First performance measurements of the Fast Tracker Real Time Processor at ATLAS

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On behalf of the ATLAS Collaboration
Overview

- The ATLAS detector:
  - The inner detector
  - The LHC environment

- What is Fast TracKer (FTK)?
  - Track processor at trigger level

- How does it work?
  - The algorithm
  - The system
  - Parallel processing and slices

- System performances
  - Expected
  - Measured!!!

- Future of FTK
The ATLAS detector

**ATLAS** is a general purpose detector operating at the CERN LHC
- Reconstructs paths and energy deposits of particles
- Uses multi-layer sub-detectors

**Inner Detector:**
- Reconstruct charged particle paths: tracking

**Calorimeters:**
- Reconstruct particle energies

**Muon spectrometer:**
- Measure muons momenta

**Trigger:**
- Multi-level trigger to reduce event rate
The trigger and data acquisition system

9 orders of magnitude between total and Higgs boson production cross section:

- $\sigma_{\text{tot}} \sim 10^8 \text{ nb}; \sigma_{\text{H}} \sim 10^{-1} \text{ nb}
- need to save only interesting data without stopping data flow

Two level trigger system:

- LHC event rate 40 MHz
- Level 1
  - hardware based
  - simple algorithms
  - output: 100 kHz
  - latency: 2.5 $\mu$s
- High level trigger (HLT):
  - software based
  - complex algorithms
  - output 1.5 kHz
  - latency: 0.2 s
The ATLAS inner silicon detector

IBL:
- first pixel layer
- ~3.2 cm from beam axis

Pixel:
- O(100) million pixels
- 3 layers in barrel

SCT:
- O(10) million silicon strips
- 8 layers in barrel: 4 stereo layers
Luminosity and pile up

The average number of interactions per bunch crossing:

- 2018: ~37 interaction per crossing
- 2021: ~60 interaction per crossing
- HL-LHC: ~200 interaction per crossing

Tracking means fitting a helix to the ID hits:

- During HLT for limited regions O(10-100) ms
- Full detector tracking requires O(1) second per event

Different approach is required
What is the Fast TracKer?

Fast TracKer (FTK) is a track reconstruction processor: it is an upgrade to the ATLAS trigger system

- Gathers data from IBL, Pixel and SCT
- Performs full event tracking
- At L1 trigger acceptance rate of 100 kHz
- Peak latency of $\approx 200\mu s$ [FTK-TDR]

Fixed latency obtained with the usage of:

- FPGAs
  - clustering
  - track fitting
  - data management
  - system configuration

- Associative memory ASIC
  - pattern recognition
How does it work?

The idea

**Offline:**
- Simulate all possible tracks
- Store the expected hits in a LUT
- Generate fit constants (used in linearised fit)

**Online:**
- Cluster close-by pixels
- Compare detector hits with simulated tracks
- Use only matched detector hits to perform a 2-stage linearised fit of the tracks
  - 1\textsuperscript{st} stage: uses 8 detector layers
  - 2\textsuperscript{nd} stage: extend fit to 12 detector layers.
The FTK System

- **Input mezzanine:**
  - data from the ID & clustering
  - **Poster by Takashi Mitani,** Thursday in “Trigger” session

- **Data Formatter:**
  - distribution of data into 64 towers

- **Associative Memory Board:**
  - Pattern matching with simulated tracks

- **Auxiliary card:**
  - 8 layers track fitting

- **Second Stage Board:**
  - 12 layers track fitting

- **FLIC:**
  - Data formatting for HLT
Parallel processing: towers and slices

Parallel processing of detector regions:
- 64 $\eta - \phi$ partially overlapping regions [towers]
- send data to replicas of the same hardware

The system performances are related to the number of detector regions:
- higher pile-up $\rightarrow$ more towers

Today results based on data collected from two towers:
- Tower 40
- Tower 22
Expected tracking performances

Expected performances assessed by comparing the offline simulation and the FTK Simulation

- tracking efficiency greater than 90%
- track parameter resolution is comparable for all analysed parameters

More plots at “Fast TracKer (FTK) Technical Design Report” and “FTK Public results”
FTK will improve object identification and allow for better pile-up suppression at the HLT stage.

Few application examples:

- τ-lepton identification
- b-tagging
- lepton isolation
- JVT at HLT
- vertexing
- ...

ATLAS Simulation

- $|s| = 14$ TeV, $<\mu> = 60$
- $L1=2\text{TAU121\_TAU201\_J25\_DR28}$

**Plots:**

- PV, FTK L2, PV + FTK L2, Calorimeter L2, Calorimeter L2 + $E_T^{1st} < 32$ GeV, $E_T^{2nd} < 25$ GeV

Efficiency for QCD multijet background vs. Efficiency for Boosted events of $ggH \rightarrow \tau_h \tau_h$
Two slices with different hardware configuration used in ATLAS for testing purposes. Both slices process p-p collision data at a rate of 75 kHz.

**Tower 22:**
- complete FTK slice
- outputs 12 layers tracks

**Tower 40:**
- partial slice
- outputs 8 layers tracks
First studies performed on hit coordinates from 8 layer tracks:

- low number of tracks per event
  - small detector region (tower 40):
    - $-0.2 < \eta < 1.2$
    - $2.4 < \varphi < 2.8$
  - efficiency < 1

System performances evaluated using data included in the ATLAS bitstream:
- here 500 events
System level performances evaluated running the simulation on raw data:
- data included in the ATLAS bitstream
- observed differences w.r.t. offline simulation:
  - partially expected
  - to be fully understood

No strong biases observed
- track parameters not saved in the partial slice
- Track parameter studied by comparing FTK simulation output

More studies performed using 12 layer tracks are currently ongoing.
Summary and Outlook

- System commissioning ongoing
  - Installation progressing
    - system finalization ongoing
  - Good progress on tower 22 and tower 40:
    - often included in ATLAS and under commissioning
  - **First studies of 8 layer and 12 layer tracks**
    - with increasing statistics
- System will be ready for run-3
  - 5 weeks of p-p collisions
  - 4 weeks of Pb-Pb Ion collisions
  - commissioning completed during long shutdown

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Thank you for listening!
Back-up!
Run Number: 358656, Event Number: 913511153
Date: 2018-08-20 03:37:04 CEST
Fraction of Tracks

- Hits in all layers
- Missing hit in Pixel
- Missing hit in SCT

ATLAS Preliminary
2018 Data, $\sqrt{s}=13$ TeV
Run 358395, $\langle \mu \rangle = 31$
859196 Events Processed

Event Number
ATLAS Preliminary

2018 Data, $\sqrt{s}=13$ TeV
Run 358395, $\langle \mu \rangle = 31$
500 Events Processed