Inclusive searches for squarks and gluinos in final states with jets and E_T^{miss} with the ATLAS detector

Otilia Ducu, on behalf of the ATLAS collaboration

Université de Montréal (Canada), IFIN-HH (Romania)

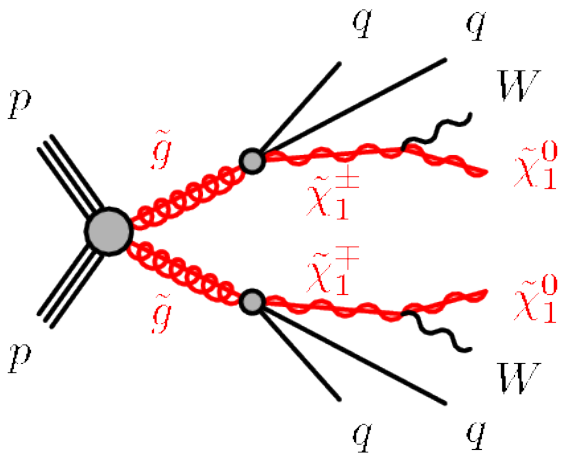
July 6, 2017

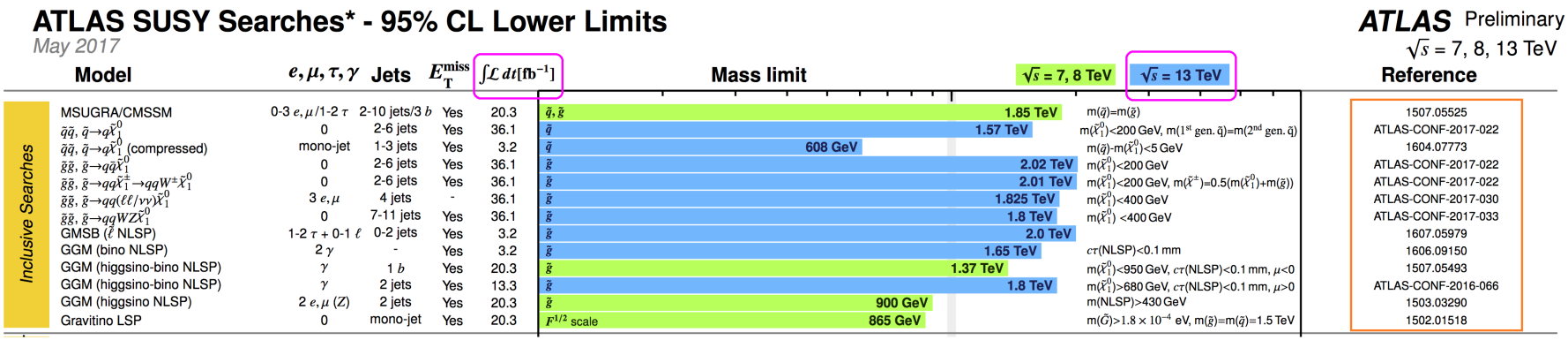
EPS Conference on High Energy Physics, Venice, Italy

SUSY STRONG PRODUCTION

Gluinos ($\tilde{g}$) and squarks ($\tilde{q}$) decay either directly or via a cascade into:

- Several jets $\rightarrow$ b-tagged or not
- Leptons $\rightarrow$ from slepton or chargino decays
- Lightest Supersymmetric Particle (LSP, a viable Dark Matter candidate) $\rightarrow$ escaping the detector, leading to high missing transverse energy (E_T^{miss})





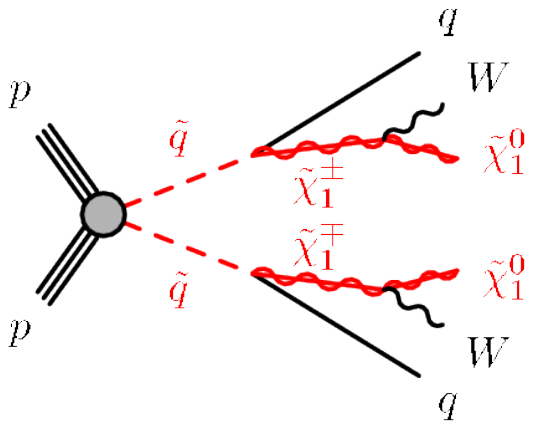
- Today: searches for $\tilde{g}$ and $\tilde{q}$ in final states with jets and E_T^{miss} using 13 TeV ATLAS data
- Corresponding to an integrated luminosity of $\sim$36 fb^{-1}
  - Results are interpreted using SUSY simplified models, where particles not involved in production or decays are decoupled

0 Lepton searches, CONF-2017-022

2→6 jets and no leptons final states, where the signal regions (SR) are defined with:

1) Simple cuts on effective mass variable, m_{eff}
(jets transverse momentum (p_T) plus E_T^{miss})

2) Recursive Jigsaw Reconstruction (RJR) techniques
   - RJR impose specific decay hypothesis on event and assign 4-momenta to invisible states
   - Improves the sensitivity to models with small mass splittings between the sparticles
   - See Paul Jackson and Julien Maurer presentations later in the day



- Typical m_{eff}-based signal regions:

Targeted signal	$\tilde{g}\tilde{g}$, $\tilde{g} \to q\bar{q}W\tilde{\chi}_1^0$ and $\tilde{q}\tilde{q}$, $\tilde{q} \to qW\tilde{\chi}_1^0$	
Requirement	Signal Region	
	Meff-2jB-1600	**Meff-2jB-2400**
$E_{\text{T}}^{\text{miss}}$ [GeV] >	250	
p_{T}(Large-R j_1) [GeV] >	200	
p_{T}(Large-R j_2) [GeV] >	200	
m(Large-R j_1) [GeV]	[60,110]	
m(Large-R j_2) [GeV]	[60,110]	
$\Delta\phi(\text{jet}_{1,2,(3)}, \boldsymbol{E}_{\text{T}}^{\text{miss}})_{\text{min}}$ >	0.6	
$\Delta\phi(\text{jet}_{i>3}, \boldsymbol{E}_{\text{T}}^{\text{miss}})_{\text{min}}$ >	0.4	
$E_{\text{T}}^{\text{miss}}/\sqrt{H_{\text{T}}}$ [GeV$^{1/2}$] >	20	
m_{eff}(incl.) [GeV] >	1600	2400

- Depending on the SR, $m_{\text{eff}} > 1$ - 2.8 TeV
- $E_T^{miss} > 200$ - 250 GeV
- Leading jet > 200 - 700 GeV
- Additional cuts on No. jets, $\Delta\Phi(\text{jet}_i, E_T^{miss})_{\text{min}}$, E_T^{miss}/H_T (where H_T is $\sum$ of jets p_T)

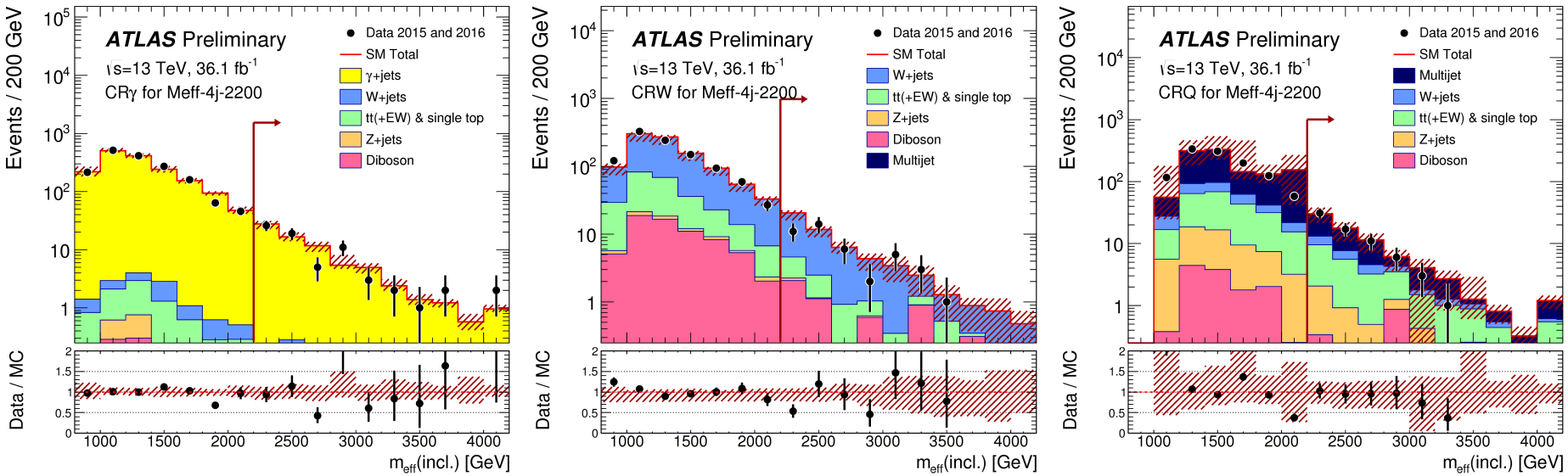
Backgrounds, CONF-2017-022

Main backgrounds: W/Z +jets, $t\bar{t}$, single top, di-boson and multi-jets processes:

1) $Z \to \nu\nu$ +jets: estimated with a γ +jets control region (CR), with γ ($p_T > 150$ GeV) treated as invisible in the E_T^{miss} computation

2) $W \to \tau\nu$ (e, μ) +jets and semi-leptonic $t\bar{t}$: 1-lepton CRs, with ℓ ($p_T > 27$ GeV) treated as a jet, to model bkg events with hadronically decaying τ

3) Multi-jets: using a data-driven technique which applies a resolution function to well measured multi-jets events

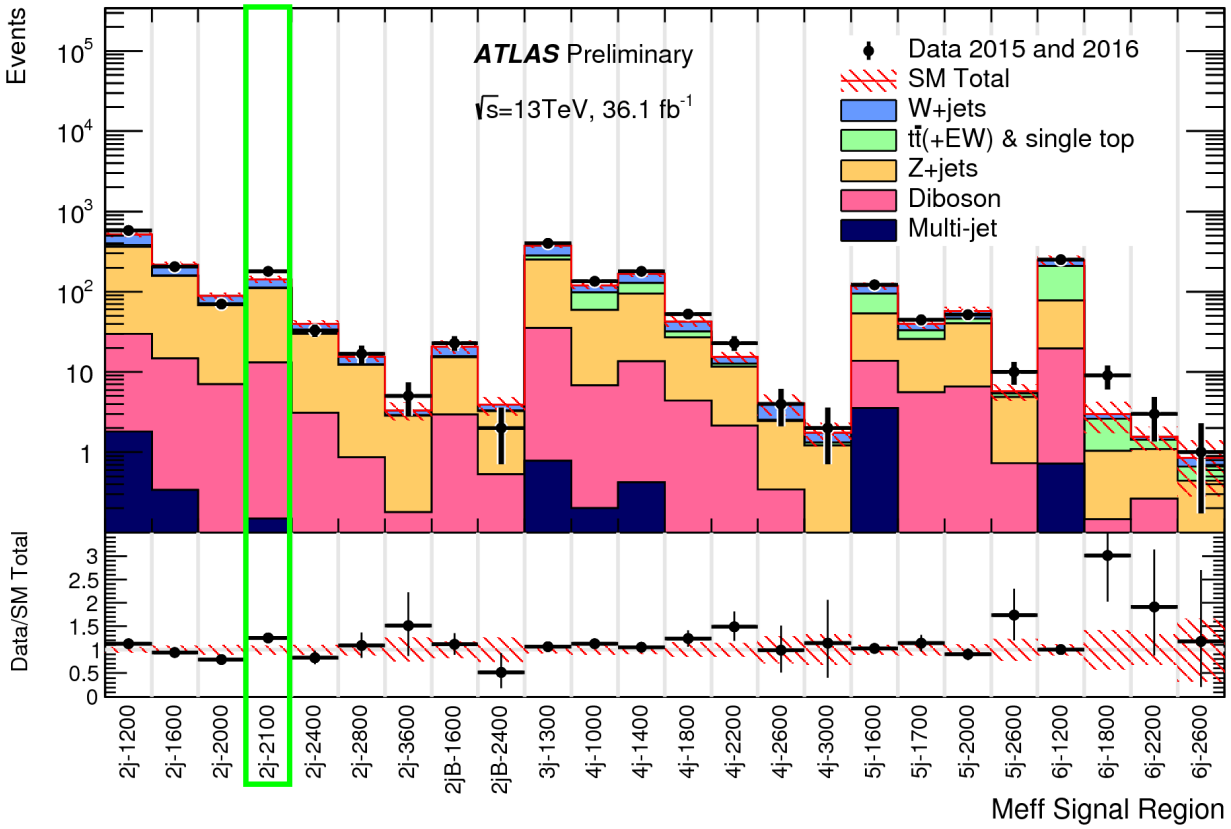


*Observed m_{eff} distributions in three control regions, after applying all selection requirements except those on the plotted variable

Results in the SRs, CONF-2017-022

Results in the SRs: look for significant difference between observed data and bkg estimation

- When considering the m_{eff}-based signal regions:

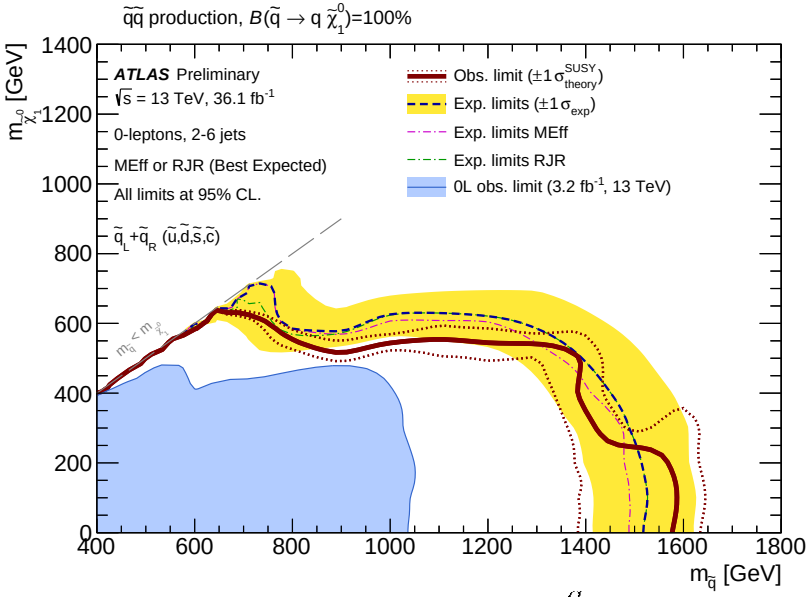


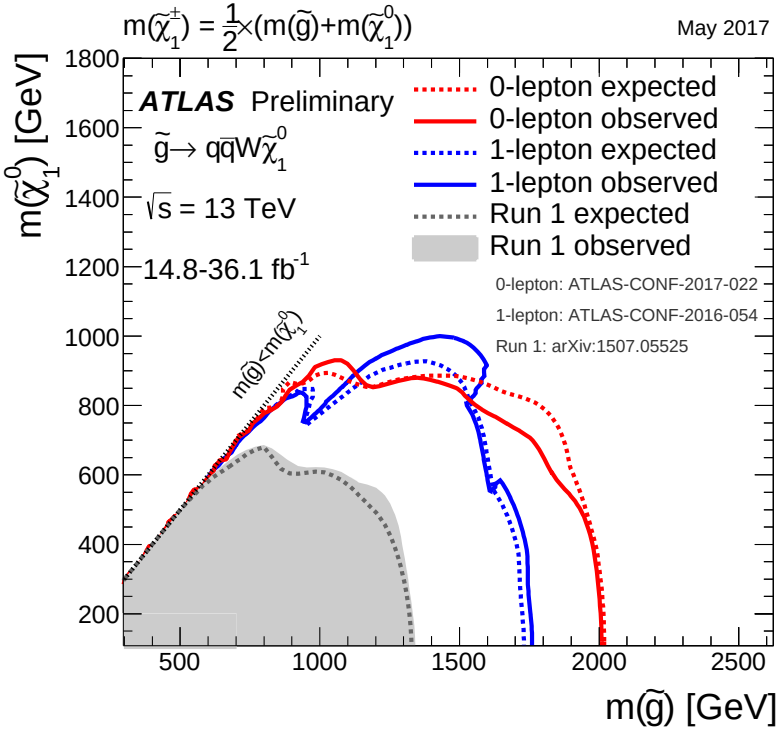
- Most significant excesses: Meff-2j-2100 (a local significance of 2.14 standard deviations)

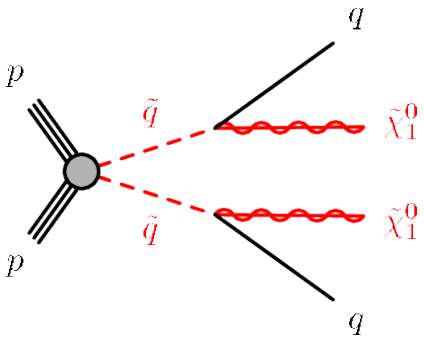
Exclusion limits, CONF-2017-022

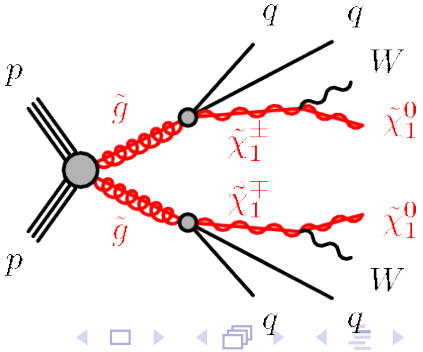
No significant excess → place limits on sparticles masses using simplified SUSY models

- Limits also with other final states (RHS, blue) → complementary of the ATLAS searches









Multi-jets searches, ATLAS-CONF-2017-033

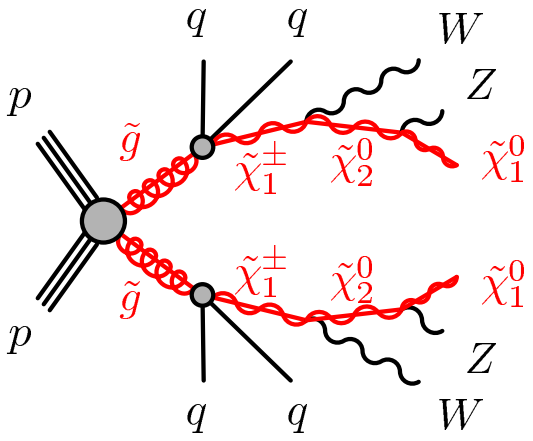
7→11 jets and no leptons final states: analysis targeting long decay chains of gluinos

1) *Heavy flavor* channel: 1→3 b-jets ($p_T > 50$ GeV)

2.A) *Large-R jet mass* channel: target final states with boosted heavy particles such as top quarks or bosons forming heavy large-R jets

- Large-R jets: composite jets with $p_T^{R=1.0} > 100$ GeV and $\eta^{R=1.0} < 1.5$
- SRs with large-R jets mass > 340 GeV or 500 GeV

2.B) Rare Standard Model bkg: not many events with large-R jets heavier than the top mass



Summary of the selection criteria used to define the signal regions:

Criterion	Heavy flavour channel		Jet mass channel
Jet $\lvert\eta\rvert$	< 2.0		
Jet p_T	> 50 GeV	> 80 GeV	> 50 GeV
N_{jet}	$\geq 8, 9, 10, 11$	$\geq 7, 8, 9$	$\geq 8, 9, 10$
Lepton veto	No preselected e or μ after overlap removal		

Criterion	Heavy flavour channel	Jet mass channel
b-jet selection	$p_T > 50$ GeV, $\lvert\eta\rvert < 2.0$	
Large-R-jet selection	$p_T > 100$ GeV, $\lvert\eta\rvert < 1.0$	
$N_{b\text{-tag}}$	$\geq 0, 1, 2$	≥ 0
M_J^{Σ}	≥ 0	$\geq 340, 500$ GeV
$E_T^{\text{miss}}/\sqrt{H_T}$	$> 5\,\text{GeV}^{1/2}$	

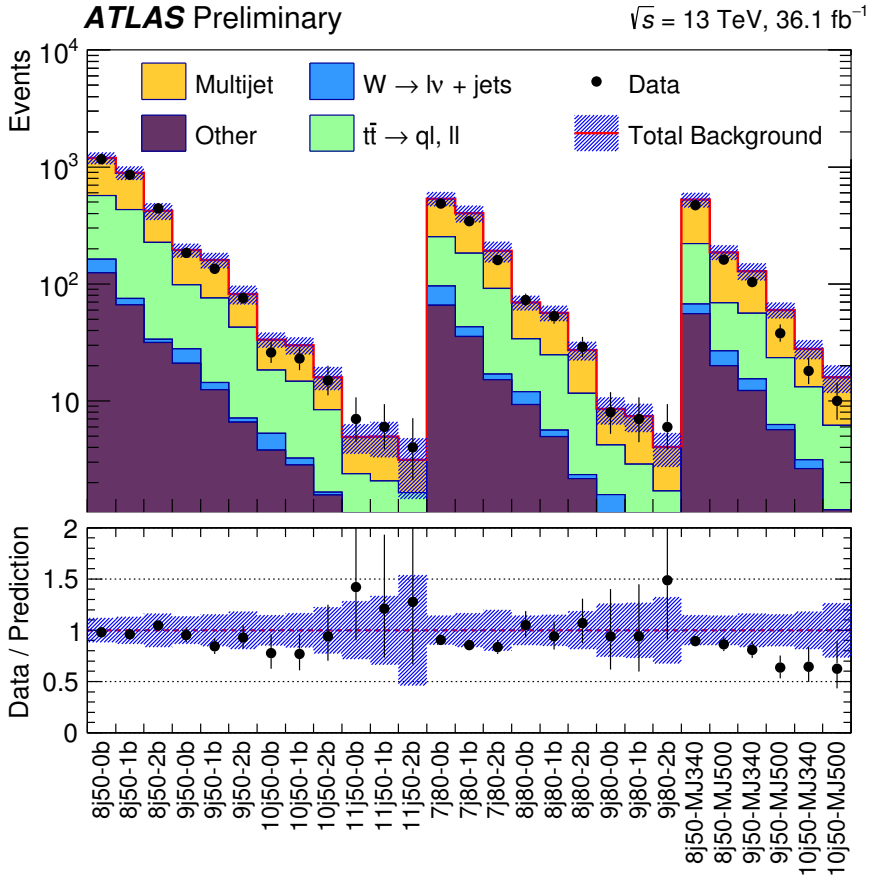
Uses multi-jets triggers: lower (implicit) requirement on E_T^{miss} than in the previous analysis

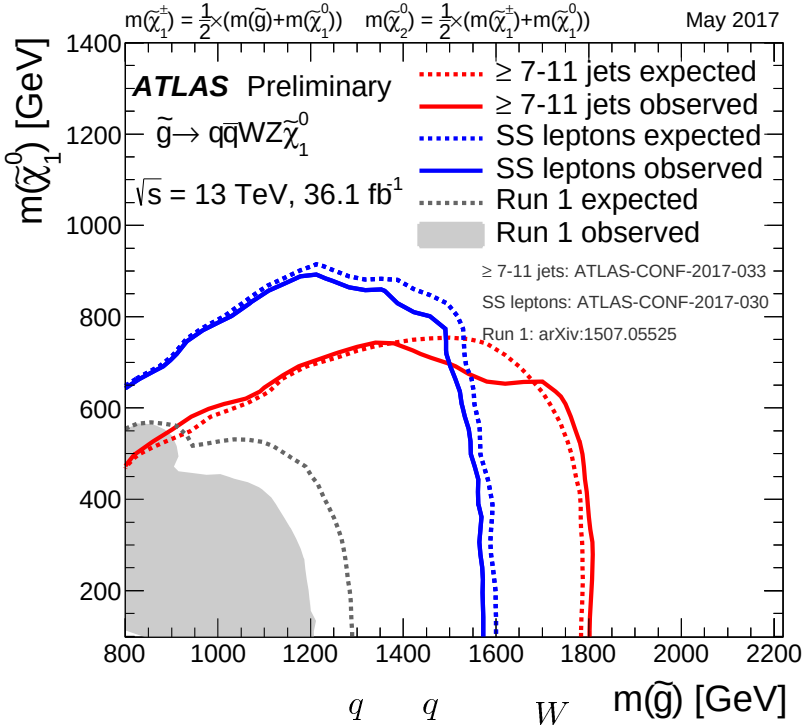
- QCD a relevant background → estimated using a data-driven method

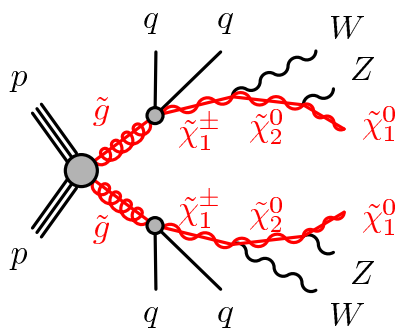
Results, ATLAS-CONF-2017-033

No excess in the SRs → place limits on sparticles masses using simplified SUSY models

- Limits with other final states (RHS, blue) → complementary of the ATLAS searches



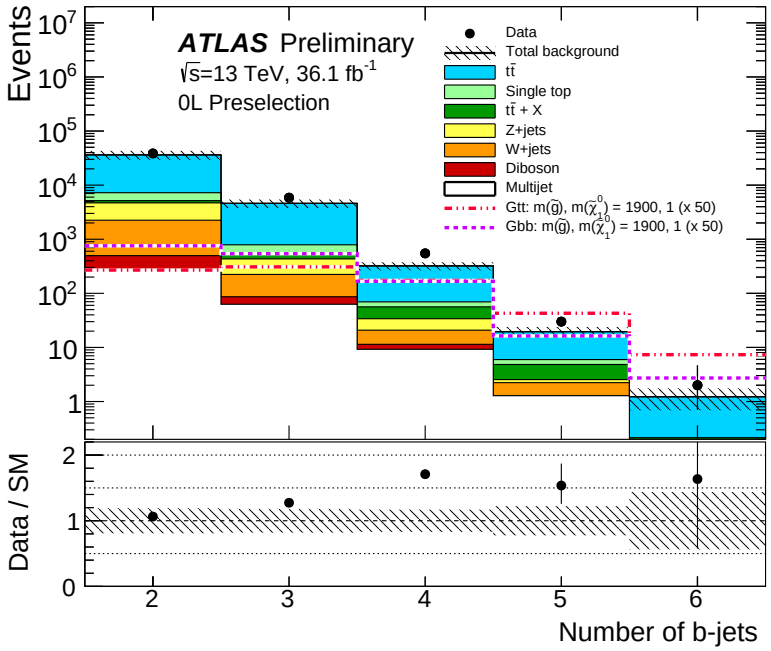


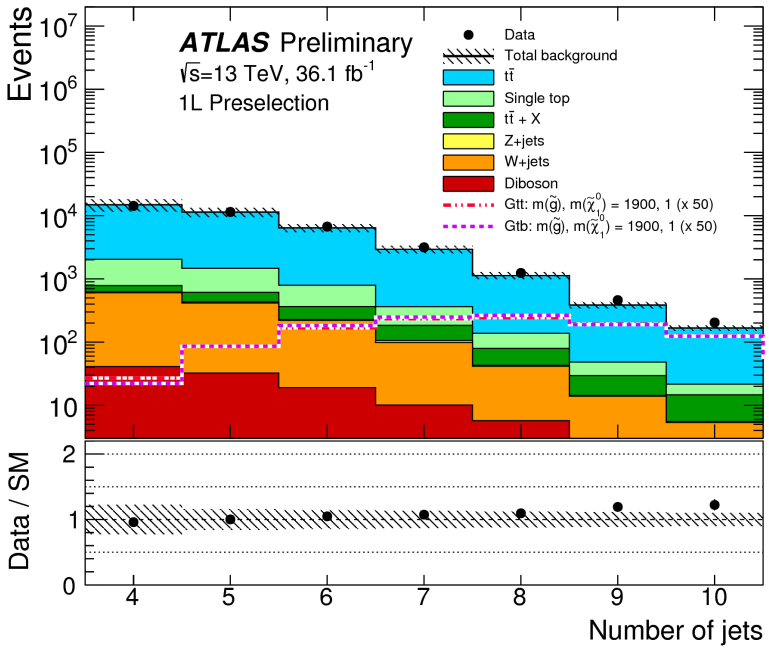


Final states with multi-b jets

Search for SUSY with 0 or 1 lepton and $\geq$3 b-jets, ATLAS-CONF-2017-021

- Discovery strategy: several cut-and-count SRs
- Exclusion strategy: multi-bin fit across binned orthogonal SRs in N_j and m_{eff}
- Key variables: nr. of leptons and (b-)jets, E_T^{miss}, m_{eff}, m_T, M_J^{Σ}, $\Delta\Phi(\mathrm{jet}_{1\to4}, E_T^{miss})_{\mathrm{min}}$
- Dominant background: $t\bar{t}$ pairs with additional high p_T jets



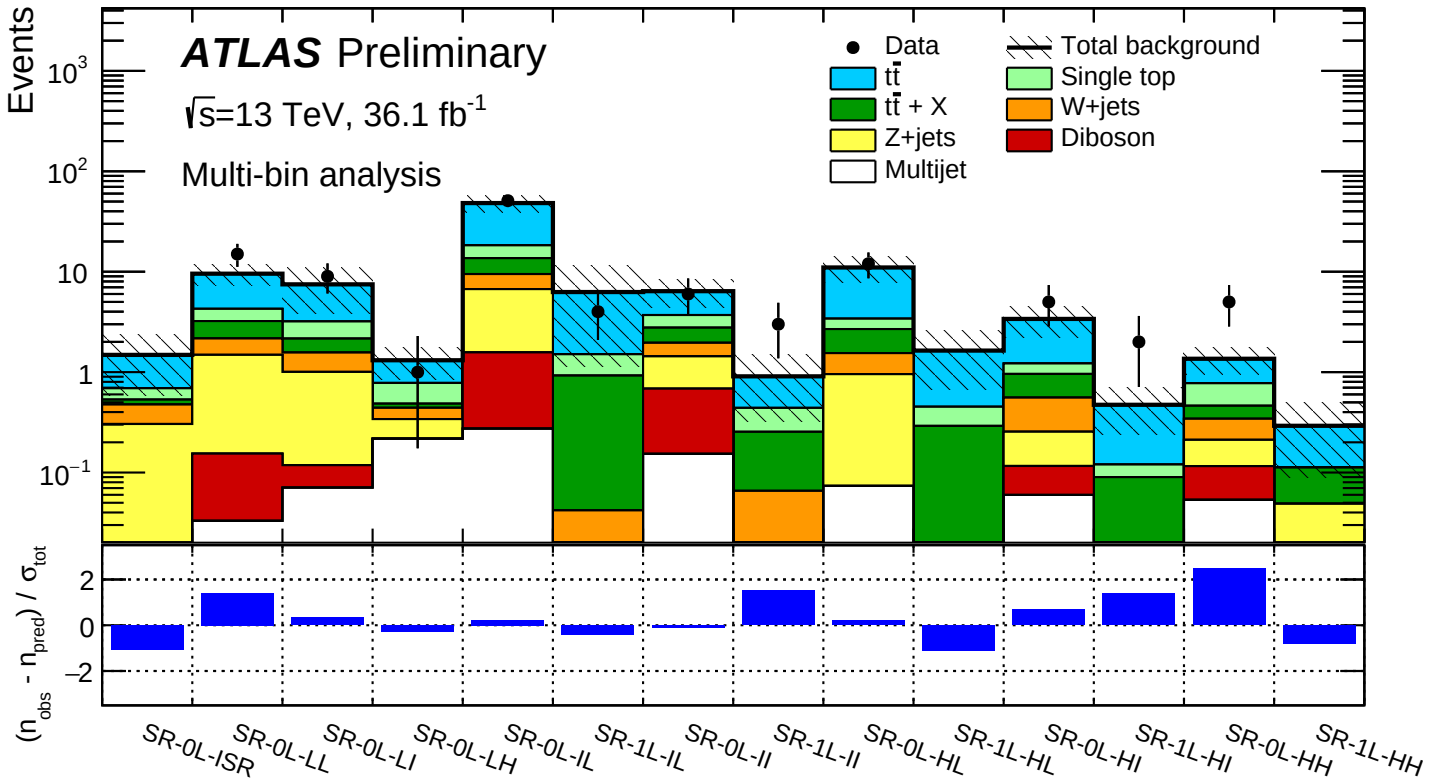


* *pre-fit distributions!*

- $t\bar{t}$ MC simulations normalized in an 1-lepton CR and extrapolated to VRs and SRs
- Other backgrounds (W/Z+jets, di-boson, single top, etc) estimated from MC simulations

Results, ATLAS-CONF-2017-021

Results in the signal regions:

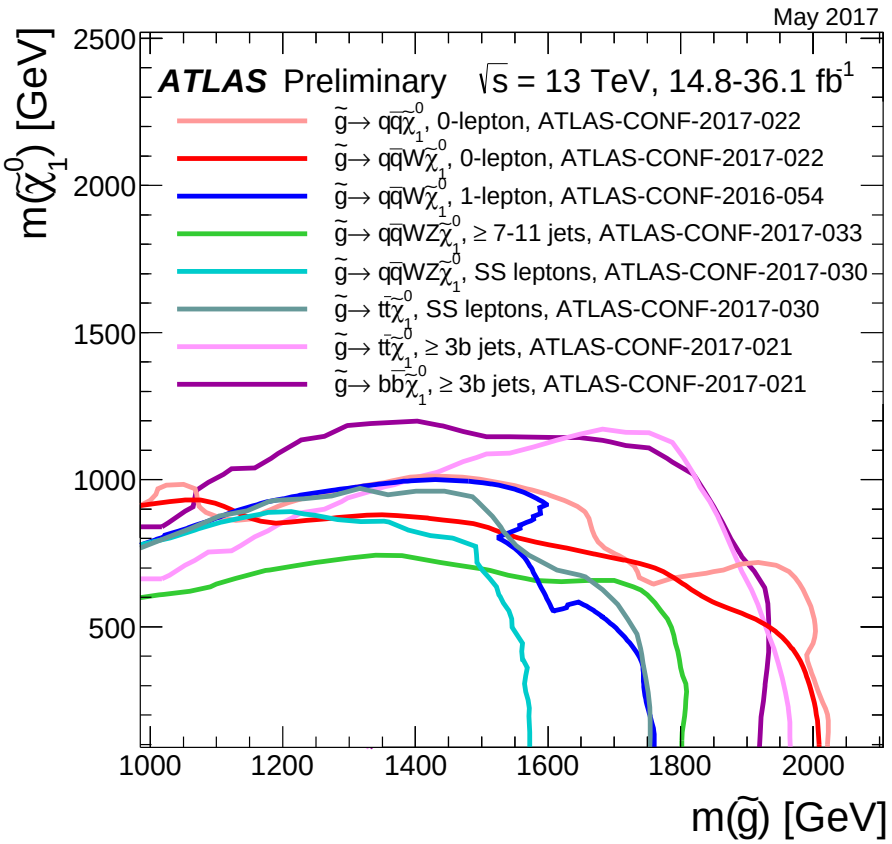


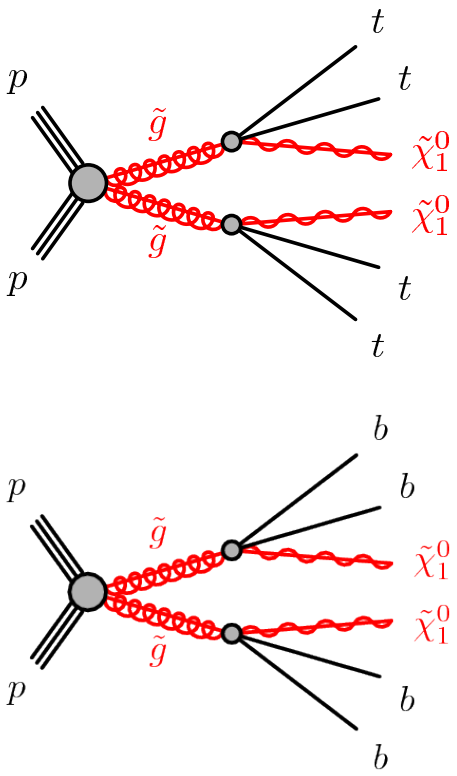
- No significant excess found above the predicted background in the SRs

Exclusion limits, ATLAS-CONF-2017-021

Limits on sparticles masses using simplified SUSY models (dark magenta):

- Limits with other final states → complementary of the ATLAS searches





- Gluino masses excluded up to 1.9 TeV → strongest limits among all ATLAS searches

Conclusions

- Excellent LHC performance!
- As for today, (unfortunately) no evidence of SUSY
- New limits significantly extend the Run 1 results $\rightarrow$ check out also the ATLAS public page
- Exciting future in front of us: at the end of the LHC Run-2 expect 120-150 fb^{-1} and by 2035 $\sim$ 3000 fb^{-1} of data!

BACKUP

ATLAS strategy to search for BSM physics

SM backgrounds
tt / t, tt + Z/W,
di-bosons, V+jets, multi-jets
estimation

Check bkg estimate in validation regions (close to SRs)

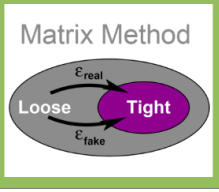
Look in signal regions → is there any excess?

IF NOT

Main prompt SM backgrounds: semi – data driven
– using control regions (CRs) kinematically close to SRs → to min. syst. due to SR-CR extrapolation
– estimate the bkg in the signal regions (SRs) relying on MC shape using transfer factors

Minor prompt SM backgrounds: purely MC

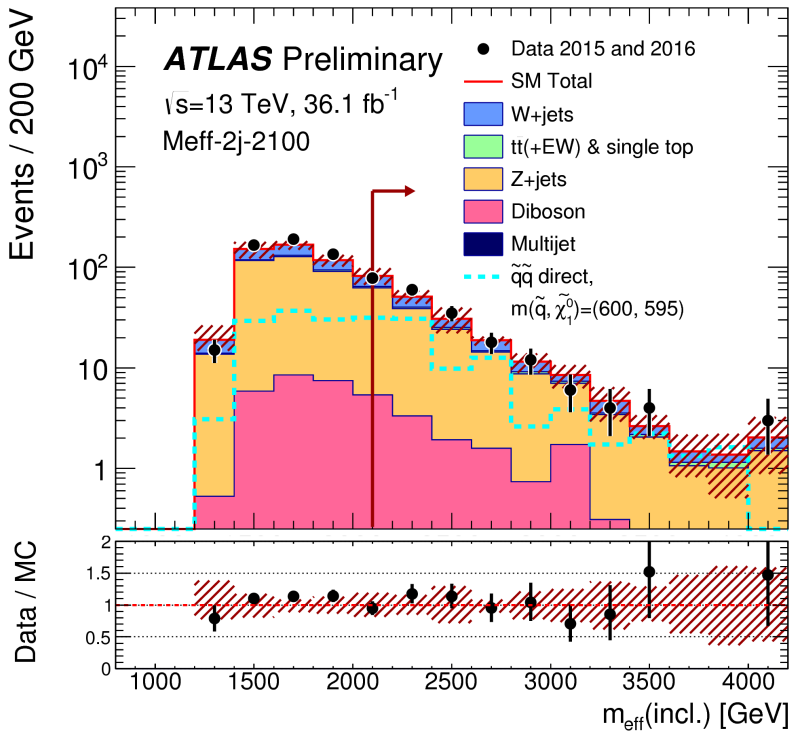
Detector background (fakes): fully data – driven
– Using a matrix method
– Jet smearing
– Templates

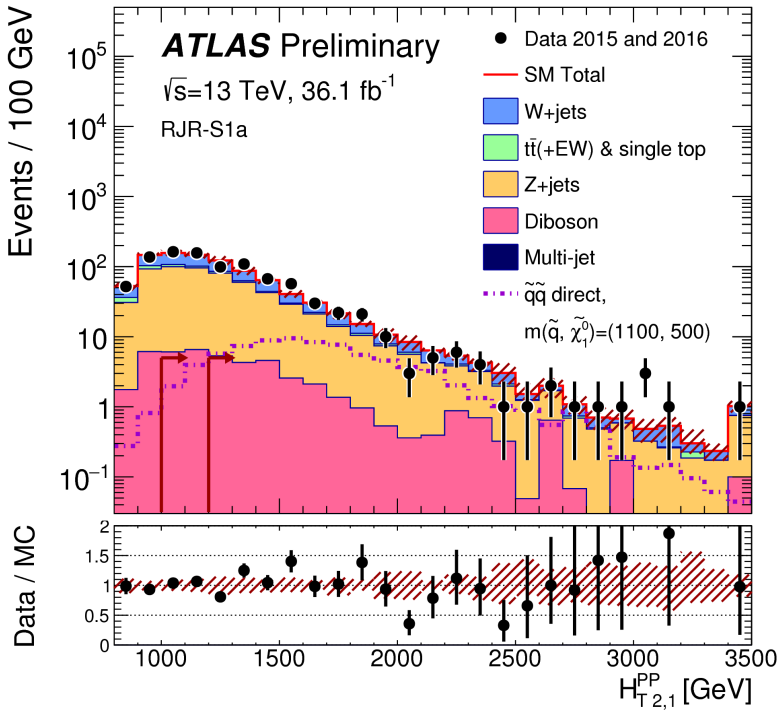


Set model dependent / independent exclusion limits
– cut & count
– or combined fit using CL_S formalism
(using mainly simplified BSM models)

2→6 jets and 0 leptons

- Most significant excess across m_{eff}-based SRs occurs in SR Meff-2j-2100 (LHS plot, a significance of 2.14 standard deviations)
- In RJR-based SRs, most significant excess RJR-S1a (RHS plot, 2.22σ)

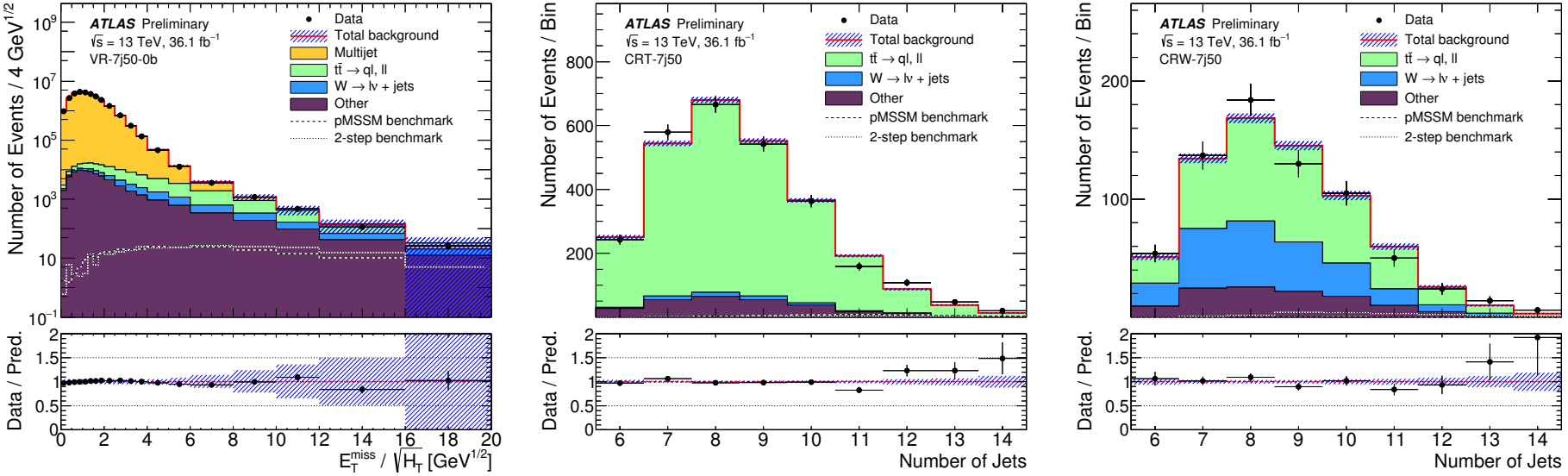




Search for SUSY with multi-jets final states

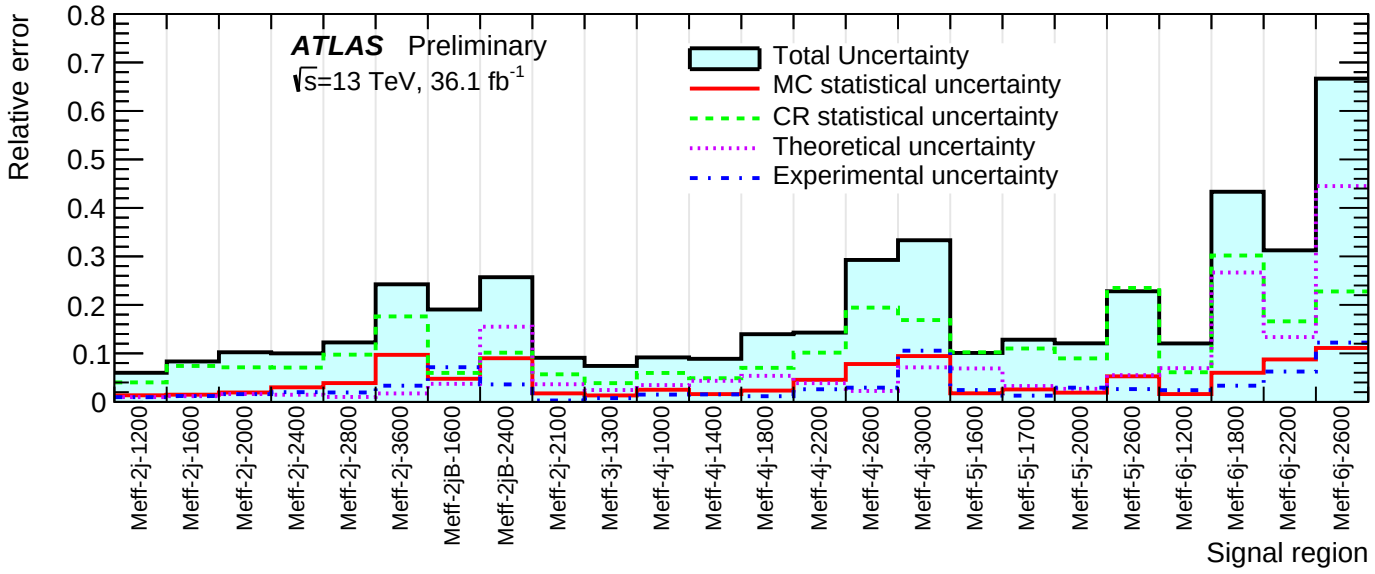
Final states with 0-leptons and 7→11 jets CONF note

- Discriminants: E_T^{miss} over sqrt of sum of jets p_T (H_T), sum of the large-R Jets mass (M_J^{Σ})
- Main backgrounds: multi-jets, $t\bar{t}$ and W+jets processes
  - Multi-jets: using a data template fit method (LHS plot)
  - $t\bar{t}$ and W+jets: MC normalized in dedicated CRs (middle & RHS plots, after norm)



- Very good data-bkg estimation agreement in all CRs/VRs

Results in the SRs: uncertainties



SUSY PARTICLE

Gauge sm. Chiral supermultiplets

	Proper states in		Spartners	Proper states in	
	interaction term	mass term		interaction term	mass term
Leptons $S=1/2$	$\begin{pmatrix}\nu_e\\ e_L\end{pmatrix}, e_R$ $\begin{pmatrix}\nu_\mu\\ \mu_L\end{pmatrix}, \mu_R$ $\begin{pmatrix}\nu_\tau\\ \tau_L\end{pmatrix}, \tau_R$		Sleptons $S=0$	$\begin{pmatrix}\tilde{\nu}_e\\ \tilde{e}_L\end{pmatrix}, \tilde{e}_R$ $\begin{pmatrix}\tilde{\nu}_\mu\\ \tilde{\mu}_L\end{pmatrix}, \tilde{\mu}_R$	
				$\begin{pmatrix}\tilde{\nu}_\tau\\ \tilde{\tau}_L\end{pmatrix}, \tilde{\tau}_R$	$\tilde{\tau}_1, \tilde{\tau}_2, \tilde{\nu}_\tau$
Quarks $S=1/2$	$\begin{pmatrix}u_L\\ d_L\end{pmatrix}, u_R, d_R$ $\begin{pmatrix}c_L\\ s_L\end{pmatrix}, c_R, s_R$ $\begin{pmatrix}t_L\\ b_L\end{pmatrix}, t_R, b_R$		Squarks $S=0$	$\begin{pmatrix}\tilde{u}_L\\ \tilde{d}_L\end{pmatrix}, \tilde{u}_R, \tilde{d}_R$ $\begin{pmatrix}\tilde{c}_L\\ \tilde{s}_L\end{pmatrix}, \tilde{c}_R, \tilde{s}_R$	
				$\begin{pmatrix}\tilde{t}_L\\ \tilde{b}_L\end{pmatrix}, \tilde{t}_R, \tilde{b}_R$	$\tilde{t}_1, \tilde{t}_2, \tilde{b}_1, \tilde{b}_2$
Gauge Bosons $S=1$	$W^\pm, W^0, B, g$	$W^\pm, Z^0, \gamma, g$	Gauginos $S=1/2$	$\widetilde{W}^\pm, \widetilde{W}^0, \widetilde{B}, \widetilde{g}$	Gluino $\widetilde{g}$ Neutralinos $\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_3^0, \tilde{\chi}_4^0$ Charginos $\tilde{\chi}_1^\pm, \tilde{\chi}_2^\pm$
Higgs Boson $S=0$	$\begin{pmatrix}H_u^+\\ H_u^0\end{pmatrix}, \begin{pmatrix}H_d^0\\ H_d^-\end{pmatrix}$	$h^0, H^0, A^0, H^\pm$	Higgsinos $S=1/2$	$\begin{pmatrix}\widetilde{H}_u^+\\ \widetilde{H}_u^0\end{pmatrix}, \begin{pmatrix}\widetilde{H}_d^0\\ \widetilde{H}_d^-\end{pmatrix}$	
Graviton $S=2$	G		Gravitino $S=\frac{3}{2}$	$\tilde{G}$	

Fermions and bosons in the same supermultiplet

Cross-sections