The ATLAS Pixel Detector Calibration Procedure

Nicoletta Garelli

INFN & University Genoa

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**MOTIVATION**: Find Higgs Boson and New Physics Beyond the Standard Model

LHC is being built in a circular tunnel 27 km in circumference, 50-175 m underground.

<table>
<thead>
<tr>
<th>Machine</th>
<th>Beams</th>
<th>Energy</th>
<th>Luminosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>LHC</td>
<td>p p</td>
<td>14 TeV</td>
<td>$10^{34} \text{ cm}^{-2}\text{s}^{-1}$</td>
</tr>
<tr>
<td>LHC</td>
<td>Pb Pb</td>
<td>5.5 TeV</td>
<td>$10^{27} \text{ cm}^{-2}\text{s}^{-1}$</td>
</tr>
<tr>
<td>Tevatron</td>
<td>p anti-p</td>
<td>2.0 TeV</td>
<td>$10^{32} \text{ cm}^{-2}\text{s}^{-1}$</td>
</tr>
<tr>
<td>LEP</td>
<td>$e^+ e^-$</td>
<td>200 GeV</td>
<td>$10^{32} \text{ cm}^{-2}\text{s}^{-1}$</td>
</tr>
</tbody>
</table>

- Beams inside continuous vacuum guided by *superconducting magnets*.
- **Bunch cross every 25 ns** ☢️ 600 million collisions per second
SM Higgs Boson

LEP direct search: $m_H > 114.4 \text{ GeV/c}^2$ @95%CL

LEP Electroweak Fit Limit: $m_H < 144 \text{ GeV/c}^2$ @95%CL
Higgs Mass Range – Detector Requirements

114.5 < $M_H < 130$ GeV
Golden channel: $H \rightarrow \gamma \gamma$
But small decay rate!
QCD background.

130 < $M_H < 800$ GeV
Golden channel: $H \rightarrow ZZ/ZZ^* \rightarrow 4l$
Huge Background

800 < $M_H < 1000$ GeV
$H \rightarrow WW \rightarrow l\nu jj$
$E_T$ missing

- **Powerful inner tracking systems** in magnetic field with high granularity and secondary vertex reconstruction capability. Crucial for background rejection.

- **High granularity hadronic calorimeter with full coverage** for good missing $E_T$ resolution, jet trigger and reconstruction.

- **Electromagnetic calorimeter** with good energy and spatial resolution, capability to separate $\gamma/\pi^0$.

- **Efficient muon spectrometer** for identification, trigger, and momentum measurement of high energetic muons.

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ATLAS
A Thoroidal LHC ApparatuS

Cylindrical ‘Onion-like’ Detector
The ATLAS Inner Detector

**Technique:** high granularity + low occupancy + 2D track measurement

**Geometry:** 3 Barrel layers ($r = 5, 9, 12$ cm) + 2 End-Caps with 3 Disks each

3 space points for $\eta < 2.5$ with resolution $16 \mu m - 115 \mu m$
The Pixel Detector

High multiplicity tracking detector:
\(~ 1200 \text{ tracks per bunch crossing } \Rightarrow \text{ high granularity (80 million channels!)}\)

High impact parameter resolution:
\(~ 12 \, \mu m \text{ vertex resolution – secondary vertex reconstruction} \)

Low interaction length:
\(~ 10\% \, \chi_0 \)

High time resolution:
40 MHz bunch crossing rate

High radiation dose tolerance:
\(~ 50 \, \text{Mrad} \)
The Readout System

1 Module = ~50k pixels
Detector = 1744 Modules

Signal: discriminator decision on amplified charge deposition within the pixels.

Optimize detector response ➔ calibrate readout electronics, tune on-line and store results.
Module Tuning

Motivation: Mean energy loss in pixels changes in time due to irradiation

Calibration source: Directly inject charge (VCal) - No sensor involved (except dedicated scans)

Calibration procedures: Many! Vary VCal and determine distribution for
- discriminator threshold
- noise (slope of signal rise)
- Time-Over-Threshold (ToT) indirect charge deposit measurement
- ...

for all pixels in modules

Scan histo chip 6 col 6 row 84

Threshold

Noise

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Optical Communication Tuning

Tune link between on-detector Optoboards and off-detector Back-Of-Crate cards:
1. Laser Power for the Optoboard (ViSet)
2. Threshold at the BOC
3. Delays at the BOC

Find optimal values for individual module by varying the three parameters
## Calibration Procedures

<table>
<thead>
<tr>
<th>Scan type</th>
<th>LHC condition</th>
<th>How often?</th>
<th>How long?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Threshold Scan</td>
<td>Stable beam</td>
<td>Every Fill(^{(1)})</td>
<td>30 min</td>
</tr>
<tr>
<td>ToT Scan</td>
<td>Stable beam</td>
<td>Every Fill</td>
<td>30 min</td>
</tr>
<tr>
<td>Optical Tuning</td>
<td>-</td>
<td>Weekly</td>
<td>1 h</td>
</tr>
<tr>
<td>Threshold Tuning</td>
<td>A “Threshold Scan” at each discriminator threshold value</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ToT Tuning</td>
<td>A “ToT Scan” at each amplifier feedback current value</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leakage current</td>
<td>Study of the sensor radiation damage</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^{(1)}\): Fill = LHC beam injection. A fill lasts ~10h

### Huge amount of histograms

- **On-line**
- **Off-line**

### Need efficient on-line histogram dispatching system
Histogram Dispatching

**USER INTERFACE**

**GOAL**
- Huge amount of data
- On-line

**INSTRUMENTS**
- Multi-threaded and distributed software
- Inter Process Communication

Currently in use during commissioning

**ATLAS on-line Histogramming**

**Pixel book-keeping**

Customized and fast histogram book-keeping mechanism!

**Permanent Storage**
Summary

- **Pixel Detector Challenge:** read out and calibrate 80 million pixels!
- **Calibration Procedure:** read out electronic response, optimized for on-line use
- **Histogram Dispatching:** developed fast calibration result dispatching system within a highly distributed environment