Searches for Higgsinos and related challenges in ATLAS

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(on behalf of the ATLAS collaboration)

53rd Rencontres de Moriond
Electroweak interactions and unified theories
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Supersymmetry (SUSY)

- SUSY : A framework, many realizations - not magic

- **Space-time symmetry** that postulates <u>a partner particle to each SM particle whose spin differs by one-half unit</u>

Copyright: STFC/Ben Gilliland

- <u>Loop corrections</u> from SUSY particles **cancel quadratic divergences**: m_H is saved!?

- <u>If R-parity conserved</u> lightest SUSY particle (**LSP**) is a **dark matter candidate**

R-parity : $(-1)^{3(B-L)+2s}$
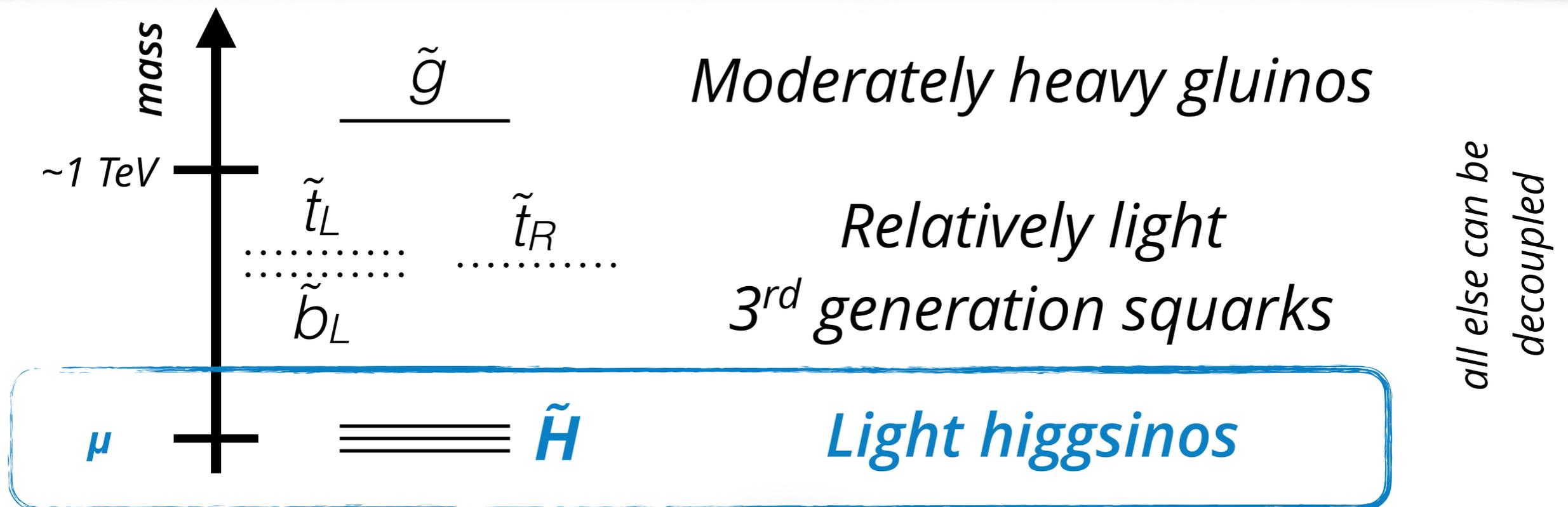+1 for SM and -1 for SUSY
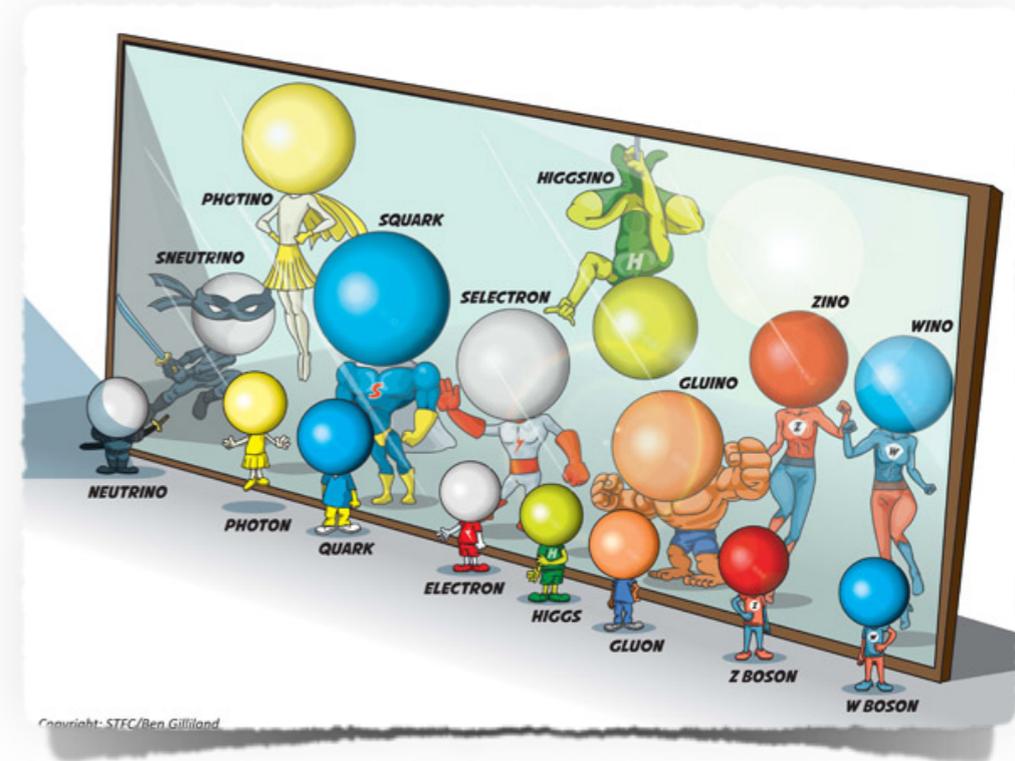
Electroweak Sector:

$\tilde{B}$ (bino), $\tilde{W}$ (wino), $\tilde{H}$ (higgsino)

mixing

$\tilde{\chi}_i^{\pm}$ w/ $i \in [1,2]$ (charginos)
$\tilde{\chi}_i^0$ w/ $i \in [1,4]$ (neutralinos)

Why Higgsinos in all SUSY-land?
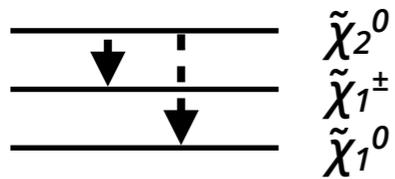
- We know that SUSY must be a <u>broken symmetry</u>

- <u>Implications of many other experimental measurements:</u>

  - Cosmological constraints on the dark matter relic density

  - Higgs related measurements (mass, BRs etc.)
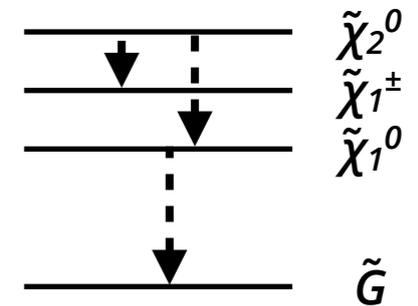
- **Natural** SUSY scenarios typically favor:

mass

$\tilde{g}$ *Moderately heavy gluinos*

~1 TeV

$\tilde{t}_L$ $\tilde{t}_R$ *Relatively light*
$\tilde{b}_L$ *3rd generation squarks*

all else can be decoupled

μ $\tilde{H}$ **Light higgsinos**

Higgsino Searches in ATLAS

Scenario 1
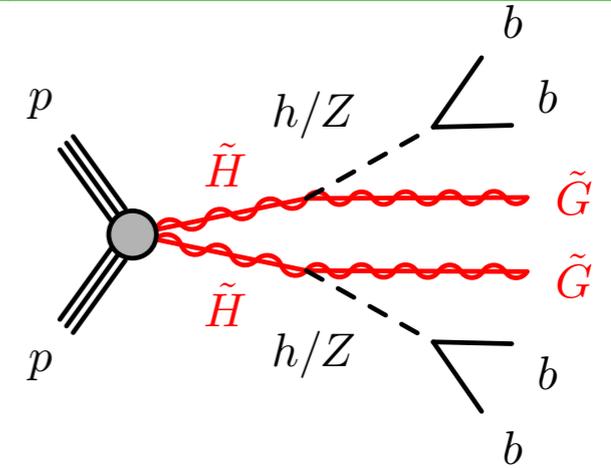

$\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^\pm, \tilde{\chi}_1^0) \sim$ a few GeV

- Decays via *off-shell W/Z*
- Soft-leptons + jets

arxiv:1712.08119

Scenario 2

$\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^\pm, \tilde{\chi}_1^0) \sim$ 300 MeV
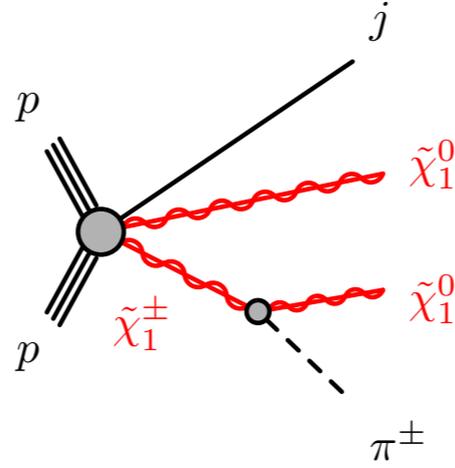
- Extremely compressed
- Disappearing tracks

arxiv:1712.02118
ATL-PHYS-PUB-2017-019

Scenario 3

$\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^\pm, \tilde{\chi}_1^0) \sim$ a few GeV

- Decays via *on-shell h/Z*
- ≥3*b*-jets

ATLAS-CONF-2017-081

Scenario 1 : Soft-leptons + jets
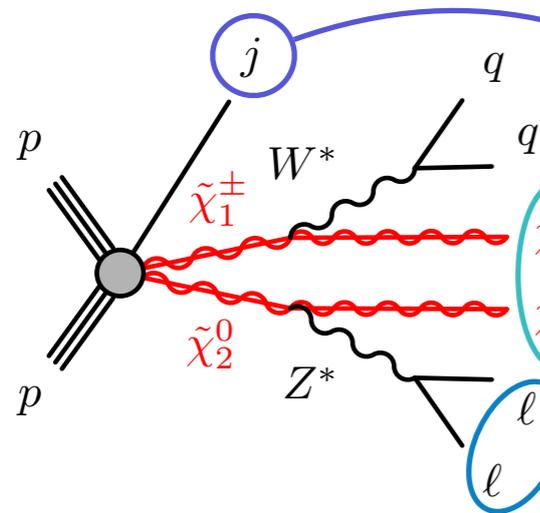
Experimental signature:

Initial-state radiation to boost final state objects,

missing transverse momentum (MET) from $\tilde{\chi}_1^0$,

and 2 low-p_T opposite-sign leptons from Z^*

Signal region selection:

Variable	Common requirement	
Number of leptons	$= 2$	
Lepton charge and flavor	e^+e^- or $\mu^+\mu^-$	
Leading lepton $p_T^{\ell_1}$	$> 5\,(5)$ GeV for electron (muon)	
Subleading lepton $p_T^{\ell_2}$	$> 4.5\,(4)$ GeV for electron (muon)	
$\Delta R_{\ell\ell}$	> 0.05	
$m_{\ell\ell}$	$\in [1, 60]$ GeV excluding $[3.0, 3.2]$ GeV	
E_T^{miss}	> 200 GeV	
Number of jets	≥ 1	
Leading jet p_T	> 100 GeV	
$\Delta\phi(j_1, \mathbf{p}_T^{miss})$	> 2.0	
$\min(\Delta\phi(\text{any jet}, \mathbf{p}_T^{miss}))$	> 0.4	
Number of b-tagged jets	$= 0$	
$m_{\tau\tau}$	< 0 or > 160 GeV	
	Electroweakino SRs	Slepton SRs
$\Delta R_{\ell\ell}$	< 2	—
$m_T^{\ell_1}$	< 70 GeV	—
E_T^{miss}/H_T^{lep}	$> \max\left(5, 15 - 2\frac{m_{\ell\ell}}{1\,\text{GeV}}\right)$	$> \max\left(3, 15 - 2\left(\frac{m_{T2}^{100}}{1\,\text{GeV}} - 100\right)\right)$
Binned in	$m_{\ell\ell}$	m_{T2}^{100}

Key aspects of the search:

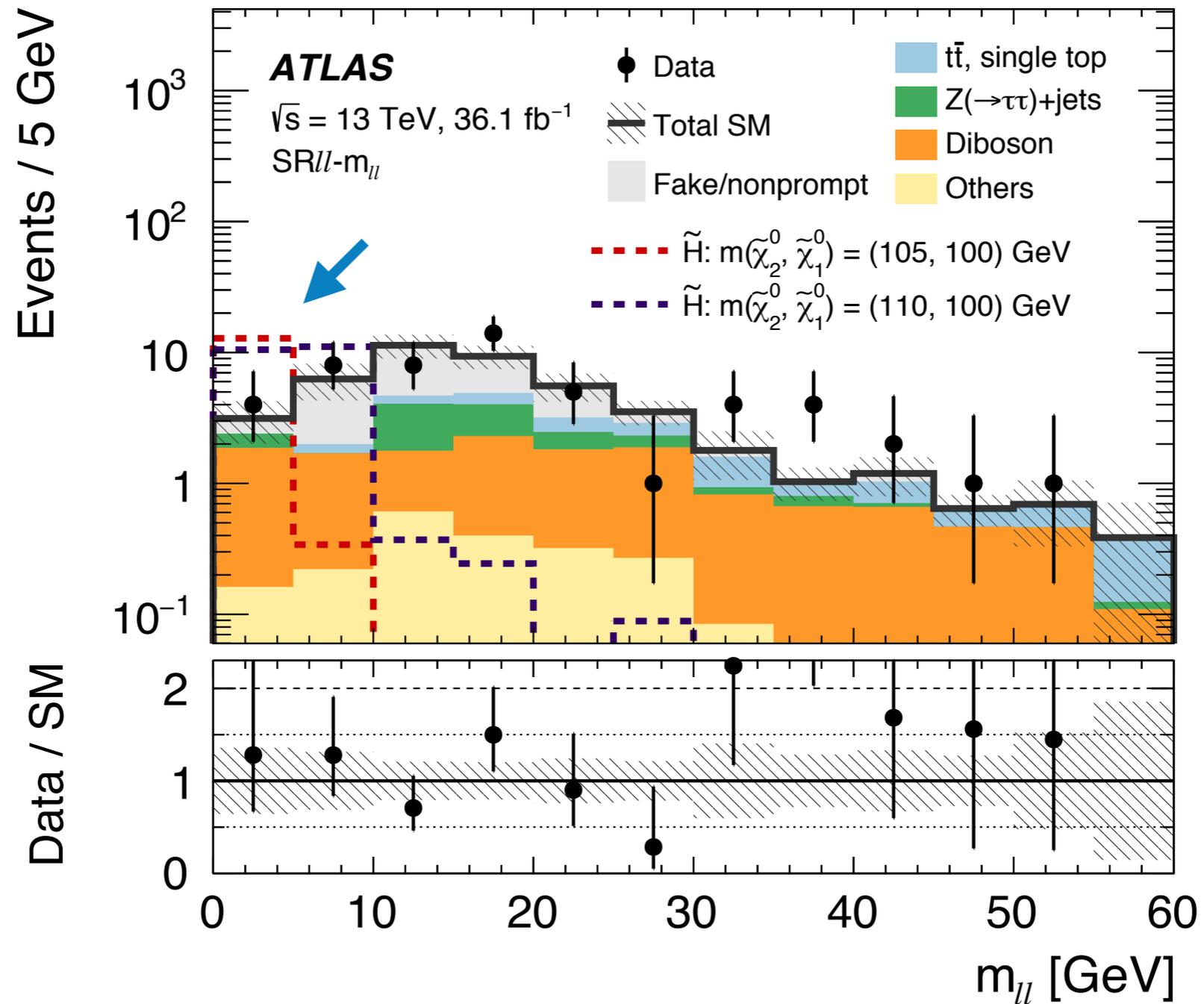Sensitivity driven by low-p_T leptons
(lower than any other ATLAS search!)

Binned m_{ll} starting from 1 GeV!
(Higgsino scenario)

High-p_T jet(s) and MET
(well separated)

Binned m_{T2} starting from 100 GeV
(Slepton scenario)

m$_{ll}$ distribution in the Higgsino signal region

Scenario 1 : Challenges

Signal localized in low m_{ll} - leptons can have low-p_T :
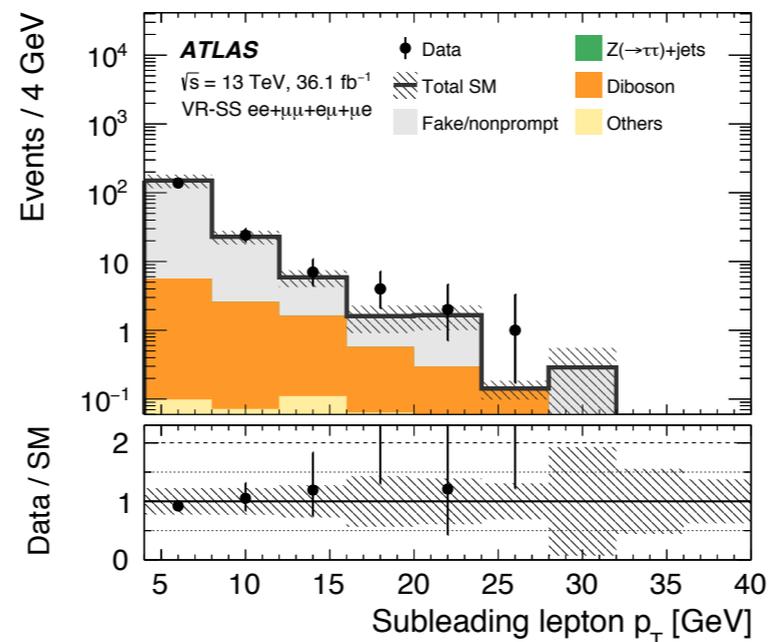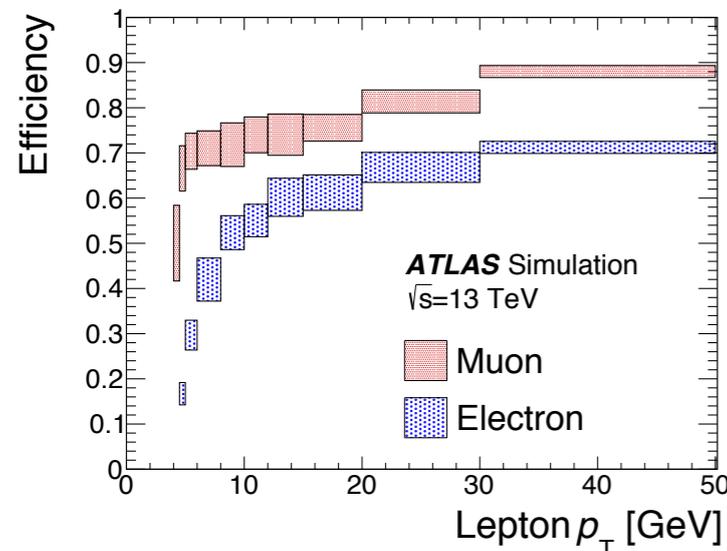
Need robust fake/non-prompt lepton background modeling

Need understanding lepton identification in low-p_T regime

Need to keep low-mass resonances under control

Need to suppress backgrounds from mis-measurements

Signal lepton efficiencies

Data-driven fake/non-prompt lepton background estimation (so-called *Fake Factor* method)

Carefully tested in validation regions

Special effort to keep the uncertainties under control, i.e. <50% in $m_{ll} \in$ [1-3] GeV, (largest source of uncertainty)

Other major backgrounds (top, $Z \rightarrow \tau\tau$) corrected
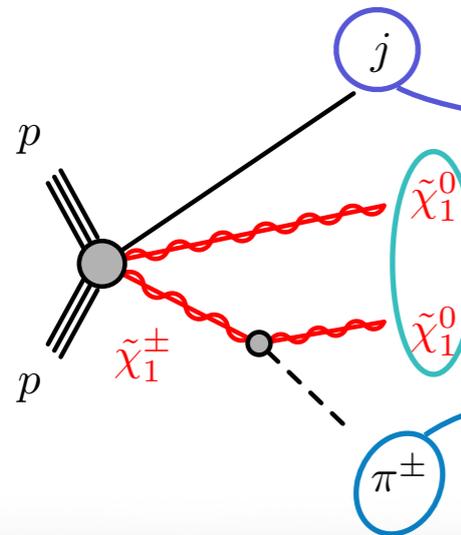*w/ data-driven normalization factors and are also validated*
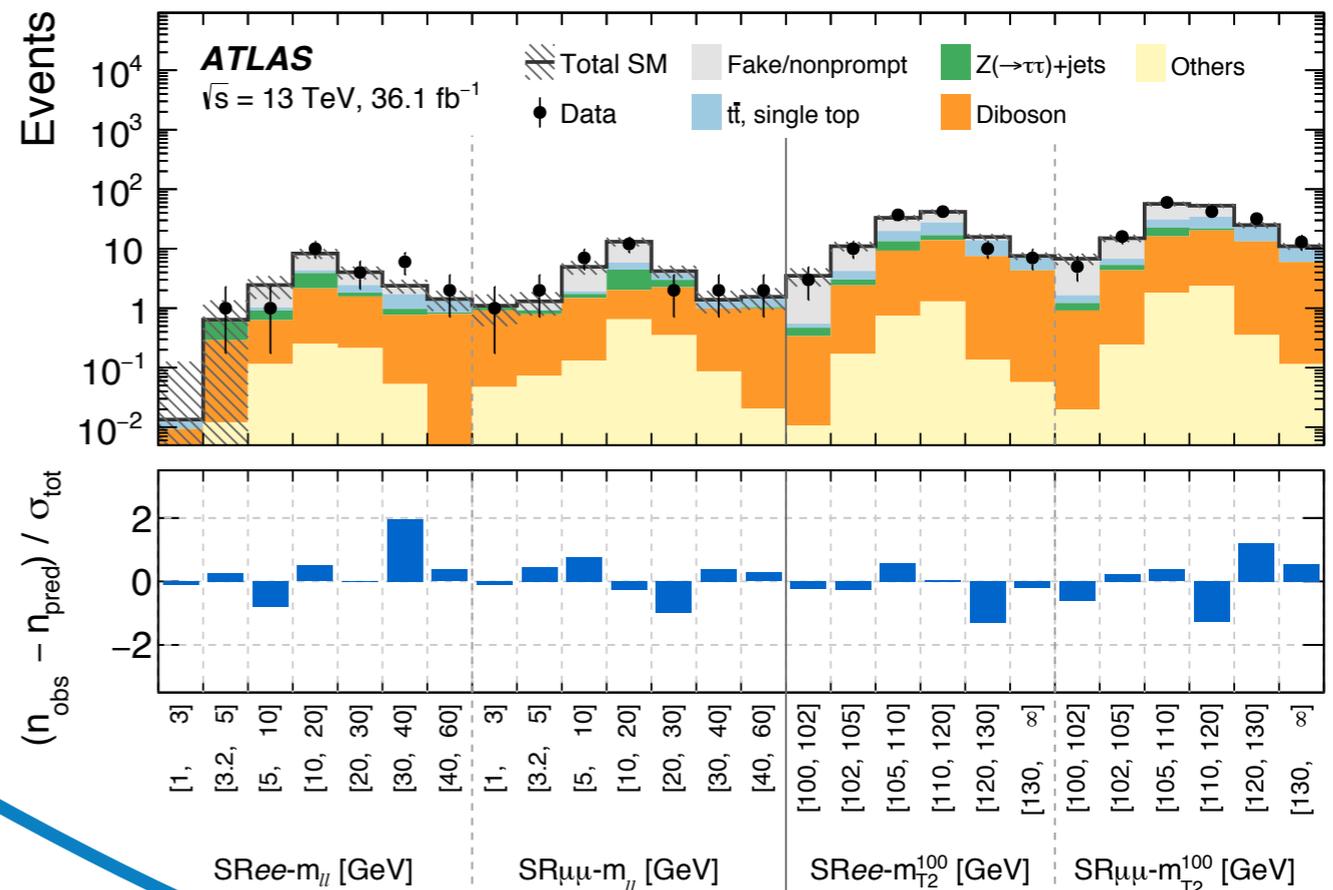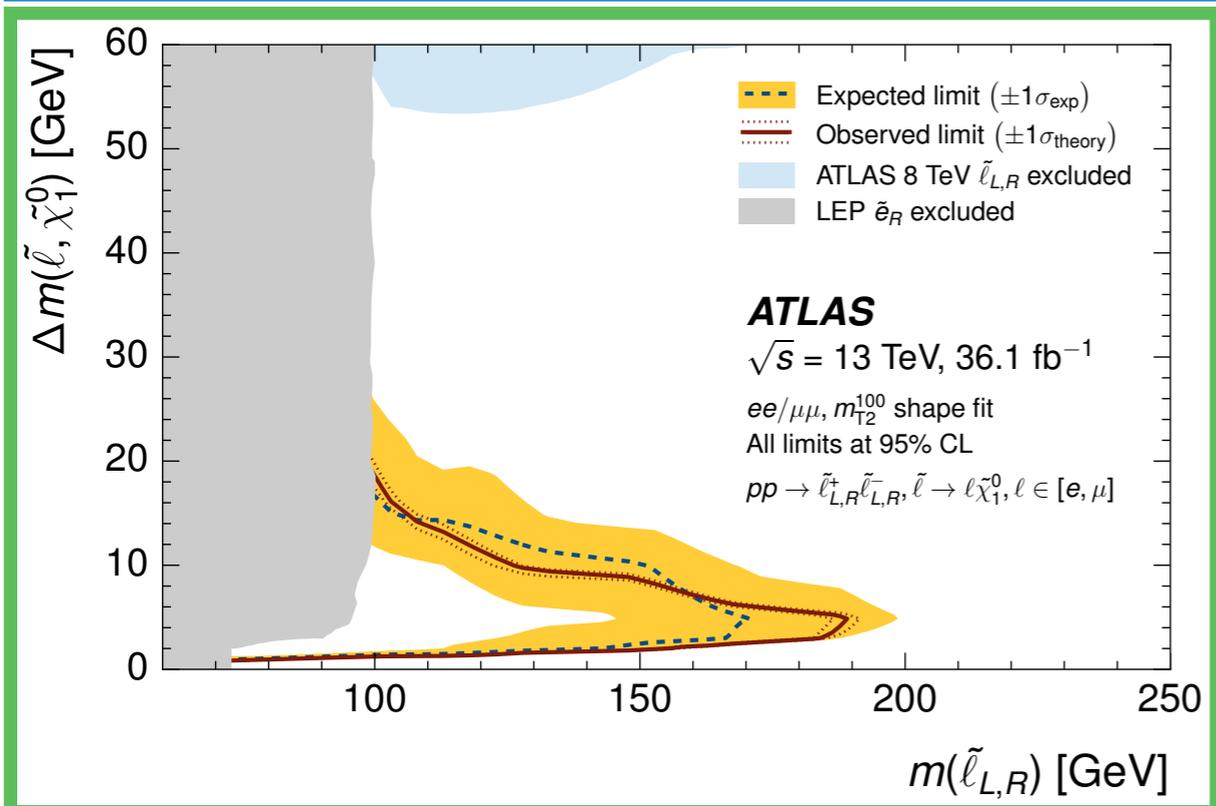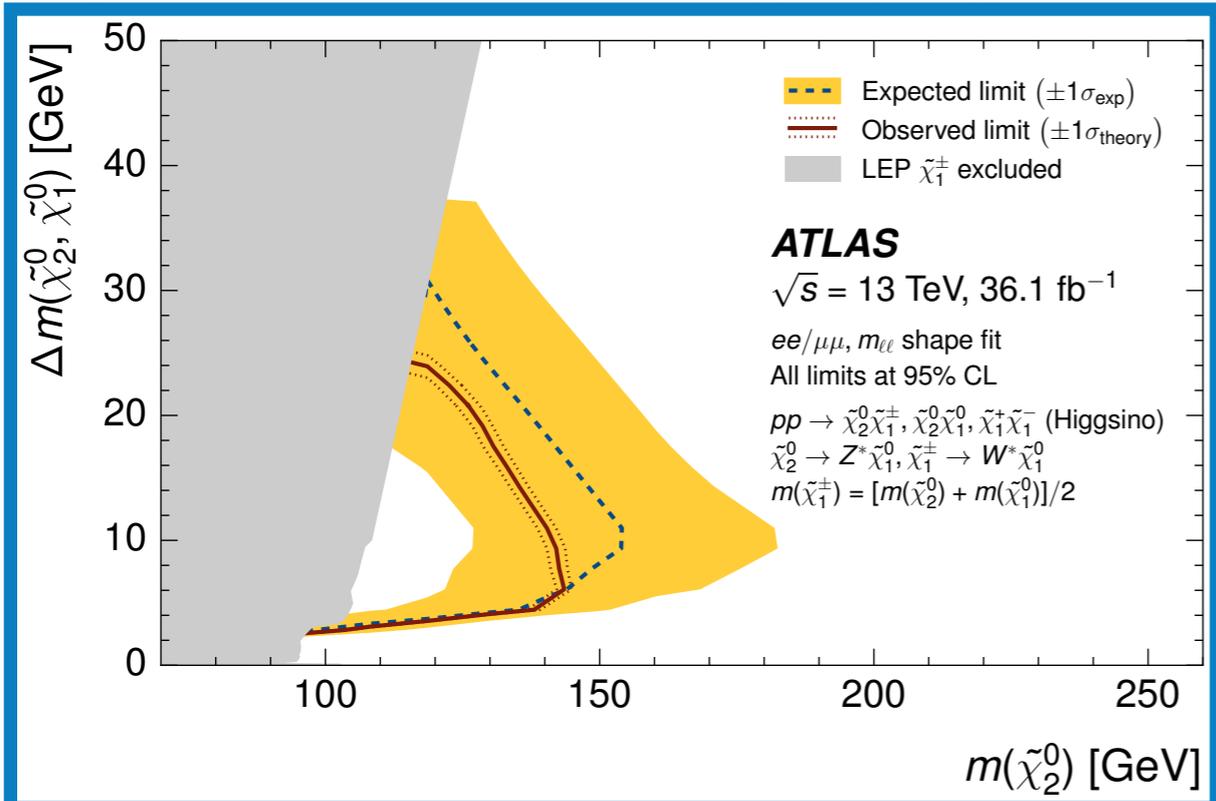
signal regions targeting higgsino-pairs

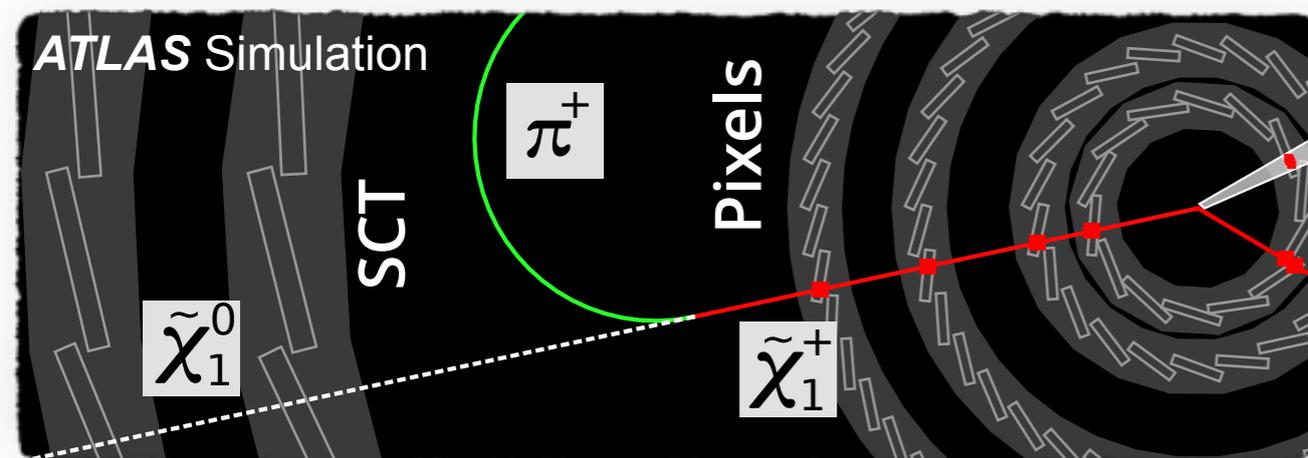*signal regions targeting slepton-pairs*

Sensitivity beyond LEP limits in fairly compressed scenarios!

Scenario 2 : Disappearing tracks

Experimental signature:

Initial-state radiation to boost final state objects,

missing transverse momentum (MET) from $\tilde{\chi}_1^0$,

low-p_T *pion*, "disappearing" $\tilde{\chi}_1^\pm$ track(s)

For the Higgsino scenario:

$\tilde{\chi}_1^\pm$ lifetime of ~0.05 ns w/ $c\tau$ ~ 10-ish mm y ~ 1

$\tilde{\chi}_1^\pm$ track w/ a few <u>pixel hits but no SCT hit</u>
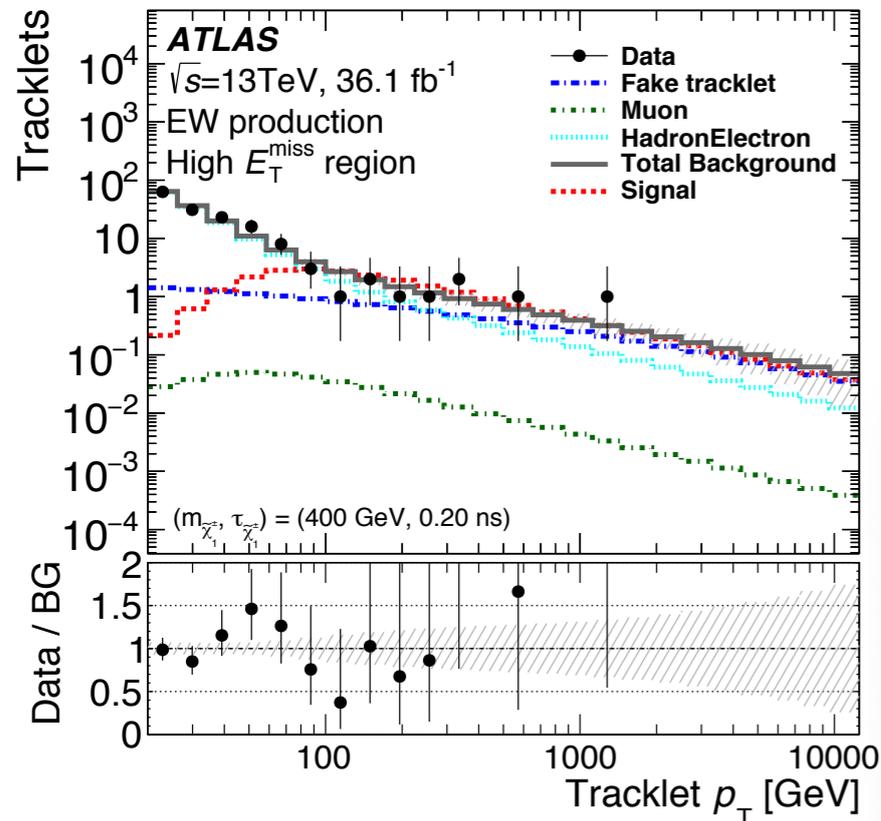
(referred to as *pixel tracklets*)

Signal region selection:

≥1 jet (p_T > 140 GeV) and MET > 140 GeV

Well separated jets and MET

≥1 pixel tracklet

Key aspects of the search:

Backgrounds from data-driven templates

(likelihood fit to pixel tracklet p_T spectrum)

Analysis specific track reconstruction

ATLAS
$\sqrt{s}$=13TeV, 36.1 fb^{-1}
EW production
High E_T^{miss} region

Data
Fake tracklet
Muon
HadronElectron
Total Background
Signal

$(m_{\tilde{\chi}_1^\pm}, \tau_{\tilde{\chi}_1^\pm})$ = (400 GeV, 0.20 ns)

Tracklets

Data / BG

Tracklet p_T [GeV]

1. Data-driven templates for each source
2. Likelihood fit to pixel tracklet p$_T$ spectrum
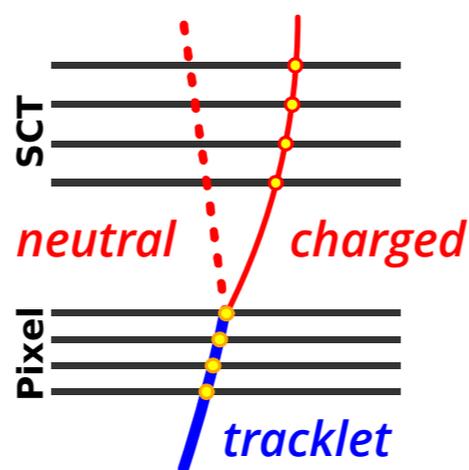3. Search for an excess

Unique signature requires non-standard methodologies:

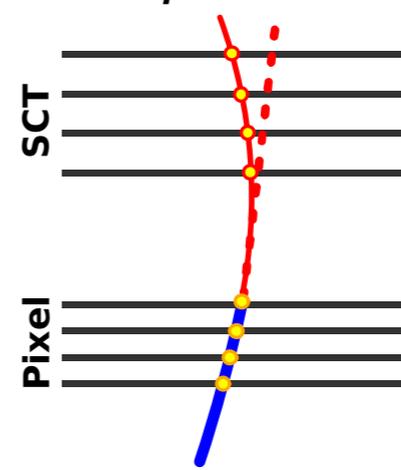Need custom track reconstruction logic and algorithm

Need unique data-driven background estimations techniques

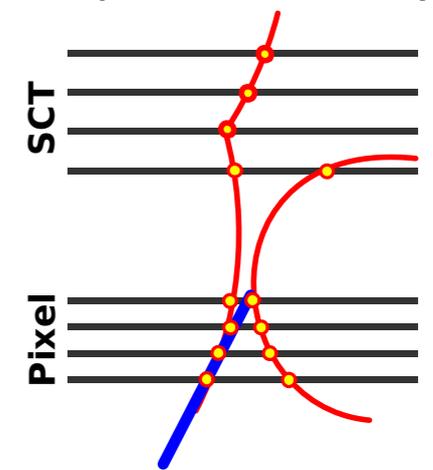Need to suppress backgrounds from mis-measurements/fakes

Hadron emitting hard scatter

Lepton emitting photon

Random hits (combinatorics)

SCT

neutral *charged*

Pixel

tracklet

Standard track reconstruction → Unassociated pixel hits → *Tracklets*

Number of observed events		
	9	
Number of expected events		
Hadron+electron background	6.1	± 0.6
Muon background	0.15	± 0.09
Fake background	5.5	± 3.3
Total background	11.8	± 3.1
Number of expected signal events for the higgsino LSP model with $(m_{\tilde{\chi}_1^\pm}, \tau_{\tilde{\chi}_1^\pm}) = (160\,\text{GeV}, 0.05\,\text{ns})$		
	10.3	± 2.1
Number of expected signal events for the wino LSP model with $(m_{\tilde{\chi}_1^\pm}, \tau_{\tilde{\chi}_1^\pm}) = (400\,\text{GeV}, 0.2\,\text{ns})$		
	13.5	± 2.1
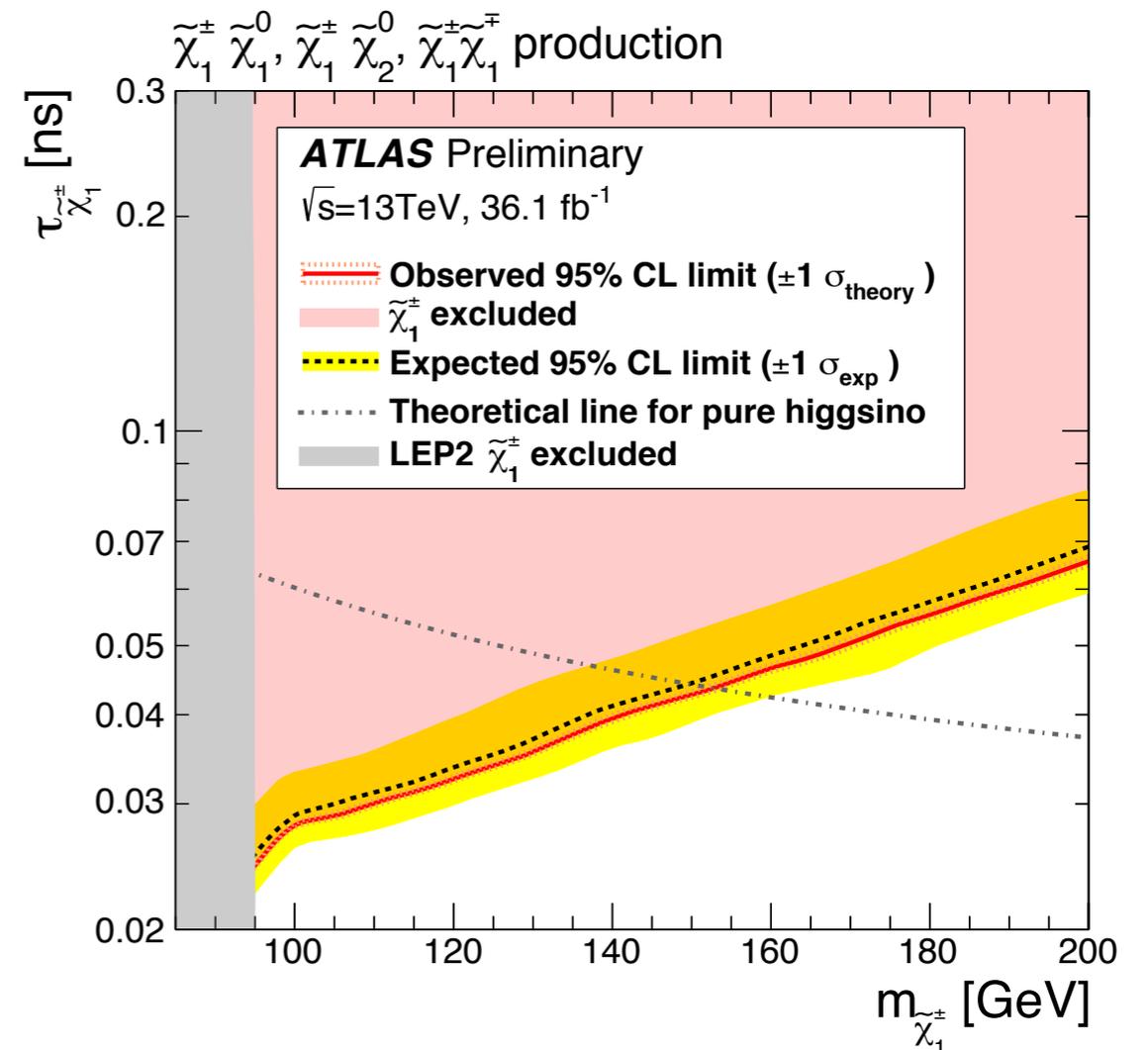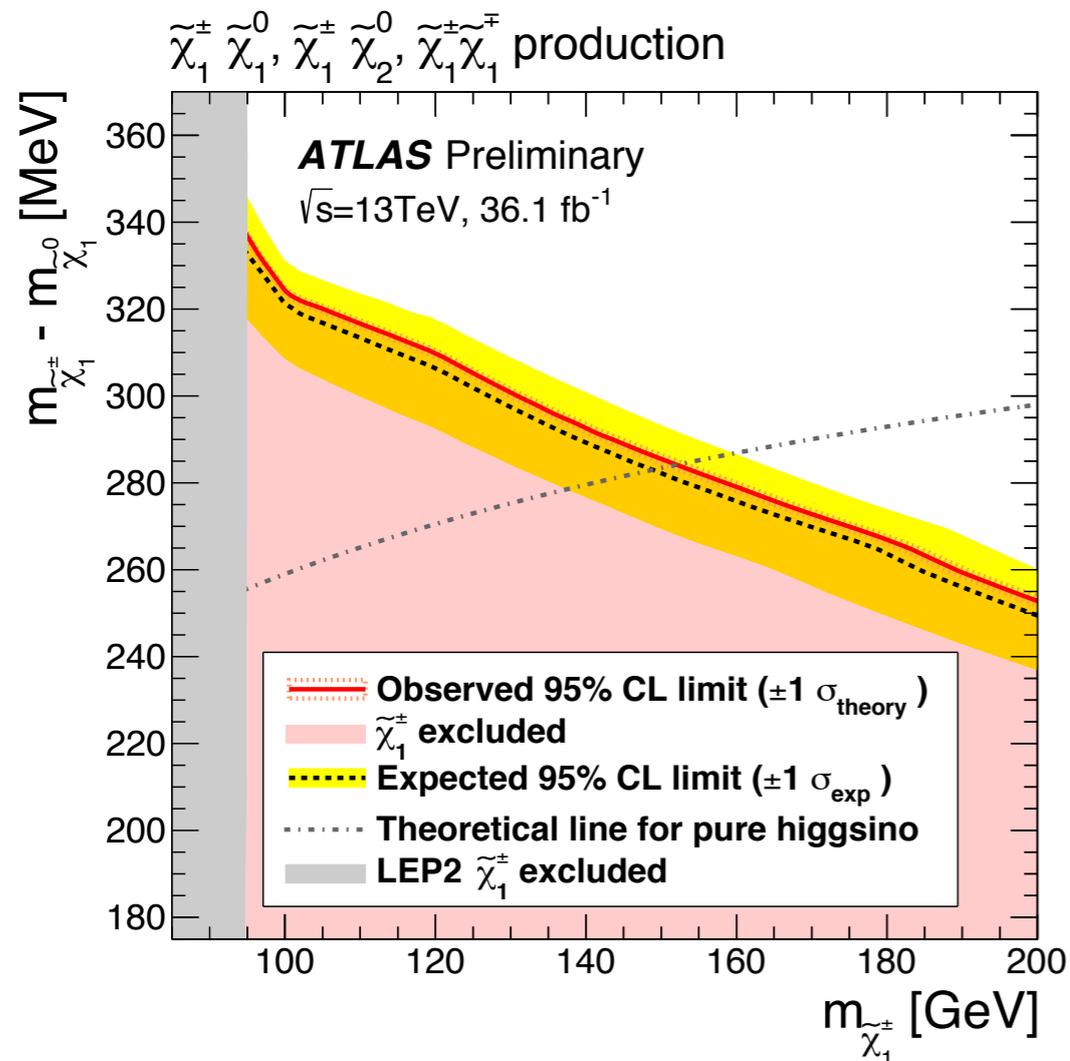
Scenario 3 : ≥3b-jets
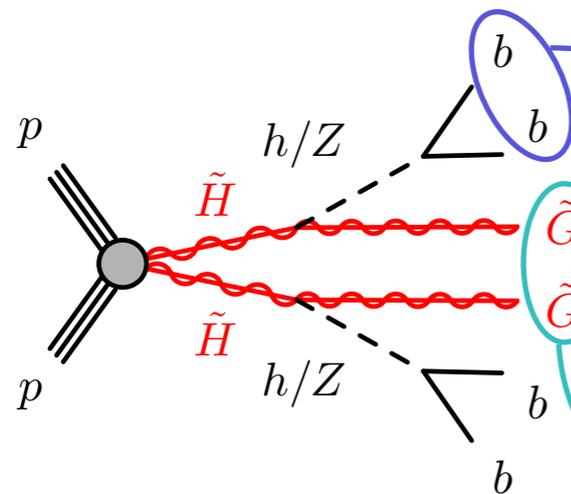
Experimental signature:

Massless $\tilde{G}$ allows on-shell h/Z decays,

$h \rightarrow b\bar{b}$ gives powerful $4b$ final state w/ large branching ratios,

missing transverse momentum (MET) from $\tilde{G}$

Low-mass search ($m_{\tilde{H}} < 300$ GeV):

b-jet triggers
(allows probing low-MET)

≥4b-jets
(use 4 w/ highest b-tag score)
paired based on ΔR_{jj} and m_{jj}

Multi-bins in MET and m_{eff} (Σp_T^j+MET)

Data-driven background from 2b-jets

High-mass search ($m_{\tilde{H}} > 300$ GeV):

MET >200 GeV
(triggering)

≥4 jets (≥3 b-tagged),
paired based on ΔR_{jj} (captures both h/Z)

Separated jets and large m_{eff}

$t\bar{t}$ normalized to data,
other backgrounds from Monte-Carlo
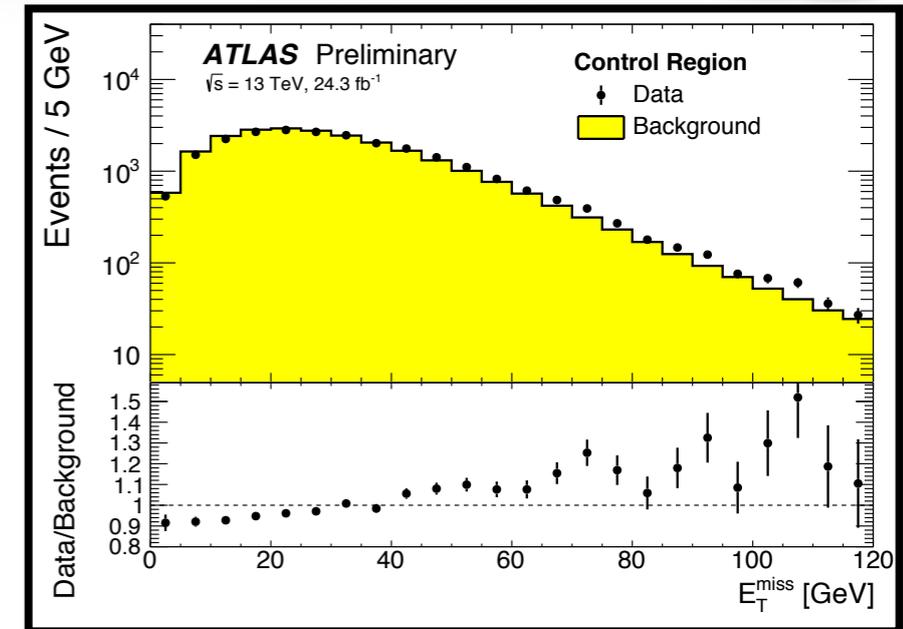
Scenario 3 : Challenges

Analysis aims to cover both low- and high-$m_{\tilde{H}}$:

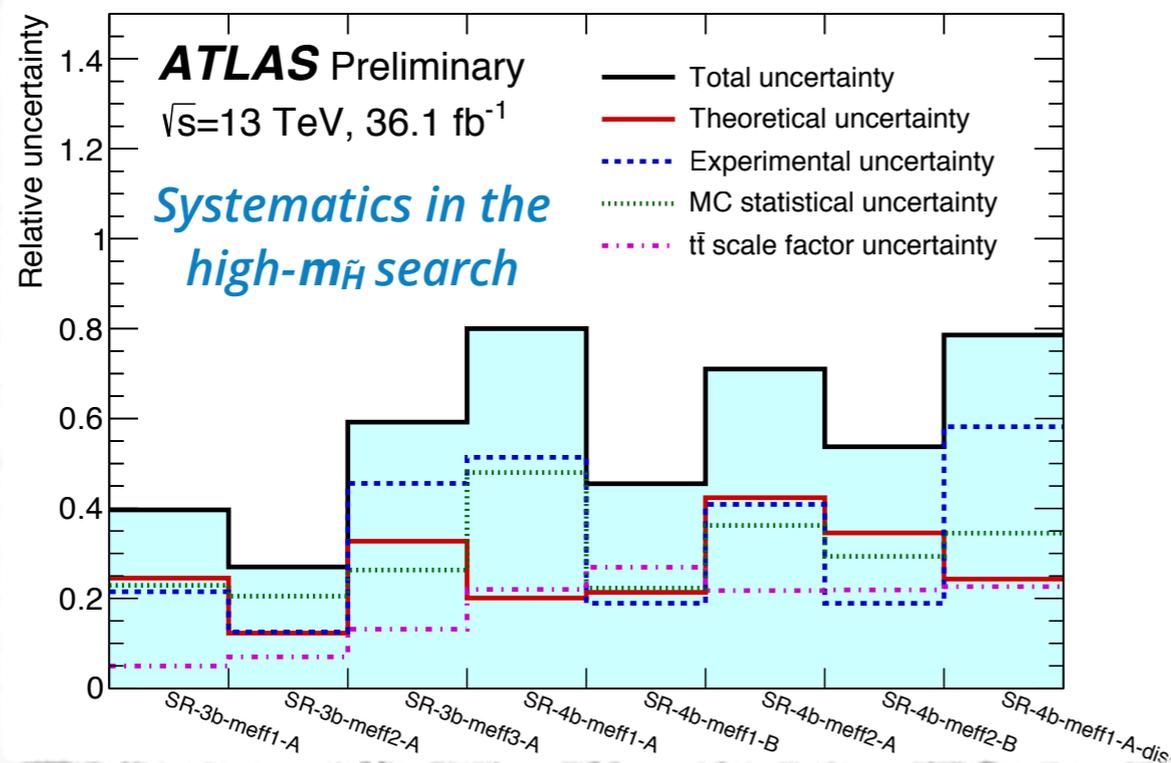Need independent trigger strategies to maximize sensitivity

Need to keep optimization a bit generic to capture both h/Z

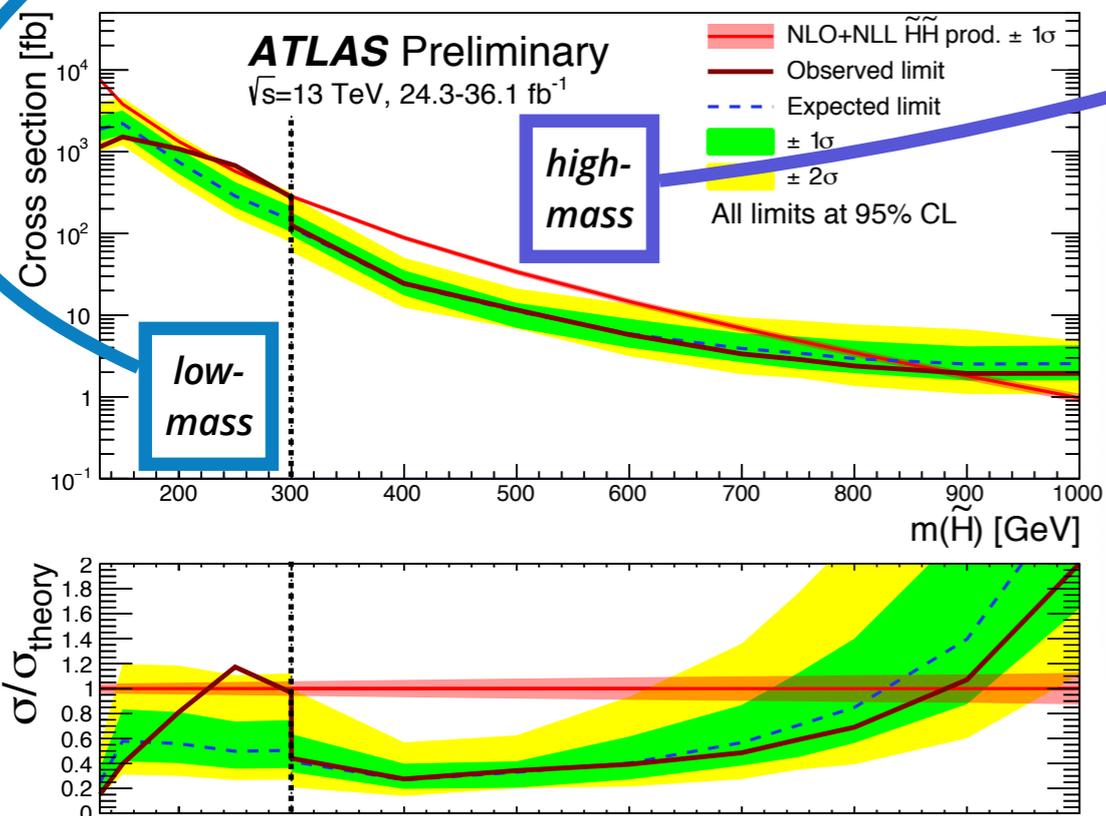Need to carefully optimize flavor tagging strategy
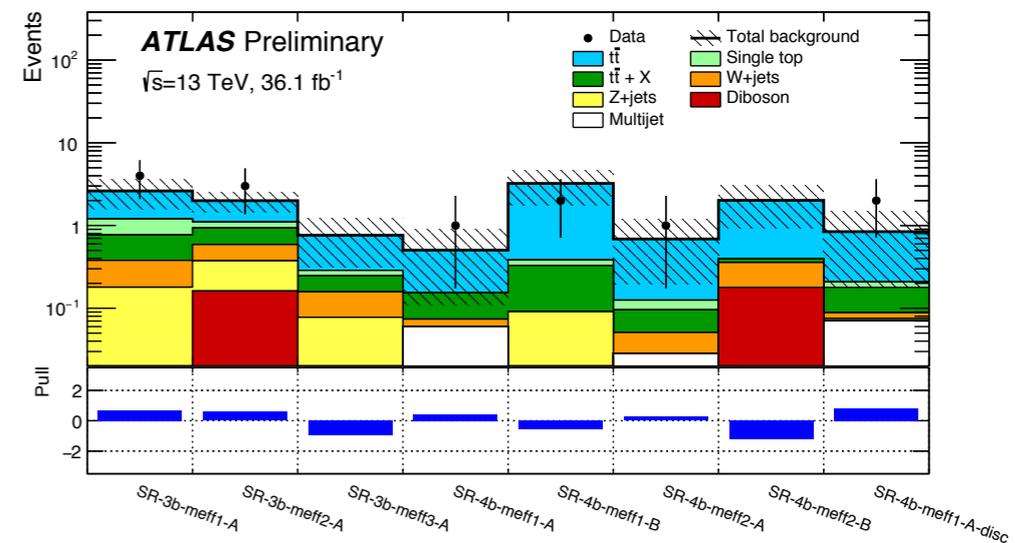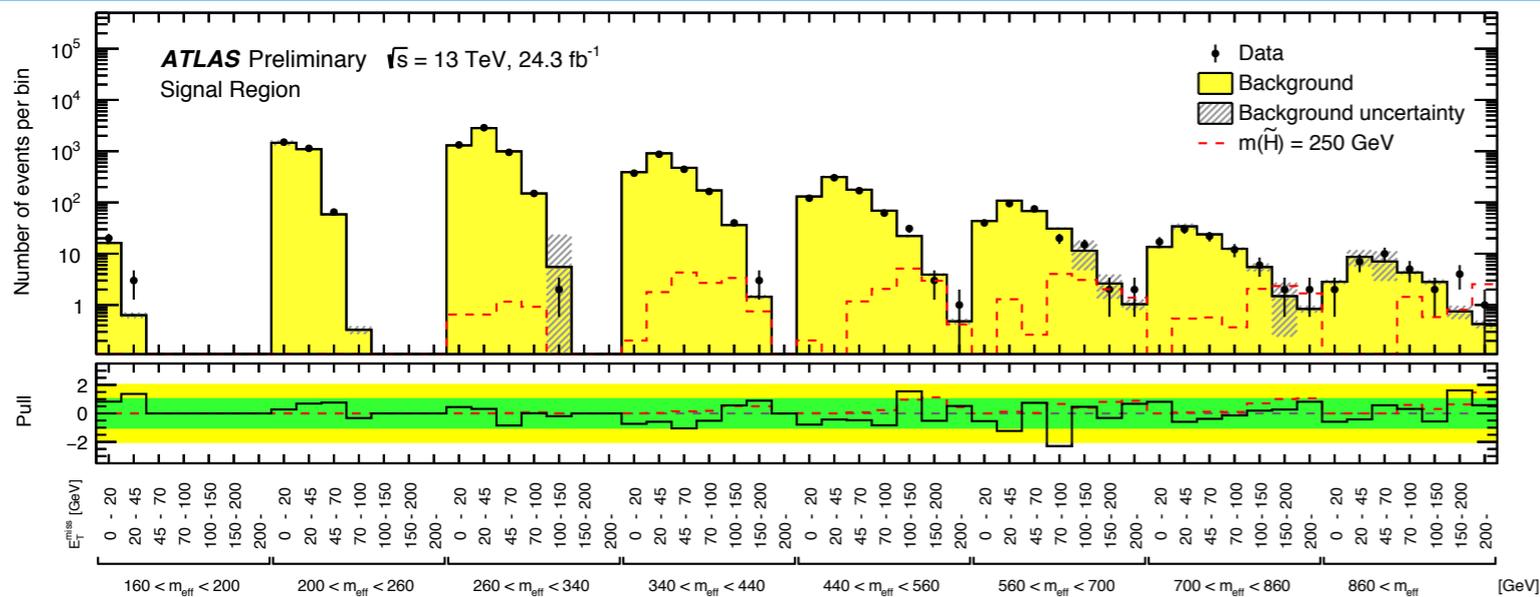
Need careful data-driven background estimate (i.e. low-$m_{\tilde{H}}$)

In low-$m_{\tilde{H}}$ search extract 2-tag → 4-tag *normalization* and *shape* corrections in dedicated regions using BDT (purely *data-driven*)
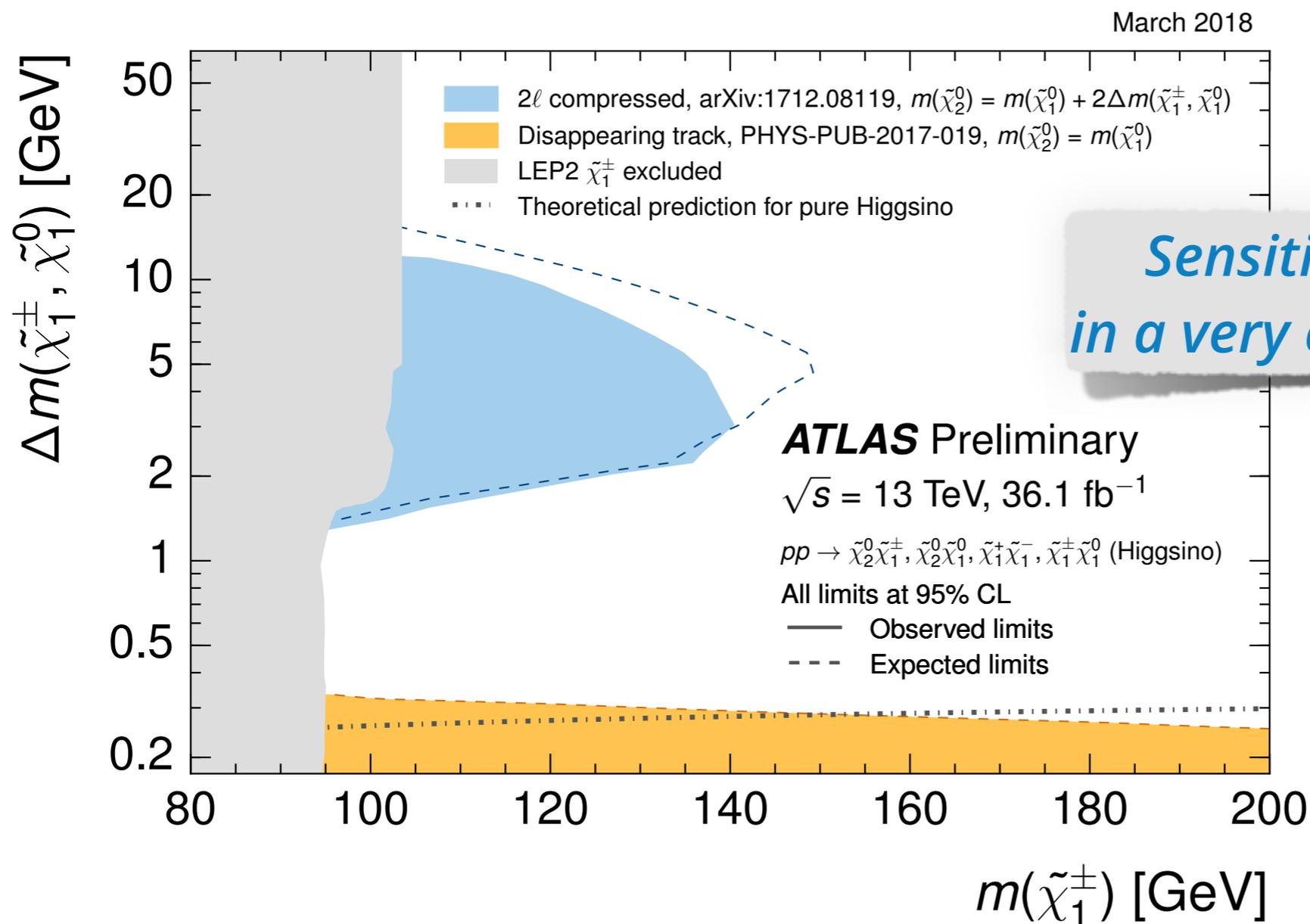
Total of
56 complementary bins in low-mass selection
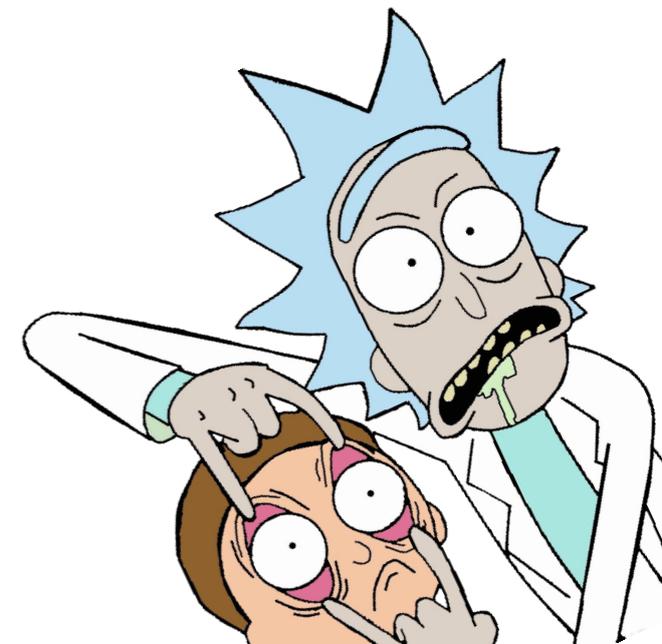**8 complementary bins in high-mass selection**

Largest excess is ~2σ
(4 data vs 1.0±0.2 background)

Conclusions and Outlook

- ATLAS has a strong Higgsino search program that's getting even stronger!
  - Many more results to come, stay tuned…

March 2018

Sensitivity beyond LEP limits in a very challenging phase-space!

The figure shows a plot with axes $\Delta m(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0)$ [GeV] versus $m(\tilde{\chi}_1^\pm)$ [GeV]. Legend entries:
- 2ℓ compressed, arXiv:1712.08119, $m(\tilde{\chi}_2^0) = m(\tilde{\chi}_1^0) + 2\Delta m(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0)$
- Disappearing track, PHYS-PUB-2017-019, $m(\tilde{\chi}_2^0) = m(\tilde{\chi}_1^0)$
- LEP2 $\tilde{\chi}_1^\pm$ excluded
- Theoretical prediction for pure Higgsino

ATLAS Preliminary

$\sqrt{s}$ = 13 TeV, 36.1 fb^{-1}

$pp \to \tilde{\chi}_2^0\tilde{\chi}_1^\pm, \tilde{\chi}_2^0\tilde{\chi}_1^0, \tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^\pm\tilde{\chi}_1^0$ (Higgsino)

All limits at 95% CL
- Observed limits
- - - Expected limits

Backup

Scenario 1 : Soft-leptons + jets

m_{T2} distribution in the Slepton signal region