

国家重点研发计划·项目实施方案汇报

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

Report from the 2021 Annual Meeting

所属专项：大科学装置前沿研究

项目负责人：João Guimarães da Costa

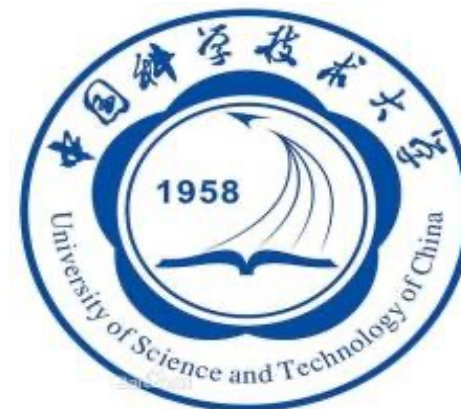
项目承担单位：中国科学院 高能物理研究所

May 12, 2021



中国科学院高能物理研究所

*Institute of High Energy Physics
Chinese Academy of Sciences*

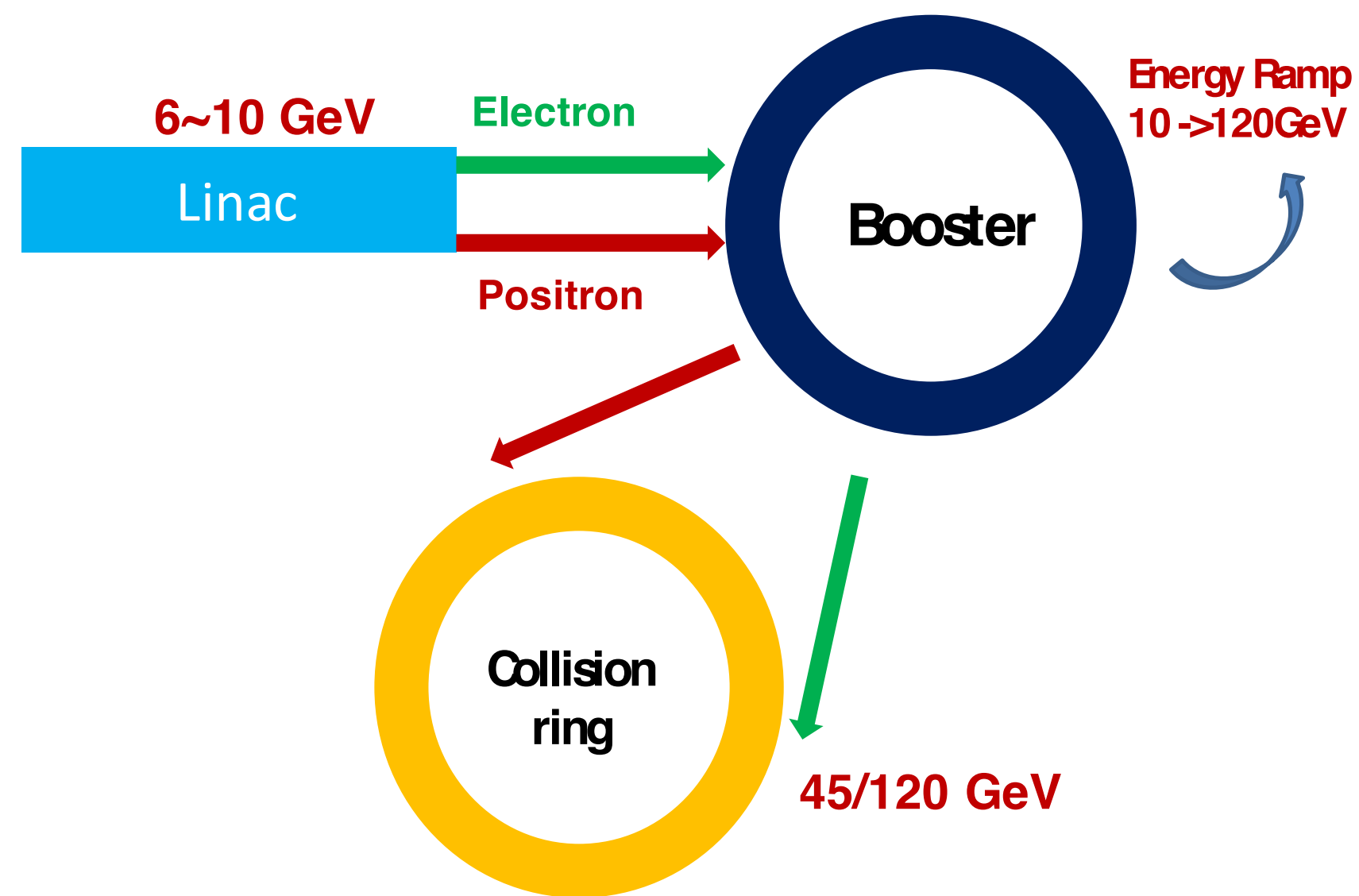


Main contents and objectives of the project

Advance research and validation on key technologies of accelerator and detector

Accelerator

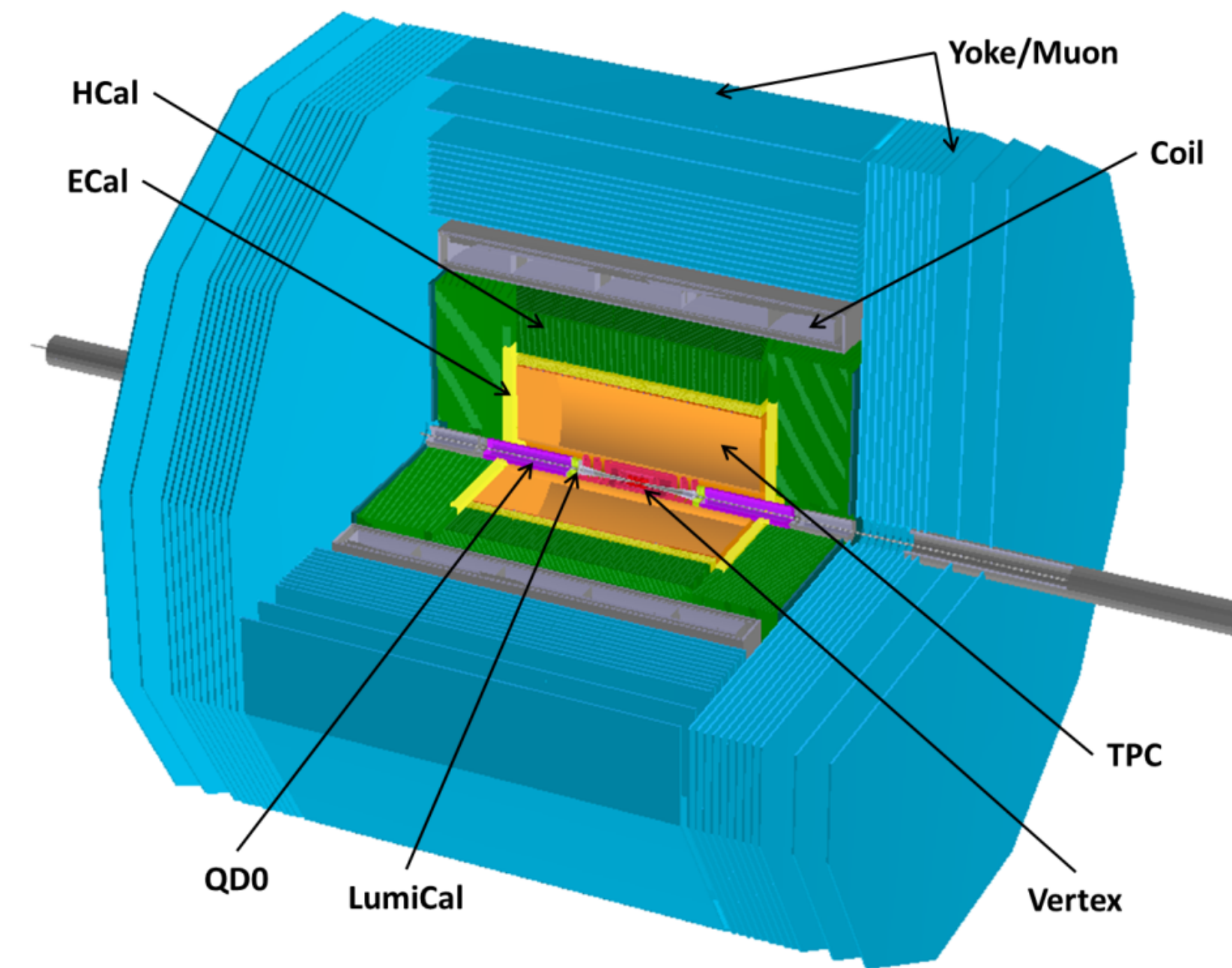
Aim for high-luminosity, low cost



课题1: Key accelerator technologies

Detector

High-precision, high-resolution to insure physics goals



课题2: Silicon pixel detector

课题3: Hadronic calorimeter

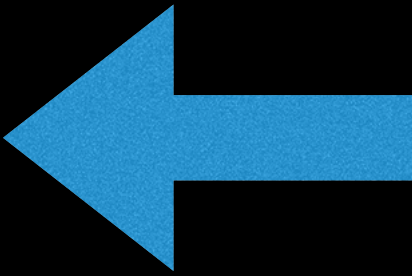
Build prototypes: Demonstrate technologies
Meet possible technical limitations

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, main ring vacuum system, electrostatic separator; Beam polarization design	974万
Task 2: Silicon Detector	João Guimarães da Costa IHEP	Prototype: silicon vertex 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

Major Project Milestones:

- Official starting date: May 1, 2018
- Official kick-off meeting: November 28, 2018
- First Annual Meeting: April 2019
- Midterm review: August 2020
- 2021 Annual review: April 2021 
- Final report: April 2023

Agenda for meeting

<https://indico.ihep.ac.cn/event/14211/>

Friday, April 23, 2021

- 08:00 - 18:00 Review Meeting
- 09:00 **Project Overview (30'+10')** 项目进展汇报 40'
Speaker: Joao Guimaraes Costa
- 09:40 **Task 1 Progress report** 课题一进展汇报: 高能环形正负电子对撞机加速器关键技术验证 50'
Speaker: Prof. 云龙 池 (高能所)
- 10:30 **Group photo and Coffee break** 30'
- 11:00 **Task 3 Progress Report** 课题三进展汇报: 成像型强子量能器技术验证 50'
Speaker: Dr. Jianbei Liu (University of Science and Technology of China)
- 12:00 **Lunch** 1h30'
- 13:30 **Task 2 Progress Report** 课题二进展汇报: 硅径迹探测器关键技术验证 50'
Speakers: Joao Guimaraes Costa, Prof. LIANG Zhijun
- 14:20 **Coffee Break** 20'
- 14:40 **Discussion (Project Team Only)** 1h0' (229)
- 14:40 **Discussion (Referees only)** 评委内部讨论与撰写评审意见 1h0'
- 15:40 **Close out session** 总结 2h20'
- 18:00 - 20:00 **Dinner**

Agenda for meeting

Detailed internal discussions happened
the two days beforehand

Wednesday, April 21, 2021	
09:30 - 12:00	Internal Meeting: HCAL Location: Multi-subject Building (229)
09:30	Overview 20' Speaker: Dr. Jianbei Liu (University of Science and Technology of China) Material: Slides
10:05	AHCAL design and optimization 20' Speaker: 禹坤 石 (中国科学技术大学) Material: Slides
10:25	Status of production and quality control of scintillator tiles 20' Speaker: Dr. Yanyun Duan (TDLI/SJTU) Material: Slides
10:45	Status of readout electronics and HBU development 20' Speaker: 仲弢 沈 (University of Science and Technology of China) Material: Slides
11:05	Discussion 55'

Lively discussions!

Dinner 2.5 hours later



Thursday, April 22, 2021	
09:00 - 12:00	Internal Meeting: Accelerator
09:15	Progress of Prototype Dipole Magnet for CEPC Booster (20'+5') 25' Speaker: Dr. Wen 康文 (Accelerator Centor, IHEP) Material: Slides
09:40	R&D progress of CEPC vacuum system (20'+5') 25' Speaker: MA Yongsheng (高能所) Material: Slides
10:05	Coffee break 20'
10:25	CEPC MOST Project Midterm Review Meeting-separator (20'+5') 25' Speaker: Mr. bin 陈斌 (高能所) Material: Slides
10:50	Polarization (20'+5') 25' Speaker: Dr. Zhe DUAN (高能所) Material: Slides
11:15	Discussion 45'
12:00 - 14:00	Lunch Box
14:00 - 17:30	Internal Meeting: Silicon
14:00	Overview of Silicon Task 20' Speaker: Prof. LIANG Zhijun Material: Paper Slides
14:35	Status of the TaichuPix chip for the high-rate CEPC Vertex Detector 25' Speaker: Mr. Wei WEI (高能所) Material: Slides
15:00	Detector optimization and software 15' Speaker: Hao Zeng (IHEP) Material: Slides
15:15	Mechanical Design of Silicon Vertex Detector Prototype 25' Speaker: Jinyu (高能所) Material: Slides
15:40	Coffee break 20'
16:00	Vertex detector geometry implementation 15' Speaker: Kewei Wu Material: Slides
16:15	Plan for flex PCB design 25' Speaker: Mr. 俊 胡 (高能所) Material: Slides
16:40	Plan for DAQ system development 25' Speaker: Hongyu ZHANG (EPC, IHEP, CAS, China) Material: Slides
17:05	Discussion 25'
17:30 - 19:00	Dinner

Project management organization

- **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 Janguang** (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)

第二年 (2019.5-2020.4) — Up to midterm

Main Milestones

- **Task 1: Accelerator**

- ✓ Manufacture the high-precision low-field dipole magnet small experimental prototype
- ✓ Finish engineering design of vacuum tube and bellows, and electrostatic separator
- ✓ Simulation program for storage ring polarization is developed

- **Task 2: Vertex Detector**

- ✓ Engineering designs of mechanics structure
- ✓ Second ASIC MPW submitted

- **Task 3: Calorimeter**

- ✓ Simulate whole HCAL prototype and develop software framework
- ✓ Carry out production of scintillator units
- ✓ Prototype absorber and supporting structure are designed

Delays in the implementation of the “tile production” due to re-optimization of the tile size, and COVID-19

Outcome

- Mid-term report

Midterm indicators achieved
for all tasks

第三年（2020.5-2021.4）

Main Milestones

- **Task 1: Accelerator** IHEP
 - Small 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: Vertex Detector
 - Mechanical structure completed
 - Second ASIC MPW tested
 - ASIC design optimized and completed
- Task 3: Calorimeter
 - Batch production of readout electronics, development of data acquisition system
 - Development of beam test platform and cosmic ray test platform

Outcome

- Annual report

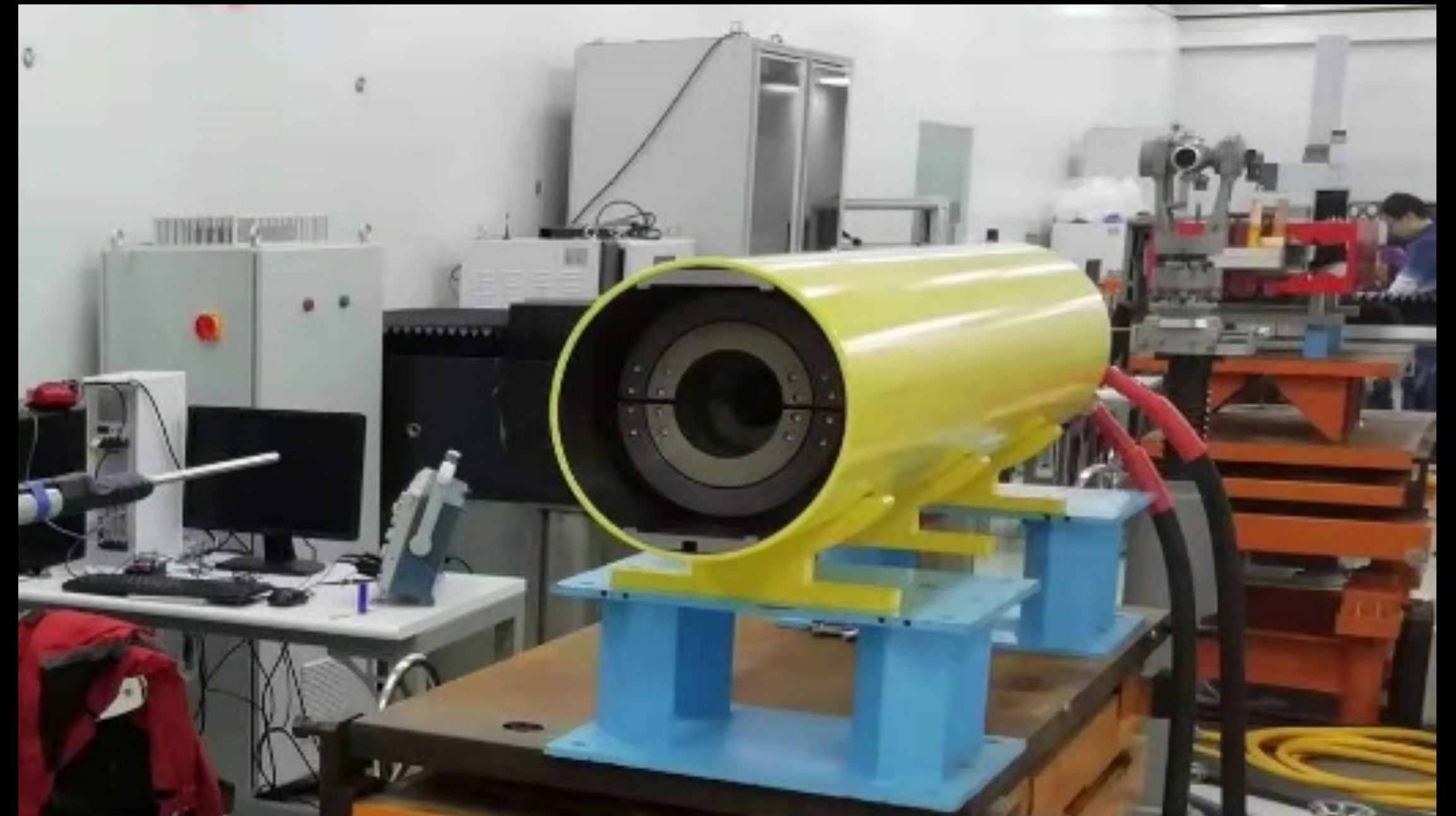
Task 1 - Mission 1: High precision low-field dipole magnet

Two small low-field dipole magnet prototypes built and tested

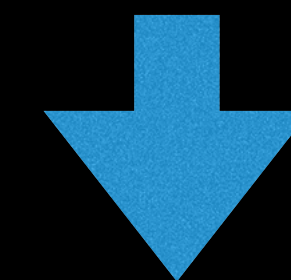
Iron core



CT Coil — no iron core



Better performance in testing

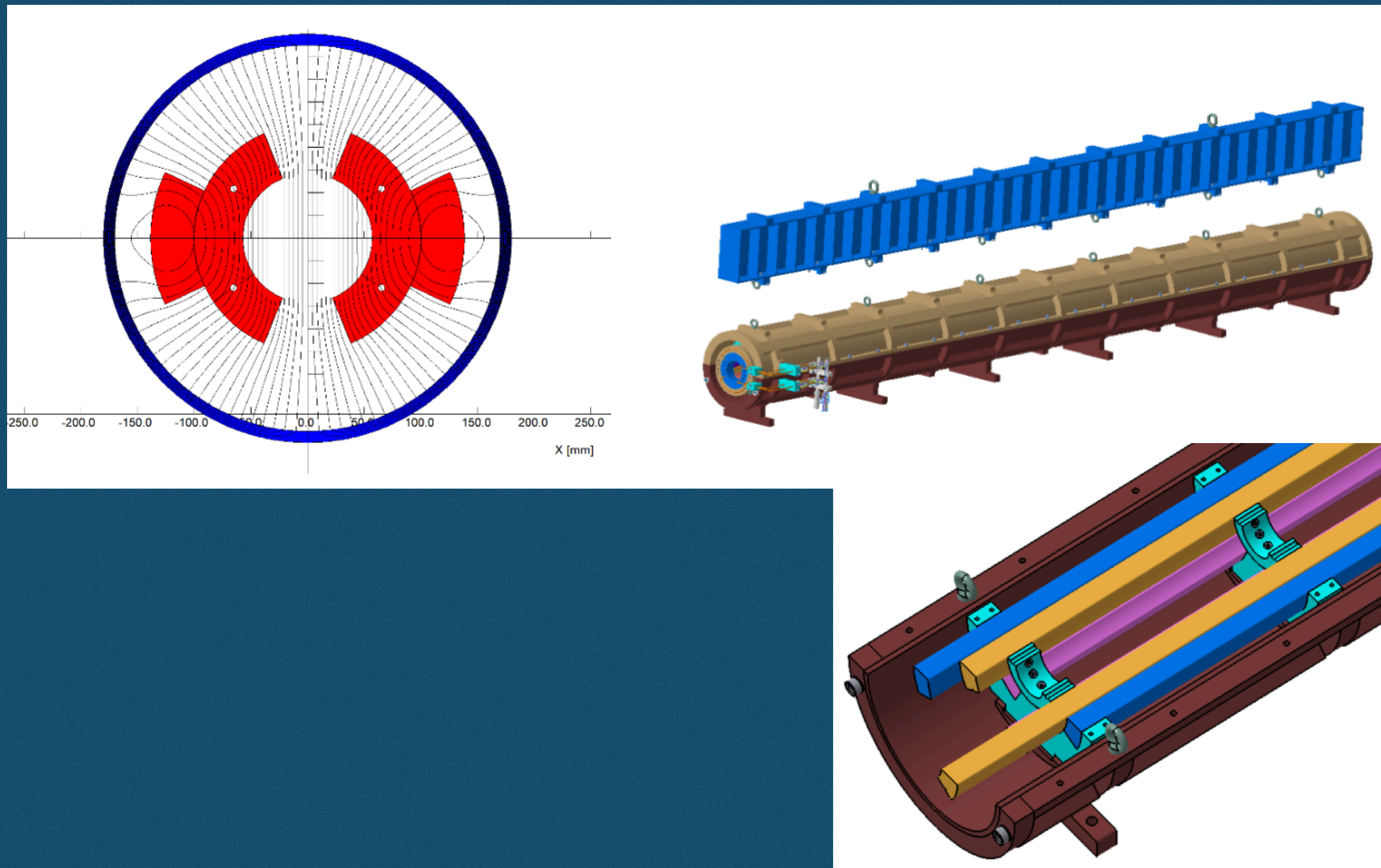


Design full size prototype

Task 1 - Mission 1: High precision low-field dipole magnet

Full-scale prototype CT coil dipole magnet

Design complete



Production already underway



2.5 m conductor bars

(ahead of schedule)

Task 1 - Mission 2: Main ring vacuum system

6-m long vacuum tubes



(meets engineering requirements)

RF shielding bellows



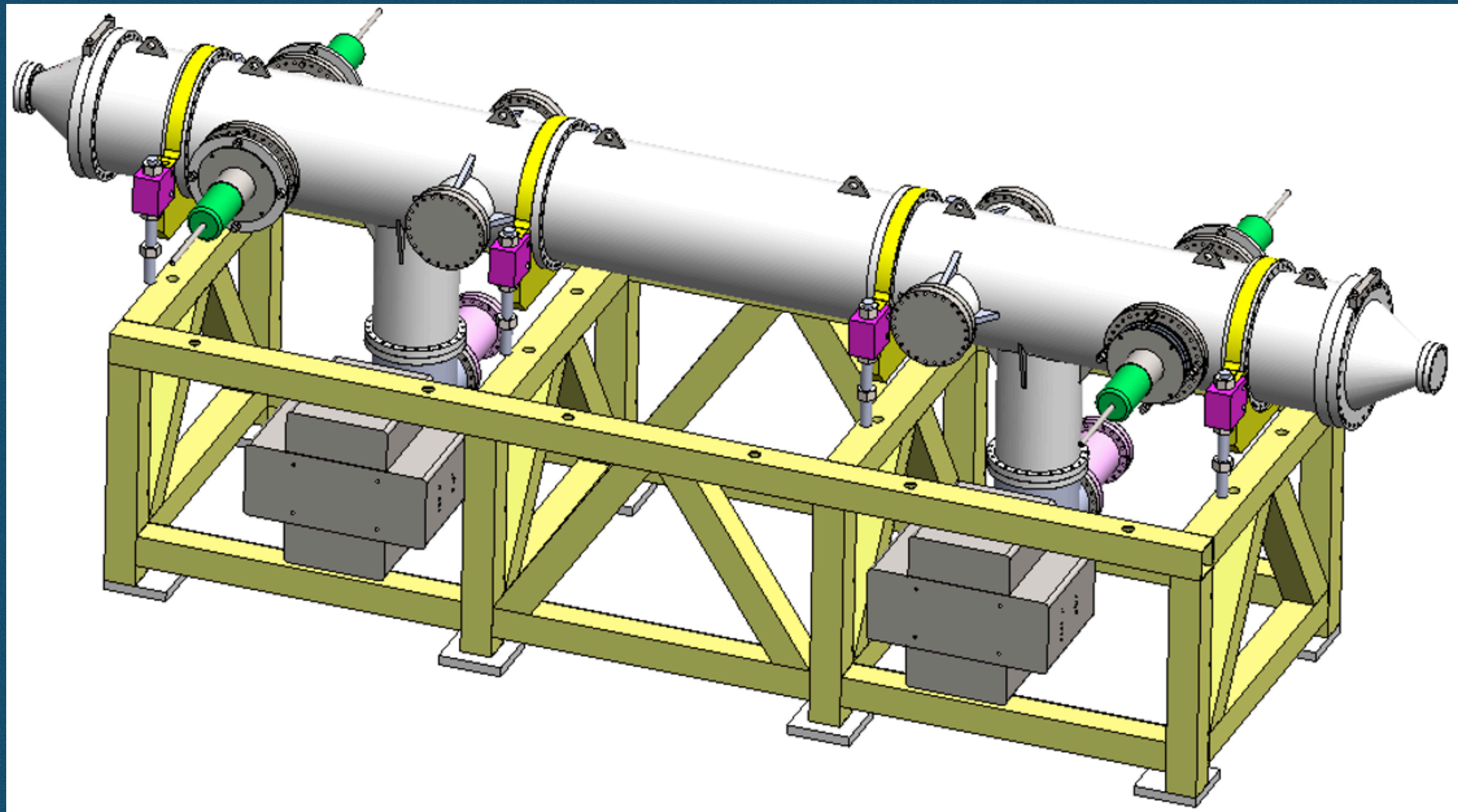
(finished - meets target)

NEG Coating setup (6 m tubes)



Task 1 - Mission 3: Electrostatic separator

Design was finished last year and prototype construction started ahead of schedule



Design improvements implemented this year



Testing platform built

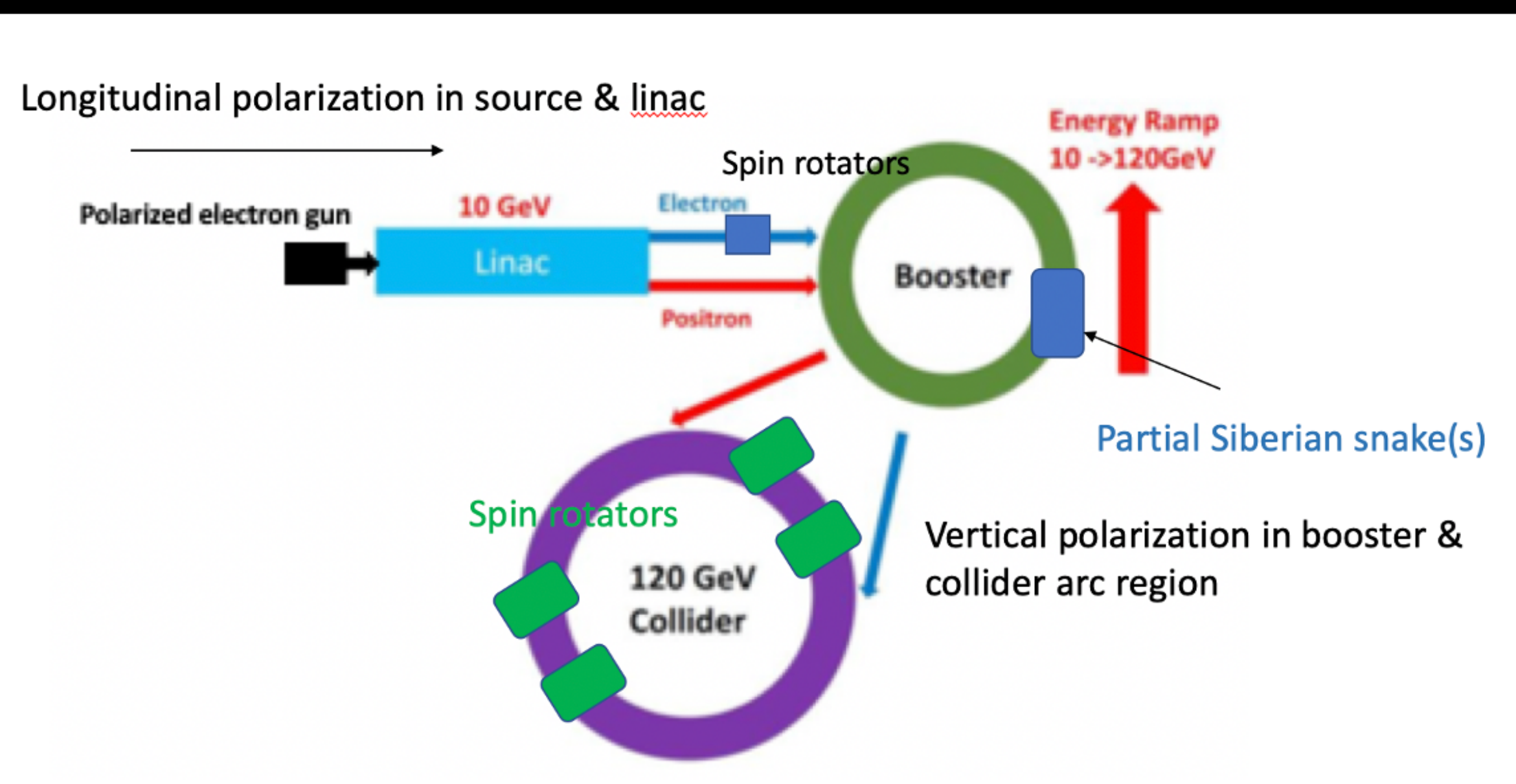


Separator to be shipped to IHEP soon

Task 1 - Mission 4: Beam Polarization at Z-pole

Goals

- Transverse polarization —> beam energy measurement:
 - A small fraction of **non-colliding bunches** with at least 5% vertical polarization in the arc, depolarize one-by-one to carry out resonant depolarization measurements
- Longitudinal polarization —> physics:
 - All **colliding bunches** have > 50% time-averaged longitudinal polarization at IPs



	Non-colliding bunches	Colliding bunches
Beam lifetime	20~100 hours, a high bunch current is not necessary	~2 hours
Injection frequency	Every 20~100 hours	Top-up injection, every ~ 10 seconds
Evolution of beam polarization	Exponential build-up Time scale ~ several hundred hours	Saw-tooth near the level of injected beam polarization
Usage	Resonant depolarization	Colliding beam experiments
Method to realize desired beam polarization	Use asymmetric wigglers to reduce self-polarization build-up time	Inject polarized beam

Simulation and design work on-going

第三年 (2020.5-2021.4)

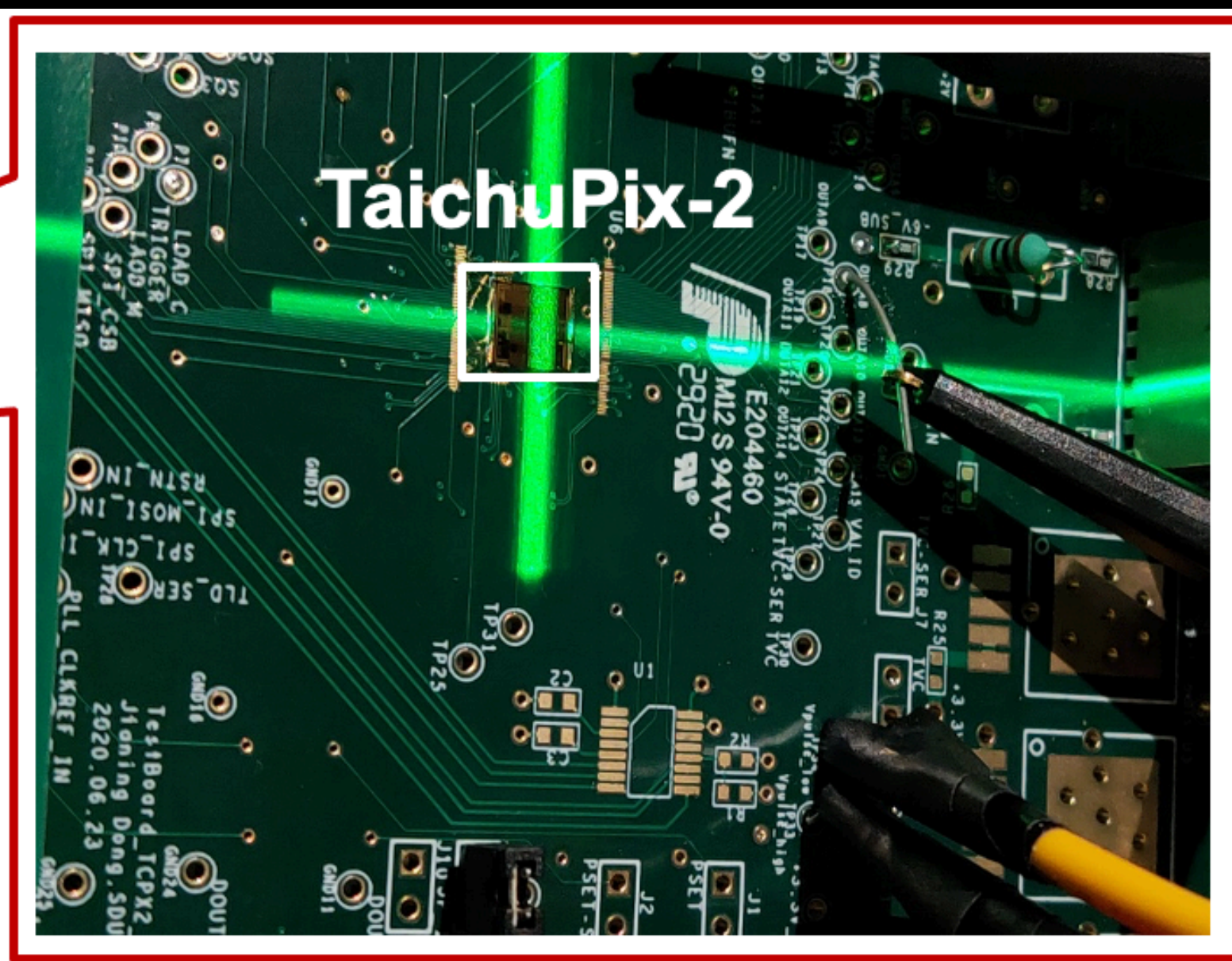
Main Milestones

- Task 1: Accelerator
 - ✓ Small 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: Vertex Detector
 - IHEP, SDU, NJU, NWPU, (IFAE & CCNU)
 - Mechanical structure completed
 - Second ASIC MPW tested
 - ASIC design optimized and completed
- Task 3: Calorimeter
 - Batch production of readout electronics, development of data acquisition system
 - Development of beam test platform and cosmic ray test platform

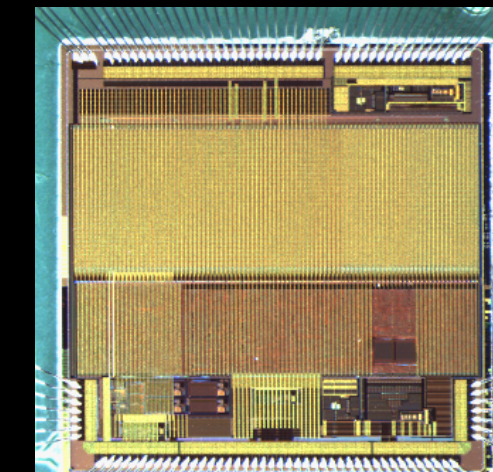
Outcome

- Annual report

Task 2: Vertex Detector Highlights



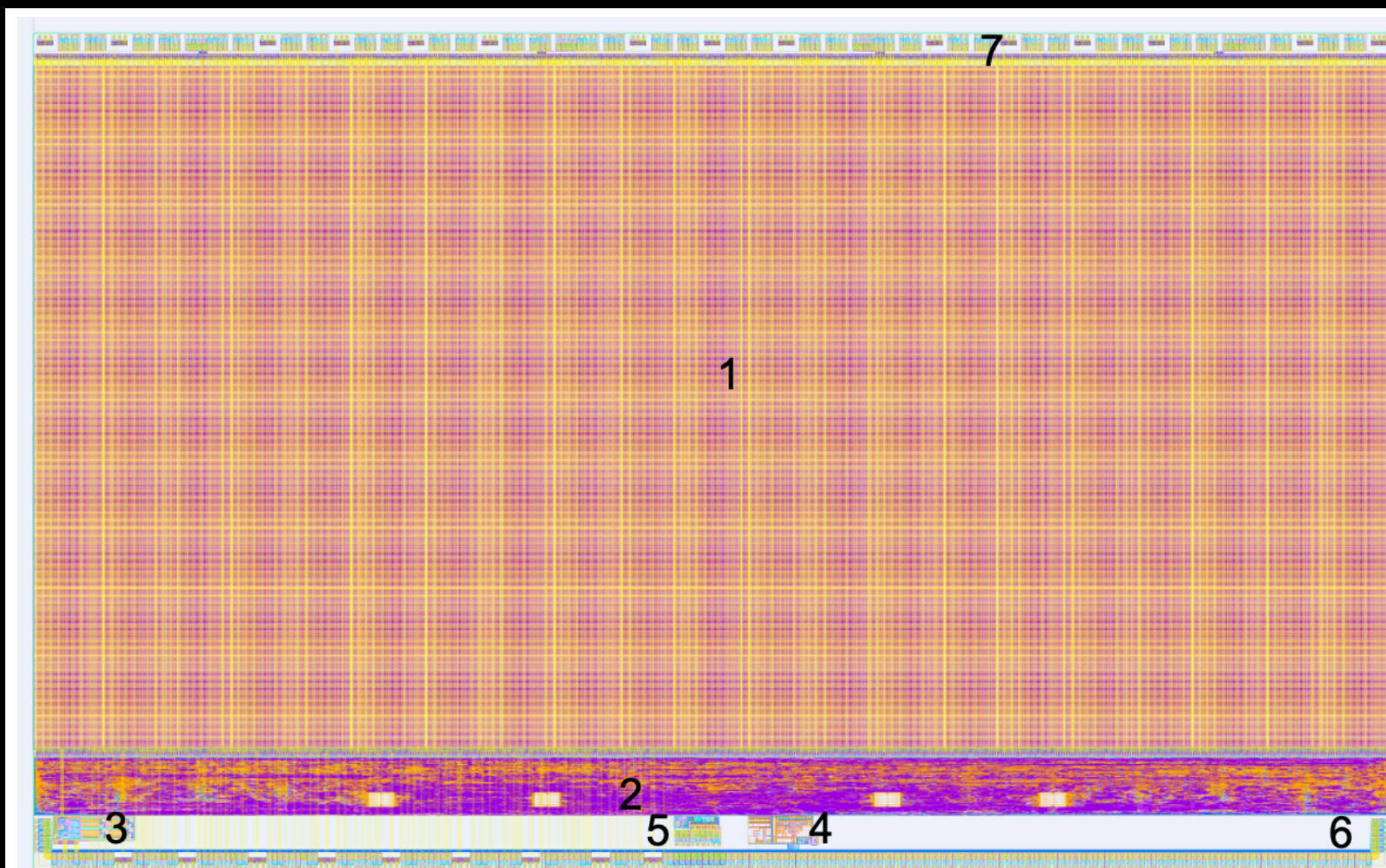
**TaichuPix-2 irradiated at IHEP
(6 keV X-ray)**



Pitch: $25/24 \times 25 \mu\text{m}^2$
Power: 100-150 mW/cm²
Size: 5 × 5 mm²

Good chip function and noise performance
up to **30 Mrad** TID

MOST project goals achieved



1. Pixel array
1024*512
2. Periphery
3. DAC & Bias
generation
4. Data interface
5. LDO (test
blocks)
6. Chip inter-
connection
features
7. Scribe-able top
power
connection
features

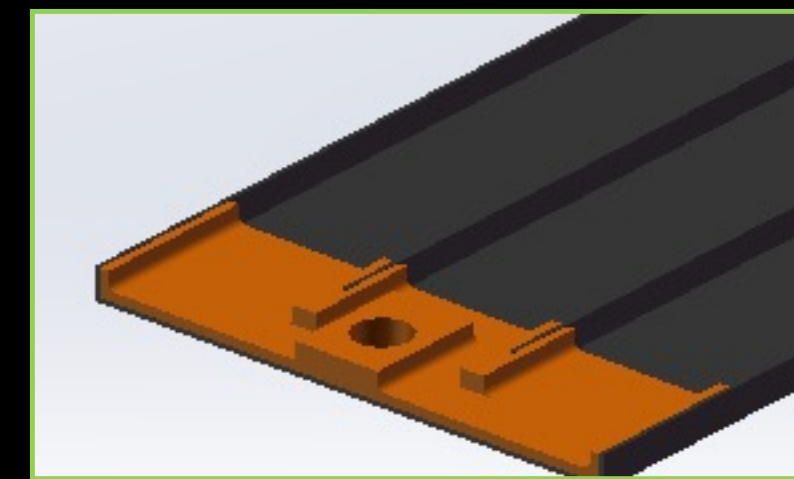
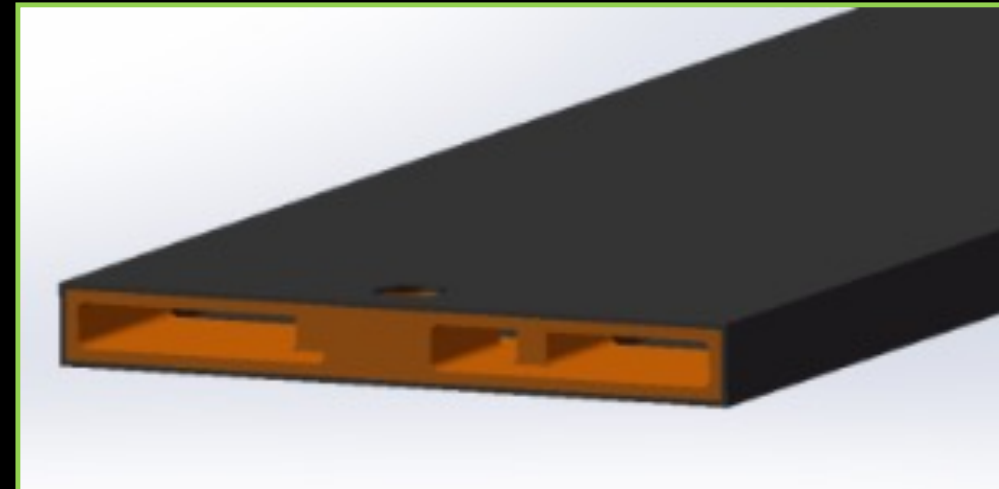
Full size chip ready to submit this month

Engineering run for Pixel Vertex
detector prototype

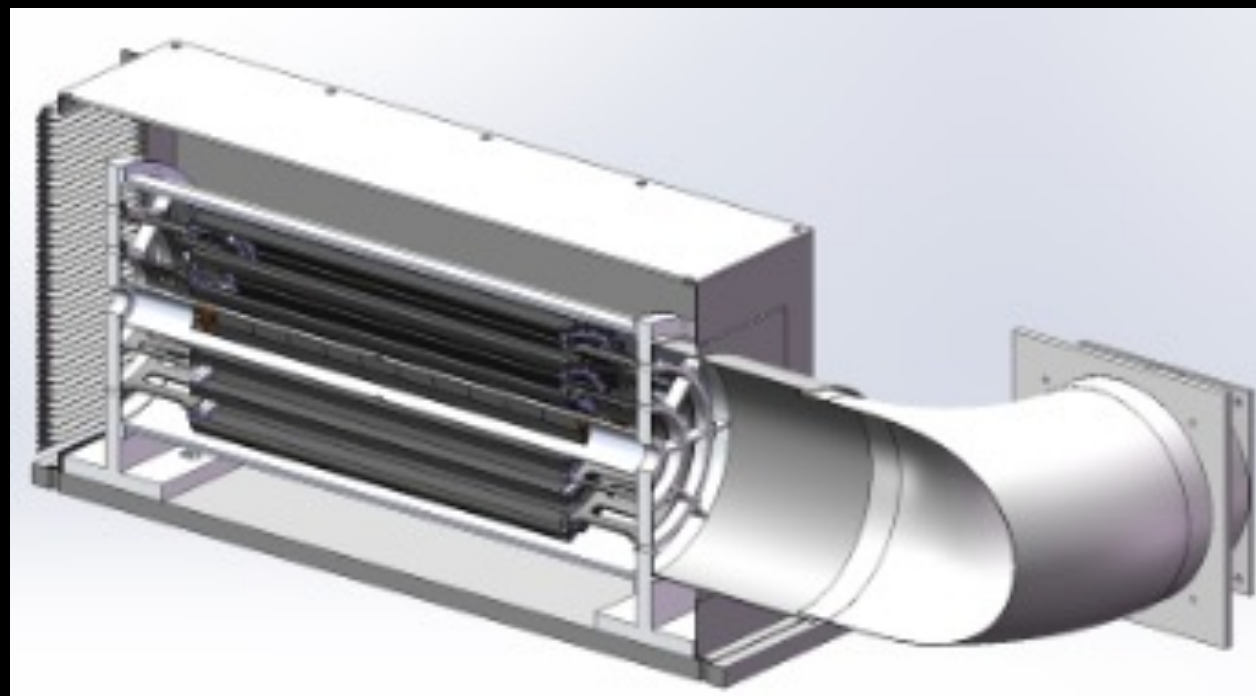
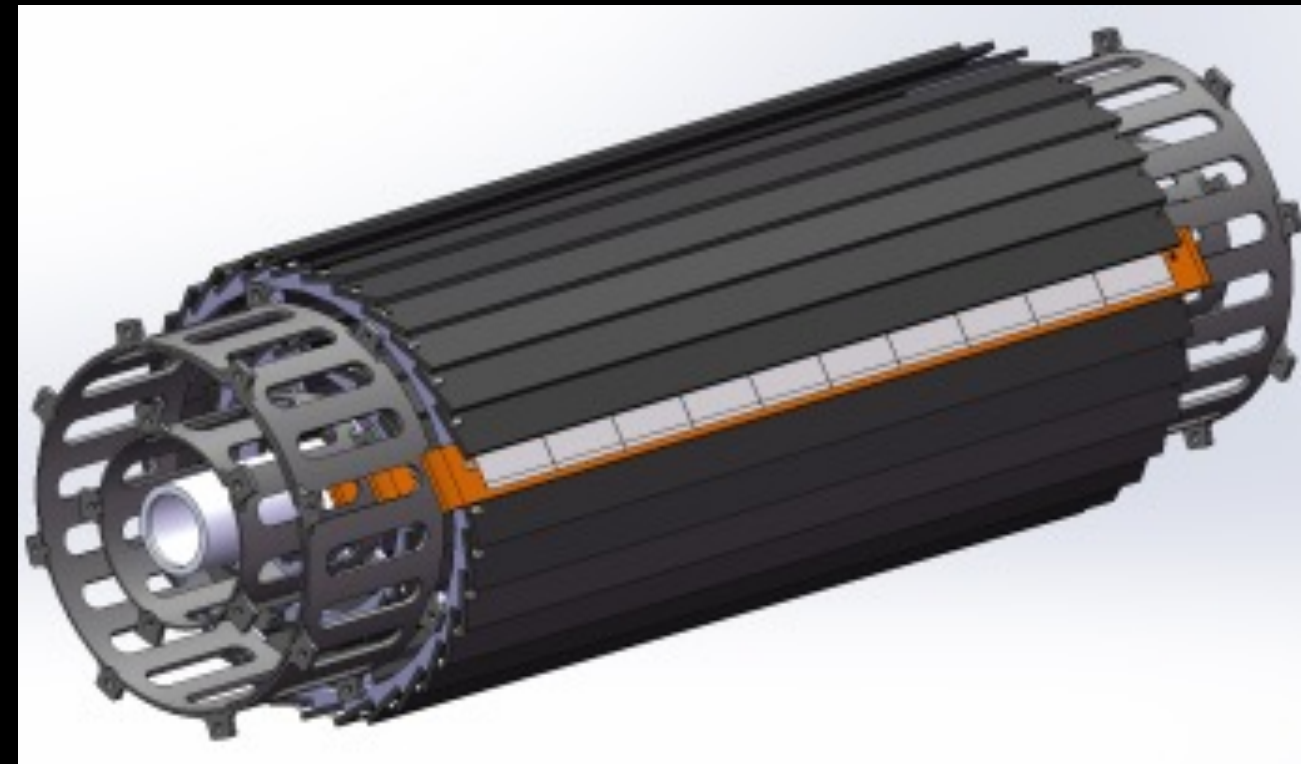
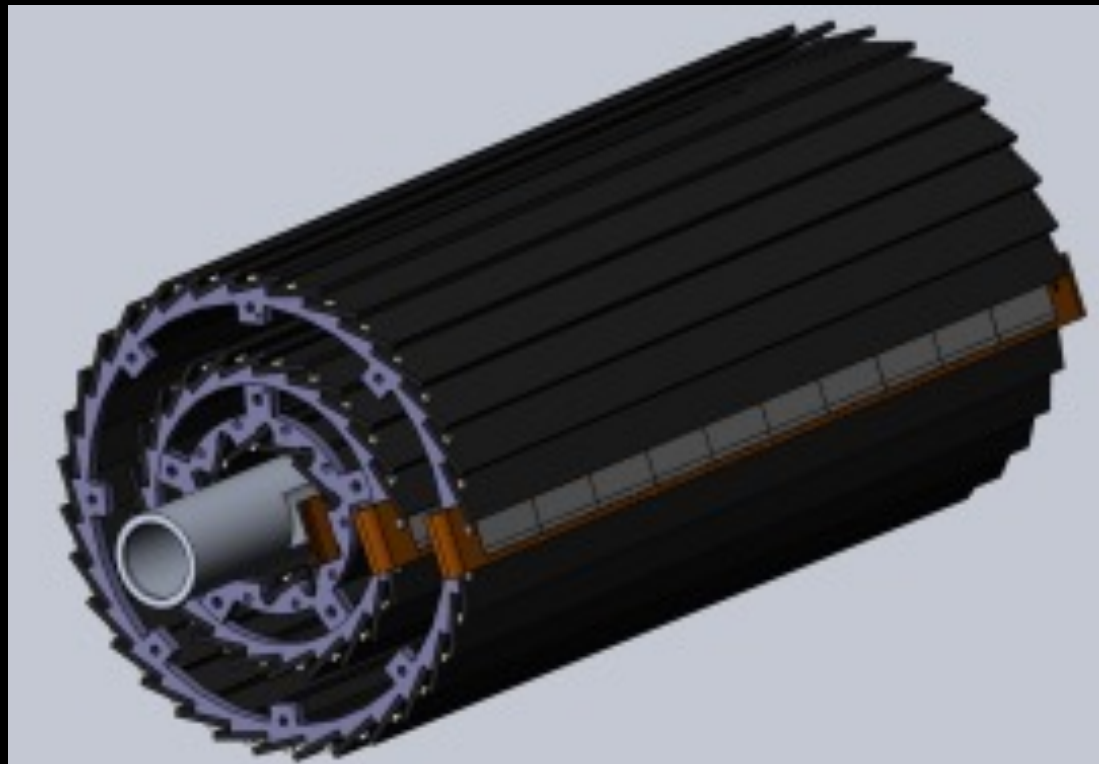
(ahead of schedule)

Task 2: Vertex Detector Highlights

The design model of ladder support

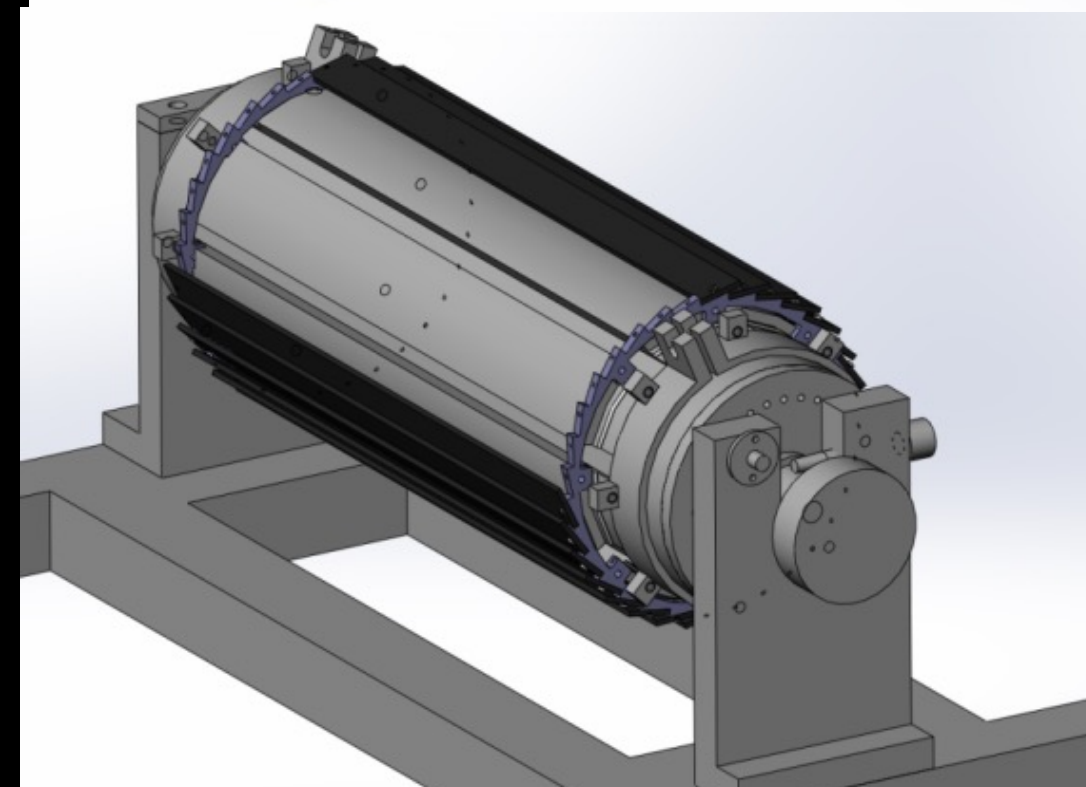
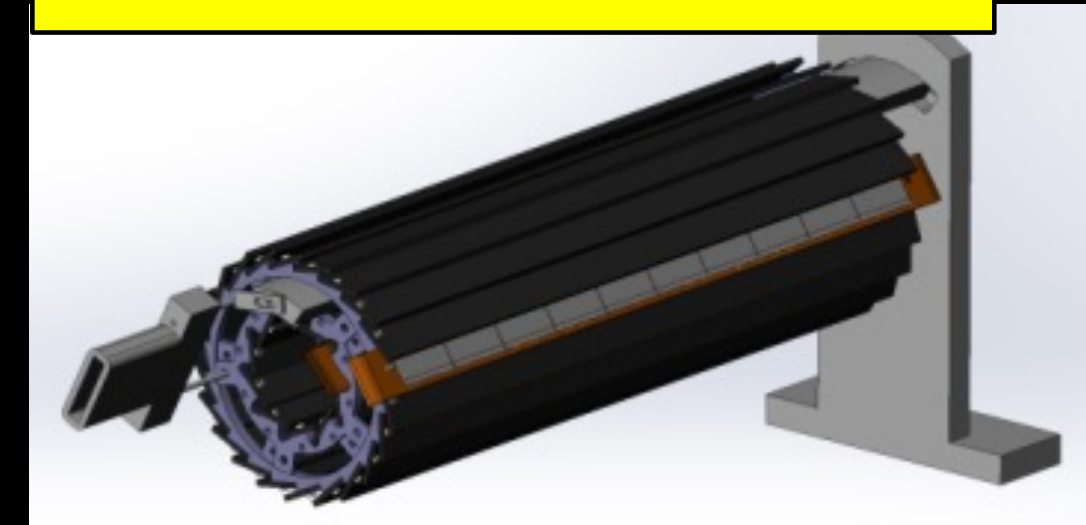


Vertex Detector Structure



Assembling Tooling

Inner and middle barrels combination and customized tool



第三年（2020.5-2021.4）

Main Milestones

- Task 1:
 - Small 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: USTC, IHEP, SJTU
 - Batch production of readout electronics, development of data acquisition system
 - Development of beam test platform and cosmic ray test platform

Outcome

- Annual report

Task 3: Calorimeter Highlights

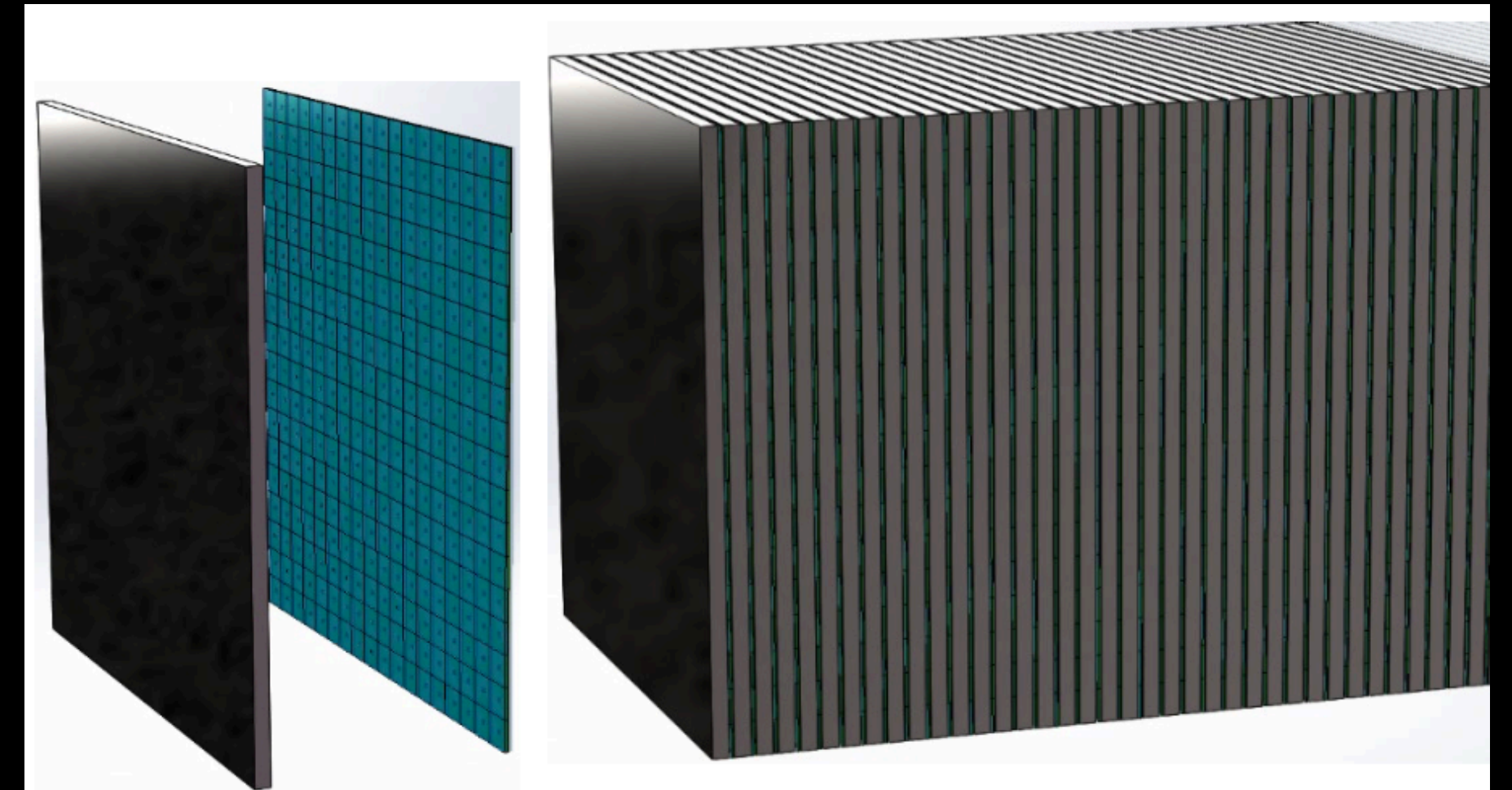
$$\text{Resolution: } \frac{60\%}{\sqrt{E(\text{GeV})}} \oplus 3\%$$

AHCAL Scintillator and SiPM

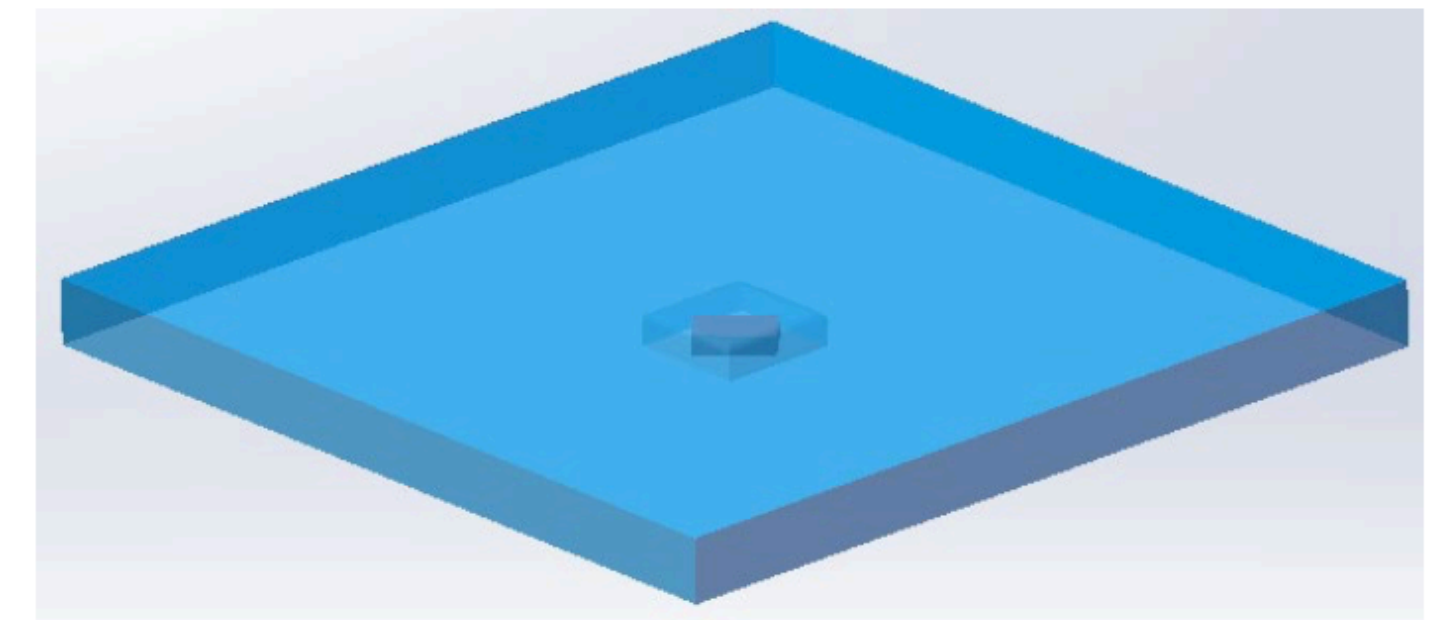
40 layers of 20 mm stainless steel
+ 3 mm scintillator
+ 2 mm PCB

Transverse size: $72 \times 72 \text{ cm}^2$

Length: 1.3 m



Single layer and detector part



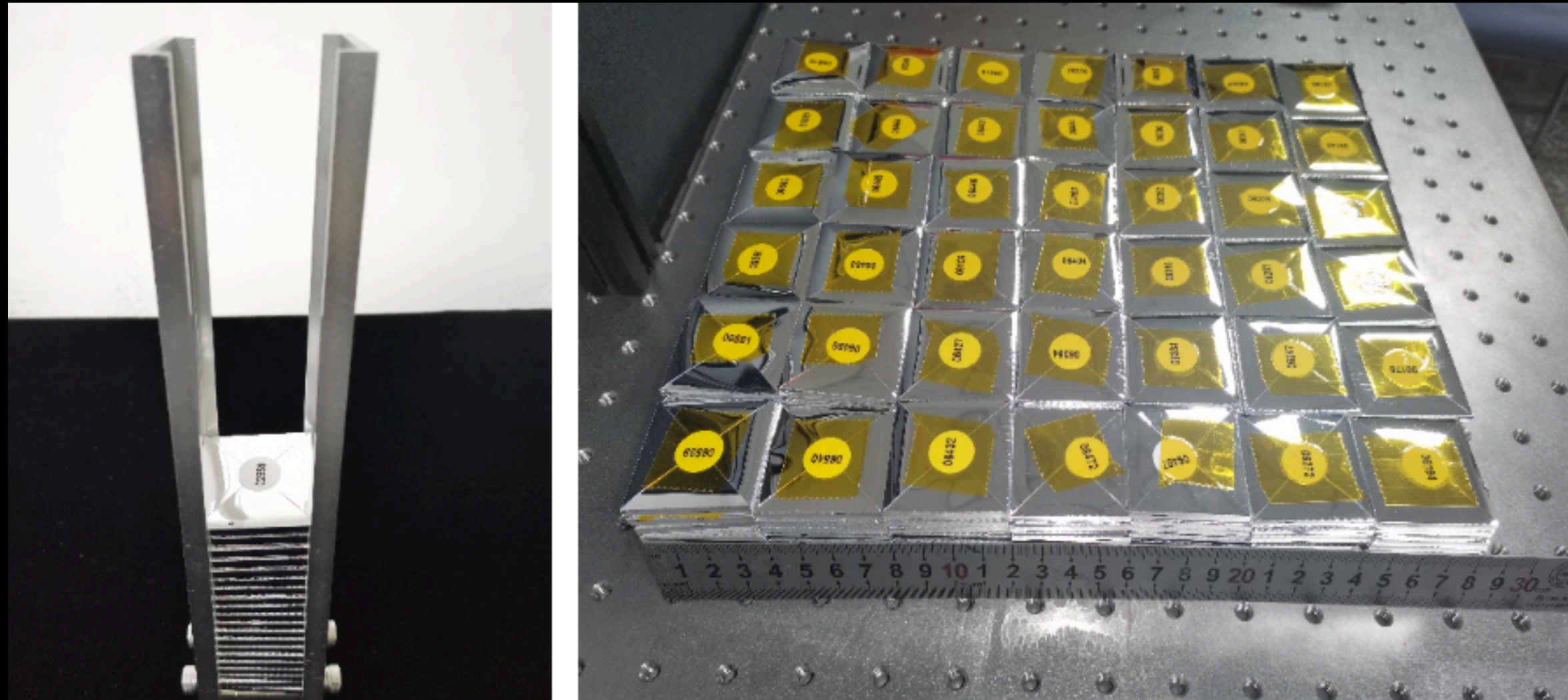
Cell size: $4 \times 4 \text{ cm}^2$

Task 3: Calorimeter Highlights

10000 scintillators have been produced using the injection molding technique

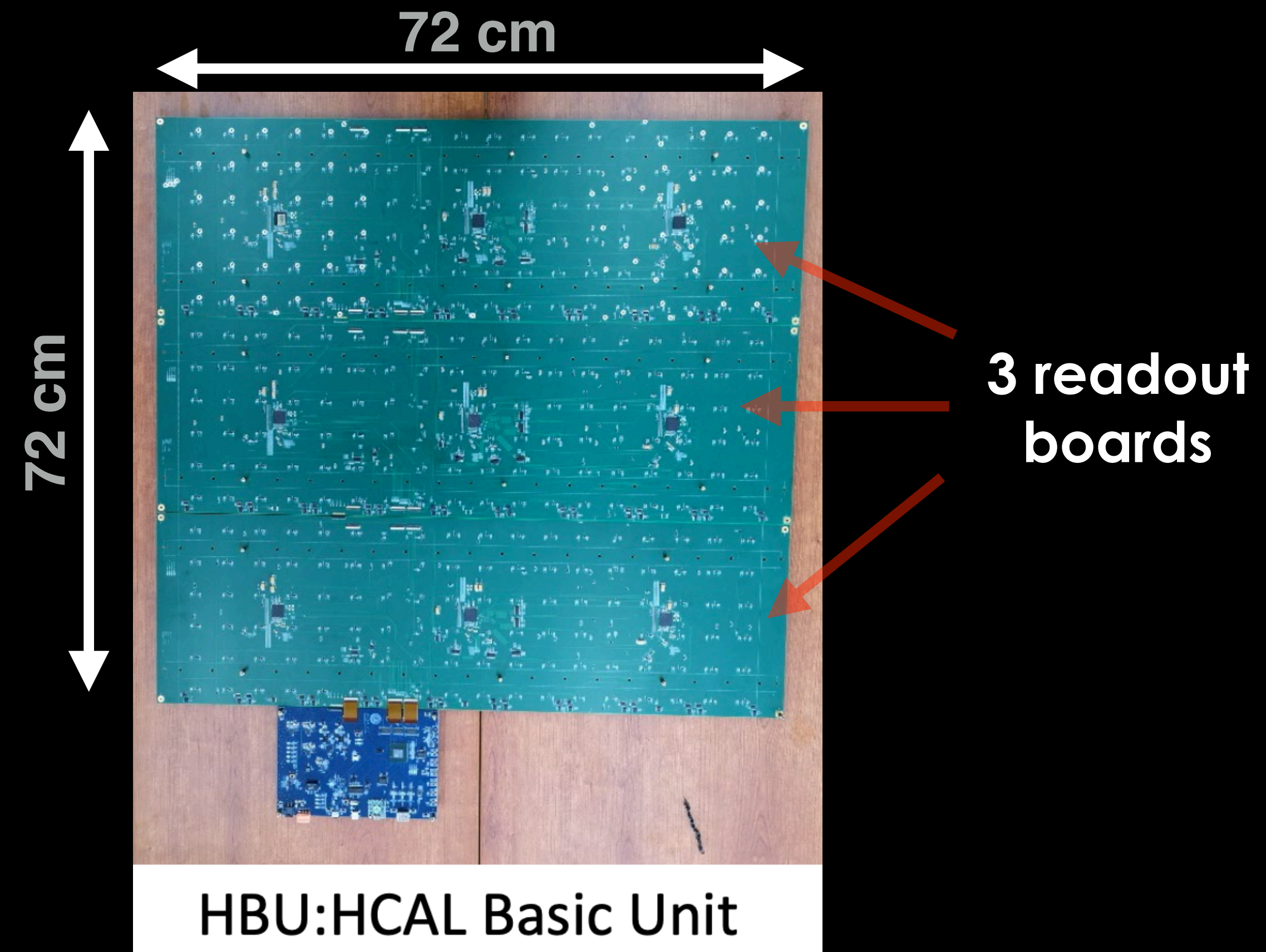
Light yield of each scintillator is about 40 p.e.,
tested with NDL-22-1313-15S

Automatic wrapping and labelling



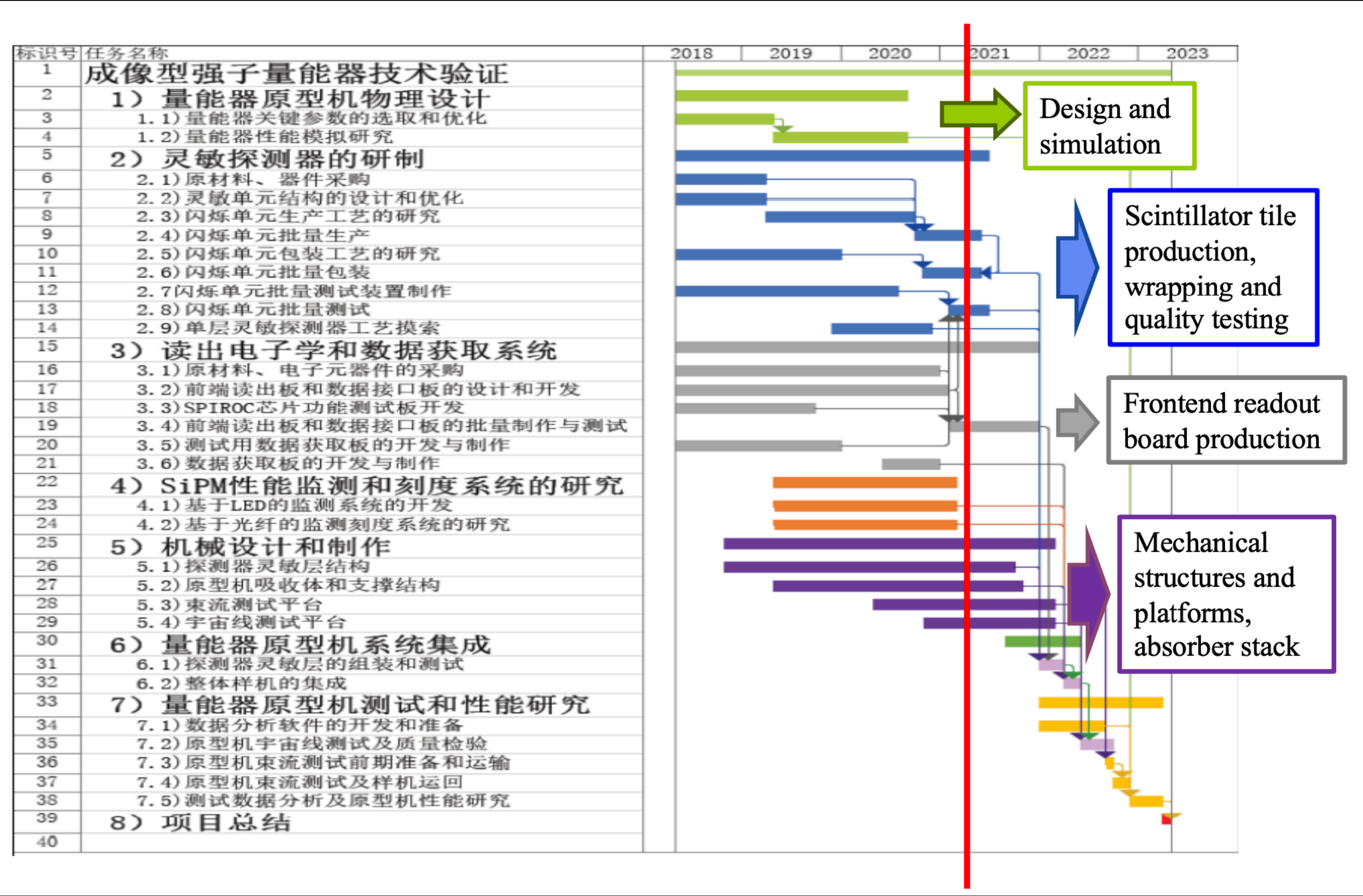
**3 batch testing platforms built
(USTC, SJTU, IHEP)**

**SPIROC chip packaged and available
Front-end readout board prototype built**



Mass production to start soon

Task 3: Calorimeter Highlights



- 5000 scintillator tiles still to be test (IHEP batch)
- Mechanical design of prototype needs help
- Not yet ready for mass production of electronics

Funding Allocation and Implementation

Project Funds Allocation

Implementation:

Direct fee	Task 1	Task 2	Task 3
by today	66%	60%	35%
Total	50%	34%	25%

Bulk of expenses to build and test prototypes still in the future

Planning

Future Integrated Plan (Microsoft Project)

by end 2021, complete:

- dipole magnet prototype
- vacuum tubes and RF bellows

by end 2022, complete:

- electrostatic separator
- polarization studies

by end 2021, complete:

- first chip engineering run produced
- manufacturing of detector support structure finished
- single ladder DAQ ready

early 2022, complete:

- prototype
- by end 2022, complete:
- prototype test beam

by end 2021, complete:

- batch production and wrapping of scintillator tiles
- batch production of front end electronics

early 2022, complete:

- prototype
- by end 2022, complete:
- prototype test beam

Task 1: Accelerator

Task 2: Vertex

Task 3: Calorimeter

Problems and Main Risks

- COVID-19 had significant impact on the calorimeter task schedule. **Still trying to recover the lost time.**
- Continuation of travel restrictions due to COVID-19 could impact tasks long term:
 - CEPC Beam Polarization design. **Trying to implement video-based collaboration.**
 - Longer timescale, beam testing of vertex and **calorimeter prototypes**
- Trade conflict with USA affected purchase of gantry for precision assembly of silicon vertex detector. **Purchase of gantry from chinese vendor completed but cause delays in preparation for assembly.**
- Funding for 2nd engineering run of vertex chip not available, and schedule very tight. **Skipped 3rd MPW, hoping that 1st engineering run chip works**
- **Access to international test beam facility**

Summary

- The project is progressing well towards completion
 - **Accelerator** and **Vertex** tasks meeting or exceeding expectations of work package
 - **Calorimeter** task still needs to accelerate production and design of prototype
- Impact due to COVID-19 partially recovered, but some delays persist.
 - Possible impact on the availability of beam test time
- Expenses are not uniform and are expected to ramp up when final prototypes are produced and paid for

Extra Slides

“大科学装置前沿研究”重点专项2018年度项目申报指南

3. 新一代粒子加速器和探测器关键技术预研

3.1 高能环形正负电子对撞机关键技术验证

Research content: Prototype Verification of Key Technologies and High Resolution Detection Technologies for Electron Positron Colliders

Assessment indicators:

Validation of key technologies for high energy circular electron positron accelerators.

Complete the prototype of the enhancer alternating two-pole low-field magnet. The magnetic field is from 31-620 Gs, the field uniformity is 5×10^{-4} ; Complete the prototype of bending vacuum chamber and RF shielded bellows,

the total leakage rate is less than 2×10^{-10} Torr • L/s; Complete the prototype of electron and positron beam electrostatic separator, the maximum working field strength is 2MV/m, field uniformity is (1‰) $10 \times 10 \text{ mm}^2$;

Complete the design of polarized beam collision in the Z energy region, beam polarization degree is larger than 50%, life time is larger than 60 minutes; Complete the prototype of polarization beam core device, spiral superconducting undulator.

Verification of High Resolution Detecting Technology on High Energy Accelerator. Complete the prototype of inner silicon track detector, verify the main design indicators through beam test, spatial resolution is 3-5 microns (μm);

Design a silicon detector with 1MRad Total ionization dose; Complete the original prototype of high granulated imaging type of HCAL, solving the key issues for process and test. Doing beam test to certify the main design conclusion.

3. 项目实施关键节点和具体实施计划:

Key Points and Project Implementation Plans

第三年（2020.5-2021.4）

Main Milestones

- **Task 1:**
 - **Small 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**

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

Task 1: Accelerator Plan

WBS	Chinese Name	Task Name	Duration	Start	Finish		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
							H2	H1	H2	H1	H2	H1	H2	H1	H2	H1	H2	H1	H2	H1	H2
1	高能环形成电子对撞机加速	Key technology verification of accelerator	1261 days	18/5/1	23/3/1																
1.1	CEPC高精度低场二极磁铁样机	CEPC high precision and low field dipole magnet prototype	1111 days	18/5/1	22/8/2																
1.1.1	小型实验样机	Miniature experimental prototype	568 days	18/5/1	20/7/2																
1.1.1.1	物理设计	Physical design	153 days	18/5/1	18/11/29																
1.1.1.2	工程机械设计	Construction machinery design	153 days	18/11/30	19/7/2																
1.1.1.3	加工制造	Processing and manufacturing	153 days	19/7/3	20/1/31																
1.1.1.4	实验验证	Experimental verification	109 days	20/2/3	20/7/2																
1.1.1.5	样机改进及测试	Prototype improvement and testing	66 days	20/3/3	20/6/2																
1.1.2	正式磁铁样机	Formal magnet prototype	543 days	20/7/3	22/8/2																
1.1.2.1	物理设计	Physical design	108 days	20/7/3	20/12/1																
1.1.2.2	工程机械设计	Construction machinery design	153 days	20/12/2	21/7/2																
1.1.2.3	加工制造	Processing and manufacturing	151 days	21/7/5	22/1/31																
1.1.2.4	实验研究	Experimental study	66 days	21/5/3	21/8/2																
1.1.2.5	样机改进	improve the prototype	88 days	21/8/3	21/12/2																
1.1.2.6	实验验证	Experimental verification	107 days	21/12/3	22/5/2																
1.1.2.7	测试验收	Acceptance testing	66 days	22/5/3	22/8/2																
1.2	真空系统	Vacuum system	1217 days	18/5/1	22/12/28																
1.2.1	真空盒、RF屏蔽波纹管、镀膜装置初步设计	Preliminary design of vacuum box, RF shielded bellows and coating device	220 days	18/5/1	19/3/4																
1.2.2	工程设计、招投标、签订技术合同	Engineering design, bidding and signing of technical contracts	220 days	19/3/5	20/1/6																
1.2.3	样机加工和制造	Prototype processing and manufacturing	220 days	20/1/7	20/11/9																
1.2.4	真空盒、RF屏蔽波纹管验收，真空盒内壁镀膜实验	Acceptance of vacuum box and RF shielded bellows, coating experiment on inner wall of vacuum box	220 days	20/11/10	21/9/13																
1.2.5	镀膜样品检测，抽速测试	Coating sample test, pumping speed test	220 days	21/9/14	22/7/18																
1.2.6	评审验收，资料归档	Review and acceptance, document filing	117 days	22/7/19	22/12/28																
1.3	静电分离器	Electrostatic separator	1261 days	18/5/1	23/3/1																
1.3.1	完成静电分离器参数计算	Complete the parameter calculation of electrostatic separator	200 days	18/5/1	19/2/4																
1.3.2	完成静电分离器束流阻抗分析	The beam impedance analysis of electrostatic separator is completed	240 days	18/7/10	19/6/10																
1.3.3	完成静电分离器的整体方案设计	Complete the overall scheme design of the electrostatic separator	190 days	19/6/11	20/3/2																
1.3.4	完成绝缘支撑件、高压馈电穿墙件设计	Complete the design of insulation support parts, high voltage feed through wall parts	220 days	19/4/30	20/3/2																
1.3.5	完成静电分离器各关键部件的机械设计及加工	Complete the mechanical design and processing of the key components of the electrostatic separator	140 days	20/5/4	20/11/13																
1.3.6	完成静电分离器整体组装	Complete the assembly of the electrostatic separator	20 days	20/11/16	20/12/11																
1.3.7	搭建测试平台，进行静电场初步高压老练	Build test platform for electrostatic field preliminary high voltage sophistication	140 days	20/12/14	21/6/25																
1.3.8	完成高阶模吸收器的设计及加工	Complete the design and manufacture of high order mode absorber	280 days	20/6/1	21/6/25																
1.3.9	进行冷却系统和高阶模吸收器的优化设计	Optimize the design of cooling system and high order mode absorber	210 days	21/8/16	22/6/3																
1.3.10	完成静电分离器高压老练和测试	Complete electrostatic separator high voltage sophistication and testing	210 days	22/2/3	22/11/23																
1.3.11	项目结题评审	Final project review	0 days	23/3/1	23/3/1																
1.4	Z能区极化束流的研究与设计	Study and Design of Z energy region polarized beam	1217 days	18/5/1	22/12/28																
1.4.1	基于共振退极化的精确能量测量	Accurate energy measurement based on resonance depolarization	1050 days	18/5/1	22/5/9																
1.4.1.1	极化扭摆器的参数选择	Parameter selection of polarized torsional pendulum	150 days	18/5/1	18/11/26																
1.4.1.2	精确能量测量的工作模式	A mode of operation for accurate energy measurement	178 days	18/11/27	19/8/1																
1.4.1.3	精确能量测量的误差分析	Error analysis for accurate energy measurements	500 days	20/6/9	22/5/9																
1.4.2	极化束流对撞	Polarized beam collisions	1108 days	18/5/1	22/7/28																
1.4.2.1	极化束流的产生和保持	Generation and retention of polarized beams	1108 days	18/5/1	22/7/28																
1.4.2.1.1	注入器设计	Injector design	861 days	18/5/1	21/8/17																
1.4.2.1.2	束流极化度保持数值模拟	Beam polarization is simulated numerically	247 days	21/8/18	22/7/28																
1.4.2.2	纵向极化束流对撞	Longitudinally polarized beam collisions	1100 days	18/5/1	22/7/18																
1.4.2.2.1	自旋旋转器参数选择与设计	Selection and design of spin rotator parameters	400 days	18/5/1	19/11/11																
1.4.2.2.2	储存环磁聚焦结构设计与优化	Design and optimization of storage ring magnetic focusing structure	700 days	19/11/12	22/7/18																
1.4.3	项目总结	Project summary	117 days	22/7/19	22/12/28																
1.4.3.1	撰写极化束流运行的物理设计报告	Write the physical design report of the polarized beam operation	117 days	22/7/19	22/12/28																
1.4.3.2	同行评议和项目验收	Peer review and project acceptance	0 days	22/12/28	22/12/28																

Task 2: Vertex Detector Prototype Plan

WBS	Chinese Name	Task Name	Duration	Start	Finish		2018		2019		2020		2021		2022		2023		2024		2025		2026	
						H2	H1	H2	H1	H2	H1	H2	H1	H2	H1	H2	H1	H2	H1	H2	H1	H2	H1	H2
2	硅径迹探测器关键技术验证	Key technology verification of silicon track detector	1261 days	18/5/1	23/2/28																			
2.1	力学支撑结构	Mechanical support structure	934 days	18/5/1	21/11/26																			
2.1.1	探测器模块几何排布优化	Layout Optimization	436 days	18/5/1	19/12/31																			
2.1.2	探测器模块支撑结构初步设计	Preliminary design of ladder supporting structure	130 days	18/5/1	18/10/29																			
2.1.3	探测器整机支撑结构初步设计	Preliminary design of detector supporting structure	260 days	18/10/30	19/10/28																			
2.1.4	制造模块支撑结构样品	Production of prototype of ladder support	87 days	20/12/31	21/4/30																			
2.1.5	探测器模块支撑结构最终设计	Final design of ladder supporting structure	43 days	21/5/3	21/6/30																			
2.1.6	探测器整机支撑结构最终设计和工程图	Final design of detector supporting structure and engineering plot drawing	416 days	19/10/29	21/6/1																			
2.1.7	制造探测器整机支撑结构	Manufacture supporting structure of detector	128 days	21/6/2	21/11/26																			
2.1.8	完成所有力学支撑结构的研制	Complete the Manufacture of all mechanical support structures	0 days	21/11/26	21/11/26																			
2.2	传感器	The sensor	919 days	18/5/1	21/11/5																			
2.2.1	传感器像素内的电子学设计，抗辐照元件设计	Electronics design in sensor pixel, design of anti - irradiation element	170 days	18/5/1	18/12/24																			
2.2.2	外围数字电路、触发、时钟与电源等模块设计，与芯片抗辐照性能模拟	Peripheral digital circuit, trigger, clock and power supply ladder design, and chip anti-radiation performance simulation	261 days	18/5/1	19/4/30																			
2.2.3	第一次多项目晶圆（MPW）流片	1st MPW	100 days	19/6/17	19/11/1																			
2.2.4	第二次多项目晶圆（MPW）流片	2nd MPW	90 days	20/2/18	20/6/22																			
2.2.5	整合全功能的小面积芯片设计	Integration of fully functional small area chip design	190 days	19/5/1	20/1/21																			
2.2.6	第三次多项目晶圆（MPW）流片	3rd MPW	108 days	21/1/1	21/6/1																			
2.2.7	设计大面积，全功能的传感器芯片	Design large area, full function sensor chip	328 days	20/5/13	21/8/13																			
2.2.8	第一次工程批硅晶圆加工	First engineering batch silicon wafer process	60 days	21/8/16	21/11/5																			
2.3	读出电子学与数据获取系统	Readout electronix and data acquisition system	1066 days	18/5/1	22/5/31																			
2.3.1	为初次MPW的芯片研制前端电路板	Development of the front end circuit board for the initial MPW chip	261 days	18/5/1	19/4/30																			
2.3.2	研制单个传感器芯片的数据获取系统	Development of data acquisition system for a single sensor chip	220 days	19/5/1	20/3/3																			
2.3.3	ladder的读出电子学	ladder readout electronic	218 days	20/8/31	21/6/30																			
2.3.4	研制单个探测器模块的数据获取系统	Development of data acquisition system for a single detector ladder	472 days	20/3/12	21/12/31																			
2.3.5	原型机的读出电子学	Prototype readout electronic	132 days	21/7/1	21/12/31																			
2.3.6	研制探测器原型机的数据获取系统	Development of data acquisition system for the prototype detector	107 days	22/1/3	22/5/31																			
2.4	探测器原型机整体设计与组装	The overall design and assembly of the prototype	1066 days	18/5/1	22/5/31																			
2.4.1	制定探测器模块的组装流程	Develop the assembly process of detector ladder	260 days	18/5/1	19/4/29																			
2.4.2	制定探测器原型机的组装流程，开发自动组装系统	Develop the assembly process of detector prototype and develop the automatic assembly system	430 days	19/4/30	20/12/21																			
2.4.3	探测模块模型试制	detector ladder trail production	66 days	21/4/30	21/7/30																			
2.4.4	组装与调试首批探测器模块	Assemble and test the first detector ladder	38 days	21/11/24	22/1/14																			
2.4.5	组装与测试探测器模块	Assemble and test the rest of detector ladder	75 days	22/1/17	22/4/29																			
2.4.6	组装与调试探测器原型机	Assemble and debug detector prototype	22 days	22/5/2	22/5/31																			
2.4.7	完成探测器原型机的组装调试	Complete the assembly and debugging of detector prototype	0 days	22/5/31	22/5/31																			
2.5	测试与数据分析	Test and data analysis	1086 days	19/1/1	23/2/28																			
2.5.1	对第一次MPW芯片做测试	Test 1st MPW chip	157 days	19/1/14	20/6/9																			
2.5.2	对第二次MPW的芯片做测试	Test the second MPW chip	93 days	20/8/4	20/12/10																			
2.5.3	对第三次MPW的芯片做测试	Test the third MPW chip	53 days	21/6/2	21/8/13																			
2.5.4	对工程批芯片做测试	Test engineering chip	12 days	21/11/8	21/11/23																			
2.5.5	束流测试与数据分析	Beam testing and data analysis	1086 days	19/1/1	23/2/28																			
2.5.5.1	束流测试模拟、重建和分析软件开发	development of the simulaiton, reconstruction and analysis software	784 days	19/1/1	21/12/31																			
2.5.5.1.1	模拟软件开发	development of the simulaiton software	261 days	19/1/1	19/12/31																			
2.5.5.1.2	重建软件开发	development of the reconstruction software	784 days	19/1/1	21/12/31																			
2.5.5.2	分析软件开发	development of the analysis software	784 days	19/1/1	21/12/31																			
2.5.5.3	束流测试实验	Beam test experiment	60 days	22/6/1	22/8/23																			
2.5.5.4	数据分析	The data analysis	85 days	22/8/24	22/12/20																			
2.5.5.5	发表测试结果，撰写终期报告	Publish test results and write final report	50 days	22/12/21	23/2/28																			
2.5.6	完成项目终期报告	Complete the final project report	0 days	23/2/28	23/2/28																			

Task 3: Calorimeter Prototype Plan

WBS	Chinese Name	Task Name	Duration	Start	Finish	<																															
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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 and 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	高精度低场二极磁铁 Dipole Magnet	☐ 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 ☒ 加工工艺 ☐ 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和测试报告
	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 ☒ 加工工艺 ☐ 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 镀膜 Vacuum pipe	☐专利 ☒论文 ☐ 其他						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			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
	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@ $\pm 60\text{kV}$ 工作 电压	完成静电分 离器的初步 设计, 以实 现: $2\text{MV/m@}\pm 1$ 10kV 工作 电压的电场 强度要求	$2\text{MV/m@}\pm 1$ 10kV 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
CEPC 在 Z 能区极化束流运行的整体物理设计 Polarization	☐ 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究和验证	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

研制出硅径迹探测器原型机 Silicon Detector	☐ 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 $60\%/\sqrt{(E/G\text{ eV})\oplus 3\%(10\text{ GeV}<E<80\text{ GeV})}$	$60\%/\sqrt{(E/G\text{ eV})\oplus 3\%(10\text{ GeV}<E<80\text{ GeV})}$	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 $3\%(10\text{ GeV}<E<80\text{ GeV})$	$3\%(10\text{ GeV}<E<80\text{ GeV})$	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。

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"