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ATLAS ITk

Module development for the ATLAS ITk Pixel Detector

Kenneth Wraight
University of Glasgow

PSD12: 13/09/21

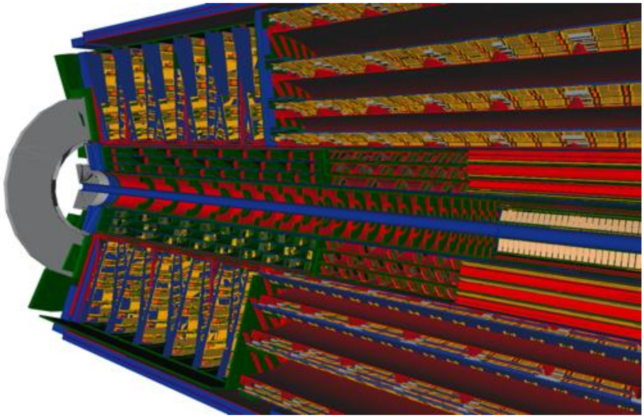
ATLAS ITk Upgrade

High Luminosity (HL) LHC

- Upgrade in collisions → statistics → physics

	HL-LHC	Run-II (2018)
Luminosity	$7.5 \times 10^{34} cm^2 s^{-1}$	$\leq 1.9 \times 10^{34} cm^2 s^{-1}$
$\left\langle \frac{interactions}{Bunch\ crossing} \right\rangle$	35	200

- *Pre-covid* scheduled installation LS3, 2026
  - Since: global pressures to supply chains



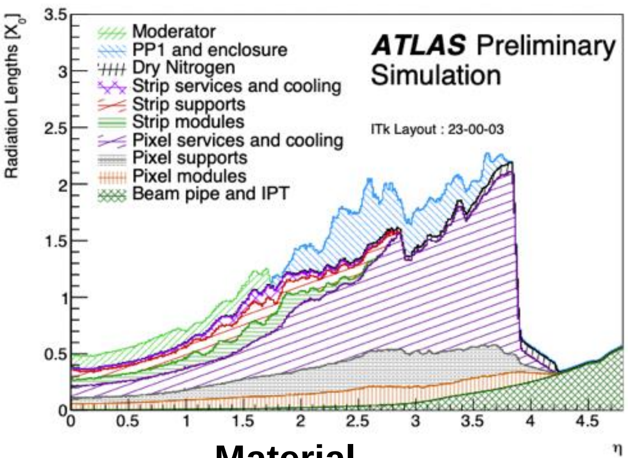
ATLAS ITk upgrade

Desired physics performance relies on precision tracking

→ **I**nner **T**rac**k**er (ITk) upgrade for new environment

- All silicon inner tracker
- Improved performance
  - Track Pattern reco.: speed, efficiency and fakes
  - Radiation tolerance
  - Material budget: detectors + services

See ATL-PHYS-PUB-2021-024 for full details



Material

ATL-PHYS-PUB-2021-024

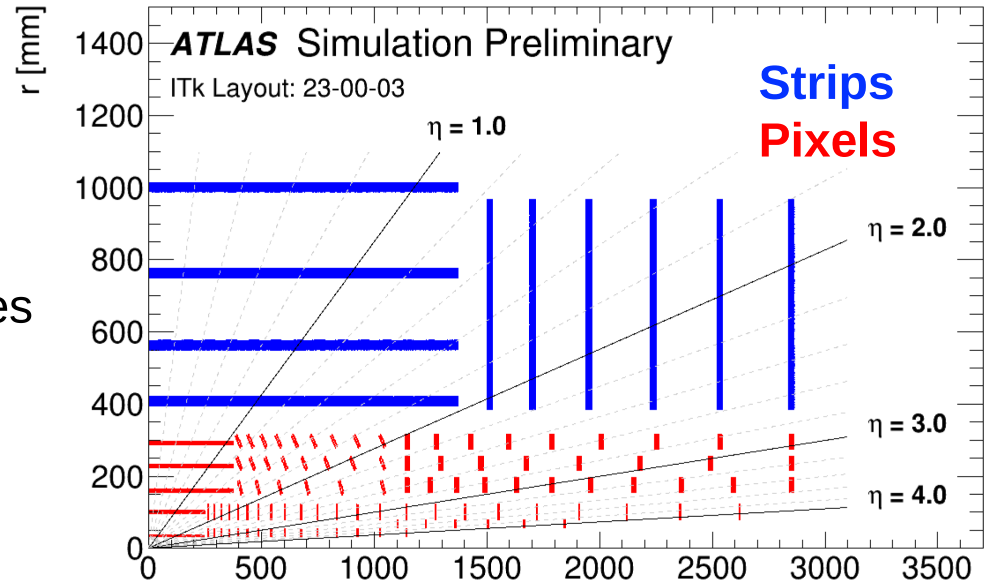
Inner Tracker

All silicon inner tracker
Specification for ≥9 precision measurements per track

$$\eta \equiv -\ln(\tan\frac{\theta}{2})$$

Pixels

- pseudo-rapidity coverage: $|\eta| < 4$
- 3 outer barrel layers & endcaps
- 2 replaceable inner barrel & endcaps
- Innermost layer 3D single chip modules
  - barrel: 25x100μm^2
  - endcap: 50x50μm^2
- Other layers planar quad modules
  - sensor + 4 chips, 50x50μm^2



ITk quadrant: [ATL-PHYS-PUB-2021-024]

Strips

- pseudo-rapidity coverage: $|\eta| < 2.7$
- 4 barrel layers, 6 endcap discs
- 10/20 chips per barrel module
- 12-28 chips per endcap module

Pixels: Expected radiation dose

Outer Barrel	1.7MGy @ 4000fb^{-1}
Outer Endcap	3.5MGy @ 4000fb^{-1}
Inner Barrel	>7.3MGy @ 2000 fb-1

ITk Pixel Modules

Hybrid module consists in frontend + sensor on flex

Front End

Final Chip: ITkPixV2

- ASIC in TSMC 65nm CMOS
- 400x384 pixels, 20.1x21.6mm^2
- 4 (1.28 Gbps) data lines, output data compression
- shared uplink with command forwarding
- Single Event Effect hardened

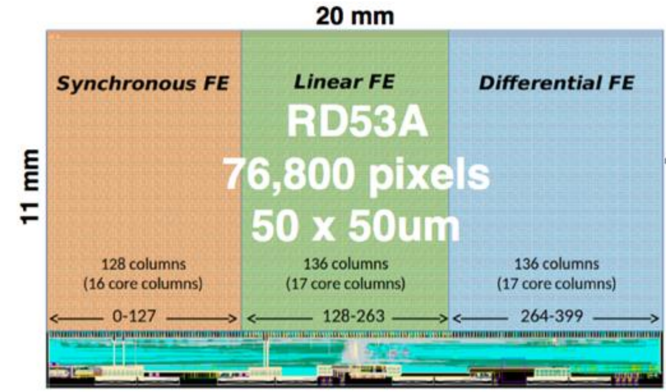
Test chip: RD53A

- Joint ATLAS, CMS prototype (½ final size)
- Low threshold ~600 e-
- Radiation hardness up to 5 MGy

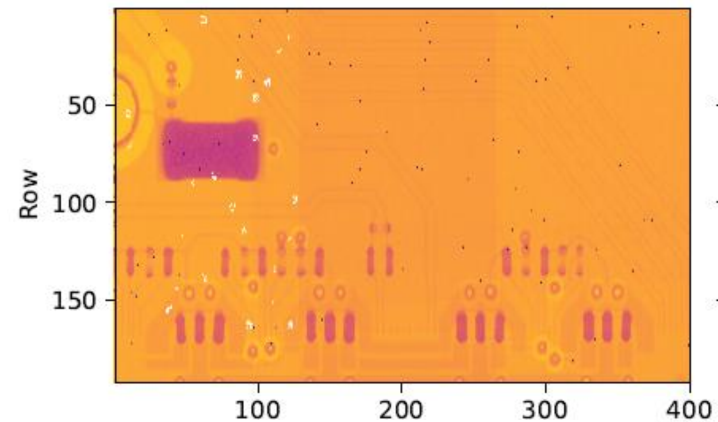
Sensor

- Inner layer (L0): 3D single chip sensors
  - 150µm active thickness + 100µm support wafer
- All else: *n-in-p* planar quad chip sensor
  - L1: 100µm thick sensor
  - All else: 150µm thick sensor

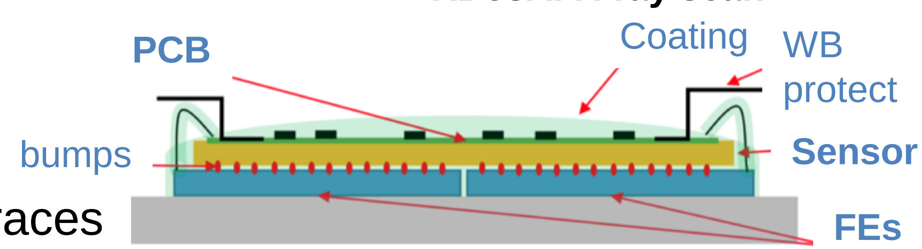
Flex PCB – thin, low Cu with high datarate traces



RD53A: CERN-RD53-PUB-17-001



RD53A: X-ray scan



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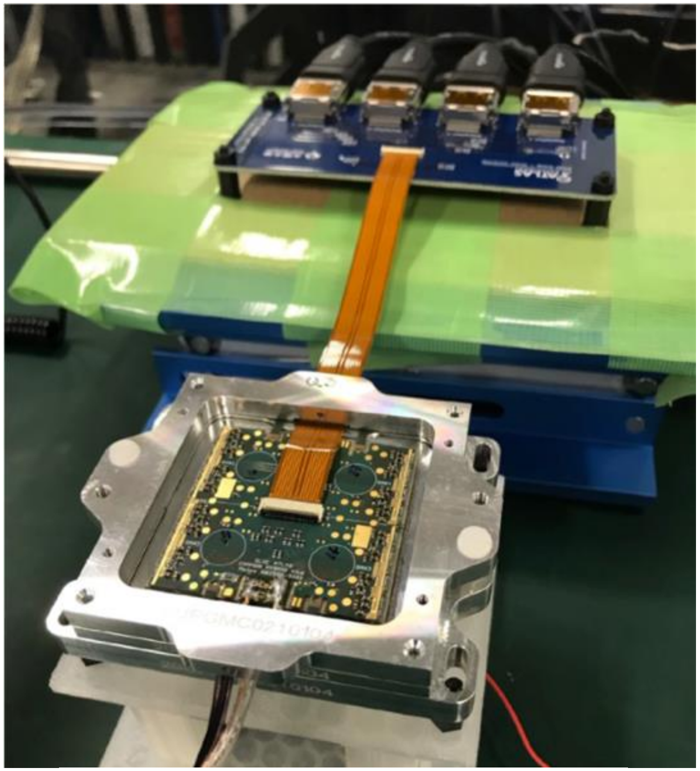
Pixel Module Assembly I

Hybrid detector: multi-component and multi-stage assembly process

Front End
Single vendor
Chip thinned to 150µm

Sensor
Multi vendor selection through *Market Survey*

Hybridisation
1. Sensor wafer: Under Bump Metallisation
2. Front end wafer: Bump Deposition
    - fine pitch: ~10s µm, high density: 400/mm^2
3. Wafer thinning, dicing & flip-chipping
    - Challenging: thin FE and thin sensor



RD53A: Quad module readout

Ideal (**real**): single (**multiple**) vendor process at one (**across several**) sites
- Reception measurements required

Vendors selection through *Market Survey* procedure

Pixel Module Assembly II

"bare" modules dressed for loading

Flex PCB mounting

Thin, low Cu (see later)

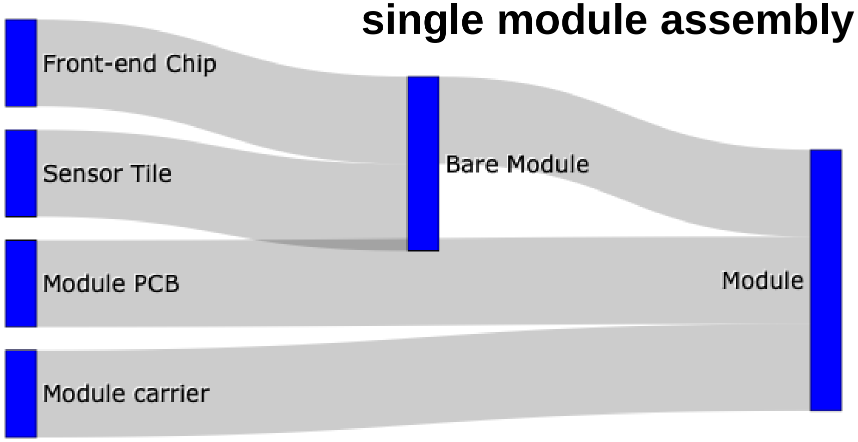
- Commercially unusual but possible

Wirebond front ends to PCB

- Fine bond pitch limits reworking

First QC/QA tests performed on module

single module assembly



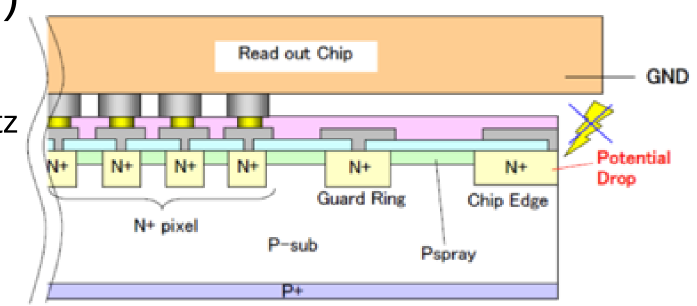
QA:
Single test
QC:
repeated check

HV encapsulation

Parylene-N: chlorine free to avoid halogen corrosion

- Primary (>5µm): stop discharge between HV sensor and chip
  - High voltages necessary after irradiation (>500V)
- Secondary (>>5µm):
  - Protect wirebonds from foot corrosion and $F_{Lorentz}$
  - Mitigate external stresses

  (e.g. loading, transport, thermal cycling)



Qualification of assembly vendors with RD53A modules

QA/QC

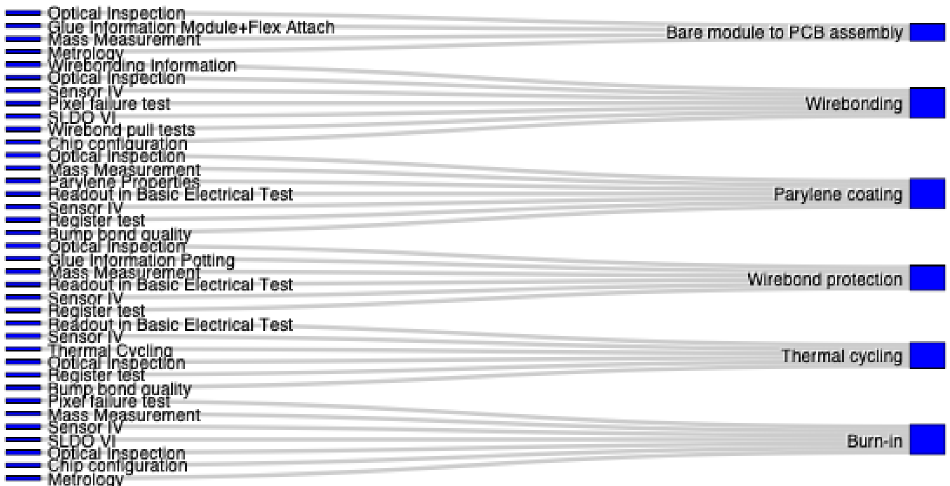
QA/QC tests across production to ensure production standards and performance over lifetime

Range of tests over assembly stages:

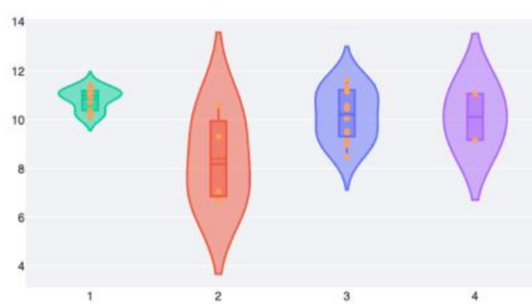
- Optical inspection
- Mass measurements
- Metrology
- Wire bond checks
  - E.g. breaks: type & force
- Electrical tests
  - E.g. sensor CVs, IVs
  - E.g. front end configurations
- Thermal cycling
  - Module robustness (see next)

NB Generated test data is retained

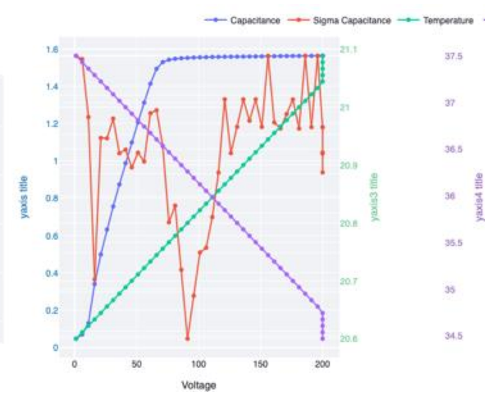
- see PDB below



Module assembly stages and tests



Module WB breaks



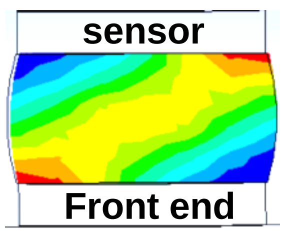
Sensor tile CV

Thermal Cycling & Irradiation

Demanding temperature range specification
- 20ºC below run-II (-25ºC)

Thermal stress from CTE mismatch
is known issue caused by flex Cu content
- Induces bow and breaks bump bonds

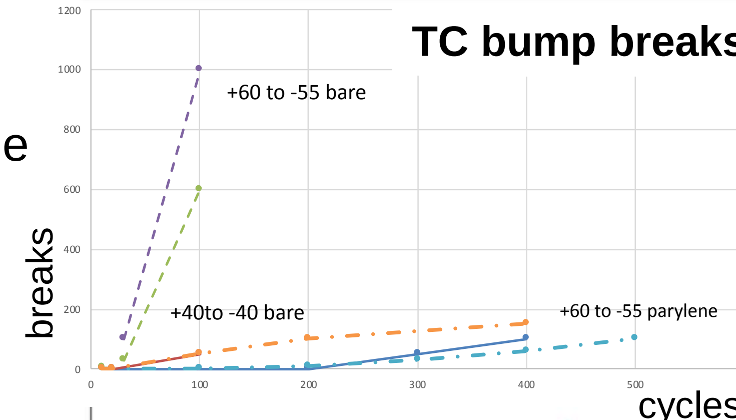
Finite Element Analysis predict bump breaks
- Degradation by strain over many cycles → lifetime
- Match well with laboratory studies

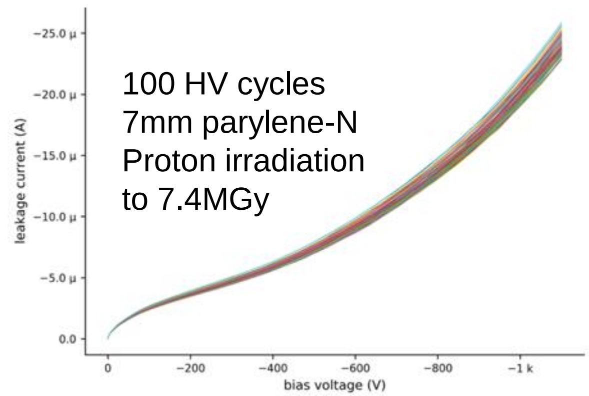


Irradiation
- Irradiations to levels of outer barrel and endcap
    - HV encapsulation holds @ 1000V
    - Sensor characteristics remain in spec.

TC ranges

+60ºC→ -55ºC	prototyping + production QA Motive: rapid coolant leak
+40ºC→ -45ºC	QC Motive (hi): cooling plant shutdown Motive (lo): power outage
-20ºC→ -40ºC	Motive: module power cycle



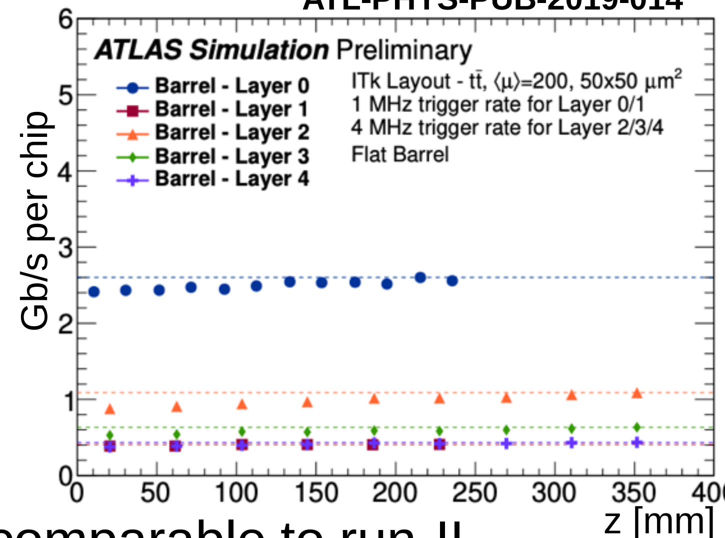


Data rates

1% chip occupancy for usable pattern recognition with HL-LHC pile-up

- ITk (run-II): ~9.5k (2k) modules with 1.4G (92M) channels
- 1.28Gbps data lanes, 80% link occupancy, 1MHz trigger
  - Links per module varies across detector
- Custom encoding suppresses addressing per chip
  - Naive: 16 bit address + 16 bit ToT

Central barrel: ATL-PHYS-PUB-2019-014



Simulated performance validates encoding

- ATLAS event simulation software for pseudo-data

Datarates are manageably low and event sizes comparable to run-II

- Important for trigger processing and transfer to disk

Consequences of high datarates

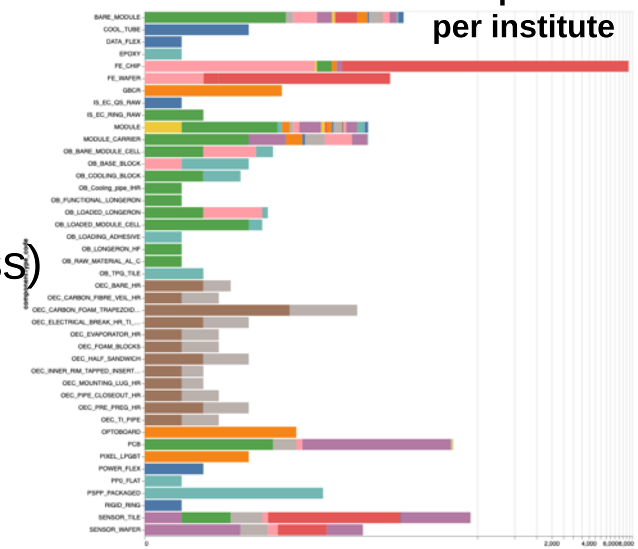
- Cross-talk shielding (beware X_0!)
- Impedance matching
- PCB design (corners!)

ITk Production Database

Scale of ITk production involves large dataset to track progress

- ~9,500 pixel modules; ~17,000 strip modules
- Inter-continental, multi-stage production chain

Pixel components per institute



Common Production Database for all ITk projects

- Custom database built upon mongoDB (with API access)
- Store data & images
- Expected data upload until end of production
- Resource during operation

Functionality: registration, test upload, shipping, reporting

API access allows interface customization

- Diverse user profiles: technicians, engineers, students, RAs, academics, engineers
- Custom interfaces: GUIs, webapps, notebooks, scripts

Summary

Pre-production for Atlas ITk pixel modules nears

Atlas upgrade physics programme drives performance and design
- High precision, radiation hard, rapid readout pixel modules
- Large scale HEP production for inner tracker upgrade

Multi-component and multi-stage assembly process
- Vendor selection based on market survey tender process
  - sensor foundries, hybridisation sites
- Module assembly steps finalising
  - Techniques to specification across sites
    - Specification documents for each stage
  - Defined QC/QA measurements
    - Track stages and consistency across sites

Atlas experiment (and other LHC) modern HEP schedule
- Process of reports and reviews
- ITk Pixels Final Design Reports pending before Pre-Production
- *Hurtling* towards installation in LS3

Back-up

Back-up

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ATLAS ITk @ PSD12

Results from ATLAS-ITk Strip Sensors Quality Assurance Testchip

The pre-production of the strip sensors for the Inner Tracker (ITk) of the ATLAS Upgrade detector at

Èric Bach (IMB-CNM, CSIC)
15 September 2021 15:54
Teaching and Learning Building (University of Birmingham)
PSD12: The 12th International Conference on Position Sensitive Detectors

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Application of material budget imaging for the design of the ATLAS ITk strip detector

material samples planned in the design of the local support structures of the new ATLAS Inner Tracker (ITk

Jan-Hendrik Arling (Deutsches Elektronen-Synchrotron (DE))
15 September 2021 15:53
Teaching and Learning Building (University of Birmingham)
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The ATLAS ITk Strip Detector System for the Phase-II LHC Upgrade

For this, an all-silicon Inner Tracker (ITk) is under development with a pixel detector surrounded by

William Trischuk (University of Toronto (CA)), *Alessandra Ciocio* (Lawrence Berkeley National Lab. (US))
Teaching and Learning Building (University of Birmingham)
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Characterisation of HV-MAPS ATLASPix3 and its applications for future lepton colliders

It is designed to meet the specifications of outer layers of the ATLAS inner tracker (ITk) pixel subsystem

Bianca Raciti (Università degli Studi di Milano), *Ivan Peric* (KIT - Karlsruhe Institute of Technology (DE)), *et al.*
17 September 2021 08:09
Teaching and Learning Building (University of Birmingham)
PSD12: The 12th International Conference on Position Sensitive Detectors