Overview of ATLAS Results from Last Year
Detector Performance and Physics Highlights

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On behalf of the ATLAS Experiment

TOP 2019
Overview

- The LHC & ATLAS Detector
- ATLAS Run 2 Datasets
- Reconstruction / Calibration
- Physics Highlights
- The Preparations for Run 3
The LHC and ATLAS Detector in 2018

- Excellent performance of the LHC in 2018 !!!
- Peak luminosity > x2 LHC design luminosity
- ATLAS performance continuously improving:

<table>
<thead>
<tr>
<th></th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Taking</td>
<td>92.4 %</td>
<td>92.5 %</td>
<td>93.4 %</td>
<td>95.7 %</td>
</tr>
<tr>
<td>Data Quality</td>
<td>87.1 %</td>
<td>92.8 %</td>
<td>93.6 %</td>
<td>97.5 %</td>
</tr>
</tbody>
</table>

ATLAS Online Luminosity

\[ \sqrt{s} = 13 \text{ TeV} \]

Peak Lumi: \( 21.0 \times 10^{33} \text{ cm}^2 \text{ s}^{-1} \)

LHC design luminosity

Day in 2018

ATLAS pp data: April 25-October 24 2018

<table>
<thead>
<tr>
<th>Inner Tracker</th>
<th>Calorimeters</th>
<th>Muon Spectrometer</th>
<th>Magnets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pixel</td>
<td>LAr, Tile</td>
<td>MDT, RPC, CSC, TGC</td>
<td>Solenoid, Toroid</td>
</tr>
<tr>
<td>SCT</td>
<td></td>
<td></td>
<td>100, 99.6</td>
</tr>
<tr>
<td>TRT</td>
<td></td>
<td></td>
<td>100, 100</td>
</tr>
</tbody>
</table>

Good for physics: 97.5% (60.1 fb\(^{-1}\))

Luminosity weighted relative detector uptime and good data quality efficiencies (in %) during stable beam in pp collisions at \( \sqrt{s} = 13 \text{ TeV} \) between April 25 – October 24 2018, corresponding to a delivered integrated luminosity of 63.8 fb\(^{-1}\) and a recorded integrated luminosity of 61.7 fb\(^{-1}\). Dedicated luminosity calibration activities during LHC fills used 0.7% of recorded data and are included in the inefficiency. The luminosity includes 193 pb\(^{-2}\) of good data taken at an average pileup of \( \mu = 2 \).
ATLAS Run 2 Datasets (2015 - 2018)

Proton-Proton $\sqrt{s} = 13$ TeV Dataset

- 156 fb$^{-1}$ delivered – thanks to CERN accelerators team!
- 147 fb$^{-1}$ recorded (94 %)
- 139 fb$^{-1}$ good for physics (95 %)

Measured to a precision of 1.7 % [ATLAS-CONF-2019-021]

- Average number of interactions per bunch crossing = 34

Other Datasets

- Pb-Pb, proton-Pb, Xe-Xe
- Data with low $<\mu>$ for precision W physics
- Data with different beam energies / optics for diffractive physics

The LHC is a very versatile machine!
Pile-up in Run 2

Continues to pose a number of challenges... eg. particle identification/reconstruction, trigger rates/bandwidth
Reconstruction and Calibration

Data-driven calibration of muon efficiency

- ~per-mil uncertainty on muon efficiency

Data-driven energy calibration of jets

- ~percent precision on jet energy scale

Data-driven calibration of b-tagging efficiency

- ~percent uncertainty on b-tagging efficiency

Resonance Search ($Z' \rightarrow bb$)
ATLAS Physics Program

The LHC is an **EVERYTHING** factory!

Large dataset facilitates a broad physics program

- Probing SM / Higgs processes with high precision
  - Detecting very rare processes
- Exploring vast kinematic domain for new physics

Produced in $139 \text{ fb}^{-1}$ @ $\sqrt{s} = 13$ TeV

<table>
<thead>
<tr>
<th>Particle</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higgs Bosons</td>
<td>7.7 million</td>
</tr>
<tr>
<td>Top Quarks</td>
<td>275 million</td>
</tr>
<tr>
<td>Z Bosons</td>
<td>2.8 billion</td>
</tr>
<tr>
<td>W Bosons</td>
<td>12 billion</td>
</tr>
<tr>
<td>Bottom Quarks</td>
<td>~40 trillion</td>
</tr>
</tbody>
</table>

2019 has seen the first ATLAS analyses based on the full (139 fb$^{-1}$) Run 2 dataset

- 7 papers submitted to journals (so far)
- 26 conference notes

The following is a brief selection of these results
Precision Tests of the Standard Model

Many cross section measurements have been performed by ATLAS

Theoretical predictions here at NLO or higher

So far... all measurements agree with SM predictions
Vector Boson Scattering

Massive VBS provides a key avenue to probe EWSB – here focus on electroweak production of ZZjj

Multivariate discriminants are used to separate signal from (irreducible) QCD background

EW ZZjj

Observed with (expected) significance of 5.5σ (4.3σ)

σ_{fid} = 0.82 ± 0.21 fb
SM = 0.61 ± 0.03 fb

All VVjj processes have now been observed (>5σ) in ATLAS

EW WWjj (6.5σ)
EW WZjj (5.3σ)
Charge Asymmetry in tt-bar

Large sample of ttbar events allows study of production asymmetry (H.O. QCD effects from qq-bar and qg)

Central-forward charge asymmetry:  
\[
A_C = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)}
\]

Asymmetry measured using resolved and boosted top-quark decays to lepton + jets  
(Bayesian unfolding procedure used to infer \(A_c\) at parton level – correcting for detector/acceptance)

\[A_C = 0.0060 \pm 0.0011_{\text{stat}} \pm 0.0010_{\text{syst}}\]

Non-zero at 4\(\sigma\) - first evidence of charge asymmetry @ LHC

Inclusive and differential measurements consistent with SM predictions

Several BSM processes predict different \(A_c\) values

\(\sqrt{s} = 13\,\text{TeV}, 139\,\text{fb}^{-1}\)

\(\text{ATLAS Preliminary}\)
Top-Quark Decay Width

Deviations from SM prediction may hint at non-SM decay channels of top-quark / modification of top quark couplings

Direct measurement of top-quark decay width
Based on m(lb) distribution in dileptonic tt-bar events

\[ \Gamma_{\text{top}} = 1.9 \pm 0.5 \text{ GeV} \]

SM: 1.32 GeV @ \( m_{\text{top}} = 172.5 \text{ GeV} \)
Higgs Physics in ATLAS

All major production / decay modes of the Higgs have been observed (≥ 5σ) in ATLAS.
The Higgs (Re-)Discovery

Inclusive and differential cross sections measured in the $H \rightarrow ZZ^* \rightarrow 4l$ and $H \rightarrow \gamma\gamma$ channels

We're now moving into realm of precision Higgs physics… *(many more Higgs to play with!)*

**H→ZZ*→4l**

$\sigma_{\text{fid}} = 3.35 \pm 0.30(\text{stat.}) \pm 0.12(\text{syst.})$ fb

$\text{SM} = 3.41 \pm 0.18$ fb

**H→γγ**

$\sigma_{\text{fid}} = 65.2 \pm 4.5(\text{stat.}) \pm 5.6(\text{syst.}) \pm 0.3(\text{theo.})$ fb

$\text{SM} = 63.6 \pm 3.3$ fb

Measurements are in agreement with SM

* Improved lepton isolation
* Constrained ZZ* background
* Improved photon ID

See Tamara’s Talk Tomorrow
(Z)H → 4Lepton Candidate Event

$m_{4\text{-lepton}} = 121.9$ GeV

Run: 339849
Event: 1914311665
2017-11-03 00:50:49 CEST
Higgs Boson Cross Sections

Statistical combination of $H \rightarrow ZZ^{\ast} \rightarrow 4l$ and $H \rightarrow \gamma\gamma$ channels provides more precise inclusive and differential cross section measurements.

Total Higgs boson production cross section:

$$\sigma(pp \rightarrow H) = 56.7^{+6.4}_{-6.2}(\gamma\gamma), 54.4^{+5.6}_{-5.4}(4l)$$

$$\sigma(pp \rightarrow H) = 55.6 \pm 2.5 \text{ pb (Theory)} \quad (N^3\text{LO-NLO in QCD, NLO in EW})$$
Higgs Coupling to 2\textsuperscript{nd} Gen. Fermions

\begin{align*}
H \rightarrow \mu\mu & \\
H \rightarrow \epsilon\epsilon &
\end{align*}

Very challenging! Small couplings in the SM & overwhelming background from $Z/\gamma^* \rightarrow \mu\mu$

**H→μμ**

* multivariate discriminants exploit different kinematics of ggF + VBF signal and DY background events

No significant excess is observed

Upper limit on BR = $3.6 \times 10^{-4}$ (obs)

$3.5 \times 10^{-4}$ (exp) \quad x5 improvement

50% improvement

Expect ~15% precision on BR with 3000 fb\textsuperscript{-1} [ATL-PHYS-PUB-2018-054]

\begin{figure}
\centering
\includegraphics[width=0.45\textwidth]{H→μμ_graph.png}
\caption{ATLAS Preliminary $\sqrt{s}=13$ TeV, 139 fb\textsuperscript{-1} $H \rightarrow \mu\mu$ log$(1+S/B)$ weighted}
\end{figure}

No sensitivity at LHC to SM couplings

\begin{figure}
\centering
\includegraphics[width=0.45\textwidth]{H→εε_graph.png}
\caption{ATLAS Preliminary $\sqrt{s}=13$ TeV, 139 fb\textsuperscript{-1}}$
\end{figure}
Lepton Flavour Violating Higgs Decays

Large sample of Higgs bosons allows us to search for non-SM decays

**Higgs LFV Limits**

- Backgrounds = top quarks, diboson production, W+jets, multi-jets
- No significant excess observed
- Upper limit on BR = $6.1 \times 10^{-5}$ (obs) $5.8 \times 10^{-5}$ (exp)
**Di-Higgs Production**

Search for Higgs boson pair production via vector boson fusion, where HH → bbbb

**Signature = 4 b-jets + 2 jets with large Δy**

Sensitive to production of heavy boson decaying to HH

Can help constrain parameters of VVHH coupling

No significant excess is observed

Upper limit on non-resonant production cross-section is 1600 fb (obs) 1000 fb (exp)

The excluded region corresponds to...

\[ c_{2V} < -1.02 \text{ and } c_{2V} > 2.71 \text{ (obs)} \]

\[ c_{2V} < -1.09 \text{ and } c_{2V} > 2.82 \text{ (exp)} \]

Observation of Di-Higgs would require HL-LHC
Searches for High-Mass Resonances

Here we're looking for a resonance / bump on top of a smoothly falling background distribution.

**dilepton search ($m_{ll}$)**

- Data
- Background-only fit
- Generic signal at 1.34 TeV, $\Gamma/m = 0\%$
- Generic signal at 2 TeV, $\Gamma/m = 0\%$
- Generic signal at 3 TeV, $\Gamma/m = 0\%$

* **Improved $e/\mu$ reconstruction and ID-MS alignment wrt. previous searches**

* **Data-driven background estimate**

**lepton + MET search ($m_T$)**

No significant excess observed in either search.

<table>
<thead>
<tr>
<th>Model</th>
<th>Lower limits on $m_{Z'}$ [TeV]</th>
<th>$m(W')$ lower limit [TeV]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$ee$</td>
<td>$\mu\mu$</td>
</tr>
<tr>
<td>$Z'_{\psi}$</td>
<td>4.1</td>
<td>4.0</td>
</tr>
<tr>
<td>$Z'_{\chi}$</td>
<td>4.6</td>
<td>4.2</td>
</tr>
<tr>
<td>$Z_{SSM}$</td>
<td>4.9</td>
<td>4.5</td>
</tr>
</tbody>
</table>

Upper limits on cross-section are also provided for generic resonances with fixed $\Gamma/m$ (to allow for reinterpretation).
Dielectron Candidate Event

$m_{ee} = 4.06$ TeV

Dielectron candidate with highest invariant mass in Run 2

Run Number: 336852, Event Number: 1440436043
Date: 2017–09–29 11:44:35 CEST
Searches for High-Mass Resonances

**ATLAS** Preliminary

\[ \sqrt{s} = 13 \, \text{TeV}, \, 139 \, \text{fb}^{-1} \]

- Data
- Background fit
- BumpHunter interval
- \( q^*, m_{q^*} = 4.0 \, \text{TeV} \)
- \( q^*, m_{q^*} = 5.0 \, \text{TeV} \)

**Signature**

- Two high-\( p_T \), large-radius jets

No significant excess observed in either search

Upper limits on cross-section are also provided for generic resonances with fixed \( \Gamma / m \) values

**Lower mass limit for \( q^* \): 6.7 TeV (obs) 6.4 TeV (exp)**

**Search for narrow resonances decaying to WW, WZ, ZZ in fully hadronic final states**

**Signature**

- Two high-\( p_T \), large-radius jets

**Jet substructure of W/Z exploited to suppress large multi-jet background**

* Track-calor-clusters, 3D boosted boson tagger

**Table: Excluded mass range**

<table>
<thead>
<tr>
<th>Model</th>
<th>Signal Region</th>
<th>Excluded mass range [TeV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>WW</td>
<td></td>
<td>1.3–2.9</td>
</tr>
<tr>
<td>HVT model A, ( g_V = 1 )</td>
<td>WW</td>
<td>1.3–3.4</td>
</tr>
<tr>
<td></td>
<td>WZ</td>
<td>1.3–3.5</td>
</tr>
<tr>
<td></td>
<td>WW + WZ</td>
<td>1.3–3.5</td>
</tr>
<tr>
<td>HVT model B, ( g_V = 3 )</td>
<td>WW</td>
<td>1.3–3.1</td>
</tr>
<tr>
<td></td>
<td>WZ</td>
<td>1.3–3.6</td>
</tr>
<tr>
<td></td>
<td>WW + WZ</td>
<td>1.3–3.8</td>
</tr>
<tr>
<td>Bulk RS, ( k/\tilde{M}_\tilde{t} = 1 )</td>
<td>WW</td>
<td>1.3–1.6</td>
</tr>
<tr>
<td></td>
<td>ZZ</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td>WW + ZZ</td>
<td>1.3–1.8</td>
</tr>
</tbody>
</table>
Dijet Candidate Event

Dijet candidate with highest invariant mass in Run 2

$m_{jj} = 8.02$ TeV
Diboson Candidate Event

Diboson candidate event with the highest invariant mass in Run 2

$M(JJ) = 4.4 \text{ TeV}$
Run: 338846
Event: 2998836394
2017-10-01 21:17:47 UTC

$m_{JJ} = 4.44 \text{ TeV}$
## Searches for SUSY

**ATLAS SUSY Searches** - 95% CL Lower Limits

*July 2019*

### Model

<table>
<thead>
<tr>
<th>Model</th>
<th>Signature</th>
<th>$\mathcal{L} dt$ (fb$^{-1}$)</th>
<th>Mass limit</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>$q\bar{q}, \tau\tau$</td>
<td>$0 , e, \mu$</td>
<td>2.6 jets</td>
<td>0.56</td>
<td>1.55</td>
</tr>
<tr>
<td></td>
<td>$1-3 , jets$</td>
<td></td>
<td>0.71</td>
<td></td>
</tr>
<tr>
<td>$t\bar{t}$, $\tau\tau$</td>
<td>$0 , e, \mu$</td>
<td>2.6 jets</td>
<td>0.43</td>
<td>2.0</td>
</tr>
<tr>
<td>$\tau$</td>
<td>1-3 jets</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$t\bar{t}, \tau\tau$</td>
<td>$0 , \tau_i \mu$</td>
<td>7-11 jets</td>
<td>0.85</td>
<td></td>
</tr>
<tr>
<td>$\nu \bar{\nu}$</td>
<td>6 jets</td>
<td></td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>$\tau\tau$</td>
<td>$0 , \tau_i \mu$</td>
<td>3 $\tau_{i-n}$</td>
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<tr>
<td>$\tau\tau$</td>
<td>6 jets</td>
<td></td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>Inclusive Searches</td>
<td>$\tau\tau$</td>
<td>$0 , \tau_i \mu$</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>$\tau\tau$</td>
<td>6 jets</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### ATLAS

**Preliminary**

$$\sqrt{s} = 13 \, \text{TeV}$$

1. **Searches for SUSY**: 

   - SUSY: 2019-022

2. **Mass scale [TeV]**

   - $m_{\chi_1^0} = 100 \, \text{GeV}$
   - $m_{\chi_1^0} = 200 \, \text{GeV}$
   - $m_{\chi_1^0} = 900 \, \text{GeV}$
   - $m_{\chi_1^0} = 800 \, \text{GeV}$
   - $m_{\chi_1^0} = 500 \, \text{GeV}$
   - $m_{\chi_1^0} = 400 \, \text{GeV}$
   - $m_{\chi_1^0} = 300 \, \text{GeV}$

3. **Direct $\tilde{t} \tilde{t}$ production**: 

   - Pure Winos: 1712.02118
   - Pure Higgsinos: 1902.01606, 1900.04995

4. **Long-lived particles**: 

   - Disapp. trk: $m_{\tilde{t}_{\tilde{l}}} = 10$ TeV

5. **Metastable $\tilde{t}$ production**: 

   - $m_{\tilde{t}_{\tilde{l}}} = 100$ TeV

6. **Soft $W$ and $Z$ production**: 

   - $m_{\tilde{t}_{\tilde{l}}} = 200$ TeV

7. **Large $\chi^0_1$**: 

   - $m_{\tilde{t}_{\tilde{l}}} = 500$ TeV

8. **BR(s)$\to$2j+20%**: 

   - $m_{\tilde{t}_{\tilde{l}}} = 1000$ TeV

9. **BR(s)$\to$2j+20%**: 

   - $m_{\tilde{t}_{\tilde{l}}} = 1000$ TeV

10. **BR(s)$\to$2j+20%**: 

    - $m_{\tilde{t}_{\tilde{l}}} = 1000$ TeV

*NOnly a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.*
# Searches for SUSY

## ATLAS SUSY Searches - 95% CL Lower Limits

<table>
<thead>
<tr>
<th>Model</th>
<th>Signature</th>
<th>$\mathcal{L} , dt , (\text{fb}^{-1})$</th>
<th>Mass limit</th>
</tr>
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<tbody>
<tr>
<td>$\tilde{g} \to q\bar{q}$</td>
<td>0 jets, 2-6 jets</td>
<td>36.1</td>
<td>0.9</td>
</tr>
<tr>
<td>$\tilde{q} \to \tilde{t}W$</td>
<td>1-5 jets</td>
<td>36.1</td>
<td>0.43</td>
</tr>
<tr>
<td>$\tilde{q} \to \tilde{t}Z$</td>
<td>2 jets</td>
<td>28.5</td>
<td>0.95</td>
</tr>
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<tr>
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<td>0.65</td>
</tr>
</tbody>
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## ATLAS Preliminary

$\sqrt{s} = 13$ TeV

*Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.*
Search for Strong SUSY

Stop Pair Production (3 body decay)

 Looking for some specific signatures in some difficult channels

A machine learning approach is used to discriminate the signal from the large dominant tt-bar background

Extends the limits on top squark masses to 720 GeV (with neutralino masses up to 580 GeV).

Signature = one (isolated) lepton + high-p_T jets + MET

See Stephanie's Talk on Thursday
Search for Electroweak SUSY

Stau Pair Production

Staus theoretically interesting (e.g., a light stau / DM) but experimentally challenging due to...

* Extremely low production rate
* Difficulties in reconstructing tau decays at the LHC

First time sensitivity in ATLAS!
Extends the LEP limit of around 90 GeV

**ATLAS Preliminary**

\( \sqrt{s} = 13 \text{ TeV}, 139 \text{ fb}^{-1} \)

SR-highMass
post-fit

\[ m(\tilde{\tau}, \tilde{\chi}^0_1) = (120, 1) \text{ GeV} \]

\[ m(\tilde{\tau}, \tilde{\chi}^0_1) = (280, 1) \text{ GeV} \]

**ATLAS Preliminary**

\( \sqrt{s} = 13 \text{ TeV}, 139 \text{ fb}^{-1} \)
All limits at 95% CL

Excluding 120 GeV - 390 GeV where lightest neutralino is massless
Many BSM models predict long lived (weakly interacting) particles → displaced objects in detector

e.g. a top squark with a particular RPV coupling

Signature = displaced muon + displaced vertex

Reconstructing these events required developing dedicated techniques for displaced muons/vertices
Light-by-Light Scattering

Observation of light by light scattering ($\gamma\gamma \rightarrow \gamma\gamma$) in ultra-peripheral collisions of Pb+Pb @ 5.02 TeV

(For UPCs impact parameter > x2 radius of ions)

Very rare process – sensitive to new physics

Signature = Exclusive production of two low $E_T$, back-to-back photons in otherwise empty event

59 candidate events observed for $12 \pm 3$ events expected from background ($8.2\sigma$)

This result demonstrates the power and flexibility of the ATLAS detector
γγ → γγ

Candidate Event

Pb+Pb collisions $\sqrt{s_{NN}} = 5.02$ TeV

Run: 366994
Event: 453765663
2018-11-26 18:32:03 CEST

Two $\gamma$ with $A_\phi = 0.002$

+ no additional activity in event
# Other New ATLAS Results

## Summary of ATLAS 13 TeV results using the full 2015–2018 (Run 2) dataset

This page provides a compact summary of published and preliminary ATLAS physics and performance results on 13 TeV proton–proton collision data based on the Run-2 data-set taken between 2015 and 2018. For questions, please, contact the ATLAS physics coordinators. See the [central publications page](https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ResultswithData2018) for other results from ATLAS.

This page also provides links to [ATLAS Physics Briefings](https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ResultswithData2018) for specific results. These are intended to provide a general introduction to ATLAS physics results for a non-specialist audience.

## Physics results

<table>
<thead>
<tr>
<th>Group</th>
<th>Format</th>
<th>Short Title</th>
<th>Date</th>
<th>V&lt;sub&gt;f&lt;/sub&gt; (TeV)</th>
<th>L</th>
<th>Links</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUSY</td>
<td>Paper</td>
<td>Chargino pair, slepton pair: 2 leptons NEW</td>
<td>21-AUG-19</td>
<td>13</td>
<td>130 ± 2</td>
<td>Documents</td>
</tr>
<tr>
<td>HDBS</td>
<td>Paper</td>
<td>$H\rightarrow b\bar{b}WW \rightarrow b\bar{b}WV$ NEW</td>
<td>19-AUG-19</td>
<td>13</td>
<td>130 ± 3</td>
<td>Documents</td>
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<tr>
<td>SUSY</td>
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<td>Search BSM $H(125)\rightarrow\nu\nu$ lepton flavor violating decay and $H(125)\rightarrow\tau\tau$</td>
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<td>$H(125)$ combination differential cross-sections gamma gamma and 4l</td>
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</table>

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ResultswithData2018
Preparations for Run 3 (and Beyond)

**LHC / HL-LHC Plan**

### Upgrade Phase 1
- New LAr calorimeter electronics
- New small wheels for muon system
- TDAQ upgrades (wrt. above items)

### Upgrade Phase 2
- New all-silicon inner tracker
- New electronics in calorimeter / muon systems
- TDAQ upgrades (HPC, parallelization, GPUs?)
Excellent performance of LHC and ATLAS detector → Run 2 dataset of 139 fb^{-1}

• High precision measurements of Higgs, multi-boson and top quark properties
  • Progress in some very rare physics searches
• Searches for new physics through new signatures and improved sensitivities

No significant deviations from SM predictions… so far!

Improvements/repairs to ATLAS detector are ongoing for Run 3 (and HL-LHC)

Much more to come… stay tuned!
Backup Slides
Zγ → ℓ⁺ℓ⁻γ Production

Provides tests of EW sector of SM / sensitive to new physics effects (eg. direct couplings of Z to photons)

Differential cross sections measured wrt. the ℓ⁺ℓ⁻γ system

Precision better than 5% in most measurement bins

compared with parton shower MC generators and parton-level generator generator Matrix (corrected to particle level).

[ATLAS-CONF-2019-034]
Resonance Search in $b\mu\mu$ Final State

Recent result on archived LEP data reported excess in dimuon invariant mass spectrum in events with a $b$-quark – with a local (global) significance of 5.0σ (2.6σ)

[arXiv:1610.06536]

CMS reported excess at 28 GeV in 8 TeV data:

@ 8 TeV
SR 1  4.2σ
SR 2  2.9σ

@ 13 TeV
SR 1  2.0σ
SR 2  1.4σ deficit

ATLAS has since targeted the same topology using Run 1 & Run 2 data:

No significant excess is observed
Higgs Combined Measurements

**global signal strength**

\[ \mu = 1.11 \pm 0.09(-0.08) \]

[arXiv:1909.02845]
Higgs Combined Measurements

BSM Higgses searched for both directly and indirectly → couplings measurement provides indirect limit on $m_A$ (hMSSM)

$\tan \beta$

ATLAS

$s = 13$ TeV, 24.5 - 79.8 fb$^{-1}$

$m_H = 125.09$ GeV, $|y_H| < 2.5$

hMSSM

[arXiv:1909.02845]
Di-Higgs Combined Measurements

Non-resonant Higgs boson pair production cross-section is $6.9 \times \sigma_{SM}^{ggF}$ @ 95% CL

<table>
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<th>Process</th>
<th>Obs.</th>
<th>Exp.</th>
<th>Exp. stat.</th>
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<td>12.5</td>
<td>15</td>
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<tr>
<td>$HH \rightarrow b\bar{b}b\bar{b}$</td>
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<td>$HH \rightarrow W^+W^-W^+W^-$</td>
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<td>$HH \rightarrow b\bar{b}W^+W^-$</td>
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<tr>
<td>Combined</td>
<td>6.9</td>
<td>10</td>
<td>8.8</td>
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Higgs Self-Coupling Constraints

\[ -3.2 < \kappa_\lambda < 11.9 \text{ @ 95\% CL} \]

\[ -5.0 < \kappa_\lambda < 12.0 \text{ @ 95\% CL} \]

\( \lambda(HHH) \) contributes to single Higgs processes at NLO EW via Higgs self energy loop correction (+ additional diagrams).

Therefore an indirect constraint on \( \lambda(HHH) \) can be extracted by comparing precise measurements of production yields and SM predictions.