The design and performance of the ATLAS Inner Detector trigger in high Pile Up collisions at 13 TeV at the Large Hadron Collider

CALLIOPE-LOUISA SOTIROPOULOU (ON BEHALF OF THE ATLAS COLLABORATION)

Email: c.sotiropoulou@cern.ch
The ATLAS Inner Detector

- The **Inner Detector (ID)** is the ATLAS sub-detector dedicated to track and vertex reconstruction

- It consists of **3 sub-systems:**
  - Pixel Detector – closest to the beamline and the Interaction Point (IP)
    - 3 layers of barrel and endcap silicon pixel modules
    - Insertable B layer (IBL) – 1 Barrel layer added for LHC Run 2
  - Semiconducting Tracker (SCT)
    - 4 barrel and 9 endcap layers of silicon microstrip modules
  - Transition Radiation Tracker (TRT)
    - Barrel and endcap modules of thin-walled drift tubes
The ATLAS Trigger System – Run 2

- **L1 (100kHz, <2.5μs, HW based):**
  - new Central Trigger Processor and Topological Processor based on FPGA
  - deployment of a new post L1 hardware tracking stage called Fast Tracker (FTK)

- **High Level Trigger - HLT (1 kHz, ~200ms):**
  - For Run 2, the previous two software stages were merged into a single High Level Trigger (HLT) stage
  - Dataflow simplification, no need to request data twice, common storage and data preparation
  - The HLT is prepared for the FTK that will provide HW tracks in the full detector volume
  - The IBL fully exploited for the tracking
The ID Trigger System

- The **ID Trigger** system is part of the **HLT** system and it performs fast Online Track and Vertex finding.
- Tracking is essential in triggers for nearly all physics signatures → online selection with sufficient resolution.
- As pile up increases tracking becomes even more important → time consumption grows nonlinearly.
- But Tracking is very computationally intensive → possible bottleneck for the HLT.
The ID Trigger System (Methods)

- Various methods are used to ensure speed while keeping good performance
  - Tracking is split into: pattern recognition stage, the Fast Track Finder (FTF), and Precision Tracking (PT), which processes tracks and clusters from the first stage, and improves their quality while applying tighter requirements
    - Spatial Regions of Interest (RoIs) allow tracking and vertexing in reduced volumes
    - Multi-stage RoI methods define multiple RoIs in sequence to allow for reduced RoI volumes, tailored for different stages of tracking and vertexing
Multi-stage methods: Two stage tracking

- **Added for LHC Run 2**, RoI sizes can be reduced by using multiple RoIs in sequence, reducing latency of track finding

- **Two-stage tracking:**
  1) Perform initial **FTF tracking** in RoI with large range along beamline, but narrow width in $\phi$ and pseudorapidity
  2) Determine **track or vertex of interest**
  3) Seed **second RoI** around this position, with narrower range along beamline, but widened in $\phi$ and pseudorapidity
  4) Perform **FTF in second RoI**, followed by **Precision Tracking**

- Employed in **jet** and **hadronic-decay tau** triggers, where $z$-position of the primary vertex is not known from L1 information
Multi-stage methods - performance

**ATLAS Operations**

Data 13 TeV, August 2015, 25 ns running

Tau trigger: Fast Track Finder

- Two-stage: 1st stage mean = 23.1 ± 0.11 ms
- Two-stage: 2nd stage mean = 21.4 ± 0.09 ms
- Single-stage: mean = 66.2 ± 0.34 ms
Multi-stage methods - performance

**ATLAS Operations**
Data 13 TeV, August 2015, 25 ns running
Tau trigger: Precision Tracking
- Two-stage: mean = 4.8 ± 0.04 ms
- Single-stage: mean = 12.0 ± 0.07 ms
Multi-stage methods: Super RoIs

- **Added for LHC Run 2**, RoI overlap can be avoided by combining RoIs

- **Super RoIs:**
  - Define RoIs with **large range along beamline**, but **narrow width in \( \phi \) and pseudorapidity**, and **combine into a single region**
  - Perform **tracking and vertexing over the combined region**

- Avoids multiple processing and double counting of tracks that could occur when using multiple RoIs

**Pseudorapidity-\( \phi \) plane**

- a) Standard RoI
- b) Super - RoI
Multi-stage methods: Super Rols

- Employed in \textit{b}-quark jet triggers, along with \textit{two-stage tracking}
  - Perform initial FTF tracking in Super RoI defined around jets passing L1 trigger
  - Perform primary vertex reconstruction using Super RoI track collection
  - Define individual secondary RoIs around jets, originating from the primary vertex
  - Perform FTF in secondary RoIs, followed by Precision Tracking, and secondary vertexing needed for \textit{b}-hadron tagging

Pseudorapidity-$\phi$ plane

a) Standard RoI

b) Super - RoI
Performance in 2017 data: Definitions of performance evaluation

- Plots produced from 13 TeV collisions, using current 2017 dataset
- Events are taken from dedicated performance triggers
  - Tracks are not used in trigger decision making, so as not to bias the performance
- Performance is measured by matching and comparing tracks found by Online ID trigger algorithms (FTF and Precision Tracking) to tracks found by full Offline track reconstruction
  - For muon trigger performance, the Offline track matched to the Offline-reconstructed muon is used
  - For jet trigger performance, all Offline tracks from within the RoIs are used
Performance in 2017 data - Muon triggers: Efficiency vs average collision pileup

- Efficiency $\sim 100\%$ as a function of pileup, including at highest pileup conditions in LHC 2017 running

ATLAS Preliminary
Data 2017 $\sqrt{s} = 13$ TeV
Offline medium Muons $p_T > 4$ GeV
- 10 GeV Muon trigger: Fast Track Finder
- 10 GeV Muon trigger: Precision Tracking
- 24 GeV Muon trigger: Fast Track Finder
- 24 GeV Muon trigger: Precision Tracking
Performance in 2017 data - Muon triggers: Efficiency vs Offline muon pseudorapidity and $p_T$

- **Efficiency for muons uniformly ~100% across muon pseudorapidity and $p_T$**

### ATLAS Preliminary

Data 2017 $\sqrt{s} = 13$ TeV

- Offline medium Muons $p_T > 4$ GeV

- 10 GeV Muon trigger: Fast Track Finder
- 10 GeV Muon trigger: Precision Tracking
- 24 GeV Muon trigger: Fast Track Finder
- 24 GeV Muon trigger: Precision Tracking

### ATLAS Preliminary

Data 2017 $\sqrt{s} = 13$ TeV

- Offline medium Muons $p_T > 4$ GeV

- 10 GeV Muon trigger: Fast Track Finder
- 10 GeV Muon trigger: Precision Tracking
- 24 GeV Muon trigger: Fast Track Finder
- 24 GeV Muon trigger: Precision Tracking
Performance in 2017 data - Muon triggers: $d_0$ and $z_0$ resolution vs Offline muon $p_T$

- $d_0$ and $z_0$ are the transverse and longitudinal impact parameters
- New precision tracking algorithm improves resolution, down to $\sim 10\mu m$ for $d_0$ and $\sim 50\mu m$ for $z_0$ at best
Performance in 2017 data - Jet triggers: Efficiency vs average collision pileup

- Efficiency shows little dependence on pileup, including high pileup conditions
Performance in 2017 data - Jet triggers: Efficiency vs Offline track pseudorapidity and $p_T$

- Efficiency for central pseudorapidity $> 98\%$
- Efficiency generally $> 98\%$ as a function of $p_T$

**ATLAS Preliminary**
Data 2017 $\sqrt{s} = 13$ TeV
55 GeV jet trigger

- Fast Track Finder
- Precision Tracking
Performance in 2017 data - Jet triggers: $d_0$ and $z_0$ resolution vs Offline track pseudorapidity

- **Good resolution performance**
- Resolution degrades as a function of pseudorapidity due to tracks passing through more detector material, giving larger multiple scattering for tracks at larger angles
Conclusions

- The ID Trigger is fundamental for the performance of the ATLAS trigger system
- The ATLAS Trigger has been upgraded to cope with the requirements of Run 2

Upgrades for Run 2:
- **Two stage reconstruction**: Fast Track Finder (FTF) and Precision Tracking (PT)
- **Multi-stage RoI methods** for low latency while maintaining excellent performance
  - **Two-stage tracking**: reduces spatial volume
  - **Super RoIs**: avoid multiple processing and double counting of tracks

- **Excellent tracking performance** seen in high rate and pileup conditions in data taken in 2017 so far
  - **Tracking efficiency insensitive to pileup**, including at highest pileup conditions observed

- The ID Trigger continues to provide the excellent performance from Run 1 in Run 2
References

- Based on the ATLAS presentation ATL-DAQ-SLIDE-2017-924
  - [https://cds.cern.ch/record/2290541](https://cds.cern.ch/record/2290541)

- Slide 2: Inner Detector cutaway - ATL-PHYS-PUB-2015-018

- Slide 3, 4, 22: ATLAS Online System schematic, ATLAS Trigger System schematic
  - [https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ApprovedPlotsDAQ](https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ApprovedPlotsDAQ)

- Slide 6, 7: Two-stage tracking diagram and timing plot
  - [https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HLTTrackingPublicResults#ATL_COM_DAQ_2015_148_Run_2_HLT_t](https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HLTTrackingPublicResults#ATL_COM_DAQ_2015_148_Run_2_HLT_t)

- Slides 11 – 17: 2017 data performance plots
  - [https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HLTTrackingPublicResults#ATL_COM_DAQ_2017_107_The_ATLAS_I](https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HLTTrackingPublicResults#ATL_COM_DAQ_2017_107_The_ATLAS_I)

- Slide 21: Inner Detector schematic - ATL-PHYS-PUB-2015-050
Thank you!
Back Up
CALLIOPE-LOUISA SOTIROPOULOU, THE DESIGN AND PERFORMANCE OF THE ATLAS INNER DETECTOR TRIGGER IN HIGH PILE UP COLLISIONS AT 13 TEV AT THE LHC
ATLAS Trigger System Run 2

CALLIOPE-LOUISA SOTIROPOULOU, THE DESIGN AND PERFORMANCE OF THE ATLAS INNER DETECTOR TRIGGER IN HIGH PILE UP COLLISIONS AT 13 TEV AT THE LHC