Recent Results from ATLAS

M.C. Vetterli
Simon Fraser University
and TRIUMF
- on behalf of the -
ATLAS Collaboration

String Pheno 2017
July 3-7, 2017
ATLAS Spectrometer in a Nutshell

Inner Tracker:
Pixels, SCT, TRT

Calorimeters:
EM, Hadronic, FCAL

Muon Spectrometer

Hermetic (almost):
Good MET measurement
=> crucial for searches for new physics

M. Vetterli – String Pheno – July 2017 - #2
Luminosity and Pileup

Recorded luminosity:
2011 (7 TeV): 5.08 fb⁻¹
2012 (8 TeV): 21.3 fb⁻¹
2015 (13 TeV): 3.9 fb⁻¹
2016 (13 TeV): 35.6 fb⁻¹

Pileup is a significant issue at the LHC!
Sample ATLAS Event Display

Still at relatively small $N_{PV}(7)$

M. Vetterli – String Pheno – July 2017 - #4
ATLAS Physics Program

**A very broad program** - ATLAS Physics Groups

**Heavy Ions:** Jets, Electroweak/quarkonium, correlations

**B-Physics & Light States:** rare decays, $B \rightarrow J/\psi$, onia

**Standard Model:** electroweak, jets & photons, soft QCD, PDFs

**Top:** $x$-section, mass, properties, single-top

**Higgs:** $\gamma\gamma, ZZ, WW, H_{\text{top}}, H_{\text{bb}}, H_{\text{lep}}$, properties, BSM

**Supersymmetry:** strong production ($q, g$), electroweak production, $3^{\text{rd}}$ generation, RPV

**Exotics:** jets & DM, lepton+$X$ ($Z', W, \text{LFV}$), heavy $q$ & composite $H$, dibosons/multileptons/extra dimensions, unconventional signatures

**Combined Performance:** tracking, jets, egamma, muons, tau, flavour tag

=> Must be selective for this talk
W Boson Mass

From 2011 data (7 TeV, 4.6 fb\(^{-1}\))

Very careful modeling of the detector & the various processes involved e.g. the transverse mass in \(W \rightarrow e(\mu) \nu\)

\[
M_W = 80.370 \pm 0.019 \text{ GeV}
\]

\[\pm 7 \text{ MeV (statistical)}\]
\[\pm 11 \text{ MeV (systematic)}\]
\[\pm 14 \text{ MeV (modeling)}\]

[arXiv:1701.07240]

Very good precision with just 4.6 fb\(^{-1}\) syst. limited
W Boson Mass

From 2011 data (7 TeV, 4.6 fb⁻¹)

Very careful modeling of the detector & the various processes involved e.g. the transverse mass in $W \rightarrow e(\mu)\nu$

A lot more SM results (see iCHEP & EPS), which are interesting in their own right but also serve to determine the backgrounds for searches (what we are mostly interested here).

$W$ mass:

- ± 7 MeV (statistical)
- ± 11 MeV (systematic)
- ± 14 MeV (modeling)

[arXiv:1701.07240]
Higgs(750) in 2015

Caused a big commotion!
CMS had an excess too.

Local significance: 3.9 \sigma
BUT, global significance: only 2.1 \sigma

Di-photon triggers: (35/25 GeV)
Bkgd: \gamma-\gamma; \gamma+jet; jet+jet

M. Vetterli – String Pheno – July 2017 - #8
Higgs(750) in 2016

ATLAS Preliminary

$M_{\gamma\gamma}$

Data

Background-only fit

Spin-0 Selection

$\sqrt{s} = 13$ TeV, 2016, 12.2 fb$^{-1}$

2016 data only

M. Vetterli – String Pheno – July 2017 - #9
Higgs(750) in 2016

Higgs(750) in 2016

ATLAS-CONF-2016-059

It was a fluctuation 😞

Combined local significance < 2 sigma

2015 + 2016 data
Higgs(125) in 2016

But the $H(125)$ is still there

ATLAS Preliminary

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

13 TeV, 36.1 fb$^{-1}$

Events / 2.5 GeV

$m_{4l}$ [GeV]
Higgs(125) in 2016

But the H(125) is still there 😊

Starting to get useful statistics; e.g. differential X-sections

ATLAS Preliminary

H → ZZ* → 4ℓ
13 TeV, 36.1 fb⁻¹

Events / 2.5 GeV

ATLAS Preliminary

H → ZZ* → 4ℓ
13 TeV, 36.1 fb⁻¹

pT,4l [GeV]

m₄l [GeV]
Higgs(125) in 2016

But the $H(125)$ is still there 😊

Also new results on rare decay modes ($\mu\mu$, $Z\gamma$), as well as the $t\bar{t}H$ channel.

$\mu\mu$ is now at limit of SM sensitivity.

See this year’s iCHEP & EPS conferences
Search Philosophy

- Keep triggers as open as possible (e.g. single lepton, MET, ...)
- Be as unbiased as possible
- Use signature-based searches – signatures are of course motivated by signal models, but minimize this
- Separate search and limit-setting phases
Search Philosophy

• Keep triggers as open as possible (e.g. single lepton, MET,...)
• Be as unbiased as possible
• Use signature-based searches - signatures are of course motivated by signal models, but minimize this
• Separate search and limit-setting phases
• When we find nothing, generate toy experiments with background+signal model and determine the max X-section at 95% CL; do this for each mass point
• Superimpose the calculation of the X-section for each model; see where the curves cross => Set the limit
• We generally use simplified models
Searches for New Physics (a sample)

New resonances through s-channel production

Di-lepton mass spectrum

Di-jet mass spectrum
Searches for New Physics *(a sample)*

*New resonances through s-channel production*

- **Di-lepton mass spectrum**
- **Di-jet mass spectrum**
- **Trigger on ISR**
  **Access to lower masses**

M. Vetterli – String Pheno – July 2017 - #17
Searches for New Physics (a sample)

New resonances through s-channel production

Di-lepton mass spectrum

Di-jet mass spectrum

Trigger on ISR
Access to lower masses

Dark Matter example

Nothing in the final state!!
Searches for New Physics (a sample)

New resonances through s-channel production

Di-lepton mass spectrum

Di-jet mass spectrum

Trigger on ISR
Access to lower masses

Dark Matter example

Trigger on ISR (jet or $\gamma$)
“Mono-$X$”
**ATLAS Event Displays**

**Highest mass dijet event:**

\[ p_T (\text{both jets}) = 3.79 \text{ TeV}, \]
\[ |y^*| = 0.38 \text{ m(dijet)} = 8.12 \text{ TeV} \]

\[ ZZ \rightarrow e^+e^- \mu^+\mu^- \]
**Dijet Resonance Search**

*Event selection:*

- ≥ 2 jets
- $p_T(lead\ jet) > 440\ GeV$
- $p_T(sub\ lead) > 60\ GeV$
- $|y^*| < 0.6\ (QCD\ bkgd)$

Fully efficient for $m_{jj} > 1.1\ TeV$

*SM background too complicated to model* => *data driven background fits*

⇒ No significant excess seen (e.g. bottom panel)

*arXiv:1703.09127*
Dijet Resonance Search

SM background too complicated to model => data driven background fits

=> No significant excess seen (e.g. bottom panel)

Superimposed models: \( q^* (m = 4, 5 \text{ TeV}) \) to show sensitivity
Dijet Limits

Extract 95% CL upper limits on the X-section. Superimpose theory prediction and extract limits on new physics where the curves cross.

**Excited quarks:** $m(q^*) > 6.0 \text{ TeV}$

**Quantum BH:** $m(\text{QBH}) > 8.9 \text{ TeV}$
Dilepton Resonance Search

**Event selection:**
- 2 electrons: $E_T \geq 30$ GeV; $|\eta| < 2.47$
- 2 muons: $p_T \geq 30$ GeV; $|\eta| < 2.5$

*isolation criteria (fake jets)*

Same type of procedure as the dijet mass spectrum search
Dilepton Resonance Search

Mass limits on new Z bosons:
4.5 TeV for the $Z_{SSM}$
4.1 TeV for the $Z_{\chi}$
3.8 TeV for the $Z_{\psi}$

Limit on $llqq$ CI scale: 23.5-40.1 TeV

Same type of procedure as the dijet mass spectrum search
**Mono-Jet DM Search**

**Event selection:**  
- $E_T^{\text{miss}} > 250 \text{ GeV}$
- $p_T(\text{lead jet}) > 250 \text{ GeV} \ ; |\eta| < 2.4$
- $N_{\text{jet}} \leq 4 \ ; \Delta\phi(\text{jet},E_T^{\text{miss}}) > 0.4$
- no $\mu$ or $e$

**Backgrounds:**  
- $Z(\nu\nu)+\text{jets}$, $W(l\nu)+\text{jets}$
- $Z/\gamma^*(\tau^+\tau^-)+\text{jets}$ [or $(\mu^+\mu^-)$]

normalized to data in control regions  
(e.g. require a lepton) ; SF: 0.8-1.2

3.2 fb^{-1} only => full 36.1 fb^{-1} results  
later this week at EPS
Mono-Jet DM Search

**Signal Region**

**ATLAS**

- $\sqrt{s} = 13$ TeV, 3.2 fb$^{-1}$
- Signal Region
  - $p_T > 250$ GeV, $E_T^{miss} > 250$ GeV

**Consistent with the Standard Model**

**Leading jet $p_T$ [GeV]**

**Leading jet $\eta$**

**Number of jets**

**Events**

- Data 2015
- Standard Model
- SM
- Z$\rightarrow\nu\nu$ + jets
- W$\rightarrow\nu\nu$ + jets
- W$\rightarrow\ell\nu$ + jets
- Z$\rightarrow\ell\ell$ + jets
- Dibosons
- $f+\text{single top}$
- $m_{E_\text{T}} (150, 1000)$ GeV
- ADD, $m_{\phi} = 6600$ GeV

**Events**

- Data 2015
- Standard Model
- SM
- Z$\rightarrow\nu\nu$ + jets
- W$\rightarrow\nu\nu$ + jets
- W$\rightarrow\ell\nu$ + jets
- W$\rightarrow\ell\ell$ + jets
- Z$\rightarrow\ell\ell$ + jets
- Dibosons
- $f+\text{single top}$
- $m_{E_\text{T}} (150, 1000)$ GeV
- ADD, $m_{\phi} = 6600$ GeV
Mono-Jet DM Search

$E_T^{\text{Miss}}>250$ GeV:

$\#$ events observed = 21447; SM prediction = $21730\pm940$

95% $CL_S$ modified frequentist limit: $\sigma^{95}(\text{obs}) < 553$ fb

$E_T^{\text{Miss}}>700$ GeV: $\sigma^{95}(\text{obs}) < 19$ fb

**ADD model:** $M_{PL}^2 = M_D^{2+n} R^n$

$n$: # of extra dimensions

95% CL lower limits on $M_D$:

<table>
<thead>
<tr>
<th>n extra dim</th>
<th>$M_D$ lower [TeV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>6.58 (+0.52 -0.42)</td>
</tr>
<tr>
<td>3</td>
<td>5.46 (+0.45 -0.34)</td>
</tr>
<tr>
<td>4</td>
<td>4.81 (+0.41 -0.29)</td>
</tr>
<tr>
<td>5</td>
<td>4.48 (+0.41 -0.26)</td>
</tr>
<tr>
<td>6</td>
<td>4.31 (+0.41 -0.24)</td>
</tr>
</tbody>
</table>
Mono-Jet DM Search

$E_T^{\text{Miss}} > 250 \text{ GeV}$:
# events observed = 21447; SM prediction = $21730 \pm 940$
95% $C_{LS}$ modified frequentist limit: $\sigma^{95}(\text{obs}) < 553$ fb

$E_T^{\text{Miss}} > 700 \text{ GeV}$: $\sigma^{95}(\text{obs}) < 19$ fb

Limits on WIMPs coupled to an axial-vector mediator:

- Perturbativity Limit comes from unitarity
- Relic Density is from Planck & WMAP

- WIMP masses below about 200-250 GeV excluded
Mono Photon DM Search


Control regions:
1 muon; 2 muons; 2 electrons; photon+jet

M. Vetterli – String Pheno – July 2017 - #31
Mono Photon DM Search


Control regions:
1 muon; 2 muons; 2 electrons; photon+jet

SM bkgds:
Z(νν) γ
W(lν) γ
fake photons
γ + jets
Z(ll) γ

Data/Bkg

Events / 75 GeV

ATLAS
γs=13 TeV, 36.1 fb⁻¹

Signal Region

Signal Region

data
Z(→νν)γ
W(→lν)γ
Fake Photons
γ + jets
Z(→ ll)γ
m_{T}/m_{W}=10/700 GeV

E_{T}^{Miss} [GeV]

10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}

M. Vetterli – String Pheno – July 2017 - #32
Mono Photon DM Search


Control regions:
1 muon; 2 muons; 2 electrons; photon+jet

Exclude mediator particles up to 1.2 TeV for light DM particles; up to about 1 TeV for heavier DM particles
Limits on Exotic Physics

ATLAS Exotics Searches* - 95% CL Exclusion

Status: August 2016

$|\Delta t| = (3.2 - 20.3) fb^{-1}$

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

**Extra dimensions**

**Gauge bosons**

**CI**

**Dark Matter**

**Lepto-quarks**

**Heavy Quarks**

**Excited Fermions**

**Other**

---

**Model**

$\ell, \gamma$ Jets $E_{\text{miss}}^T$ $|\Delta t|$ [fb$^{-1}$] Limit

**ADD $\Delta Q = g/g$**

$2, e, \mu, \tau$ at least 1 Yes 3.2 $M_{\Delta Q}$ 4.7 TeV

**ADD non-resonant $\ell^+\ell^-$**

$2, e, \mu, \tau$ at least 1 Yes 20.3 $M_{\ell^+\ell^-}$ 2.4 TeV

**ADD $Q$Z**

$2, e, \mu, \tau$ at least 1 Yes 15.7 $M_{QZ}$ 3.2 TeV

**ADD $Q$ mass**

$2, e, \mu, \tau$ at least 1 Yes 3.6 $M_{Q}$ 2.08 TeV

**RSI $\Delta Q = g/g$**

$2, e, \mu, \tau$ at least 1 Yes 13.3 $M_{\Delta Q}$ 1.0 TeV

**Bulk RS $\Delta Q = g/g$**

$2, e, \mu, \tau$ at least 1 Yes 20.3 $M_{\Delta Q}$ 1.36 TeV

**Bulk RS $\Delta Q = g/g$**

$2, e, \mu, \tau$ at least 1 Yes 13.3 $M_{\Delta Q}$ 360-860 GeV 6.2 TeV

**2UED / RPP**

$1, e, \mu, \tau$ at least 2 b, 3 l Yes 3.2 $M_{\text{SI}}$ 8.47 TeV

**SMM $\Delta Q = g/g$**

$2, e, \mu, \tau$ at least 1 Yes 13.3 $M_{\Delta Q}$ 4.05 TeV

**CIT**

$1, e, \mu, \tau$ at least 1 Yes 19.9 TeV $|\Delta t| = 1$

**DM**

$e, \mu, \tau$ at least 1 Yes 3.2 $m_e$ 1 TeV

**Scalar LG 1st gen**

$2, e, \mu, \tau$ at least 1 Yes 3.2 $M_{\text{LQ}}$ 710 GeV

**Scalar LG 2nd gen**

$2, e, \mu, \tau$ at least 1 Yes 3.2 $M_{\text{LQ}}$ 550 GeV

**VLO $T^+T^- + X$**

$1, e, \mu, \tau$ at least 2 b, 3 l Yes 20.3 $T$ mass 855 GeV

**VLO $W^+W^- + X$**

$2, e, \mu, \tau$ at least 2 b, 3 l Yes 20.3 $W$ mass 770 GeV

**VLO $BB^+ + X$**

$2, e, \mu, \tau$ at least 2 b, 3 l Yes 20.3 $B$ mass 775 GeV

**VLO $QQ + WW$**

$1, e, \mu, \tau$ at least 2 b, 3 l Yes 20.3 $Q$ mass 860 GeV

**VLO $t\bar{t}, T^3, T^3 + WW$**

$2, e, \mu, \tau$ at least 2 b, 3 l Yes 20.3 $t^\pm$ mass 900 GeV

**Excited vector boson**

$1, e, \mu, \tau$ at least 1 Yes 3.2 $M^*$ mass 4.4 TeV

**LSTC $\gamma$**

$1, e, \mu, \tau$ at least 1 Yes 20.3 $M^*$ mass 900 GeV

**LRSM Majorana**

$2, e, \mu, \tau$ at least 1 Yes 20.3 $M^*$ mass 4.7 TeV

**Higgs triplet**

$3, e, \mu, \tau$ at least 1 Yes 20.3 $M^*$ mass 3.0 TeV

**Monotop (non-res prod)**

$1, e, \mu, \tau$ at least 1 Yes 20.3 $M^*$ mass 4.7 TeV

**Multi-charged particles**

$-\ldots$ at least 1 Yes 20.3 $m_{\tilde{e}_1}$ mass 1.0 TeV

**Magnetic monopoles**

$-\ldots$ at least 1 Yes 20.3 $m_{\tilde{e}_1}$ mass 1.0 TeV

---

*Only a selection of the available mass limits on new states or phenomena is shown. Lower bounds are indicated by the letter (d).
SuperSymmetry Searches

**SUSY is a consequence of String Theory => a view on the Planck scale**

**ATLAS searches for SUSY in many channels**

<table>
<thead>
<tr>
<th>Names</th>
<th>Spin</th>
<th>$P_R$</th>
<th>Gauge Eigenstates</th>
<th>Mass Eigenstates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higgs bosons</td>
<td>0</td>
<td>+1</td>
<td>$H_u^0 H_d^0 H_u^+ H_d^-$</td>
<td>$h^0 H^0 A^0 H^\pm$</td>
</tr>
<tr>
<td>squarks</td>
<td>0</td>
<td>-1</td>
<td>$\tilde{u}_L \tilde{u}_R \tilde{d}_L \tilde{d}_R$ (same)</td>
<td>$\tilde{e}_L \tilde{e}_R \tilde{\nu}_L \tilde{\nu}_R$ (same)</td>
</tr>
<tr>
<td>sleptons</td>
<td>0</td>
<td>-1</td>
<td>$\tilde{\ell}_L \tilde{\ell}_R \tilde{\nu}_e$ (same)</td>
<td>$\tilde{\tau}_L \tilde{\tau}<em>R \tilde{\nu}</em>\tau$ (same)</td>
</tr>
<tr>
<td>neutralinos</td>
<td>1/2</td>
<td>-1</td>
<td>$\tilde{B}^0 \tilde{W}^0 \tilde{H}_u^0 \tilde{H}_d^0$</td>
<td>$\tilde{N}_1 \tilde{N}_2 \tilde{N}_3 \tilde{N}_4$</td>
</tr>
<tr>
<td>charginos</td>
<td>1/2</td>
<td>-1</td>
<td>$\tilde{W}^\pm \tilde{H}_u^\pm \tilde{H}_d^-$</td>
<td>$\tilde{C}_1^\pm \tilde{C}_2^\pm$</td>
</tr>
<tr>
<td>gluino</td>
<td>1/2</td>
<td>-1</td>
<td>$\tilde{g}$ (same)</td>
<td></td>
</tr>
<tr>
<td>goldstino (gravitino)</td>
<td>$1/2$ (2/3)</td>
<td>-1</td>
<td>$G$ (same)</td>
<td></td>
</tr>
</tbody>
</table>

NLO + NLL, pp, $\sqrt{s} = 13$ TeV

Cross-section [pb]

SUSY particle mass [GeV]

M. Vetterli – String Pheno – July 2017 - #35
Squark and Gluino Searches

<table>
<thead>
<tr>
<th>Names</th>
<th>Spin</th>
<th>$P_R$</th>
<th>Gauge Eigenstates</th>
<th>Mass Eigenstates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higgs bosons</td>
<td>0</td>
<td>+1</td>
<td>$H^0, H^0, H^+, H^-$</td>
<td>$H^0, H^0, A^0, H^\pm$</td>
</tr>
<tr>
<td>squarks</td>
<td>0</td>
<td>-1</td>
<td>$\bar{u}_L \bar{u}_R, \bar{d}_L \bar{d}_R$</td>
<td>(same)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$s_L \bar{s}_R, \bar{c}_L \bar{c}_R$</td>
<td>(same)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$\bar{t}_L \bar{t}_R, \bar{b}_L \bar{b}_R$</td>
<td>$\bar{t}_1 \bar{t}_2 \bar{b}_1 \bar{b}_2$</td>
</tr>
<tr>
<td>sleptons</td>
<td>0</td>
<td>-1</td>
<td>$\tilde{e}_L \tilde{e}_R, \tilde{\nu}_c$</td>
<td>(same)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$\tilde{\mu}_L \tilde{\mu}<em>R, \tilde{\nu}</em>\mu$</td>
<td>(same)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$\tilde{\tau}_L \tilde{\tau}<em>R, \tilde{\nu}</em>\tau$</td>
<td>$\tilde{\tau}_1 \tilde{\tau}<em>2 \tilde{\nu}</em>\tau$</td>
</tr>
<tr>
<td>neutralinos</td>
<td>1/2</td>
<td>-1</td>
<td>$\tilde{B}^0, \tilde{W}^0, \tilde{H}_d^0, \tilde{H}_u^0$</td>
<td>$\tilde{N}_1 \tilde{N}_2 \tilde{N}_3 \tilde{N}_4$</td>
</tr>
<tr>
<td>charinos</td>
<td>1/2</td>
<td>-1</td>
<td>$\tilde{W}^\pm, \tilde{H}_d^+, \tilde{H}_d^-$</td>
<td>$\tilde{C}_1^\pm, \tilde{C}_2^\pm$</td>
</tr>
<tr>
<td>gluino</td>
<td>1/2</td>
<td>-1</td>
<td>$\tilde{g}$</td>
<td>(same)</td>
</tr>
<tr>
<td>goldstino</td>
<td>1/2</td>
<td>-1</td>
<td>$\tilde{G}$</td>
<td>(same)</td>
</tr>
</tbody>
</table>

NLO + NLL, pp, $\sqrt{s} = 13$ TeV

Cross-section [pb]

SUSY particle mass [GeV]

Jets + $E_T^{\text{Miss}}$

M. Vetterli –String Pheno– July 2017 - #36
Squark and Gluino Searches

\[ M_{\text{eff}} = \sum_j p_T(j) + E_T^{\text{Miss}} \]

**ATLAS Preliminary**

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

Meff-2j-2100

\[ \tilde{q} \tilde{q} \text{ direct} \]

\[ \tilde{g} \tilde{g} \text{ direct} \]

\[ M_{\text{eff}} \text{ (incl)} \ [\text{GeV}] \]
M. Vetterli – String Pheno – July 2017 - #38

Squark and Gluino Searches

$M_{\text{eff}} = \sum_j p_T(j) + E_T^{\text{miss}}$

Limits on gluino & squark masses reaching 2-3 TeV
EW-SUSY Searches

ATLAS-CONF-2017-039

<table>
<thead>
<tr>
<th>Names</th>
<th>Spin</th>
<th>$P_R$</th>
<th>Gauge Eigenstates</th>
<th>Mass Eigenstates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higgs bosons</td>
<td>0</td>
<td>+1</td>
<td>$H_0^0$, $H_0^0$, $H_0^0$, $H_0^0$</td>
<td>$h^0$, $H^0$, $A^0$, $H^0$</td>
</tr>
<tr>
<td>squarks</td>
<td>0</td>
<td>−1</td>
<td>$\tilde{u}_L$, $\tilde{u}_R$, $\tilde{d}_L$, $\tilde{d}_R$</td>
<td>(same)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$\tilde{s}_L$, $\tilde{s}_R$, $\tilde{c}_L$, $\tilde{c}_R$</td>
<td>(same)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$\tilde{t}_L$, $\tilde{t}_R$, $\tilde{b}_L$, $\tilde{b}_R$</td>
<td>(same)</td>
</tr>
<tr>
<td>sleptons</td>
<td>0</td>
<td></td>
<td>$\tilde{e}_L$, $\tilde{e}_R$, $\tilde{\nu}_c$</td>
<td>(same)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$\tilde{\mu}_L$, $\tilde{\mu}<em>R$, $\tilde{\nu}</em>\mu$</td>
<td>(same)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$\tilde{\tau}_L$, $\tilde{\tau}<em>R$, $\tilde{\nu}</em>\tau$</td>
<td>(same)</td>
</tr>
<tr>
<td>neutralinos</td>
<td>1/2</td>
<td>−1</td>
<td>$\tilde{B}^0$, $\tilde{W}^0$, $\tilde{H}_d^0$, $\tilde{H}_u^0$</td>
<td>$\tilde{N}_1$, $\tilde{N}_2$, $\tilde{N}_3$, $\tilde{N}_4$</td>
</tr>
<tr>
<td>charginos</td>
<td>1/2</td>
<td>−1</td>
<td>$\tilde{W}^\pm$, $\tilde{H}_d^0$, $\tilde{H}_u^0$</td>
<td>$\tilde{C}_1^\pm$, $\tilde{C}_2^\pm$</td>
</tr>
<tr>
<td>gluino</td>
<td>1/2</td>
<td>−1</td>
<td>$\tilde{g}$</td>
<td>(same)</td>
</tr>
<tr>
<td>goldstino (gravitino)</td>
<td>1/2 (3/2)</td>
<td>−1</td>
<td>$\tilde{G}$</td>
<td>(same)</td>
</tr>
</tbody>
</table>

NLO + NLL, pp, $\sqrt{s} = 13$ TeV

Cross-section [pb]

SUSY particle mass [GeV]

e.g. Leptons + $E_T^{Miss}$

M. Vetterli – String Pheno – July 2017 - #39
EW-SUSY Searches

\[ m_{T2} = \min_{q_T} \left[ \max \left( m_T(p_T^{\ell_1}, q_T), m_T(p_T^{\ell_2}, p_T^{\text{miss}} - q_T) \right) \right] \]

\[ q_T \text{ is a transverse vector that minimizes the larger of } m_T(p_T^{\ell_1}, q_T) \text{ and } m_T(p_T^{\ell_2}, p_T^{\text{miss}} - q_T), \text{ where:} \]

\[ m_T(p_T, q_T) = \sqrt{2((p_T q_T) - p_T \cdot q_T)}. \]
Limits on sleptons and charginos are 500-750 GeV for heavy neutralinos.

Neutralino limits are 250-300 GeV for heavier sleptons and charginos.
We have looked in a lot of channels

**Strong SUSY**

\[ m(\tilde{g}) < 2 \text{ TeV} \]

**Electroweak SUSY**

\[ m(\text{gaugino}) < 1.1 \text{ TeV} \]

\[ m(\tilde{\chi}_1^0) < 600-1000 \text{ GeV} \]
SUSY Summaries

We have looked in a lot of channels

**Strong SUSY**

\[ m(\tilde{g}) < 2 \text{ TeV} \]

**Weak SUSY**

\[ m(\text{gaugino}) < 1.1 \text{ TeV} \]

\[ m(\chi_0) \sim 0.1 \text{ TeV} \]

\[ m(t) \sim 1 \text{ TeV} \]
Blue bars are Run-2; quite a few results

Minimal SUSY models are getting (strained, uncomfortable,...)

Particularly true for the strongly coupled sector

But the weak sector limits are still mostly below 1 TeV

1 TeV 2 TeV
A lot more data coming!

Measure $H(125)$ properties to high precision
Refine searches at large mass and small $X$-section
Conclusions

• The LHC has had a spectacular Run-1 and Run-2 (so far)
• We discovered the long-sought-after Higgs boson
• But, although we have looked in a multitude of channels, nothing further has been found
• Mass limits on a lot of new physics have pushed up to 2 TeV, but there are still channels with limits below 1 TeV
• Of relevance to string theory, no SUSY or DM candidate yet. What if we don’t find anything?
• Don’t worry, we will keep looking and there are LOTS of new data coming!
We will not be this guy!!

Thank you for your attention
Backup
Standard Model Summary

Standard Model Total Production Cross Section Measurements

ATLAS  Preliminary
Run 1,2  $\sqrt{s} = 7, 8, 13$ TeV

- LHC pp $\sqrt{s} = 7$ TeV
  - Data 4.5–4.9 fb$^{-1}$
- LHC pp $\sqrt{s} = 8$ TeV
  - Data 20.3 fb$^{-1}$
- LHC pp $\sqrt{s} = 13$ TeV
  - Data 0.08–13.3 fb$^{-1}$

M. Vetterli – String Pheno – July 2017 - #49
Summary of DM Searches

DM Simplified Model Exclusions

ATLAS Preliminary March 2017

- Dijet
  \( \sqrt{s} = 13 \text{ TeV}, 37.0 \text{ fb}^{-1} \)
  arXiv:1703.09127 [hep-ex]

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

- Dijet TLA
  \( \sqrt{s} = 13 \text{ TeV}, 3.4 \text{ fb}^{-1} \)
  ATLAS-CONF-2016-030

- Dijet + ISR
  \( \sqrt{s} = 13 \text{ TeV}, 15.5 \text{ fb}^{-1} \)
  ATLAS-CONF-2016-070

- \( E_T^{\text{miss}} + \gamma \)
  \( \sqrt{s} = 13 \text{ TeV}, 36.4 \text{ fb}^{-1} \)
  CERN-EP-2017-044

- \( E_T^{\text{miss}} + \text{jet} \)
  \( \sqrt{s} = 13 \text{ TeV}, 3.2 \text{ fb}^{-1} \)

Axial-vector mediator, Dirac DM

- \( g_q = 0.25, g_j = 0, g_{DM} = 1 \)
- All limits at 95% CL