Searches for long lived supersymmetric particles with the ATLAS detector

Helen Hayward on behalf of the ATLAS collaboration

Long-lived SUSY particles

R-parity violating:

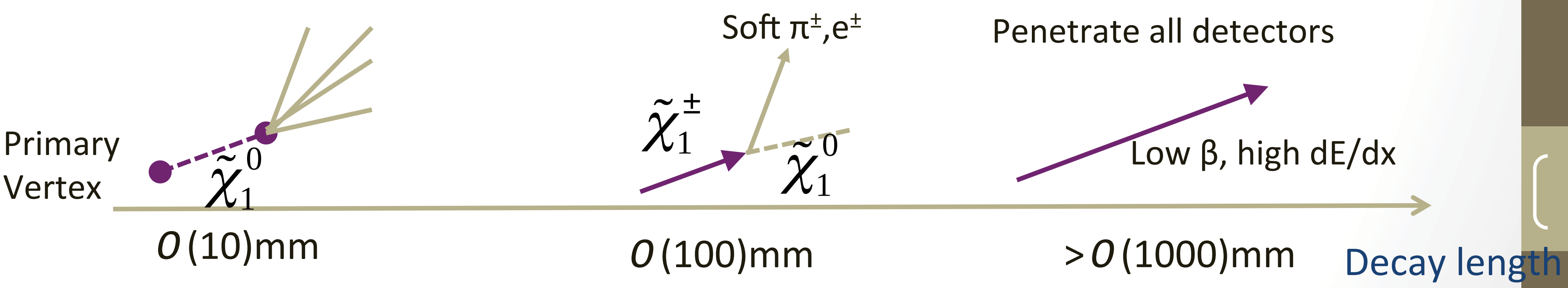
$$W_{RPV} = \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \kappa_i L_i H_2 + \lambda''_{ijk} \bar{D}_i \bar{D}_j \bar{D}_k$$

If $\lambda, \lambda', \lambda''$ are small, LSP can have a long lifetime.

(lifetime proportional to $\lambda^{-2}, \lambda'^{-2}, \lambda''^{-2}$)

R-parity conserving:

- $\Delta M(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^{0})$ ~ 100 MeV, e.g. AMSB: long lived chargino
- Long-lived gluino due to very heavy squarks mediating its decay : Rhadrons
- Weak coupling NLSP-gravitino in GMSB : long-lived sleptons, or neutralino
  - (neutralino can decay to photon or Z-boson)



We are sensitive to a large range in lifetimes!

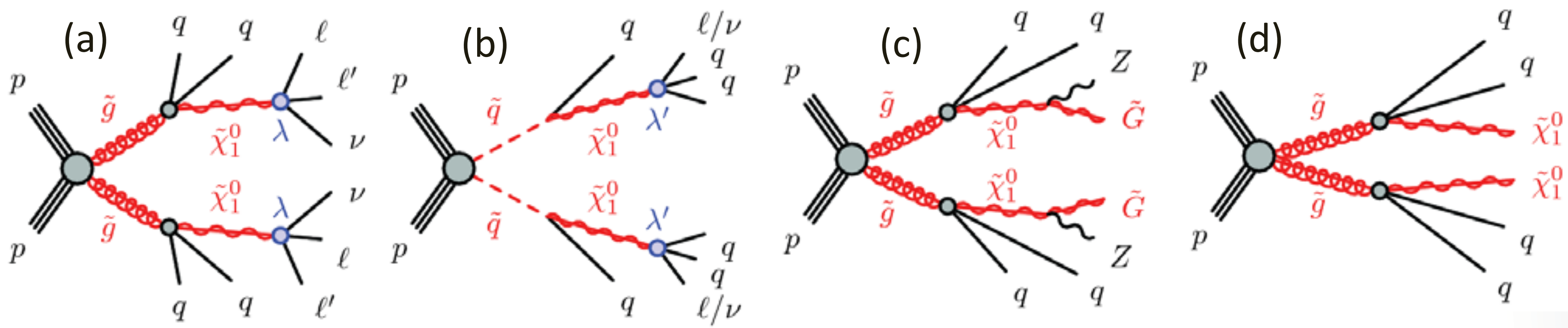
Outline

Lifetime

Displaced Vertices	8TeV	20.3	Preliminary New!
Displaced Hadronic Jets	8TeV	19.5 and 20.3 fb^{-1}	Preliminary New!
Pixel detector dE/dx	8TeV	18.4	ATLAS-CONF-2015-013 New!
Disappearing Track	8TeV	20.3fb^{-1}	Phys. Rev. D 88, 112006 (2013)
Re-interpretation of prompt jets+MET analyses	8 TeV	20.3fb^{-1}	ATLAS-CONF-2014-037
non-pointing and delayed photons	8TeV	20.3fb^{-1}	Phys. Rev. D. 90, 112005 (2014)
heavy long-lived particles	8TeV	19.1fb^{-1}	JHEP01 (2015) 068
long-lived stopped R-hadrons	7+8 TeV	5.0 and 22.9 fb^{-1}	Phys. Rev. D 88, 112003 (2013)

New!

Displaced Vertices



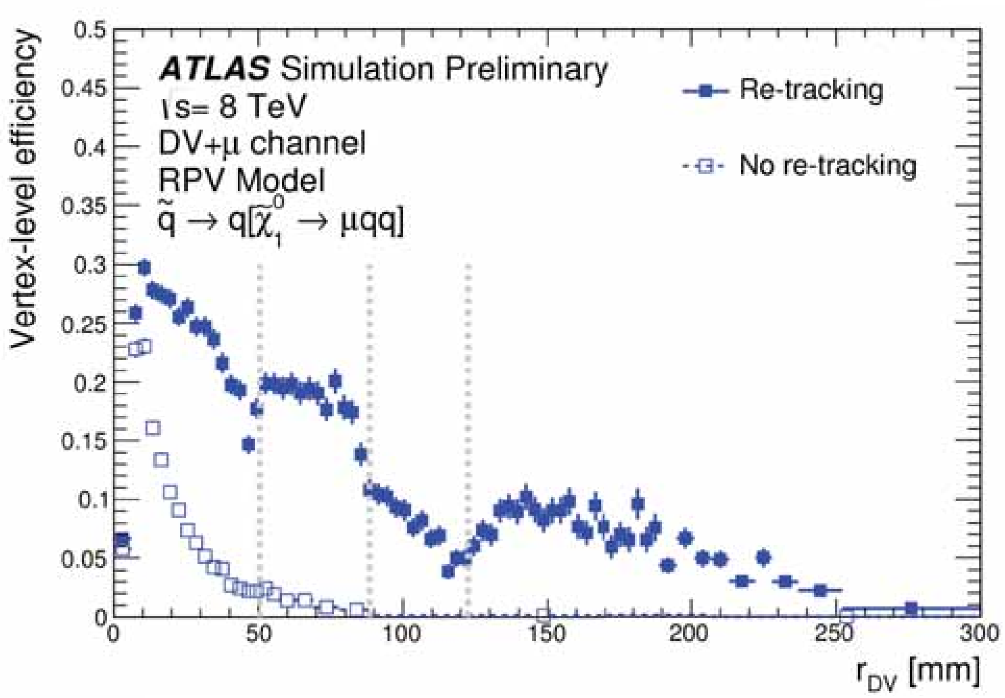
- Motivated by many theories:
  - R-parity violating SUSY – neutralino decays via λ, λ' or λ'' couplings (a, b)
  - GGM – Long-lived neutralino decaying to gravitino and Z (c)
  - Split SUSY – Long-lived gluinos (d)
- Search for a displaced vertex (DV) in the region of the inner detector: z<300 mm, r<300 mm

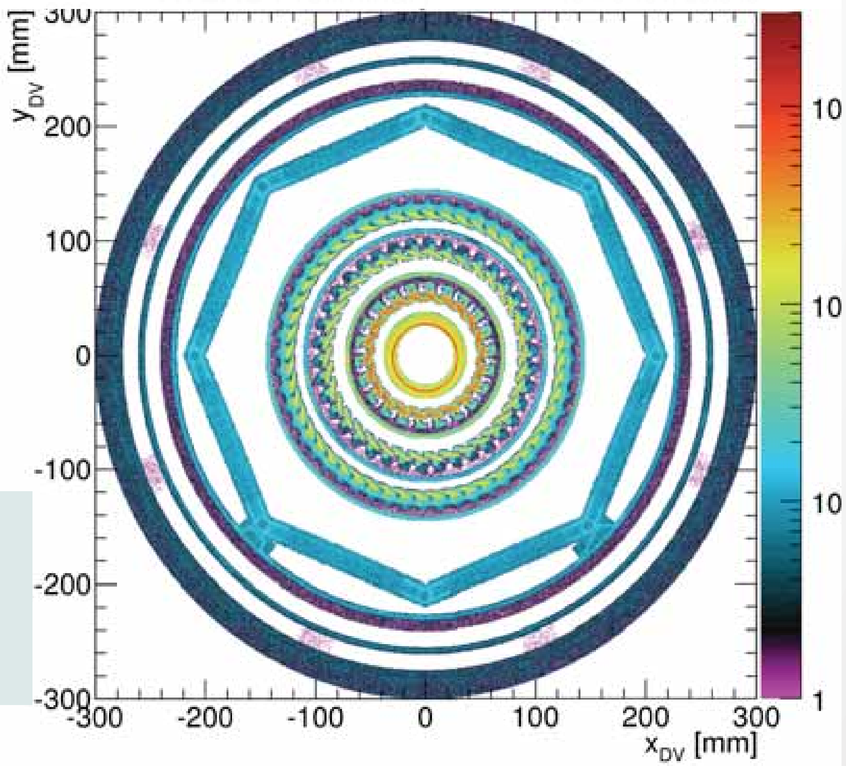
- Two types of searches:
  - A "multi-track" search: DV+μ, DV+e, DV+jets, DV+MET
  - A "di-lepton" search: μμ, ee, μe (opposite charges)

New!

Displaced Vertices

- Re-run tracking to find tracks with large d0
  - Default tracking uses d0<10mm
- Veto vertices in material layers (3D material map)
  - Other appropriate selection depending on the channel
- Signal Region
  - DV mass > 10 GeV
  - Number of track in DV > 4 (for multi-track)





Transverse-plane density of vertices regions that are excluded by the material veto.

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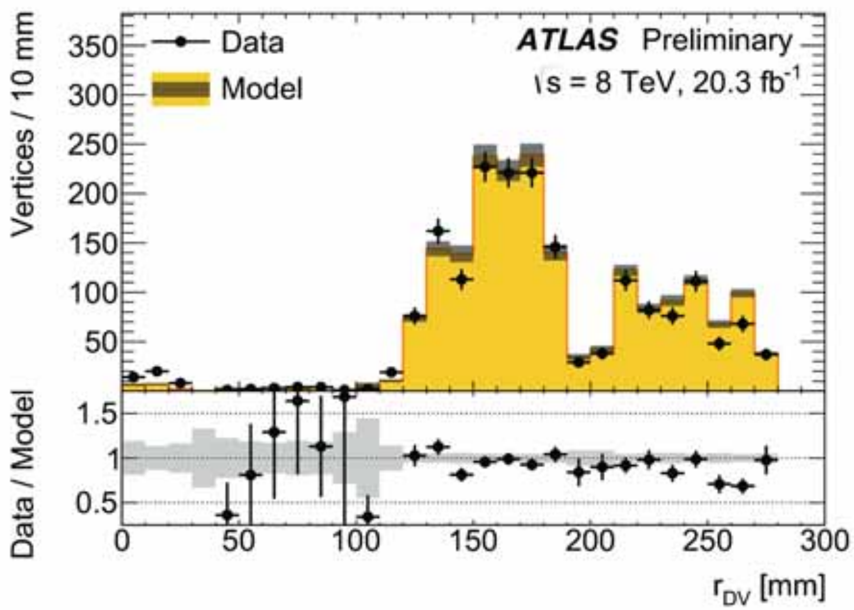
New!

Displaced Vertices

- vertex position radius for vertices composed of two non-lepton tracks



- Main source of background:
  - Low mass DV's that are crossed by an unrelated high-pT track at a large angle, making their reconstructed mass seem high (multi-track)
  - Two unrelated leptons crossing close enough for the vertexing method to combine (di-lepton)
- Data driven methods of estimation

Channel	No. of background vertices ($\times 10^{-3}$)
e^+e^-	$1.0 \pm 0.2\ ^{+0.3}_{-0.6}$
$e^\pm\mu^\mp$	$2.4 \pm 0.9\ ^{+0.8}_{-1.5}$
$\mu^+\mu-$	$2.0 \pm 0.5\ ^{+0.3}_{-1.4}$

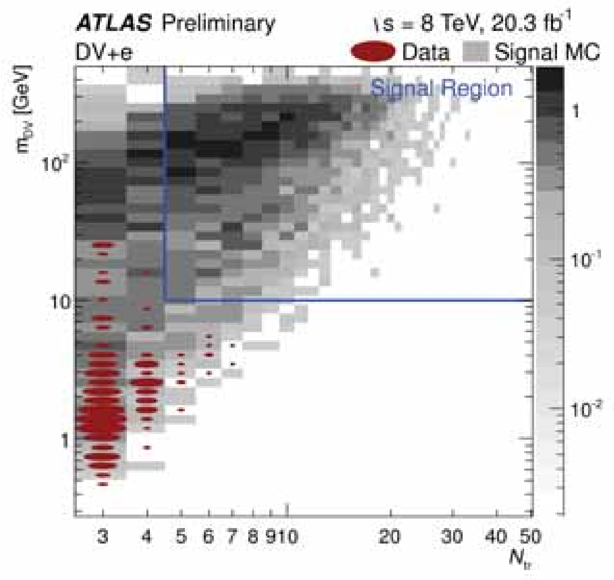
Channel	No. of background vertices ($\times 10^{-3}$)
DV+jet	$410 \pm 7 \pm 60$
DV+E_T^{miss}	$10.9 \pm 0.2 \pm 1.5$
DV+muon	$1.5 \pm 0.1 \pm 0.2$
DV+electron	$207 \pm 9 \pm 29$

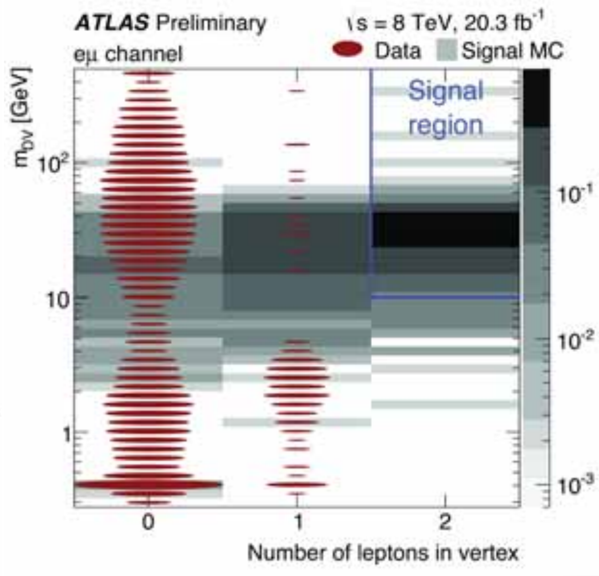
New!

Displaced Vertices

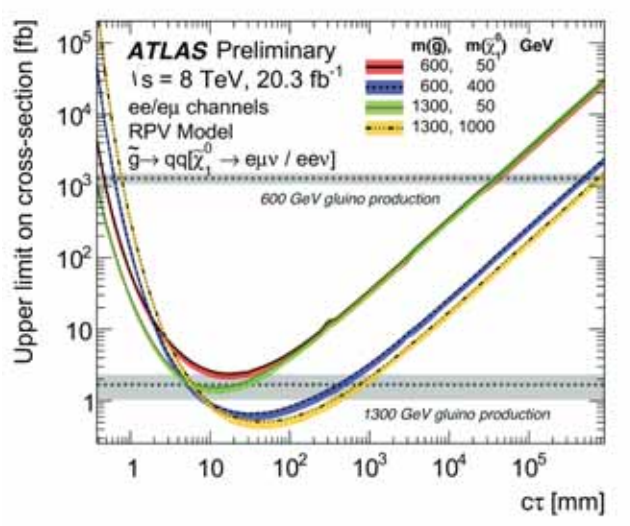
With **no events observed in any signal region**, we set upper-limits on the signal yields and production cross-sections as a function of the LLP proper lifetime cτ

- For Split SUSY also limits on the gluino mass vs. cτ

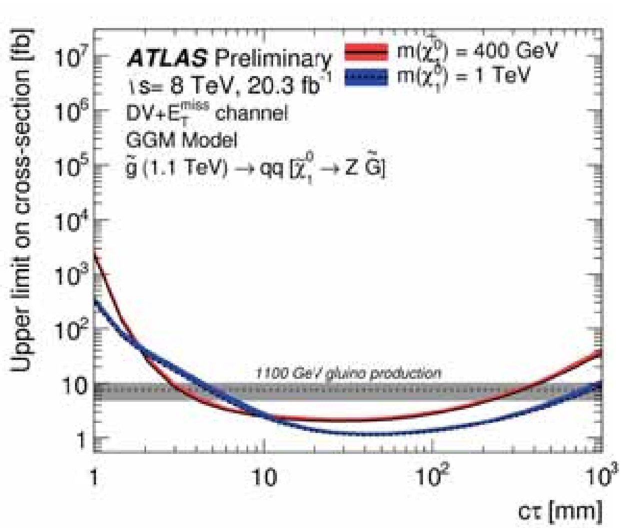




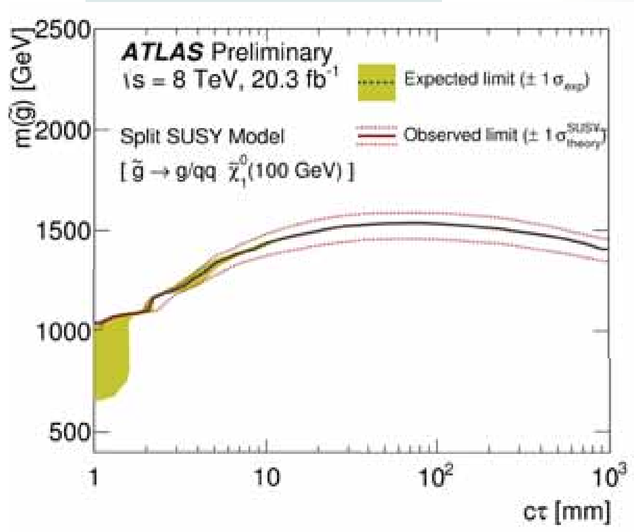
RPV



GGM



Split SUSY

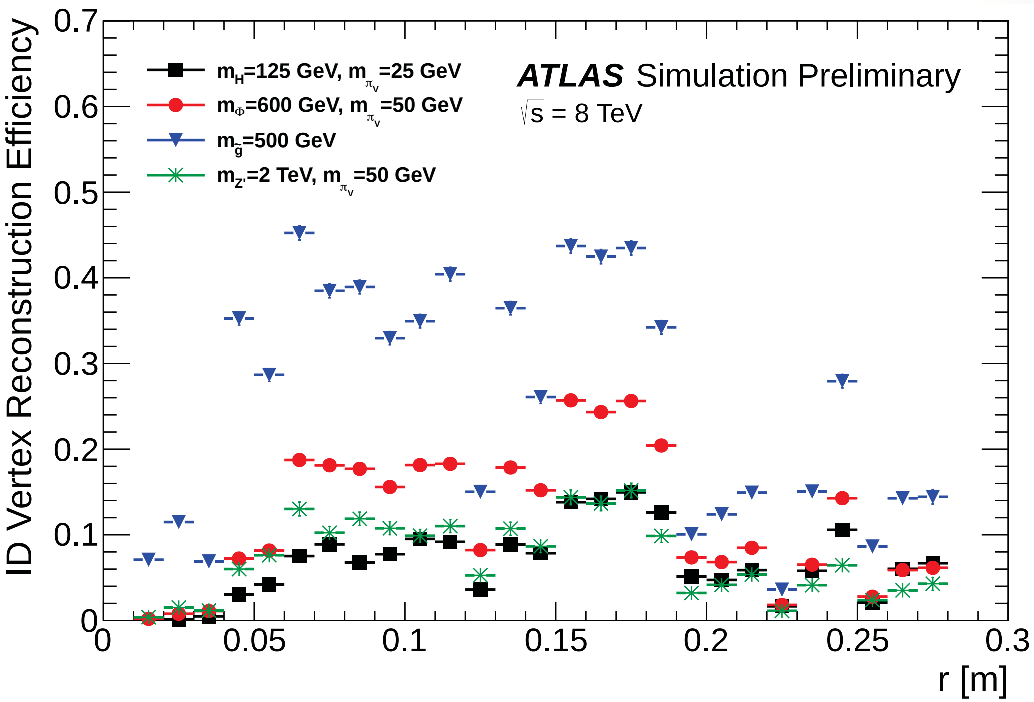


New!

Displaced Jets

- Search for events with 2 displaced vertices in either InnerDetector, Muon Spectrometer or both
- Displaced jets appear in :
  - **Stealth susy**
  - Scalar boson
  - Hidden Valley Z'
- Trigger
  - Jet/Met (Z')
  - Muon ROI Cluster
    - Designed to select decays of neutral particles in the MS.
    - cluster of muon RoIs that are preceded by little or no activity in the ID or calorimeters.

- Selection:
  - Good quality vertex, not consistent with coming from material
  - Minimum Ntrack per vertex required : 5 (7 for Z')
  - Vertex close to jet : ΔR<0.4 (0.6 for Z')



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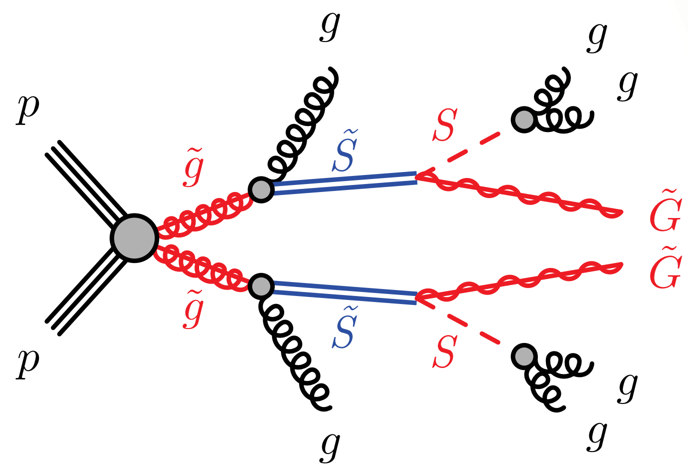
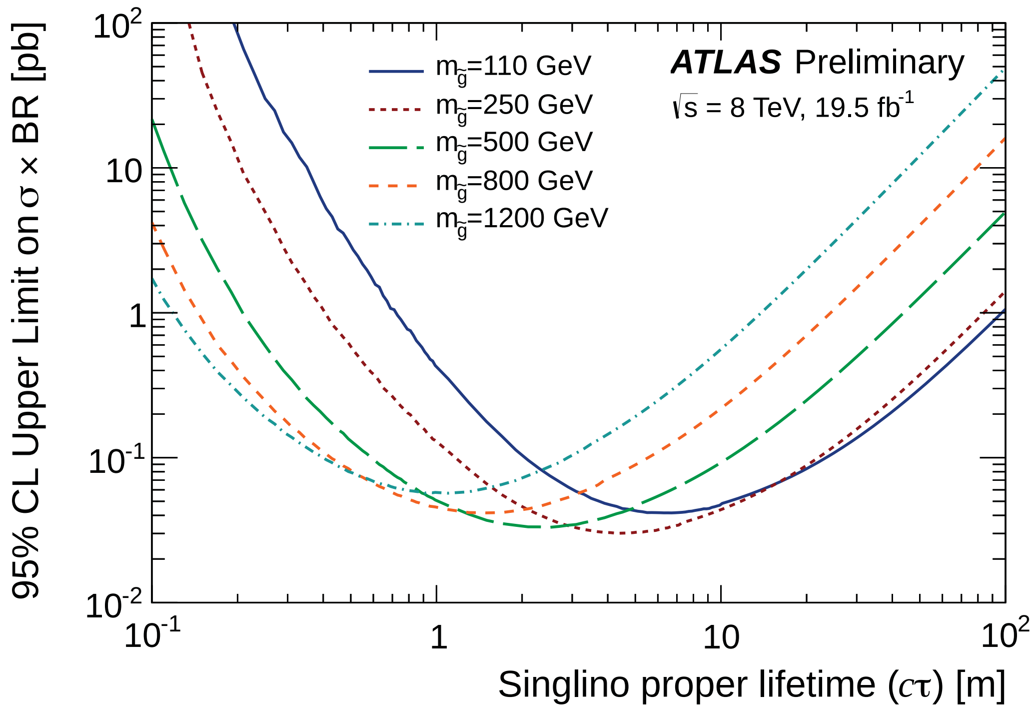




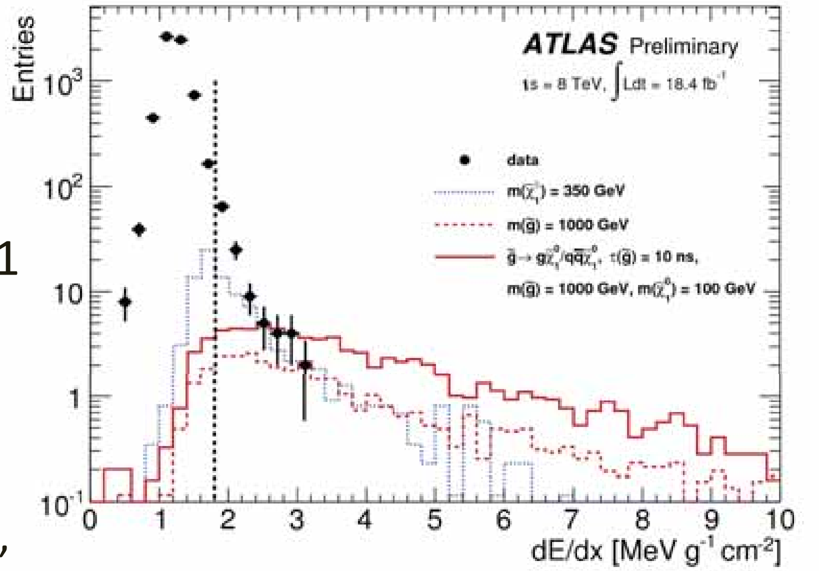
New!

ATLAS-CONF-2015-013

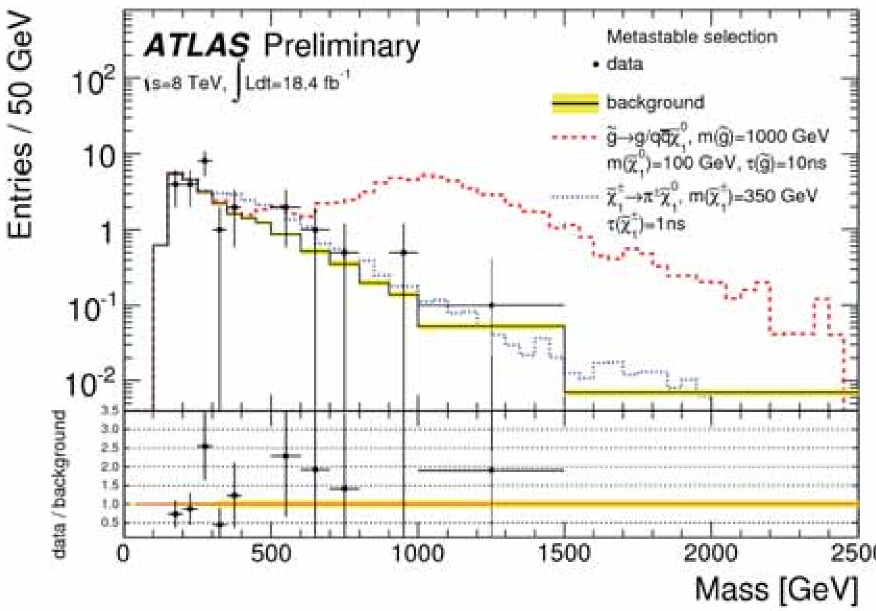
Using the pixel detector to search for meta-stable LLP

- Search for heavy muon-like particles with β<<1
  - high dE/dx measured from pixel detector
- If particle travels at least 45 cm (in r) can be studied,
  - Little dependence on interactions in calorimeter, muon spectrometer or on LLP decay mode
- Met Trigger, Met> 100 GeV,
- Rejection of muons from W decays
  - M_T> 130 GeV
  - For stable signal region : veto on the track candidate being matched to a reconstructed muon
- Track level (at least one track with):
  - High momentum, isolated track: pT>80 GeV
  - high ionization:
    - dE/dx > 1.800 - 0.034|η| + 0.101|η|^2 - 0.029|η|^3 MeV/g cm^{-2}

Event Selection



MetaStable Search



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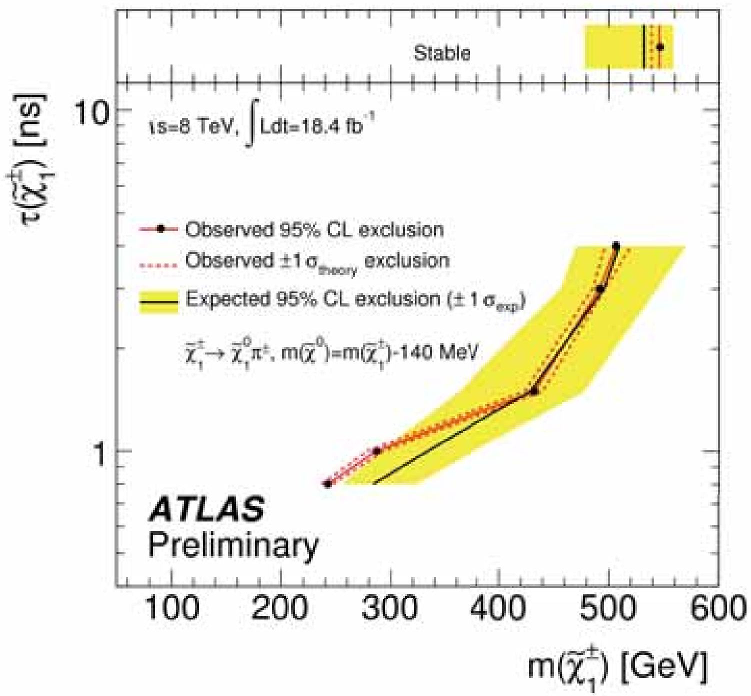
New!

Using the pixel detector to search for meta-stable LLP

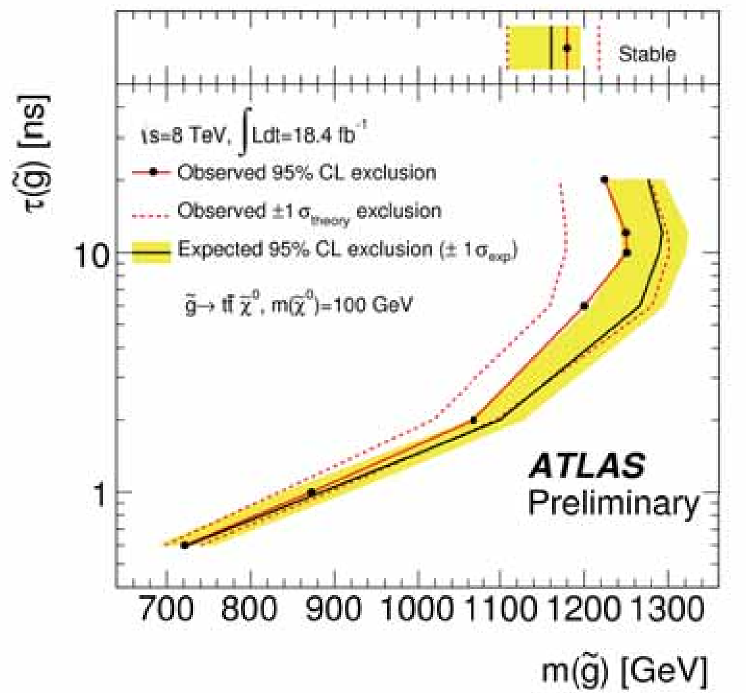
- Background is estimated by data driven approach
  - Randomly sampling p,η, dE/dx values from control sample distributions and combining
- No significant deviation from background expectations is observed.
- Exclude:
  - Stable charginos with mass smaller than 549 GeV
  - stable gluino (sbottom, stop) R-hadrons with masses smaller than 1102 (745, 758) GeV respectively.
  - In the metastable case masses exceeding ≈1200 GeV are excluded for R-hadrons of 12 ns
- **This is the first measurement of lifetime dependent mass limit for charged R-hadrons in the 1-10 ns range, with little dependence on their decay mode.**

ATLAS-CONF-2015-013

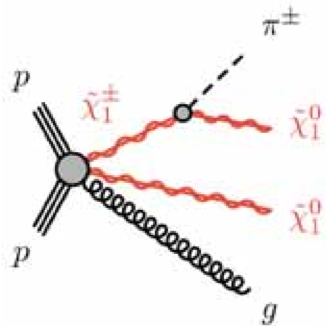
Chargino



Rhadron decay with light neutrino



Disappearing Track

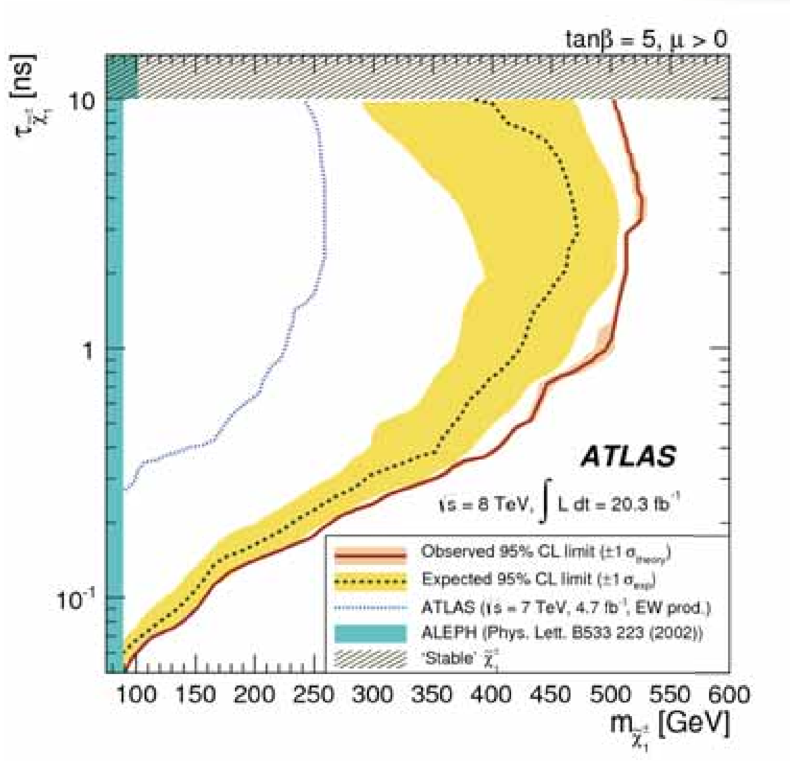


Phys. Rev. D 88, 112006 (2013)

- If the lowest gauginos are approximately mass-degenerate
  - $\tilde{\chi}_1^\pm$ has lifetime O(0.1ns-10ns) and decays to $\tilde{\chi}_1^0$ and a (100 MeV-~1GeV) π±
- Look for production processes:

$$pp \rightarrow \tilde{\chi}_1^\pm \tilde{\chi}_1^0 + jet \qquad pp \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_1^- + jet$$

- Event Selection:
  - High pT jet
    - (jet from ISR, needed to trigger on event).
  - Large missing transverse momentum.
  - A track that has less than 5 hits in the TRT



For Δm ~ 160 MeV (most probable in AMSB), m(chargino) up to 245^{+25}_{-30} GeV is excluded

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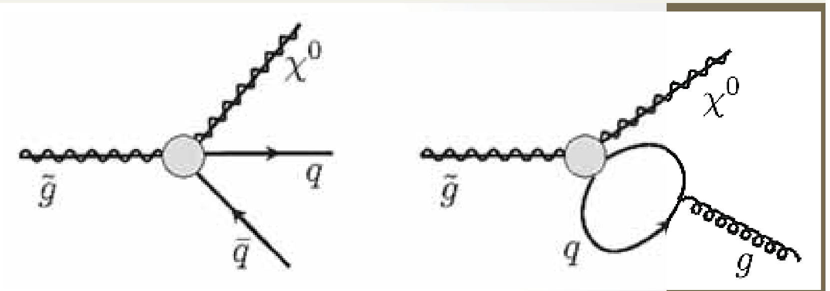
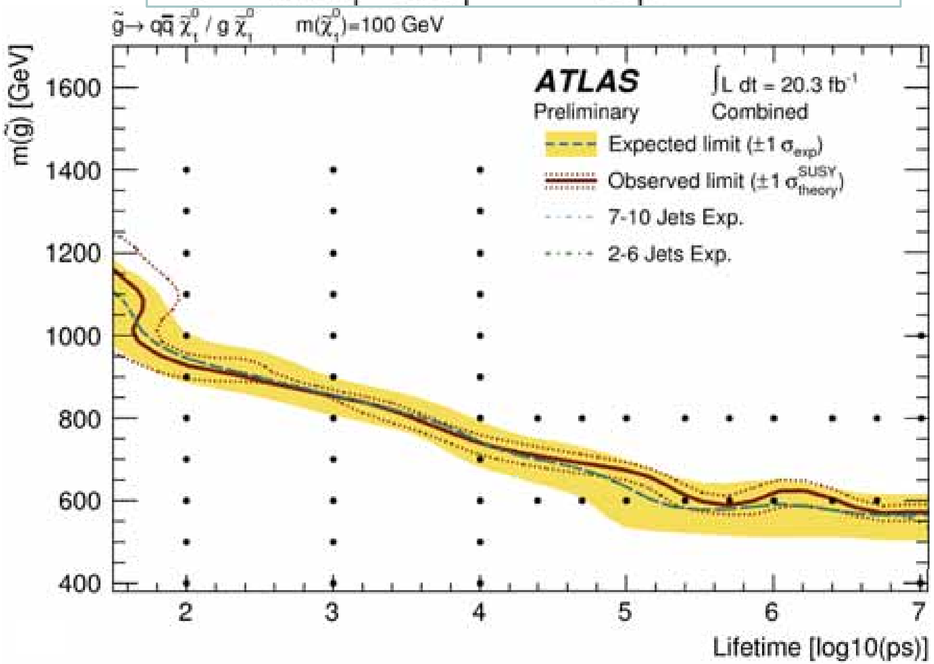
Re-interpretation of prompt jets+MET analyses

ATLAS-CONF-2014-037

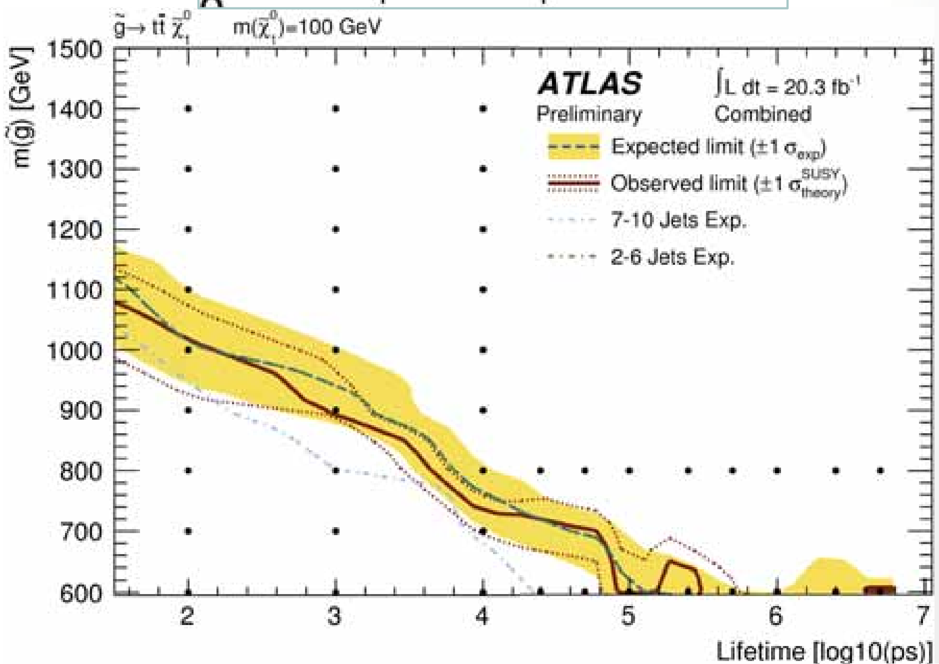


- What if gluino is just a little long-lived, about 1 ns? (mini-split SUSY)
- Standard jets+MET SUSY searches should still apply (up to what lifetime?)
  - Leptons vetos may start to fail impact-parameter cuts (when?)
  - Jets will start to be identified as b-jets (when?)
  - Jets may fail cleaning cuts using track pT fraction, EM fraction (when?)
- First explicit re-interpretation of prompt SUSY searches for long-lived gluinos!

$\tilde{g} \to q\bar{q}\,\tilde{\chi}_1^0 / g\,\tilde{\chi}_1^0$ $m(\tilde{\chi}_1^0)$=100 GeV



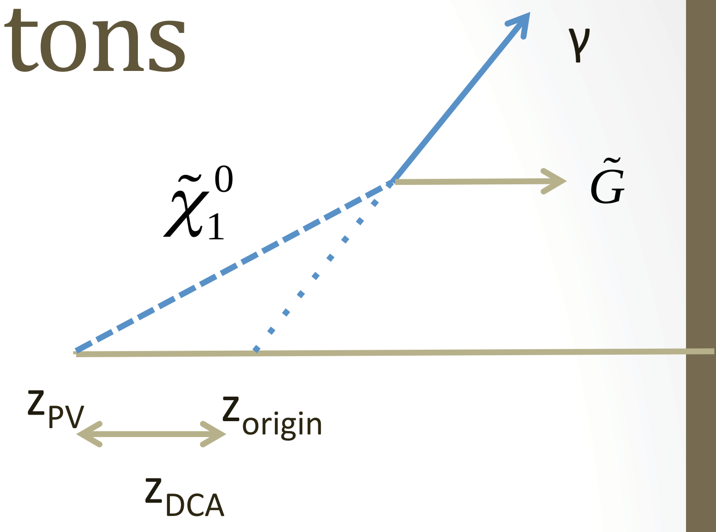
$\tilde{g} \to t\bar{t}\,\tilde{\chi}_1^0$ $m(\tilde{\chi}_1^0)$=100 GeV

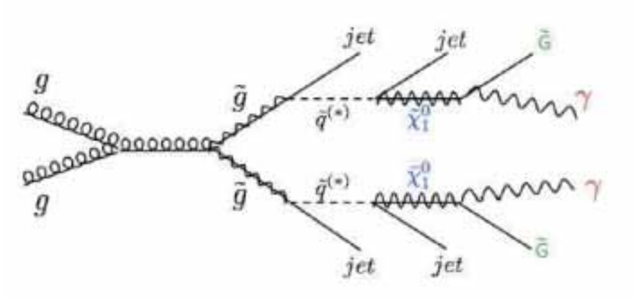


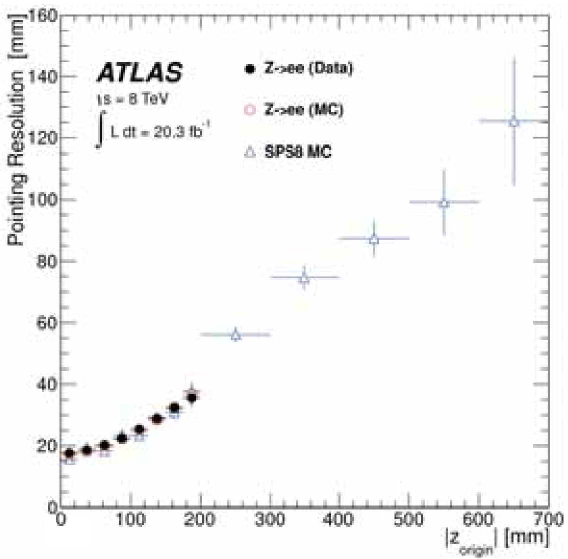
Phys. Rev. D. 90, 112005 (2014)

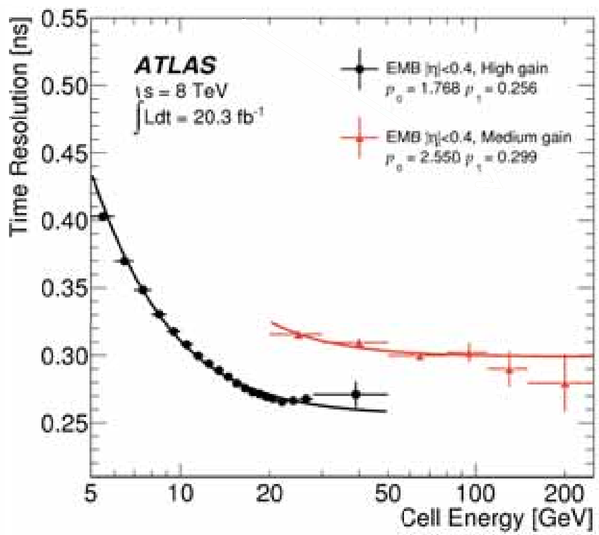
Delayed and Displaced photons

- Delayed and Displaced Photon search performed in the context of GMSB
- This distinct signature arises from finite lifetime (τ) of the NLSP $\tilde{\chi}_1^0$
- 2 SUSY chains with Lightest Neutralino decays to a photon and Gravitino (LSP)
- The photons appears as delayed and may not "point-back" to the PV









Event Selection

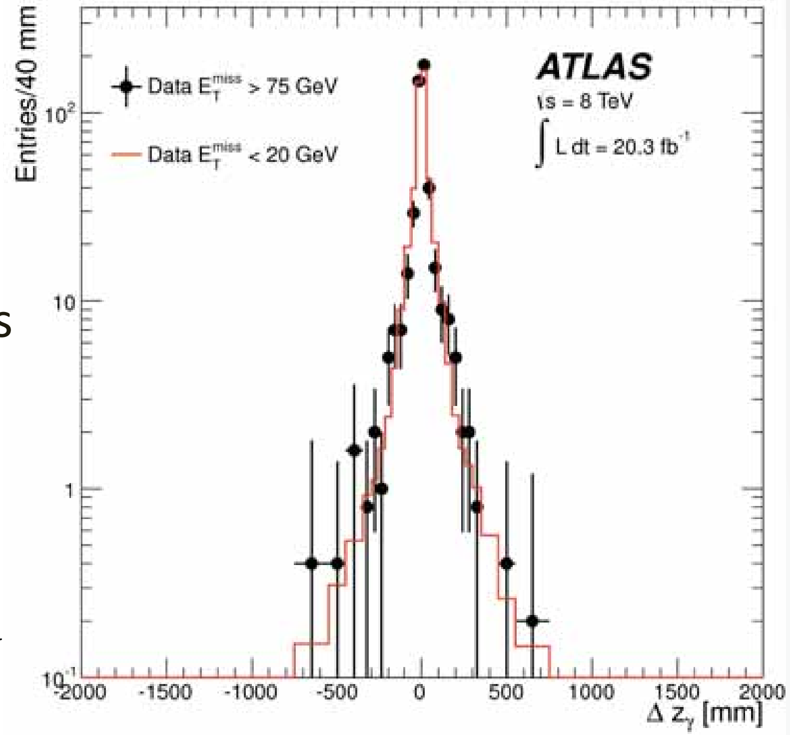
- Searching for 2 Loose Photons + Missing Energy
- Signal Region:
  - MET> 75 GeV, E_T^{γ}>50GeV
- Low MET regions used as control regions
- Signal photons may point away from PV and are delayed
- Use **Pointing (z_{DCA})**, and **LAr Timing (t_{γ})** to perform a 2D search

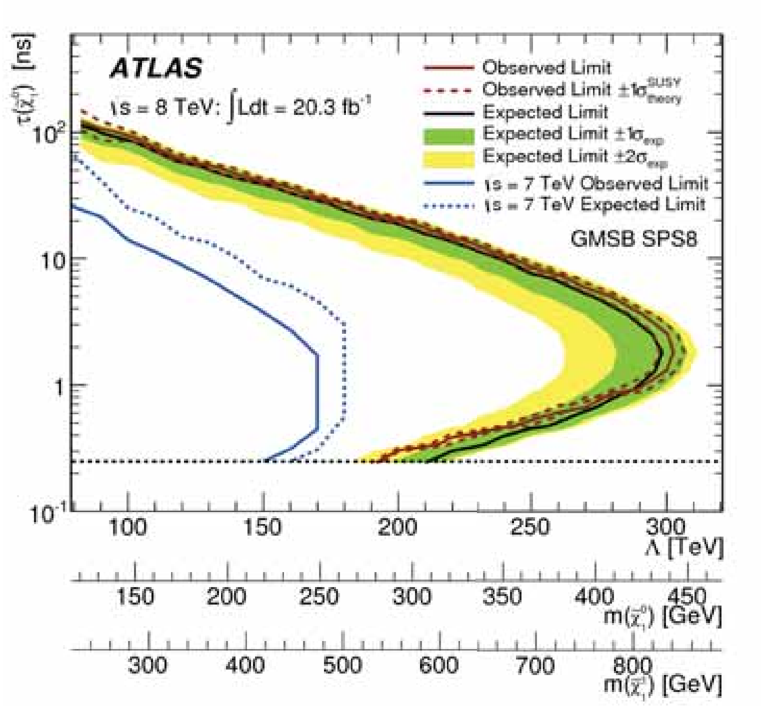
Phys. Rev. D. 90, 112005 (2014)

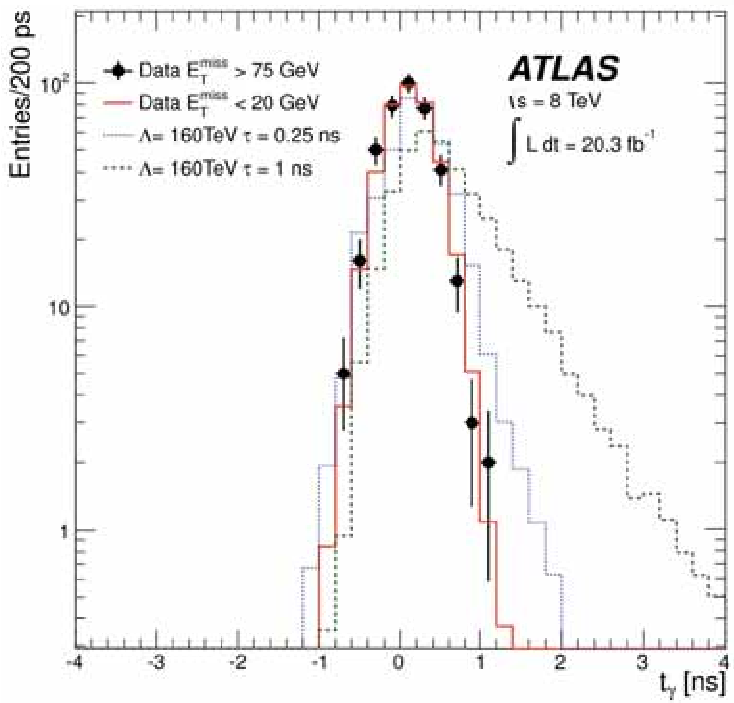
Delayed and Displaced photons

- 386 events in our signal region
- No evidence of non-pointing and delayed photons
- Results are interpreted in context of GMSB SPS8 model
  - Λ = 302 TeV at a lifetime of τ = 1.83 ns.
  - Corresponding to:

$$m(\tilde{\chi}_1^0) = 442GeV, m(\tilde{\chi}^{\pm}) = 841GeV$$





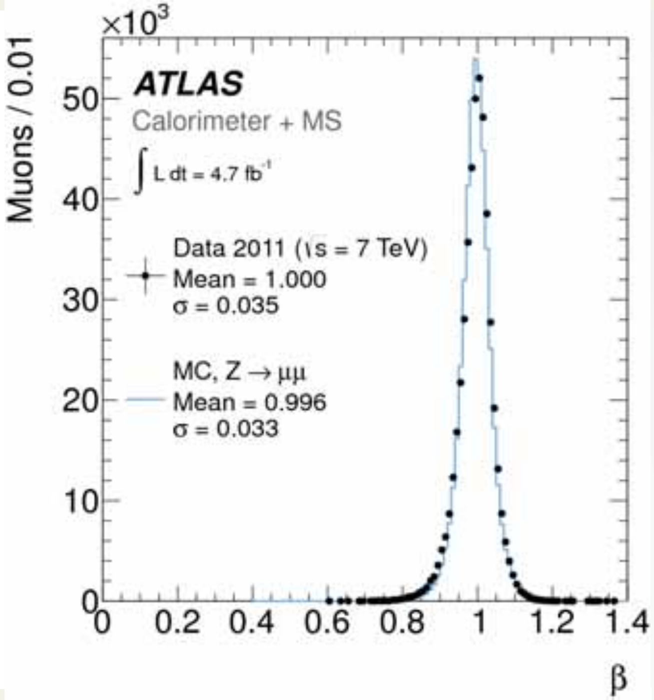


Stable Massive Particles (SMPs)

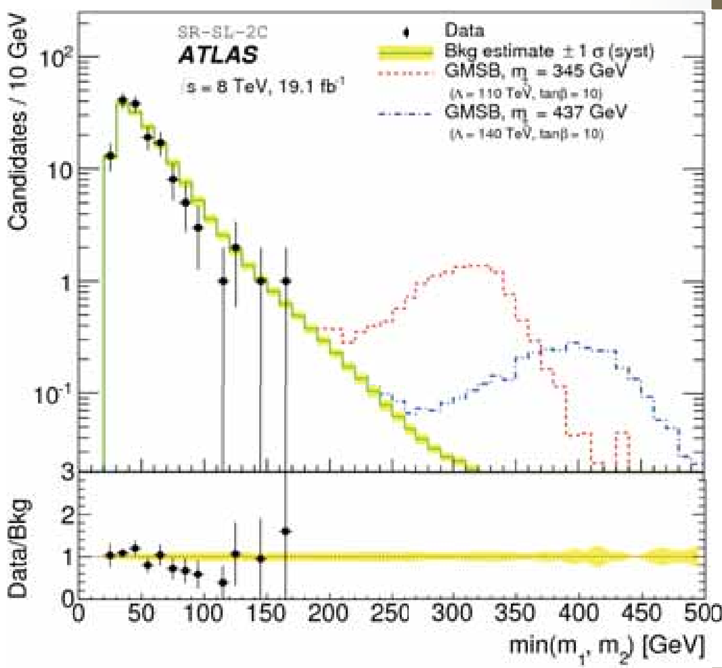
- Several candidate particles, including:
  - Long-lived sleptons in GMSB models.
  - Directly produced charginos, in simplified models where they are nearly degenerate with the lightest neutralino
  - R-hadrons in split-SUSY models
- Common feature: if they are massive, they will be produced with low velocities: $\beta < 1$.

$$m_\beta = \frac{p}{\gamma\beta}$$

- Search for heavy muon-like particles
  - low β using muon chambers and Calorimeter timing
  - high dE/dx measured from pixel detector (related to $\gamma\beta$)
- Main background for both slepton and R-hadron searches is high-p_T muons with mis-measured β.



Overall very good agreement between data and expectation



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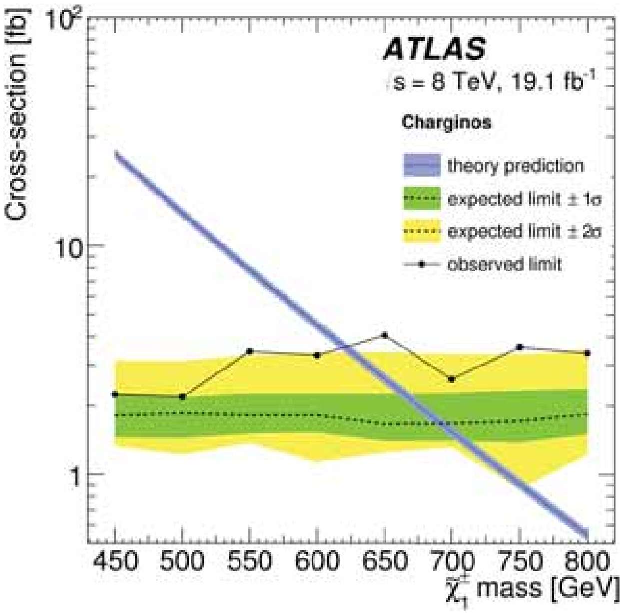
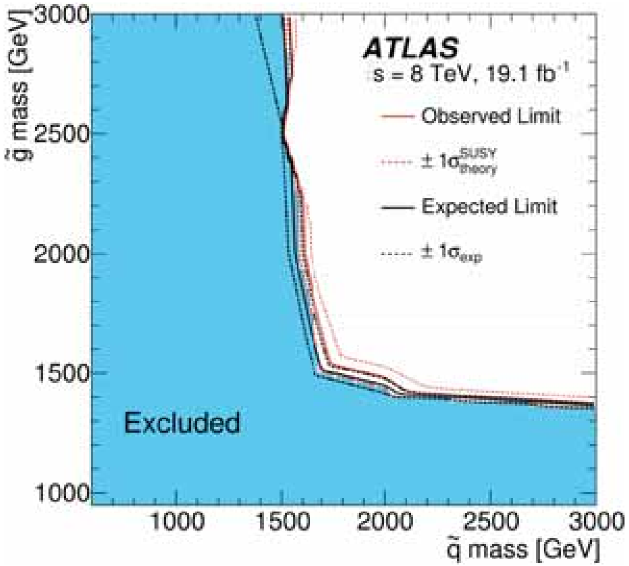
Stable Massive Particles

- long-lived staus excluded between 440 and 385 GeV for tanβ between 10 and 50

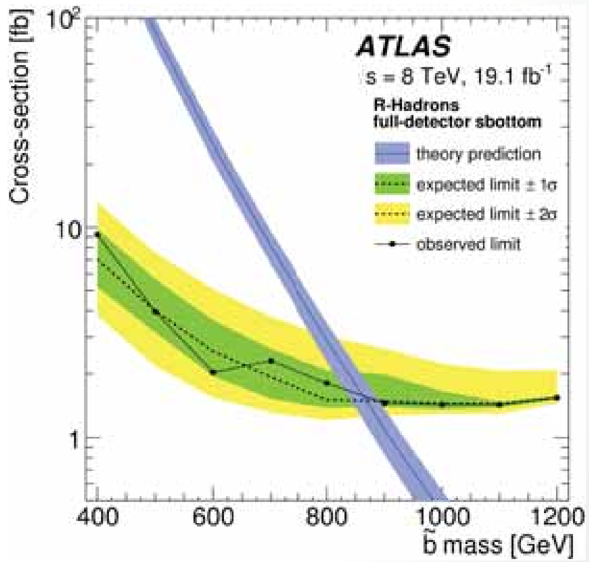


R-hadrons :

Containing …	Excluded up to mass…
gluino	1270 GeV
sbottom	845 GeV
stop	900 GeV



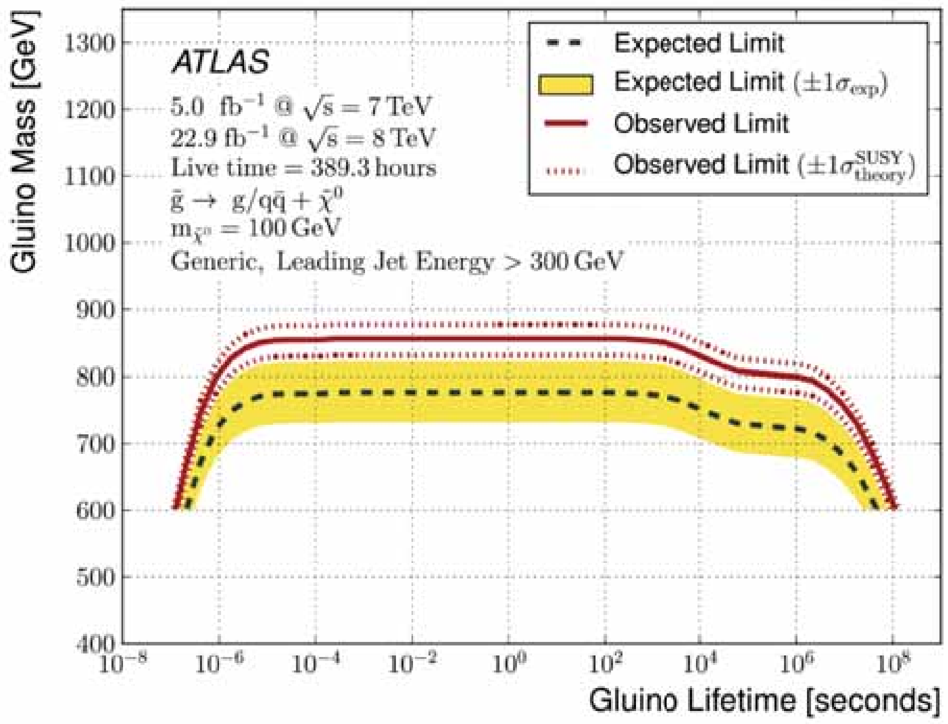
Charginos excluded up to mass 620 GeV



Phys. Rev. D 88, 112003 (2013)

long-lived stopped R-hadrons

- search is for R-hadrons that have come to rest within the ATLAS calorimeter,
  - **decay at some later time to hadronic jets and a neutralino**
- Not every bunch slot of the LHC is filled.
- Search in “empty-events” when 2 empty bunches cross at ATLAS
- Require:
  - At least 1 high energy jet
  - No muon segments identified in Muon detectors



- BG:
  - Beam halo
  - Cosmic ray

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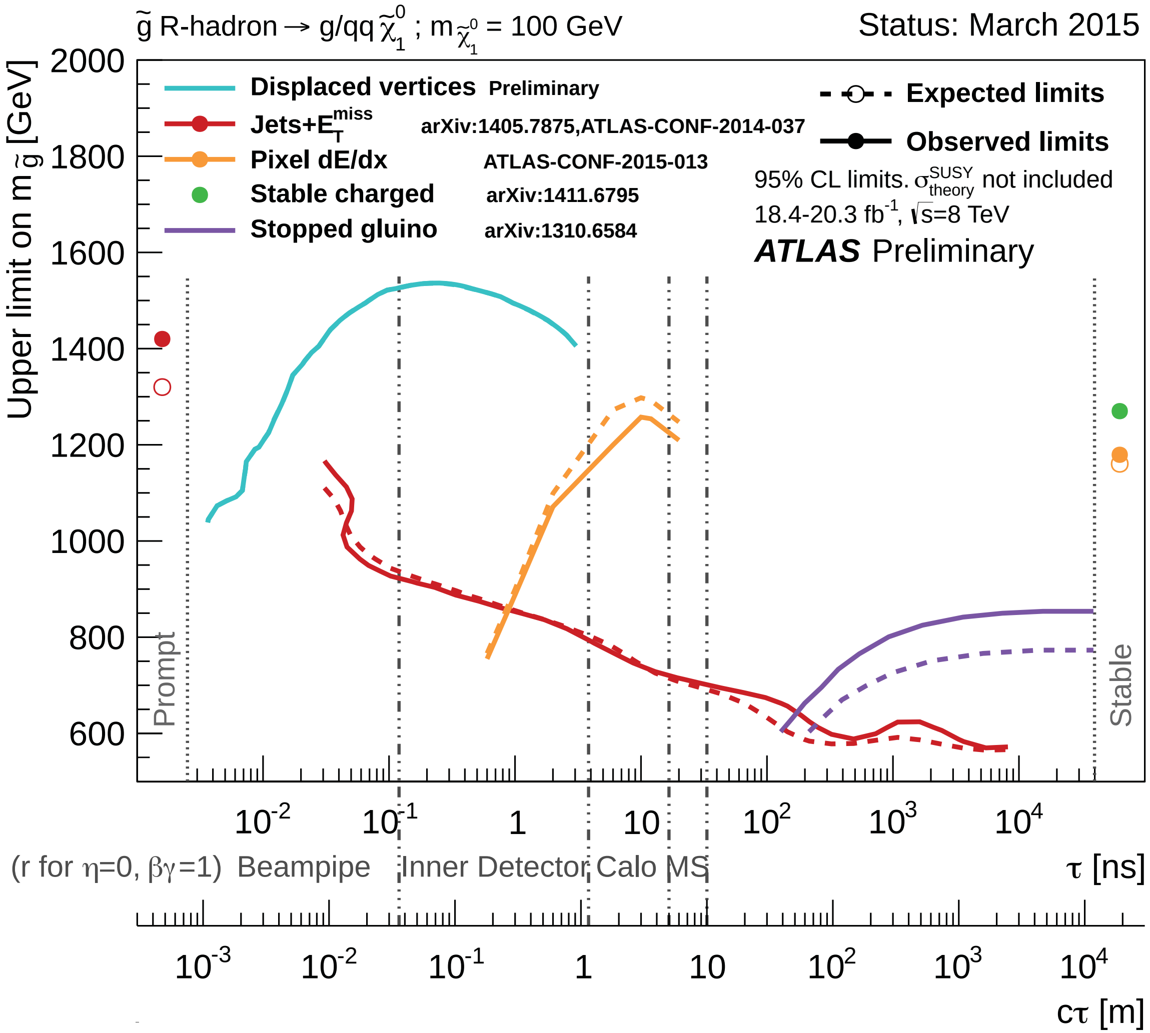
Summary



- With no sign of prompt SUSY decays there has been much speculation **that SUSY could be hiding in stable, meta-stable, displaced decays.**
  - We are actively addressing this experimentally challenging regime with a number of analyses.
- **Good coverage of different lifetimes is achieved** by complementary analyses using different detector systems and novel techniques
- Unfortunately no sign of a signal
- We are looking forward to the increased discovery potential of Run-2