Searches for New Physics in Events with Leptons+Jets at CMS

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Introduction

In final states with **leptons and jets**, CMS searches for

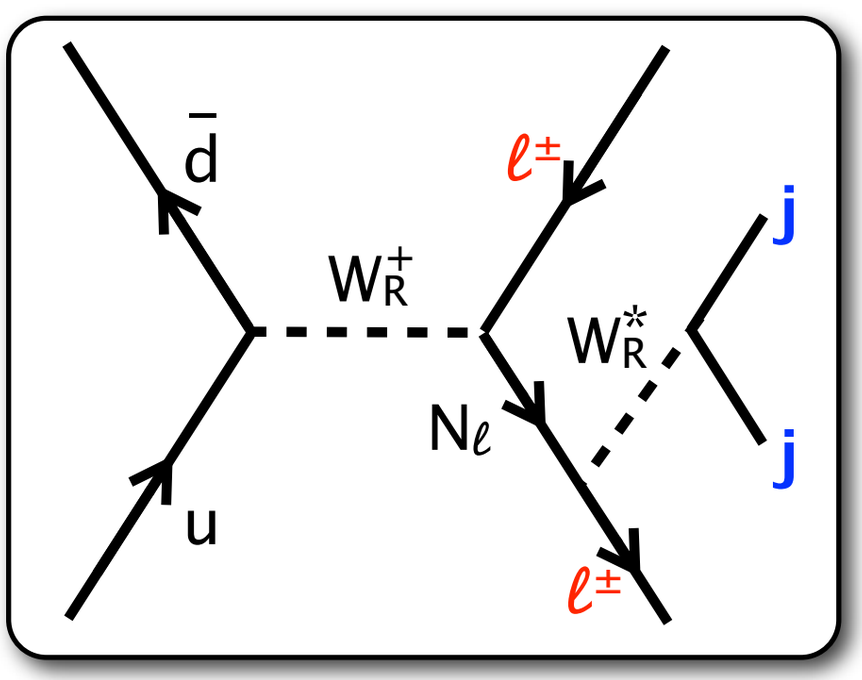
- **Heavy neutrinos** : left-right symmetric model (LRSM), $SU(2)_L$ isosinglet
- Three generations of **leptoquarks** (LQ)

Search	Dataset	Final State	Documentation
Heavy N and W_R of LRSM	3.6/fb, $\sqrt{s}$=8 TeV	μμjj, eejj	EXO-12-017
	5.0/fb, $\sqrt{s}$=7 TeV	μμjj	EXO-11-091
Heavy Majorana N	5.0/fb, $\sqrt{s}$=7 TeV	$\mu^+\mu^+$jj, e^+e^+jj	EXO-12-076
1st Gen. LQ	5.0/fb, $\sqrt{s}$=7 TeV	eejj, eνjj	EXO-11-027
2nd Gen. LQ	5.0/fb, $\sqrt{s}$=7 TeV	μμjj, μμjj	EXO-11-028
3rd Gen. LQ + light RPV stop	4.8/fb, $\sqrt{s}$=7 TeV	τebb, τμbb	EXO-12-002
3rd Gen. LQ	1.8/fb, $\sqrt{s}$=7 TeV	ννbb	EXO-11-030

All results: https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO

Left/Right Symmetric Model

	Standard Model	Left-Right-Symmetric Extension (LRSM) [1–3]
Gauge group	$SU(2)_L$ X $U(1)_Y$	$SU(2)_L$ **X $SU(2)_R$** X $U(1)_{B-L}$
Fermions	LH doublets: $Q_L = (u^i, d^i)_L$, $L_L = (l^i, \nu^i)_L$ RH singlets: $Q_R = u^i_R$, d^i_R , $L_R = l^i_R$	LH doublets: $Q_L = (u^i, d^i)_L$, $L_L = (l^i, \nu^i)_L$ RH doublets: $Q_R = (u^i, d^i)_R$, $L_R = (l^i, N^i)_R$
Neutrinos	ν^i_R do not exist ν^i_L are massless & pure chiral	N^i_R are heavy partners to the ν^i_L N^i_R Majorana in the Minimal LRSM
Gauge bosons	$W^{\pm}_L$, Z^0, γ	$W^{\pm}_L$, **$W^{\pm}_R$**, Z^0, **Z'**, γ



- **Explains parity violation** from LR symmetry breaking at intermediate scale.
- Heavy LRSM neutrino + seesaw mechanism [4] **explains small M_ν in SM**.
- Assumptions: $g_R = g_L$ @ M_{WR}, small W_R–W_L and N_ℓ–$N_{\ell'}$ mixing, **only one lepton channel kinematically accessible**.
- Search for decay of W_R to μμjj and eejj.

Heavy Neutrino and W_R of LRSM

Search for decay of W_R to μμjj and eejj.

Selection

- Decay topology → asymmetric lepton p_T requirements (60/40GeV),
- Jet p_T>40 GeV,
- $M_{\ell\ell}$ > 200 GeV reduces DY+jets.

Background Estimation

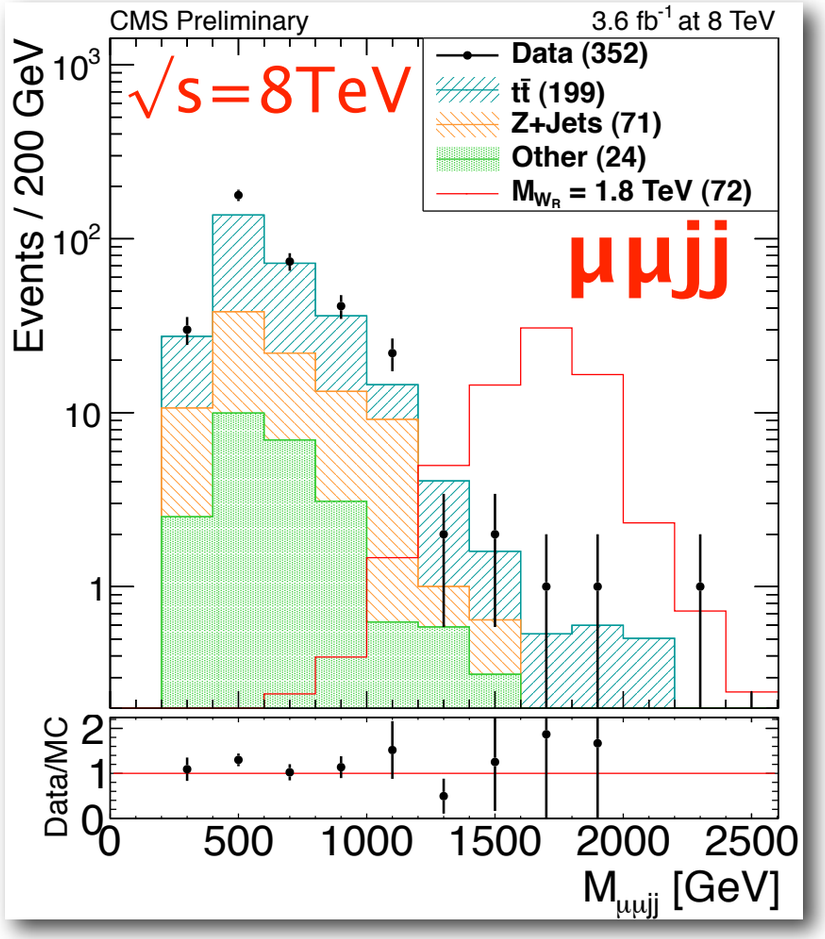
Top: completely data-driven from eμjj data control sample.

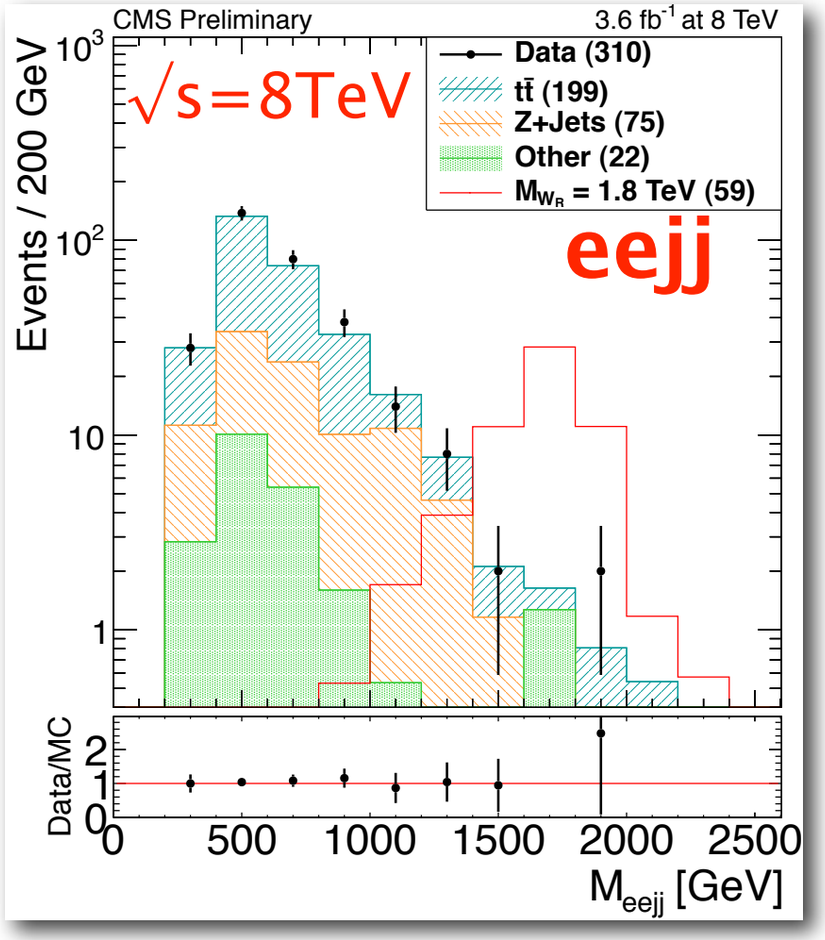
DY+jets: normalize MC shape in Z-peak.

QCD: data-driven fake rate

VV, single top: from MC

EXO-12-017, EXO-11-091





Heavy Neutrino and W_R of LRSM (2)

Dominant Systematic Uncertainty

Signal Efficiency: 6–10% for ℓ reco/ID/iso.

Background:

~50% from DY+jets shape.

~16% from top shape

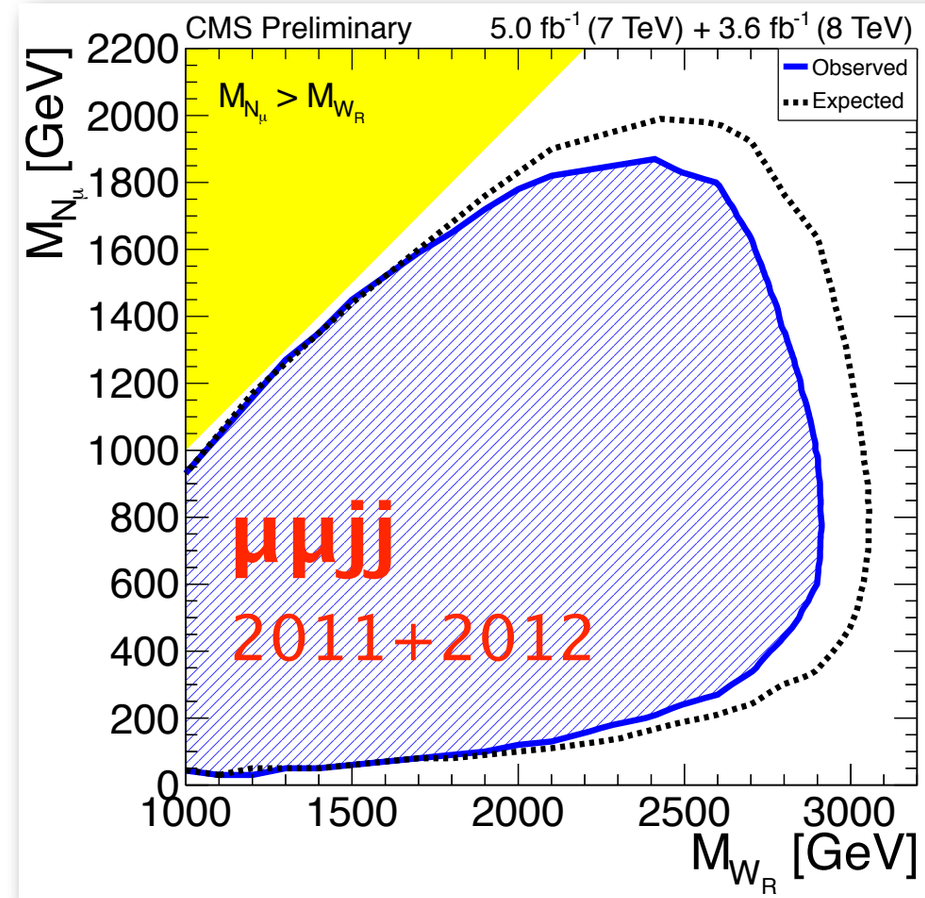
Signal Kinematics

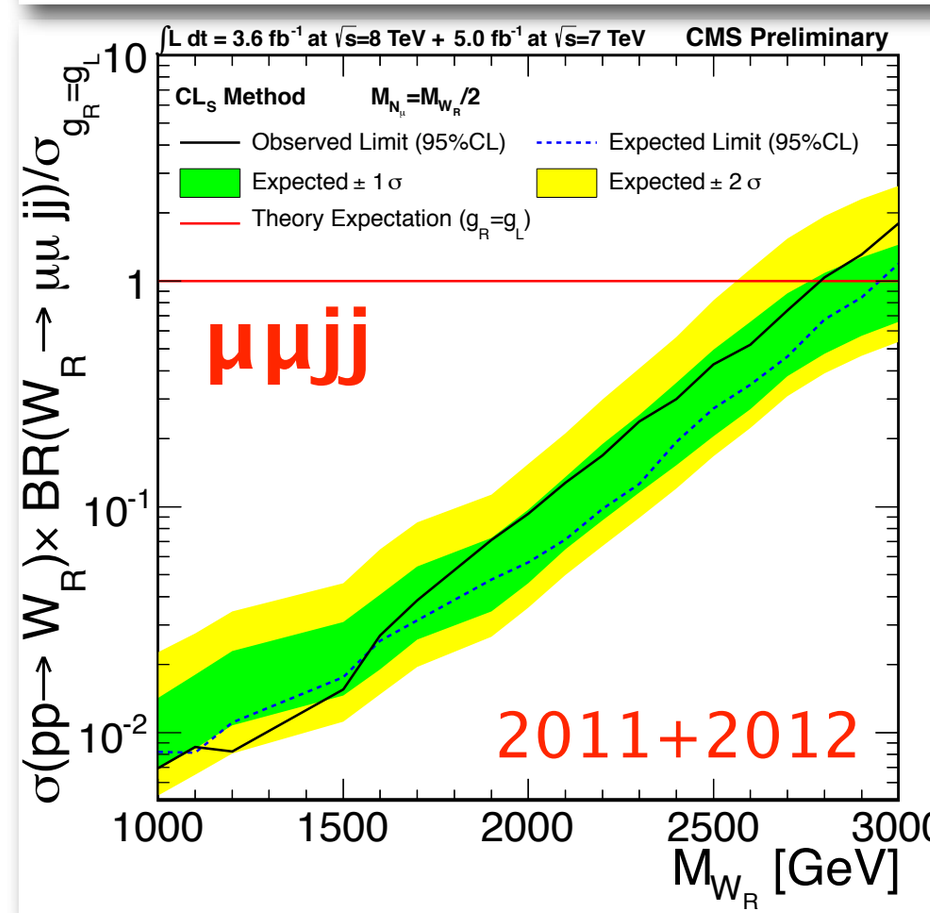
Acceptance: 70–80% at $M_N \approx M_{WR}/2$, goes to zero as $M_N \rightarrow 0$.

Efficiency: 75–80% for events within acceptance.

M_{WR} > 2.8 TeV for $M_N = M_{WR}/2$ from 2011+2012 combination of μμjj.

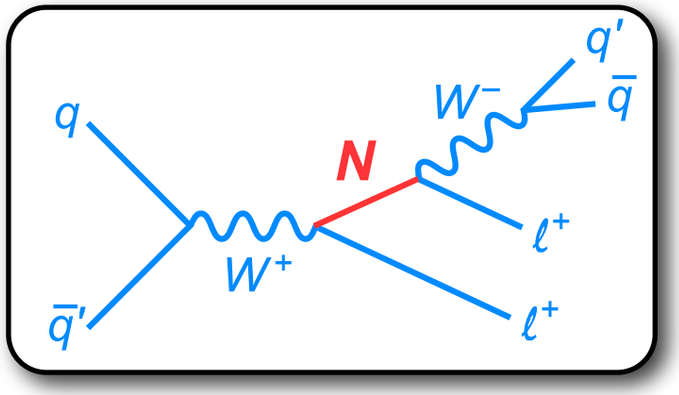
EXO-12-017, EXO-11-091





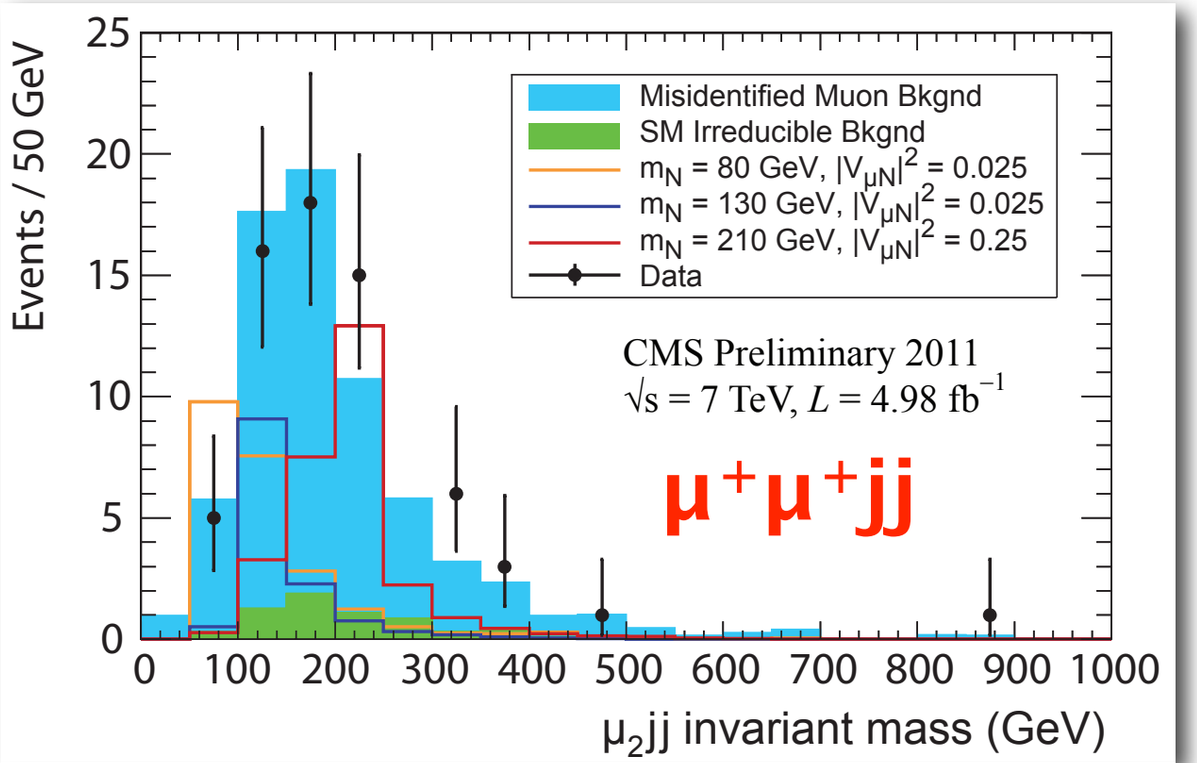
Heavy Majorana Neutrino

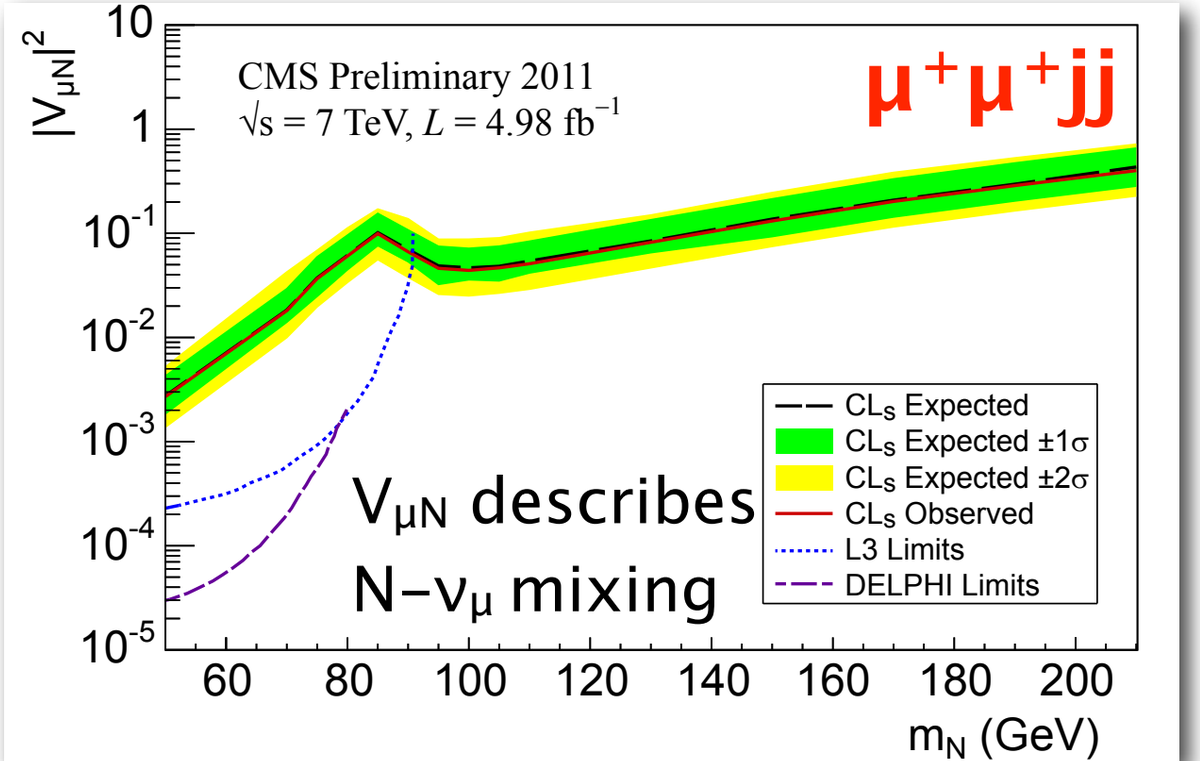
Search for $\mu^+\mu^+$ or e^+e^+ + jets:



Model: phenomenological $SU(2)_L$ isosinglet [5,6]

Selection: $p_{T,jet}>30$, $p_{T,\ell}>20$, MET<50 GeV





Background estimation:

lepton mis-ID: data-driven, validated in MC and MET>50GeV data sample.

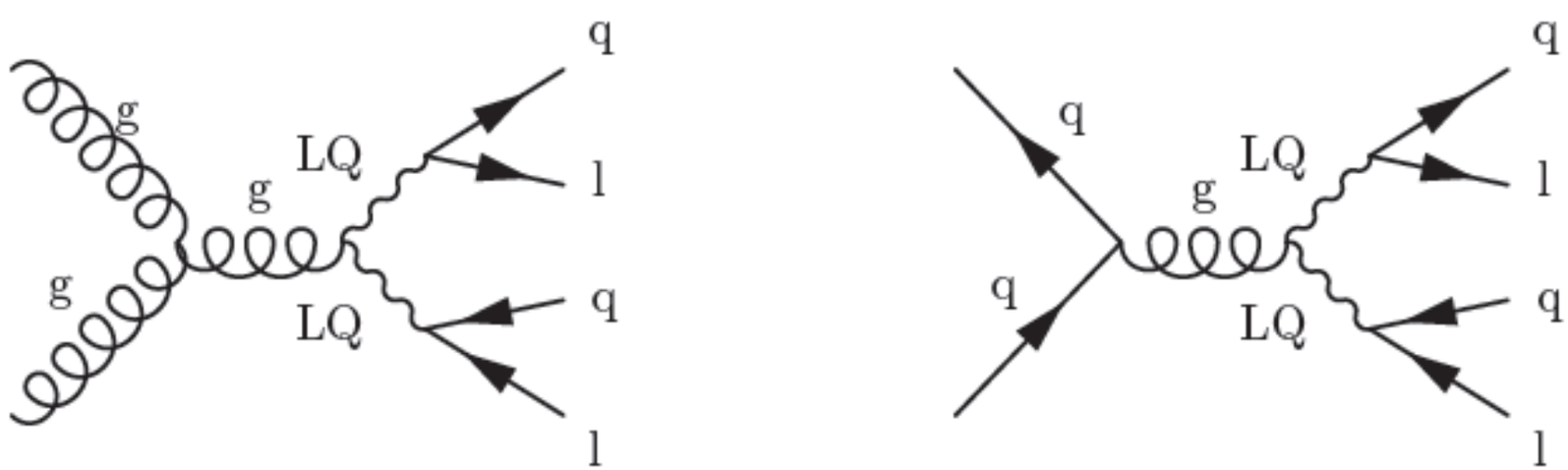
charge mis-ID: from MC with data validation.

EXO-11-076

Extend LEP limits beyond M_N =90 GeV

Leptoquarks

- **Predicted by many BSM theories**: GUTs [1,7], composite models [8], technicolor [9–11], and superstring-inspired E_6 [12].
  - Natural explanation for observed **quark-lepton symmetry of SM**.
- Spin 0 or 1, fractional charge, carry **both baryon and lepton number**.
  - In general, we search for spin 0; consider also spin 1 in LQ3 search.
  - Observed FCNC constraints → **no coupling b/w three generations**.
- Production at LHC from model-independent LQ-gluon coupling:

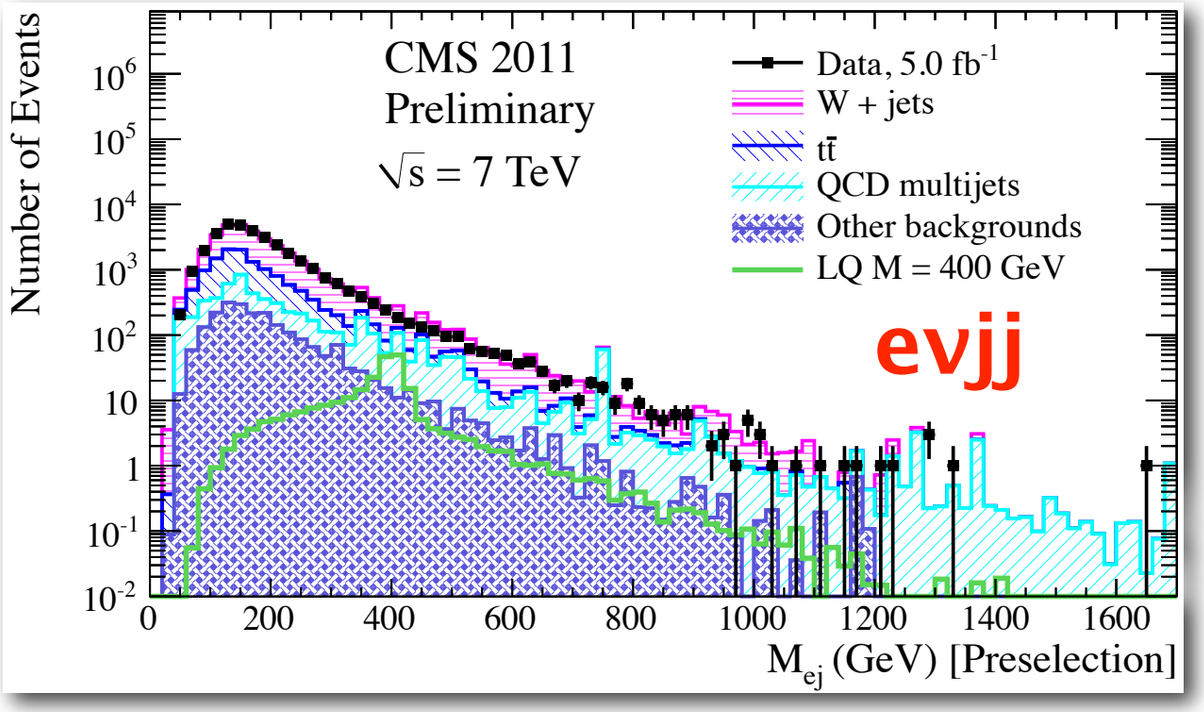


- NLO cross sections from Kramer et al. [13].
- Search in **final states**:
  - $1^{st}/2^{nd}$ Gen: $\ell j+\ell j$, $\nu j+\ell j$ for $\ell=e,\mu$
  - 3rd Gen: $\tau_{had}b+\ell b$ for $\ell=e,\mu$ (and $\nu b+\nu b$, not discussed today).

$1^{st}/2^{nd}$ Generation Leptoquarks

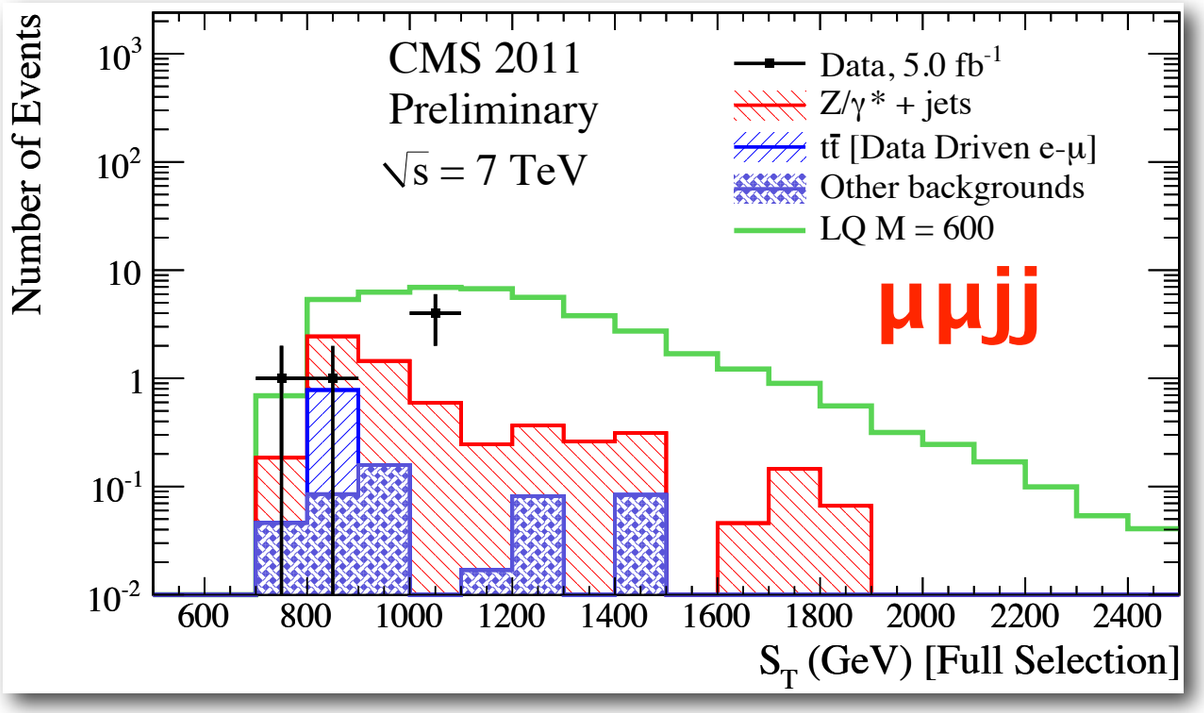
Optimized requirements on
[Example value from $\ell\ell jj/\ell\nu jj$ M_{LQ}=650GeV]

- **S_T = scalar sum of $\ell,\ell/\nu,j,j$ p_T** [810 GeV]
- **$M_{\ell\ell}$** removes Z+jets in $\ell\ell jj$ [130 GeV]
- **MET** removes W+jets in $\ell\nu jj$ [180 GeV]
- $\ell\ell jj$: **$M_{\ell j}$** (lighter of pair that minimizes $\Delta M(LQ,\overline{LQ})$) [400 GeV]
- $\ell\nu jj$: **$M_T(\ell,j)$** from pairing that minimizes $\Delta M_T(LQ,\overline{LQ})$ [540 GeV]



Background estimation

Z+jets: MC shape normalized in Z-peak.
top: Shape and norm from eμjj for $\ell\ell jj$
W+jets, top (for $\ell\nu jj$): MC shape normalized in $M_T(\ell,MET)$ sideband.



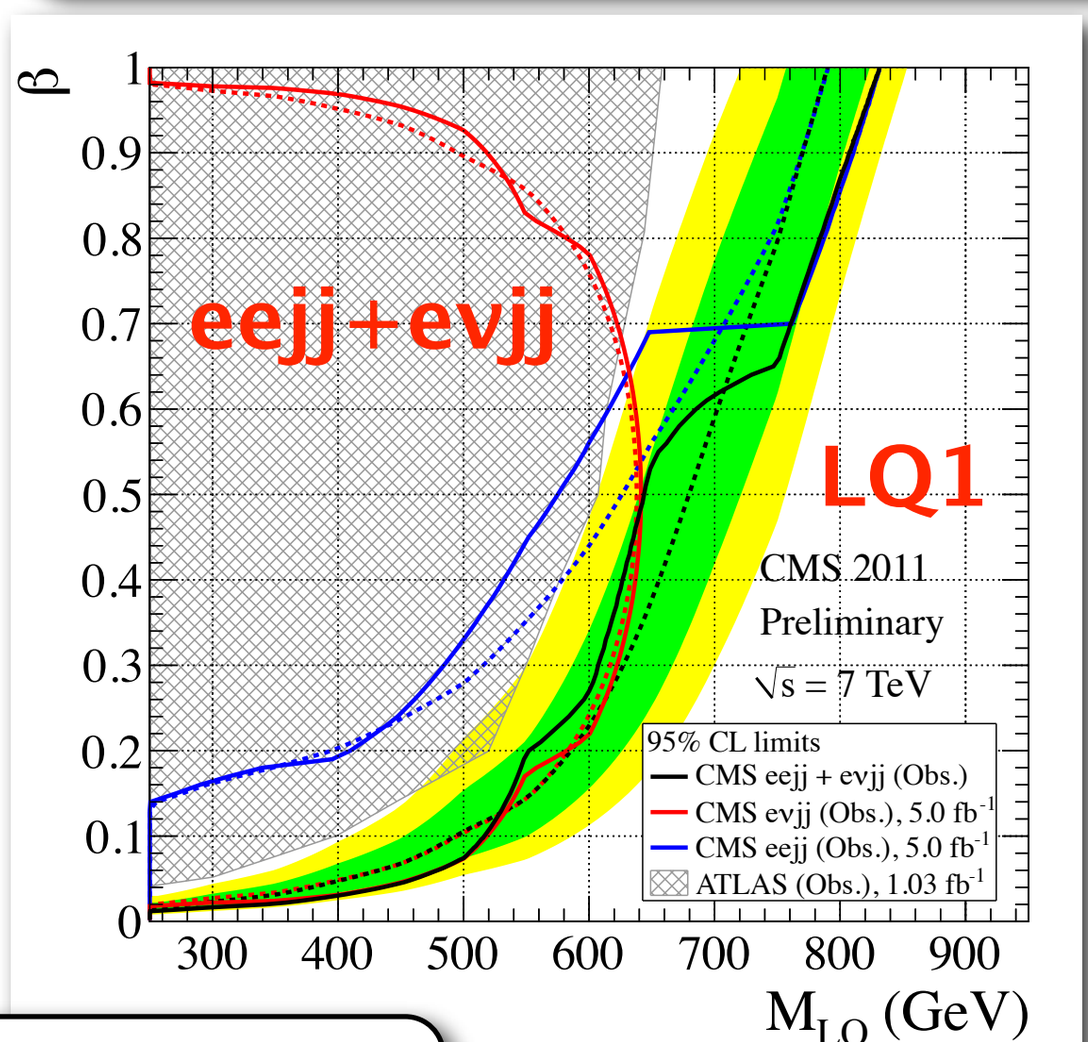
EXO-11-027/28

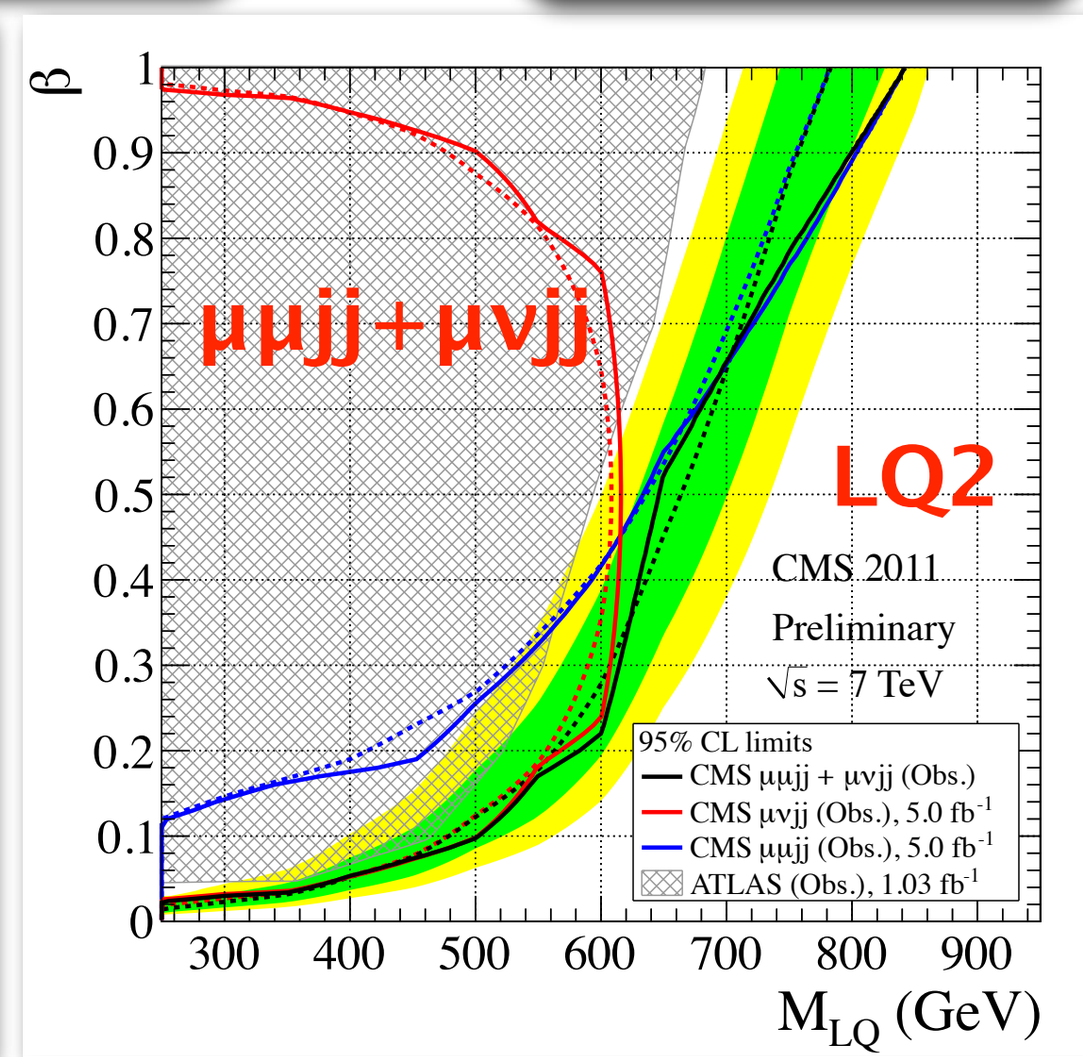
$1^{st}/2^{nd}$ Generation Leptoquarks (2)

- Statistics dominated; bkg. modeling largest source of uncertainty
- Mass exclusion:

  - $M_{LQ1} > 830\ (640)$ GeV for $\beta = 1.0\ (0.5)$
  - $M_{LQ2} > 840\ (650)$ GeV for $\beta = 1.0\ (0.5)$

$\beta \equiv BR(LQ \rightarrow \ell^{\pm} q)$

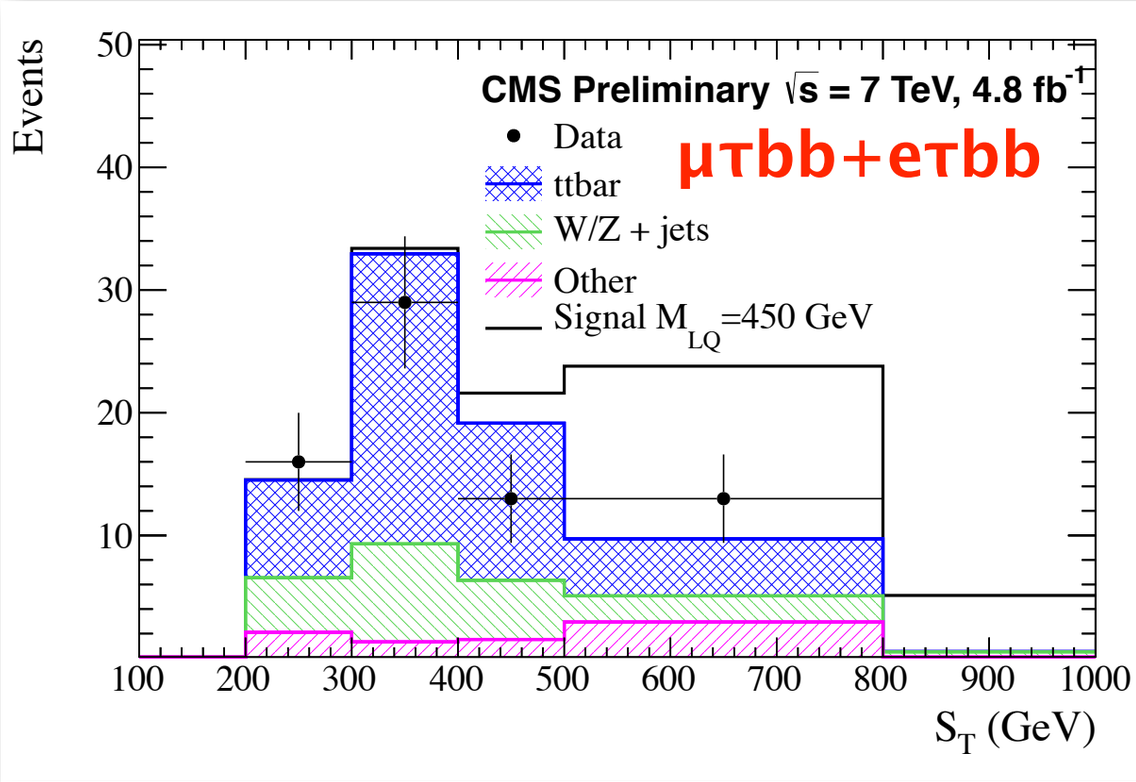




EXO-11-027/28

3rd Generation LQ + light RPV stop

Search for **LQ3**, **SU(5) vector LQ** (VLQ) [14], and **light RPV stop** [15] pairs decaying to τb+τb, assuming one leptonic τ decay: **$\ell\tau_{had}$bb** (ℓ=e,μ).



Selection

- $p_{T,jet}$>30, $p_{T,\mu}$>30, $p_{T,\tau}$>50 GeV
- **$M_{\tau b}$**>170 (190) GeV depending on M_{LQ} where $M_{\tau b}$ minimizes $\Delta M(\tau b,\ell b)$

Background estimation:

top: MC validated in $M_{\tau b}$ sideband,

V+jets: Rate of jet misID as τ_{had} measured in data,

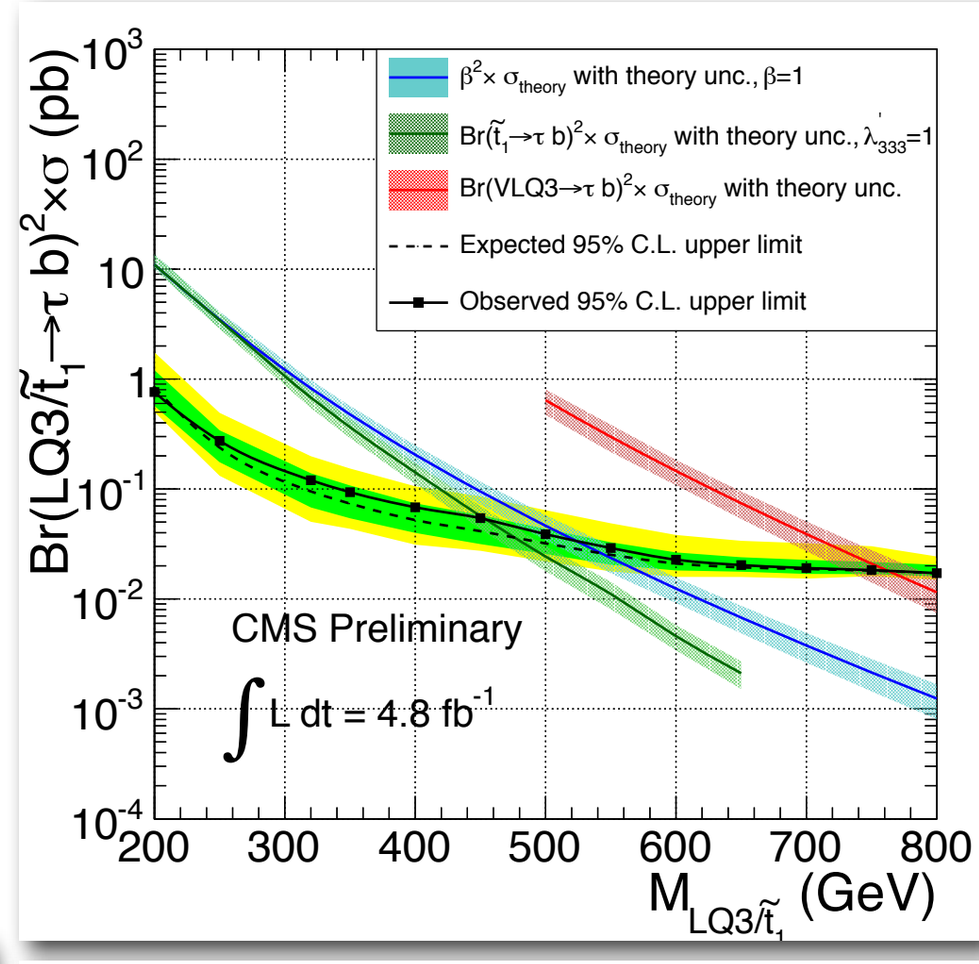
Z→ℓℓ/ττ and diboson: From MC

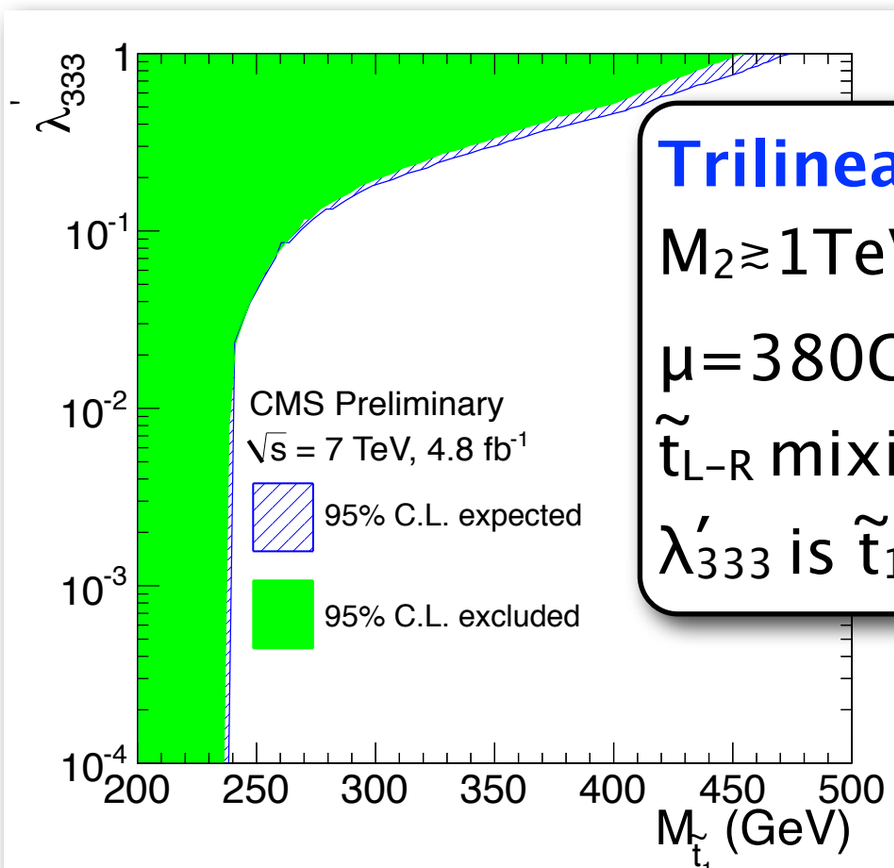
	$\mu+\tau$ channel	$e+\tau$ channel
$t\bar{t}$	$38.1 \pm 3.4 \pm 4.9$	$10.9 \pm 1.8 \pm 1.4$
W+jets/Z+jets	$11.6 \pm 0.1 \pm 2.6$	$8.4 \pm 0.1 \pm 1.8$
$Z(\tau\tau/ll)$	$5.0 \pm 1.6 \pm 0.7$	$2.1 \pm 1.5 \pm 0.3$
diboson	$0.5 \pm 0.1 \pm 0.2$	$0.3 \pm 0.1 \pm 0.1$
Total Bkg.	$55.2 \pm 5.2 \pm 8.4$	$21.8 \pm 3.5 \pm 3.6$
Data	46	25
Signal (450 GeV)	$13.2 \pm 0.3 \pm 0.9$	$8.4 \pm 0.2 \pm 0.6$

EXO-12-002

3rd Generation LQ + light RPV stop (2)

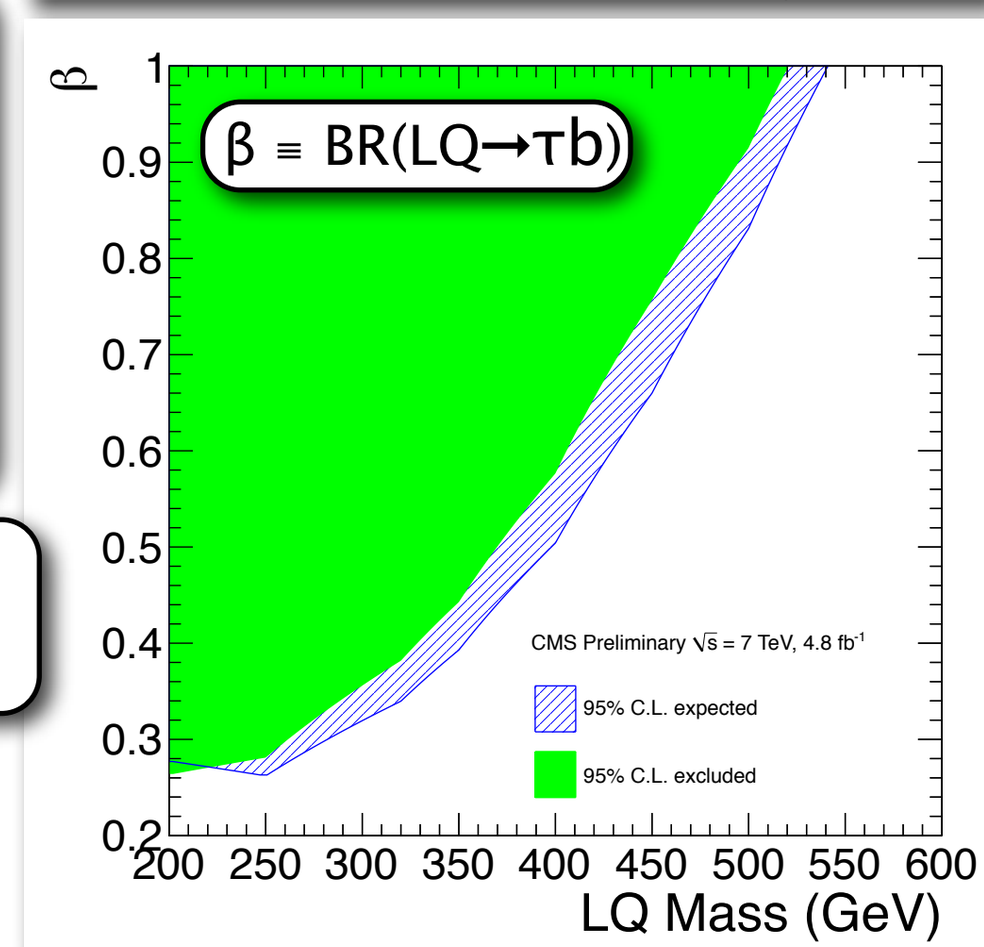
M_{LQ3} > 525 (370) GeV for β = 1.0 (0.5).
M_{VLQ3} > 763 GeV for β = 1.0.
M_{stop} > 453 (240) GeV for λ'_{333}=1 (→0).





Trilinear RPV model [15]
$M_2 \gtrsim 1$TeV → $BR(\tilde{t}_1\to\tau b)\sim 1$,
μ=380GeV, tanβ=40,
$\tilde{t}_{L-R}$ mixing angle θ=0,
λ'_{333} is $\tilde{t}_1$–τb coupling.

No sensitivity to $\lambda'_{333} < 5\times10^{-6}$.



EXO-12-002

Summary

- CMS has an active search program for new physics manifesting in **leptons+jets** final states.
- Results from **complete 2011 dataset** appearing now (soon).
- **First look at 2012 data** in the LRSM search.
- Much more to come, of course!

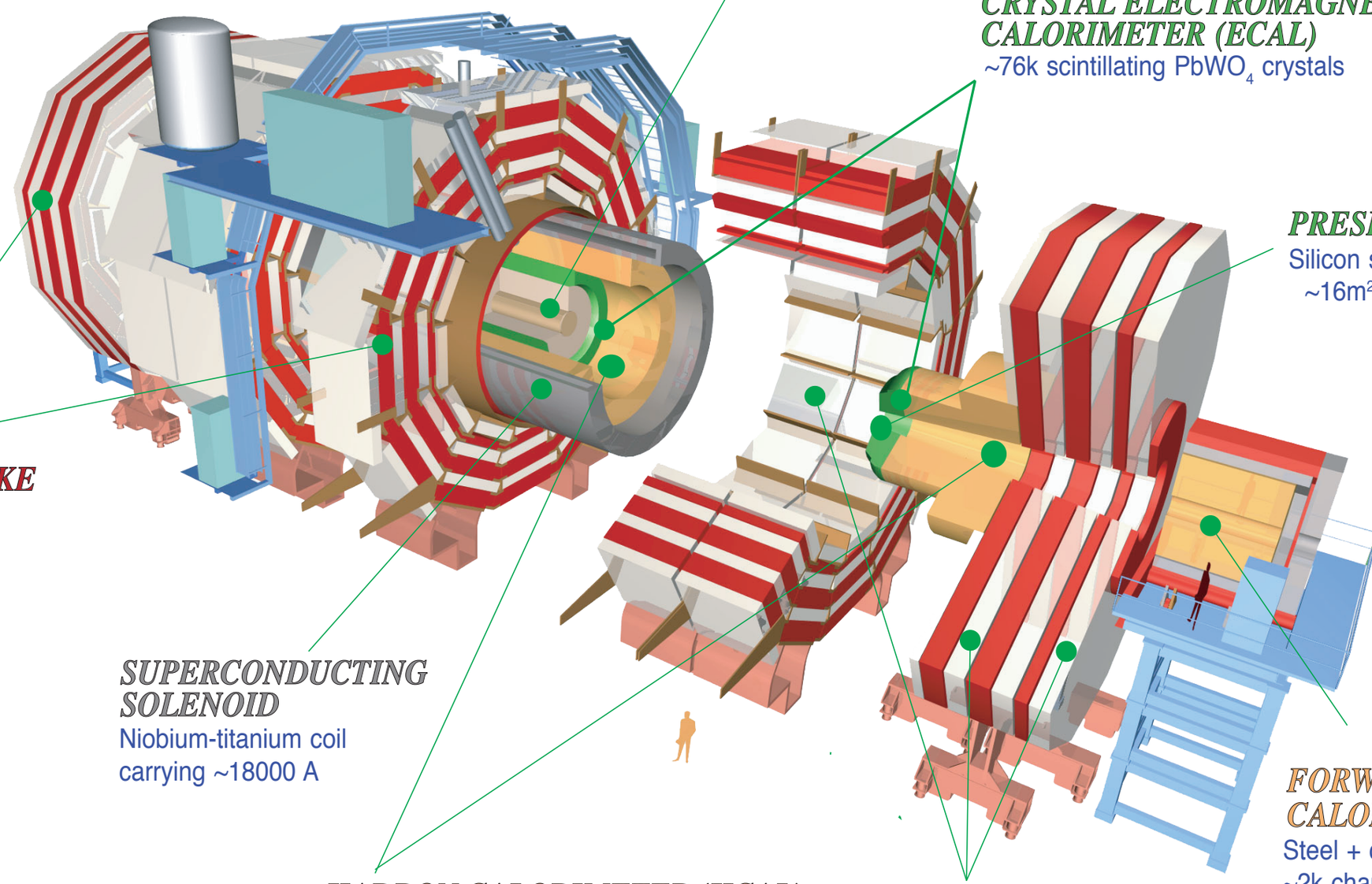
Theory References

[1] Pati and Salam PRD 10 (1974) 275.
[2] Mohapatra and Pati PRD 11 (1975) 366.
[3] Senjanovic and Mohapatra PRD 12 (1975) 1502.
[4] Mohapatra and Senjanovic PRL 44 (1980) 912.
[5] Han and Zhang PRL 97 (2006) 171804.
[6] Aguila, Aguilar-Saavedra, Pittau JHEP 0710 (2007) 047.
[7] Georgi and Glashow PRL 32 (1974) 438.
[8] Buchmuller and Wyler PLB 177 (1986) 377.
[9] Dimopoulos and Susskind Nucl. Phys. B155 (1979) 237.
[10] Dimopoulos Nucl. Phys. B168 (1980) 69.
[11] Eichten and Lane PLB90 (1980) 85.
[12] Angelopoulos et al. Nucl. Phys. B292 (1987) 59.
[13] Kramer et al. PRD 71 (2005) 057503.
[14] Chakdar et al. arXiv:hep-ph/1206.0409 (2012).
[15] Barbier et al. Physics Reports 420 (2005), 16, 1-195.

Additional Material

CMS Detector

Pixels
Tracker
ECAL
HCAL
Solenoid
Steel Yoke
Muons



SILICON TRACKER
Pixels (100 x 150 μm^2)
~1m^2 ~66M channels
Microstrips (80-180μm)
~200m^2 ~9.6M channels

CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
~76k scintillating $PbWO_4$ crystals

PRESHOWER
Silicon strips
~16m^2 ~137k channels

STEEL RETURN YOKE
~13000 tonnes

SUPERCONDUCTING SOLENOID
Niobium-titanium coil
carrying ~18000 A

FORWARD CALORIMETER
Steel + quartz fibres
~2k channels

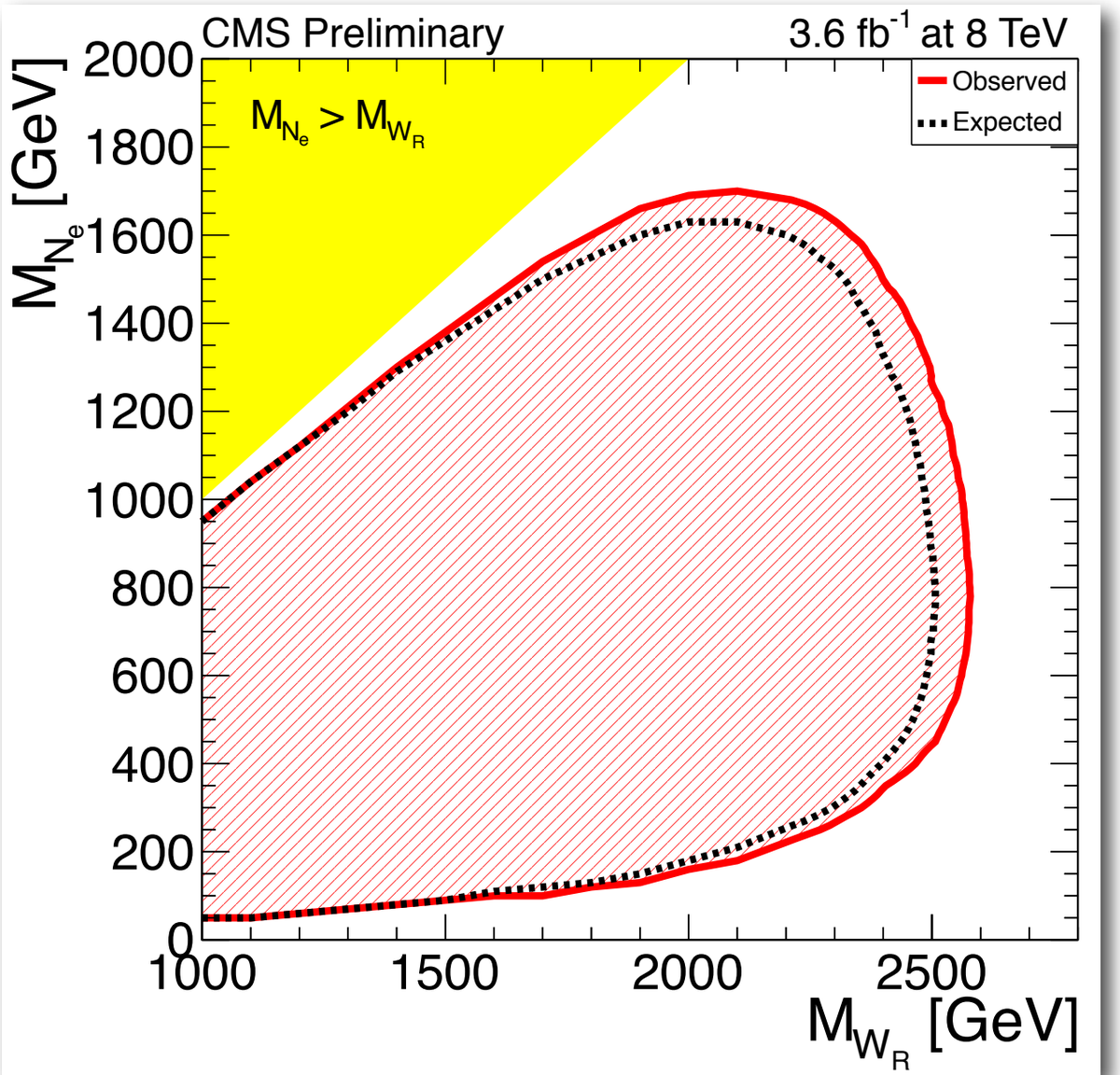
HADRON CALORIMETER (HCAL)
Brass + plastic scintillator
~7k channels

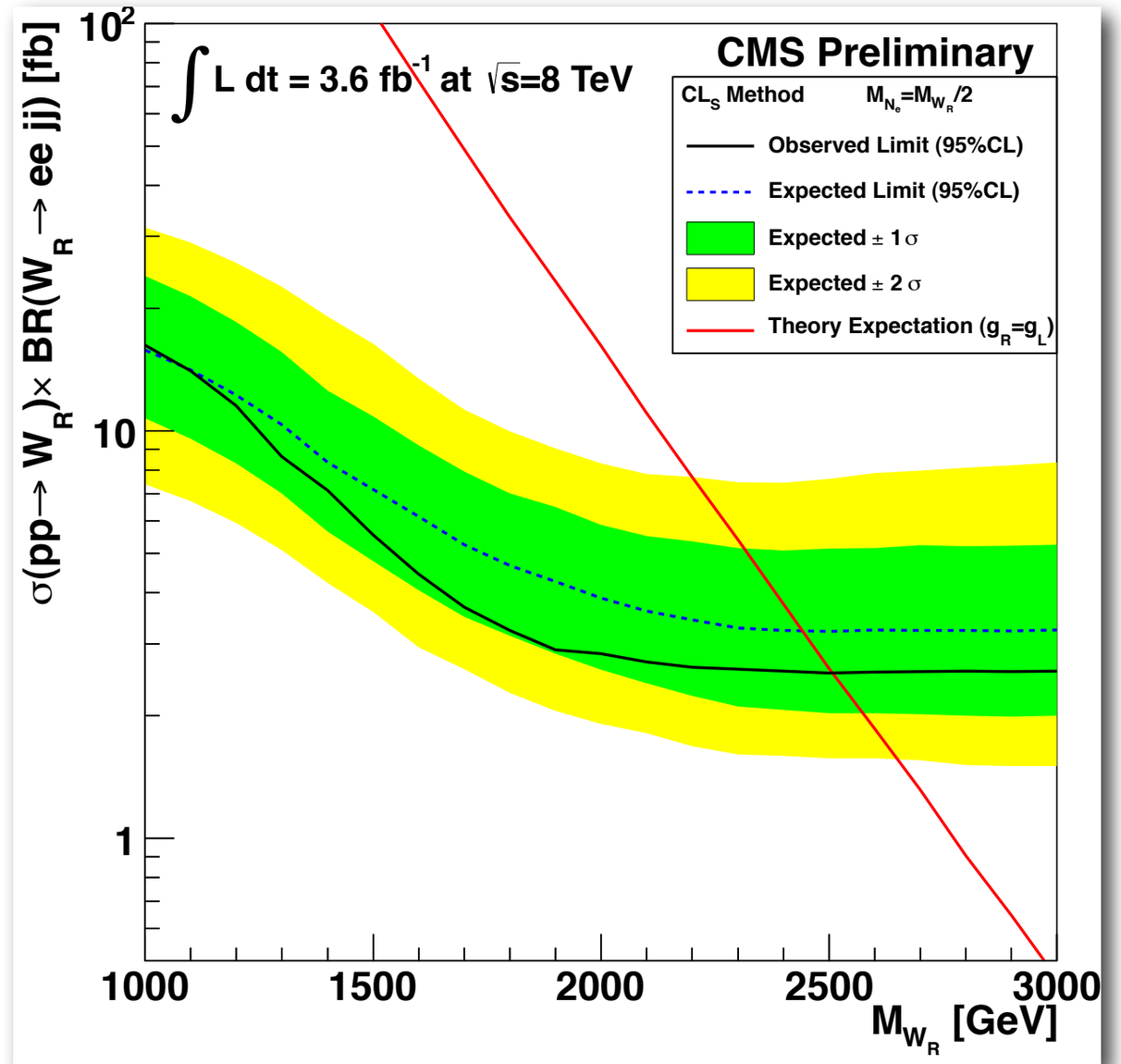
MUON CHAMBERS
Barrel: 250 Drift Tube & 480 Resistive Plate Chambers
Endcaps: 468 Cathode Strip & 432 Resistive Plate Chambers

Total weight	**: 14000 tonnes**
Overall diameter	**: 15.0 m**
Overall length	**: 28.7 m**
Magnetic field	**: 3.8 T**

Search for Heavy N and W_R of LRSM

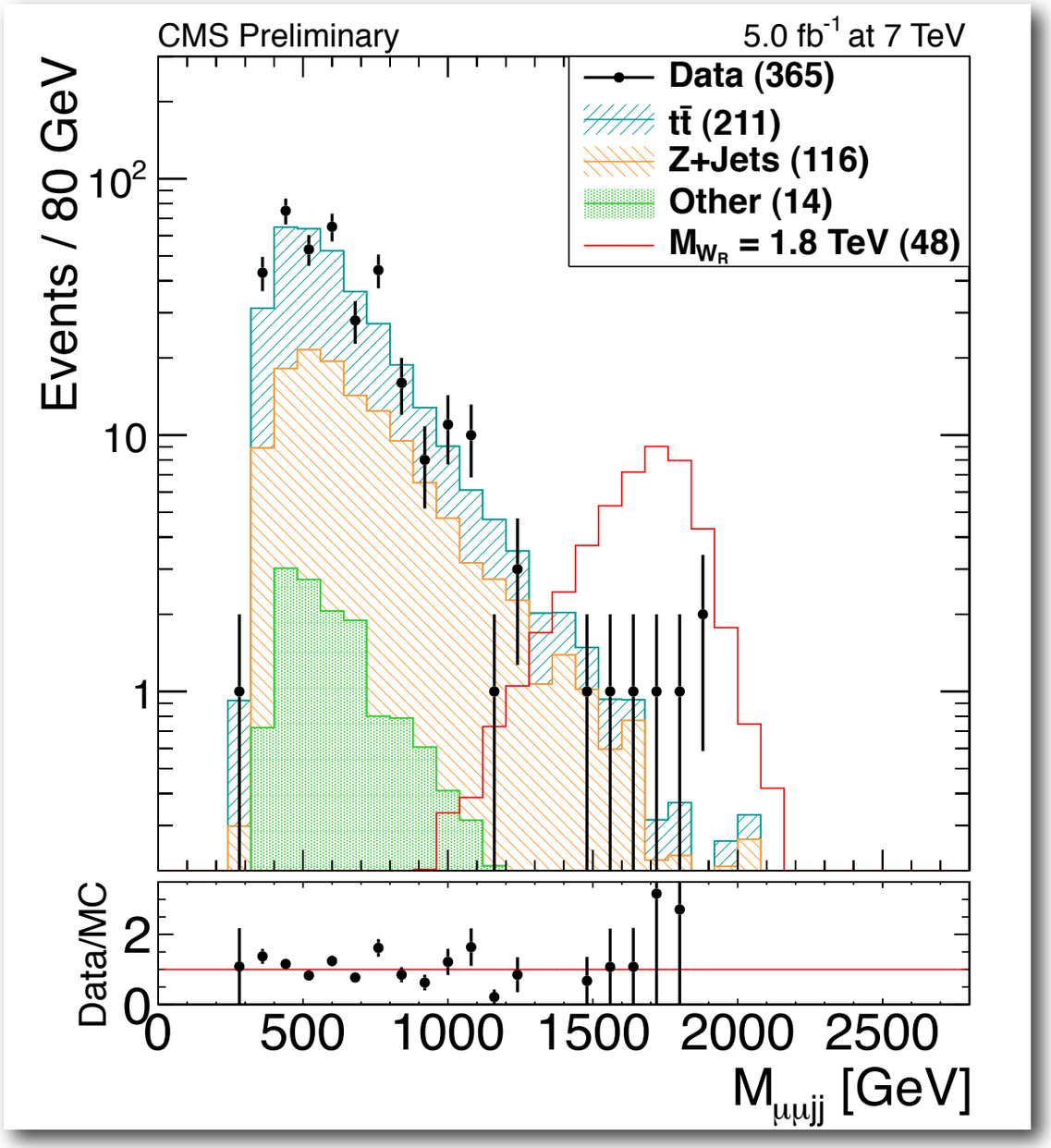
Final state eejj, 2012 data.





Search for Heavy N and W_R of LRSM

Final state μμjj, 2011 data.



Heavy Majorana Neutrino

Expected background and observed data:

Source	$\mu^\pm\mu^\pm$	$e^\pm e^\pm$
Irreducible SM Backgrounds:		
WZ	$3.2 \pm 0.3 \pm 0.1$	$4.9 \pm 0.3 \pm 0.2$
ZZ	$1.0 \pm 0.1 \pm 0.04$	$2.1 \pm 0.1 \pm 0.08$
$W\gamma$	$0.75 \pm 0.27 \pm 0.07$	$1.7 \pm 0.4 \pm 0.2$
$t\bar{t}W$	$1.06 \pm 0.05 \pm 0.53$	$0.62 \pm 0.04 \pm 0.31$
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	$70.4 \pm 4.2 \pm 22.1$	$219.3 \pm 5.5 \pm 62.4$
Observed in Data	65	201

$1^{st}/2^{nd}$ Generation Leptoquarks

Table 1: Initial selection criteria in the $eejj$, $\mu\mu jj$, $e\nu jj$, and $\mu\nu jj$ channels.

Variable	$eejj$	$\mu\mu jj$	$e\nu jj$	$\mu\nu jj$
$p_{\mathrm{T}}(l_1)$ [GeV]	40	40	40	40
$p_{\mathrm{T}}(l_2)$[GeV]	40	40	—	—
$\lvert\eta(l_1)\rvert$	2.5	2.1	2.2	2.1
$\lvert\eta(l_2)\rvert$	2.5	2.1	—	—
$p_{\mathrm{T}}(j_1)$ [GeV]	30	30	40	40
$p_{\mathrm{T}}(j_2)$ [GeV]	30	30	40	40
$\Delta R(l,j)$	0.3	0.3	0.3	0.3
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	—	—	55	55
$\lvert\Delta\phi(E_{\mathrm{T}}^{\mathrm{miss}}, j_1)\rvert$	—	—	0.5	0.5
$\lvert\Delta\phi(E_{\mathrm{T}}^{\mathrm{miss}}, l)\rvert$	—	—	0.8	0.8
M_{ll} [GeV]	60	50	—	—
$M_{\mathrm{T}}^{l\nu}$ [GeV]	—	—	50	50
S_{T}^{ll} [GeV]	250	250	—	—
$S_{\mathrm{T}}^{l\nu}$ [GeV]	—	—	250	250

$1^{st}/2^{nd}$ Generation Leptoquarks

Table 2: Optimized thresholds for different mass hypothesis of the $lljj$ signal.

M_{LQ} (GeV)	250	350	400	450	500	550	600	650	750	850	900
$S_T^{ll} >$ (GeV)	330	450	530	610	690	720	770	810	880	900	920
$M_{ll} >$ (GeV)	100	110	120	130	130	130	130	130	140	150	150
$minM(l,\text{jet}) >$ (GeV)	60	160	200	250	300	340	370	400	470	500	520

Table 3: Optimized thresholds for different mass hypotheses of the $l\nu jj$ signal.

M_{LQ} (GeV)	250	350	400	450	500	550	600	650	750	850
$S_T^{l\nu} >$ (GeV)	450	570	650	700	800	850	890	970	1000	1000
$E_T^{\text{miss}} >$ (GeV)	100	120	120	140	160	160	180	180	220	240
$M(l,\text{jet}) >$ (GeV)	150	300	360	360	360	480	480	540	540	540