Searching for SUSY

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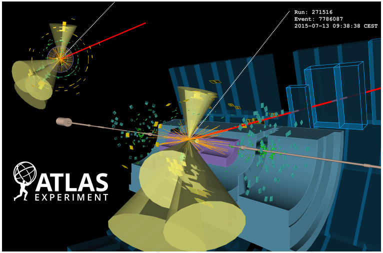
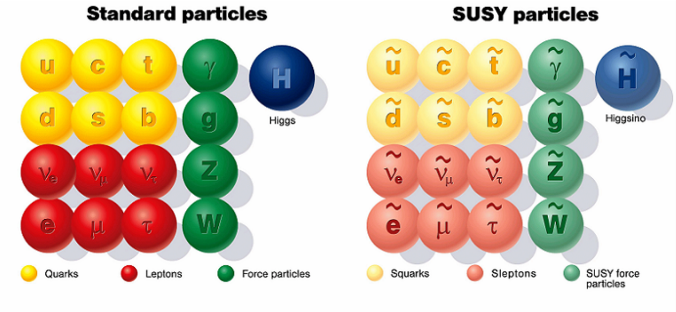
Overview

- What is supersymmetry?
- Why search for it?
- How to search for it:
  ATLAS Multijet analysis



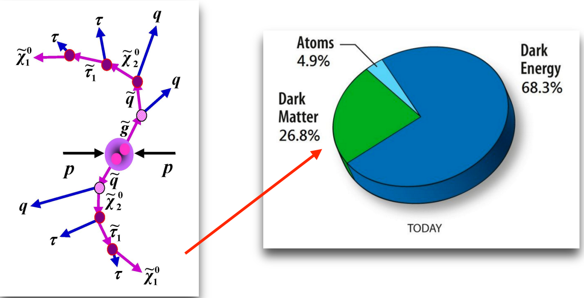
What is SUSY?

- Predicts a new particle for every SM particle
- Spin differs by 1/2
- Heavier than SM particles, but we don't know their masses
- Dark Matter, Hierarchy problem, gauge couplings



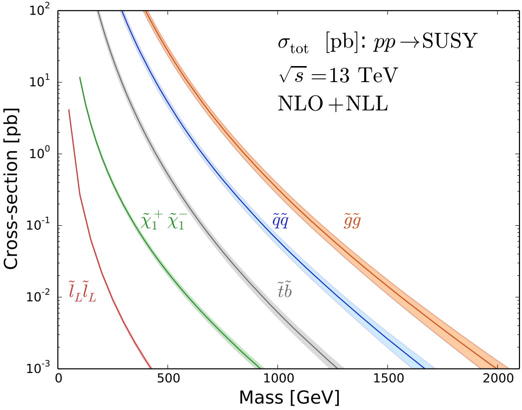
Dark Matter

- R-parity is conserved: SM $P_R = +1$, SUSY $P_R = -1$
- Sparticles must decay into sparticles!
- Must be a stable, lightest SUSY particle: the neutralino $\tilde{\chi}_1^0$
- Ideal dark matter candidate, also escapes detector
- Leads to momentum imbalance



Where to look: strong production

- The gluino $\tilde{g}$ can be produced in strong interactions at the LHC
- $pp \rightarrow \tilde{g}\tilde{g}$



Eur. Phys. J. C74 (2014) 12. LHC cross-section working group

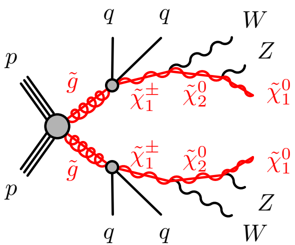
Multijet analysis

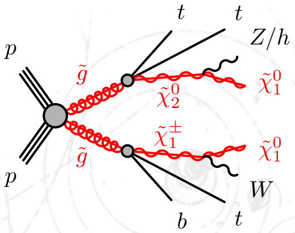
Analysis overview

- Standard model processes rarely produces event with many jets
- $\rightarrow$ search for events with highest jet multiplicities: ≥ 7 to ≥ 10
- Lepton veto, and b-quark tagged-jets
- Key variable: Missing transverse energy significance $E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}}$
- $H_{\mathrm{T}} = \sum_{jets} p_{\mathrm{T}}$
- First SUSY paper to be made public: arXiv:1602.06194

Multijet: Signal Models

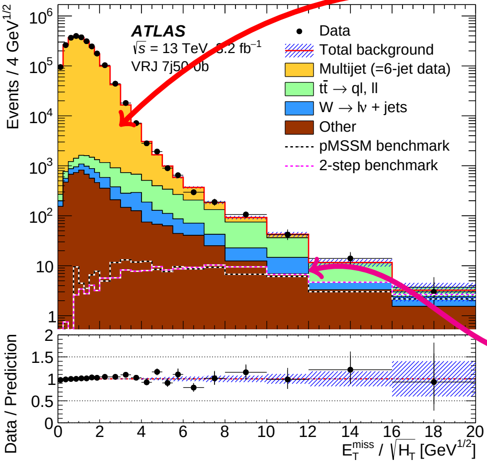
- Longer decay chains:
  - More jets
  - Less missing transverse momentum
- 2-step model
  - Tested in Run-1
  - Allows direct comparison
- phenomenological-MSSM slice
  - Inspired by ATLAS pMSSM scan
  - Unique sensitivity
  - Difficult to discover by other means





Backgrounds to the Multijet analysis

arXiv:1602.06194



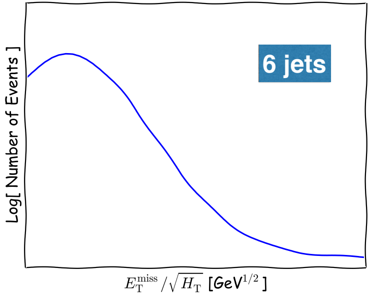
QCD background, estimated with template method

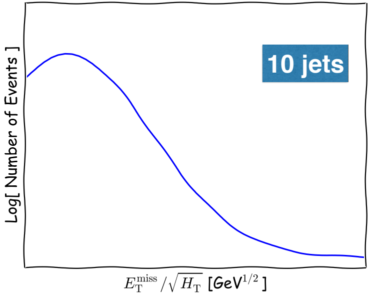
Other backgrounds, estimated with MC (& constrained in CRs)

Template method

arXiv:1602.06194

- Expect the shape of the $E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}}$ distribution is invariant under changes in jet multiplicity for a high jet multiplicity event
- Property was also **observed** in Run-1 data

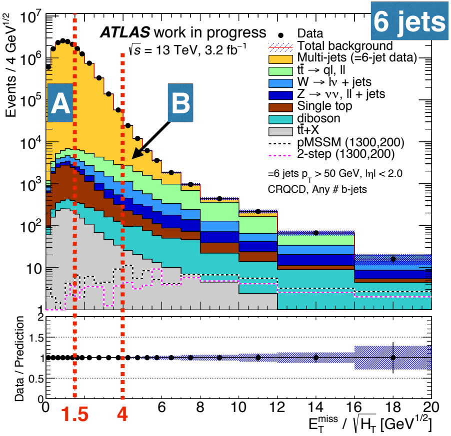




Template method

arXiv:1602.06194

- For a many jet event, $E_{\mathrm{T}}^{\mathrm{miss}}$ is dominated by jet mis-measurement
- Then, shape of $E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}}$ will be independent of jet multiplicity



Subtract other backgrounds

$$\frac{A}{B} = const$$

Normalise in region where multijet background dwarves others, and any signal: $E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}} < 1.5\,\mathrm{GeV}^{1/2}$

Template method

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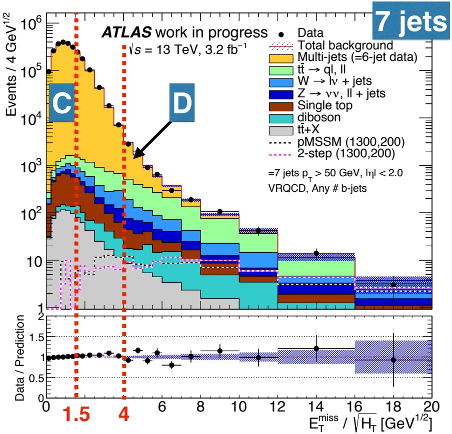


Subtract other backgrounds

$$\frac{A}{B} = const = \frac{C}{D}$$

Can estimate QCD background in Signal region:

$$D = \frac{BC}{A}$$

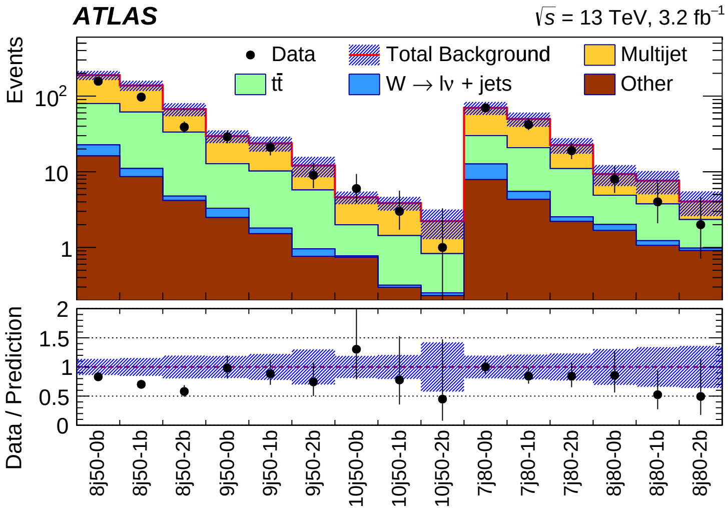
Template binned in H_{T} to account for MET not from jet

Signal regions

- Veto events with leptons (e, μ)
- Count the number of (anti-k_t 0.4) jets with:
  1. $p_{\mathrm{T}} > 50$ GeV
  2. $p_{\mathrm{T}} > 80$ GeV
- Define signal regions as:
  1. $n_{jet}(50) \geq 8, \ \geq 9, \ \geq 10$
  2. $n_{jet}(80) \geq 7, \ \geq 8$
- Further split by the number of jets tagged with a b-quark
- Finally, all require $E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}} > 4$ GeV$^{1/2}$ (key discriminating variable)
- Total of 15 signal regions

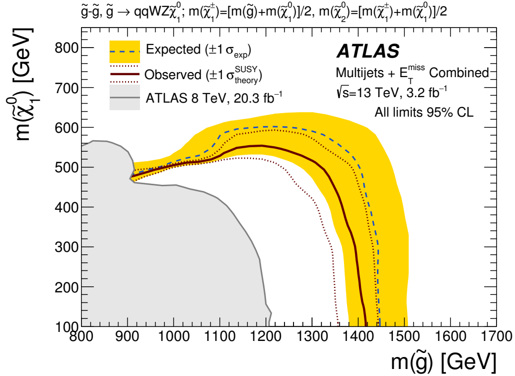
Results: signal regions

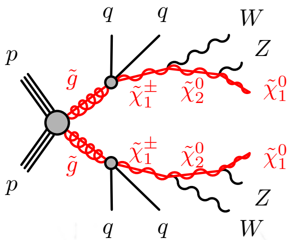
arXiv:1602.06194



Results

arXiv:1602.06194





Conclusions

- SUSY is a promising candidate for BSM physics
- Searched for SUSY in final states with many jets
- Data-driven technique used to estimate QCD background
- No significant excess $\rightarrow$ limits set
- First SUSY search from LHC: arXiv:1602.06194
- The persuit of SUSY will continue with more data in 2016!

Thanks for listening, any questions?

Will,

on behalf of the multi-jet analysis team

Backup

More Information

- Paper: "Search for new phenomena in final states with large jet multiplicities and missing transverse momentum with ATLAS using $\sqrt{s} = 13$ TeV proton–proton collisions"
  arXiv:1602.06194

MET Significance

For a many jet event $E_{\mathrm{T}}^{\mathrm{miss}}$ is dominated by jet mis-measurement

$$E_{\mathrm{T}}^{\mathrm{miss}} \cong -\sum \vec{p_{\mathrm{T}}}$$

Jet resolution: $\sigma(p_{\mathrm{T}}) \propto \sqrt{p_{\mathrm{T}}}$ (for a large p_{T} range)

$$\Rightarrow \sigma^2(E_{\mathrm{T}}^{\mathrm{miss}}) \propto \sum |\vec{p_{\mathrm{T}}}|$$

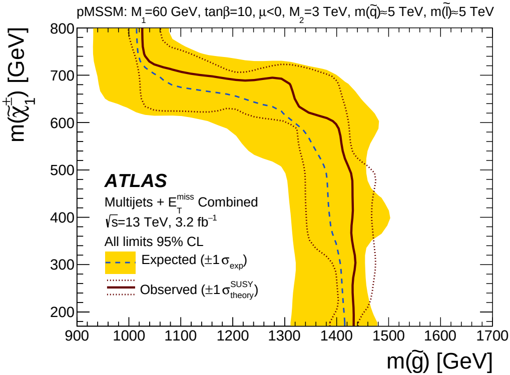
$$\Rightarrow \sigma(E_{\mathrm{T}}^{\mathrm{miss}}) \propto \sqrt{H_{\mathrm{T}}}$$

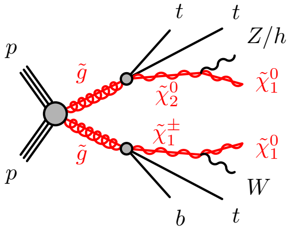
MET significance: $E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}}$

Shape of $E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}}$ will be independent of jet multiplicity, if $E_{\mathrm{T}}^{\mathrm{miss}}$ is dominated by jet mis-measurement.

Results

arXiv:1602.06194





Why can't we estimate QCD with MC?

- High orders of QCD calculation are difficult. $\sim$ factoral growth in the number of diagrams
- NNNLO is about the limit (and is very slow)
- Can get 6 jets from LO $t\bar{t}$, can reasonably also do $t\bar{t}$+JJ in matrix element calculation (so we can predict this background with MC)
- However, only get 2 jets from QCD at LO
- Therefore much higer orders are required

SUSY isn't dead

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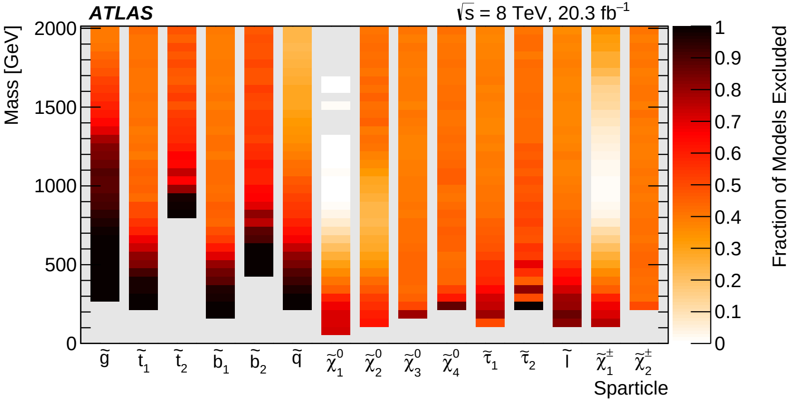
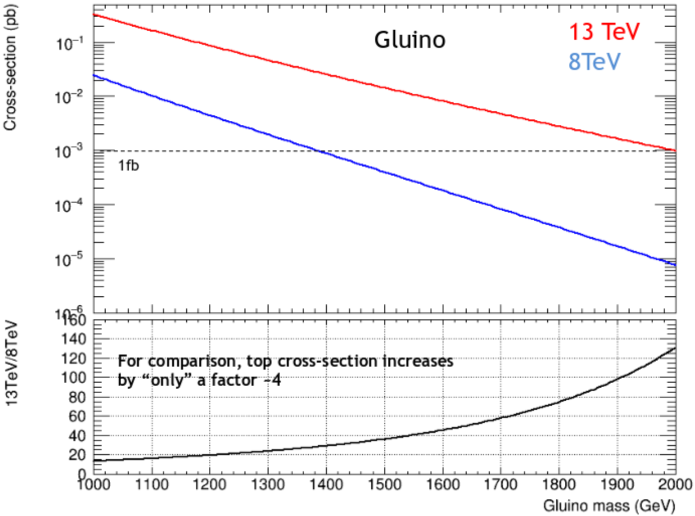


From Run-1 to Run-2



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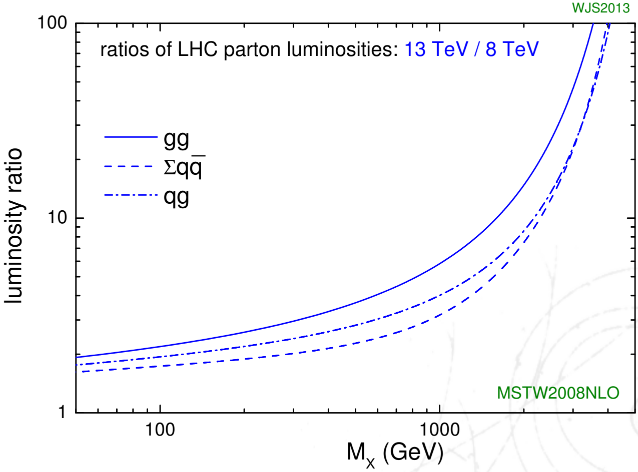
Luminosity ratio

Higher mass particles gain a larger sensitivity boost



Signal regions

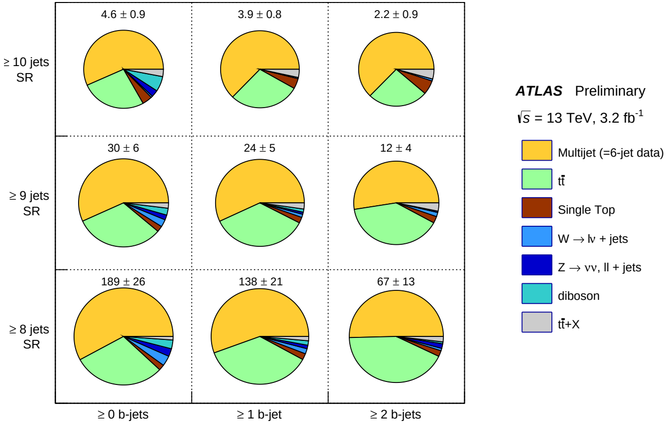
Jet Multiplicity	Jet pT	b-jet Multiplicity	METSig		
==6			< 1.5 $GeV^{1/2}$		> 4 $GeV^{1/2}$
==7			< 1.5 $GeV^{1/2}$	1.5—3.5 $GeV^{1/2}$	> 4 $GeV^{1/2}$
>=8	50 GeV	0+, 1+, 2+	< 1.5 $GeV^{1/2}$	1.5—3.5 $GeV^{1/2}$	> 4 $GeV^{1/2}$
>=9			< 1.5 $GeV^{1/2}$	1.5—3.5 $GeV^{1/2}$	> 4 $GeV^{1/2}$
>=10			< 1.5 $GeV^{1/2}$	1.5—3.5 $GeV^{1/2}$	> 4 $GeV^{1/2}$
==5			< 1.5 $GeV^{1/2}$		> 4 $GeV^{1/2}$
==6	80 GeV	0+, 1+, 2+	< 1.5 $GeV^{1/2}$	1.5—3.5 $GeV^{1/2}$	> 4 $GeV^{1/2}$
>=7			< 1.5 $GeV^{1/2}$	1.5—3.5 $GeV^{1/2}$	> 4 $GeV^{1/2}$
>=8			< 1.5 $GeV^{1/2}$	1.5—3.5 $GeV^{1/2}$	> 4 $GeV^{1/2}$

Key: control regions, validation regions, signal regions

Background composition: 50 GeV SR

arXiv:1602.06194

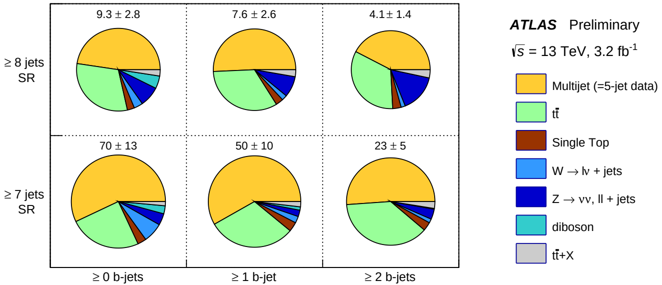
Pie charts show post-fit background composition in signal regions



Background composition 80 GeV SR

arXiv:1602.06194

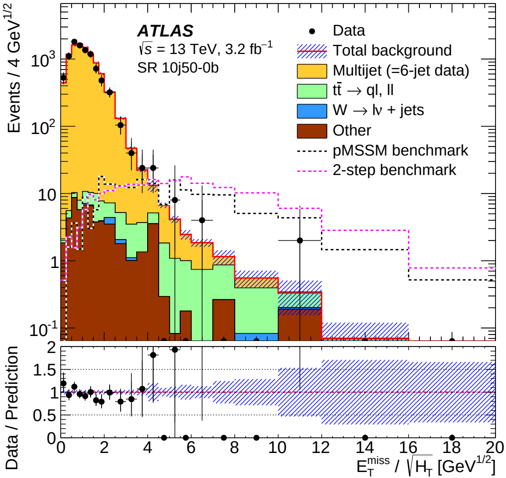
Pie charts show post-fit background composition in signal regions



Signal region distribution

arXiv:1602.06194

No statistically significant excess beyond SM expectation



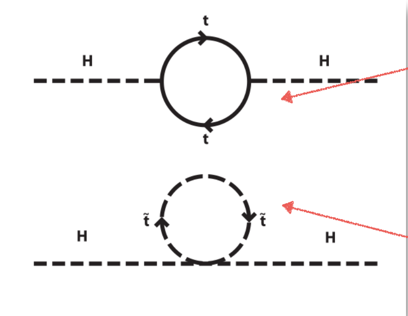
H_{T} binning for template method

What happens when MET no-longer dominated by jet mis-measurement?

- At low $H_{\mathrm{T}}(< 1000\,\mathrm{GeV})$, relatively more events with low $E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}}$ in the lower H_{T} bins
- At low H_{T}, terms other than jet mis-measurement become more important
- Template built in bins of H_{T} to factorise out this dependence

Hierarchy problem

- Sparticles cancel SM divergences
- Higgs mass stabilised by a sufficiently heavy stop



$$\Delta m^2_{H,SM} = -\frac{|\lambda_f|^2}{8\pi^2}[\Lambda^2_{UV} + ...]$$

$$\Delta m^2_{H,SUSY} = 2 \times \frac{|\lambda_S|^2}{16\pi^2}[\Lambda^2_{UV} + ...]$$

Grand unification

- Unification at 10^{16} GeV achieved with SUSY