ATLAS ITk Strip Detector for High-Luminosity LHC

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On behalf of the ATLAS Collaboration
Outline

• Overview
  • ATLAS Upgrade For HL-LHC
  • The Inner Tracker (ITk)
  • ITk Layout

• ITk Strips
  • Sensors
  • Modules
  • Local Supports
  • Global Mechanics

• Current R&D

• Looking ahead
ATLAS Upgrade for HL-LHC

- An Upgrade of the Large Hadron Collider (LHC) to the High Luminosity-LHC foreseen in 2026
- Instantaneous luminosity of up to $7.5 \times 10^{34} \text{cm}^{-2} \text{s}^{-1}$
  - Triggering with high rate & increased event sizes
- Delivering an integrated luminosity of 4000 fb$^{-1}$
- Up to 200 simultaneous interactions per bunch crossing
  - Limit occupancy to 1%
- High particle fluences
  - Radiation hardness of up to $1.3 \times 10^{16} \text{neq/cm}^2$ (Inner pixel layer) required
  - x1.5 Safety factor
- Low material budget
  - Reduction in scattering & fluences from secondary interactions
**Inner Tracker System**

- The new inner tracker (ITk) will be an all Si Tracker system
  - Will replace the current ID (Pixels, SCT + TRT)
  - ’All Silicon’ -> no TRT
- $2T$ magnetic field, $\sim 6m$ long, $\sim 1m$ radius & up to $|\eta|=4$
- 5 Central and multiple Forward Pixel layers
- 4 Central and 6 Forward Strip layers

- Strips system consists of
  - $\sim 18k$ Modules
  - 59.87 million channels
  - 165 m² of Silicon

101 Institutes from 22 countries
R&D - Strips

- **Strips TDR** was approved early 2017

- Strips have began transition from R&D phase into production preparation. However lot of work still going on
  - Sensor Characterisation
  - UV Curing of Glues
  - First Modules built with ABC130 ASICs
  - Irradiation & Testing of Components
  - Electrical & Thermo-mechanical Stave/Petal tests
ITk Strip Sensors

- Silicon used by ITk strips are 320µm thick n-in-p float zone Si sensors
- n-in-p sensors allow for
  - Improved tolerance against radiation damage (no p-bulk type conversion)
  - Collection of electrons (fast charge carriers)
  - Single sided processing (easier processing, handling and cost)
- The Central region (barrel) has 1 sensor shape with 74.5µm strip pitch, and with strip lengths of 23.9mm & 47.75mm (Short & Long Strips)
- The Forward regions (Endcap) has 5 sensor shapes with strip lengths from 8.1mm to 49.9 mm
Sensor Evaluation

• Community has tested several iterations of sensors
  • Barrel Long Strip & Short Strip
  • Endcap R0 (innermost sensor of the petal)

• Measured expected signal from Alibava system (Sr-90 source)
  • Consistent with previous measurements
  • Over a range of irradiation sources and fluencies
Sensor Evaluation

• As well as electrical characterisation, mechanical properties look consistent across batches

• All R0 sensors measured have a total bow (max minus min point) below 70 μm, which is within specification of 200 μm
ITk Strip Modules

Silicon Modules consist of:

- **Binary readout chips (ABC) and hybrid controller chips (HCC)**
  - Glued & wire bonded to a hybrid
  - Data transfer on hybrid at 320 Mbit/s
- **Hybrids are glued to the surface of the Si sensor**
  - Wire bonds connect Front End ABC channels to Si strips
  - ~5200 wire bonds /module
- **DC-DC powering allows powering of all modules**
  - Unlike SCT each module cannot have own Voltage Cables
Modules – UV Curing

• With the high throughput of modules needed for the ITk, it is necessary to optimise the build time
  • Module Count - SCT: 4088 v ITk: 17,888
• Strips have baselined the use of UV Cure glues
  • For glue between ASICs and Hybrids
  • Glues exposed to UV light will cure within 6 minutes
  • Conventional glue takes > 12hrs
Modules – Electrical Tests

• Fully functioning electrical modules have been made by many of the assembly sites (for both Barrel and Endcap)

We test a binary readout using Threshold Scans

• Have a known input signal
  • Set low threshold
  • Apply signal x n(200)
  • Count the number of recorded hits
  • Increase threshold
  • Apply signal x n (200)
  • Count hits

Loop
Modules – Electrical Tests

• Fully functioning electrical modules have been made by many of the assembly sites (for both Barrel and Endcap)

A Barrel Module operated at 400 V bias.

The average noise on hybrid is $710e^-$

The row of strips under the hybrid has higher noise by $41e^-$. 
Modules - Testbeam

- Conducted a series of successful testbeam campaigns since 2015
  - Both pre and post irradiated Modules
- Latest studies conducted on Endcap R0 Modules
  - Track reconstruction more complex due to Radial Strips
  - However efficiency measurements seen to match well to previously studied Barrel Modules
ITk Strip Electronics

**EOS**
- IpGBTx (I2C interface) + VTRx+

**HV-MUX**
- controlled HV switch,
- connection/disconnection of module from HV,
- GaN FET or 3D Trench Vertical JFET transistor gate controlled by HV multiplexer

**DC-DC converter**
- built around a buck converter upFEAST chip
- distribution of LV to module (5-12 V -> 0.6-5 V with FAEST2.1)

**AMAC**
- monitoring of LV and HV, temperatures and sensor bias current on module (1 sample / ms)

Comparison of daisy chain signal routing of prototype ABC ASICs and new ABCStar design.
ABCstar Front End Prototypes

- Important to demonstrate all components used are radiation hard to the expected end of life dose of the HL-LHC
- The new readout chip (ABCstar) has been tested to examine any noise increase after irradiation
  - Reduction in noise of Front End prototype compared to current ABC130 chips

![Graph showing noise (ENC) vs. capacitance (C) for different measurements and prototypes.](image)
ITk Strip Local Supports

- There are 28 barrel modules on each stave (14 modules per side)
  - Modules on each side of the stave are rotated with respect to the beam line by 26 mrad
    - A total rotation of 52 mrad
- There are 18 endcap modules on each petal (9 modules per side, rings R0 - R5)
  - Stereo angle of 20 mrad directly implemented in sensor geometry
    - Total stereo angle of 40 mrad
ITk Strip Local Supports

• Staves (barrel) and Petals (endcap) provides mechanical, geometric, thermal and electrical support to modules:
  • **Mechanical and Geometric**: local supports interface to global support structures through a series of position locators and locking points
  • **Thermal**: titanium cooling tubes connected to CO\textsuperscript{2} cooling system working with temperatures between +20C and -40C
  • **Electrical**: electrical power (LV and HV), TTC (Timing, Trigger and Control) data, DCS (Detector Control System) data and measured data transfer services required by the modules are carried by a copper/kapton bus tape mounted on both sides of structure and operated by EoS (End of Substructure) card
Local Supports – Prototype Staves

End-of-Stave region
Co-cured facing (Kapton bus tape cured into carbon fiber facesheet)
Locking points for stave mounting

Locking point insert
Carbon honeycomb
Carbon foam enclosing titanium pipe
C-channel
End closeout
Electrical Stave tests

- Electrical Staves are being assembled at institutes in the UK (Rutherford Laboratories) and USA (Brookhaven National Labs)
  - BNL: 12 Electrical Short Strip modules
  - RAL: 2 real SS modules and 11 Electro-Mechanical SS modules (dummy sensor)

- In Addition a 5 module 'Stavelet' was assembled and fully tested
  - Comparison made of 3 point gain measurements before and after mounting to the stavelet
    - Do we see an electrical noise increase?
    - Early systems test
Comparison of Noise Results: On & Off Stavelet

Chip Mean Noise

Noise Correlations

Run 955 Scan 3 (3PG On Stave)
Run 0 Scan 27 (3PG Off Stave)
Thermo-Mechanical Local Supports

- Thermo-Mechanical Staves and Petals have been assembled
  - Using dummy module with same dimensions and thermal outputs as electrical modules

- Performance can then be compared to Finite Element Analysis (FEA) simulations

- For Barrel TM Stave, measured difference from simulation $\sim 0.2^\circ C$
ITk Strip Global Structures

The Barrel is constructed from

- 4 Layers (392 Staves in total)
  - Outer 2 Layers have Long Strip Modules
  - Inner 2 layers have Short Strip Modules
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The Endcaps are constructed from

- 32 petals per disk
- 6 disks per Endcap
Transitioning to Production

• As well as finalisation of the prototyping of components, ITk Strips is making the transition through to the production phase
  • Internal Technical Reviews (8 this year alone)
  • Organisation of procurements
  • Understanding production rates and part flow
  • Preparing for site qualification (Late 2019)

Modelling the ramping of production rates for module building
Conclusions

• The HL-LHC will be a challenging but exciting new stage for the LHC
• The ITk is making the transition from R&D to a pre production phase
• ITk Strips are continuing to finalise the prototyping of components from Sensors -> Global Structures
• Now beginning the process of getting ready for production!
Backup
Star Chipset Submissions

Andrew Blue - ITK Strips