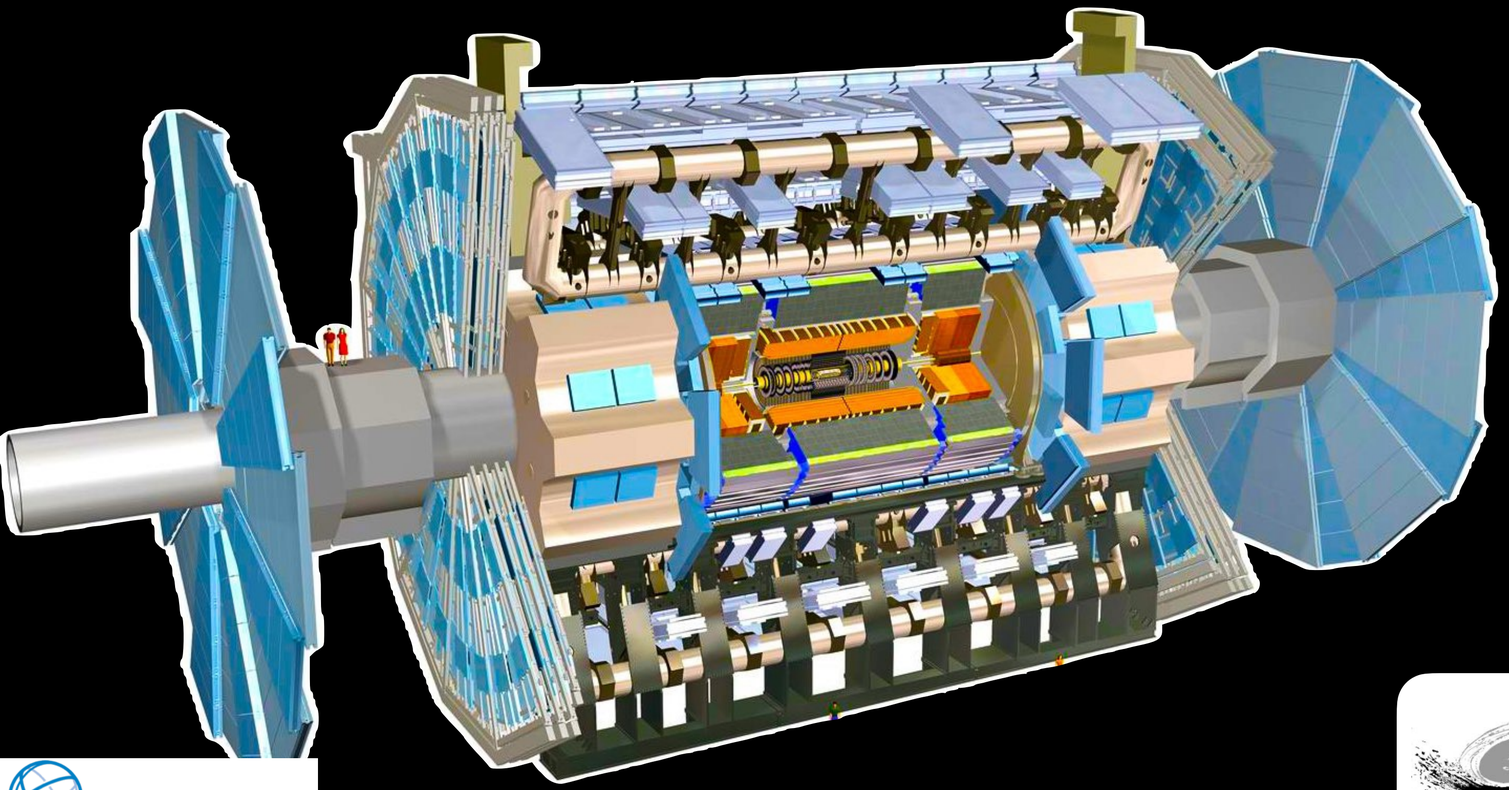
2023年国家重点研发计划“大科学装置前沿研究”

ATLAS 探测器升级

First Annual Meeting



汇报人:

项目负责人: João Guimarães Costa

中国科学院高能物理研究所

课题 1: 梁志均 (Liang Zhijun)

中国科学院高能物理研究所

课题 2: 史欣 (Shi Xin)

中国科学院高能物理研究所

课题 3: 孙勇杰 (Sun Yongjie)

中国科学技术大学

2025年06月07日

Project Expert Team

Present today:

Name	Affiliation
Yugang Ma (MOST expert)	Fudan Univ.
Yangheng Zheng	UCAS
Qiang Li	PKU
Zheng Li	LDU
Qun Ouyang	IHEP, CAS
Xiangming Sun	CCNU
Zhankui Li	IMP, CAS
Daicui Zhou	CCNU

Excused:

Name	Affiliation
Jin Li	IHEP
Cheng Li	USTC
Yuekun Heng	IHEP
Jianbei Liu	USTC
Zhenwei Yang	THU
Chengxin Zhao	IMP, CAS
Yuanning Gao	PKU

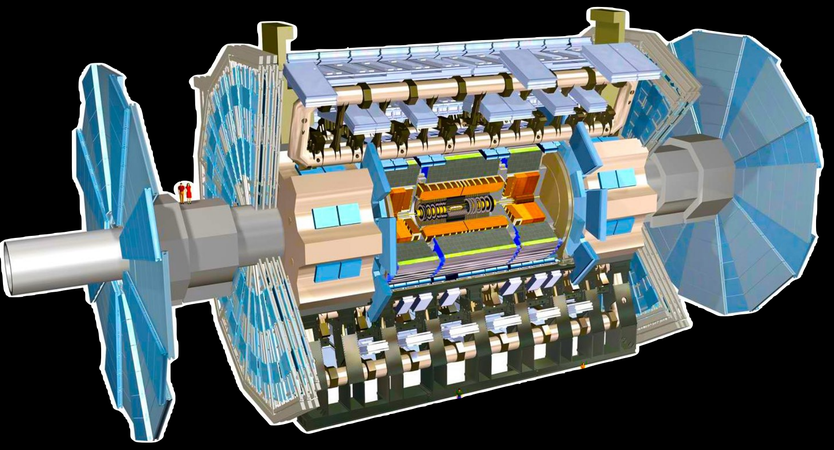
Report Outline

1. Project overview - Background
2. Project (Task) arrangement and main research work
3. Progress highlights from each task
4. Research team and talent training
5. Achievements and implementation
6. Project schedule and planning
7. Conclusions

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:

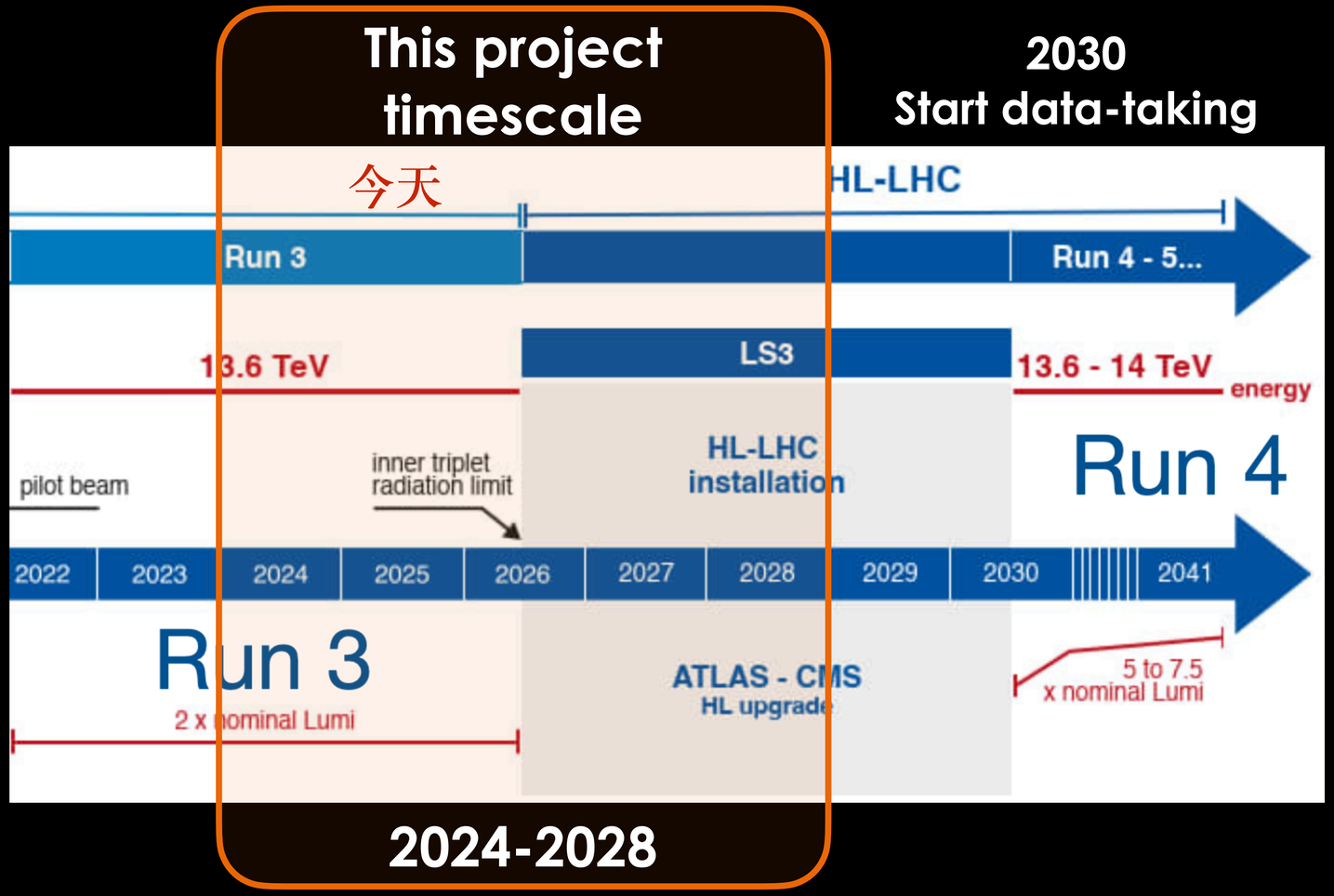
- **Study Higgs Boson in detail**
- **Search for new physics beyond SM (BSM)**

The main limitation to progress is the amount of available data

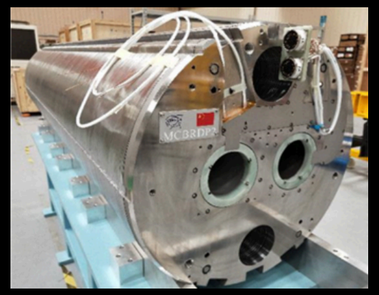
	Energy (TeV)	Luminosity (fb^{-1})
Run 1 (2010-12)	7-8 TeV	~ 26
Run 2 (2015-18)	13 TeV	~139
Run 3 (2022-26)	13.6 TeV	~370

The High-Luminosity-LHC Upgrade

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



by 2030 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}

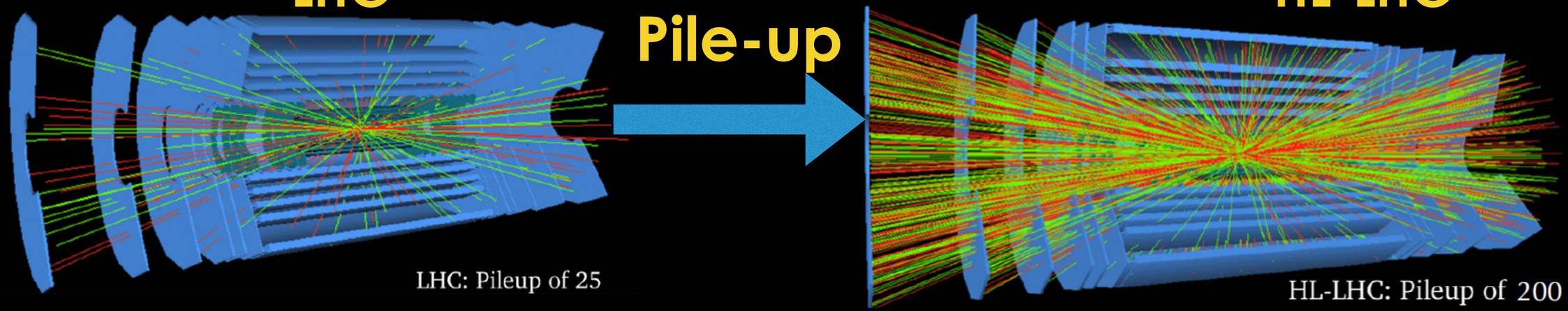
→

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

LHC

Pile-up

HL-LHC



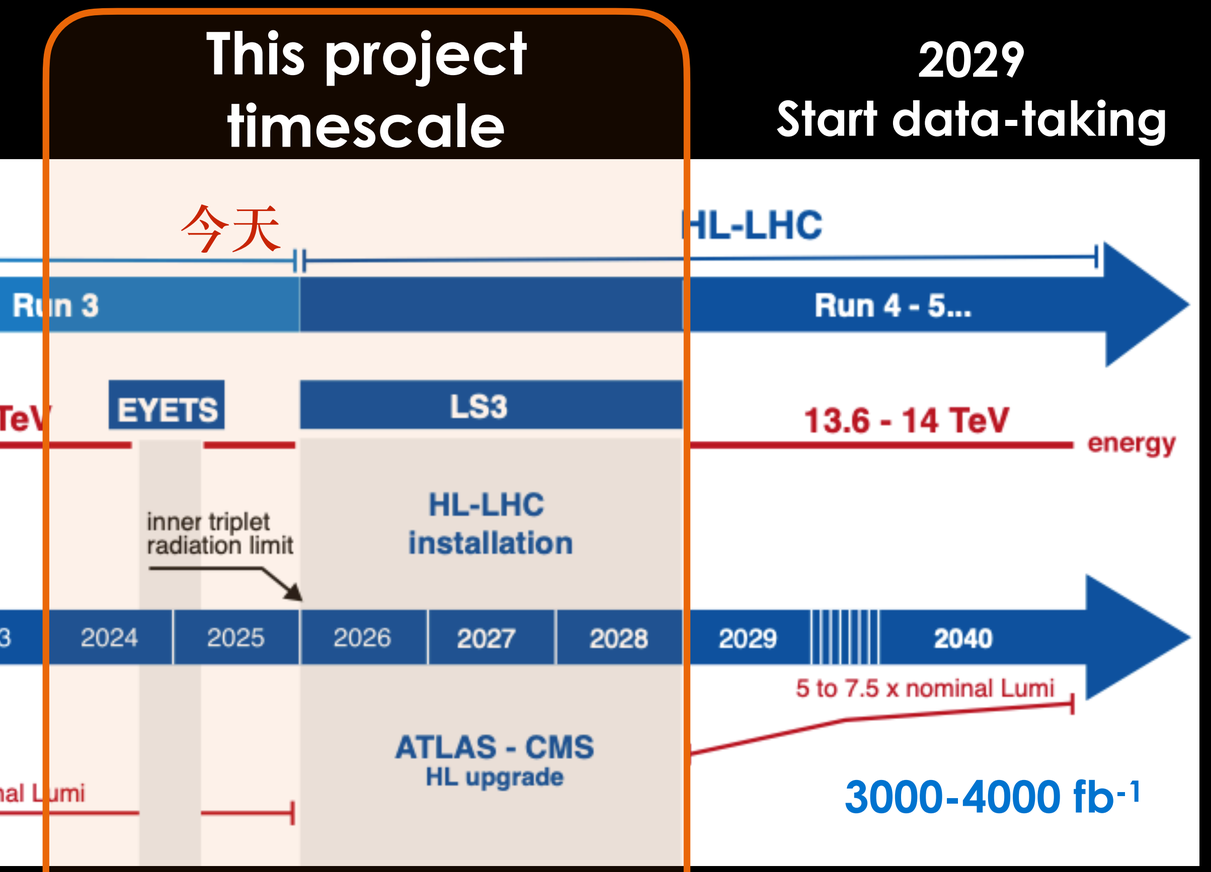
Data rates increased 5 to 7.5x nominal design rates

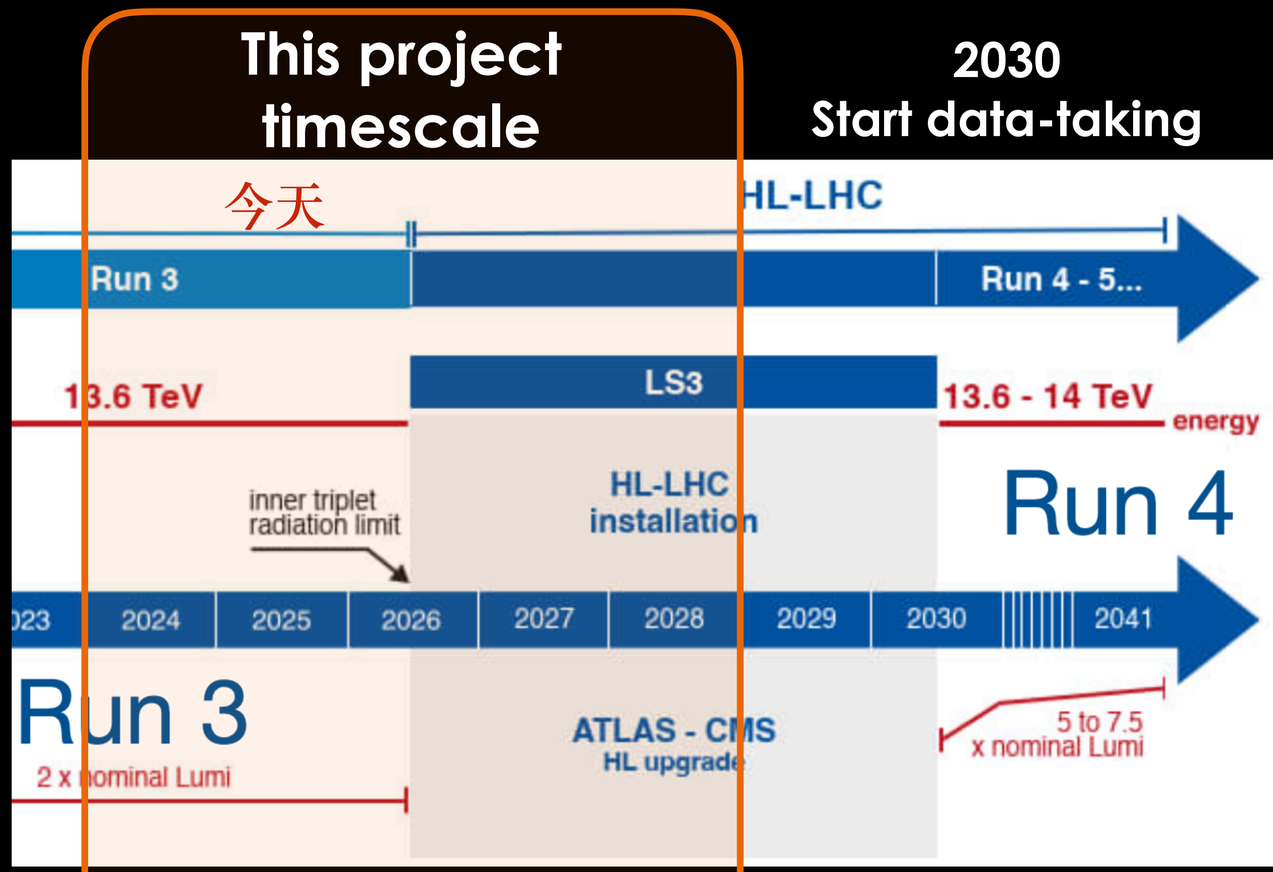
Current detectors cannot cope with such large rates, need:

Larger granularity
Faster trigger rates
New technologies (fast timing)

The High-Luminosity-LHC Upgrade Delays

HL-LHC startup delayed by 1.5 years during this project





Need to make same achievements but earlier relative to HL-LHC schedule

Task arrangement and main research work

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

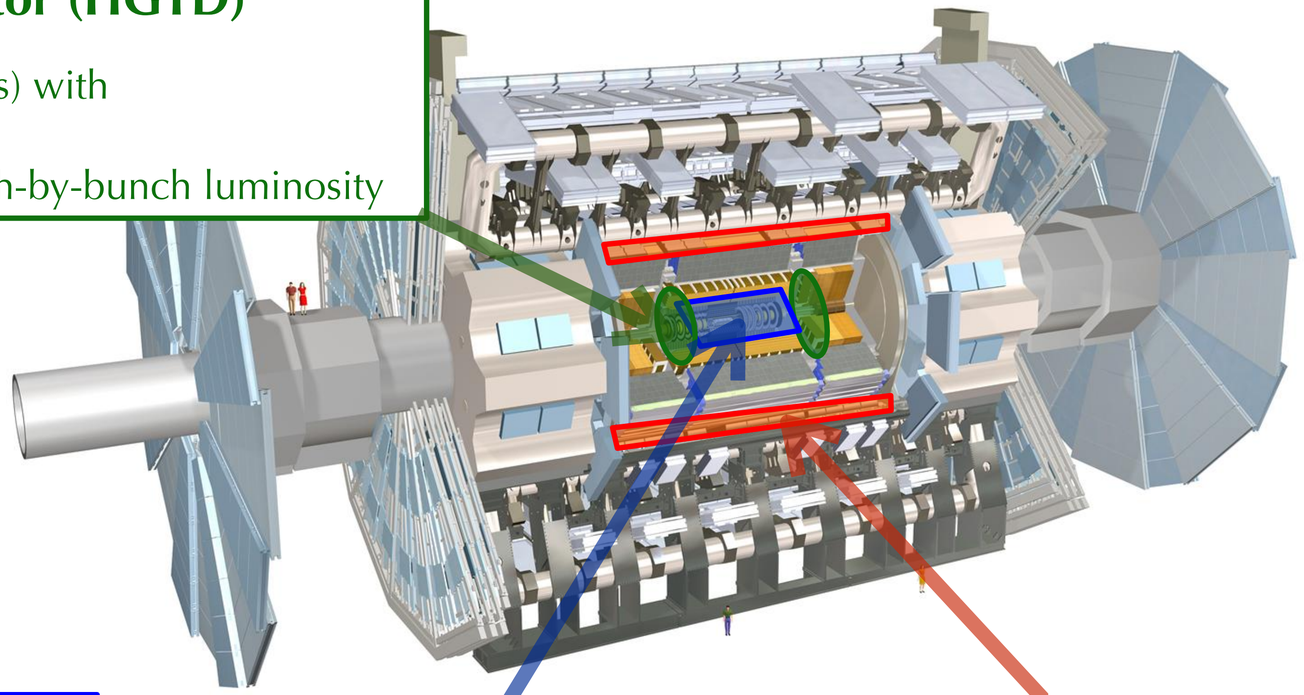
一起 searching for new physics with ATLAS detector

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

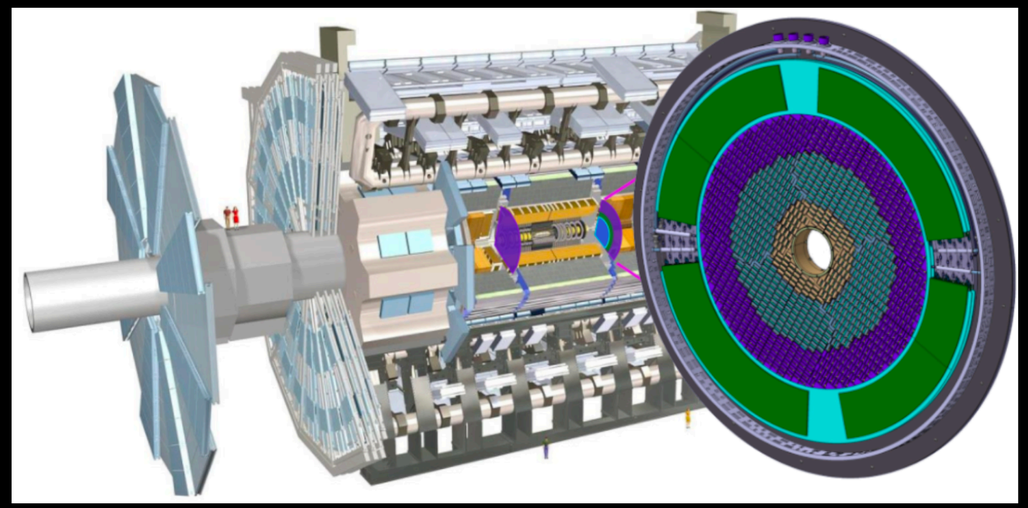
Collisions spread ~250 ps time scale → reach **30-50 ps** timing resolution

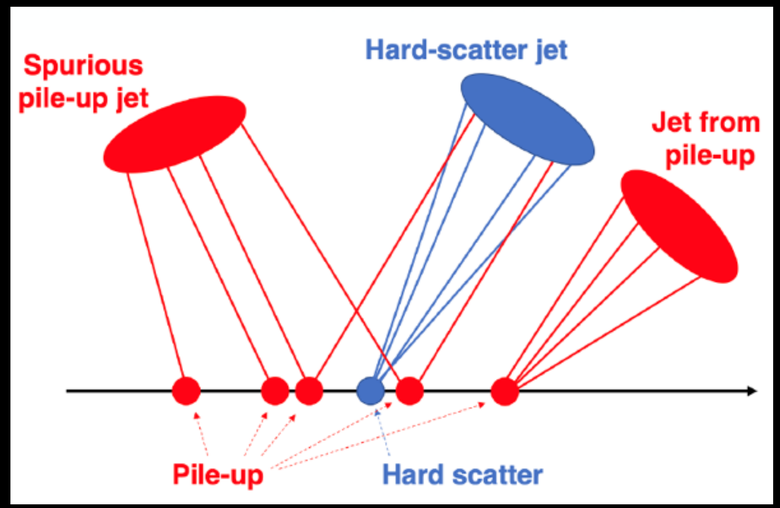
Significantly improve compared to ~1 ns precision in conventional silicon sensor

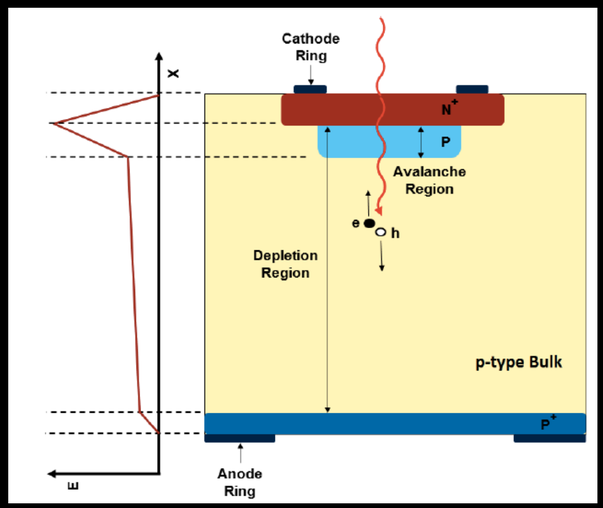
Adding 4th dimension information for the first time

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

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



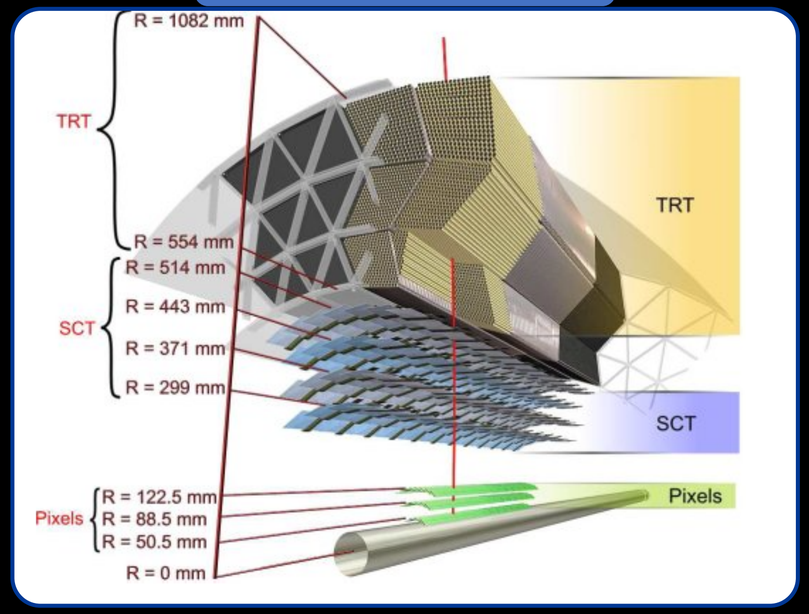




课题2：Inner Silicon Tracker Upgrade

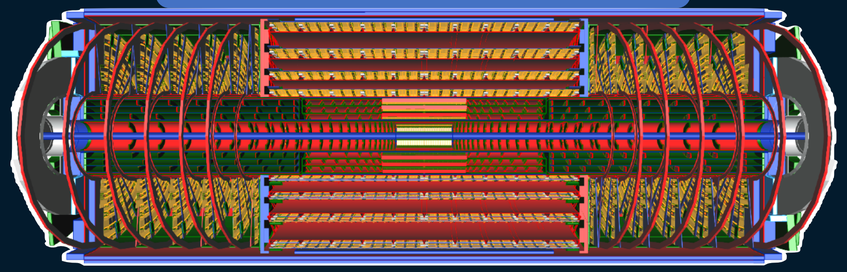
Physics Requirements and Key Technologies

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

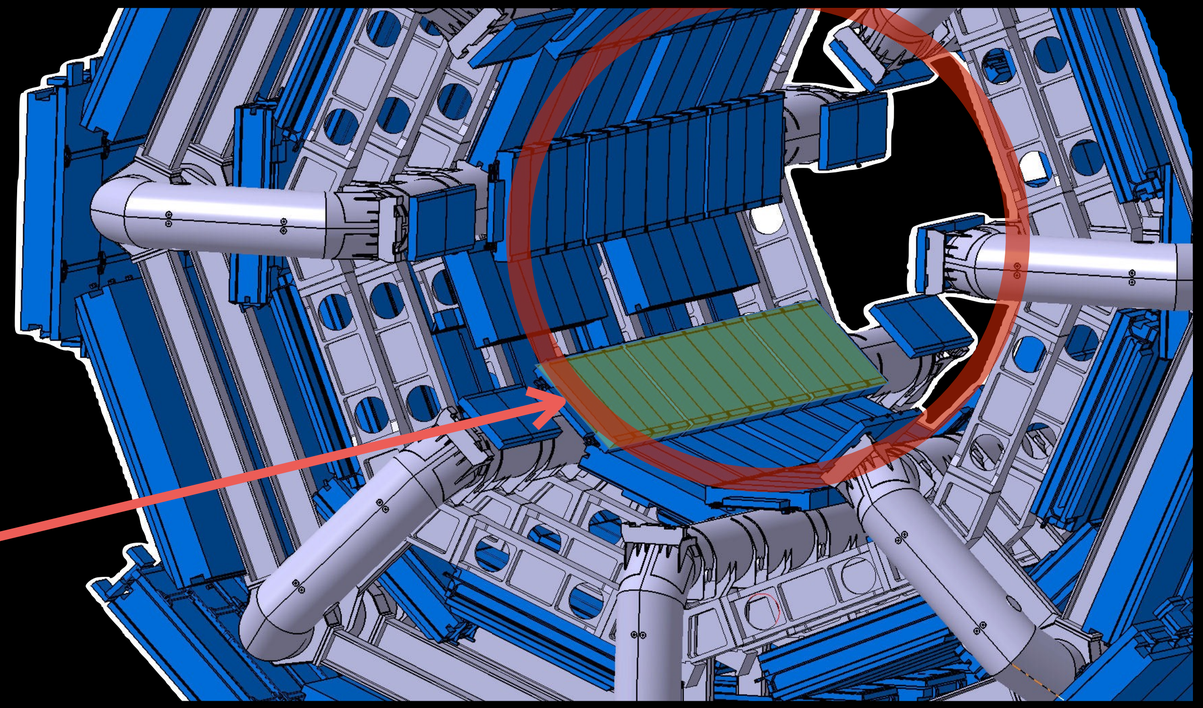
Further improvement against pile-up

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

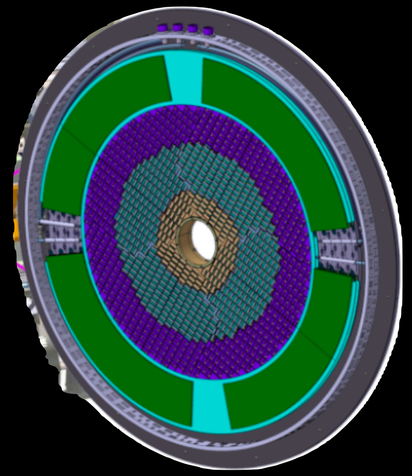
Progress highlights from each task

课题1： High Granularity Timing Detector

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

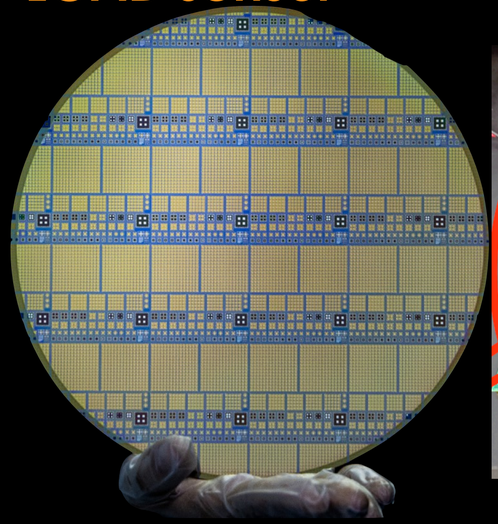
Develop all key components for the Timing Detector

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

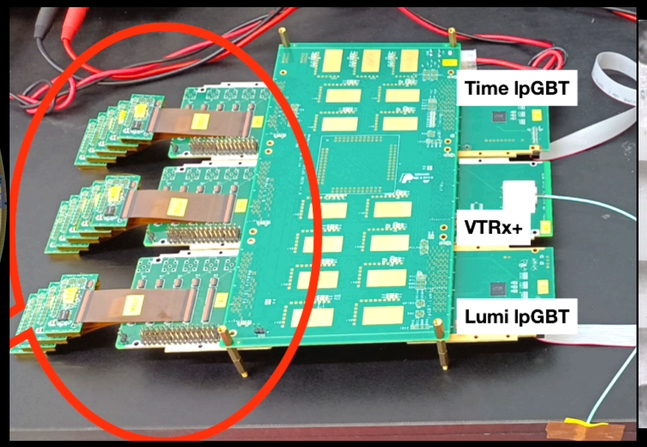


- **Assessment index （考核指标）:**
  - Sensor and detector module time resolution reach **30-50 ps**

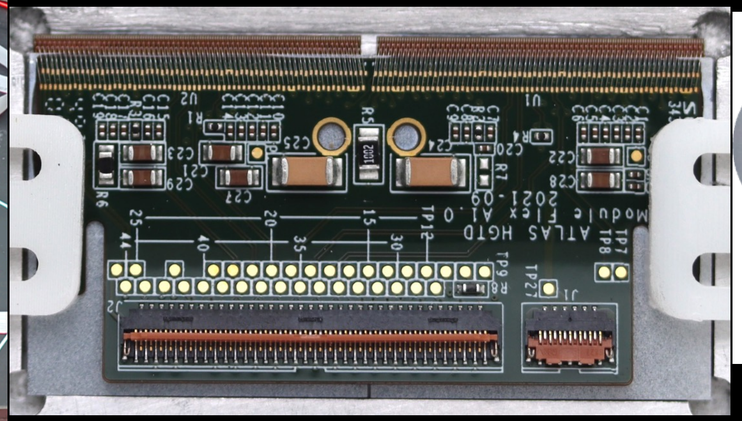
LGAD sensor



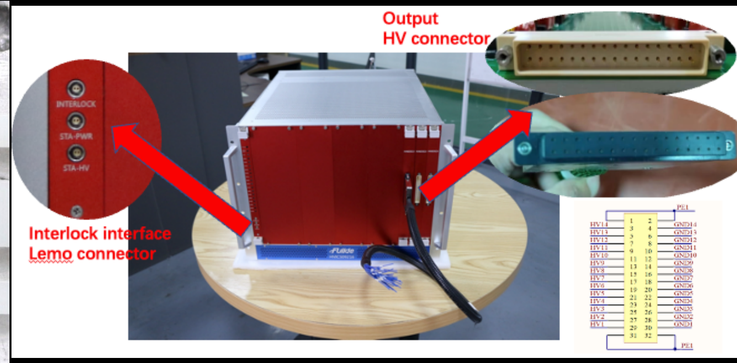
Electronics



Module
ASIC+LGAD



High Voltage supply



High Granularity Timing Detector (HGTD)

Chinese team is making key contributions

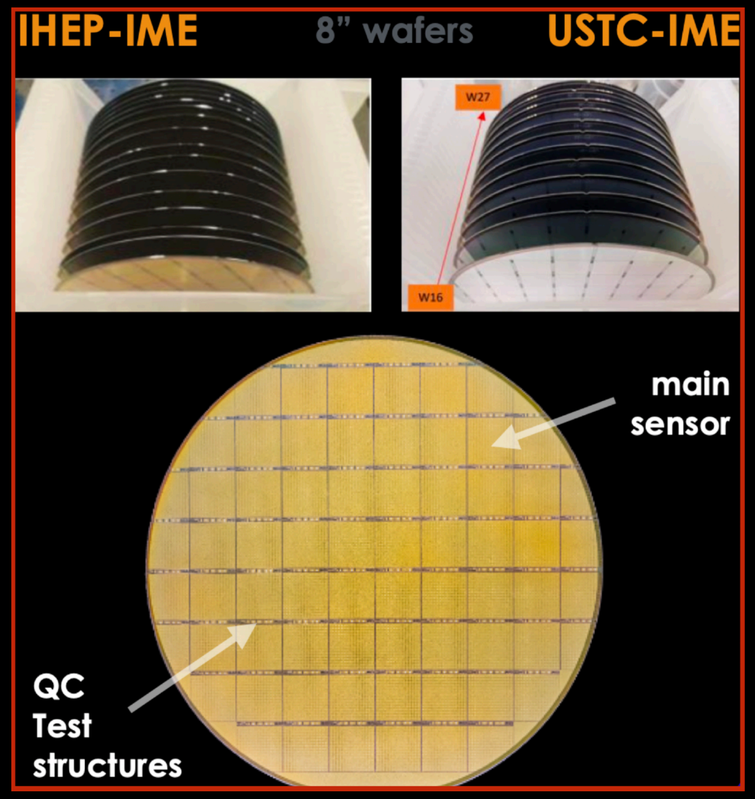
100%	LGAD Sensors (with 56% monetary international contribution)	90% IHEP + 10% USTC
50%	ASIC testing	IHEP
100%	Module Flex electronics	IHEP
44%	Module and Detector Units assembly	34% IHEP + 10% USTC
100%	Front-end electronics board (PEB)	IHEP + NJU
33%	Flex tails	SDU
100%	High-Voltage system (with 84% monetary international contribution)	IHEP + SDU
	Software and performance	USTC + IHEP

课题1： High Granularity Timing Detector

Progress Highlights

Self-developed radiation-hard silicon sensor based on domestic foundry

- Our LGAD sensors are the most radiation resistant in the World
- CERN is purchasing 66% of IME LGADs → 90% IHEP-IME sensors + 10% USTC-IME sensors



Sensor pre-production has been completed

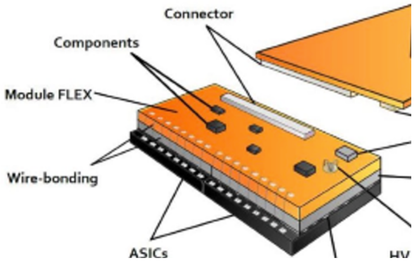
Sensor production for CERN purchased sensors started

(Pilot batch: 400 good sensors already delivered)

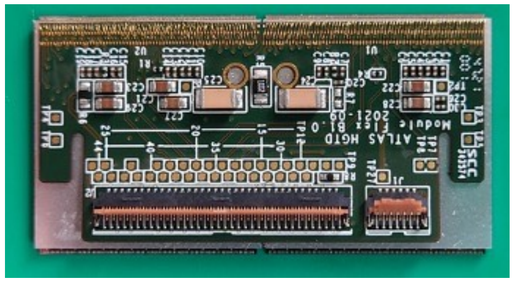
Negotiating with IME for domestic/in-kind contracts to start production of the sensors for this project (34% IHEP-IME; 10% USTC-IME)

High Granularity Timing Detector (HGTD)

- **Other key contributions:**
  - **50%** ASIC probing to be done in China, pre-production started
  - **50%** hybridization, 1st batch of pre-production ALTIROC-A hybrid from IHEP/NCAP
  - **100%** module flex, pre-production started
  - **34%** module assembly, loaded two ALTIROC3 detector unit. Approved for pre-production
  - **33%** flex tails, prototypes done. Approved for pre-production
  - **100%** front-end electronics board, pre-production starting now
  - **100%** high-voltage electronic systems, prototyped HV supply, pre-production started

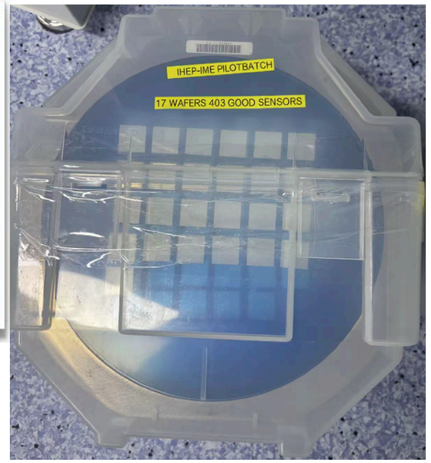


Module Flex



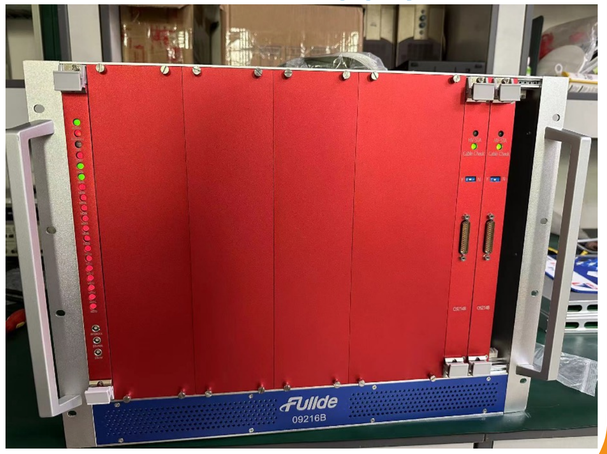
PEB @ demonstrator

LGAD production



ALTIROC3 DU loading

HV supply



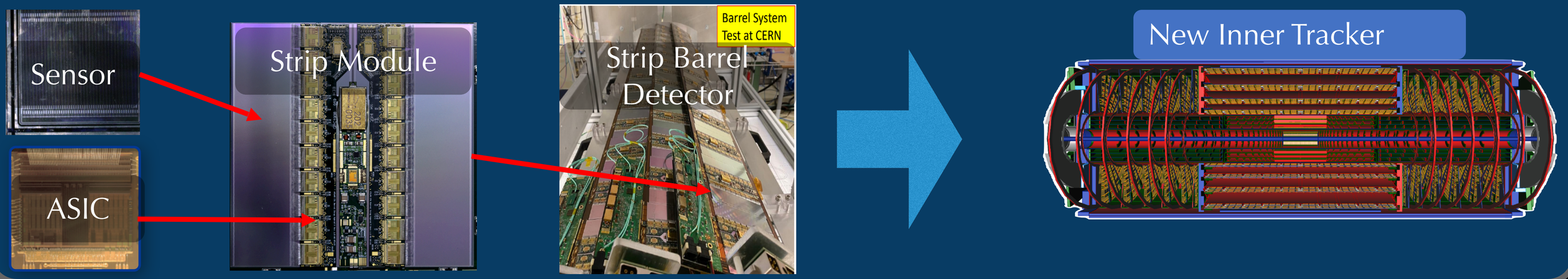
Contributing at CERN to assembly, integration and installation

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 (1000 for China)
- 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

Progress Highlights

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

The project team plans to deliver 10% Strip barrel modules

(for this project 200 modules)

Two teams are working in parallel (IHEP and RAL, UK)

Key achievements:

IHEP site approved for production: 17 preseries hybrids + 7 modules

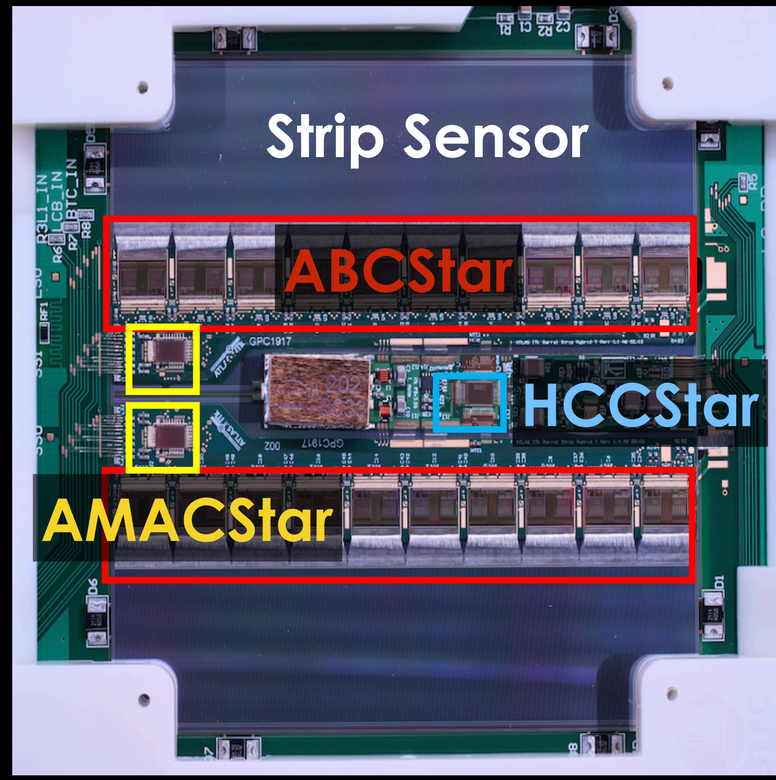
RAL contributions: 20 module prototypes + loading contributions

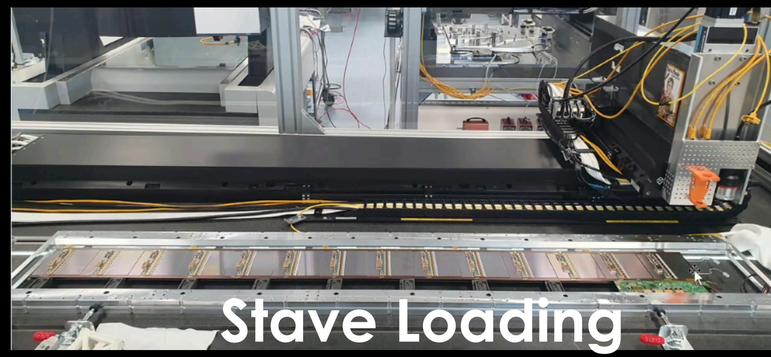
R&D on Timing Pixel Detector

New Pixelated AC LGAD sensor designed and submitted for fabrication

Timing Pixel Readout electronics digital design done

Strip Module





课题3：Muon Detector Upgrade

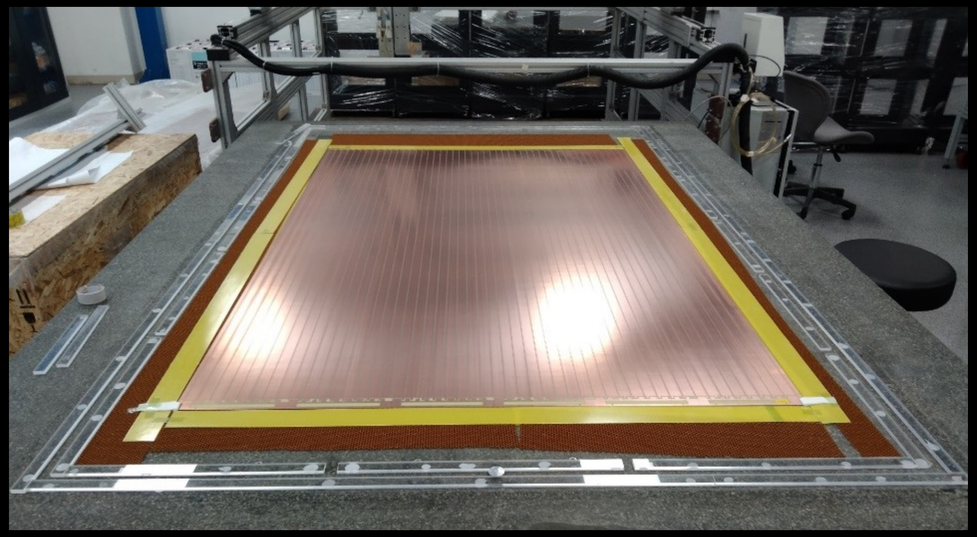
Research Content, Assessment Index (研究内容, 考核指标)

- 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)



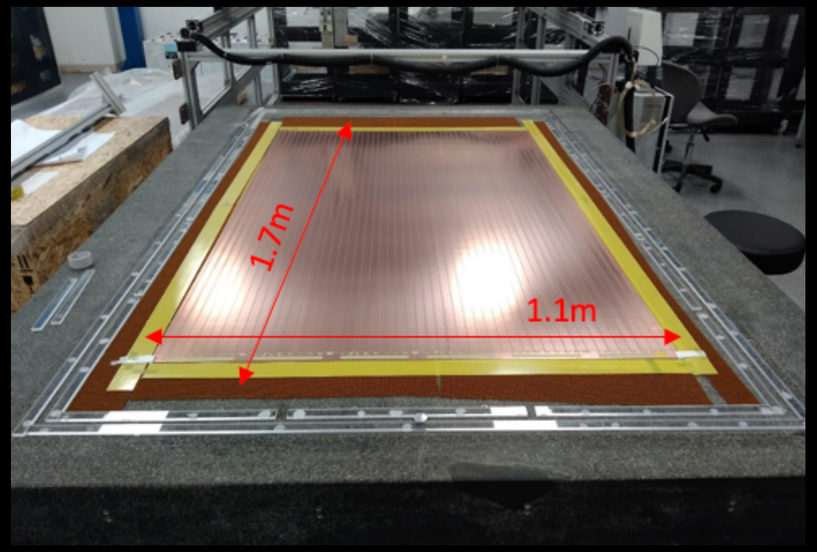
Assessment index （考核指标）

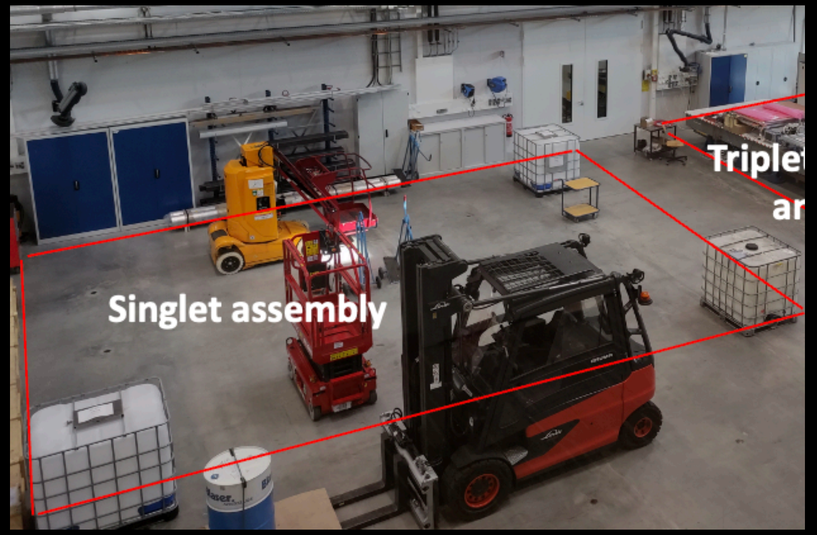
- Parameters to be achieved by all singlet layers (考核指标):
  - Counting rate: >1 kHz/cm^2 (old operational RPC specifications: 300 Hz/cm^2)
  - Time resolution: <1 ns (old operational RPC specifications: > 1 ns)
  - Efficiency: >95%

课题3：Muon Detector Upgrade

Progress Highlights

- All BIS panel production finished (~580 panels) in China
- Singlets assembly started at CERN
- Front-end electronics boards delayed but pre-production of 500 boards started
- Restrictions on FE chips required moving singlet assembly to MPP
  - Plan: start assembly in September



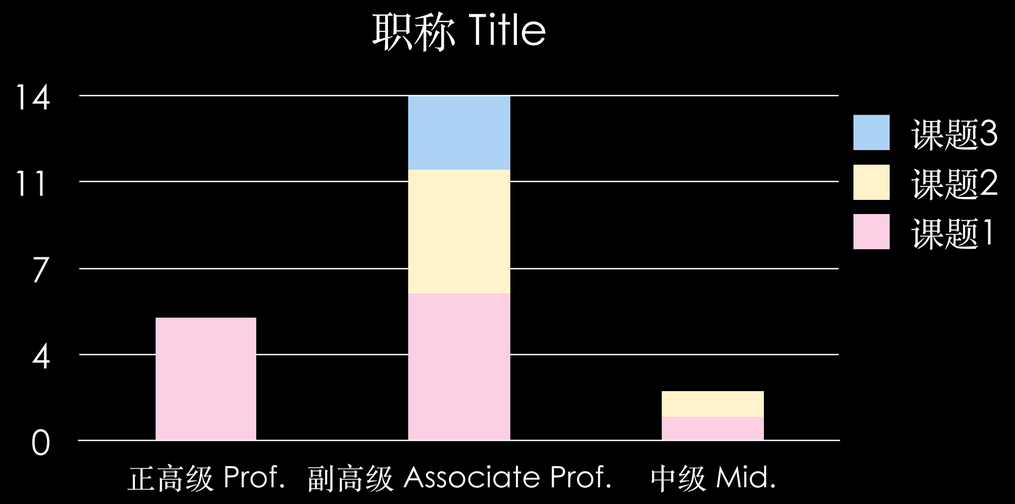


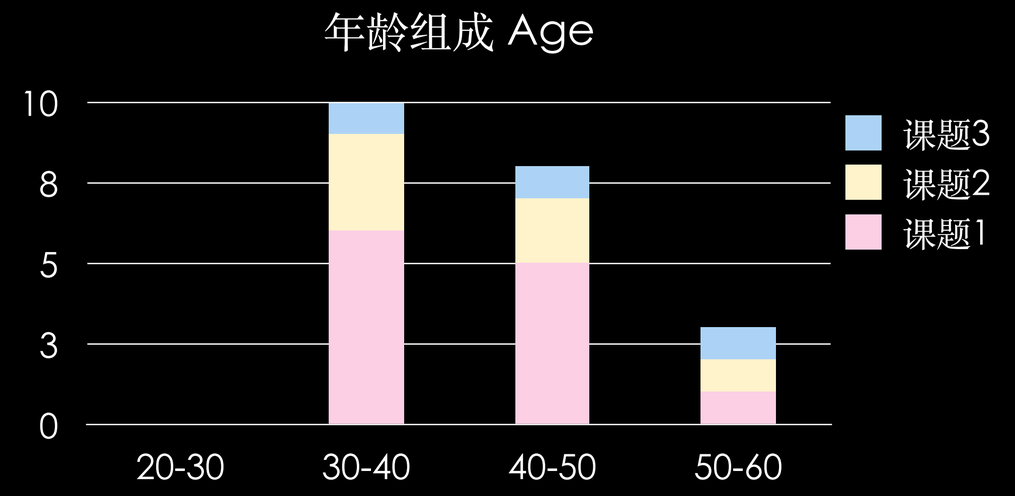
Research team and talent training

Research Team (研究团队)

Total number of team members: 21

Average age 42 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）

Research Team (研究团队)

Total number of staff team members: 21 team members + 24 others = 45 people

Members listed in task book

- **Task 1**
  - **IHEP:** Joao, Zhijun Liang, Jie Zhang, Mei Zhao, Lei Fan, Jinyu Fu, Zhaoru Zhang
  - **USTC:** Yanwen Liu
  - **SDU:** Kun Hu, Yanwen Liu
  - **NJU:** Ligang Xia
- **Task 2**
  - **IHEP:** Xin Shi, Peilian Liu, Xiyuan Zhang, Weiguo Lu
  - **THU:** Yibao Chen
  - **USTC:** Zhe Cao
- **Task 3**
  - **USTC:** Yongjie Sun, Dongshuo Du, Hao Liang
  - **SJTU:** Jun Guo

Other contributors

- **Task 1**
  - **IHEP:** Yunyun Fan, Hideki Okawa
  - **USTC:** Lailin Xu, Yusheng Wu, Yongjie Sun, Lei Zhao, Jiajun Qin, Zhengguo Zhao
  - **NJU:** Zhenwu Ge, Yimin Che, Liangliang Han, Lei Zhang, Ming Qi
- **Task 2**
  - **IHEP:** Zijun Xu, Yinhong Zhang
  - **THU:** Xin Chen
  - **USTC:** Hongtao Yang, Jiajun Qin, Lei Zhao, Jiaming Li, Kairen Chen
- **Task 3**
  - **USTC:** Lailin Xu, Yanwen Liu, Yusheng Wu, Zhengguo Zhao
  - **SJTU:** Haijun Yang

Research Team (研究团队)

Total number of active members: 21 + 24 + 7 + 35 = 87 people

		Team members	Other Staffs	Postdoc	Students
Task 1	**Sum**	**11**	**13**	**4**	**24**
	IHEP	7	2	2	5
	NJU	1	5	1	5
	USTC	1	6	1	8
	SDU	2			6
Task 2	**Sum**	**6**	**8**	**4**	**8**
	IHEP	4	2	2	3
	USTC	1	5	2	2
	THU	1	1		3
Task 3	**Sum**	**4**	**5**	**1**	**8**
	USTC	3	4		5
	SJTU	1	1	1	3
Sum		**21**	**24**	**7**	**35**

Talents:

- Yunyun Fan, IHEP, CAS "100 talents" project
- Francois Lagarde, USTC, Special Professor

Graduated Postdocs (5):

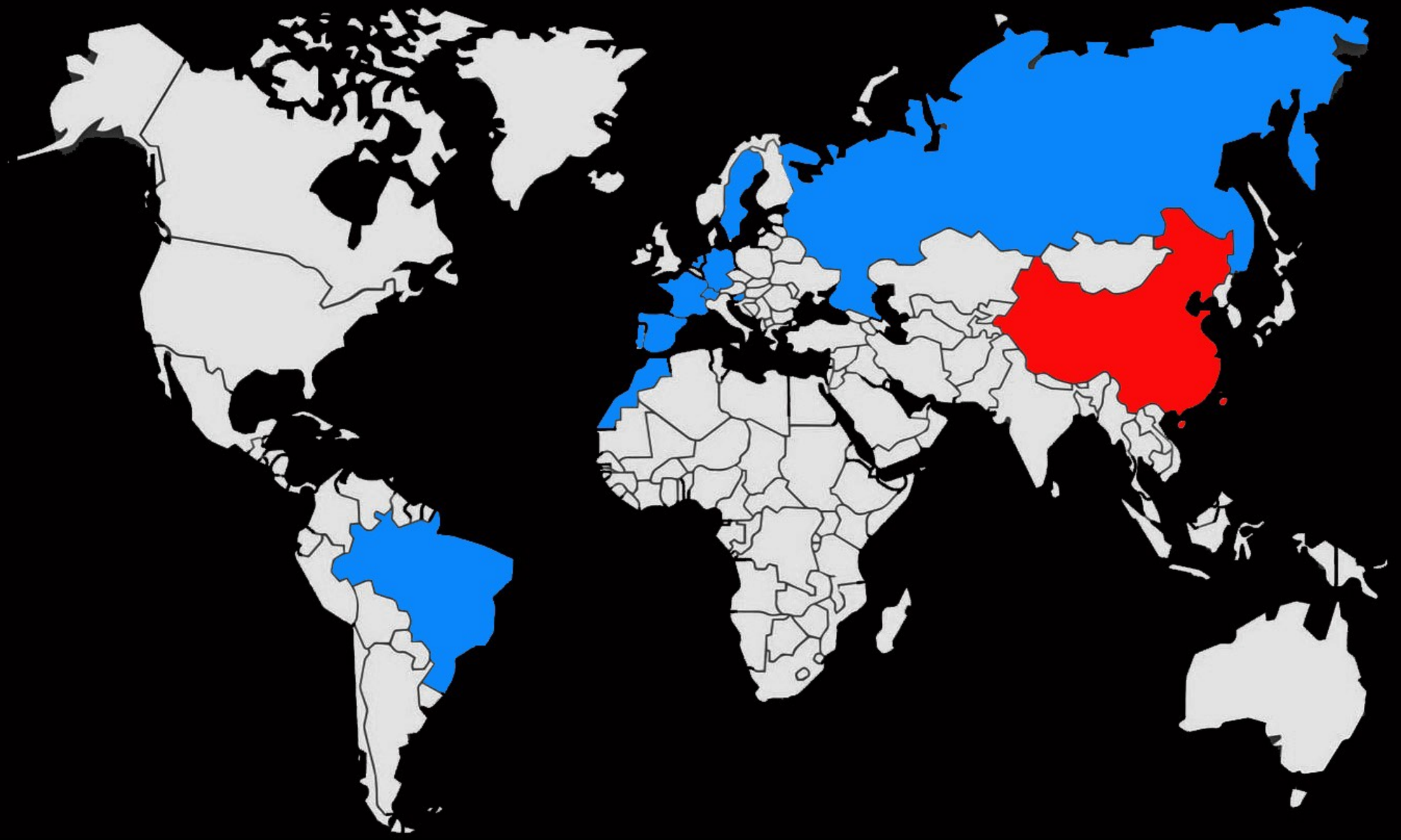
- Tianya Wu, Nanchang University
- Bo Liu, Nankai University
- ……

Graduated PhD and Master (>10)

International Cooperation (国际合作)

课题1 (HGTD):

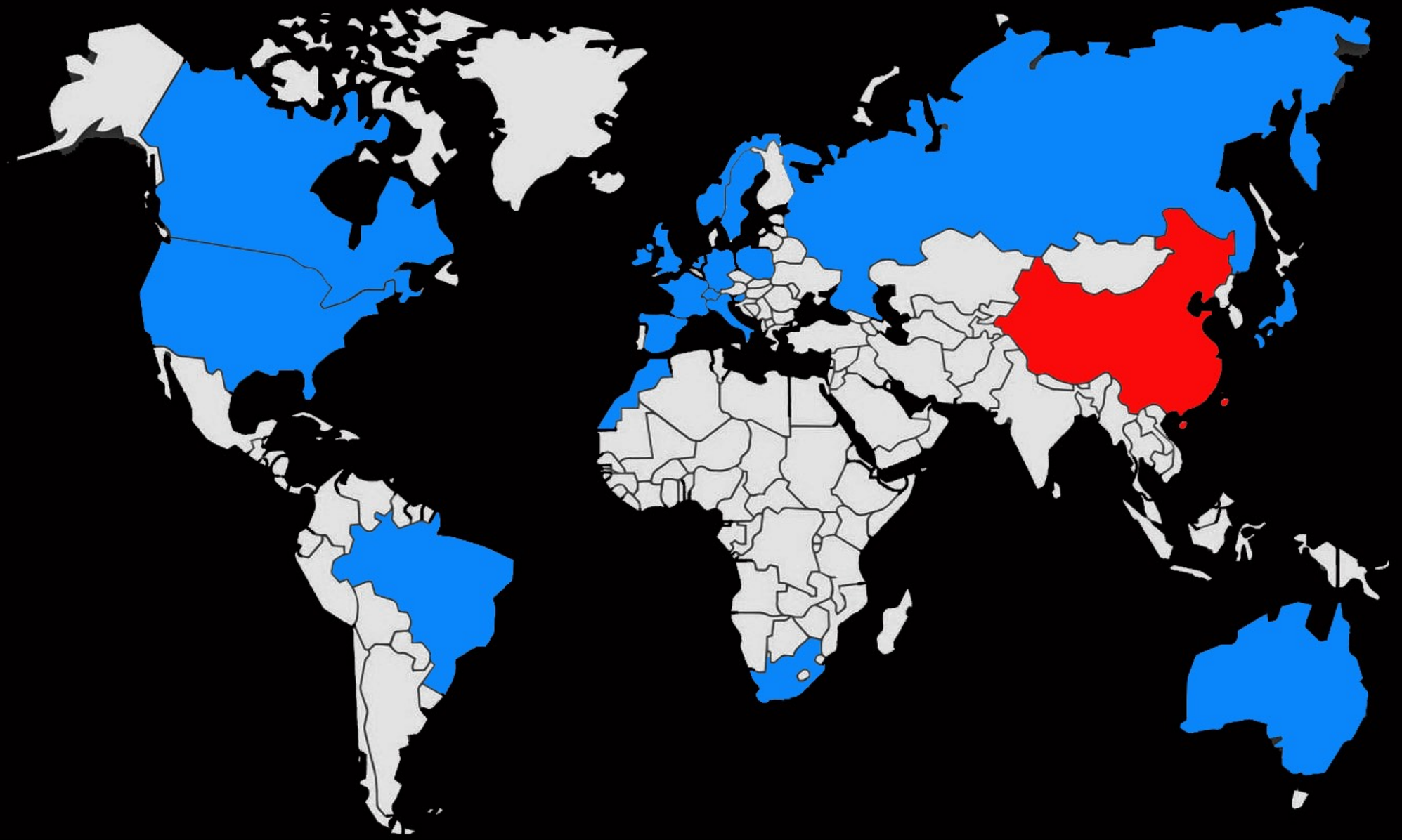
Brazil
China
France
Germany
JINR
Morocco
Netherlands
Portugal
Russia
Slovenia
Spain
Sweden
CERN



International Cooperation (国际合作)

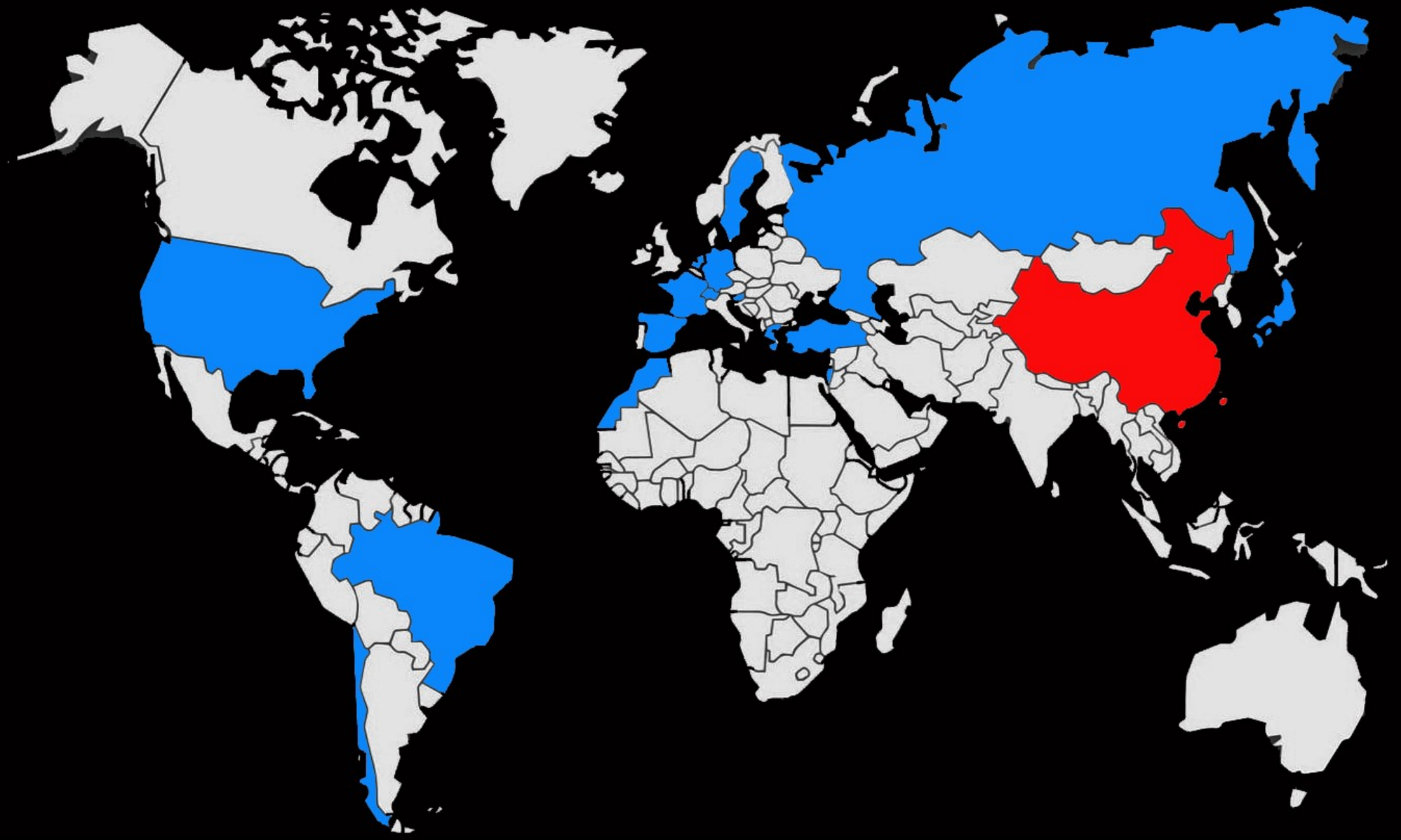
课题2 (ITK):

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

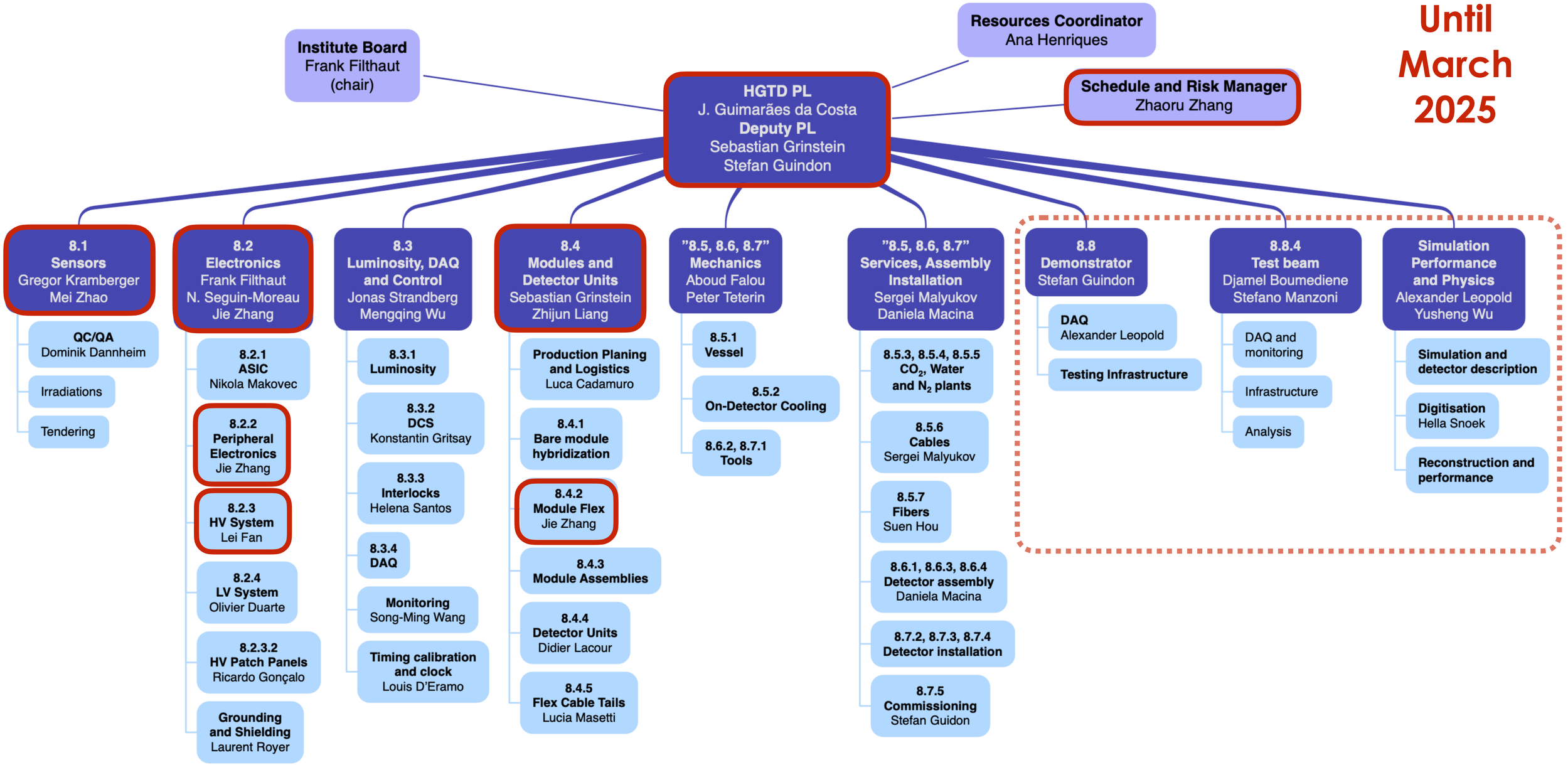


International Cooperation (国际合作)

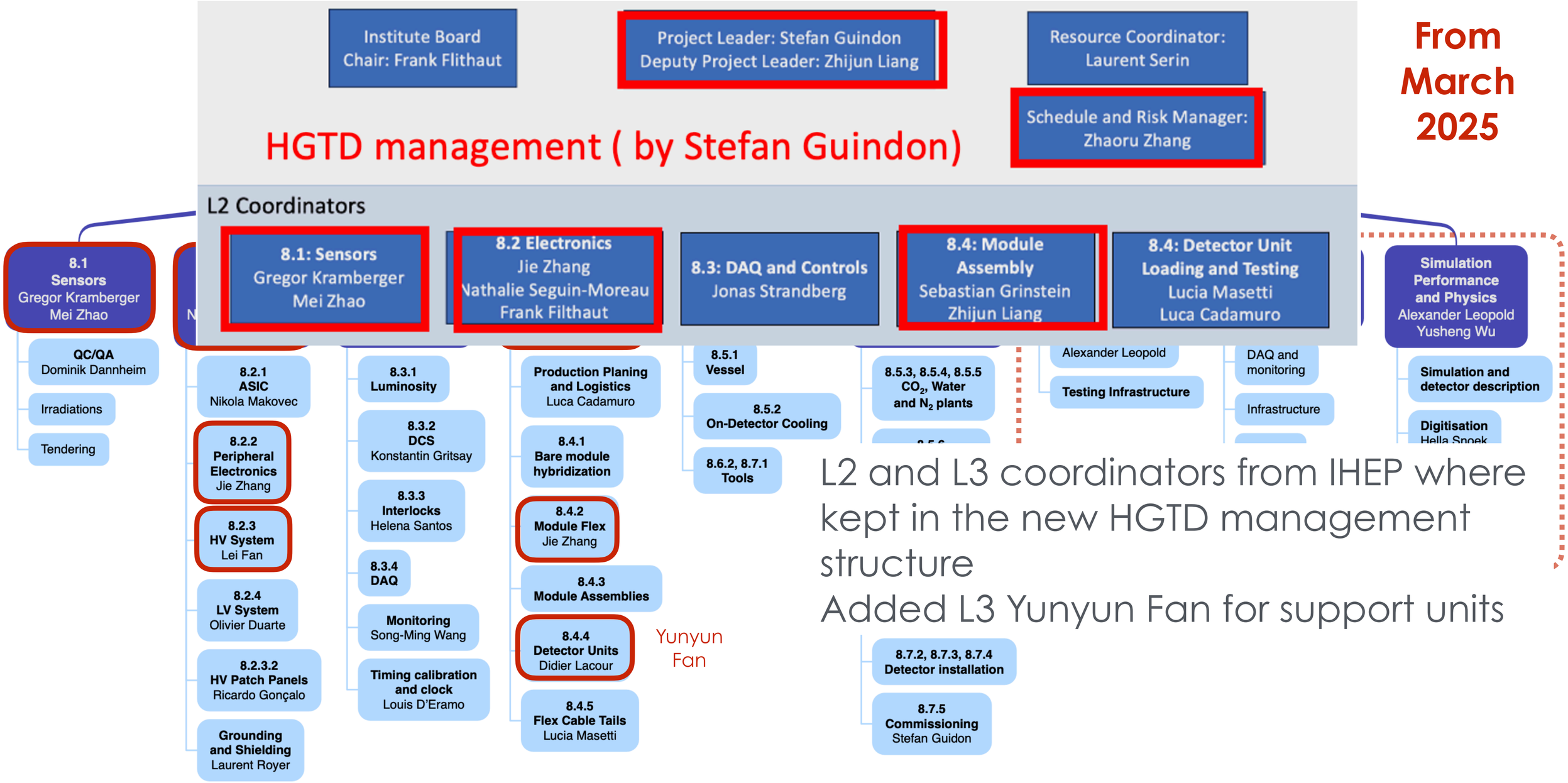
课题3 (Muon):
Chile
China
France
Germany
Greece
Israel
Italy
Japan
Netherlands
Russia
JINR
Turkey
USA
CERN



HGTD Organization/Management Structure



HGTD Organization/Management Structure



L2 and L3 coordinators from IHEP where kept in the new HGTD management structure

Added L3 Yunyun Fan for support units

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 ~5.2%

(surpassed CERN, 6th largest fraction just below France)

Achievements and implementation

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

Papers and conference talks

Papers: 3 **Talks: 35 + 10 = 45 talks**

	Papers	Domestic talks	International talks	Poster
Task 1	**3**	25	**8**	
Task 2		5	1	3
Task 3		5	1	
Sum	**3**	**35**	**10**	**3**

Need to try to publish some results from Task 2 and Task 3

* Note: there are another 5 papers which didn't mention the project in ackownledgements
We are trying to contact journals to add it.

Funding current implementation

Total funds: 2200万元 (48% received, 65% used)

	万	Total Budget	Received funds	Total Expense	Rate %
Project		**2200.0**	**1066.0**	**691.0**	**31.41%**
Task 1	**Sum**	**1135.0**	**550.0**	**332.6**	**29.30%**
	IHEP	500.0	242.3	172.2	34.45%
	USTC	255.0	123.6	29.5	11.58%
	NJU	130.0	63.0	57.6	44.32%
	SDU	250.0	121.1	73.2	29.28%
Task 2	**Sum**	**600.0**	**290.7**	**217.9**	**36.32%**
	IHEP	350.0	169.6	135.3	38.67%
	USTC	100.0	48.5	16.4	16.45%
	THU	150.0	72.7	66.1	44.09%
Task 3	**Sum**	**465.0**	**225.3**	**140.5**	**30.22%**
	USTC	315.0	152.6	74.2	23.55%
	SJTU	150.0	72.7	66.3	44.22%

Funds for ATLAS CORE production items need to be spent according to implementation of ATLAS project

Task 1	Budget	Expense	Rate
1 Direct fee	932	243.7	26.15%
1) Device fee	70	1.5	
2) Business fee	734	132.1	17.99%
3) Labor fee	128	110.2	86.09%

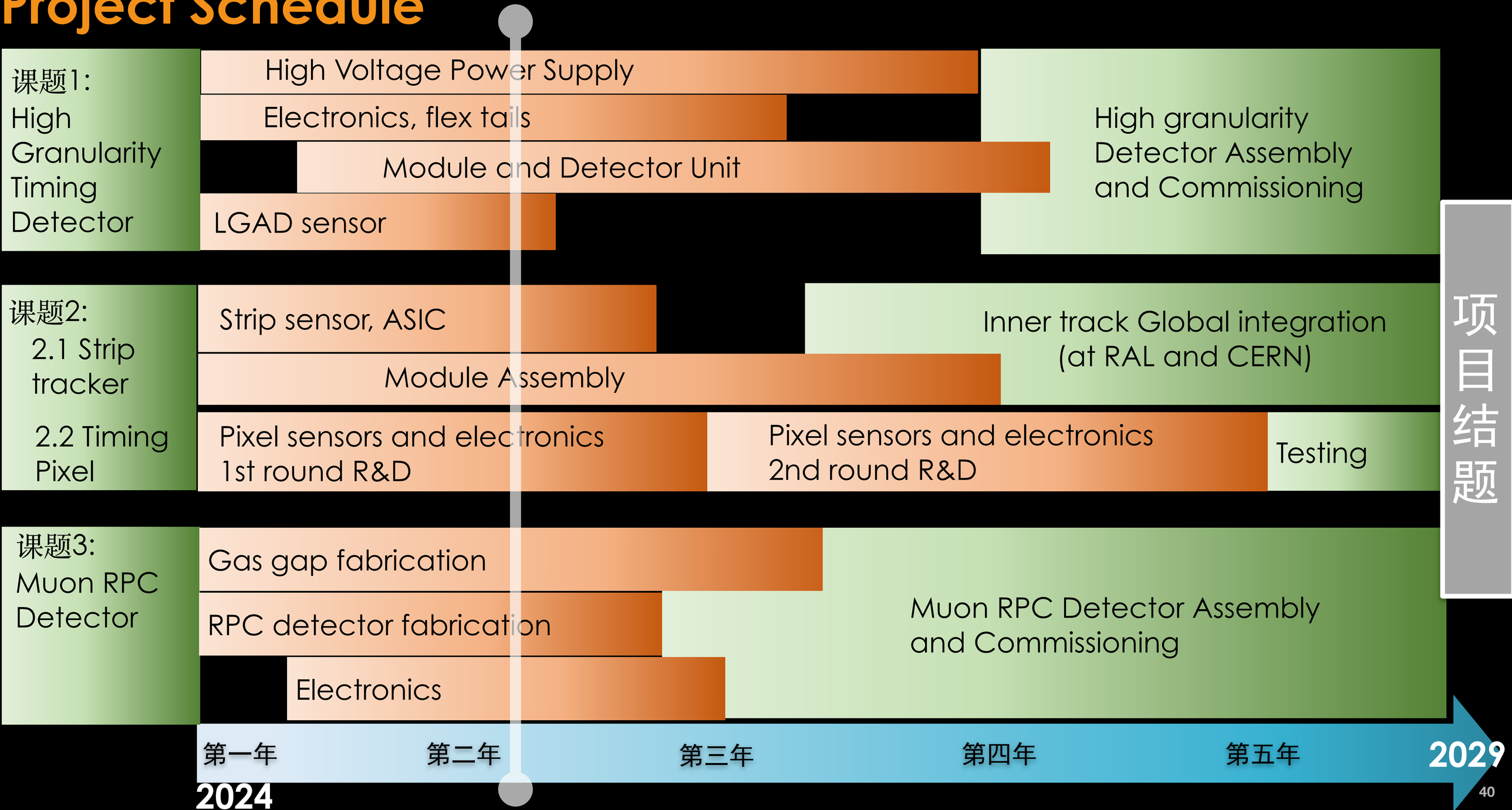
Task 2	Budget	Expense	Rate
1 Direct fee	475	149.5	31.48%
1) Device fee			
2) Business fee	415	81.2	19.55%
3) Labor fee	60	68.4	113.93%

Task 3	Budget	Expense	Rate
1 Direct fee	358	88.6	24.74%
1) Device fee			
2) Business fee	328	74.4	22.69%
3) Labor fee	30	14.2	47.17%

Project	Budget	Expense	Rate
1 Direct fee	1765	481.8	27.30%
1) Device fee	70	1.5	2.10%
2) Business fee	1477	287.6	19.48%
3) Labor fee	218	192.7	88.40%

Project schedule and planning

Project Schedule



项目结题

International Integration in ATLAS

China is making significant contributions to the ATLAS Upgrade project

May 2024	**Visit of ATLAS Management** ATLAS Spokesperson ATLAS Resources Coordinator ATLAS Upgrade Coordinator
July 2024	**HGTD Week** IHEP, Beijing
June 2024	**Visit of ATLAS Management** ATLAS Spokesperson ATLAS Upgrade Coordinator HGTD Project Leader

Timeline

- **2024.07.02 Project Kickoff Meeting (Beijing)**
- **2024.12 Annual Technical Progress Report**

- **2025.04.28 Progress Exchange Meeting (Nanjing)**
- **2025.06.07 Progress Exchange Meeting (Beijing)**
- **2025.12 Annual Technical Progress Report**

- **2026.04 Mid-term Evaluation Preparation Meeting**
- **2026.06 Mid-term Progress Report**
- **2026.07 Mid-term Evaluation Meeting**
- **2026.11 Progress Exchange Meeting (Beijing)**

- 2027.05 Progress Exchange Meeting
- 2027.11 Progress Exchange Meeting
- 2027.12 Annual Technical Progress Report

- 2028.05 Progress Exchange Meeting
- 2028.09 Project Conclusion Preparation Meeting
- 2028.11-12 Project Final Report
- 2028.11-12 Project Final Review Meeting

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 first batch of silicon modules, develop time pixel sensor, 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

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), collaborate internally to help each other achieve the project goals
  - 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.

both risks have already materialized → working to mitigate impact

Assessment indicators and 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

Assessment indicators and 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

Conclusions - 结语

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

It is promoting Chinese industry on frontier technologies driving development

- Task 1: All items approved, or just about to be approved, to start pre-production
  - Sensor production already on-going
- Task 2: Production of modules starting at both IHEP+RAL sites
  - Accumulated delays in the overall ITk project are expected to be overcome
- Task 3: Production and qualification of BIS readout panels (580 pieces) finished
  - Assembly of singlets moved to MPP

Need to keep a careful monitoring of the schedule due to HL-LHC delays but currently the project is still feasible on time

谢谢您

Extra Slides

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

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

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.

Assessment Indicators (考核指标)

对应的课题	考核指标				考核方式（方法）及评价手段
	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	
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				考核方式（方法）及评价手段
	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	
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

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 Leader (项目负责人)

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

就读于:

JOHNS HOPKINS UNIVERSITY

UNIVERSITY OF MICHIGAN

VE RI TAS HARVARD

- 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

All hold management positions within ATLAS for the corresponding projects

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

Papers

1. ATLAS HGTD collaboration, HGTD DC/DC converter in low temperature and magnetic field operation, Journal of Instrumentation, 19, C02006 (2024).
2. Zhenwu Ge et al, An FPGA-based front-end module emulator for the High Granularity Timing Detector, 2024 JINST 19 C03055
3. Low Gain Avalanche Detectors for the ATLAS High Granularity Timing Detector: Laboratory and test beam campaigns，NIMA1063（2024）169237
4. ATLAS HGTD collaboration, An FPGA-based front-end module emulator for the High Granularity Timing Detector, Journal of Instrumentation, 19, C03055 (2024).
5. ATLAS HGTD collaboration, Evaluation of the prototype Peripheral Electronics Board for the High Granularity Timing Detector, Journal of Instrumentation, 19, C12012 (2024).
6. Z. Xu et al., MUX64, an analogue 64-to-1 multiplexer ASIC for the ATLAS high granularity timing detector, Journal of Instrumentation, 18, C03012 (2023).
7. C. Wang et al., Radiation tolerance of the MUX64 for the High Granularity Timing Detector of ATLAS, Journal of Instrumentation, 19, C03044 (2024).

Domestic conference talks

1. Status of ATLAS HGTD Peripheral Electronics Board, The 8th China LHC Physics Workshop, Nanjing, Nov 2022, Parallel Session
2. The Prototype Design of PEB--a Component of the HGTD On-detector Electronics for the ATLAS Phase-II Upgrade, The 9th China LHC Physics Workshop, Shanghai, Nov 2023, Parallel Session
3. ATLAS HGTD 工程样机及数据获取系统进展简介,第五届半导体辐射探测器研讨会，2025.4.17～20， 大会
4. LGAD与ALTIROC芯片和LATIC芯片倒装键合后的性能表现，第五届半导体辐射探测器研讨会，2025.4.17～20， 大会
5. ATLAS HGTD 项目中USTC-IME预量产传感器的表征与性能研究，第五届半导体辐射探测器研讨会，2025.4.17～20， 大会
6. LGAD读出电子学，第五届半导体辐射探测器研讨会，2025年4月17-20日，分会报告，西安
7. Construction and Upgrade of ALTIROC Chip Testing System，The 10th China LHC Physics Conference (CLHCP2024)，Nov 13 – 17, 2024，分会报告，青岛
8. 梁志均，ATLAS中国组进展总结，第十届中国LHC物理会议， 11月13-18日，青岛
9. 赵梅，ATLAS upgrade，第十届中国LHC物理会议，第十届中国LHC物理会议， 11月13-18日，青岛
10. 梁志均，高时间分辨率硅探测器的研究现状与发展趋势， 第四届半导体辐射探测器研讨会， 5月23-26日，青岛
11. 张杰，ATLAS HGTD 电子学进展，第四届半导体辐射探测器研讨会， 5月23-26日，青岛
12. 马阔，LGAD 探测器研发进展与展望， 中国物理学会高能物理分会第十四届全国粒子物理学术会，2024.8.14-18
13. 张杰，The Prototype of the Peripheral Electronics Board for ATLAS High Granularity Timing Detector，第十届中国LHC物理会议，第十届中国LHC物理会议， 11月13-18日，青岛
14. 杨轩，Development of HGTD Module assembly and loading at IHEP，第十届中国LHC物理会议，第十届中国LHC物理会议， 11月13-18日，青岛
15. 李煜龙，Research on HGTD module thermal cycle，第十届中国LHC物理会议，第十届中国LHC物理会议， 11月13-18日，青岛
16. 孙维益，Researches of radiation-resistant LGAD sensors for ATLAS High Granularity Timing Detector，第十届中国LHC物理会议，第十届中国LHC物理会议， 11月13-18日，青岛
17. 赵梅，Researches of irradiation-resistant LGAD detector for ATLAS HGTD，第二十二届全国核电子学与核探测技术学术年会，7月15-17日，青岛
18. 杨轩，ATLAS探测器升级的时间探测器（HGTD)项目中的探测器模块组装与测试，第二十二届全国核电子学与核探测技术学术年会，7月15-17日，青岛

Domestic conference talks

19. 梁志均，ATLAS探测器升级的时间探测器， 中国物理学会高能物理分会第十四届全国粒子物理学术会议，8月12-18日，青岛
20. 赵梅，Researches of irradiation-resistant LGAD detector for ATLAS HGTD，中国物理学会高能物理分会第十四届全国粒子物理学术会议，8月12-18日，青岛
21. 黄鑫辉，Automatic module assembly and loading system development for ATLAS HGTD， 中国物理学会高能物理分会第十四届全国粒子物理学术会议，8月12-18日，青岛
22. 李寒，Readiness of the detector assembly at USTC for ATLAS HGTD，第四届半导体辐射探测器研讨会，2024.5.23-26
23. 任浩泉，Pre-production of USTC-IME LGAD for ATLAS HGTD，第四届半导体辐射探测器研讨会，2024.5.23-26
24. 马阔，Characterization of USTC-IME LGAD pre-production sensors for the HGTD，第十届LHC物理研讨会，2024.11.13-17
25. 周展航，Development of data acquisition system for the HGTD，第十届LHC物理研讨会，2024.11.13-17
26. Development of ATLAS ITk strip module 第十届中国LHC物理会议 王成伟 2024.11.13-17
27. Radiation effects of ASICs for ATLAS ITk strip upgrade 第十届中国LHC物理会议 周研、陆卫国 2024.11.13-17
28. ATLAS ITk Strip Sensor Irradiation at CSNS 第十届中国LHC物理会议 黄英峻 2024.11.13-17
29. Irradiation test of HCCStar ASICs in CSNS Topical Workshop on Electronics for Particle Physics 2024 彭少刚 2024.9.30-10.4
30. Irradiation test for BETSEE at CSNS for ATLAS ITk strip upgrade Topical Workshop on Electronics for Particle Physics 2024 陆卫国 2024.9.30-10.4
31. ATLAS硅微条探测器升级进展 第四届半导体探测器升级进展 陆卫国 2024.5.23-26
32. 4H-SiC 粒子探测器的研究潜力及其器件研发 第四届半导体探测器升级进展 张希媛 2024.5.23-26
33. Mass production of RPC readout panels for ATLAS Phase-II upgrade and R&D on thin gas gap production at USTC 第十四届全国粒子物理学术会议 杜东硕 2024.8.12-18
34. The thin RPC gas gap development for the ATLAS Phase-II upgrade 第十届中国LHC物理会议 杜东硕 2024.11.13-16
35. The RPC assembly for the ATLAS Phase-II upgrade 第十届中国LHC物理会议 Francois Lagarde 2024.11.13-17

International conference talks

1. HGTD Status Overview, ATLAS WEEK, Thessaloniki, Greece, Jun 2024, Plenary Session.
2. Tests of the Prototype Peripheral Electronics Board for the High Granularity Timing Detector, Topical Workshop on Electronics for Particle Physics 2024, Glasgow, Scotland, Sep 2024, Poster.
3. Low Gain Avalanche Detectors for the ATLAS High Granularity Timing Detector: laboratory and test beam campaigns，PSD2023，2023.12.3～8，大会
4. SiC AC-LGAD Timing Pixel Detector 1st DRD3 week on Solid State Detectors R&D 史欣 2024.06.17-21
5. Mass production of RPC readout panels for ATLAS Phase-II upgrade and R&D on thin gas gap production at USTC XVII international Conference on Resistive Plate Chambers and Related Detectors (RPC2024) Dongshuo Du 2024.9.9-13
6. Zhijun Liang，Module assembly in HGTD, ATLAS week, 2月10日-14日，瑞士日内瓦
7. 梁志均，The High-Granularity Timing Detector for ATLAS at HL-LHC， 国际像素探测器会议（Pixel2024），11月18-22日，法国斯特拉斯堡
8. Jingbo Ye, Overview of the ATLAS High-Granularity Timing Detector: project status and result, 国际辐射探测器会议（HSTD2023），12月3-8日，加拿大温哥华
9. Zhenwu Ge，HGTD status overview，ATLAS Week，20 June, 2024
10. Yinmin Che，HGTD status report，ATLAS Upgrade Week，14 November, 2024

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

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