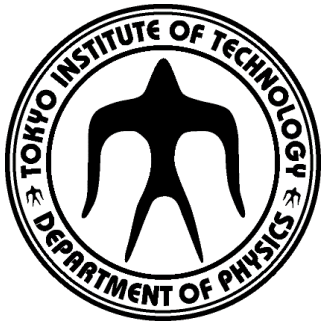

ATLAS searches for supersymmetry with long-lived particles

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on behalf of the ATLAS Collaboration

XIV Latin American Symposium on High Energy Physics

November 14-18th, 2022

LLP Search in ATLAS

Many supersymmetry (SUSY) models predict long-lived particles (LLPs):

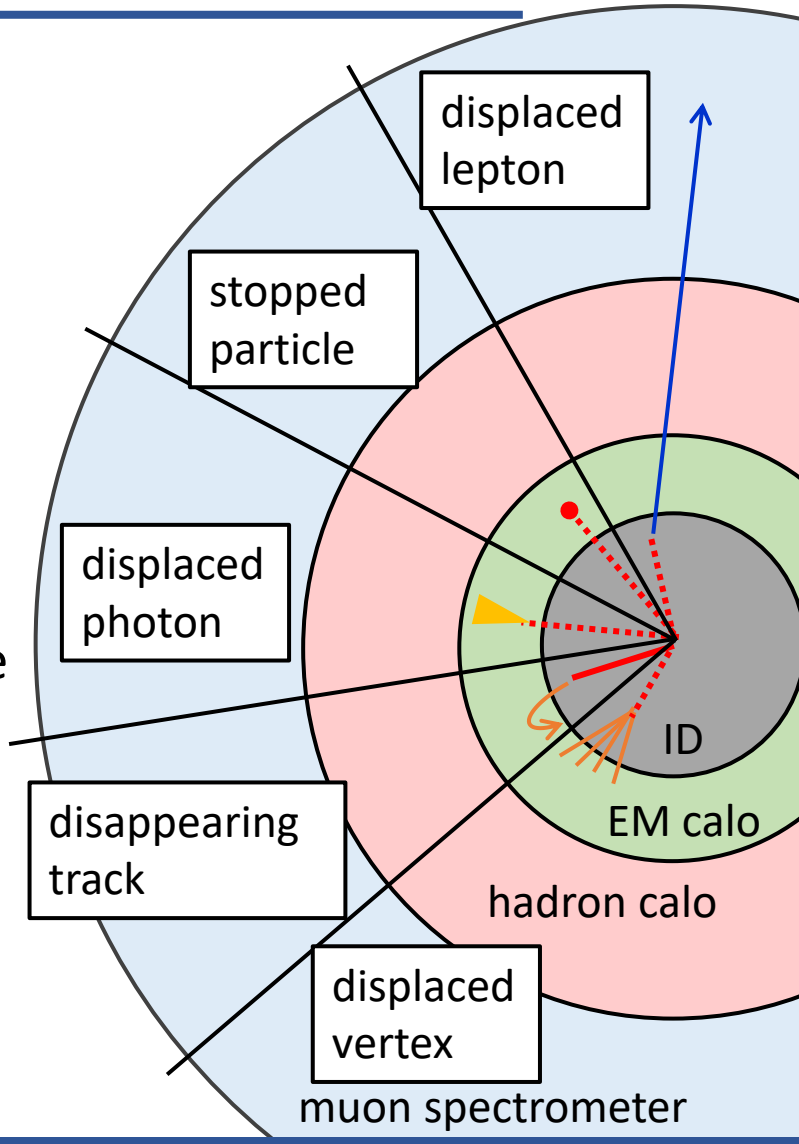
- R-parity violation (RPV)
- Gauge-Mediated SUSY Breaking (GMSB)
- Mini-Split SUSY

etc.

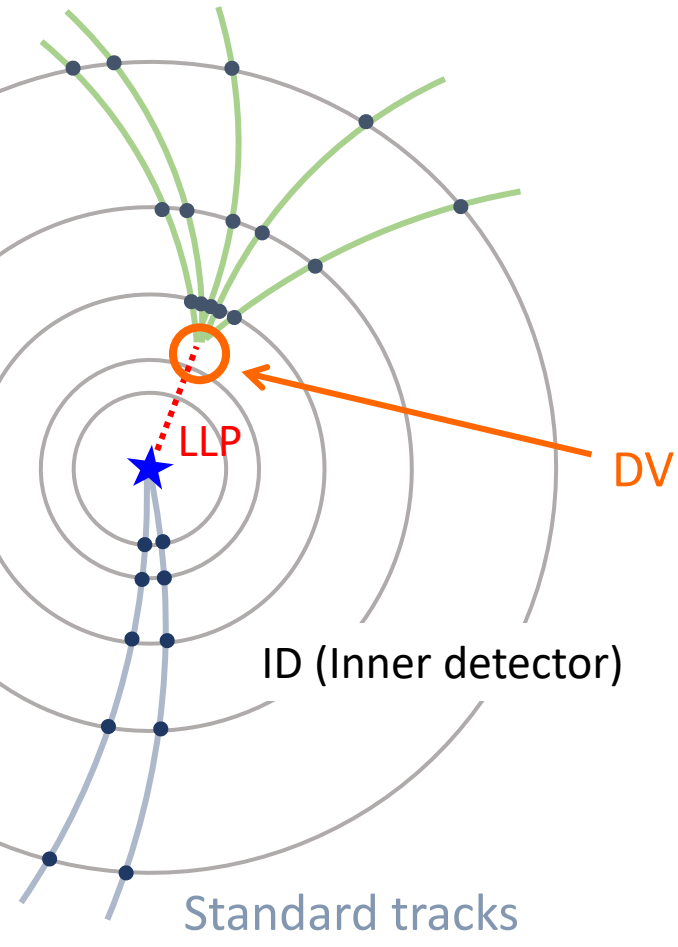
ATLAS detector is not originally designed for LLP search but can capture LLP's unique signatures by using special technics.

Run 2 data

- pp collision at $\sqrt{s}$ = 13 TeV
- Integrated luminosity = 139 fb^{-1}

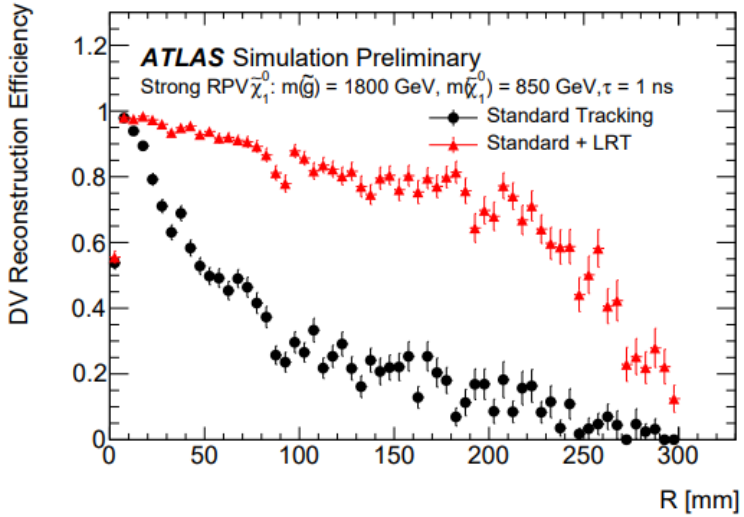


Displaced Vertex (DV)



1. Large radius tracking

Displaced tracks, which have large impact parameters, are reconstructed with unused hits after standard tracking.



2. Displaced vertices (DVs) are reconstructed using both standard and displaced tracks.

BG sources include material interaction, randomly intersecting track, and merged vertices.

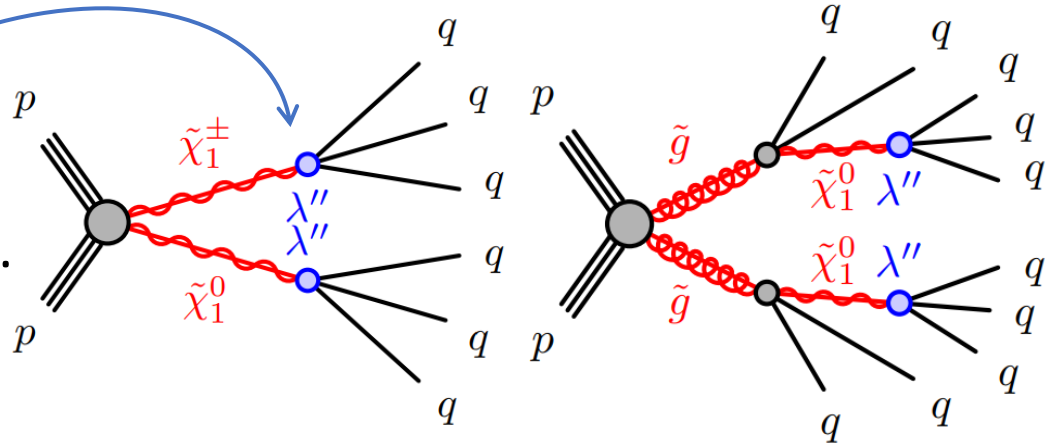
DV + jets

ATLAS-CONF-2022-054

Motivation

Small RPV coupling λ".

→ Electroweakinos are LLPs, decaying into three quarks.



Strategy

- Multi-jet trigger
- Events with four or more jets and DV ($N_{\mathrm{trk}} \geq 5$, $m > 10$ GeV)
- BGs are estimated using jet-DV probability

BG DVs ⟷ (correlation) track density ⟷ (correlation) presence of track jet

1. Calculate jet-DV probability using control region.

   Jet-DV probability ($p_{\mathrm{T}}^{\mathrm{jet}}$, $N_{\mathrm{trk}}^{\mathrm{jet}}$) = (# jets matched to DVs) ÷ (# jets)

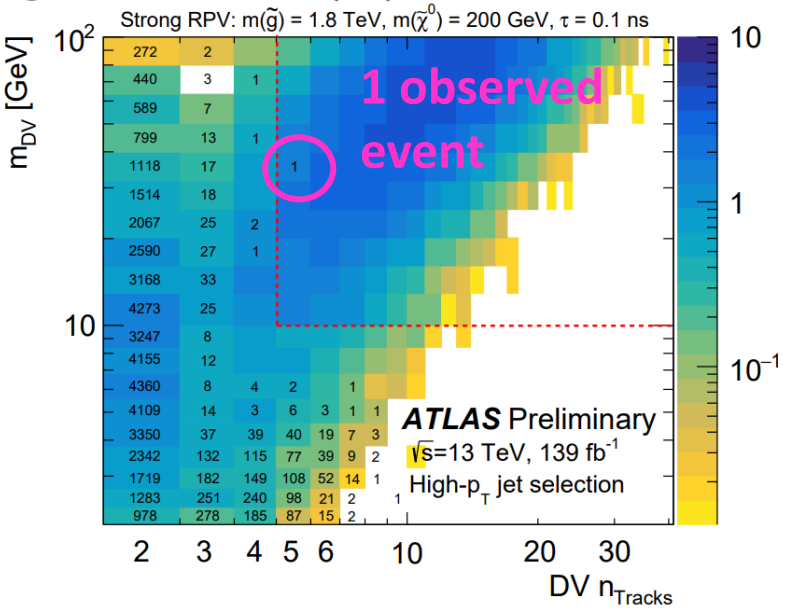
2. Estimate # BGs in signal region by multiplying jet-DV probability and # events satisfying jet selection.

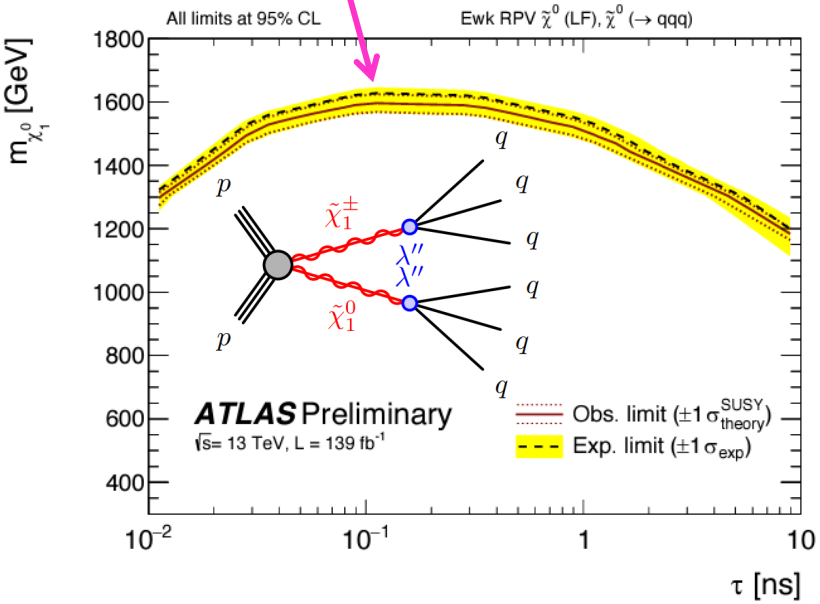
DV + jets

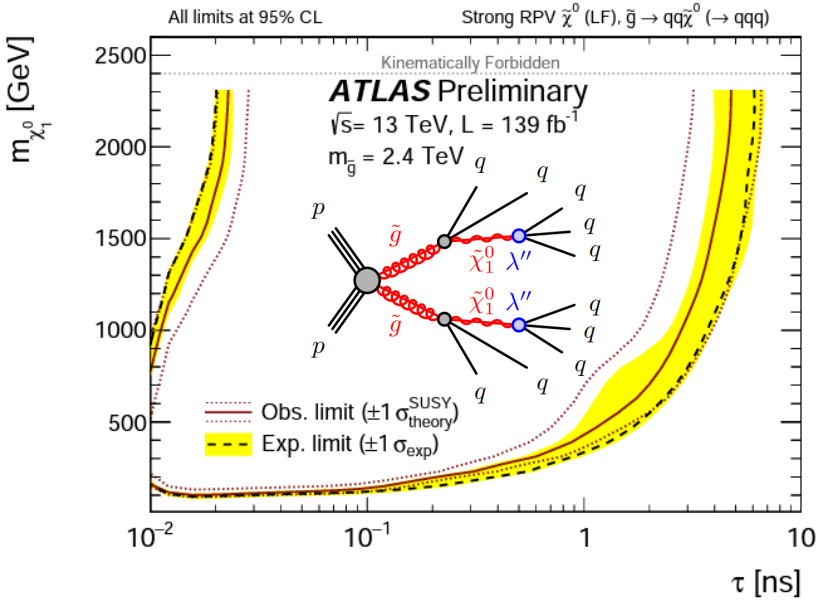
$m(\tilde{g}) = 1.8$ TeV, $m(\tilde{\chi}^0) = 200$ GeV, $\tau = 0.1$ ns

Result

- 1 event in signal region, no excess
- Interpretation in RPV model
- Exclude $m(\tilde{\chi}_1^0)$ up to 1.5 TeV for $\tau(\tilde{\chi}_1^0)$ from 0.03 ns to 1 ns







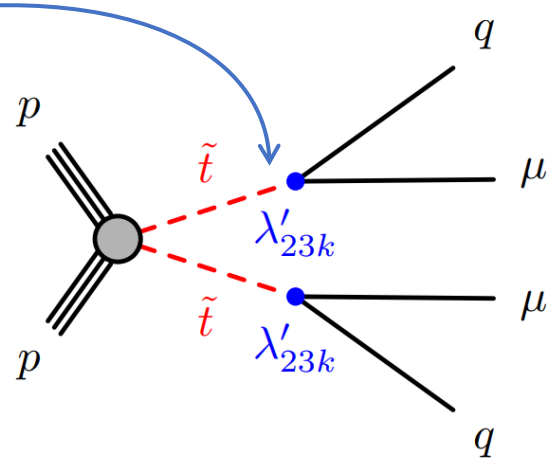
DV + mu

Phys. Rev. D 102, 032006 (2020)

Motivation

Small RPV coupling λ'_{23k}.

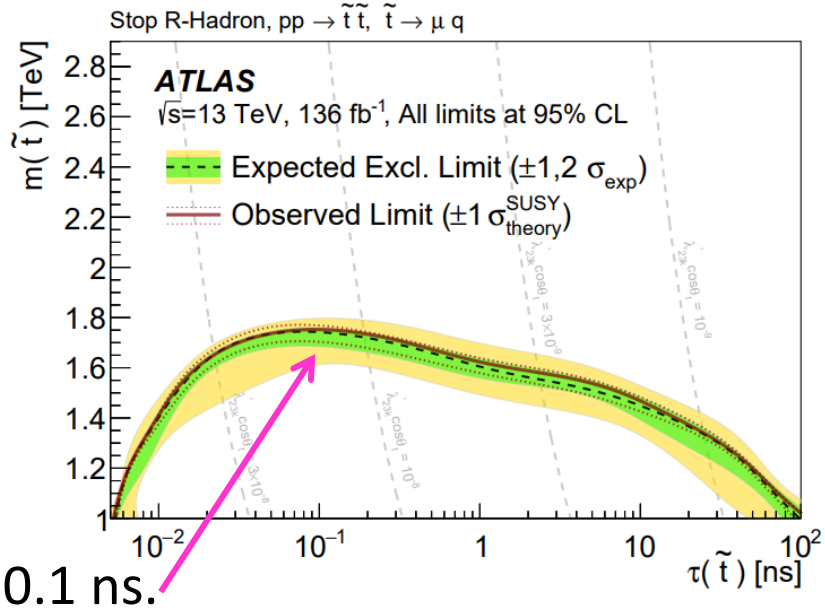
→ Top squark is LLP, decaying to muon and k-th generation down-type quark.



Strategy

- Missing Et (MET) or muon trigger
- Events with DV ($N_{\mathrm{trk}} \geq 3$, $m_{\mathrm{DV}} > 20$ GeV) and muon ($|d_0| > 2$ mm)
- BG estimation using dedicated control regions
  - Cosmic-ray muon
  - Muon from Heavy-flavor decay

  etc.

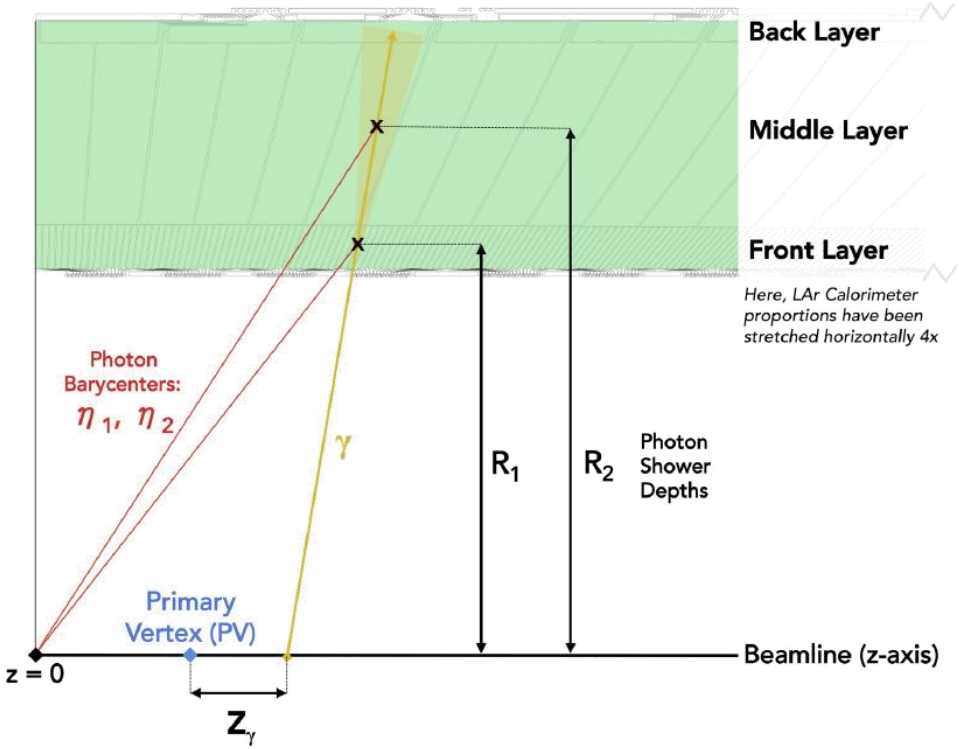


Result Exclude mass up to 1.7 TeV @τ = 0.1 ns.

Displaced photons

Photons originated from LLP have two signatures.

- Timing is delayed: $t_\gamma > 0$
- Not pointing back to the collision point: large $|Z_\gamma|$



Pointing measurement

1. Measure energy deposit on the first and second EM calorimeter layers.
2. Flight direction of photons are determined.
3. Calculate pointing value, Z_γ.

BGs include mis-reconstructed prompt photons and fake photons.

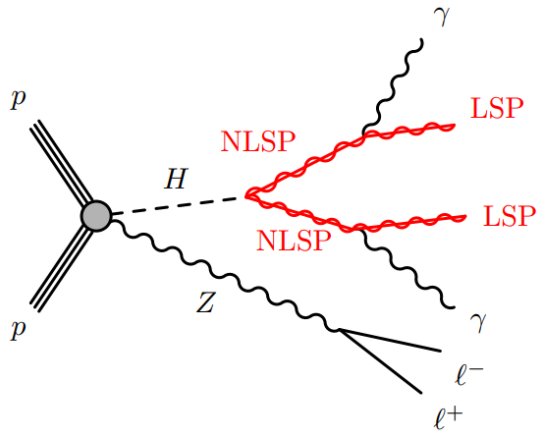
Submitted to PRD6

Displaced photons in Exotic Higgs decay

Motivation

- GMSB model
- Small coupling between neutral NLSP and LSP ($\tilde{G}$) → NLSP is LLP.
- Higgs boson decays to NLSPs, decaying into LSP and photon

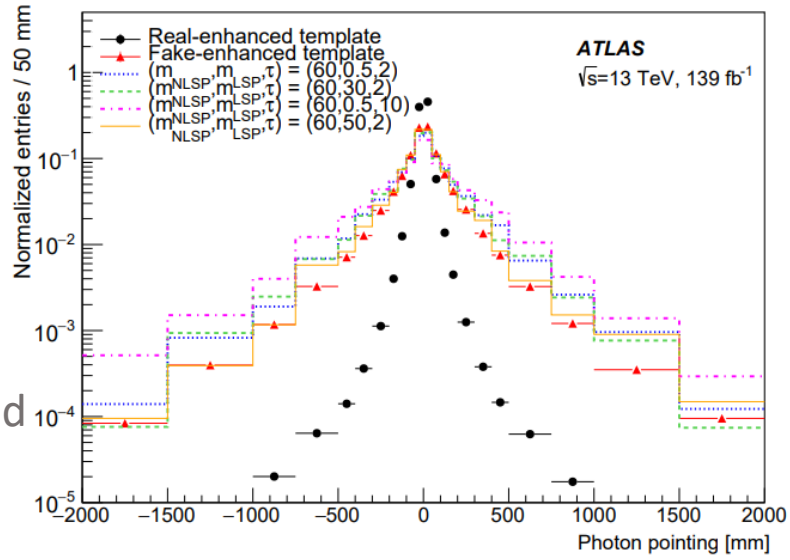
  → Benefit on potential Higgs boson to BSM branching ratio.



Strategy

- Electron or muon trigger
- Events with at least one photon ($t_\gamma > 0$) and MET
- Binned by t_γ and Z_γ

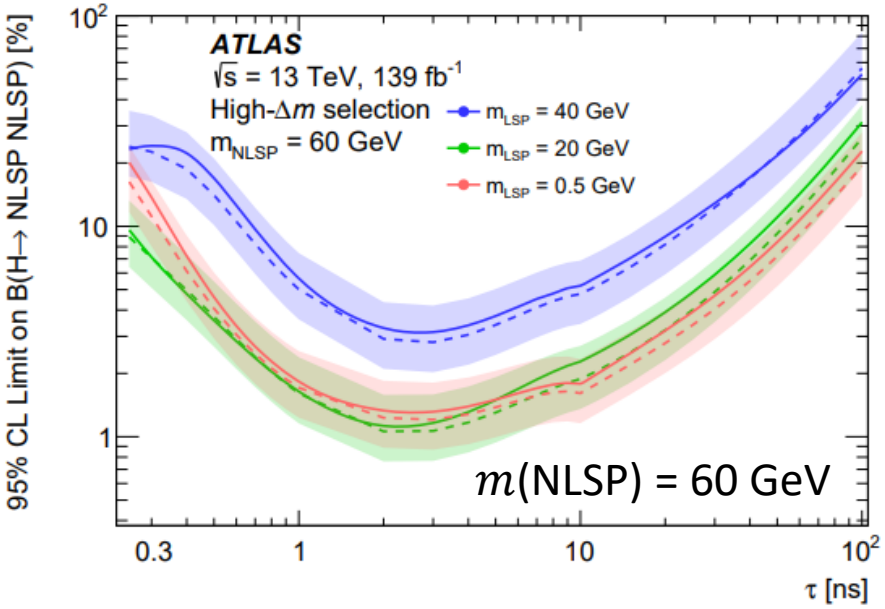
— Prompt-γ-enriched
— Fake-γ-enriched
others: signals

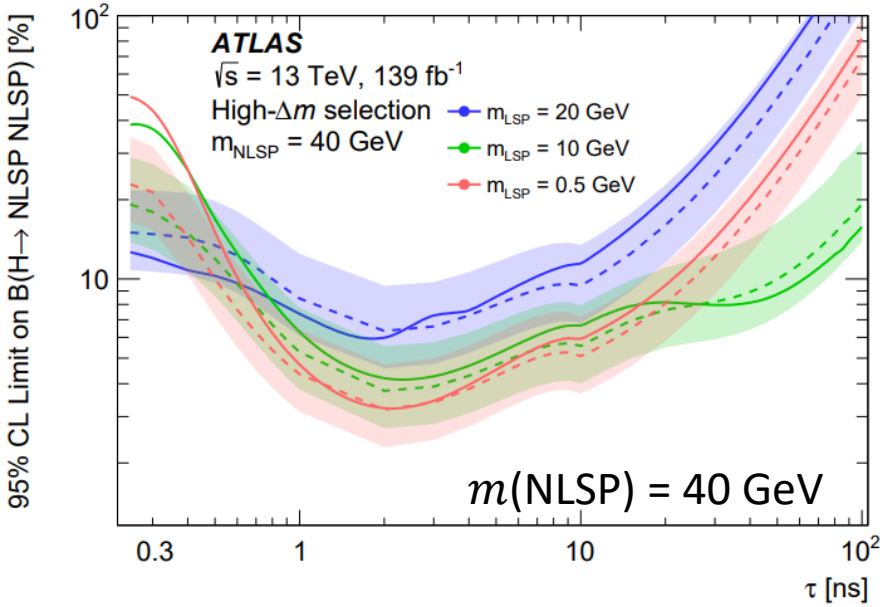


Displaced photons in Exotic Higgs decay

Result

- No excess
- Limits on BR($H \rightarrow$ NLSP NLSP) assuming BR(NLSP $\rightarrow$ LSP γ) = 100% in NLSP mass from 30 GeV to 60 GeV





As reference, observed limit on BR($H \rightarrow$ invisible) was set to 14.5% by $H \rightarrow$ invisible search with vector-boson-fusion. JHEP08(2022)104

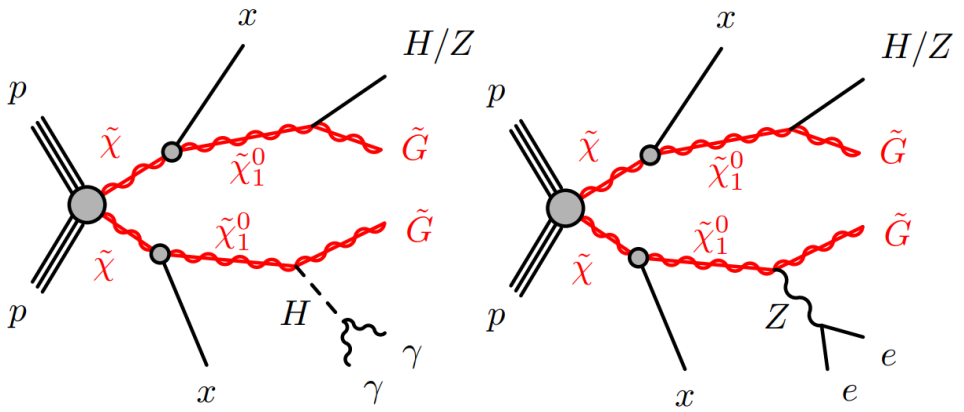
ATLAS-CONF-2022-051

Displaced photons from displaced H/Z

x: SM particle
$\tilde{\chi}$: $\tilde{\chi}_2^0$ or $\tilde{\chi}_1^{\pm}$

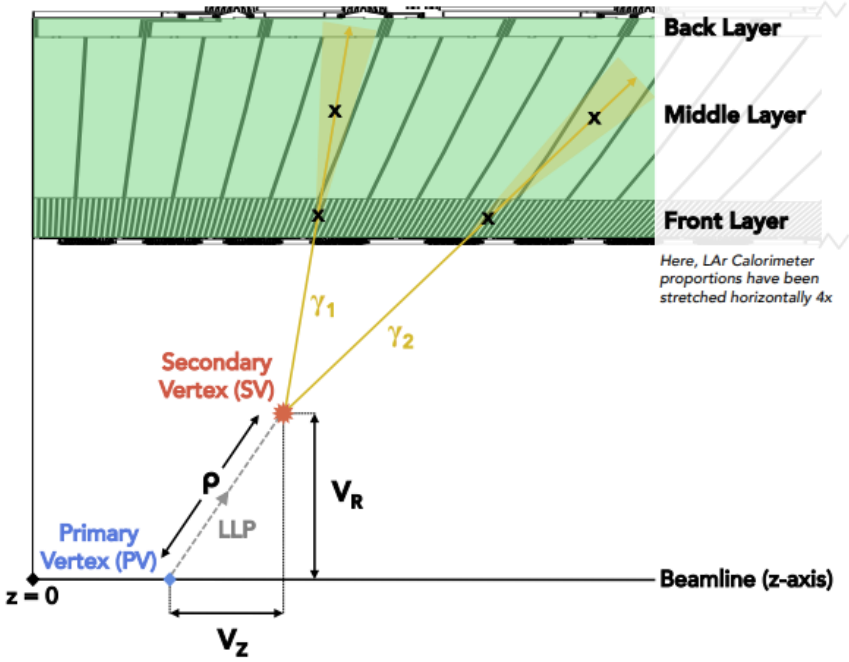
Motivation

- GMSB model
- Small coupling between NLSP ($\tilde{\chi}_1^0$) and LSP ($\tilde{G}$) → $\tilde{\chi}_1^0$ is LLP
- $\tilde{\chi}_1^0$ decays to $\tilde{G}$ via H/Z emission



Strategy

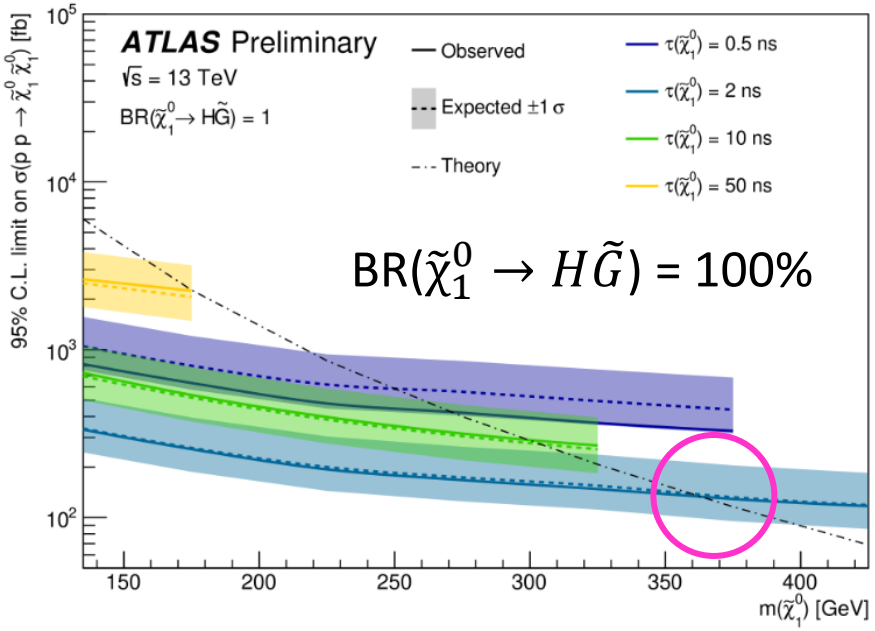
- Di-photon trigger
- Form a vertex using displaced $\gamma\gamma/ee$
- Events with photon vertex ($t_\gamma > 0$, $m_{\gamma\gamma} \in [60, 135]$ GeV) and MET
- Binned by average t_γ and ρ

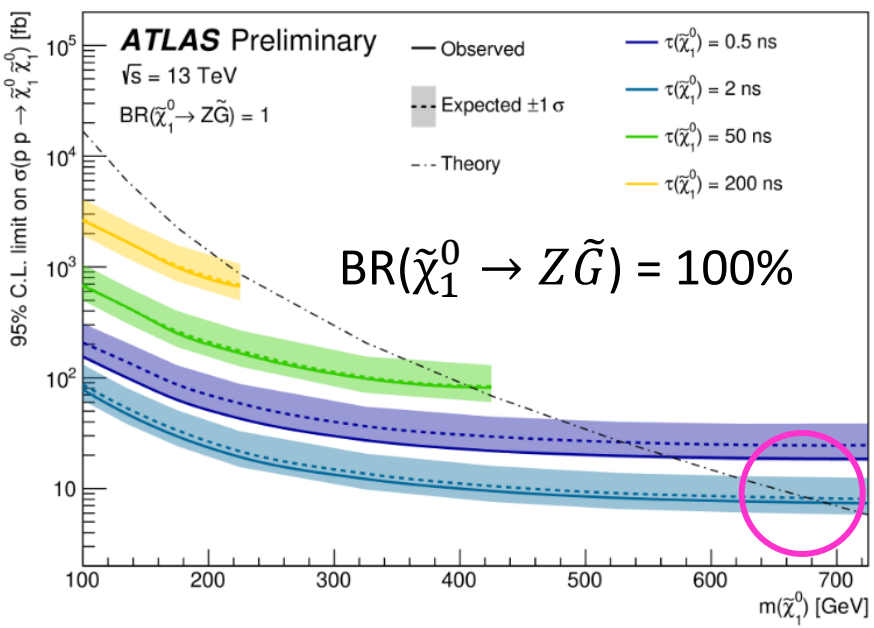


Displaced photons from displaced H/Z

Result

- No excess
- Interpretation in a GMSB model
- Exclude $m(\tilde{\chi}_1^0)$ up to 369 GeV @τ = 2 ns for BR($\tilde{\chi}_1^0 \rightarrow H\tilde{G}$) = 100%,
  $m(\tilde{\chi}_1^0)$ up to 704 GeV @τ = 2 ns for BR($\tilde{\chi}_1^0 \rightarrow Z\tilde{G}$) = 100%





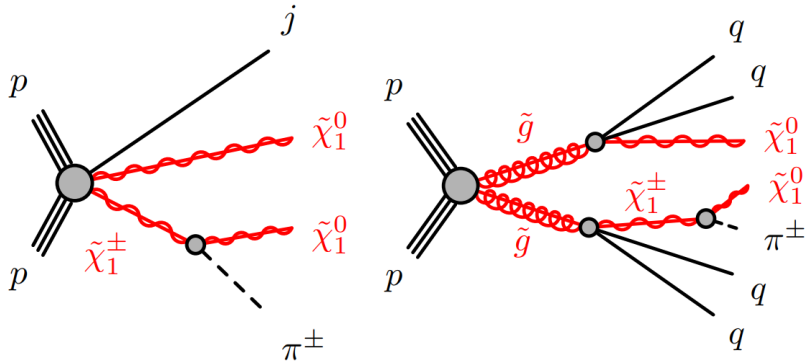
Disappearing track

Eur. Phys. J. C 82 (2022) 606

Motivation

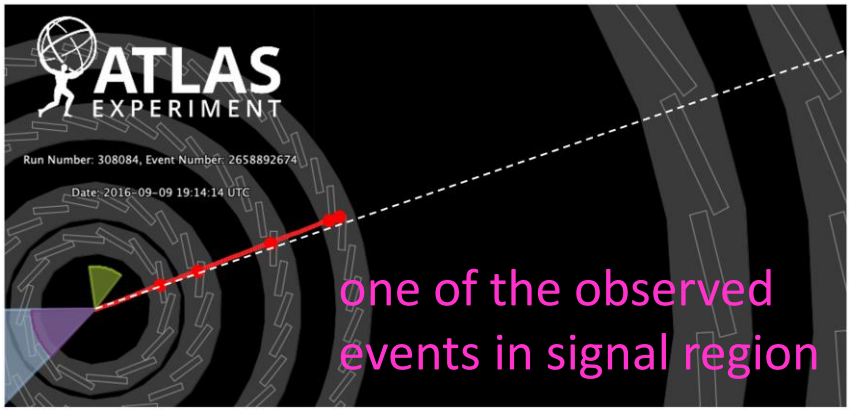
wino/higgsino LSP → small $\Delta m(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0)$

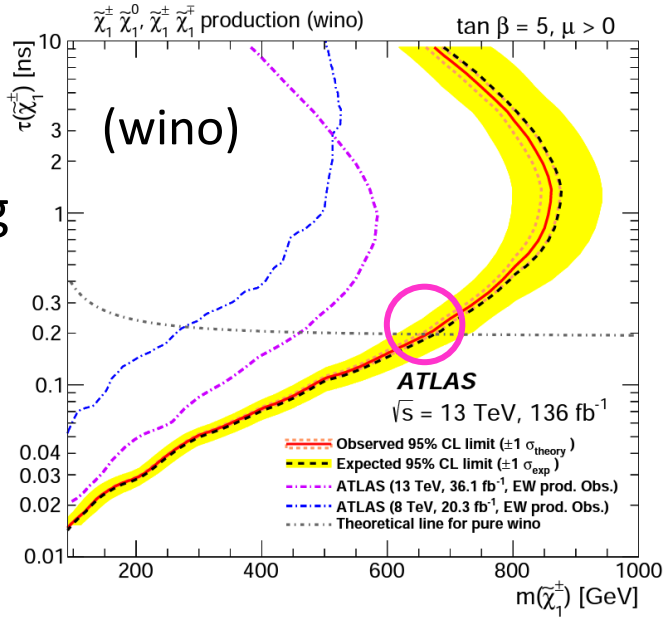
→ $\tilde{\chi}_1^{\pm}$ is LLP, decaying to $\tilde{\chi}_1^0$ + pion



Strategy

- MET trigger
- Find a disappearing track inside detector
  - Reconstruct "tracklets" using four unused Pixel hits after standard tracking
  - No outer hits or calorimeter activity





Result

Exclude mass up to 660 (210) GeV @τ = 0.2 ns for wino (higgsino) LSP.

Stopped particle

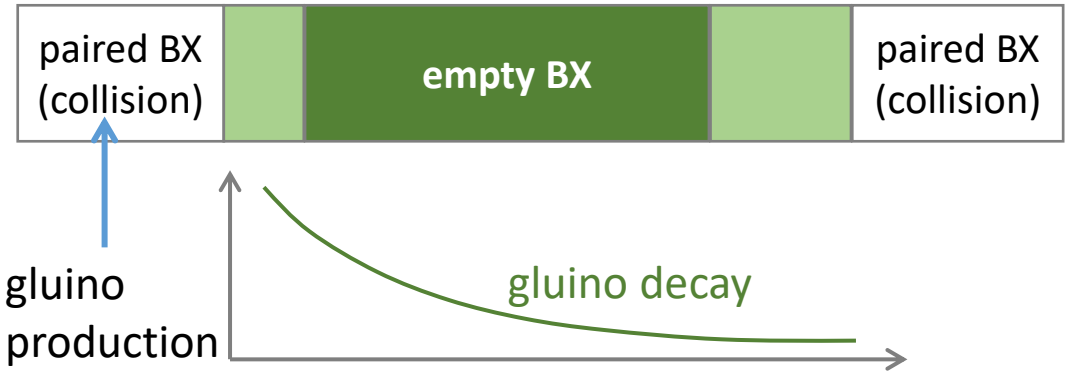
JHEP 07 (2021) 173

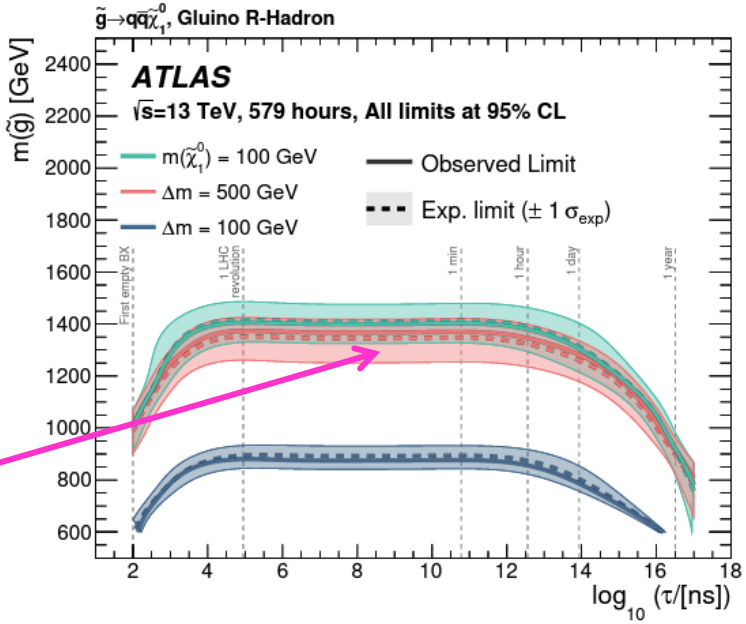
Motivation

Long-lived gluino → hadronizes with SM particles
→ Interacts with material and stops inside the detector
→ Decays later than bunch crossing (BXs)

Strategy

- Calorimeter activities in the empty BXs → No BG from collision





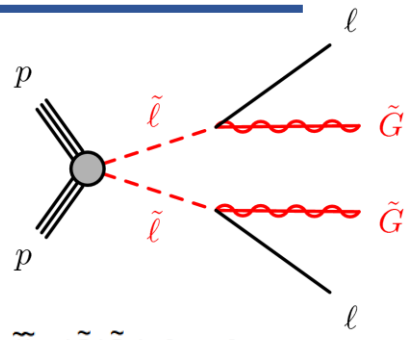
Result Exclude $m(\tilde{g})$ up to 1.4 TeV
@$m(\tilde{\chi}_1^0)$ = 100 GeV,
τ from microseconds to hours.

Displaced leptons

Phys. Rev. Lett. 127, 051802 (2021)

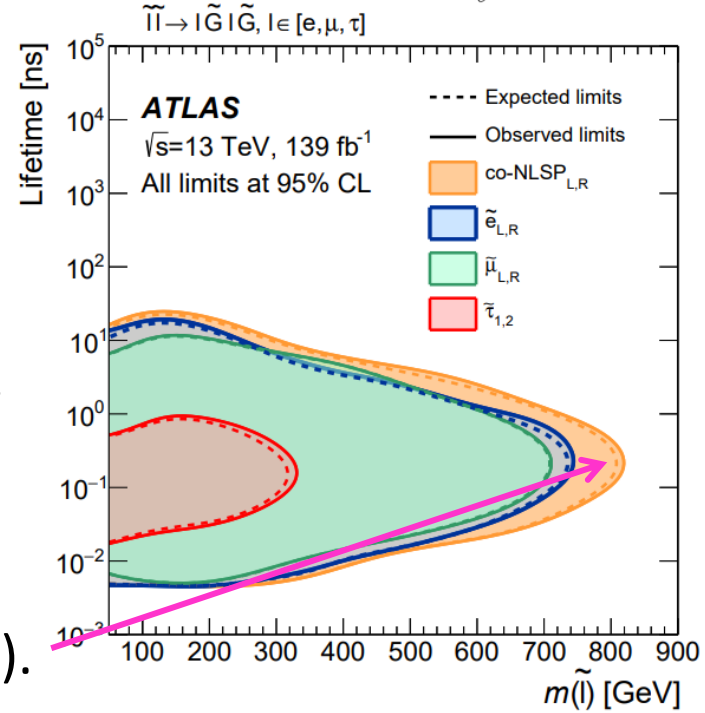
Motivation

- GMSB model
- Small coupling between NLSP ($\tilde{l}$) and LSP ($\tilde{G}$)
  → $\tilde{l}$ is LLP, decaying to lepton and $\tilde{G}$



Strategy

- Photon (electron without track) or muon trigger
- Large radius tracking and looser lepton identification requirements
  → Drastic increase in reconstruction efficiency.
- Events with $ee/e\mu/\mu\mu$ ($|d_0| > 3$ mm)



Results

Exclude mass up to 820 GeV @0.1 ns (co-NLSP).

Analysis targeting shorter lifetime is ongoing.

Summary

- Many SUSY models predict long-lived new particles.
- ATLAS searches for LLPs using various methods suitable for each LLP characteristic.
- No evidence of LLP was found so far, but the analysis results provide the constraints of the parameter spaces.
- Several remaining analyses with full Run 2.
- Run 3 just started in July and the signs of new physics that have never been seen before are expected.

Backup

DV

Standard tracking
- $|d_0|$ < 10 mm
- $|z_0|$ < 250 mm
- p_{T} > 500 MeV
- # silicon hits $\geq$ 7

Large radius tracking
- hits not used in standard tracking
- $|d_0|$ < 300 mm
- $|z_0|$ < 1500 mm

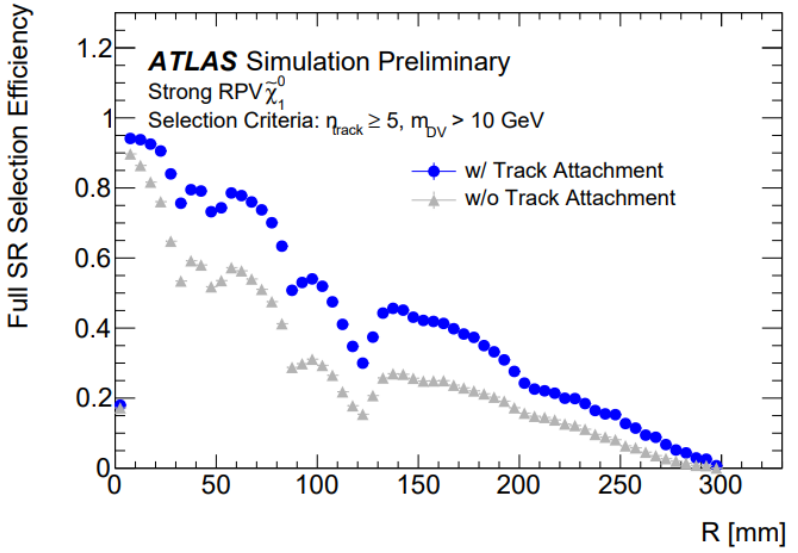
1. Two-track seed vertices using selected tracks

Seed track selection:
- p_{T} > 1 GeV
- At least one of two tracks has $|d_0|$ > 2 mm

2. Seeds merging to n-track vertex

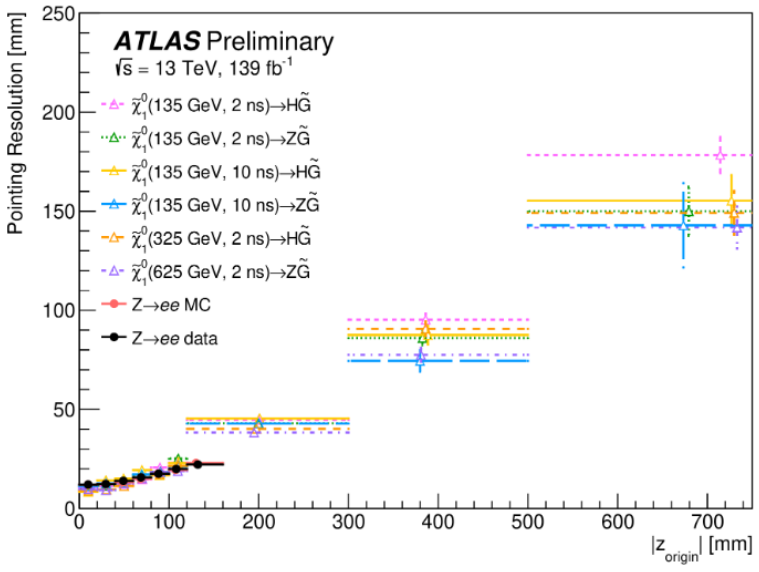
Ambiguities are resolved by comparing χ^2, or by merging the vertices.

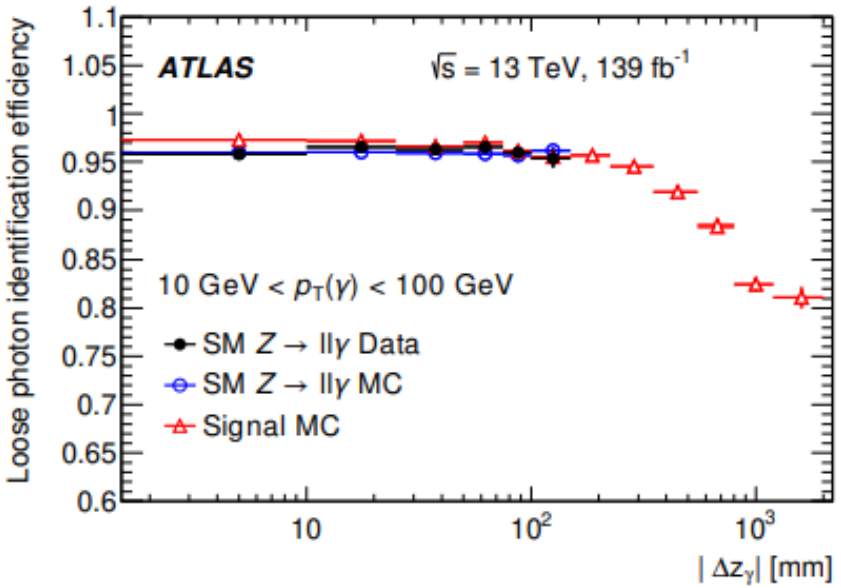
3. Track (non-selected) attachment .



Displaced photon

- Timing resolution in EM calorimeter: 100 ps
- Segment on the first later : $\Delta\eta \times \Delta\phi = 0.003 \times 0.1$
- Segment on the second later : $\Delta\eta \times \Delta\phi = 0.025 \times 0.025$
- Pointing resolution: ~15 mm in barrel (energy 50-100 GeV)





Disappearing track

Bad momentum resolution due to short lever arm.

Chargino (p_{T} > 60 GeV) case:

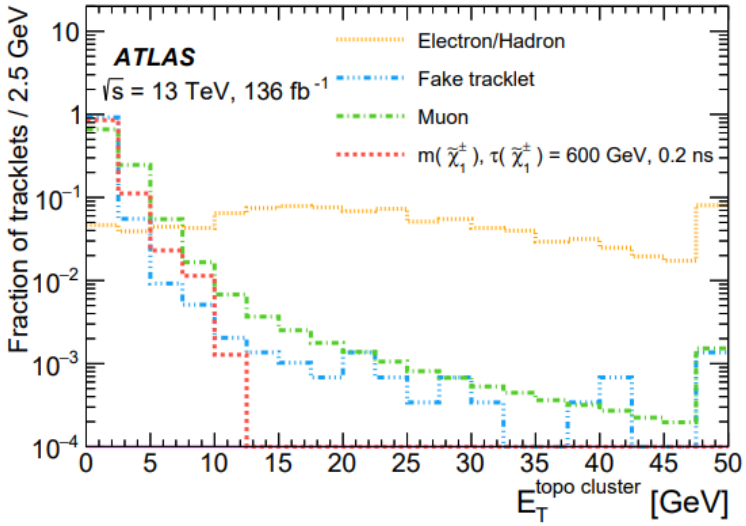
Normal track (at least seven SCT hits)

- q/p_{T} resolution: 0.532+-0.005 TeV^{-1}
- angle resolution: 0.0801+-0.0008 mrad

Pixel tracklet

- q/p_{T} resolution: 8.28+-0.05 TeV^{-1}
- angle resolution: 0.4065+-0.0027 mrad

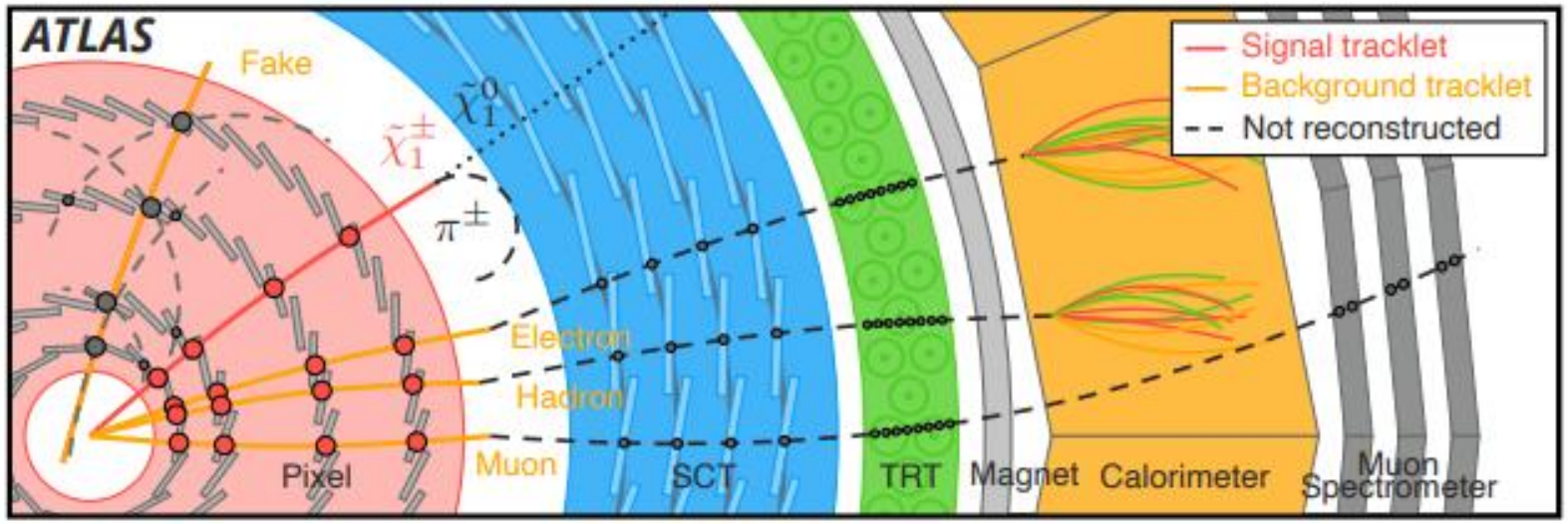
The pointing resolution in both η and ϕ is better than 1 mrad.



Disappearing track

BGs

- Charged-particle scattering (electron/muon/hadron)
- Combinatorial fake



Stopped particle

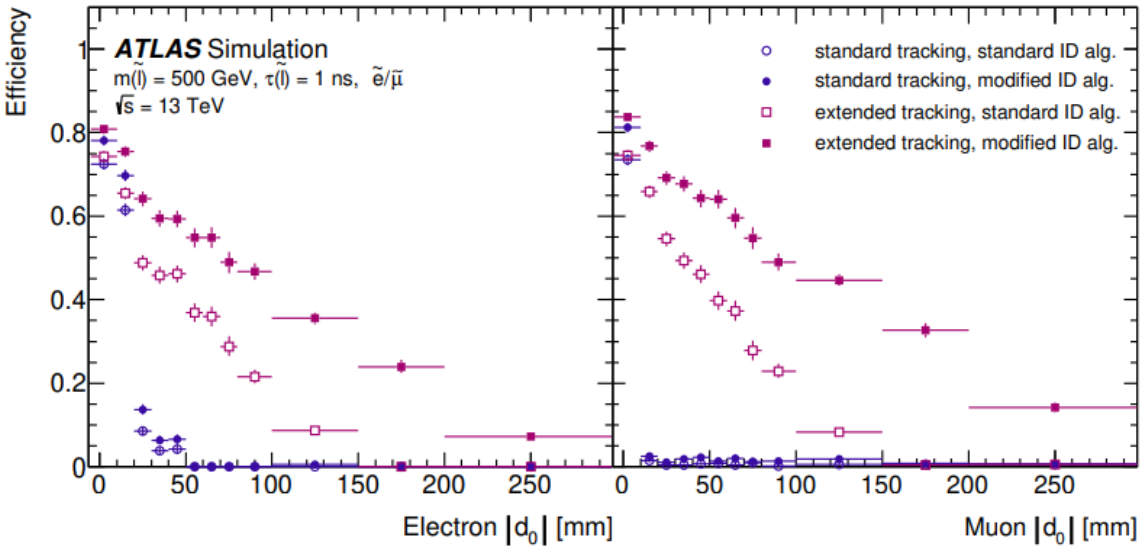
BGs

- Beam-induced BG: Beam protons interact with material upstream from detector, resulting in energetic muon traversing the detector

  → Estimate using unpaired bunch (only one bunch is filled)
- Cosmic ray muon

  → Estimate using data collected without LHC beam

Displaced leptons



Cosmic-tag:

A cosmic muon moves though ATLAS.

→ Reconstructed as back-to-back two muons.

- When one of them is reconstructed, it is tagged as cosmic if it is back-to-back with any MS activity.
- Events with muons back-to-back with a detector gap are also vetoed.