Disappearing Tracks in ATLAS Searches for Electroweak Dark Matter

Mariana Vivas Albornoz (DESY)
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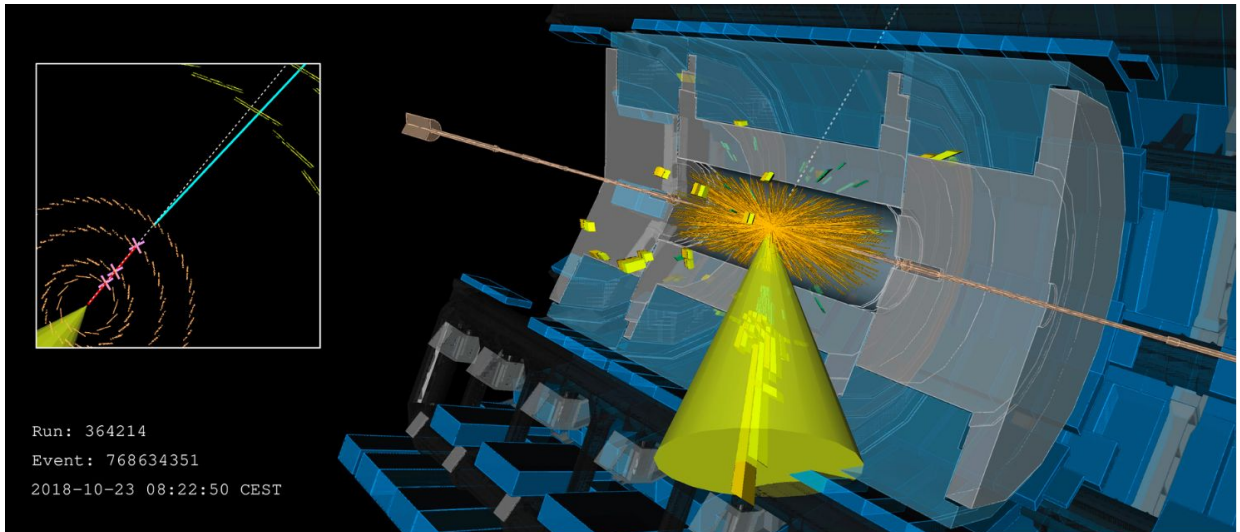
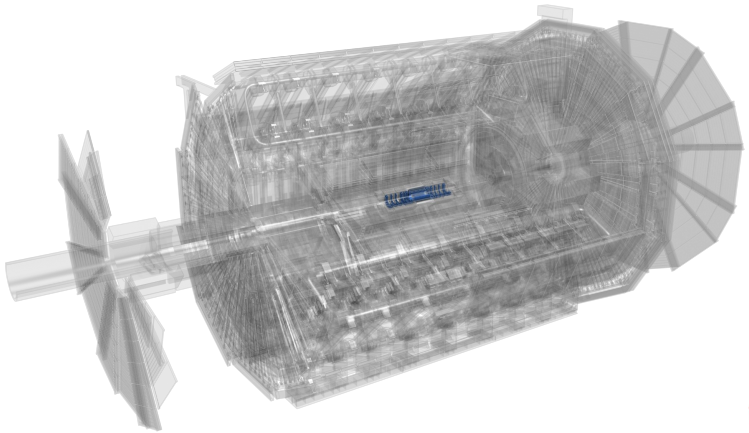
Herbstschule of High-Energy Physics



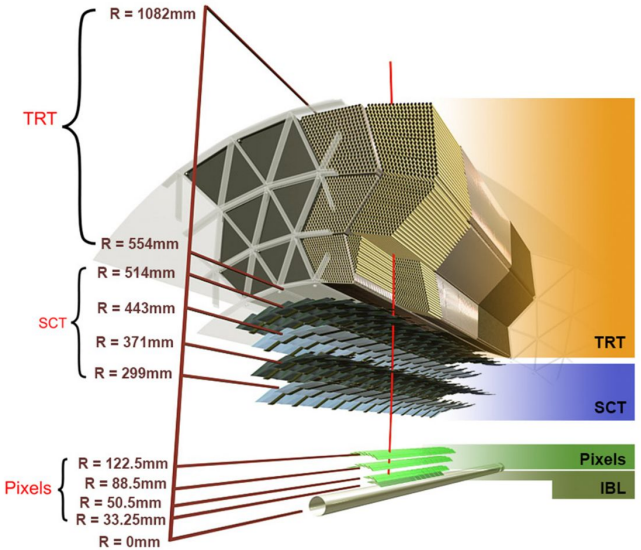
ATLAS inner detector

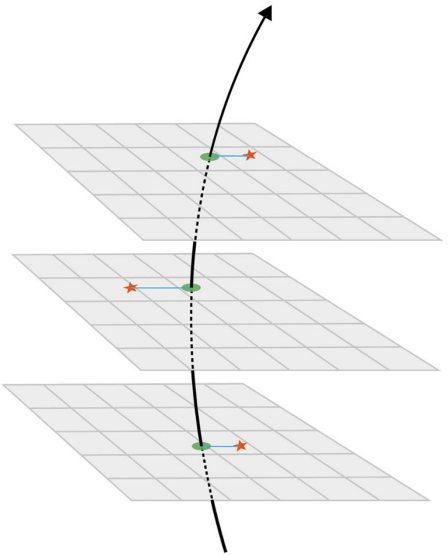


Surrounding the interaction point, at the center of the ATLAS detector, we have the **Inner Detector**.

As charged particles traverse these layers, they leave hits, which are combined to reconstruct their trajectory and momentum.

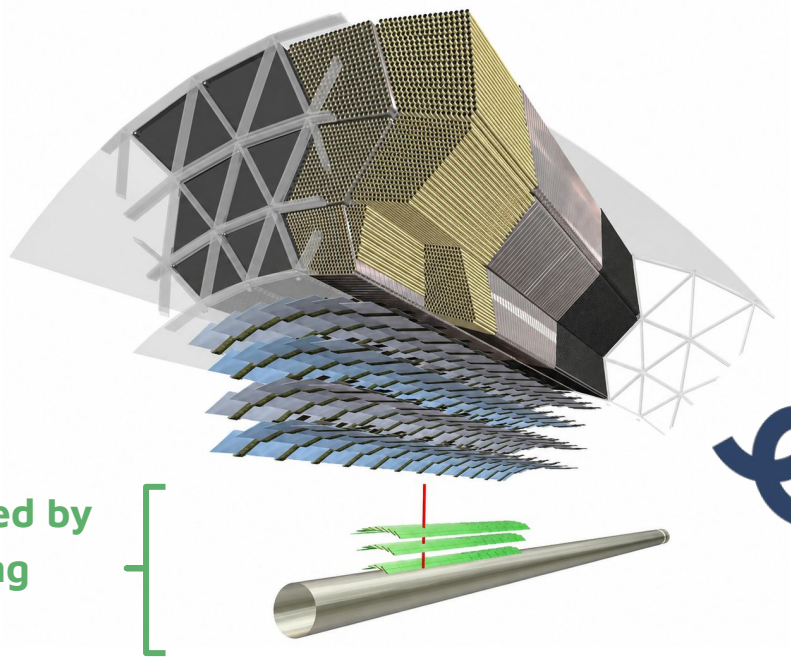
Standard track reconstruction requires at least seven silicon hits.



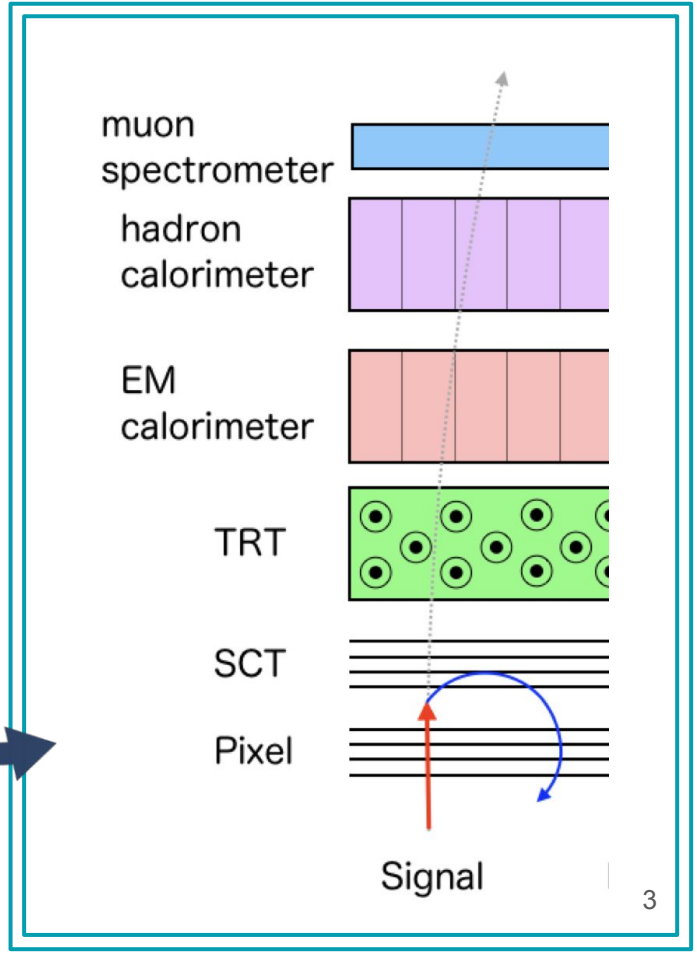


What are disappearing tracks?

Particles that decay after traversing only three or four layers of the Pixel detector, producing a short track that disappears before reaching the SCT.



Not reconstructed by standard tracking algorithms



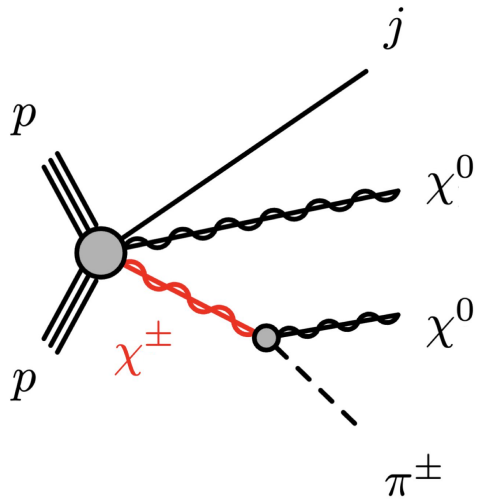
Motivation

Disappearing track signatures arise in models that introduce new electroweak particles. These particles can form electroweak multiplets containing both charged and neutral states that are nearly mass-degenerate.

E.g. Minimal Dark Matter.

$$\mathscr{L} = \mathscr{L}_{\mathrm{SM}} + c \begin{cases} \bar{\mathcal{X}}(i\not{D} + M)\mathcal{X} & \text{when } \mathcal{X} \text{ is a spin } 1/2 \text{ fermionic multiplet} \\ |D_\mu \mathcal{X}|^2 - M^2|\mathcal{X}|^2 & \text{when } \mathcal{X} \text{ is a spin } 0 \text{ bosonic multiplet} \end{cases}$$

X: new $SU(2)_L$ multiplet



Electroweak symmetry breaking lifts the degeneracy. Loop corrections make the charged state slightly heavier than the neutral state:

$$\Delta M = M_{X^\pm} - M_{X^0} \simeq 166 \text{ MeV}.$$

A small mass splitting gives a long-lived charged state whose decay to an invisible neutral state and a soft pion produces a **disappearing track**.

The same mechanism arises in supersymmetric electroweakino and slepton models.

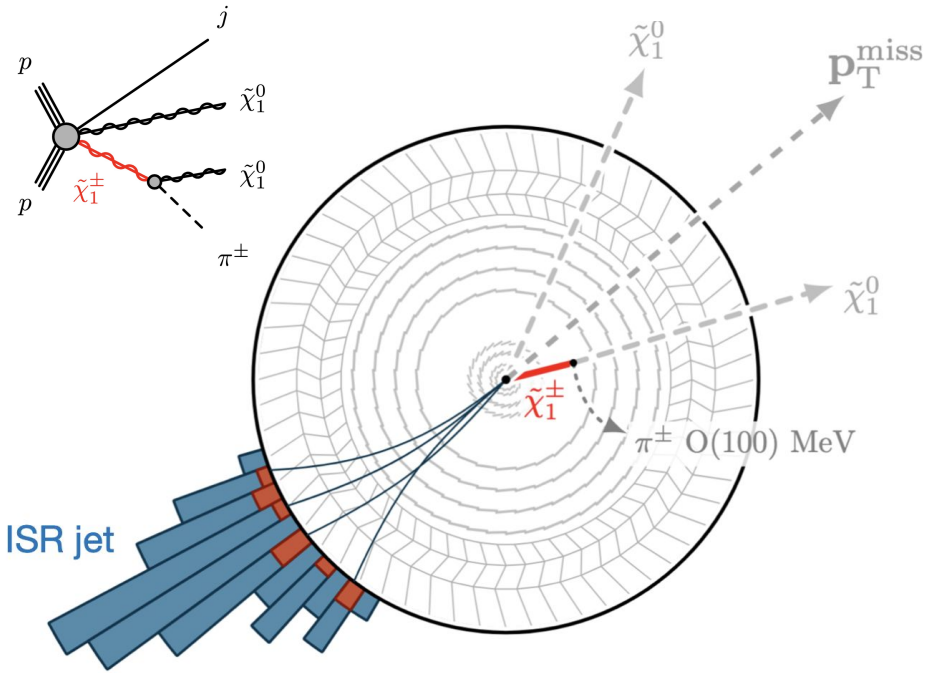
Disappearing track in the detector

The mass splitting sets the lifetime of the charged state → how far it typically travels through the tracker.

Within supersymmetric models: **wino-like** and **higgsino-like** electroweakinos.

These differ in the composition of the charged and neutral states.

Wino	**Higgsino**
ΔM ~160 MeV	ΔM ~280-350 MeV
τ ~ 0.2 ns	τ ~ 0.03 - 0.05 ns
cτ ~ 6 cm	**cτ ~ 0.9–1.5 cm**

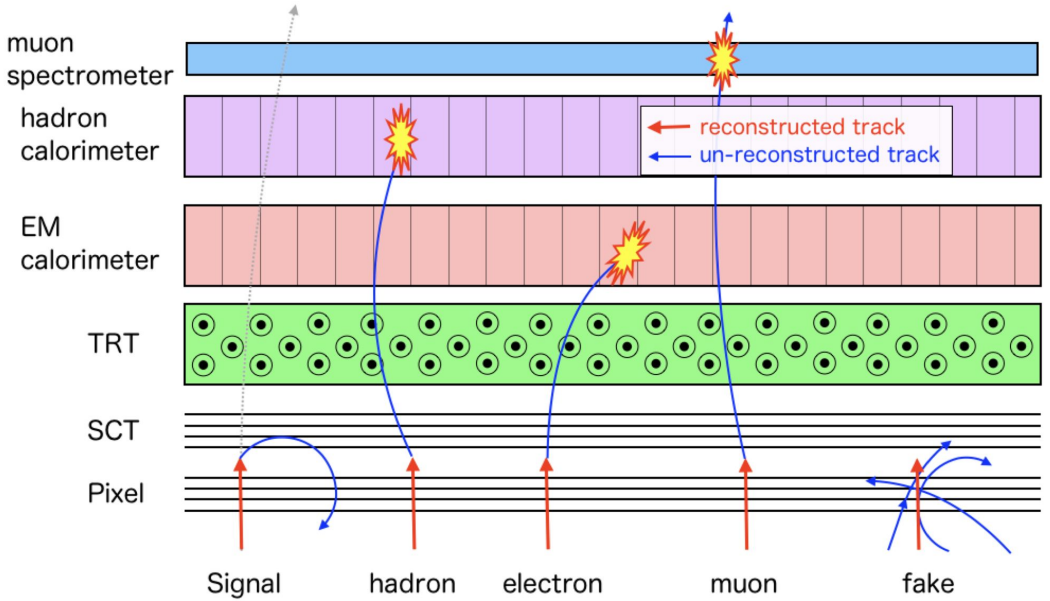


Experimental challenge

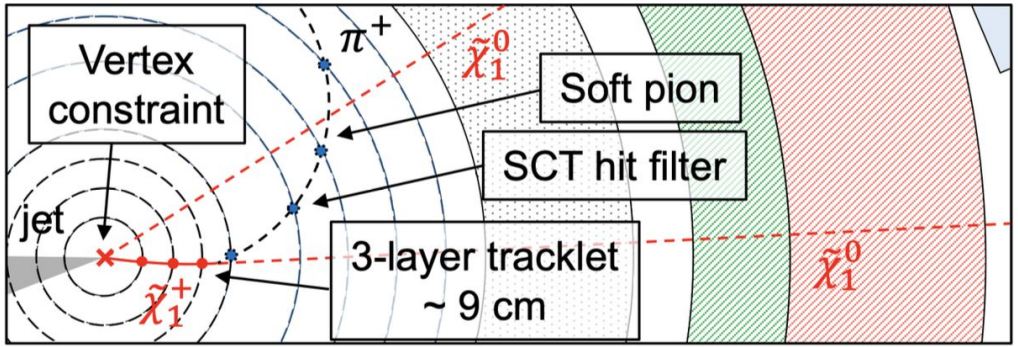
Dedicated reconstruction is needed to recover short tracks, or tracklets, as the standard reconstruction algorithm don't preserve short tracks.

However, the **main experimental challenge** is the suppression and estimation of **backgrounds** that can mimic the signal.

- Electrons, muons and hadrons may appear as short tracks after interacting with detector material
- Unrelated Pixel hits can be combined into fake tracklets.



Run-2 analysis improvements



Three-Hit Tracklet Reconstruction

Dedicated second-pass reconstruction reaches shorter lifetimes, previously inaccessible.

Soft Pion Reconstruction

Adds discrimination power for electroweakino scenarios.

Stronger Track Quality

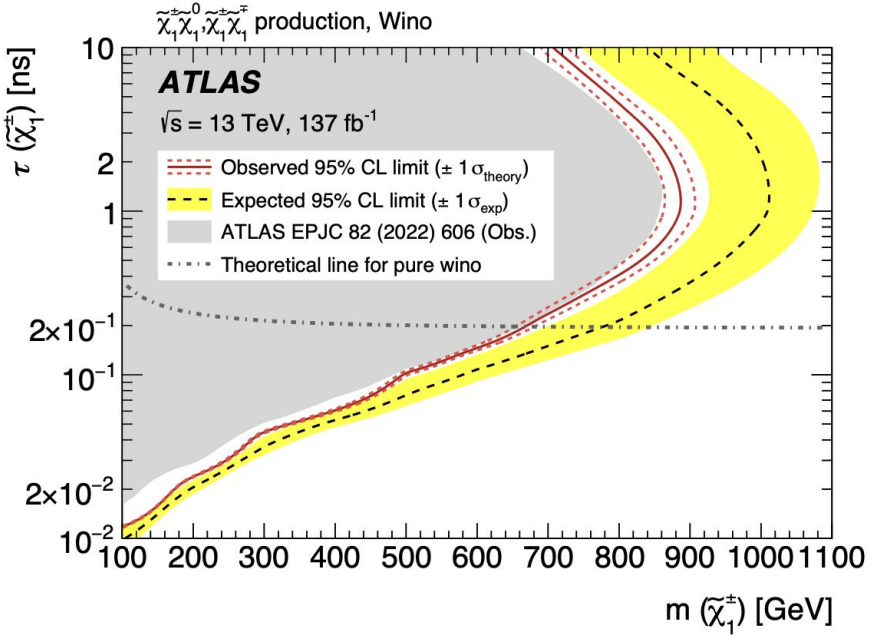
Calorimeter-veto rejection accounts for ≈ 2/3 of the wino mass-reach improvement.

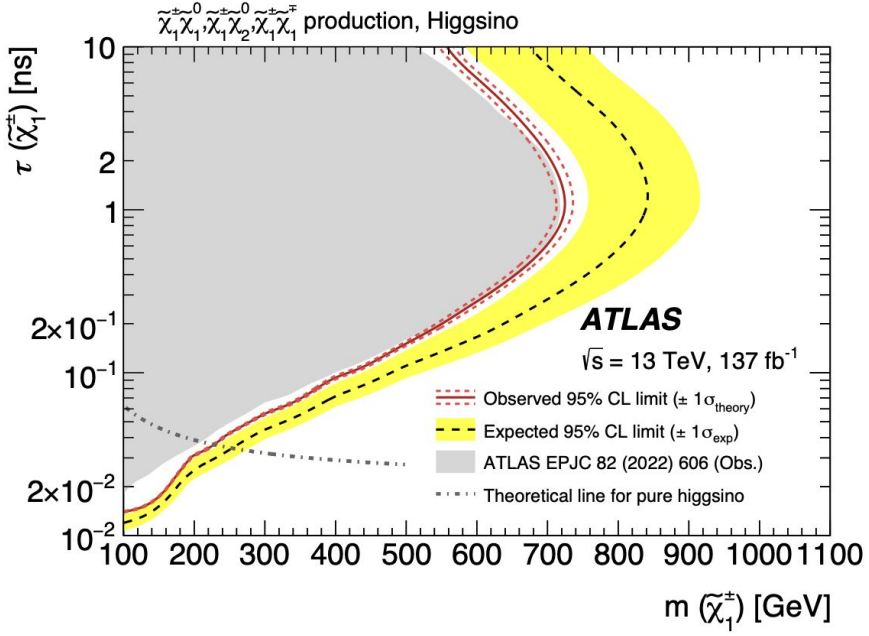
Together, these improved sensitivity, especially for short lifetimes and higgsino-like scenarios.

Run-2 result

No significant excess over the SM expectation was observed.

For the pure-wino and pure-higgsino scenarios, wino-like charginos were excluded up to masses of 670 GeV, while higgsino-like charginos were excluded up to 225 GeV.





A complementary handle: Pixel dE/dx

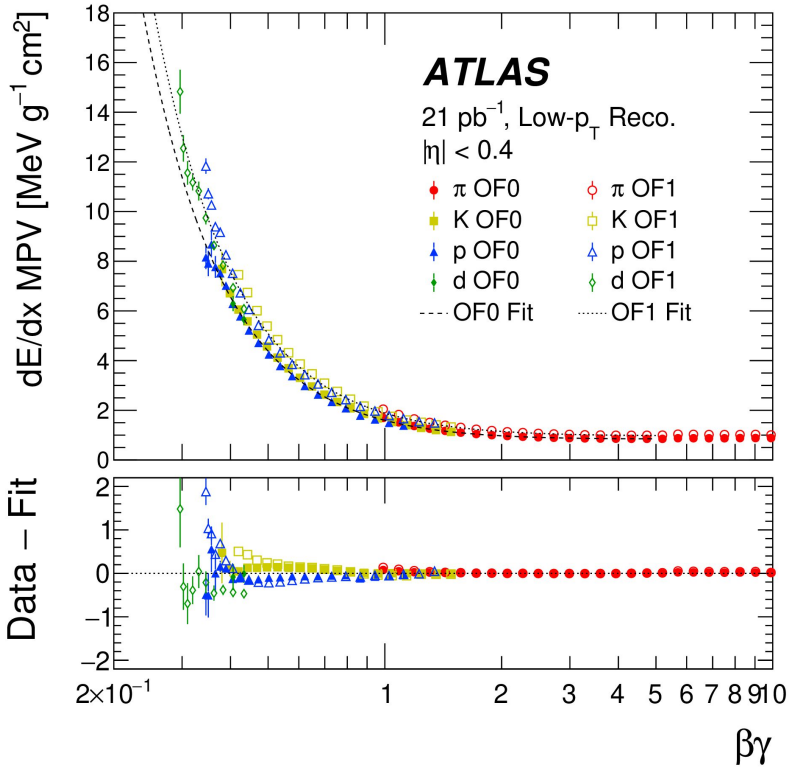
Pixel hits also measure deposited charge

$$\beta\gamma = p/m$$

At the same momentum, a heavier particle has a lower βγ and can therefore have a larger dE/dx.

→ **Disappearing track**: how far did it travel?
→ **dE/dx**: how strongly did it ionize?

Particularly useful for wino-like charginos ($\tau \sim 0.2$ ns), where existing disappearing track searches already probe masses close to the TeV scale.



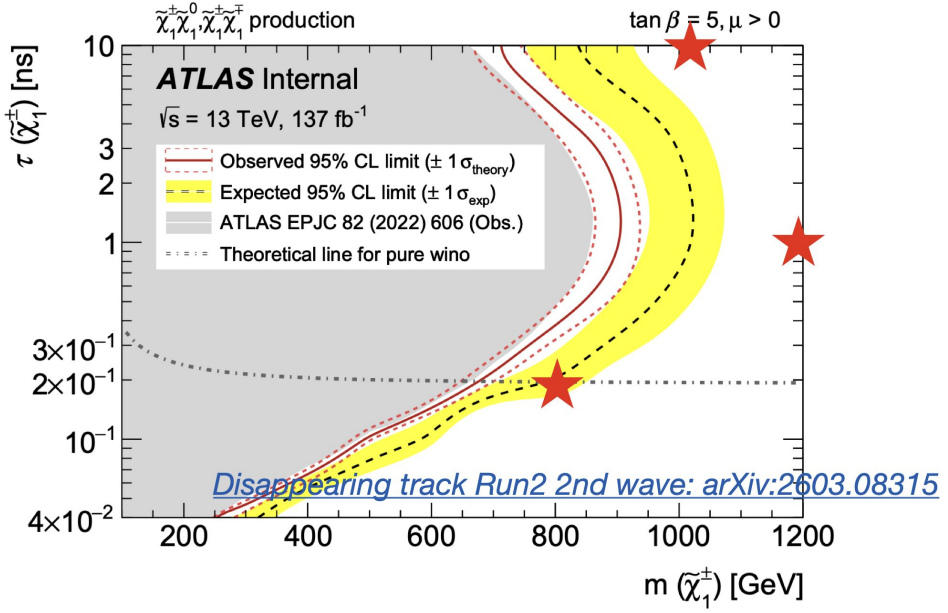
Current work: disappearing track + Pixel dE/dx

Currently, my work is focused in an **analysis combining disappearing track reconstruction with the specific ionization energy loss**, dE/dx, measured in the Pixel detector.

It uses the full Run-2 dataset together with the first part of Run 3.

First ATLAS search to combine the disappearing track reconstruction with dE/dx.

Preliminary studies indicate sensitivity beyond that of the
Run-2 disappearing track search.



The future tracker: ITk as an open question

Disappearing track searches will have to adapt to a different tracking detector.

How can the sensitivity gained for very short-lived particles, particularly higgsino-like electroweakinos, **be retained with the ITk geometry?**