

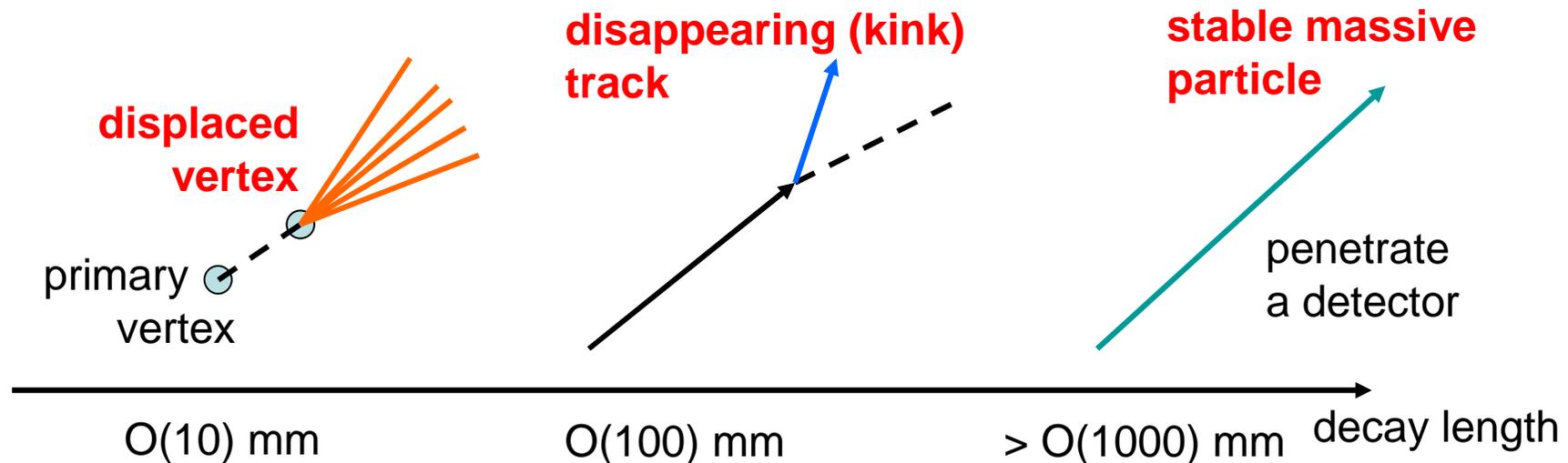
SUSY searches with Displaced Vertices (Disappearing Tracks) in ATLAS

Berkeley Workshop on Searches for Supersymmetry at the LHC

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on behalf of the ATLAS Collaboration

Long-lived SUSY scenario

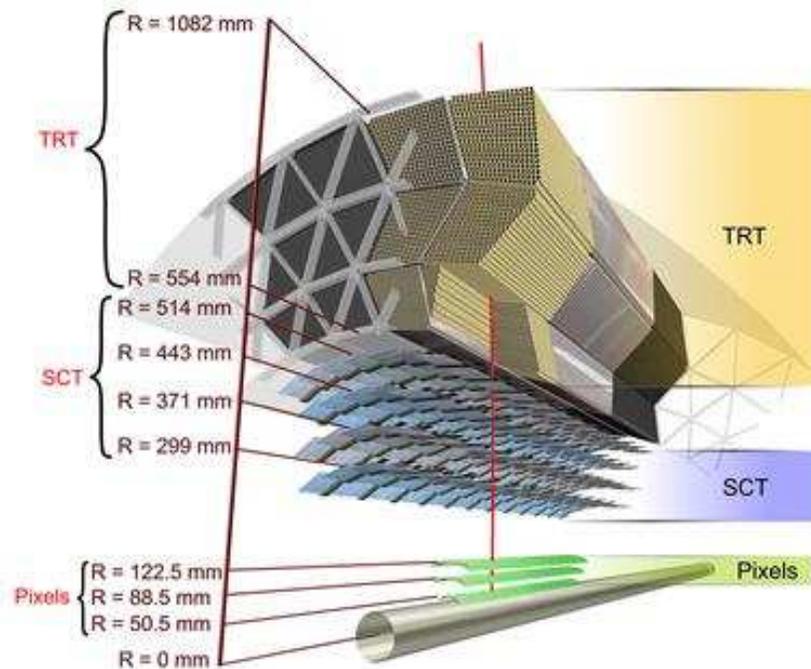
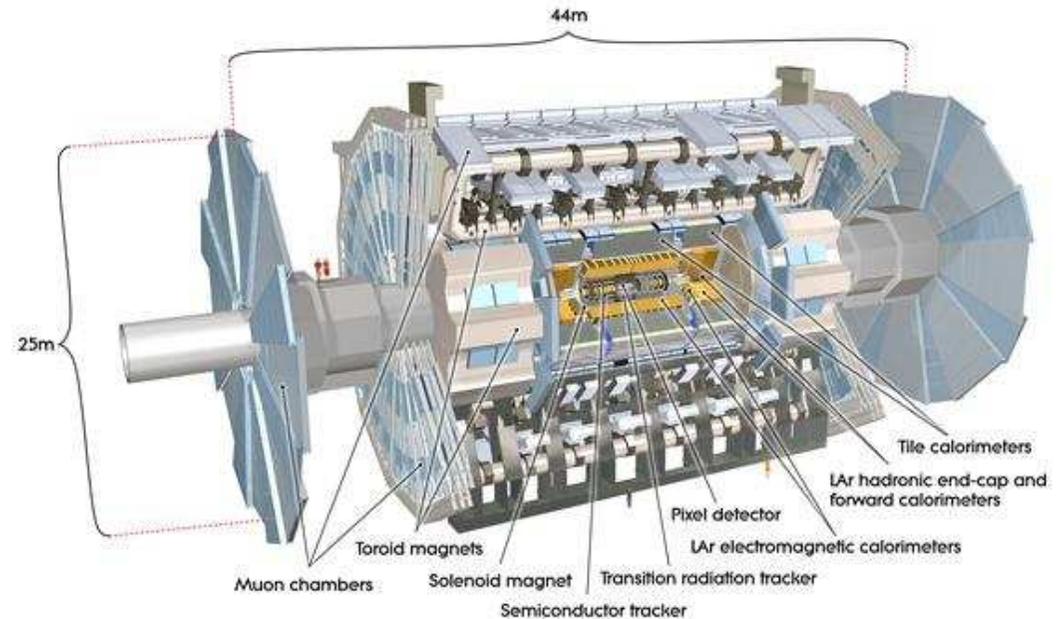
- There are many SUSY models predicting the long-lived SUSY particle ex.
 - SUGRA with R-parity violation
 - Anomaly mediated supersymmetry (AMSB)
 - Gauge mediated supersymmetry (GMSB)
- These signals depend on the lifetime of the particles



- 2 analysis will be shown in this talk
 - * Displaced Vertex search with 33 pb^{-1} data ; arXiv:1109.2242 [hep-ex]
 - * Disappearing track search with 1.02 fb^{-1} data
; CERN Document Server, ATLAS-SUSY-2011-014

ATLAS Experiment

- ATLAS experiment is obtaining the pp collision data at $E_{CM} = 7\text{TeV}$
- ATLAS consist of the Inner Detector, Calorimeter and Muon Spectrometers



Inner Detector of the ATLAS

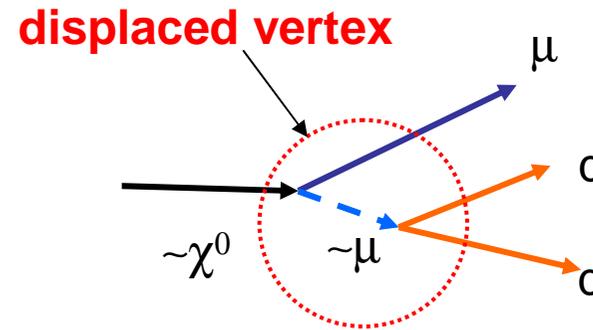
The ID consists of the 3 sub-detector

- Pixel : This detector has 3 module layers.
- Semiconductor Tracker (SCT) : The detector is the silicon strip detector. There are 4 layers in barrel region.
- Transition Radiation Tracker (TRT) : This detector consists of the 73 straw layers. The barrel detector has 3 modules. (Number of layers are 19,24, and 30)

Displaced Vertices analysis

Analysis overview

- In the RPV (R-parity violation) scenario, LSP (neutralino) can decay into two jets and muons via a virtual smuon.
- For the current limits on RPV couplings, decay vertex of LSP is allowed to be displaced from interaction point. ($\sim O(10)$ mm)



- This studies are focused on the signature of a highly displaced vertex with high track multiplicity and high mass, associated with a high- p_T muon.

- Signal sample
- di-squark production process

m(squark) [GeV]	σ [fb]	m(neutralino) [GeV]	$\langle\gamma\beta\rangle$ (neutralino)
700	66.4	494	1.0
700	66.4	108	3.1
150	539e+03	108	1.5
1500	0.2	494	1.9

Displaced vertex search

Dataset

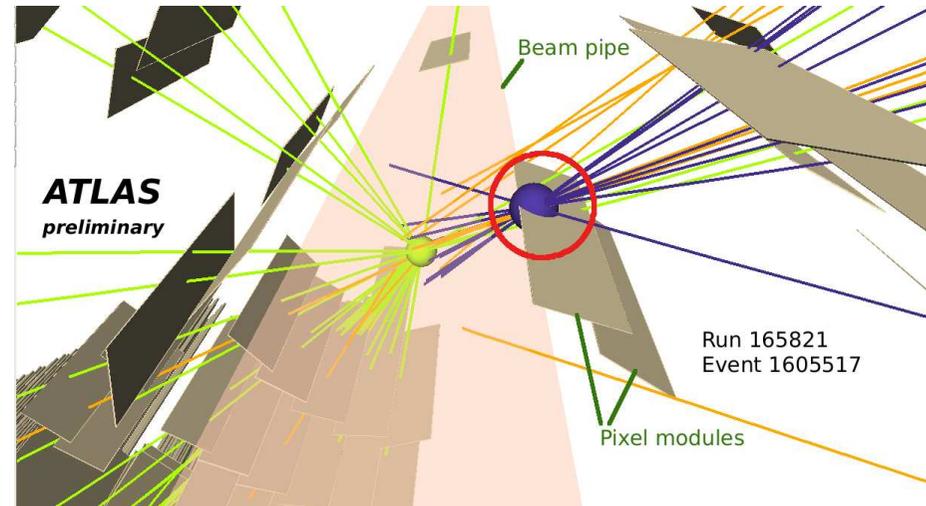
- Integrated luminosity 33 pb^{-1}
- Trigger : with Muon $p_T > 40 \text{ GeV}$

Background

- The main background is the hadronic interaction of primary tracks with the detector material.



Example of the DV originating from hadron interaction

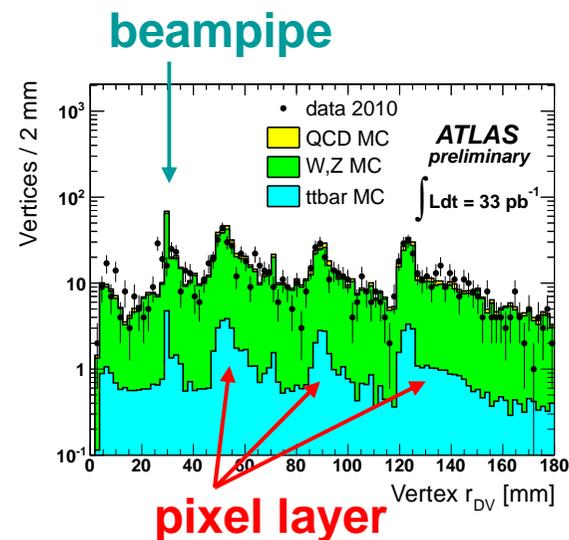
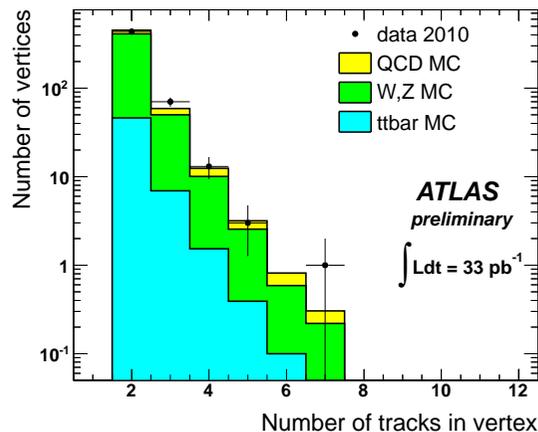
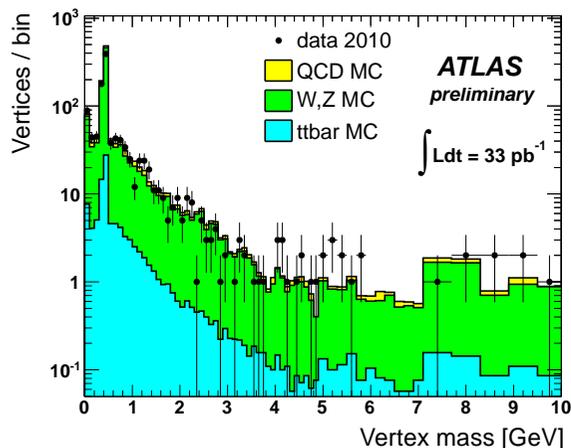


Selection

- DV is significantly apart from primary vertex. ($>4\text{mm}$)
- **Invariant mass of DV, $m_{DV} > 10\text{GeV}$ and the number of tracks, $N_{\text{trk}} > 4$**
- **Remove DVs in the detector material**
- Muon $p_T > 45 \text{ GeV}$

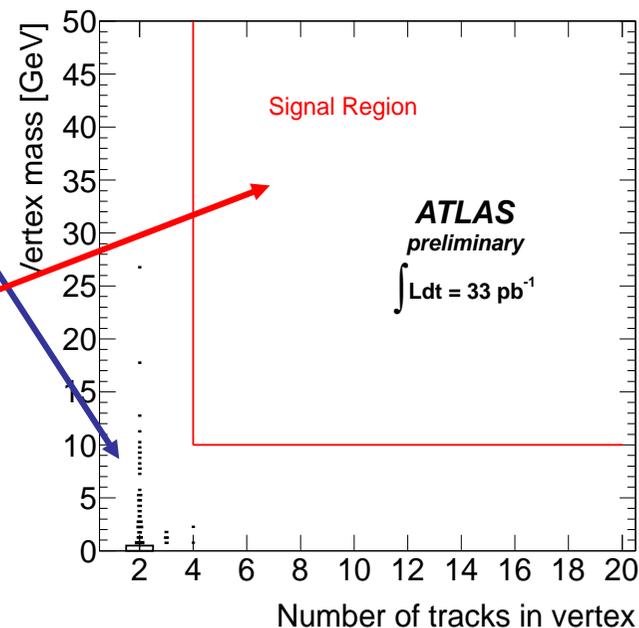
To suppress the BG originating from the hadron interaction

Search results



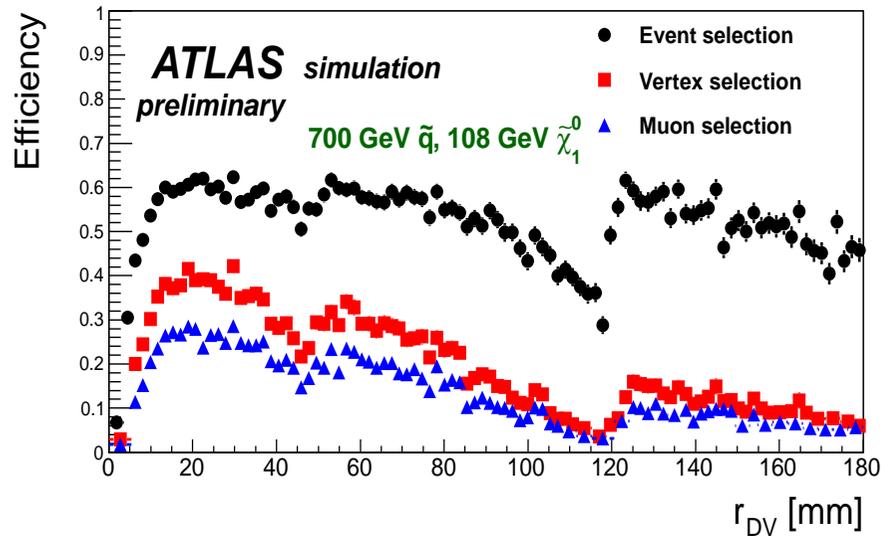
m_{DV} , N_{trk} and r_{DV} distributions in control region without material veto

- Detector material is well described.
- $W (\rightarrow \mu\nu)$ process is dominant in the BG.
- **After all the selections, 0 events are observed.**
- In order to estimate the BG precisely, the efficiency for muon selection and the other selection is obtained separately and the combine the results.
- Number of BG is less than 0.03 for 33 pb^{-1} .

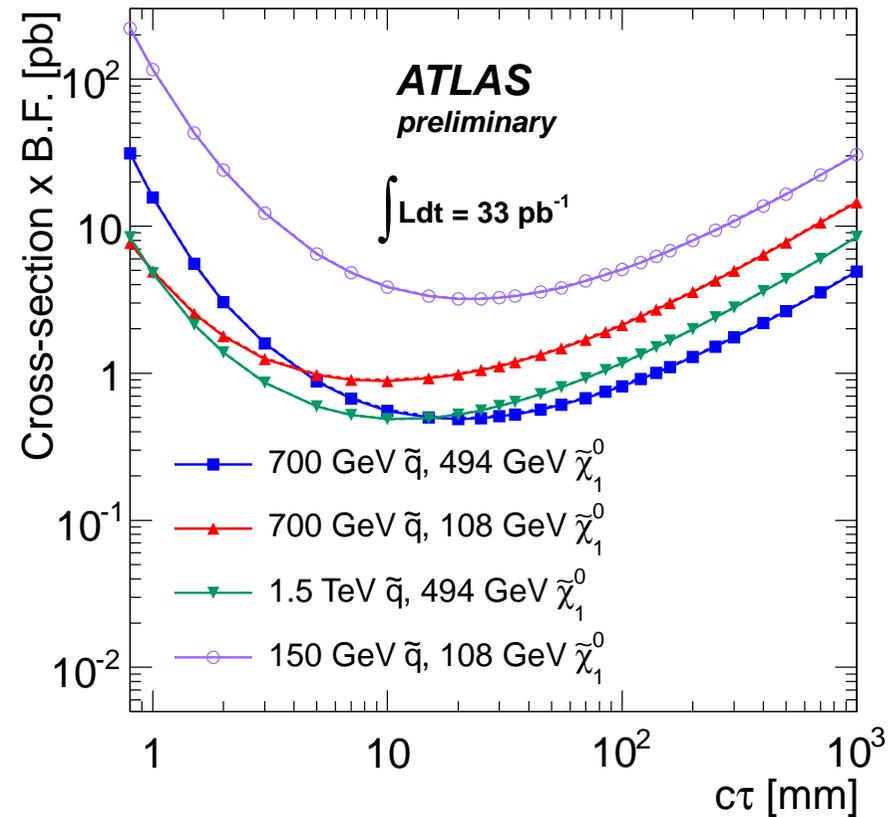


Upper limits

- The signal efficiency depends on the efficiencies for track reconstruction and selection.
 - Track finding algorithm is not optimized for this search and this results in low efficiency at large r_{DV} .
 - Due to the standard ID tracking, the structure is seen.



- Upper limits at 95% C.L. on the production X-sec times branching fraction vs. the neutralino lifetime.
 - O(10) mm is the best limits on X-sec times B.F .



Disappearing track analysis

AMSB chargino signal

AMSB signal

production process : gluino pair production
 + multiple energetic jets from gluino decay
 + large missing E_T made by neutralinos
 + high- p_T decaying track of charginos

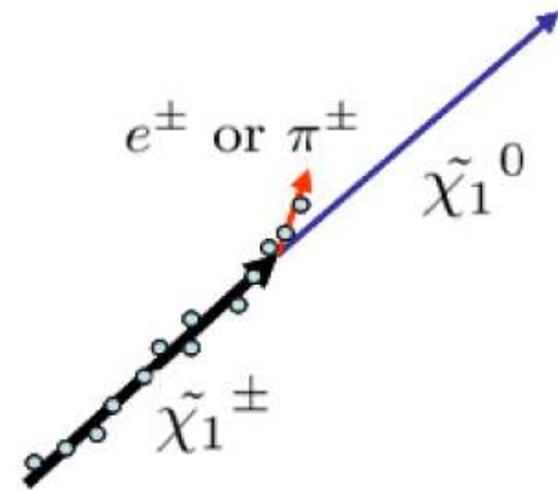
bench-mark point :

$m(\text{chargino}) = 90.2\text{GeV}$, $X\text{-sec} = 0.061\text{pb}$

- Wino is the lightest gaugino in this model.
 $m(\text{bino}) : m(\text{wino}) : m(\text{gluino}) \sim 3:1:7$
- NLSP (chargino) and LSP (neutralino) are highly degenerated. ($dM \sim 200\text{MeV}$.)
- The lifetime of chargino becomes long ($c\tau \sim O(100)\text{ mm}$) due to the mass degeneracy.
- Long-lived chargino decays to the neutralino and soft $\pi/e\nu$.
- Decaying long-lived charginos are reconstructed as disappearing/kink tracks.

$$\tilde{g}\tilde{g} \rightarrow q\bar{q}'\tilde{\chi}_1^- q\bar{q}'\tilde{\chi}_1^-$$

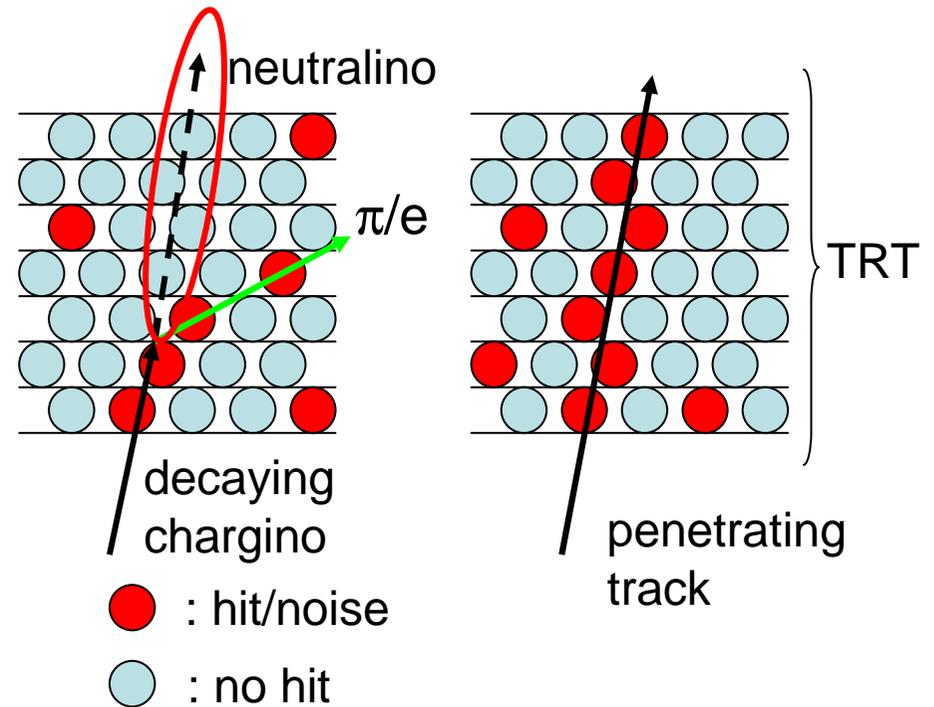
$$\begin{array}{l} \swarrow \quad \searrow \\ \tilde{\chi}_1^0\pi^- \quad \tilde{\chi}_1^0\pi^- \end{array}$$



Chargino selection

How to find chargino signal

- use the TRT (consists of many straw layers)
- count the TRT 3rd module hits on track; N_{TRT3} (assume charginos decay before the TRT3)
- N_{TRT3} on chargino track is small, on the other hand, N_{TRT3} is large on the penetrating track.



Dataset

- Integrated luminosity 1.02 fb^{-1}
- Trigger : with jet $p_T > 75 \text{ GeV}$ and $E_T^{\text{miss}} > 55 \text{ GeV}$

Selection

- $E_T^{\text{miss}} > 130 \text{ GeV}$ && 1st jet $p_T > 130 \text{ GeV}$ && 2nd/3rd jet $p_T > 60 \text{ GeV}$
- leading track $p_T > 10 \text{ GeV}$
- leading track $N_{TRT3} < 5$ (**chargino track selection**)

High- p_T disappearing track

There are 2 types of BG and signal after the requiring the chargino selection ($N_{\text{TRT3}} < 5$)

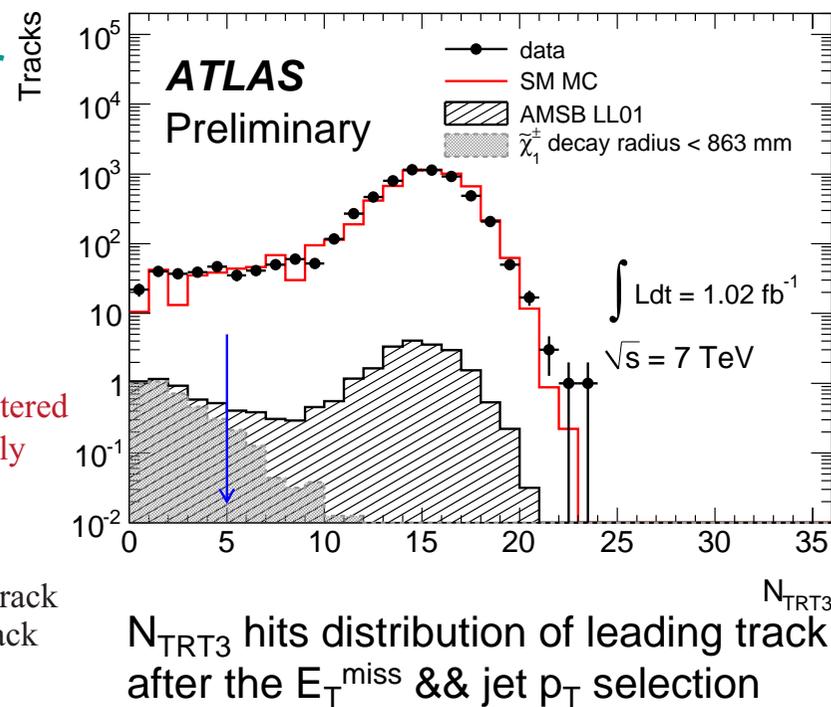
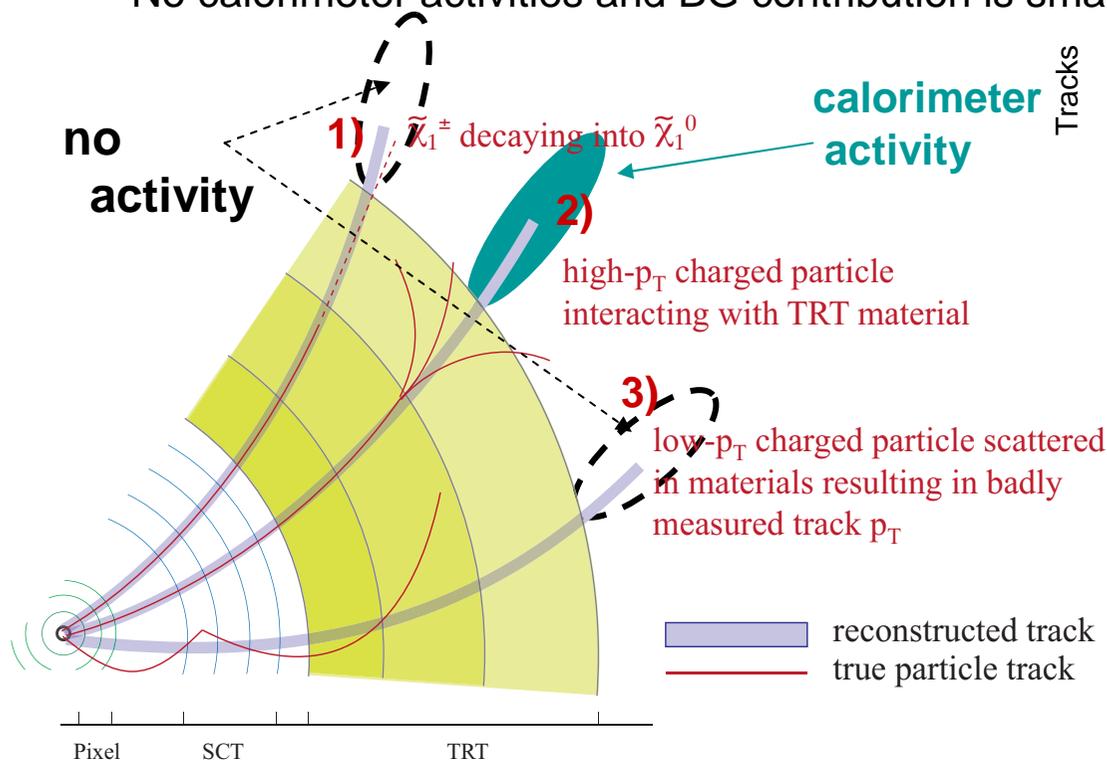
1) Chargino track

2) Interacting hadron track

Originating from interacting hadron track. This track has calorimeter activity.
Dominant BG.

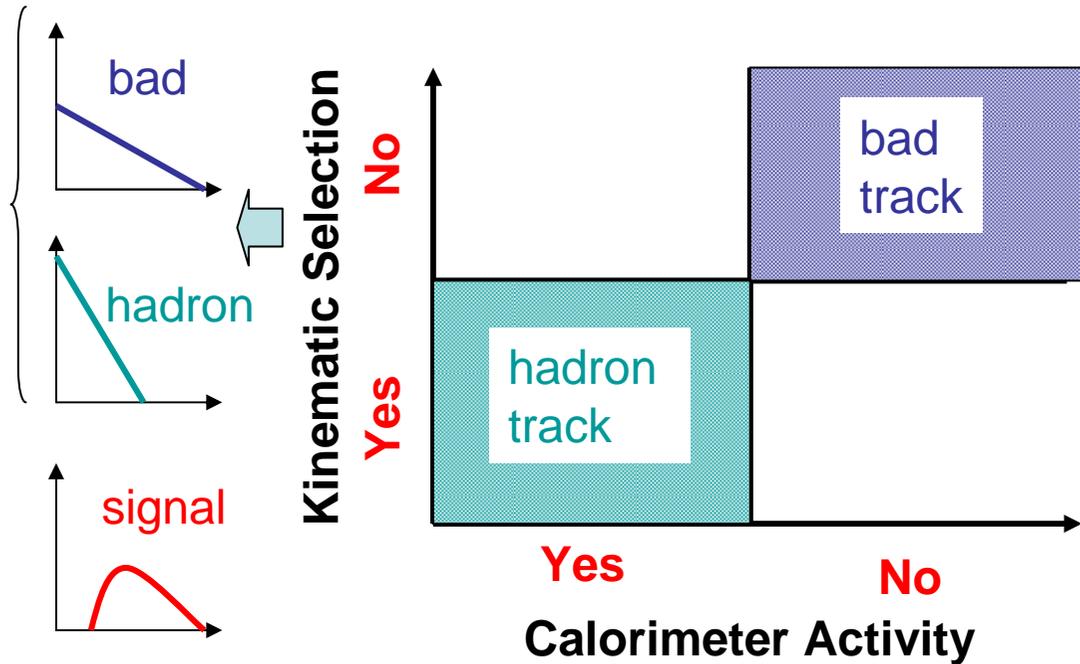
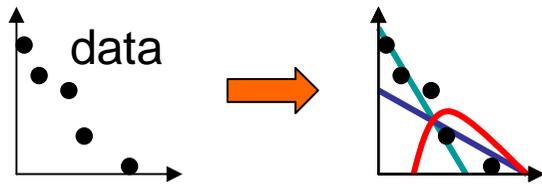
3) Badly reconstructed track

Miss measured track of the low- p_T particle scattered in the silicon detector.
No calorimeter activities and BG contribution is small

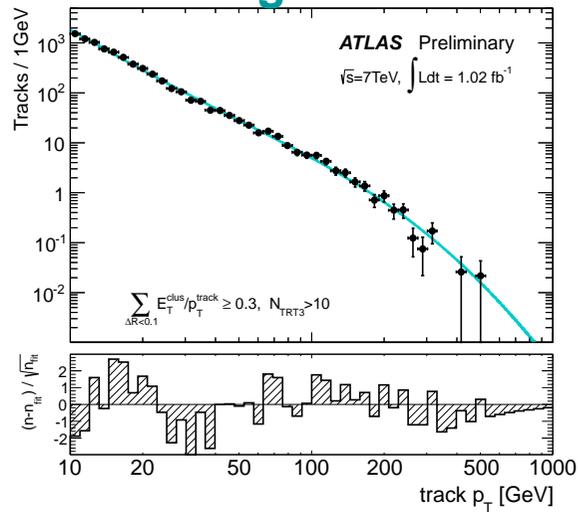


BG estimation

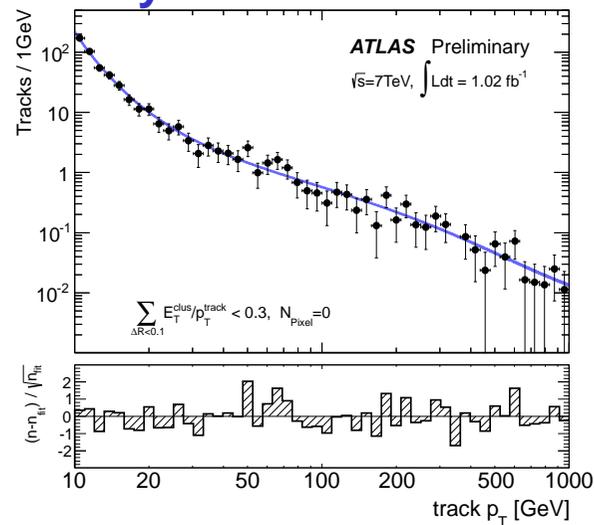
- Extract the BG shapes (track p_T) from control samples.
 - Fit BG shape and signal shape to the candidate tracks using the unbinned ML method.
- (Free parameters : signal norm. and numbers of BG)



interacting hadron track



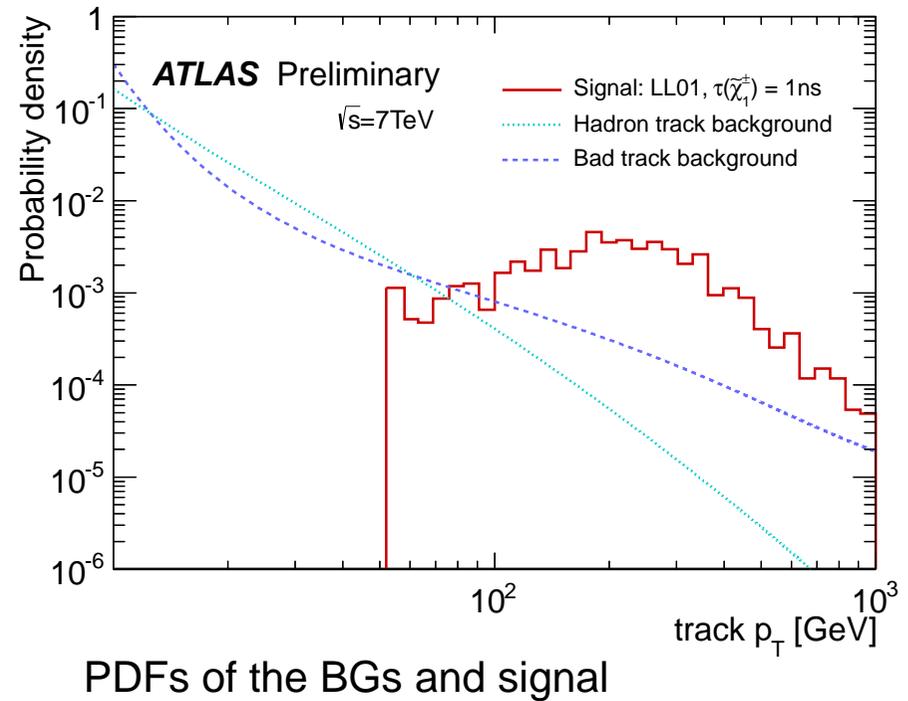
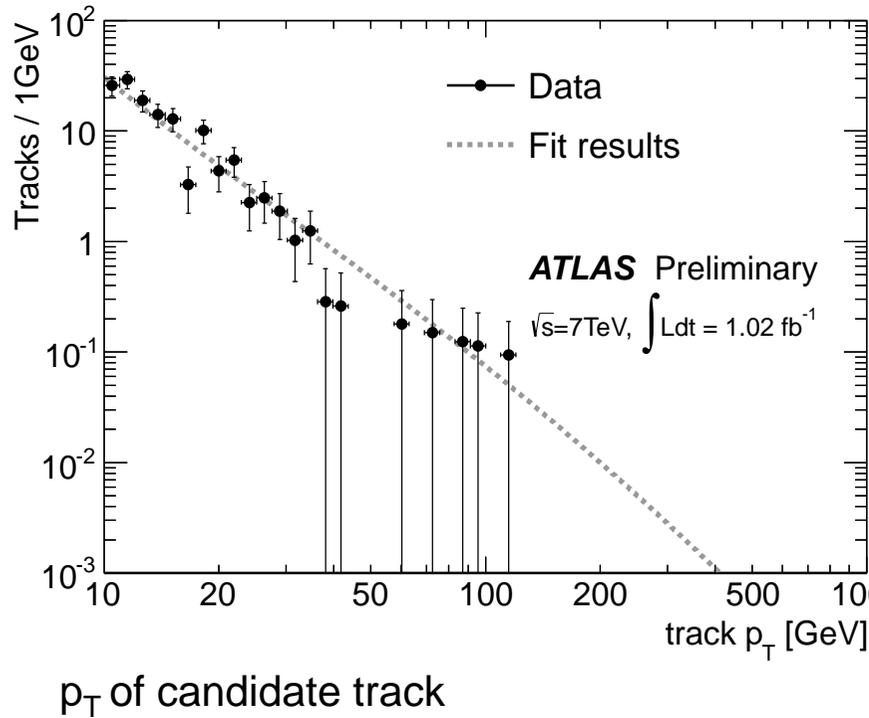
badly reconstructed track



Functional form has the power law term and exponential tail term.

Results

- PDFs of signal and BG are different from each other.
- These PDFs are fit to the candidate tracks.
 - Number of the candidate track is 185.
 - Hadron interaction track is dominant in the candidate tracks.
 - Contribution from bad track is small.
- There is no significant excess with 1.02 fb^{-1} data.



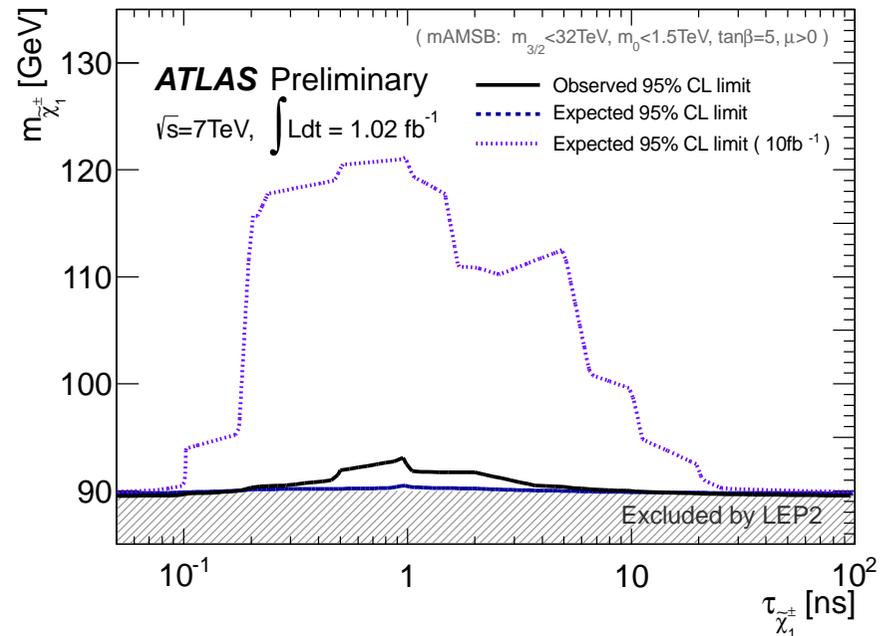
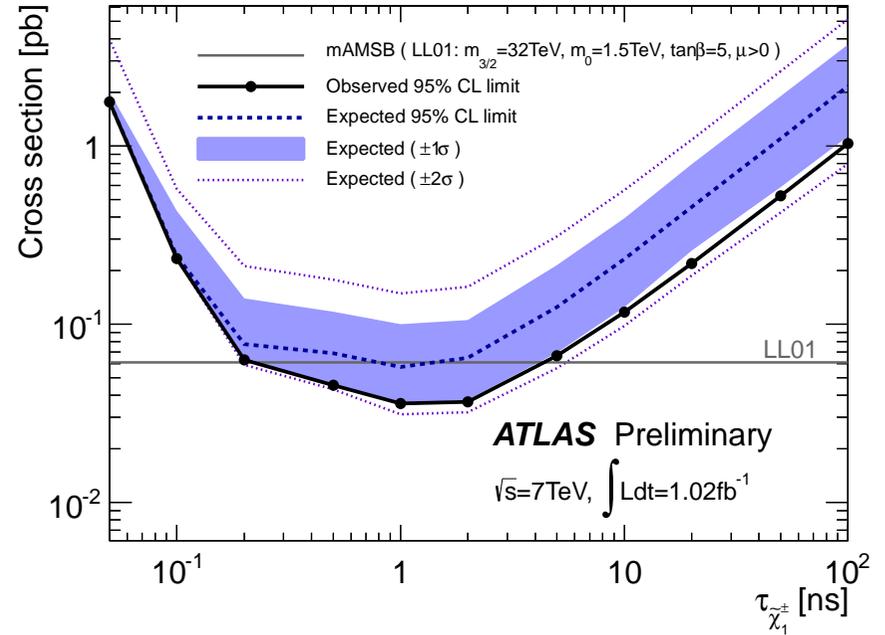
Upper limits

- **Upper limits on the signal X-sec for at 95% C.L. for $m(\text{chargino}) = 90.2\text{GeV}$**

- $\tau \sim O(1)$ ns is the best limit on the signal X-sec.
- This is corresponding to the position of the TRT detector.

- **The constraints on the chargino mass and lifetime**

- A chargino that $m < 92\text{GeV}$ and the $0.5 < \tau < 2\text{ns}$ is excluded in this analysis with 1.02 fb^{-1} .
- This results reaches at LEP2 results. (The chargino mass $< 90 \text{ GeV}$ is excluded by the LEP2 search.)



Conclusions

2 analysis on the long-lived SUSY searches at ATLAS are shown.

- * **Displaced vertices search**

- Some RPV models predicts the Displaced Vertex signal.
- Upper limits on Cross-section \times B.F. vs. $c\tau$ with 33 pb⁻¹.
- Details are described in the paper ; [arXiv:1109.2242 \[hep-ex\]](#)

- * **Disappearing track search**

- Search for the decaying long-lived chargino track using the TRT detector.
- A chargino that $m < 92\text{GeV}$ and the $0.5 < \tau < 2\text{ns}$ is excluded for 1.02 fb⁻¹.
- Details are shown in **CDS, ATLAS-SUSY-2011-014**

Prospects

- **Displaced Vertices**

- * This analysis is performed with 33 pb⁻¹ and the sensitivity will be improved with 2011 data ($\sim 5\text{ fb}^{-1}$!).
- * Improve tracking algorithm
- * Different decay topologies : DV + e, DV + E_T^{miss}, ...

- **Disappearing track**

- * The improvement on the sensitivity for the disappearing track search is expected with the more statistics.
- * The short chargino lifetime case is also being studied. Chargino search with high dE/dx tracklets with pixel detector is expected to be good sensitivity.

Backup for DV analysis

Displaced vertex reconstruction

- 1) Select the track which $p_T > 1\text{GeV}$ and transverse impact parameter $|d_0| > 2\text{mm}$.
- 2) Make 2-track vertex which χ^2 is small (less than 5) with all combination.
- 3) To ensure the uniqueness track-vertex association, calculate the χ^2 of track to the vertex. If bad ($\chi^2 > 6$), the track is removed. Otherwise, if the significance of the distance between the vertices which have shearing track is small (<3), these vertices are merged. This procedure is continued until there are no more track sharing vertices.
- 4) If the distance between adjacent vertices are less than 1mm, they are merged and refitted.

Event selection for DV analysis

- Dataset for this analysis is obtained with the muon trigger; muon $p_T > 40\text{GeV}$
- The integrated luminosity is result in 33 pb^{-1} .
- Event selection
 - 1) $|z_{DV}| < 300\text{mm}$ && $R_{DV} < 180\text{mm}$
 - 2) χ^2/DOF of displaced vertex candidate is less than 5.
 - 3) The distance from primary vertex, $|\mathbf{r}_{DV} - \mathbf{r}_{PV}| > 4\text{mm}$.
(Suppress the candidates originating from accidental combination of primary tracks)
 - 4) Invariant mass of DV, $m_{DV} > 10\text{GeV}$ and the number of tracks, $N_{\text{trk}} > 4$.
(Suppress the candidates originating from hadronic interaction.)
 - 5) Reject the vertices in the region of detector material
(Supress the candidates in the high mass region originating from hadronic interaction)
 - 6) Muon $p_T > 45\text{ GeV}$

Backup for disappearing track analysis

Event selection for disappearing track analysis

* Analysis with 1.02 fb^{-1} data obtained by jet & MET trigger. ($E_{\text{T}}^{\text{miss}} > 55 \text{ GeV}$ && jet $p_{\text{T}} > 75 \text{ GeV}$)

* **Event selection**

- $E_{\text{T}}^{\text{miss}} > 130 \text{ GeV}$
- 1st leading jet $p_{\text{T}} > 130 \text{ GeV}$
- 2nd/3rd leading jet $p_{\text{T}} > 60 \text{ GeV}$
- leading isolated inner track $p_{\text{T}} > 10 \text{ GeV}$
 - track selection :
 - $|\eta| < 0.63$
 - $N_{\text{pixel}} \geq 1$ && $N_{\text{SCT}} \geq 6$
 - $|d_0| < 1.5 \text{ mm}$ && $|z_0 \sin(\theta)| < 1.5 \text{ mm}$
 - isolation : No tracks in $dR < 0.05$
- N_{TRT3} of inner track < 5

Background estimation

In order to estimate the background and the signal yields, fully data-driven method is used.

- 1) Select the control samples and extract the track pT distribution of 2 types of BG.
- 2) Perform the simultaneous fit the 2 BG shapes and signal distribution to the candidate track pT spectrum after the selection

Summary of the selection for the control sample

	Hadron interaction	Badly reconstructed
Kinematic selection		
Missing Et	Missing $E_T > 130$ GeV	Missing $E_T < 100$ GeV
Jet Pt	1st Jet $p_T > 130$ GeV	
	3rd Jet $p_T > 60$ GeV	
Track selection		
N_{pixel}	≥ 1	$= 0$
N_{TRT3}	> 10	< 5
Calorimeter Activity	Yes ($\sum_{\Delta R < 0.1} E_T^{\text{clus}}/p_T^{\text{track}} > 0.3$)	No ($\sum_{\Delta R < 0.1} E_T^{\text{clus}}/p_T^{\text{track}} < 0.3$)

- Spectrum of interacting hadron track depend on the kinematics so the same kinematic selection is needed to be required.
- In order to select the bad track, bad quality and no calorimeter activity is required.

Results of fitting

Summary of fit results

Candidate track	185	
	Background only	Background + signal
Signal strength		< 0.15
Fraction of bad track	< 0.04	< 0.04
P-value (null hypothesis)	0.5	

- For the “BG+signal” model fit, numbers of the signal are 0 consistent.
- For the “BG” model fit , the BG numbers are consistent to the “BG+signal” fit results.
- Number of bad track is small as expected.