The status of ITk for ATLAS Phase-II upgrade

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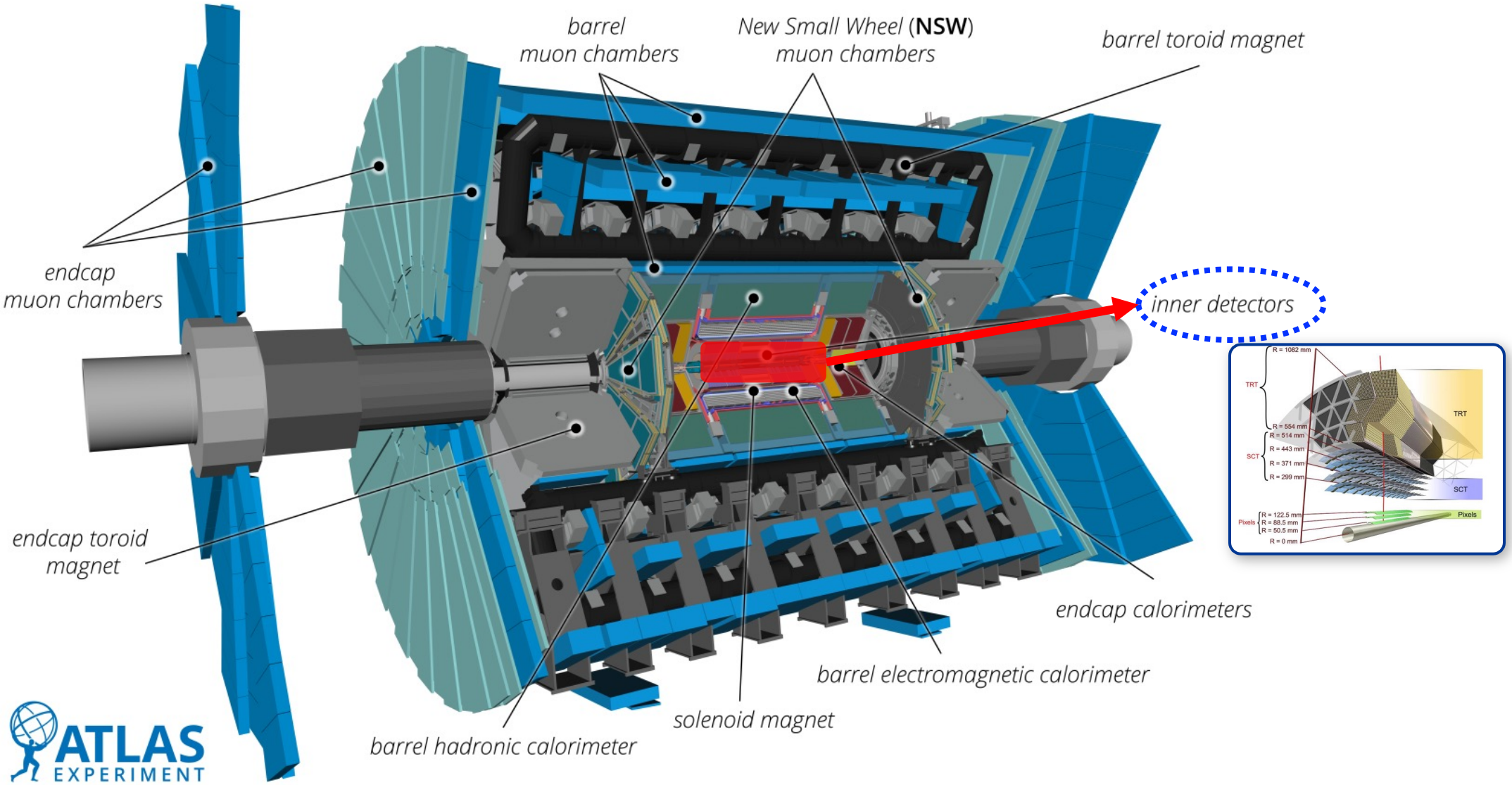
On behalf of subtask 2 Team



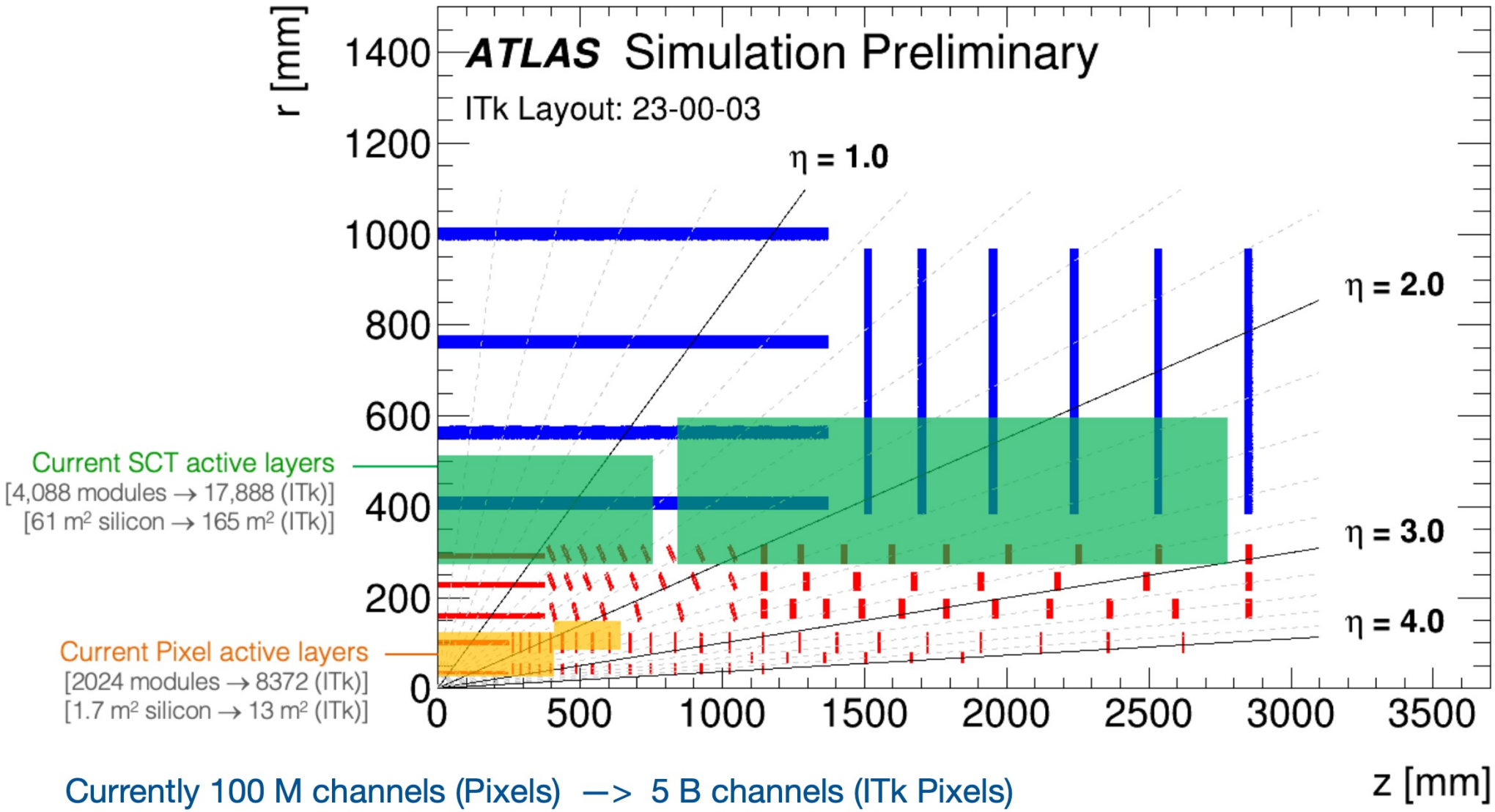
28 May 2026

MOST ATLAS Detector Upgrade Project Midterm Review Meeting

Current ATLAS Detector

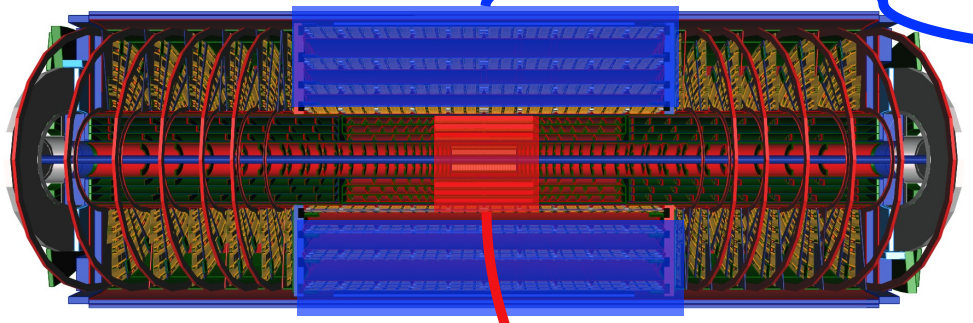


ATLAS New Inner Tracker (ITk)



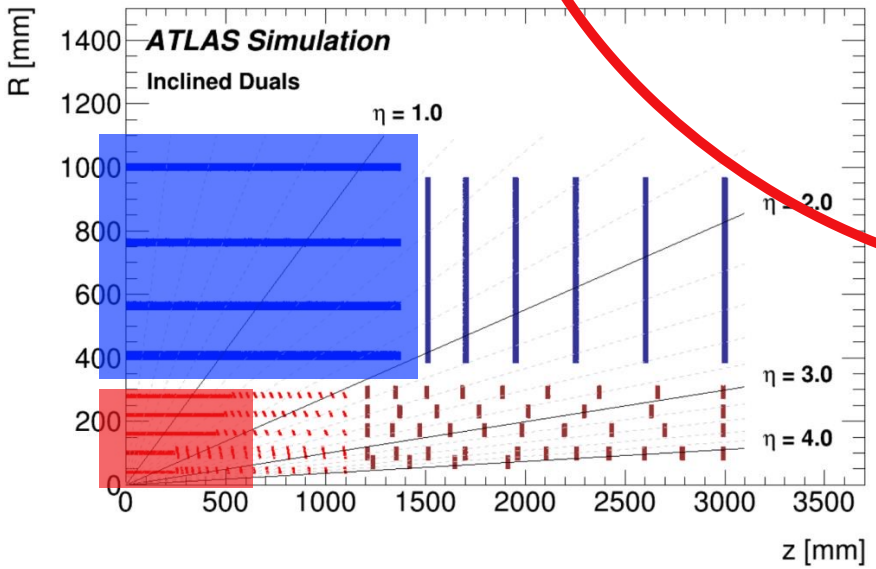
Currently 100 M channels (Pixels) —> 5 B channels (ITk Pixels)

Subtask 2: Inner Tracker (ITk) Upgrade



2.1 ITk Strip Barrel Detector

- Radiation hard sensor and ASIC study
- Strip detector module production
- Complex silicon tracker system integration



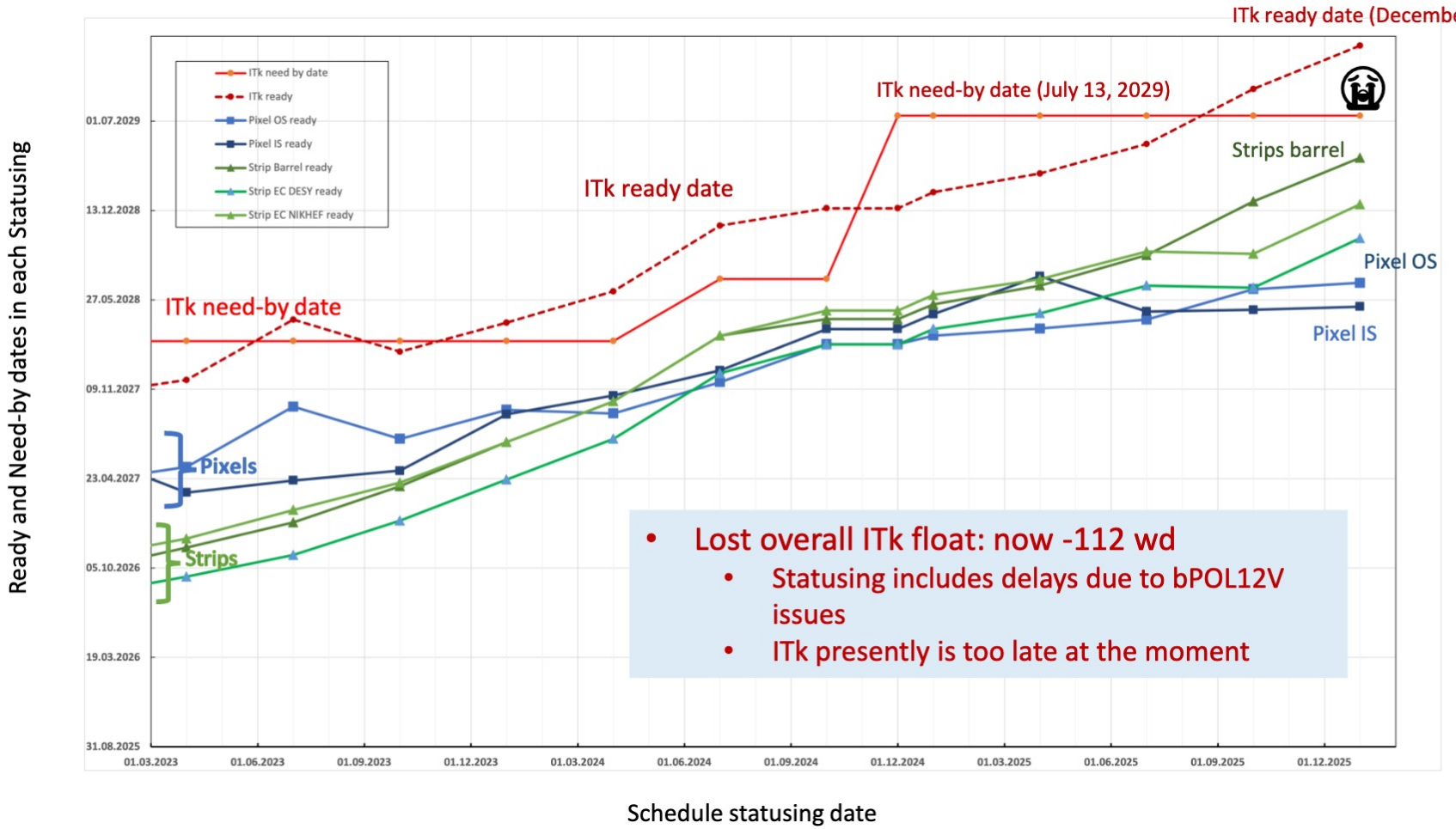
2.2 Timing Pixel Detector

- Pixelated LGAD sensor R&D
- Fast front-end electronics R&D

Task 2 – Overall Indicator

项目目标	预期成果				对应的课题	考核指标				考核方式（方法）及评价手段
	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	完成时指标值/状态	
2. 研制硅微条径迹探测器，空间分辨率达到 25 微米。 3.在新一代有时间信息的硅像素探测器的关键技术研发方面，研发时间分辨率在 100 皮秒以下的抗辐照传感器及前端电子学。	主要成果									
		2	硅径迹探测器模块	□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____	课题 2：ATLAS 实验内径迹探测器升级	硅微条径迹探测器空间分辨率（关键核心指标）	原型模块 25 微米	预生产模块 25 微米	径迹探测器 25 微米	测试报告、同行评审。
		3	有时间信息的硅像素探测器	□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____		硅像素探测器时间分辨率（关键核心指标）	好于 10ns	好于 1ns	好于 100ps	仿真验证和实验室测试，测试报告

ATLAS ITk Strip schedule

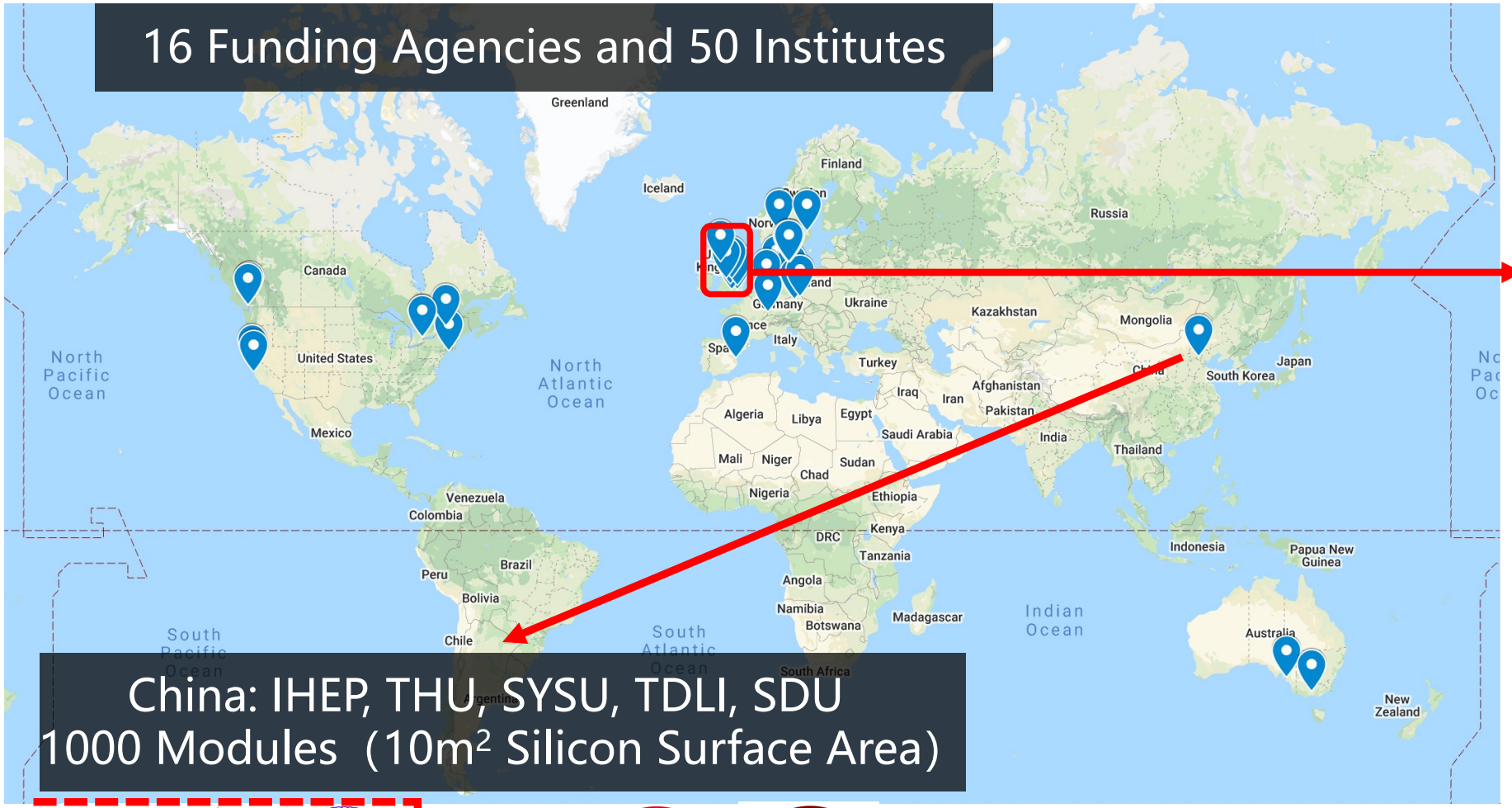


- ITk ready : 12 Dec 2029 (-112 wd float)
- Mainly driven by strip barrel
- Does not include potential delays due to bPOL12V issues

- ITk Strips Barrel ready for installation: 12 Sep 2029
- ITk Strips Barrel need-by date: 13 July 2029

ATLAS ITk Strip Project World Wide

16 Funding Agencies and 50 Institutes



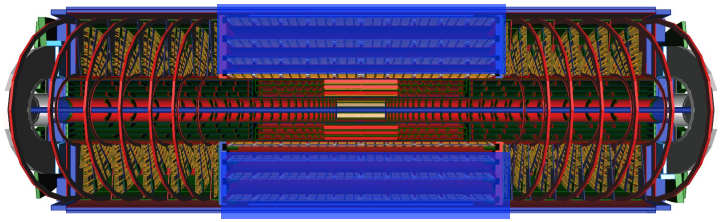
China: IHEP, THU, SYSU, TDLI, SDU
1000 Modules (10m² Silicon Surface Area)

UK/China Cluster
50% Barrel Strip Detector

IHEP

- Xin Shi as UK/China Cluster Manager since 2022

2.1 ITk Strip Barrel Detector

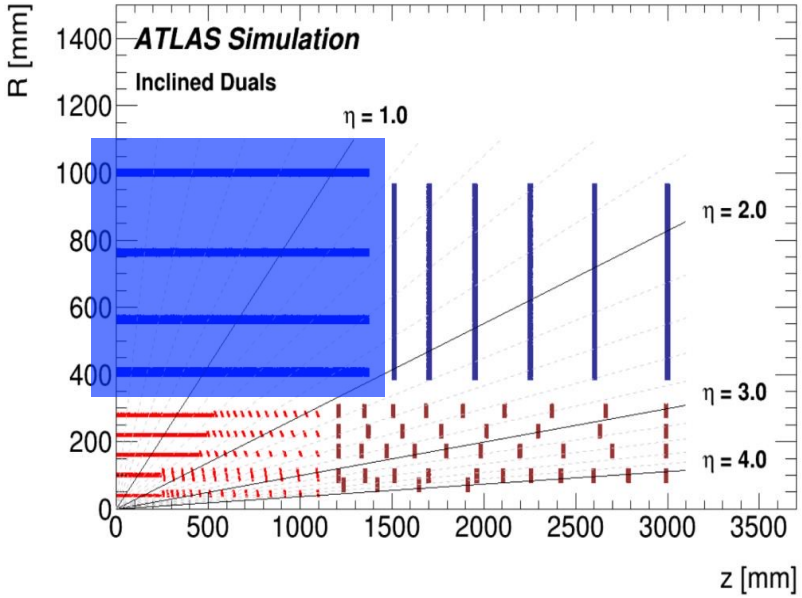


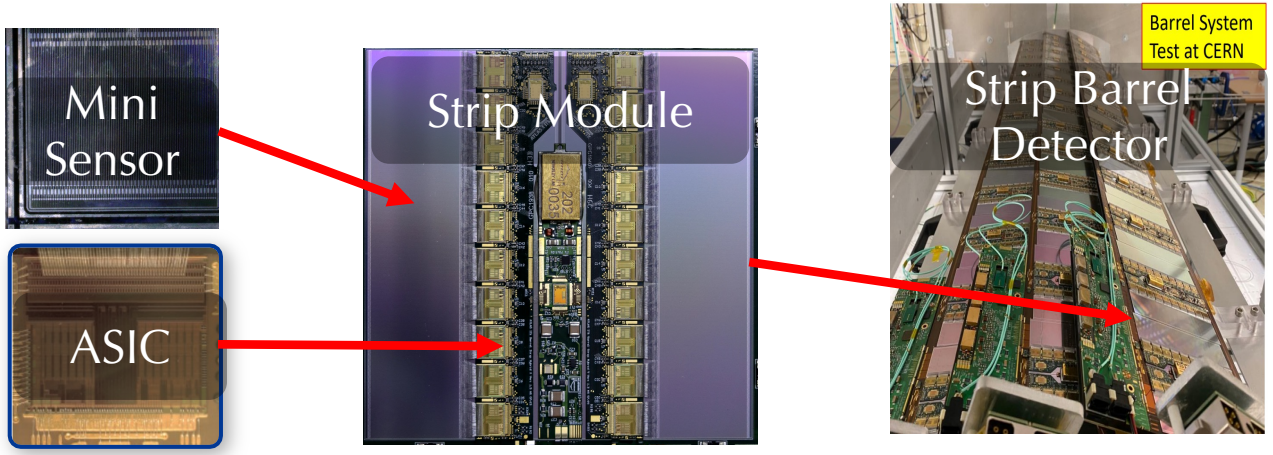
Deliverables

- Complete strip barrel detector with 25μm spacial resolution
- Provide strip module spacial resolution evaluation report

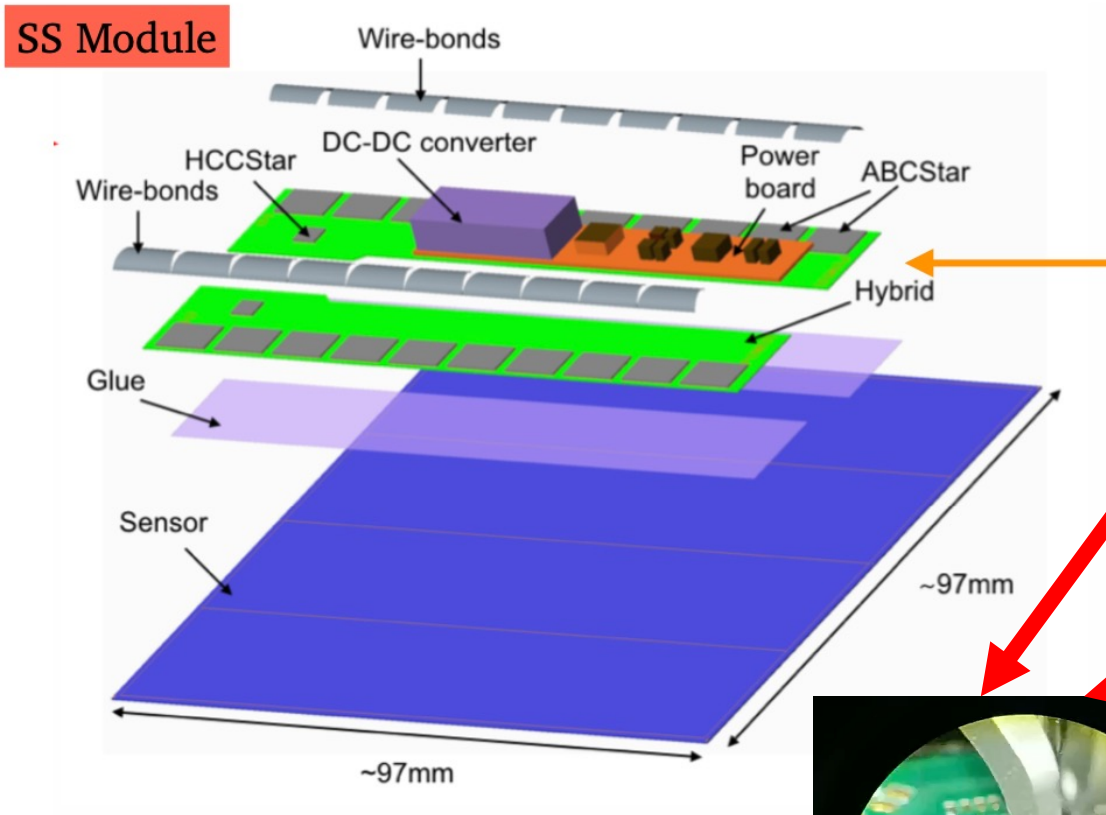
Contents

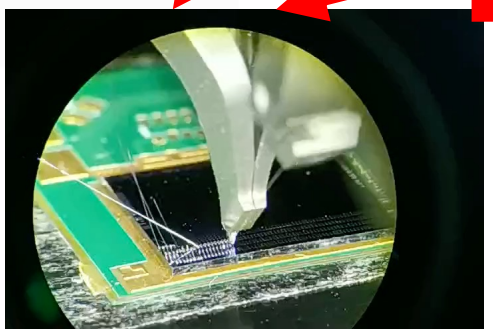
- Radiation hard sensor and readout ASIC study
- High performance strip detector module production
- Complex silicon detector system integration

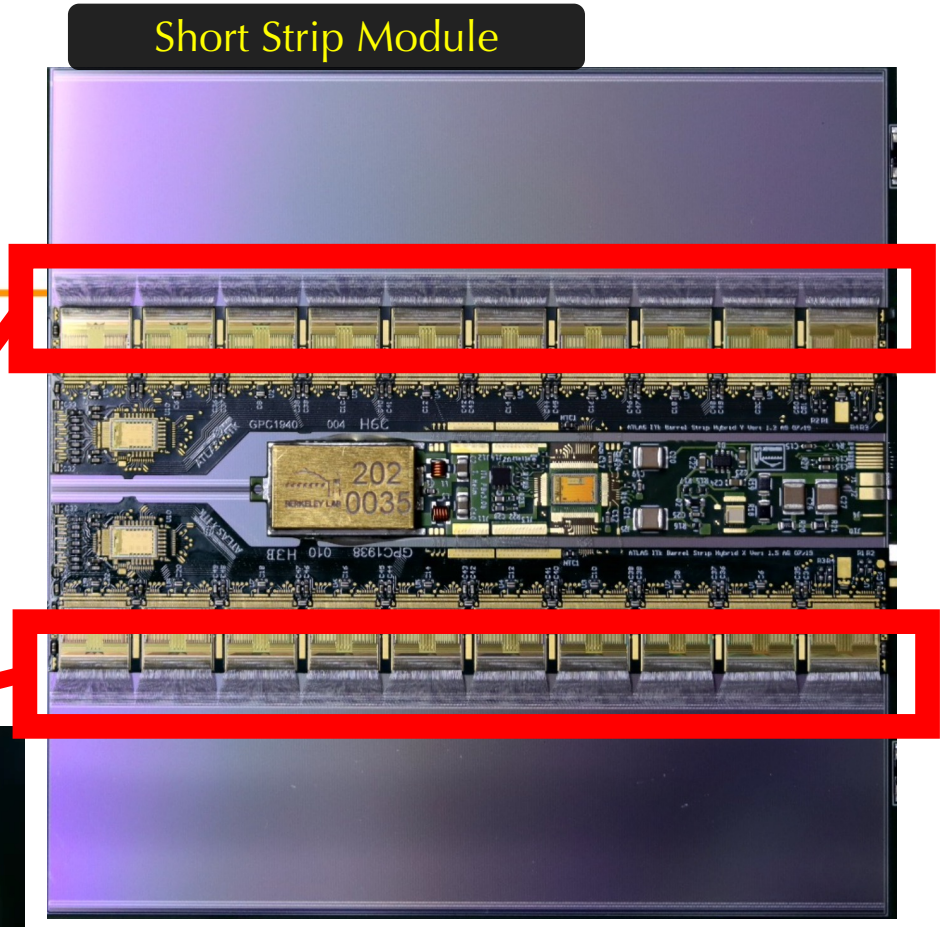




Strip Module Component

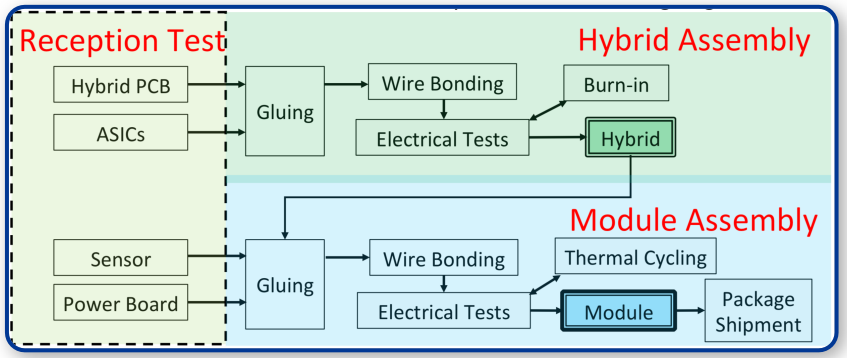






ITk Strip Module Production Procedure

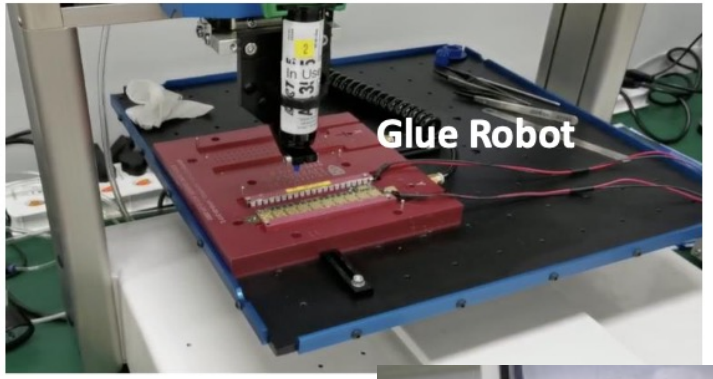
- Well defined module production steps to ensure High Quality Modules



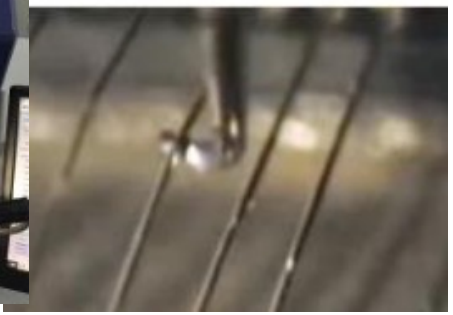
Step Number	Qualification Step	Review End Date
3.2	Sensor Storage	finished: 2021-06-17
6.1	PB Reception	finished: 2022-01-11
6.2	PB E tests	finished: 2022-07-14
6.3	PB Vis Insp	finished: 2021-12-16
6.4	PB Storage	finished: 2021-06-17
8.2	Storage + shipping of glue	finished: 2021-08-26
8.3	Assembling hybrids	finished: 2021-11-20
8.4	Glue weight measurements	finished: 2021-11-21
8.5	Bonding procedures: hybrids	finished: 2022-05-31
8.6	Metrology: hybrids	finished: 2023-03-07
8.7	Visual inspection: hybrids	finished: 2021-08-06
8.8	Hybrid Burn-In	finished: 2023-05-25
8.10	Hybrid Storage	finished: 2021-06-17
8.11	hybrid QC: single panel testing	finished: 2022-08-25
11.1	Storage of modules	finished: 2021-06-17
11.2	Cleaning module jigs	finished: 2021-06-16
11.4	Storage of modules	finished: 2021-11-29
11.5	Removing hybrids from panel	finished: 2021-12-09?
11.6	Module Assembly	finished: 2022-02-25
11.7	Metrology: modules	finished: 2023-07-10
11.8	Bonding procedures: modules	finished: 2022-05-25
11.9	Visual inspection: modules	finished: 2021-07-19
11.10	Module Thermal Cycling	finished: 2023-10-29
11.11	Single Module Electrical Test	finished: 2022-10-23
12.1	Shipping modules	finished: 2022-04-25
13.1	Cleanroom standards	finished: 2021-11-25
13.2	ASIC Compliance & Handling	finished: 2021-06-03
13.3	Bond Pulling Procedures	finished: 2021-12-03
14.1	Module Reception	Finished: 2022-01-25

29 Steps

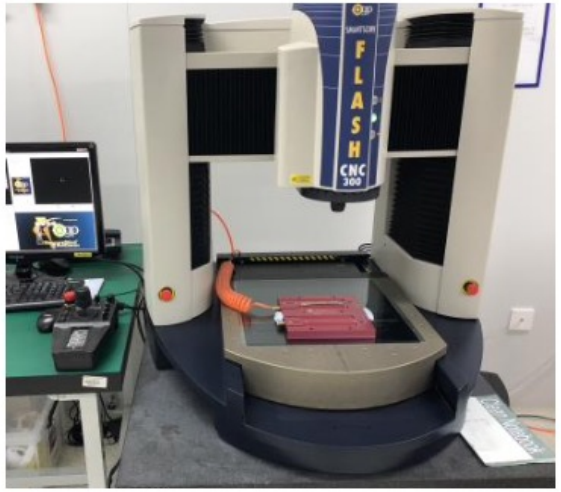
Calibration of glue amount



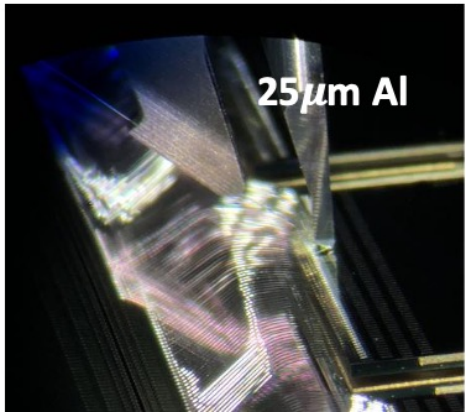
Pull force test



Metrology of glue thickness



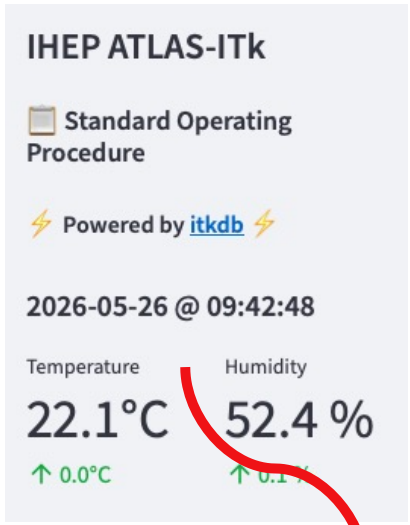
Wire bonding



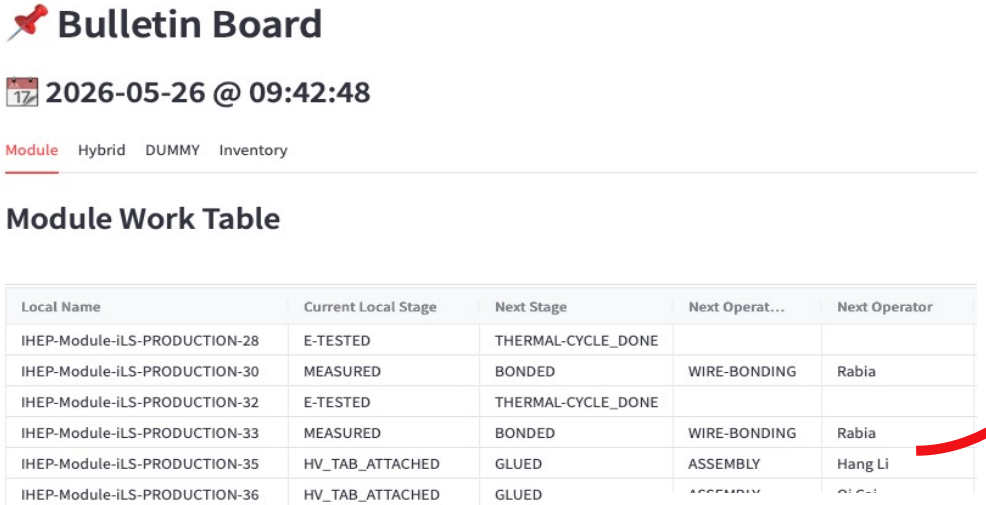
Standard Operating Procedure (SOP)

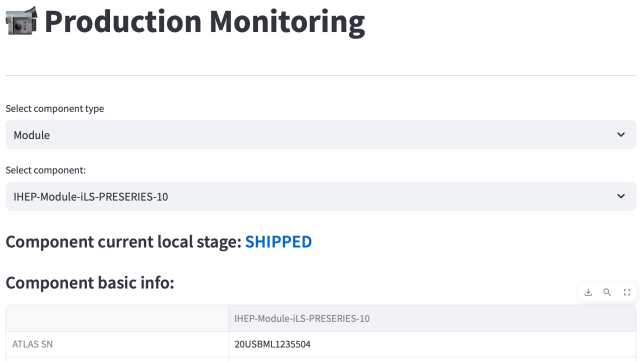
- Developed at IHEP for local production
  - All SQ 29 steps have been implemented in SOP
  - Interact with ITk central Production Database

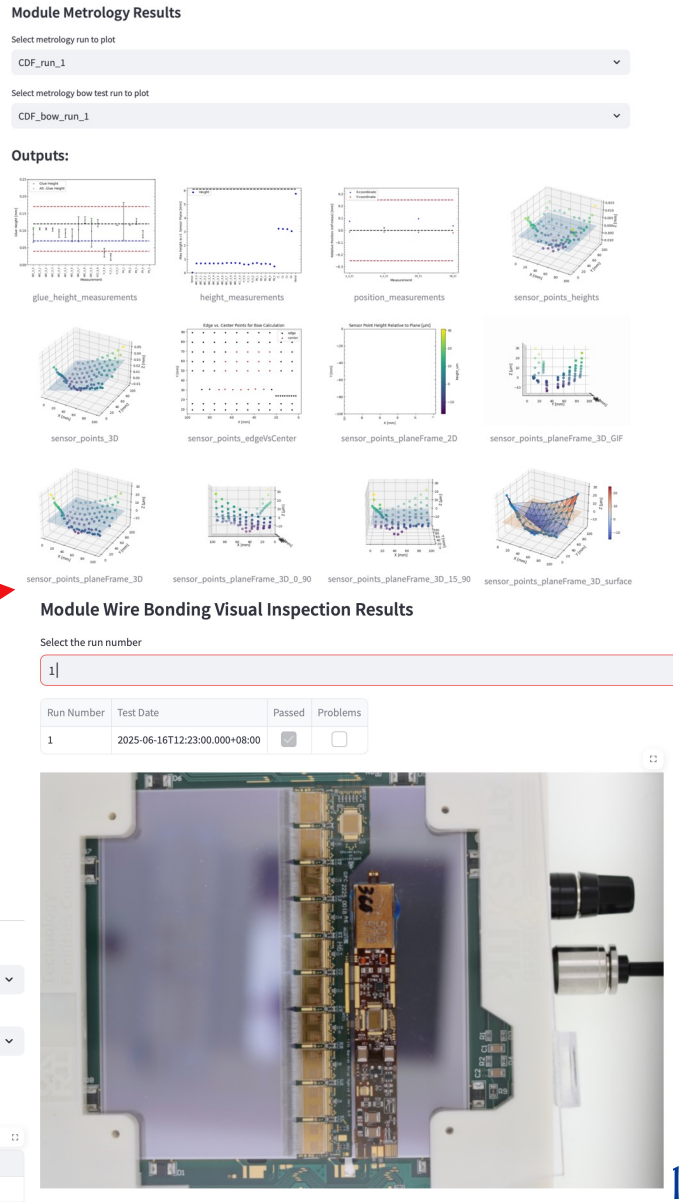
http://atlasitk.ihep.ac.cn



Connect to ITk Production Database

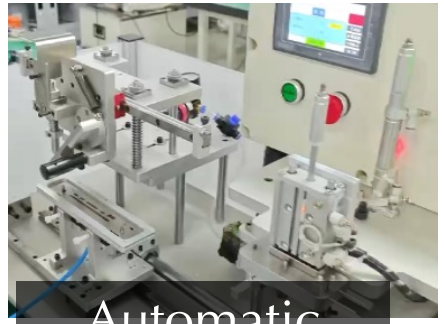




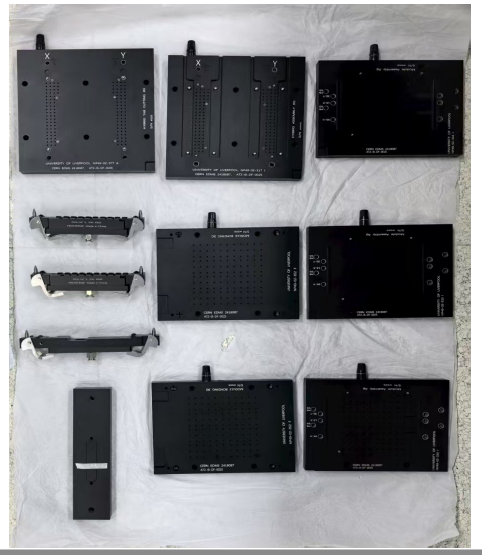


IHEP Site Module Production Status

- Passed PRESERIES stage for Module production
  - Produced 75 PRESERIES modules (15@IHEP / ~ 50@ RAL)
  - Produced ~134 PRODUCTION modules (34 @IHEP / ~100@RAL)
- Manufactured 11 production tooling set and one automatic machine in China

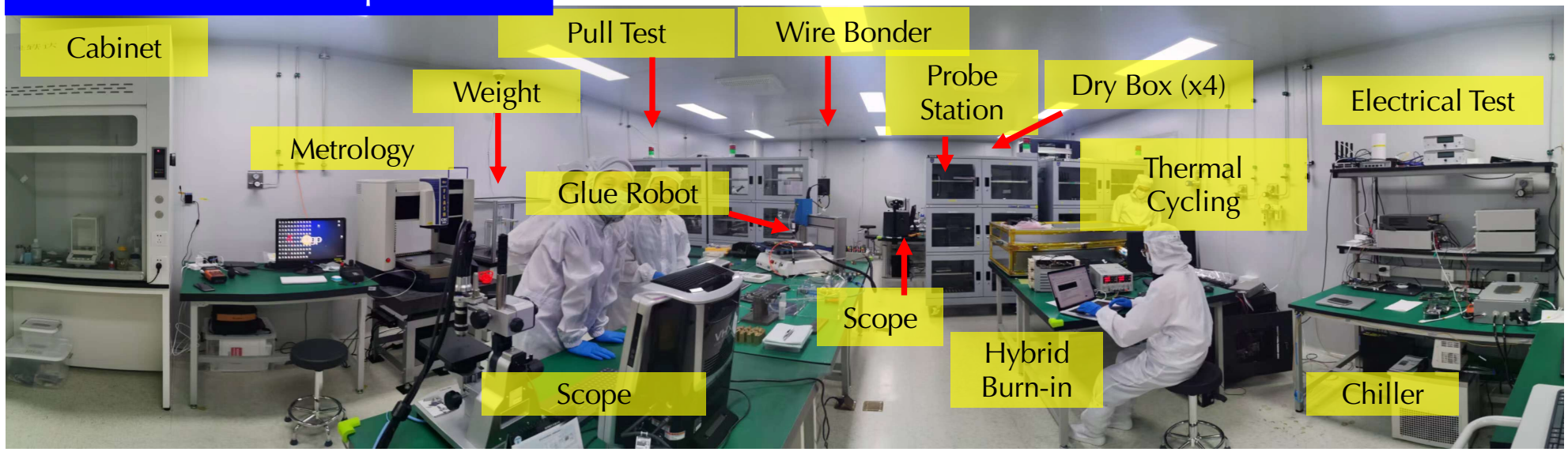


Automatic Tool at IHEP



New tools made in China

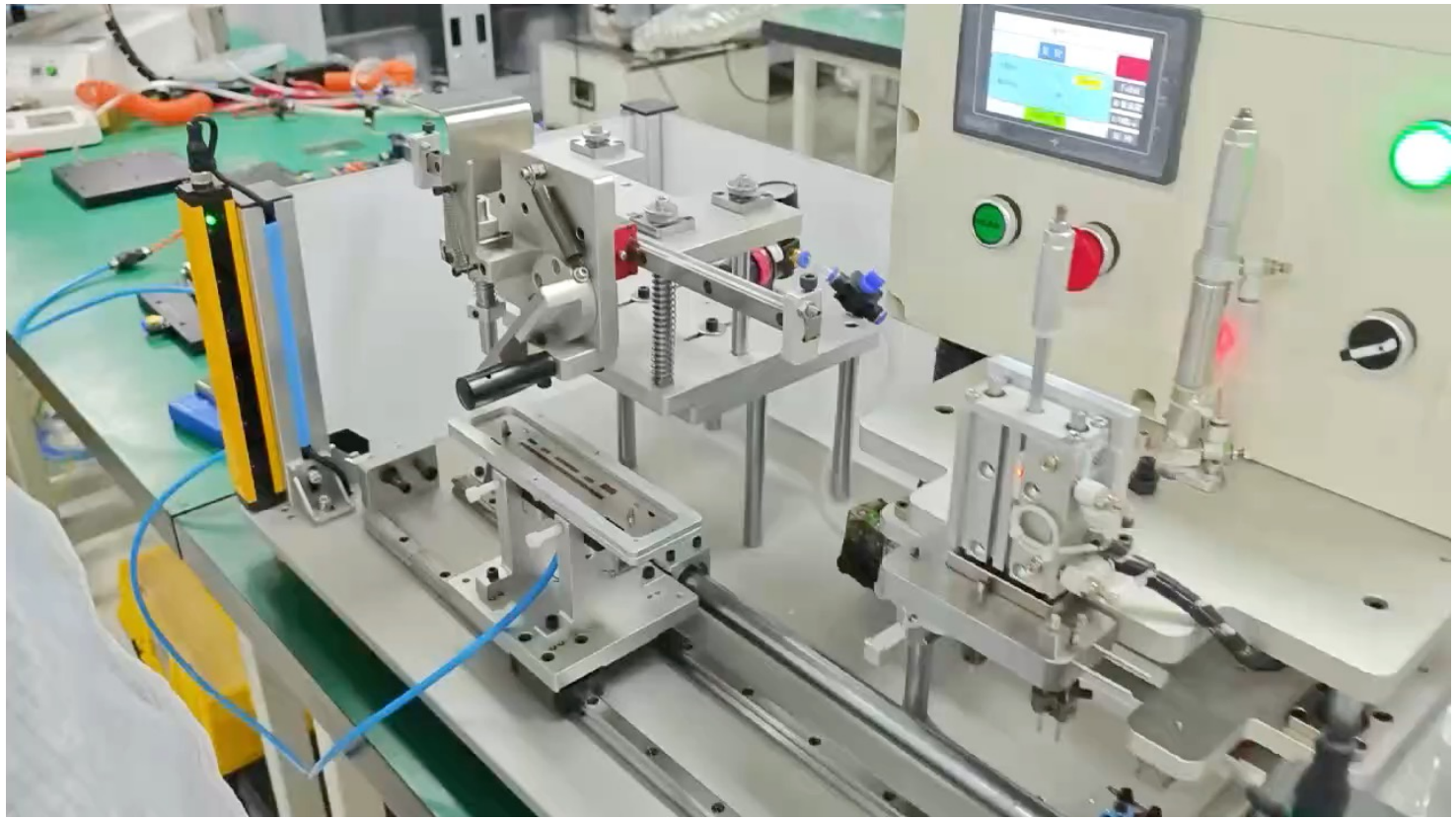
IHEP Site for ITk Strip Module



PRODUCTION Module (x134)

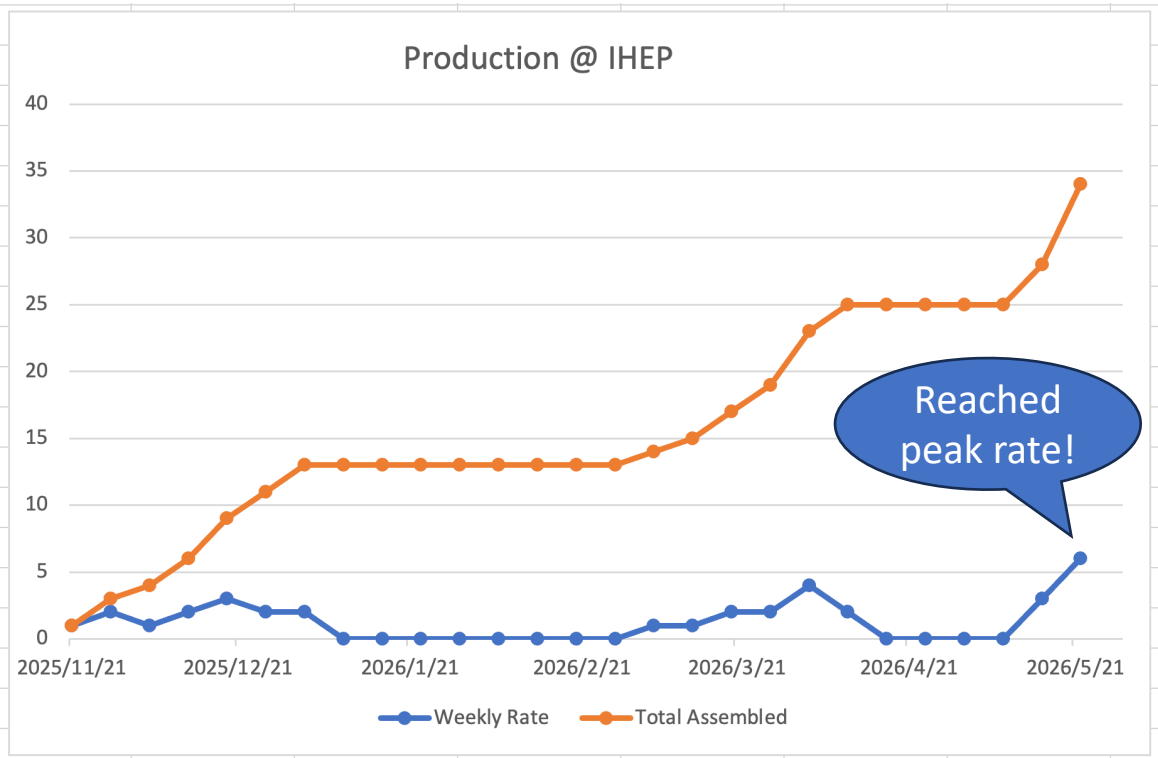
Automatic Module Assembly Machine at IHEP

- Steamline the lifting procedure after apply the glue
- Improve the uniformity between different operators



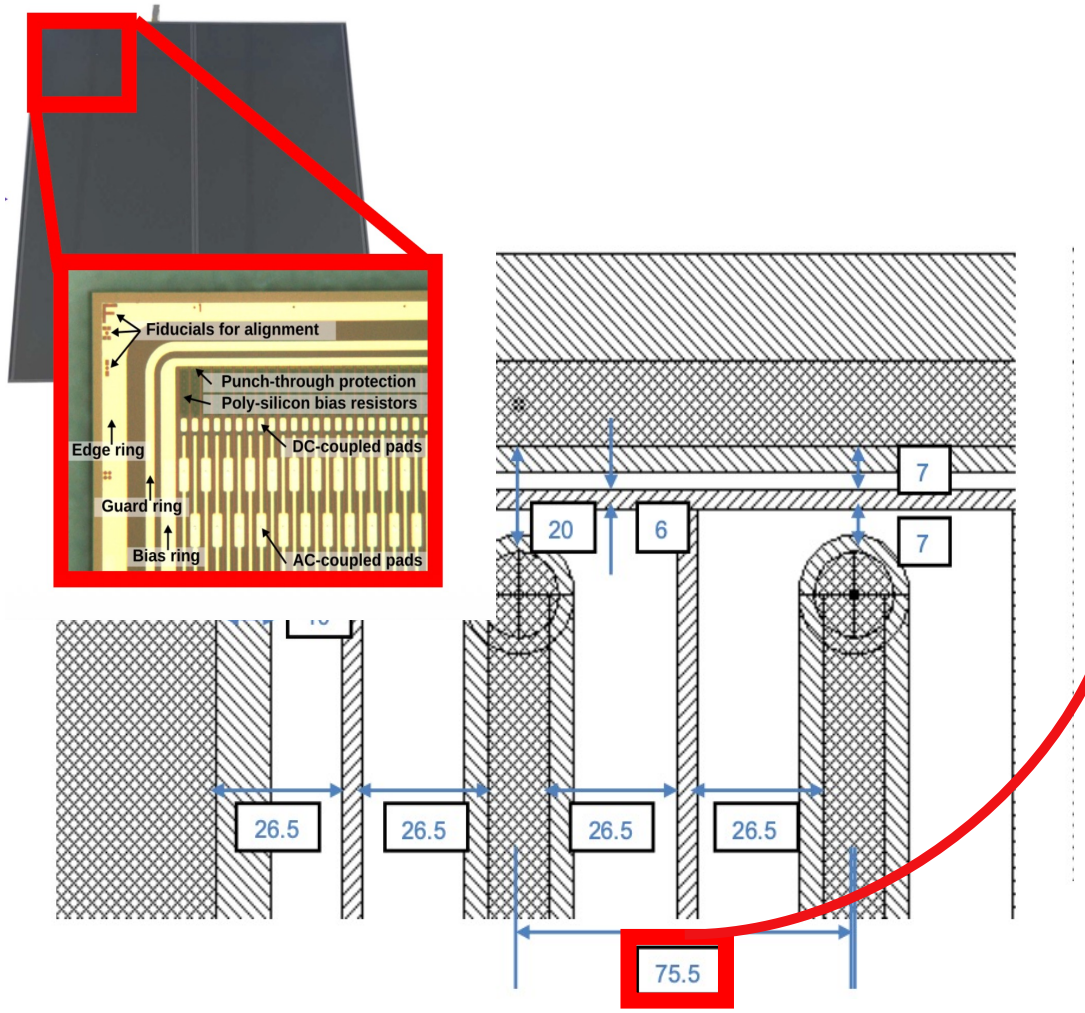
Modules @ IHEP

- 16 Pre-Production Modules
- 15 PRESERIES modules
- 34 PRODUCTION modules @ IHEP
  - Yield > 95 %
  - Reached peak rate 6 modules/week
    (current expect for IHEP: 3)

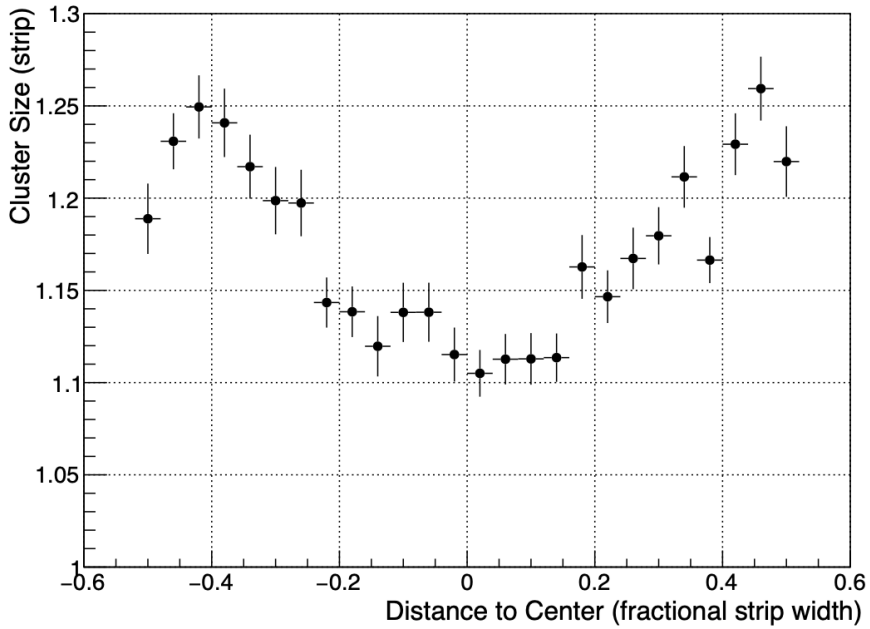


- Flat due to lack of sensors from UK
- Helping CERN logistic team with one staff from IHEP

Strip Module Spacial resolution

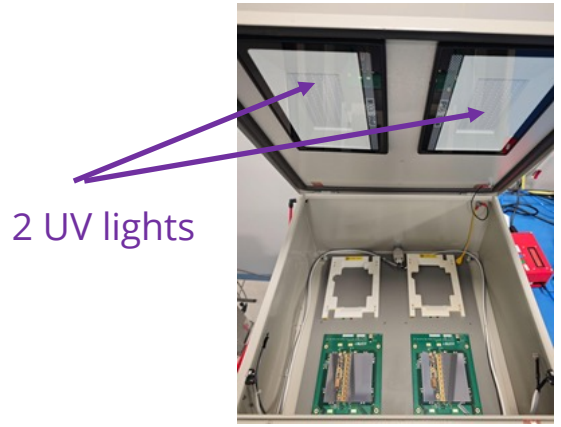


- For a single hit cluster, the resolution limited to (strip pitch)/√12 ~ 22 μm
- Higher resolution can be achieved for larger clusters



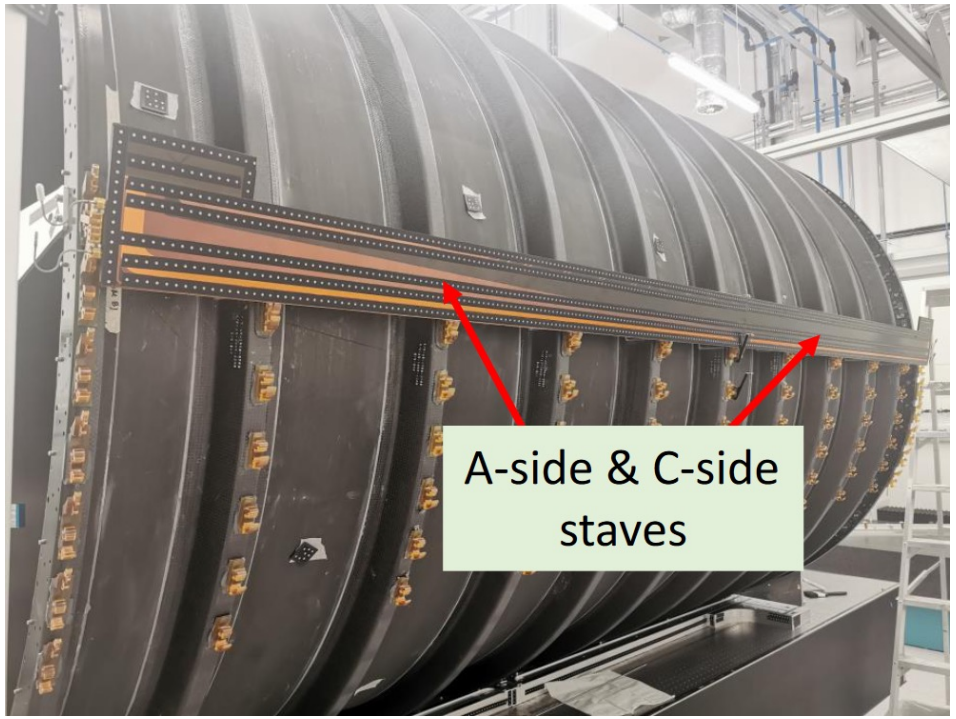
China ITk @ RAL

- Two FTEs from China based at RAL
- Assembled ~100 modules for China share
- Participated in stave loading activities
- Assist in logistics for IHEP and UV light setup for module recovery



CERN Integration

- Strip barrel stave loading
  - Mount 28 modules (14 each side) on the stave
    - Modules on each side rotated by +/-26 mrad
  - Thermal cycle the stave after loading

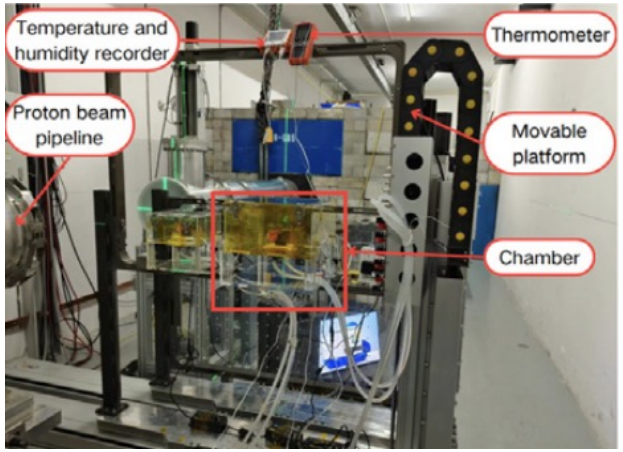


- Barrel tracker system integration
  - Tracker with four concentric carbon cylinders
  - Four-barrel layers consists 392 staves
  - Perform power, cooling, data acquisition, system test
  - Started stave reception test at CERN

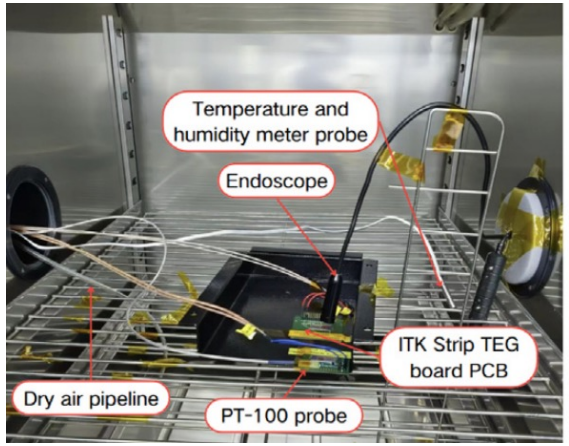
Strip Sensor Irradiation Study

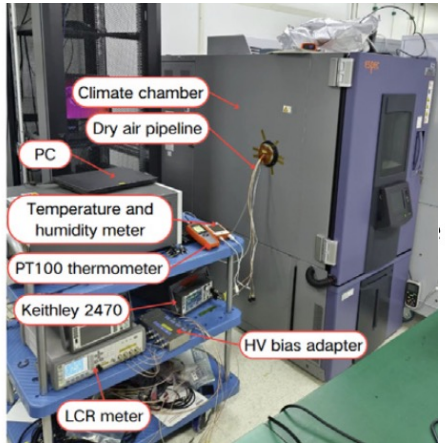
- Proton irradiation of strip mini-sensor at CSNS
- Sensor characterization at IHEP
- Qualified as Sensor Qualification Assurance (QA) site (CSNS as irradiation site / IHEP as sensor testing site)

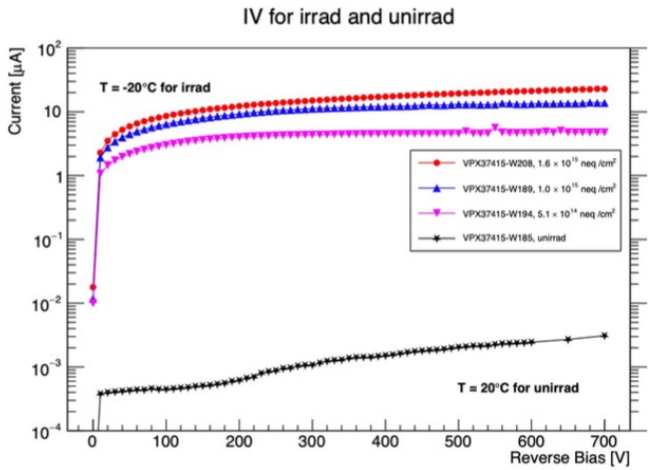
CSNS

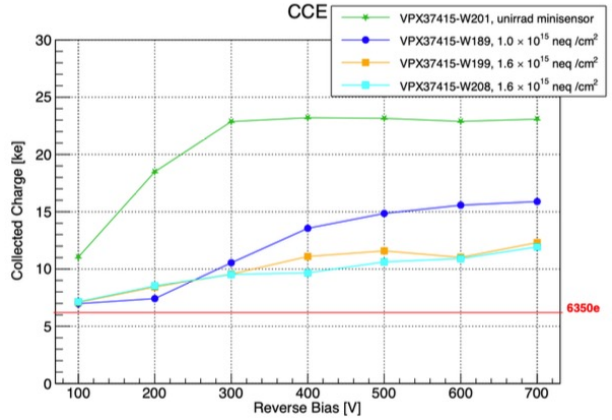


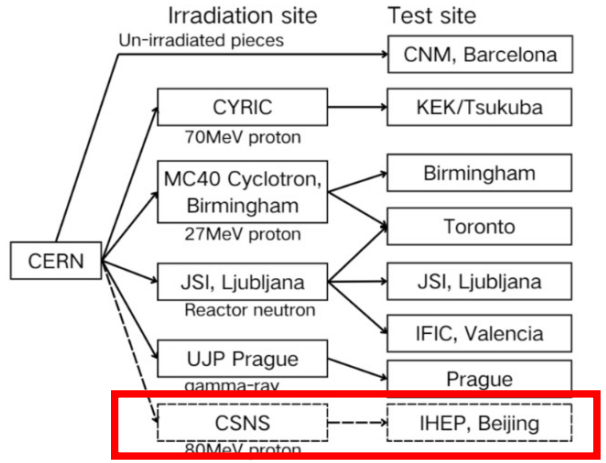
IHEP







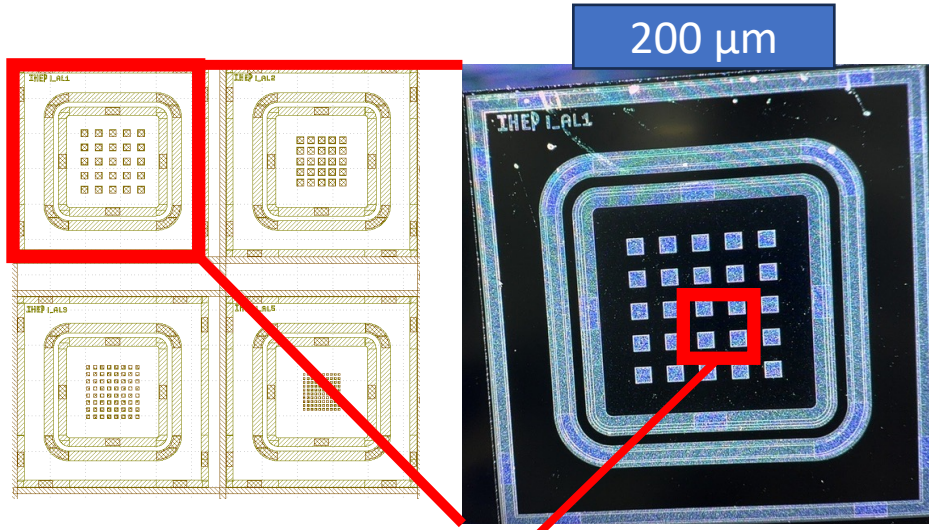


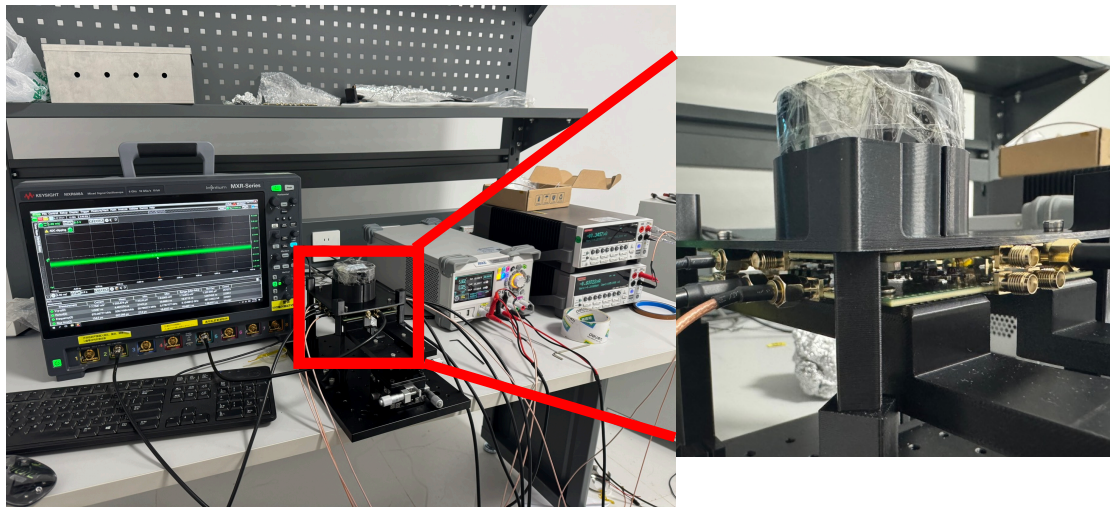


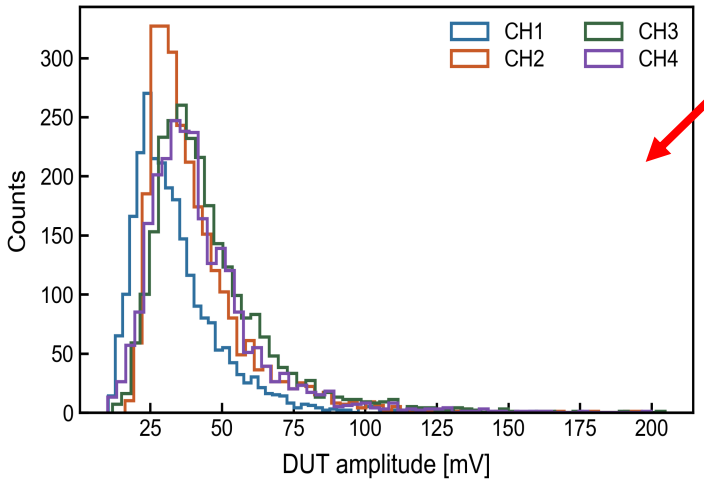
- Received 10 batches of sensor samples for irradiation

2.2 Timing Pixel Sensors – Si AC-LGAD R&D

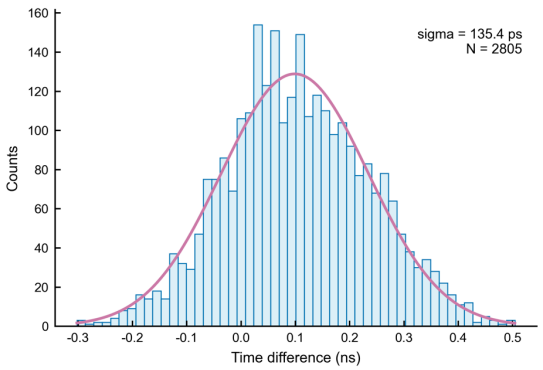
- Pixelated AC-LGAD R&D
- New design with different pad-pitch size
  - 55um, 100um, 150um, 200um
  - Received the first batch in early 2026
  - 4-pixel from 200um tested with 136 ps





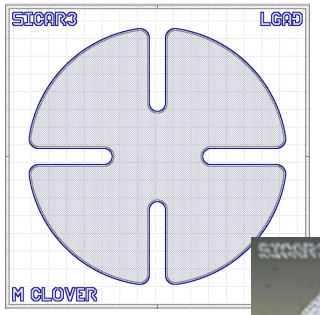


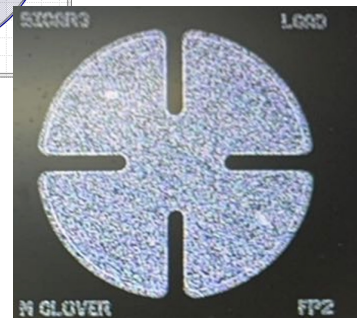
~136ps

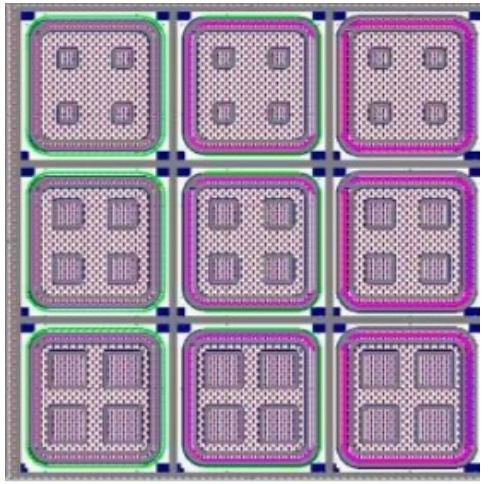


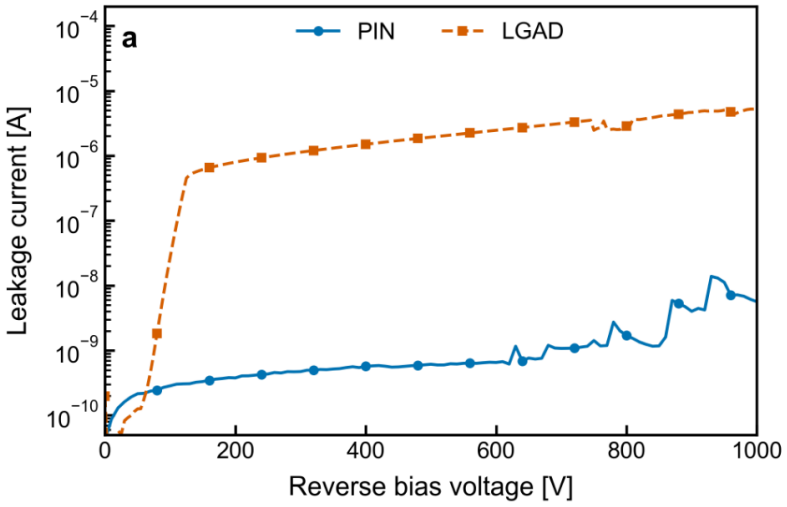
SiC AC-LGAD R&D

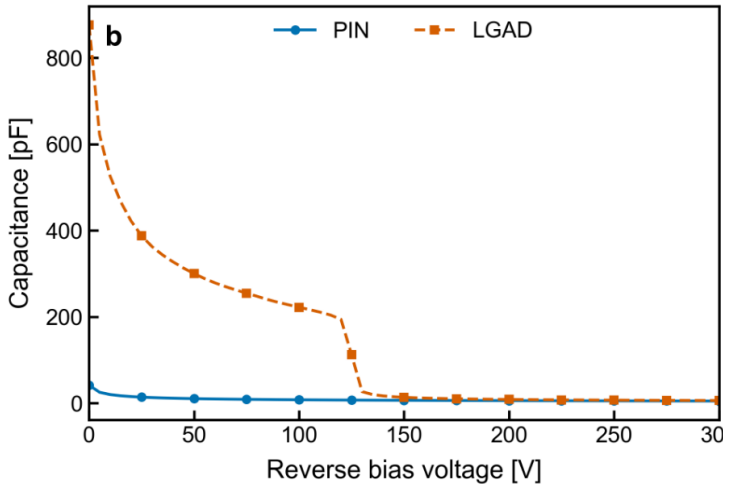
- SiC-LGAD R&D
  - Designed SiC AC-LGAD SICAR3
  - Received first batch in May 2026
  - LGAD/PIN with 1.4mm diameter pad tested
  - Reached time resolusion ~60ps @400V



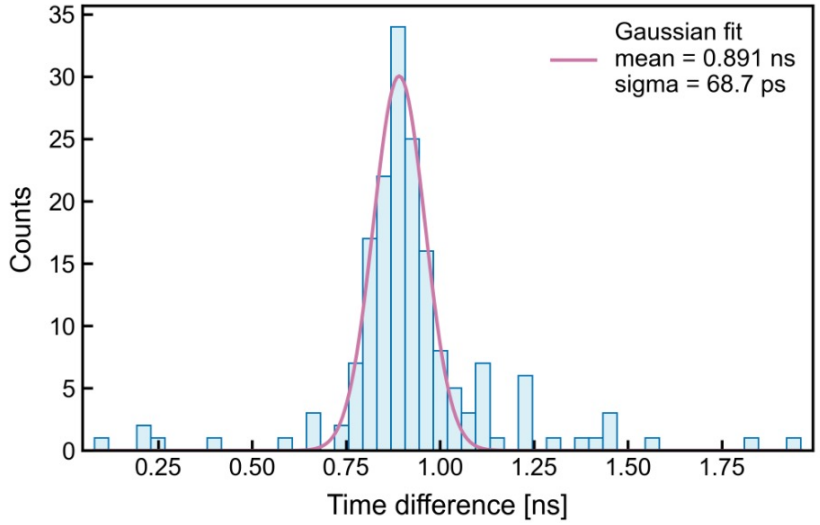






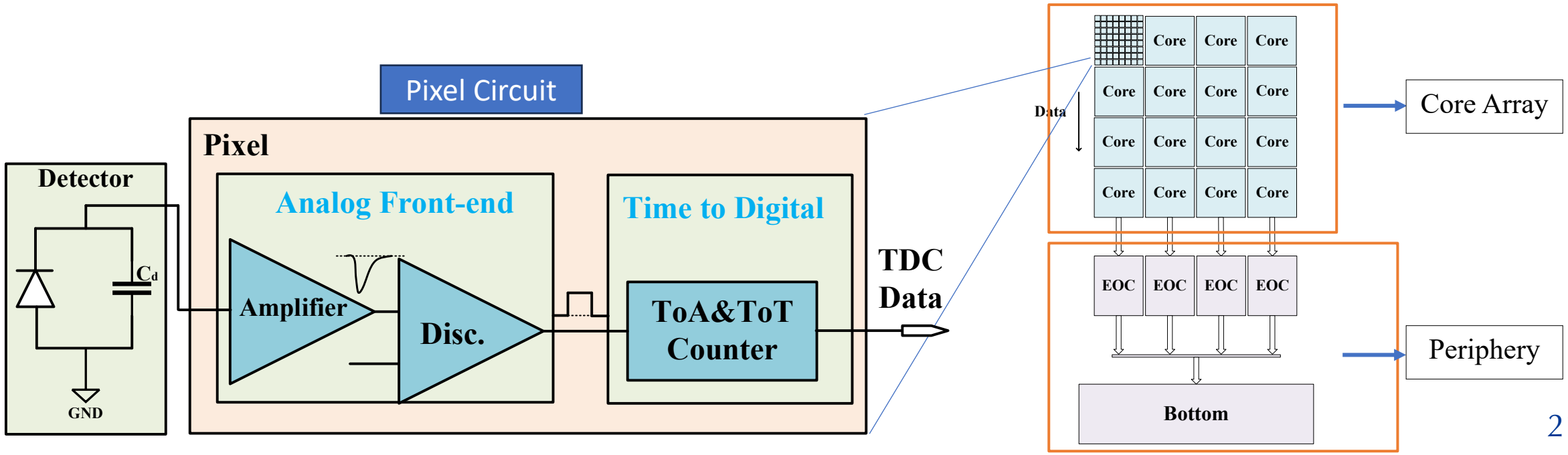


~ 60 ps



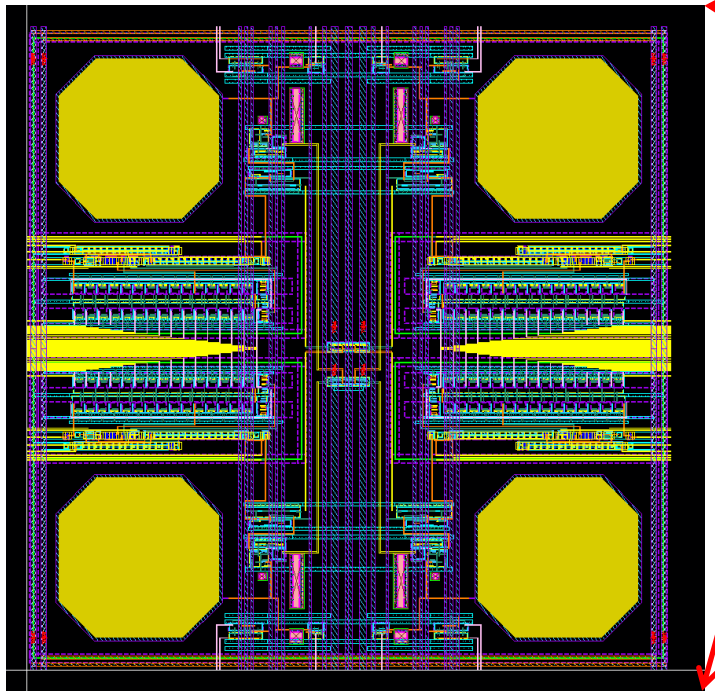
2.2 Timing Pixel Readout Electronics

- Timing Pixel Modules for the Readout ASIC (<100 ps):
- Total precision: $\sqrt{jitter_{Amp}^2 + jitter_{Disc}^2 + jitter_{TDC}^2} = \sqrt{80^2 + 50^2} \approx 94\,ps < 100\,ps$
  - Analog Front-end: Amplifier, Discriminator (< 80 ps)
  - Time-to-digital Converter (< 50 ps)
  - Digital readout circuit: Core Array (8×8 pixels), End of Column, Chip Bottom.

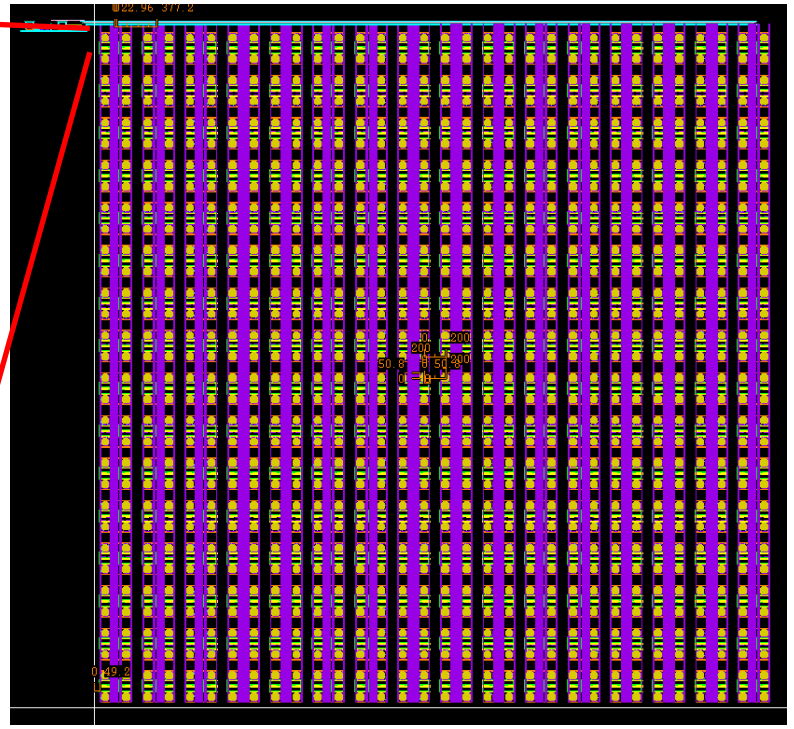


Layouts for the readout ASIC

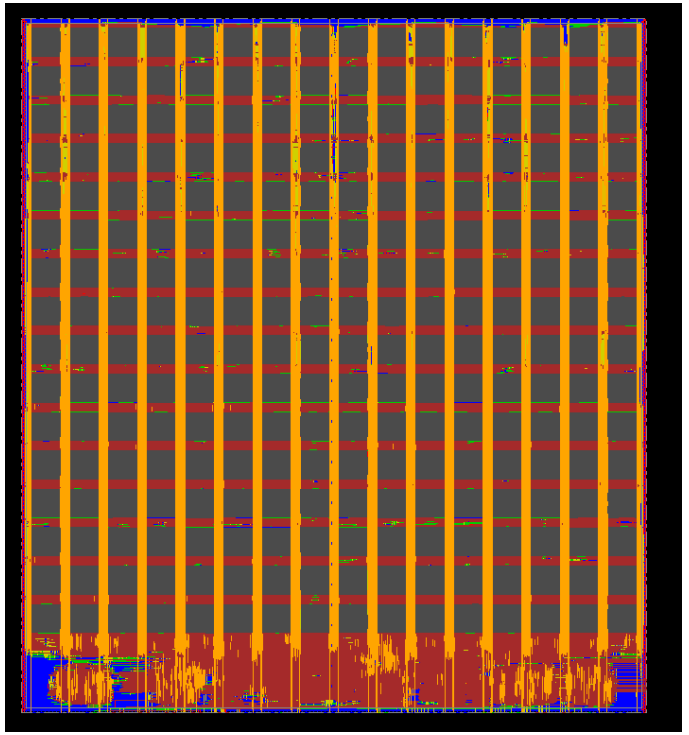
- Pixel Array + Digital readout circuit



Layout of analog island



Layout of pixel array



Layout of digital circuit

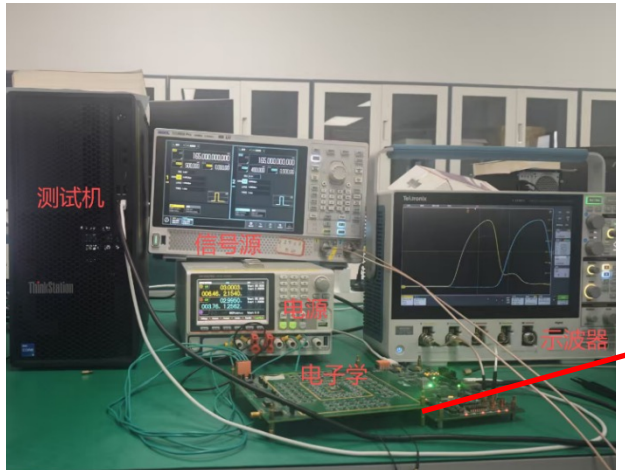
Verification based on discrete devices

- Electronics module:
  - Three-stage Amplifier
  - Discriminator
  - FPGA TDC: delay line

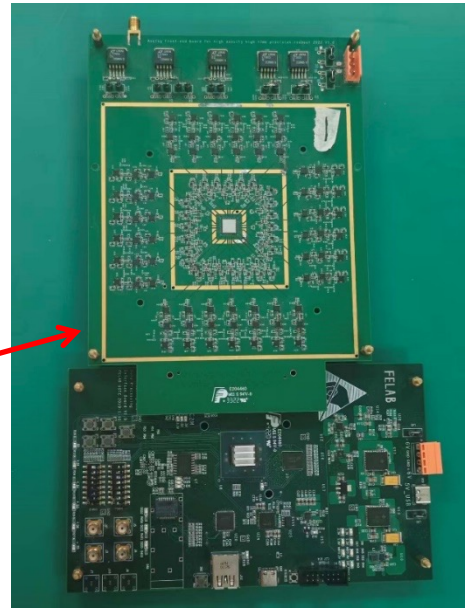
➢ FPGA TDC test: bin size (90.6 ps)

➢ Precision of FPGA TDC two ch~ 46.3 ps

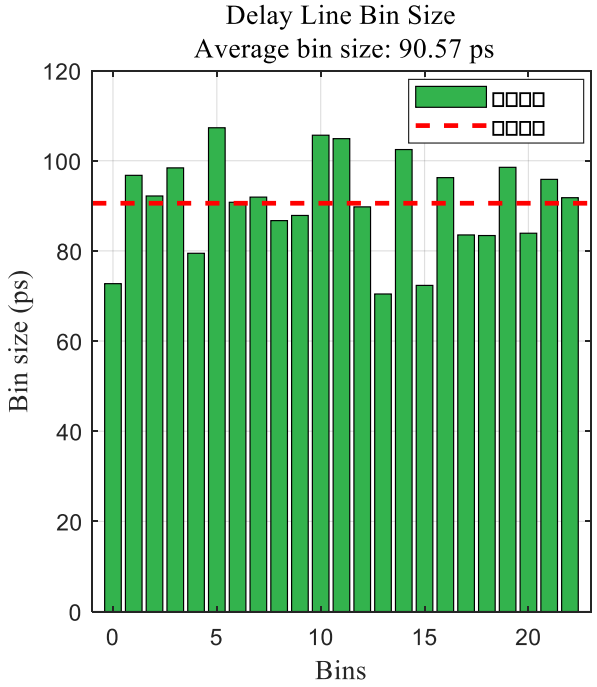
Precision of discrete devices : $\frac{68}{\sqrt{2}} \approx 48.1\ ps$



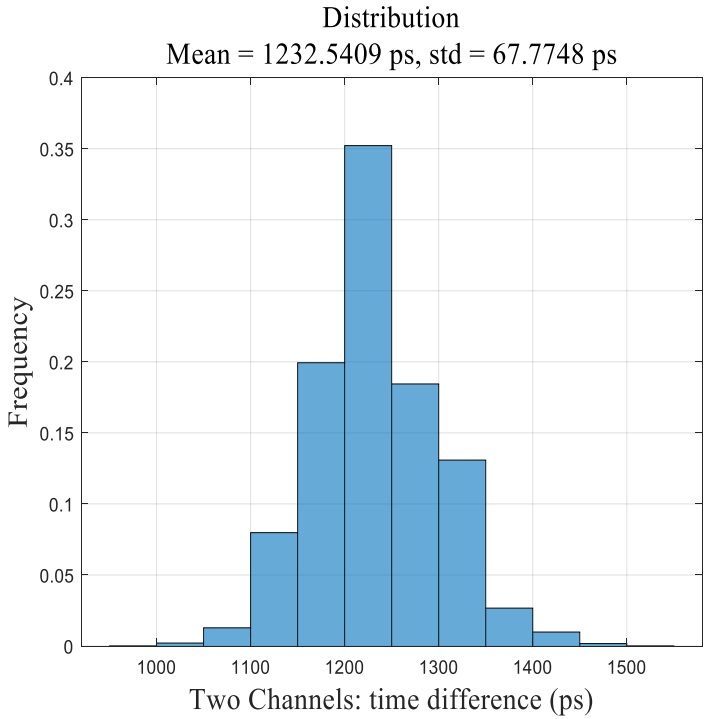
Discrete devices



Test system



FPGA TDC Bins' Size



Distribution for Two Channel's Delay

Overall timing pixel ASIC

- Electronics Design:
  - Analog Front-end (Two stage Amp. + Discriminator) (< 80ps)
  - TDC (Delay line + Loop counter) (Bin size 80~110 ps)
  - Digital readout circuits (Shared memory)
  - Total precision < 100 ps
- Verification based on discrete devices
  - time precision < 55ps
  - Only FPGA TDC ~33 ps

Completion of R&D Tasks – All DONE

- 2023.12-2024.5: Testing silicon sensor, master module assembly. Investigate timing pixel design
- 2024.6 - 2024.11: test ASICs, start asemble long strip module, test stave at RAL, build the stave reception at CERN. Complete timing pixel sensor and ASICs design
- 2024.12 – 2025.5: test irradiated sensor and ASICs, assemble long strip module. Complete timing pixel sensor gain layer desing and readout electronics functional level design.
- 2025.6– 2025.11: mass production stable test for long strip modules, sending modules to CERN. Mask desgin for timing pixel sensor, readout electronics register design.
- 2025.12-2026.5: production for long strip module, mount the IHEP modules at RAL stave; first batch of pixel sensor returned, desing the main verification electronics program.

Completion of Assesment Indicators – all DONE

- Mid-Term goal have been achieved
  - Strip Module Pre and PRODUCTION have started at IHEP with 25 μm spacial resolution
  - Timing pixel sensor reached better than 1ns for Si/SiC LGAD
  - Timing pixel ASICs finished design and verified better than 1ns

硅微条径迹探测器空间分辨率（关键核心指标）	原型模块 25 微米	预生产模块 25 微米 ★	径迹探测器 25 微米	测试报告、同行评审。
硅像素探测器时间分辨率（关键核心指标）	好于 10ns	好于 1ns ★	好于 100ps	仿真验证和实验室测试，测试报告

Orgnization and Management Performance

- IHEP hold weekly meeting, including all tasks with RAL and CERN
  - Mainly discuss strip modules
  - Occationally invite timing pixel report progress

- USTC hold bi-weekly meeting for timing pixel readout electronics
  - Discussion with US colleagues

- IHEP hold weekly sensor discussion with Si and SiC LGAD activities
  - Joint effort from Task 1 & Task 2

Potential Issues

- ASICs export license from US may get delayed
  - Shift the production to RAL for the worst case
- bPOLV12 issue to reduce the production rate
  - Speed up the module production rate in later stage

Beneficial to society

- SiC sensors to be used for fusion reactor and proton beam monitor

CSNS Phase 2 Upgrade

Research Team

- Members listed in task book
  - IHEP: Xin Shi, Peilian Liu, Xiyuan Zhang, Weiguo Lu
  - THU: Yibao Chen
  - USTC: Zhe Cao

- Other contributors
  - IHEP: Xinchou Lou, Yiming Li, Yanping Huang, Zijun Xu, Xuai Zhuang Mei Zhao, Yinhong Zhang
  - THU: Xin Chen
  - USTC: Hongtao Yang, Jiajun Qin, Lei Zhao, Kairen Chen
  - SDU: Kun Hu, Peilian Liu
  - SJTU: Kun Liu
  - SYSU: Yang Liu

- Students and Postdocs : ~ 12

Papers

- 1. Simulation of radiation damage effect on silicon detectors using RASER, JINST 20 (2025) P12009
- 2. Irradiation study using QA test pieces of ATLAS18 ITk strip sensors with 80 MeV protons, NIMA, 1080 (2025) 170707.
- 3. Radiation Tolerance of Epitaxial 4H-SiC LGAD Under 80-MeV Proton Irradiation，IEEE TNS 73 (2026) 157
- 4. Mechanisms of proton irradiation-induced defects on the electrical performance of 4H-SiC PIN detectors, JINST 21 (2026) P03010
- 5. Temperature-dependent performance characterization of 4H-SiC PIN detectors for alpha-particle detection (25–90 ◦C), NIMA 1084 (2026) 171178
- 6. A simulation-based design of the CEPC fast luminosity monitor detector using 4H-SiC, JINST 21 (2026) T02009

Domestic conference talks

- 1. 陆卫国，ATLAS硅微条探测器升级进展，第四届半导体探测器研讨会，2024年5月23日–26日。
- 2. 张希媛，4H-SiC 粒子探测器的研究潜力及其器件研发，第四届半导体探测器研讨会，2024年5月23日–26日。
- 3. 王成伟，Development of ATLAS ITk strip module，第十届中国LHC物理会议，2024年11月13日–17日。
- 4. 周研、陆卫国，Radiation effects of ASICs for ATLAS ITk strip upgrade，第十届中国LHC物理会议，2024年11月13日–17日。
- 5. 黄英峻，ATLAS ITk Strip Sensor Irradiation at CSNS，第十届中国LHC物理会议，2024年11月13日–17日。
- 6. 蔡孟珂, The ATLAS ITk Strip Detector for the HL-LHC Upgrade，第五届半导体辐射探测器研讨会，2025年4月17-20日
- 7. 史欣, ATLAS ITk Strip Module Status in China，第十一届中国 LHC 物理会议，2025年10月29日-11月2日
- 8. 李瞻, ATLAS ITk Strip Sensor Quality Assurance，第十一届中国 LHC 物理会议，2025年10月29日-11月2日
- 9. 杨林, ATLAS ITk Strip Module Testbeam，第十一届中国 LHC 物理会议，2025年10月29日-11月2日
- 10. 王延祺Progress on ACTS-based 4D tracking and a design of timing pixel digital chip 第十一届中国LHC物理会议（CLHCP2025）2025年10月31日
- 11. 陆卫国，ATLAS 内径迹硅微条探测器升级进展与挑战，第六届半导体辐射探测器研讨会，2026年4月16日–4月19日。
- 12. 张希媛，强辐照环境的 4H-SiC 传感器研发进展，第六届半导体辐射探测器研讨会，2026年4月16日–4月19日。

International conference talks

1. 彭少刚，Irradiation test of HCCStar ASICs in CSNS，Topical Workshop on Electronics for Particle Physics 2024，2024年9月30日–10月4日。
2. 陆卫国，Irradiation test for BETSEE at CSNS for ATLAS ITk strip upgrade，Topical Workshop on Electronics for Particle Physics 2024，2024年9月30日–10月4日。
3. 史欣，SiC AC-LGAD Timing Pixel Detector，1st DRD3 Week on Solid State Detectors R&D，2024年6月17日–21日。
4. 史欣，Prototype of SiC-LGAD Detector, 2nd DRD3 Week on Solid State Detectors R&D, 2024年 12 月2 日-6 日。
5. 张希媛，Fabrication Progress and Performance Characterization of SiC detectors, 3rd DRD3 Week on Solid State Detectors R&D, 2025年 6 月 2 日- 6 日。
6. 符晨曦， RASER - A python package for solid-state radiation detector simulation, 3rd DRD3 Week on Solid State Detectors R&D, 2025年 6 月 2 日- 6 日。
7. 史欣，Status and Plans for the DRD3 collaboration, The 2025 International Workshop on the High Energy Circular Electron Position Collider, 2025年 11 月 5 日-10 日。
8. 周嘉奇，Radiation hardness of 4H-SiC detectors for the CEPC Fast Luminosity Monitor Detector, The 2025 International Workshop on the High Energy Circular Electron Position Collider, 2025年 11 月 5 日-10 日。
9. 符晨曦， RASER simulation of 4D tracking detectors, 4th DRD3 Week on Solid State Detectors R&D, 2025年 11 月 10 日- 14日。
10. 张希媛，Update on SICAR, 4th DRD3 Week on Solid State Detectors R&D, 2025年 11 月 10 日- 14日。

Funding Status

	Task 2	Task 2	Task 2	Task 2
	Sum	IHEP	USTC	THU
Total Budget	600.00	350.00	100.00	150.00
Received funds	480.00	274.07	82.37	123.56
Pending to allocated	120.00	75.93	17.63	26.44
Implementation rate %	**48.70%**	**50.54%**	**30.97%**	**56.23%**
Total Expense	292.18	176.87	30.97	84.34
1 Direct fee	212.11	156.41	7.13	48.57
1) Device fee	0.00	0.00	0.00	0.00
2) Business fee	90.06	86.76	3.30	0.00
3) Labor fee	94.62	69.65	3.83	21.14
2 Indirect fee	80.08	20.46	23.84	35.77

- Reached ~50% level for the overall project
- Low rate for USTC to spend for later 2026 with MPW

Summary and Plan

- Mid-Term goal have been achieved
  - Strip Module Pre and PRODUCTION have started at IHEP with 25 μm spacial resolution
  - Timing pixel sensor reached better than 1ns for Si/SiC LGAD
  - Timing pixel ASICs finished design and verified better than 1ns

- Plan
  - Complete the modules assembly and participate in the CERN integration
  - Complete the assessment of timing pixel detector and ASICs test once ready

硅微条径迹探测器空间分辨率（关键核心指标）	原型模块 25 微米	预生产模块 25 微米 ★	径迹探测器 25 微米	测试报告、同行评审。
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