Searches for supersymmetric Higgsinos with the ATLAS detector

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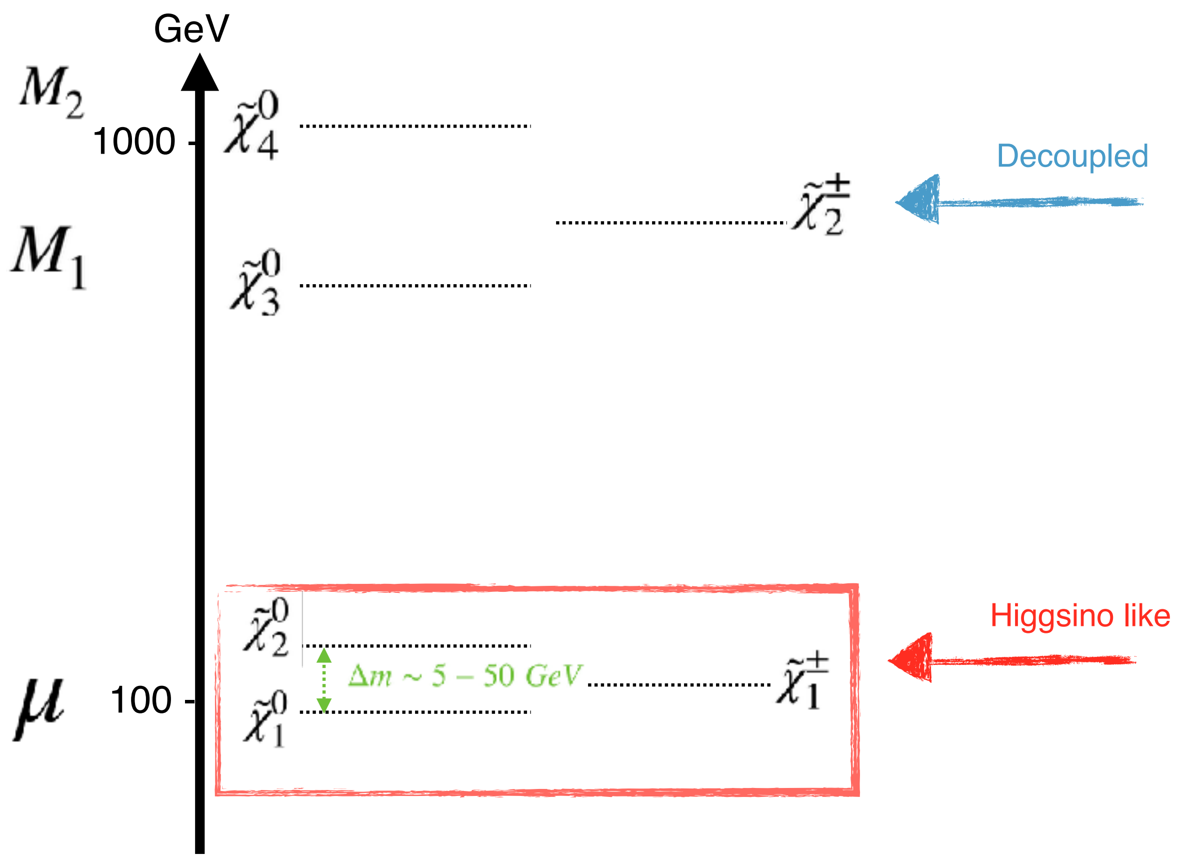
Naturalness and Higgsinos

Compressed spectra motivated in many SUSY scenarios

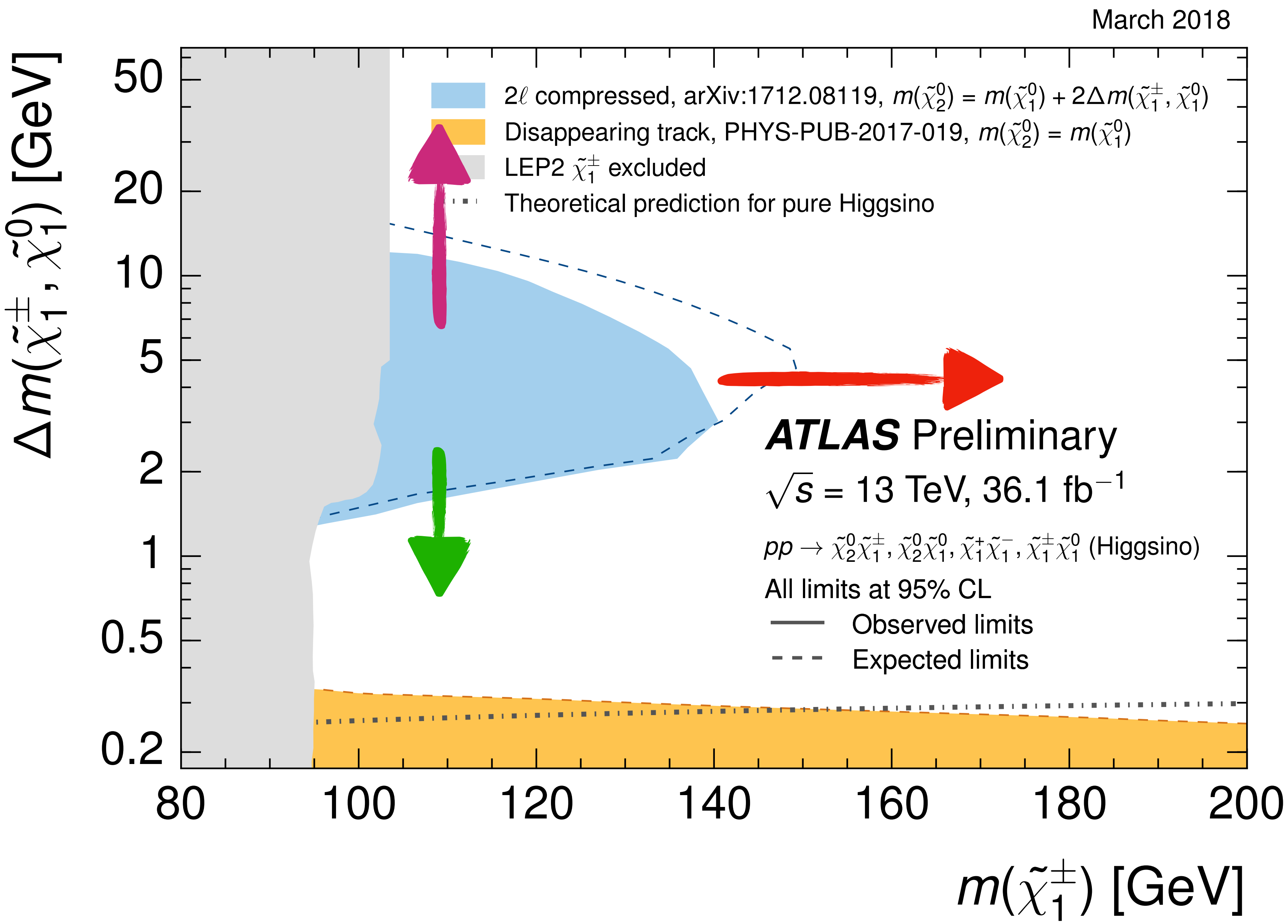


- μ is the tree level higgs mass, must be light for naturalness
- **Pure Higgsinos** could have very small mass splitting: $\mathcal{O}$**(100 MeV)**
- **Moderate mixing** could get to $\mathcal{O}$**(1-10 GeV)**
- Soft decay product from higgsinos decay
  - challenging to detect!

Current Limits

SUSY-2016-25 analysis targeting very compressed spectra

How can we improve our results?

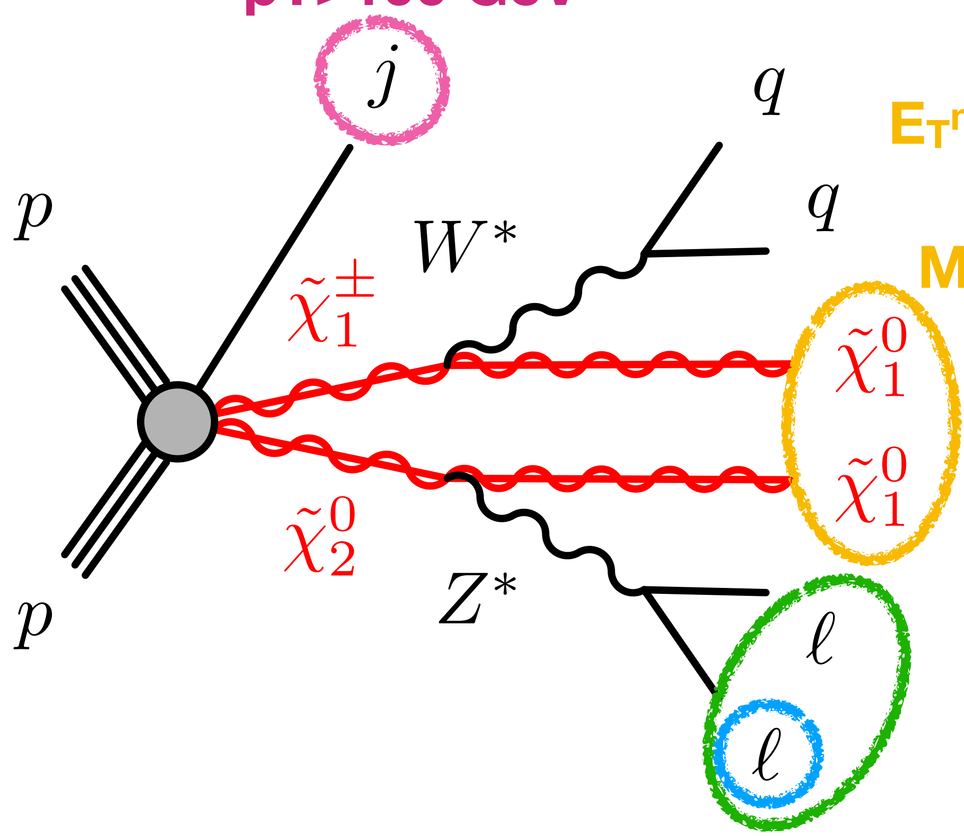


- **Better optimization**
- **More luminosity**
- **New R&D**

Higgsino signal

ATLAS-CONF-2019-014 analysis targeting very compressed spectra :

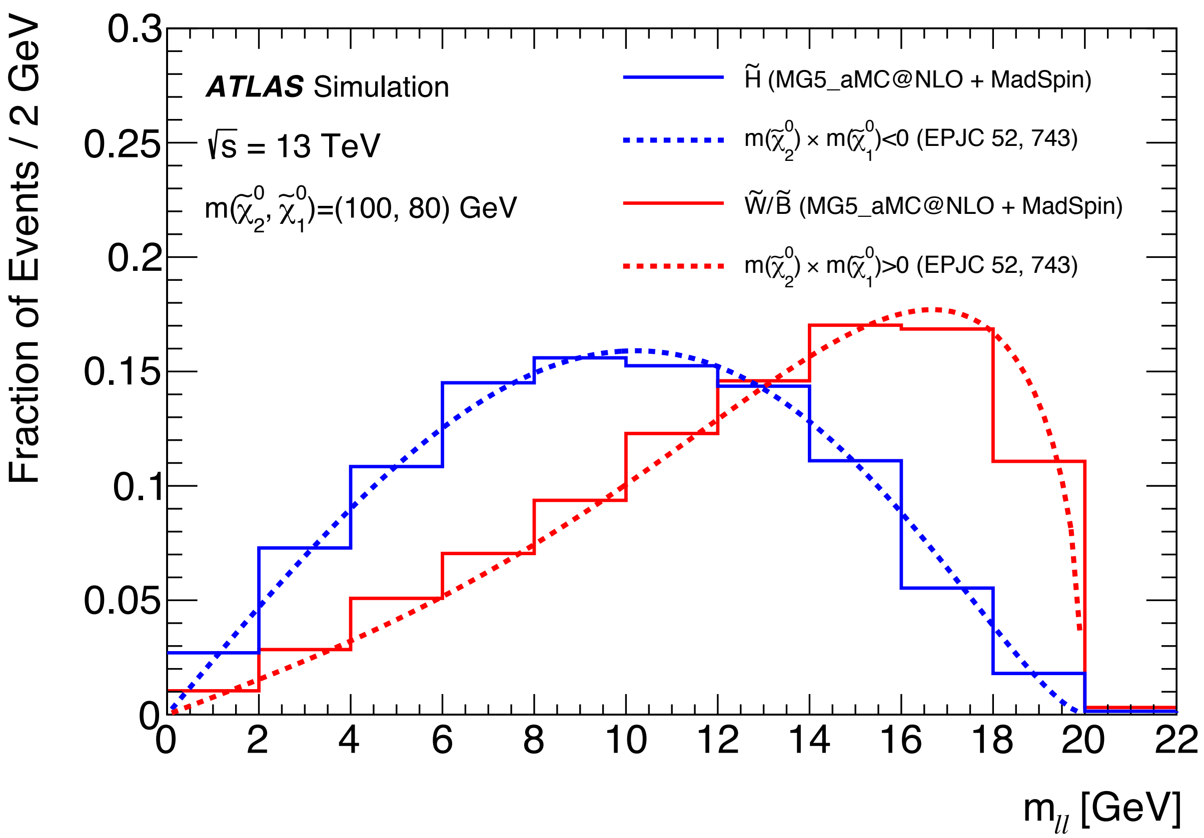
Boost to MET from ISR jet
pT>100 GeV



E_T^{miss}> 100 GeV
+
MET Triggers

Very soft leptons
p_T>3(4.5) GeV for muons (electrons)

1 lepton + 1 track
p_T>1 GeV for tracks



Targeting low $m_{\ell\ell}$ region

- Kinematic edge at $\Delta m(\chi_2,\chi_1)$
- shape fit in $m_{\ell\ell}$>1 GeV & $m_{\ell\ell}$<60 GeV

Signal Region

Preselection common to all SR:

Variable	Preselection requirements: 2ℓ	$1\ell 1T$
Number of leptons (tracks)	= 2 leptons	= 1 lepton and $\geq$ 1 track
Lepton p_{T} [GeV]	$p_{\mathrm{T}}^{\ell_1} > 5$	$p_{\mathrm{T}}^{\ell} < 10$
$\Delta R_{\ell\ell}$	$\Delta R_{ee} > 0.30$, $\Delta R_{\mu\mu} > 0.05$, $\Delta R_{e\mu} > 0.2$	$0.05 < \Delta R_{\ell \mathrm{track}} < 1.5$
Lepton (track) charge and flavor	$e^{\pm}e^{\mp}$ or $\mu^{\pm}\mu^{\mp}$	$e^{\pm}e^{\mp}$ or $\mu^{\pm}\mu^{\mp}$
Lepton (track) invariant mass [GeV]	$3 < m_{ee} < 60$, $1 < m_{\mu\mu} < 60$	$0.5 < m_{\ell \mathrm{track}} < 5$
J/ψ invariant mass [GeV]	veto $3 < m_{\ell\ell} < 3.2$	veto $3 < m_{\ell \mathrm{track}} < 3.2$
$m_{\tau\tau}$ [GeV]	< 0 or > 160	no requirement
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 100	> 100
Number of jets	≥ 1	≥ 1
Number of b-tagged jets	$= 0$	no requirement
Leading jet p_{T} [GeV]	≥ 100	≥ 100
$\min(\Delta\phi(\text{any jet}, \mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}))$	> 0.4	> 0.4
$\Delta\phi(j_1, \mathbf{p}_{\mathrm{T}}^{\mathrm{miss}})$	≥ 2.0	≥ 2.0

- Select soft leptons from the N2 decay
- Remove resonance and Z $\to\tau\tau$
- Remove top contribution
- Select ISR topology

Signal Region

Different Signal Regions (SR) targetting different scenarios

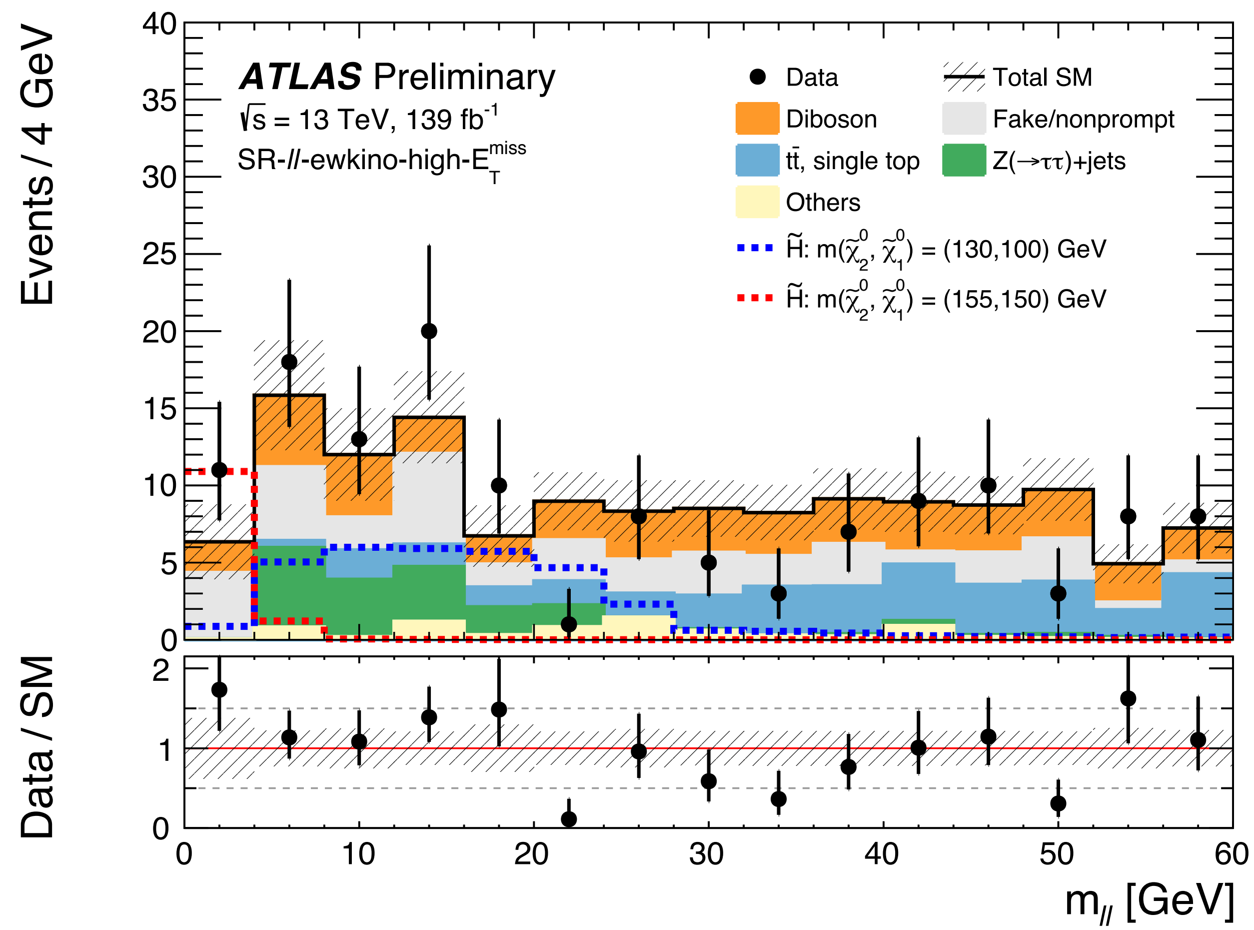
	Electroweakino SR Requirements			
Variable	Low-E_T^{miss}, low-Δm	Low-E_T^{miss}, high-Δm	High-E_T^{miss}	$1\ell 1T$
E_T^{miss} [GeV]	$[120, 200]$	$[120, 200]$	> 200	> 200
E_T^{miss}/H_T^{lep}	> 10	< 10	–	> 30
$\Delta\phi(\text{lep}, \mathbf{p}_T^{miss})$	–	–	–	< 1.0
Lepton or track p_T [GeV]	–	$p_T^{\ell_2} > 5 + m_{\ell\ell}/4$	$p_T^{\ell_2} > \min(10, 2 + m_{\ell\ell}/3)$	$p_T^{track} < 5$
M_T^S [GeV]	< 50	–	–	–
$m_T^{\ell_1}$ [GeV]	–	$[10, 60]$	< 60	–
R_{ISR}	–	$[0.8, 1.0]$	$[\max(0.85, 0.98 - 0.02 \times m_{\ell\ell}),\ 1.0]$	–

- Low E_T^{miss} Use 2 OS leptons. SRs targets events on the turn-on of the E_T^{miss} trigger. Scale factors are applied to the MC to properly model the trigger efficiency observed in data
- High E_T^{miss} Uses 2 OS leptons. SR to target middle-to-high Δm regions
- $1\ell 1T$ Uses 1 lepton and 1 track (OS). SR target scenario with especially low Δm. Background estimate is completely data driven

Background estimation: 2ℓ

Different strategies to estimate backgrounds

Background process	Origin in signal region	Estimation strategy
$t\bar{t}$, tW	b-jet fails identification	CR inverting b-tagging
Diboson	Irreducible leptonic decays	CR inverting R_{ISR}
$(Z \to \tau\tau)$ + jets	Irreducible fully leptonic taus	CR inverting $m_{\tau\tau}$
$(W \to \ell\nu)$ + jets	Jet fakes second lepton	Fake factor, same sign VR
$(Z \to ee, \mu\mu)$ + jets	Instrumental $E_{\mathrm{T}}^{\mathrm{miss}}$	Monte Carlo
Low mass Drell-Yan	Instrumental $E_{\mathrm{T}}^{\mathrm{miss}}$	Monte Carlo
Other rare processes	Irreducible leptonic decays	Monte Carlo

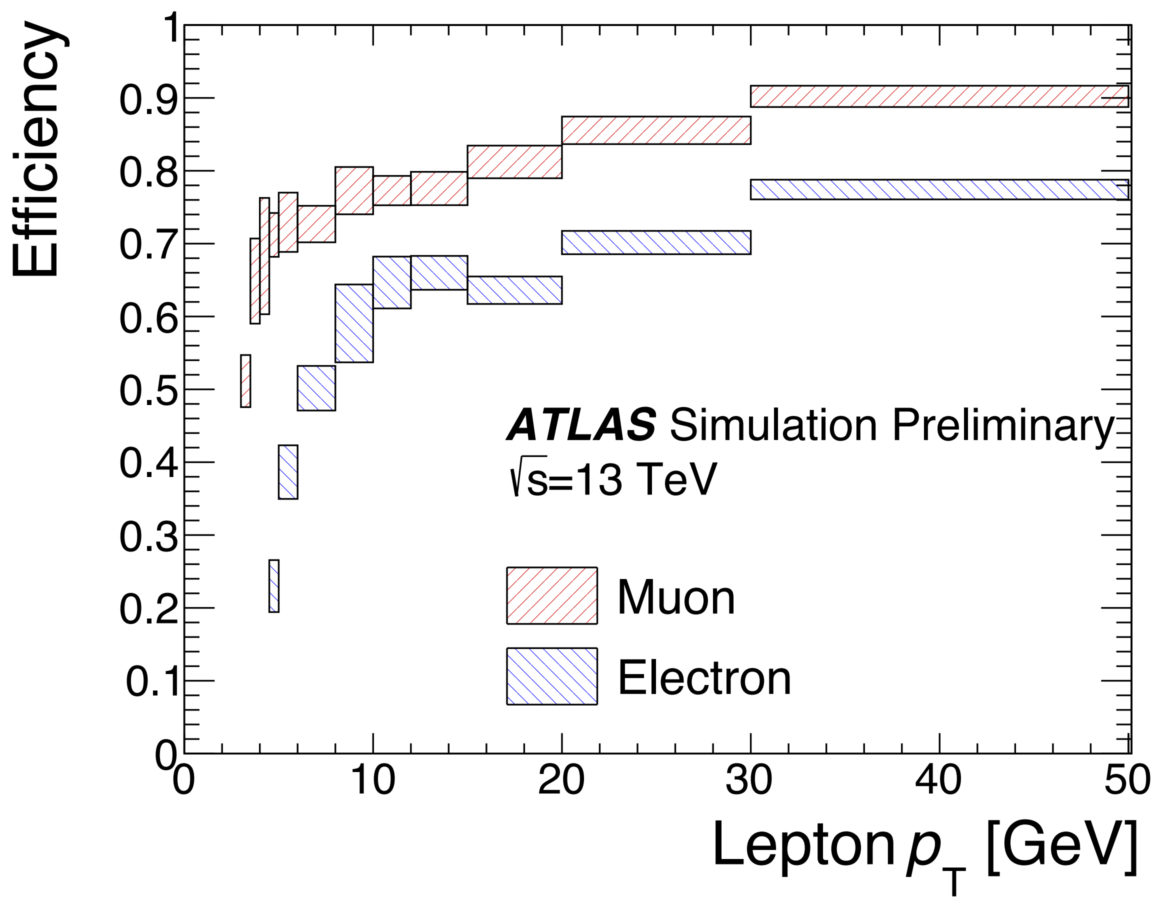


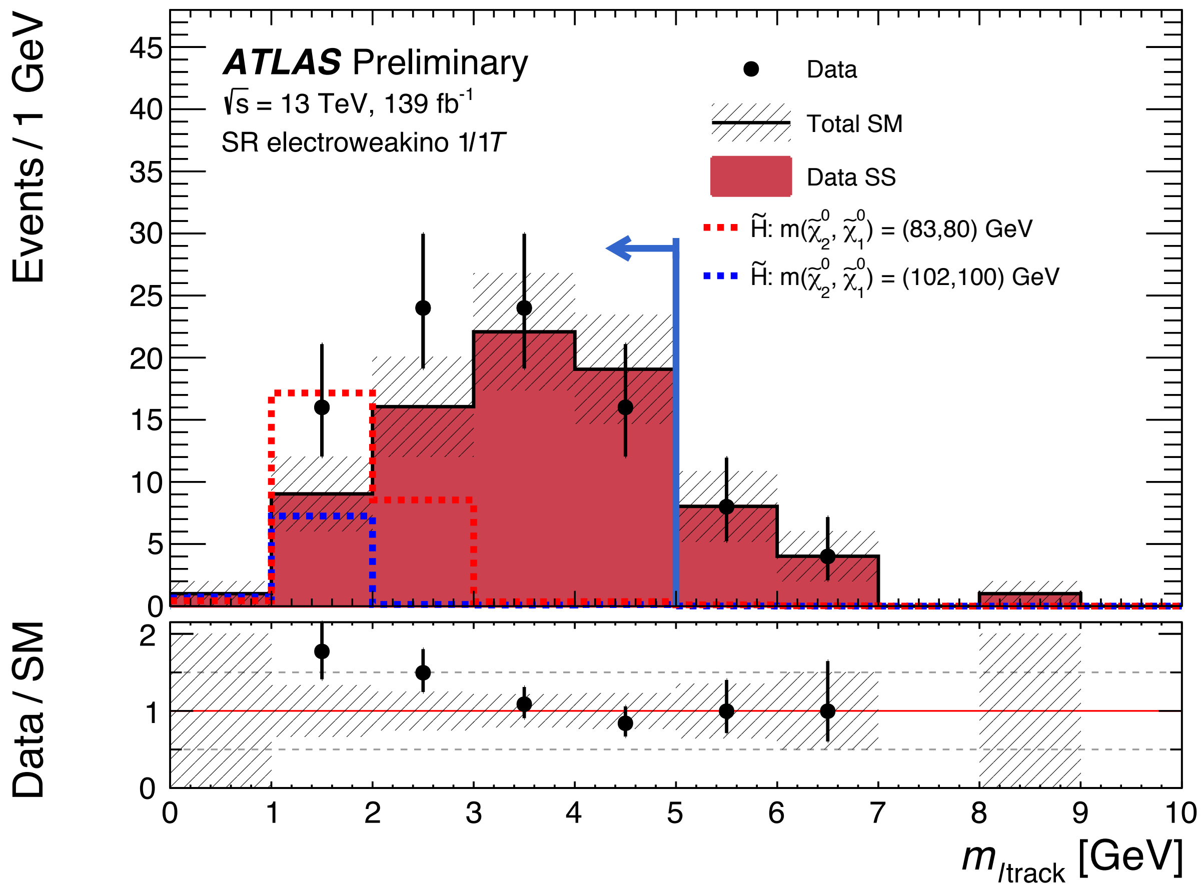
- Control Region to constraint MC to observed data
- Validation Region to compare estimate to data
- Fake factor uses Data Driven method

Main backgrounds comes from non prompt leptons (fakes), top, and dibosons.

Background estimation: $1\ell 1T$

For very compressed higgsinos most of the signal has $p_T^{lep} < 5$ GeV.
Replace second (softer) lepton with a track with a match to a reconstructed electron/muon candidate without identification.
Use Same Sign data as a proxy for background.

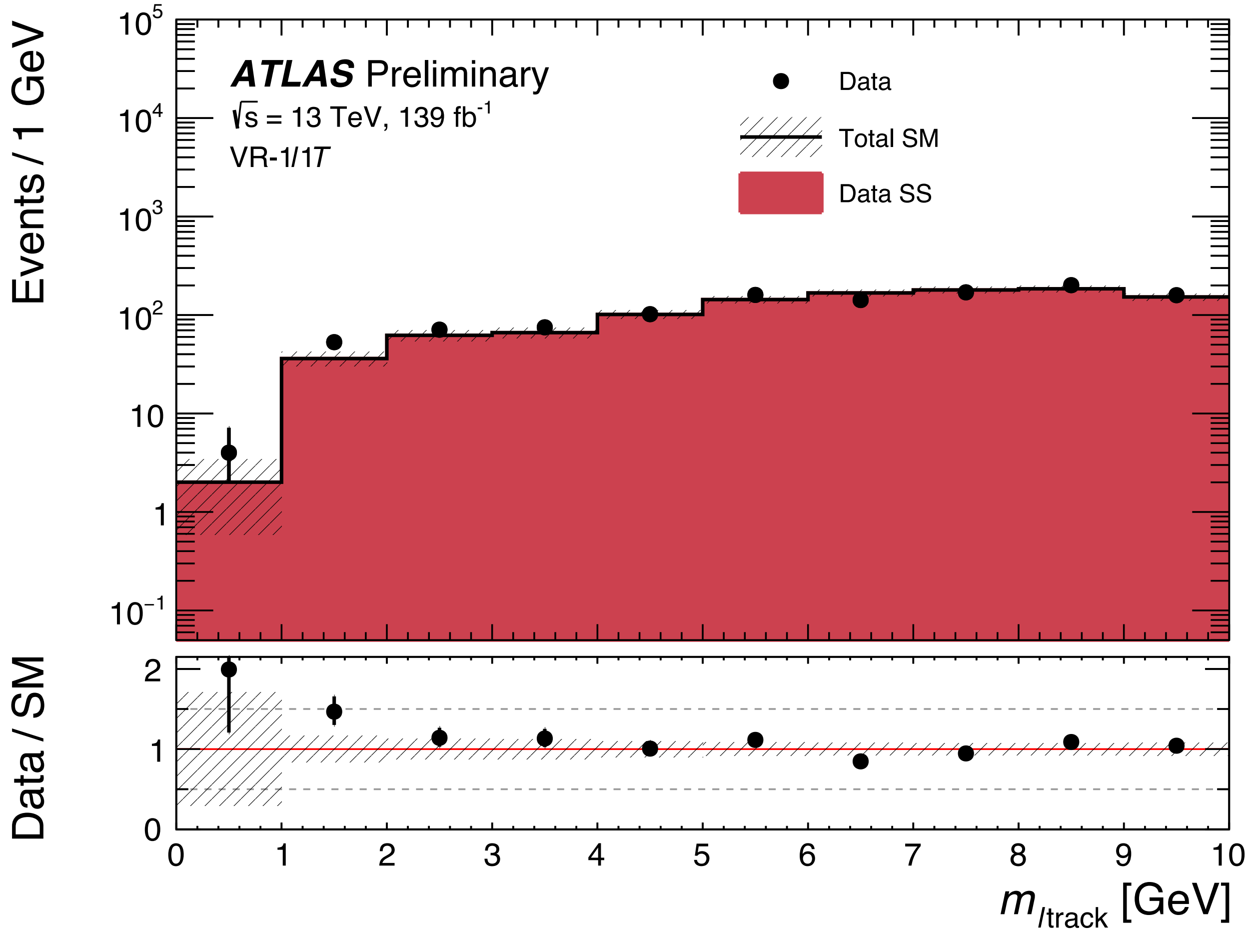


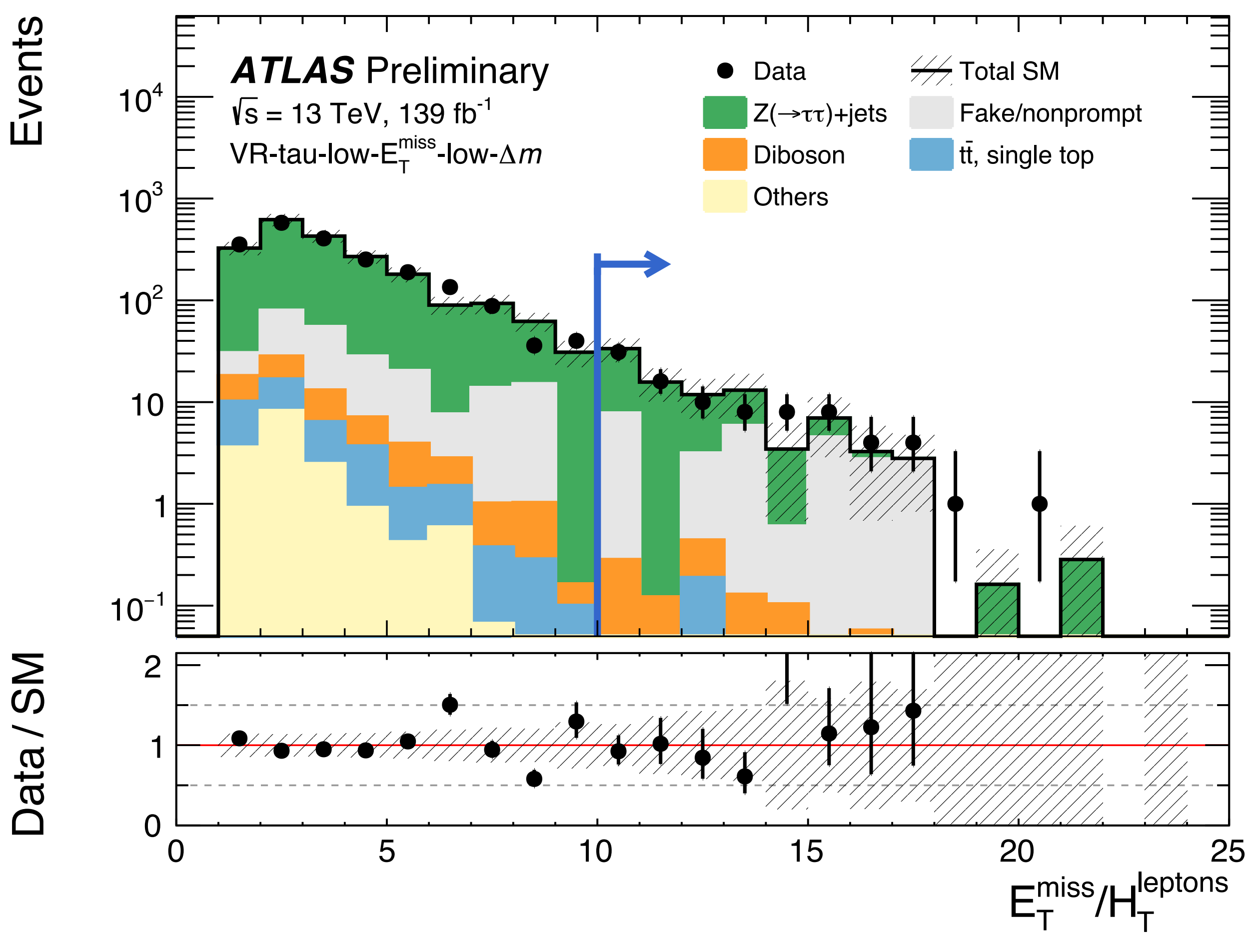


Tracks Electrons 3 GeV< p_T < 4 GeV: 20 %
Tracks Muons 2 GeV< p_T < 3 GeV: 35 %

Background estimation

Background under control

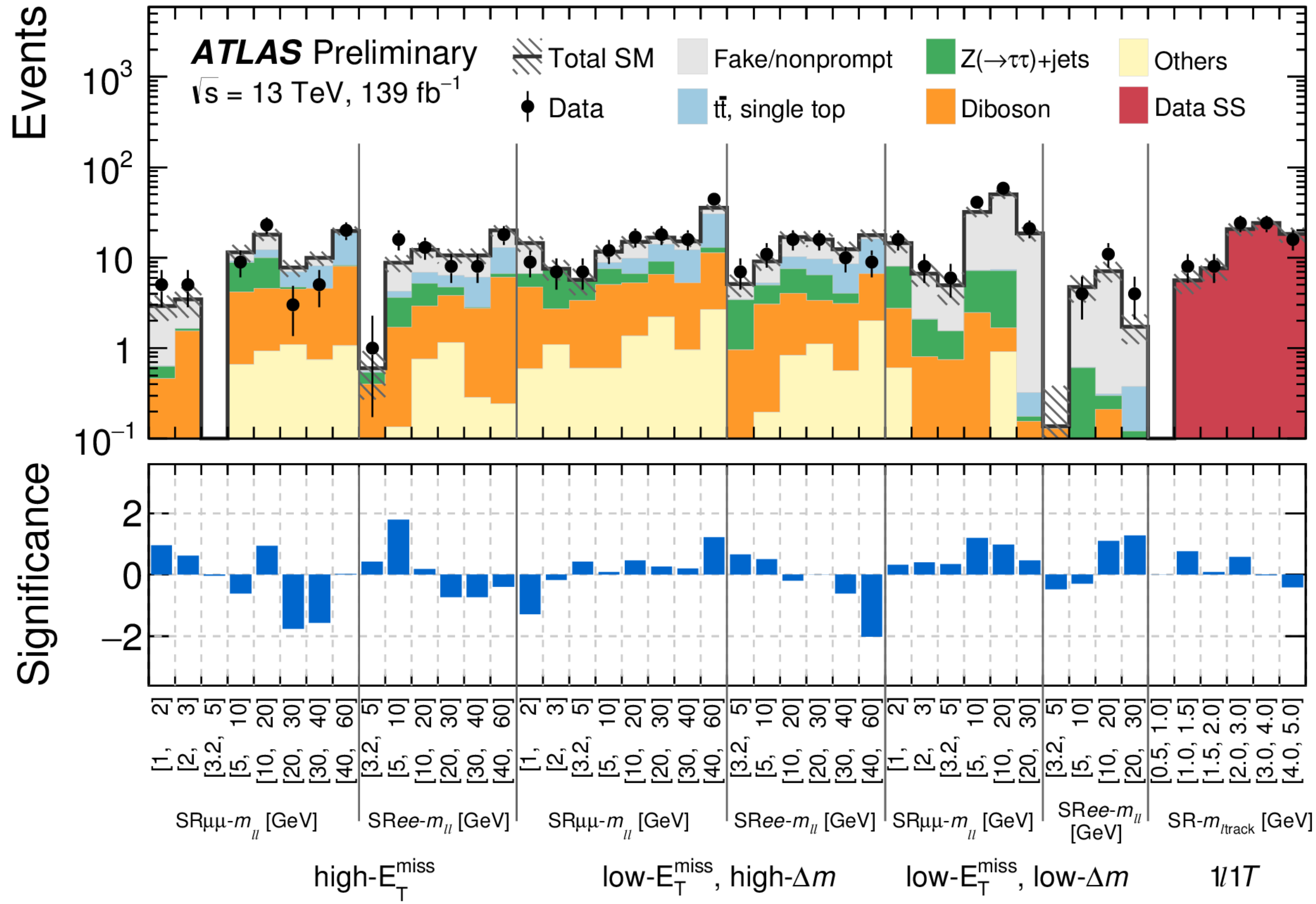




1l1T VR (inverted $\Delta\phi(lep, E_T^{miss})$ cut):
Difference assigned as systematic

$Z\rightarrow\tau\tau$ VR (inverted $m_{\tau\tau}$ cut):
E_T^{miss}/H_T^{lep} correctly modeled

Results: Signal Region Yields

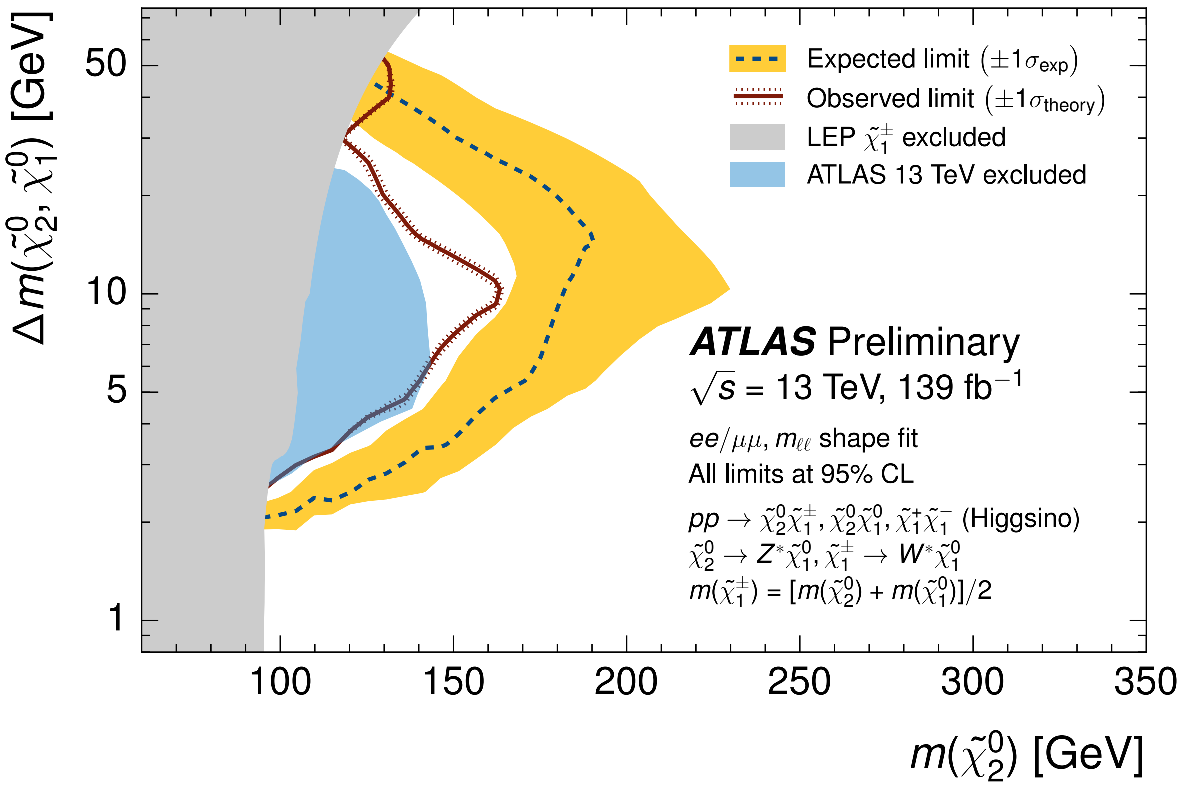


No significant excess observed!

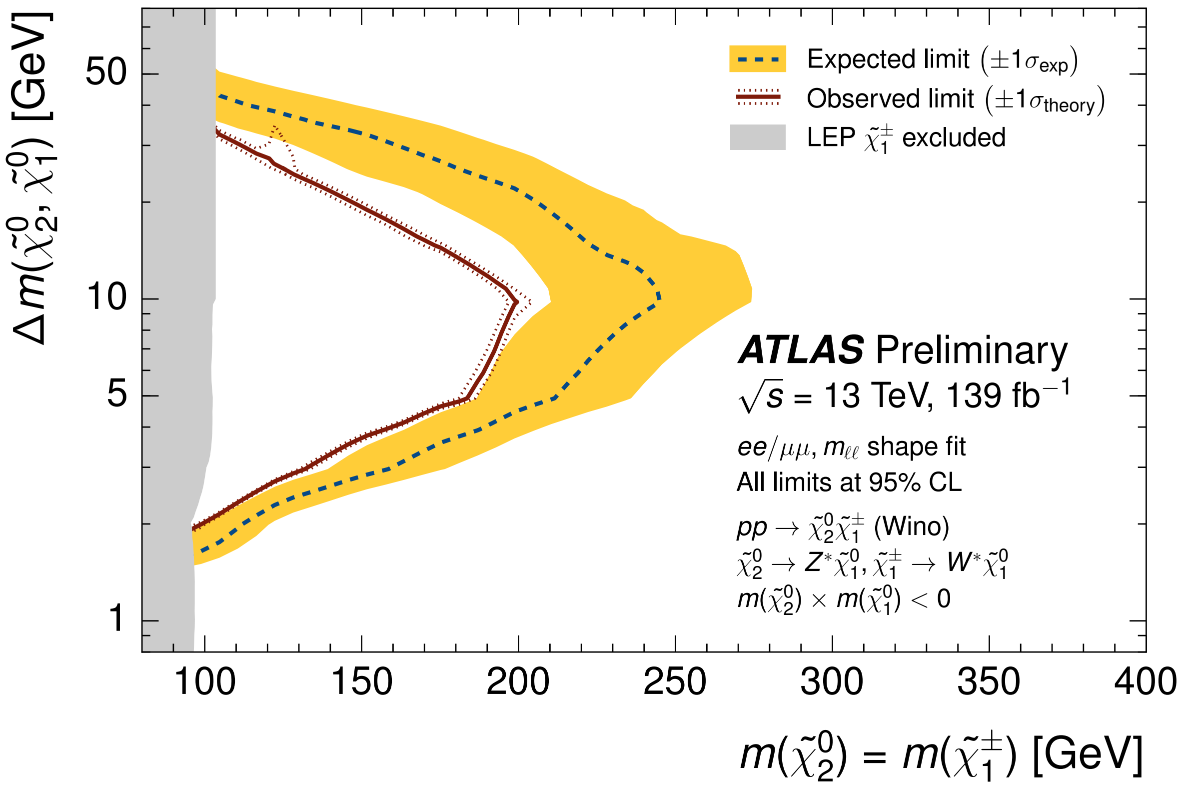
Set limits on supersymmetric particles mass

Interpretation: setting limits

Higgsino limits



Wino-Bino limits



Set limits on supersymmetric particles masses.
Also reinterpret results as Wino-Bino scenario

- Higgsino: $\Delta m(\chi_2,\chi_1)$=3 GeV and m_{χ_2} = 150 GeV
- Wino-Bino: $\Delta m(\chi_2,\chi_1)$=2 GeV and m_{χ_2} = 200 GeV

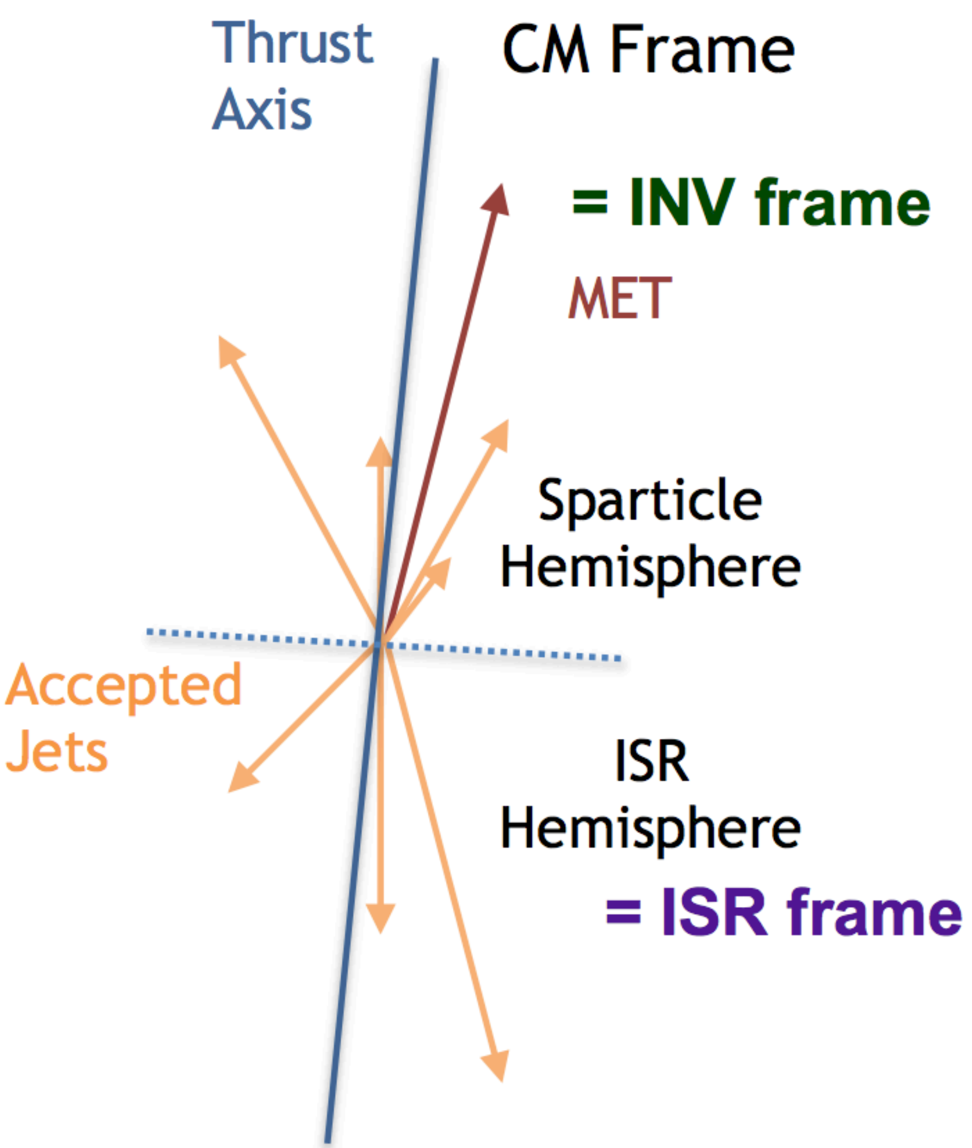
Conclusions

- Higgsinos searches are well motivated by naturalness
  - Compressed scenarios with very soft leptons
- No excess observed. Set limits
  - Higgsinos excluded up to 150 GeV and 3 GeV mass splitting
  - Wino-Bino excluded up to 200 GeV and 2 GeV mass splitting

BACK UP

RJR Variables

Using thrust-based ISR identification via RJR



$$R_{\mathrm{ISR}} \equiv \frac{|\vec{p}^{\,\mathbf{CM}}_{\mathbf{I},T} \cdot \hat{p}^{\,\mathbf{CM}}_{\mathbf{ISR},T}|}{|\vec{p}^{\,\mathbf{CM}}_{\mathbf{ISR},T}|}$$

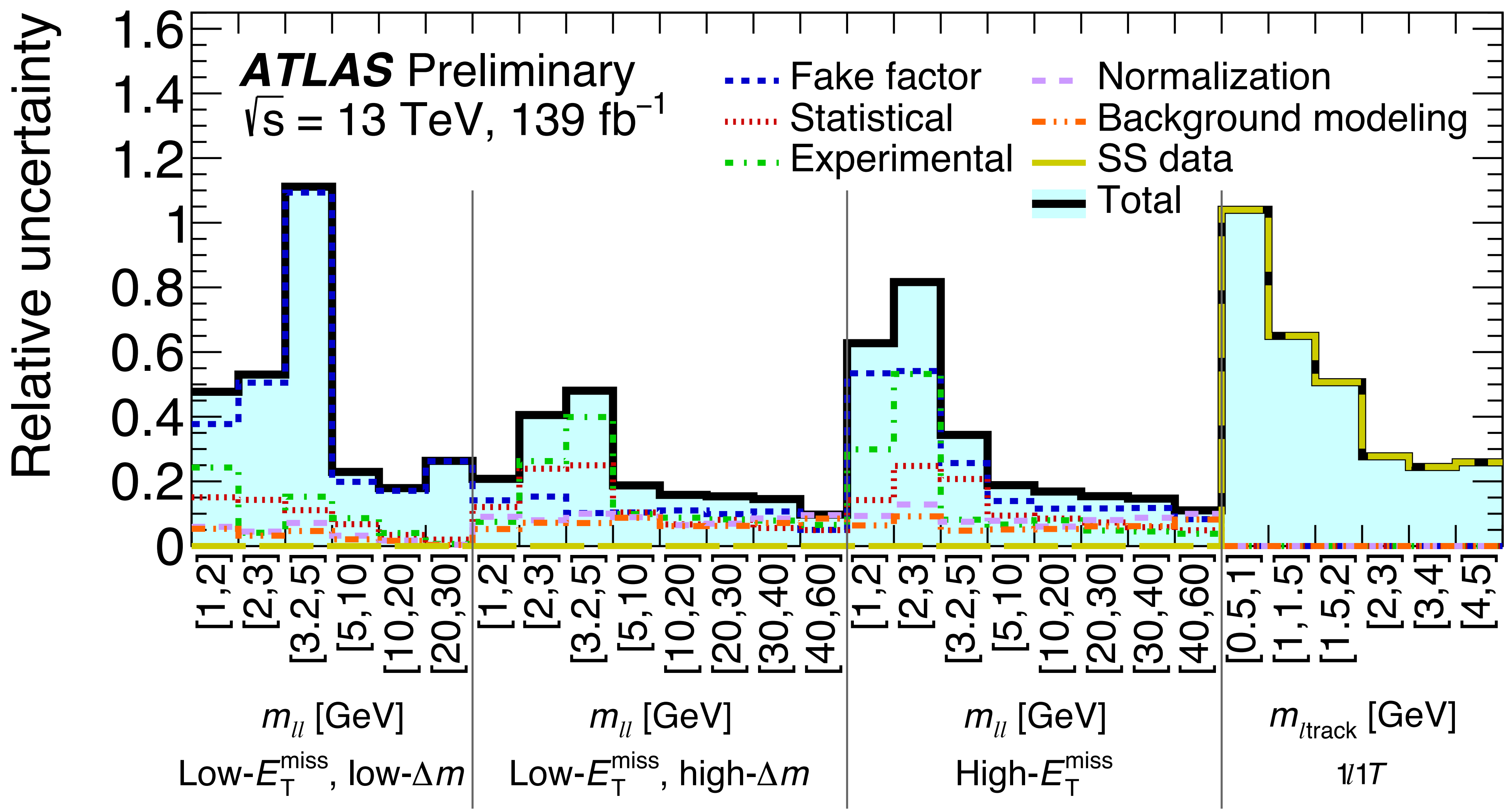
$$\sim \frac{m_{daughter}}{m_{parent}}$$

(for very small mass splittings)

$m_{T,S}$ = transverse mass of the sparticle system

Systematic uncertainties

Statistical uncertainties dominates in the very first bin. In higher bins uncertainty due to non-prompt leptons estimation is dominant

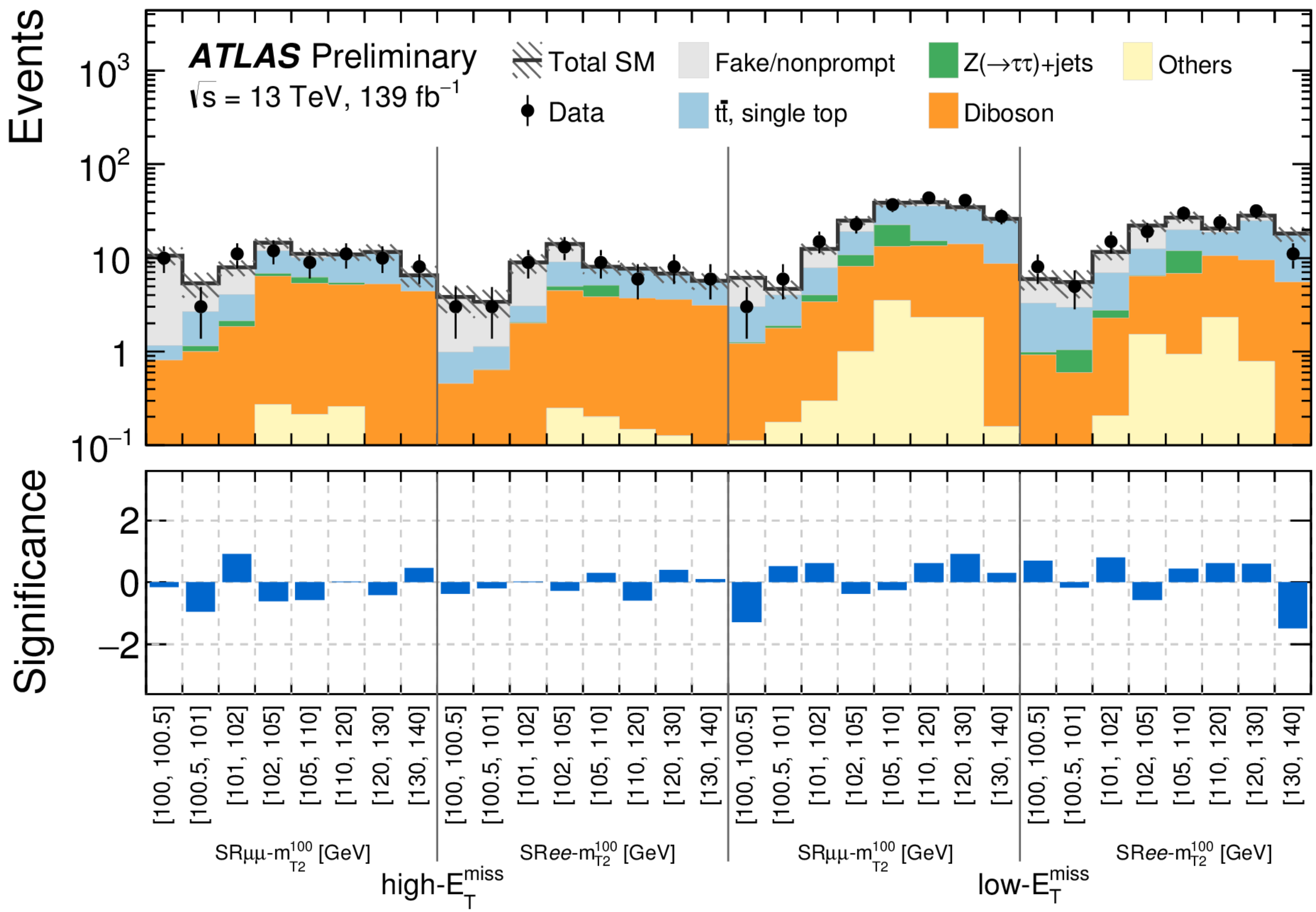


CR and VR definitions

Region	SR orthogonality	Lepton Flavor	Additional requirements
CR-top-ewkino-high-E_T^{miss} CR-top-ewkino-low-E_T^{miss}-high-Δm	$N_{b-jet}^{20} \geq 1$	$ee + \mu\mu + e\mu + \mu e$	$R_{ISR} \in [0.7, 1.0]$, $m_T^{\ell_1}$ removed E_T^{miss}/H_T^{lep} and $m_T^{\ell_1}$ removed
CR-tau-ewkino-high-E_T^{miss} CR-tau-ewkino-low-E_T^{miss}-high-Δm VR-tau-ewkino-low-E_T^{miss}-low-Δm	$m_{\tau\tau} \in [60, 120]$ GeV	$ee + \mu\mu + e\mu + \mu e$	$R_{ISR} \in [0.7, 1.0]$, $m_T^{\ell_1}$ removed $R_{ISR} \in [0.6, 1.0]$, $m_T^{\ell_1}$ removed –
CR-VV-ewkino-high-E_T^{miss} CR-VV-ewkino-low-E_T^{miss}-high-Δm	$R_{ISR} \in [0.7, 0.85]$ $R_{ISR} \in [0.6, 0.8]$	$ee + \mu\mu + e\mu + \mu e$	$m_T^{\ell_1}$ removed $m_T^{\ell_1} > 30$ GeV, $N_{jets} = 1$, E_T^{miss}/H_T^{lep} removed
VR-SS-ewkino-high-E_T^{miss} VR-SS-ewkino-low-E_T^{miss}-high-Δm VR-SS-ewkino-low-E_T^{miss}-low-Δm	Same sign $\ell^{\pm}\ell^{\pm}$	$ee + \mu e$, $\mu\mu + e\mu$	$R_{ISR} \in [0.7, 1.0]$, $m_T^{\ell_1}$ and $p_T^{\ell_2}$ removed E_T^{miss}/H_T^{lep}, $m_T^{\ell_1}$ and $p_T^{\ell_2}$ removed –
VR-DF-ewkino-high-E_T^{miss} VR-DF-ewkino-low-E_T^{miss}-high-Δm VR-DF-ewkino-low-E_T^{miss}-low-Δm	$e\mu + \mu e$	$e\mu + \mu e$	– – –

Control Region		Normalization Parameters electroweakino	slepton
CR-top	high-E_T^{miss}	1.07 ± 0.04	1.03 ± 0.05
	low-E_T^{miss}	1.01 ± 0.02	1.00 ± 0.02
CR-tau	high-E_T^{miss}	0.95 ± 0.09	0.80 ± 0.13
	low-E_T^{miss}	0.99 ± 0.05	1.02 ± 0.06
CR-VV	high-E_T^{miss}	0.88 ± 0.19	0.83 ± 0.23
	low-E_T^{miss}	0.75 ± 0.14	0.72 ± 0.15

Yields in VR



ATLAS Preliminary
√s = 13 TeV, 139 fb⁻¹
Total SM
Data
Fake/nonprompt
tt̄, single top
Z(→ττ)+jets
Diboson
Others
Events
Significance
SRμμ-m$_{T2}^{100}$ [GeV]
SRee-m$_{T2}^{100}$ [GeV]
high-E_T^{miss}
low-E_T^{miss}
[100, 100.5]
[100.5, 101]
[101, 102]
[102, 105]
[105, 110]
[110, 120]
[120, 130]
[130, 140]