Long-lived particle searches at ATLAS

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Exotic long-lived particles

- Categorise putative LLPs in terms of experimentally relevant charge quantum numbers.

Electric charge	Colour charge	Magnetic charge	Signature	Example in theory
$\|Q\|>e$	-	-	**Very highly ionising, slow**	**Q-ball, black hole**
$Q=e$	-	-	**Highly ionising, slow**	**Slepton (SUSY)**
$Q=0,1/3e,2/3e$ ↓ $Q=0.e,2e$	**Octet,triplet**	-	**Highly ionising, slow, charge exchange**	**R-hadrons, LQ-hadrons**

- Lifetime and decay topologies unconstrained
  - Displaced vertices , out-of-time decays, stable massive particles
  - Long term goal to search over fullest range of mass, charges, and lifetimes.

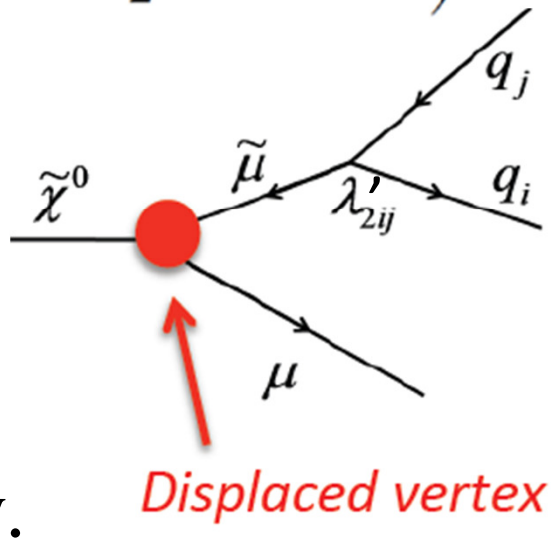
Displaced vertices

Assume RPV-SUSY scenario

$$W_{\mathrm{RPV}} = \sum_i \mu_i L_i H_u + \sum_{i,j,k} \left(\frac{1}{2} \lambda_{ijk} L_i L_j E_k^c + \lambda'_{ijk} L_i Q_j D_k^c + \frac{1}{2} \lambda''_{ijk} U_i^c D_j^c D_k^c \right)$$

Non-zero $\lambda' \Rightarrow$ L-violating

Tag muon (trigger) and look for secondary vertices from jets.

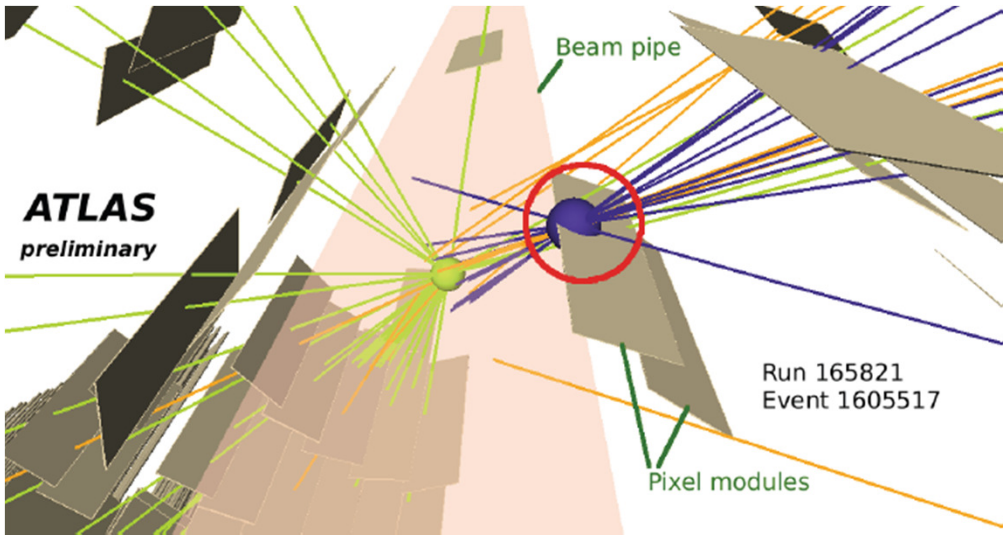


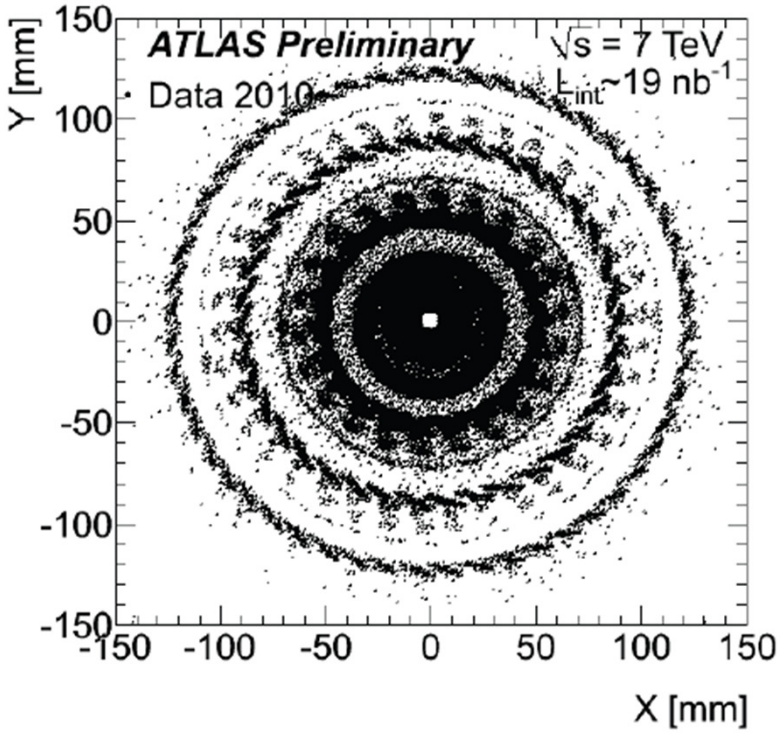
Generic approach for above topology.

Decay vertices at z and radii up to ~ 300 and 180mm

$\Rightarrow$ within ATLAS pixel detector.

Material interactions





Background vertices dominantly from hadronic interactions with detector material.

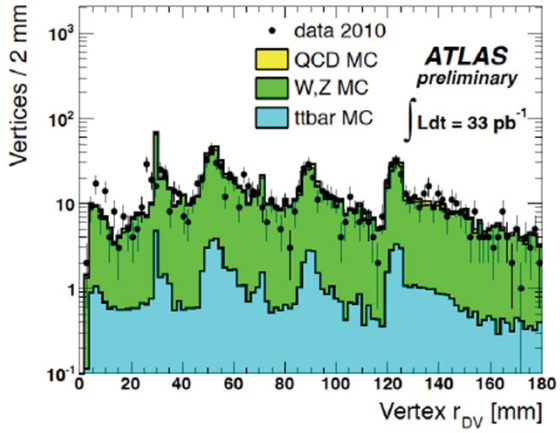
Typically low mass but extra tracks can be misassignedwith high mass vertices.

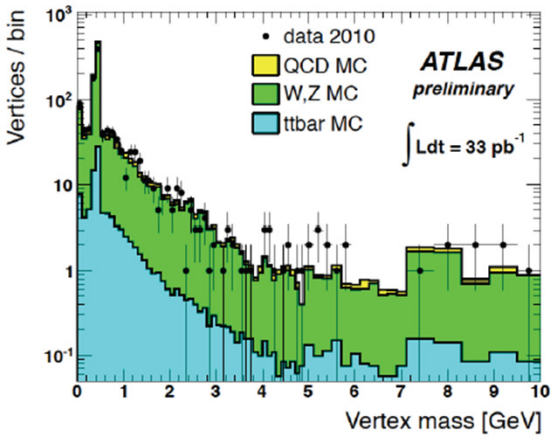
Veto material interactions with material map from 2010 data.

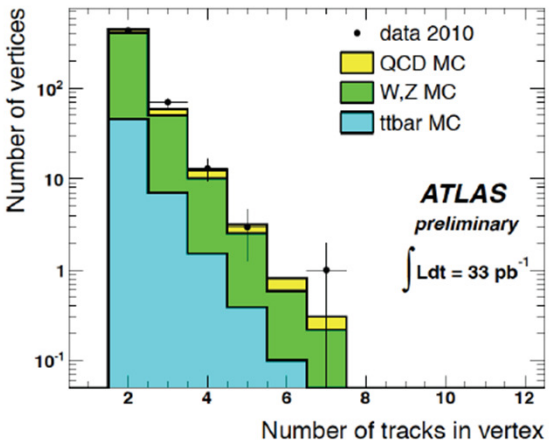
Simulation vs data

Employ loose selection for data-simulation comparison

- Two-track vertices
- Low vertex mass< 10 GeV
- Before material veto

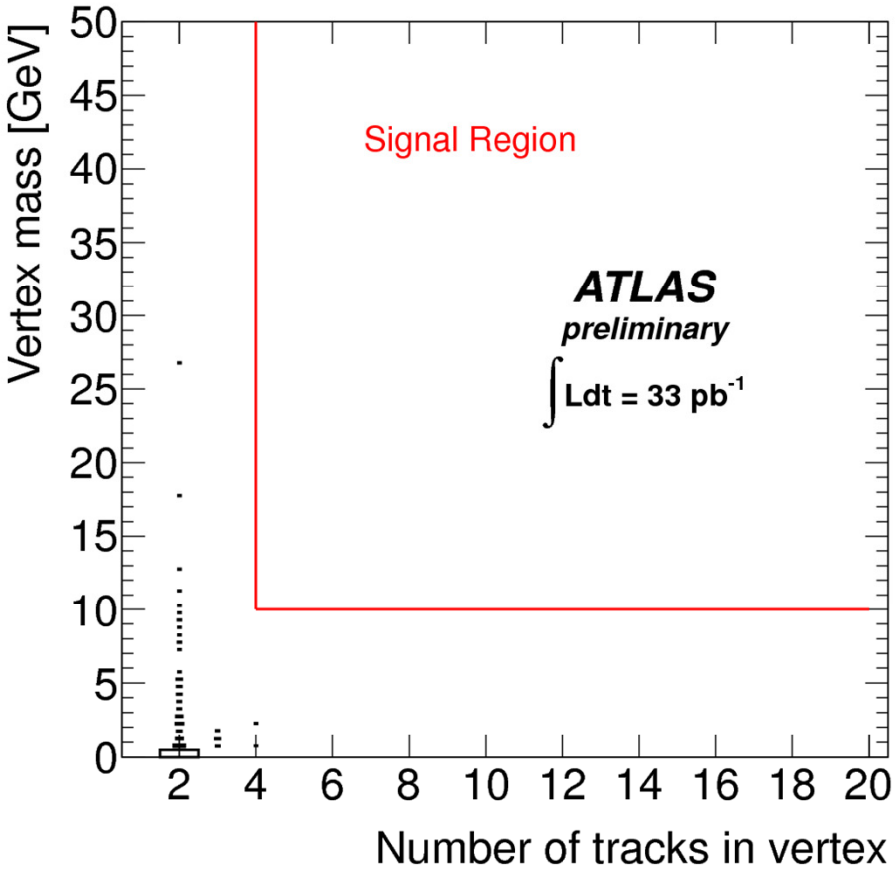


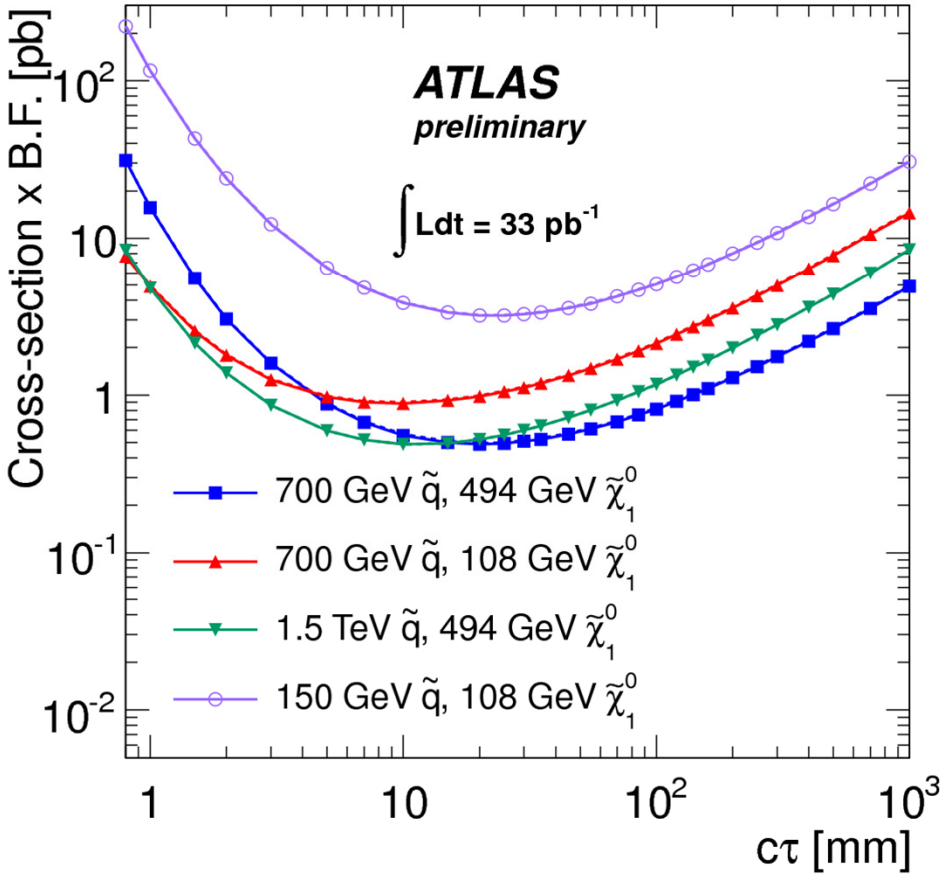




Excellent agreement in shape and yield.

Results





Signal region defined with vertex mass and track-multiplicity

Upper limits at 90% C.L. as function of cτ for different SUSY mass splittings scenarios.

Tiny BG - W,Z, dijet, $t\bar{t}$

Stopped gluinos

LLP can be stopped in dense calorimeter material by electromagnetic (and hadronic) interactions

Consider Split-SUSY, eg meta-stable gluino in R hadron.

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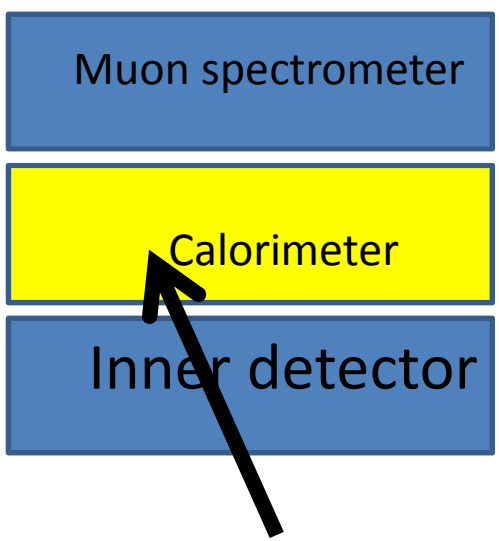
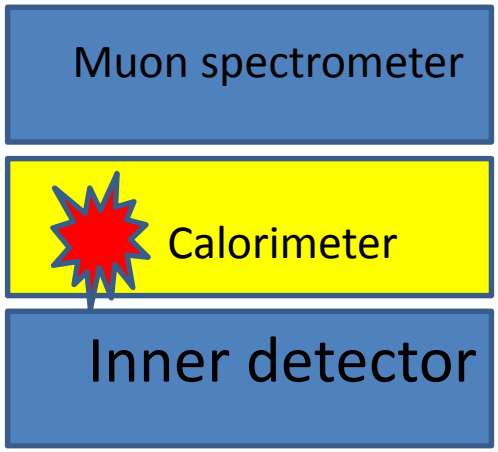
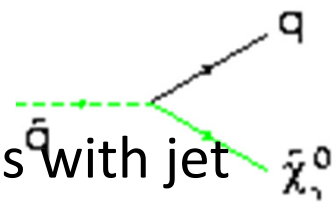


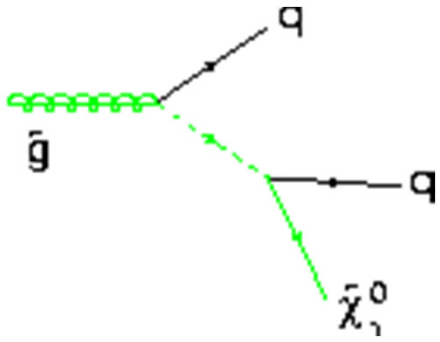


Stopped R-hadron subsequently decays.

Observe decays in empty bunches with jet trigger (E_T> 10GeV, HLT: E_T> 25 GeV)

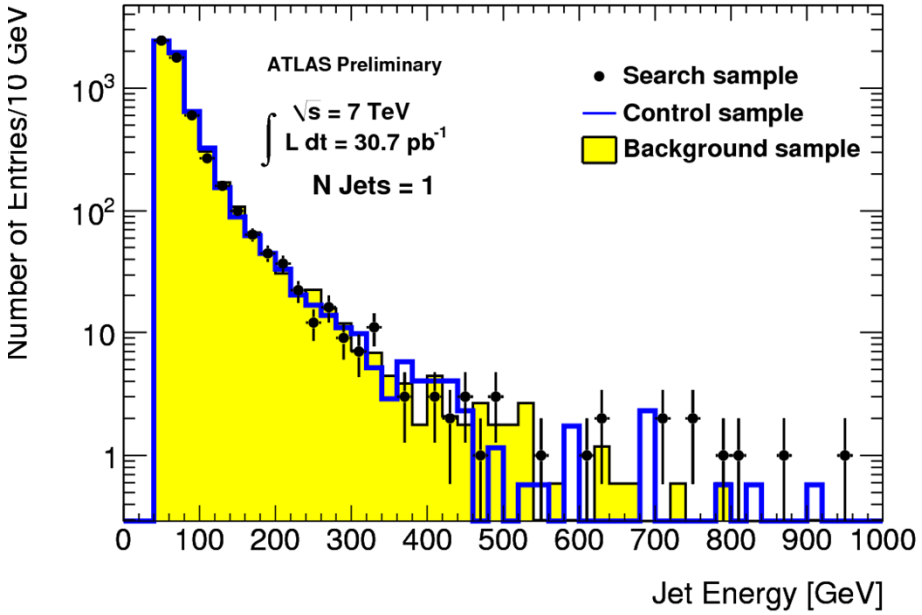
Lifetime range ~ 10^{-5}-10^{3}s



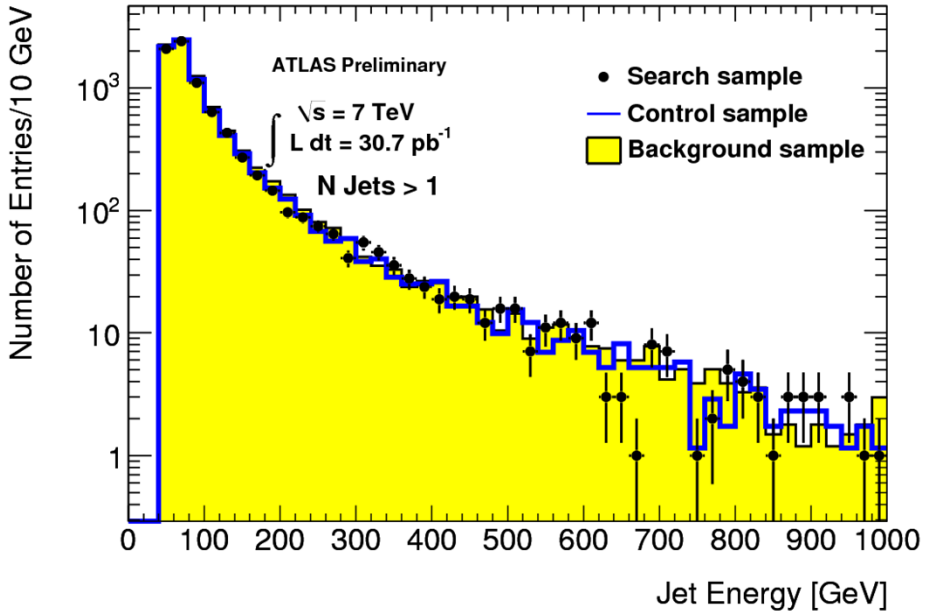


Stopped gluinos

- 3 samples : bg (low inst lum.), control sample ,signal sample
- 31pb-1
- Beam, detector and DQ selections
- Muon veto and jet cleaning selections.
- 1 jet and > 1jet samples (E_T> 50GeV)
- BG from cosmic muons, halo muons, calo noise .

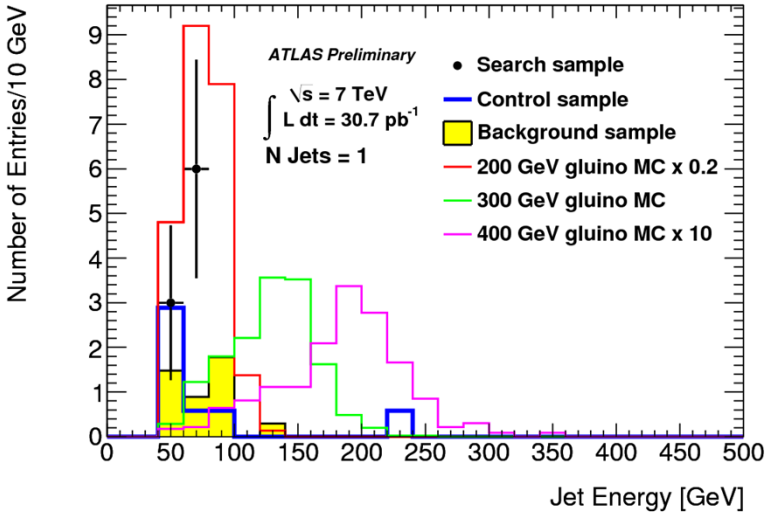


Singlet jet energy (no muon veto)

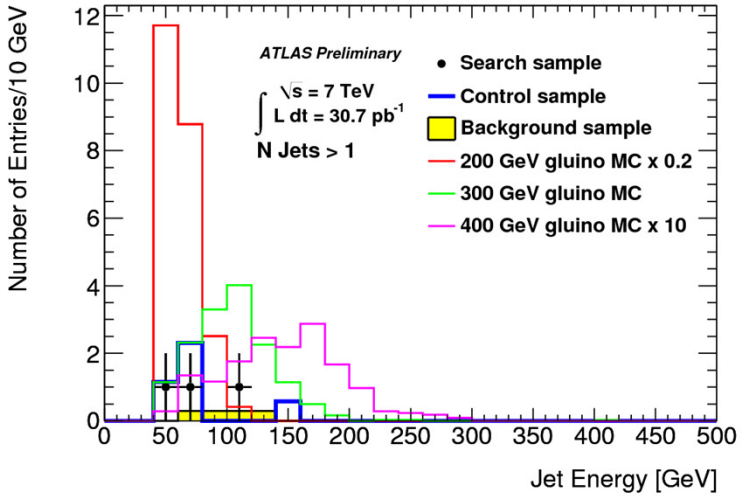


Leading jet energy (no muon veto) in multijet sample

Jet energy after all selections



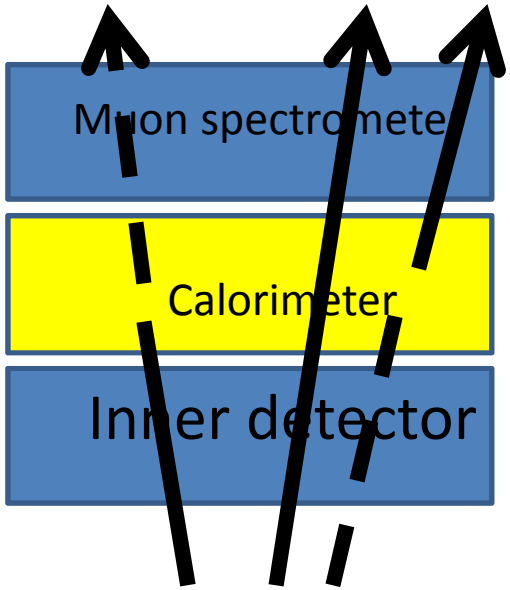
Single jet energy



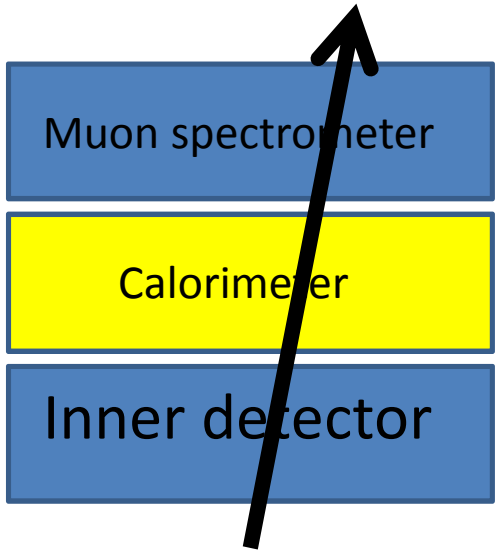
Leading jet energy (multijet sample)

Sensitivity to gluino masses in 300-400 GeV range.

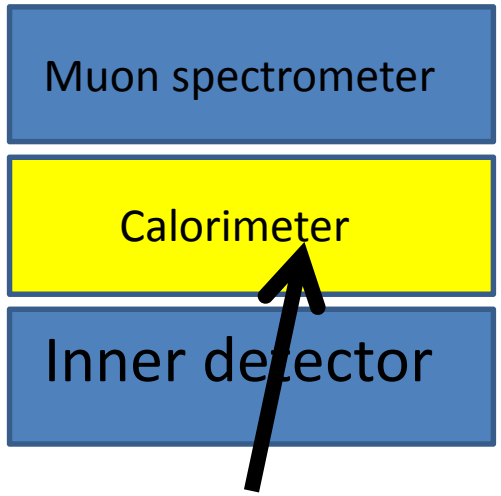
Non-decaying long-lived particles



Heavy hadronic object
R-hadron can be dominantly neutral before (~gg) or after (charge exchange) calorimeter.
Muon and muon-agnostic searches needed.



Heavy lepton-like object
Penetrating muon-like



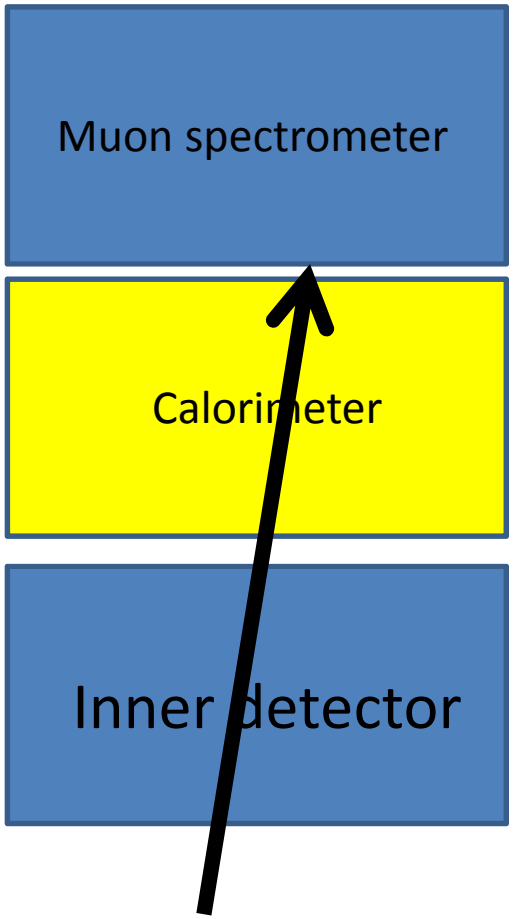
Heavy multi-charged object (|q|>>e)

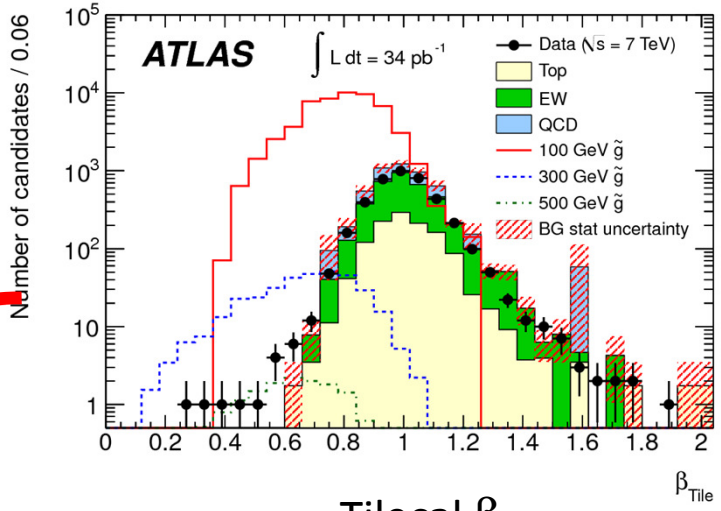
Very highly ionising.
Stop in or before electromagnetic calorimetrer

Interpret within SUSY framework

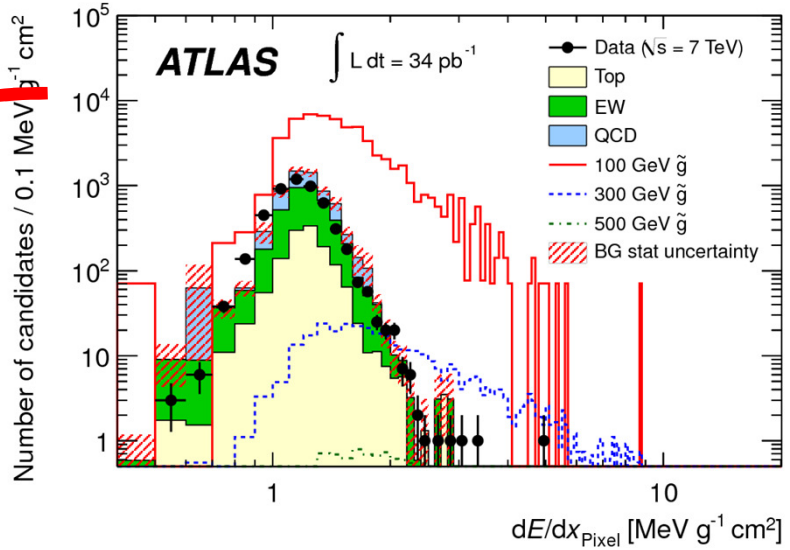
Generic search

Muon-agnostic search





Tilecal β



Pixel dE/dx

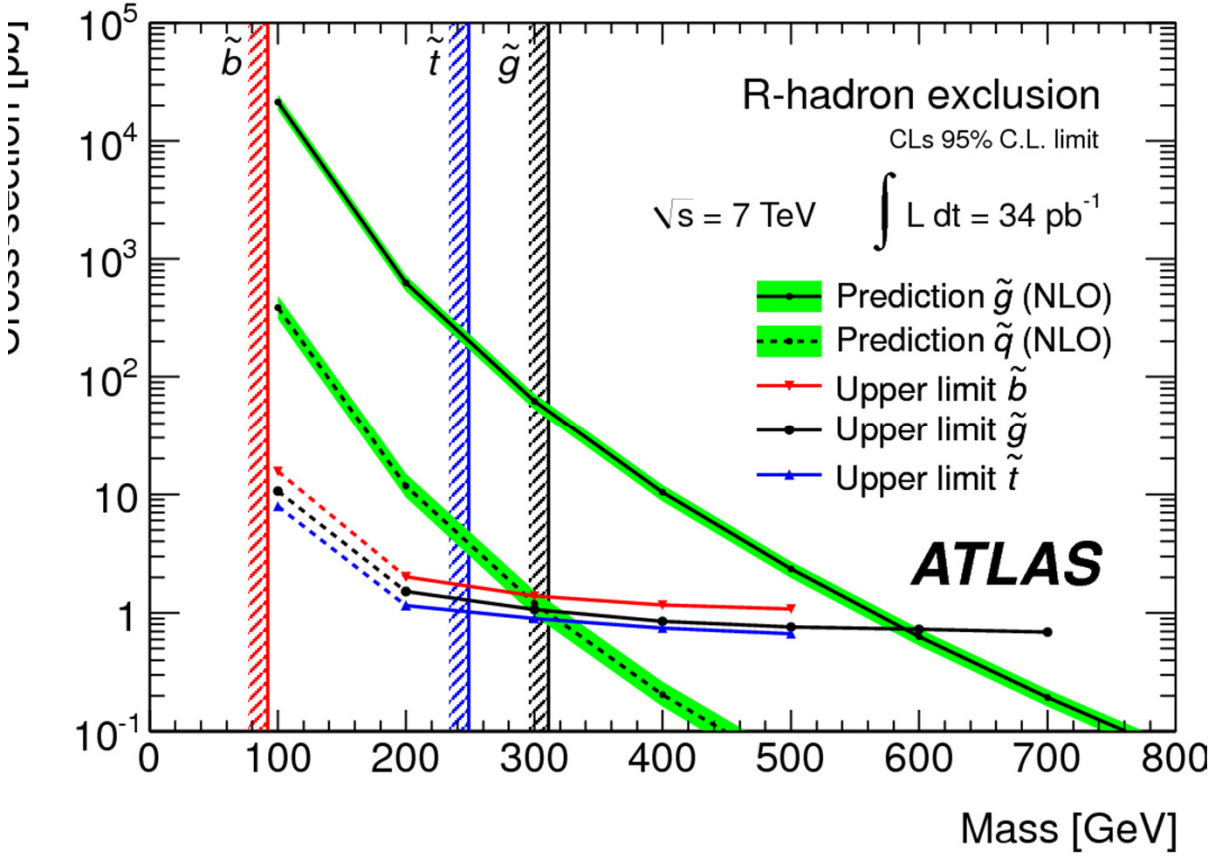
34pb-1

Use TileCal and pixel detector as timing-sensitive detectors

High pt (pt>50 GeV) candidates with MET

Data-driven BG approach.

Results from muon-agnostic LLP search



Mass limits (95% CL)

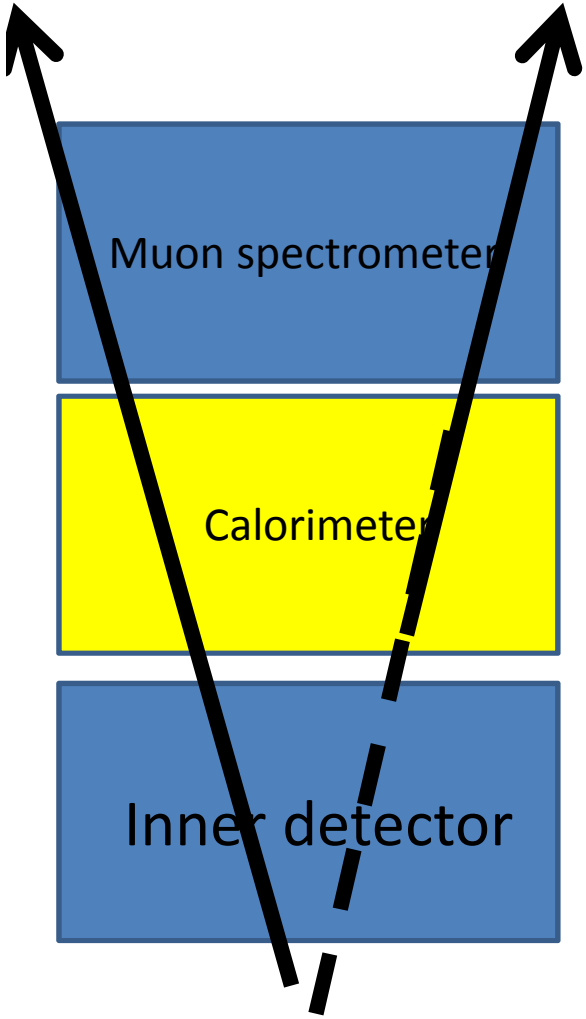
$\tilde{g}$ 562-586

$\tilde{t}$ ($\tilde{b}$) 309 (294) GeV

Direct pair production assumed.

arXiv:1103.1984 [hep-ex]

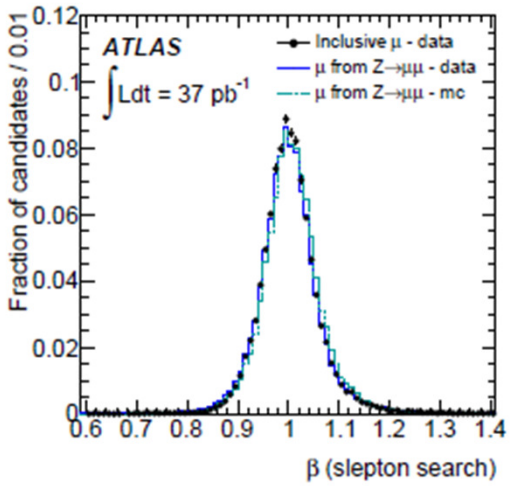
Muon-like LLP search

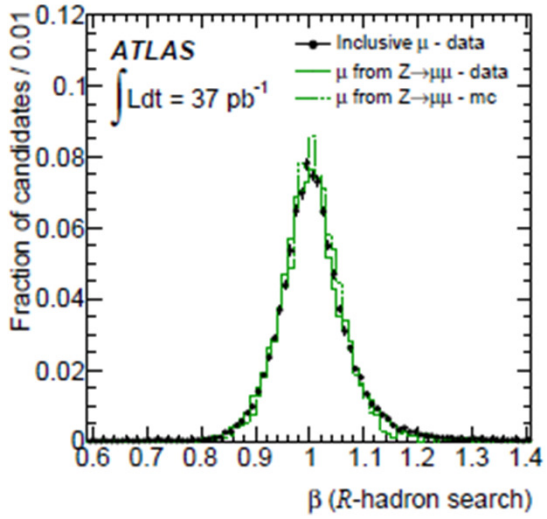


Heavy lepton-like object
Penetrating slow muon

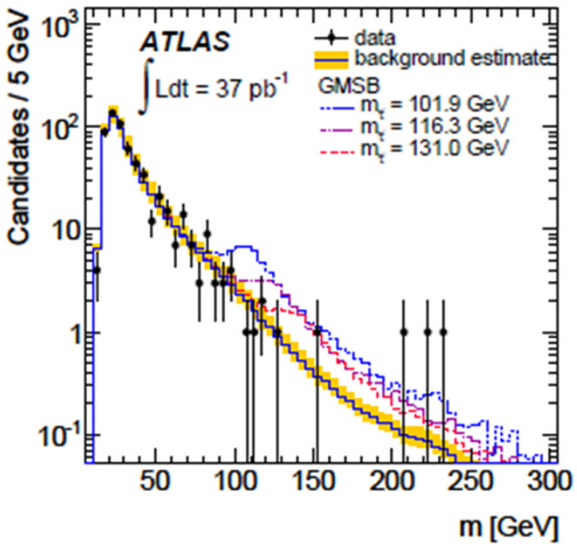
Muon-like SMPs
Two analyses:

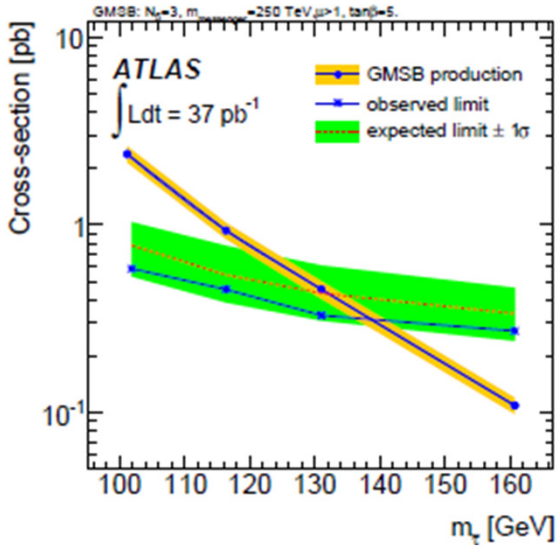
- Slepton-like object visible throughout detector
  - MS+ID : β from MS+Tile
- R-hadron (visible in whole detector or appearing only in MS)
  - MS





Results of muon-like LLP search



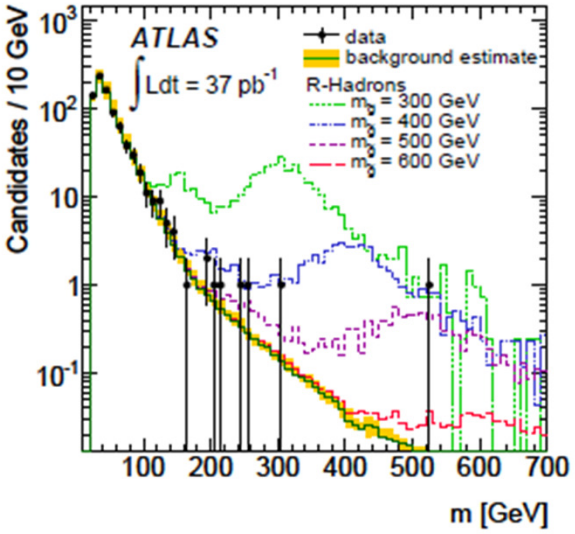


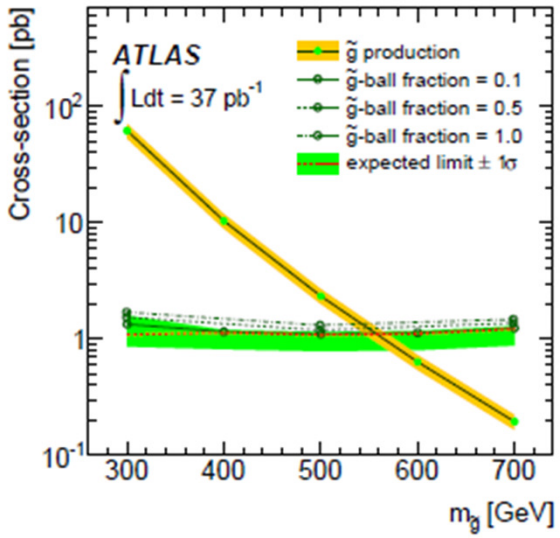
GMSB scenario

$\tilde{\ell}$ mass (95 % CL)

>136 GeV (all prod.)

> 110 GeV (EW prod.)





$\tilde{g}$ mass (95% CL)

> 544 GeV ($f_{\tilde{g}g} = 0.1$)

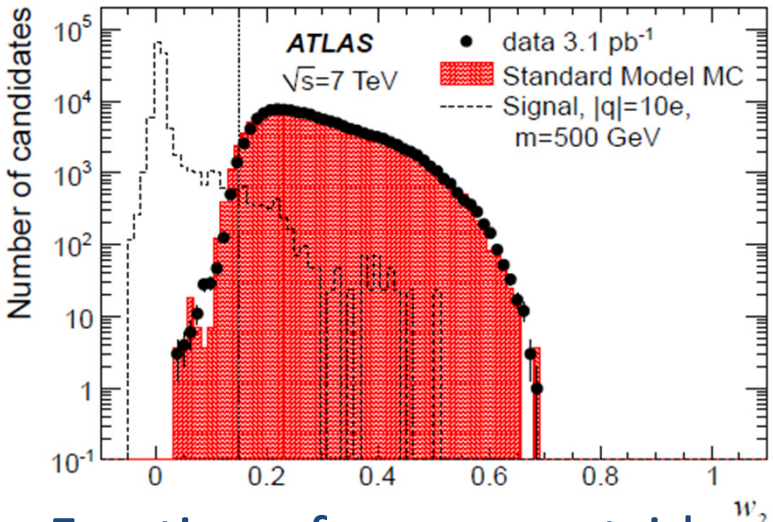
> 537 GeV ($f_{\tilde{g}g} = 0.5$)

> 530 GeV ($f_{\tilde{g}g} = 1.0$)

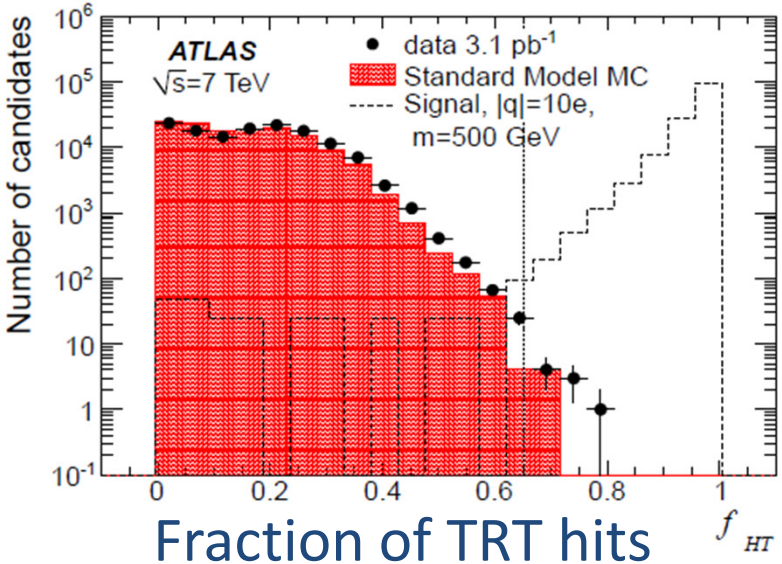
arXiv:1106.4495 [hep-ex]

Search for multicharged LLPs

Electron-like object with high ionisation and narrow cluster



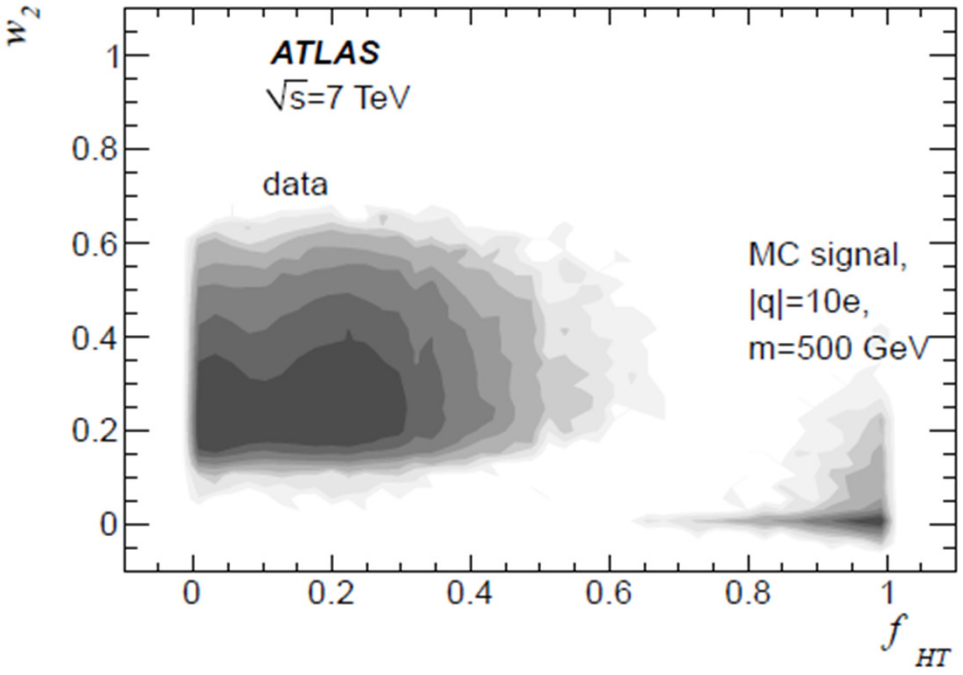
Fraction of energy outside of the 3 most energetic cells in second LAr layer ω_2



Fraction of TRT hits which are high threshold f_{HT}

Sensitivity to 6e<|q|<17e

Multicharged LLPs



Cluster E_T>15 GeV

ω_1 < 0.20

ω_2 < 0.15

m [GeV]	$\|q\| = 6e$	$\|q\| = 10e$	$\|q\| = 17e$
200	11.5	5.9	9.1
500	7.2	4.3	5.3
1000	9.3	3.4	4.3

Upper limits (pb) at 95% CL on pair production of multicharged LLPs at 95% CL

arXiv:1102.0459 [hep-ex]

Summary

- Search for heavy exotic particles with long lifetimes essential part of ATLAS search strategy.
- Featured in many BSM theories
- Searches made for stable and late decaying particles
- Limits on particles with range of electric and colour charges for different lifetimes taking into account different possible detector interactions and final state topologies.