ATLAS ITk Layout Design and Optimisation

Noemi Calace – noemi.calace@cern.ch
On behalf of the ATLAS Collaboration
Overview

• The Phase-II Scenario
  → The ATLAS Inner Tracker Upgrade

• Evolution of design options
  ○ From the Letter of Intent to the current layouts

• Next Steps
The ATLAS Phase-II Inner Tracker

ITk (Inner Tracker) is a full upgrade of the ATLAS Inner Detector as part of the Phase-II upgrade
→ includes new pixel and strip detectors, “all-silicon” detector

→ Designed to operate successfully under HL-LHC operating conditions corresponding to:
  • Leveled peak luminosities up to $7.5 \cdot 10^{34}$ cm$^{-2}$ s$^{-1}$
  • 25 ns bunch spacing
  • Mean number of interactions per bunch crossing up to 200
  • Integrated luminosity $L_{\text{int}} \sim 3000$ fb$^{-1}$
  • 14 TeV energy in the center of mass
The ATLAS Phase-II Inner Tracker

→ More stringent requirements to cope with the new environment
  ◦ $\leq 0.1\%$ occupancy in the pixel layers and $\leq 1\%$ occupancy in the strip layers
  ◦ Requires new sensor technologies
  ◦ Radiation tolerance: possibility to extract and replace inner parts of the pixel detector if needed

→ Reduce the amount of material in the tracking volume
  ◦ The tracker material is a major limitation for the overall performance
    ▪ Thinner silicon sensors

→ Pileup Robustness
  ◦ Stable performance with respect to increasing pileup

→ System Redundancy
  ◦ Robustness against limited detector defects
ATLAS Phase-II
Physics Performance Requirements

- Must be possible to precisely reconstruct tracks within \( z_{\text{beam}} = [-150, 150] \) mm around interaction region up to \( |\eta| < 2.7 \)

- Track efficiencies:
  - Muons with \( p_T > 3 \) GeV: 99.8\% for \( |\eta| < 2.7 \) under all pileup and assumed component failure conditions
  - Pions (Electrons) with \( p_T > 2 \) GeV (5 GeV): 90\% for \( |\eta| < 1 \), 85\% for \( 1 < |\eta| < 2.7 \), dependence on pileup less than 5\% 

- Tracking in dense environments:
  - Average track inefficiency for primary hadrons within jets should not increase by more than 1\% from truth jets up to \( p_T = 1 \) TeV
  - The average track reconstruction efficiency within a jet should not decrease by more than 5 (10\%) when moving from outer jet regions towards the jet axis for light (b-)jets in the truth jet \( p_T \) range of \( 450 \) GeV < \( p_T < 650 \) GeV

→ Requirements met by an “All-silicon” Pixel + Strip tracker!

→ See next talk: Tracking, vertexing, b and tau tagging performance – Nicholas Styles
The ATLAS Letter of Intent Layout

→ LoI Layout guided by the requirement of at least 14 hits and coverage up to $|\eta| \sim 2.7$

- **Pixel Detector:**
  → 4 pixel layers + 6 disks
    - Two inner pixel barrel layers removable

- **Strip Detector:**
  → 5 barrel layers + stubs + 7 disks
    - Stubs are inserted to maintain hermeticity and provide good momentum resolution in the barrel-endcap transition region
    - Barrel layers and endcap disks have back-to-back small stereo-angle sensors
    - Reduced strip length is used in the innermost layers to limit occupancy

→ Letter of Intent (LoI) Layout – ATL-UPGRADE-PUB-2012-004
More on the ATLAS LoI Layout Design Consideration

- The services, the material budget, the placement of patch panels and manifolds, and the service routing, affect performance.

- Many service layouts have been considered to study the effect on performance, e.g. impact parameter and momentum resolution, in the tracking volume.

→ Letter of Intent (LoI) Layout – ATL-UPGRADE-PUB-2012-004
The Extended Coverage Scenario

- **Extended tracking acceptance: up to $|\eta| \sim 4$**
  - concerns mostly the pixel detector
  - Improved sensitivity and acceptance in VBS, VBF Higgs studies, $bbH$, $H \rightarrow 4l$, etc.
  - Improved impact parameter and vertex resolution $\rightarrow$ pileup rejection and $b$ tagging
  - Improved MET resolution in particular from track soft term
  - Forward electron identification
  - ...

- As an example: pileup jets are rejected based on the **momentum of tracks within a jet** associated with the primary vertex:

  \[ R_{p_T} = \frac{\sum_i (p_{T \text{track},i})}{p_{T \text{jet}}} \]

  Measuring tracks at high pseudo-rapidity extends the range of this technique.
The ATLAS Lol-Very Forward Layout

- Extended coverage up to $|\eta| \sim 4$
  - Not yet optimised in terms of mechanical construction and maximum performance for a given silicon area
  - Very challenging routing of services
  - Used for studies up to $|\eta| \sim 4$ and starting point for optimisation
    → For both Strips and Pixels

- The optimised layouts will be presented in:
  - Strip Technical Design Report (end 2016):
    → 1 Strip Layout + 2 Pixel Layouts
  - Pixel Technical Design Report (end 2017):
    → 1 Pixel Layout

→ ATLAS Phase-II Upgrade Scoping Document – LHCC-G-166
The ATLAS ITk Strip Layout

- In the last years, the LoI layout has been modified to move towards more realistic ITk candidates
  - 4 Pixel + 5 Strip → 5 Pixel + 4 Strip
    - Goal: e.g. do better in jet cores
    - (Track In Dense Environment)
  - Longer staves in strip barrel
    - 14 modules
    - Region of best momentum resolution extends to $|\eta| = 1.1$
    - Allows to remove stubs
    - reduce complexity of engineering
    - Allows to move from 7 to 6 disks → moved accordingly to provide good momentum resolution
The ATLAS ITk Strip Layout

Much **more realistic** structure for the strip detector

**Barrel:**
- 4 double-sided layers
- Stereo angle: +/- 26 mrad

**Endcap:**
- 6 discs: double-sided petals
  → 6 different types of sensors in radius
- Sensor’s **irregular shape**
  → two tilted straight edges: +/- 20 mrad stereo angle built in
  → two circular edges: uniform gap between the sensors
  → Strips are pointing to the strip focus (not the beampipe)

→ See next talk: **Strip Tracker R&D – Ingrid-Maria Gregor**
The ATLAS ITk Pixel Layouts

- In the last years, the LoI layout has been modified to move towards more realistic ITk candidates

- Increasing the pixel volume to host a 5th barrel layer of pixels

- Rings instead of disks in the pixel endcap region
  - Services are routed on the support structure
  - Very peculiar pattern to provide constant number of hits versus $\eta$
  - Large-$|\eta|$ region entirely in the pixel volume → increased the number of rings at very high $|\eta|$
The Extended Layout Concept

→ Combine classical barrel with ring system

- Long barrel layers extend tracking acceptance up to $|\eta| \sim 4$
- Ring system was optimized for at least 9 hits, for $z_0$ in [-15 cm, 15 cm]

Mean number of hits per track as a function of $\eta$ for single muons with $p_T=10$ GeV

Composition of the simulated material in radiation lengths as a function of $|\eta|$
The Extended Layout Concept

- **Two long innermost layers** with conventional barrel mechanics.
  - Not too challenging to build
- With sensors placed parallel to the beam pipe at high $|\eta|$, we expect to measure **long pixel clusters** at low incidence angle
- Main benefits of measuring long clusters:
  - Very efficient measurement as close as possible to the interaction point
  - Potential to reduce fake track rates by rejecting clusters with incompatible length
  - Luminosity measurement by cluster counting
  - Room for even more improvement by making use of the full cluster information
    - $\theta$ and $z_0$ from cluster length, better $d_0$ from charge sharing, dE/dX, $\Phi$ shape

$$\tan \theta = \frac{t}{N_{\text{pixel}} \cdot \text{pitch}}$$
Extended Stave Design and Prototyping

→ Support structure design bound to layout choice

- For the extended layout the “I-beam” design has been proposed:
  - Modules are always “outward” facing
  - Services and cooling planned to run within the structure
  - Coupled layers with different widths available
  - Adaptable height and tilt angle
The Inclined Layout Concept

- With tilted sensors in the high $|\eta|$ region we expect **several hits per layer (tracklets)** and **less material crossed** given the low incidence angle.

- **Main benefits:**
  - Less silicon wrt extended outer barrel ($\sim 2.5 \text{ m}^2$)
  - Less material in front of the “inclined” rings and less material crossed ($\rightarrow$ less material effects) in front of the calorimeter at high pseudorapidity $\rightarrow$ compared to classical disk system
  - Better constraint on the impact parameter $\rightarrow$ Improved $d_0$ and $z_0$ resolution
  - Improvements in tracking efficiency from having many tracklets as close as possible to the interaction point
The Inclined Layout Concept

→ The Inclined Layout provides many hits at large $|\eta|$ close to the beam spot

- Using the same ring system of the extended layout, it provides more hits compared to the extended option in the forward region

Mean number of hits per track as a function of $\eta$ for single muons with $p_T=10$ GeV
Inclined Stave Design and Prototyping

→ **Support structure design bound to layout choice**
  - For the inclined layout two designs have been proposed: **Alpine** and **SLIM**

→ **Process to join the two efforts ongoing**

**Alpine**
- T. Todorov† pioneer of the “inclined” idea
- Two types of modules: barrel and inclined
  - carbon foam + carbon fibre “IBL-like” stave design

**SLIM: Stiff Longeron for ITk Modules**
- Two types of modules: barrel and inclined
- Inspired from ALICE: common structure (“Longeron”) supporting two layers of modules
- Two longeron designs: Shell and Truss

→ See next talk: **Pixel Tracker R&D – Joern Grosse-Knetter**
Summary and Next Steps

- **Strong design effort** starting from LoI layout to establish the ATLAS ITk tracker design for Phase-II
  - All silicon tracker with 5 pixel layers and 4 strip layers and extension to $|\eta| \sim 4$

- Final strip system design for TDR (currently being written)
  - Petal endcap structure to **minimise silicon overlap and material budget**

- Pixel system with **two alternative** layout concepts
  - Extended barrel with long cluster measurements in the forward
  - Inclined module solution with many hits at large $|\eta|$ close to the beam spot
  - Both concepts have been **prototyped and demonstrators exist**
    - **General good performance** from simulation of both layout
      → See next talk: **Tracking, vertexing, b and tau tagging performance**
      Nicholas Styles – ATL-PHYS-PUB-2016-025

- Pixel TDR → Decision on the stave technology for the inner and outer barrel layers
  → **much more in the next talks!**
Extra Slides
ATLAS Lol Layout Design Consideration

- The radius of the innermost pixel layer is chosen to be as close as possible to the beam pipe.

- Length of inner barrel layer is given to provide coverage up to $|\eta| \sim 2.7$

- Length of outer barrel layers is mainly given by construction constraints and costs.

- For both sub-detectors, fixed the position of the first disk, the radius of the last layer is determined in order to provide hermeticity.

- The next disks are added taking into account the fall-off of the layers.

**Inverse-p_T resolution using resolution model, measured as a function of $|\eta|$ for the Lol layout, and comparison with the existing ATLAS experiment.**
Extended Coverage Scenario

Pileup jets are rejected based on the momentum of tracks within a jet associated with the primary vertex:

\[ R_{p_T} = \frac{\sum_i (p_{T,i}^{\text{track}})}{p_{T,jet}} \]

Measuring tracks at high pseudo-rapidity extends the range of this technique.

Distribution of the number of pile-up jets per event with no tracking confirmation (TC), and applying the TC algorithm tuned to give 2% pile-up jet acceptance, for each of the three scoping scenarios.