The curious case of the disappearing track: searching for long-lived charginos with ATLAS

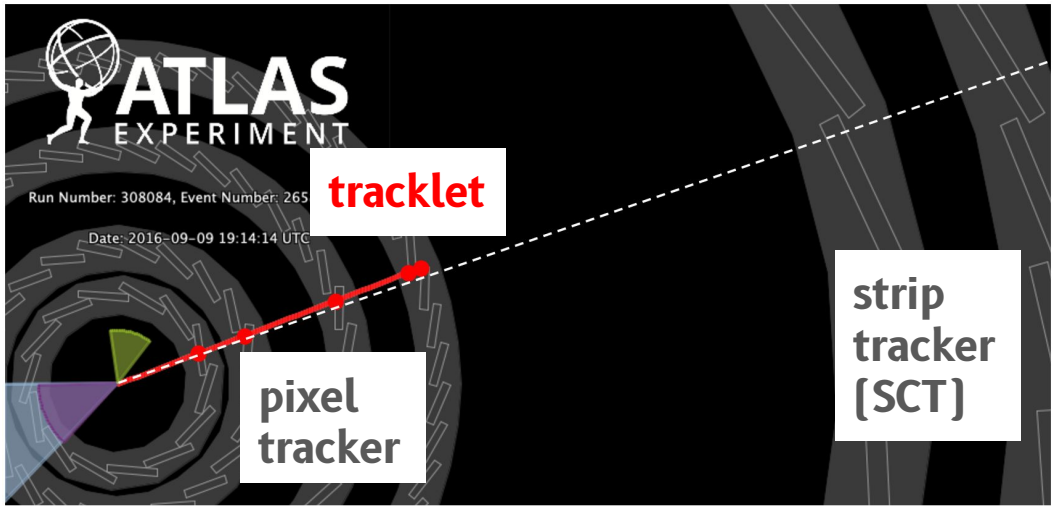
Jakub Kremer [AGH University of Kraków]

23 October 2026
Białasówka HEP seminar

What do we mean by “disappearing tracks”?

Event signature with **short tracks** [“**tracklets**“]

- pass only part of tracking detector
- no significant calorimeter or muon activity along tracklet direction



SUSY-2018-19

Some characteristics of disappearing tracks

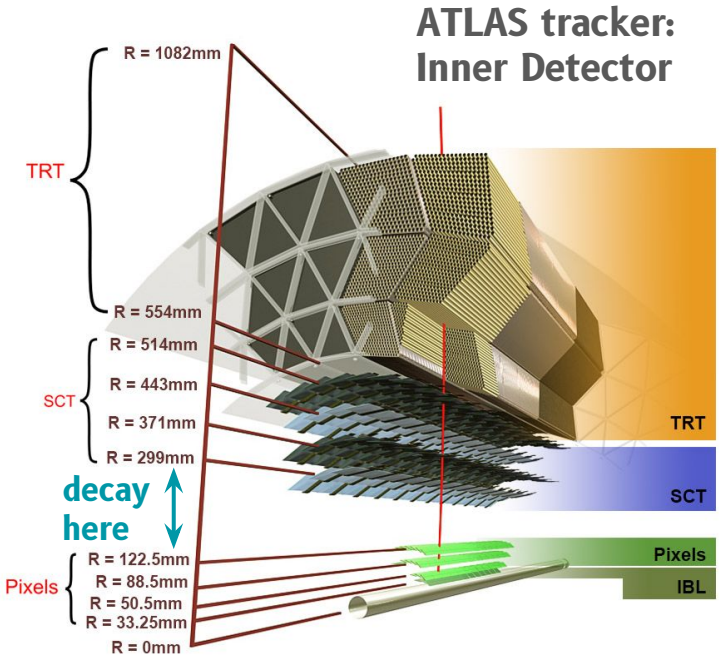
How short is “short”?

- ATLAS/CMS: **pixel** [+strip] **detector**

Targets?

- need track → charged particles
- decay between pixel and SCT detectors
  ↳ lifetime O[0.4-1] ns
- decay compatible with “disappearing”, i.e. no significant downstream activity

SM particles? **unlikely**



EPJC 80 [2020] 1194

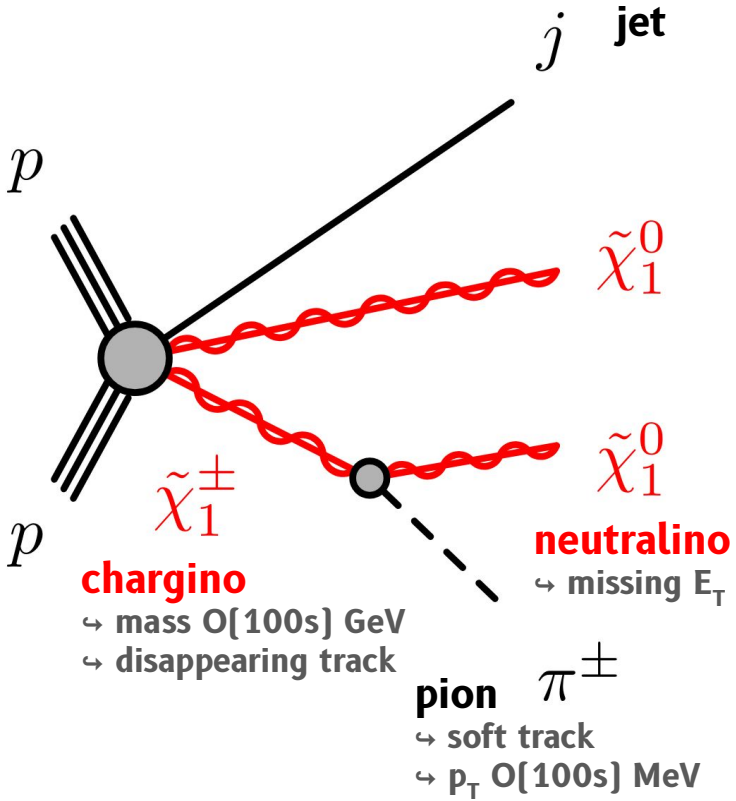
If not SM particles, what else?

Supersymmetric partners of SM W/Z/H bosons mix to form mass eigenstates
↳ **neutralinos** $\tilde{\chi}_i^0$ [i = 1, 2, 3, 4]
↳ **charginos** $\tilde{\chi}_i^\pm$ [i = 1, 2]

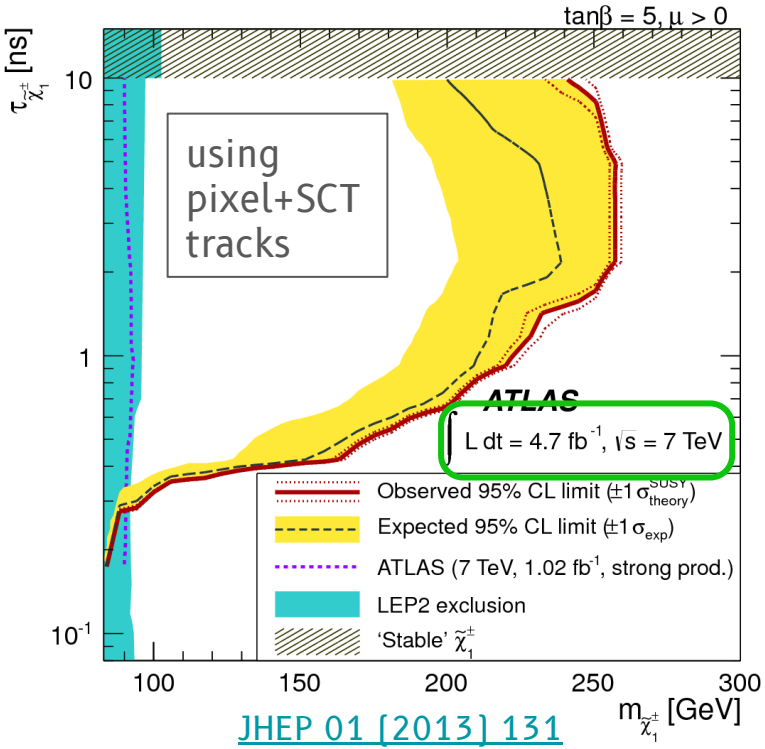
Neutralinos **(winos/higgsinos)** can be lightest SUSY particles and stable

Potential **Dark Matter candidates** for masses up to a few TeV

Radiative corrections → O(100s) MeV mass difference between charginos and neutralinos → O(0.1) ns lifetime!



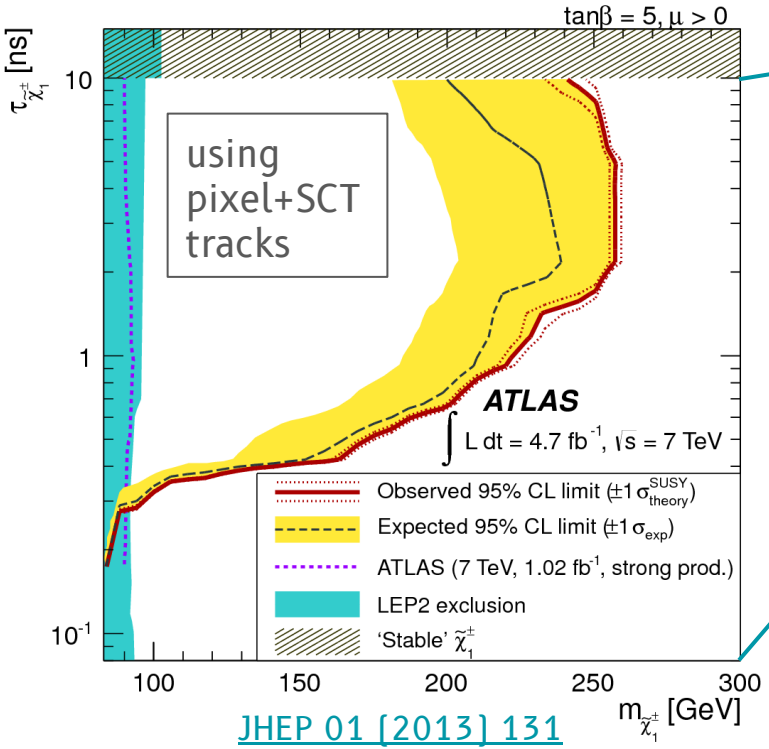
Disappearing tracks history in ATLAS



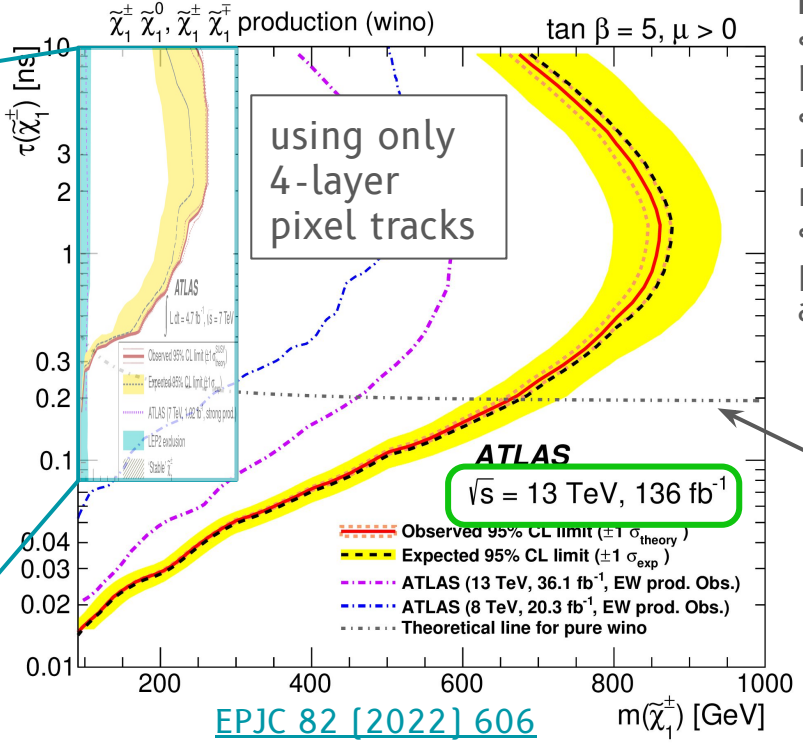
JHEP 01 [2013] 131

disappearing track searches pursued since early in **Run 1**

Disappearing tracks history in ATLAS



JHEP 01 [2013] 131

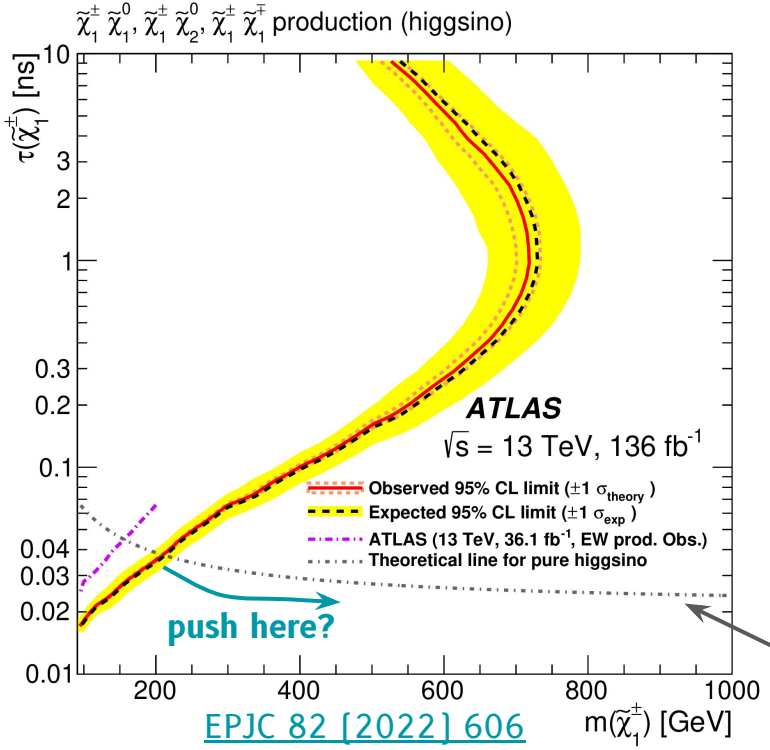


EPJC 82 [2022] 606

many changes
↪ larger dataset, higher energy
↪ advances in reco/analysis methods
↪ innermost pixel layer (IBL) added for **Run 2**!

pure wino excluded up to 660 GeV

What about the higgsino?



EPJC 82 [2022] 606

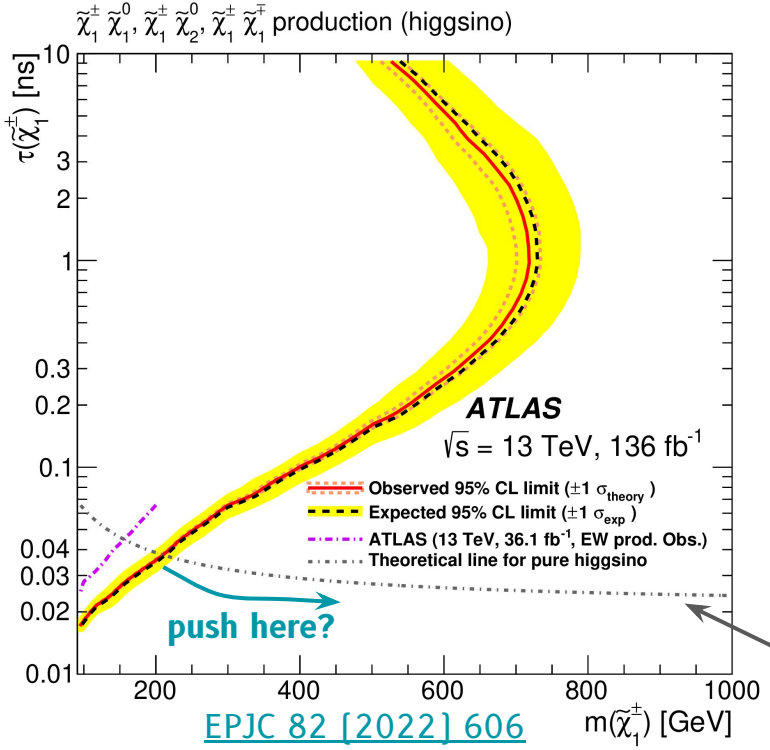
Shorter lifetime than wino → more challenging to reconstruct the signal

Far away from limit for higgsino as Dark Matter candidate [~1.1 TeV]

This result uses full Run 2 dataset
↳ **Can we still do better with this data?**

pure higgsino excluded up to 210 GeV

What about the higgsino?



EPJC 82 [2022] 606

Shorter lifetime than wino → more challenging to reconstruct the signal

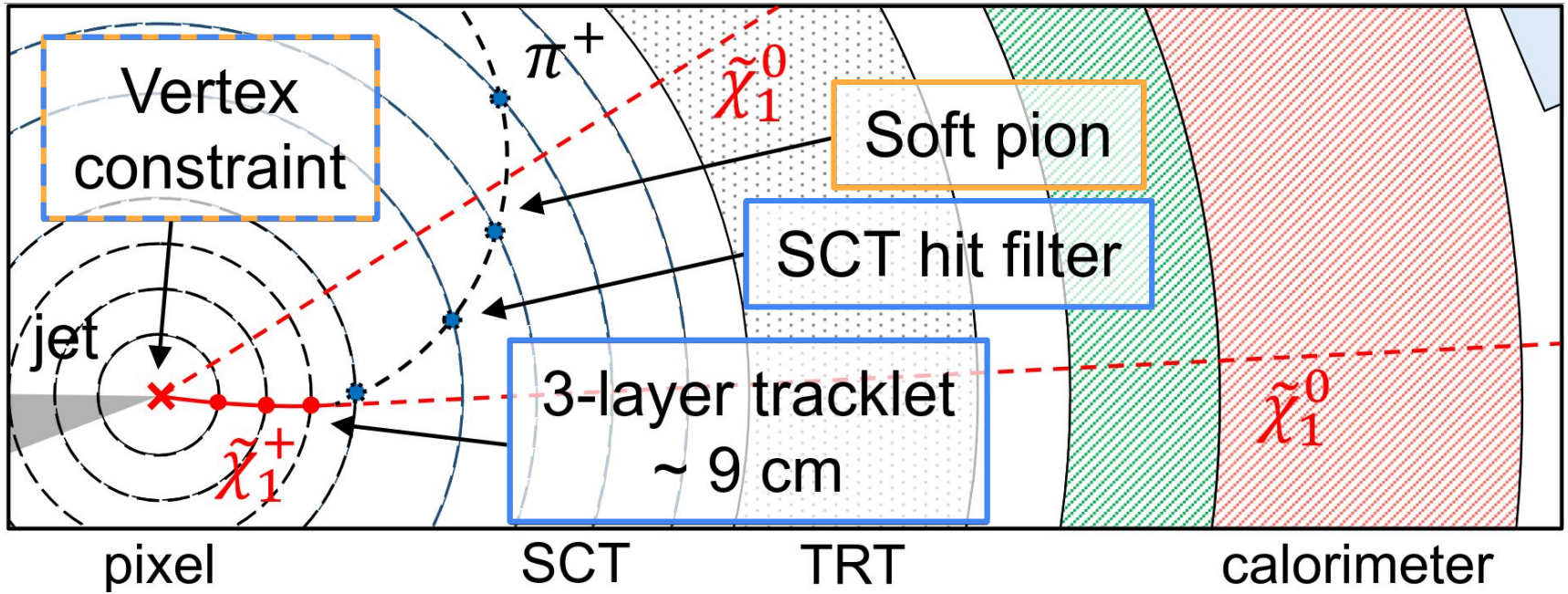
Far away from limit for higgsino as Dark Matter candidate [~1.1 TeV]

This result uses full Run 2 dataset
↳ **Can we still do better with this data?**

pure higgsino excluded up to 210 GeV

Yes! Improved result with full Run 2 dataset:
JHEP 07 [2026] 152

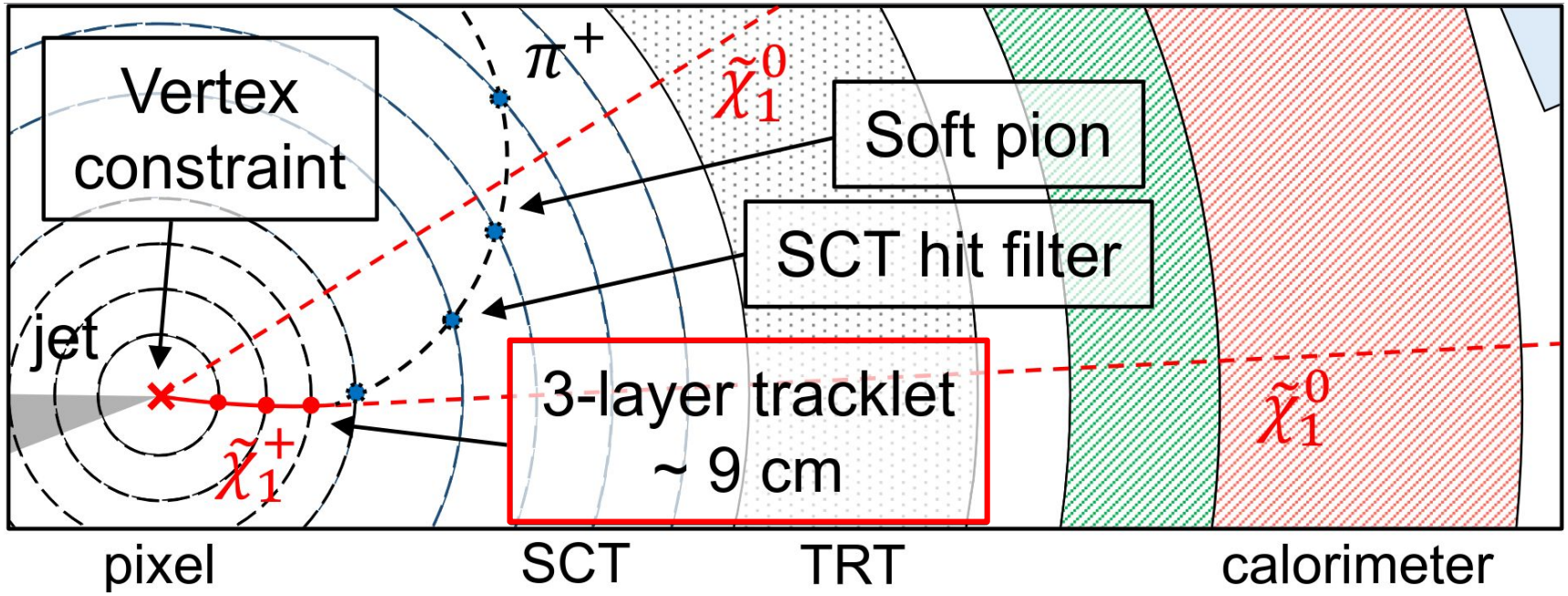
How to improve?



credit: Daiya Akiyama

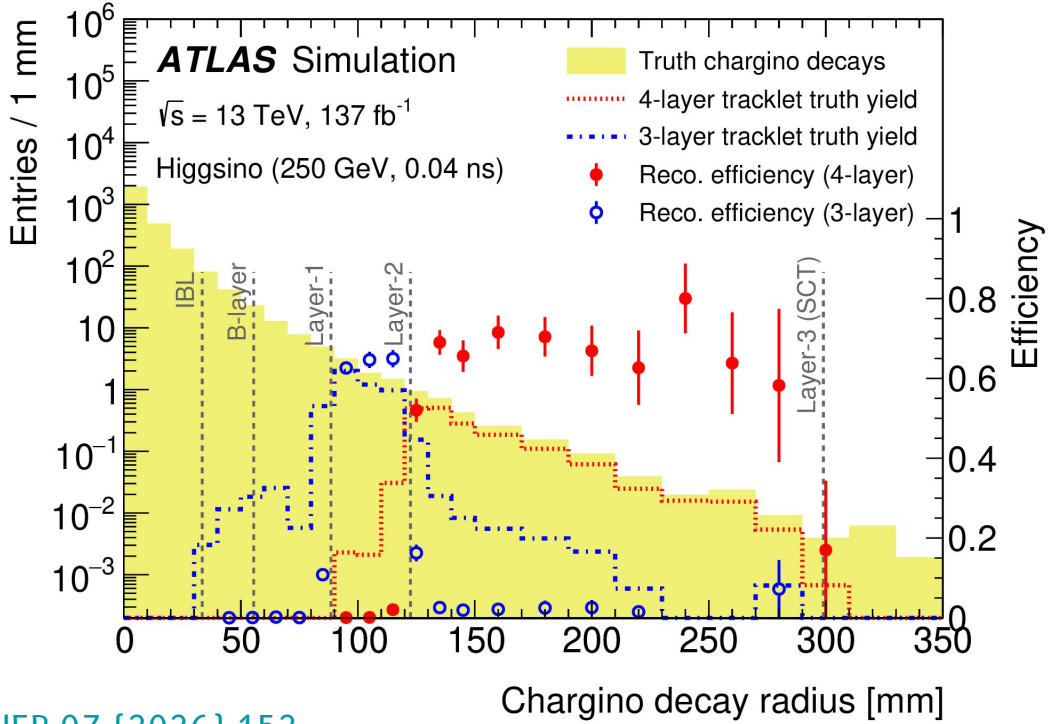
signal reconstruction efficiency
background rejection

How to improve?



credit: Daiya Akiyama

3-layer tracklets



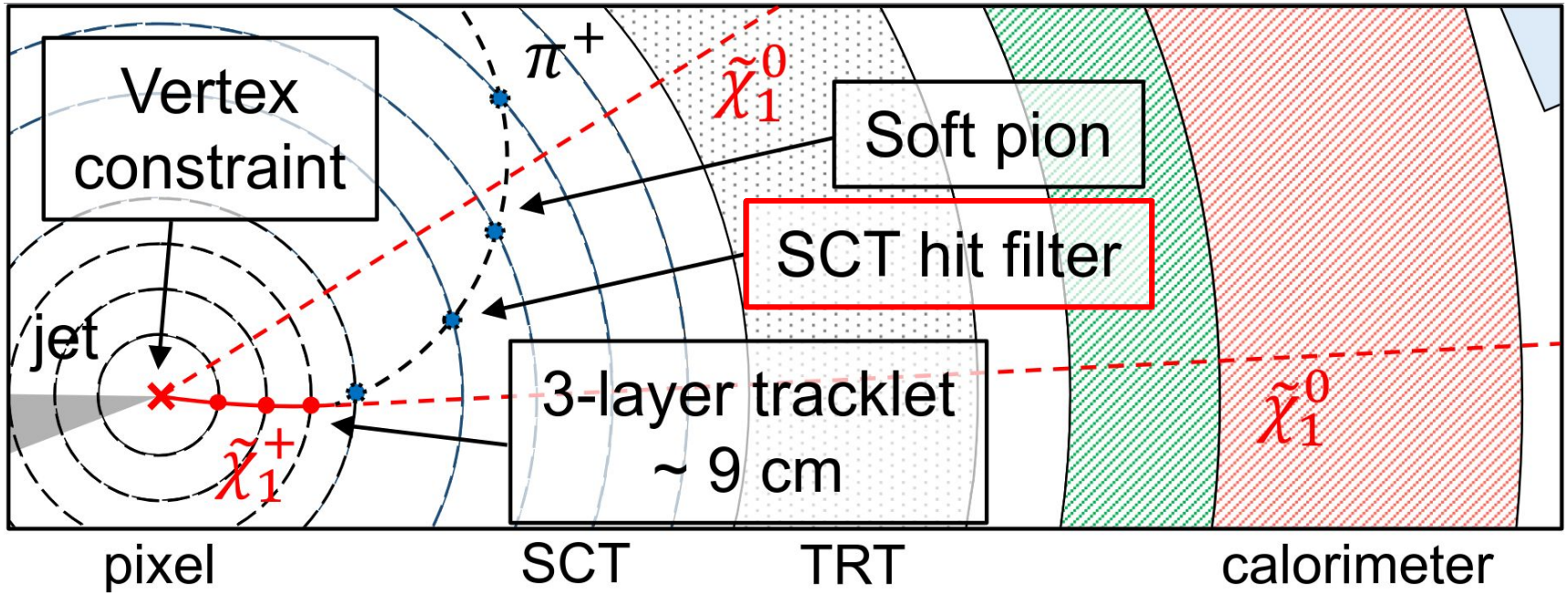
4-layer tracklets: used in previous analyses, performance well understood

Additional acceptance for signal using 3-layer tracklets

Reconstruction efficiency on par with 4-layer tracklets

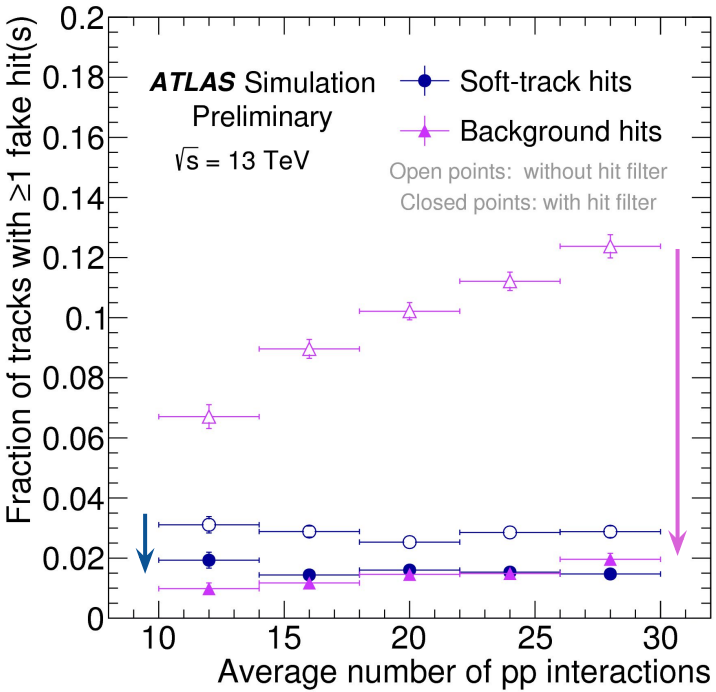
JHEP 07 [2026] 152

How to improve?



credit: Daiya Akiyama

SCT hit filter



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Reco algorithm can add SCT hits to pixel tracklet [**random** / **from soft pion**]

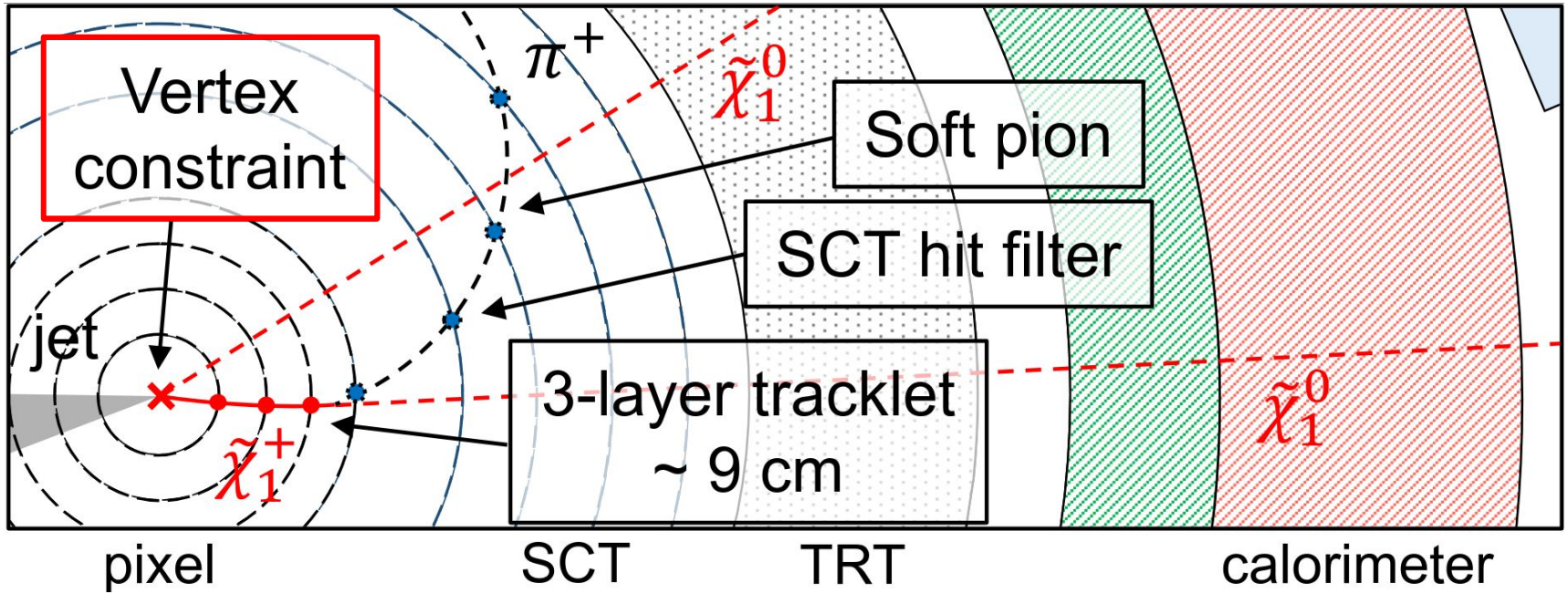
Don't want this: analysis vetoes tracklets with SCT hits...

Filter* **SCT hits** before attempting to attach them → **~40%/5% more signal/background pixel-only tracklets!**

Bonus: effect less dependent on pileup

*filter: don't attach single SCT hits or 2 SCT hits from different layers

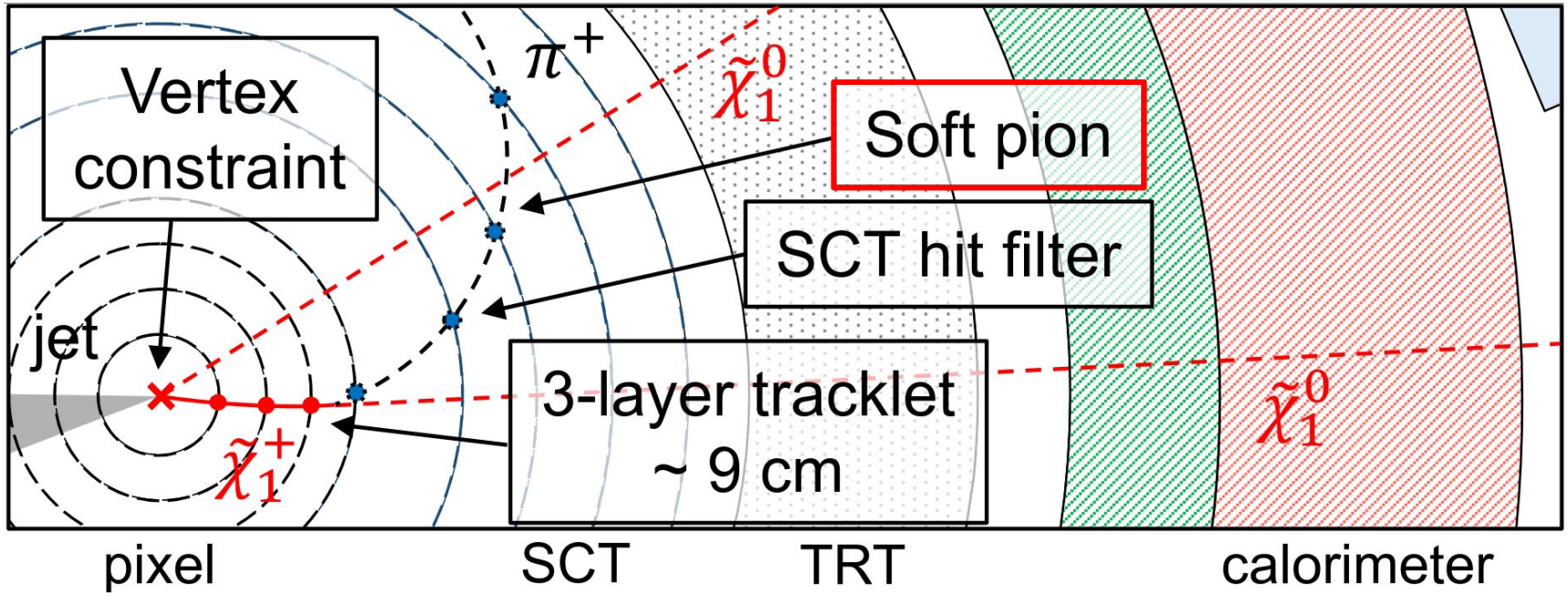
How to improve?



credit: Daiya Akiyama

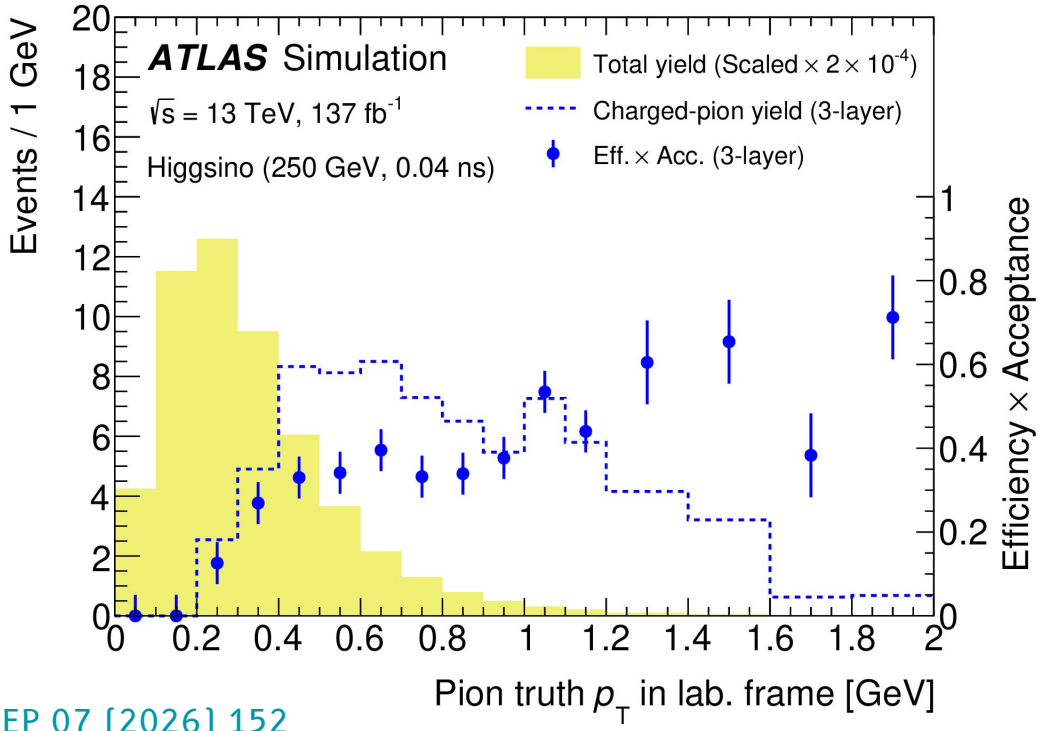
Re-fit tracklet with primary vertex as additional point
↪ significantly improved p_T resolution
↪ better signal/background separation

How to improve?



credit: Daiya Akiyama

Soft track reconstruction



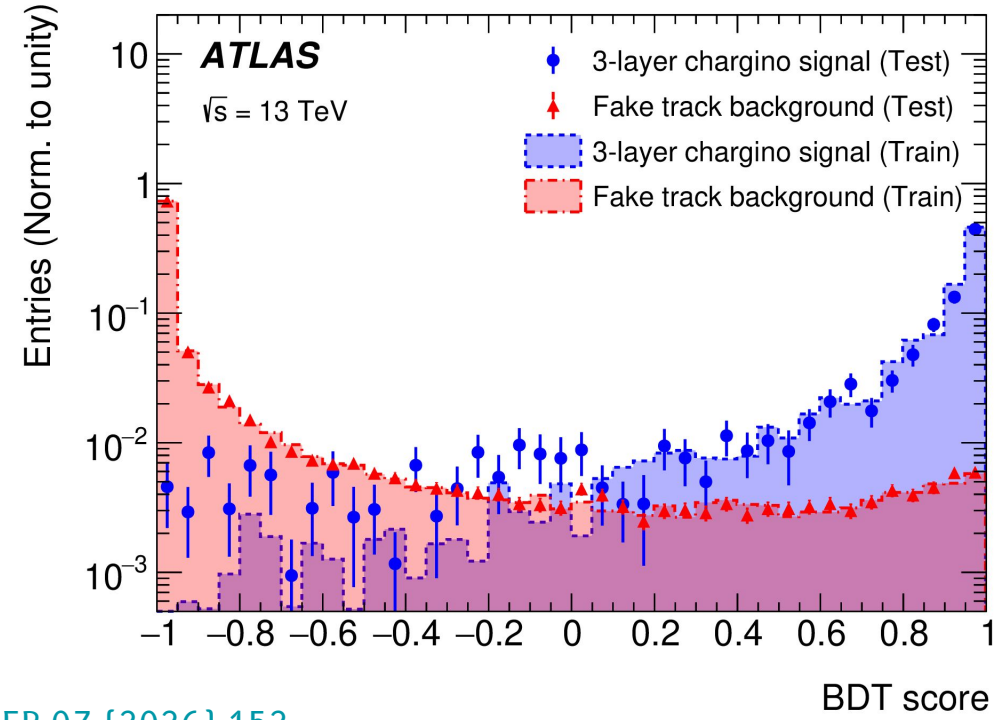
JHEP 07 (2026) 152

Soft pions from chargino decays → **O(100s) MeV tracks**

Challenging to reconstruct with high pileup → seeded with SCT hits in **region of interest around pixel tracklet** (ΔR<0.8)

Soft track efficiency quite high for p_T>~300 MeV, reasonably robust against pileup (backup)

Soft track selection



[JHEP 07 (2026) 152]

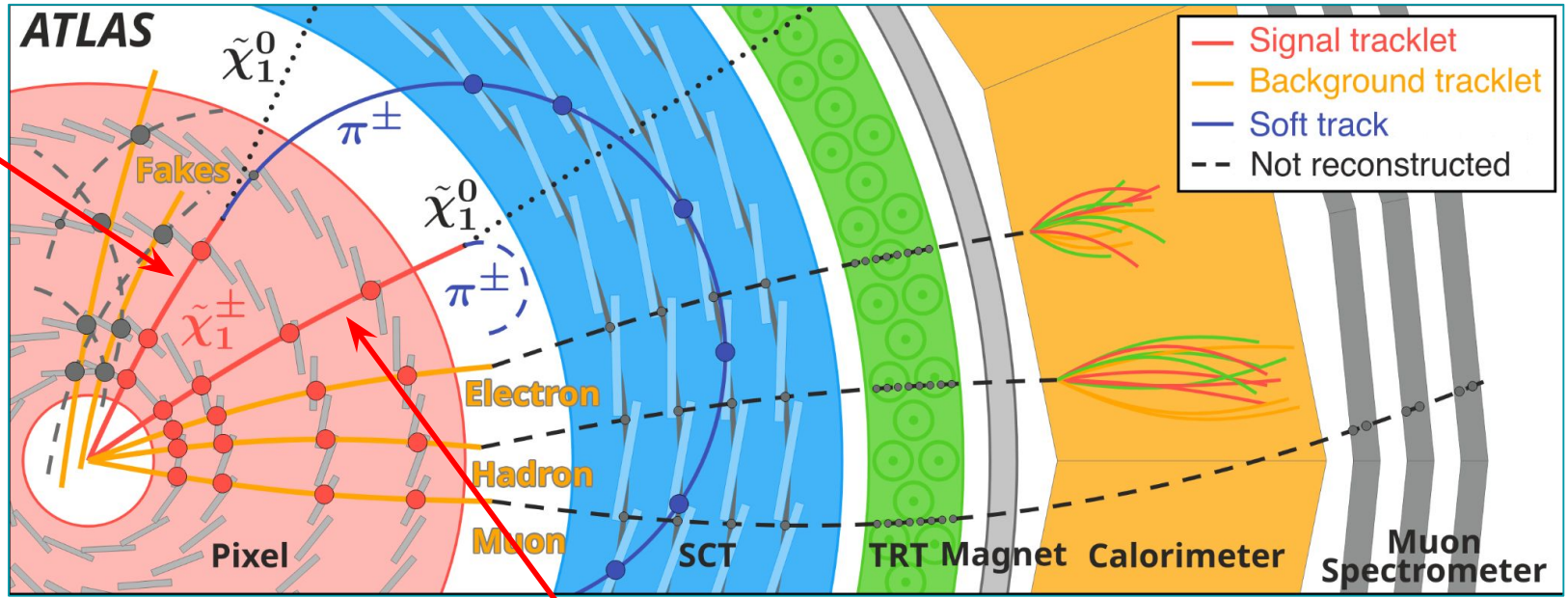
Large number of soft tracks associated with each tracklet **despite optimised reco**

Boosted Decision Tree (BDT) trained to select signal-like soft tracks using
- ↳ soft track kinematics
- ↳ soft track quality
- ↳ tracklet-soft track distance

Achieves good separation between **signal-like** and **background-like** soft tracks

How do we select our signal?

3-layer tracklets
↳ two signal regions
↳ with and without **soft tracks**

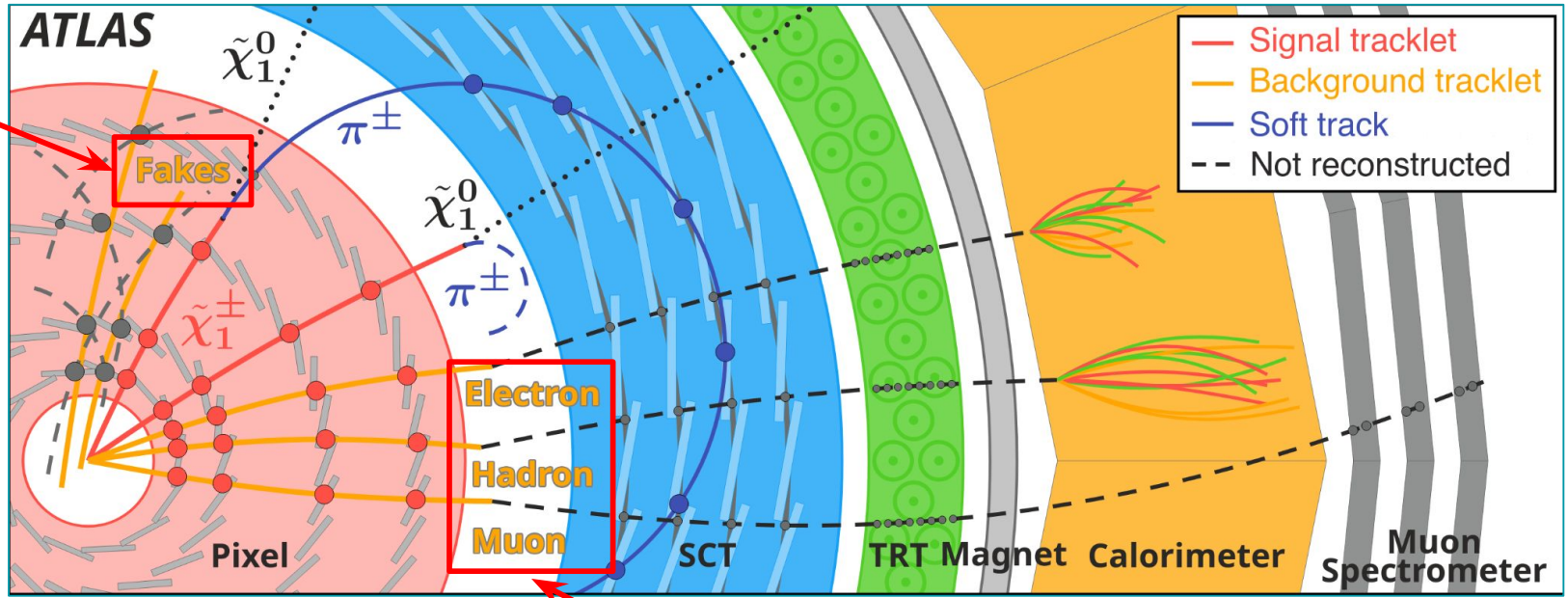


4-layer tracklets
↳ two signal regions (different missing E_T thresholds)
↳ not using **soft track** information

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What are the backgrounds?

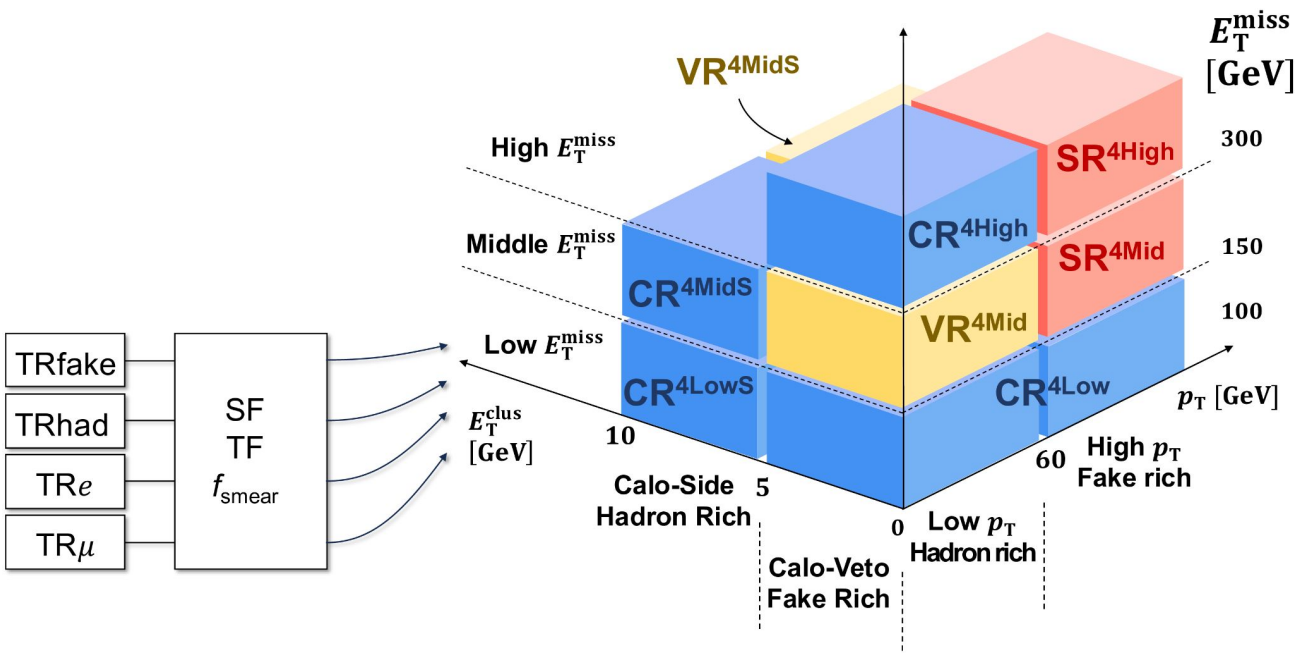
Fake background
tracklets built with hits from
↳ pileup particles
↳ other particles from same collision
↳ detector noise



Scattering backgrounds
particles scattered in detector material
↳ can't be reconstructed as full tracks

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How to estimate the backgrounds?



Complex data-driven scheme to get **template in tracklet p_T** for each type of background

↪ several template regions (TRs) and relaxed selections to calculate transfer factors (TFs)

↪ fit background yields in control regions (CRs) and validate in dedicated regions (VRs)

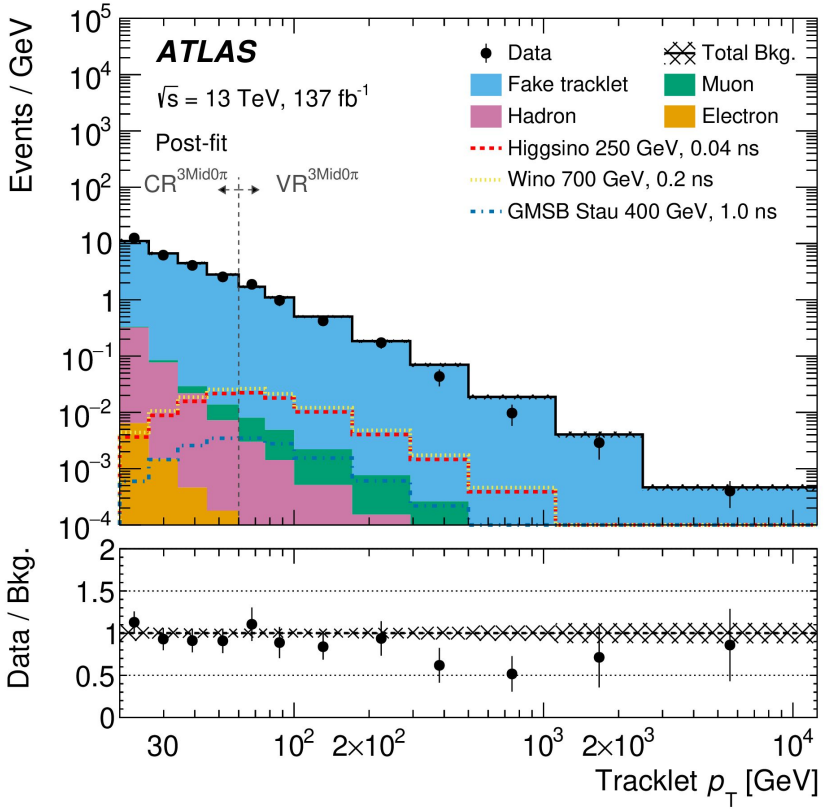
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How to estimate the backgrounds?

Tracklet p_T is the main discriminant between signal and background

Electron/muon/hadron backgrounds
↳ start from events with single electrons/muons/tracks
↳ correct for probability to end up as isolated tracklets
↳ smear p_T to account for worse tracklet momentum resolution

Fake background
↳ use events with low missing E_T, 3-layer tracklets not pointing to primary vertex
↳ extrapolate to: high missing E_T, 4-layer tracklets, pointing to primary vertex



} various signal models

[JHEP 07 (2026) 152]

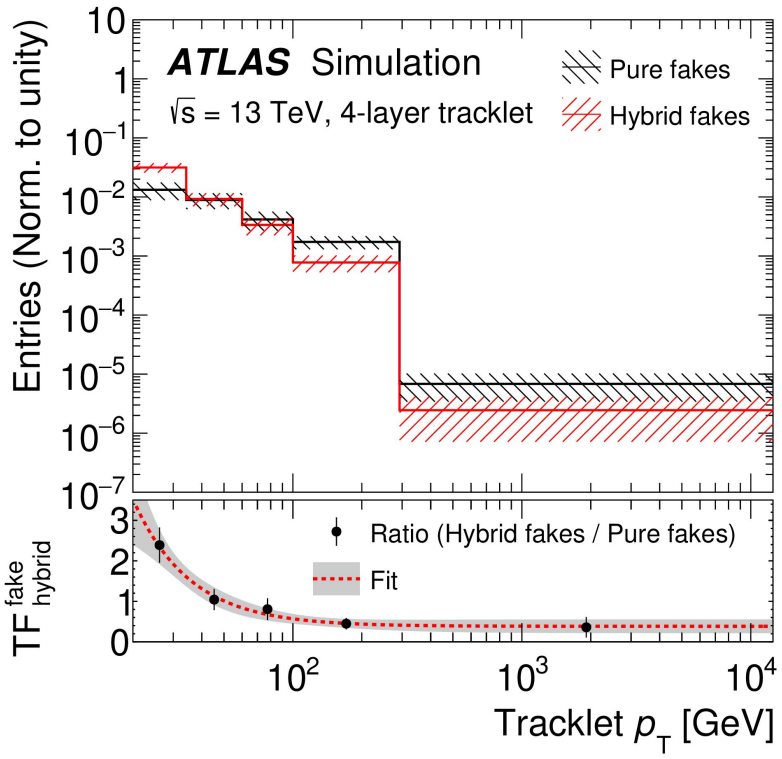
Fake background: hybrid fakes

Tracklets entering the **fake background** can have different hit compositions

- **purely random** combination of hits
- mixing hits from real particles with random hits → **hybrid fakes**

Shapes of p_T distribution different → **need correction**

- ratio of p_T shapes from simulation
- estimate fractions of random and hybrid fakes in data

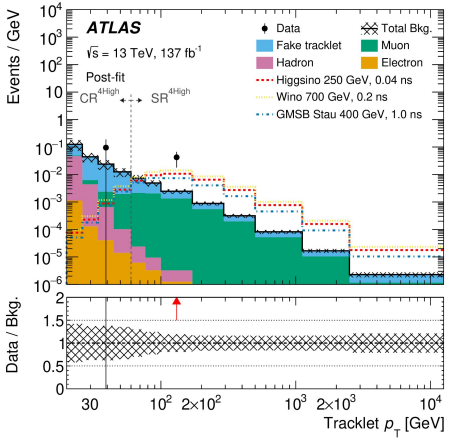


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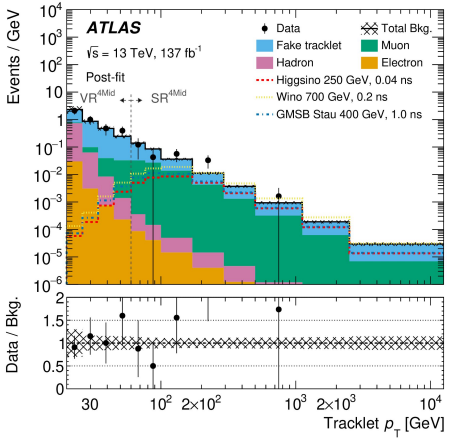
Putting it all together

Fit backgrounds in control regions using **tracklet p_T** distribution
↪ after unblinding check data in signal regions!

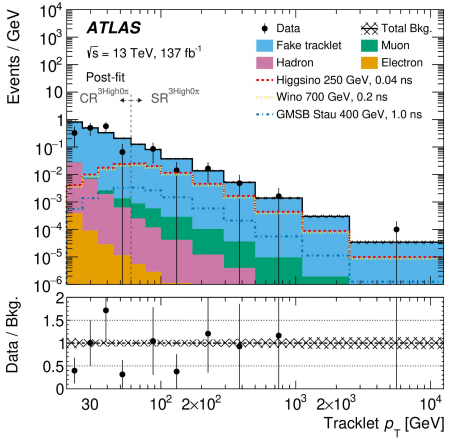
4-layer, high MET



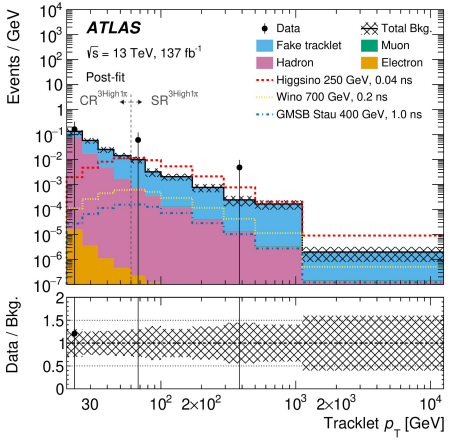
4-layer, medium MET



3-layer, no soft track



3-layer + soft track



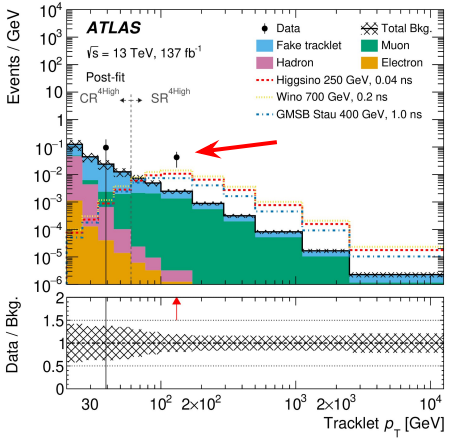
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↪ good agreement between **data** [🔴] and estimated **background** [—]

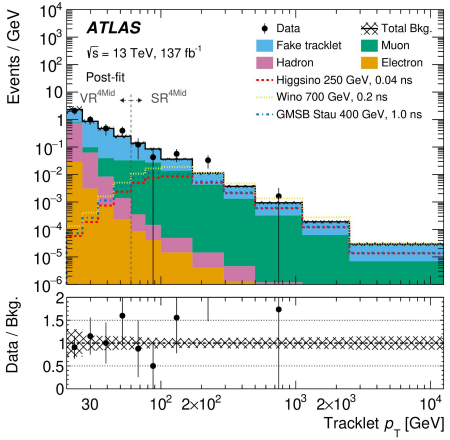
Putting it all together

Fit backgrounds in control regions using **tr**
↪ after unblinding check data in signal reg

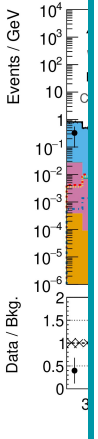
4-layer, high MET

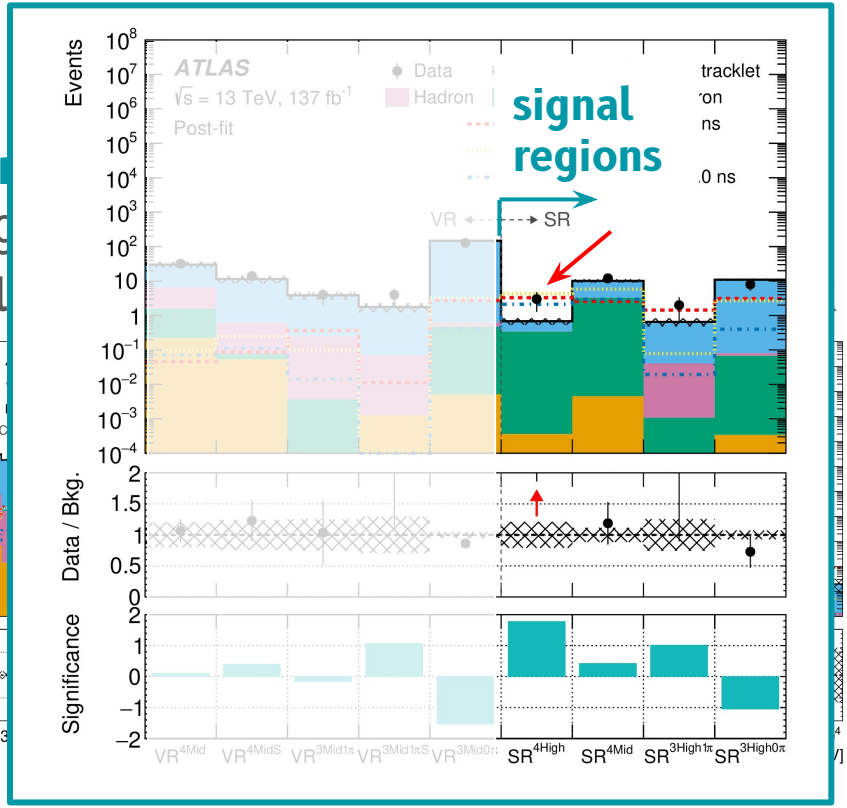


4-layer, medium MET



3-l



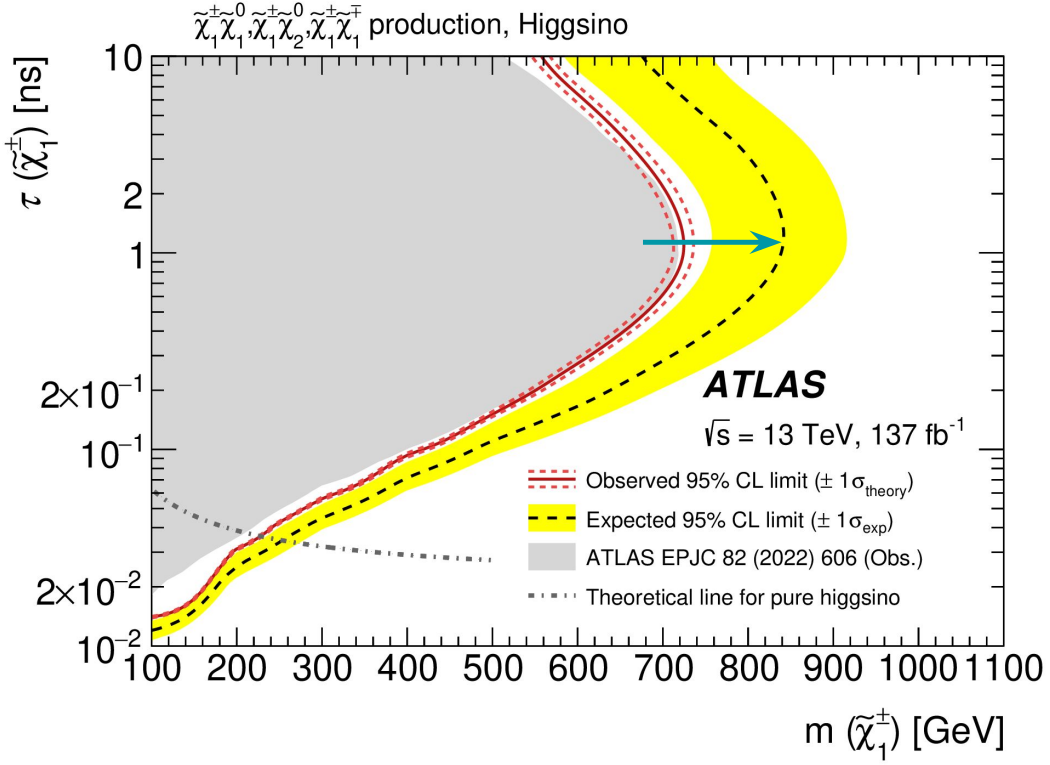


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↪ small excess in **4-layer, high MET region** (3 obs., 0.7 exp.)
↪ event characteristics consistent with background

New limits: higgsino interpretation

Improved sensitivity from
new analysis techniques

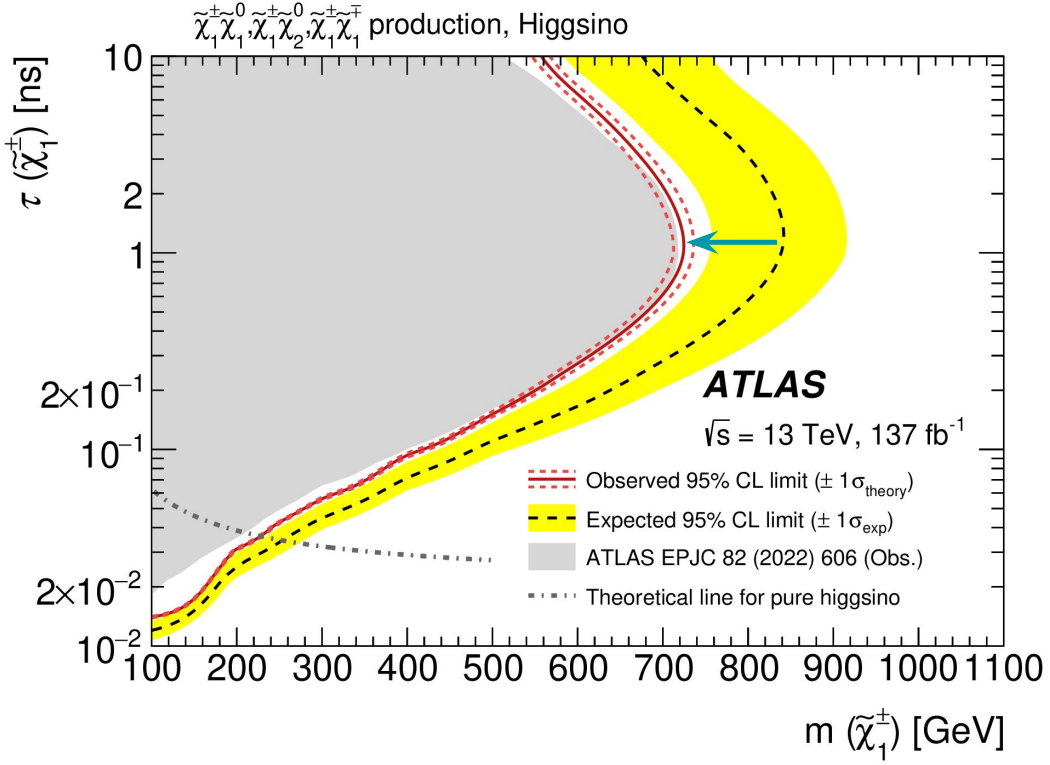


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New limits: higgsino interpretation

Improved sensitivity from new analysis techniques

Ultimately **less gain than expected** due to high yield in 4-layer, high MET signal region



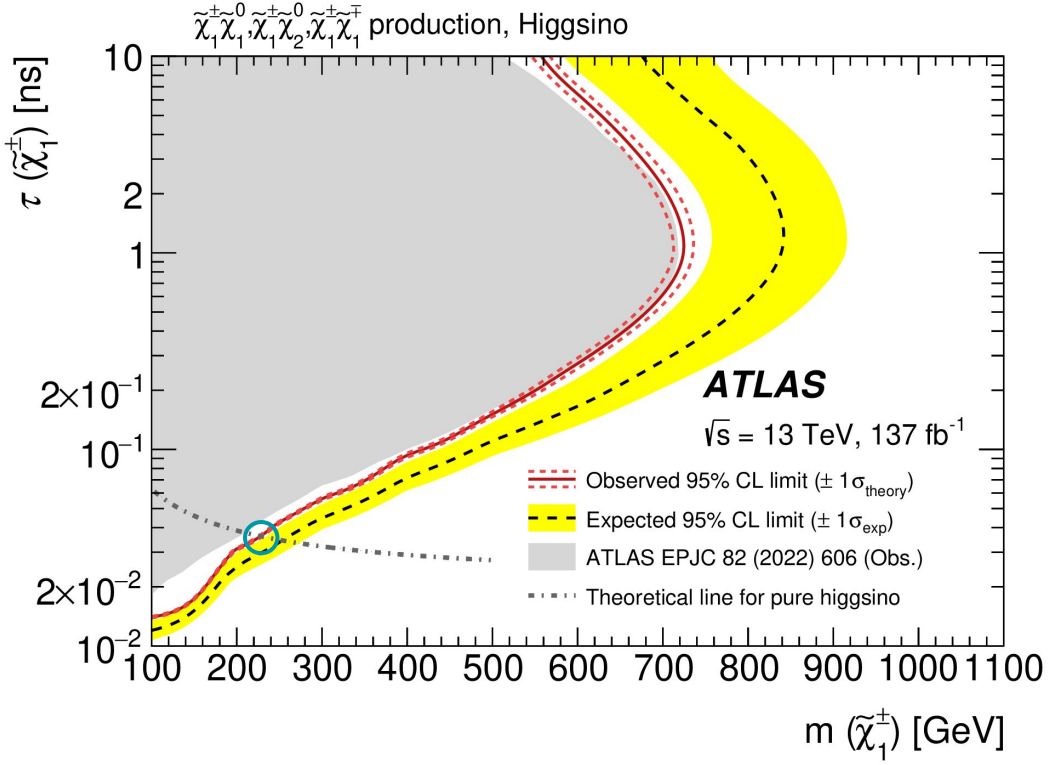
JHEP 07 (2026) 152

New limits: higgsino interpretation

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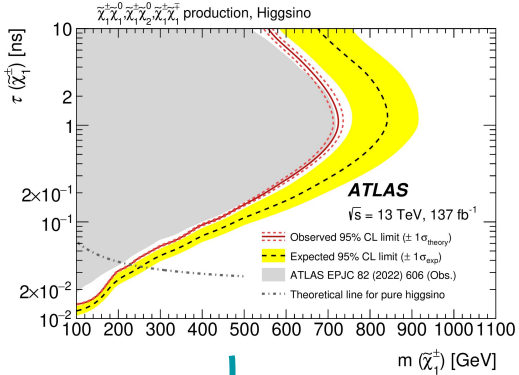
Mass reach: ~225 GeV for pure higgsino
[~670 GeV for pure wino, see backup]



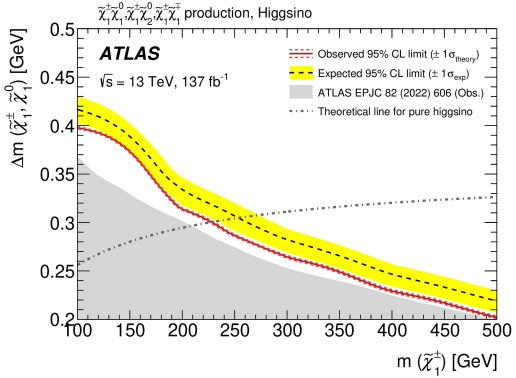
JHEP 07 [2026] 152

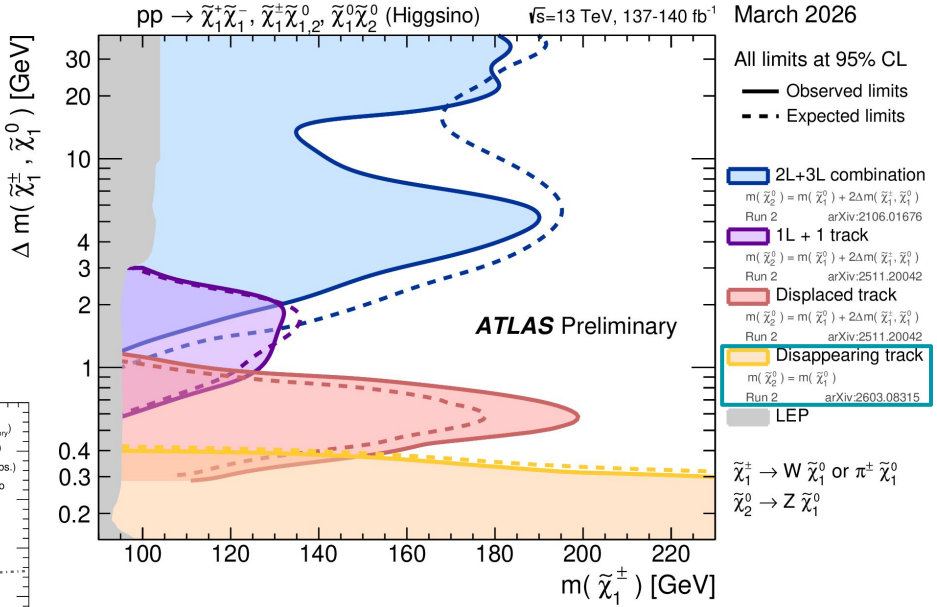
Higgsino interpretation: full picture

ATL-PHYS-PUB-2026-003



convert chargino lifetime to mass splitting between chargino and neutralino





↪ **unique sensitivity** to the smallest mass splittings
↪ together with other **recent results** improve over **LEP exclusion limits** across full range of mass splittings for the first time!

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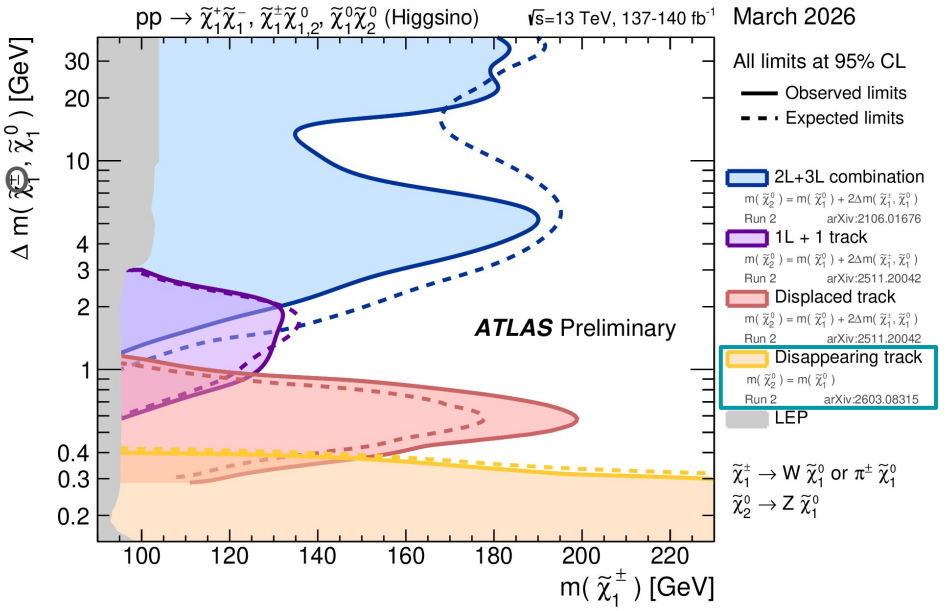
Summary / Outlook

Final word from ATLAS on disappearing tracks in Run 2: JHEP 07 [2026] 152

- several **new analysis techniques**
- **improved sensitivity** to short charginо lifetimes

What's next?

- **Run 3**: higher pileup → use pixel dE/dx for additional sensitivity?
- **HL-LHC**: even higher pileup, new tracker (ITk) → new ideas needed?

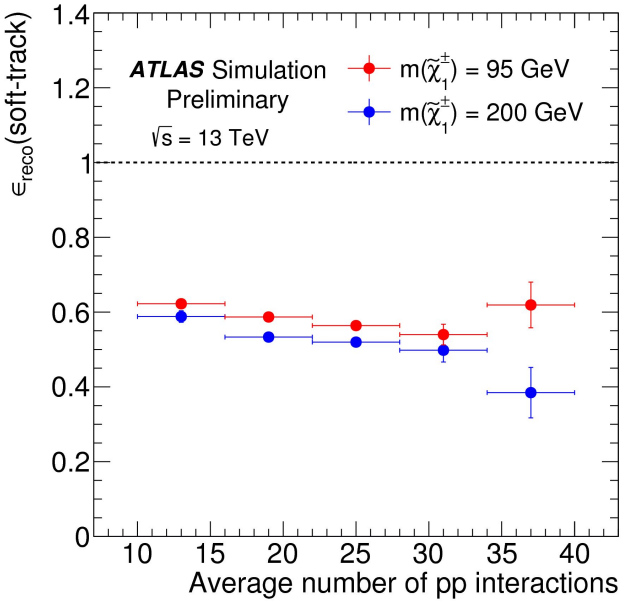


ATL-PHYS-PUB-2026-003

Additional slides

How to improve?

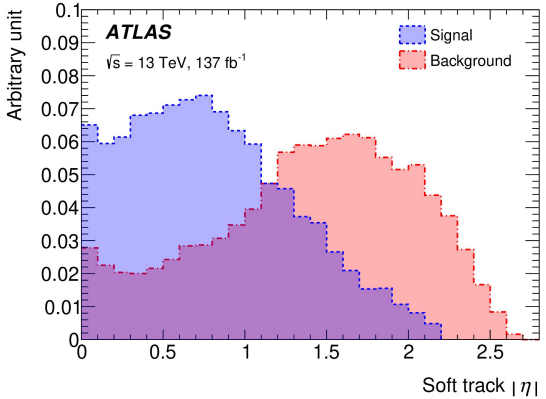
Soft track reconstruction: efficiency vs pileup

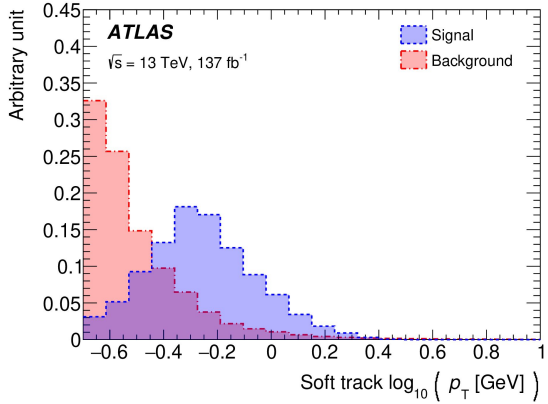


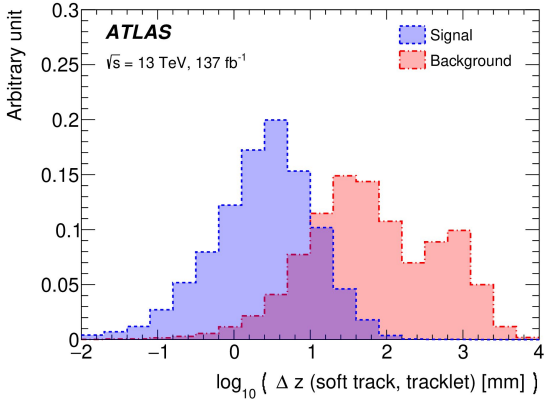
ATL-PHYS-PUB-2019-011

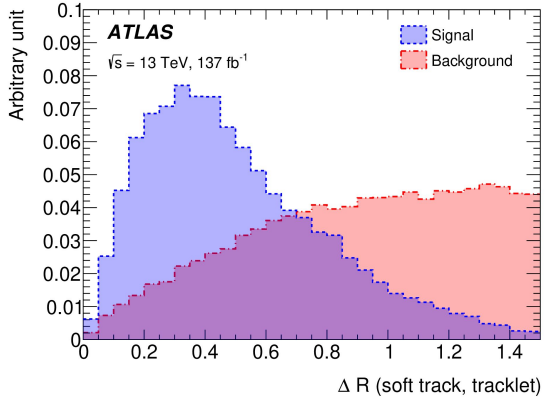
How to improve?

Soft track BDT: input variables





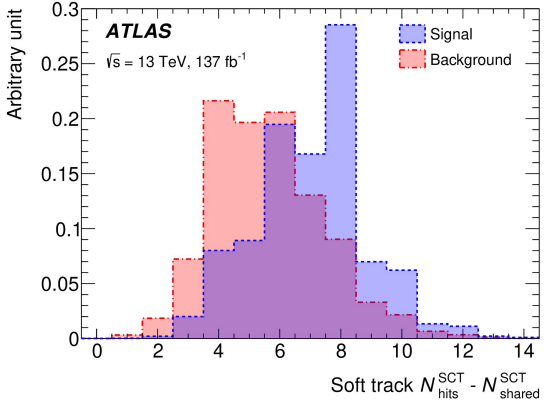


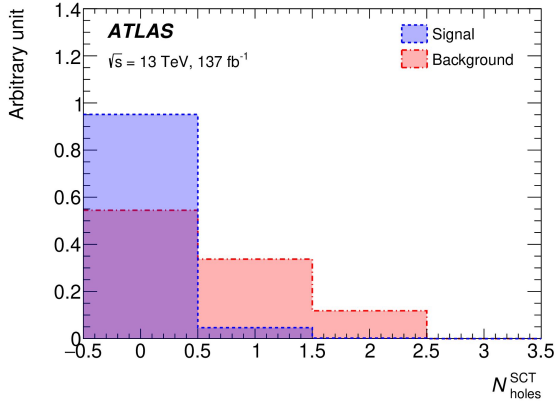


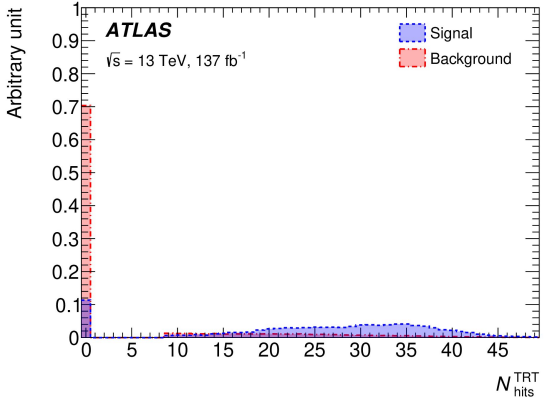
[ATLAS: HMBS-2024-66]

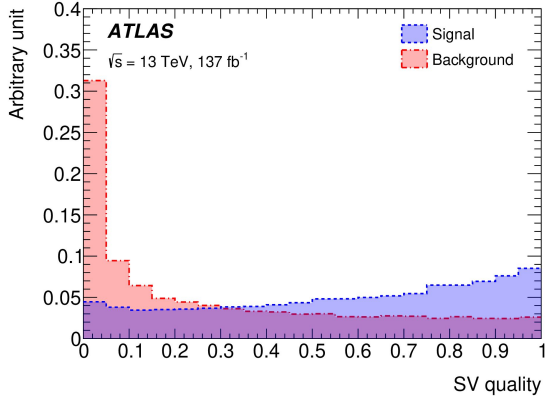
How to improve?

Soft track BDT: input variables









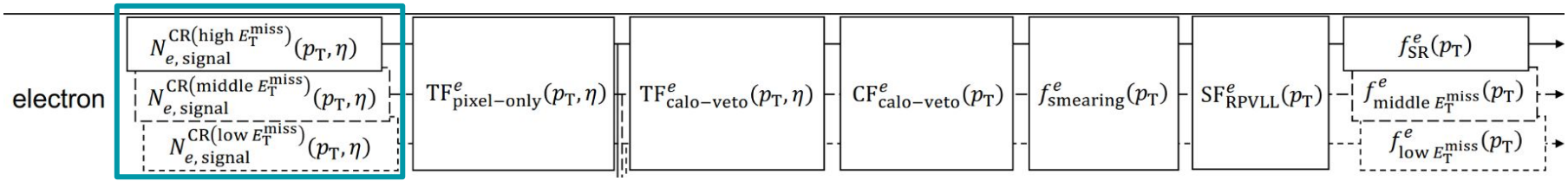
[ATLAS: HMBS-2024-66]

Scattering backgrounds: general scheme

Single electron control region

↳ kinematic selections as in nominal analysis regions

↳ require single electron instead of pixel tracklet



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Scattering backgrounds: general scheme

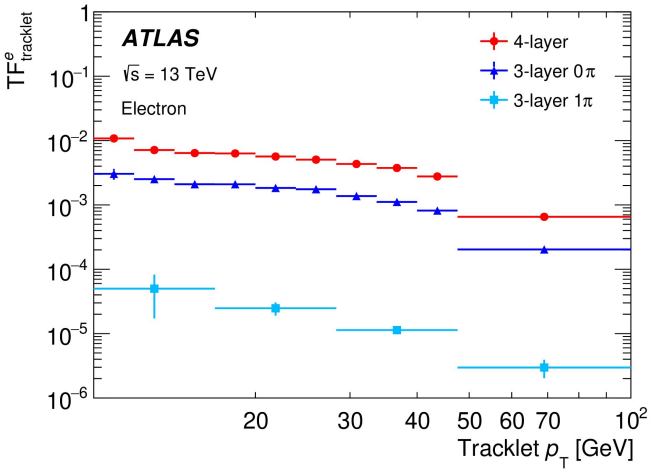
Single electron control region

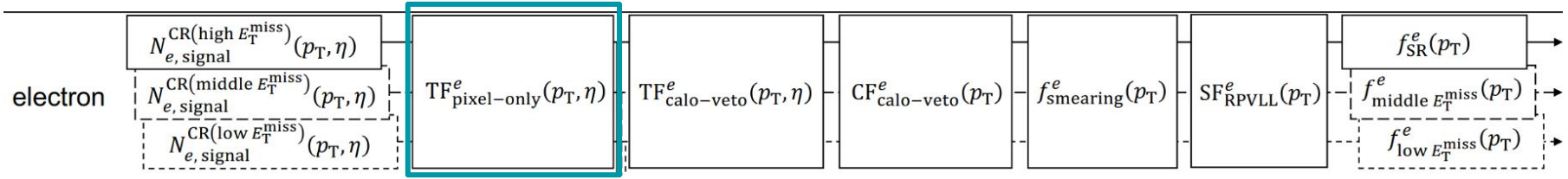
Transfer factor for pixel tracklets

↳ probability for electron to end up as pixel tracklet

↳ separate transfer factor if requiring soft track

↳ measured using Z→ee tag-and-probe events



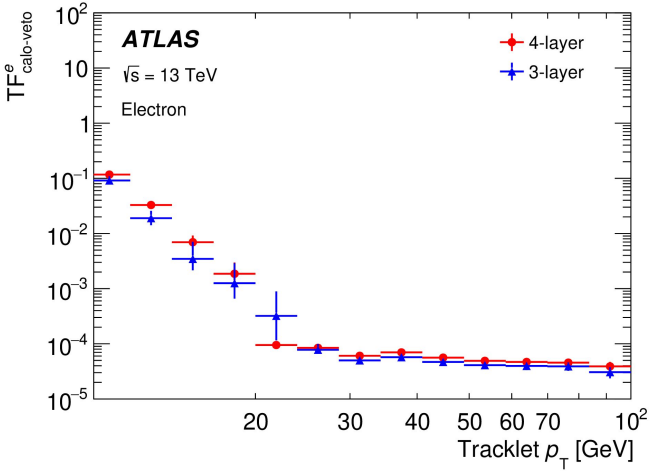


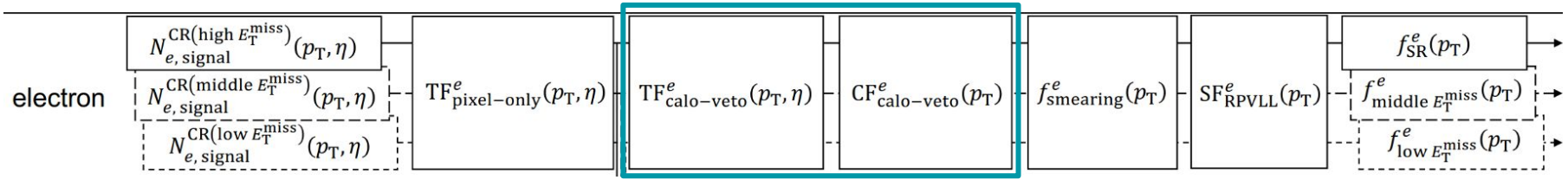
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Scattering backgrounds: general scheme

Single electron control region
Transfer factor for pixel tracklets
Transfer factor for calorimeter veto

- ↳ probability for pixel tracklet from electron to be isolated in calorimeter
- ↳ additional correction for different calorimeter veto efficiencies of standard tracks and pixel tracklets
- ↳ measured using Z→ee tag-and-probe events





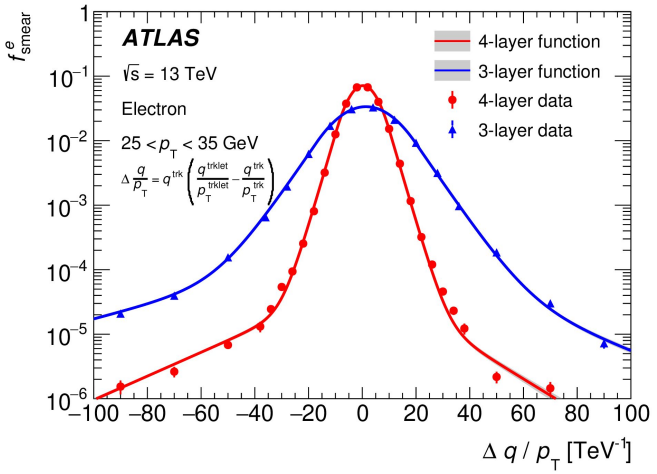
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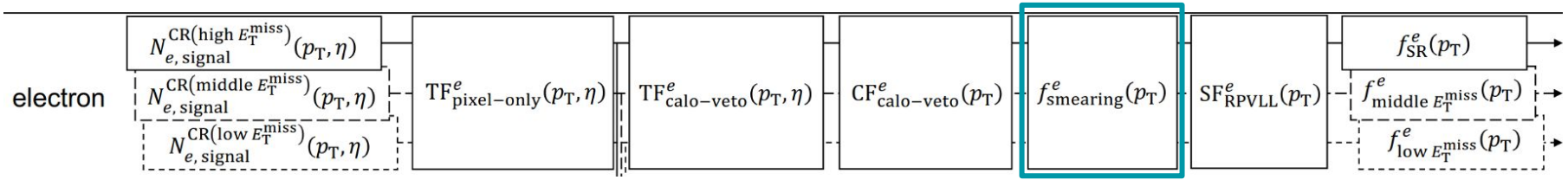
Scattering backgrounds: general scheme

Single electron control region
Transfer factor for pixel tracklets
Transfer factor for calorimeter veto
Smearing in p_T

↳ accounts for different p_T resolutions of standard tracks and pixel tracklets

↳ measured in Z→ee events, extrapolated to low p_T using single-electron MC

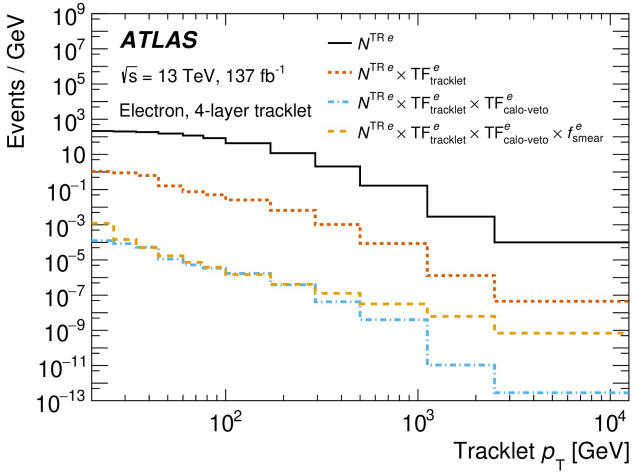


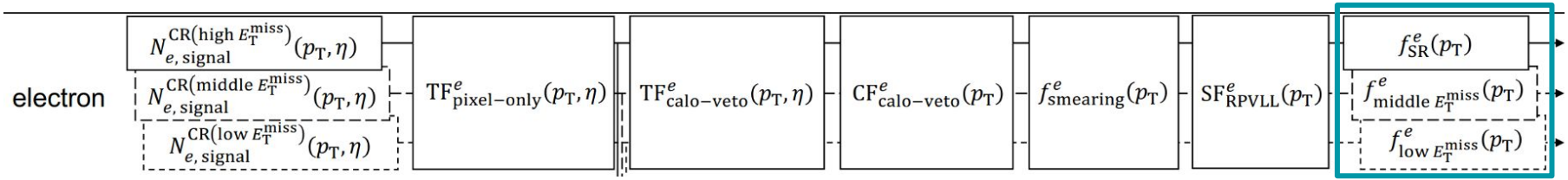


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Scattering backgrounds: general scheme

- Single electron control regions
- Transfer factor for pixel tracklets
- Transfer factor for calorimeter veto
- Smearing in p_T
- RPVLL filter scale factor
- **Templates in tracklet p_T**





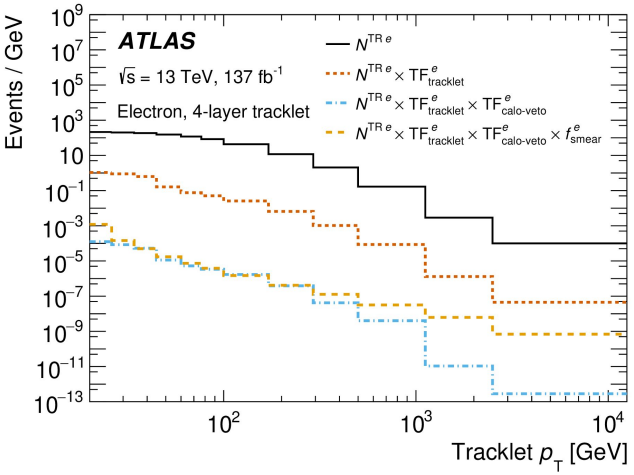
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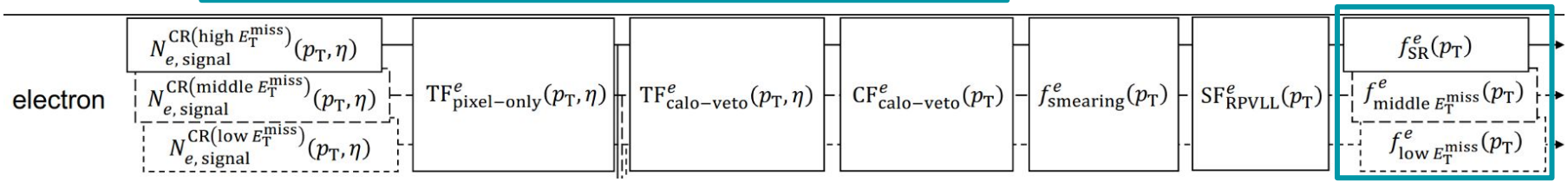
Scattering backgrounds: general scheme

Single ele
Transfer f
Transfer f
Smearing
RPVLL fil
Templates

Procedure similar for muon
↪ start from single muon control region
↪ use Z→μμ events to derive corrections
↪ veto overlap with muon spectrometer tracks instead of calorimeter veto

and hadron backgrounds
↪ start from single track control region
↪ reuse electron corrections, adjust for differences between electrons and hadrons



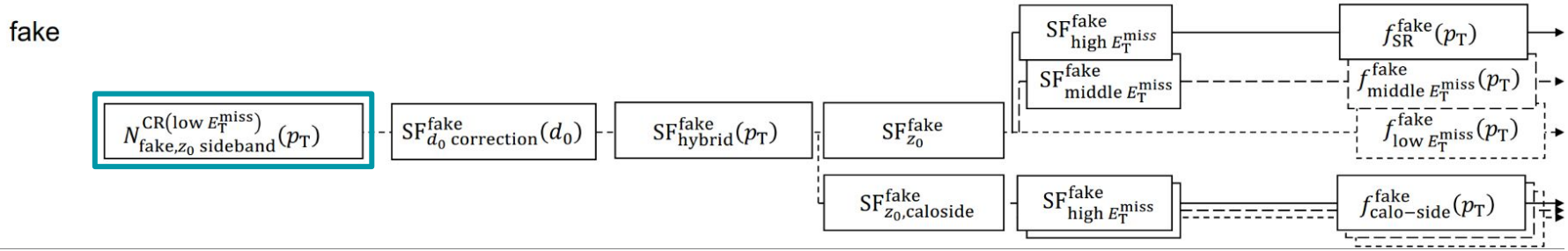


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Fake background

Fake background control region

↳ low missing E_T events, high z_0 3-layer tracklets
↳ completely dominated by fake tracklets



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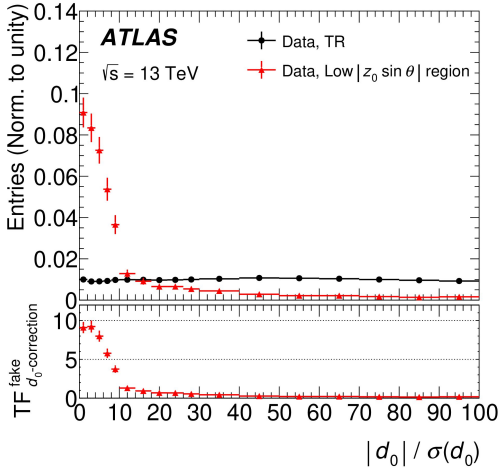
Fake background

Fake background control region

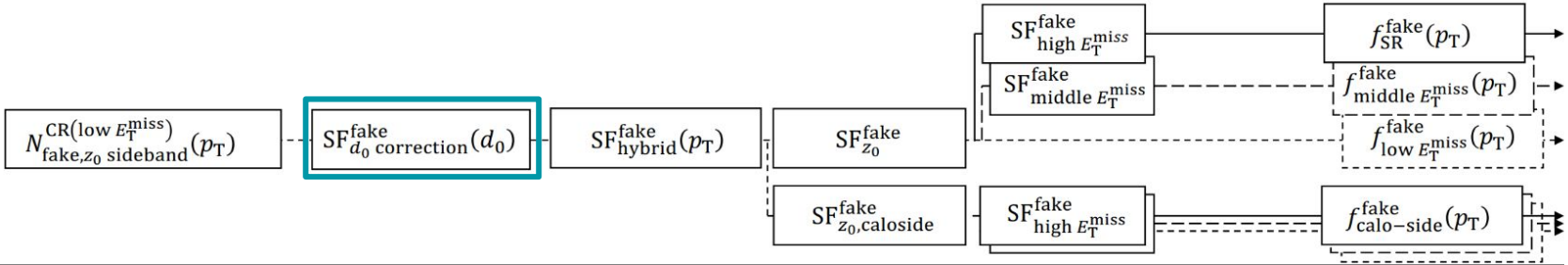
d_0 correction

↳ 3-layer and 4-layer tracklets have different correlations between d_0 and p_T resolution

↳ correct shape of 4-layer fake tracklet template



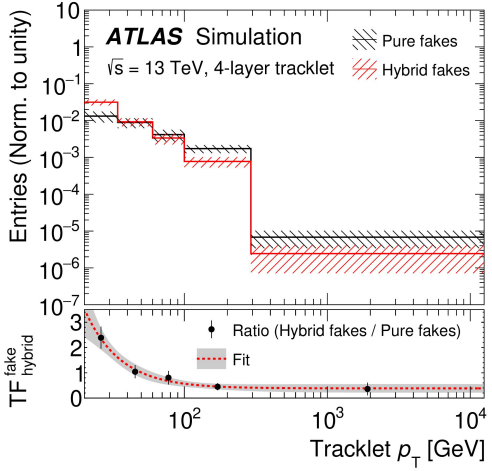
fake



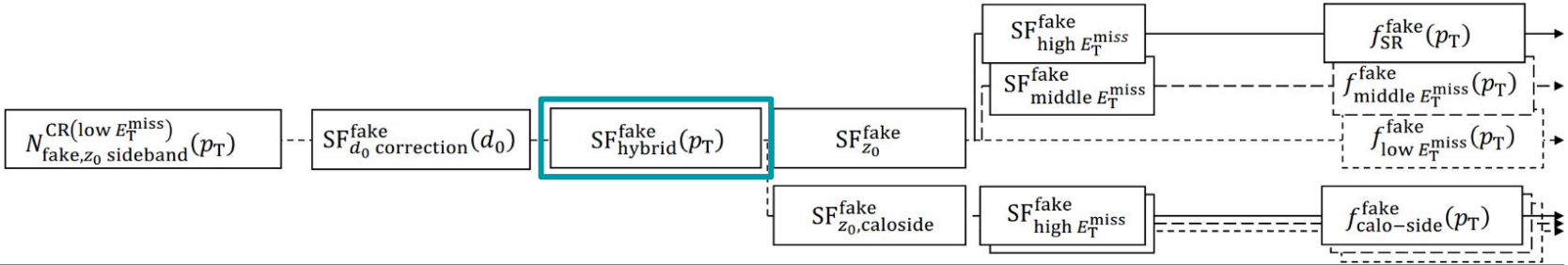
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Fake background

Fake background control region
d_0 correction
Hybrid fake correction
↳ fake tracklets can be purely random or mix hits from real particles with random ones (hybrid fakes)
↳ shapes of p_T distribution different, need correction



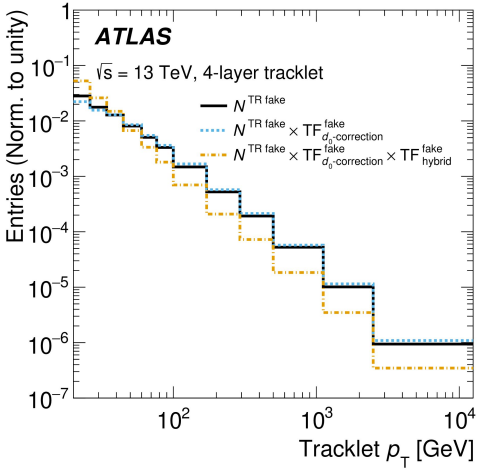
fake



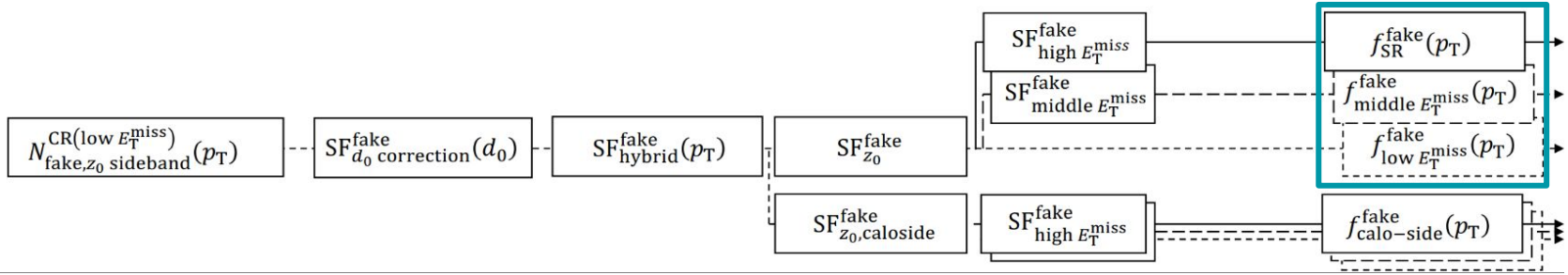
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Fake background

Fake background control region
d_0 correction
Hybrid fake correction
Normalisation
Templates in tracklet p_T



fake



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Signal region selections

Variable	SR^{4High}	SR^{4Mid}	$SR^{3High1\pi}$	$SR^{3High0\pi}$
E_T^{miss} trigger	Passed			
Number of leptons	$= 0$			
Number of jets ($p_T > 20$ GeV)	≥ 1			
Leading jet p_T	> 100 GeV			
$\lvert\Delta\phi(j_1, \vec{p}_T^{miss})\rvert$	> 1.0			
Number of four-layer tracklets	≥ 1		$= 0$	
Number of three-layer tracklets	-		≥ 1	
Number of charged pions	-		≥ 1	$= 0$
Tracklet p_T	> 60 GeV	> 60 GeV	> 60 GeV	> 60 GeV
Tracklet $\lvert\eta\rvert$	0.1–1.9	0.1–1.9	0.1–1.9	0.1–1.7
E_T^{miss}	> 300 GeV	150–300 GeV	> 240 GeV	> 280 GeV

Selections	Higgsino (250 GeV, 0.04 ns) Events	(Eff. [%])	Wino (700 GeV, 0.2 ns) Events	(Eff. [%])	GMSB stau (400 GeV, 1.0 ns) Events	(Eff. [%])
Kinematic selection						
Initial Yield (137 fb^{-1})	65043.32	(–)	1915.87	(–)	255.45	(–)
$E_T^{miss} > 50$ GeV (Generator)	22969.53	(35.31)	–	(–)	–	(–)
$E_T^{miss} > 60$ GeV (Generator)	–	(–)	808.21	(42.19)	–	(–)
Data Quality	22436.73	(99.99)	786.52	(99.99)	108.17	(99.94)
E_T^{miss} trigger	8145.48	(36.30)	403.94	(51.36)	61.24	(56.61)
Lepton veto	8127.13	(99.77)	402.73	(99.70)	60.86	(99.38)
Leading-jet $p_T > 100$ GeV	6679.19	(82.18)	341.99	(84.92)	58.25	(95.71)
$\lvert\Delta\phi(j_1, E_T^{miss})\rvert > 1.0$	6268.40	(93.85)	323.55	(94.61)	38.24	(65.65)
SR^{4High}						
4-layer tracklets ≥ 1	6.97	(0.11)	12.26	(3.79)	6.08	(16.00)
Tracklet $p_T > 60$ GeV	6.86	(98.42)	12.05	(98.27)	5.95	(97.85)
Tracklet $\lvert\eta\rvert \in [0.1, 1.9]$	6.31	(91.98)	11.28	(93.63)	5.73	(96.34)
$E_T^{miss} > 300$ GeV	3.29	(52.14)	4.28	(37.91)	2.10	(36.63)
SR^{4Mid}						
4-layer tracklets ≥ 1	6.97	(0.11)	12.26	(3.79)	6.08	(16.00)
Tracklet $p_T > 60$ GeV	6.76	(98.42)	12.05	(98.27)	5.95	(97.85)
Tracklet $\lvert\eta\rvert \in [0.1, 1.9]$	6.31	(91.98)	11.28	(93.63)	5.73	(96.34)
$150 < E_T^{miss} < 300$ GeV	2.57	(40.73)	5.77	(51.17)	3.00	(52.30)
$SR^{3High1\pi}$						
≥ 1 3-layer tracklet	11.28	(0.18)	10.10	(3.12)	1.59	(0.49)
Tracklet $p_T > 60$ GeV	10.78	(95.57)	9.24	(91.53)	1.43	(90.23)
Tracklet $\lvert\eta\rvert \in [0.1, 1.9]$	8.60	(79.78)	8.36	(82.83)	1.24	(86.38)
$E_T^{miss} > 240$ GeV	5.21	(65.58)	4.17	(49.82)	0.66	(53.63)
Charged pions ≥ 1	1.43	(27.45)	0.02	(0.48)	0.02	(30.30)
$SR^{3High0\pi}$						
≥ 1 3-layer tracklet	11.28	(0.18)	10.10	(3.12)	1.59	(0.49)
Tracklet $p_T > 60$ GeV	10.78	(95.57)	9.24	(91.53)	1.43	(90.23)
Tracklet $\lvert\eta\rvert \in [0.1, 1.7]$	8.34	(77.37)	7.90	(85.52)	1.13	(78.64)
$E_T^{miss} > 280$ GeV	4.31	(51.68)	2.68	(33.92)	0.40	(35.40)
Charged pions = 0	3.09	(71.69)	2.68	(100.00)	0.40	(100.00)

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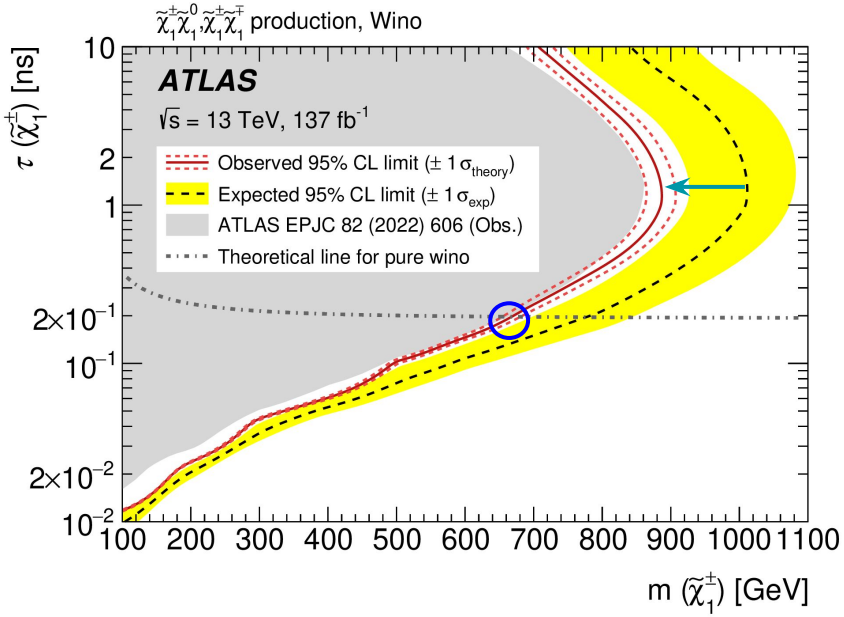
Signal region yields

	SR^{4High}	SR^{4Mid}	$SR^{3High1\pi}$	$SR^{3High0\pi}$
Fake Bkg.	0.33 ± 0.14	6.8 ± 1.1	0.62 ± 0.16	10.9 ± 0.8
Hadron Bkg.	$(5 \pm 4) \times 10^{-4}$	$(7 \pm 7) \times 10^{-3}$	0.029 ± 0.014	0.011 ± 0.021
Electron Bkg.	$(3.7 \pm 2.1) \times 10^{-4}$	$(4.6 \pm 2.7) \times 10^{-3}$	$(10 \pm 9) \times 10^{-6}$	$(2.5 \pm 1.3) \times 10^{-4}$
Muon Bkg.	0.342 ± 0.015	3.28 ± 0.14	$(1.1 \pm 0.6) \times 10^{-3}$	0.068 ± 0.009
Total Bkg.	0.68 ± 0.14	10.1 ± 1.1	0.65 ± 0.16	11.0 ± 0.8
Observed	3	12	2	8
p_0 (Z)	0.033 (1.9)	0.26 (0.6)	0.14 (1.1)	0.5 (0)
S^{95}_{exp}	$3.7^{+0.8}_{-0.6}$	$12.3^{+3.6}_{-2.9}$	$3.2^{+1.0}_{-0.2}$	$8.3^{+2.8}_{-2.6}$
S^{95}_{obs}	6.0	12.4	5.0	5.8
σ^{95}_{obs} [fb]	0.044	0.090	0.037	0.043

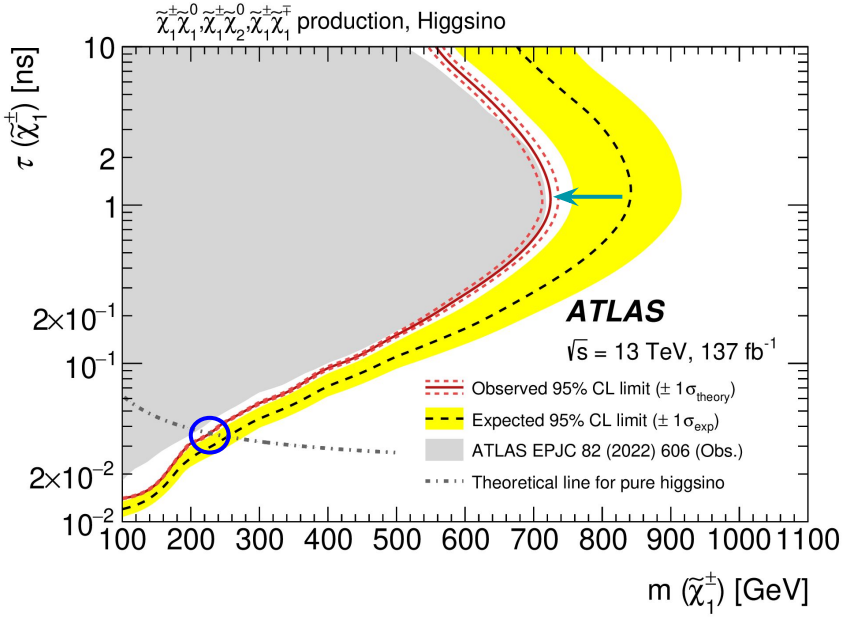
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New limits

wino interpretation



higgsino interpretation



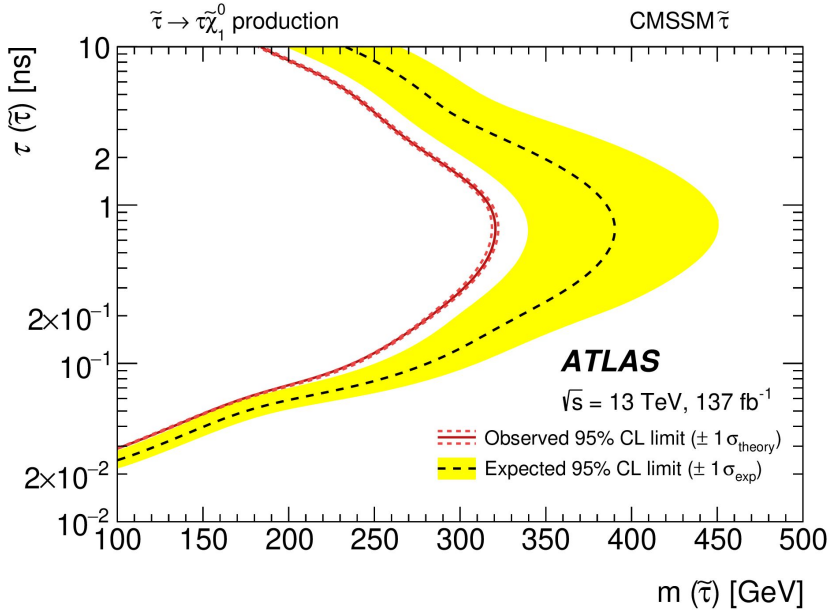
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↳ ultimately **less gain than expected** due to high yield in 4-layer, high MET signal region

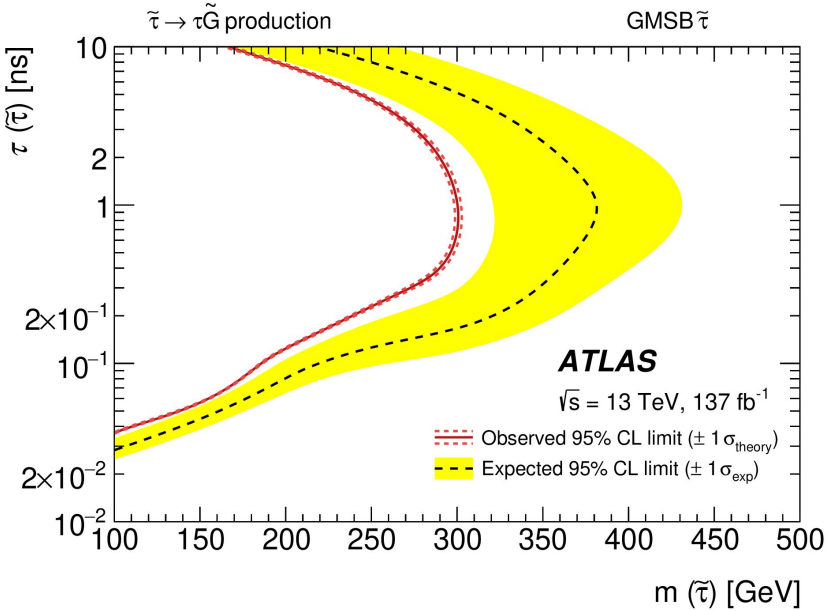
↳ **mass reach**: ~670 GeV (wino), ~225 GeV (higgsino)

New limits

CMSSM stau interpretation



GMSB stau interpretation



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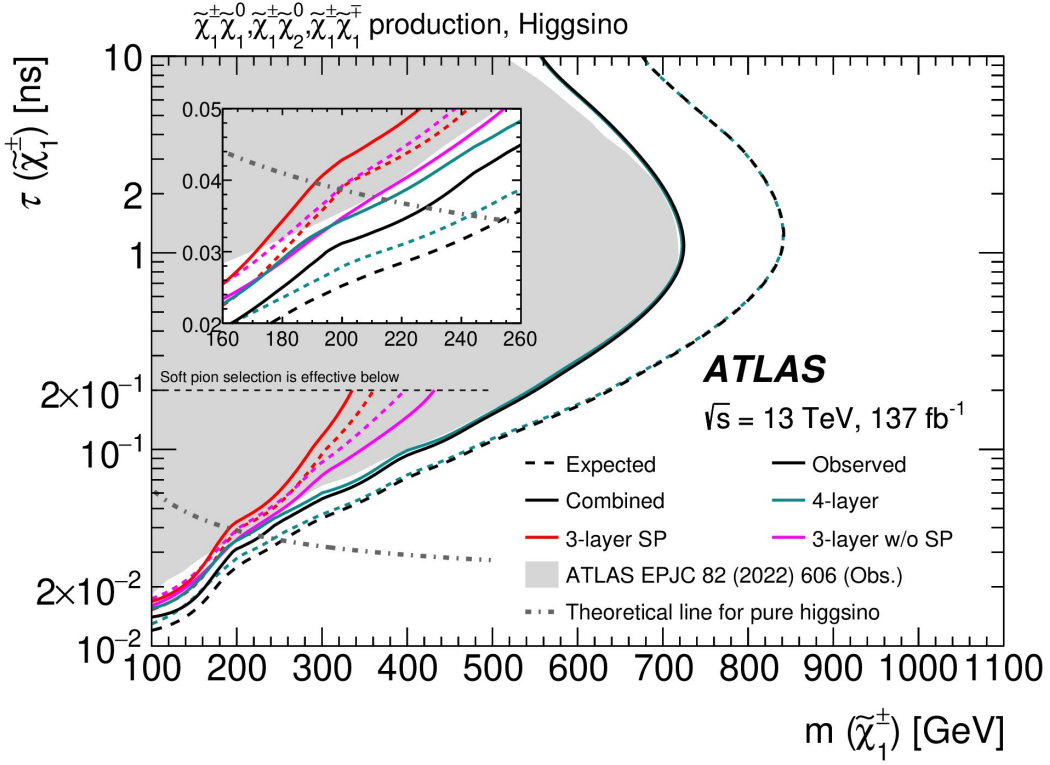
↳ mass reach at 1 ns lifetime:
~320 GeV (CMSSM), ~300 GeV (GMSB)

New limits: higgsino interpretation

Improved sensitivity from new analysis techniques

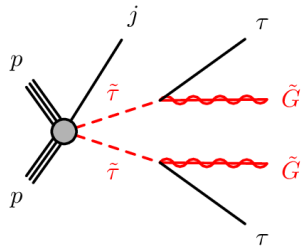
Ultimately less gain than expected due to high yield in 4-layer, high MET signal region

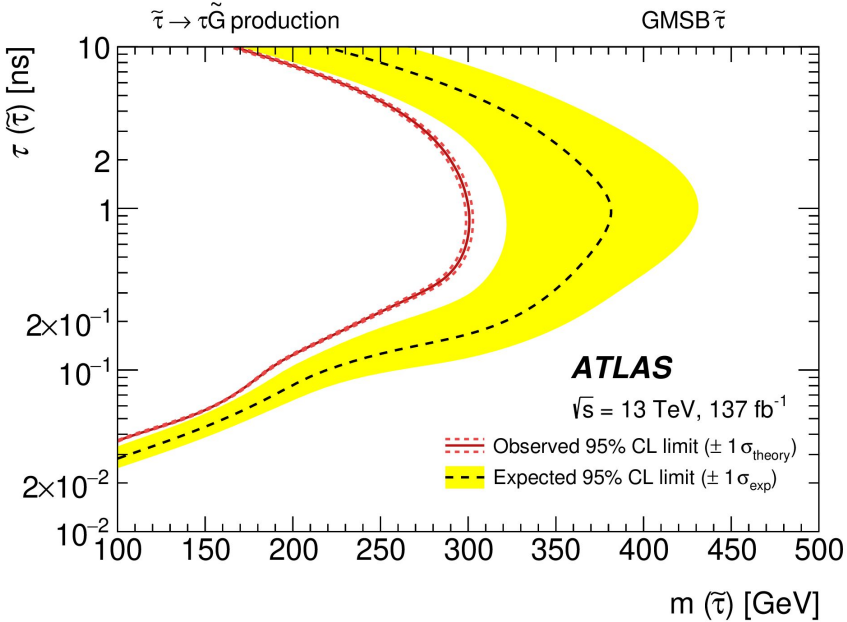
Mass reach: ~225 GeV for pure higgsino

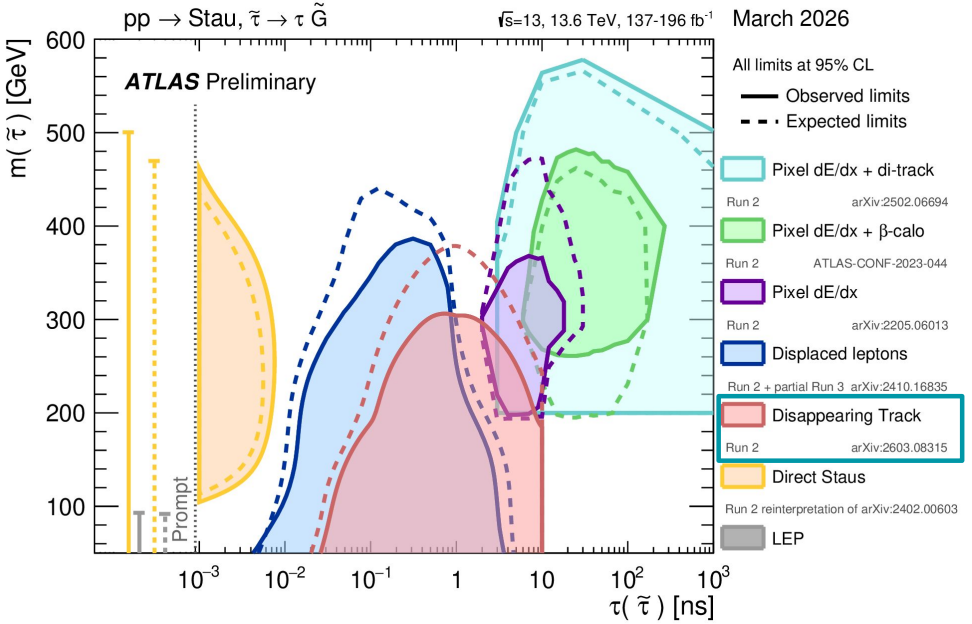


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Bonus: stau interpretation







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↪ mass reach at 1 ns lifetime: ~300 GeV
↪ complementary to specialised analyses searching for staus

[ATL-PHYS-PUB-2026-003](#)