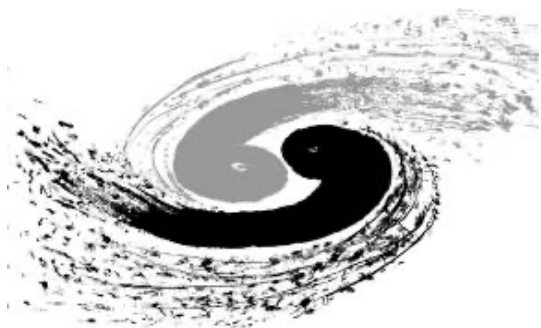

ATLAS High Granularity Timing Detector

ATLAS实验高颗粒度时间探测器升级

Zhijun Liang

(The Institute of High Energy Physics, the Chinese Academy of Sciences)

梁志均（中国科学院高能物理研究所）



南京大學



Outline

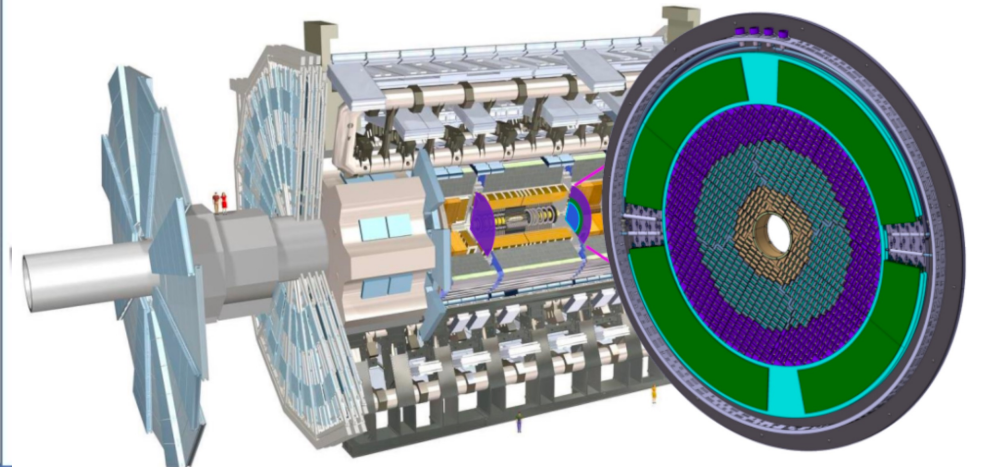
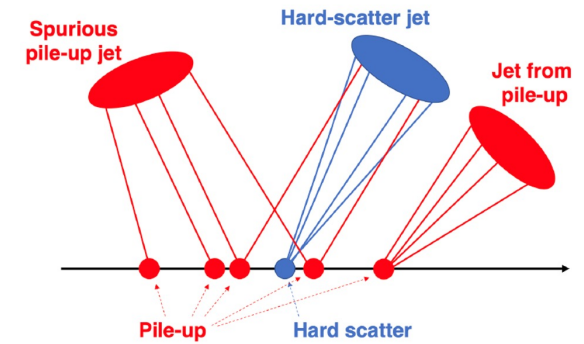
- 考核指标完成情况
- 研发任务完成情况
- 研究成果的水平及创新性
- 组织管理情况

High Granularity Timing Detector (HGTD)

- HGTD aim to reduce pileup contribution at HL-LHC
 - Timing resolution is better than **30 ps (start) - 50 ps (end) ps per track**
 - **6.4 m² area** silicon detector and **$\sim 3.6 \times 10^6$** channels
- 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

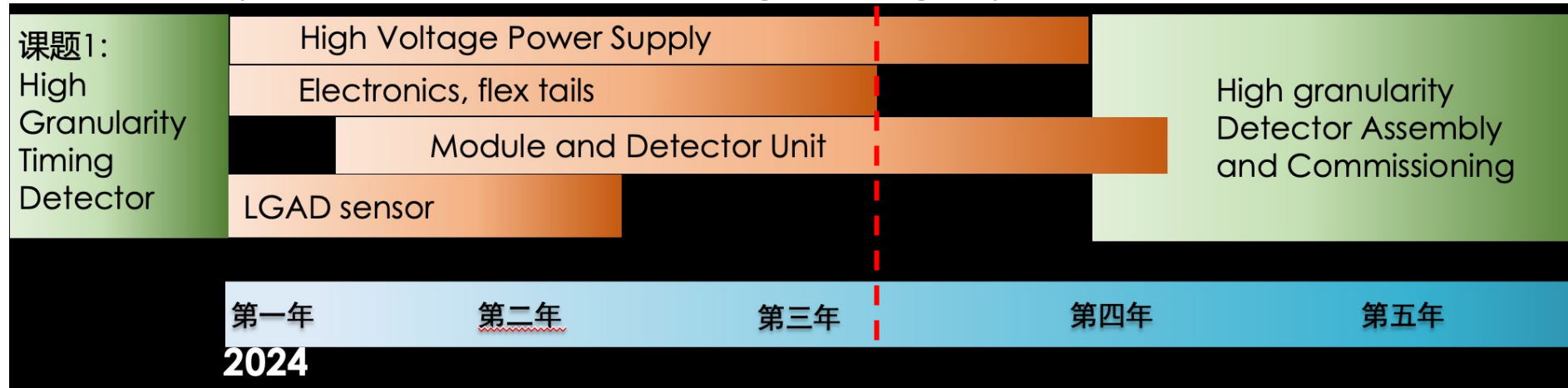
- **China team is making key contributions to HGTD**

- **100%** LGAD sensor (90% **IHEP** + 10% **USTC**)
- **44%** detector assembly (34% **IHEP** + 10% **USTC**)
- **100%** front-end electronics board (**IHEP** + **NJU**)
- **~33%** flex tail (**SDU**)
- **50%** ASIC testing (**IHEP**)
- **>16%** high-voltage electronic systems (**IHEP** + **SDU**)
- Software and performance (**USTC**, **IHEP**)

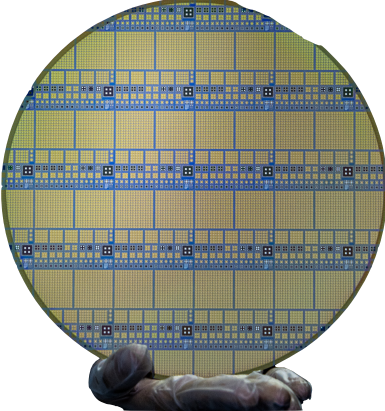


Research Content, Assessment Index (考核指标, 研究内容)

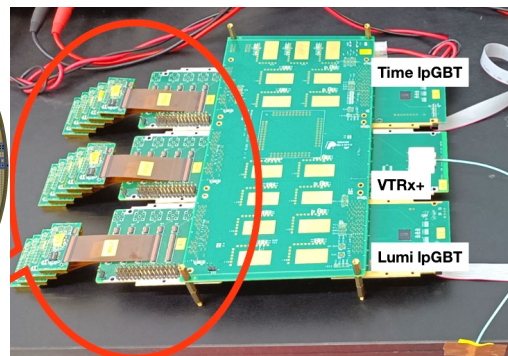
- 研究内容： Develop all key components for the Timing Detector
- Developed radiation hard LGAD silicon sensor
- Build large-area ASIC+Sensor Module with robot
- Develop Front-end electronics, high voltage system, flexible cable



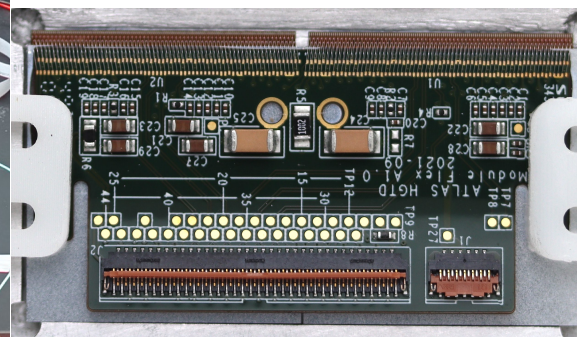
LGAD sensor



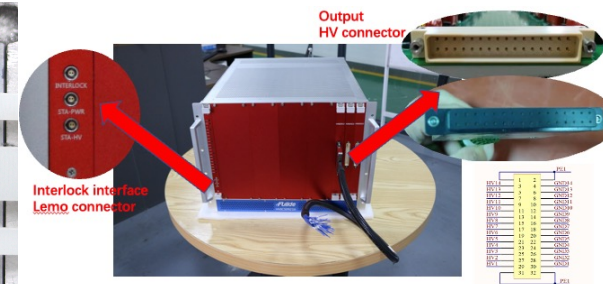
Electronics



Modules



High Voltage supply



Assessment index status (考核指标) :

- Midterm goal (中期指标) :
 - (pre-)production sensor timing resolution reach 30 - 50ps
 - ATLAS升级研制出正式的硅传感器，时间分辨率达到30-50皮秒
- Final goal:
 - Final production sensor and detector module time resolution **30-50 ps**

课目标、预期成果与考核指标表

| 课目标 ¹ | 预期成果 | | 考核指标 ² | | | | 考核方式(方法)及评价手段 ⁴ | 本年度指标状态 |
|--|-----------|--|-------------------|----------------------|-----------------------------------|---------------------|----------------------------|--------------------------------|
| | 预期成果名称 | 预期成果类型 | 指标名称 | 立项时已有指标值/状态 | 中期指标值/状态 ³ | 完成时指标值/状态 | | |
| 在高颗粒度时间探测器方面，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。 | 主要成果 1 | 高精度时间探测器 <input type="checkbox"/> 新理论 <input type="checkbox"/> 新原理 <input type="checkbox"/> 新产品 <input checked="" type="checkbox"/> 新技术 <input type="checkbox"/> 新方法 <input type="checkbox"/> 关键部件 <input type="checkbox"/> 数据库 <input type="checkbox"/> 软件 <input type="checkbox"/> 应用解决方案 <input type="checkbox"/> 实验装置/系统 <input type="checkbox"/> 临床指南/规范 <input type="checkbox"/> 工程工艺 <input type="checkbox"/> 标准 <input type="checkbox"/> 论文 <input type="checkbox"/> 发明专利 <input type="checkbox"/> 其他____ | 时间分辨率 (关键核心指标) | 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。 | 为ATLAS升级研制出正式的硅传感器，时间分辨率好于40皮秒 |

Outline

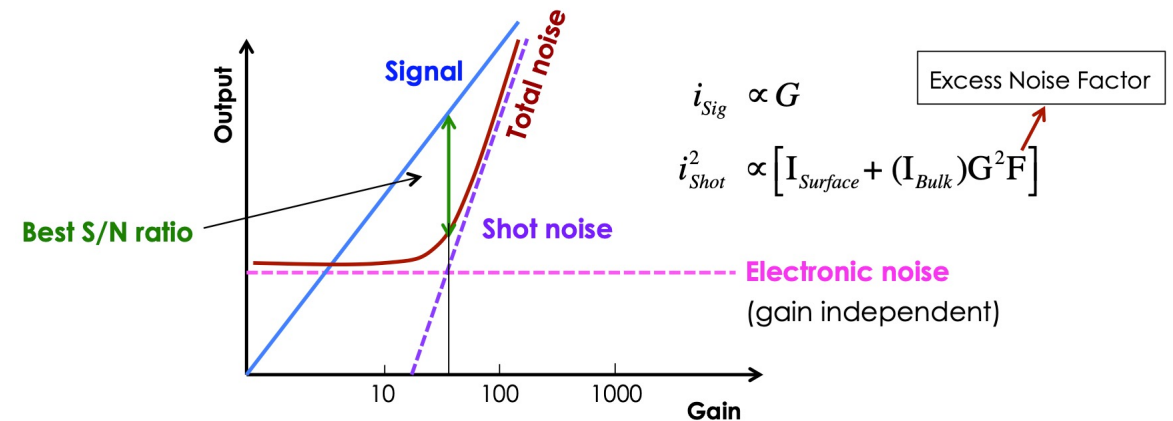
- 考核指标完成情况
- 研发任务完成情况
- 研究成果的水平及创新性
- 组织管理情况

Innovation: Low Gain Avalanche Diodes (LGAD)

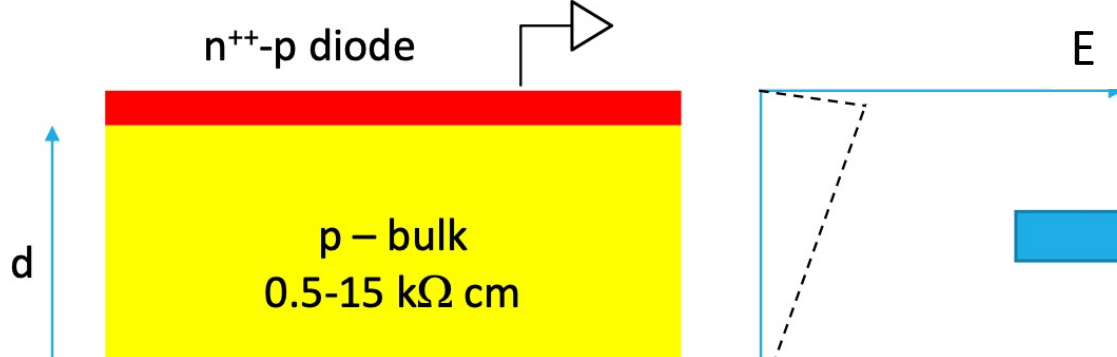
- Key technology developed in HGTD: LGAD sensor
- Innovation: high-granularity Radiation-hard LGAD developed for Collider
- LGAD has modest gain (~50), optimized to get the best S/N and fast timing

$$\sigma_{jitter}^2 = \left(\frac{t_{rise}}{S/N} \right)^2$$

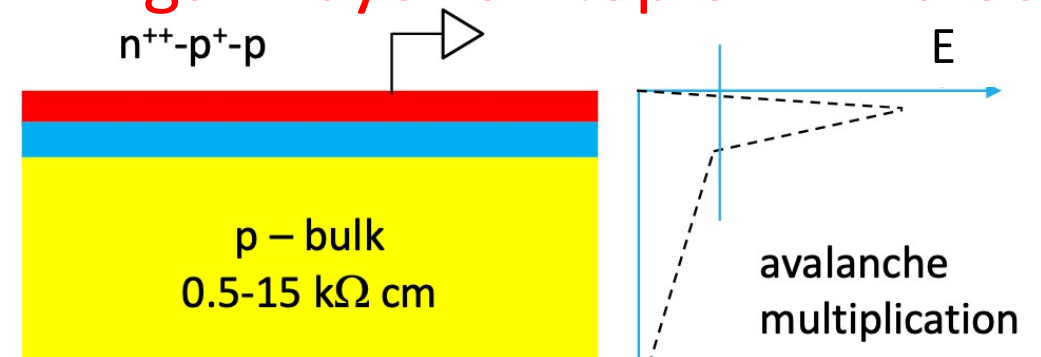
- Modest gain to increase S/N
- Thin detector to reduce t_{rise}



Conventional PiN diode



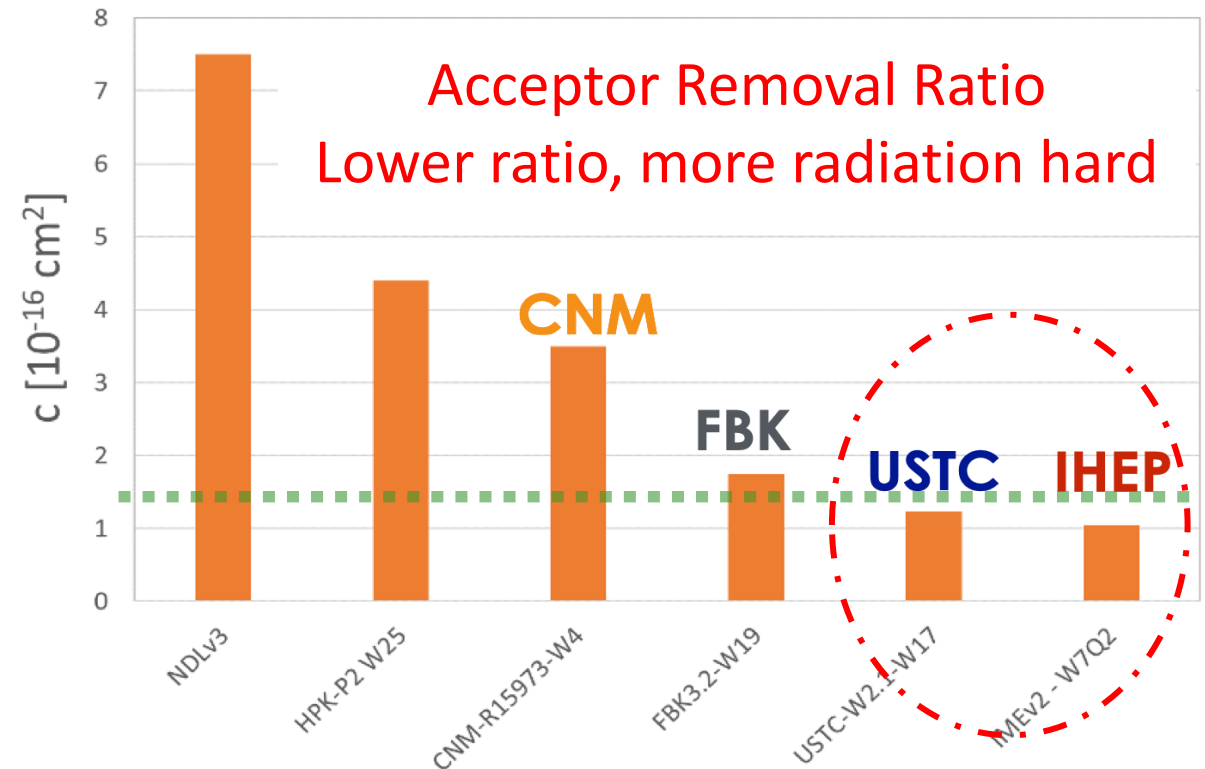
LGAD: P+ gain layer on top of PIN diode



Innovation: LGAD sensor after Irradiation

- IHEP and USTC developed IHEP-IME and USTC-IME LGAD with carbon doping independently
 - Increased radiation hardness, met HGTD requirement, survive at fluence $2.5 \times 10^{15} n_{eq}/cm^2$
- After $2.5 \times 10^{15} n_{eq}/cm^2$, IHEP LGADs can operated much below 550 V
 - Avoid single event burnout

Single Event Burnout (SEB) effect CNM LGAD

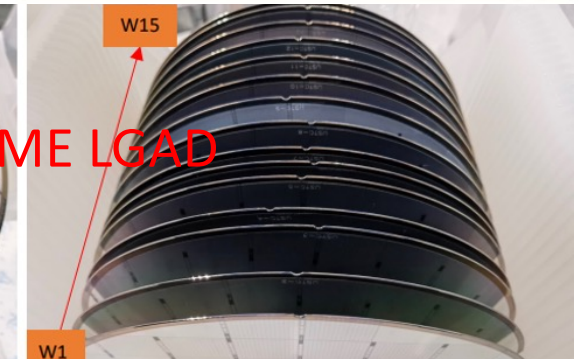
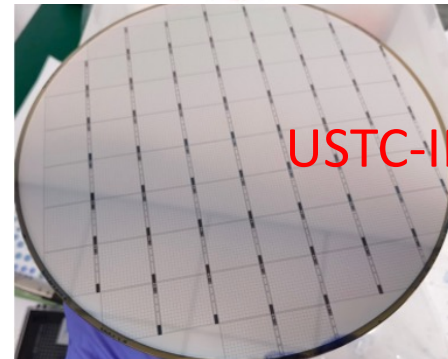
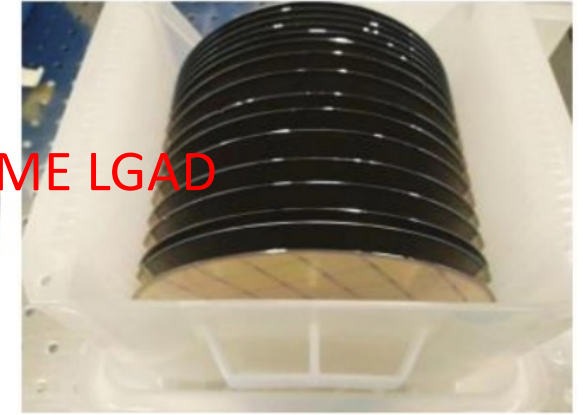
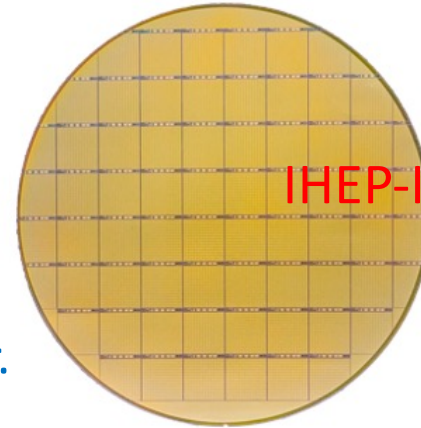


LGAD sensors pre-production and production

- Passed CERN review at 2024. The sensor production will be 100% done by China
 - First time domestic silicon sensor was used by CERN
 - IHEP-IME: 90% (66% from CERN tendering+24% in-kind contribution) : $\sim 8 \text{ m}^2$
 - CERN chosen IHEP-IME sensor in tendering, contract signed in Feb 2025
 - USTC-IME: 10% in-kind contribution ($\sim 0.8 \text{ m}^2$)

• Production status

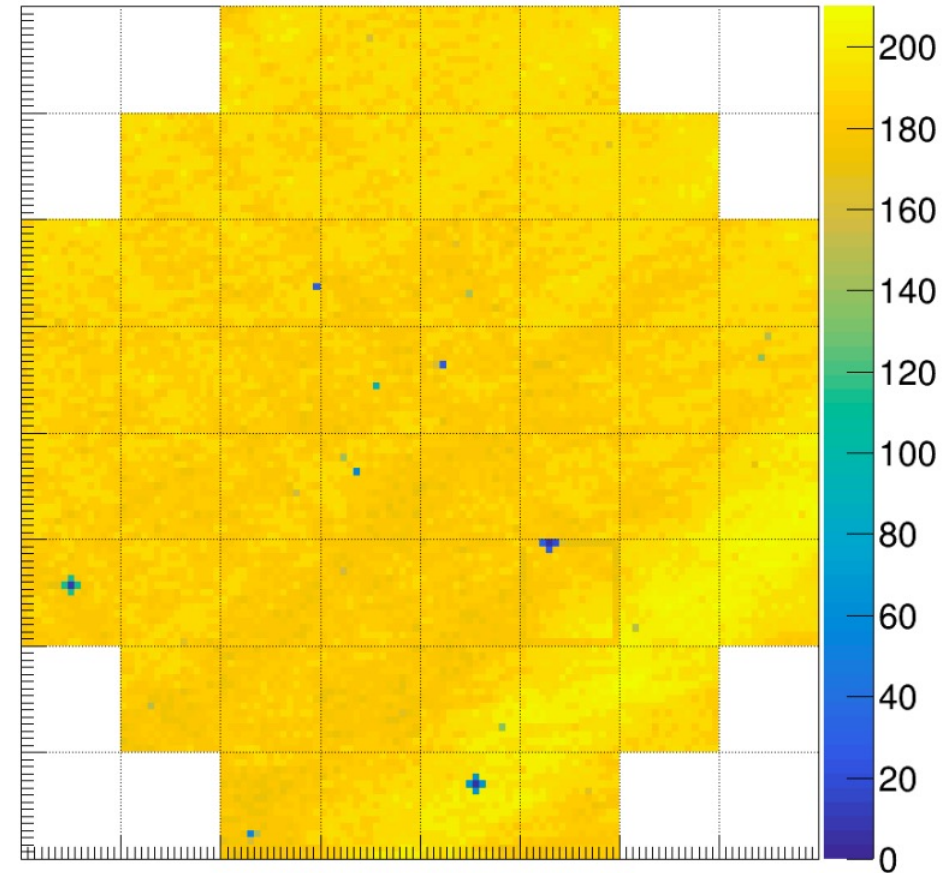
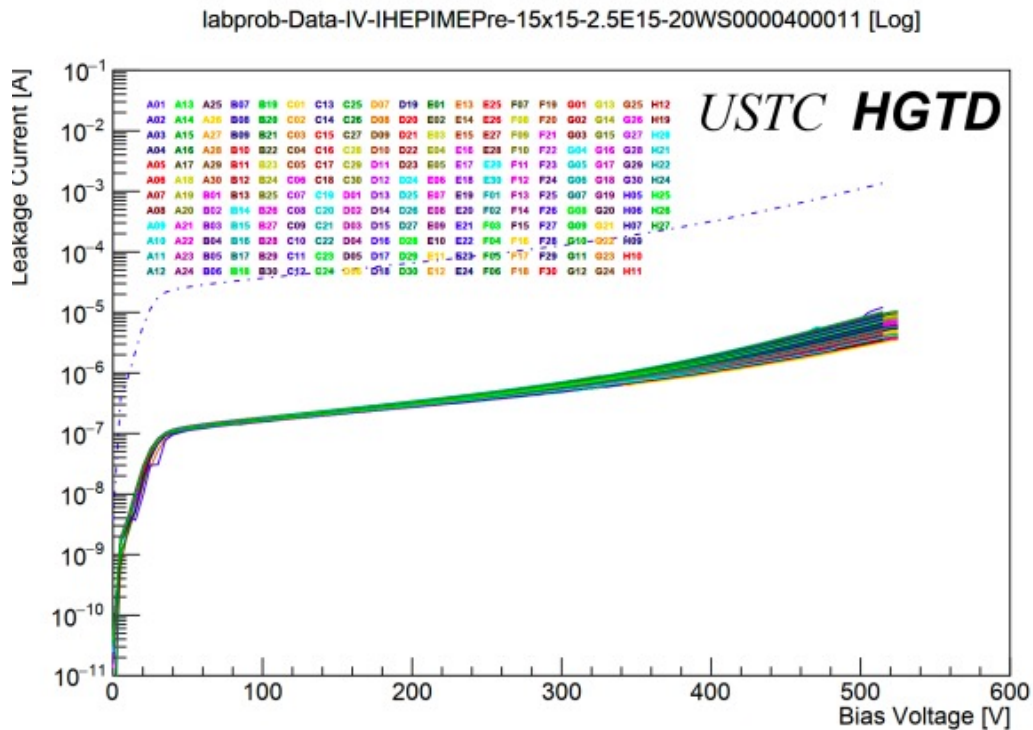
- IHEP
 - Pre-production: ~ 1700 sensor fabricated
 - Production: ~ 6000 sensor fabricated ($\sim 30\%$ of total)
 - To do: complete remaining 60% of LGAD in one year.
- USTC
 - pre-production: ~ 270 sensor fabricated
 - Production ~ 2300 sensor fabricated ($\sim 10\%$ of total)
 - USTC finished its share in production
 - Next step is to finish the testing



LGAD sensors pre-production and production

- Good uniformity of leakage current and breakdown voltage

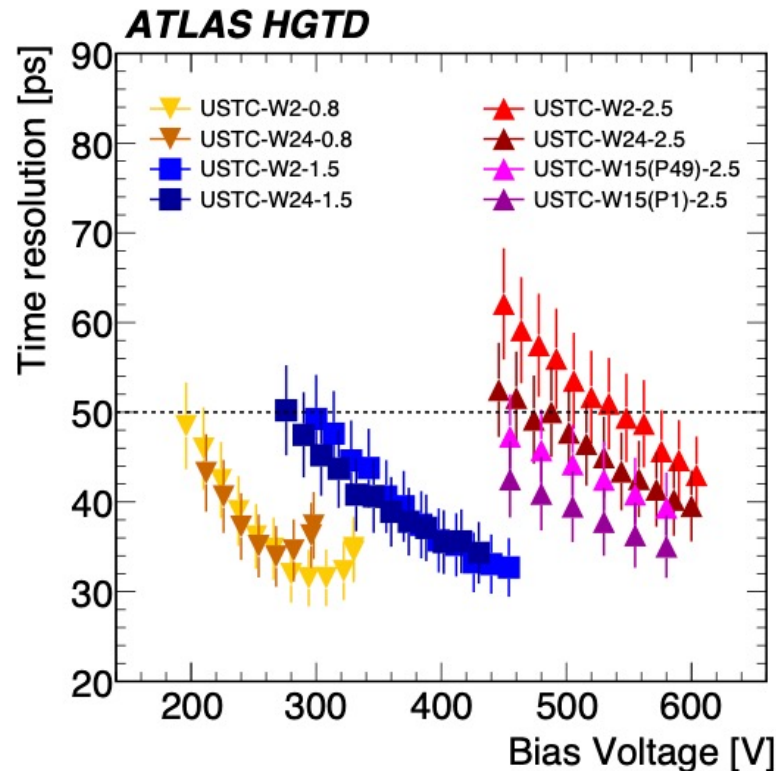
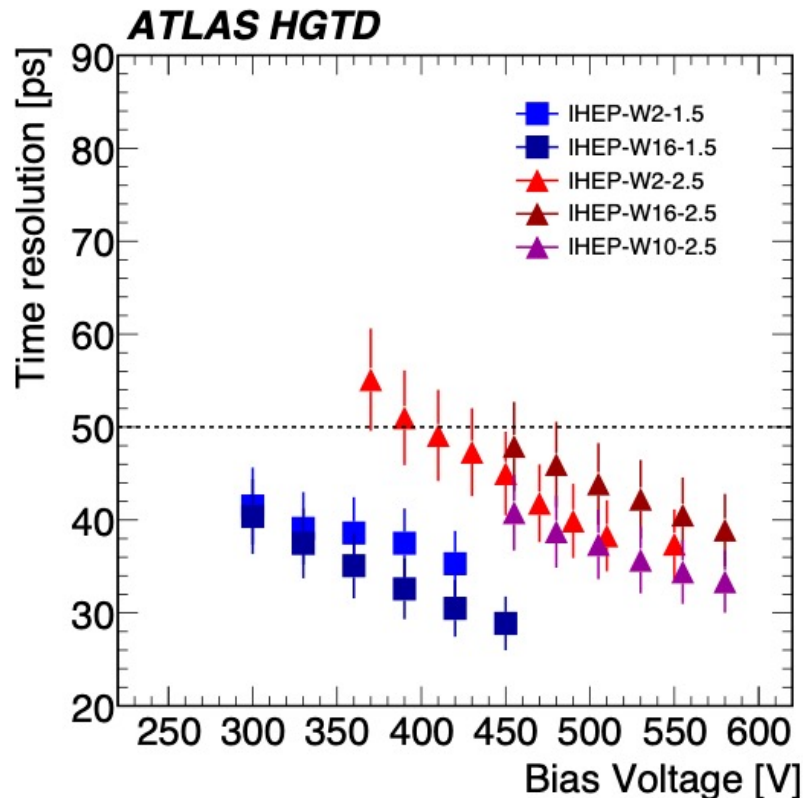
20WS0000400011 @ $2.5E15 \text{ n}_{\text{eq}}/\text{cm}^2$



V_{BD} Map

LGAD sensors performance at testbeam

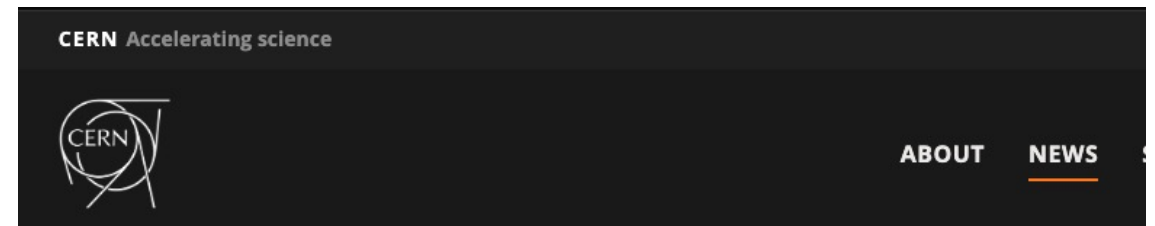
- Pre-production sensor performance
 - Timing resolution measured at test beam at CERN and DESY
 - Better than 40ps after irradiation for both IHEP-IME and USTC-IME sensor
 - Reach the goal of midterm:
 - (pre-)production sensor timing resolution reach 30 - 50ps at operational voltage
 - 达到中期指标：ATLAS升级研制出正式的硅传感器，在工作电压下时间分辨率达到30-50皮秒



JINST 21 (2026) P03021.

ATLAS Outstanding Achievement Award

- IHEP and USTC members won the 2025 Outstanding Achievement Award
 - for their development of the LGAD sensor in HGTD project
 - The list of ATLAS award for HGTD project: Bojan Hiti (Ljubljana), Alissa Howard (Ljubljana), Xuwei Jia (Munich MPI), Mengzhao Li (Beijing IHEP), Chihao Li (Michigan), Kuo Ma (Hefei), Theodoros Manoussos (CERN), Weiyi Sun (Beijing IHEP), Guilherme Tomio Saito (Sao Paulo), Iskra Velkovska (Ljubljana), Xiao Yang (CERN), Mei Zhao (Beijing IHEP)



News › News › Topic: Experiments

Voir en [français](#)

Celebrating the outstanding achievements of the ATLAS collaboration

The ATLAS collaboration celebrated the dedication, ingenuity and collaborative spirit of its members at the 8th Outstanding Achievement Awards

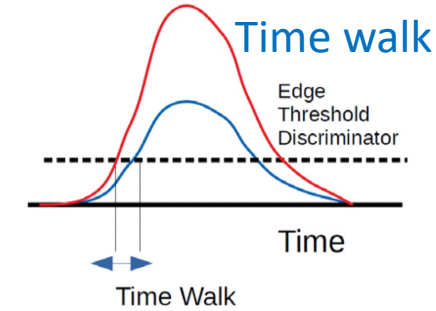
8 JULY, 2025 | By [ATLAS collaboration](#)

ALTIROC : Fast Timing ASIC

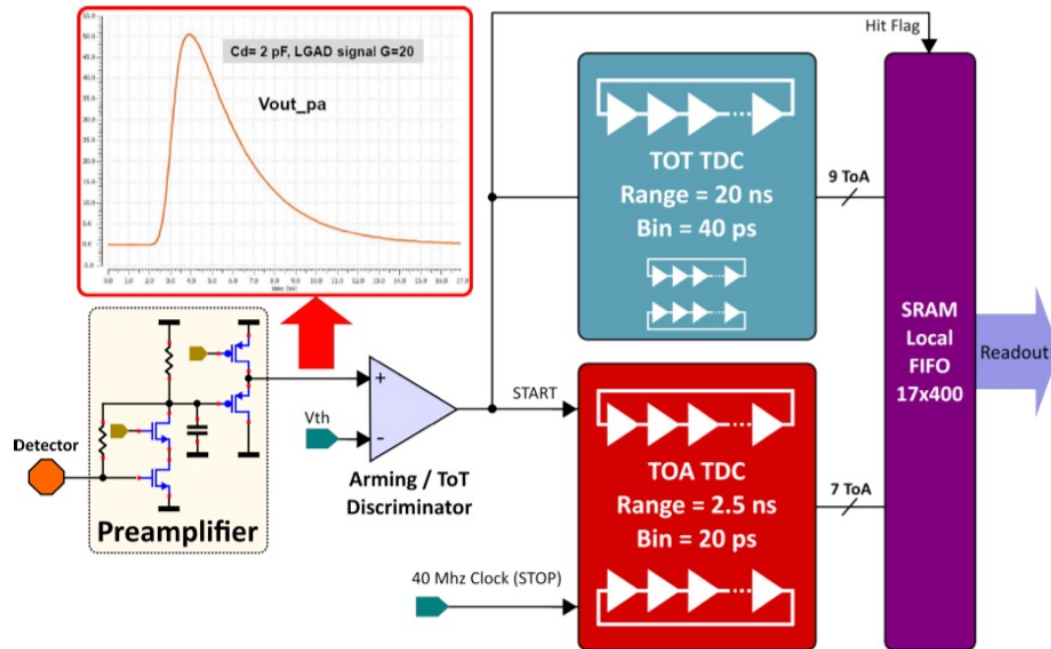


- **225 front-end channels** in ALTIROC, each channel has

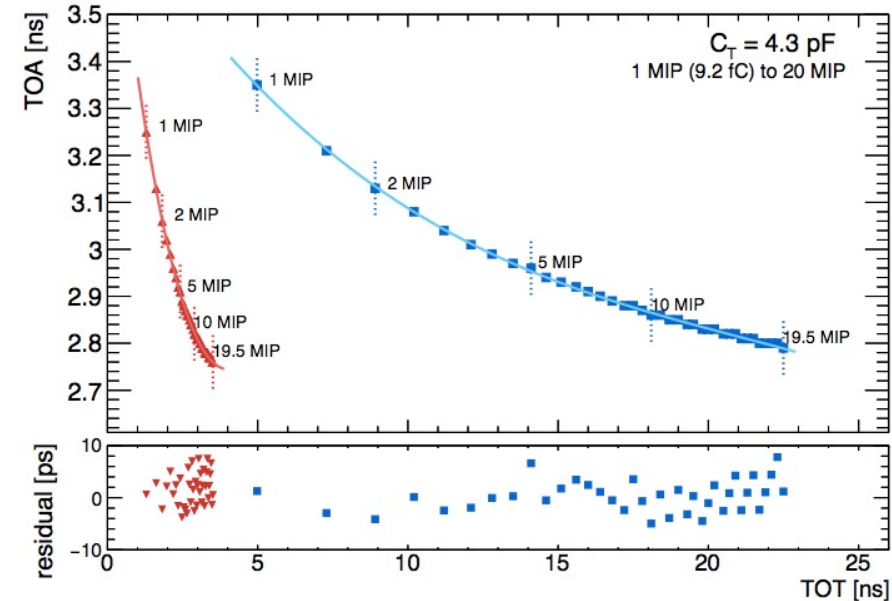
- A preamplifier followed by a discriminator:
- Two TDC (Time to Digital Converter) to provide digital **Hit data**
 - Time of Arrival (TOA) : Range of **2.5 ns** and a bin of **20 ps** (7 bits)
 - Time Over Threshold (TOT) : range of **20 ns** and a bin of **40 ps** (9 bits)
- Local memory: to store the 17 bits of the time measurement until LU/L1 trigger (~ 1 MHz)



ALTIROC timing ASIC in nutshell

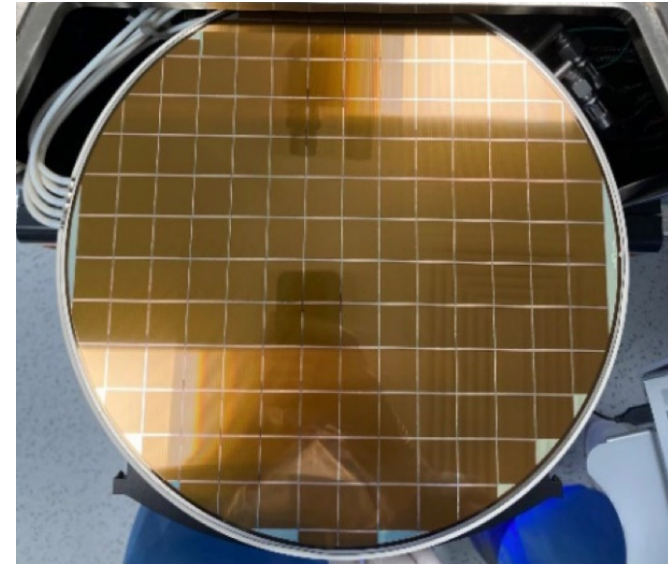
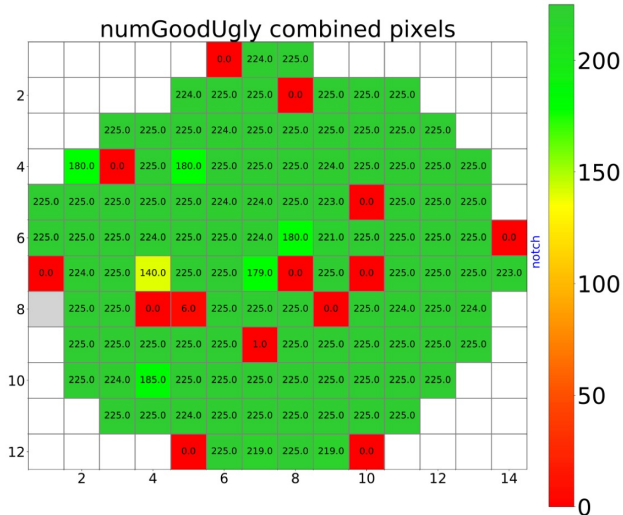
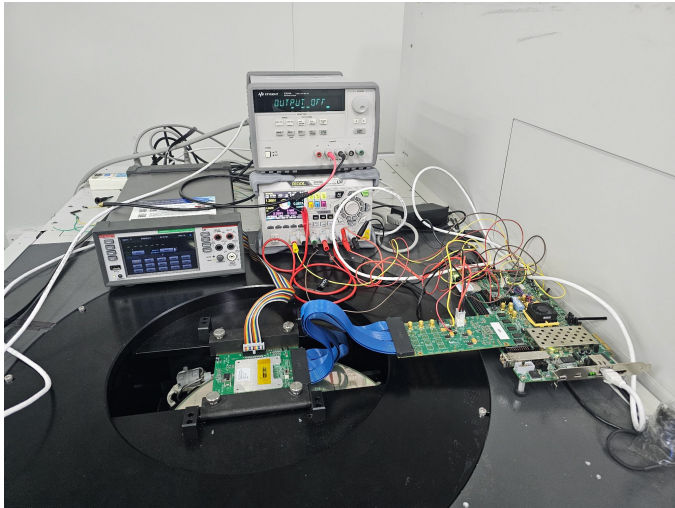


Time walk correction with TOT

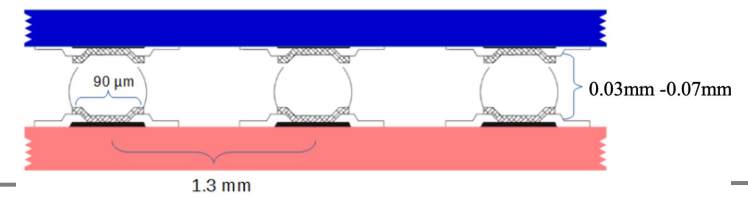


ASIC production and testing

- IJClab/Omega was leading
- China and IJClab/Omega share **50%** of wafer probe test (~225 wafers)
 - Agreements was probe cards, and evaluation criteria should have been defined by IJClab
 - IHEP is now much advanced, IJClab gave up testing in France at the end of 2025, will move to China for testing
- Update:
 - **ASIC wafer testing delayed significantly, has been the bottle neck for the project for sometime (in critical path)**
 - TSMC finished production, probe testing just started in May 2026
 - **Risk:** Probe testing delays, the yield may be lower than expected.
ASIC Yield is 70 ~ 80%

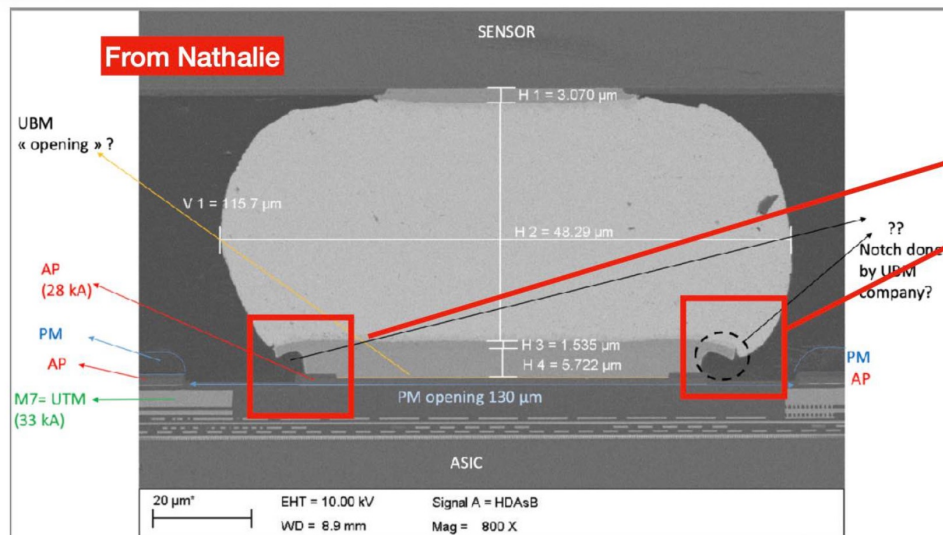


Sensor + ASIC Hybrid

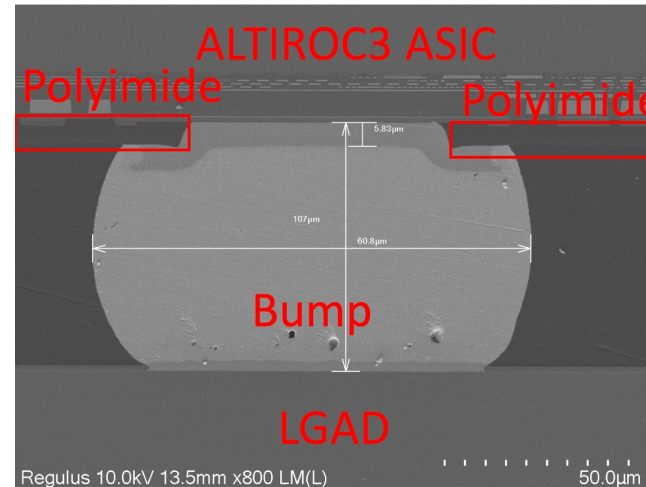


- IHEP is in charge of **50%** of hybrids assembly
- **挑战** : ATLAS ITK pixel has hybrid bump delamination issue, was delaying HL-LHC
- IHEP solved the bump delamination issue in old ALTIROC2 hybrids, addressed by
 - Softer Polyimide layer; Thicker sensors ...
- Passed CERN review, Good stability after improvement, published in JINST

ALTIROC2 hybrid incorrect Polyimide by TSMC

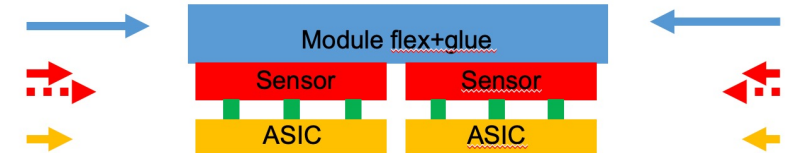


ALTIROC3 hybrids with correct Polyimide by IHEP/NCAP



JINST 20 (2025) P11003.

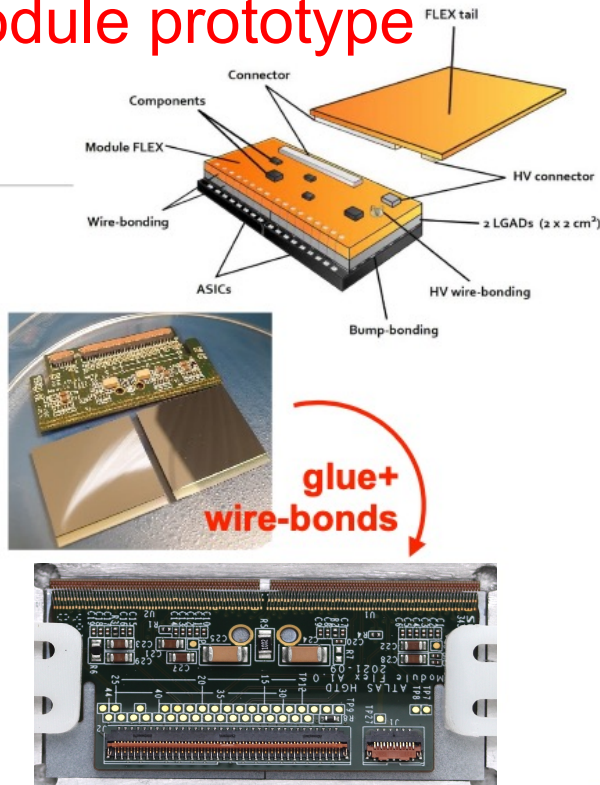
Consider low temperature (shrinking) situation
Length of arrow means deformation magnitude



HGTD detector unit prototyping

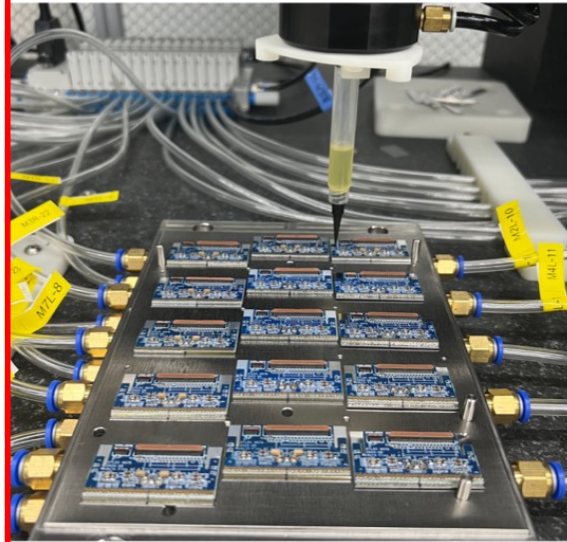
- The team led the first modules and detector unit prototyping
 - Develop automatic robot for module assembly and glue dispensing

Module prototype

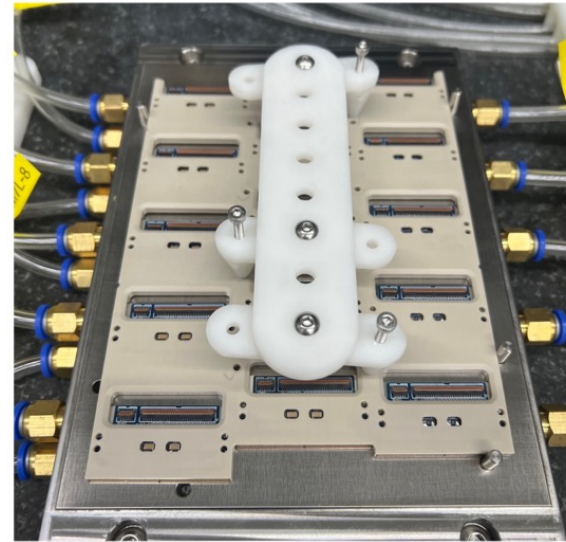


Detector unit prototype

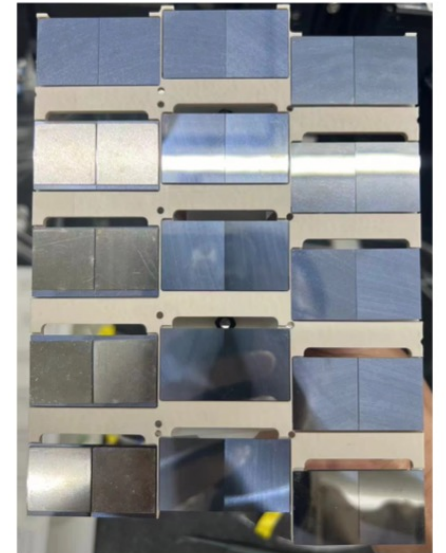
Dispensing with GluingTool



Put the support unit



Backside view after removal



Module and detector units

- 5 production site at HGTD (China, Mainz (Germany), France, IFAE(Spain), Morocco)
 - China is largest site, will assemble 44% of the module (~4000 modules)
 - China module team included IHEP/USTC/SDU/SJTU/Nankai, assembly lab is in IHEP
 - Pre-production: 100% ASIC wafer bumping, 50% ALTIROC-A Hybrids flip-chip
 - IHEP and USTC sites merged
 - USTC team explored using AMS gantry in IHEP hall 3 for module loading
 - Two dummy detector unit loaded
 - Supported unit prototyped and metrology, ready for pre-production
 - Both IHEP/USTC did metrology for support unit

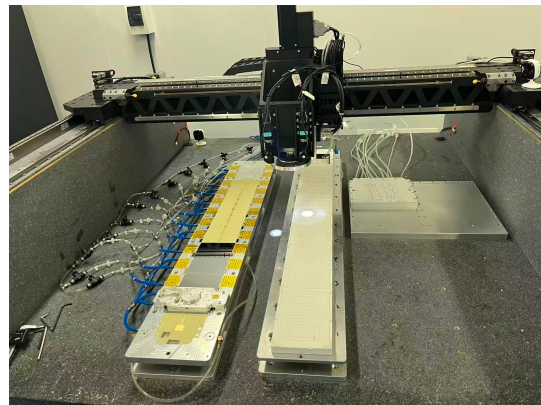
ALTIROC-A Hybrids



Support units



Gantry robot @IHEP hall 3

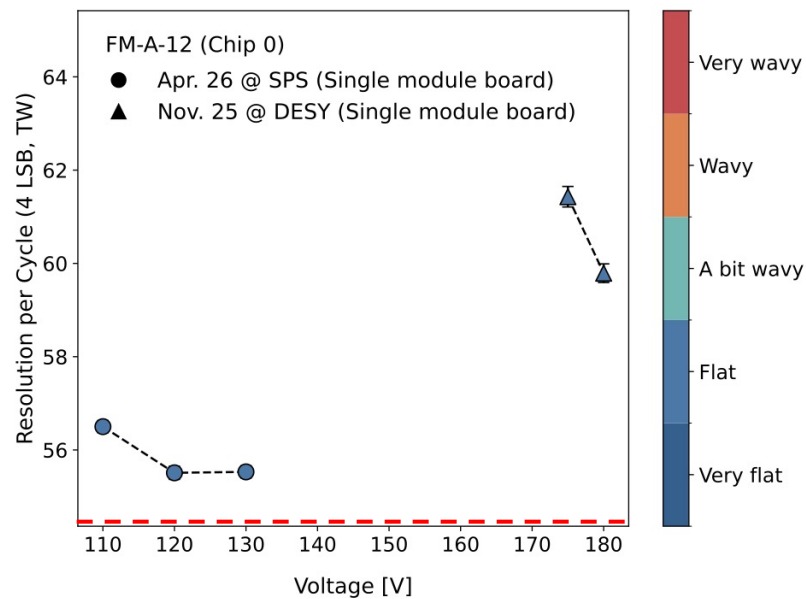
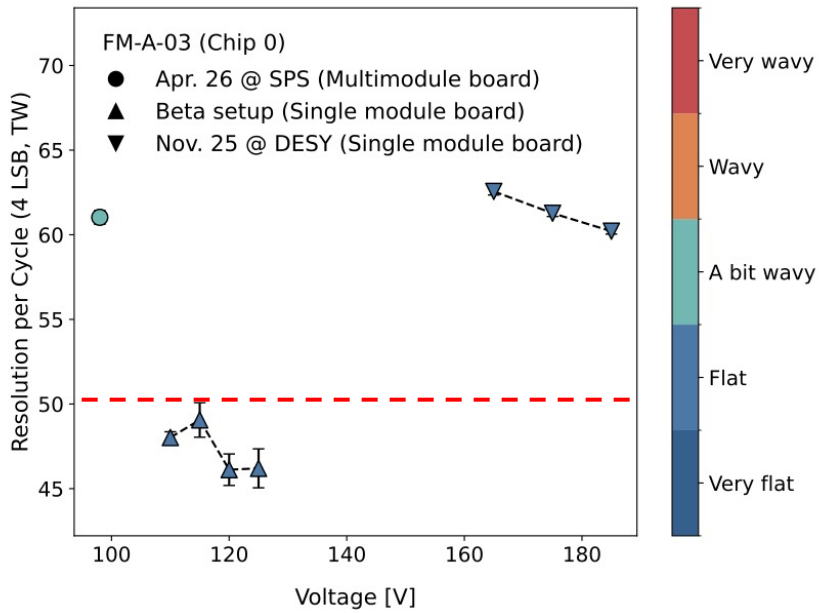


Module flex pre-production



Module performance in test beam

- Module performance in testbeam is under study
 - Some modules and some setup have better performance
 - Some fraction of modules has non-flat “Time of Arrival” (TOA) distribution
 - Giving impact to final timing resolution of the modules
 - Understand the TOA behavior and try to calibrate them using data

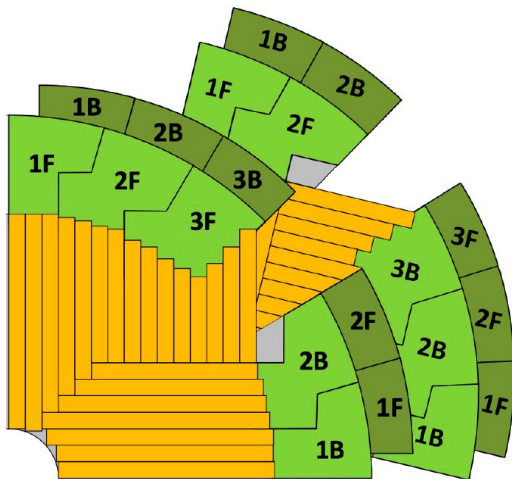


| | TOA chip 0 | TOA chip 1 | TOA plot |
|--------------|------------|------------|----------------------------|
| eems wavy* | | x | TOAST link |
| ~flat? | | wavy | TOAST link |
| little wavy* | | flatish* | TOAST link |

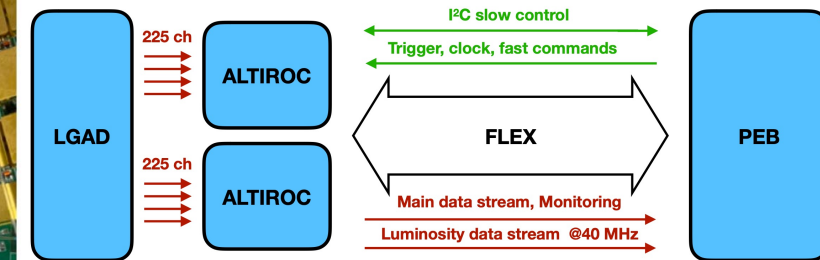
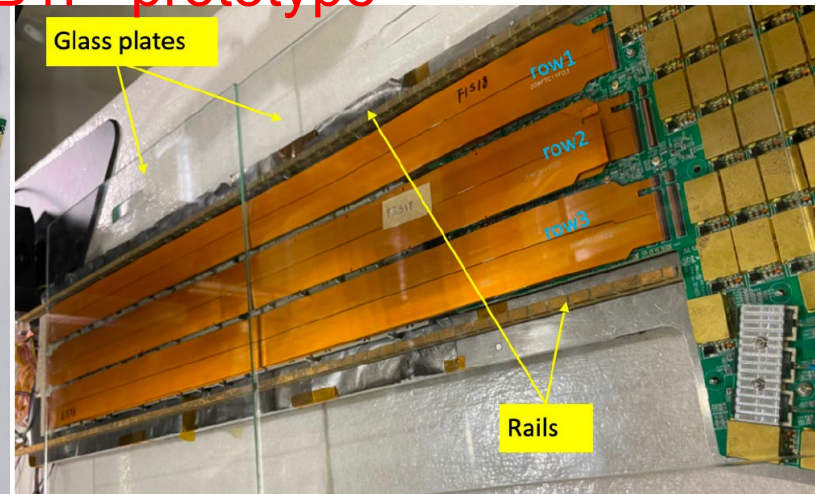
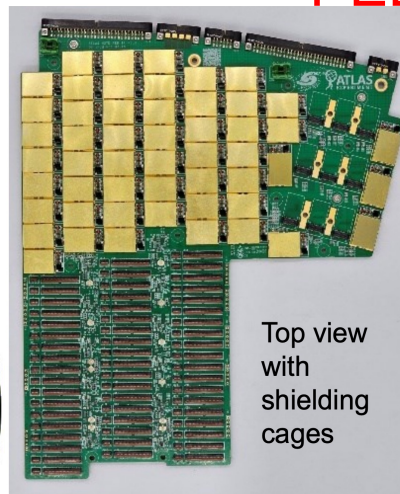
Peripheral Electronics Board (PEB)

- China (IHEP/NJU) will design and produce 100% PEB (PCB fabrication)
- Challenge: fast communication with 55 modules, 24 metal layers in PCB
 - Comments in CERN review: Comparable with the most difficult boards for HEP projects
- Update :
 - IHEP and NJU developed 1st Peripheral Electronics Boards at 2024
 - 2nd Peripheral Electronics Boards designed in 2026
 - Delayed due to Bpol chip radiation hardness issue by CERN
 - Keep in touch with CERN team to avoid any risk

6 types of PEB



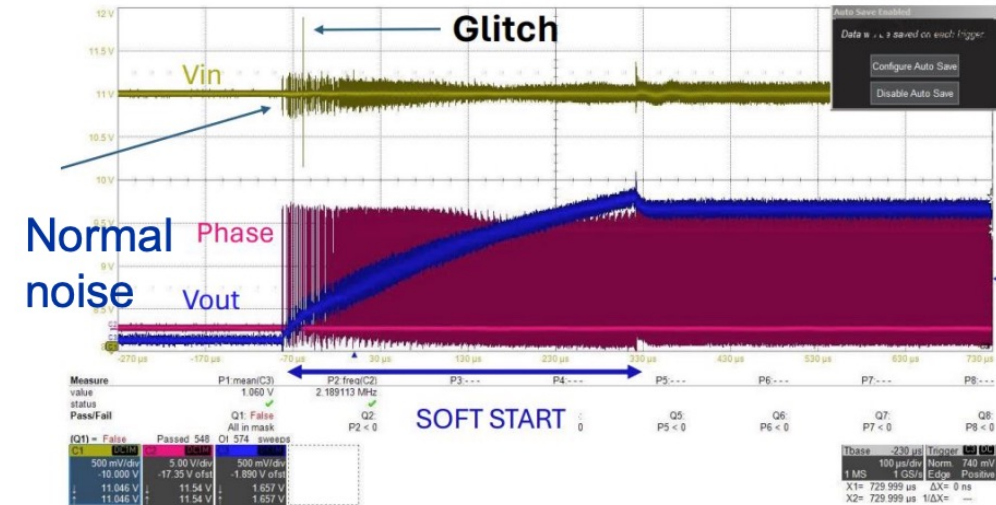
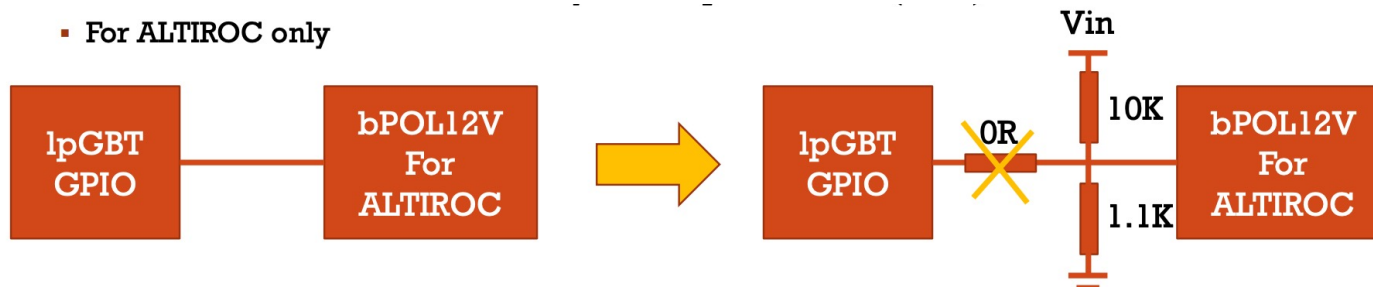
PEB1F prototype



Peripheral Electronics Board (PEB): issue

- People found CERN BPOL chip irradiation hardness issue in 2025
 - Output voltage is too high (glitch) after irradiation
 - Impact to the whole LHC upgrade project.
 - Need to use voltage divider solution to re-design the PEB board

• For ALTIROC only

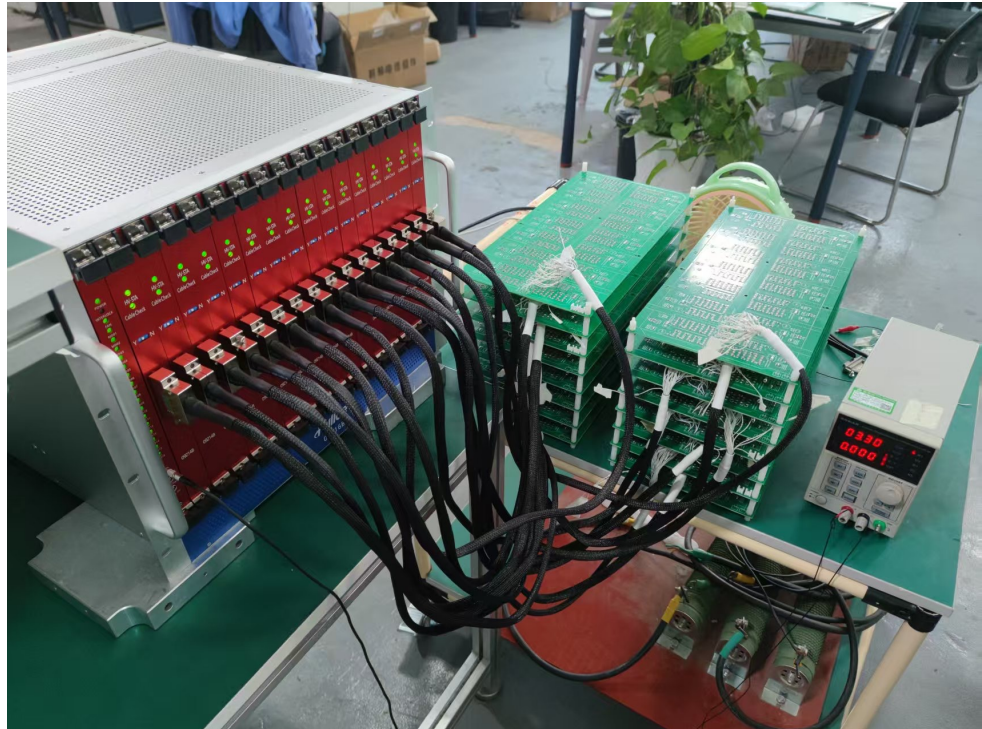
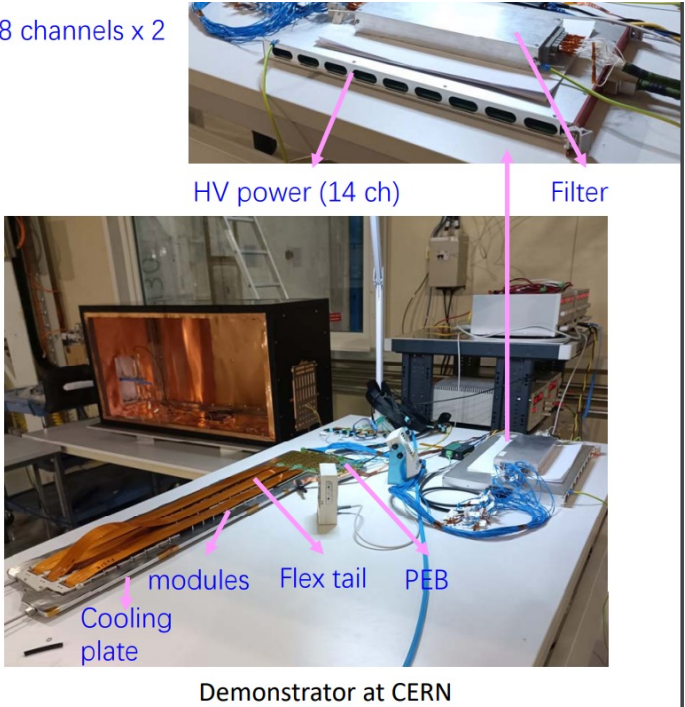
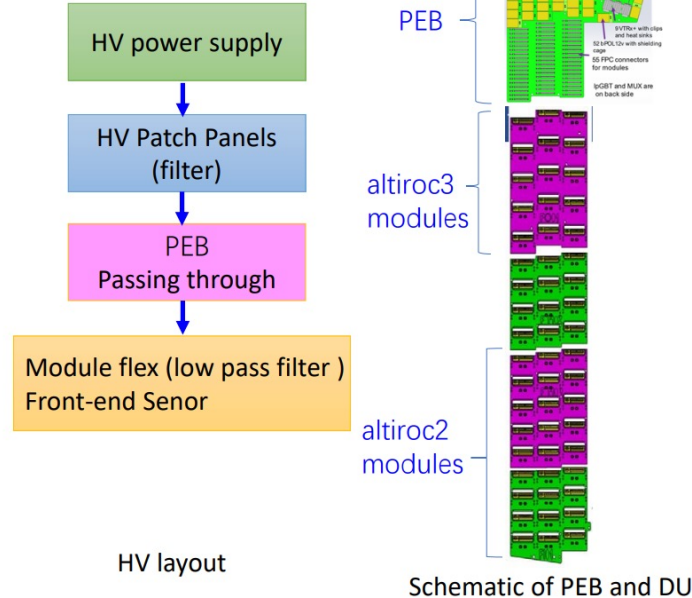


High voltage (HV) power supply

- China (IHEP/SDU) prototyped and oversee HV supply production and do quality tests
- **Challenge: 1000V voltage, 100nA precision in current measurement**
- Latest update : pre-production finished in 2025.
 - IHEP/SDU team in FULLDE company for quality assurance tests
 - Two HV crates delivered to CERN in Sep. 2025. SDU student did reception tests.

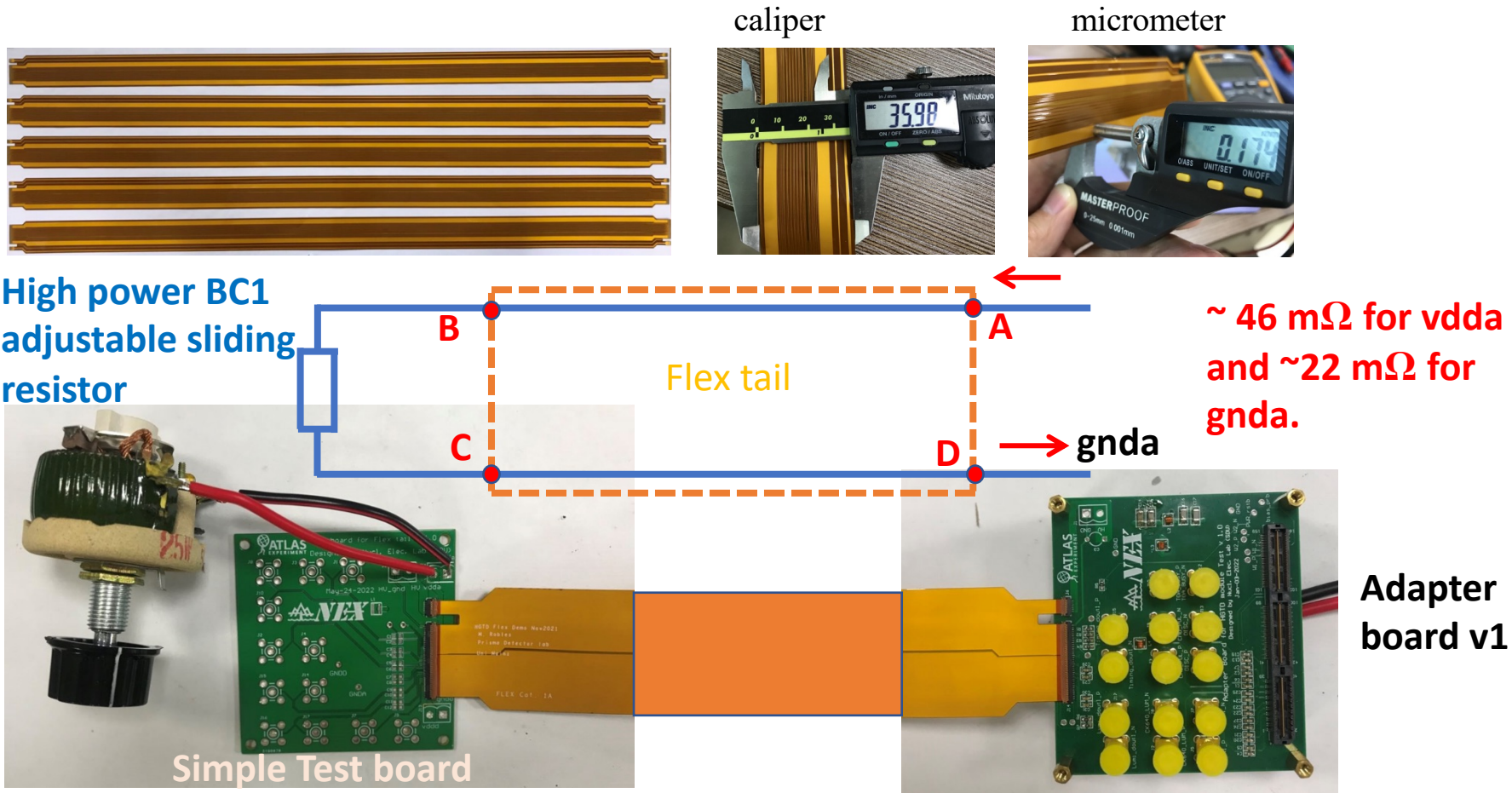
HV pre-production quality tests

HV layout



Flex tails (柔性电子学尾板)

- SDU is responsible for 33% of flex tails production
- Prototype has been made, and satisfied the requirement, Ready for pre-production



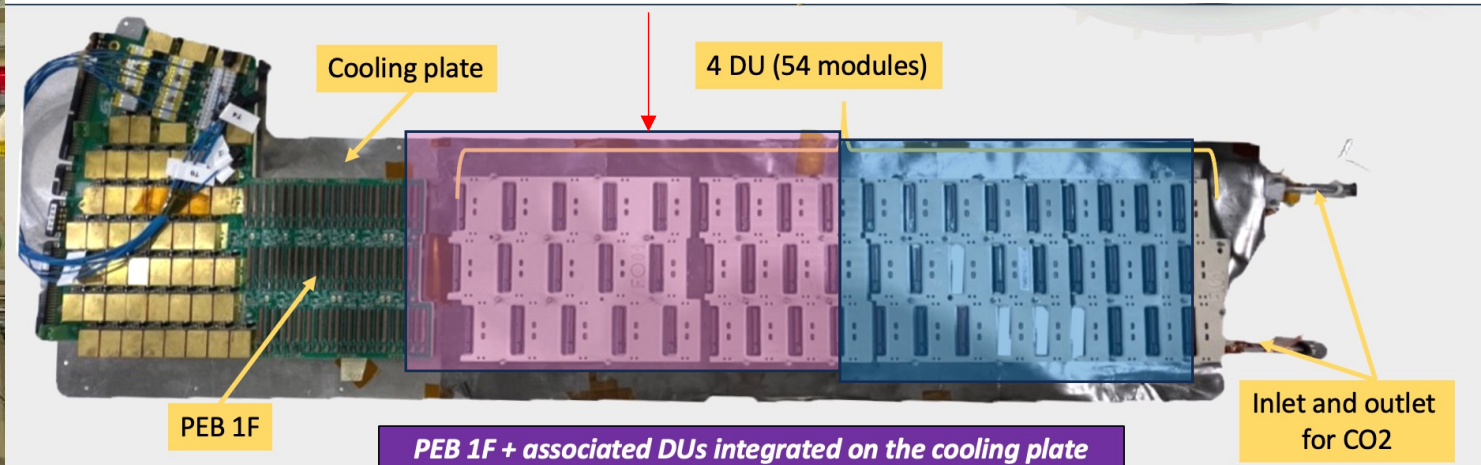
Demonstrator system

- The China team played key role testing demonstrator system at CERN
 - System level testing with **54** modules
 - **1st time to demonstrate silicon timing detector in a large-scale system**

ATLAS phase 2 upgrade review
HGTD lab visit @CERN



Demonstrator system



Outline

- 考核指标完成情况
- 研发任务完成情况
- 研究成果的水平及创新性
- 组织管理情况

Innovation points summary

- IHEP-IME and USTC-IME LGAD performance reach world class level
 - The most radiation hard LGAD sensors, passed CERN review
 - Timing resolution Better than 40ps after irradiation
 - First time domestic silicon sensor was used by CERN
 - HGTD sensor 100% by China. (90% from IHEP-IME, 10% from USTC-IME)
- China team played a major in demonstrator timing detector system
 - 1st time to demonstrate silicon timing detector in a large-scale system
 - China team provide key components
 - Detector units, PEB boards, HV supply, flex tails ...

Publication list

➤ The team Published 8 papers

1. Yimin Che et al., *Comprehensive full-power testing of demonstrator system for the High Granularity Timing Detector*, JINST 21 (2026) C03026.
2. A. Aboulhorma, G. Di Gregorio, K. Tariq et al., *Beam-test evaluation of pre-production Low Gain Avalanche Detectors for the ATLAS High Granularity Timing Detector*, JINST 21 (2026) P03021.
3. Thermal cycling reliability of hybrid pixel sensor modules for the ATLAS High Granularity Timing Detector, JINST 20 (2025) P11003.
4. ATLAS HGTD Collaboration, *Evaluation of the prototype Peripheral Electronics Board for the High Granularity Timing Detector*, JINST 19 (2024) C12012.
5. Low Gain Avalanche Detectors for the ATLAS High Granularity Timing Detector: Laboratory and test beam campaigns, NIMA 1063 (2024) 169237.
6. Zhenwu Ge et al., *An FPGA-based front-end module emulator for the High Granularity Timing Detector*, JINST 19 (2024) C03055.
7. C. Wang et al., *Radiation tolerance of the MUX64 for the High Granularity Timing Detector of ATLAS*, JINST 19 (2024) C03044.
8. ATLAS HGTD Collaboration, *HGTD DC/DC converter in low temperature and magnetic field operation*, JINST 19 (2024) C02006.

International conference

➤ 14 个国际会议报告, 32个国内报告

1. 梁志均, ATLAS HGTD module overview, ATLAS HGTD Week in Rabat, 摩洛哥, 2026.5.18-22.
2. 周展航, IHEP/USTC status in HGTD module assembly, ATLAS HGTD Week in Rabat, 摩洛哥, 2026.5.18-22.
3. Yimin Che, Comprehensive Full-Power Testing of Demonstrator System for the High Granularity Timing Detector, TWEPP2025, 2025.10.6-10.
4. 梁志均, ATLAS HGTD module overview, ATLAS HGTD Week in Clermont, 法国, 2025.6.30.
5. 黄鑫辉, ATLAS HGTD module assembly at IHEP, ATLAS HGTD Week in Clermont, 法国, 2025.6.30.
6. Joao Guimaraes da Costa, HGTD Update Project, ATLAS-China Faculty Meeting 2025, 2025.4.25.
7. 梁志均, The High-Granularity Timing Detector for ATLAS at HL-LHC, Pixel2024, 2024.11.18-22, 法国斯特拉斯堡。
8. Yinmin Che, HGTD status report, ATLAS Upgrade Week, 2024.11.14.
9. Tests of the Prototype Peripheral Electronics Board for the High Granularity Timing Detector, Topical Workshop on Electronics for Particle Physics 2024 (TWEPP2024), 2024.9, Glasgow, Scotland, Poster.
10. HGTD Status Overview, ATLAS Week, 2024.6, Thessaloniki, Greece, Plenary Session.
11. Zhenwu Ge, HGTD status overview, ATLAS Week, 2024.6.20.
12. Zhijun Liang, Module assembly in HGTD, ATLAS Week, 2024.2.10-14, Geneva, Switzerland.
13. Low Gain Avalanche Detectors for the ATLAS High Granularity Timing Detector: laboratory and test beam campaigns, PSD2023, 2023.12.3-8, 大会报告。
14. Jingbo Ye, Overview of the ATLAS High-Granularity Timing Detector: project status and result, HSTD2023, 2023.12.3-8, Vancouver, Canada.

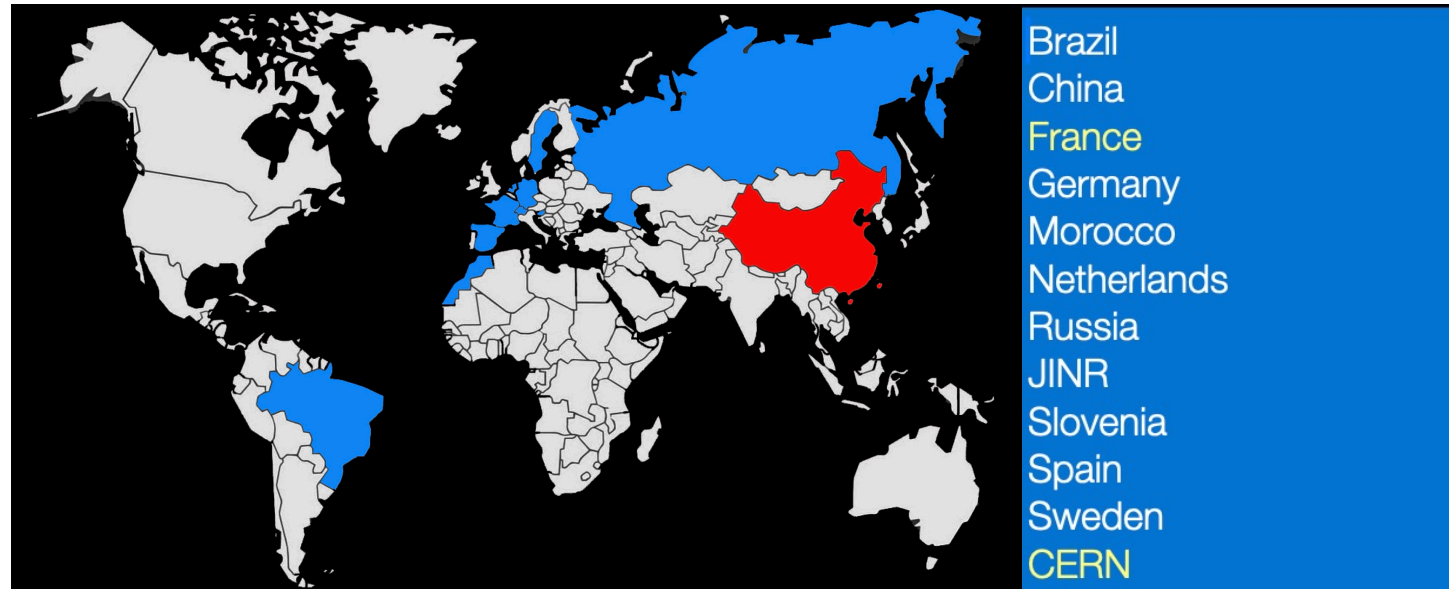
Outline

- 考核指标完成情况
- 研发任务完成情况
- 研究成果的水平及创新性
- 组织管理情况

International landscape of this task in HGTD project

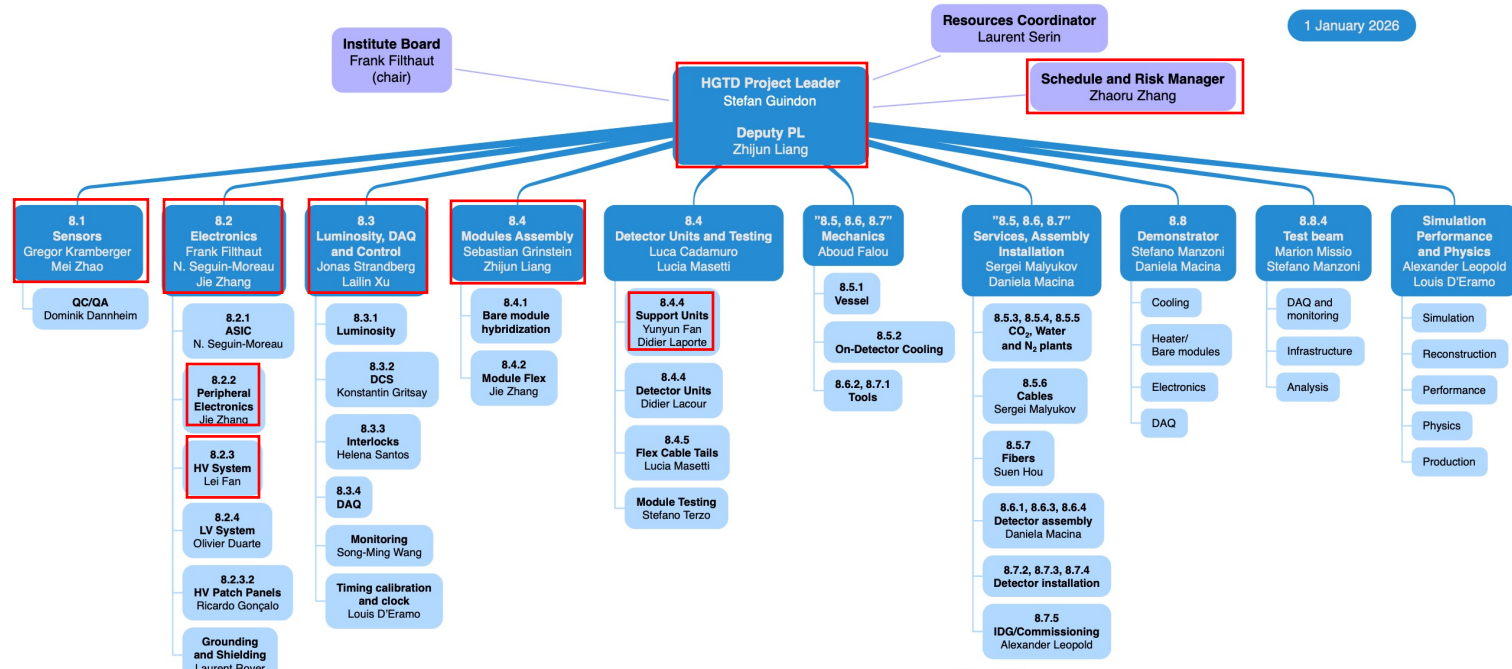
- The primary objective of this project is to support the successful construction, integration, and commissioning of the ATLAS High Granularity Timing Detector.
- Enables the China team play a key role in cutting-edge HGTD detector development

ATLAS HGTD is international project



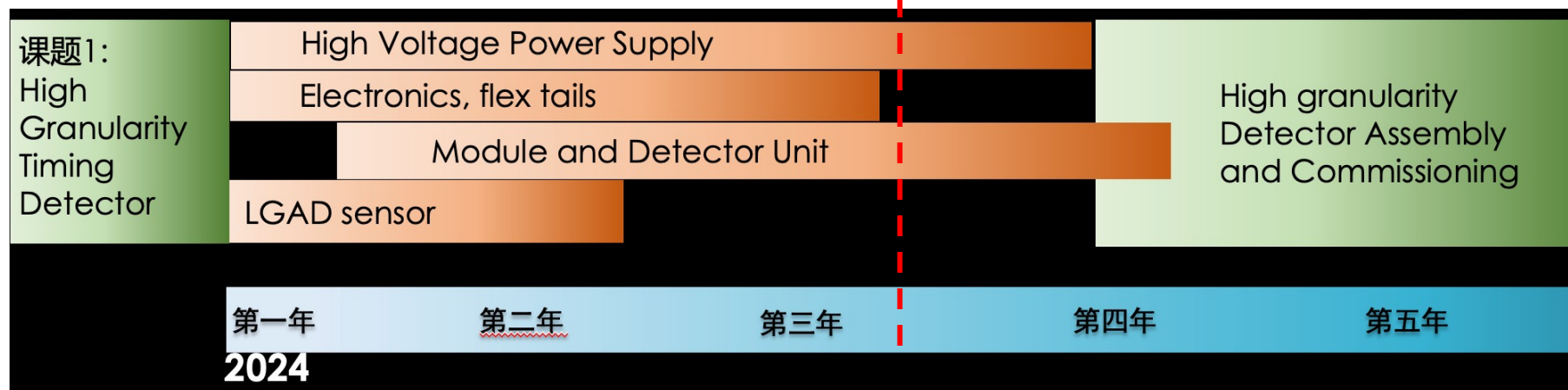
Project management

- Project has both internal meeting and international meeting for management.
- ATLAS China team played an important role in HGTD management team
 - Mar. 2021- Feb 2025 , Joao was HGTD project leader, 1st PL in China LHC community
 - Mar 2025 - Feb 2027, Zhijun is serving as deputy project leader
 - 6 person as L2 conveners (Jie Zhang, Mei Zhao, Zhaoru, Zhijun, Yusheng, Lailin)
 - 3 person as Level-3 convener (Yunyun, Jie, Lei Fan)
 - 2 person as speaker committee (Yanwen, Lailin)



Project management : schedule

- HGTD is an international project, not all the schedule can be determined by the project team
- LGAD sensor
 - IHEP-IME Production will be completed in one year. (30% finished, 60% of LGAD still needs to be produced)
 - USTC-IME Production is finished, in the middle of testing
- Module assembly
 - Delayed about 1 year due to ALTIROC-A ASIC performance.
 - Will speed up the production, has done R & D to increase capability
- Electronics
 - PEB delayed about 1 year, due to CERN Bpol power chip radiation hardness issue. Re-design PEB to avoid the risk.
- High voltage power supply
 - Ready for production since Sep. 2025. Waiting for HV filter provided by international collaborator.



Project management: Risk

- PEB Electronics boards
 - CERN Bpol chip technical risk, may cause over voltage and damage the device after irradiation
 - Solution: Re-designed PEB board board electronics using voltage-divider solution
 - CERN Bpol chip policy risk (US foundry), The license for importing it to China expired.
 - Collaborate with CERN to request for new license from US.
 - Look for PEB board assembly site in EU if new license is not available
- Module assembly
 - ALTIROC-A ASIC performance may lower than expected.
 - Time of arrival (TOA) bin was not flat, meaning the bin size of TDC was not uniform.
 - Difficult to reach 50ps in module level
 - Try to explore the TDC calibration method
 - Work with HGTD community to understand and improve module performance

Project management: Funding Status

➤ 课题总体执行率：45.16%

| | Task 1 | Task 1 | Task 1 | Task 1 | Task 1 |
|-----------------------|---------------|---------------|---------------|---------------|---------------|
| | Sum | IHEP | USTC | NJU | SDU |
| Total Budget | 1135 | 500 | 255 | 130 | 250 |
| Received funds | 908.14 | 400.25 | 203.95 | 103.97 | 199.97 |
| Pending to allocated | 226.86 | 99.75 | 51.05 | 26.03 | 50.03 |
| Implementation rate % | 45.16% | 59.19% | 17.12% | 54.06% | 41.07% |
| Total Expense | 512.56 | 295.97 | 43.66 | 70.27 | 102.66 |
| 1 Direct fee | 397.36 | 276.43 | 15.56 | 46.42 | 58.95 |
| 1) Device fee | 2.69 | 2.69 | | | |
| 2) Business fee | 241.34 | 155.81 | 15.56 | 22.42 | 47.55 |
| 3) Labor fee | 153.34 | 117.94 | | 24.00 | 11.40 |
| 2 Indirect fee | 115.21 | 19.54 | 28.10 | 23.85 | 43.72 |

Research team

| | | Staffs in project | Other Staffs | Postdoc in total | Graduated postdoc 出站的博后 | Students in total | Graduated student 毕业的学生 |
|--------|------|-------------------|--------------|------------------|----------------------------|-------------------|----------------------------|
| Task 1 | Sum | 11 | 14 | 8 | 4 | 31 | 10 |
| | IHEP | 7 | 7 | 6 | 4 | 8 | 4 |
| | NJU | 1 | 2 | 1 | | 5 | 3 |
| | USTC | 1 | 4 | 1 | | 12 | 2 |
| | SDU | 2 | 1 | | | 6 | 1 |

Awards : ATLAS Outstanding award 2025 (HGTD LGAD) , 4 IHEP members + 3 USTC members

Talents:

Yunyun Fan, IHEP, CAS “100 talents” project

PhD and Master: more than 20 (10 graduated)

Graduated Postdocs :

- Tianya Wu, IHEP → Nanchang University
- Bo Liu, IHEP → Nankai University
- Xuan Yang, IHEP → SINAP
- MengZhao Li , IHEP → IHEP (CSNS)

Summary and plan

- Reach the goal of midterm:
 - (pre-) production sensor timing resolution is better than 40ps
 - 达到中期指标：ATLAS升级研制出正式的硅传感器，时间分辨率达到40皮秒
 - Finalized Module, PEB readout board, flex tails, HV power supply prototyping.
- Next Milestones
 - Sensor production finished in one year
 - Electronics boards, flex tails and HV power supply to be completed in 2027
 - Module and detector unit to be completed in 2028
 - Detector assembly and Commissioning at CERN (2026 -2028)

Backup

Schedule

2025 年11 月—2026 年5月

- 探测器模块、柔性电路板尾板的正式生产研制； (module, flex tails production)
- 电子学外围电路板的测试； (PEB production and testing)
- 高压电源的正式生产研制 (HV power supply production)

➤ 2026 年6 月—2026 年11 月

- 探测器模块正式生产研制； (module production)
- 电子学外围电路板在欧洲核子中心开始总体组装； (PEB assembly at CERN)
- 高压电源的正式生产研制 (HV power supply production)