Task 1: High Granularity Timing Detector

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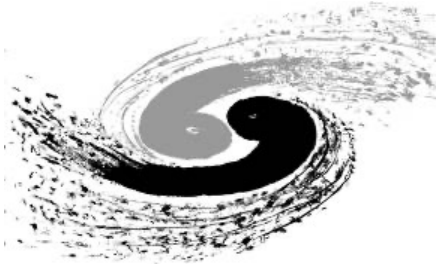
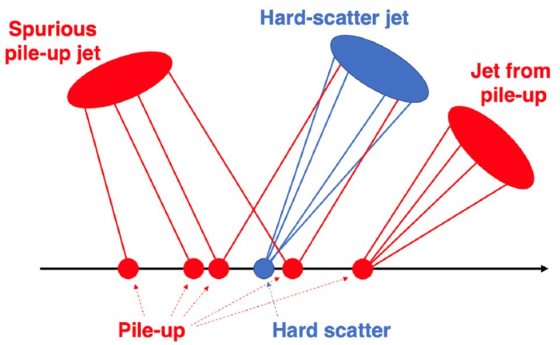
代表课题1



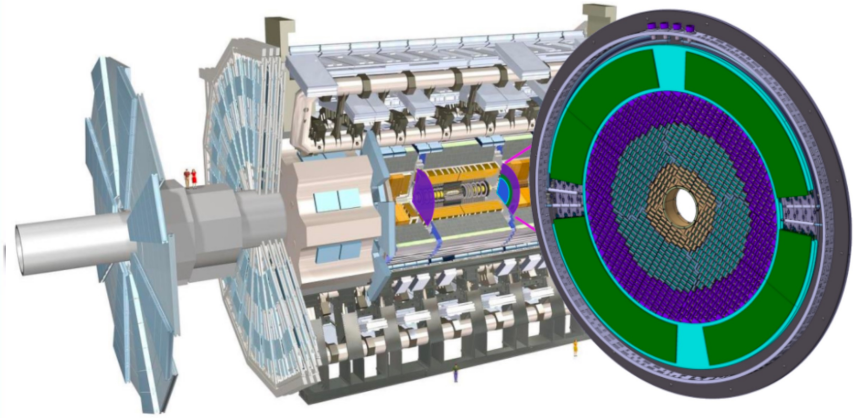

High Granularity Timing Detector (HGTD)

- **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 m^2 area silicon detector and ~ 3.6 × 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)

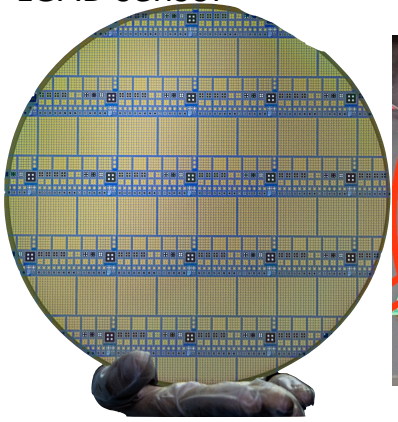
研究内容： Develop all key components for the Timing Detector

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

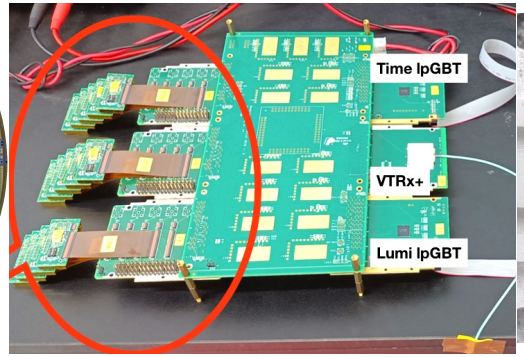
Assessment index （考核指标）：

Sensor and detector module time resolution reach 30-50 ps

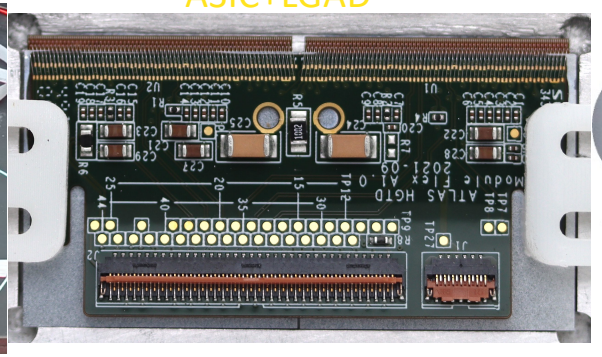
LGAD sensor



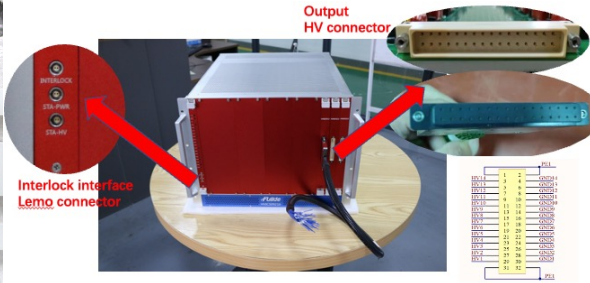
Electronics



Module
ASIC+LGAD

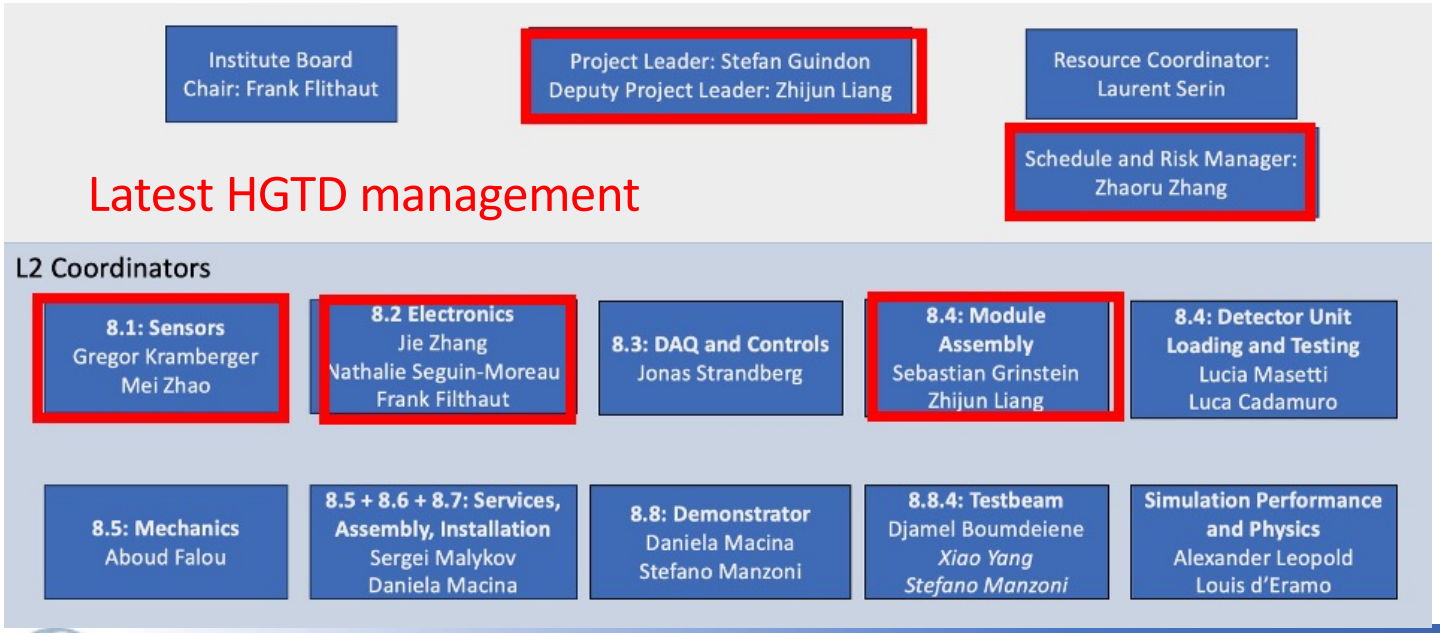


High Voltage supply



China team in HGTD 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 2023 - Feb 2027, Zhijun is serving as deputy project leader
  - 5 person as L2 conveners (Jie Zhang, Mei Zhao, Zhaoru, Zhijun,Yusheng)
  - 3 person as Level-3 convener （Yunyun,Jie, Lei Fan）
  - 1 person as speaker committee (Yanwen)

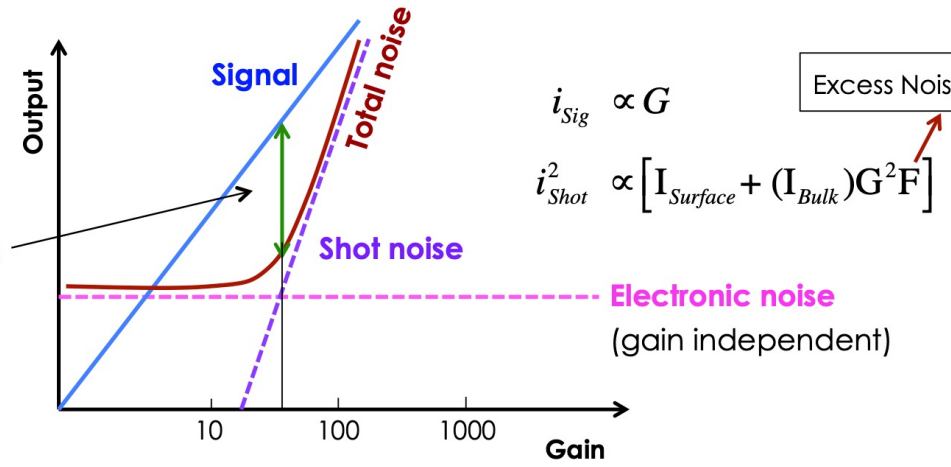


Low Gain Avalanche Detectors (LGAD)

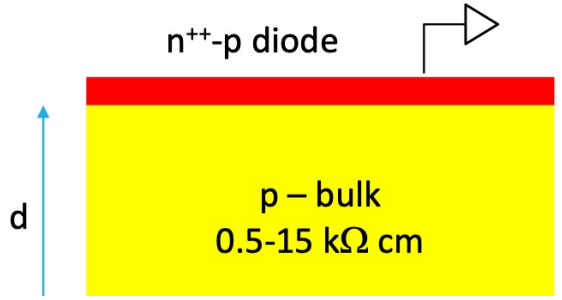
- Compared to APD and SiPM, LGAD has modest gain (10-50)
- High drift velocity, thin active layer (fast timing)
- High S/B, no self-triggering

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

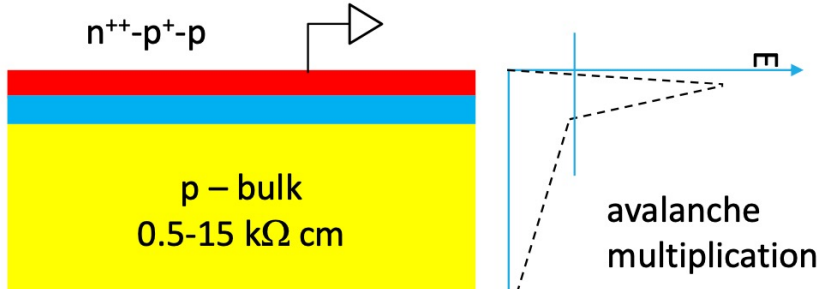
- **Modest gain to increase S/N**
- **Thin detector to reduce t_{rise}**



Conventional PiN diode

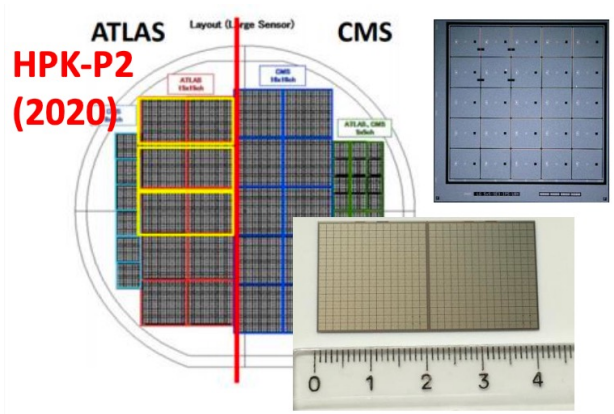


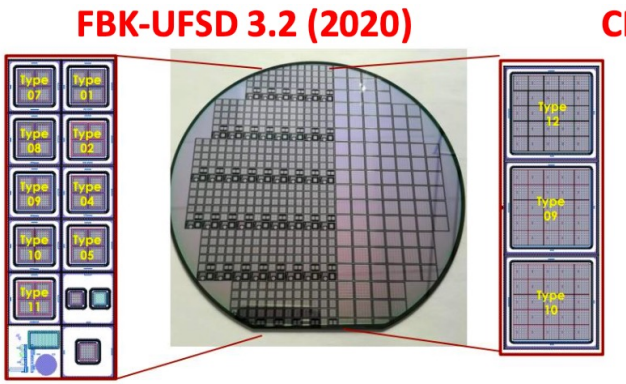
LGAD
P+ gain layer on top of PIN diode

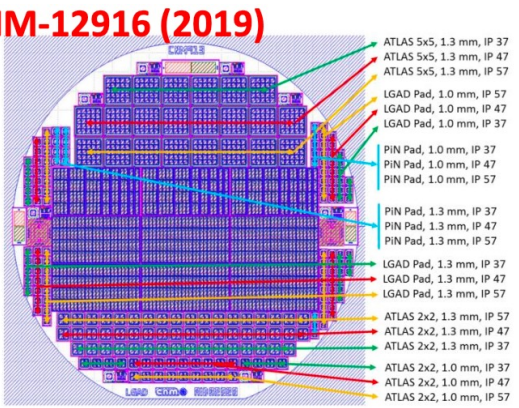


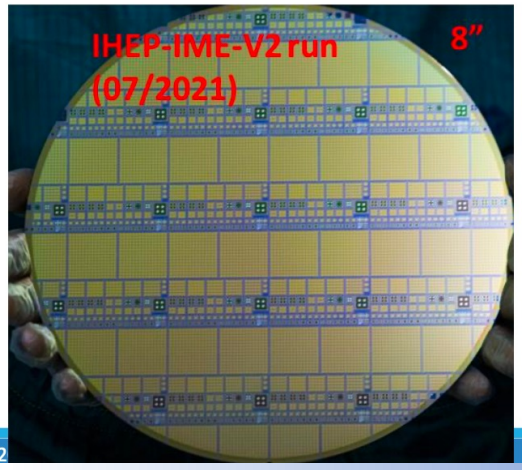
国际形势： strong completion in LGAD development

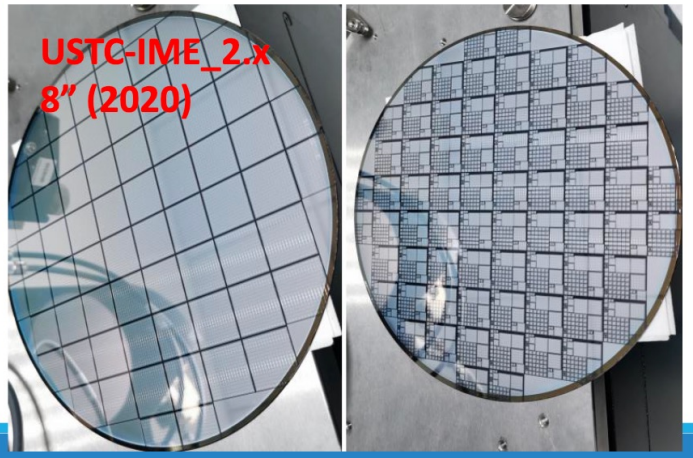
- Lots of prototypes R & D in LGAD in last few years, active vendors includes:
  - IHEP-IME (China), USTC-IME (China), IHEP-NDL(China), FBK (Italy), CNM (Spain), HPK (Japan) …

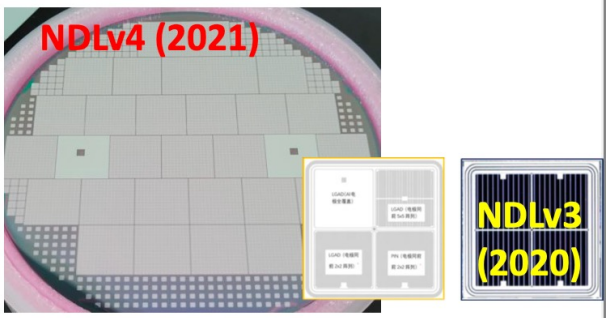












PLANAR TECHNOLOGY – more vendors
(e2V, BNL, Micron …)

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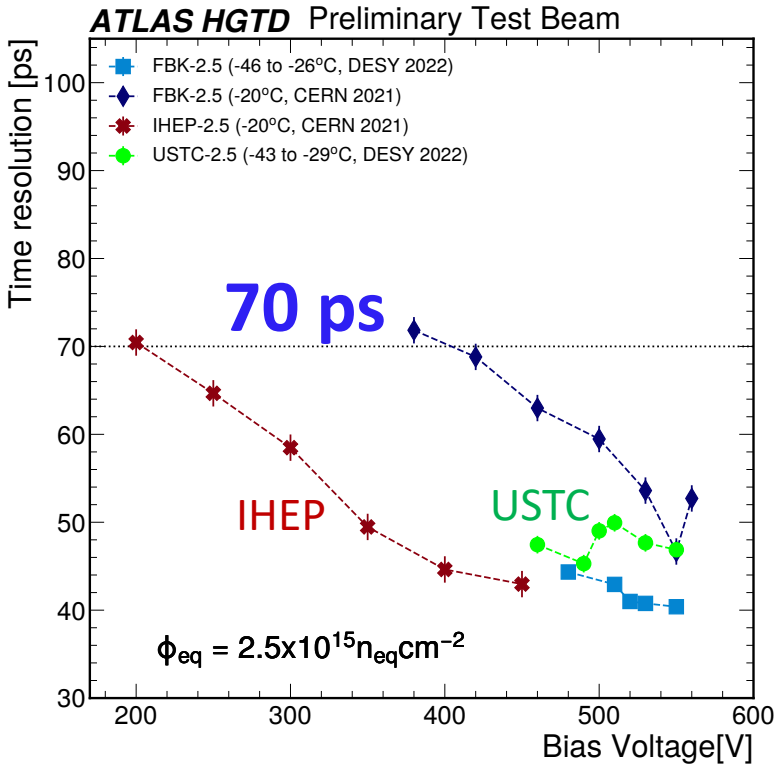
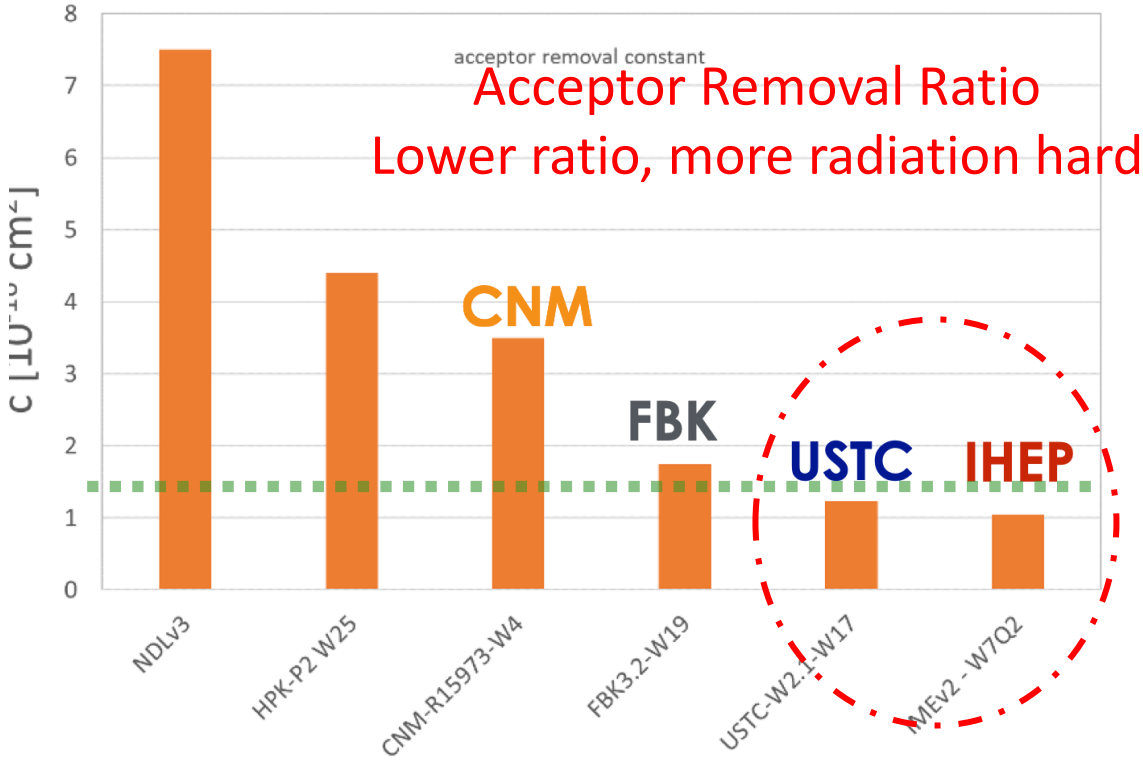
LGAD sensor after Irradiation

- 挑战：LGAD超快硅传感器技术首次用在对撞机实验，抗辐照能力是最大难点
- IHEP-IME and USTC-IME LGAD with carbon-enriched doping
  - Significantly lower acceptor removal ratio, the most radiation hard
- After 2.5×10^{15} n_{eq}/cm^2, LGADs can operated below 550 V → avoid single event breakdown

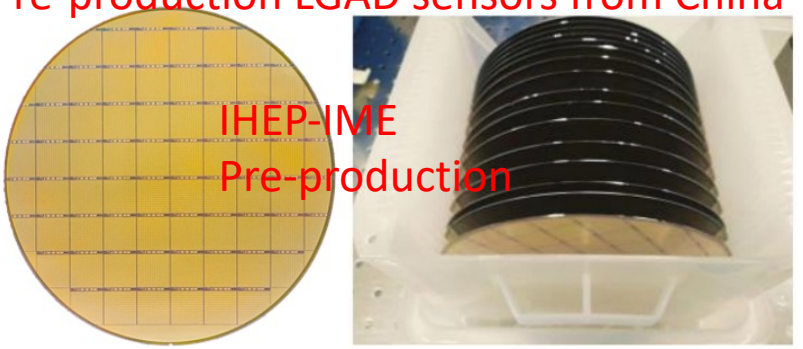


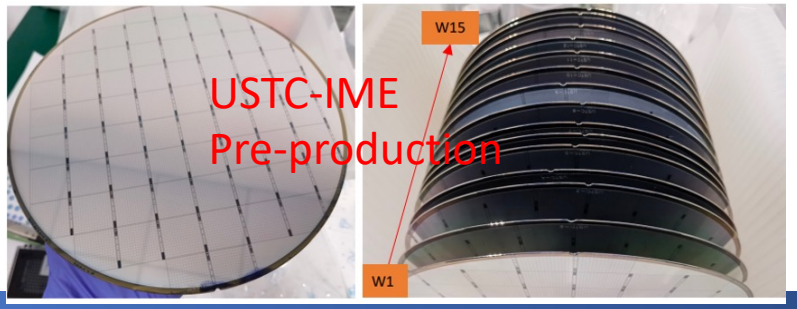


LGAD sensors pre-production

- CERN chosen IHEP-IME sensor in tendering, contract signed in Feb 2025
  - IHEP-IME, FBK(Italy) and HPK(Japan) were completing in CERN contract
- The sensor production will be 100% done by China
  - First time domestic silicon sensor was used by CERN in LHC experiment
  - IHEP-IME: 90% (66% from CERN tendering+24% in-kind contribution): ~8 m^2
  - USTC-IME: 10% in-kind contribution (~0.8 m^2)
- Production status
  - IHEP
    - 1.7k sensor fabricated in pre-production
    - 0.4k sensor fabricated in Production
  - USTC
    - 0.27k sensor fabricated in pre-production
  - Overall status:
    - PRR review passed at July 25, 2024
    - Production is on-going
    - Pushing for the in-kind sensor contract

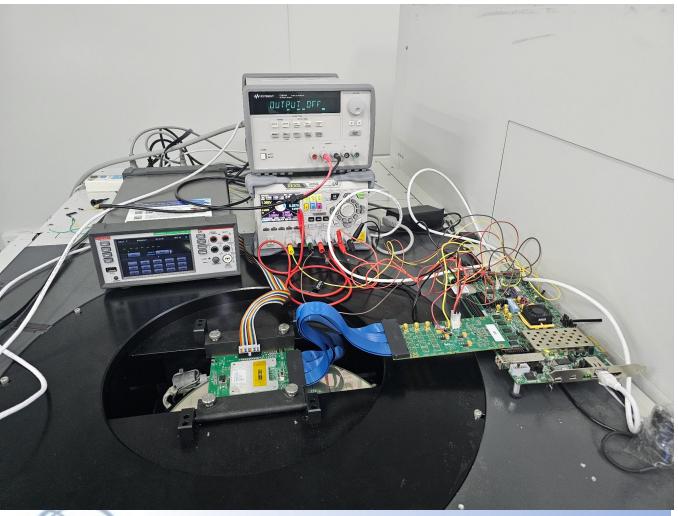
Pre-production LGAD sensors from China

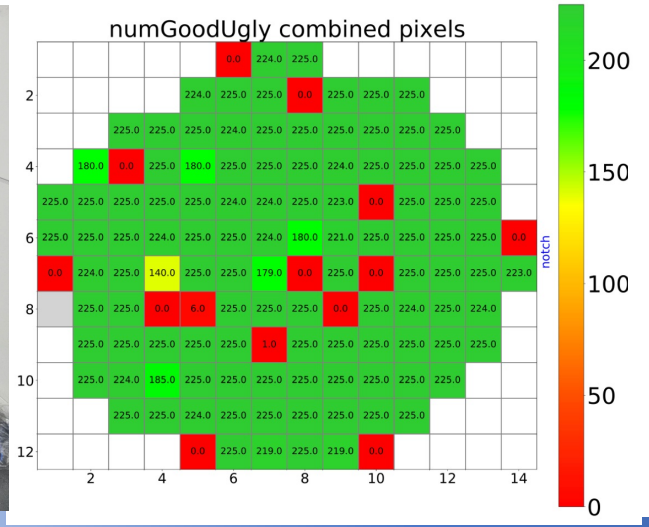




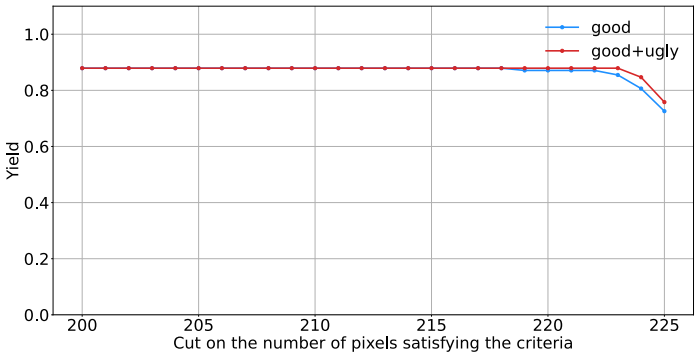
ALTIROC ASIC wafer process

- IHEP 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 compared to IJClab, leading in probe tests
- Probing full ASIC wafers before moving into production is essential.
  - 挑战：Has been the bottle neck for the project for sometime (in critical path)
  - FDR was scheduled at Oct 2024, now delayed to June 2025 (delayed by 8+ months)
  - Need to probe at least 10 wafer before ASIC PRR review
    - IHEP probed 7 wafers, IJClab has not probed a full wafer yet

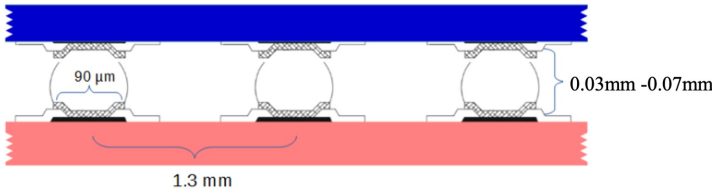




ASIC Yield is 70 ~ 80%

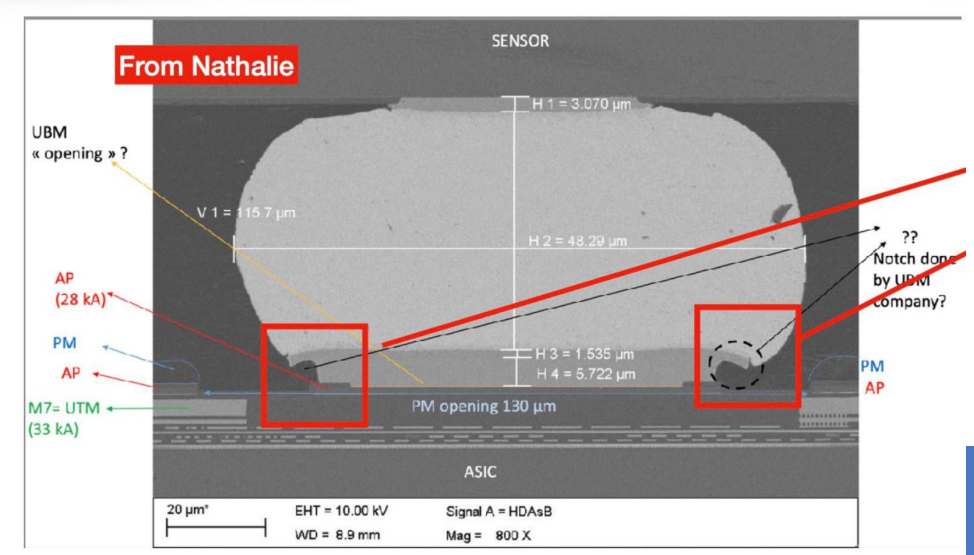


Sensor + ASIC Hybrid

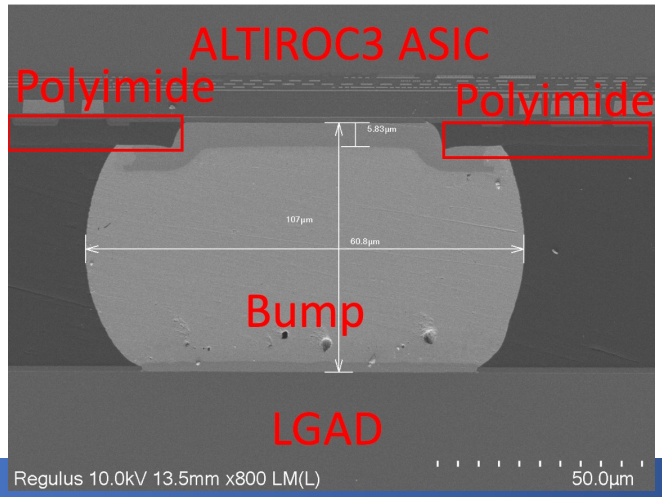


- IHEP is in charge of 50% of hybrids assembly
- 挑战： ATLAS ITK pixel has hybrid bump delamination issue, was delaying HL-LHC
- IHEP solved the bump delamination issue in old ALTIROC2 hybrids, addressed by
  - Switch to using thick sPolyimide layer for ALTIROC3/ALTIROC-A wafer → Softer with correct openin
  - ensor as baseline (775um), instead of thin sensor (300um)
- All ASIC wafers will send to IHEP for Polyimide layer deposition

ALTIROC2 hybrid incorrect Polyimide by TSMC



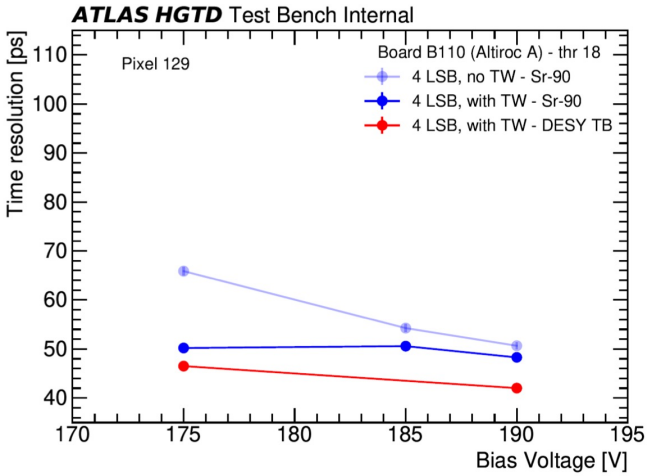
ALTIROC3 hybrids with correct Polyimide by IHEP/NCAP



Hybrid (bare module) performance

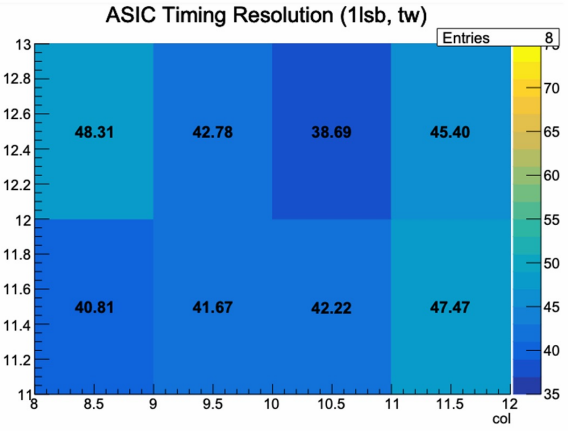
- IHEP and USTC made key contribution to test beam,
  - IHEP member is the editor of HGTD sensor testbeam paper
- Pre-production sensor+ ASIC(Altiroc3 and AltirocA) hybridization tested
  - at CERN and DESY test beam.
- The timing resolution can reach <50ps.

IHEP LGAD+ ALTIROCA



best time resolution reached O(42 ps)

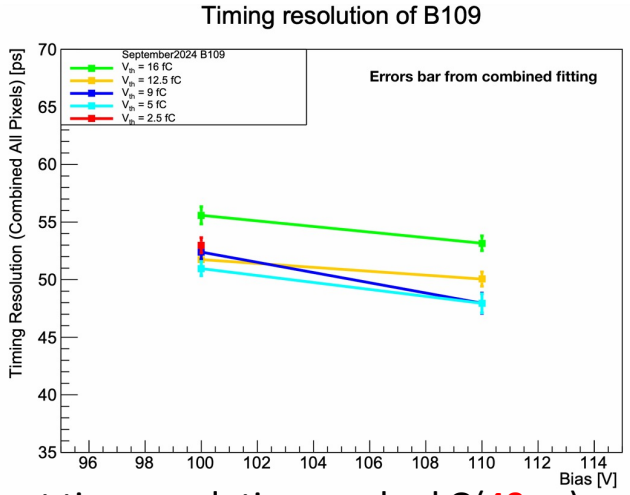
Irradiated IHEP LGAD + ALTIROCA



Irradiated sensors(2.5e15 n_{eq}/cm^2) with AltirocA

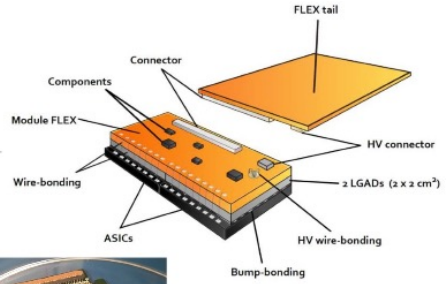
Best time resolution:~43ps

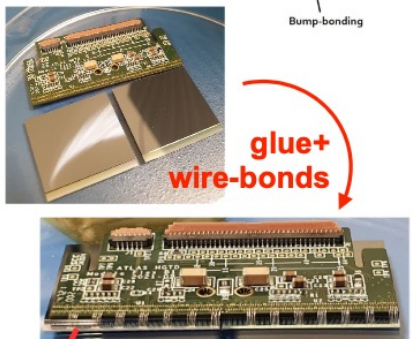
USTC LGAD+ ALTIROCA



best time resolution reached O(48 ps)

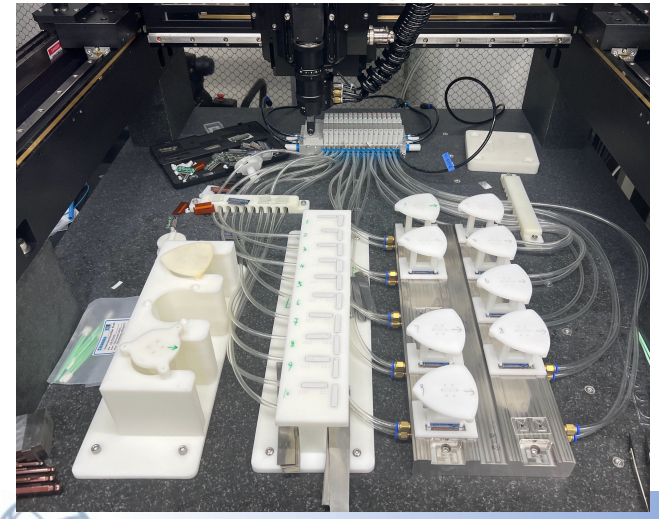
HGTD module assembly



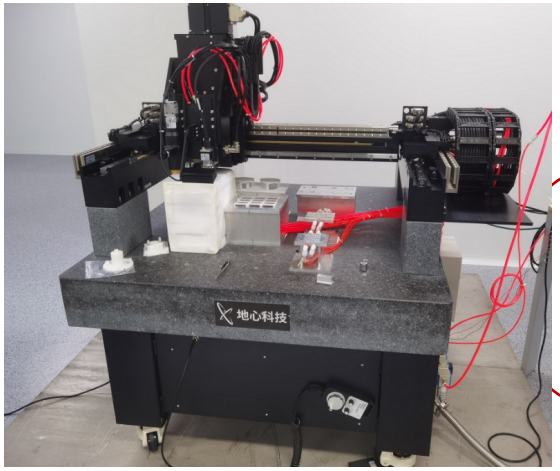


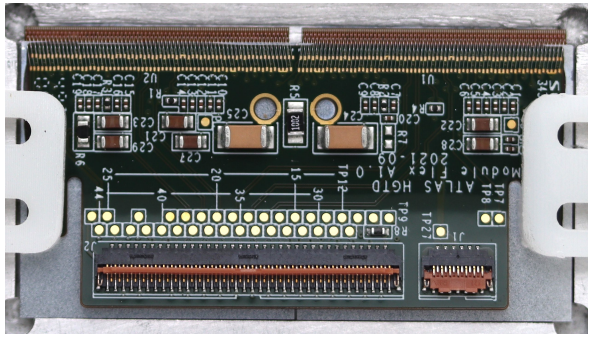
- 6 module assembly site at HGTD (IHEP, USTC, Mainz, France, IFAE, Morocco)
  - IHEP is largest site, 34% of module (~3000)
  - USTC, 10% of module (~1000)
- IHEP designed and fabricated module flex
- IHEP and USTC developed gantry robot for automatic assembly
  - IHEP has set up for production, will produce 10 modules each time
  - USTC completed preparation, but can not get ASIC (US restriction)
    - Plan to do assemble at IHEP (share gantries, detailed plan being workded out with IHEP)

Gantry robot @IHEP



Gantry robot @USTC

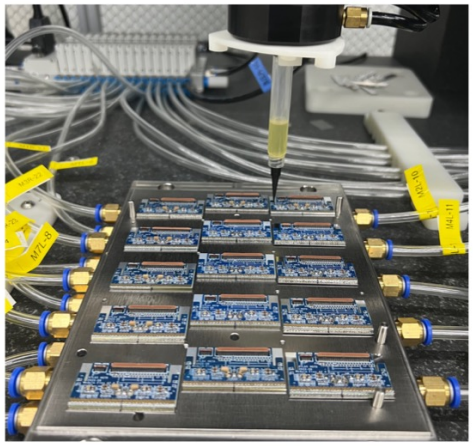




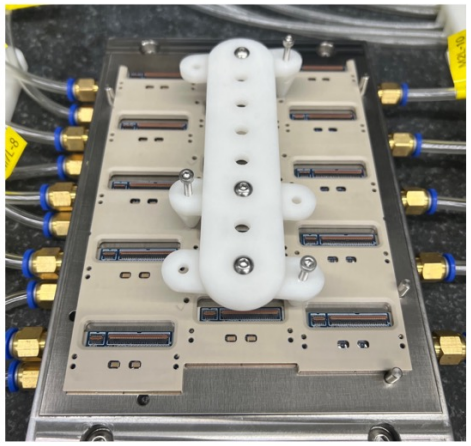
HGTD module loading

- Achievement: IHEP made the first two ALTIROC3 detector unit
  - Use Gantry robot system to position all 15 modules and glue dispending
- USTC assembled detector unit with dummy modules.
- IHEP/LPNHE-Paris shared 50% of support unit (PEEK) manufacture
  - Support unit 100% fabricated in Chinese company

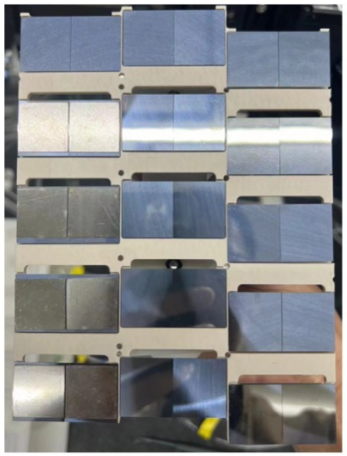
Dispensing with GluingTool



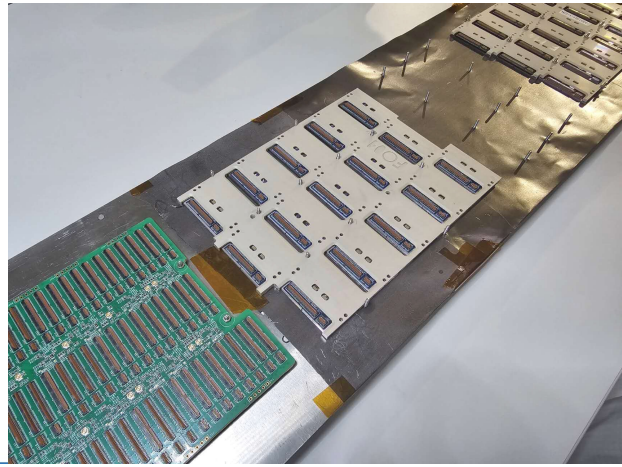
Put the support unit



Backside view after removal

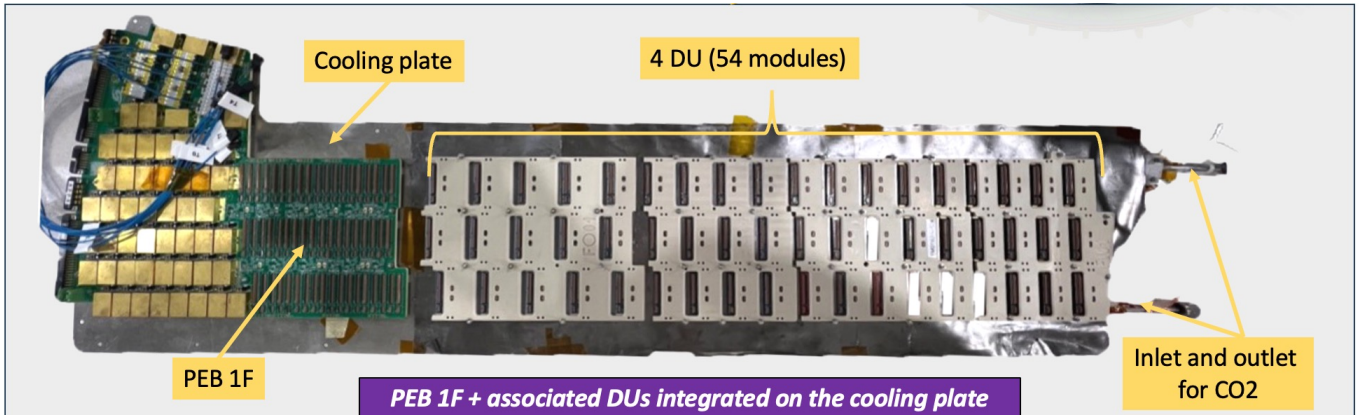


Detector unit shipped to CERN



#Modules for ALTIROC-A/ALTIROC3/ALTIROC2

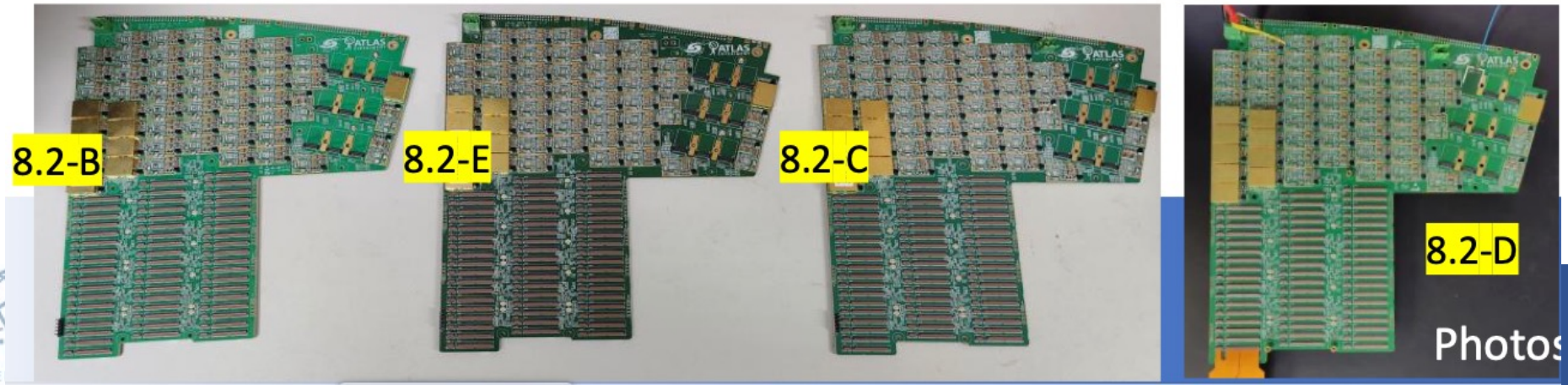
- 54 modules (4 detector units) installed in demonstrator
  - IHEP is leading module and detector unit prototyping
  - Contributed two detector units with ALTIORC3 modules



	# Hybrids	#modules	Usage
ALTIROC-A	25 (23 by IHEP)	7	Test beams, hybrids irradiation
ALTIROC-3	219 (121 by IHEP)	106	Demonstrator, thermal cycle study, test beam, irradiations

Peripheral Electronics Boards (PEB)

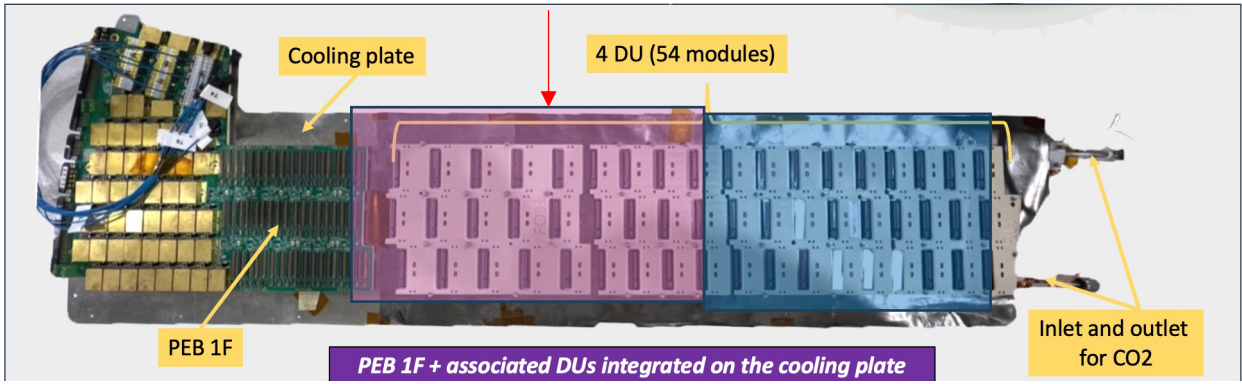
- IHEP and NJU is responsible for 100% PEB production .
- PEB is very challenging, Comments from P2UG review 2023 about PEB :
  - Comparable with the most difficult boards for HEP projects
- IHEP and NJU developed 1st Peripheral Electronics Boards at early 2024
  - IHEP led designed PEB 1F, NJU manufactured 4 PEB prototyping
  - Selected the best company for production
- PEB FDR review in (May 2025), conditional passed
- PEB design in next step
  - Design: PEB 1B/2F/2B by IHEP; PEB 3B by NJU; PEB 3F by Morocco
    - IHEP/ Jie Zhang will coordinate and verify all the designs

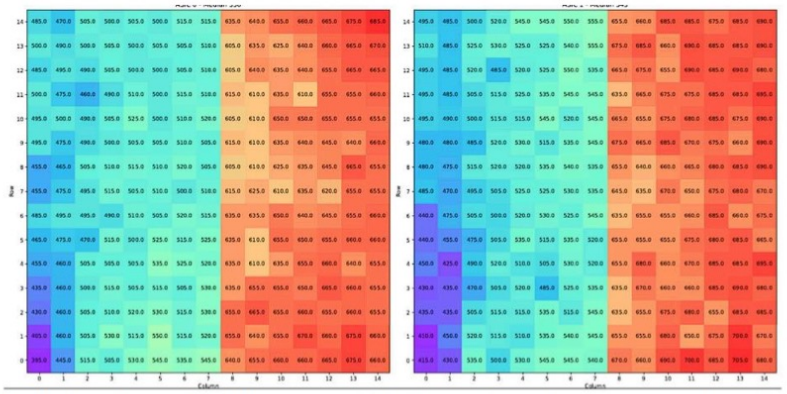


Demonstrator (大规模时间探测器样机)

- IHEP and NJU played important role testing demonstrator system at CERN
  - Noise levels were measured with 54 modules, no major problem
  - 挑战： 1st time to demonstrate that in large-scale system level

ALTIROC3 detector units



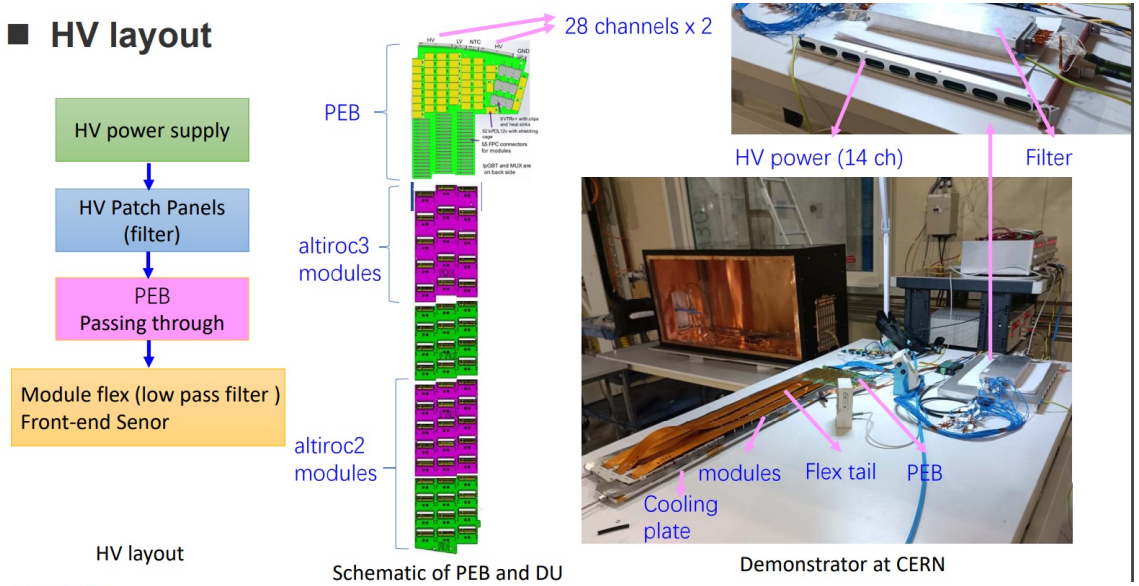


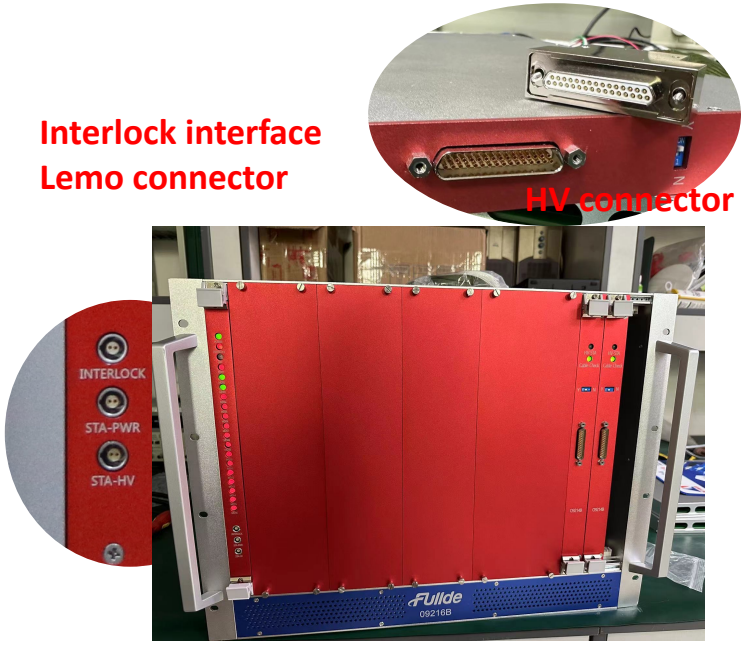
Module threshold scan obtained in demonstrator test

High voltage power supply for HGTD

- IHEP developed HV power supplies with FULLDE Chinese company
  - Tested at IHEP and CERN, Passed FDR, now in pre-production
  - 挑战：100nA current precision, completion with CANE
- 100% contract of HV assigned to FULLDE.
  - IHEP/SDU will contribute to 17.7% of the cost, including testing

HV supply testing setup at HGTD demonstrator





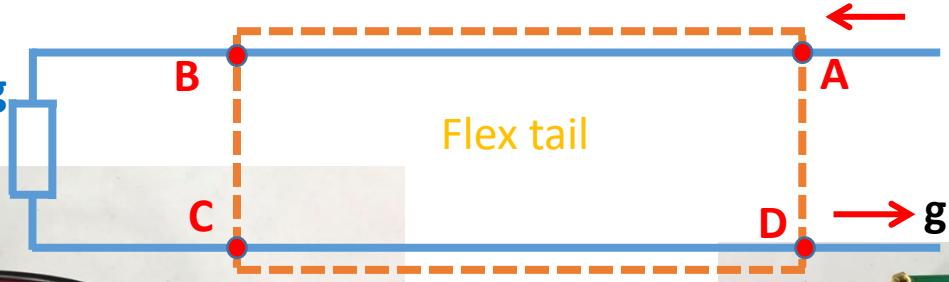
Flex tails（柔性电子学尾板）

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

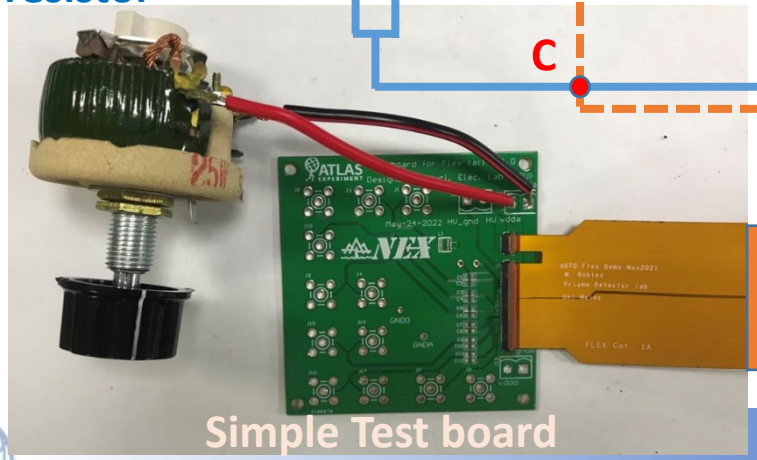
caliper

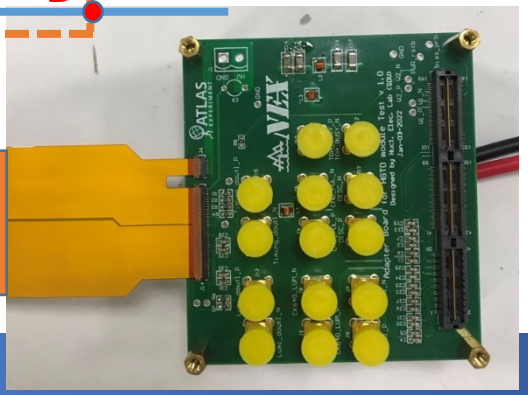
micrometer

High power BC1 adjustable sliding resistor



~ 46 mΩ for vdda and ~22 mΩ for gnda.





Adapter board v1

Assessment index status （考核指标）：

- Final goal:
  - Final production sensor and detector module time resolution 30-50 ps
- This year (1st year):
  - pre-production sensor and hybrids resolution better than 50ps
    - Irradiated sensor +ASIC hybrids can reach 43ps in test beam

课题目标[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	□新理论 □新原理 □新产品 ■新技术 □新方法 □关键部件 □数据库 □软件 □应用解决方案 □实验装置/系统 □临床指南/规范 □工程工艺 □标准 □论文 □发明专利 □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 升级项目研制出预生产的硅传感器，以及传感器倒装焊后做出裸模块，时间分辨好于 50 皮秒

Summary and plan

- Summary :
  - Sensor pre-production done, passed CERN review, production on-going
  - Prototyping done for Module and Electronics Boards , HV power, flex tails
- Next Milestones
  - Sensor production finished in 2026
  - Electronics boards and flex tails completed in 2027
  - Module and detector unit and HV power supply completed in 2028
  - Detector assembly and Commissioning at CERN (2026 -2029)