Searches for stopped gluinos and long-lived charged sparticles at ATLAS

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Introduction

- Several SUSY scenarios predict existence of Long-Lived Particles (LLPs).
  - e.g. Weak RPV couplings, split SUSY, GMSB with small mass differences.
  - Heavy particles could be sleptons, or “R-hadrons”, where a coloured sparticle hadronises with SM quarks.
  - Can be slow-moving ($\beta < 1$), highly ionizing.
    - R-hadrons can also change charge as they traverse the detector, as quarks take part in nuclear interactions.
- Will describe three analyses here, all using 2010 dataset:
  - Stable massive charged particle search
    - “Muon agnostic” search, based on 34pb^{-1} PLB 701 (2011) 1
    - “Muon spectrometer based” search, based on 37pb^{-1} PLB 703 (2011) 428
  - Stopped particle search, based on 33pb^{-1}

Charged LLP searches

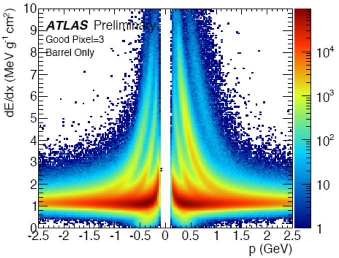
- ATLAS has several sub-detectors that could potentially identify slow-moving, highly-ionizing particles:
  - Pixel : innermost part of Inner Detector (ID), 3 barrel layers plus 3 endcap disks per side, can measure dE/dx.
  - TRT (Transition Radiation Tracker) - straw tracker, outermost part of inner tracking system, can measure dE/dx via time-over-threshold.
  - Tile calorimeter: Sampling calorimeter, forming the barrel part of the ATLAS hadronic calorimeter. Excellent time resolution ($\approx 1\mathrm{ns}$) - can measure β via time-of-flight.
  - RPC (Resistive Plate Chambers) - part of the muon spectrometer (MS), delivering fast trigger information for muons traversing the barrel (intrinsic time resolution $\approx 1\mathrm{ns}$).
  - MDT (Monitored Drift Tubes) - precision muon momentum measurements in the barrel region. Segment reconstruction uses known drift time - drift distance relation, will be skewed if particle arrives late.
- Divide into two separate analyses - one using Pixel and Tile (with TRT as a cross-check), and one based primarily on MS information.

Calo + ID based LLP search - strategy

- R-hadrons typically only deposit small fraction of energy in the detector.
  - Trigger on missing E_T
- Require central ($|\eta| < 1.7$), high-p_T ($> 50\mathrm{GeV}$) ID track, associated to Tile cluster, and isolated from jets.

Pixel

- Use Bethe-Bloch to calculate mass from measured dE/dx and momentum.

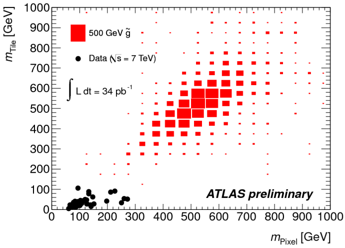


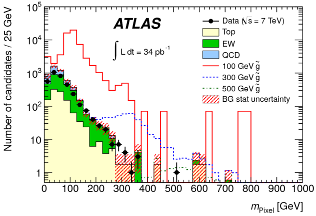
Tile

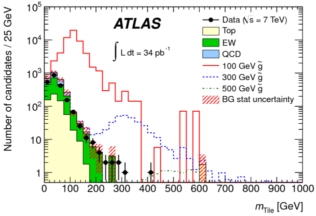
- SMPs would tend to traverse entire Tile calorimeter, giving independent measurements in up to six cells, each of which has time resolution $1 - 2\mathrm{ns}$.
- Correct measured times to account for drifts in LHC clock.
- Calculate mass from $p = \beta\gamma m$

Calo + ID based LLP search - background

- Main background is from tails in β and dE/dx distributions due to instumental effects.
- Use data-driven method to estimate background, exploiting lack of correlation between p, dE/dx, and β measurements.
- Sample randomly from p, dE/dx, and β distributions and combine values to get mass estimates.





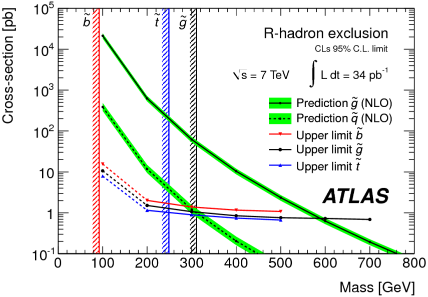


Calo + ID based LLP search - results

Cut	Data	Background	600 GeV $\tilde{g}$ signal
Preselection	49205	49.4×10^3	4.13
$p_T > 50\mathrm{GeV}$	5116	6.56×10^3	3.95
1 mass cut	36	56.0	2.73
both mass cuts	0	0.028	2.62

Systematic uncertainties of 17-20% on signal (lumi, E_T^{miss} scale), and 30% on background (dE/dx and β distributions, and normalization method).

- No excess observed - set limits



Exclude

$m_{\tilde{g}} < 562 - 586\mathrm{GeV}$
$m_{\tilde{t}} < 309\mathrm{GeV}$
$m_{\tilde{b}} < 294\mathrm{GeV}$

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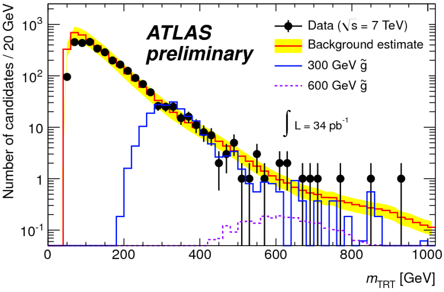
Calo + ID based LLP search - cross-check with TRT

- Slight correlation between mass estimate from TRT time-over-threshold and momentum.
- Estimate background by combining dE/dx and momentum values randomly sampled from a PDF that takes correlation into account.



- No signal observed, consistent with Pixel+Tile measurement.

Muon spectrometer-based LLP search - strategy

- Trigger on high-p_T muon candidate.
- Use time-of-flight in RPC, and find the value of β that gives the best fit to drift times in MDT tubes.
- Optimize two sets of search criteria:

sleptons

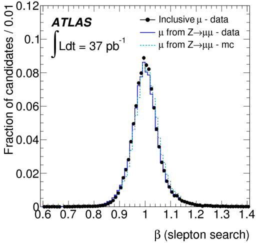
- In GMSB scenario, $\tilde{\tau}$ LSP, would look like heavy muon.
- Require ID and MS track ($p_T > 40\mathrm{GeV}$).
- Require two candidates per event (as sleptons pair-produced), and veto invariant mass of combination around Z-mass.

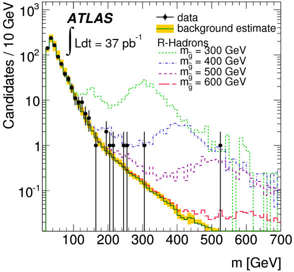
R-hadrons

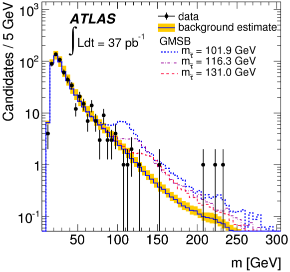
- $\tilde{g}$ R-hadrons, may not be charged when traversing ID.
  - Do not require ID track (but use one if it's there).
  - Complementary to ID+Calo-based search.
- Interpret in framework of split-SUSY.

Muon spectrometer-based LLP search - background

- Backgrounds come from high-p_T muons with mis-measured β.
- Use data-driven estimate - for each candidate, combine measured p with a β value randomly sampled from β PDF.
- Use different PDF for different η.



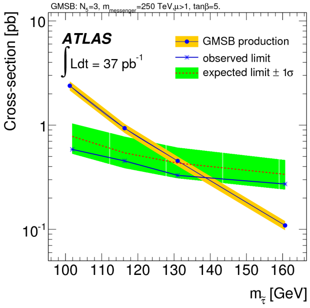




Muon spectrometer-based LLP search - slepton results

$m(\tilde{\tau})$ (GeV)	Mass cut (GeV)	Exp. signal	Exp. bkg	Data
101.9	90	35.9	19.2	16
116.3	110	13.6	9.8	8
131.0	120	7.3	7.2	5
160.7	130	2.0	5.4	4

Systematic uncertainties on signal and background expectations are 6% and 15% respectively.

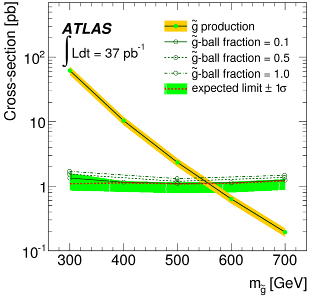


- No excess seen.
- Exclude at 95% CL $m(\tilde{\tau}) < 136\text{GeV}$ in GMSB models with $N_5 = 3$, $m_{messenger} = 250\text{TeV}$, $\mu > 0$, $\tan\beta = 5$.

Muon spectrometer-based LLP search - R-hadron results

$m(\tilde{g})$ (GeV)	Mass cut (GeV)	Exp. signal	Exp. bkg	Data
300	250	254.4	2.3	3
400	350	36.2	0.7	1
500	350	8.7	0.7	1
600	350	2.2	0.7	1
700	350	0.6	0.7	1

Systematic uncertainties on signal and background expectations are 6% and 20% respectively.

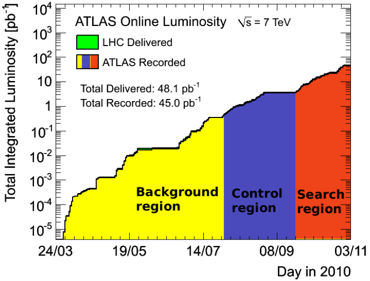


- No excess seen.
- Exclude at 95% CL. $m(\tilde{g})$ below 530-544 GeV, depending on the fraction of R-hadrons produced as $\tilde{g}$-balls.

Stopped LLP search

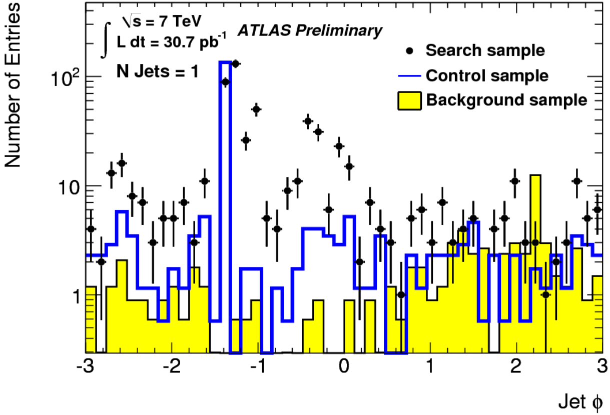
- Long-lived particles produced with low β can stop in detector material and decay much later.
- Most likely to stop in densest part of ATLAS $\Rightarrow$ calorimeters.
- Look for events with large energy deposits in calorimeter in "empty" bunches.

- Divide 2010 dataset into:
  - Background region - large detector live-time, but not much integrated lumi.
  - Control region - used to check background estimates.
  - Search region - best expected ratio of signal to background.



Stopped LLP search - backgrounds

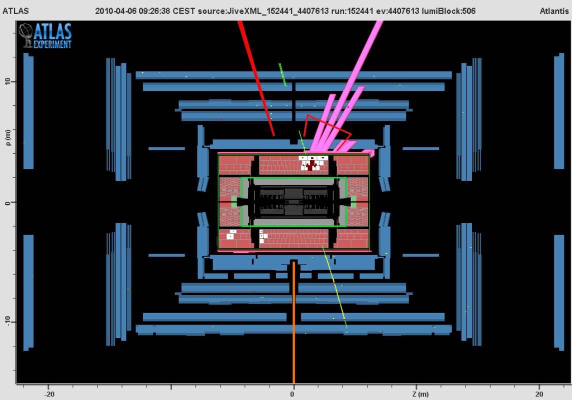
- Calorimeter noise: can fake high energy jets.



- Remove using data quality flags and “jet-cleaning” cuts.

Stopped LLP search - backgrounds

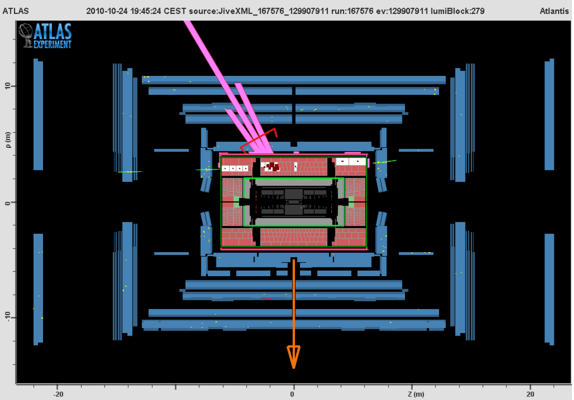
- Cosmics:



- Almost all are removed by vetoing events containing muon segments, and requiring $> 50\mathrm{GeV}$ jet.
- Estimate remainder by using fact that number of cosmics events is proportional to live-time rather than luminosity.

Stopped LLP search - backgrounds

- Beam background: even supposedly empty bunches can contain some protons.
- Study beam halo and beam gas events in unpaired bunches.

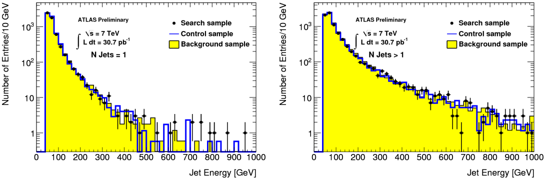


- Veto events with reconstructed tracks in the inner detector (beam gas or *pp* collisions), and with muon segments (beam halo).

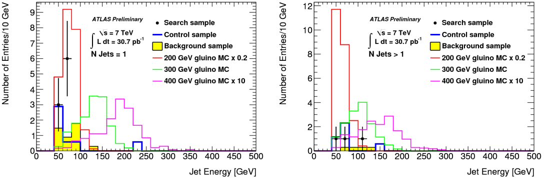
Stopped LLP search - selection

- Trigger on calorimeter energy in empty bunch crossings.
- Veto events with ID tracks and muon segments.
- Require cleaned, central ($|\eta| < 1.2$) *Anti-Kt* jets with $R = 0.4$.
- Different loose ($p_T^{\rm jet} > 50\,\mathrm{GeV}$) and tight ($p_T^{\rm jet} > 100\,\mathrm{GeV}$) signal regions for events with exactly 1 jet and events with > 1 jet.

Before muon segment veto

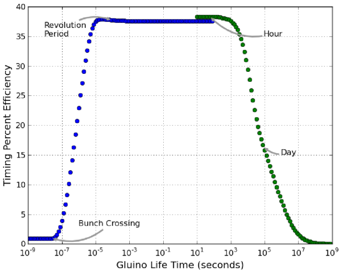


After muon segment veto



Stopped LLP search - efficiency

- Overall efficiency depends on:
  - Efficiency of event selection cuts.
  - Probability of gluinos to stop (depends on interaction model).
  - Probability that ATLAS was recording data when gluino decayed.



- Use many different hypothesised lifetimes.
- For short lifetime hypotheses, look at bunch structure and luminosity-per-bunch for each run.
- For long lifetime hypotheses, look at full run schedule.

Stopped LLP search - results

("Tight" signal regions)

# Jets	# Obs.	# Exp	Fractional Sig.error	Fractional Bkg. error
1	0	0.3	0.23	1.06
> 1	1	0.6	0.23	1.06

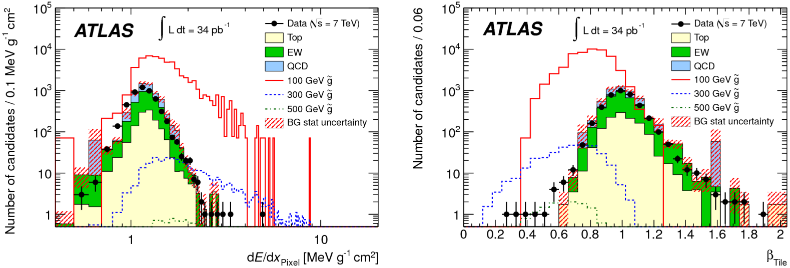
- No excess of events observed in $31\mathrm{pb}^{-1}$ 2010 dataset.
- Overall efficiency $\approx$ 0.3%.
- Limits coming soon!

Conclusions

- These are challenging analyses that use the detector in interesting and non-standard ways.
- But, very worthwhile in order to explore some parts of SUSY parameter space!
- Updates with factor $>$ 100 more data, plus analysis improvements, are under way on 2011 dataset - stay tuned!

Backup

dE/dx and beta measurements

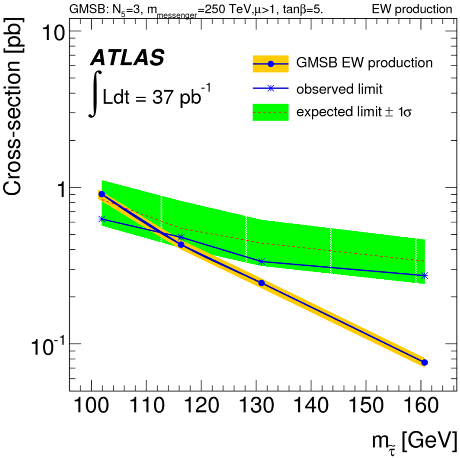


- Calculate mass from simplified Bethe-Bloch:

$$MPV_{\frac{dE}{dx}}(\beta\gamma) = \frac{p_1}{\beta^{p_3}} \ln(1 + (p_2\beta\gamma)^{p_5}) - p_4 \qquad (1)$$

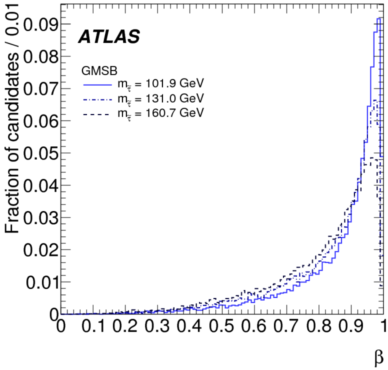
- Invert this and find parameters $p_1 - p_5$ from fits to SM particles (p, π, K).

Limits on stau produced via EW processes only



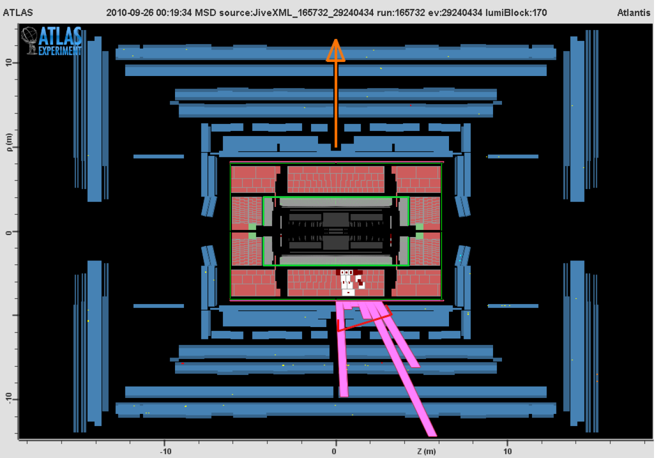
- Exclude $m(\tilde{\tau}) < 110\,\mathrm{GeV}$ at 95% CL.

Generated β distribution



(stau (left) and R-hadron (right))

Event display, empty bunch



Event display, empty bunch