Status and startup for physics with ATLAS

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Staged commissioning plan for protons

I. **Pilot physics run**
   - First collisions
   - 43 bunches, no crossing angle, no squeeze, moderate intensities
   - Push performance (156 bunches, partial squeeze in 1 and 5, push intensity)
   - Performance limit $10^{32} \text{ cm}^{-2} \text{s}^{-1}$ (event pileup)

II. **75ns operation**
   - Establish multi-bunch operation, moderate intensities
   - Relaxed machine parameters (squeeze and crossing angle)
   - Push squeeze and crossing angle
   - Performance limit $10^{33} \text{ cm}^{-2} \text{s}^{-1}$ (event pileup)

III. **25ns operation I**
   - Nominal crossing angle
   - Push squeeze
   - Increase intensity to 50% nominal
   - Performance limit $2 \times 10^{33} \text{ cm}^{-2} \text{s}^{-1}$

IV. **25ns operation II**
   - Push towards nominal performance

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<tr>
<th>Stage</th>
<th>Description</th>
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<tr>
<td>I</td>
<td>No beam</td>
</tr>
<tr>
<td>II</td>
<td>Beam commissioning</td>
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<tr>
<td>III</td>
<td>43 bunch operation</td>
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<td>IV</td>
<td>75ns ops</td>
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<td>V</td>
<td>25ns ops I</td>
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<td>VI</td>
<td>Install Phase II and MKB</td>
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<td>VII</td>
<td>25ns ops II</td>
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</tbody>
</table>

**Timeline:**
- **2007 ? up to 100 pb⁻¹ ?**
- **early 2008**
- **2008-2009**
- **≥ 2010**
- **O(100) fb⁻¹**
Length: ~45 m
Radius: ~12 m
Weight: ~7000 tons
Electronic channels: ~10^8
~3000 km of cables

• **Tracking** (|η|<2.5, B=2T):
  - Si pixels and strips
  - Transition Radiation Detector (e/π separation)

• **Calorimetry** (|η|<5):
  - EM: Pb-LAr
  - HAD: Fe/scintillator (central), Cu/W-LAr (fwd)

• **Muon Spectrometer** (|η|<2.7):
  - air-core toroids with muon chambers
Barrel toroid: cool down starting April 2006, first full current excitation end of May

End-cap toroids will go to the pit in August and November 2006
End of February: barrel SCT inserted into the barrel TRT → ready for the installation in the pit in June 2006

Each of 4 Si layer tested: 99.7% of channels fully functional
TRT: will contribute to tracking and to electron/pion separation by detecting transition radiation X-rays in gas mixture with ~ 70% Xe

Two completed end-cap Pixel disks, each with 2.2 M channels

Cosmic muon registered in the barrel TRT in surface clean room

Inner Detector end-caps in the pit in October-November 2006
Barrel calorimeter (EM LAr + Fe/scintillator Tilecal) in final position at Z=0
Cool down of barrel EM calorimeter started
(barrel and end-cap LAr calorimeters tested at cold on the surface: <1% of dead channels)
First end-cap calorimeter (EM, HAD LAr, FCAL inside common cryostat plus Tilecal) temporarily moved to final position; second end-cap being assembled in the pit.

ATLAS calorimetry cold and fully operational end 2006
MUON SPECTROMETER Measurement chambers: MDT, CSC (innermost forward) Trigger chamber: RPC (barrel), TGC (end-cap)

Construction completed; now assembly, integration, cosmic ray tests, installation

Barrel chamber installation to be completed end Summer 2006
Spectacular operations …
The pre-series of final TDAQ system with 8 racks (10% of final dataflow) is now in operation at the pit site.
Towards Physics: the 2004 combined test beam

Full “vertical slice” of ATLAS tested on CERN H8 beam line May-November 2004

Geant4 simulation of test-beam set-up

Monitored Drift Tubes & Resistive Plate Chamber

Monitored Drift Tubes-Cathode Strip Chamber-Thin Gap Chamber end-cap

Tile hadronic barrel calorimeter & ext.

Liquid Argon electromagnetic calorimeter

Transition Radiation Tracker

Magnet

SCT

Pixel

O(1%) of ATLAS

Production modules in most cases

All ATLAS sub-detectors (and LVL1 trigger) integrated and run together with common DAQ and monitoring, “final” electronics, slow-control, etc. Data analyzed with common ATLAS software. 6 month run.
~ 90 million events collected
~ 4.5 TB of data:
e\pm, \pi\pm \rightarrow 250 \text{ GeV}
\mu\pm, \pi\pm, p \rightarrow \text{up to 350 GeV}
\gamma \rightarrow 20-100 \text{ GeV}
B-field (ID) = 0 \rightarrow 1.4 \text{ T}

Many configurations
(e.g. additional material in ID, 25 ns runs, etc.)
Towards Physics: cosmics ….

From ATLAS simulations and measurements in the underground cavern: rate is ~ Hz
→ expect few $10^6$ events in ~ 2 months of data taking (at 30% efficiency)
→ enough for initial shake-down, to catalog problems, to gain operation experience,
  for detector synchronization, for initial calibration/alignment

First cosmic muons observed by ATLAS in the pit on 20/6/2005
(recorded by hadron Tilecal calorimeter)

Tower energies:
~ 2.5 GeV
Cosmics test for ID

- Final TRT barrel
- Final SCT barrel
- 1 sector cabled for both
**Which detector performance on day one?**

Based on detector construction quality, test-beam results, cosmics, simulation

<table>
<thead>
<tr>
<th></th>
<th>Expected performance day 1</th>
<th>Physics samples to improve</th>
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<tbody>
<tr>
<td>ECAL uniformity</td>
<td>~ 1%</td>
<td>Minimum-bias, $Z \rightarrow ee$</td>
</tr>
<tr>
<td>$e/\gamma$ scale</td>
<td>~ 2%</td>
<td>$Z \rightarrow ee$</td>
</tr>
<tr>
<td>HCAL uniformity</td>
<td>~ 3%</td>
<td>Single pions, QCD jets</td>
</tr>
<tr>
<td>Jet scale events</td>
<td>&lt; 10%</td>
<td>$Z (\rightarrow \ell \ell) +1j, W \rightarrow jj$ in $tt$</td>
</tr>
<tr>
<td>Tracking alignment</td>
<td>20-200 $\mu$m in $R\phi$ ?</td>
<td>Generic tracks, isolated $\mu$, $Z$</td>
</tr>
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</table>

Ultimate statistical precision achievable after few weeks of operation. Then face systematics....

E.g. : tracker alignment:

100 $\mu$m (1 month) $\rightarrow$ 20$\mu$m (4 months) $\rightarrow$ 5 $\mu$m (1 year) ?
In the new physics era! The first 10-100 pb⁻¹

Understand/calibrate detector and trigger in situ using “candles” samples
  e.g.  - Z → ee, μμ tracker, ECAL, muon chamber calibration and alignment, etc.
  - tt → blν bjj jet scale from W→jj, b-tag performance, etc.

Understand basic SM physics at √s = 14 TeV
  - measure cross-sections for e.g. minimum bias, W, Z, tt, QCD jets (to ~20 %),
  - start to tune Monte Carlo
  - measure top mass (to ~ 7 GeV ?) → give feedback on detector performance
  Note: statistical error negligible with O(10 pb⁻¹)

Prepare the road to discovery:
  - measure backgrounds to New Physics: e.g. tt and W/Z+ jets (omnipresent …)
  - look at specific “control samples” for the individual channels:
    e.g. ttjj with j ≠ b “calibrates” ttbb irreducible background to ttH → ttbb

Look for New Physics potentially accessible in first year(s)
  e.g. Z’, SUSY, Higgs ?
How many events per experiment at the beginning?

- 10 pb⁻¹ ≡ 1 month at 10³⁰ and < 2 weeks at 10³¹, ε=50%
- 100 pb⁻¹ ≡ few days at 10³², ε=50%

Assumed selection efficiency:
W → ℓν, Z → ℓℓ : 20%
tt → ℓν+X : 1.5% (no b-tag, inside mass bin)

Similar statistics to CDF, D0 today

+ lots of minimum-bias and jets (10⁷ events in 2 weeks of data taking if 20% of trigger bandwidth allocated)

End 2007?
Knowledge of SM physics on day 1?

\[ \text{W, Z cross-sections: to 3-4\% (NNLO calculation \rightarrow dominated by PDF)} \]
\[ \text{tt cross-section to \sim 7\% (NLO+PDF)} \]

\[ <N_{ch}> \text{ at } \eta = 0 \text{ for generic pp collisions (minimum bias)} \]

Candidate to very early measurement:
- few \(10^4\) events enough to get \(dN_{ch}/d\eta, dN_{ch}/dp_T\)
- \(\rightarrow\) tuning of MC models
- \(\rightarrow\) understand basics of pp collisions, occupancy, pile-up, …

Lot of progress with NLO matrix element
- MC interfaced to parton shower MC
  - (MC@ NLO, AlpGen, … )

LHC?
Minimum Bias

Not exactly what the LHC was built for! But…..

- Physics: measure $dN/d\eta|\eta=0$
  - Compare to NSD data from SppS and Tevatron
- MB samples for pile-up studies
  - Calorimeter
  - Physics analyses
- Overlap with UE
  - analyses eg VBF, Jets…
- Demonstrate that ATLAS is operational
  - Intercalibrate detector elements
    - Uniform events
  - Alignment
- **Event characteristics**
  - Non-single diffractive~non-diffractive inelastic
  - Soft tracks: $p_T^{\text{peak}} \sim 250\text{MeV}$
  - Approx flat distribution in $\eta$ to $|\eta| \sim 3$ and in $\phi$
  - $N_{\text{ch}} \sim 30; |\eta| < 2.5$

- **Trigger rates**
  - $\sigma \sim 70\text{mb (NSD!)}$
  - $R \sim 700\text{kHz @ } L = 10^{31}\text{cm}^{-2}\text{s}^{-1}$
  - For $dN/d\eta$ require $\sim 10k$
  - For UE need $\sim 20M$ MB events to get some with leading jets $P_T \sim 30\text{GeV}$
Tracking: Startup-Initial Alignment

- Very first alignment based on:
  - Mechanical precision
  - Detailed survey data
  - Cosmics data (SR1/Pit)
  - Minimum bias events and inclusive \(_bb\)

Studies indicate good \(\varepsilon\) after initial alignment

- Precision will need Zs and resonances to fix energy scales, constrain twists, etc…
Tracking in MB events

- Acceptance limited in $\eta$ and $p_T$
- Rapidity coverage
  - Tracking covers $|\eta|<2.5$
- $p_T$ problem
  - Need to extrapolate by $\sim x2$
  - Need to understand low $p_T$ charge track reconstruction

![Graph](image)

$\frac{dN_{ch}}{d\eta}$

Black = Generated (Pythia6.2)
Blue = TrkTrack: iPatRec
Red = TrkTrack: xKalman

Reconstruct tracks with:
1) $p_T>500\text{MeV}$
2) $|d_0|<1\text{mm}$
3) # B-layer hits $\geq 1$
4) # precision hits $\geq 8$
What is the momentum limit?

- Tracker is in principle sensitive to soft tracks
  \[ P_T = 400 \text{ MeV} \] - tracks reach end of TRT
  \[ P_T = 150 \text{ MeV} \] - tracks reach last SCT layer
  \[ P_T = 50 \text{ MeV} \] - tracks reach all Pixel layers

→ Do not need to run with low field
PDFs

- In most of relevant x regions accessible at LHC, HERA data are important source of information in PDF determinations (low-x sea and gluon PDFs)

- HERA now in second stage of operation (HERA-II)
  - substantial increase in luminosity
  - possibilities for new measurements

- HERA-II projection: improvement to high-x PDF uncertainties
  ⇒ relevant for high-scale physics at the LHC
  → where we expect new physics !!

- significant improvement to valence-quark uncertainties over all-x

- significant improvement to sea and gluon uncertainties at mid-to-high-x

- little visible improvement to sea and gluon uncertainties at low-x
Gluon fractional error

- $Q^2 = 100 \text{ GeV}^2$
- $Q^2 = 1000 \text{ GeV}^2$
- $Q^2 = 10000 \text{ GeV}^2$
- $Q^2 = 30000 \text{ GeV}^2$
- $Q^2 = 50000 \text{ GeV}^2$
- $Q^2 = 100000 \text{ GeV}^2$

Legend:
- NO-JETS fit
- ZEUS-JETS fit
- HERA-II projected fit

$x$-axis: $10^{-4}$ to 1
$y$-axis: $-0.4$ to 0.4
LHC Kinematic regime

Kinematic regime for LHC much broader than currently explored

Test of QCD:

- Test DGLAP evolution at small $x$:
  - Is NLO DGLAP evolution sufficient at so small $x$?
  - Are higher orders $\sim \alpha_s^n \log^m x$ important?
- Improve information of high $x$ gluon distribution

At TeV scale New Physics $\sigma$’s predictions are dominated by high-$x$ gluon uncertainty (not sufficiently well constrained by PDF fits)

At the EW scale theoretical predictions for LHC are dominated by low-$x$ gluon uncertainty (i.e. $W$ and $Z$ masses) => see later slides

How can we constrain PDF’s at LHC?
$W \rightarrow e\nu$ rapidity distributions

$x_{1,2} = \frac{M}{\sqrt{s}} \exp(\pm y)$

- $W$ production over $|y|<2.5$ at LHC involves $10^{-4} < x_{1,2} < 0.1$
- Region dominated by $g \rightarrow qq$

**HERWIG MC Simulations with NLO Corrections**

At $y=0$ the total PDF uncertainty is

- $\sim \pm 5.2\%$ from ZEUS-S
- $\sim \pm 3.6\%$ from MRST01E
- $\sim \pm 8.7\%$ from CTEQ6.1M

- ZEUS-S to MRST01E central value difference $\sim 5\%$
- ZEUS-S to CTEQ61 central value difference $\sim 3.5\%$

**Error boxes are the Full PDF Uncertainties**

**ATLAS Detector Level with sel. cuts**

**GOAL: syst. exp. error $\sim 4\%$**
Simulate real experimental conditions:
Generate 1M “data” sample with CTEQ6.1 PDF through ATLFAST detector simulation and then include this pseudo-data (with imposed 4% error) in the global ZEUS PDF fit (with Det.->Gen. level correction).
Central value of ZEUS-PDF prediction shifts and uncertainty is reduced:

**ZEUS-PDF BEFORE including W data**

**ZEUS-PDF AFTER including W data**

**low-x gluon** shape parameter $\lambda$, $xg(x) \sim x^{-\lambda}$

BEFORE $\lambda = -0.199 \pm 0.046$
AFTER $\lambda = -0.181 \pm 0.030$

41% error reduction

Systematics (e.g. $e^\pm$ acceptance vs $\eta$) can be controlled to few % with $Z \rightarrow ee$

(N ~ 30000 events for 100 pb$^{-1}$)
Top events to calibrate ATLAS!

Large ttbar production cross section at LHC
Effect of large $\sqrt{s}$ at LHC $\rightarrow$ threshold for ttbar production at lower $x$

$X = s x_1 x_2 ; \quad x_1 x_2 \sim 10^{-3}$

$\sigma_{tt}(\text{tot}) = 759 \pm 100 \text{ pb}$

qq$\rightarrow$tt
Dominate at Tevatron

$\sigma$ about 100 times larger than at Tevatron (lumi also much larger)

N$_{\text{evt}} \sim 700$/hour
Expect ~ 100 events inside mass peak with only 30 pb⁻¹
→top signal observable in early days with no b-tagging and simple analysis
→W+jets background can be understood with MC+data (Z+jets)

tt excellent sample to:
- commission b-tagging, set jet E-scale using W→jj peak and MW constraint
- understand detector performance and reconstruction tools
  (e, μ, jets, b-jets, missing E_T, ..)
- understand / tune MC generators using e.g. p_T spectra
Early discovery: Z’ with SM-like couplings

<table>
<thead>
<tr>
<th>Mass</th>
<th>Expected events for 1 fb⁻¹ (after all cuts)</th>
<th>∫L dt needed for discovery (corresponds to 10 observed evts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 TeV</td>
<td>~ 160</td>
<td>~ 70 pb⁻¹</td>
</tr>
<tr>
<td>1.5 TeV</td>
<td>~ 30</td>
<td>~ 300 pb⁻¹</td>
</tr>
<tr>
<td>2 TeV</td>
<td>~ 7</td>
<td>~ 1.5 fb⁻¹</td>
</tr>
</tbody>
</table>

• large enough signal sample with ∫L dt ~ 100 pb⁻¹ up to m ≈ 1 TeV if “reasonable” Z’ee couplings

• dominant Drell-Yan background small (< 0.2 events in the region 1.4-1.6 TeV, 100 pb⁻¹)

• signal as mass peak on top of background

Z → ll +jet samples and DY needed for E-calibration and determination of lepton efficiency
Early discovery: SUSY?

If SUSY stabilizes $m_H \rightarrow$ at TeV
$\rightarrow$ could be found quickly ....

thanks to:

- large $\tilde{q}\tilde{q}, \tilde{q}\tilde{g}, \tilde{g}\tilde{g}$ cross-section $\rightarrow$
  $\approx$10 events/day at $10^{32}$ with
  $m(\tilde{q}, \tilde{g}) \sim 1$ TeV

- spectacular signatures (many jets, leptons, missing transverse energy)

With 100 (good) pb$^{-1}$ LHC can say if
SUSY accessible to 1 TeV linear collider

But: it will take a lot time to understand
detectors and backgrounds ...
Main backgrounds to SUSY searches in jets + $E_T^{\text{miss}}$ topology (one of the most “dirty” signatures ...):

- $W/Z + \text{jets}$ with $Z \rightarrow \nu\nu$, $W \rightarrow \tau\nu$, $tt$; etc.
- QCD multijet events with fake $E_T^{\text{miss}}$ from jet mis-measurements (calorimeter resolution and non-compensation, cracks, ...)
- cosmics, beam-halo, detector problems overlapped with high-$p_T$ triggers,

Estimate backgrounds using as much as possible data (control samples) and MC

Understanding $E_T^{\text{miss}}$ spectrum:

<table>
<thead>
<tr>
<th>Background process (examples ....)</th>
<th>Control sample (examples ....)</th>
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<tbody>
<tr>
<td>$Z (\rightarrow \nu\nu) + \text{jets}$</td>
<td>$Z (\rightarrow ee, \mu\mu) + \text{jets}$</td>
</tr>
<tr>
<td>$W (\rightarrow \tau\nu) + \text{jets}$</td>
<td>$W (\rightarrow e\nu, \mu\nu) + \text{jets}$</td>
</tr>
<tr>
<td>$tt \rightarrow b\nu b\nu$</td>
<td>$tt \rightarrow b\nu b\nu$</td>
</tr>
<tr>
<td>QCD multijets</td>
<td>lower $E_T$ sample</td>
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</tbody>
</table>

one of most crucial experimental issues for SUSY searches at hadron colliders. Note: can also use final states with leptons (cleaner ...)

Early discovery: Higgs?

K-factors ≡ σ(NLO)/σ(LO) ≈ 2 not included

1 fb⁻¹: 95% C.L. exclusion
5 fb⁻¹: 5σ discovery
over full allowed mass range

$m_H \sim 115$ GeV

<table>
<thead>
<tr>
<th>ATLAS</th>
<th>$H \rightarrow \gamma\gamma$</th>
<th>$ttH \rightarrow ttbb$</th>
<th>$qqH \rightarrow qq\tau\tau$ (ll + l-had)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>130</td>
<td>15</td>
<td>~ 10</td>
</tr>
<tr>
<td>B</td>
<td>4300</td>
<td>45</td>
<td>~ 10</td>
</tr>
<tr>
<td>S/\sqrt{B}</td>
<td>2.0</td>
<td>2.2</td>
<td>~ 2.7</td>
</tr>
</tbody>
</table>

total $S/\sqrt{B} \approx 4^{+2.2}_{-1.3}$
Each channel contributes $\sim 2\sigma$ to total significance → observation of all channels important to extract convincing signal in first year(s)

3 channels are complementary → robustness:

- different production and decay modes
- different backgrounds
- different detector/performance requirements:
  - ECAL crucial for $H \rightarrow \gamma\gamma$ (in particular response uniformity) : $\sigma/m \sim 1\%$ needed
  - b-tagging crucial for $ttH$ : 4 b-tagged jets needed to reduce combinatorics
  - efficient jet reconstruction over $|\eta| < 5$ crucial for $qqH \rightarrow qq\tau\tau$
    - forward jet tag and central jet veto needed against background

Note: -- all require “low” trigger thresholds
  - E.g. $ttH$ analysis cuts : $p_T (l) > 20$ GeV, $p_T$ (jets) > 15-30 GeV
  - all require very good understanding (1-10%) of backgrounds
Conclusions

- **Main goals for 2007:**
  - complete installation by February 2007
  - deliver first collisions in Summer 2007

- **Emphasis now on integration, installation, commissioning:**
  Unprecedented complexity, technology and performance

- **With first data measure and understand:**
  - detector performance in situ ↔ physics
  - particle multiplicity in minimum bias
  - QCD jets (>10^3 events with E_T (j) > 1 TeV with 100 pb^{-1}) and UE
  - W,Z cross-sections: to 15% with <10 pb^{-1} and 10% with 100 pb^{-1}?
  - top signal with ~ 30 pb^{-1}
  - σ(tt) to 20% and M_{top} to 7-10 GeV with 100 pb^{-1}?
  - PDF (low-x gluons !) with W/Z (O(100) pb^{-1} ?)
  - first tuning of MC (MB, UE, tt, W/Z+jets, QCD jets,...)
And, later on ....

The LHC will explore in detail the highly-motivated TeV-scale with a direct discovery potential up to $m \approx 5-6$ TeV

- if New Physics is there, the LHC will find it
- it will say the final word about the SM Higgs mechanism and many TeV-scale predictions
- it may add crucial pieces to our knowledge of fundamental physics → impact also on astroparticle physics and cosmology
- It will tell us which are the right questions to ask, and how to go on
CERN Building 40 (ATLAS and CMS building)