ATLAS Status and performance
Recorded luminosity in 2012
Measured with forward detectors, calibrated with beam separation scans

ATLAS integrated luminosity in 2012

- Peak $L = 7.7 \times 10^{33}$ s$^{-1}$cm$^{-2}$ (Aug)
- Max $L$/fill: 237 pb$^{-1}$ (June)
- Weekly record: 1350 pb$^{-1}$ (June)
- Longest stable beams: 22.8 h (July)
- Fastest turn-around between stable beams: 2.1 h (April)
- Best weekly data-taking efficiency: 92 h (55%) (July)

At $L = 7 \times 10^{33}$ s$^{-1}$cm$^{-2}$ and 8 TeV $pp$ collisions, 560 Higgs bosons of mass 125 GeV ($\sigma_{pp\rightarrow H} = 22.3$ pb) are produced in ATLAS and CMS per hour

Or: every 45 min. $1 H \rightarrow \gamma\gamma$, need ~2 typical 160 pb$^{-1}$ fills to produced one $H \rightarrow 4l$ ($l=e/\mu$)
Luminosity and pileup in 2012
Measured with forward detectors, calibrated with beam separation scans

Peak luminosity & pileup profiles

Current 2012 luminosity uncertainty 3.6%
• Dominated by non-linearities in beam profiles of April & July 2012 van-der-Meer scans

New van-der-Meer scan performed 22 Nov ($\beta^* = 11m$)
• First look promising: Gaussian shapes
• 3D beam shaping in injectors pays off

Luminosity profile during Nov 22 van-der-Meer scan

Test fits of horizontal (left) and vertical (right) scan profiles
In general, do not expect a significant impact on tracking, nor muons, nor even electrons and photons

However, sizable impact on jets, $E_T^{\text{miss}}$ and tau reconstruction as well as on trigger rates and computing

$Z \rightarrow \mu\mu$ event in ATLAS with 25 reconstructed vertices Display with track $p_T$ threshold of 0.4 GeV and all tracks are required to have at least 3 Pixel and 6 SCT hits
Stability of electron energy response versus pileup
With bipolar LAr pulse shape bunch-integrated pileup contribution cancels*

Reconstructed $e$ energy in $Z \rightarrow ee$ and $W \rightarrow e\nu$ $(E/p)$

- **Left plot:** relative stability versus $<\mu>$ better than 0.1%
- **Center:** however, energy rise versus *number of vertices* seen: expected from in-time versus out-of time selection bias
- **Right:** data / MC ratio: effect well reproduced by simulation

*Designed for 25 ns bunches and uniform bunch luminosity*
$E_T^{\text{miss}}$ and tau reconstruction versus pileup

Pileup dependence from soft activity in calorimeter

Including tracking information helps to mitigate effects from pileup interactions

$E_T^{\text{miss}}$ resolution in $Z \rightarrow \mu\mu$ events with and without soft-term vertex fraction correction

![Graph showing $E_T^{\text{miss}}$ resolution versus number of reconstructed vertices](image)

$Z \rightarrow \mu\mu$  
$\sqrt{s} = 8 \text{ TeV}$  
$\int L dt = 1.7 \text{ fb}^{-1}$  
0 jets $p_T > 20 \text{ GeV}$

ATLAS Preliminary

Sigma (E_{T}^{miss}) [GeV]  
Number of reconstructed vertices

- MC12 default
- MC12 Pile-up suppression STVF
- Data 2012 default
- Data 2012 Pile-up suppression STVF

Tau BDT reconstruction efficiencies versus number of vertices

![Graph showing Tau BDT reconstruction efficiencies](image)

- Multi Prong
- $p_T > 20 \text{ GeV}, |\eta| < 2.3$

Efficiencies predicted by PYTHIA8 MC

Tested in data with $Z \rightarrow \tau\tau$ tag-and-probe analysis

Background efficiencies measured from dijet data samples

ATLAS Preliminary
Flavour tagging

Understanding of $b$-tagging efficiencies crucial for many analyses ($SM, H \rightarrow bb, searches$)

Default tagger: ‘MV1’ neural network using other taggers as input

Several methods available to determine $b$-tagging efficiency versus $b$-jet $p_T$. Compatible results found among all of them, including those using $tt$ and dijet events

Comparison of all $tt$-based scale factors with the combined scale factors from the $System8$ and $pT_{rel}$ calibration methods [see: ATLAS-CONF-2011-089]

Scale factors close to unity, systematic uncertainties between 5% and 15% versus $p_T$
**Data taking efficiency**

Continued excellent performance of detector, trigger and reconstruction

Average data taking efficiency: $\sim 94\%$
- Deadtime is dominant inefficiency source ($\sim 4\%$)

**Stable detector performance**

<table>
<thead>
<tr>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner Tracker</td>
</tr>
<tr>
<td>Pixel</td>
</tr>
<tr>
<td>100</td>
</tr>
</tbody>
</table>

**All good for physics: 93.7%**

Luminosity weighted relative detector uptime and good quality data delivery during 2012 stable beams in pp collisions at $\sqrt{s}=8$ TeV between April 4\textsuperscript{th} and September 17\textsuperscript{th} (in %) – corresponding to 14.0 fb\textsuperscript{-1} of recorded data. The inefficiencies in the LAr calorimeter will partially be recovered in the future.

**Total efficiency (delivered $\rightarrow$ physics): $\sim 88\%$**
2012 Trigger
Baseline menu designed for $L = 8 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$ and mostly unchanged during 2012 run

Average trigger rate during stable beam:

**ATLAS** Trigger Operation 2012

- Additional / looser $E_T^{\text{miss}}$ & tau as well as VBF triggers added to increase sensitivity for 125 GeV Higgs in $bb$ and $\tau\tau$ modes
- Prompt Tier-0 reconstruction
  - 0.8 B events so far
- Delayed reconstruction
  - 2.4 B events so far
- Average rate of 400 Hz over 2012 run for prompt trigger streams
  - (~1700 stable beam hours)
## Primary triggers in 2012

*Looser selection available later in 2012 data in either prompt or delayed streams*

<table>
<thead>
<tr>
<th>Signature</th>
<th>Offline selection</th>
<th>Trigger selection</th>
<th>L1 Peak (kHz)</th>
<th>EF Ave (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>L1</td>
<td>EF</td>
<td>L_peak = 7\times 10^{33}</td>
</tr>
<tr>
<td></td>
<td>Single electron $p_T &gt; 25$ GeV</td>
<td>18 GeV</td>
<td>24 GeV</td>
<td>17</td>
</tr>
<tr>
<td>Two leptons</td>
<td>$2$ muons $p_T &gt; 6$ GeV</td>
<td>$2 \times 6$ GeV</td>
<td>$2 \times 6$ GeV</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>$2$ muons $p_T &gt; 15$ GeV</td>
<td>$2 \times 10$ GeV</td>
<td>$2 \times 13$ GeV</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>$2$ muons $p_T &gt; 20, 10$ GeV</td>
<td>15 GeV</td>
<td>18.8 GeV</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>$2$ electrons, each $p_T &gt; 15$ GeV</td>
<td>$2 \times 10$ GeV</td>
<td>$2 \times 12$ GeV</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>$2$ taus $p_T &gt; 45, 30$ GeV</td>
<td>15,11 GeV</td>
<td>29,20 GeV</td>
<td>12</td>
</tr>
<tr>
<td>Two photons</td>
<td>$2$ photons, each $p_T &gt; 25$ GeV</td>
<td>$2 \times 10$ GeV</td>
<td>$2 \times 20$ GeV</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>$2$ loose photons, $p_T &gt; 40, 30$ GeV</td>
<td>12,16 GeV</td>
<td>35, 25 GeV</td>
<td>6</td>
</tr>
<tr>
<td>Single jet</td>
<td>Jet $p_T &gt; 360$ GeV</td>
<td>75 GeV</td>
<td>360 GeV</td>
<td>2</td>
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<tr>
<td>$E_T^{\text{miss}}$</td>
<td>$E_T^{\text{miss}} &gt; 120$ GeV</td>
<td>40 GeV</td>
<td>80 GeV</td>
<td>2</td>
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<tr>
<td>Multi-jets</td>
<td>$5$ jets, each $p_T &gt; 60$ GeV</td>
<td>4\times 15 GeV</td>
<td>5 \times 55 GeV</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>$6$ jets, each $p_T &gt; 50$ GeV</td>
<td>4\times 15 GeV</td>
<td>6 \times 45 GeV</td>
<td>1</td>
</tr>
<tr>
<td>$b$-jets</td>
<td>$b + 3$ other jets $p_T &gt; 45$ GeV</td>
<td>$4 \times 15$ GeV</td>
<td>$4 \times 45$ GeV + b-tag</td>
<td>1</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>$&lt; 75$</td>
<td>$\sim 400$ (ave)</td>
<td></td>
</tr>
</tbody>
</table>
2012 high pileup challenge

- 6k CPUs in Tier-0 (up to 7.5k when heavy load)
- Reco. time / event: 10–50 sec for $\langle \mu \rangle = 5–50$

Reprocessing of 2012 data ongoing (~2B events)

- Conditions updates only (calibration & alignment, data quality, other fixes), no MC reprocessing
ATLAS Physics

ATLAS publications
http://atlasresults.web.cern.ch/atlasresults

On Nov 30:
- ATLAS produced 220 papers using collision data
- 421 preliminary conference notes

Small extract of huge amount of results available
ATLAS Physics — Recent Highlights

Standard Model Physics

Available statistics allows to perform powerful fiducial and differential and cross-section measurements even in rare channels as dibosons
**Differential $\Upsilon(1S/2S/3S)$ production cross-section**

Sensitivity greatly improved compared to previous measurements (increased $p_T$ range)

**Dimuon final state for $p_T(\mu) > 4$ GeV, $|\eta_\mu| < 2.3$**

- Comparison of the three states interesting because of contributions from direct production and feed-down from decays of higher mass states ($\Upsilon$'s, $\chi$'s)
- Comparison with theory models reveals problems at high $p_T$

---

**Fiducial cross section**

\[ \frac{d^2\sigma}{dp_T^2} \cdot \frac{dy}{dy} \cdot \text{Br}(\Upsilon \rightarrow \bar{\mu}^+\mu^-) \quad [\text{pb/GeV}] \]

**Corrected cross section**

\[ \frac{d^2\sigma}{dp_T^2} \cdot \frac{dy}{dy} \cdot \text{Br}(\Upsilon(1S) \rightarrow \bar{\mu}^+\mu^-) \quad [\text{pb/GeV}] \]

**ATLAS**

$\sqrt{s} = 7$ TeV $\int L dt = 1.8$ fb$^{-1}$

**Data**

$\sqrt{s} = 7$ TeV $\int L dt = 1.8$ fb$^{-1}$

**Spin-alignment envelope**

**NNLO* CSM (corrected)**

**CEM (corrected)**

Extreme spin alignment scenarios in envelope
**W and Z physics — differential measurements**

Large statistics allows precise tests of generators/theory, PDFs and bkg to searches

**Measurement of W + b-jets fiducial (p_T > 25 GeV, |\eta| < 2.1) & differential cross section**

Fiducial cross section within 1.5\sigma of theory prediction

p_T spectrum harder in data, but compatible within uncertainties with generators
Diboson physics: \(WW, WZ, ZZ, W\gamma, Z\gamma, \gamma\gamma\)

**ATLAS** performed total, fiducial & differential diboson cross-sections measurements

Measured 11 diboson fiducial cross-sections: most are slightly above theory expectation (but syst. and theo. errors correlated)

---

**Examples for differential cross section measurements:** \(WW, ZZ\) (7 TeV, 4.6 fb\(^{-1}\))

So far, satisfying agreement with NLO generators, also for mass spectra. Same for \(WZ\)

Also searched for diboson resonance production (\(ZZ\) [8 TeV, ATLAS-CONF-2012-150], \(W\gamma, Z\gamma\))
Diboson physics: \( WW, WZ, ZZ, W\gamma, Z\gamma, \gamma\gamma \)

ATLAS performed total, fiducial & differential diboson cross-sections measurements

Measured 11 diboson fiducial cross-sections: most are slightly above theory expectation (but syst. and theo. errors correlated)

See last week’s ATLAS diboson seminar by Shih-Chieh Hsu: http://indico.cern.ch/conferenceDisplay.py?confId=218398

Examples for differential cross section measurements: \( W\gamma, Z\gamma \) (7 TeV, 4.6 fb\(^{-1}\))

Too low incl. cross-section by MCFM (NLO, parton-level). Scaled ALPGEN/SHERPA (LO) with multiple quark/gluon emission in ME more accurate \( \rightarrow \) Similar for \( \gamma\gamma \) [1211.1913]
Top pair production cross-section measurement
Precision measurement already — all the work is on understanding systematics

Large variety of 7 TeV measurements public: 0/1/2-lepton (incl. taus) — agreement with theory
Measurement of 8 TeV cross-section in 1-lepton channel (5.8 fb⁻¹) using likelihood template fit

Inclusive $tt$ cross section
(using $m(t) = 172.5$ GeV):

$\sigma = 241 \pm 2$ (stat)
$\pm 31$ (syst)
$\pm 9$ (lumi) pb

Syst. dominated by MC signal modeling (ISR/FSR, generator, parton shower, PDF)

Agreement with theory:
$238^{+22}_{-24}$ pb (HATHOR, approx. NNLO)
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\]

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Agreement with theory:

\[
238^{+22}_{-24} \text{ pb} \quad \text{(HATHOR, approx. NNLO)}
\]
Understanding top pair production at the LHC

Top pairs in association with jets are dominant background for many BSM searches

Prelim. measurement of fiducial jet multiplicity in $t \bar{t}$ production (lepton+jets) at 7 TeV (4.7 fb$^{-1}$)

MC scaled to approx. NNLO inclusive prediction (as always)

Rapidity gap fraction(*) measurements vs. $|y|$ help to assess uncertainties related to ISR/FSR

Variation of $\alpha_{S}$ and PS parameters describes ISR/FSR uncertainties

Q$_{0}$ is the fraction of events with no additional jet radiated within a considered rapidity interval

LHCC Open Session, 5 Dec 2012

— ATLAS Status Report —
ATLAS Physics — Recent Highlights

Higgs (-like)

A new era, new challenges

Higgs physics moves from searches to measurements

Huge efforts spent on scrutinising systematic effects and designing robust analyses
Higgs status after Summer 2012

One new boson with Higgs-like properties ... nothing else around

Combination of 7 TeV (~4.7 fb\(^{-1}\)) and 8 TeV (~5.8 fb\(^{-1}\)) data

Discovery \(p\)-value with contributions from \(\gamma\gamma\), \(ZZ^*\) and \(WW\), slighter stronger signal than SM

For HCP 2012: update of \(H \rightarrow WW, \tau\tau, bb\) analyses with 13.0 fb\(^{-1}\) at 8 TeV
$H \rightarrow WW(\ast) \rightarrow e\mu + 2\nu$

Different-flavour channel and 8 TeV (13 fb$^{-1}$) uncombined result only for this update

Numerous relevant backgrounds: diboson, top, $W/Z$+jets, estimated from control regions

Distinguish 0/1 jet and leading lepton → 4 categories, main discrimination with: $m_{ll}$, $\Delta\phi_{ll}$, $m_T$
\[ H \rightarrow WW^{(*)} \rightarrow e\mu + 2\nu \]

Different-flavour channel and 8 TeV (13 fb\(^{-1}\)) uncombined result only for this update

Background subtracted transverse mass (stat errors only) with expected \(H(125)\) signal (left)
Background-only \(p\)-value (right)

\[ \mu(125) = 1.5 \pm 0.6 \quad \text{Significance (125): 2.6\sigma [ exp: 1.9\sigma ]} \]

\[ \sigma(pp \rightarrow H(125)) \cdot \text{BR}(H \rightarrow WW) = 7.0^{+1.7}_{-1.6} \text{(stat)}^{+1.7}_{-1.6} \text{(syst Theo)} \pm 1.3\text{(syst Exp)} \pm 0.3\text{(lumi)} \text{ pb} \]
$H \rightarrow \tau\tau$

Combined and reoptimised 7+8 TeV analysis

Build exclusive categories: lep-lep, lep-had, had-had and jets: 0, 1 (boosted or not), 2 (VBF, VH)

BDT-based tau identification, Higgs discrimination based on $m_{\tau\tau}$

Use MMC (missing mass calculator) to estimate $m_{\tau\tau}$, $\sigma(m_{\tau\tau}) = 13\% \sim 20\%$, best for boosted $\tau$

Backgrounds dominated by $Z \rightarrow \tau\tau$, use “$\tau$ embedded” $Z \rightarrow \mu\mu$, also top and fakes important
$H \rightarrow \tau\tau$ (doubly hadronic) candidate in VBF channel ($m_{\text{MMC}} = 131$ GeV)

Run Number: 209109, Event Number: 86250372
Date: 2012-08-24 07:59:04 UTC
$H \rightarrow \tau\tau$

Combined and reoptimised 7+8 TeV analysis → total of 25 exclusive fit categories

Available statistics allows meaningful VFB vs. non-VBF scan, similar sensitivity in both modes, but best VBF constraint from all Higgs decays

\[ \mu(125) = 0.7 \pm 0.7 \]

95% CL limit (125): 1.9 [ exp: 1.2 ] × SM / Significance (125): 1.1σ [ exp: 1.7σ ]
VH production with $H \rightarrow bb$

Combined and reoptimised 7+8 TeV analysis

Require 2 $b$-tags and distinguish 0, 1, 2 lepton channels, where 0-lepton uses $E_T^{\text{miss}}$ trigger
Higgs discrimination based on $m_{bb}$, resolution of $\sim 16\%$, improved by including muons
Categories in $E_T^{\text{miss}}$, jets, $p_T(V)$ [depending on channel] $\rightarrow$ reduced background for boosted Higgs
Obtain $W/Z + \text{light}/c/b \& \text{top}$ scale factors from flavour pre-fit, $W/Z+b$ and top vary in final fit
Dominant systematics from the $b$ and $c$ tagging and jet/$E_T^{\text{miss}}$ scales
$VH$ production with $H \rightarrow bb$

Combined and reoptimised 7+8 TeV analysis $\rightarrow$ 16 exclusive fit categories

Fitting cross check (left): detect expected $WZ$ and $ZZ$ peak with $Z \rightarrow bb$.
Plot sums over categories, all non-diboson bkgs subtracted. Significance of peak: $4\sigma$

$\mu(125) = -0.4 \pm 0.7\text{(stat)} \pm 0.8\text{(syst)} \ / \ 95\% \text{ CL limit (125): } 1.8 \ [\text{ exp: 1.9 }] \times \text{ SM}$
Updated Higgs combination

Simplest analysis only: combination of three new results to derive combined $\mu$

Previous result [July paper, using 7 TeV analyses of $\tau\tau$, $bb$, 5.8 fb$^{-1}$ analyses for $\gamma\gamma$, $ZZ$, $WW$] gave: $\mu = 1.4 \pm 0.3$

New result: $\mu = 1.3 \pm 0.3$

Compatibility with common $\mu$ is 36%

Compatibility with SM $\mu = 1$ is 23%

Higgs or Higgs-like, that is the ...
ATLAS Physics — Recent Highlights

Searches

LHC reaches deeply into matter

ATLAS responds with a broad and intense BSM research programme
ATLAS mines its data for new physics in events with jets ... gradually approaching the limits of phase space.
The highest-mass central dijet event collected. The two central high-$p_T$ jets have an invariant mass of 4.69 TeV.
ATLAS mines its data for new resonances decaying to top pairs ...

If the $Z'$ is very heavy, the outgoing tops will be strongly boosted; hadronic tops will be merged
A powerful semileptonic $tt$ resonance search w/ boosted techniques already presented last time

Maybe the $Z'$ is leptophobic and has topcolour only?
ATLAS mines its data for new resonances decaying to top pairs ... searching for $tt$ fully-hadronic resonances in boosted regime

Two methods identify merged hadronic top decays

- **HEP-Top-Tagger** uses substructure of “fat jets”
- **Top-Template-Tagger** uses calorimeter templates

Jet mass of leading jets in Top-Template-Tagger signal region

Leptophobic topcolour $Z'$ excluded up to 1 TeV at 95% CL

Boosted technique also exploited for other searches
ATLAS mines its data for new resonances in events with leptons ... for example: dilepton, like-sign dilepton, lepton-γ resonances

Dilepton resonance search: $m(Z'_{SSM}) > 2.49$ TeV (95% CL, 6.1 fb$^{-1}$) ATLAS-CONF-2012-129

Doubly charged Higgs produce narrow like-sign resonance

For compositeness scale $\Lambda = m(l^*)$: exclude excited leptons < 2.2 TeV (95% CL)
Supersymmetry

Not only that! Very rich phenomenology

Broad and deep SUSY research programme in ATLAS

See recent (Oct 23) ATLAS seminar by Nick Barlow reviewing results on long-lived particle searches with ATLAS
The scalar precipice

EW scale\(^{-1}\)

GUT scale\(^{-1}\)

Fundamental scalar length scale

---

Mrs. SUSY

Mr. Higgs

---

After ...

- 25 papers at 7 TeV with full 2011 statistics
- 13 preliminary 8 TeV results

No discovery yet ...

Limits from this model:

\[ m(\bar{q}) \approx m(\bar{g}) < 1.5 \text{ TeV} \]

\[ m(\bar{q}) < 1.4 \text{ TeV} \quad (\forall \ m(\bar{g}) < 2 \text{ TeV}) \]

\[ m(\bar{g}) < 1 \text{ TeV} \quad (\forall \ m(\bar{q}) < 2 \text{ TeV}) \]
“Natural” SUSY

Lightest squarks are stop/sbottom, gluinos possibly too heavy, gauginos accessible?

Lower cross-sections and larger SM backgrounds require dedicated searches

Strong & strategic approach by ATLAS

Gluino-mediated $\tilde{b}/\tilde{t}$ production

Direct $\tilde{b}/\tilde{t}$ pair production

Associated gaugino production

Direct slepton-pair production
“Natural” SUSY

Gluino-mediated stop production

Characteristic signatures:

Gluino-mediated stop/sbottom produces 4 $b$-quarks and/or multileptons, additional jets and $E_T$\text{miss} in finals state.
“Natural” SUSY

Direct sbottom production (here $2b + E_T^{\text{miss}}$ final state)

Direct sbottom production can lead to $2b + E_T^{\text{miss}}$ (shown here) or also to multilepton + jets + $E_T^{\text{miss}}$ final states

$m_{\text{CT}}$: boost-corrected contransverse mass

ATLAS Preliminary

\[ \int L \, dt = 12.8 \, fb^{-1}, \sqrt{s} = 8 \, TeV \]

<table>
<thead>
<tr>
<th>$m_{\tilde{b}^{\pm}_1}$ (GeV)</th>
<th>$m_{\tilde{\chi}_1^0}$ (GeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$100$</td>
<td>$100$</td>
</tr>
<tr>
<td>$200$</td>
<td>$200$</td>
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<td>$300$</td>
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<td>$600$</td>
<td>$600$</td>
</tr>
<tr>
<td>$700$</td>
<td>$700$</td>
</tr>
</tbody>
</table>

CDF: 2.65 fb$^{-1}$
D0: 5.2 fb$^{-1}$
ATLAS: 2.05 fb$^{-1}$, $\sqrt{s} = 7$ TeV
ATLAS: 4.7 fb$^{-1}$, $\sqrt{s} = 7$ TeV

All limits at 95% CL
“Natural” SUSY

Direct stop production, including decays to top + neutralino and $b +$ chargino

Direct stop production features similar final states as top pairs, searches use 0/1/2-lepton final states and depend on sparticle masses and stop decays

New results on 8 TeV 13 fb$^{-1}$ in 1-L and 2-L final states, optimising for stop $\rightarrow$ top + $N$ and stop $\rightarrow$ $b + C$ decays

$E_T^{\text{miss}}$ distributions in top + $N$ (left) and $b + C$ (right) signal regions [1-L analysis]

$m_{T2}$ distributions in $b + C$ (right) signal region [2-L analysis]
Direct stop search - status SUSY-12 workshop

\[ \tilde{t} \tilde{t}, \text{production: } \tilde{t}_1 \rightarrow b + \tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow W^+ + \tilde{\chi}_1^0 \text{ (BR=1, } m_{\tilde{t}_1} < 200 \text{ GeV)}; \tilde{t}_1 \rightarrow t + \tilde{\chi}_1^0 \text{ (BR=1, } m_{\tilde{t}_1} > 200 \text{ GeV)} \]

\[ \int L \, dt = 4.7 \text{ fb}^{-1}, \sqrt{s} = 7 \text{ TeV} \]

ATLAS

Observed limits (-1σ_{\text{SUSY}}^{\text{theory}})

Expected limits (nominal)

Observed limits (nominal)

All limits at 95% CL_{\text{b}}

\[ \tilde{t}_1 \rightarrow b + \tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow W^+ + \tilde{\chi}_1^0 \text{ (} m_{\tilde{t}_1} < 200 \text{ GeV)} \]

- 2-lepton (} m_{\tilde{t}_1} = 106 \text{ GeV)
- 1/2-leptons + b-jets (} m_{\tilde{t}_1} = 106 \text{ GeV)
- 1/2-leptons + b-jets (} m_{\tilde{t}_1} = 2 \times m_{\tilde{\chi}_1^0} \)

\[ \tilde{t}_1 \rightarrow t + \tilde{\chi}_1^0 \text{ (} m_{\tilde{t}_1} > 200 \text{ GeV)} \]

- 0-lepton
- 1-lepton
- 2-lepton

\[ m_{\tilde{\chi}_1^0} \text{ [GeV]} \]

\[ m_{\tilde{t}_1} \text{ [GeV]} \]
Significantly improved sensitivity at high stop mass with exp. limits up to 620 GeV (before 500 GeV)
Also, strongly enhanced sensitivity for lower mass stop decaying into $b + \text{chargino}$
Significantly improved sensitivity at high stop mass with exp. limits up to 620 GeV (before 500 GeV)
Also, strongly enhanced sensitivity for lower mass stop decaying into $b +$ chargino
There is still room at low mass – remember: our models are simplified
What about Dark Matter?
Detection of invisible particle production

Should we give up on natural SUSY and directly search for WIMP (dark matter) production in proton-proton collisions?

Exploit "ISR technique" (huge potential!)

Energetic gluon/photon radiation in the initial state

→ Search for mono-jets events

Interpretation in variety of models: extra dimensions, WIMP, gravitinos

\[ \int \text{Ldt}=10.5\text{fb}^{-1} \]

\[ \sqrt{s}=8\text{ TeV} \]

\[ \text{Data} / \text{BG} \]

\[ 0.5 \quad 1 \quad 1.5 \]

\[ 300 \quad 400 \quad 500 \quad 600 \quad 700 \quad 800 \quad 900 \quad 1000 \quad 1100 \quad 1200 \]

\[ E_T^{\text{miss}} \quad [\text{GeV}] \]

\[ \text{DIBOSONS} \]

\[ \text{ADD n=2, } M_\phi=670\text{GeV} \]

\[ \text{D5 M}=80\text{GeV}, M_{\phi}=10^{-4}\text{eV} \]

\[ \text{\bar{q}} + \bar{q}, M_{\phi}=1\text{TeV}, M_g=10^{-4}\text{eV} \]
What about Dark Matter?
Detection of invisible particle production

Should we give up on natural SUSY and directly search for WIMP (dark matter) production in proton-proton collisions?
Exploit “ISR technique” (huge potential!)

Energetic gluon/photon radiation in the initial state

\[ q \rightarrow q, \bar{q} \rightarrow \bar{q}, \chi \rightarrow \chi, \bar{\chi} \]

→ Search for mono-jets events

Complementarity between accelerator-based and space-based particle physics
ATLAS thoroughly studies signatures for new physics... 

Huge variety of models probed, but also model-independent results

**ATLAS Exotics Searches** - 95% CL Lower Limits (Status: HCP 2012)

<table>
<thead>
<tr>
<th>Mass [TeV]</th>
<th>Lower Limit</th>
</tr>
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<tr>
<td>3.0</td>
<td>4.7 fb</td>
</tr>
</tbody>
</table>

**Exotics Models:**

- Extra dimensions: RS KK Graviton (dibosons, dileptons, diphotons) RS KK gluons (top antitop)
- ADD (monojets, monophotons, dileptons, diphotons)
- KK Z/γ bosons (dileptons)
- Grand Unification symmetries (dielectons, dimuons, ditau)
- Leptophobic topcolor Z' boson (dilepton tbar+jet, all had)
- S8- color octet scalars (dijets)
- String resonance (dijets.)
- Benchmark Sequential SM Z' W' (lepton+MET, dijets, tb)
- W* (lepton+MET, dijets)
- Quantum Black Holes (dijet)
- Black Holes (t+jets, same sign leptons)
- Technihadrons (dileptons, dibosons)
- Dark Matter
  - WIMPs (Monojet, monophotons)
  - Excited fermions q*, Excited quarks (dijets, photon-jet)
  - t*, excited leptons (dileptons-photon)
- Leptoquarks (1st, 2nd, 3rd generations)
- Higgs → hidden sector
  - (displaced vertices, lepton jets)
- Contact Interaction
  - llqq CI
  - 4q CI (dijets)
- Doubly charged Higgs (multi leptons, same sign leptons)
- 4th generation
  - E'→Wb, t'→tb, b'→Wt (dileptons, same sign leptons, l+j)
- VLO-Vector Like quarks
- Magnetic Monopoles (and HIP)
- Heavy Majorana neutrino and RH W

**ATLAS Status Report**

LHCC Open Session, 5 Dec 2012
...and deeply mines SUSY signature and model space

Strong push on naturalness dedicated searches, but also long-lived particles and RPV

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**ATLAS SUSY Searches** - 95% CL Lower Limits (Status: Dec 2012)

![ATLAS SUSY Search Diagram]

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*Only a selection of the available mass limits on new states or phenomena shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.*
I attempted a (necessarily incomplete) overview of the ATLAS status and recent physics highlights after 3 years of running

— The accelerator (thanks to the LHC team!) and ATLAS detector are continuously delivering data of excellent quality and efficiency; 88% of the delivered luminosity is included in our physics results

— We strive to further improve the detector understanding and to cope with the pileup exceeding expectations

— The 2011 and 2012 data samples provide huge opportunities in all areas of the LHC physics programme

— ATLAS, as well as the other LHC experiments, has proven to deliver high-quality analyses. Fully exploiting the available data will engage the collaborations for years, and engages the theorists to continue improving MC tools allowing us to exploit our data for precision measurements and searches

— Measuring the properties of the new particle is a central pillar of the ATLAS physics programme. It needs all the prerequisites mentioned above. The Higgs-like boson also re-emphasises the importance of our searches

— Physics beyond the SM did not show up yet. There is no need for preliminary conclusions. Let’s continue our work and look were we haven’t looked so far
Extra slides...
LS1 and more

LS1 consolidation and upgrade work

• New Insertable Pixel B-layer (IBL) [installation either on surface (preferred) or in situ / decision end of Jan 2013]
• New Pixel service quarter panels (nSQP) [if IBL installed on surface]
• New ID evaporative cooling plant
• New Al forward beam pipe
• New calorimeter LVPS
• Consolidation of other detectors and infrastructure
• Complete muon spectrometer (EE, RPC, feet)
• Add specific muon shielding
• Upgrade magnet cryogenics
• Detector readout for Level-1 100 kHz rate

Towards the Phase-1 upgrade

• Lol submitted Marc 2012 / received strong support from LHCC
• Work for TDRs in full swift: four (new μ SW, FTK, LAr+Tiles, TDAQ) expected to be completed in 2013, AFP in 2014

LHC timeline

2009 Start of LHC
Run 1, 7+8 TeV, ~25 fb⁻¹ int. lumi
2013/14 LS1: prepare LHC for design E & lumi
Collect ~30 fb⁻¹ per year at 13/14 TeV
2018 Phase-1 upgrade for ultimate lumi
Twice nominal lumi at 14 TeV, ~100 fb⁻¹ per year
~2022 Phase-2 upgrade to HL-LHC
~300 fb⁻¹ per year, run up to > 3 ab⁻¹ collected
~2030
Integrated Simulation Framework (ISF) developments

Need to increase simulation flexibility to cope with vast MC needs: \sim 4B events / year

[ some fits, eg, W mass templates, require \(10^8\) events per parameter setting ]

Several analyses MC stat. limited (eg, \(H \rightarrow bb\), searches), all would benefit from more MC

ISF allows to mix into detector regions by particle type and dynamically per event:

- Full simulation (Geant4)
- Calorimeter shower parametrisation (FastCaloSim)
- Fast track simulation (Fatras)
- and possible future technologies

<table>
<thead>
<tr>
<th>MC sample for (gg \rightarrow H \rightarrow \gamma\gamma) (no pileup)</th>
<th>ISF exec time/event</th>
<th>Speed-up factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Geant4 (G4)</td>
<td>560 s</td>
<td>1</td>
</tr>
<tr>
<td>ATLFAST-2 (G4 + FastCaloSim)</td>
<td>25 s</td>
<td>\sim 25</td>
</tr>
<tr>
<td>ATLAST-2-F (ATLFAST-2 + Fatras)</td>
<td>0.75 s</td>
<td>\sim 750</td>
</tr>
<tr>
<td>FastGamma (ATLFAST-2-F with partial sim. only)</td>
<td>0.18 s</td>
<td>\sim 3000</td>
</tr>
</tbody>
</table>
Forward detectors: ALFA
2 LHC fills at $\beta^* = 1\text{ km}$ run on Oct 24/25

- De-squeeze to $\beta^* = 1\text{ km}$ in $\sim 45\text{ min}$
- Repeated scraping with primary collimators to $2\sigma$, followed by retraction to $2.5\sigma$ to reduce backgrounds
- About 10 h data taking with Roman Pots at $3\sigma$, about 0.85 mm distance to beam centers
- About 300k elastic events and many diffractive triggers recorded

$t$-range for $\beta^* = 1\text{ km}$
RPs at $3\sigma$, $\varepsilon = 2.4\text{ µm}$

$\epsilon_{\text{min}} \sim 0.0005\text{ GeV}^2$: first measurement in the Coulomb-Nuclear interference region
Beam induced backgrounds (BIB)

Measured with various subdetectors, monitored throughout the year

BIB rates low in 2012 as in 2011
- No significant change between years

BIB can nevertheless be harmful in searches
- Relatively loose cleaning applied everywhere
- Tighter cleaning in, eg, monojet analysis:
  require minimum charge and EM fractions for jets

ATLAS Preliminary

Data 2011, √s = 7 TeV

Events selected for the monojet analysis

“Two-sided method” requires Δt > 25 ns between forward and backward CSC muon segments to identify BIB

BCM background rates in unpaired bunched

ATLAS Preliminary
2012 Unpaired iso BCM Background rate per ATLAS run
Beam Energy 4 TeV

BCM: diamond sensors at z = ±1.8 m, |η| = 4.2,
total of 8 sensors with 8×8 mm² active area
**W and Z physics — differential measurements**

Large statistics allows precise tests of generators/theory, PDFs and bkg to searches

**Measurement of Z/γ**

\( \phi_\eta^* \) distribution

- \( \phi_\eta^* \) is measure of scattering angle of leptons wrt. \( z \) in \( Z/\gamma \) rest frame
- Depends on lepton angles only, more precisely measured than momenta
- \( \phi_\eta^* \) correlated to \( p_{T,z}/m_{\ell\ell} \)
  \( \rightarrow \) probes same physics

ResBos provides best description (within 4%), large deviations for POWHEG / MC@NLO

\[ \sqrt{s} = 7 \text{ TeV} \]
\[ |\eta| < 2.4 \]
\[ p_T > 20 \text{ GeV} \]
\[ 66 \text{ GeV} < m_{\ell\ell} < 116 \text{ GeV} \]
Diboson physics: $WW$, $WZ$, $ZZ$, $W\gamma$, $Z\gamma$, $\gamma\gamma$

ATLAS performed total, fiducial & differential diboson cross-sections measurements

Examples for differential cross section measurements: $\gamma\gamma$ (7 TeV, 4.9 fb$^{-1}$)

- **Rescaled LO PS generators describe spectra better than HO FO generators (DIPHOX, 2$\gamma$NNLO)** w/o soft gluon resummation

**Powerful test of perturbative QCD and quark fragmentation**

- “Direct” quark annihilation (dominant: $O(\alpha^2)$)
- Collinear fragmentation, $O(\alpha^2\alpha_s)$, but non-isolated $\gamma$
- Box diagram, $O(\alpha^2\alpha_s^2)$, but due to $gg$ luminosity comparable to LO terms
Diboson physics: $WW, WZ, ZZ, W\gamma, Z\gamma, \gamma\gamma$

ATLAS performed total, fiducial & differential diboson cross-sections measurements

Examples for differential cross section measurements: $\gamma\gamma$ (7 TeV, 4.9 fb$^{-1}$)

Fixed-order generators lack soft gluon resummation (IR divergence)

Powerful test of perturbative QCD and quark fragmentation

“Direct” quark annihilation (dominant: $O(\alpha^2)$)

Collinear fragmentation, $O(\alpha^2\alpha_s)$, but non-isolated $\gamma$

Box diagram, $O(\alpha^2\alpha_s^2)$, but due to $gg$ luminosity comparable to LO terms
Understanding top pair production at the LHC

Top pairs in association with jets probe ISR/FSR activity

Rapidity gap fraction(*) measurements vs. $|y|$ help to assess uncertainties related to ISR/FSR

ALPGEN+PYTHIA $\alpha_s$ up/down variations used in $t\bar{t}$ differential cross section measurement

Satisfying description for $|y| < 1.5$, but for large $|y|$ too much jet activity predicted

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* $Q_0$ is the fraction of events with no additional jet radiated within a considered rapidity interval
ATLAS mines its data for new physics in events with leptons...

Unification of forces? Left-right symmetric models? Extra dimensions? Technicolour? Contact interactions? Compositness? ...

Also: new 7 TeV dilepton limits on $llqq$ contact interaction between 9.5 and 12.9 TeV [1211.1150]
ATLAS mines its data for new resonances with leptons

Many other searches, for example: dilepton, like-sign dilepton, lepton-γ resonances

Doubly charged Higgs gives rise to a narrow like-sign resonance (left)
RS bulk graviton with strong coupling to SM can decay to a photon pair (right)

Prompt like-sign leptons powerful probe for many forms of new physics
ATLAS mines its data for new physics in events with leptons ... searching for compositeness w/ excited leptons in $ll^* \rightarrow ll + \gamma$

For compositeness scale $\Lambda = m(l^*)$: exclude excited leptons below 2.2 TeV at 95% CL
ATLAS mines its data for diboson resonances
Search for narrow resonance decaying to ZZ (→ llqq)

RS graviton with κ/m_{Pl} = 1.0 excluded below 850 GeV with 95% CL
ATLAS mines its data for diboson resonances
Search for narrow resonance decaying to $W\gamma$ or $Z\gamma$

Limits obtained on fiducial cross-sections of narrow resonances. Low scale TC
Once mass spectrum fixed, all cross-sections predicted
Spin structure of SUSY spectrum: lower \( \sigma \) than other BSM models, harder to find!

Direct squark pair production (example)

Direct gaugino/slepton pair production (example)

SUSY cross-section versus sparticle mass

Also: dedicated searches for SUSY with long-lived particles and \( R \)-parity violation

Recent (Oct 23) ATLAS seminar by Nick Barlow reviewing results on long-lived particle searches with ATLAS
Inclusive squark and gluino searches
Complete “jets + X + $E_T^{miss}$ ” programme, for example: GM

Gauge-mediated SUSY breaking scenarios feature very light gravitino. Phenomenology determined by nature of next-to-LSP

Dedicated search programme including final states with $E_T^{miss} + \tau$s, dilepton ($Z$ & non-$Z$), diphotons, photon + lepton, photon + $b$
“Natural” SUSY
Are squarks & gluinos too heavy to be produced at 8 TeV? Look at EW production!

Dedicated searches for EW slepton/gaugino production in multilepton final states published this summer; 8 TeV 13 fb\(^{-1}\) update of 3-\(L\) search

Interpretation in simplified models but also in a phenomenological MSSM model (less “naïve”)

Significant background from WZ production; measured in dedicated control region

Limit on C+N2 production with intermediate sleptons

Limit on C+N2 production without intermediate sleptons
**R-parity violating SUSY scenarios**

Decays of LSP in RPV models can lead to many leptons, many jets, resonances

---

Dedicated research programme designed to assess extremely broad RPV phenomenology

Search for strong and EW SUSY-RPV production in events with \( \geq 4-L \)

\[
\tilde{\chi}_1^0 \xrightarrow{\nu_e (\nu_\mu)} e^+ \\
\tilde{\nu}_e (\tilde{\nu}_\mu) \xrightarrow{\nu_e (\nu_\mu)} \mu^{-} (e^{-}) \\
\lambda_{121}
\]

Search for RPV sneutrino production and decay through LFV into \( LL' \)

Search pairs of gluino decays to \( 3 \) \( q \)

- Powerful limit from jet multiplicity and \( p_T \) (no mass reconstruction)
- Boosted and resolved jets analysis

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**ATLAS**

Preliminary explored LSP mass range:
10 GeV < \( m_{\chi} < m_{\chi} - 10 \) GeV

\[ \int L \ dt = 13.0 \text{ fb}^{-1}, \sqrt{s} = 8 \text{ TeV} \]

simplified model, \( \lambda_{121} > 0 \)

- Expected limit (\( 1\sigma_{\text{exp}} \))
- Observed limit (\( 1\sigma_{\text{obs}} \))
- prev. ATLAS exclusion
- Tevatron exclusion
- LEP exclusion
- not explored

ATLAS Preliminary

\[ m_{\chi} \leq 700 \text{ GeV} \]

Events / 10 GeV

All limits at 95% CL

\[ \int L \ dt = 4.6 \text{ fb}^{-1}, \sqrt{s} = 7 \text{ TeV} \]

ATLAS

\[ m_\chi \leq 600 \text{ GeV} \]

Events / 10 GeV

All limits at 95% CL

\[ \int L \ dt = 4.6 \text{ fb}^{-1}, \sqrt{s} = 7 \text{ TeV} \]

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LHCC Open Session, 5 Dec 2012

ATLAS Status Report — 70
What about Dark Matter?
Limits on WIMP production assuming high-scale contact interaction

Limit on WIMP pair production cross-section can be transformed into limit on effective WIMP-hadronic contact interaction:

Vector (SI): \((\bar{\chi} \gamma_\mu \chi)(\bar{q} \gamma^\mu q) \cdot \Lambda^{-2}\)

Axial-v. (SD): \((\bar{\chi} \gamma_\mu \gamma^5 \chi)(\bar{q} \gamma^\mu \gamma^5 q) \cdot \Lambda^{-2}\)

WIMP-nucleon scattering cross-section: \(\sigma \propto \frac{1}{\Lambda^4}\)

\[\begin{align*}
q &\rightarrow \text{DM} & \bar{q} &\rightarrow \text{DM} \\
\text{DM} &\rightarrow q & \text{DM} &\rightarrow q
\end{align*}\]
Monojet analysis as search for gravitino production
Same signature as WIMP production, but not ISR search (similar to ADD)

In GM SUSY, gravitino LSP with mass related to SUSY breaking scale
At LHC with low-scale SUSY breaking, direct $\tilde{G}+\tilde{q}$ or $\tilde{G}+\tilde{g}$ production can dominate. Cross-section $\sim 1/m^2(\tilde{G})$

$\tilde{g} \rightarrow \text{jet} + E_T^{\text{miss}}$

$\tilde{q} \rightarrow \text{jet} + E_T^{\text{miss}}$

Lower limits on gravitino mass as function of squark/gluino masses
Improves existing limits by $O(\text{magnitude})$