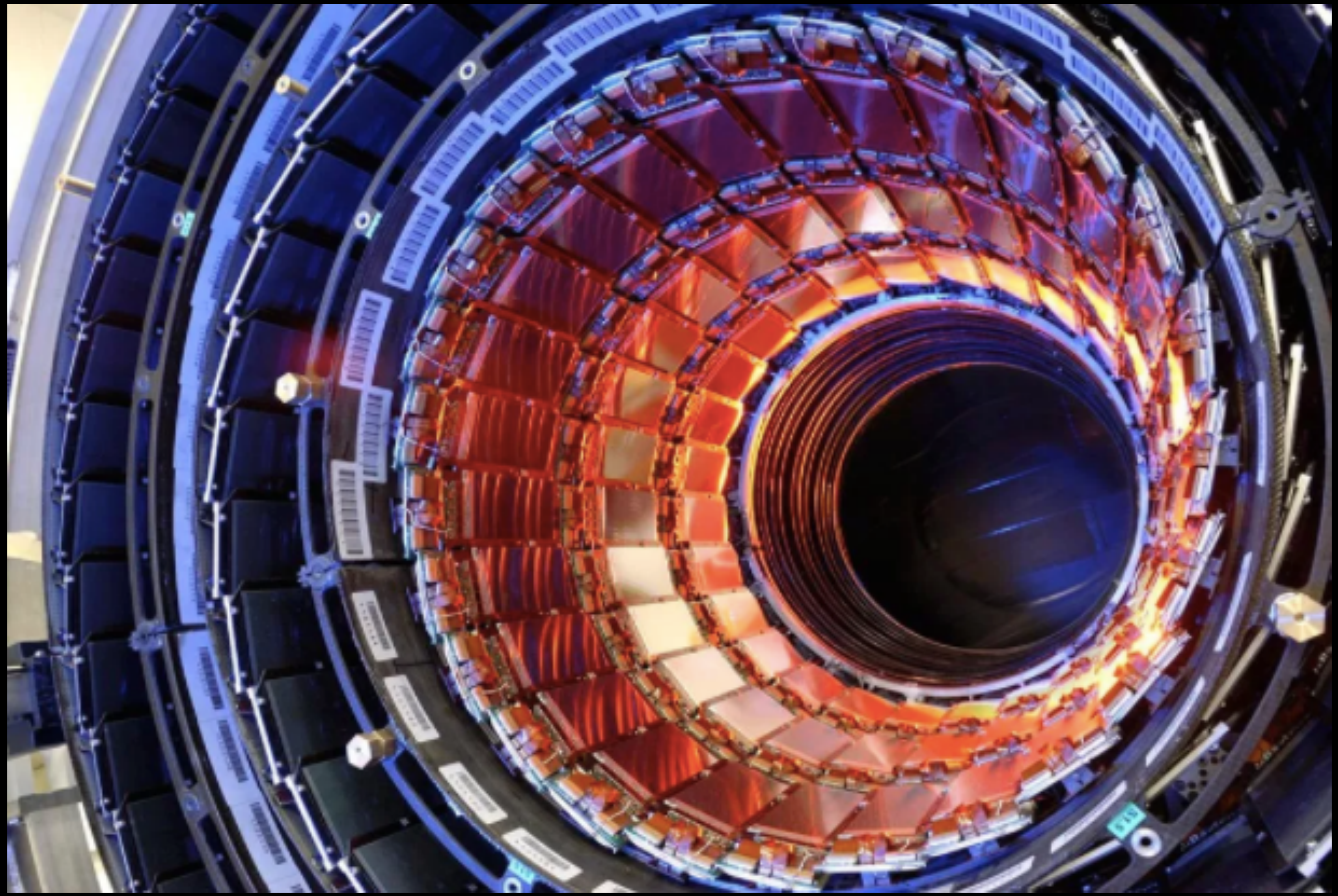
Task 2: Research Goal

- **Produce a world class vertex detector prototype**
  - Spatial resolution 3~5 μm (pixel detector)
  - Radiation hard (>1 MRad)
- **Preliminary design of prototype**
  - Three layer, module ~1 cm × 6-12 cm^2

Typical module



Typical tracker



Resolution

ATLAS/CMS upgrade (15 μm)

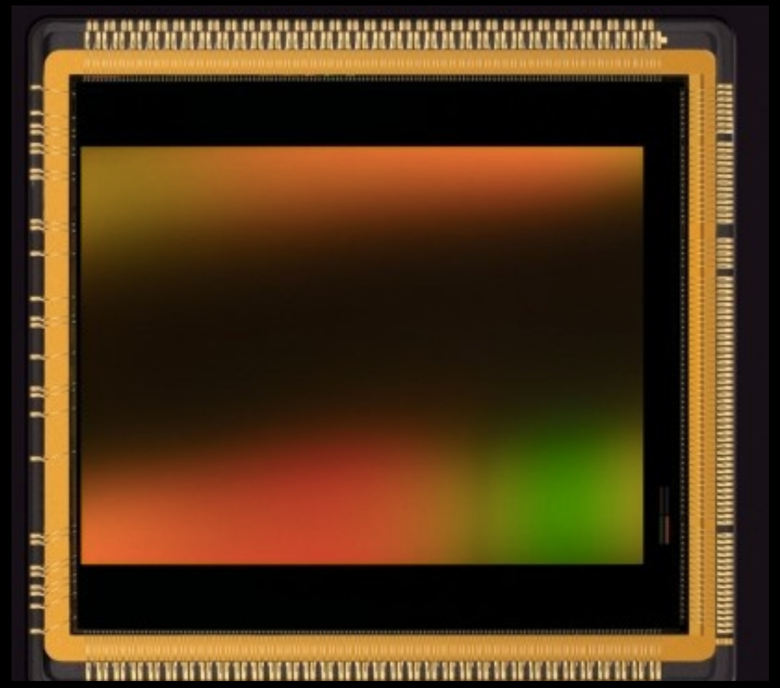
Alice upgrade (8~10 μm)

World leading — This project (3~5 μm)

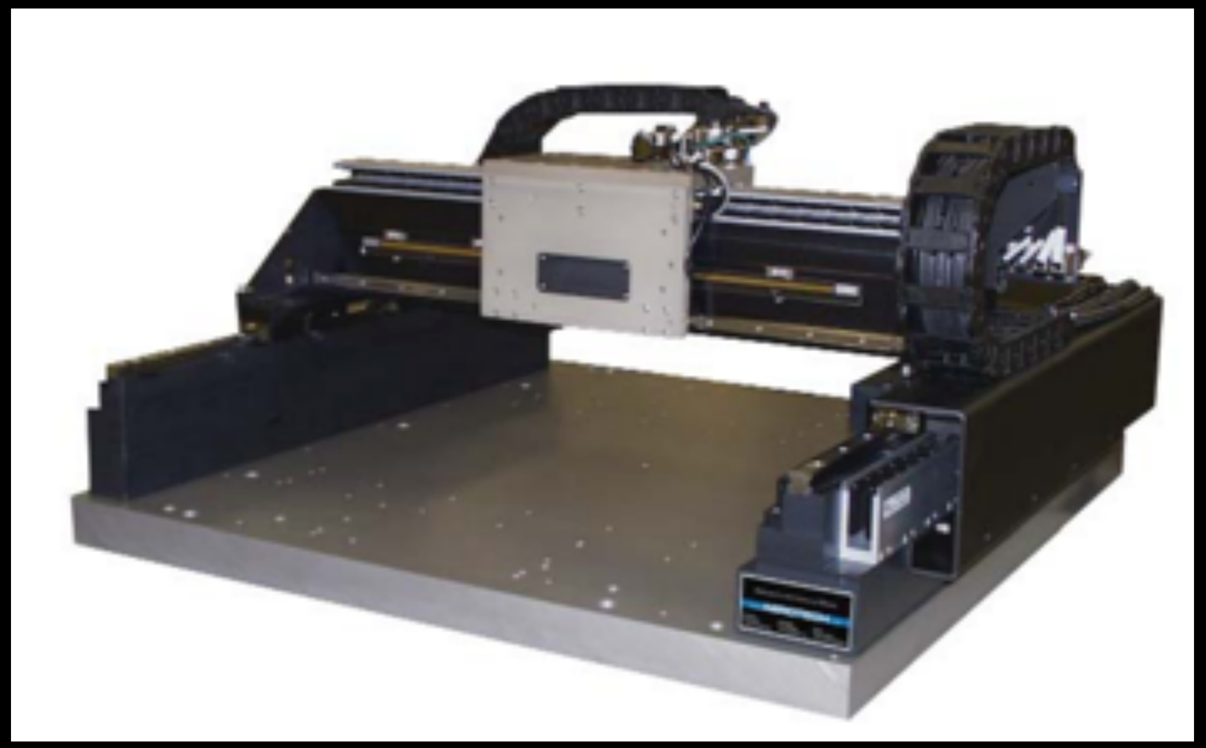
Task 2: Technical route and schedule

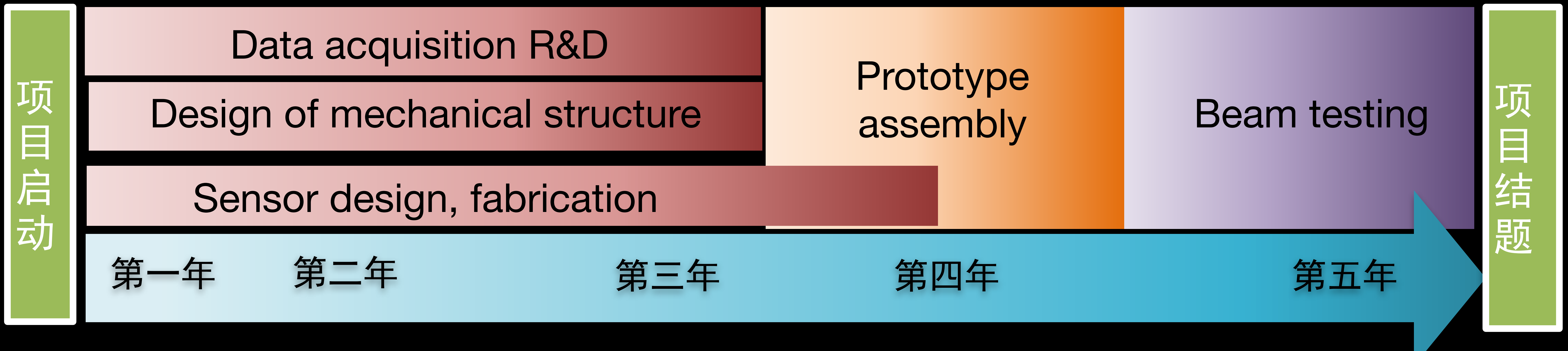
- Use CMOS image sensor technology
- Optimize pixel circuitry, reduce size → High resolution
- Special design and latest technology → Radiation hard
- Use carbon fiber, polyamide, graphene, and other light materials for mechanical structure → Low mass
- Robot automatic mechanical assembly → High accuracy

CMOS imaging sensor



Gantry



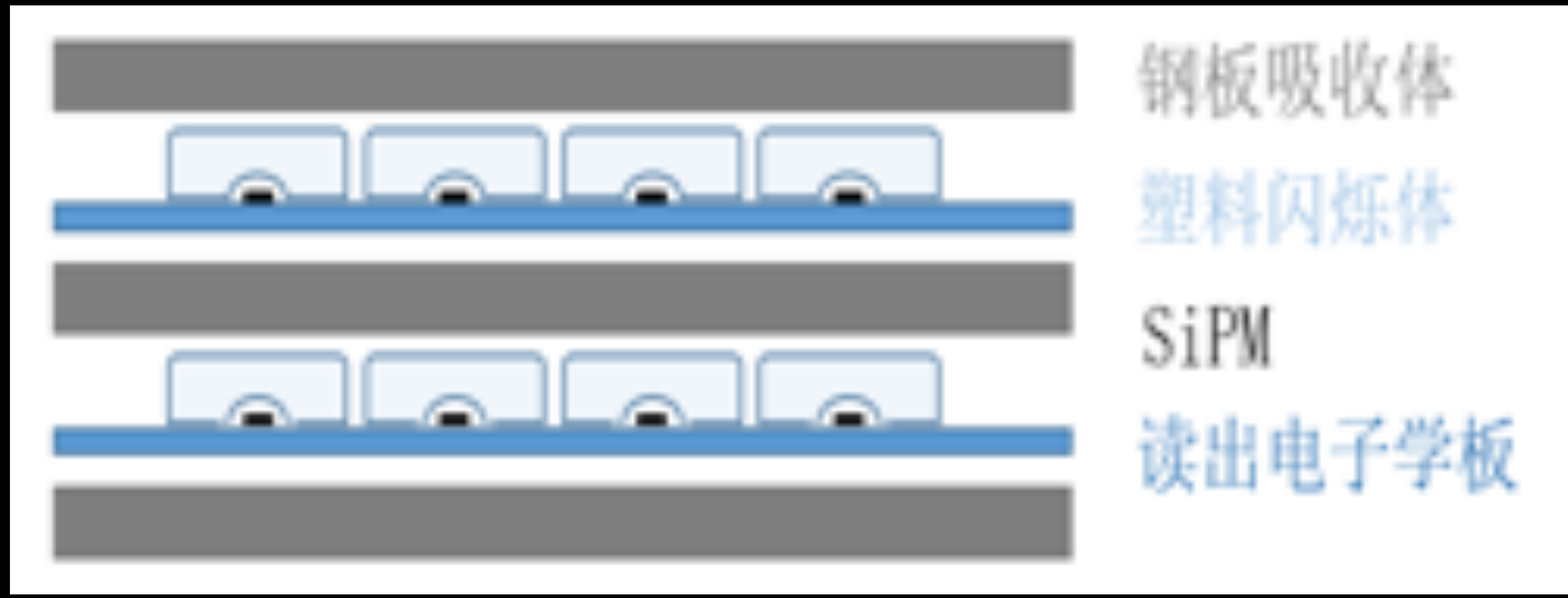


Task 3: HCAL — Research content and assessment

- R&D of SiPM based HCAL prototype
  - High energy resolution ($60\%/\sqrt{E/GeV} \oplus 3\%$)
  - High linearity（non-linearity <3%）
- Prototype design
  - $0.5\times0.5\ m^2$， 35 layer (4λ)， $3\times3cm^2$ module
  - SiPM and scintillator coupling

Typical HCAL

first design of HCAL prototype



Task 3: Technical route and schedule

Scintillator automatic packaging device → Uniformity

Embedded SiPM into Scintillator → High coupling efficiency, High resolution

LED based monitoring → High linearity

项目启动

样机设计 — 第一年

模块生成 — 第二年、第三年

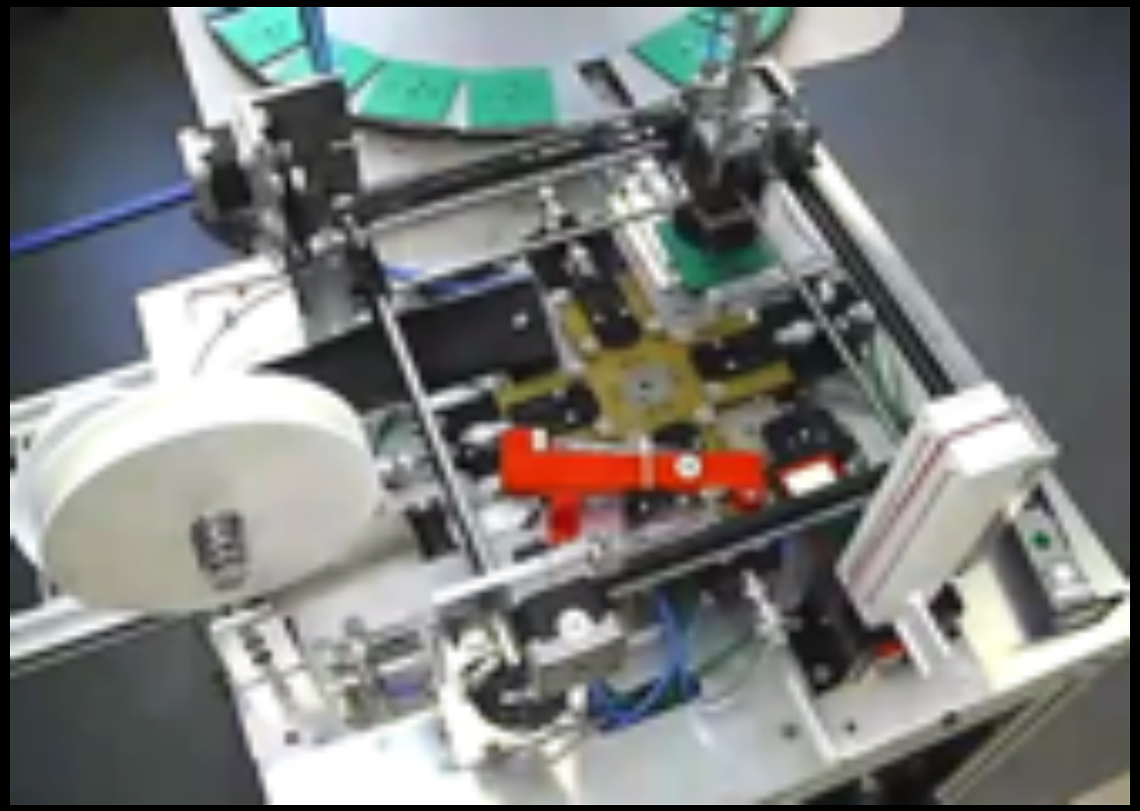
样机集成 — 第四年

束流测试 — 第五年

项目结题

Embedded SiPM into Scintillator

Automatic packaging machine



International Collaboration

课题1 （加速器）

俄罗斯BINP实验室 ✔

课题2 （硅像素探测器）

西班牙巴塞罗那大学 ✔
英国利物浦大学
英国牛津大学
英国卢瑟福实验室
美国马萨诸塞大学

Added：德国DESY实验室

课题3 （量能器）

法国欧米伽微电子技术中心
德国DESY实验室
CALICE Collaboration

✔

3. 项目实施关键节点和具体实施计划:
Key Points and Project Implementation Plans

第五年（2022.5-2023.4）

Main Milestones

- Task 1:
  - Complete the performance test of dipole prototype
  - Complete tests of prototypes of vacuum tube, RF bellows and electrostatic separator
  - High pressure experiment was carried out on the electrostatic separator
- Task 2:
  - Test beam and data analysis
  - Finish assembling of prototype
- Task 3:
  - Test beam and data analysis
  - Finish assembling of prototype

Outcome

- Final report, paper and experimental equipment

Challenges faced by tasks:

overcomed/not overcomed?

- COVID:
  - What were the limitations due to covid that affected the project implementation
    - Break of international collaboration on the vertex detector with UK institutes. Collaboration still continued successfully with Spain since that was aimed at the chip design that started before COVID
  - Delays in testing of HE Separator
- Technical embargo:
  - Chip submission complicated by achieved after some delay
- other:
  -

Innovations from each tasks:

- **Task 1:**
- **Task 2:**
- **Task 3:**

I would like to have a list by the end of this internal meeting, so that we emphasize in the final report

5. 成果呈现形式及测试方法:
Achievement Presentation and Assessment Methods

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	**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
	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"

Achievement Presentation and Assessment Methods

Silicon Detector 研制出硅径迹探测器原型机	☐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 2：硅径迹探测器关键技术验证	硅径迹探测器原型机的空间分辨率	无	研制出小型传感器芯片，像素单元尺寸小于或等于 25 微米 ×25 微米。	3-5 微米	同行专家评审。(通过束流实验，离线分析数据获得空间分辨率。该测试结果写入原型机设计与测试报告，以供同行专家评审)
			所设计的抗辐照硅传感器能承受的总剂量	无	完成传感器的初步设计，通过仿真初步验证其抗辐照性能	1 MRad	同行专家评审(提供传感器的设计与测试报告供专家评审)

Assessment method and means of evaluation:

- **Peer expert review**
- **Beam test and offline analysis; report to be included in final report (2)**

- **Peer expert review**
- **Provide sensor design and test report for expert evaluation**

(2) Final report: "CEPC Detectors Test Report"

Achievement Presentation and Assessment Methods

Calorimeter	□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 □临床指南/规范 □工程工艺 □标准	课题 3：成像型强子量能器技术验证	量能器能量分辨	无	完成原型机物理设计，模拟得到原型机能量分辨达到 $60\%/\sqrt{E/GeV} \oplus 3\%$ (10 GeV<E<80 GeV)	$60\%/\sqrt{E/GeV} \oplus 3\%$ (10 GeV<E<80 GeV)	利用高能粒子束对原型机进行测试，离线分析测试数据获得性能指标。同行专家评审测试报告。
Calorimeter	■论文 □发明专利 □其他		量能器能量线性	无	完成原型机物理设计，模拟得到原型机能量线性达到 3%(10GeV<E<80GeV)	3%(10GeV<E<80GeV)	利用高能粒子束对原型机进行测试，离线分析测试数据获得性能指标。同行专家评审测试报告。

Assessment method and means of evaluation:

- **Peer expert review**
- **Beam test and offline analysis; report to be included in final report (2)**

- **Peer expert review**
- **Beam test and offline analysis; report to be included in final report (2)**

*** Final report: "CEPC Detectors Test Report"**

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

Steps for final approval of project:

1. **Testing report （测试报告）**
   - How prototype tests were performed and how they compare to indicators
2. **Final Technical Progress Report （最终科技进展报告）**
   - Refers to the Testing Report above
   - Accelerator has the first draft of final progress report
   - Silicon and Calorimeter tasks need to provide first draft of final report
   - Provide draft to reviewers before the final review meeting on June 19-20 ?
3. **Final Assessment report (自评估报告)** - to be filled in the MOST system
   - Refers to the two reports above

4. **Review reports from referees**
   - Referee report on the test plan and test results for all tasks - to be done before June 19 review meeting
     - Done for accelerator, missing for calorimeter and vertex detector (can be same or different referees)
     - Reports can be used to create the final referee report
   - Referee report from final review meeting on June 19-20
     - Need to prepare these in advance

4. 项目组织管理机制:
Project Management Organization

Project management organization - Initial Expert Team

- MOST Project Responsibility Expert
  - Zhao Hongwei (Institute of Modern Physics, CAS)
  - Wang Qiuliang (Institute of Electrical Engineering, CAS)
  - Xu HongJie (Shanghai Institute of Application Physics, CAS)
- Expert Team (8 people)
  - Xu Nu (Institute of Modern Physics, CAS)
  - Tang Chuanxiang (Tsinghua University)
  - Lv Junguang (Institute of High Energy Physics, CAS)
  - Li Jin (Institute of High Energy Physics, CAS)
  - Gao Yuanning (Peking University)
  - Youjin Yuan (Institute of Modern Physics, CAS)
  - Hu Guo Chaoying (IN2P3-CNRS-University of Strasbourg, IPHC)
  - Zhentang Zhao (Shanghai Institute of Applied Physics, CAS)

Project management organization - Expert Team for Final Review

- MOST Project Responsibility Expert
  - Zhao Hongwei (Institute of Modern Physics, CAS) ★ maybe online — accelerator
  - Wang Qiuliang (Institute of Electrical Engineering, CAS) ★ — accelerator
  - Xu HongJie (Shanghai Institute of Application Physics, CAS)
- Expert Team (8 people)
  - Xu Nu (Institute of Modern Physics, CAS)
  - Tang Chuanxiang (Tsinghua University) ★ — accelerator
  - ~~Lv Junguang (Institute of High Energy Physics, CAS)~~
  - ~~Li Jin (Institute of High Energy Physics, CAS)~~

    } Cannot participate because from IHEP
  - Gao Yuanning (Peking University)
  - Youjin Yuan (Institute of Modern Physics, CAS) ★ — accelerator
  - Hu Guo Chaoying (IN2P3-CNRS-University of Strasbourg, IPHC) ★ online — silicon
  - Zhentang Zhao (Shanghai Institute of Applied Physics, CAS)

Project management organization

- **MOST Project Responsibility Expert**
  - Zhao Hongwei (Institute of Modern Physics, CAS) — maybe online — accelerator
  - Wang Qiuliang (Institute of Electrical Engineering, CAS) — accelerator
- **Expert Team (6 people)**
  - Tang Chuanxiang (Tsinghua University) — accelerator
  - Han Dejun (Beijing Normal University) — calorimeter
  - Wang Yi (Tsinghua University) — calorimeter
  - Youjin Yuan (Institute of Modern Physics, CAS) — accelerator
  - Hu Guo Chaoying (IN2P3-CNRS-University of Strasbourg, IPHC) — online — silicon
  - Gaobo Xu (Institute of Microelectronics, CAS) — silicon

Invited:
Chengxin Zhao Modern Physics Institute, CAS - Silicon
Sun Xiangming, CCNU - Silicon

Project management organization

- Project office
  - Contact person： Zhaoru Zhang
  - Academic assistant： Zhijun Liang (Associate professor)
  - Financial assistant： Zhaoru Zhang
  - Contact person of Task 1： Yunlong Chi （task leader)
    - Financial assistant: Jie Zhou
  - Contact person of Task 2： Joao Guimaraes da Costa （task leader)
    - Financial assistant: Zhaoru Zhang
  - Contact person of Task 1： Jianbei Liu （task leader)
    - Financial assistant: Limin Wang

小结

- Goal for today: Plan the final review on June 19-20 — how results will be presented
- Highlight indicators and achievements
  - How tests were performed and indicators demonstrated to have been achieved? Emphasize problems, if any persist
- Highlight innovations and challenges
- Plan the test report review of calorimeter and silicon (need to be available before June 19)
- Plan the referee report for final review

谢谢

The end

3. 项目实施关键节点和具体实施计划:
Key Points and Project Implementation Plans

第一年（2018.5-2019.4）

Main Milestones

- Task 1:
  - Low-field dipoles: physical and structural design of various small prototypes
  - Preliminary design of vacuum box and bellows, and electrostatic separator
  - Parameter selection of polarization working mode
- Task 2:
  - Preliminary designs of mechanics, readout electronics and ASIC
  - First ASIC MPW submitted
- Task 3:
  - Design of calorimeter prototype, and parameters optimized
  - Batch production of scintillator unit studied and started
  - Design front-end electronics

Outcome

- Annual report

第二年（2019.5-2020.4）

Main Milestones

- Task 1:
  - Manufacture the high-precision low field dipole magnet small experimental prototype
  - Finish engineering design of vacuum box and bellows, and electrostatic separator
  - Simulation program for storage ring polarization is developed
- Task 2:
  - Engineering designs of mechanics structure
  - Second ASIC MPW submitted
- Task 3:
  - Simulate whole HCAL prototype and develop software framework
  - Carry out production of scintillator units
  - Prototype absorber and supporting structure are designed.

Outcome

- Mid-term report

第三年（2020.5-2021.4）

Main Milestones

- Task 1:
  - Smal prototype of magnet fully tested
  - Design of magnet complete
  - Processing of the vacuum tube, the coating experiment device and the shielding bellows are completed
- Task 2:
  - Mechanical structure completed
  - Second ASIC MPW tested
  - ASIC design optimized and completed
- Task 3:
  - Batch production of readout electronics, development of data acquisition system
  - Development of beam test platform and cosmic ray test platform

Outcome

- Annual report

第四年（2021.5-2022.4）

Main Milestones

- Task 1:
  - Completed the formal prototype of the dipole magnet and measurement system
  - Prototypes of vacuum tube and RF bellows completed
  - High pressure experiment was carried out on the electrostatic separator
- Task 2:
  - Silicon wafer processing of large area sensor submitted
  - Assembling and installing the prototype
- Task 3:
  - Integrated calorimeter prototype.
  - Carry out the cosmic ray test of the prototype

Outcome

- Annual report

4. 项目组织管理机制:
Project Management Organization

Project management organization

- ## Risks and Response Measures
  - There may be some risks in the implementation of this project, but they can be effectively avoided by different kinds of methods:
    - Intermediate small-scale prototypes
    - Strengthening international communication/collaboration
  - Examples:
    - Precision of accelerator dipole magnet can be explored and achieved by means of small prototype
    - Technical limit of coating for bending vacuum box and Detector design errors can be effectively avoided through international communication and learning from the experience of others
    - Due to the installation accuracy of detector and the delay risk of calorimeter packaging process, automatic control system and automatic packaging scheme can be used to ensure the accuracy and progress.
    - Chip embargo/submission rules: problem can be managed by integrating into international collaboration (e.g. ATLAS)

Backup Slides

Information on previously received support

Type	Periods	Project name	Funds	PI
MOST National Key R&D Project	6/2016 - 6/2021	Pre-R&D of physics and key technologies related to Circular Electron-Positron Collider	36M RMB	Gao Yuanning
IHEP Innovation Project	1/2015 - 12/2018	R&D of physics simulation and key technologies of detectors of CEPC	6M RMB	Lou Xinchou
Other 10+ from NSFC …				

This project (2018.7-2023.6) is based on or continuing the study of those of the above, whose completion will be the basis of TDR and construction of CEPC.