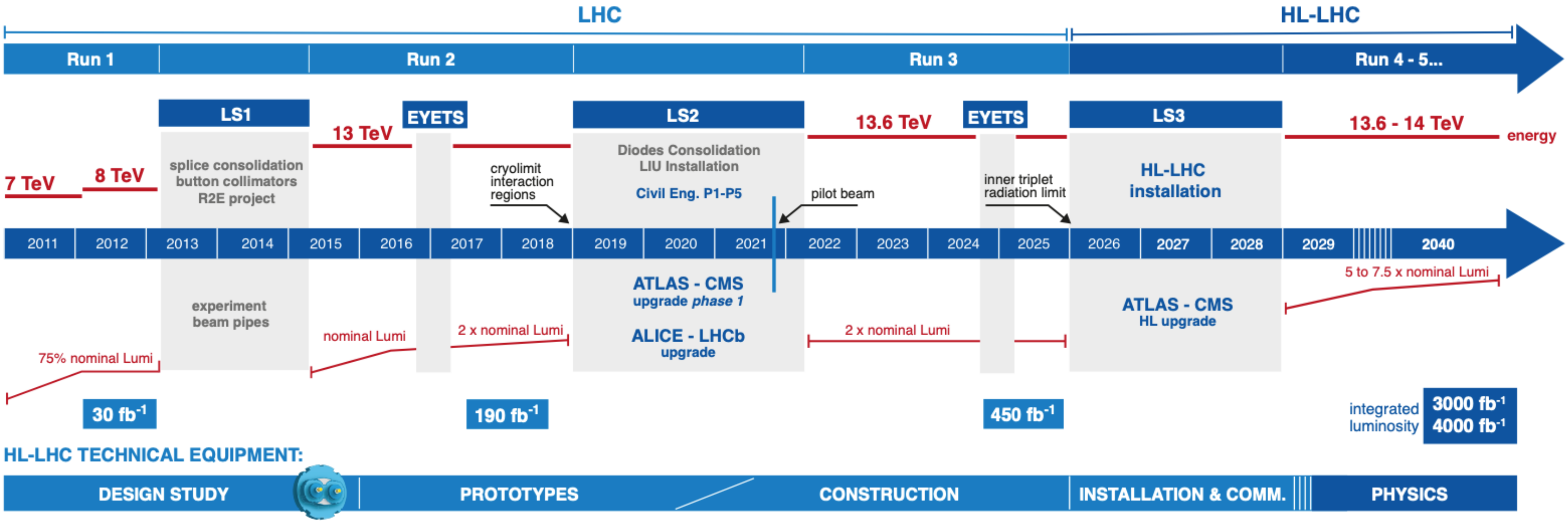
ATLAS Detector Upgrade

Xin Shi (IHEP)

On behalf of ATLAS China Clusters

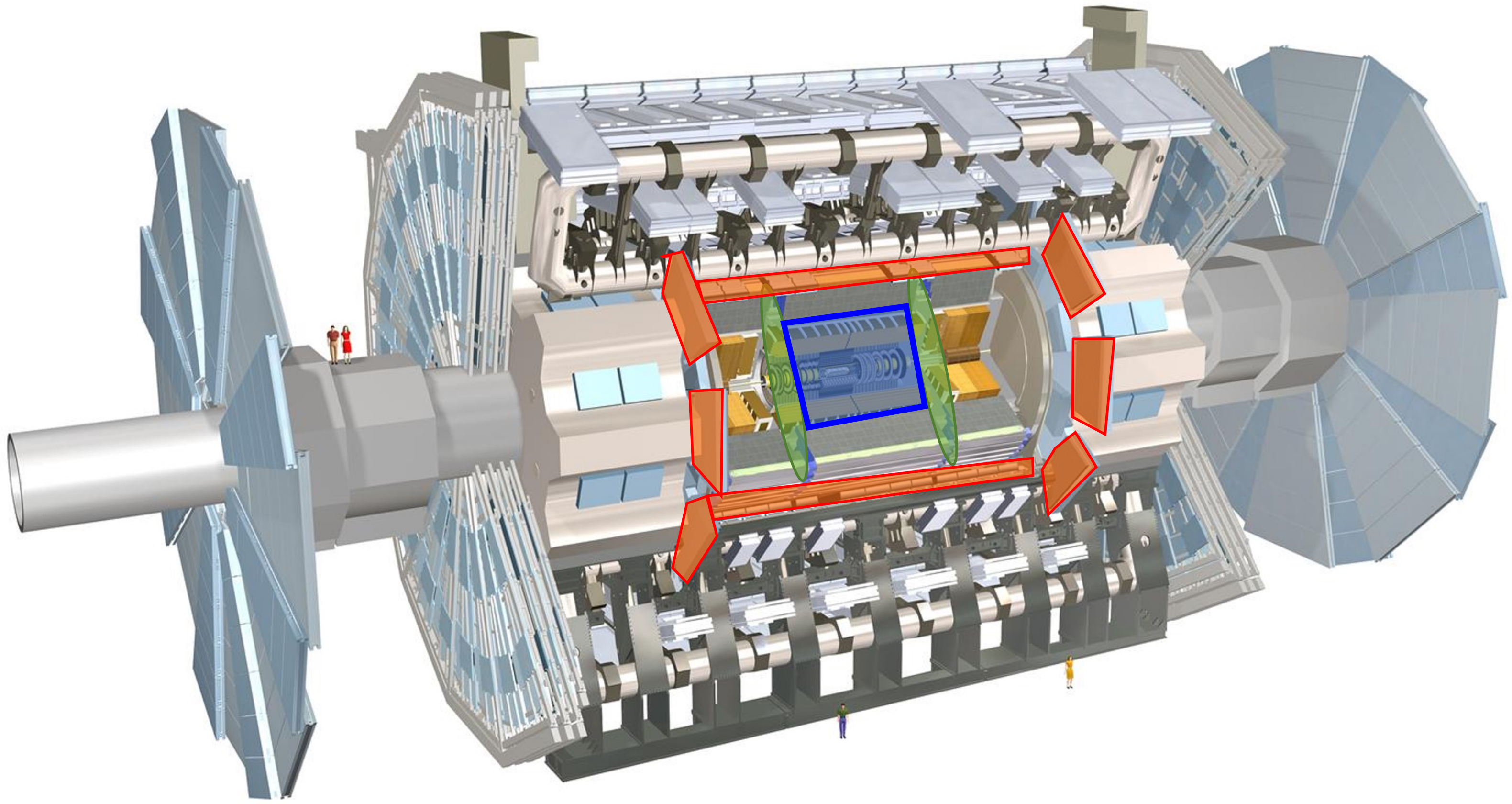
LHC / High Luminosity LHC Plan



https://hilumilhc.web.cern.ch/article/ls3-schedule-change

- HL-LHC will start in ~ 2029, ultimate goal of 4000 fb^{-1}
- Instantaneous luminosity 7.5×10^{34} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$, 5~7.5x increase
- Average number of interactions per bunch crossing (pile-up events) ~ 200

ATLAS Phase-2 Upgrade



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 small upgrades

- Luminosity detectors (1% precision)
- HL-ZDC (Heavy Ion physics)

High Granularity Timing Detector (HGTD)

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

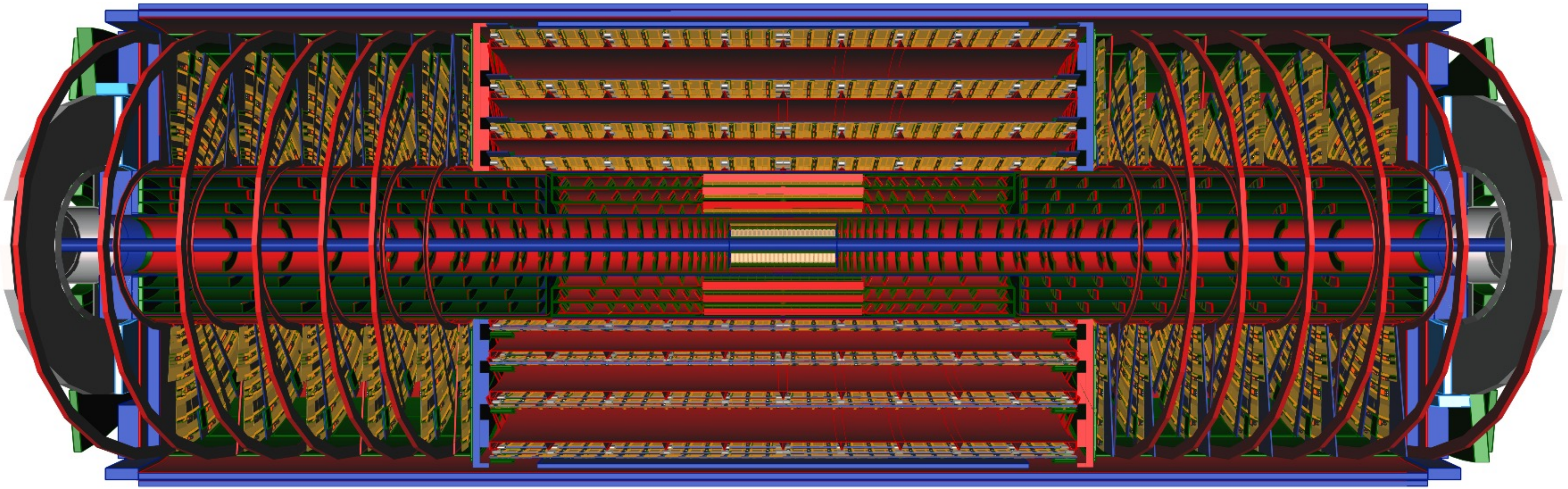
New Muon Chambers

- Inner barrel region with new RPCs, sMDTs, and TGCs
- Improved trigger efficiency/momentum resolution, reduced fake rate

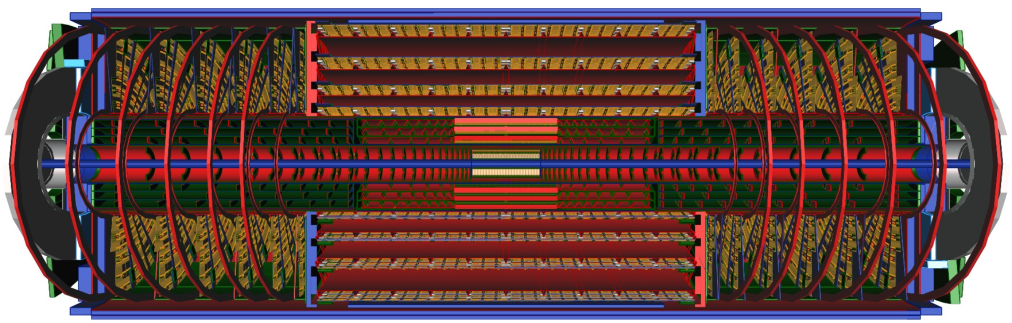
New Inner Tracking Detector (ITk)

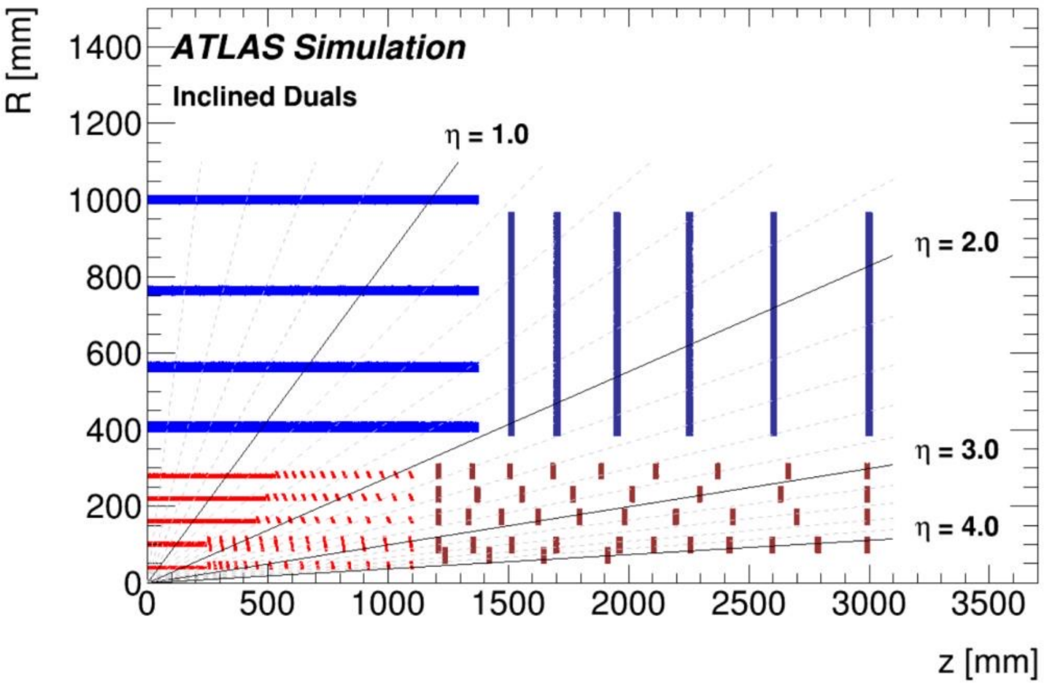
- All silicon with at least 9 layers up to $|\eta| = 4$
- Less material, finer segmentation

Inner Tracker (ITk) Detector



Inner Tracker (ITk) Strips Silicon Tracker





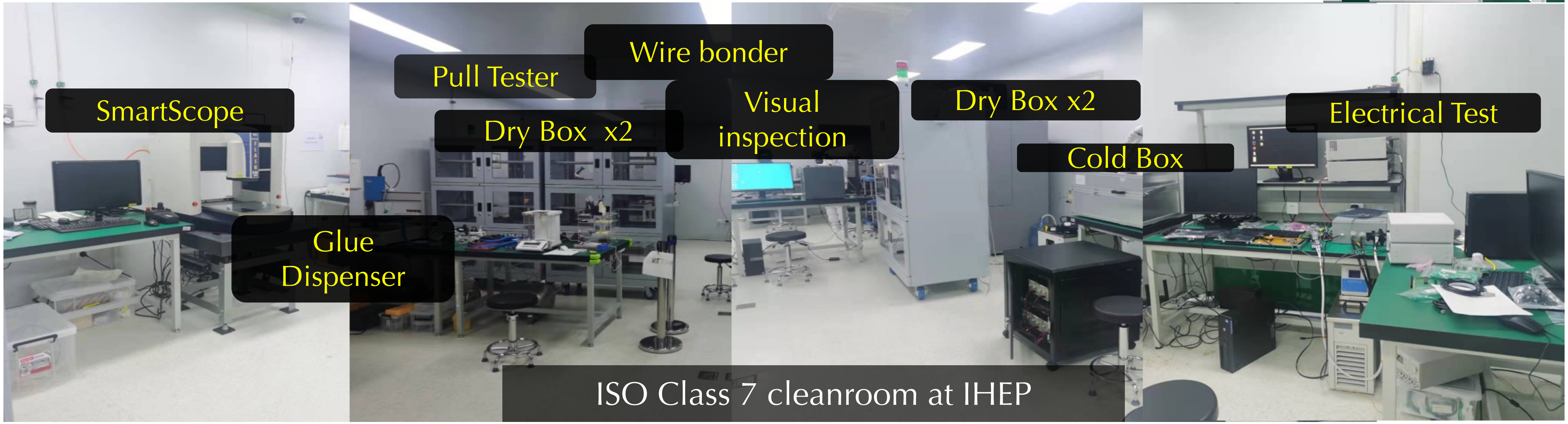
- All-silicon Inner Tracker (ITk) with extended coverage ($|\eta|<4$) to improved the tracking performance
- IHEP and THU committed to deliver 1000 strip barrel modules ($10m^2$ of sensor surface)
- 10% of total strip barrel modules (US 50% + UK 40%)
- Additional contributions to strip barrel system integration, installation and commissioning

Objectives

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

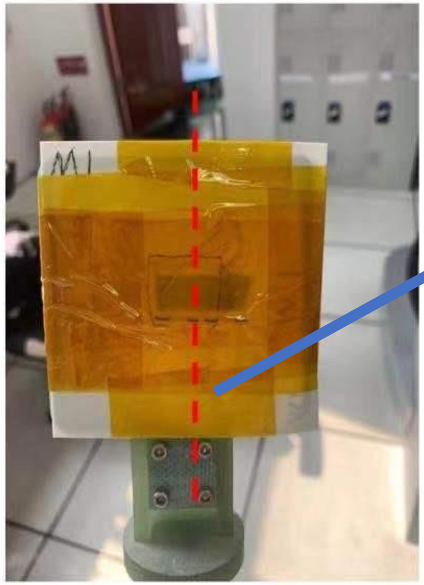
IHEP Site Module Production Status

- Passed Pre-Production A Module SQ
- Produced two PPA strip modules
- X. Shi as UK/China cluster manager for 50% barrel production
- Aim to pass all SQ steps by 2022



Radiation Hard Strip Sensor Study

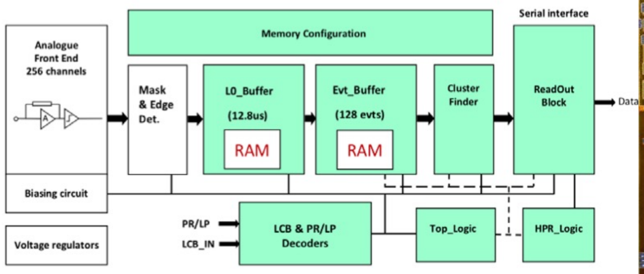
- Carried out one irradiation with two fluence points on Dec 2021
- Reported on the collaboration meeting Feb 2022
- Approved as a Qualification Task by ATLAS ITk on Mar 2022 to evaluate the possibility of proton irradiations at the Associated Proton Experiment Platform (APEP) in China Spallation Neutron Source (CSNS) for ITk strip sensor production quality assurance (QA)
- Working on the second irradiation with controlled temperature and relative humidity

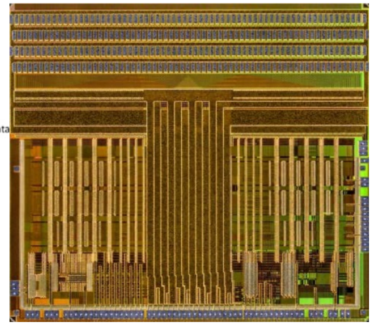


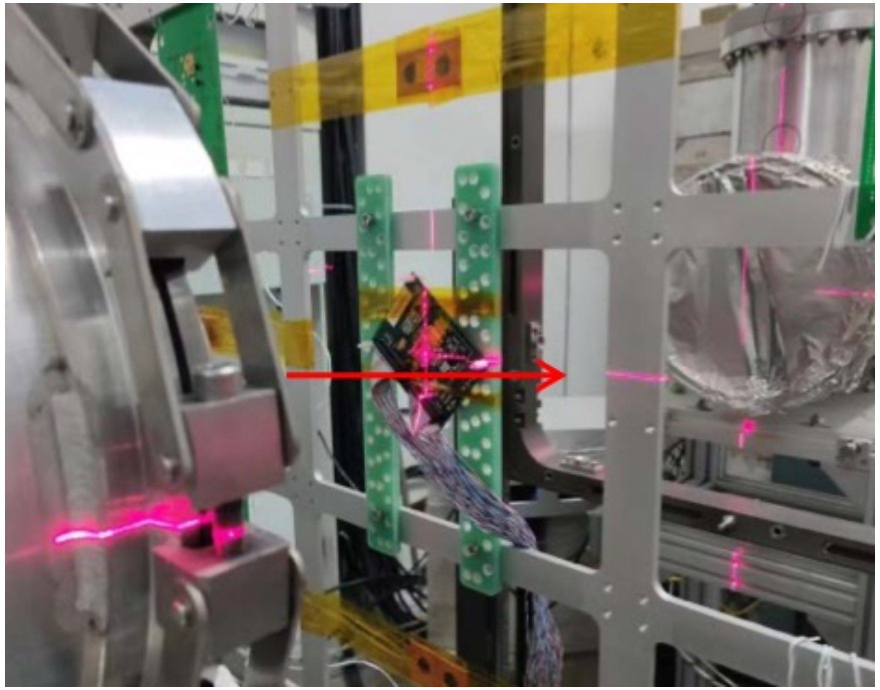
beam energy [MeV]	proton fluence [p/cm^2/s]	Conversion factor	neutron fluence [n_{eq}/cm^2]	total proton fluence [p/cm^2]	run time [h]
80	3.40E+09	1.427	2.02E+14	1.42E+14	11.59
80	3.40E+09	1.427	1.03E+15	7.23E+14	59.09

Radiation Hard ASICs Study

- The ABCStar (ATLAS Binary Chip) front end readout ASIC for strip sensor
- Process of signals from 256 silicon strips with multi-trigger data flow control
- Key component of ITk strip module, ~300,000 needed for production
- TID studied with X-ray machine at IHEP
- Carried first SEE test at CSNS in 2022
- Further SEE test for the latest chips: ABCStarV1, HCC and AMAC

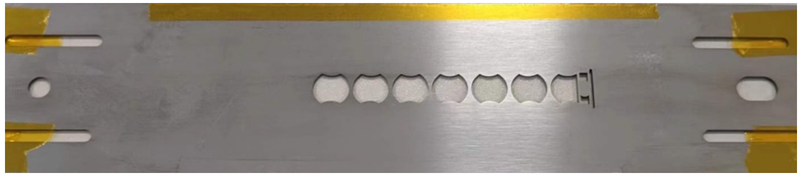


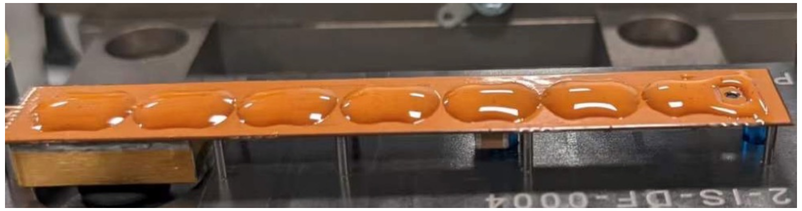


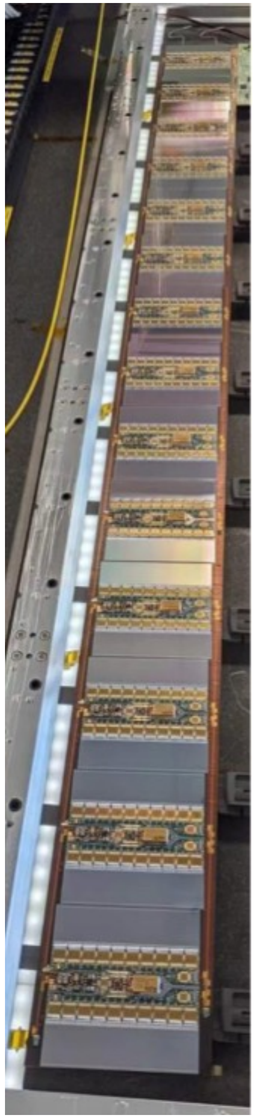


RAL Site Module Production and Stave Loading

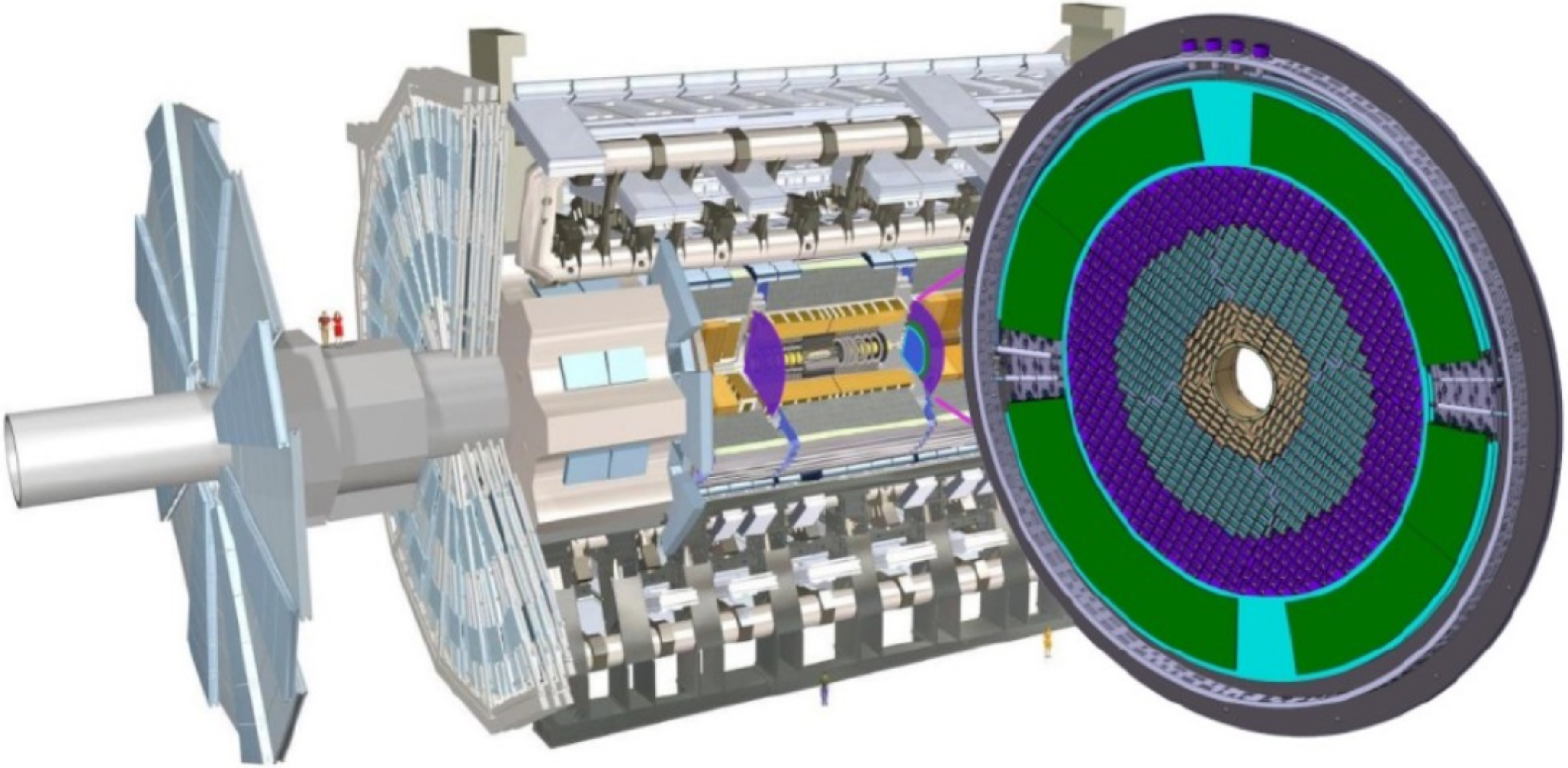
- Two FTEs from IHEP based at RAL (one postdoc + one student)
- Contributed to RAL site module production and stave loading
- Contributed to beam test and analysis
- Active on tools design tweak, cold noise study, wire bond oscillation test, etc
- Involve in the tracker system integration in the future





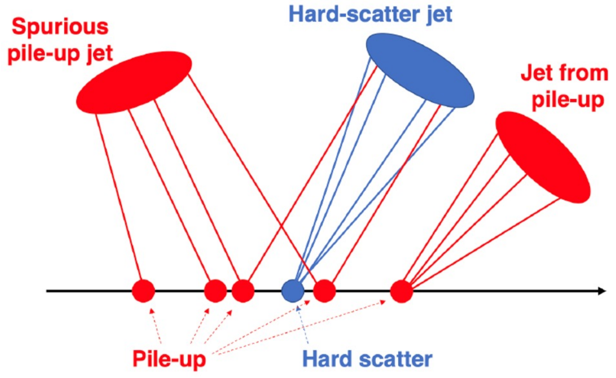


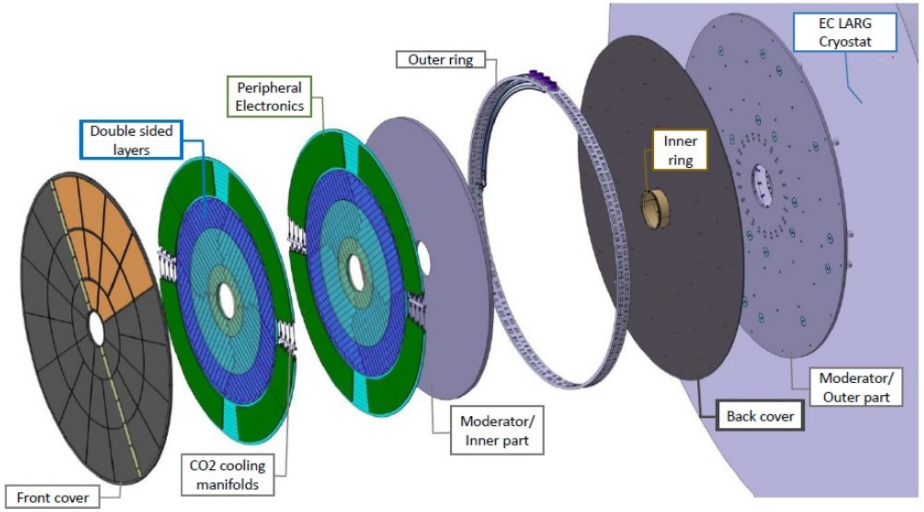
High Granularity Timing Detector (HGTD)



High Granularity Timing Detector (HGTD)

- Improve the forward region with increased pile-up
- Improve time resolution by two orders of magnitude
  - Several nano seconds to 30 pico-seconds
- Millimeter granularity and 3M readout channels
- Target irradiation fluence: $2.5 \times 10^{15}\ n_{eq}/cm^2$



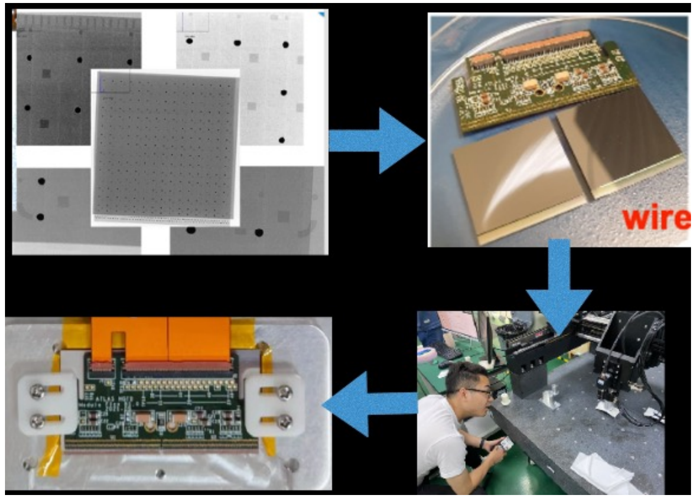


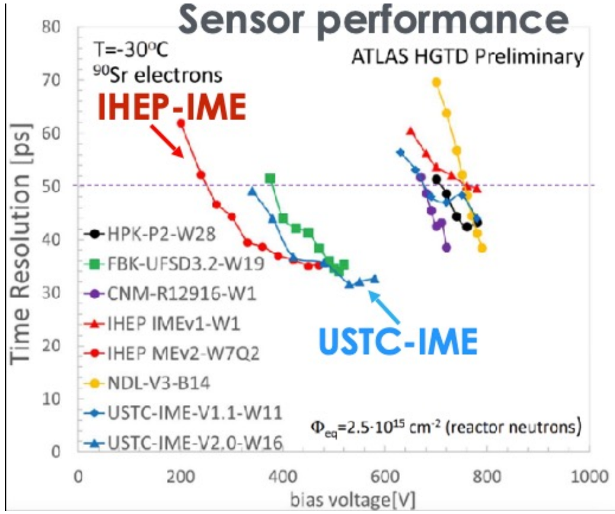
- Located between barrel and endcap calorimeters ($|z| = 3.5$ m)
- Silicon detector modules mounted on disks
- Two sensor layers/disk
- Two disks/side
- Active area: 12 cm < r < 64 cm
- Coverage: $2.4 < |\eta| < 4.0$

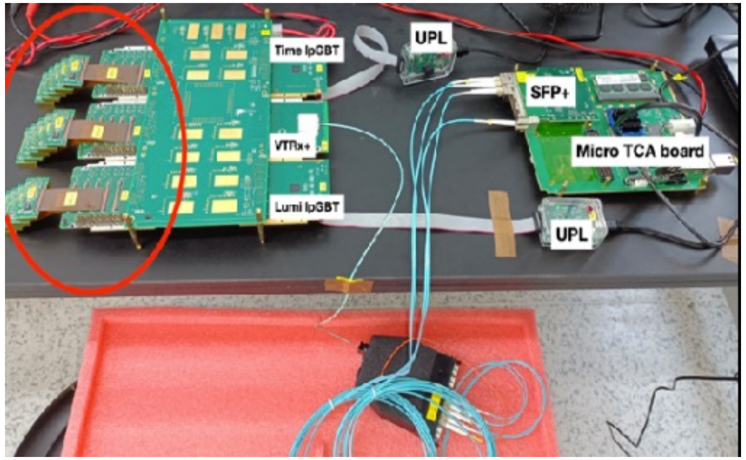
China contribution in HGTD

- 34% of LGAD sensors (IHEP-IME, USTC-IME)
- 100% module flex electronics
- 50% module hybridization
- 44% module assembly
- 50% module supports
- 33% flex cables
- 67% design/100% production peripheral electronics
- Low voltages power supplies

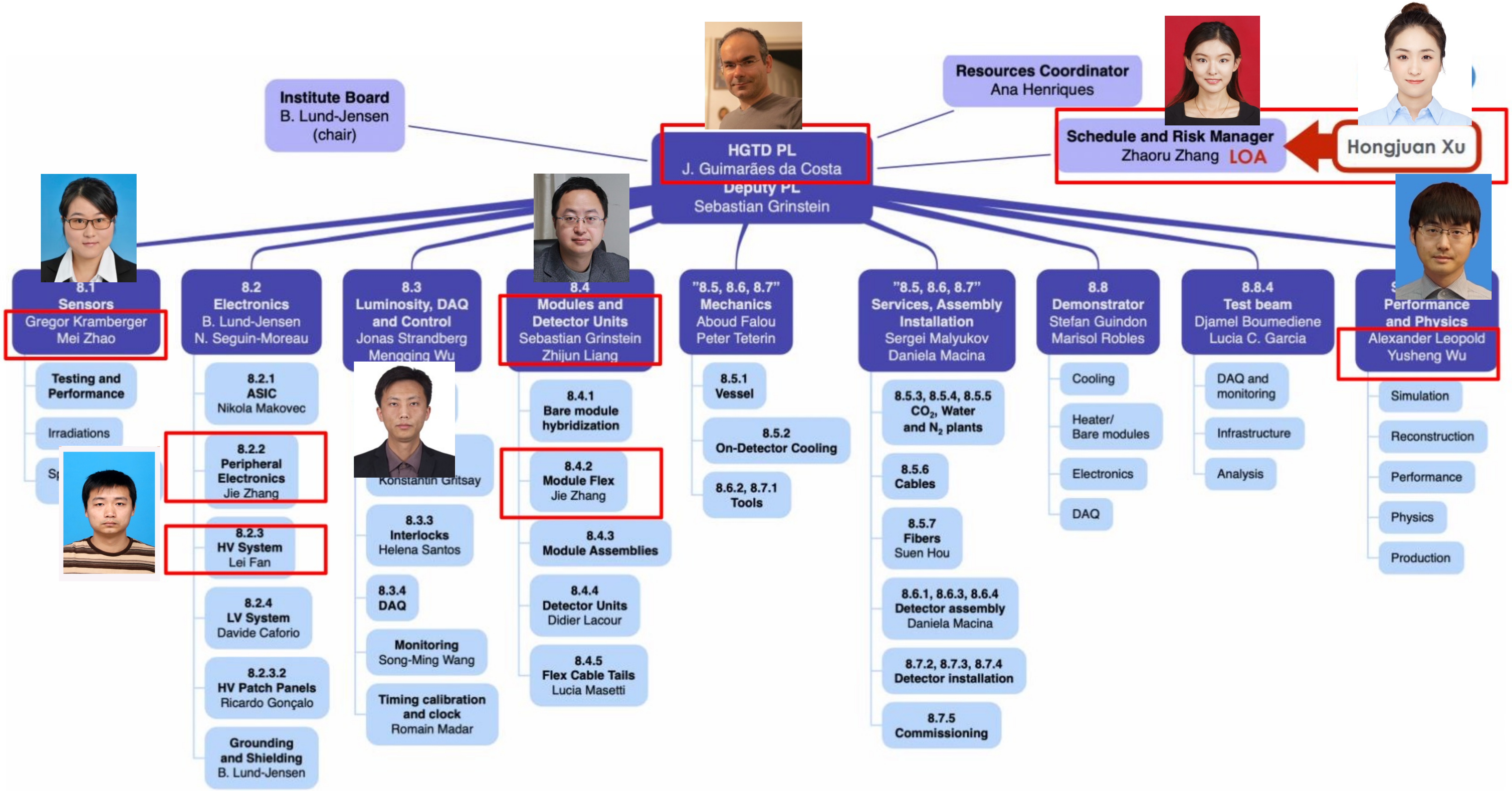
- Project leader
- HGTD risk and schedule coordinator
- L2 Sensors coordinator
- L2 Module coordinator
- L3 Module flex coordinator
- L2 software coordinator
- L3 Peripheral electronics coordinator
- L3 High Voltage coordinator
- HGTD Speakers committee Chair





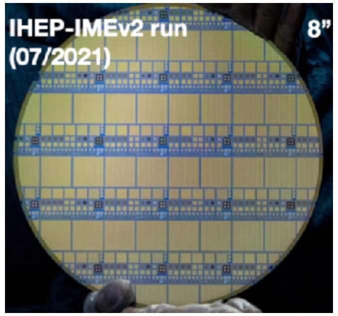


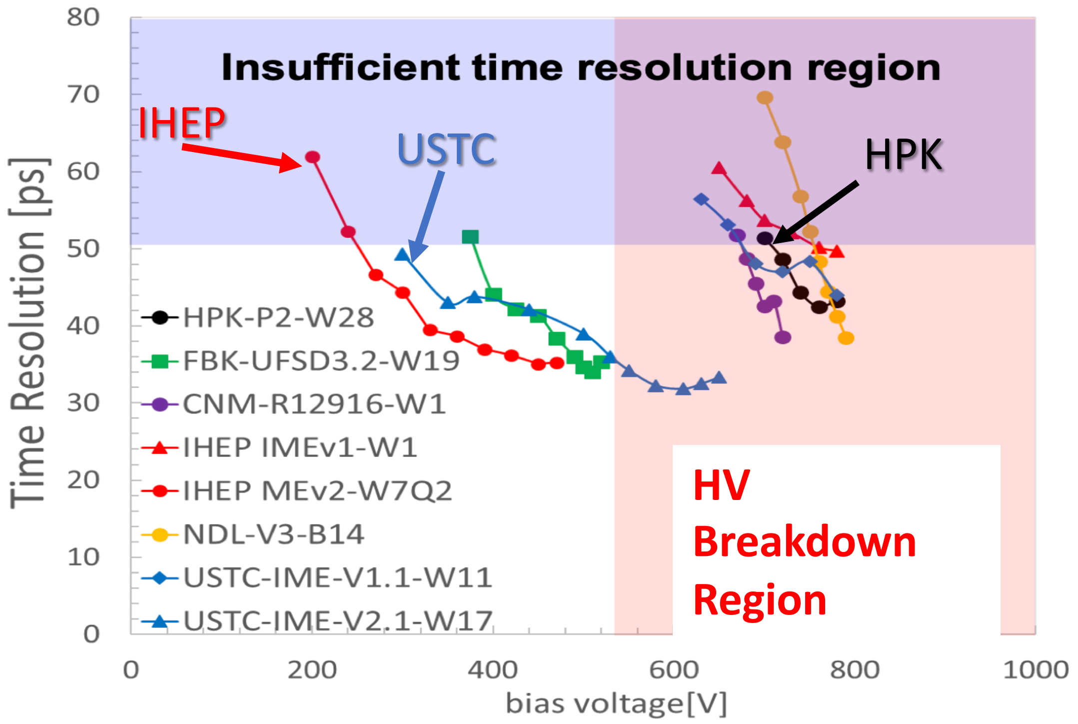
HGTD Management Contribution from China

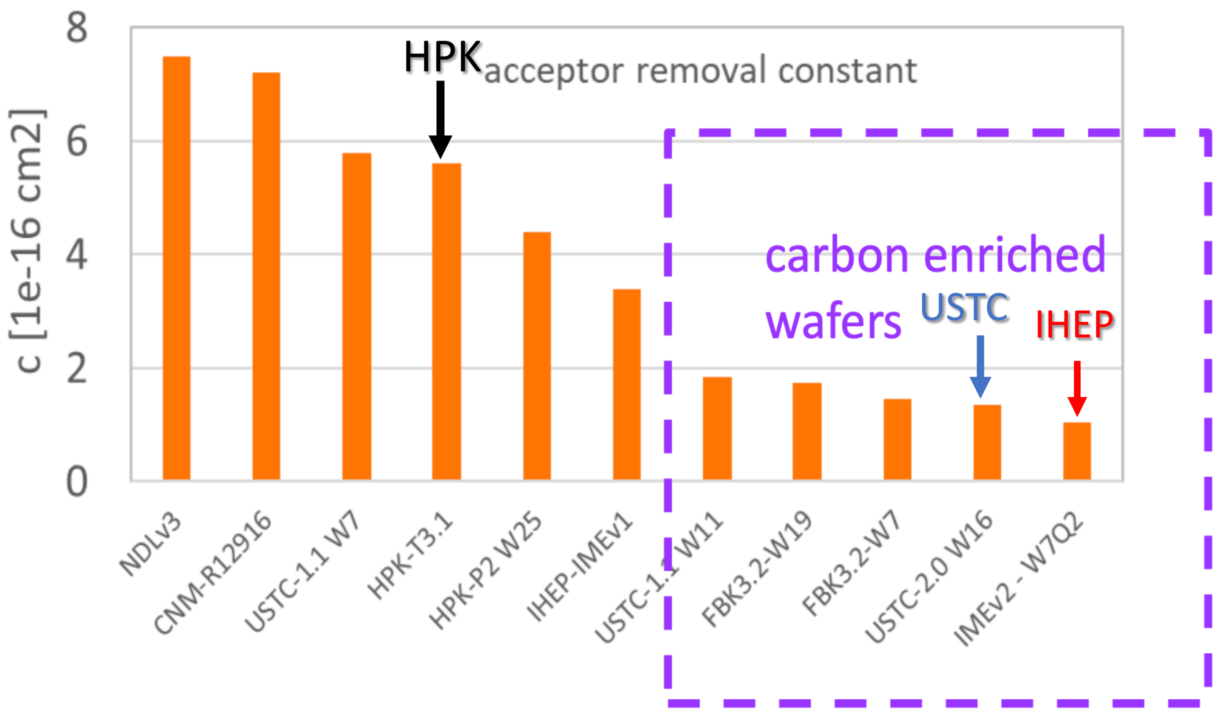


LGAD Sensor R&D

- IHEP and USTC developed radiation hard LGAD
  - Reach 30-50ps after $2.5\times10^{15}\ n_{eq}/cm^2$
  - Significant more radiation hard than HPK sensor
  - Passed ATLAS market survey > 34% to HGTD

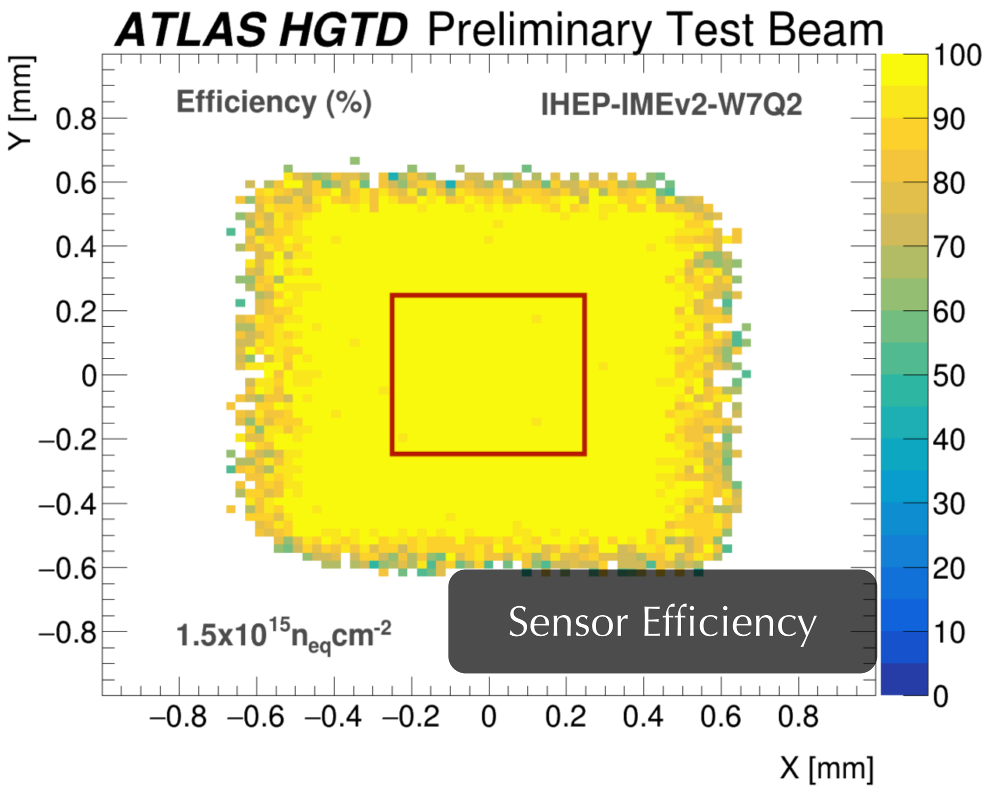


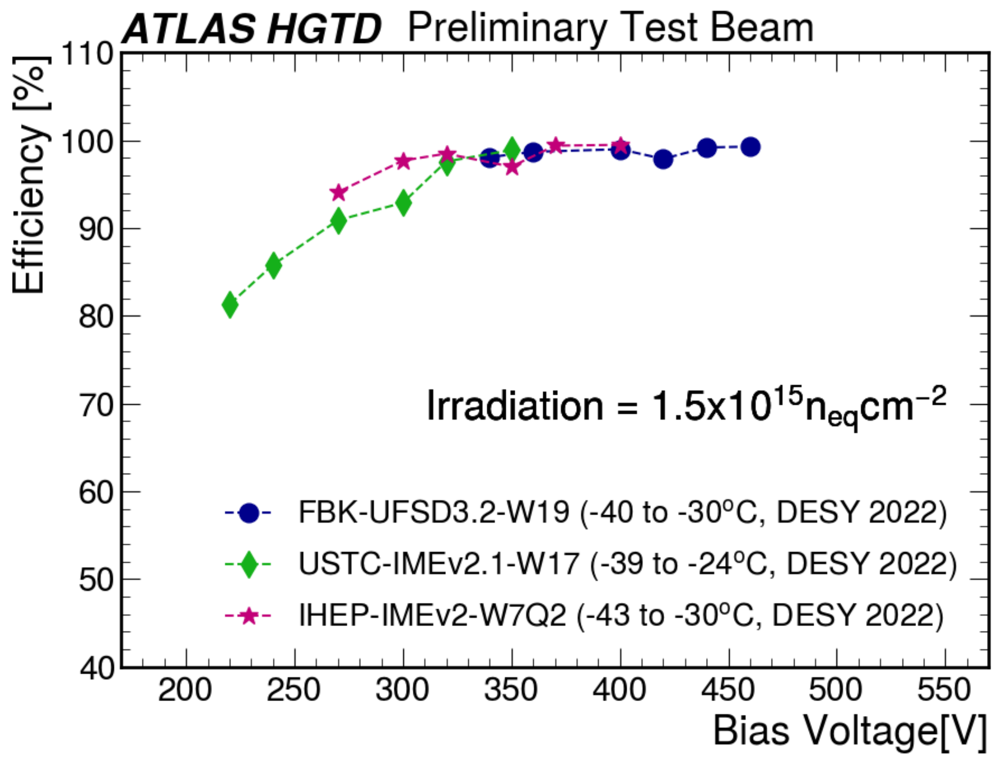




LGAD sensor performance

- LGAD sensors ~100% efficiency in test beam after irradiation
  - Both for IHEP and USTC
- Passed single-event-burnout test at CERN test beam

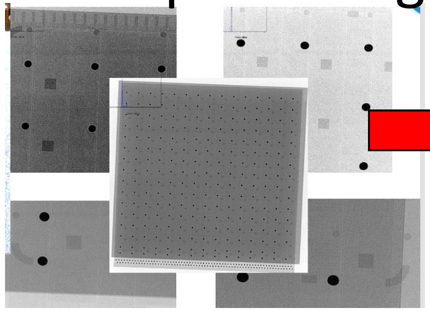




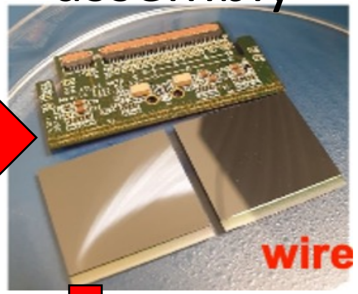
HGTD module production

- China will produce ~4000 modules (44%)
  - 6 module production sites:
    IHEP, USTC, Germany, France, Spain, Morocco
- IHEP is the largest production center (34%)
  - IHEP developed 1st module in HGTD
    with automatic assembly procedure
  - Module Flex design and production
- USTC will deliver 10% modules

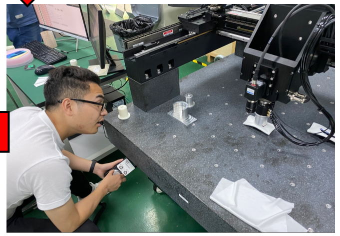
ASIC and LGAD Bump bonding

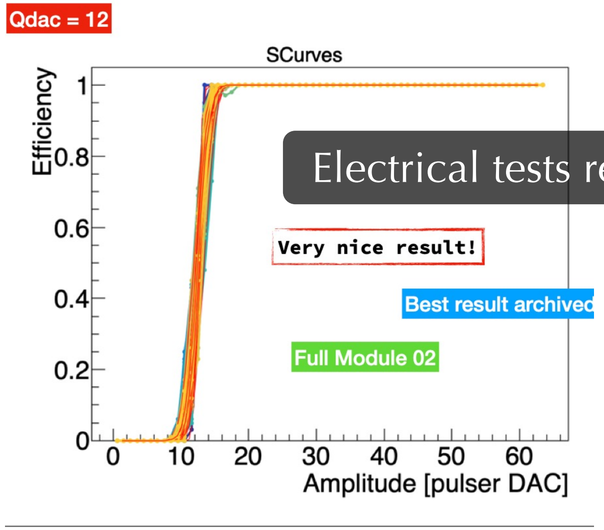


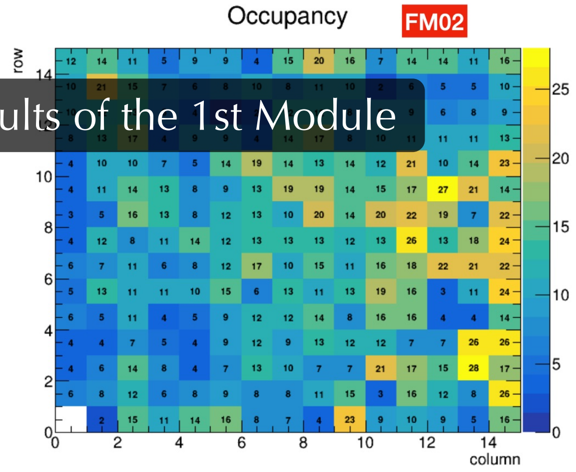
Module assembly



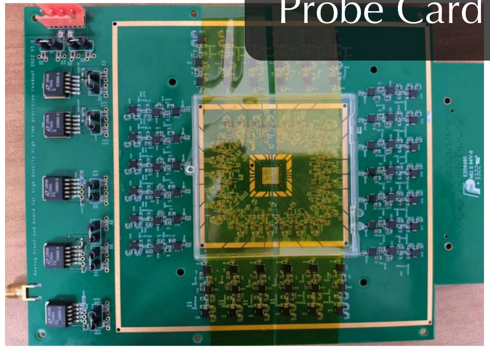
full-size module

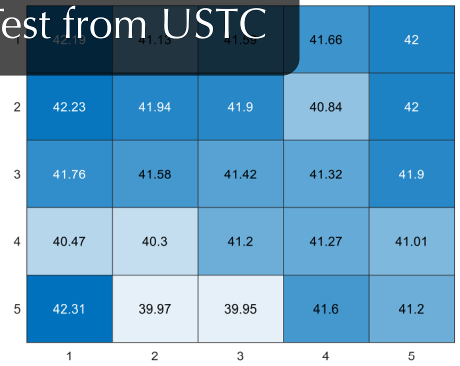






Electrical tests results of the 1st Module

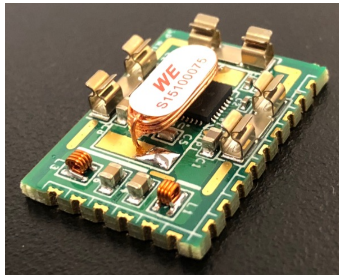




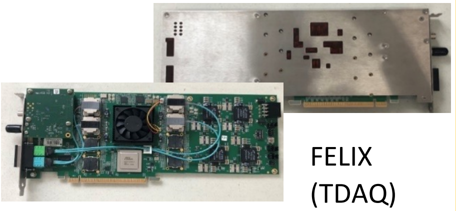
Probe Card Test from USTC

Peripheral Electronics and DAQ Demo System

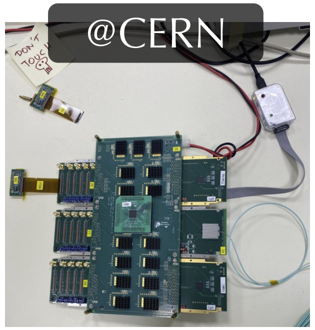
- Peripheral Electronics Boards
  - Design and test each sub-module circuit lpGBT&VTRx+, bPOL12V, MUX64
  - Pass the proton irradiation test at CSNS
- Demonstration System
  - Complete prototype demonstration system
  - Full chain readout from front-end modules to back-end TDAQ
  - Small-lot production and delivery to collaboration

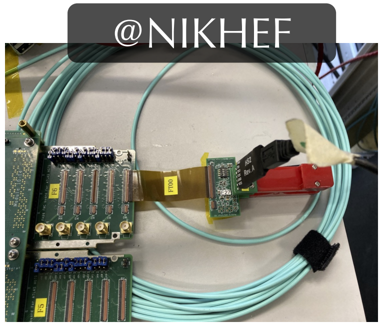


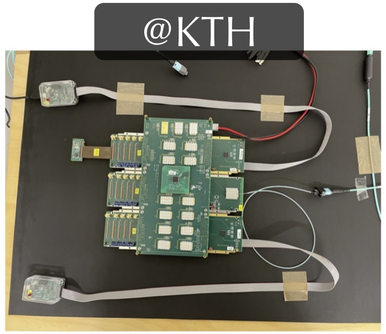
Power block without shield

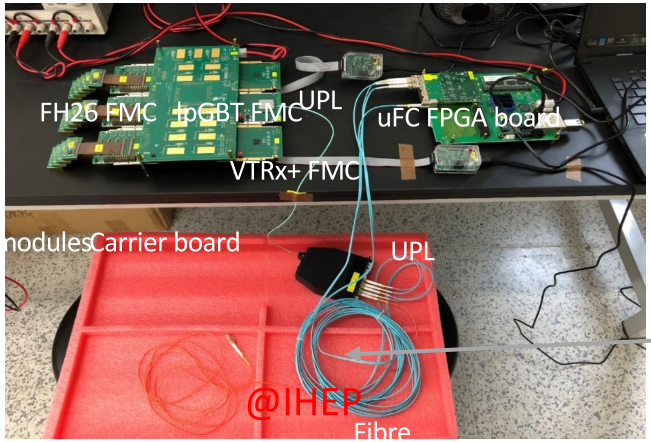


FELIX (TDAQ)







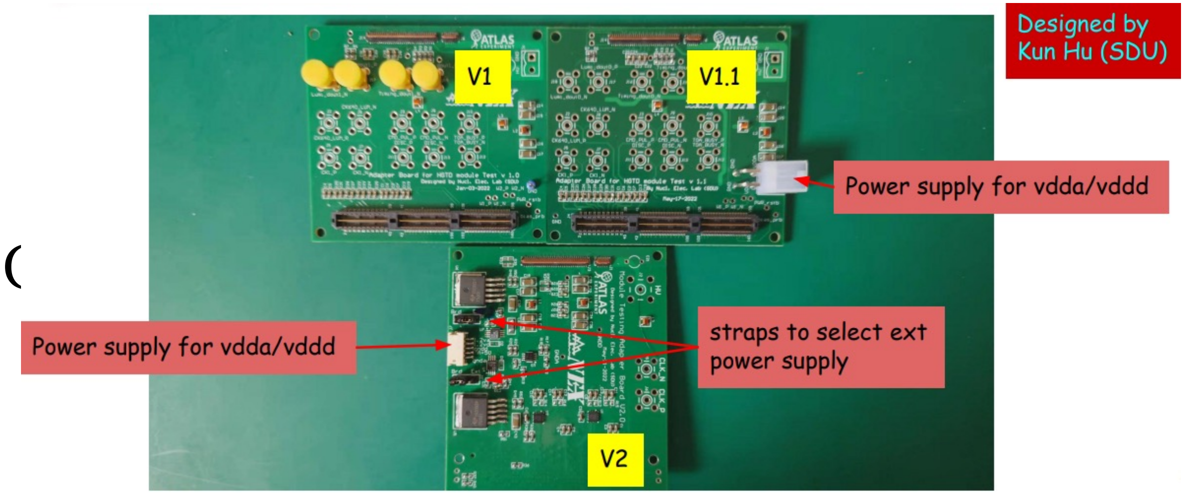


FELIX Server in IHEP

Highlights from SDU

Frontend ASICs Test

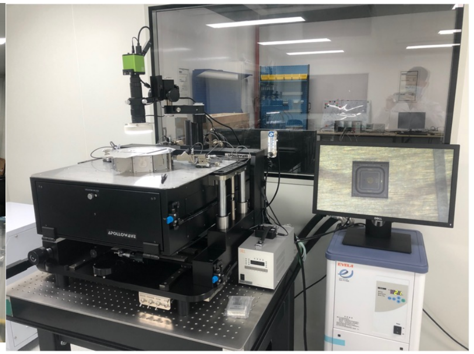
- Adapter board design and tests
  - V1 and V1.1 for single ALTIROC ASIC
  - V2 for detector module test

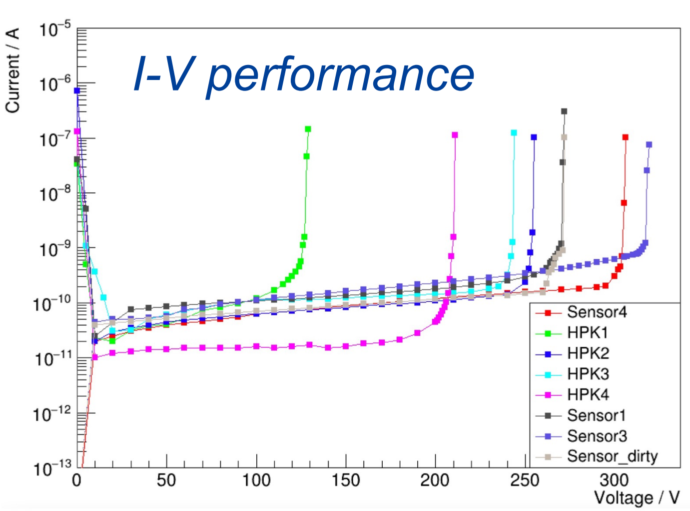


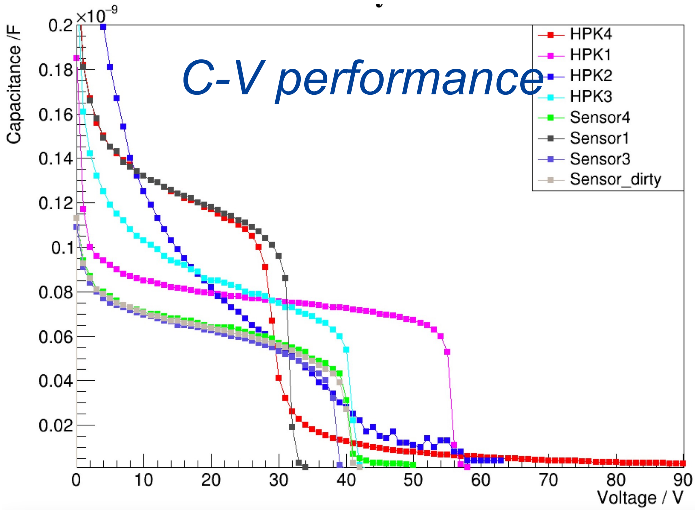
- Finished two prototypes of flex tail production and tests
  - Tests include thickness, length, impedance, voltage-drop
  - Solved over-thickness of both ends for the flex

Highlight from SJTU/TDLI

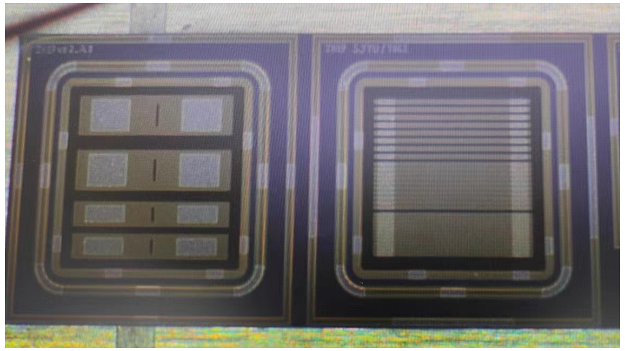
- Setup 45m^2 clean room, and probe station (- 40 ^{o}C ~ 50 ^{o}C)
- Contributed to LGARD sensors I-V/C-V performance test with USTC



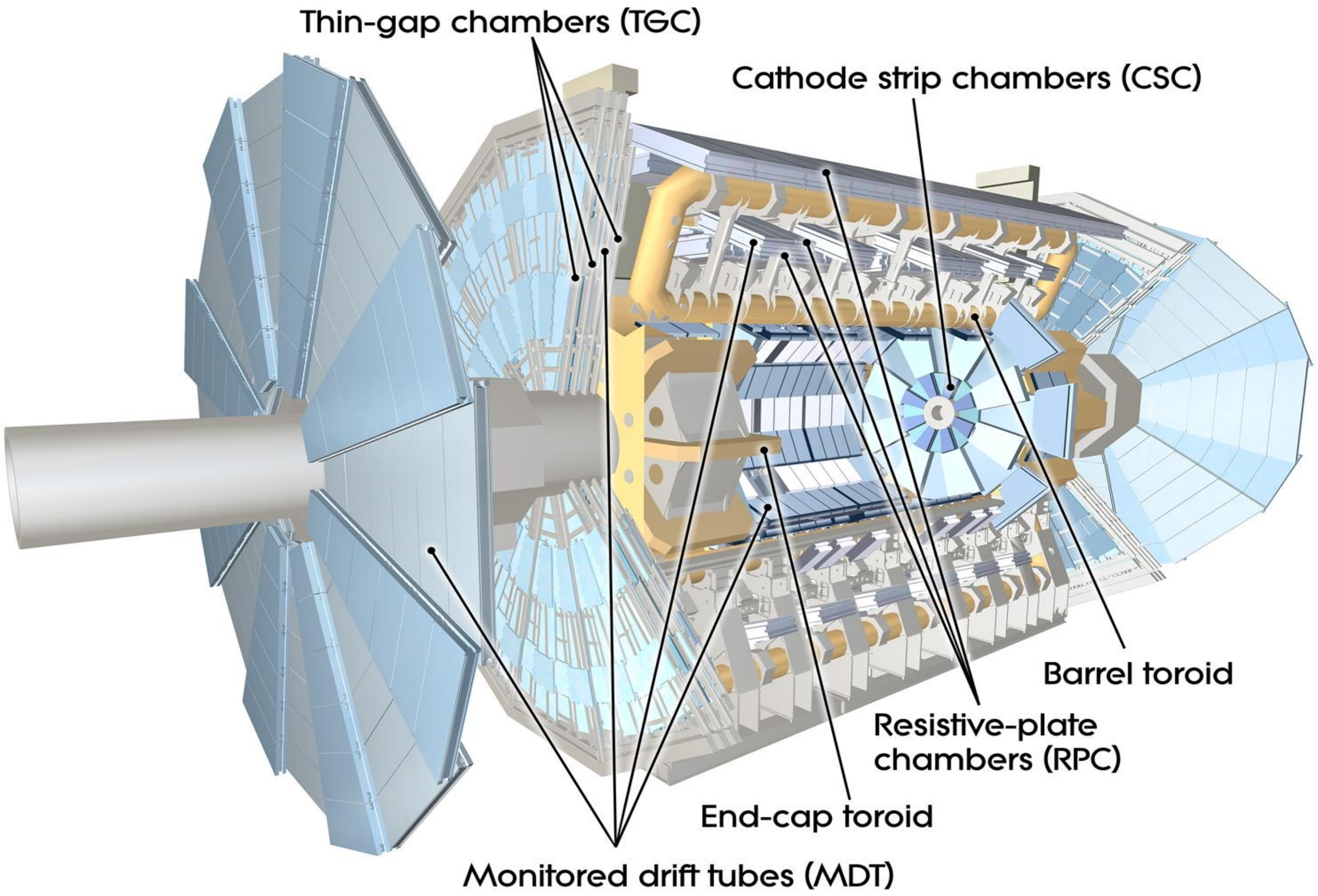




- Also working on DarkSHINE tracker R&D, silicon strips using LGARD.



Muon Resistive-plate chambers (RPC)



Overview of Phase-II RPC upgrade

- Honeycomb readout panel - Built full BIS size (1706x1070 mm) panels, the flatness of the Readout panel < 100um, satisfy the design requirement

- Double-end readout method - Validated with real phase II RPC electronics, the resolution meet the design requirement

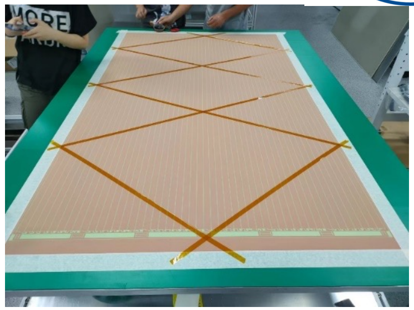
- R&D on RPC signal integrity - Simulation of signal transmission

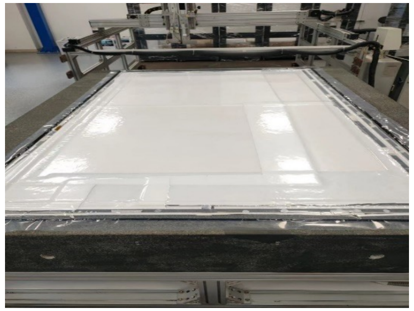
- RPC gas gap production

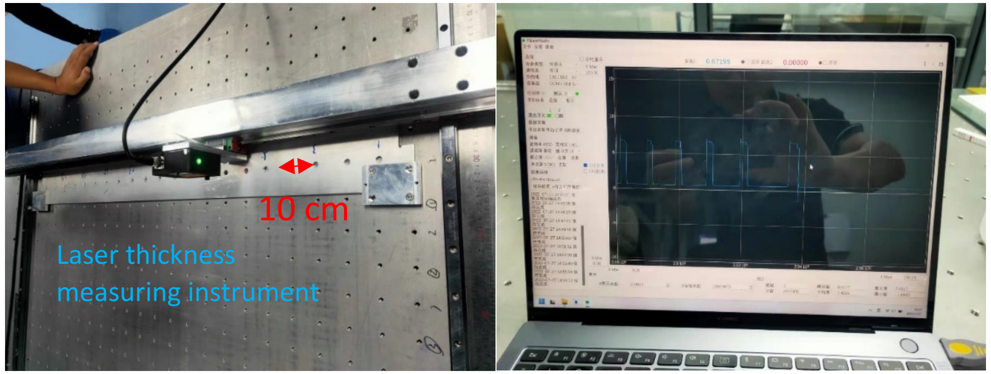
- In the coming mass production, Chinese cluster will construct singlets of BIS type (~300) + BIL type (~60).

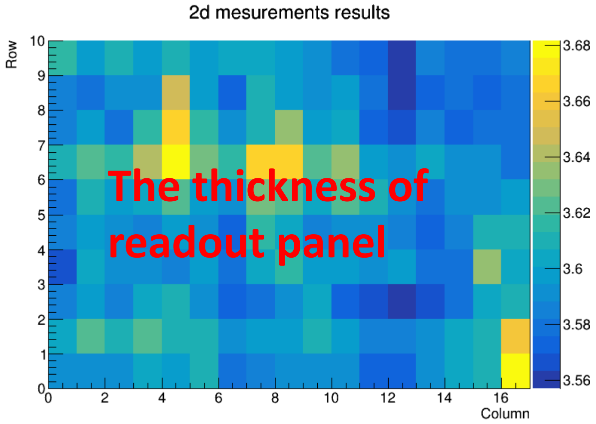
The honeycomb readout panel

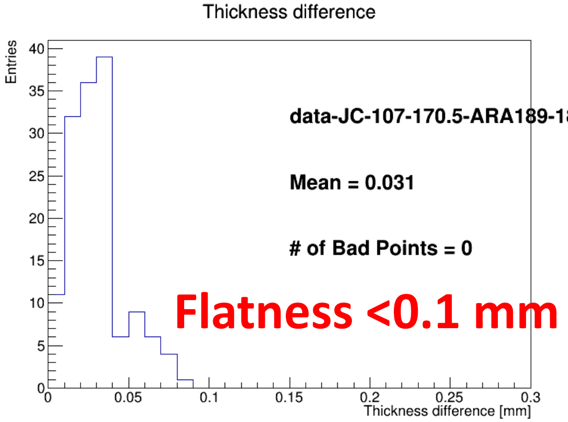
- Assembly procedures:
  - Sticking X shape tape on the PCB, and mix the epoxy glue
  - Spreading Araldite 2011 glue on the PCB
  - Gluing Aramid paper honeycomb on the PCB with the vacuum bag
  - Aligning 2PCBs + honeycomb layers
  - Gluing 3 layers (2PCBs + honeycomb) with the vacuum bag
- Quality check
  - The flatness of the readout panel in 10 cm * 10cm less than 100 um





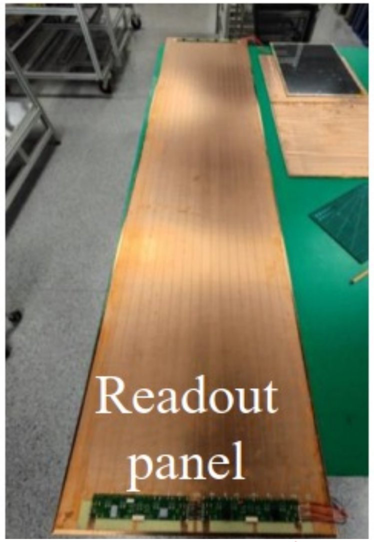


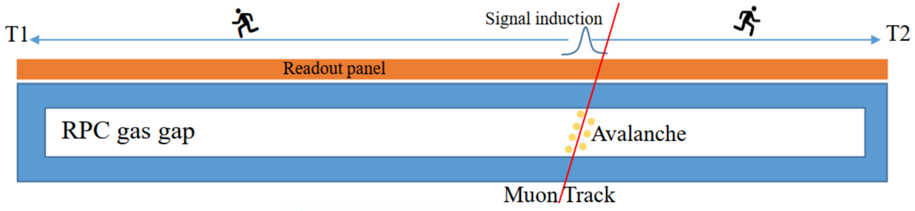


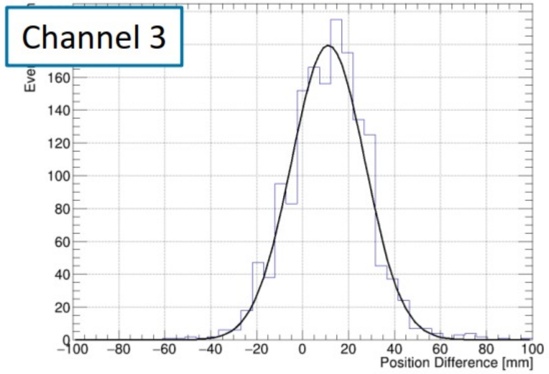


Double-end readout with RPC electronics

- Motivation
  - To check if FEE works properly in double-end scheme
  - To check the space resolution performance
- Experimental setup
  - FEE board: chip-based, which will be used in RPC Phase II upgrade
  - 32 BIS7s RPC gives reference position
  - TDC: V1190 (100 ps resolution)
- Reconstruction
  - Reconstructed hit position: $x' = (T2-T1)*v/2$
  - Reference position x is the center of the reference strip
- Results: meet the requirement (<2cm)





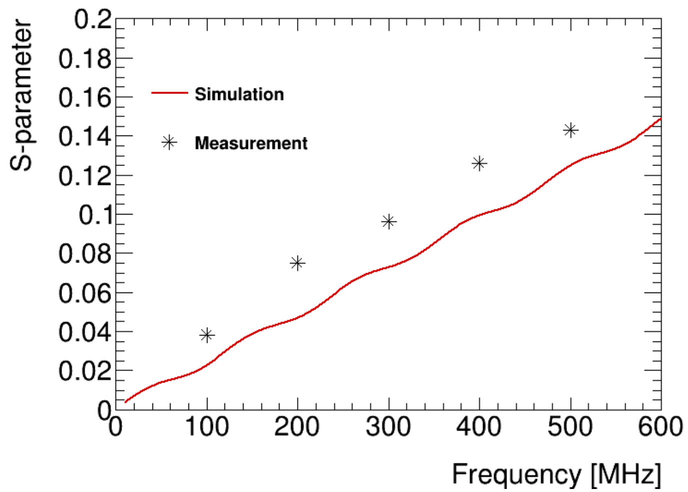


Simulation of signal propagation

- Motivation:
  - Suppress the cluster size in the RPC readout
  - Focusing on the signal integrity during propagation process: reflection and crosstalk
- Method:
  - Lossless Multi-conductor Transmission Line theory
  - Software simulation: MAXWELL + Mathematica
  - Impedance and crosstalk calculated and validated
- Results:
  - Suppress reflection: the value of matching resistor should equal the strip impedance
  - Suppress crosstalk: the guard strips reduce the crosstalk amplitude from 6% → 5%
  - Applicable to different geometries and novel readout schemes, such as double-end and η–η readout

See also Zirui's talk "R&D of RPC signal transmission"

Impedance [Ω]	Bare strip	Assembled
Measurement	32.20	18.51
Simulation	32.3	18.3



Gas-gap production

- Assembly procedures:
    1. Glass and platform cleaning
    2. Gluing the gas distributer to the glass
    3. Gluing the spacers on the glass with distance of 10 cm
    4. Gluing the frame on the glass
    5. Put another glass on the spacers/frames
    6. Press the gas-gap for at least 6 hours
    7. Graphite coating
    8. bond the PET film to the Graphite layer

1

2

3

4

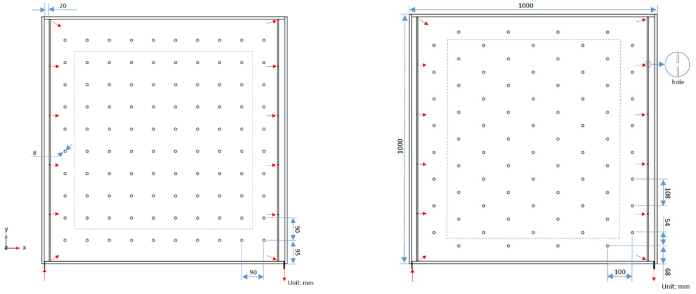
5

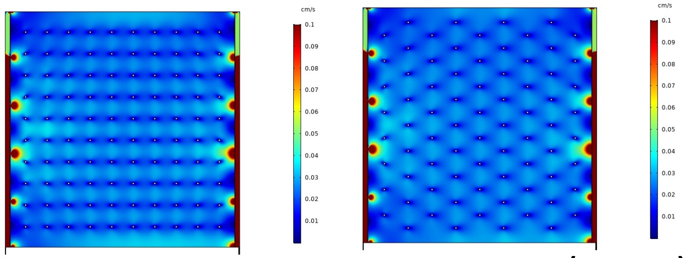
6

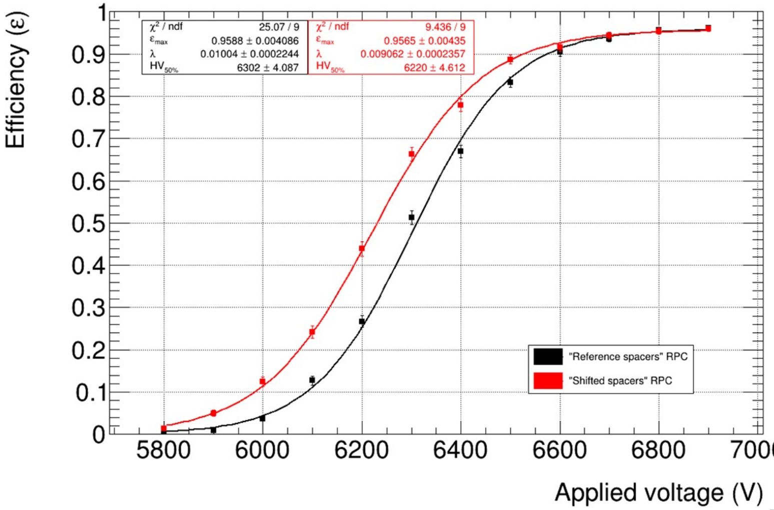
7

RPC spacer optimization in SJTU

- Multiphysics simulation:
  - Based on COMSOL Multiphysics software
  - Simulated the gas velocity, gas vorticity, electrode deformation of two different spacer configuration RPCs
- Experiment setup
  - Built glass RPC chamber based on new design
  - Tested under cosmic ray







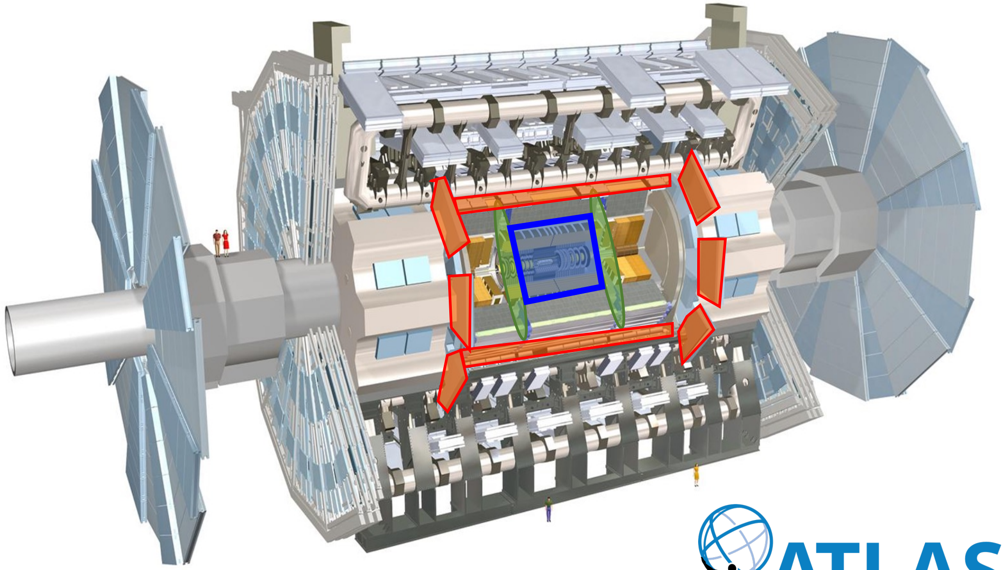
JINST 16 P12022 (2021)

- Achieved
  - Optimized the gas velocity & vorticity distribution
  - Maintained similar electrode deformation distribution
  - Decreased the spacer number by ~20%

Summary

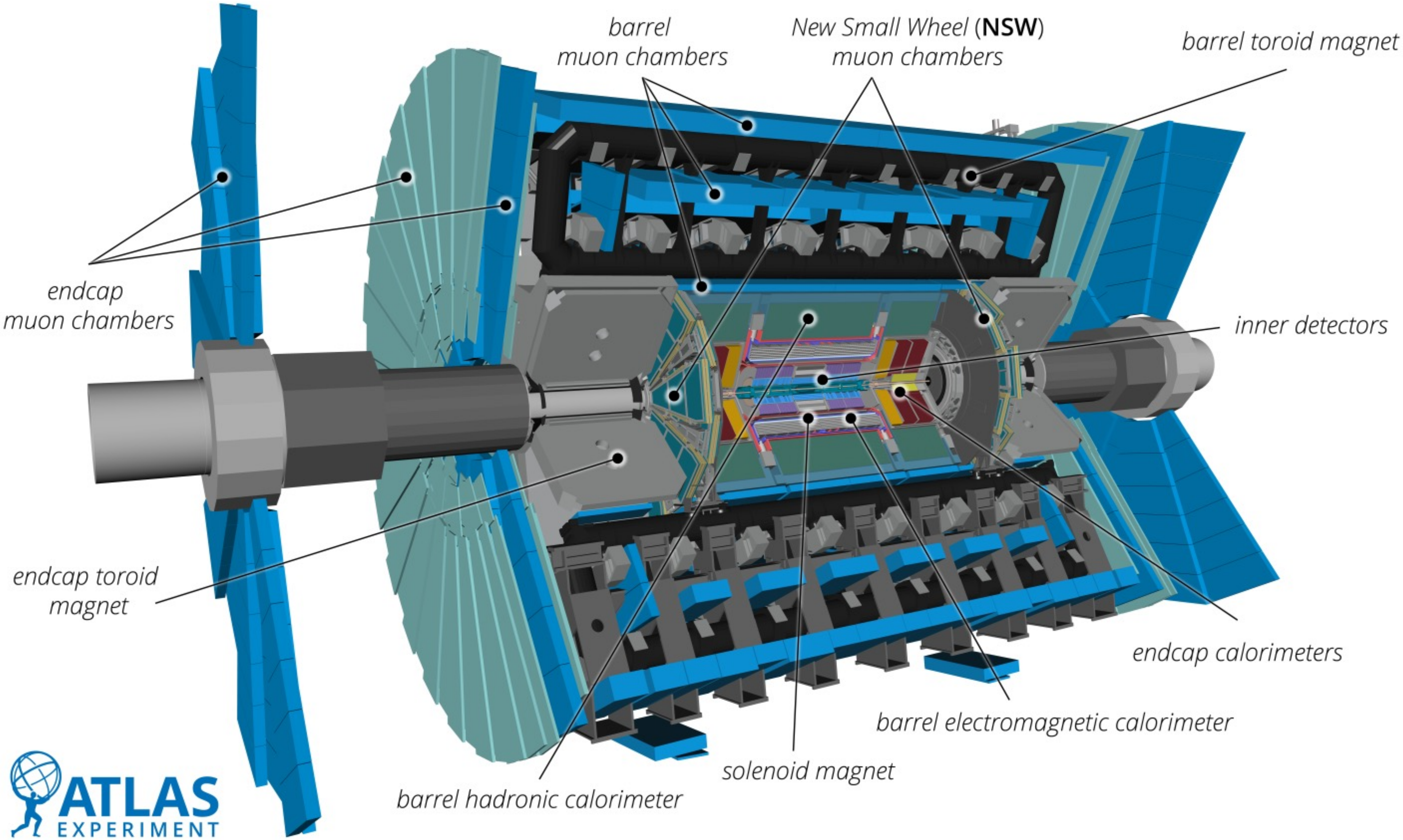
- ATLAS Phase-2 upgrade to meet the challenge of HL-LHC

- China clusters actively participating in several sub-detectors
  - Inner Tracker (ITk)
  - High Granularity Timing Detector (HGTD)
  - Muon Resistive-place Chambers (PRC)



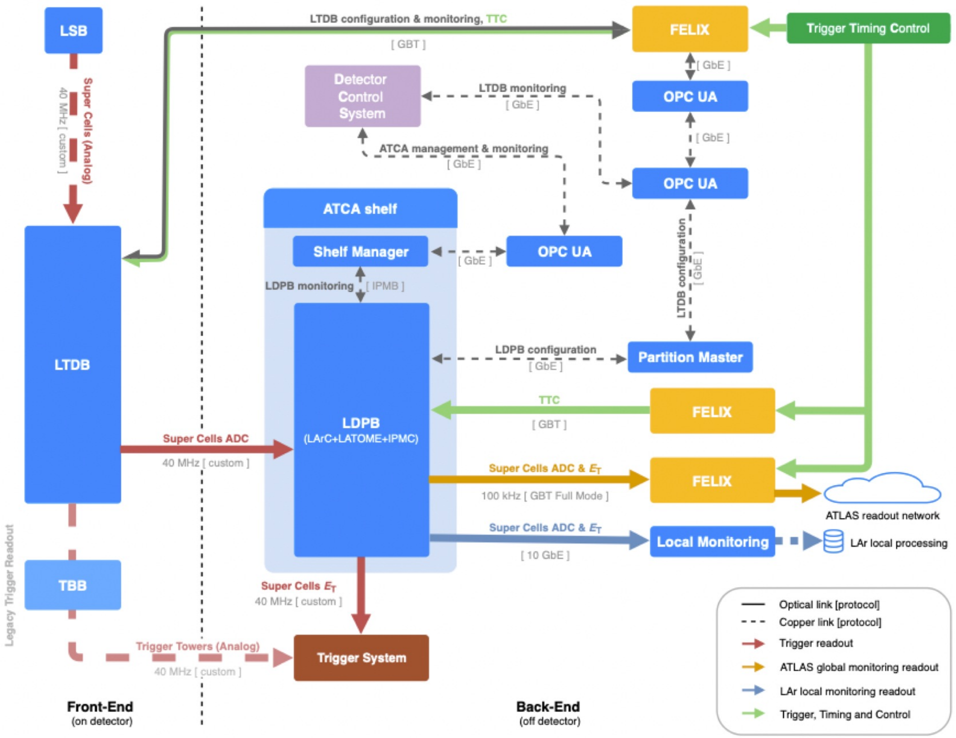
- Achieved significant progress and taking some leading roles
  - HGTD PL, ITk UK/China CM, etc …

Back up

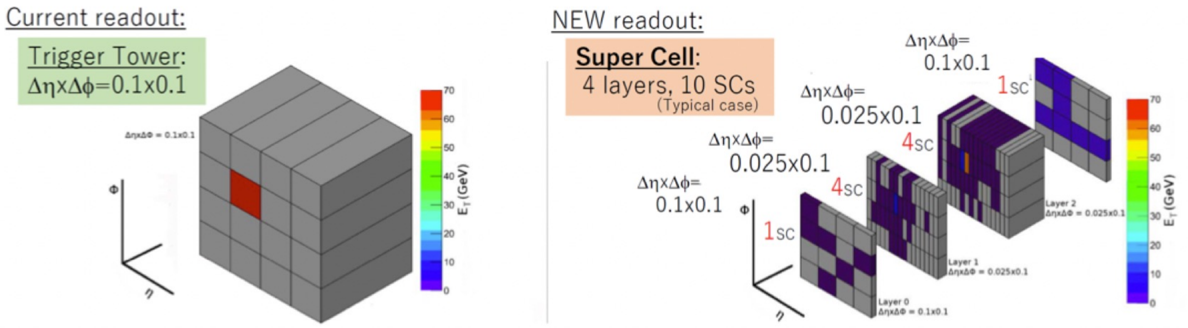

barrel
muon chambers
New Small Wheel (**NSW**)
muon chambers
barrel toroid magnet
endcap
muon chambers
inner detectors
endcap toroid
magnet
endcap calorimeters
barrel electromagnetic calorimeter
solenoid magnet
barrel hadronic calorimeter
ATLAS
EXPERIMENT

Liquid Argon Calorimeter Phase-I Upgrade

- LAr Phase-I upgrade expanded the readout granularity by introducing the new readout “Super Cells (SCs)” instead of “Trigger Towers (TTs)”.



JINST 17 P05024 (2022)



LAr electronics upgrade extends the legacy system with new Front-End and Back-End components, computes and delivers the SCs ET to the new L1 trigger system.

In parallel, another local monitoring path is developed to validate the condition of all Super Cells of LAr calorimeters:
Cover all components: (EMB, EMEC, HEC and FCal)
Under different calibration modes (Pedestal, Ramp, Delay)

Publications from USTC-HGTD 2022

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

An ultra-fast low-noise preamplifier for Low Gain Avalanche Detectors

J.J. Ge [a,b], C.H. Li [a,b], D. Zhang [a,b], Y.F. Yang [a,b], A.N. Wang [a,b], X. Yang [a,b], H. Liang [a,b], Y.W. Liu [a,b,*]

[a] Department of Modern Physics, University of Science and Technology of China, Hefei 230026, China

[b] State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei 230026, China

ARTICLE INFO

Keywords:
Low Gain Avalanche Detectors (LGAD)
Preamplifier
Transimpedance Amplifier (TIA)
β-scope
Transient Current Technique (TCT)

ABSTRACT

The Low Gain Avalanche Detector (LGAD) is a novel Silicon detector with precise timing and fast response. To study the transient response of LGADs, we need to obtain the detector signal using Transient Current Technique (TCT), for which a preamplifier with high bandwidth and low noise is required. Currently, the most widely used preamplifier board in the LGAD community is developed by University of California, Santa Cruz (UCSC). In this paper, we will introduce a newly designed LGAD preamplifier board. Compared with the UCSC board, the performance has been fully improved. The board contains a transimpedance amplifier and two-stage voltage amplifiers. The total charge gain of our preamplifier reaches 20.58 mV ns/fC, with good linearity in the input dynamic range of [0.7 fC, 66 fC]. The −3-dB bandwidth is about 870 MHz, meeting the demands of LGAD amplification. We conducted ^{90}Sr β-scope tests using our preamplifiers and HPK 3.1 single sensors. The equivalent noise charge at 20 °C is 0.27 fC. The jitter contributed by our preamplifier is about 7.12 ps. The results show that our single-channel preamplifier has lower noise and better time resolution than the UCSC boards. Besides, a 9-channel preamplifier board is developed for multi-pad LGAD readout. All channels ... r-scanning

PAPER • OPEN ACCESS

Performance in beam tests of irradiated Low Gain Avalanche Detectors for the ATLAS High Granularity Timing Detector

C. Agapopoulou[1], S. Alderweireldt[2], S. Ali[3], M.K. Ayoub[4], D. Benchekroun[5], L. Castillo García[6], Y.H. Chan[7], H. El Jarrari[3,8], A. Falou[1], A. Ferreira[2], E.L. Gkougkousis[6], C. Grieco[6], S. Grinstein[6,9], J. Große-Knetter[10], J. Guimarães da Costa[4], S. Guindon[2], A.M. Henriques Correia[2], S. Hidalgo[11], A. Howard[12], P.J. Hsu[7], Y.C. Huang[7], Y. Khoulaki[5], G. Kramberger[12], E.S. Kuwertz[2], J. Lange[10], C. Li[13], Q. Li[13], H.C. Lin[7], Y.J. Lu[7], N. Makovec[1], L. Masetti[14], R. Mazini[3], S.M. Mazza[15], I. Nikolic[16], G. Pellegrini[11], A. Quadt[10], B. Reynolds[17], C. Rizzi[2], M. Robles Manzano[14], A. Rummler[2], S. Sacerdoti[1], L. Serin[1], J. Soengen[14], Y. Tayalati[8], S. Terzo[6], E. Tolley[17], S. Trincaz-Duvoid[16], S.M. Wang[3] and X. Yang[13]

━Hide full author list

Published 21 September 2022 • © 2022 CERN

Journal of Instrumentation, Volume 17, September 2022

Citation C. Agapopoulou *et al* 2022 *JINST* **17** P09026

DOI 10.1088/1748-0221/17/09/P09026

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

Performance of LGAD sensors with carbon enriched gain layer produced by USTC

C.H. Li, X. Yang, J.J. Ge, T. Wang, X.X. Zheng, Y.J. Sun, Y.W. Liu *

State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei 230026, China

Department of Modern Physics, University of Science and Technology of China, Hefei 230026, China

ARTICLE INFO

Keywords:
Low Gain Avalanche Detector
Timing detector
Radiation hardness
Charge collection

ABSTRACT

The Low Gain Avalanche Detector (LGAD) technology is proposed for the ATLAS High Granularity Timing Detector (HGTD) and the CMS Endcap Timing Layer (ETL) towards the High-Luminosity Large Hadron Collider (HL-LHC), for which radiation hardness is one of the key requirements. In this paper we report results from the measurements on LGAD sensors designed by the University of Science and Technology of China (USTC) and fabricated by the Institute of Microelectronics of the Chinese Academy of Science (IME, CAS). These sensors

http://justc.ustc.edu.cn

Received: September 13, 2021; Accepted: November 16, 2021

Radiation hardness characterization of low gain avalanche detector prototypes for the high granularity timing detector

Xiao Yang[1,2], Kuo Ma[1,2], Xiangxuan Zheng[1,2], and Yanwen Liu[1,2] ✉

[1]Department of Modern Physics, University of Science and Technology of China, Hefei 230026, China;

[2]State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei 230026, China

✉Correspondence: Yanwen Liu, E-mail: yanwen@ustc.edu.cn

Cite This: *JUSTC*, **2022**, 52(1): 3 (6pp)   Read Online   SI Supporting Information

Abstract: The high granularity timing detector (HGTD) is a crucial component of the ATLAS phase II upgrade to cope with the extremely high pile-up (the average number of interactions per bunch crossing can be as high as 200). With the precise timing information (σ_t~30 ps) of the tracks, the track-to-vertex association can be performed in the "4-D" space. The Low Gain Avalanche Detector (LGAD) technology is chosen for the sensors, which can provide the required timing resolution and good signal-to-noise ratio. Hamamatsu Photonics K.K. (HPK) has produced the LGAD with thicknesses of 35 μm and 50 μm. The University of Science and Technology of China(USTC) has also developed and produced 50 μm LGADs prototypes with the Institute of Microelectronics (IME) of Chinese Academy of Sciences. To evaluate the irradiation hardness, the sensors are irradiated with the neutron at the JSI reactor facility and tested at USTC. The irradiation effects on both the gain layer and the bulk are characterized by *I-V* and *C-V* measurements at room temperature (20 ℃) or −30 ℃. The breakdown voltages and depletion voltages are extracted and presented as a function of the fluences. The final fitting of the acceptor removal model yielded the *c*-factor of 3.06×10^{-16} cm^{-2}, 3.89×10^{-16} cm^{-2} and 4.12×10^{-16} cm^{-2} for the HPK-1.2, HPK-3.2 and USTC-1.1-W8, respectively, showing that the HPK-1.2 sensors have the most irradiation resistant gain layer. A novel analysis method is used to further exploit the data to get the relationship between the *c*-factor and initial doping density.

Keywords: LGAD; HGTD; timing detector; silicon detectors

CLC number: TL814   **Document code:** A