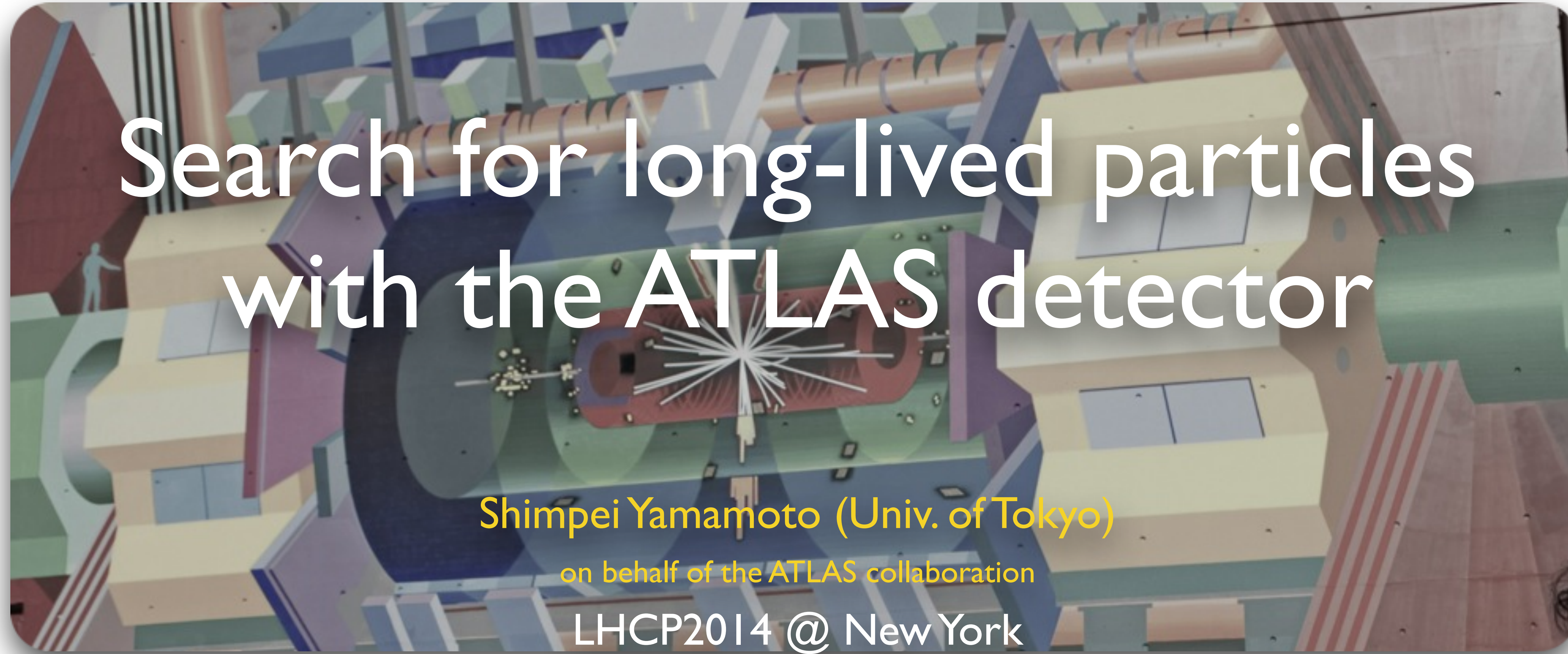

Search for long-lived particles with the ATLAS detector

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on behalf of the ATLAS collaboration

LHCP2014 @ New York

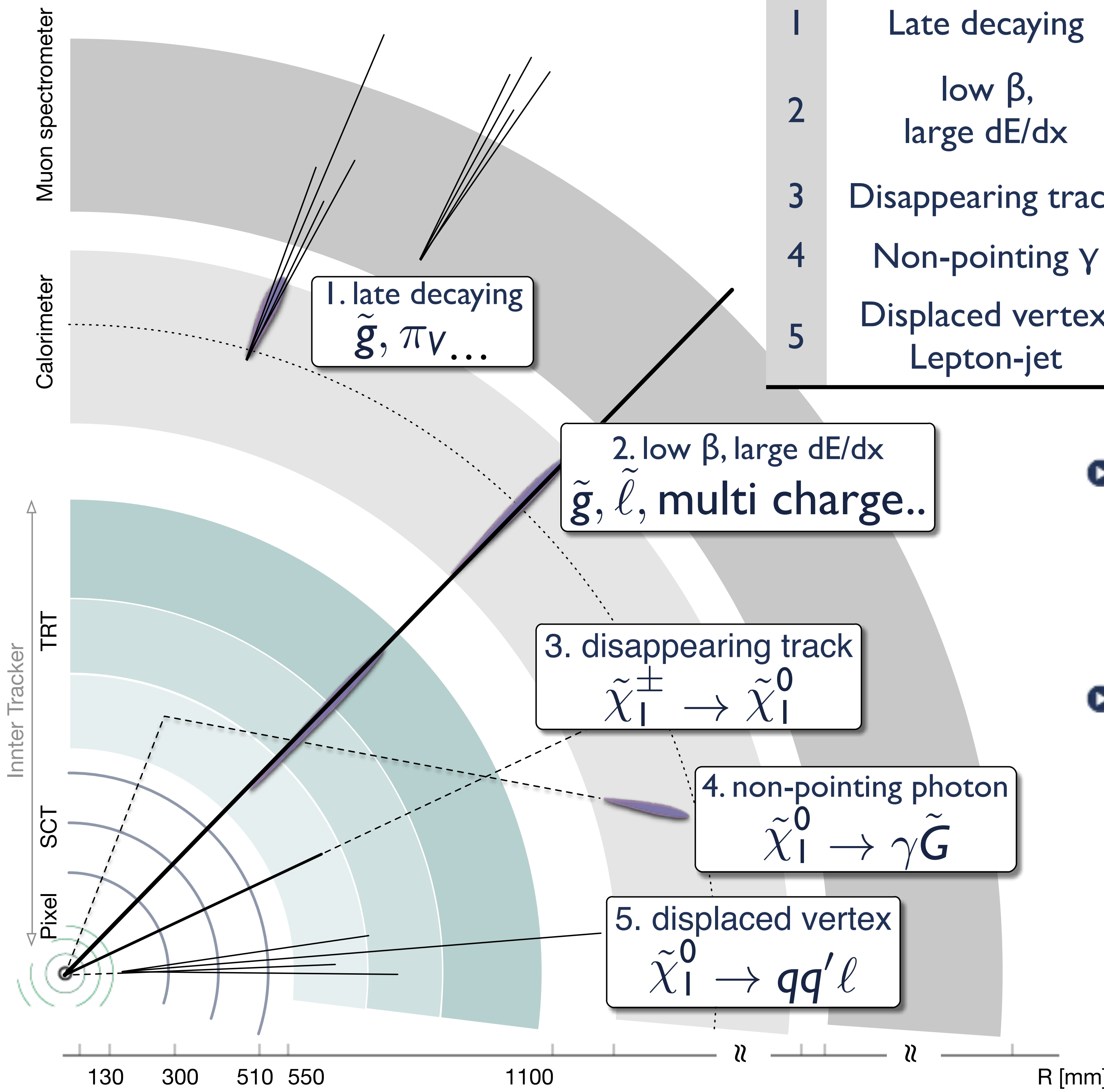
Outline

- Introduction
- Long-lived particle signatures and BSM examples
- Highlights of ATLAS searches with 8 TeV data
  - Late-decaying particles (SUSY-2013-03)
  - Slow massive charged particles (ATLAS-CONF-2013-058)
  - Disappearing tracks (SUSY-2013-01)
  - Displaced vertices (ATLAS-CONF-2013-092)
- Summary

Introduction

- Though no sign of BSM yet, the measured Higgs mass of ~126 GeV may imply the existence of unknown particles related the hierarchy problem.
- This also motivates us to:
  - SUSY
    - High-scale supersymmetry breaking (or heavy scalars): split SUSY, AMSB, ..
    - Stealth SUSY, RPV scenarios, ..
  - Non-SUSY : Less constrained. Some could also give a solution to the hierarchy problem, a good dark matter candidate
    - e.g. Hidden Valley, Higgs portal, multi-charged particles(monopoles, Q-balls), quirks, ..
- All these models/scenarios predict various long-lived particle signatures at the LHC!
  - *Easily go undetected! Cover loopholes in generic BSM searches.* *(Could be only the one we can observe in the LHC data?)*

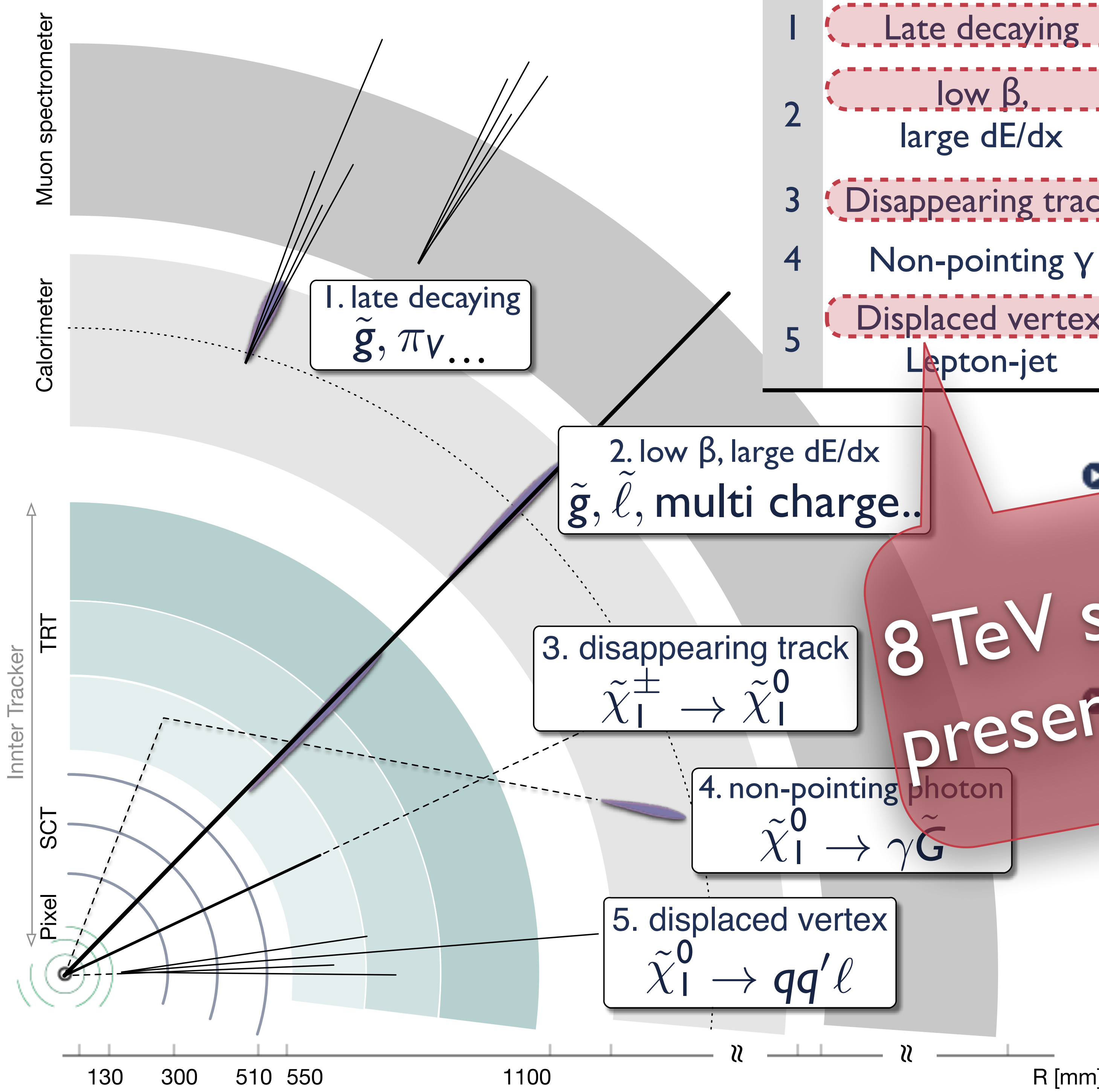
Signatures and BSM examples



	Signature	Scenario	decay-length sensitivity
1	Late decaying	split SUSY, Hidden Valley	—
2	low β, large dE/dx	GMSB, Split-SUSY, Stealth SUSY, Multi-charged	>1000mm
3	Disappearing track	AMSB (wino-LSP)	O(100-1000)mm
4	Non-pointing γ	GMSB	O(100-1000)mm
5	Displaced vertex, Lepton-jet	RPV, GMSB, Hidden Valley	O(10-100)mm

- Comprehensive searches in ATLAS, covering almost all possible experimental signatures with innovative analysis techniques.
- Few SM background process in general, but instrumental background dominates. The searches require full understanding of
  - material effects
  - alignment
  - timing calibration
  - non-collision background

Signatures and BSM examples



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8 TeV search results available, presented today!

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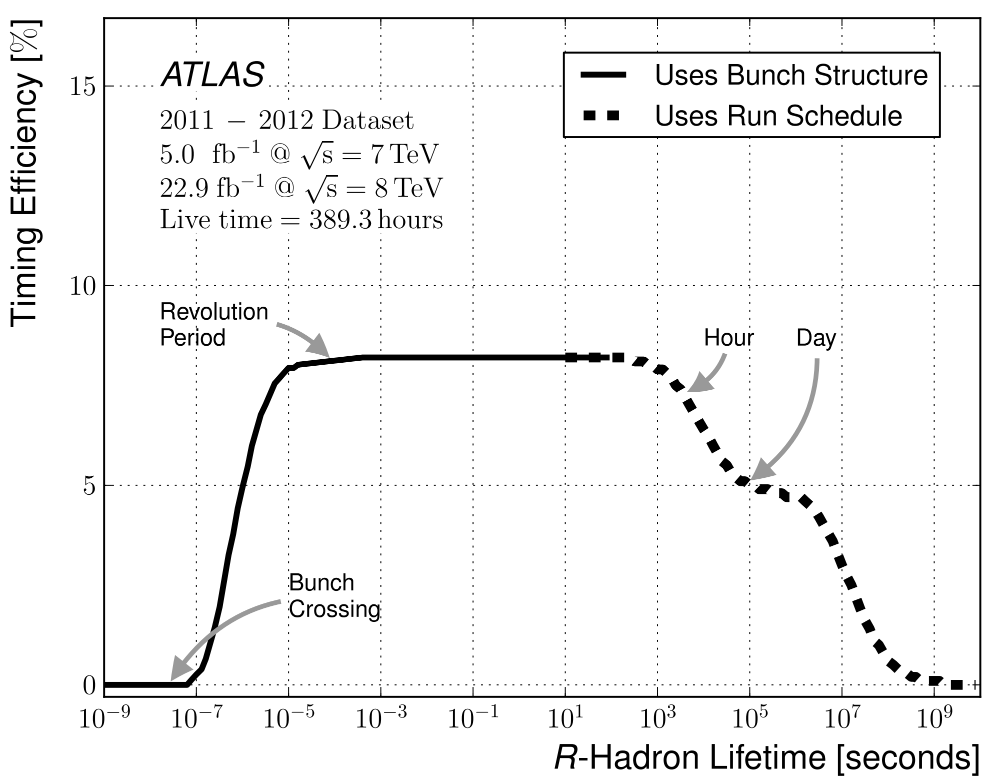
Late-decaying particles

- Benchmark model: Split SUSY
  - Gluinos decay via internal heavy squark lines, become meta-stable and form bound states (R-hadrons)
- Signature to explore:
  - Special case that gluinos are produced near threshold:
    - Some R-hadrons have low β and "stop" in the detector. Then they decay much later.
  - ⇒ Look for energetic jets (from R-hadron decays) in "empty bunches".
    - Small background mainly comes from cosmic, noise and beam halo interactions.



The signal efficiency depends on the lifetime:

$$\epsilon = \epsilon_{stop} \times \epsilon_T \times \epsilon_{rec}$$

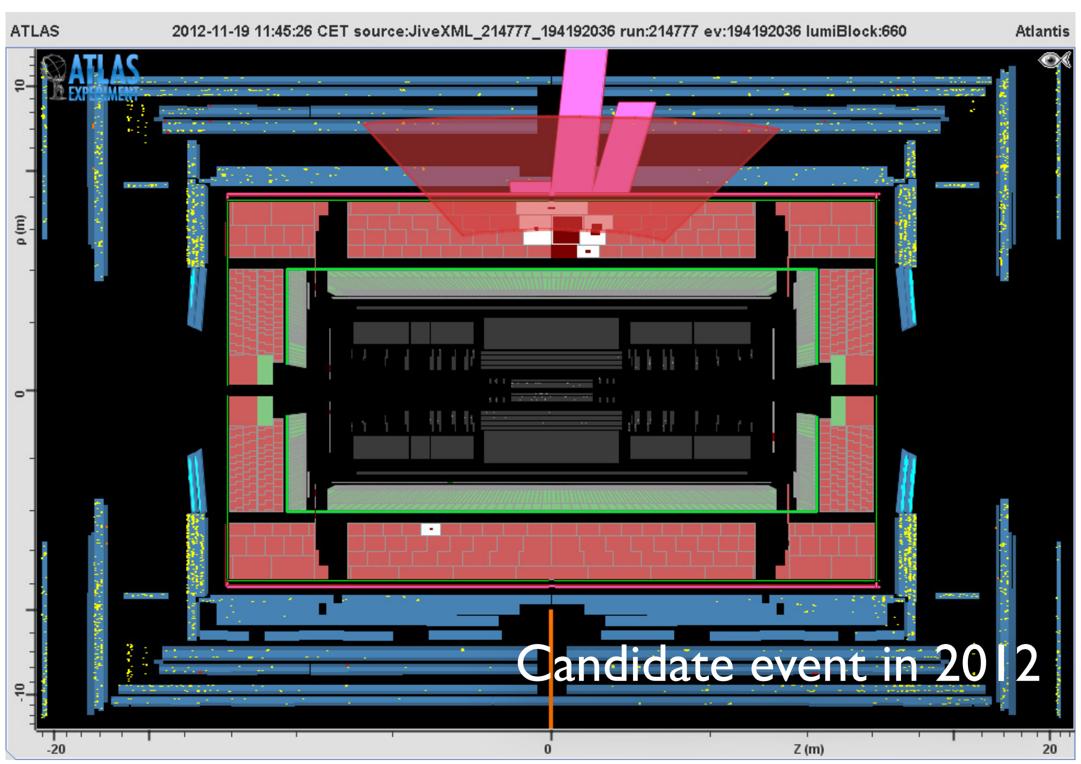
Stopping fraction

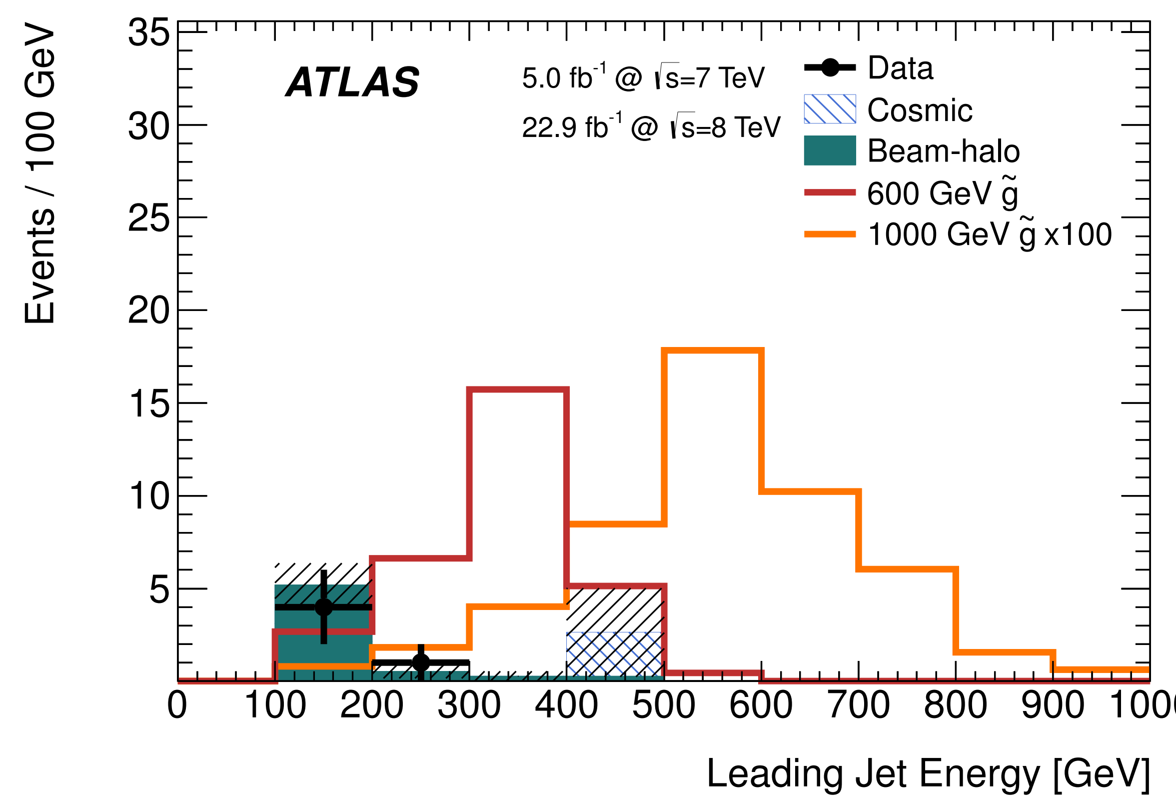
Timing acceptance (depending on lifetime)

Reconstruction efficiency

Late-decaying particles

- **Selection**
  - Events trigger in empty bunches, containing large calorimeter activity
  - Offline jet with E>100(300) GeV and |eta|<1.2
  - Muon activity veto to remove cosmic/beam-halo backgrounds
- **Background**
  - Estimated using low-luminosity data (cosmic) and unpaired crossings (beam halo).
- **No excess observed..**

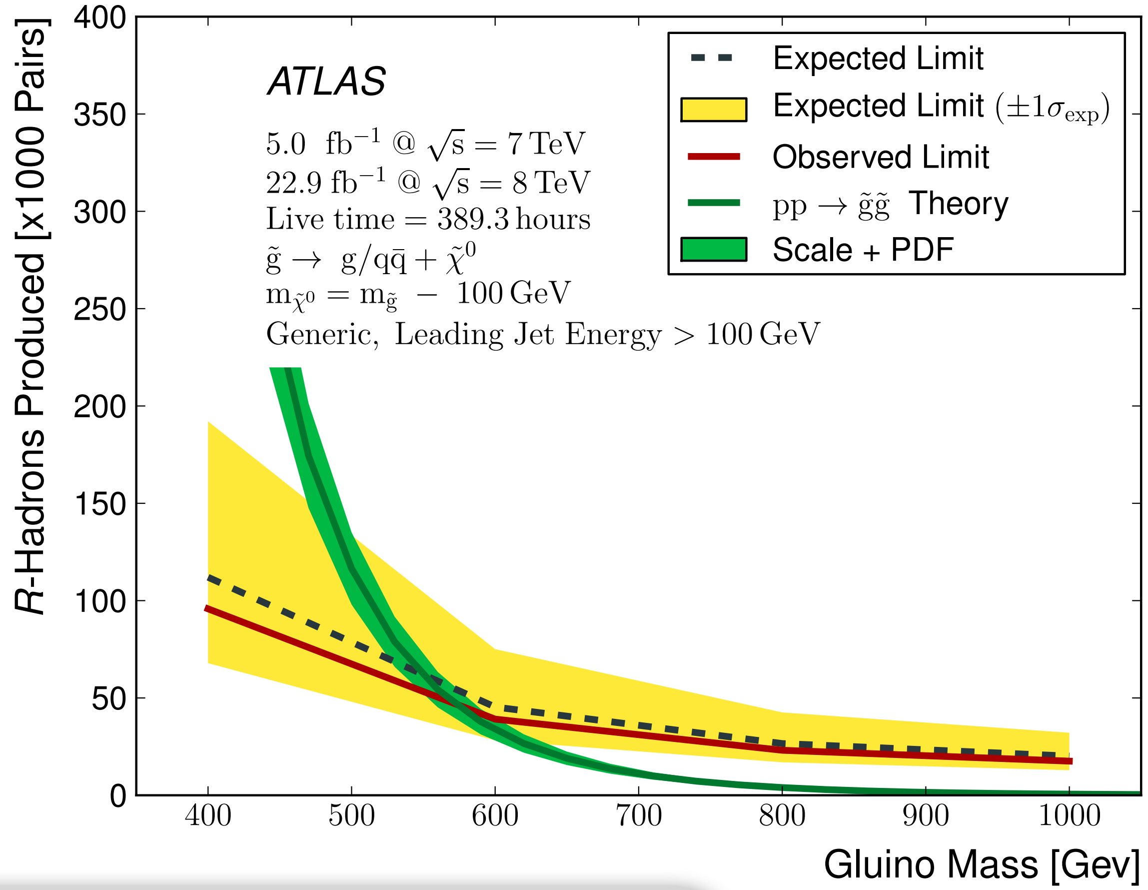




Late-decaying particles

Results

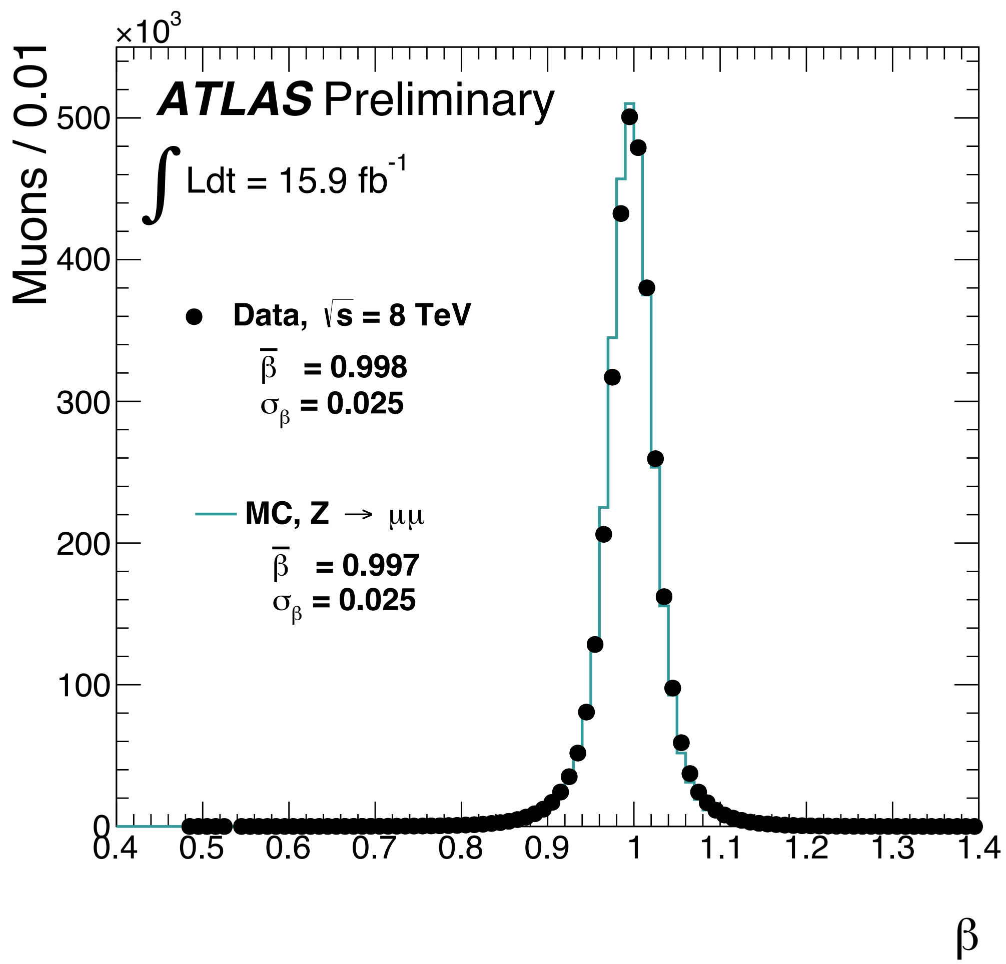
- **A limit of > 545-784 GeV is set for $10^{-6}<\tau<10^{3}$ sec.**
- Limits with different R-hadron decays and interaction models (resulting in different stopping fractions) are also given.



Leading jet energy (GeV)	R-hadron model	Gluino/squark decay	Neutralino mass (GeV)	Gluino/squark mass limit (GeV) Expected	Observed
100	Generic	$\tilde{g}\rightarrow g/q\bar{q}+\tilde{\chi}^0$	$m_{\tilde{g}}-100$	526	545
100	Generic	$\tilde{g}\rightarrow t\bar{t}+\tilde{\chi}^0$	$m_{\tilde{g}}-380$	694	705
300	Generic	$\tilde{g}\rightarrow g/q\bar{q}+\tilde{\chi}^0$	100	731	832
300	Generic	$\tilde{g}\rightarrow t\bar{t}+\tilde{\chi}^0$	100	700	784
300	Intermediate	$\tilde{g}\rightarrow g/q\bar{q}+\tilde{\chi}^0$	100	615	699
300	Regge	$\tilde{g}\rightarrow g/q\bar{q}+\tilde{\chi}^0$	100	664	758
100	Generic	$\tilde{t}\rightarrow t+\tilde{\chi}^0$	$m_{\tilde{t}}-200$	389	397
100	Generic	$\tilde{t}\rightarrow t+\tilde{\chi}^0$	100	384	392
100	Regge	$\tilde{t}\rightarrow t+\tilde{\chi}^0$	100	371	379
100	Regge	$\tilde{b}\rightarrow b+\tilde{\chi}^0$	100	334	344

Slow massive charged particles

- Nearly-stable NSLP staus in GMSB. Can be observed as "slow heavy muons".
- **Select slow muon-like particles with p_T>50 GeV, β<0.95 and reconstruct mass by:** $m = p/\beta\gamma$
  - ***p*** **taken from track, β measured by muon detector** (also required to be consistent with the calorimeter-based measurement)

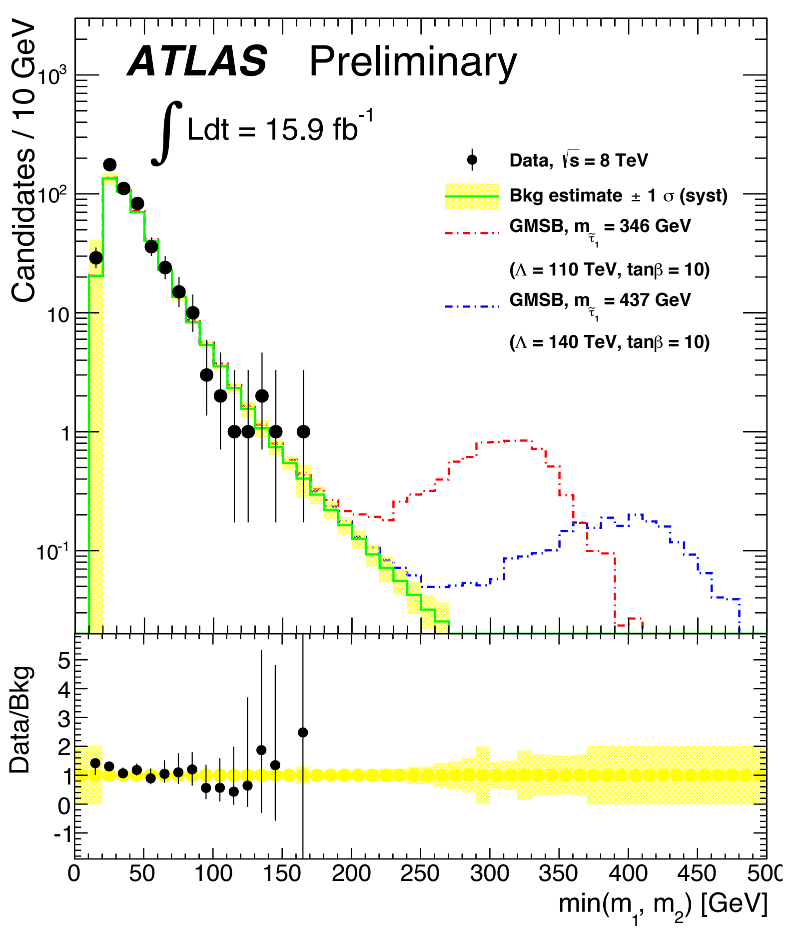


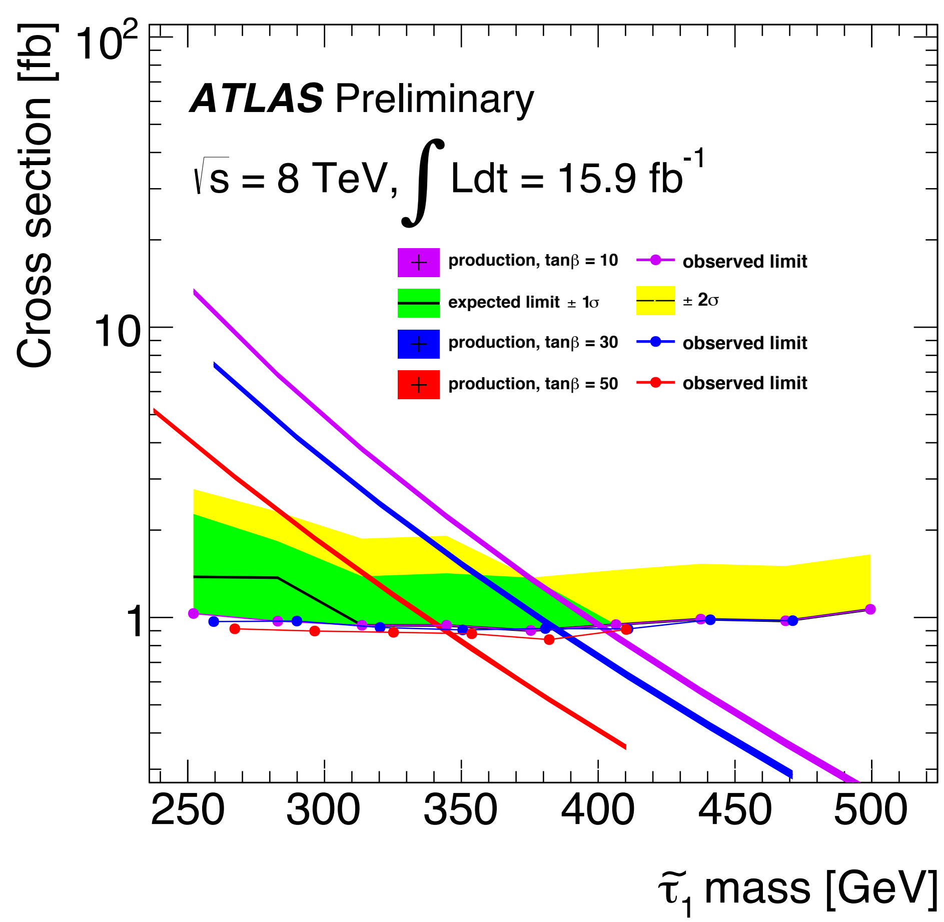
- Timing calibration crucial!!
  - Performed using Z→μμ events
  - Resolution: ~2.5%
- Background dominated by muons with mismeasured β.
  - Estimated by generating combination of the p of a candidate track with a randomly extracted β from muon-β distribution.

Slow massive charged particles

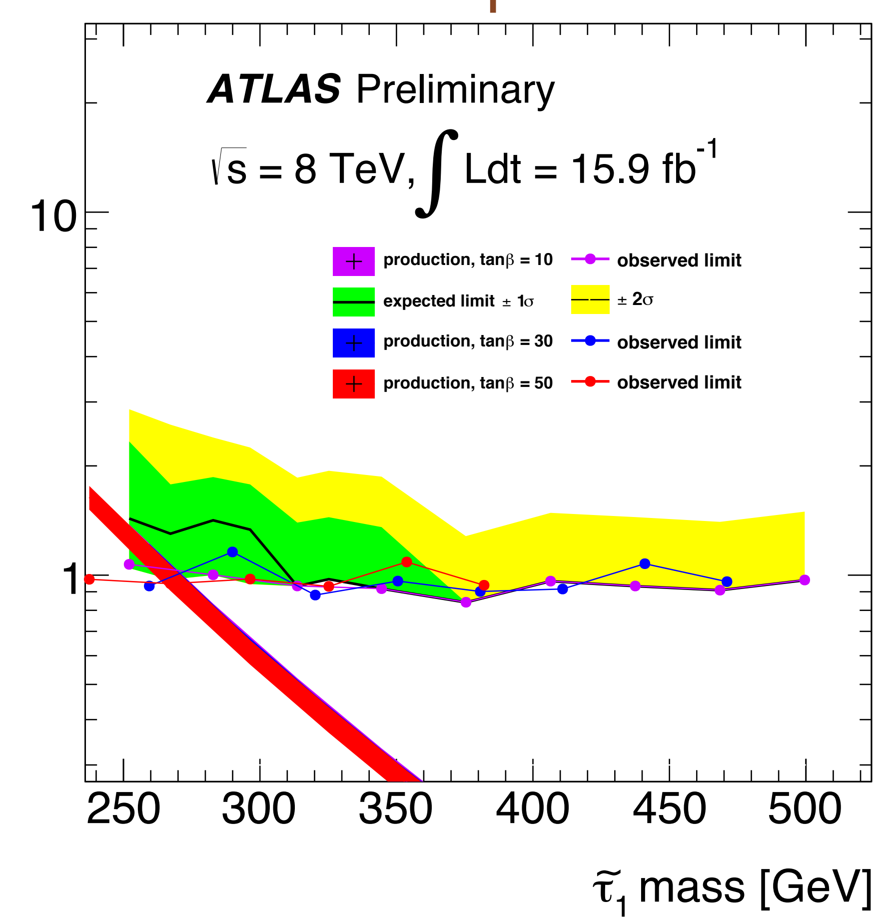
Results

- Significant signal-to-background ratios expected in two-track-candidates events.
  - **No excess above SM expectation.**
- Interpretations in context of GMSB:
  - **Stau mass >402–347 GeV (tanβ=5-50)**
  - **>267 GeV (assuming direct pair production)**





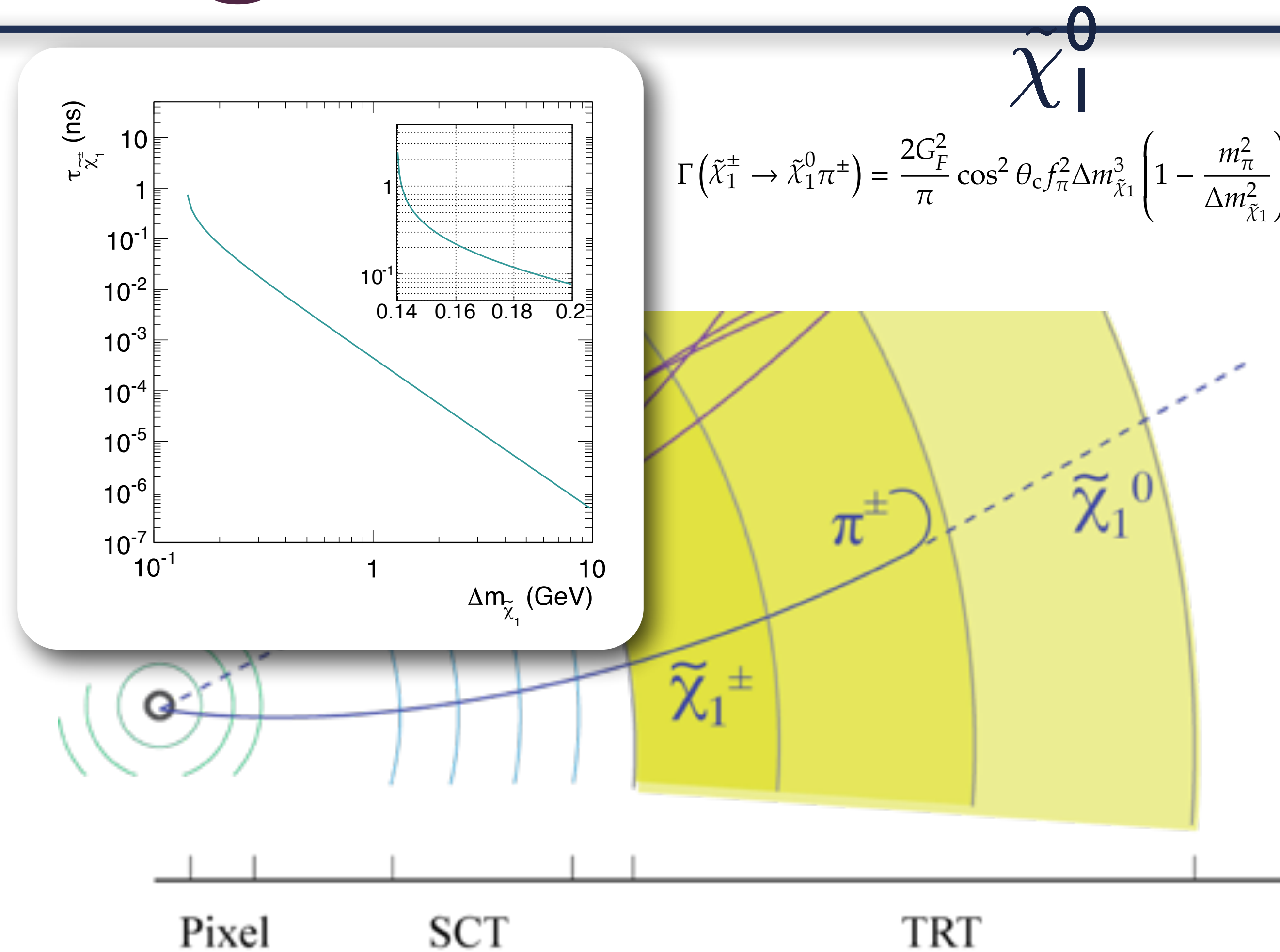
direct stau production

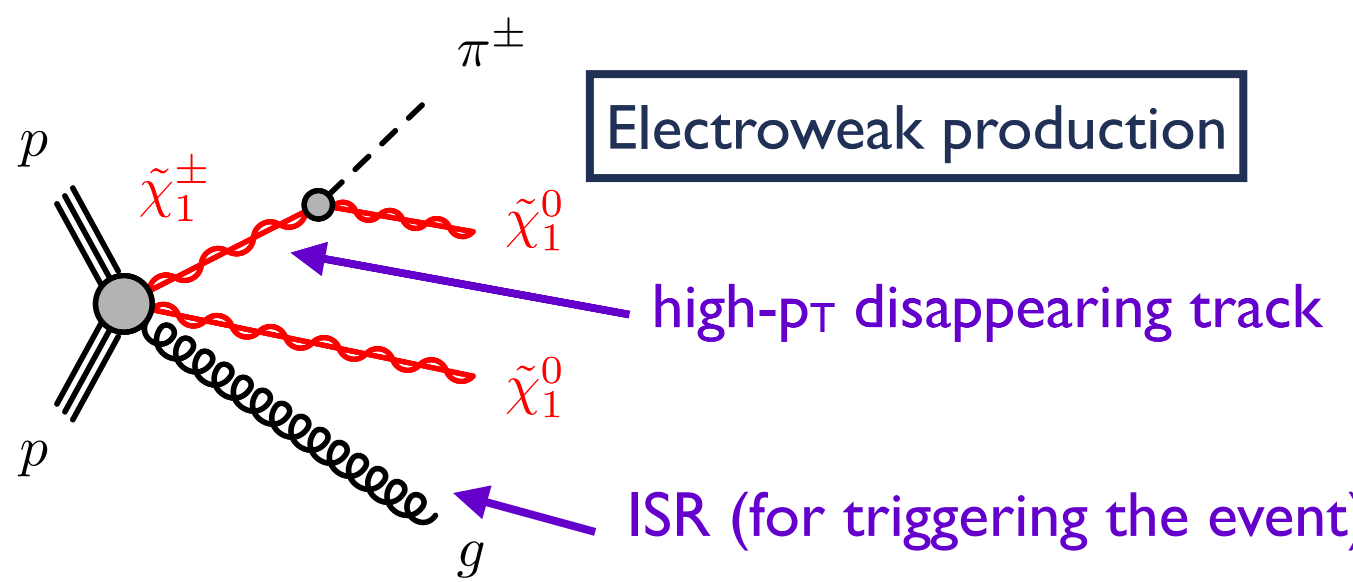


Disappearing tracks

- Wino-LSP SUSY scenarios predict the mass-degenerate $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_1^0$, resulting in a significant $\tilde{\chi}_1^\pm$ lifetime:
  - $m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0} \sim$ 160 MeV
  - $\tau_{\tilde{\chi}_1^\pm} \sim$ 0.2 ns
- Some decaying $\tilde{\chi}_1^\pm$ could be reconstructed as a ***"high-p_T disappearing track"***.
  - $\tilde{\chi}_1^\pm \to \tilde{\chi}_1^0 \pi^\pm$: charged pion is to soft to be reconstructed (~100MeV).
  - Need to be highly boosted (high p_T) to get reconstructed.
- Explore EW production using events containing ***"ISR jet + disappearing track"***

$$\Gamma\left(\tilde{\chi}_1^\pm \to \tilde{\chi}_1^0 \pi^\pm\right) = \frac{2G_F^2}{\pi}\cos^2\theta_c f_\pi^2 \Delta m_{\tilde{\chi}_1}^3 \left(1 - \frac{m_\pi^2}{\Delta m_{\tilde{\chi}_1}^2}\right)^{\frac{1}{2}}$$





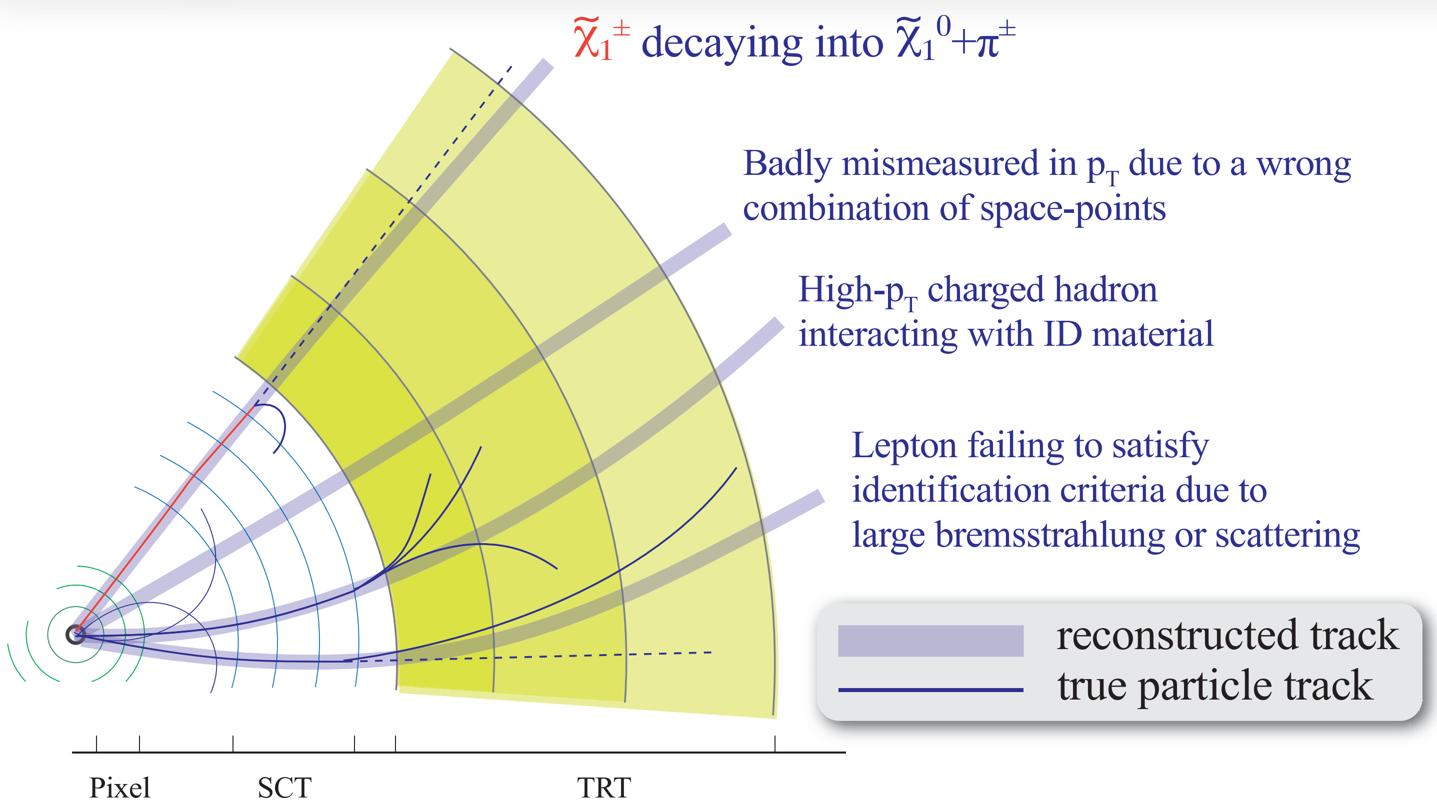
Disappearing track

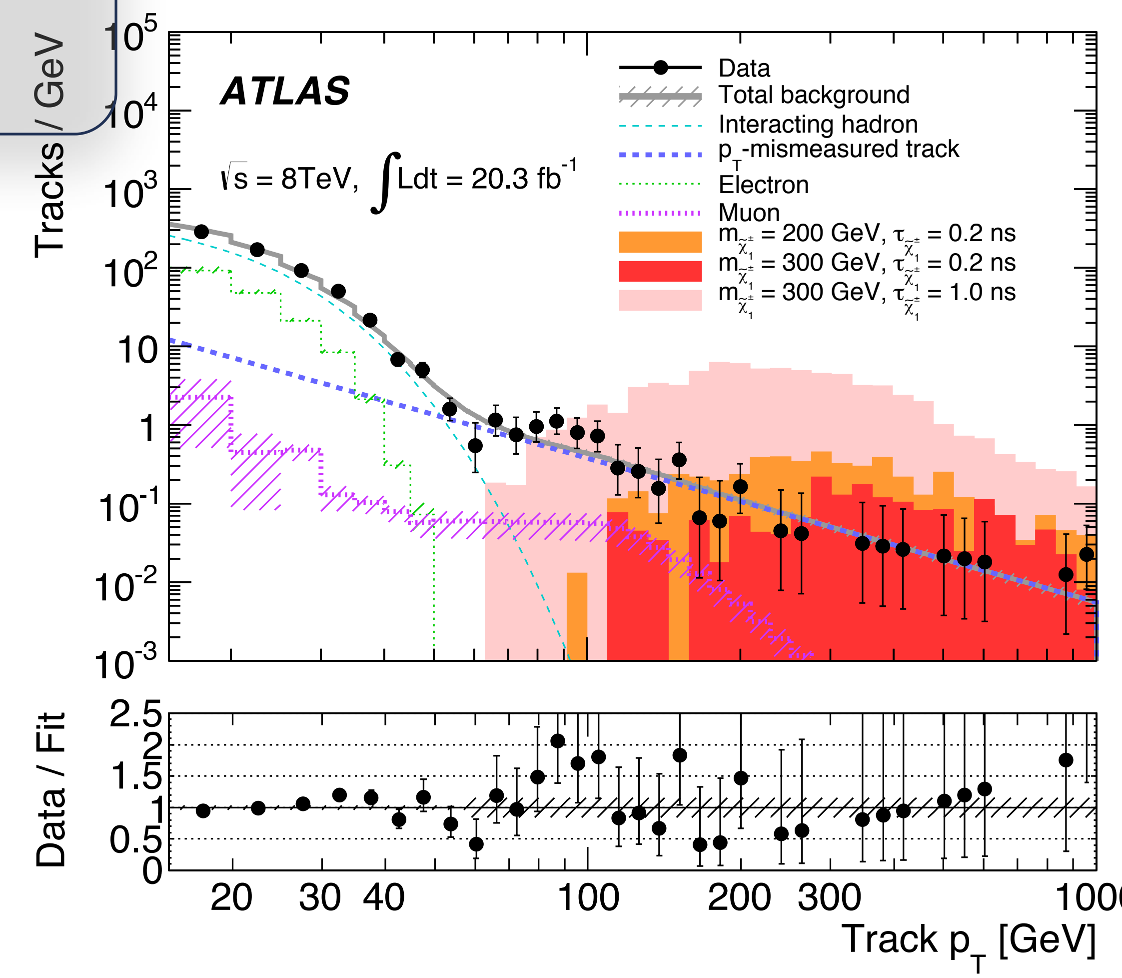
Selection

- Monojet-like final state: $\Delta\varphi(\text{jet,MET}) \sim \pi$
- Disappearing track: isolated, highest p_T, few associated hits in the outer tracking volume(<5 TRT hits)
  - Dedicated tracking using Pixel-only seeds to enhance the short-track rec. efficiency.

Finally look for an excess in the track-p_T spectrum:

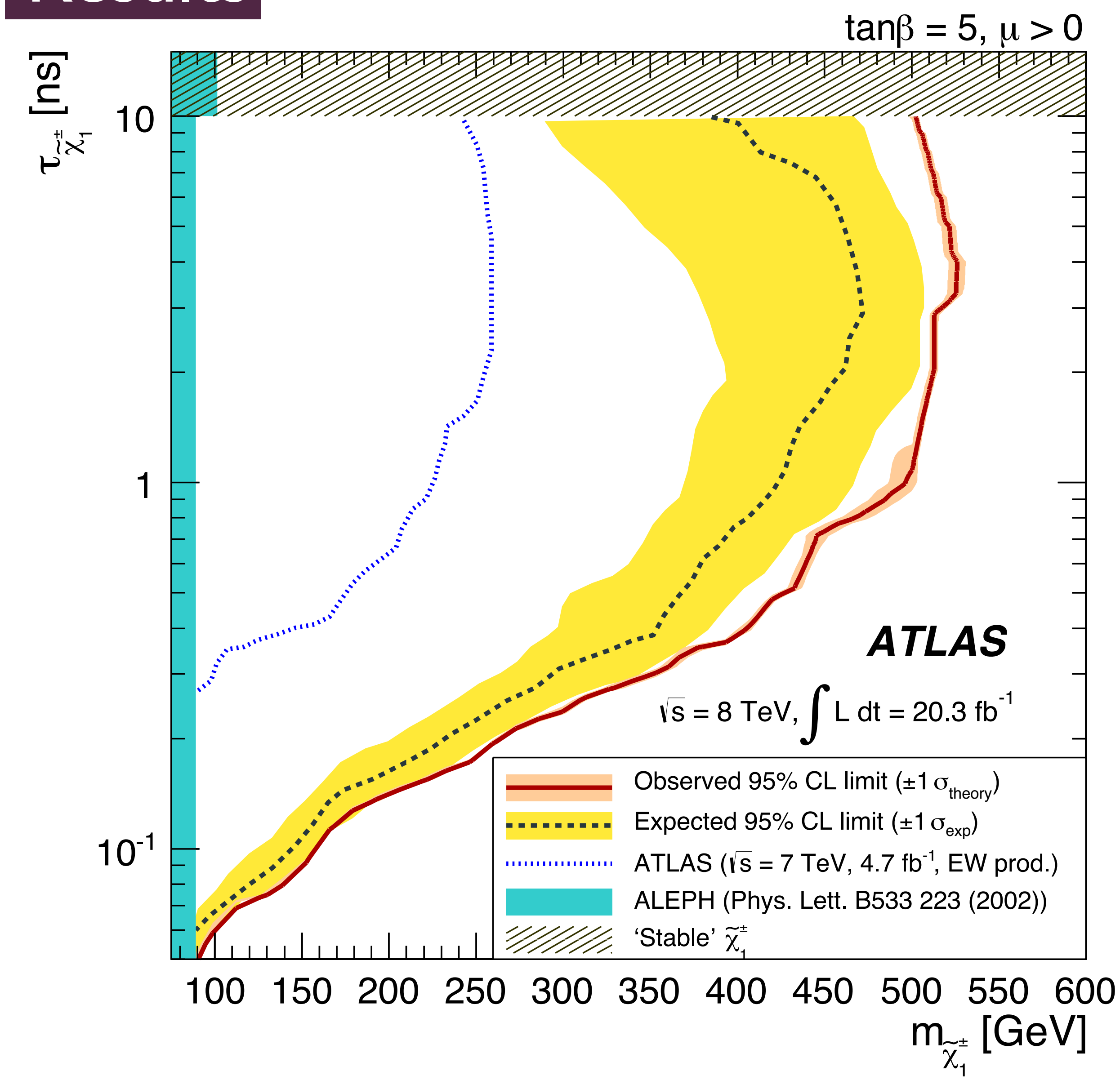
- Backgrounds derived from each control data.
- **No significant excess observed.**

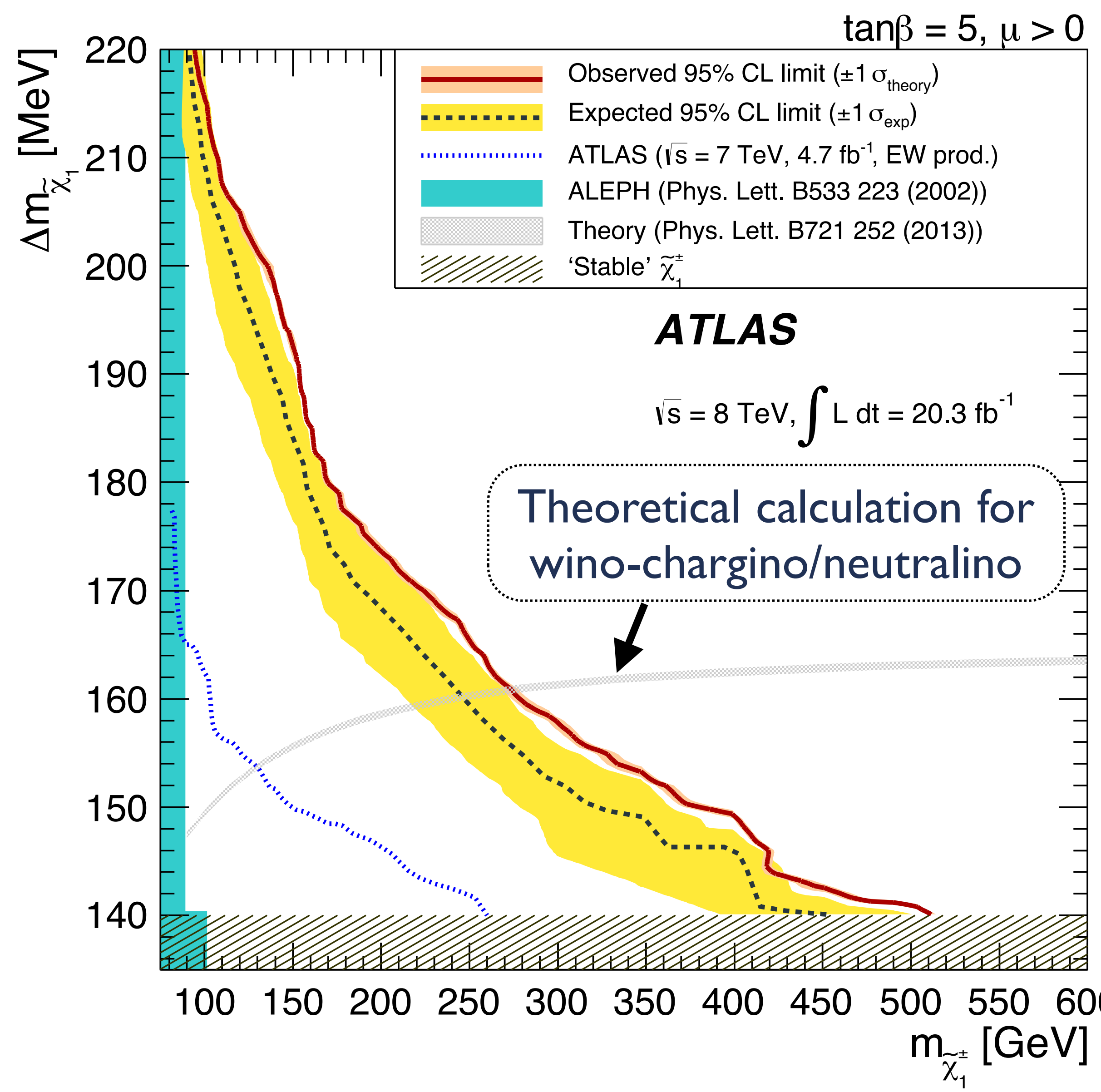




Disappearing track

Results



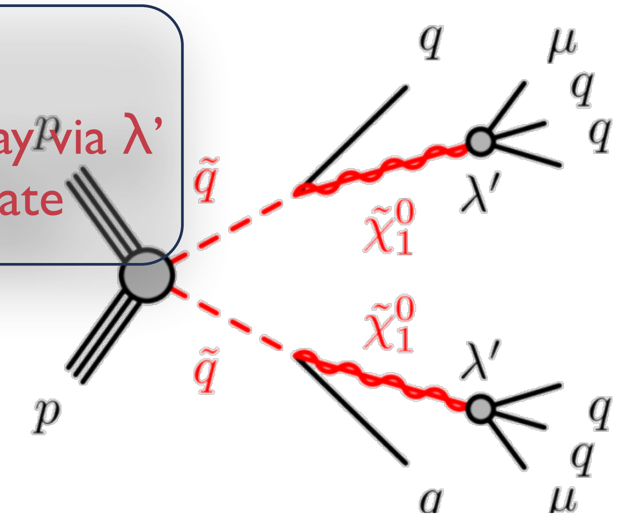


- Chargino mass < 270 GeV excluded.
- Directly constraining the wino dark matter mass.

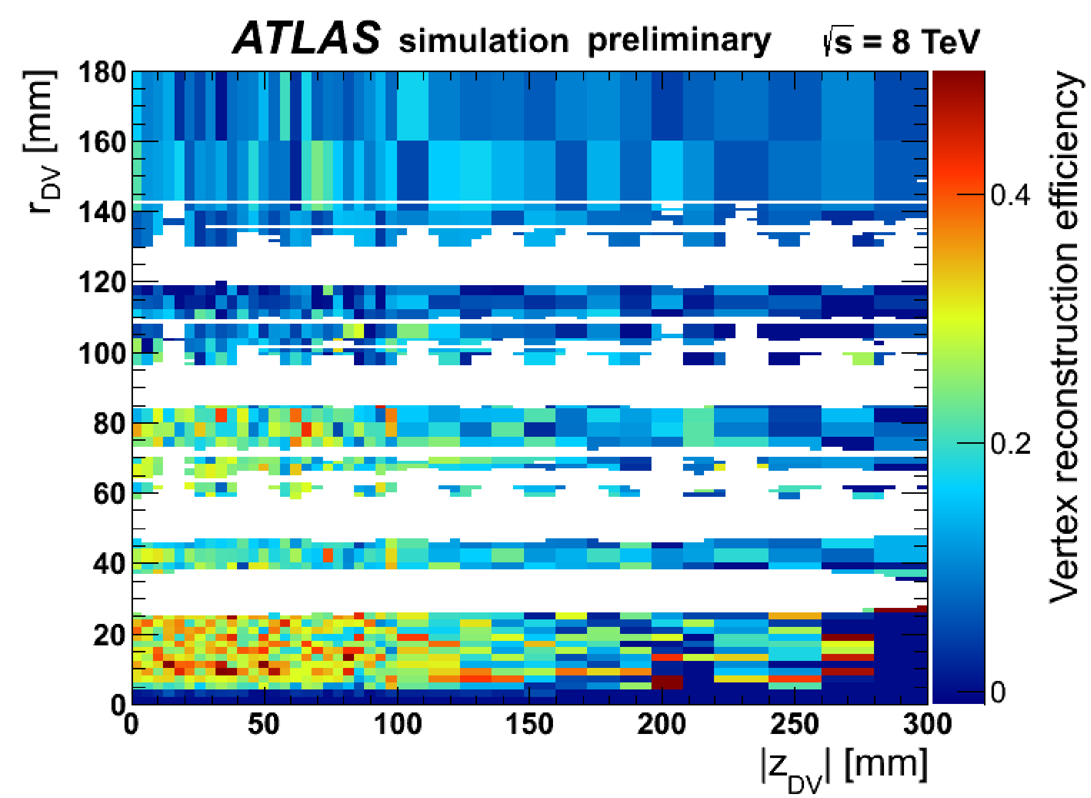
Displaced vertex

- Small RPV couplings result in a significant lifetime of neutralino
  - $\tau \propto (\text{RPV coupling})^{-2}$
- Good displaced-vertex(DV) rec. efficiency for decaying neutralinos thanks to dedicated tracking.
  - Allows large impact parameters.

Benchmark model
- RPV neutralino decay via λ'
- "DV+muon" final state



- Selection:
  - Muon: $p_T(\mu)$>55 GeV, $|\eta|$<1.07, $|d_0|$>1.5mm
  - DV fiducial volume r_{DV}<180mm, $|z_{DV}|$<300mm
  - Veto vertices in detector material layers
  - DV mass > 10GeV
  - Number of tracks in DV > 4

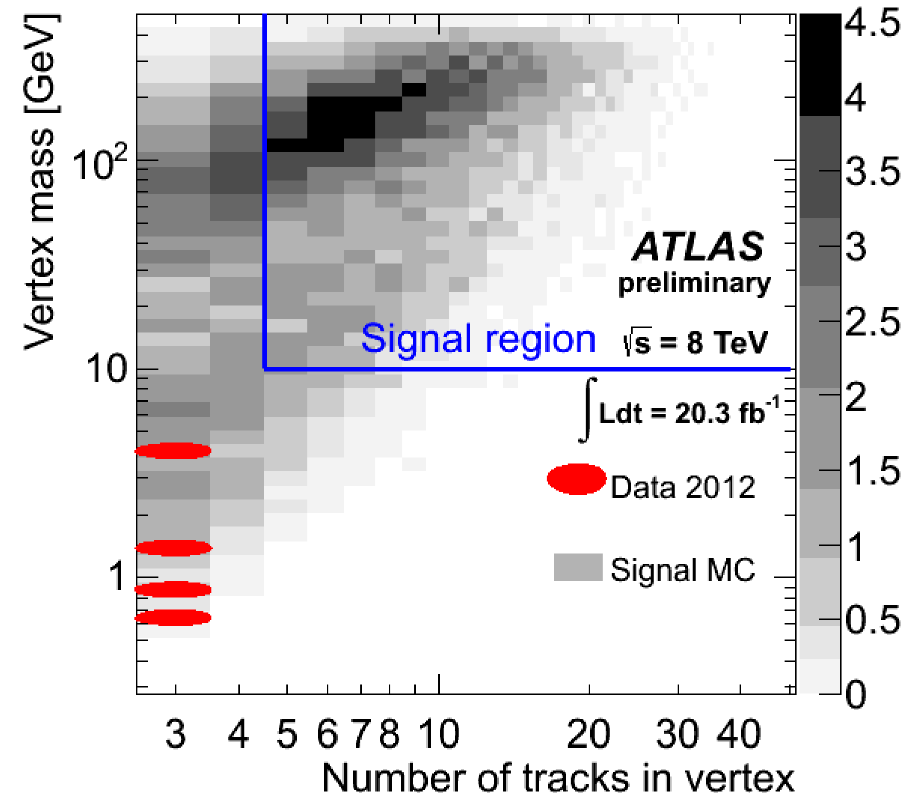


- Small background expected (~0.02 event), estimated in a data-driven way.
  - Hadronic interactions with gas molecules (outside beampipe)
  - Random combinations of tracks

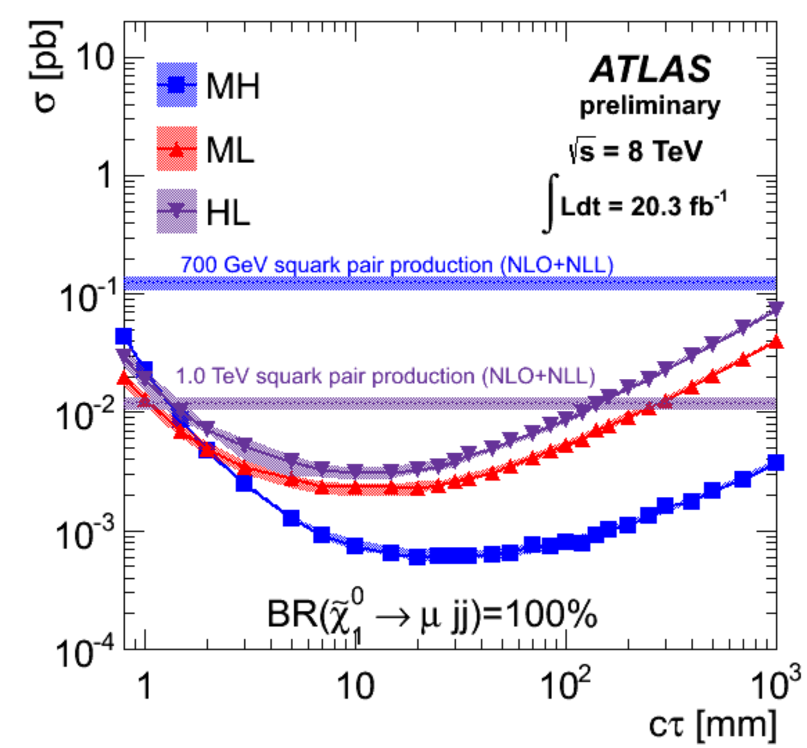
Displaced vertex

Results

- No candidate event observed.
  - A limit of <0.14 fb on the visible cross section
- Interpretations in 3 models with different squark/neutralino masses:
  - for a range of lifetime
  - (assuming 100% branching fraction)



Sample	$m_{\tilde{q}}$ [GeV]	σ [fb]	$m_{\tilde{\chi}_1^0}$ [GeV]	$\langle\gamma\beta\rangle_{\tilde{\chi}_1^0}$	$c\tau_{MC}$ [mm]	λ'_{211}
MH	700	124.3	494	1.0	175	0.2×10^{-5}
ML	700	124.3	108	3.1	101	1.5×10^{-5}
HL	1000	11.9	108	5.5	220	20.0×10^{-5}



Summary

- Various searches for long-lived particles have been performed in ATLAS.
  - Almost all possible signatures/final states being covered.
- "Long-lived particle signatures" fill loopholes in generic BSM searches.
  - Also highly motivated following the current Higgs/SUSY results.
- More updates to come (with 8TeV data), including more final states and BSM scenarios.

Backup slides