ATLAS Upgrade

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On behalf of the ATLAS Chinese Clusters

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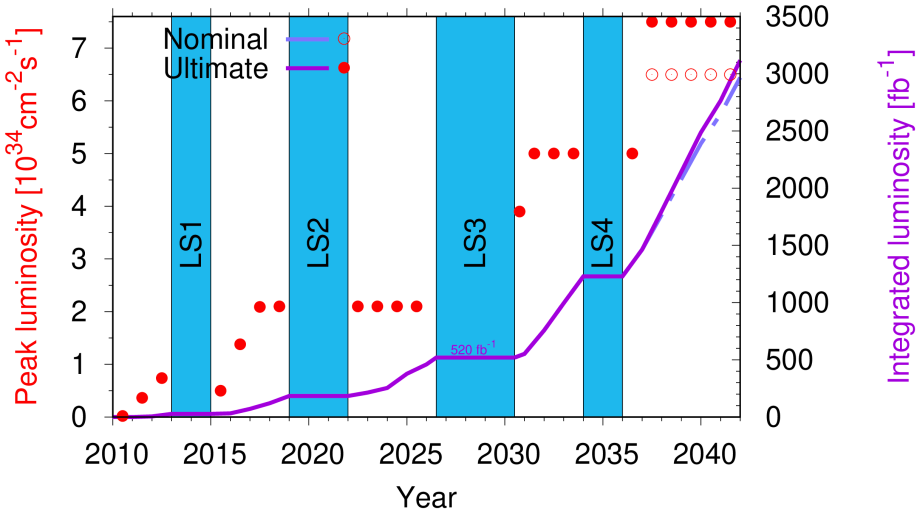
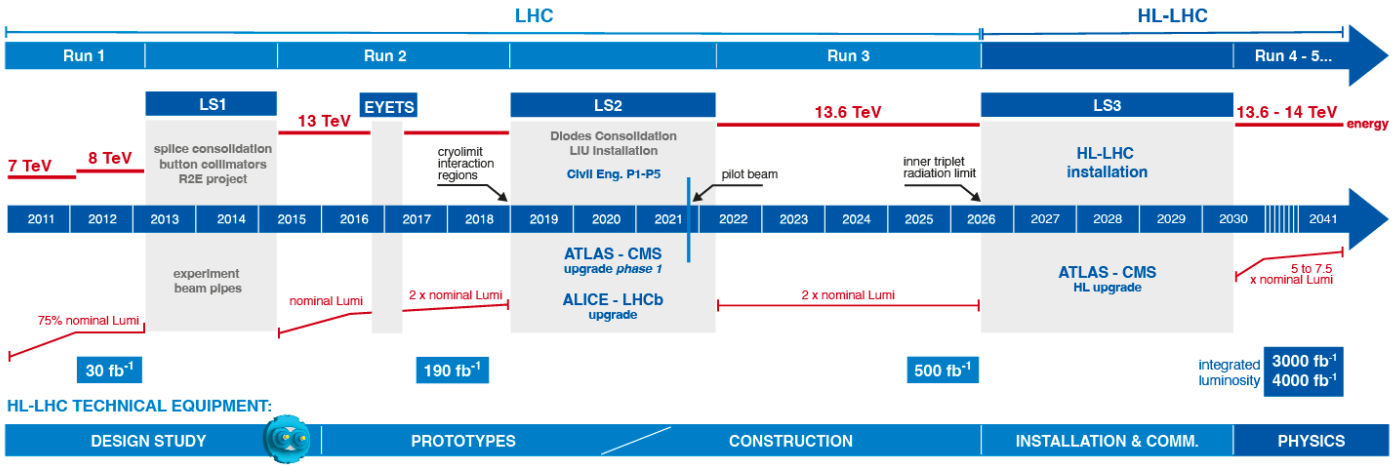
HL-LHC Challenges

- HL-LHC program will start in 2030 and continue until 2041
  - Increased luminosity – from 2 x 10^{34} cm^{-2} s^{-1} up to 7.5 x 10^{34} cm^{-2} s^{-1}, increased L1-trigger rates from 100 kHz to 1 MHz.
  - Higher pile-up conditions – from <μ> = 20 of LHC design up to <μ> = 200 for HL-LHC, high detector occupancies.
  - Increased radiation doses – about 20x increase up to a few MGy TID for 4000 fb^{-1}, radiation hard electronics.
  - Long term operation – Approx. 15 additional years on top of the original 15, ageing component replacement.





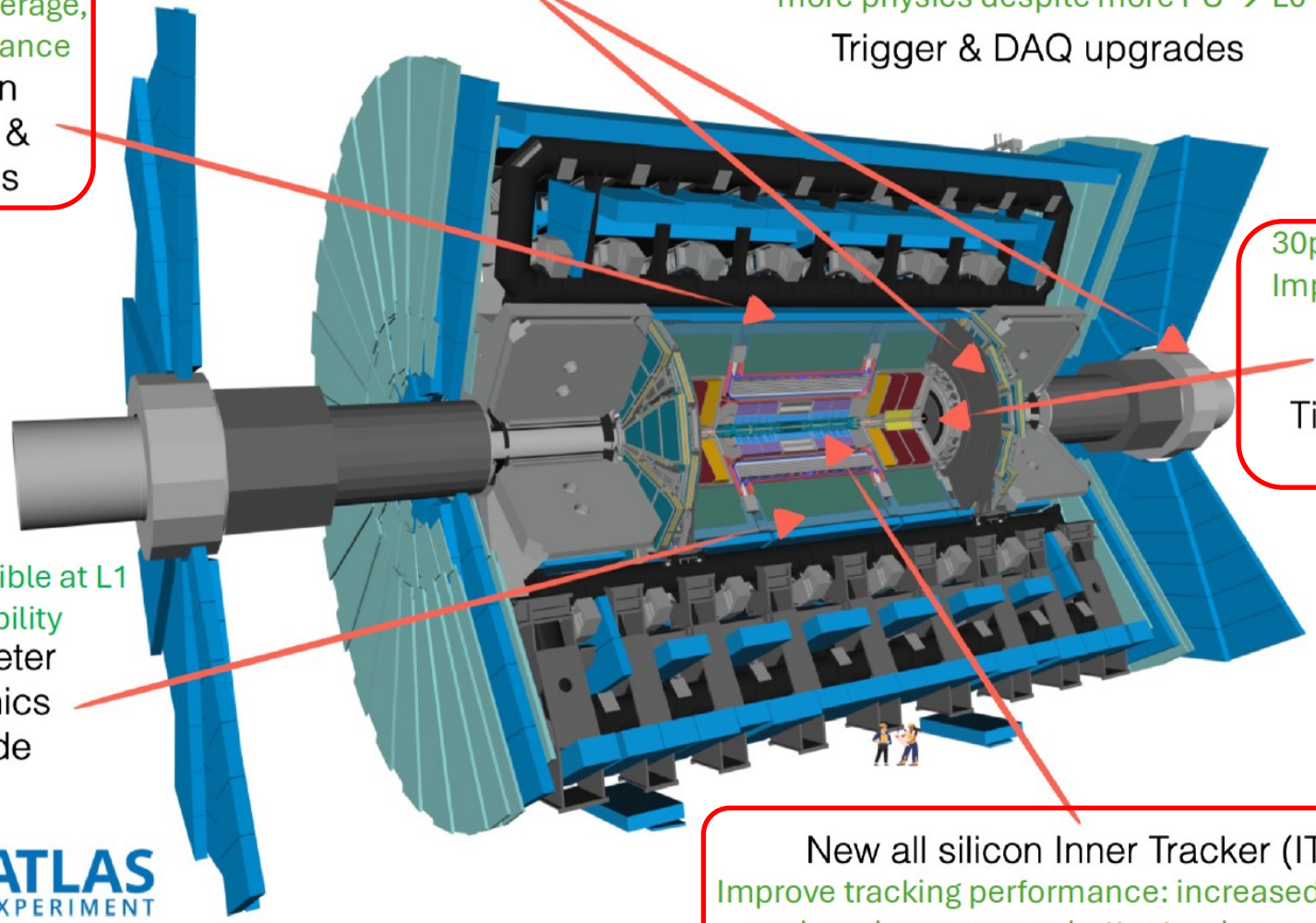
Phase-2 upgrade

ATL-UPGRADE-PUB-2025-001/

1% luminosity accuracy
New and upgraded forward and luminosity detectors

Improve trigger performance/rate:
more physics despite more PU → L0 trigger at 1 MHz, EF 10kHz
Trigger & DAQ upgrades

Improve muon trigger coverage, electronics and performance
New muon chambers & electronics



30ps time resolution per track
Improve PU rejection in forward region
New High Granularity Timing Detector (HGTD)

Full granularity data accessible at L1 trigger, increased rate capability
Calorimeter electronics upgrade

New all silicon Inner Tracker (ITk)
Improve tracking performance: increased coverage, reduced occupancy, better track p_T resolution

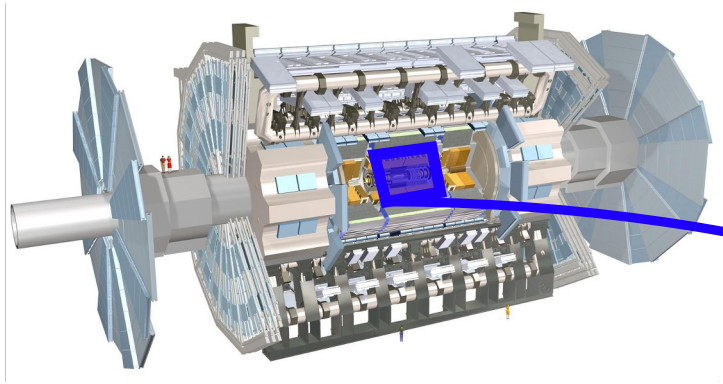
China contributions of Phase-2 upgrade

- Inner Tracking System (ITk): IHEP, THU, SYSU, SJTU, SDU
  - 10% strip barrel modules (> 1000 modules, ~10m^2 of sensor surface)
  - 500@IHEP / 500@RAL (UK)

- High Granularity Timing Detector (HGTD): IHEP, USTC, NJU, SDU, SJTU
  - 100% LGAD sensor
  - 44% detector assembly
  - 100% front-end electronics board
  - …

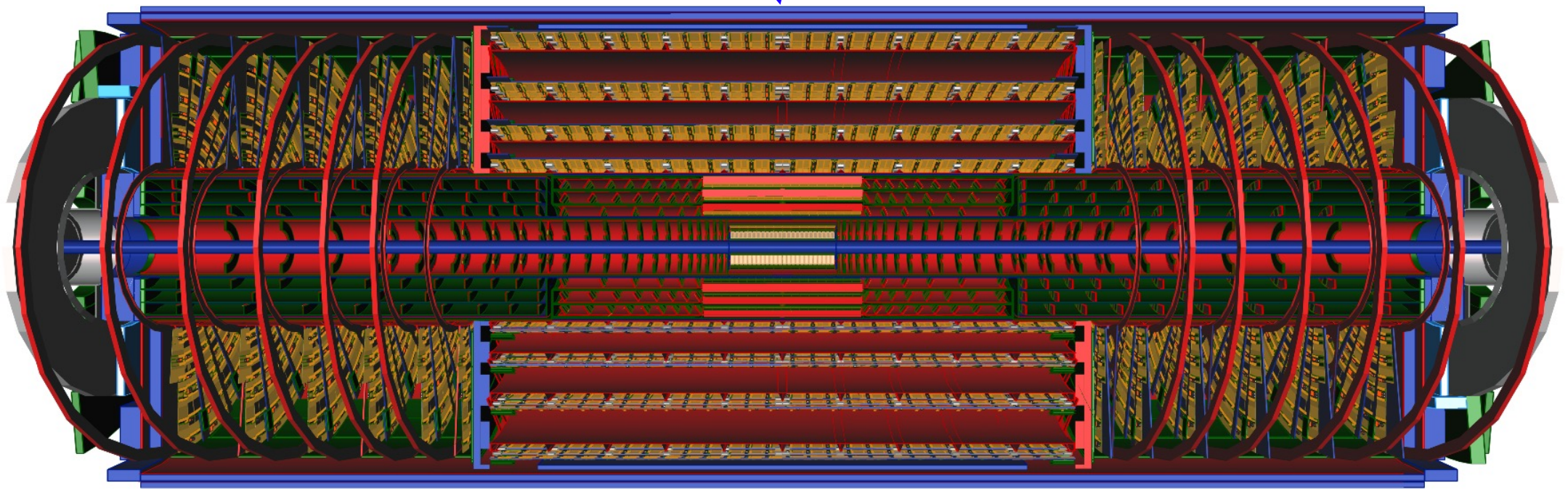
- Muon trigger (RPC): USTC, SJTU, SDU, ZZU
  - 912 readout panels and 72 gas gaps
  - Assembly of 360 singlets
  - Manufacture and test of ~5000 front-end electronic boards

ATLAS Inner Tracker (ITk) Upgrade

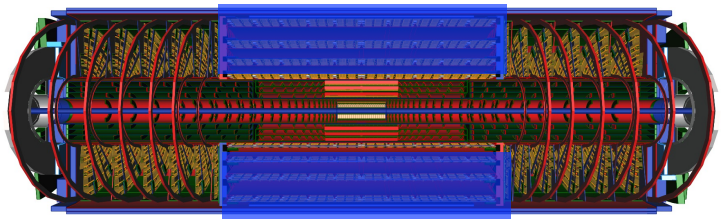


Inner Tracking Detector (ITk)

- All silicon with at least 9 layers up to $|\eta| = 4$
- Less material, finer segmentation



China ITk Strip Detector Contribution

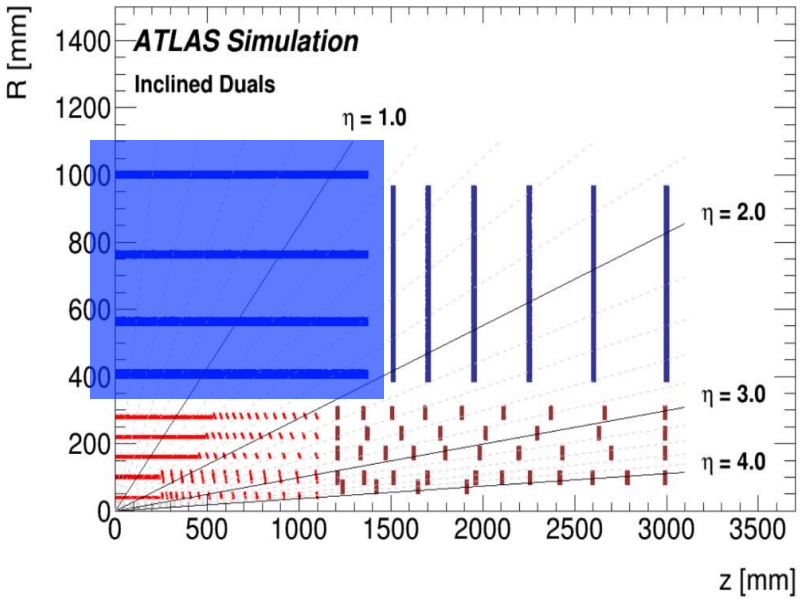


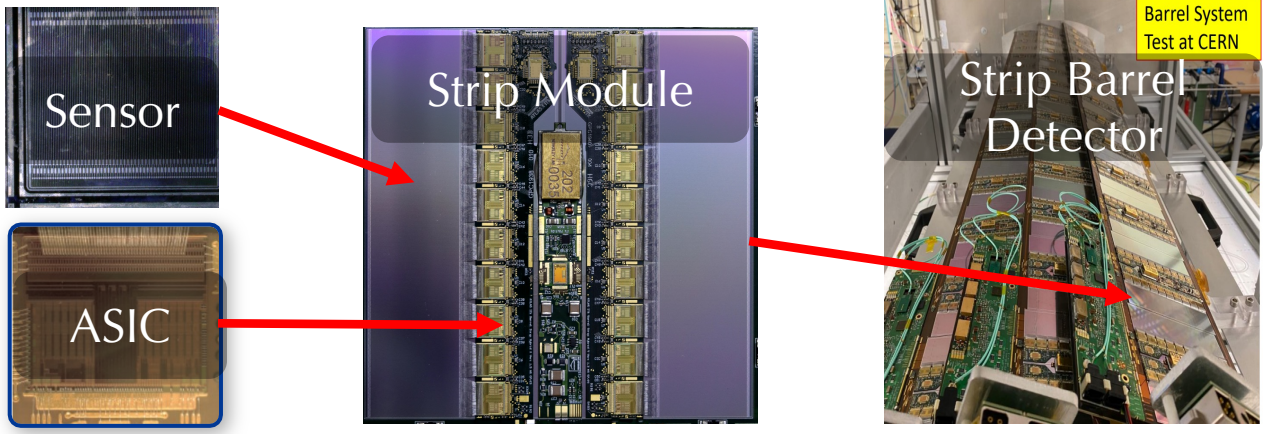
CORE Deliverables

- China [IHEP/THU/SYSU/SJTU/SDU] deliver 10% strip barrel modules (> 1000, ~10m^2 of sensor surface)
- 500@IHEP / 500@RAL (UK)

Contents

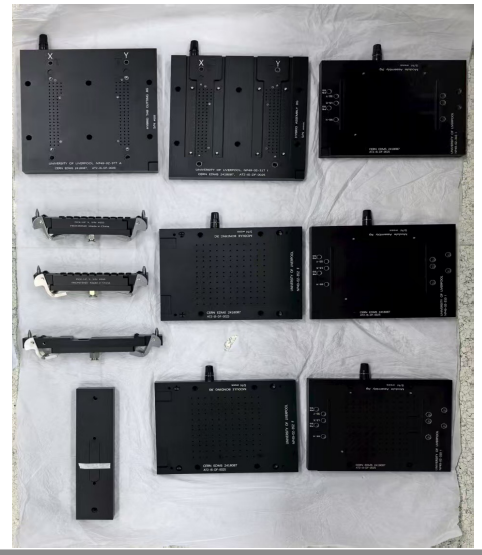
- Radiation hard sensor and readout ASIC study
- High performance strip detector module production
- Complex silicon detector system integration





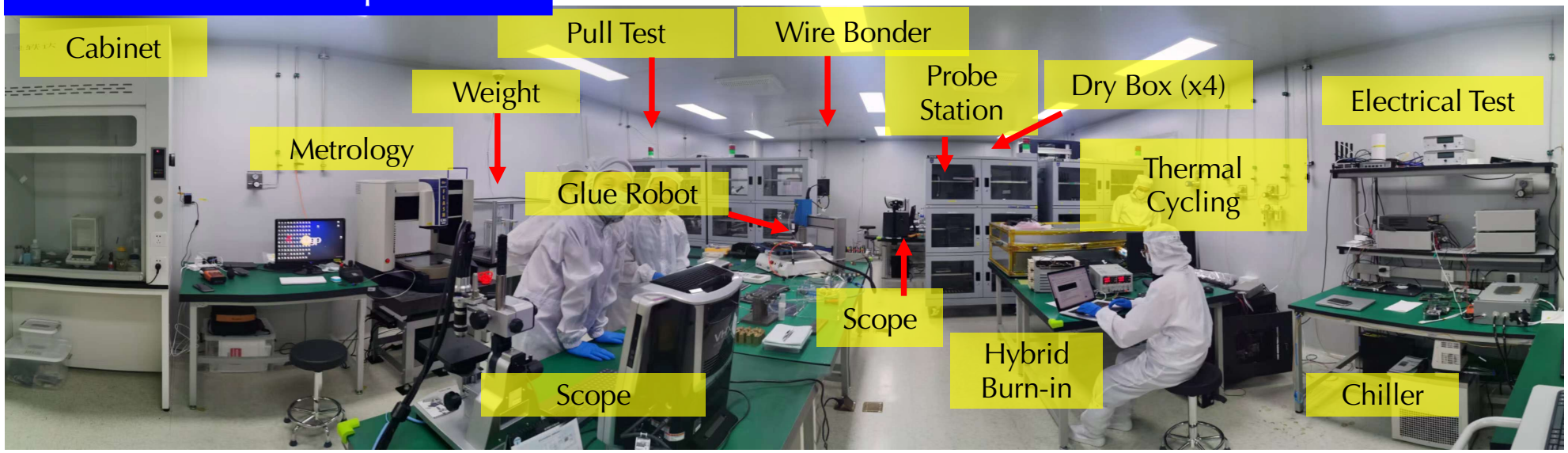
IHEP Site Module Production Status

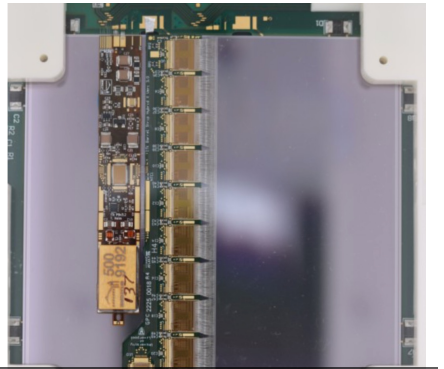
- Passed PRESERIES stage for Module production
  - Produced 15 PRESERIES modules
  - Contributed to 150 PRESERIES modules at RAL
- Manufactured 11 production tooling in China



New tools made in China

IHEP Site for ITk Strip Module



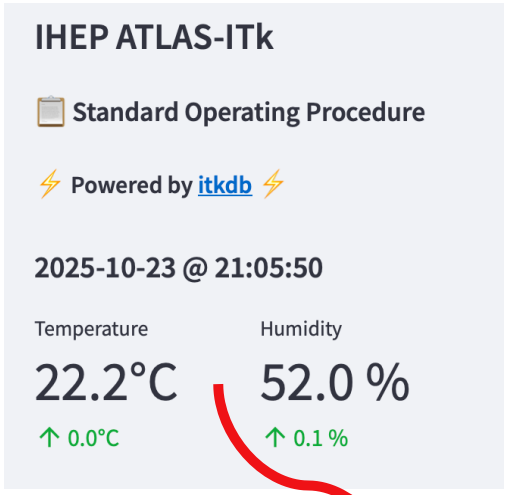


IHEP REPSERIES Module (x15)

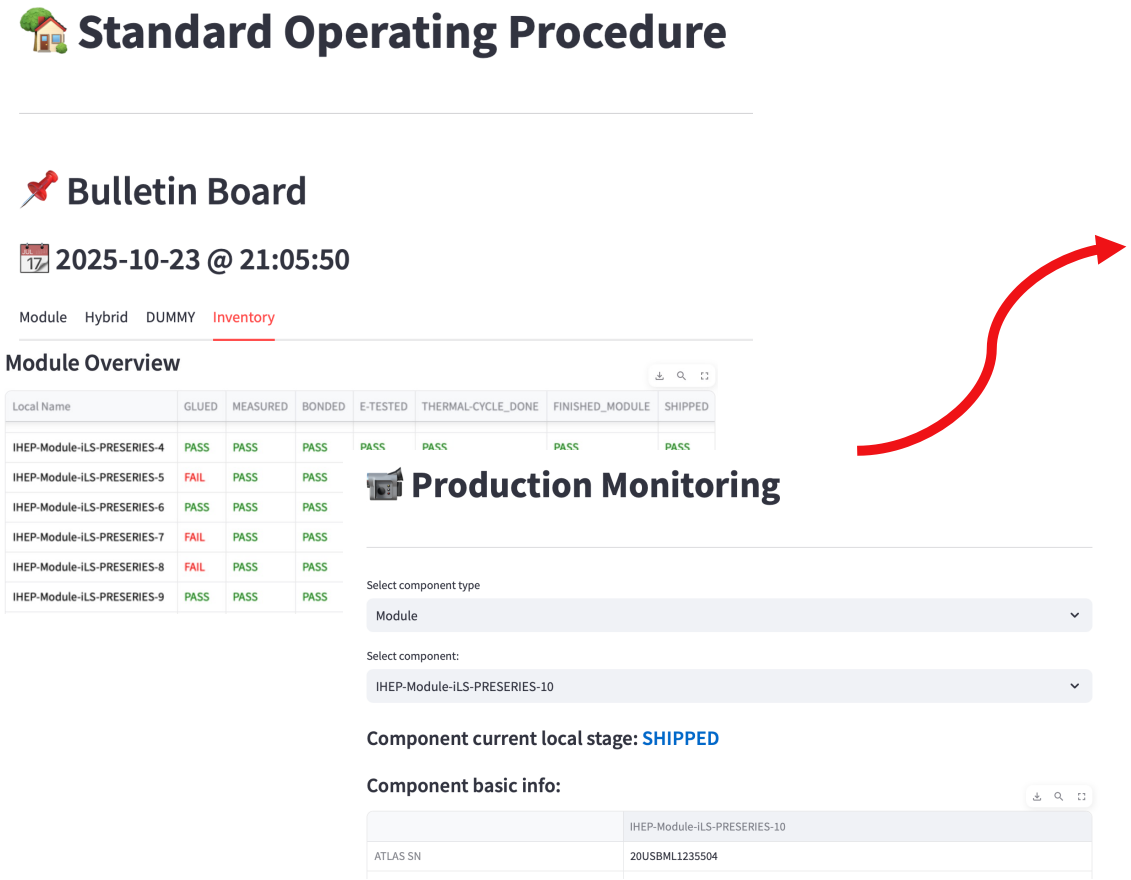
Standard Operating Procedure (SOP)

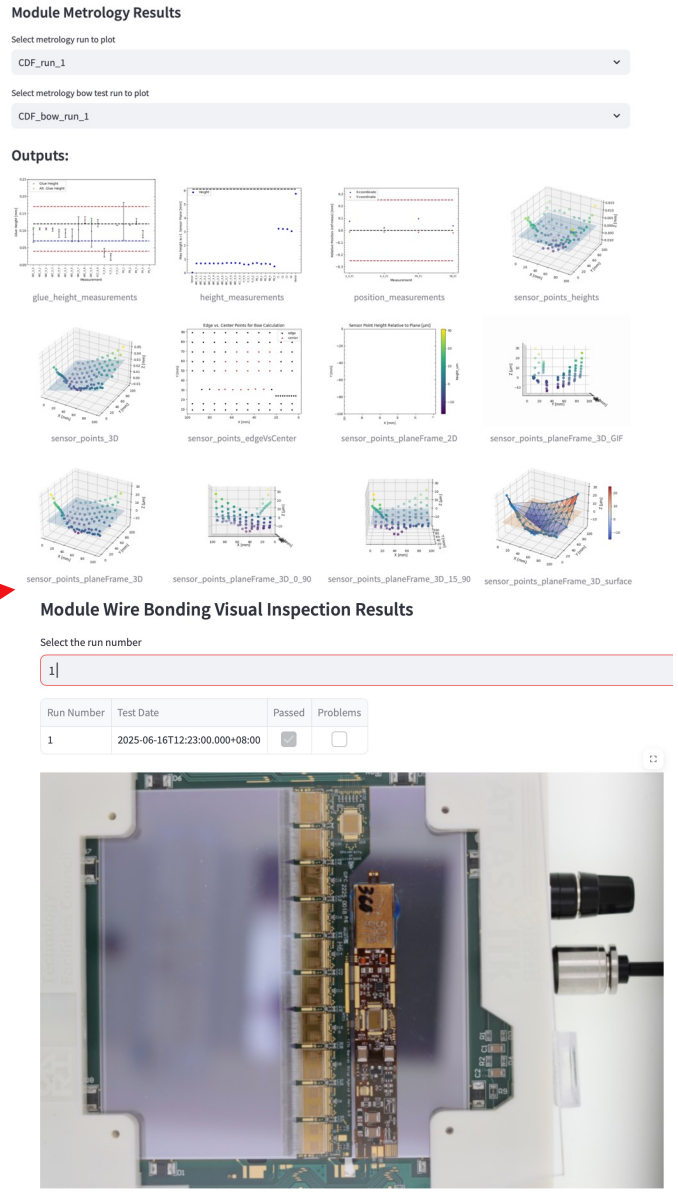
- Developed at IHEP for local production
  - Accessible to PC and Tablets with internal network
  - All SQ 29 steps have been implemented in SOP

http://atlasitk.ihep.ac.cn



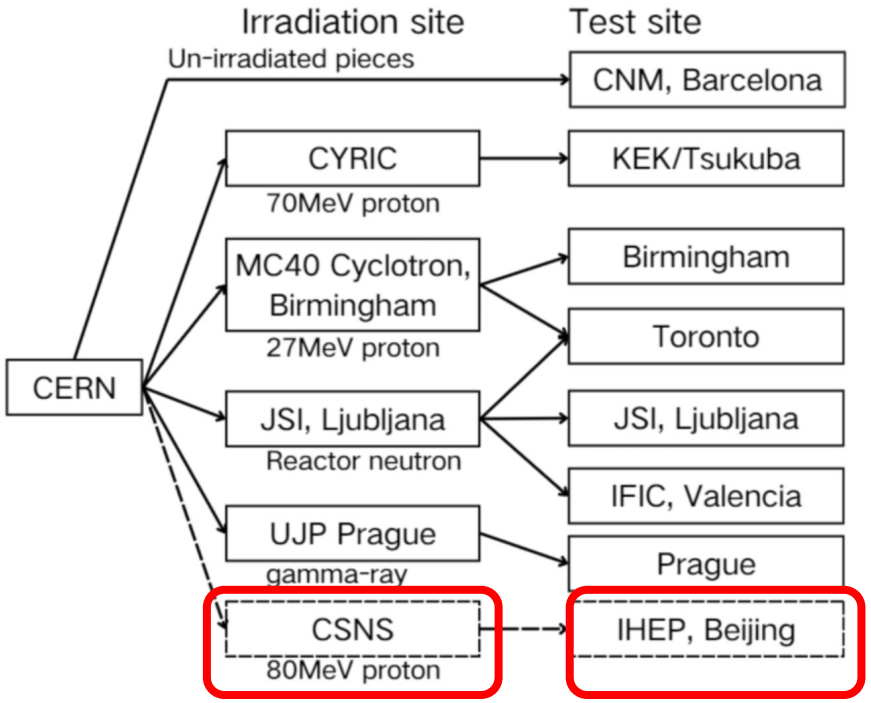
Connect to ITk Production Database

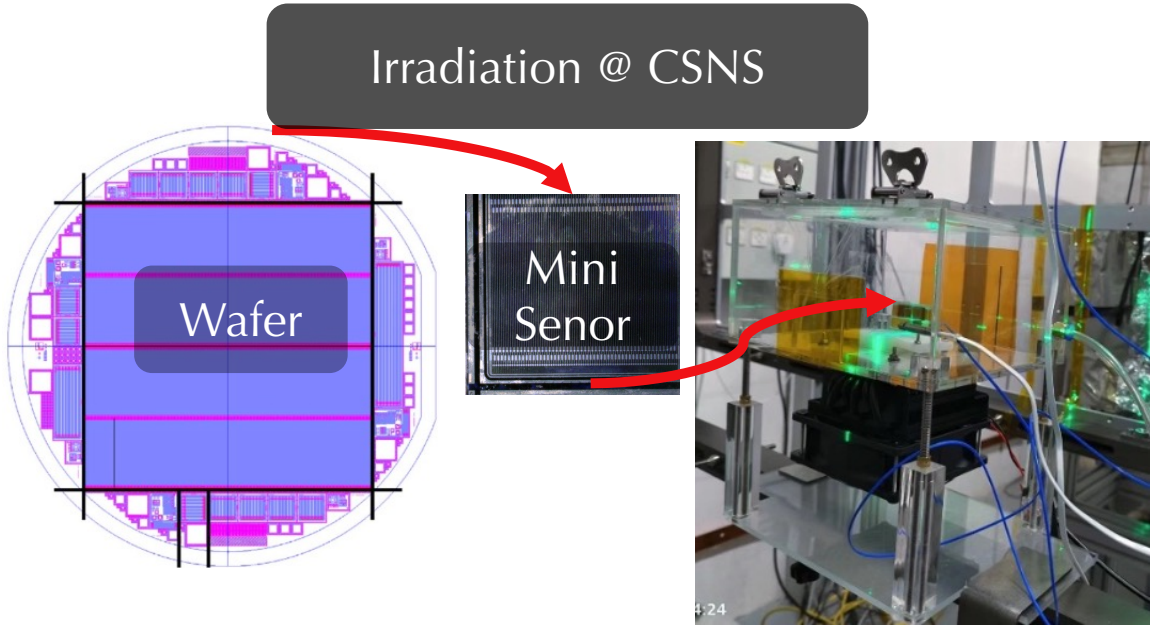


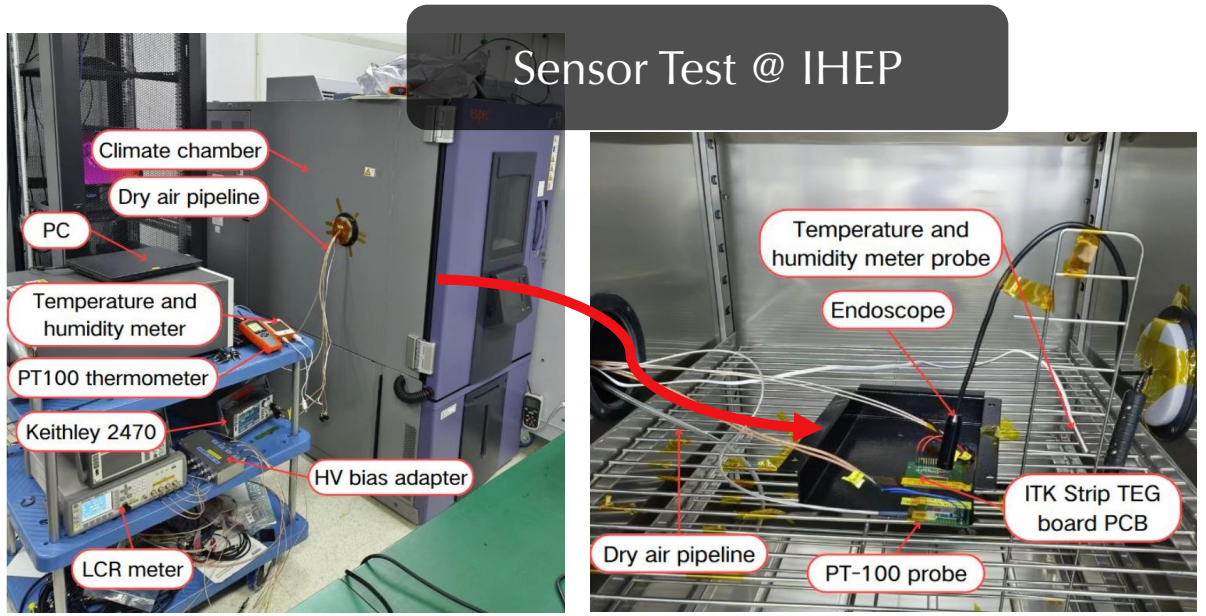


Sensor Irradiation Study

- CSNS **Qualified** as quality assurance (QA) site
  - 80 MeV proton fluence up to 1.6x10^{15} n_{eq}/cm^2
- IHEP **Qualified** as Sensor characterization site
  - I-V, C-V, CCE (Charge Collection Efficiency)

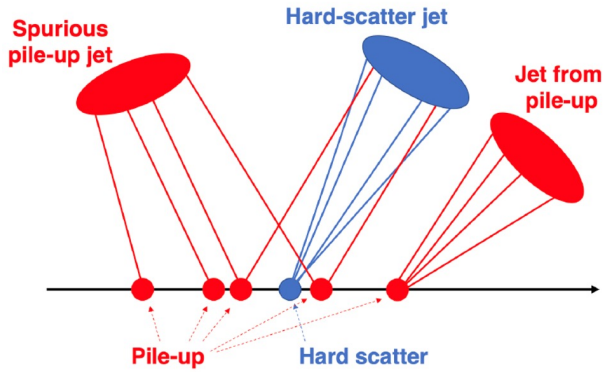




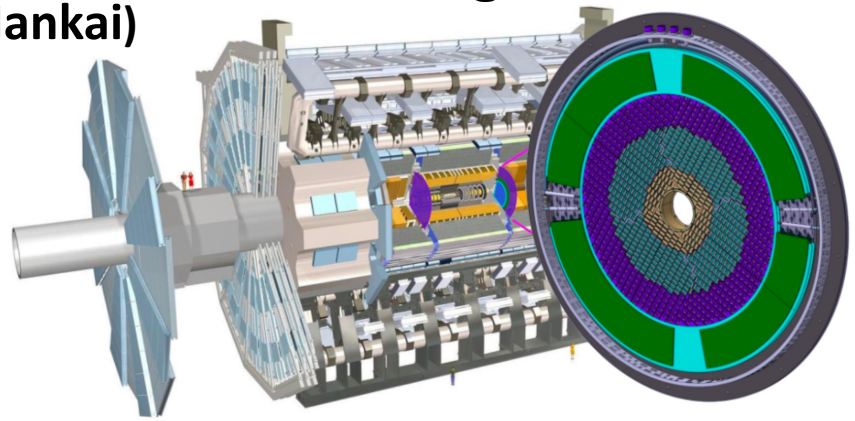


High Granularity Timing Detector (HGTD)

- HGTD aim to reduce pileup contribution at HL-LHC
  - Timing resolution is required to be better than 30 ps (start) - 50 ps (end) ps per track
- 6.4 m^2 area silicon detector and ~ 3.6 × 10^6 channels
- High Granularity: Pixel pad size: 1.3 mm × 1.3 mm
- Radiation hardness : 2.5x10^{15} N_{eq} /cm^2 and 2 Mgy
- China team is making key contributions to HGTD
  - 100% LGAD sensor (90% IHEP + 10% USTC)
  - 44% detector assembly (IHEP,USTC,SDU, Shanghai ,Nankai)
  - 100% front-end electronics board (IHEP +NJU)
  - ~33% flex tail (SDU)
  - 50% ASIC testing (IHEP,Shanghai,SDU)
  - >16% high-voltage electronic systems (IHEP+ SDU)
  - TDAQ(USTC,IHEP,SDU)
  - Software and performance (USTC, IHEP)

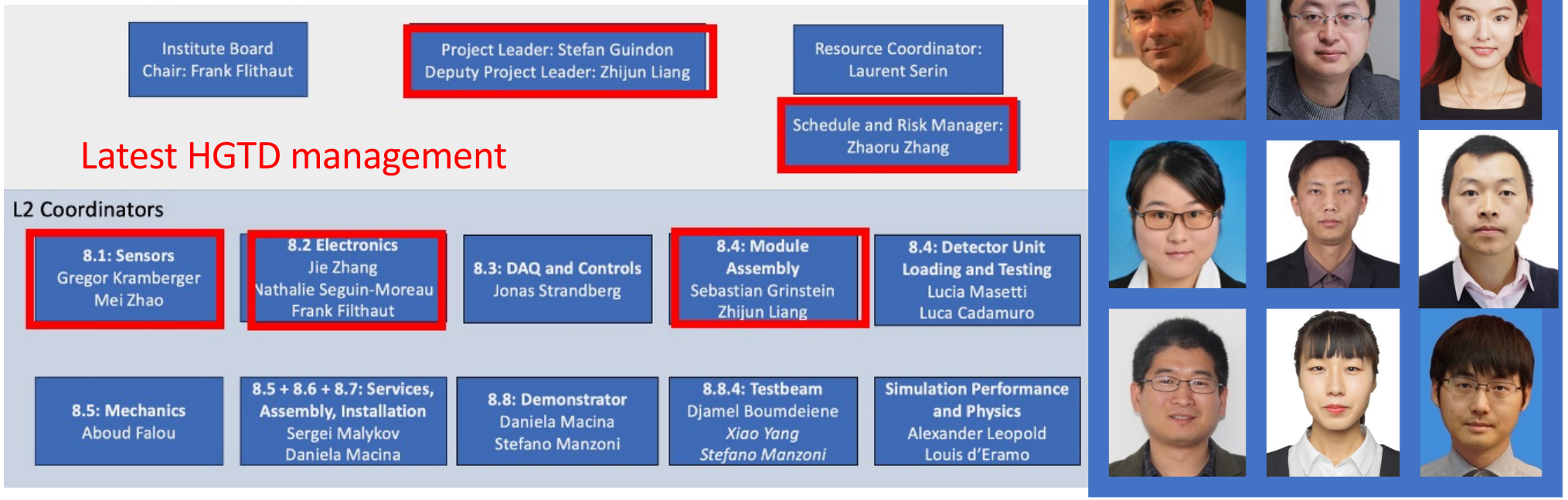


HGTD @ ATLAS



China team in HGTD management

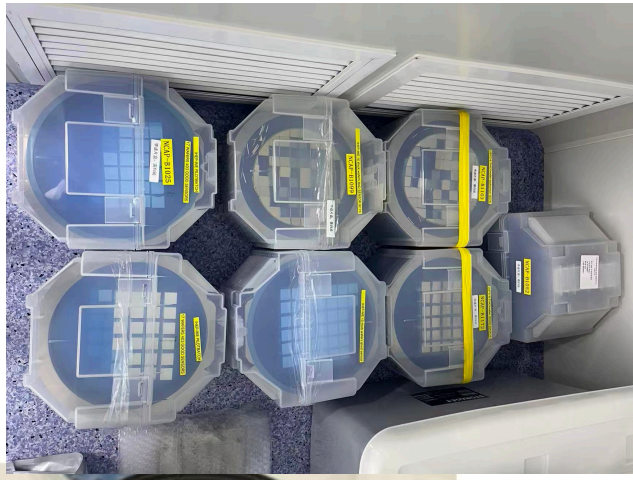
- ATLAS China team played an important role in HGTD management team
  - Mar 2025 - Feb 2027, Zhijun is serving as deputy project leader
  - Mar. 2021- Feb 2025 , Joao was HGTD project leader
  - 5 person as L2 conveners (Jie Zhang, Mei Zhao, Zhaoru Zhang, Zhijun Liang,Lailin Xu)
  - 3 person as Level-3 conveners（Yunyun Fan, Lei Fan, Jie Zhang ）
  - 1 person was speaker committee (Yanwen)

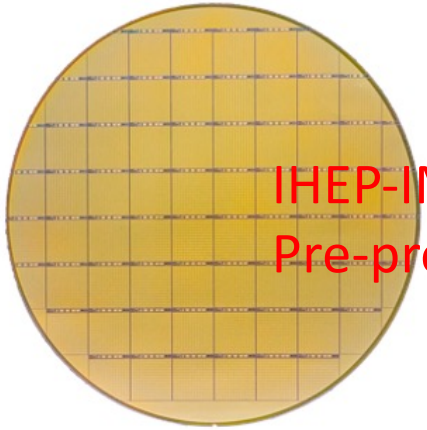


LGAD sensors pre-production

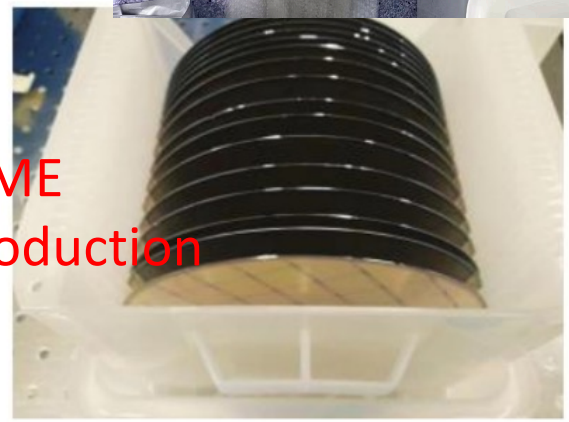
- CERN chosen IHEP-IME sensor in tendering, contract signed in Feb 2025
  - IHEP-IME, FBK(Italy) and HPK(Japan) were competing
- The sensor production will be 100% done by China
  - First time domestic silicon sensor was used by CERN
  - IHEP-IME: 90% (66% from CERN tendering+24% in-kind): ~8 m^2
  - USTC-IME: 10% in-kind contribution (~0.8 m^2)
- Production status
  - IHEP
    - pre-production: ~1700 sensor fabricated
    - Production: ~3000 sensor fabricated (~15%)
    - Production still on-going
  - USTC
    - pre-production: ~270 sensor fabricated

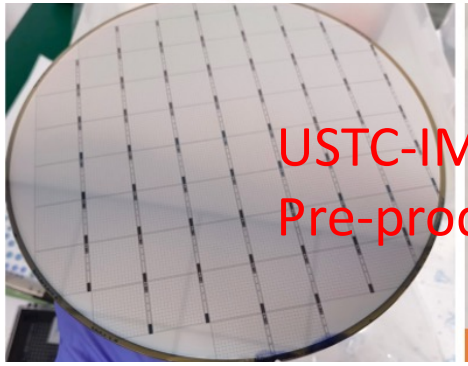
IHEP-IME production



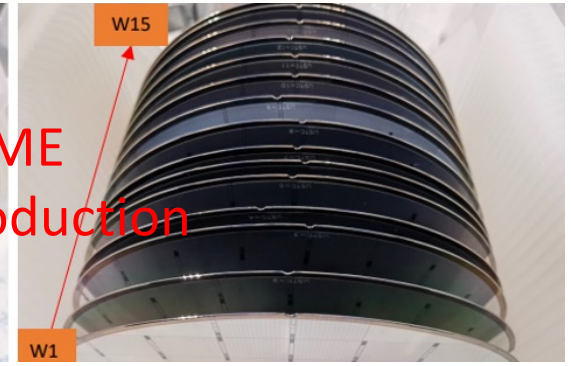


IHEP-IME
Pre-production





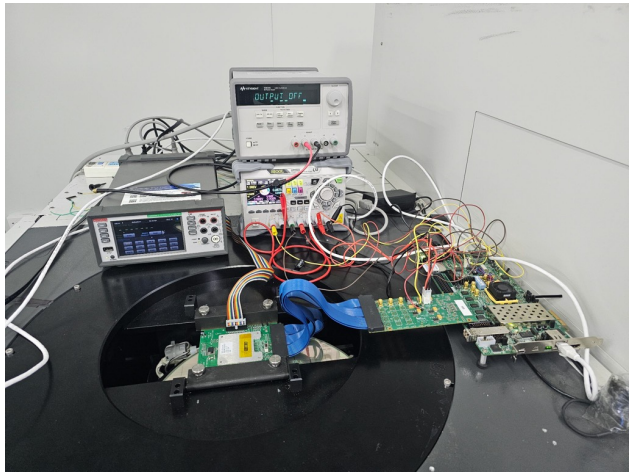
USTC-IME
Pre-production



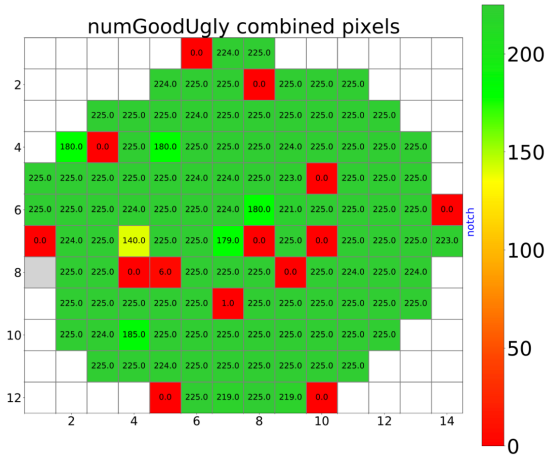
ALTIROC ASIC wafer testing

- The ALTIROC ASIC is a radiation-hard, 130 nm CMOS front-end chip for HGTD
- China and IJClab (France) share 50% of wafer probe test （225 ASIC wafers in total)
- China team (IHEP, SJTU/TDLI, SDU) will complete the full ASIC testing from 2025 to 2027
  - China team setup a ASIC wafer test system based on fully automatic probe station
  - Important to test all ASICs and select the good ones, typical yield is 70% ~ 80%
  - Tested 7 ASIC wafers, is more advanced compared to international collaborators
  - Passed CERN Production Readiness Review

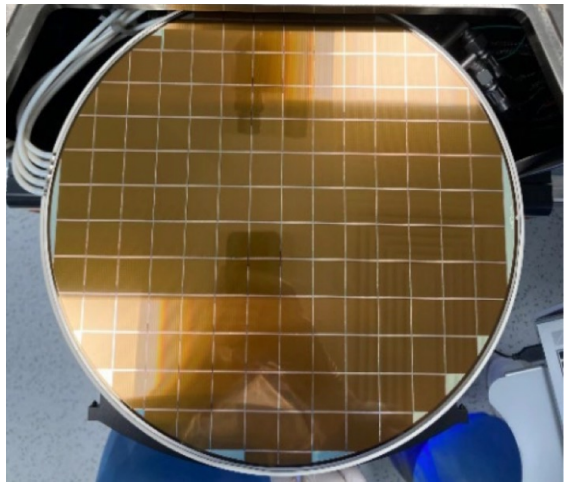
ASIC wafer test system



ASIC wafer test result



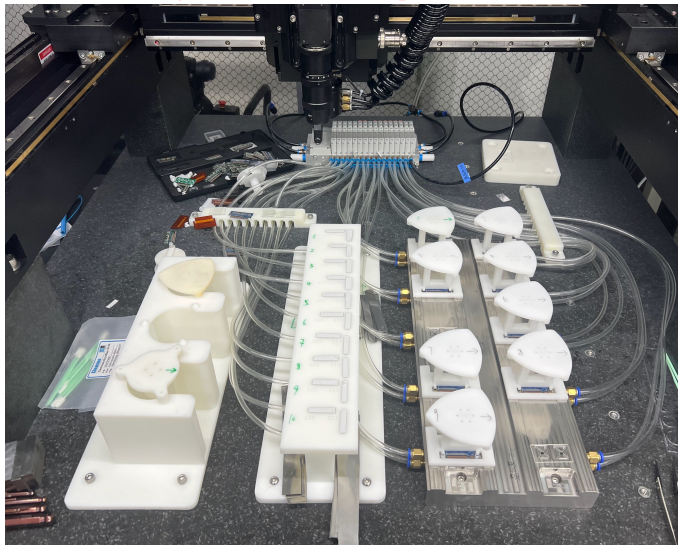
ALTIROC-A wafer



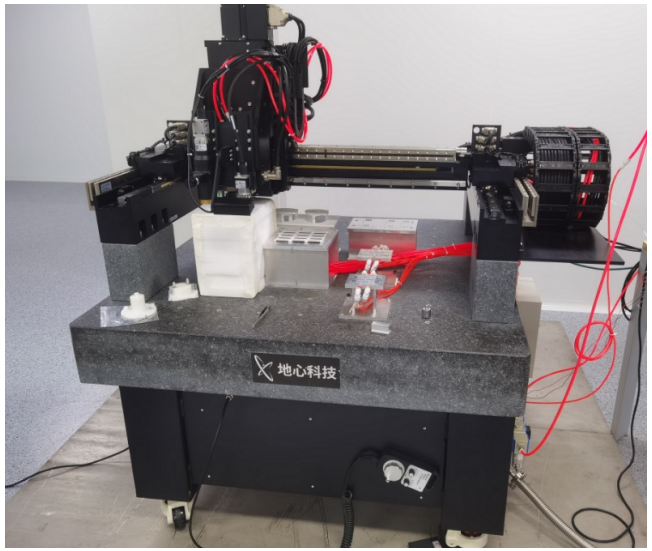
Module and detector units

- 5 production sites of HGTD (China, Mainz (Germany), France, IFAE(Spain), Morocco)
  - China is largest site, will assemble 44% of the module (~4000 modules)
    - China's module team included IHEP/USTC/SDU/SJTU/Naikai, assembly lab is in IHEP
- Latest update
  - IHEP finished module flex pre-production (400 module flexes)
  - IHEP and USTC developed gantry robot for automatic assembly
  - IHEP team prototyped more than 100 modules, including ~10 ALTIROC-A modules

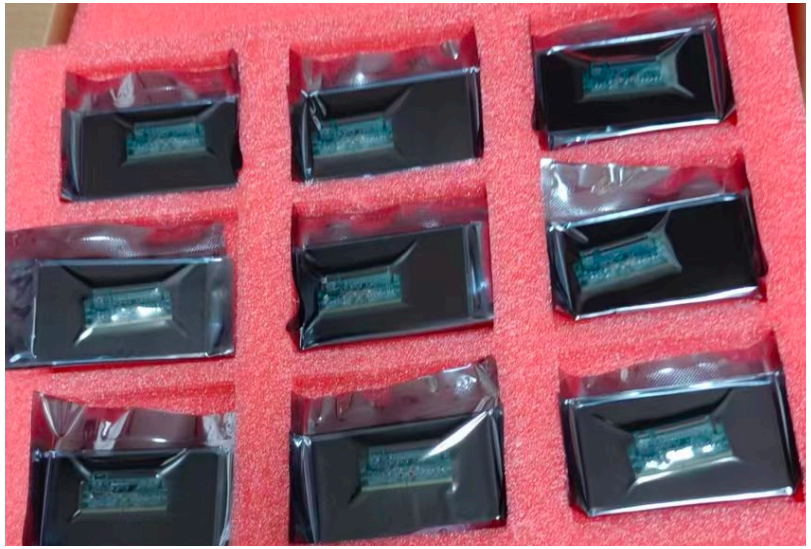
Gantry robot @IHEP



Gantry robot @USTC



Module flex pre-production @ IHEP

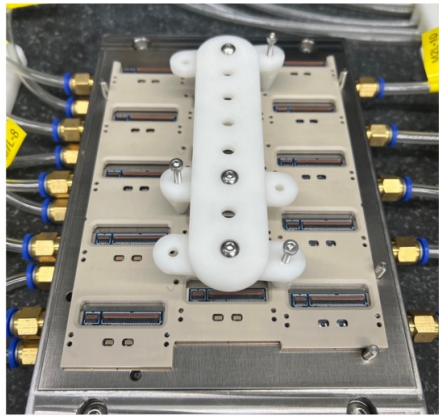


HGTD module loading

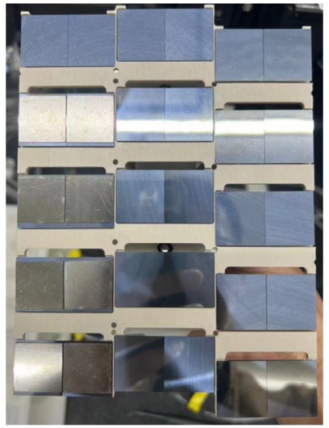
- IHEP loaded the two ALTIROC3 detector units for demonstrator
  - Use Gantry system to position all 15 modules and glue dispending
  - Delivered to CERN, and integrated in 54-modules demonstrator
- USTC/IHEP are developing program with gantry robot in IHEP hall 3
  - New gantry robot is 4 times larger than previous one
  - Finalizing the setup for production

Dispensing with GluingTool

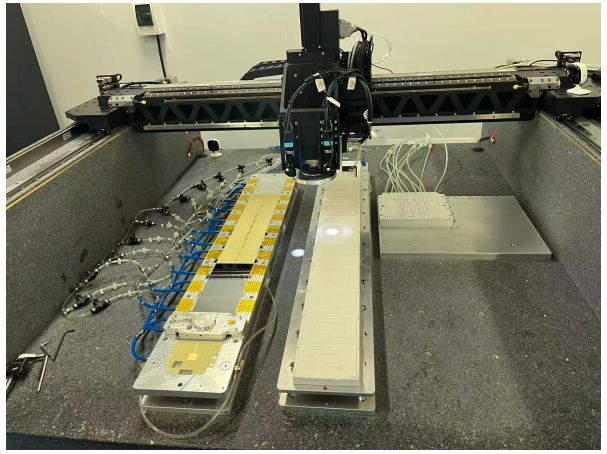
Put the support unit



Backside view after removal

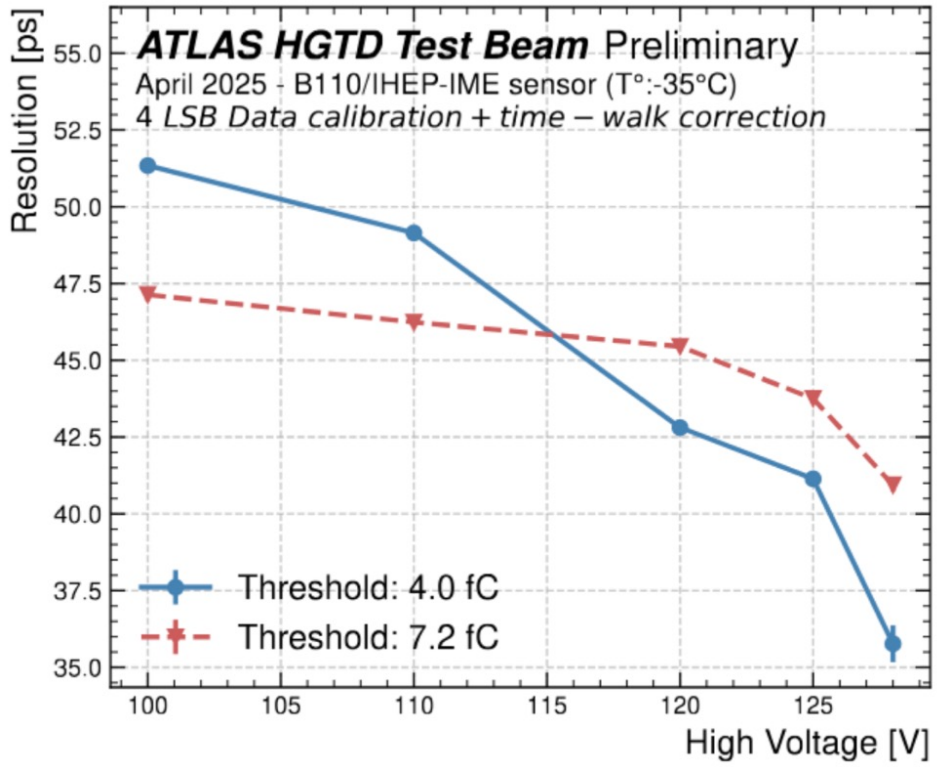


Gantry robot in IHEP hall 3



HGTD Module beam tests

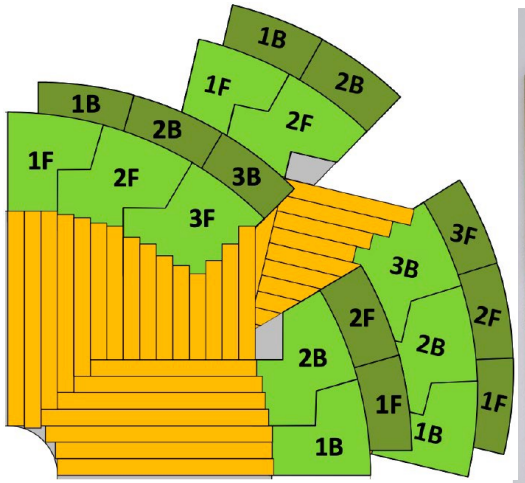
- Module level Test beam showed that
  - Individual channels is better than 50ps timing resolution
  - In next few years, HGTD will have more than 3M channels @ ~50ps resolution



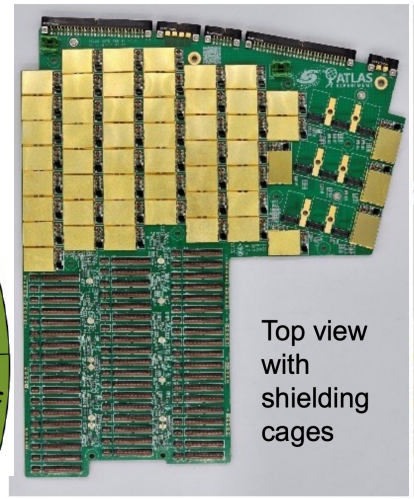
Peripheral Electronics Board (PEB) and flex tails

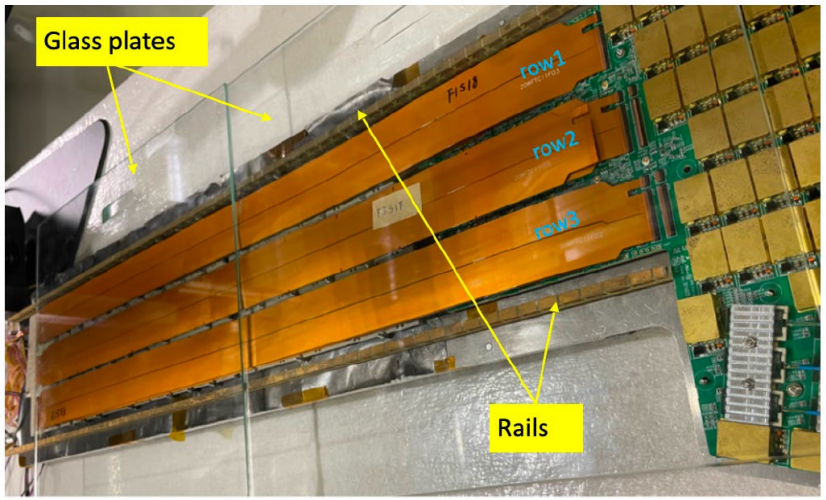
- China (IHEP/NJU) will design and produce 100% PEB (PCB fabrication)
- Challenge: fast communication with 55 modules, 24 metal layers in PCB
- IHEP and NJU developed 1st Peripheral Electronics Boards
  - Designed by IHEP, fabricated by NJU in domestic company
- SDU prototyped the flex tails

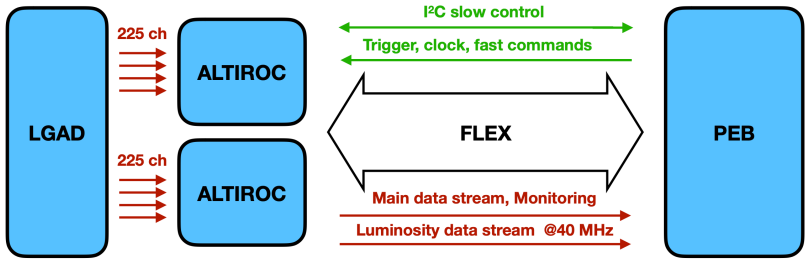
6 types of PEB



PEB1F and flex tails prototype

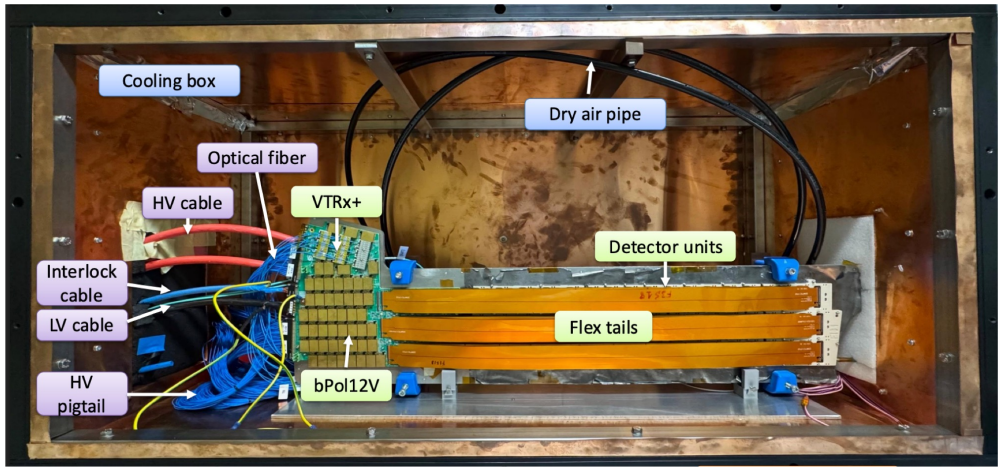






Demonstrator

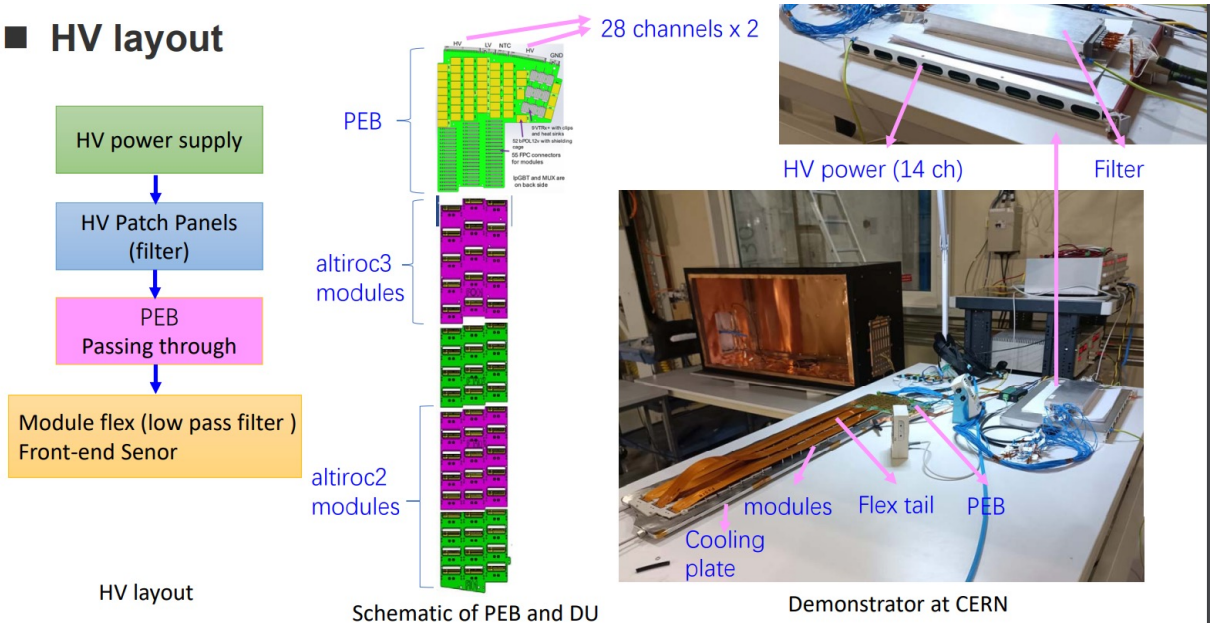
- Demonstrator setup at CERN with full chain from module to DAQ server
- IHEP/NJU/USTC/SDU played an important role on demonstrator system at CERN
  - System level tests with 55 modules
  - 1st time to demonstrate the detector system



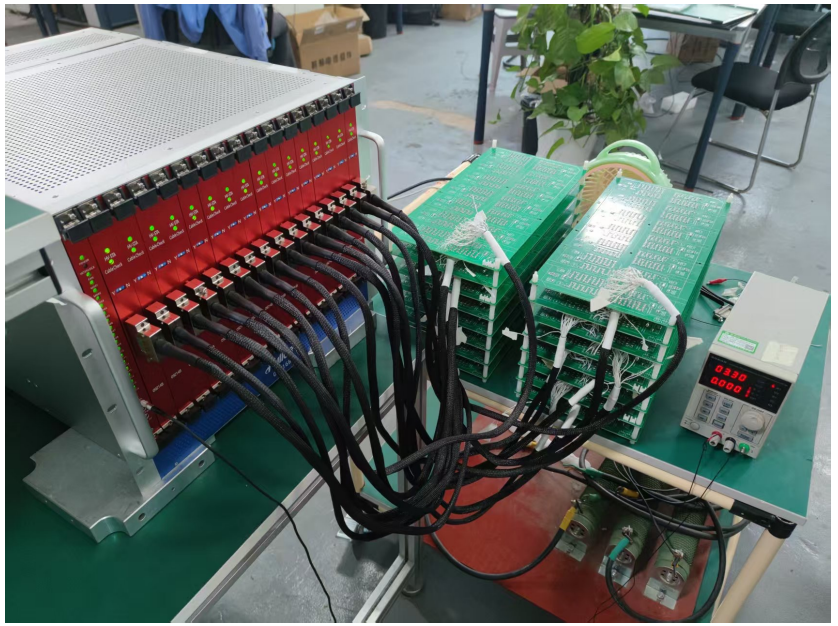
High voltage power supply

- IHEP/SDU team is developing HV power supply prototype for HGTD
  - high resolution current measurement, Dedicated Interlock for ATLAS
  - Passed HV supply FDR review
- Finished HV power supply in pre-production in Sep 2025

HV supply testing setup at HGTD demonstrator



pre-production HV power supply



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), Xuewei 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)

CERN Accelerating science

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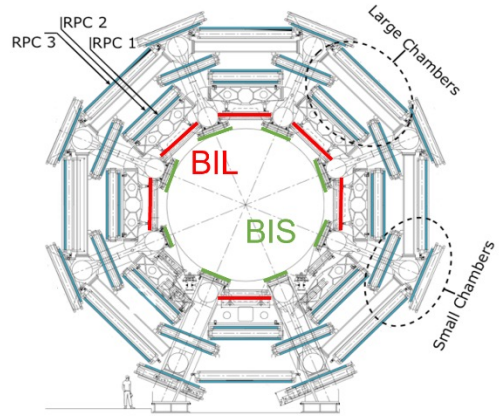
Voir en français

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

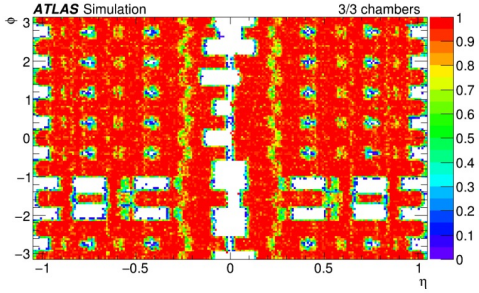
8 JULY, 2025 | By ATLAS collaboration

RPC Phase-II upgrade

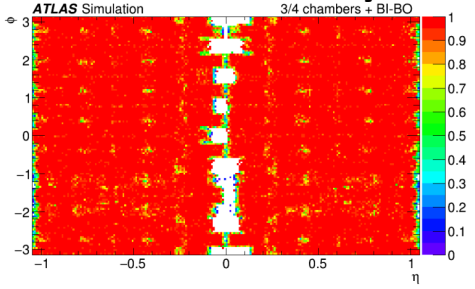


- A new generation of thin-gap RPCs in the barrel inner(BI) region
  - Higher rate capability with 1mm gas gap: 300 Hz/cm^2 → 1k Hz/cm^2
  - Higher acceptance with 3 more layers: 70% → 96%
- BI-RPC:
  - Max size of singlets: 1820mm*1096mm
  - 9000 front-end boards
- New Front-End Electronics
  - Higher sensitivity ASICs to compensate for amplification factor
  - Dedicated Faraday cage and grounding needed
- New readout design: η- η readout for 2D

Run2



With new BI Layer

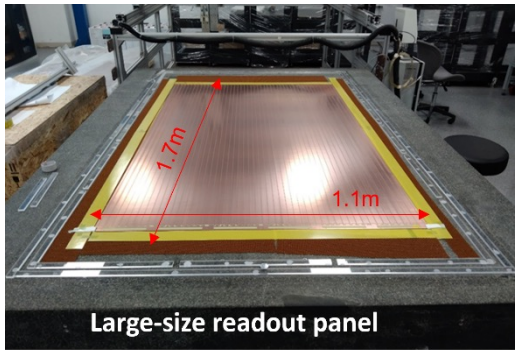


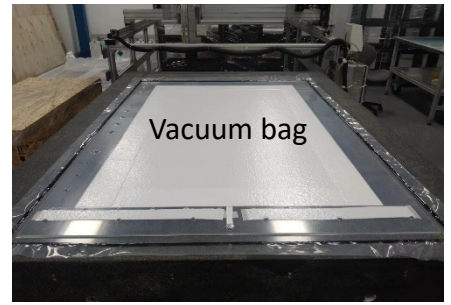
- China contribution (USTC-SDU-SJTU-ZZU)
  - Mass production of 912 readout panels and 72 gas gaps
  - Assembly of 360 singlets
  - Manufacture and test of about 5000 front-end electronic boards

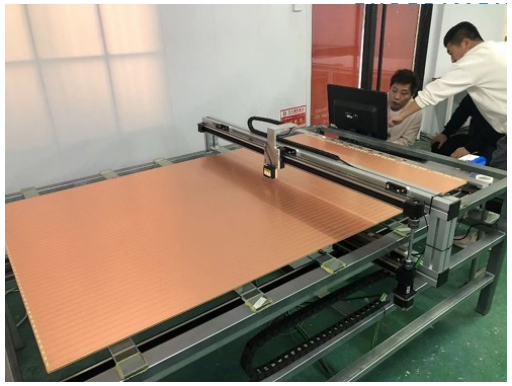
- Main activities:
  - Readout panel production
  - RPC gas gap production
  - Singlet assembly
  - Data acquisition system

Readout panel production

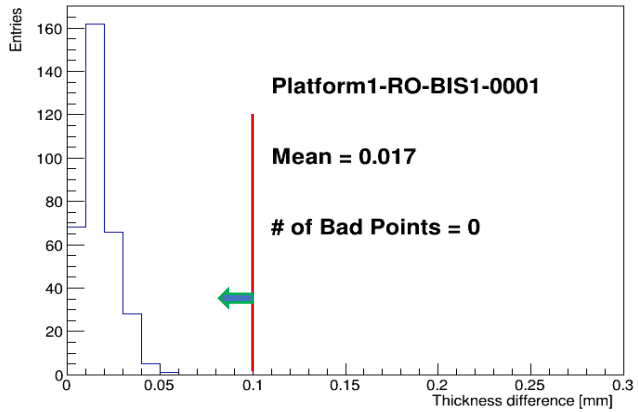
- New paper honeycomb structure
  - Lighter & stiffer: better uniformity
  - Honeycomb core (3mm) sandwiched by two PCBs (0.4mm)
- Key technologies and challenges
  - Large-size PCB production: full BIS size of 1705x1072mm
  - Flatness and uniformity over the full panel: vacuum bag pressure on marble table
- All BIS panels (576) have been produced and qualified
  - All satisfied the specifications (Flatness: < 100 μm in 7 cm x 7cm matrix)



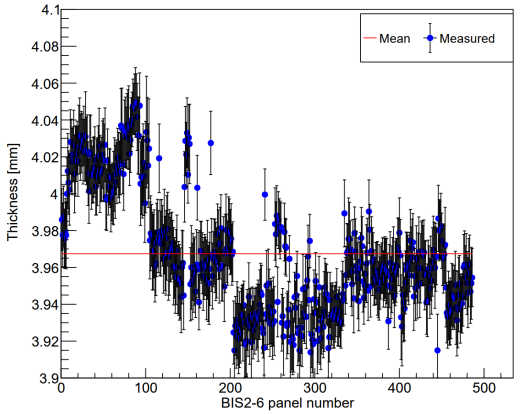




Automatic thickness measurement
(~400 points scanned in 15min)



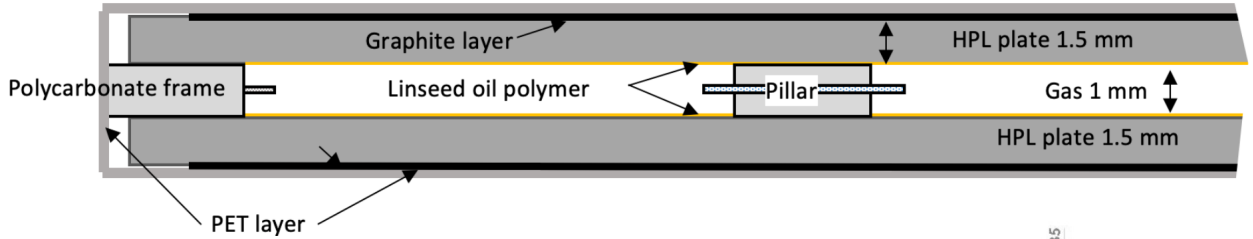
Thickness variation in 7x7cm matrix

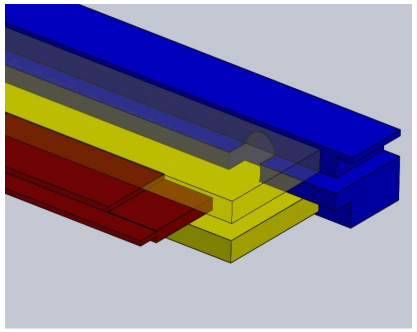


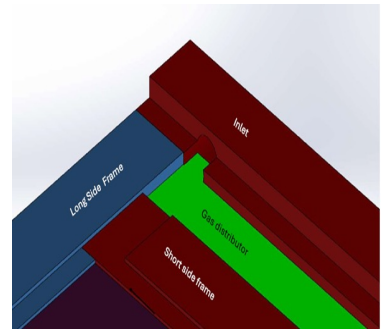
Quality of all panels

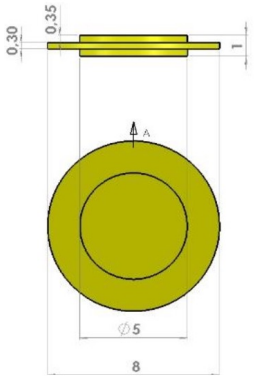
Gas-gap production

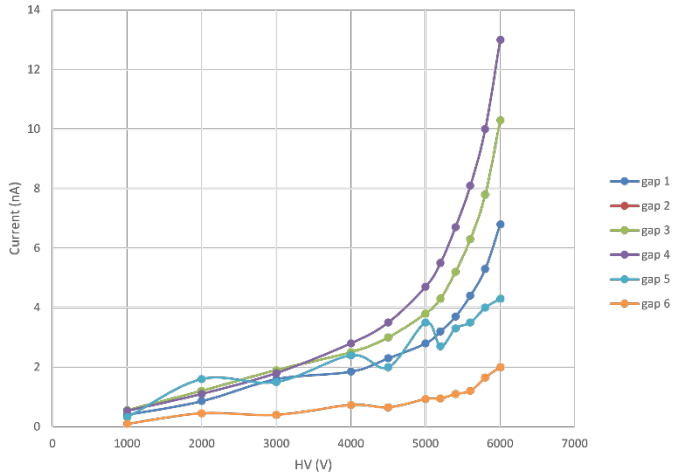
- Gas gap components:
  - 1.5 mm High Pressure Laminates plates (HPL)
  - 1.0 mm spacers and frames
  - Graphite electrodes
  - Insulating PET foils
- Key technologies and challenges
  - Spacer and frame production: precision machining
  - Graphite coating:
    - ✓ Surface resistivity uniformity: 350±100 kΩ/□
  - PET foiling
    - ✓ automatic thermal laminating machine
  - Gas gap tightness and flatness
    - ✓ Vacuum bag + marble table with proper pressure.
  - Linseed oiling
    - ✓ Improve the smoothness of the electrode surface
    - ✓ Ensure that the final linseed oil coating is thin and well polymerized.
- 8 RPC gas gap (130cm x 68 cm) prototypes built
  - Six are under qualification in GIF++



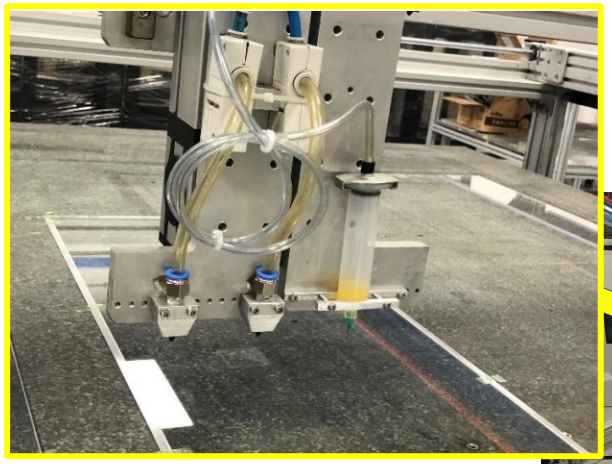


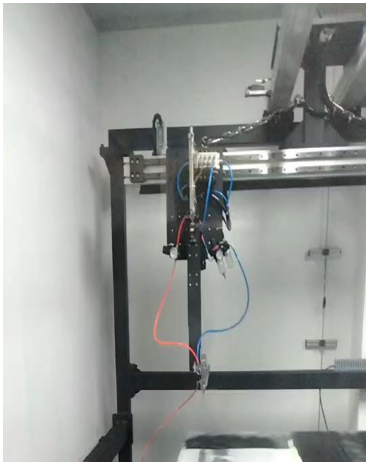






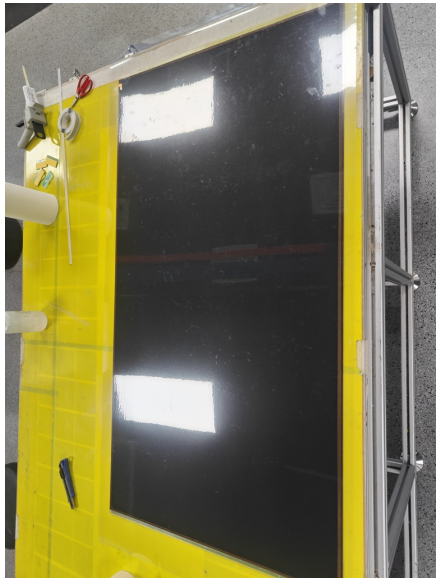
Gas-gap production



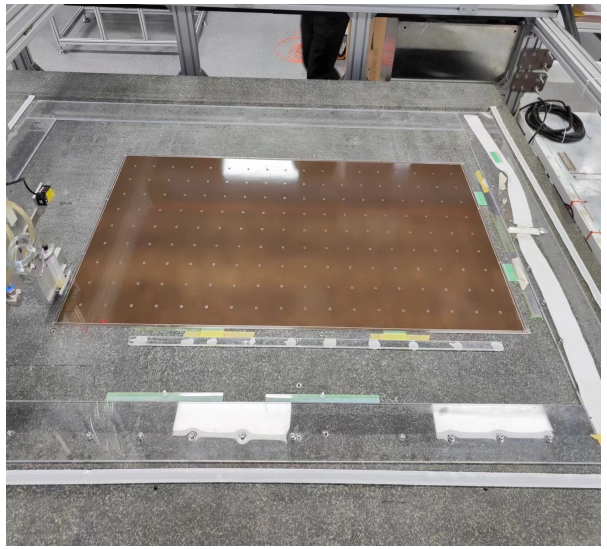


Graphite spraying system

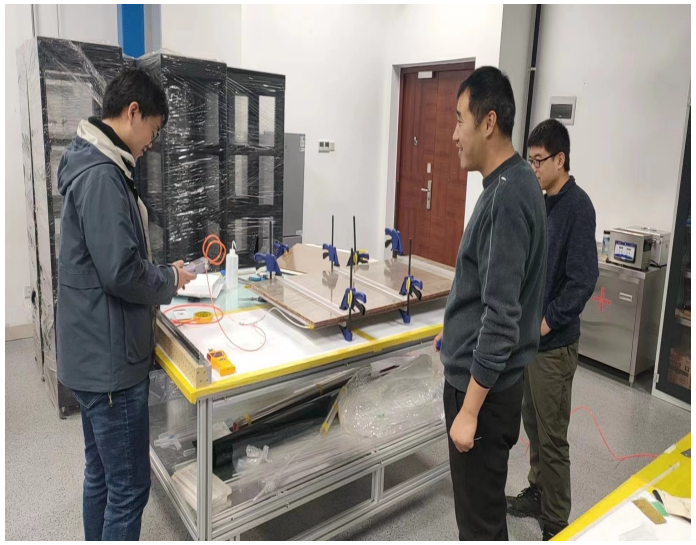
Graphite coating



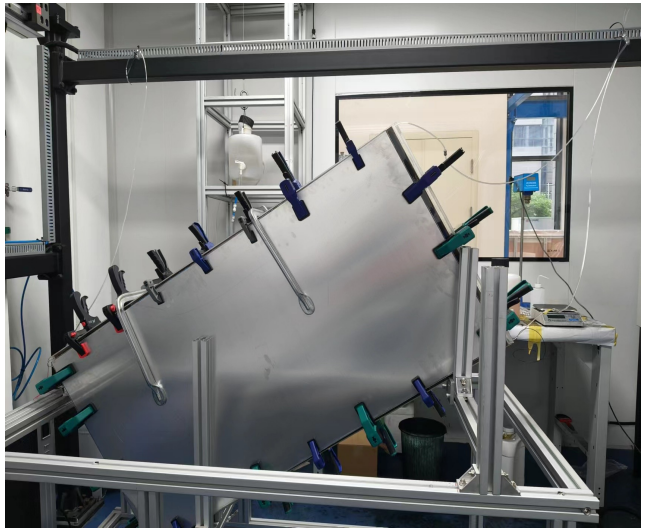
PET foiling



Glue spacers on HPL

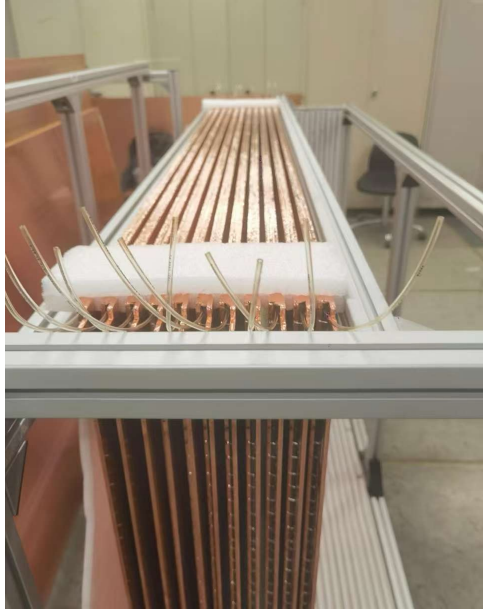


Gas gap tightness test

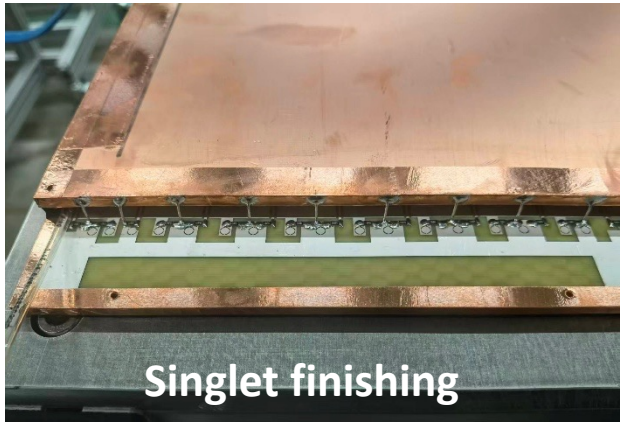


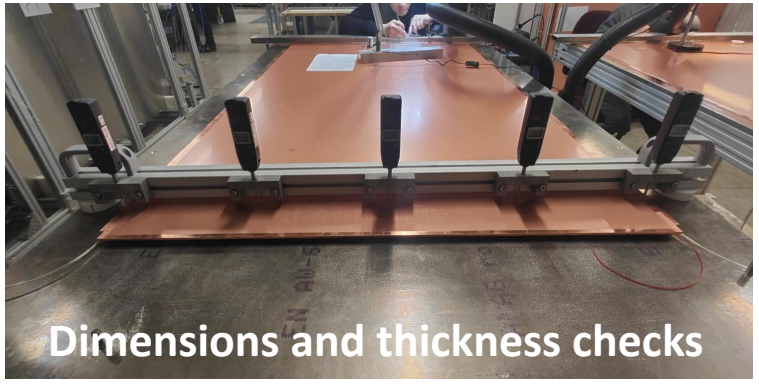
Linseed oiling

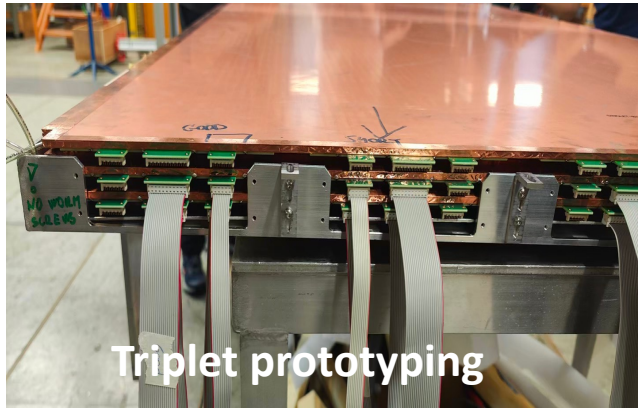
Singlet assembly work

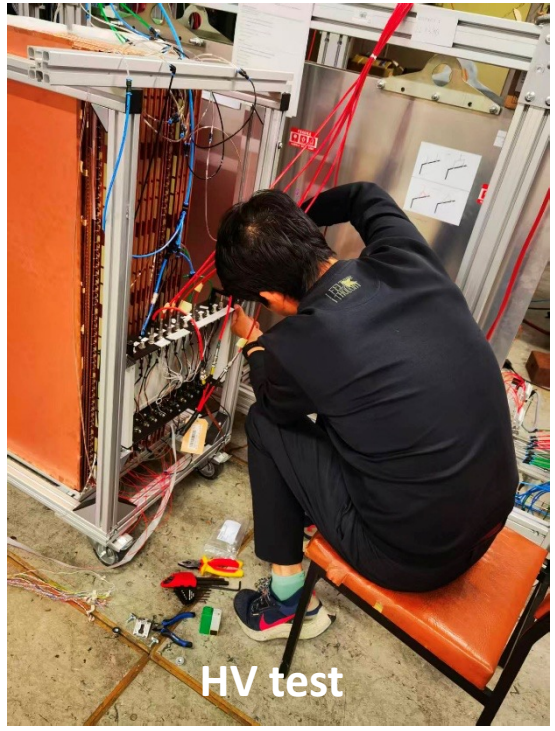


- BIS RPC singlets assembly at CERN
  - Join the assembly training task in July to fully set up the assembly procedure
  - 24 BIS singlets have been produced
  - Dimensional, gas-tight, and HV test performed on the singlets
  - Waiting for the readiness of the FE boards



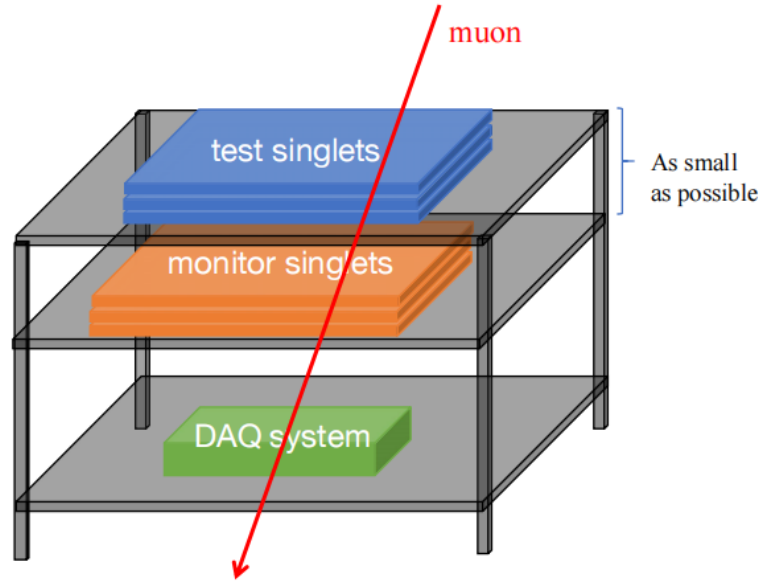




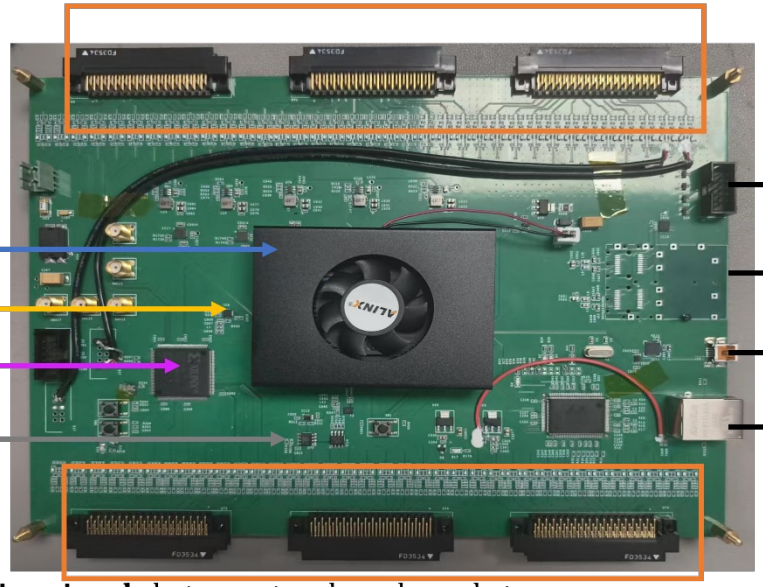


Data acquisition system

- For RPC qualification in the cosmic ray station.
- Design goals
  - 288 channels for one test station
  - TDC function compatible with backup and baseline FE ASIC
  - three trigger modes: external/self/master-slave



Receive data from FE board
18 FE boards = **144 channels** in total.
Integrates 144 channels **polarization circuitry**. Capable of receiving signals from **baseline or backup FE**

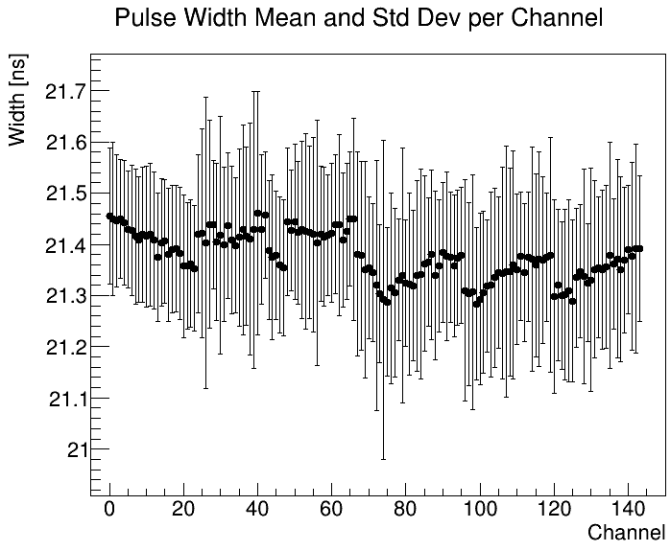


Xilinx KINTEX UltraSacale: XCKU060
Central processing and control
Manchester decoder or TDC

Clock buffer
40 MHz LVDS clock output from FPGA.
Split into 2 channels,
then further distributed into 18 channels.

CPLD:XC95144XL
Processes 18 fast_or signals from FE board.

Other
Temperature sensor, SMA, buttons, fan, **cascading signals** between two boards, and etc.



Summary

- Phase-2 upgrade is undergoing to make the detector keep up with the upcoming HL-LHC running
  - 200 interactions/bunch crossing to reach 3 ab^{-1}
- Chinese clusters have contributed greatly in ITk, HGTD and RPC
  - Detector production, test and assembly
  - Electronics, …
- Taking leading roles and made significant progresses in the past year

Backup

Motivation of Inner Tracker Upgrade

- Radiation Damage
  - Current tracking detector can not meet the HL-LHC: 4000 /fb
    Pixels (400 /fb), SCT (700/fb), IBL (850/fb)
  - Above the design fluences, the intrinsic hit efficiencies drop and leakage currents exceed power supplies limits, affect on-detector power and cooling system
- Bandwidth Saturation
  - Current front-end electronics can not handle luminosity 7.5×10^{34} $cm^{-2}s^{-1}$, <PU>200
    Pixel and SCT: 2×10^{34} $cm^{-2}s^{-1}$, <PU>50
- Detector Occupancy
  - TRT occupancy will reach 100%