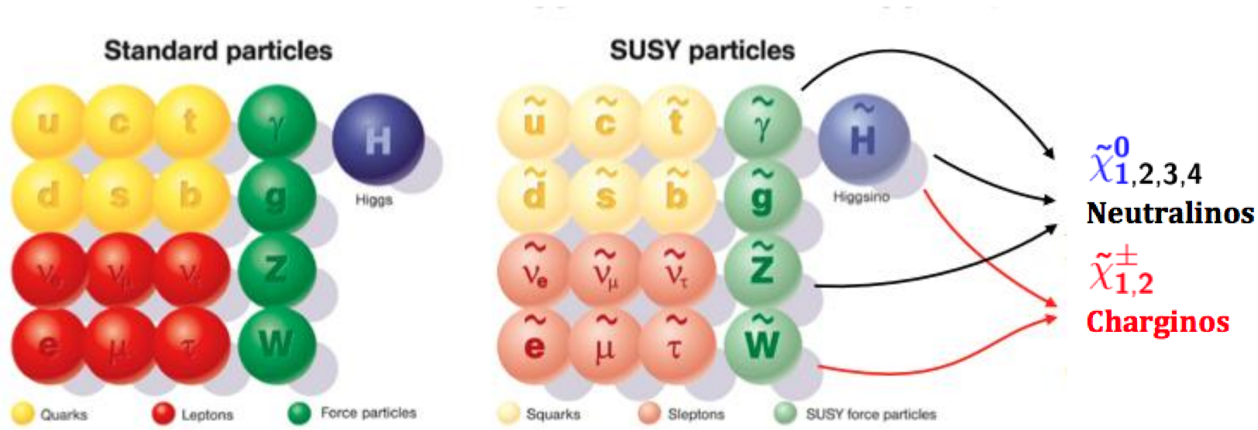
Search for supersymmetry in events with electrons or muons, jets and missing transverse momentum

Da XU

On behalf of the ATLAS Collaboration

Introduction



LHC Run 2: Cross-section for strongly produced signal grows dramatically!

Supersymmetry: one of the most appealing BSM theory.

- Moderates the hierarchy problem.
- Helps with the grand unification of gauge couplings.
- Provides a suitable dark matter candidate.

Strongly produced supersymmetry

- Large cross-section
- Heavy SUSY mass scale
- Generic experimental signatures: multiple jets + leptons + large MET

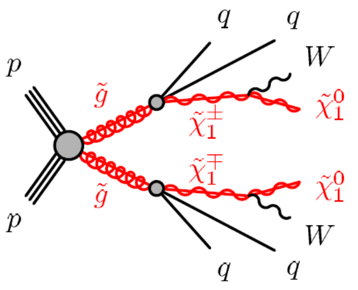
Benchmark searches

Targeting final states with electrons/muons, jets and missing transfer momentum

* All analyses are based on 3.2/3.3 fb^{-1} LHC Run 2 data.

1 lepton

- Final states: one lepton(e/μ)+jets+MET



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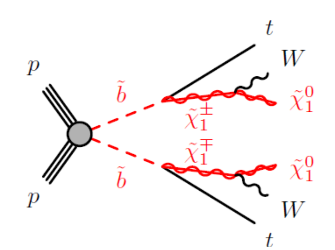
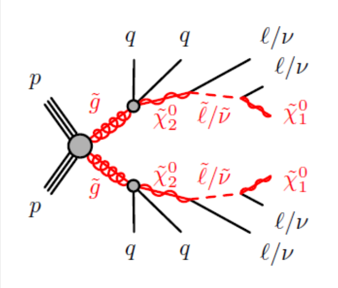
SS2L/3L

- Final states: Same-sign two/three leptons (e/μ)+jets+MET





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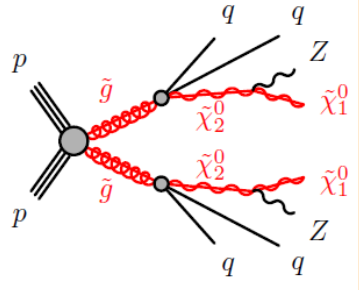
2L Z+MET

- Final states: on-shell Z (leptonic) +jets+MET



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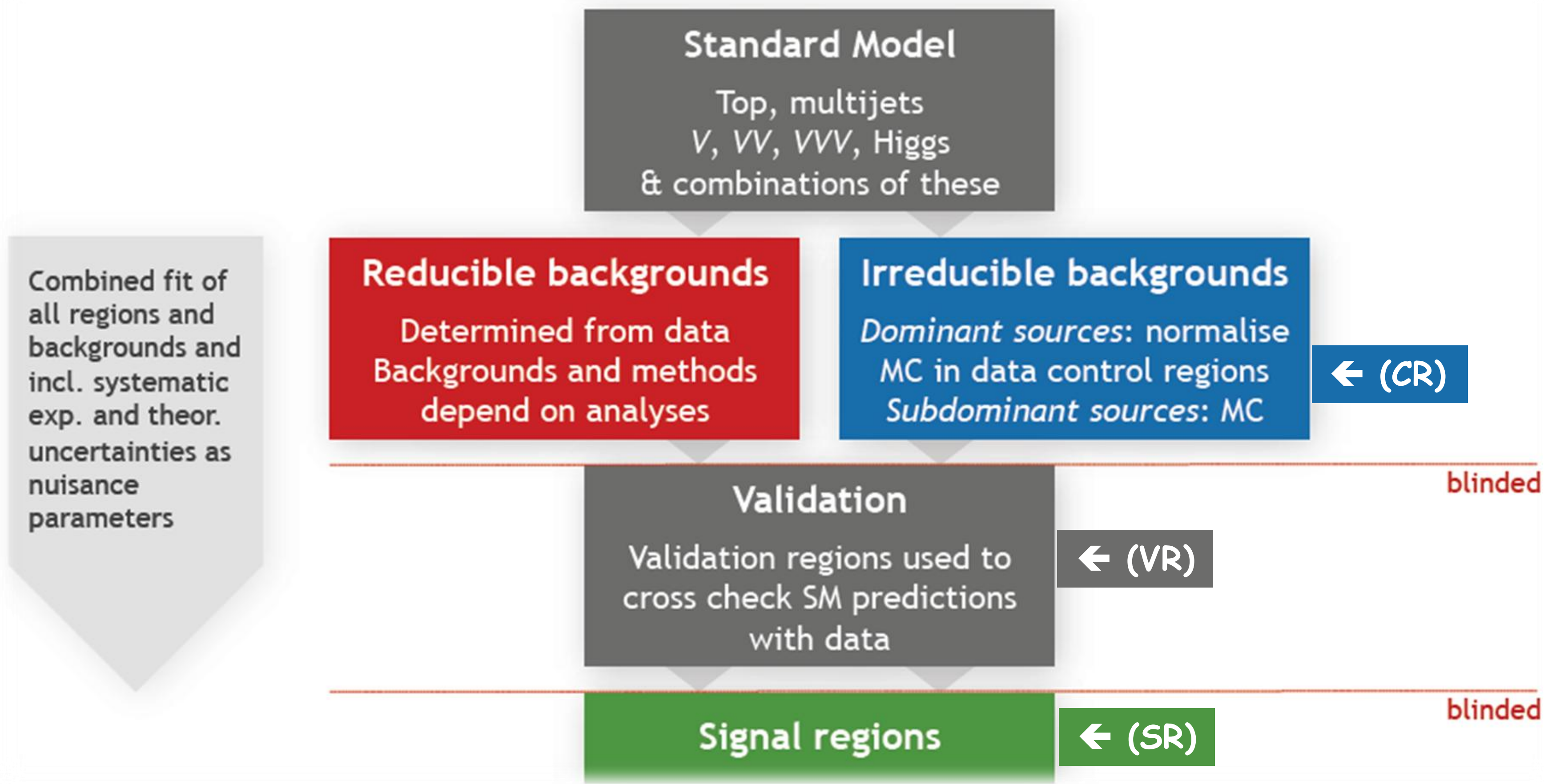
** R-parity conservation is assumed in models presented here.*

SM Background Modelling

- SUSY searches rely on accurate modelling of the Standard Model backgrounds.



1-lepton: Overview

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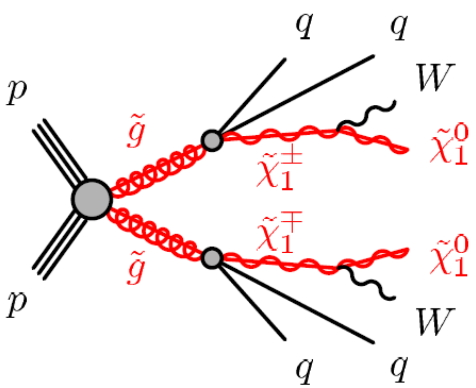
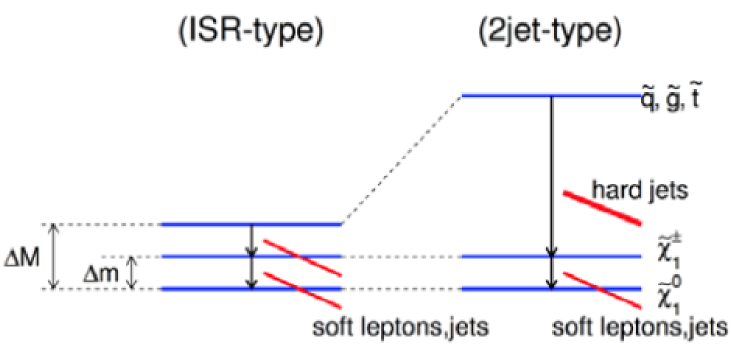


$\tilde{g}\tilde{g}$ pair production decay via $\tilde{\chi}_1^\pm$

- Free parameters: m_$\tilde{g}$, m_$\tilde{\chi}_1^0$; m_$\tilde{\chi}_1^\pm$ fixed at (m_$\tilde{g}$ + m_$\tilde{\chi}_1^0$)/2
- Free parameters: m_$\tilde{g}$, m_$\tilde{\chi}_1^\pm$; m_$\tilde{\chi}_1^0$ fixed at 60GeV



Target semi-leptonic decay: search for 1 lepton, jets and MET.

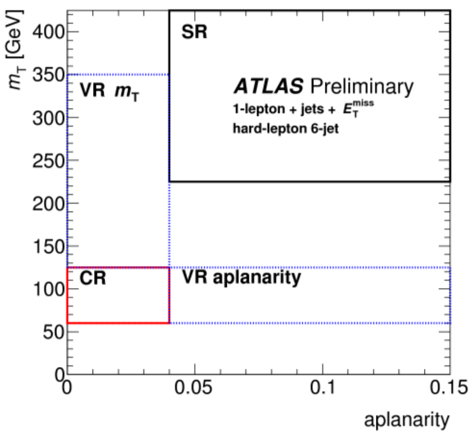
"hard lepton channel"

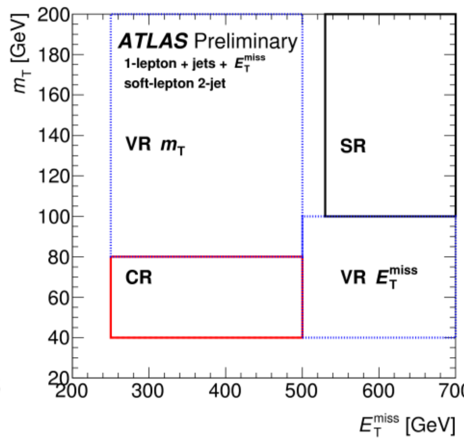
- SUSY scenarios with large mass splitting between $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_1^0$
- Hard lepton e/μ pT > 35GeV; large MET and mT
- 4 SRs with jet multiplicity ranging from 4 to 6

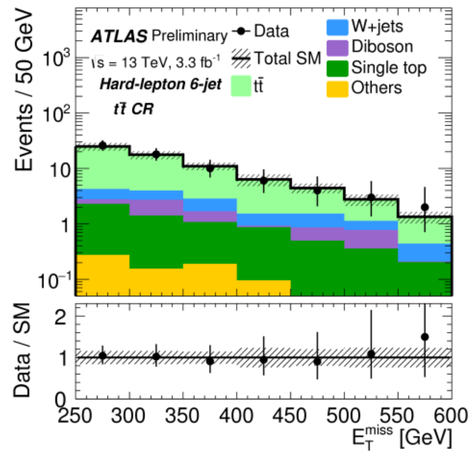
"soft lepton channel"

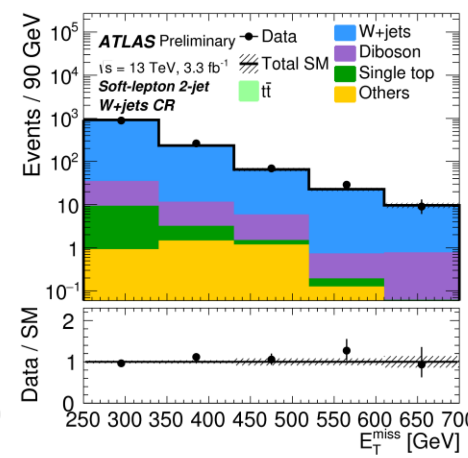
- SUSY scenarios with compressed mass spectra: ISR and 2-jet type
- Soft lepton e/μ pT: 7/6 - 35GeV; large MET
- 2 SRs: ≥2jets and ≥ 5jets

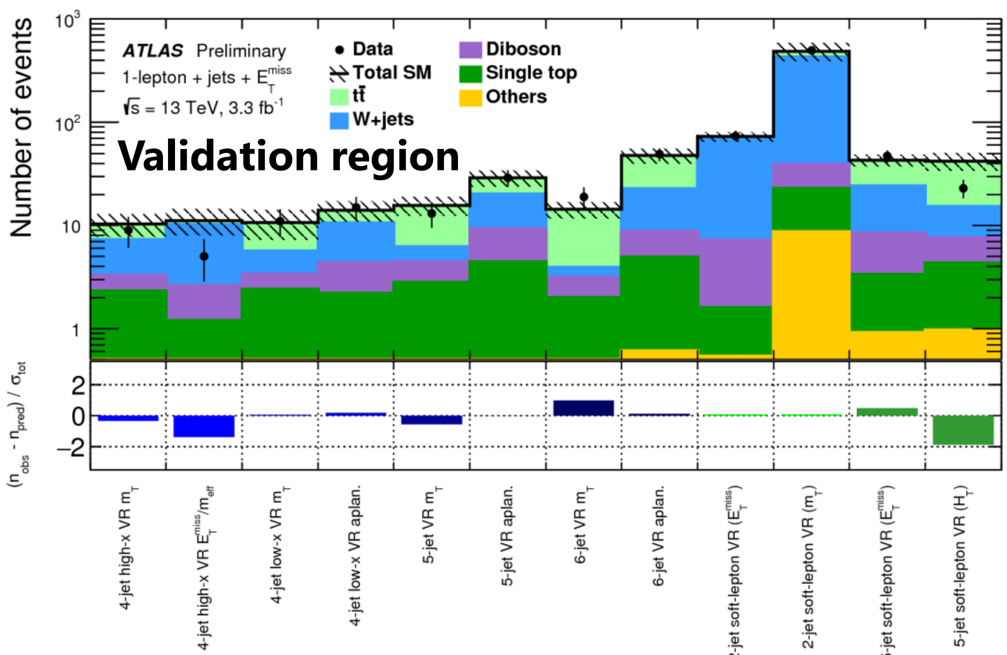
1-lepton: Analysis strategy









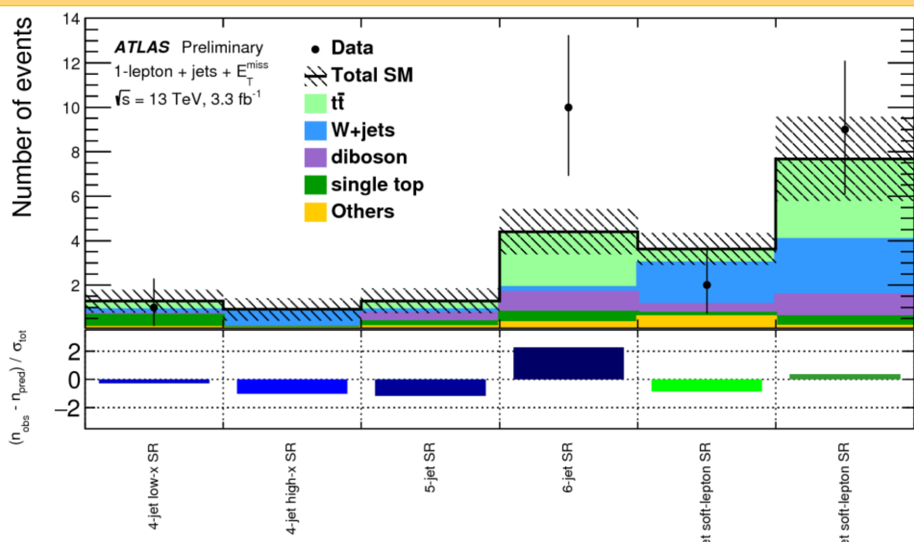


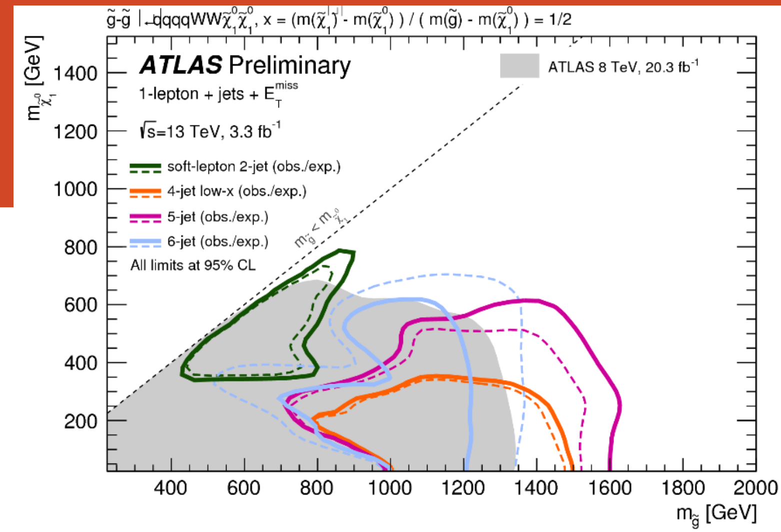
- Main background: ttbar, W+jets
- Discriminants: MET, mT, Aplanarity*
- Good agreement between predicted and observed event yields in all validation regions: largest deviations ≤2σ.

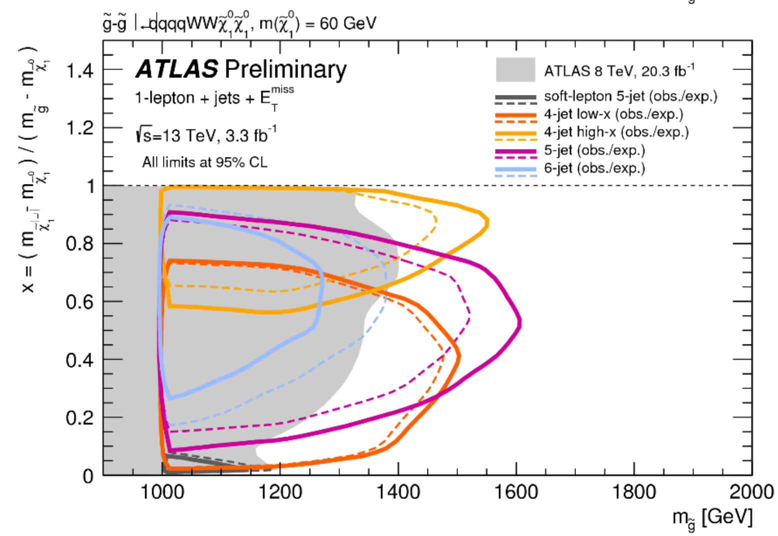
****Aplanarity: a variable designed to allow more global information about the full momentum tensor. More in BackUp.***

1-lepton: Results

- Good agreement between predictions and observed data in most signal regions.
- In the 6-jet SR, a 2σ excess is observed. This mainly arises from μ channel(local significance of 2.5σ): 2.5±0.8 expected, 8 observed.
- Without (hugely) significant observation, the exclusion limit has been set on the models: gluinos are excluded up to ~1.6TeV (for a massless $\tilde{\chi}_1^0$).







- Cannot exclude region covered by 6-jet SR due to moderate excess.
- Soft lepton SR performs well in the mass compressed region.

2L same-sign/3L: Overview

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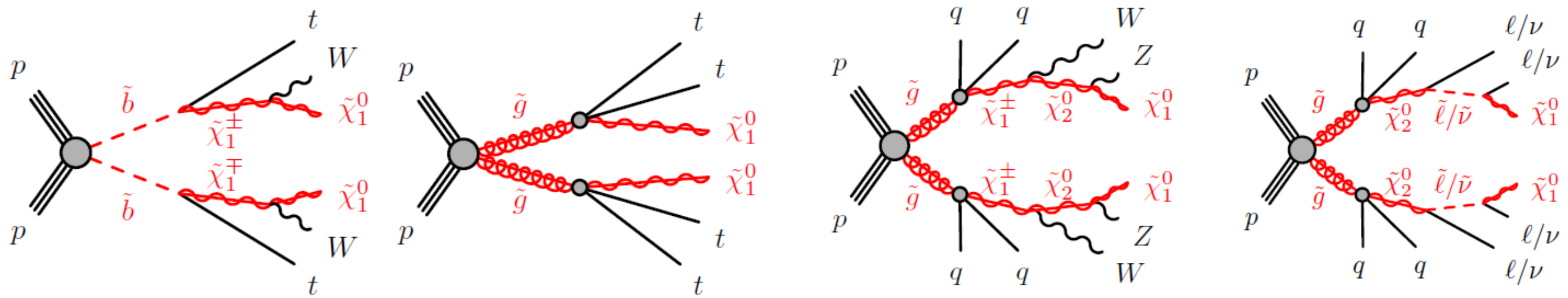


- Lighter third generation squarks favoring the production of leptons and heavy flavor quarks
  → 2 SRs enriched in b-jets

- Leptons produced in EWKinos cascade decays leading to W/Z bosons and via sleptons
  → 2 SRs with b-jet vetoes

Searching for jets and either two same sign leptons (e/μ) or at least three leptons.

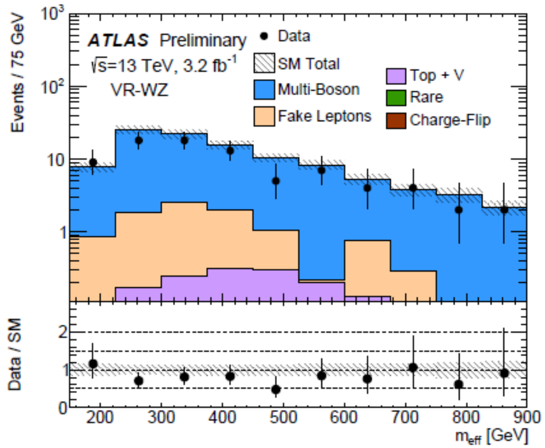
- Low SM background allows loose MET requirement and gain in sensitivity to compressed SUSY.

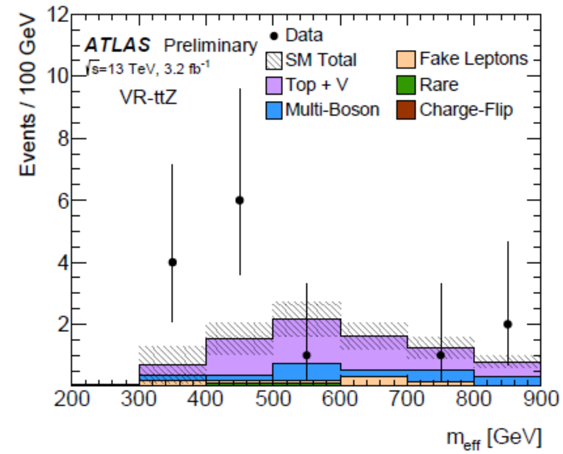
Sensitive variables: #lep, #(b)jets, jet pT, MET, meff

Signal region	$N_{\text{lept}}^{\text{signal}}$	$N_{b\text{jets}}^{20}$	N_{jets}^{50}	$E_{\text{T}}^{\text{miss}}$ [GeV]	m_{eff} [GeV]
SR0b3j	≥ 3	$=0$	≥ 3	>200	>550
SR0b5j	≥ 2	$=0$	≥ 5	>125	>650
SR1b	≥ 2	≥ 1	≥ 4	>150	>550
SR3b	≥ 2	≥ 3	-	>125	>650

2L same-sign/3L: Analysis strategy

- Irreducible backgrounds (MC): ttV, diboson, triboson (prompt leptons)





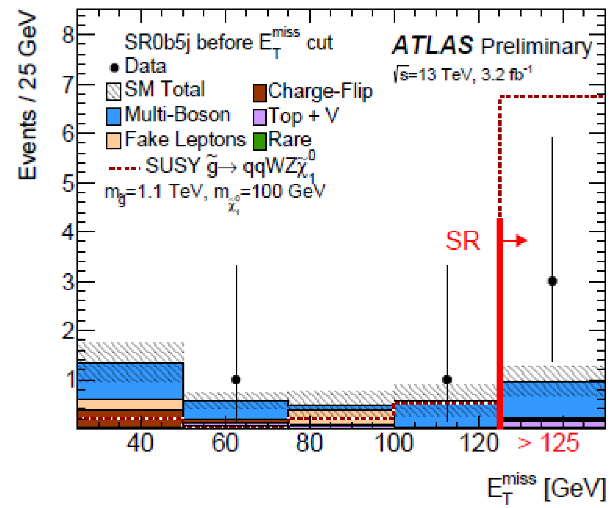
	VR-WW	VR-WZ	VR-ttV	VR-ttZ
Observed events	4	82	19	14
Total bkg events	4.1 ± 0.9	106 ± 16	11.6 ± 2.8	8.4 ± 2.0

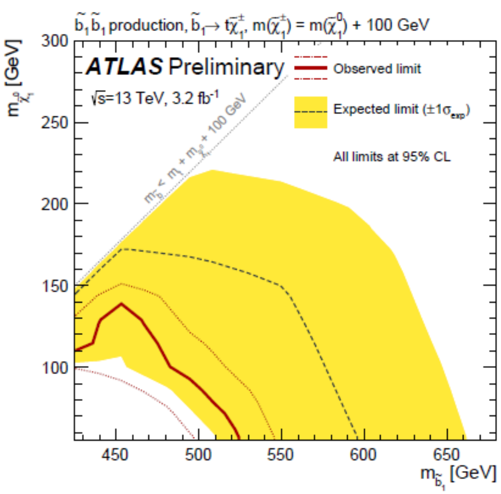
- Reducible backgrounds (data-driven): dominanted by ttbar in SR
  - Fake and non-prompt leptons (ttbar decaying semi-leptonically, Wjets): Matrix method to estimate fake leptons passing signal-like cuts.
  - Charge flip electrons (ttbar decaying fully leptonically, Z): Likelihood method to determine flip probability, further used to reweight OS data.
  - Predictions validated in dedicated regions, and cross checked by an independent method.

2L same-sign/3L: Results

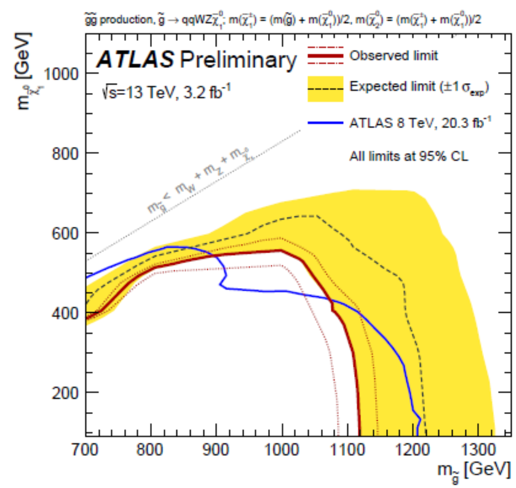
- Data agrees well with SM prediction in all SRs.
- Significant improvement over Run 1 limit in much of the phase space.

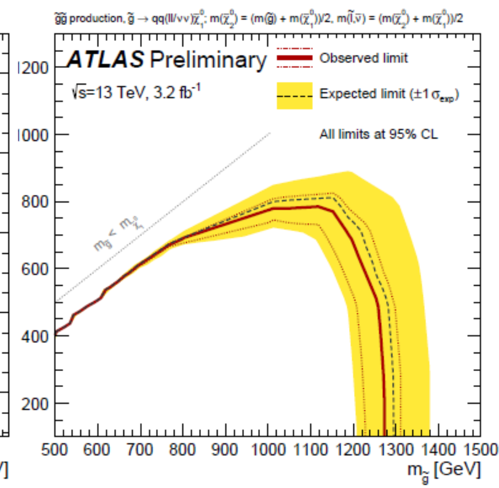
	SR0b3j	SR0b5j	SR1b	SR3b
Observed events	3	3	7	1
Total bkg events	2.4 ± 0.7	0.98 ± 0.32	4.3 ± 1.0	0.78 ± 0.24
$p(s = 0)$	0.33	0.06	0.12	0.36





- Left: Bottom squark masses <525GeV are excluded for a light $\tilde{\chi}_1^0$.
- Right: $m\_\tilde{g}$ ≤1.1-1.3TeV and $m\_\tilde{\chi}_1^{\pm}$ ≤ 550-800GeV are excluded depending on the model parameters.





2L Z+MET: Overview

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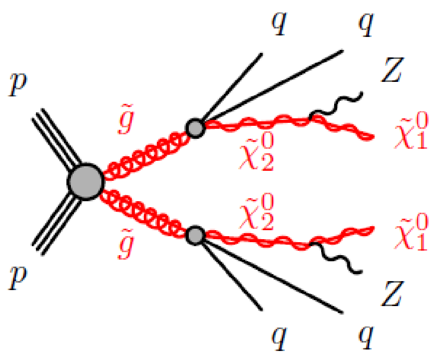
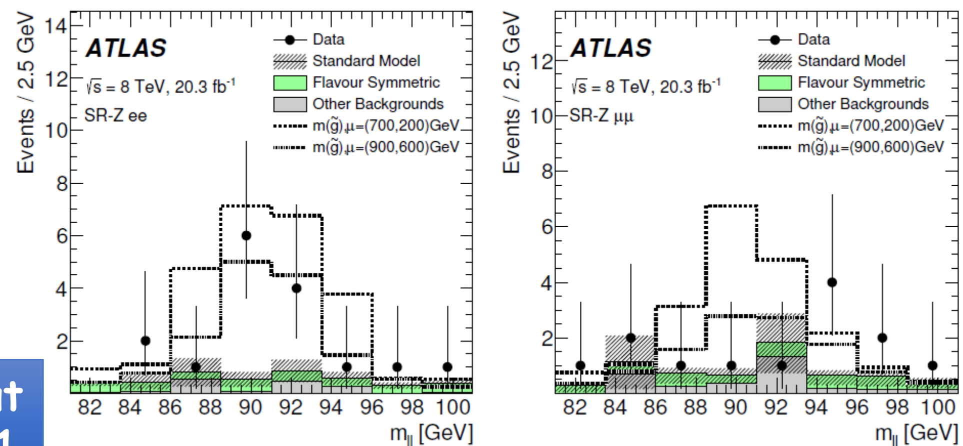
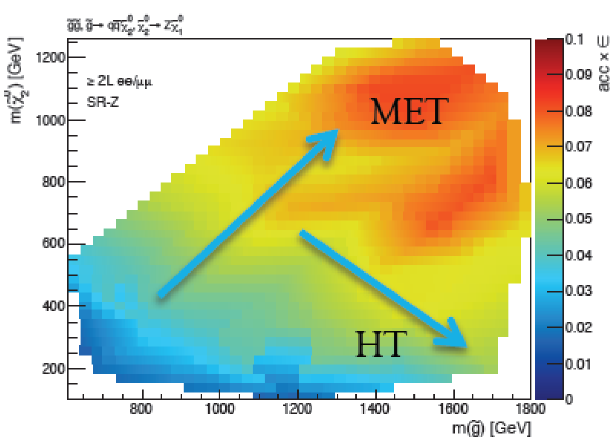
Reminder: Run 1 @ 8 TeV analysis saw excess of 3σ (ee) / 1.7σ (μμ)! LINK



Run 2: simplified model: different but approximating the process from Run 1



Searching for final state with on-shell Z (leptonic), jets and MET.



Region	E_T^{miss} [GeV]	H_T [GeV]	n_{jets}	$m_{\ell\ell}$ [GeV]	SF/DF	$\Delta\phi(\text{jet}_{12}, p_T^{miss})$
SRZ	> 225	> 600	≥ 2	$81 < m_{\ell\ell} < 101$	SF	> 0.4

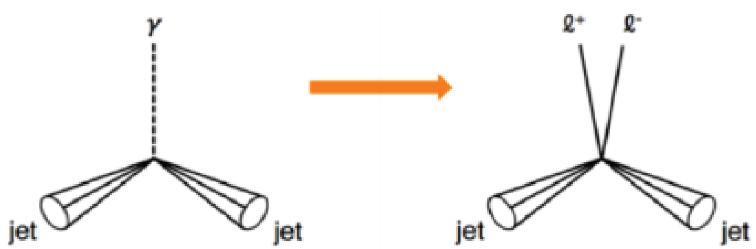
- SR is kinematically identical to Run 1 analysis: confirm or deny the excess quickly!
- Discriminants: dilepton invariant mass, Ht (high Ht→ high $\tilde{g}$ mass) and MET (high MET→ high $\tilde{\chi}_2^0$ mass).

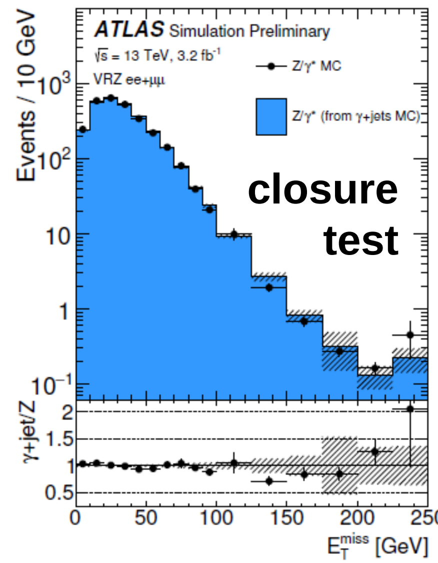
$$H_T = p_T^{\ell} + \sum_{j=1}^{N_{jet}} p_{T,j}$$

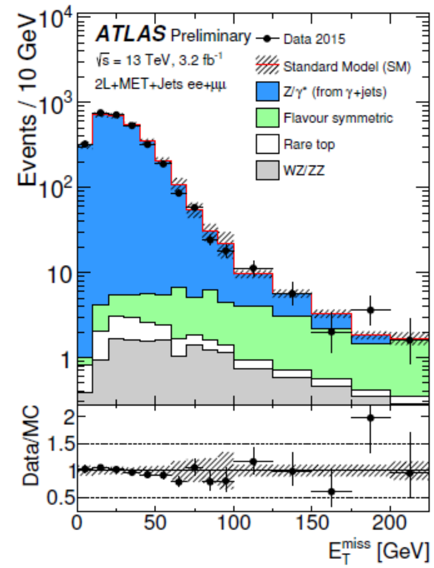
2L Z+MET: Analysis strategy

- Ttbar(plus WW/Wt/Ztautau): dominant (~60%). "Flavour symmetry method" use data in eμ channel to estimate the contribution in the same flavour channels. Cross-checked with "sideband-fit".

Region	Flavour-symmetry	Sideband fit
SRZ	5.1 ± 2.0	6.1 ± 1.7
VRS	18.9 ± 4.8	20.5 ± 5.6

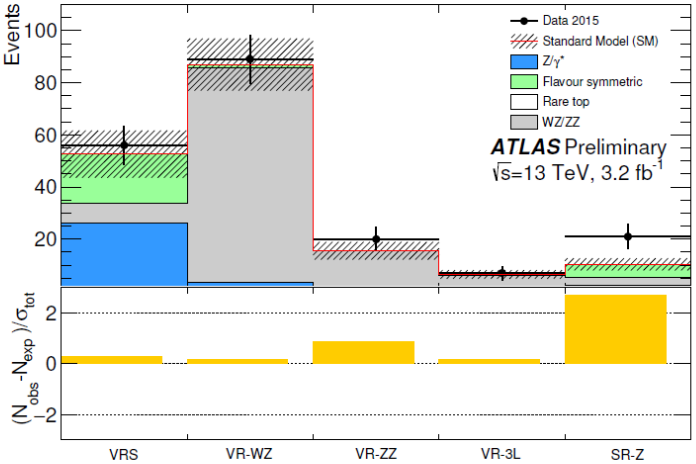




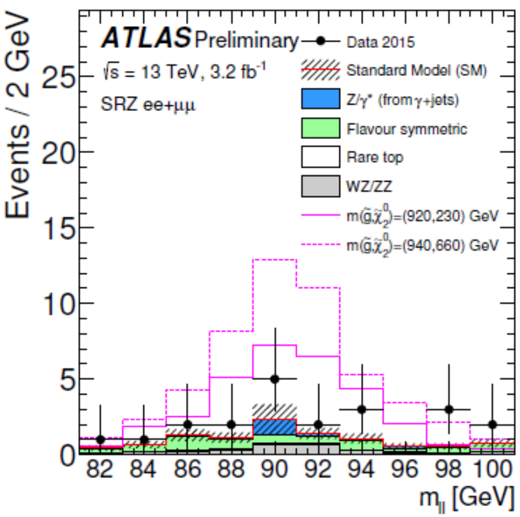


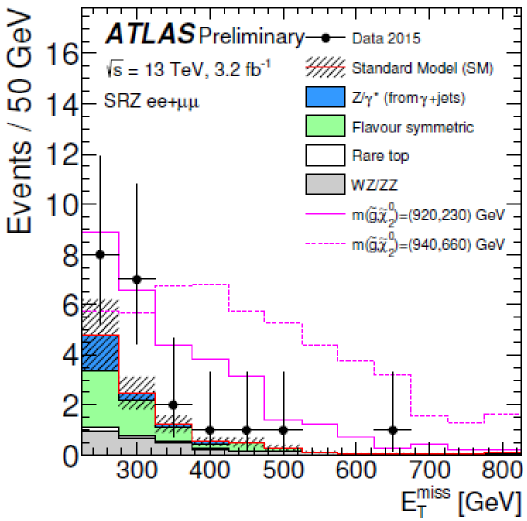
- Z+jets: small but must be careful (would peak in the Z-window). Use photon+jets events in data to model the MET contribution. Cross check with MC.

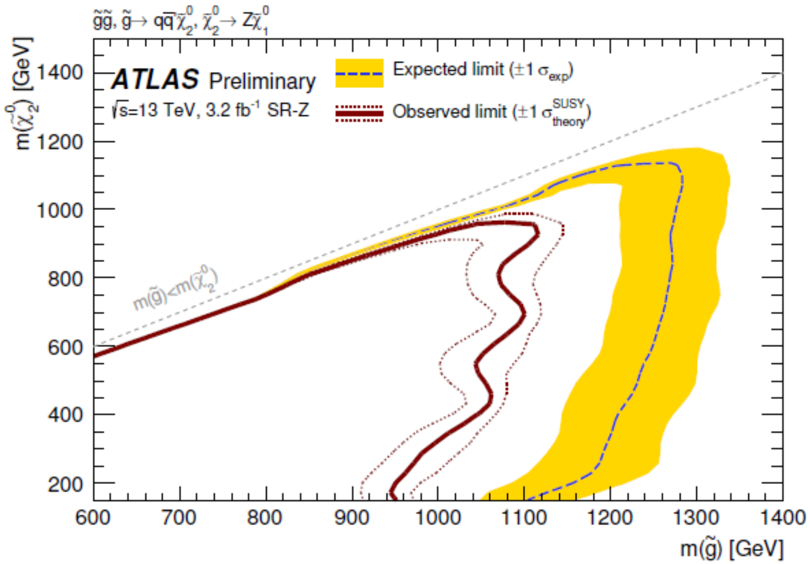
2L Z+MET: Results



- Run 2 result very intriguing: 2.2σ excess.
- 21 events observed, 10.3±2.3 expected.
- Flavor symmetric this time: 11 in μμ, 10 in ee.
- Exclude up to m_$\tilde{g}$ ~1.1TeV for a $\tilde{\chi}_2^0$ mass of 700GeV.







Summary

- ATLAS Run 2 data (13TeV,~3.3fb^{-1}) has improved sensitivity to strongly produced SUSY over Run 1 (8TeV, 20.3fb^{-1}).
- Analyses of strongly produced SUSY with leptons (e,μ)+jets+MET see no significant excesses over the SM predictions.
- Largest excesses observed in 1-lepton and Z+MET channels, with a significance of 2.0 and 2.2 sigma respectively.
- Exciting time to study SUSY: looking forward to ICHEP2016 and beyond!

Extra slides

Thanks ☺

The aplanarity, $\mathcal{A}$ is a variable designed to allow more global information about the full momentum tensor of the event, M_{xyz}, via its eigenvalues λ_1, λ_2 and λ_3:

$$\sum_{i\ jet} \begin{pmatrix} P_x^2 & P_x P_y & P_x P_z \\ P_y P_x & P_y^2 & P_y P_z \\ P_z P_x & P_z P_y & P_z^2 \end{pmatrix} \xrightarrow[Av = \lambda v]{\text{Find the eigenvalues}}$$

Ordered: $\lambda 1 > \lambda 2 > \lambda 3$

Normalised: $\sum_i \lambda_i = 1$

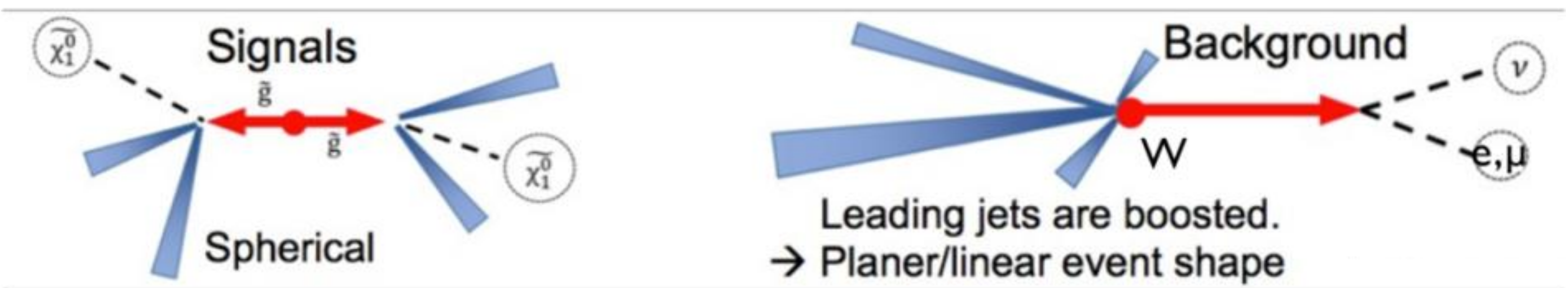
- Three categories of events:

$\lambda 1 >> \lambda 2, \lambda 3$ ‣**Linear** event: most of momentum concentrated along 1 line

$\lambda 1 \gtrsim \lambda 2 >> \lambda 3$ ‣**Planar** event: most of momentum concentrated in a plane

$\lambda 1 \gtrsim \lambda 2 \gtrsim \lambda 3$ ‣**Aplanar** event: momentum activity in all 3 directions

- **Aplanarity** = $\frac{3}{2}\lambda_3$



Discriminating variables

The transverse mass (m_{T}) of the lepton (ℓ) and $\boldsymbol{p}_{\mathrm{T}}^{\mathrm{miss}}$ is defined as

$$m_{\mathrm{T}} = \sqrt{2 p_{\mathrm{T}}^{\ell} E_{\mathrm{T}}^{\mathrm{miss}} (1 - \cos[\Delta\phi(\vec{\ell}, \boldsymbol{p}_{\mathrm{T}}^{\mathrm{miss}})])}, \quad (1)$$

where $\Delta\phi(\vec{\ell}, \boldsymbol{p}_{\mathrm{T}}^{\mathrm{miss}})$ is the azimuthal angle between the lepton and the missing transverse momentum. This is used in the soft-lepton 2-jet signal region and all hard-lepton signal regions to reject W+jets and semileptonic $t\bar{t}$ events.

The inclusive effective mass ($m_{\mathrm{eff}}^{\mathrm{inc}}$) is the scalar sum of the p_{T} of the lepton, the jets and $E_{\mathrm{T}}^{\mathrm{miss}}$:

$$m_{\mathrm{eff}}^{\mathrm{inc}} = p_{\mathrm{T}}^{\ell} + \sum_{j=1}^{N_{\mathrm{jet}}} p_{\mathrm{T},j} + E_{\mathrm{T}}^{\mathrm{miss}}, \quad (2)$$

where the index j runs over all the signal jets in the event with $\mathrm{p_T} > 30$ GeV. The inclusive effective mass provides good discrimination against SM backgrounds, without being too sensitive to the details of the SUSY cascade decay chain.

The transverse scalar sum (H_{T}) is defined as

$$H_{\mathrm{T}} = p_{\mathrm{T}}^{\ell} + \sum_{j=1}^{N_{\mathrm{jet}}} p_{\mathrm{T},j},$$