Design of the new ATLAS Inner Tracker (ITk) for the High Luminosity LHC

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• In year 2015, ATLAS and CMS went into Run2
• Till now have already collected up to ~40 \( fb^{-1} \) \( pp \) collision data at 13 TeV.
• Detector will be upgraded after ~10 years (phase 2), then go to the HL-LHC running
**HL-LHC Tracker of ATLAS: ITk**

- **ITk** is a full upgrade of the current ATLAS Inner Detector (ID) as part of the Phase-II upgrade.
- Consists of a **new Pixel and Strip** detectors, **“all-silicon”** detector.
  - ID can't survive with $3000 \, fb^{-1}$ (radiation damage), has to be replaced.
  - Remove the TRT (Transition Radiation Tracker). It can't work under HL-LHC multiplicity.
HL-LHC Tracker of ATLAS: ITk

- HL-LHC upgrade would unlock much larger physics potential:
  - VBF $h \rightarrow ZZ \rightarrow 4l$, BSM $hh \rightarrow 4b$, higgs self-coupling, etc
- The ITk would be the most important detector component, will be crucial for:
  - lepton measurements, b-tagging
  - pileup jet rejection in wide kinematic and pseudo-rapidity range, etc.
- There will also be huge challenge: enormous pileup of up to $\mu = 200$
  - Vital to optimize the layout to maximize tracking and vertexing
- Need to carefully re-design the Tracker

Pileup: the additional pp collisions except the hard-scattering one
How to Design the ITk

• The basic idea is to build the whole detector, mimic the HL-LHC collision situation, implement the particle-detector interaction etc., using simulation; and use the simulated samples to look and compare the performances

• Only detecting technique/sensor is good doesn't mean the built detector is good
  - the shape of the sensor may not optimized; the sensor may not survive the radiation in HL-LHC; need to optimize how to arrange the sensors to minimize the material amounts; need to ensure the $4\pi$ coverage etc.

• Need to tightly coordinate with engineering electrically and mechanically
  - e.g. get information from them about which sensor/layouts are interested, then look; our optimized layouts may impossible in terms of engineering or cost too much …
  - write conclusions into reports/documents, to guide the building

• A very important component towards building ITk
The ITk Layout Evolution

There are the following important steps:

• Lol, ~2012

• Lol-VF, ~2013-2014

• Inclined vs. Extended, ~2015-2016

• Decided on Inclined, achieved the Strip TDR layout, used for Strip TDR results. ~2016

• Now: converging on Pixel TDR layout, will be used for releasing the Pixel TDR.

• Features a so-called "stub" layer, a short barrel layer between the 4th/5th layer of the Strip, to give robustness in the barrel to end-cap transition region

• $|\eta| \sim 2.7; 4$ pixel + 5 strip
LoI-VF (Very Forward) Layout

• Studies showed that many performances and physics at HL-LHC can benefit from larger Tracker coverage. One e.g.:

![Graph showing RMS vs. Σ ET (GeV)]

• LoI-VF:
  - simple extension, |η|~4
  - was not optimized in terms of mechanical construction and maximum performance for a given silicon area.
Have 5 Pixel Layers

• There were strong motivations to change from 4 pixel + 5 strip \( \Rightarrow \) 5 pixel + 4 strip
  - better efficiency/fake balance at \( \mu = 200 \)
  - improve the performance of tracking in dense environment, etc

- For example, left plot shows \( \tau \) reconstruction performance vs. \( p_T \) in the 3-prong decay channel
- Better efficiency with more pixel information, especially for highly boosted case
Pixel Optimizations

- **Extended vs. Inclined**, both push the material of the end of barrel services and support region to large $Z$.

  - the difference between the two are in the treatment of the forward part of the barrel layers.
  - Extended use long barrel; Inclined uses rings
Pixel Optimizations

- Preliminary estimation of the material budget for the two layouts
  - as expected inclined has less material: the tracks are more perpendicular to the sensor

- Extended has another intrinsic problem: the long clusters and the corresponding bad quality space points, make the seeding problematic.
  - Inclined is preferred.
Strip Description: General Idea

• A new **Xml-based** detector description framework has been developed
  - easy to understand and maintain
  - has highly flexibility geometry building and detector description

[A barrel module]  
[A barrel stave]

GeoModelXml, SCT_GeoModelXml convert the gmx files into GeoModel objects

Feed into Geant4

Xml files (geometry, services, material, hierarchical structures, etc)
Strip Design: Endcap

Sensors $\Rightarrow$ Petals $\Rightarrow$ Endcap

- Completely new endcaps
  - Complicated new sensor shape (stereo annulus).
  - Petals are overlapping like turbo fans. Different sensor geometries for each petal.
The Milestone: Strip TDR Layout

- 4 pixel + 5 strip ⇒ 5 pixel + 4 strip
- Remove “stub”
- Inclined is picked up for Pixel

- Baseline used for the recently released Strip TDR (Apr/2017)
  - CERN-LHCC-2017-005
Various Tracking Performance Plots

- Reasonable distributions
- Demonstrate that the layout geometry implementation and the algorithms (simulation, reconstruction) are working well
Summary

• Extremely challenging situation at HL-LHC makes very hard to design the new Tracker.

• Several years' work successfully converged on the Strip TDR layout, used for the results in the Strip TDR

• Now trying to converge on Pixel TDR layout, then will be used for results for the Pixel TDR
Backup Slides
Loi-VF Layout

Long (47.8mm)
Strips x 2
(r=762mm, 1000mm)

Stub
Layer x 1 (r=862mm)

Discs
Strips x 7
(z=1415mm, 1582mm, 1800mm,
2040mm, 2320mm, 2620mm, 3000mm)

Pixel Barrel x 4
(r=39mm, 78mm, 155mm,
250mm)

Short (23.8mm)
Strips x 3
(r=405mm, 519mm,
631mm)

Pixel Discs x 12
877mm, 1059mm, 1209mm, 1358mm,
1509mm, 1675mm, 1875mm, 2075mm,
2275mm, 2500mm, 2750mm, 3000mm
Look Beyond: Pixel and Strip

• To build the Inclined, two concepts are under study

  - Alpine: builds on the technologies used for the IBL project. Each stave contains two titanium pipes embedded in a carbon foam

  - SLIM: relies on the module cells. In these cells the silicon module is supported by a pyrolytic graphite plate used as a heat spreader

• Some further studies for the Strip are also ongoing
  - e.g. more investigation about the necessity and feasibility of better coverage in the barrel-endacp transition region