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

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On behalf of the CMS colaboration

LHC on the march

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LRSM: What and Why

	Standard Model	Left-Right-Symmetric Extension
Gauge group	$SU(2)_L \times U(1)_Y$	$SU(2)_L$ **X $SU(2)_R$** $\times U(1)_{B-L}$
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	$W^\pm_L, Z^0, \gamma$	$W^\pm_L$, $\mathbf{W^\pm_R}$ Z^0, **Z´**, γ

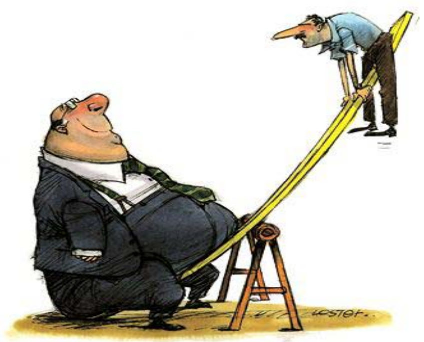
Parity Violation, in SM is not explained

LRSM explains by symmetry breaking at an intermediate mass scale

Neutrino Oscillations ⇒ Mass, turns out to be very small

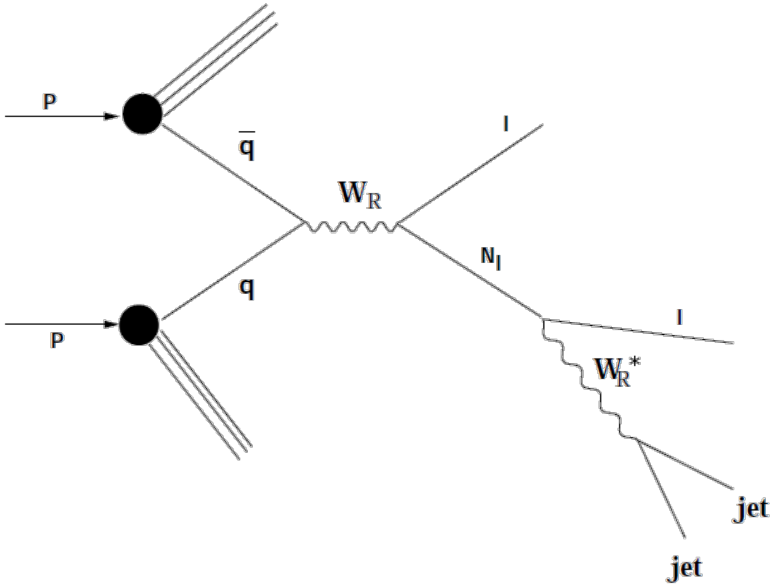
LRSM deploys a "see-saw mechanism" to explain smallness of mass

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



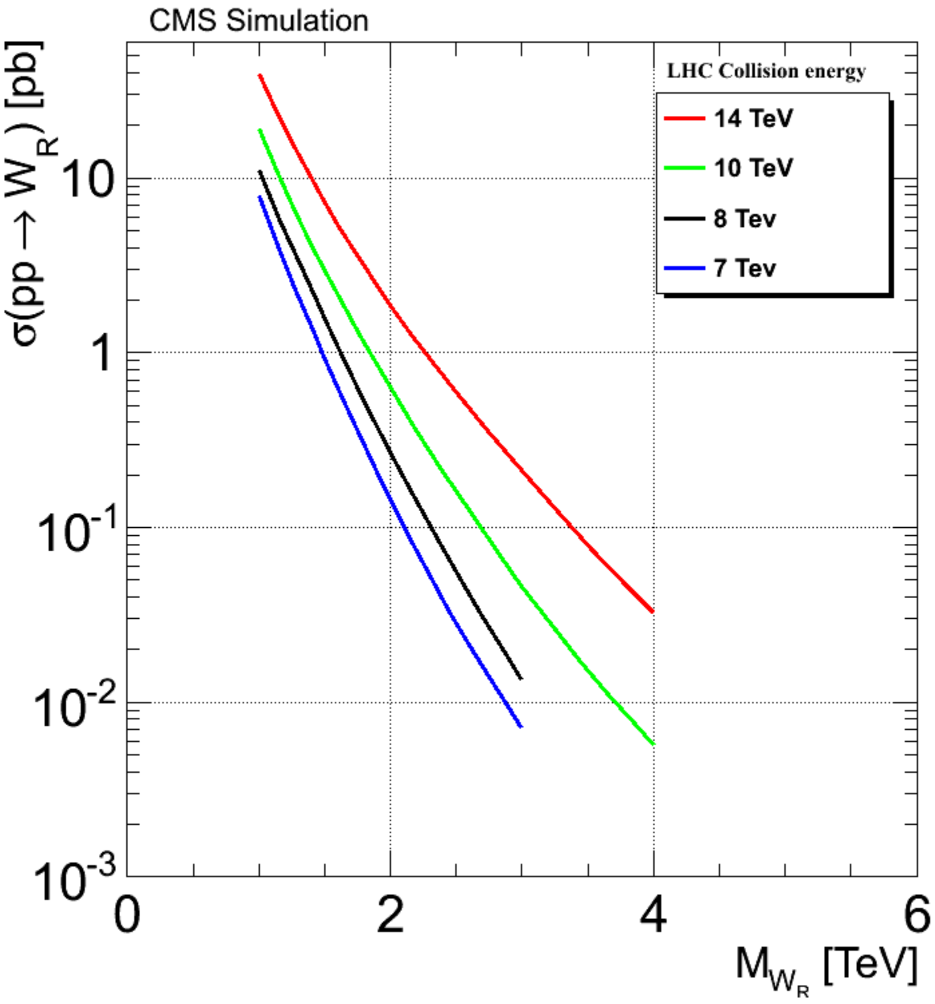
LRSM: 6 new particles: $\mathbf{W^\pm_R}$, **Z´**, $\mathbf{N_l}$ (3 heavy neutrinos)

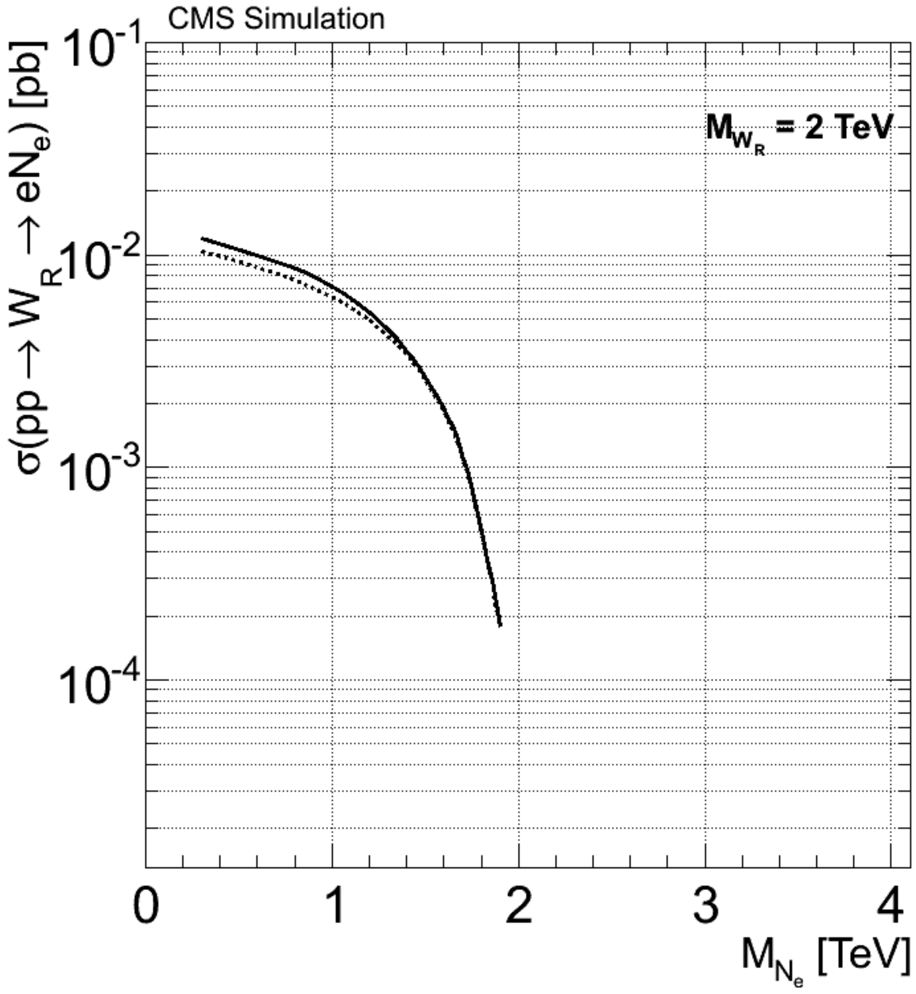
Signature and channels



- 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

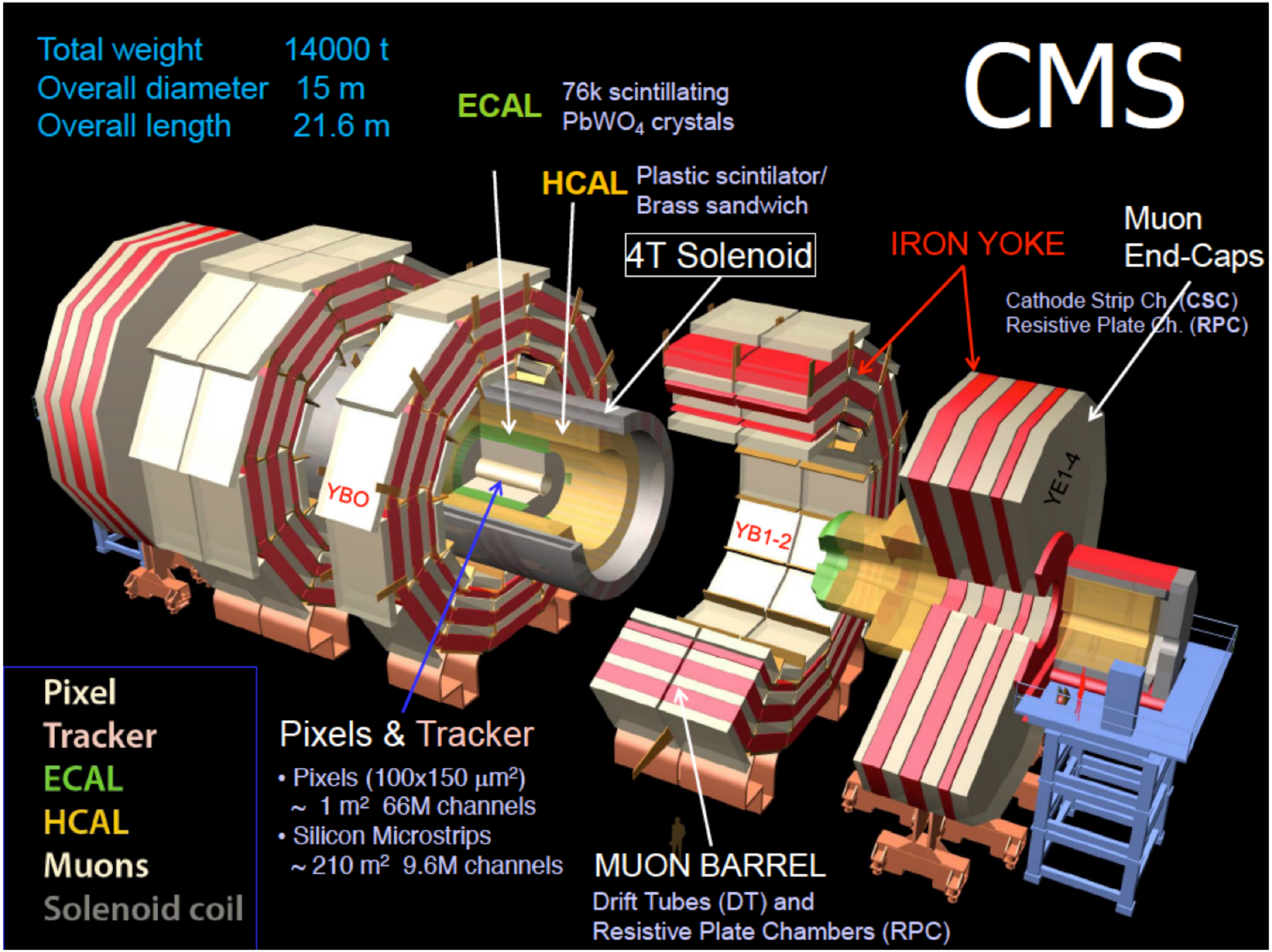
Cross sections





Existing limits

- Indirect from K_L-K_S mixing: ~2.5 TeV on $M(W_R)$ (model dependent)
- Direct from Tevatron using W_R->qq $M(W_R)$ ~760 GeV
- Direct from Tevatron using W_R->tb $M(W_R)$ ~890 GeV
- Direct from LHC using W_R->tb $M(W_R)$ ~1.85 TeV
- ATLAS: similar analysis, but they only considered the case of degenerate N masses. For this reason they combined electrons and muons and obtained exclusion region up to 2.5 TeV


Total weight 14000 t
Overall diameter 15 m
Overall length 21.6 m
CMS
ECAL 76k scintillating $PbWO_4$ 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
- 2-level trigger system L1-> O(100kHz)->L2->~300Hz

Analysis

- Previous analysis using 240 pb^{-1} (EXO-11-002) reported last year
- EXO-11-091 5 fb^{-1} at 7 TeV CERN-PH-EP-2012-235
- EXO-12-004 5 fb^{-1} at 7 TeV
- EXO-12-017 +3 fb^{-1} at 8 TeV

MC signal simulation (PYTHIA)

- Too many mass points needed (up to $M(W_R)$=3TeV)
- Simulate instead points with M(N) ~ $M(W_R)/2$
- Use acceptance corrections for other M(N), calculated using generator level simulation
- Checked using several full simulation mass points
- Only one neutrino flavor assumed reachable
- $M(W_R)$ – dependent k-factor ~1.30 is used ($1.24 < k < 1.33$ in the search region). Calculated with the FEWZ program

Triggers

- Double electron trigger with threshold 33 GeV (instead of single electron trigger in previous analysis, using it would require a significant increase of the pT cut on electrons). Efficiency estimated using prescaled double photon triggers.

- Single muon triggers with threshold from 24 to 40 GeV depending on the luminocity. Efficiency estimated using tag & probe method using muons from Z (in the peak)

- Trigger efficiency close to 100%.

Physical objects

- Electrons p_T cut 40 GeV. Selection optimized for high p_T. Isolation in tracker and calorimeters required (p_T dependent cuts)
- Muons p_T cut 30 GeV (40 GeV for 2012 8 TeV data). Isolation in tracker required (relative cut)
- Jets anti-kt algorithm R=0.5, p_T cut 40 GeV, energy corrections applied

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. However, the sensitivity in the electron channel is not worse because the energy resolution is slightly better.

Backgrounds

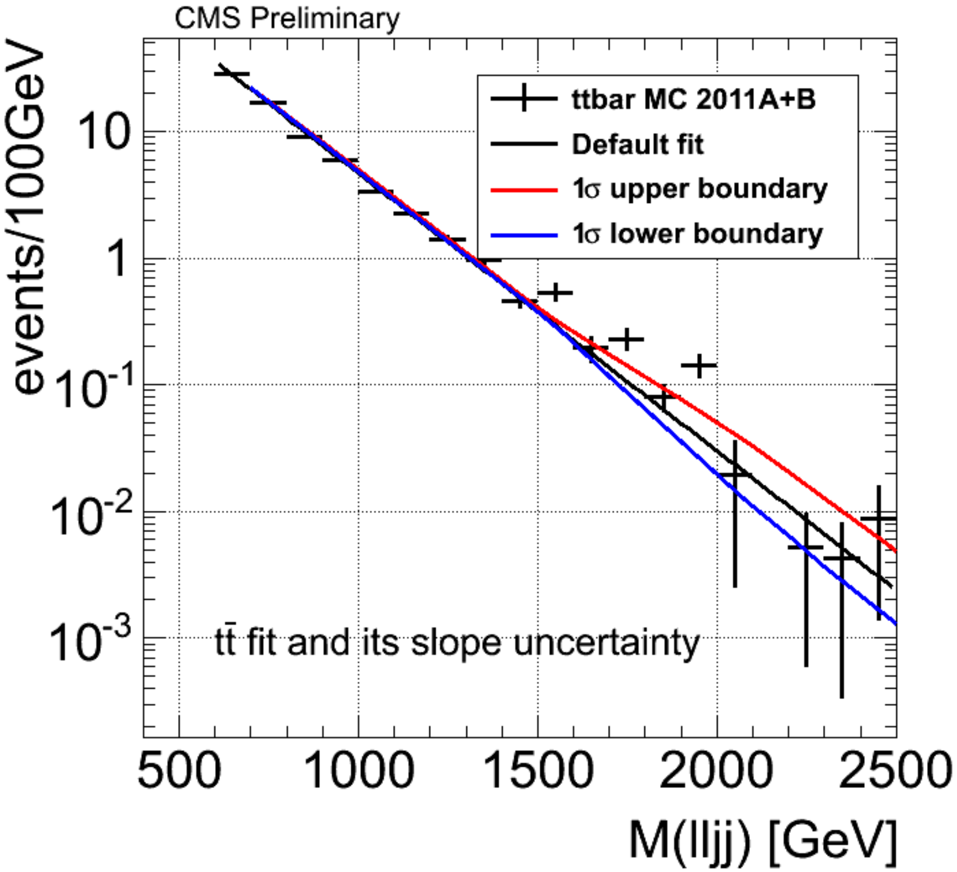
- Expected from the SM processes with 2 or more real leptons and with jets
- Some contribution from the QCD processes with fake leptons
- Most important backgrounds: tt production, Z+jets Normalized to data, shape partly from MC. Use the exponential fits because of small MC statistics at high masses M(lljj), with shape uncertainty
- QCD – from data
- Other, small backgrounds: W+jets, ZZ, ZW, WW, tW from MC

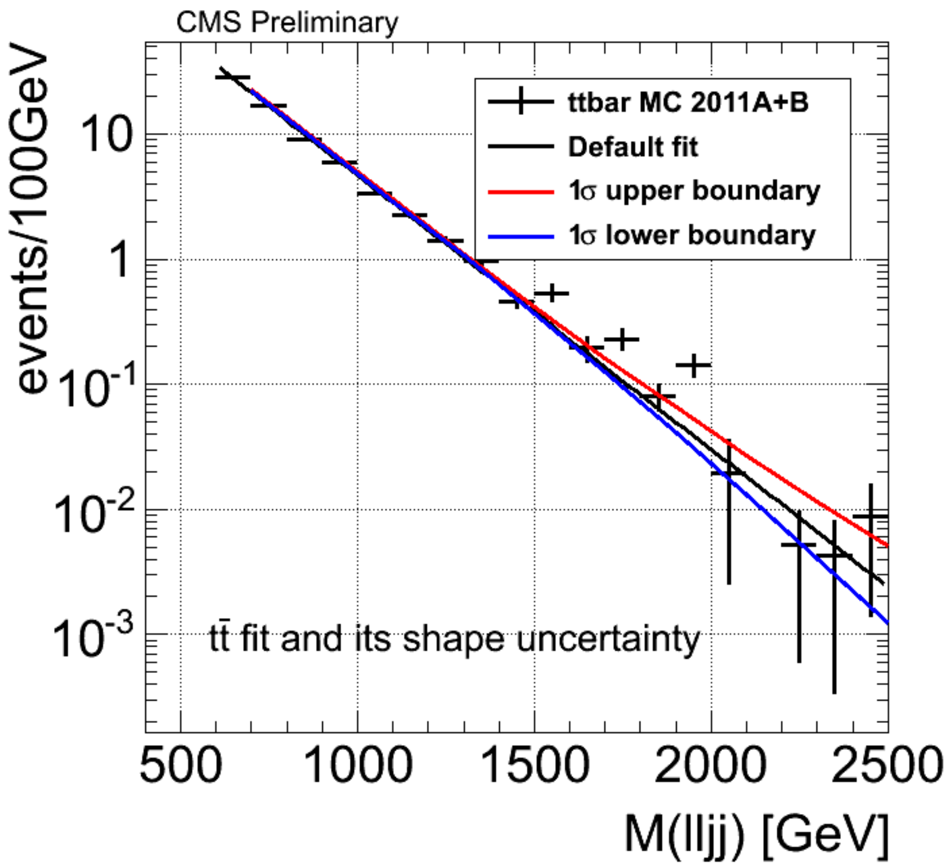
Ttbar and Z+jets normalization

- CMS cross section measurement used initially for Ttbar CMS PAS TOP-10-005 **(2010)**
- Ttbar normalized to data in the control region 250<M(*lljj*)<600 & M(*ll*)>120 for the electron channel
- Ttbar normalized to data using electron – muon events for the muon channel
- 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

Ttbar fits

Slope uncertainty: ±1 σ of the main fit slope, fit separately high M(lljj) region
Shape uncertainty: various exponential functions (M*log(M), $M+M^2$, $M+M^3$, c+exp(a+b*M)





QCD BG Electron channel

- Select events with a GSF electron (before used ECAL cluster as a denominator) and a jet, missing E_T < 20 GeV
- Probability to accept a GSF electron as high p_T electron of the analysis is a fake rate
- Contamination from gamma, W subtracted using MC
- Fake rate determined separately in the barrel and endcap
- Select events with 2 GSF electrons and 2 jets and build from them the QCD background sample

Event flow, 7 TeV run

Electron channel

	Data	Signal	Tot.Bg	$t\bar{t}$	Z+jets	QCD	Other
Primary selection	8896	44	9028	969	7830	61	168
One electron with $p_T > 60$ GeV/c	6283	44	6234	779	5277	46	132
At least one electron in Barrel	5516	43	5478	762	4566	32	118
$M_{ee} > 200$ GeV	311	42	311	192	92	13	14
$M_{eejj} > 600$ GeV	124	42	132	71	48	7	6

Muon channel

Selection stage	Data	Signal	Total bkgd	$t\bar{t}$	Z+jets	Other
Two muons, two jets	21769	50	21061	1603	19136	322
μ_1 $p_T > 60$ GeV	13328	50	12862	1106	11531	225
$M_{\mu\mu} > 200$ GeV	365	48	341	211	116	14
$M_{\mu\mu jj} > 600$ GeV	164	48 ± 13	152 ± 22	81 ± 18	65 ± 9	6 ± 3

Signal here corresponds to the mass point (1800, 1000)

Event flow, 8 TeV run

Electron Channel

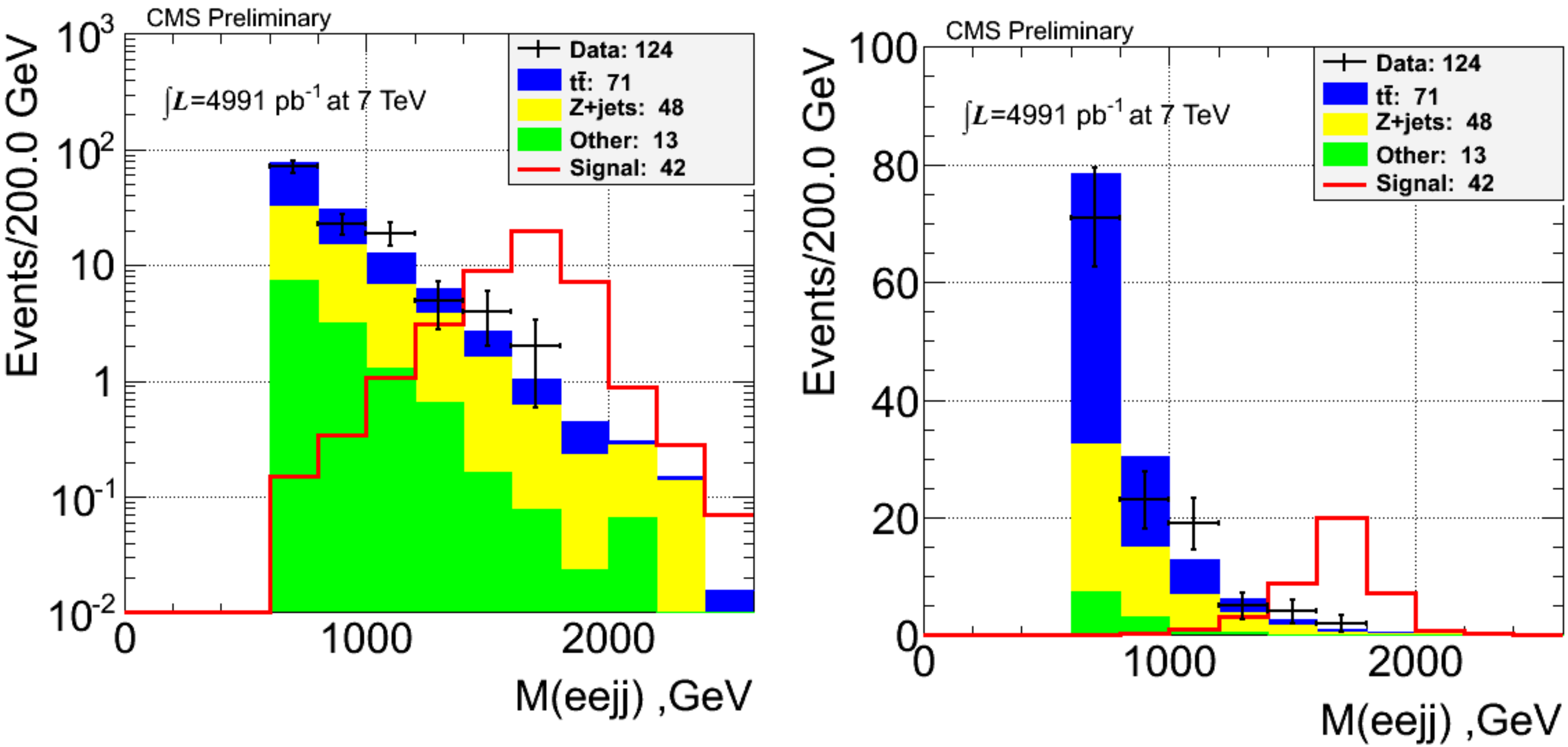
Selection Stage	Data	Signal	Total Bkgd	$t\bar{t}$	Z+jets	QCD	Other
Two electron, two jets	8807	61	8943	968	7821	8	146
e_1 $p_T > 60$ GeV	6054	61	5905	767	5014	3	121
$M_{ee} > 200$ GeV	310	59	296	199	75	3	20
$M_{eejj} > 600$ GeV	144	59 ± 12	135 ± 30	83 ± 18	43 ± 23	2 ± 1	9 ± 3

Muon Channel

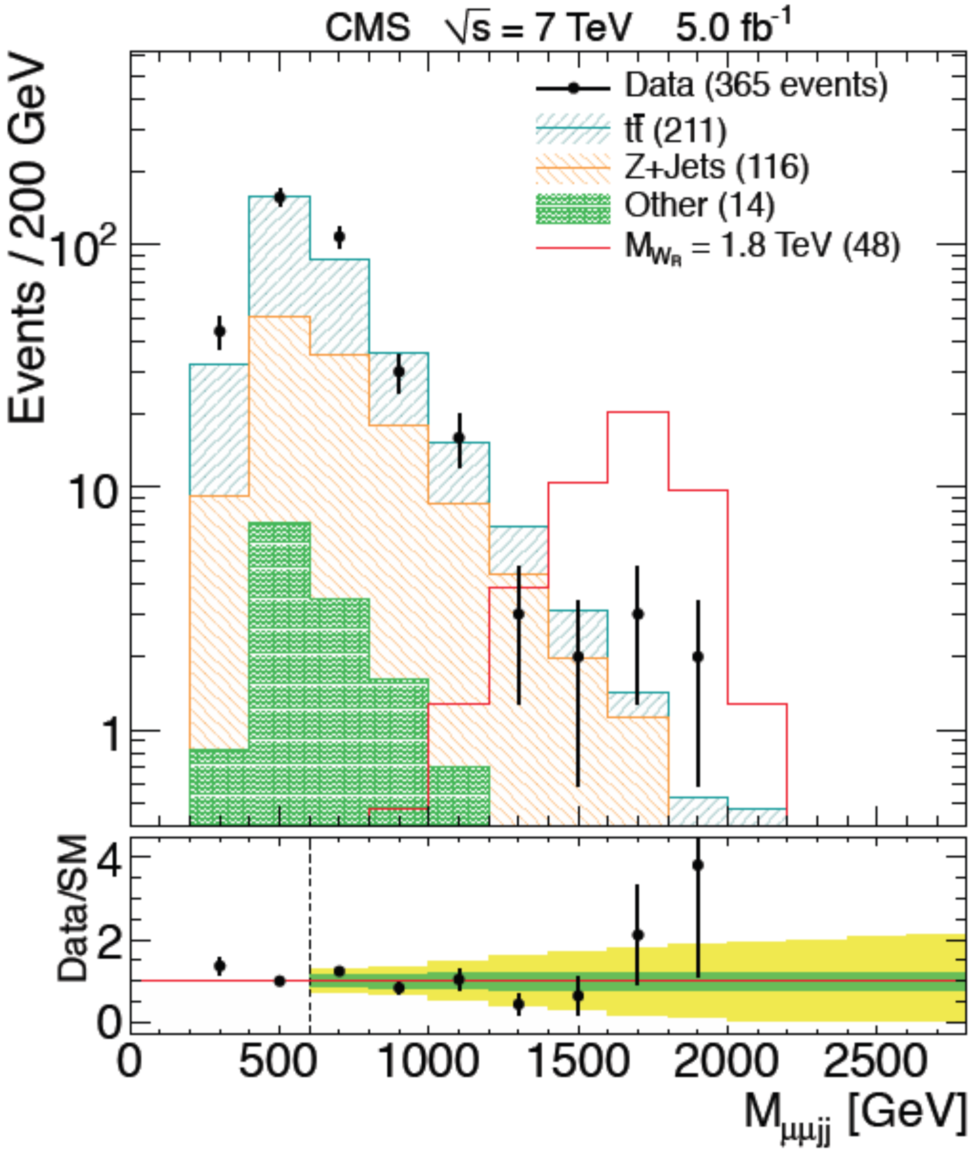
Selection Stage	Data	Signal	Total Bkgd	$t\bar{t}$	Z+jets	QCD	Other
Two muons, two jets	10333	75	10016	968	8830	3	215
μ_1 $p_T > 60$ GeV	7058	75	6873	767	5933	2	171
$M_{\mu\mu} > 200$ GeV	352	72	294	199	71	0.7	23
$M_{\mu\mu jj} > 600$ GeV	144	72 ± 13	130 ± 24	83 ± 17	35 ± 17	0.7 ± 0.4	11 ± 4

Signal here corresponds to the mass point (1800, 1000)

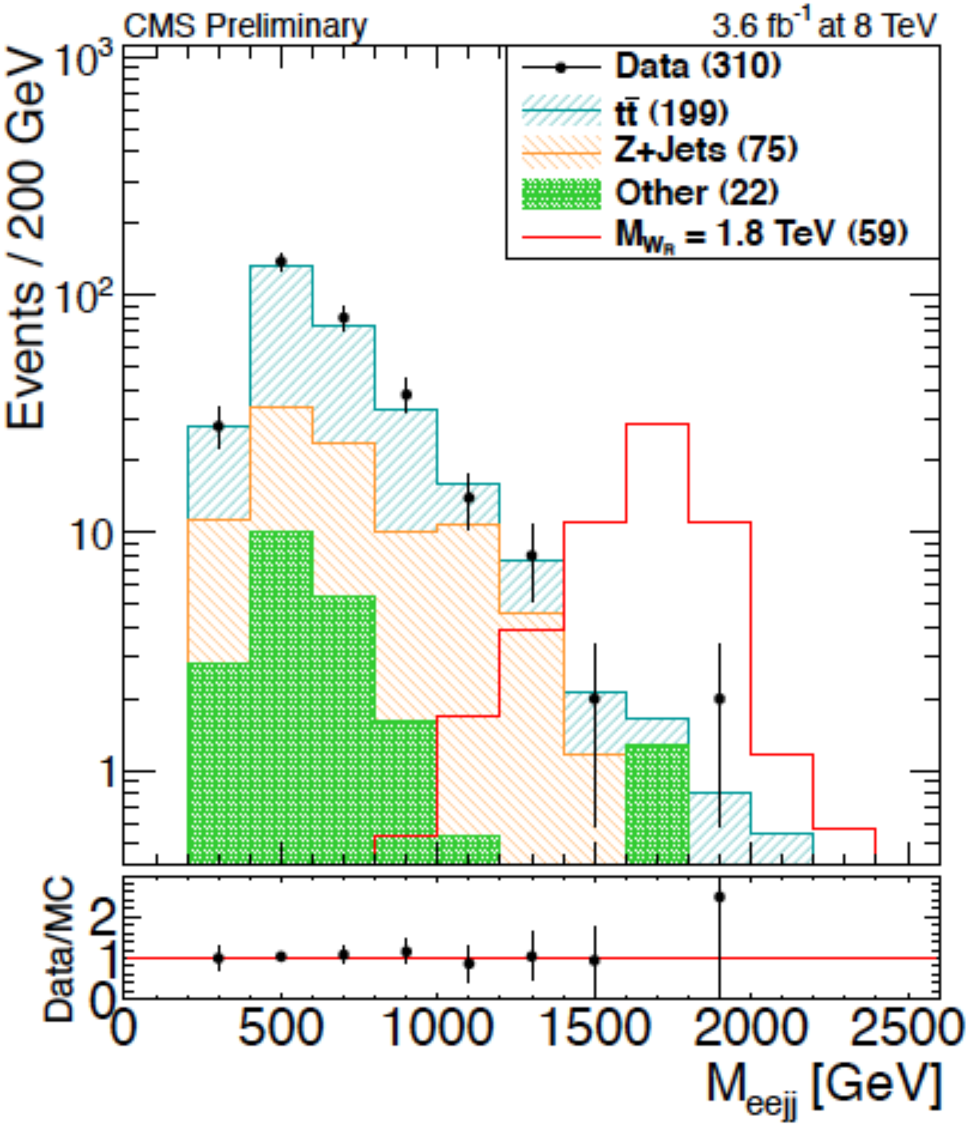
Distribution, electron channel, 7 TeV

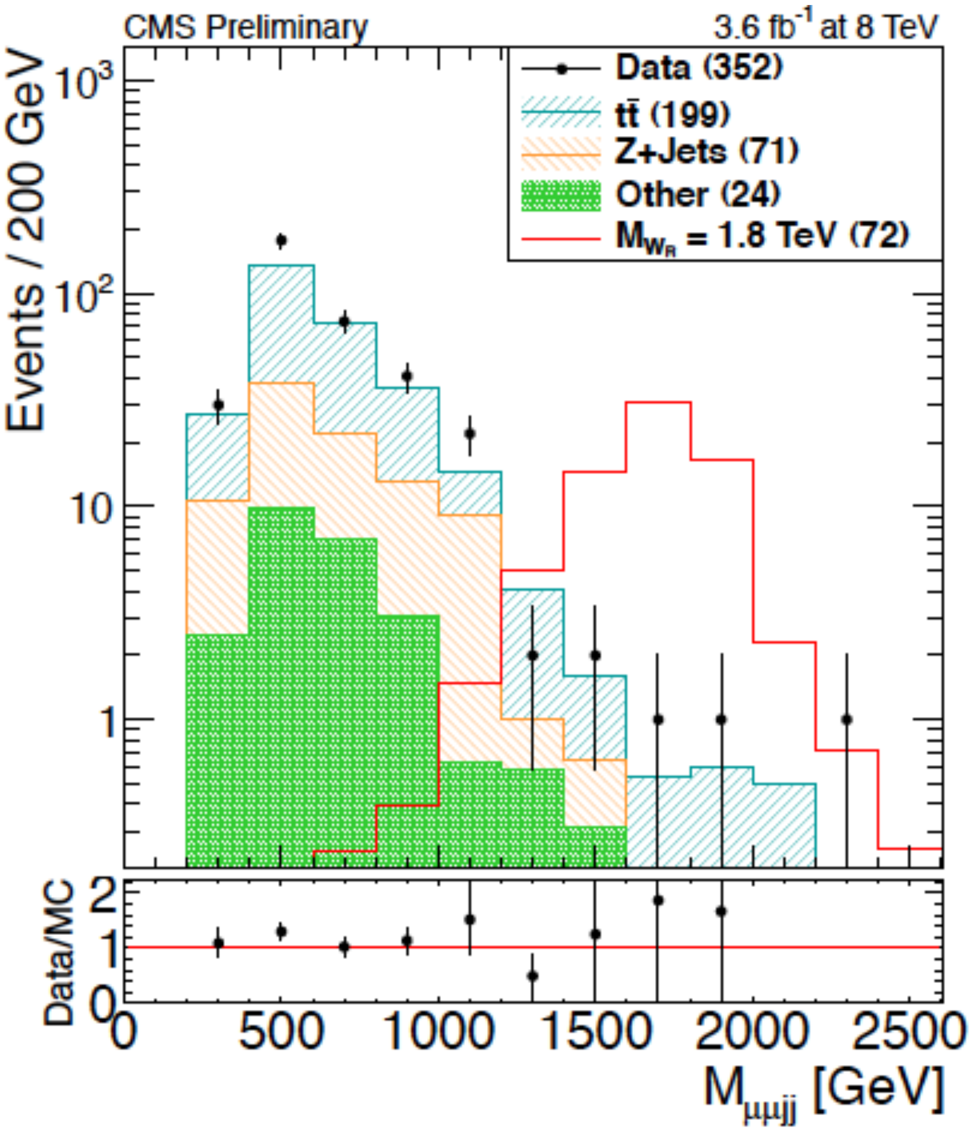


Muon channel, 7 TeV



Distributions, 8 TeV run





Systematics, electrons, 7 TeV run

Systematic Uncertainty	Signal eff.	$t\bar{t}$	Z+jets	QCD	Other bkgd
Jet Energy Scale	±0.3-9%	±10%	±2%	–	±5%
Jet Energy Resolution	±0-1%	±0.6%	±1%	–	±2%
Electron Energy Scale	±0.1%	±1.5%	±2%	–	±1.2%
Electron Energy Resolution	<0.1%	<0.1%	±0.5%	–	±0.5%
Electron Reco/ID/Iso	±12-17%	±2%	±5%	–	±8%
Trigger Efficiency	±1%	±1%	±1%	–	±1%
Pileup, runs A (B)	±2(11)%	±2(11)%	±2(11)%	–	±2(11)%
Background shape		±20%	±15%	±25%	±25%
N_{signal}, Bkgd normalization	±5-20%	±9%	±3%	–	±6%
ISR/FSR	±1-3%	–	–	–	–
PDF	±8-40%	±0.4%	±0.4%	–	±9%
Fact./Ren. scale	0%	±7%	±5%	–	±8%
QCD estimate	–	–	–	±33%	–
Total	±16-49%	±30%	±21%	±42%	±34%

Systematics, muons, 7 TeV run

Systematic Uncertainty	Signal eff.	$t\bar{t}$	Z+jets	QCD	Other bkgd
Jet Energy Scale	±0.3-13%	±9%	±3%	–	±8%
Jet Energy Resolution	±0-0.4%	±0.4%	±0.2%	–	±0.2%
Muon Energy Scale	±0-0.4%	±0.2%	±3.0%	–	±0.4%
Muon Reco/ID/Iso	±15-18%	±3%	±6.0%	–	±7%
Trigger Efficiency	±0.6-1.5%	±0.2%	±0.3%	–	±4%
Pileup	±0-0.4%	±0.2%	±1.0%	–	±2%
Background shape	–	±15%	±11%	–	±40%
Simulation statistics	±5-20%	–	–	–	–
Background normalization	–	±9%	±1%	–	±7%
PDF	±8-40%	±0.4%	±0.4%	–	±9%
Fact./Ren. scale, ISR/FSR	±1-2%	±7%	±5%	–	±8%
QCD estimate	–	–	–	±60%	–
Total	±18-50%	±21%	±14%	±60%	±44%

Systematics 8 TeV run

Systematic Uncertainty	Signal eff.	$t\bar{t}$	Z+jets	QCD	Other bkgd
Jet Energy Scale	±0.1-1%	–	±3%	–	±2%
Jet Energy Resolution	±0.1-1%	–	±1%	–	±1%
Electron Energy Scale	±0.1-1%	–	±0.3%	–	±2%
Electron Reco/ID/Iso	±9-10%	–	±0.1%	–	±9%
Trigger Efficiency	±1-2%	–	±0.2%	–	±1%
Background shape	–	±16%	±53%	–	±35%
Simulation statistics	±2%	–	–	–	–
Background normalization	–	±15%	±3%	–	±4%
PDF	±4-22%	–	±0.4%	–	±9%
Fact./Ren. scale, ISR/FSR	±1-2%	–	±5%	–	±8%
QCD estimate	–	–	–	±50%	–
Total	±10-24%	±22%	±53%	±50%	±38%

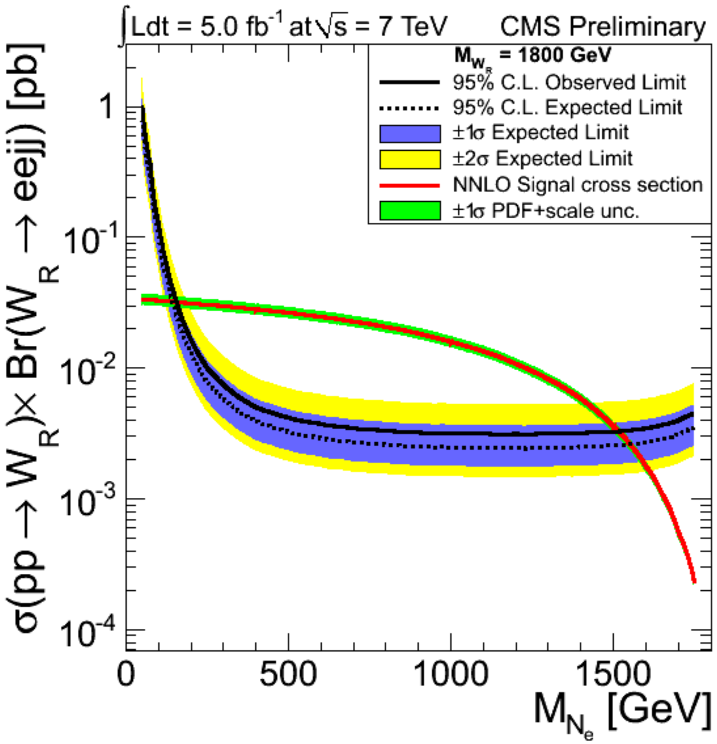
Muon Channel

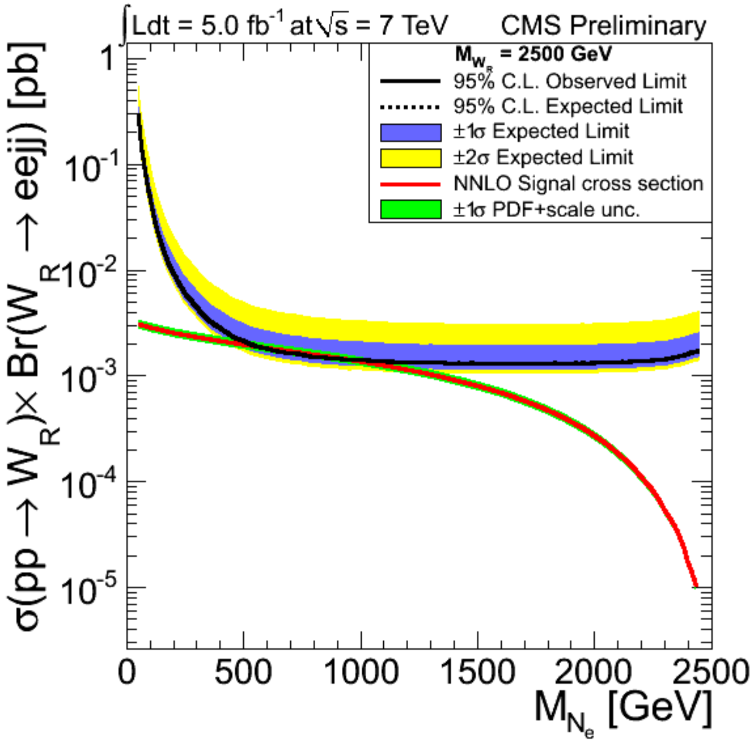
Systematic Uncertainty	Signal eff.	$t\bar{t}$	Z+jets	QCD	Other bkgd
Jet Energy Scale	±0.1-1%	–	±2%	–	±2%
Jet Energy Resolution	±0.1-1%	–	±1%	–	±1%
Muon Energy Scale	±0.1-0.5%	–	±2%	–	±1%
Muon Reco/ID/Iso	±6%	–	±0.1%	–	±6%
Trigger Efficiency	±0.1-0.3%	–	±0.5%	–	±0.1%
Background shape	–	±16%	±49%	–	±30%
Simulation statistics	±2%	–	–	–	–
Background normalization	–	±11%	±3%	–	±4%
PDF	±4-22%	–	±0.4%	–	±9%
Fact./Ren. scale, ISR/FSR	±1-2%	–	±5%	–	±8%
QCD estimate	–	–	–	±50%	–
Total	±8-23%	±20%	±49%	±50%	±33%

Limits setting

- Multibin limit setting technique based on the RooStats package
- M(*lljj*) as a final variable, in 200 GeV bins, BG systematic errors calculated separately for each bin, this is important for high masses
- CL_S technique for the limits on the signal cross section

1-D Limits electrons 7 TeV

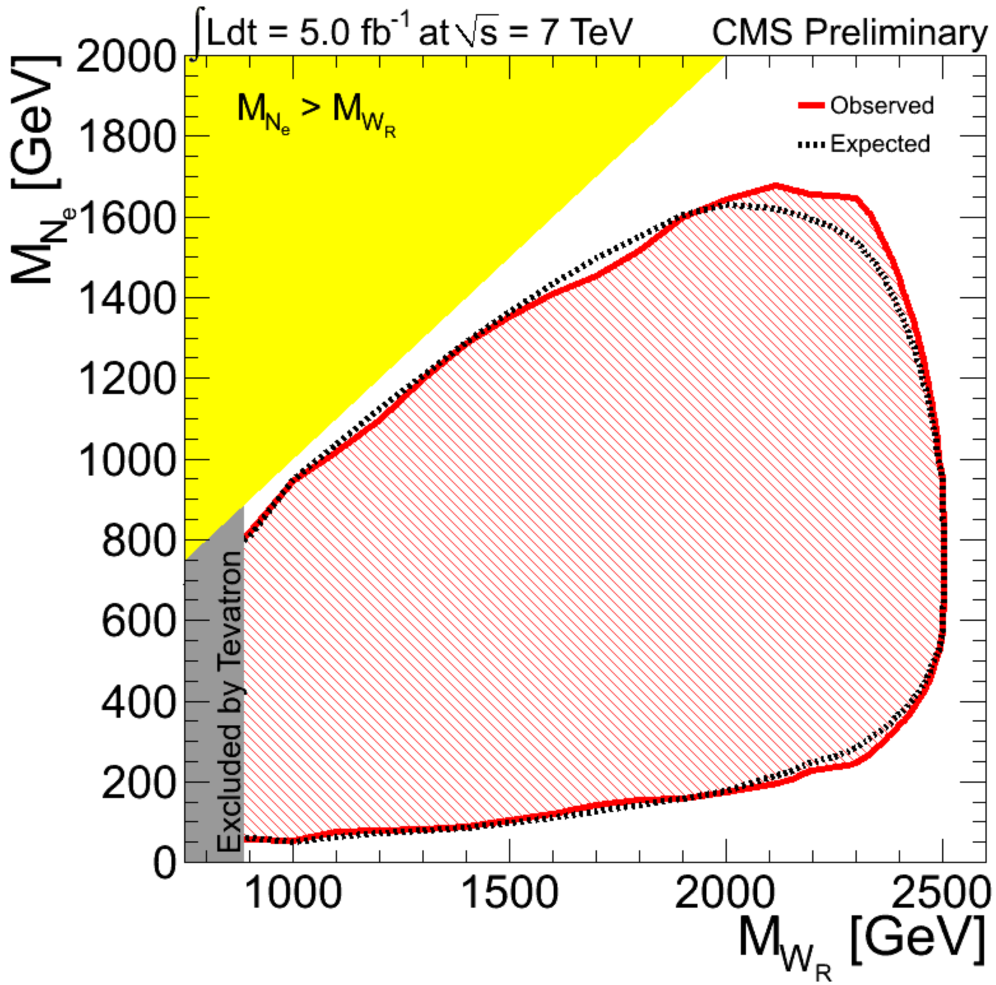


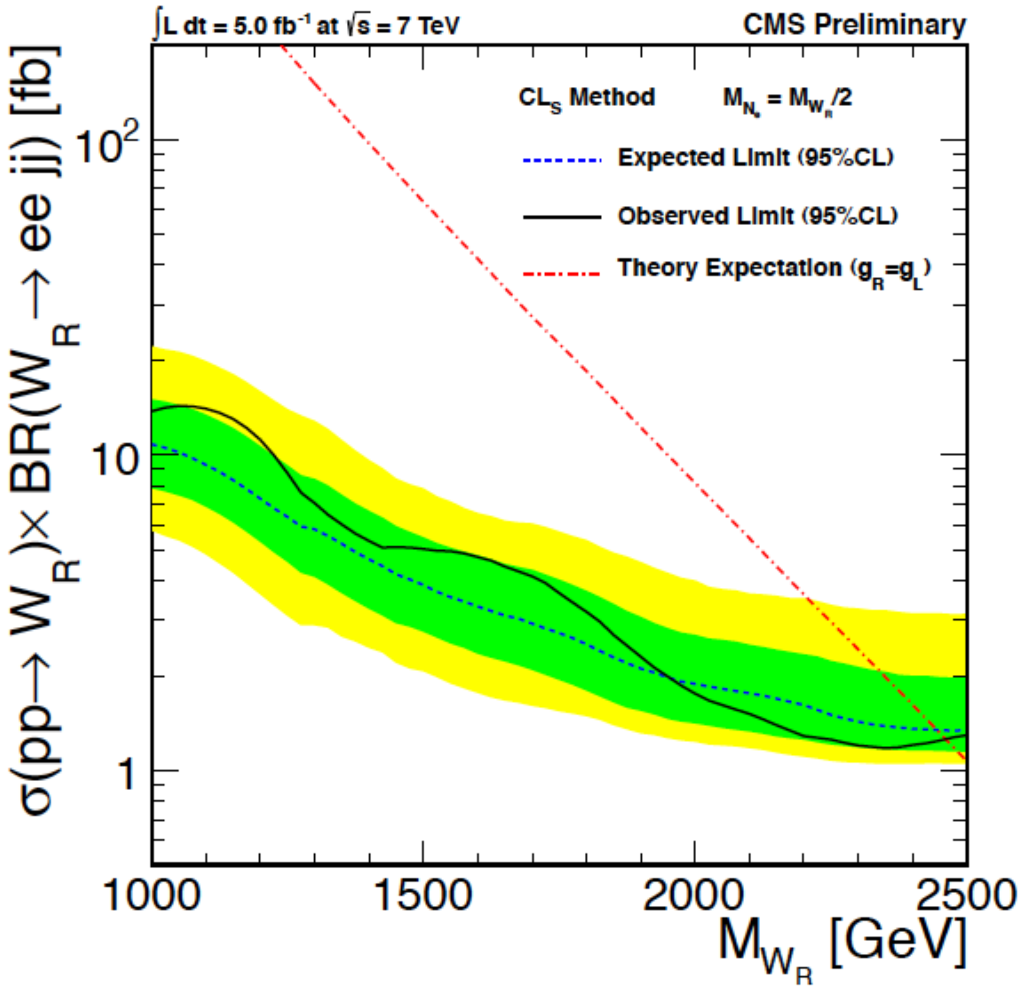


Model Assumptions:

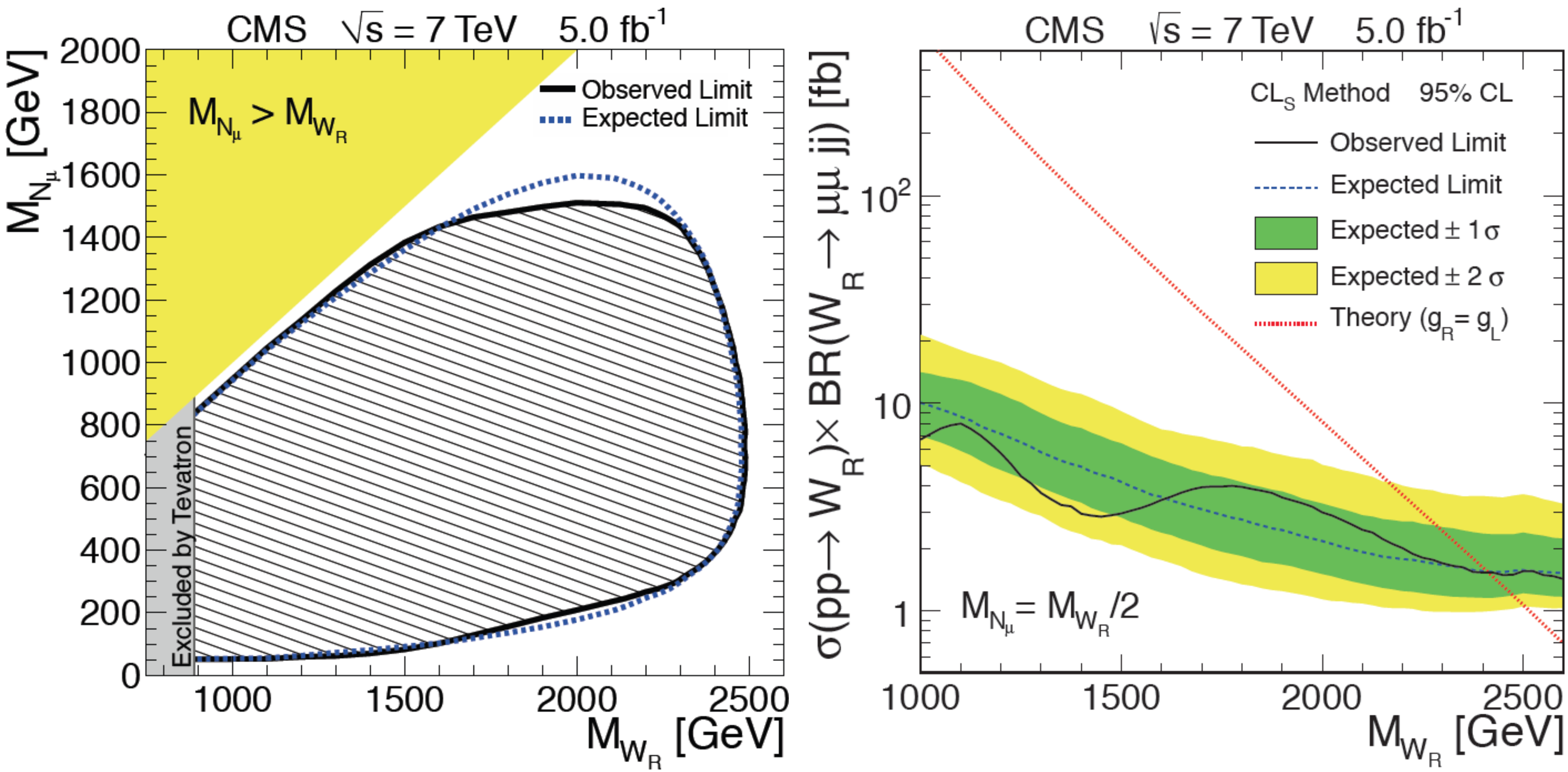
- Small mixing angles between L-R
- $g_R = g_L$ due to LR symmetry
- Right-handed CKM matrix is identical to the left-handed
- $M_N > M_W$ allowed, but suppressed

2D Limits electrons 7 TeV

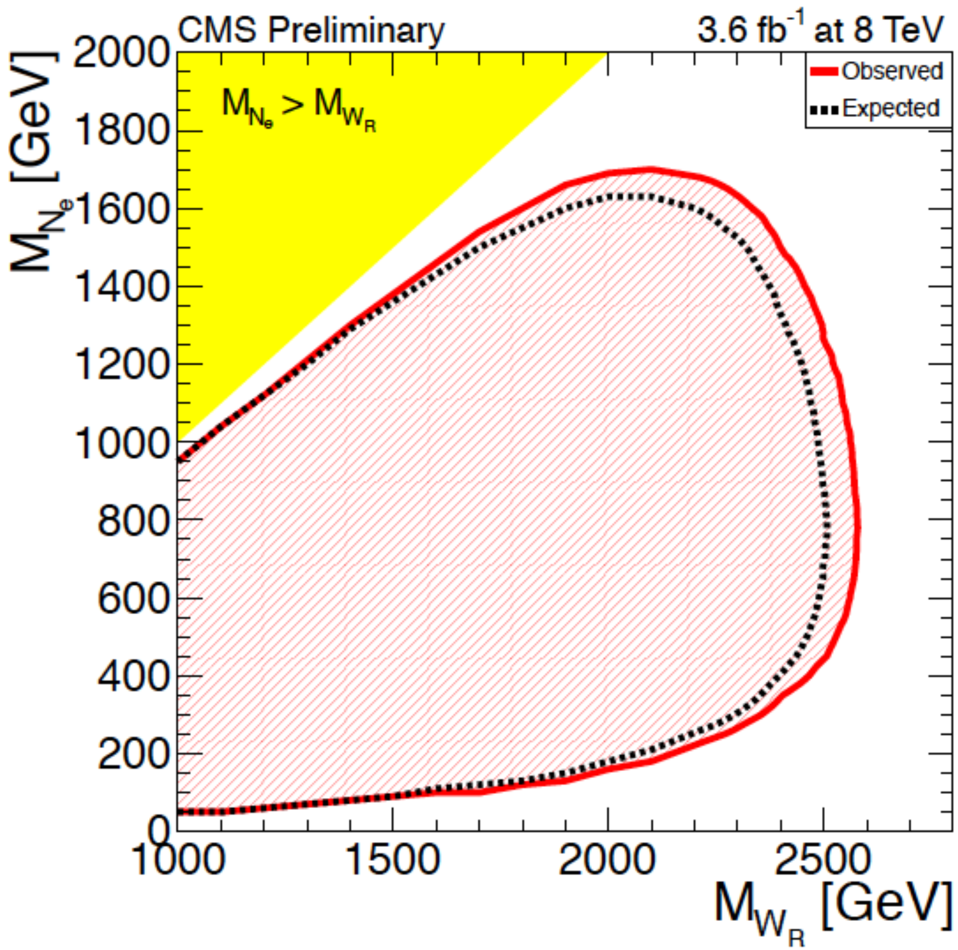


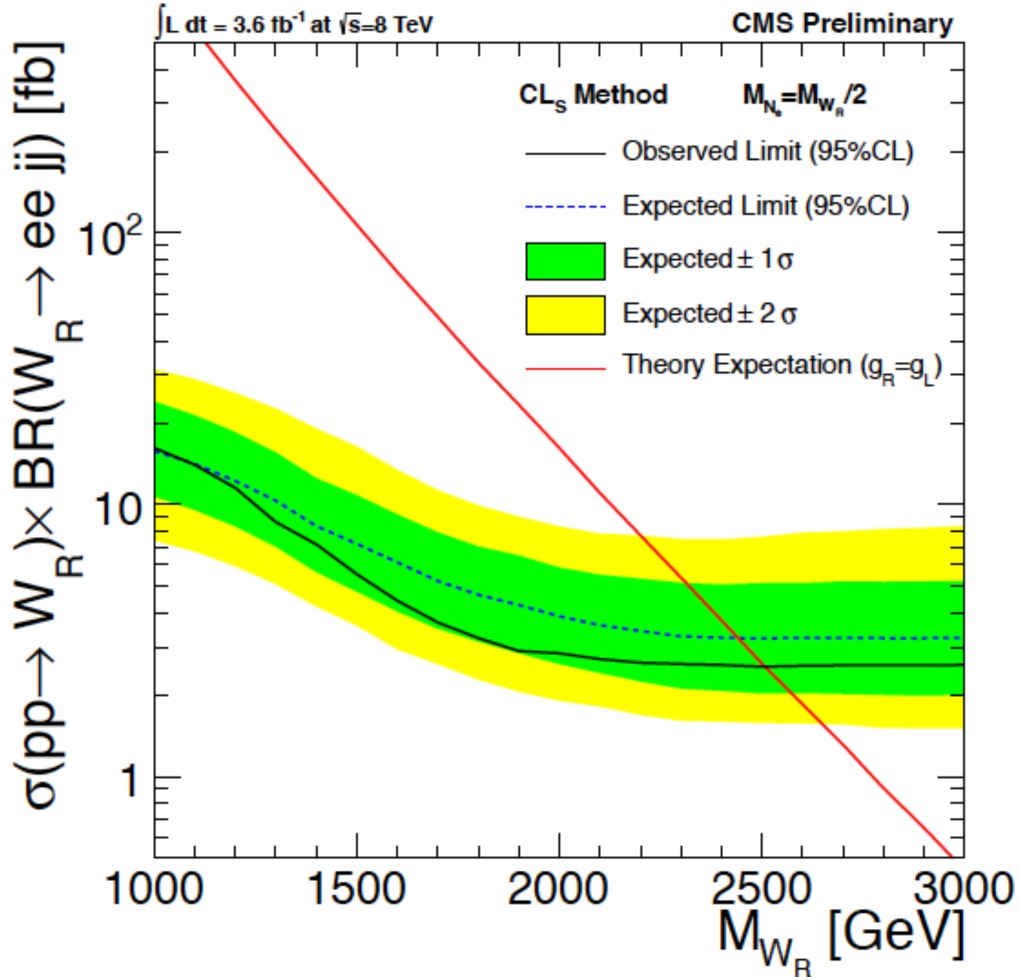


2D Limits muons 7 TeV

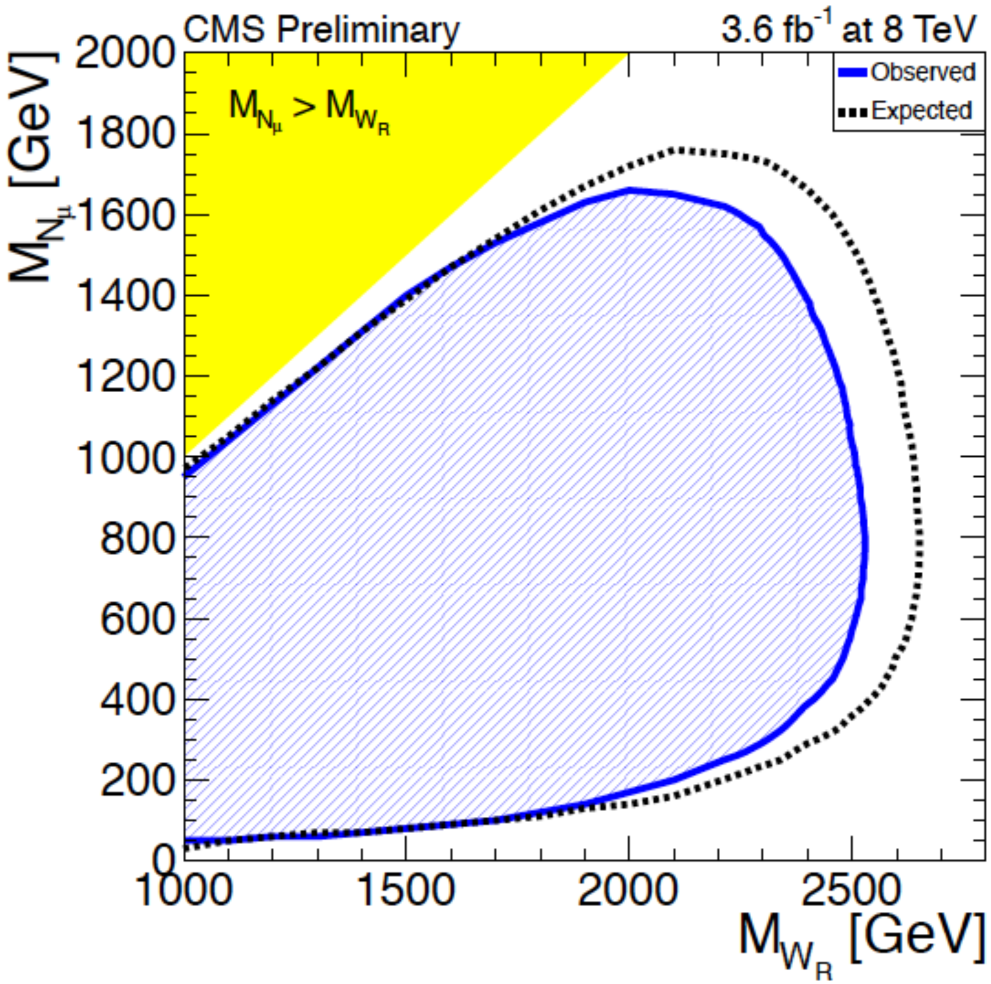


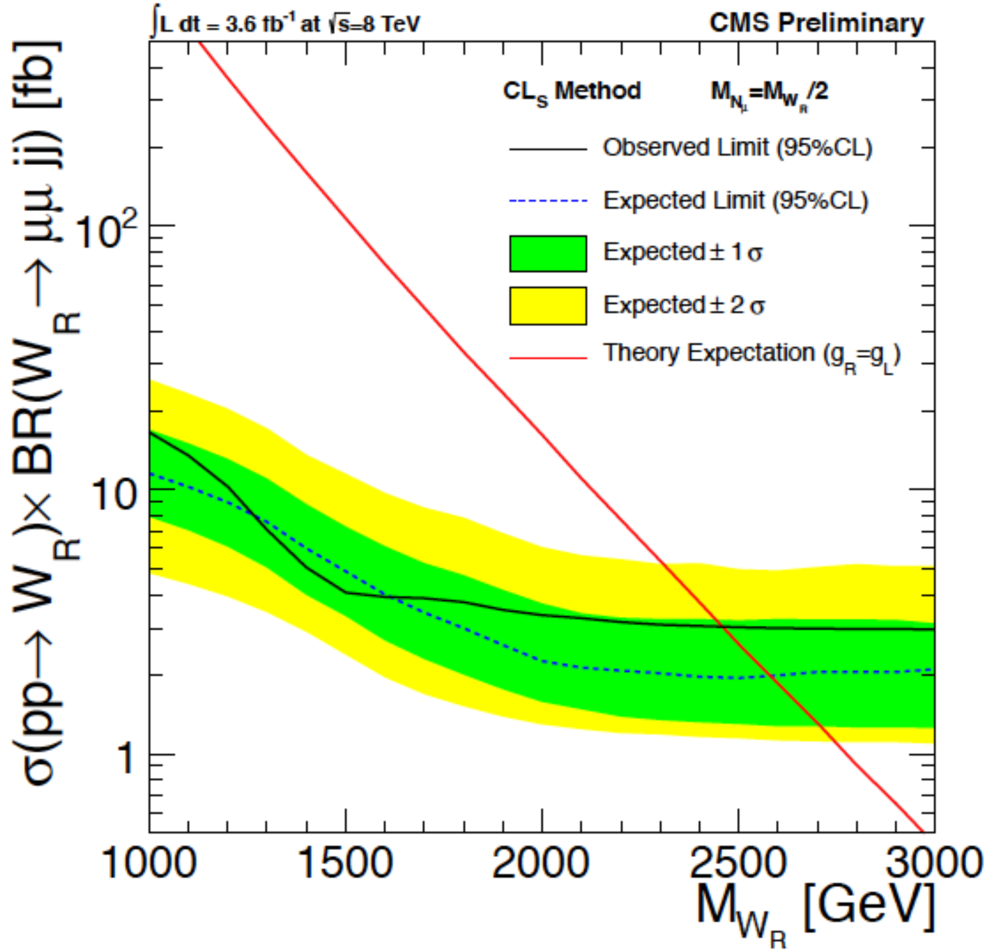
2D Limits electrons 8 TeV



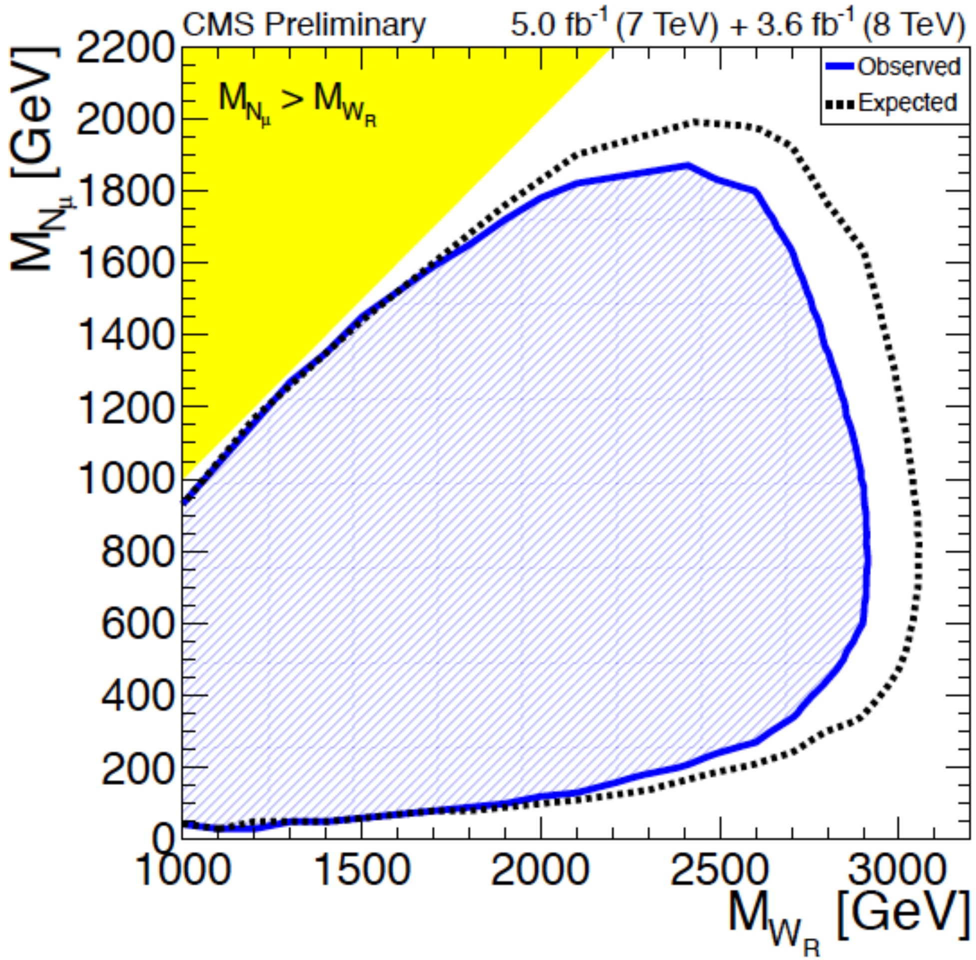


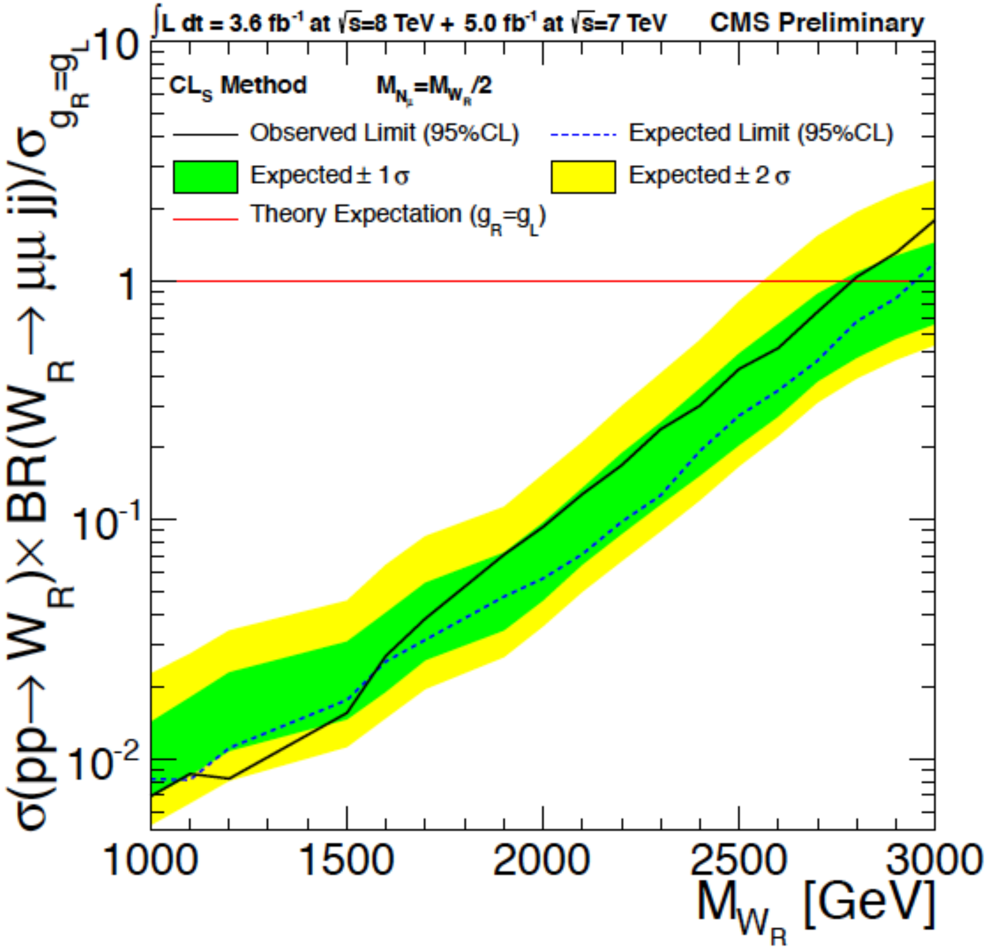
2D Limits muons 8 TeV





2D Limits muons 7+8 TeV





Summary

- 5 fb^{-1} of 7 TeV data and 3.6 fb^{-1} of 8 TeV 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 $M(W_R) \sim 2900$ GeV