Searches for electroweak production of higgsino with ATLAS

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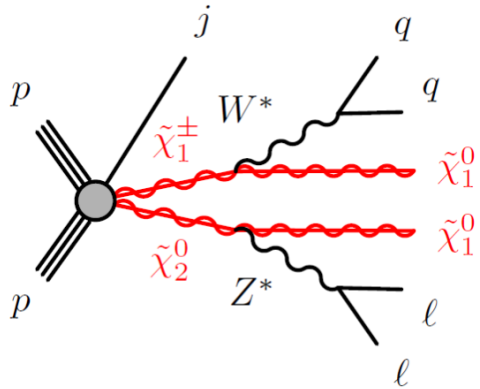
Introduction

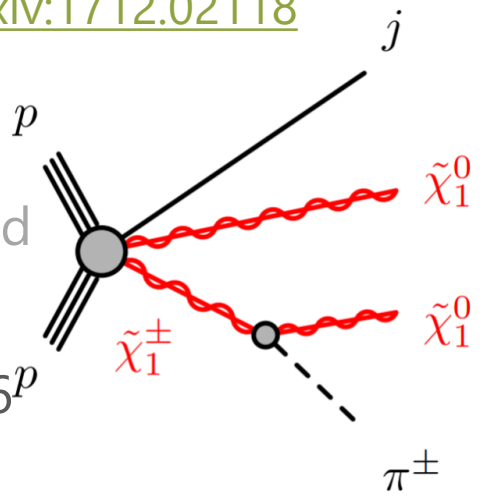
- Electroweakinos
  - Higgsino, Bino and Wino are mixed and form electroweakinos
    - 4 neutralinos $\tilde{\chi}^0_{i=1,2,3,4}$ and 2 charginos $\tilde{\chi}^{\pm}_{i=1,2}$
- "Naturalness" criterion suggests that the Higgsino mass parameter (μ) is near the weak scale (arxiv:1110.6926)
  - Naturalness in MSSM (tree level): $-\frac{m_Z^2}{2} = |\mu|^2 + m_{H_u}^2$
  - **In naturalness scenario, $\tilde{\chi}^0_1$, $\tilde{\chi}^{\pm}_1$ and $\tilde{\chi}^0_2$ are dominated by Higgsino**
    - Those lightest electroweakinos are separated by O(0.1) - O(10) GeV
- Higgsino search is well motivated, but it is challenging
  - Low production cross section
  - Soft decay products (next page)

Overview of Higgsino search

- Depending on $\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0)$, different signal characteristics are expected
- $\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0) \approx$ few GeV: **Soft lepton** arxiv:1712.08119
  - NLSPs decay via off shell W/Z
  - Due to small mass gap, very soft leptons are expected



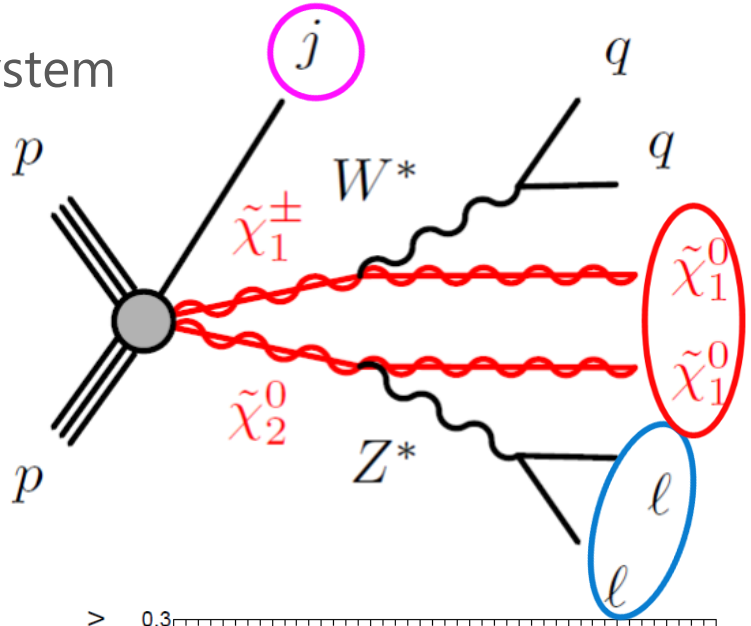
- $\Delta m(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0) \approx$ few hundred MeV: **disappearing track** ATL-PHYS-PUB-2017-019 arxiv:1712.02118
  - $\tilde{\chi}_1^\pm$ decay via soft $\pi^\pm$ with long lifetime
  - Non-standard "disappearing" chargino track is expected
- Higgsino search with assuming GGM was also performed (arxiv: 1806.04030, arxiv: 1804.03602)
- All results are with 36.1 fb^{-1} data collected in 2015+2016

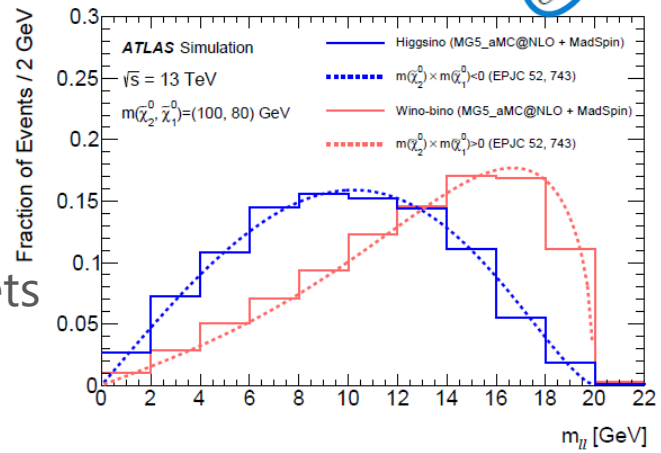


Soft lepton

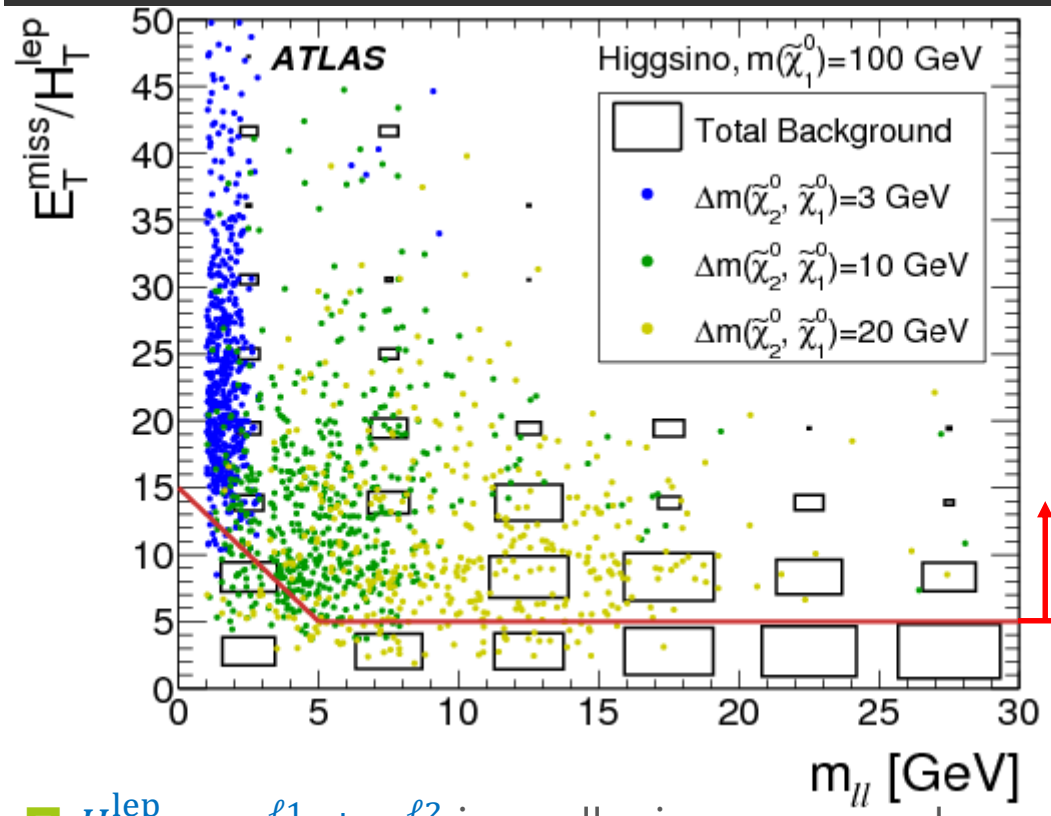
Soft lepton: Overview

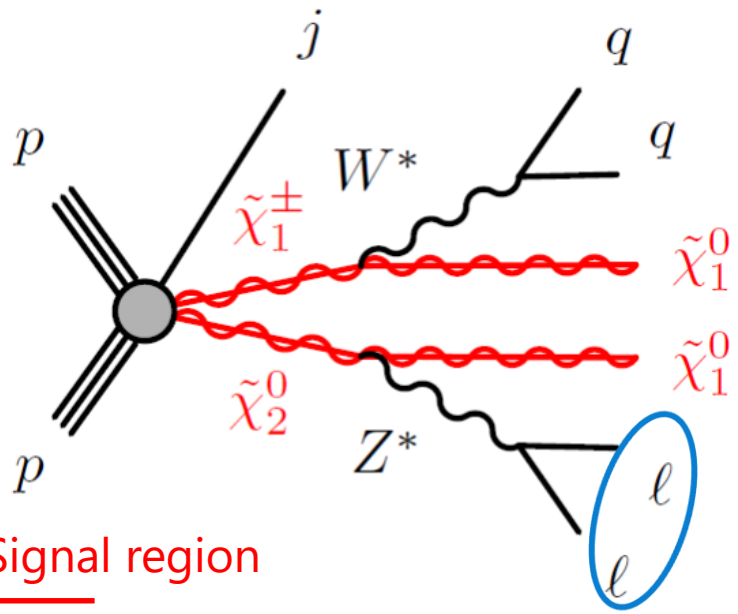
- High p_T (> 100 GeV) ISR jet boosts $\tilde{\chi}_2^0\tilde{\chi}_1^\pm$ system
  - E_T^{miss} is enhanced and used as trigger (>200 GeV is requested)
- $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 Z^* \to \tilde{\chi}_1^0 \ell\ell$ is essential
  - $m_{\ell\ell}$ has kinematic endpoint at $\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0)$
  - $m_{\ell\ell}$ is used as a final discriminant
- Final state:
  - Same flavor exactly two leptons
  - At least one jet
  - Large E_T^{miss}
- Backgrounds:
  - Irreducible: Diboson+jets, tt, tW, and Z→ττ + jets
  - Reducible: Fake/non-prompt leptons





Soft lepton: Suppress diboson

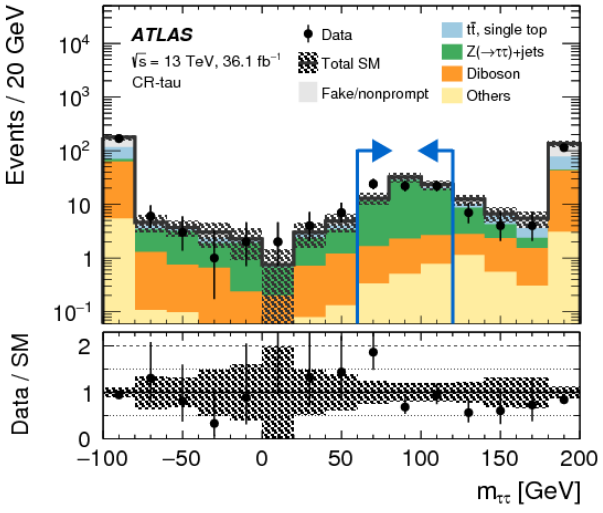




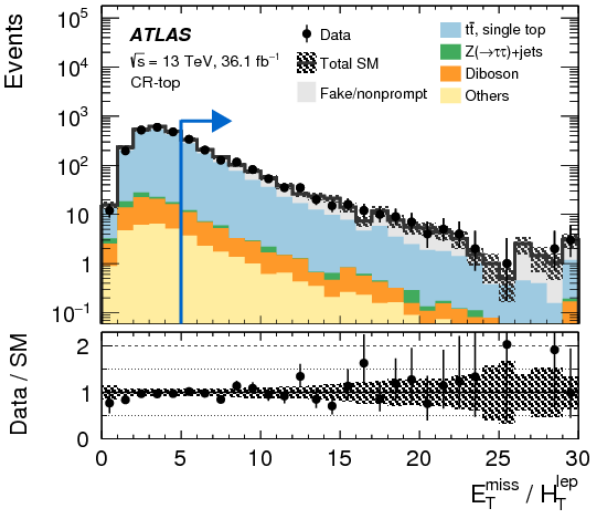
- $H_T^{\mathrm{lep}} = p_T^{\ell 1} + p_T^{\ell 2}$ is smaller in compressed-scenario signal than in diboson+jets
- Especially for small mass splitting, large $E_T^{miss}/H_T^{\mathrm{lep}}$ is expected
  - Tight requirement is applied for smaller mass splitting

Soft lepton: Other backgrounds

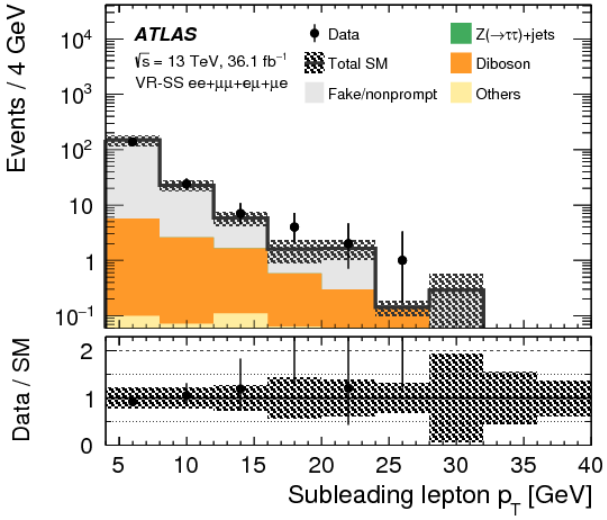
- Z→ττ control region



- Top control region

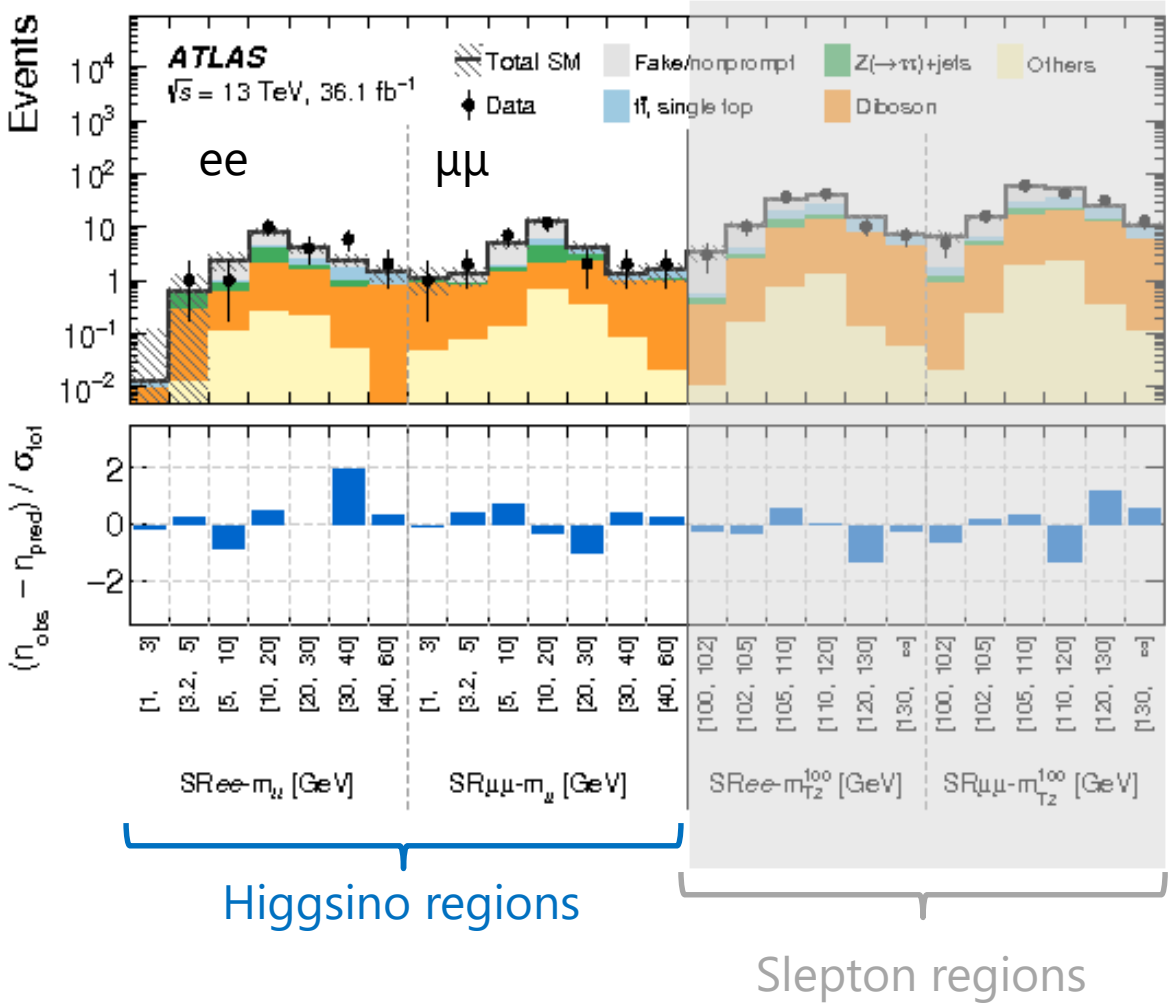


- Validation region



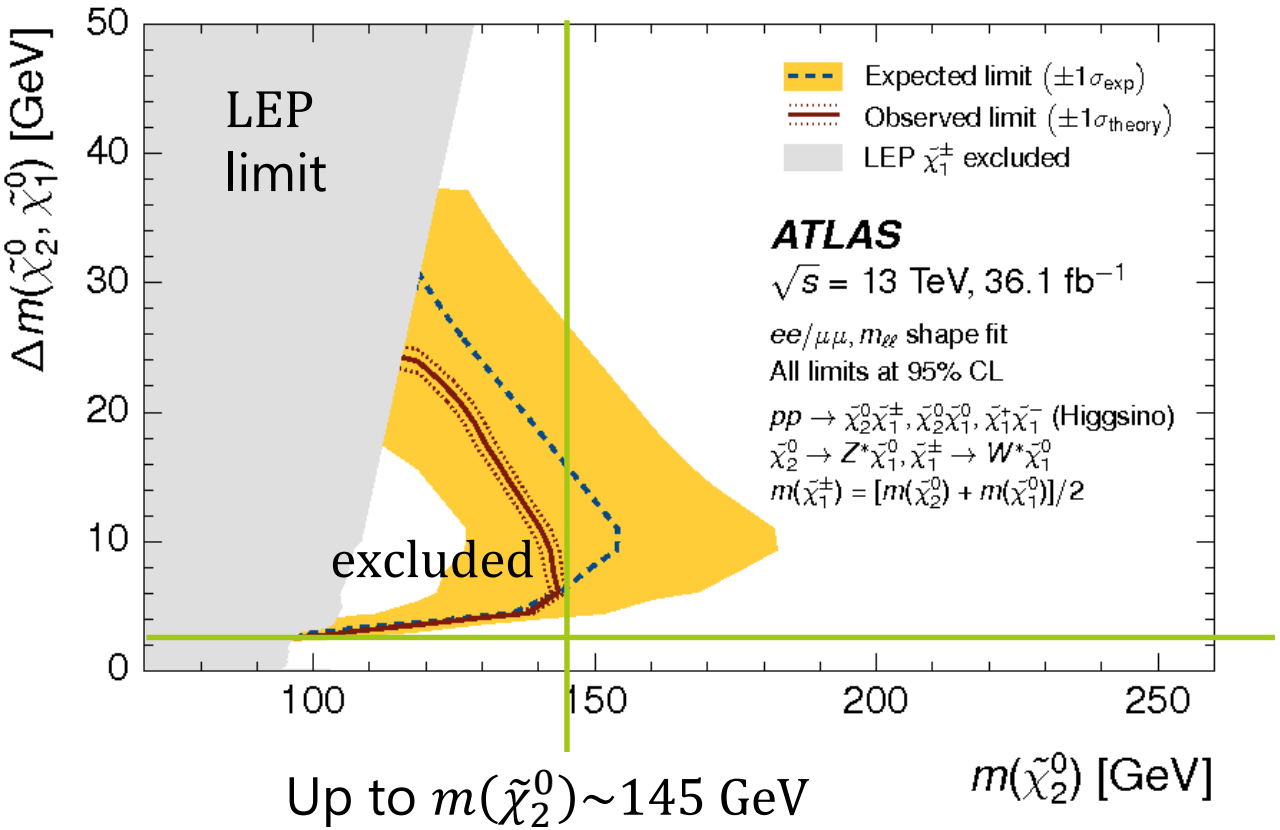
- Z→ττ + jets, tt and tW
  - $m_{\tau\tau}$ selection and b-jet veto
  - MC normalized using data in control regions
- Fake/non-prompt leptons
  - estimated using data-driven Fake Factor method
  - Validated using data in same-sign dilepton region

Soft lepton: Results



- $m_{\ell\ell}$ distribution of observed data are compared with SM expectation
- No significant excess
- Based on $m_{\ell\ell}$ shape, some signal mass are excluded (next page)

Soft lepton: Interpretation



Up to $m(\tilde{\chi}_2^0)$~145 GeV

Down to $\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0)$~2.5 GeV

- **New limits beyond LEP result!**

Disappearing track

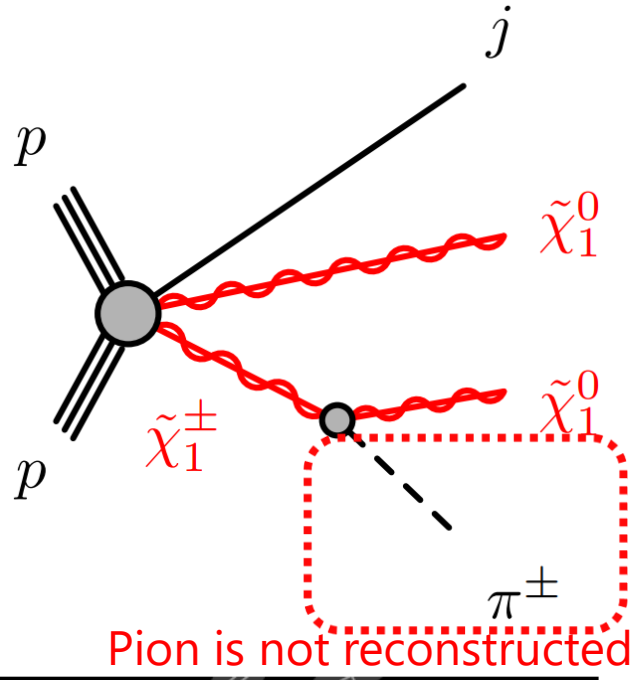
Disappearing track: Overview

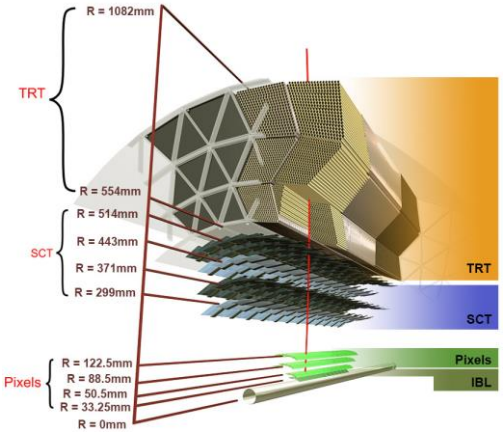
- In compressed scenario, $\tilde{\chi}_1^{\pm}$ has long lifetime

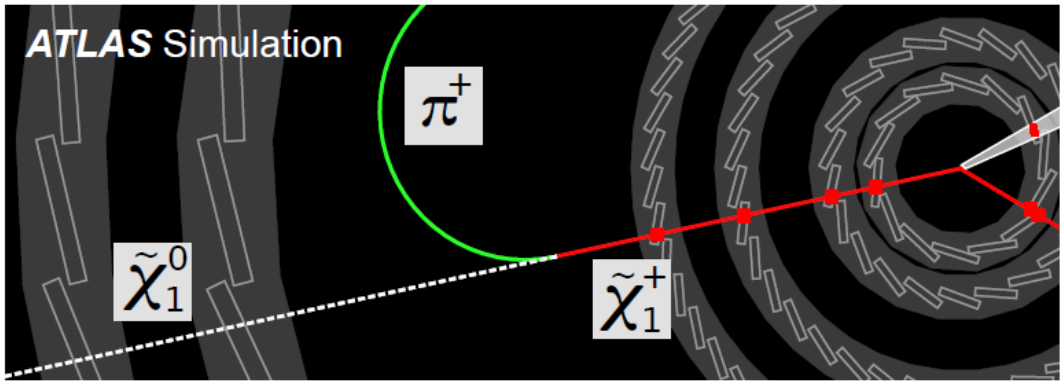
$$c\tau[\mathrm{mm}] \sim 7 \times \left[\left(\frac{\Delta m\left(\tilde{\chi}_1^{\pm}, \tilde{\chi}_{1,2}^{0}\right)}{340\,\mathrm{MeV}} \right)^3 \sqrt{1 - \frac{m_\pi^2}{\Delta m\left(\tilde{\chi}_1^{\pm}, \tilde{\chi}_{1,2}^{0}\right)^2}} \right]^{-1}$$

  - Expected cτ range: 8 mm to 20 mm

- Pion from $\tilde{\chi}_1^{\pm}$ decay has too low momentum to reconstruct track
  - Therefore, track is "disappearing"

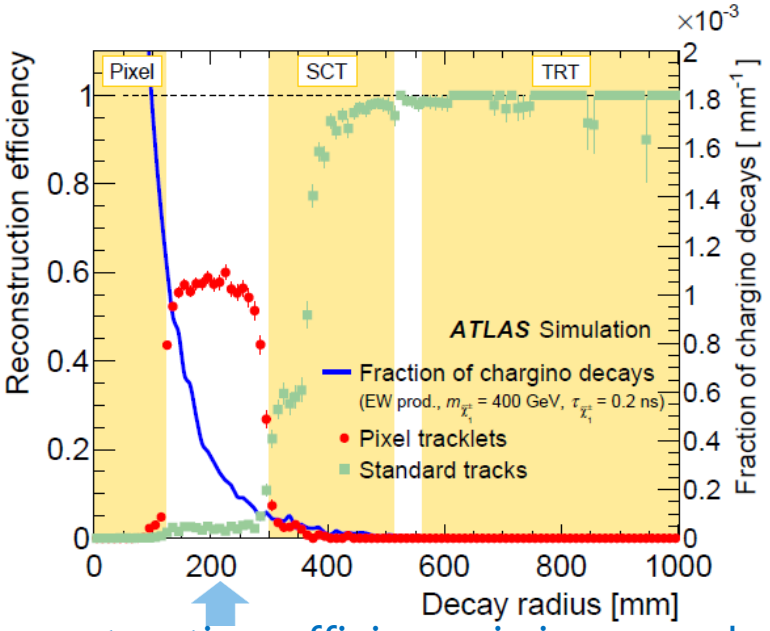




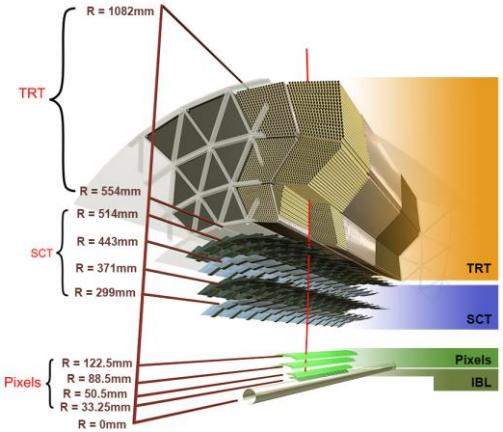


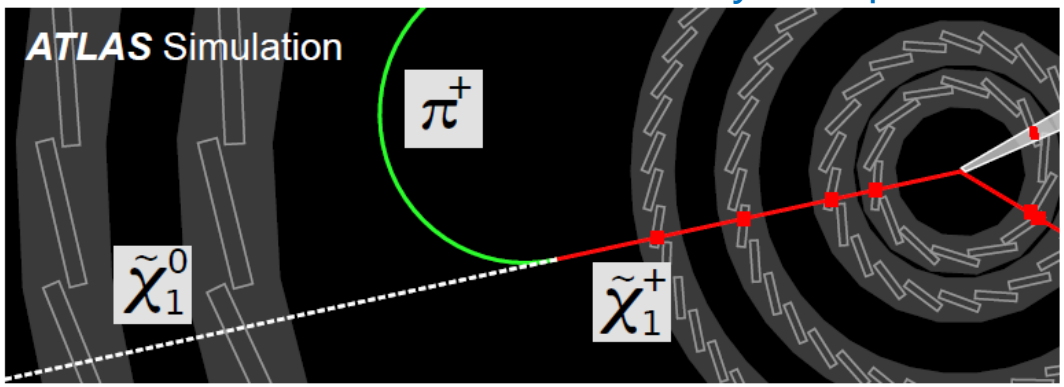
Disappearing track: Track reconstruction

- Inner Detector consists of:
  - Pixels: r = [30,120] mm ← installed IBL!
  - SCT: r = [300,520] mm
  - TRT: r = [560,1080] mm
- $\tilde{\chi}_1^{\pm}$ may decay between Pixels and SCT
  - After standard track reconstruction, hits not associated to standard track are used for "tracklet" reconstruction



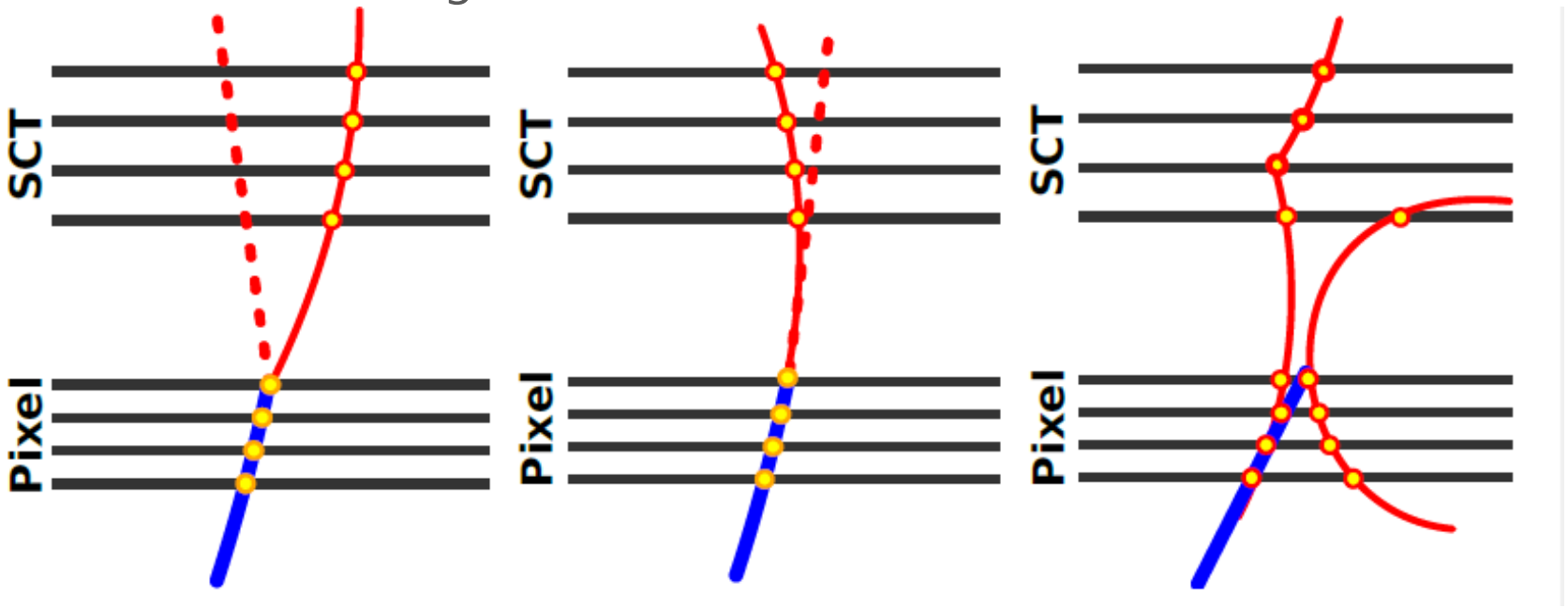
Reconstruction efficiency is improved





Disappearing track: Background

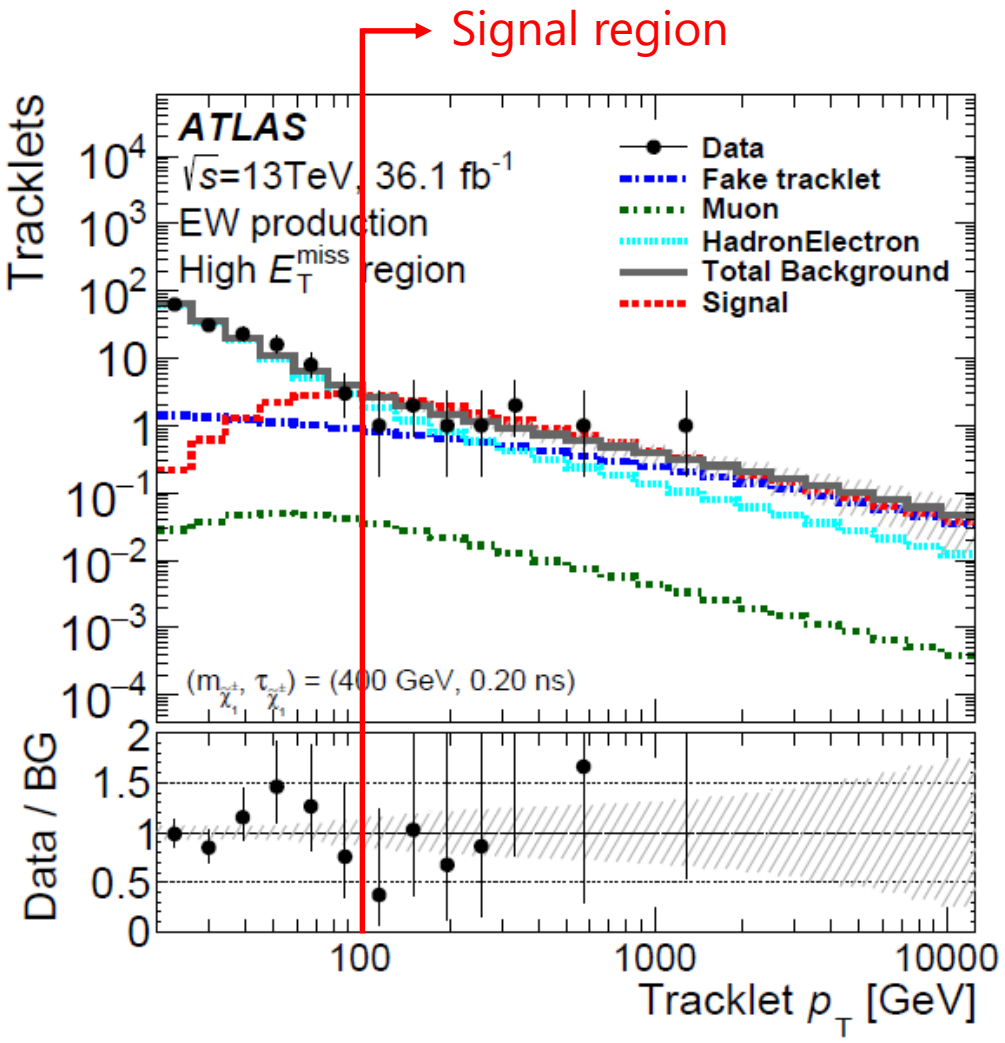
- Hadron scattering
- Photon emission
- Fake tracklet



- Suppression: isolation, impact parameter of tracklet requirement
- Estimation: templates for background components are estimated from data
  - Templates are fitted to control samples

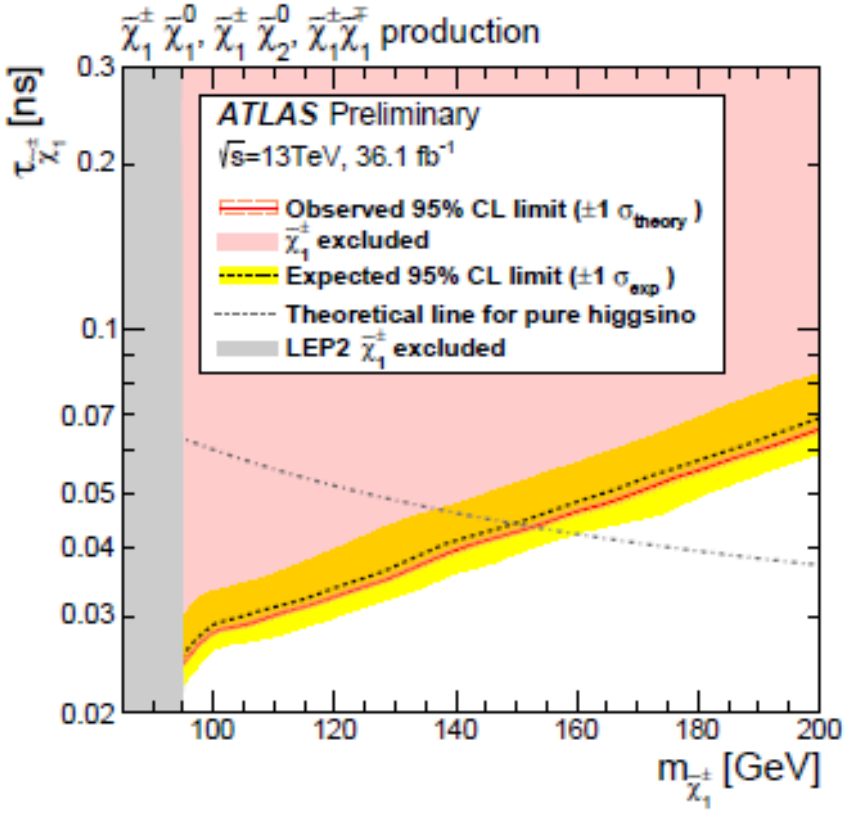
Disappearing track: Results

- Expected events: 11.8 ± 3.1
  - Hadron+electron: 6.1 ± 0.6
  - Muon: 0.15 ± 0.09
  - Fake tracklet: 5.5 ± 3.3
- Observed events: 9
- No excess
  - Based on profile-likelihood fits, some signal mass and lifetime are excluded (next page)

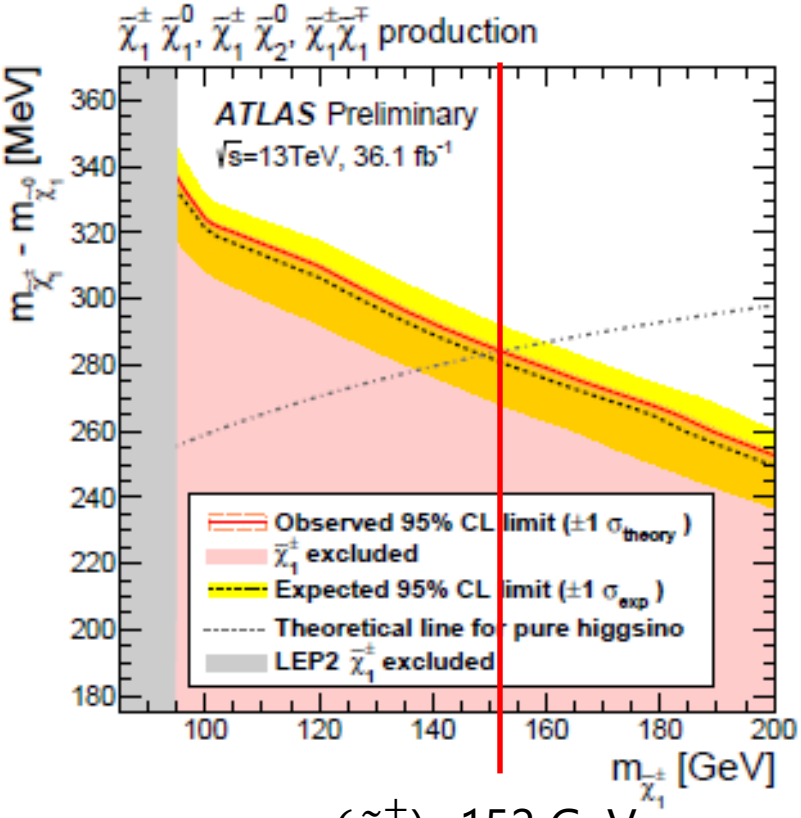


Disappearing track: Interpretation

- Limit on lifetime of $\tilde{\chi}_1^{\pm}$



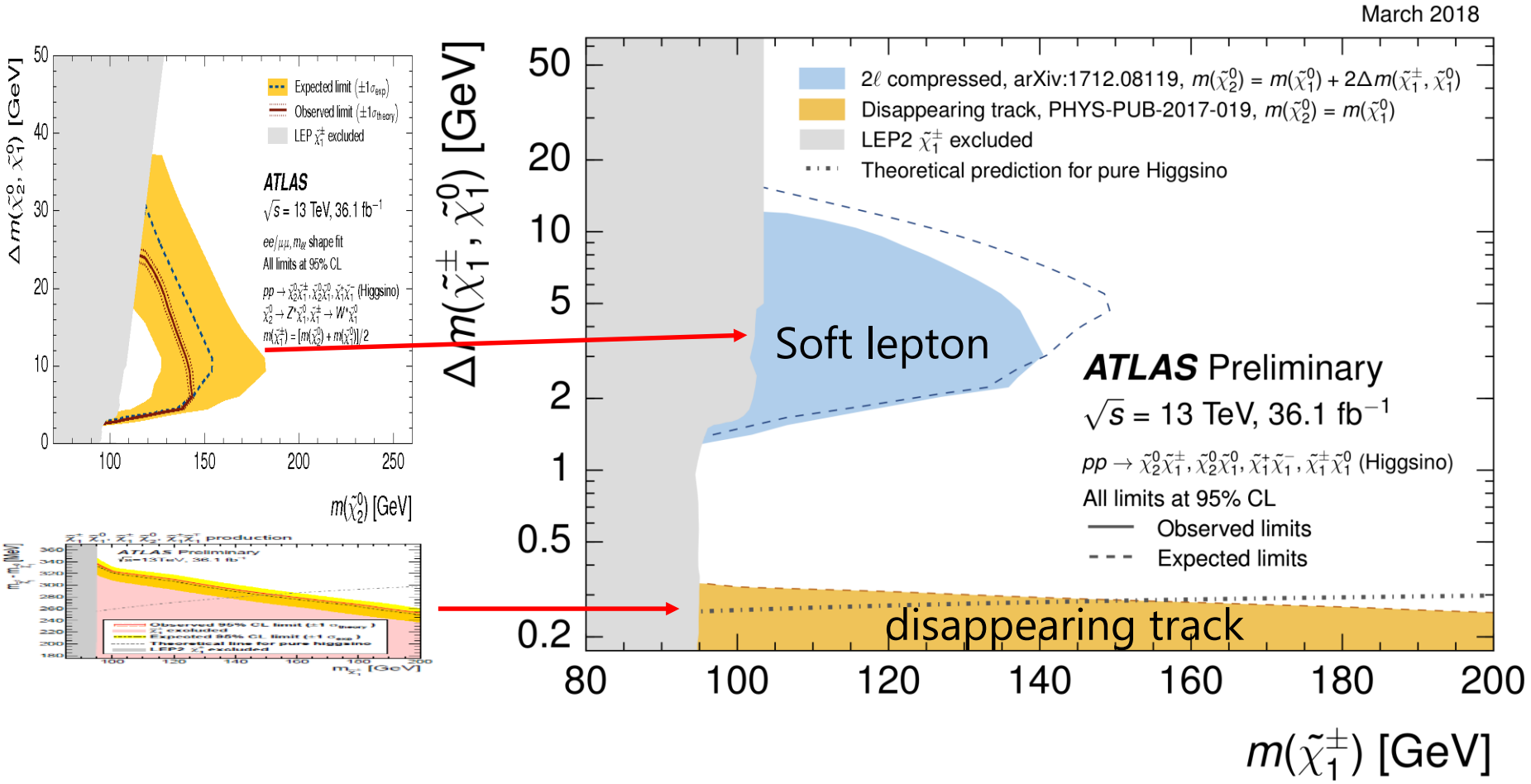
- Limit on $\Delta m(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0)$



$m(\tilde{\chi}_1^{\pm})$=152 GeV

- $\tilde{\chi}_1^{\pm}$ mass up to 152 GeV are excluded for pure higgsino model

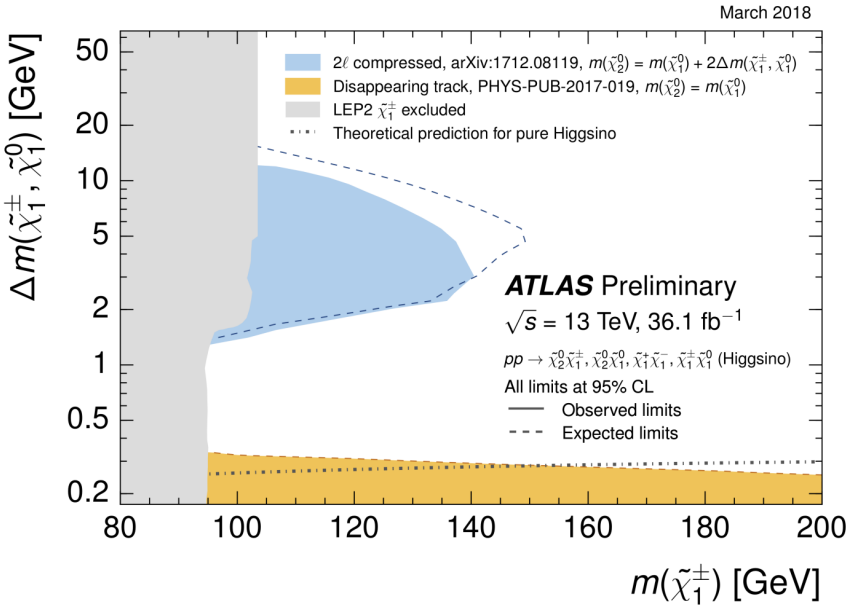
Combined result



- Soft lepton search and disappearing track search are complementary

Summary

- Higgsino search is motivated by “naturalness”
- Depending on $\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0)$ scenario, two types of search were performed
  With 36.1 fb^{-1} data collected in 2015+2016
  - $\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0) \approx$ few GeV: **Soft lepton**
  - $\Delta m(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0) \approx$ few hundred MeV: **disappearing track**
- **New limits beyond LEP result!**



backup

Soft lepton: Assumptions

- Cross-section calculation:
  - Assuming pure Higgsino

- Mass splitting:
  - $m(\tilde{\chi}_1^{\pm})=1/2[m(\tilde{\chi}_1^0)+m(\tilde{\chi}_2^0)]$
  - O(100) MeV splittings are generated by radiative correction
  - >O(100) MeV splittings are requiring mixing with Wino or Bino

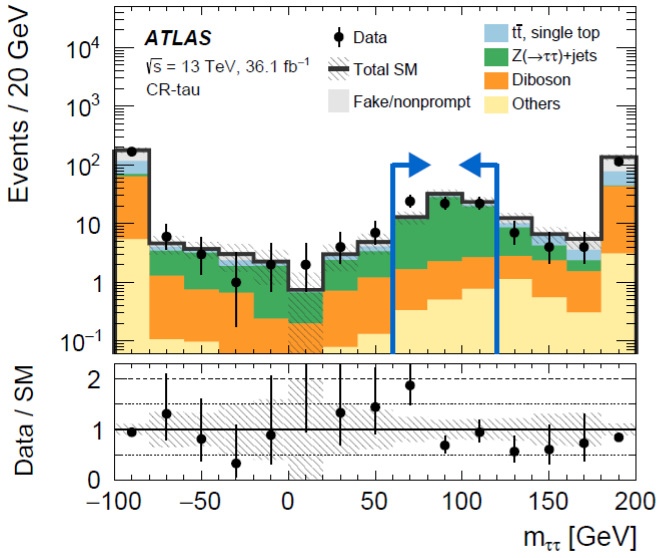
- Branching ratio
  - $BR(\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 Z^{*}) = BR(\tilde{\chi}_1^{\pm} \to \tilde{\chi}_1^0 W^{*}) = 100\%$

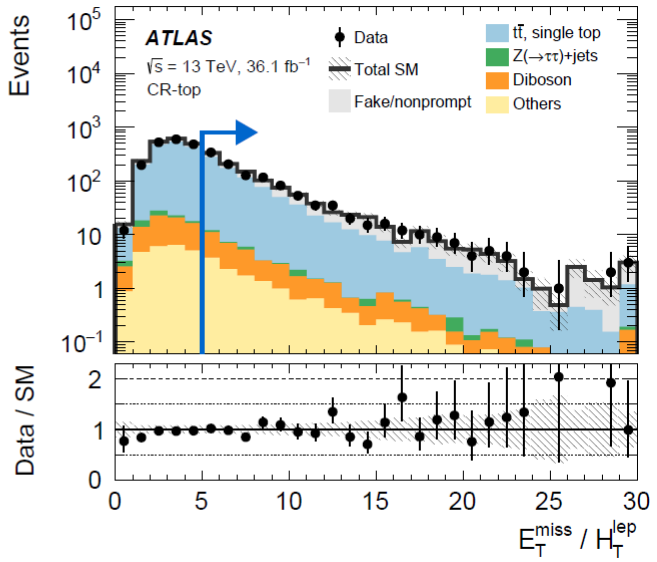
Soft lepton: Signal region

Variable	Common requirement	
Number of leptons	= 2	
Lepton charge and flavor	e^+e^- or $\mu^+\mu^-$	
Leading lepton $p_{\mathrm{T}}^{\ell_1}$	> 5 (5) GeV for electron (muon)	
Subleading lepton $p_{\mathrm{T}}^{\ell_2}$	> 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	←suppress J/ψ, Z
$E_{\mathrm{T}}^{\mathrm{miss}}$	> 200 GeV	
Number of jets	$\geq$ 1	
Leading jet p_{T}	> 100 GeV	
$\Delta\phi(j_1, \mathbf{p}_{\mathrm{T}}^{\mathrm{miss}})$	> 2.0	
$\min(\Delta\phi(\text{any jet}, \mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}))$	> 0.4	
Number of b-tagged jets	= 0	
$m_{\tau\tau}$	< 0 or > 160 GeV	
	Electroweakino SRs	Slepton SRs
$\Delta R_{\ell\ell}$	< 2	—
$m_{\mathrm{T}}^{\ell_1}$	< 70 GeV	—
$E_{\mathrm{T}}^{\mathrm{miss}}/H_{\mathrm{T}}^{\mathrm{lep}}$	$> \max\left(5, 15 - 2\frac{m_{\ell\ell}}{1\ \mathrm{GeV}}\right)$	$> \max\left(3, 15 - 2\left(\frac{m_{\mathrm{T2}}^{100}}{1\ \mathrm{GeV}} - 100\right)\right)$
Binned in	$m_{\ell\ell}$	m_{T2}^{100}

Soft lepton: CR and VR

Region	Leptons	$E_{\mathrm{T}}^{\mathrm{miss}}/H_{\mathrm{T}}^{\mathrm{lep}}$	Additional requirements
CR-top	$e^{\pm}e^{\mp}$, $\mu^{\pm}\mu^{\mp}$, $e^{\pm}\mu^{\mp}$, $\mu^{\pm}e^{\mp}$	> 5	≥ 1 b-tagged jet(s)
CR-tau	$e^{\pm}e^{\mp}$, $\mu^{\pm}\mu^{\mp}$, $e^{\pm}\mu^{\mp}$, $\mu^{\pm}e^{\mp}$	$\in [4, 8]$	$m_{\tau\tau} \in [60, 120]$ GeV
VR-VV	$e^{\pm}e^{\mp}$, $\mu^{\pm}\mu^{\mp}$, $e^{\pm}\mu^{\mp}$, $\mu^{\pm}e^{\mp}$	< 3	
VR-SS	$e^{\pm}e^{\pm}$, $\mu^{\pm}\mu^{\pm}$, $e^{\pm}\mu^{\pm}$, $\mu^{\pm}e^{\pm}$	> 5	
VRDF-$m_{\ell\ell}$	$e^{\pm}\mu^{\mp}$, $\mu^{\pm}e^{\mp}$	$> \max\left(5, 15 - 2\frac{m_{\ell\ell}}{1\ \mathrm{GeV}}\right)$	$\Delta R_{\ell\ell} < 2$, $m_{\mathrm{T}}^{\ell_1} < 70$ GeV
VRDF-m_{T2}^{100}	$e^{\pm}\mu^{\mp}$, $\mu^{\pm}e^{\mp}$	$> \max\left(3, 15 - 2\left(\frac{m_{\mathrm{T2}}^{100}}{1\ \mathrm{GeV}} - 100\right)\right)$	



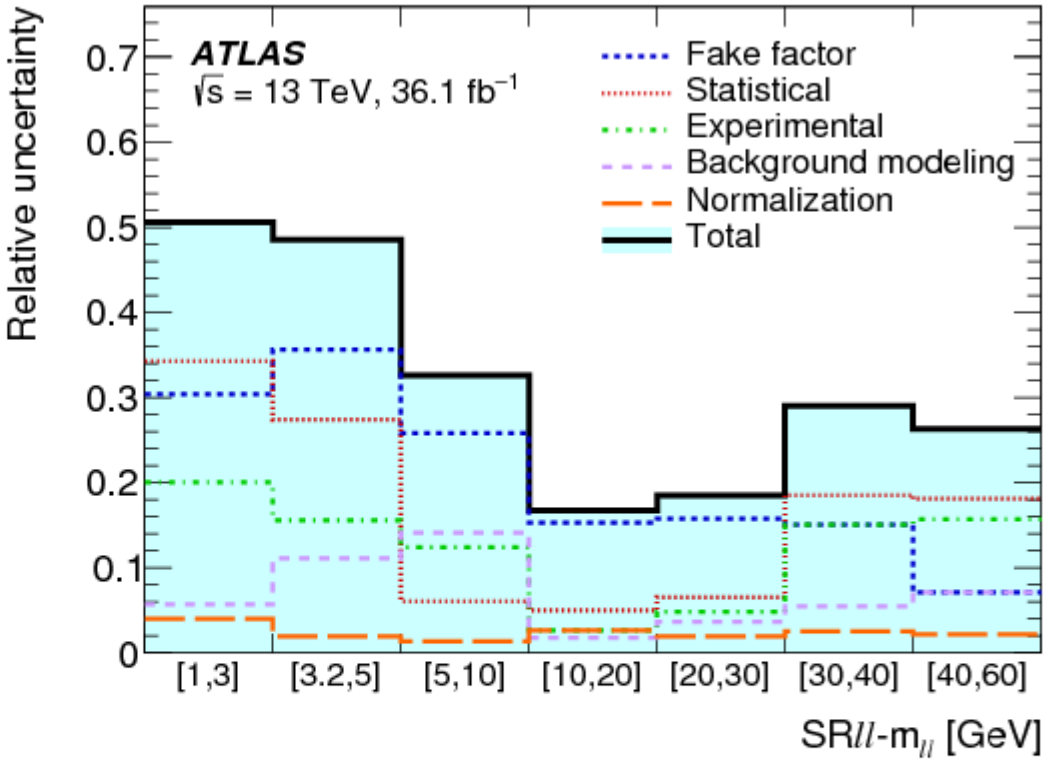


$$m_{\tau\tau} = \mathrm{sign}\left(m_{\tau\tau}^2\right)\sqrt{\left|m_{\tau\tau}^2\right|},$$

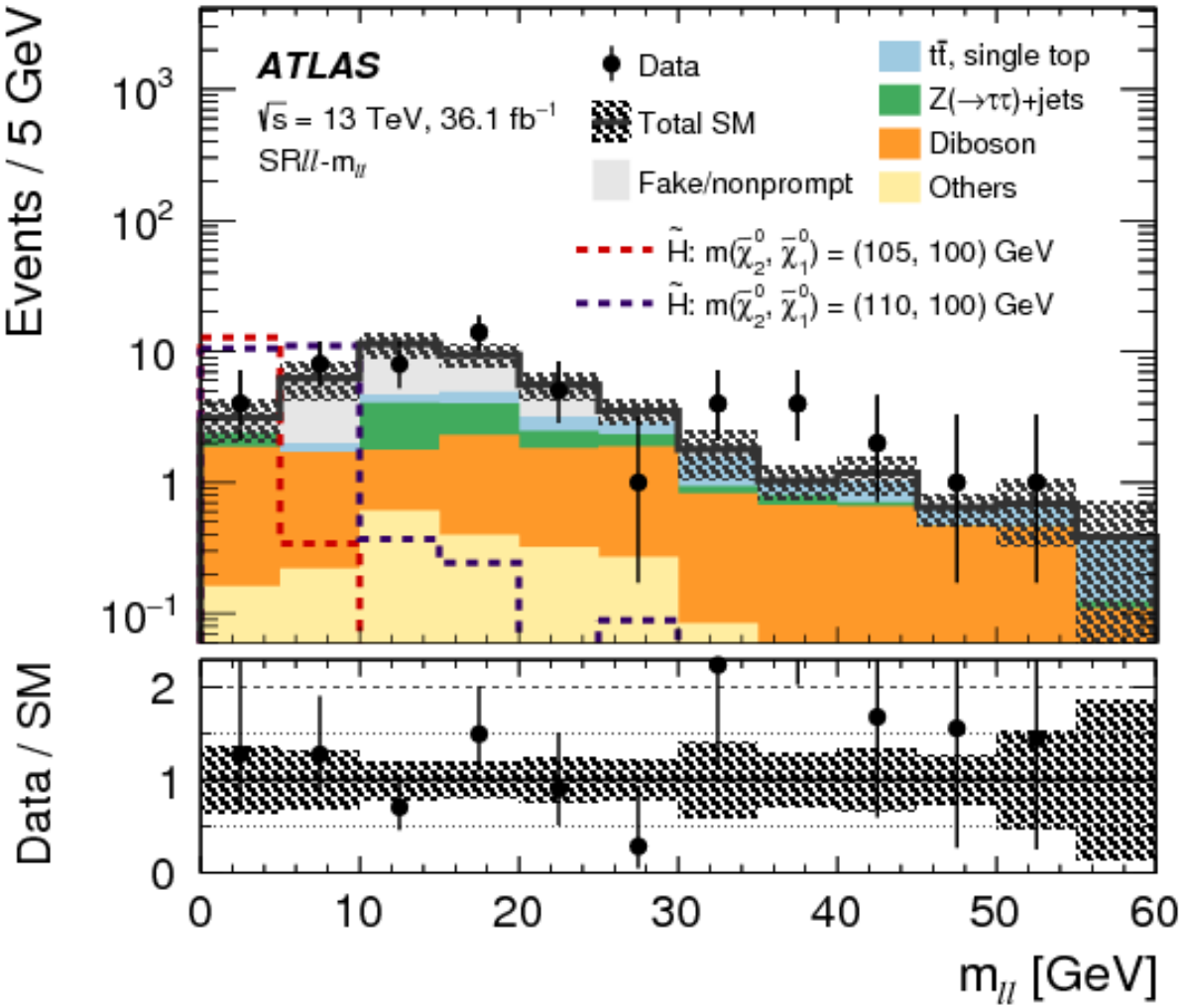
$$m_{\tau\tau}^2 \equiv 2p_{\ell_1}\cdot p_{\ell_2}(1+\xi_1)(1+\xi_2)$$

$$\mathbf{p}_{\mathrm{T}}^{\mathrm{miss}} = \xi_1\mathbf{p}_{\mathrm{T}}^{\ell_1} + \xi_2\mathbf{p}_{\mathrm{T}}^{\ell_2}$$

Soft lepton: Systematics



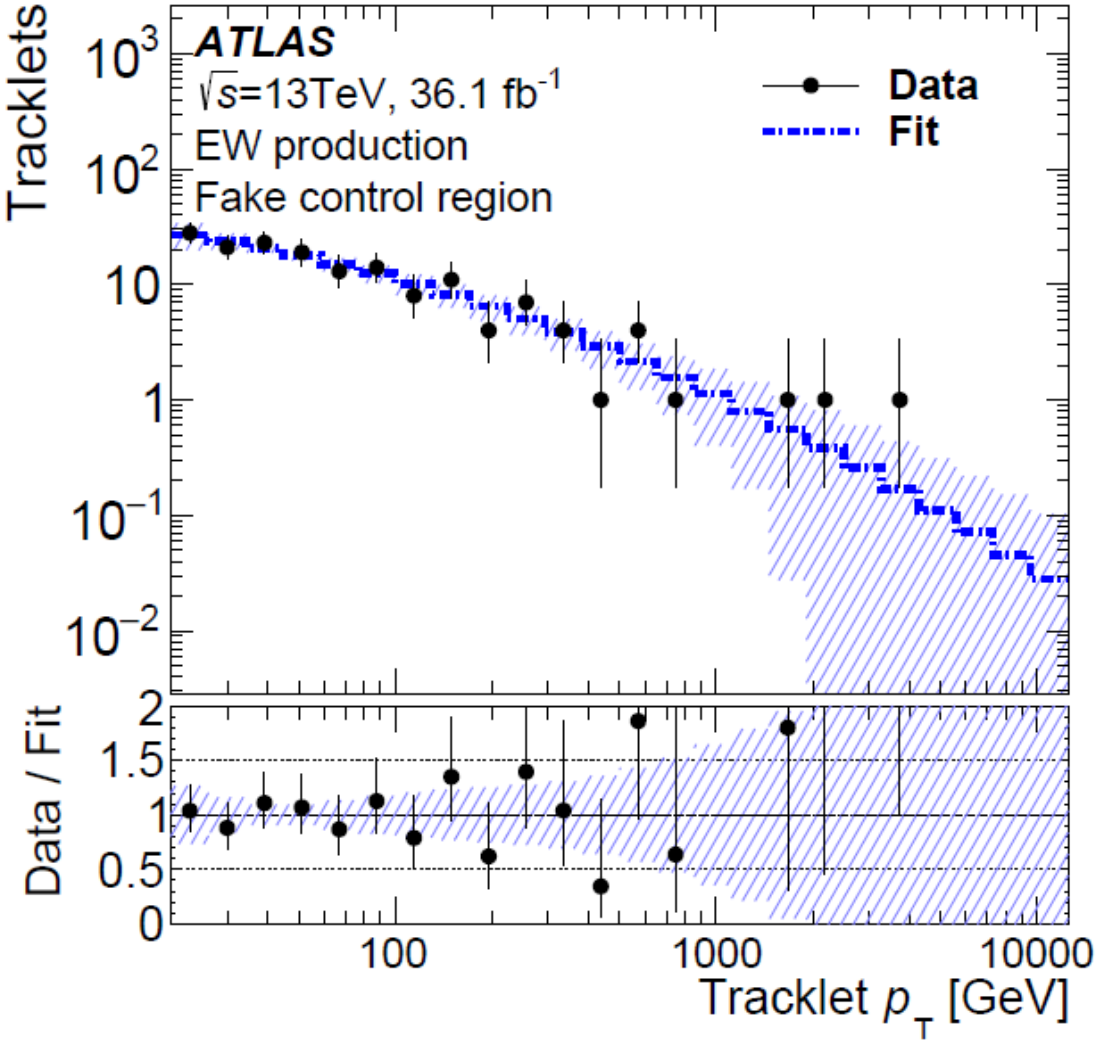
Soft lepton: $m_{\ell\ell}$ shape



Disappearing track: Fake tracklet template

- Fit function:

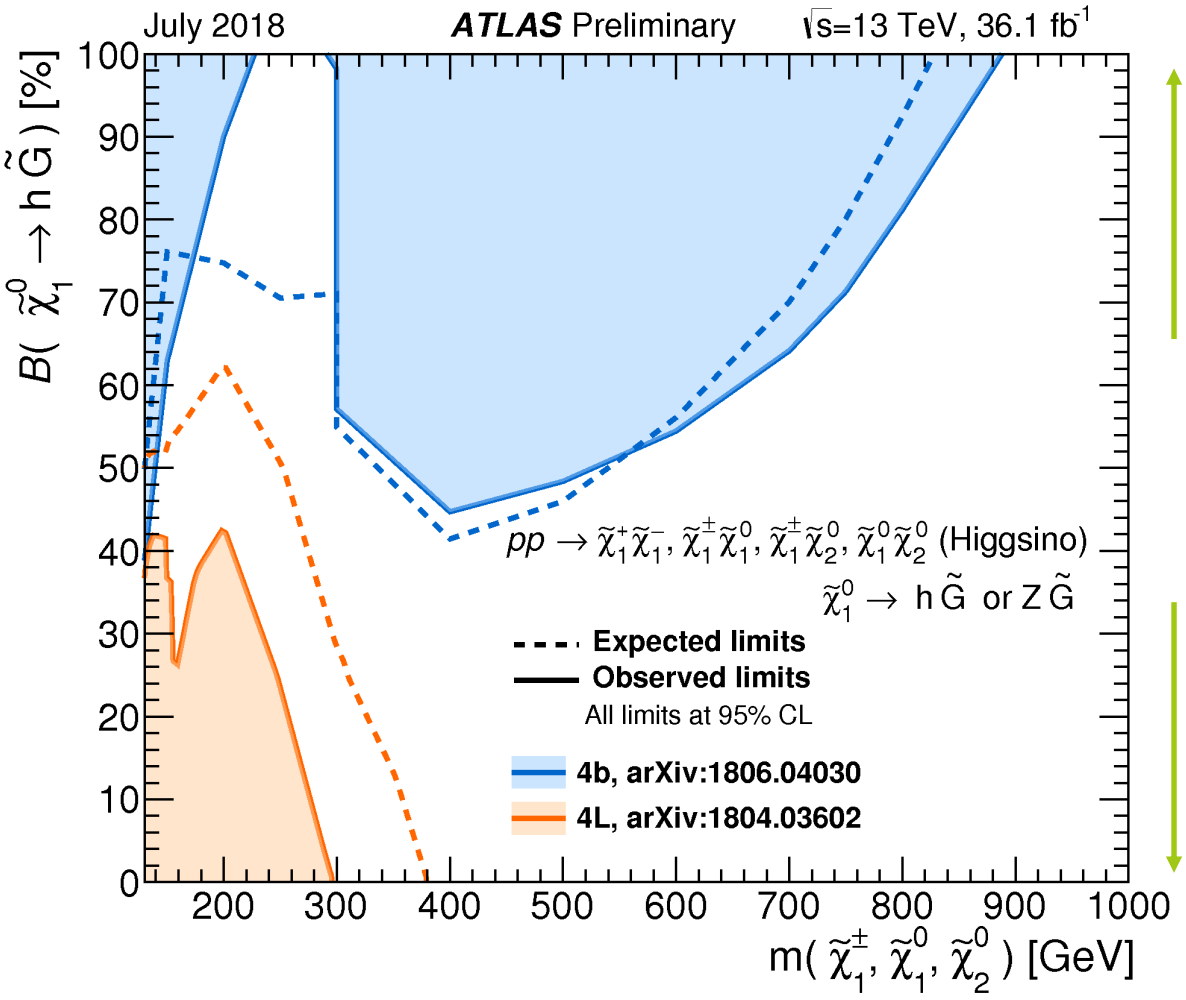
$$f(p_{\mathrm{T}}) = \exp\left(-p_0 \cdot \log(p_{\mathrm{T}}) - p_1 \cdot (\log(p_{\mathrm{T}}))^2\right)$$



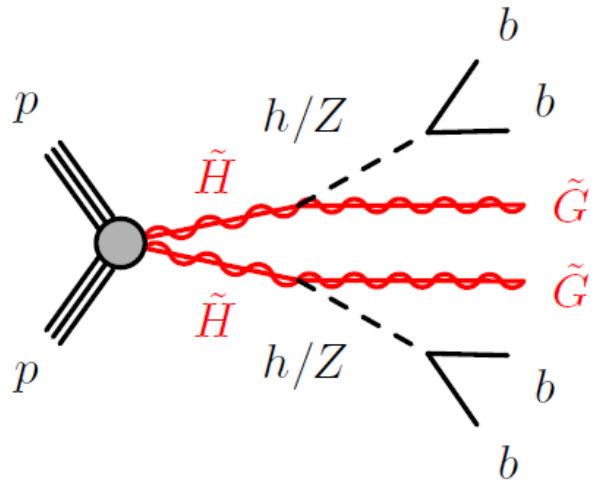
Disappearing track: Systematics

Relative uncertainties [%]	Electroweak channel	Strong channel
MC statistical uncertainty	6.6	6.5
ISR/FSR	7.6	0.2
Jet energy scale and resolution	2.0	0.7
Trigger efficiency	0.2	<0.1
Pile-up modelling	11	
Tracklet efficiency	6.9	
Luminosity	3.2	
Sub-total	17	15
Cross-section	6.4	28
Total	18	32

GGM result



Much B($\tilde{\chi}_1^0 \to h\tilde{G}$)



Much B($\tilde{\chi}_1^0 \to Z\tilde{G}$)