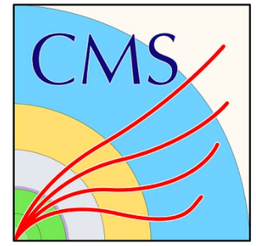
Searches for disappearing tracks, HSCPs and stopped particles at the LHC

LHCP 2021

Emma Kuwertz on behalf of the ATLAS and CMS Collaborations

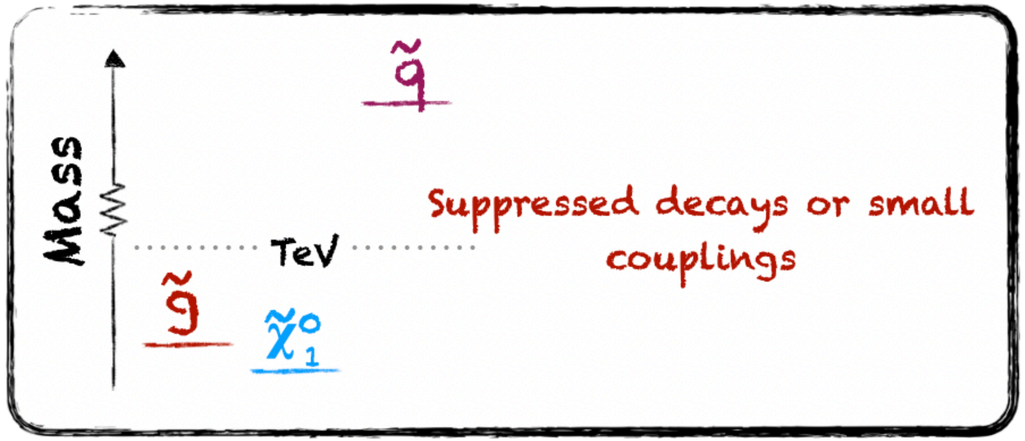


Searching for long-lived particles

- Though new physics is strongly motivated, we have so far **found no direct evidence** of beyond Standard Model (BSM) particle production at the LHC

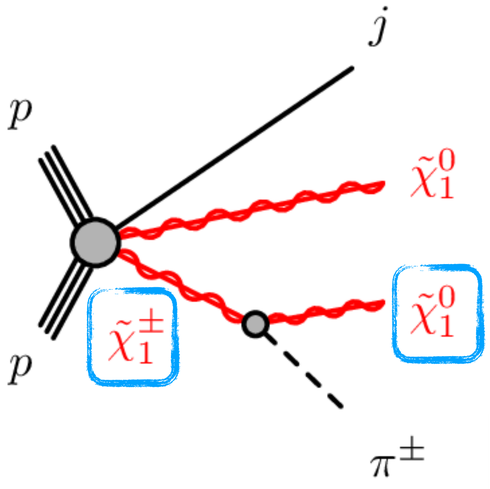
- With no evidence for BSM physics in conventional channels, it's important to invest the time to **improve sensitivity** to these **challenging signatures**

- In models with split spectra, very compressed mass-splittings or weak couplings, particles become **long-lived**



- **In this talk:**
  - Searches for long lived particles using a **disappearing track** signature
  - Searches for the decays of **stopped** long-lived particles

Disappearing tracks

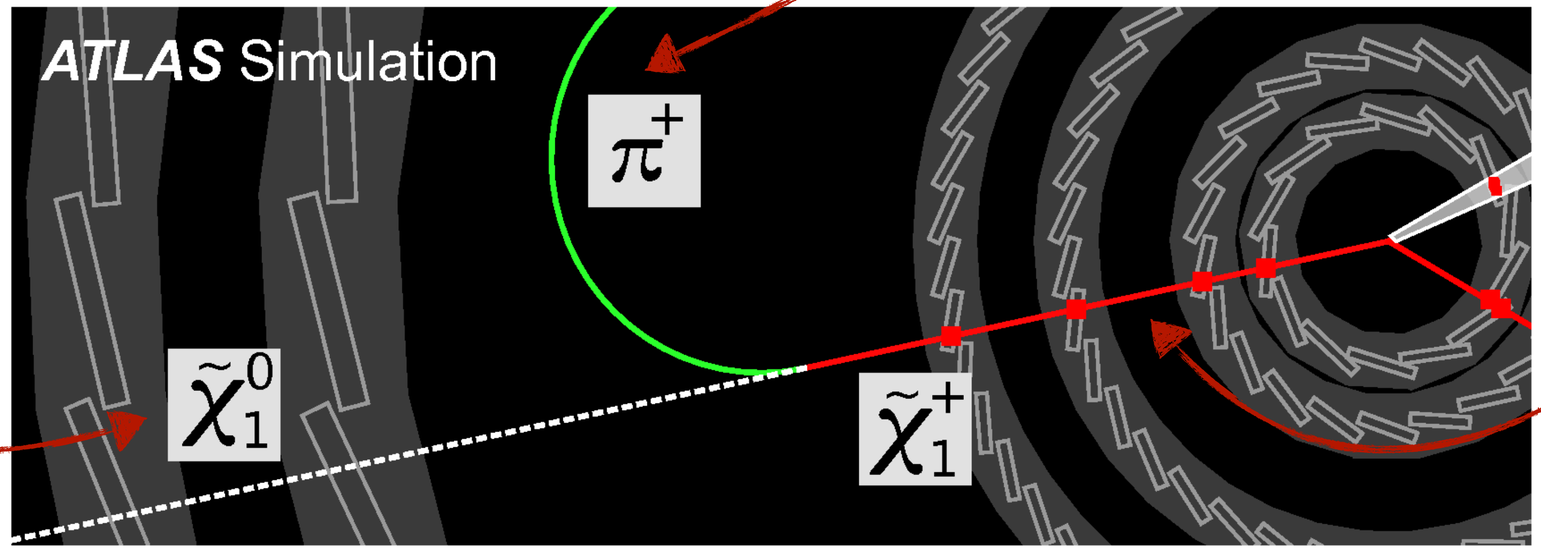


- Targeting models with **higgsino** / **wino** **L**ightest **S**upersymmetric **P**article
  (Benchmark for generic Dark Matter models with compressed multiplets)
- Compressed spectrum predicted, with **small $\tilde{\chi}_1^\pm \to \tilde{\chi}_1^0$ mass splitting**
- Non-negligible $\tilde{\chi}_1^\pm$ **lifetime**:

Pure wino:
$\tau = 0.2$ ns
$c\tau \sim 6$ cm

Pure higgsino:
$\tau = 0.02 - 0.05$ ns
$c\tau \sim 0.7 - 1.4$ cm

Pion
(too soft to reconstruct)



Neutral LSP

Chargino track
disappears

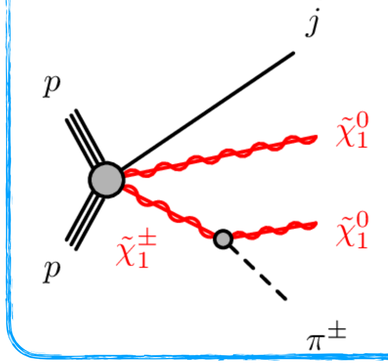
Latest results from ATLAS and CMS:

Search for disappearing tracks [CMS] Phys. Lett. B 806 (2020) 135502

Search for long-lived charginos based on a disappearing-track signature [ATLAS] ATLAS-CONF-2021-015

Disappearing tracks [ATLAS-CONF-2021-015]

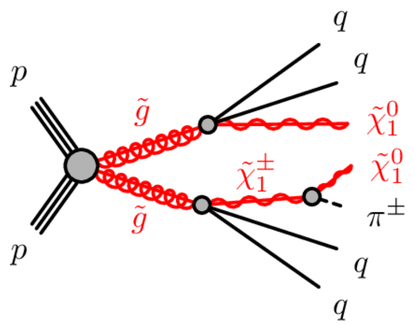
Electroweak production:



≥ 1 jet

$E_{\mathrm{T}}^{miss} > 200$ GeV

Strong production:

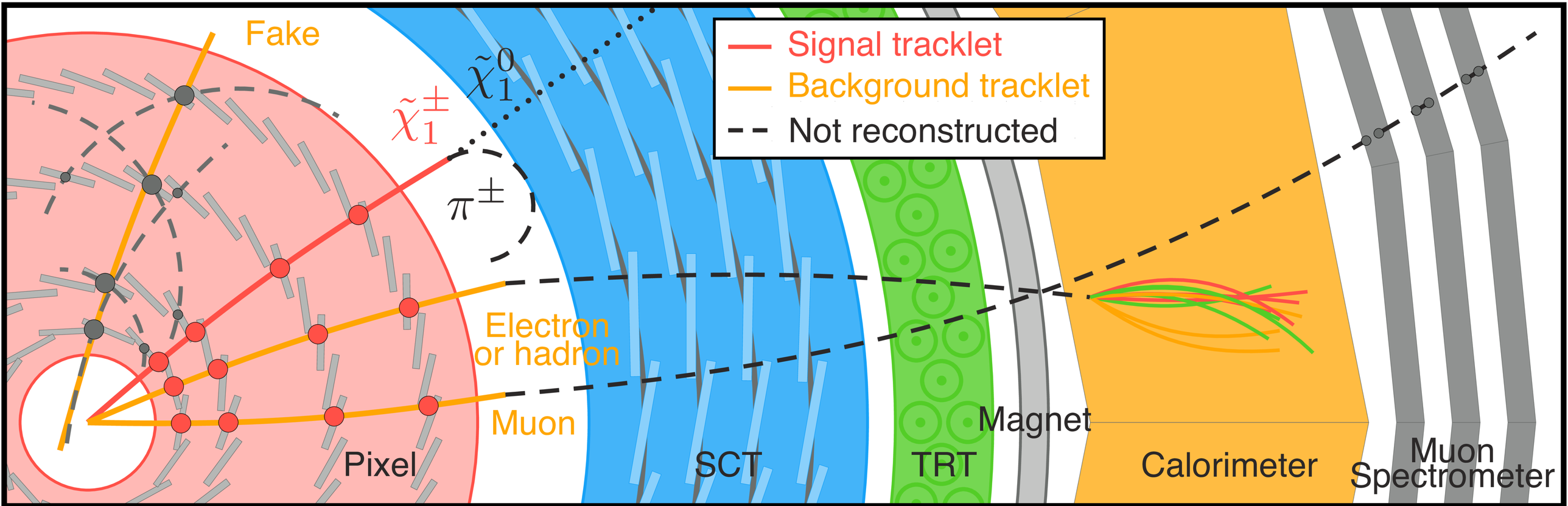


≥ 3 jets

$E_{\mathrm{T}}^{miss} > 250$ GeV

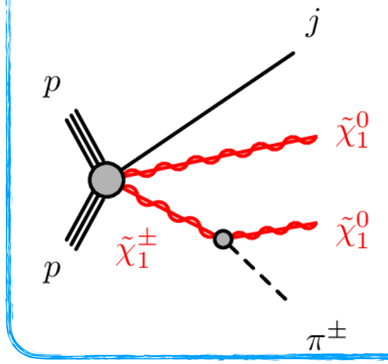
≥ 1 ***disappearing tracklet:*** **ATLAS**

- 4 pixel layer hits
- No SCT hits
- Good χ^2 quality
- Isolated from other tracks
- Isolated from calorimeter activity



Disappearing tracks [Phys. Lett. B 806 (2020) 135502]

Electroweak production:



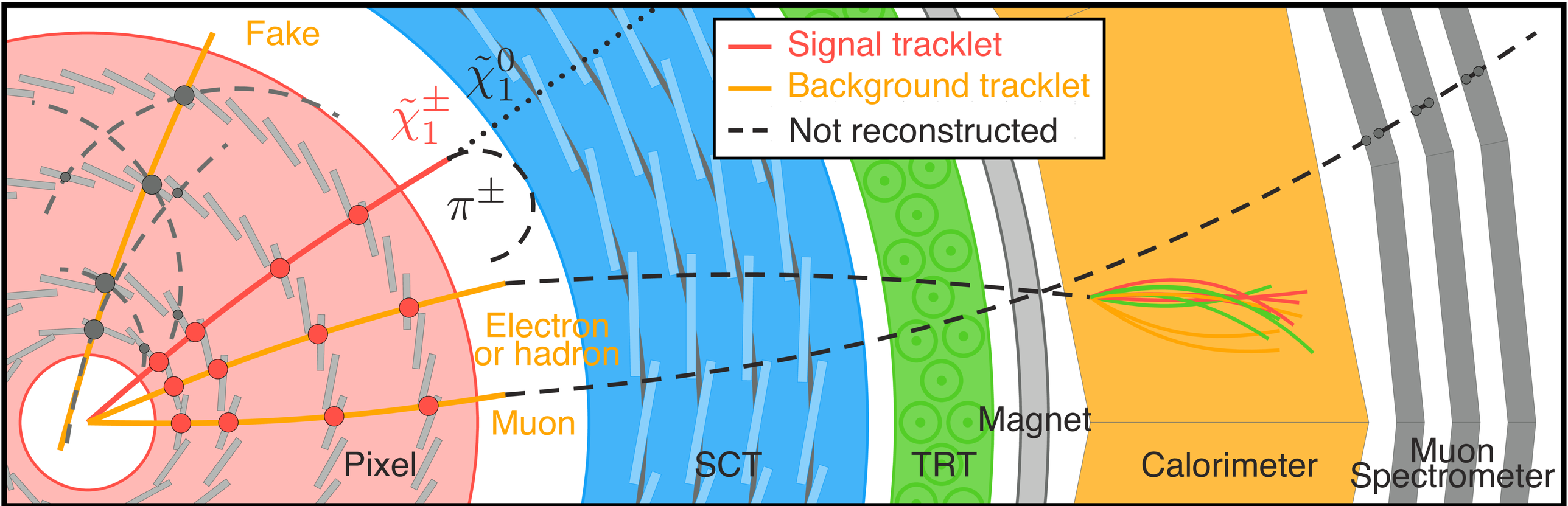
≥ 1 jet

$E_{\mathrm{T}}^{miss} > 120$ GeV

CMS

≥ 1 ***disappearing track:***

- $\geq$4 pixel layer hits
- $\geq$3 missing outer hits
- No missing inner/middle hits
- Good χ^2 quality
- Isolated from other tracks
- Isolated from calorimeter activity

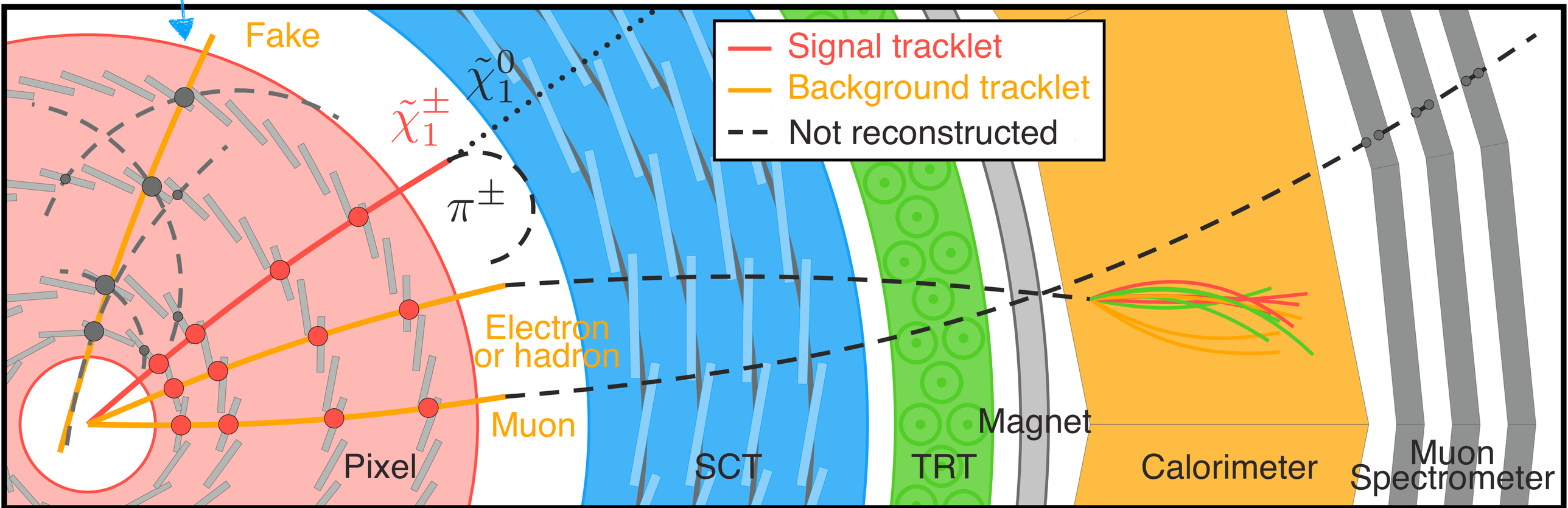


Disappearing tracks

Fakes from random hit combinations

≥ 1 ***disappearing tracklet:*** **ATLAS**

- 4 pixel layer hits
- No SCT hits
- **Good χ^2 quality**
- Isolated from other tracks
- Isolated from calorimeter activity

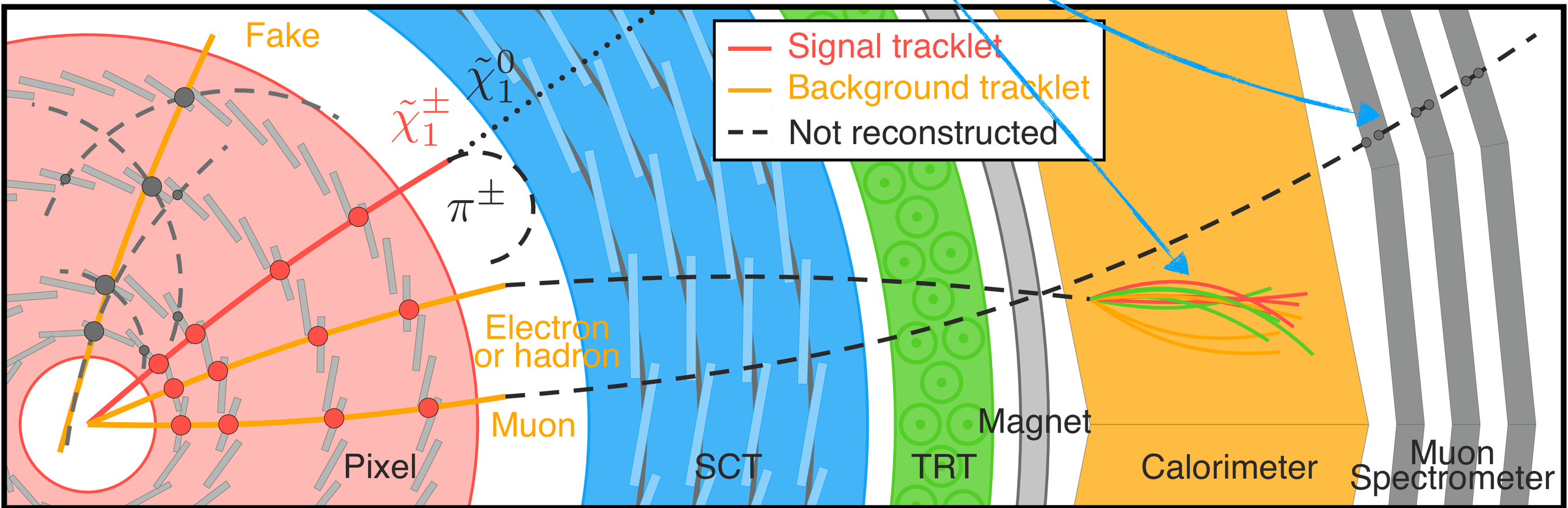


Disappearing tracks

Material scattering and Bremsstrahlung

≥ 1 ***disappearing tracklet:*** **ATLAS**

- 4 pixel layer hits
- No SCT hits
- Good χ^2 quality
- Isolated from other tracks
- **Isolated from calorimeter activity**



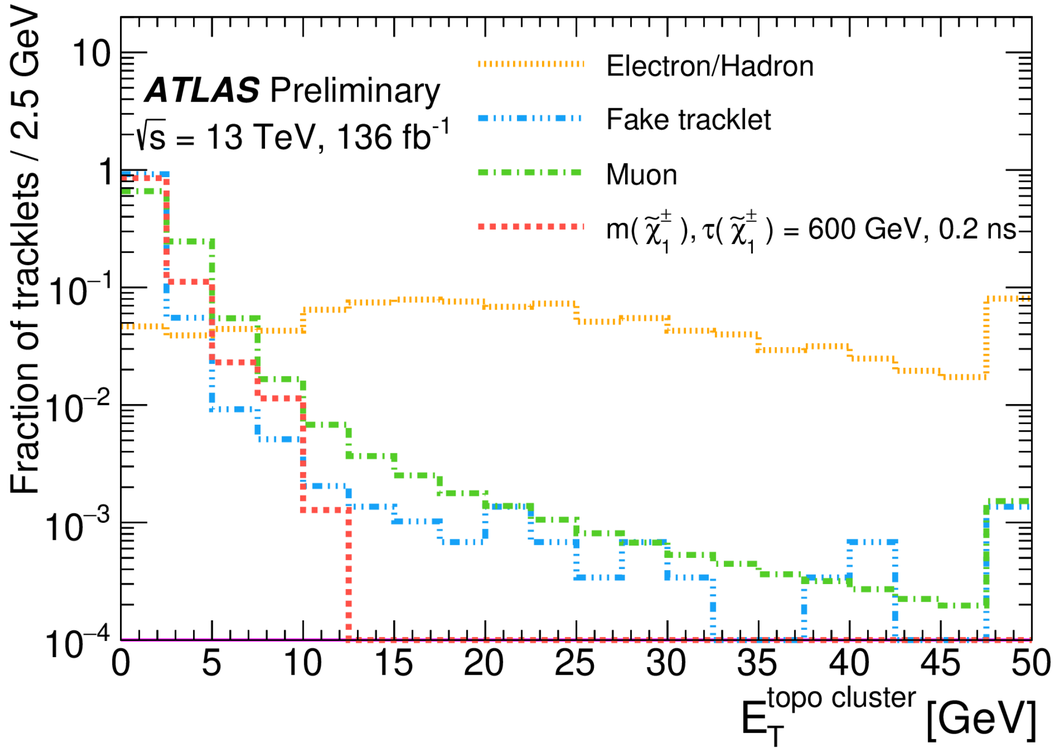
Disappearing tracks

Veto calorimeter activity to suppress electron/hadron backgrounds

CMS: $E_{\mathrm{T}} < 10$ GeV within $\Delta R = 0.5$

ATLAS: $E_{\mathrm{T}} < 5$ GeV within $\Delta R = 0.2$

$$\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$$



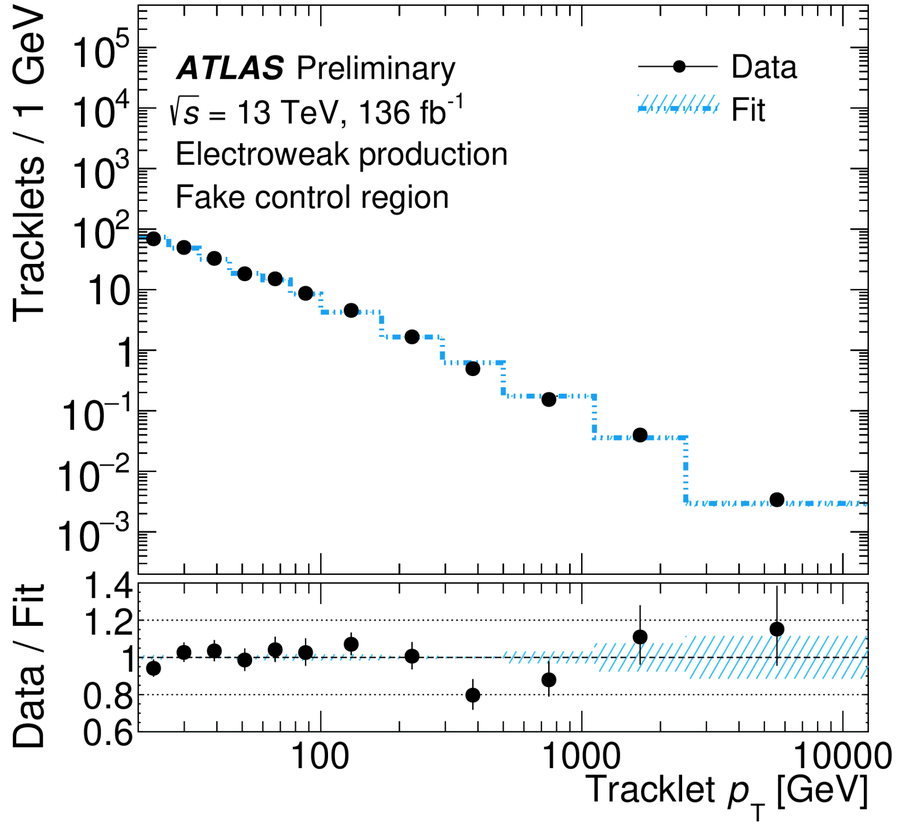
Dominant fake background from random tracks

CMS:

- reject tracks with missing inner/middle hits
- estimate random track probability using $Z \rightarrow \mu\mu$ + track events

ATLAS:

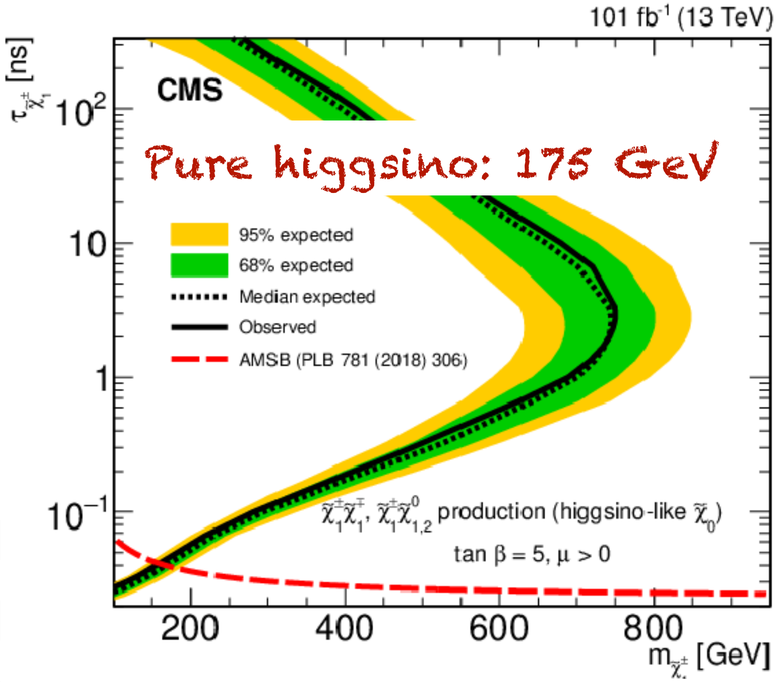
- estimate using pT template from high-d0 tracklet control region
- Fit to tracklet pT in the signal region



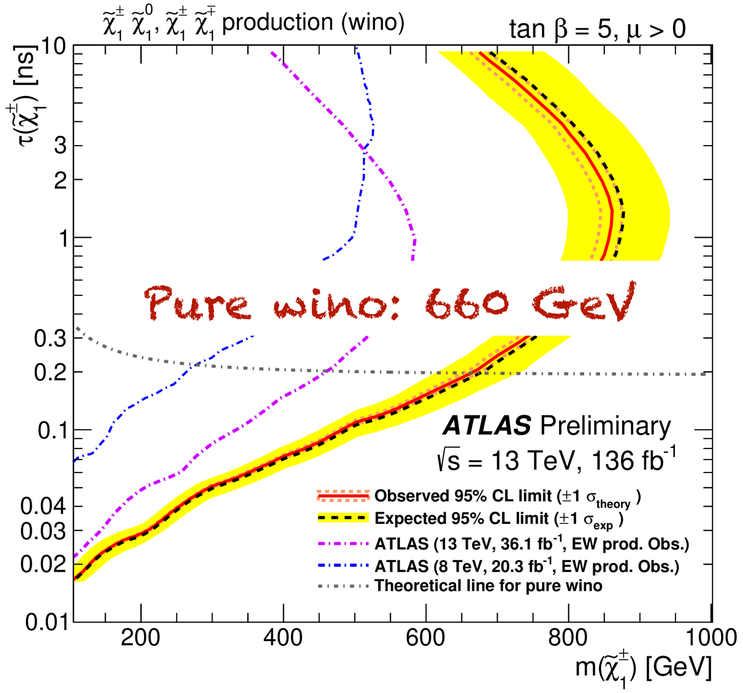
Disappearing tracks

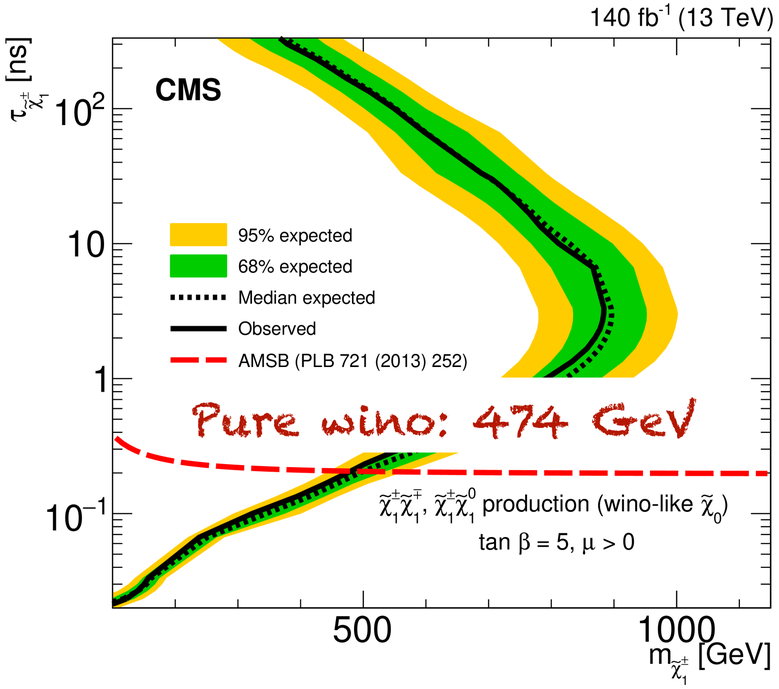
- CMS results benefit from Phase 1 pixel upgrade, extending sensitivity to shorter lifetimes than before
- ATLAS sensitivity boost resulting from addition of Calorimeter veto

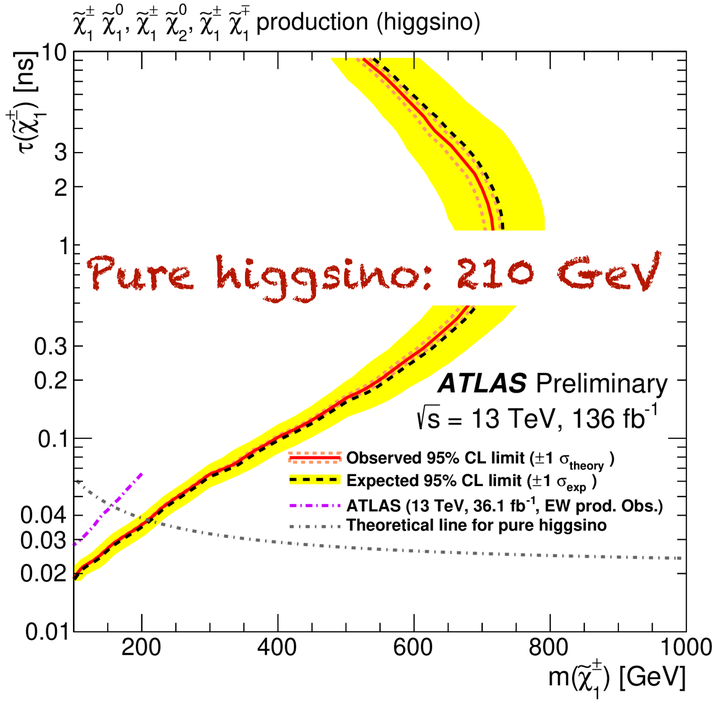
higgsino-like $\tilde{\chi}_1^0$



wino-like $\tilde{\chi}_1^0$



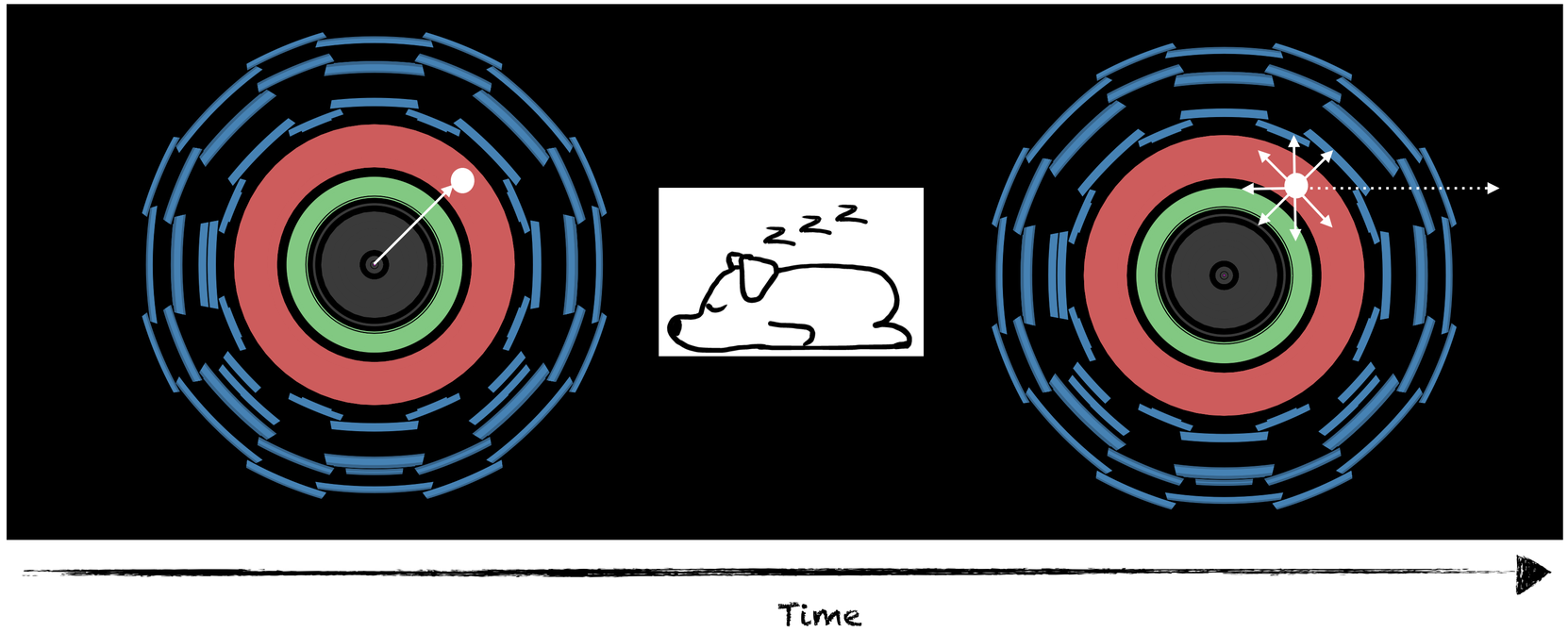


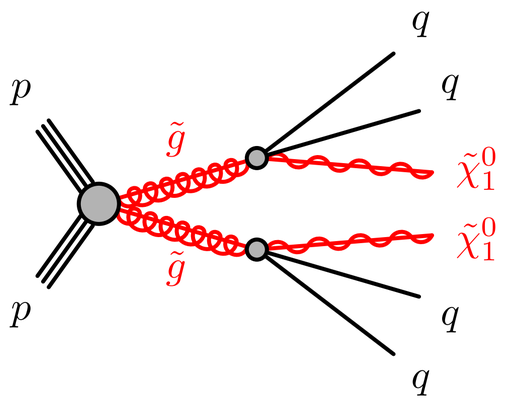


Stopped particles

Generic search for long-lived particles that could **come to a stop** within the detector material…

… these particles subsequently **decay some time later**, leaving large **out-of-time energy deposits** within the calorimeters





- Example split-SUSY inspired simplified model with long-lived gluino.
- Gluino binds with SM quarks to form R-hadron.
- R-hadron loses kinetic energy via nuclear scattering and EM interactions.
- Some **stop** before leaving the detector.

Latest results from ATLAS and CMS:

Search for decays of stopped exotic long-lived particles [CMS] JHEP 05 (2018) 127

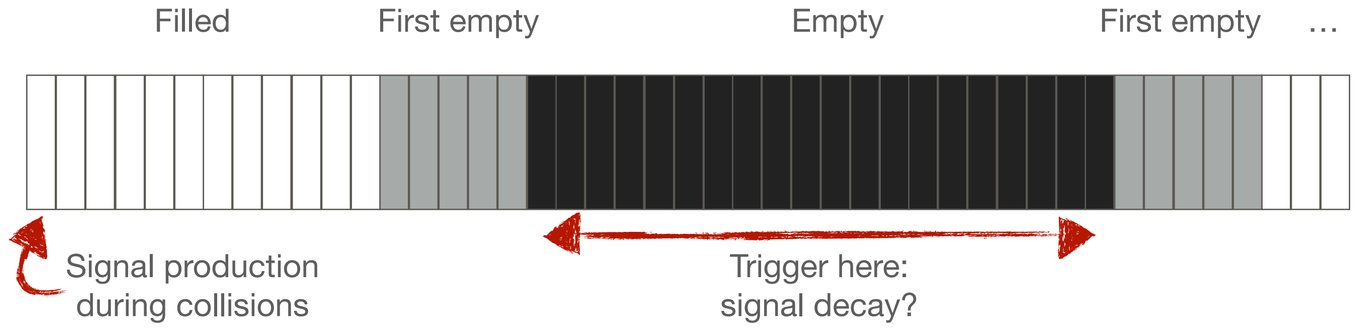
Search for decays of stopped long-lived particles [ATLAS] arxiv:2104.03050

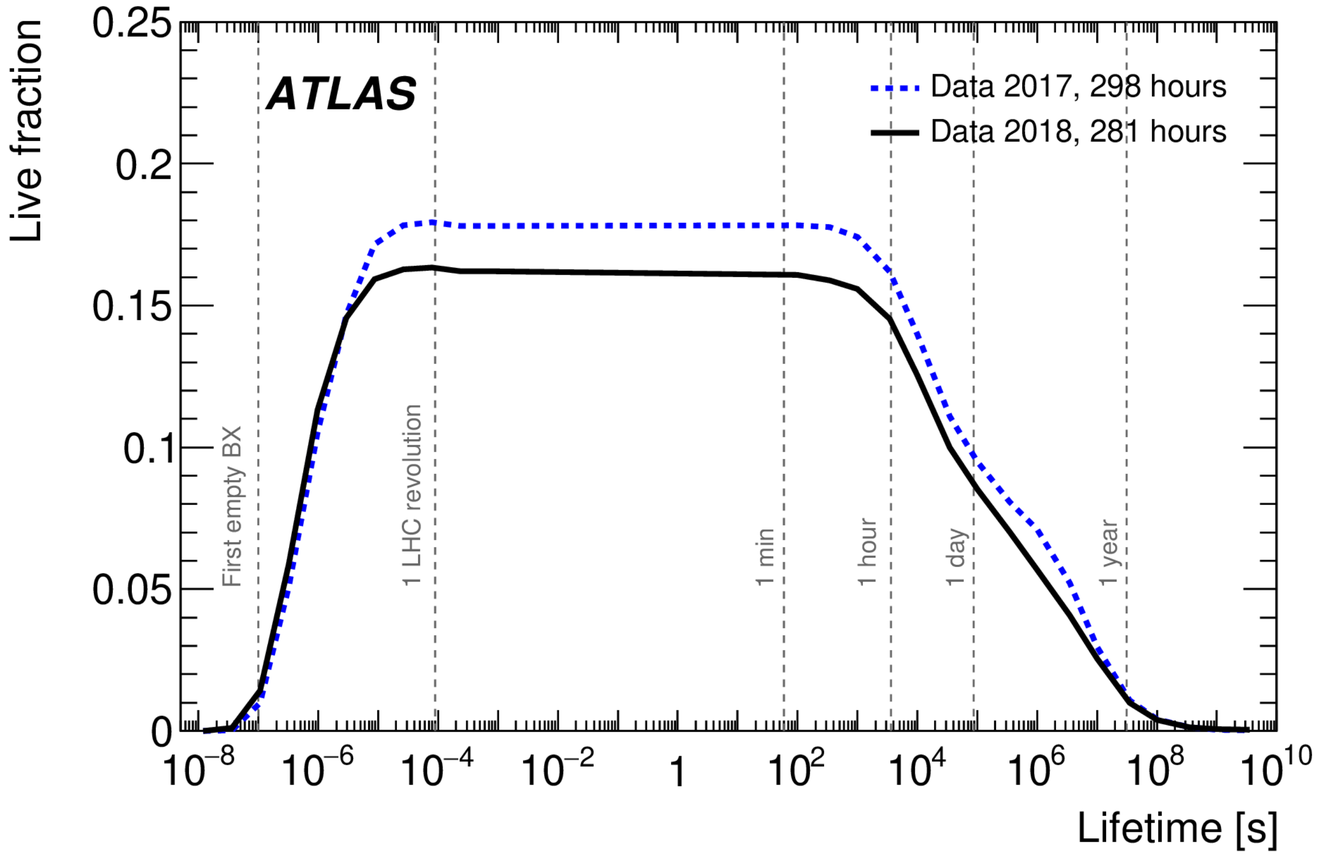
Focus on more recent ATLAS result here

Stopped particles

Search is performed using **empty bunch crossings** to minimize collision backgrounds

Require ≥ 1 jet pT>90 GeV (150 GeV in signal regions)



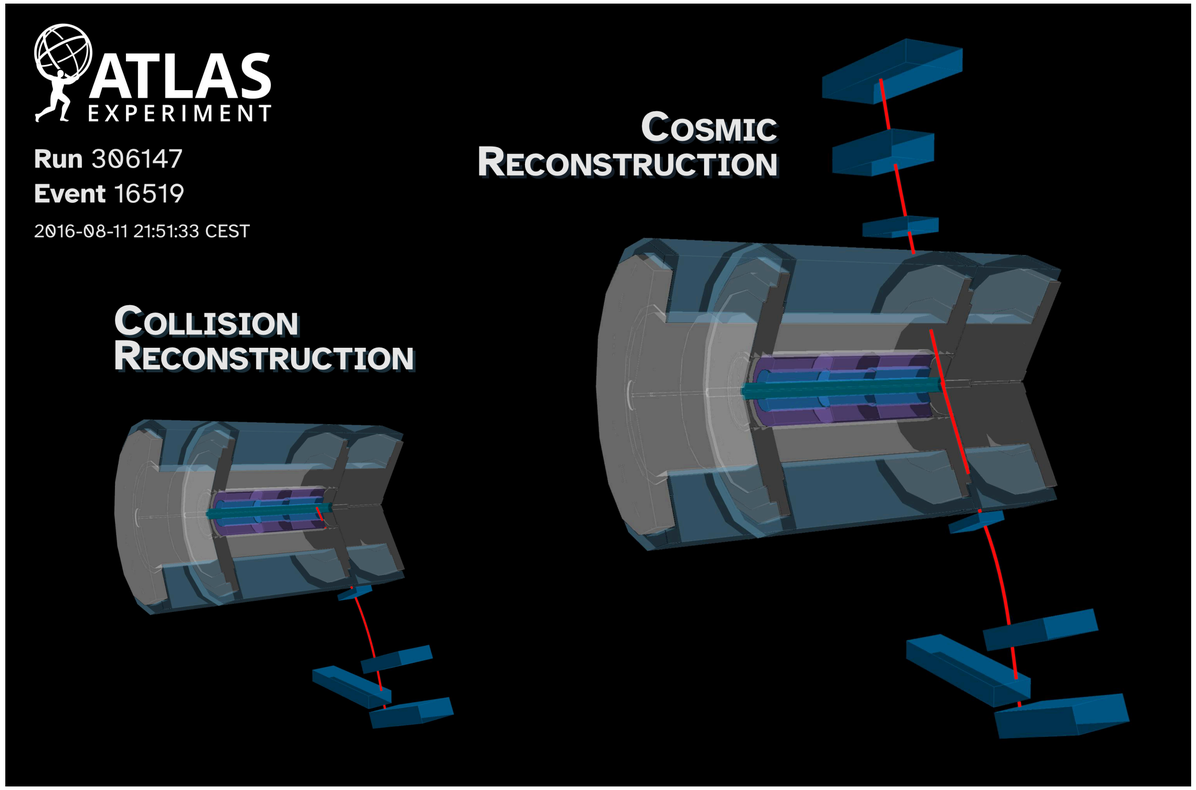


- Calculate fraction of trigger-able time available to detect particle decays across the range of lifetimes:
  - based on LHC bunch structure (LHC filling scheme) and run schedule
- Signal acceptance scales with live time and integrated luminosity
- Non-collision background processes scale with live time

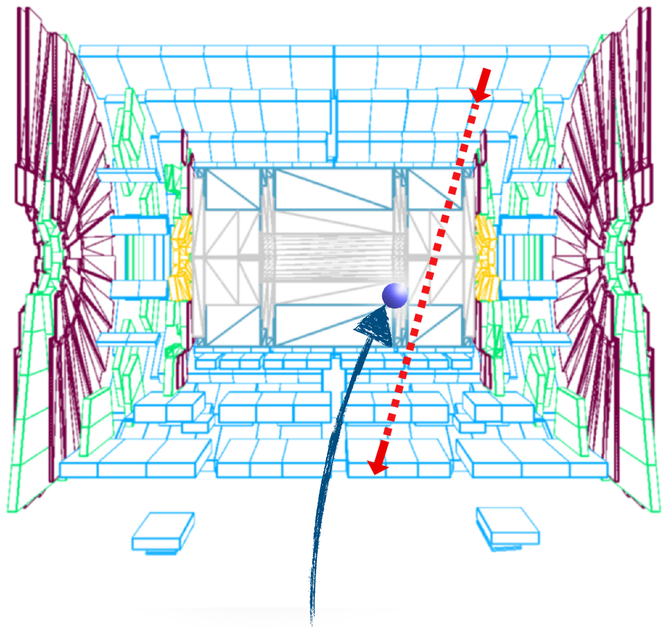
Stopped particles

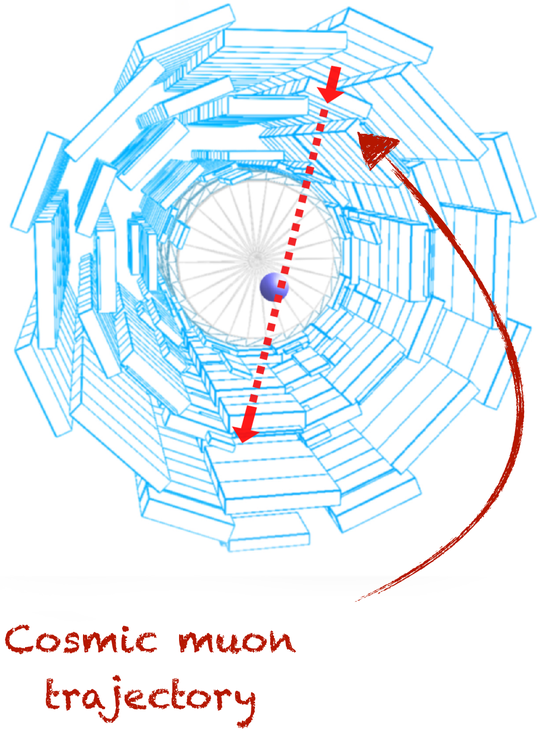
Main backgrounds:

- **Cosmic**-induced jets
- **Beam-induced backgrounds** depositing energy in the calorimeters



- Identify **muon segment pairs** in opposite detector hemispheres
- Check for **proximity to the jet** in the event
- Cut on this proximity to **reject cosmic backgrounds**.
- Extract jet-pT templates from cosmic-enriched regions, and transfer factors from **dedicated comic datasets** to extrapolate to the signal regions



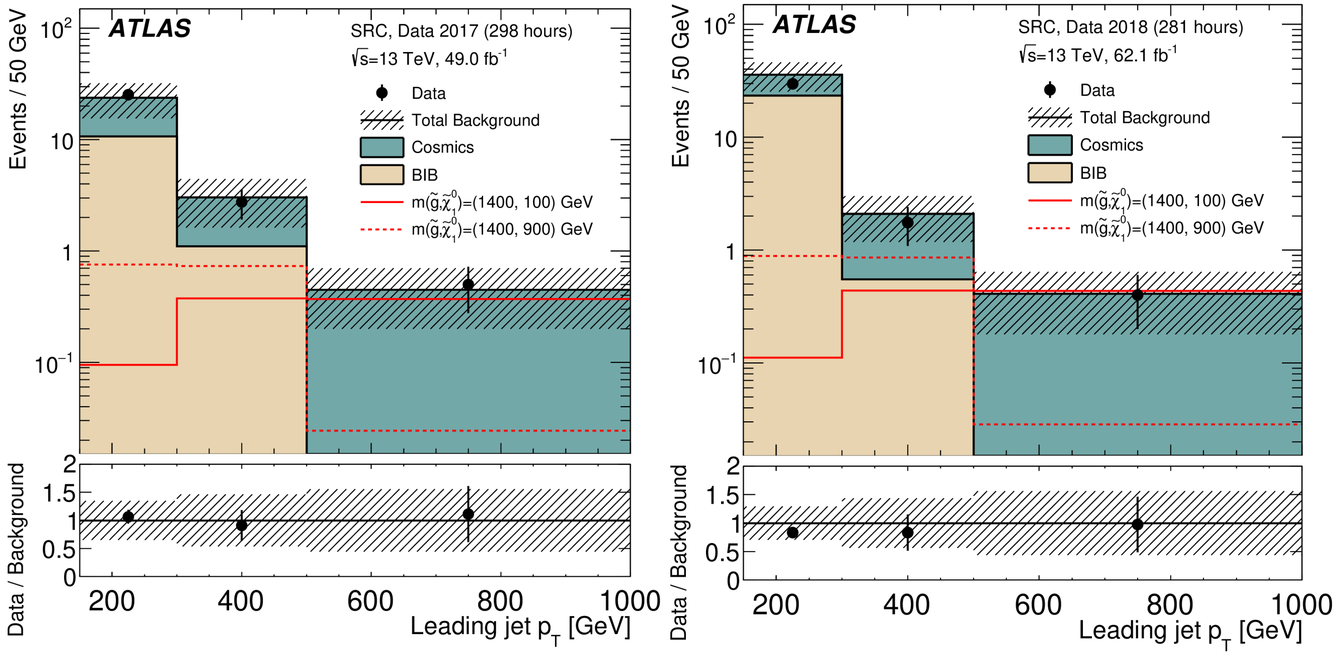


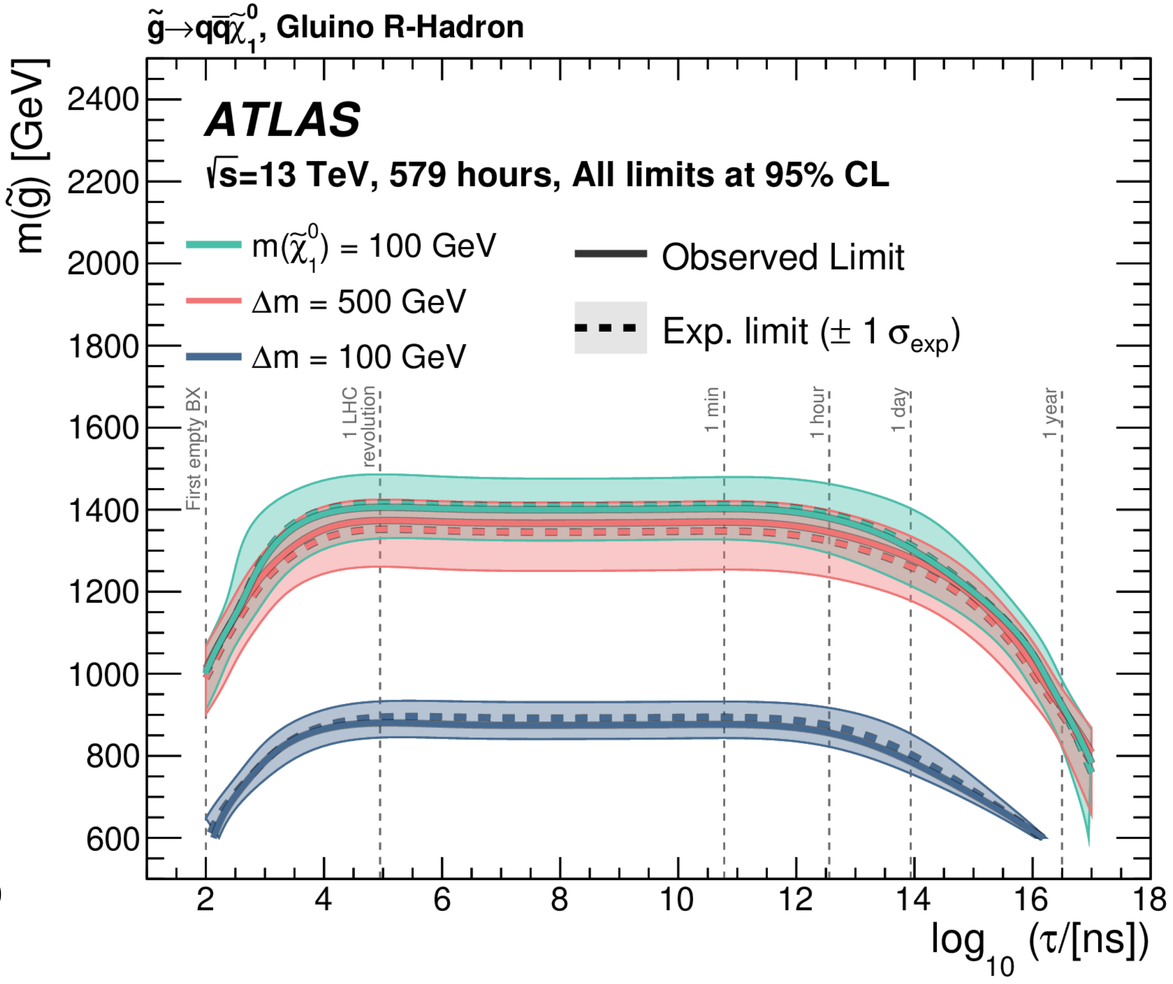
Use **cosmic reconstruction settings** to improve out-of-time reconstruction efficiency

Stopped particles

- Data consistent with background expectation in the signal regions
- Exclude gluino masses up to 1.4 TeV in the live time plateau (between 1000 ns and 1000 s)

Updated R-hadron signal generation and simulation:
ATL-PHYS-PUB-2019-019





Summary

- **Recent searches for disappearing tracks and stopped long-lived particles presented**
  - Analyses make use of the complete Run 2 dataset collected at the LHC

- **Exploring new methods to enhance sensitivity**
  - These searches require **specialized techniques**, **dedicated data samples** and often **modified reconstruction**
  - Implementation of improvements and/or new strategies shown in these results

- **Data are compatible with SM predictions**
  - So far…

- **New results yet to come with the full Run 2 dataset**
  - With Run 3 and HL-LHC still ahead.