SUSY searches with ATLAS

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on behalf of the ATLAS Collaboration

University of Victoria / TRIUMF, Canada

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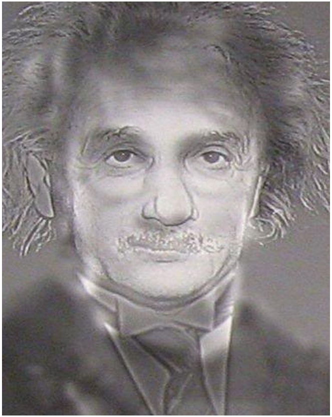
QFTHEP - Samara

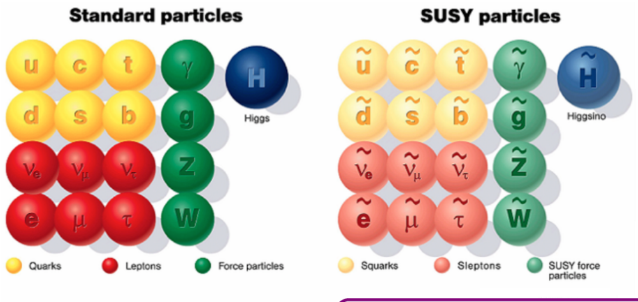
Outline: From Mysterious to Science



ATLAS and the LHC are **zooming in** *on the world to understand the unknown.*

- Supersymmetry (SUSY) = theory that can explain some of the holes in the Standard Model
- Summarise status of ATLAS searches for SUSY:
  - **Bulk and small corners** of phase space
  - **Variety** of different combinations of objects in **final states**
  - Statistical **exclusion limits** on some models
  - Searches with **hints of new physics**

Supersymmetry



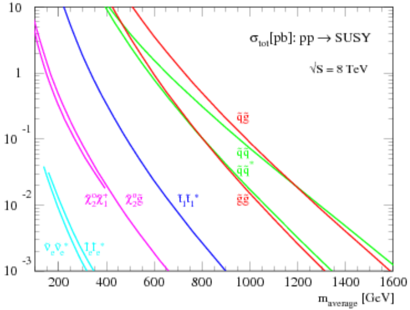
$$W^{\pm}\ W^{0}\ B \xrightarrow{\text{mixing}} W^{\pm}\ Z\ \gamma$$

$$\tilde{H}_u^0\ \tilde{H}_d^0\ \tilde{W}^0\ \tilde{B}^0 \xrightarrow{\text{mixing}} \tilde{\chi}_1^0\ \tilde{\chi}_2^0\ \tilde{\chi}_3^0\ \tilde{\chi}_4^0 \quad \text{neutralinos}$$

$$\tilde{H}_u^+\ \tilde{H}_d^-\ \tilde{W}^+\ \tilde{W}^- \xrightarrow{\text{mixing}} \tilde{\chi}_1^{\pm}\ \tilde{\chi}_2^{\pm} \quad \text{charginos}$$

- SM particles $\rightarrow 1/2$ spin $\rightarrow$ SUSY particles
- R-Parity conservation: SUSY particles come in **pairs**
  - Lightest supersymmetric particle (**LSP**) is a dark matter candidate $\rightarrow$ **missing energy**
- Scalar top $\rightarrow$ hierarchy problem / fine tuning

Supersymmetry with ATLAS

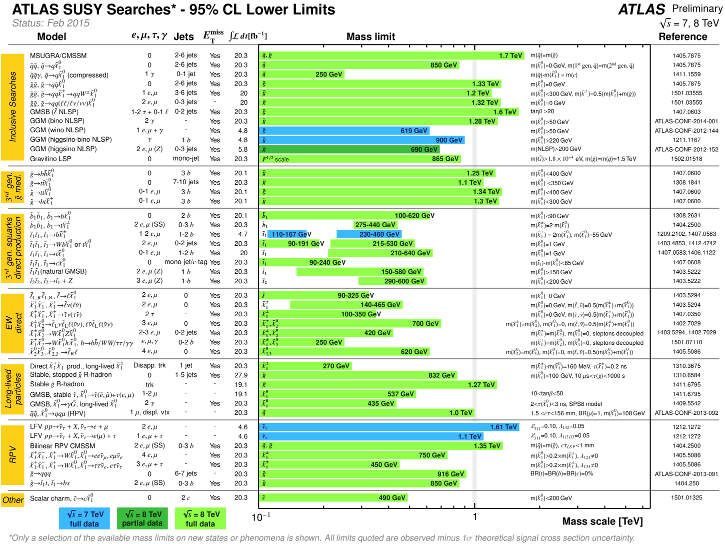


Classify searches based on:

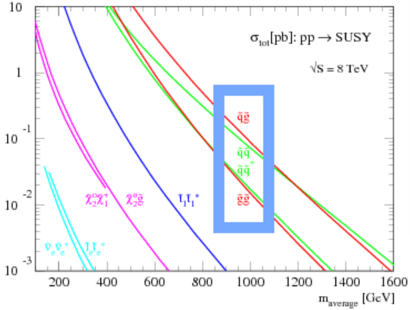
- Production cross-section
- Final states after decays
- Decay chain
- Lifetime
- R-parity conservation/breaking

- Simplified models
- LSP $= \tilde{\chi}_1^0$ or $\tilde{G}$ or ...
- Assume prompt decays unless specified otherwise
- Frequently main backgrounds: $t\bar{t}$ & single top, W+jets, Z+jets, and multijets
- Discriminating variables: p_T of objects, number of leptons, number of jets, scalar sums of p_T (e.g. m_eff), $E_\mathrm{T}^\mathrm{miss}$, $E_\mathrm{T}^\mathrm{miss}/m_\mathrm{eff}$, m_T, m_T2

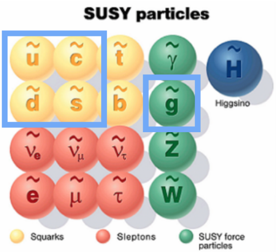
8 TeV Exclusion Summary



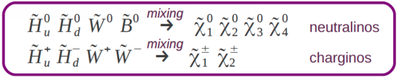
Many searches performed but SUSY not (yet?) discovered



σ_{tot}[pb]: pp → SUSY
$\sqrt{S}$ = 8 TeV
$\tilde{q}\tilde{g}$
$\tilde{q}\tilde{q}$
$\tilde{q}\tilde{q}^*$
$\tilde{g}\tilde{g}$
$\tilde{t}_1\tilde{t}_1^*$
$\chi_2^0\chi_1^+$
$\chi_2^0\tilde{g}$
$m_{average}$ [GeV]

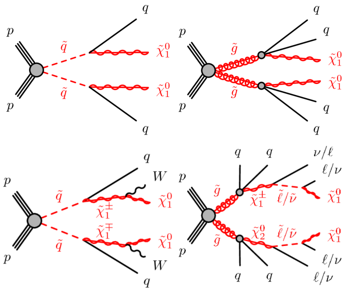


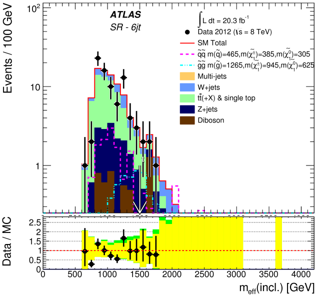
SUSY particles
Higgsino
Squarks
Sleptons
SUSY force particles



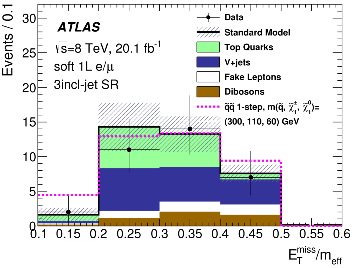
$\tilde{H}_u^0\ \tilde{H}_d^0\ \tilde{W}^0\ \tilde{B}^0 \xrightarrow{mixing} \tilde{\chi}_1^0\ \tilde{\chi}_2^0\ \tilde{\chi}_3^0\ \tilde{\chi}_4^0$ neutralinos
$\tilde{H}_u^+\ \tilde{H}_d^-\ \tilde{W}^+\ \tilde{W}^- \xrightarrow{mixing} \tilde{\chi}_1^\pm\ \tilde{\chi}_2^\pm$ charginos

Strong Production: Search for gluinos ($\tilde{g}$) and 1st, 2nd generation sclar quarks ($\tilde{q}$) - 0ℓ and $\geq 1\ell$ analyses





0ℓ

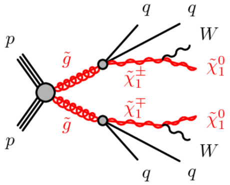


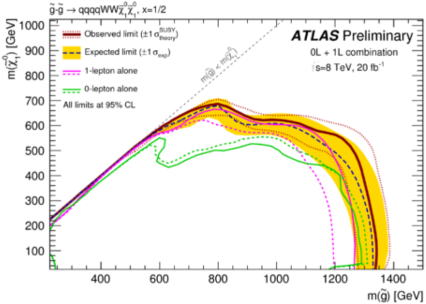
1ℓ

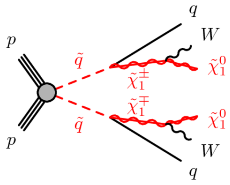
- Searches cover a wide range of signal models
- Important discriminating variables: m_{eff}, $E_{\text{T}}^{\text{miss}}$, number of leptons, number of jets, lepton p_{T}

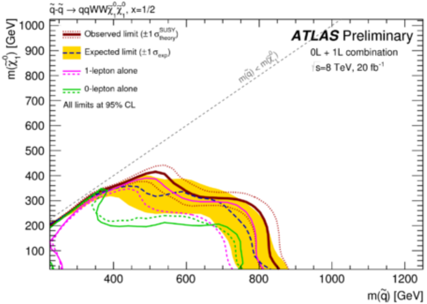
10.1007/JHEP04(2015)116, 10.1007/JHEP09(2014)176

Strong Production: Search for $\tilde{g}$ and 1st, 2nd generation $\tilde{q}$ - recently combined 0ℓ and $\geq 1\ell$ analyses



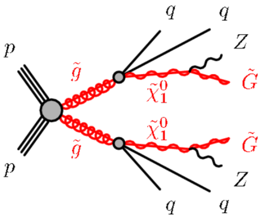


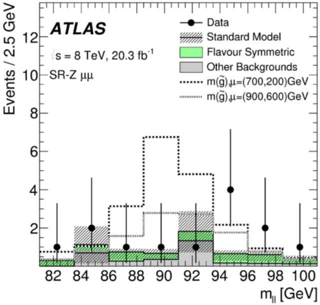


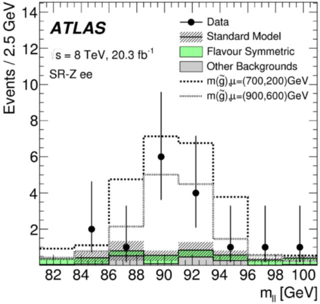


Combination extends exclusion reach

Z+MET+jets has 3σ excess







- Of the many strong production searches, this one saw an excess of 3σ
- Gauge Mediated model above = example signal model that can produce this excess
- $Z \to \ell^+\ell^-$: $81 < m_{\ell\ell} < 101$ GeV
- Main backgrounds estimated using data. E.g. Z+jets: produce $E_{\mathrm{T}}^{\mathrm{miss}}$ by smearing jets in p_{T}, ϕ

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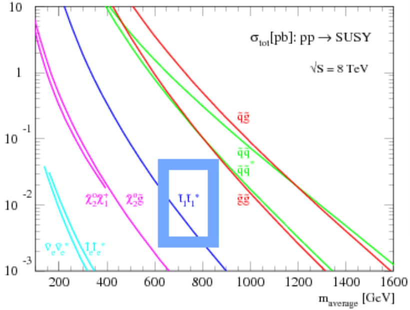
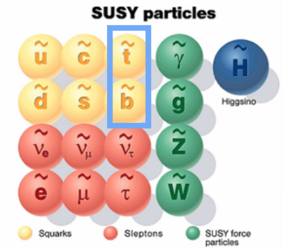
Third Generation Direct Production





$\tilde{H}_u^0\ \tilde{H}_d^0\ \tilde{W}^0\ \tilde{B}^0 \xrightarrow{mixing} \tilde{\chi}_1^0\ \tilde{\chi}_2^0\ \tilde{\chi}_3^0\ \tilde{\chi}_4^0$ neutralinos

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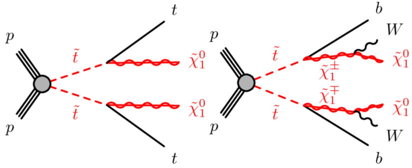
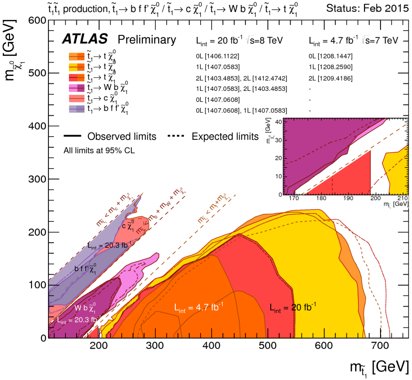
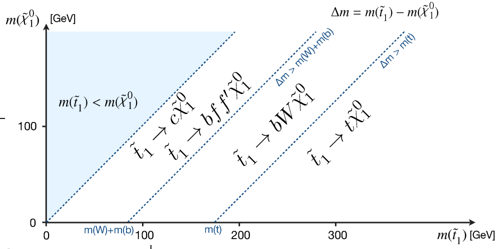
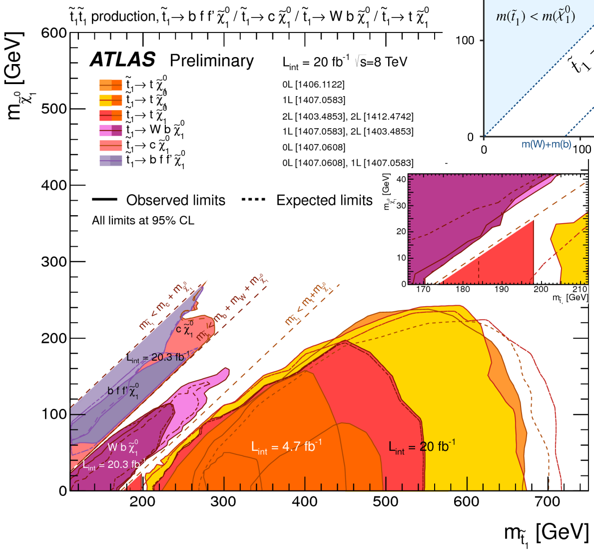




- $0 - 2\ell$ searches
- Some important discriminating variables: m_{T}, m_{T2}, $E_{\mathrm{T}}^{\mathrm{miss}}$, b-quark jet tagging
- 2-4 body decays

3rd Generation: Search for scalar tops summary structure





Diagonal lines
= kinematic boundaries:

$$m(\tilde{t}) = \sum_i^{all} m(\text{child i})$$

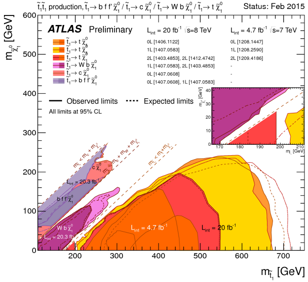
3rd Generation: Scalar tops - Specialised Tools for Specific Features

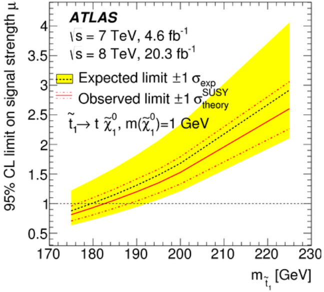
Boosted parent particles

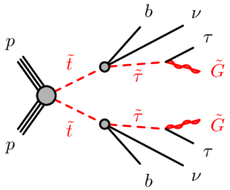
- Large sized jets (top figure : heavy $\tilde{t}$, light $\tilde{\chi}_1^0$)
  (doi: JHEP11(2014)118)

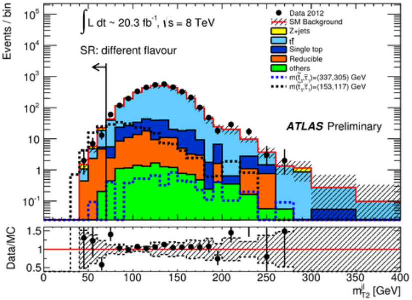
Scalar top masses just above top quark mass

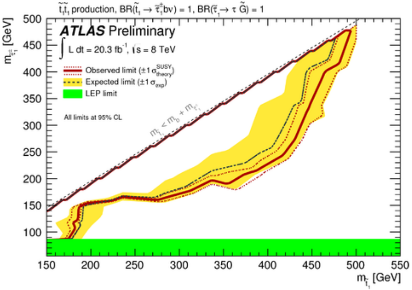
- Spin correlation (top figure inset)
  (doi: PhysRevLett.114.142001)
- Re-interpret $t\bar{t}$ cross-section measurement (bottom figure)
  (doi: EPJC/s10052-014-3109-7)







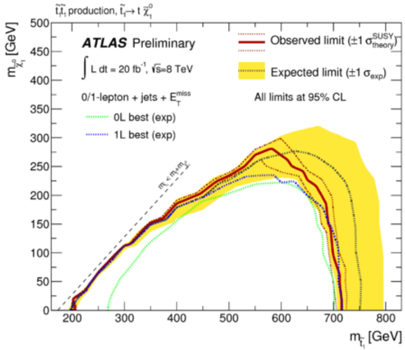




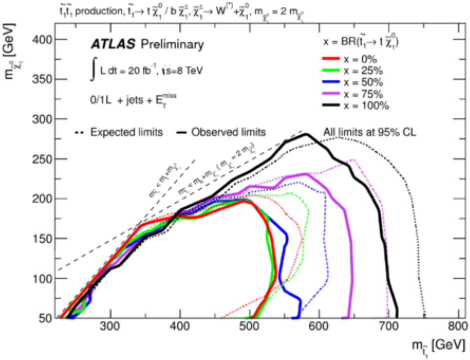
- Many additional signatures possible $\rightarrow$ check all the different corners of phase space
- Re-interpretation of a 2ℓ search + additional signal region
- LSP $= \tilde{G} \sim$ massless
- Targets diagonal boundary
- Signal regions:
  Vary jet p_{T}, m_{T2}

ATLAS-CONF-2014-014

3rd Generation: Search for scalar tops - recently combined 0ℓ and 1ℓ analyses



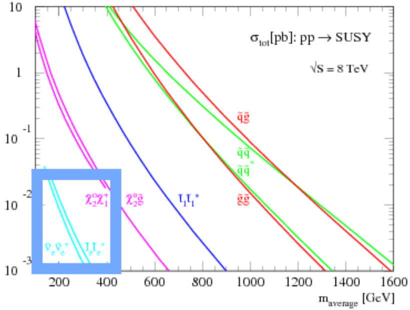
Statistically combining results extends exclusion

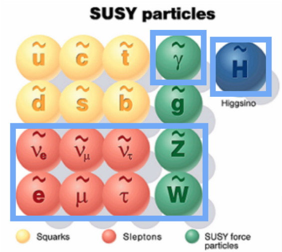


Test different branching ratios for $\tilde{t} \to t\tilde{\chi}_1^0, \quad \tilde{t} \to b\tilde{\chi}_1^{\pm}$

ATLAS-CONF-2015-010

Electroweak Direct Production





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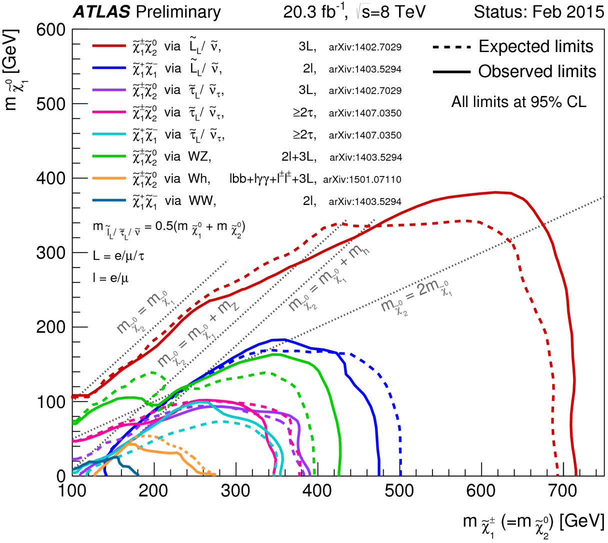
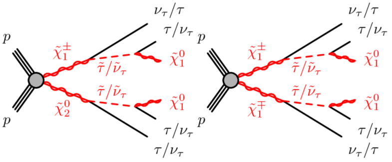
$\tilde{H}_u^+\ \tilde{H}_d^-\ \tilde{W}^+\ \tilde{W}^- \xrightarrow{mixing} \tilde{\chi}_1^\pm\ \tilde{\chi}_2^\pm$ charginos

Electroweak Summary

- Small cross-sections
- Clean multi-lepton final states
- Low hadronic activity
- Searches using e, μ, τ

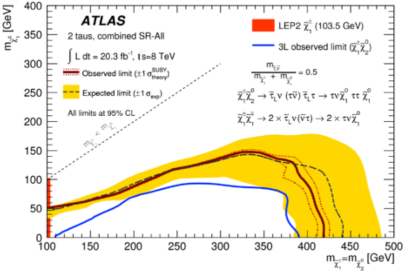


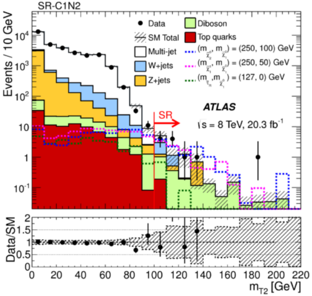
Electroweak: Search for Charginos ($\tilde{\chi}_1^{\pm}$) and next-to-lightest Neutralinos ($\tilde{\chi}_2^0$)



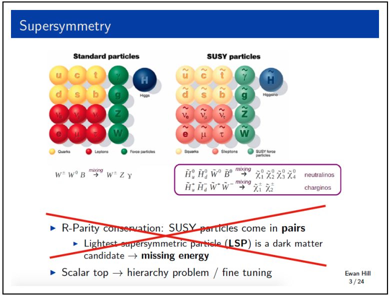
- Hadronically decaying taus (0 e/μ)
- Not the best search channel; included for variety
- Minimize number of jets
- Some discriminating variables: $E_{\mathrm{T}}^{\mathrm{miss}}$, m_{T2}, and $m_{\mathrm{T}}(\tau_1) + m_{\mathrm{T}}(\tau_2)$

10.1007/JHEP10(2014)096



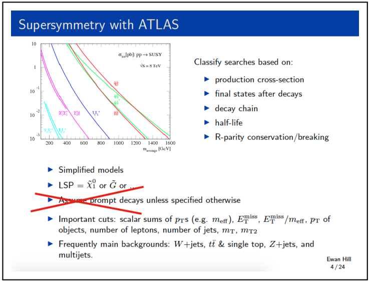


Long Lived and R-Parity Violating



What about if SUSY particles **can decay** into SM particles (R-parity violating)?

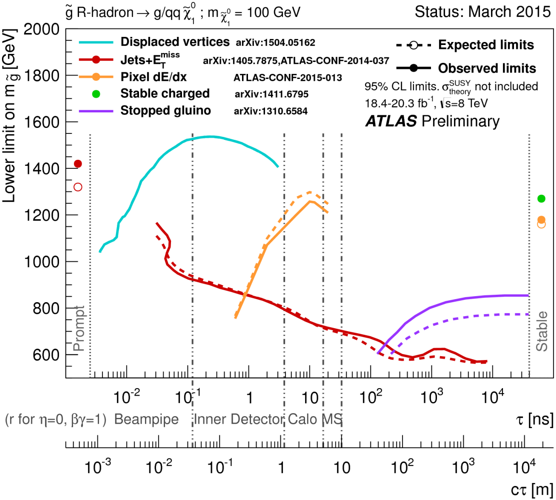
→ final state without SUSY particles ∼ no stable LSP.

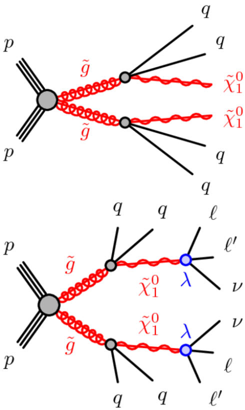


What about if the SUSY particles have **long lifetimes**?

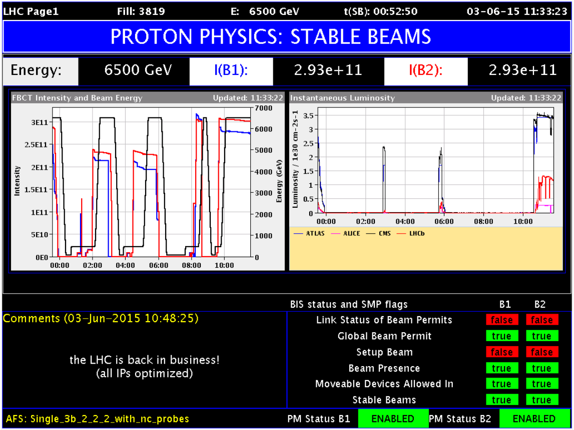
Long Lived / RPV

- SUSY particles with long lifetimes (e.g. $\tilde{g}$ or $\tilde{\chi}_1^0$)
- Analyses depend on where in the detector the decay occurs





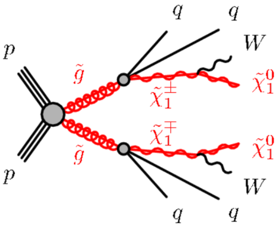
What's next?

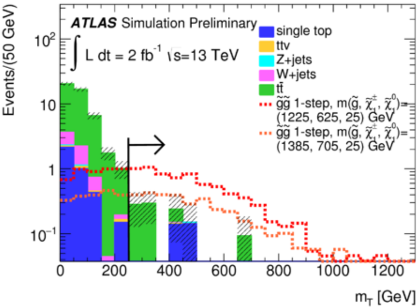


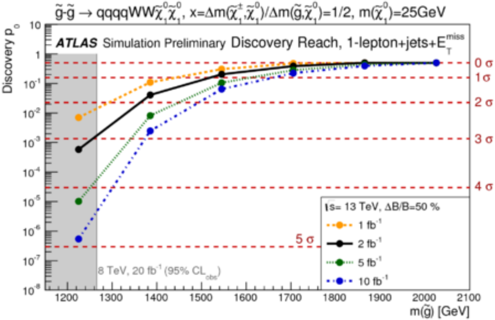
What is coming up in the near future ?

- LHC 2015 = 13 TeV
- How much data is needed before we publish?

13 TeV Strong Direct Production



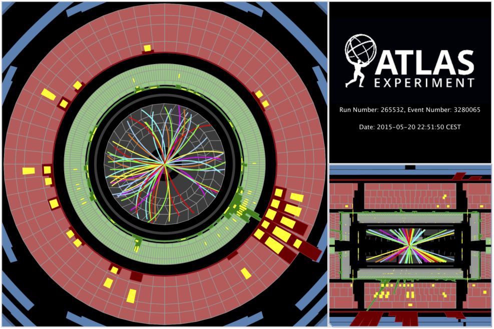




- Production cross-section 8 TeV → 13 TeV:
  - Main backgrounds: $\times\ 2-3$
  - Gluino pairs: $\times \sim 10$
- **Discovery sensitivity:** $\sim 3\sigma$ with $2-10$ fb^{-1} for masses heavier than those excluded at 8 TeV

Conclusions

- ATLAS has probed a significant amount of phase space
- No SUSY particles discovered ... yet?
- Study the $Z + E_{\mathrm{T}}^{\mathrm{miss}}$+jets excess further with 13 TeV data
- First signs of SUSY at 13 TeV could be seen with just $2 - 10\mathrm{fb}^{-1}$



13 TeV data taking has started !

Z+MET details

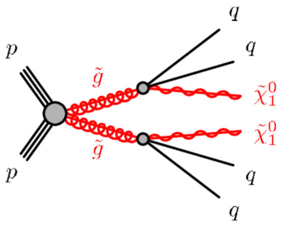
On-Z Region	E_T^{miss} [GeV]	H_T [GeV]	n_{jets}	$m_{\ell\ell}$ [GeV]	SF/DF	E_T^{miss} sig. [$\sqrt{GeV}$]	f_{ST}	$\Delta\phi(jet_{12}, E_T^{miss})$
Signal regions								
SR-Z	> 225	> 600	≥ 2	$81 < m_{\ell\ell} < 101$	SF	-	-	> 0.4
Control regions								
Seed region	-	> 600	≥ 2	$81 < m_{\ell\ell} < 101$	SF	< 0.9	< 0.6	-
CR$e\mu$	> 225	> 600	≥ 2	$81 < m_{\ell\ell} < 101$	DF	-	-	> 0.4
CRT	> 225	> 600	≥ 2	$m_{\ell\ell} \notin [81, 101]$	SF	-	-	> 0.4
Validation regions								
VRZ	< 150	> 600	≥ 2	$81 < m_{\ell\ell} < 101$	SF	-	-	-
VRT	150–225	> 500	≥ 2	$m_{\ell\ell} \notin [81, 101]$	SF	-	-	> 0.4
VRTZ	150–225	> 500	≥ 2	$81 < m_{\ell\ell} < 101$	SF	-	-	> 0.4

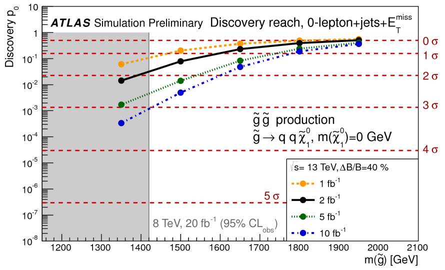
$$H_T = \sum_i p_T^{\text{jet i}} + p_T^{\text{lepton 1}} + p_T^{\text{lepton 2}}$$

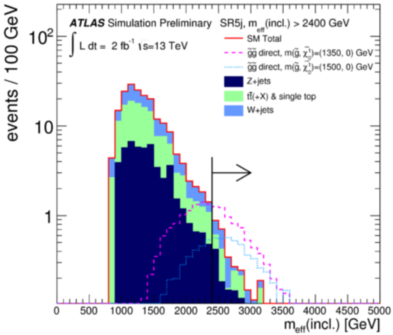
$p_T^{\text{lepton 1}} > 25$ GeV, $p_T^{\text{lepton 2}} > 10 - 14$ GeV, $p_T^{\text{jet}} > 35$ GeV

Other cuts for $10\text{ GeV} < p_T^{\text{lepton}} < 25\text{ GeV}$ leptons are tighter than for $p_T^{\text{lepton}} > 25\text{ GeV}$ leptons

Other cuts for $35\text{ GeV} < p_T^{\text{jet}} < 50\text{ GeV}$ jets are tighter than for $p_T^{\text{jet}} > 50\text{ GeV}$ jets







- Sensitivity at $\sim 2\sigma$ with $5 - 10\text{fb}^{-1}$ for masses heavier than those excluded at 8 TeV

ATL-PHYS-PUB-2015-005

Variable definitions

$$m_T\left(a\right) = \sqrt{2p_{\mathrm{T}}^{a}p_{\mathrm{T}}^{miss}\left(1-\cos\left(\Delta\phi\right)\right)}$$

where a = e/μ/τ (assumed massless).

$$m_{\mathrm{T2}}\left(b,c\right) = \sqrt{\min_{\mathbf{q}_{\mathrm{T}}^{\mathbf{b}}+\mathbf{q}_{\mathrm{T}}^{\mathbf{c}}=\mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}}\left(\max\left[m_{\mathrm{T}}^{2}\left(\mathbf{p}_{\mathrm{T}}^{b},\mathbf{q}_{\mathrm{T}}^{b}\right),m_{\mathrm{T}}^{2}\left(\mathbf{p}_{\mathrm{T}}^{c},\mathbf{q}_{\mathrm{T}}^{c}\right)\right]\right)}$$

where b,c = hadronic tau, jet, lepton+jet, etc.

$$H_T = \sum_i p_{\mathrm{T}}^{\text{jet i}}$$

$$m_{eff} = E_{\mathrm{T}}^{\mathrm{miss}} + \sum_i p_{\mathrm{T}}^{\text{jet i}} + \sum_j p_{\mathrm{T}}^{\text{lepton j}} + \sum_k p_{\mathrm{T}}^{\text{hadronic tau k}}$$

Exact definitions are highly analysis dependent (number of jets, pt cut off, etc.).