Real-time Analysis with the ALICE High Level Trigger

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for the ALICE collaboration

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CERN/LHCC 2003-062

http://www.ikf.physik.uni-frankfurt.de/~loizides/
ALICE = A Large Ion Collider Experiment

Large Hadron Collider at CERN starting operation 2007

Heavy Ion Reaction to Study New State of Matter

UrQMD model,
M. Bleicher et al.
(1999) 1859-1896
Jets in PbPb

Pythia,
dN/dy=2000
LHC Parameters for PbPb (and pp)

- Energy $\sqrt{s} = 1150$ TeV = 0.18 mJ (14 TeV) macroscopic energy deposited in a microscopic volume
- Bunch spacing 100ns (125ns)
- Luminosity of roughly $10^{27}$ cm$^{-2}$s$^{-1}$ ($10^{30}$-$10^{34}$ cm$^{-2}$s$^{-1}$)
- Expectation for produced particles within ALICE: ∼ $10^4$ (∼$10^2$)

ALICE resulting data rate (TPC only)

- Event rates
  - Central Pb-Pb < 200 Hz (past/future protected)
  - Min. bias pp < 1000 Hz (roughly 25-100 piles)

- Event sizes (after zero suppression)
  - for PbPb ∼ 75 Mbyte
  - for pp ∼ 0.5 Mbyte

- Data rates
  - for PbPb < ∼ 15 Gbyte/sec
  - for pp < ∼ 2.5 Gbyte/sec (25 piles)

TPC is the largest data source with ∼ 600000 channels, 512 timebins and 10 bit ADC value.
TPC data rate by far exceeds the foreseen total DAQ bandwidth of ∼ 1-2 Gbyte/sec.

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Reducing the Data Rate: the HLT System

Without HLT
\(~10^7\) PbPb events
\(~10^9\) pp events

With HLT
\(~20 \times 10^7\) PbPb events
\(~10 \times 10^9\) pp events

Can be processed per Ay (using the TPC).

Low XSection Signals
- \(10^{10}\) pp events lead to
  \(~10^5\) 100 GeV jets
  \(~10^3\) Ypsilon
  \(~10^5\) Omegas
- \(2 \times 10^8\) PbPb events lead to
  \(~10^4\) >100 GeV jets
  \(~2 \times 10^4\) Ypsilon

**Trigger** events based on detailed online analysis of its physics content.
**Select** relevant parts of the event, or regions of interest, including the entire event.
**Compress** those parts of the event which are being selected for readout reducing taping rate and associated costs without any loss to the containing physics.

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Logical View of the ALICE Event Flow

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Connectivity of the HLT System

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Components of the HLT System

- Commercial off-the-shelf PCs
  ~300 PCs equipped with FPGA-Coprocessor cards (RORC)
  ~300-500 Compute Nodes

- Light-Weight Communication
  NIC (GE, Infini-Band, SCI, Myrinet,...)
  Protocol Stack (TCP, STP,...)

- Publisher-Subscriber Interface

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Online Pattern Recognition Schemes (TPC)

HLT Task:
Reconstruct ~10000 tracks produced by the charged particles traversing the TPC within ~5 ms.

• **Sequential** feature extraction:
  Cluster Finder and Track Follower on space points (conventional approach)

• **Iterative** feature extraction:
  Tracklet finder on raw data (Hough Transform) and cluster evaluation (Deconvoluter, Refitter)

Due to the solenoidal magnetic field inside the TPC, the tracks follow helical trajectories.

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Low Multiplicity Tracker: Cluster Finder and Track Follower

Step 1: Cluster Centroid Finding

Each padrow can be processed independently, clusters are calculated as the weighted mean of the ADC values in time and pad direction.

Step 2: Conformal Mapping

Convert all space points with
\[
\begin{align*}
x_v &= \frac{(x-x_p)}{r} \\
y_v &= \frac{(y-y_p)}{r} \\
r &= (x-x_v)^2 + (y-y_v)^2
\end{align*}
\]

So that bended tracks become straight lines. (requires knowledge of vertex or first point of the track)

Step 3: Track Follower

- **Segments:**
  Starting at the outermost padrow track segments are formed by connecting nearby hits.

- **Tracks:**
  When segments are long enough, they will be fitted. Only new hits will added which (within certain cuts) are closest to the fit.

Reconstruct the positions of space points, which are then interpreted as the crossing points between tracks and the center of padrows. Around 100 such space points assigned to one helix form a found track.

P. Yepes, A Fast Track Pattern Recognition, NIM A380 (1996) 582

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Low Multiplicity Tracker: Efficiency and Timing

**Efficiency:**
The ratio of *good* found tracks versus *findable* monte carlo tracks.

\[
P_t \text{ resolution } 1-5\%
\]
\[
\text{Fakes } < 1 \%
\]

---

**Timing Setup**

**Timing Results**

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Cluster Finder FPGA implementation:

- **FPGA Cluster Finder**: Synthesized on Altera APEX 20K-1x, uses 1860 LE (11%) + 8448 Bits (4%), Clock speed: 50 Mhz

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Pileup Removal for pp (at high lumi)

Assumption: Vertex of the triggered event is known to a few centimeter!

Track complete event and apply cut on vertex position!
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<table>
<thead>
<tr>
<th>Efficiency</th>
<th>Fakes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good tracks for 25 piles, min. 5 trigger tracks</td>
<td>Fake tracks (relative to good triggered tracks)</td>
</tr>
<tr>
<td>0.995</td>
<td>1</td>
</tr>
<tr>
<td>0.99</td>
<td>6</td>
</tr>
<tr>
<td>0.985</td>
<td></td>
</tr>
<tr>
<td>0.98</td>
<td></td>
</tr>
<tr>
<td>0.975</td>
<td></td>
</tr>
</tbody>
</table>

Lambda

Cut around 40 cm:
- all primaries,
- 3/25 compression,
- loose 40% lambdas
Simulated pp events with 25 piles (~400 particles in TPC per Event) achieved 430 Events/sec.
Track Candidate Finding before Cluster Finding:

- Provide track seeds for cluster fitting
  - Hough Transform
- Fit & unfold clusters based on track parameters
  - 2D gaussfit of clusters
- Perform final track fits

The Hough Transform (HT) is a widely adopted technique in pattern recognition. The global detection of certain geometrical properties in image space is converted into a local peak detection in a suitable parameter space.

Every charge value votes for all tracks it possibly belongs to. The intersection of these curves (peaks) define the track candidates (segments), which in turn are used to deconvolute overlapping clusters.

Cluster shape depends on no.of tracks contributing to it, track crossing angle with the padrow plane and drift length. Once the track parameters are roughly known we can fit the clusters to the given shape and unfolding becomes straight forward.
HighMultiplicityTracker: Circle HT

- Divide raw data into small slices in eta.
- Search all primary track candidates by applying a Circle Hough Transform to every digit.
- Find the peaks with a simple Peak Finder.
- Merge track candidates crossing slices.

**HT on Raw Data**

\[
R = \sqrt{x^2 + \rho^2} \\
\phi = \arctan \left( \frac{y}{x} \right) \\
\kappa = \frac{2}{R} \arcsin (\phi - \phi_0) .
\]

Detect all possible primary vertex tracks

Peaks = Track Candidates

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Efficiency is high (>90%), but that's only after evaluating the raw data with a painful slow method.

Problem: Relative no. of fake tracks is high: ~100-200%

VHDL simulation is working, but not synthesizable yet.
Cluster fitting utilities were adapted from NA49:
- Clusters are fitted to a 2D gauss function with 5 parameters
  - pad, time, charge, widths in pad & time
- Widths in pad and time are provided from track parameters:
  \[
  \begin{align*}
  \sigma_T^2 &= \sigma_{\text{RF}}^2 + D_T^2 s_{\text{drift}} + \frac{l^2 \tan^2(\beta)}{12} + \frac{d^2 (\tan(\alpha) - \tan(\psi))^2}{12} \\
  \sigma_L^2 &= \sigma_0^2 + D_L^2 s_{\text{drift}} + \frac{l^2 \tan^2(\lambda)}{12}
  \end{align*}
  \]

In order to check the performance of the cluster fitting algorithm, offline track parameters were used as input:

Before cluster fitting | After cluster fitting
--- | ---
Relative Pt res. | 1.17% | 1.07%
Phi res. | 2.19% | 1.90%
Theta res. | 1.28% | 1.25%
dN/dy=8000, Bfield = 0.4T

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Different Hough schemes are being evaluated
- Conventional tracker as seeds in outer padrows
- Local versus global transform
- Error propagation into parameter space
Data Compression using Modeling Techniques

- Store quantized cluster centroid deviation from track model
- Cluster widths are parametrized according to track parameters
- Remaining clusters (not assigned to any track) may be stored in addition to the compressed data

<table>
<thead>
<tr>
<th>Track parameters</th>
<th>Size (byte)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curvature</td>
<td>4 (float)</td>
</tr>
<tr>
<td>Begin X,Y,Z</td>
<td>4 (float)</td>
</tr>
<tr>
<td>Dip angle</td>
<td>4 (float)</td>
</tr>
<tr>
<td>Azimuthal angle</td>
<td>4 (float)</td>
</tr>
<tr>
<td>Track length</td>
<td>2 (int)</td>
</tr>
<tr>
<td>No. of clusters</td>
<td>1 (int)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cluster parameters</th>
<th>Size (bit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cluster present</td>
<td>1</td>
</tr>
<tr>
<td>Pad residual</td>
<td>10</td>
</tr>
<tr>
<td>Time residual</td>
<td>10</td>
</tr>
<tr>
<td>Cluster charge</td>
<td>13</td>
</tr>
</tbody>
</table>

Spatial resolution:
- Pad: 0.5 mm
- Time: 0.8 mm
Compression ratio critically depend on the remaining clusters:
- Mainly comes from low Pt tracks (< 100 MeV/c), delta-electrons
Data Compression Results

Zero suppressed 8 bit RLE ADC data: 100%
Compressed data relative size: ~14% (12%)
Remaining clusters relative size (no coding): ~41% (28%)

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Summary

• The HLT system consists of 500 to 1000 Pcs partially equipped with FPGA-Coprocessor cards connected in a “light-weight” network.

• Physics topics include rare X-signals as jets etc. or pileup removal.

• The Low Multiplicity Tracker (conventionell tracking scheme) is fully implemented. The timing benchmark for pp (pileup) is very satisfactory.

• The FPGA Cluster Finder is synthesized and currently being tested on the RORC hardware.

• The High Multiplicity Tracker shows reasonable results, but needs further investigation and research effort in order to be really useful.

• The Cluster Deconvoluter works when the number of fake tracks is low. Needs further evaluation with different kinds of track candidates.

• Using modeling techniques for compression we might achieve a factor of ~10 in compression with acceptable efficiency loss.
Natural Readout of Detectors: B1

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Cluster Finder Algorithm: Details

Input: List of sequences on each pad

Sequence matching at neighboring pads

Only 2 pads in memory: Current and previous

- Loop over each pad only once
- Sequences of each cluster are not stored internally

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Low Multiplicity Tracker: Efficiency and Resolution (detailed)
Cluster Finder FPGA implementation: B4

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