Search for long-lived particles in final states with a muon and displaced vertex at ATLAS

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Introduction : R-parity violation SUSY

❖ R-parity : $R = (-1)^{3(B-L)+2S}$ → R = +1 for SM particles
-1 for SUSY particles

❖ R-parity violation (RPV) is part of superpotential.

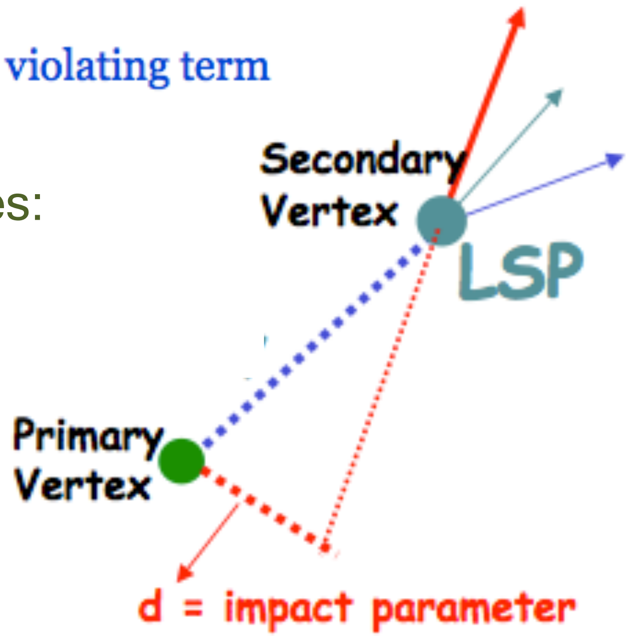
L-number violating terms

bilinear terms

$$W_{RpV} = \lambda_{ijk} L_i L_j E_k + \lambda'_{ijk} L_i Q_j D_k + \varepsilon_i L_i H_u$$
$$+ \lambda''_{ijk} U_i D_j D_k$$

B-number violating term

❖ RPV couplings may lead to a wide range of signatures:
decaying LSP with many leptons;
No MET;
Displaced vertices.



❖ For small RPV couplings, the Lightest Supersymmetric Particle (LSP) can decay away from the Interaction Point (IP).

Search for displaced vertex with 2011 data

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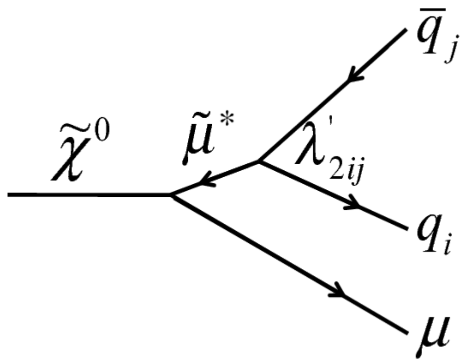
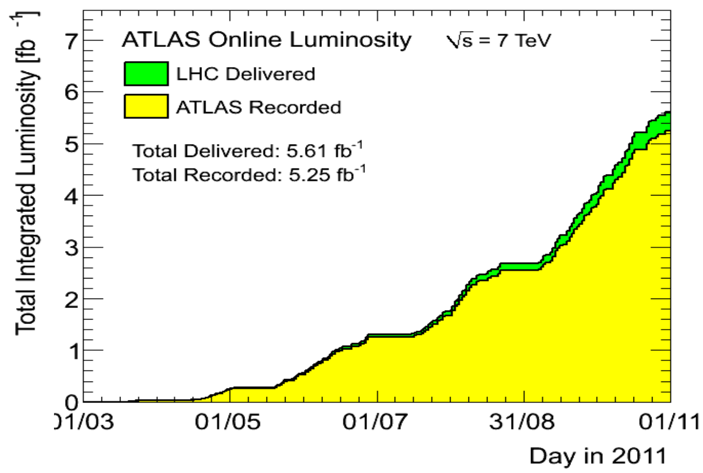
- Particles with average lifetimes up to a few nanoseconds could decay within the Inner dectector, giving rise to displaced vertices.
- Standard Model processes do not produce displaced multi-track vertices at large distance from IP.
- The result presented today is based on 2011 data, non-zero λ' with muon final state.
- Neutralino decays to muon plus jets.
  - Muon is useful for triggering and background rejection.
  - High track multiplicity helps vertex reconstruction.



Data and simulation

❖ Data

- ATLAS recorded 5.3 fb^{-1} data in 2011.
- After "all good" data quality requirements, used about 4.4 fb^{-1}.



❖ MC samples are generated by pythia6.

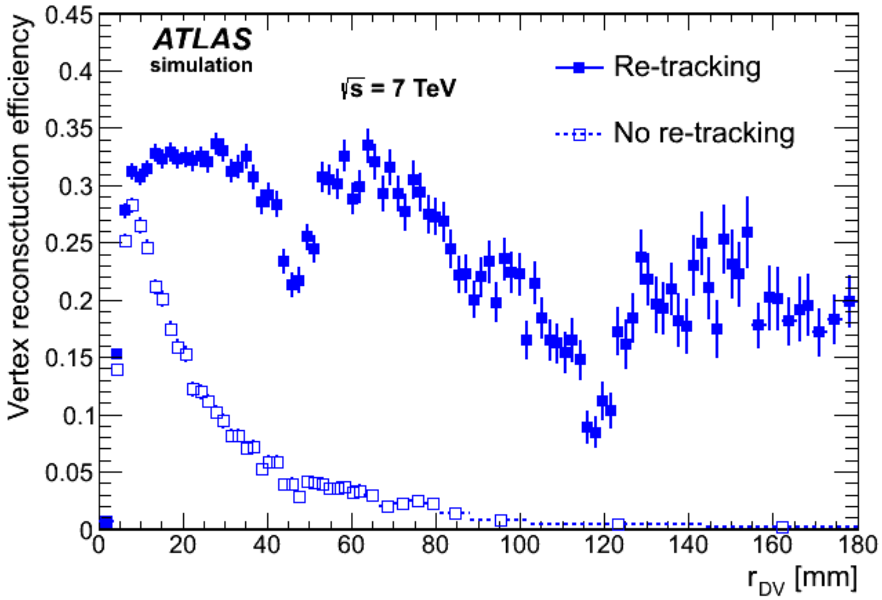
- Squark-squark, squark-antisquark production.
- $\tilde{q}\tilde{q}(\tilde{q}\bar{\tilde{q}}) \rightarrow \tilde{\chi}_1^0 q \rightarrow \mu q q q$
- Several squark and neutralino masses are used.

Label	Mode	$m_{\tilde{\chi}^0}$ [GeV]	$m_{\tilde{q}}$ [GeV]	λ'_{211}	$c\tau_{MC}$ [mm]	$<\beta\gamma>$	X-sec [pb]	N_{evt}
"MH"	114006	494	700	3×10^{-6}	78	1.0	0.066	60K
"ML"	106499	108	700	150×10^{-6}	101	3.1	0.066	60K
"HH"	118554	494	1500	15×10^{-6}	82	1.9	2.0×10^{-4}	25K

Vertex Reconstruction

- Standard ATLAS tracking is highly optimized for tracks coming from the primary interaction point (IP).

- To increase efficiency for secondary tracks, we re-run Silicon-seeded tracking algorithm, with looser cuts on transverse impact parameter, using "left-over" hits from Standard tracking.



r_{DV} is the distance of DV from middle of ATLAS.

- Select tracks with $p_T > 1$GeV and |d0| > 2mm wrt first primary vertex in event.

- Make 2-track "seed" vertices.

- Make all possible N-track combinations, then iteratively split, merge, remove tracks etc. until there are no tracks shared between vertices.

Selections

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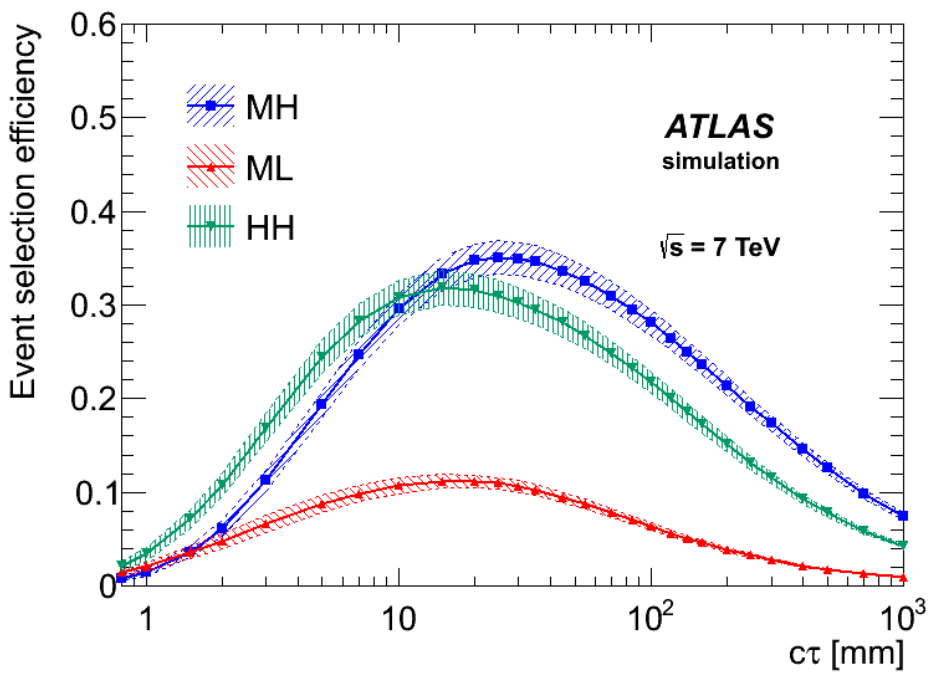
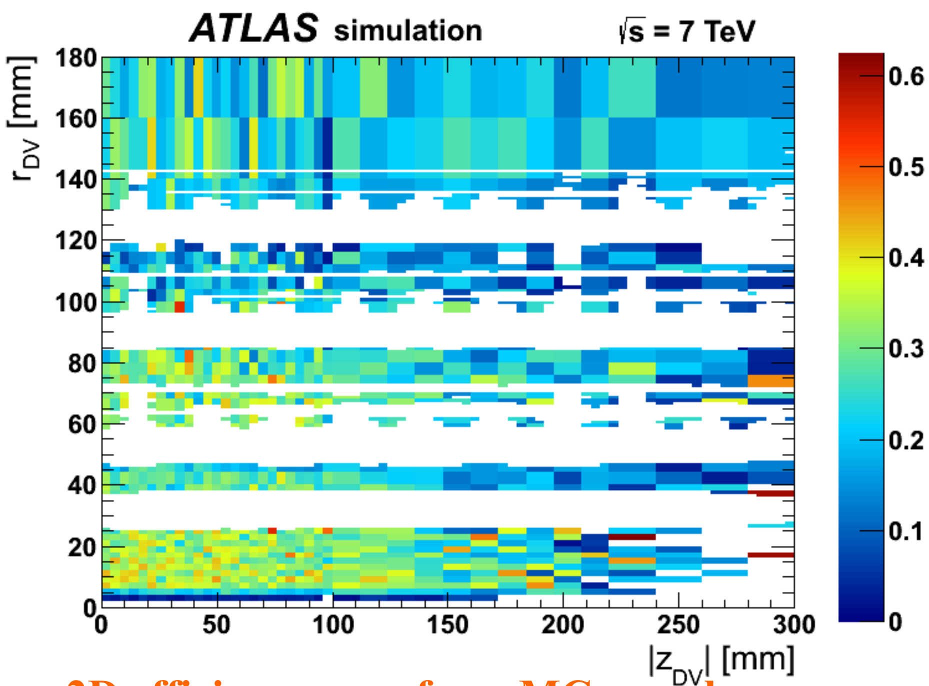
- Event selection
  - Triggered by high-pT muon trigger, with no inner detector track requirement.
  - At least one primary vertex, with a *z* position in the range $|z_{PV}|< 200$ mm and at least 5 tracks in it.
  - At least a muon with p_T >50 GeV and |d0|>1.7 mm.
  - Veto events where leading two muons are back-to-back.
- Vertex selection
  - $|r_{DV}| > 180$ mm and $|z_{DV}| > 300$ mm, roughly corresponding to pixel barrel.
  - $|r_{PV} - r_{DV}| < 4$ mm (r_{PV} : radial position of primary vertex).
  - With a muon passing within 0.5 mm of reconstructed vertex.
  - Outside material region (material veto).
  - Associated muon not back-to-back with any of tracks in the vertex.
  - **At least 5 tracks in vertex and mass m_{DV} > 10 GeV (signal region).**

Signal efficiency

- Use Toy MC (based on η-vs-βγ (p/m) distributions of signal samples) to get decay position distributions for different values of *cτ*.
- Combine with 2D efficiency maps to get vertex efficiency-vs-cτ.
- Convert to event-level efficiency: $\varepsilon_{ev} = 2*\varepsilon_{DV} - \varepsilon_{DV}^2$





2D efficiency map from MC sample

Systematic correction and uncertainty

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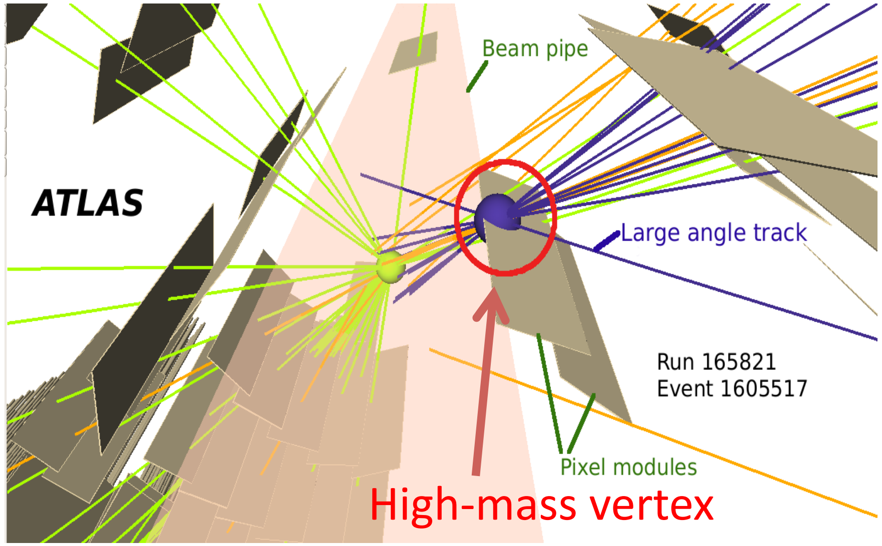
- The following corrections are applied:
  - Difference in z_{PV} distributions between data and MC.
  - Pile-up and data period reweighting from PileupReweightingTool.
  - Trigger efficiency difference between data and MC from Tag &Probe study on Z $\rightarrow \mu\mu$.
  - Muon reconstruction efficiency differences between data and MC and comparison of d0 distribution in cosmics and signal MC.
- Systematic uncertainties on efficiency from statistics, muon reco efficiency, trigger efficiency and tracking efficiency.

Background estimation

- Fully data driven methods.

- Purely random combinations of tracks.
  - Arise inside of beam pipe.
  - Determine control samples with
    i) jet-triggered events
    ii) vertices with $4 < m_{DV} < 10$ GeV



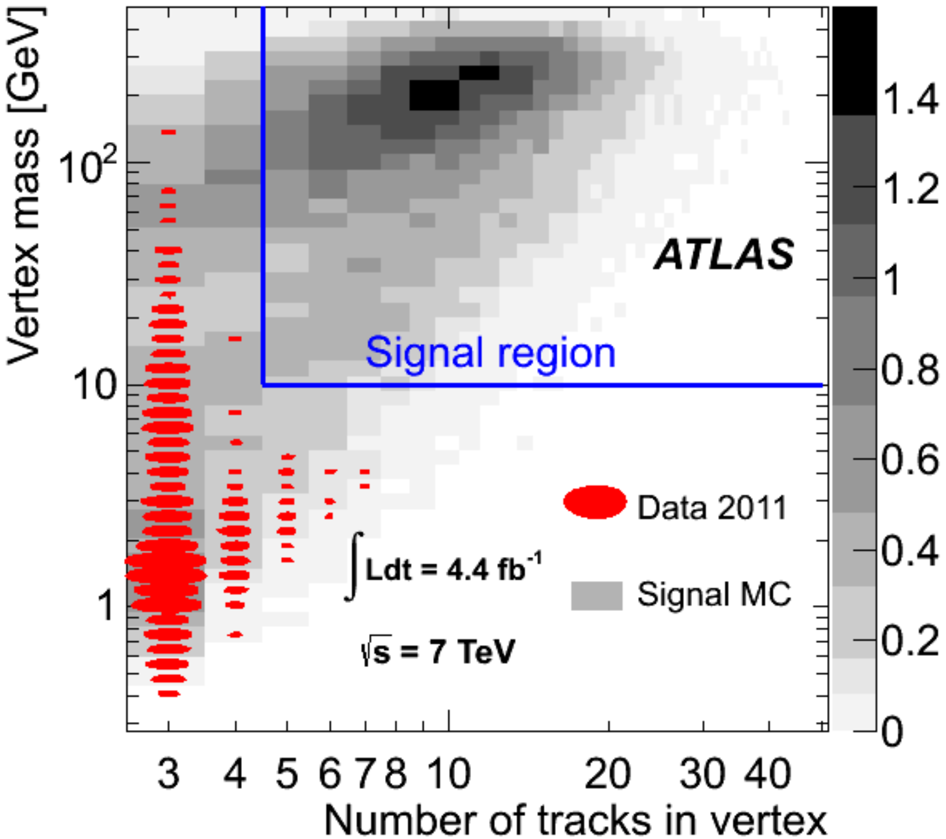
Example of high-mass vertex forming with low-mass vertex from hadronic interactions and a high-pT track at large angle.

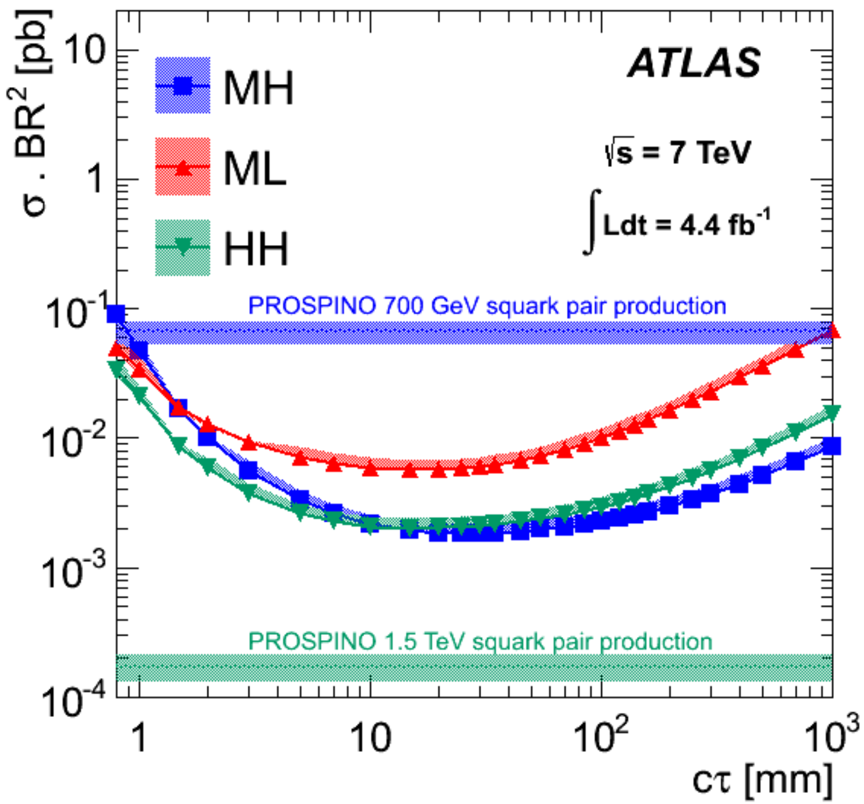
- High-mass vertices from hadronic interactions.
  - Arise outside beam pipe.
  - Random track (real or fake) crossing at large angle.
  - Obtain m_{DV} distributions of **i)** n-track vertices without large-angle tracks and **ii)** (n-1)-track vertices plus four-momentum of a randomly-selected track.
  - Obtain the numbers of vertex in non-material regions from maximum likelihood fit.
  - Normalize the m_{DV} distribution with the number from the previous procedure.

- Total estimate is $(4^{+60}_{-4})*10^{-3}$ vertices in signal region.

Result

- Signal region is defined by high multiplicity and high mass.
- Set limits on the product of the production cross-section and the branching ratio of the neutralino to the selected decay mode.
  - Limits are established as a function of the $c\tau$ of the neutralino.





Summary

- A search of neutralino decaying to a muon and two hadronic jets is presented with 4.4 fb-1 2011 data.
  - submitted to PLB : arXiv:1210.7451.

- There are no events observed.

- Limits are calculated on the product of di-squark production cross section and decay chain branching fraction.

  - The limits are presented as a function of the neutralino lifetime.