Latest Beyond Standard Model results with the ATLAS detector

Arturo Sánchez, on behalf the ATLAS Collaboration
University of Udine, ICTP and INFN
February 14th, KEK-PH 2018, Tokyo, Japan
Outline

- Motivations
- Resonant searches
  - Leptons
    - Dileptons
    - Lepton + Missing Et
  - Dibosons
    - $\gamma \gamma$
    - $VV$
  - Dijets & ttbar
- Non-resonant searches
  - Vector-Like Quarks
  - Dark Matter
- Summary
- Backup
Motivations

The Standard Model (SM) measurements give a nice agreement with the theory predictions

However, SM can not explain other important questions in physics, like:

- Hierarchy/naturalness/fine-tuning?
- Dark matter?
- Matter/anti-matter asymmetry?
- ... and the known observation of neutrino masses

For that reason, ATLAS, as many other experiments has a very large program in Exotics searches!
Motivations

And… we have evidence of the existence of Beyond SM (BSM) physics, particularly when talking about Dark Matter

- Astrophysical and cosmological anomalies
  - Inconsistent with current understanding of gravitation & cosmology
  - Bullet cluster
- Dark matter (DM)
  - Non-luminous, non-interacting particle
  - Universe is 5% ordinary matter and 26% dark matter
- Many DM theories
  - Black holes, axions, unknown particles, etc
- Weakly Interacting Massive Particles
  - Assume that DM couples weakly to the Standard Model (SM)
  - Produced in early universe
  - Thermal relic density

- Composite Credit: X-ray: NASA/CXC/CfA/ M.Markevitch et al.; Lensing Map: NASA/STScI; ESO WFI; Magellan/U.Arizona/ D.Clowe et al.
- Optical: NASA/STScI; Magellan/U.Arizona/ D.Clowe et al.

Visible Galaxies

X-ray emitting gas

Gravitational lensing
Resonant Searches
**Signature**
A pair of $e/\mu$ with $p_T > 30$ GeV
Fully reconstructed, high signal-selection efficiency, small & well-understood backgrounds

**Dominant background**
- Drell-Yan (DY)

**Systematic uncertainties**
- DY PDF variations
- $\mu$ reconstruction efficiency (high $p_T$)
- Calorimeter-based $e$ isolation efficiency

**No excess found in data**
$M_{Z'}$, exclusion limit up to 3.8 TeV
Signature
A well defined e/μ with $p_T > 55/65 \text{ GeV}$
MeT > 55/65 GeV

Resonances


Electron + Muon

$\mu^+\nu^-$

No excess found in data
$M_{W'}$ exclusion limit up to 5.1 TeV

$m_T = \sqrt{2p_T E_T^{\text{miss}} (1 - \cos \phi_{\ell\nu})}$

Dominant background
- $W \rightarrow l^\pm$ with $p_T > 55/65 \text{ GeV}$
- MeT > 55/65 GeV
- $W^\pm \rightarrow l^\pm + \nu$ + Single top
- Systematic Uncertainties
  - PDF variation in $W \rightarrow l^\pm$ bkg.
  - Muon reconstruction and electron ID eff.

$\gamma,Z$

$W$
In hMSSM scenario, exclude tan$\beta$$>$1.0 for $m_A = 0.25$ TeV and tan$\beta$$>$42 for $m_A = 1.5$ TeV @95% CL.

For Sequential SM, $Z'$$_{SSM}$ with $m_{Z'}$$<2.42$ TeV is excluded @95% CL, while $Z'$$_{NU}$ with $m_{Z'}$$<2.25$ TeV is excluded for the non-universal G(221) model.

No statistically significant excess above the SM observed

Model-independent upper limits are set on the visible $\tau\nu$ x-section.

$W'$ bosons with $m_{W'} < 3.7$ TeV in the Sequential SM & $m_{W'} < 2.2-3.8$ TeV depending on the coupling in the non-universal G(221) model are excluded @95% CL.
**Signature**

Two prompt, isolated, high-\( p_T \) leptons with the same charge

---

Low irreducible background, but with jets misidentified as leptons (data-driven factors) and charge flip backgrounds (using Z → ee data sample)

Complicated estimation: **Background is done in a simultaneous fit to 5 CRs and validated in 8 VRs**

---

No excess found in data
A visualization of the highest-mass dijet event. The two central high-pT jets each have transverse momenta of 3.79 TeV, they have a $|y^*|$ of 0.38 and their invariant mass is 8.12 TeV. The missing transverse momentum in this event is 44 GeV.
No excess found in data

Expected limits for a narrow signal

Observed limits for signal with width ranges from 0 to 15% $m_{JJ}$

No excess found in data

Signature/Selection

> 1 jet with $p_T > 440$ (60) GeV

$|y^*| < 0.6$ where $y^*$ is the rapidity difference $= (y_1 - y_2)/2$ of the jets

Important: Limits have been extracted on specific models as well, please check the reference for more details!
Diboson Searches
Motivations

The existence of new heavy resonance will be able to help to

- resolve Hierarchy problem
- understand the mechanism of EWSB
- understand flavour structure of the SM

3 types of productions

Many models predict the existence of new heavy resonances decaying into diboson!
Jet Tagging of W/Z/H bosons

Resolved (2 small-R jets)
- Excellent precision on jet energy scale (even at very high $p_T$)

Boost (collimated 1 large-R jet)
- Reconstructed large-R jet substructure used to discriminate W/Z jet against multi-jets: mass, D2 (ratios of the energy correlation functions)

For Higgs-jet: b-hadron identification (R=0.2 b-tagged jet)
No evidence of the production of heavy resonance is observed.

Other (4l) results in https://arxiv.org/abs/1712.06386

Main background
- Z + jets, data-driven (normalisation) from CRs (sideband $m_j$ or $m_{jj}$)
- ttbar dedicated CRs

Systematic Uncertainties
- Background modelling (llqq: shape difference in CR, vvqq: PDF + $\alpha$’s variations)
- Large-R jet energy resolution

X → ZZ → llqq

X → ZZ → vvqq

X → ZW → llqq

X → ZW → vvqq
\[ X \rightarrow W[W,Z] \rightarrow l\nu qq \quad X \rightarrow VV \rightarrow JJ \]

Signatures

- 2 large-R jets from hadronic \( W/Z \) boson decay
- 1 lepton and Missing \( E_T \) from \( W \) and hadronic decay of \( W/Z \)

Background

- \( W \)-jets (norm, data-driven, CRs with \( m_J \) or \( m_{JJ} \) sideband)

Systematic uncertainties

- \( W \)+jets modeling (PDF+\( \alpha ' \)’s variations)
- large-R jet mass/D2 resolution

No evidence of the production of heavy resonance is observed

\[ X \rightarrow WW \rightarrow l\nu qq \]
\[ X \rightarrow WZ \rightarrow l\nu qq \]
\[ X \rightarrow ZZ \rightarrow JJ \]
**Signature**

Use of $H \rightarrow bb$ as a tag ($bbH$)

**Backgrounds**

- $t\bar{t}$bar ($V \rightarrow \ell\nu$, $\nu\nu$), and $Z$+jets ($V \rightarrow \ell\ell$), shape is MC estimated, normalisation is constrained from CRs
- Multi-jet ($V \rightarrow q\bar{q}$), both shape and normalisation are data-driven, re-weighting from untagged regions

**Systematics Uncertainties**

- jet energy scale/resolution,
- b-tagging,
- $t\bar{t}$bar/Multi-jet and $V$+jets normalisations

**No evidence of heavy resonance is observed**
$m_{W'} < 2.8$ TeV is excluded

\[ X \rightarrow VH(bb) \]

$X \rightarrow [W/Z]V$ - Spin 1

$m_{Z'} < 2.7$ TeV is excluded

$m_{W'} < 3.3$ TeV is excluded

[ATLAS Preliminary]
\[ \sqrt{s} = 13 \text{ TeV}, \ 36.1 \text{ fb}^{-1} \]

95% C.L. exclusion limits

- HVT model B $g_\nu=3$
- Observed
- Expected
- $qqbb$
- $lvbb$

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/EXOTICS/
Two selection have been optimised for

Spin-0: “heavy Higgs”
- \( E_T > 0.4 \text{ m} \) for the leading \( \gamma \)
- \( E_T > 0.3 \text{ m} \) for the subleading \( \gamma \)

Spin-2: resonant RS1 and non-resonant ADD graviton
- \( E_T > 55 \text{ GeV} \) for the two \( \gamma \)'s

Upper limits on the production x-section times branching ratio of two \( \gamma \) @13 TeV of the lightest KK graviton as a function of its mass \( m_{G^*} \) for \( k/M_{Pl} = 0.1 \)

No significant excess found in data
Non-resonant Searches
Dijet: Angular Analysis

Looking for deviations in angular distributions

7 signal regions with $m_{jj}$ above 3.4 TeV

Main uncertainties

- Jet energy scale and factorisation & renormalisation scales

No significant deviations found in data

$\chi = e^{2|y^*|} \sim \frac{1 + \cos \theta^*}{1 - \cos \theta^*}$

BSM signal is expected to be more prominent at low $\chi$

Limits for a four-fermion EFT (contact interaction) model, and $\Lambda$ scale of ~30 TeV

ATLAS

- Data
- SM
- CI $\eta_{LL} = -1, \Lambda = 22$ TeV
- CI $\eta_{LL} = +1, \Lambda = 15$ TeV

$\sqrt{s} = 13$ TeV, 37.0 fb$^{-1}$

$m_{jj} > 5.4$ TeV

4.9 < $m_{jj}$ < 5.4 TeV

4.6 < $m_{jj}$ < 4.9 TeV

4.3 < $m_{jj}$ < 4.6 TeV

4.0 < $m_{jj}$ < 4.3 TeV

3.7 < $m_{jj}$ < 4.0 TeV

3.4 < $m_{jj}$ < 3.7 TeV
Motivations

Vector-Like quarks (VLQ)

- Color-triplet spin-½ fermions, left-handed and right-handed components transform in a same way under the SM gauge group

- Masses of the VLQ are not generated by a Yukawa coupling, not excluded by existing Higgs measurements
- The VLQs couple preferentially to 3\textsuperscript{rd}-generation quarks, they have both charged-current decays (T → W_b; B → W_t) and neutral current decays (T → Z_t; B → Z_b; H_b)
- Contrary to sequential fourth generation
Vector-Like Quarks

Analysis with 20 Signal regions and 15 Validation regions combined Fit!

No excess found in data

TT → Z(ww)\(\tilde{t} \bar{t}\) + X: 1 lepton, jets, MET

TT → H(bb)\(\tilde{t} \bar{t}\) + X: 0/1 lepton, jets, b-jets


Vector-Like Quarks (3)

No excess found in data

a) $TT \rightarrow W(qq)b + X$: 1 lepton, 1 large-R W tagged jet, >1 b-tagged Small-R jets, MET

b) $BB \rightarrow W^+W^-t\bar{t}$ / $WtZb$: > 1 same-sign leptons, > 1 jets, >0 b-tagged Small-R jets

Dark Matter Searches

Arturo Sánchez, KEK-PH 2018, Tokyo, Japan
define benchmark models for kinematically distinct signals for the so-called Run-2 searches:

**LHC Run-1:** “traditional” Effective Field Theory (EFT) approach *(some searches on Run-2)*
- Assume mediator too heavy to be produced
- 2 parameters: WIMP mass \((m_\chi)\) & suppression scale \((M^*)\)
- Some comparisons to simplified models

**For Run-2:** benchmark Simplified Models*
- Provide basis for re-interpretations (distinct kinematics)
- Collected by LHC DM forum
- Dirac-fermionic WIMPs

* (where possible)
General Analyses Remarks

Similar strategy in all the mono-X searches:

- Event Selection
  - High MET, compatible with $\chi\chi$ production
  - If $X=\gamma$, jet $\rightarrow$ high $p_T(X)$ with quality criteria
  - If $X=W, Z, h$ $\rightarrow$ reconstruct mass within a windows
  - Large $\Delta\phi(X,\text{MET})$
  - Veto events with other “good” physics objects, like leptons

Finally, the search focus in look for excess in different regions of high MET, and in case of absence of excess, exclusion limits are extracted for the model
MET $> 150$ GeV
\[ \gamma, p_T > 150 \text{ GeV} \]
\[ |\eta| < 2.37 \]
Tight, isolated Jet: 
\[ # < 2 \]
\[ p_T > 30 \text{ GeV} \]
- High $p_T \gamma + \text{MET} (+ < 2 \text{ jets})$

**Signature**

Main bkgs normalized to data in specific CRs:
- $Z \rightarrow \nu\nu + \gamma \rightarrow 2\mu\text{CR} + 2\text{eCR}$
- $W \rightarrow l\nu + \gamma \rightarrow 1\mu\text{CR}$
- $\gamma + \text{jets} \rightarrow \gamma + \text{jetCR}$

- SR: $\mu$ and e veto
- Bkg in SR derived: simultaneous single-bin fit to CRs
- Statistically limited: 4-10% stat. uncertainty from CRs (total: 6-14%)

Simplified Model:
Axial-vector mediator
95% CL exclusion limit on \((m_\chi, m_{med})\) plane, excluding the area of \(m_{med} < 1200 \text{ GeV}, m_\chi < 340 \text{ GeV}\)

EFT Model:
Lower limit for M* (eff. mass scale) as function of \(m_\chi\): M* < 790 GeV excluded
Truncation: remove events with \(\sqrt{s} > gM^*\) for various values of \(g\)

No excess found in data
**Signature**
High $p_T$ Jet + MET (+ < 4 jets)

**Main bkgs normalized to data in specific CRs:**
- $Z \rightarrow \nu \nu + \text{jets}$, $W \rightarrow \mu \nu + \text{jets}$ → $1\mu\text{CR}$
- $W \rightarrow e \nu (\tau \nu) + \text{jets}$, $Z \rightarrow \tau \tau + \text{jets}$ → $1e\text{CR}$
- $Z \rightarrow \mu \mu + \text{jets}$ → $2\mu\text{CR}$

**Theory corrections** are used to reweight V+jets backgrounds

**- Largest uncertainties:**
- Data statistics in CRs: up to 5%
- Theory uncertainties: < 6%
- Others in others of 0.5% to 2%

---

Jet: $p_T > 250$ GeV  
$|\eta| < 2.4$

Tight cleaning

$\mu/e$ veto

Jets: 
# < 4 $p_T > 30$ GeV

MET > 150 GeV

---

No excess found in data

**Simplified Model:**
Axial-vector mediator
95% CL exclusion limit on $(m_\chi', m_{\text{med}})$ plane, excluding the area of $m_{\text{med}} < 1 \text{ TeV}$, $m_\chi < 250 \text{ GeV}$

**Complementary w/direct detection**
90% CL exclusion limit on the spin-dependent $\chi$-proton scattering $\sigma$:
- model dependent,
- excluding $\sigma_{\text{SD}}(\chi-p) > 10^{-42}\text{ cm}$, low $m_\chi$
Large R Jet: $p_T > 200 \text{ GeV}$

Boson tagged

Signature

High $p_T$ large-R Jet + MET

Main bkgds normalized to data in specific CRs:

- $Z + \text{jets} \rightarrow 2\mu CR$
- $W + \text{jets} \rightarrow 1\mu CR$, not $b$-jets
- $\text{ttbar} \rightarrow 1\mu CR + < 2 b$-jets

- **SR:** $\mu$ and e veto
- **Bkg in SR derived:** simultaneous single-bin fit to CRs
- **W / Z / ttbar CRs:** leptons selected, relaxed mass cuts, (anti-)b-tagging, $\text{MET} > 200 \text{ GeV}$
- **Largest uncertainties:**
  - Large-R jet parameter modelling: $\sim 10%$
  - **Simultaneous fit** with the three normalization factors coming from the CRs.
- **Boson Tagging algorithms are used to identify the W/Z** independently. Based in the internal structure of the large-R jet
Simplified Model:
Axial-vector mediator
Exclusion limit on signal strength
(m_{\chi}, m_{\text{med}}) plane.
For \( g_q = 0.25 \) and \( g_\chi = 1 \)

No excess found in data
Mono-Z ($l^+l^-) + X$

Backgrounds
- ZZ: MC estimated; WZ: data-driven
- Z/γ*+jets: fake MET from instrumental effects extrapolate from 2D sideband regions using MET and MET/HT (50-90% systematic)
- Top/WW/Z → τ+τ−: estimated from e/mu events in data (systematic uncertainties: 14%)

No excess found in data
Models in which the higgs couples to dark sector particles, e.g. higgs couplings to the mediator

- Not ISR (small coupling)
- Mainly Simplified Models:
  - s-channel vector mediator radiating Higgs
- Other models considered:
  - s-channel scalar mediator radiating Higgs
  - Z'-2HD simplified model
  - scalar 2HD simplified model
- Additional parameters as: $g_{Z'Z'h}$, mixing angles...
Signature:
Two $\gamma + \text{MET}$

**Simplified Model:** Vector mediator

4 categories:
cuts on MET, $p_T^{\gamma\gamma}$, $p_T$ [\(\gamma\)'s, jets]

Largest uncertainties: vertex selection and MET estimation

95% CL exclusion limit on $m_{\text{med}}$

**EFT model:**

In both model cases a simultaneous fit to all regions was applied

No excess found in data

Exclusion contours for
- The $Z'$-2HDM exclusion contour in the ($m_{Z'}, m_A$) plane for \( \tan\beta = 1, \ g_{Z'} = 0.8, \ m_t = 100 \ GeV \) and \( m_X = 300 \ GeV \)

Upper limits at 95% CL on \( \sigma_{\text{vis}, h(bb)+DM} \) of h+DM events with \( h \rightarrow bb \) in the four \( E_T^{\text{miss}} \) regions at detector level

No excess found in data
Selection
- Multiple jets (>=2/1/0 b-jets), 0/1/2 well-identified leptons, and MET

Main backgrounds
- Z+jets (0 lepton), ttbar (1/2 leptons), backgrounds are constrained in different CRs
Exclusion limits at 95% CL for higgsino pair production $\chi_1^+\chi_1^-\chi_2^0\chi_1^0$, $\chi_1^0\chi_2^0$, and $\chi_1^+\chi_1^-\chi_1^0\chi_1^0$ with off-shell SM-boson-mediated decays to the lightest neutralino, $\chi_1^0$, as a function of the $\chi_1^\pm$ and $\chi_1^0$ masses. The production cross-section is for pure higgsinos.

Expected (black dashed) and observed (red solid) 95% CL exclusion limit in the plane of (left) the chargino mass and its lifetime, and (right) the chargino mass and the mass-splitting between the chargino and the LSP. The pink-coloured region is excluded. The black dot-dashed curve crossing over the exclusion line shows a theoretical prediction in the pure-higgsino scenario.

No significant excess is observed over the estimated SM backgrounds. Exclusion limits at 95% CL are derived for direct production of higgsinos. Chargino masses up to 152 GeV are excluded in the pure-higgsino LSP model.
### ATLAS Exotics Searches - 95% CL Upper Exclusion Limits

**Status: July 2017**

**$\sqrt{s} = 8$, 13 TeV**

#### Model

<table>
<thead>
<tr>
<th>Model</th>
<th>$\ell$, $\gamma$, Jets</th>
<th>$E^{\text{miss}}_T$</th>
<th>Limit</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADD $g_\gamma \to q\bar{q}$</td>
<td>$0, \mu$, $1, 2$</td>
<td>Yes</td>
<td>$8.9$ TeV</td>
<td>ATLAS-COM-2017-040</td>
</tr>
<tr>
<td>ADD non-resonant $gg$</td>
<td>$2, \gamma$</td>
<td>-</td>
<td>$9.3$ TeV</td>
<td>CERN-PH-EP-2017-132</td>
</tr>
<tr>
<td>ADD QSH</td>
<td>$2, \gamma$</td>
<td>-</td>
<td>$9.0$ TeV</td>
<td>ATLAS-COM-2017-040</td>
</tr>
<tr>
<td>ADD BH $\gamma\gamma \to \gamma\gamma$</td>
<td>$0, \gamma, \mu, \tau$</td>
<td>-</td>
<td>$8.7$ TeV</td>
<td>CERN-PH-EP-2017-132</td>
</tr>
<tr>
<td>ADD BH multijet</td>
<td>$2, \gamma$</td>
<td>-</td>
<td>$6.9$ TeV</td>
<td>ATLAS-COM-2017-040</td>
</tr>
<tr>
<td>RS1 $G_{1,2} \to \gamma\gamma$</td>
<td>$2, \gamma$</td>
<td>-</td>
<td>$4.1$ TeV</td>
<td>CERN-PH-EP-2017-132</td>
</tr>
<tr>
<td>Bulk RS $G_{1,2} \to WW \to q\bar{q}g$</td>
<td>$1, \mu, \gamma$</td>
<td>Yes</td>
<td>$1.73$ TeV</td>
<td>ATLAS-COM-2017-040</td>
</tr>
<tr>
<td>2UED/BPP</td>
<td>$1, \mu, \gamma$</td>
<td>Yes</td>
<td>$1.6$ TeV</td>
<td>ATLAS-COM-2017-040</td>
</tr>
<tr>
<td><strong>Extra-dimensional</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSM $Z \to \ell\ell$</td>
<td>$2, \gamma$</td>
<td>-</td>
<td>$4.5$ TeV</td>
<td>ATLAS-COM-2017-027</td>
</tr>
<tr>
<td>SSM $Z \to \ell\ell$</td>
<td>-</td>
<td>$2.4$ TeV</td>
<td>CERN-PH-EP-2017-132</td>
<td></td>
</tr>
<tr>
<td>Lepotoplastic $Z \to b\bar{b}$</td>
<td>$2, \gamma$</td>
<td>-</td>
<td>$1.3$ TeV</td>
<td>ATLAS-COM-2017-040</td>
</tr>
<tr>
<td>Lepotoplastic $Z \to b\tau$</td>
<td>$2, \gamma$</td>
<td>-</td>
<td>$3.0$ TeV</td>
<td>CERN-PH-EP-2017-132</td>
</tr>
<tr>
<td>LHT $W' \to WW$</td>
<td>$0, \mu, \tau$</td>
<td>-</td>
<td>$5.1$ TeV</td>
<td>ATLAS-COM-2017-040</td>
</tr>
<tr>
<td>LHT $W' \to WW$</td>
<td>$0, \mu, \gamma$</td>
<td>-</td>
<td>$3.5$ TeV</td>
<td>ATLAS-COM-2017-040</td>
</tr>
<tr>
<td>LHT $W' \to WW$</td>
<td>$0, \mu, \mu$</td>
<td>-</td>
<td>$2.9$ TeV</td>
<td>ATLAS-COM-2017-040</td>
</tr>
<tr>
<td>LRSM $W_1 \to \ell\nu$</td>
<td>$2, \gamma$</td>
<td>$2.9$ TeV</td>
<td>CERN-PH-EP-2017-144</td>
<td></td>
</tr>
<tr>
<td>LRSM $W_1 \to \ell\nu$</td>
<td>$0, \mu, \tau$</td>
<td>-</td>
<td>$1.92$ TeV</td>
<td>ATLAS-COM-2017-055</td>
</tr>
<tr>
<td><strong>Gauge bosons</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CI $\gamma\gamma$</td>
<td>$0, \mu, \gamma$</td>
<td>-</td>
<td>$1.76$ TeV</td>
<td>ATLAS-COM-2017-027</td>
</tr>
<tr>
<td>CI $\gamma\gamma$</td>
<td>$0, \mu, \gamma$</td>
<td>-</td>
<td>$40.1$ TeV</td>
<td>CERN-PH-EP-2017-144</td>
</tr>
<tr>
<td>CI $\gamma\gamma$</td>
<td>$0, \mu, \gamma$</td>
<td>-</td>
<td>$21.8$ TeV</td>
<td>ATLAS-COM-2017-040</td>
</tr>
<tr>
<td>CI $\gamma\gamma$</td>
<td>$0, \mu, \gamma$</td>
<td>-</td>
<td>$21.8$ TeV</td>
<td>ATLAS-COM-2017-040</td>
</tr>
<tr>
<td>CI $\gamma\gamma$</td>
<td>$0, \mu, \gamma$</td>
<td>-</td>
<td>$21.8$ TeV</td>
<td>ATLAS-COM-2017-040</td>
</tr>
<tr>
<td><strong>Axial-vector mediator (Dirac DM)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\sigma_0$</td>
<td>$0, \mu, \gamma$</td>
<td>-</td>
<td>$1.9$ TeV</td>
<td>ATLAS-COM-2017-040</td>
</tr>
<tr>
<td><strong>Vector mediator (Dirac DM)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\sigma_0$</td>
<td>$0, \mu, \gamma$</td>
<td>-</td>
<td>$1.2$ TeV</td>
<td>ATLAS-COM-2017-040</td>
</tr>
<tr>
<td><strong>Scalar mediator (Dirac DM)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\sigma_0$</td>
<td>$0, \mu, \gamma$</td>
<td>-</td>
<td>$2.1$ TeV</td>
<td>ATLAS-COM-2017-040</td>
</tr>
<tr>
<td><strong>Higgs bosons</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LQ $LQ_{1,2}$ gen</td>
<td>$2, e, \mu, \tau$</td>
<td>-</td>
<td>$1.1$ TeV</td>
<td>ATLAS-COM-2017-040</td>
</tr>
<tr>
<td>LQ $LQ_{2,3}$ gen</td>
<td>$2, e, \mu, \tau$</td>
<td>-</td>
<td>$1.1$ TeV</td>
<td>ATLAS-COM-2017-040</td>
</tr>
<tr>
<td>LQ $LQ_{3,4}$ gen</td>
<td>$2, e, \mu, \tau$</td>
<td>-</td>
<td>$1.1$ TeV</td>
<td>ATLAS-COM-2017-040</td>
</tr>
<tr>
<td>LQ</td>
<td>$2, e, \mu, \tau$</td>
<td>-</td>
<td>$0.6$ TeV</td>
<td>CERN-PH-EP-2013-039</td>
</tr>
<tr>
<td><strong>Exotic fermions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excited quark $q' \to qg'$</td>
<td>$2, e, \mu, \tau$</td>
<td>-</td>
<td>$2.3$ TeV</td>
<td>CERN-PH-EP-2017-148</td>
</tr>
<tr>
<td>Excited quark $q'' \to qg''$</td>
<td>$2, e, \mu, \tau$</td>
<td>-</td>
<td>$2.3$ TeV</td>
<td>CERN-PH-EP-2017-148</td>
</tr>
<tr>
<td>Excited quark $q'' \to qg''$</td>
<td>$2, e, \mu, \tau$</td>
<td>-</td>
<td>$2.3$ TeV</td>
<td>CERN-PH-EP-2017-148</td>
</tr>
<tr>
<td>Excited quark $q'' \to Wq''$</td>
<td>$1, e, \mu, \tau$</td>
<td>-</td>
<td>$2.3$ TeV</td>
<td>CERN-PH-EP-2017-148</td>
</tr>
<tr>
<td>Excited lepton $\ell$</td>
<td>$3, e, \mu, \tau$</td>
<td>-</td>
<td>$3.0$ TeV</td>
<td>CERN-PH-EP-2017-148</td>
</tr>
<tr>
<td>Excited lepton $\nu$</td>
<td>$3, e, \mu, \tau$</td>
<td>-</td>
<td>$1.6$ TeV</td>
<td>CERN-PH-EP-2017-148</td>
</tr>
<tr>
<td><strong>Heavy quarks</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LQ $LQ_{1,2}$ gen</td>
<td>$2, e, \mu, \tau$</td>
<td>-</td>
<td>$0.6$ TeV</td>
<td>ATLAS-COM-2017-040</td>
</tr>
<tr>
<td>LQ $LQ_{2,3}$ gen</td>
<td>$2, e, \mu, \tau$</td>
<td>-</td>
<td>$0.6$ TeV</td>
<td>ATLAS-COM-2017-040</td>
</tr>
<tr>
<td>LQ $LQ_{3,4}$ gen</td>
<td>$2, e, \mu, \tau$</td>
<td>-</td>
<td>$0.6$ TeV</td>
<td>ATLAS-COM-2017-040</td>
</tr>
<tr>
<td>LQ</td>
<td>$2, e, \mu, \tau$</td>
<td>-</td>
<td>$0.6$ TeV</td>
<td>ATLAS-COM-2017-040</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LRSM Majorana $\nu$</td>
<td>$2, e, \mu, \tau$</td>
<td>-</td>
<td>$2.9$ TeV</td>
<td>ATLAS-COM-2017-040</td>
</tr>
<tr>
<td>Higgs triplet $H^{+} \to \ell\ell$</td>
<td>$2.3, e, \mu, \tau$</td>
<td>-</td>
<td>$0.3$ TeV</td>
<td>ATLAS-COM-2017-040</td>
</tr>
<tr>
<td>Higgs triplet $H^{+} \to \ell\ell$</td>
<td>$3, e, \mu, \tau$</td>
<td>-</td>
<td>$0.3$ TeV</td>
<td>ATLAS-COM-2017-040</td>
</tr>
<tr>
<td>Monopole (non-res prod)</td>
<td>$1, e, \mu, \tau$</td>
<td>-</td>
<td>$0.2$ TeV</td>
<td>ATLAS-COM-2017-040</td>
</tr>
<tr>
<td>Monopole (charged)</td>
<td>$1, e, \mu, \tau$</td>
<td>-</td>
<td>$0.2$ TeV</td>
<td>ATLAS-COM-2017-040</td>
</tr>
<tr>
<td>Magnetic monopoles</td>
<td>-</td>
<td>-</td>
<td>$0.2$ TeV</td>
<td>ATLAS-COM-2017-040</td>
</tr>
</tbody>
</table>

*Only a selection of the available mass limits on new states or phenomena is shown.*

$\dagger$ Small-radius (large-radius) jets are denoted by the letter j (J).
Summary
Summary

- ATLAS has a very extensive set of BSM analyses in place at 8 and 13 TeV
  - We presented here the latest exotic searches, particularly: Di-lepton, Di-jet, Di-photon, VV, VH, $\gamma\gamma$ VLQs and Dark Matter
  - Multiple models and analysis explore in direct way at the TeV scale
- New techniques are developed to probe high/low mass new physics with the increase in total luminosity wrt the previous results
  - Boosted object tagging, trigger-level analysis, combinations of searches regions,...
  - No evidence for any BSM physics at ATLAS yet
- In 2017 and 2018 more data is to be added (expected \(\sim 100\text{fb}^{-1}\))
  - Increasing the discovery and exclusion power of the current and future searches!

Thank You!
To expand the dijet search analysis at low $m_{jj}$ region:

- Lower the jet thresholds @trigger level, but with an exponential increase of bandwidth.
- The limits are obtained from the $m_{jj}$ distribution on the coupling to quarks, $g_{q'}$, as a function of the mass, $m_{Z'}$. 

Upper limits for a leptophobic $Z'$ simplified model. The limits are obtained from the $m_{jj}$ distribution on the coupling to quarks, $g_{q'}$, as a function of the mass, $m_{Z'}$. 

Trigger selection ISR objects to reach low $m_{jj}$ region:

- $JJ + \gamma$: single-photon trigger (ET > 140 GeV)
- $JJ + J$: single-jet trigger (pT > 380 GeV)
- Lepton-plus-jets topology: $t \rightarrow bW(l\nu), t \rightarrow bW(qq)$

- ~30% of ttbar events decay this way & the non-ttbar bkg is far smaller than in the all-hadronic topology.

- Bkgs: SM ttbar (MC estimated), W+jets, Multi-jets (data-driven)

- Systematic uncertainties: SM ttbar normalisation + shape (variation event generators, Parton shower, PDF, QCD radiation, EWK corrections)

- No excess is found in the reconstructed ttbar invariant mass spectrum

\[ 0.7 < m_{Z'} < 2.0 \text{ TeV is excluded for } \Gamma/m = 1.2\% \]
Analysis selection strategy

\[ X \rightarrow Z[W,Z] \rightarrow \ell\ell qq, \nu\nu qq \quad (1) \]

Direct Detection  
DM-nucleon scattering

Indirect Detection  
DM-DM annihilation

Mono-X Signatures  
DM pair production in association with X  
($\gamma$, jet, $W^\pm$, $Z$, $h$)  
Where object X is needed for event to be visible in the detector
Limits on modified Higgs boson decays

- The limits are extracted in the plane of $\epsilon_L$ and $\epsilon_R$
- The limits with tested parameters are $\epsilon_L$ and $\kappa$

The latter modifies the coupling of the Higgs boson to $Z$ bosons.

Signature
Four leptons ($\mu/e$) + MET ($> 100$ GeV)