A Self Seeded First Level Track Trigger for ATLAS

André Schöning
for the ATLAS collaboration

Institute of Physics, University Heidelberg
Motivation

• Today, no clear picture about full spectrum of physics analysis at Phase II (L=5\cdot10^{34} \text{ cm}^{-2}\text{ s}^{-1}, \text{ Year}>2022)

• Need to design a robust and flexible L1 Trigger system that can cope with the unexpected, i.e. with enough redundancy

• Many of the scenarios we can think of today involve objects at (or near) the electroweak scale

First studies show that track matching at L1 allow for \(~20\text{ GeV}\) object triggers (e, \mu, \tau)
Rate Reduction using Track Cluster Match

Using track-cluster matching in $E_T / p_T$, a rate reduction of up to a factor $\sim 10$ can be achieved.

ATLAS Monte Carlo
Challenges of L1 Track Trigger

Challenges

\(O(10^7)\) channels in strip detectors

\(O(10^8)\) channels in pixel detectors

\(O(5000)\) central tracks per collision at LHC phase II

\(O(10)\) Tbit/s data in tracker central region

Simplifications → Data Reduction

- only (selected layers of) strip detectors
- reduce data rate by:
  - regional filtering → Region of Interest Track Trigger
  - kinematical filtering → Self Seeded Track Trigger
two baseline concepts for L1 Track Trigger in ATLAS:

**“Region of Interest”**
- spatial cluster filter
- external trigger information (calo, muon, ...)
- new level L0 trigger required
- all tracks in regions

**“Self Seeded Track Trigger”**
- momentum filter of clusters
- cluster size + local coincidence
- special HW design required
- all high \( p_T \) tracks

Double Frontend Buffer → talk D.Wardrope
Utopia Geometry

- Pixel
- Short Strip Sensors
- Long Strip Sensors

eta=1.4

studies only for central region
ATLAS Utopia Strip Layer Design for Phase II

- Double strip layers
  - gap 7.35 mm
  - tilted by 10 (16) degrees
  - 80 μm pitch
  - stereo angle (standard)
  - no stereo angle for track trigger
Pixel + Strip Sensor Layers

Long Strips ($\Delta z=10\text{cm}$)
Short Strips ($\Delta z=2.5\text{cm}$)

Pixel (not used)

Layer combinations studied for track trigger:
- #0, #1, #2 (only short strips)
- #3, #4 (only long strips)
- #2, #3, #4 (mixed, outer layers)
Questions addressed

- Study of high $p_T$ local filter algorithms (Frontend)
  - cluster size filter algorithm
  - “offset method”
- Best number of silicon double layers for triggers (2,3,4,...)?
- Best layer combinations?
  - study combinations “012”, “34”, “234”
- Performance:
  - data reduction versus $p_T$-threshold
  - data reduction versus track finding efficiency
Cluster Size Filter

Due to the rectangular strip geometry several strips collect charge if low momentum tracks are bent in the magnetic field.

“cluster size method”

Complication: strip layers are tilted (10 degrees)
Results Cluster Method (layer #0)

- **muons**
- **anti-muons**

Keep clusters with 1 or 2 hits.

**Graphs:**
- **muons**
  - pT [MeV] percentage of hits by cluster size (1-8+ hits)
  - ATLAS Montecarlo

- **anti-muons**
  - pT [MeV] percentage of hits by cluster size (1-8+ hits)
  - ATLAS Montecarlo

- 1 hit
- 2 hits
- 3 hits
Coincidence “Offset” Method

“offset method”

Two steps:
- find coincidence
- measure distance (“offset”) between hits

- can be combined in a single step by defining acceptance windows

rejection of low momentum hit pairs
Muon Momentum Selectivity (layer #0)

Good momentum discrimination!

ATLAS Montecarlo

Rejected hits [%] vs. pT [GeV]

- Cluster size cut: > 2
- Cluster size cut: > 3

Offset method
Possible Hardware Realisation

The communicating between the two sides

Need to get from here to here

Fast Clustering Block → M.Newcomer
Simulation

- GEANT4: ATLAS modified Utopia layout
- Strip Sensors
  - tilt angle 10 degrees
  - no stereo angle
- Minimum Bias Events (PYTHIA) with 50, 100, 200, 400 events
- Signal tracks:
  - high $p_T$ muons implanted in Minimum Bias events
- $\chi^2$ fit simulates track trigger processor (varied $\chi^2$ cut)
  - trigger rate calculation
- Matching with truth information
  - efficiency calculation
  - purity calculation
most tracks (at low $p_T$) are rejected already with a low $p_T$ threshold
- rejection power higher if cluster size and offset cut are used
- rejection power affected by high pileup
e, $\mu$, $\pi^\pm$ Rejection (single particle)

hit reduction also above $p_T$ threshold due to secondary IA
Secondary Interactions

Source of (low momentum) background
Performance of Detector Filters

- pileup 100 minimum bias (Pythia)
- \( p_T > 10 \text{ GeV} \) (offset)

<table>
<thead>
<tr>
<th></th>
<th># hits (layer)</th>
<th># hits (SS 3 accept.)</th>
<th># hits (LS 2 accept.)</th>
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<tr>
<td>SS 1</td>
<td>6.4%</td>
<td>4.3%</td>
<td>2.8%</td>
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<tr>
<td>SS 2</td>
<td>5.5%</td>
<td>4.7%</td>
<td>2.9%</td>
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<tr>
<td>SS 3</td>
<td>5.1%</td>
<td>5.1%</td>
<td>3.4%</td>
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<tr>
<td>LS 1</td>
<td>8.0%</td>
<td>8.0%</td>
<td>6.2%</td>
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<tr>
<td>LS 2</td>
<td>6.5%</td>
<td>6.5%</td>
<td>6.5%</td>
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</table>

Reduction factors of: 15-30 on short strip layers
~15 on long strip layers
Performance of Detector Filters

- pileup 100 minimum bias (Pythia)
- $p_T > 10$ GeV (offset)

**cluster+offset cut**

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<th># hits (LS 2 accept.)</th>
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</thead>
<tbody>
<tr>
<td>SS 1:</td>
<td>4.0%</td>
<td>3.7%</td>
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<tr>
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<td>2.9%</td>
<td>1.8%</td>
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<tr>
<td>SS 3:</td>
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<td>LS 1:</td>
<td>4.5%</td>
<td>4.5%</td>
<td>3.5%</td>
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<tr>
<td>LS 2:</td>
<td>4.0%</td>
<td>4.0%</td>
<td>4.0%</td>
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</tbody>
</table>

Reduction factors of: 25-50 on short strip layers
~25 on long strip layers
Simulation of Full Track Trigger

- Local hit filtering (cluster size + offset method)
- Link hits in all used layers (no redundancy)

Chi$^2$ fit in 3D

Hardware Implementation:

fast lookups using next generation of associative memory chips (→3D)
Track Efficiency vs Track Rate

- Cluster size
- Offset cut $p_T > 10$ GeV
- 3 double layers give sufficient low rate

Chi$^2$ cut varied

ATLAS Monte Carlo

Pileup: 100 Layers: 012
Pileup: 100 Layers: 234
Pileup: 100 Layers: 34
Pileup: 200 Layers: 012
Pileup: 200 Layers: 234
Pileup: 200 Layers: 34
Track Efficiency vs Purity

Cluster size + offset cut $p_T>10$ GeV

$\chi^2$ cut varied

3 double layers good purity

ATLAS Monte Carlo

Efficiency vs Purity

Pileup 100
Pileup 200

Chi$^2$ cut varied

Pileup 100 Layers: 012
Pileup 100 Layers: 234
Pileup 100 Layers: 34
Pileup 200 Layers: 012
Pileup 200 Layers: 234
Pileup 200 Layers: 34
No Pileup Layers: 012
No Pileup Layers: 234
No Pileup Layers: 34
Track Efficiency vs Purity

only offset cut \( p_T > 10 \text{ GeV} \) higher efficiency w/o cluster size cut

Chi\(^2\) cut varied

ATLAS Monte Carlo

Efficiency vs Purity graph with different pileup conditions and Chi\(^2\) cuts.
Parameter Studies

Choose chi\(^2\) cut which maximises product: \(\text{efficiency}^2 \times \text{purity}\)

<table>
<thead>
<tr>
<th>(p_T) threshold</th>
<th>layer set</th>
<th>efficiency</th>
<th>purity</th>
<th>rate</th>
<th>(\chi^2)-cut</th>
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<td>0.097</td>
<td>10.0</td>
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<tr>
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<td>6.0</td>
</tr>
</tbody>
</table>

For \(p_T\) threshold of 15 GeV rates of “only” 0.1 tracks/event
Analysis of Efficiency Losses

Set #012 (short strips)

- single hit efficiency ~98% in six layers → ~12% loss
- cluster size cut ~1% per layer → ~6% loss
- inefficiency of offset method ~0.4% → ~1.2% loss
- inefficiency track fit → >1% loss

filtering algorithms affected by high pileup by up to 5%

Higher efficiency >95% possible by adding more redundancy:
- e.g. requiring 2x3 hits out of four double layers

→ more studies required
Summary

- Design of a Self-Seeded First Level Track Trigger studies
- Local filtering algorithms: cluster size and coincidence
- At least 3 double layers for reasonable purity and trigger rate
- Design with more redundancy (4 double layers) would improve track efficiency
- Self Seeded Track Trigger at ATLAS possible with “minor” design changes of the Utopia design (no stereo angle, frontend electronics)