Search for resonant slepton production in R-parity violating SUSY scenarios with CMS

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PHYSICS AT THE TERA SCALE Helmholtz Alliance

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INTRODUCTION

- SUSY offers solutions to a lot of open questions in particle physics:
  hierarchy problem, coupling unification, dark matter
- remaining issue: list of sparticles found at LHC so far $== \emptyset$
- main benchmark model in the past (CMSSM) strongly constrained
- possible solutions
  - more extensive models (e.g. pMSSM)
  - models with R-parity violation
- RPV models can be very relevant for LHC data:

PHYSICAL REVIEW D **91,** 015011 (2015)

Resonant slepton production yields CMS *eejj* and $e\not{p}_T jj$ excesses

Ben Allanach, Sanjoy Biswas, Subhadeep Mondal, and Manimala Mitra

(Received 11 November 2014; published 13 January 2015)

Recent CMS searches for dileptoquark production report local excesses of 2.4σ in an $eejj$ channel and 2.6σ in an $e\not{p}_T jj$ channel. Here, we simultaneously explain both excesses with resonant slepton production in $\mathcal{R}$-parity violating supersymmetry. We consider resonant slepton production, which decays to a lepton and a chargino/neutralino, followed by three-body decays of the neutralino/chargino via an $\mathcal{R}$-parity violating coupling. There are regions of parameter space which are also compatible at the 95% confidence level with a 2.8σ $eejj$ excess in a recent CMS W_R search, while being compatible with other direct search constraints. Phase II of the GERDA neutrinoless double beta decay ($0\nu\beta\beta$) experiment will probe a sizable portion of the good-fit region.

DOI: 10.1103/PhysRevD.91.015011

PHYSICAL REVIEW D **93,** 115022 (2016)

750 GeV diphoton excess explained by a resonant sneutrino in *R*-parity violating supersymmetry

B. C. Allanach, P. S. Bhupal Dev, S. A. Renner, and Kazuki Sakurai

(Received 20 April 2016; published 16 June 2016)

We explain the recent excess seen by ATLAS and CMS experiments at around 750 GeV in the diphoton invariant mass as a narrow-width sneutrino decaying to diphotons via a stau loop in R-parity violating supersymmetry. The stau mass is predicted to be somewhere between half the resonant sneutrino mass and half the sneutrino mass plus 14 GeV. The scenario also predicts further signal channels at an invariant mass of 750 GeV, the most promising being into dijets and WW. We also predict a left-handed charged slepton decaying into WZ and $W\gamma$ at a mass 750–754 GeV.

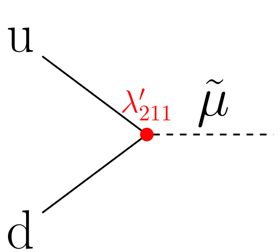
DOI: 10.1103/PhysRevD.93.115022

RESONANT SLEPTON PRODUCTION

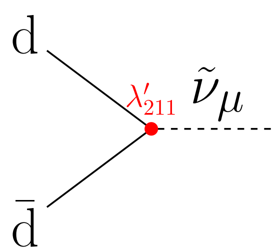
- R-parity: $\mathrm{P_R} = (-1)^{\mathrm{3B+L+2s}}$
- R-parity-violation allows additional terms in superpotential

$$W_{LNV+BNV} = \underbrace{\epsilon_{ab}[\frac{1}{2}\lambda_{ijk}L_i^a L_j^b \bar{E}_k + \lambda'_{ijk} L_i^a Q_j^{xb} \bar{D}_{kx}]}_{\text{lepton number violation}} + \underbrace{\frac{1}{2}\epsilon_{xyz}\lambda''_{ijk}\bar{U}_i^x \bar{D}_j^y \bar{D}_k^z}_{\text{baryon number violation}}$$

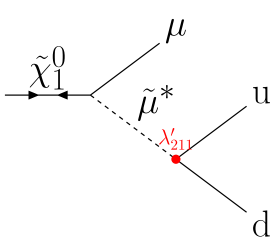
- 45 new parameters $\lambda_{ijk}, \lambda'_{ijk}, \lambda''_{ijk}$
- here: assume single coupling dominance:
  - $\lambda'_{211} \neq 0, \lambda_{ijk} = \lambda'_{ijk} = \lambda''_{ijk} = 0$
- λ'_{211} allows for:



resonant smuon production



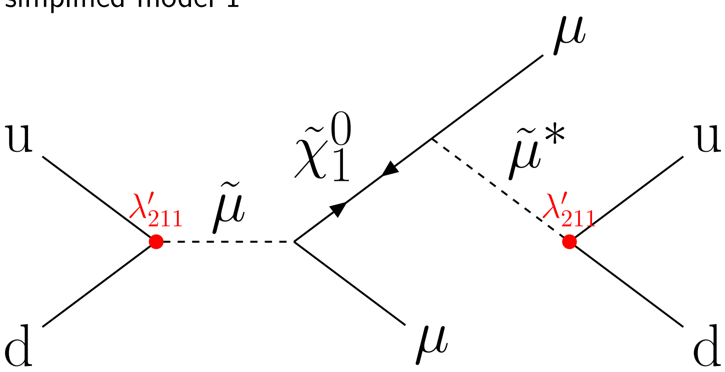
resonant sneutrino production



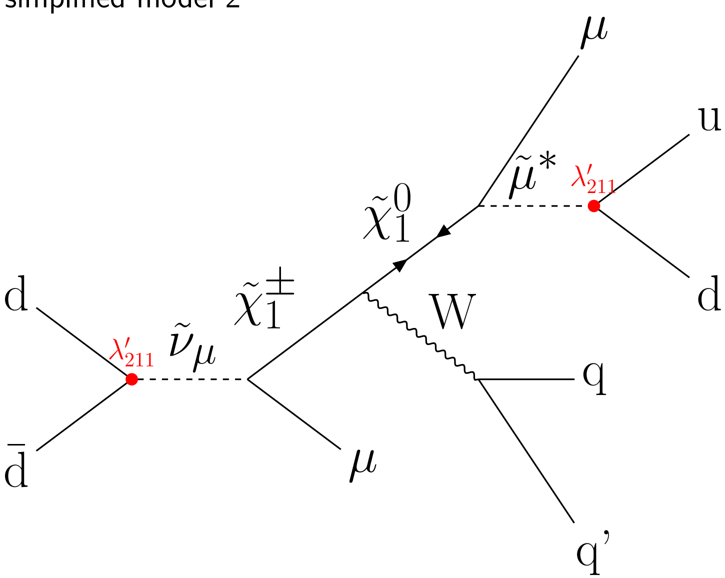
LSP decay

SIGNAL MODELS

simplified model 1



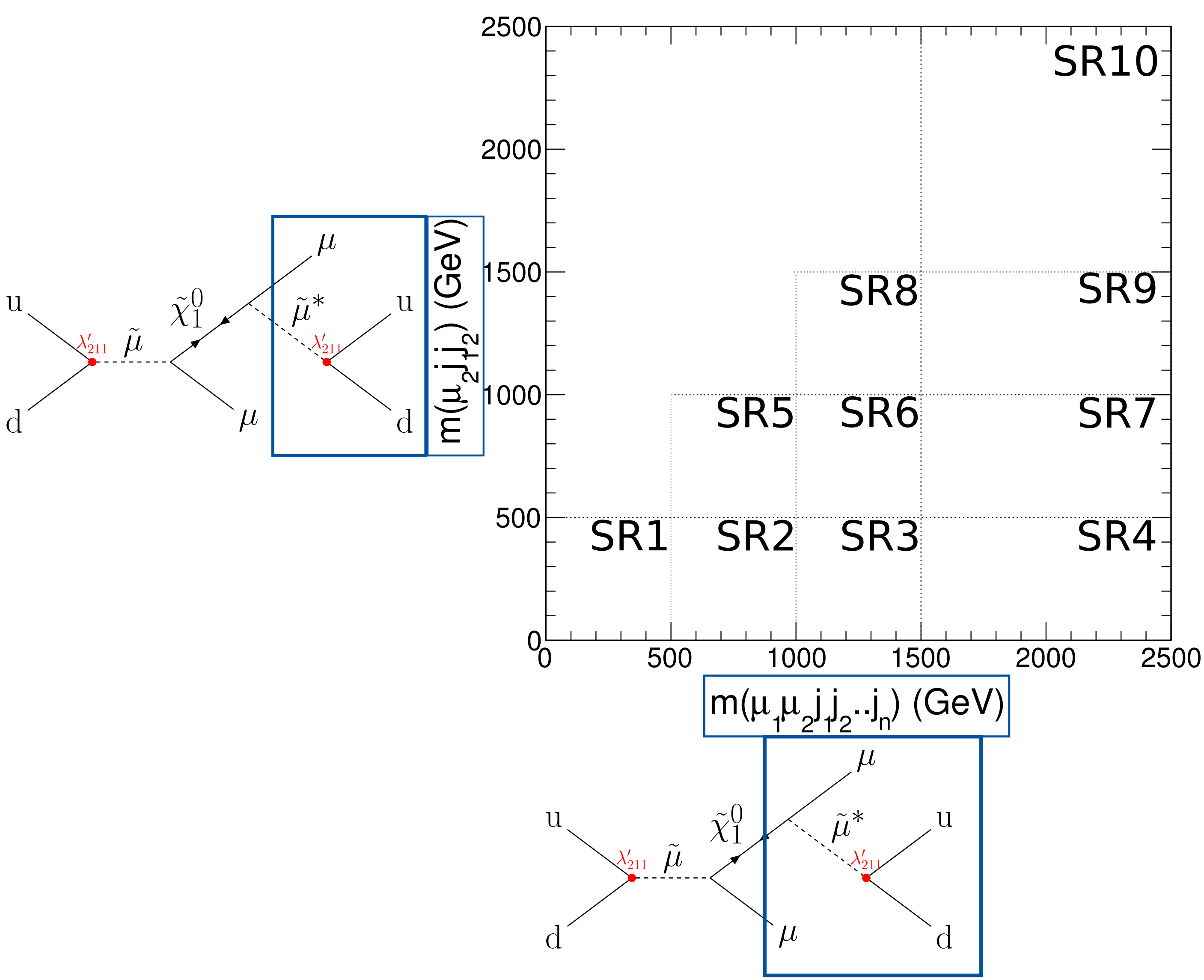
simplified model 2



- produced 2 simplified models
- covers dominant processes
- simplified model 1 parameters
  - $\tilde{\mu}$ mass
  - $\tilde{\chi}_1^0$ mass
- simplified model 2 parameters
  - $\tilde{\nu}$ mass
  - $\tilde{\chi}_1^0$ mass
  - scaling parameter x

    $(m_{\tilde{\chi}_1^\pm} = m_{\tilde{\chi}_1^0} + x(m_{\tilde{\nu}} - m_{\tilde{\chi}_1^0}))$
- models implemented in MadGraph [1,2]

SIGNAL REGIONS



EVENT SELECTION - TRIGGER

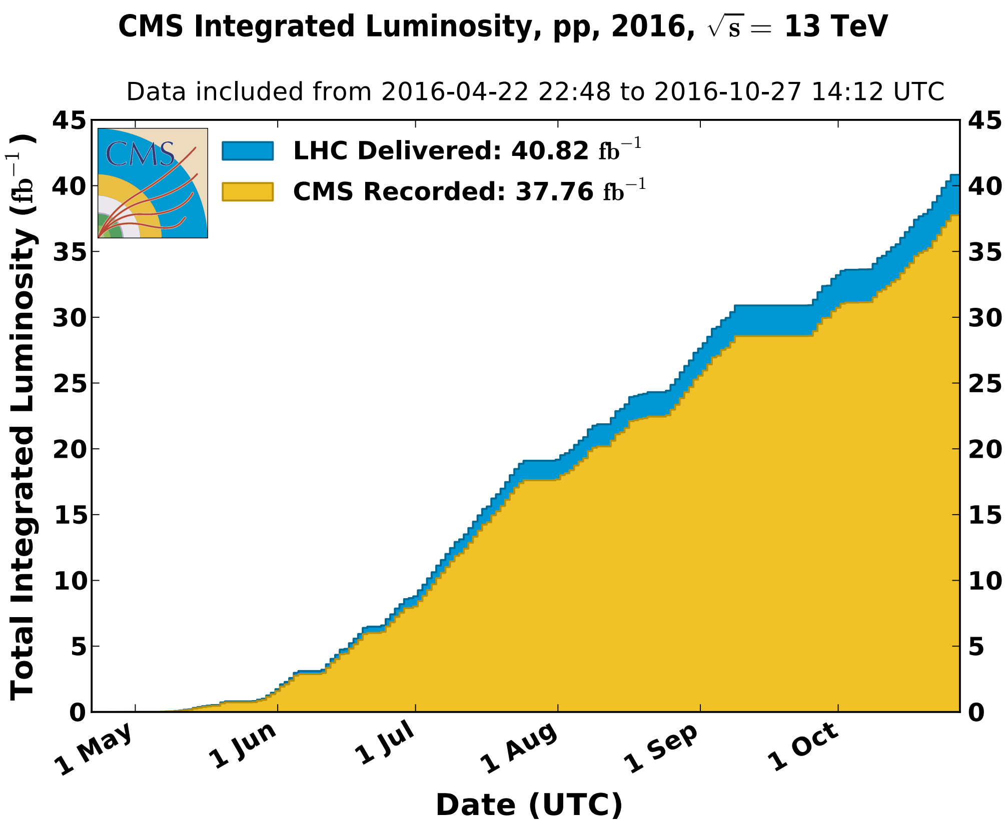
trigger
- trigger: single-μ triggers with $p_T > 50$ GeV

μ selection

jet selection

b-tag veto

μ charge



EVENT SELECTION - MUONS

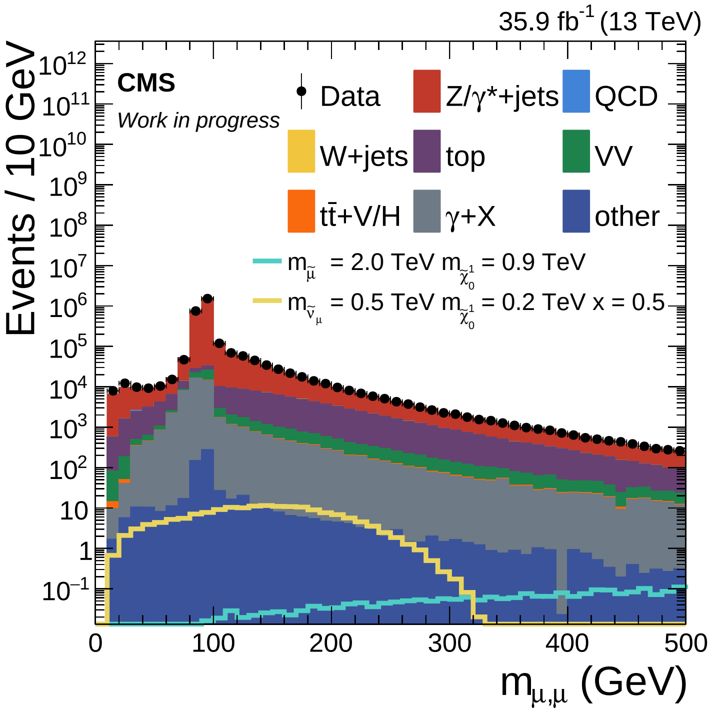
trigger
- trigger: single-μ trigger with $\mathrm{p_T} > 50$ GeV
- exactly 2 μ fulfilling:

μ selection
  - ID & isolation
  - $|\eta| < 2.4$
  - $p_T(\mu_1) > 60$ GeV, $p_T(\mu_2) > 20$ GeV

jet selection

b-tag veto

μ charge



EVENT SELECTION - JETS

trigger

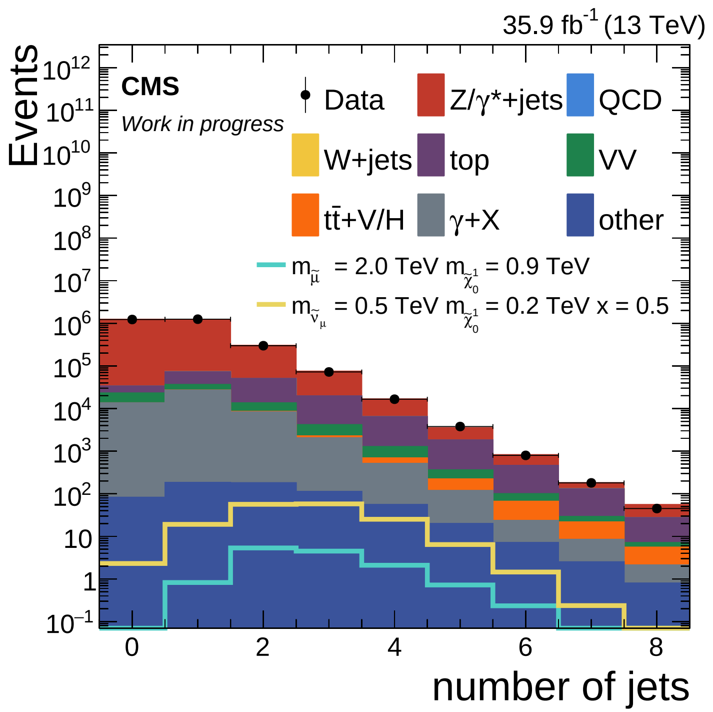
μ selection

jet selection

b-tag veto

μ charge

- trigger: single-μ trigger with $\mathrm{p_T} > 50$ GeV
- exactly 2 μ ($p_T(\mu) > 60(20)$ GeV, $|\eta| < 2.4$)
- $\geq$ 2 jets fulfilling:
  - loose jet ID
  - $|\eta| < 2.4$
  - $p_T > 40$ GeV



EVENT SELECTION - B-TAG VETO

trigger

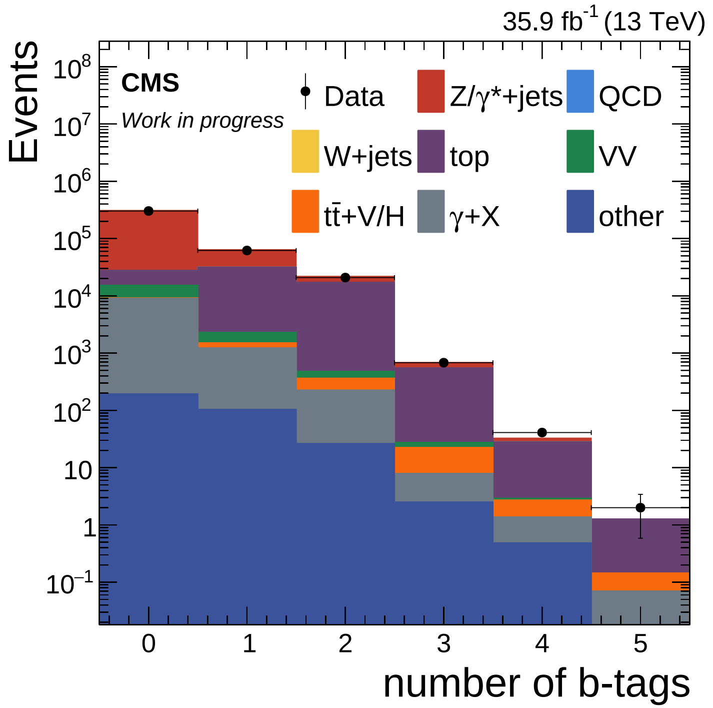
μ selection

jet selection

b-tag veto

μ charge

- trigger: single-μ trigger with $\mathrm{p_T} > 50$ GeV
- exactly 2 μ ($p_T(\mu) > 60(20)$ GeV, $|\eta| < 2.4$)
- $\geq$ 2 jets ($p_T > 40$ GeV, $|\eta| < 2.4$)
- reject events with ≥ 1 b-tagged jets



EVENT SELECTION - MUON CHARGE

trigger

- trigger: single-μ trigger with $\mathrm{p_T} > 50$ GeV

μ selection

- exactly 2 μ ($p_T(\mu) > 60(20)$ GeV, $|\eta| < 2.4$)

jet selection

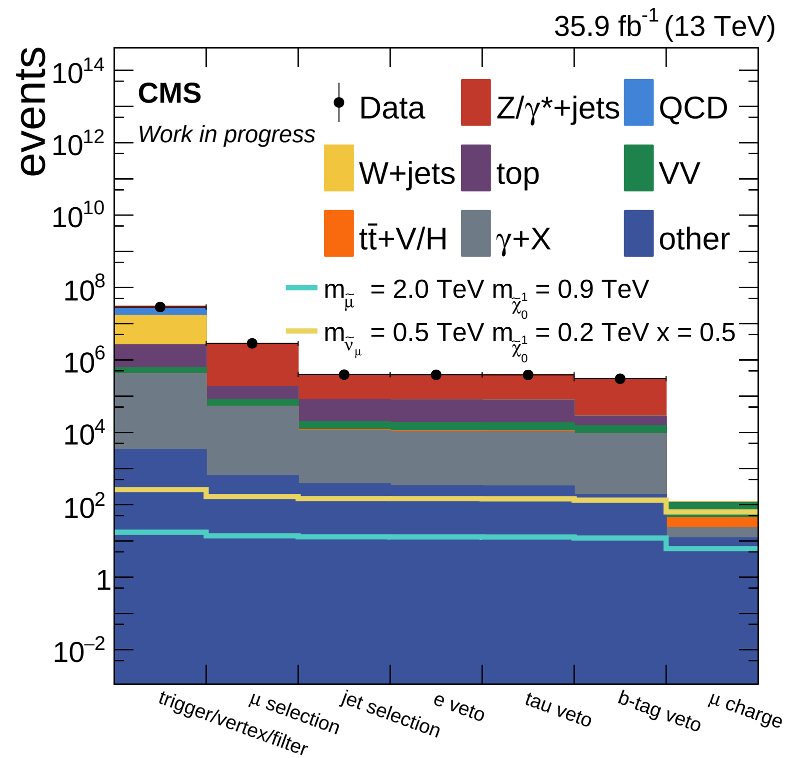
- $\geq$ 2 jets ($p_T > 40$ GeV, $|\eta| < 2.4$)

b-tag veto

- reject events with ≥ 1 b-tagged jets

μ charge

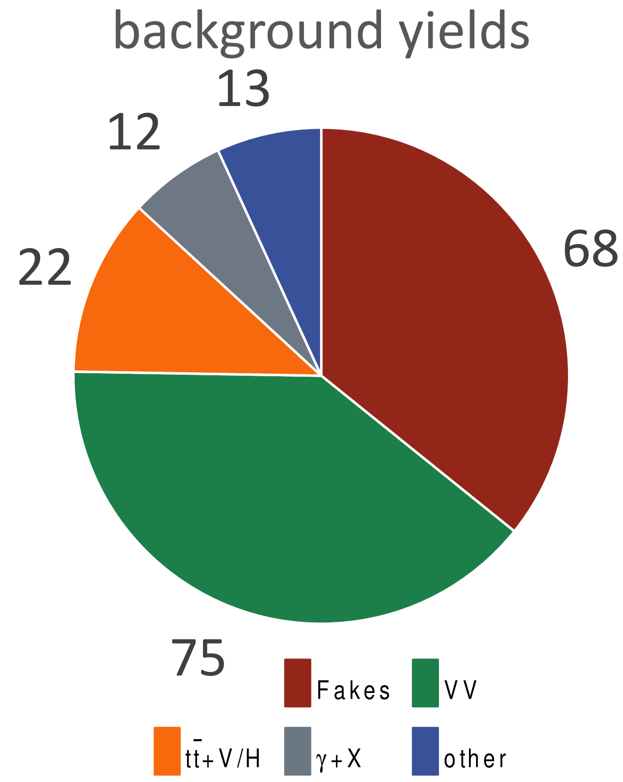
- reject events with opposite sign μ-pairs



BACKGROUND COMPOSITION

remaining sources of background:

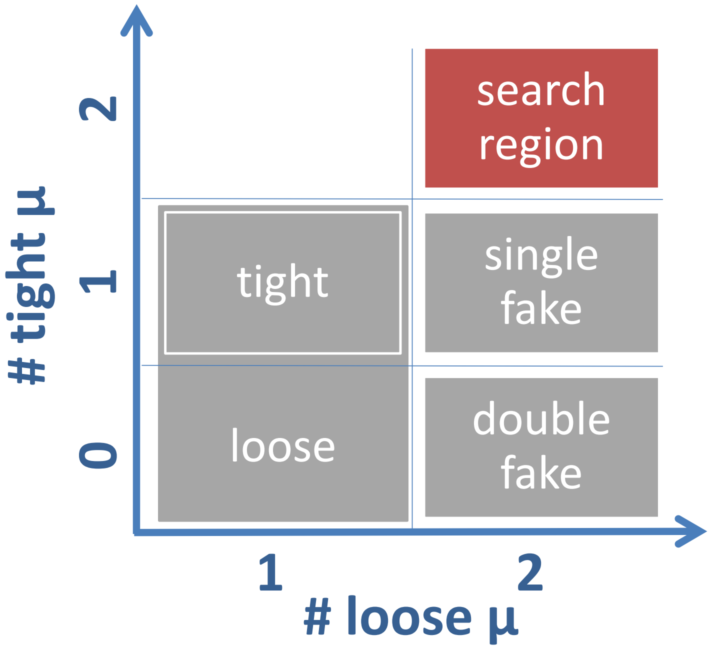
- non-prompt μ ($t\bar{t}$, W/Z+jets)
- diboson (WZ, same-sign WW)
- $t\bar{t}$V production (V=W, Z, H):
- asymmetrical internal γ conversions (Wγ)
- other rare processes (VVV, DPS, ..)



BACKGROUND ESTIMATION FROM DATA

goal: estimate contribution of non-prompt muon background to signal region

tight to loose ratio method:

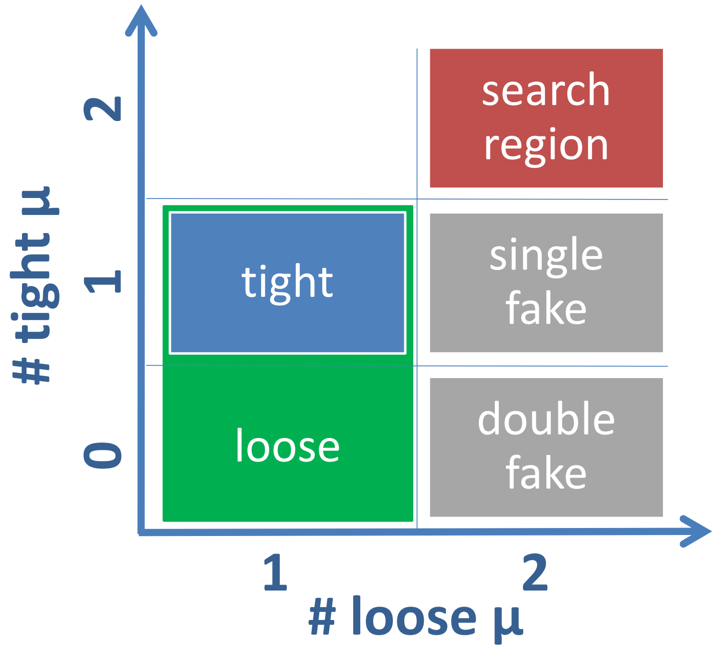


BACKGROUND ESTIMATION FROM DATA

goal: estimate contribution of non-prompt muon background to signal region

tight to loose ratio method:

1. measure ratio r_{TL} of tight to loose μ
   - tight μ
     - identical to analysis requirements
   - loose μ
     - relaxed isolation w.r.t. analysis requirements
   - [tight μ] $\subset$ [loose μ]
   - measurement region
     - orthogonal to signal region
     - enriched in QCD



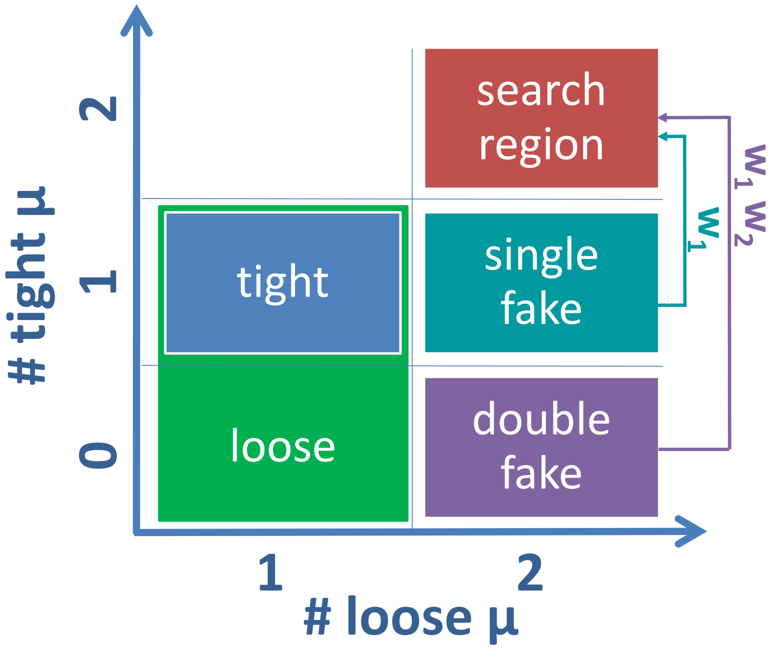
BACKGROUND ESTIMATION FROM DATA

goal: estimate contribution of non-prompt muon background to signal region

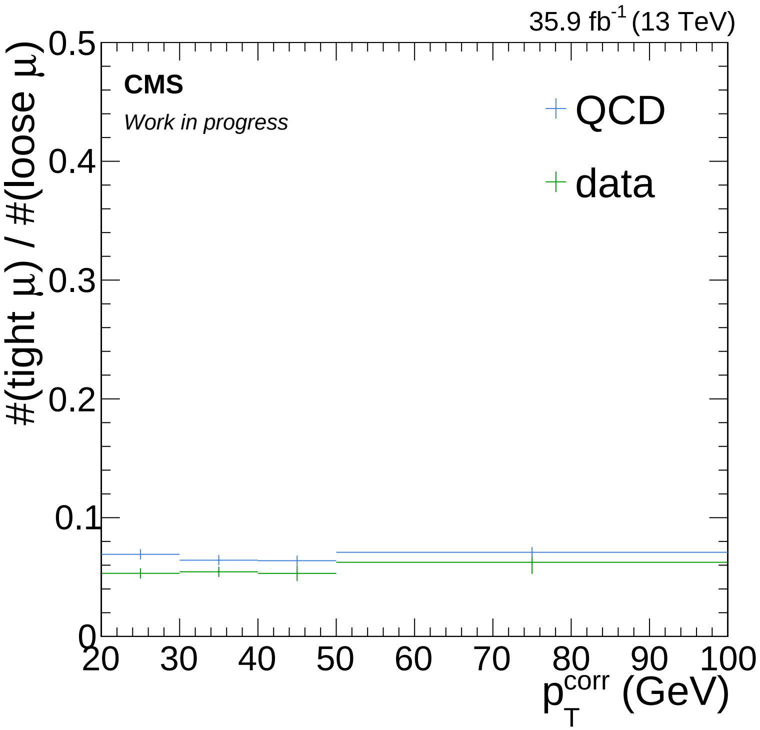
tight to loose ratio method:

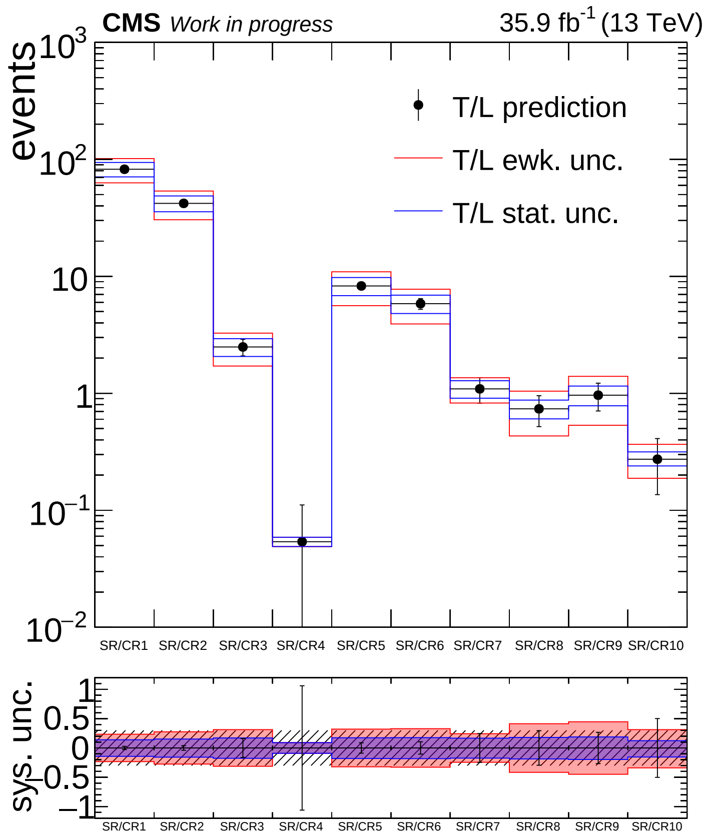
2. extrapolate to signal region

   - use events in application regions
   - reweight based on r_{tl}
   - $w = \frac{r_{tl}}{1-r_{tl}}$
   - single fake region
     - events with 1 loose $\wedge$ ¬tight and 1 tight μ
   - double fake region
     - events with 2 loose $\wedge$ ¬tight μ



TIGHT TO LOOSE RATIO - MEASUREMENT & CLOSURE



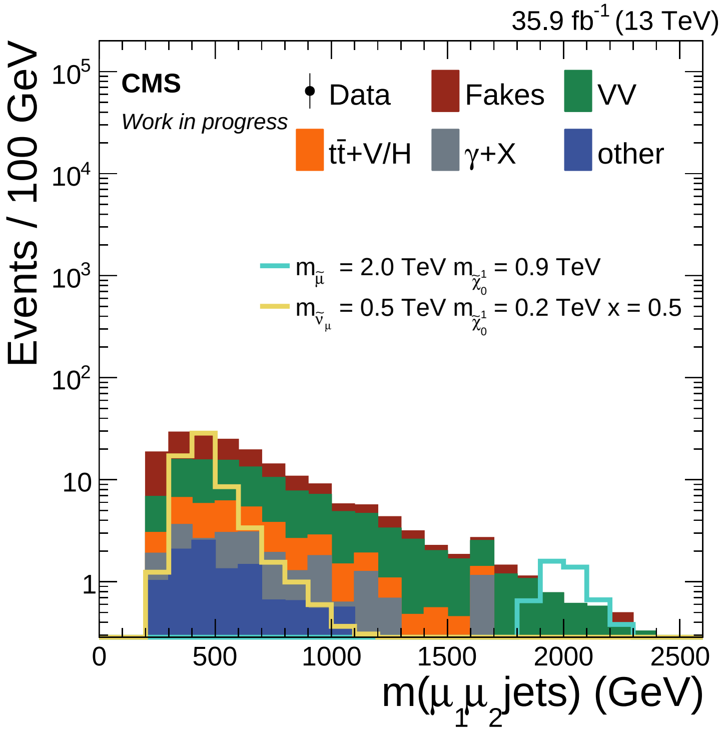


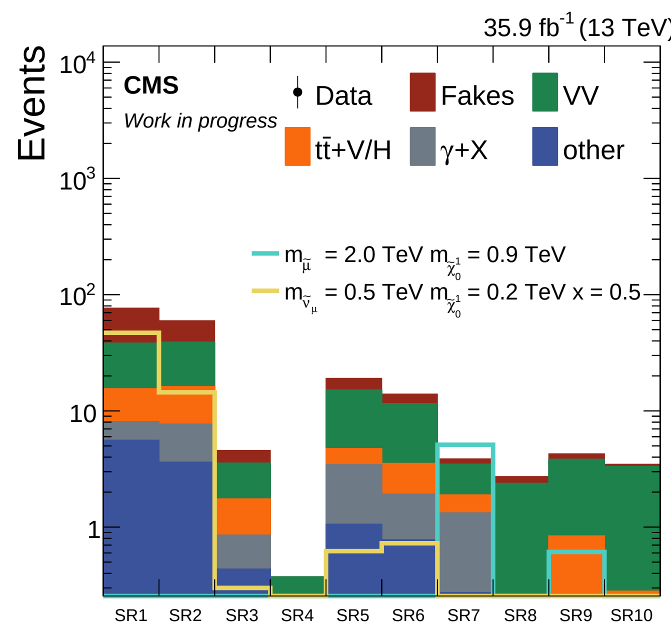
- ewk contamination reduced via $\mathrm{M_T}$ cuts
- remaing contamination subtracted with MC
- measure $\mathrm{r_{tl}}$ as function of η and $\mathrm{p_T^{corr}}$
- $\mathrm{p_T} \rightarrow \mathrm{p_T^{corr}}$ corrects for differences between:
  - measurement region (QCD dominated)
  - application region ($\mathrm{t\bar{t}}$ dominated)

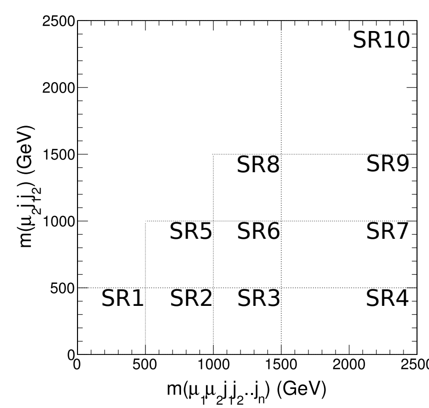
systematics uncertainties assigned based on:

- closure tests (close at $\mathcal{O}(10-20\%)$)
- limited statistics in T/L measurement region
- limited statistics in application region
- variation of ewk contamination

SIGNAL REGION YIELDS







- expected yields in signal region
- observed signal region yields not public yet
- signal normalization $\equiv \lambda'_{211}$ of:

  m$_{\tilde{\mu}} = 2$ TeV, m$_{\tilde{\chi}} = 0.9$ TeV: $\lambda'_{211} \approx 0.01$

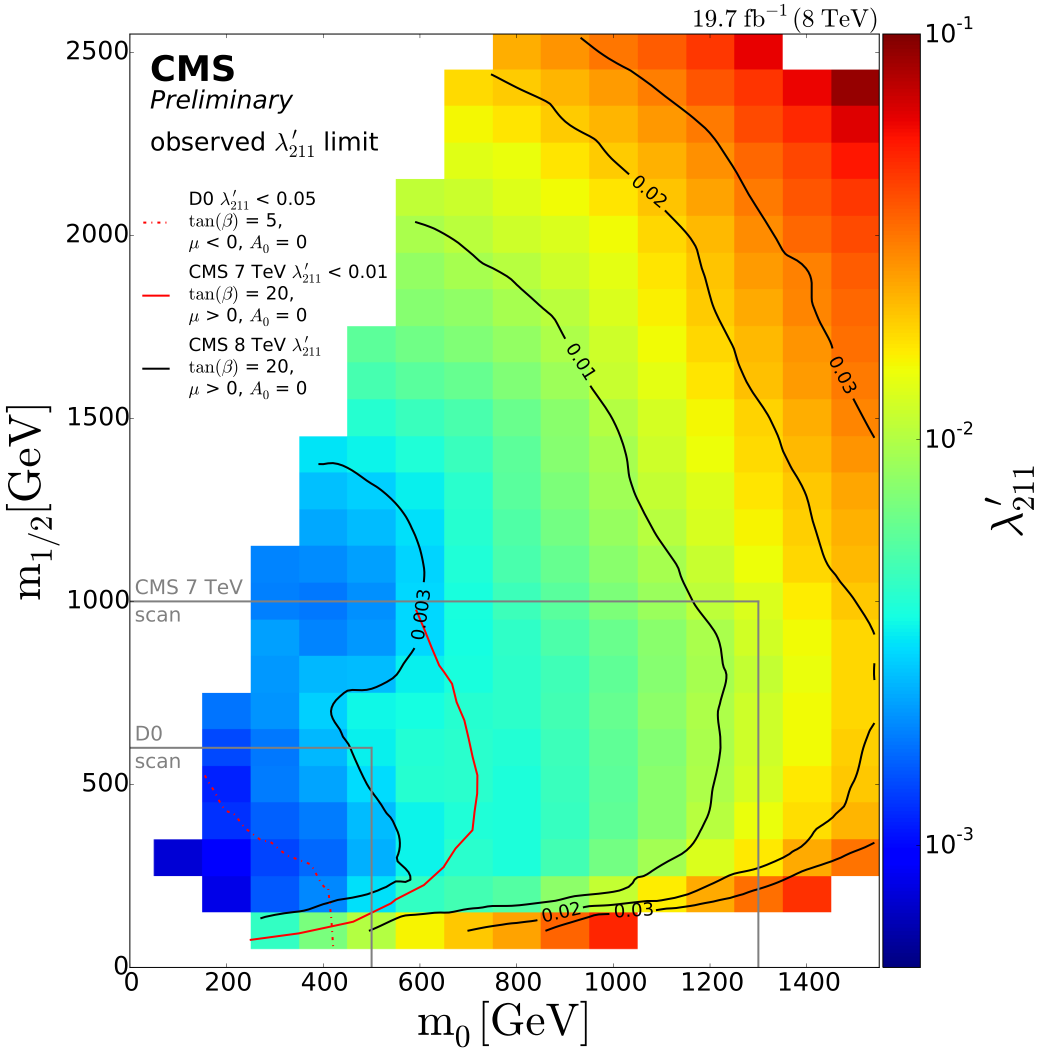
  m$_{\tilde{\nu}} = 0.5$ TeV, m$_{\tilde{\chi}} = 0.2$ TeV, x $= 0.5$: $\lambda'_{211} \approx 0.004$

INTERPRETATION

- 13 TeV couplings limits work in progress
- set σ limits for simplified models
- translate limits to λ'_{211} limits
- $\sigma_{\text{CMSSM}} \propto \lambda'^2_{211}$
- for $m_0 = 1500$ GeV, $m_{1/2} = 2000$ GeV

  8TeV limit $\lambda'_{211} < 0.036$

  13TeV limit $\lambda'_{211} <\approx 0.01$ (expected)



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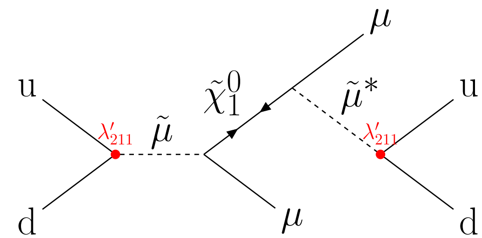
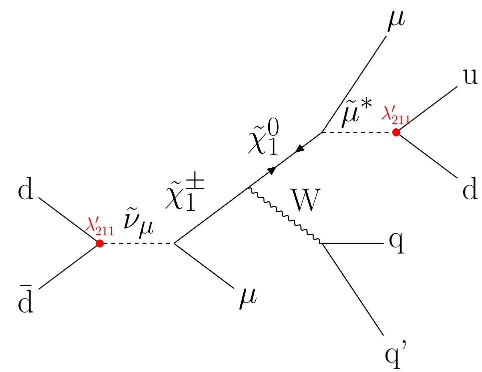
CONCLUSION

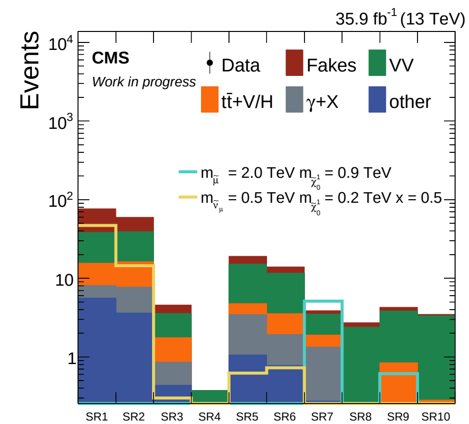
- presented search for resonant slepton production
- based on 2016 13 TeV CMS pp collision dataset
- model:
  - signal production / decay via RPV coupling λ'_{211}
  - simplified models for dominant contributions
  - signature:
    - 2 same-sign μ
    - $\geq$ 2 jets
- currently in the CMS approval process
- for $m_0 = 1500$ GeV, $m_{1/2} = 2000$ GeV

  8TeV limit $\lambda'_{211} < 0.036$

  13TeV limit $\lambda'_{211} <\approx 0.01$ (expected)







Thank you for your attention

REFERENCES

[1] based on MSSM-RpVTriRpV model by F. Staub https://sarah.hepforge.org/trac/wiki/MSSM-RpV-TriRpV

[2] MG5_aMC_2_3_3 (see JHEP 07 (2014) 079, Eur.Phys.J.C53:473-500)

RPV (Sho Iwamoto)

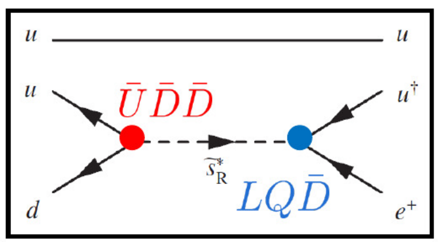
- Superpotential of the MSSM

$$W \ni \; H_u H_d, \; H_d L\bar{E}, \; H_d Q\bar{D}, \; H_u Q\bar{U},$$
$$\not{L} \; \; LH_u, \; LL\bar{E}, \; LQ\bar{D}, \; \; \bar{U}\bar{D}\bar{D} \; \not{B}$$

$$W \supset \lambda'_{ijk} L_i Q_j \bar{D}_k + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k$$

Both $\not{B}$ and $\not{L}$ ⇨ **Proton Decay**

$$p \to e^+ \pi^0$$



$$\tau \sim \frac{(9 \times 10^{-13}\,\mathrm{s})}{|\lambda'_{112}\lambda''_{112}|^2} \left(\frac{m_{\tilde{s}_R}}{1\,\mathrm{TeV}}\right)^4$$

RPV (Sho Iwamoto)

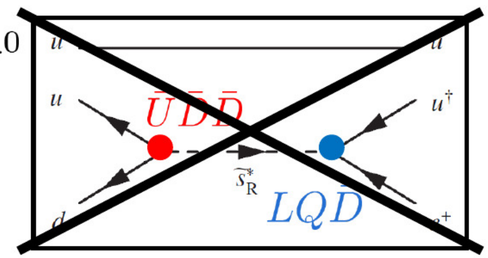
- Superpotential of the MSSM **with *R*-Parity** conservation

$$W \ni H_u H_d,\ H_d L\bar{E},\ H_d Q\bar{D},\ H_u Q\bar{U},$$

$$\not{L}\ \ \cancel{LH_u},\ \cancel{LL\bar{E}},\ \cancel{LQ\bar{D}},\ \ \cancel{\bar{U}\bar{D}\bar{D}}\ \ \not{B}$$

~~**Both** $\not{B}$ and $\not{L}$~~ ⇒ **Proton is stable.**

$p \to e^+\pi^0$



$\tau \sim \infty$

RPV (Sho Iwamoto)

However, since **proton decay needs both $\not{B}$ and $\not{L}$,**
we have other two possibilities!

- To **forbid** $\not{B}$ with Baryon-parity etc.

$$W \ni H_u H_d,\ H_d L\bar{E},\ H_d Q\bar{D},\ H_u Q\bar{U},\ LH_u,\ LL\bar{E},\ LQ\bar{D},\ \cancel{\bar{U}\bar{D}\bar{D}}$$

(Allowing $\not{L}$)

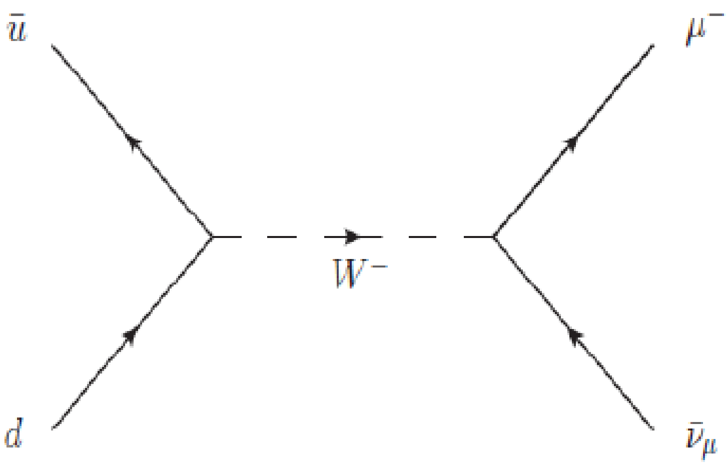
- To **forbid** $\not{L}$ with Lepton-parity etc.
with assuming $m_{\rm LSP} > m_{\rm proton}$.

$$W \ni H_u H_d,\ H_d L\bar{E},\ H_d Q\bar{D},\ H_u Q\bar{U},\ \cancel{LH_u},\ \cancel{LL\bar{E}},\ \cancel{LQ\bar{D}},\ \bar{U}\bar{D}\bar{D}$$

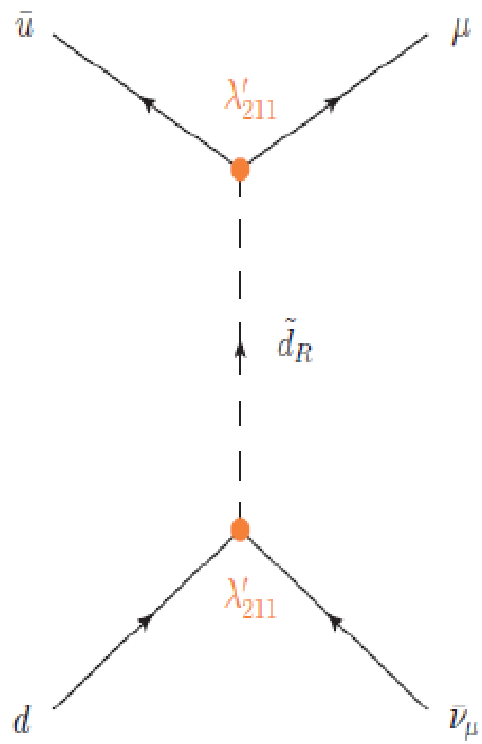
(Allowing $\not{B}$)

INDIRECT LIMITS

SM decay



SUSY decay



- $\lambda'_{21i} < 0.059 \cdot m_{\tilde{d}_{k,R}}/100\,\text{GeV}$
- Reinterpretation of 2002 PDG world average $R = \dfrac{\Gamma(\pi^+ \to \bar{e}\nu)}{\Gamma(\pi^+ \to \bar{\mu}\nu)}$

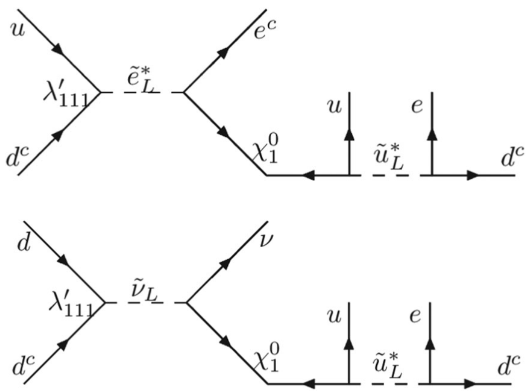


FIG. 1. Feynman diagrams for single slepton production leading to an $eejj(e\nu jj)$ signal at the LHC. Other diagrams, where the χ_1^0 is replaced by $\chi_1^\pm$ (among other replacements), also contribute.

Requiring a certain set of cuts (called "$M_{LQ} = 650$ GeV" cuts), CMS reported 36 events on a background[2] of 20.5 ± 3.5 in the $eejj$ channel, and 18 events on a background of 7.5 ± 1.6 in the $e\nu jj$ channel [1]. Taken simultaneously and ignoring correlations between the systematics, these excesses amount to a 3.5σ effect. In addition, a W_R search (with different cuts to the dileptoquark search) reported a 2.8σ excess in the $eejj$ channel at 1.8 TeV $< M_{eejj} <$ 2.2 TeV [2]. These excesses are not significant enough to claim a discovery, or even evidence. They are similar enough to attempt a unified explanation of all three, and a timely explanation before the next LHC run (run II) in terms of new physics such that further tests can be applied and analysis strategies can be set for run II.

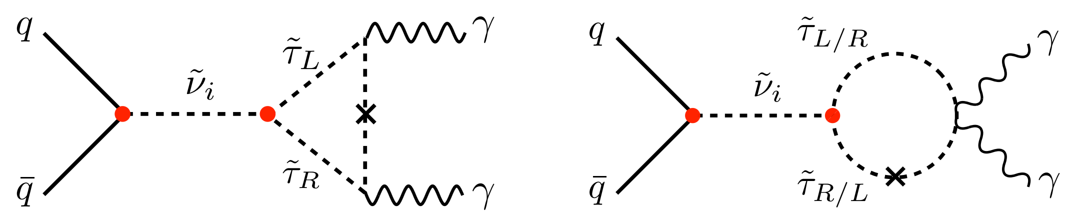


FIG. 1. Example Feynman diagrams for resonant sneutrino production via the $L_i Q_1 \bar{D}_1$ operator in Eq. (1) and its decay to two photons via the soft term $\tilde{\ell}_i \tilde{\ell}_3 \tilde{\tau}_R^+$ in Eq. (2). There are two kinds of diagrams: (left) through the triangle stau loop, and (right) through the $\tilde{\tau}_{R/L} \tilde{\tau}^*_{L/R} \gamma\gamma$ vertex, which must be included in the calculation to cancel the divergences in the loop integrals. The cross in the stau propagators represents the LR mixing in the stau sector, which must be nonzero to have a diphoton signal.

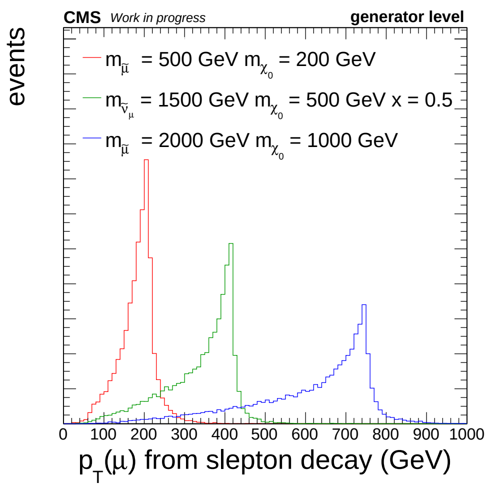
$$W_{\rm LV} = \lambda'_{i11} L_i Q_1 \overline{D}_1, \tag{1}$$

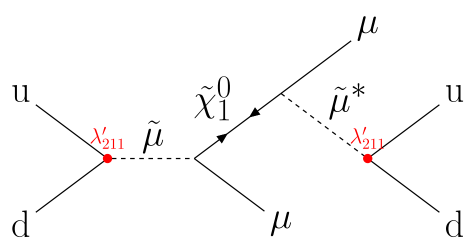
where i is the family index of the sneutrino. The sneutrino may decay into two photons through a stau loop with a left-right (LR) stau mixing via the RPV soft supersymmetry (SUSY)-breaking term

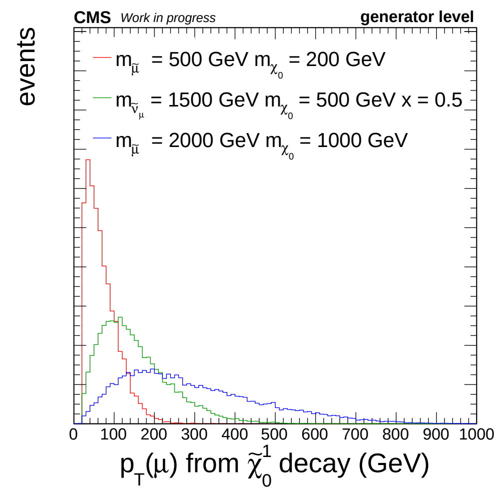
$$\mathcal{L}_{\rm LV}^{\rm soft} = A_{i33} \tilde{\ell}_i \tilde{\ell}_3 \tilde{\tau}_R^+ + ({\rm H.c.}), \tag{2}$$

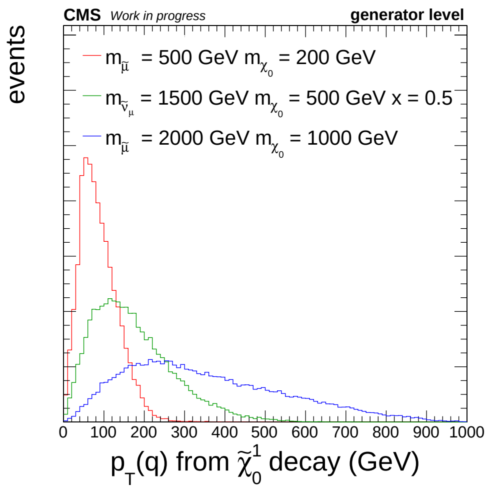
where the $SU(2)_L$ indices of $\tilde{\ell}_i$ and $\tilde{\ell}_3$ are antisymmetrically contracted implicitly, which forbids i to be 3, so the 750 GeV sneutrino has to be of electron or muon type in our scenario.

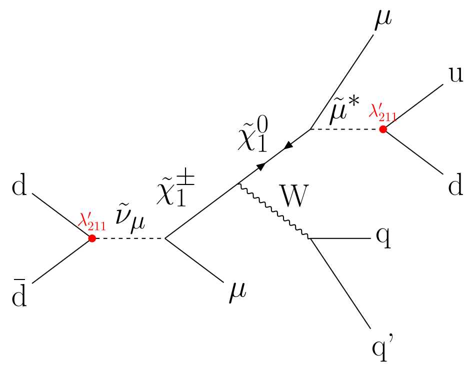
SIGNAL SIGNATURE

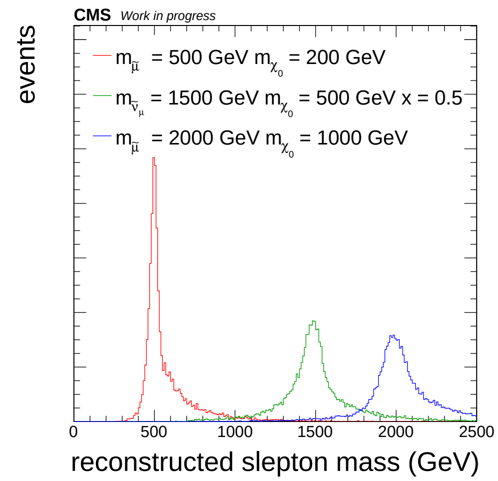










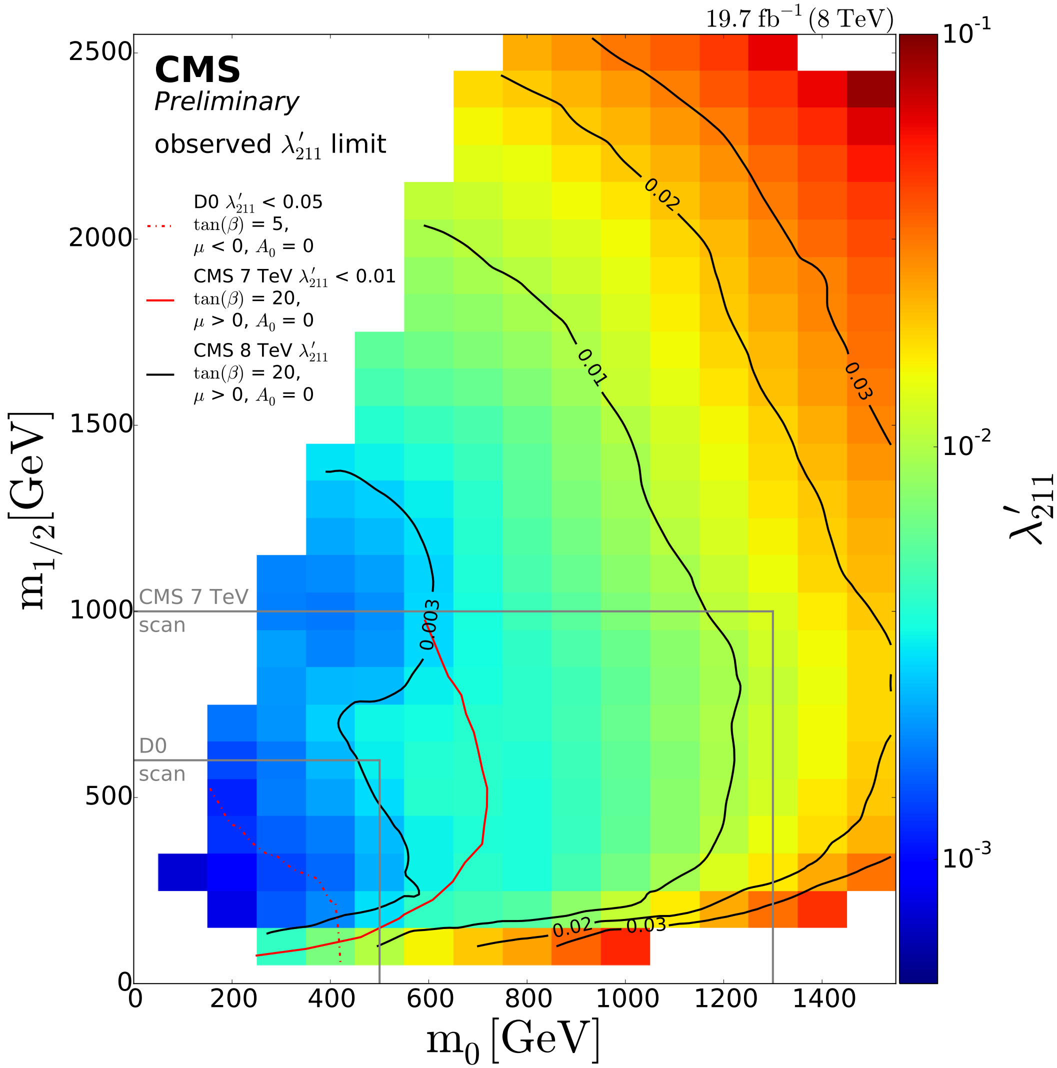


SYSTEMATIC UNCERTAINTIES

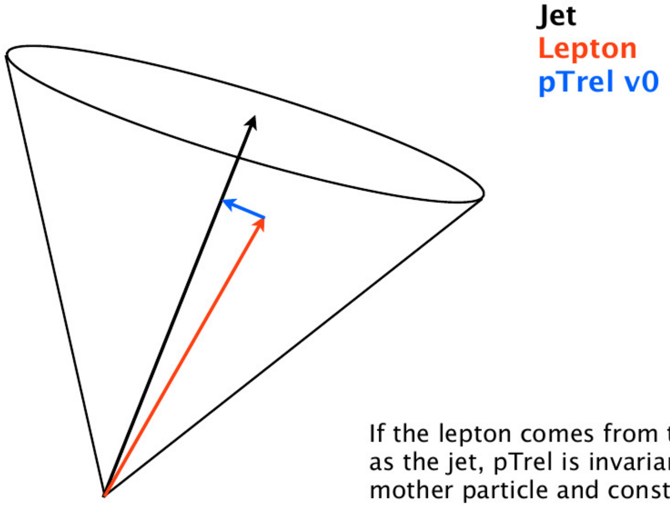
SR	fakes	WZ	$W^{\pm}W^{\pm}$	$t\bar{t}W$	$t\bar{t}Z/H$	γX	other	Σ
lumi	-	-	± 0.99 (2.5%)	± 0.37 (2.5%)	-	± 0.29 (2.5%)	± 0.32 (2.5%)	± 1.97 (1.0%)
pileup	-	± 0.26 (0.7%)	± 0.14 (0.3%)	± 0.12 (0.8%)	± 0.04 (0.6%)	± 0.61 (5.3%)	± 0.17 (1.3%)	± 0.97 (0.5%)
trigger scf	-	± 0.35 (1.0%)	± 0.34 (0.9%)	± 0.13 (0.9%)	± 0.06 (0.9%)	± 0.13 (1.1%)	± 0.12 (0.9%)	± 1.13 (0.6%)
μ scf	-	± 2.23 (6.3%)	± 2.46 (6.2%)	± 0.92 (6.2%)	± 0.41 (6.2%)	± 0.73 (6.2%)	± 0.81 (6.2%)	± 7.56 (4.0%)
b-tag scf	-	± 0.16 (0.4%)	± 0.24 (0.6%)	± 0.45 (3.1%)	± 0.21 (3.2%)	± 0.06 (0.5%)	± 0.10 (0.8%)	± 1.22 (0.6%)
JEC	-	± 1.40 (3.9%)	± 0.31 (0.8%)	± 0.09 (0.6%)	± 0.00 (0.1%)	± 0.42 (3.6%)	± 0.49 (3.8%)	± 1.87 (1.0%)
JER	-	± 0.45 (1.3%)	± 0.03 (0.1%)	± 0.06 (0.4%)	± 0.04 (0.7%)	± 0.40 (3.4%)	± 0.24 (1.8%)	± 0.79 (0.4%)
T/L method	± 28.50 (42.1%)	-	-	-	-	-	-	± 28.50 (15.1%)
norm. (WZ)	-	± 4.99 (14.0%)	-	-	-	-	-	± 4.99 (2.6%)
norm. ($W^{\pm}W^{\pm}$)	-	-	± 8.69 (22.0%)	-	-	-	-	± 8.69 (4.6%)
norm. ($t\bar{t}W$)	-	-	-	± 2.06 (14.0%)	-	-	-	± 2.06 (1.1%)
norm. ($t\bar{t}Z/H$)	-	-	-	-	± 1.65 (25.0%)	-	-	± 1.65 (0.9%)
norm. (γX)	-	-	-	-	-	± 5.81 (50.0%)	-	± 5.81 (3.1%)
norm. (other)	-	-	-	-	-	-	± 6.47 (50.0%)	± 6.47 (3.4%)

Table 12: Systematic Uncertainties for each process.

8 TEV LIMITS SUS-14-018



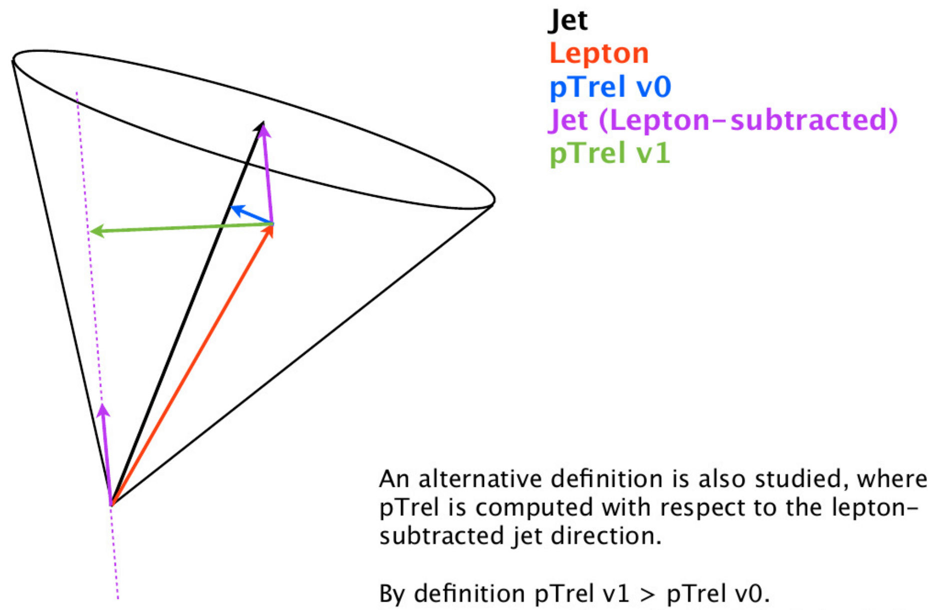
I_3 ILLUSTRATION (G. Cerati)



If the lepton comes from the same mother particle as the jet, pTrel is invariant under the boost of the mother particle and constrained by its mass.

For accidental overlap jet-lepton overlap, no upper bound on pTrel.

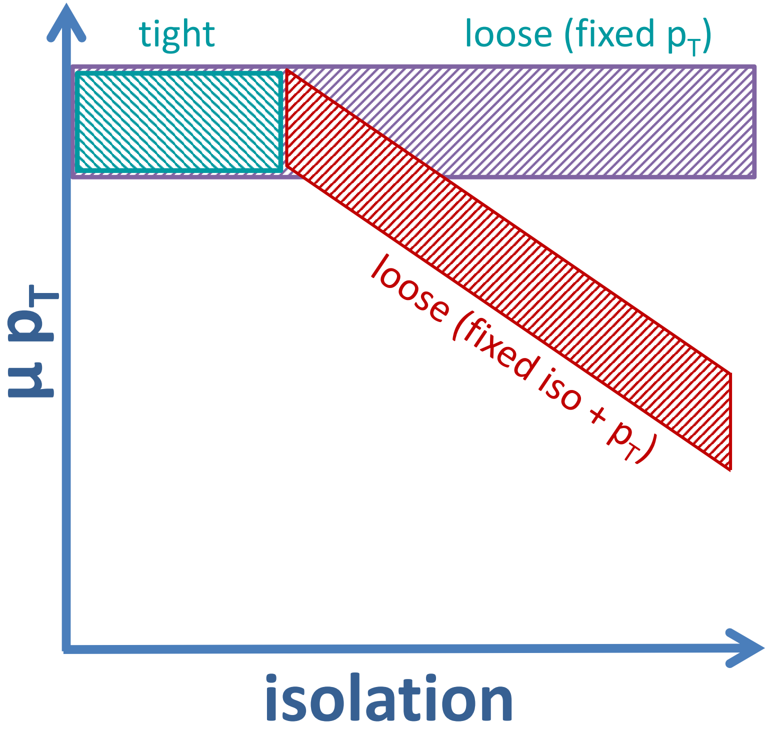
I_3 ILLUSTRATION (G. Cerati)



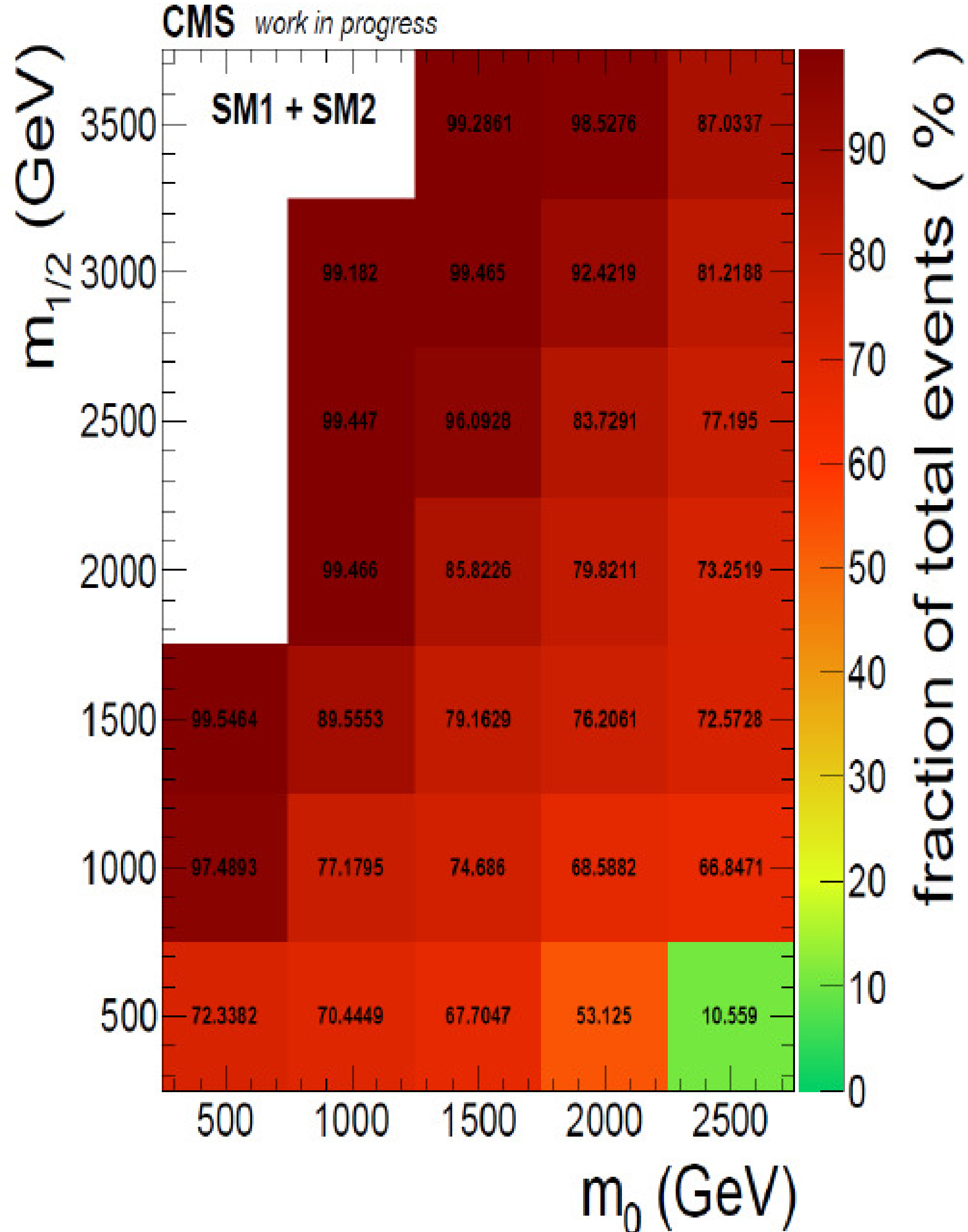
An alternative definition is also studied, where pTrel is computed with respect to the lepton-subtracted jet direction.

By definition pTrel v1 > pTrel v0.
Less clean from theoretical point of view but sensitive to different topology in signal and background events.

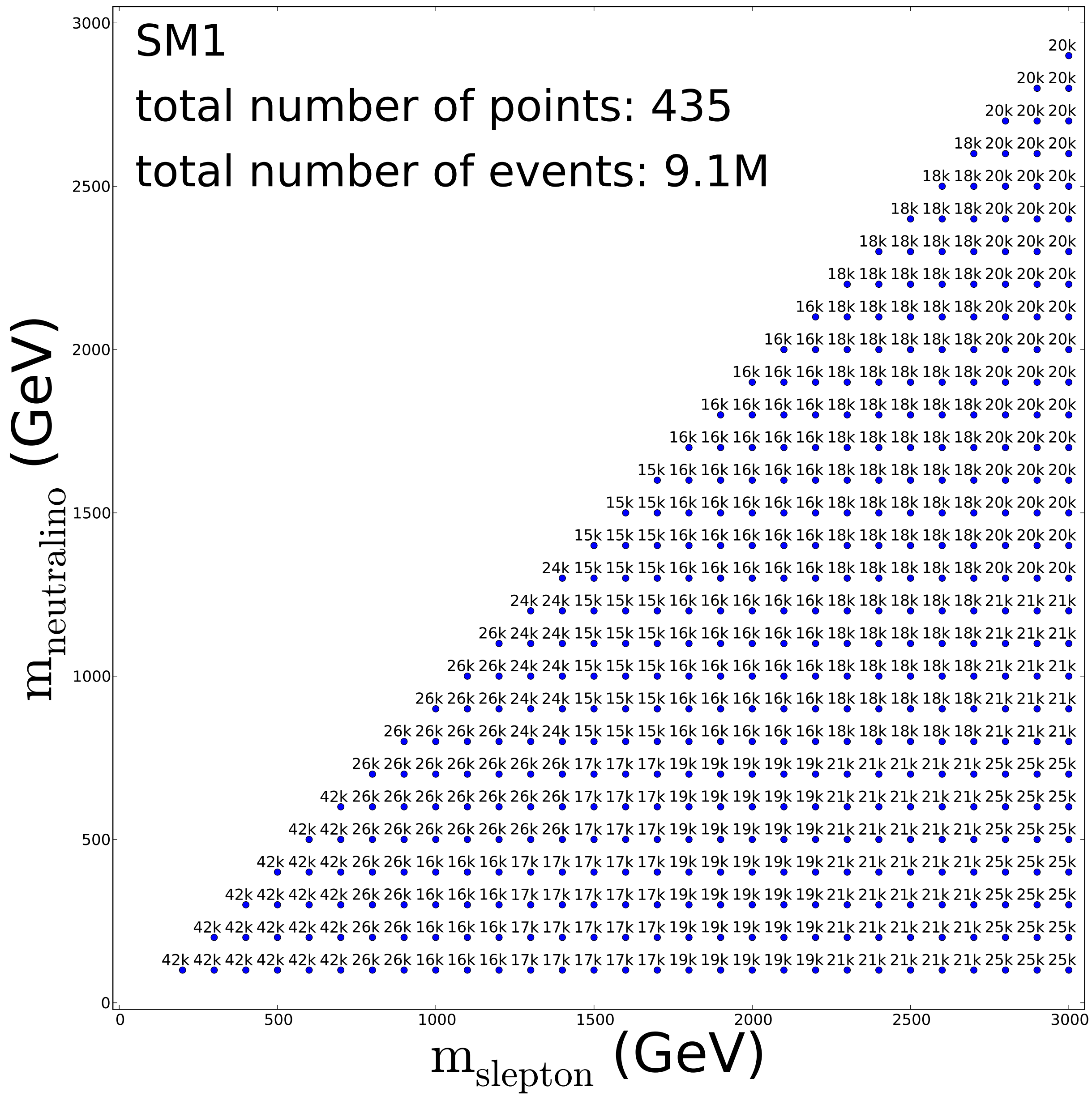
p_T^{cor}



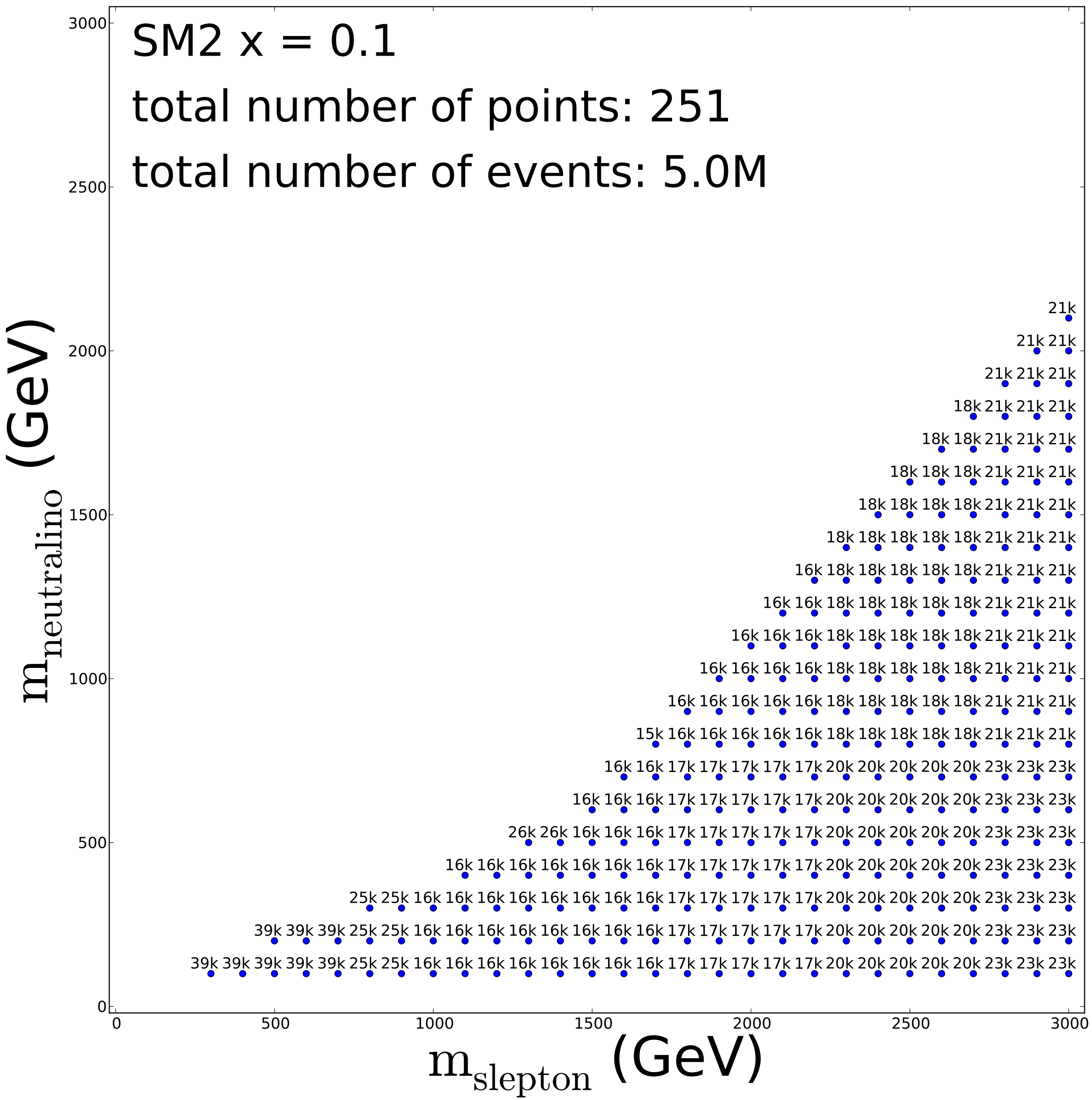
SIMPLIFIED MODEL COVERAGE



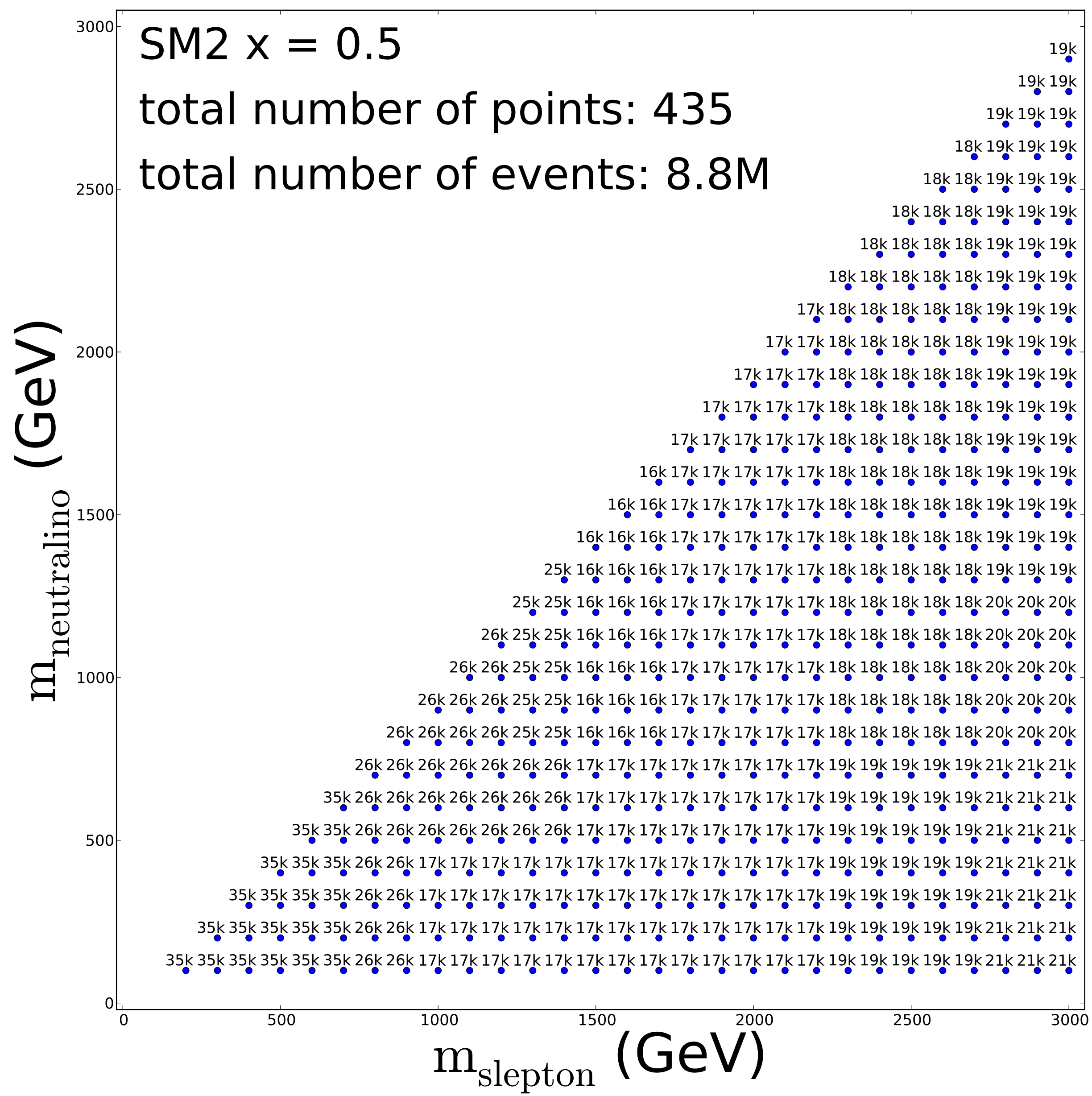
SIGNAL SCAN SM1



SIGNAL SCAN SM2



SIGNAL SCAN SM2



SIGNAL SCAN SM2