ATLAS Silicon Strip Detector Phase-2 Upgrade

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China LHC Upgrade Meeting in Weihai

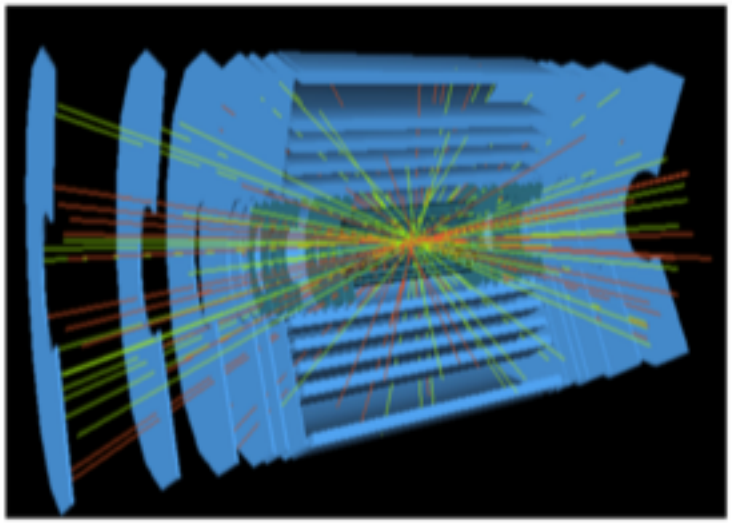
Outline

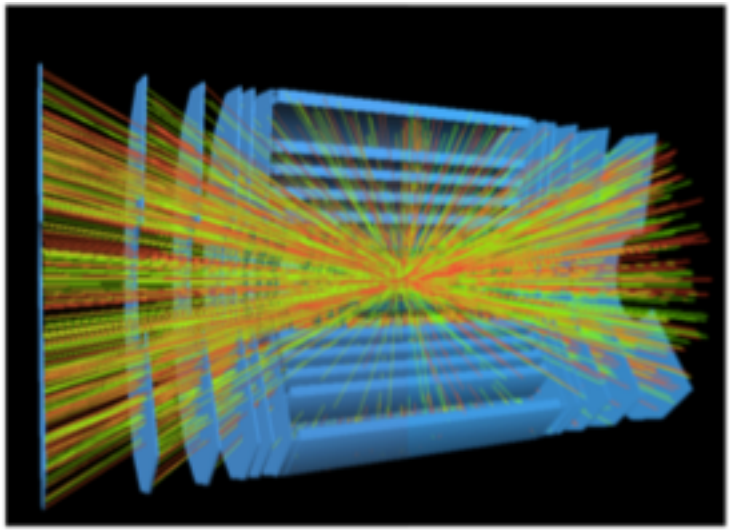
- Overview of ATLAS ITk
- IHEP/THU activities
  - Baseline design
  - Module construction and test
  - Novel detector R&D
- Summary

ATLAS ITk Upgrade Overview

Introduction to LHC phase II upgrade

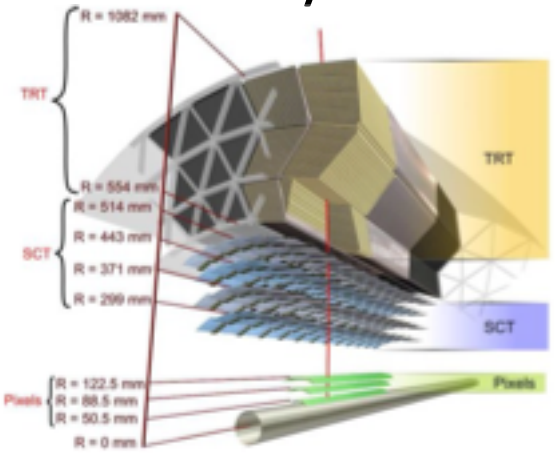
- High Luminosity-LHC (HL-LHC) is foreseen to be completed in 2026
  - Will substantially improved Higgs measurement precision
  - Aim to increase the integrated luminosity to about ten times the LHC design.
  - Instant luminosity $\sim 5 - 7.5 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$, deliver 3000 fb^{-1}
  - Expect to have 200 collision per bunch crossing



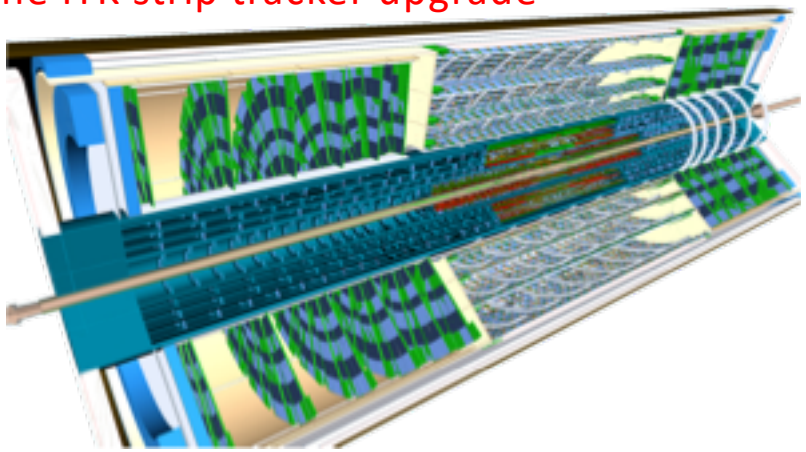


ATLAS Inner TracKer (ITK) upgrade

- Require a new full-silicon tracker for upgrade (more area/channels)

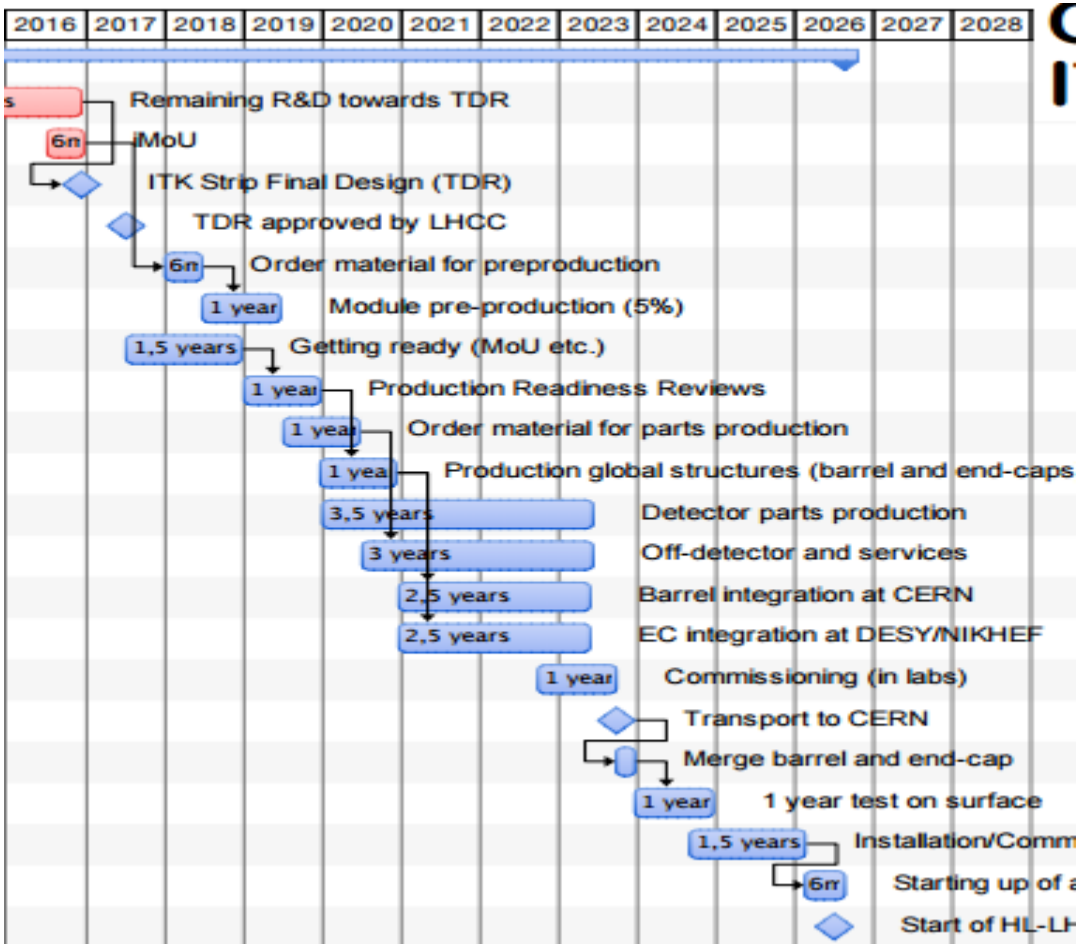


IHEP will contribute 1000 modules (10 m^2 silicon) In the ITK strip tracker upgrade



Strip detector comparisons	Current Inner strip tracker (SCT)	Future ITK strip tracker
Radial distance	300-560mm	400-1000mm
Channels	~8 millions	~100 millions
Modules	4 thousands	~20 thousands (165m^2 silicon)

Timeline of ATLAS strip detector upgrade



End of 2016 , technical design report (TDR)

2018-2019 pre-production

2020-2023 production

IHEP/THU Activities

Baseline design
Module construction and test
Novel detector R&D

The IHEP/THU ATLAS ITk team

8 Staff Members (7 IHEP + 1 THU)

Xinchou Lou

Joao da Costa

Hongbo Zhu

Weiguo Lu

Xin Shi

Zhijun Liang

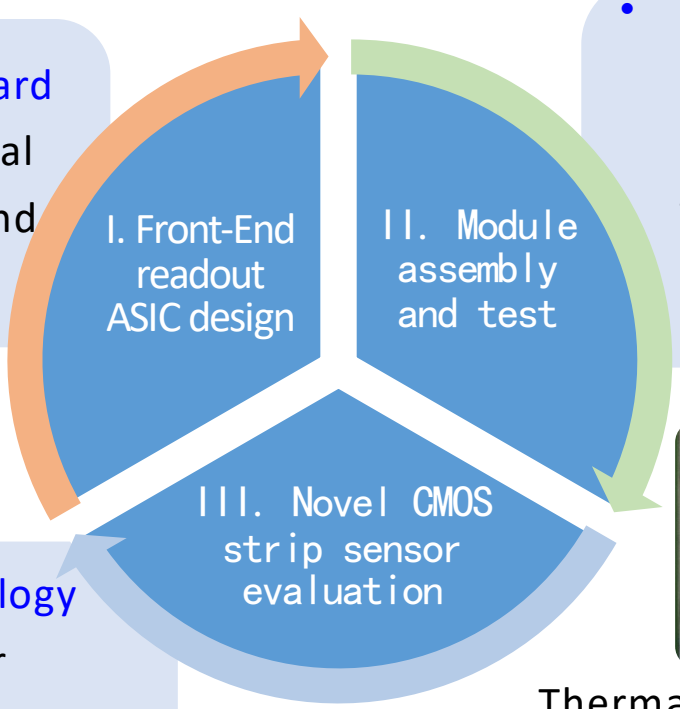
Yiming Li

Xin Chen

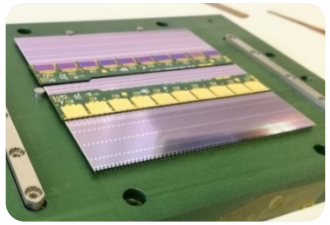
Current Activities

R&D and small-scale mass production funded by the MOST; to be matched by NSFC to complete the mass production ~ 1000 barrel strip detector modules

- Baseline design, rad-hard digital circuit: functional blocks development and verification with UVM



- Ultimate commitment: in close collaboration with RAL (UK), and to learn the full procedure of module assembly and quality control/assurance (QA/QC)



Thermal mechanical modules assembled by colleagues visiting RAL

- Novel detector technology R&D: prototype sensor performance characterization and feasibility evaluation

IHEP/THU Activities

Baseline design

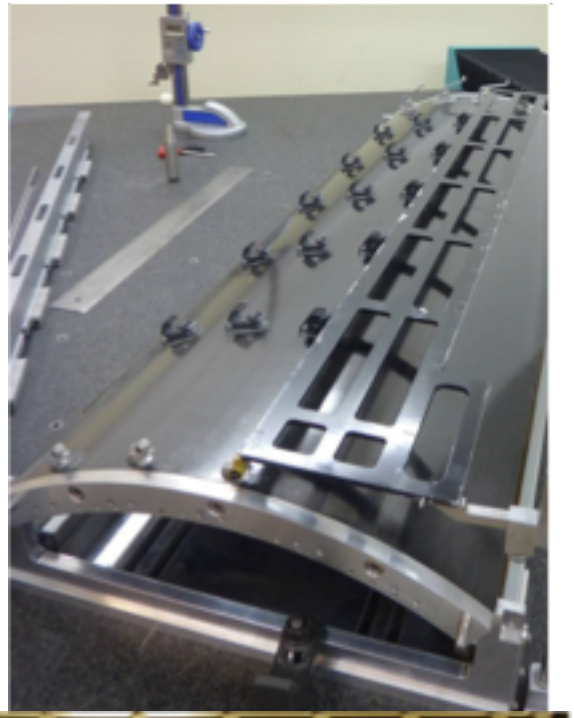
Module construction and test

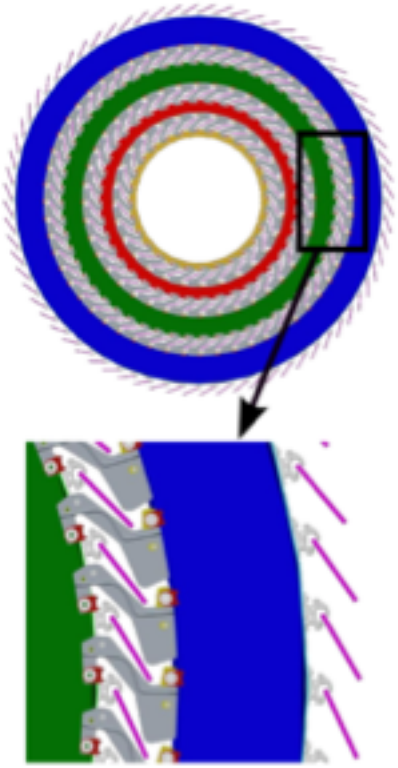
Novel detector R&D

Structure of the silicon strip tracker

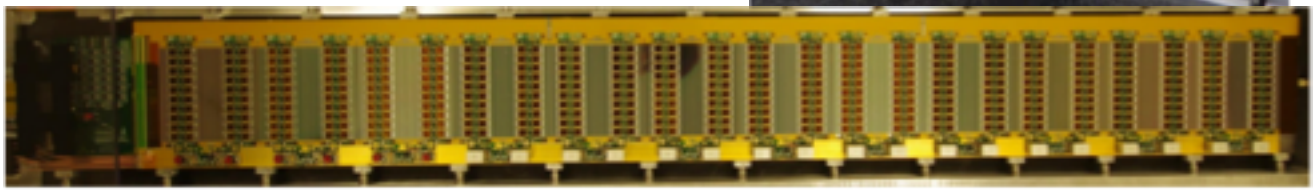
- Global structure: 4 layers of silicon strip tracker in Barrel
- Local structure (Stave)： 28 barrel modules on each stave

Local structure: Stave
= 28 modules
+ electronic (bus tape)
+ thermal (cooling pipe)
+mechanics (carbon fibre）





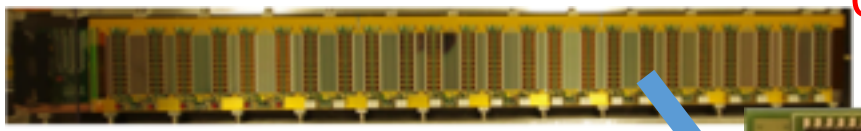
Stave prototype

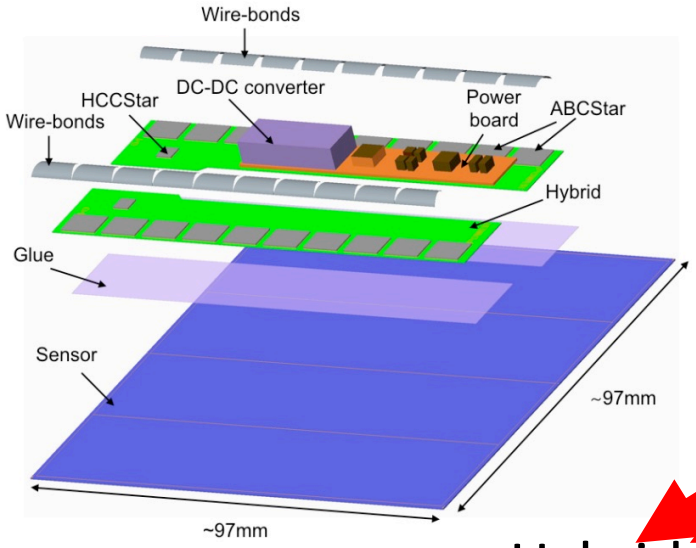


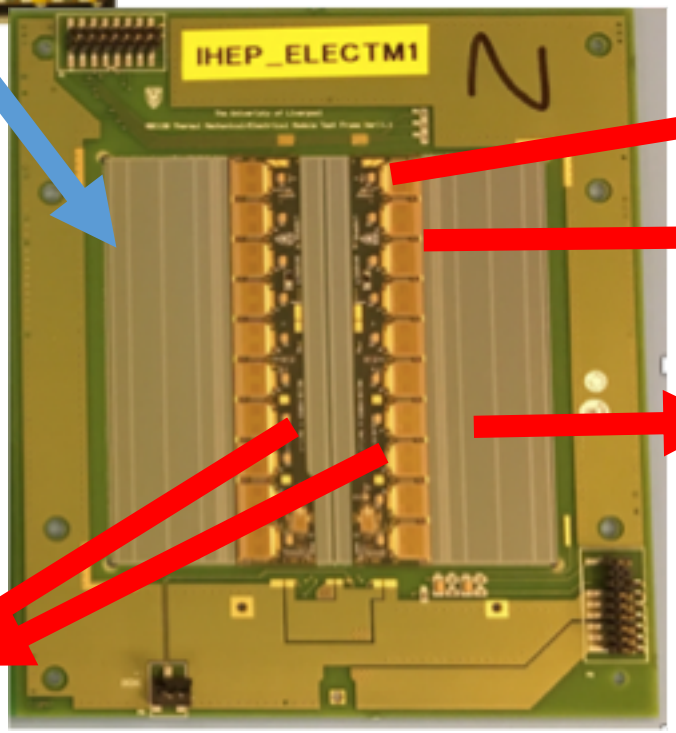
Module: the basic detector unit

- 10 readout ASIC (ABC130) wire-bonded on one hybrid
- Two Hybrids are glued on short strip sensor, and wire bonded to sensor to readout 2560 channels each

One Module prototype by IHEP







Readout ASICs

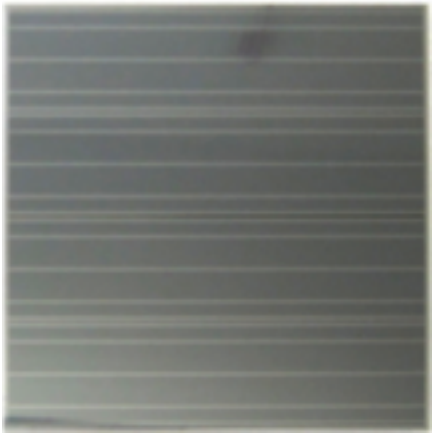
Wire bond

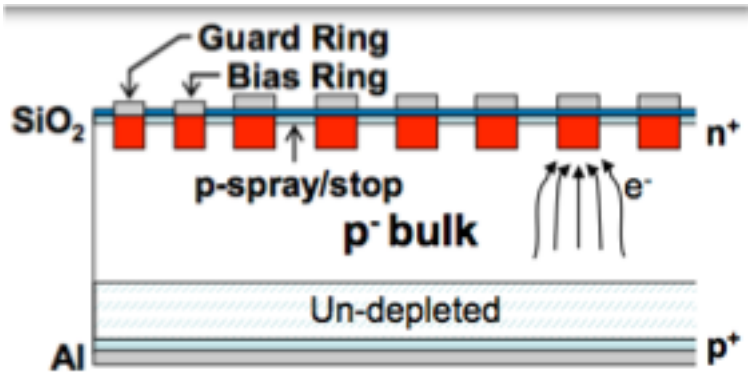
Silicon Sensor

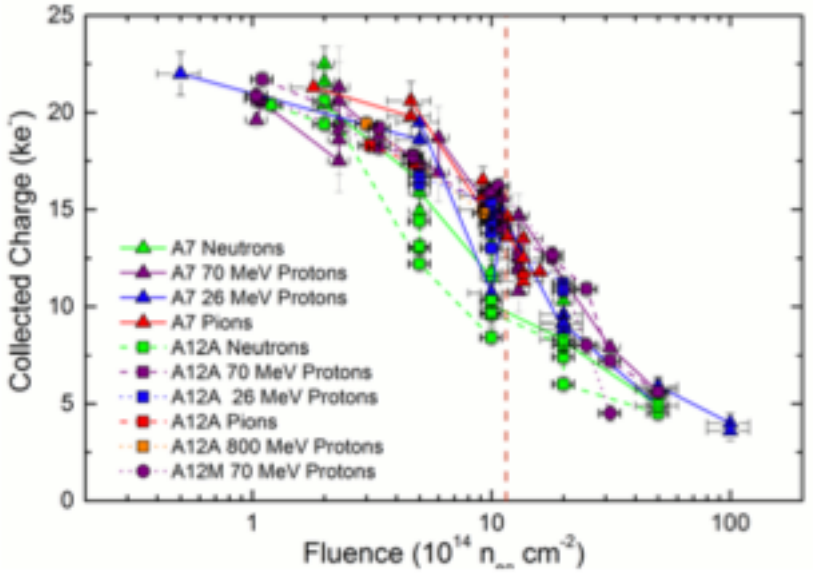
Hybrid

Radiation hard strip Sensor

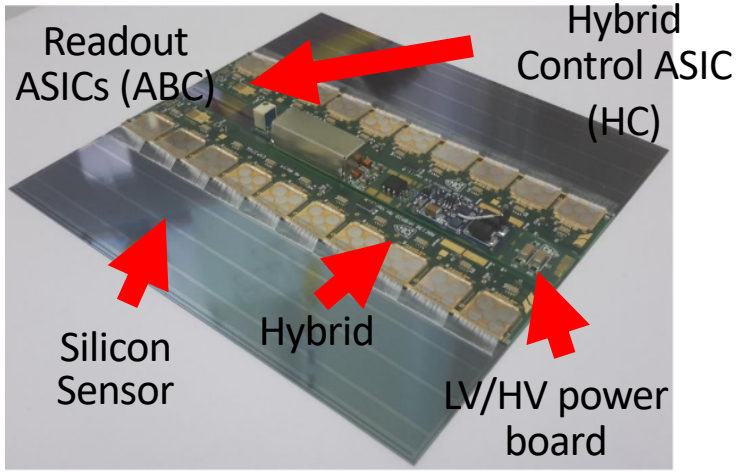
- N+-on-p strip sensor (9.7 cm^2 X 9.7 cm^2)
  - Collect electrons (fast carriers, reduce charge trapping)
  - >22k （10k） electrons for MIP before (after) irradiation
- Market survey for two company (Infineon and Hamamatsu)
  - Infineon gave up the project recently
  - final sensor is likely to order from Hamamatsu.
  - Final round of prototyping this year, IHEP contribute to testing and qualifying sensors.



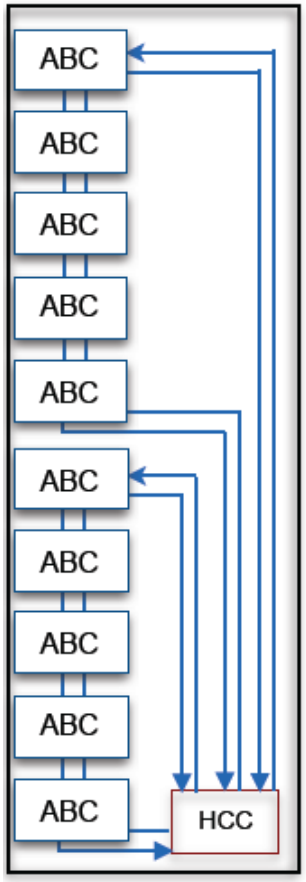


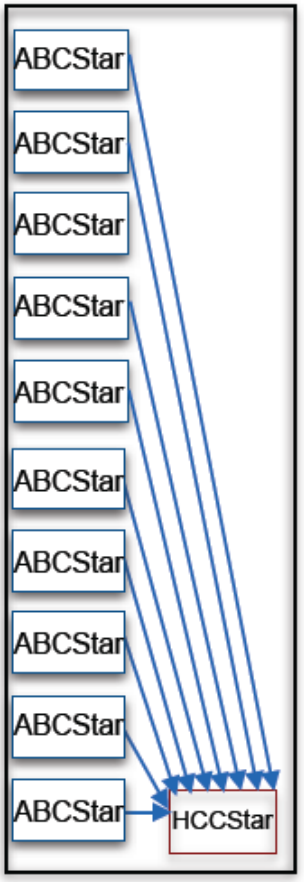


Star chips for ITk Strip



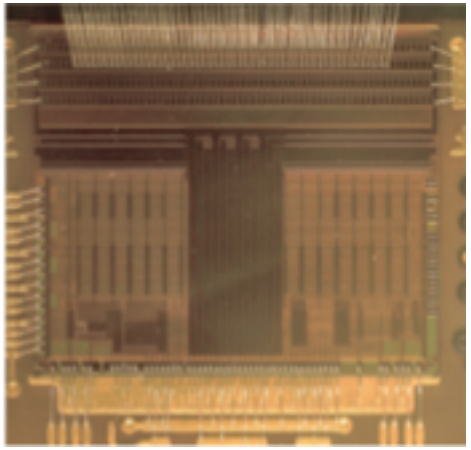
- Challenge for ITk Strip upgrade
  - Higher luminosity , finer granularity, larger scale, harsher radiation…
- Chipset on module
  - ABC--ATLAS Binary Chip
  - HCC--Hybrid Control Chip
- Star architecture on hybrid
  - Increased trigger rate->1MHz L0
  - shorter latency
  - From serial transfer to star connection

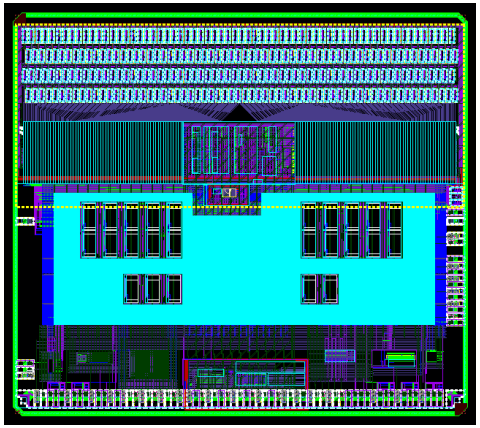


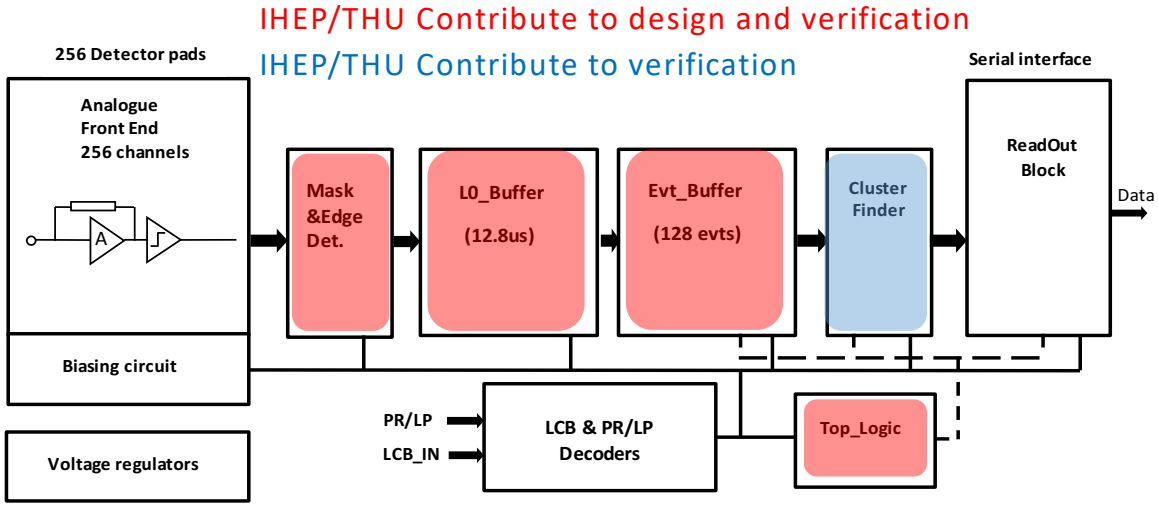


Frontend ASIC: ABCStar chip

- IHEP/THU contributed to ASIC digital design
- ABCStar readout chip
  - Standard binary readout architecture
  - Radiation hard design
  - IBM/GF 130nm technology



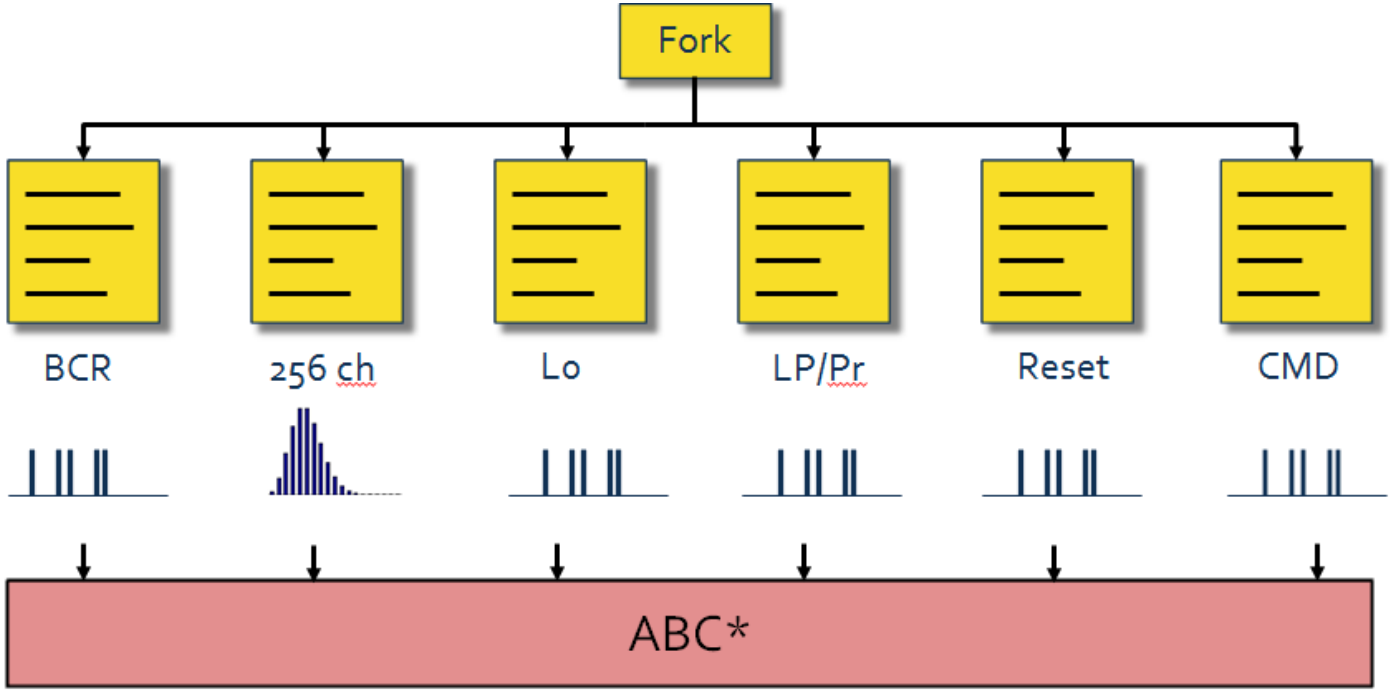




See more from Weiguo Lu's talk.

Frontend ASIC: Functional Verification

- IHEP/THU contributed to digital design and verification
- A top verification setup based on (UVM) Universal Verification Methodology was built for ABCStar
  - Functional coverage with customized random stimulus
  - SystemVerilog assertions for validating key design features



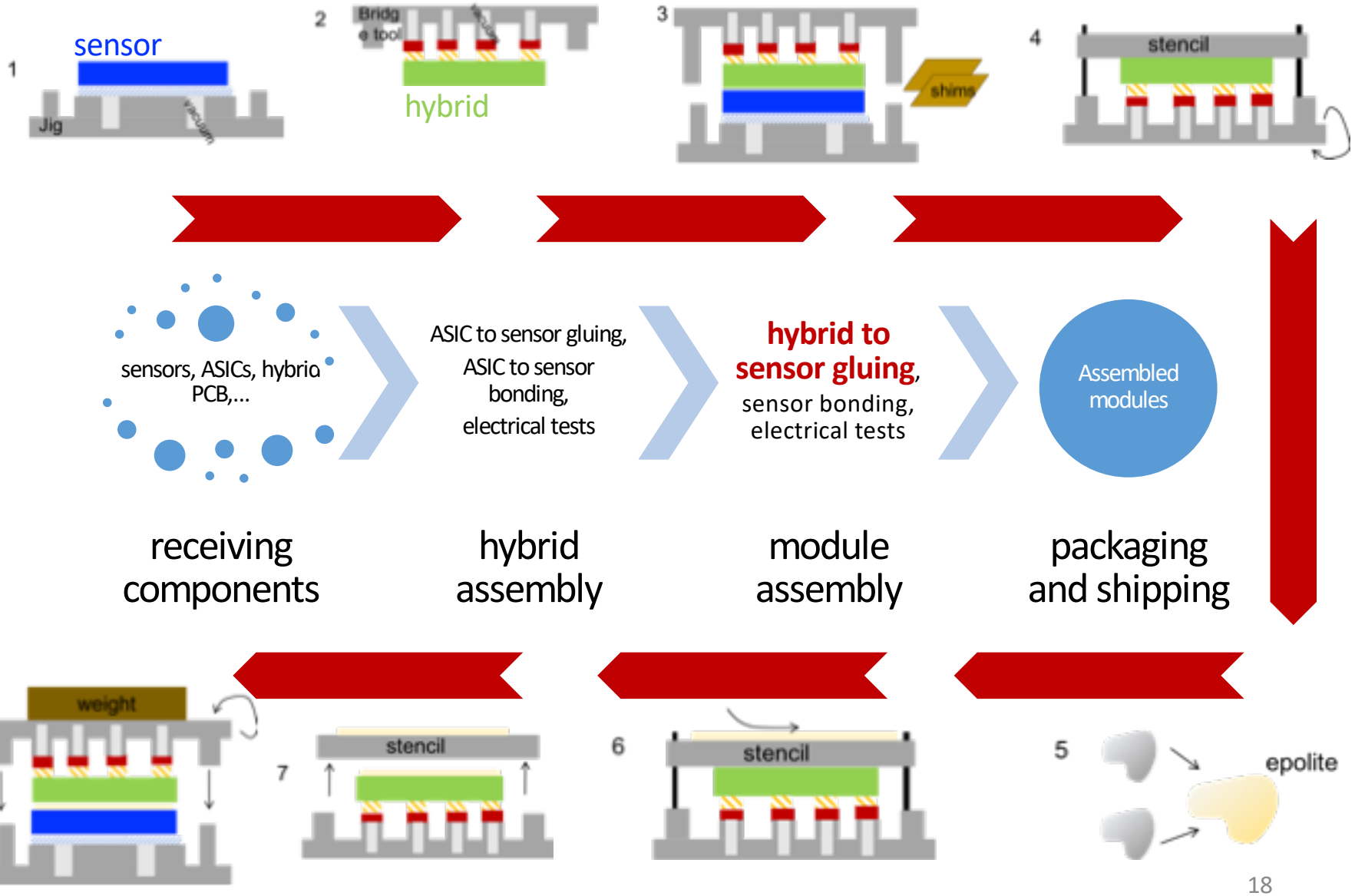
IHEP/THU Activities

Baseline design

Module construction and test

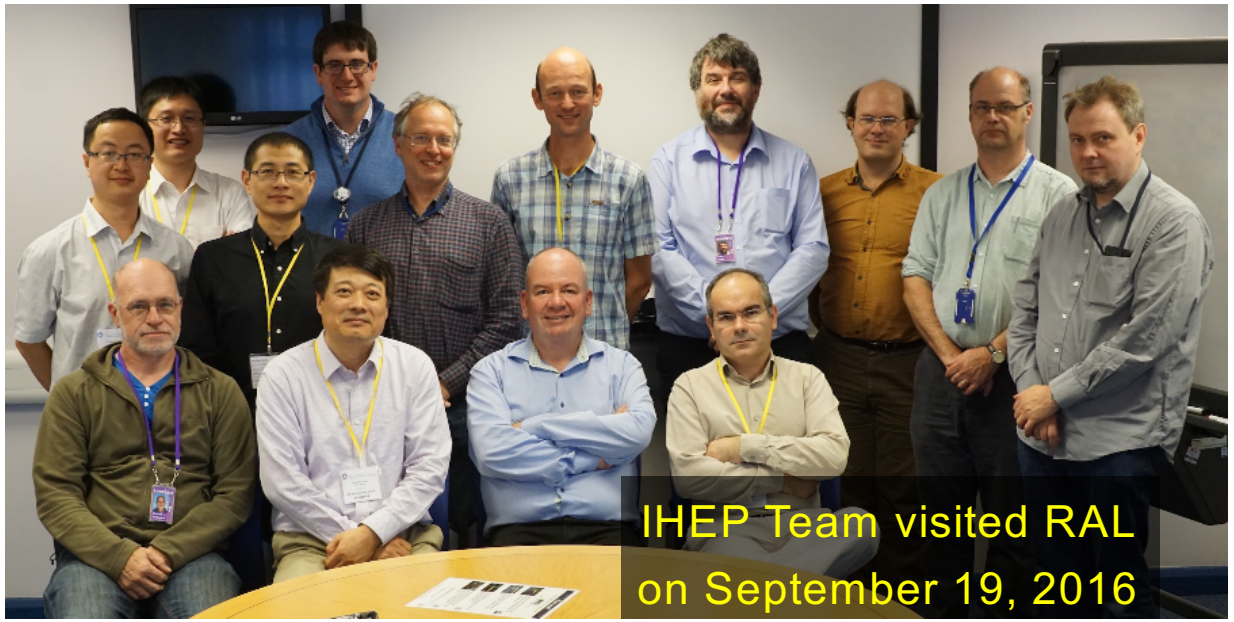
Novel detector R&D

Module production workflow



Collaboration with RAL in UK

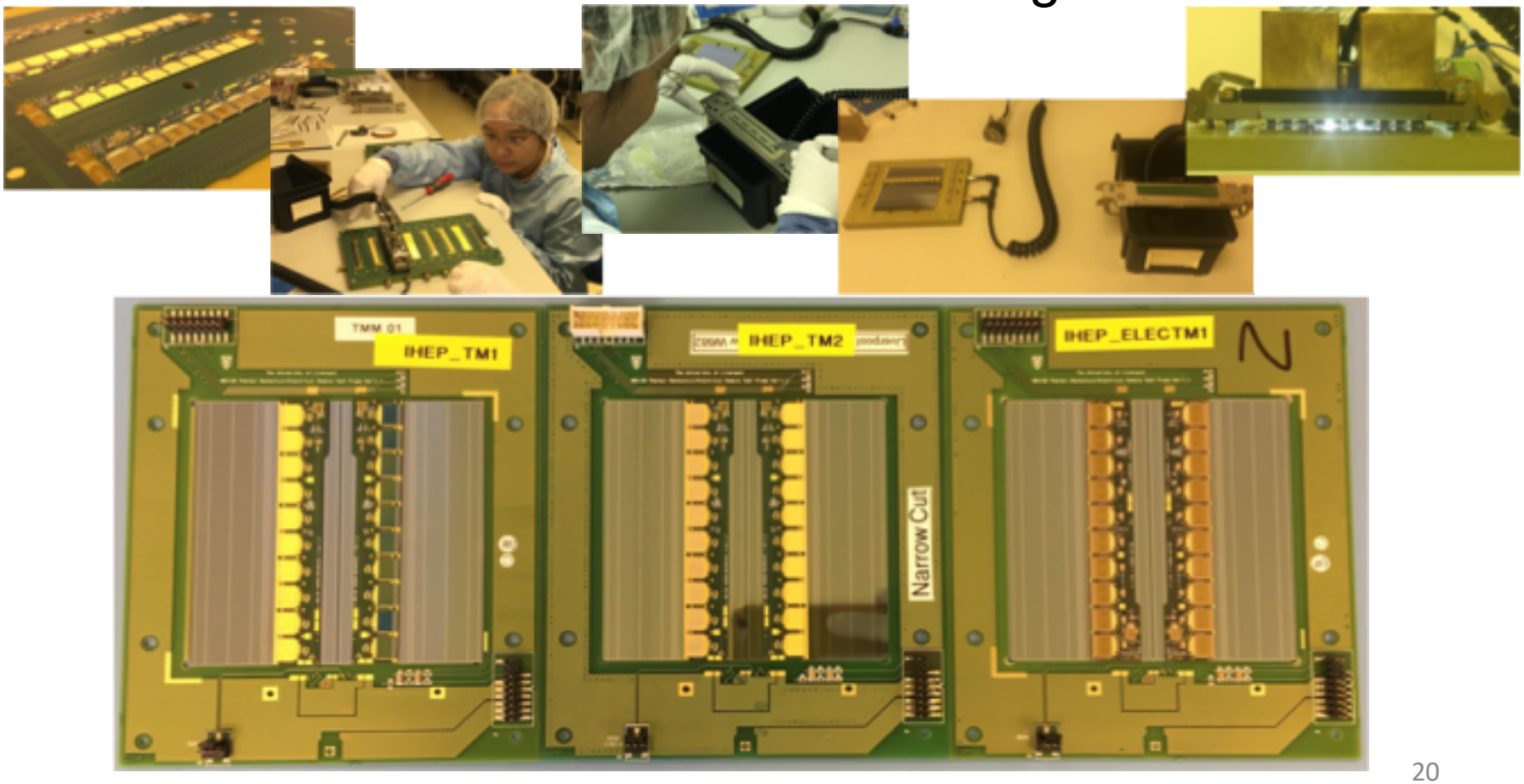
- RAL in UK is the leading institution on ATLAS ITk upgrade.



- MoU to be signed with RAL
  (500 modules at RAL , 500 modules at IHEP)
- Staff rotation plan to maintain 2 FTE's at RAL for the coming years.
- Invited RAL collaborators to China.
  - Giulio Villani visited IHEP in Dec 2017
  - Craig Sawyer visited IHEP in Jan 2018

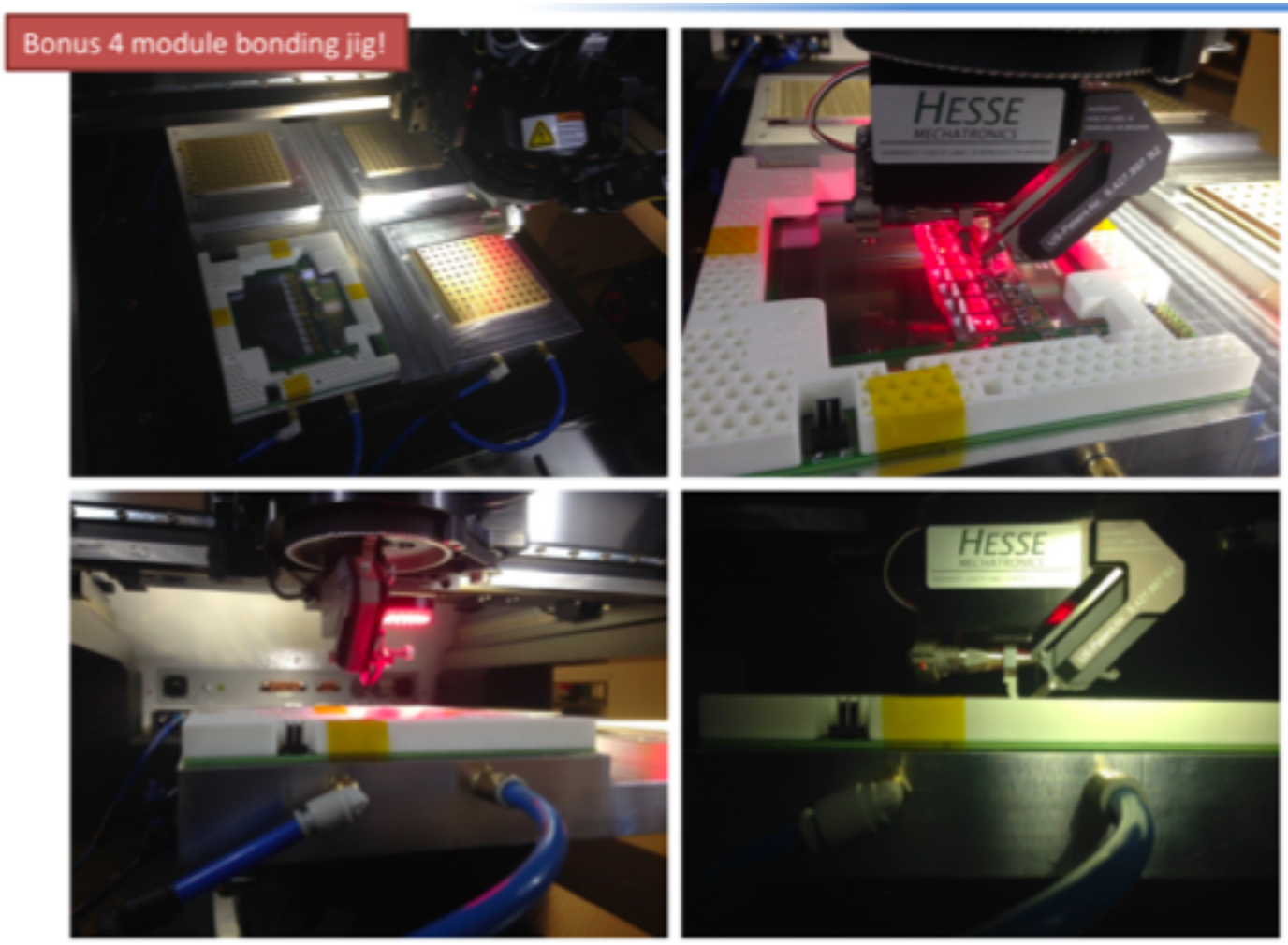
Module production at RAL

- Glued three modules (two thermal mechanical and one electrical)
- Passed electrical test after wire bonding.



New Module production tool by IHEP: 2X2 jig

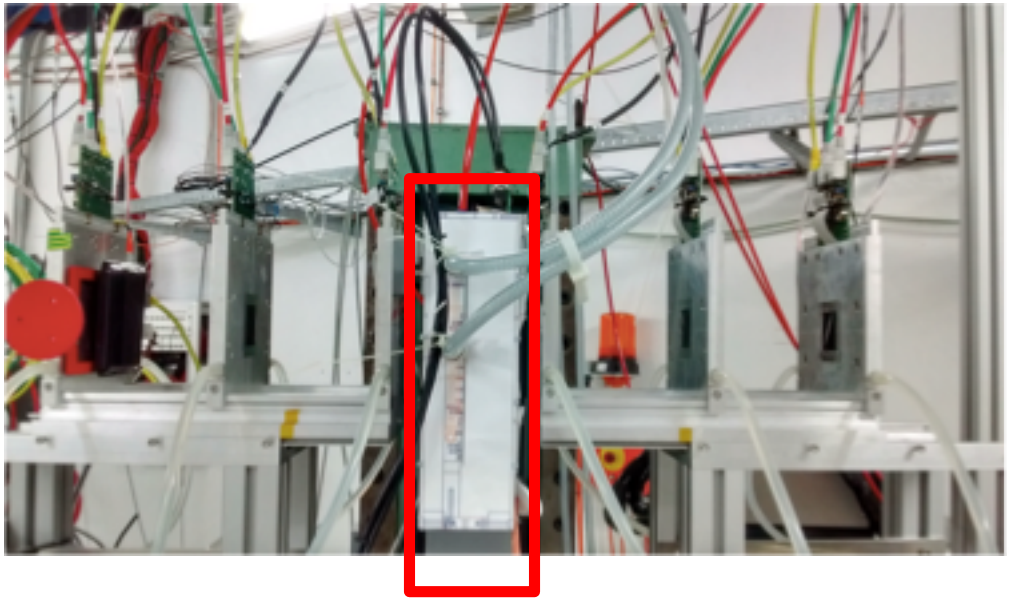
- IHEP developed new tool to improve the module production efficiency
  - One module each time -> 4 module each time (by Yuzhen)

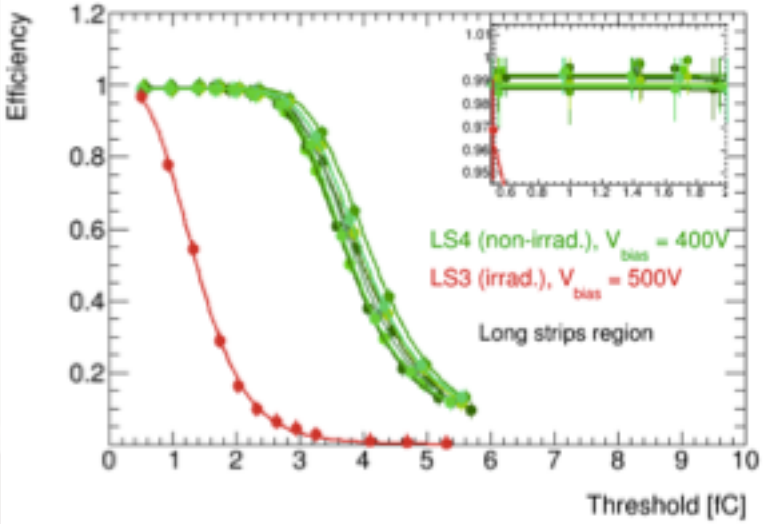


Detail from Liejian Chen

Module test beam at DESY

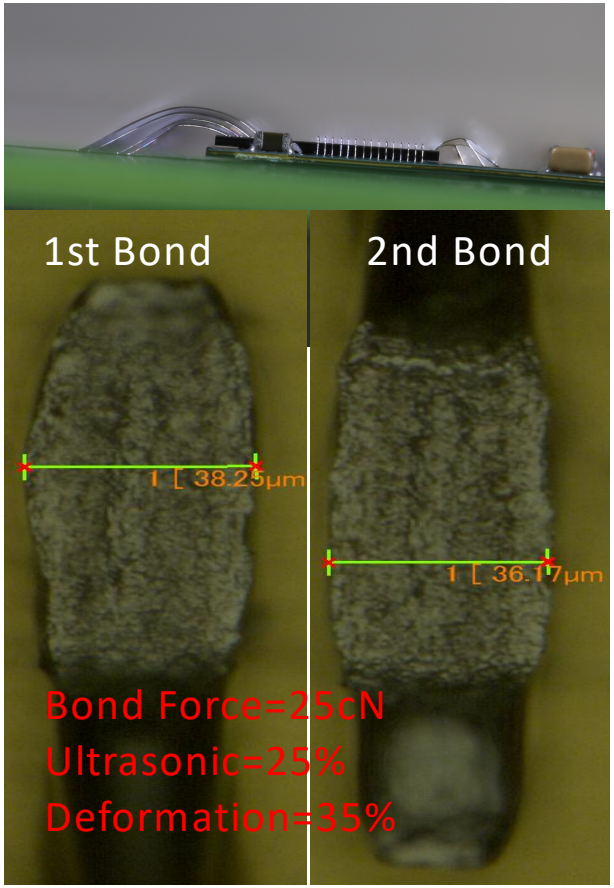
- We contribute to module test beam at DESY
  - Xiaocong Ai, Liejian Chen and Yi Liu
  - EUDAQ telescope DAQ support , data analysis, data taking shifts
- ATLAS R0 module and SS module test at E-lab in DESY May 2017
  - S/N>20, detection efficiency > 99% after irradiation

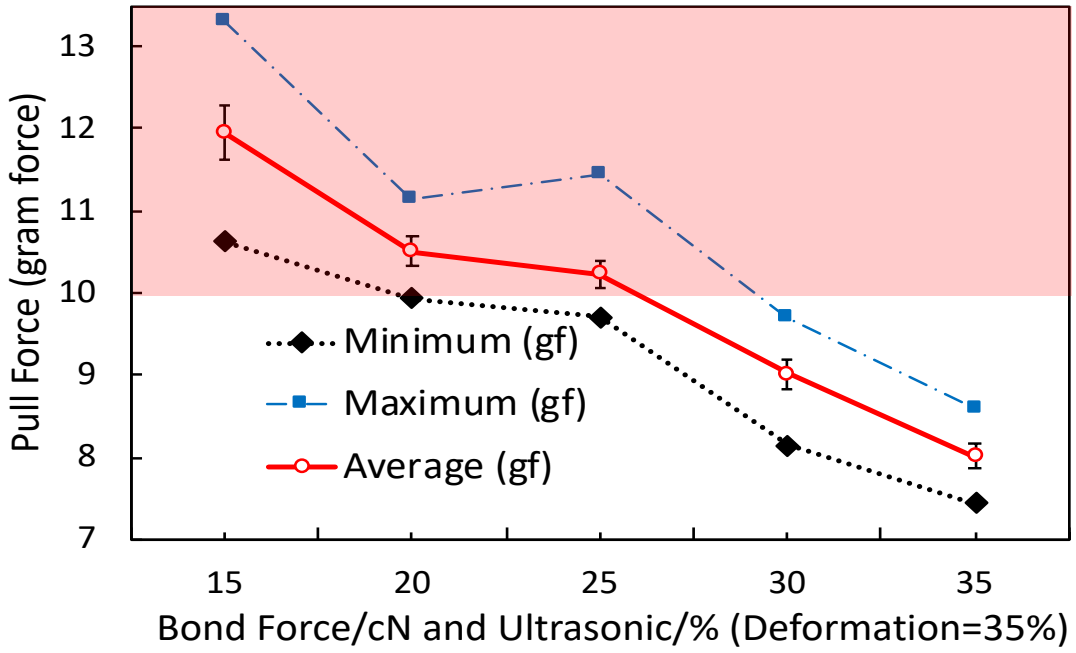




Wire bonding study for module production

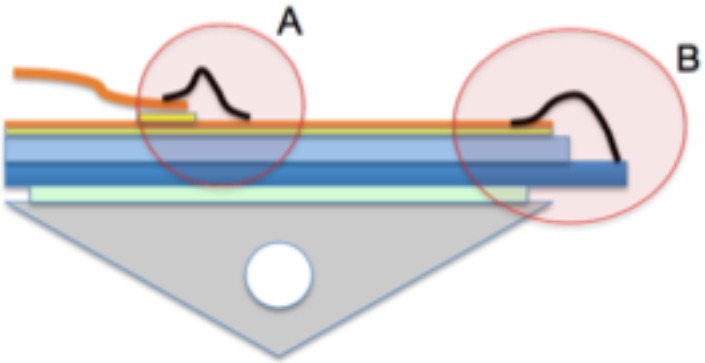
- Wire bonding is one of key issue for module production
  - key parameter study: deformation, ultrasonic and force
- How to evaluate the quality ?
  - pull test： important step in QA/QC

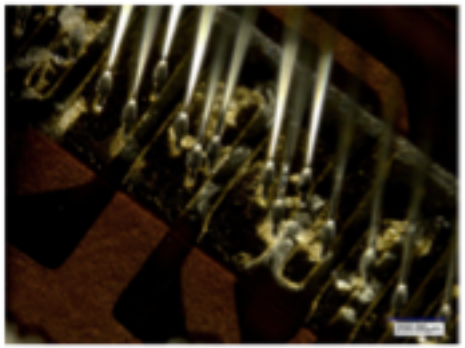




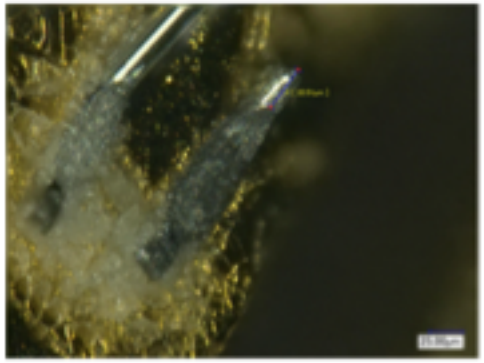
Issue in production: wire bond corrosion

- Lesson from IBL pixel detector:
  - Al wire Bond Corrosion due to humidity
  - White remnants which are likely Al(OH)3
  - Humidity control became most important step in quality control
    - Humidity at <5%



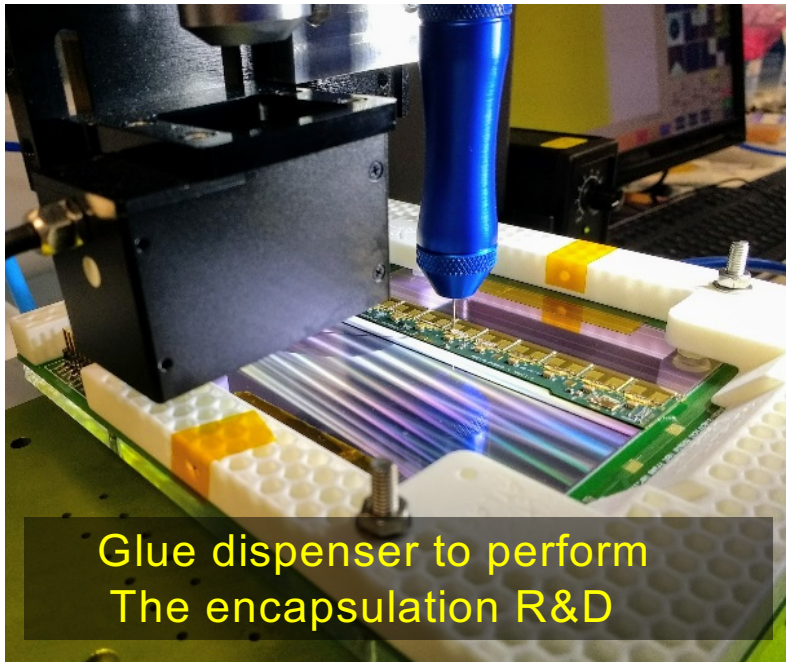


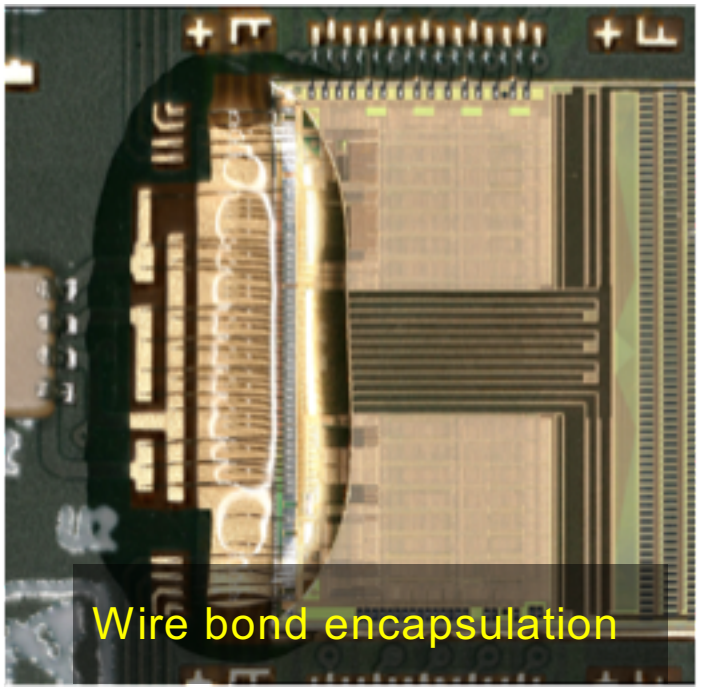
White remnants which are likely Al(OH)3



Wire bond protection (encapsulation)

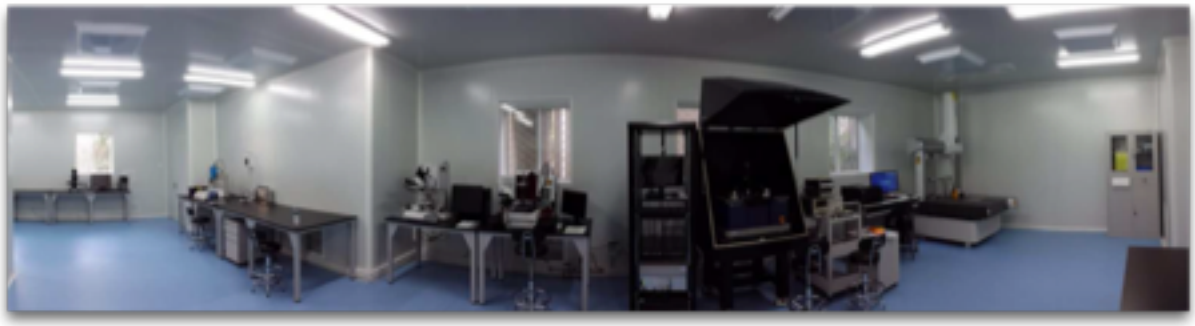
- Another way to protect wire bond: encapsulation
- IHEP/THU group with Oxford contribute to this R & D.
  - Fully encapsulate ASIC back-end wires (ASIC to hybrid)
  - More tests on going check the performance before and after


Glue dispenser to perform
The encapsulation R&D

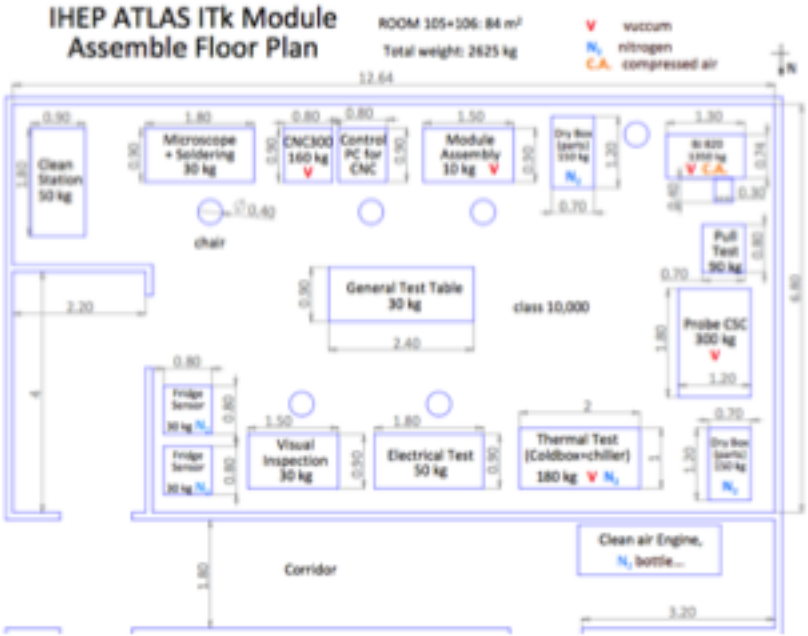

Wire bond encapsulation

IHEP Lab for module production

- An existing class 1000 Cleanroom with 150m^2



- An new class 10000 cleanroom with 80m^2 is on the way



OGP Flash CNC 300

Smart scope

Visual inspections

Flash CNC 300

Hesse BondJet820

Fast auto wire bonder

HESSE BJ820

ITK project irradiation

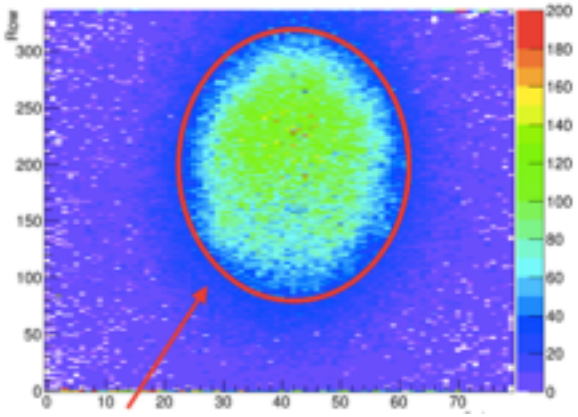
- IHEP/THU group coordinated the ITK irradiation at SPS (CERN)
  - C. Bertella presented this study in HSTD2017 conference

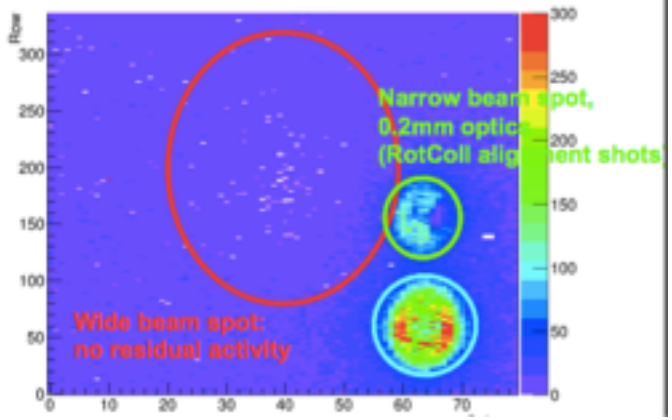
Global irradiation: 2 mm beam

- Completed few hours
  - RotColl out of the beam (no interference)
  - 1, 4, 12, 24, 36, 72, 144, 288 bunches (0.5 x 10^{11}p), 288 bunches (10^{11}p)
- Beam spot due to material activation (after glow).
- The intensity of the spot was increasing after each shot.
- The intensity of the spot was decreasing with time
- After each shot, module configuration was lost

Local Irradiation: 0.4mm beam

- after Global irradiation
  - RotColl out of the beam (no interference)
  - 1, 12 bunches (10^{11}protons).
- During RotColl operation
  - Secondaries impacting the test-box
- After RotColl 72, 288 bunches
- Detector dead after 288 bunches
  - Not responding to reconfiguration





IHEP/THU Activities

Baseline design

Module construction and test

Novel detector R&D

See more in Yubo's talk

CMOS strip sensor for ITk

- Working Principle of conventional MAPS (e.g. MIMOSA28 for STAR PXL):

  electron-hole pair produced when there is a particle going through the epitaxial layer; charge collected by the electrode via diffusion

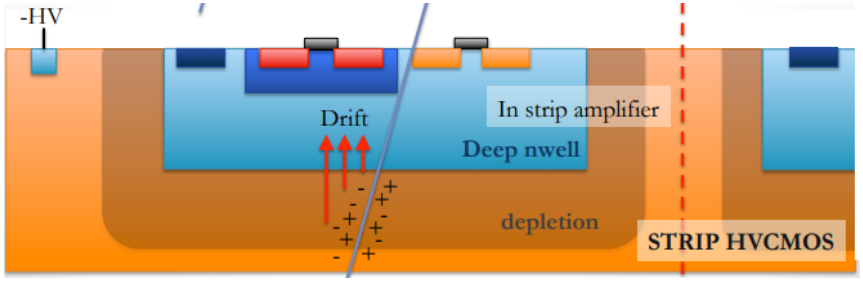
- Advantages:

  Combine both silicon sensors and readout processing circuitry on one single chip

  Small feature size : moderate radiation hardness, high granularity, less cost and material budget (could be thinned down to 50μm)

- Draw back: small signal ->

  in-pixel amplifier (built-in amplifier) needed.



- HR/HV CMOS could bring larger depletion depths thus obtain the sufficient signal and fast collection time(e-h pair collected via drifting).

- CHESS (CMOS HV/HR Evaluation for Strip Sensors)

Summary

- ATLAS Silicon strip track (ITk) is essential to meet the challenge for the HL-LHC upgrade
- IHEP/THU team in China will produce 1000 modules as key contribution
- Steady progresses have been made in **design**, **module production** and **novel detector R&D**.
- Some details will be covered by the Weiguo, Yubo, and Liejian.

Thank you!

Backup

Local production: Radiation-hard ASICs Import issue

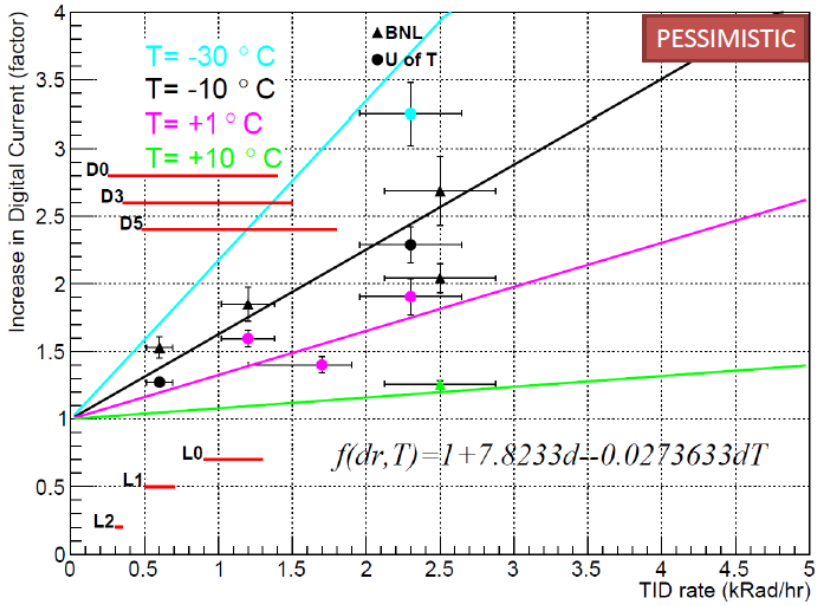
- **Rad-hard ASICs under export control** → obstacle
- **Main driving factors**:
  - China's deeper involvements in operation, upgrade and analyses
- Discussion with ATLAS and CERN
  - obtained export license from US DoC
    - Overall package (valid for ATLAS/CMS projects), valid for seven years
    - Obtained SECO for ABC130 (Swiss export license)

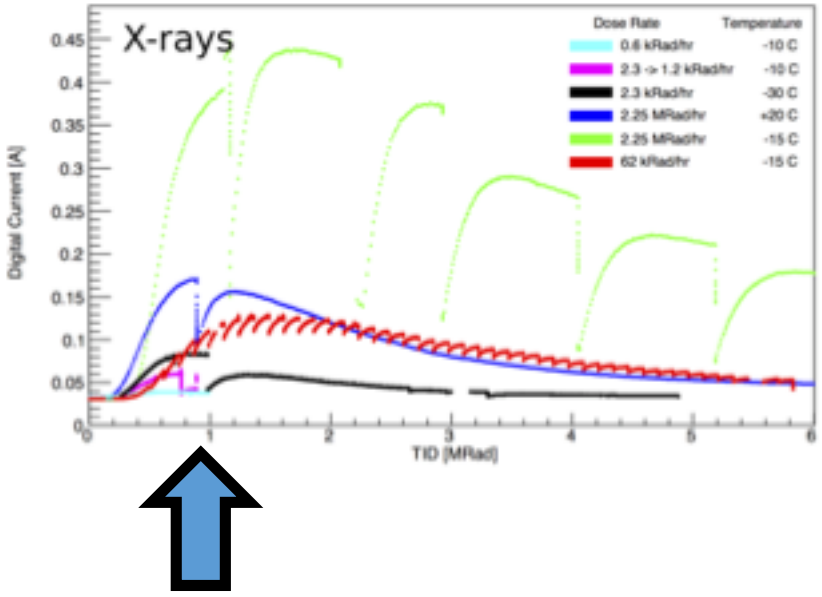
已获得芯片

抗辐照芯片	实验项目	工艺	主要功能
VMM	ATLAS NSW （一期升级）	IBM 130nm CMOS	快速前方、成形、甄别前端芯片
SCA		130 nm CMOS	慢控芯片
FEAST		AMS 0.35um HV-CMOS	供电控制芯片
ABC130	ATLAS ITk-Strip（二期升级）	IBM 130nm CMOS	硅微条前端读出芯片
CHESS 2		AMS 0.35um HV-CMOS	集成模拟、部分数字电路
HGCROC（正在办理）	CMS HGCAL（二期升级）	TSMC 130nm CMOS	高粒度量能器读出芯片

TID current bump in ASIC

- ABC130 chip Digital current increase after irradiation
- Low rate, low temperature irradiations of ABC130 have been done
- Expected the digital current increase by 100% after irradiation.





Bump at 1Mrad

Local structure: Stave

- Designed to minimize material, large scale assembly
  - Carbon fibre sandwich panel, low mass.
  - Titanium cooling tube and Bus tapes for power and data
- 28 barrel modules on each stave (14 per side), 18 endcap modules on each petal (9 per side)