

# TIPP2023

## TECHNOLOGY IN INSTRUMENTATION & PARTICLE PHYSICS CONFERENCE

4 - 8 SEPTEMBER 2023



Cape Town International  
Convention Centre (CTICC)



science & innovation  
Department  
Science and Innovation  
REPUBLIC OF SOUTH AFRICA



iThemba  
LABS  
National Research  
Foundation  
Laboratory for Accelerator  
Based Sciences



International Union of Pure and Applied Physics



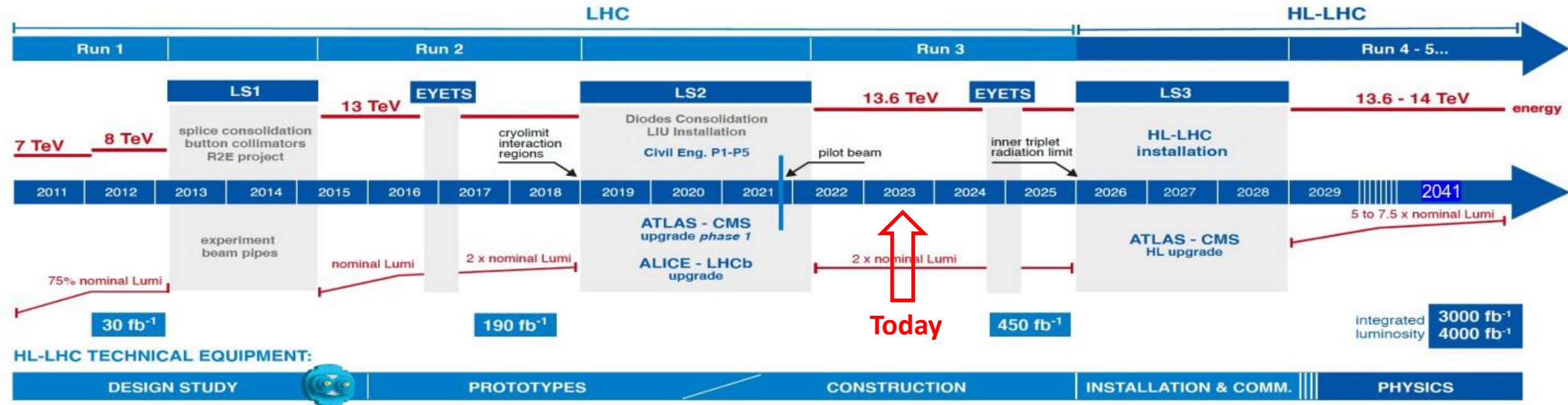
# ATLAS ITk Pixel Overview

Koji Nakamura *On-behalf of ITk Pixel collaboration*





# High Luminosity LHC



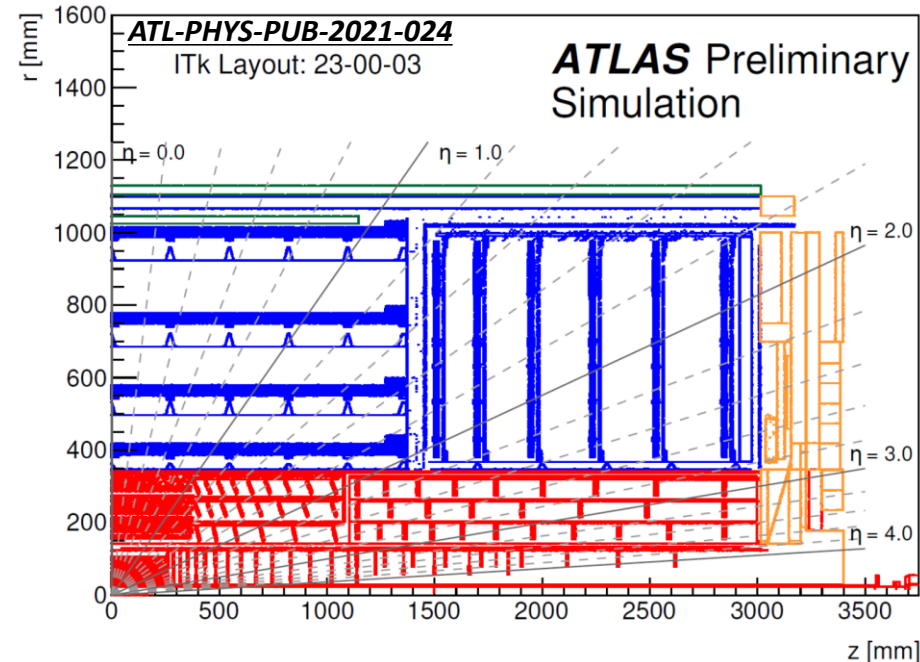
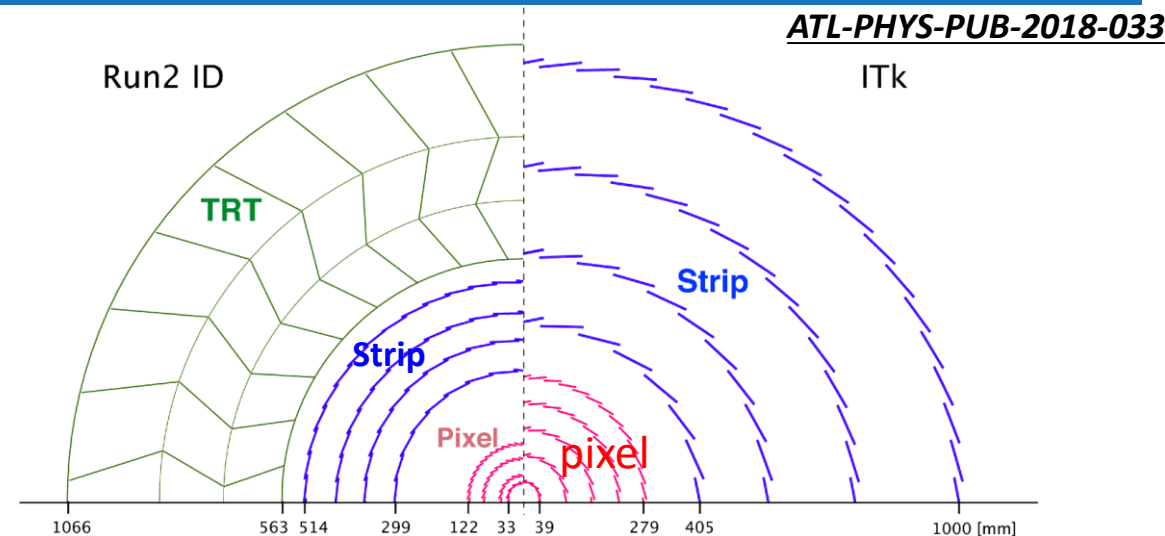
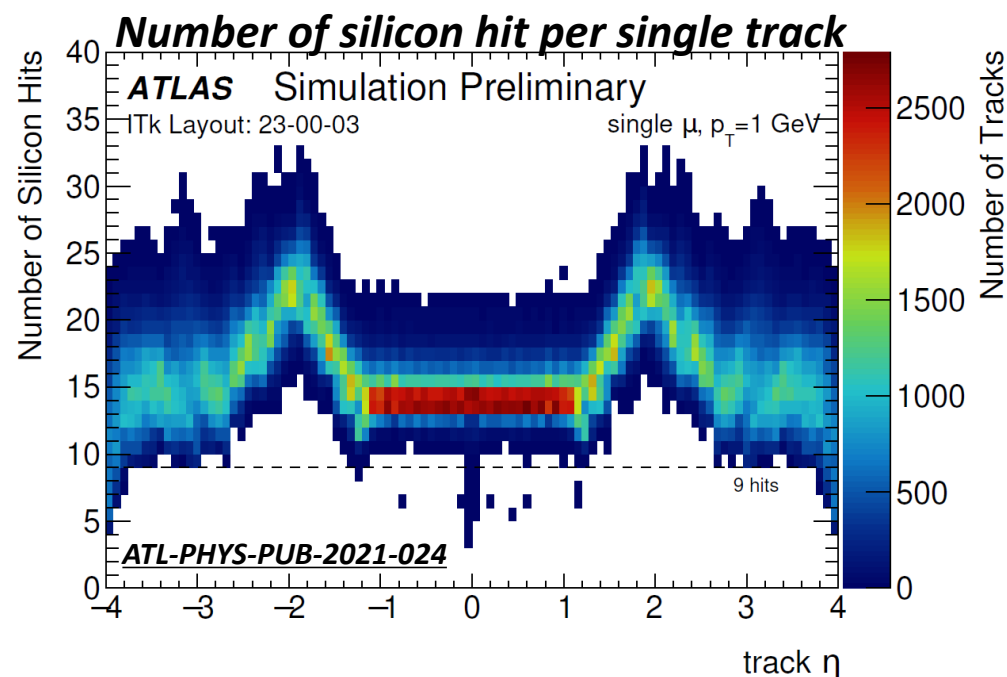
- LHC and its experiments are running well (Run 3) and produced many results.
- The “HL-LHC” period will start in ~2029 and will accumulate  $\int L dt \sim 4000 \text{ fb}^{-1}$ .
- Need to upgrade Inner detector of ATLAS experiment to deal with more radiation damage, more “dense” events.

# Inner Tracker (ITk) and Pixel detector

## • Inner Tracker (ITk)

- Instantaneous Luminosity :  $7 \times 10^{34} \text{cm}^2/\text{s}$ 
  - **x3.1 times** Run3 peak lumi
- Increased Pile-up
  - Up to **200 pile-up events** per bunch crossing.

→ Full Silicon based system



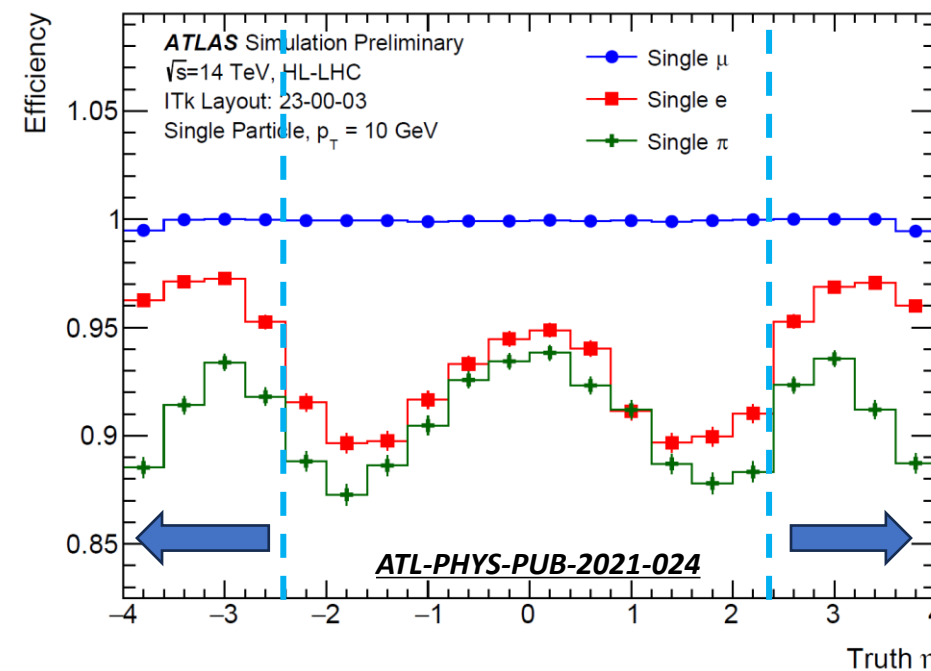
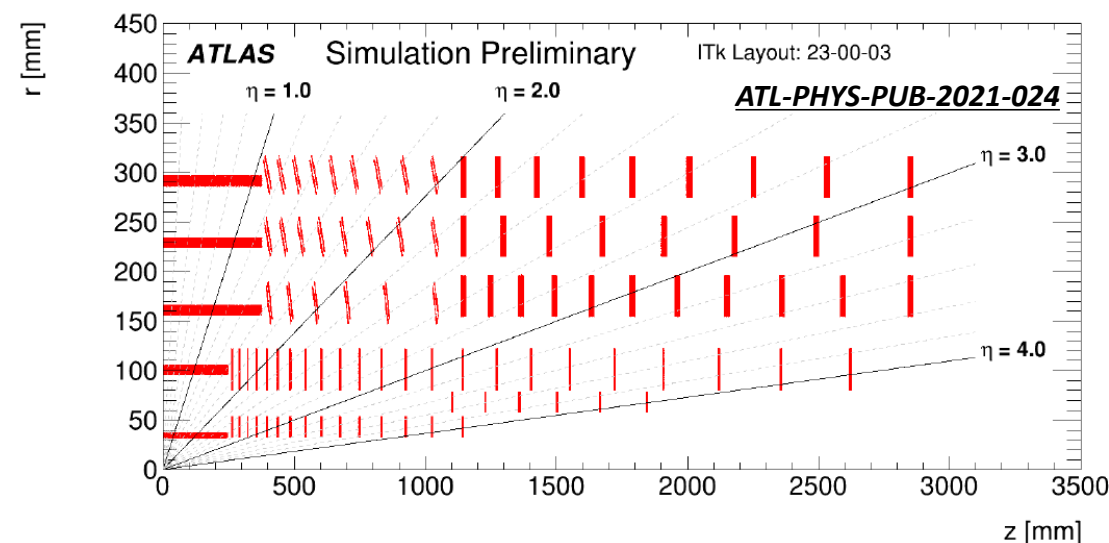
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## • ITk Pixel system

- Larger coverage area
  - Pixel : current  $1.9 \text{m}^2$  → **upgrade  $13.5 \text{m}^2$**
- Higher Forward coverage
  - Current  $\eta < 2.5$  → **upgrade  $\eta < 4.0$**
  - Better Pileup removal & background rejection**



# Inner Tracker (ITk) and Pixel detector

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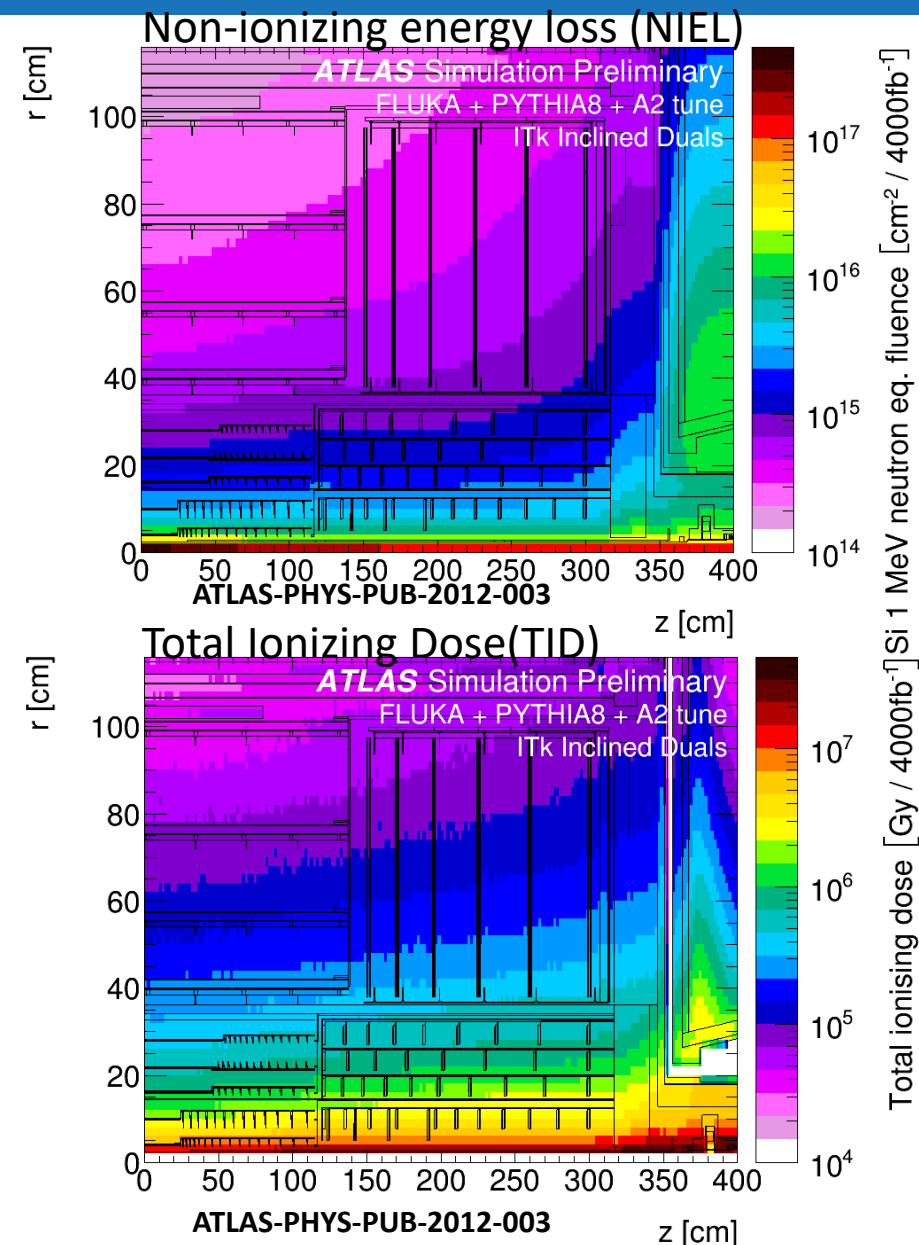
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## • Required high radiation tolerance.

- x10 increase of Radiation damage:
  - Requirement (including safety factor)
    - $17 \times 10^{15} \text{neq/cm}^2$**  at inner layers\*
    - $5 \times 10^{15} \text{neq/cm}^2$**  at outer layers

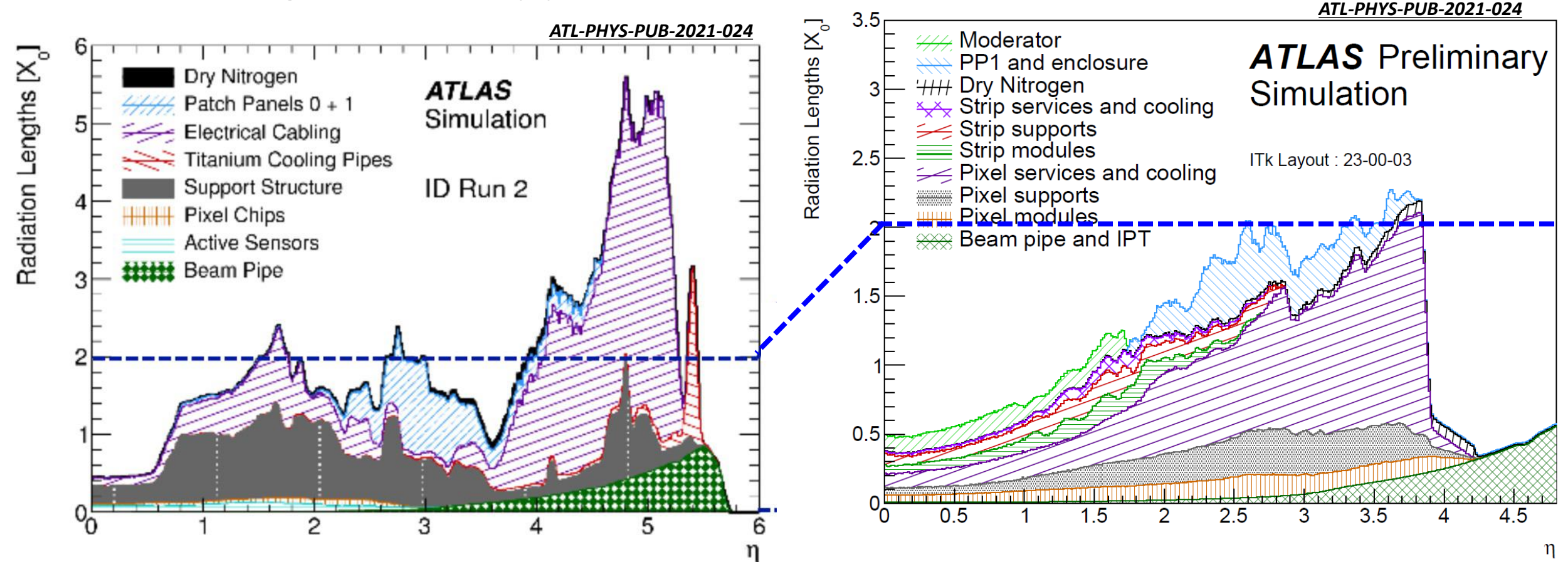
\*Inner 2 layers will be replaced at half.



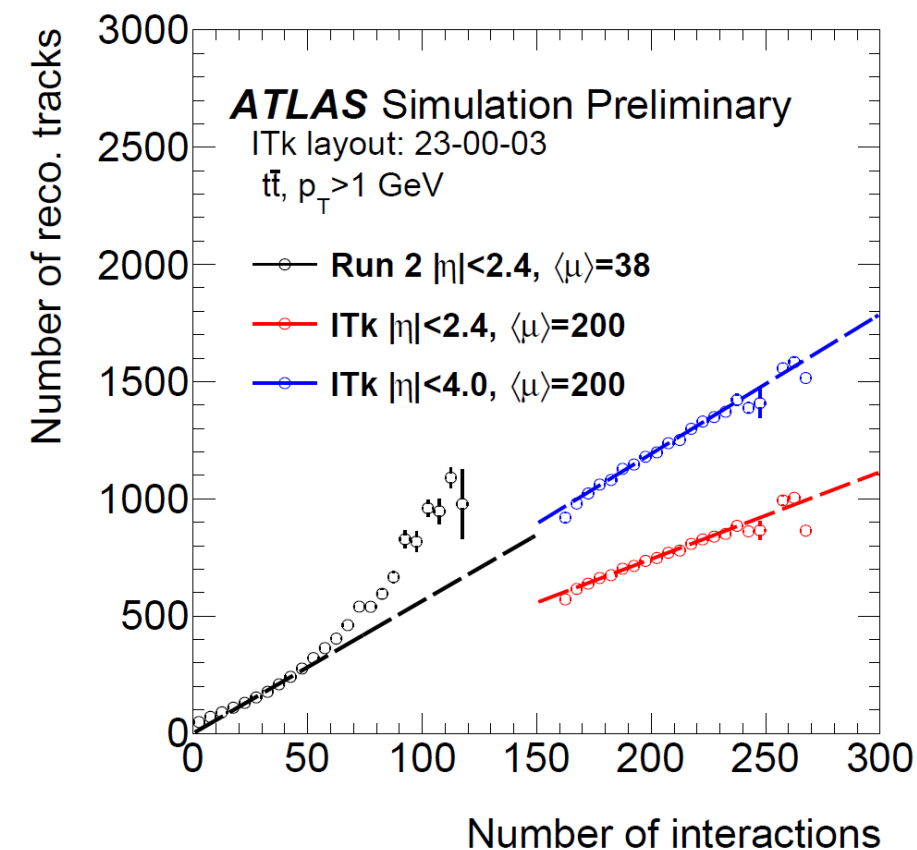


# Material budget

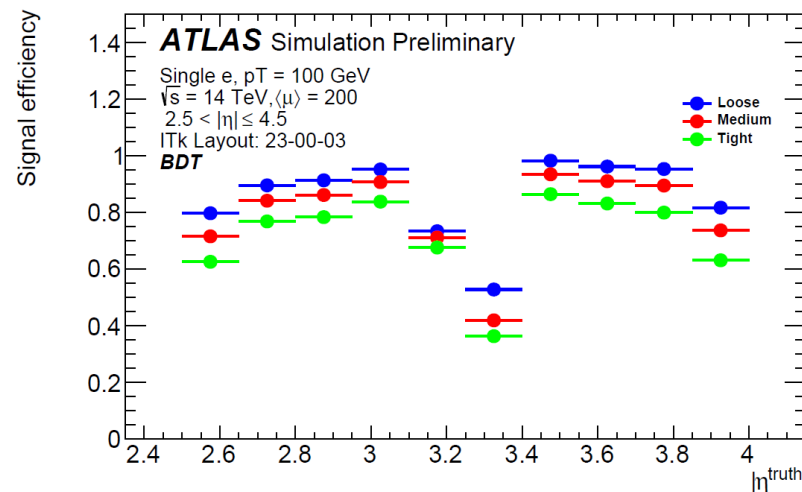
- Reduce material by
  - **Advanced cabling: serial powering for pixels, data link sharing**
  - **Minimize material in modules using thin Sensor and FE-chip**
  - CO2 cooling with titanium pipes, Low-mass carbon structure



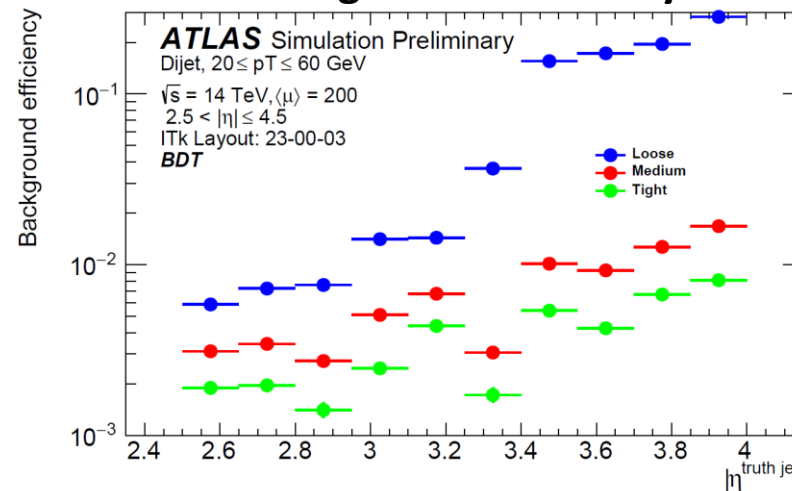
## Number of tracks v.s. Pile-up



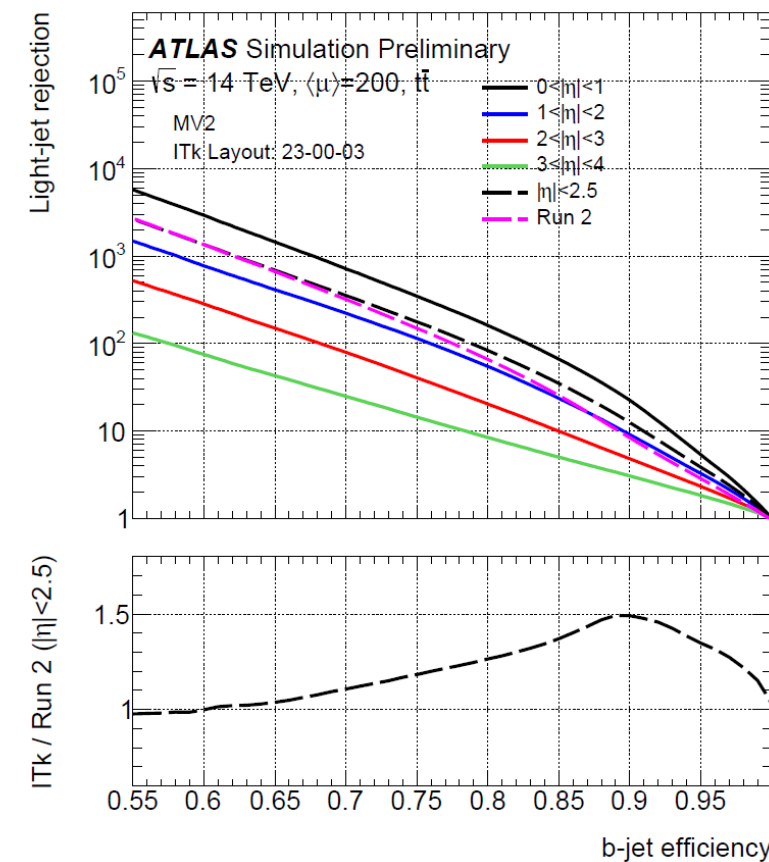
## Forward Electron reconstruction efficiency



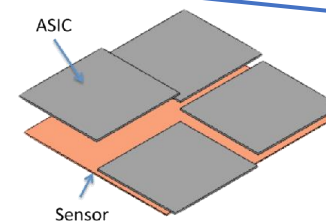
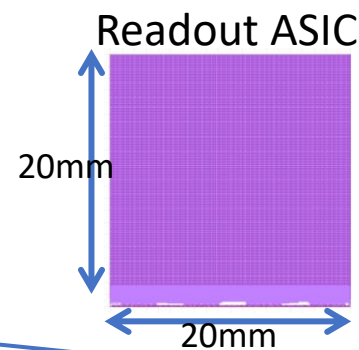
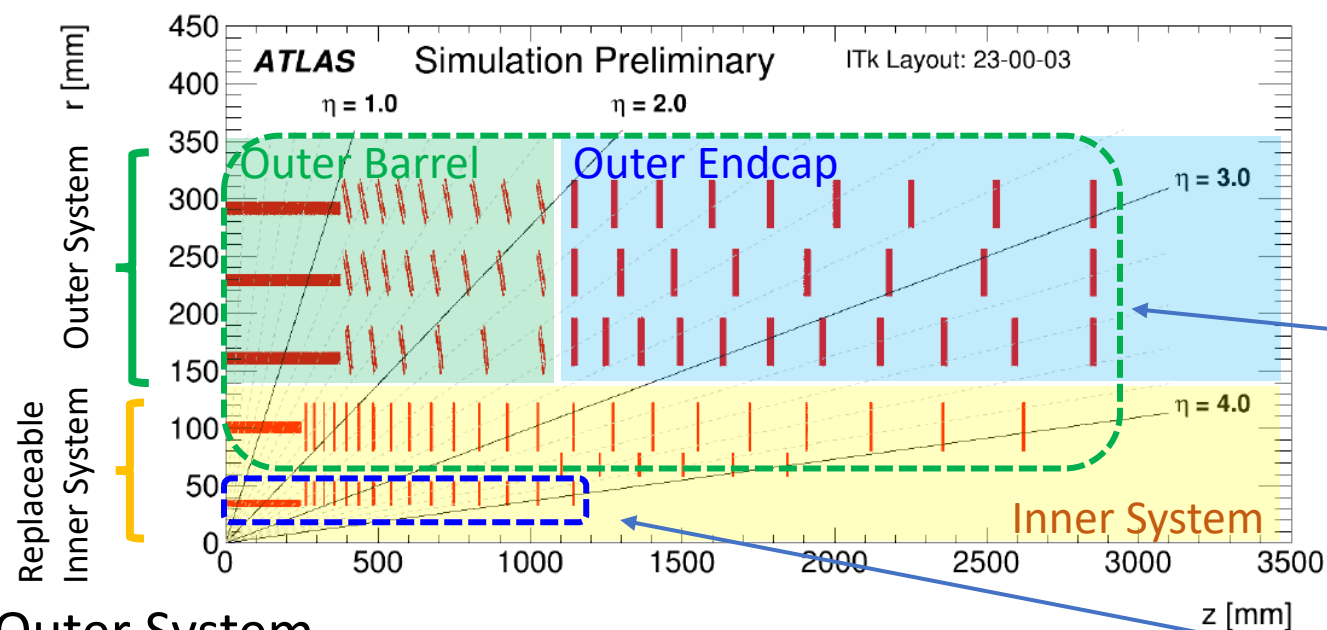
## Forward Background efficiency



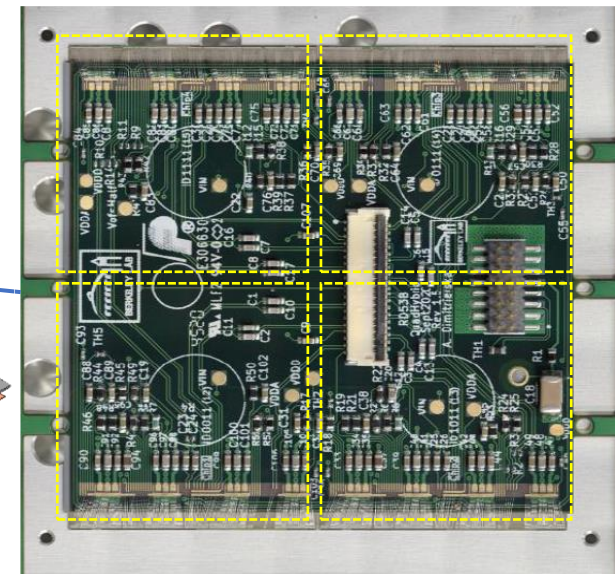
## B-tagging Performance



# ITk Pixel detector Layout

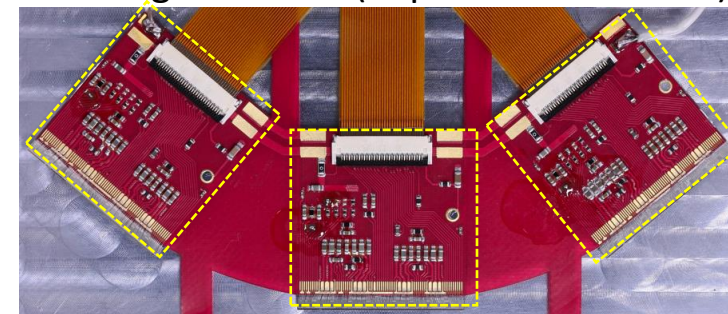


**Layer 1-4**  
Planar : Quad module (single sensor)



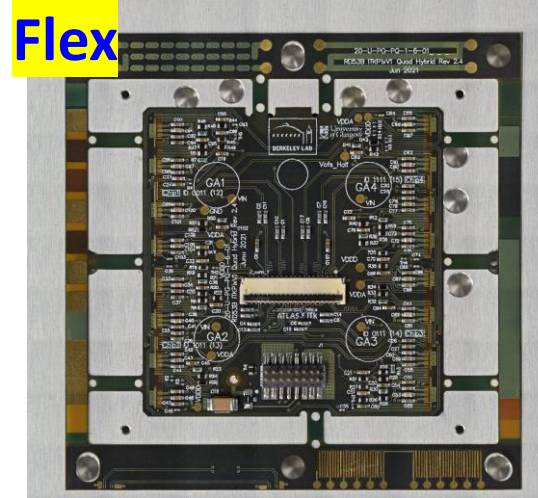
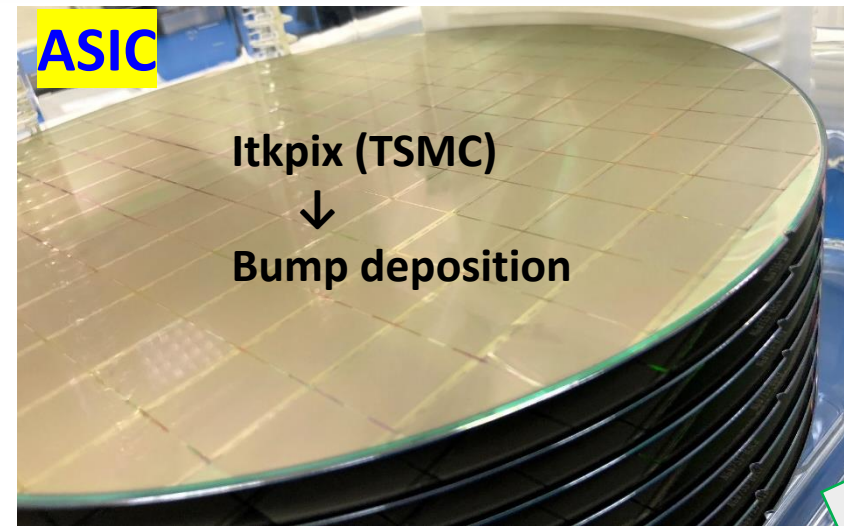
- Outer System
  - 3 layers of flat staves and inclined rings
  - **6816 planar quad modules** with 150um thick sensor + 150um thick ASIC (50x50um<sup>2</sup> pixel size)  
**Produce ~11,000 modules including yield**
- Inner System
  - 2 layer of flat staves and rings
  - L0 : **1188 3D single modules** (25x100um<sup>2</sup> for flat and 50x50um<sup>2</sup> for endcap)
  - L1 : **1200 planar quad modules** with 100um thick sensor +150um thick ASIC (50x50um<sup>2</sup> pixel size)  
**Produce ~2,000 modules for each type including yield**

**Layer 0**  
3D : Single module (Triplet with one PCB)

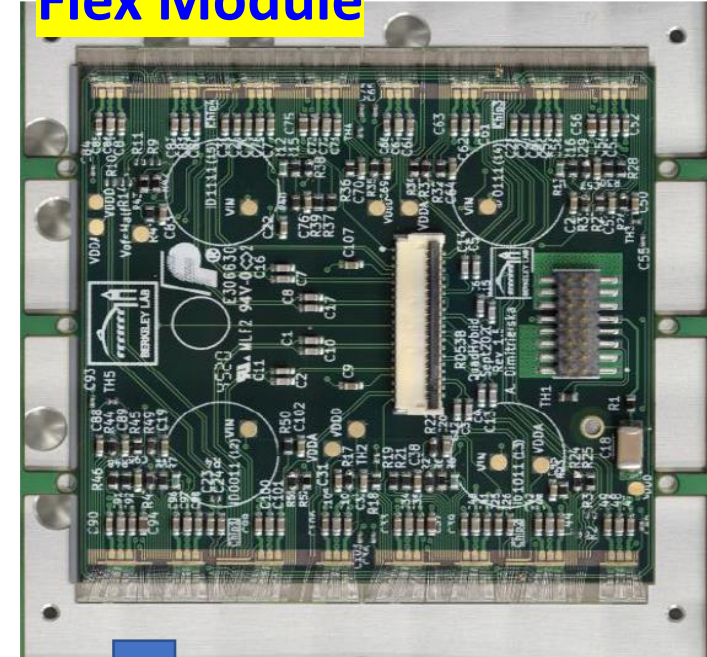




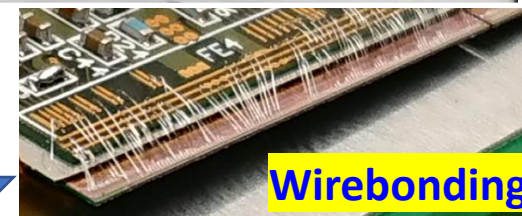
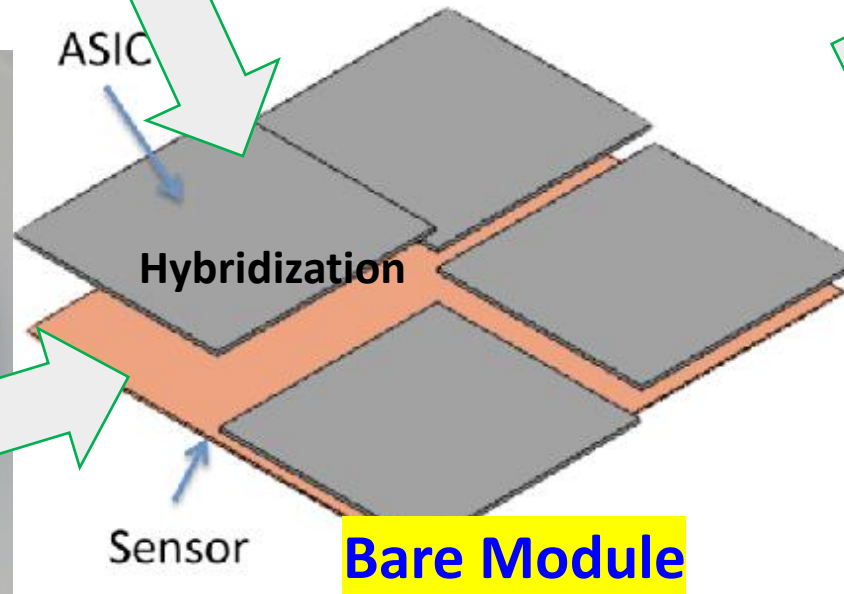
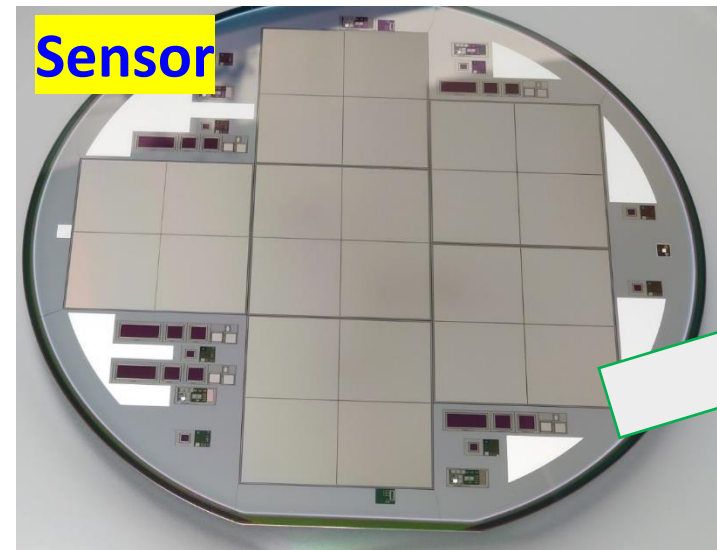
# Production flow



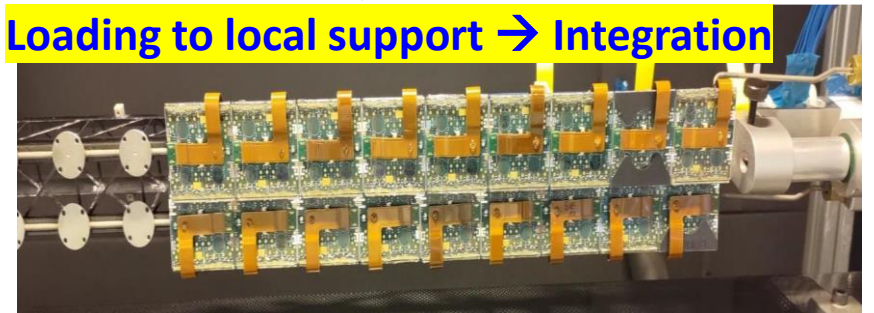
**Flex Module**



Assembly

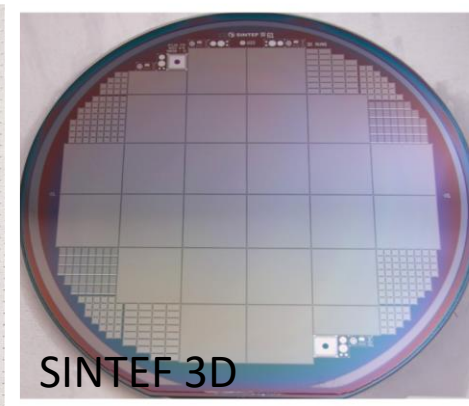
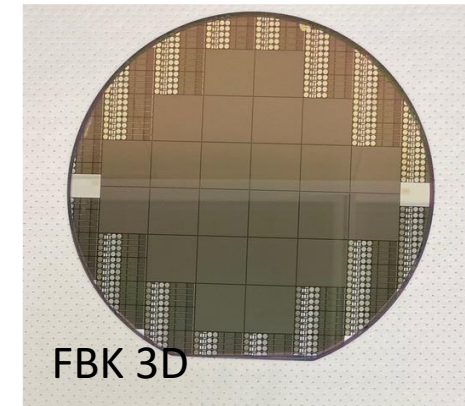
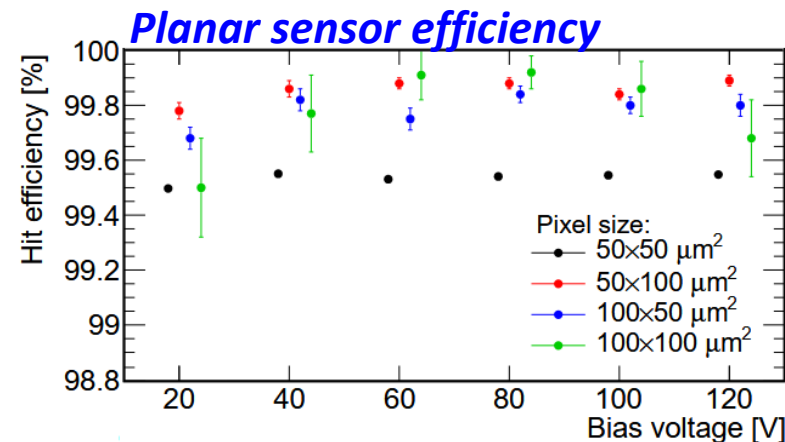
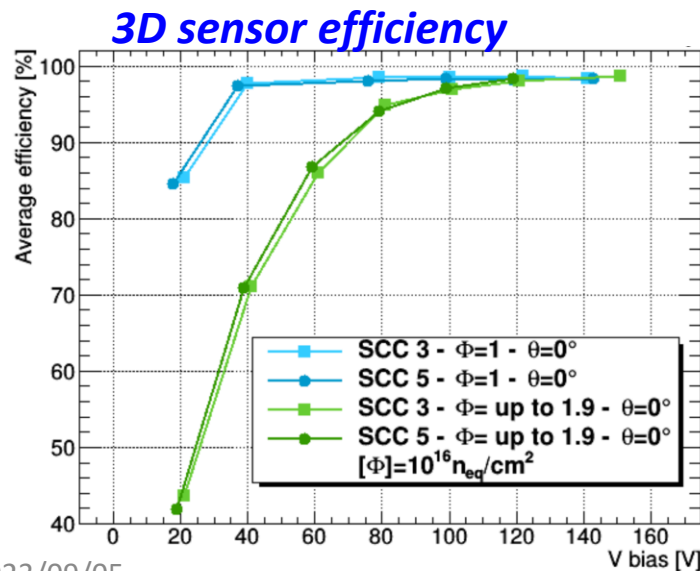
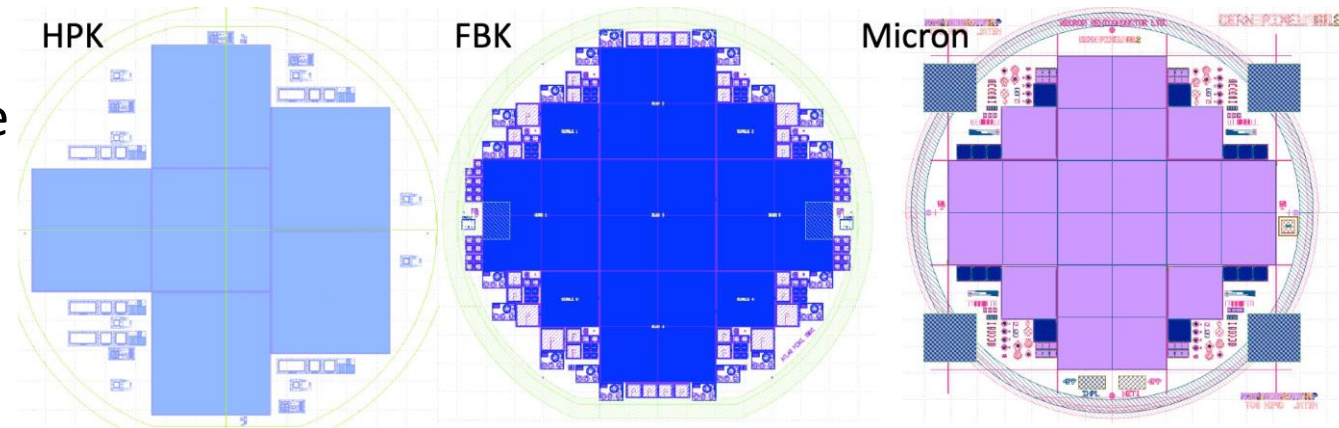


Loading to local support → Integration

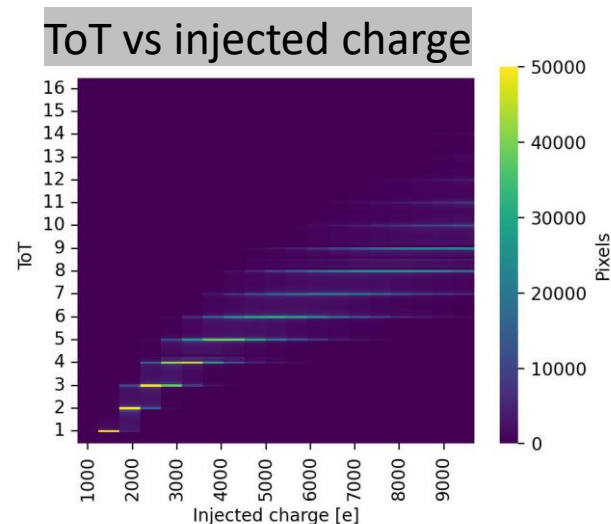
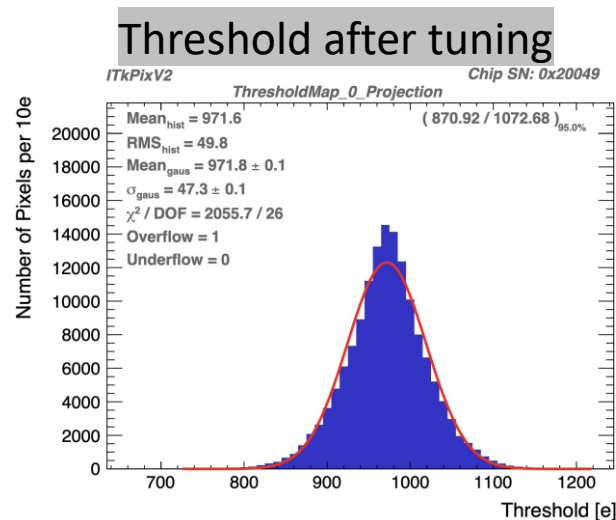




- **Pre-Production (10% of install amount) finished in 2022.**
  - Planar : 845 quad sensors from HPK(150um), FBK(100um) and Micron(150um+100um).
  - 3D : 210 single sensors from FBK(50x50um<sup>2</sup> + 25x100um<sup>2</sup>) and SINTEF(50x50um<sup>2</sup>) delivered
- **Evaluation of quality (QC/QA)**
  - Basic performance measured.
  - Several Hybridization module tested at the testbeam.
  - Qualification for Production order almost completed. (some of Production order placed.)



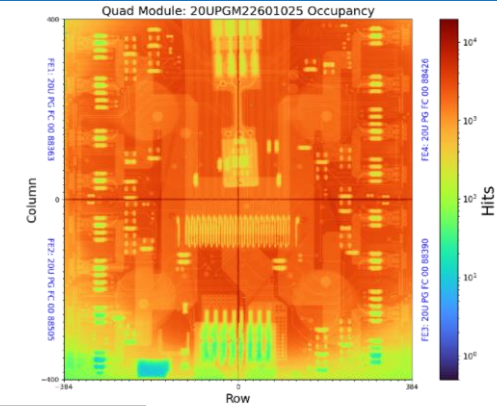
- **Prototype chips RD53A and ITkpix-v1 were validated and used as prototype program**
  - 65nm TSMC process, 4x1.28Gbps data link, differential comparator, ~50e ENC, 500Mrad TID tolerance
- **ATLAS approved final FE-chip (ITkpix-v2) submission on 17<sup>th</sup> March 2023**
  - **First delivery of 20 wafers (engineering run) 26<sup>th</sup> June.**
  - Production of 100 wafers released when engineering run delivered (with risk but to mitigate schedule)
- **First verification of new chip and preparation for chip testing:**
  - **In the first verification, basic functions are working as expected. Detailed checks are ongoing.**
  - Reduced time for wafer level probing from 48hrs->24hrs (5 wafer/week/site)



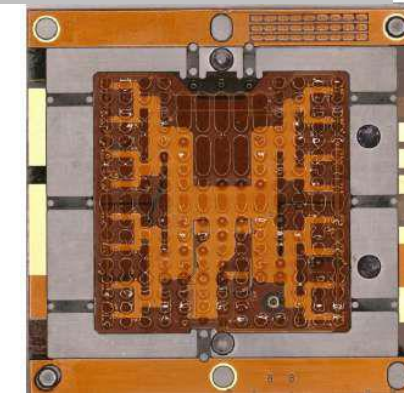


- Hybridization (Flip-chip)
  - Qualify bump-strength after thermal cycle
    - Design validated by prototype, follow-up during pre-production
  - Cross check with FEA and share stress measurement
- Flex PCB
  - Common design for Layer 1-4 (all Quad)
  - Triplet hybrid for Layer 0.
  - Optimized Copper thickness :
    - Low Cu required by thermal stress
    - High Cu required low power consumption
- Module assembly and readout test
  - Exercise production across module sites
    - Site-qualification
  - Extensive module QC
    - Electrical readout, metrology, bump-stress, operation at low temperature

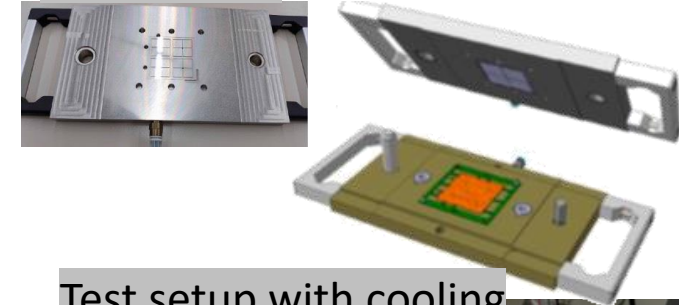
Xray source



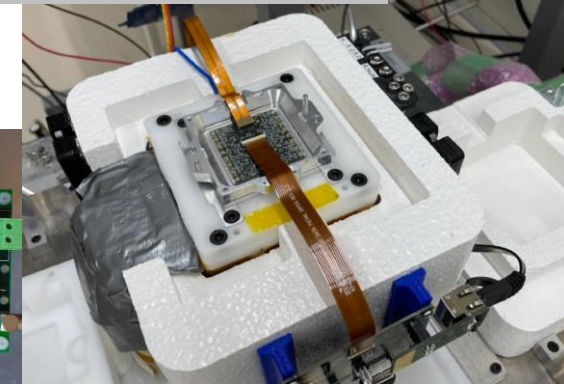
Glue pattern for Flex



Assembly jig



Test setup with cooling



Test setup

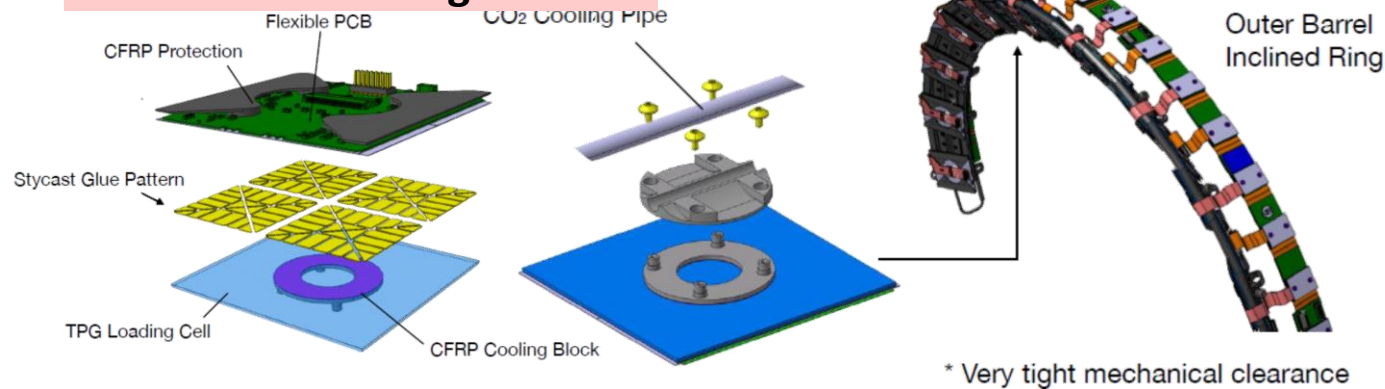


# Local support & Mechanical prototype

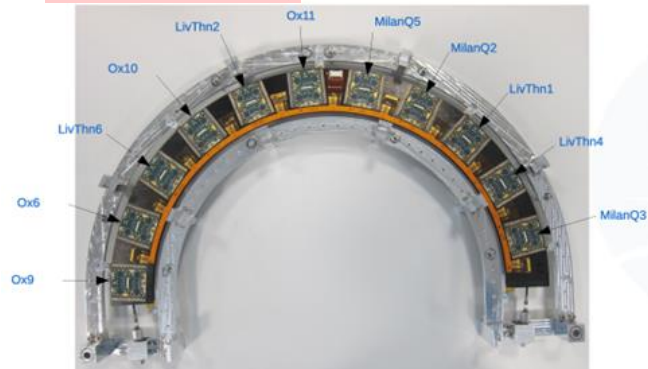
## • Local support

- stable low-mass support
- Critical element is interface to cooling pipe

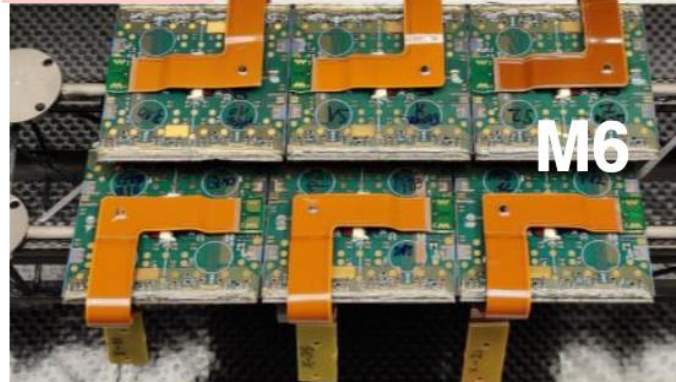
### Outer Barrel Cooling interface



### Inclined Ring



### Flat region



## • Mechanical prototypes

Details in Gabriele's [talk](#)  
Steven's [talk](#)

- Bare local support pre-production for outer barrel and outer endcap on-going
- Inner system pre-production about to start

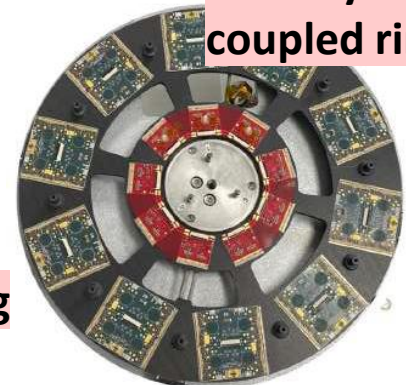
### Outer Barrel Longeron



### Endcap half-ring



### Inner system coupled ring



### Outer Barrel inclined half-ring





# Conclusion

**ASIC**

Itknix (TSMC)

**ITk pix-v2 chip : engineering run received.  
Basic functionality works as expected.**

**Flex**

**Taking time for tender process  
Available parts for pre-production**

**Flex Module**

**A lot of effort for Site Qualification.  
Just started Pre-Production**

**Pre-Production → Production**

**Sensor**

ASIC

**Pre-production on-going  
Identifying a few issues of Flip-Chip.  
Will sorted out and finish pre-prod**

Hybridization

**Pre-Production**

**Will start Pre-production**

**Wirebonding**

**LLS and Off-det service : final design fixed.  
Procurement for Pre-production parts started.**

Sensor

**Bare Module**



