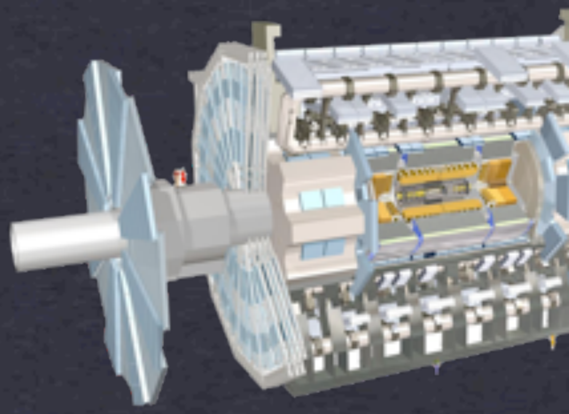
Searches for supersymmetry in resonance production, R-parity violating signatures and events with long-lived particles with the ATLAS detector

Jorge Armando Benitez
York University
on behalf of the ATLAS collaboration



19th International Symposium on Particles, Strings, and Cosmology (PASCOS 2013)

Outline

- R-Parity Violating (RPV) SUSY searches:
  - Four or more leptons
  - Two same-sign leptons and jets
  - Heavy narrow resonance searches decaying to $e - \mu$, $e - \tau$ or $\mu - \tau$
  - Multi-jet resonances searches:
    - Pair-produced of massive particles decaying to multijets
- Long-Lived Particle searches:
  - Non-pointing photons in diphoton E_T^{miss} final state
  - Muons and multitrack displaced vertex final states
  - Charginos based on a disappearing tracks signature
  - Heavy long-lived sleptons
  - Stopped gluinos R-Hadrons

R-Parity Violating (RPV) SUSY Searches

- Many SUSY models assume R-parity conservation (RPC), where

  $$R = (-1)^{2S + 3B + L} \quad ,$$

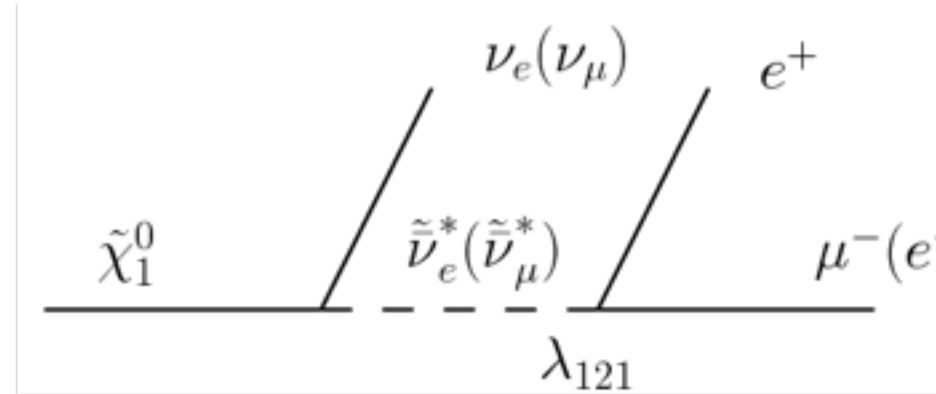
  - Lepton and baryon number violation forbidden
  - Stable lightest SUSY particle (LSP) -> dark matter candidate
- There is no experimental evidence forbidding a RPV potential for which either the lepton or baryon number is conserved

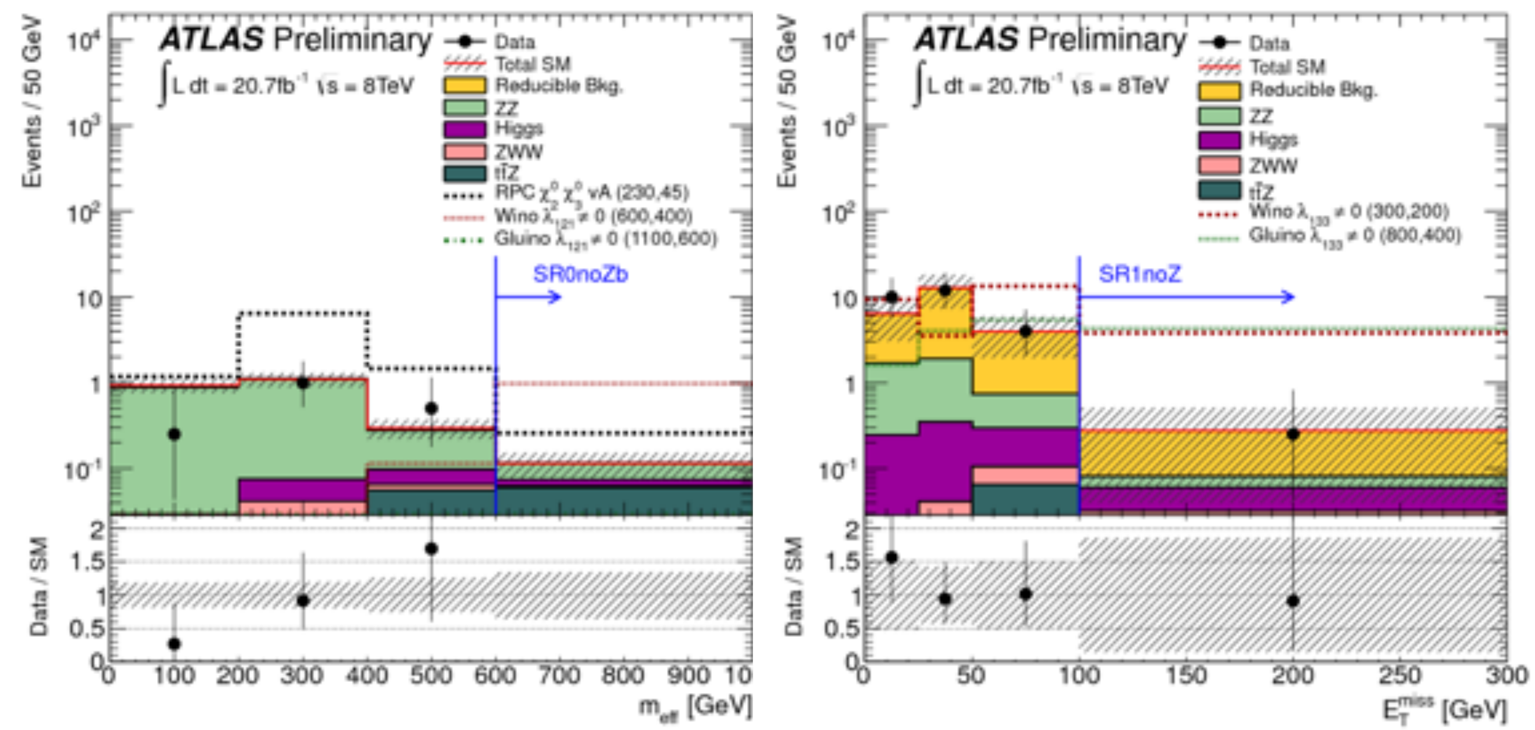
$$L_{RPV} = \underbrace{\lambda_{ijk} L_i L_j \overline{E}_k + \lambda'_{ijk} L_i Q_j \overline{D}_k + \kappa_i L_i H_2}_{\text{lepton number violating}} + \underbrace{\lambda''_{ijk} U_i \overline{U}_j \overline{D}_k}_{\text{baryon number violating}}$$

  - The stability of the proton forbids simultaneous lepton and baryon number violation
- We search for both multi-leptonic and multi-jet final states

Four or more leptons search, RPV, *20.7 fb⁻¹*

- High lepton multiplicity can be indicative of lepton violating SUSY
- After event selection there is a high signal to background (BG) ratio (low SM BG, mainly WZ and ZZ)
- Event Selection Criteria
  - Inclusive single and double electron and muon triggers
  - $\geq$ 4 leptons ($p_T{}^{min}$ > 10 *GeV*), $\geq$ 1(2) above the trigger $p_T{}^{min}$
  - Z Candidate veto
  - 2 Signal regions





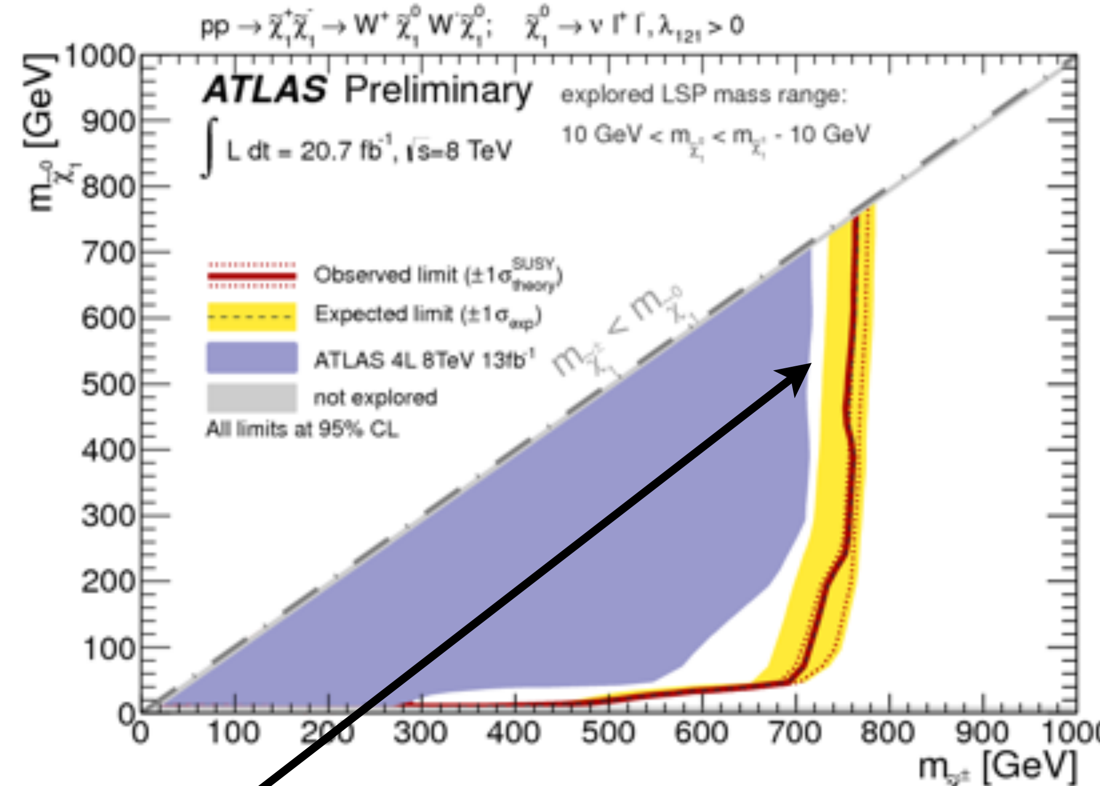
SR	$N_{(e,\mu)}$	N(τ)	E^T_{miss} or m_{eff} [GeV]
$SR0noZ_b$	$\geqslant 4$	$= 0$	> 75 or > 600
$SR1noZ$	$= 3$	$\geqslant 1$	> 100 or > 400

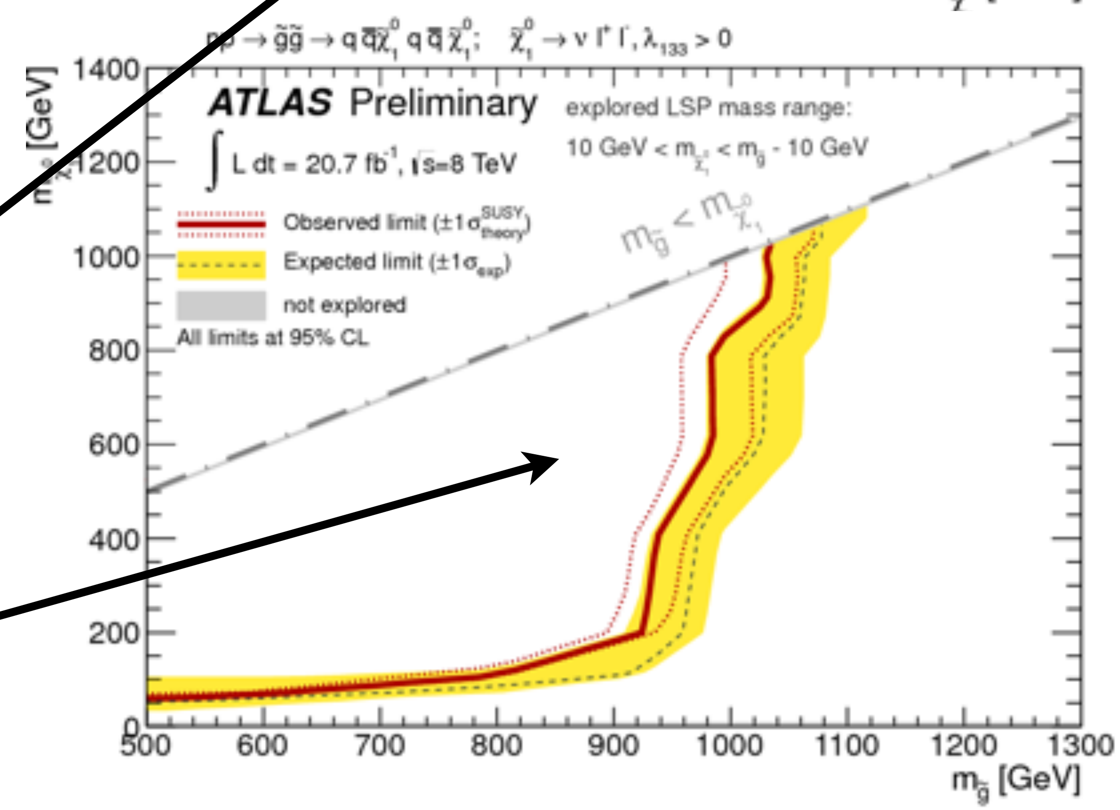
- Irreducible BGs (4 real leptons) are estimated from MC

- Reducible BGs (>1 fake lepton) are estimated from DATA

Four or more leptons search, RPV, *20.7 fb^{-1}*

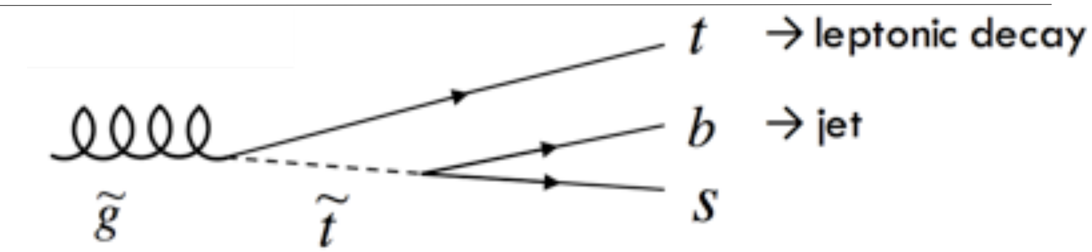
- No excess over SM background is observed
- Results are interpreted in simplified SUSY models with ≥ 1 NLSP
  - LSP: Bino-like neutralino
  - NLSP: Wino charginos, left-handed sleptons, sneutrinos, gluino
- Exclusion Limits:
  - Chargino excl: ~ *750 GeV (λ_{121})*
    ~ *400 GeV (λ_{133})*
  - Gluino excl: ~ *1400 GeV (λ_{121})*
    ~ *1000 GeV (λ_{133})*





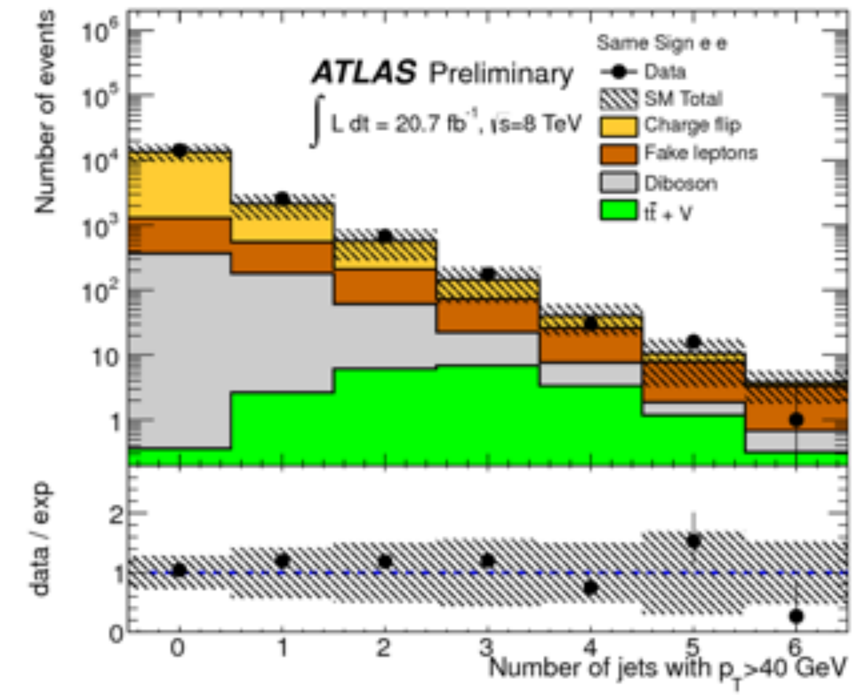
ATLAS-CONF-2013-007

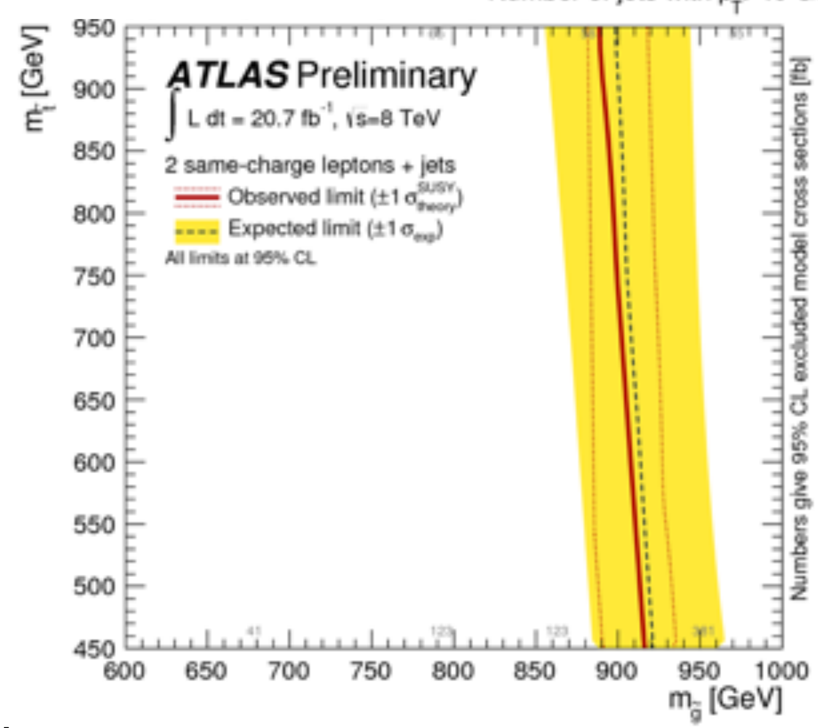
Two same-sign leptons and jets, RPV, $20.7\ fb^{-1}$



- Same-sign leptons events are rare in SM
  → low background scenario
- RPV scenario:
  - gluino pair production,
    gluino decays to $t\tilde{t}$ pair
  - assume only one RPV and baryon number violating term, $\lambda''_{323} = 1$ therefore $\tilde{t} \rightarrow b\ s$
  - Same-sign lepton combinations come from the leptonic decay of the top quark
- Signal region:
  - 2 same sign light leptons (e/μ),
  - $\geq$ 3 b-jets, $\geq$ 5 jets
  - $E_T^{miss} < 150\ GeV$ or $m_T < 100\ GeV$

$m_{\tilde{g}} \lesssim 860\ GeV$ excluded for stop mass up to 1 TeV

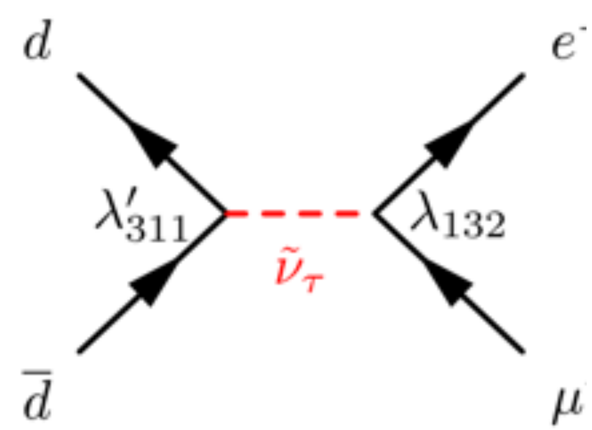


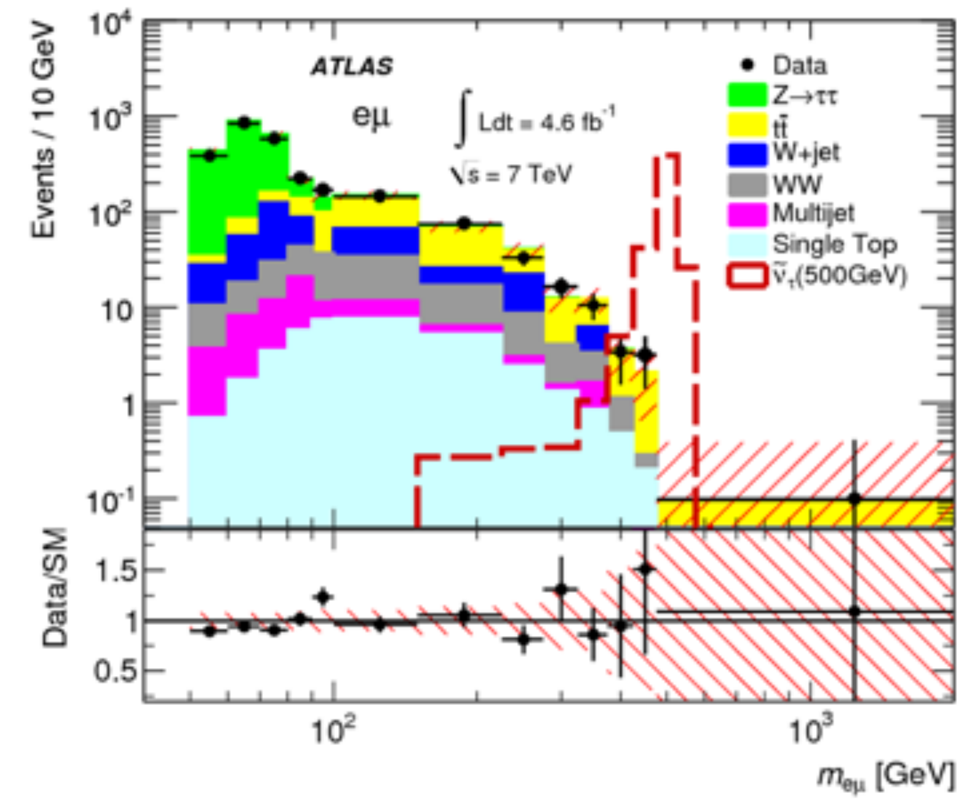


Phys. Lett. B 723 (2013) 15-32

Heavy resonances decaying to: eμ, eτ, μτ, *4.6 fb⁻¹*

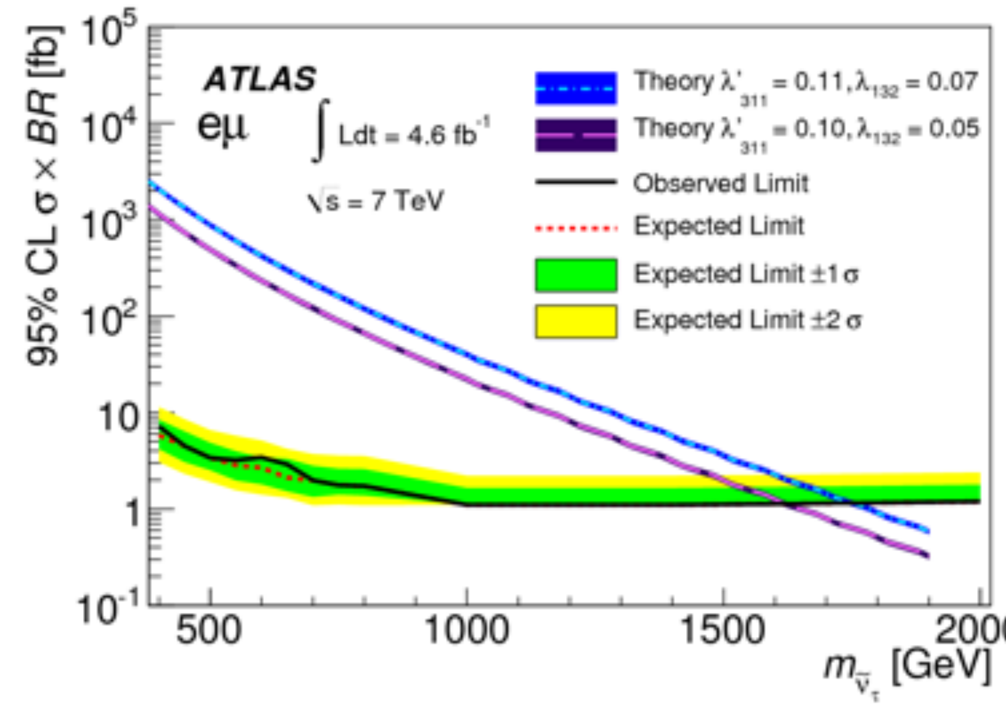
- Search for heavy particles decaying to di-lepton events with different flavour leptons and opposite sign
  - Results interpreted for $\nu_{\tilde{\tau}}$ decays
- Selection (*e μ* channel):
  - Single lepton trigger
  - $p_T(e,\mu) > 25$ *GeV*
  - $Q(e) * Q(\mu) < 0$, $\Delta\phi > 2.7$
  - Search $m_{ll'}$ spectrum for resonance





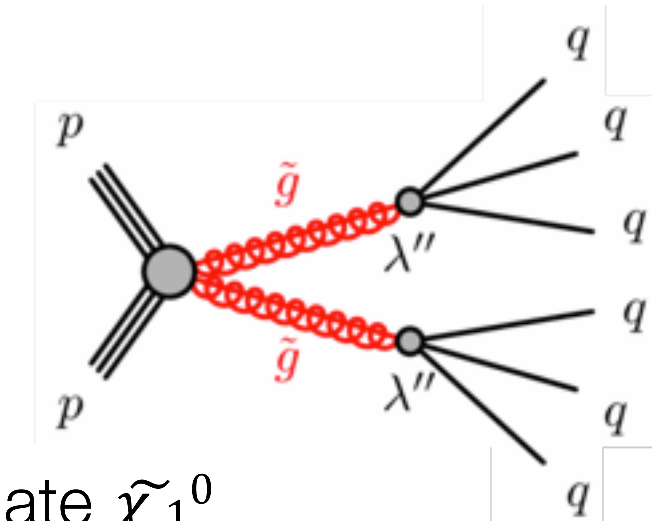
Limits: For a sneutrino mass of *500 (2000) GeV*, the production cross section times branching ratio:

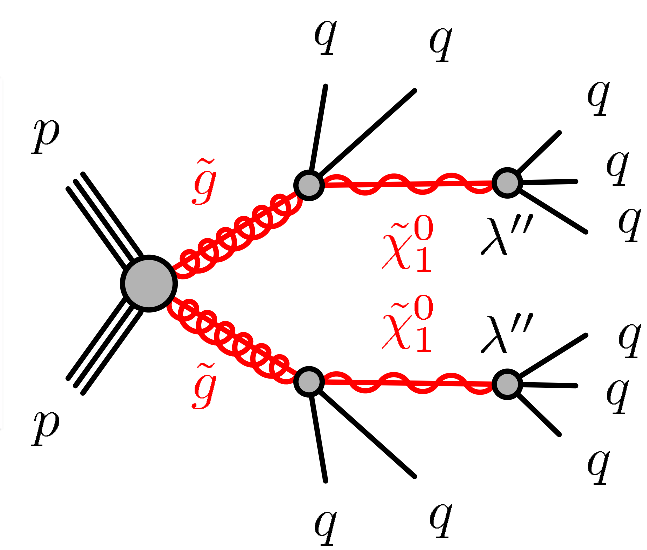
e μ channel:	*3.2*	*(1.4) fb*
e τ channel:	*42.0*	*(17.0) fb*
μ τ channel:	*40.0*	*(18.0) fb*



Pair-produced massive particles decaying to multi-jets

- RPV scenario:
  gluino decays into three quarks





- Two orthogonal search channels:
  - High $\tilde{g}$ mass: resolve all 6 jets (Resolved)
    10 jets final state, intermediate $\tilde{\chi}_1^0$
  - Low $\tilde{g}$ mass: - jets are boosted and difficult to resolve
    - reconstruct 2 large jet with substructure (Boosted)

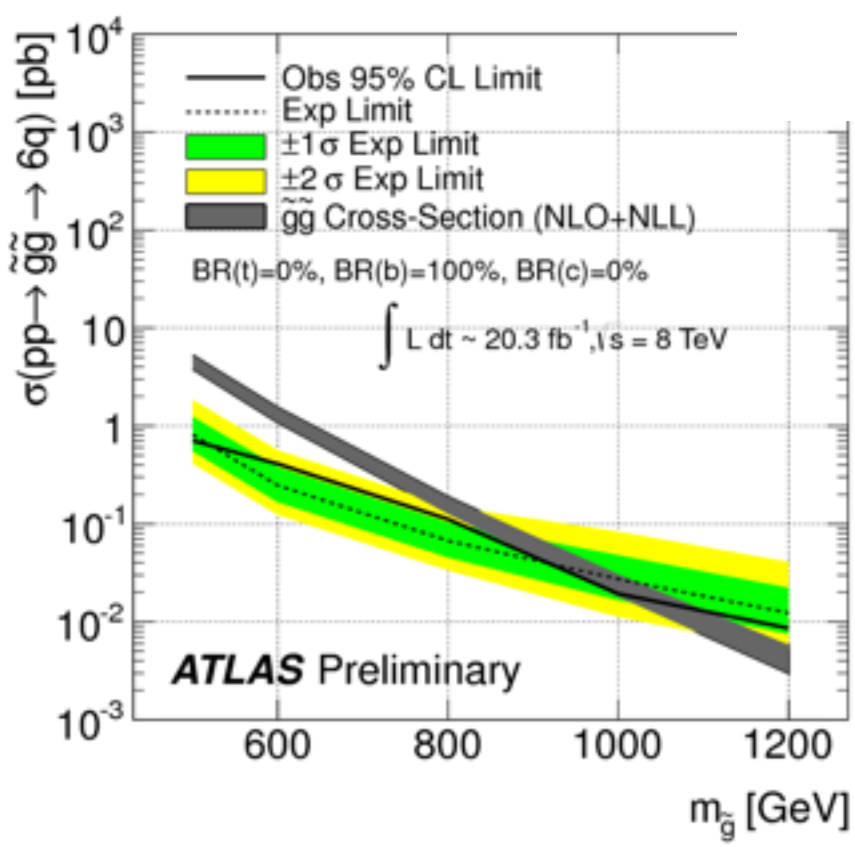
Resolved

20.3 fb^{-1}

Excluded

$m_{\tilde{g}}$ < *917 GeV* for
$\tilde{g}$ -> *3* light-flavour jets

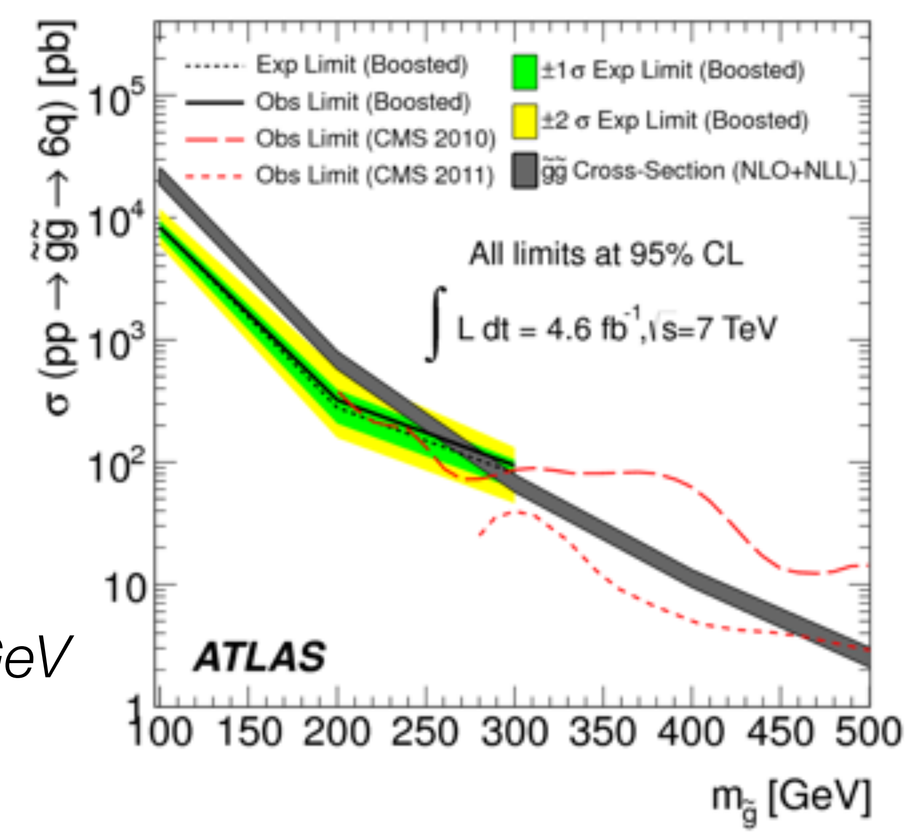
$m_{\tilde{g}}$ < *929 GeV* , for
$\tilde{g}$ -> *2* light-flavour jets
+1 b-jet



Boosted

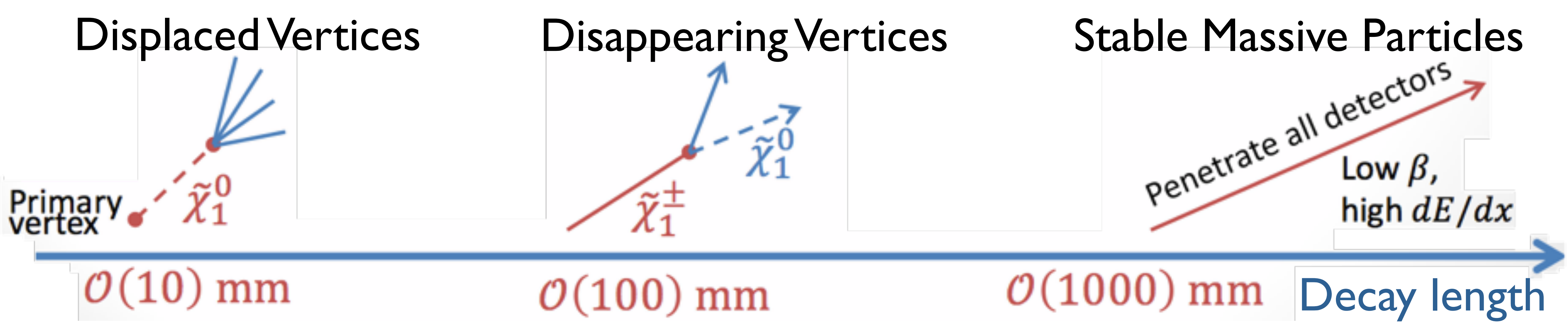
4.6 fb^{-1}

Excluded
$m_{\tilde{g}}$ < *255 GeV*



Long-Lived Particles

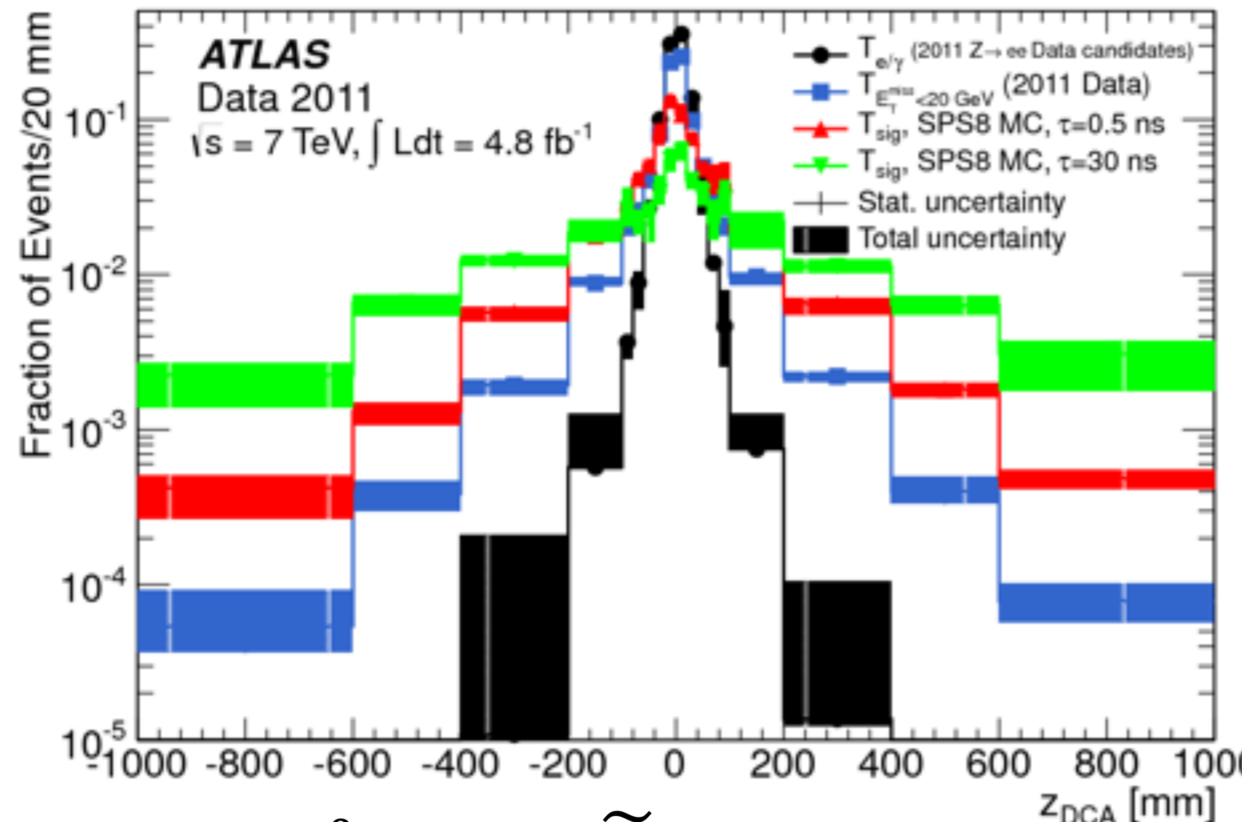
- RPV scenarios:
  - Lifetime proportional to λ^{-2}, λ'^{-2}, λ''^{-2}
    - if λ is small, LSP can have a long lifetime
- RPC scenarios:
  - Slow NLSP decay to LSP due to mass degeneracy, weak coupling or virtual heavy mediator particles
    - Chargino in Anomaly-Mediated SUSY Breaking (AMSB) model
    - R-hadron in Split SUSY model
    - stau in Gauge-Mediated SUSY Breaking (GMSB) model



Phys. Rev. D 88, 012001 (2013)

Non-pointing photons in diphoton Etmiss final state, *4.8 fb-1*

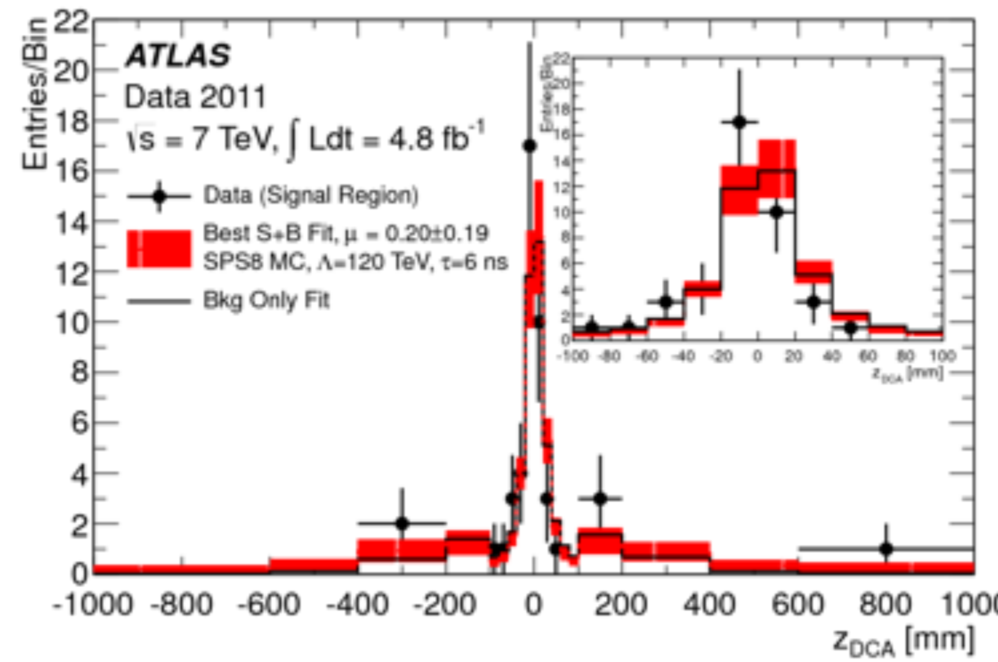
photon's degree of non-pointing

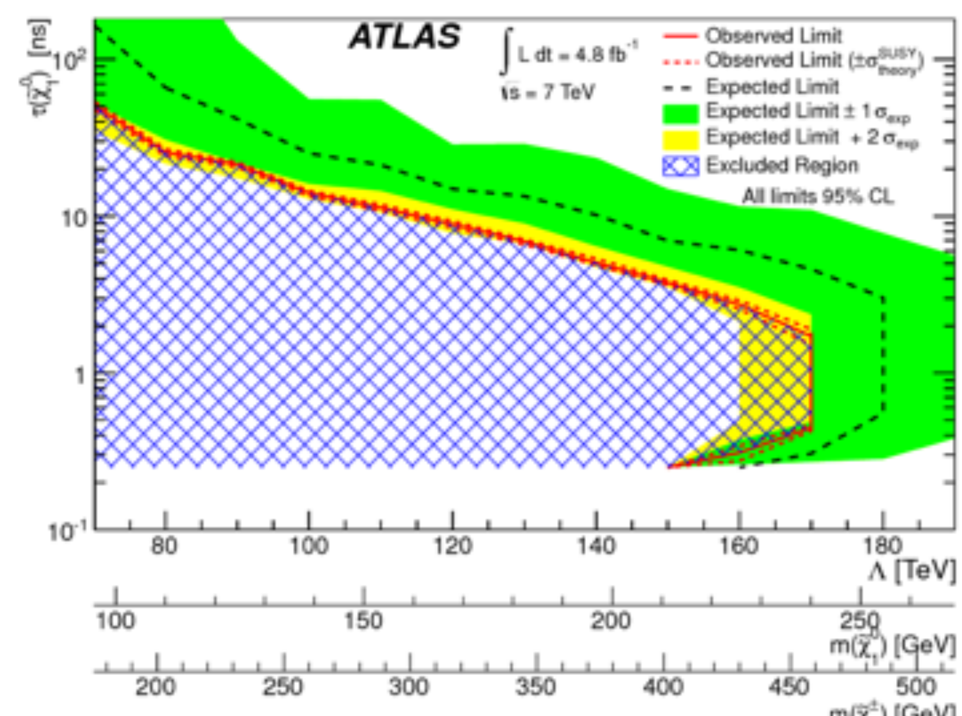


- Results are presented in the context of **SPS8,** for a minimal GMSB model
- SUSY production is dominated by electroweak pair production of gauginos, and, in particular: $\tilde{\chi}_2^0\tilde{\chi}_1^\pm$ and $\tilde{\chi}_1^+\tilde{\chi}_1^-$
- NLSP: $\tilde{\chi}_1^0$ it is long-lived and decays to $\tilde{\chi}_1^0 \rightarrow \gamma + \tilde{G}$, with the photon being produced after a finite delay and with a flight direction that does not point back to the primary vertex
- The search is performed by fitting the shape of the *z_{DCA}* (*$z_{DCA} = z_\gamma - z_{PV}$*) for the diphoton events with *E_T^{miss} > 75 GeV (Signal Region)* to a combination of templates

Non-pointing photons in diphoton Etmiss final state, *4.8 fb-1*

- Analysis: Select tight-loose diphoton events, tag with the tight photon and probe timing and pointing with the loose photon
- Background estimation:
  - Control region $E_T^{miss} < 20$ *GeV,* obtain jet background shape
  - From data $Z \rightarrow ee$ Obtain prompt e/γ background shape
- No significant evidence of non-pointing photons is observed.
  For $\Lambda > 70$ *GeV (160 TeV)*, NLSP lifetimes between *0.25 ns* and *50.7 ns (2.7 ns)* are excluded at 95% C.L.

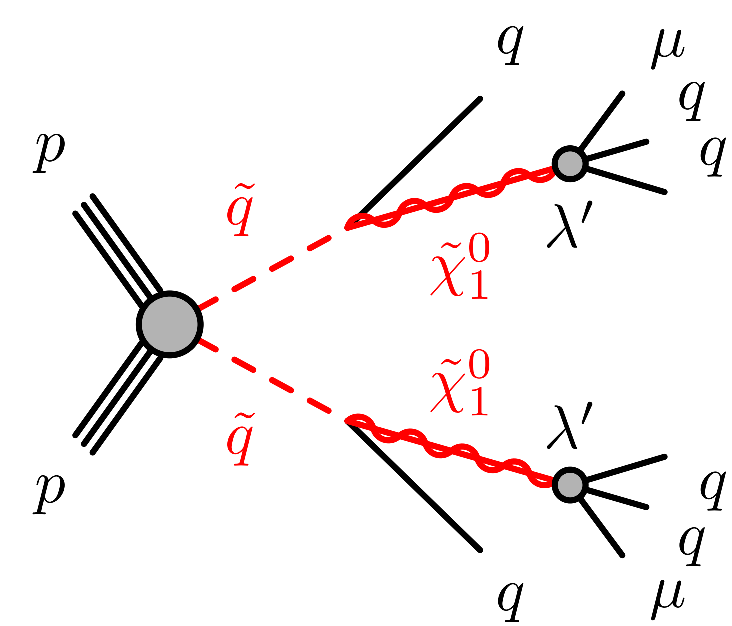




The expected and observed limits in the plane of NLSP lifetime versus Lambda

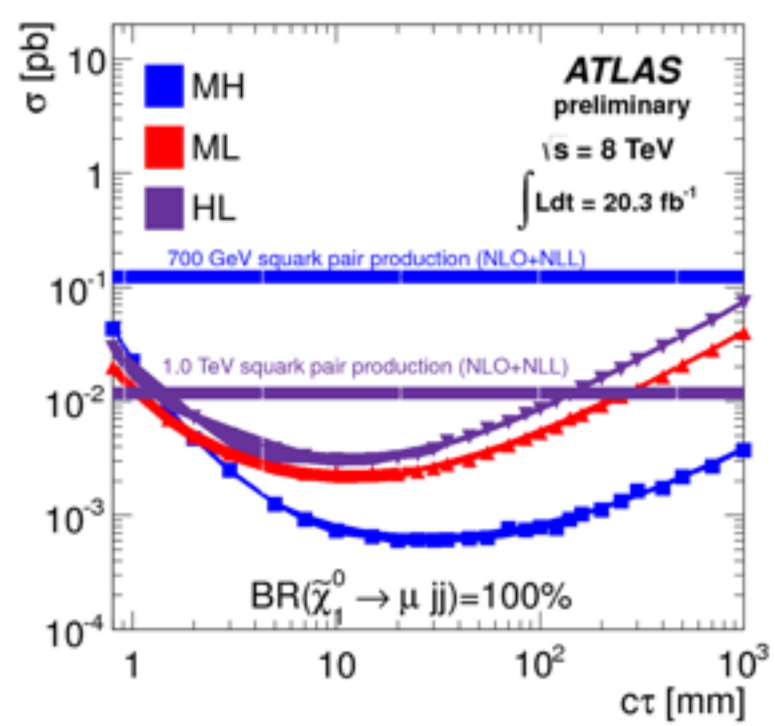
Muons and multitrack displaced vertex final states, *20.3 fb^{-1}*

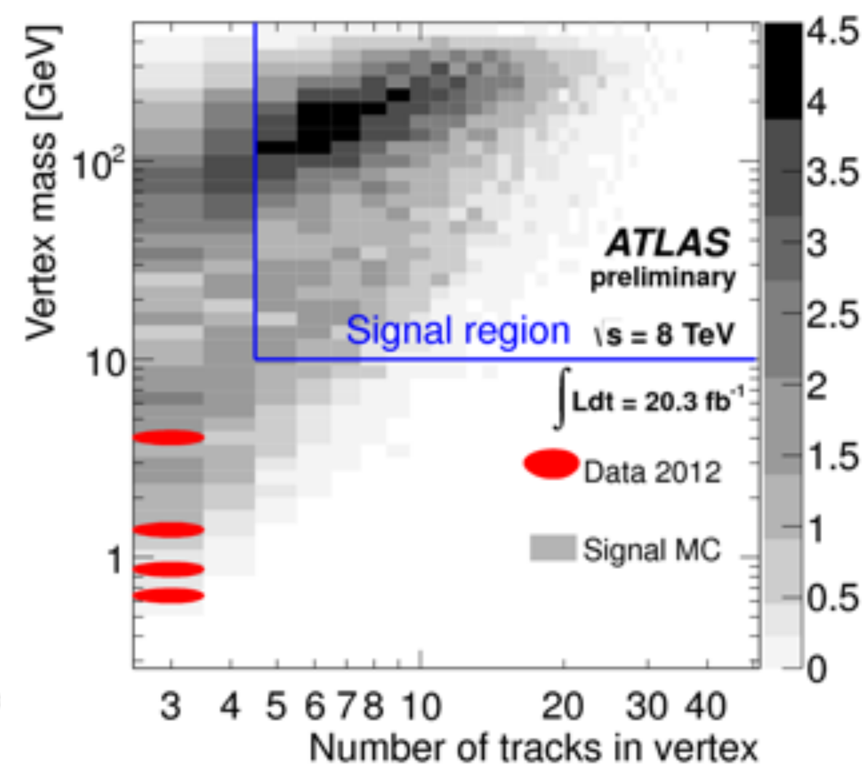
- RPV scenario: search for a heavy particles that decay at a radial distance between *4mm* and *180mm* from the interaction point. The particle decay produces multi-track *(≥ 5)* displaced vertex, and an associated muon with high p_T
- The LSP decays via a weak RPV coupling to produce two quarks and a muon
- Vertices from regions of the detector with high density material are vetoed to reduce the background from hadronic interactions.
- The expected background is very low (0.02+/-0.02 events).
- No events are observed in the signal region



Model Masses *(GeV)*

	$m_{\tilde{q}}$	$m[\tilde{\chi}_1^0]$
MH	700	494
ML	700	108
HL	1000	108

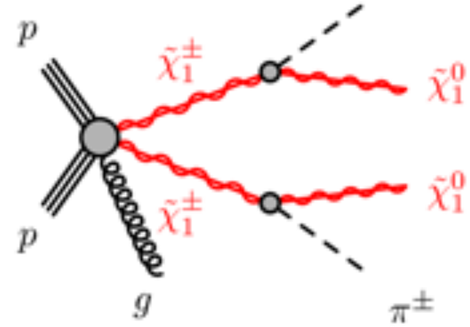




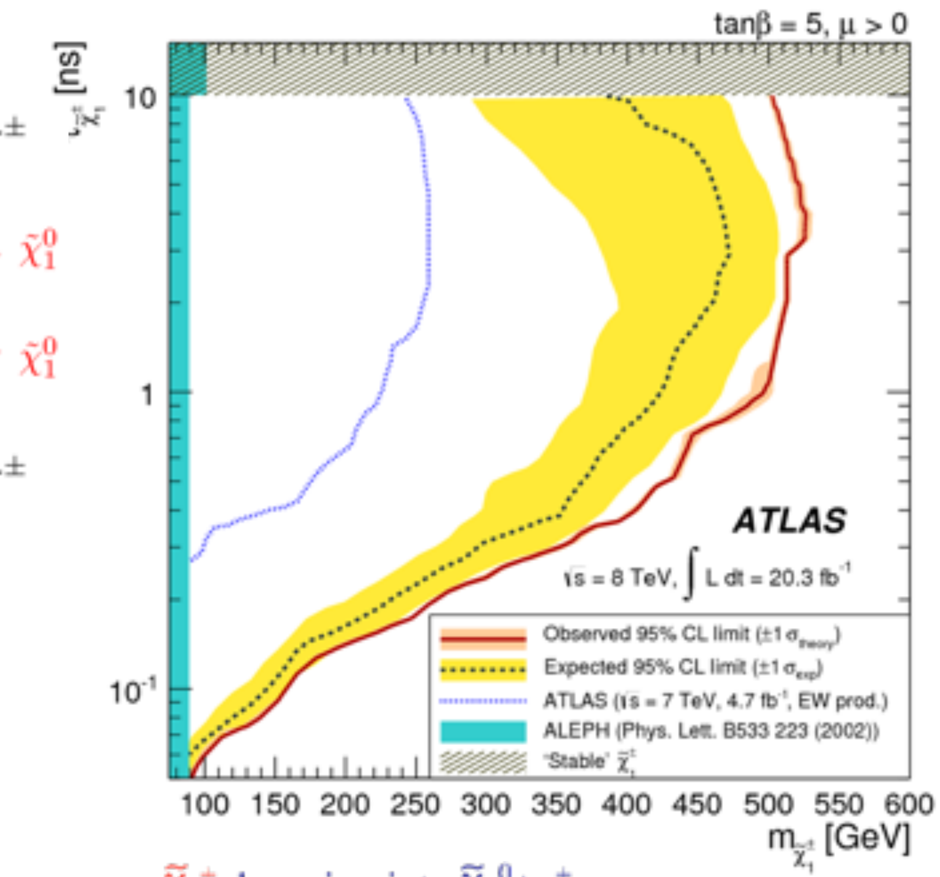
arXiv:1310.3675

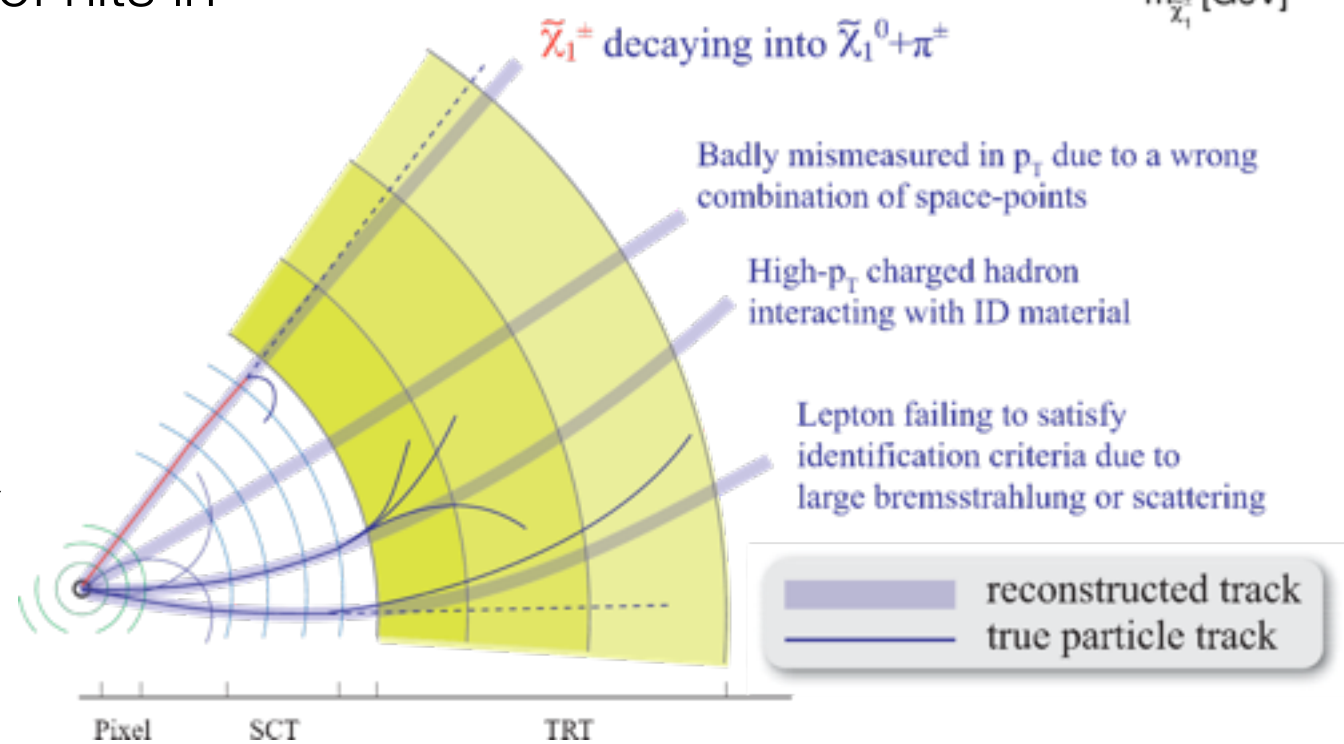
Direct chargino search - disappearing-tracks signatures, *20.3 fb^{-1}*

- In AMSB models, the lightest chargino ($\tilde{\chi}_1^{\pm}$) is almost mass degenerate with the lightest neutralino $\tilde{\chi}_1^0$ *$\Delta m_{\tilde{\chi}1}$ ~ 160 MeV and* $\tilde{\chi}_1^{\pm}$ life time *O(0.1ns)*



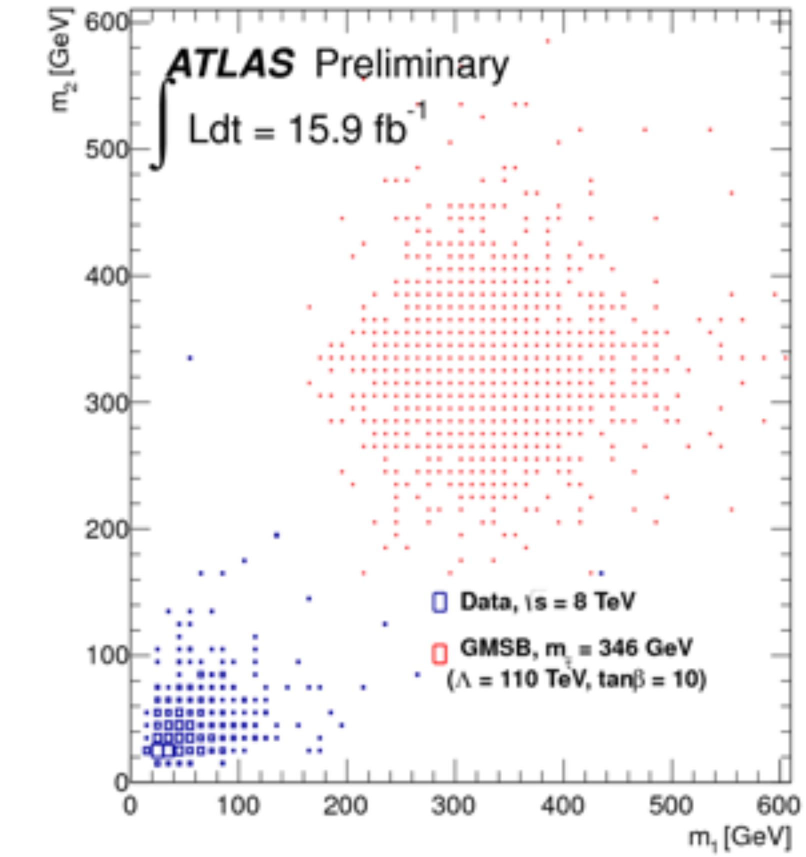
- $\tilde{\chi}_1^{\pm}$ decays to $\tilde{\chi}_1^0$ + low momentum $\pi^{\pm}$
- When decaying in the ATLAS detector, the chargino decays are expected to be observed as "disappearing tracks" inside the ATLAS tracking detector
- **Strategy**: Look for well reconstructed tracks in the inner tracker (silicon detectors), but with low number of hits in the outer tracker.
- The background is determined by a fit to the p_T spectrum of the disappearing tracks.
- No excess over SM background is observed
- A new limit excluding charginos *$m_{\tilde{\chi}1}$ < 270 GeV at 95 % C.L.* for *$\Delta m_{\tilde{\chi}1}$ = 160 MeV and* $\tilde{\chi}_1^{\pm}$ life time 0.2 ns in AMSB models.

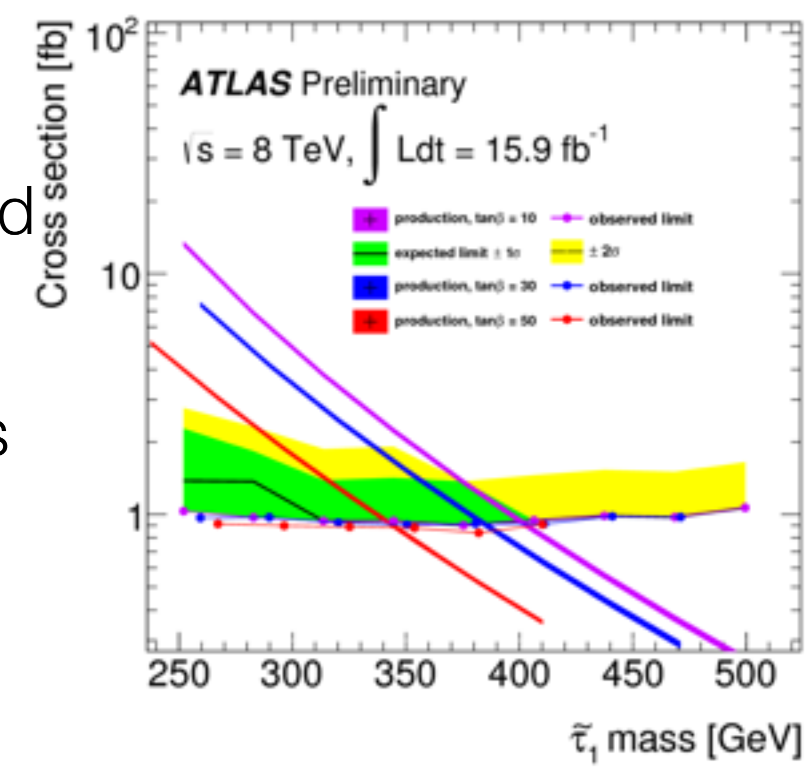




Search for long-lived sleptons, *16 fb*$^{-1}$

- Interpretation of the results are given in the GMSB model with the stau ($\tilde{\tau}_1$) being the NLSP. $\tilde{\tau}_1$ decays outside the detector
- Long-lived $\tilde{\tau}_1$ appear in the detector as if they are heavy muons
- The $\tilde{\tau}_1$ mass is estimated using $m = p / (\gamma \beta)$
- β is estimated using the time of flight (calorimeter and muon system). $\beta \gamma$ is estimated from the Silicon tracking detector
- Small background, mainly composed of missmeasured high p_T muons
- signal regions: 1 tight candidate or 2 loose candidates
- Results matched SM expectations, limits:
  $\tilde{\tau}_1$ mass = 402 - 347 GeV, for tan β = 5 - 50



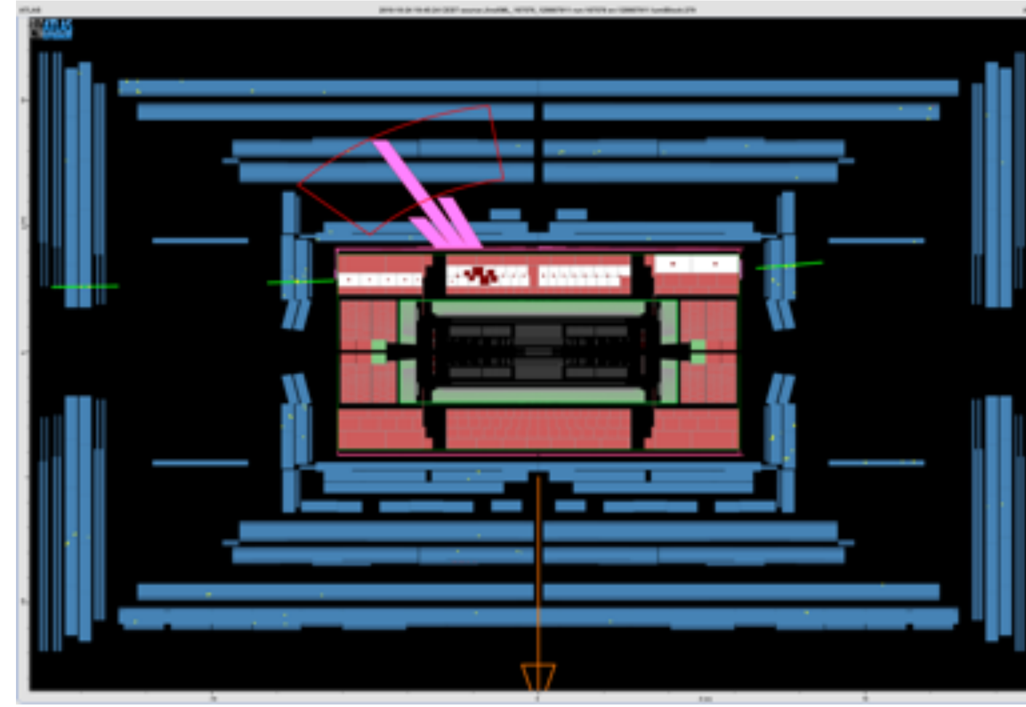


arXiv:1310.6584

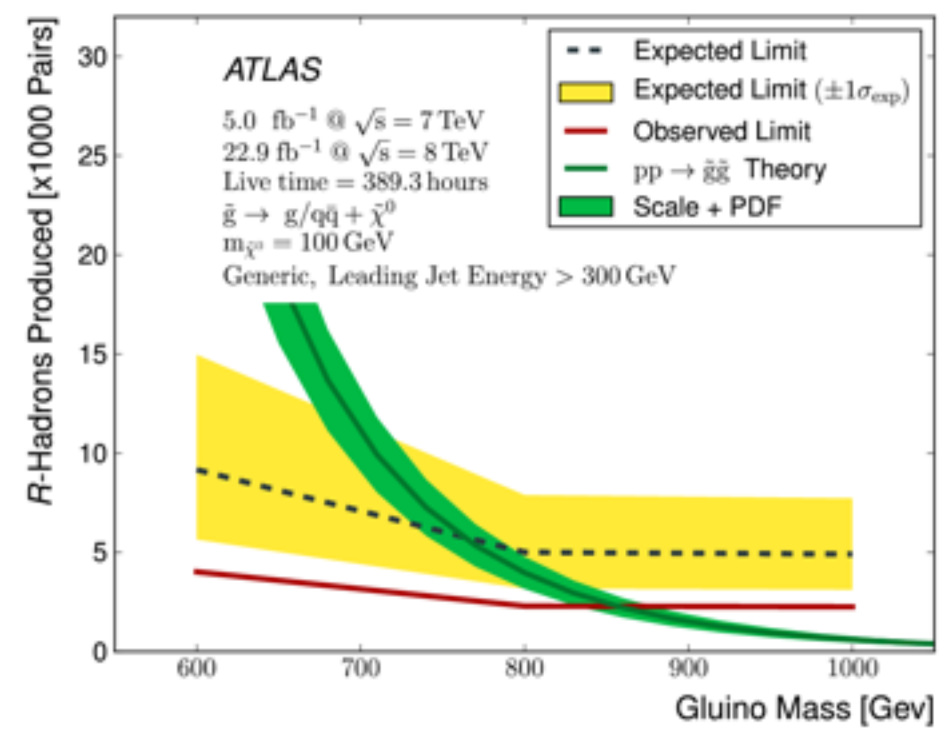
Stopped gluino R-hadron search

5.0 fb-1 @7 TeV   22.9 fb-1 @8 TeV

- Search for long-lived stopped $\tilde{g}$ R-hadrons, beyond the time between bunches. (decay is associated with later bunch)
- Selection:
  - Trigger on empty bunch crossings with calorimeter activity.
  - Leading jet: $|\eta| < 1.2$, $E_{jet} > 100, 300$ GeV
  - Muon activity veto
- Main backgrounds:
  Cosmic rays and beam halo
- Data is consistent with the background
- Limits: $m_{\tilde{g}} < 832$ GeV excluded,
  for $1\ \mu s < \tau_{\tilde{g}} < 1000$
  $m_{\tilde{g}} > 600$GeV excluded,
  for lifetimes of up to 2 years!
- Also exclude long-lived stops and sbottoms (limits in backup slides)



This event passed all the selection criteria except for the muon segment veto



Outlook

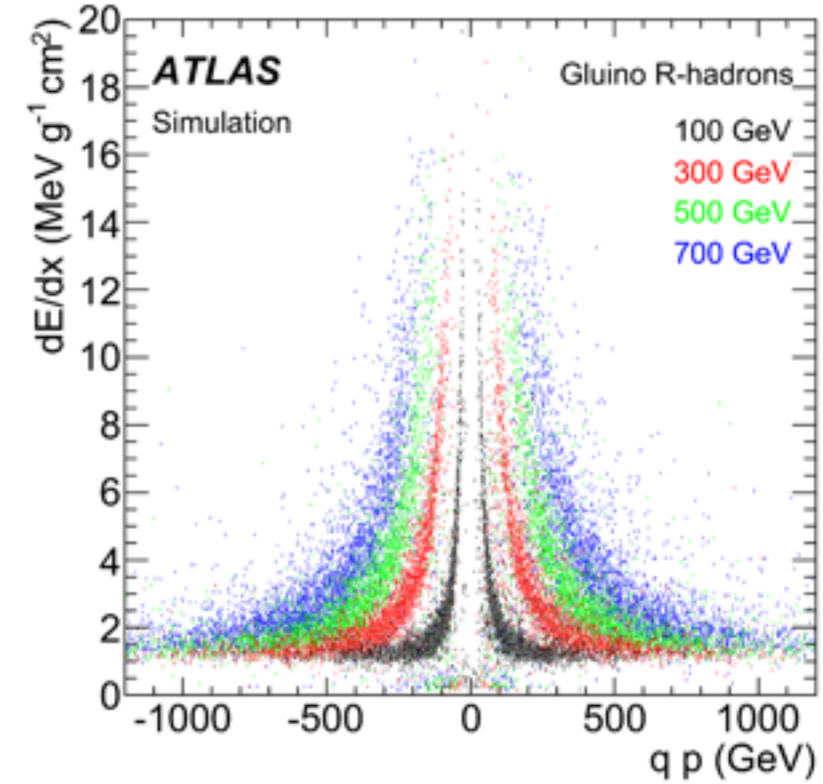
- The ATLAS collaboration has covered a comprehensive range of analysis for RPV, resonances and long-lived searches
- These type of analyses require different strategies compared to other more conventional searches
- No excess over the SM background has been observed - no evidence of SUSY so far
- Limits in SUSY parameter space continues to expand

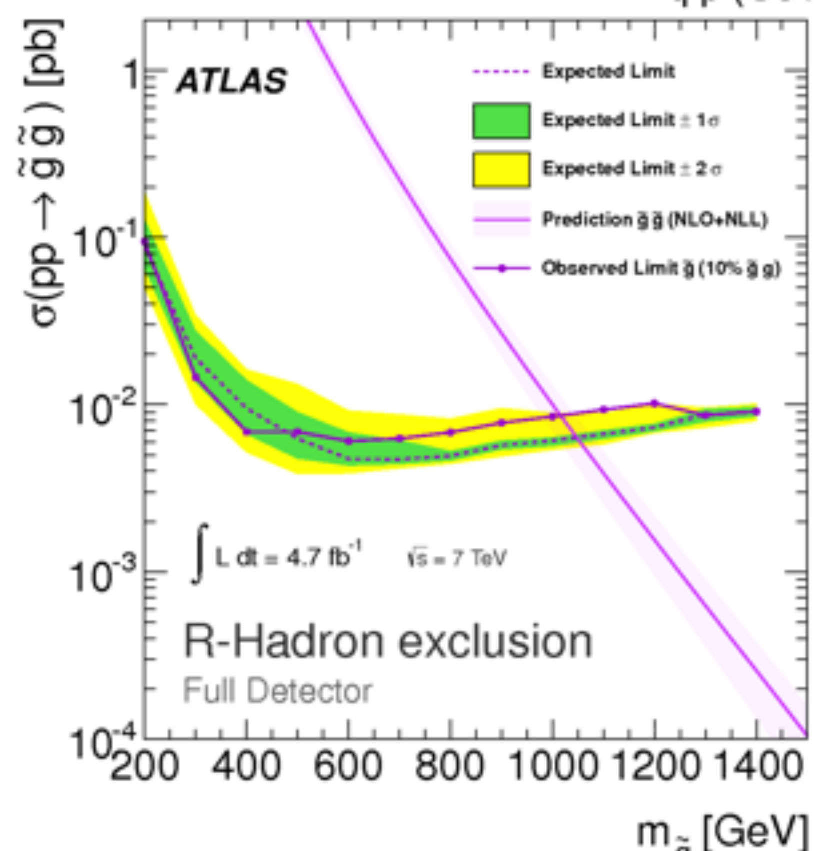
Backup Slides

Phys. Lett. B 720 (2013) 277-308

Search for long-lived RHadrons, 4.7 fb^{-1}

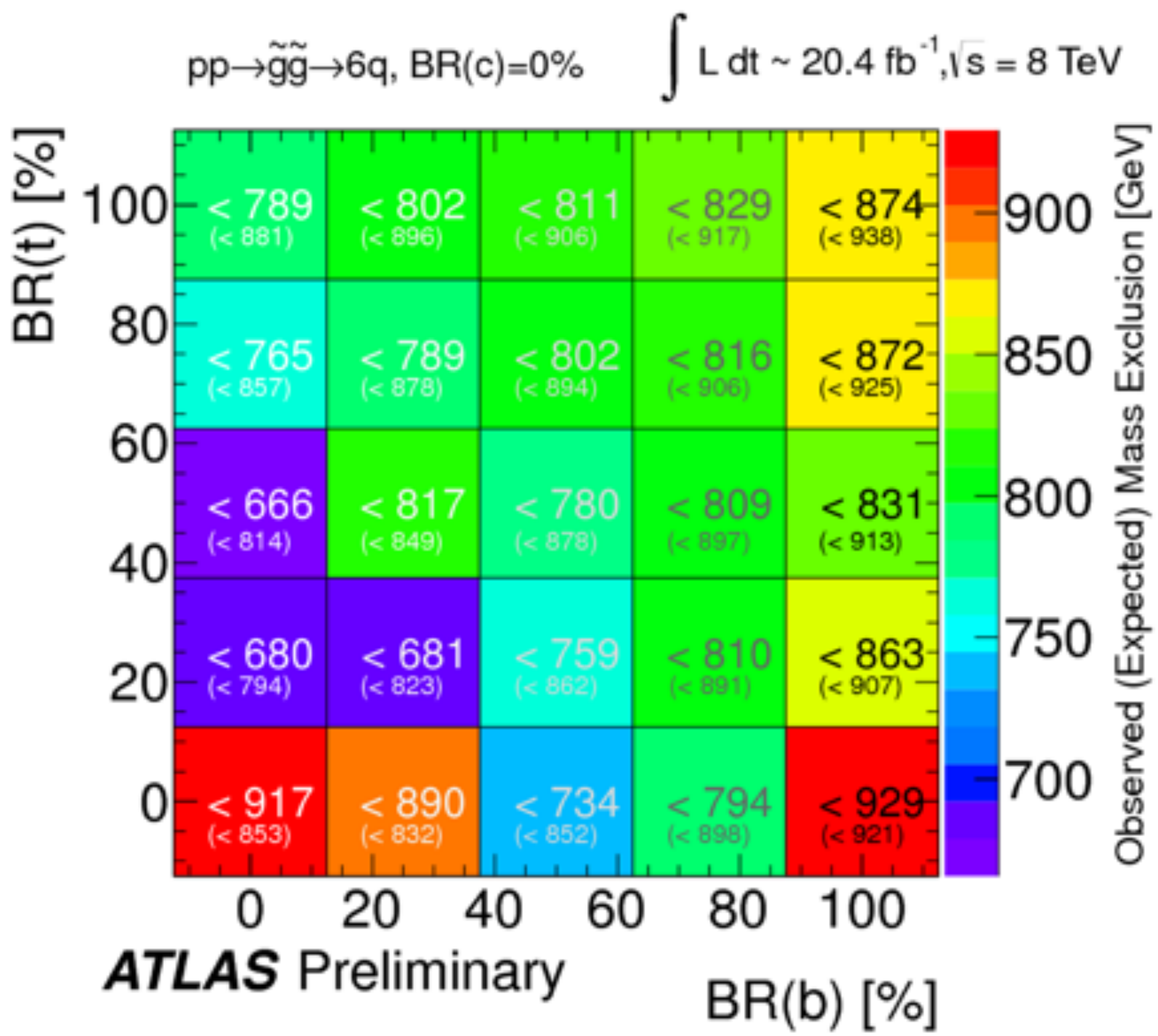
- R-hadrons are composites of a gluino or squark with SM partons
- R-Hadron charge can change during flight, and have a high energy loss
- Results are interpreted with the R-hadrons being stable throughout the ATLAS detector
- Strategy: three different R-hadron searches: “full detector”, “MS-agnostic” and “ID-only”
- No indication of signal over expected backgrounds
- R-hadrons are excluded for masses up-to *985 GeV*, in “full detector” search

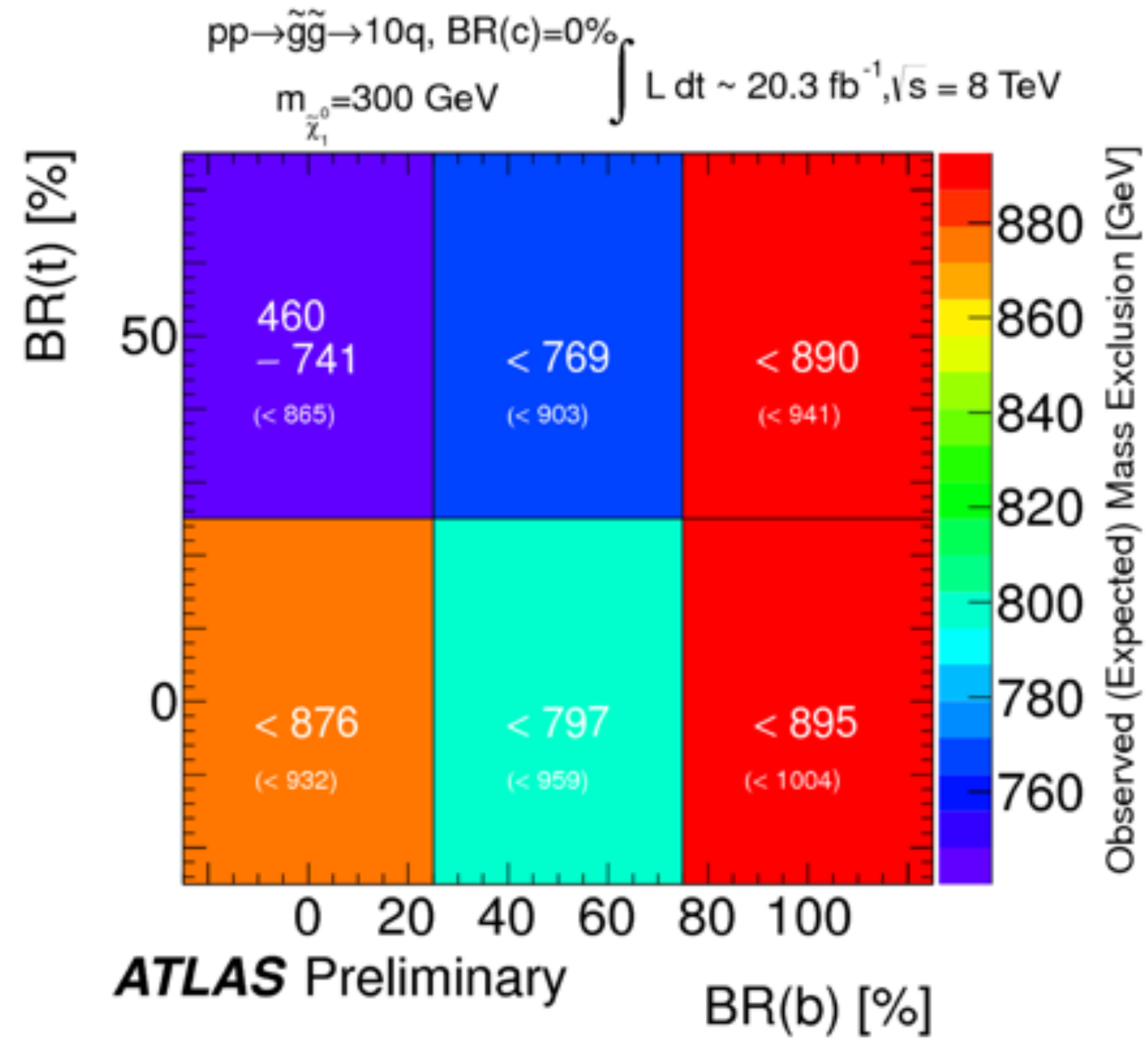




Pair produced massive particles decaying multi-jets

Resolved *20.3 fb^{-1}*

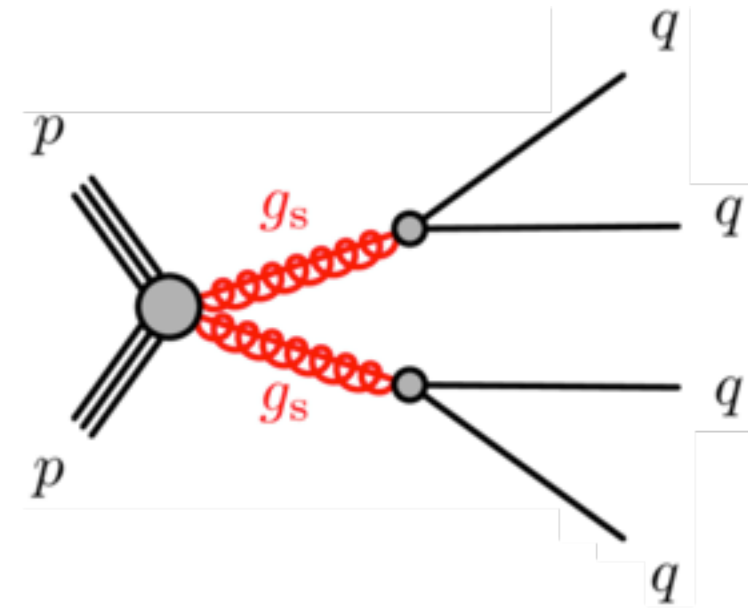


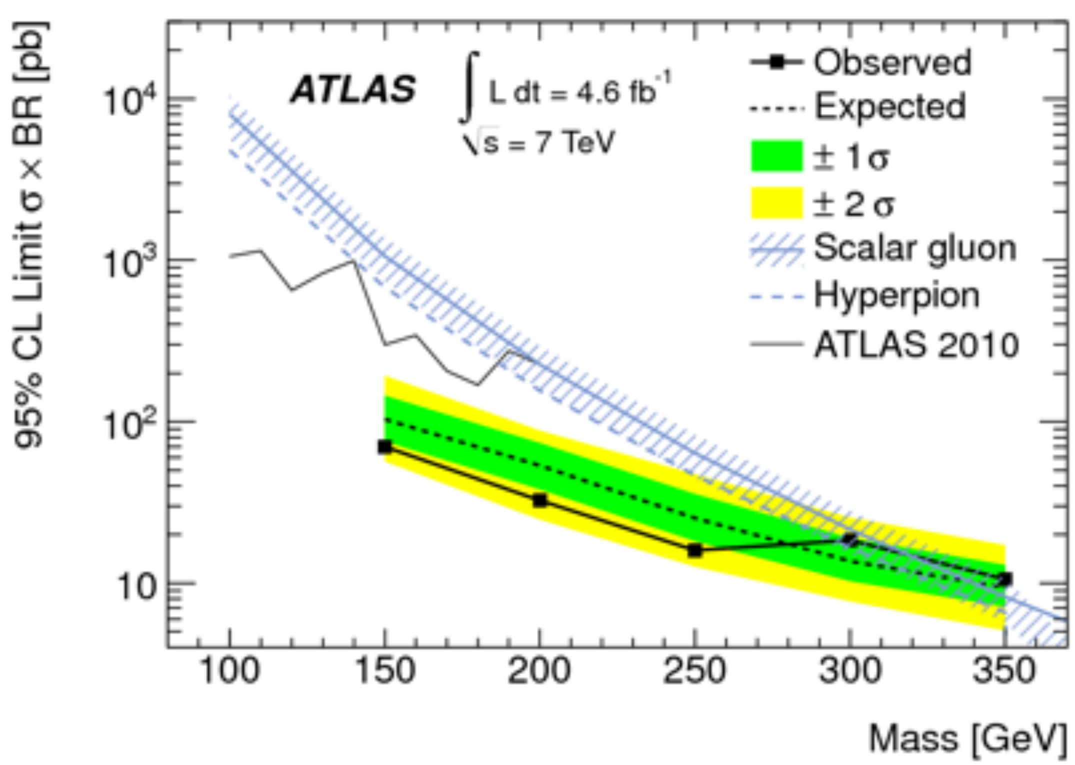


Eur. Phys. J. C (2013) 73: 2263

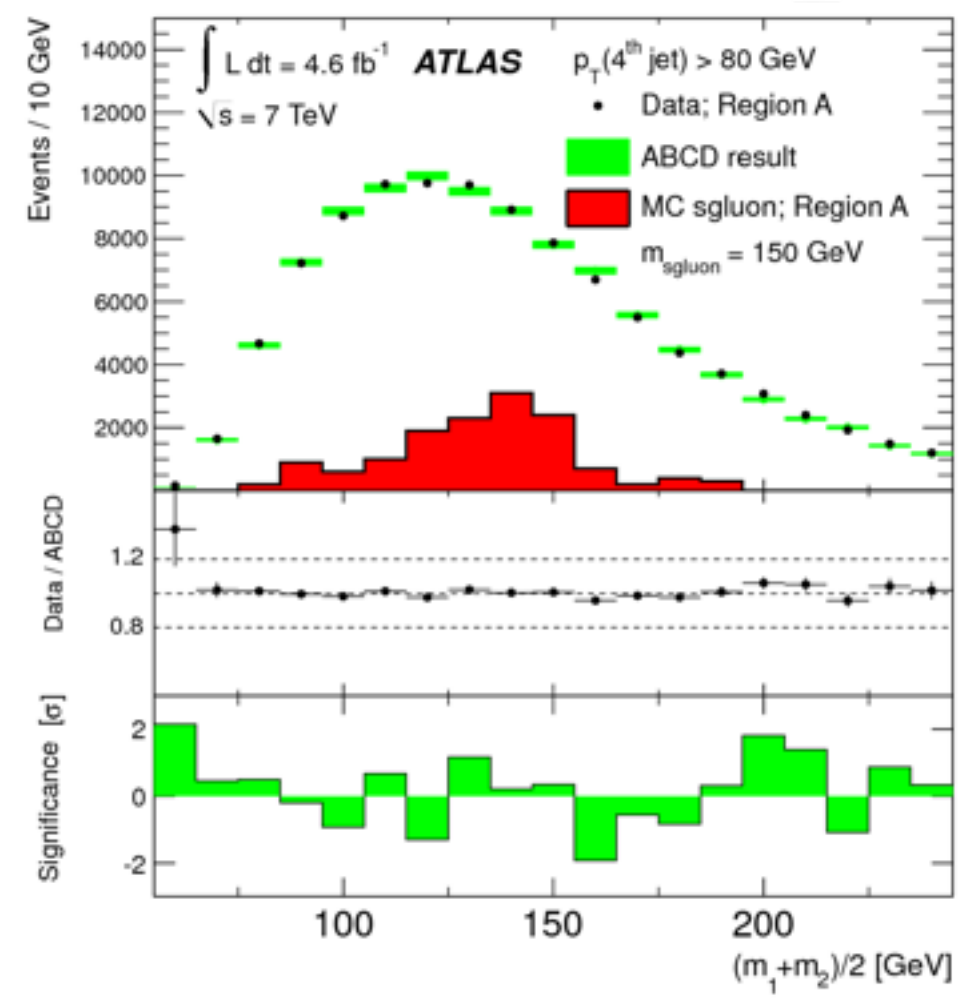
Pair produced massive coloured scalar to four jet, 4.6 fb-1

- Models with massive scalars gluons (sgluons)
  - gluon decays to 2-jet
- Candidates are reconstructed based on jets with $\Delta R < 1$ and similar mass
- Signal region:
  $|m_1 - m_2| / (m_1 + m_2) < 0.15$ and $|\cos\theta^*| < 0.5$



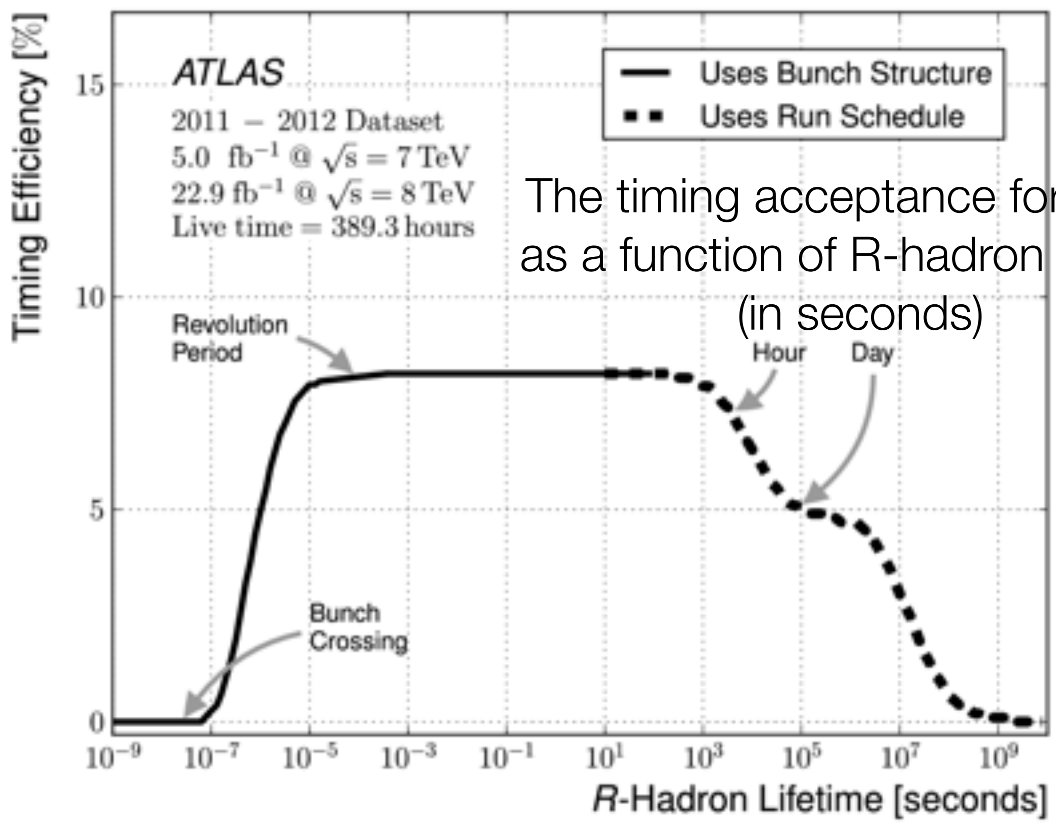


$150\ GeV < m_{\tilde{g}} < 287\ GeV$ **Excluded**

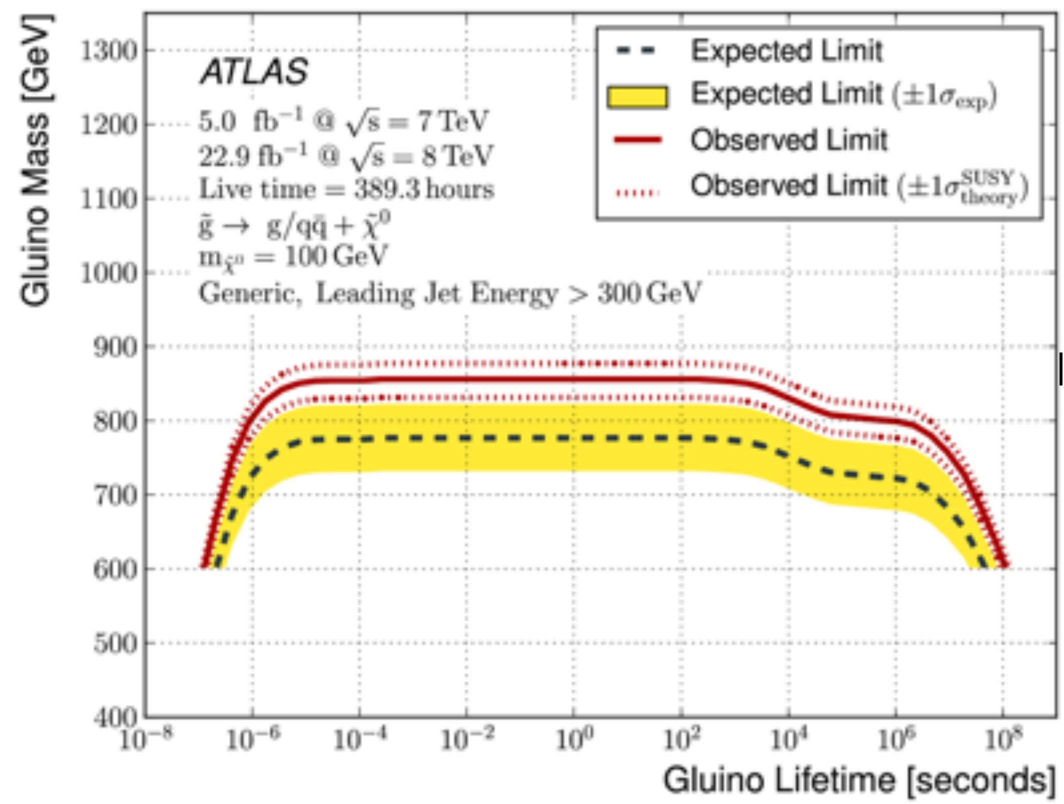


arXiv:1310.6584

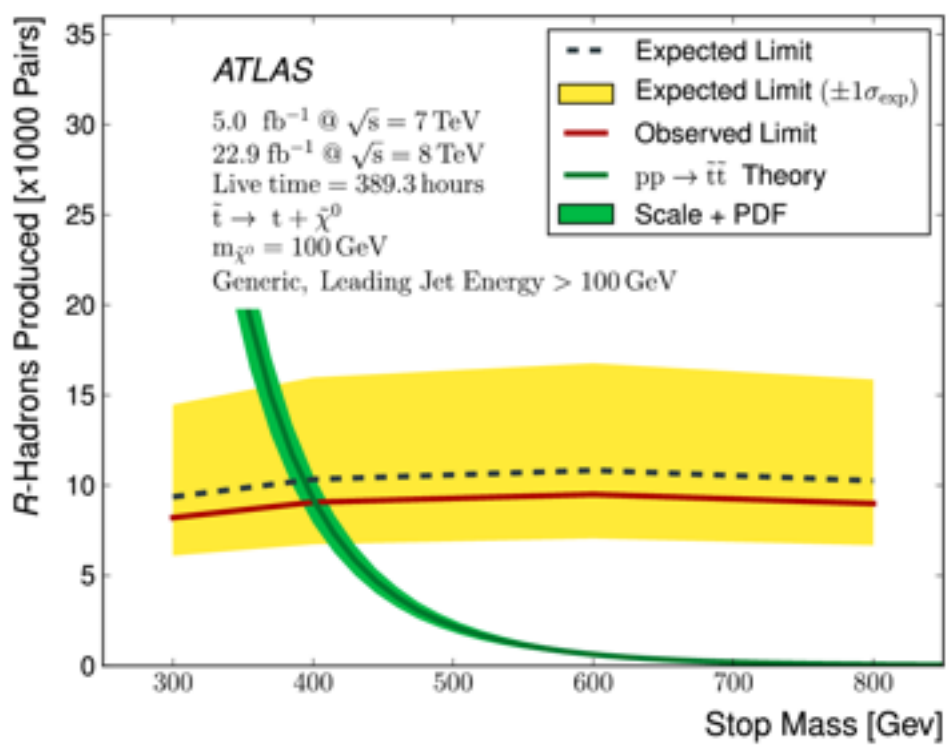
Stopped gluino R-hadron search 5.0 fb-1 @7 TeV 22.9 fb-1 @8 TeV

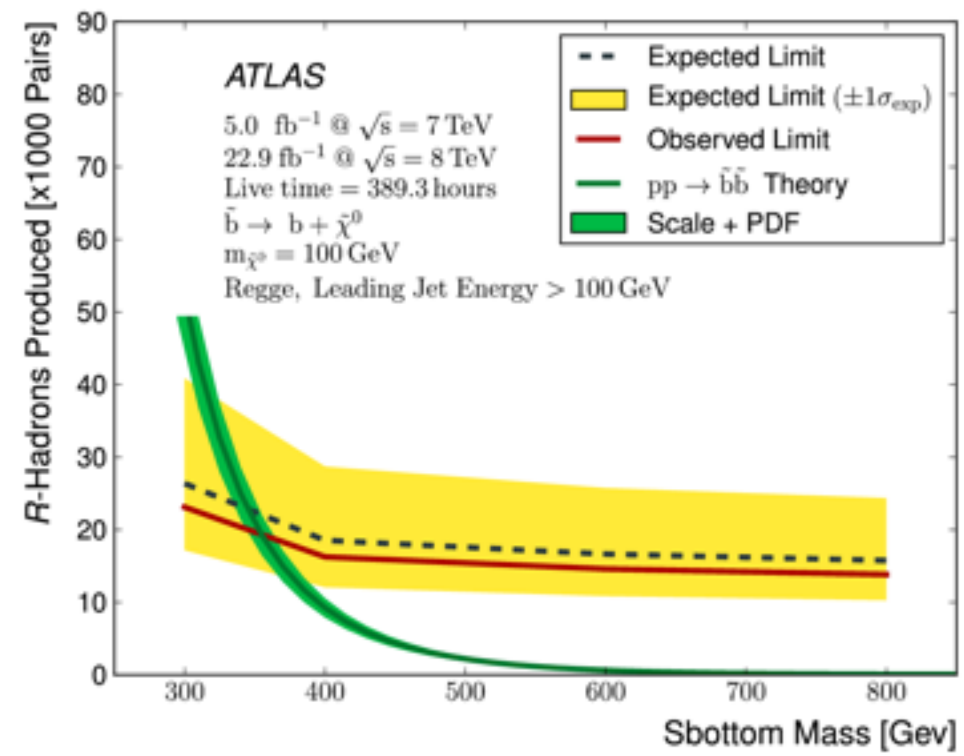


The timing acceptance for signal as a function of R-hadron lifetime (in seconds)

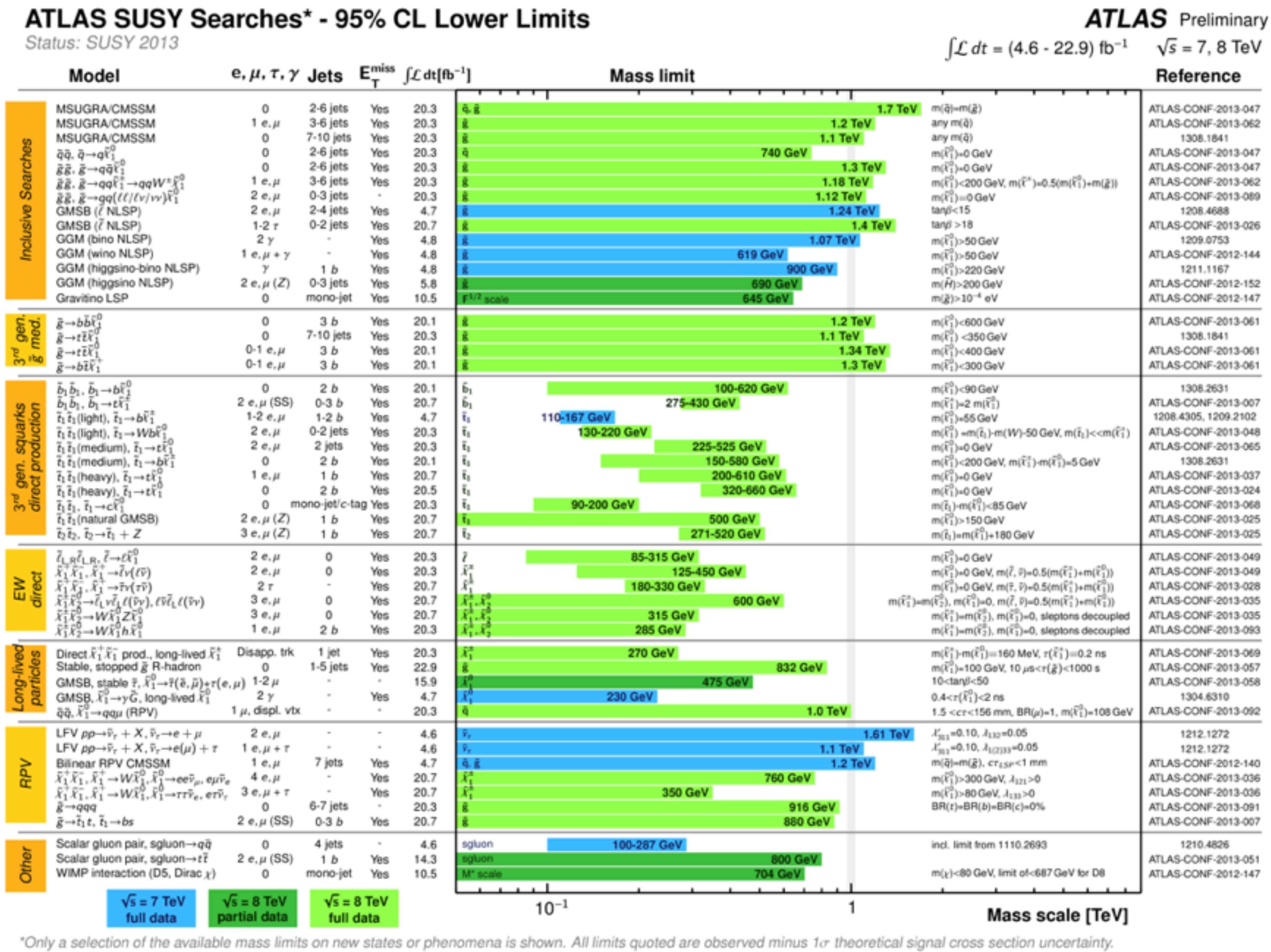


Bayesian lower limits on gluino mass versus its lifetime, for the two signal regions, with R-hadron lifetimes in the plateau acceptance

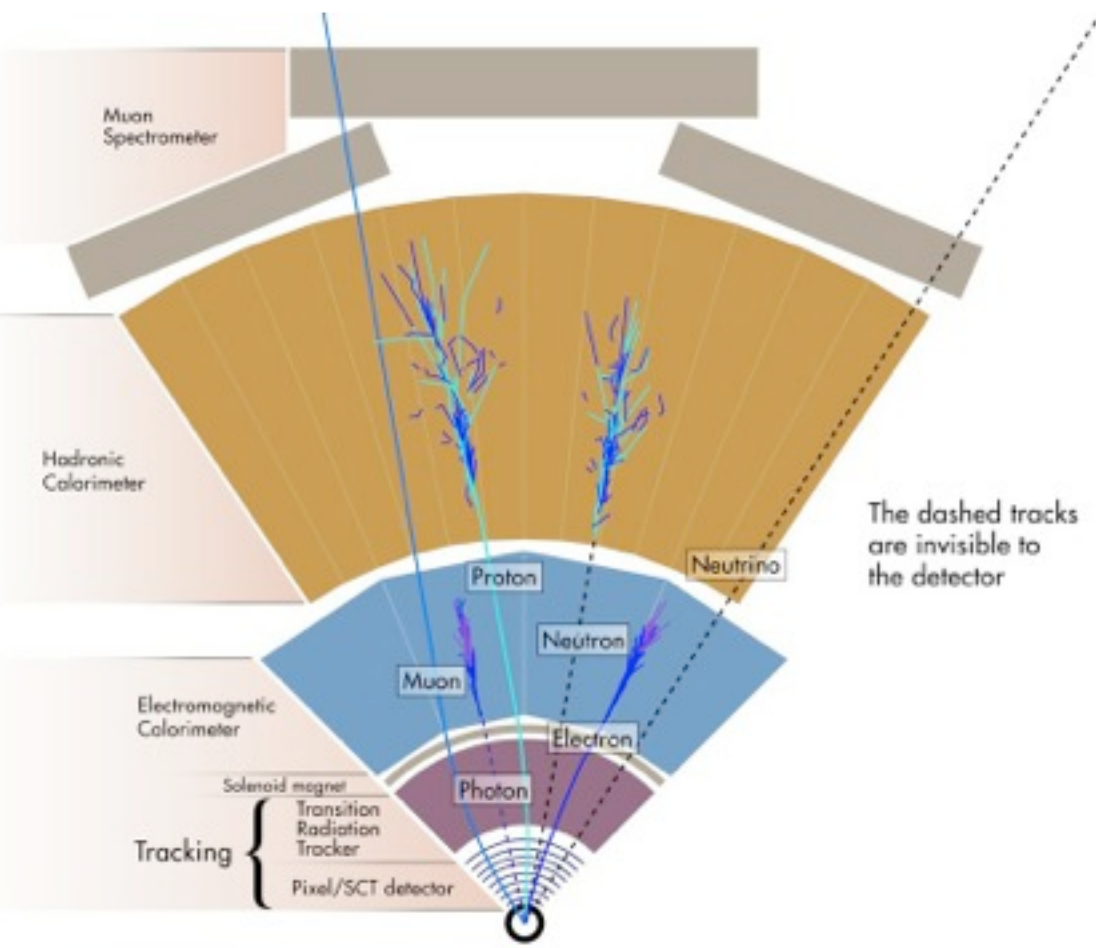


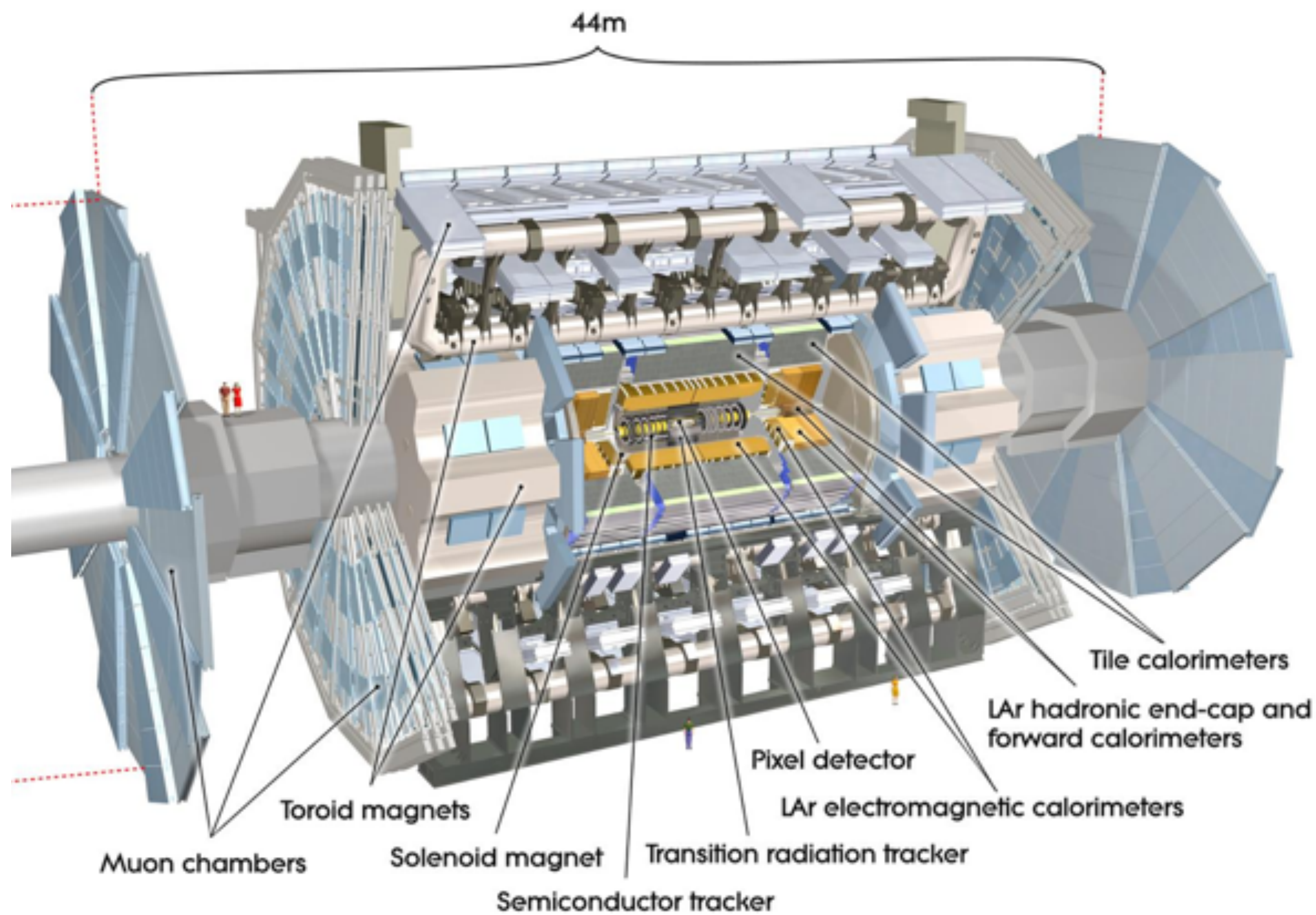


SUSY Searches

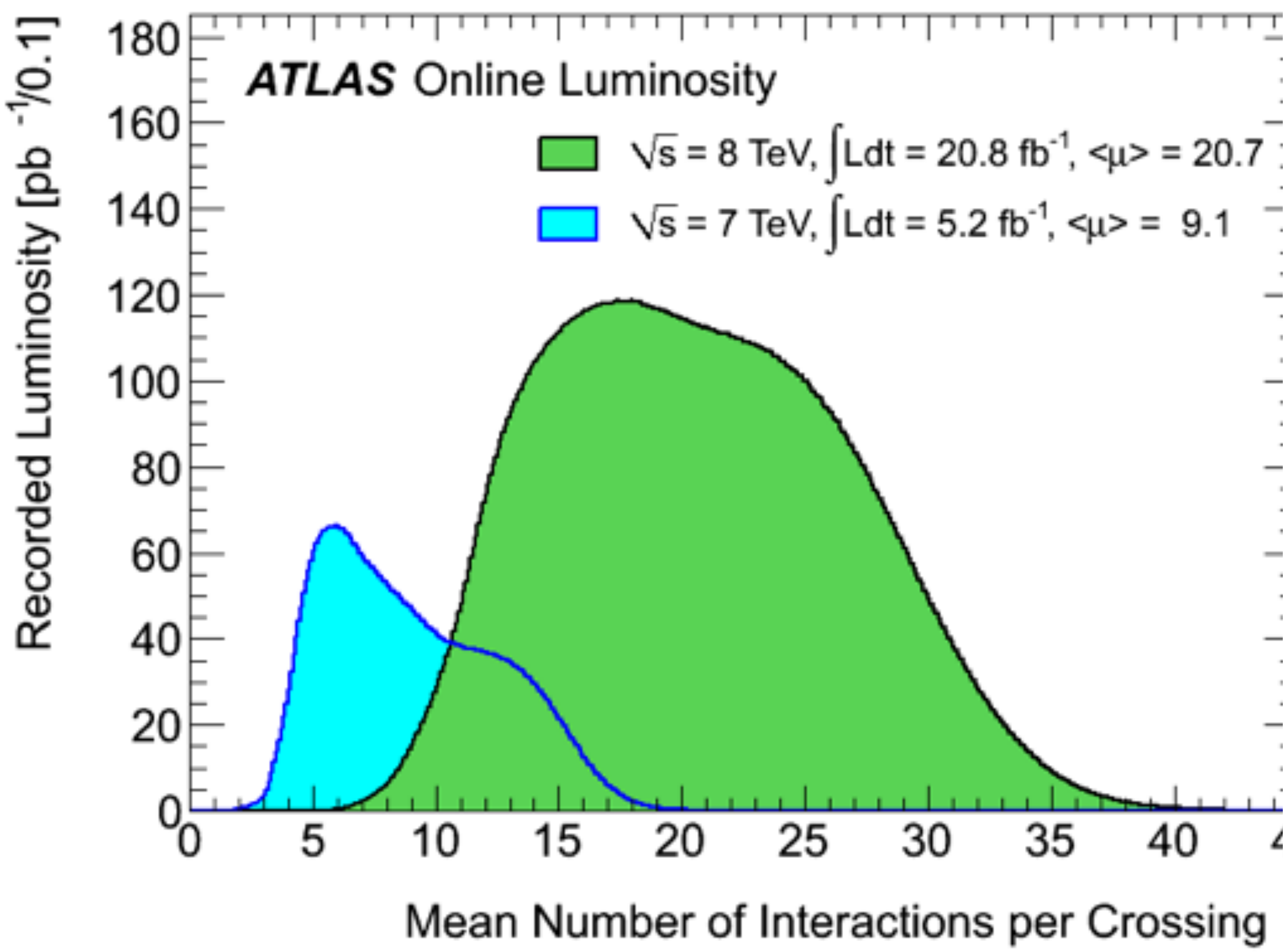


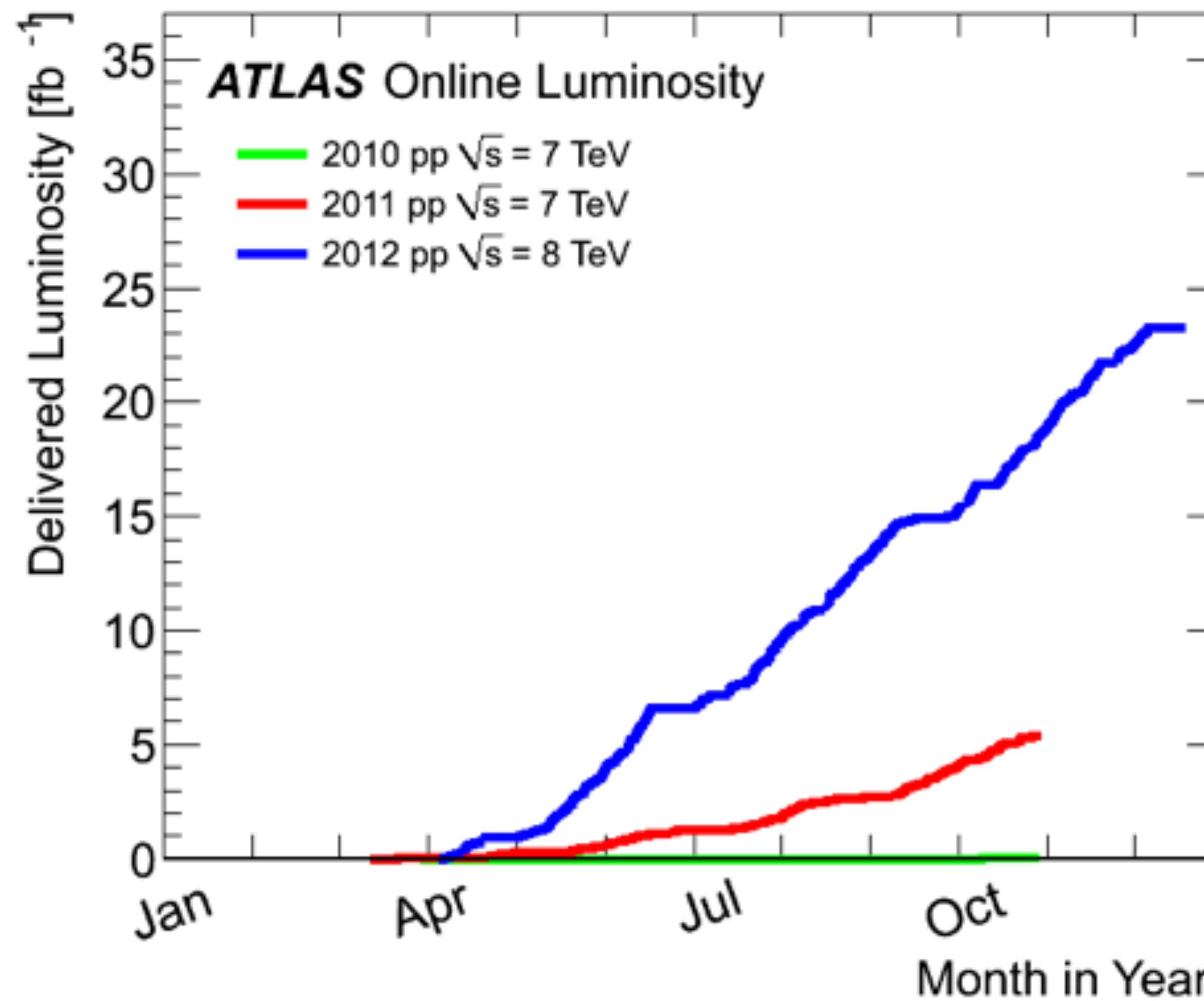
ATLAS DETECTOR





LHC


ATLAS Online Luminosity
$\sqrt{s}$ = 8 TeV, $\int$Ldt = 20.8 fb^{-1}, <μ> = 20.7
$\sqrt{s}$ = 7 TeV, $\int$Ldt = 5.2 fb^{-1}, <μ> = 9.1
Recorded Luminosity [pb $^{-1}$/0.1]
Mean Number of Interactions per Crossing
0
20
40
60
80
100
120
140
160
180
0
5
10
15
20
25
30
35
40


ATLAS Online Luminosity
2010 pp $\sqrt{s}$ = 7 TeV
2011 pp $\sqrt{s}$ = 7 TeV
2012 pp $\sqrt{s}$ = 8 TeV
Delivered Luminosity [fb $^{-1}$]
Month in Year
0
5
10
15
20
25
30
35
Jan
Apr
Jul
Oct