Recent results and highlights from the ATLAS experiment

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on behalf of the ATLAS collaboration

Diffraction 2016, 03/09/2016
Overview

1. The ATLAS detector
   - Overall data-taking efficiency and detector status
   - Detector performance

2. Overview of the most recent results
   - W and Z production at 13 TeV
   - Di-boson production
   - Top quark
   - Higgs
   - Summary of SM results
   - BSM results
   - Diphoton resonances
   - Supersymmetry
   - Dark matter

3. Summary and conclusions
ATLAS at the LHC

The ATLAS collaboration

- ~3000 physicists
- 180 institutions
- 38 countries

The Large Hadron Collider

- two rings 27 km long
- 1,232 superconducting dipoles
- dipole operating temperature: -271.3°C
- ultrahigh vacuum: $10^{-13}$ atm
- 40 MHz collision rate
The ATLAS detector

- Inner Detector: Pixel, SCT, TRT
- Calorimeters: LAr (EM + hadronic + forward), TileCal (hadronic)
- Muon Spectrometers: barrel and endcaps
- Forward detectors: AFP, ALFA, LUCID, ZDC
- 2 magnetic fields: solenoidal (ID) and toroidal (MS)
- 150 · 10^6 read-out channels

The ATLAS trigger system

- Three levels: L1 is fully hardware, implemented in the calorimeters and the Muon Spectrometer
- L2 and the Event Filter (EF) are software based: the L2 accepts data from defined Regions Of Interests (ROI) of L1
- EF provides a full event reconstruction on computer farms
- 10^{14} B/s raw data flux
Overall data-taking efficiency and detector status

- 3.9 fb-1 pp at 13TeV recorded in 2015 (92% DAQ efficiency)
- 19.3 fb-1 pp at 13TeV recorded in 2016 (as of August 15th)
- peak luminosity delivered by LHC: $1.15 \cdot 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ (greater than design value $1 \cdot 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$)
### ATLAS pp 25ns run: April-July 2016

<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</td>
<td>MDT</td>
<td>Solenoid</td>
</tr>
<tr>
<td>98.9</td>
<td>99.8</td>
<td>99.6</td>
<td>99.7</td>
</tr>
<tr>
<td>SCT</td>
<td>Tile</td>
<td>RPC</td>
<td>Toroid</td>
</tr>
<tr>
<td>99.9</td>
<td>100</td>
<td>99.8</td>
<td></td>
</tr>
<tr>
<td>TRT</td>
<td></td>
<td>CSC</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td></td>
<td>TGC</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Good for physics: 91-98% (10.1-10.7 fb⁻¹)**

Luminosity weighted relative detector uptime and good data quality efficiencies (in %) during stable beam in pp collisions with 25ns bunch spacing at $\sqrt{s}=13$ TeV between 28th April and 10th July 2016, corresponding to an integrated luminosity of 11.0 fb⁻¹. The toroid magnet was off for some runs, leading to a loss of 0.7 fb⁻¹. Analyses that don’t require the toroid magnet can use that data.

- fraction of operational channels >96%
- DQ losses <1% for each individual system
Detector performance

Momentum scale and resolution of the Muon Spectrometer studied in detail using $J/\psi \rightarrow \mu\mu$ and $Z \rightarrow \mu\mu$ decays

Jet energy scale uncertainty at the level of 2012 data
W and Z production at 13 TeV

- Both absolute cross sections and ratios measured.
- Measurements of cross-section ratios benefit from the cancellation of some experimental uncertainties, and are powerful tools to constrain PDF fits.
- $\frac{W^+}{W^-}$: sensitive to u and d quark valence distribution, measured to a precision of 0.8%.
- $\frac{W^+}{Z}$: sensitive to strange quark content.

Di-boson production

- test of the SM at TeV scale
- important for background estimations needed for many measurements
- new physics could manifest in $W^\pm Z$ final states as a modification of the TGC and QGC strength
- precise knowledge of the $W^\pm Z$ production cross section is necessary in the search for new physics
- only a short selection shown here: more results available
Di-boson production: WZ

- Run-1 results were above the NLO predictions
- Run-2 total cross-section found to be consistent with very recent NNLO calculations

arXiv:1606.04017
Di-boson production: WW

- cross-section measurement of $W^+ W^- \rightarrow e^\pm \nu \mu^\mp \nu$ production at 13 TeV
- agreement with NNLO prediction at 13 TeV

**ATLAS Preliminary**

Fiducial cross section

<table>
<thead>
<tr>
<th>$\sqrt{s}$ [TeV]</th>
<th>$\sigma_{WW} [\text{fb}]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>5.3</td>
</tr>
</tbody>
</table>

**ATLAS**

Preliminary

NNLO WW (MSTW PDF) (arXiv:1408.5243 [hep-ph])
+ NNLO H→WW (MSTW PDF) (arXiv:1307.1347 [hep-ph])

LHC Data 2015 ($\sqrt{s}=13$ TeV)
- ATLAS WW (3.2 fb$^{-1}$)
- LHC Data 2012 ($\sqrt{s}=8$ TeV)
- ATLAS WW (20.3 fb$^{-1}$)
- LHC Data 2011 ($\sqrt{s}=7$ TeV)
- ATLAS WW (4.6 fb$^{-1}$)
- CDF WW (3.7 fb$^{-1}$)
- D0 WW (3.6 fb$^{-1}$)
- Tevatron ($\sqrt{s}=1.96$ TeV)

ATLAS-CONF-2016-090

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Top quark

- heaviest of the known fundamental particles
- at LHC, with luminosity $\sim 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$, top pair production rate is $\sim 8 \text{ pairs/s}$
- it decays before hadronisation: its properties are transferred directly to its decay products (information on “bare quarks”)
- the Standard Model predicts all its properties given the mass
  - deviations may point to “new physics”
  - $ttH$ coupling studied also in $ttH$ production: precision measurements of Higgs boson coupling to top quarks can reveal BSM effects
Top pair production cross-section

- inclusive top pair production in good agreement with NNLO prediction
- experimental measurements have reached the theoretical calculation

\[ \sigma_{t\bar{t}} = 818 \pm 8 \text{ (stat)} \pm 27 \text{ (syst)} \pm 19 \text{ (lumi)} \pm 12 \text{ (beam)} \text{ pb at } \sqrt{s} = 13 \text{ TeV} \]

arXiv:1606.02699
Top quark mass

Measured both directly from invariant mass and derived from cross-section (pole mass determination)

Recent direct measurement from $tt \rightarrow $ dilepton at 8 TeV

$$m_{\text{top}} = 172.84 \pm 0.34 \text{ (stat)} \pm 0.61 \text{ (syst)} \text{ GeV} = 172.84 \pm 0.70 \text{ GeV}$$

arXiv:1606.02179
Top couplings with Z and W

- Associated production of $t\bar{t}$ with a Z boson allow to extract information on the neutral current coupling of the top quark.
- Production rate of a top-quark pair with a massive vector boson could be altered in the presence of physics beyond the Standard Model (vector-like quarks, strongly coupled Higgs bosons or technicolor).
- At 13 TeV the SM cross sections of the $ttZ$ and $ttW$ processes increase by factors of 3.5 and 2.4, respectively, compared to 8 TeV.

Both measurements consistent with the NLO QCD theoretical calculations

ATLAS-CONF-2016-003
2015+2016 data
- fiducial and differential cross section measurements
- event categories enhancesensitivity to measurement of production mode cross sections: sigma_{ggH}, sigma_{VBF}, ...

ATLAS results
Diffraction 2016, 03/09/2016
Combining $\gamma\gamma + 4l$ channels (combination of fiducial cross sections):

$$\sigma(pp\to H+X, \ 13 \ \text{TeV}) = 59.0^{+9.7}_{-9.2} \text{(stat.)}^{+4.4}_{-3.5} \text{(syst.)} \ \text{pb}$$

- SM prediction: $55.5^{+2.4}_{-3.4} \ \text{pb}$
- overall significance at 13 TeV: $\sim 10 \ \sigma$
**ttH production**

- Direct probe of top Yukawa coupling
- Cross-section at 13 TeV 4 times larger than at 8 TeV
Summary of selected SM results

- $p p \rightarrow X$
  - 7 TeV, 20 $\mu$b$^{-1}$, Nat. Commun. 2, 463 (2011)
  - 8 TeV, 500 $\mu$b$^{-1}$, arXiv:1607.06605
  - 13 TeV, 60 $\mu$b$^{-1}$, arXiv:1606.02625

- $p p \rightarrow W$
  - 7 TeV, 36 pb$^{-1}$, PRD 85, 072004 (2012)
  - 13 TeV, 81 pb$^{-1}$, PLB 759 (2016) 601

- $p p \rightarrow Z / \gamma^*$
  - 13 TeV, 3.2 fb$^{-1}$, arXiv:1606.02699

- $p p \rightarrow t \bar{t}$
  - 7 TeV, 4.6 fb$^{-1}$, PRD 90, 112006 (2014)
  - 8 TeV, 20.3 fb$^{-1}$, ATLAS-CONF-2014-007
  - 13 TeV, 3.2 fb$^{-1}$, ATLAS-CONF-2015-079

- $p p \rightarrow t q$
  - 7 TeV, 4.6 fb$^{-1}$, PRD 90, 112006 (2014)
  - 8 TeV, 20.3 fb$^{-1}$, ATLAS-CONF-2014-007
  - 13 TeV, 3.2 fb$^{-1}$, ATLAS-CONF-2015-079

- $p p \rightarrow H$
  - 13 TeV, 13.3 fb$^{-1}$, ATLAS-CONF-2016-081

- $p p \rightarrow WW$
  - 7 TeV, 4.6 fb$^{-1}$, PRD 87, 112001 (2013)
  - 8 TeV, 20.3 fb$^{-1}$, arXiv:1608.03086
  - 13 TeV, 3.2 fb$^{-1}$, ATLAS-CONF-2016-090

- $p p \rightarrow WZ$
  - 8 TeV, 20.3 fb$^{-1}$, PRD 93, 092004 (2016)
  - 13 TeV, 3.2 fb$^{-1}$, arXiv:1608.04017

- $p p \rightarrow ZZ$
  - 7 TeV, 4.6 fb$^{-1}$, JHEP 03, 128 (2013)
  - 8 TeV, 20.3 fb$^{-1}$, ATLAS-CONF-2013-020
  - 13 TeV, 3.2 fb$^{-1}$, PRL 116, 101801 (2016)
**Selected summary of Exotics results**

only a representative selection of the available results is shown

### ATLAS Preliminary

\[ \mathcal{L} dt = (3.2 - 20.3) \text{ fb}^{-1} \]

\[ \sqrt{s} = 8, 13 \text{ TeV} \]

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**ATLAS Exotics Searches** - 95% CL Exclusion

**Status: August 2016**

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<table>
<thead>
<tr>
<th>Model</th>
<th>( t, \gamma )</th>
<th>Jets ( ^{\dagger} )</th>
<th>( E_{\text{miss}}^{\text{T}} )</th>
<th>ATLAS results</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADD ( G_{\chi} \to 6/4 )</td>
<td>–</td>
<td>( \geq 1 )</td>
<td>Yes</td>
<td>3.2</td>
</tr>
<tr>
<td>ADD non-resonant ( t\bar{t} )</td>
<td>2, ( e, \mu )</td>
<td>–</td>
<td>–</td>
<td>20.3</td>
</tr>
<tr>
<td>ADD QBH</td>
<td>1, ( e, \mu )</td>
<td>1</td>
<td>–</td>
<td>20.3</td>
</tr>
<tr>
<td>ADD BH high ( \Sigma_{B}^{+} )</td>
<td>( \geq 2 )</td>
<td>( \geq 1 )</td>
<td>Yes</td>
<td>3.2</td>
</tr>
<tr>
<td>ADD BH multijet</td>
<td>–</td>
<td>( \geq 3 )</td>
<td>Yes</td>
<td>3.6</td>
</tr>
<tr>
<td>RS1 ( G_{\chi} \to 6/4 )</td>
<td>2, ( e, \mu )</td>
<td>–</td>
<td>–</td>
<td>20.3</td>
</tr>
<tr>
<td>Bulk RS ( G_{\chi} \to WW \to q\bar{q}g )</td>
<td>1, ( e, \mu )</td>
<td>1</td>
<td>–</td>
<td>13.2</td>
</tr>
<tr>
<td>Bulk RS ( G_{\chi} \to H\bar{H} \to b\bar{b}b )</td>
<td>–</td>
<td>4</td>
<td>–</td>
<td>13.3</td>
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<tr>
<td>Bulk RS ( g \to \tau \tau )</td>
<td>1, ( e, \mu )</td>
<td>( \geq 1 )</td>
<td>Yes</td>
<td>20.3</td>
</tr>
<tr>
<td>2UED / RPP</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>3.2</td>
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<tr>
<td>SSM ( Z \to t\bar{t} )</td>
<td>2, ( e, \mu )</td>
<td>–</td>
<td>–</td>
<td>13.3</td>
</tr>
<tr>
<td>SSM ( Z \to \tau \tau )</td>
<td>2, ( \tau )</td>
<td>–</td>
<td>–</td>
<td>19.5</td>
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<td>Laplactofobic ( Z \to b\bar{b} )</td>
<td>3</td>
<td>–</td>
<td>–</td>
<td>3.2</td>
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<tr>
<td>SSM ( W \to t\bar{t} )</td>
<td>1, ( e, \mu )</td>
<td>–</td>
<td>Yes</td>
<td>13.3</td>
</tr>
<tr>
<td>HVT ( W \to ZZ \to q\bar{q}q\bar{q} )</td>
<td>Yes</td>
<td>1</td>
<td>Yes</td>
<td>13.2</td>
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<tr>
<td>HVT ( W \to ZZ \to q\bar{q}q\bar{q} )</td>
<td>( \geq 2 )</td>
<td>–</td>
<td>Yes</td>
<td>15.5</td>
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<tr>
<td>HVT ( V \to WH/ZH )</td>
<td>( \geq 3 )</td>
<td>–</td>
<td>Yes</td>
<td>20.3</td>
</tr>
<tr>
<td>LRSM ( W_{c} \to b\bar{b} )</td>
<td>0, ( e, \mu )</td>
<td>( \geq 1 )</td>
<td>–</td>
<td>13.7</td>
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<tr>
<td>LRSM ( W_{c} \to Wt )</td>
<td>0, ( e, \mu )</td>
<td>( \geq 1 )</td>
<td>Yes</td>
<td>20.3</td>
</tr>
<tr>
<td>CI ( \gamma \gamma )</td>
<td>–</td>
<td>2, ( e, \mu )</td>
<td>–</td>
<td>Yes</td>
</tr>
<tr>
<td>CI ( e\mu )</td>
<td>2, ( e, \mu )</td>
<td>–</td>
<td>Yes</td>
<td>2.25</td>
</tr>
<tr>
<td>CI ( e\mu )</td>
<td>1, ( e, \mu )</td>
<td>( \geq 1 )</td>
<td>Yes</td>
<td>20.3</td>
</tr>
<tr>
<td>DM</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>3.2</td>
</tr>
<tr>
<td>Scalar LQ 1st gen</td>
<td>0, ( e, \mu )</td>
<td>( \geq 1 )</td>
<td>Yes</td>
<td>3.2</td>
</tr>
<tr>
<td>Scalar LQ 1st gen</td>
<td>0, ( e, \mu )</td>
<td>( \geq 1 )</td>
<td>Yes</td>
<td>3.2</td>
</tr>
<tr>
<td>Scalar LQ 2nd gen</td>
<td>2, ( e, \mu )</td>
<td>( \geq 2 )</td>
<td>Yes</td>
<td>3.2</td>
</tr>
<tr>
<td>Scalar LQ 3rd gen</td>
<td>2, ( e, \mu )</td>
<td>( \geq 2 )</td>
<td>Yes</td>
<td>3.2</td>
</tr>
<tr>
<td>VLG ( T \to H^{0} \pm X )</td>
<td>1, ( e, \mu )</td>
<td>( \geq 2, \geq 3 )</td>
<td>Yes</td>
<td>3.2</td>
</tr>
<tr>
<td>VLG ( B\bar{B} \to H^{0} \pm X )</td>
<td>1, ( e, \mu )</td>
<td>( \geq 2, \geq 3 )</td>
<td>Yes</td>
<td>3.2</td>
</tr>
<tr>
<td>VLG ( V \to Zh/\chi^{\pm} )</td>
<td>2, ( e, \mu )</td>
<td>( \geq 2 )</td>
<td>Yes</td>
<td>3.2</td>
</tr>
<tr>
<td>VLG ( G_{\chi} \to WW )</td>
<td>( \geq 4 )</td>
<td>–</td>
<td>Yes</td>
<td>3.2</td>
</tr>
<tr>
<td>VLG ( t_{\chi} \to \ell^{\pm} )</td>
<td>2, ( e, \mu )</td>
<td>( \geq 2 )</td>
<td>Yes</td>
<td>3.2</td>
</tr>
</tbody>
</table>

**Heavy fermions**

| Excited fermions | \( q \to \bar{q} \) | \( \gamma \) | 1, \( e, \mu \) | 1 | Yes | 3.2 | \( 4.4 \text{ TeV} \) |
| Excited fermions | \( q \to \bar{q} \) | \( \gamma \) | 1, \( e, \mu \) | 1 | Yes | 3.2 | \( 5.6 \text{ TeV} \) |
| Excited fermions | \( q \to \bar{q} \) | \( \gamma \) | 1, \( e, \mu \) | 1 | Yes | 3.2 | \( 2.3 \text{ TeV} \) |
| Excited fermions | \( q \to \bar{q} \) | \( \gamma \) | 1, \( e, \mu \) | 1 | Yes | 3.2 | \( 1.5 \text{ TeV} \) |
| Excited fermions | \( q \to \bar{q} \) | \( \gamma \) | 1, \( e, \mu \) | 1 | Yes | 3.2 | \( 1.5 \text{ TeV} \) |
| Excited fermions | \( q \to \bar{q} \) | \( \gamma \) | 1, \( e, \mu \) | 1 | Yes | 3.2 | \( 1.5 \text{ TeV} \) |
| Excited fermions | \( q \to \bar{q} \) | \( \gamma \) | 1, \( e, \mu \) | 1 | Yes | 3.2 | \( 1.5 \text{ TeV} \) |

**Other**

| CST \( \gamma \to W \gamma \) | 1, \( e, \mu \) | 1 | Yes | 20.3 | \( 900 \text{ GeV} \) |
| LRSM Majranka \( \gamma \to W \gamma \) | 2, \( e, \mu \) | 2 | Yes | 20.3 | \( 2.7 \text{ TeV} \) |
| Higgs Inlet \( H^{0} \to \gamma \gamma \) | 2, \( e, \mu \) | 2 | Yes | 13.2 | \( 570 \text{ GeV} \) |
| Higgs Inlet \( H^{0} \to W^{\pm} W^{\pm} \) | 3, \( e, \mu \) | 2 | Yes | 20.3 | \( 1.5 \text{ TeV} \) |
| Monotop (non-res prod) | 1, \( e, \mu \) | 1 | Yes | 20.3 | \( 1.5 \text{ TeV} \) |
| Magnetic monopoles | – | – | – | 1.7 | \( 1.8 \text{ TeV} \) |

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

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

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*Only a selection of the available mass limits on new states or phenomena is shown. Lower bounds are specified only when explicitly not excluded.*

\( ^{\dagger} \) Small-radius (large-radius) jets are denoted by the letter (\( J \)).

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Some MSSM models predict high mass scalar decaying in high mass $\tau\tau$:

- two decay modes: lepton + hadron and hadron-hadron
- main backgrounds: $Z\tau\tau$ and multijets
Diphoton resonances

2015 data:
- excess at 750 GeV (after reprocessing, at 730 GeV)
- local significance $3.9\sigma$, global $2.1\sigma$
  (after reprocessing: local significance $3.4\sigma$)

2015+2016 data:
- small excess at 710 GeV
- local significance $1.4\sigma$, global $<1\sigma$
Selected summary of Supersymmetry results

only a representative selection of the available results is shown
Jets + $E_T^{miss} \ (0\ell)$

- expect large increase of SUSY cross-sections going from 8 → 13 TeV: $\sigma(\tilde{g}\tilde{g}) \times 30$ for $m(\tilde{g}) = 1.4$ TeV
- signature: 0 lepton + jets (2 to 6) + $E_T^{miss}$
- main backgrounds: $Z/W+jets$ and $t\bar{t}$
- example: $M_{eff}$ analysis

**ATLAS Preliminary**

$\sqrt{s}=13 \text{ TeV, 13.3 fb}^{-1}$

<table>
<thead>
<tr>
<th>$M_{eff}$-4j-2200</th>
<th>Events / 200 GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data 2015 and 2016</td>
<td></td>
</tr>
<tr>
<td>SM Total</td>
<td></td>
</tr>
<tr>
<td>W+jets</td>
<td></td>
</tr>
<tr>
<td>$t\bar{t}$ (+EW) &amp; single top</td>
<td></td>
</tr>
<tr>
<td>$Z$+jets</td>
<td></td>
</tr>
<tr>
<td>Diboson</td>
<td></td>
</tr>
<tr>
<td>Multijet</td>
<td></td>
</tr>
<tr>
<td>$\tilde{g}\tilde{g}$ direct, $m(\tilde{g}, \chi) = (1800, 0)$</td>
<td></td>
</tr>
</tbody>
</table>

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Jets + $E_T^{miss}$ ($0\ell$)

- final limits in 0L final states with 2-6 jets
- no significant excesses
- new Recursive Jigsaw Reconstruction (RJR) technique implemented (not shown here)
- signature: 1 lepton + jets + $E_T^{miss}$
- main backgrounds: Z/W+jets and $t\bar{t}$
- largest excess: 3.3 $\sigma$ (local)

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ATLAS-CONF-2016-050
summary of the dedicated ATLAS searches for top squark (stop) pair production based on 13 fb-1 of pp collision data taken at $\sqrt{s} = 13$ TeV

the yellow limit shows the result of the analysis discussed in the previous slide
Dark matter

- searches for weakly-interacting dark matter production in association with other SM particles
- distinct signature of significant missing transverse momentum
- example: $E_T^{\text{miss}} + ZZ \ (\rightarrow \ell\ell)$

ATLAS-CONF-2016-056

- no significant excesses observed
- limits have been set, search continues
Summary and conclusions

- ATLAS is coping very well with LHC approaching (and overcoming) design luminosity
- many results already available:
  - Higgs properties
  - towards a ttH coupling measurement: observed significance of 2.8 $\sigma$
    (combined photon, multilepton, and b-quark decays)
  - increased sensitivity to BSM searches
  - almost 600 publications
- no significant excesses yet, more data coming soon
- expect more exciting Run-2 results within next 2 years: 100 fb-1 expected