ATLAS status and operation

Lidia Smirnova

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SINP MSU
~3000 scientists, 174 Institutions and 38 Countries, ~1000 PhD students.

Argentina, Armenia, Australia, Austria, Azerbaijan, Belarus, Brazil, Canada, Chile, China, Colombia, Czech Republic, Denmark, France, Georgia, Germany, Greece, Israel, Italy, Japan, Morocco, Netherlands, Norway, Poland, Portugal, Romania, Russia, Serbia, Slovakia, Slovenia, South Africa, Spain, Sweden, Switzerland, Taiwan, Turkey, UK, USA, CERN, JINR.

IHEP (Protvino), BINP (Novosibirsk), ITEP (Moscow), LPI (Moscow), MEPhI (Moscow), PNPI (Gatchina), SINP MSU (Moscow).
ATLAS detector

JINST 3 (2008) S08003

~7000 tons

44 m

25 m

Muon spectrometer

Inner Detector

Calorimeters

Final installation - August 2008

Trigger Scintillators (MBTS) at z=± 3.5 m

Tile calorimeters

LAr hadronic end-cap and forward calorimeters

Pixel detector

LAr electromagnetic calorimeters

Transition radiation tracks

Solenoid magnet

Toroid magnets

44 m

~7000 tons

25 m
- Precise tracking and vertexing,
- $e/\pi$ separation
- Momentum resolution: $\sigma/p_T \sim 3.8 \times 10^{-4} \ p_T \ \text{(GeV)} \oplus 0.015$

**Inner detector**

- **Pixel detector**
  - 3 barrel layers, 2x3 disks
  - $\sigma(r\phi) = 10 \ \mu m$, $\sigma(z) = 115 \ \mu m$
- **Silicon strip detector (SCT)**
  - 4 barrel layers, 2x9 disks
  - Pairs of single-sided sensors
  - $\sigma(r\phi) = 17 \ \mu m$, $\sigma(z) = 580 \ \mu m$
- **Transition Radiation Tracker (TRT)**
  - $\sigma(r\phi) = 130 \ \mu m$
- **Covers $|\eta| < 2.5$ (2.0 for TRT)**
- **2 T solenoidal field**
Muon spectrometer

Muon Spectrometer ($|\eta|<2.7$) : air-core toroids with gas-based muon chambers

Muon trigger and measurement

with momentum resolution $< 10\%$ up to $P_T(\mu) \sim 1$ TeV

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**Trigger chambers:** RPC/TGC

**Precision chambers:** MDT/CSC

**Magnetic field:** \(\sim 0.5\ T\)

**Bending power:** \(\sim 2-5\ Tm\)

**Coverage**

\(|\eta|< 2.7\)

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**W-\(\mu\nu\) candidate at 7 TeV**
HAD calorimetry (|η|<5) 
Trigger and measurement of jets and missing $E_T$ 
E-resolution: $\sigma/E \sim 50%/\sqrt{E} \mp 0.03$

EMCAL: $e/\gamma$ trigger, identification and measurement 
E-resolution: $\sigma/E \sim 10%/\sqrt{E}$
### Overall 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>97.4%</td>
</tr>
<tr>
<td>SCT Silicon Strips</td>
<td>6.3 M</td>
<td>99.2%</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>99.9%</td>
</tr>
<tr>
<td>LVL1 Muon RPC trigger</td>
<td>370 k</td>
<td>99.5%</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>97.0%</td>
</tr>
<tr>
<td>TGC Endcap Muon Chambers</td>
<td>320 k</td>
<td>98.6%</td>
</tr>
</tbody>
</table>

More than 97% of channels in operation

ATLAS status
**Operation**

<table>
<thead>
<tr>
<th>Data collected</th>
<th>Integrated luminosity</th>
<th>Time period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cosmic rays</td>
<td></td>
<td>2008,2009</td>
</tr>
<tr>
<td>pp collisions at 2.36 TeV</td>
<td>~ 0.7 μb⁻¹</td>
<td>Dec.2009</td>
</tr>
<tr>
<td>pp collisions at 7 TeV</td>
<td>~ 3.46 pb⁻¹</td>
<td>From 30 March 2010- up to now</td>
</tr>
<tr>
<td></td>
<td>247x10⁹ events</td>
<td></td>
</tr>
</tbody>
</table>

*Particle multiplicities and momentum spectra in pp minimum-bias events at 900 GeV (PhysLettB688:21,2010)*

*FIRST published results at 15 March*

*the latest presented at ICHEP2010 – 55 reports*
LHC milestones continue to be passed with satisfying regularity.

An inverse picobarn is a small step on the way to an inverse femtobarn.

Overall data taking efficiency 93.9%
Total fraction of good quality data (green “traffic light”)

<table>
<thead>
<tr>
<th>Inner Tracking Detectors</th>
<th>Calorimeters</th>
<th>Muon Detectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pixel</td>
<td>SCT</td>
<td>TRT</td>
</tr>
<tr>
<td>97.7</td>
<td>96.4</td>
<td>100</td>
</tr>
</tbody>
</table>

Luminosity weighted relative detector uptime and good quality data delivery during 2010 stable beams at $\sqrt{s} = 7$ TeV between March 30th and August 14th (in %)

Peak luminosity in ATLAS
$L \sim 1.03 \times 10^{31}$ cm$^{-2}$ s$^{-1}$
Decided Scenario 2010-2011

Following the technical discussions in Chamonix (Jan 2010) the CERN management and the LHC experiments decided

- Run at 3.5 TeV/beam up to a integrated luminosity of around 1 fb$^{-1}$.
- Then consolidate the whole machine for 7 TeV/beam (during a shutdown in 2012)
- From 2013 onwards LHC will be capable of maximum energies and luminosities

- requires a peak luminosity of $\geq 1 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$ during 2011
- must reach $\sim 1 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$ during 2010
Trigger commissioning and operation

ATLAS Trigger has 3 levels: LVL1, LVL2, Event Filter (EF)
High-Level-Trigger (HLT): LVL2 and EF

Typical L1 output 300 Hz in conditions:

\[ L \sim 10^{29} \text{ cm}^{-2} \text{ s}^{-1} \]:
start to activate HLT chains to cope with increasing rate while running with low LVL1 thresholds.

Jet items: lowest thresholds prescaled
(HLT rejection small)

Figure gives examples for L up to \( 7 \times 10^{29} \text{ cm}^{-2} \text{ s}^{-1} \)
• **Trigger performance**

LVL1 jet trigger efficiency for the lowest threshold (J5)

[Graph showing LVL1 jet trigger efficiency with ATLAS Preliminary text]

- Crucial for jet cross-section

LVL1 forward muon trigger efficiency for the lowest threshold (MU0)

[Graph showing LVL1 forward muon trigger efficiency with ATLAS Preliminary text]

- Crucial for di-muon resonances

**ATLAS operation**

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**Trigger performance**

Tracking efficiency at HLT for electron candidates with $E_T^{\text{off}}$ (calo) > 5 GeV

- **Crucial for $J/\psi \rightarrow ee$**
- **Important for SM and SUSY Higgs**

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**ATLAS operation**
**Event selection**

Primary vertex:
1) $n_{\text{track}} \geq 3$ ($p_t > 150$ MeV/c)
2) closest transverse distance to nominal interaction point
3) single hit in one or two MSTB wheels as trigger
4) selection on timing difference from EC or Fcal (5 or 10 nc, respectively), or two MSTB wheels

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**Time difference without any selection and with well reconstructed vertex**
Primary Vertex reconstruction at 7 TeV

Primary vertices in the x-y plane, it shows beam spot: RMS $=0.024$ and $0.04$ mm in x in y

Estimated vertex resolution in 7 TeV data as a function of the number of tracks N.

Reconstructed primary vertices in the x-z plane as beam spot
Event with four reconstructed primary vertices
the same beam-crossing
~ 10-45 tracks with $p_T > 150$ MeV per vertex
ID Alignment pre-collisions and post-collisions

Local x residuals, mm

pixel

SCT

TRT

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ID tracking performance $100 < p_T < 500$ MeV/c (similar to it for $p_T > 500$ MeV/c, relative to MC) at 7 TeV.

Numbers of hits in SCT and Pixel vs $\eta$.

Track Impact parameters:
- $d_0$, mm
- $Z_0 \sin \Theta$, mm

ATLAS performance

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**Particle multiplicities measurements**

Charged particles with $pt>500$ MeV/c $\mid \eta \mid < 2.5$; $n_{ch} \geq 1$ at 0.9, 2.36 and 7 TeV

- No subtraction for single/double diffractive components
- Distributions corrected back to hadron level

Charged particles with $pt>100$ MeV/c $\mid \eta \mid < 2.5$; $n_{ch} \geq 2$ at 0.9 and 7 TeV

**ATLAS performance and results**
Particle Multiplicities at 0.9 and 7 TeV on $\eta$ and $n(\text{ch})$ for $p_t > 100$ MeV/c and $|\eta| < 2.5$; $n(\text{ch}) \geq 2$ with models predictions

- Measured over a well-defined kinematic region
- No subtraction for single/double diffractive components
- Distributions corrected back to hadron level
- High-precision minimally model-dependent measurements
- Provide strong experimental constraints on MC models
Pt measurements for charged particles with $p_T > 100 \text{ MeV/c} \ |\eta| < 2.5; \ N_{\text{ch}} \geq 2$ at 0.9 and 7 TeV

ATLAS Preliminary

$N_{\text{ch}}$ at 0.9 and 7 TeV

Pt at 0.9 and 7 TeV

Pt at 7 TeV vs models

ATLAS performance and results

Data 7 TeV vs models

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<table>
<thead>
<tr>
<th>Energy (TeV)</th>
<th>CMS $\frac{1}{N_{\text{ev}}} N_{\text{ch}}/d\eta$ at $\eta = 0$</th>
<th>Pt &gt; 0 CMS</th>
<th>Pt &gt; 100 MeV/c ATLAS Nch≥2</th>
<th>Pt &gt; 500 MeV/c ATLAS Nch≥1</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9 TeV</td>
<td>$3.48\pm0.02_{\text{stat}}\pm0.13_{\text{syst}}$</td>
<td>$3.486\pm0.008_{\text{stat}}\pm0.077_{\text{syst}}$</td>
<td>$1.333\pm0.003_{\text{stat}}\pm0.040_{\text{syst}}$</td>
<td></td>
</tr>
<tr>
<td>2.36 TeV</td>
<td>$4.47\pm0.04_{\text{stat}}\pm0.16_{\text{syst}}$</td>
<td>$\text{---}$</td>
<td>$1.739\pm0.019_{\text{stat}}\pm0.058_{\text{syst}}$</td>
<td></td>
</tr>
<tr>
<td>7 TeV</td>
<td>$5.78\pm0.01_{\text{stat}}\pm0.23_{\text{syst}}$</td>
<td>$5.635\pm0.002_{\text{stat}}\pm0.149_{\text{syst}}$</td>
<td>$2.418\pm0.004_{\text{stat}}\pm0.076_{\text{syst}}$</td>
<td></td>
</tr>
</tbody>
</table>

**ATLAS and CMS data for charged particle multiplicities at $\eta = 0$**

Particle Density Angular Correlation

- Define the event orientation by the azimuthal angle of the track with the highest $p_T$
- Plots are reflected about $\varphi=0$; highest $p_T$ track is not included

Monte Carlo tunes only reproduce the general features
  - Disagreement in rates both in the transverse region (UE) and in the Toward and Away regions (MPI/Hard Core)
Diffraction enhanced events at 7 TeV

$R_{ss}$ — The ratio of events with hits only on one side of the MBTS scintillators to events with any hits in the MBTS scintillators.

ATLAS performance and results

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Secondary vertices and cascade decays

$\Lambda \pi \rightarrow \Lambda \pi$

$\Xi \rightarrow \Lambda \pi$

$D^{\pm} \rightarrow K\pi\pi$

$K^{0}s$, $\Lambda$, $\Xi$, $\Omega$, $\varphi$, $D$, $D^{*}$ mesons are reconstructed in Inner Detector

Good agreement with MC

Resolution as expected (dominated by multiple scattering)

Fitted invariant masses agree with PDG values

PDG: 1321.32

PDG: 1869.6
Mapping the Inner Detector material with $\gamma \rightarrow e^+e^-$ conversions

Goal is to know material to better than 5% (over-constraining with several methods)
Present understanding: at the level of ~ 10%

Beam pipe
Pixel 1
Pixel 2
Pixel 3
SCT 1
SCT 2

Pixel support structures

Reconstructed conversion point in the radial direction of $\gamma \rightarrow e^+e^-$ from minimum bias events (sensitive to $X_0$)

Data show that Pixel supports are displaced in the simulation → to be fixed

$\pi^0$ Dalitz Decays allow to constrain material in beam pipe

$\sqrt{s} = 7$ TeV

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Reconstructed secondary vertices due to hadronic interactions in minimum-bias events in the first layer of the Pixel detector (sensitive to interaction length \( \lambda \rightarrow \) complementary to \( \gamma \) conversion studies)

Mapping ID material with secondary hadronic interactions

ATLAS Prelim.
\( \sqrt{s} = 7 \text{ TeV} \)
L_{int} \sim 0.2 \text{ nb}
Data 2010

ATLAS Prelim.
\( \sqrt{s} = 7 \text{ TeV} \)
Non-diff.
MC

Already very good, but can be improved
$E_t^{\text{miss}}$ in 15.2 million selected minimum bias events at 7 TeV, recorded in April 2010.

$E_t^{\text{miss}}$ in the events with at least one reconstructed muon at 7 TeV

Good agreement with MC simulations
**$e/\gamma$ reconstruction and identification**

Based on:

- Finest segmentation of EM
- Tracking performance
- TR measurements
- Hit on track in B-layer (select $e$ from conversions)

**Signal of $9920 \pm 160$ (stat) $\pm 990$ (syst) electrons predominantly from $b,c \rightarrow e$ is measured for $E_t > 7$ GeV and within $|\eta| < 2$**

**13.8 nb$^{-1}$**
Decays to $\gamma$, prompt $\gamma$

Trigger efficiency for $\gamma$ vs $E_t$

Efficiency $\geq 99.3\%$ for $E_t > 10$ GeV
Prompt photon purity for $E_t > 20$ GeV $(72\pm7)\%$

Minimum Bias 900 GeV

$7$ TeV, $\sim 16$ nb$^{-1}$

$\gamma$ with $\pi^0$ and $\eta$ mesons signals, MeV

$E_t$, GeV

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**J/ψ → e^+e^-**

Signal: 222 ± 11 events
Background: 28 ± 2 events
Mass peak: 3.09 ± 0.01 GeV
Mass resolution: 0.07 ± 0.01 GeV

**J/ψ → μ^+μ^-**

PDG: 3.0969

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To extract signal from background:
- 2 EM clusters matched to tracks
- $p_T$ (e$^\pm$ tracks) > 4, 2 GeV
- Track quality, calo shower shapes
- Key handle: large transition radiation in TRT
- Invariant mass from track parameters after Brem recovery (GSF)

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Measurements results presented at this workshop by K. Toms
Muon performance

- LVL1 muon trigger with $p_T \sim 6$ GeV threshold
- 2 opposite-sign muons reconstructed by combining tracker and muon spectrometer
- both muons with $|z|<1$ cm from primary vertex

Prompt muon fraction in end-caps

$P_T$ muon resolution from collisions
Z→μμ candidate (collected on 10 May)

Event properties:
- $p_T(\mu^+) = 45$ GeV
- $\eta(\mu^+) = 2.2$
- $p_T(\mu^-) = 27$ GeV
- $\eta(\mu^-) = 0.7$
- $m_{\mu\mu} = 87$ GeV
Background estimation: QCD, μ

- “ABCD” method to predict background in signal region from control regions dominated by bkg (jets, π/K decays)
- **Uncorrelated** variables: ME\(_T\) and track Isolation/\(p_T\)
- QCD in signal region: \(0.9 \pm 0.3\) (stat) \(\pm 0.6\) (syst)
### W cross-section

<table>
<thead>
<tr>
<th>L (nb⁻¹)</th>
<th>Estimated N(signal)</th>
<th>cross-section (nb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>W(ev)</td>
<td>46</td>
<td>8.5 ± 1.3 (stat) ± 0.7 (syst) ± 0.9 (lumi)</td>
</tr>
<tr>
<td>W(μν)</td>
<td>72</td>
<td>10.3 ± 1.3 (stat) ± 0.8 (syst) ± 1.1 (lumi)</td>
</tr>
<tr>
<td>Combined</td>
<td>118</td>
<td>9.3 ± 0.9 (stat) ± 0.6 (syst) ± 1.0 (lumi)</td>
</tr>
</tbody>
</table>

**Theory:**

\[ \sigma_{\text{NNLO}}^{W \rightarrow \gamma^*} = 10.46 \text{ nb} \quad \sigma_{\text{NNLO}}^{W \rightarrow \gamma^*} = 6.16 \text{ nb} \quad \sigma_{\text{NNLO}}^{W \rightarrow \gamma^*} = 4.30 \text{ nb} \]

### Z cross-section

<table>
<thead>
<tr>
<th>L (nb⁻¹)</th>
<th>Estimated N(signal)</th>
<th>cross-section (nb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-225</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Z(ev)</td>
<td>46</td>
<td>0.72 ± 0.11 (stat) ± 0.10 (syst) ± 0.08 (lumi)</td>
</tr>
<tr>
<td>Z(μν)</td>
<td>79</td>
<td>0.89 ± 0.10 (stat) ± 0.07 (syst) ± 0.10 (lumi)</td>
</tr>
<tr>
<td>Combined</td>
<td>125</td>
<td>0.83 ± 0.07 (stat) ± 0.06 (syst) ± 0.09 (lumi)</td>
</tr>
</tbody>
</table>

**Theory:**

\[ \sigma_{\text{NNLO}}^{Z \rightarrow \gamma^* \rightarrow \ell \ell} = 0.99 \text{ nb} \quad (66 \text{ GeV} < M(\ell\ell) < 116 \text{ GeV}) \]

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**Remarkable agreement with theory (4% theor. uncertainty not shown)**

**W⁺⁻ asymmetry due to parton composition in protons observed**

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**First point at 7 TeV...**

- Good agreement with theory
- 4% theoretical uncertainty not shown
High mass quarkonia production

\( \Upsilon(1s, 2s, 3s) \rightarrow \mu \mu \) candidates

Level 1 muon trigger with no \( p_T \) cut

Cuts on muons: 2.5 and 4 GeV

Open charm and Onia summary

- Signals from \( D^{\pm}, D^{*} \) and \( D_s^{\pm} \) observed by the ATLAS detector with 1.4 nb\(^{-1}\) integrated luminosity
  - Signal yields: \( D^{\pm} (2020 \pm 120); D^{*} (1667 \pm 86); D_s^{\pm} (326 \pm 57) \)
  - Good agreement with PDG in reconstructed mass position
- \( J/\psi \) signal has been observed
  - Excellent agreement with MC predictions and PDG mass position
  - Now have enough statistics (6820\pm90) in peak with 290 nb\(^{-1}\) data for performance studies
  - Studies of these particles show tracking, vertexing and muon system working well, and in line with expectation
  - Expect to be making first ratio and differential production cross-section measurements shortly, with a strong program of measurements into the charmonium production mechanism to follow
Measured Inclusive jet cross-section extended up to jet $p_T = 500\text{ GeV/c}$ and dijet masses of 2 TeV
Data are well described by fixed-order NLO pQCD, corrected for non-perturbative effects
Search for new particles decaying in dijets

- Sensitive for possible new states in dijet resonances: excited quarks $q^*$, $Z'$, $W'$, graviton and others
- Tevatron exclusion for $q^*$: $260 < m_{q^*} < 870$ GeV @ 95% CL
- New ATLAS limit: $400 < m_{q^*} < 1290$ GeV @ 95% CL (more details here: http://arxiv.org/abs/1008.2461, paper submitted to PRL)
Inclusive jet measurements with ID: numbers of track distributions and fragmentation functions

Corrected fragmentation function in anti-$k_t$ jets with R = 0.6 for charged jet $p_T$ from 15 - 24 GeV

Number of tracks per jet with R = 0.6 for jet $p_T$ from 15 GeV to 24 GeV. (Data are not corrected. Differences between data and Pythia MC09 are accounted for the fragmentation/underlying event systematic.)

ATLAS Preliminary

$\int d\Omega = 370 \mu b^{-1}$

Data 2010 $\sqrt{s} = 7$ TeV
Pythia ATLAS MC09
anti-$k_t$ track jets R=0.6
15 GeV < $p_T$,Track Jet < 24 GeV

N track

Z track
Important for TOP measurements

b-jet identification rely on:
Tracks impact parameters
Secondary vertex reconstruction

Signed transverse impact parameter for b, c and light jets in MC simulation and Data

Tracks impact parameter resolution vs Pt and $\theta$

ATLAS Preliminary

L = 15 nb$^{-1}$
b-tagged jet in pp collisions at 7 TeV
One soft b-tagged jet in events with two electrons, passed cuts, at 7 TeV with int. luminosity 280 nb$^{-1}$

In GeV:
- $P_t$ of ee: 55.2/40.6
- $E_t^{\text{miss}}$: 42.4
- $H_t$: 271 GeV
- #jets $>20$ GeV - 3
- b-tag jet - 1

$M_{ee} = 36.9$ GeV

Top candidate
Red: Isolated muon track ($p_T = 48$ GeV); Green: isolated electron track pointing to a green Calo cluster ($E_T = 23$ GeV)
blue circle in lego plot: b-tagged jet. Dashed line in lego plot: direction of the missing transverse energy ($77$ GeV)

e + µ candidate!
Conclusion

- **ATLAS successfully operate with beam collisions** - pp at 7 TeV from 30.03.2010
- Calibration, alignment, synchronization, reconstruction software and trigger on real data were realized and continued with improvements
- Good detector and reconstruction performance is achieved
- First physics results for Soft QCD are received
- Hard QCD and EW objects are observed (jets, W/Z, tau, b-jet)
- Information on results could be found on [atlas.web.cern.ch](http://atlas.web.cern.ch) in Public ATLAS Results