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David Miller

For the ATLAS Collaboration
BASIC PROBLEM 1/2

- ATLAS trigger algorithms use the beam spot to maintain higher efficiency of interesting events
  - Beam spot: location and size of luminous region
  - Precise measurement of beam phase space at interaction point (IP)
  - Used for tracking algorithms and displaced vertices
  - Measure via distribution of charged particle vertices found from hits on ATLAS silicon detectors

We provide with errors:
- Ellipsoid Mean (xyz)
- Ellipsoid Width (xyz)
- Ellipsoid Tilt (xz, yz)
BASIC PROBLEM 2/2

- But, luminous region changes during a fill

- The High Level Trigger needs feedback!
  - “Software” trigger working on Linux server farm
Algorithmic:
• Vertex resolution ~25 μm, but beam spot < 20 μm
• Operate on the trigger farm: limited bandwidth and CPU
• Only one chance to use event
• One event has many vertices!

Commissioning:
• Not in the original design
• Like changing the engine in a moving car
• Takes stable beams to test full system and feedback

Communication:
• Calculating beam spot needs > 100,000 vertices for 1300 bunches
• 13,000 processes need to know beam spot
• Cannot read out entire detector at the hardware trigger rate
• Shouldn’t disrupt data taking
PILE UP VERTICES

- At current luminosities there are **15-20 vertices** per bunch crossing!
  - “Pile-up”
- Many vertices to fit! However...
- Computationally extremely expensive to reconstruct in real time
**GENERAL SOLUTIONS**

**Algorithmic:**
- High rate/quality of vertices
- Specialized resolution determination via “split vertex”
- Use pile up vertices as well
- Share bandwidth/CPU with other tracking intensive algorithms

**Commissioning:**
- Emulate online system for test and development
- LHC down time → test changes
- Special data taking calibration stream

**Communication:**
- Parallelize Parallelize Parallelize!
- **Fan In/Out** calculations’ input and output to central locations
- Piggy back on **event data**

Focus of this talk
**SOLUTION OVERVIEW**

LumiBlock: n. 60 second period of time with similar conditions in ATLAS DAQ. Often written LB

**Fan Out**

**Beam spot**

**Trigger Farm**

**Fan In**

**Monitoring**

\[
\begin{align*}
\langle x \rangle &= -26 \pm 0.049 \mu m \\
\langle y \rangle &= 1099 \pm 0.048 \mu m \\
\langle z \rangle &= -6066 \pm 65 \mu m \\
\langle \sigma_x \rangle &= 22 \pm 0.10 \mu m \\
\langle \sigma_y \rangle &= 20 \pm 0.10 \mu m \\
\langle \sigma_z \rangle &= 59,800 \pm 80 \mu m
\end{align*}
\]

**Did the beam spot change?**

Yes / No

**Flow**

- Event Data
- Monitoring
- Control
- Conditions
- Requests

**Blocks**

- Hardware
- Software

**LHC**
**High Level Trigger**

Use infrastructure of the High Level Trigger
- Runs on commercial H/W & Linux
- Reconstructs physics objects (jets, e-, ...)
- Executes trigger decisions
- Histograms monitoring quantities!
- Each processor takes \( \sim 50 \text{ ms} / \text{event} \)

- For each event the beam spot algorithm
  - Calculates vertices locations
  - Produces resolution primitives
  - Adds these to local histograms
**High Level Trigger**

Use infrastructure of the High Level Trigger
- Runs on commercial H/W & Linux
- Reconstructs physics objects (jets, e-, ...)
- Executes trigger decisions
- Histograms monitoring quantities!
- Each processor takes ~50 ms / event

- For each event the beam spot algorithm
  - Calculates vertices locations
  - Produces resolution primitives
  - Adds these to local histograms

**Gatherer**

Processes needs to cooperate!
- Need $O(10^5)$ vertices for a beam spot
- Each event/processor are independent
- Merge those histograms across farm

Over 6,000 processors: how to merge?
- Aggregate at rack and farm level
- Rack: merge ~240 processors
- Top: merge ~30 racks

**Online Monitoring**

Vertex histograms

**Flow**

- Event Data
- Monitoring
- Control
- Conditions
- Requests

**Blocks**

- Hardware
- Software

**Pixel Hits**

- Fragments
- Pixel Read-Out System

**Central Trigger Processor**

**Data Fragment**

**ATLAS**

1. Next event please
2. Hits on Silicon Detector

1. L1 Trigger Info
2. Time

**LB = 1**

**LB = 2**

**LB = 3**

**LB = 4**
Calculation

Histograms → Beam spot
- Input data now centralized
- Calculate beam spot from histograms
- Fit gaussians, calculate resolutions, ...
- Write values to file and send to LHC
- Is there a significant difference between current and nominal values?

Online Monitoring

Vertex histograms

Total Execution: 15 seconds

- Historical Archive
- Vertex plots
- Calc beam spot

Wakes up every minute

Flow
- Event Data
- Monitoring
- Control
- Conditions
- Requests

Blocks
- Hardware
- Software
**Calculation**

- Histograms → Beam spot
  - Input data now centralized
  - Calculate beam spot from histograms
  - Fit gaussians, calculate resolutions, ...
  - Write values to file and send to LHC
  - Is there a significant difference between current and nominal values?

**Feedback**

- 13,000 processes need new beam spot
  - They don't know their out-of-date yet!
  - Put new values in conditions DB
  - Invalidate old beam spot via event flow
  - This ensures reproducibility
  - Each process uses same values

Processes will fetch new beam spot from conditions database

**Online Monitoring**

- **Vertex histograms**
  - Historical Archive
  - 2. Vertex plots
  - 3. Calc beam spot
  - 4. Publish new beam spot
  - 5. Update HLT beam spot!
  - 6. New Beam spot
  - 7. Store new beam spot
  - 8. Your beam spot is out of date

---

**Flow**

- Event Data
- Monitoring
- Control
- Conditions
- Requests

**Blocks**

- Hardware
- Software

---

**ATLAS**

10/14/11
ICALEPCS2011
FEEDBACK CRITERIA

- Compare two sets of beam spot parameters
  - \textit{Current}: from histograms just out of \textbf{trigger farm}
  - \textit{Nominal}: from the last update--stored in conditions DB and used by the trigger farm for tracking algorithms

- Decide to update (feedback) if:
  1. Position offset > 10\% width
  2. Width offset > 10\% of itself
  3. Error on any measurement decreases by 50\%
  4. Nominal is invalid (and current is valid)

- Criteria are completely configurable!
  - Meet the needs of clients but easy to do better

We invalidate after beam dump
**Conditions Database**

*Beam spot parameters*

Once an update is triggered, there will be 13,000 identical queries on the DB within ~100 ms!

**Oracle Conditions Database**

**IOV DB Service**

Holds a local cache of the conditions data
- Can be told to drop / refresh data
- Uses CORAL layer to communicate with
  - Proxy, or directly to CORAL server
  - Both route to conditions DB on Oracle

Conditions DB Entries associate with
"Interval Of Validity"
- Query: "What's the beam spot at LB 5?"
- Writing an entry closes the previous Interval Of Validity

**Flow**
- Event Data
- Monitoring
- Control
- Conditions
- Requests

**Blocks**
- Hardware
- Software

**Your beam spot is out of date**

**Command Handler**

**Central Trigger Processor**

**b-jet Trigger**

**Trigger Processor**

**Data Fragment**
**Conditions Database**

*Beam spot parameters*

- Top Proxy
- CORAL ↔ Oracle
- Oracle Conditions Database
- Proxy
- Farm's Beam spot

**IOV DB Service**

Holds a local cache of the conditions data
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*Conditions DB Entries associate with “Interval Of Validity”*
- Query: “What's the beam spot at LB 5?”
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**CORAL Proxies**

Nodes ask same question at same time
- Just like gathering, use a multiplex tree
- Each proxy looks like a server & client
- Whole tree capable of answering 10000's of identical request in ~10 ms

CORAL is a open server/client API
- High performance routing and caching
- Decouples HLT from DB engine
RESULTS: FEEDBACK 1/2

- Latency ~ 240 seconds: Analyzing event → feedback
  - 140 seconds: Gathering at fixed intervals
  - 60 seconds: Waiting for update at LB increase
  - 15 seconds: Fitting Gaussians, calculating beam spot
  - Could force updates but 5 minutes fast compared to beam

- Frequency of actual feedback. N.B. *not* periodic!
  - At **start of run** need to **bootstrap** (start from scratch)
    - Prevents large tracking errors in case beam moved significantly
    - Errors on the values drop rapidly as statistics grow
    - First update 5 minutes after data taking starts (*invalid before this*)
    - ~4 updates in first 25 minutes of data taking
  - During the fill, **beam changes slowly**
    - Emittance blow up, IP orbit variations …
    - ~1 update every few hours after bootstrap phase
RESULTS FEEDBACK: 2/2

- Process pause: ~10 ms to fetch new beam spot
  - Proxy tree & event time stagger → most don’t wait
  - No deadtime! No DAQ busy!
- Difference between current and nominal

![Graph showing luminous centroid and distance from nominal over time]

- Luminous Centroid Y Position [mm]
- Luminous Centroid Y Distance from Nominal [mm]

40 μm

10/14/11

ICALEPCS2011
# LHC Configuration Page

**04-Oct-2011 21:14:23**  
**Fill #: 2182**  
**Energy: 3500 GeV**  
**l(B1): 1.76e+14**  
**l(B2): 1.77e+14**

<table>
<thead>
<tr>
<th>Accelerator Mode:</th>
<th>PROTON PHYSICS</th>
<th>Beam Mode:</th>
<th>STABLE BEAMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active Filling Scheme:</td>
<td>50ns_1380b+1small_1318_39_1296_144bpi</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Active Hypercycle:</td>
<td>3.5TeV_10Aps_1m</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>ATLAS</th>
<th>ALICE</th>
<th>CMS</th>
<th>LHCb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beta*</td>
<td>1.00 m</td>
<td>10.00 m</td>
<td>1.00 m</td>
<td>3.00 m</td>
</tr>
<tr>
<td>Crossing Angle (urad)</td>
<td>−120(V)</td>
<td>−80(V)</td>
<td>120(H)</td>
<td>−250(H)</td>
</tr>
<tr>
<td>Spectrometer Angle (urad)</td>
<td>no_value(V)</td>
<td>no_value(V)</td>
<td>no_value(H)</td>
<td></td>
</tr>
<tr>
<td>Beam Separation (mm)</td>
<td>0(H)</td>
<td>.3(H)</td>
<td>−.5(V)</td>
<td>−.08(V)</td>
</tr>
<tr>
<td>Expected Collisions per turn</td>
<td>1318</td>
<td>39</td>
<td>1318</td>
<td>1296</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>BPTX: deltaT of IP (B1–B2)</td>
<td>−0.03 ns</td>
<td>−0.07 ns</td>
<td>−0.06 ns</td>
<td>−0.11 ns</td>
</tr>
<tr>
<td>Luminous size (x,y) in um</td>
<td>19.6,20.7</td>
<td>−999.0,−999.0</td>
<td>19.1,13.8</td>
<td>44.2,45.1</td>
</tr>
<tr>
<td>Luminous size (z) in mm</td>
<td>55.0</td>
<td>−999.0</td>
<td>44.5</td>
<td>52.6</td>
</tr>
<tr>
<td>Lumi Centroid (x,y) in um</td>
<td>−49.1,1056.8</td>
<td>−999.0,−999.0</td>
<td>156.4,−674.2</td>
<td>465.5,−14.1</td>
</tr>
<tr>
<td>Lumi Centroid (z) in mm</td>
<td>−7.3</td>
<td>−999.0</td>
<td>7.9</td>
<td>6.6</td>
</tr>
<tr>
<td>Luminous Tilt in urads</td>
<td>−6.11,−60.37</td>
<td>−999.00,−999.00</td>
<td>105.43,205.42</td>
<td>−63.43,32.75</td>
</tr>
</tbody>
</table>
RESULTS: PHYSICS 1/2

- ATLAS b-jet triggers (dependent on beam spot)
  - High up time, fast bootstrap at beginning of fill
- Provided a plethora of data for beam studies
  - Follow position with sub micron statistical uncertainty

![Graph showing Luminous Centroid X Position and Width over time](image)
RESULTS: PHYSICS 2/2

- Measure position and width of each bunch (>1300)
- Needs high rate and devoted resolution calculation
- See unambiguous effects of beam-beam kicks on orbit
CONCLUSION

- Built a system to measure the beam spot
  - On the HLT in **near real** time with large rate
  - Measure position with $< 1 \mu m$ statistical uncertainty
- Feedback the answer to 13,000 processes
  - Sharp change across the LumiBlock boundary
  - So fast to update with **proxies, with no DAQ busy!**
  - Tracks beam parameter drifts within $2 \mu m$
- Provide new data for LHC development
  - Extremely **accurate per bunch** measurements
  - Trending during runs, after long stops, etc ...
BACK UPS

- Many distributions of LHC beam parameters
VERTEX DISTRIBUTIONS

ATLAS Operations
May 29 2011
LHC Fill: 1815
$\sqrt{s} = 7$ TeV
Online Primary Vertex

Gaussian Fit:
Mean = -0.046 ± < 0.001 mm
Raw Width = 0.049 ± < 0.001 mm

Number of Vertices

Vertex x [mm]

$\times 10^3$

$\times 10^3$

ATLAS Operations
May 29 2011
LHC Fill: 1815
$\sqrt{s} = 7$ TeV
Online Primary Vertex

Gaussian Fit:
Mean = 1.082 ± < 0.001 mm
Raw Width = 0.048 ± < 0.001 mm

Number of Vertices

Vertex y [mm]

ATLAS Operations
May 29 2011
LHC Fill: 1815
$\sqrt{s} = 7$ TeV
Online Primary Vertex

Gaussian Fit:
Mean = -4.594 ± 0.721 mm
Raw Width = 62.007 ± 2.138 mm

Number of Vertices

Vertex z [mm]
TILTS

**ATLAS Operations**
May 29 2011
LHC Fill: 1815
\( \sqrt{s} = 7 \text{ TeV} \)

**Linear Fit:**
Slope = -47.93 ± 0.34 μrad

**Vertex y [mm]**

-1.090 to 1.088

**Vertex z [mm]**

-80 to 80

---

**ATLAS Operations**
May 29 2011
LHC Fill: 1815
\( \sqrt{s} = 7 \text{ TeV} \)

**Linear Fit:**
Slope = -7.65 ± 0.34 μrad

**Vertex x [mm]**

-0.040 to -0.042

**Vertex z [mm]**

-80 to 80
D0 VS $\Phi$

**ATLAS Operations**
May 29 2011
LHC Fill: 1815
$\sqrt{s} = 7$ TeV

**Sinusoid Fit:**
$x = -0.045 \pm <0.001$ mm

$y = 1.082 \pm <0.001$ mm
SPLIT VERTEX RESOLUTION VS NUMBER OF TRACKS

ATLAS Operations
May 29 2011
LHC Fill: 1815
\( \sqrt{s} = 7 \text{ TeV} \)

\( \Delta x \) Between Half Vertices [mm]

Average Number of Tracks per Half Vertex

\( \Delta y \) Between Half Vertices [mm]

Average Number of Tracks per Half Vertex

\( \Delta z \) Between Half Vertices [mm]

Average Number of Tracks per Half Vertex

ATLAS Operations
May 29 2011
LHC Fill: 1815
\( \sqrt{s} = 7 \text{ TeV} \)
RESOLUTION VS NUMBER OF TRACKS

ATLAS Preliminary
May 29, 2011
LHC Fill: 1815
$\sqrt{s} = 7$ TeV
$\int L dt = 38 \text{ pb}^{-1}$

- Beamspot Width, No Resolution Correction
- Beamspot Resolution
- Beamspot Width, Corrected for Resolution

Number of Tracks per Reconstructed Vertex
PER BUNCH POSITIONS

ATLAS Operations
May 29 2011 $\sqrt{s} = 7$ TeV
LHC Fill: 1815 Online Primary Vertex

ATLAS Operations
May 29 2011 $\sqrt{s} = 7$ TeV
LHC Fill: 1815 Online Primary Vertex

ATLAS Operations
May 29 2011 $\sqrt{s} = 7$ TeV
LHC Fill: 1815 Online Primary Vertex
PER BUNCH WIDTHS

ATLAS Operations

May 29 2011 \(\sqrt{s} = 7\) TeV
LHC Fill: 1815 Online Primary Vertex

Luminous x Width [mm]

Bunch Crossing Identifier

Luminous y Width [mm]

Bunch Crossing Identifier

Luminous z Width [mm]

Bunch Crossing Identifier
WHAT’S THE PROBLEM?

- ATLAS produces crap-tons of data!
- Wait, why?
  - Collisions are usually pretty “boring”
  - Inelastic scattering
  - Dijet production
  - W/Z/γ
  - ...
- Yesterday’s signal is today’s background and tomorrow’s noise
WHY SO MUCH DATA?

- Only rarely does something “interesting” happen

Diagram:
- Extra Large Dim.’s
- Higgs
- Super Symmetry
- Not imagined
- SMP

Legend:
- p
- BOOM
CONTEXT

- ATLAS one of several large detectors at LHC
- LHC delivers ~15 Million bunch crossing/second
  - Most collisions are “boring” and can be thrown out
  - Rare few could be a Higgs, black hole, SUSY etc.
- Recording all the data would be 20 TB/second!
  - Need to trigger data acquisition on interesting events