The long road to understanding LHC data

Philip Bechtle

January 15th and 22nd 2010
Disclaimer

- I’m by far not an expert on all of what I’ll show, so we’ll have lots of fun in the discussions
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These are very interesting times, so if you look at this in a few months, probably a lot will be different.

Further Reading:

- ATLAS public results: https://twiki.cern.ch/twiki/bin/view/Atlas/AtlasResults
- Interesting reading:
  - Expected Performance of the ATLAS Experiment - Detector, Trigger and Physics arXiv:0901.0512
  - The ATLAS Experiment at the CERN Large Hadron Collider JINST 3:S08003,2008
  - CMS physics: Technical design report CERN-LHCC-2006-001
  - Experimental prospects at the Large Hadron Collider arXiv:0905.0258
Outline

1. Why are the Detectors built as they are?

2. How do we understand the data?
Outline

1. Why are the Detectors built as they are?

2. How do we understand the data?
Why are the Detectors built as they are? How do we understand the data?

**Der Large Hadron Collider**

**Proton-Proton Kollisionen bei höchster Energie und Luminosität**
- **Umfang**: 27 km
- **Schwerpunktsenergie**: $10 - 14 \text{ TeV}$
- **Design-Luminosität**: $10^{34} \text{ cm}^{-2} \text{s}^{-1}$
- **Zahl der Protonpakete**: 2808
- **Abstand zwischen Kollisionen**: 25 ns
- **Zahl der Wechselwirkungen pro Kollision**: bis zu 25
- **Protonen pro Paket**: $10^{11}$
- **Zahl der Dipolmagnete**: 1232
- **Gespeicherte Energie**: 362 MJ

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SFB Lecture 01/2010
The Fundamental Challenge

Why are the Detectors built as they are?
How do we understand the data?
Why are the Detectors built as they are? How do we understand the data? 

... at hadron machines, in contrast to others:
Why are the Detectors built as they are?

How do we understand the data?
ATLAS

- Multi-purpose detector, largest collider detector built to date (height 25m, length 45m)
- Small (in spatial size) 2 T solenoidal field (superconducting coil inside calorimeter)
- Large but only 0.5T toroidal magnetic field in the muon system
- Aim for high spacial granularity
Why are the Detectors built as they are?
How do we understand the data?

CMS
Why are the Detectors built as they are?

How do we understand the data?

CMS

- Multi purpose detector, very heavy (12 500 tons), height 15m, length 22m
- Very large (6m diameter) solenoidal coil (4 T inside, ≈ 2 T outside): Constraint on calorimeter depth, but less material in front
- All tracking made of silicon detectors, aim for higher point resolution, lower granularity
- Overall expected performance of CMS and ATLAS trackers comparable: $\Delta p_T/p_T < 2\%$ for the central parts

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Why are the Detectors built as they are?  
How do we understand the data?

Different Particles in CMS

Key:  
- Muon (blue)  
- Electron (red)  
- Charged Hadron (e.g., Pion) (green)  
- Neutral Hadron (e.g., Neutron) (dashed green)  
- Photon (dashed blue)  

Transverse slice through CMS  
Silicon Tracker  
Electromagnetic Calorimeter  
Hadron Calorimeter  
Superconducting Solenoid  

Iron return yoke interspersed with Muon chambers
Why are the Detectors built as they are?
How do we understand the data?

ATLAS Inner Detector

- TRT
  - R = 1082 mm
  - R = 554 mm
  - R = 514 mm
  - R = 443 mm
  - R = 371 mm
  - R = 299 mm

- SCT
  - R = 122.5 mm
  - R = 88.5 mm
  - R = 50.5 mm
  - R = 0 mm

- Pixels

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ATLAS Calorimeters

Why are the Detectors built as they are?
How do we understand the data?

A TLAS Calorimeters

Tile barrel
Tile extended barrel

LAr hadronic end-cap (HEC)
LAr electromagnetic end-cap (EMEC)

LAr electromagnetic barrel
LAr forward (FCal)
Why are the Detectors built as they are?
How do we understand the data?

Electromagnetic Calorimeters
Why are the Detectors built as they are?
How do we understand the data?

Pileup

Photon converts at $R = 40$ cm and electron pair is visible in ATLAS TRT and EM calo
Why are the Detectors built as they are?
How do we understand the data?

Pileup

ATLAS barrel

$H \rightarrow ZZ^* \rightarrow e^+e^-\mu^+\mu^- (m_\mu = 130 \text{ GeV})$
Why are the Detectors built as they are?
How do we understand the data?

Pileup

ATLAS Barrel Inner Detector

$H \rightarrow b \bar{b}$

ATLAS Barrel Inner Detector

$H \rightarrow b \bar{b}$
Why are the Detectors built as they are?
How do we understand the data?

Material Budget

\[ \eta = - \ln \left( \tan \left( \frac{\theta}{2} \right) \right) \]

- Why did it get so much worse?
- Number of channels, readout speed up ⇒ Power up ⇒ Cooling up
- \( \approx 70 \text{ kW} \) in through power lines and out through cooling!
Why are the Detectors built as they are?
How do we understand the data?

Generic Requirements

- Radiation damage to materials and electronics in the whole experimental area $> 10^{16}$ particles ($E > 1\text{MeV}$)/$cm^2$/year
- Need very precise timing and be as fast as possible: 25 ns bunch spacing, several interactions in the detector at the same time
- Need excellent spatial granularity to minimise pileup effects
- Need to identify extremely rare events:
  - Lepton identification above huge QCD background
  - e/jet ratio $\approx 10^{-5}$, i.e. $\mathcal{O}(100)$ worse than Tevatron
- Signal $\sigma$ as low as $10^{-14}$ of $\sigma_{tot}$
- Trigger rejection $\approx 10^{-7}$
- Store huge data on disk ($\approx 10^{+9}$ events of 1.5 MB size per year)
Main specific design choices of ATLAS/CMS

- Size of ATLAS/CMS ~ energies of particles produced:
  1 TeV electrons (30 $X_0$ or 18 cm of Pb), 1 TeV pions (11 $\lambda$ or 2 m Fe), 1 TeV muons outside calorimeters (optimize $BL^2$)

- Choice of magnet system has shaped the experiments

  - ATLAS: separate magnet systems (small 2 T solenoid for tracker and huge toroids with large $BL^2$ for muon spectrometer)
    **Pros**: large acceptance in polar angle for muons and excellent momentum resolution without using inner tracker
    **Cons**: very expensive and largescale toroid magnet system

  - CMS: one large 4 T solenoid with instrumented return yoke
    **Pros**: excellent momentum resolution using inner tracker and more compact experiment
    **Cons**: limited performance for standalone muon measurements (and trigger) and limited space for calorimeter inside coil
Main specific design choices of ATLAS/CMS

- Electrons are relatively easy to measure precisely in EM calorimeters but very hard to identify ($e/\text{jet} \approx 10^{-5}$).
- Muons are relatively easy to identify behind calorimeters but very hard to measure accurately at high energies.
- ATLAS uses LAr sampling calorimeter with good energy resolution and excellent lateral and longitudinal segmentation ($e/\gamma$ identification).
- CMS use PbWO$_4$ scintillating crystals with excellent energy resolution and lateral segmentation but no longitudinal segmentation.
- Signals from $H \rightarrow \gamma\gamma$ or $H \rightarrow ZZ^* \rightarrow 4e$ should appear as narrow peaks (intrinsically much narrower in CMS) above essentially pure background from same final state (intrinsically background from fakes smaller in ATLAS).
Examples for the most important processes: Higgs
Examples for the most important processes: Higgs
Why are the Detectors built as they are?

How do we understand the data?

Examples for the most important processes: Higgs
Examples for the most important processes: Higgs
Examples for the most important processes: SUSY

- For fastest possible discovery:
  Use inclusive spectra
- Very challenging because detector needs to be understood very well with little data (ca. \( \mathcal{L} \approx 1 \text{ fb}^{-1} \))

\[
M_{\text{eff}} = \sum_i p_{T,i} + E_{\text{Tmiss}}
\]
Examples for the most important processes: SUSY

- For fastest possible discovery:
  Use inclusive spectra
- Very challenging because detector needs to be understood very well with little data (ca. $L \approx 1 \text{ fb}^{-1}$)
- Is it really SUSY?
- Which particles, which masses, which couplings, which quantum numbers?

\[ \chi^2 / \text{ndf} \quad 40.11 / 45 \]
\[ \text{Prob} \quad 0.679 \]
\[ \text{Endpoint} \quad 99.66 \pm 1.399 \]
\[ \text{Norm.} \quad -0.3882 \pm 0.02563 \]
\[ \text{Smearing} \quad 2.273 \pm 1.339 \]

kinematic edges $\Rightarrow$ mass information
### Expectations: Tracking

<table>
<thead>
<tr>
<th>Tracking properties</th>
<th>ATLAS</th>
<th>CMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reconstruction efficiency for pions with $p_T = 1$ GeV</td>
<td>84.0%</td>
<td>80.0%</td>
</tr>
<tr>
<td>Reconstruction efficiency for electrons with $p_T = 5$ GeV</td>
<td>90.0%</td>
<td>85.0%</td>
</tr>
<tr>
<td>Momentum resolution at $p_T = 100$ GeV and $\eta \approx 0$</td>
<td>3.8%</td>
<td>1.5%</td>
</tr>
<tr>
<td>Momentum resolution at $p_T = 100$ GeV and $\eta \approx 2.5$</td>
<td>11%</td>
<td>7%</td>
</tr>
<tr>
<td>Transverse i.p. resolution at $p_T = 1000$ GeV and $\eta \approx 0$</td>
<td>11 µm</td>
<td>9 µm</td>
</tr>
<tr>
<td>Transverse i.p. resolution at $p_T = 1000$ GeV and $\eta \approx 2.5$</td>
<td>11 µm</td>
<td>11 µm</td>
</tr>
<tr>
<td>Longitudinal i.p. resolution at $p_T = 1000$ GeV and $\eta \approx 0$</td>
<td>90 µm</td>
<td>22–42 µm</td>
</tr>
<tr>
<td>Longitudinal i.p. resolution at $p_T = 1000$ GeV and $\eta \approx 2.5$</td>
<td>190 µm</td>
<td>70 µm</td>
</tr>
</tbody>
</table>
### Expectations: Muons

<table>
<thead>
<tr>
<th>Momentum and pseudorapidity</th>
<th>ATLAS</th>
<th>CMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>( p = 10 \text{ GeV and } \eta \approx 0 )</td>
<td>1.4% (3.9%)</td>
<td>0.8% (8%)</td>
</tr>
<tr>
<td>( p = 10 \text{ GeV and } \eta \approx 2 )</td>
<td>2.4% (6.4%)</td>
<td>2.0% (11%)</td>
</tr>
<tr>
<td>( p = 100 \text{ GeV and } \eta \approx 0 )</td>
<td>2.6% (3.1%)</td>
<td>1.2% (9%)</td>
</tr>
<tr>
<td>( p = 100 \text{ GeV and } \eta \approx 2 )</td>
<td>2.1% (3.1%)</td>
<td>1.7% (18%)</td>
</tr>
<tr>
<td>( p = 1000 \text{ GeV and } \eta \approx 0 )</td>
<td>10.4% (10.5%)</td>
<td>4.5% (13%)</td>
</tr>
<tr>
<td>( p = 1000 \text{ GeV and } \eta \approx 2 )</td>
<td>4.4% (4.6%)</td>
<td>7.0% (35%)</td>
</tr>
</tbody>
</table>
## Expectations: Hadronic Calorimeters

<table>
<thead>
<tr>
<th></th>
<th>ATLAS</th>
<th>CMS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Barrel LAr/Tile</td>
<td>End-cap LAr</td>
</tr>
<tr>
<td>Tile</td>
<td>1.36</td>
<td>1.49</td>
</tr>
<tr>
<td>Combined</td>
<td>1.37</td>
<td>85%/√E</td>
</tr>
<tr>
<td>HEC</td>
<td>75%/√E</td>
<td>&lt; 1%</td>
</tr>
<tr>
<td>Combined</td>
<td>5.8%</td>
<td>8.0%</td>
</tr>
<tr>
<td>Electron/hadron</td>
<td>1.36</td>
<td>1.49</td>
</tr>
<tr>
<td>ratio</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stochastic term</td>
<td>45%/√E</td>
<td>100%/√E</td>
</tr>
<tr>
<td>Constant term</td>
<td>1.3%</td>
<td>5.8%</td>
</tr>
<tr>
<td>Noise</td>
<td>Small</td>
<td>Small</td>
</tr>
<tr>
<td></td>
<td>2.3%</td>
<td>1.2 GeV</td>
</tr>
<tr>
<td></td>
<td>5.8%</td>
<td>&lt; 1%</td>
</tr>
</tbody>
</table>
Why are the Detectors built as they are?  
How do we understand the data?

Expectations: EM Calorimeters

Photons at 100 GeV
ATLAS: 1-1.5\% energy resol. (all $\gamma$)  
CMS: 0.8\% energy resol.  
($\varepsilon_\gamma \sim 70\%$)

Electrons at 50 GeV
ATLAS: 1.5-2.5\% energy resol.  
(use EM calo only)  
CMS: $\sim 2.0\%$ energy resol.  
(combine EM calo and tracker)
Outline

1. Why are the Detectors built as they are?

2. How do we understand the data?
### ATLAS Detector Status

<table>
<thead>
<tr>
<th>Subdetector</th>
<th>Number of Channels</th>
<th>Approximate Operational Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pixels</td>
<td>80 M</td>
<td>97.9%</td>
</tr>
<tr>
<td>SCT Silicon Strips</td>
<td>6.3 M</td>
<td>99.3%</td>
</tr>
<tr>
<td>TRT Transition Radiation Tracker</td>
<td>350 k</td>
<td>98.2%</td>
</tr>
<tr>
<td>LAr EM Calorimeter</td>
<td>170 k</td>
<td>98.8%</td>
</tr>
<tr>
<td>Tile calorimeter</td>
<td>9800</td>
<td>99.2%</td>
</tr>
<tr>
<td>Hadronic endcap LAr calorimeter</td>
<td>5600</td>
<td>99.9%</td>
</tr>
<tr>
<td>Forward LAr calorimeter</td>
<td>3500</td>
<td>100%</td>
</tr>
<tr>
<td>MDT Muon Drift Tubes</td>
<td>350 k</td>
<td>99.7%</td>
</tr>
<tr>
<td>CSC Cathode Strip Chambers</td>
<td>31 k</td>
<td>98.4%</td>
</tr>
<tr>
<td>RPC Barrel Muon Trigger</td>
<td>370 k</td>
<td>98.5%</td>
</tr>
<tr>
<td>TGC Endcap Muon Trigger</td>
<td>320 k</td>
<td>99.4%</td>
</tr>
<tr>
<td>LVL1 Calo trigger</td>
<td>7160</td>
<td>99.8%</td>
</tr>
</tbody>
</table>
Why are the Detectors built as they are?
How do we understand the data?

First: We’ve got data now!

2-Jet Event at 2.36 TeV

ATLAS EXPERIMENT

2009-12-08, 21:40 CET
Run 142065, Event 116969
Why are the Detectors built as they are?
How do we understand the data?

Not so unimportant: Inspect the data!

ATLAS EXPERIMENT
2009-12-05, 18:24 CET
Run 141749, Event 460865

Event with \(K_S \rightarrow \pi^+ \pi^-\)
Candidate

Why are the Detectors built as they are?
How do we understand the data?

Not so unimportant: Inspect the data!

Collision Event with 2 primary Interactions ("pileup")

ATLAS EXPERIMENT
2009-12-11, 03:38 CET
Run 142165, Event 1115603

Why are the Detectors built as they are?
How do we understand the data?

Triggers

**ATLAS**

- L1
- Regions of Interest
- L2 farm
- EF
- 3kHz

**CMS**

- L1
- Event builder network
  - 3kHz
  - 100kHz
- Computer Farm
  - ~ O(100)Hz
- HLT

**ATLAS**

- 40 MHz
- FE pipeline (~ 3 μs)
- 100 kHz
- Readout buffers
Why are the Detectors built as they are?
How do we understand the data?

Triggers
Why are the Detectors built as they are?
How do we understand the data?

Triggers
Triggers: What to do and to measure

- Timing
- Efficiencies
- Resolutions in comparison with offline
- Deadtime
- Configuration correct?
- ...
Why are the Detectors built as they are?
How do we understand the data?

Number of recorded events

ATLAS Collision Candidates
MBTS A/C-side Coincidence Trigger

Cumulative Number of Events

Day in December

Total
During Stable Beams

\times 10^3

0
100
200
300
400
500
600
700
800
900
1000

2
4
6
8
10
12
14
16
Why are the Detectors built as they are?

How do we understand the data?

Luminosity

ATLAS Preliminary

- MBTS Online
- Lucid Offline
- Liquid Argon Offline

Run 142193: Dec 12 2009

UTC Time
Why are the Detectors built as they are?
How do we understand the data?

Luminosity Measurement

- IP
- TAS
- Q1, Q2, Q3
- D1
- TAN
- D2
- Q4
- Q5
- Q6
- 17m
- 140 m
- 237m
- 4m

Dump resistor boxes
beam 1
beam 2

LUCID
ZDC
ALFA
What’s a collision, anyway?
What’s a collision, anyway?

ATLAS Preliminary

- two beams
- single beam 1
- single beam 2

Difference between MBTS times (A - C) [ns]
Why are the Detectors built as they are?
How do we understand the data?

So what’s the event rate?

Rates in time runs: 141748:141811

Cosmic muon trigger enabled

ATLAS Preliminary

- L1_MBTS_1_TAV
- L1_MBTS_2_TAV
- L1_MBTS_1_1_TAV
- EF_total_output
Why are the Detectors built as they are?
How do we understand the data?

Silicon System
Why are the Detectors built as they are?

How do we understand the data?

Silicon Sensors
Silicon Sensors

Why are the Detectors built as they are?
How do we understand the data?

Basic unit is Bare Module, with sensor + 16 FE chips.
Active area is 10 cm², contains 46,080 channels with pitch of 50 μ.
Beyond commercial pitches (200 μ), work with non-standard vendors.

Indium Bumps
Solder Bumps

OR

16 chips, 46,080 bump bonds

Sensor
ICs

X-ray of bumps

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Why are the Detectors built as they are?
How do we understand the data?

Silicon Sensors

- grounded
- read out chip
- 10 - 20 μm
- 0 V
- n⁺-implant at the edge region
- n⁺-pixel
- n-substrate
- p⁺-implantation
- p-spray
- guard rings
- scribe line
- controlled potential drop
- bias voltage (>200V)
- centre of the sensor
Why are the Detectors built as they are?
How do we understand the data?

Silicon Sensors
Silicon Sensors: What to do and to measure

- Incredibly complex:
  - e.g. ATLAS Pixel system: within $r < 20\text{ cm}$:
    - 80M channels in 1744 modules
- Dead and hot channels
- Noise
- Alignment!
- Timing
- Lorentz Angle
- Spacial resolutions of single hits
- Track resolutions & vertex resolution
- Hit & track efficiencies
Why are the Detectors built as they are?
How do we understand the data?

Inner Detector Performance

Scatter Plot of Hits on Tracks

ATLAS preliminary
real data run 141811
Why are the Detectors built as they are?
How do we understand the data?

Pixel Detector Timing and Clusters

**ATLAS Preliminary**
**Pixel timing**
Minimum Bias Stream
Solenoid on runs 141749 to 142154

- Red: Clusters off track
- Blue: Clusters on track

**ATLAS Preliminary**
Mean cluster width (number of pixels)

- Simulation
- Run 141811 (solenoid on)
- Run 141994 (solenoid off)

**dE/dx [ke]**

- Data 900 GeV
- MC 900 GeV

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TRT Timing and Resolutions

- Why are the Detectors built as they are?
- How do we understand the data?

**ATLAS preliminary**

### TRT timing and resolutions

<table>
<thead>
<tr>
<th>Track to wire distance (mm)</th>
<th>Number of hits (run 141749)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>2000</td>
</tr>
<tr>
<td>0.4</td>
<td>4000</td>
</tr>
<tr>
<td>0.6</td>
<td>6000</td>
</tr>
<tr>
<td>0.8</td>
<td>8000</td>
</tr>
<tr>
<td>1.0</td>
<td>10000</td>
</tr>
</tbody>
</table>

**Residual [mm]**

- $\mu=0 \mu m$, $\sigma=165 \mu m$

**ATLAS preliminary**

- TRT Barrel
- Combined ID Tracks

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Why are the Detectors built as they are?
How do we understand the data?

TRT Timing

Run 140541, event 140973

Run 140541, event 171897

ATLAS preliminary
Why are the Detectors built as they are?

How do we understand the data?

TRT PID

**ATLAS preliminary**

- Electron candidates
- Generic tracks
- Electrons (MC)
- Generic tracks (MC)

**TRT end-cap**

High-threshold probability

- Electron candidates
- Generic tracks
- Electrons (MC)
- Generic tracks (MC)

Pion momentum (GeV)

Electron momentum (GeV)
Why are the Detectors built as they are?
How do we understand the data?

Check Resolutions and Alignment

<table>
<thead>
<tr>
<th>x residual [mm]</th>
<th>number of hits on tracks</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.2</td>
<td>0</td>
</tr>
<tr>
<td>-0.1</td>
<td>500</td>
</tr>
<tr>
<td>0</td>
<td>1000</td>
</tr>
<tr>
<td>0.1</td>
<td>1500</td>
</tr>
<tr>
<td>0.2</td>
<td>2000</td>
</tr>
<tr>
<td>0.3</td>
<td>2500</td>
</tr>
<tr>
<td>0.4</td>
<td>3000</td>
</tr>
</tbody>
</table>

- **MC perfect alignment**: $\mu=0\mu m, \sigma=46\mu m$
- **Collision alignment**: $\mu=0\mu m, \sigma=86\mu m$
- **Cosmics alignment**: $\mu=-5\mu m, \sigma=122\mu m$

*ATLAS Preliminary*  
SCT ECC  
Run 141749+141811
Why are the Detectors built as they are?
How do we understand the data?

Once the Inner Detector is working . . .

![Graph showing offline track Z0 distribution for ATLAS Preliminary Candidate Collision Events Run 140541. The graph compares LBN < 140 vs LBN > 145 conditions with track hits > 10, N_{TRT} track hits ≥ 6, and |d_0| < 10 mm.]
Performance Goals at the beginning and at the end

<table>
<thead>
<tr>
<th>Performance</th>
<th>Start-up of LHC</th>
<th>Ultimate goal</th>
<th>Physics goals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electromagnetic energy uniformity</td>
<td>1–2%</td>
<td>0.5%</td>
<td>( H \rightarrow \gamma\gamma )</td>
</tr>
<tr>
<td>Electron energy scale</td>
<td>~2%</td>
<td>0.02%</td>
<td>( W ) mass</td>
</tr>
<tr>
<td>Hadronic energy uniformity</td>
<td>2–3%</td>
<td>&lt; 1%</td>
<td>( E_T^{\text{miss}} )</td>
</tr>
<tr>
<td>Jet energy scale</td>
<td>&lt; 10%</td>
<td>1%</td>
<td>Top-quark mass</td>
</tr>
<tr>
<td>Inner-detector alignment</td>
<td>50–100 ( \mu m )</td>
<td>&lt; 10 ( \mu m )</td>
<td>( b )-tagging</td>
</tr>
<tr>
<td>Muon-spectrometer alignment</td>
<td>&lt; 200 ( \mu m )</td>
<td>30 ( \mu m )</td>
<td>( Z' \rightarrow \mu\mu )</td>
</tr>
<tr>
<td>Muon momentum scale</td>
<td>~1%</td>
<td>0.02%</td>
<td>( W ) mass</td>
</tr>
</tbody>
</table>
Why are the Detectors built as they are?
How do we understand the data?

Measure tracking resolutions already with cosmics
Why are the Detectors built as they are?
How do we understand the data?

Validate tracking resolutions with first collisions

Minimum Bias Stream, Data 2009 (\(\sqrt{s}=900\) GeV)

**ATLAS Preliminary**
**K\(_S^0\)** Invariant Mass

- Data
- Simulation
- Gauss (+poly) fit

\[
\begin{align*}
\mu &= 497.5 \pm 0.1 \text{ (stat) MeV} \\
\sigma &= 8.2 \pm 0.1 \text{ (stat) MeV} \\
\text{PDG (2009)} \, m_{K^0} &= 497.614 \pm 0.024 \text{ MeV}
\end{align*}
\]

Minimum Bias Stream, Data 2009 (\(\sqrt{s}=900\) GeV)

**ATLAS Preliminary**
**\(\Lambda\)** Invariant Mass

- Gauss (+poly) fit

\[
\begin{align*}
\mu &= 1116.0 \pm 0.1 \text{ (stat) MeV} \\
\sigma &= 3.2 \pm 0.1 \text{ (stat) MeV} \\
\text{PDG (2009)} \, m_{\Lambda} &= 1115.683 \pm 0.006 \text{ MeV}
\end{align*}
\]

Minimum Bias Stream, Data 2009 (\(\sqrt{s}=900\) GeV)

**ATLAS Preliminary**

- Data
- Simulation

Mean 0.00155
RMS 0.195
Mean 5.37e-05
RMS 0.191

\(p_T > 1\) GeV/c
\(|\eta| < 2.0\)
#hits b-layer>0
Why are the Detectors built as they are?
How do we understand the data?

Similar for CMS . . .
Why are the Detectors built as they are?

How do we understand the data?

Electromagnetic Calorimeters

<table>
<thead>
<tr>
<th></th>
<th>Nal(Tl)</th>
<th>CsI(Tl)</th>
<th>CsI</th>
<th>BaF$_2$</th>
<th>BGO</th>
<th>PbWO$_4$</th>
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<tr>
<td>Dichte (g/cm$^3$)</td>
<td>3.67</td>
<td>4.53</td>
<td>4.53</td>
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<td>$X_0$ (cm)</td>
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<td>$R_M$ (cm)</td>
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<td>1</td>
<td>$10^5$</td>
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Electromagnetic Calorimeters
Electromagnetic Calorimeters
Why are the Detectors built as they are?
How do we understand the data?

Hadronic Calorimeters
Hadronic Calorimeters
Calorimeters: What to do and to measure

- Spacial resolution obviously not so important . . .
- Timing
- Noise
- Dead and noisy channels
- Calibration!
- Energy Resolution
- Response to individual particles: each object has to be calibrated separately, e.g. electrons leave a different fraction of energy in the absorber than hadrons, strongly different spatial distributions of energy deposits etc.
Why are the Detectors built as they are?  
How do we understand the data?

\[ \pi^0 \]

\[ \sigma_{\text{data}} = 19 \text{ MeV} \]

![Graph showing ATLAS preliminary data with entries and uncorrected \( m_{\gamma\gamma} \) (MeV) on the x-axis and entries/(10 MeV) on the y-axis. The graph includes data points, a fit to the data, and non-diffractive minimum bias MC.](image_url)
Again similar for CMS...
Why are the Detectors built as they are?
How do we understand the data?

Map the detector material using conversions
Why are the Detectors built as they are?
How do we understand the data?

Map the detector material using conversions

(P. Bechtle: The long road to understanding LHC data SFB Lecture 01/2010)
Why are the Detectors built as they are?
How do we understand the data?

Muon System
Muon System

- Cross plate
- Multilayer
- In-plane alignment
- Longitudinal beam
Muon System: What to do and to measure

- Alignment
- magnetic Field
- Noise
- Dead and Noisy Channels
- Timing
- Resolutions
- Efficiencies
Why are the Detectors built as they are?  
How do we understand the data?

Not too many muons yet . . .

![Histogram of muons with categories: ATLAS preliminary, Muon Spectrometer, Standalone Tracks, Run 141749 & 141811.](image)
Why are the Detectors built as they are?
How do we understand the data?

Jets test $E_{T \text{miss}}$, noise
Why are the Detectors built as they are? How do we understand the data?

Probably no τ yet, but many candidates (from jets)
## Outlook for 2010

### 2010 LHC Schedule

#### Draft

<table>
<thead>
<tr>
<th>Wk</th>
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<td>INJ TEST</td>
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<tr>
<td>Su</td>
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<td>MACHINE CHECKOUT</td>
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- **nQPS commissioning**
- **MPS COMMISSIONING BEAM COMMISSIONING PILOT PHYSICS**

**Start non-LHC physics program**

**Possible step-up in energy - no beam**

**Re-commissioning with beam to higher energy**

### April

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**Easter**

**Ascension**

**1 May**

**Whit**

### May

### June
Why are the Detectors built as they are?
How do we understand the data?

**Outlook for 2010**

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- Ion Beam to SPS

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- Technical Stop
- Recomissioning with beam
- SPS et al - physics

**IONS** (approx 4 weeks)
Why are the Detectors built as they are?
How do we understand the data?

Outlook for your favourite physics

- $H \to \gamma\gamma$
- $H \to ZZ^* \to 4l$
- $H \to \tau\tau$
- $H \to WW \to e\nu\mu\nu$

**ATLAS**

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$m_{H} \text{ [GeV]}$

- $0.5 \text{ TeV}$
- $1.0 \text{ TeV}$
- $1.5 \text{ TeV}$
- $2.0 \text{ TeV}$
- $2.5 \text{ TeV}$

**FITTINO**

- NO EWSB
- $\tau \sim (10^{3} \text{ GeV})^+$
- $\chi \sim (10^{3} \text{ GeV})^+$

4 jets 0 lepton
4 jets 1 lepton
4 jets 2 leptons OS
1 jet 3 leptons

mSUGRA Entdeckungspotential mit 1 fb$^{-1}$
Why are the Detectors built as they are?
How do we understand the data?

Outlook for your favourite physics

Vgl. SM-Higgs mit mSUGRA erlaubt weil leichtestes mSUGRA-Higgs extrem SM-Higgs-ähnlich

- Entdeckung neuer Physik wahrscheinlich lange vor Higgs-Entdeckung
- Brauchen Information der Higgs-Suchen bei der Interpretation neuer Physik
A lot has been achieved thanks to the incredible efforts of the machine group and the collaborations.

But so much remains to be done...

calibrate jets, $E_{Tmis}$, and so on

Accumulate lots of luminosity!

Find surprising and unexpected new physics!