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ATLAS ITk Pixel Detector Overview

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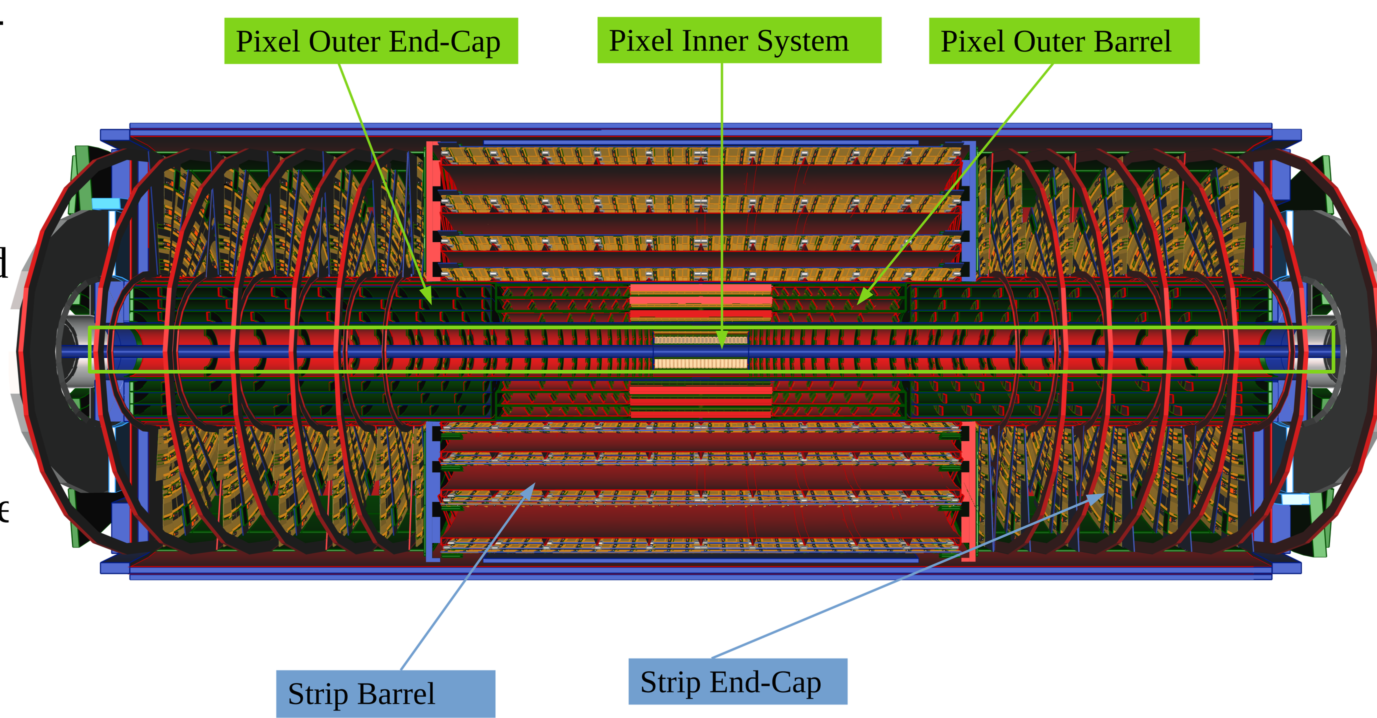
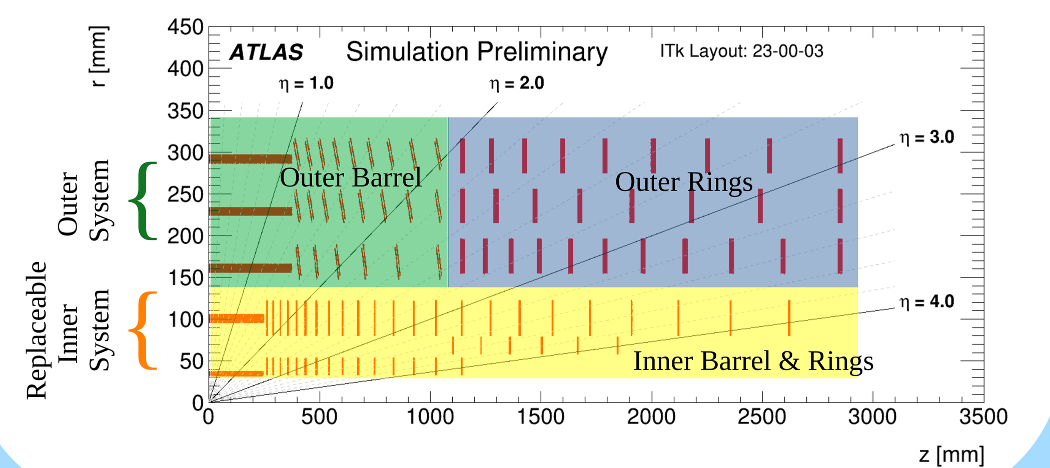
The ATLAS Inner Tracker at HL-LHC

- The High Luminosity LHC (HL-LHC) will bring a 5-fold increase in instantaneous luminosity (x10 integrated) beyond LHC.
- ATLAS detector will be upgraded to face challenges of radiation hardness, track multiplicity and increased data rates.
- The ATLAS Inner Detector (ID), closest to the interaction point, will be replaced by an all-silicon Inner Tracker (ITk) with silicon strips and hybrid pixel detectors.
- The innermost part of the ITk will consist of a Pixel Detector, with an active area of about 13 m² [1].



ITk Pixel Detector Layout

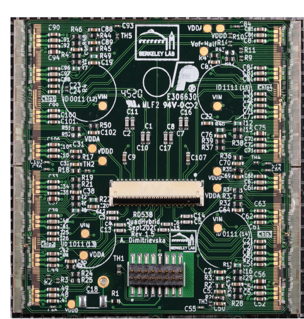
Detector	η Coverage	Strip (m²)	Pixel (m²)	Pixel Count	Pixel Modules
ID	|η| < 2.5	61	1.9	9.2 x 10⁶	2000
ITk	|η| < 4	165	13	5.9 x 10⁹	9600



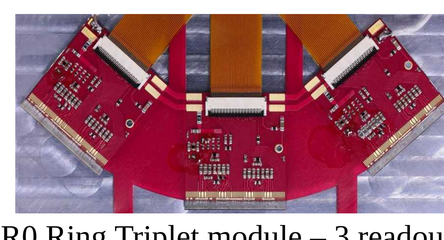
Pixel Module

The fundamental building block of the ITk is the pixel module. ITk pixel modules use hybrid pixel detectors.

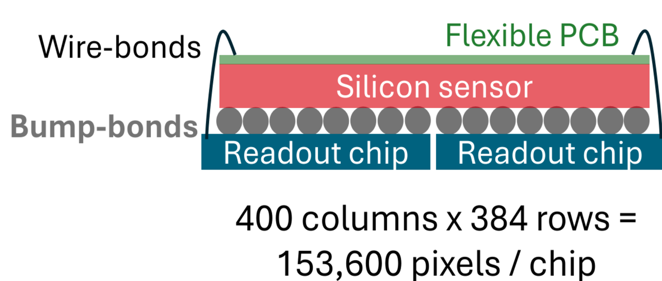
- Quad modules in the outer system (OS).
- Quad modules in the second innermost barrel layer (L1) and rings (R1).
- Linear triplets in the innermost barrel layer (L0).
- Ring triplets in the innermost ring layers (R0, R0.5).



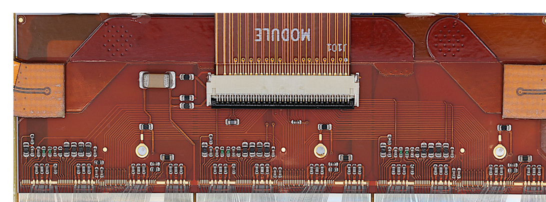
Quad module
Composed by a planar n-on-p silicon sensor bump-bonded over 4 readout chips.



R0 Ring Triplet module – 3 readout chips
Composed by 3 × (25×100 µm² pitch) 3D silicon sensors



400 columns x 384 rows = 153,600 pixels / chip



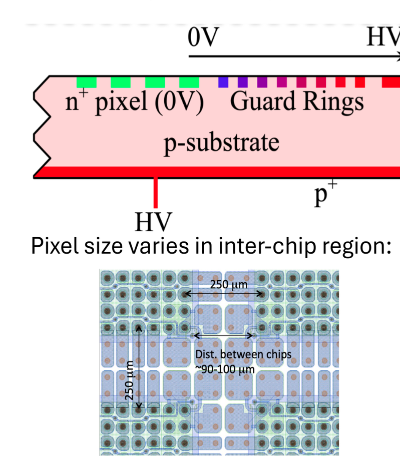
L0 Linear Triplet module – 3 readout chips
Composed by 3 × (50×50 µm² pitch) 3D silicon sensors

Sensors

Extensive R&D has been conducted to design silicon sensors capable of withstanding the intense radiation of the HL-LHC.

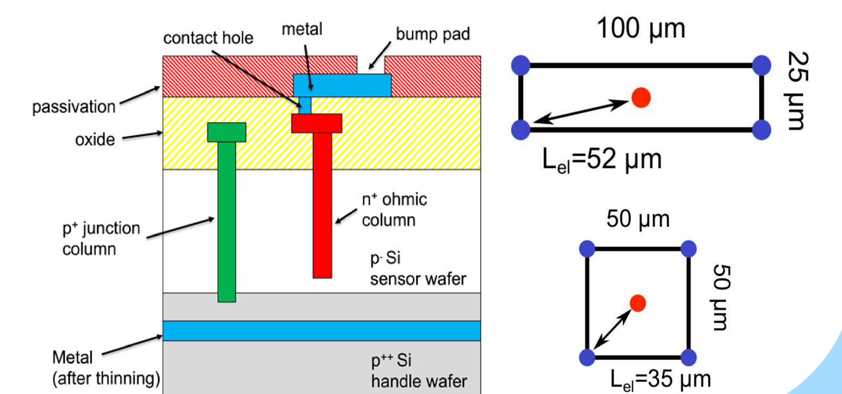
Planar Sensor:

- Radiation hard up to 5×10^{15} n_{eq}/cm^2 (@ 4000 fb⁻¹)
- n-in-p technology
- Pitch: 50×50 µm²
- Active thickness: 100 µm (L1), 150 µm (OS)
- Vendors: HPK, Micron, FBK

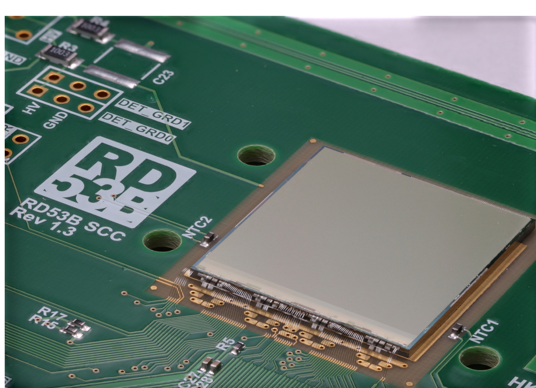


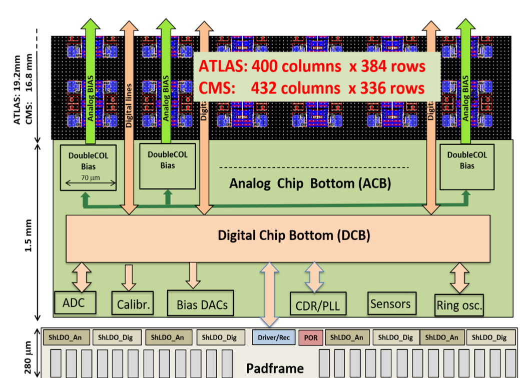
3D Sensor:

- Radiation hard ≈ 2×10^{16} n_{eq}/cm^2 (@ 2000 fb⁻¹)
- Thickness: 150 µm(active), 250 µm(total)
- Pitch: 50×50 µm² (Rings), 25×100 µm² (L0)
- Vendors: SINTEF, FBK



ITkPix Pixel Readout Chip





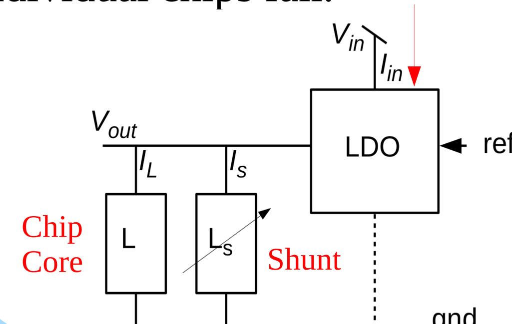
Features:

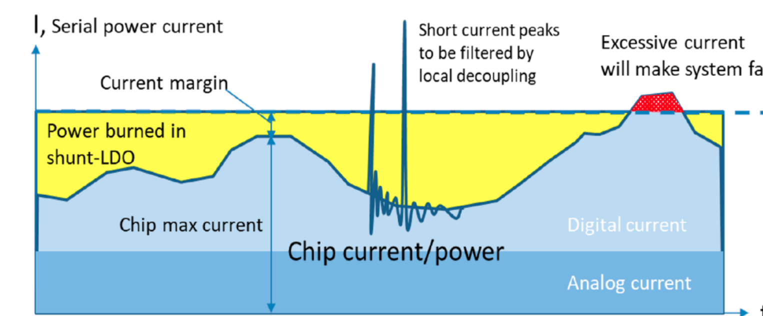
- 65 nm CMOS technology
- Radiation hard up to 1 Grad
- 4-bit charge measurement / pixel (ToT)
- Designed by RD-53 collaboration over ~ 10 years
- 1 differential FE in 2×2 cm² (final design)
- 384×400 pixels with pitch of 50×50 µm²
- Minimum threshold ~ 600e⁻
- High bandwidth for 1MHz L1 trigger rate
- 4 data links per chip at 1.28 Gb/s

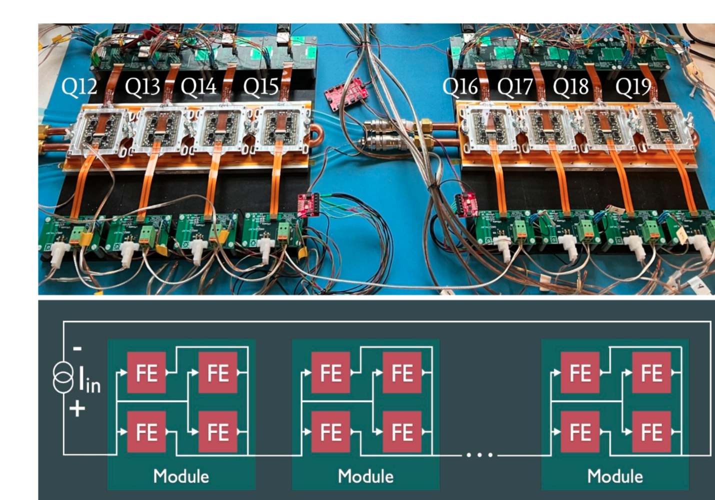
RD53A used for prototyping
ITkPixV1.1 used for pre-production
ITkPixV2.0 will be used for production

Serial Powering

To minimize the material budget, a serial powering scheme will be used. ITkPix chips with SLDO regulators will maintain stable voltages with constant current. Modules will be powered in series with constant current, while chips on each module will be powered in parallel, enhancing reliability even if individual chips fail.





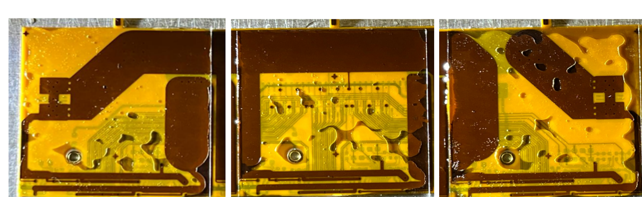


- *Low mass*
  - *Power cabling reduction ∝ length of chain*
- *On-chip integrated solution*
- *Radiation hard*
- *Not sensitive to voltage drops*
- *Smooth operation with low noise independent of load variations*

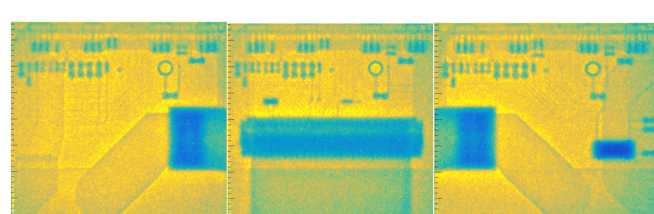
Module Assembly + Testing (QC + QA)

- Each Bare Module (BM) is glued onto a flexible PCB.
- Due to tight constraints on the triplet's width and geometry, parts undergo strict metrology, visual inspection, and QC before assembly.
- During assembly, precise alignment (~50 µm tolerance) and glue deposition are required.
- Post-assembly metrology is followed by wire-bonding.
- Consistent electrical QC tests are performed at room and cold temperatures, including thermal cycles from -55ºC to 60ºC.
- Key tests include source scans to estimate disconnected bumps [2].

- Other assembly & testing sites for the triplets include:
  - Italy: INFN Genova (R0), INFN Milano (R0)
  - Norway: University of Bergen (Testing), University of Oslo (R0.5)
  - Spain: IFAE, Barcelona (L0)

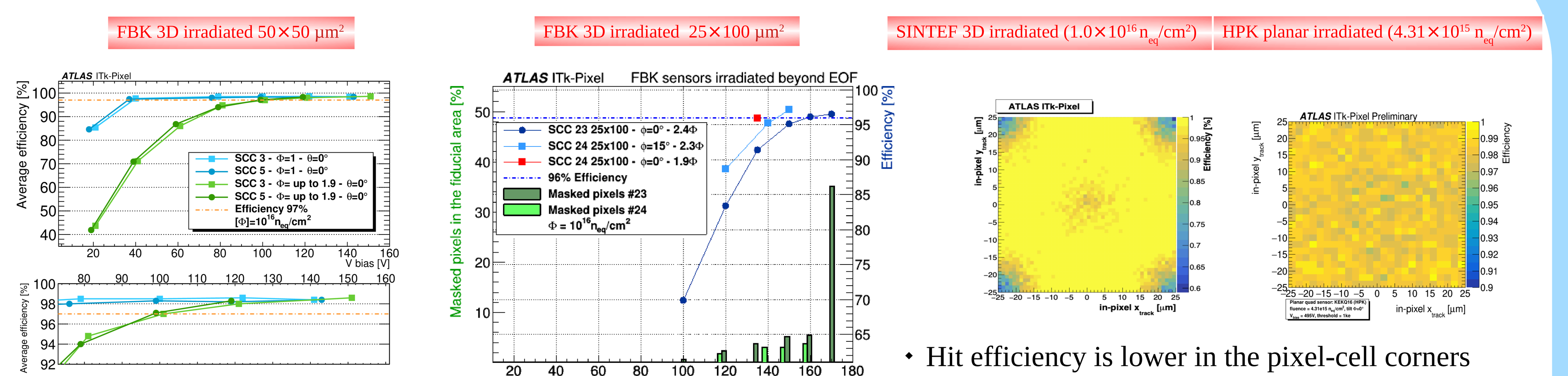


Glue deposition studies with glass dummies



Source Scan performed with ^{90}Sr source

Test Beam Results



- 50×50 3D sensors 97% efficiency at 40V (1.0×10^{16} n_{eq}/cm^2) and 100 V (1.9×10^{16} n_{eq}/cm^2)
- 25×100 3D sensors 96% efficiency at 130 V (1.9×10^{16} n_{eq}/cm^2) and 160 V (2.4×10^{16} n_{eq}/cm^2)
- <3% masked pixels up to 150 V (non-uniform irradiation).

- Hit efficiency is lower in the pixel-cell corners and center due to readout electrode columns.
- Perpendicular tracks are the worst case; in the final detector, most tracks will hit at an angle, increasing efficiency in electrode regions.
- HPK 150 µm thick planar sensors reach 97% hit efficiency at 400 V.
- SINTEF 50×50 3D sensor reaches 97% at 40 V.

Conclusion

- Sensor Pre-productions have been completed. Sensor production is underway.
- Module Pre-production is in the final stages.
- Module Production is scheduled to start in September.
- Closest-to-real demonstrators have been built using module, electric and cooling service prototypes.

References:
[1] ATLAS Collaboration, "Technical Design Report for the ATLAS Inner Tracker Pixel Detector." CERN, Geneva, 2017. Report No. CERN-LHCC-2017-021, ATLAS-TDR-030.(https://cds.cern.ch/record/2285585).
[2] Carlotto, Juan Ignacio, ATLAS Collaboration. "Qualification of Pixel Detectors for the Upgrade of the ATLAS Inner Detector with Beam Tests." 2024. (https://cds.cern.ch/record/2896744).