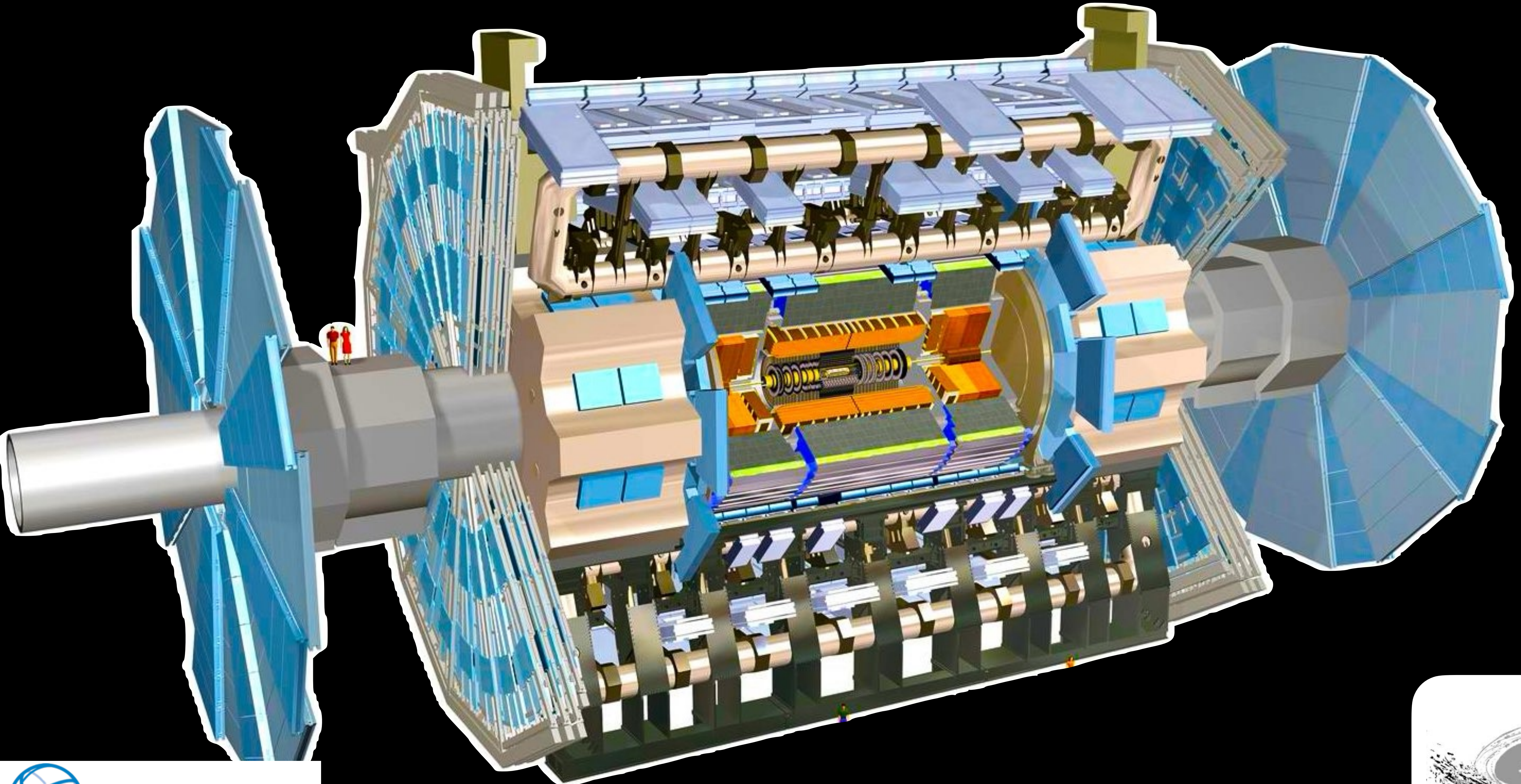
2023年国家重点研发计划“大科学装置前沿研究”

ATLAS 探测器升级

项目实施方案汇报



汇报人:

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中国科学院高能物理研究所

课题 1: 梁志均 (Liang Zhijun)
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中国科学技术大学

2024年07月05日

ATLAS EXPERIMENT

Requirement of Kick-off Meeting

HTRDC 高技术研究发展中心

四、Project Management Workflow

- **Kick-off**
- Annual Report
- Annual Budget Enforcement
- Mid-term Assessment
- Project Adjustment
- Project Check and Acceptance
- Achievement Management

Project Kick-off

Kick-off Meeting:

- Clarify the scientific goal of the project
- Specify, arrange the research tasks, clarify the responsibility of each task
- Establish project internal management system: project and funding management, internal academic communication, data sharing mechanism, out-reach methods
- Establish the project experts panel
- Set up the project management office
- Work bulletin and project briefing system
- Preparation of the project organization implementation plan

Report Outline (报告提纲)

1. Project Overview (项目概要)

2. Project (Task) Arrangement and Main Research Work (项目任务（课题）分解和主要研究工作)

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

4. Project Organization and Management (项目组织管理机制)

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

Guidance:“大科学装置前沿研究”重点专项2023年度项目申报指南

1. 粒子物理

1.3. ATLAS探测器升级 （共性关键技术）

研究内容:

按照与 ATLAS 合作协议规定，完成硅径迹探测 器、缪子谱仪和高颗粒度时间探测器相关研发、制造和安装等工 作。针对 LHC 高能量、高亮度的升级，改造 ATLAS 实验的粒子 探测器系统，开展相关探测器研制、建造和运行,提升 ATLAS 实 验对物理过程的灵敏度。

主要包括:

硅径迹探测器模块建造，径 迹探测器系统集成和运行;缪子谱仪阻性板探测器及相关电子学的研制和运行;高颗粒度时间探测器研发和建造;新一代有时间 信息的硅像素探测器的研发。

考核指标:硅微条径迹探测器空间分辨率达到 25 微米。阻性板室探测器:计数率达 1 kHz/cm2，探测效率高于 95%，时间分 辨率好于 1 ns。高颗粒度时间探测器:研发硅传感器、前端电子 学、探测器模块组装等，研制出高时间分辨率的探测器模块与前 端读出电路板，其时间分辨率好于 50 皮秒。新一代有时间信息 的硅像素探测器:研发时间分辨率在 100 皮秒以下的抗辐照传感 器及前端电子学。

Guidance: “Frontier Research of Large Scientific Devices" Key Special 2023 Project Application Guide

1. Particle Physics

1.3. ATLAS Detector upgrade (common key technology)

Research content:

In accordance with the provisions of the cooperation agreement with ATLAS, complete the research and development, manufacturing and installation of silicon track detectors, muon spectrometers and high-granularity time detectors. For the upgrade of LHC high energy and high luminosity, transform the particle detector system of ATLAS experiments, carry out the development, construction and operation of related detectors, and improve the sensitivity of ATLAS experiments to physical processes.

Mainly including:

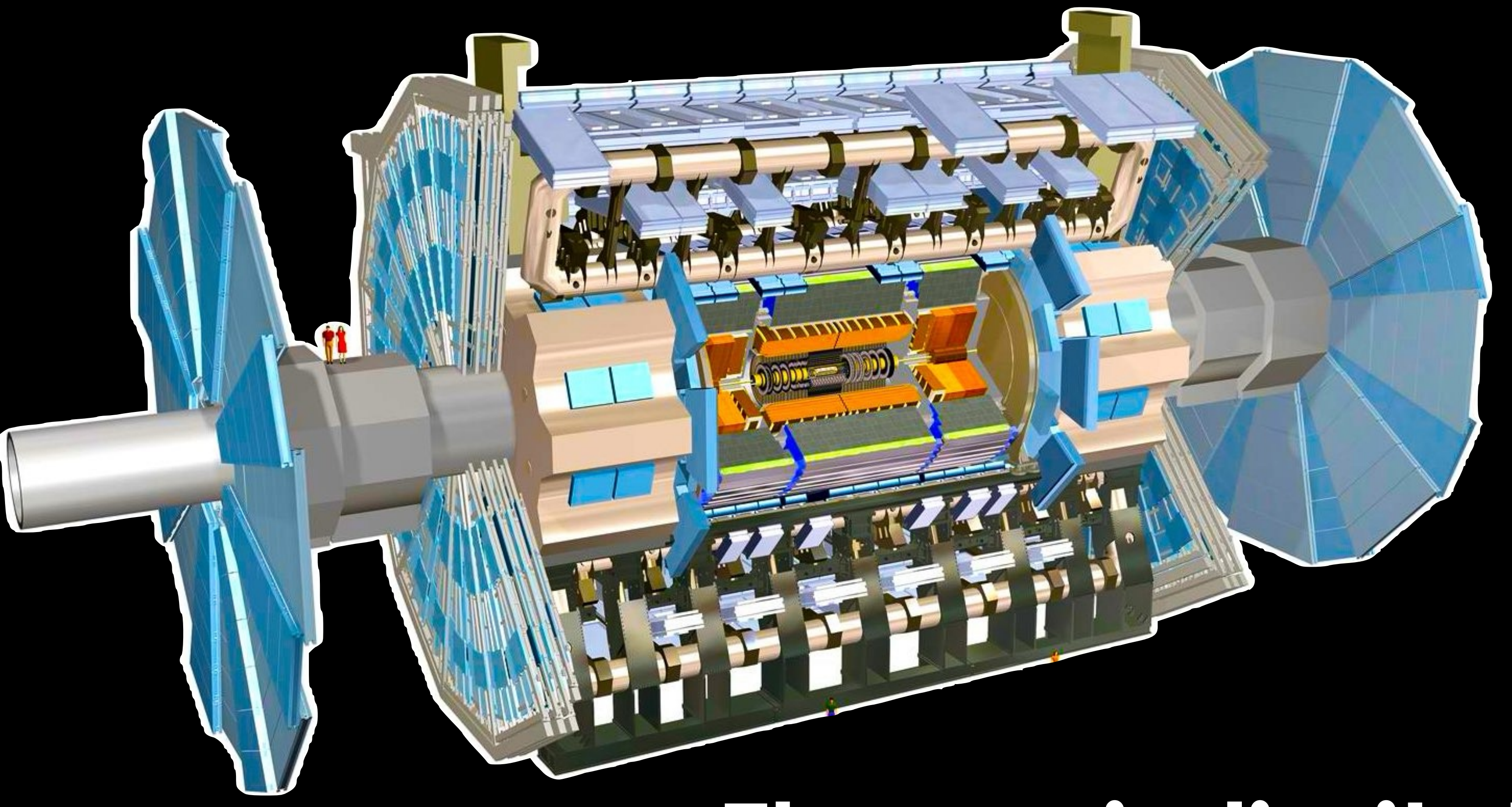
Construction of silicon track detector module, integration and operation of track detector system; development and operation of resistance plate detector and related electronics; research and development and construction of high granularity time detector; research and development of a new generation of silicon pixel detector with time information.

Assessment index: The spatial resolution of the silicon micro strip track detector reaches 25 microns. Resistive chamber detector: the counting rate is 1 kHz/cm2, the detection efficiency is higher than 95%, and the time resolution is better than 1 ns. High granularity time detector: develop silicon sensors, front-end electronics, detector module assembly, etc., and develop a high-time-resolution detector module and front-end readout circuit board, with a time resolution of more than 50 pics. A new generation of silicon pixel detectors with time information: develop anti-irradiation sensors and front-end electronics with a time resolution of less than 100 picoseconds.

1. 项目概要:
Project Overview — Background

The Large Hadron Collider (LHC) Physics Program

ATLAS is one of two large multi-purpose experiments at the LHC at CERN



After Higgs Particle discovery in 2012, the main goals are:

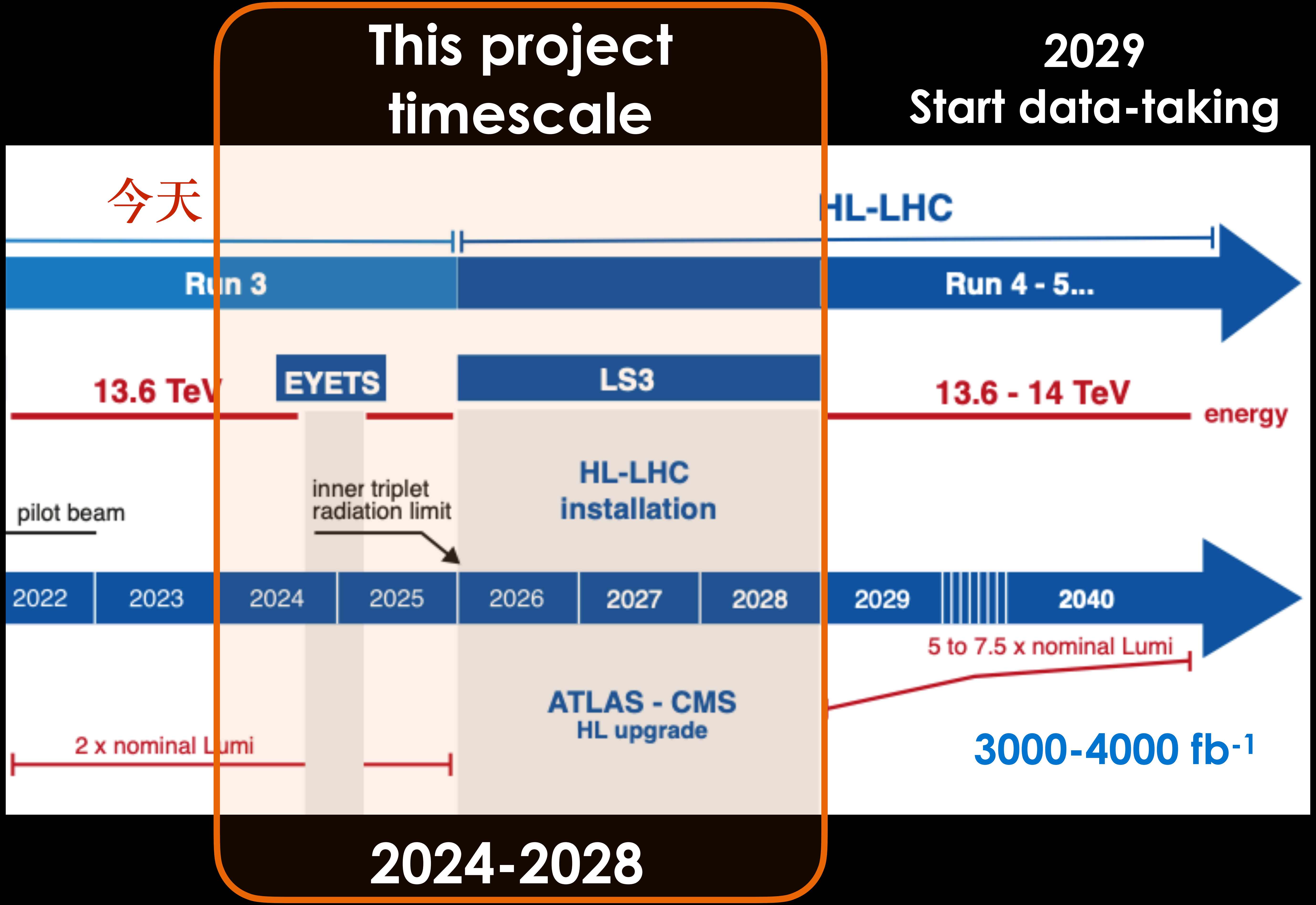
- Study Higgs Boson in detail
- Search for new physics beyond SM (BSM)

The main limitation to progress is the amount of available data

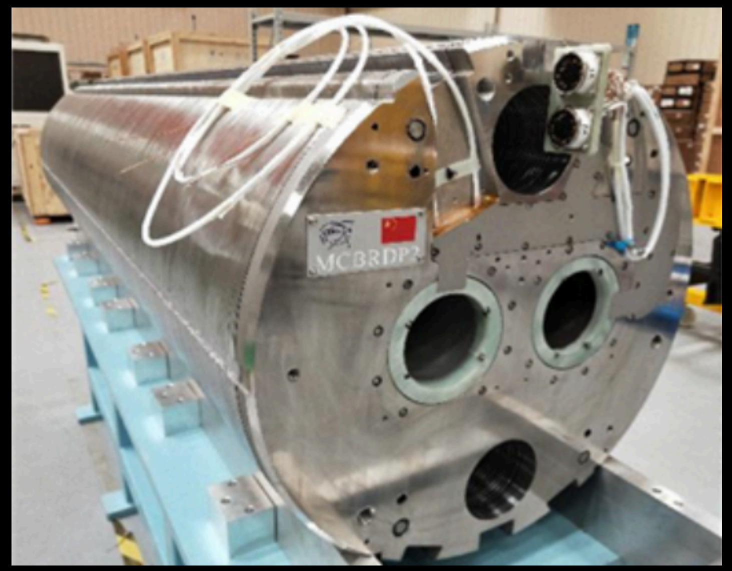
	对撞能量	积分亮度
Run1 (2010-12)	7/8 TeV	~ 26 fb^{-1}
Run2 (2015-18)	13 TeV	~ 139 fb^{-1}
Run3 (2022-25)	13.6 TeV	~ 301 fb^{-1} (计划取数)

The High-Luminosity-LHC Upgrade

Need 10x more data: ~300 fb^{-1} to 3000-4000 fb^{-1}



by 2029 LHC accelerator will be upgraded to deliver higher luminosity



including 12 CCT superconducting magnets from China

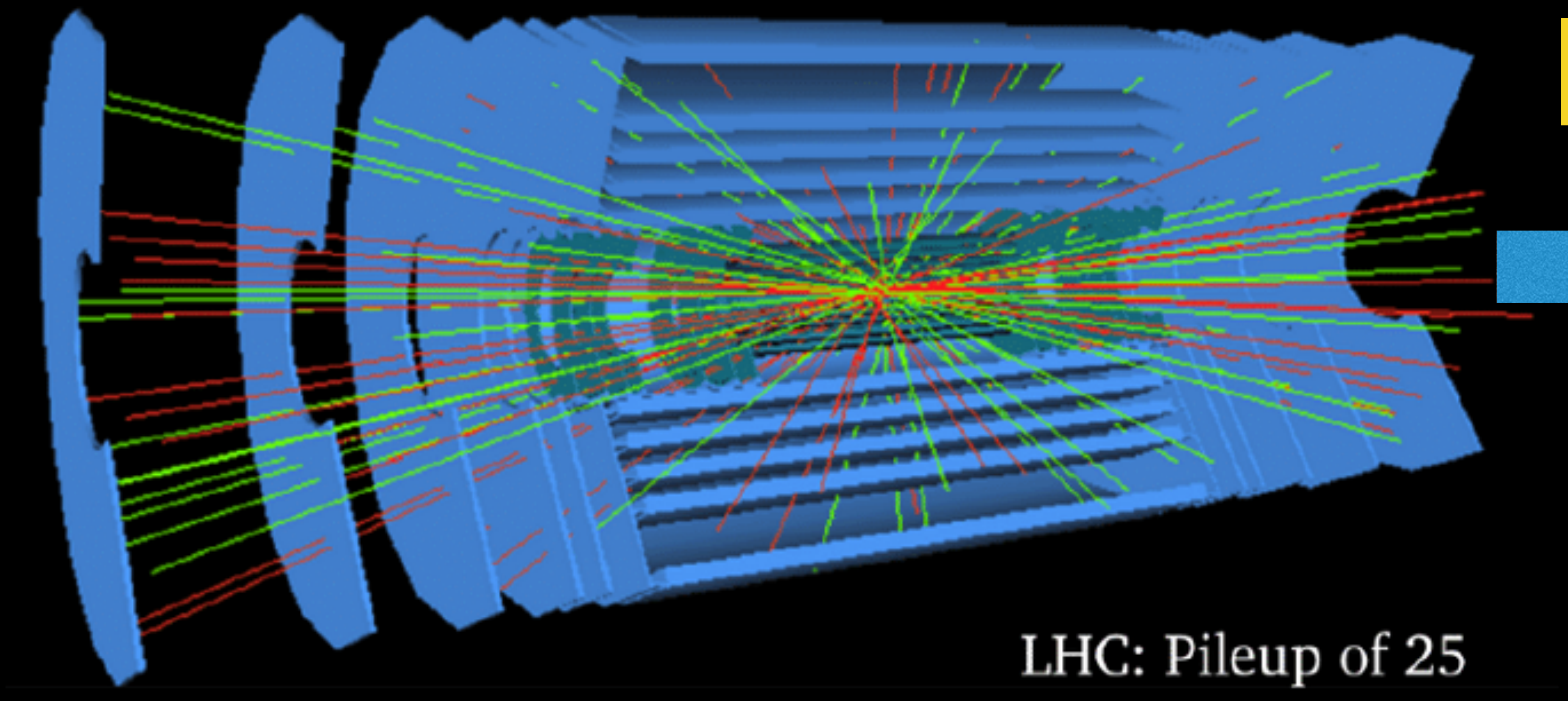
This project relates to the corresponding detector upgrades

The High-Luminosity-LHC Challenges to Detectors

Instantaneous luminosity
7.5×10^{34} $cm^{-2}s^{-1}$

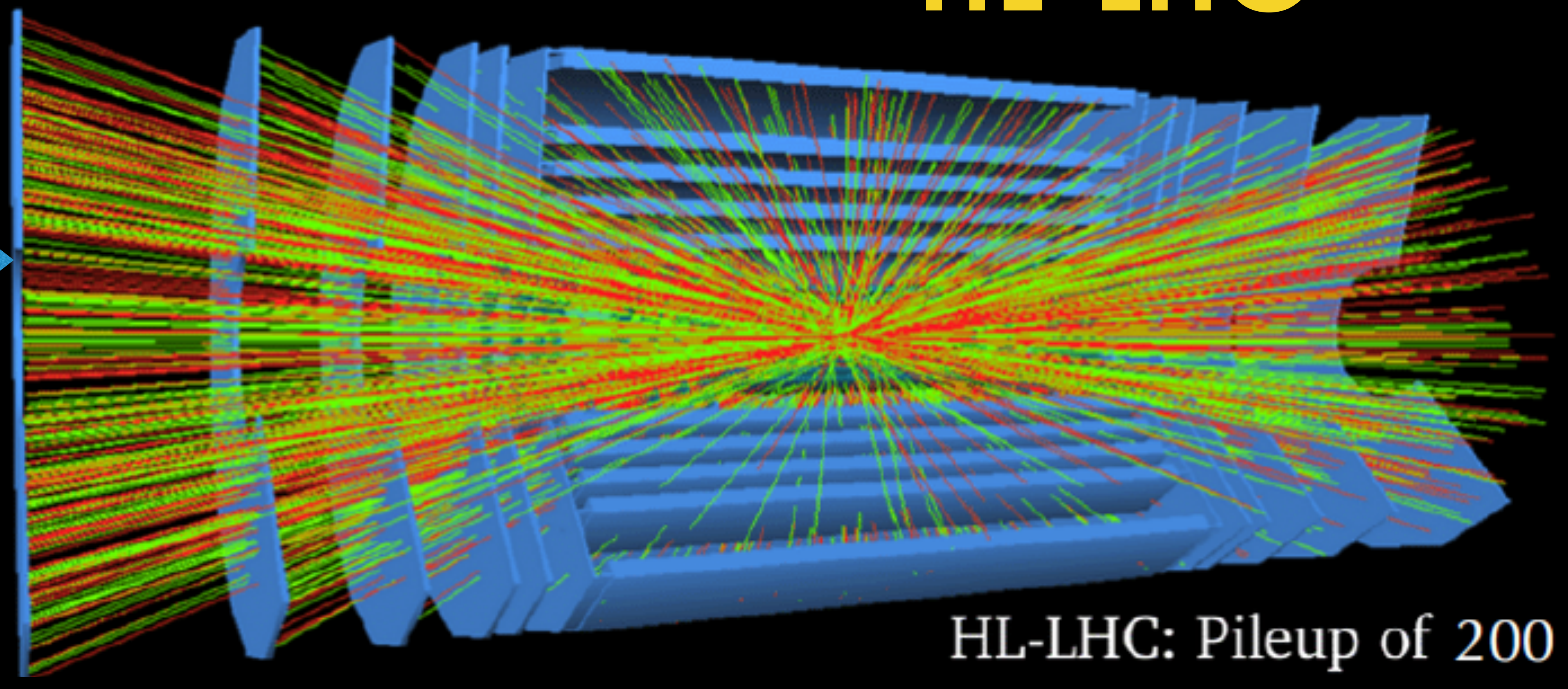
→ Average number of interactions per bunch crossing (pile-up events) ~ 200

LHC



Pile-up →

HL-LHC



Data rates increased 5 to 7.5x nominal design rates

Current detectors cannot cope with such large rates, need:
Larger granularity
Faster trigger rates
New technologies (fast timing)

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

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

ATLAS Upgrade	课题名称	Leading Unit	Funds (万元)
课题 1	High Granularity Timing Detector	中国科学院高能物理研究所 (IHEP)	1135
课题 2	Inner Silicon Tracker	中国科学院高能物理研究所 (IHEP)	600
课题 3	Muon Detector	中国科学技术大学(USTC)	465

Total funding: 2200 万元

This Project: ATLAS Phase-2 Upgrade

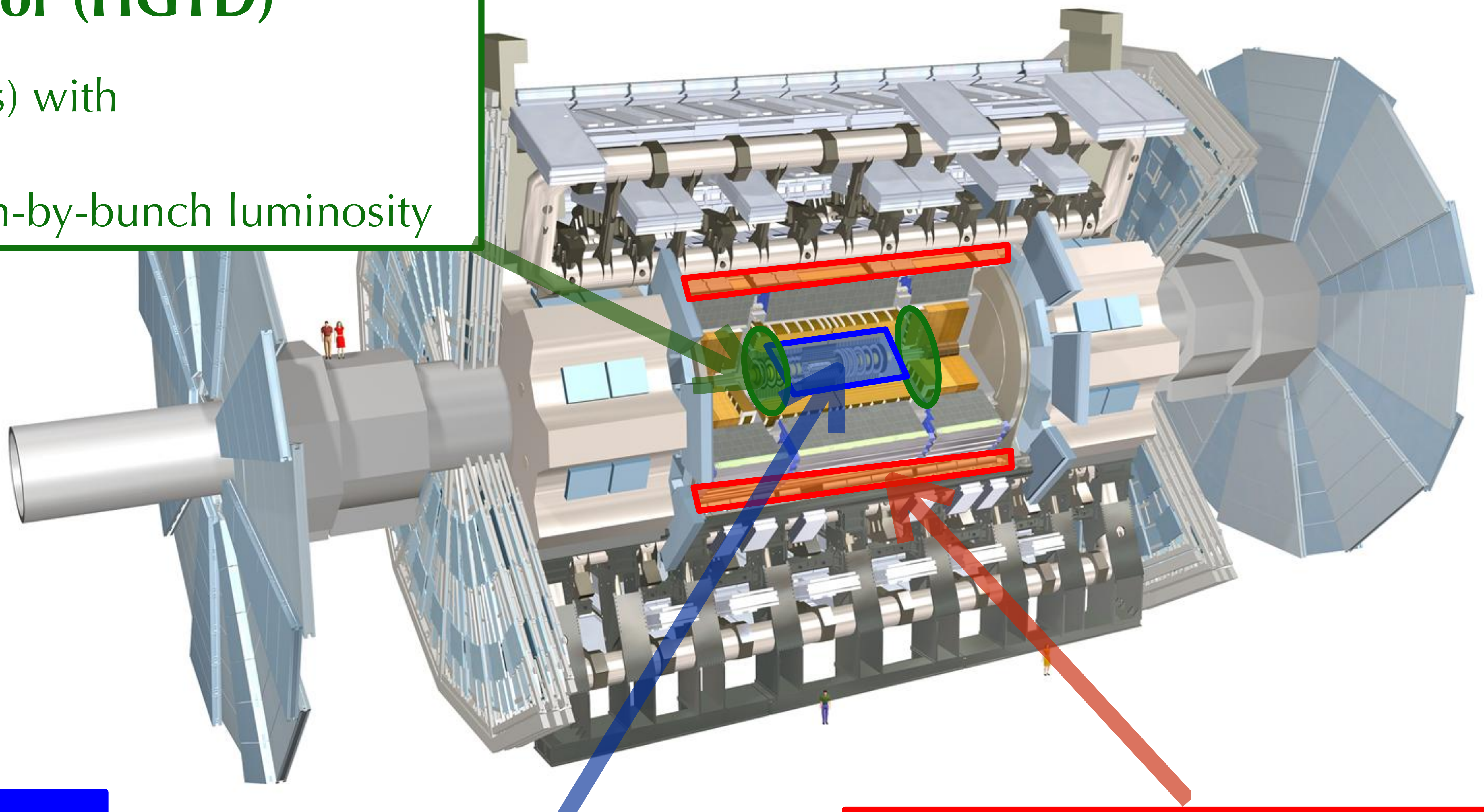
一起 searching for new physics with ATLAS detector

课题1: IHEP-USTC-NJU-SDU

High Granularity Timing Detector (HGTD)

- Precision time reconstruction (30-50 ps) with Low-Gain Avalanche Diodes (LGAD)
- Improved pile-up separation and bunch-by-bunch luminosity

新



Other

Upgraded Trigger and Data Acquisition System
- Single Level Trigger with 1 MHz output
- Improved 10 kHZ Event Farm

Electronics Upgrades
- On-detector/off-detector electronics upgrades of LAr Calorimeter, Tile Calorimeter & Muon Detectors
- 40 MHz continuous readout with finer segmentation to trigger

Additional smaller upgrades
- Luminosity detectors (1% precision)
- HL-ZDC (Heavy Ion physics)
- Muon sMDT chambers

课题2: IHEP-THU-NJU

New Inner Tracking Detector (ITk)
- All silicon with at least 9 layers up to $|\eta| = 4$
- Less material, finer segmentation

课题3: USTC-SJTU

New Muon Chambers
- Inner barrel region with new RPCs and electronics
- Improved trigger efficiency/momentum resolution, reduced fake rate

Project Decomposition (项目课题分解)

ATLAS detector phase II upgrade

Development of detectors with higher counting rates and more radiation resistance
Upgrade to more advanced and faster electronics and readout systems

课题1:
High Granularity Timing Detector

中国科学院高能物理研究所（IHEP）
中国科学技术大学（USTC）
南京大学（NJU）
山东大学（SDU）

High time resolution silicon detector technology

课题2:
Inner Tracker Detector

2.1: Silicon Strip Detector
2.2: Timing Pixel Detector

中国科学院高能物理研究所（IHEP）
中国科学技术大学（USTC）
清华大学（THU）

课题3:
Muon Detector

中国科学技术大学（USTC）
上海交通大学（SJTU）

ATLAS experimental physics targets

Improve the precise accuracy of Higgs boson property measurements
Increase the sensitivity of new physics

课题1： High Granularity Timing Detector

Physics Requirements and Key Technologies

Timing Detector (HGTD) to reduce pileup at LHC + precise Luminosity measurement

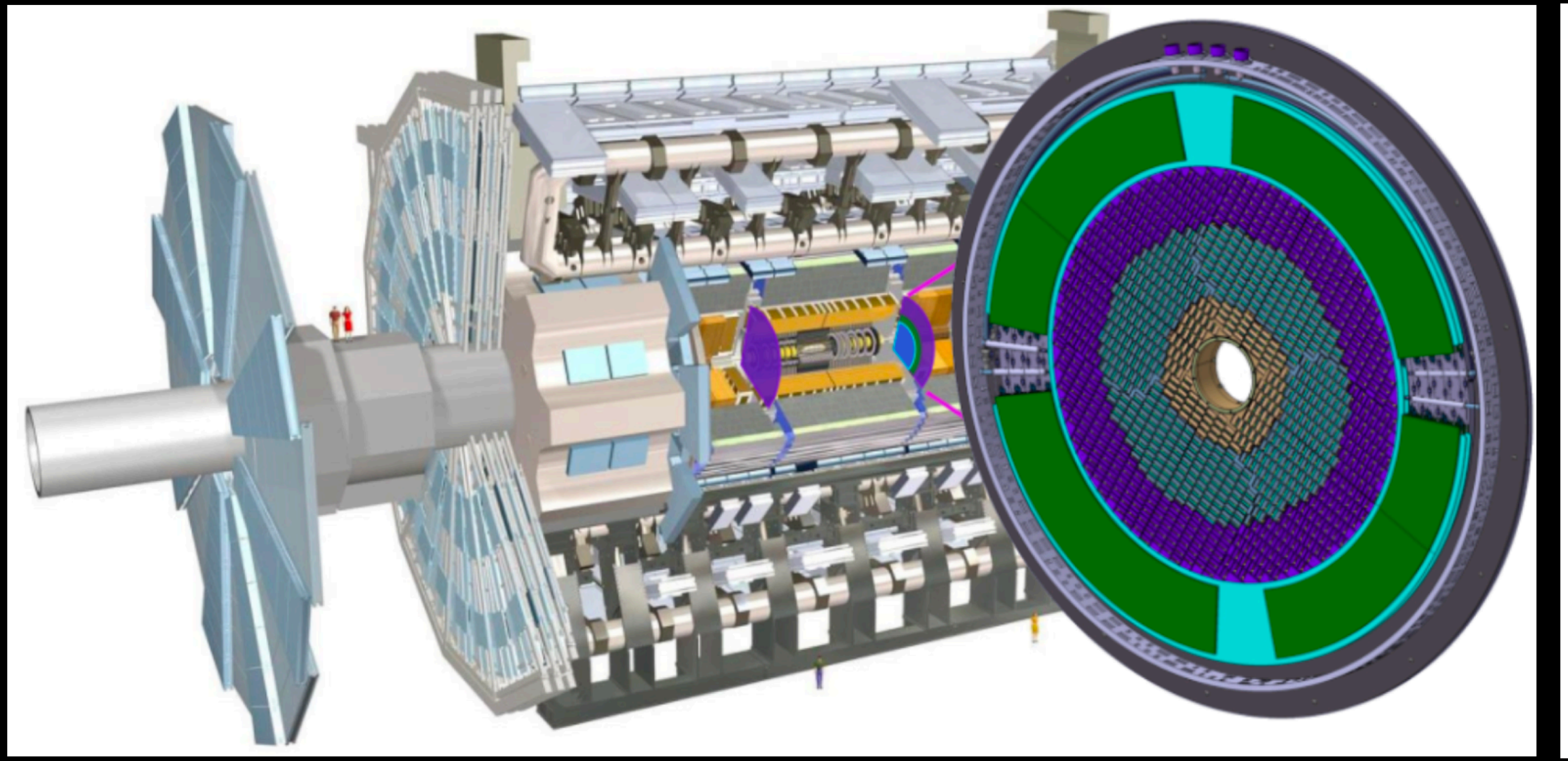
Collisions spread ~250 ps time scale → reach **30-50 ps** timing resolution

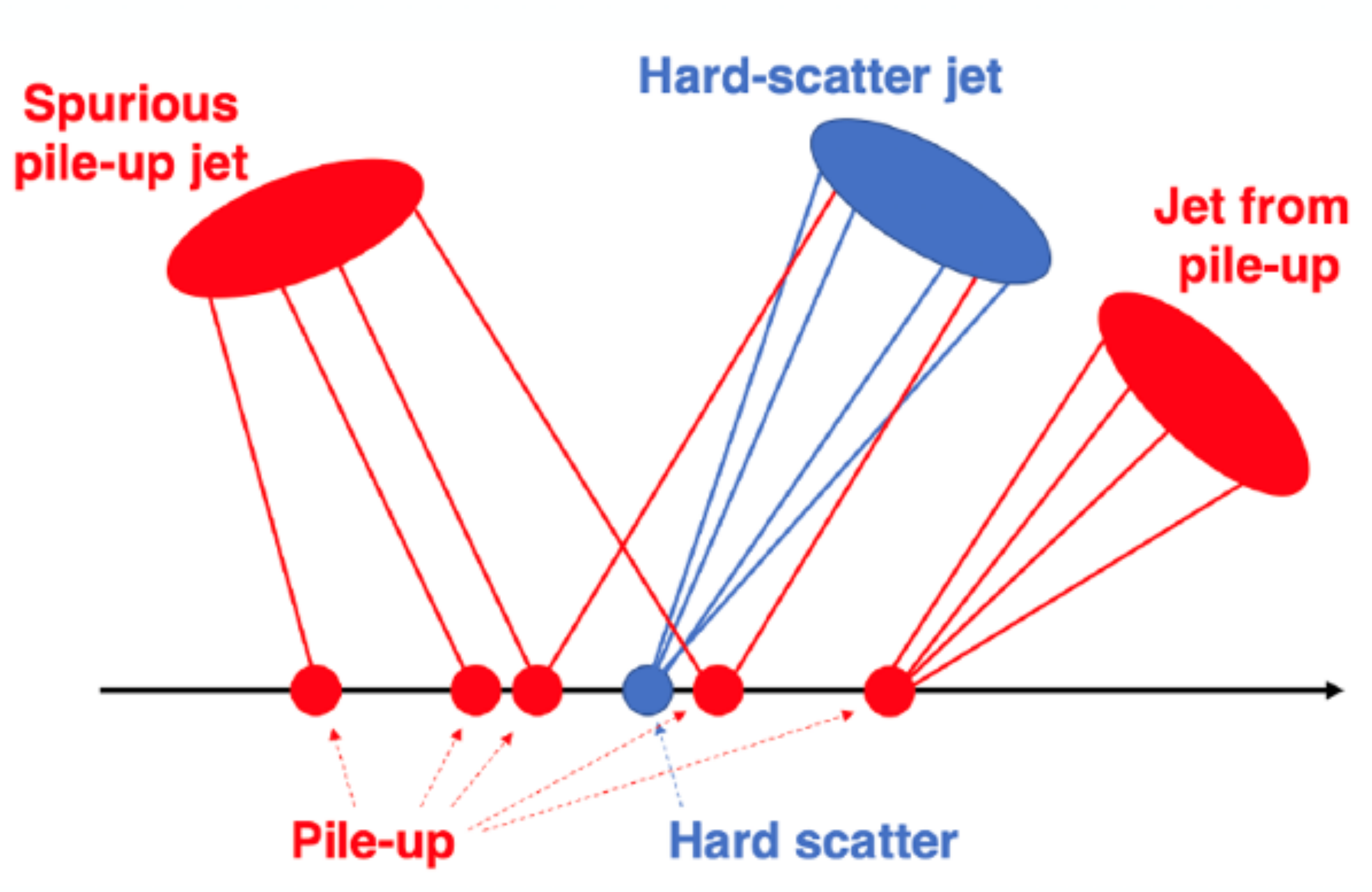
Significantly improve compared to ~1 ns precision in conventional silicon sensor

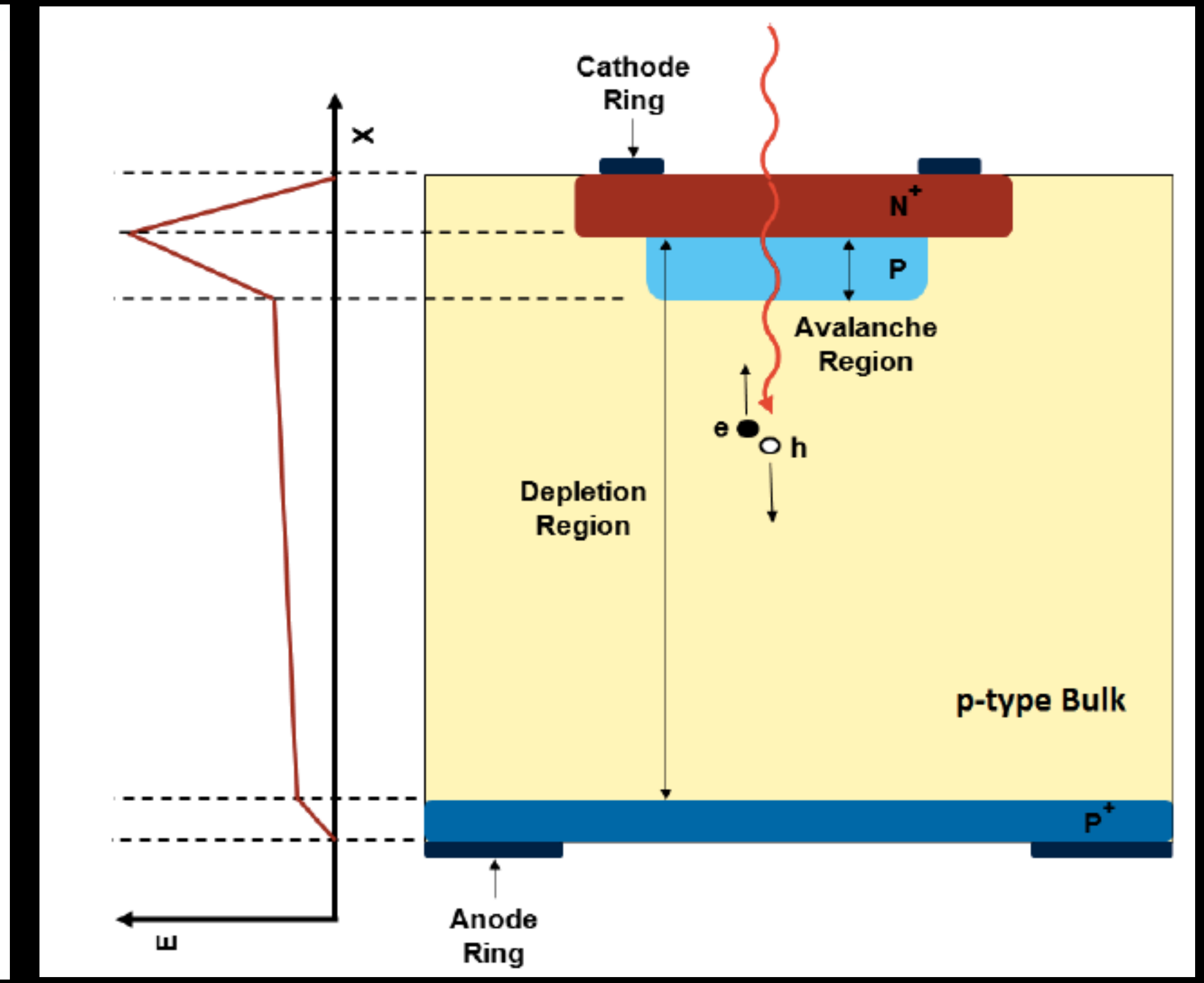
Adding 4th dimension information for the first time

Introduce a new Silicon technology Low Gain Avalanche Diode (LGAD)

Strong Competitions: HPK (Japan), FBK (Italy), CNM (Spain), Micron (UK), IME (China)



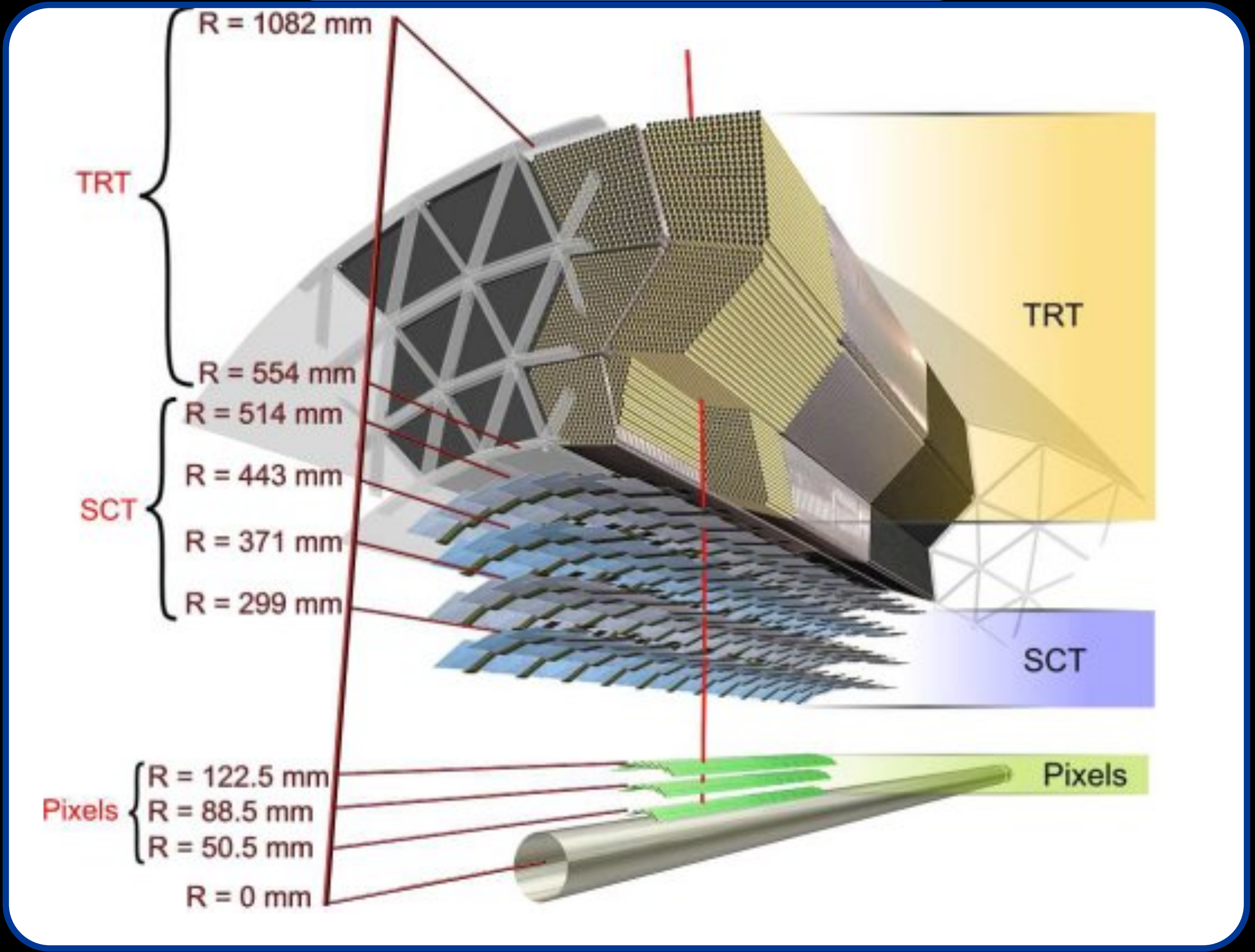




课题2：Inner Silicon Tracker Upgrade

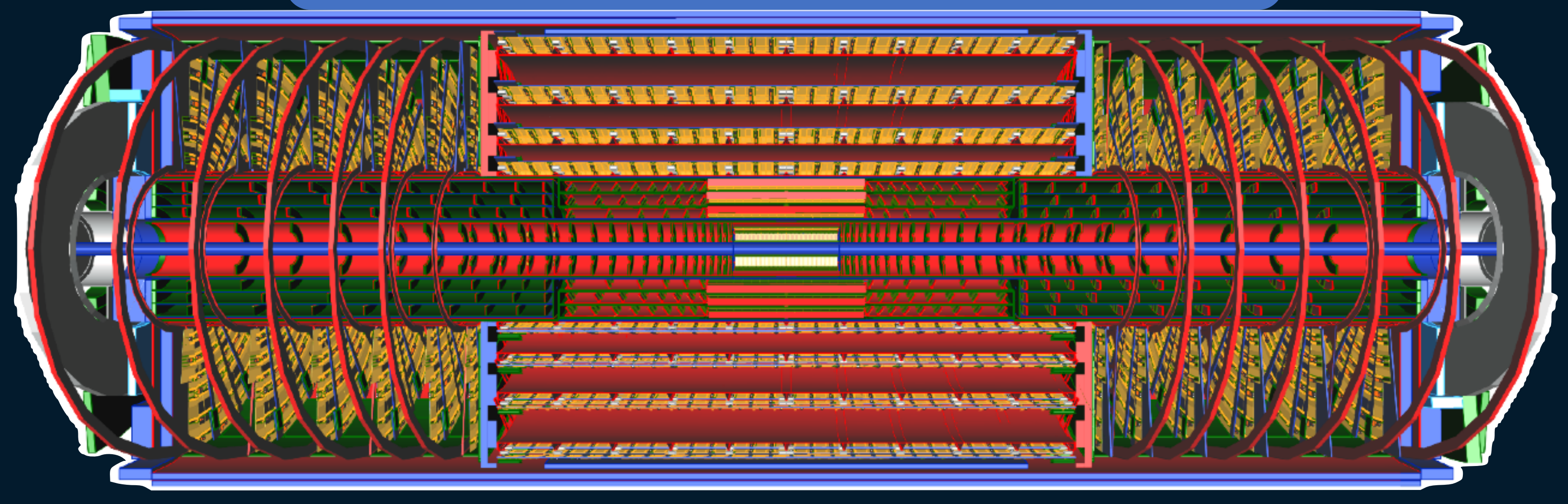
Physics Requirements and Key Technologies

Current Tracker



- **Detector Occupancy**
  - TRT occupancy will reach 100%
- **Radiation Damage**
  - Current tracking detector can not reach the HL-LHC 4000 fb^{-1} (ID (400 fb^{-1}), SCT (700 fb^{-1}), IBL (850 fb^{-1}))
- **Bandwidth Saturation**
  - Current front-end electronics can not handle the new event rates (Pixel and SCT: max 2×10^{34} $cm^{-2}s^{-1}$)

New Inner Tracker



New full silicon tracker of large dimensions

60 m^2 → 165 m^2

larger solid angle

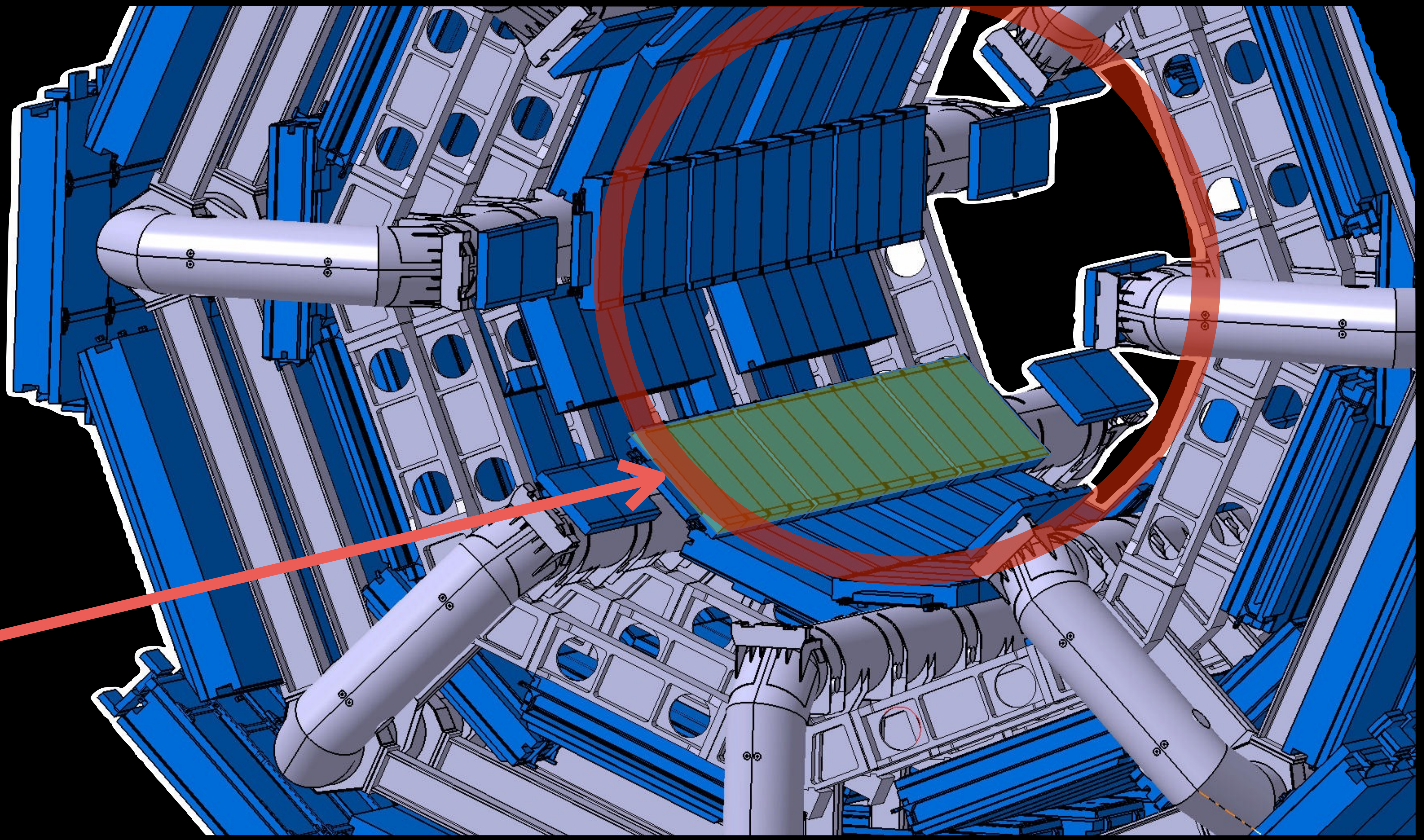
R&D for possible future timing pixel detector

Further improvement against pile-up

课题3：Muon Detector Upgrade

Physics Requirements and Key Technologies

To cope with the HL-LHC event rates
NEW highly performant muon chambers
are required for **trigger**



3 layers of **"Thin-gap" RPC muon singlets**
will be installed in the **Barrel Inner region**

Thin-gap RPC controls the avalanche charges by decreasing the gap size
The loss in gas gain will be compensated by **GeSi based front-end electronics** with higher sensitivity and S/N ratio

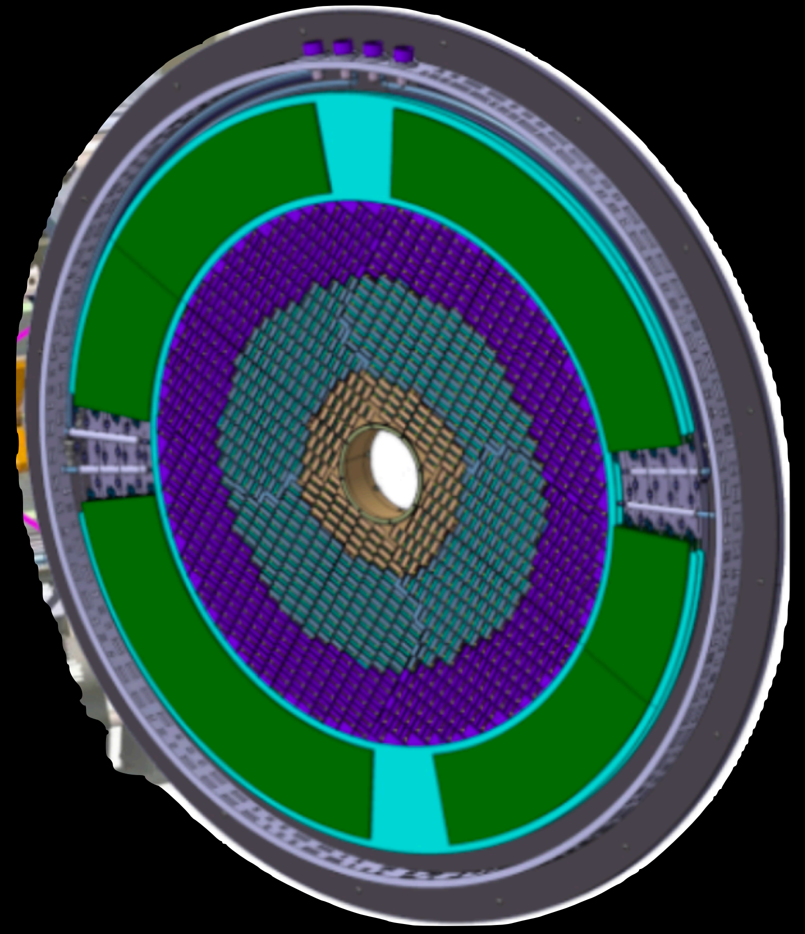
Task decomposition and schedule
(任务分解和进度安排)

课题1：High Granularity Timing Detector

Research Content, Assessment Index (考核指标，研究内容)

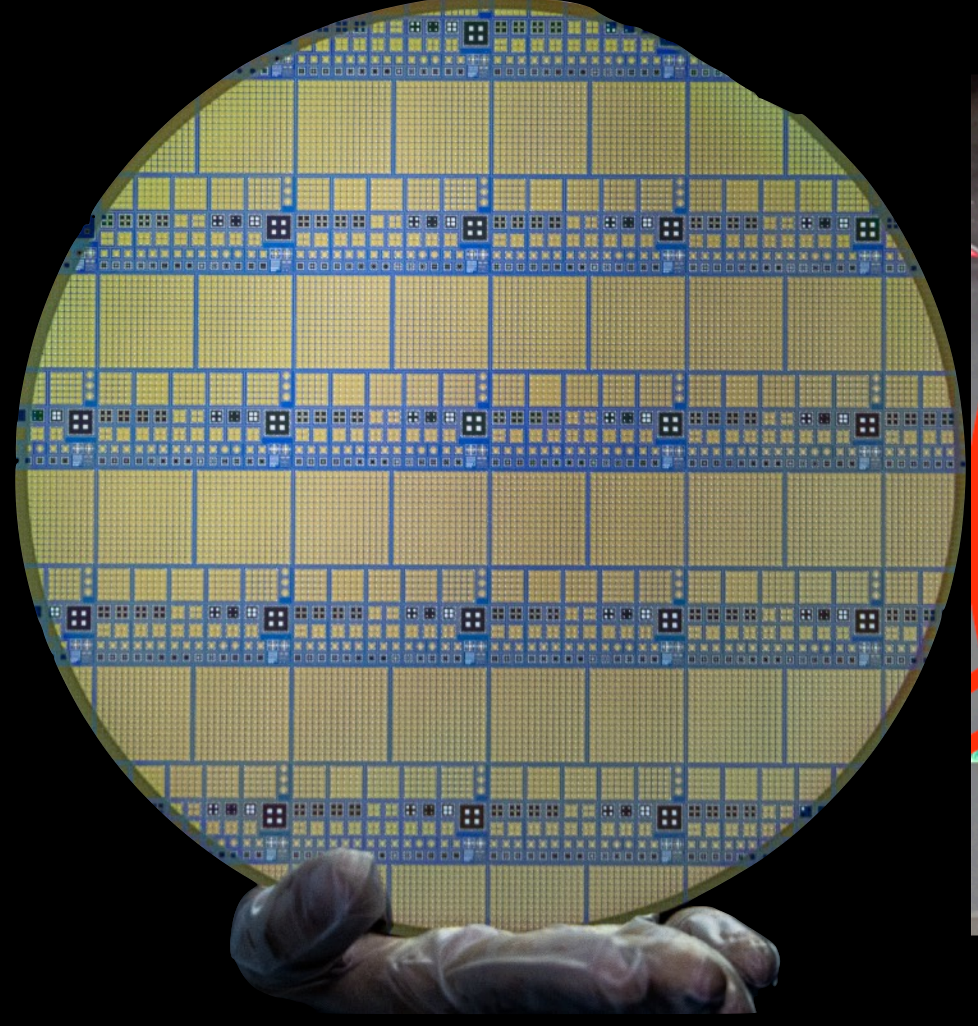
Develop all key components for the Timing Detector

- Developed radiation hard LGAD silicon sensor
- Build large-area ASIC+Sensor Module with robot
- Develop Front-end electronics, high voltage system, flexible cable

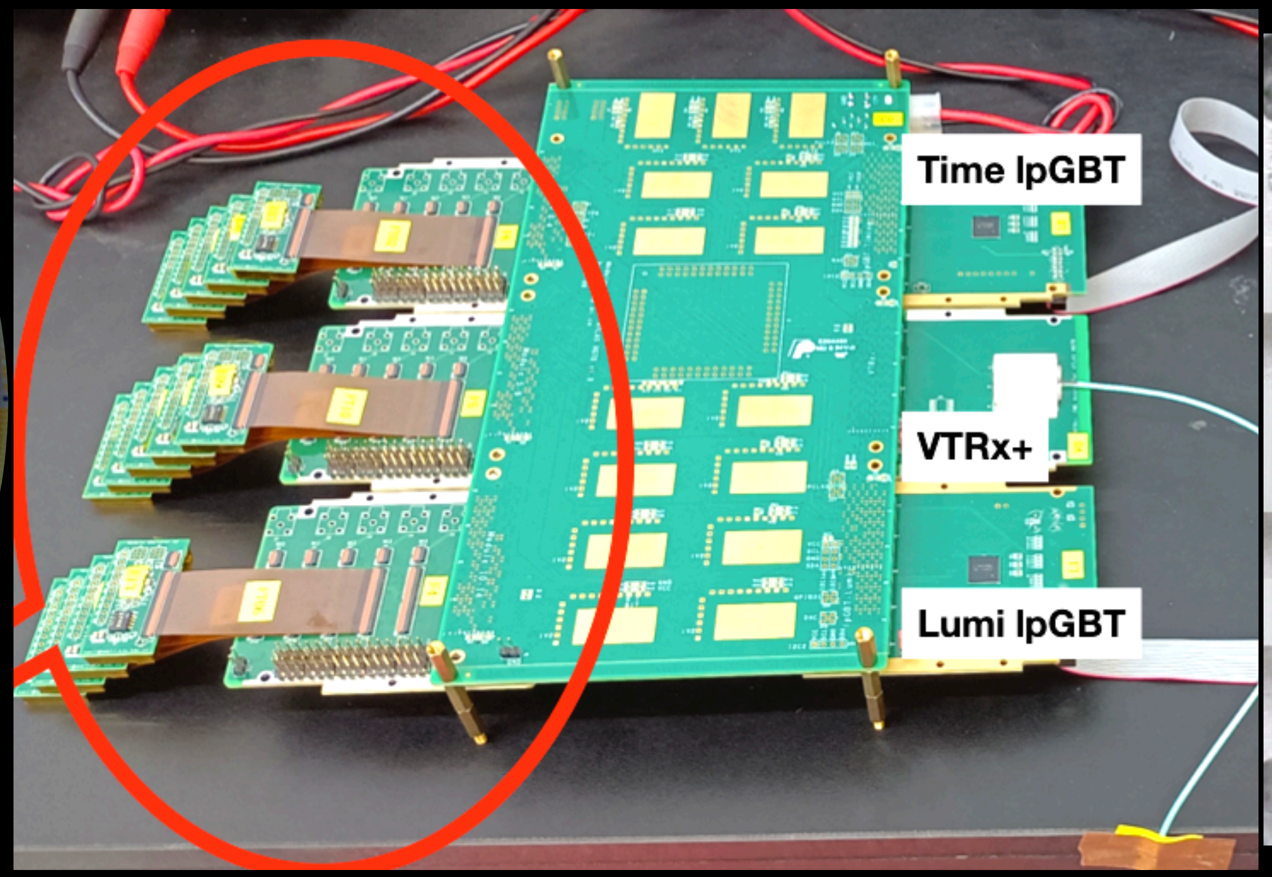


- **Assessment index （考核指标）：**
  - Sensor and detector module time resolution reach **30-50 ps**

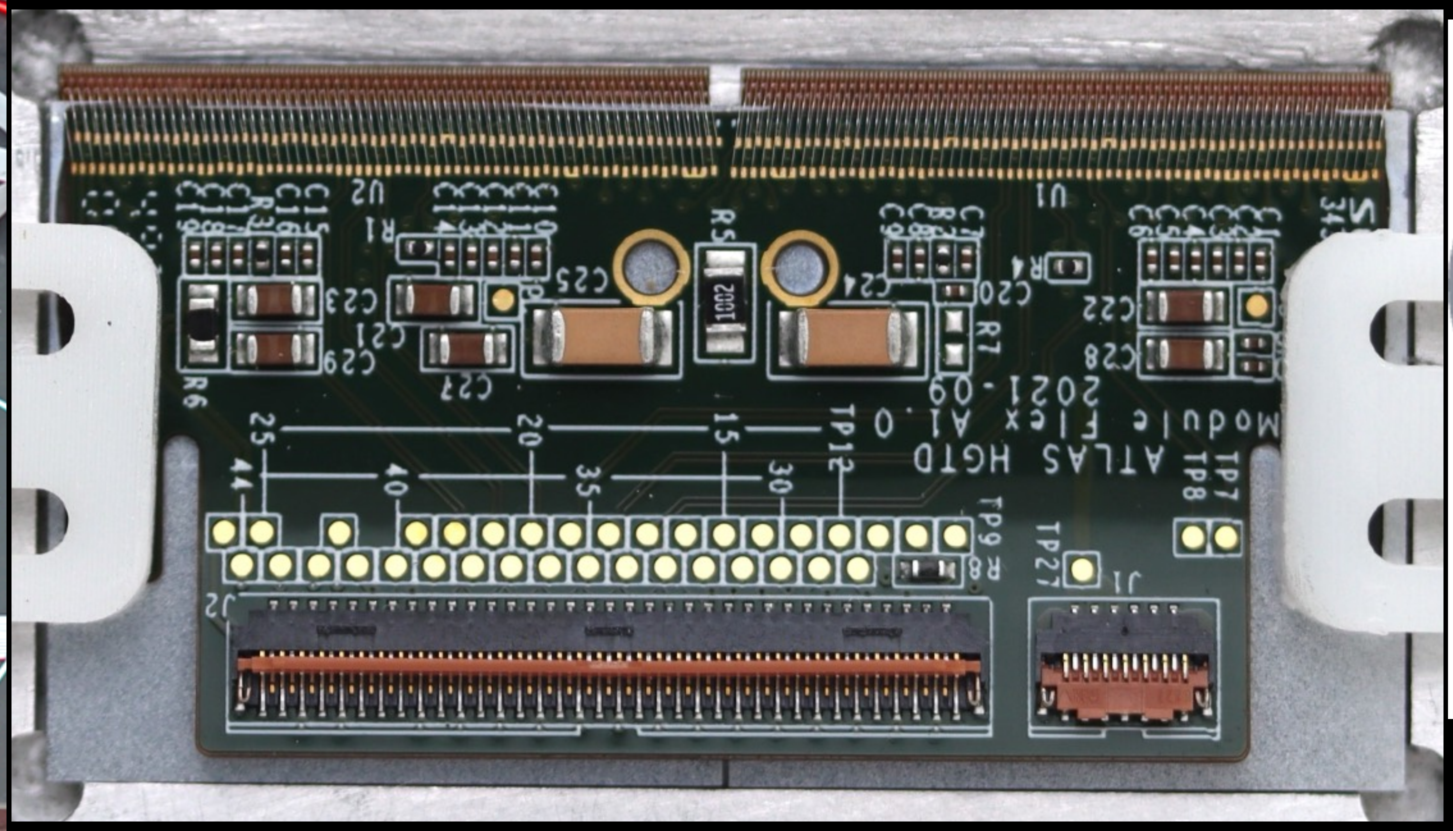
LGAD sensor



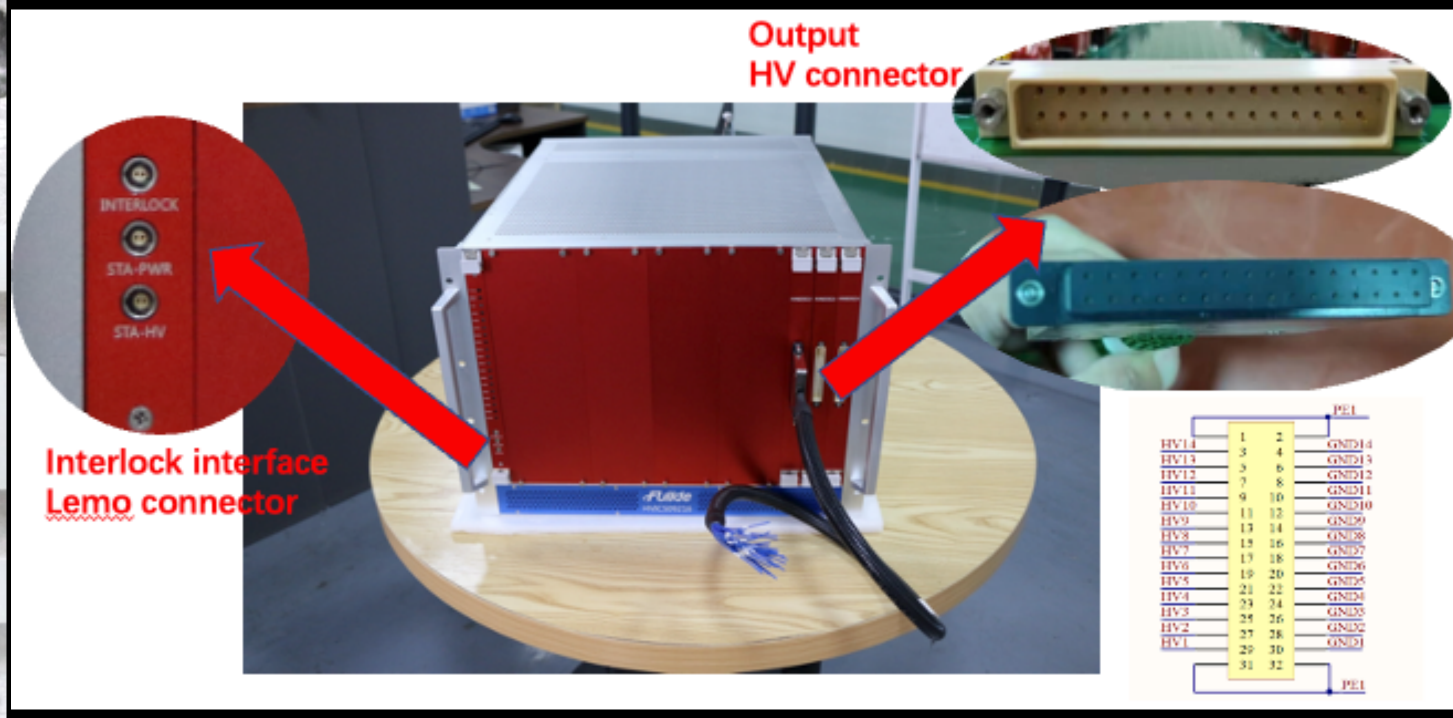
Electronics



Module
ASIC+LGAD



High Voltage supply



课题1： High Granularity Timing Detector

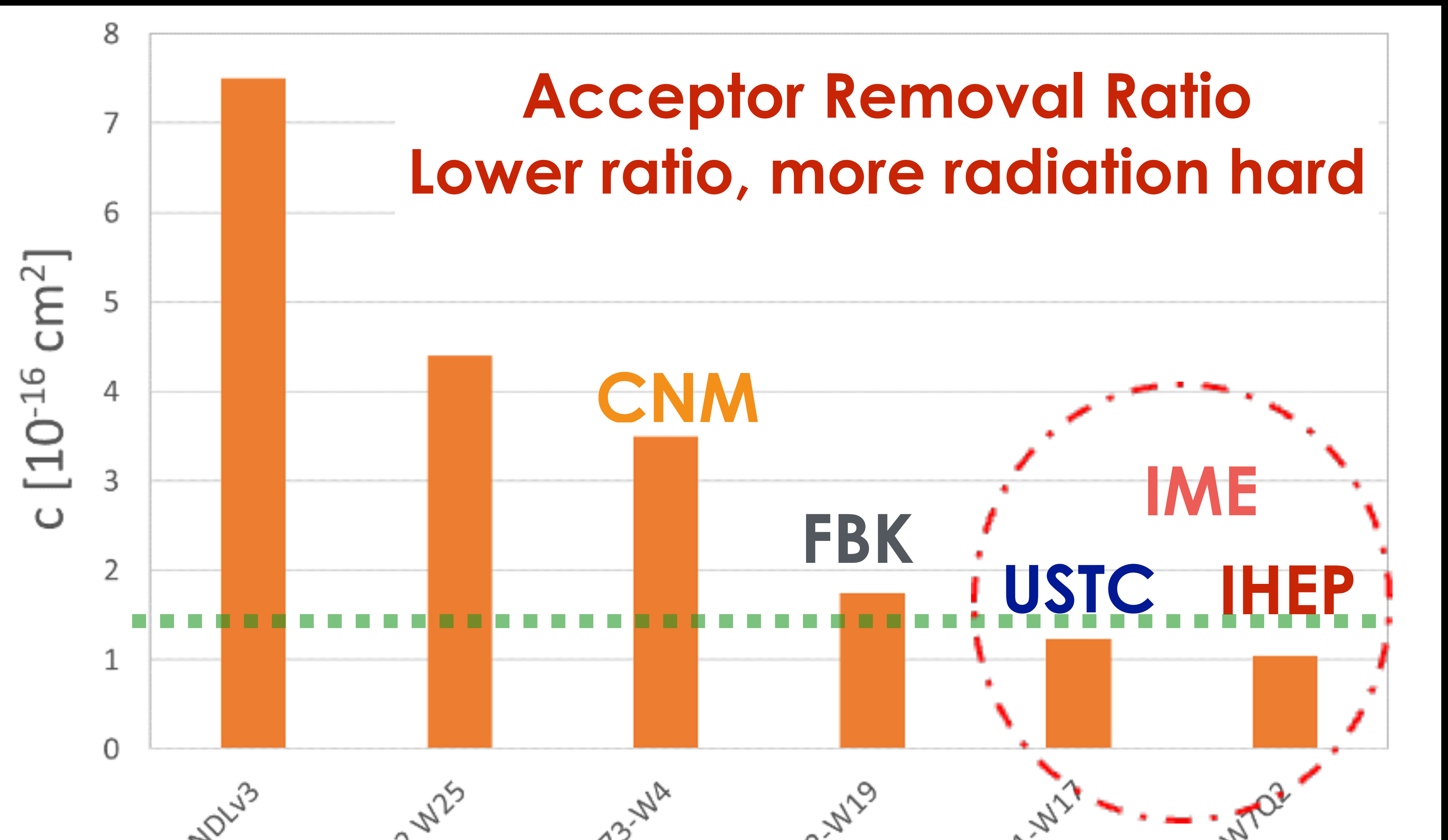
Research Method

Self-developed irradiation hard silicon sensor based on domestic foundry

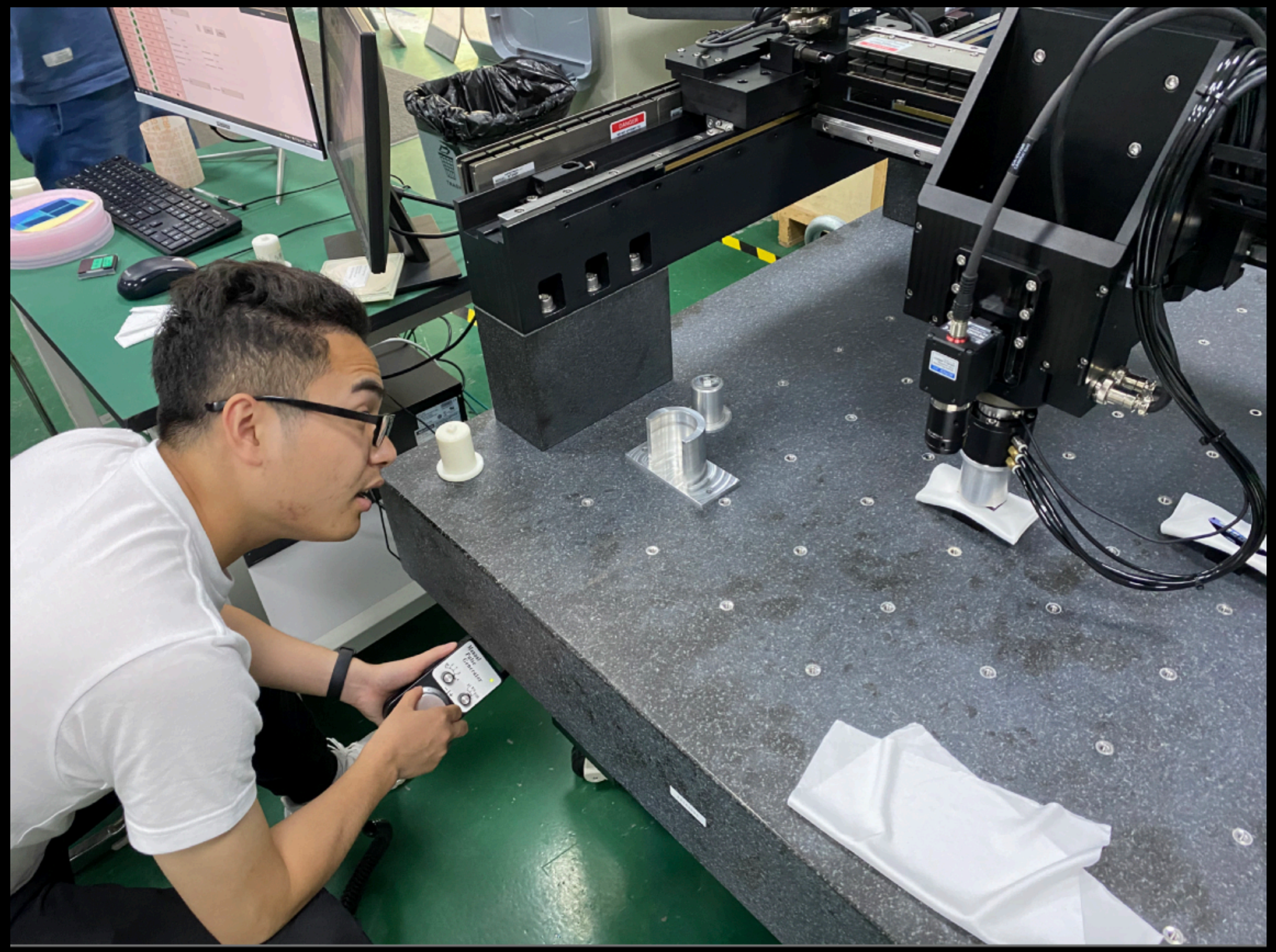
- Our LGAD sensors prototype is the most radiation resistant in the World
- CERN is purchasing 66% of our LGADs; We provided 1/3 as in-kind contribution

- Develop **automatic** large area module assembly with **robot**
- Use Beta source electron (~MeV), electron test beam at DESY(~GeV), or cosmic muon

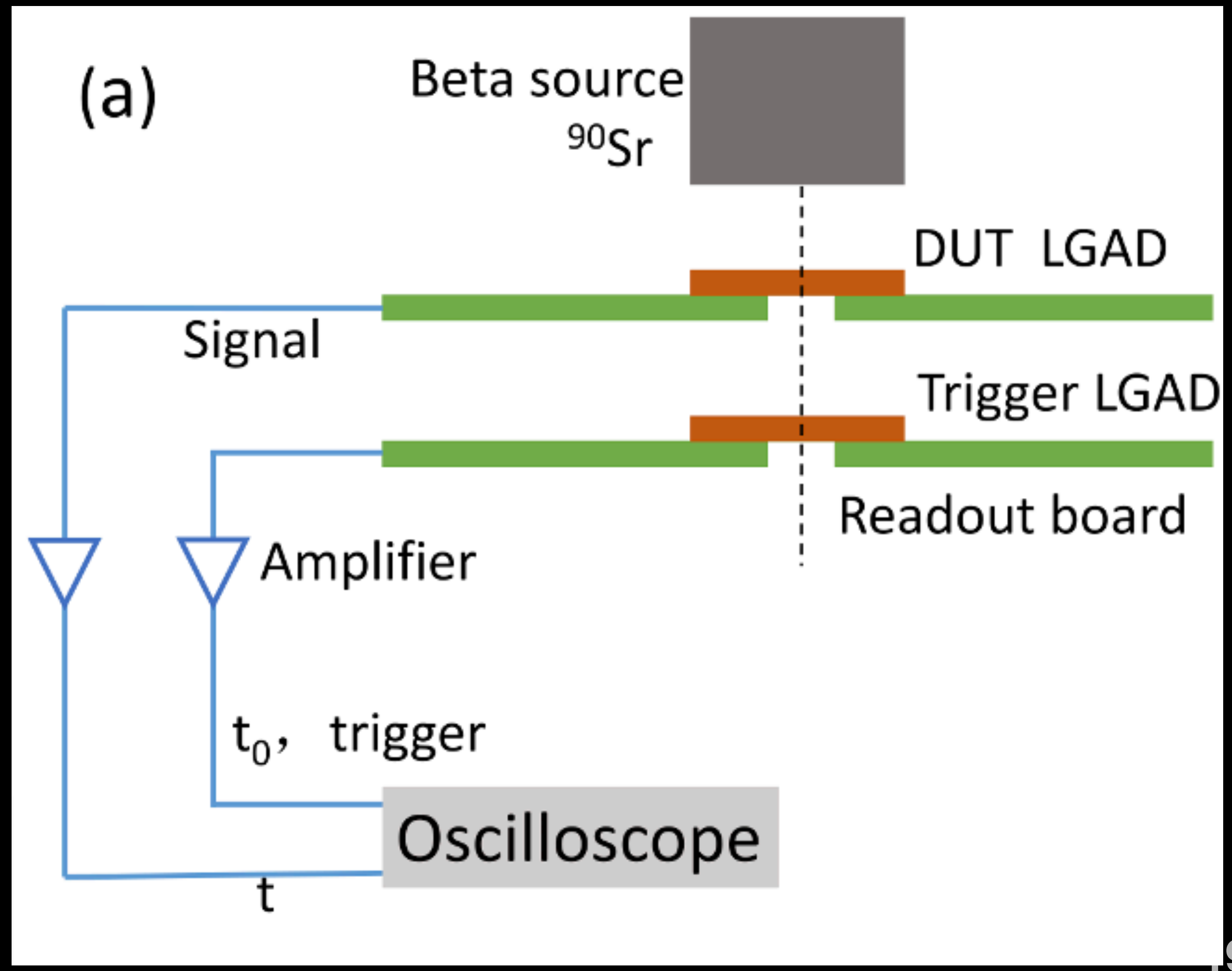
Radiation hardness



Automatic assembly robot



Timing measurement setup With beta source

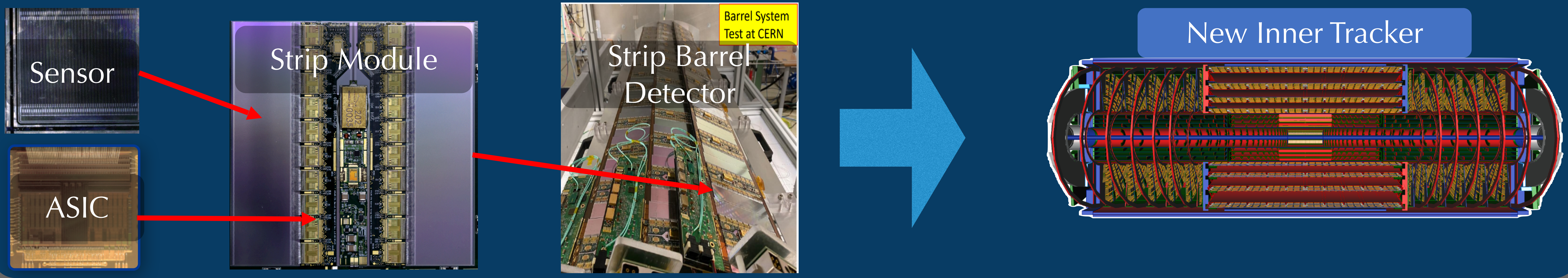


课题2：Inner Silicon Tracker Upgrade

Research Content, Assessment Index (研究内容, 考核指标)

2.1: Inner Tracker construction

- Study radiation hard sensor and readout ASIC
- Produce strip detector module
- Integrate silicon modules into tracker



2.2: Timing Pixel Detector R&D

- Pixelated LGAD sensor R&D
- Fast front-end electronics data buffering, readout, transmission

Assessment index （考核指标）

- Complete strip barrel detector with modules with 25 μm spacial resolution
- Timing Pixel detector R&D: Sensor and electronics with time resolution better than 100 ps

课题2：Inner Silicon Tracker Upgrade

Research Method

Sensor and ASIC irradiation studies will be carried out at CSNS with proton beam

The project team plans to deliver 10% Strip barrel modules

(for this project 200 modules)

Two teams will work in parallel (IHEP and RAL, UK)

Participate in:

Strip Barrel Stave loading at RAL, UK

Barrel tracker system integration at CERN

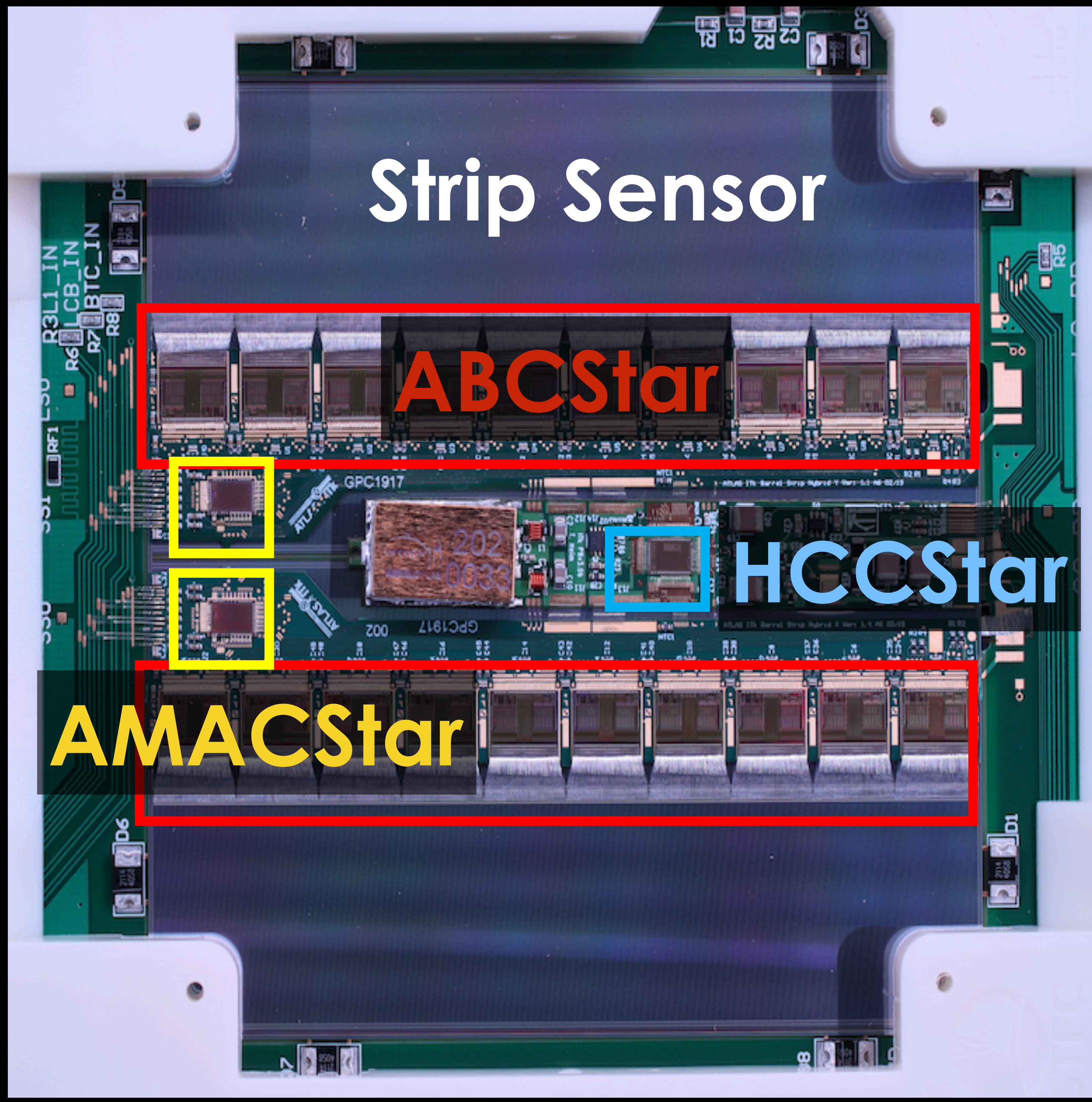
R&D on Timing Pixel Detector

Pixelated AC LGAD sensor will be designed and fabricated

Timing Pixel Readout Module design with high precision TDC (collaboration with Berkeley Labs, et al)

Testing on bench

Strip Module



课题3：Muon Detector Upgrade

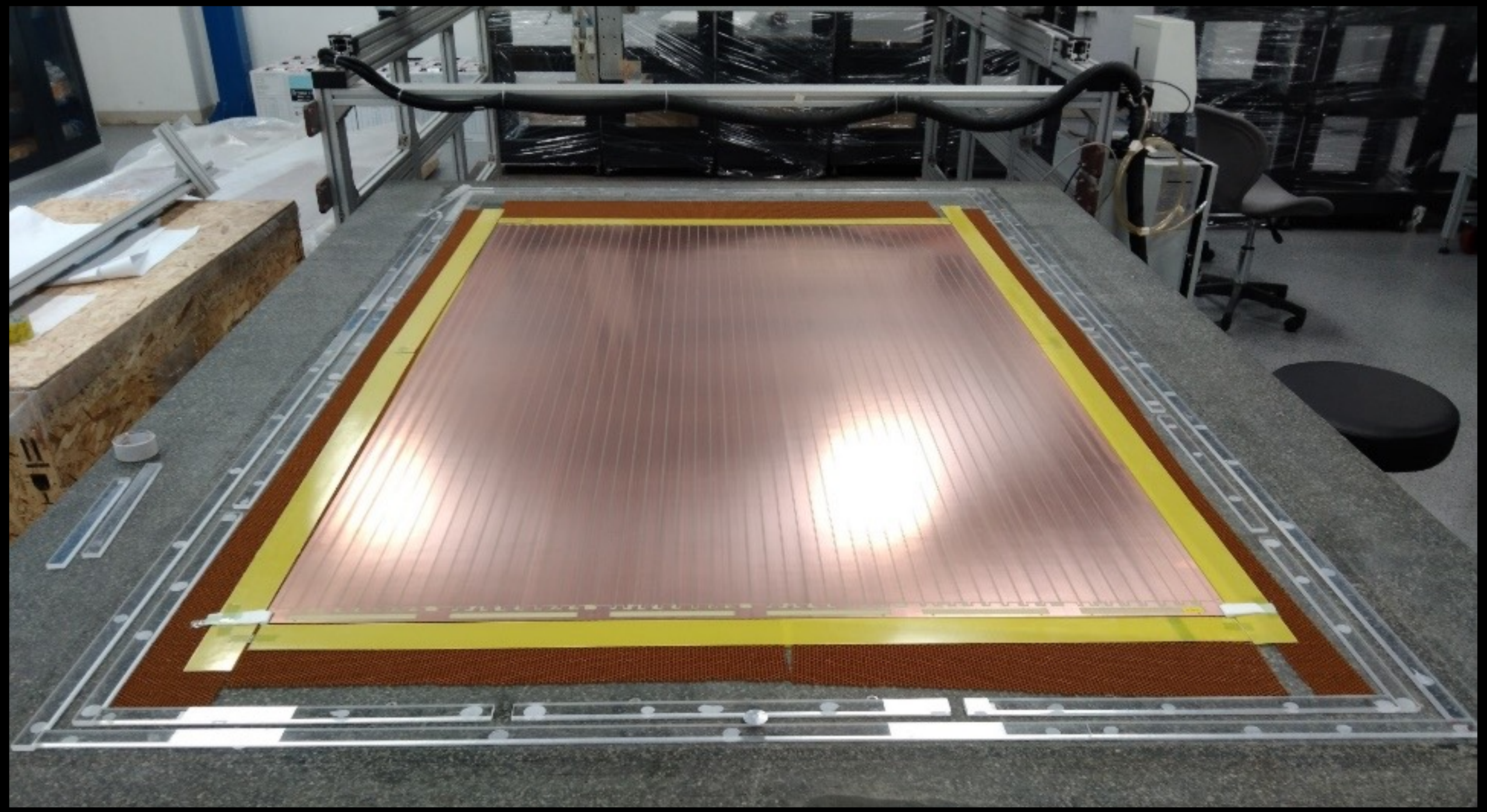
Research Content, Assessment Index (研究内容, 考核指标)

- ATLAS NEW Barrel Inner layer RPC muon chambers contain: ~1400 m^2 RPC singlets and ~100k channels

China will contribute:

50% of the muon singlet layer (including readout panels)
50% of the front end electronics board (FEE) and testing

This project: 1/3 of the muon singlet layers and QA/QC of front end electronics (FEE)



Assessment index （考核指标）

- Parameters to be achieved by all singlet layers (考核指标):
  - Counting rate: >1 kHz/cm^2 (old operational RPC specifications: 300 Hz/cm^2)
  - Time resolution: <1 ns (old operational RPC specifications: > 1 ns)
  - Efficiency: >95%

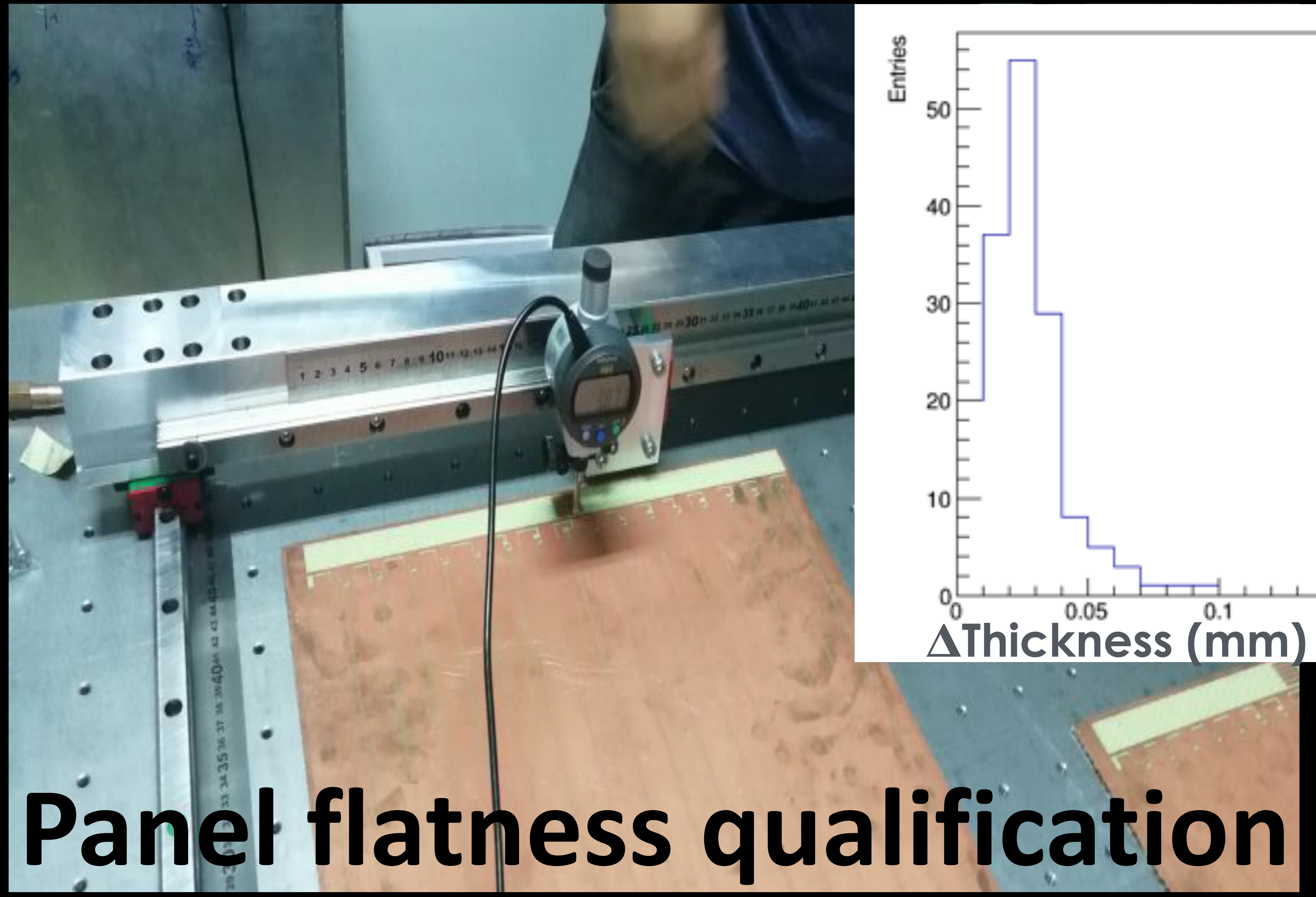
课题3：Muon Detector Upgrade

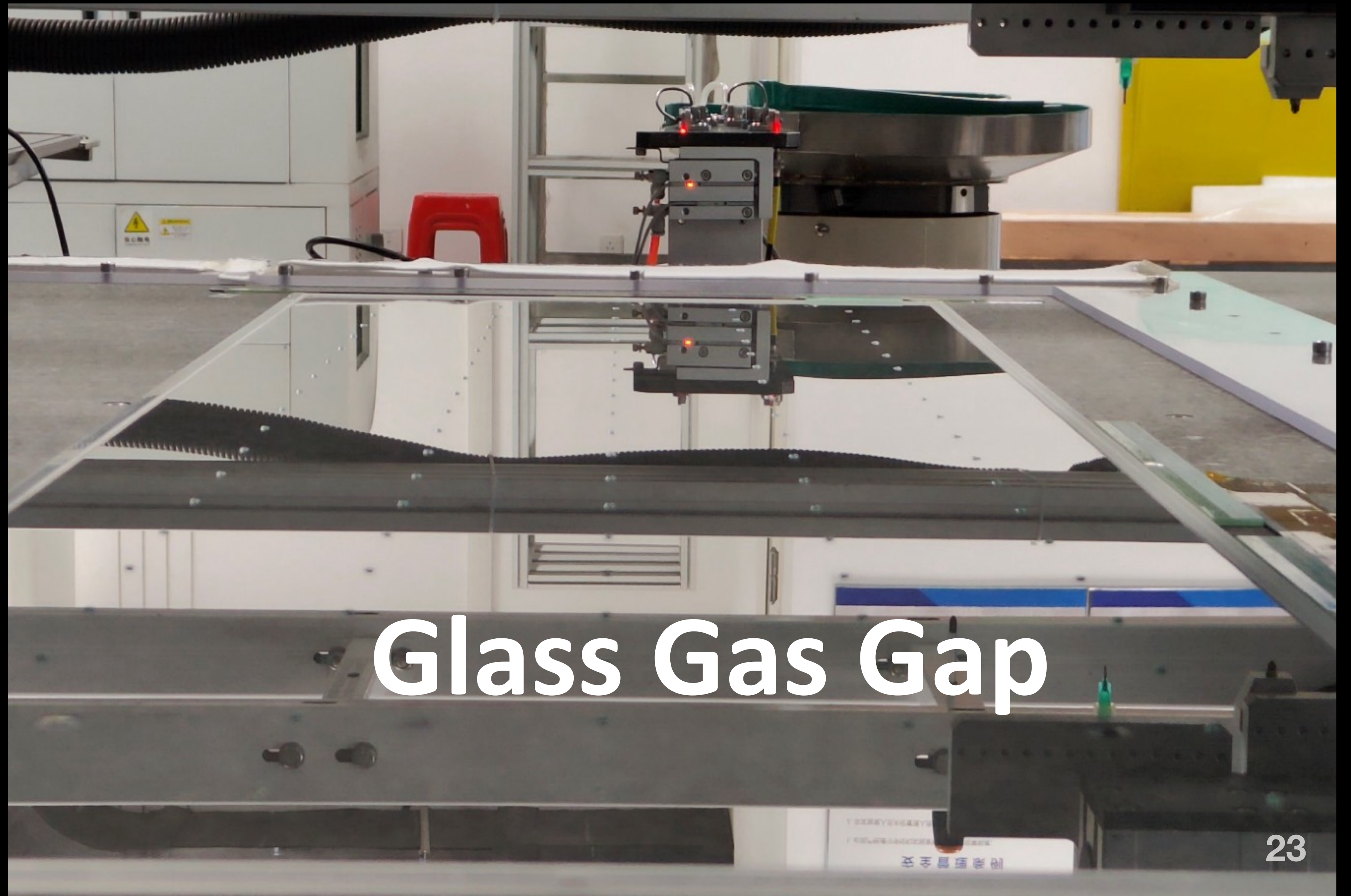
Research Method

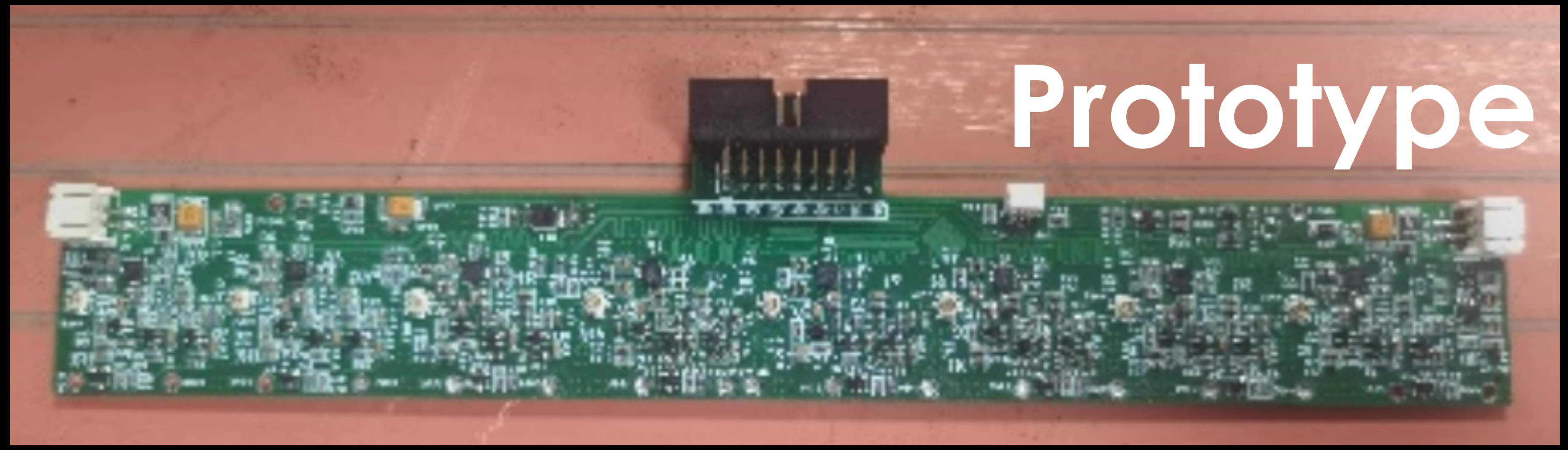
- Optimize and finalize the readout panel design
  - Such large PCB panels can only be produced in China: 1705 mm x 1072 mm
  - Panel flatness of <100 μm

- Optimize the assembly procedures for the large size detector
- Set up proper quality control and testing

- Setup automatic procedure to test 50,000 channels of front end electronics







Project Schedule

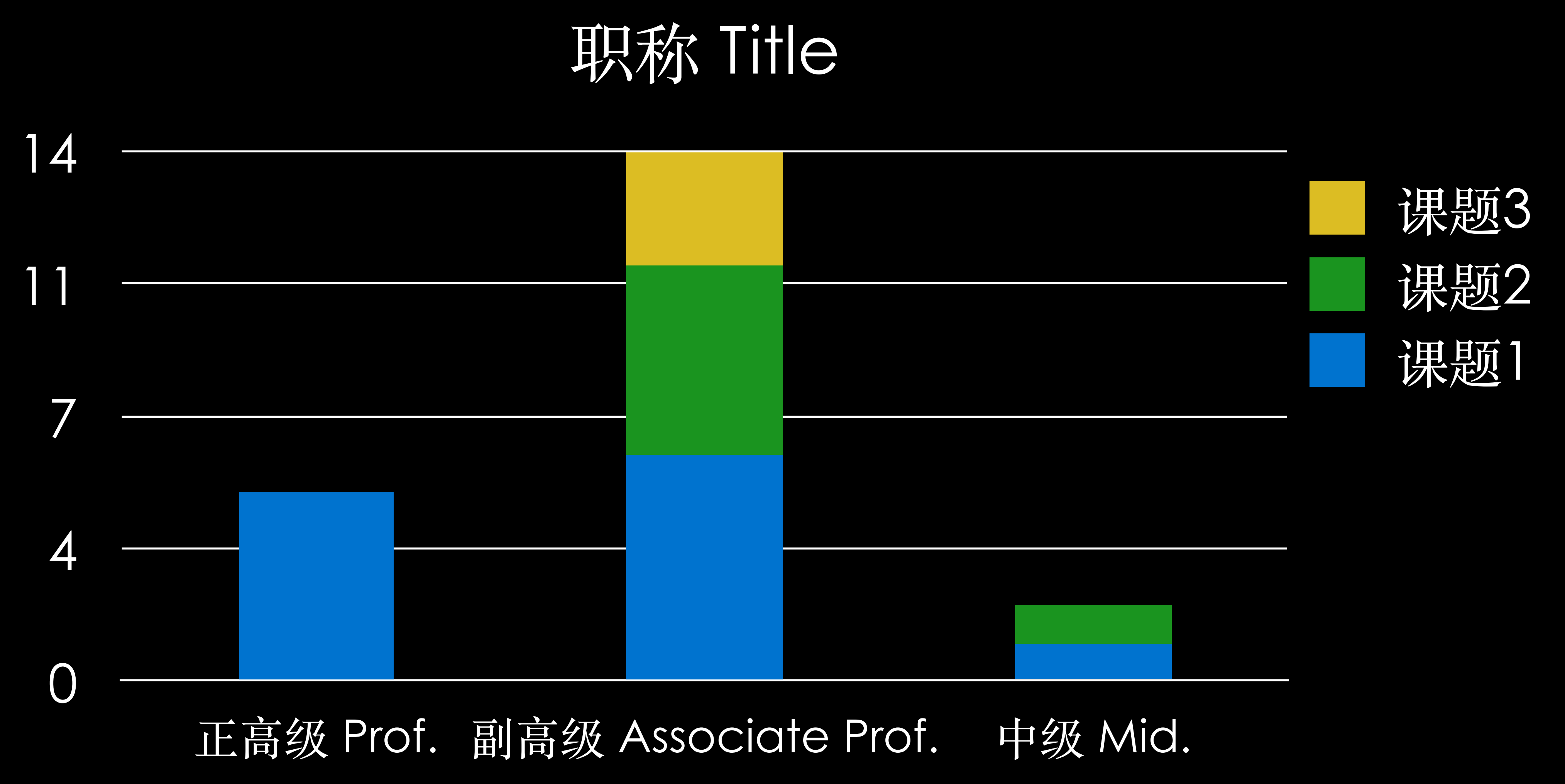
2. 任务分解和主要研究:

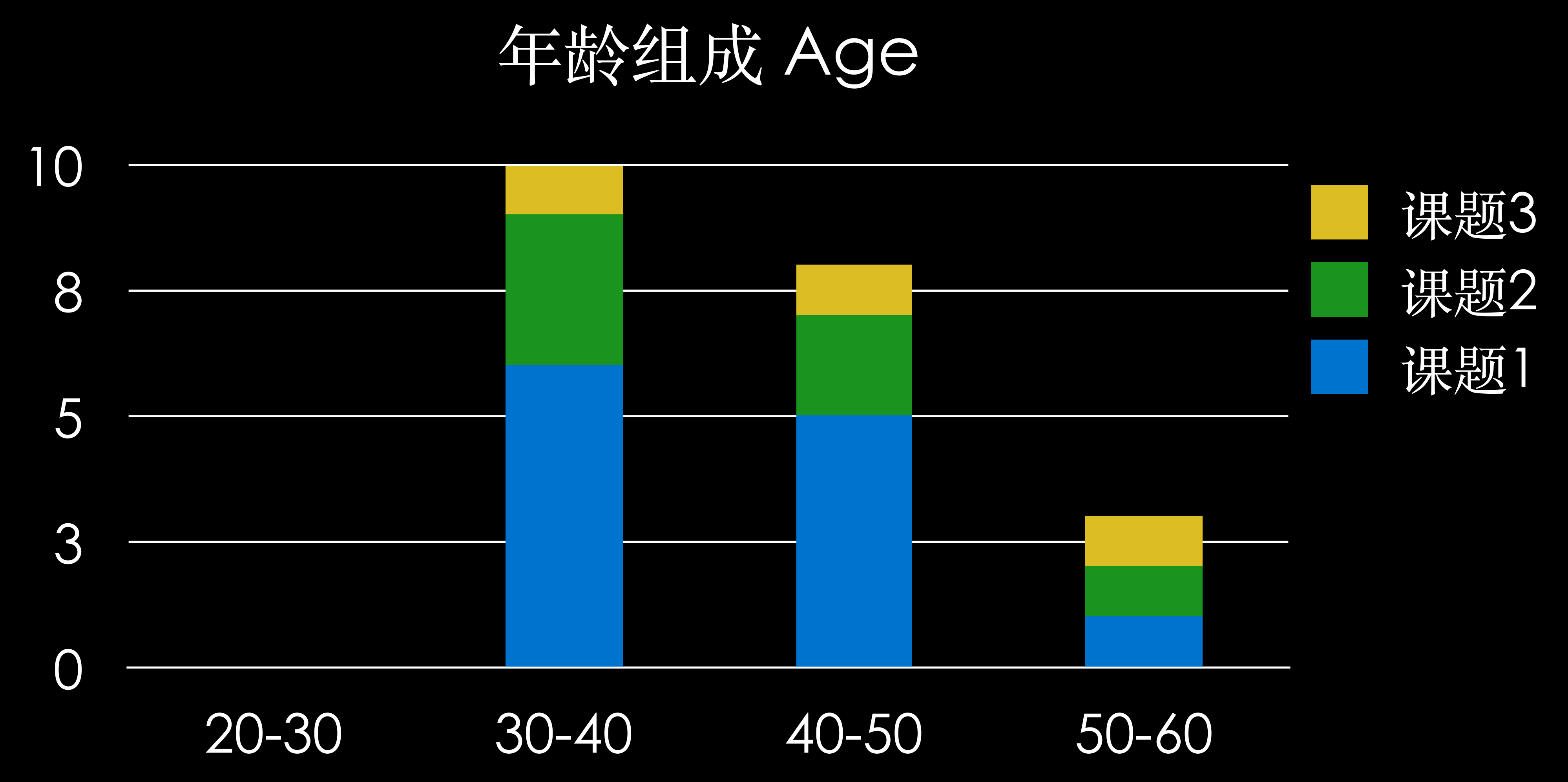
Task Arrangement and Main Research

The team

Research Team (研究团队)

Total number of team members: 21





Average age 41 years old

课题1：
中国科学院高能物理研究所（IHEP）
中国科学技术大学（USTC）
南京大学（NJU）
山东大学（SDU）

课题2：
中国科学院高能物理研究所（IHEP）
中国科学技术大学（USTC）
清华大学（THU）

课题3：
中国科学技术大学（USTC）
上海交通大学（SJTU）

Project Leader (项目负责人)

就读于:

João Guimarães da Costa

中国科学院高能物理研究所研究员，博士生导师

Engaged in track detector research and construction (drift chamber, silicon detector) NA38 → CDF → ATLAS, and physics research

Since 2015， Professor of IHEP, ATLAS Group leader of IHEP

2006-2015， Assistant and Associate Professor at Harvard University

In 2016, got "1000 talents" grant 国家"千人计划"高层次外国专家长期项目资助

- Since 2021, member of ATLAS Executive Board
- Since 2021, ATLAS HGTD project leader
- 2019-2021, ATLAS HGTD project Resource Coordinator and Deputy Project Leader
- Since 2016, Convener of CEPC Detector and Physics Group
    - 2019-2023, 作为项目负责人，承担国家重点研发项目"高能环形正负电子对撞机关键技术研发和验证"
- Until 2016, member of the ATLAS Muon Detector Steering Group
- Former convener of the ATLAS Standard Model Physics Group and the Higgs to WW Physics Group

Task Leaders (课题负责人)

Zhijun Liang (Task 1 leader) 梁志均（课题1负责人）

- 中国科学院高能物理研究所研究员，中国科学院“百人计划”，博士生导师

2020-now: ATLAS High Granularity Timing Detector Level-2 convener: Module assembly
2021-2023: ATLAS publication committee members
2014-2015: LHC electroweak physics subgroup convener
2012-2013: ATLAS electroweak physics group convener

Xin Shi (Task 2 leader) 史欣（课题2负责人）

- 中国科学院高能物理研究所副研究员，博士生导师

2022-now: ATLAS ITk Strip Barrel UK/China Cluster Manager
2018-now: CERN RD50 (Radiation Detector R&D) IHEP Team leader
2015 – now: ATLAS Inner Tracker Phase-II upgrade
2011 – 2015: CMS Pixel Detector Phase-I upgrade

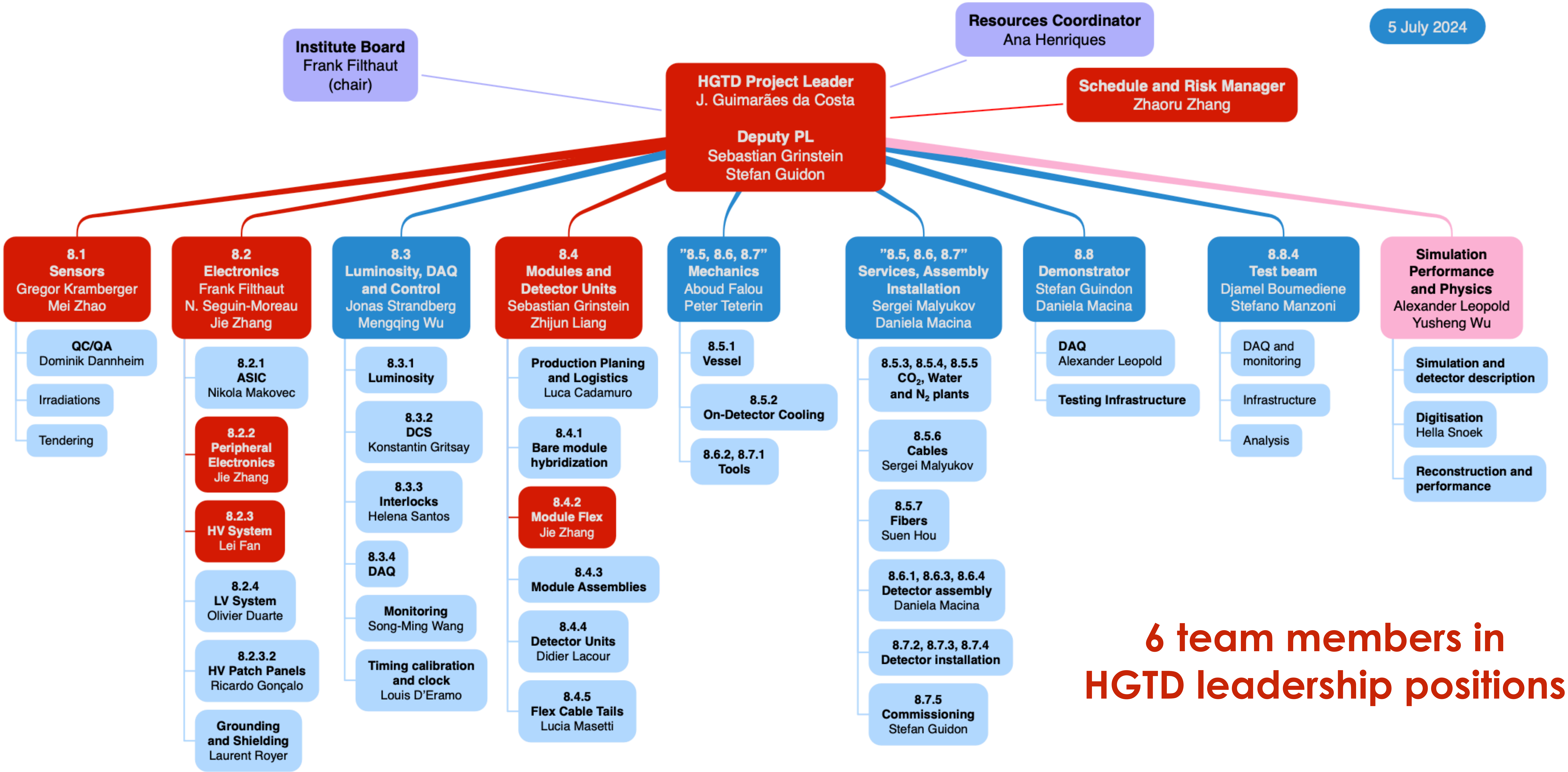
Yongjie Sun (Task 3 leader) 孙勇杰（课题3负责人）

- 中国科学技术大学副教授

Since 2015: Muon RPC Phase-II Upgrade of ATLAS (LV3 coordinator)
2009-2015: End-cap Time-of-Flight system upgrade for BESIII
2008-now: Time-of-Flight system for Compressed Baryonic Matter (CBM) on FAIR at GSI (Collaboration Board)
2006-2013: Muon Telescope Detector (MTD) for RHIC/STAR, U.S.A
2004-2010: Time-of-Flight system for the STAR Experiment on RHIC at BNL, U.S.A

All hold management positions within ATLAS for the corresponding projects

ATLAS Timing Detector Management

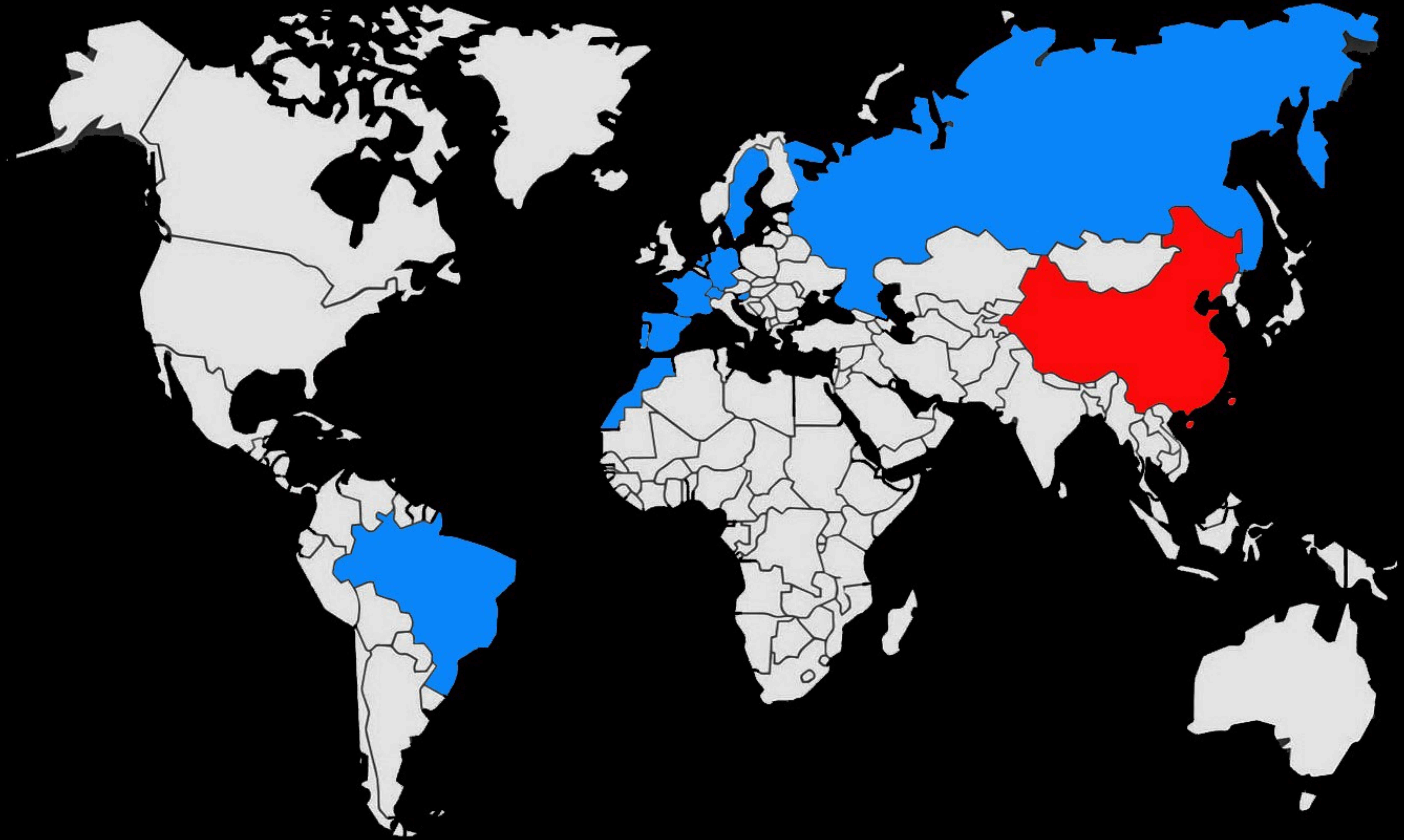


6 team members in HGTD leadership positions

International Cooperation (国际合作）

课题1 (HGTD):

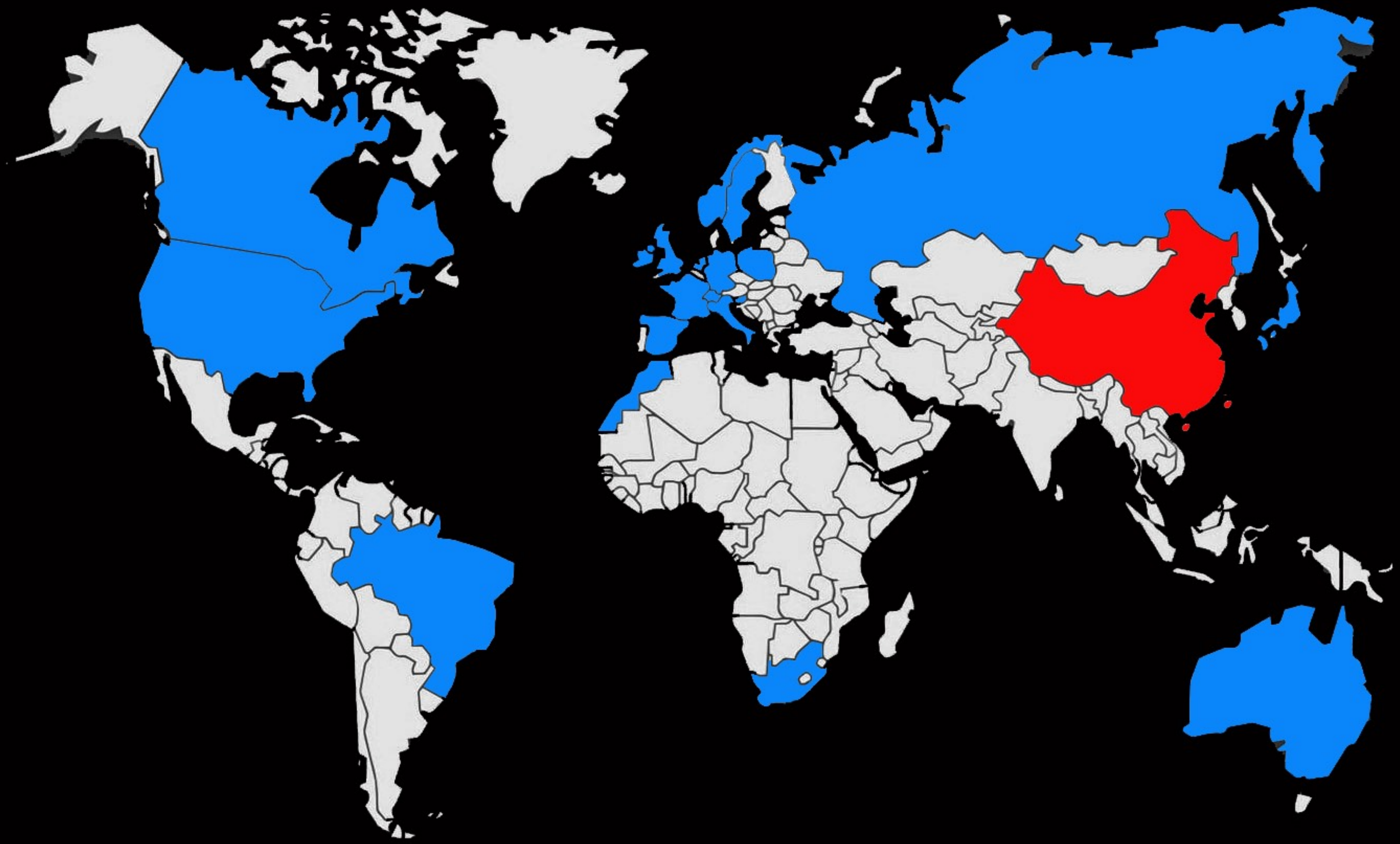
Brazil
China
France
Germany
JINR
Morocco
Netherlands
Portugal
Russia
Slovenia
Spain
Sweden
CERN



International Cooperation (国际合作)

课题2 (ITK):

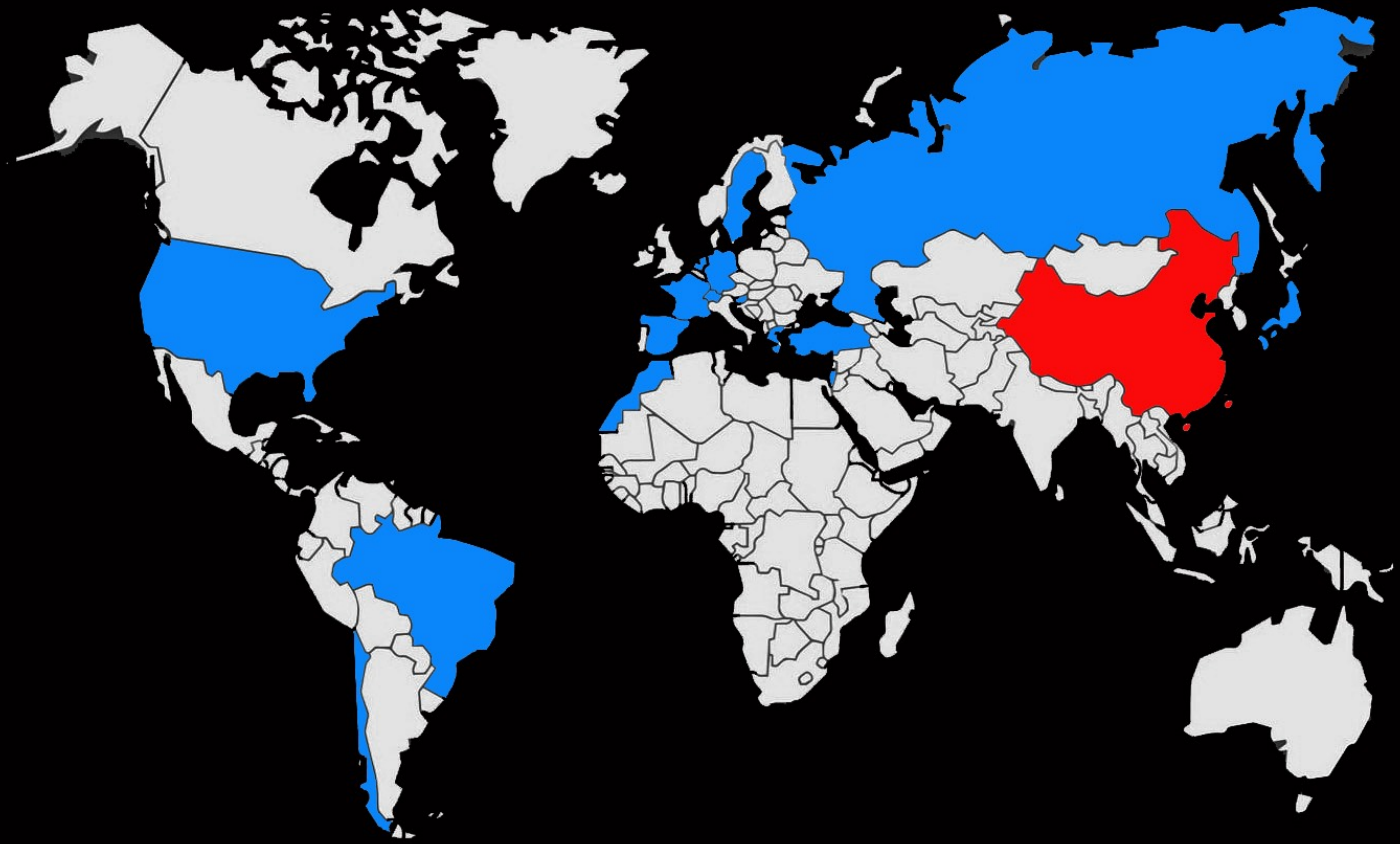
Australia
Canada
China
Czech Republic
Denmark
France
Germany
Italy
Japan
Netherlands
Norway
Poland
Russia
Slovenia
South Africa
Spain
Sweden
Switzerland
United Kingdom
USA
CERN



International Cooperation (国际合作)

课题3 (Muon):

Chile
China
France
Germany
Greece
Israel
Italy
Japan
Netherlands
Russia
JINR
Turkey
USA
CERN



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（2023.12 - 2024.11）

Main Milestones

- Tasks 1:
  - Develop full-scale LGAD ultrafast silicon sensors and detector modules
  - Create prototypes of electronics peripheral circuit boards, flexible circuit boards, and high-voltage power supplies
- Task 2:
  - Test silicon microstrip sensor performance and master module production process
  - Conduct literature research on time pixel detector and analyze design requirements
  - Test readout chip performance, prepare long silicon modules, and complete system tests.
- Task 3:
  - Design RPC air gap, fabricate key components, and test
  - Design large-area readout board, start fabrication and testing
  - Fabricate prototype RPC detector, test, and produce readout plates and detectors

Outcome

- Annual report, design report, test report, ATLAS review report

第二年（2024.12 - 2025.11）

Main Milestones

- Tasks 1:
  - Develop full-scale LGAD ultrafast silicon sensors and electronic peripheral circuit boards
  - Produce detector modules, flexible circuit board tail boards, and high-voltage power supplies
- Task 2:
  - Test sensor and chip performance under various irradiation conditions
  - Complete design of time pixel detector sensor gain layer and prototype circuit
  - Participate in reliability testing, produce silicon modules, test cask plates, develop time pixel sensor optics, and verify circuit functionality
- Task 3:
  - Design RPC gas chamber at BIM/BIR position
  - Fabricate and test 300 honeycomb readout boards
  - Produce 150 single-layer RPC detectors, test front-end electronics, and perform cosmic ray tests

Outcome

- Midterm report, design report, test report, ATLAS review report

第三年（2025.12 - 2026.11）

Main Milestones

- **Tasks 1:**
  - Production and development of detector modules and flexible circuit boards
  - Testing electronic peripheral circuit boards
  - Production and development of high-voltage power supplies
- **Task 2:**
  - Make long silicon microstrip module and load Chinese group's detector at Rutherford Lab
  - Develop first version of time pixel sensor film and prototype circuit program
  - Build short microstrip module, test in Rutherford Laboratory, and integrate into barrel detector. Test time pixel sensor and verify prototype circuit performance
- **Task 3:**
  - Complete cosmic ray test of 150 single-layer RPCs
  - Participate in assembly and testing of three-layer detector chamber
  - Improve air gap production process, ensure stability, and participate in CERN site assembly and debugging

Outcome

- Annual report, test report, ATLAS review report

第四年（2026.12 - 2027.11）

Main Milestones

- **Tasks 1:**
  - Complete production and development of detector units with multiple modules
  - Assemble electronic circuit boards at CERN
  - Install high-granularity detector disk and all detectors at CERN, start joint commissioning
- **Task 2:**
  - Produce short silicon strip module for barrel detector sealing, evaluate time pixel sensor Version 1 and test electronics Version 1
  - Produce short silicon microstrip modules, participate in track detector test at CERN, design and simulate second version of time pixel detector sensor and circuit
- **Task 3:**
  - Participate in on-site installation and commissioning of detector, establish testing platform at CERN
  - Continue on-site installation and commissioning, promptly address and repair any issues

Outcome

- Annual report, design report, test report, ATLAS review report

第五年（2027.12 - 2028.11）

Main Milestones

- Tasks 1:
  - Conduct overall detector debugging and joint commissioning at CERN for high-particle detectors, and finalize project report
- Task 2:
  - Participate in joint testing of track detector, test time pixel sensor and electronics, write technical design document, and summarize experience
- Task 3:
  - Complete on-site installation, commissioning, and testing of detector, and prepare for project completion and acceptance

Outcome

- Final report, detector performance test report

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

Project management organization

- MOST Project Responsibility Expert
  - Ma Yugang (Shanghai Institute of Applied Physics, CAS) (Excused today)

- Expert Team (9 people)
  - Li Ji (Institute of High Energy Physics, CAS) (Chair)
  - Xiang Dao (Shanghai Jiao Tong University) (MOST expert team)
  - Li Qiang (Peking University)
  - Li Zhankui (Institute of Modern Physics, CAS)
  - Liu Jianbei (University of Science and Technology of China)
  - Sun Xiangming (Central China Normal University)
  - Zhou Daicui (Central China Normal University)
  - Heng Yuekun (Institute of High Energy Physics, CAS)
  - Ouyang Qun (Institute of High Energy Physics, CAS)

Project leader — Management responsibilities

HTRDC
高技术研究发展中心

- Edit and sign project task book, review project task book;
- Establish a project management office and a project expert group based on the project leading institute;
- Formulate the project research plan, make sure the academic direction and research focus of the project;
- Carry out academic and technical communication and integration among tasks, and promote data sharing;
- Review the annual summary, technical report and other materials, compile and report project information, achievements and other progress reports;
- Develop project publicity plans and programs to enhance the impact of the project;
- Formulate the project (task) implementation management system, formulate the approval system of funding allocation process;
- Propose major adjustment suggestions for projects (tasks), including adjustment or change of research objectives, contents, personnel and funding;
- Compile the mid-term assessment and annual report of the project, and cooperate with the completion of the mid-term assessment and acceptance of the tasks;
- Cooperate with MOST to complete the project assessment and acceptance;
- Complete other tasks entrusted by MOST

Project management organization

- Project office
  - Contact person： Zhaoru Zhang
  - Academic assistant： Zhijun Liang (Associate professor)
  - Financial assistant： Zhaoru Zhang
  - Contact person of Task 1: Zhijun Liang （task leader)
    - Financial assistant: Ran Lou
  - Contact person of Task 2: Xin Shi （task leader)
    - Financial assistant: Ran Lou
  - Contact person of Task 1: Yongjie Sun （task leader)
    - Financial assistant: Gongxiu Dong

- Project implementation scheme is finalized

Project management organization

- Members of this project have good experience in large scale projects (ATLAS, CMS, RHIC, BES, JUNO, CEPC) and International Collaborations
  - Extensive experience with international publications, international conferences, paper reviews, scientific analysis and results verification, scientific research integrity, etc…
- The project is well integrated in the overall goals of the ATLAS Collaboration and the wider HEP international community
  - All members are part of the ATLAS Collaboration and several hold relevant leadership positions within the international structure of the Collaboration → hence have full support from a wider range of resources
- In strict compliance with the relevant policies, regulations and requirements of the Ministry of Science and Technology, the project will be responsible for organizing academic exchanges, urging task leaders and project members to complete research work on schedule, and actively cooperate with the Ministry of Science and Technology to report project progress and work inspection on time
- Provisions for fund management have been formulated, and the project office will supervise the regular use of funds (afternoon discussion)

Project management organization

- **Communication and Inspection Mechanisms**
  - **Exchange mechanism:**
    - Strong integration in the ATLAS global activities, meetings and workshops
      - Regular international meetings being held weekly on diverse topics
    - Weekly internal task-level meetings to coordinate evolution of project
      - (e.g. international meeting on ASIC design every monday)
    - Monthly videoconference meetings on the global project
  - **Special meetings**
    - Conduct academic exchanges (e.g. ATLAS HGTD Workshop at IHEP next week)
    - Annual meetings: including mid-term meeting and projection completion meeting
  - **Documentation archiving:**
    - ATLAS Collaboration provides excellent tools for documentation archiving:
      - Indico: Meetings and minutes
      - EDMS database: Specifications and long-term technical documentation archiving
      - CDS: Internal reports and technical working reports archiving
    - Establish a project shared web area in IHEP for sharing and archiving documentation locally

Risk Analysis (风险分析)

The project is challenging and a key contribution to the ATLAS upgrade

- The overall risk of the project is low
  - The project team has rich experience in research and development
  - The research unit is supported by multiple detector research and development platforms
- The two main risks (两个最主要的风险)
  - 风险1: Degradation of international relations prevent access to some advanced technologies from abroad (e.g. ASICs)
    - Mitigation: Collaborate with international colleagues to execute some of the tasks abroad (e.g. tracker modules construction at RAL)
  - 风险2: Delay of LHC Upgrade Project — the ATLAS upgrade is organized in a large international collaboration involving many institutions with interconnected work with centralized overall planning, so delays can occur due to issues outside our control
    - Mitigation: Work with ATLAS management to minimize impact to the project. The large international team will ensure that the project is feasible even if delays occur.

5. 成果呈现形式及测试方法:

Achievement Presentation and Assessment Methods

Expected achievements and Innovations (预期成果与创新点)

第一个用于对撞机实验的硅基高精度时间探测器

- First silicon-based timing detector in particle physics
  - Built with the most radiation resistant silicon timing sensors only available in China

ATLAS内径迹探测器是最大硅基径迹探测器之一

- ATLAS Inner Tracker will be one of the largest silicon-based tracking detector
  - Research on the new timing pixel detector has the potential to be used for the next generation of the ATLAS pixel detector

ATLAS的窄气隙RPC将是此类探测器首次大规模运行

- The thin-gap RPC in ATLAS will be the first large-scale operation of such detectors
  - Built with the largest PCBs only available in China

Results from this research can be used for future generation detectors

Social and economical benefits (预期经济社会效益)

- The high granularity time detector and inner track detector developed in this project are the most advanced semiconductors in the field of particle physics detectors.
  - They can be widely applied in nuclear physics experiments, synchrotron radiation imaging, X-ray imaging, medical imaging, aerospace exploration, etc.
- Large RPCs can be used in medical imaging and Tomography / Muography in many fields, such as archaeology, civil engineering, mining exploration, geology, nuclear reactor monitoring, nuclear waste characterization, underground surveys, etc.
- Conduct research on advanced detector technology to promote relevant domestic manufacturers to master key technologies.
- Outcome is crucial to the completion of the ATLAS Upgrade and future physics

Achievement Presentation and Assessment Methods

	Assessment indicators				Assessment methods and evaluation methods
	Indicator	**Indicator at the time of project initiation**	**Midterm indicator**	**Final assessment indicator**	
Task 1: HGTD	**Time resolution**	Small-area prototype silicon sensors: better than 50 ps	Official silicon sensors for ATLAS upgrade: 30-50 ps	Final detector module: 30-50 ps	Test reports, project peer reviews.
Task 2: Inner tracker	**Spatial resolution of silicon microstrip track detectors**	Prototype module: 25 microns	Pre-production module: 25 microns	Full detector: 25 microns	Test reports, project peer reviews.
	Silicon pixel detector time resolution	Better than 10 ns	Better than 1 ns	Better than 100 ps	Simulation verification and laboratory testing, test reports

In addition: ATLAS organizes peer-reviews, with external reviewers, at each step of each upgrade project. Such reports, will provide an additional basis for each task progress and achievement assessment

Achievement Presentation and Assessment Methods

	Assessment indicators				Assessment methods and evaluation methods
	Indicator	**Indicator at the time of project initiation**	**Midterm indicator**	**Final assessment indicator**	
Task 3: Muon Detector	**Counting rate**	Prototype detector: 1 kHz/cm2	Pre-production detector: 1 kHz/cm2	RPC mounted to ATLAS: >1 kHz/cm2	Experimental test or acceptance by ATLAS
	Probing efficiency	RPC Prototype: > 95%	Pre-production detectors: >95%	RPC mounted to ATLAS: > 95%.	Experimental test or acceptance by ATLAS
	Time Resolution	Prototype detector: 1 ns	Pre-production detector: 1 ns	RPC installed into the ATLAS experiment < 1 ns	Experimental test or acceptance by ATLAS

In addition: ATLAS organizes peer-reviews, with external reviewers, at each step of each upgrade project. Such reports, will provide an additional basis for each task progress and achievement assessment

Assessment Indicators of Science and Technology Report

序号	Report type	数量	Submission time	公开类别及时限
1	Annual technical progress report of project	1	December 2024	公开
2	Mid-project technical progress report	1	Before the mid-term examination	公开
3	Annual technical progress report of project	1	December 2026	公开
4	Annual technical progress report of project	1	December 2027	公开
5	Final technical progress report of the project	1	December 2028	公开

Conclusions - 结语

This project is crucial to the completion of the ATLAS Upgrade and future physics outcome

It will promote Chinese industry on frontier technologies driving development

- The management system has been established and the implementation plan has been formulated
- The research work has already started for all three tasks
- The project has very good foundations:
  - The institutions have good support and infrastructure for the project
  - The staff ranks at high level and has strong experience in detector research

谢谢您

Extra Slides

Assessment Indicators (考核指标)

对应的课题	考核指标：指标名称	立项时已有指标值/状态	中期指标值/状态	完成时指标值/状态	考核方式（方法）及评价手段
课题 1：ATLAS 实验高粒度时间探测器升级 **HGTD**	时间分辨率	小面积原型硅传感器时间分辨率好于 50 皮秒	为 ATLAS 升级研制出正式的硅传感器，时间分辨率达到 30-50 皮秒	探测器模块时间分辨率达到 30-50 皮秒	测试报告、同行评审。
课题 2：ATLAS 实验内径迹探测器升级：**Tracker**	硅微条径迹探测器空间分辨率	原型模块 25 微米	预生产模块 25 微米	径迹探测器 25 微米	测试报告、同行评审。
	硅像素探测器时间分辨率	好于 10ns	好于 1ns	好于 100ps	仿真验证和实验室测试，测试报告

对应的课题	考核指标：指标名称	立项时已有指标值/状态	中期指标值/状态	完成时指标值/状态	考核方式（方法）及评价手段
课题 3：ATLAS 实验缪子探测器升级 **Muons**	计数率	原型探测器 1 kHz/cm2	预生产探测器 1 kHz/cm2	安装到 ATLAS 实验的 RPC：>1 kHz/cm2	实验测试或由 ATLAS 验收
	探测效率	RPC 样机>95%	预生产探测器>95%	安装到 ATLAS 实验的 RPC >95%	实验测试或由 ATLAS 验收
	时间分辨	原型探测器 1 ns	预生产探测器 1 ns	安装到 ATLAS 实验的 RPC <1 ns	实验测试或由 ATLAS 验收

Guidance:“大科学装置前沿研究”重点专项2023年度项目申报指南

1. 粒子物理

1.3. ATLAS探测器升级

Research content: According to the cooperation agreement with ATLAS, complete the research, development, manufacturing and installation of silicon track detector, muon spectrometer and high Granularity time detector. In view of the upgrade of LHC's high energy and high brightness, the Particle detector system of ATLAS experiment was modified, and the development, construction and operation of related detectors were carried out to improve the sensitivity of ATLAS experiment to physical processes. Mainly including: construction of silicon track detector modules, integration and operation of track detector systems; Development and operation of muon spectrometer resistive plate detector and related electronics; R&D and construction of high Granularity time detector; The development of a new generation of silicon pixel detectors with time information.

Assessment indicator:

HGTD: develop silicon sensor, front-end electronics, detector module assembly, etc., and develop a detector module and front-end readout circuit board with high time resolution, whose time resolution is better than 50 picoseconds.

ITK: The spatial resolution of the silicon microstrip track detector reaches 25 micrometers. A new generation of **silicon pixel detectors with time information**: Develop radiation resistant sensors and front-end electronics with a time resolution of less than 100 picoseconds.

RPC detector: The counting rate reaches 1kHz/cm2, the detection efficiency is higher than 95%, and the time resolution is better than 1ns.

Chinese CORE contribution to ATLAS Phase-II Detector Upgrade

ATLAS	ITk	HGTD	Muons	NSW (phase I)	Total (kCHF)
kCHF	2043	2100	1028	733	5904
%	3.4%	21%	3.6%	6.5%	2.3%

Focus on key projects to make a sizable contribution with limited resources

Chinese contribution to upgrades of the order of ~2.3% of total cost

Percentage of Chinese authorship on physics analysis papers ~4.3%

Risk Analysis

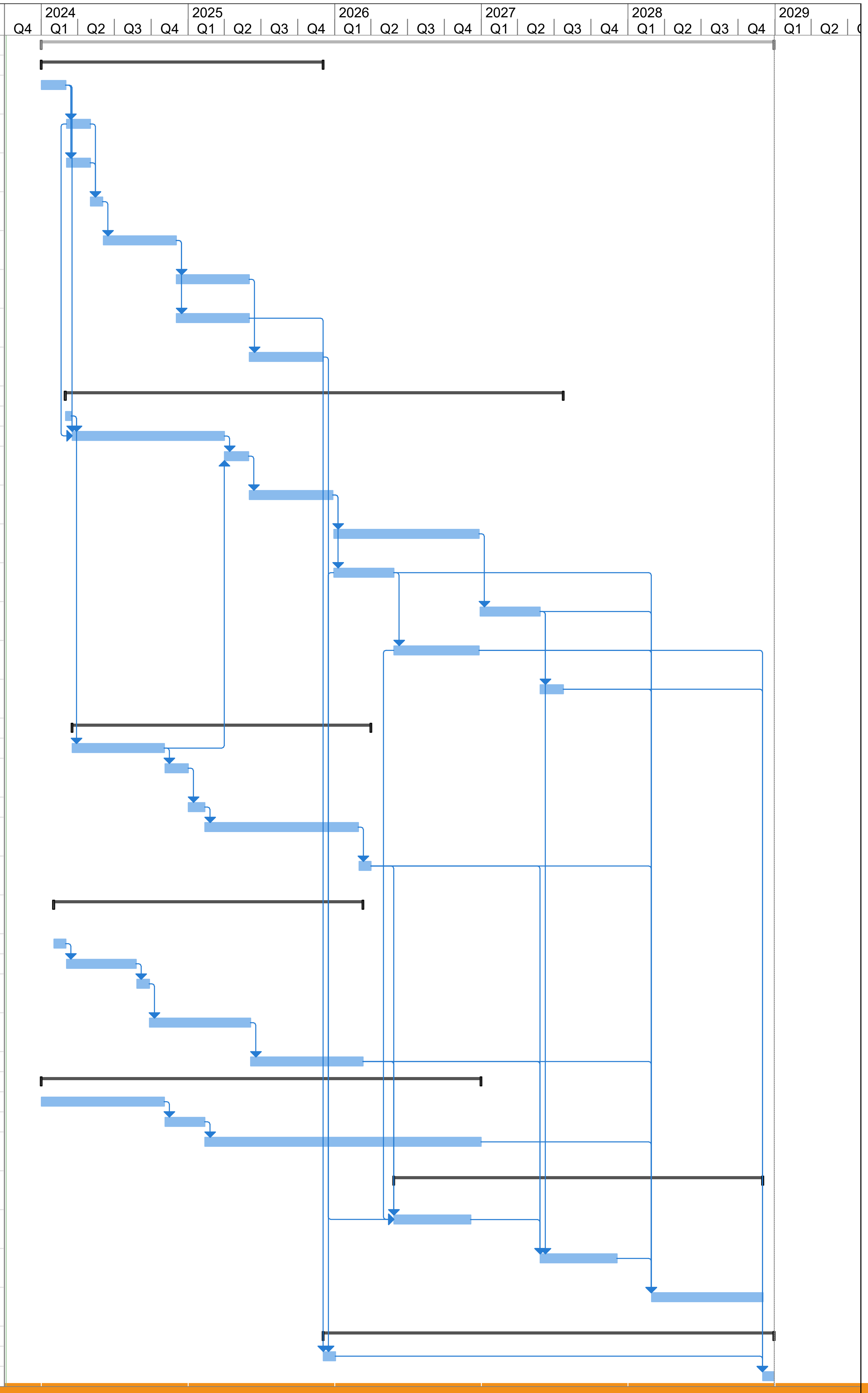
- Delay of LHC Project
  - Type: policy
  - Risk Level: middle
  - Mitigation plan: keep communication with CERN and ATLAS, reduce the uncertainty of LHC to this project
- ASICs for ITk not able to import to China
  - Type: policy
  - Risk level: middle
  - Mitigation plan: send people to RAL in UK to complete the module assembly task
- Timing pixel front end electronics not able to import to China
  - Type: policy
  - Risk level: middle
  - Mitigation plan: send people to US or CERN to continue the study. Investigate technology based on China

Detailed schedule

Timing Detector Detailed Schedule

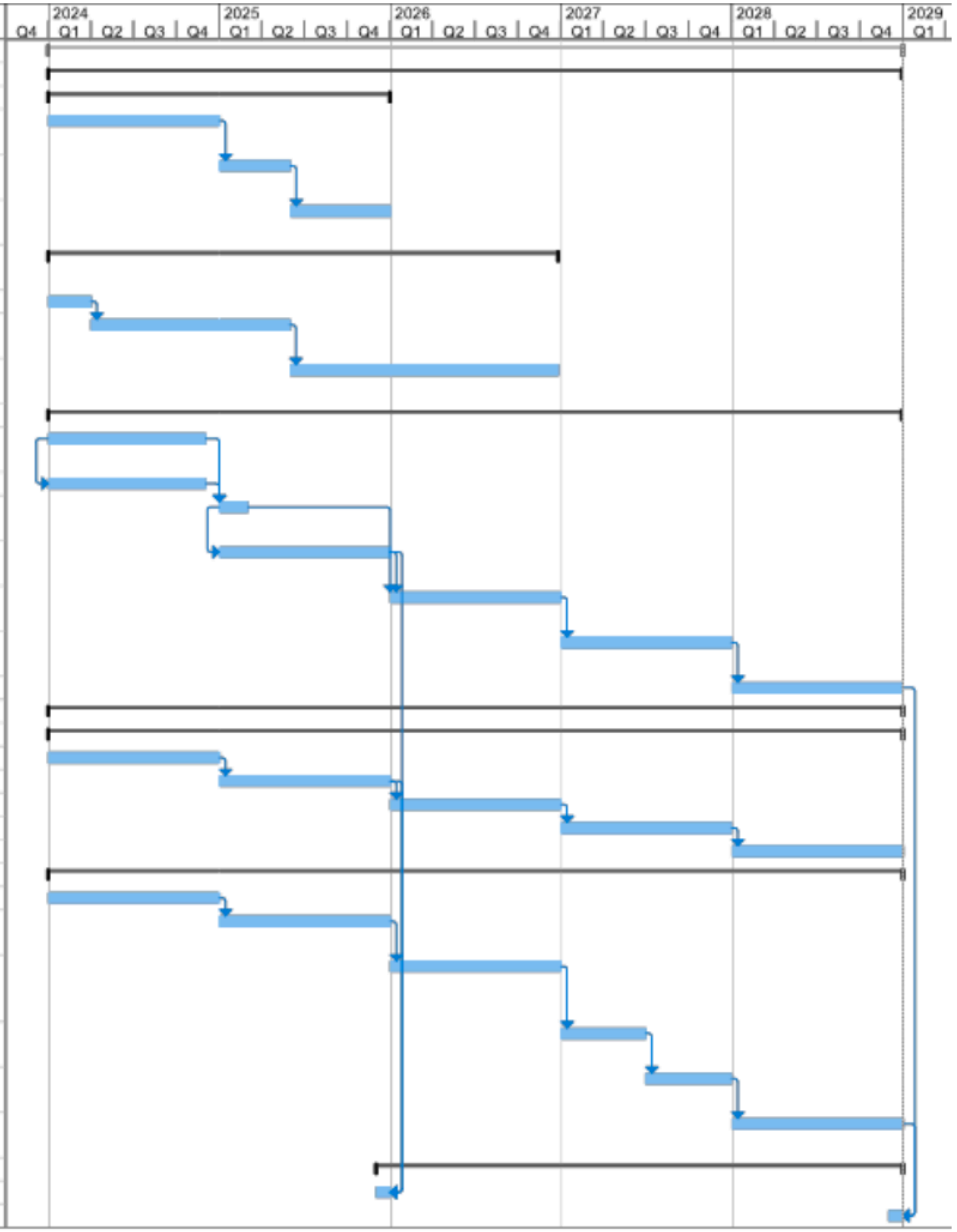
ATLAS EXPERIMENT

ID	Task Name	Text1	Duration	Start	Finish
0	1）高粒度时间探测器	**1) High granularity time detector**	**1305 days**	**2024/1/1**	**2028/12/29**
1	1.1）传感器	**1.1) sensor**	**502 days**	**2024/1/1**	**2025/12/2**
2	1.1.1）预生产研制（第一批）	1.1.1) pre production development (the first batch)	45 days	2024/1/1	2024/3/1
3	1.1.2）预生产研制（第二批）	1.1.2) pre production development (the second batch)	43 days	2024/3/4	2024/5/1
4	1.1.3）预生产传感器性能测试	1.1.3) pre production sensor performance test	43 days	2024/3/4	2024/5/1
5	1.1.4）预生产传感器评审（PRR）	1.1.4) pre production sensor review (PRR)	22 days	2024/5/2	2024/6/1
6	1.1.5）正式生产研制（第一批）	1.1.5) formal production and development (the first batch)	130 days	2024/6/3	2024/12/1
7	1.1.6）正式生产研制（第二批）	1.1.6) formal production and development (the second batch)	130 days	2024/12/2	2025/6/1
8	1.1.7）正式生产传感器性能测试（第一批）	1.1.7) performance test of formally produced sensors (the	130 days	2024/12/2	2025/6/1
9	1.1.8）正式生产传感器性能测试（第二批）	1.1.8) performance test of formally produced sensors (the	132 days	2025/6/2	2025/12/2
10	1.2）探测器模块	**1.2) detector module**	**886 days**	**2024/3/1**	**2027/7/23**
11	1.2.1）原型模块评审（FDR）	1.2.1) prototype module review (FI	11 days	2024/3/1	2024/3/15
12	1.2.2）预生产研制	1.2.2) pre production developmen	271 days	2024/3/18	2025/3/31
13	1.2.3）预生产的模块评审（PRR）	1.2.3) pre production module review (PRR)	44 days	2025/4/1	2025/5/30
14	1.2.4）模块正式研制（第一批）	1.2.4) formal development of modules (the first batch)	150 days	2025/6/2	2025/12/26
15	1.2.5）模块正式研制（第二批）	1.2.5) formal development of modules (the second batch)	260 days	2025/12/29	2026/12/25
16	1.2.6）多模块探测器单元研制（第一批）	1.2.6) development of multi module detector unit (the first	108 days	2025/12/29	2026/5/27
17	1.2.7）多模块探测器单元研制（第二批）	1.2.7) development of multi module detector unit (the second	108 days	2026/12/28	2027/5/26
18	1.2.8）探测器模块性能测量（第一批）	1.2.8) performance measurement of detector module (the first	152 days	2026/5/28	2026/12/25
19	1.2.9）探测器模块性能测量（第二批）	1.2.9) performance measurement of detector module (the second	42 days	2027/5/27	2027/7/23
20	1.3）柔性电路尾板	**1.3) flexible circuit tail board**	**532 days**	**2024/3/18**	**2026/3/31**
21	1.3.1）预生产研制	1.3.1) pre production developmen	165 days	2024/3/18	2024/11/1
22	1.3.2）预生产柔性板测试	1.3.2) pre production flexible plate test	42 days	2024/11/4	2024/12/31
23	1.3.3）预生产的评审（PRR）	1.3.3) pre production review (PRR)	29 days	2025/1/1	2025/2/10
24	1.3.3）正式生产研制	1.3.3) formal production and development	274 days	2025/2/11	2026/2/27
25	1.3.4）正式生产柔性板测试	1.3.4) formal production flexible plate test	22 days	2026/3/2	2026/3/31
26	1.4）外围电子学电路板	**1.4) peripheral electronics circuit board**	**550 days**	**2024/2/1**	**2026/3/11**
27	1.4.1）原型模块评审（FDR）	1.4.1) prototype module review (FI	22 days	2024/2/1	2024/3/1
28	1.4.2）预生产研制	1.4.2) pre production developmen	125 days	2024/3/4	2024/8/23
29	1.4.3）预生产的模块评审（PRR）	1.4.3) pre production module review (PRR)	23 days	2024/8/26	2024/9/25
30	1.4.4）正式生产研制	1.4.4) formal production and development	180 days	2024/9/26	2025/6/4
31	1.4.5）电路板测试	1.4.5) circuit board test	200 days	2025/6/5	2026/3/11
32	1.5）高压电源	**1.5) high voltage power supply**	**783 days**	**2024/1/1**	**2026/12/30**
33	1.5.1）预生产研制	1.5.1) pre production development	220 days	2024/1/1	2024/11/1
34	1.5.2）预生产的评审（PRR）	1.5.2) pre production review (PRR)	71 days	2024/11/4	2025/2/10
35	1.5.3）正式生产研制	1.5.3) formal production and development	492 days	2025/2/11	2026/12/30
36	1.6）探测器整体联调	**1.6) overall joint commissioning of detector**	**657 days**	**2026/5/28**	**2028/12/1**
37	1.6.1）探测器单元安装（第一批）	1.6.2) installation of detector unit (the first batch)	137 days	2026/5/28	2026/12/4
38	1.6.2）探测器单元安装（第二批）	1.6.2) detector unit installation (the second batch)	137 days	2027/5/27	2027/12/3
39	1.6.3）探测器整体联调	1.6.3) overall joint commissioning of detector	200 days	2028/2/28	2028/12/1
40	1.7）项目文档	**1.7) project documents**	**803 days**	**2025/12/3**	**2028/12/29**
41	1.7.1）项目中期测试报告	1.7.1) Interim test report of the proje	22 days	2025/12/3	2026/1/1
42	1.7.1）项目结题报告	1.7.1) project conclusion report	21 days	2028/12/1	2028/12/29



Silicon Tracker Detailed Schedule

ID	Task Name	Text1	Duration	Start	Finish
0	硅径迹探测器	**Silicon track detector**	**1305 days**	**2024/1/1**	**2028/12/31**
1	**1**）硅微条探测器	**1) Silicon micro strip detector**	**1305 days**	**2024/1/1**	**2028/12/29**
2	**1.1**）传感器与读出芯片	**1.1) sensor and readout chip**	**523 days**	**2024/1/1**	**2025/12/31**
3	1.1.1）传感器与读出芯片关键性能测试	1.1.1) key performance test of sensor and readout chip	262 days	2024/1/1	2024/12/31
4	1.1.2）传感器、芯片在不同辐照条件下的性能表现	1.1.2) performance of sensors and chips under different irradiation conditions	108 days	2025/1/1	2025/5/31
5	1.1.3）参与批量生产阶段可靠性测试	1.1.3) participate in reliability test in batch production stage	153 days	2025/6/2	2025/12/31
6	**1.2**）硅微条探测器研制	**1.2) development of silicon micro strip detector**	**780 days**	**2024/1/1**	**2026/12/25**
7	1.2.1) 模块站点考核	1.2.1) module site assessment	65 days	2024/1/1	2024/3/31
8	1.2.2) 制备长硅微条模块	1.2.2) preparation of long silicon micro strip module	305 days	2024/4/1	2025/5/30
9	1.2.3) 制备短硅微条模块	1.2.3) preparation of short silicon micro strip module	410 days	2025/6/2	2026/12/25
10	**1.3**）系统集成	**1.3) system integration**	**1305 days**	**2024/1/1**	**2028/12/29**
11	1.3.1) 多桶板小系统联调测试	1.3.1) joint commissioning test of multi barrel small system	240 days	2024/1/1	2024/12/1
12	1.3.2) 搭建桶板接收测试系统	1.3.2) build a barrel receiving test system	240 days	2024/1/1	2024/12/1
13	1.3.3) 接收、测试运往 CERN 的首批桶板	1.3.3) receive and test the first batch of barrels shipped to CERN	43 days	2025/1/1	2025/3/1
14	1.3.4) 中国生产的硅探测器模块加载到 RAL 的桶板上	1.3.4) the silicon detector module made in China is loaded on the barrel of ral	261 days	2025/1/1	2025/12/31
15	1.3.5) 完成测试后运往 CERN 安装点	1.3.5) transport to CERN installation site after testing	261 days	2026/1/1	2026/12/31
16	1.3.6) 封闭桶部探测器，联调测试	1.3.6) closed barrel detector, joint commissioning test	261 days	2027/1/1	2027/12/31
17	1.3.7) 早期运行	1.3.7) early operation	260 days	2028/1/3	2028/12/29
18	**2**）时间像素探测器	**2) Time pixel detector**	**1305 days**	**2024/1/1**	**2028/12/31**
19	**2.1**）传感器	**2.1) sensor**	**1305 days**	**2024/1/1**	**2028/12/31**
20	2.1.1）整体架构设计	2.1.1) overall architecture design	262 days	2024/1/1	2024/12/31
21	2.1.2）第一版设计	2.1.2) first edition design	261 days	2025/1/1	2025/12/31
22	2.1.3）第一版测试	2.1.3) first version test	261 days	2026/1/1	2026/12/31
23	2.1.4）第二版设计	2.1.4) second edition design	261 days	2027/1/1	2027/12/31
24	2.1.5）性能评估	2.1.5) performance evaluation	260 days	2028/1/3	2028/12/31
25	**2.2**）电子学	**2.2) Electronics**	**1305 days**	**2024/1/1**	**2028/12/31**
26	2.2.1）整体架构设计	2.2.1) overall architecture design	262 days	2024/1/1	2024/12/31
27	2.2.2）第一版原型验证电路设计	2.2.2) design of the first version prototype verification circuit	261 days	2025/1/1	2025/12/31
28	2.2.3) 第一版原型验证电路性能的仿真验证	2.2.3) simulation verification of circuit performance in the first version of prototype verification	261 days	2026/1/1	2026/12/31
29	2.2.4）第一版性能评估测试	2.2.4) first edition performance evaluation test	129 days	2027/1/1	2027/6/30
30	2.2.5) 第二版电路设计和仿真	2.2.5) circuit design and Simulation of the second edition	132 days	2027/7/1	2027/12/31
31	2.2.6）完成电子学性能评估测试	2.2.6) complete the electronic performance evaluation test	260 days	2028/1/3	2028/12/31
32	**3**）项目文档	**3) Project documentation**	**804 days**	**2025/12/2**	**2028/12/31**
33	3.1）项目中期测试报告	3.1) Interim test report of the project	22 days	2025/12/2	2025/12/31
34	3.2）项目结题报告	3.2) project conclusion report	21 days	2028/12/1	2028/12/31



Schedule – Strip Detector

- 2024: Finish the sensor and ASICs key evaluation test; pass the site qualification, start producing long strip module; complete multi-stave small system test at RAL, start system integration such as stave reception at CERN
- 2025: Evaluate the performance of strip sensor and ASICs after irradiation, participate in the reliability test during production; produce long strip module; receive, test and ship the barrel stave to CERN, complete the workflow.
- 2026: Complete the long strip module production, start the short strip module production; modules make in China will be loaded on stave at RAL and send to CERN to integrate onto barrel strip tracker
- 2027: Complete the short strip module production; barrel strip tracker test with different stage.
- 2028: Complete the strip tracker system test, participate the early run.

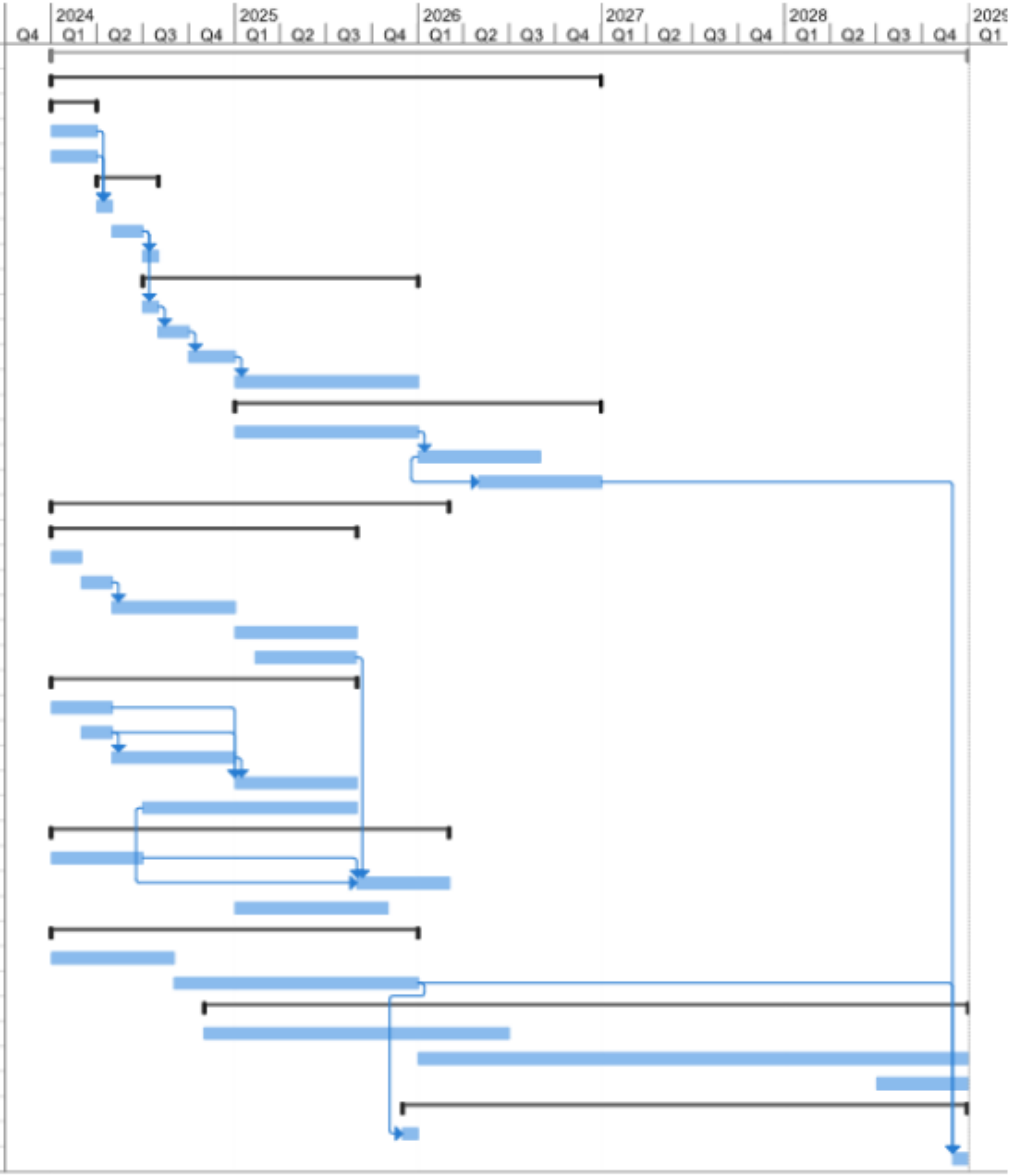
Schedule – Timing Pixel Detector

- 2024: Complete literature survey, clarify the design specifications and technical path, finish the framework and functional module design of sensor and front-end electronics.
- 2025: Complete design of the first sensor, finish the prototype design of the first front-end electronics.
- 2026: Complete the first sensor test, validate the simulation of the first front-end electronics
- 2027: Complete the second sensor design, evaluate the first front-end electronics, improve the circuit structure and parameters, design the second version of electronics.
- 2028: Complete the sensor and front-end electronics evaluation, release document.

Muon Detector Detailed Schedule

ATLAS EXPERIMENT

ID	Task Name	Text1	Duration	Start	Finish
0	缪子探测器	**Muon detector**	**1305 days**	**2024/1/1**	**2028/12/31**
1	**1**）气隙制作和工艺控制	**1) Air gap fabrication and process control**	**784 days**	**2024/1/1**	**2026/12/31**
2	**1.1**）气室边框垫片等机械结构加工和测试	**1.1) machining and testing of mechanical structu**	**65 days**	**2024/1/1**	**2024/3/31**
3	1.1.1）边框加工和测试	1.1.1) frame processing and testing	65 days	2024/1/1	2024/3/31
4	1.1.2）垫片加工和测试	1.1.2) gasket processing and testing	65 days	2024/1/1	2024/3/31
5	**1.2**）小面积气隙制作和测试	**1.2) fabrication and test of small air gap**	**88 days**	**2024/4/1**	**2024/7/31**
6	1.2.1）自动垫片点胶装置调试	1.2.1) commissioning of automatic gasket dispen	22 days	2024/4/1	2024/4/30
7	1.2.2）小面积气隙制作和工艺优化	1.2.2) small area air gap fabrication and process	43 days	2024/5/1	2024/6/30
8	1.2.3）小面积气隙性能测试	1.2.3) small area air gap performance test	23 days	2024/7/1	2024/7/31
9	**1.3**）大面积气隙制作和测试	**1.3) large area air gap fabrication and testing**	**393 days**	**2024/7/1**	**2025/12/31**
10	1.3.1）大面积气隙制作程序优化	1.3.1) optimization of large area air gap fabricati	23 days	2024/7/1	2024/7/31
11	1.3.2）大面积气隙制作	1.3.2) large area air gap fabrication	43 days	2024/8/1	2024/9/30
12	1.3.3）大面积气隙测试	1.3.3) large area air gap test	66 days	2024/10/1	2024/12/31
13	1.3.4）大面积气隙老化锻炼	1.3.4) large area air gap aging exercise	261 days	2025/1/1	2025/12/31
14	**1.4**）**BIM/BIR**位置气隙设计和制作	**1.4) bim/bir position air gap design and fabricat**	**522 days**	**2025/1/1**	**2026/12/31**
15	1.4.1）BIM/BIR气隙设计	1.4.1) bim/bir air gap design	261 days	2025/1/1	2025/12/31
16	1.4.2）BIM/BIR气隙制作	1.4.2) bim/bir air gap fabrication	173 days	2026/1/1	2026/8/31
17	1.4.3）BIM/BIR气隙测试	1.4.3) bim/bir air gap test	175 days	2026/5/1	2026/12/31
18	**2**）单层**RPC**探测器的设计、制作和性能测试	**2) Design, fabrication and performance test of s**	**567 days**	**2024/1/1**	**2026/3/3**
19	**2.1**）大面积蜂窝板设计、制作和测试	**2.1) design, fabrication and testing of large area**	**435 days**	**2024/1/1**	**2025/8/31**
20	2.1.1）大面积蜂窝板设计和工程确认	2.1.1) large area honeycomb panel design and er	44 days	2024/1/1	2024/2/29
21	2.1.2）大面积蜂窝板材料采购	2.1.2) procurement of large area honeycomb par	43 days	2024/3/1	2024/4/30
22	2.1.3）大面积蜂窝板制作（前50%）	2.1.3) large area honeycomb panel production (t	175 days	2024/5/1	2024/12/31
23	2.1.4）大面积蜂窝板制作（后50%）	2.1.4) large area honeycomb panel production (t	173 days	2025/1/1	2025/8/31
24	2.1.5）大面积蜂窝板质量检测	2.1.5) quality inspection of large area honeycom	145 days	2025/2/10	2025/8/29
25	**2.2**）前端电子学制作和测试	**2.2) front end electronics fabrication and testing**	**435 days**	**2024/1/1**	**2025/8/31**
26	2.2.1）批量测试方法研究	2.2.1) research on batch test method	87 days	2024/1/1	2024/4/30
27	2.2.2）前放板材料订货	2.2.2) material ordering for front placing plate	43 days	2024/3/1	2024/4/30
28	2.2.3）前放板制作（前50%）	2.2.3) production of front plate (top 50%)	175 days	2024/5/1	2024/12/31
29	2.2.4）前放板制作（后50%）	2.2.4) fabrication of front plate (rear 50%)	173 days	2025/1/1	2025/8/31
30	2.2.5）前放板性能测试	2.2.5) performance test of front plate	305 days	2024/7/1	2025/8/31
31	**2.3**）单层探测器设计、制作	**2.3) design and fabrication of single-layer detec**	**567 days**	**2024/1/1**	**2026/3/3**
32	2.3.1）单层探测器设计工程确认	2.3.1) single layer detector design engineering co	130 days	2024/1/1	2024/6/30
33	2.3.2）单层探测器制作（前150个）	2.3.2) fabrication of single-layer detectors (top 1	132 days	2025/9/1	2026/3/3
34	2.3.3）单层探测器制作（后150个）	2.3.3) fabrication of single-layer detectors (the la	218 days	2025/1/1	2025/10/31
35	**2.4**）单层探测器性能测试	**2.4) single layer detector performance test**	**523 days**	**2024/1/1**	**2025/12/31**
36	2.4.1）大规模RPC测试平台搭建	2.4.1) construction of large-scale RPC test platfor	175 days	2024/1/1	2024/8/31
37	2.4.2）单层探测器性能测试	2.4.2) single layer detector performance test	348 days	2024/9/2	2025/12/31
38	**3**）探测器组装、调试、试运行	**3) Detector assembly, commissioning and trial c**	**1086 days**	**2024/11/1**	**2028/12/31**
39	3.1）三层探测器的测试、故障排除（@MPI）	3.1) test and troubleshooting of three-layer dete	433 days	2024/11/1	2026/6/30
40	3.2）现场组装和调试（CERN）	3.2) site assembly and commissioning (CERN)	782 days	2026/1/1	2028/12/31
41	3.3）无束流状态试运行（CERN）	3.3) no beam test run (CERN)	130 days	2028/7/3	2028/12/31
42	**4**）项目文档	**4) Project documentation**	**805 days**	**2025/12/1**	**2028/12/29**
43	4.1）项目中期测试报告	4.1) Interim test report of the project	22 days	2025/12/1	2025/12/30
44	4.2）项目结题报告	4.2) project conclusion report	21 days	2028/12/1	2028/12/29



Detailed Budget

课题1: High Granularity Timing Detector Budget

Content	Budget (10k RMB)	Description
1. Equipment	70	Work stations, LCR meters, HV/LV power supply …
2 Operation	**734**	
2.1 LGAD	267	150 LGAD sensors wafers
2.2 flexible cable	105	7500 flexible cable
2.3 high voltage	70	750 channels of HV modules
2.4 PEB boards	200	160 PEB boards with components and testing
2.5 modules	68	Wire-bonding, 1000 hybrids
2.3 Travel, meeting, collaboration	24	Travels , meeting
3 Labor	**128**	Postdocs, graduate students
Indirect	**203**	
Total	**1135**	

课题2: Silicon Inner Tracker Budget

Content	Budget (10k RMB)	Description
1. Equipment	0	No equipment
2 Operation	**415**	
2.1 Material	356	
2.1.1 Strip Barrel Detector	286	Material for making 200 strip modules, including sensors, ASICs, hybrid readout flexes, glues
2.1.2 Timing Pixel Detector	70	One readout electronics prototype, two sensors prototypes
2.2 Test and machining	39	Tooling for strip detector module, Al bonding wires, testing material for timing pixel sensor and readout
2.3 Travel, meeting, collaboration	15	Support research activities
2.4 Publication, Patents	5	Publications, patents, etc.
3 Labor	**60**	Postdocs, graduate students, financial service
Indirect	**125**	
Total	**600**	

课题3: Muon Detector (RPC) Budget

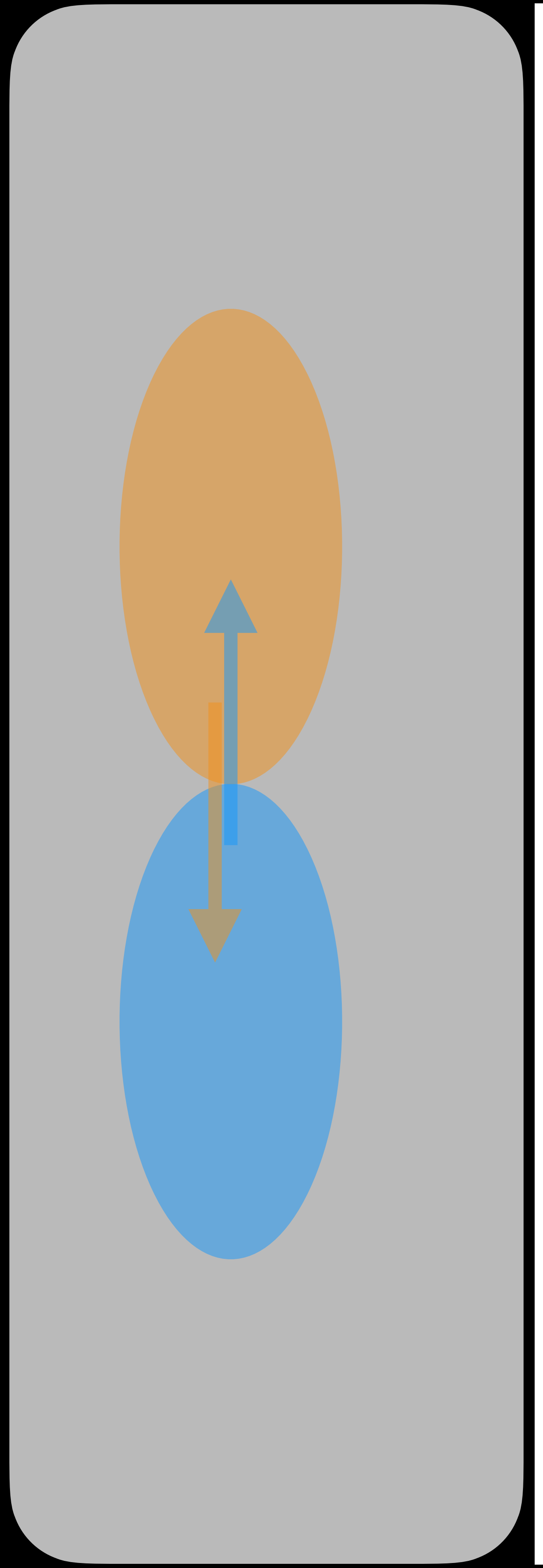
Content	Budget (10k RMB)	Description
1. Equipment	0	No equipment
2 Operation	**328**	
2.1 Material	209	
2.1.1 RPC gas gaps	67.5	Material for making 90m² RPC gas gap
2.1.2 BIS readout panel	112	Material for making 160 readout panels
2.1.3 Cosmic test station and DAQ	17	Support structure, DCT boards and cables for the test station
2.1.4 RPC working gas	12.5	Gases for RPC test: Freon, iso-butane, SF_6, Ar
2.2 Test and machining	22	Test of the impedance, surface characters, electronics with the instruments in commom pool
2.3 Detector shipment	48	Shipment of the detectors to MPI, 8 x 6 times
2.4 Travel, meeting, collaboration	9	Support research activities
2.5 ATLAS M&O	40	Support the ATLAS Common Fund for 1 key member
3 Labor	**30**	Postdocs, graduate students
Indirect	**107**	
Total	**465**	

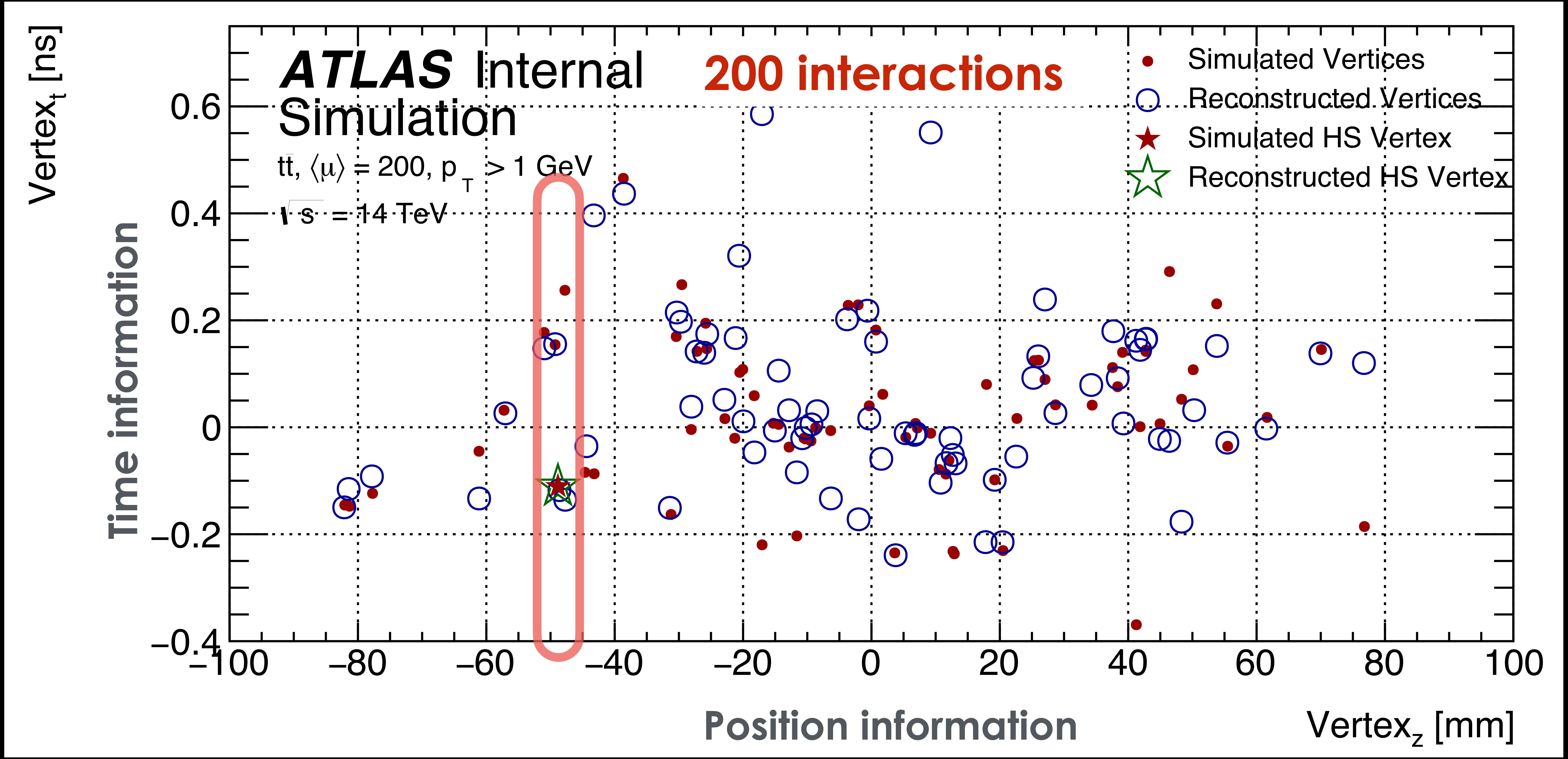
Timing Detector Detailed Information

Motivation

Pileup is a major challenges at high luminosity

- Additional fake jets
- Affects reconstruction of physics objects





Motivation

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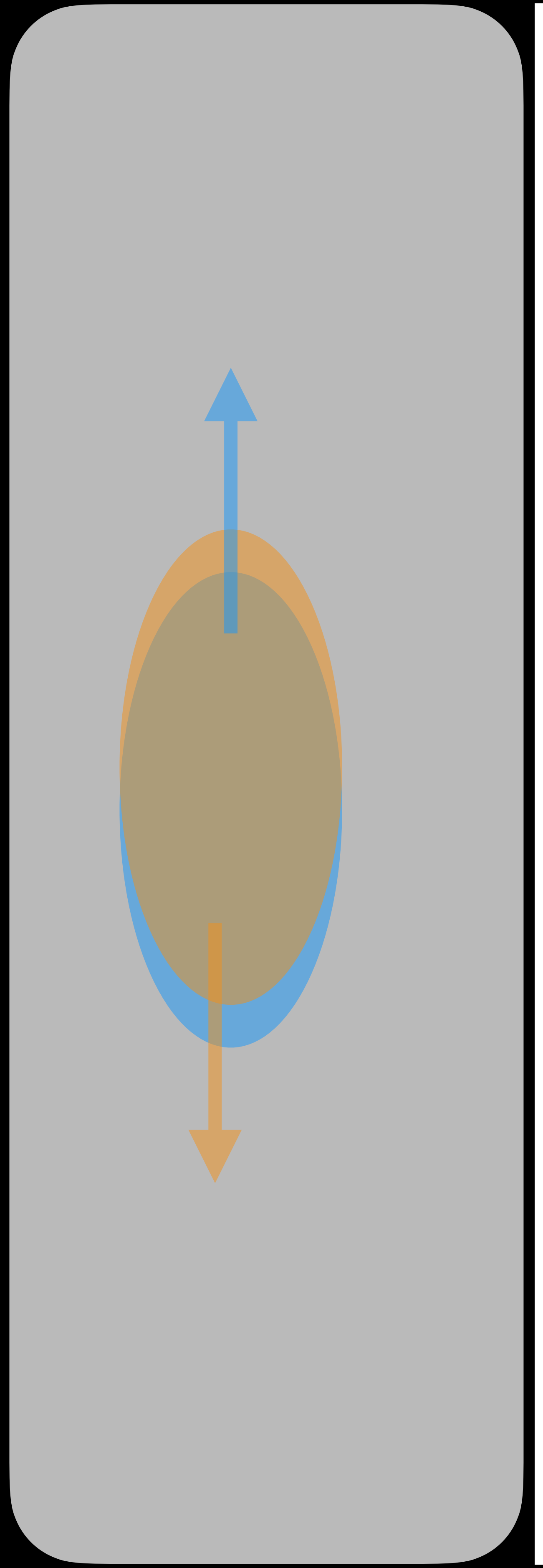

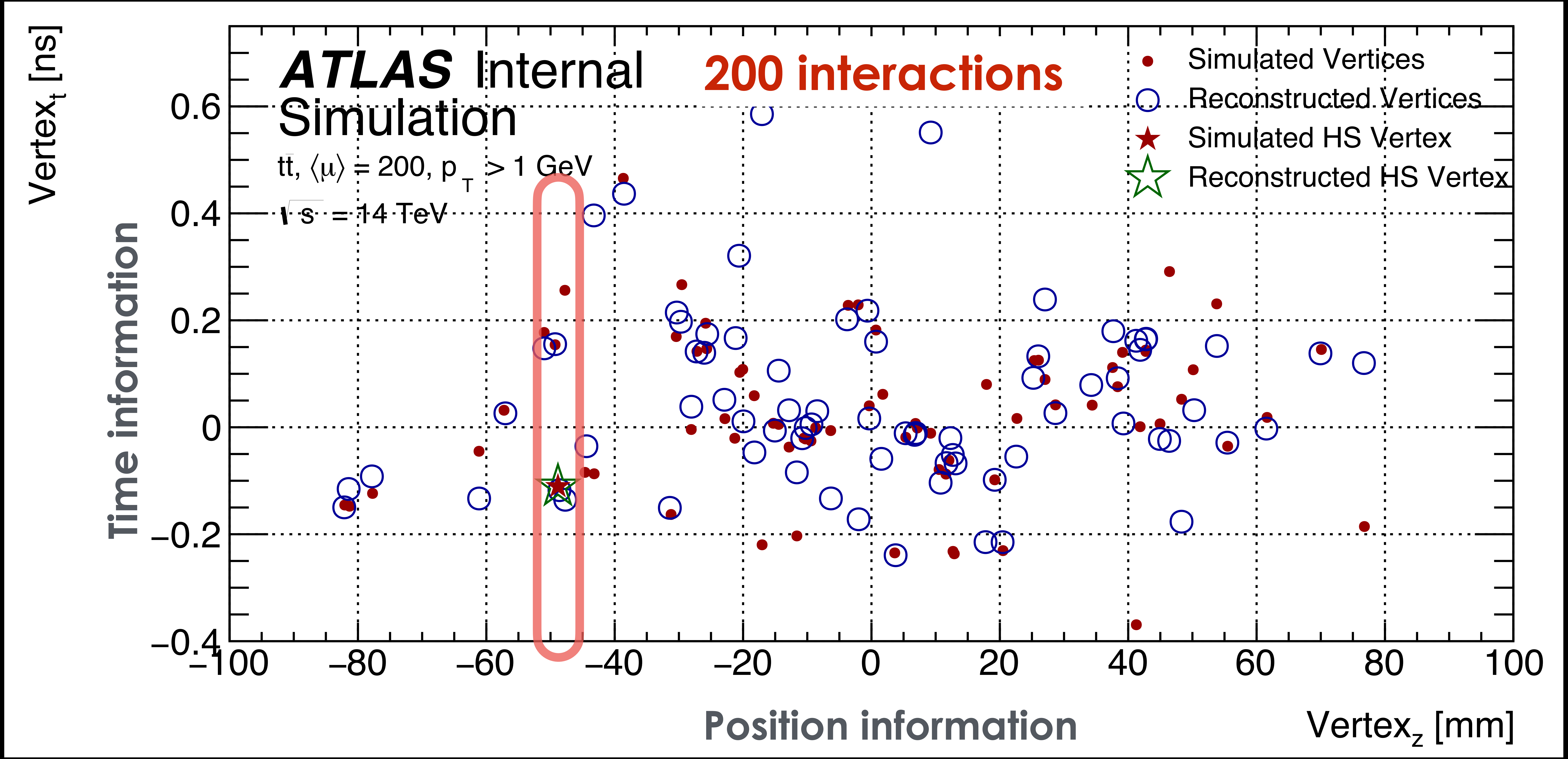

Motivation

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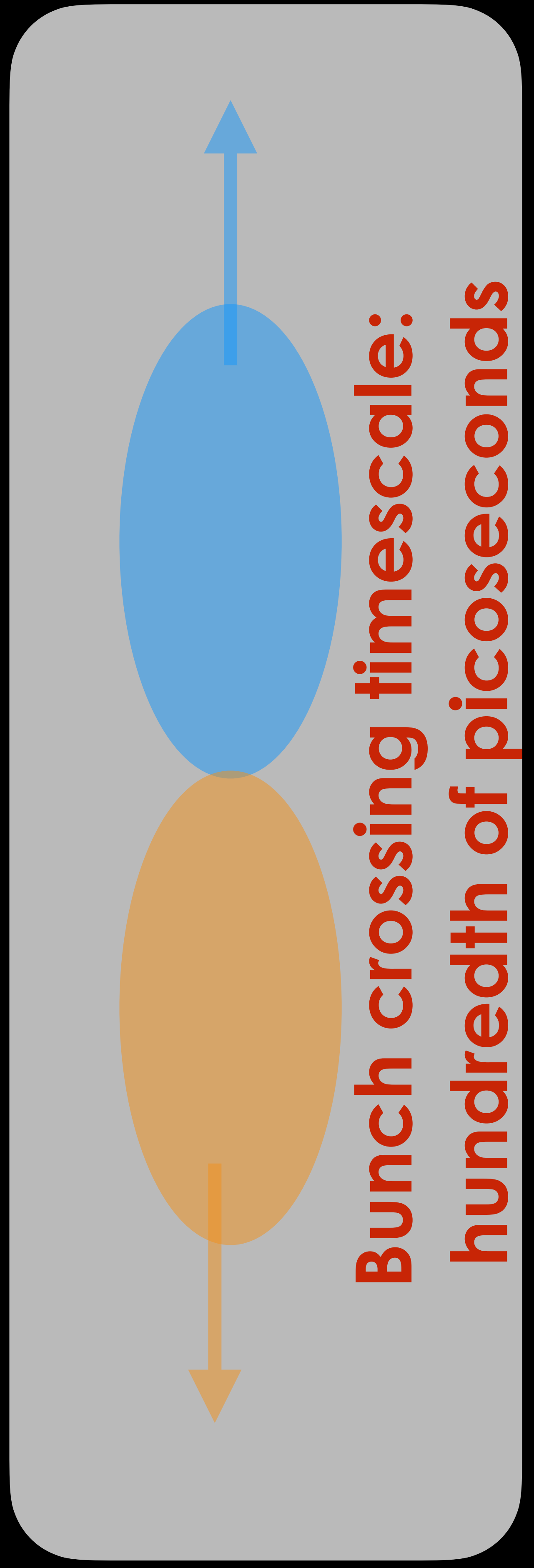
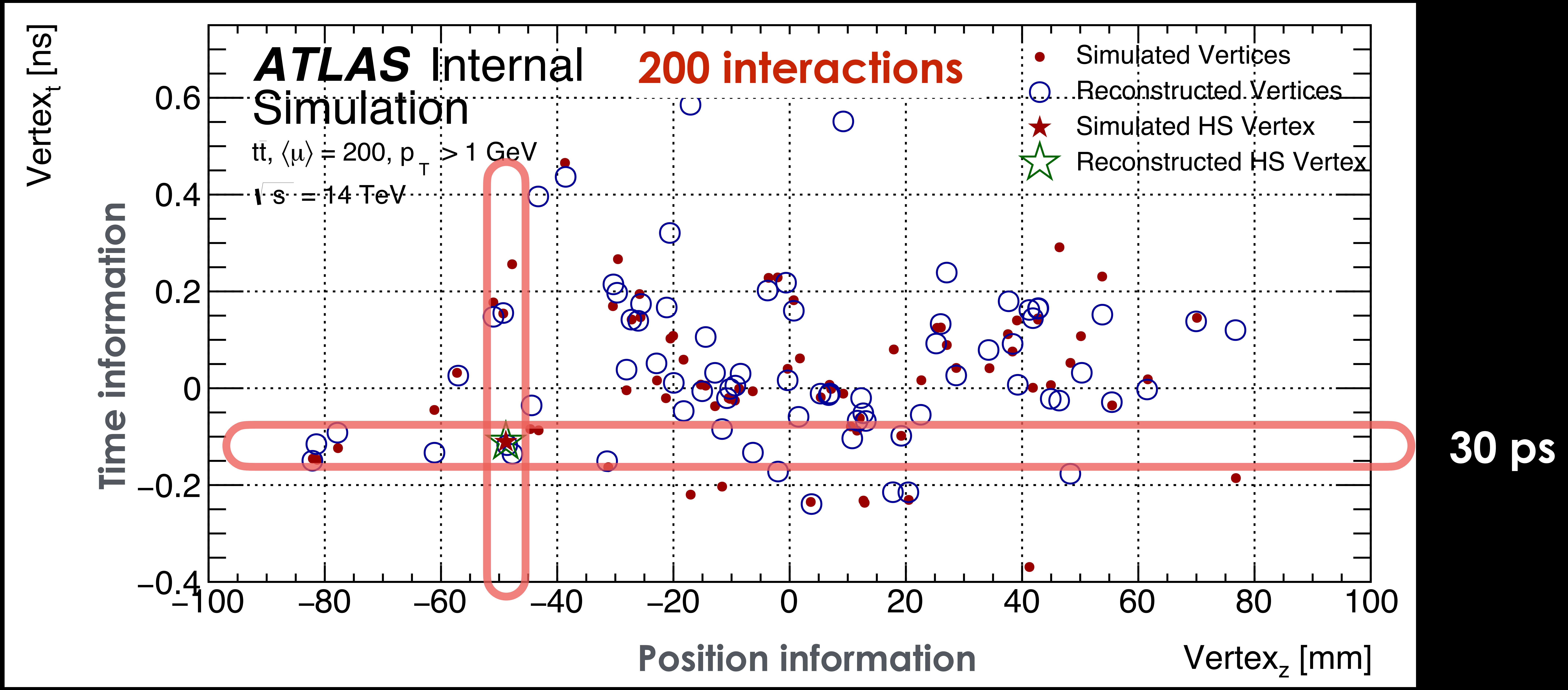




At v = c, 1 mm corresponds to 3 ps ⇒ Gain is not from time-of-flight information, but from knowing times of each vertex collision

The High Granularity Timing Detector

Pixel detector with coarse spatial resolution but precision timing (30-40 ps per track)

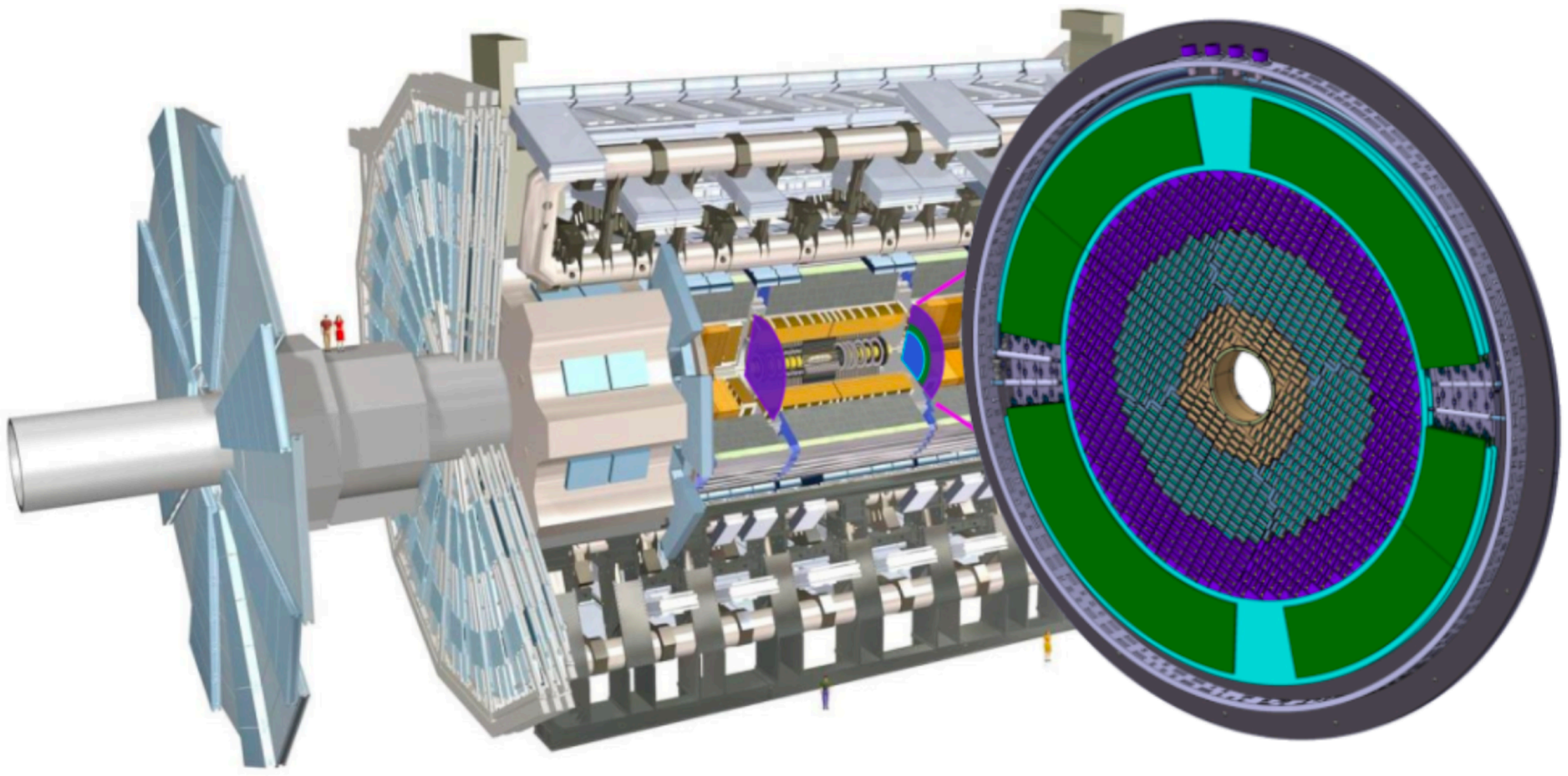
σ_t ~ 40-85 ps/hit up to 4000 fb^{-1}

Pseudorapidity coverage: $2.4<|\eta|<4.0$
Radial extension: 12 cm < R < 64 cm

2 rings per disk:
inner ring replaced at 2000 fb^{-1}

High Granularity Timing Detector (HGTD)

- HGTD aim to reduce pileup contribution at HL-LHC
  - Timing resolution is required to be better than 30 ps (start) - 50 ps (end) ps per track
- 6.4 m^2 area silicon detector and ~ 3.6×10^6 channe
- High Granularity: Pixel pad size: 1.3 mm × 1.3 mm
- Radiation hardness : 2.5×10^{15} N_{eq}/cm^2 and 2 Mgy
- Chinese team is making key contributions:
  - >88% LGAD sensor (IHEP + USTC) - 15%
  - 45% detector assembly (IHEP + USTC) - 10%
  - 100% front-end electronics board (IHEP +NJU) - 100%
  - ~33% flex tail (SDU) - 33%
  - 50% ASIC testing (IHEP)
  - 16% high-voltage electronic systems (IHEP+ SDU) - 16%
  - Software and performance (USTC)



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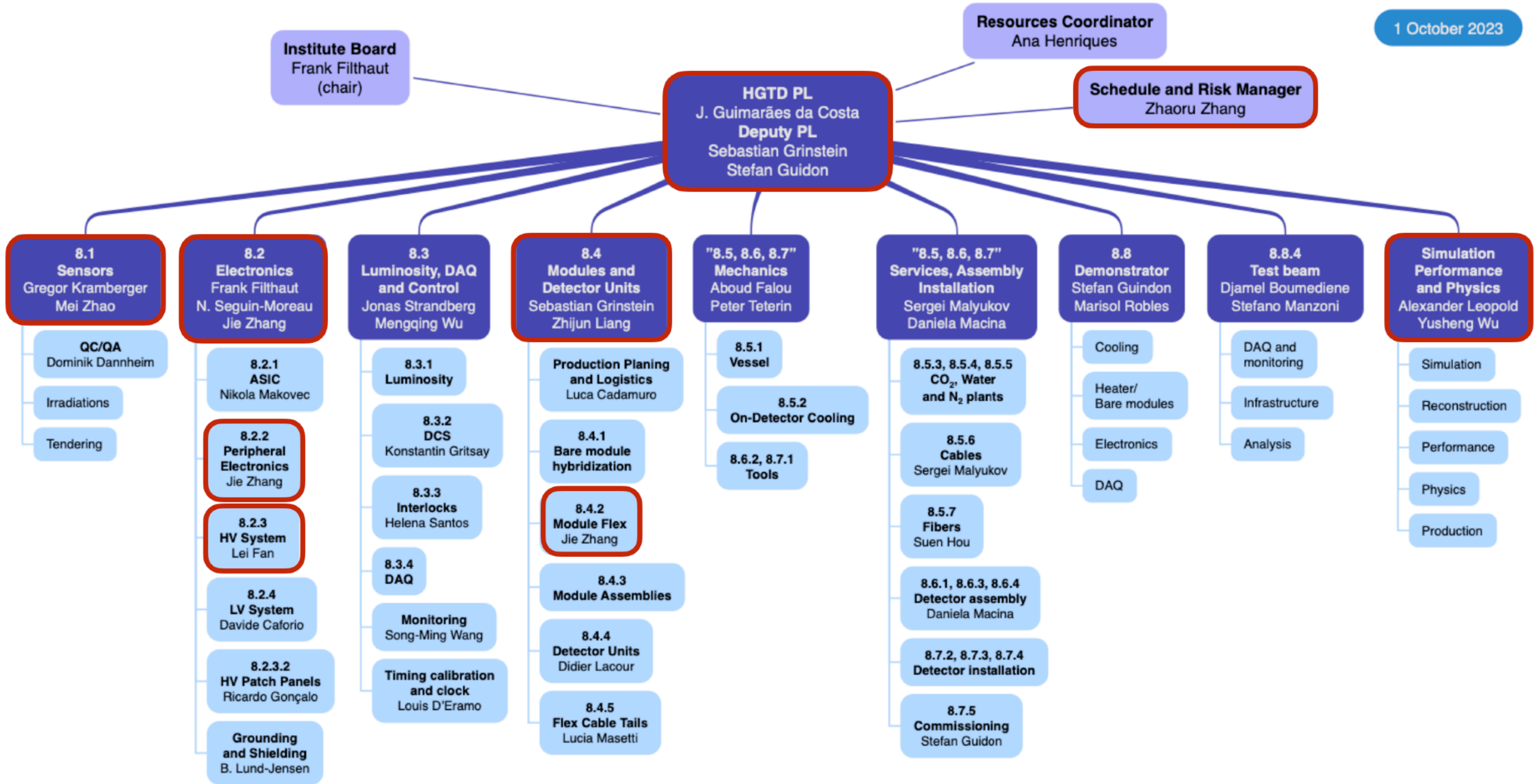
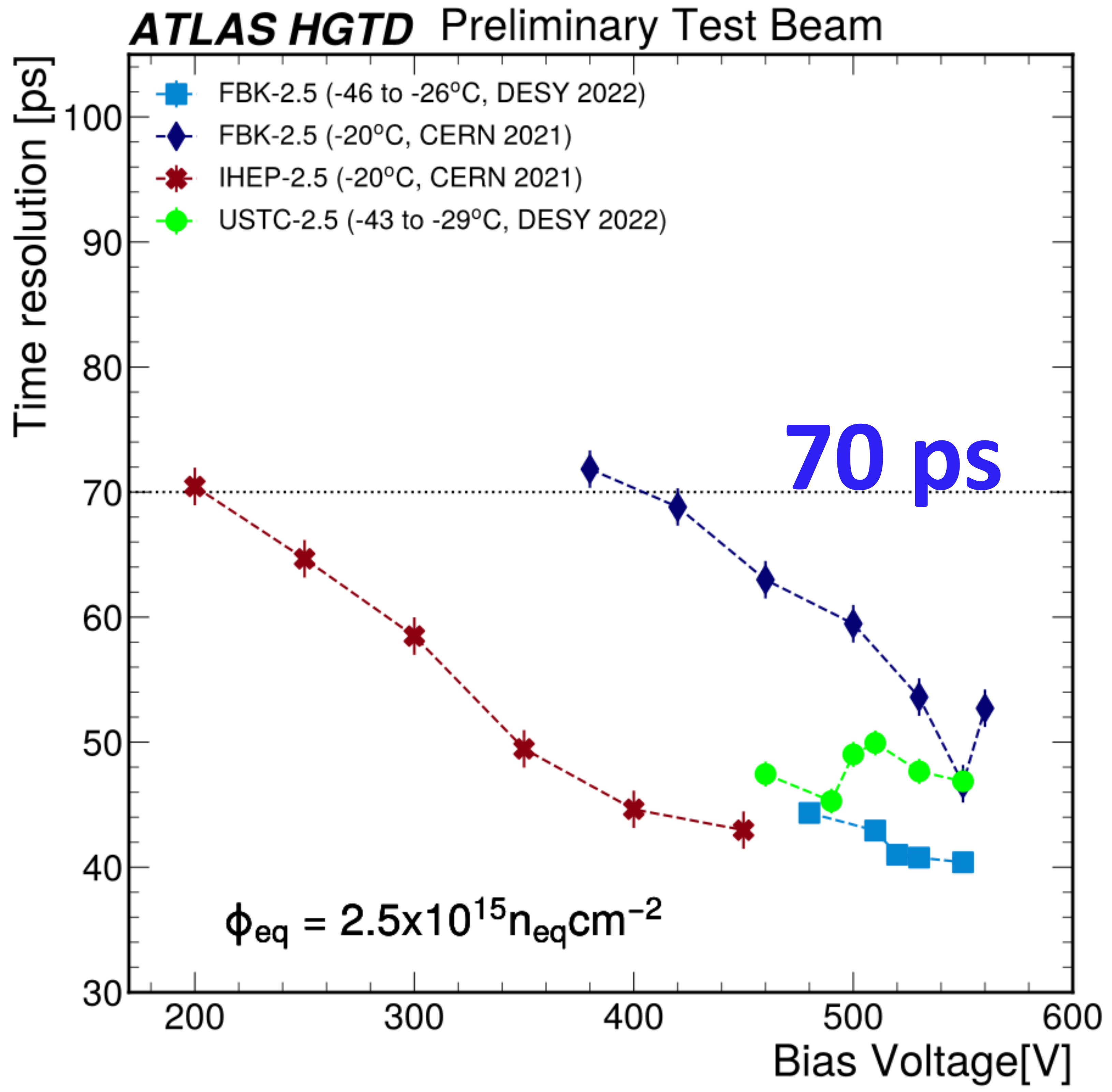
ATLAS China team in HGTD management

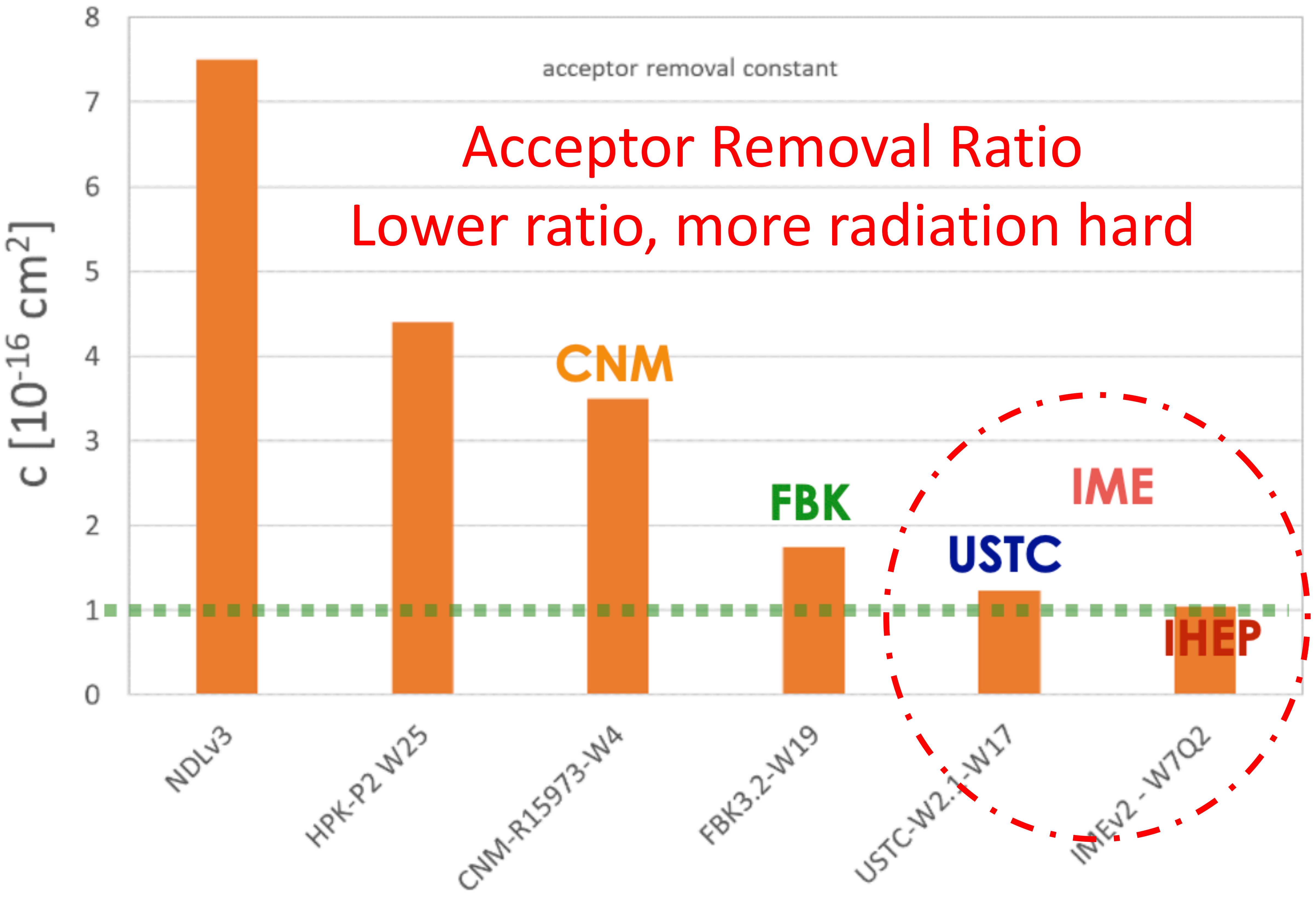
- ATLAS China team played a leading role in HGTD
  - Joao (IHEP) is project leader, Level-1 management role in ATLAS
    - The first project leader in ATLAS China team
  - 5 Level-2 conveners (Module, Sensor, Electronics, Risk, Simulation)
  - 2 Level-3 conveners (PEB, high-voltage)
  - 1 Speaker committee



LGAD sensor after Irradiation

- IHEP-IME/FBK/USTC-IME LGAD with carbon-enriched doping
  - Significantly lower acceptor removal ratio, more radiation hard
- After 2.5×10^{15} n_{eq}/cm^2, LGADs were operated at voltages below 550 V
  - Test beams at CERN and DESY, confirm the feasibility of LGAD timing detector for HL-LHC
  - IHEP and USTC made leading contribution to radiation hard LGAD sensors



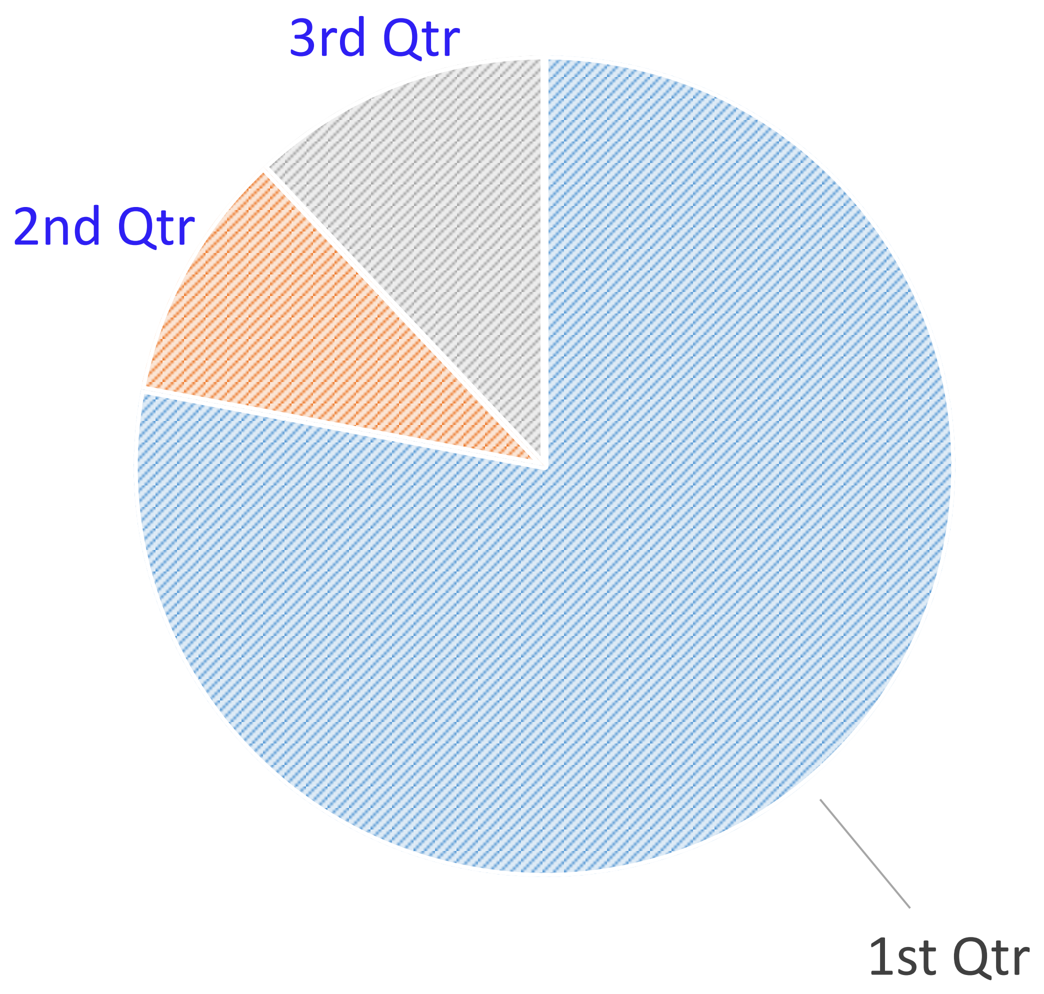


LGAD sensors pre-production

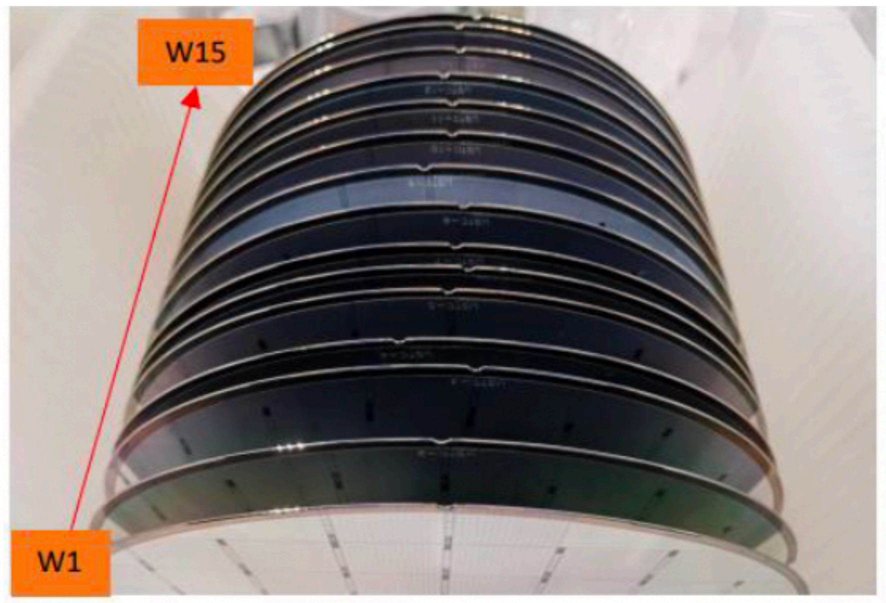
- Lots of prototypes R&D in LGAD in last few years, active vendors includes:
  - IHEP-IME (China), USTC-IME (China), IHEP-NDL(China), FBK (Italy), CNM (Spain), HPK (Japan) …
- HGTD just finalized the CERN tendering. The preliminary production plan:
  - IHEP-IME: 78% (54% from CERN tendering+24% in-kind contribution)
  - CNM: 12% in-kind contribution
  - USTC-IME: 10% in-kind contribution

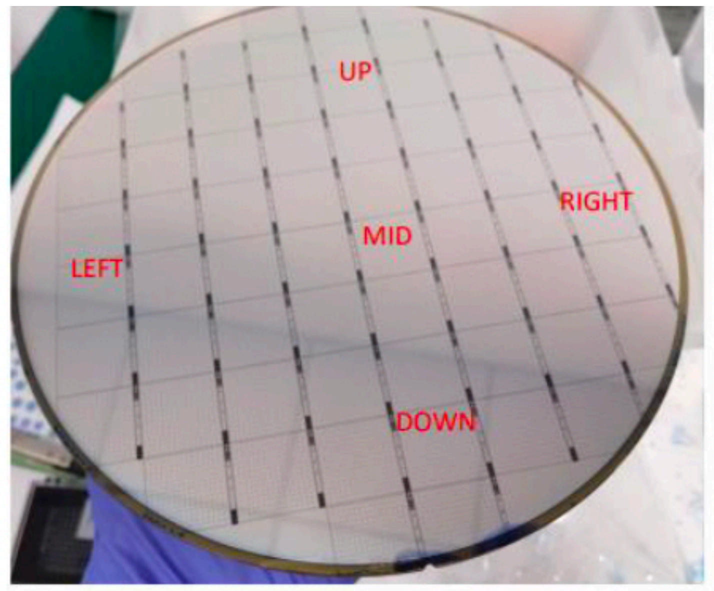
Pre-production LGAD sensors from China

Share of production between vendors

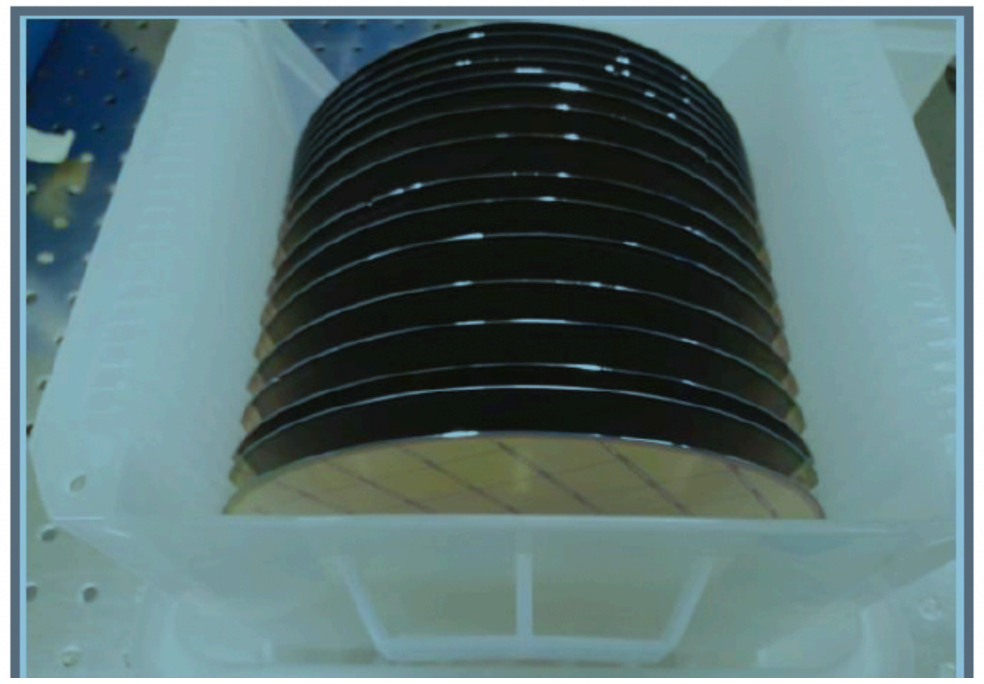


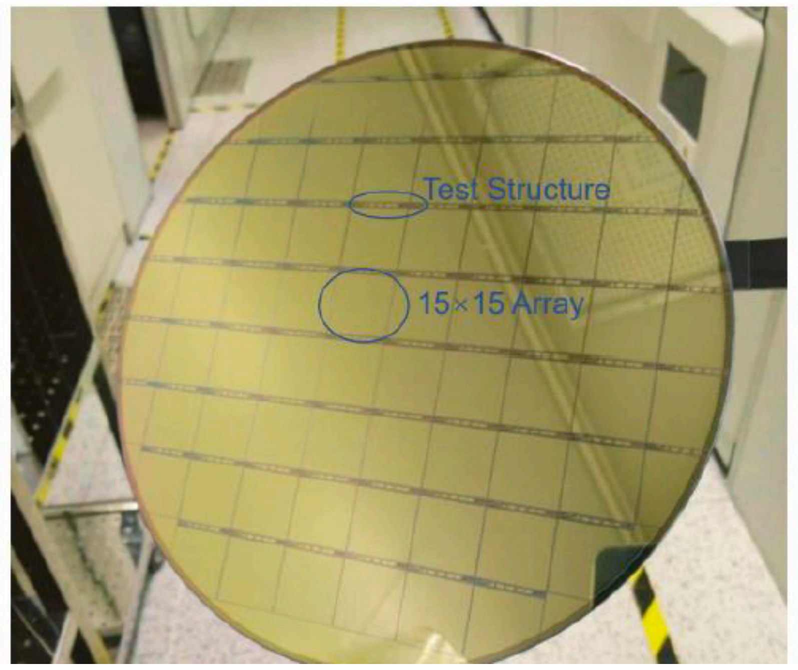
USTC-IME Pre-production





IHEP-IME Pre-production





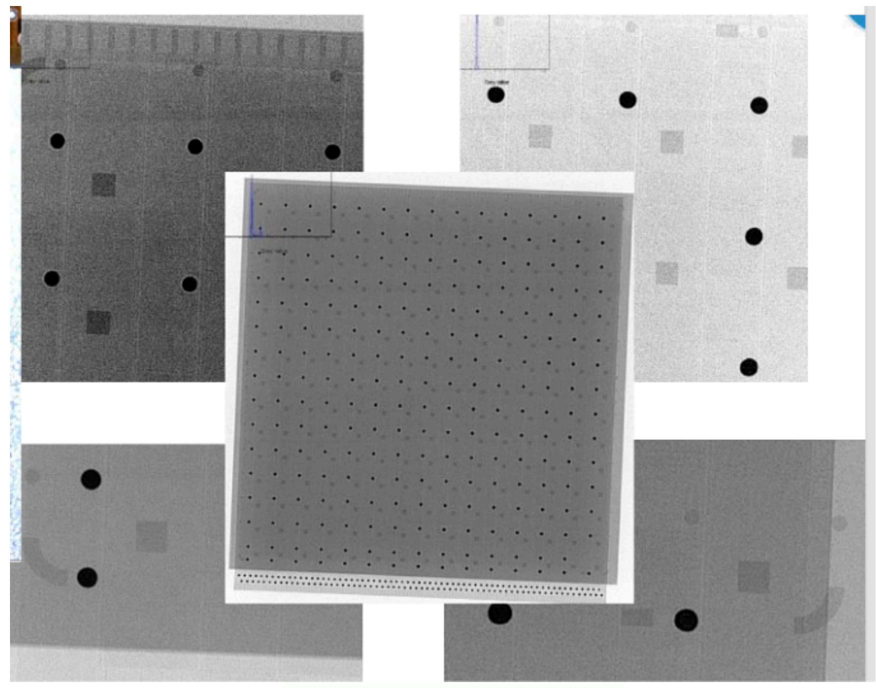
- 15x15 array sensors and test structure
- 52 sensors on one 8inch wafer

HGTD module assembly

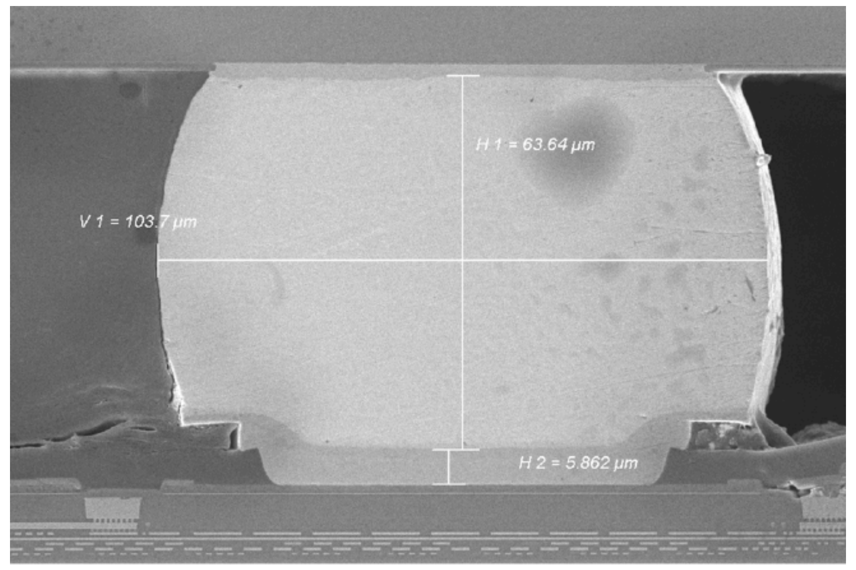
- IHEP is contributing 50% of HGTD hybrids
  - Bump bonding to hybridized LGAD and ASIC
  - IHEP made full size hybrids with ALTIROC chip
- 6 module assembly site at HGTD project
  - IHEP, USTC, Mainz, France, IFAE, Morocco
    - IHEP is largest site, 34% of module assembly
    - USTC is responsible for 11% of assembly
  - IHEP/USTC developed gantry system
    - Automatic glue dispending, assembly

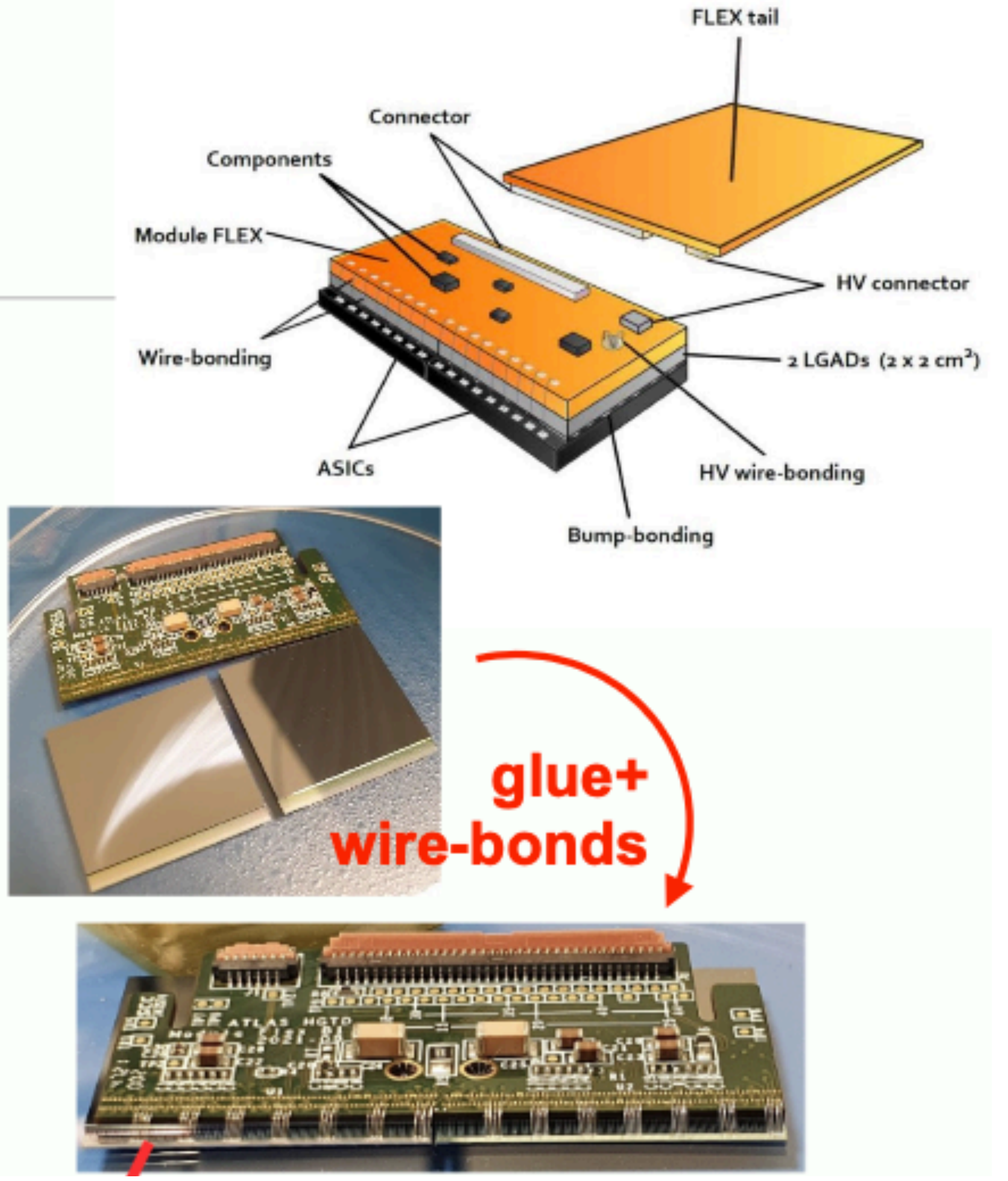
China 45%

Hybrids in X ray image

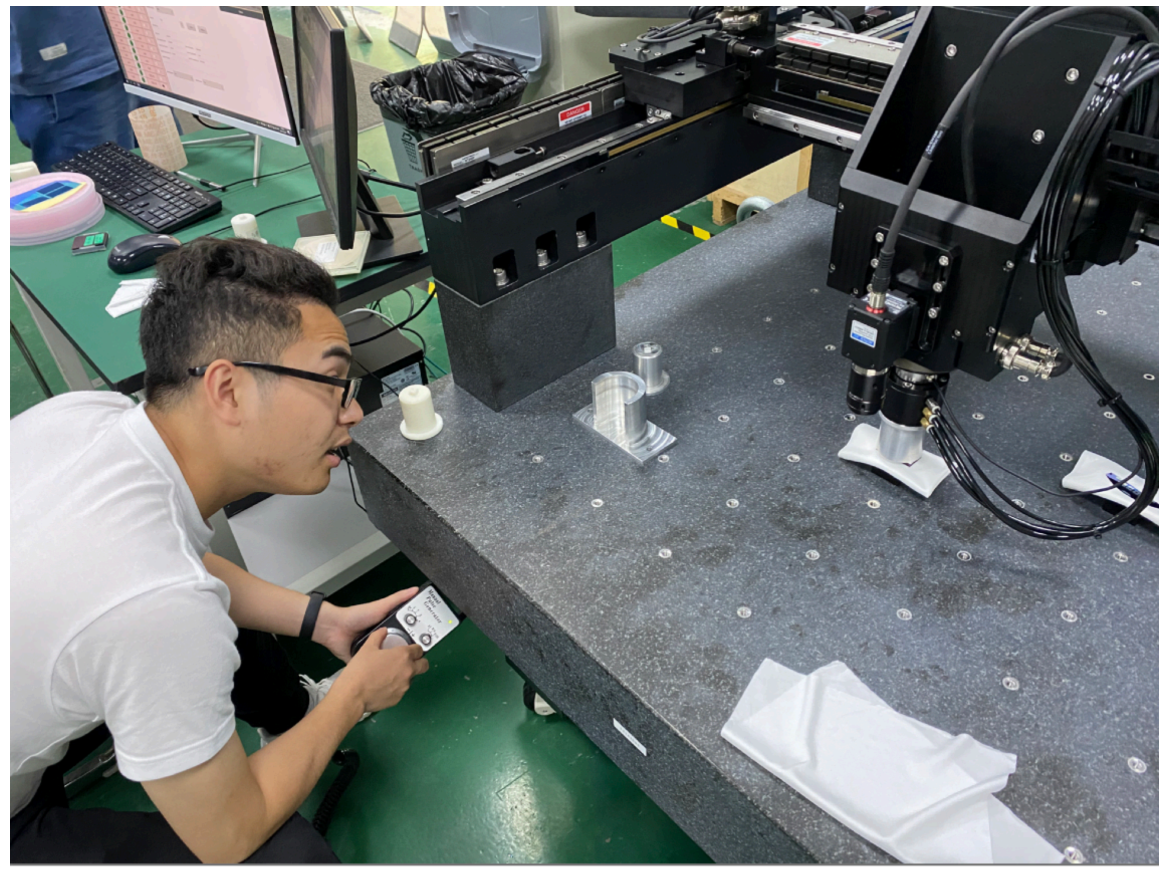


Hybrids Profile view

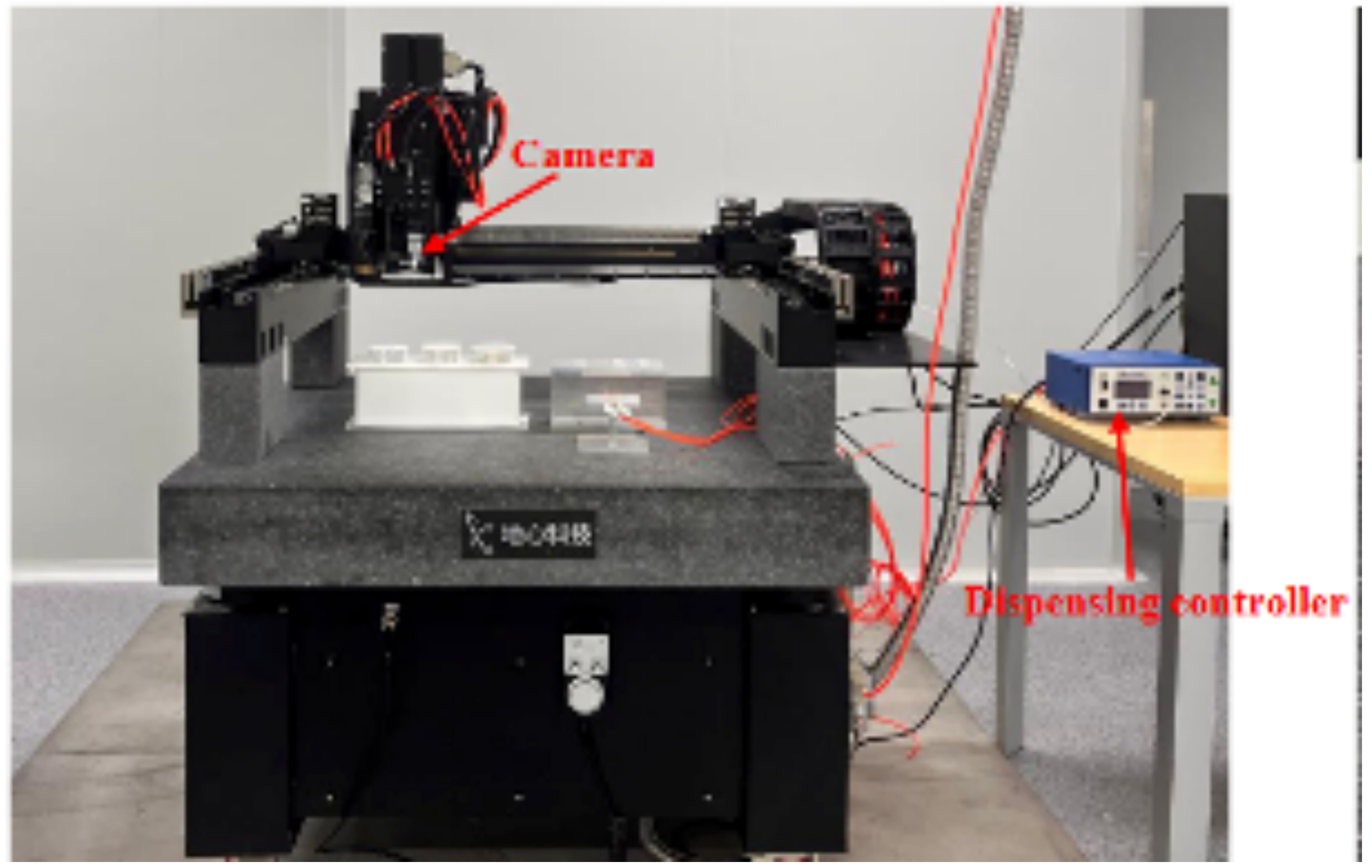




Gantry @ IHEP

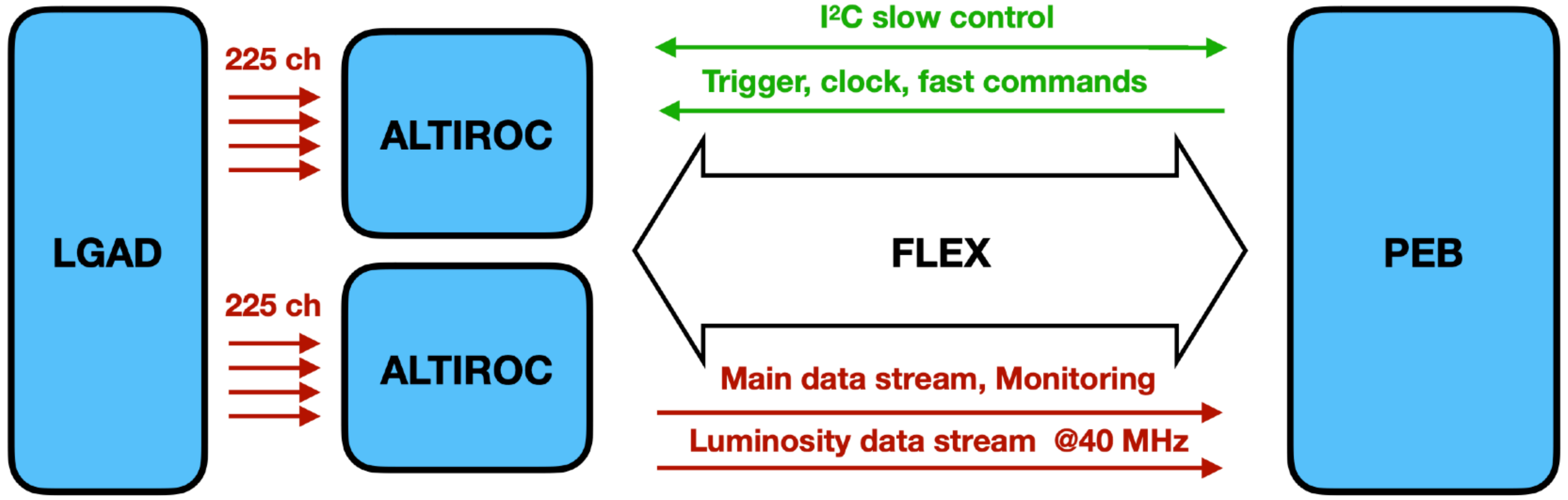


Gantry @ USTC

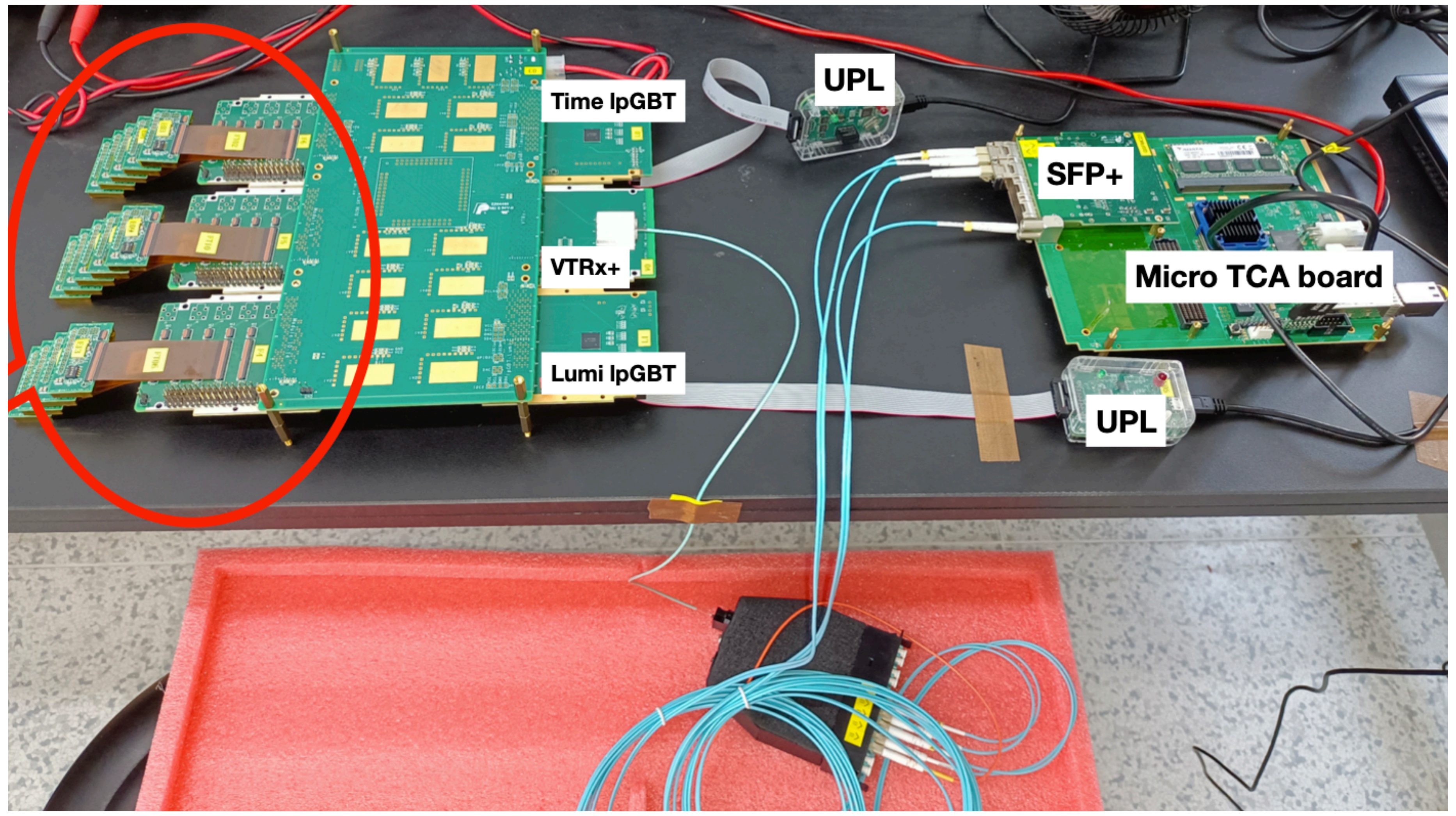


Peripheral Electronics Boards, flex tail, HV power supply

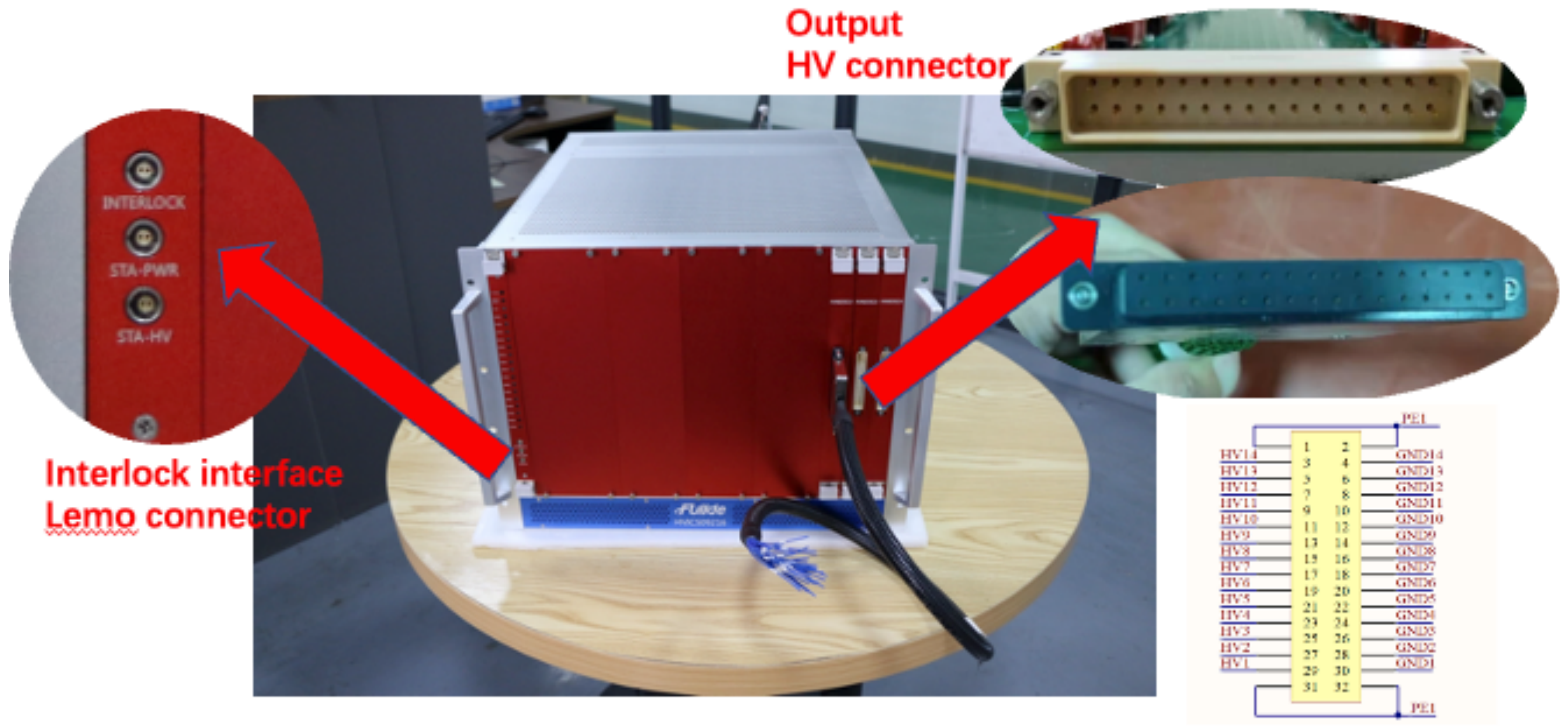
- ➢ IHEP and NJU developed Peripheral Electronics Boards prototype
- ➢ SDU developed long flex tail prototype (75cm)
- ➢ IHEP developed high voltage power supply prototype



Modular Peripheral Electronics Boards prototype



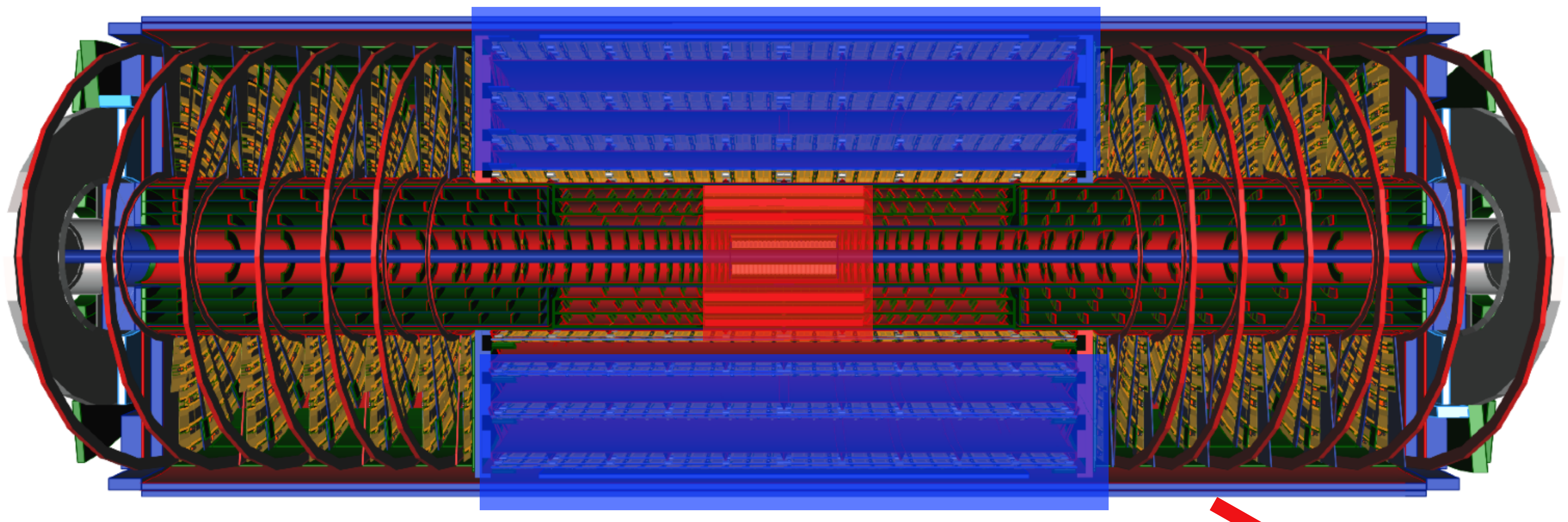
High voltage power supply prototype

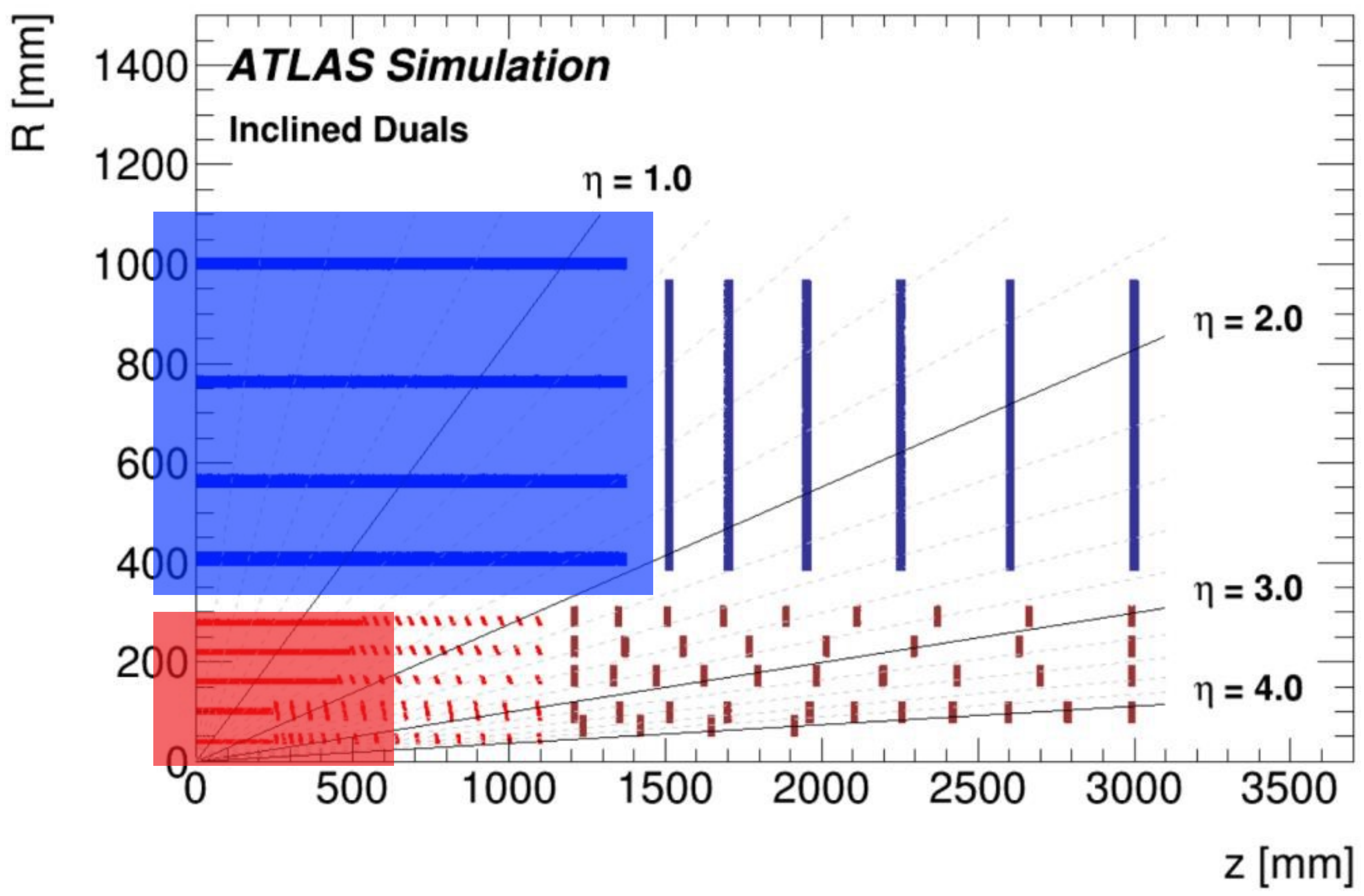


Long Flex tail prototype (75cm)

Silicon Tracker Detailed Information

Subtask 2: Inner Tracker (ITk) Upgrade





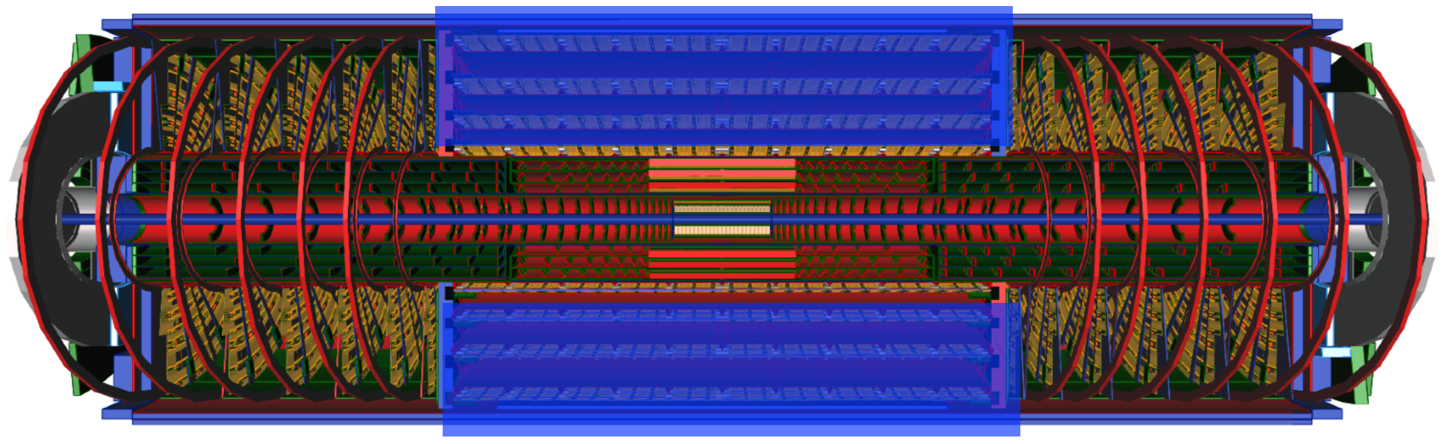
2.1 ITk Strip Barrel Detector

- Radiation hard sensor and ASIC study
- Strip detector module production
- Complex silicon tracker system integration

2.2 Timing Pixel Detector

- Pixelated LGAD sensor R&D
- Fast front-end electronics R&D

2.1 ITk Strip Barrel Detector

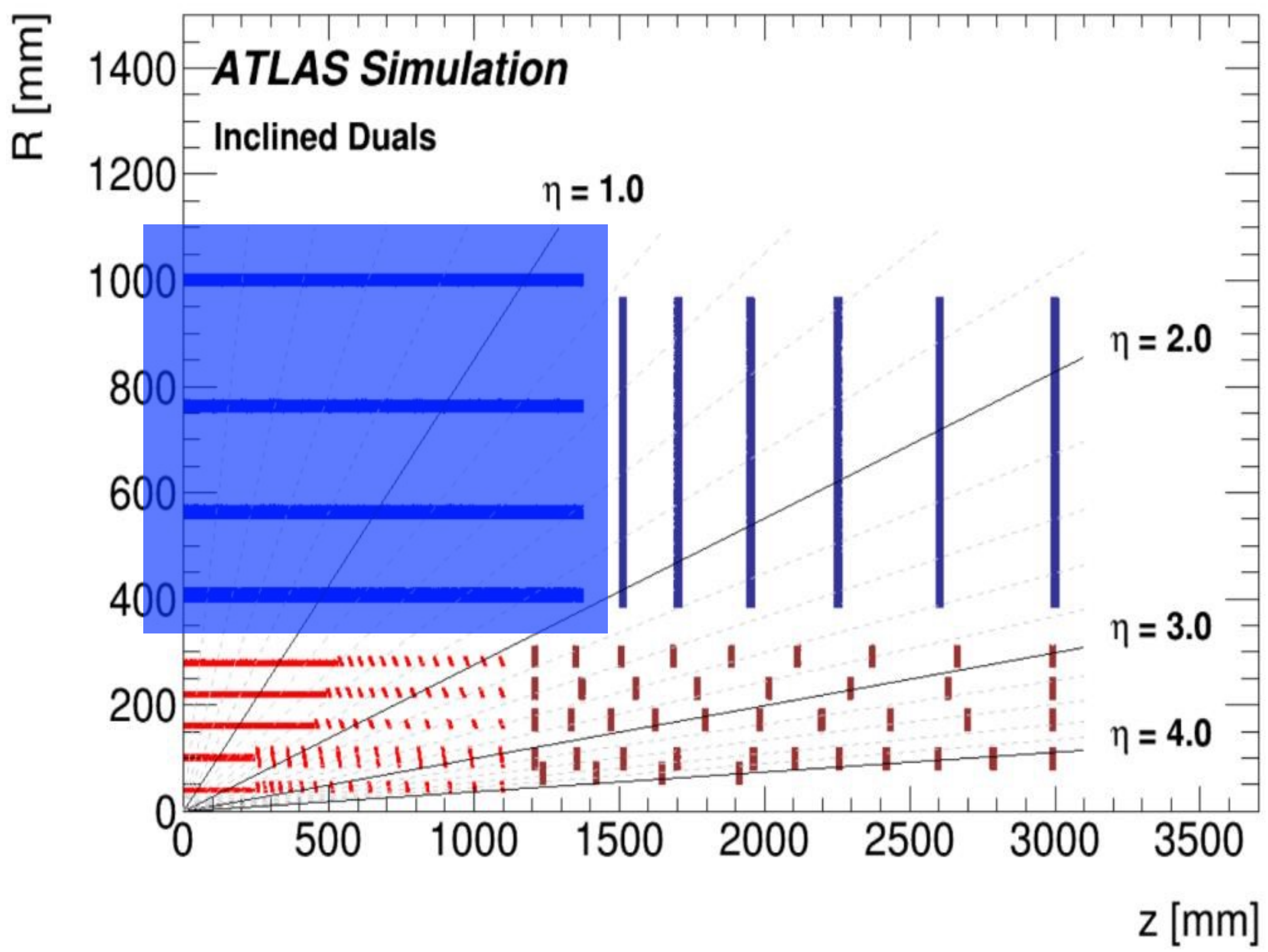


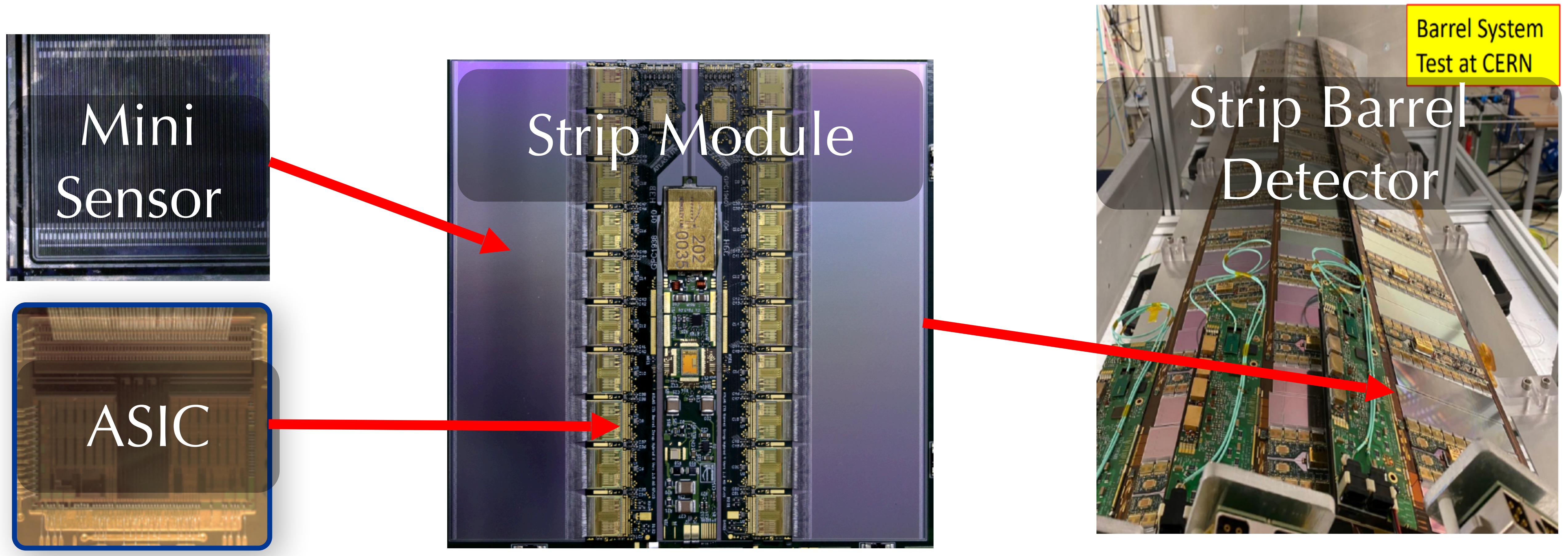
Deliverables

- Complete strip barrel detector with 25μm spacial resolution
- Provide strip module spacial resolution evaluation report

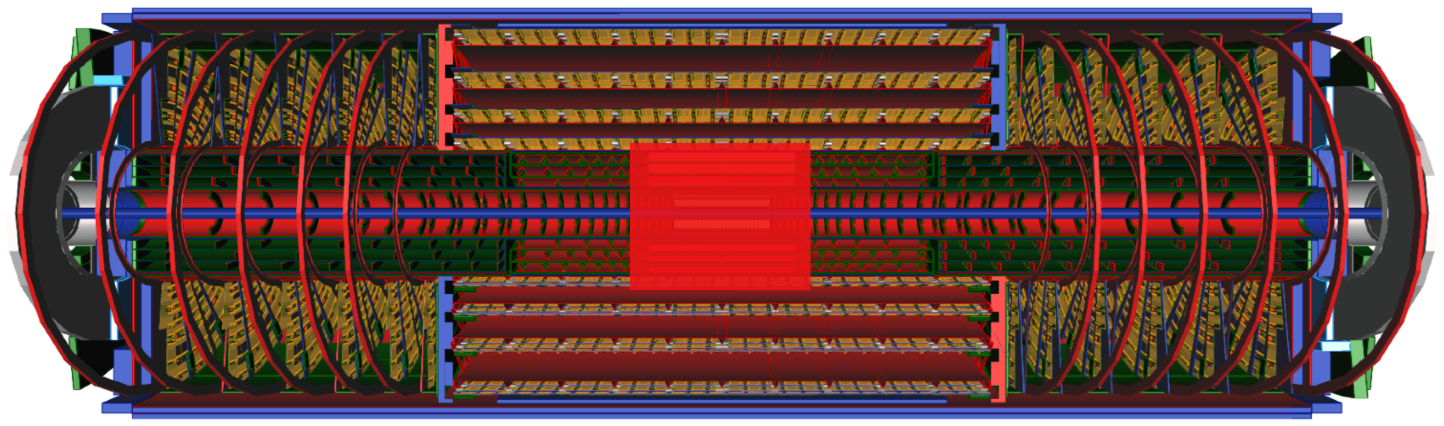
Contents

- Radiation hard sensor and readout ASIC study
- High performance strip detector module production
- Complex silicon detector system integration





2.2 Timing Pixel Detector

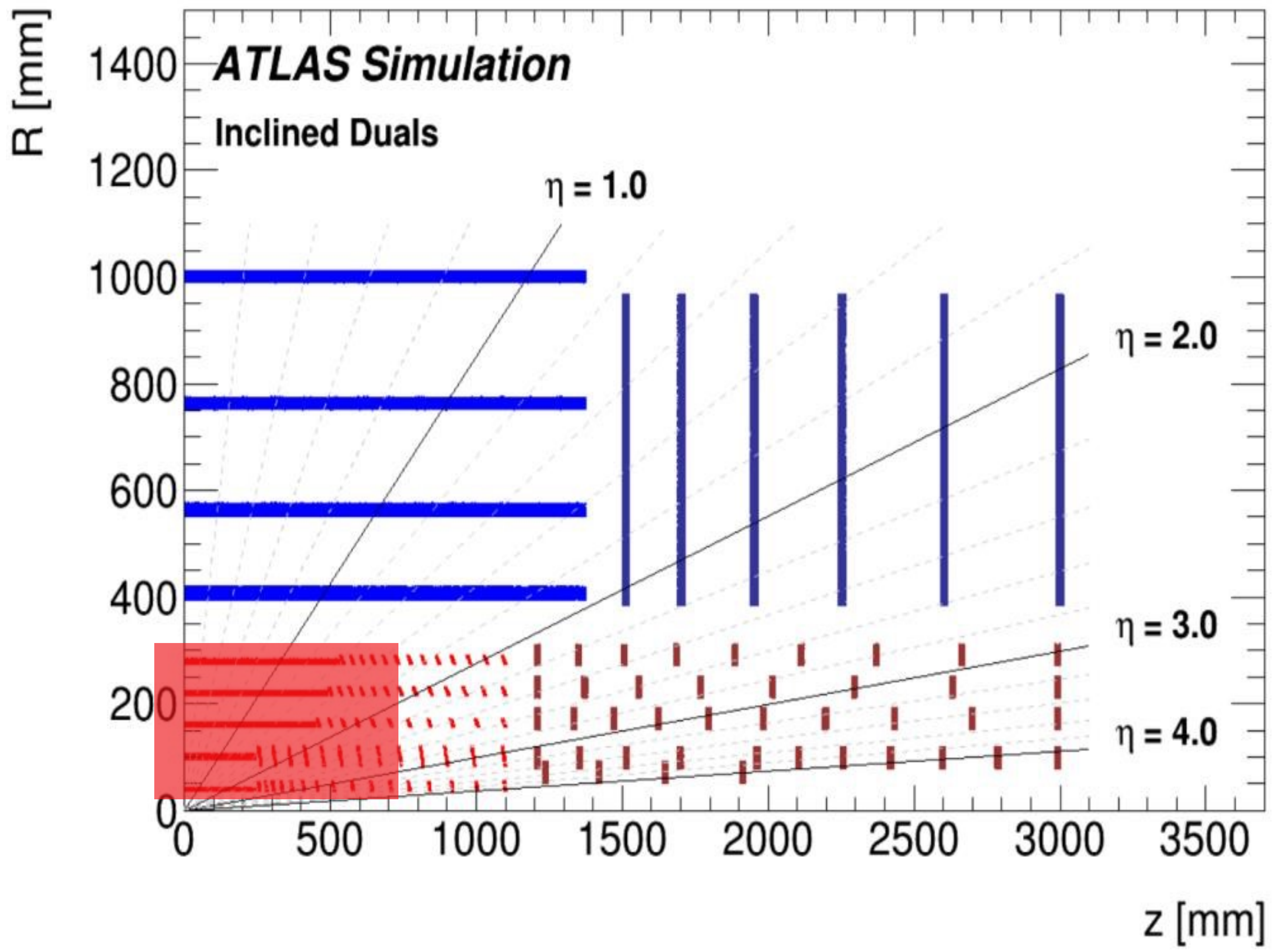


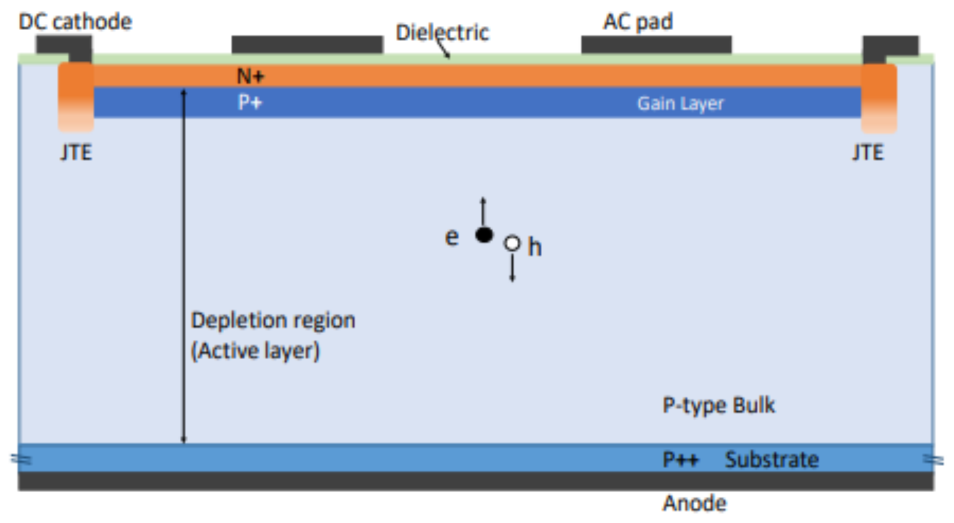
Deliverables

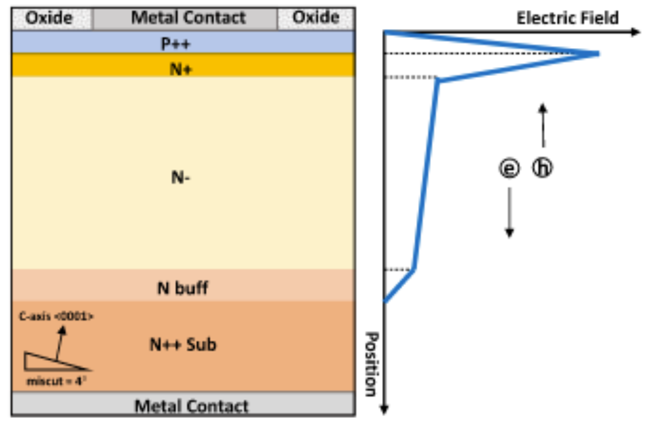
- Complete timing pixel sensor prototype with timing test report
- Advance fast front-end pixel electronics key technology

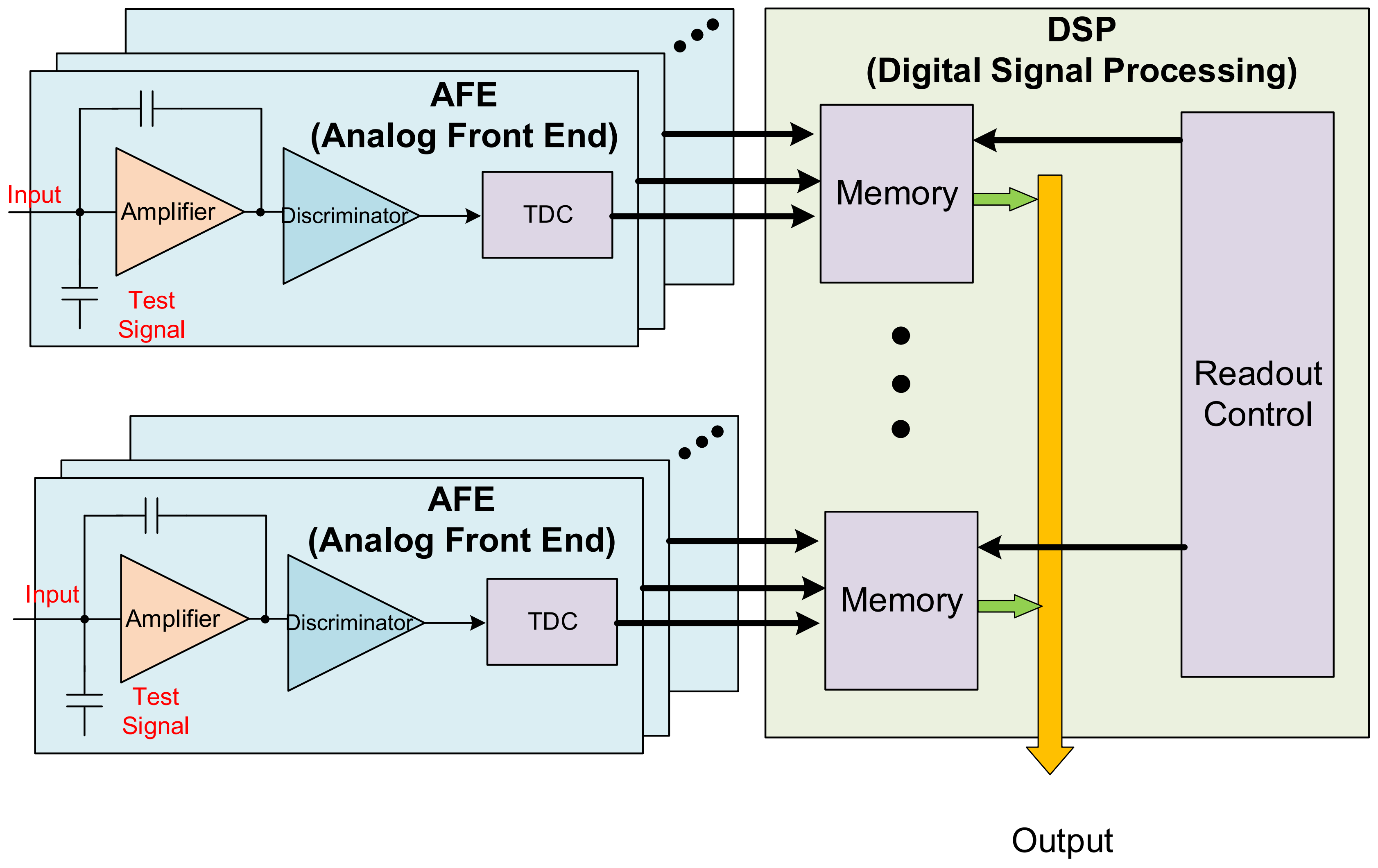
Contents

- Pixelated LGAD sensor fabrication and timing evaluation
- Fast front-end electronics data buffering, readout, transmission







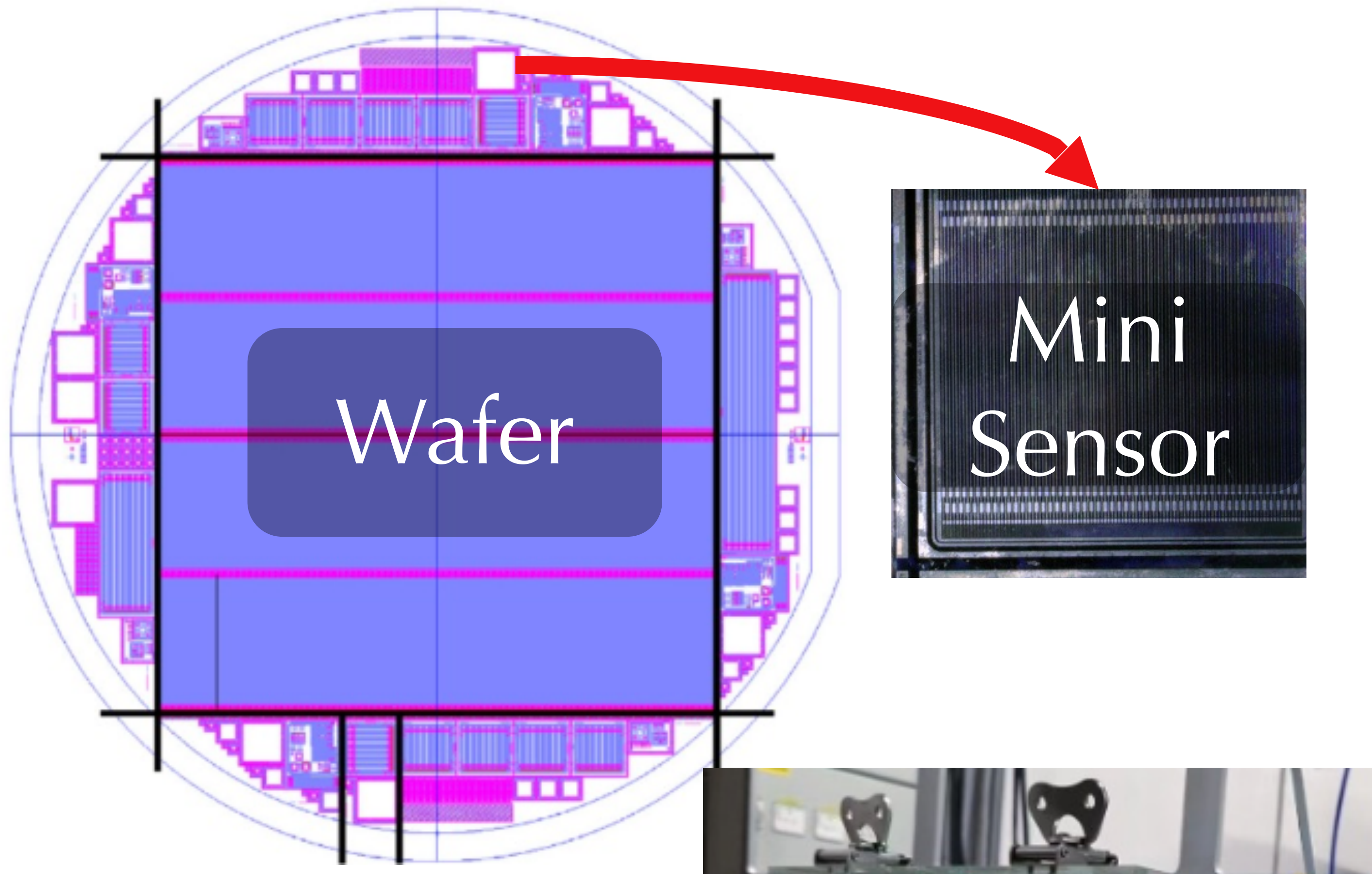


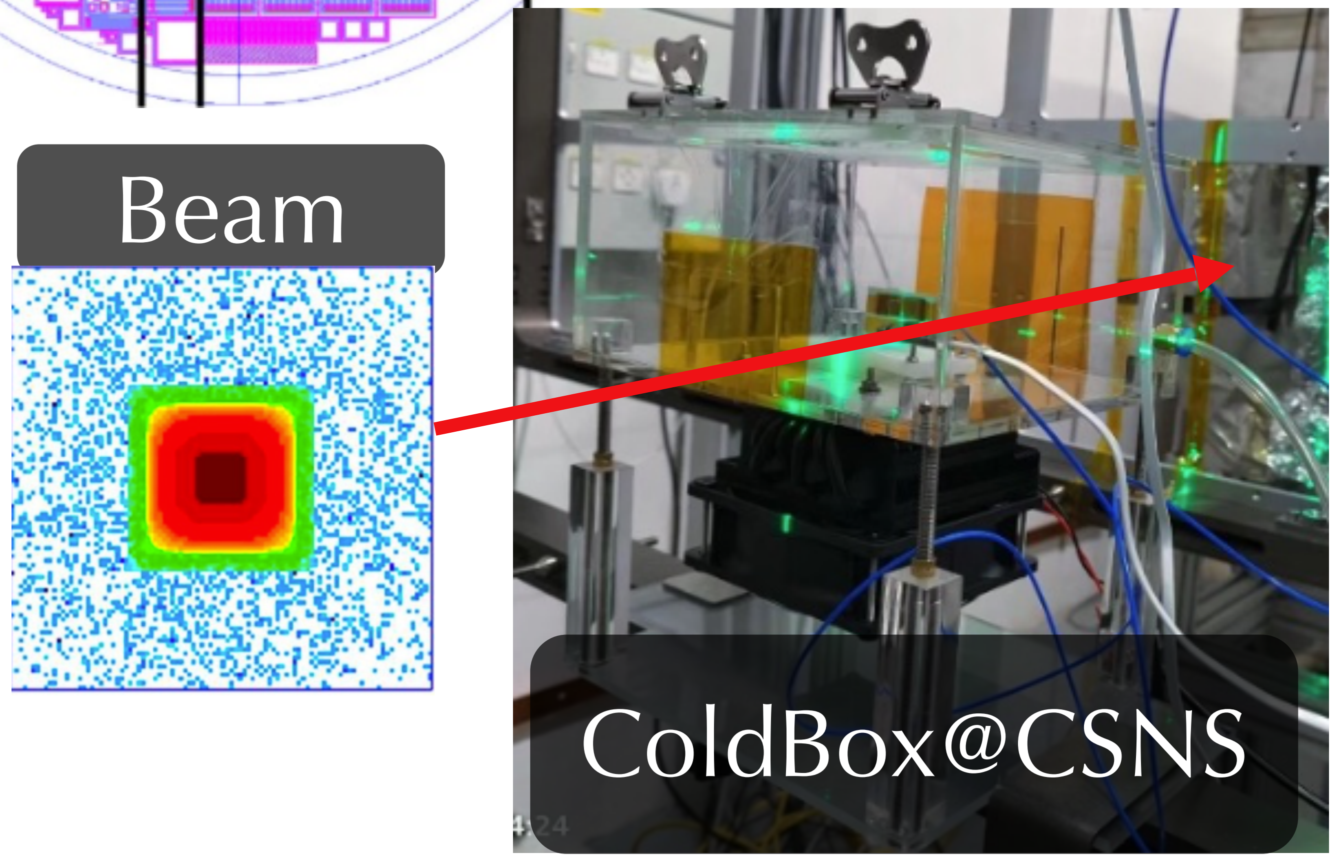
Innovation Point

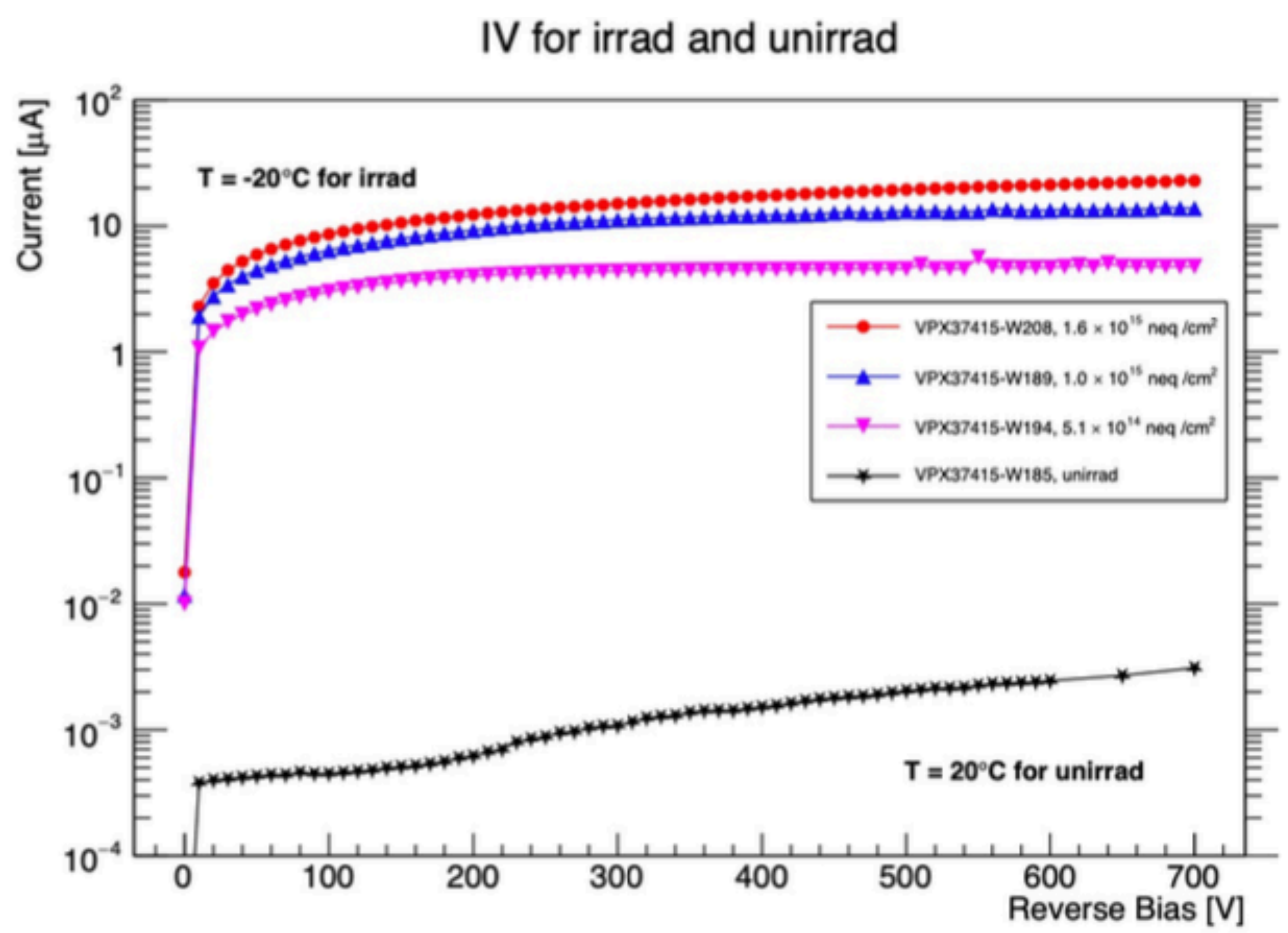
- ATLAS Inner Tracker will be the large charged tracking detector for the energy and luminosity frontier.
  - High tracking reconstruction efficiency and pattern recognition while keeping the material budget low
  - The radiation hardness and complexity of the system represents the large scientific instrument of this kind
- The new timing pixel detector has the potential to be used for the next generation of the ATLAS pixel detector to explore new physics

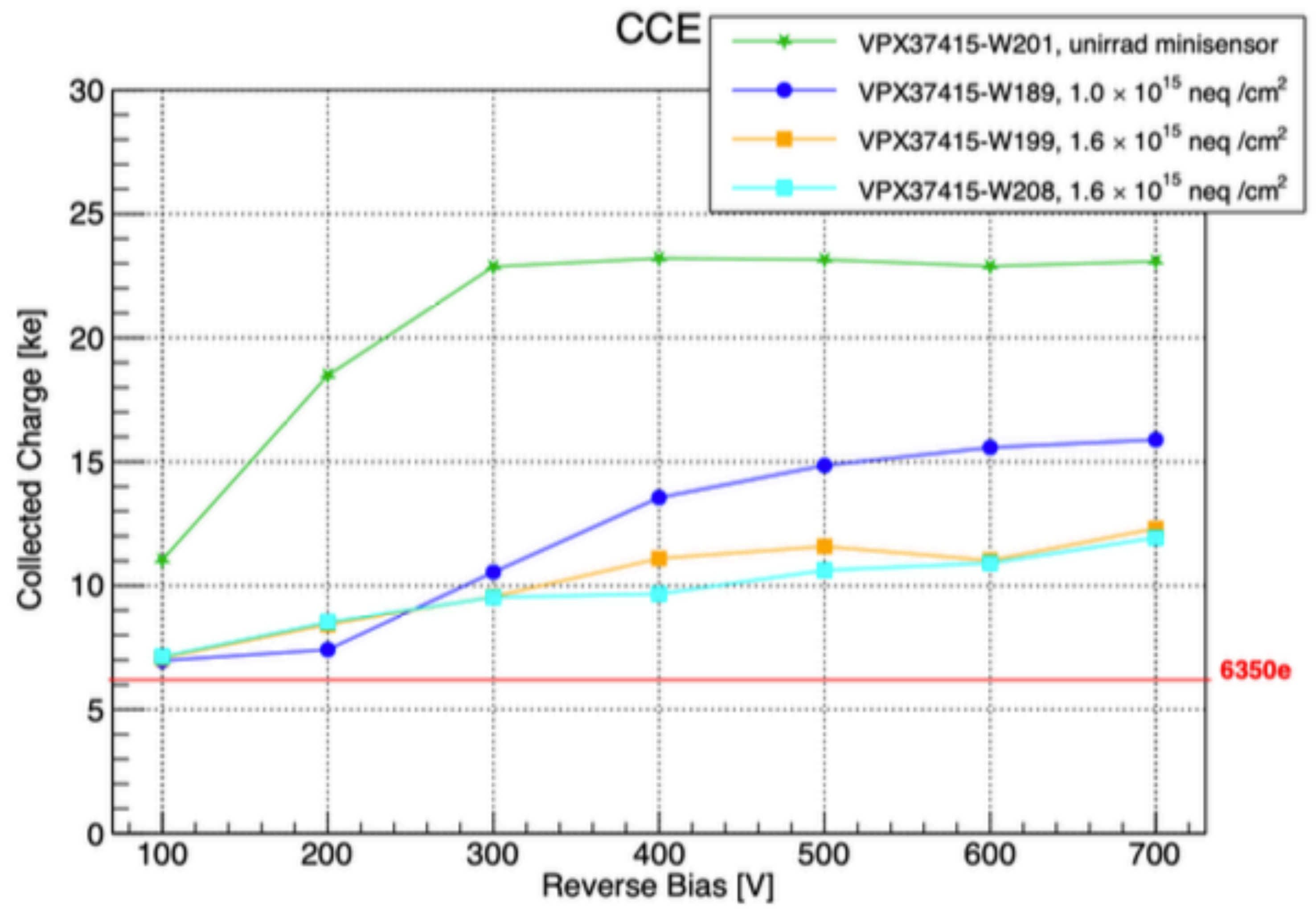
Sensor Irradiation Study

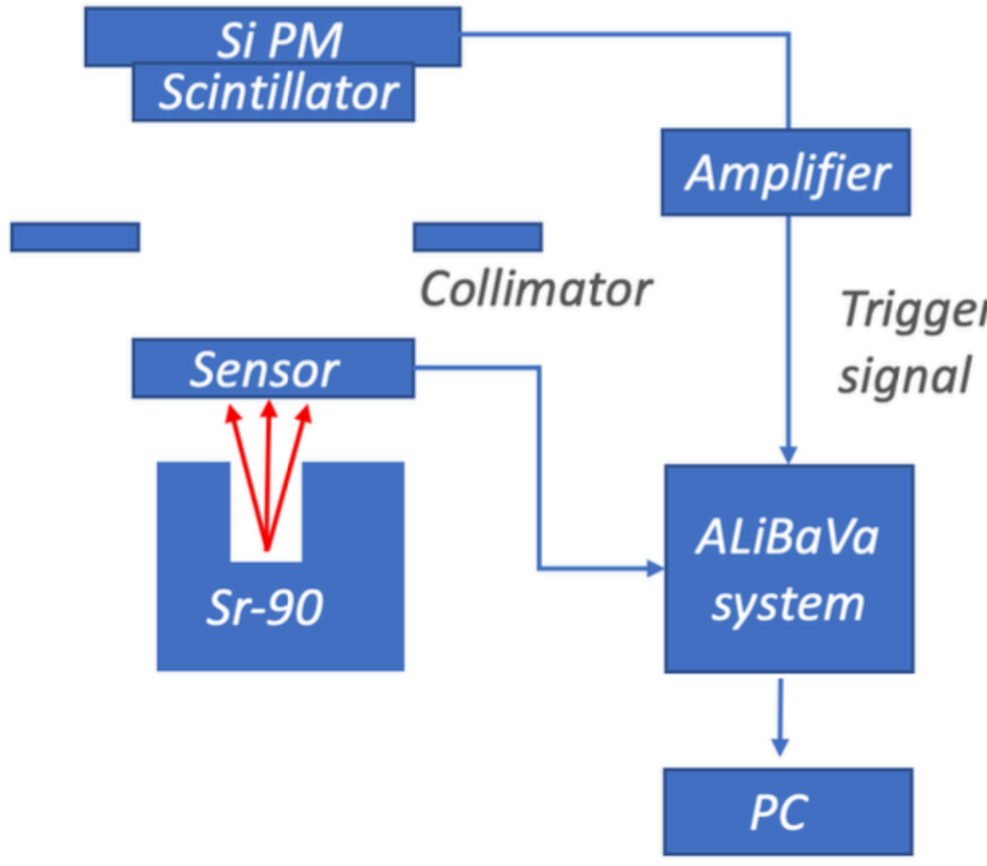
- Carried proton irradiation of strip mini-sensor at CSNS for quality assurance (QA) site
  - 80 MeV proton fluence up to $1.6x10^{15}\ n_{eq}/cm^2$
  - Developed temperature and humidity control chamber
- Sensor characterization at IHEP
  - I-V, C-V, to check if any early breakdown
  - CCE (Charge Collection Efficiency)





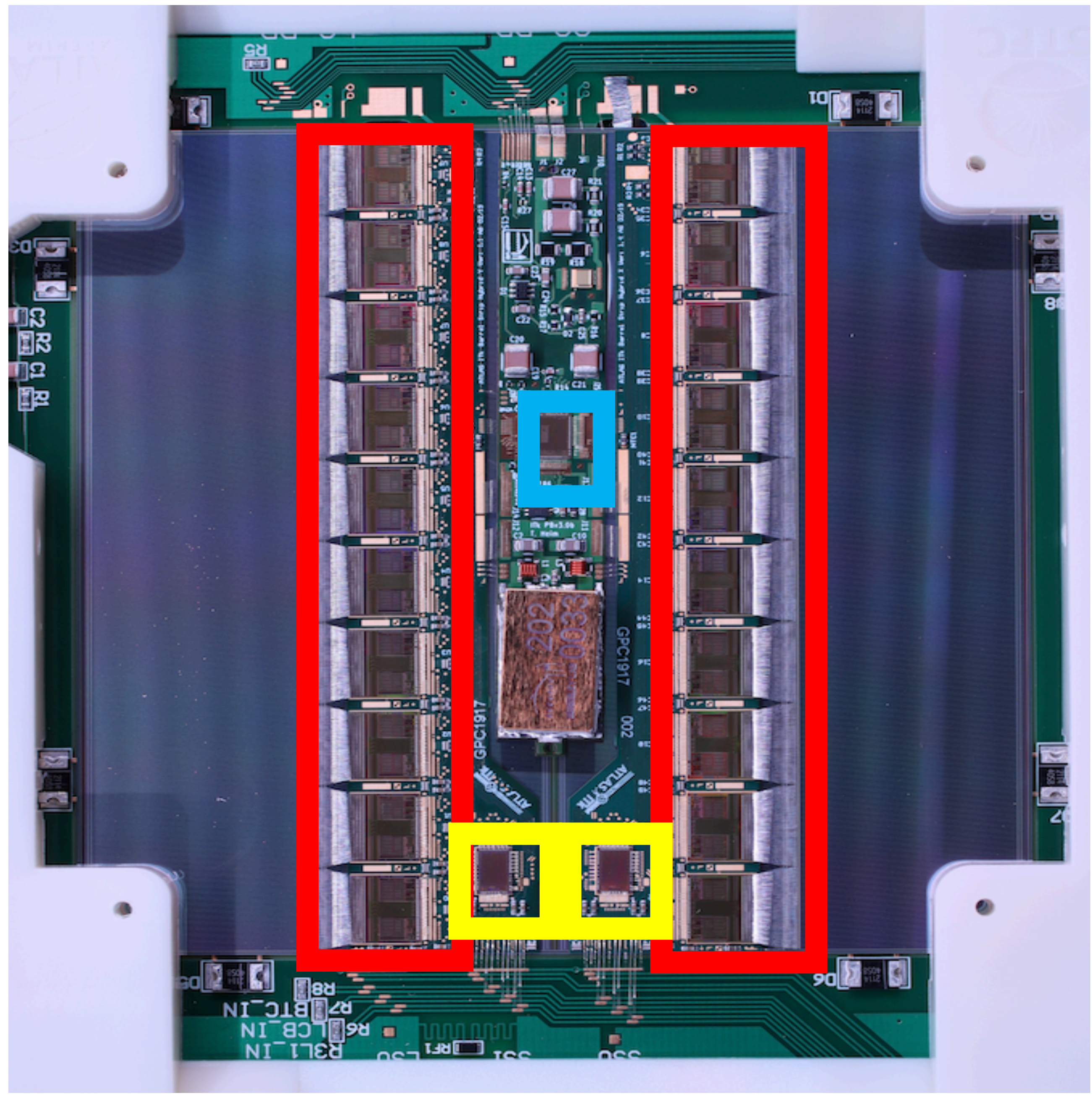


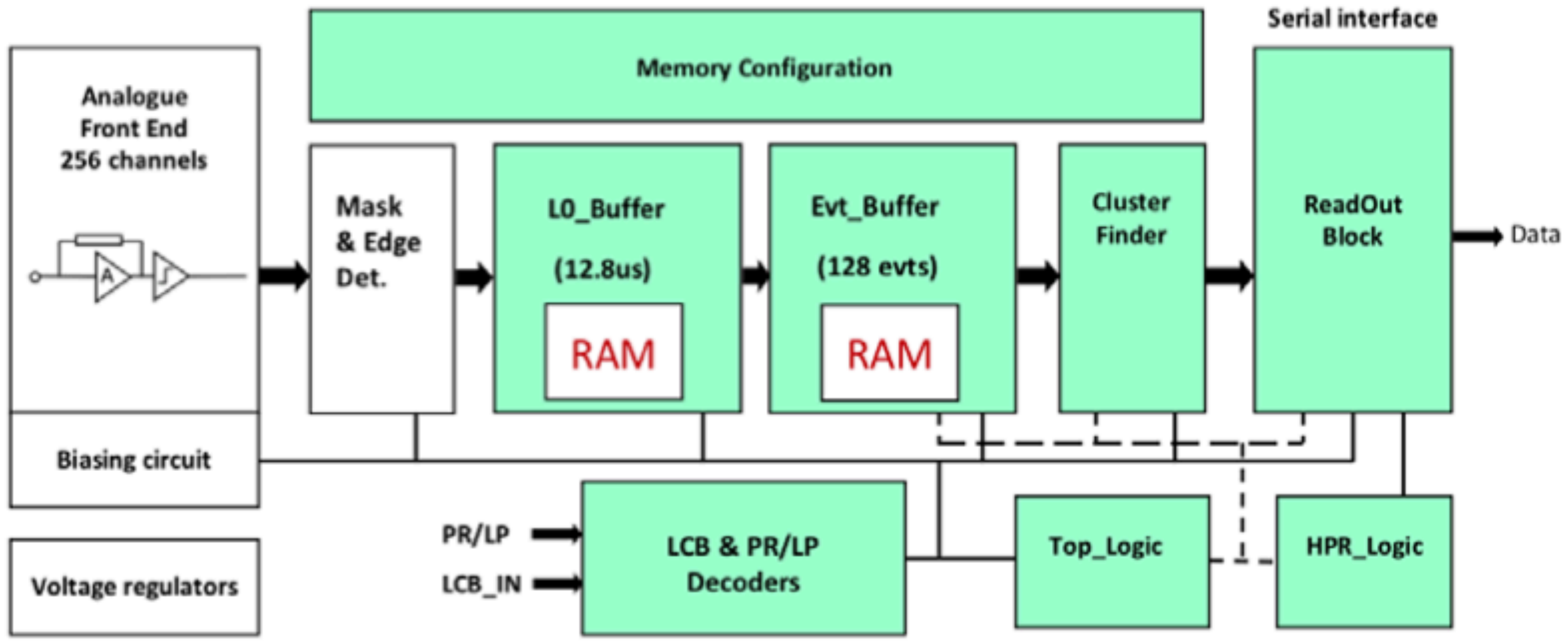


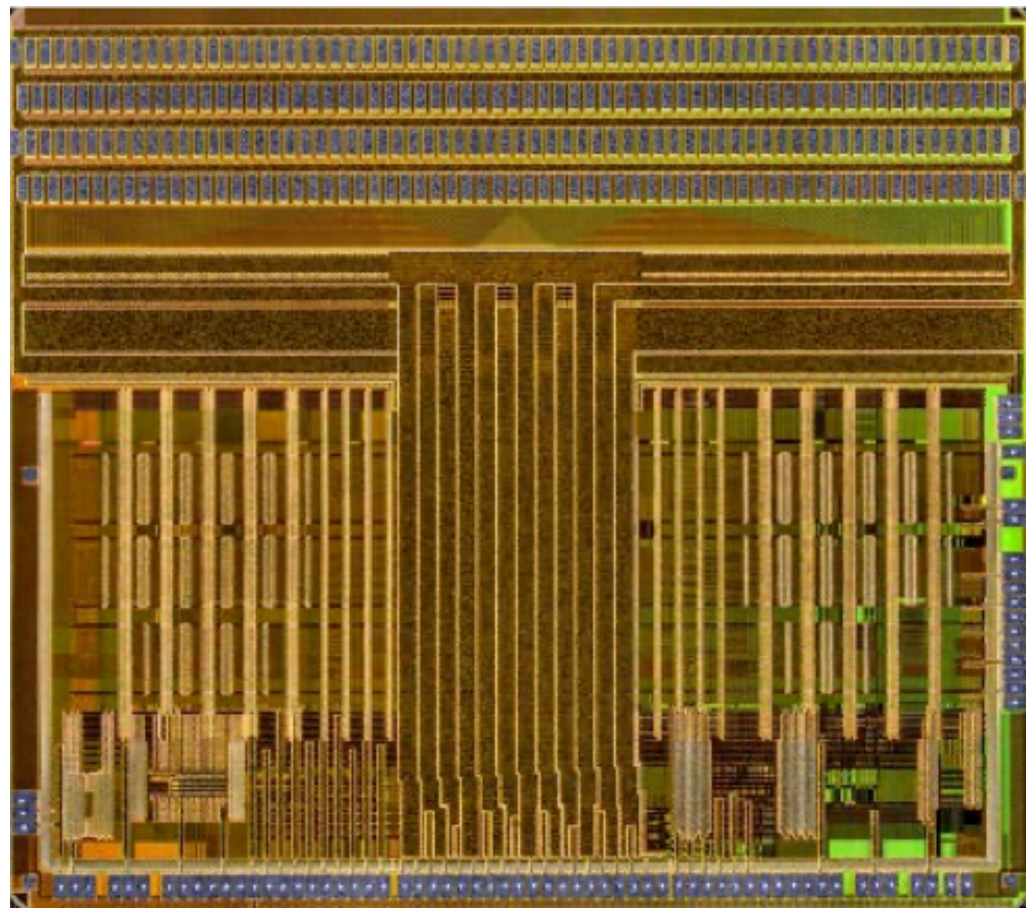


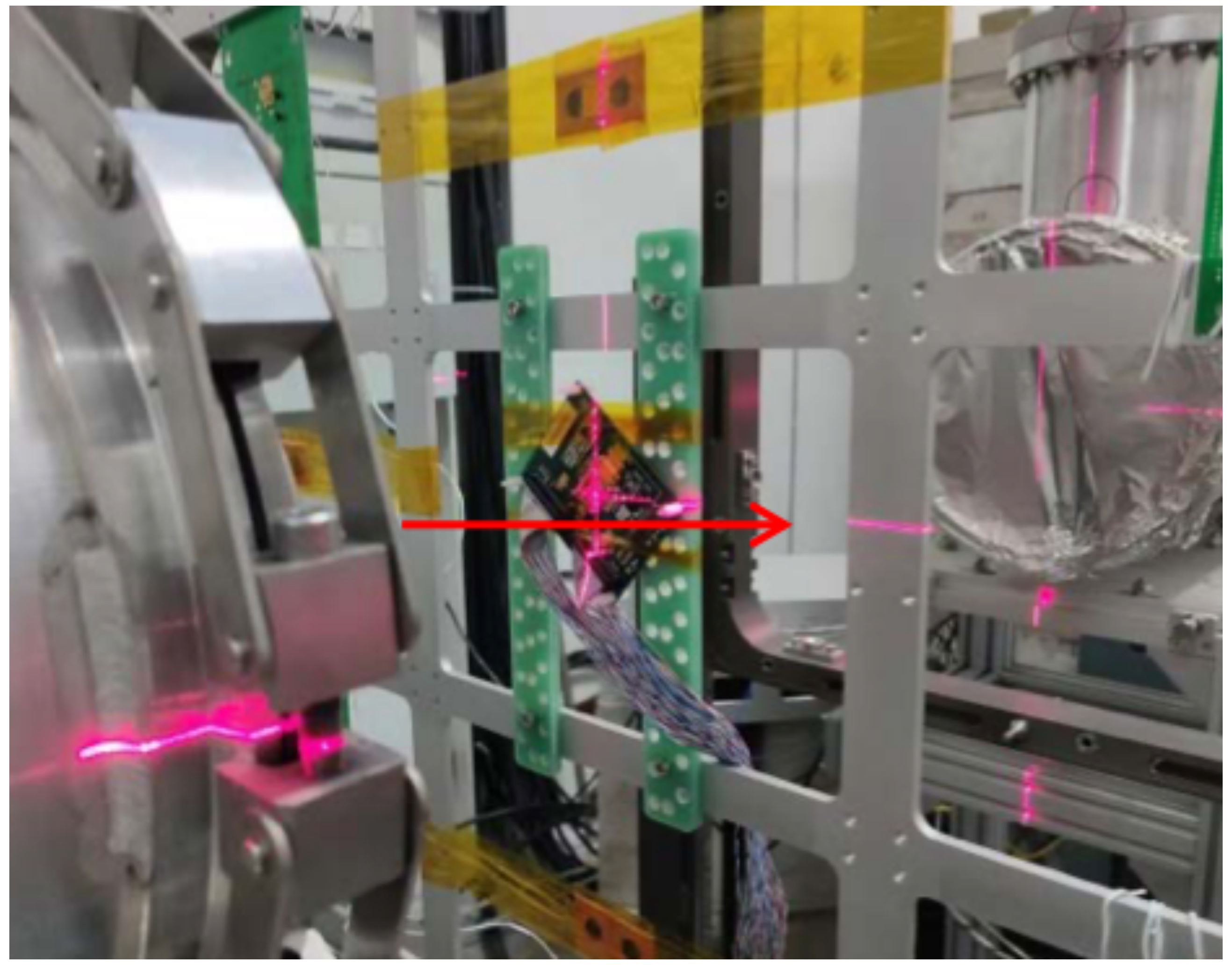
ASICs Irradiation Study

- Three types of ASIC on strip module
  - ABCStar : Strips readout front-end chip)
  - HCCStar : Interface between hybrid and stave
  - AMACStar: Monitor and control voltage, current, temp
- Contributed to design and verification of ABCStar
- ASICs TID studied with X-ray machine at IHEP
- Carry SEE test for ASICs at CSNS



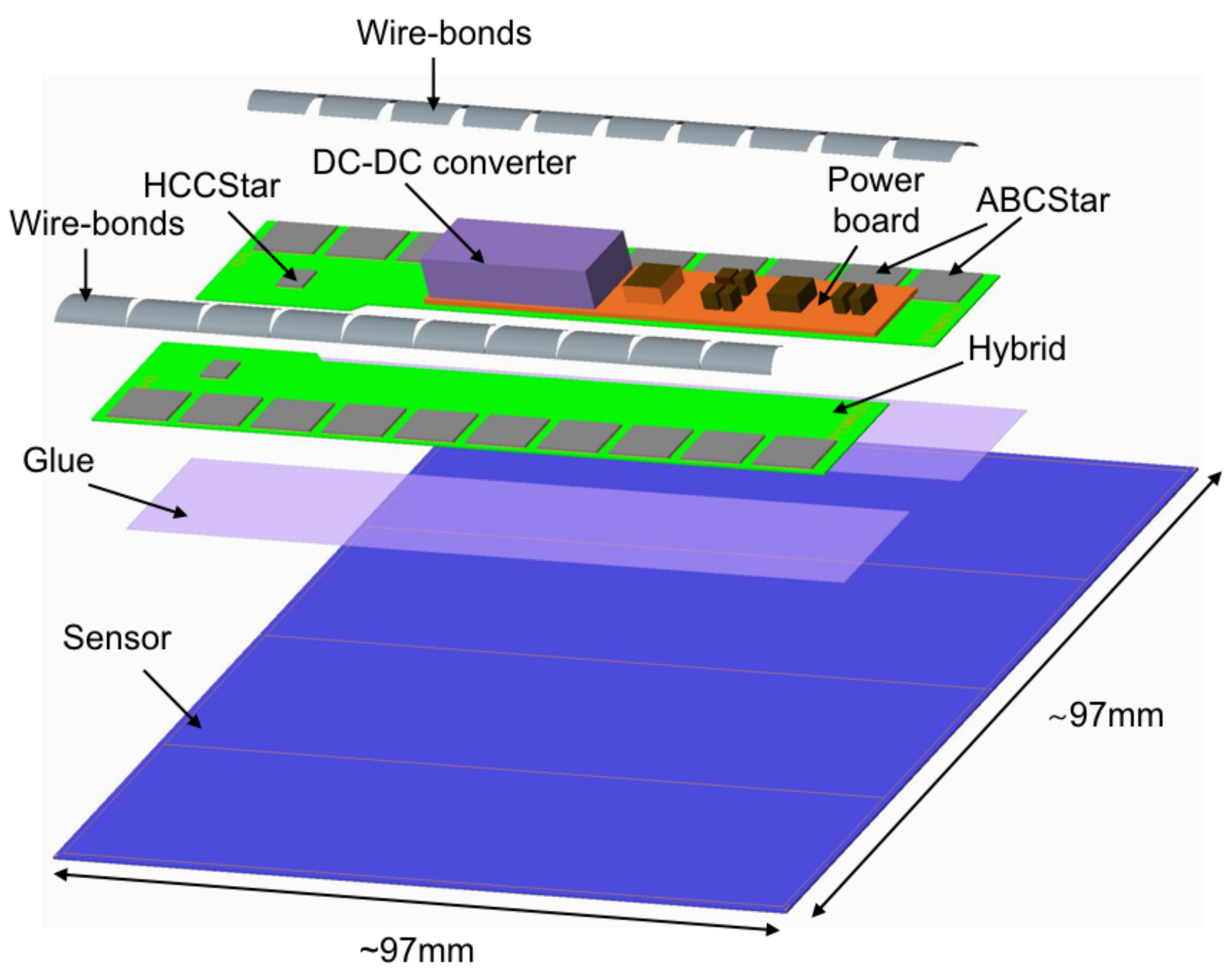


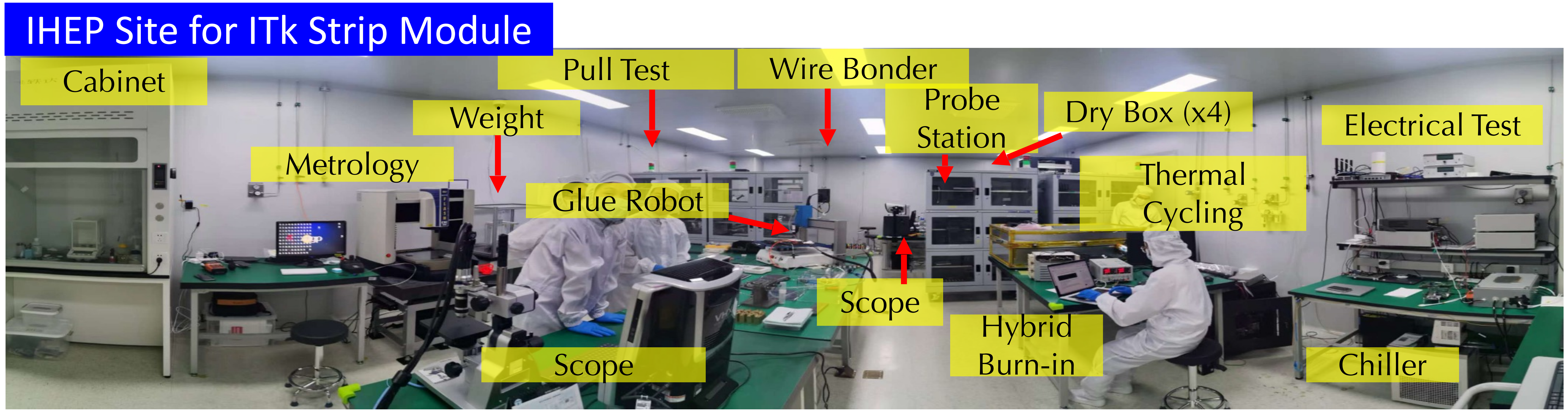




Strip Barrel Module Assembly

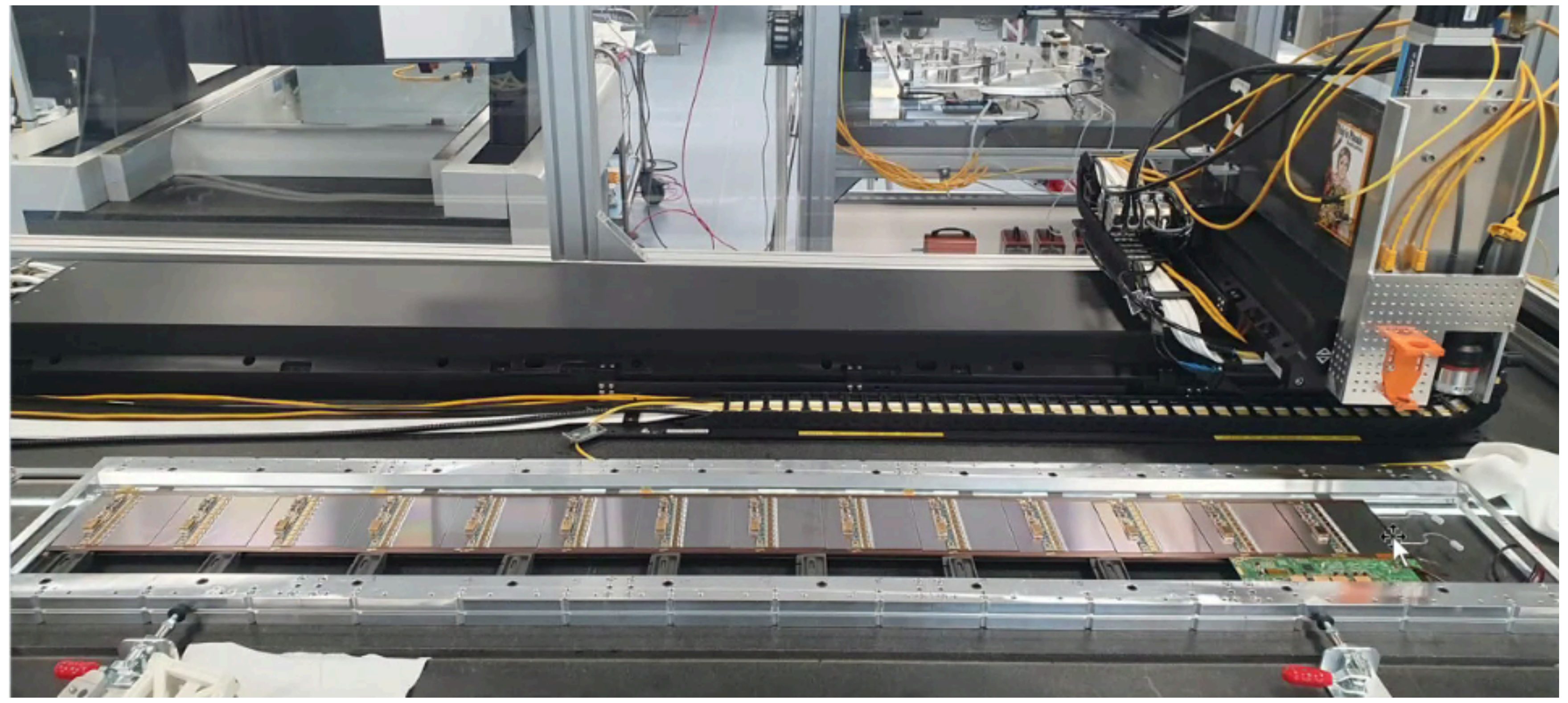
- China plan to deliver 10% strip barrel modules
  - For this project 200 modules
- Assemble detector modules precisely metrology and glue robot machines
- Thermal cycle modules 10x from -35°C to +40°C
  - Mimic the experimental situation at ATLAS



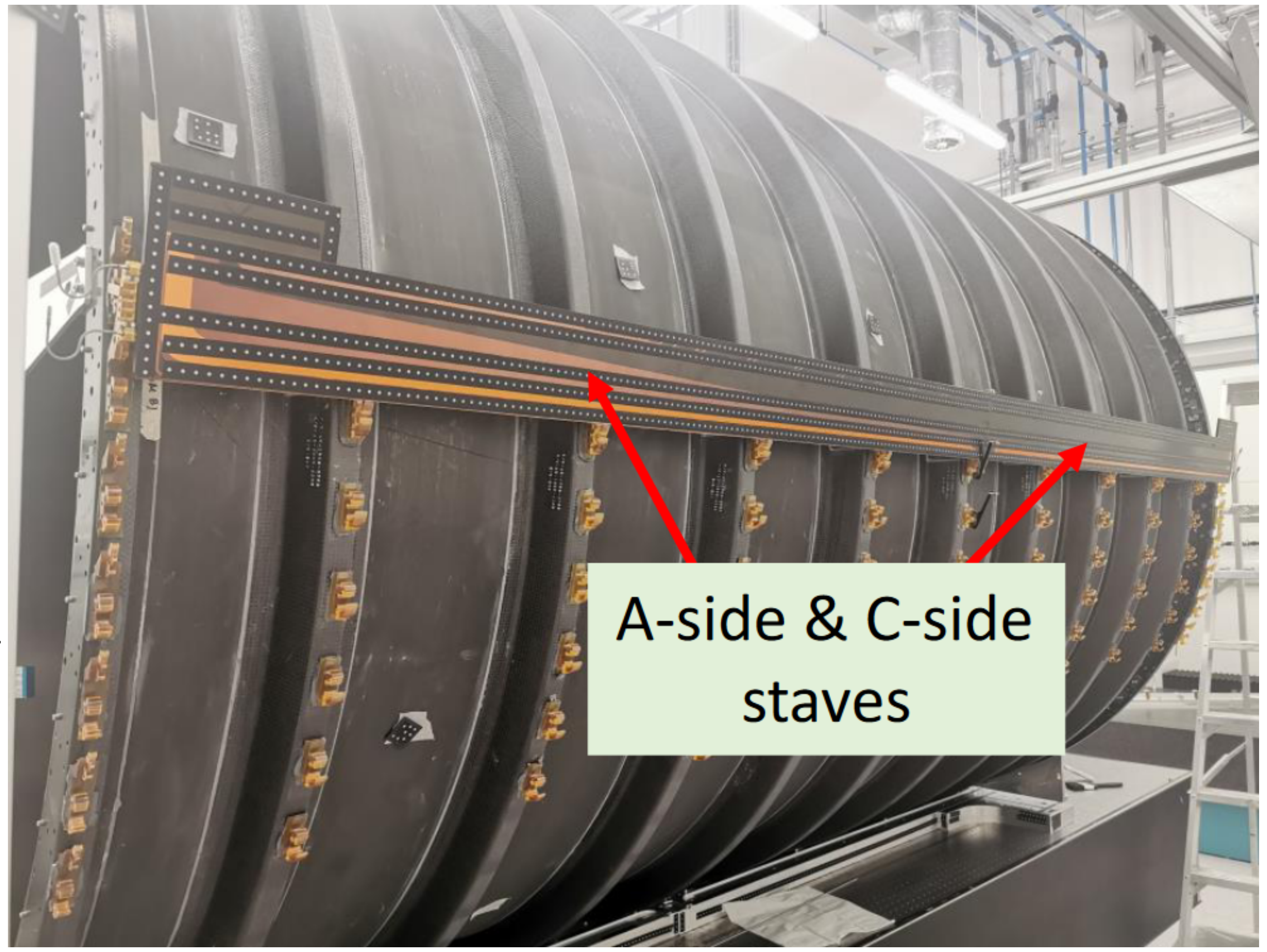


Barrel Tracker System Integration

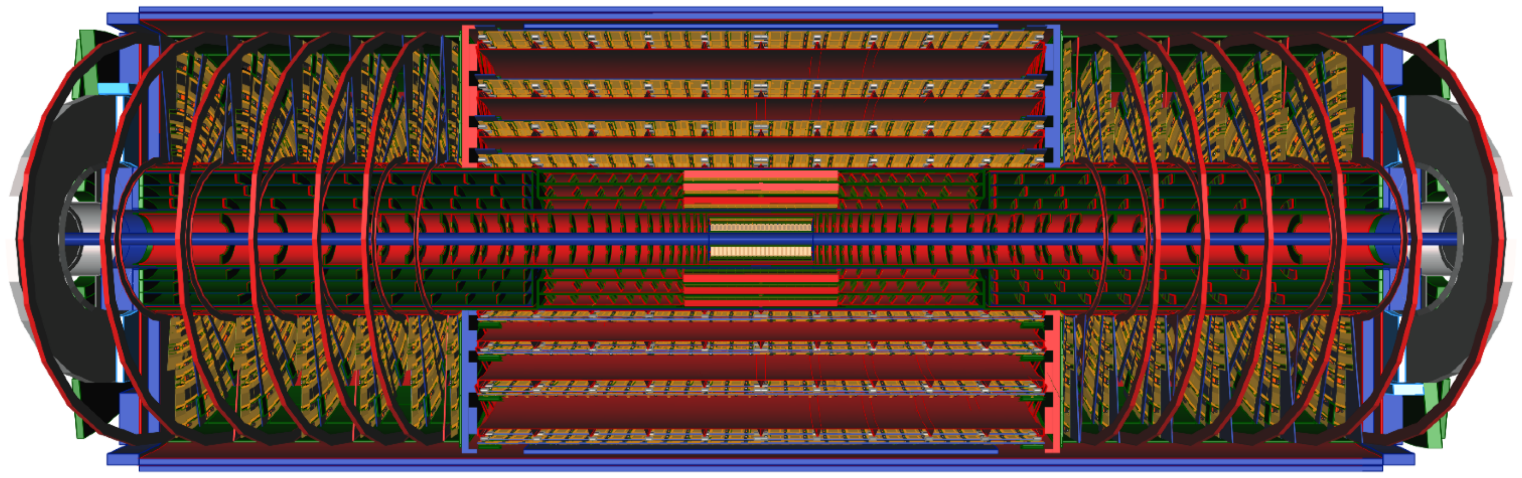
- Strip barrel stave loading
  - Mount 28 modules (14 each side) on the stave
    - Modules on each side rotated by +/-26 mrad
  - Thermal cycle the stave after loading

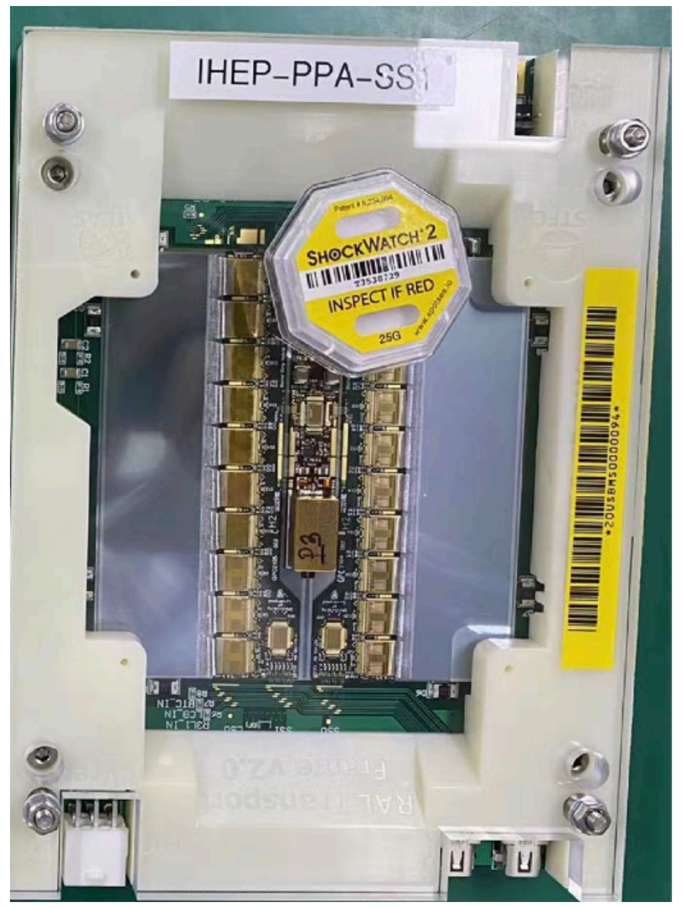


- Barrel tracker system integration
  - Tracker with four concentric carbon cylinders
  - Four barrel layers consists 392 staves
  - Perform power, cooling, data acquisition, system test



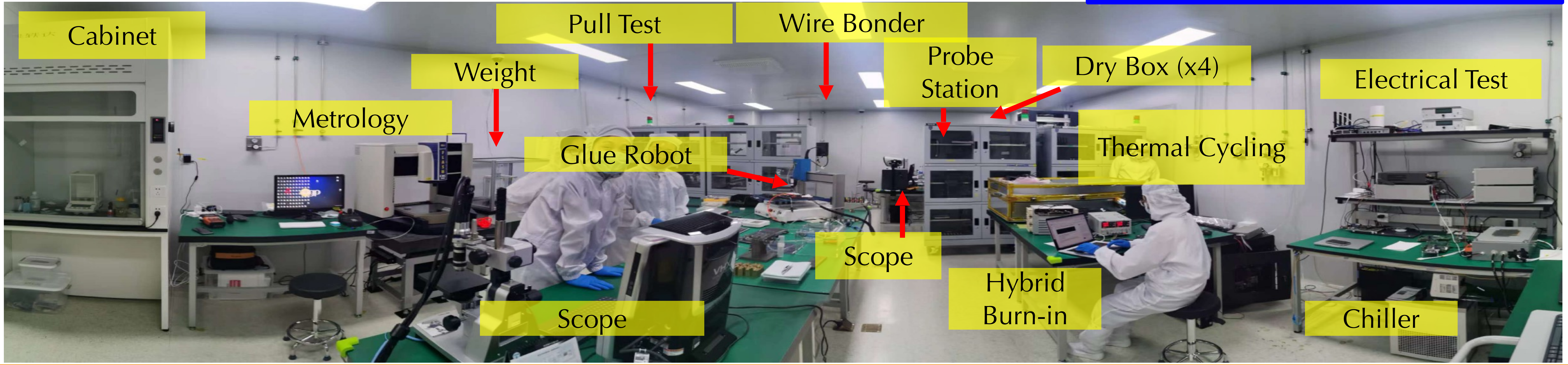
Inner Tracker (ITk) Strips Silicon Tracker





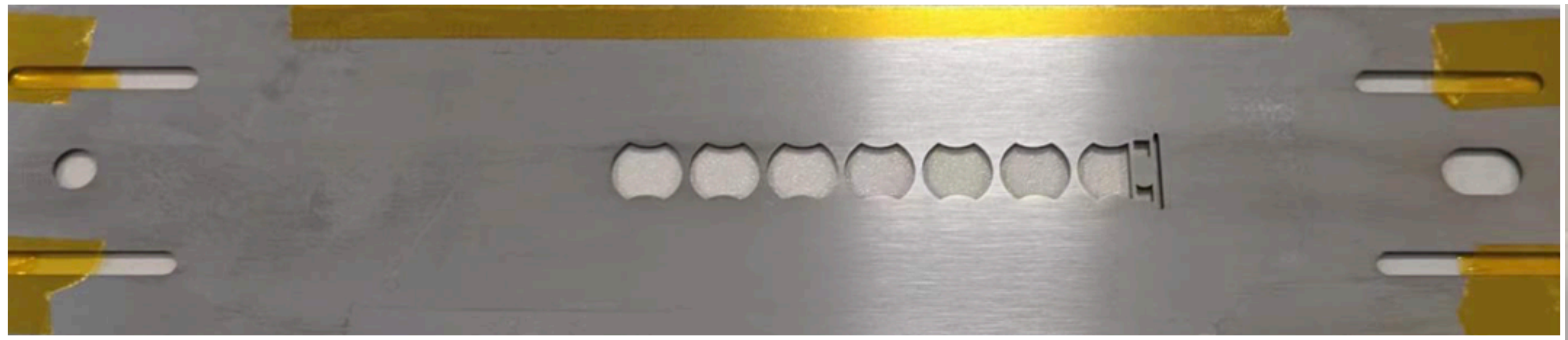
- **China-ITk will deliver 10% strip barrel modules**
  - 1000+ strip modules, 10m^2 sensor area
  - 500 modules done at RAL + 500 modules at IHEP
- **Contributions to strip sensor and ASICs**
  - Design and verification of **ABCStar** chip
  - Sensor and ASICs Irradiation @CSNS
- **Will contribute to strip barrel system integration, installation and commissioning**

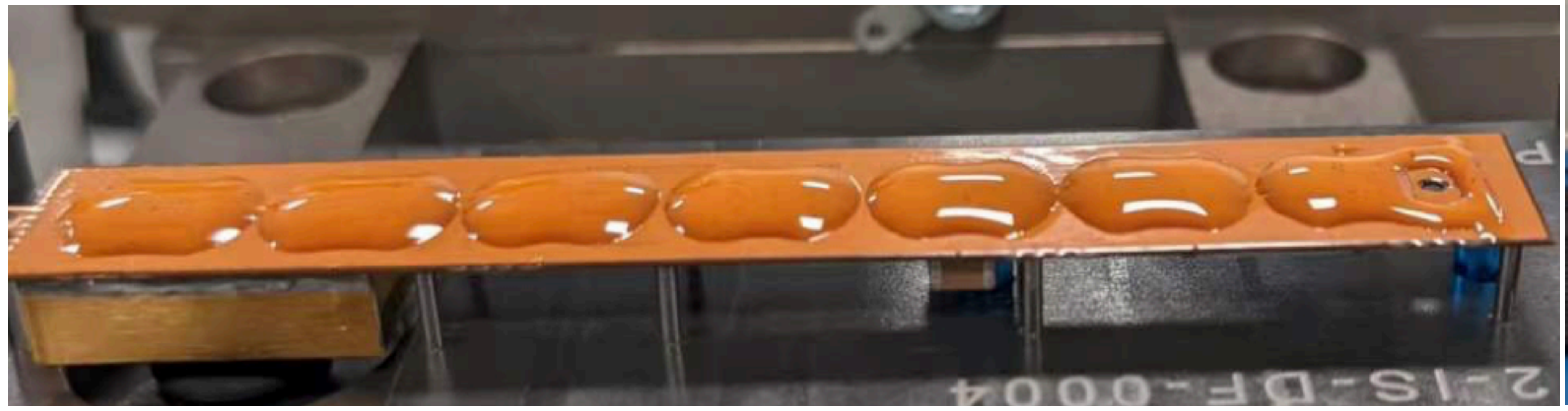
IHEP Site for ITk Strip Module



RAL Site Module Production and Stave Loading

- **Two FTEs from IHEP based at RAL (one postdoc + one student)**
- **Contributed to RAL site module production and stave loading**
- Contributed to beam test and analysis
- Active on tools design tweak, wire bond oscillation test, etc
- **IHEP postdoc instrumental in study of recent "cold noise" problem**
- Will be involved in the tracker system integration in the future

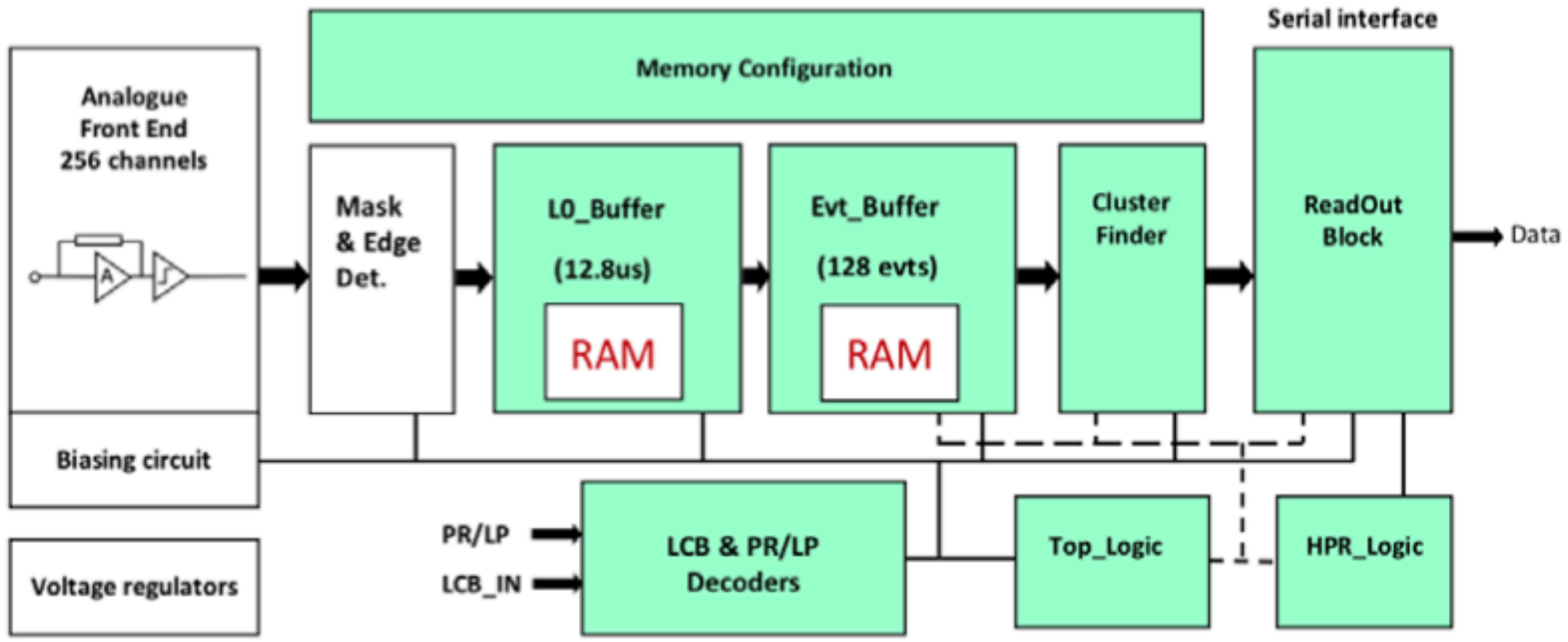


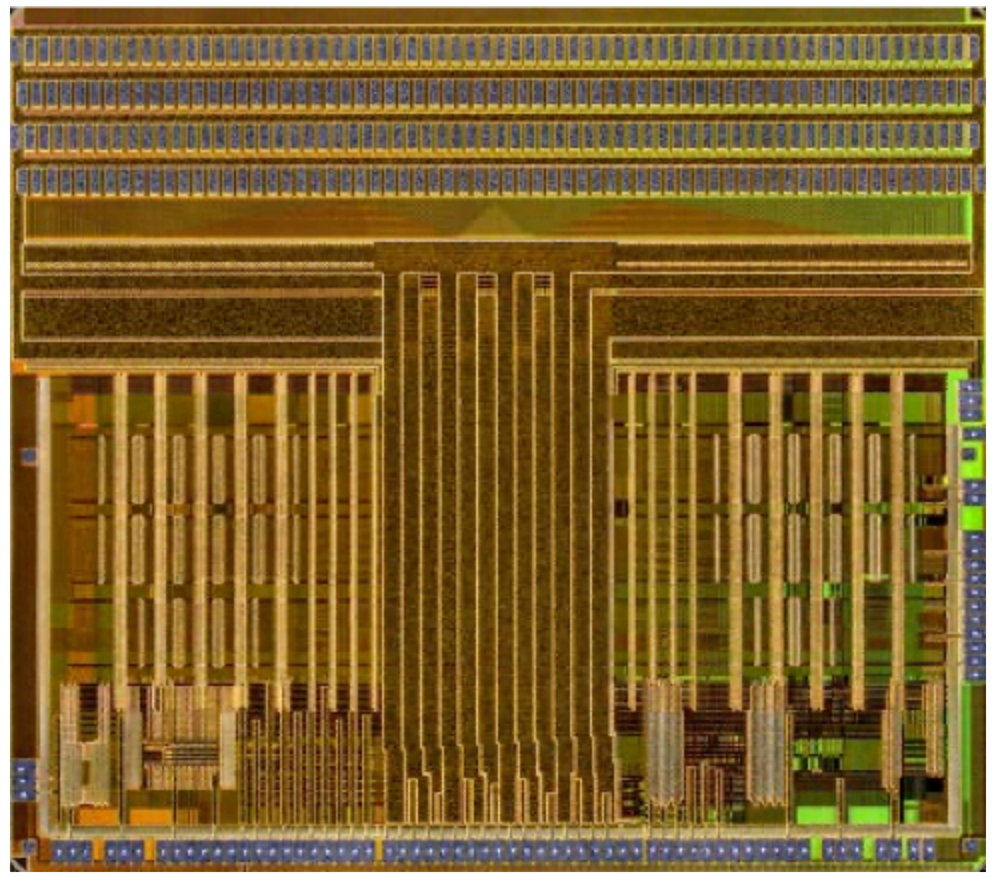


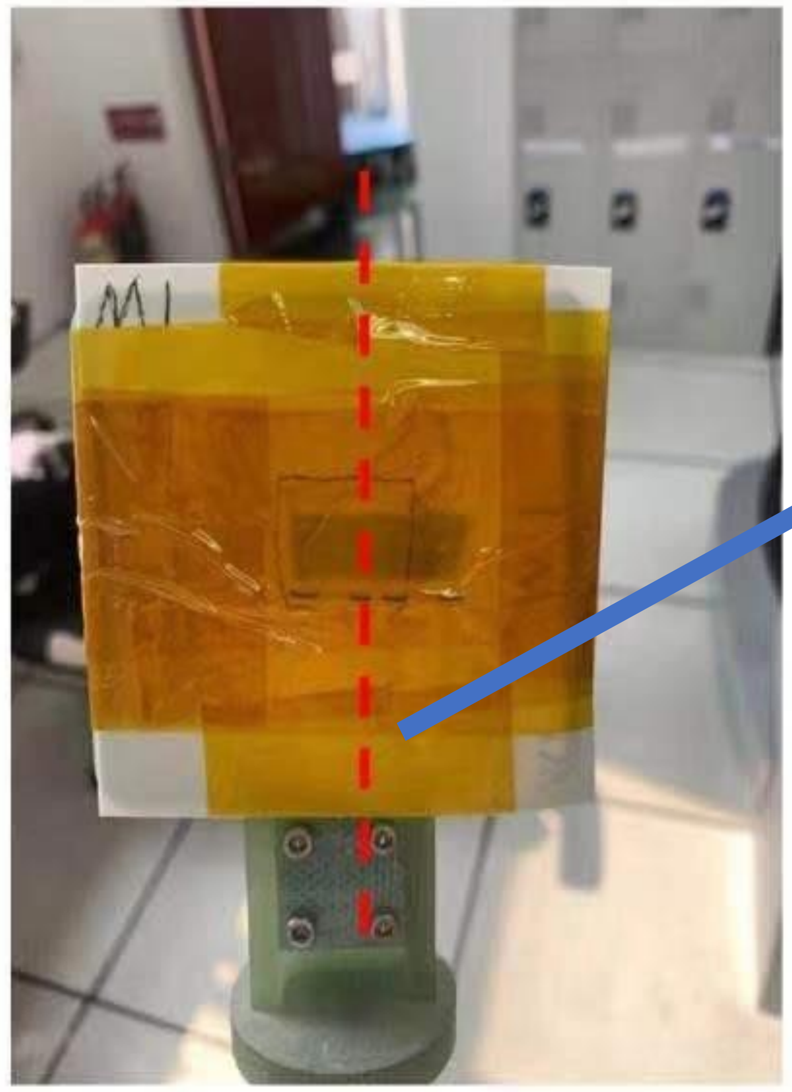
Radiation Hard Strip Sensor & ASIC Study

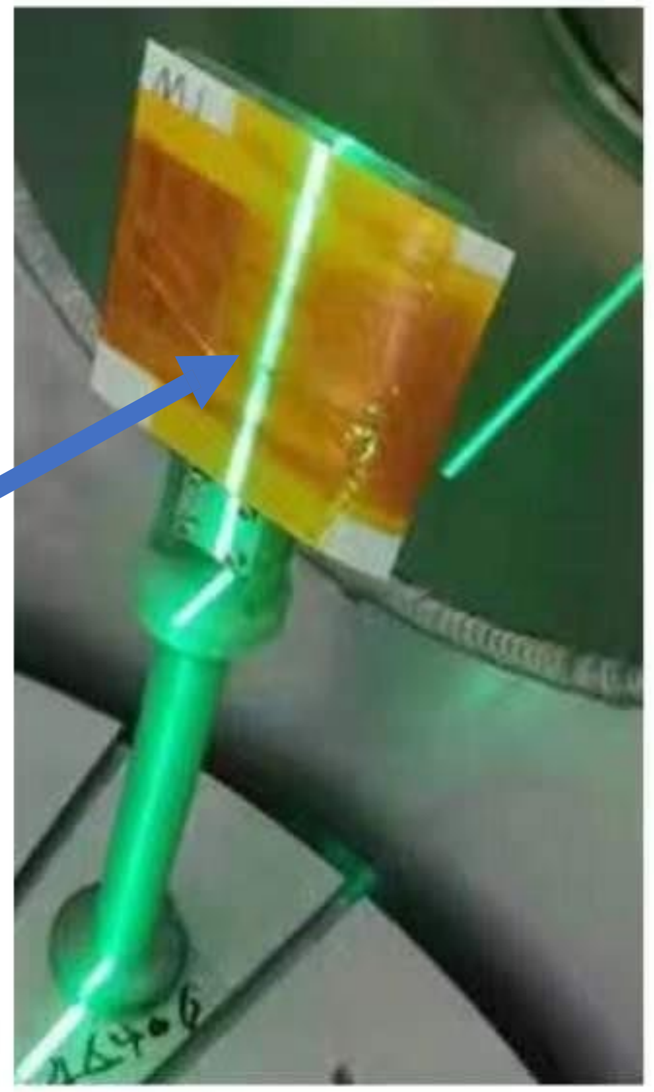
- Carried proton irradiation of ITk strip mini-sensor @CSNS for quality assurance (QA) site
- Sensor irradiation characterization @IHEP

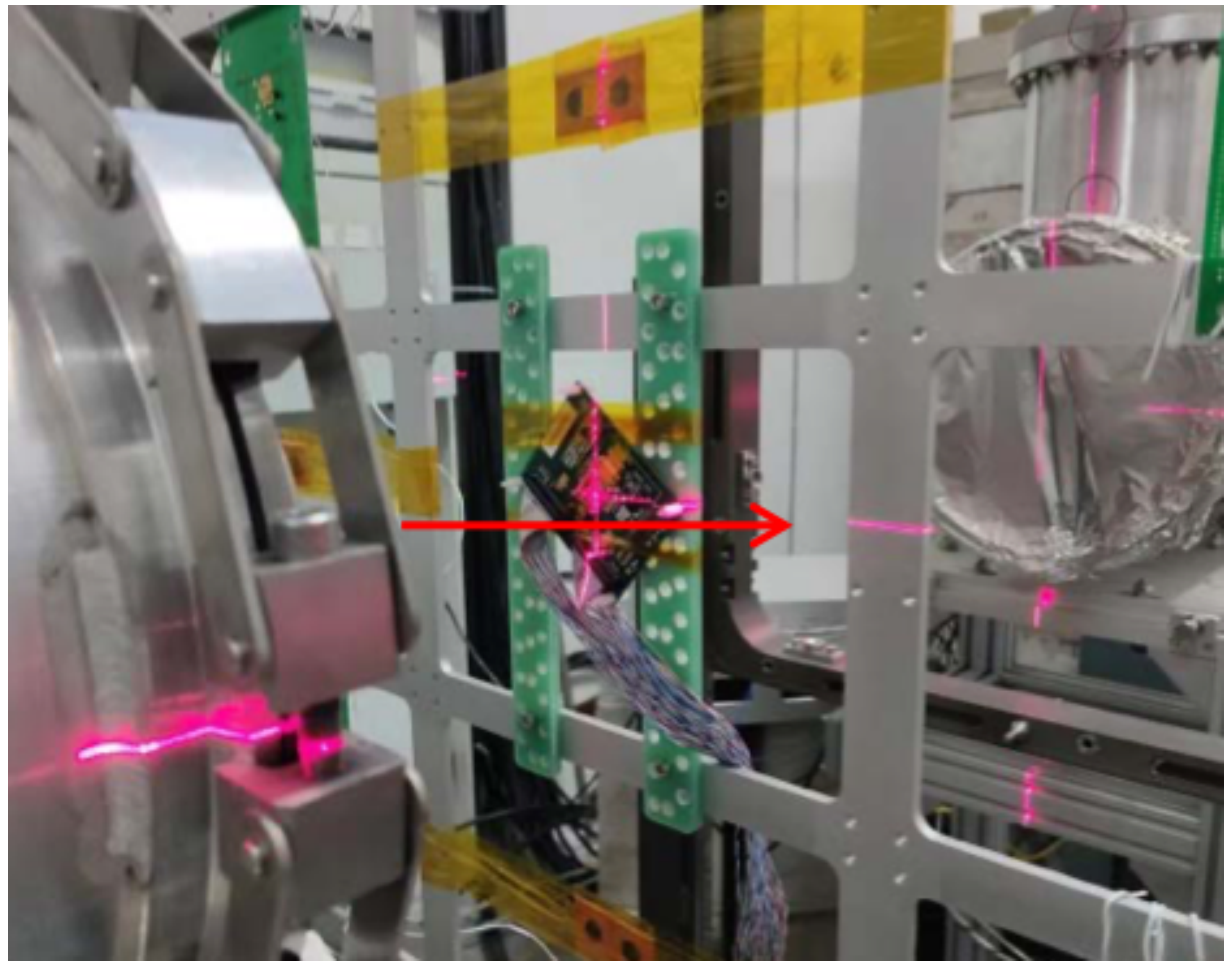
- **Contributed to design and verification of ABCStarV0**
- ASICs TID studied with X-ray machine at IHEP
- Carried SEE test at CSNS for ABCStarV1, HCC and AMAC



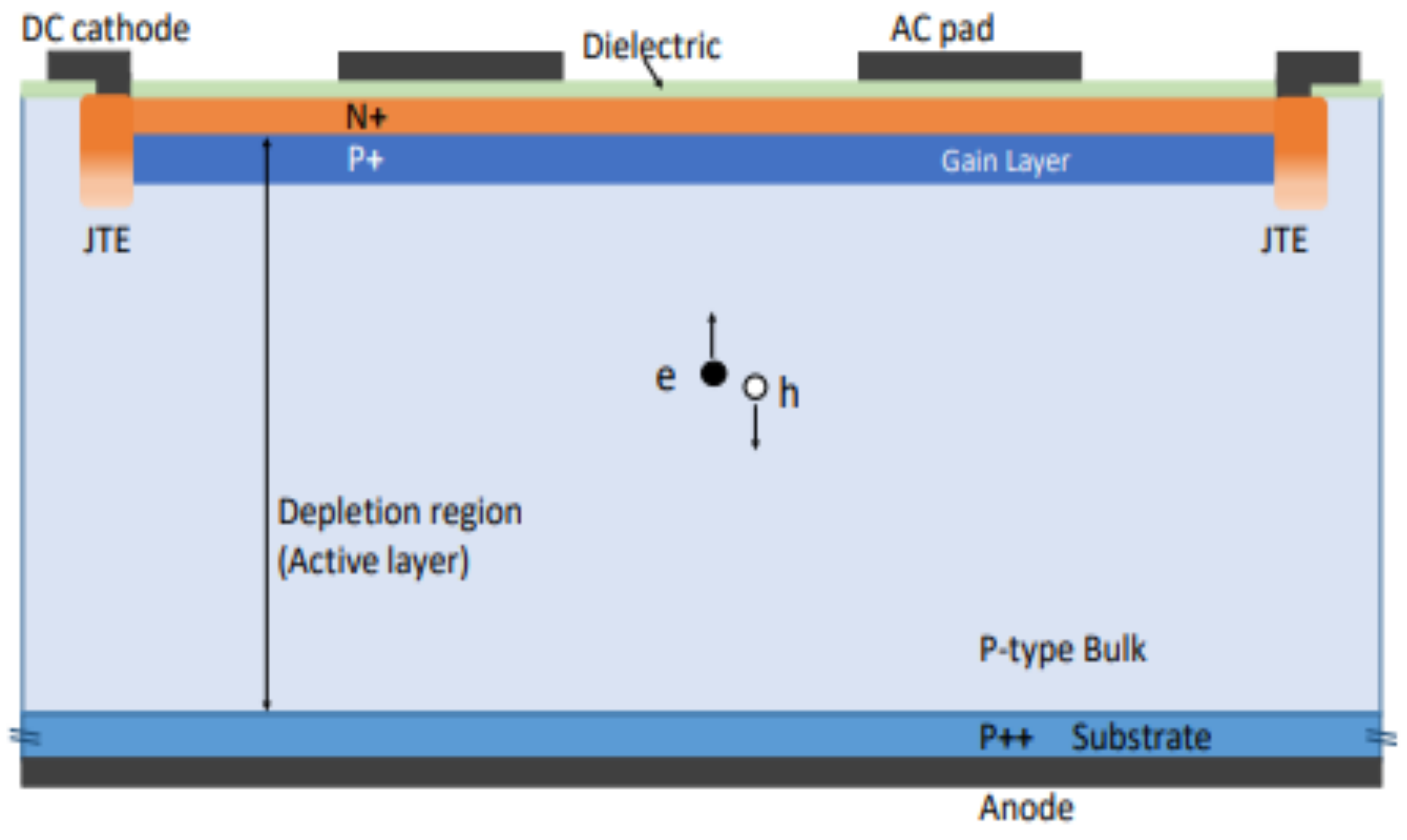


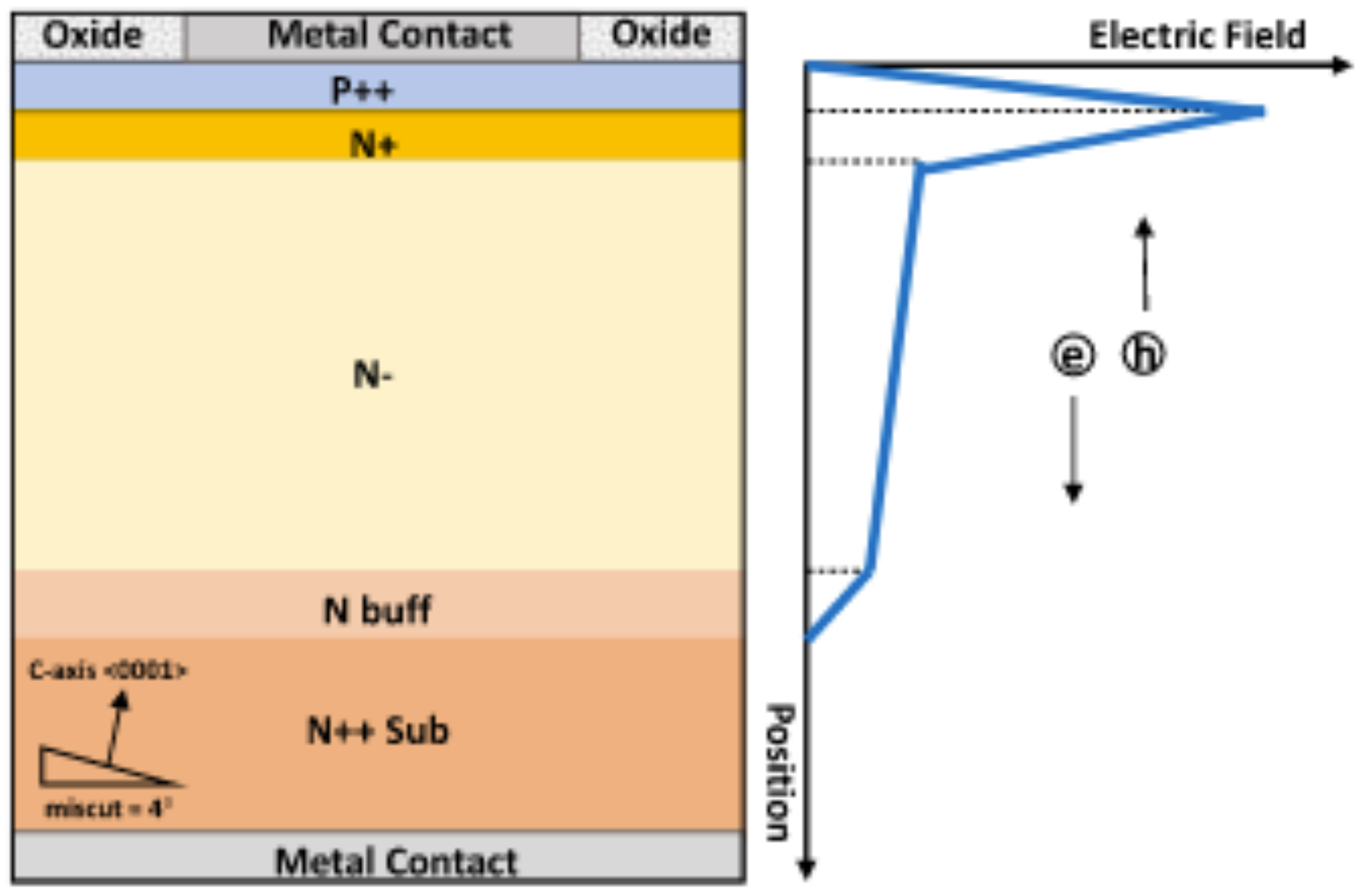




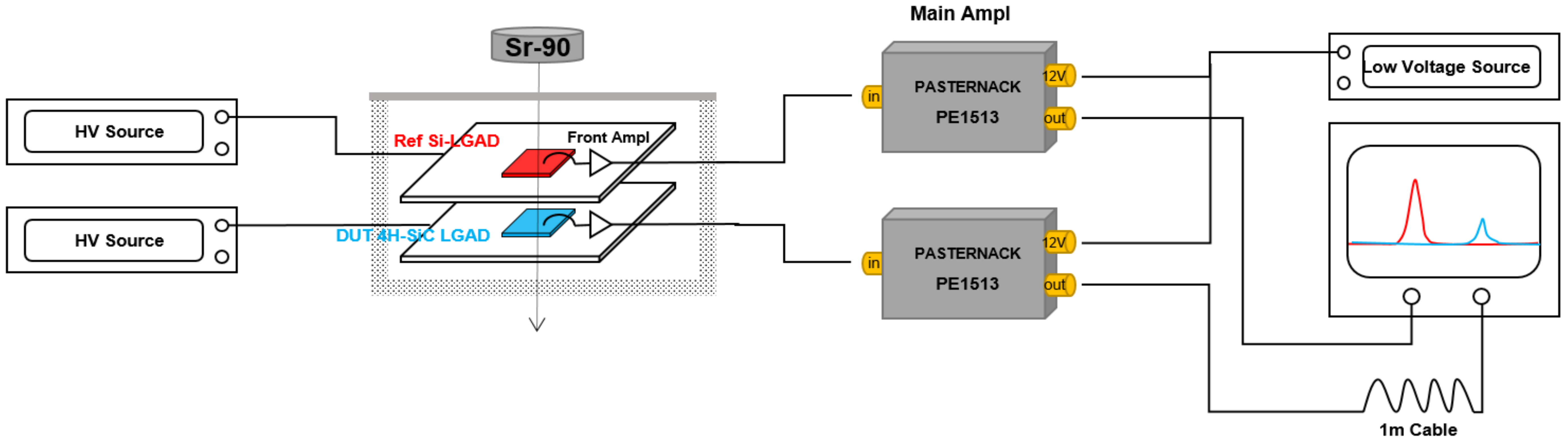


Timing Pixel Sensors R&D



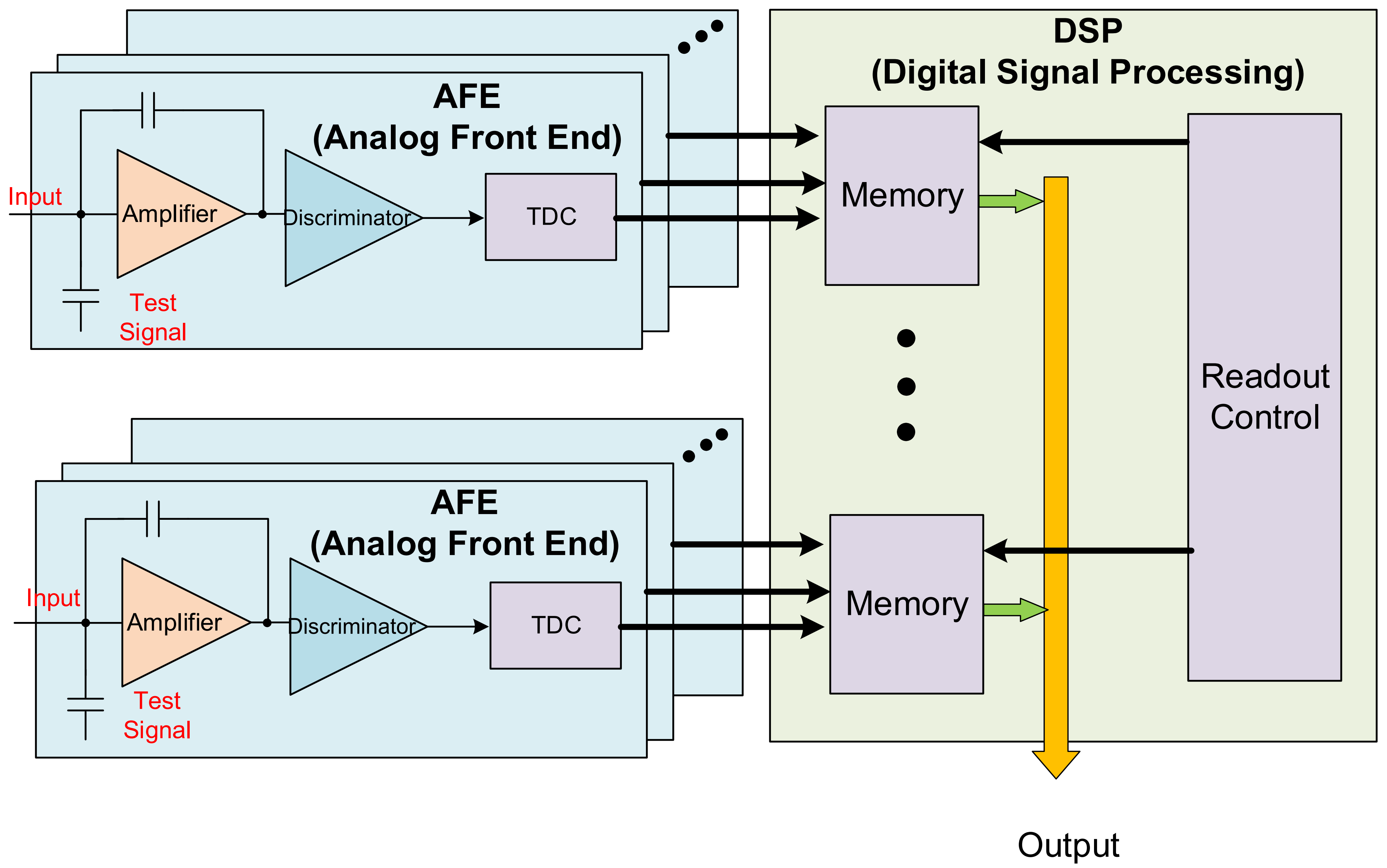


- Pixeled LGAD sensor will be designed and fabricated
- TCAD simulation and design
  - sensors geometry structure, substrate properties, process parameters
  - Sensor Layout and fabrication:
- Mask design and controllable fabrication process
- Electrical system for timing information, Beta source testing
- Timing resolution before and after irradiation be less than 100ps

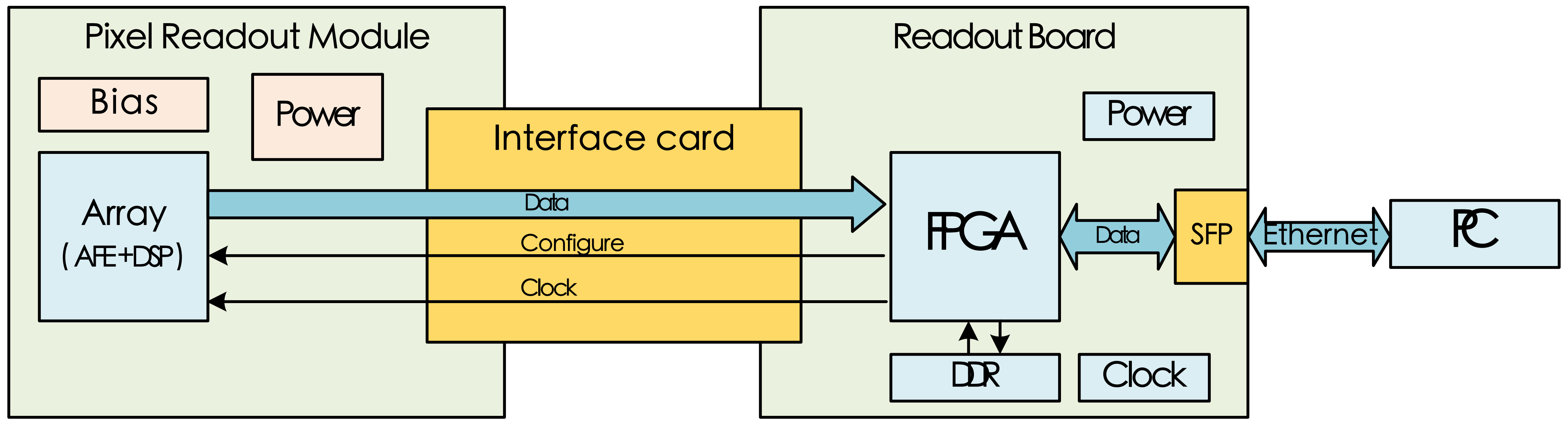


Timing Pixel Readout Electronics

- Timing Pixel Readout Module design
  - Analog front end design: Amplification and discrimination combined with high-precision TDC to extract time information
    (By international cooperation)
  - Strategy and architecture design for TDC data buffering and fast readout



- Readout system prototype design
  - Pixel Readout Module provides power supply and bias for the AFE array and DSP
  - Readout Board is responsible for the data collection, data transmission, and configuration
  - Interface card connects the Pixel Readout Module and Readout Board



Muon Detector Detailed Information

Task 3: Participating units and personnel

- Lead unit: University of Science and Technology of China, project leader: Sun Yongjie
- Participating unit: Shanghai Jiaotong University, head of the unit: Guo Jun
- Participants: 12 people
  - University of Science and Technology of China: 9 people, including: 4 deputy seniors and 5 others
  - Shanghai Jiaotong University: 3 people, including: 1 deputy senior, 2 others

- 分工：
  - 关键技术研究部分：根据已有基础条件和专长合理分工，最大程度发挥各单位的研究力量，保证各关键技术研究按时完成。
  - 探测器与电子学的制作和测试：共同集中人力，在中科大完成，尽量避免大面积探测器的运输专场。
  - 探测器的现场安装和调试：则由两家单位按合适比例共同承担

- Division of labor:
  - Key technology research part: According to the existing basic conditions and expertise, give full play to the research force of each unit to the maximum extent, and ensure that the research of each key technology is completed on time.
  - Production and testing of detectors and electronics: gather manpower together, complete it at the University of Science and Technology of China, and try to avoid the transportation of large-area detectors.
  - On-site installation and commissioning of the detector: it shall be jointly undertaken by the two units in an appropriate proportion.

Task 3: Organizational management and safeguards

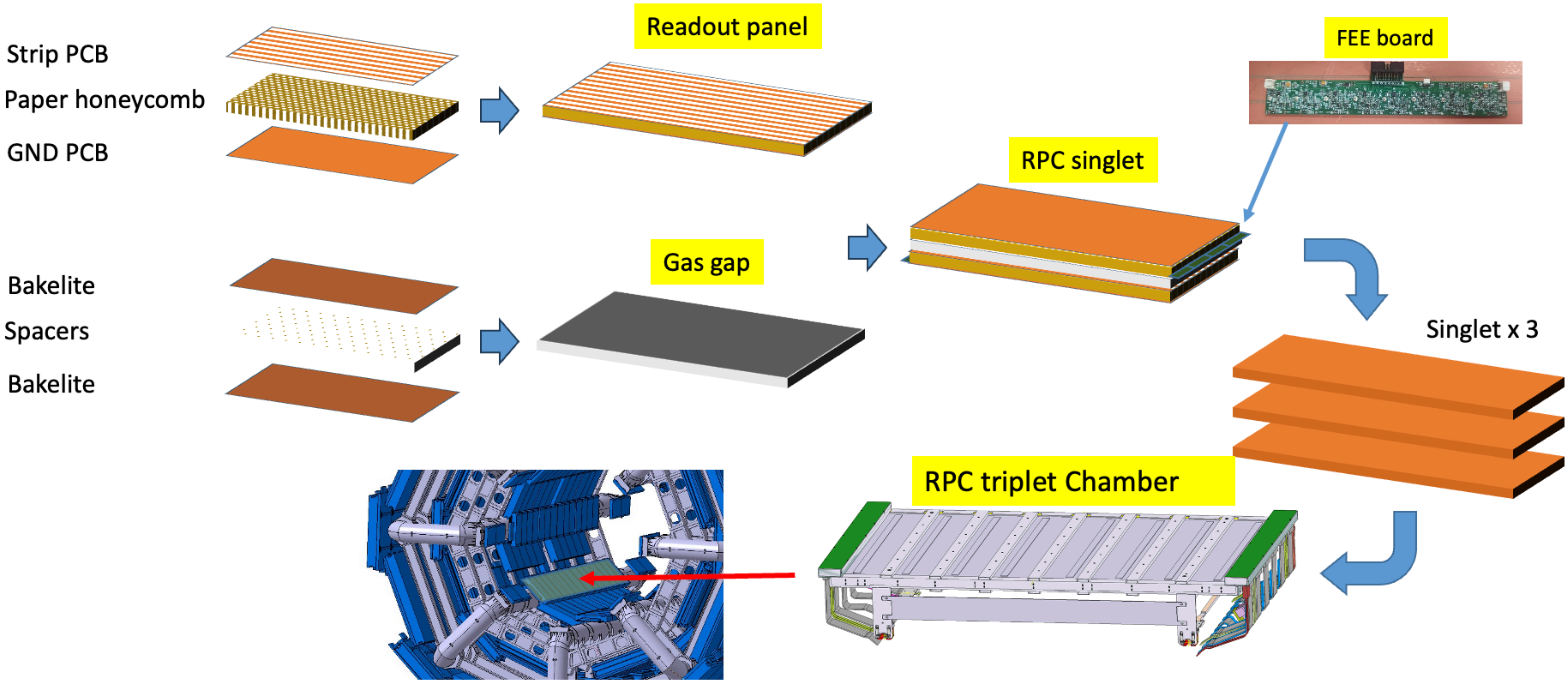
- This topic implements the overall responsibility system of the person in charge of the project.
- The person in charge of the project organizes and coordinates the development and implementation of various research work of the project. The project leader designates the specific person in charge of all aspects according to the research content of the project. They maintain close communication and exchange with the project leader and carry out various research work under the leadership of the project leader.
- The project will regularly organize regular meetings of the research group to discuss and solve specific technical problems; hold a second research group seminar every year to discuss the important issues in the implementation of the project; hold a year-end summary meeting every year to check the progress of the project and arrange the specific work of the year.
- The project will strictly implement the policy requirements of the State and the Ministry of Science and Technology for the "National Key Research Plan". The participating units of the project and the countries where the participating units are located and the key laboratories of the Ministry of Education will support human resources, laboratory sites and related conditions such as researchers, support personnel and graduate students to ensure the smoothness of the project. Implement and achieve the goal.

Task 3: Risk analysis and countermeasures

- The risk of adjusting the progress of large-scale international cooperation: there are many participating units, and the tasks undertaken by each unit are intertwined and supported by each other; and are affected by the entire ATLAS experiment and HL-LHC upgrade plan.
  - Response measures: Actively participate in the communication and discussion related to the upgrade project, keep abreast of the latest developments of each task, reasonably adjust the specific work arrangement, and ensure that each task is completed on time.

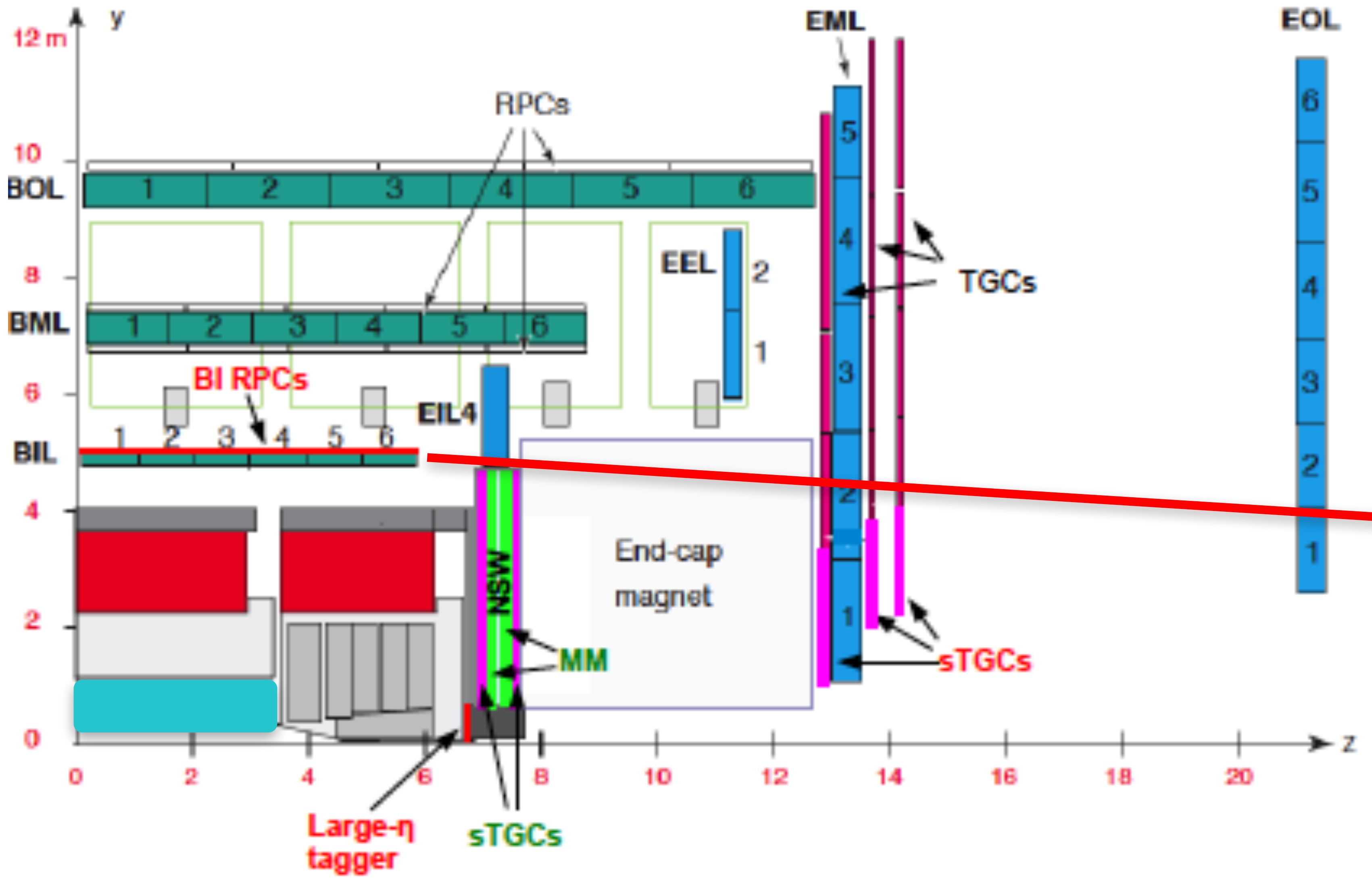
- Risk of long-distance transportation of large-area detectors: Each unit undertakes different assembly steps, involving the detector transportation chain of Italy, China, Germany and Switzerland.
  - Countermeasures: Reasonable design of detector support, packaging and protection structure to avoid damage to detector transportation

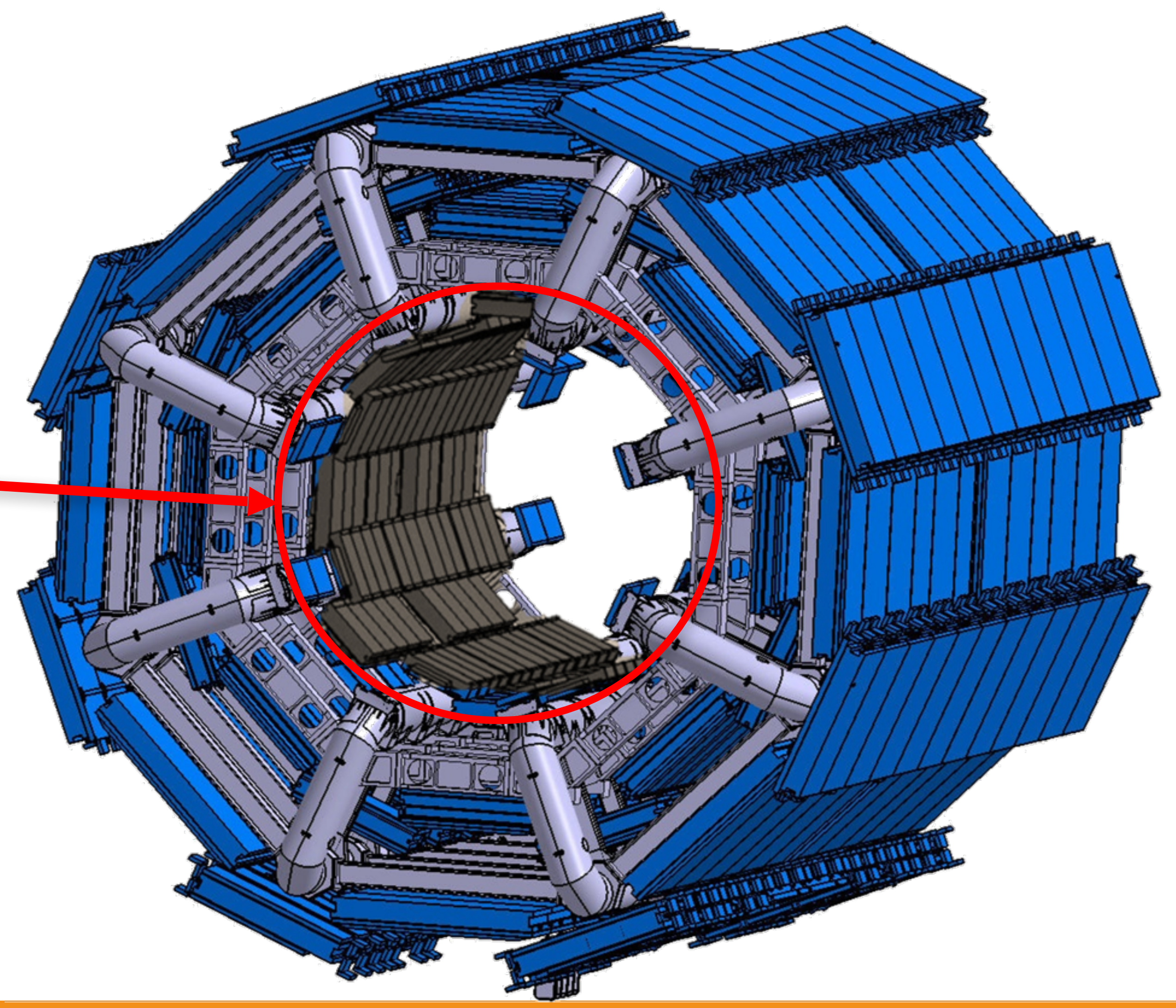
RPC Detailed Construction Scheme



Thin-gap RPC for Muon trigger

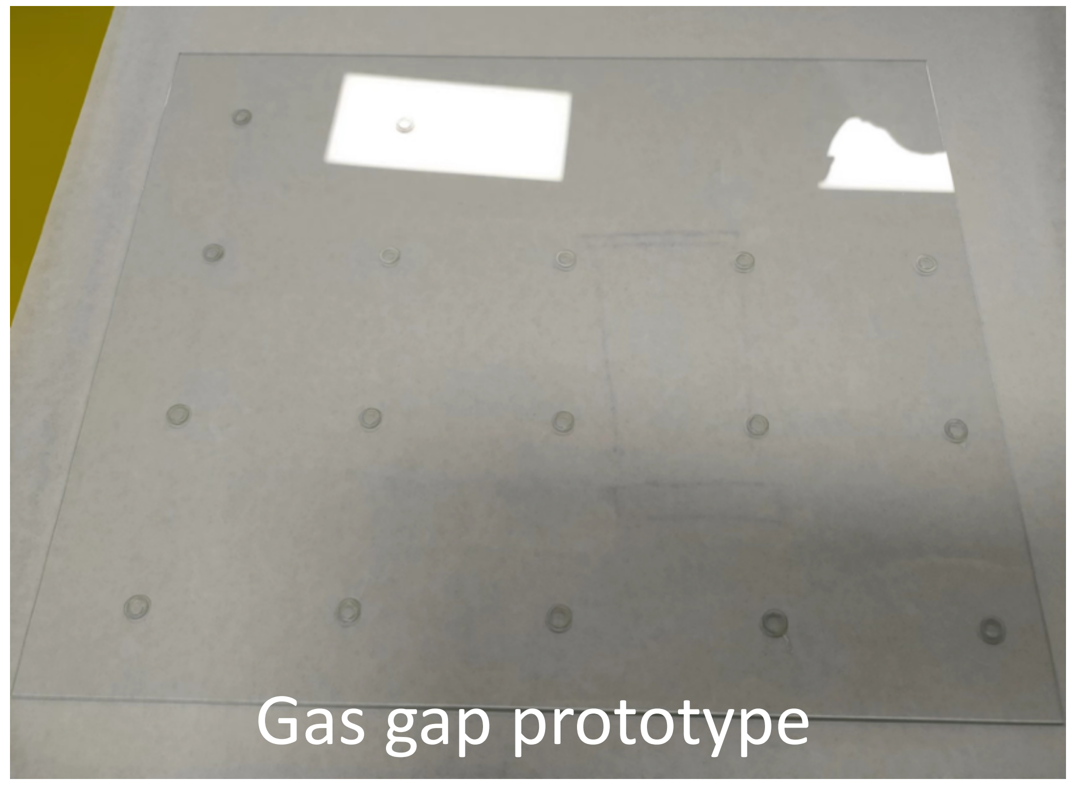
- Thin-gap RPC will be installed in the ATLAS Barrel Inner region to cope with HL-LHC: ~1400 m^2 area, ~100k channels in total.
- USTC-SJTU-SDU cluster will contribute ~½ of the readout panel production, ½ of RPC singlet assembly, ½ of FEE board construction and correlating QA&QC.(→2026.6)
- R&D carried out with various improvements: honeycomb panel, double-end readout method, signal attenuation study, etc.
- 4 prototypes has been constructed. Get ready for mass production, Quality Control and Assurance for ~300 Large size RPC singlets.



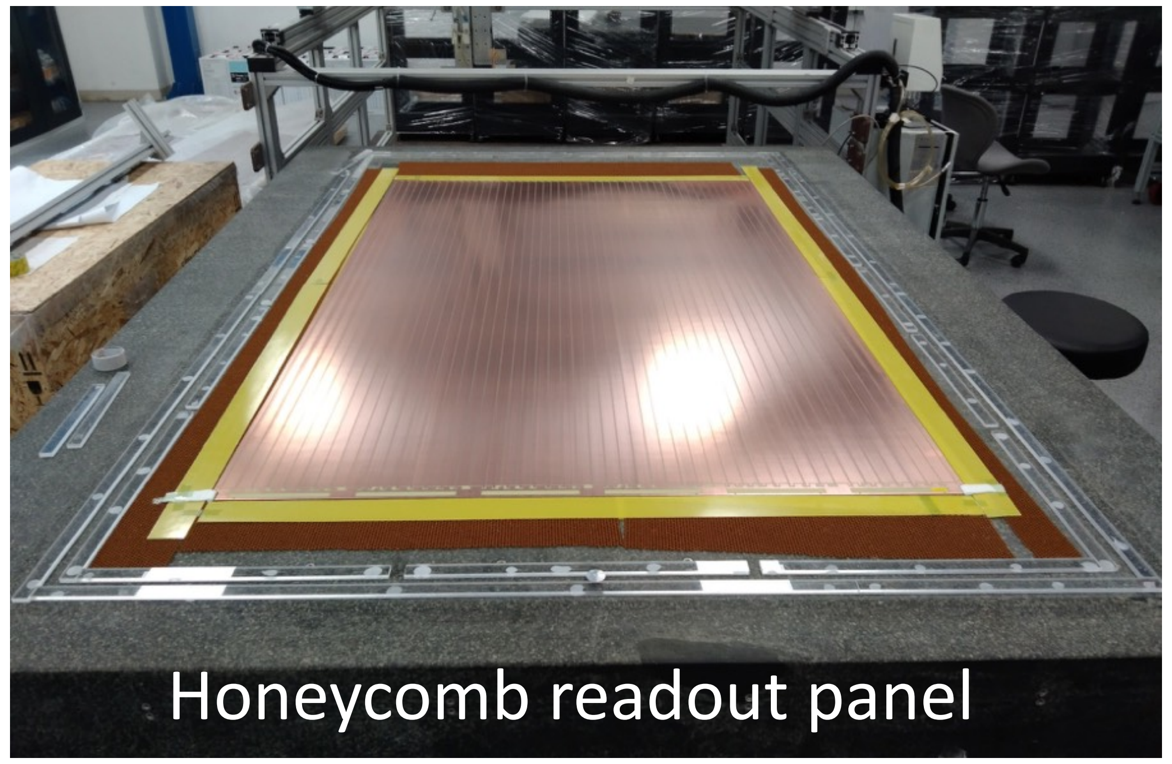


Thin-gap RPC for Muon trigger

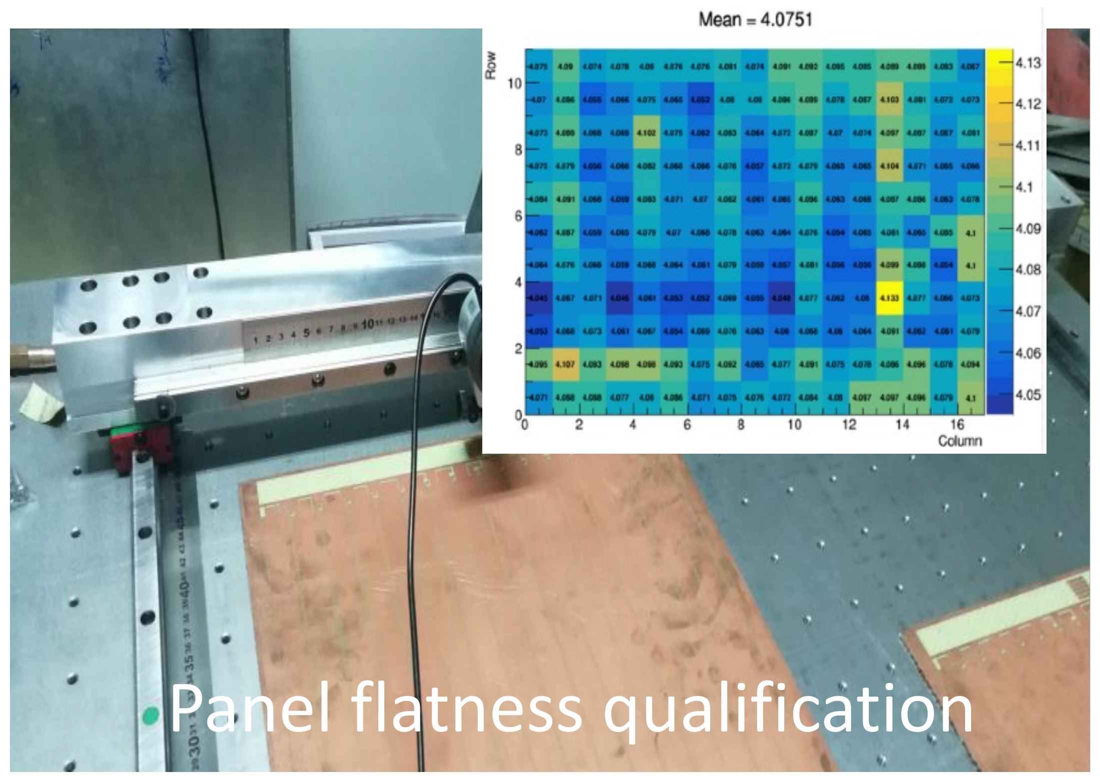
R&D activities and preparation for production



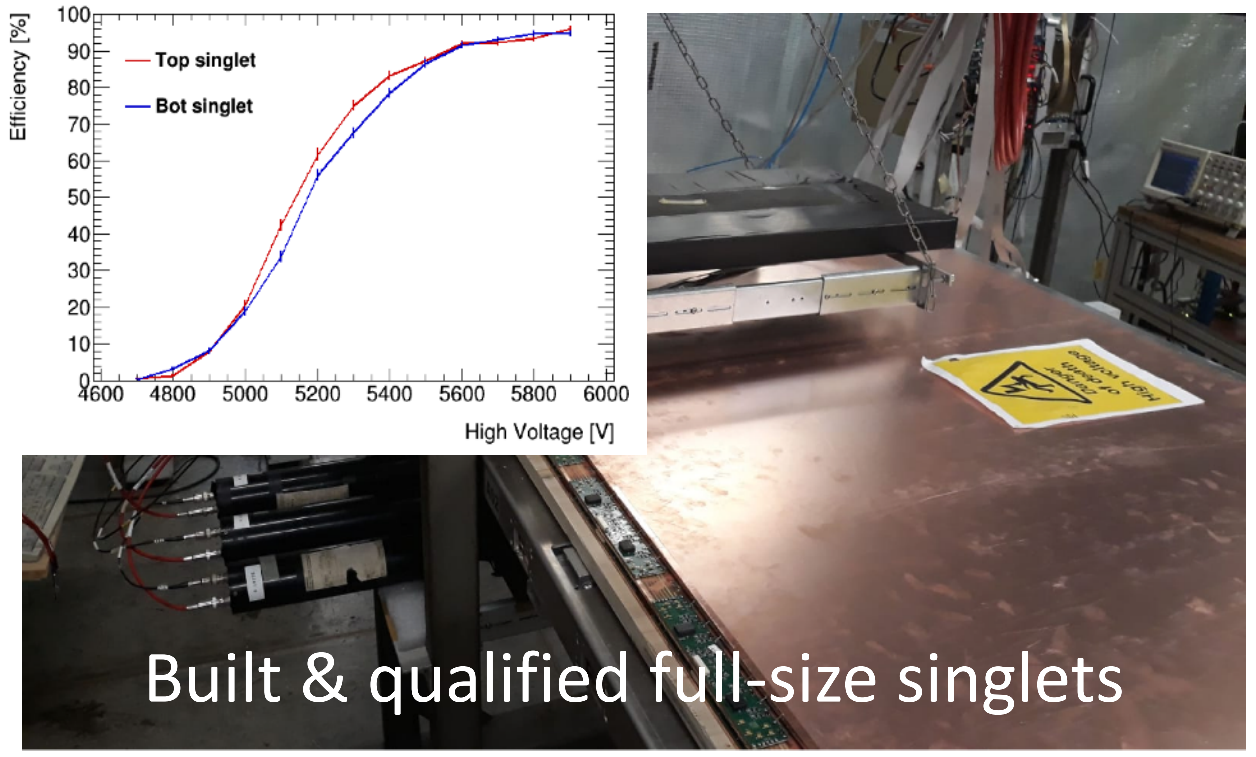
Gas gap prototype



Honeycomb readout panel



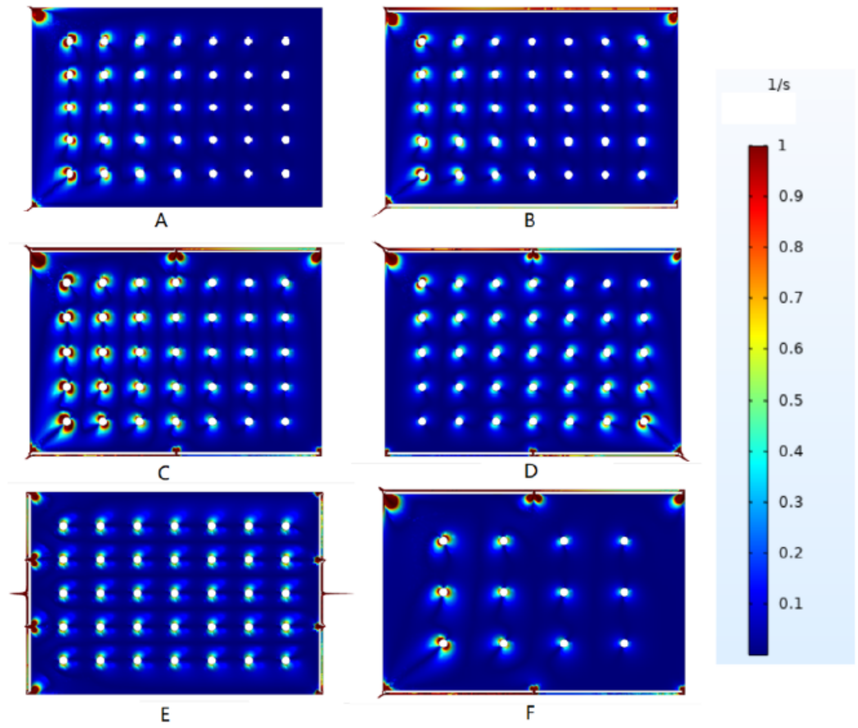
Panel flatness qualification



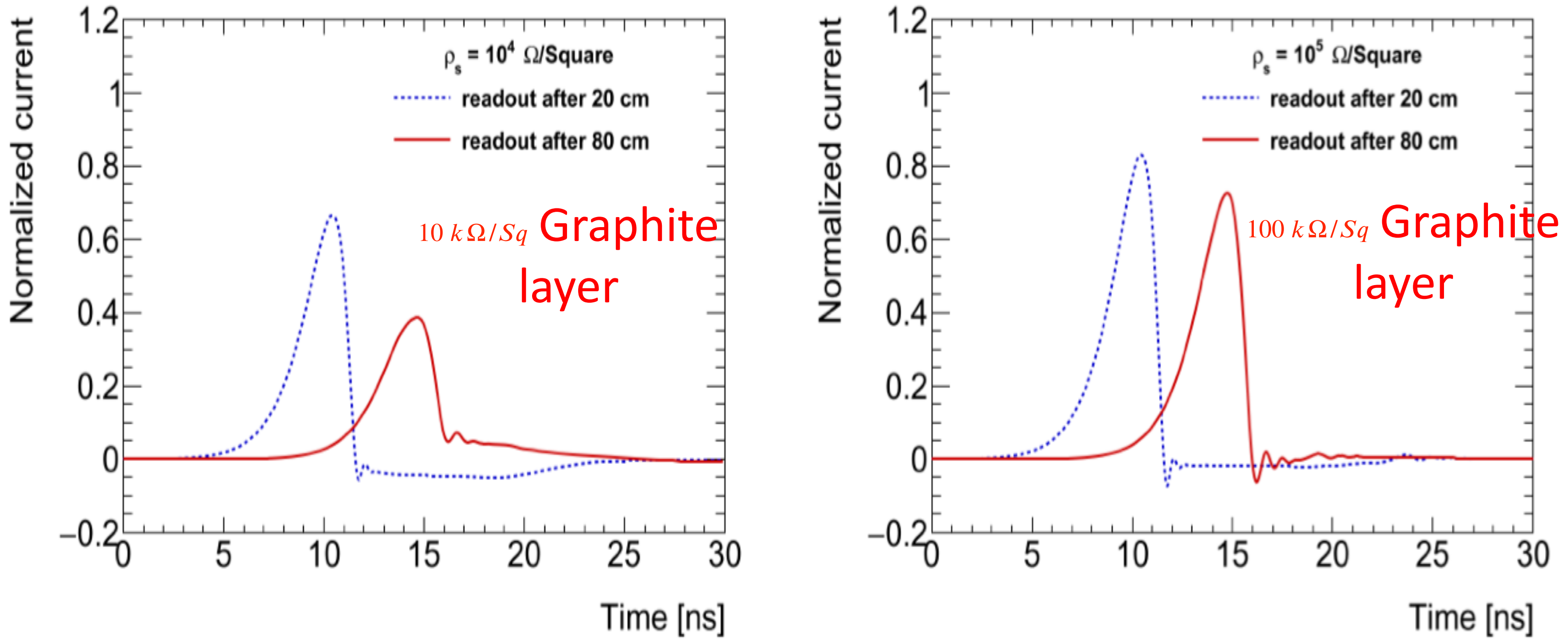
Built & qualified full-size singlets

Trigger size: 200 x 130 cm²

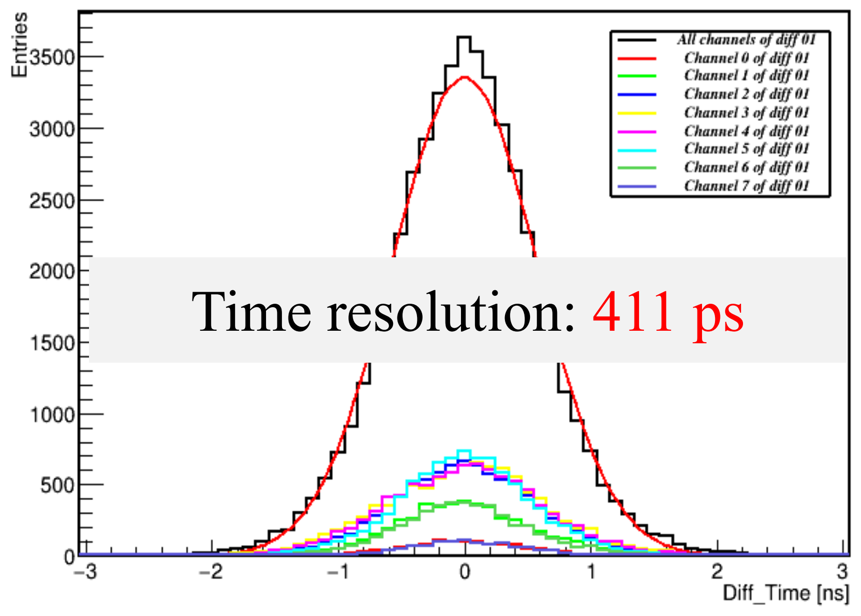
Cosmic ray trigger system by SDU



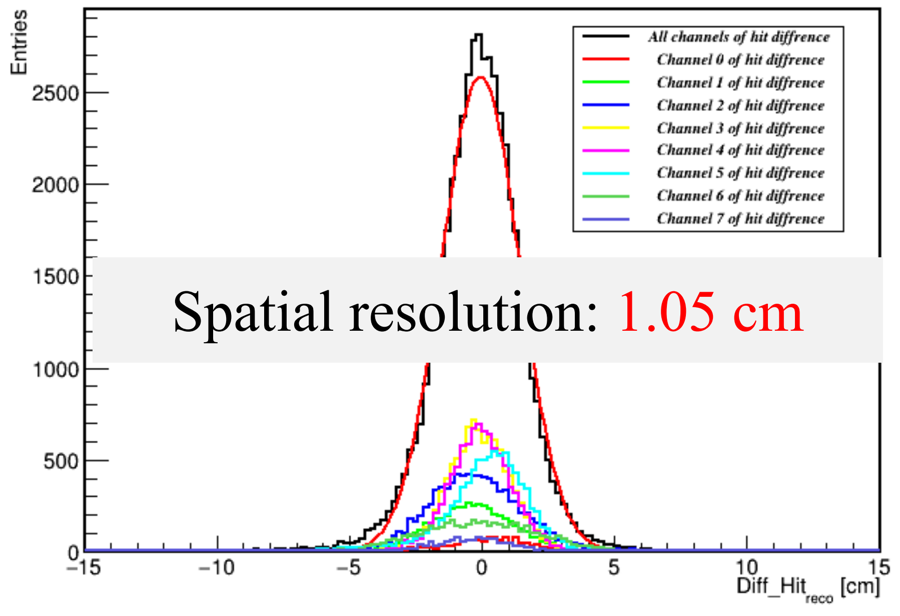
Gas flow simulation @ SJTU



R&D on signal attenuation



Distribution of time difference [ns]

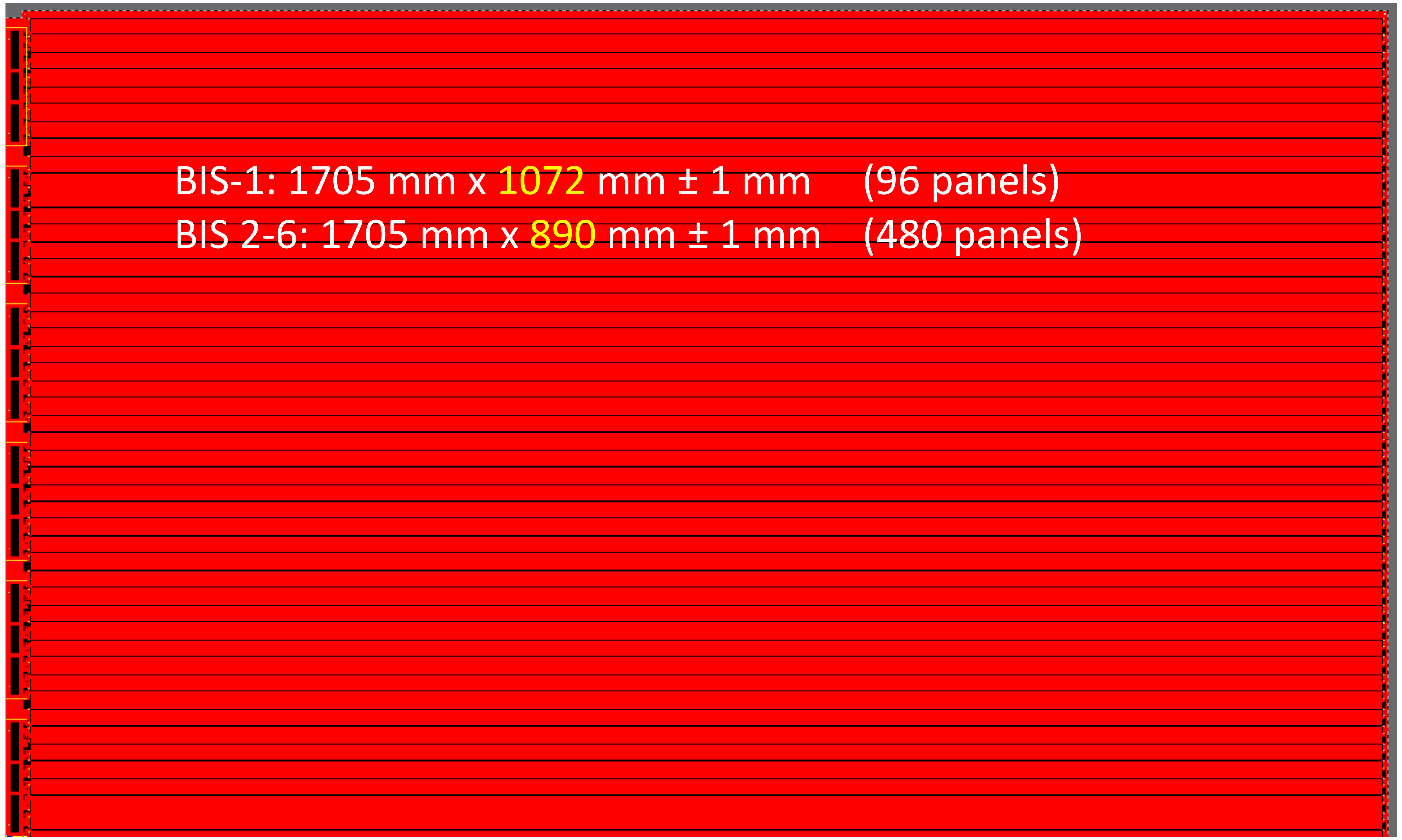


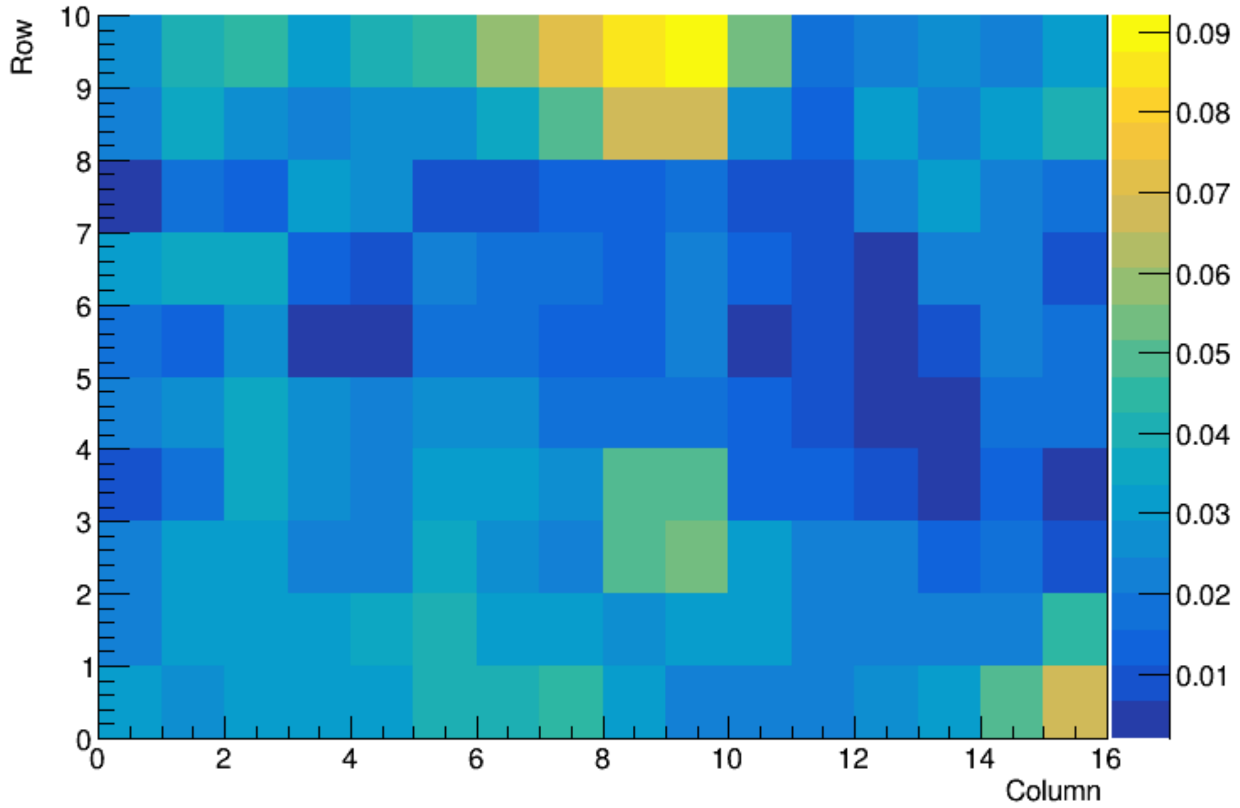
Difference of Hit Position [cm]

Double-end readout

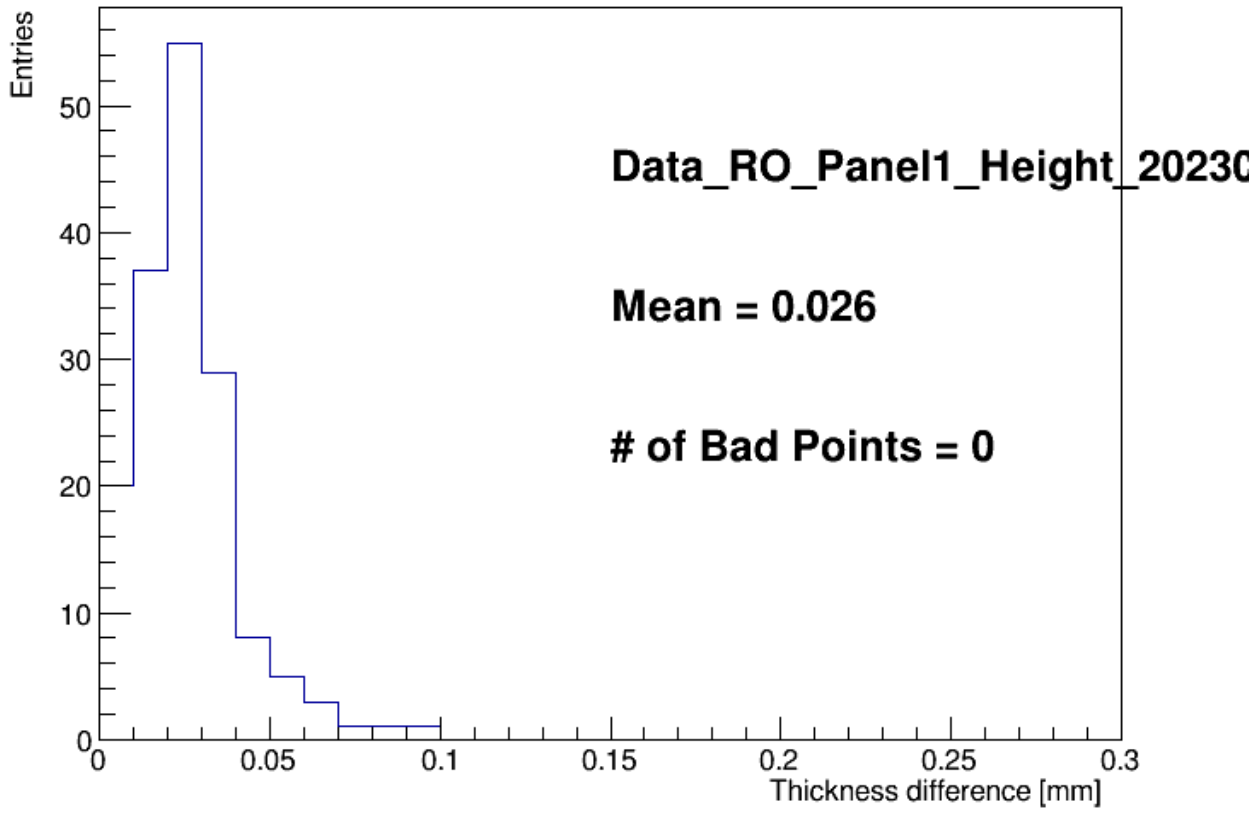
BIS type RPC

- BIS-1 is the largest RPC in the phase-2 upgrade.
- Both BIS-1 and BIS 2-6 types are very wide, which is out of the capability of normal photo-etching facilities.
- A Chinese factory is the only supplier in the world for such large PCBs.
- The production of such large honeycomb readout panels is also time and space consuming.
- The flatness of the readout panel is strict, to ensure the flatness of the gas volume.

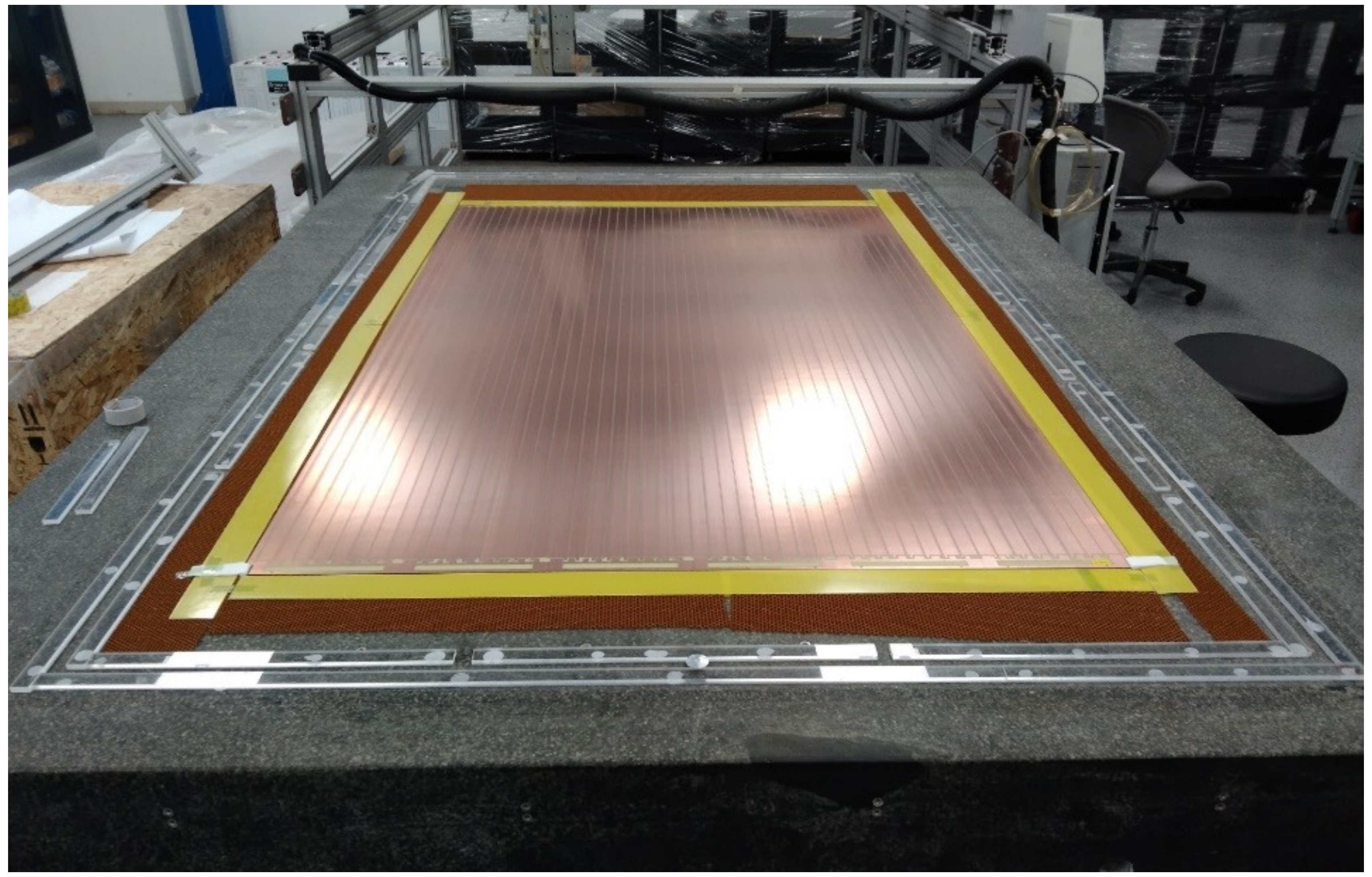




Flatness-2D

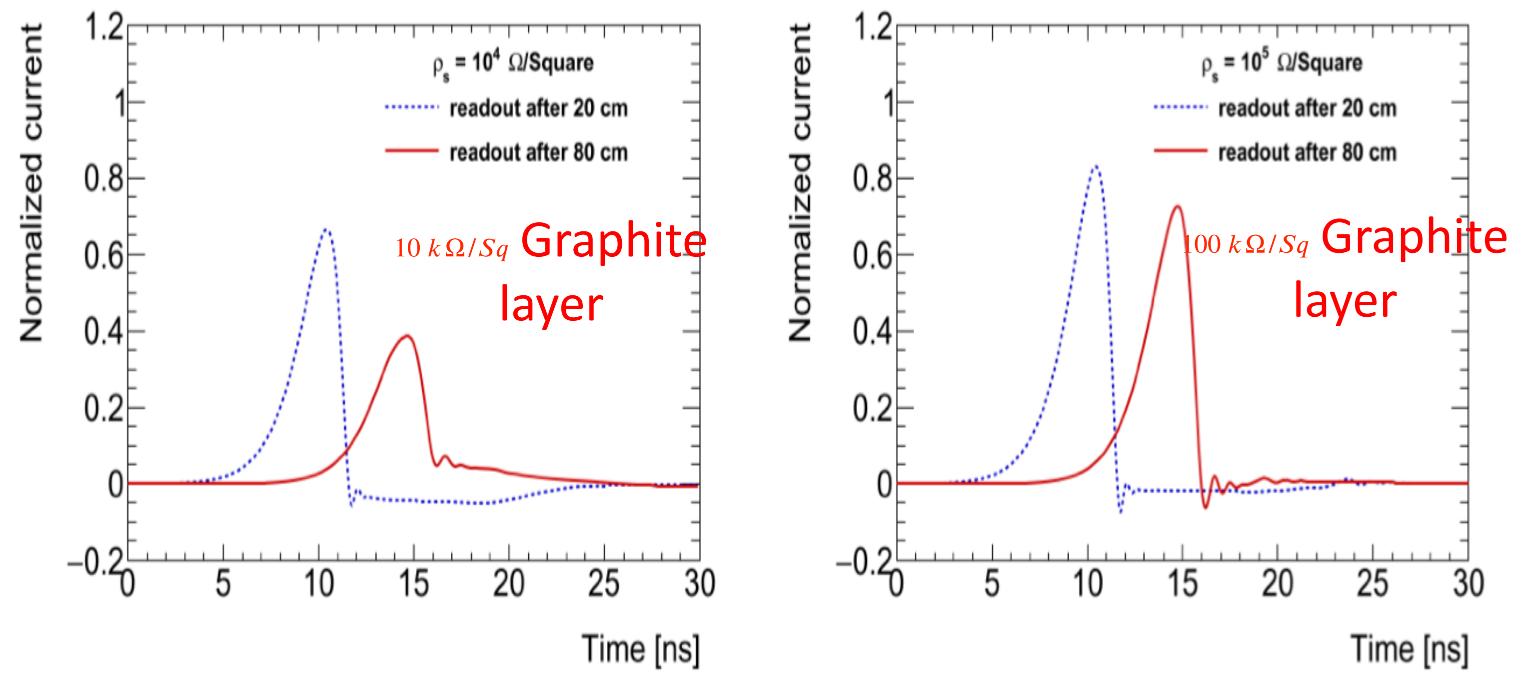


Flatness-1D

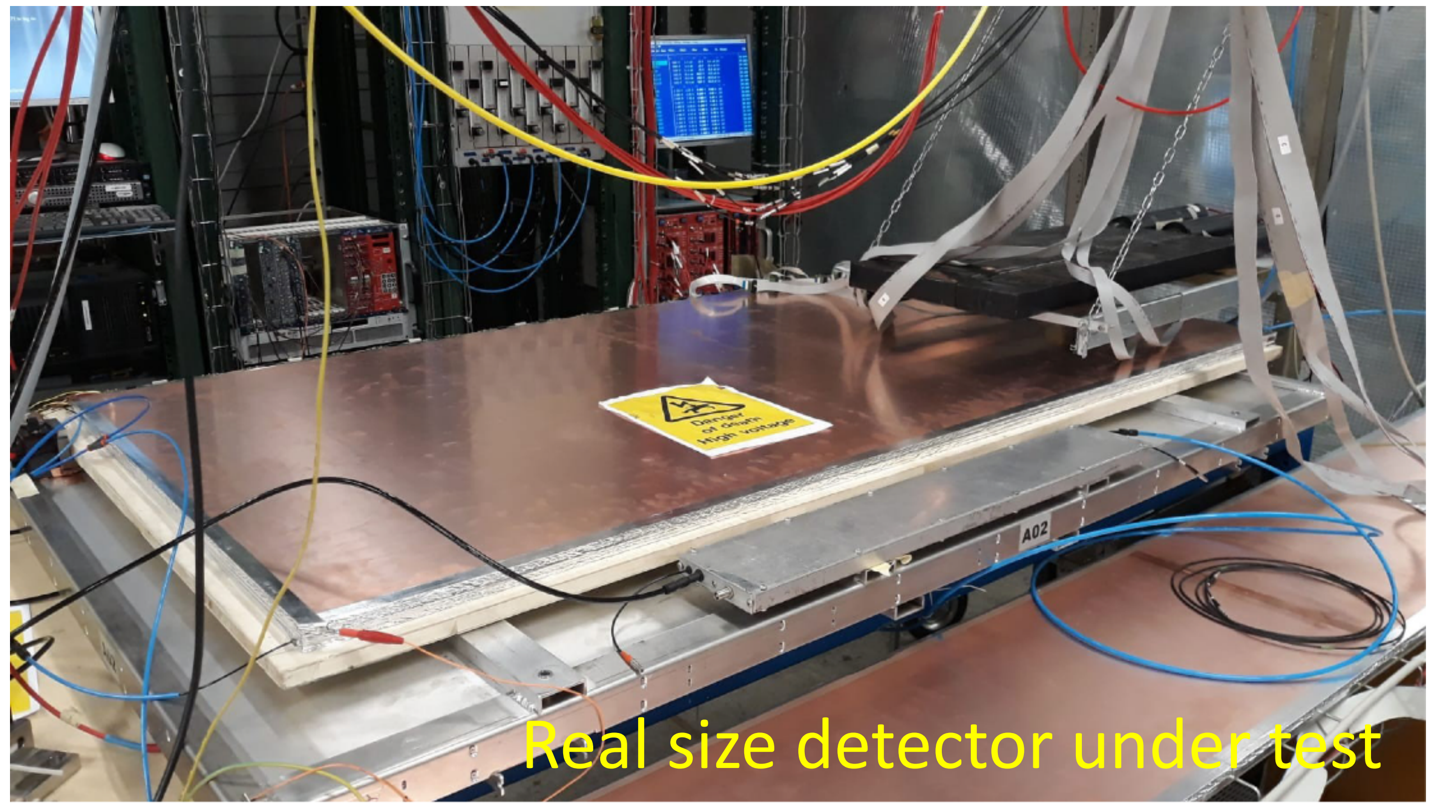


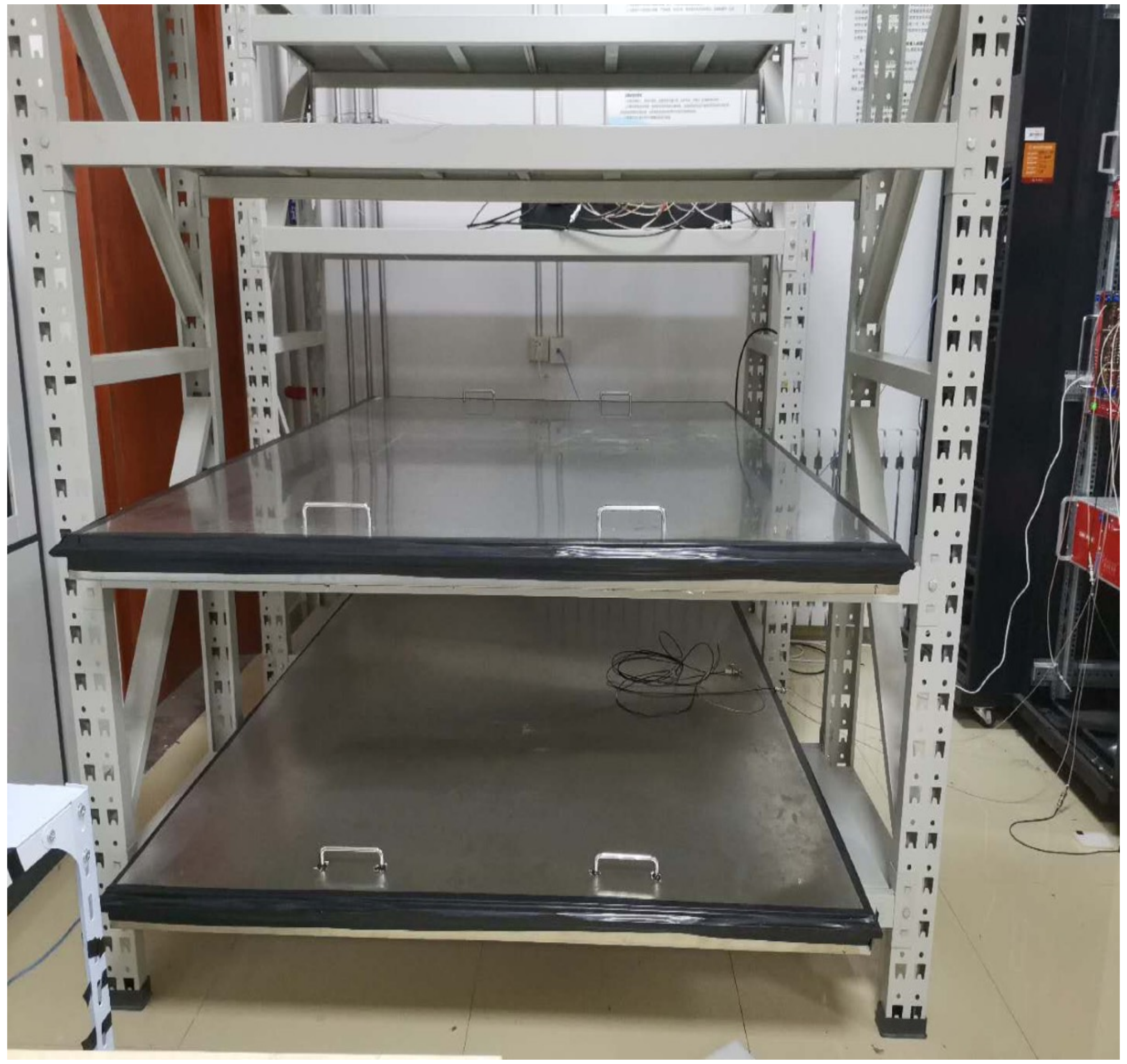
Work basis and background

- USTC take charge of the tast#3, the ATLAS muon detector upgrade, is one of the national key institutes in the field of the particle detector and related electronics.
- USTC has take part in BEPC-BES, LHAASO, HIRFL-CEE, etc. for detector and electronics R&D.
- USTC has made great progress on the thin-gap RPC in the last MOST project.

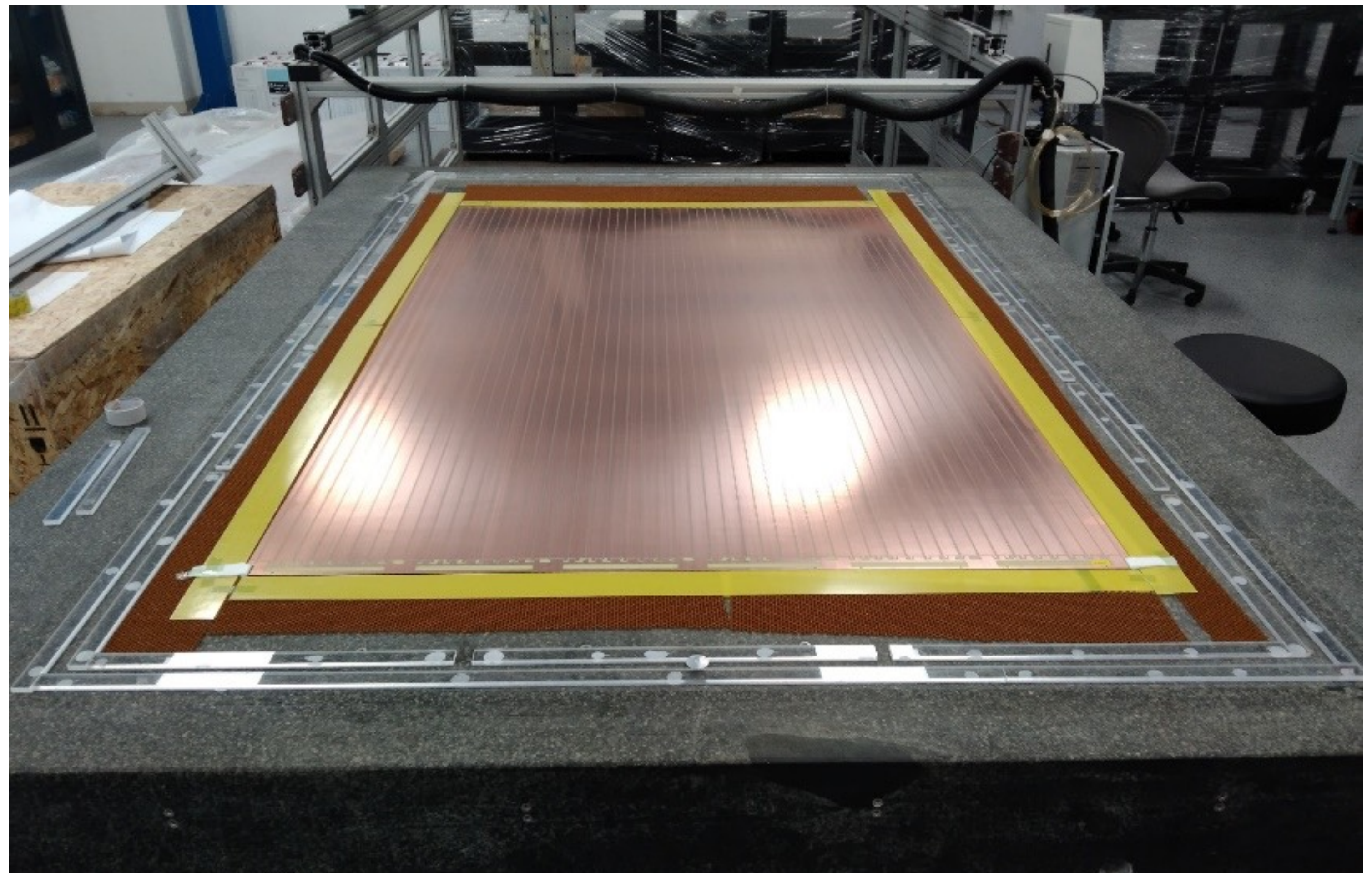


R&D on signal attenuation





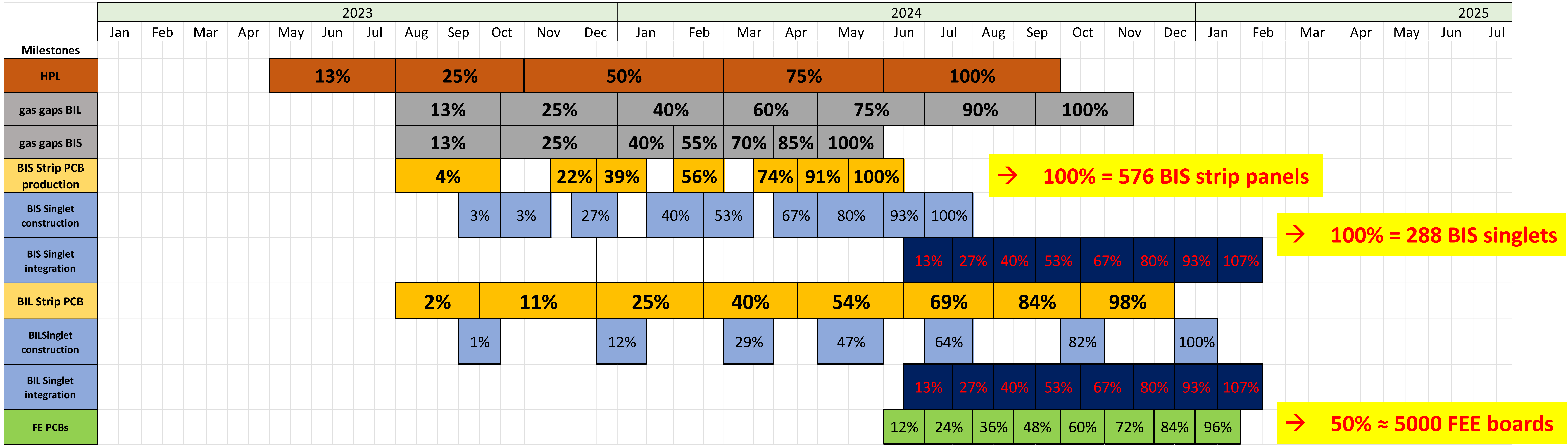
Large-scale cosmic ray trigger system



Production of the large readout panel

RPC gas gap production facility

The up-to-date RPC production time line



- This table shows the up-to-date RPC production time line with the first priority, which contains the core part of the production.
- The main task for China-cluster is the BIS part (which covers all of 8 small sectors), including the strip PCB production, the honeycomb readout panel production, (half of) the FEE board production, the singlet construction and integration, and the QA&QC of all the products.
- In total, the work related to 288 BIS singlets.
- (From the time line, we can also find the "singlet integration" time is very limited. This is due to the fact that the delivery of the FEE ASIC is delayed again. This also makes the time for the QA&QC on the singlets very tight.)
- The table doesn't contain the QA&QC on the chambers, which needs also manpower contributions from China.
- From 2026 to 2028, the main work will be the installation and commissioning at CERN.

Work sharing (under discussion)

PRIORITY			Number	GTE	INFN	MPI	USTC	HK	TK
1	BIL (excluding s7)	gas gap	312	100%					
		strip panel	624		100%				
		singlet	312		100%				
		triplet	**104**		100%				
1	BIL s7	gas gap 5-9 S7	30	backup			100%		
		gas gap(1-4+10)S7	30	100%					
		strip panel	120		50%		50%		
		singlet	60		50%		50%		
		triplet	**20**		50%		50%		
2	S9 @ Eta=0	gas gap S9@E=0	18	backup			100%		
		strip panel	36				100%		
		singlet	18				100%		
		triplet	**6**				100%		
1	BIS1-6	gas gap	288	100%					
		strip panel	576				100%		
		singlet	288				100%		
		triplet	**96**			100%			
2	BOR/BOM	gas gap	240	backup		100%			
		strip panel	480		50%		50%		
		singlet	240		25%	25%		25%	25%
		triplet	**80**		25%	25%		25%	25%
3	BIS7C	gas gap	24	100%					
		strip panel	48						
		singlet	24		100%			100%	
		triplet	**8**		100%			100%	
3	BIS8C	gas gap	24	backup			100%		
		strip panel	48						
		singlet	24				100%		
		triplet	**8**				100%		
3	BIS78A	electronics replaceme	48		50%			50%	
		triplet	**16**		50%			50%	
			Number	GTE	INFN	MPI	USTC	HK	TK
	Total Singlets assigned to be built		942	624	402	60	360	60	60
	Total Chambers assigned to be built		314		134	116	24	20	20
	Total Singlets unassigned		24		24			24	
	Total Chambers unassigned		8		8			8	
	Total refurbishing unassigned		16		16			16	

The core part! →

- Stations 5-9@S7 are not critical in installation sequence
- 30 gas gaps to be assigned to USTC-cluster.
- (very likely,) ½ of the strip panel production, single assembly and triplet assembly

- Eta=0@S9 has priority-2 in installation sequence
- 18 gas gaps to be assigned to USTC-cluster.
- And also the strip panel production, single assembly and triplet assembly

- BIS8C has priority-3 in installation sequence
- 24 gas gaps to be assigned to USTC-cluster.
- And also the single assembly and triplet assembly

Risk

- The ATLAS upgrade is organized in a large collaboration. The plan and the scheme of the upgrade are decided by the collaboration.

➔Take in-depth cooperation with the collaboration and other institutes.

➔Be aware of the plan and scheme at all the time.

➔Take responsive actions in case of new situation.

➔Keep the responsible work in healthy condition.