The 22nd International Conference on Supersymmetry and Unification of Fundamental Interactions
22 July 2014, Manchester, England

Searches for long-lived particles in ATLAS

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Outline

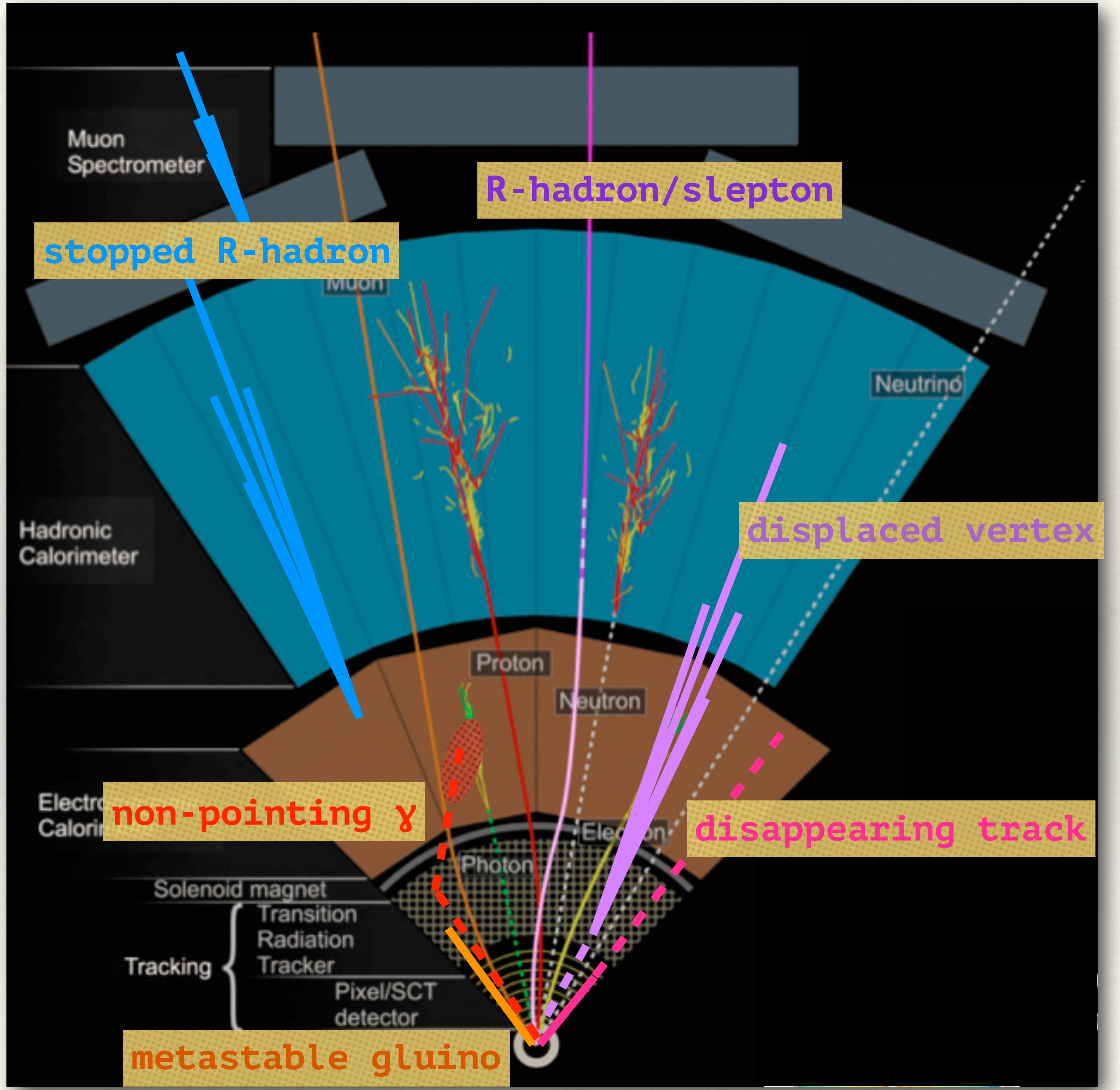
- Long-lived particles signatures
- Highlights of ATLAS searches with 8 TeV (or 7+8 TeV) data:
  - **Displaced vertices**
    ATLAS-CONF-2013-092
  - **Disappearing tracks**
    PRD 88, 112006 (2013)
  - **Heavy long-lived sleptons**
    ATLAS-CONF-2013-58
  - **Long-lived stopped R-hadrons**
    PRD 88, 112003 (2013)
  - **Metastable gluinos**
    ATLAS-CONF-2014-037
- Summary

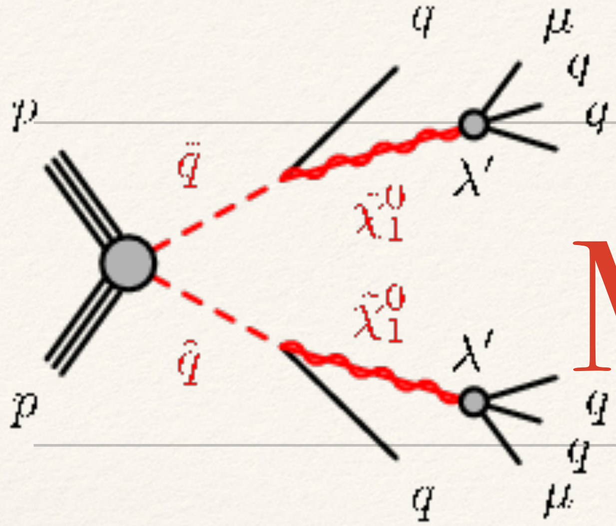
Long-lived particles

- Long-lived particles (**LLPs**) predicted by a number of BSM theories:
  - SUSY models (split SUSY, AMSB, GMSB, RPV scenarios…)
  - non-SUSY models (Hidden Valley, Higgs portal, monopoles, Q-balls, quirks…)
- This talk is focused on LLP searches within SUSY models only
- LLPs can be observable at the LHC: interesting chapter among the SUSY searches
- Their lifetimes can originate from:
  - nearly conserved symmetry
  - low couplings between the particle and its final state
  - mass degeneracy between the particle and its final state
- Different lifetimes —> different signatures in the detector

Examples of LLPs signatures at ATLAS

- ATLAS searches are extensive and exploit at best the different possible signatures of the LLPs, and the peculiar features of each sub-detector
- Displaced vertices —> secondary vertex (RPV)
- Disappearing tracks —> high-p_T isolated tracks, with few associated hits in the outer tracking volume (AMSB)
- R-hadrons, sleptons —> low β, large dE/dx (split SUSY, GMSB, LeptoSUSY)
- Non-pointing photons —> not associated to primary vertex (GMSB)
- Long-lived stopped R-hadrons —> out-of-time decay (split SUSY)
- Metastable gluinos —> decay within the detector with an observable decay length (split SUSY)



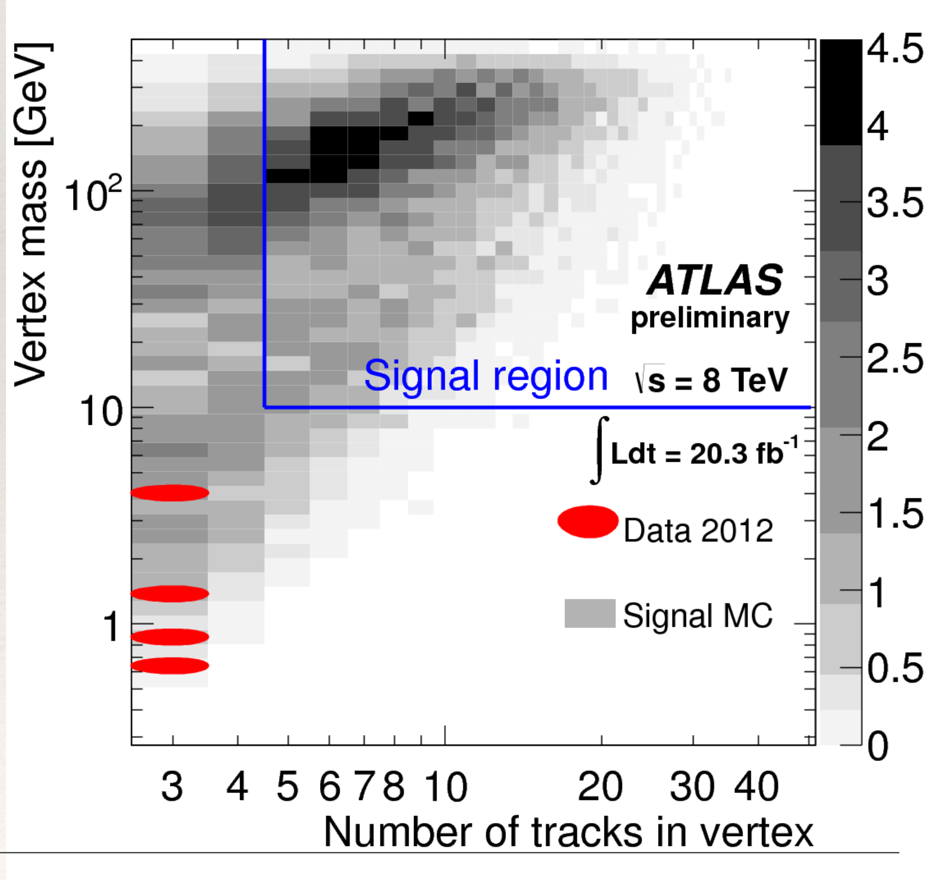


ATLAS-CONF-2013-092

Muon + Displaced vertex

- Small RPV couplings —> significant neutralino lifetime. $\tilde{\chi}_1^0$ —> μ + many charged tracks originating from a displaced vertex (DV). Lifetimes O(ps-ns).
- Selection:
  - high-p_T μ not coming from primary vertex ($|d_0|$>1.5 mm)
  - high-quality tracks: dedicated re-tracking on Inner Detector hits not used for the standard tracking. Not coming from primary vertex ($|d_0|$>2 mm)
    - DV reconstructed from more than 4 selected tracks, and with mass > 10 GeV
    - vertices vetoed in detector material layers
- Signal efficiency (dominated by reconstruction) strongly depends on:
  - neutralino mass (heavier —> larger number of tracks from DV)
  - neutralino boost (more boosted —> more tracks fail $|d_0|$>2 mm)
  - neutralino lifetime
- Backgrounds (expected 0.02±0.02 events):
  - real hadronic interactions with gas outside the beam pipe
  - real or fake random combinations of tracks

8 TeV data



Observation of zero candidates in data
—> UL of 0.14 fb on the visible cross section at 95% CL

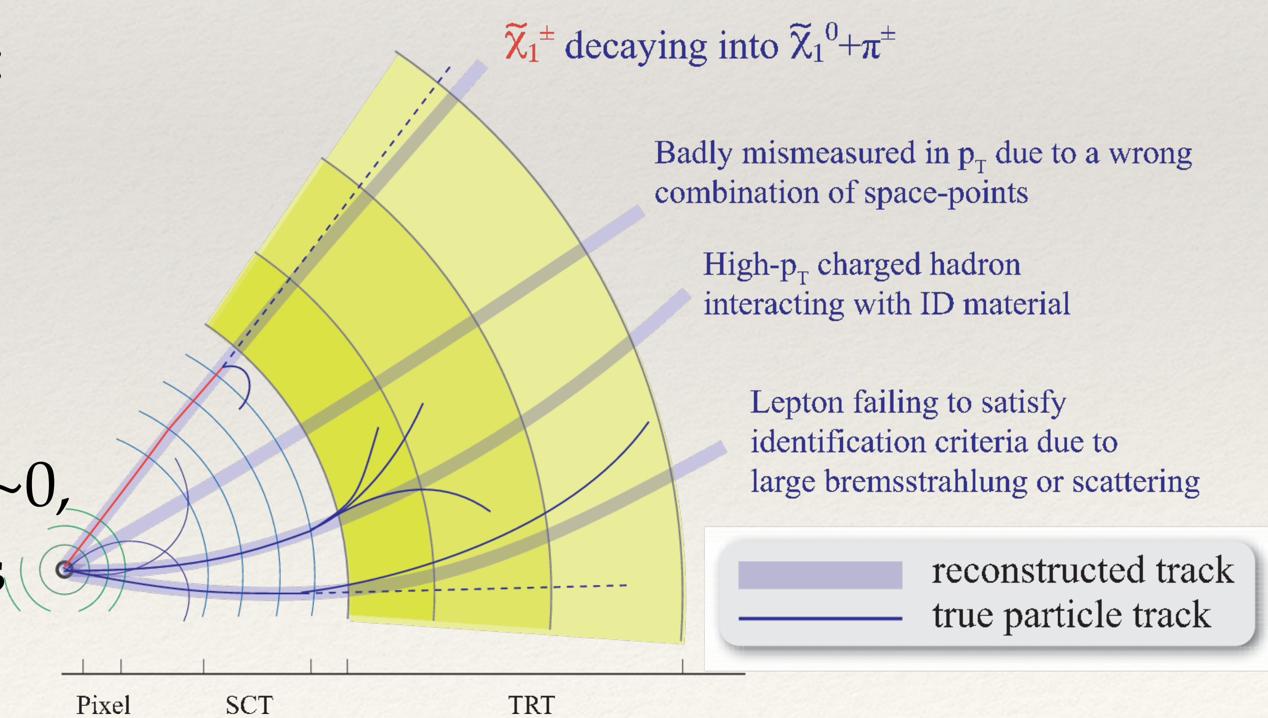
PRD 88, 112006 (2013)

Disappearing tracks

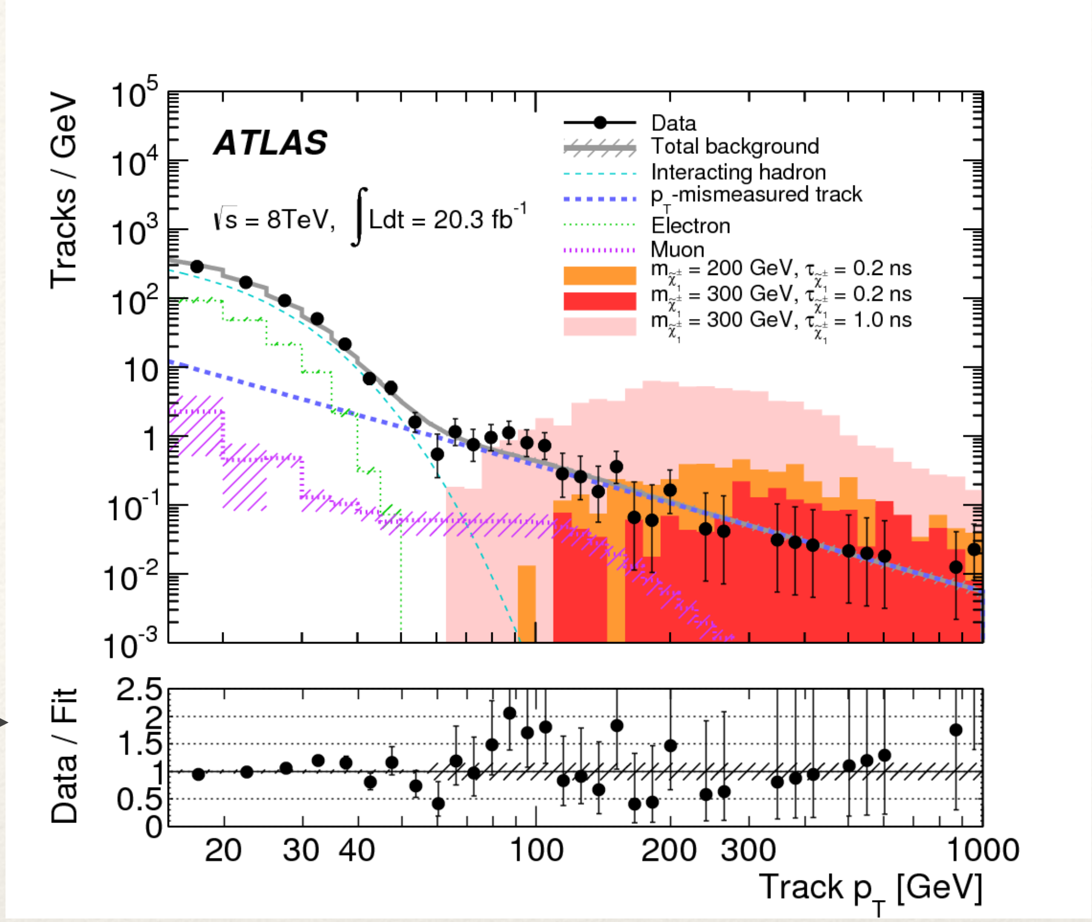
- In AMSB models where the lightest particle is the neutral wino, the mass degeneracy between neutralino $\tilde{\chi}_1^0$ and charginos $\tilde{\chi}_1^\pm$ results in a considerable lifetime (~0.2 ns if $\Delta m(\tilde{\chi}_1^\pm)$~160 MeV)
- Some charginos could have decay lengths of ~10 cm
- When decaying in the sensitive volume, expected to be observed as **high-p_T disappearing tracks**
  - no more than a few associated hits in the outer tracker region
  - $\pi^\pm$ not reconstructed (softly emitted)

$$\tilde{\chi}_1^\pm \rightarrow \tilde{\chi}_1^0 \pi^\pm$$

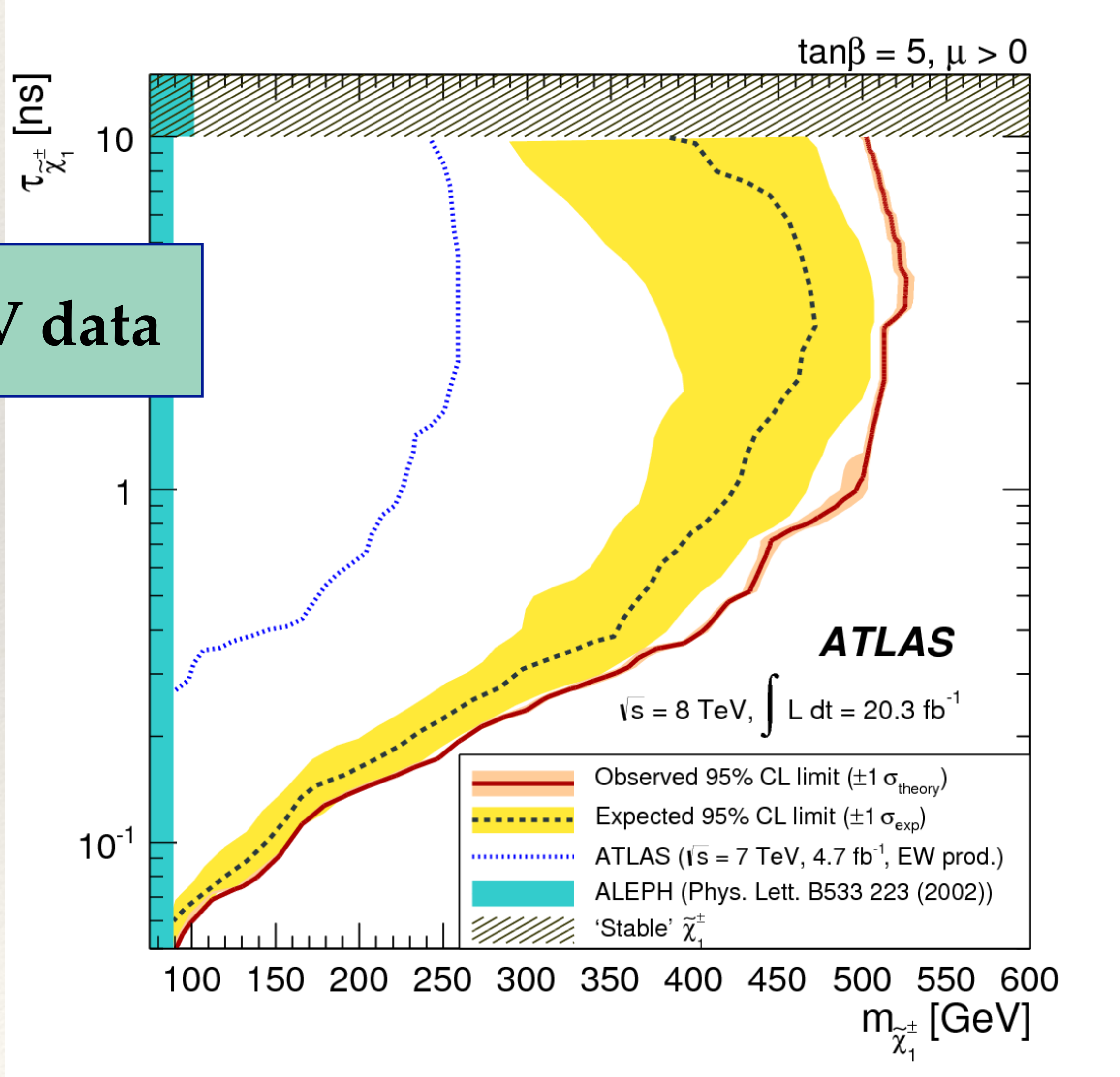
- Makes use of a dedicated topological trigger:
  - at least 1 high-p_T jet + large transverse missing energy (MET) + $\Delta\phi^{jet,MET}$>1 (the smallest azimuthal separation in case of multiple high-p_T jets)
  - suppress SM multijets (peaks at $\Delta\phi^{jet,MET}$~0, since MET comes from mis-measured jets —> aligned with high-p_T jets)



- Makes also use of a <u>dedicated tracking</u>, using Pixel-only seeds in order to enhance the short track reconstruction efficiency
- Backgrounds (estimated from data):
  - interacting hadrons
  - non-identified prompt leptons
  - mis-measured low-p_T charged tracks
- Looking for an excess in the track p_T spectrum →



8 TeV data



- No significant excess observed
- Limits in terms either of chargino lifetime (shown here), or of chargino-neutralino mass splitting

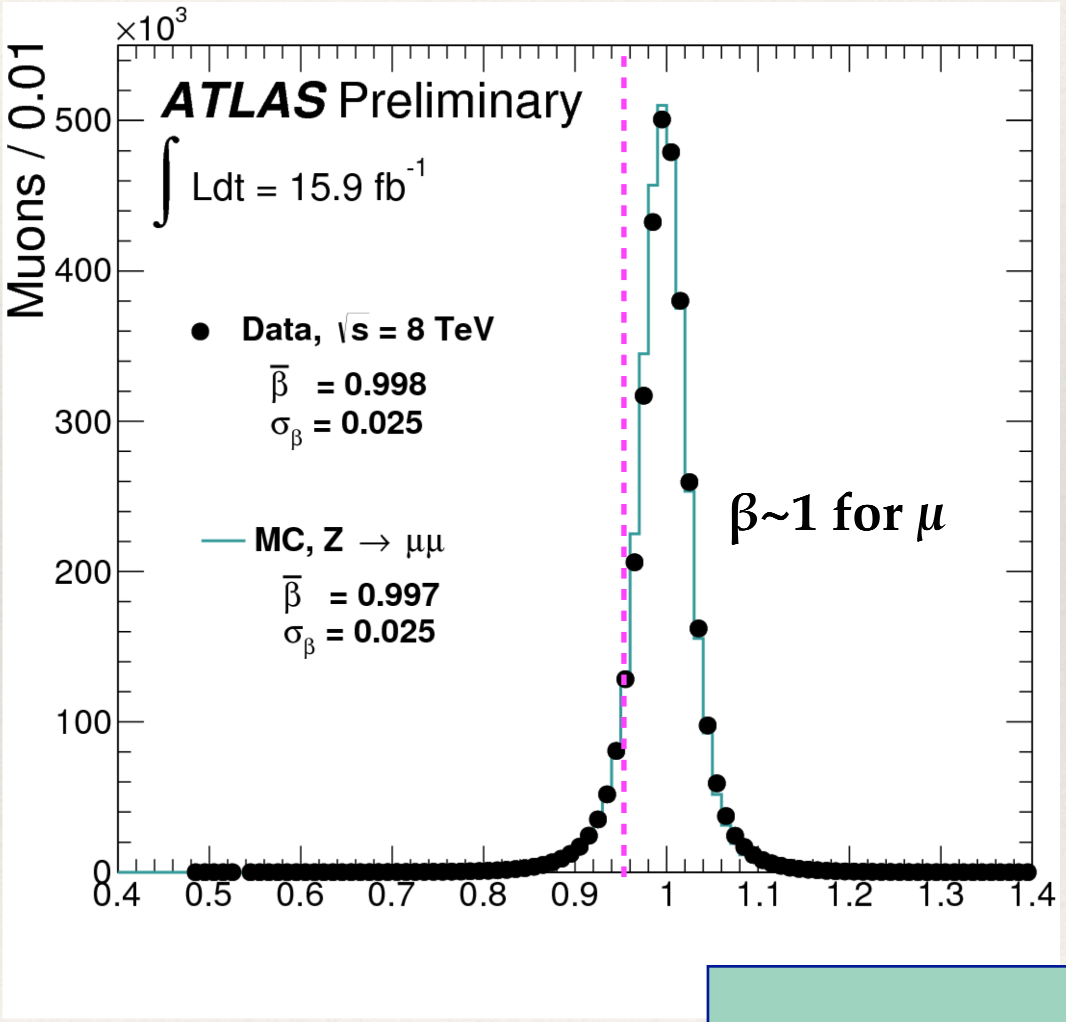
Excluded charginos with **m<270 GeV** (and τ~0.2 ns) at 95% CL

ATLAS-CONF-2013-58

Heavy long-lived sleptons

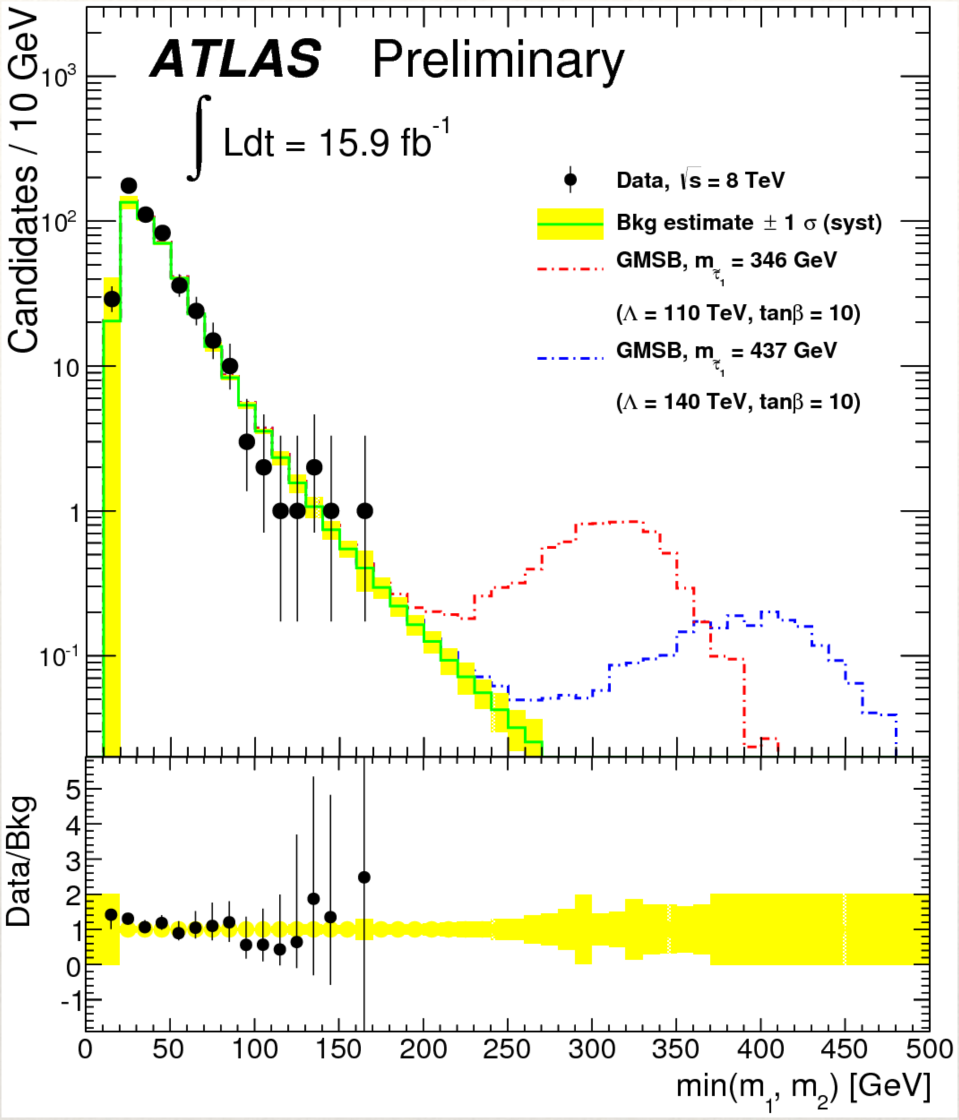
- In GMSB models with stau as the next to lightest SUSY particle, and the scale factor for the gravitino chosen such that stau does not decay in the detector
- Slow-moving particles —> time-of-flight from calorimeters and muon detectors (β) and specific ionization loss from Pixel (βγ) allow mass measurement
    - good detector calibrations are crucial
    - consistency of the observables between and within the different sub-detectors

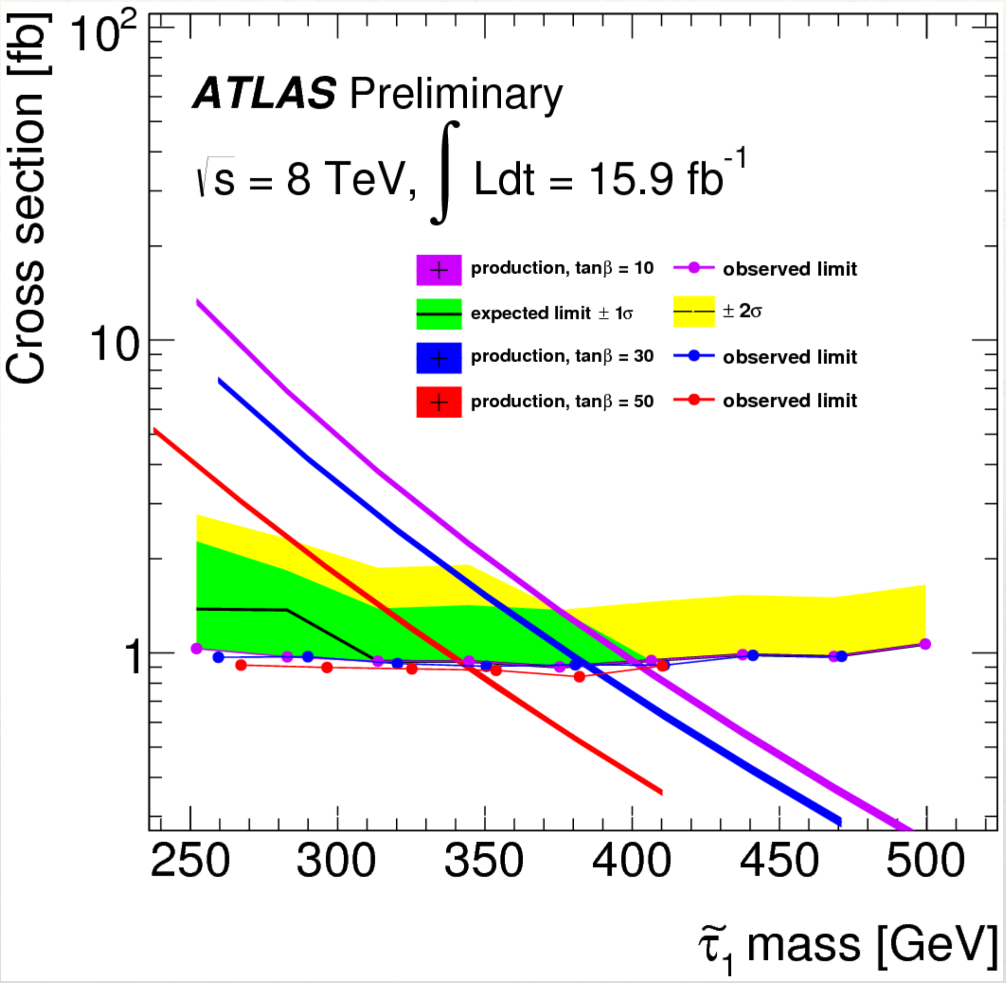
	sleptons
Model	**GMSB stau**
Trigger	single μ
Signal regions	1. 2 candidates with pT>50 GeV and β<0.95 (*loose selection*) 2. 1 candidate pT>70 GeV and β<0.95 (*tight selection*). Used to assess systematics



8 TeV data

- Background: high-p_T μ with mis-measured β and/or large ionization. Data-driven estimate.
  - **No excess above background expectations**





	95% CL limit
GMSB staus	$m(\tilde{\tau}) > 402$ - 347 GeV(for $\tan\beta=5$ - 50)

[PRD 88, 112003 (2013)](#)

Long-lived stopped R-hadrons

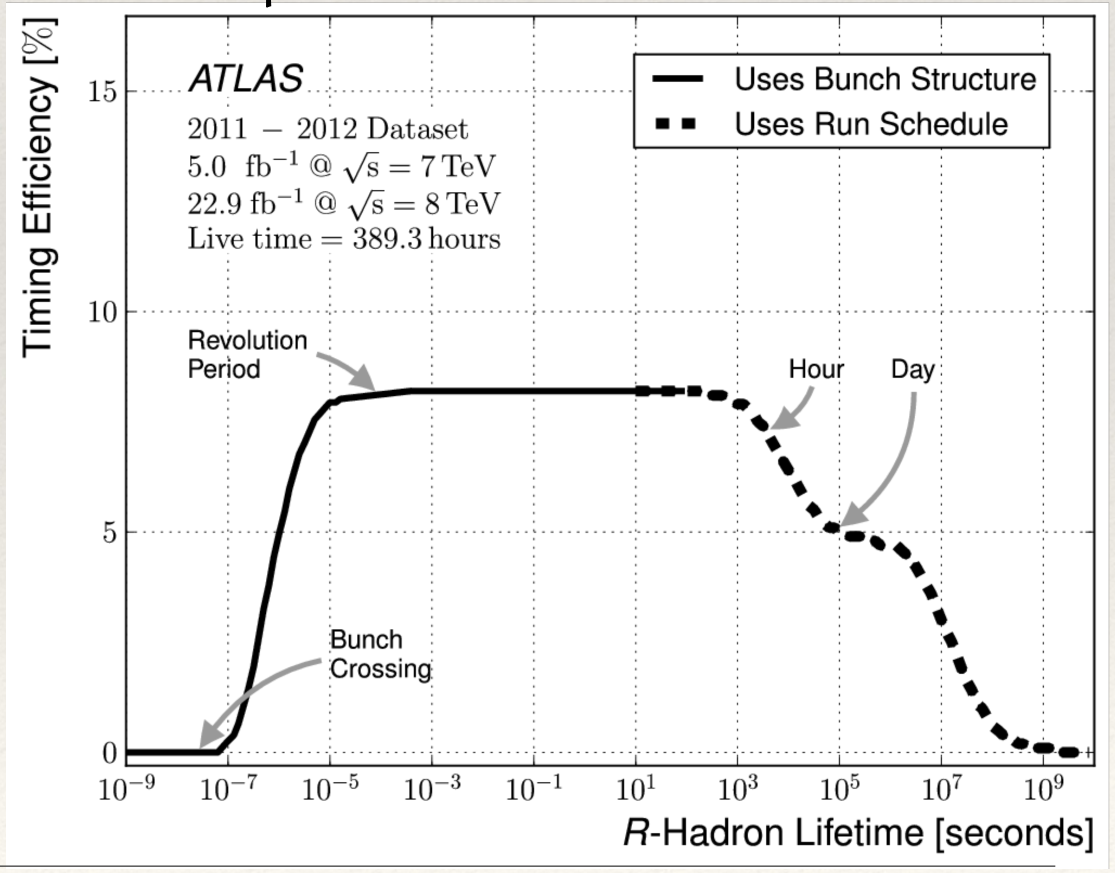
- R-hadrons are bound states composed of a squark or a gluino + light SM quarks and gluons (split SUSY models)
- R-hadrons produced in collisions may stop in the calorimeter, decaying (to a neutralino + hadronic jets) at some later time not associated with colliding bunches
- Look for energetic jets
- Small background from cosmics, noise and beam halo interactions
- Complementary to long-lived searches (less sensitive to initial β<<1)
- Relies primarily on calorimetric measurements
—> sensitive to charge-flipped R-hadrons

$$\epsilon = \epsilon_{stop} \times \epsilon_T(\tau) \times \epsilon_{reco}$$

stopping fraction

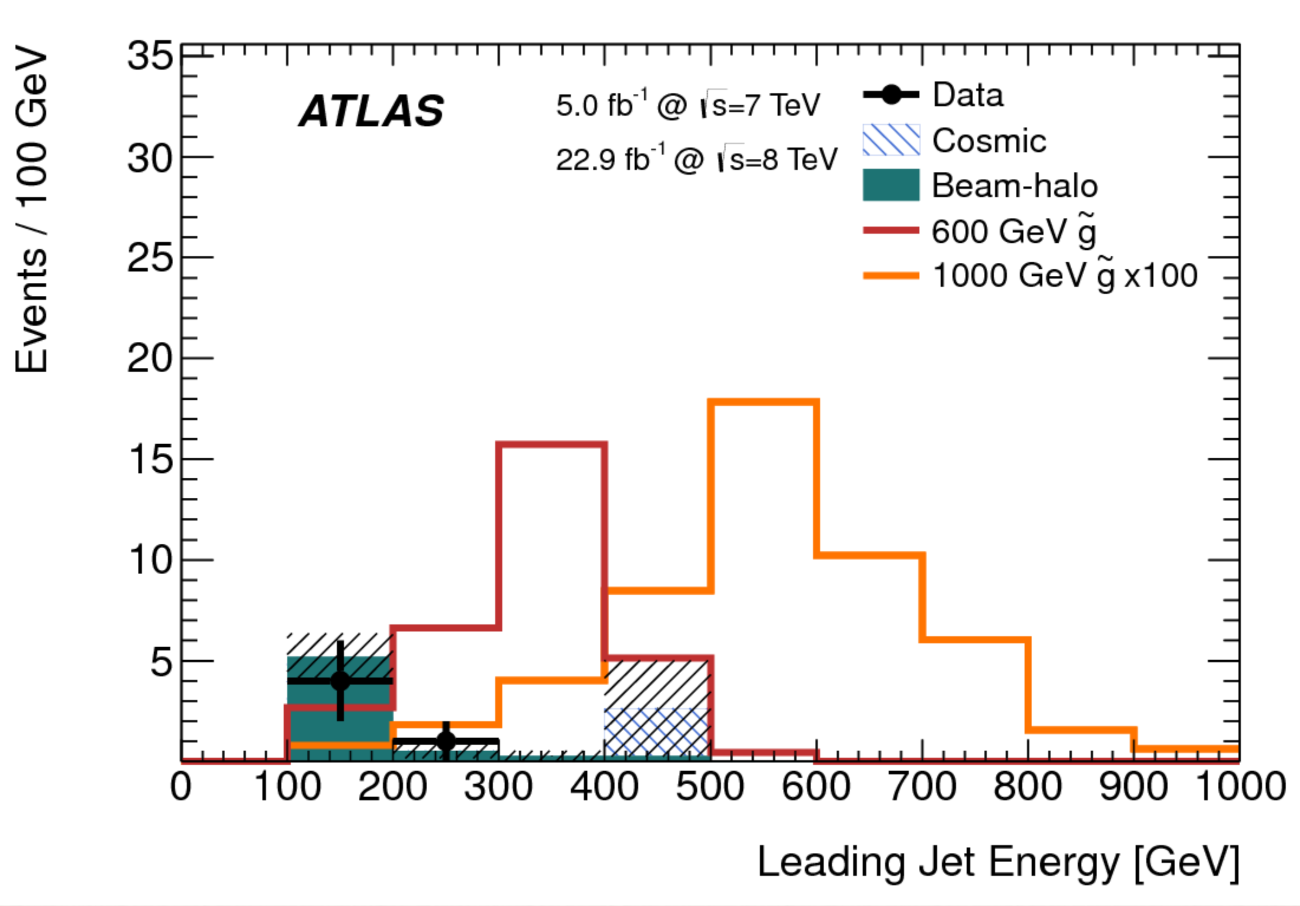
timing acceptance (probability that the decay occurs in an empty crossing)

reconstruction efficiency



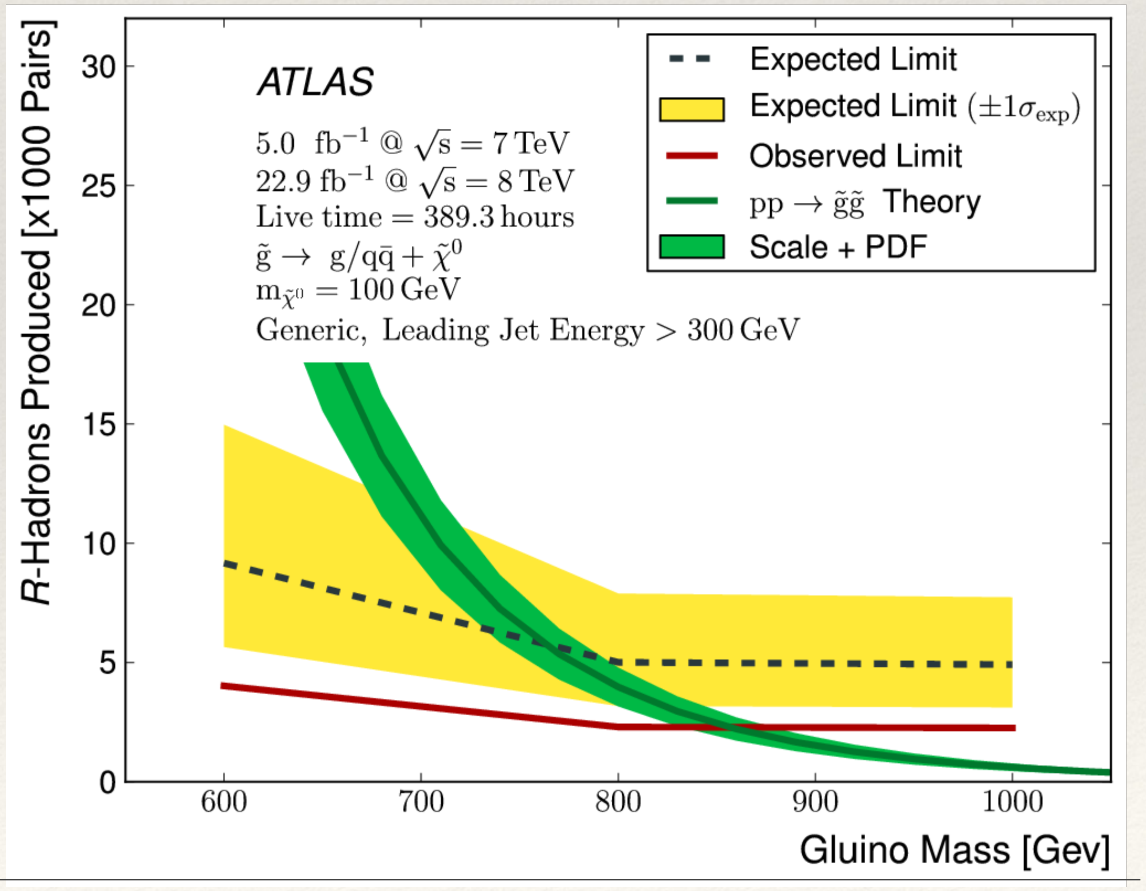
7+8 TeV data

- Events selected in empty bunches
- Large calorimetric activity: leading jet energy > 100 (300) GeV
- Events with muon segments reconstructed vetoed (rejects cosmics)
- Events with spike-like signals in the calorimeter vetoed (rejects random noise & beam halo)



- Background estimated using low-luminosity data (cosmics) and unpaired crossings (beam halo)
- No excess observed

For $\tau=10^{-6}$- 10^{3}s and $m(\tilde{\chi}^0)$=100 GeV, at 95% CL:
$m(\tilde{g})$>832 GeV



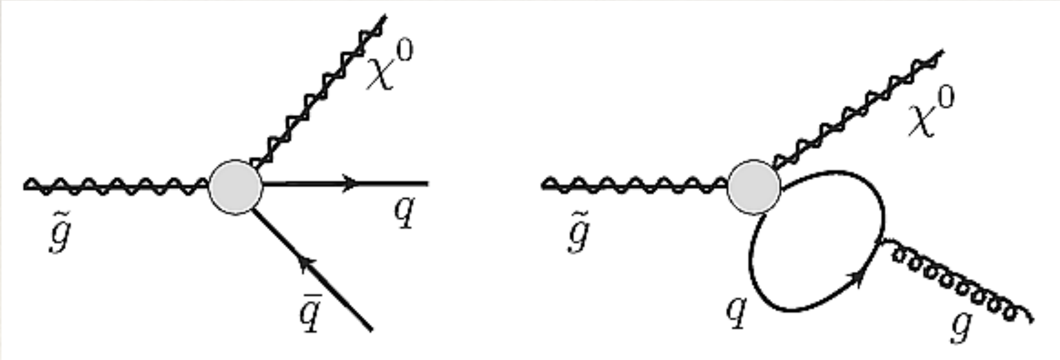
- Limits with different R-hadron decays and interaction models (—> different stopping fractions) also given
- Limits for stop and sbottom also given

8 TeV data

Metastable gluinos

ATLAS-CONF-2014-037

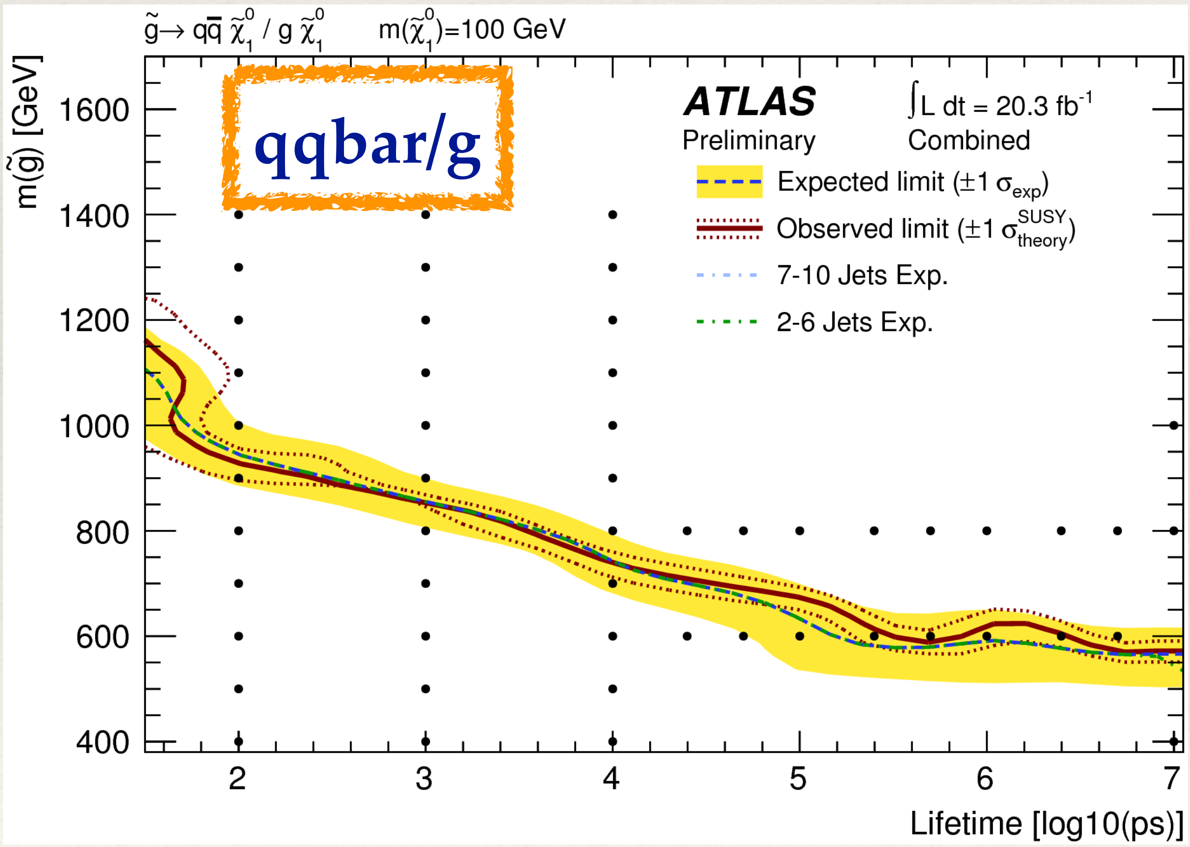
- Previous searches for gluinos assumed either prompt decays or very long lifetimes (to escape or stop inside the detector)
- ATLAS searches for promptly decaying gluinos are also sensitive to intermediate lifetimes not considered so far —> complementary to other ATLAS long-lived searches
- Analyses re-interpreted:
  - b-jets + MET (*displaced jets from metastable gluinos identified as b-jets*) —>"2-6 jets" analysis [arXiv:1405.7875]: 19 signal regions based on [7,8,9,≥10] jets, [0,1,≥2] b-jets and MET
  - high-energy jets + MET (*metastable gluino decaying before the calorimeters*) —> "7-10 jets" analysis [JHEP 1310, 130 (2013)]: 15 signal regions based on [2,3,4,5,≥6] jets and MET
- Two decay models considered:

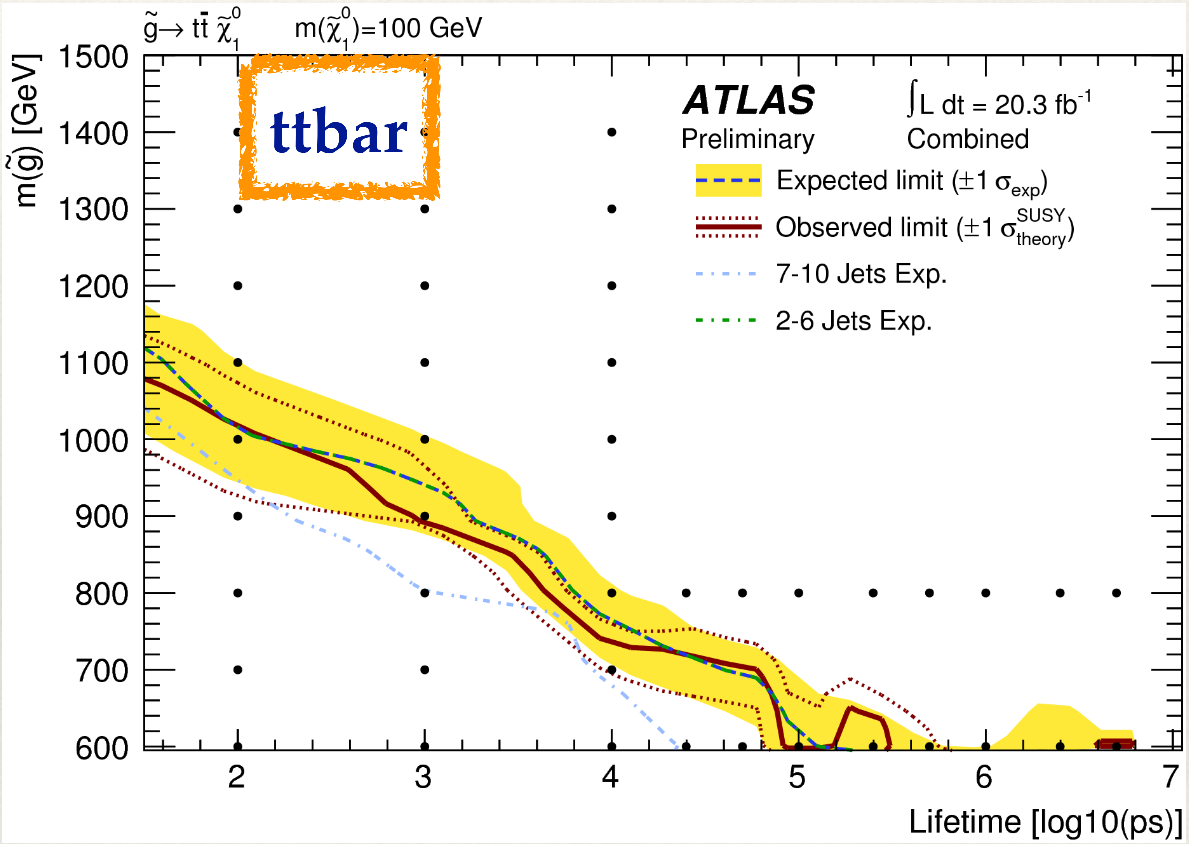


$\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$ *dominant if stop is the lightest squark*

$\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^0, g\tilde{\chi}_1^0$ *(with q≠t) if squarks masses are degenerate*

- "7-10 jets" analysis has no sensitivity to $q\bar{q}/g$ decays (this model leads to a relatively small jet multiplicity)
- Both analyses have a good sensitivity to $t\bar{t}$ decays
- Jet multiplicity (and therefore sensitivity) decreases with lifetime
- <u>Limits as a function of the gluino lifetime</u> on:
  - neutralino mass for gluino masses = 600, 800 GeV
  - gluino mass for neutralino mass = 100 GeV, or in a compressed scenario (close to gluino mass)





For τ=1ns and m($\tilde{\chi}^0$)=100 GeV, at 95% CL:
m($\tilde{g}$)>850 GeV for qqbar/g decays
m($\tilde{g}$)>900 GeV for ttbar decays

Summary

- Extensive searches for long-lived particles in ATLAS
- Peculiar capabilities of each sub-detector are exploited, looking for different signatures
- Dedicated reconstruction techniques developed for some of these searches
- A set of new updates on 8 TeV (and 7+8 TeV) data has been shown
- No evidence of excess above expected backgrounds found so far
- More results in the pipeline: stay tuned!

Backup

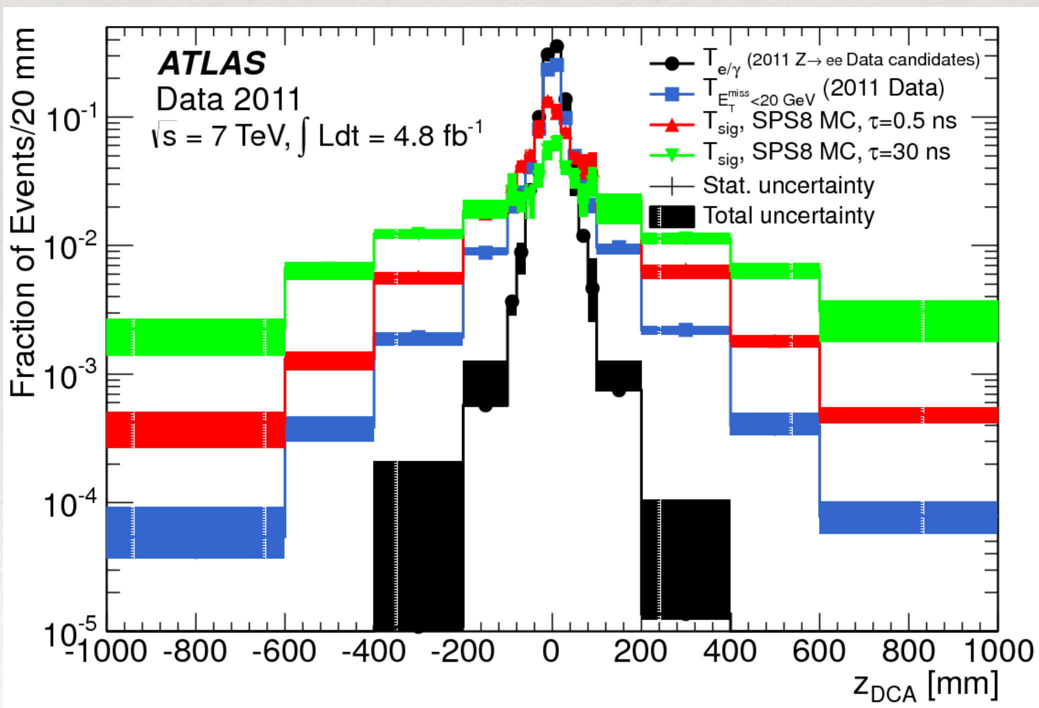
[PRD 88, 012001 (2013)](#)

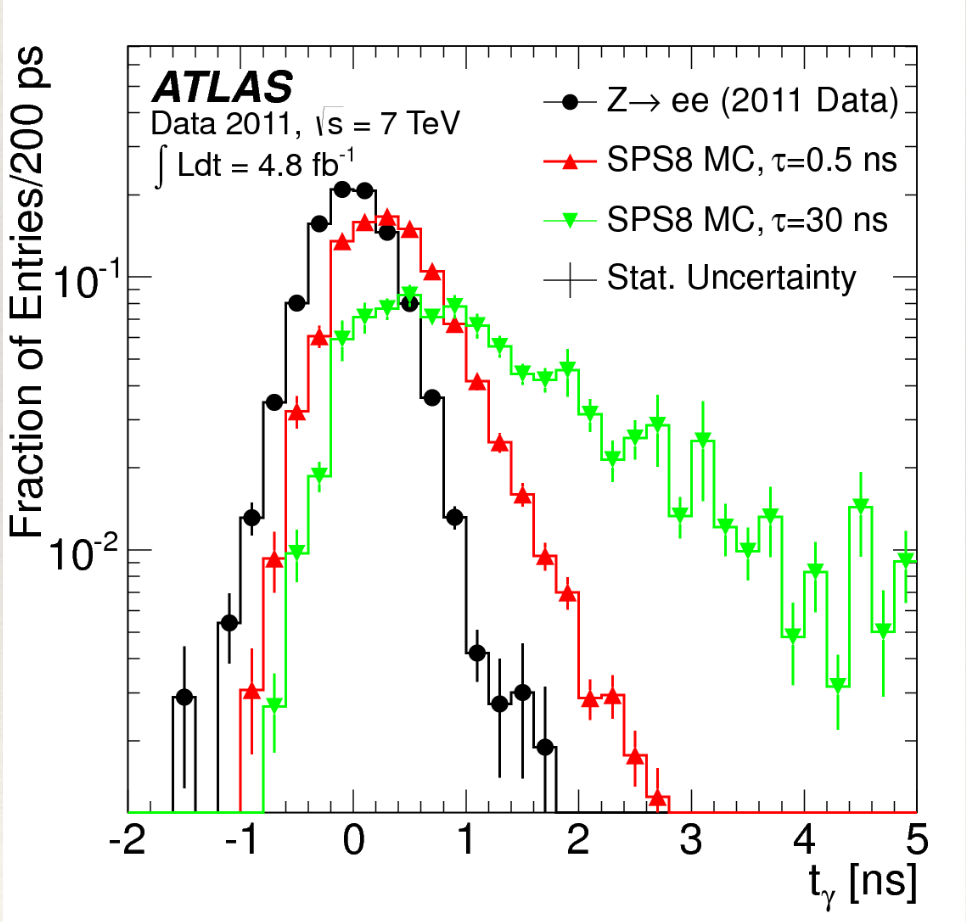
Non-pointing photons

$\tilde{\chi}_1^0 \rightarrow \tilde{G}\gamma$

- In the context of GMSB models, neutralino may decay to a photon + a gravitino with a lifetime in the range 250 ps - 100 ns
- Exploits EM calorimeter: precise measurements of the flight direction (pointing measurement) and of the time-of-flight (timing measureament) of photons
- Search for MET (from the escaping gravitino) along with pairs of high-energy photons (E_T>75 GeV) not pointing back to primary vertex
  - crosscheck with any evidence of late photon detection

7 TeV data





- Backgrounds: prompt photons, electrons or jets mis-identified as photons
  - prompt photons modeled on Z—>e^+e^- events (similar pointing and timing resolutions)
  - jet background estimated from a data control sample with low MET (contains jets with properties as in the signal region, but signal free)
- No excess over SM expectation found
- Exclusion limits in the plane of neutralino lifetime $\tau(\tilde{\chi}^0{}_1)$ vs. the effective scale of SUSY breaking Λ:
  - $0.25 < \tau(\tilde{\chi}^0{}_1) < 50.7$ (2.7) ns excluded for $\Lambda = 70$ (160) TeV