Search for R-Parity Violating Supersymmetry with the ATLAS detector

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Fermilab

R-Parity

$$R = (-1)^{3B+L+2s} = \begin{cases} +1 \text{ for SM particles} \\ -1 \text{ for SUSY particles} \end{cases}$$

- Standard SUSY searches involve R-Parity Conservation (RPC)
- Lepton and/or baryon number violation constrained by previous experiments but not forbidden.

L-number violating terms

$$W_{\not{RP}} = \overbrace{\sum_i \varepsilon_i \hat{L}_i \hat{H}_u + \sum_{i,j,k} \lambda_{ijk} \hat{L}_i \hat{L}_j \hat{E}_k + \sum_{i,j,k} \lambda'_{ijk} \hat{L}_i \hat{Q}_j \hat{D}_k} + \underbrace{\sum_{i,j,k} \lambda''_{ijk} \hat{U}^c_i \hat{D}^c_j \hat{D}^c_k}_{\text{B-number violating terms}}$$

i,j,k = quark and lepton generations

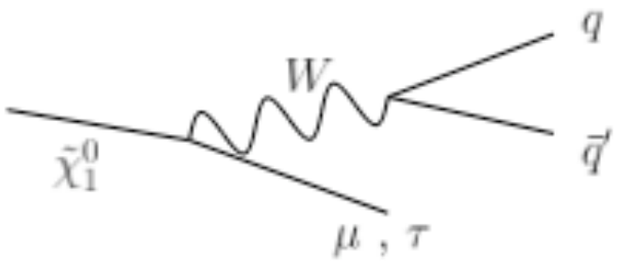
RPConserving SUSY models:	RPViolating SUSY models:
- Neutral Stable LSP	- LSP: no need to be neutral nor stable. - LSP decay: possibility to explore new signals, exploit LSP invariant mass and decay properties
- Sparticles produced in pairs - Large E_T^{miss}	- Single Sparticles production is possible - Not so large E_T^{miss}

RPV models presented

Bilinear RPV:

- $\tilde{\chi}_1^0$ LSP not stable, prompt decaying to a muon and two jets
- Analysis optimised for 1 lepton RPC requiring exactly one muon and several jets.
- Analysis performed using 1.04 fb^{-1} of 2011 collision data

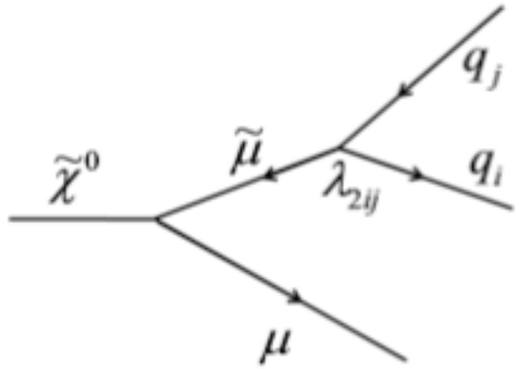
$\varepsilon_i \neq 0$



Displaced Vertices:

- $\tilde{\chi}_1^0$ decaying to a muon and two jets in the pixel
- Generically sensitive to heavy long-lived particles decays to muon + jets
- Analysis performed using 33 pb^{-1} of 2010 collision data

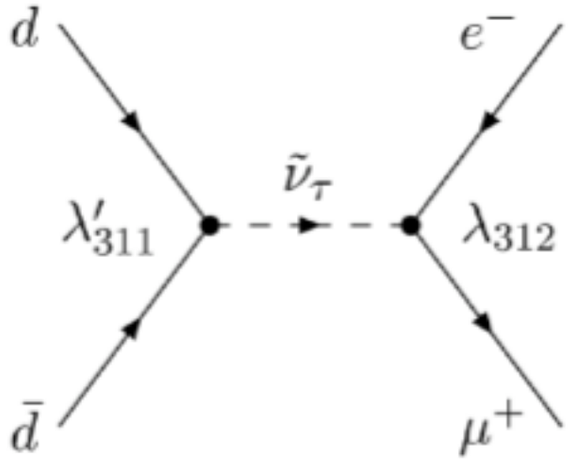
$\lambda'_{2ij} \neq 0$



resonant sneutrino LSP:

- $\tilde{\nu}_\tau$ LSP which can decay to an electron and a muon.
- Search for an excess of high invariant mass eμ ($m_{e\mu}$)
- Analysis performed using 0.87 fb^{-1} of 2011 collision data
- Details in Junjie Zhu's talk

$\lambda'_{131} \times \lambda_{312} \neq 0$



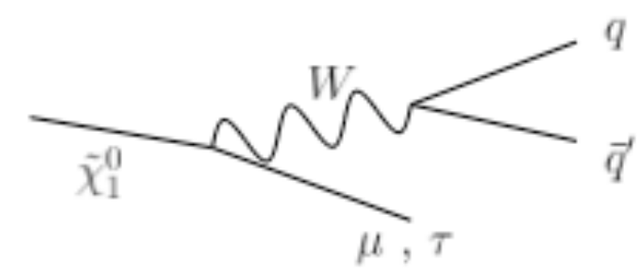
Bilinear RPV: description

- bilinear RPV model with $\tilde{\chi}_1^0$ LSP not stable, connected to neutrino physics through:

$$\frac{BR(\tilde{\chi}_1^0 \rightarrow W\ \mu)}{BR(\tilde{\chi}_1^0 \rightarrow W\ \tau)} \approx \tan^2 \theta_{atm}$$

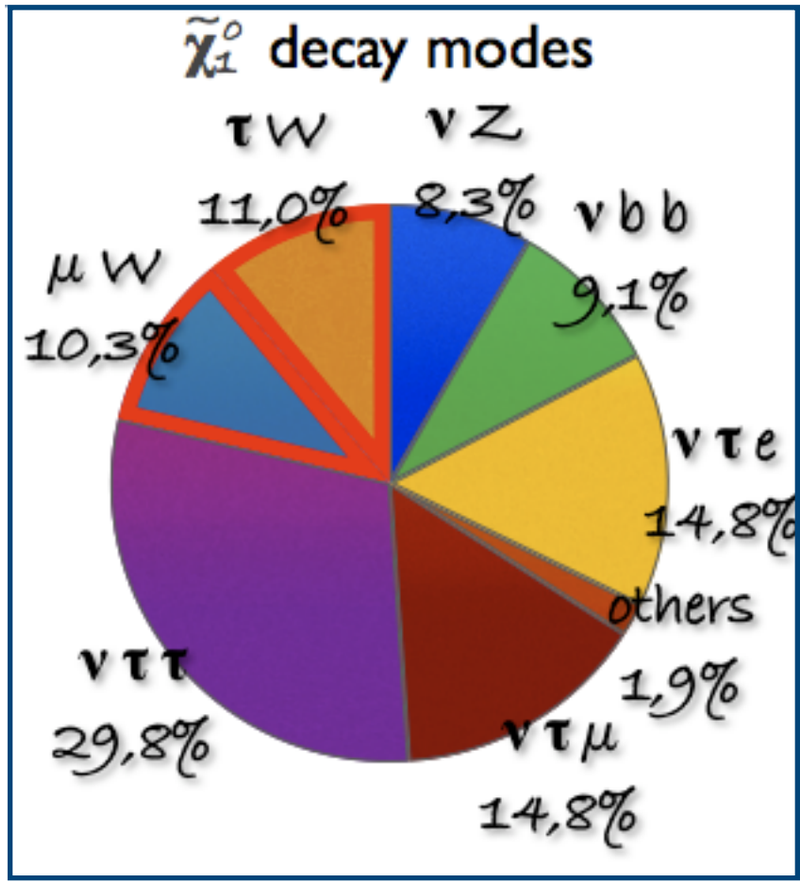
- RPV parameters chosen to be consistent with constraints from neutrino experiments: Δm_{atm}^2, Δm_{sol}^2, $\tan^2\theta_{atm}$, $\tan^2\theta_{sol}$

$\varepsilon_i \neq 0$



- Analysis optimised for RPC with one lepton searches. Interpretation of this analysis on bRPV.

RPC	bRPV
mSUGRA scenario assumed, trigger based on muons, object definition, GRL...	
→ long cascade decay	→ long cascade decay, same as RPC but with neutralino decaying.
→ Kinematic selection: 1 lepton and at least 3 jets	→ Minimal Kinematic selection: at least 1 lepton and at least 2 jets
→ MET due to (2) stable LSPs	→ MET mainly due to LSP-decay neutrinos



Bilinear RPV: signal regions

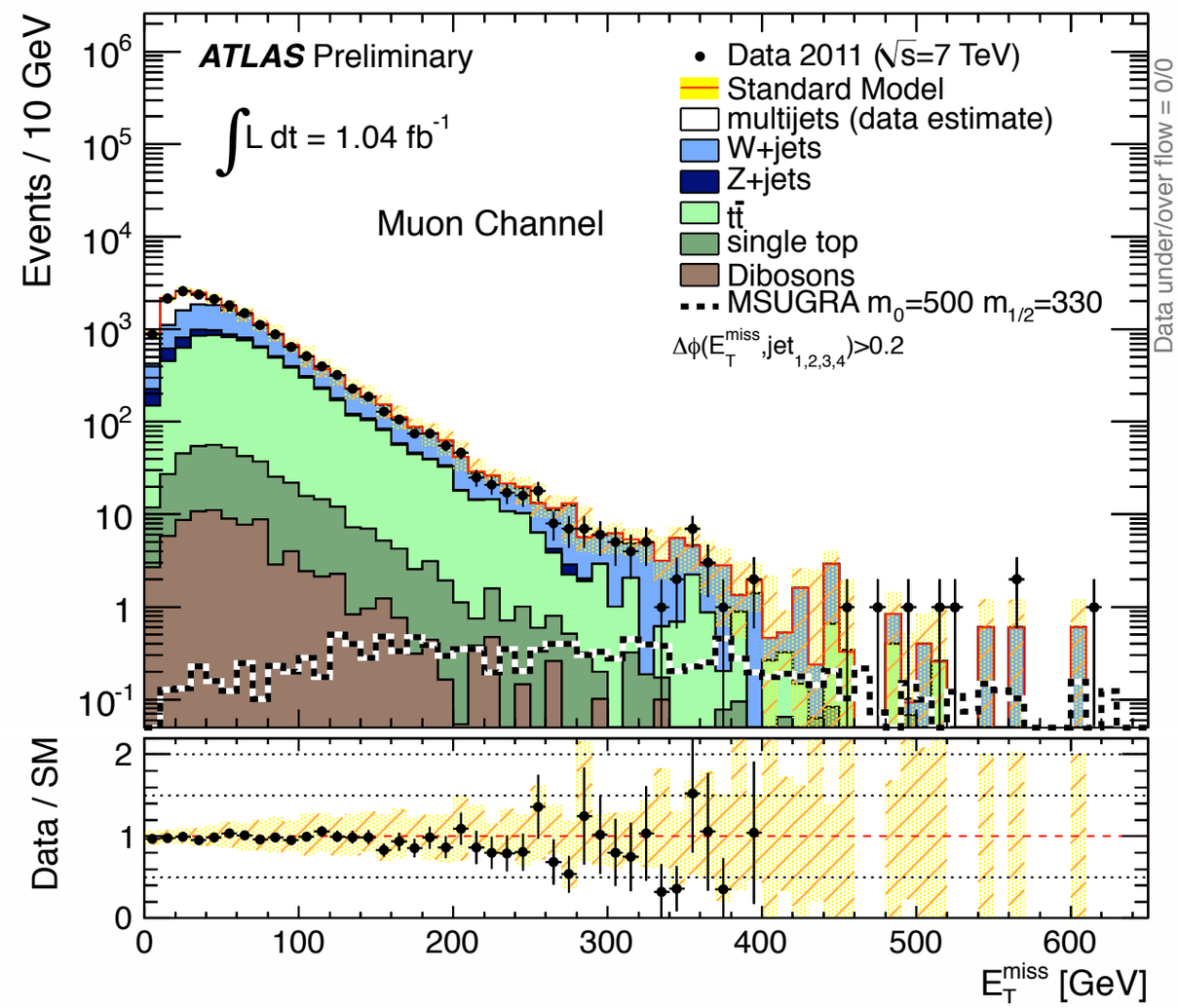
- 4 different Signal Regions analysed: 3-jet loose selection (3JL), 3-jet tight selection (3JT), 4-jet loose selection (4JL) and 4-jet tight selection (4JT).
- Common Event Selection:
- exactly one isolated muon with p_T > 20 GeV, used to trigger the events.
- veto for events with at least one electron with p_T > 20 GeV, aimed to avoid overlap with other analyses.

$\varepsilon_i \neq 0$

Selection	3JL	3JT	4JL	4JT'
Number of jets	≥ 3		≥ 4	
Leading jet p_T (GeV)	60	80	60	60
Subsequent jet p_T (GeV)	25	25	25	40
$\Delta\Phi$(jet, E^{miss}_T)	[>0.2(mod. π)]for all 3 (4) jets			
m_T (GeV)	> 100			
E^{miss}_T (GeV)	> 125	> 240	> 140	> 200
E^{miss}_T / M_{eff}	> 0.25	> 0.15	> 0.30	> 0.15
M_{eff} (GeV)	> 500	> 600	> 300	> 500

$$m_{\rm eff} = H_T + E_{\rm T}^{\rm miss} = p_T^{\ell} + \sum_{i=1}^{3(4)} p_T^{jet_i} + E_{\rm T}^{\rm miss}$$

$$m_{\rm T} = \sqrt{2 \cdot p_T^{\ell} \cdot E_{\rm T}^{\rm miss} \cdot (1 - cos(\Delta\phi(\ell, E_{\rm T}^{\rm miss})))}$$

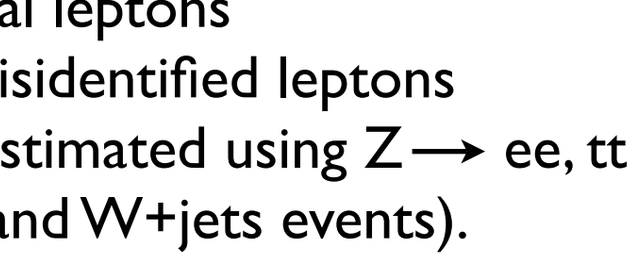


Bilinear RPV: background studies

- Separate Control Regions (CR) for the 3-jet, 4-jet selections defined
- Same lepton and jets requirements as in the corresponding SR.
- 2 types of CR: W+jets (WR) and Top (TR)

Control Region	WR	TR
$\Delta\Phi(\text{jet}, E^{miss}_T)$	>0.2 (mod.π)	
m_T (GeV)	40 GeV < m_T < 80 GeV	
E^{miss}_T (GeV)	30 GeV < E^{miss}_T < 80 GeV	
M_{eff} (GeV)	> 500 (3J) ; > 300 (4J)	
Number of the 3 or 4 jets with higher p_T tagged as a b-jet	0	≥ 1

$\varepsilon_i \neq 0$



- Normalize MC to data in background specific CR
- Extrapolate to Signal Regions using MC shapes:

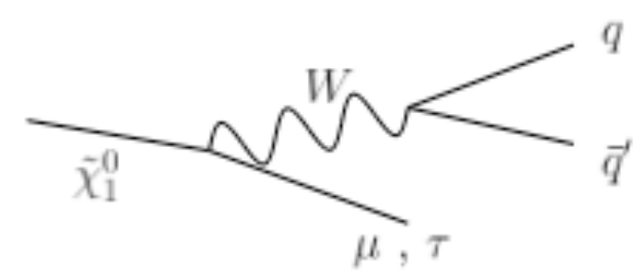
$$N_{pred,j}^{SR} = N_{data}^{iR} \times \frac{N_{MC,j}^{SR}}{N_{MC,j}^{iR}} \quad ,$$

i= W, T; j = W+jets, top

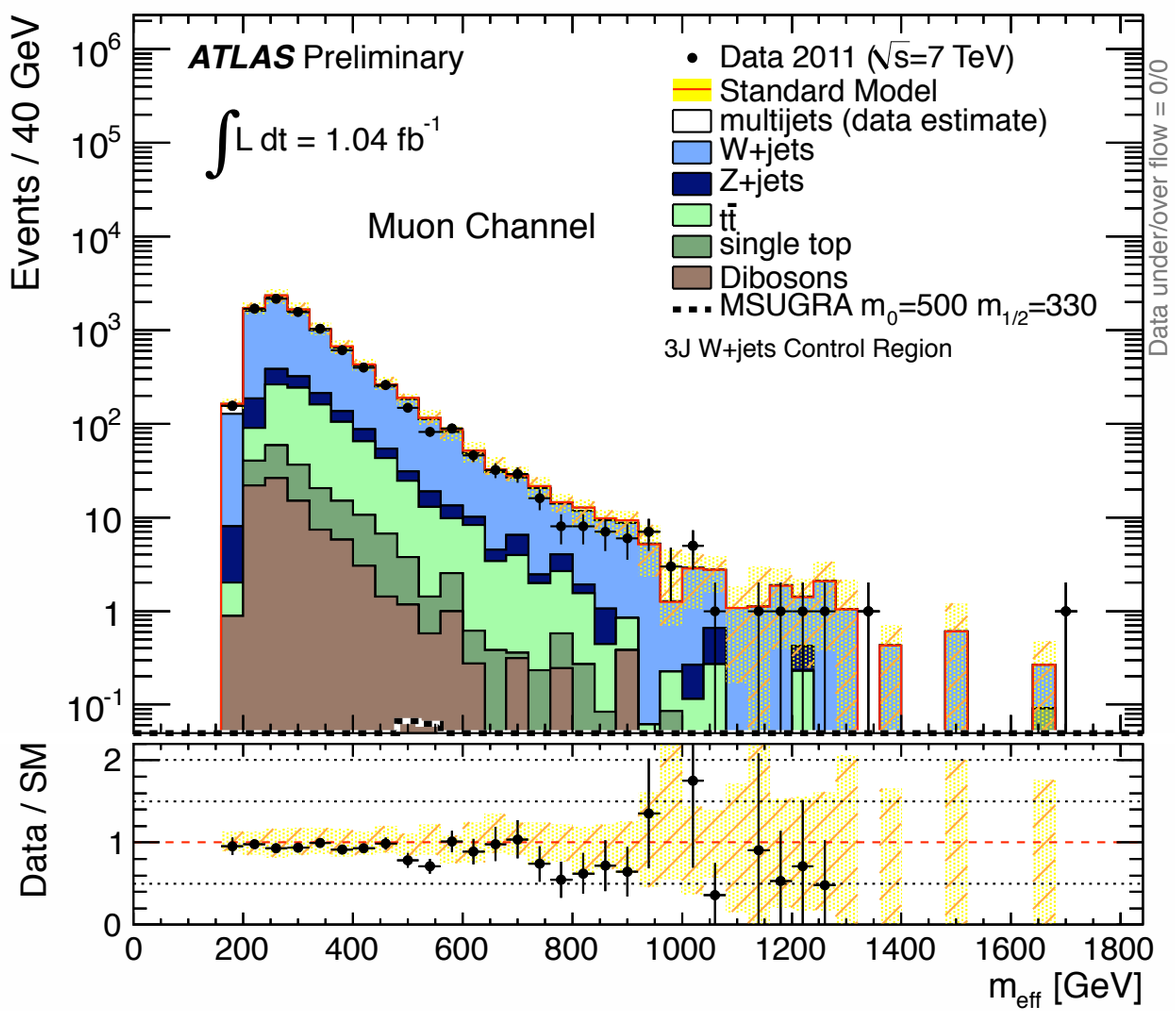
- QCD multijet treatment:
  - Estimation of contamination of QCD background in each of the regions with data-driven methods (Matrix Method).
  - Take into account contamination from QCD events with → real leptons
    → misidentified leptons (estimated using Z → ee, tt and W+jets events).

Bilinear RPV: background studies

$\varepsilon_i \neq 0$



- Final determination of background is done performing a simultaneous likelihood fit of the different CR to account for cross contamination.
- The determination of the QCD multijet contribution to the various regions is performed as part of the fit procedure.



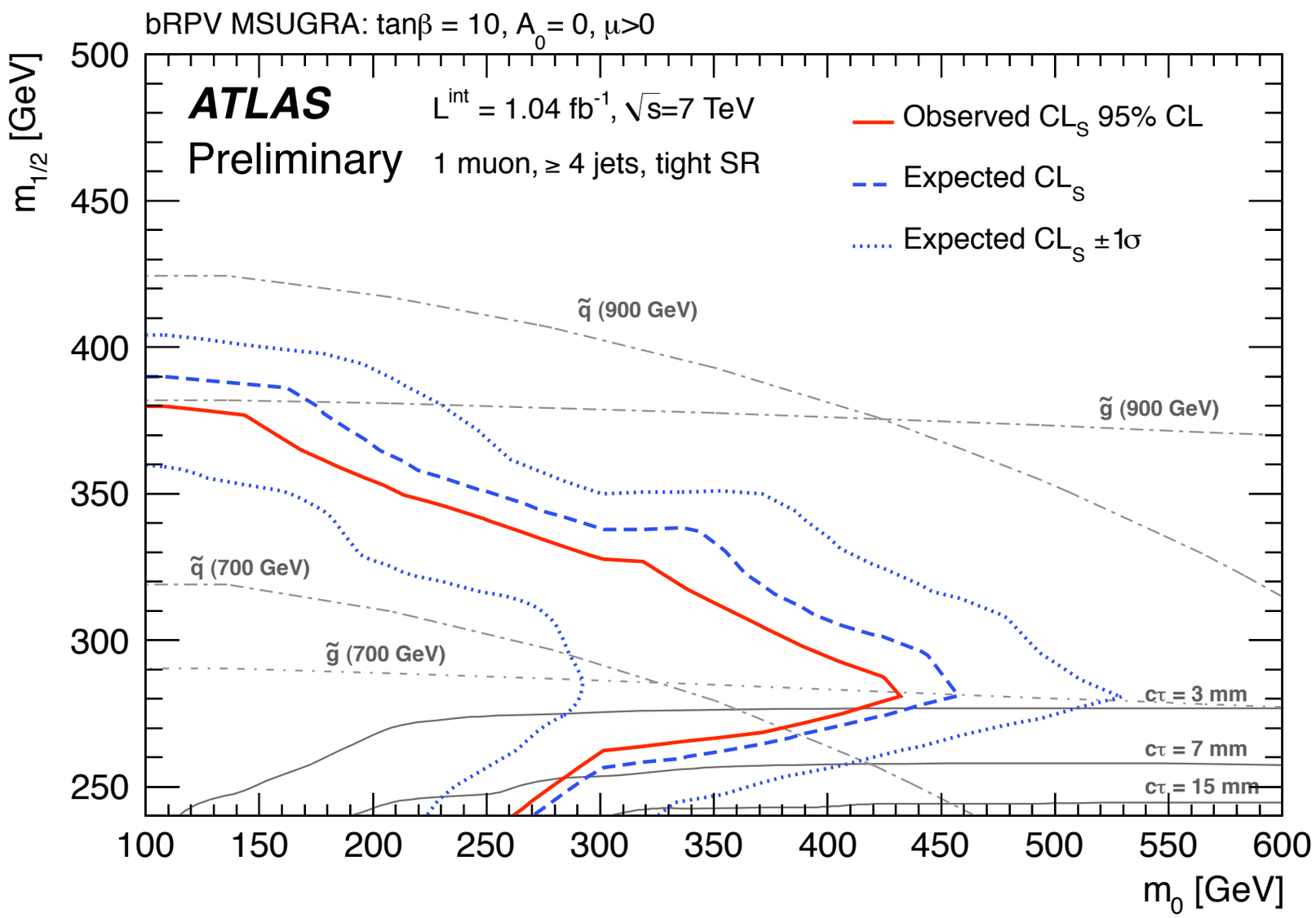
- Good agreement data / MC

- The assumption that the MC simulation is able to predict the backgrounds in the signal regions is validated by checking additional Control Regions.
- Possible contamination from atmospheric muons is studied and found to be negligible for $|z_\mu - z_{PV}| > 5$ mm.
- Background from single top and dibosons studied, found to be small.

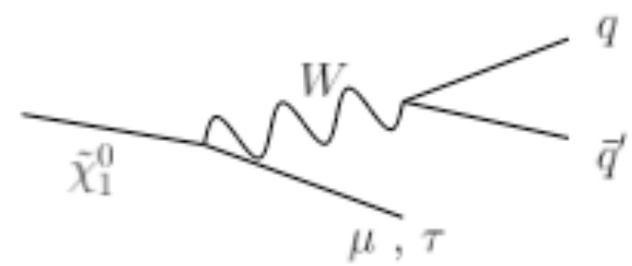
- Systematic uncertainties: dominated by theoretical uncertainties (20 to 30 %), the rest below 10%.

Bilinear RPV: results

- No excess of events observed!
- 95% CL exclusion limits in the 4JT SR for mSUGRA bRPV
- tan β = 10; A_0 = 0; μ > 0



$\varepsilon_i \neq 0$

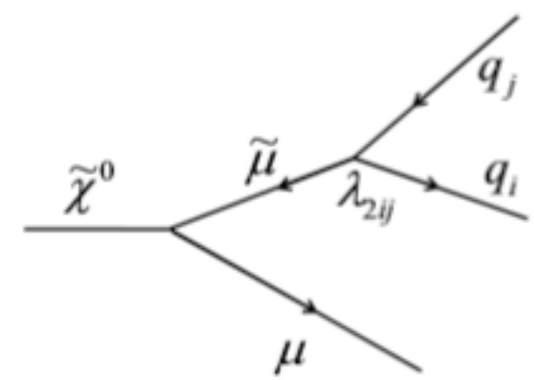


	Muon channel	
	Observed Events	Fitted sum of background Events
3JL SR	58	63 ± 19
3JT SR	11	13.9 ± 4.3
4JL SR	50	53 ± 16
4JT SR	7	6.0 ± 2.7

Displaced vertices: description

- decays between 4mm to 180 mm to the interaction point in association with a high-transverse-momentum muon studied
- Broad range of neutralino velocities and daughter-particle multiplicities studied.
- Results obtained are independent of the value used for λ'_{2ij} .

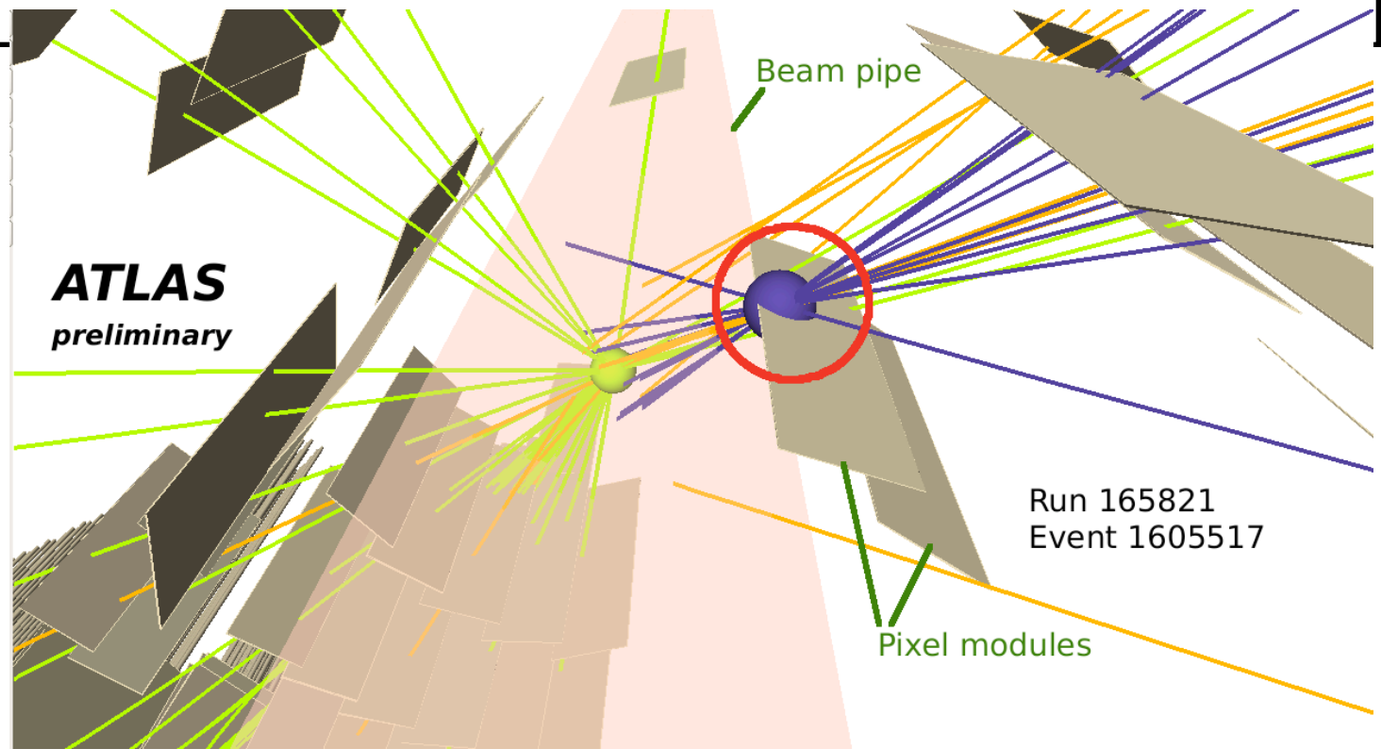
$\lambda'_{2ij} \neq 0$



- Reconstruction of the displaced vertex (DV):
- Take every pair of tracks (p_T > 1 GeV; impact parameter > 2mm) with no hit between the PV and the DV.
- Combine vertices which share tracks and are close to each other.
- DV within $|z_{DV}|$ < 300mm and $|r_{DV}|$ < 180mm
- Extra requirements to remove tracks from the PV.
- At least 4 tracks in every DV.

- Main source of background: interaction with detector material.
- Generally low mass vertices but if a track overlaps → high mass vertex reconstructed.

Veto to vertices reconstructed within regions of high-density material. Removes bkg from interaction with material + high-p_T track.

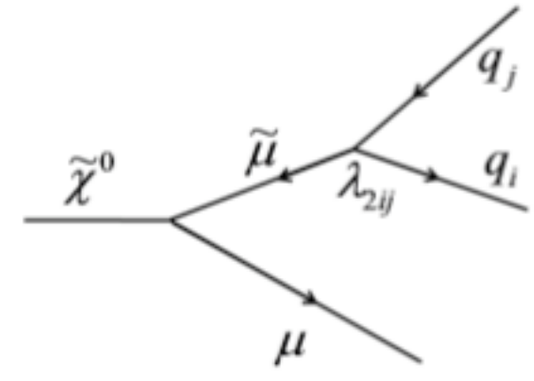


Displaced vertices: signal region

-Event selection:

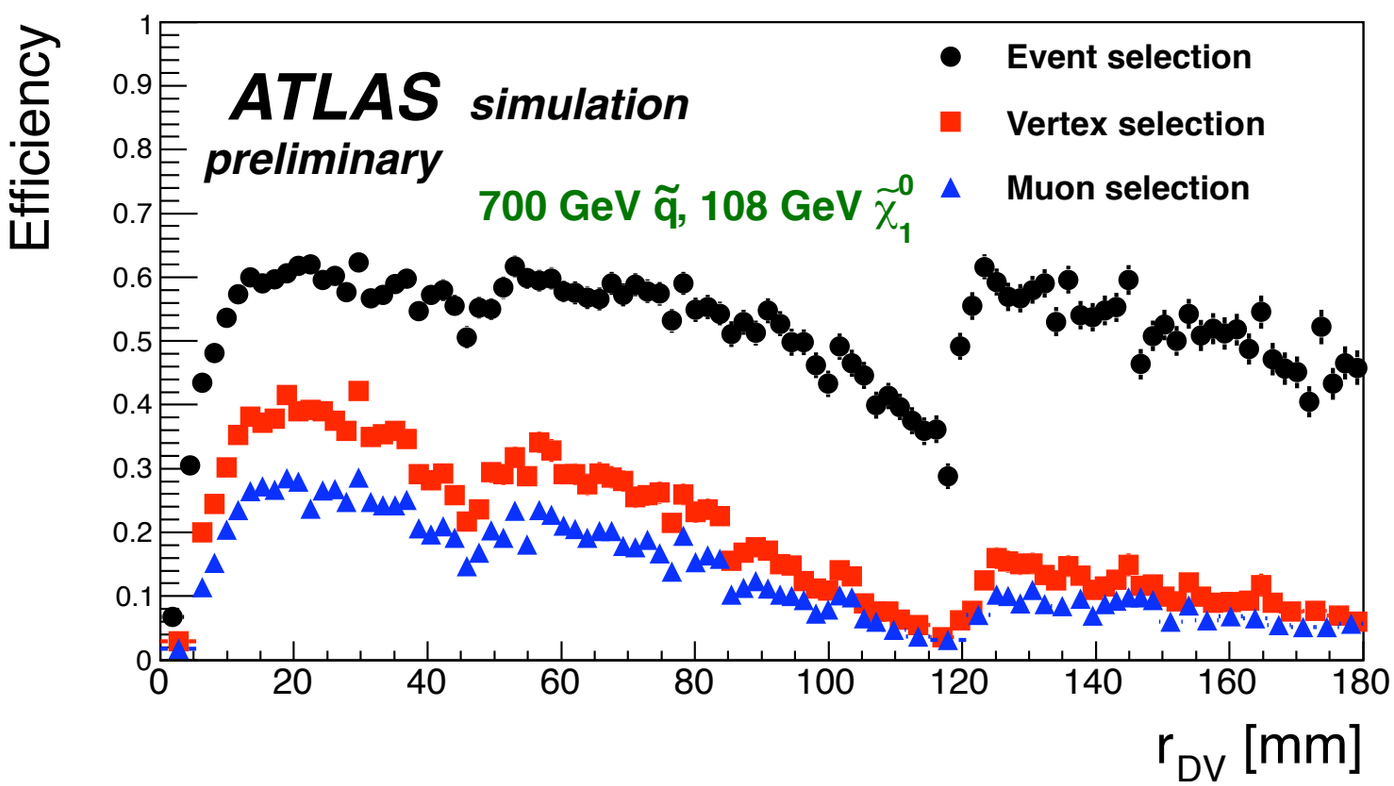
- At least one PV with more than 4 tracks and a z position < 200 mm.
- m_{DV} > 10 GeV. Removes bkg from interaction with material.
- Veto to vertices reconstructed within regions of high-density material. Removes bkg from interaction with material + high-p_T track.
- At least 1 DV per event and a muon candidate with p_T >45 GeV

$\lambda'_{2ij} \neq 0$

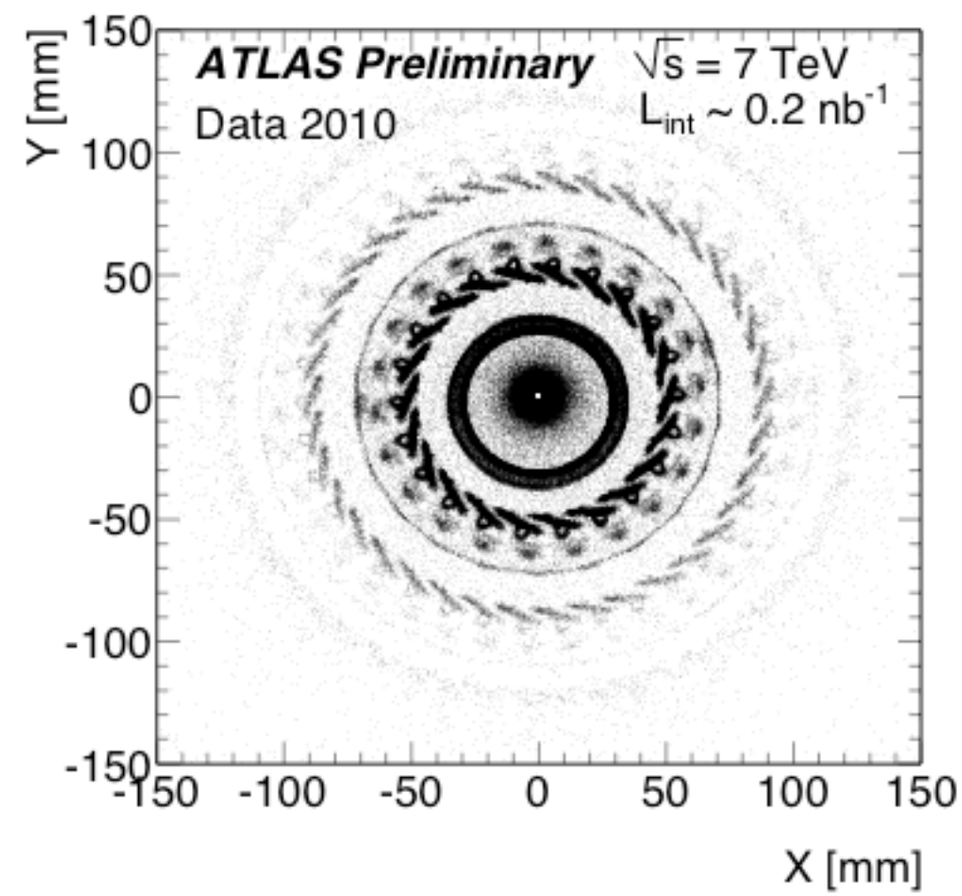


Efficiency for signal MC events:

- Event selection: eff. of finding at least one DV after trigger and PV requirements.



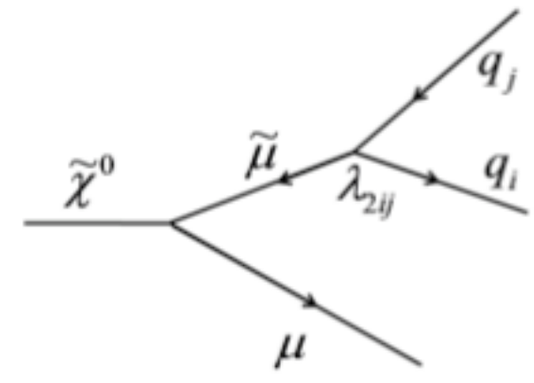
- Good estimation of the density of DV due to interaction with material in each pixel layer and air-gap.



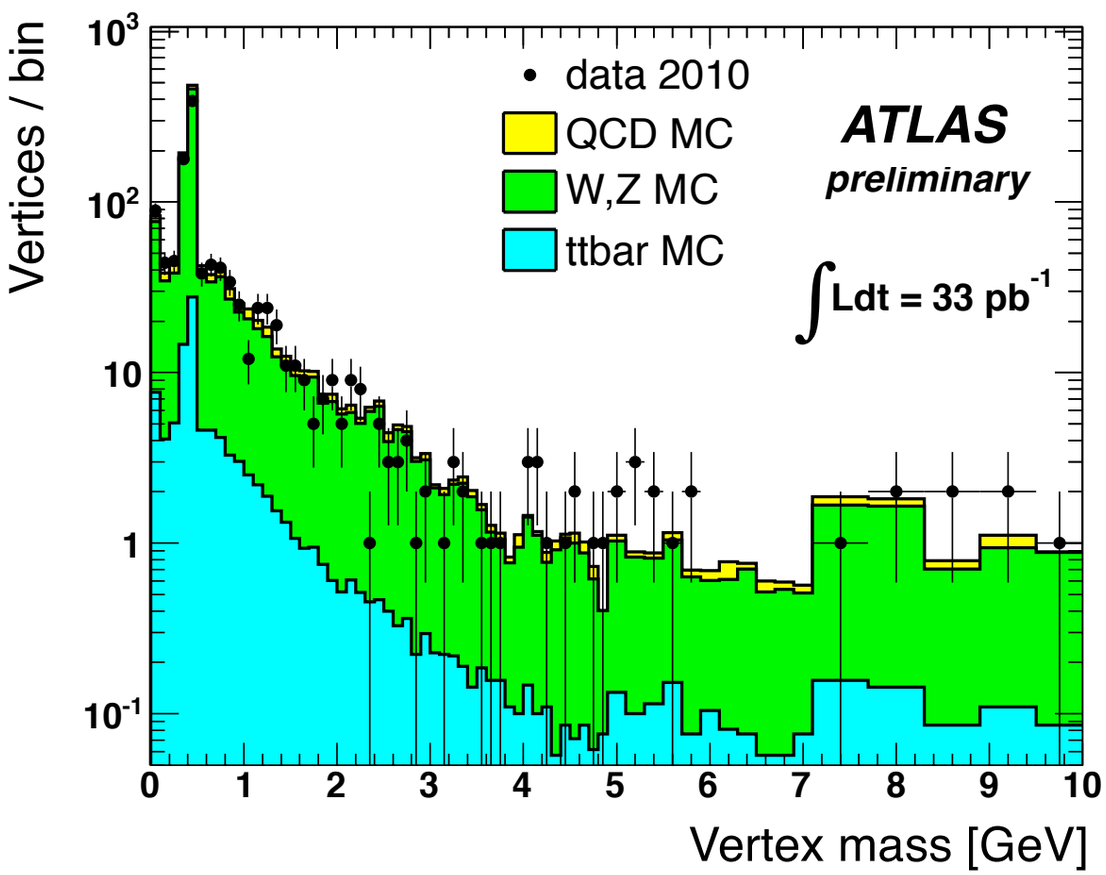
Displaced vertices: background studies

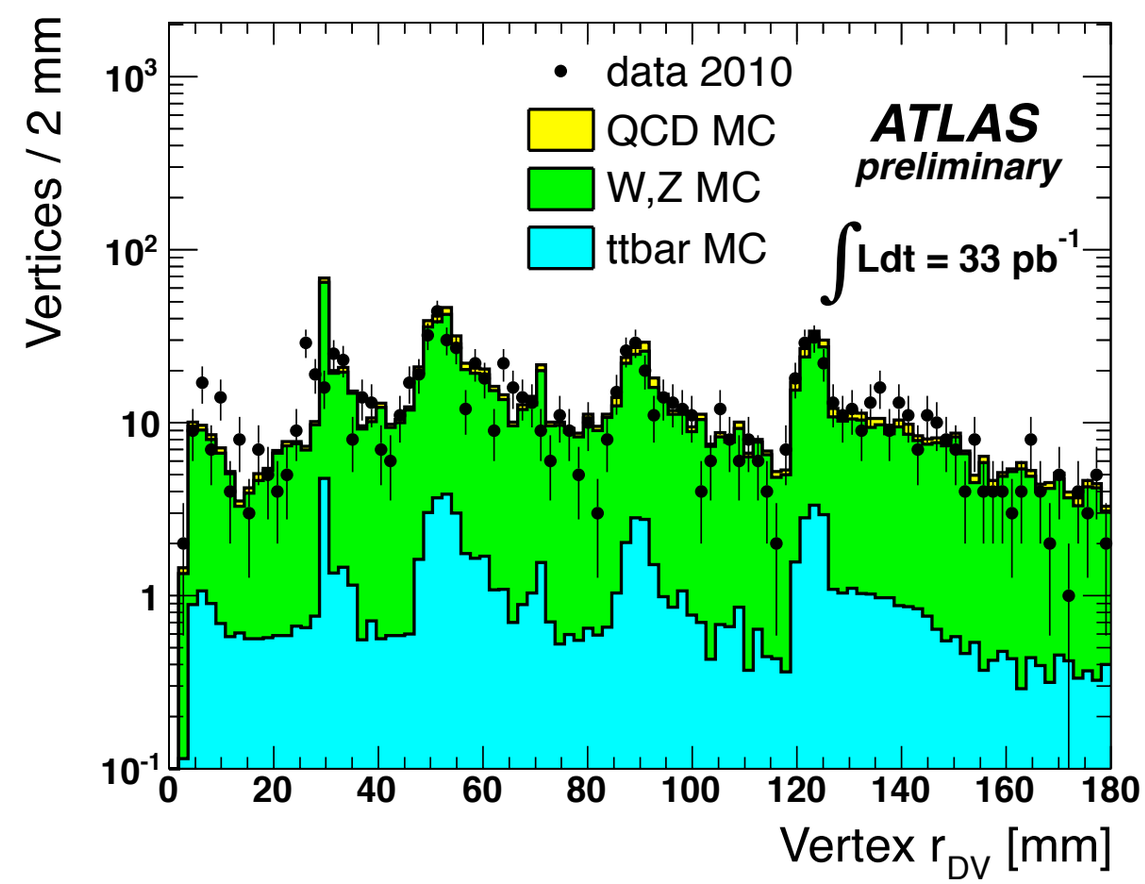
- Control Region: m_{DV} < 10 GeV, before applying the material veto.
- $W \rightarrow \mu\ \nu_\mu$ has high eff. for muon selection but no events selected for vertex criteria. N_{exp} < 0.03, for other bkgs, an order of magnitude smaller.
- Other sources of systematic uncertainties have been studied. Their influence on the limit is small compared to the large, conservative estimate on the background.

$\lambda'_{2ij} \neq 0$



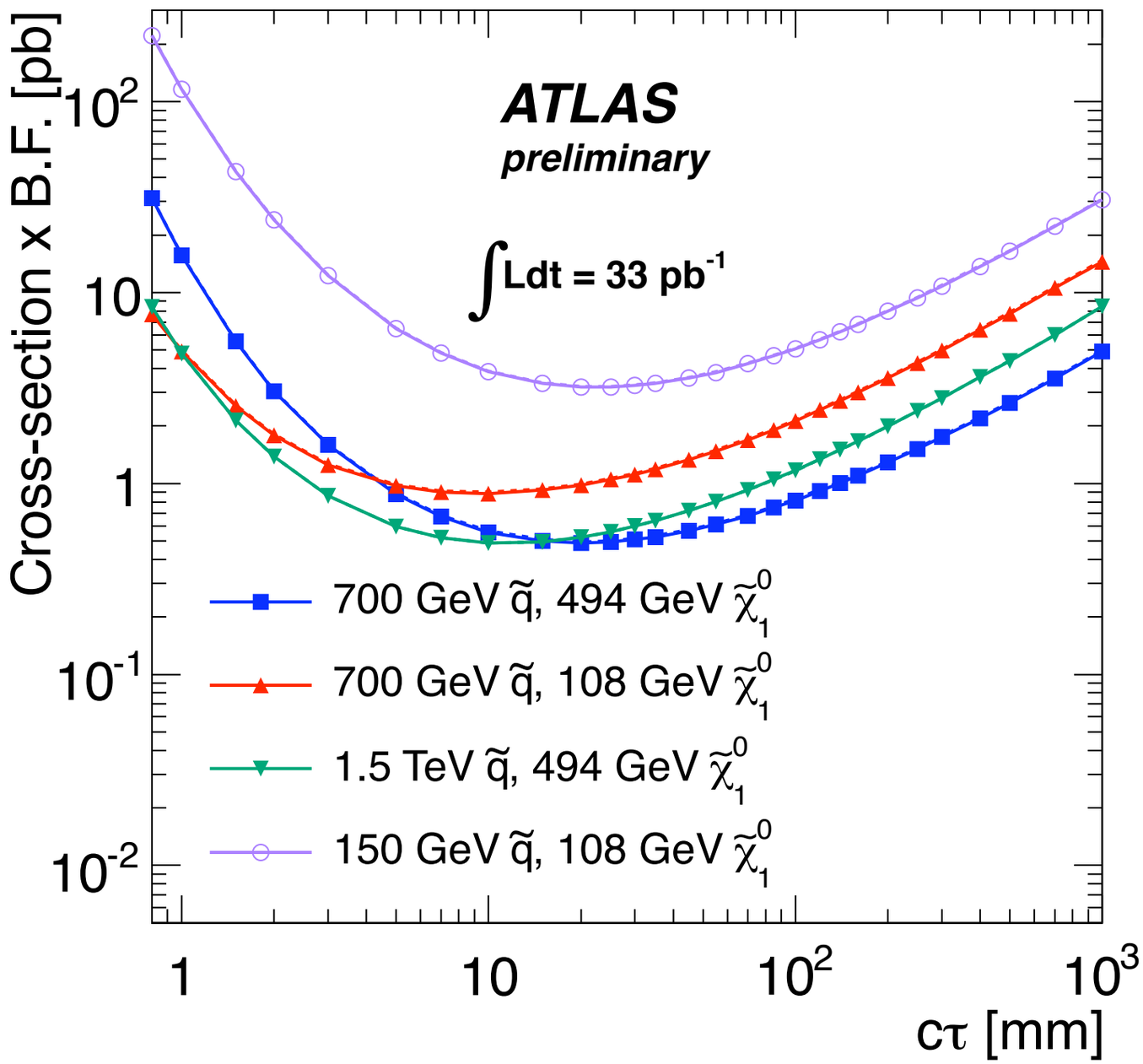
- Good agreement data / MC



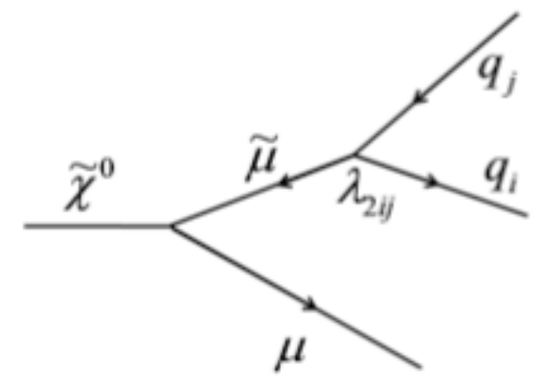


Displaced vertices: Results

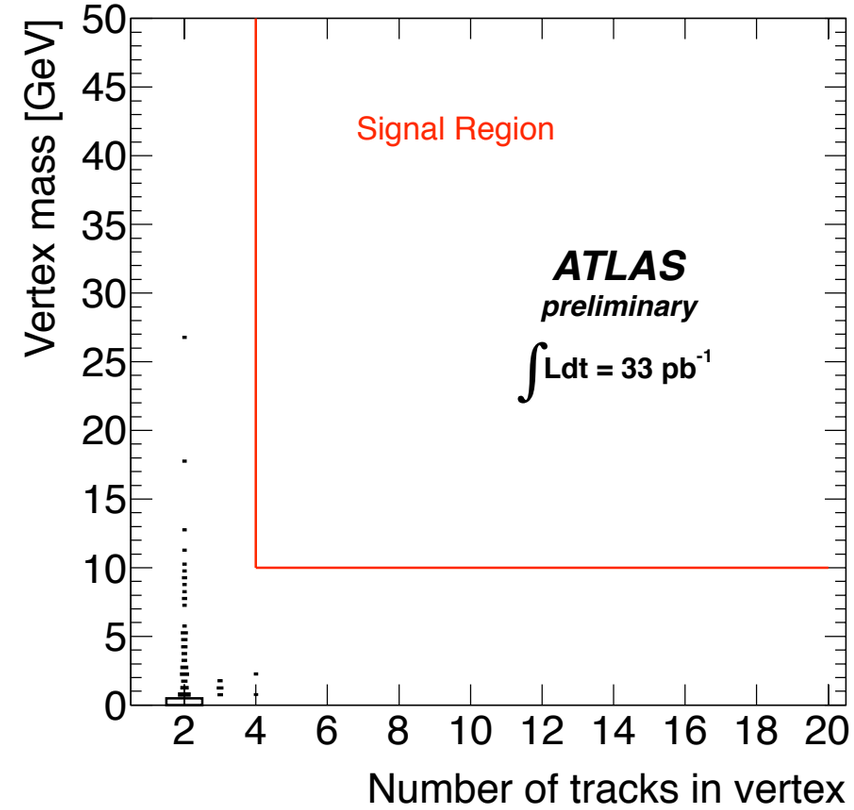
Upper exclusion limits at 95% CL for different squark and neutralino masses.



$\lambda'_{2ij} \neq 0$



Number of events passing the selected requirements except for the m_{DV} and N_{DV}^{tracks}. No data events observed in the SR.



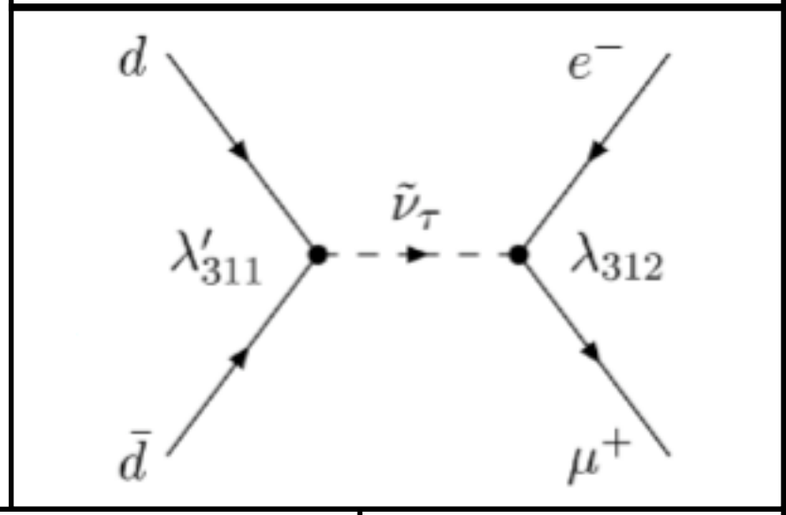
e μ resonance: description

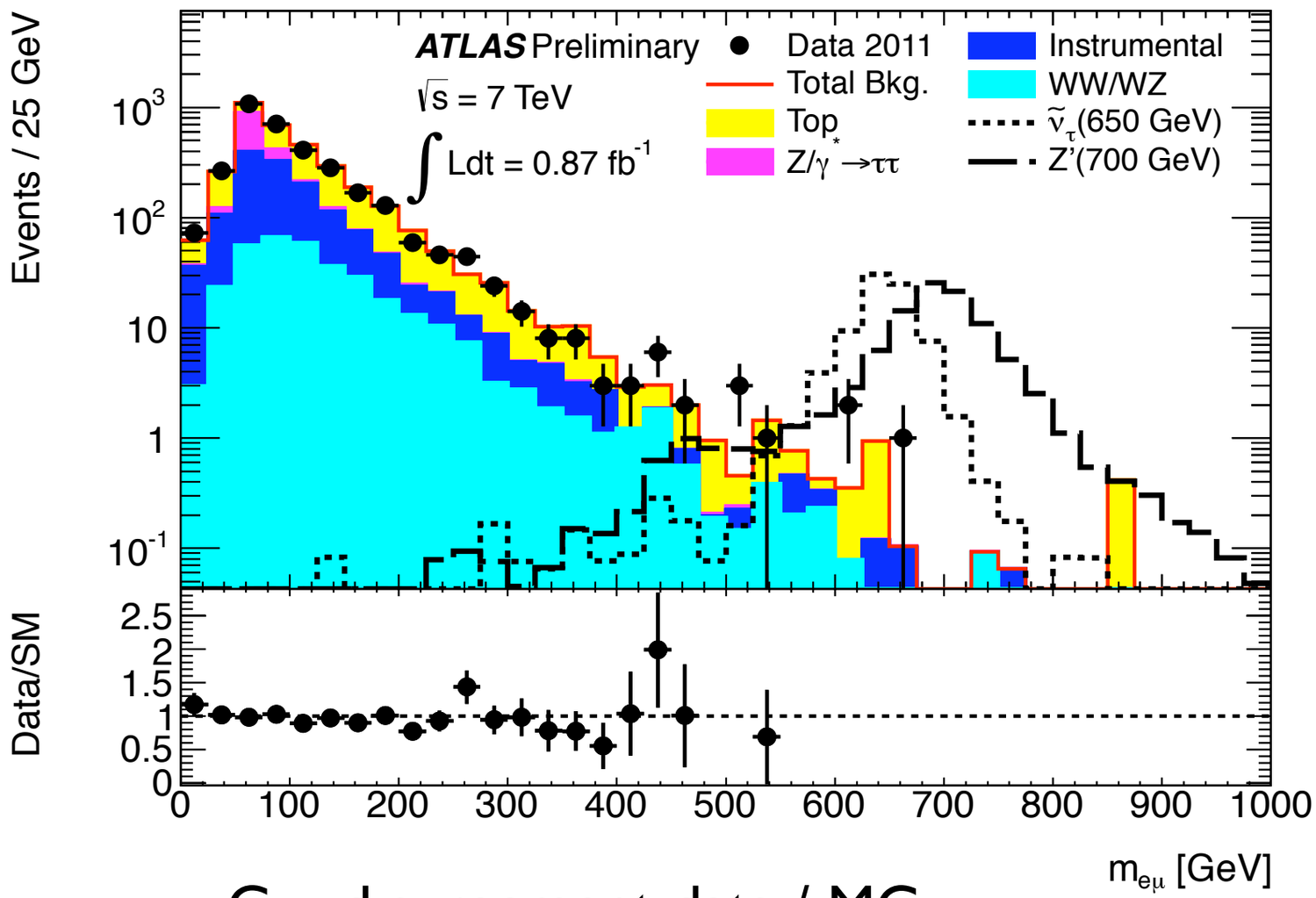
- Search for an excess of high invariant mass eμ ($m_{e\mu}$)
- Clean detector signal: look for exactly one isolated electron and exactly one isolated muon with opposite charge
- Low SM background in the high $m_{e\mu}$ region due to:

•Processes which can produce electrons and muons in the final state

•Instrumental background: a photon or some jet in the final state is reconstructed as a lepton

$\lambda'_{131} \times \lambda_{312} \neq 0$

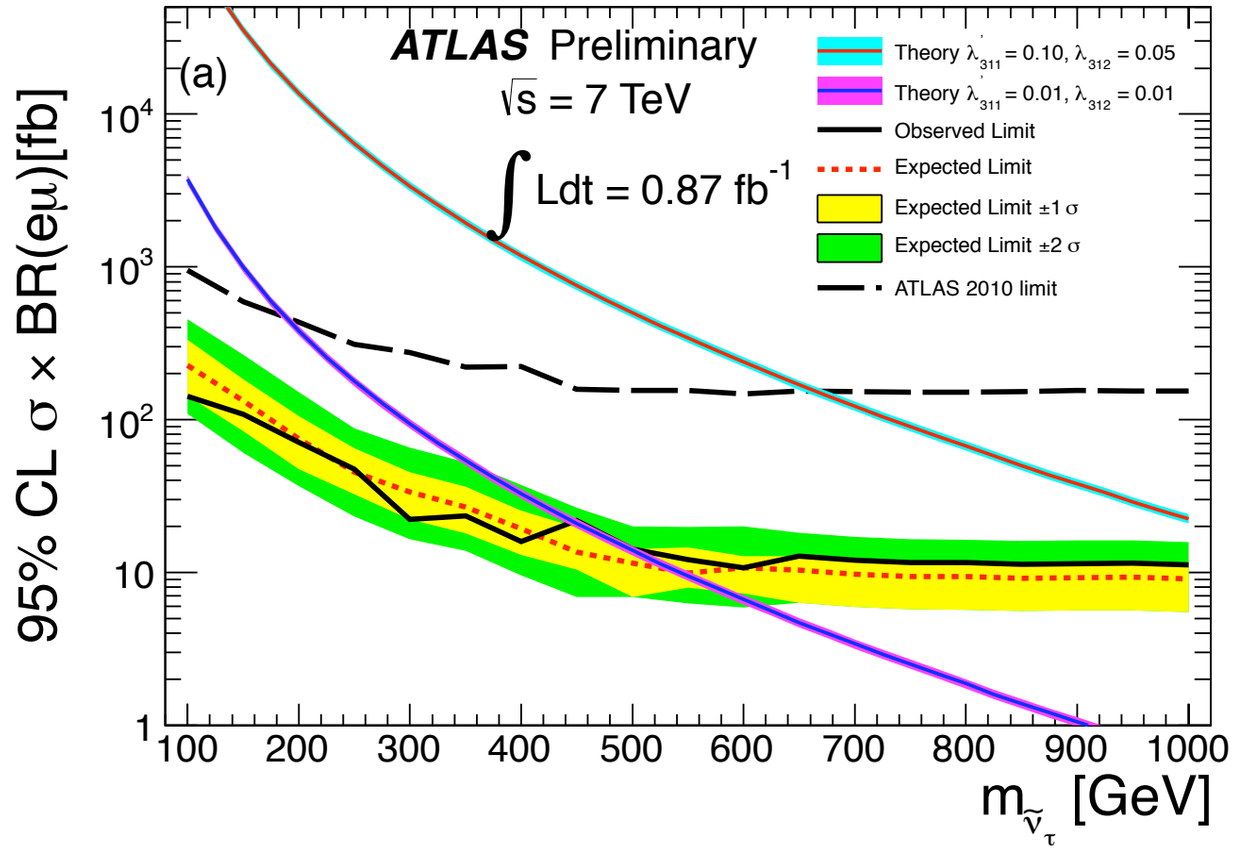




Process	Number of events
tt	1281 ± 168
Jet instrumental background	984 ± 195
Z / γ* ττ	614 ± 53
WW	318 ± 24
Single top	125 ± 17
W / Z + γ	67 ± 11
WZ	18.2 ± 1.9
Total background	3408 ± 230
Data	3338

- Good agreement data / MC

e μ resonance: results



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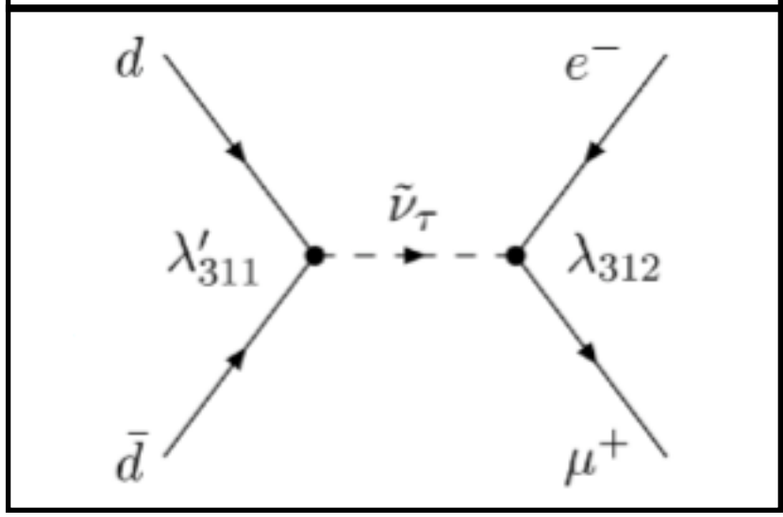
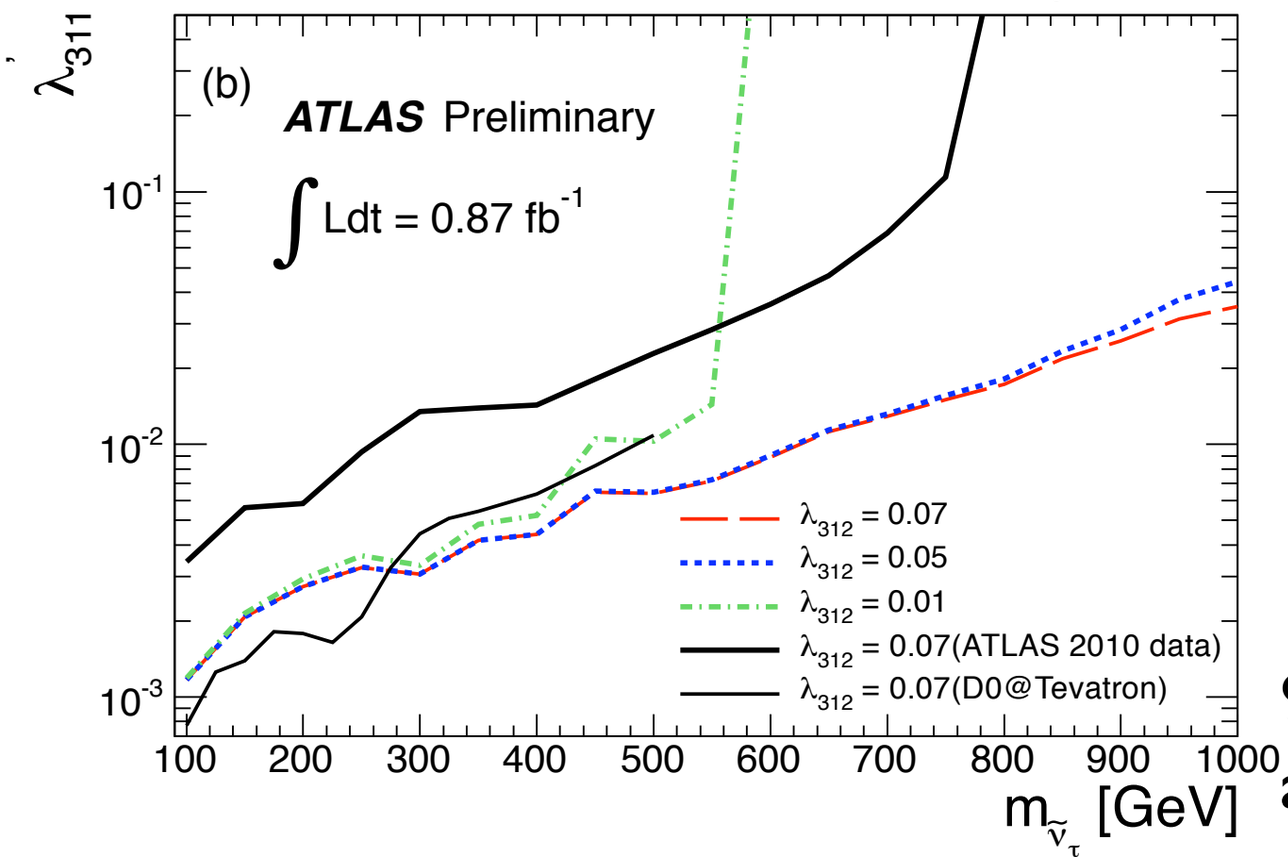


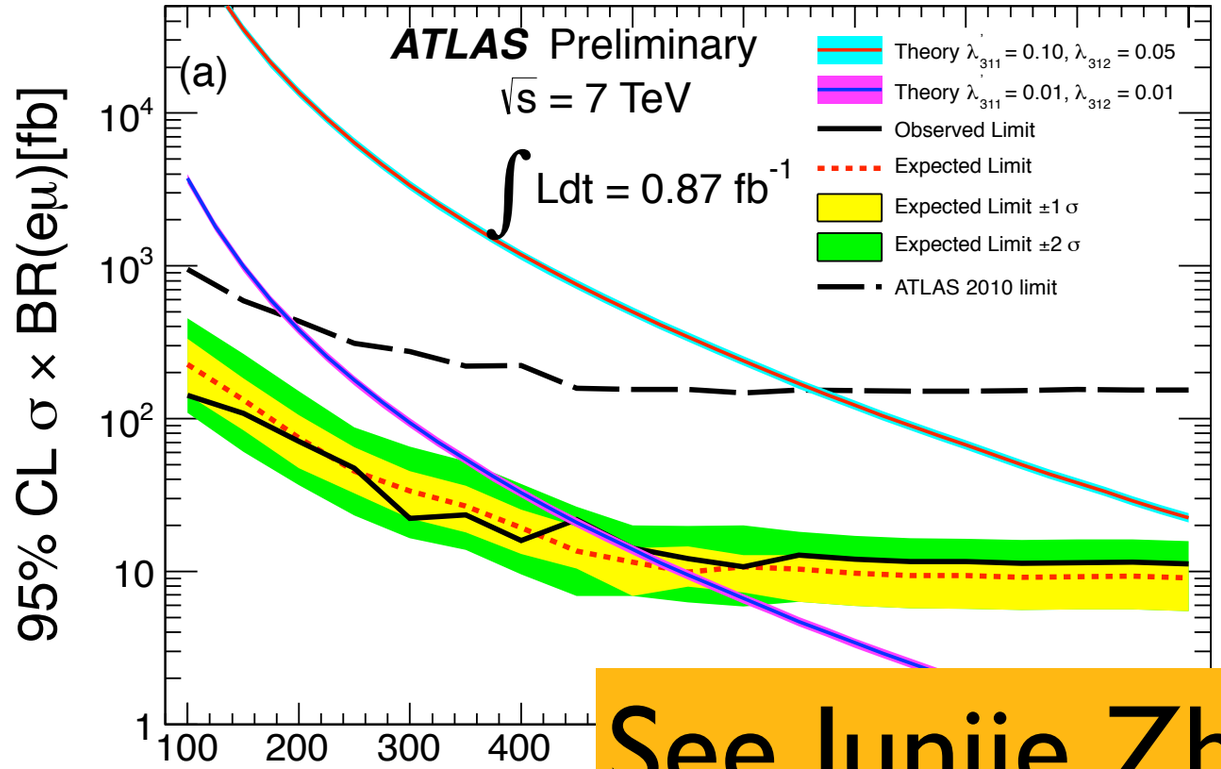
95% CL upper limits on $\sigma(pp \rightarrow \tilde{\nu}_\tau) \times BR(\tilde{\nu}_\tau \rightarrow e\mu)$ as a function of $m_{\tilde{\nu}}$



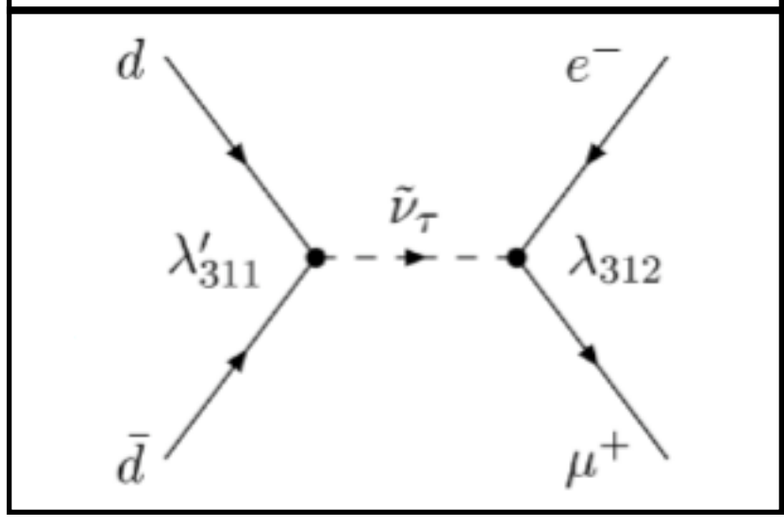
$m_{e\mu}$	Data	SM prediction
> 200 GeV	224	236 ± 21
> 250 GeV	119	111 ± 11
> 300 GeV	51	55 ± 6
> 350 GeV	29	30 ± 4
> 400 GeV	18	14.2 ± 2.2
> 450 GeV	9	8.2 ± 1.5
> 500 GeV	7	5.3 ± 1.1
> 550 GeV	3	3.4 ± 0.8
> 600 GeV	3	2.2 ± 0.7
> 650 GeV	1	0.9 ± 0.4
> 700 GeV	0	0.8 ± 0.4

95% CL upper limits on the λ'_{311} couplings as a function of m_ν for three values of λ_{312}

e μ resonance: results

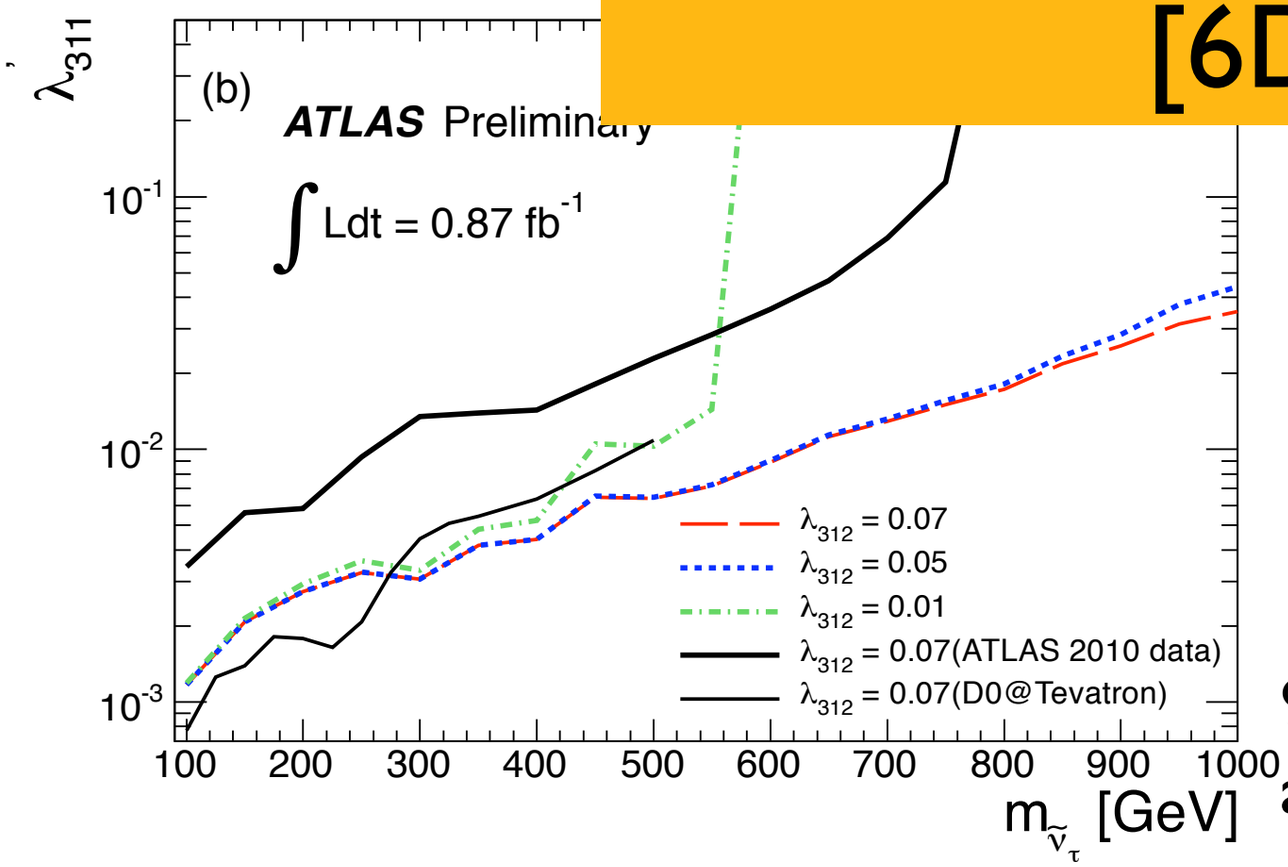


$\lambda'_{131} \times \lambda_{312} \neq 0$



95% CL upper limits on $\sigma(pp \to \tilde{\nu}_\tau) \times BR(\tilde{\nu}_\tau \to e\mu)$

See Junjie Zhu's talk for details [6D Tue]



		ediction
		: 21
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95% CL upper limits on the λ'_{311} couplings as a function of m_ν for three values of λ_{312}

Conclusions and outlook

- ATLAS results in searches for RPV SUSY presented.
  - good understanding of detector performance & physics objects have been demonstrated, which are essential for these analysis
  - background processes well under control

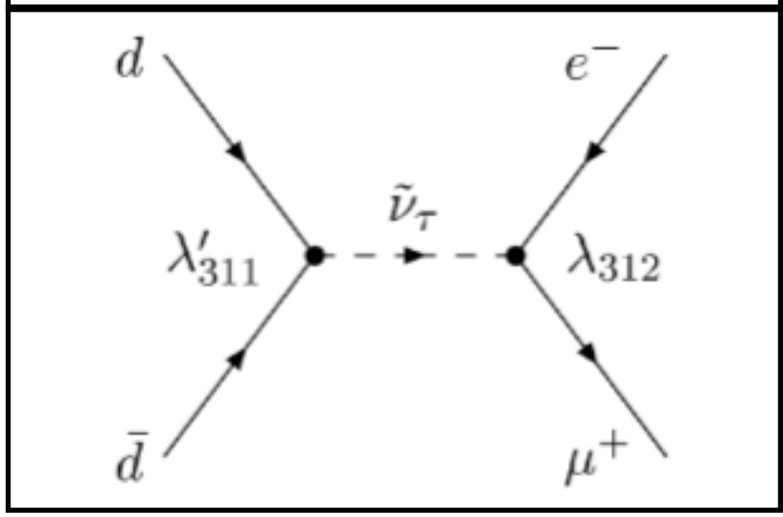
- Limit setting for three different scenarios within RPV.
  - sneutrino decaying to e μ resonances, displaced vertices and bilinear RPV studied.
  - no significant deviations from SM observed so far
  - exclusion limits set have been extended to wider parameter space ranges.
  - limits presented are the most stringent to date

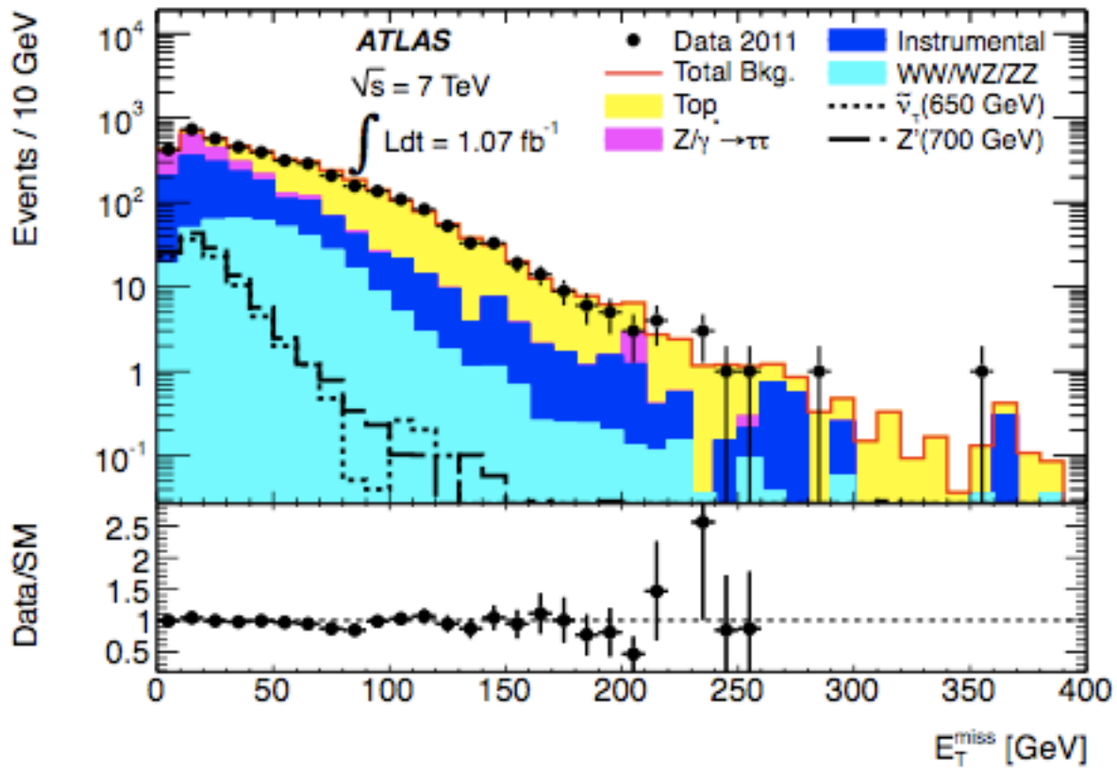
BACKUP

e μ resonance: background studies

- Comparison of data / MC distributions for some kinematic variables.
- Good agreement data / SM background found for all regions.

$\lambda'_{131} \times \lambda_{312} \neq 0$





$m_{\tilde{\nu}}$ = 650 GeV
λ'_{311} = 0.10
λ_{312} = 0.05