Inclusive SUSY search with one isolated lepton

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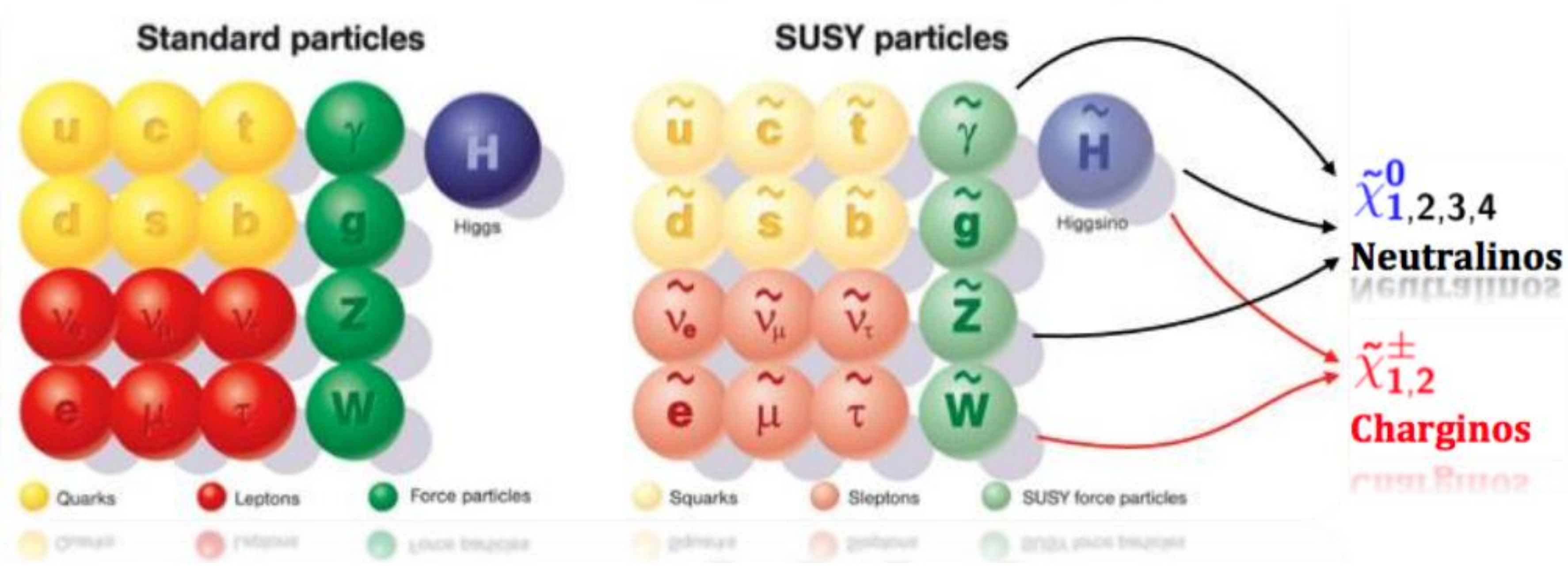
Content

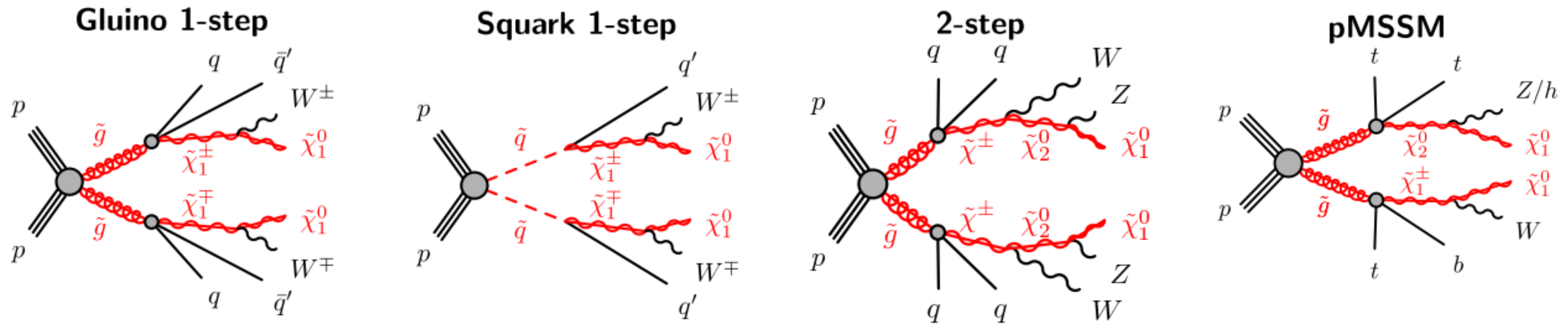
Introduction



- The Supersymmetry is a well motivated and favored extension of the Stand Model (SM):
  - solves hierarchy problem, dark matter candidate…
- This talk will focus on the results of SUSY search with 1l+jets at ATLAS. The results are included in the latest paper (1708.08232).

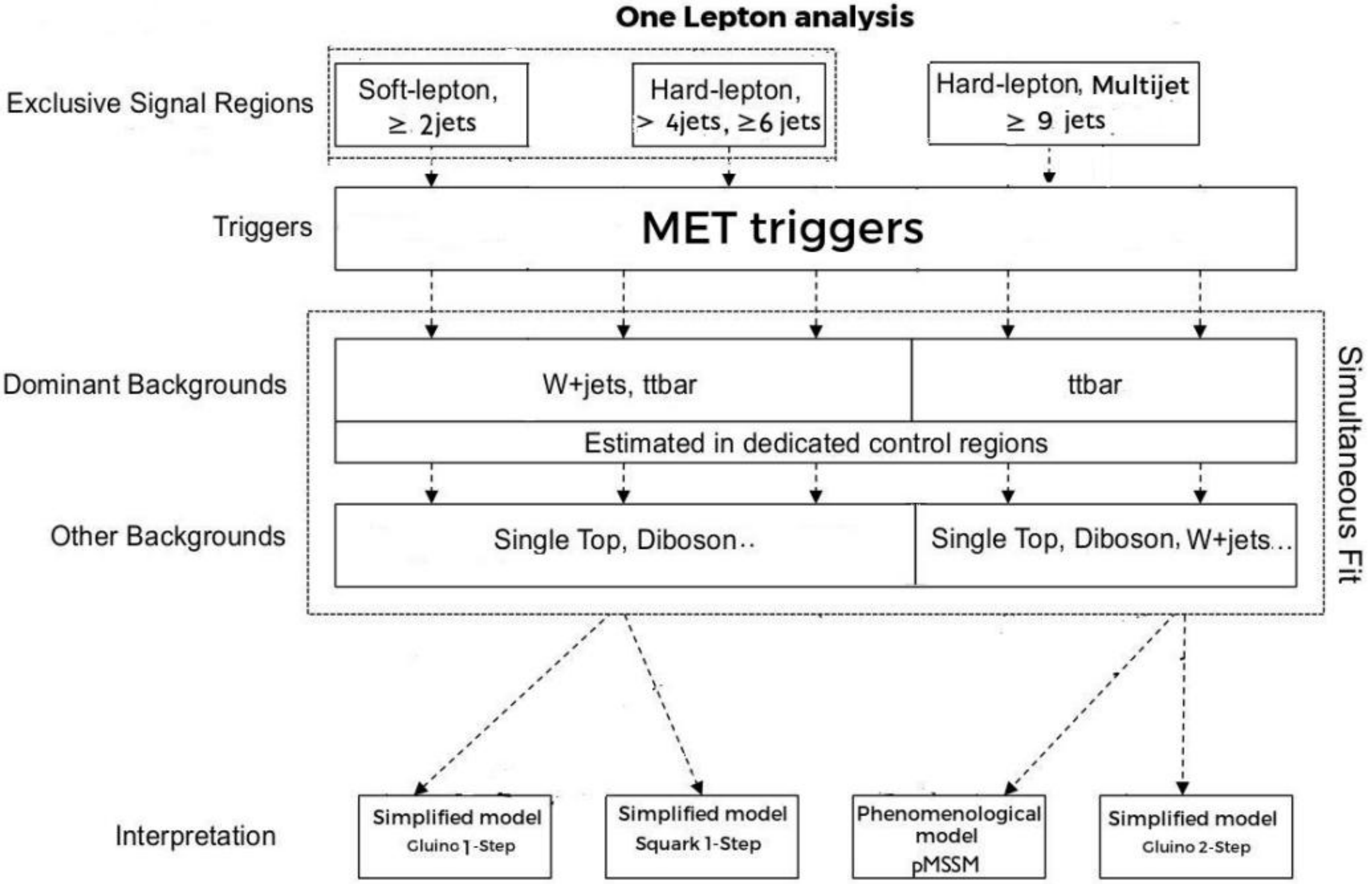
Analysis Overview

- Signature: **1 lepton + jets + MET**, decay from **gluinos** or **squarks** produced in a strong interaction.



- **Large cross sections**, especially with 13TeV in Run2, one lepton requirement can largely suppress SM backgrounds.
- Dominant backgrounds are **W+jets** and **ttbar** which are studied in dedicated control regions (CR); other backgrounds estimated in Monte Carlo simulation.
- The contributions in SRs are derived using a **simultaneous fit**.

Analysis Overview



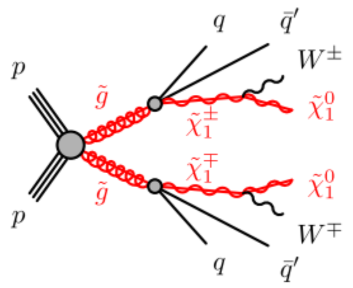
Signal Region (I)

$$x \equiv (m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0})/(m_{\tilde{g}/\tilde{q}} - m_{\tilde{\chi}_1^0})$$

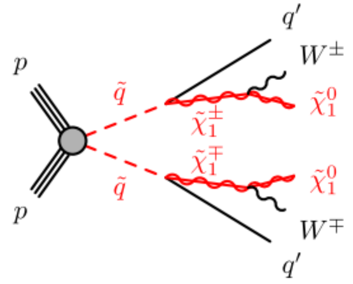
- Orthogonal signal regions are defined targeting **1-step gluino and squark** decays for different mass regions.

	Compressed region	High-x region	Low-x region	High mass region
SR	**2J**	**4J high-x**	**4J low-x**	**6J**
N_ℓ		$= 1$		
p_T^ℓ [GeV]	$> 7(6)$ for $e(\mu)$ and $< \min(5 \cdot N_{\text{jet}}, 35)$	> 35	> 35	> 35
N_{jet}	≥ 2	4–5	4–5	≥ 6
E_T^{miss} [GeV]	> 430	> 300	> 250	> 350
m_T [GeV]	> 100	> 450	150–450	> 175
Aplanarity	–	> 0.01	> 0.05	> 0.06
$E_T^{\text{miss}}/m_{\text{eff}}$	> 0.25	> 0.25	–	–
$N_{b\text{-jet}}$ (excl)		$= 0$ for b-veto, ≥ 1 for b-tag		
m_{eff} [GeV] (excl)	3 bins $\in$ [700,1900] + [> 1900]	2 bins $\in$ [1000,2000] + [> 2000]	2 bins $\in$ [1300,2000] + [> 2000]	3 bins $\in$ [700,2300] + [> 2300]
m_{eff} [GeV] (disc)	> 1100	> 1500	$> 1650(1300)$ for gluino (squark)	$> 2300(1233)$ for gluino (squark)

Gluino 1-step



Squark 1-step

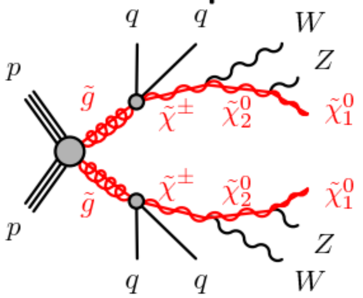


Signal Region (II)

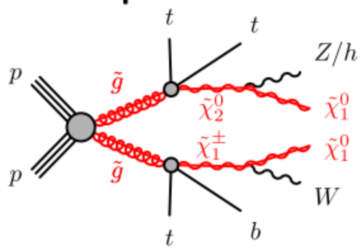
- Signal regions defined **targeting 2-step gluino decay** and **pMSSM model**.
- Looser cut for MET and meff than SR 2-6J, but with higher number of jets.

SR	9J
N_ℓ	$= 1$
p_T^ℓ [GeV]	≥ 35
N_{jet}	≥ 9
E_T^{miss} [GeV]	> 200
m_T [GeV]	> 175
Aplanarity	> 0.07
$E_T^{\text{miss}}/\sqrt{H_T}$ [GeV$^{1/2}$]	≥ 8
m_{eff} [GeV] (excl)	[1000, 1500], [>1500]
m_{eff} [GeV] (disc)	> 1500

2-step



pMSSM

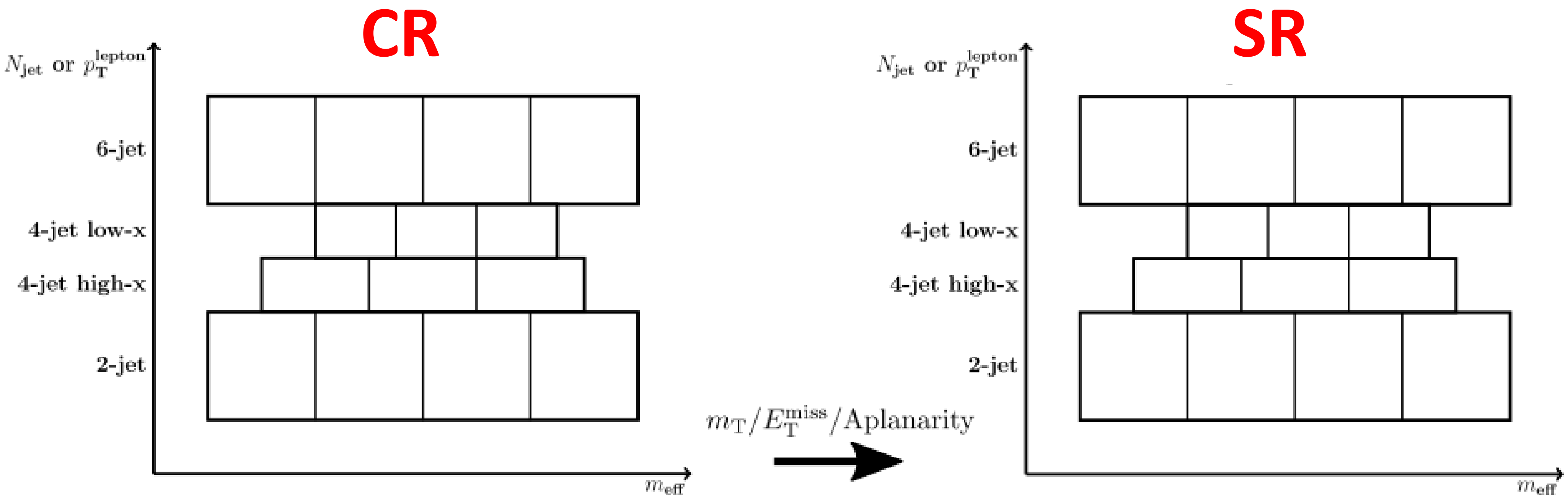


Background estimation

- **2-6J SR:** (for gluino/squark 1 step decay)
  - Dominant backgrounds (ttbar, single top and W+jets):
    - Use **semi-data driven method**
    - An alternative “object replacement method” is developed independently for cross check
  - Small backgrounds (ttV, Z+jets and diboson) are estimated based on **MC simulation**.
  - Fake lepton background is considered to be **negligible** due to the stringent requirement on MET.

- **9J SR:** (for gluino 2 step and pMSSM model)
  - Data driven **ABCD method** is used to reduce the dependence on the modelling of the additional jets (ISR/FSR).

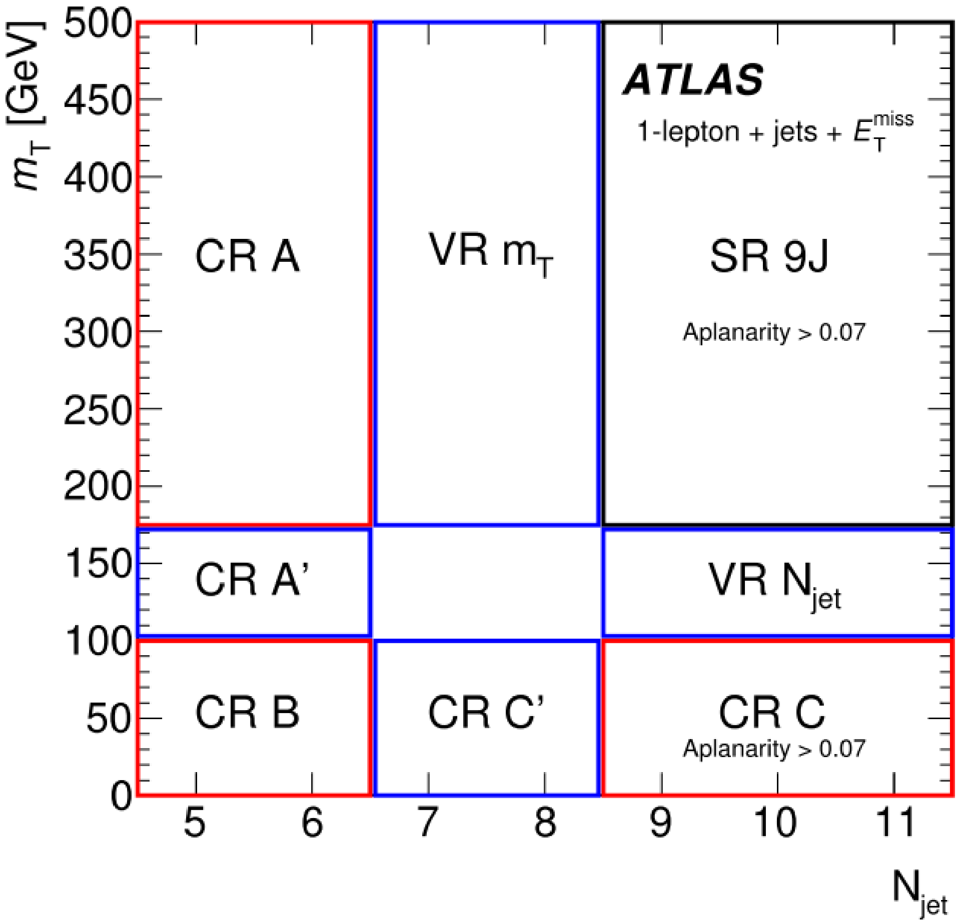
Background estimation (2-6J SR)



extrapolate bin-by-bin in m_{eff}

- Both CRs and SRs split in **b-tag** and **b-veto**.
- Orthogonal **signal regions** and **control regions** are fitted **simultaneously**.
- Bin-by-bin normalization factors correct for mismodelling in meff shape.

Background estimation (9J SR)



$$
\begin{aligned}
N^{est}_{SR_{9J}} &= f_{closure} \cdot \frac{N^{obs}_{CR_A}}{N^{obs}_{CR_B}} \cdot N^{obs}_{CR_C} \\
&= N^{sim}_{SR_{9J}} \cdot \left(\frac{N_{CR_A}}{N_{CR_B}} N_{CR_C}\right)^{obs} \Bigg/ \left(\frac{N_{CR_A}}{N_{CR_B}} N_{CR_C}\right)^{sim} \\
&= N^{sim}_{SR_{9J}} \cdot \underbrace{\frac{N^{obs}_{CR_C}}{N^{sim}_{CR_C}}}_{\mu_C} \cdot \underbrace{\frac{\left(\frac{N_{CR_A}}{N_{CR_B}}\right)^{obs}}{\left(\frac{N_{CR_A}}{N_{CR_B}}\right)^{sim}}}_{\mu_{A/B}},
\end{aligned}
$$

- Assume $\mathbf{m_T}$ shape **invariant** for different $\mathbf{N_{jet}}$.
- Fit **simultaneously** for **all regions**.

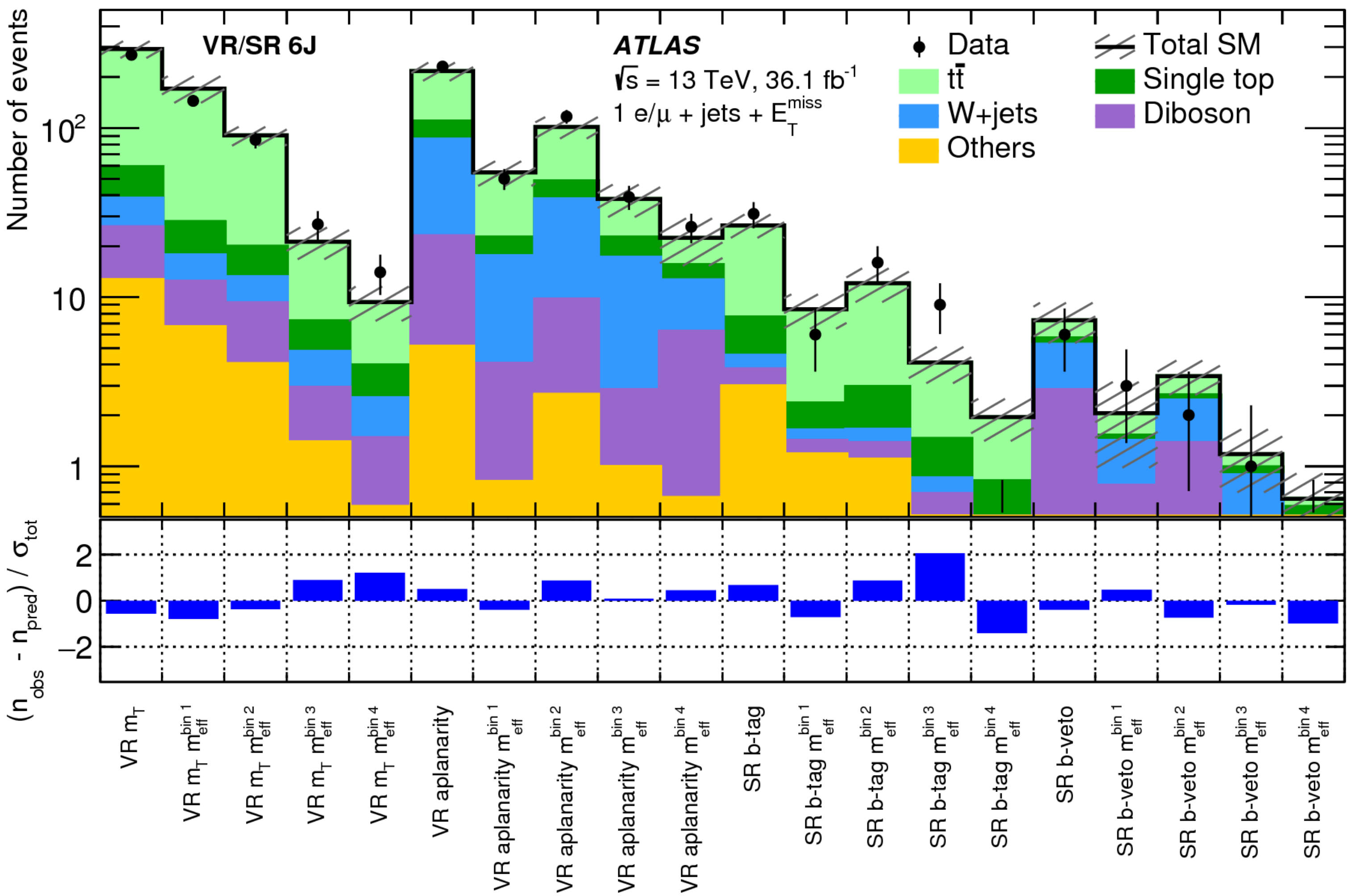
Systematic uncertainties

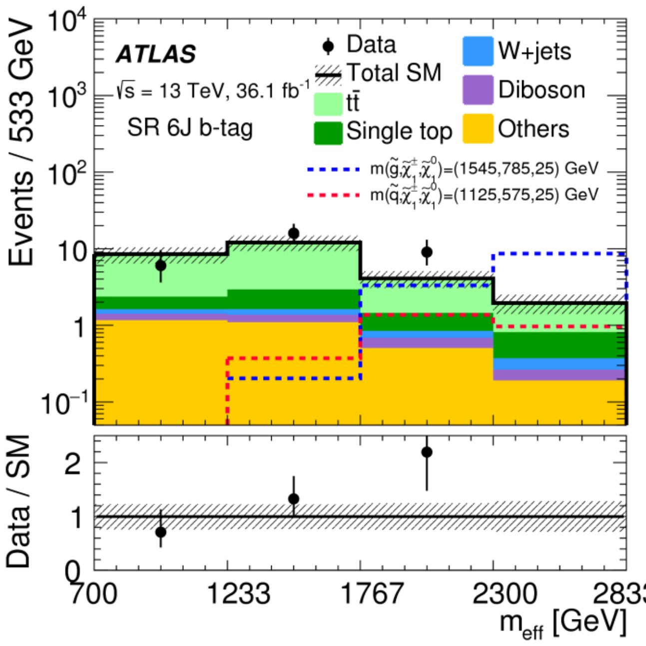
- **Experimental systematics**
  - Lepton scale factors, MET, JES and JER, b-tagging efficiencies, etc…

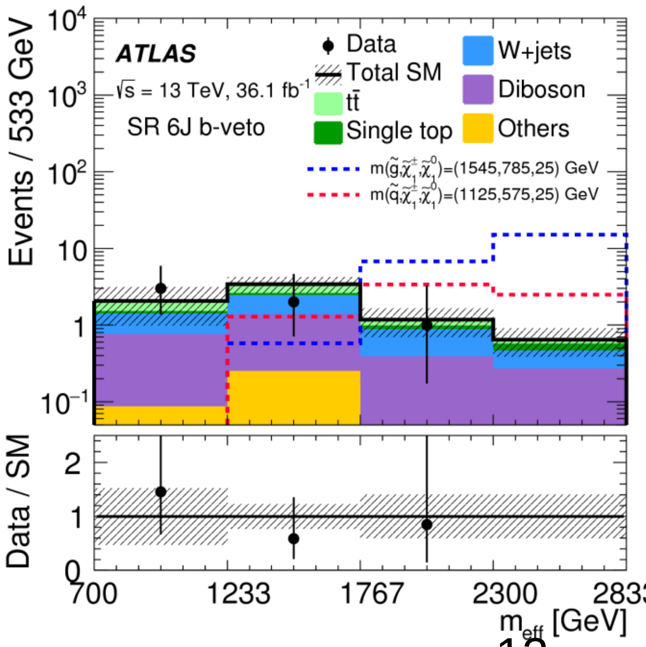
- **Theoretical uncertainties**
  - For SM backgrounds, uncertainties computed on TF/yields by generator comparison and scale variations (e.g. renormalization, factorization…)
  - For signal uncertainties on x-section and acceptance are calculated

- The **dominant uncertainties** in SRs are coming from **theoretical uncertainties**, **MC statistics** and **uncertainties on ttbar normalization factor**.

Results for 6J SR







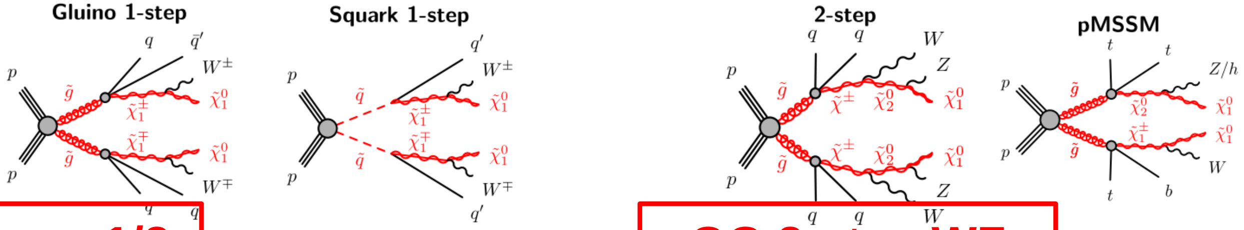
- **Good data/MC agreement in all VRs.**
- **No significant excess observed in the 6J SRs.**

Model independent upper limits

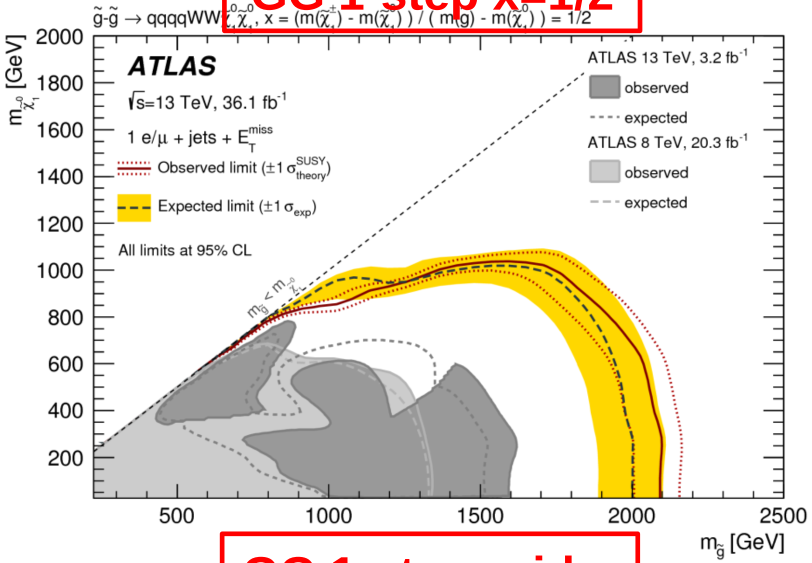
- No significant excess observed in all SRs.
- Calculate the **model independent** upper limits for each discovery SR: the **visible cross-section**, the **observed and expected 95% CL upper limits on the BSM event yield**, and the **one-sided discovery p-value**.
- Model dependent limits are shown in next slide (interpreted in simplified model and pMSSM model).

SR_{disc}	2J	4J high-x	4J low-x (gluino)	4J low-x (squark)	6J (gluino)	6J (squark)	9J
Observed events	80	16	24	50	0	28	4
Fitted bkg events	67 ± 6	17.7 ± 2.7	17.2 ± 3.2	47 ± 7	2.6 ± 0.6	23.4 ± 3.1	3.1 ± 1.6
$\langle \epsilon\sigma \rangle^{95}_{obs}$ [fb]	0.92	0.27	0.50	0.62	0.08	0.46	0.20
S^{95}_{obs}	33.1	9.8	18.0	22.5	3.0	16.6	7.1
S^{95}_{exp}	$21.6^{+9.2}_{-5.6}$	$10.8^{+3.7}_{-3.0}$	$11.8^{+4.8}_{-2.7}$	$19.9^{+7.5}_{-5.6}$	$4.5^{+1.8}_{-1.0}$	$12.7^{+5.0}_{-4.0}$	$6.0^{+2.2}_{-1.2}$
$p(s = 0)$	0.10	0.50	0.10	0.35	0.50	0.21	0.34

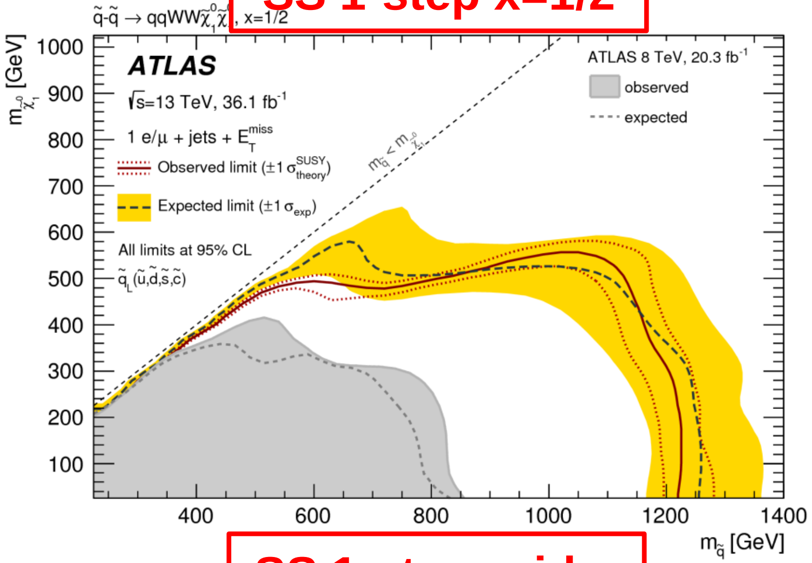
Model dependent limits



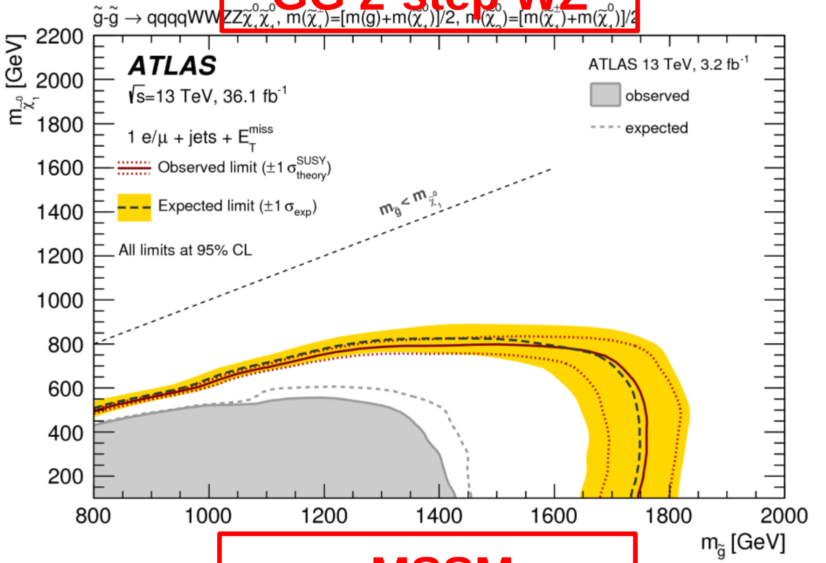
GG 1-step x=1/2



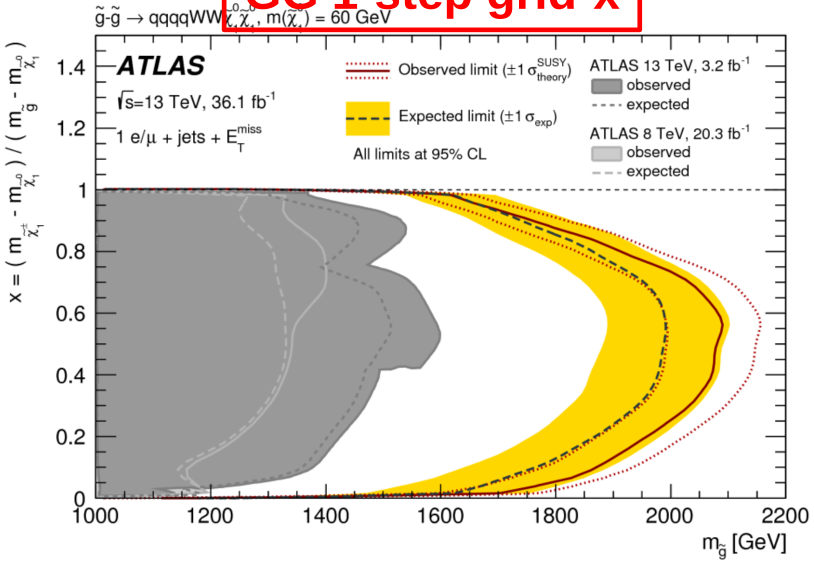
SS 1-step x=1/2



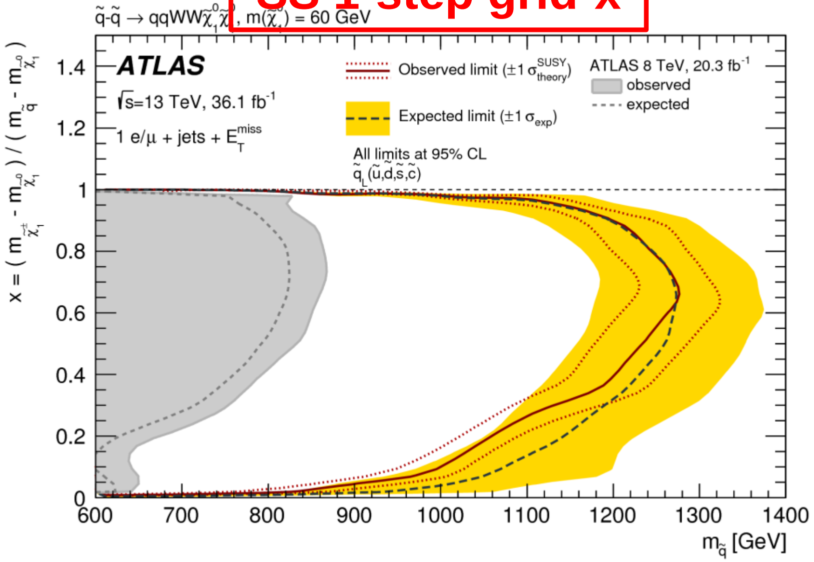
GG 2-step WZ



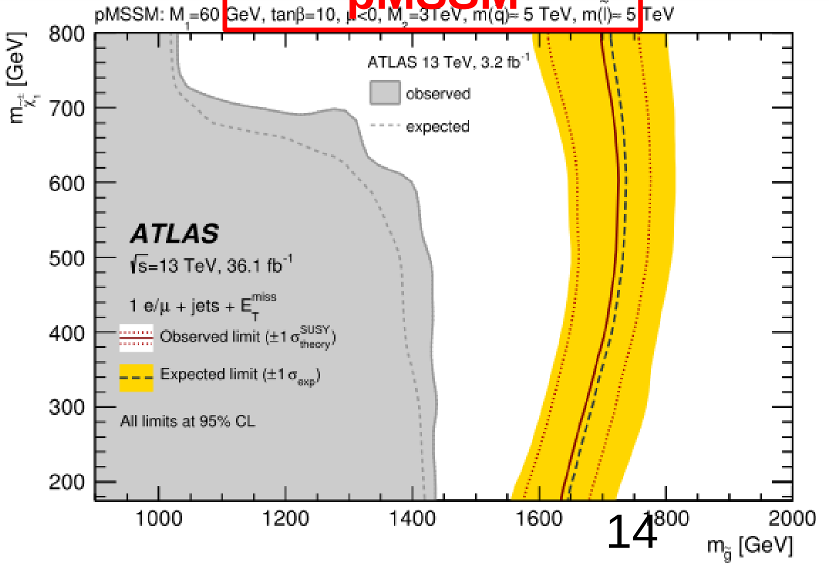
GG 1-step grid-x



SS 1-step grid-x



pMSSM



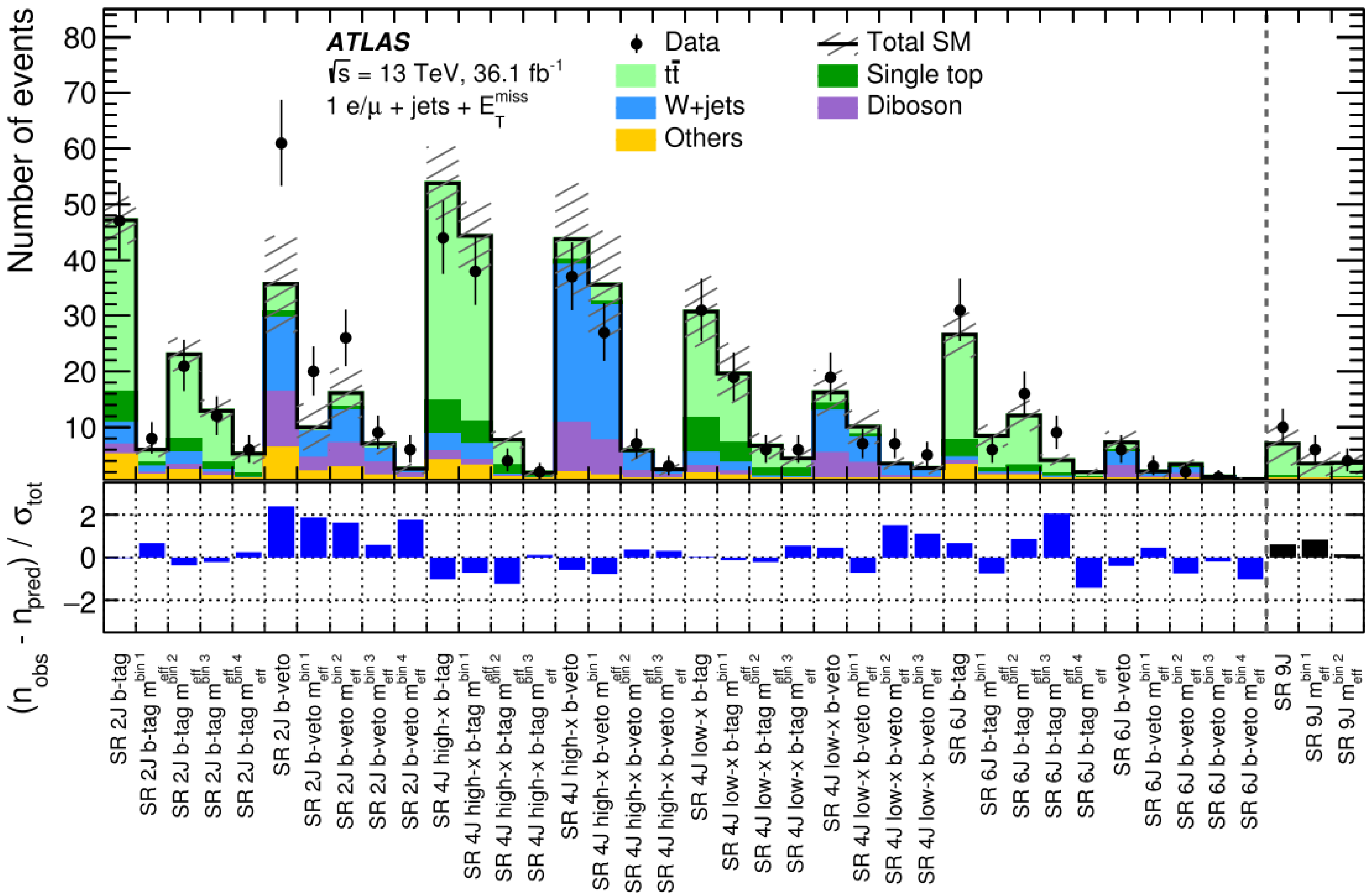
Summary

- The inclusive SUSY search with 1 lepton + jets + MET in the final state is performed with 2015+2016 data (36.1 fb-1).

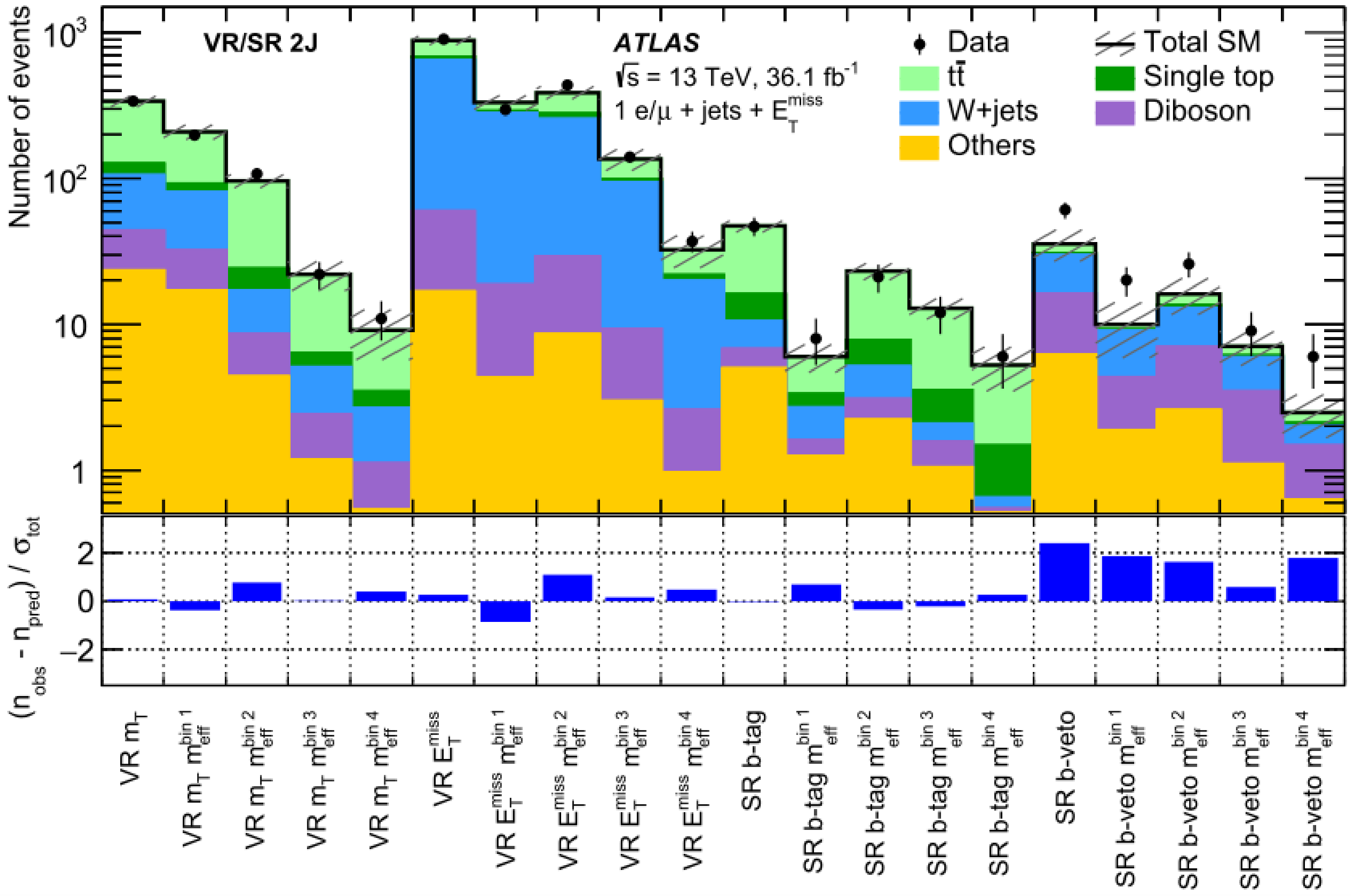
- No significant excess beyond the SM expectation observed yet
  → limits up to 2.1 TeV in gluino and 1.25 TeV in squark mass
  → limits up to 1.8 TeV (2-step grid) and 1.7 TeV (pMSSM grid)

- More data is coming! Will update this analysis with full Run2 data.
  Stay tuned!

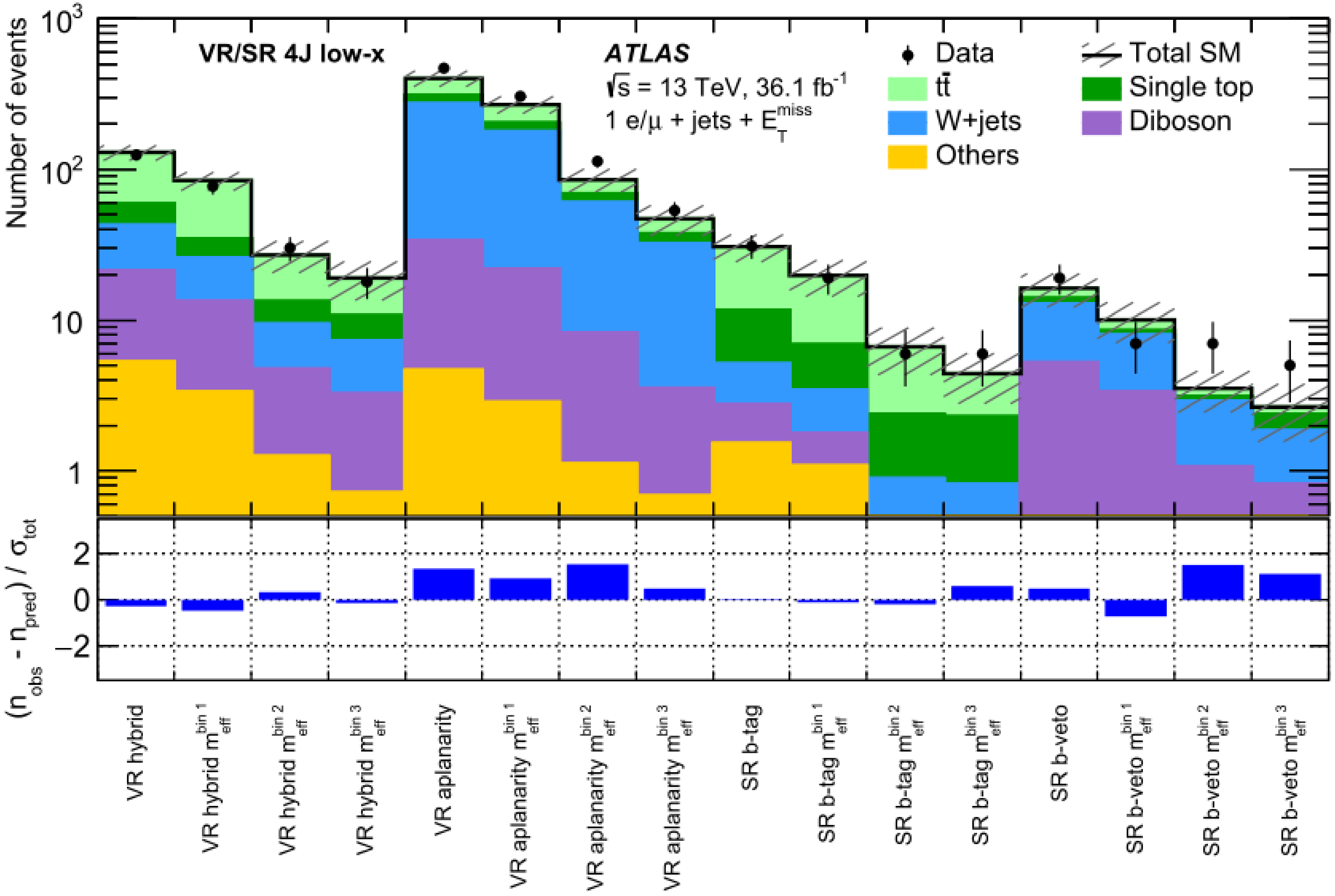
Observed and expected event yields in all SRs



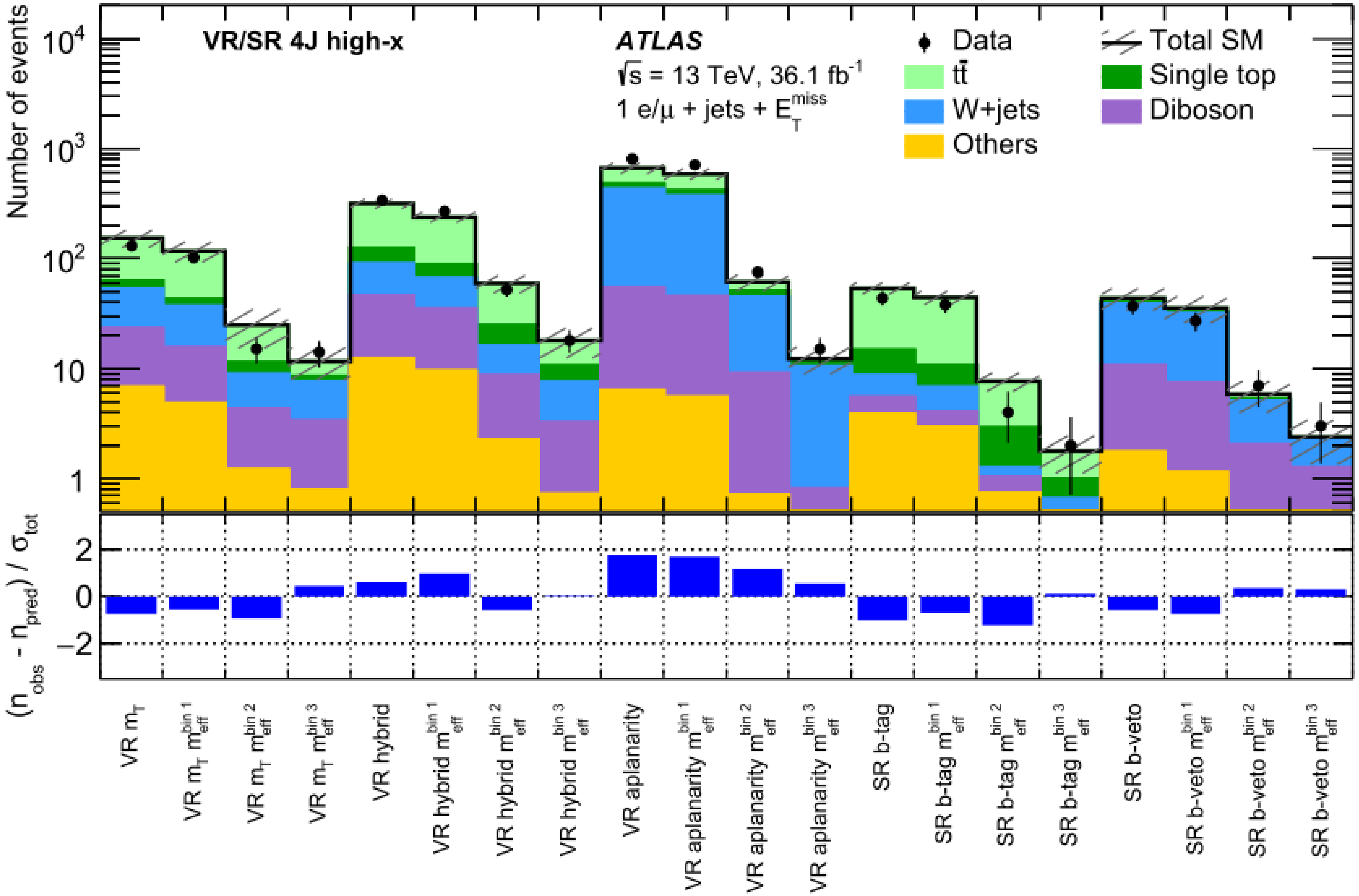
Pull plots in VR/SR 2J



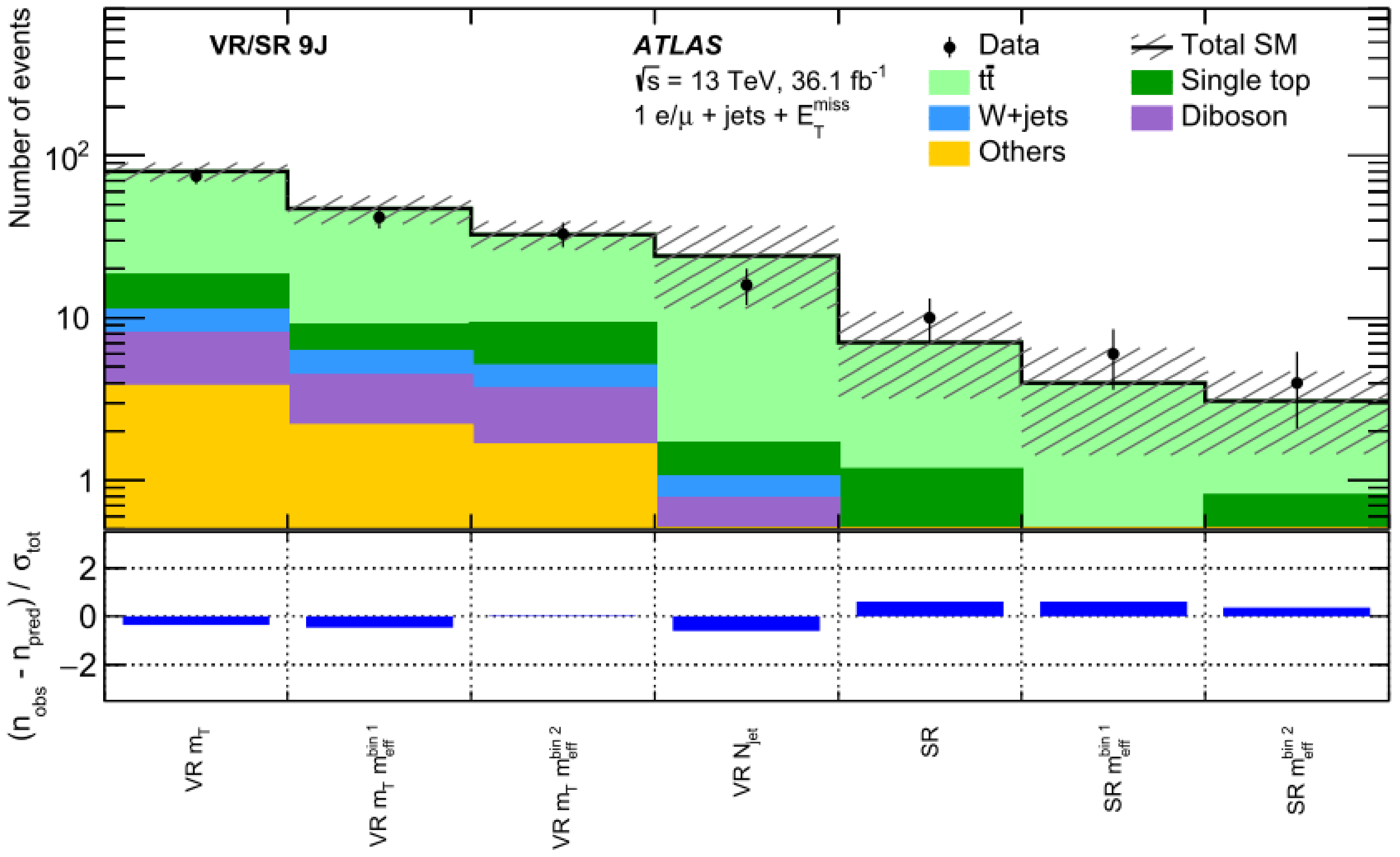
Pull plots in VR/SR 4J low-x



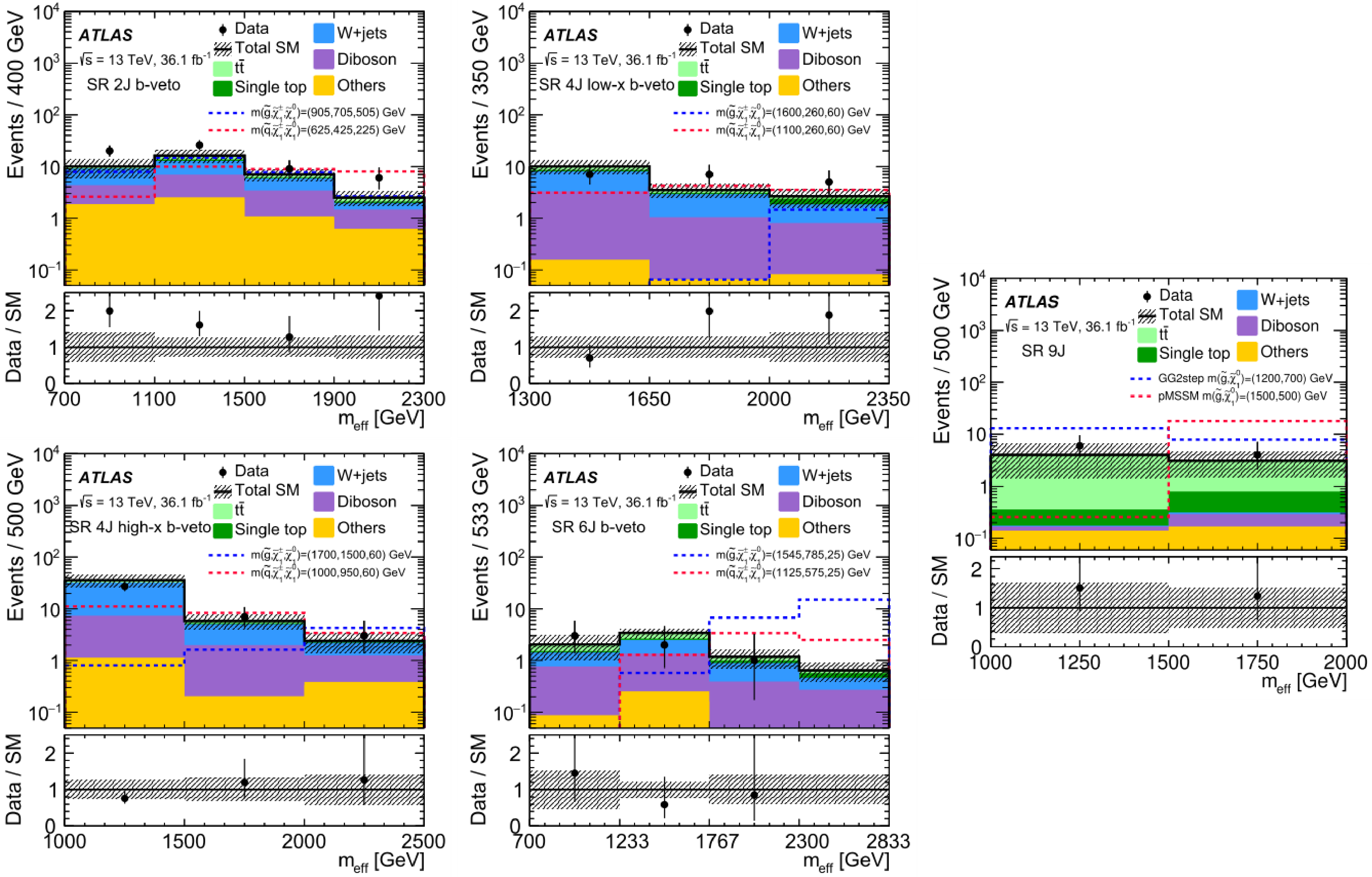
Pull plots in VR/SR 4J high-x



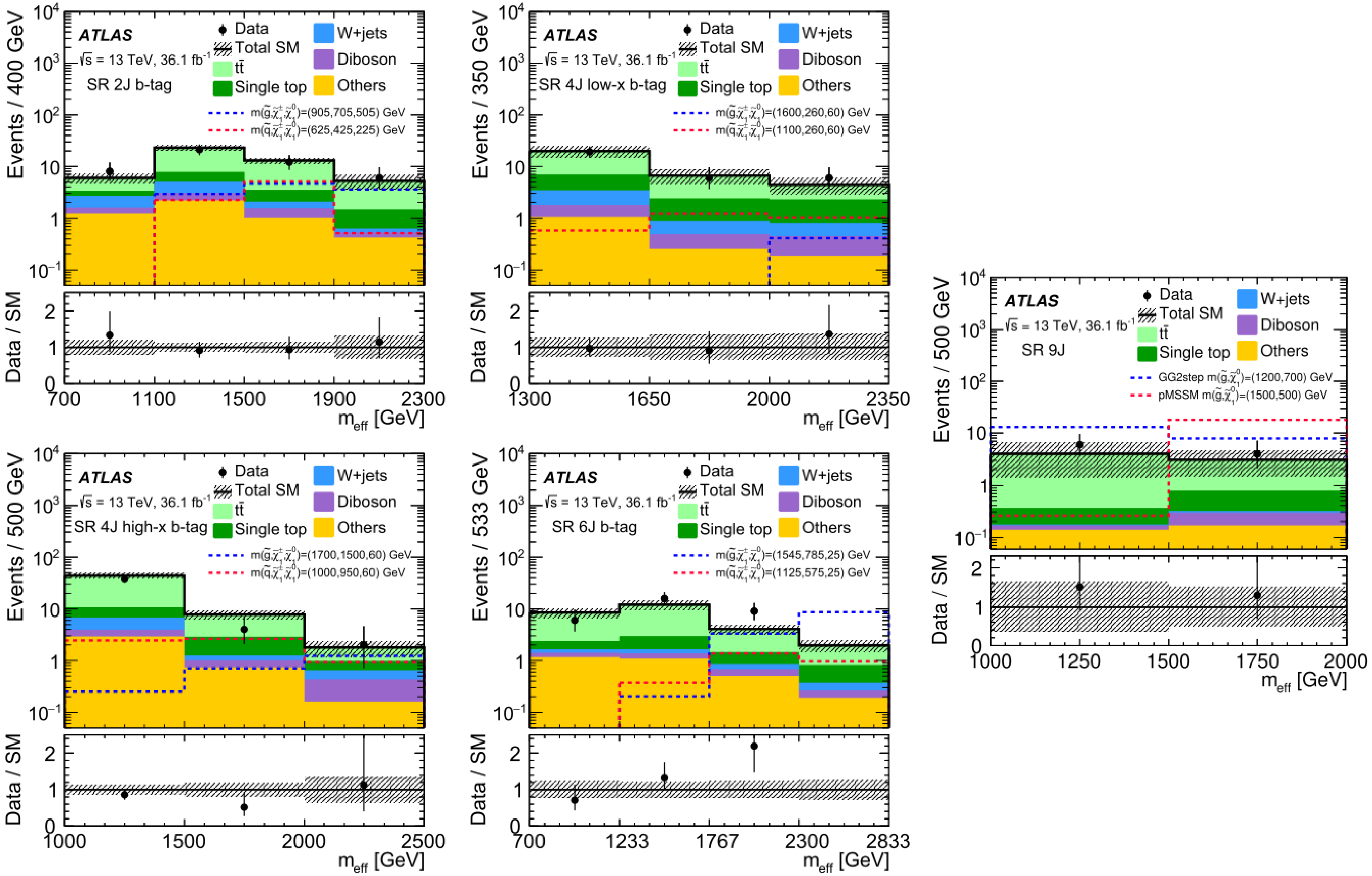
Pull plots in VR/SR 9J



Meff distributions in SRs



Meff distributions in SRs



Signal grids

- **Gluino/Squark 1-step:**
  - Decay of gluinos or squarks via the lighest chargino into the LSP.
  - With 2 assumptions:
    - X = ½ grid: Free parameters gluino/squark and LSP masses, C1 mass is set between the gluino/squark mass and the LSP mass
    - Gird-x: Free parameters gluino/squark and C1 masses, LSP mass fixed to 60GeV

- **Gluino 2-step:**
  - Decay of the gluino via chargino and LSP (long decay chains)
    - Free parameters gluino and LSP masses
- **Phenomenological models**
  - 19-parameter pMSSM, in which the LSP is a neutralino
  - The selected models have:
    - A bino-dominated LSP
    - Kinemaically accessible gluinos
    - Higgsino-dominated multiplet at intermediate mass

Object definition

Electrons

Cut	Value/description
Preselected Electron	
Algorithm	AuthorElectron
Acceptance	$p_T > 7$, GeV, $\|\eta^{clust}\| < 2.47$
Quality	LooseLLH
Signal Electron	
Acceptance	$p_T > 7$ GeV
Quality	TightLLH
Isolation	GradientLoose
IP	$\|z_0^{PV}\| < 0.5$ mm $\|d_0^{PV}\|/\sigma(d_0^{PV}) < 5$

Muons

Cut	Value/description
Preselected muon	
Acceptance	$p_T > 6$ GeV, $\|\eta\| < 2.5$
Quality	Medium
Signal muon	
Acceptance	$p_T > 6$ GeV
Isolation	GradientLoose
IP	$\|z_0^{PV}\| < 0.5$ mm $\|d_0^{PV}\|/\sigma(d_0^{PV}) < 3$

Jets

Cut	Value/description
Preselected jet	
Algorithm	anti-k_t4Topo
Acceptance	$p_T > 20$ GeV, $\|\eta\| < 2.8$
Signal jet	
Acceptance	$p_T > 30$ GeV, $\|\eta\| < 2.8$
JetVertexTagger	JVT @ 92 % working point for $p_T < 60$ GeV and $\|\eta\| < 2.4$
Signal *b*-jet	
b-tagger Algorithm	MV2c20 @ 77 % working point
Acceptance	$p_T > 30$ GeV , $\|\eta\| < 2.5$

- The overlap removal procedure relies on the SUSY background forum recommendation.
- The 2nd lepton veto is at 7/6 GeV.
- Rebuild MET from calibrated jets, electrons, muons and taus (photons not included).
- Old production uses: AnalysisBase 2.4.22, SUSYTools-00-08-25
- New production uses: AnalysisBase,2.4.28, SUSYTools-00-08-54

Discriminating variables

- Transverse mass (cut in each signal region)

$$m_{\mathrm{T}} = \sqrt{2p_{\mathrm{T}}^{\ell}\,\not{E}_T(1 - \cos[\Delta\phi(\boldsymbol{p}_{\mathrm{T}}^{\ell}, \boldsymbol{p}_{\mathrm{T}}^{miss})])}$$

- Effective mass (shape fit)

$$m_{\mathrm{eff}} = p_{\mathrm{T}}^{\ell} + \sum_{j=1}^{N_{\mathrm{jet}}} p_{\mathrm{T},j} + \not{E}_T .$$

- Aplanarity (constructed from jet and lepton momenta)
- $\not{E}_T/\sqrt{H_{\mathrm{T}}}$ (used in 9J signal region)

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

Object replacement method

The di-leptonic ttbar split into processes with **2 leptons (e/μ) where one fails to be reconstructed or identified** and **bkg with hadronically decaying tau leptons on one leg of ttbar decay chain.**

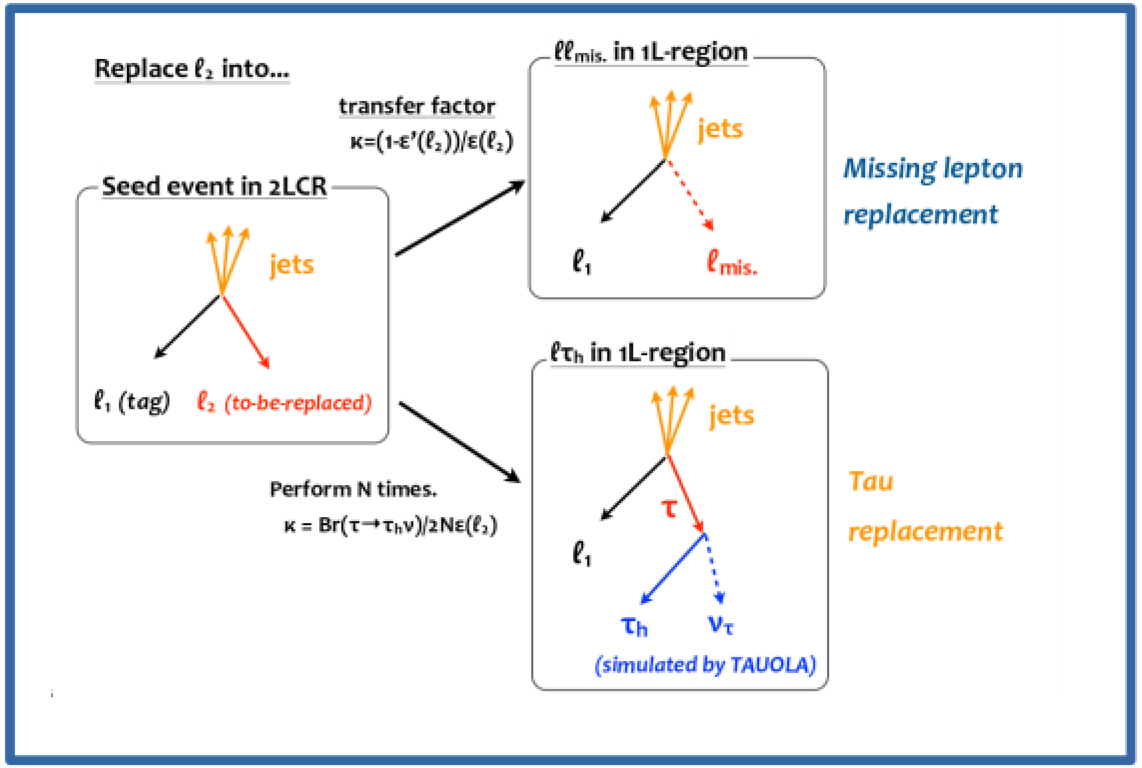
The method estimates these sources of bck by using dedicated di-lepton CR and mimicking the processes by:

1) adding one of the leptons as the unobserved lepton to the missing transverse energy balance

2) replacing it by simulation of a hadronic tau decay

The technical procedure:

- **Choose a 2LCR event ("seed");**
- **Replace one lepton into a missing lepton or a hadronic tau decay, only if the other lepton satisfies the SR requirements;**
- **Recalculate the event-level kinematics;**
- **Assign weight for each sub-events as TF from 2LCR to 1L.**



Background estimation: semi-data driven v.s object replacement