CERN: March 30th, 2010, 12:57
LHC collisions p-p at $\sqrt{s} = 7$ TeV:
HEP is finally in the new era!

Status of the ATLAS Experiment for the Open LHCC Session

Kevin Einsweiler
Lawrence Berkeley Lab
5 May, 2010
Outline

• Status of the ATLAS experiment
  – Detector Status and Operations
  – Performance results at $\sqrt{s} = 0.9$ and 7 TeV
  – First ATLAS Physics Results at 7 TeV
• “Commissioning” ATLAS for Physics, re-discovering SM
• Many results based on 0.9 TeV data samples
• Major results from 7 TeV data samples expected for Summer conferences (PLHC/ICHEP) using more than 100 times the statistics. First preview today…
• Conclusions
The ATLAS Detector: Status and Performance

- Tile calorimeters
- LAr hadronic end-cap and forward calorimeters
- Pixel detector
- LAr electromagnetic calorimeters
- Transition radiation tracker
- Semiconductor tracker
- Solenoid magnet
- Muon chambers
- Toroid magnets

25m
High operational fractions for all detector systems
Details of the Detector status have been discussed in the LHCC session of yesterday.

<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>97.5%</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>98.0%</td>
</tr>
<tr>
<td>LAr EM Calorimeter</td>
<td>170 k</td>
<td>98.5%</td>
</tr>
<tr>
<td>Tile calorimeter</td>
<td>9800</td>
<td>97.3%</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>LVL1 Calo trigger</td>
<td>7160</td>
<td>99.8%</td>
</tr>
<tr>
<td>LVL1 Muon RPC trigger</td>
<td>370 k</td>
<td>99.7%</td>
</tr>
<tr>
<td>LVL1 Muon TGC trigger</td>
<td>320 k</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>98.5%</td>
</tr>
<tr>
<td>RPC Barrel Muon Chambers</td>
<td>370 k</td>
<td>97.3%</td>
</tr>
<tr>
<td>TGC Endcap Muon Chambers</td>
<td>320 k</td>
<td>98.8%</td>
</tr>
</tbody>
</table>

Notes:
- Muons do not include the EE chambers (under installation)
Overall Statistics for 7 TeV Collisions

- Consider period through beginning of technical stop (Apr 26), 21 runs total.
- Instantaneous luminosity $L$ derived from:
  - MBTS (trigger scintillators at $\pm 3.5m$ from IP) double-side coincidence trigger rate
  - LAr offline event selection (coincidence of in-time end-cap energy deposits)
  - Measurement from dedicated LUCID forward detectors, at $\pm 17m$ from IP
  - Present overall $L$ scale uncertainty $\sim 30\%$ from systematic uncertainties (MC cross-section)
- Total luminosity about 1 nb$^{-1}$, 69M MinBias events (81M total) recorded, 1.6MB/evt
- 96.4% of luminosity delivered with Stable Beams was recorded by ATLAS
30 March: First Fill at 7 TeV

- Peak luminosity $\sim 10^{27} \text{cm}^{-2}\text{s}^{-1}$, about 6 $\mu$b$^{-1}$ integrated luminosity, and about 1M events recorded.
- ATLAS recorded 97.2% of luminosity delivered with Stable Beam flag.
- Milestones: HLT rejection deployed for MinBias, increasing L1 random rate (right: trigger rate plot).
- Data quality very high: all detectors more than 97% “green”, most at 100%.
- This fill was used for first physics results on MinBias at 7 TeV (see later).
Collision Event at 7 TeV with 2 Pile Up Vertices

Run Number: 152166, Event Number: 467776
Date: 2010-03-30 13:31:46 CEST

Beam Backgrounds

- Separation of beam backgrounds and collisions based on timing measurements using MBTS system, and comparisons with unpaired bunches (not available in 3x3 configuration).
- Typically less than 1% contamination with very loose MBTS_1 trigger requirement (one of 32 trigger scintillators fires, left plot)
- This is reduced to few $10^{-5}$ remains after primary vertex requirement (right) for 900 GeV data.
- Rate is even lower in early 7 TeV operation. **Very clean beams !!!**
Trigger Commissioning

- Initial trigger operation relies on beam pickups (BPTX) and MBTS (32-fold scintillator arrays at $\pm 3.5m$ covering $2.1 < \eta < 3.8$).
- Use these very open MinBias triggers to commission all other L1 triggers (see later slides).
- Pre-scale L1 MinBias triggers only when luminosity $> 4 \times 10^{27} \text{ cm}^{-2}\text{s}^{-1}$ (started with first $\beta^*=2m$ fill).
- Operate HLT (L2 and Event Filter) in monitoring mode to commission higher level functionality against offline reconstruction.
- Trigger menus developed to adiabatically transition system from $10^{27} \text{ cm}^{-2}\text{s}^{-1}$ operation through $10^{30} \text{ cm}^{-2}\text{s}^{-1}$ operation.
- All items controlled by pre-scales that can be updated during run. Already defined 10 prescale sets for luminosities to $10^{29} \text{ cm}^{-2}\text{s}^{-1}$.
- HLT rejection deployed for MinBias. Preserving lowest thresholds (few GeV) requires deploying rejection for electrons by $10^{29} \text{ cm}^{-2}\text{s}^{-1}$, and muons shortly afterwards. Jets use mixture of pre-scale and HLT.
- Final HLT menu for 2010 should be deployed before $10^{30} \text{ cm}^{-2}\text{s}^{-1}$. 
L1/L2 Trigger Performance Studies

- Efficiency for L1 MinBias trigger MBTS_1 (single counter of 32) at 7 TeV.
- Determined using random control trigger based on beam pick-ups, followed by HLT silicon space point trigger.
- Measure data-driven efficiency when at least one charged track is required offline.
- Foundation of inclusive MinBias analyses using charged particles.

- Efficiency for lowest threshold L1 EM cluster trigger in 2009 run.
- Determined from MinBias triggered sample using comparison to offline clusters.
- Plateau is about 5 GeV, well reproduced by MC for 900 GeV data.
L1/L2 Trigger Performance Studies

- ATLAS does not have a tracking trigger at L1.
- Efficiency for tracks reconstructed by L2 trigger compared to efficiency for full offline reconstruction.
- Limited statistics for higher PT, but efficiency is essentially 100% and agrees well with MC simulation.
- Foundation for all track-based triggers

- Efficiency for lowest threshold L1 jet cluster trigger in 2009.
- Determined from MinBias triggered sample using comparison to offline jets at EM scale.
- Plateau is about 20 GeV, well reproduced by MC for 900 GeV data.
- Have enough MinBias data to bootstrap lower PT jet trigger thresholds.
First van der Meer Scan

• Scan to measure **absolute luminosity** made Apr 26, ±6σ in 27 points.
• Online, ATLAS detectors and methods used (MBTS, LUCID, ZDC, BCM) show very consistent results. The background rates generally appear very low.
• Offline methods under study, for example vertex counting.
• Calibration of transverse length scale complete using vertex reconstruction (1-2%).
• Significant indications of non-Gaussian variation in scans (peak and tails) – due to instrumental effects (hysteresis), or underlying beam shapes non-Gaussian?
• Challenges include understanding precision of beam current (satellite bunches), beam size, time-dependent variations (emittance growth), and non-Gaussian effects.
Data Processing for 7 TeV Data

• Synchronized Tier0 and Data/MC re-processing releases in April.
• Reprocessing of 2009/2010 data and MC (about 500M events) ~ complete.
• Started 36-hour calibration loop at Tier0:
  – immediately reconstruct 10% “express stream”,
  – derive conditions (beamspot, TRT RT/T0, Pixel/SCT noisy channels, LAr dead channels),
  – After 36 hour delay, reconstruct bulk data with correct conditions.
• Next re-processing campaign for Summer conferences, with major code improvements, to be completed by early June.
Worldwide Data Distribution

Total Data Transport through the Grid from 1 Jan to 1 May

Avg MB/s per day

Jan
Feb
Mar
Apr

MC Reprocessing
2009 Data Reprocessing
First 2010 Reprocessing
7 TeV Collisions

Typically 4 hours for data to move from P1 via Tier0 to Tier2 for use on Grid
Data Processing and Analysis

• Average number of concurrent analysis jobs during the month of April 2010
• Significant use of Grid for analysis of 7 TeV Data

Statistics:
• 2.2M Jobs completed
• 16.6 billion events analyzed
• 705 users
• 350 users run more than 1000 jobs
Tracking: Data vs Monte Carlo

Detailed comparisons of Data and Monte Carlo at 7 TeV

Comparison of tracking variables: the number of hits on tracks in Pixels and SCT for 7 TeV MinBias data and Monte Carlo.

Critical to simulate missing modules and beamspot position/size very carefully. Excellent agreement!

Validate ingredients of MC-based tracking efficiency.

Compare TRT high-threshold response for MinBias tracks and for electrons from conversions in 900 GeV data/MC.
Mass Peaks in MinBias Data

Ks decays are abundant (bottom left), and provide stringent tests of tracking, including sensitivity to material effects (see later).

Reconstruction of \( \phi \) peak (bottom right) requires use of dE/dx information from Pixel detector (right) to identify \( K^{\pm} \) up to \( \sim 500 \) MeV.

Reconstructed Ks and \( \phi \) masses are consistent with PDG values, and widths are well reproduced by Monte Carlo.
Observation of $D^* \rightarrow D\pi$ at 7 TeV

Masses and Widths agree well with MC expectations (integrated $L$ about 200 $\mu$b$^{-1}$)

$\Delta(M(K\pi\pi) - M(K\pi))$:
- Require: $M(K\pi) = 1865 \pm 20$ MeV
- Right = sideband
- Results: $\Delta M = 145.6 \pm 0.1$ MeV

$M(K\pi)$:
- Require: $\Delta M = 145.4 \pm 1.5$ MeV
- Right = sideband
- Results: $M(K\pi) = 1869.2 \pm 2.4$ MeV
Material in the Inner Detector

$\gamma \rightarrow e^+e^-$ Conversion Candidate

$p_T(e^+) = 1.75$ GeV, 11 TRT high-threshold hits
$p_T(e^-) = 0.79$ GeV, 3 TRT high-threshold hits

$\gamma$ conversion point
R $\sim 30$ cm (1st SCT layer)
Material in the Inner Detector

$\gamma \rightarrow e^+e^-$ Conversions

Distribution of conversion radius for identified conversions shown for 900 GeV MinBias data.

MC distributions for “true” conversions and conversion candidates are compared to observed conversions in data. MC Dalitz decays are also shown in yellow.

Beampipe and three pixel layers are visible, along with first SCT layer at 30cm.

Expanded radial scale shows Dalitz decays, beampipe, and first Pixel layer at 5cm.

With larger statistics, this comparison can provide an absolute normalization to cross-check the accurately known beam-pipe material map.
Material in the Inner Detector

- Reconstructed $K_s$ mass is sensitive to excess material
  - Uncorrected energy loss would cause a shift: tested with dedicated MC samples with excess material of 10/20 % radiation length $X_0$. Data prefers no excess material!

- Sensitive to localized material
  - Measure efficiency to extend tracks reconstructed in Pixel detector to SCT
  - Sensitive to hadronic interactions, monitors model for material in MC relative to data.
Heavy Flavor Tagging at 900 GeV

Apply simple vertex b-tagger to 900 GeV MinBias data

In “loose” mode, most tags are Ks. Distributions of impact parameters for tracks in secondary vertices agree well with MC simulations (left).

Running the tagger in “standard” mode, find 9 events out of ~400K with significant positive decay length, one of which looks like a heavy flavor candidate:
Electron Identification

Low PT electron samples consist mainly of hadron fakes and conversions.

Use TRT high-threshold hit fraction (left) to separate the two contributions.

Use this separation to study key electron ID variables and compare distributions in data and MC (left = hadrons, right = conversions).
Calorimeter energy summed in cone of radius R=0.2 around isolated track divided by track momentum.

Validation of hadronic energy scale in simulation, and foundation for overall jet energy scale.

Preliminary indications: good to about 5% over full PT range and most of $\eta$ range (barrel/endcap transition region harder).
Jets are 310 GeV and 350 GeV at EM scale – highest PT di-jet event so far!
PT(jet) > 20 GeV

Calorimeter: Jets at 7 TeV

Observed jets with PT > 20 GeV using MinBias trigger and integrated luminosity ~ 350 µb⁻¹

Jet energy defined at EM scale, jet definition uses AntiKt R=0.6, and jets are shown for |y|< 2.8.

Specific criteria used to remove a few events with problematic detector behavior (no impact on jets).

Distributions normalized to area. Observation of two jets above 200 GeV is consistent with Pythia.

Highest PT jets from di-jet event (shown before).
Calorimeter: Missing $E_T$ at 7 TeV

Missing ET computed using noise-suppressed clusters at EM scale, integrated luminosity $\sim 110 \, \mu\text{b}^{-1}$

Specific criteria used to remove a few events with problematic detector behavior.

Excellent description over 6 orders of magnitude!
Observation of $J/\psi \rightarrow \mu\mu$

Select muons with $E > 3$ GeV at the IP.
Plot is only for opposite-sign muons (same-sign distribution is flat).
Use data for integrated luminosity $\sim 320 \, \mu b^{-1}$
Require one muon be “combined” (matched tracks in Muon Spectrometer and Inner Detector).
The other muon can be “combined” or “tagged” (Inner Detector track matched to segment in Muon Spectrometer).
Perform vertex fit to two Inner Detector tracks (no mass or pointing constraint).

Gaussian-mean mass: $3.06 \pm 0.02$ GeV
Resolution: $0.08 \pm 0.02$ GeV
Number of signal events: $49 \pm 12$
Number of background events: $28 \pm 4$
Signal and background are computed in a mass range: 2.82-3.30 GeV (3$\sigma$ around the peak).
Charged-particle multiplicities in pp interactions at $\sqrt{s} = 7$ TeV

• Model independent measurement of primary charged particle multiplicity distributions from inelastic events.
  – Kinematic range $|\eta| < 2.5$ & $p_T > 500$MeV
  – Require $n_{ch} \geq 1$ in this phase space
  – Use MBTS_1 single-arm scintillator trigger for high efficiency over phase space
  – No removal of Single Diffractive component.

• Correct reconstructed-track distributions back to hadron level for all detector effects.
  – Measure trigger and vertex corrections from data;
  – Tracking corrections from MC, perform many data cross-checks;

• Results are compared with PYTHIA 6.4.21 tunes, PHOJET 1.12 + PYTHIA 6.4.21, and other measurements.

Results at 900 GeV Published by Phys Lett B 688, Issue 1, 21-42
Charged-particle multiplicities for events with $n_{ch} \geq 1$ within the kinematic range $p_T > 500$ MeV and $|\eta| < 2.5$ at $\sqrt{s} = 7$ TeV compared to Monte Carlo predictions (left) and to the published results at $\sqrt{s} = 900$ GeV (right).

Significant increase in multiplicity from 900 GeV, not well-modeled by most MC tunes.
Charged-particle multiplicities in pp interactions at $\sqrt{s} = 7$ TeV - preliminary results

Charged-particle momenta for events with $n_{ch} \geq 1$ within the kinematic range $p_T > 500$ MeV and $|\eta| < 2.5$ at $\sqrt{s} = 7$ TeV compared to Monte Carlo predictions (left) and to the published results at $\sqrt{s} = 900$ GeV (right).

MC shows significant excess in several GeV momentum range, also seen at 900 GeV. Large impact on modeling rate for low PT objects (EM clusters, muons, jets) in data.
Charged-particle multiplicities in pp interactions at √s = 7 TeV - preliminary results – 3 -

Charged-particle multiplicities for events with n_{ch} ≥1 within the kinematic range p_T > 500 MeV and |η| < 2.5 at √s = 7 TeV compared to the published results at √s = 900 GeV. The panels compare the charged-particle multiplicities as a function of the charged-particle multiplicity (left), and the average transverse momentum as a function of the number of charged particles in the event (right).

**Next step:** perform the data analysis reducing the minimum track p_T to 100 MeV.
First observation of $W \rightarrow e\nu, \mu\nu$ candidates

Show first 4 candidates, observed in integrated luminosity $\sim 300 \mu b^{-1}$

Now have observed about one dozen candidate events.
This rate is consistent with SM expectations.
Properties of all events under intense study.
Optimization of event selection and background rejection are in progress.
Still too early to say anything quantitative.
2nd observed candidate: 5 April

Electron: 3 Pixel hits, 9 SCT hits, 37 TRT hits (20% with transition radiation), $E/p \sim 1.3$
3rd observed candidate: 10 April

Electron: 3 Pixel hits, 8 SCT hits, 34 TRT hits (35% with transition radiation), E/p~1
4th observed candidate: 12 April

Run: 152845, Event: 3338173
Date: 2010-04-12 16:56:44 CEST

$W\nu$ candidate in 7 TeV collisions

$p_T(\mu^-) = 40$ GeV
\[ \eta(\mu^-) = 2.0 \]
\[ E_T^{\text{miss}} = 41 \text{ GeV} \]
\[ M_T = 83 \text{ GeV} \]

Muon: 3 Pixel hits, 8 SCT hits, 17 TRT hits, 14 MDT hits, $Z \sim 3\text{mm from vertex}$, good tracker-spectrometer momentum match, $E(\text{calo}) \sim 4$ GeV (as expected)
Conclusions

• ATLAS detector is performing remarkably well as commissioning for physics advances in the month since first 7 TeV collisions:
  – First 1 nb\(^{-1}\) recorded with efficiency > 96%.
  – Commissioning of trigger system well-advanced. Progressed from MinBias, to L1 Physics triggers. Full suite of HLT triggers in monitoring mode, ready for L ~ 10\(^{29}\) and beyond with high efficiency for ATLAS physics goals.
  – Tracking studies very advanced, including detailed understanding of material, and first physics results. Precise comparisons of data and MC in many domains, signals for meson/baryon resonances, charm, and first hints of secondary vertices.
  – Understanding of electron/photon ID and hadron/jet response in calorimetry already at a high level of sophistication. First di-jet events with 300 GeV jets seen. Missing ET response is excellent.
  – First significant number of collision muons have led to \(J/\psi \rightarrow \mu \mu\) observation, and muon spectrometer is performing very well.
  – First \(W \rightarrow e\nu, \mu\nu\) candidates observed, combining both lepton flavors and clear Missing ET signatures – the re-discovery of the SM is progressing rapidly.

\textbf{ATLAS is prepared for physics at higher luminosity !}