The ATLAS FastTracKer
Pioneering the next era of hardware track triggers

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THE ATLAS TRIGGER
Throwing away data

ATLAS rejects more than 99.99% of collisions

Final decision on what to keep is made in around 250 ms

How do we decide if this event is worth keeping?

ATLAS public event displays

(image of an event with analysis-level “offline” reconstruction)
Throwing away data

Level 1 trigger decisions are made with rough calorimeter and muon information

High Level Trigger uses full precision information around objects identified at L1

Event @ L1

Event @ HLT
Throwing away data

Level 1 trigger decisions are made with rough calorimeter and muon information.

High Level Trigger uses full precision information around objects identified in events at Level 1.
Throwing away data

Level 1 trigger decisions are made with rough calorimeter and muon information.

High Level Trigger uses full precision information around objects identified at L1.

Tracking performed mainly in Regions of Interest (RoI).

How well can we do with just these RoIs?
~40 simultaneous $pp$ interactions per event in 2018

tracks let us identify objects from the primary vertex

(and ignore everything else)

need global tracking to do this for the full event!
Tracking at the trigger level is essential to maintaining low trigger thresholds.

$\langle N_\text{njets} \rangle$ vs $\mu$

- ATLAS Preliminary
- $\sqrt{s} = 8$ TeV, $L = 20.3$ fb$^{-1}$
- Sherpa $Z \to \mu\mu$
- Anti-$k_t$ LCW+JES $R=0.4$
- $p_T > 20$ GeV, $|\eta|<2.4$
- $Z$ boson $p_T > 20$ GeV

- MC
- Data
- MC, JVT>0.7
- Data, JVT>0.7

nJets selected without tracking
nJets selected with tracking

ATLAS-CONF-2014-018
Full-scan tracking can help identify any object with track-based signatures. If tracking is already available, it frees up CPU at HLT for other tasks.
THE ATLAS FASTTRACKER
Adding the FastTracKer (FTK) to the trigger

- FTK performs hardware-based tracking on silicon hits
- provides HLT with >1 GeV tracks ID acceptance (|\(\eta\)|<2.5)

Data from the ID is read out when a L1 trigger is fired.
FTK receives output from the ID as it is sent to HLT.
FTK passes its tracks along to HLT.
Time constraints

Offline track reconstruction for the full tracking volume requires about 10 s / event

To keep up with L1 rates, FTK must do tracking for the full event in ~.1 ms

Requires time reduction of ~5 orders of magnitude

How can we track so fast?
Making Tracking a Simpler Problem

Step 1: Only use silicon

Straight to HLT

Split signals go to HLT and FTK
Making Tracking a Simpler Problem

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SCT:
8 layers with 1 coordinate each

PIXEL:
4 layers with 2 coordinates each
Making Tracking a Simpler Problem

Step 2: Parallelize

Divide the detector into 64 overlapping towers

Send data from each tower to separate processing units
Making Tracking a Simpler Problem

Start with 8/12 silicon layers of ATLAS

Step 3: Pattern Match

Divide each layer into coarse chunks
Making Tracking a Simpler Problem

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Step 4: Fit a Subset

For matched patterns, retrieve all full resolution hits
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Perform a linearized fit on the hits in 8 layers

line: \( y = mx + b \)

each hit has a distance from the line: \( \Delta x, \Delta y \)

\( X^2 \) of fit: \( \chi^2 = \sum_{i}^{8} \sqrt{\Delta x_i^2 + \Delta y_i^2} \)
Making Tracking a Simpler Problem

Step 4: Fit a Subset

For matched patterns, retrieve all full resolution hits

Perform a linearized fit on the hits in 8 layers

Keep tracks passing a $\chi^2$ cut
Making Tracking a Simpler Problem

Step 4: Final Fit

Look for nearby hits in remaining 4 silicon layers

Refit in all 12 layers

Send tracks* passing a $\chi^2$ cut to HLT

*fit parameters also calculated linearly
FTK Boards

- IM: input from ID + hit clustering
- DF: organization of data into towers
- AMB: matching clusters to predefined patterns
- AUX: 8-layer track fitting
- SSB: 12-layer track fitting
- FLIC: data formatting for HLT

Diagram:
- Raw hits
- Clusters
- 8-layer tracks
- 12-layer tracks
FTK Status at the end of 2017

- Commissioning with vertical slices (dataflow through 1/64 towers)
- At the end of 2017, a vertical slice outputting 8-layer tracks was incorporated into ATLAS
  - validated 8-layer data output with FTK functional simulation

**Event Number**

**Matched Track Fraction**

**ATLAS Preliminary**
2017 Data, $\bar{s}=13$ TeV
Run 340453, $\langle \mu \rangle = 57$
6247 Events Processed

**Entries**

**Matched Track Fraction**

**ATLAS Preliminary**
2017 Data, $\bar{s}=13$ TeV
Run 340453, $\langle \mu \rangle = 57$
100 Events Processed
FTK Today

▷ The full system is nearly ready to be installed in the ATLAS detector
  ▷ 165/194 boards in FTK racks

▷ FTK vertical slices join in ATLAS runs and output 8- and 12-layer tracks

▷ The system works with ideal inputs
  ▷ Working on improving stability, handling real data-taking conditions in ATLAS
Going forward

- By the end of this year we aim to run stably with 50% coverage of the ATLAS detector
  - The remaining 50% will be commissioned during the long shutdown

- When LHC starts again (2021) FTK will provide the HLT full-scan tracking for all events
  - Essential for ATLAS to continue providing low-threshold triggers at high pileup

- Daily progress as we commission with beam!