Recent Results from the ATLAS Experiment

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On behalf of the ATLAS Collaboration
Outlook

- 0) ATLAS and Run 1 Data
- I) Higgs Boson Physics
- II) Top physics
- III) Search for Supersymmetry
- IV) Electroweak measurements
- V) QCD measurement
- VI) 2015: Early preliminary results
0) ATLAS and Run 1 Data

But this is a Run 2 event...
The ATLAS Detector in Run 1

- ATLAS experiment designed as a multipurpose detector, able to precisely reconstruct all kind of “objects” and measure their kinematics.
- These “objects” are electrons, muons, taus, photons, hadronic jets, heavy flavour, isolated hadrons and missing transverse energy.
- ATLAS trigger system uses a large variety of objects with thresholds as low as possible and a DAQ system able to record events up to a rate of 1 kHz.

- During Run 1, ATLAS could optimally exploit the wonderful potential offered by the LHC.
- The Higgs-Englert-Brout boson discovered.
- More than 450 publications on a large variety of particle physics measurements and searches.

- This talk: recent results of Run 1 and early preliminary results from Run 2.
- It will be of course a selection. Sorry if your favourite channel or analysis is not shown.
A total of 24.9 fb$^{-1}$ recorded in good conditions at p-p center of mass energies of 7 and 8 TeV.

With an overall efficiency of 93.5 %.
I ) Higgs Boson Physics

- Since the Higgs boson discovery, efforts are put to test the Higgs hypothesis of the new particle.
  - This means measurement of its spin, couplings, and width.
  - Looking for not yet observed decays.
  - Looking for rare production and decay modes.
  - Lot of efforts put to improve the precision of the Higgs mass.

See plenary talk by X. Chen
Higgs Boson Mass

**ATLAS** and **CMS**

**LHC Run 1**

**ATLAS** $H \rightarrow \gamma \gamma$

**CMS** $H \rightarrow \gamma \gamma$

**ATLAS** $H \rightarrow ZZ \rightarrow 4l$

**CMS** $H \rightarrow ZZ \rightarrow 4l$

**ATLAS+CMS** $\gamma \gamma$

**ATLAS+CMS** $4l$

**ATLAS+CMS** $\gamma \gamma+4l$

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$m_H$ (GeV)

- **Total**
- **Stat**
- **Syst**

- **ATLAS** $H \rightarrow \gamma \gamma$: $126.02 \pm 0.51 (\pm 0.43 \pm 0.27) \text{ GeV}$
- **CMS** $H \rightarrow \gamma \gamma$: $124.70 \pm 0.34 (\pm 0.31 \pm 0.15) \text{ GeV}$
- **ATLAS** $H \rightarrow ZZ \rightarrow 4l$: $124.51 \pm 0.52 (\pm 0.52 \pm 0.04) \text{ GeV}$
- **CMS** $H \rightarrow ZZ \rightarrow 4l$: $125.59 \pm 0.45 (\pm 0.42 \pm 0.17) \text{ GeV}$
- **ATLAS+CMS** $\gamma \gamma$: $125.07 \pm 0.29 (\pm 0.25 \pm 0.14) \text{ GeV}$
- **ATLAS+CMS** $4l$: $125.15 \pm 0.40 (\pm 0.37 \pm 0.15) \text{ GeV}$
- **ATLAS+CMS** $\gamma \gamma+4l$: $125.09 \pm 0.24 (\pm 0.21 \pm 0.11) \text{ GeV}$

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**PhysRevLett.114.191803**
Signal Strength for Production and Decay Modes

\[ \text{arXiv.1507.04548} \]

### ATLAS

<table>
<thead>
<tr>
<th>Decay Mode</th>
<th>Signal Strength</th>
<th>Total uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>( H \rightarrow \gamma \gamma )</td>
<td>( \mu = 1.17^{+0.28}_{-0.26} )</td>
<td>( \pm 1 \sigma ) on ( \mu )</td>
</tr>
<tr>
<td>( H \rightarrow ZZ^* )</td>
<td>( \mu = 1.46^{+0.40}_{-0.34} )</td>
<td></td>
</tr>
<tr>
<td>( H \rightarrow WW^* )</td>
<td>( \mu = 1.16^{+0.24}_{-0.21} )</td>
<td></td>
</tr>
<tr>
<td>( H \rightarrow \tau \tau )</td>
<td>( \mu = 1.44^{+0.42}_{-0.37} )</td>
<td></td>
</tr>
<tr>
<td>( H \rightarrow bb )</td>
<td>( \mu = 0.63^{+0.39}_{-0.37} )</td>
<td></td>
</tr>
<tr>
<td>( H \rightarrow \mu \mu )</td>
<td>( \mu = -0.7^{+3.7}_{-3.7} )</td>
<td></td>
</tr>
<tr>
<td>( H \rightarrow Z\gamma )</td>
<td>( \mu = 2.7^{+4.6}_{-4.5} )</td>
<td></td>
</tr>
<tr>
<td>Combined</td>
<td>( \mu = 1.18^{+0.15}_{-0.14} )</td>
<td></td>
</tr>
</tbody>
</table>

### ATLAS

- \( \sqrt{s} = 7 \text{ TeV, 4.5 - 4.7 fb}^{-1} \)
- \( \sqrt{s} = 8 \text{ TeV, 20.3 fb}^{-1} \)

\[ m_H = 125.36 \text{ GeV} \]
Spin and Parity Tests

- All studies support the $0^+$ hypothesis.
- Other hypothesis ruled out at 99.9 % CL

See talk by M. Queitsch-Maitland

arXiv.1506.05669
Measurements of Higgs Couplings

- Fits in the so-called \( \kappa \) framework.
- Shown here: Global coupling fits assuming universal couplings for fermions (\( \kappa_F \)) and bosons (\( \kappa_V \)).
- No BSM signal so far (under a few assumptions).

See talk by N. Lu

\[ \text{arXiv.1507.04548} \]
II ) Top Physics

- Heaviest known particle: Specific role in electroweak symmetry breaking?
- Top quark decays before hadronization: Top properties measurement.
- LHC: a copious source of top quarks: More than 5 M t-observer pairs produced during Run 1.

See plenary talk by A. Onofre
Single-top candidate from 2015
Cross Section Measurement

Measured cross section of $t\bar{t}$ pairs and single-top production at $\sqrt{s} = 7$ and 8 TeV

See talk by C. Bertsche

See talk by A. Chegwidden
Measurement of Top Mass

- Top quark mass: Already the best known quark mass.
- ATLAS measurement from different channels are consistent.
- And consistent with world and Tevatron combinations.
More on Top Mass

\[ M_{\text{pole}}^{\text{top}} = 173.7 \pm 2.1_{-2.3} \text{ GeV} \]

- Mass measurement techniques are calibrated to the mass in MC, which is not clearly related to a theoretically well defined mass.
- Exploit the dependence of gluon radiation on the top mass to extract the “pole” top mass from \( t\bar{t} \) +1 jet events.
- The measured top mass does not favor the stability of the vacuum up to the Planck scale.
- A new Symmetry needed around \( 10^{10} \) \(-10^{12} \text{ GeV} \)?
A significance of 5 and 4.2 $\sigma$ over the background only hypothesis for $ttW$ and $ttZ$ respectively.

- Tests of top couplings.
- Well within NLO QCD predictions.

Charge asymmetry: Induced from NLO corrections to $q\bar{q}$ and $qg$ initiated production.

- Measurement based on $t\bar{t}$ pair production and leptonic days of the $W$.
- Results in agreement with SM prediction: top quark is preferentially emitted in the direction of the quark.

See talk by F. Fassi for searches for BSM signals
III ) Search for SuperSymmetry

- Most popular BSM theory.
- Large number of searches, using all the variety of objects reconstructed by ATLAS.
- Large number of parameters: Searches interpreted within specific SUSY versions: pMSSM, mSUGRA, GMSB...

See plenary talk by E. S. Kuwertz
Third Generation Squarks in Run 1

- Third generation squarks required to be light (~ 1 TeV) to protect the Higgs mass.
- Several scenarios have been investigated.
- Below: Summary of ATLAS Run 1 searches for stop pairs if only LSP is involved in stop decay (left) and if only LSP and the first chargino are involved (right), assuming that the chargino mass is two times the LSP one.

See talk by J. Kenneth Anders

arXiv.1506.08616
Summary of ATLAS Searches of EWK production of charginos and neutralinos, using several decay modes (100% branching ratio is assumed for each mode).

Excluded range of lifetime as a function of chargino mass for charginos, using the ionisation rate measured by the Pixel Detector: Ionisation rate of a heavy (non relativistic) charged particle is high and depends on its mass.
Interpretation of Search Limits

- Combining statistically independent channels (both in signal and control regions) to constrain SUSY models.
- Several SUSY models have been studied.
- Shown below: mSUGRA with conserved (left) and violated (right) R-parity, with fixed $\tan \beta = 30$, $A_0 = -2 m_0$, and $\mu > 0$. 

arXiv.1507.05525
### ATLAS SUSY Searches* - 95% CL Lower Limits

**Status:** July 2015

**ICNFP 2015**

<table>
<thead>
<tr>
<th>Model</th>
<th>(e, \mu, \tau, \gamma) Jets</th>
<th>(E_{T}^{\text{miss}})</th>
<th>(\sqrt{s} = 7\text{ TeV})</th>
<th>(\sqrt{s} = 8\text{ TeV})</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MSUGRA/CMSM</strong></td>
<td>0-3 (e, \mu, \tau, \gamma)</td>
<td>20, 3</td>
<td>1.8 TeV</td>
<td></td>
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<tr>
<td>(b\bar{b}\rightarrow t\bar{t})</td>
<td>0</td>
<td>20, 3</td>
<td>850 GeV</td>
<td></td>
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<tr>
<td>(b\bar{b}\rightarrow t\bar{t}) (compressed)</td>
<td>0</td>
<td>20, 3</td>
<td>100-440 GeV</td>
<td></td>
</tr>
<tr>
<td>(b\bar{b}\rightarrow t\bar{t}) (off-Z)</td>
<td>0</td>
<td>20, 3</td>
<td>780 GeV</td>
<td></td>
</tr>
<tr>
<td>(b\bar{b}\rightarrow t\bar{t}) (with W, Z)</td>
<td>0</td>
<td>20, 3</td>
<td>1.33 TeV</td>
<td></td>
</tr>
<tr>
<td>(b\bar{b}\rightarrow t\bar{t})</td>
<td>0</td>
<td>20, 3</td>
<td>1.32 TeV</td>
<td></td>
</tr>
<tr>
<td><strong>GMSB (NLSM)</strong></td>
<td>1-2 (e, \mu, \gamma)</td>
<td>20, 3</td>
<td>1.6 TeV</td>
<td></td>
</tr>
<tr>
<td>(\tilde{b}\rightarrow t\tilde{\chi}_{1}^{0})</td>
<td>0</td>
<td>20, 3</td>
<td>1.29 TeV</td>
<td></td>
</tr>
<tr>
<td><strong>Gravitino LSP</strong></td>
<td>0</td>
<td>20, 3</td>
<td>1.25 TeV</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>EWSBM</strong></td>
<td>2 (e, \mu, \tau)</td>
<td>20, 3</td>
<td>1.37 TeV</td>
<td></td>
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<tr>
<td><strong>Direct EW direct</strong></td>
<td>1 (e, \mu, \tau, \gamma)</td>
<td>20, 3</td>
<td>1.27 TeV</td>
<td></td>
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<td></td>
<td></td>
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<td></td>
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<tr>
<td><strong>Long-lived particles</strong></td>
<td>1 (e, \mu, \tau, \gamma)</td>
<td>20, 3</td>
<td>1.07 TeV</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td>2 (e, \mu, \tau, \gamma)</td>
<td>20, 3</td>
<td>0.4-1.0 TeV</td>
<td></td>
</tr>
</tbody>
</table>

**Reference**

- 1507.05625
- 1405.7875
- 1507.05525
- 1503.32090
- 1505.2757
- 1507.05525
- 1503.32555
- 1507.05525
- 1507.05493
- 1503.02290
- 1502.01518
- 1407.0600
- 1308.1841
- 1407.0600
- 1407.0600
- 1308.2621
- 1404.2500
- 1206.2102, 1407.6683
- 1506.2816
- 1407.0608
- 1403.5222
- 1403.5222
- 1403.5222
- 1403.5222
- 1403.5222
- 1403.5222
- 1405.5689
- 1507.05493
- 1403.5222
- 1506.05332
- 1406.6584
- 1411.6705
- 1407.0542
- 1504.05162
- 1504.05162
- 1502.04430
- 1404.2500
- 1405.5686
- 1502.05666
- 1502.05666
- 1404.2500

*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1\(\sigma\) theoretical signal cross section uncertainty.*
No evidence so far...

*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.
IV ) Electroweak Measurements

- LHC is a copious source of electroweak gauge bosons and their interactions (VBF, VBS).
- EW measurements are one of the tools to look beyond SM.
- Some EW process are background to searches (VV).

See plenary talk by W. Buttinger
Lepton Forward-Backward Asymmetry

**ATLAS**

\( s = 7 \text{ TeV}, 4.8 \text{ fb}^{-1} \)

CC electron

Data, full unfolding

PYTHIA, \( Z/\gamma^* \rightarrow \text{ee} \)

\[ A_{FB}^{\text{ATLAS}}(\text{e CC}) \]

\[ A_{FB}^{\text{ATLAS}}(\mu) \]

\[ A_{FB}^{\text{ATLAS combined}} \]

\[ A_{FB}^{\text{CMS}} \]

\[ A_{FB}^{\text{D0}} \]

\[ A_{FB}^{\text{CDF}} \]

\[ A_{FB}^{\text{LEP}, \tau/\gamma^*} \]

\[ A_{FB}^{\text{SLD}, \tau} \]

\[ A_{FB}^{\text{LEP+SLC}} \]

\[ A_{FB}^{\text{PDG Fit}} \]

\[ A_{FB}^{\text{ATLAS}}(\text{e CF}) \]

Measurement “à la LEP” and extraction of an effective Weinberg angle.

\[ \text{arXiv.1503.03709} \]
Multi Bosons Production

- Multi boson production: Sensitive to new physics through TGC and QGC.
- Measurements interpreted as limits on anomalous (BSM) couplings.
- No BSM signal seen.

See talk by M. Becker

**JHEP01(2015)049**

**PhysRevLett.115.031802**
V ) QCD Measurements

- QCD tested more and more in its perturbative calculations: Many measurements became sensitive to effects beyond NLO QCD.
- QCD understanding important for other measurements: PDF, underlying events.

See plenary talk by W. Buttinger
Determination of $\sigma_{tot}$ with ALFA

- Proton-proton elastic differential cross section measured with ALFA stations (roman pots) is fitted and the $\rho$ parameter is determined.
- Total cross section is computed from it using the optical theorem.
Transverse Energy-Energy Correlation

- Transverse energy-energy correlation for jets (left) and its fit with NLO QCD.
- Measured value of $\alpha_s$ compared to other measurements at hadron colliders.

arXiv.1508.01579
Jets Measurements

- Jets and V+jets cross sections: Test QCD beyond leading order.
- No theoretical prediction able to describe all differential cross sections. Example given here: scalar sum of lepton + jets $P_T + E_T^{miss}$ in W+jets production:

![Graph showing ATLAS data and theoretical predictions for W(→lav) + ≥ 1 jet at $P_T > 30$ GeV, $|y| < 4.4$.]
LHC is delivering p-p collisions at 13 TeV.

Main improvement in ATLAS: A fourth pixel layer, at 3.3 cm from the beam axis (the closest layer was at 5.5 cm): The IBL.

Many more improvements: Additional muon chambers, repairs, new analysis model, trigger upgrade...

Next: early ATLAS results from Run 2
Tracking with IBL

$\sigma(d_0)_{[\mu m]}$

$0.0 < \eta < 0.2$

- Data 2012, $\sqrt{s} = 8\ TeV$
- Data 2015, $\sqrt{s} = 13\ TeV$

$\sigma(z_0)_{[\mu m]}$

$0.0 < \eta < 0.2$

- Data 2012, $\sqrt{s} = 8\ TeV$
- Data 2015, $\sqrt{s} = 13\ TeV$

See talk by S. Miglioranzi
**ATLAS** Preliminary

13 TeV, 85 pb\(^{-1}\)

- **ATLAS** Preliminary
- **ATLAS** Preliminary

**W^\pm**

- lumi \(\oplus\) exp. uncertainty
- exp. uncertainty
- ABM12LHC
- CT10nnlo
- NNPDF3.0
- MMHT14nnlo68CL (inner uncert.: PDF only)

\[ \sigma_{W^\pm}^{\text{tot}} \text{ [pb]} \]

**Z**

- lumi \(\oplus\) exp. uncertainty
- exp. uncertainty
- ABM12LHC
- CT10nnlo
- NNPDF3.0
- MMHT14nnlo68CL (inner uncert.: PDF only)

\[ \sigma_{Z}^{\text{tot}} \text{ [pb]} \]

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**ATLAS-CONF-2015-039**

**Bosons Cross Sections at 13 TeV**

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**ATLAS** Preliminary

Data 2015 (\(\sqrt{s} = 13\) TeV)

- \(\sigma \times \text{Br}(W \rightarrow l \nu)\) [nb]

\[ \sigma \times \text{Br}(W \rightarrow l \nu) \text{ [nb]} \]

**ATLAS** Preliminary

Data 2015 (\(\sqrt{s} = 13\) TeV)

- \(\sigma \times \text{Br}(Z^\gamma \rightarrow l^+ l^-)\) [nb]

\[ \sigma \times \text{Br}(Z^\gamma \rightarrow l^+ l^-) \text{ [nb]} \]
Jet Cross Section at 13 TeV

\[ \frac{d^2\sigma}{dp_T^2 \ dy} \ [pb/GeV] \]

- anti-\( k \) jets, \( R=0.4 \); \( |y| < 0.5 \)
- 13 TeV, 78 pb\(^{-1} \)

**ATLAS** Preliminary

![Graph showing jet cross section at 13 TeV](image)

- **Data**
- Systematic uncertainties
- NLOJET++ (CT10) ×
- Non-pert. corr.

Relative uncertainty of 9% in the integrated luminosity not included

**ATLAS-CONF-2015-034**
Inelastic p-p Cross Section at 13 TeV

ATLAS Preliminary

ATLAS MBTS data extrapolated using Pythia implementation of Donnachie-Landshoff model with $\varepsilon = 0.085$ for $d\sigma/dx$.
Cross section of $t\bar{t}$ pairs production at 13 TeV

ATLAS-CONF-2015-033
• Examples of “Loose Signal Regions” in SUSY searches at 13 TeV.
• Signals are magnified by factors of 10 and 100.
• Nice agreement between data and expected background.
Start of search for extra bosons at 13 TeV
Dimuon pair with an invariant mass of 881 GeV
Conclusions

- During Run 1, ATLAS has produced a large variety of results covering some of the more fundamental questions in particle physics.
- This includes searches, measurements and interpretations within alternative theories.
- The 2012 discovered particle looks really more and more like the SM Higgs boson.
- No signal spotted yet beyond the Standard Model.
- Run 2 has started successfully and ATLAS is willing to continue its effort.
- We all hope for some nice surprises from Nature...
Back up
Main assets of ATLAS:

- A precise tracker, able to distinguish primary vertices of a single collision as well as tracks in dense core hadronic jets.
- A hermetic calorimeter, with angular measurement capabilities.
- A precise, independent and high redundancy muon system.
CP-Mixing Terms in HVV?

- Fits exclude maximal scenarii for such terms:

![Graphs showing ATLAS data for H → ZZ^* → 4l and H → WW^* → eγνν with observed, expected, and signal strength fit to data predictions.](image)

**arXiv.1506.05669**
**J/ψ production at 13 TeV**

Proper time of $J/\psi$: Prompt and heavy-flavor components

Non-prompt fraction of the $J/\psi$ as a function of its $p_T$.

**ATLAS-CONF-2015-030**

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**ATLAS Preliminary**

$s = 13$ TeV

$|y^{\mu\mu}| < 0.75$

$10.0 < p_T^{\mu\mu} < 11.0$ GeV

- Data
- Fit
- Prompt Signal
- Non-prompt Signal
- Background

![Graph showing proper time distribution of $J/\psi$ candidates](image1)

![Graph showing non-prompt fraction as a function of $p_T^{\mu\mu}$](image2)
Properties of inelastic events at 13 TeV

ATLAS Preliminary $\sqrt{s} = 13$ TeV

$1/N_{\text{ev}} \cdot dN_{\text{ch}} / d\eta$

MC / Data

$\eta$
**Photons**

**Boson Production at 13 TeV**

**Z+jets**

**Z → μ⁺μ⁻ + jets**

**W → μν**

**Z → e⁺e⁻**
Search in diphoton spectrum at 13 TeV

Diphoton pair with an invariant mass of 940 GeV