Charged Lepton flavor Violation at the CMS experiment

1st Conference on Charged Lepton flavor Violation

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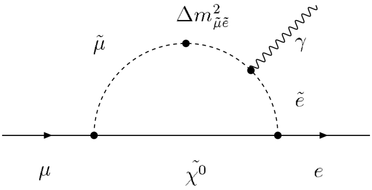
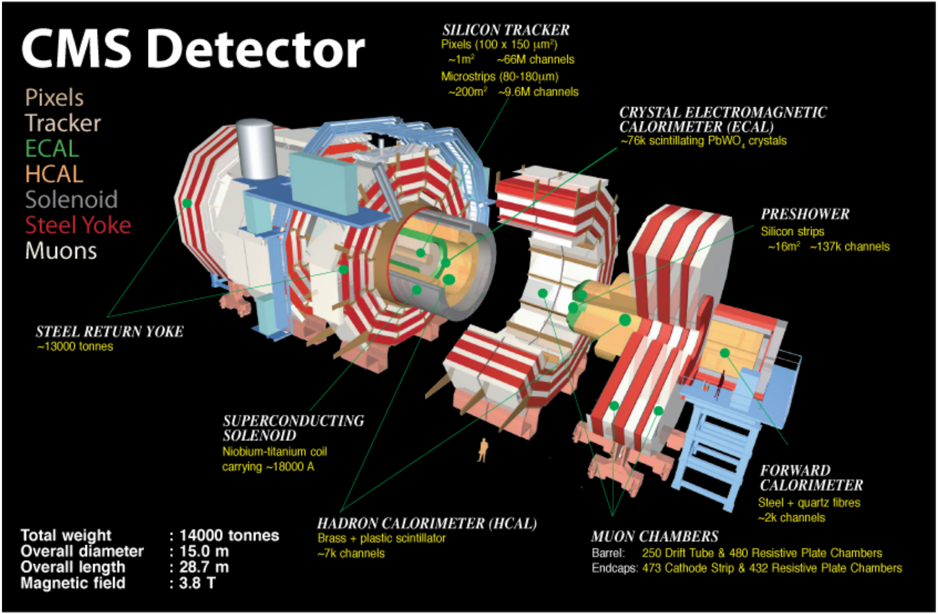
on behalf of the CMS collaboration

Outline

Physics Motivations

- Lepton flavor numbers not conserved, as established by the discovery of the neutrino masses and lepton mixing
- Charged-lepton flavor-violation (CLVF): non-zero rate in the context of New Physics models that incorporate neutrino masses
- Very clear signature, not SM-contamined
- Ex. is the MSSM slepton-neutralino contribution to $\mu \to e\gamma$.

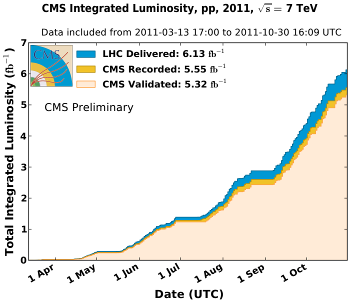


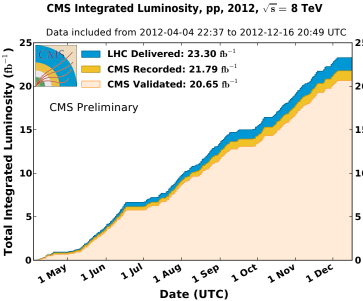

CMS Detector
Pixels
Tracker
ECAL
HCAL
Solenoid
Steel Yoke
Muons
SILICON TRACKER
Pixels (100 x 150 μm²)
~1m² ~66M channels
Microstrips (80-180μm)
~200m² ~9.6M channels
CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
~76k scintillating PbWO4 crystals
PRESHOWER
Silicon strips
~16m² ~137k channels
STEEL RETURN YOKE
~13000 tonnes
SUPERCONDUCTING SOLENOID
Niobium-titanium coil carrying ~18000 A
FORWARD CALORIMETER
Steel + quartz fibres
~2k channels
HADRON CALORIMETER (HCAL)
Brass + plastic scintillator
~7k channels
MUON CHAMBERS
Barrel: 250 Drift Tube & 480 Resistive Plate Chambers
Endcaps: 473 Cathode Strip & 432 Resistive Plate Chambers
Total weight : 14000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T

Data taking

Luminosity

$\mathcal{L}$ = 5.3 fb^{-1} at 7 TeV, $\mathcal{L}$ = 20.7 fb^{-1} at 8 TeV





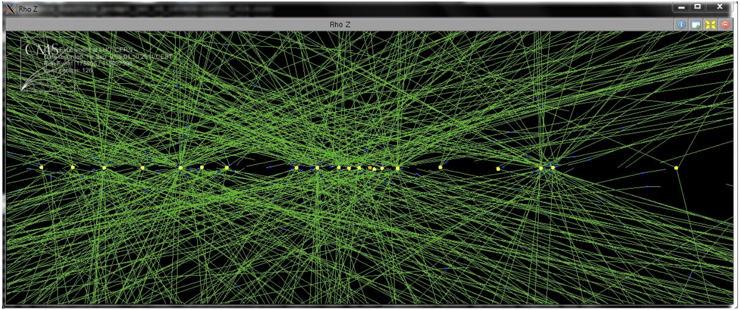
CMS Preliminary Results: Mar-Oct 2011 proton-proton collision runs									
Tracker		Calorimeters			Muon Spectrometer			Magnet	Operational
Pixel	SST	ECAL	ES	HCAL	CSC	DT	RPC		
99.7	99.5	97.4	99.9	98.0	98.3	99.9	99.6	100	99.2
All good for physics: 91.7%									

Luminosity weighted fractions (in %) of data certified as good for physics analysis relative to 5.55fb^{-1} of data recorded by the CMS experiment during 2011 proton-proton collisions at √s=7TeV between March 13th and 30th October.

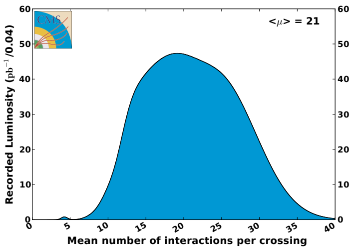
CMS Preliminary Results: Apr-Dec 2012 proton-proton collision runs									
Tracker		Calorimeters			Muon Spectrometer			Magnet	Operational
Pixel	SST	ECAL	ES	HCAL	CSC	DT	RPC		
98.9	99.6	98.6	99.3	96.6	99.3	99.8	99.4	98.6	99.2
All good for physics: 90%									

Luminosity weighted fractions (in %) of data certified as good for physics analysis relative to 21.79fb^{-1} of data recorded by the CMS experiment during 2012 proton-proton collisions at √s=8TeV between April 4th and December 17th.

The PileUp challenge



CMS Average Pileup, pp, 2012, $\sqrt{s} = 8$ TeV



LHC already achieved the design level of pileup
Event display of an event with around 20 pile-up vertices:
(maximum number of vertices goes up to 40)
CMS copes with this high level of pile-up very well
$<N_{PU}>$ = 21

Muons

- Combined fit to measurements from inner tracker and muon detectors
- Minimal number of hits in the silicon tracker
- High-quality global fit ($\chi^2/ndf\ <10$)
- Transverse and longitudinal impact parameter of the muon track relative to the Primary vertex

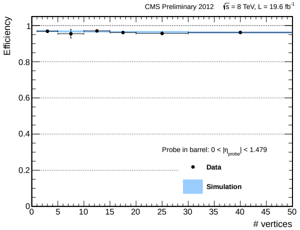
Electrons

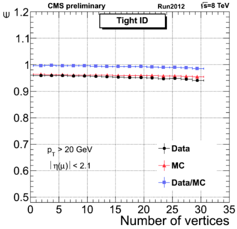
- Tracks reconstructed in the inner tracker with energy compatible with ECAL deposits
- Transverse and longitudinal impact parameters cuts
- Photon conversion rejection

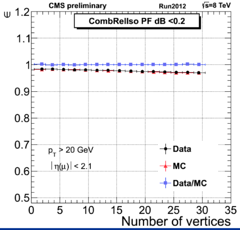
Isolation

- Relative isolation ($\Delta R > 0.3$):

$$I^{\ell}_{Rel} = \frac{E^{\ell}_{CH} + E^{\ell}_{NH} + E^{\ell}_{\gamma}}{p^{\ell}_T}$$

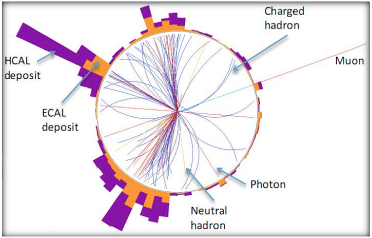






Particle Flow

- Event description in form of mutually exclusive particles identification of all stable particles produced in the event
- Optimal combination of capabilities of each sub-detector $\rightarrow$ most precise measurement of the energy and direction for each particle
- individual measurements combined by a geometrical linking algorithm, e.g. extrapolating a charged-particle track into ECAL and HCAL particle ID on blocks of linked elements

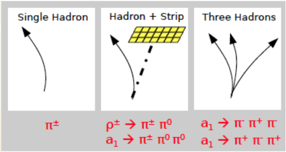


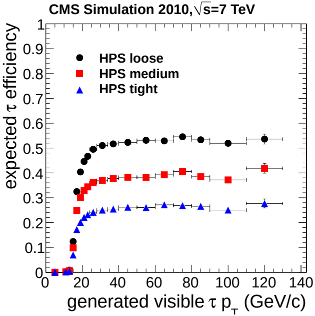
Taus: Hadron Plus Strip (HPS) algorithm

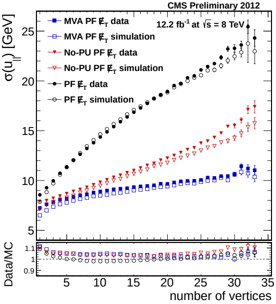
- Complete final state reconstruction of the leptonic and hadronic τ decays
- τ_{had} can have 1-prong or 3-prongs (charged tracks) with up to two ECAL strips for π^0 reconstruction.

Jets & MET

- anti-k_T algorithm jet reconstruction from Particle Flow particles, cone size = 0.5
- $\not{E}_T$ from PF constituents







Narrow resonances

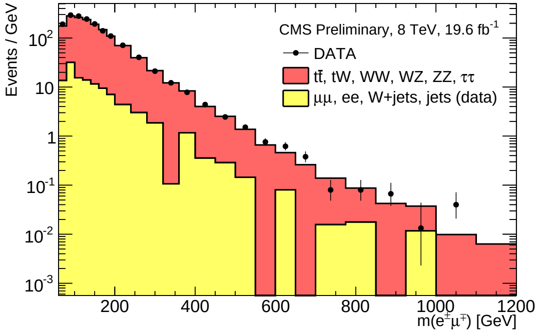
CMS PAS EXO-12-061

Search for Narrow Resonances in Dilepton Mass Spectra in pp Collisions at $\sqrt{s}$ = 8 TeV

$\sqrt{s}$ = 8 TeV,
$\mathcal{L}$ = 20.6 fb^{-1} (dimuon)
$\mathcal{L}$ = 19.6 fb^{-1} (dielectron)

General strategy

- CLFV signature at LHC: different flavor, opposite-sign leptons ($\ell\ell'$) with large transverse momenta, compatible to sneutrinos decaying to $\ell\ell'$ in the context of *R*-parity-violating (RPV) SUSY models.
- CMS does not have similar analysis but $m_{\ell\ell'}$ has been studied in searches for various Z' heavy gauge bosons.
- As a control check to demonstrate that Monte Carlo simulation is a good representation of data, the $e\mu$ spectra in data is compared to MC



The data are found to be consistent with SM predictions and no excess is observed

Heavy neutrinos

Theoretical motivations

- Origin of neutrino masses still unknown
- Seesaw mechanism

$$m_\nu \approx y_\nu^2 v^2 / m_N$$

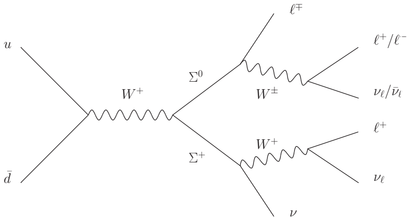
  where y_ν = Yukawa coupling of ν to the Higgs field
  v = Higgs vacuum expectation value in the SM
- due to the Majorana nature, the heavy neutrino is also its own antiparticle
- lepton-number conservation violated by two units
- searches for heavy Majorana neutrinos important for LFV

CMS PAS EXO-11-073

Search for heavy lepton partners of neutrinos in pp collisions at $\sqrt{s} = 7$ TeV, in the context of the Type III seesaw mechanism.

$\sqrt{s} = 7$ TeV, $\mathcal{L} = 4.9$ fb^{-1}

Experimental strategy (type III)

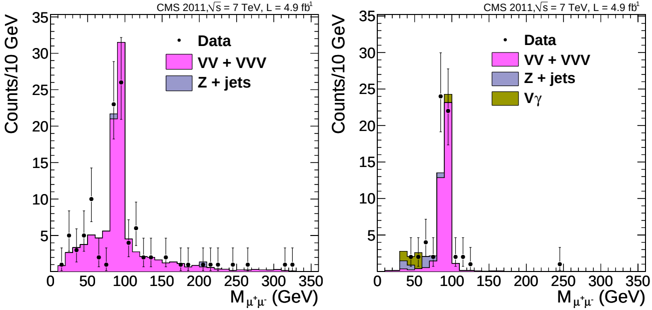


- Search for type III most promising channel: $q\bar{q}' \rightarrow \Sigma^0\Sigma^+$, where $\Sigma^0 \rightarrow \ell^\mp W^\pm$ and $\Sigma^+ \rightarrow W^+\nu$
- Final state: three charged isolated leptons (total charge +1) + $\not{E}_T$ from the fermionic weak-isospin triplets
- $\not{E}_T > 30$ GeV
- $p_T^\ell > 18, 15, 10$ GeV for the lepton of highest, second highest and lowest p_T
- $H_T < 100$ GeV (of jets with $E_T >$30 GeV and $|\eta| <$2.4)
- veto for events containing a Z boson, or a low mass $m_{\ell^+\ell^-}$
- Backgrounds: dibosons (PYTHIA), 3 EWK bosons (MADGRAPH), photons and jets misidentified as leptons, conversions of virtual radiated photons (γ^*) in $Z \rightarrow \ell^+\ell^-\gamma^*$

Results

Expected number of seesaw signal events, of SM backgrounds and number of observed events

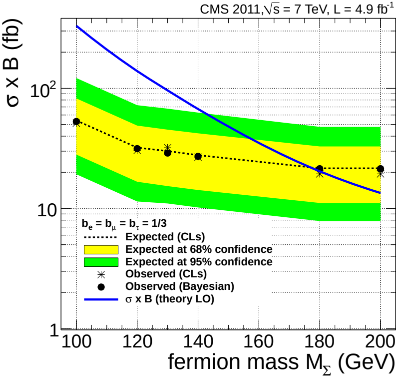
Channel	Expected signal for M_Σ (GeV) 100	120	130	140	180	Expected SM background	Data
$\mu^- e^+ e^+$	12.32	7.91	6.02	4.49	1.73	0.75 ± 0.44	2
$\mu^- e^+ \mu^+$	20.74	12.31	8.95	6.97	2.97	7.1 ± 2.1	9
$\mu^- \mu^+ \mu^+$	13.57	7.80	5.16	3.59	1.41	11.1 ± 3.6	7
$e^- \mu^+ \mu^+$	13.68	8.25	6.24	4.75	1.75	1.11 ± 0.67	0
$e^- e^+ \mu^+$	21.83	13.20	9.49	6.85	2.73	8.2 ± 2.1	7
$e^- e^+ e^+$	6.47	3.90	2.80	2.00	0.96	4.8 ± 1.4	4



no significant excess of events observed relative to SM expectations

Expected limits

95% CL limits on the $\sigma \times BR$ of $\Sigma^0\Sigma^+ \to 3\ell$ (for different mixing scenarios) and lower exclusion limits for the triplet Σ mass



Branching ratio cases	95% on M_Σ GeV		95% on $\sigma \times$ BR (fb)	
	Exp.	Obs.	Exp.	Obs.
$b_e = b_\mu = b_\tau = 1/3$	177	179	22	20
$b_\mu = 1, b_e = b_\tau = 0$	201	211	13	11
$b_e = 1, b_\mu = b_\tau = 0$	202	204	13	13

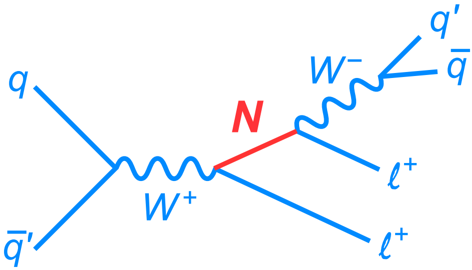
First limits on the production of seesaw Type III fermionic triplet reported by LHC

CMS PAS EXO-11-076 / Phys. Lett. B 717 (2012) 109

Search for heavy Majorana neutrinos in $\mu^{\pm}\mu^{\pm}$+jets and $e^{\pm}e^{\pm}$+jets in pp collisions at $\sqrt{s}$ = 7 TeV

$\sqrt{s}$ = 7 TeV, $\mathcal{L}$ = 4.98 fb^{-1}

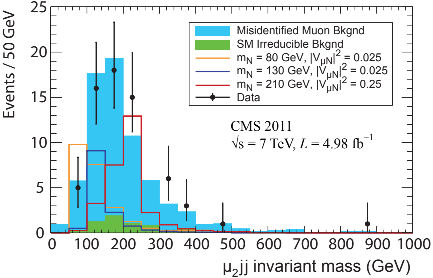
Experimental strategy



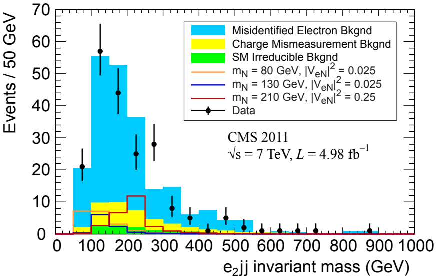
- m_N and $V_{\ell N}$ free parameters
- Heavy Majorana neutrino N can decay to ℓ with positive or negative charge $\rightarrow$ leptons can be SS or OS
- SS events have no background from SM $\rightarrow$ search for events with two isolated leptons of same sign and same flavor (plus at least two jets)
- Systematic uncertainties:
  - Estimation of the misidentified lepton background: 35%
  - Mismeasurement of the electron charge: 25%
  - Normalization of irreducible SM backgrounds (up to 50%)

Results

Source	$\mu^\pm\mu^\pm$	$e^\pm e^\pm$
Irreducible SM backgrounds:		
WZ	$3.2 \pm 0.3 \pm 0.2$	$4.9 \pm 0.3 \pm 0.3$
ZZ	$1.0 \pm 0.1 \pm 0.1$	$2.1 \pm 0.1 \pm 0.1$
Wγ	$0.75 \pm 0.27 \pm 0.07$	$1.7 \pm 0.4 \pm 0.2$
$t\bar{t}$W	$1.06 \pm 0.05 \pm 0.53$	$0.62 \pm 0.04 \pm 0.31$
W^+W^+qq	$0.76 \pm 0.06 \pm 0.38$	$0.73 \pm 0.07 \pm 0.37$
W^-W^-qq	$0.45 \pm 0.03 \pm 0.23$	$0.27 \pm 0.02 \pm 0.13$
Double-parton $W^\pm W^\pm$	$0.07 \pm 0.02 \pm 0.04$	$0.19 \pm 0.03 \pm 0.10$
Total irreducible SM background	$7.3 \pm 0.4 \pm 0.7$	$10.6 \pm 0.6 \pm 0.6$
Charge mismeasurement background	$0^{+0.2}_{-0}$	$31.9 \pm 2.7 \pm 8.0$
Misidentified lepton background	$63.1 \pm 4.2 \pm 22.1$	$176.8 \pm 4.7 \pm 61.9$
Total background	$70 \pm 4 \pm 22$	$219 \pm 6 \pm 62$
Data	65	201
Expected signal:		
$m_N = 130$ GeV/c^2, $\lvert V_{\ell N}\rvert^2 = 0.1$	$58 \pm 1 \pm 4$	$39 \pm 1 \pm 3$
$m_N = 210$ GeV/c^2, $\lvert V_{\ell N}\rvert^2 = 0.1$	$12.0 \pm 0.1 \pm 0.8$	$8.5 \pm 0.1 \pm 0.6$



Observed event yields, estimated backgrounds and expected number of signal events for two heavy Majorana neutrino mass hypotheses



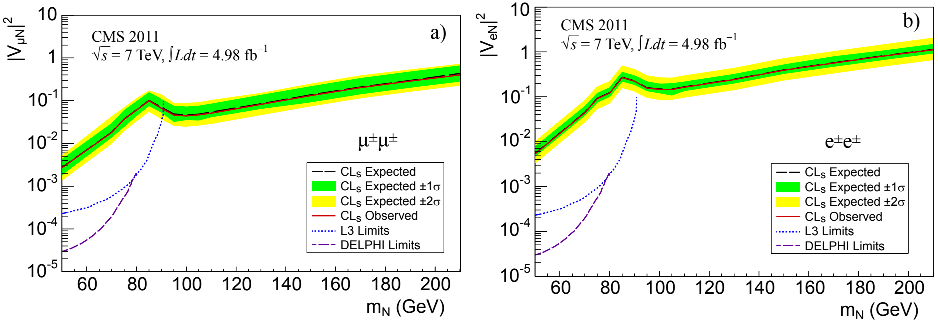
Invariant masses of the second leading p_T lepton and the two leading jets

No evidence for a significant excess in data beyond the backgrounds predicted by the SM

Exclusion limits

95% CL exclusion limits on the square of the heavy Majorana-neutrino mixing parameter as function of m_N

Muon channel: $|V_{eN}|^2 = |V_{\tau N}|^2 = 0$
Electron channel: $|V_{\mu N}|^2 = |V_{\tau N}|^2 = 0$



First direct upper limits on the heavy-Majorana-neutrino mixing for $m_N > 90$ GeV

Limits less stringent that LEP, however the mass range is extended beyond 90 GeV

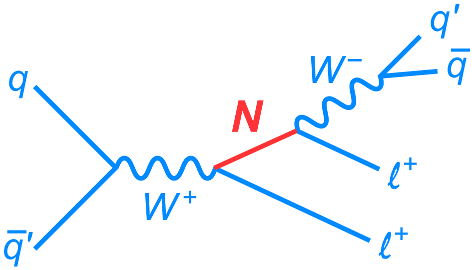
@ m_M = 90 GeV, $|V_{\mu N}|^2 < 0.07$, and $|V_{eN}|^2 < 0.22$

CMS PAS EXO-12-017

Search for heavy neutrino and right-handed W of the left-right symmetric model in pp collisions at $\sqrt{s}$ = 8 TeV

$\sqrt{s}$ = 8 TeV, $\mathcal{L}$ = 3.6 fb^{-1}

Theoretical motivations



- Extension of the SM (LRSM) to explain parity non-conservation in weak interactions:

$$SU_C(3) \otimes SU_L(2) \otimes SU_R(2) \otimes U(1)$$

- spontaneous breaking of $SU_R(2)$ symmetry group $\rightarrow$ heavy right-handed neutrino states N_ℓ, and three additional gauge bosons $W_R^\pm$ and Z'
- Two-dimensional resonance structure: $M_{\ell\ell jj}$ and $M_{\ell_2 jj}$ have narrow peaks (corresponding to W_R and N_ℓ)
- lepton leading (subleading) $p_T > 60$ (40) GeV
- jet $E_T > 40$ GeV
- $M_{\ell\ell} > 200$ GeV, $M_{\ell\ell jj} > 600$ GeV

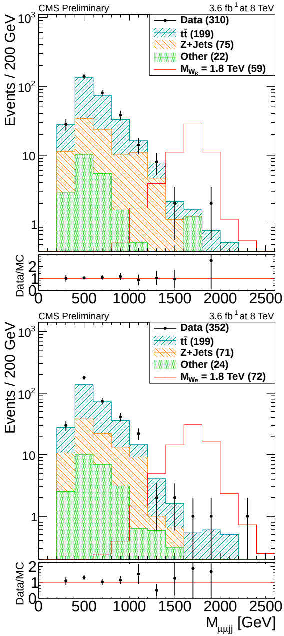
Results

Electron Channel

Selection Stage	Data	Signal	Total Bkgd	$t\bar{t}$	Z+jets	QCD	Other
Two electron, two jets	8807	61	8943	968	7821	8	146
e_1 $p_T > 60$ GeV	6054	61	5905	767	5014	3	121
$M_{ee} > 200$ GeV	310	59	296	199	75	3	20
$M_{eejj} > 600$ GeV	144	59 ± 12	135 ± 30	83 ± 18	43 ± 23	2 ± 1	9 ± 3

Muon Channel

Selection Stage	Data	Signal	Total Bkgd	$t\bar{t}$	Z+jets	QCD	Other
Two muons, two jets	10333	75	10016	968	8830	3	215
μ_1 $p_T > 60$ GeV	7058	75	6873	767	5933	2	171
$M_{\mu\mu} > 200$ GeV	352	72	294	199	71	0.7	23
$M_{\mu\mu jj} > 600$ GeV	144	72 ± 13	130 ± 24	83 ± 17	35 ± 17	0.7 ± 0.4	11 ± 4



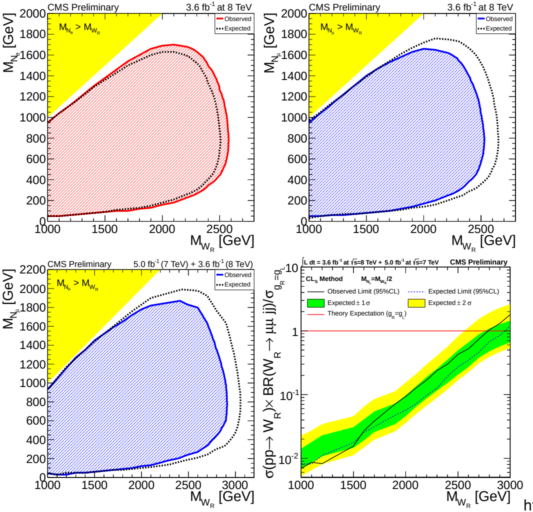
Observed event yields, estimated backgrounds and expected number of signal (M_{W_R}=1800 GeV, M_{N_μ} = 900 GeV) events

Four object mass distributions for *eejj* and $\mu\mu jj$ after the selection

No evidence for a significant excess in data beyond the backgrounds predicted by the SM

Exclusion limits

- $M_{\ell\ell jj}$-based shape analysis
- 95% CL exclusion region as a function of cross section of W_R production multiplied by BR of the $\ell\ell jj$ decay
- Limits indicate N_ℓ masses excluded as a function of W_R assuming that only one heavy neutrino flavor (e or μ) is accessible at 8 TeV collisions (the other being too heavy to be produced)



hypothesis: $M_{N_\mu} = 1/2\ M_{W_R}$

Leptonic-RPV SUSY searches

Theoretical motivations

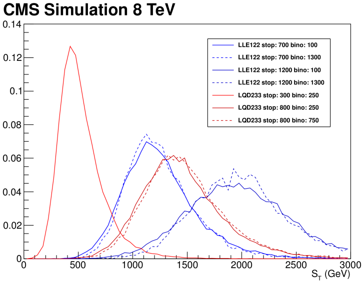
- R-parity $R_p = (-1)^{3B+L+2s}$ (R_p = +1 for SM, R_p = -1 for superparticles)
- R_p conserved: superpartners can only be produced in pairs, and the lightest superpartner (LSP) is stable and a candidate for a dark matter particle.
- in RPV the LSP is unstable,

$$\Downarrow$$

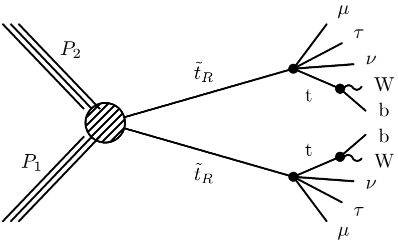
$$S_T = \not{E}_T + H_T + L_T$$

H_T = scalar sum of jet p_T L_T = scalar sum of lepton p_T

(since $\not{E}_T$ cannot be used)



Experimental strategy



- multilepton events (3 or 4)
- opposite-sign, same-flavor (OSSF) pair of isolated leptons
- topological cuts: leading lepton p_T >20 GeV, other leptons p_T >10 GeV, all leptons in $|\eta|$ <2.4
- $m_{\ell\ell}$ >12 GeV to remove low-mass $\gamma^* \rightarrow \ell^+\ell^-$
- if 75 < $m_{\ell\ell}$ <105 GeV event leptons are considered as coming from Z boson
- ΔR(jet, ℓ)>0.3
- *b*-tagging: combined secondary vertex algorithm (track impact parameter+secondary vertex information)
- Events categorised based on the number leptons: 3/4 leptons (e or μ) + 0/1 reconstructed τ_{had} (lepton flavors are sensitive to different RPV couplings)
- Events binned based on S_T

Backgrounds and systematics

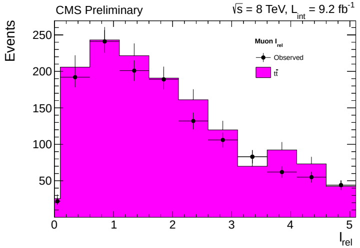
- #1: Real multi lepton events (WZ, ZZ, and rare $t\bar{t}W$ and $t\bar{t}Z$
- #2: Misidentified hadrons, leptons from hadron decay or other fakes, further classified in:
  - (a) misidentified light leptons, measured in a Z-dominated control region
    - $(0.65 \pm 0.16)\%$ (for μ) and $(0.6 \pm 0.15)\%$ (for e)
  - (b) misidentified τ_{had}, measured in jet-dominated data in an inverted-isolation sideband
    - The ratio of the number of τ_{had} in the two regions is $(15 \pm 3)\%$
  - (c) light leptons from asymmetric internal conversions
    - conversion factor measured to be $0.35\% \pm 0.1\%$ ($1.1\% \pm 0.2\%$) for muons (electrons)
  - (d) External conversions suppressed with electron ID
- Main systematics come from $t\bar{t}$ cross section and fake rate (50 %)

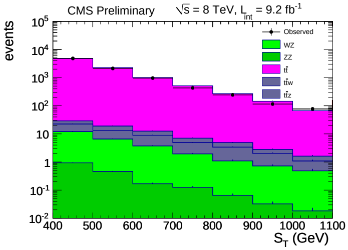
CMS PAS SUS-12-027

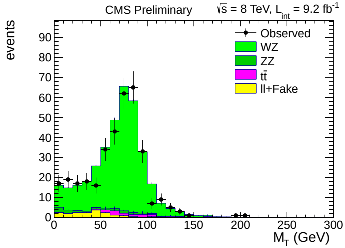
Search for RPV supersymmetry with three or more leptons and b-tags

$\sqrt{s}$ = 8 TeV, $\mathcal{L}$ = 9.2 fb^{-1}

Background estimation



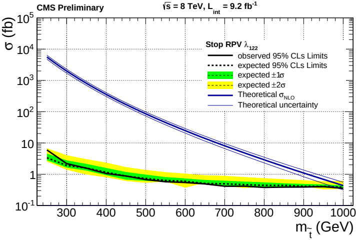




- TL: I_{rel} of muons from jets (dxy $>$ 0.02 cm) in a data sample enriched in $t\bar{t} \rightarrow \ell\nu bbjj$
- TR: S_T for events with an OS e-μ pair
- BL: M_T in a WZ-enriched data sample (OSSF pair, $m_{\ell\ell}$ in the Z-window, $50 < \not{E}_T < 100$ GeV

Results interpretation in stop RPV

The observations and SM expectations agree within uncertainties for most channels $\rightarrow$ limits are set on the stop mass

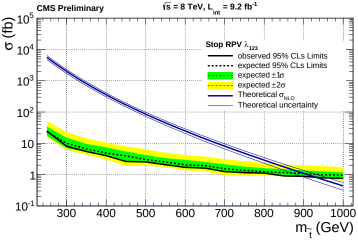


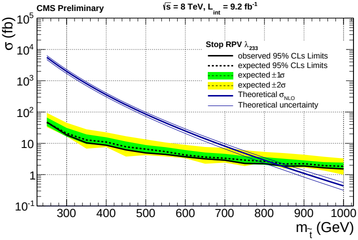
λ_{122} $\rightarrow$ at least four leptons (electrons or muons)

λ_{123} $\rightarrow$ two tau-leptons and two leptons

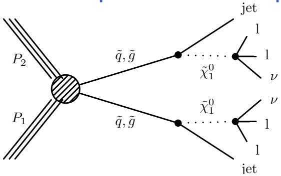
λ_{233} $\rightarrow$ four tau-leptons

All events have two b-jets from the top quark decays





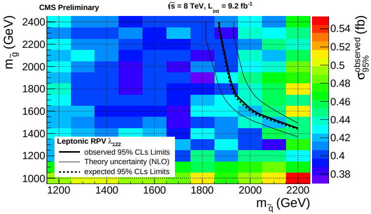
Results interpretation in leptonic RPV

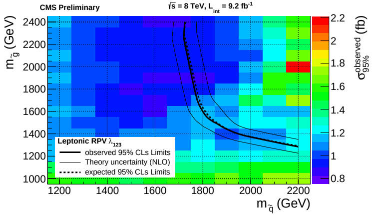


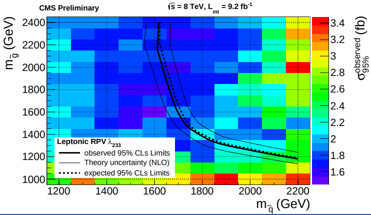
$\tilde{g} \to \tilde{\chi}^0{}_1 + jets \quad \tilde{q} \to \tilde{\chi}_1^0 + jets$

$\tilde{\chi}_1^0 \to \ell_i + \nu_j + \ell_k$ *and* $\nu_i + \ell_j + \ell_k$

superpotential coupling $W = \lambda_{ijk} L_i \bar{L}_j \bar{e}_k, \lambda_{122}, \lambda_{123}, \lambda_{233}$







The 95% exclusion limit contours in the parameter space of $m_{\tilde{g}}$ versus $m_{\tilde{q}}$ and the expected limits in the absence of observed signal.

Masses to the left of the curves are excluded.

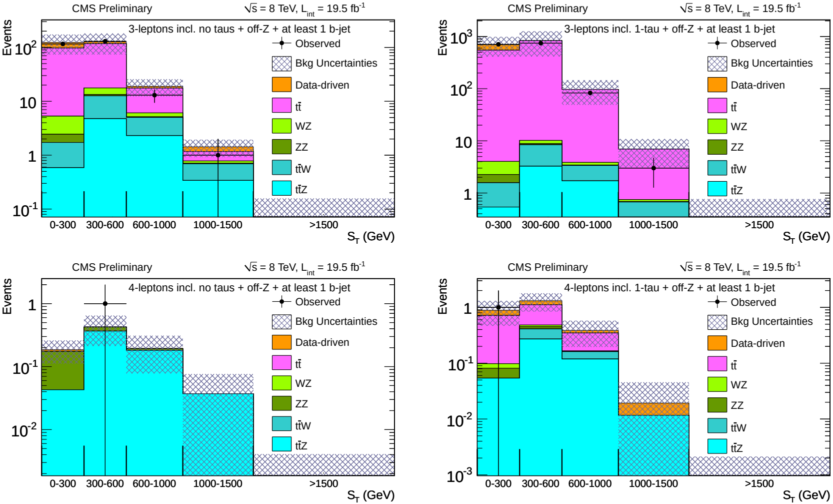
Results interpretation in $LQ\bar{D}$ RPV and Hadronic and CMSSM RPV in the Backup

CMS PAS SUS-13-003

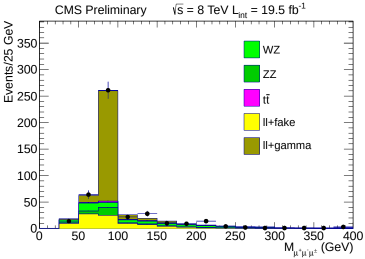
Search for stop in R-parity-violating supersymmetry with three or more leptons and b-tags

$\sqrt{s}$ = 8 TeV, $\mathcal{L}$ = 19.5 fb^{-1}

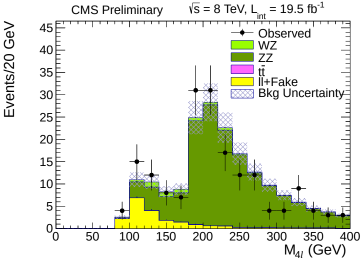
S_T control plots



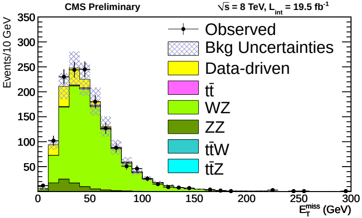
Additional control plots



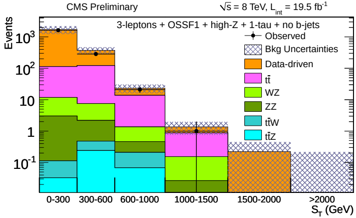
3-muon invariant mass showing asymmetric internal conversion.



4-lepton mass distribution for low-MET, low-HT ZZ control region



MET distribution in WZ control region (3-leptons + 1 on-Z OSSF pair + $H_T < 200$ GeV + $M_T \in (50, 100)$ GeV)



Example of background breakdown vs ST (3-leptons + OSSF1 + above-Z + Tau1 + no b-jets)

Event yields

Expected yields are the sum of simulation and data-driven estimates of backgrounds in each channel. The channels are exclusive.

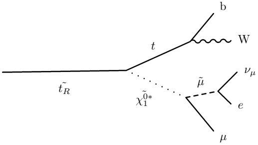
N_ℓ	N_τ	$0 < S_T < 300$		$300 < S_T < 600$		$600 < S_T < 1000$		$1000 < S_T < 1500$		$S_T > 1500$	
		obs	exp	obs	exp	obs	exp	obs	exp	obs	exp
4	0	0	0.186 ± 0.074	1	0.43 ± 0.22	0	0.19 ± 0.12	0	0.037 ± 0.039	0	0.000 ± 0.021
4	1	1	0.89 ± 0.42	0	1.31 ± 0.48	0	0.39 ± 0.19	0	0.019 ± 0.026	0	0.000 ± 0.021
3	0	116	123 ± 50	130	127 ± 54	13	18.9 ± 6.7	1	1.43 ± 0.51	0	0.208 ± 0.096
3	1	710	698 ± 287	746	837 ± 423	83	97 ± 48	3	6.9 ± 3.9	0	0.73 ± 0.49

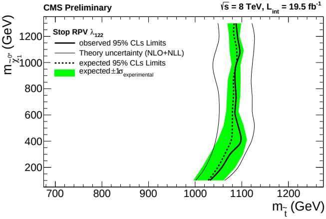
Additional sensitivity gained in regions where the top quark is off-shell, selected by relaxing the *b*-tag and on/off-Z requirements for events with $S_T > 600$ GeV

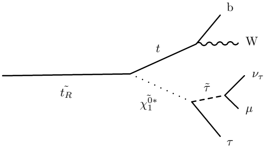
N_ℓ	N_τ	$600 < S_T < 1000$		$1000 < S_T < 1500$		$S_T > 1500$	
		obs	exp	obs	exp	obs	exp
4	0	5	8.2 ± 2.6	2	0.96 ± 0.37	0	0.113 ± 0.056
4	1	2	3.8 ± 1.3	0	0.34 ± 0.16	0	0.040 ± 0.033
3	0	165	174 ± 53	16	21.4 ± 8.4	5	2.18 ± 0.99
3	1	276	249 ± 80	17	19.9 ± 6.8	0	1.84 ± 0.83

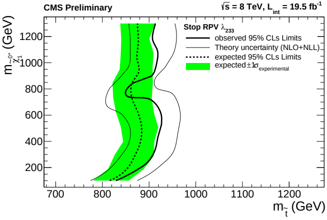
Agreement with standard model predictions in our signal regions is very good

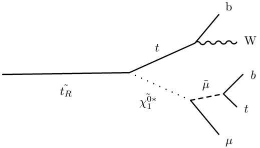
Exclusion limits

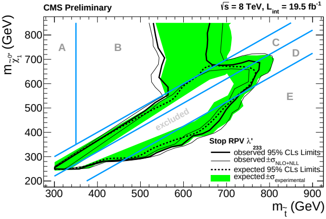












95% CL limits for stop mass in models with RPV couplings λ_{122}, λ_{233}, and λ'_{233} with diagrams of the relevant RPV decays

Conclusions

CLVF and the LHC searches

- LHC discovered no new degrees of freedom other than the SM Higgs boson $\rightarrow$ New Physics Beyond the Standard Model is heavier that the TeV scale
- gauge hierarchy problem is a poor indicator for the new physics scale
- answers can come only from indirect new physics probes ("intensity frontier"): precision studies of neutrinos and their properties, anomalous magnetic moment of muon and searches for forbidden or suppressed process like CLVF
- in fact the only direct evidence for new physics is the non-zero neutrino masses: their tiny values can be due to heavy new physics and the large lepton mixing seems to indicate that flavor numbers are not conserved in the neutrino sector
- CLVF searches are of key importance in giving an answer to the open questions in Particle Physics
- Presented studies performed by the CMS collaboration at the LHC
- Unfortunately no sign of Physics Beyond Standard Model (yet)
- Stay tuned for more results to come...

CMS Public Results

Exotica results

Susy results

Beyond Second Generation results

Backup slides

region label	kinematic region	stop decay mode(s)
A	$m_t < m_{\tilde{t}} < 2m_t, m_{\tilde{\chi}_1^0}$	$\tilde{t} \to t\nu b\bar{b}$
B	$2m_t < m_{\tilde{t}} < m_{\tilde{\chi}_1^0}$	$\tilde{t} \to t\mu t\bar{b} + t\nu b\bar{b}$
C	$m_{\tilde{\chi}_1^0} < m_{\tilde{t}} < m_W + m_{\tilde{\chi}_1^0}$	$\tilde{t} \to \ell\nu b\tilde{\chi}_1^0 + jjb\tilde{\chi}_1^0$
D	$m_W + m_{\tilde{\chi}_1^0} < m_{\tilde{t}} < m_t + m_{\tilde{\chi}_1^0}$	$\tilde{t} \to Wb\tilde{\chi}_1^0$
E	$m_t + m_{\tilde{\chi}_1^0} < m_{\tilde{t}}$	$\tilde{t} \to t\tilde{\chi}_1^0$

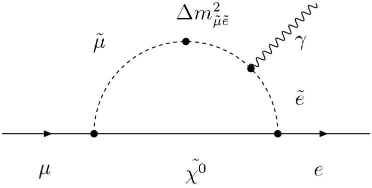
CMS PAS B2G-12-002

Baryon number violating top quark decays

$\sqrt{s}$ = 7 TeV, $\mathcal{L}$ = 5.0 fb^{-1}

CLVF and New Physics at the TeV scale

- New degrees of freedom at the TeV scale expected to mediate CLVF
- Expectations are model-dependent but if they have masses around 1 TeV they could be observed at the LHC
- Some of these models can induce for example flavor-violating magnetic-moment type effective interactions at the one-loop level
- NP induces flavor-violating magnetic-moment type effective interactions at the one-loop level
- Ex. is the MSSM slepton-neutralino contribution to $\mu \to e\gamma$.



- important to seeach for CLFV at the LHC

Baryon number violation (BNV) in top quark decays

$t \to \bar{b}\bar{c}\mu^+$ (same with e) + cc

- Search in $t\bar{t}$ events where one top quark experiences SM decay (in 3 jets), the other BNV decay
- Final state: isolated lepton, five jets, no neutrinos

Dataset	Cross section (pb)	Basic - Yield	Basic - Corrected yield	Tight - Yield
$t\bar{t}$	157.5 ± 24.4	7816 ± 1960	7715 ± 1940	584 ± 81
W+jets	31310 ± 1560	1288 ± 770	1288 ± 770	76 ± 42
Z+jets	3048 ± 132	182 ± 109	182 ± 109	36 ± 20
WW	43.0 ± 1.5	9.9 ± 6.0	9.9 ± 6.0	0.97 ± 0.53
WZ	18.2 ± 0.7	6.7 ± 4.0	6.7 ± 4.0	0.92 ± 0.51
ZZ	5.9 ± 0.1	1.24 ± 0.75	1.24 ± 0.75	0.32 ± 0.18
tW	15.7 ± 0.8	233 ± 61	230 ± 61	12.8 ± 1.8
t-ch	64.6 ± 3.4	45 ± 27	45 ± 27	2.3 ± 1.3
s-ch	4.63 ± 0.19	4.8 ± 2.9	4.8 ± 2.9	0.26 ± 0.14
ttW	0.16 ± 0.02	26 ± 16	26 ± 16	2.0 ± 1.1
QCD	-	35 ± 35	35 ± 35	9.0 ± 9.0
Total Exp.	-	9647 ± 2180	9544 ± 98	724 ± 39
Data	-	9544 ± 98	9544 ± 98	796 ± 28

Dataset	Cross section (pb)	Basic - Yield	Basic - Corrected yield	Tight - Yield
$t\bar{t}$	157.5 ± 24.4	6769 ± 1700	6387 ± 1600	497 ± 72
W+jets	31310 ± 1560	1130 ± 510	1130 ± 510	88 ± 35
Z+jets	3048 ± 132	275 ± 120	275 ± 120	82 ± 33
WW	43.0 ± 1.5	8.4 ± 3.8	8.4 ± 3.8	0.80 ± 0.32
WZ	18.2 ± 0.7	6.8 ± 3.1	6.8 ± 3.1	1.10 ± 0.44
ZZ	5.9 ± 0.1	1.67 ± 0.75	1.67 ± 0.75	0.37 ± 0.15
tW	15.7 ± 0.8	188 ± 50	178 ± 47	14.6 ± 2.1
t-ch	64.6 ± 3.4	38 ± 17	38 ± 17	3.2 ± 1.3
s-ch	4.63 ± 0.19	3.9 ± 1.8	3.9 ± 1.8	0.30 ± 0.12
ttW	0.16 ± 0.02	23 ± 10	23 ± 10	1.77 ± 0.71
QCD	-	374 ± 190	374 ± 190	109 ± 54
Total Exp.	-	8817 ± 1890	8425 ± 92	798 ± 66
Data	-	8425 ± 92	8425 ± 92	843 ± 29

	95% CL Upp. lim.	Exp. lim.	68% exp. lim. range
Muon ch.	0.0076	0.0044	[0.0028, 0.0057]
Electron ch.	0.0072	0.0054	[0.0035, 0.0087]
Combined	0.0067	0.0041	[0.0027, 0.0060]

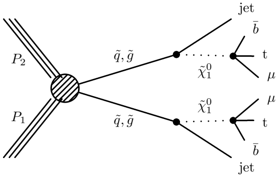
Data and general strategy

- CMS does not have similar analysis but $m_{\ell\ell'}$ has been studied in searches for various Z' heavy gauge bosons.
- Focus of the two isolated, same-flavor leptons that pass lepton ID
- Main backgrounds: Z/γ^*, prompt lepton pairs, misisdentified and non-prompt leptons
- Prompt lepton pairs originating from $t\bar{t}$, tW and diboson product are lepton flavor symmetric
- As a control check to demonstrate that Monte Carlo simulation is a good representation of data, the $e\mu$ spectra in data is compared to MC
- $t\bar{t}$, tW generated with POWHEG, dibosons with PYTHIA 6.4
- multi-jet events (both leptons are misidentified jets) estimated from data by using the same-sign $e\mu$
- The simulated backgrounds are normalised so that in the dielectron channel, the observed data and the prediction from simulation agree in the region 60$<$ m_{ee} $<$ 120 GeV.

Systematic uncertainties RPV SUSY

Source of Uncertainty	Uncertainty
Luminosity	4.5% [27]
PDF	14% [28]
Renormalization Scale	10% [28]
$E_{\mathrm{T}}^{\mathrm{miss}}$ Res ($E_{\mathrm{T}}^{\mathrm{miss}}$): 0-50 GeV, 50-100 GeV, >100 GeV	(-3%, +4%, +4%)
Jet Energy Scale $W^{\pm}Z$	0.5% (WZ)
B-Tag Veto (CSVM)	0.1% (WZ), 6% ($t\bar{t}$)
Muon ID/Isolation at 10 (100) GeV/c	11% (0.2%)
Electron ID/Isolation at 10 (100) GeV/c	14 % (0.6%)
$t\bar{t}$ xsec/fake rate	50%
WZ xsec	6%
ZZ xsec	12%

Results interpretation in $LQ\bar{D}$ RPV

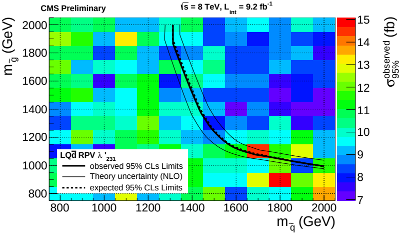


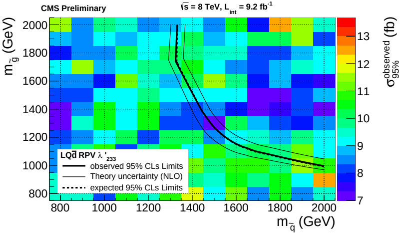
$\tilde{g} \rightarrow \tilde{\chi}_1^0 + jets \quad \tilde{q} \rightarrow \tilde{\chi}_1^0 + jets$

$\tilde{\chi}_1^0 \rightarrow \mu + t + \bar{d}$ *and* $\nu + b + \bar{d}(231)$

$\tilde{\chi}_1^0 \rightarrow \mu + t + \bar{b}$ *and* $\nu + b + \bar{b}(233)$

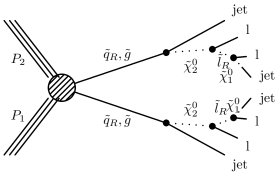
superpotential coupling $W = \lambda'_{ijk} L_i Q_j \bar{d}_k, \quad \lambda_{231}, \lambda_{233}$





The 95% exclusion limit contours in the parameter space of $m_{\tilde{g}}$ versus $m_{\tilde{q}}$ and the expected limits in the absence of observed signal.
Masses to the left of the curves are excluded.

Results interpretation in Hadronic and CMSSM RPV



$\tilde{g} \rightarrow \tilde{\chi}_2^0 + jets \quad \tilde{q}_R \rightarrow \tilde{\chi}_2^0 + jets$

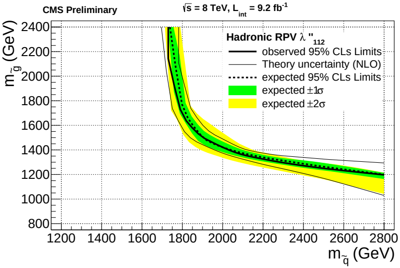
$\tilde{\chi}_2^0 \rightarrow \tilde{\ell}_R + \ell$

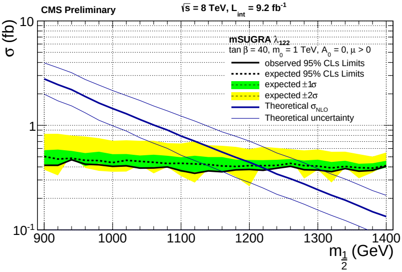
$\tilde{\ell}_R \rightarrow \tilde{\chi}_1^0 + \ell$

$\tilde{\chi}_1^0 \rightarrow jets$

superpotential coupling $W = \lambda''_{ijk}\bar{u}_i\bar{d}_j\bar{d}_k, \quad \lambda''_{112}$

(4 leptons and jets and no significant $\not{E}_T$)





Left: hadronic RPV 95% exclusion limit contours in the parameter space of $m_{\tilde{g}}$ versus $m_{\tilde{q}}$ and the expected limits in the absence of observed signal for λ''_{112}. Masses to the left of the curves are excluded. Right: 95% CL limits for RPV couplings λ_{122} as a function of $m_{\frac{1}{2}}$ in CMSSM, along with the expected limits and theoretical cross section (m_0 = 1000 GeV, A_0 = 0, $\mu > 0$)

Experimentally....

- $W_R \rightarrow \ell N_\ell$ simulated by PYTHIA + CTEQ6L1
- Backgrounds (two real leptons, multi jet) simulated with PYTHIA+MADGRAPH
- lepton leading (subleading) $p_T > 60$ (40) GeV
- jet $E_T > 40$ GeV
- $M_{\ell\ell} > 200$ GeV, $M_{\ell\ell jj}$> 600 GeV

Summary

- In leptonic RPV models, limits approximately independent of the bino mass
- If only muons and electrons in the final state, models with stop mass below approximately 1100 GeV EXCLUDED
- If τ_{had} in the final state, models with stop mass below approximately 900 GeV EXCLUDED
- In semi leptonic RPV models, decay kinematics more complicated (see Backup), region inside the curve EXCLUDED