Search for winos using a disappearing track signature in ATLAS

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on behalf of the ATLAS Collaboration

@ MoriondEW 2017

Introduction & Physics Motivation

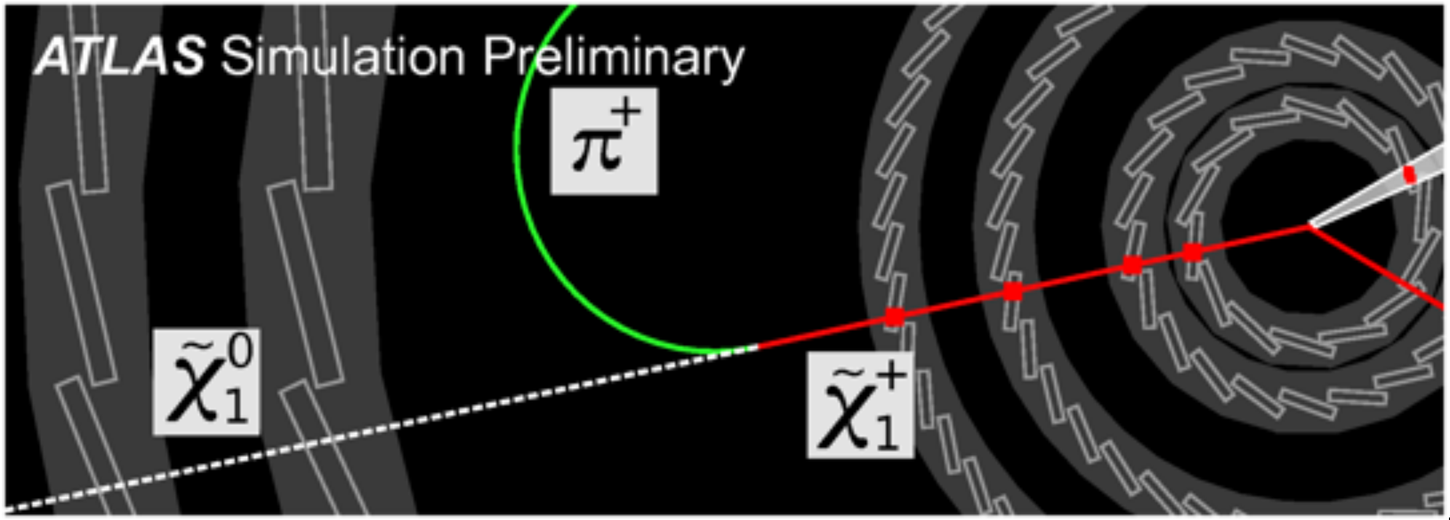
If the LSP is wino, the masses of the lightest chargino and neutralino are highly degenerate and chargino can have a long lifetime.

In the ATLAS pMSSM scan [JHEP 10 (2015) 134], about 70% of the wino-LSP models have a charged wino lifetime in between 0.15 ns and 0.25 ns, most of the other models have a larger mass splitting (shorter lifetime) due to a non-decoupled higgsino mass.

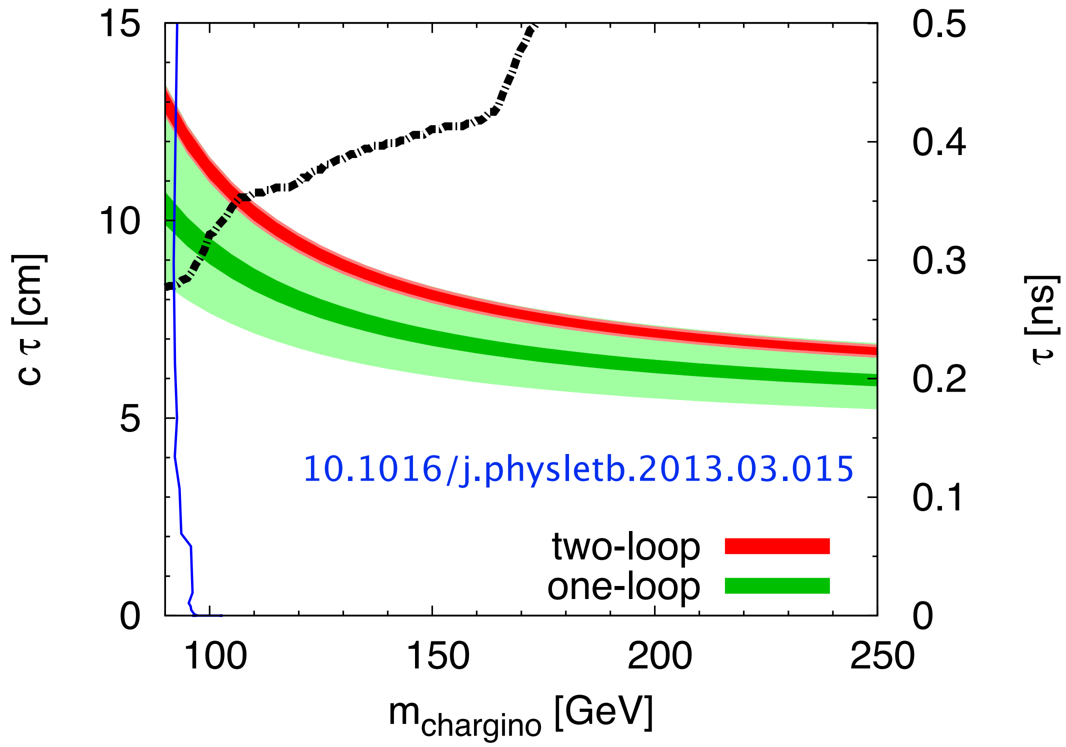
$$\tilde{\chi}_1^{\pm} \longrightarrow \tilde{\chi}_1^0 + \pi^{\pm}$$

leave hits — E_T^{miss} — Undetectable

-> disappearing track

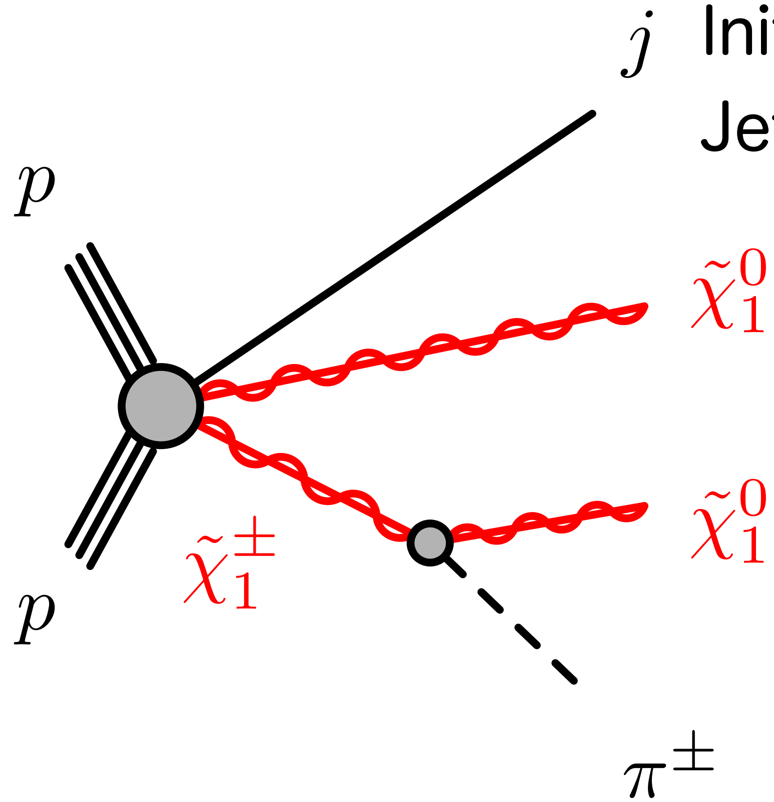


Chargino mass and lifetime



Signal Topology

"Electroweak Production"

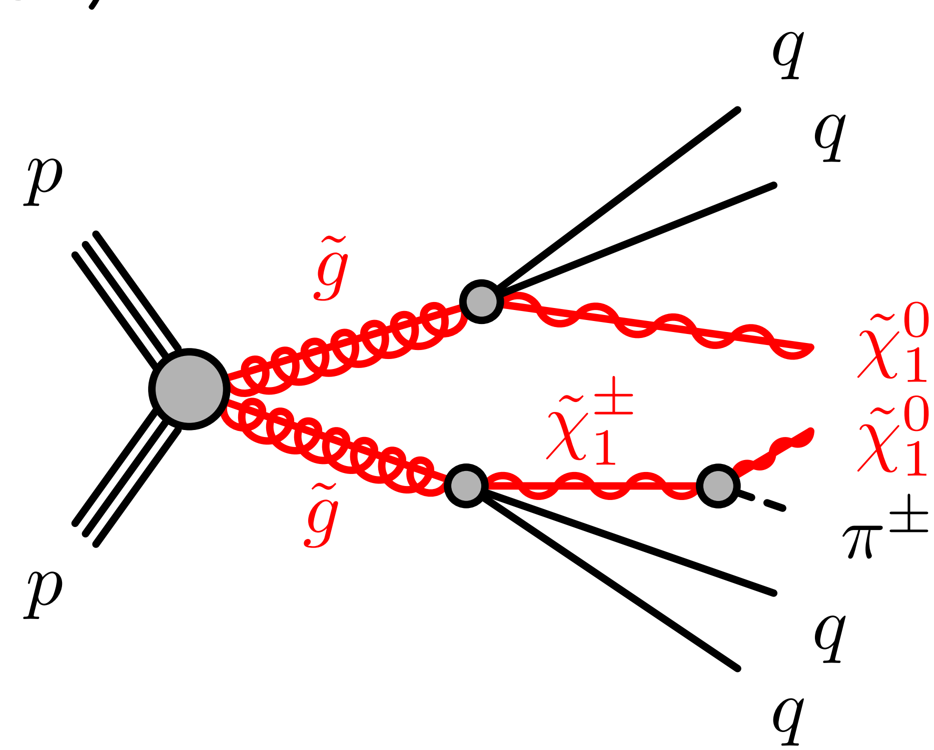


Initial State Radiation(ISR)
Jet for trigger

large E_T^{miss} + single jet +
disappearing track

- Independent of gluino mass
  - Sensitive even if gluino is heavy
- ISR is required to boost the system

"Strong Production"



large E_T^{miss} + multi-jets +
disappearing track

- High trigger efficiency due to large E_T^{miss}
- Searchable for wider chargino mass range
- Low background

Improvement from Run1 Analysis

Requirements for disappearing track candidates :

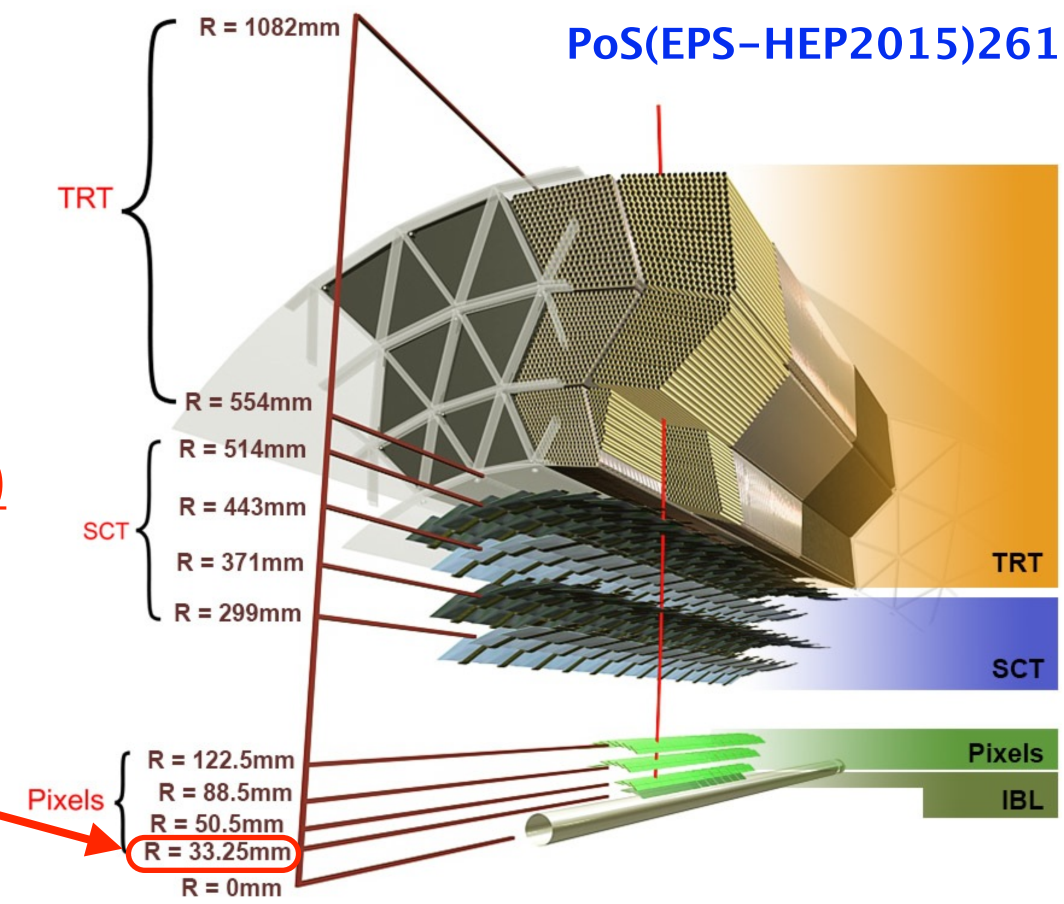
Run1 : 3 pixel + 1 SCT layers

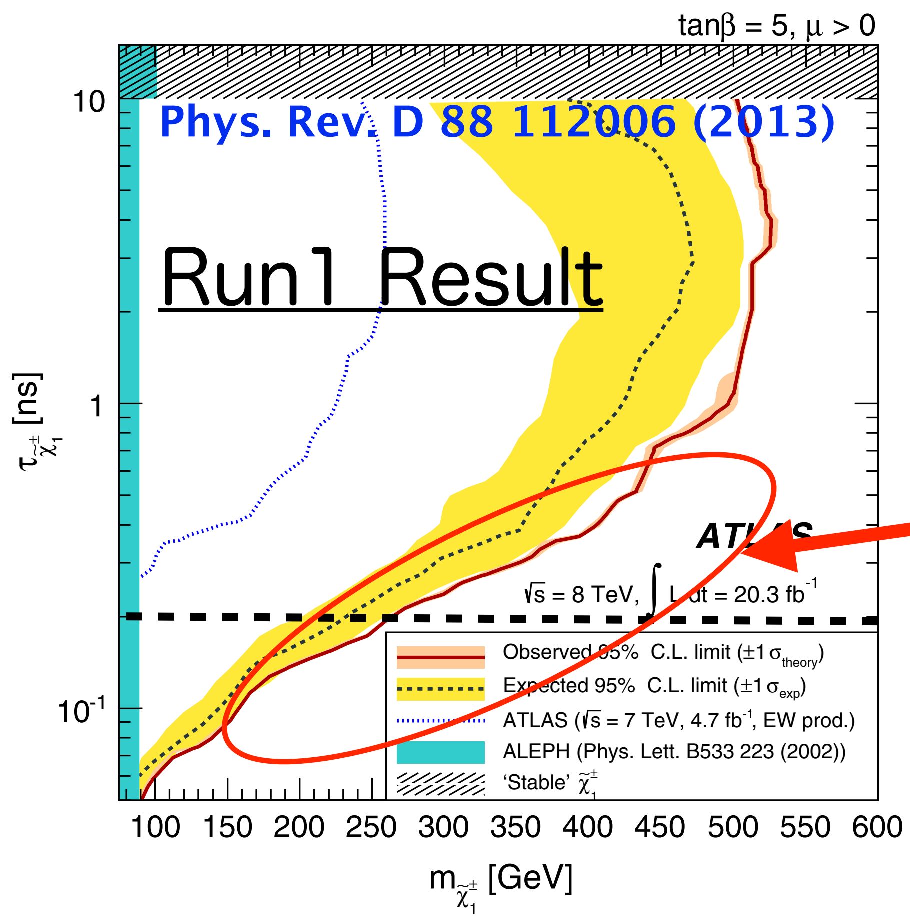
-> track length (L) ~ 30cm

Run2 : 4 pixel layers (L ~ 12cm)

- thanks to the new inner most layer (IBL)

Layout of Inner Detector (ID)





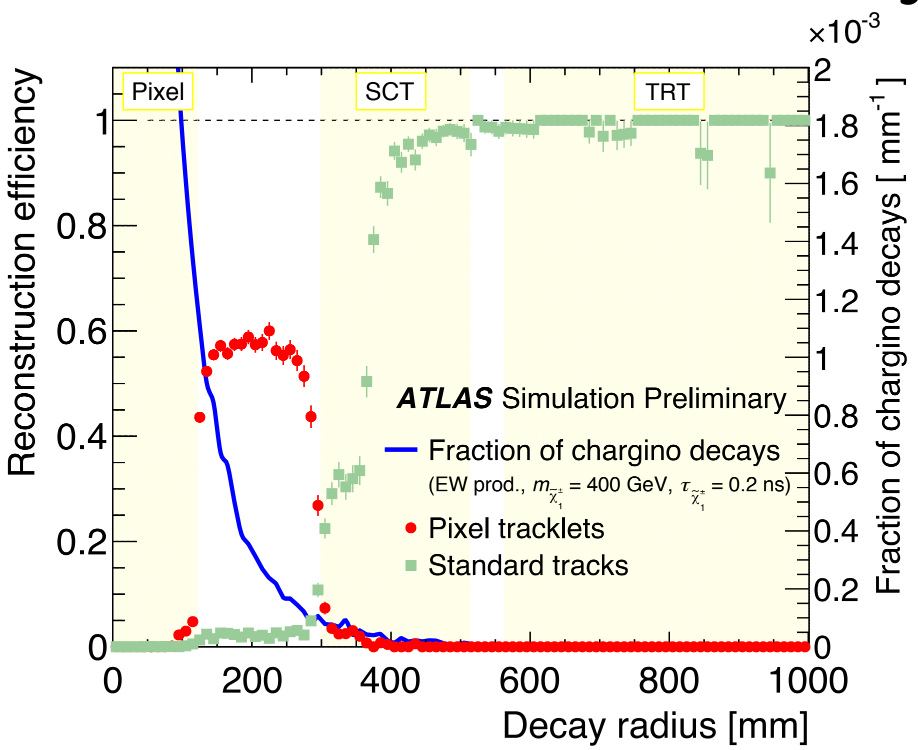
We focused on shorter lifetime region in this time.

Tracking Performances

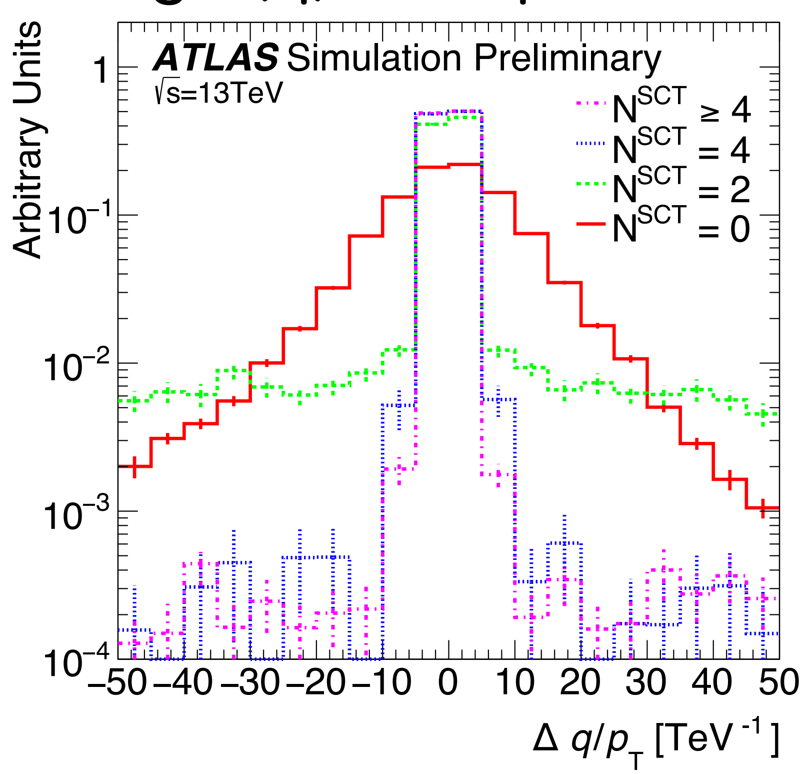
Reconstruction efficiency is improved significantly for 12cm < R < 30cm region by using pixel tracklets.

Pixel tracklets have a bad p_T resolution due to short lever arm, but pointing resolution is good enough for this search

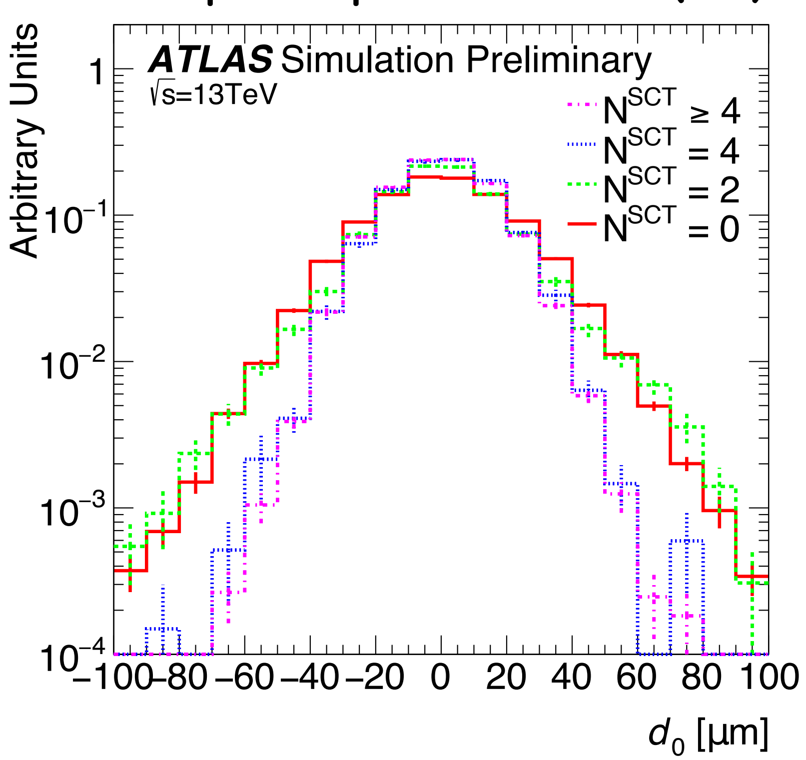
Reconstruction efficiency



Charge (q) over p_T resolution



Transverse impact parameter (d_0) resolution



Selection Criteria

Common
- 2015 - 2016 dataset (36.1 fb^{-1})
- Lowest unprescaled E_T^{miss} trigger
- Lepton veto

"Electroweak Production"
- leading Jet p_T > 140 GeV
- E_T^{miss} > 140 GeV
- $\Delta\phi_{min}(Jet_{1,2,3,4}, E_T^{miss}) > 1.0$

"Strong Production"
- leading Jet p_T > 100 GeV
- 2nd Jet p_T > 50 GeV
- 3rd Jet p_T > 50 GeV
- E_T^{miss} > 150 GeV
- $\Delta\phi_{min}(Jet_{1,2,3,4}, E_T^{miss}) > 0.4$

Selection for disappearing track candidates

(1) Isolated highest p_T selection :
- p_T > 20 GeV
- ΔR > 0.4 for any Jets (p_T > 50 GeV)
- ΔR > 0.4 for any muon spectrometer track (p_T > 10 GeV)
- $p_T^{cone40}/p_T < 0.04$

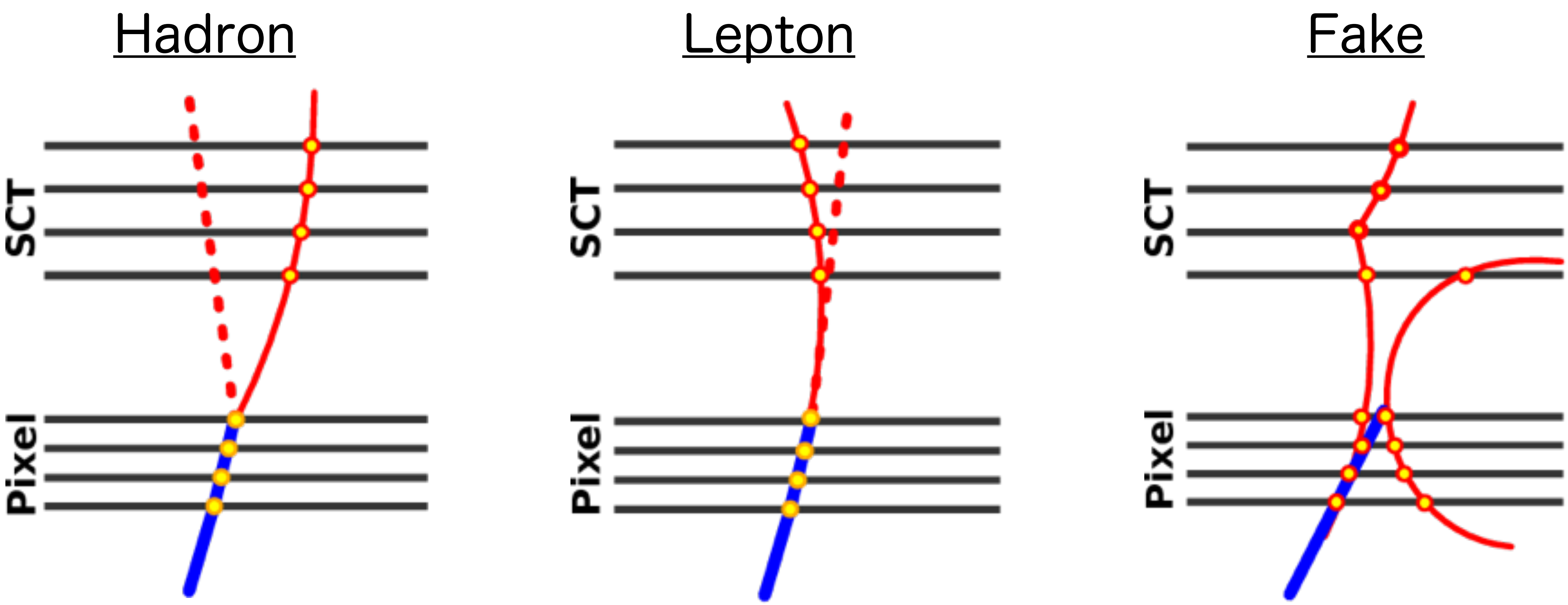
(2) Quality selection :
- # of pixel layers = 4
- $|d_0|/\sigma(d_0) < 2.0$ $\sigma(d_0)$: d_0 uncertainty
- $|z_0 \sin\theta| < 0.5$ mm
- χ^2-probability of the track fit > 10%

(3) Geometrical acceptance :
- $0.1 < |\eta| < 1.9$

(4) Disappearing condition :
- # of SCT hits = 0

Background Components

Main SM background processes : $t\bar{t}$, W+jets (with $W \rightarrow e\nu, \tau\nu$)



Categorization of background components

Background is strongly affected by detector conditions.
So data-driven background estimation is very important.

Analysis Method

Unbinned likelihood fit on the p_T distribution of pixel tracklets to search for an excess at high p_T region.

p_T templates :

<u>Hadron and lepton background template</u>

Obtain p_T spectrum of standard tracks in dedicated control regions.
Smear it to estimate p_T spectrum of pixel tracklets.
-> need to prepare smearing function

<u>Fake background template</u>

Obtain p_T spectrum from a control region with large impact parameters

<u>Signal template</u>

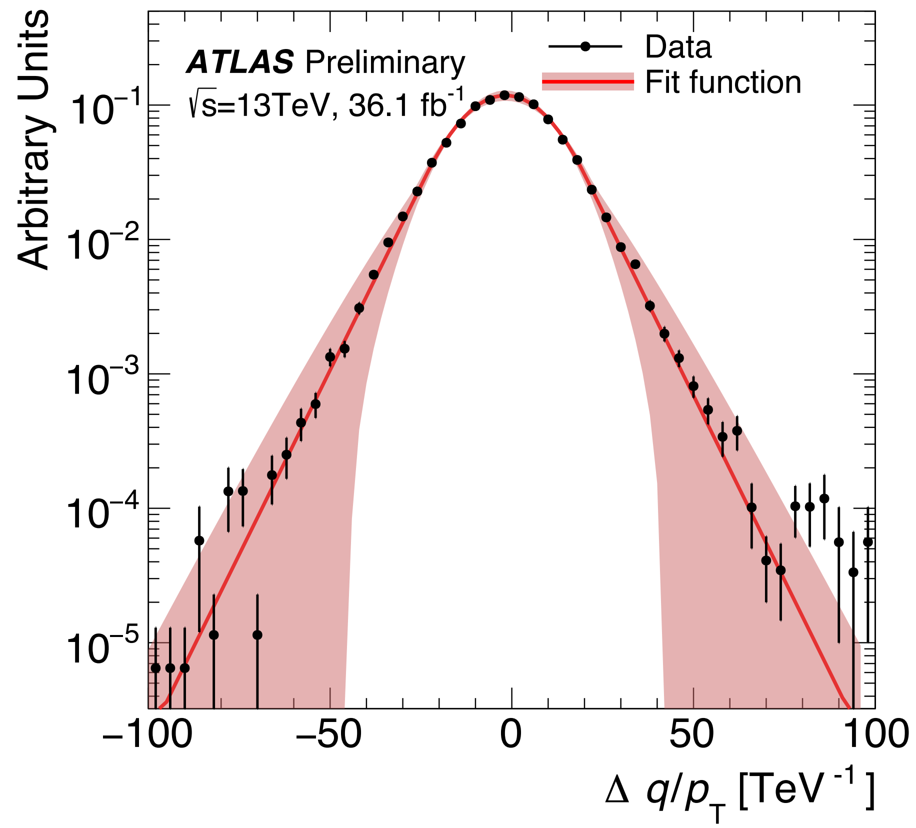
Truth level p_T in simulation is convolved with a smearing function
Trigger efficiency curve measured in data is applied

Validate the analysis and constrain the fake background yield in low-E_T^{miss} validation region.

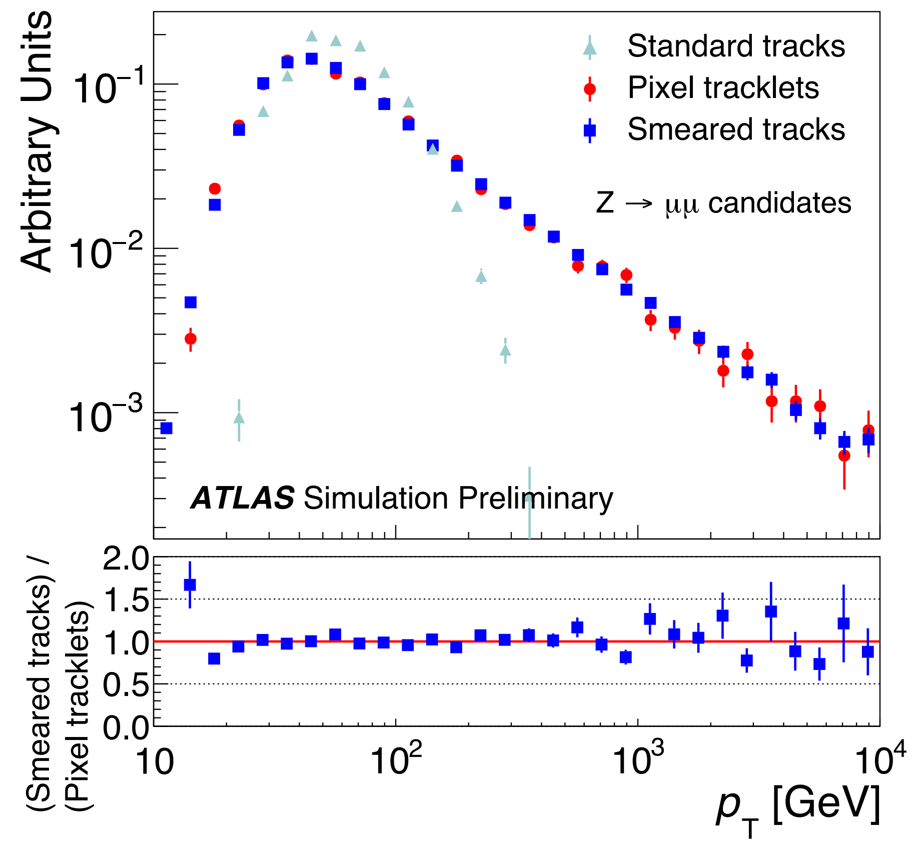
Smearing Function

- Smearing function is obtained from data.
  - Select Z->μμ events (require identified muons and kinematic selection)
  - Re-track muons with using only pixel hits
  - Compare their p_T to standard track p_T
- It was confirmed by closure test that p_T spectrum of pixel tracklets can be reproduced by smearing p_T spectrum of standard tracks.
- Dependence on p_T, η is negligible.
- Dependence of the resolution on the particle mass is included as systematic uncertainty.

Smearing function



Closure test



Hadron Background

Hadron control region

The same kinematic selection as in the signal region with additional requirements to select a sample enriched in hadrons :

- # of TRT hits ≥ 15
- # of SCT hits ≥ 6
- E_T^{cone20} > 3 GeV
- E_T^{clus40}/p_T > 0.5

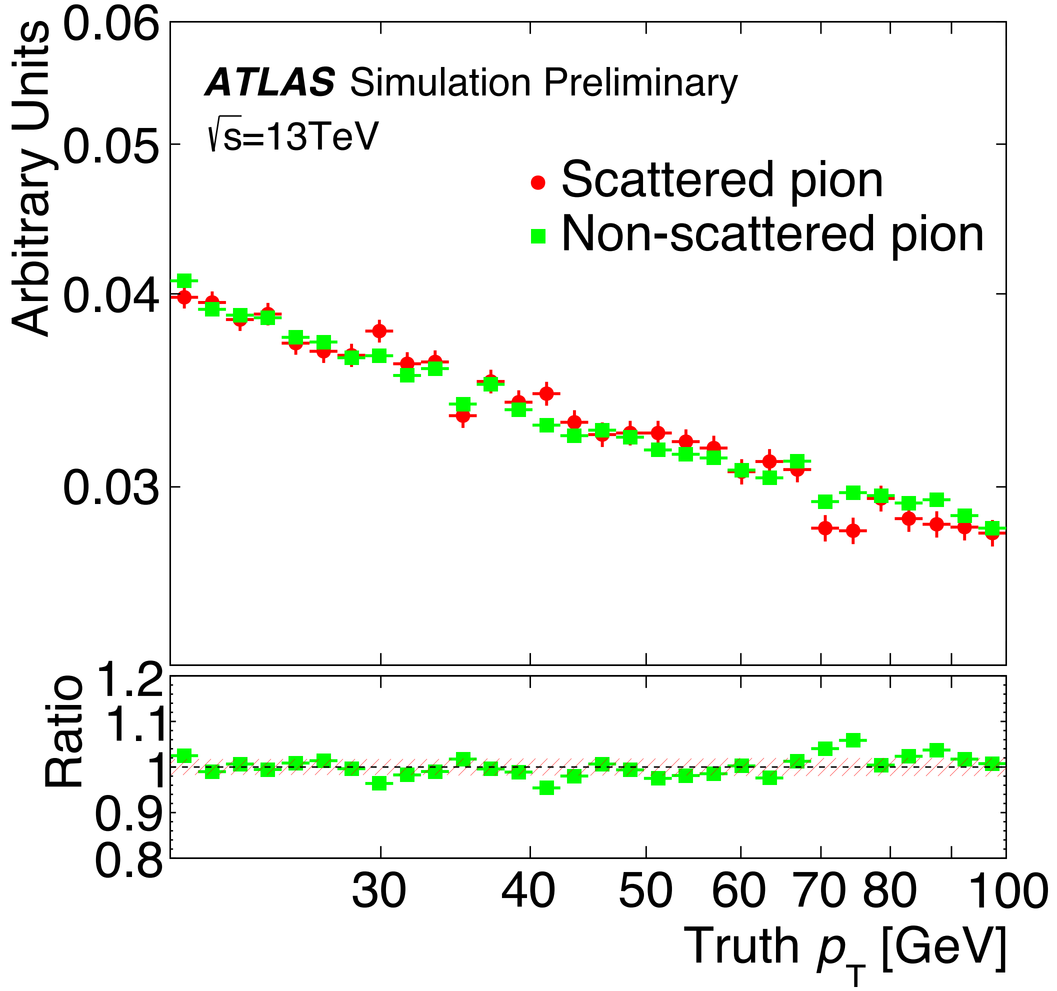
E_T^{cone20} : transverse calorimeter energy deposit in $\Delta R < 0.2$

E_T^{clus40} : sum of cluster energies in $\Delta R < 0.4$

Then smear p_T spectrum by using smearing function.

The p_T spectrum of scattered/non-scattered hadrons are confirmed to be same in simulation.

Comparison of p_T shape between scattered/non-scattered pion



Lepton Background

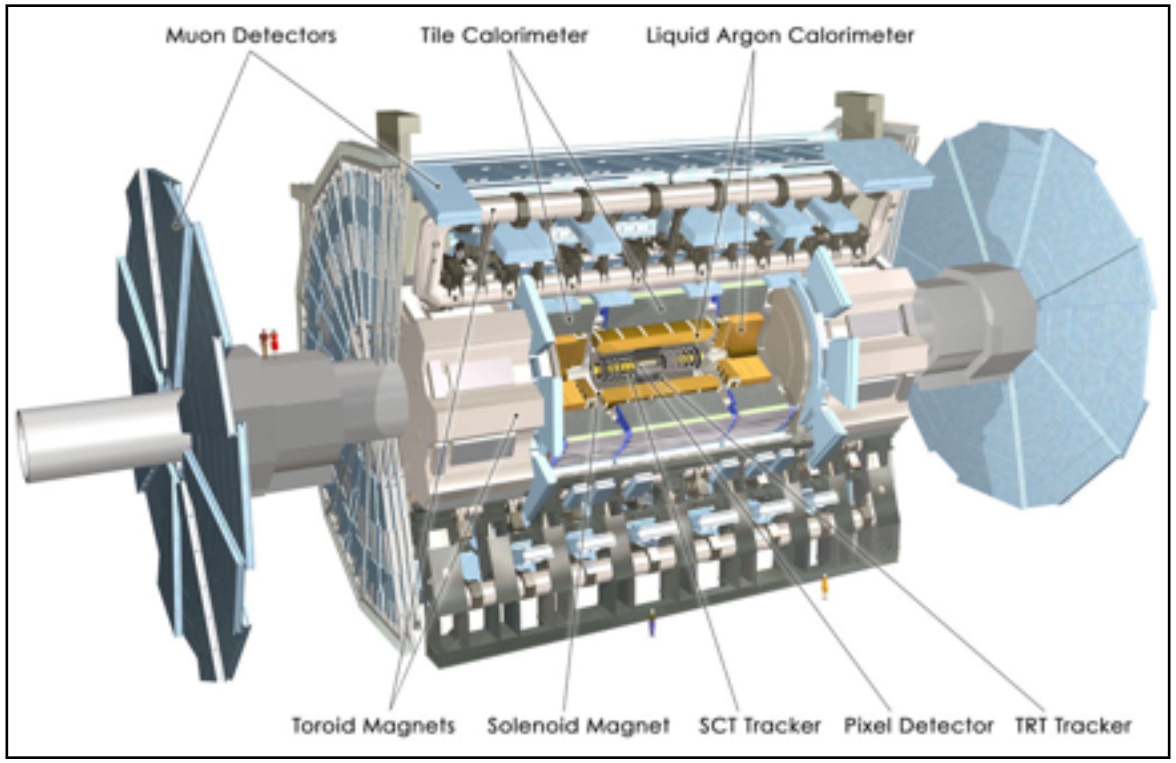
1. Obtain p_T spectrum in lepton control samples.
   - almost same selection as signal region except for requirement of one lepton instead of disappearing track
2. Apply transfer factor, which is the probability for a lepton to pass the disappearing track selection

Transfer factor calculation with a tag-and-probe method (Z -> ll)

Tag : well identified electron

Probe : e.g. EM calorimeter

(Probability of electron track is identified as disappearing) = (# of calorimeter cluster with associated disappearing tracks)/(# of calorimeter cluster with associated any tracks)



3. Smear p_T spectrum by using smearing function.

Fake Tracks

Mainly come from a wrong combination of space-points.

These tracks have a large impact parameter, whereas signal chargino tracklets have values of d_0 clustering around zero.

Obtain p_T spectrum of fake tracklets and fit with following function :

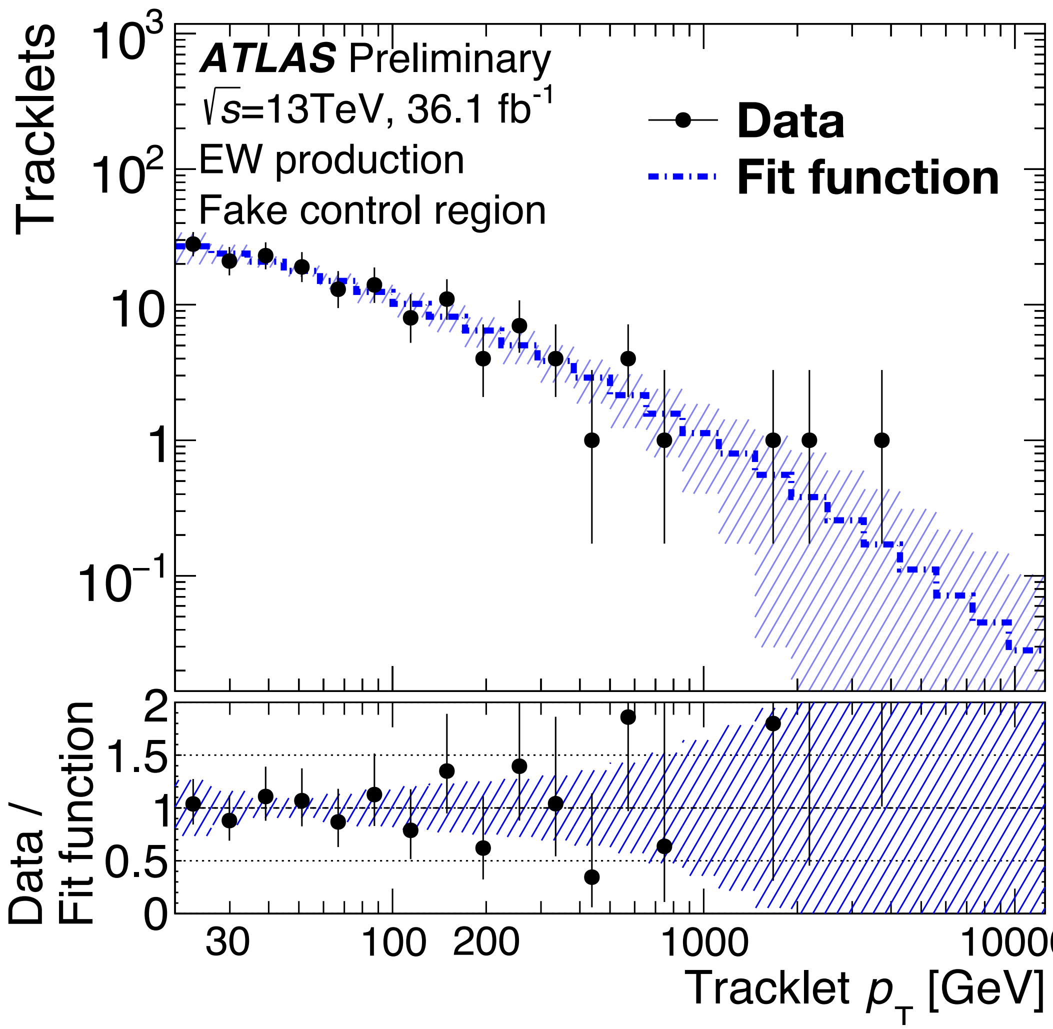
$$f\,(p_{\mathrm{T}}) = \exp\left(-p_0 \cdot \log(p_{\mathrm{T}}) - p_1 \cdot (\log(p_{\mathrm{T}}))^2\right)$$

Fake tracks selection

- $|d_0|/\sigma(d_0) > 10$
- without E_T^{miss} requirement

p_T shape is independent of E_T^{miss}.

Small dependence of impact parameter cut is added to the uncertainty of the p_T template shape.



Systematic Uncertainty

Dominant systematic uncertainties

	Electroweak channel	Strong channel
Statistics in simulation	6.6	6.5
ISR/FSR	7.6	0.2
Jet energy scale and resolution	2.0	0.7
Trigger efficiency	0.2	0.0
Pile-up modelling	11.0	4.5
Tracklet efficiency	6.9	
Luminosity	3.2	
Sub-total	16.6	11.3
Cross-section	6.4	28.1
Total	17.8	30.2

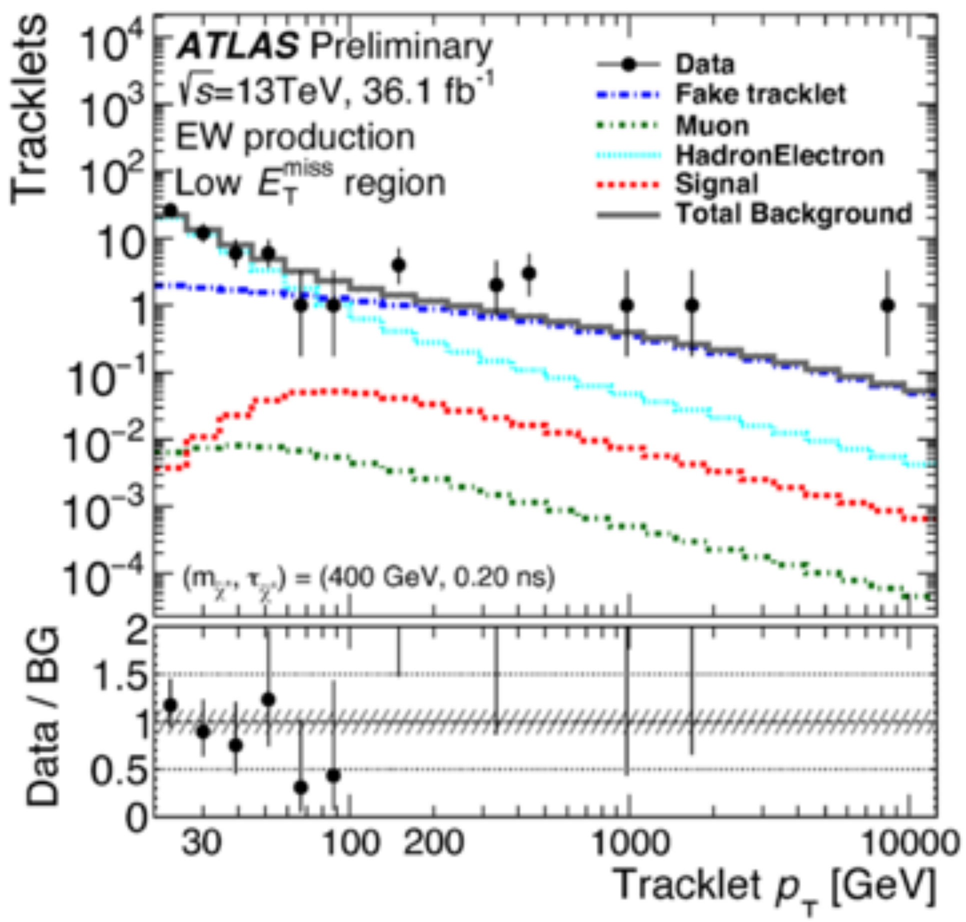
Uncertainty of tracklet efficiency is considering differences of track reconstruction efficiency between MC and data.

Calculation of tracklet reconstruction efficiency

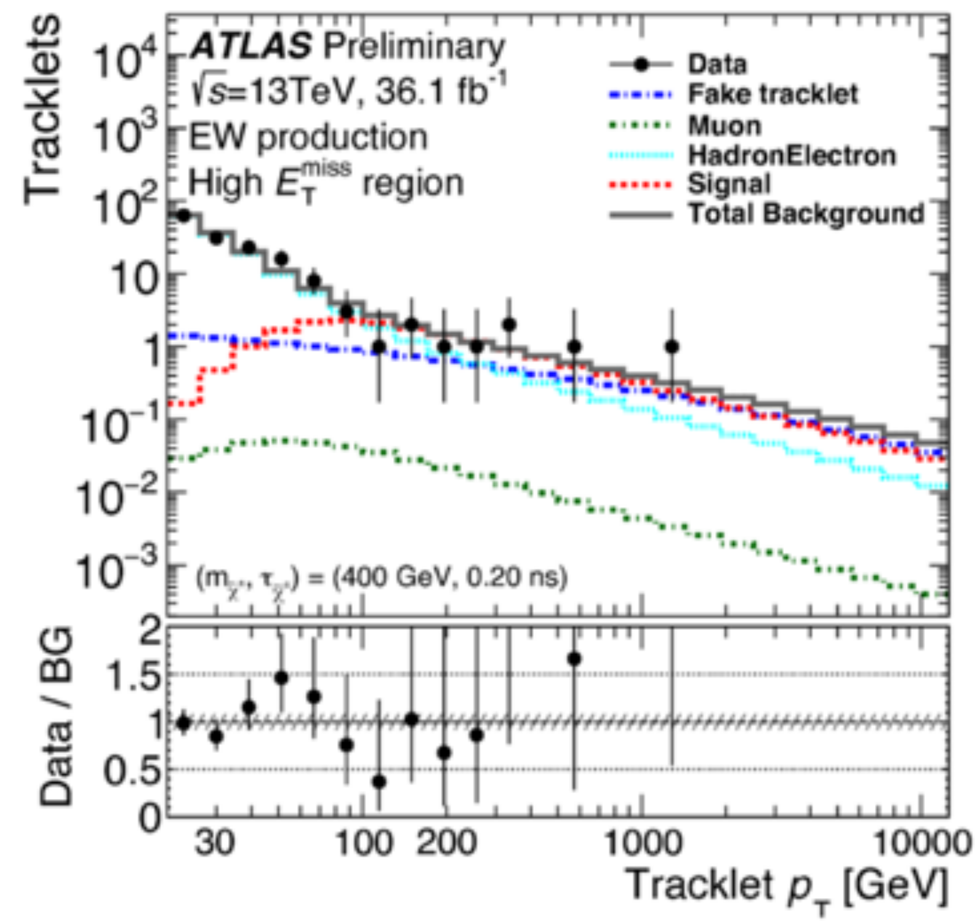
- Select Z->μμ events (require identified muons and kinematic selection)
- Re-track muons with using only pixel hits
- Apply same quality selection as signal region
- Calculate tracklet efficiency with respect to standard track

Fitting Results ("Electroweak channel")

<u>low-E_T^{miss} region</u>



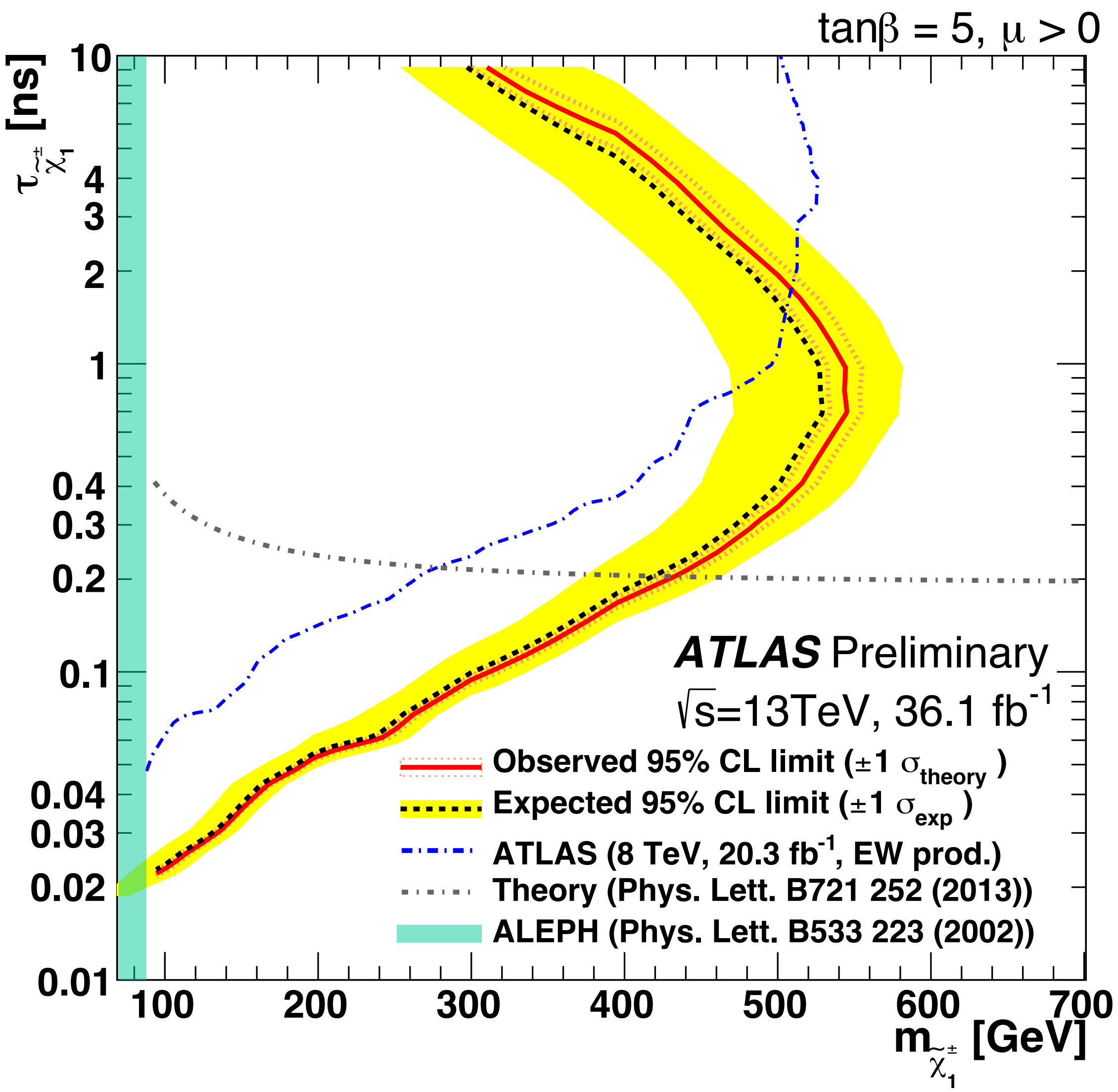
<u>high-E_T^{miss} region</u>



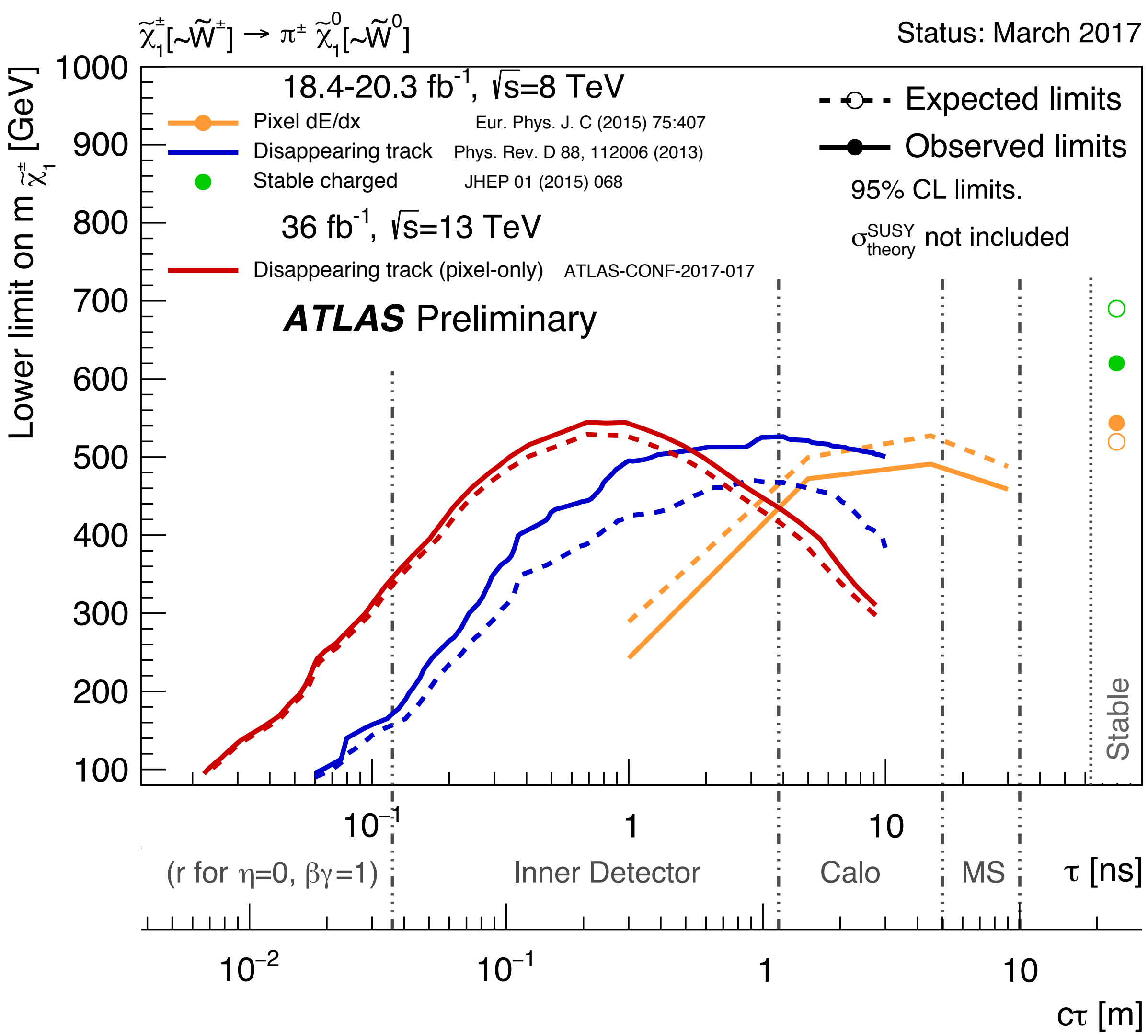
High E_T^{miss} region	Electroweak channel $(m_{\tilde{\chi}_1^\pm}, \tau_{\tilde{\chi}_1^\pm})$ =(400 GeV, 0.2 ns)
	Number of observed events with $p_T > 100$ GeV
Observed	9
	Number of expected events with $p_T > 100$ GeV
Hadron+electron background	6.1 ± 0.6
Muon background	0.1549 ± 0.0022
Fake background	5.5 ± 3.3
Total background	11.8 ± 3.1
Expected signal	10.4 ± 1.7
CL_b	0.39
Observed $\sigma_{vis}^{95\%}$ [fb]	0.22
Expected $\sigma_{vis}^{95\%}$ [fb]	$0.24^{+0.10}_{-0.07}$

<u>No excess is found</u>

Exclusion Limit ("Electroweak channel")



Summary plot for long-lived chargino

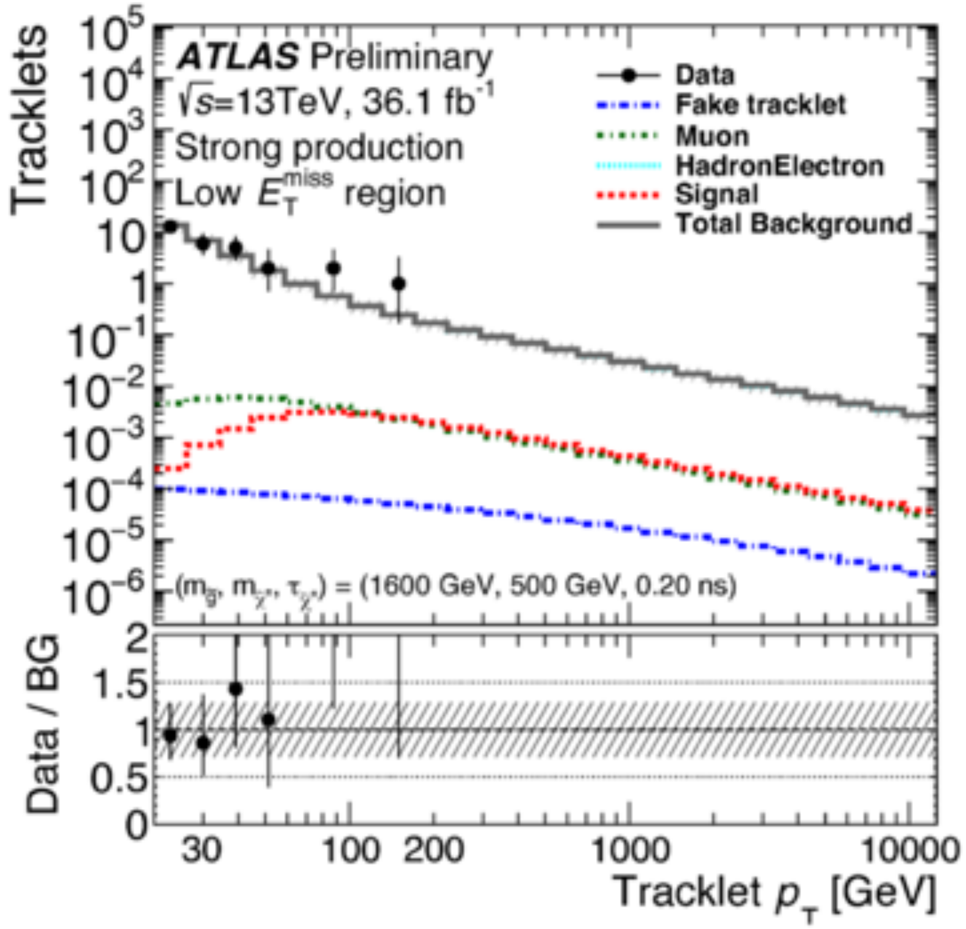


Winos with a mass up to 430 GeV are excluded at 95% C.L. for $\tau_{\tilde{\chi}_1^{\pm}} \sim 0.2$ ns

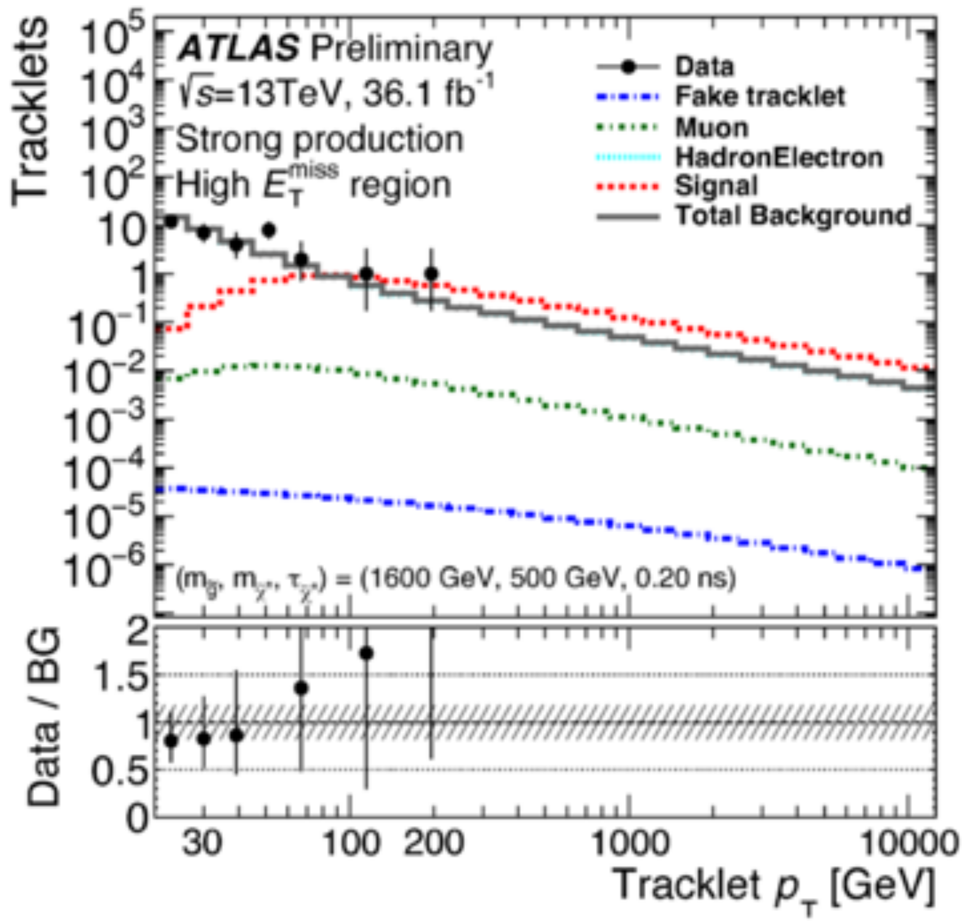
Pixel tracklets lead to significant improvement of sensitivity for the important region of small lifetimes (~ 0.2ns) w.r.t. Run1.

Fitting Results ("Strong channel")

low-E_T^{miss} region



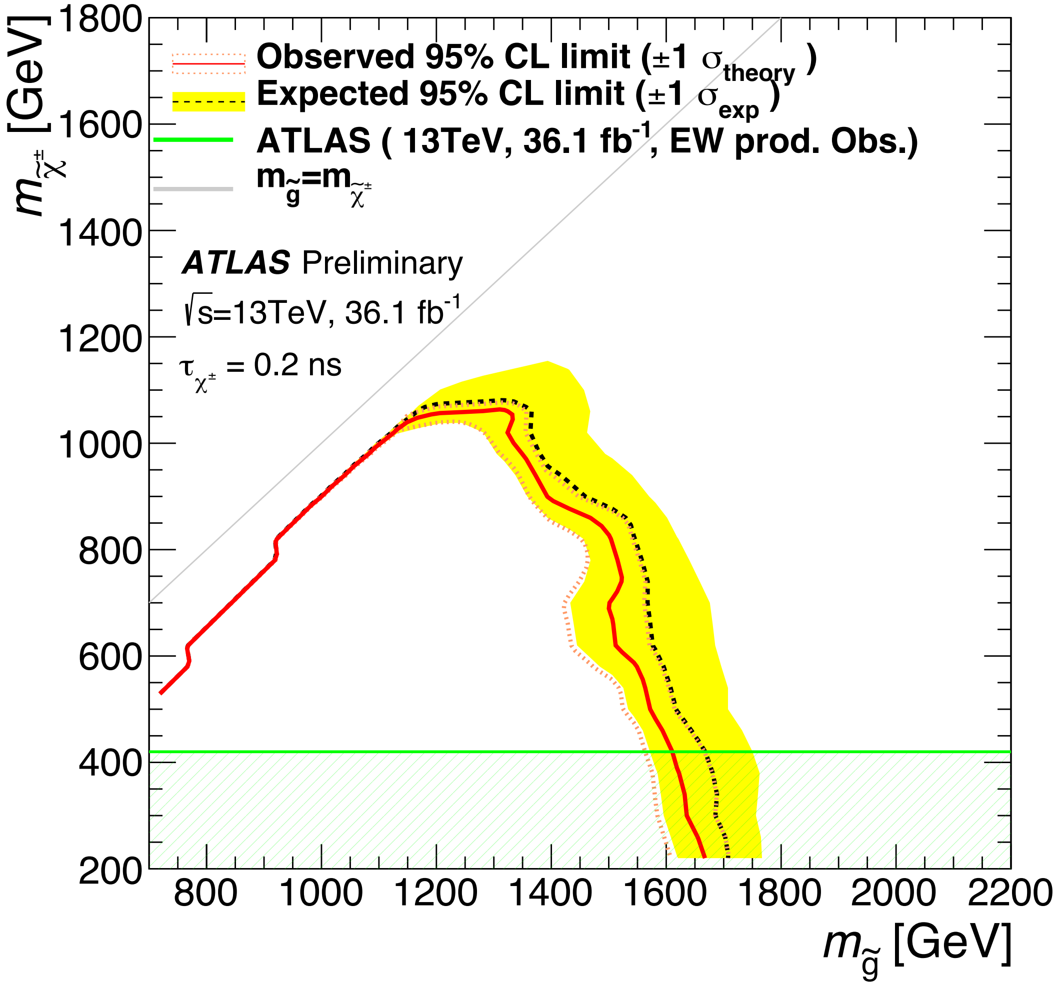
high-E_T^{miss} region

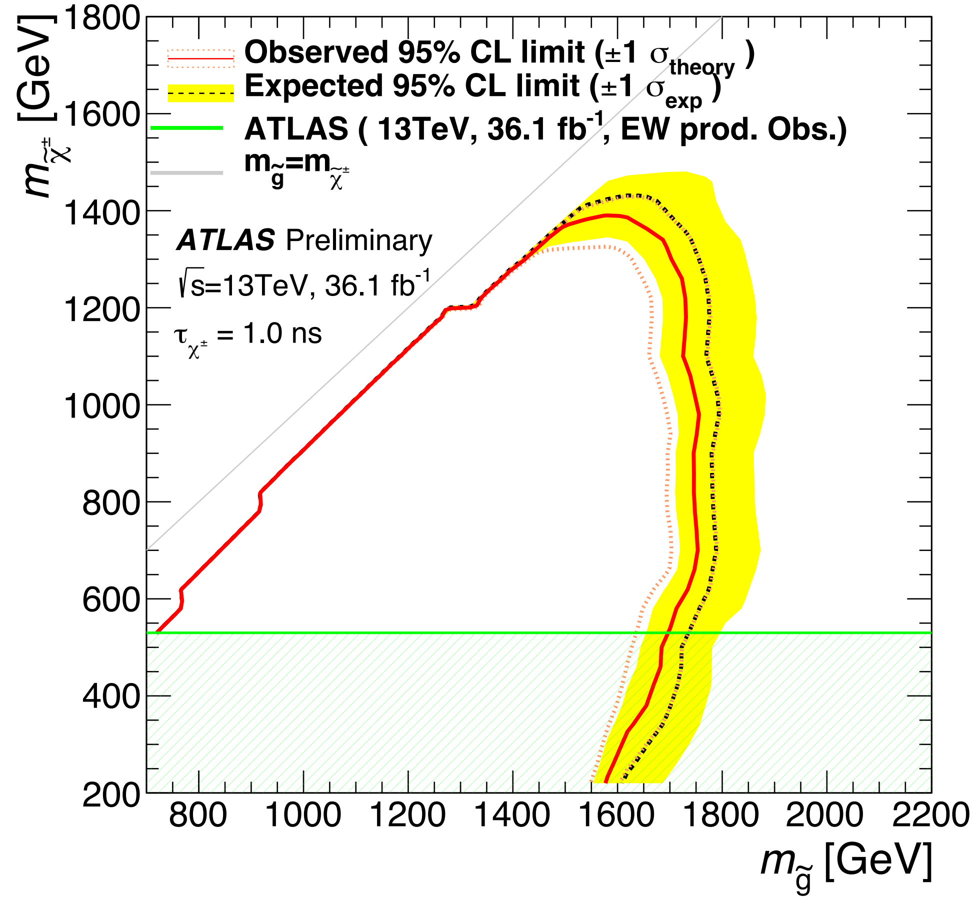


High E_T^{miss} region	Strong channel
	$(m_{\tilde{g}}, m_{\tilde{\chi}_1^\pm}, \tau_{\tilde{\chi}_1^\pm})$ =(1600 GeV, 500 GeV, 0.2 ns)
	Number of observed events with $p_T > 100$ GeV
Observed	2
	Number of expected events with $p_T > 100$ GeV
Hadron+electron background	2.08 ± 0.35
Muon background	0.0385 ± 0.0005
Fake background	0.0 ± 0.8
Total background	2.1 ± 0.9
Expected signal	4.1 ± 0.5
CL_b	0.702
Observed $\sigma_{vis}^{95\%}$ [fb]	0.14
Expected $\sigma_{vis}^{95\%}$ [fb]	$0.11^{+0.06}_{-0.04}$

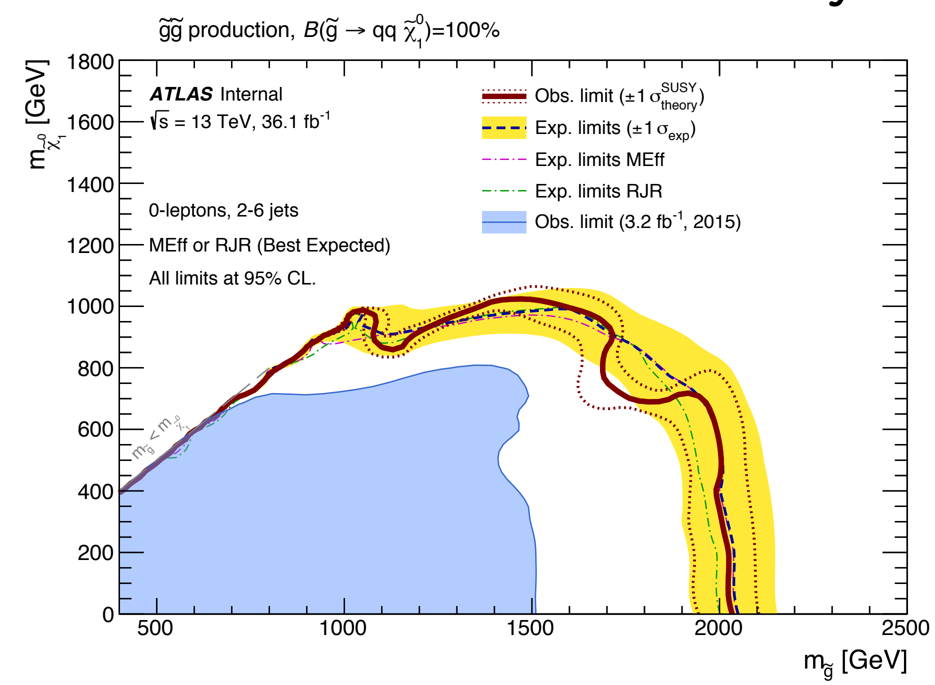
No excess is found

Exclusion Limit (“Strong channel”)





Limit from SUSY inclusive 0L analysis



Chargino masses up to 1.05 TeV are excluded for compressed spectra with mass difference between gluino and chargino of 200 GeV for a chargino lifetime of 0.2 ns, and 1.4 TeV for 1.0 ns.

Summary

- Wino search with disappearing track signature was performed based on 36.1 fb^{-1} of pp collisions collected at $\sqrt{s}$ = 13 TeV by the ATLAS experiment at the LHC.
- Pixel tracklets lead to significant improvement of sensitivity for the important region of small lifetimes (~ 0.2ns) w.r.t. Run1.
- Results are found to be consistent with SM predictions.
- For a chargino lifetime of 0.2 ns, chargino masses up to 430 GeV are excluded from electroweak channel, and 1.05 TeV are excluded for compressed spectra with mass difference between gluino and chargino of 200 GeV from strong channel.