Search for a heavy neutrino and right-handed W of the left-right symmetric model in pp collisions with the CMS detector

(EXO-11-002)

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On behalf of the CMS colaboration

LHC on the march

November 2011 Protvino, Russia

LRSM: What and Why

	Standard Model	Left-Right-Symmetric Extension
Gauge group	$SU(2)_L \times U(1)_Y$	$SU(2)_L$ **$\times$ $SU(2)_R$** $\times U(1)_{B-L}$
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

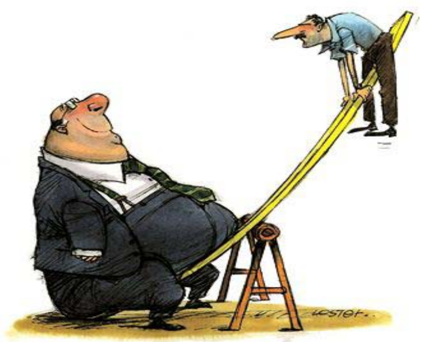
Parity Violation, in SM is not explained

LRSM explains by symmetry breaking at an intermediate mass scale

Neutrino Oscillations $\Rightarrow$ Mass, turns out to be very small

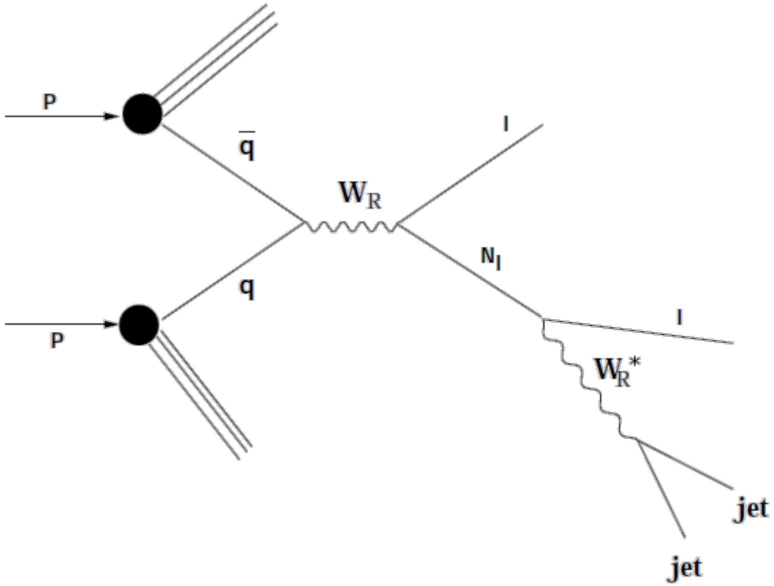
LRSM deploys a "see-saw mechanism" to explain smallness of mass

$$\nu_{heavy}\nu_{light} \sim |<H>|^2$$

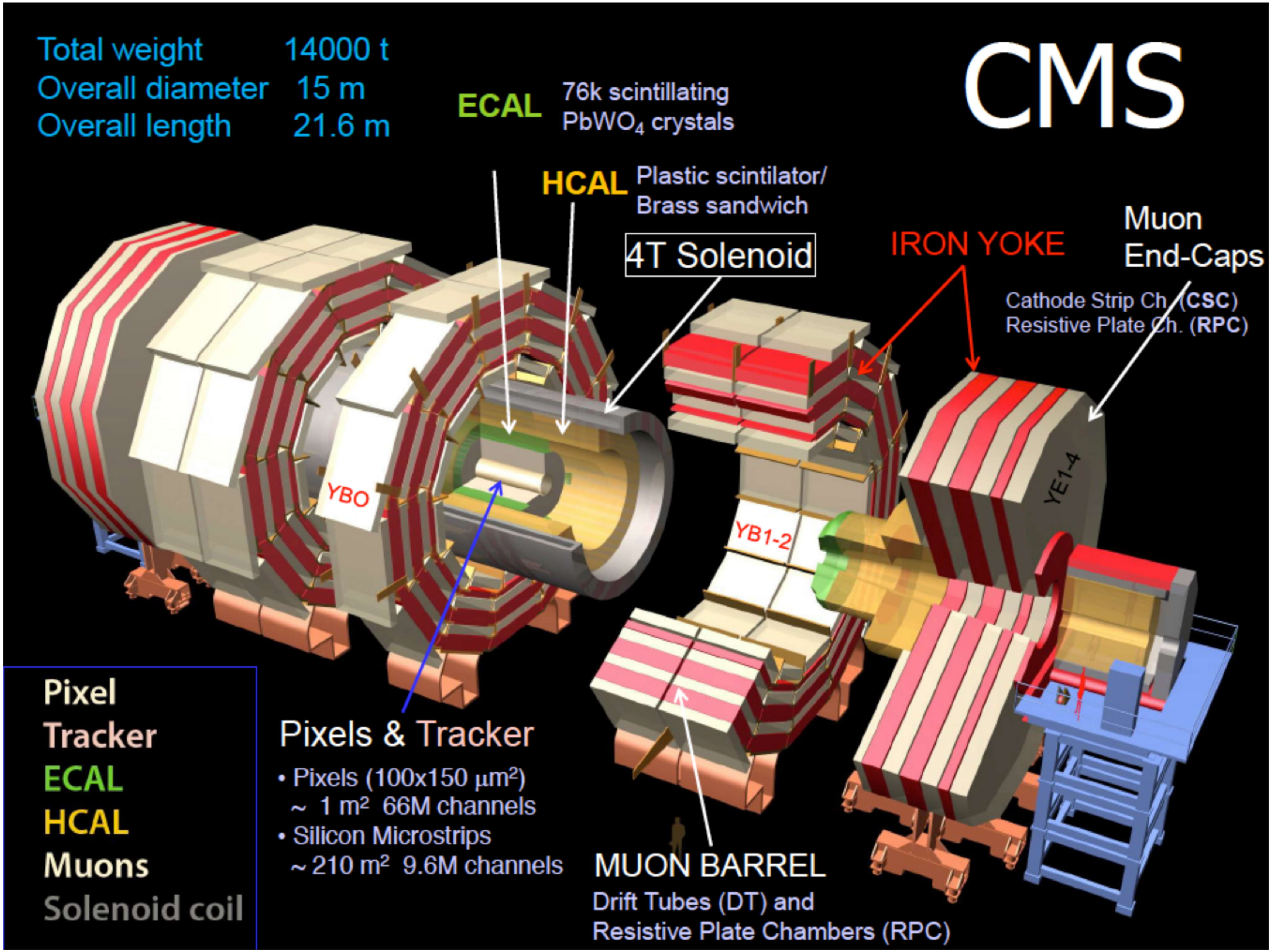


LRSM: 6 new particles: **$W^{\pm}_R$, Z', N_l** (3 heavy neutrinos)

Signature and channels



- Main production diagram: s-channel from 2 quarks
- No L-R mixing means N_l → off-shell W_R+ l → $j\,j\,l$
- Two-dimensional resonant structure
- Cross sections depend on $M(W_R)$ and M(N), ~ 1 pb at 1 TeV
- Final signature is 2 leptons + 2 jets, $l = e$ or μ


Total weight 14000 t
Overall diameter 15 m
Overall length 21.6 m
CMS
ECAL
76k scintillating
PbWO4 crystals
HCAL
Plastic scintilator/
Brass sandwich
4T Solenoid
IRON YOKE
Muon
End-Caps
Cathode Strip Ch. (CSC)
Resistive Plate Ch. (RPC)
YBO
YB1-2
YE1-4
Pixel
Tracker
ECAL
HCAL
Muons
Solenoid coil
Pixels & Tracker
• Pixels (100x150 μm²)
~ 1 m² 66M channels
• Silicon Microstrips
~ 210 m² 9.6M channels
MUON BARREL
Drift Tubes (DT) and
Resistive Plate Chambers (RPC)

CMS DETECTOR PERFORMANCE

- 3.8T solenoid
- Silicon tracker:
  $\sigma(p_T)/p_T$ = 15% at 1 TeV
- EMcal: homogeneous Pb-Tungstate crystal
  σ_E/E = 3%/sqrt(E[GeV]) + 0.5%
- HADcal: Brass-scint, $7\lambda_0$
  σ_E/E=100%/sqrt(e[GeV]) + 5%
- Muon spectrometer (Resistive Plate Counters, Drift Tubes, Cathode Strip Chambers) in magnet return yoke

MC signal simulation

- >100 mass points studied (up to $M(W_R)$=1.8TeV), 10k events per point
- Only one neutrino flavor assumed reachable
- $M(W_R)$ – dependent k-factor ~1.30 is used (1.26 < k < 1.33 in the search region). Calculated with the FEWZ program

Physical objects

- Electrons p_T cut 30 GeV. Selection optimized for high p_T. Isolation in tracker and calorimeters required (p_T dependent cuts)

- Muons p_T cut 30 GeV. Isolation in tracker required (relative cut)

- Jets anti-kt algorithm R=0.5, p_T cut 40 GeV

Event selection

Preliminary Selection:

At least 1 lepton and 1 jet

Primary Selection:

At least 2 leptons

At least 2 jets $p_t > 40$ GeV (two hardest used)

Final Selection:

Electron channel: one electron in the barrel

One lepton $p_T > 60$ GeV

Finally we apply a cut on M_{ll} (mainly against Z+jets) and analyse M_{lljj} distribution

Primary selection efficiency

- Changes from ~ 0.8 for $M_N > 0.5M_W$ to zero for $M_N < 0.05M_W$ (N decay products too close to each other)
- Low efficiency for small M_N defines the shape of the lower part of the 2D sensitivity region
- Efficiency slightly smaller (by ~10%) for the electron channel

Backgrounds

- Expected from the SM processes with 2 or more real leptons and with jets
- Some contribution from the QCD processes with fake leptons
- Most important backgrounds: tt production, Z+jets Normalized to data, shape partly from MC
- QCD – from data
- Other, small backgrounds: W+jets, ZZ, ZW, WW, tW from MC

Ttbar and Z+jets normalization

- CMS cross section measurement used for Ttbar CMS PAS TOP-10-005 **(2010)**
- Ttbar normalization checked using electron – muon events - compatible
- NNLO cross section calculation initially used for Z+jets (made with FEWZ)
- Z+jets renormalized using data and MC in the region of the Z mass peak $60 < M(ll) < 120$

QCD BG Electron channel

- Select events with an isolated ECAL cluster and a jet, missing E_T < 20 GeV
- Probability to reconstruct a cluster as electron is a fake rate
- Contamination from gamma, W subtracted using MC
- Fake rate determined separately in the barrel and endcap
- Fake rate determined separately in case of presence of "close jet" (within R=0.8)
- Select events with 2 clusters and 2 jets and build from them the QCD background sample

Event flow, electron channel

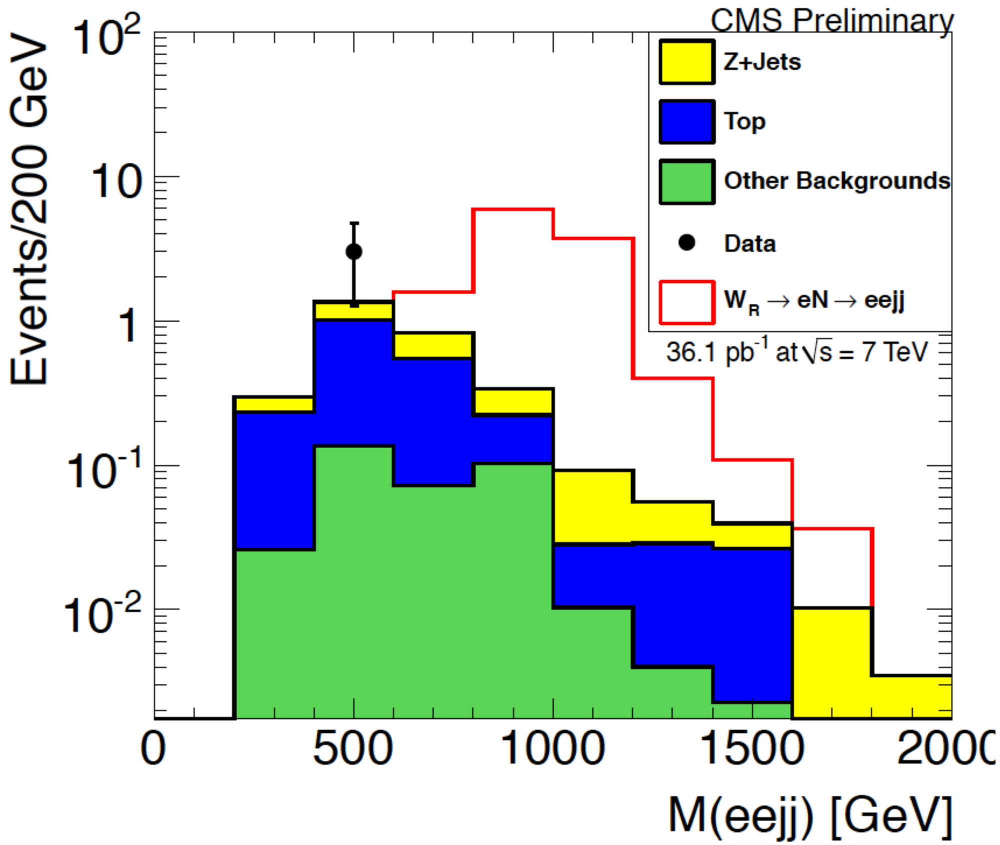
Electron Channel (2011, 204 pb^{-1})

	Data	Signal	$(\epsilon \times A)(\%)$	Tot. BG	$t\bar{t}$	Z+jets	Other
E1	1282	64	51	1126	99	992	34
E2	490	64	51	470	60	395	14
E3	445	63	50	433	51	372	10
E4	14	56	45	15	10	3.8	1.5
E5	8	56	45	9.4 ± 2.0	5.7	2.7	1.0

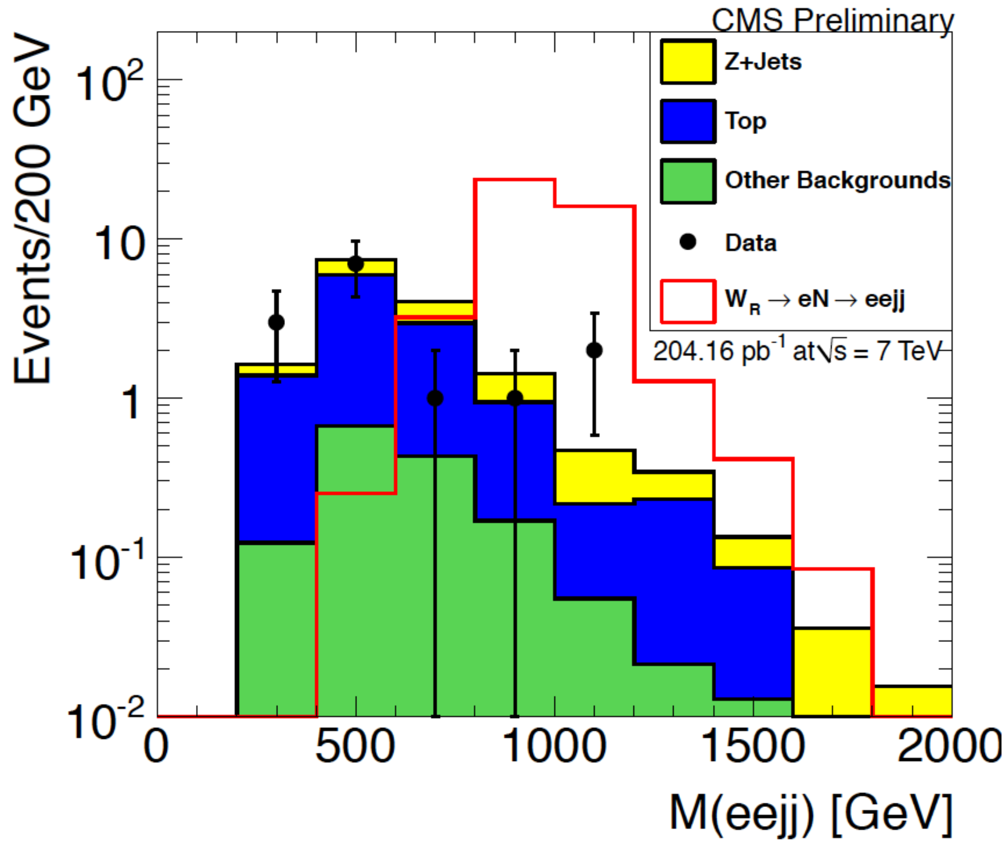
Designator	Meaning
E1	Two electrons and two jets with object requirements applied
E2	Transverse energy cut of the first electron increased to $E_T > 60$ GeV
E3	At least one electron must be in the ECAL barrel
E4	$M_{ee} > 200$ GeV
E5	$M_{eejj} > 520$ GeV

Distribution, electron channel

Run2010A+B

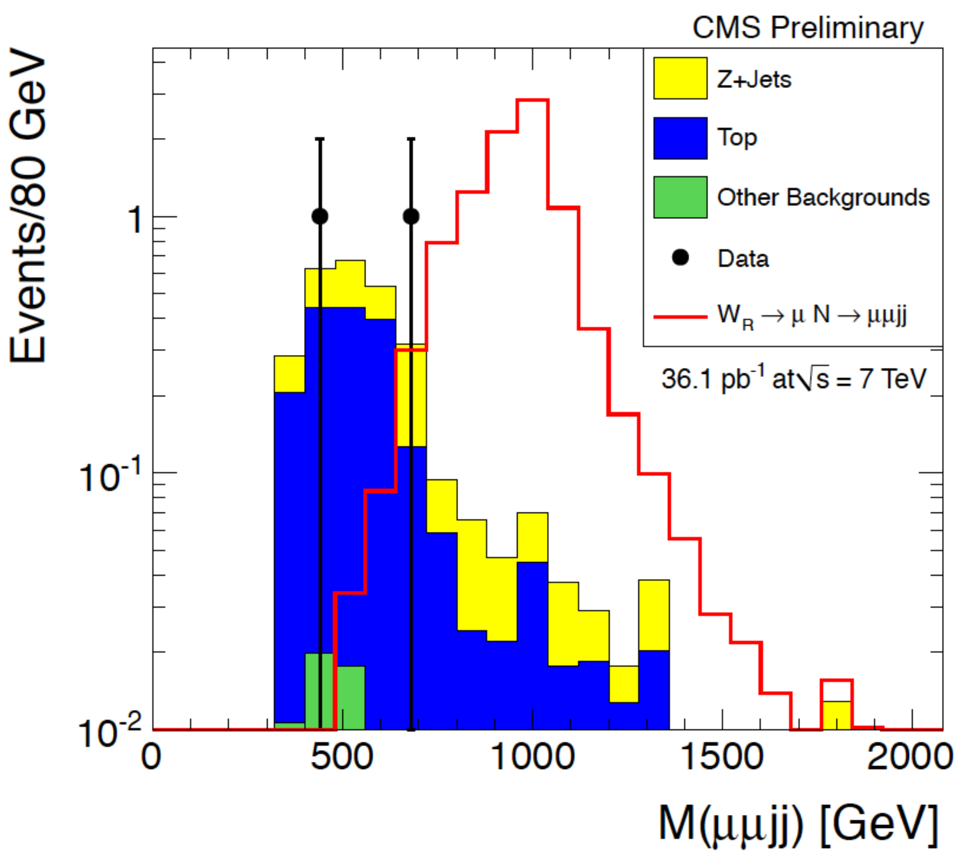


Run2011A

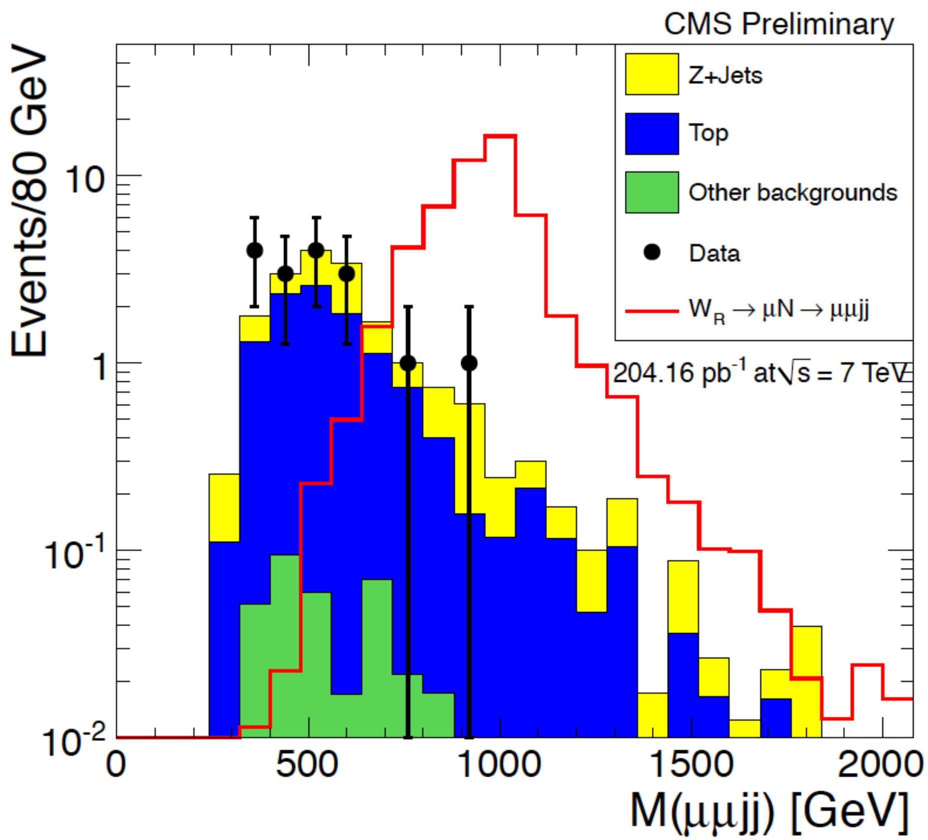


Distribution, muon channel

Run2010A+B



Run2011A



Systematics

Electron Channel

Systematic Uncertainty	Signal	$t\bar{t}$	Z+jets	QCD	Other bkgd	All bkgd
Jet Energy Scale	±2-20%	±11%	±5%	–	±12%	±7%
Electron Energy Scale	±1-3%	±4%	±3%	–	±9%	±4%
Electron Reco/ID/Iso	±10%	±10%	±10%	–	±10%	±10%
Normalization	±6%	±12%	±7%	–	±6%	±8%
Simulation Statistics	±1-7%	±5%	±4%	–	±7%	±5%
Theoretical	±5%	±13%	±19%	–	±13%	±14%
QCD estimate	–	–	–	±18%	–	±3%
Total	±12-25%	±24%	±23%	±18%	±25%	±23%

Muon Channel

Systematic Uncertainty	Signal	$t\bar{t}$	Z+jets	QCD	Other bkgd	All bkgd
Jet Energy Scale	±0.5-20%	±4%	±7%	–	±10%	±5%
Muon Energy Scale	±0-3%	±5%	±3%	–	±4%	±4%
Muon Reco/ID/Iso	±6-10%	±1%	±0.5%	–	±0.5%	±1%
Trigger Efficiency	±0.3%	±0.3%	±0.3%	–	±0.3%	±0.3%
Normalization	±6%	±12%	±8%	–	±6%	±8%
Simulation Statistics	±1-7%	±4%	±3%	–	±9%	±3%
Theoretical	±5%	±13%	±19%	–	±13%	±14%
QCD estimate	–	–	–	±25%	–	±0.1%
Total	±10-25%	±19%	±22%	±25%	±22%	±17%

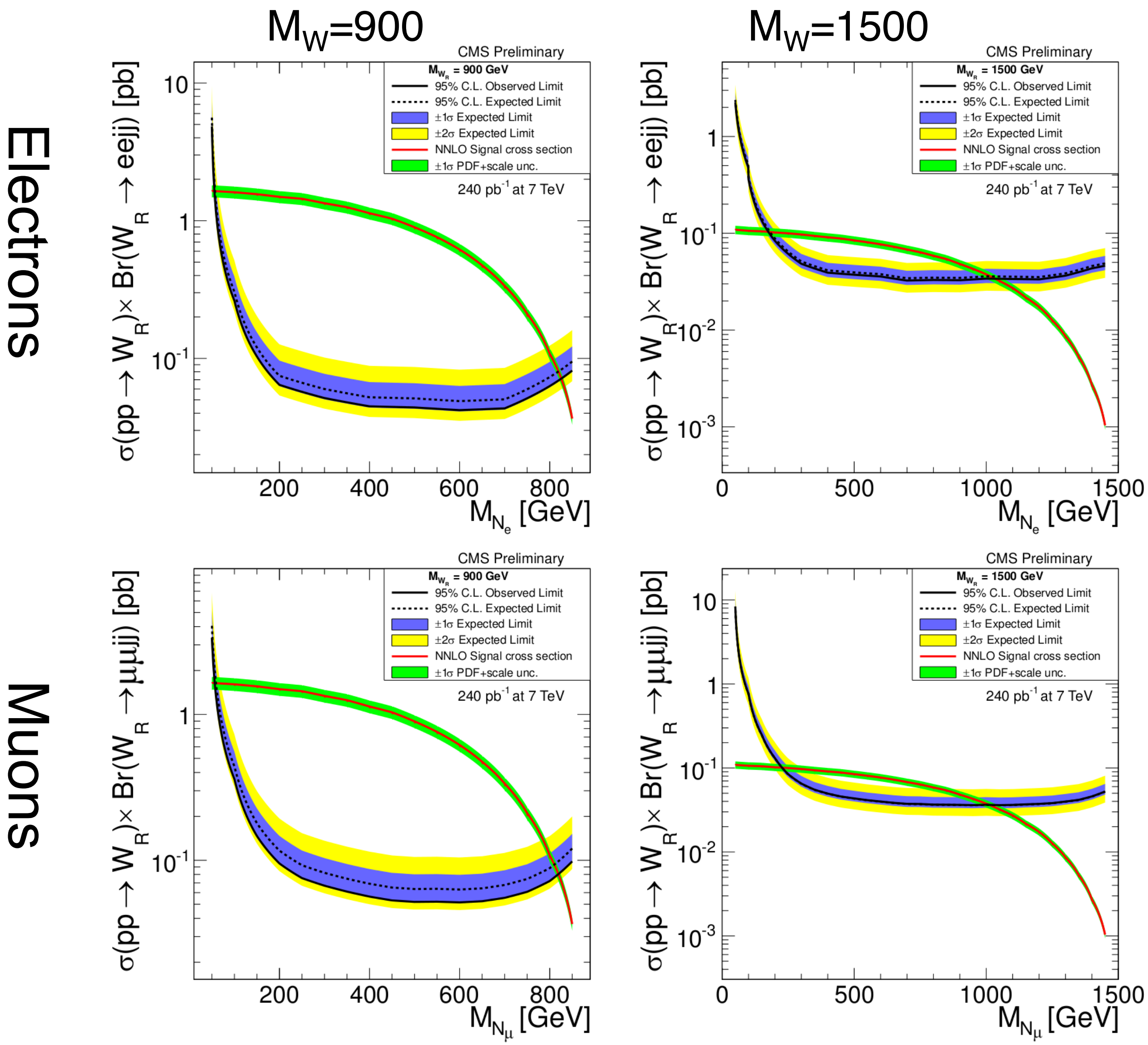
Theoretical Uncertainty:

- Scale Uncertainty
- PDF
- ISR, FSR

Limits setting

- Multibin limit setting technique based on the RooStats package
- Bayesian limit setting technique
- Systematic uncertainties: Markov Chain MC technique
- Consistent with CL_S technique

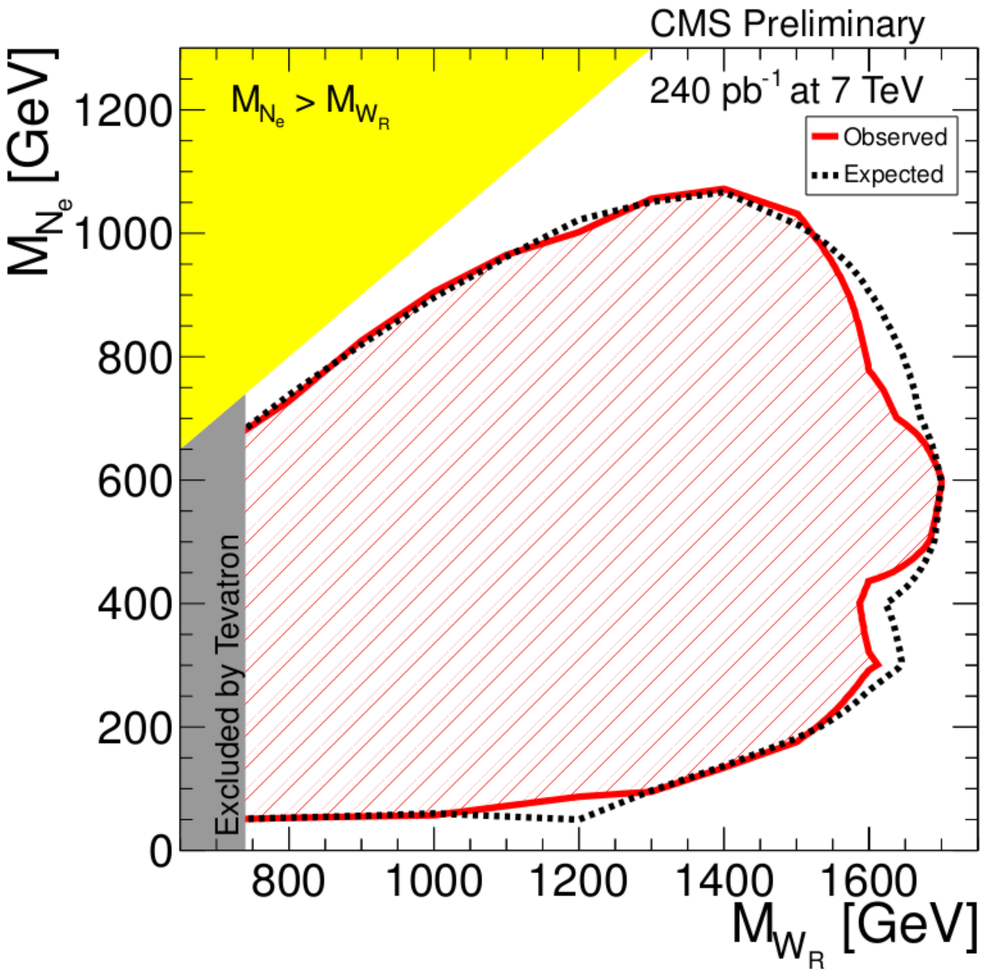
Limits



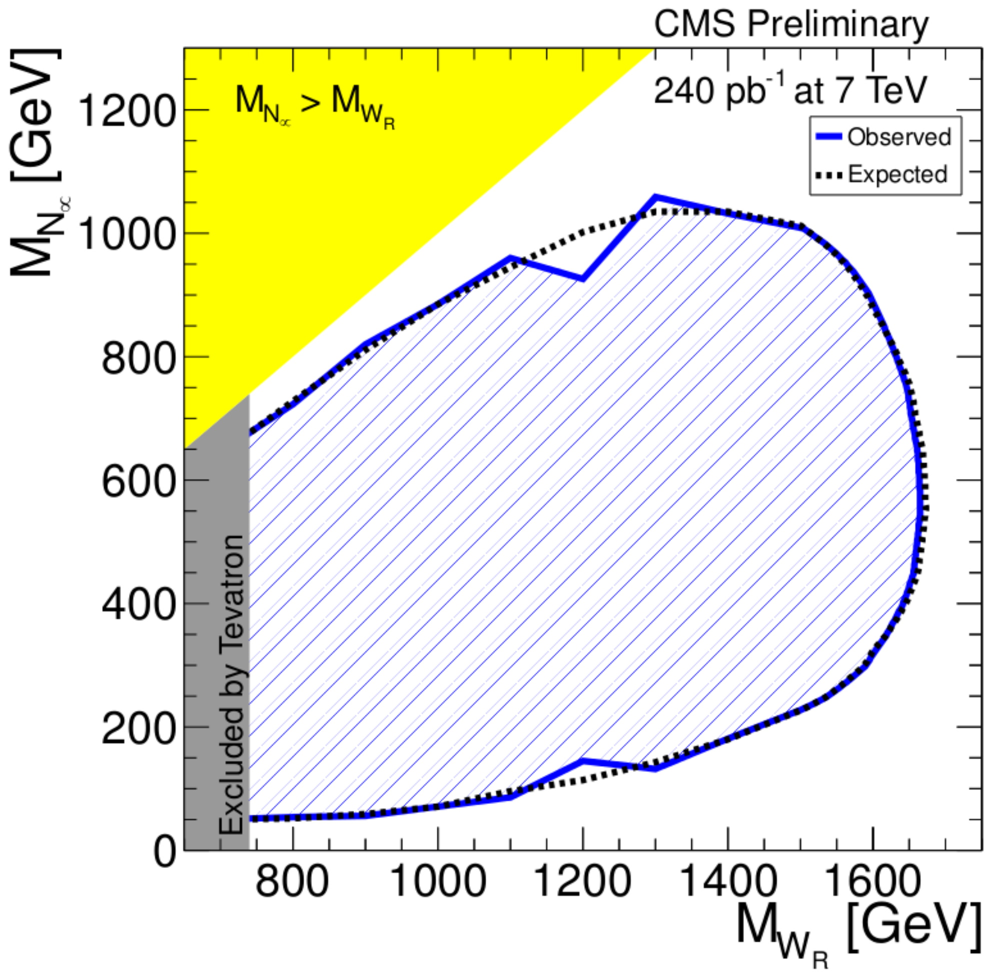
Model Assumptions

- Small mixing angles between L-R
- $g_R = g_L$ due to LR symmetry
- Right-handed CKM matrix is identical to the left-handed
- $M_N > M_W$ allowed, but suppressed

2D Limits



Electrons



Muons

Summary

- **240/pb of data analysed**
- **The search in two channels is performed: electron and muon**
- **Data are consistent with the BG expectations**
- **Regions in the two-dimensional mass plot are excluded up to $M(W_R) \sim 1700$ GeV**