Search for R-parity violating SUSY signatures with the ATLAS detector

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on behalf of the ATLAS collaboration

Outline

1. Introduction
2. RPV-SUSY searches at ATLAS
3. Summary

1. Introduction

Unexpected SUSY?

- **SUSY with R-parity ($\equiv(-1)^{3(B-L)+2S}$) conservation (RPC) is really popular:**
  - Provides elegant solutions to the dark matter and hierarchy problems.
  - Leads to natural GUT.

- **But currently one can squeeze the parameter space:**
  - No significant excess of events having large missing transverse momentum (Etmiss) at LHC searches.
  - Indication of m_H~125GeV.
  - Flavor constraints from **$b \to s\gamma$, $B \to \tau\nu$, $B_s \to \mu\mu$** etc.
  - Constraints from dark matter direct detection experiments.

- **Some viable RPC models still survive, but we certainly must all possibilities.**

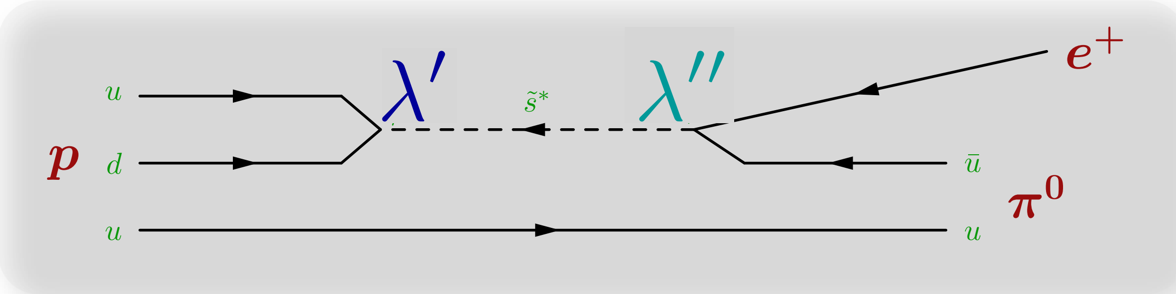
R-parity violating SUSY

- There's no reason why R-parity should be exactly conserved... R-parity violating (RPV) terms are allowed in the superpotential:

$$W = W_{MSSM} + \underbrace{\lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \kappa_i L_i H_u}_{\text{Lepton number violating (LNV)}} + \underbrace{\lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k}_{\text{Baryon number violating (BNV)}}$$

- If all terms appear, proton becomes unstable...

$$\tau_{\mathrm{p}} \propto \frac{|\lambda'||\lambda''|}{M^2_{\mathrm{SUSY}}}$$



- "**Part of them need not to be zero**" → **Proton still stable & rich phenomenology**
  - Resonant/associated single SUSY particle production is possible.
  - The lightest SUSY particle (LSP) is no longer stable.
    - *Etmiss is diluted (or absent!)*

- R-parity has played some roles.... advantages and disadvantages:
  - No dark matter candidate :-(
  - Could explain large mixing angles and hierarchical masses of neutrinos :-))

RPV signatures

So, what we're looking for is...

Signature	RPV scenario
multileptons ($ee\mu\mu$)	$\tilde{\chi}_1^0 - \mathtt{LSP}(\lambda),\ \tilde{\tau} - \mathtt{LSP}(\lambda)$
multiple τs	$\tilde{\chi}_1^0 - \mathtt{LSP}(\lambda),\ \tilde{\tau} - \mathtt{LSP}(\lambda')$
like-sign dileptons	$LL\bar{E}(\lambda),\ LQ\bar{D}(\lambda')$
dilepton resonance (ll')	$LL\bar{E} \otimes LQ\bar{D}(\lambda\lambda')$
late-decaying $\tilde{\chi}_1^0$	$\tilde{\chi}_1^0 - \mathtt{LSP}(\lambda),\ \tilde{\chi}_1^0 - \mathtt{LSP}(\lambda')$
$\ldots$	$\ldots$

(LNV)

Also for bilinear RPV(κ) and BNV (λ'').

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like-sign dileptons	$LL\bar{E}(\lambda),\ LQ\bar{D}(\lambda')$
dilepton resonance (ll')	LL [illegible]
late-decaying $\tilde{\chi}_1^0$	$\tilde{\chi}_1^0$ [illegible]
...	...

A handful of results today, but more coming soon...

Also for **bilinear RPV**(κ) and BNV (λ'').

NEW! 2 fb^{-1}

ATLAS-CONF-2012-035

2. RPV-SUSY searches

Multilepton final state

4-lepton search

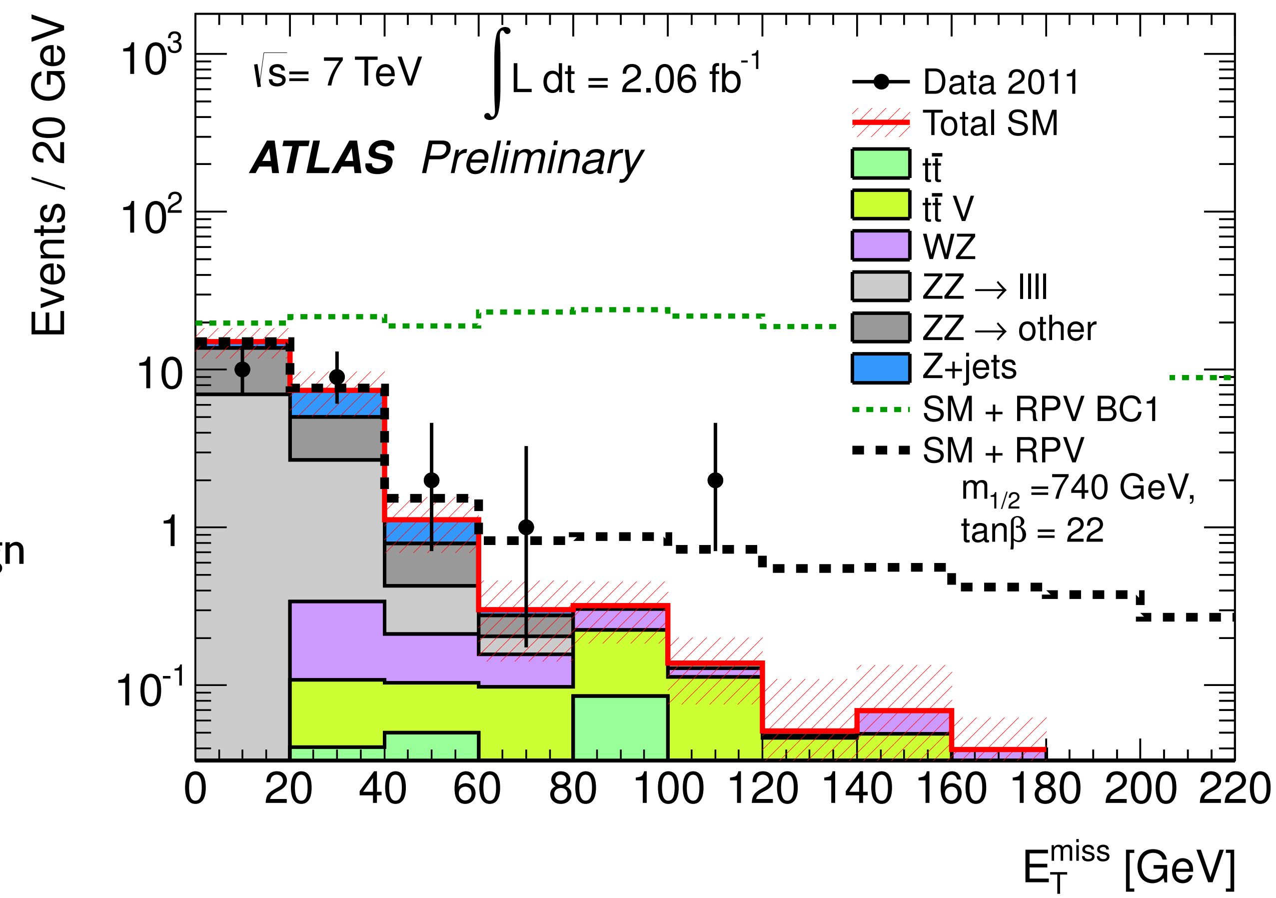
- Very low SM background, high signal-to-background ration
  - Promising channel to find something new!
  - Interpretations using the results already reported (ATLAS-CONF-2012-001)

- Selection:
  1. Single-lepton trigger followed by offline p_T cut
     - >25GeV for electron
     - >20GeV for muon
  2. 4 leptons with p_T>10GeV
  3. Etmiss > 50GeV
  4. $|M_{SFOS(*)}-M_Z|$ > 10GeV (Z-veto)

(*) Same Flavor Opposite Sign

	w/o Z-veto	W/ Z-veto
BG exp.	1.7±0.9	0.7±0.8
Observed	4	0

(24 events before Etmiss cut)



- Limits on visible cross section of BSM: <3.5(1.5) fb w(w/o) Z-veto

BG breakdown

- Very high S/B ratio, but hard to estimate SM BG processes with very low rates.
  - BG estimation fully based on MC.
  - Validation regions to confirm that nothing goes wrong in the BG model.

	≥4 leptons + Etmiss>50GeV	+ Z-veto
ttbar	0.17±0.14	0.13±0.11
single t	0±0.04	0±0.04
ttbar+V	0.48±0.21	0.07±0.04
ZZ	0.44±0.19	0.019±0.020
WZ	0.25±0.10	0.09±0.05
WW	0±0.015	0±0.015
Zγ	0±0.5	0±0.5
Z+LF-jets	0.33±0.67	0.33±0.67
Z+HFjets	0.024±0.035	0.024±0.035
Drell-Yan	0±0.05	0±0.05
BG Total	1.7±0.9	0.7±0.8
Data	4	0

- Validation samples
  - ZZ: 4 leptons + low Etmiss(<50GeV)
    MC : 23±5
    Data : 20
  - Top : 2 OFOS leptons + 2 fakes (reversed isolation) + 1 b-tagged jet.
    MC : 8.4±0.8
    Data : 8

"Z+light-flavor jets" dominates and large uncertainty due the limited MC statistics.

Signal Model

- BC1-like **tanβ-m$_{1/2}$** grid with $\tilde{\tau}$-LSP (hep-ph/0609263, arXiv:1008.1580v2)
  - **$m_0 = A_0 = 0$, $\mu > 0$, $\lambda_{121} = 0.032$** (at M_{GUT})

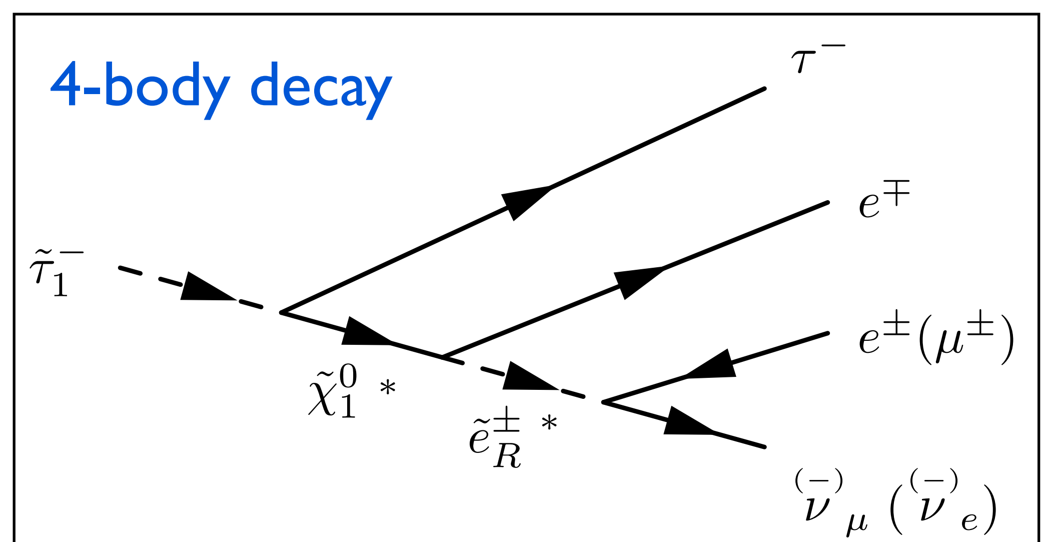
- Production mode:
  - Strong, weak($\tilde{\chi}^0, \tilde{\chi}^{\pm}$), stau-pair, slepton-pair

- Decay channel:

	Mass [GeV]	Channel	BR	Channel	BR
$\tilde{\tau}_1^-$	148	$\tau^-\mu^\pm e^\mp \overset{(-)}{\nu}_e$	50.1%	$\tau^- e^\pm e^\mp \overset{(-)}{\nu}_\mu$	49.9%
$\tilde{e}_R^-$	161	$e^-\nu_\mu$	50.0%	$\mu^-\nu_e$	50.0%
$\tilde{\mu}_R^-$	161	$\tilde{\tau}_1^\pm\tau^\mp\mu^-$	99.9%		
$\tilde{\chi}_1^0$	162	$\tilde{\tau}_1^\pm\tau^\mp$	99.6%		

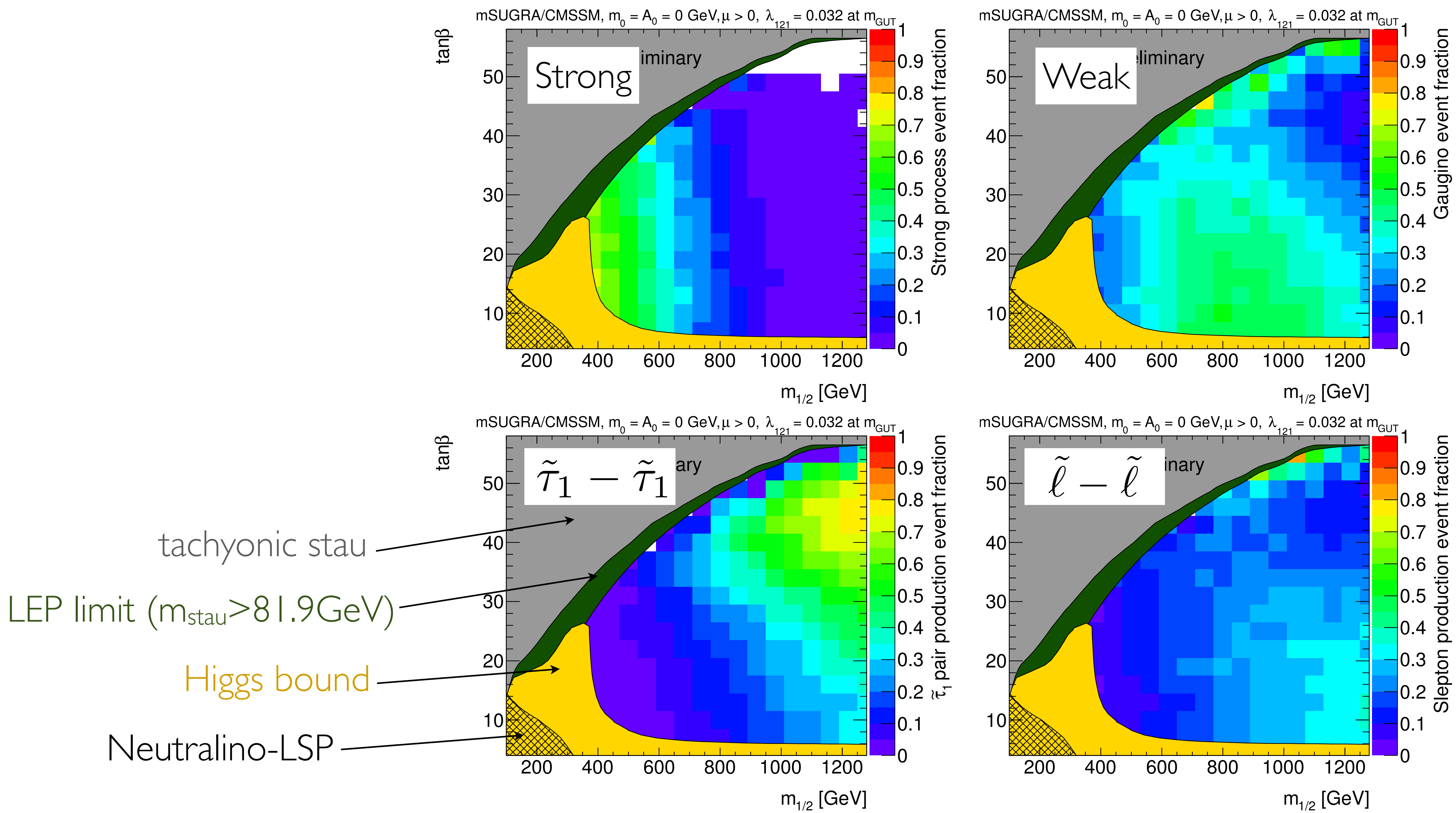
m$_{1/2}$=400GeV, tanβ=13 (BC1 benchmark)

- Final state:
  - 2e$^\pm$, 2(e or mu), 2taus + Etmiss



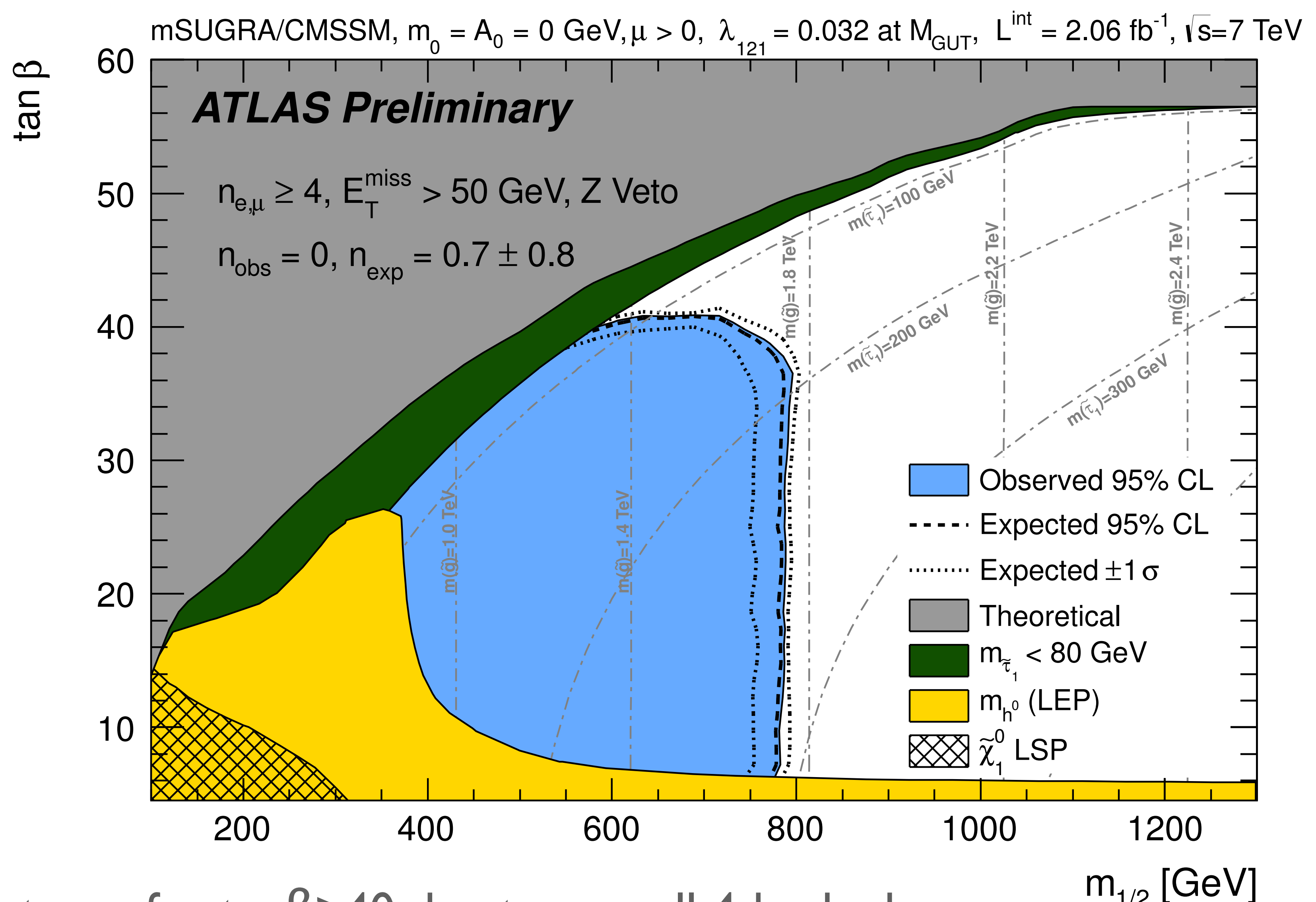
Production process

- Weak prod. dominates for most of parameter space.
- Stau-pair prod. dominates at high-tanβ region.



Interpretation

- Selection cuts with Z-veto.
- Limits on BC1-like grid:
  - $m_{1/2}$ < ~800GeV (corresponding gluino mass ~1770GeV) for tanβ < 40



(Poor acceptance for tanβ>40 due to a small 4-body decay branch and a significant lifetime of stau.)

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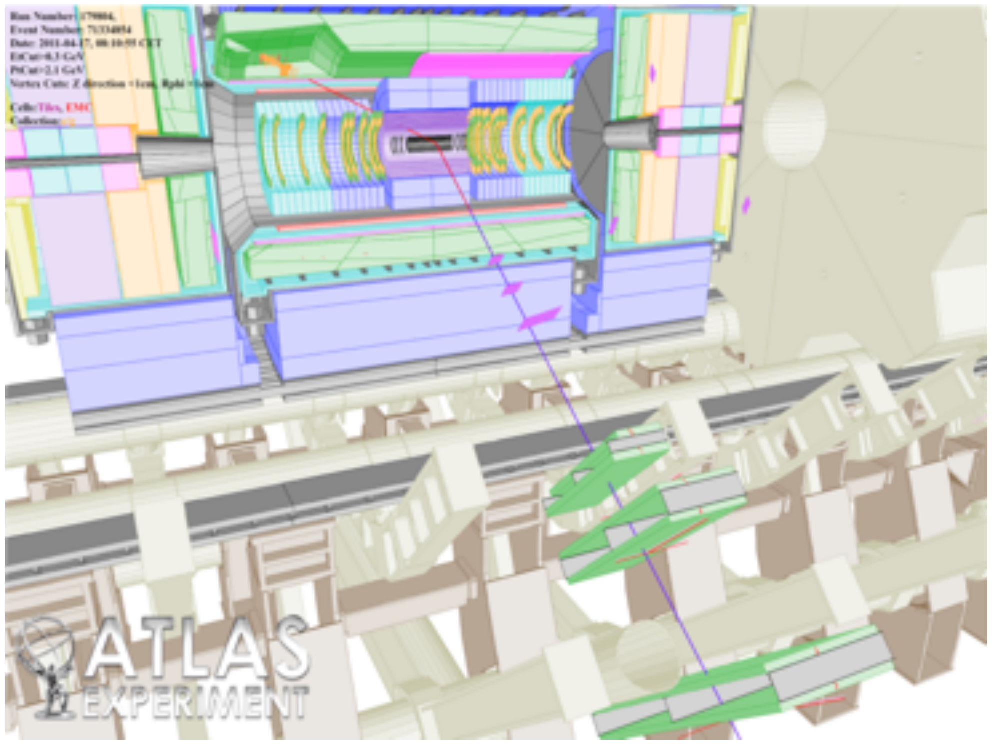
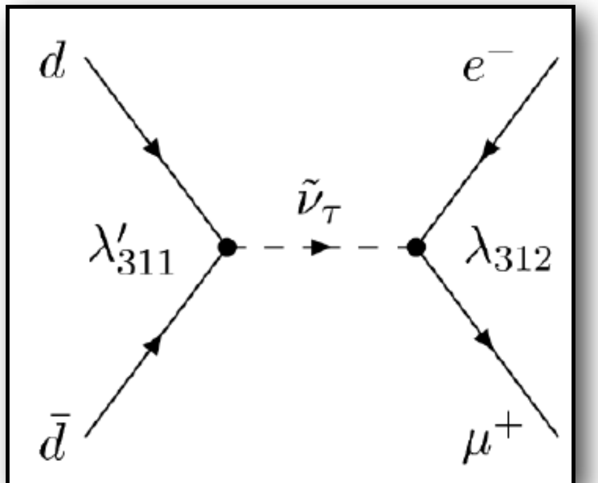
2. RPV-SUSY searches

"$e - \mu$" resonance



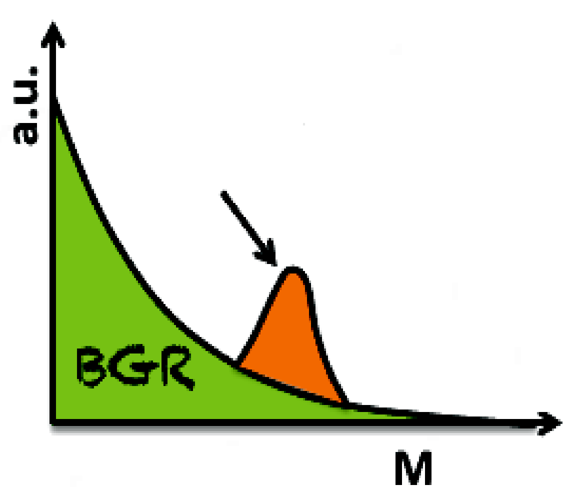
RPV sneutrino

- RPV tau sneutrino with LNV-decay:



$\lambda'_{311} \neq 0 \ \&\& \ \lambda_{312} \neq 0$

- Signature: **e-μ** resonance
  - Excess expected in $\mathbf{m_{e\mu}}$ distribution
  - Low SM background.



Electron:
- p_T > 25 GeV
- |η|<1.37 or 1.42<|η|< 2.47
- Isolated && shower shape requirements

Muon:
- p_T > 25 GeV
- |η|<2.4
- Reconstructed in Inner Detector&Muon Spectrometer.
- Isolated

Selection:
- Exactly one electron and one muon with "opposite-sign charge"
- No requirements on jets and Etmiss

BG estimate

- SM background processes:
  - **Z/γ*(→ττ), top, diboson**
  - Estimated using MC
- Instrumental background (**jet/γ faking to a lepton**)
  - W/Z+γ by MC
  - QCD/W+jets background derived using a data-driven matrix method:

$$\begin{bmatrix} N_{TT} \\ N_{TL} \\ N_{LT} \\ N_{LL} \end{bmatrix} = \begin{bmatrix} rr & rf & fr & ff \\ r(1-r) & r(1-f) & f(1-r) & f(1-f) \\ (1-r)r & (1-r)f & (1-f)r & (1-f)f \\ (1-r)(1-r) & (1-r)(1-f) & (1-f)(1-r) & (1-f)(1-f) \end{bmatrix} \begin{bmatrix} N_{RR} \\ N_{RF} \\ N_{FR} \\ N_{FF} \end{bmatrix}$$

The efficiency "r" is measured using Z→ll events selected with one tight (tag) and one loose (probe) leptons with $80 < m_{ll} < 100$GeV.

The jet fake rate "f" is measured using QCD jet events; e.g. for electrons

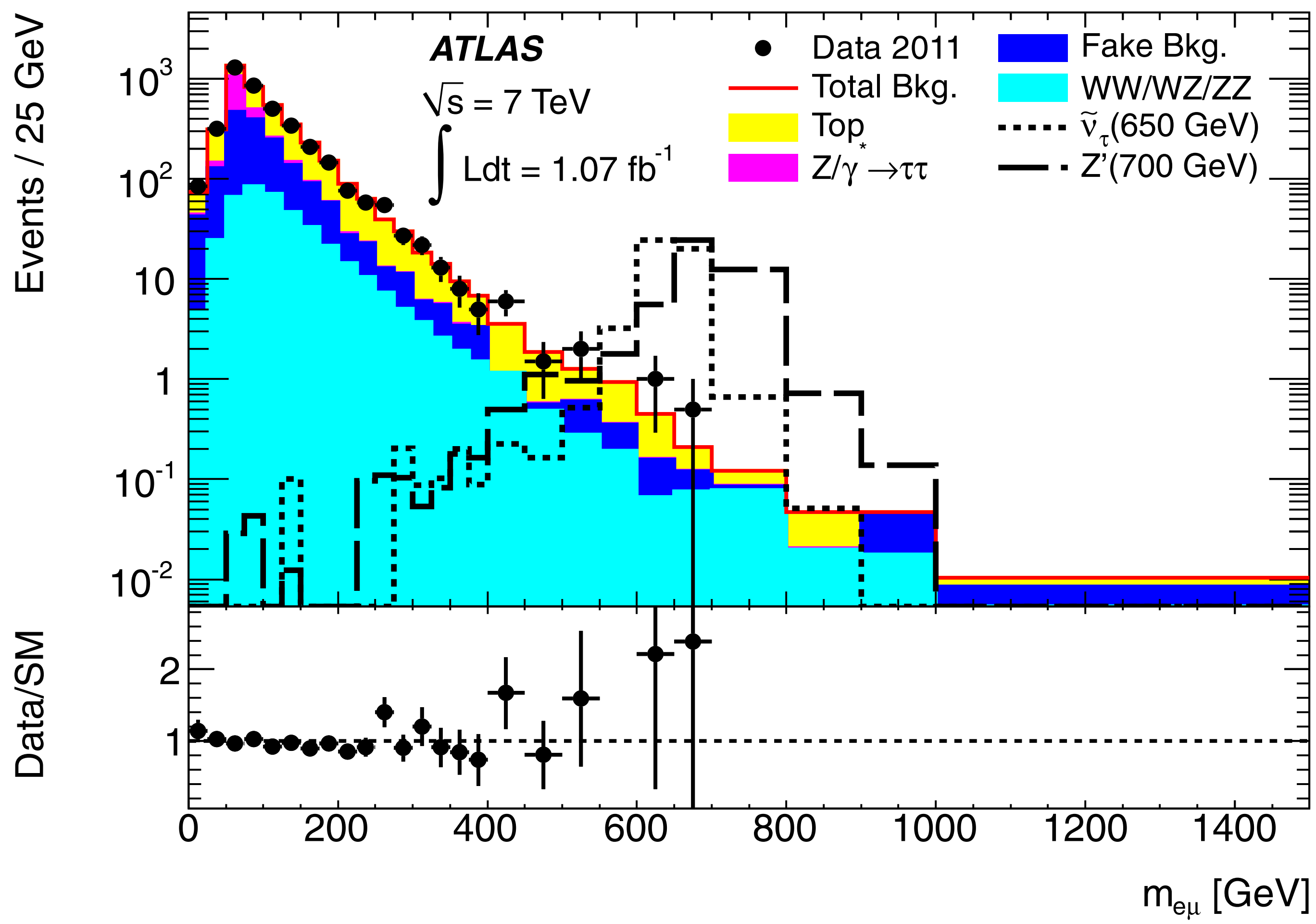
✓Select two same-sign electrons passing loose criteria but one fails tight (tag).

✓Veto real lepton from Z: $m_{ee} < 70$ or >110GeV, $\Delta\varphi_{ee} > 2$

1) Define loose/tight lepton definitions apply on all events to get N_{TT},N_{TL},N_{LT} and N_{LL}.
2) Estimate efficiency (r) and fake rate (f) for a lepton that has passed the loose definition to also pass the tight definition.
3) Solve 4×4 matrix and obtain (RF,FR,FF) contributions to TT.

Results

- Primary contributions to the systematic uncertainty on the BG estimation come from the theoretical cross section uncertainties.
  - 12% for top pair production (dominant BG) and 5-10% for the others.

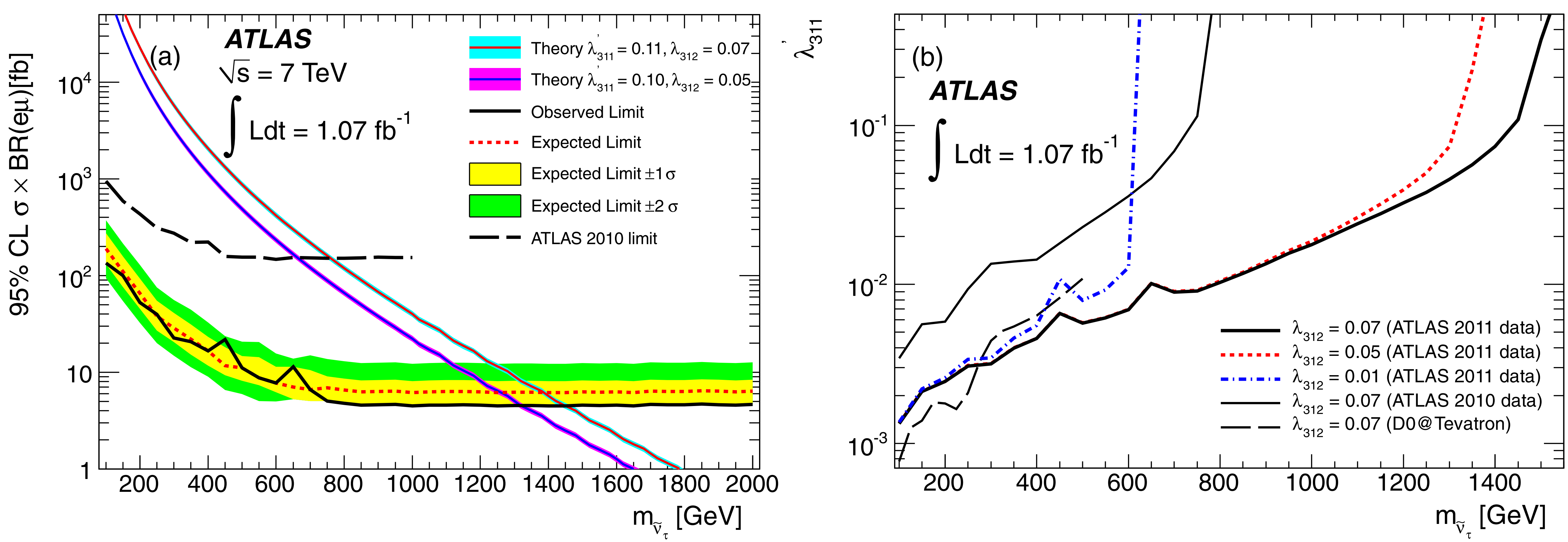


ttbar	1580 ± 170
Jet fake (QCD,W+jets)	1175 ± 120
$Z/\gamma^*(\to\tau\tau)$	750 ± 60
WW	380 ± 31
single t	154 ± 16
W/Z+γ	82 ± 13
WZ	22.4 ± 2.3
ZZ	2.48 ± 0.26
BG total	**4145 ± 250**
Data	4053

Result: no significant excess observed. (KS-test prob: 56%)

Interpretations

- Limits on $\sigma(pp \to \tilde{\nu}_\tau) \times \mathrm{BR}(\tilde{\nu}_\tau \to e\mu)$ as a function of $m_{\tilde{\nu}_\tau}$
  - tau-sneutrino having a mass below 1.32(1.45) TeV are excluded assuming $\lambda'_{311} = 0.10(0.11)$ and $\lambda_{312} = 0.05(0.07)$
- Limits on λ'_{311} coupling as a function of $m_{\tilde{\nu}_\tau}$ for various values of λ_{312}
  - sneutrino mass > 270GeV assuming $\lambda_{312} = 0.07$ (most stringent limit to date)



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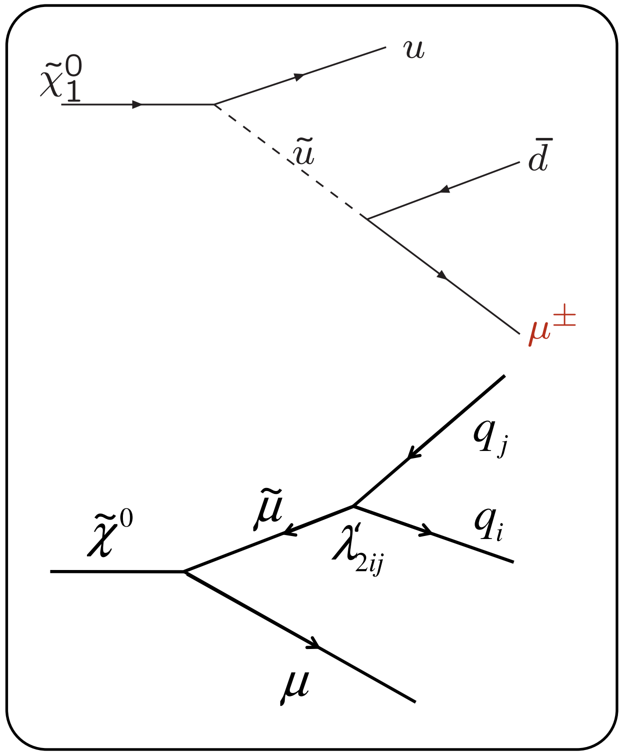
2. RPV-SUSY searches
Late-decaying $\tilde{\chi}_1^0$-LSP

Neutralino-LSP decay



- $\tilde{\chi}_1^0$ could decay via non-zero **λ, λ'** couplings:

$$LL\bar{E}(\lambda): \ \tilde{\chi}_1^0 \to ll' + \nu$$

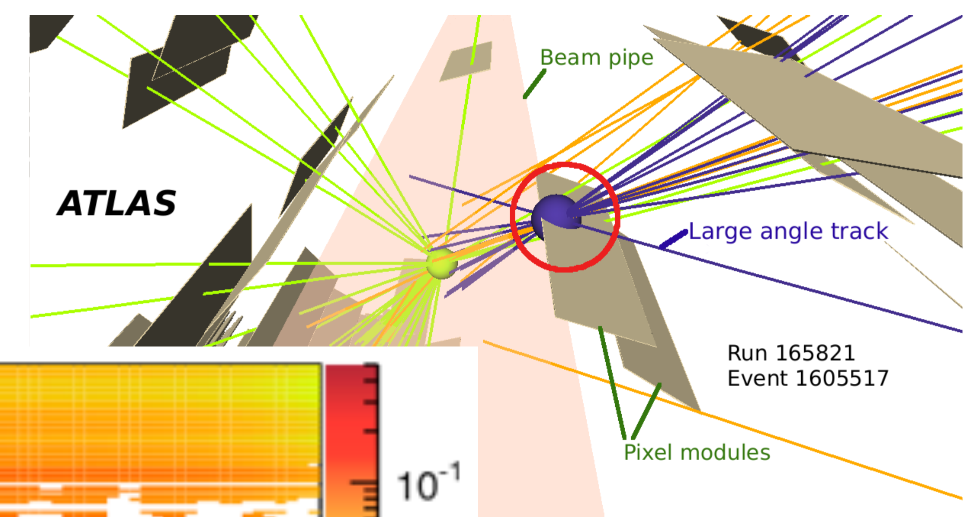
$$LQ\bar{D}(\lambda'): \ \tilde{\chi}_1^0 \to \begin{pmatrix} e, \mu, \tau \\ \nu \end{pmatrix} + 2 \text{ jets}$$

- The lifetime is proportional to $(\lambda)^{-2}$, $(\lambda')^{-2}$
  - Decay prompt for **λ**, λ' ≳ 10^{-5}.
  - If the RPV coupling is smaller than that (e.g. ≲ 10^{-7}), *a decay vertex with a significant distance from its production point* can be seen.

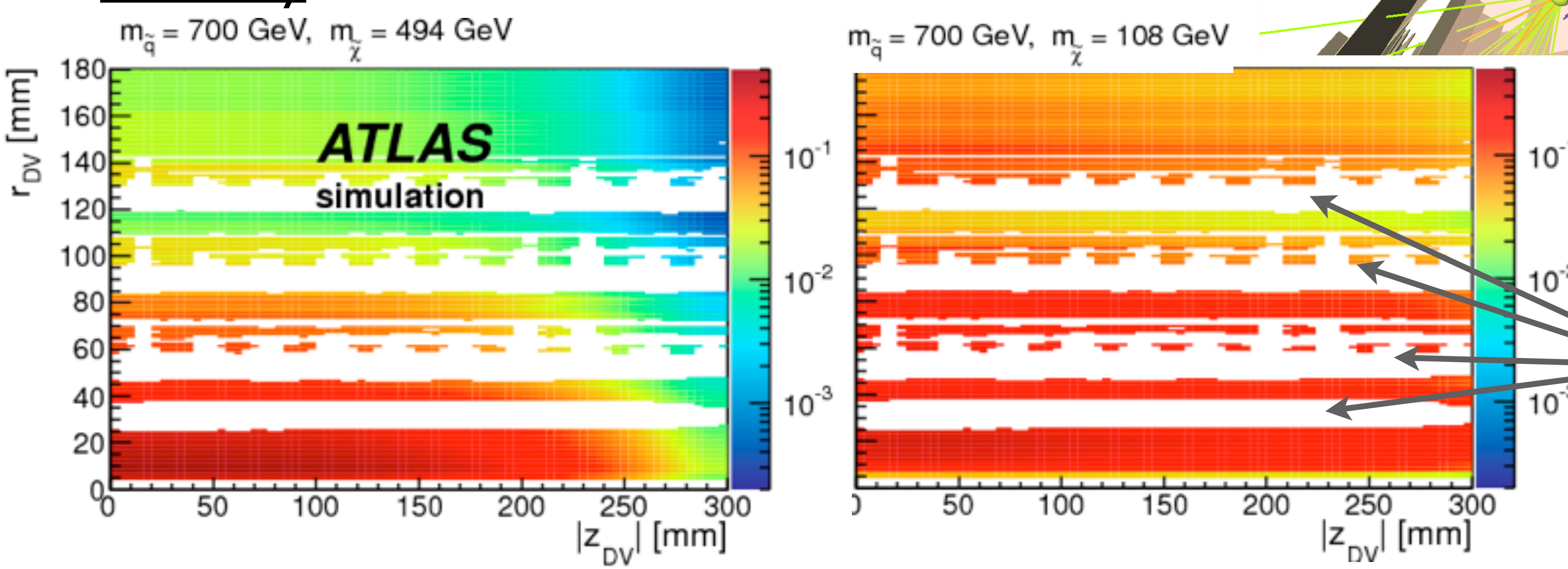
- →Perform a search using a displaced vertex (DV) reconstruction technique.
  - The result presented today is based on 2010 data, non-zero λ' with muon final states.
  - More to come using 2011 full dataset covering variety of signatures:
    - Final states including e/tau

Displaced vertex

- Vertexing:
  1. Select tracks with pT > 1GeV and $|d_0|$ > 2mm wrt the primary vertices (PVs).
  2. Make 2-track "seed" vertices.
  3. Make all possible N-track combinations, then iteratively split, merge, remove tracks etc. until there are no tracks shared between vertices.
- Selection:
  1. Vertex in $|z|$ < 300mm and r < 180mm
  2. Vertex χ^2/DOF < 5
  3. $|r_{DV} - r_{PV}|$ > 4mm
  4. One muon with p_T > 45GeV
  5. Material veto (hadronic interactions, dominant background)



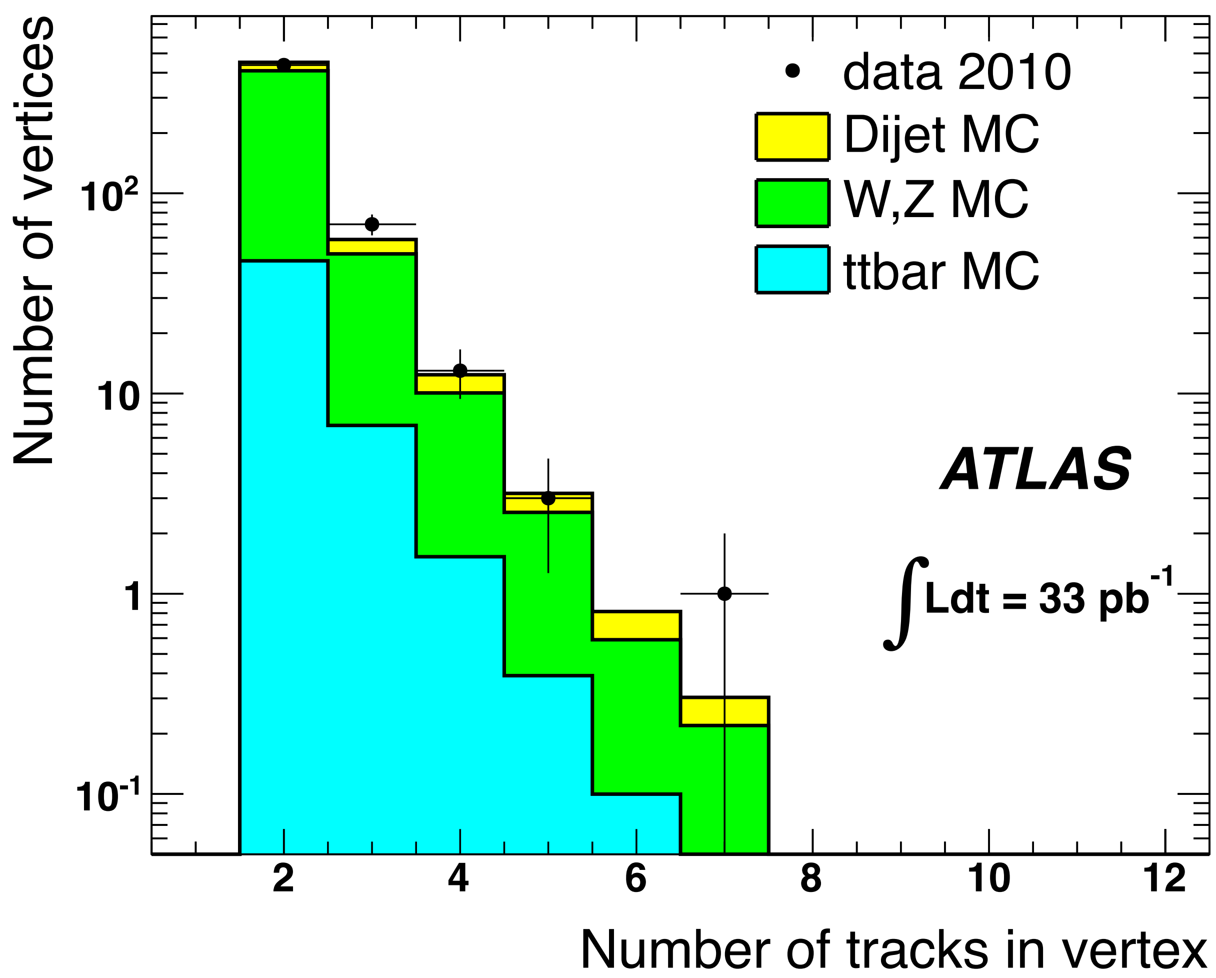
Efficiency

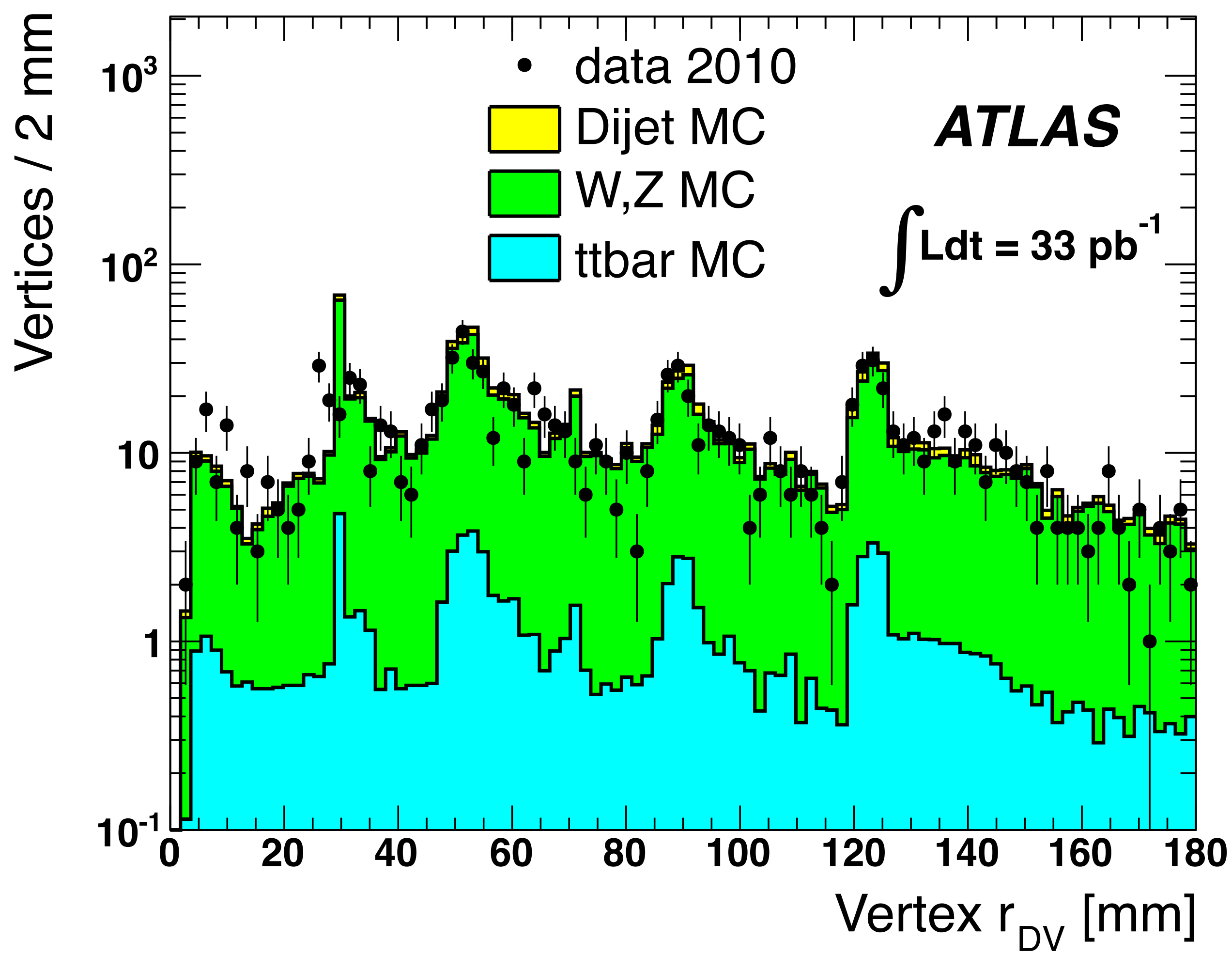


Vetoed regions
(Beam pipe, Pixel layers)

BG validation

N_{vtx}^{trk} and r_{DV} in control region (no material veto)



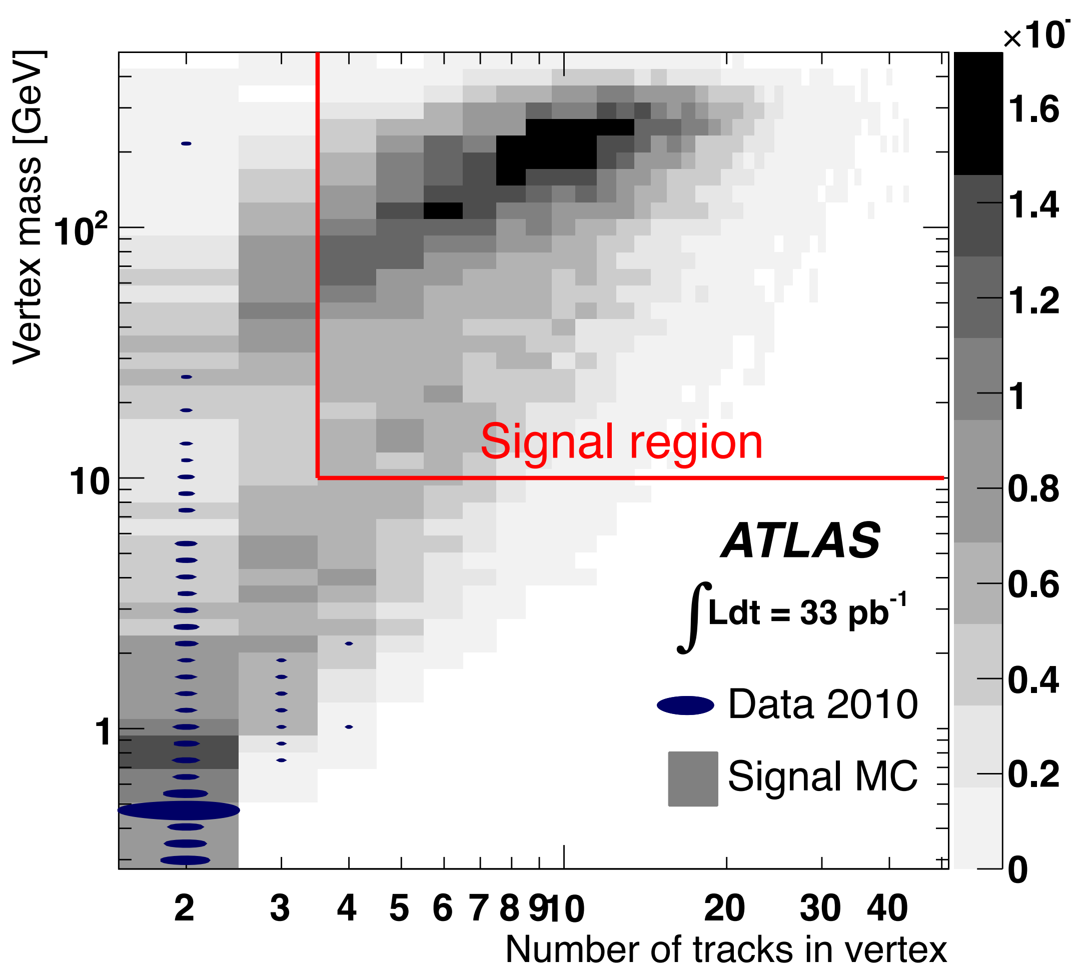


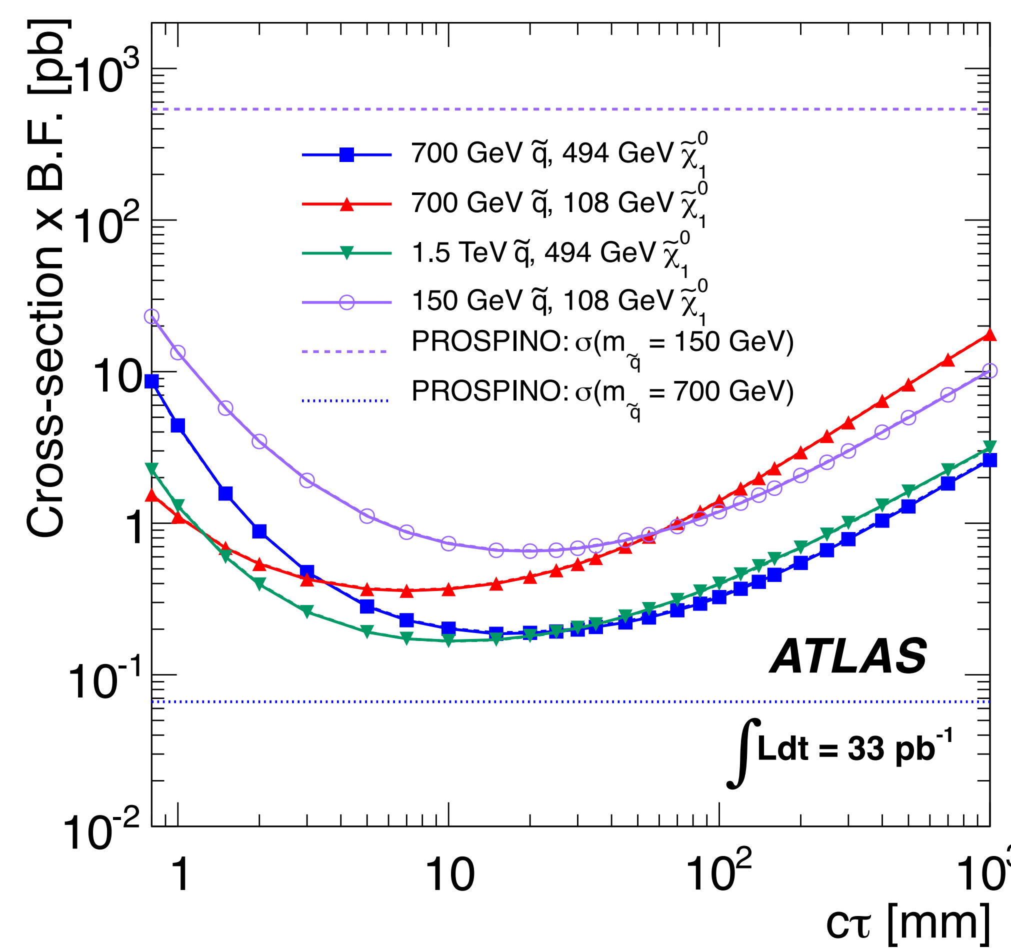
Data/MC reasonably agree. Materials are well described in MC.

Result & interpretation

- Signal region:
  - m_{DV} > 10GeV
  - # of tracks in DV ≥ 4
- SM MC background expectation
  - N_{BG} < 0.03
- *No signal observed.*

- Exclude $\varepsilon \times \sigma_{DV}$ > 0.09pb @95% CL
- Interpretation ($\lambda'_{2ij}\neq 0$):
  - m(squark)=150GeV excluded.
  - Limits on $\tilde{\chi}^0_1$ lifetime





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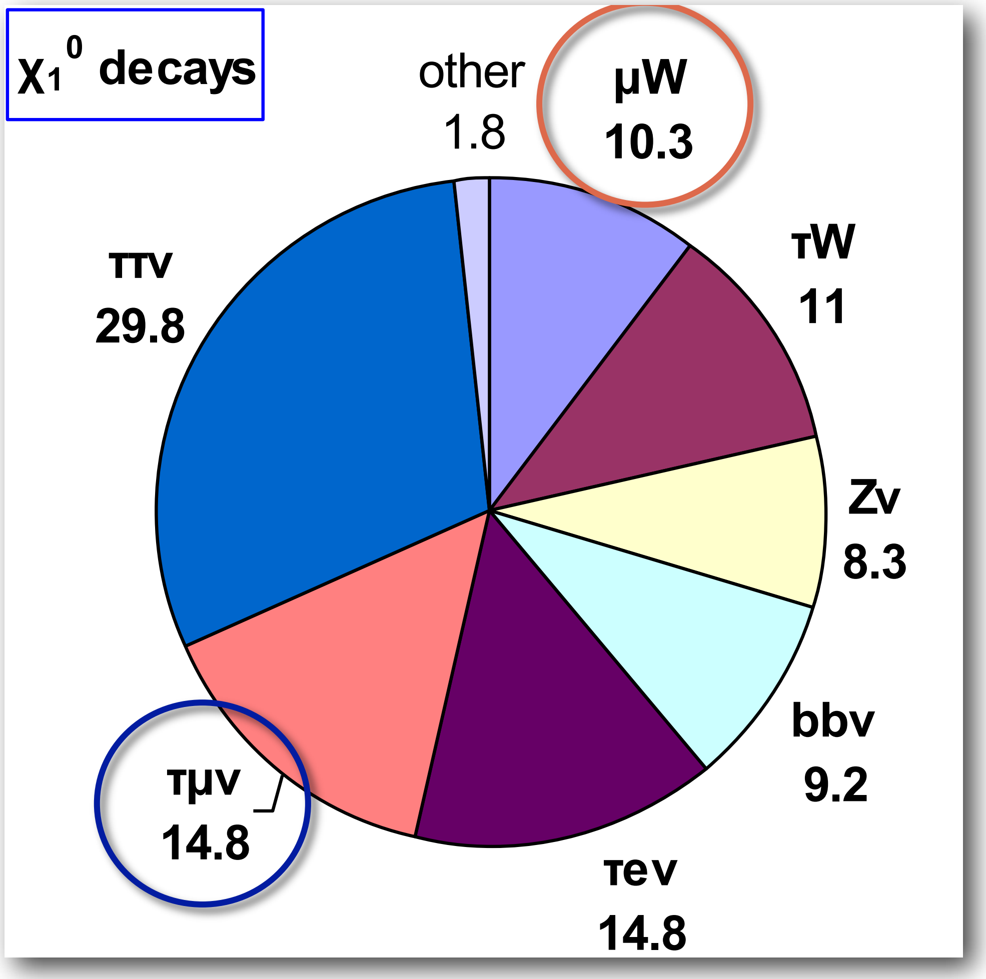
2. RPV-SUSY searches

LNV with bilinear terms

Bilinear RPV

- Bilinear RPV (bRPV) terms introduce neutrino masses and mixings.
  - Currently constrained by neutrino oscillation experiments.

- bRPV terms can be embedded in any RPC-SUSY model:
  - bRPV in mSUGRA:
    - Same cascades as in RPC scenarios
    - LSP may decay, but results in "**lepton+Etmiss+jets**" final states (most of LSP decays involve leptons/taus/neutrinos).
    - bRPV parameters are motivated by the neutrino oscillation parameters.
    - <u>bRPV interpretation based on the 1-lepton analysis result with 1fb^{-1}.</u>



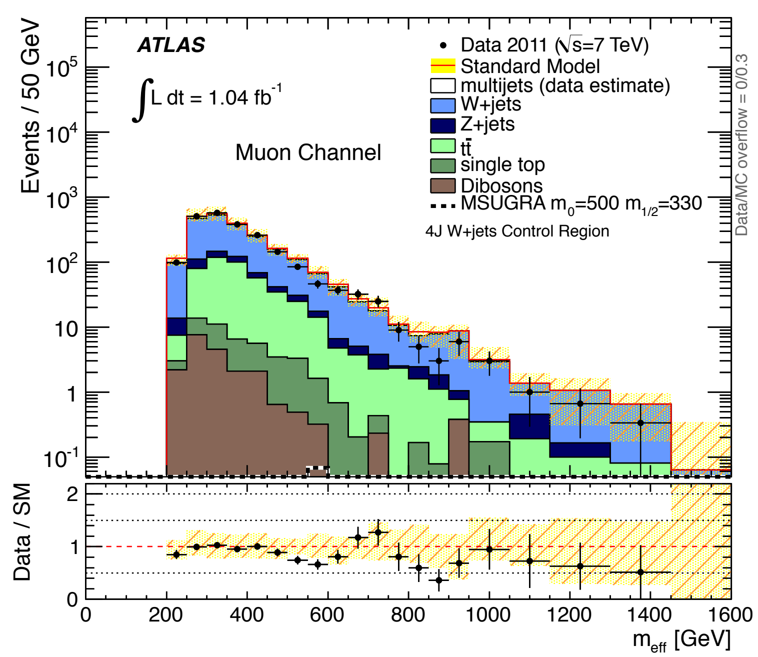
SR & BG estimate

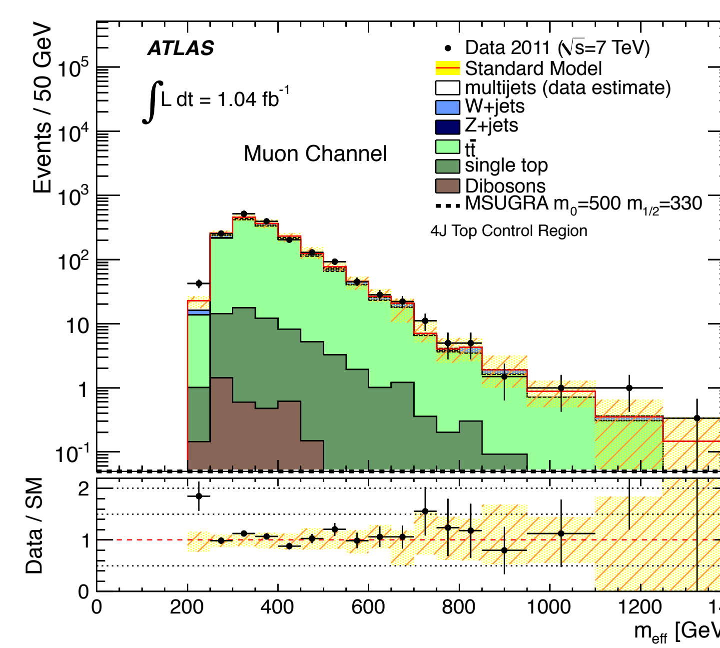
- Signal region:
  - Exactly one isolated muon with p_T>20GeV
    - (electrons are highly suppressed in the model)
  - ≥4 jets with p_T>40GeV
  - leading jet with p_T>60GeV
  - **Δφ**(jets, Etmiss) > 0.2
  - M_T > 100GeV
  - Etmiss > 200GeV
  - Etmiss/M_{eff} > 0.15
  - M_{eff} > 500GeV

- BG estimation:
  - W+jets, top
    - Normalize MC to data in background specific control regions (WR,TR).

WR	TR
Δφ(jets, Etmiss) > 0.2	
40 < M_T < 80GeV	
30 < Etmiss < 80GeV	
M_{eff} > 300GeV	
N(b-jet)=0	N(b-jet)≥1

    - Extrapolate to Signal Regions using MC shapes
  - QCD by the matrix method.

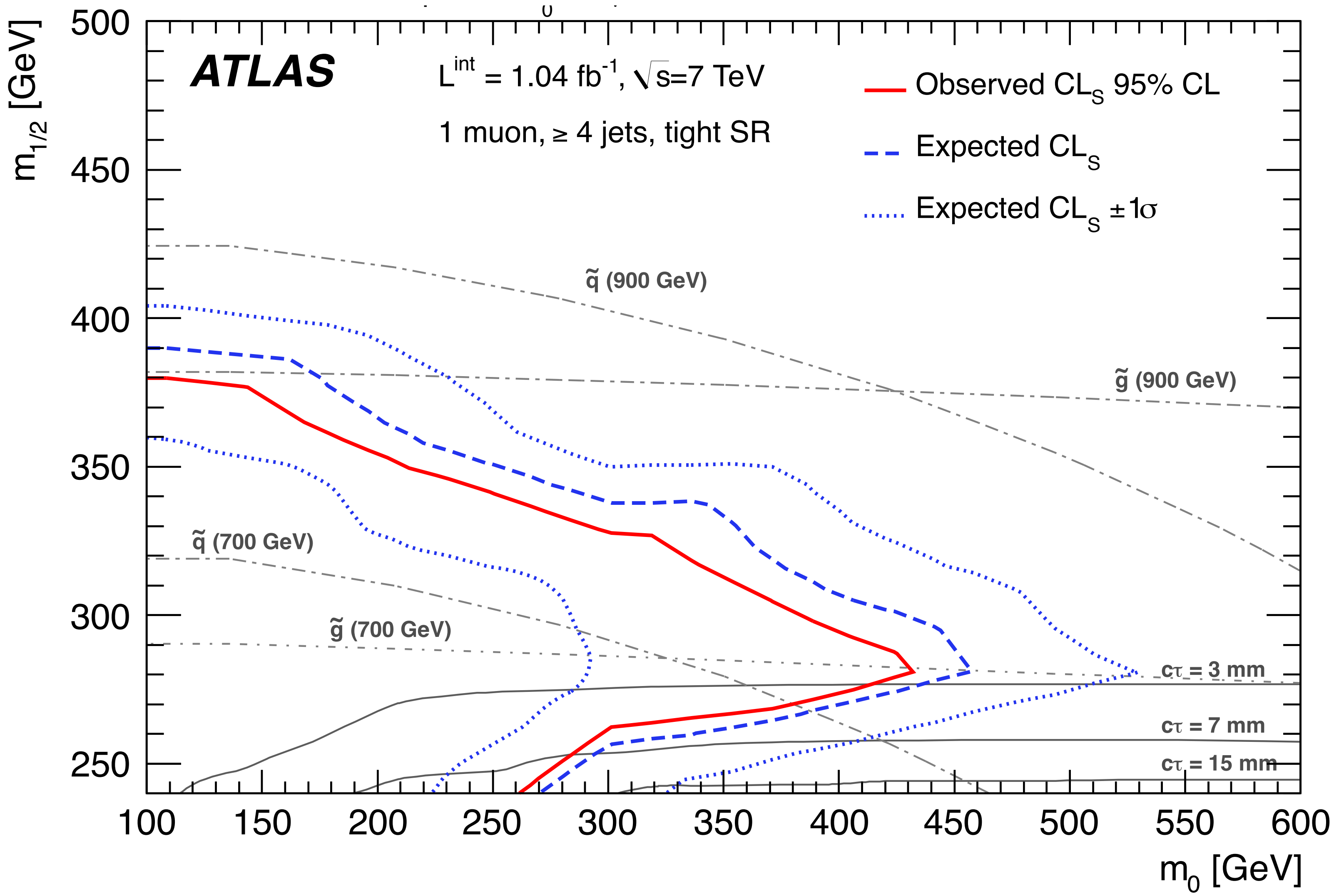




Interpretation

- bRPV interpretations were done in "1-lepton + Etmiss" RPC-SUSY search.
  - Observed: 7
  - BG exp.: 6±2.7

--- bRPV mSUGRA with neutralino with cτ<15mm ---



Summary

- No sign of RPC SUSY yet... unexpected SUSY could be there.
- R-parity is conserved or violated?
  - Pros and cons on both.
  - RPC-SUSY parameter space is being squeezed... all possibilities should be considered.

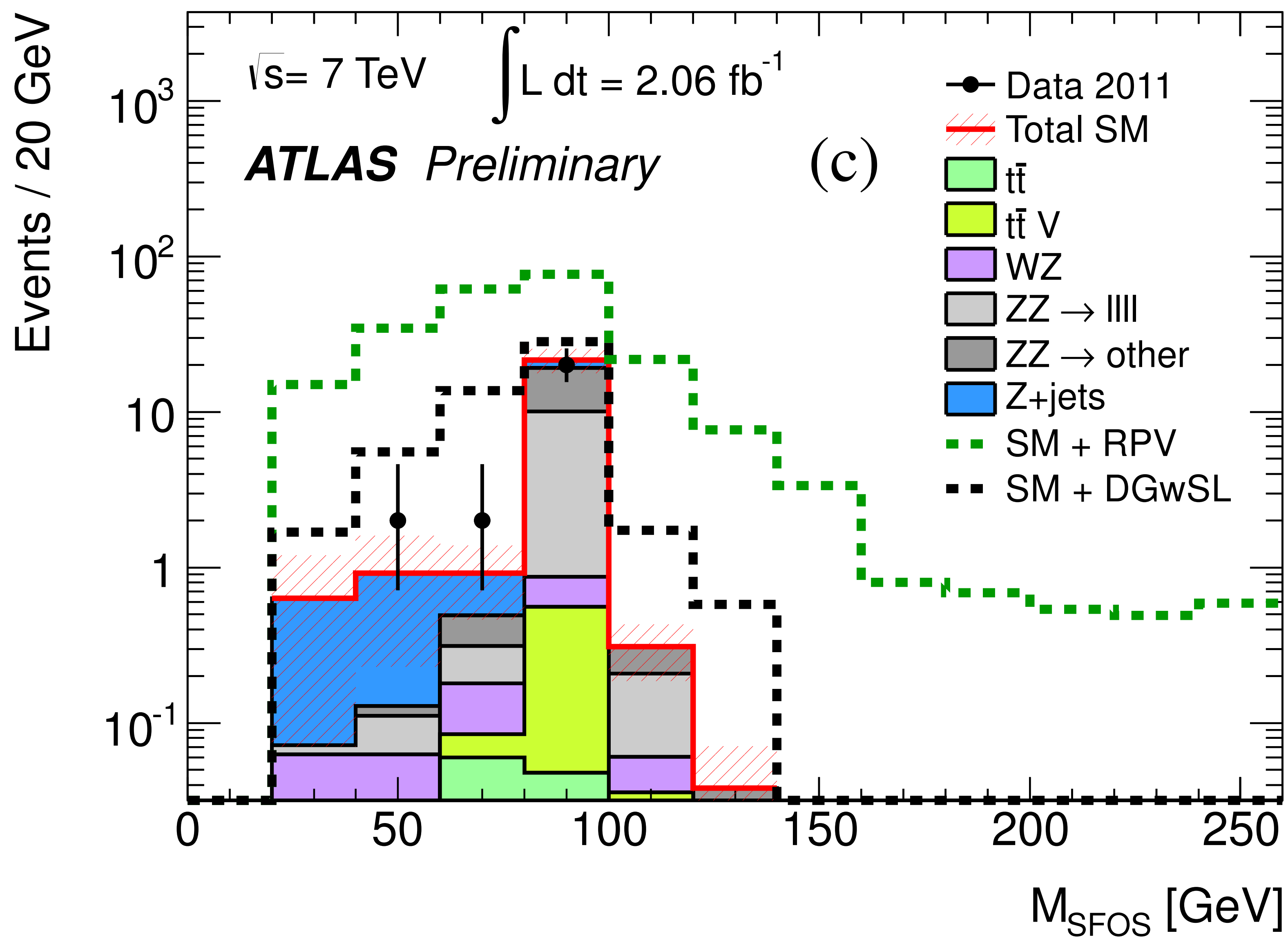
- ATLAS is trying to cover possible RPV signatures:
  - 4 results were presented in context of LLE, LQD and bilinear RPV (LNV) SUSY.
  - Many analyses are being performed.
    - More to come in coming months (BNV, variety of signatures...)

- Also keep a close eye on 8TeV collision data to find something unexpected!!

Backup

MSFOF

- Before applying Etmiss cut, 24 events remain.



RPV stau

- Branching ratio of stau 4-body decay and lifetime.