Detection of W_R Bosons and Heavy Majorana Neutrinos in CMS

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Interplay of Collider and Flavour physics, 2nd general meeting, CERN, 16 – 18 March 2009

Introduction

Heavy Right-handed Neutrino:

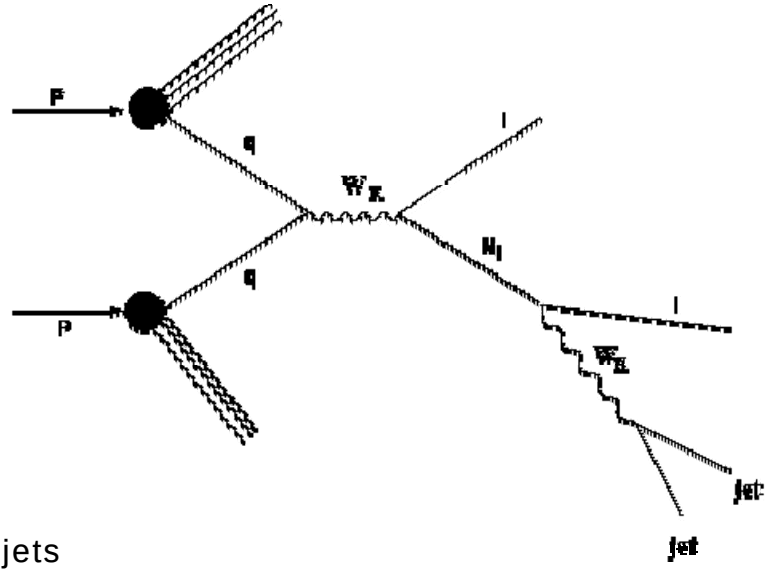
- Predicted by many models, frequently discussed: **Left-Right Symmetric Model**
  - incorporates W_R and Z' and heavy right-handed neutrino states N_l $(l=e, \mu, \tau)$, which can be the partners of light neutrinos
  - light neutrino masses are generated via See-Saw mechanism
  - explains parity violation in weak interactions
  - includes SM at $\sim 1\ TeV$ scale
- In many SM extensions
  $M(N_l) \sim 0.1\text{-}\ 1\ TeV$

Neutrinos are massive
But SM neutrino
has no mass

Enhance Motivation
to search for these
new particles at CMS!

Model parameters

At the first stage we study the minimal model, couplings in the right sector the same as in the lift one, no strong mixing



Masses:

- $M(W_R)$, $M(Z')$, $M(N_l)$; $l=e, \mu, \tau$

Reactions:

- $pp \rightarrow Z' \rightarrow N_l + N_l + X$
- $pp \rightarrow W_R \rightarrow l + N_l + X$
- $N_l \rightarrow l + jet + jet$

Signature:

- two high-Pt isolated leptons and two high-Pt jets
- If Majorana N, 50% of leptons have same sign. We don't use this feature

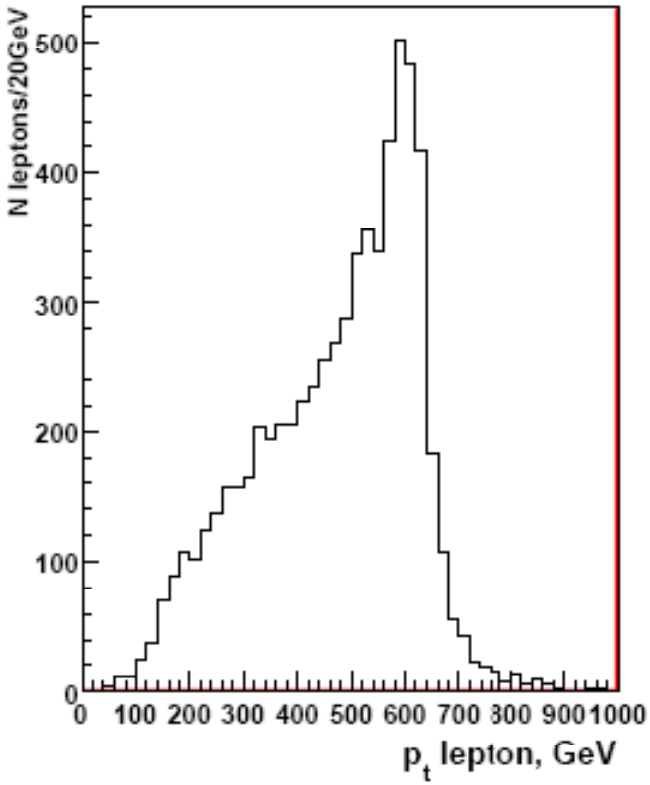
Current direct limits (by Tevatron experiments):

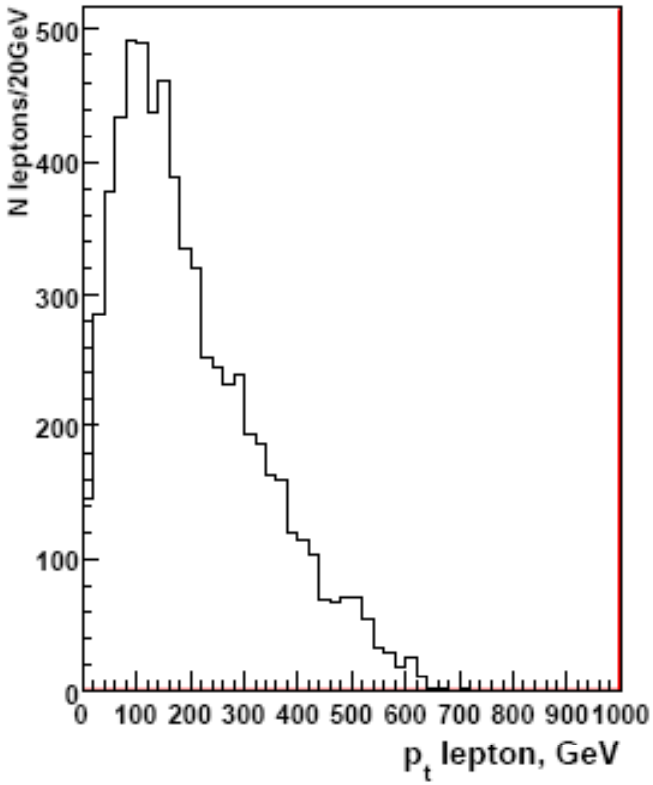
- $M(W_R) > 0.8$ TeV
- $M(N_l) > 0.3$ TeV

Our reference point: $M(W_R) = 2$ TeV, $M(N_l) = 500$ GeV

- Points for 100 pb^{-1}: $M(W_R) = 1.5$ TeV, $M(N_l) = 600$ GeV ; $M(W_R) = 1.2$ TeV, $M(N_l) = 500$ GeV
- Misalignment and miscalibration as expected for int. luminosity of 100 pb^{-1} (a few days of LHC operation at the nominal luminosity)
- Dielectron and dimuon events are studied

Leptons momenta: hardest lepton and second one





Triggers and Datasets

- Trigger menu for luminosity $L = 10^{32}\ cm^{-2}\ sec^{-1}$
- Electron channel:
  Two high threshold triggers (thr. 80 and 120 GeV)
  Sign. eff. 99%, 0.6 Hz: 100 1/pb: 300 GB
  (2 MB/event)
- Muon channel:
  Trigger candidate Pt cut 80 GeV: almost no efficiency drop: 93%

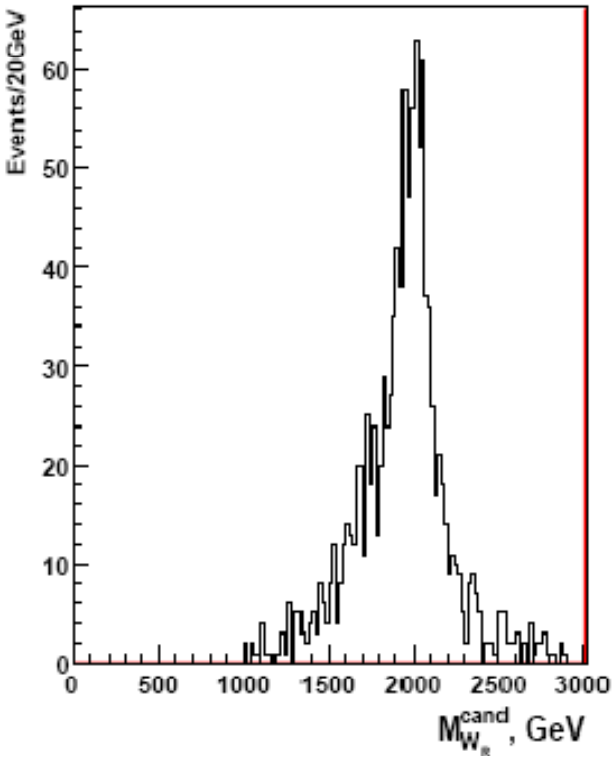
Physical objects

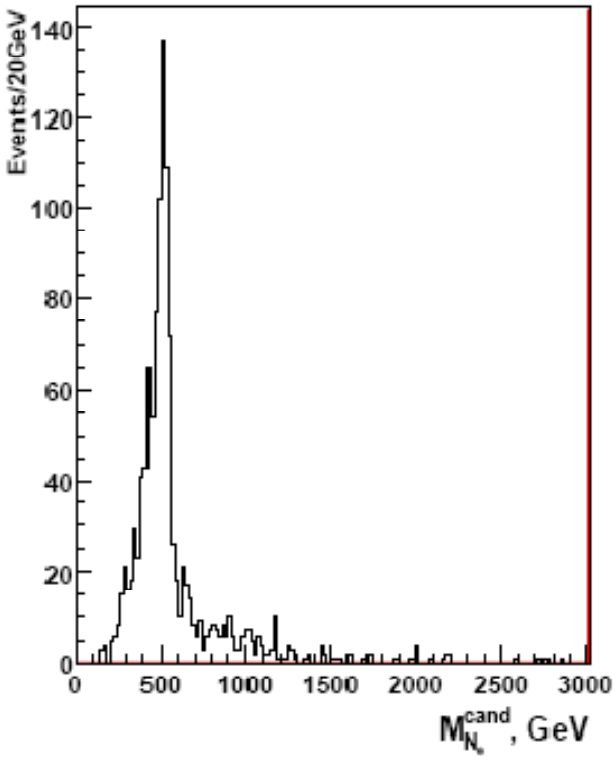
- Electrons, pt cut 20 GeV
- Muons, pt cut 20 GeV
- Isolation in a cone 0.3 required for leptons
- Jets: cone 0.5, pt cut 40 GeV

Event selection

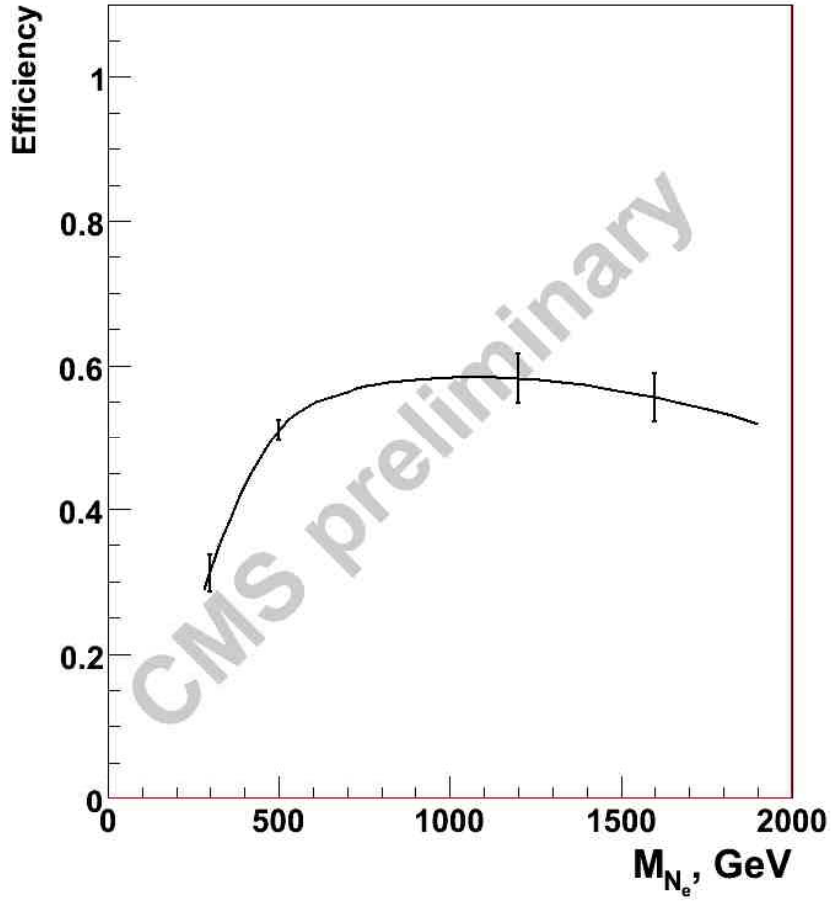
- Exactly 2 leptons and at least 2 jets
- At least 1 lepton with Pt > 80 GeV
- We take 2 jets with highest pt. In at least 90% of events – correct choice
- 4 objects – W_R candidate inv. mass
- Lowest pt lepton + two jets - N candidate inv. mass

Signal distributions, LRRP, electrons

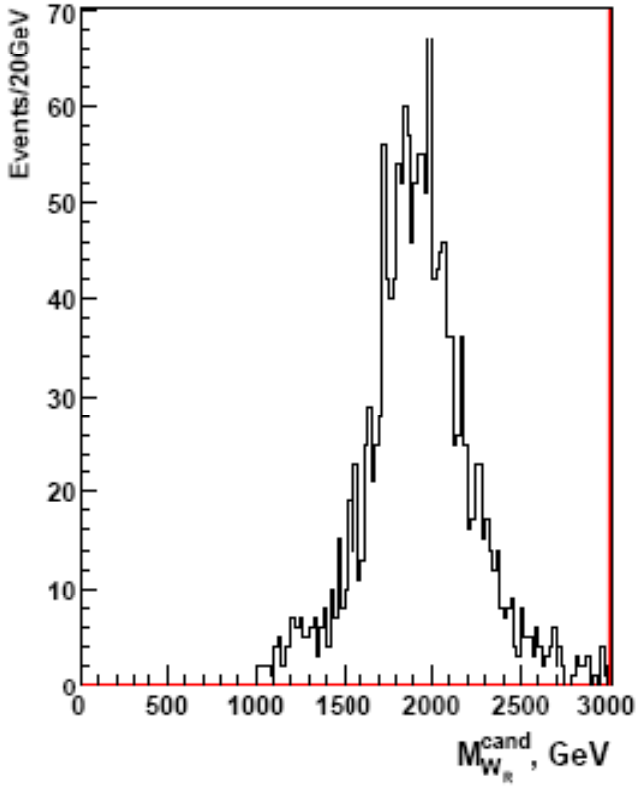


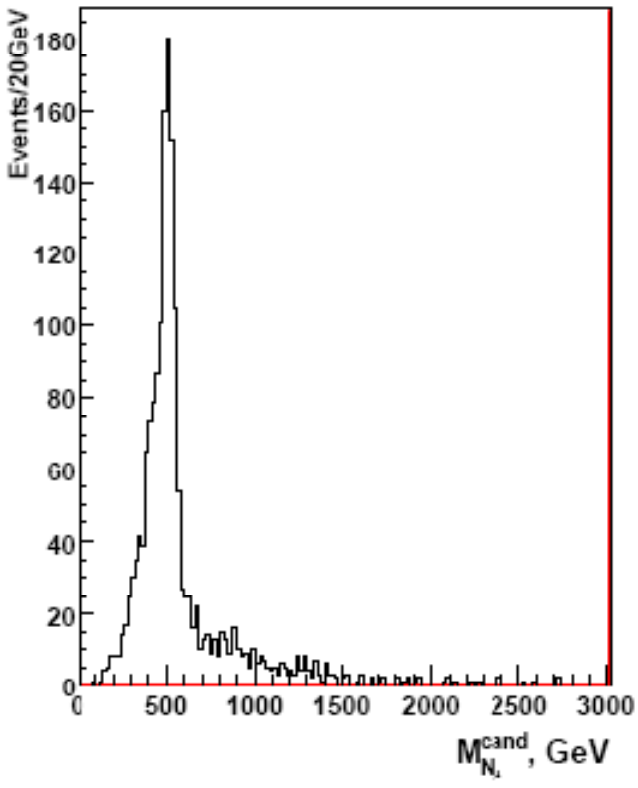


Probability to pass the primary selection, point LRRP (2000 GeV, 500 GeV), electrons

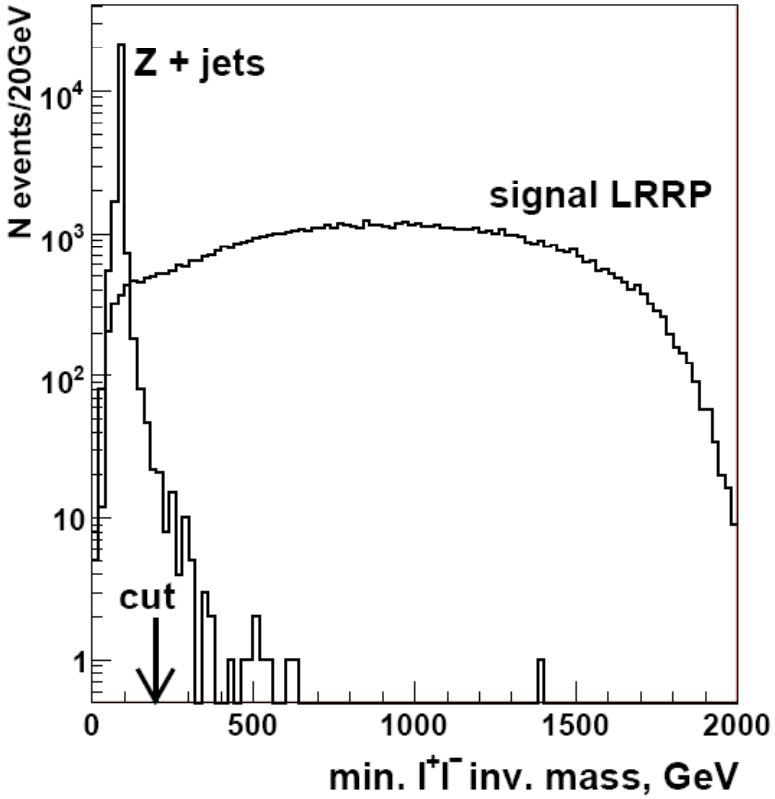


Signal distributions, LRRP, muons





Backgrouns. Studied on CSA07 and private samples
Main one tt + jets, then Z + jets



Backgrouns. Main one tt + jets, then Z + jets. Heavy flavours (stew) in the last colomn

Table 4: Evolution of the numbers of signal and background events versus selection criteria (electron channel). The numbers correspond to the statistics collected in the CMS detector for the integrated luminosity $L_t = 100\, pb^{-1}$

Step	Signal LRRP1	$t\bar{t}$	Z jets	W jets	γ jets	QCD	WW jets	WZ jets	Others
Initial, $p_t > 20$	49	83600	577 700	$5.8 \cdot 10^6$	$1.8 \cdot 10^7$	10^{11}	12800	5200	10^{10}
Primary selection	24.5	315	519	14.2	1.43	27	21.6	37.6	23.3
Two isolated $e^{\pm}$	23.7	136	504	8.7	1.31	24	8.16	31.2	20.7
M_{ll} cut	22.6	34	11	3.3	0.73	0.23	3.2	0.56	1.4
$M_{W_R}^{cand} > 600\ GeV$	23	19	7.2	2.1	0.68	0.23	2.27	0.56	1.25
Under 2D peak	14	0.44	0.15	0.031	0	0	0.084	0	0.1

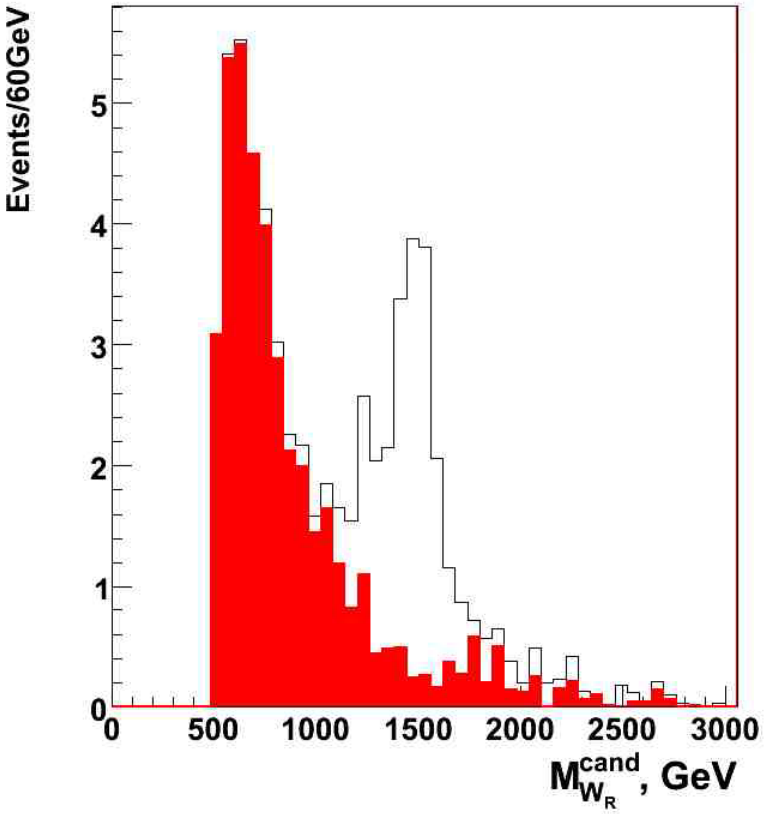
On the statistics available in CSA07 the shape of all these backgrounds is compatible

Backgrouns, muons

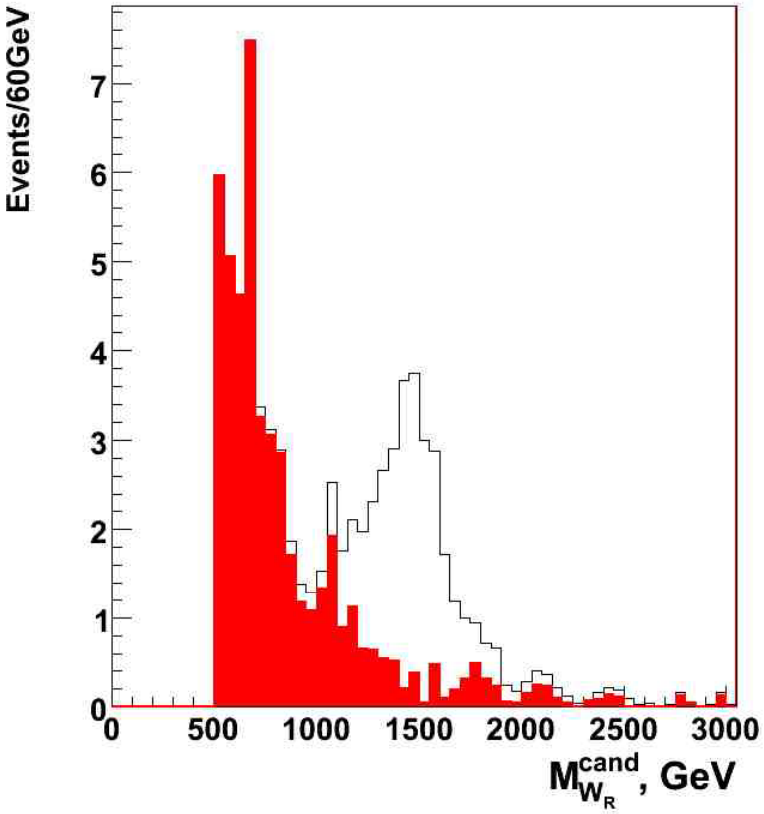
Step	Signal LRRP1	$t\bar{t}$	Z jets	W jets	γ jets	QCD	WW jets	WZ jets	Others
Initial, $p_t > 20$	49	83600	577 700	$5.8 \cdot 10^6$	$1.8 \cdot 10^7$	10^{11}	12800	5200	10^{10}
Primary selection	32	335	737	13.7	0	32	26	49	244
Two isolated $\mu^{\pm}$	31	168	730	0.97	0	8	12.2	42	233
M_{ll} cut	29.5	41	12.5	0.26	0	3.4	3.5	0.6	0.96
$M_{W_R}^{cand} > 600\ GeV$	23	22	8.7	0.025	0	3.4	2.6	0.57	0.62
Under 2D peak	17.6	0.57	0.16	0	0	0	0.19	0	0

Signal/background 100 1/pb, MW=1500 GeV

Electron channel

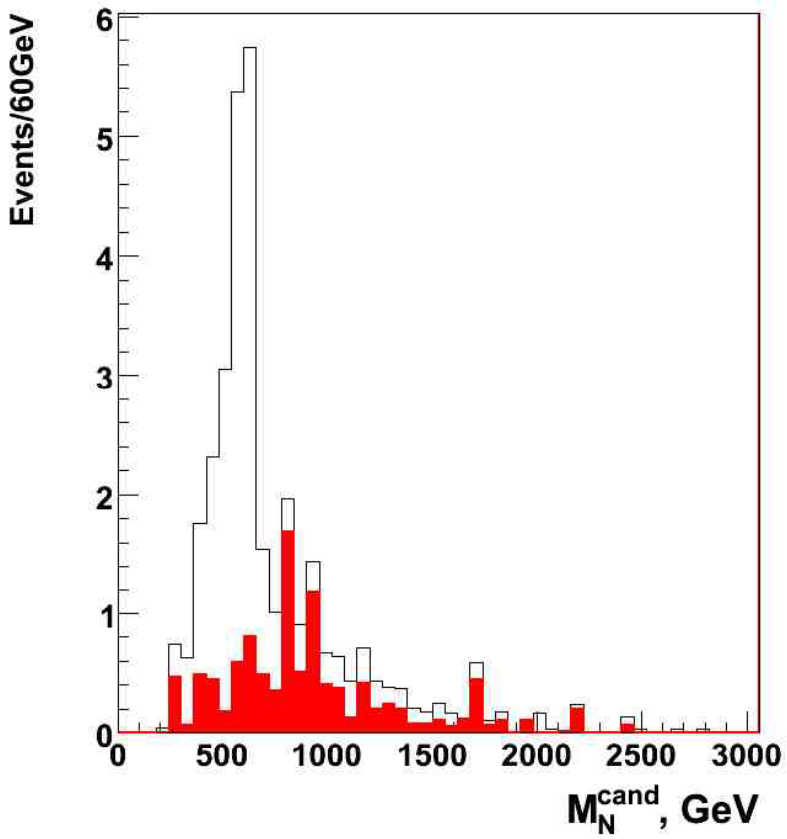


Muon channel

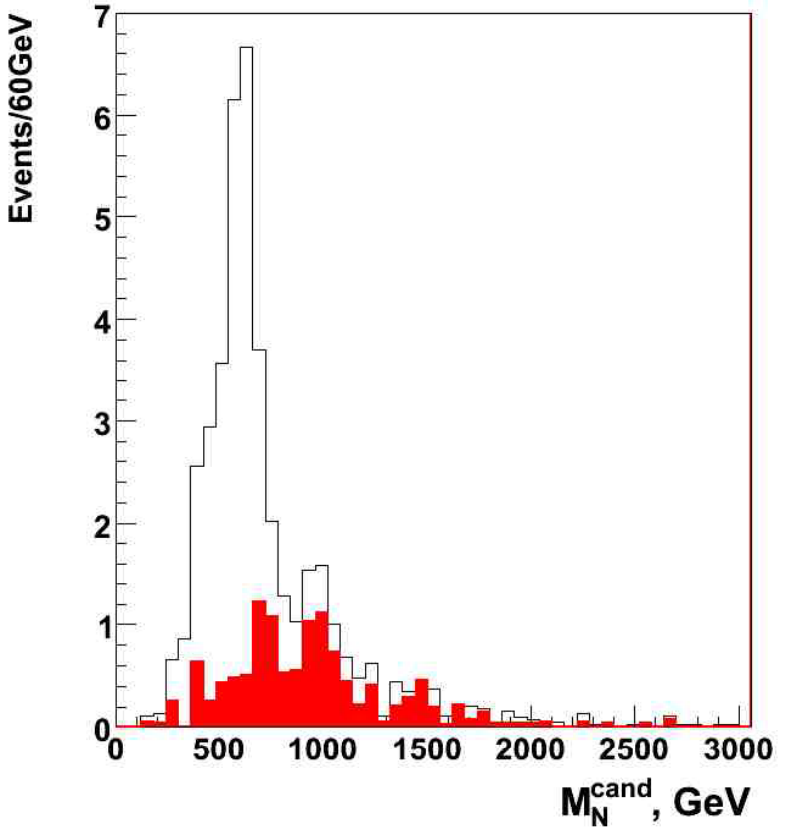


Signal/background 100 1/pb, MW=1500 GeV, MN=600 GeV (cut MWcand > 1000)

Electron channel

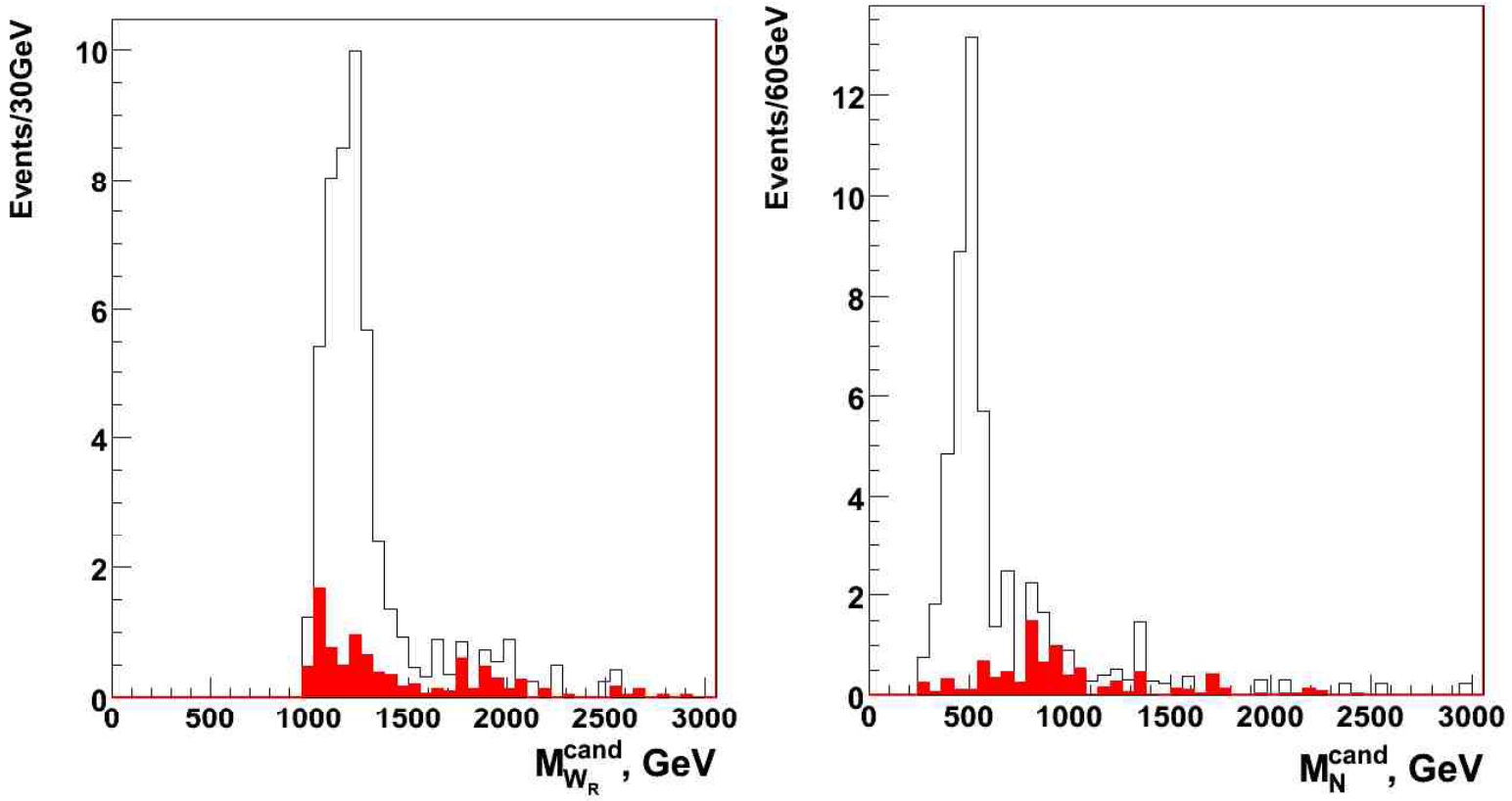


Muon channel



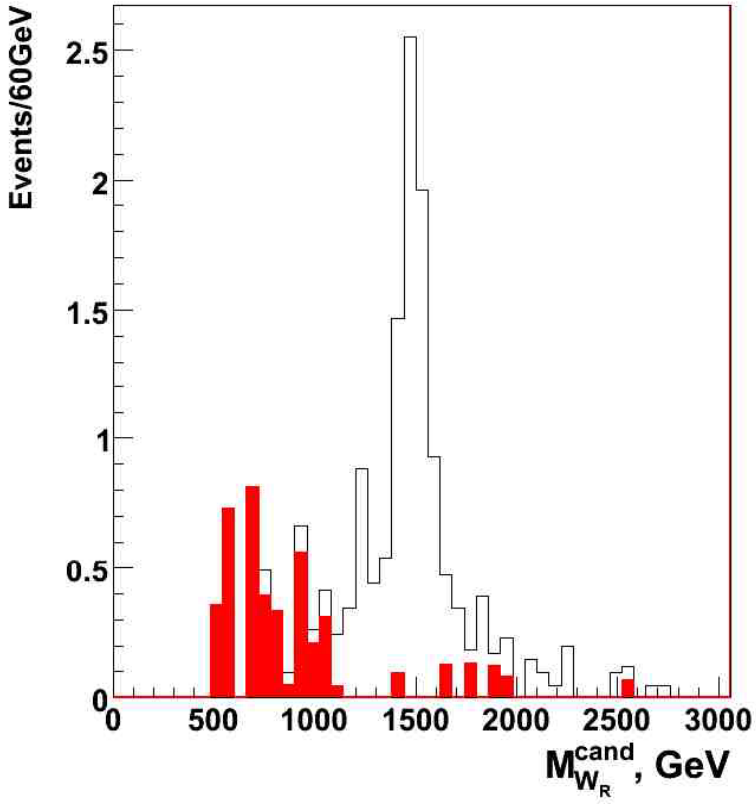
Signal/background 100 1/pb, MW=1200 GeV, MN=500 GeV

Electron channel



Like sign leptons. Signal/background 100 1/pb, MW=1500 GeV, MN=600 GeV.

Electron channel



Remarks about same sign background

Background here is smaller, but in the case of Majorana neutrino we lose 50% of signal and the sensitivity drops. It is just a good check

Composition of background, electron channel, 1500 GeV, wide W mass window:

all:	1.892
chowder:	0.7685
gumbo Gamma+jets:	0.675
Stew bbe e-enriched:	0.195
diboson WZ	0.111 (physical)
diboson WW	0.136

The measurements will not be based on the same sign signature because we lose half of signal events and the significance drops. This is only a cross-check if we see a signal. So, just absolute data correction from the same sign events in the Z peak could be sufficient

Fit

$$P(M_{Wcand}, M_{Ncand}) =$$
$$nsig * BW(M_W, W_W, M_{Wcand}) *$$
$$BW(M_N, W_N, M_{Ncand}) +$$
$$nbg * PBG(M_{Wcand}, M_{Ncand})$$

BW – Breit-Wigner function

M_{Wcand} , M_{Ncand} – inv. Masses of WR and N candidates

Fit(3)

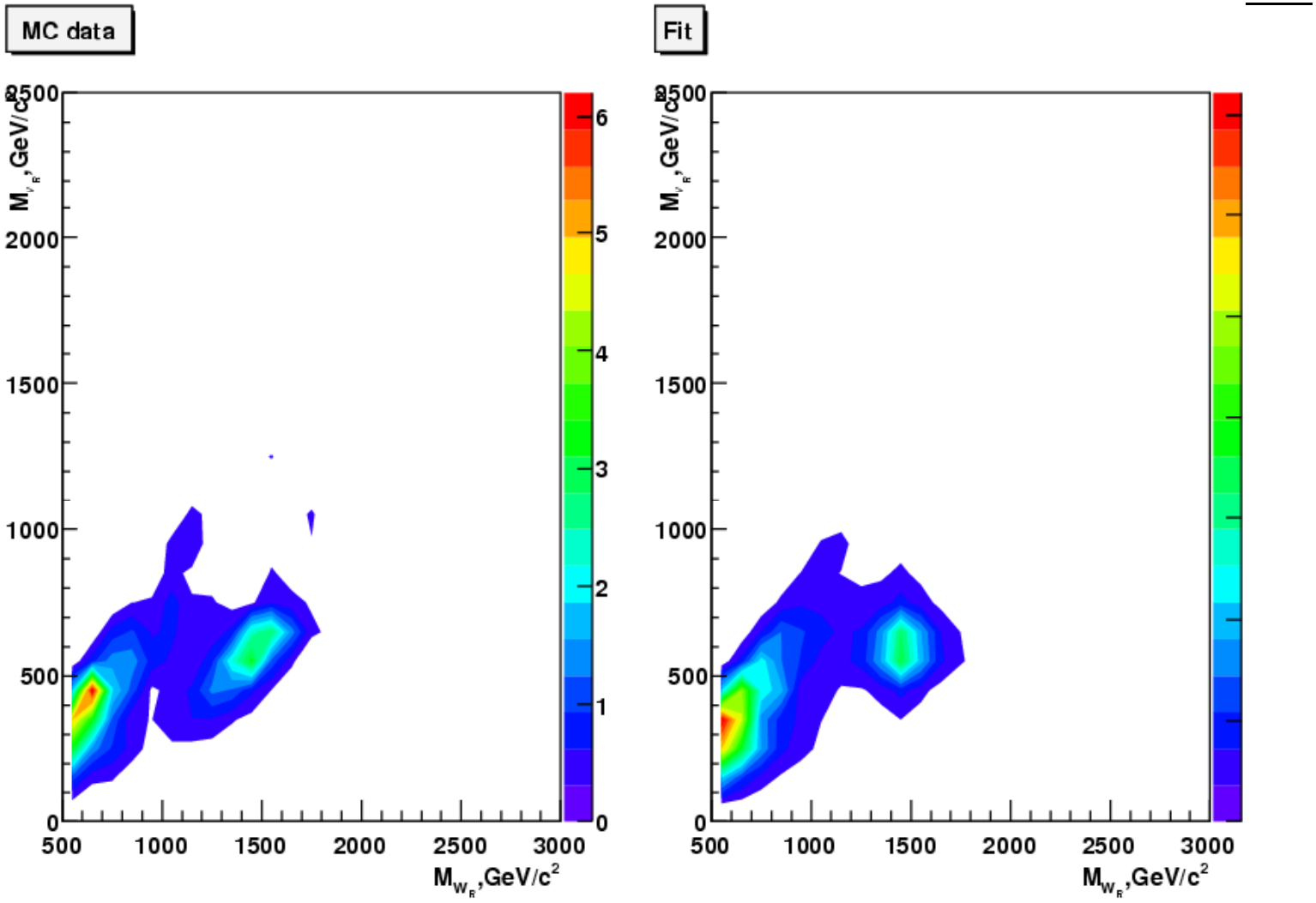
Free parameters of the fit:

nsig, *nbg*

Quasi-free parameters of the fit:

W_W, W_N (assume for the moment 2% for W_W, W_N fixed)

Fit results
(μμ channel, $M(W_R)$ = 1500 GeV/c^2)

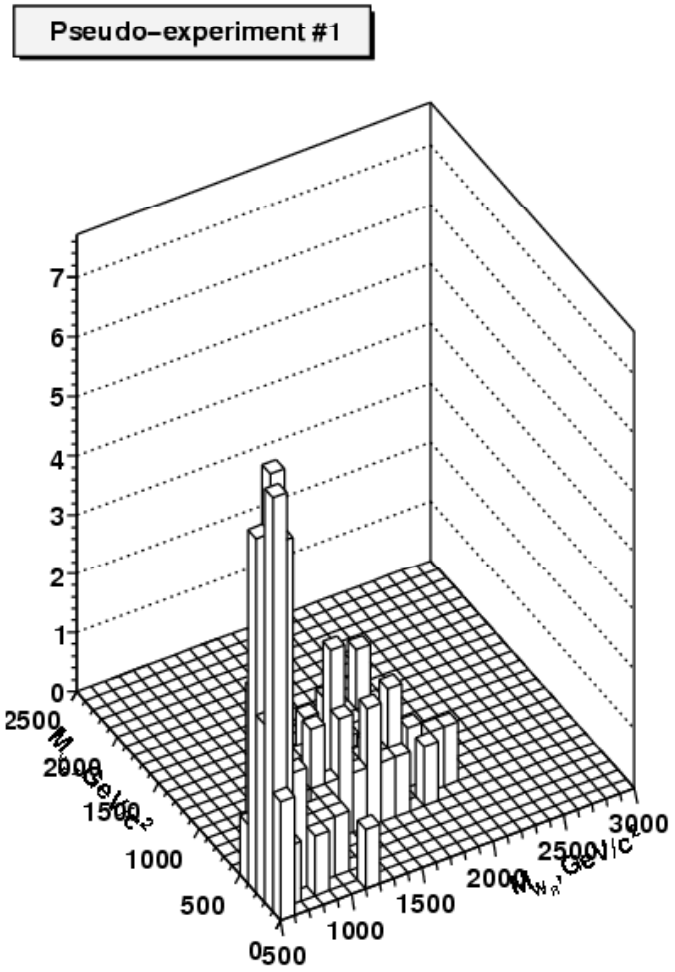


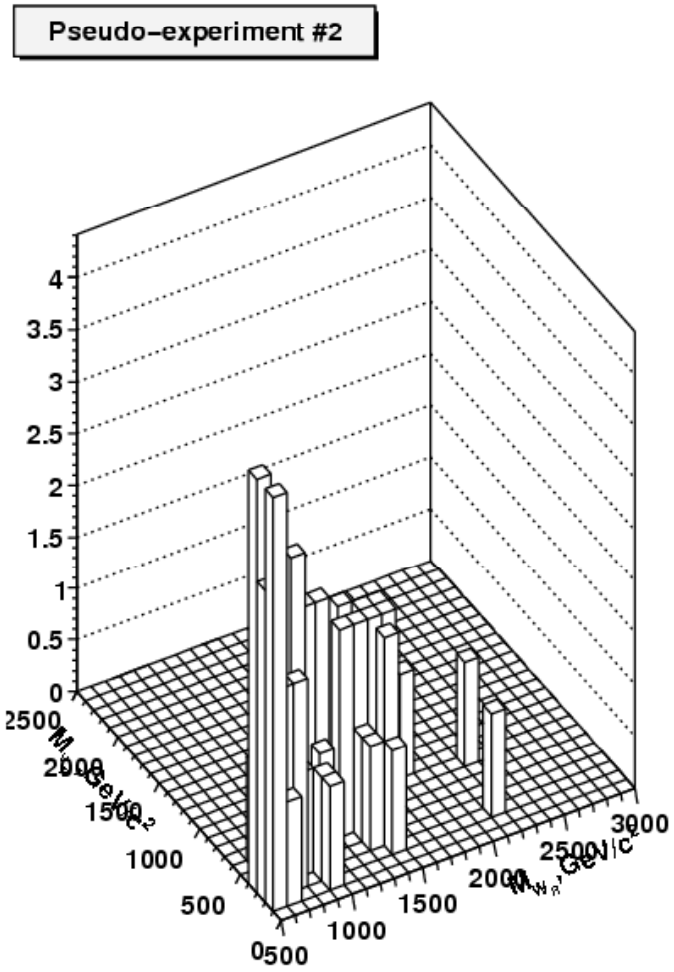
Pseudo-experiments (toy MC)

- Based on the distribution of weighted MC events the “toy MC” is performed: pseudo-experiments with unity – weight simulated events

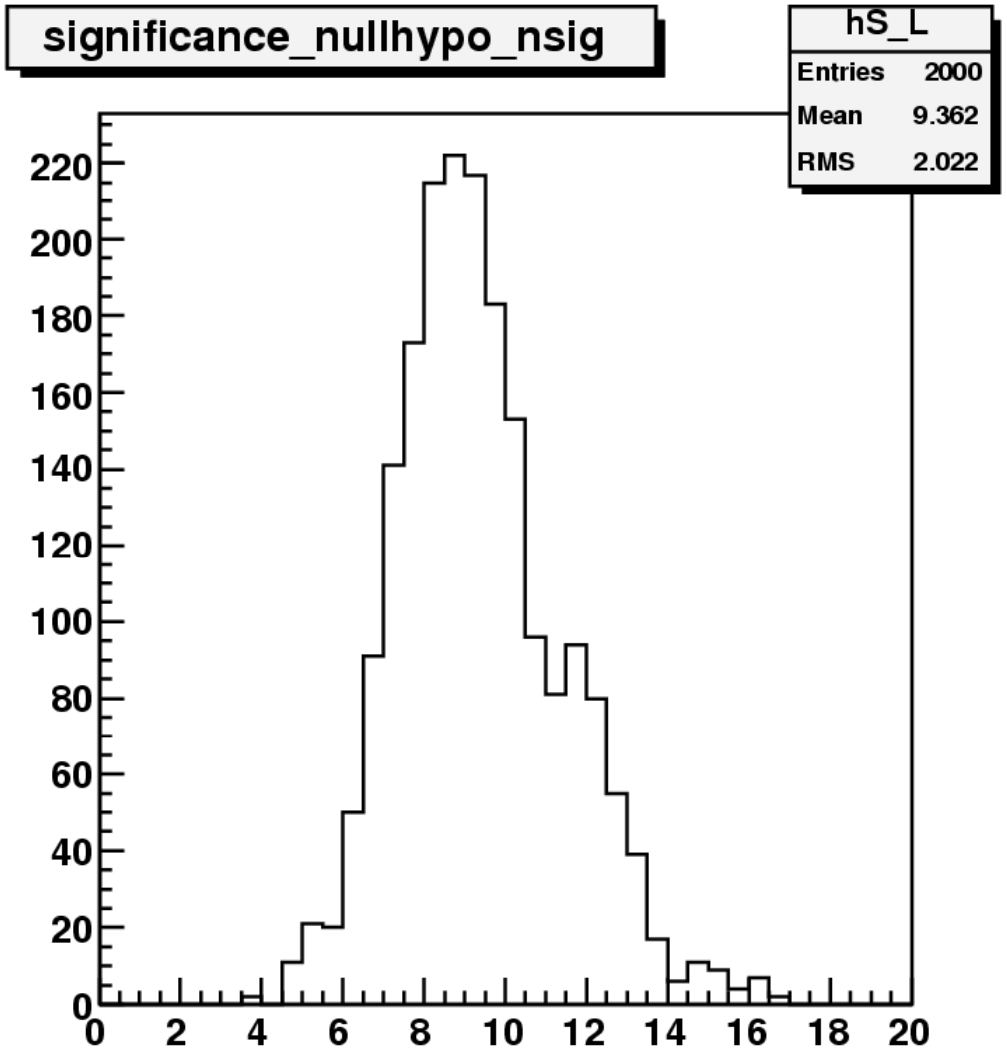
- 1000 pseudo-experiments

Examples of data generated by toy MC





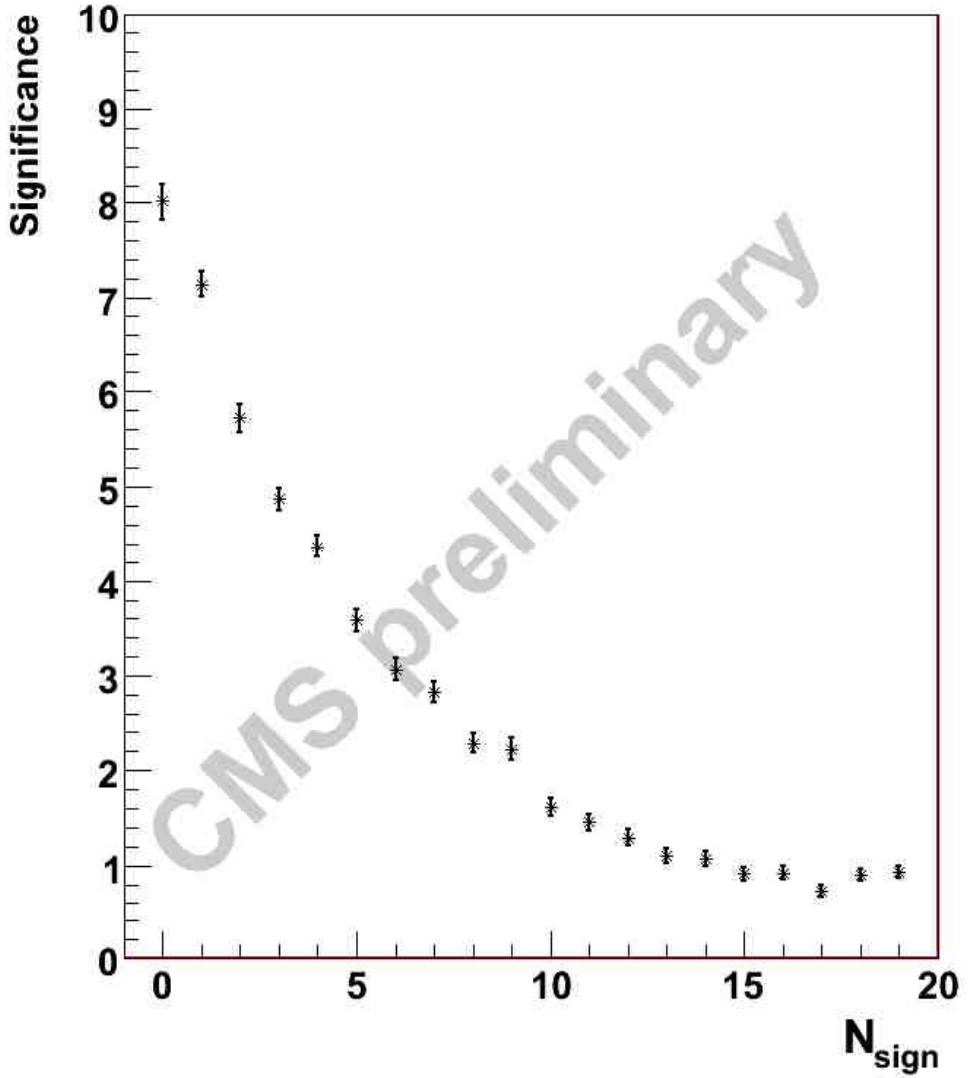
Significance (stat. only) $S = \sqrt{2\ln(L_{S+B} / L_B)}$



Checked for the point (2000,1200) with significance about 3 the probability to imitate signal: 6 out of 1000. Compatible with 2.7 as should be

Significance behaviour

$$S = \sqrt{2\ln(L_{S+B} / L_B)}$$



Signal extraction

- Our analysis is a "bump hunt"
- Signal will be extracted from a fit, absolute BG normalization – completely free parameter of the fit
- Critical for the analysis is the efficiency to the signal

Efficiency from data

- Efficiency to leptons mainly from Z sample. With our preferred triggers we should have 500 – 600 events in each lepton channel
- Tag and probe method, make use of the resonance nature of Z
- Take pairs of leptons in the Z peak, strict cuts on one (tag), loose or no on the other (probe). Study eff. on probe
- Resonant nature of Z ensures small BG
- Reconstruct Z + jets, tt events in e-mu and semileptonic channels for jet efficiency

BG control (shape only can be important)
Most important BG components:

- tt events: electron – muon sample to control
- Z+jets events: sample with relaxed Mll cut (80 GeV) to control: > 200 events with MW > 500 GeV. The shape can be different!
- Events with fake leptons (W+jets, gamma+jets, QCD): electron – muon sample with same sign to control

BG control. Electron – muon channel. Dominated by tt

Step	$t\bar{t}$	Z jets	W jets	γ jets	QCD	WW jets	WZ jets	Others
Primary selection	604	1255	25	0.05	99	43.	84	266
$e-\mu$ pair	291	9.5	14	0.05	78	22.1	5.2	21
M_{ll} cut	73	0.47	6	0	14	7.3	1.7	2.6
$M_{W_R}^{cand} > 600\ GeV$	39	0.26	4	0	1.48	5.5	1.3	1.6

BG control, e-mu same sign. Dominated by fakes. If MC is good, the number should be about 5 times smaller than in all signs

Step	$t\bar{t}$	Z jets	W jets	γ jets	QCD	WW jets	WZ jets	Others
Primary selection	604	1255	25	0.05	99	43	84	266
$e-\mu$ pair	25.6	1.2	8.2	0.05	22	1.8	2.6	5.8
M_{ll} cut	6.2	0.3	3.6	0	14	0.7	1	1.4
$M_{W_R}^{cand} > 600\ GeV$	3.8	0.1	2.27	0	1.4	0.6	0.77	0.64

One additional degree of freedom: wrong charge measurement

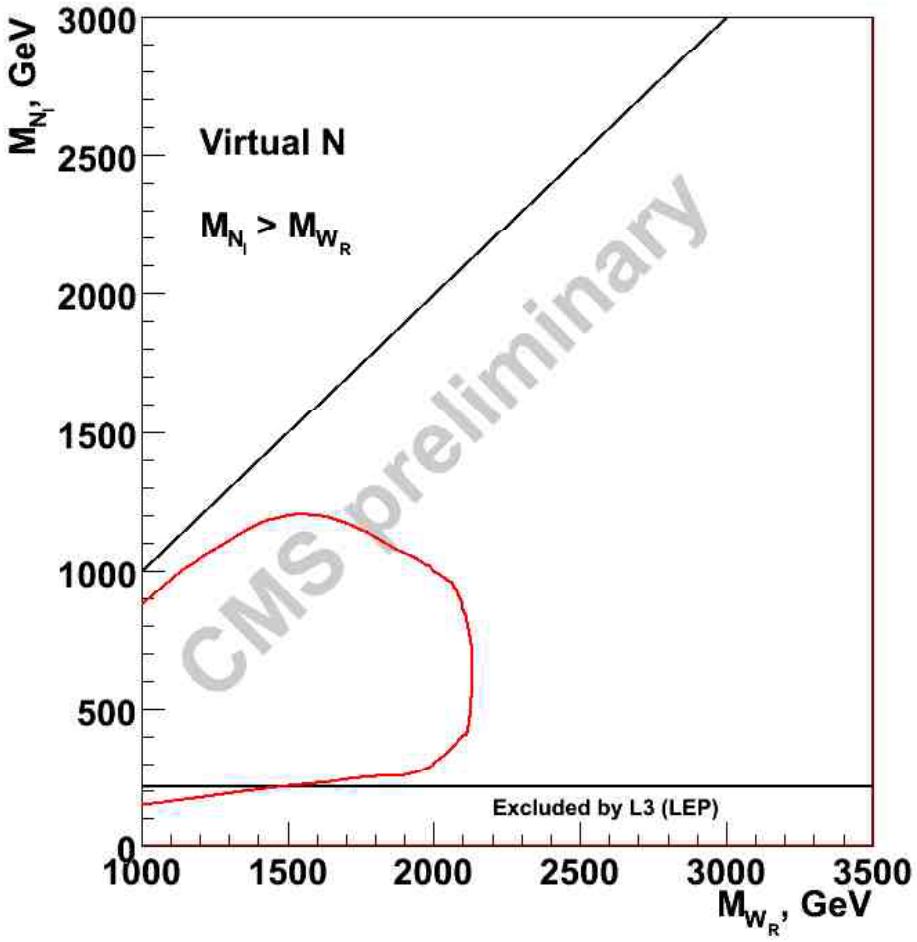
BG control procedure

- tt distribution shape: we compare 1D projections of the electron – muon sample with MC (40 events: rather big errors) and can use directly these corrections
- Z+jets distribution shape: we compare the sample with relaxed Mll cut (80 GeV) with MC. The shape can be different, so probably we cannot use directly the corrections.
- Events with fake leptons (W+jets, gamma+jets, QCD): check electron – muon sample with same sign and compare the number with all signs. If the factor is much different from 5, we introduce weight and eventually try to tighten the lepton selection cuts

Systematic uncertainties

- PDF uncertainty in the signal cross section is within 6%. Obtained by using several different PDF sets, actually 6% is the maximal difference
- Jet energy scale. Uncertainty about 10% (should be maximal at 100 1/pb) causes mass measurement uncertainty 5 – 10%. Everything, with background, could be shifted by this value. Should be taken into account if we observe the signal or if we set limits. In addition, it makes the signal peak wider by 2 - 3%
- Luminosity uncertainty 10%
- Total 15%

Discovery plot (S=5)

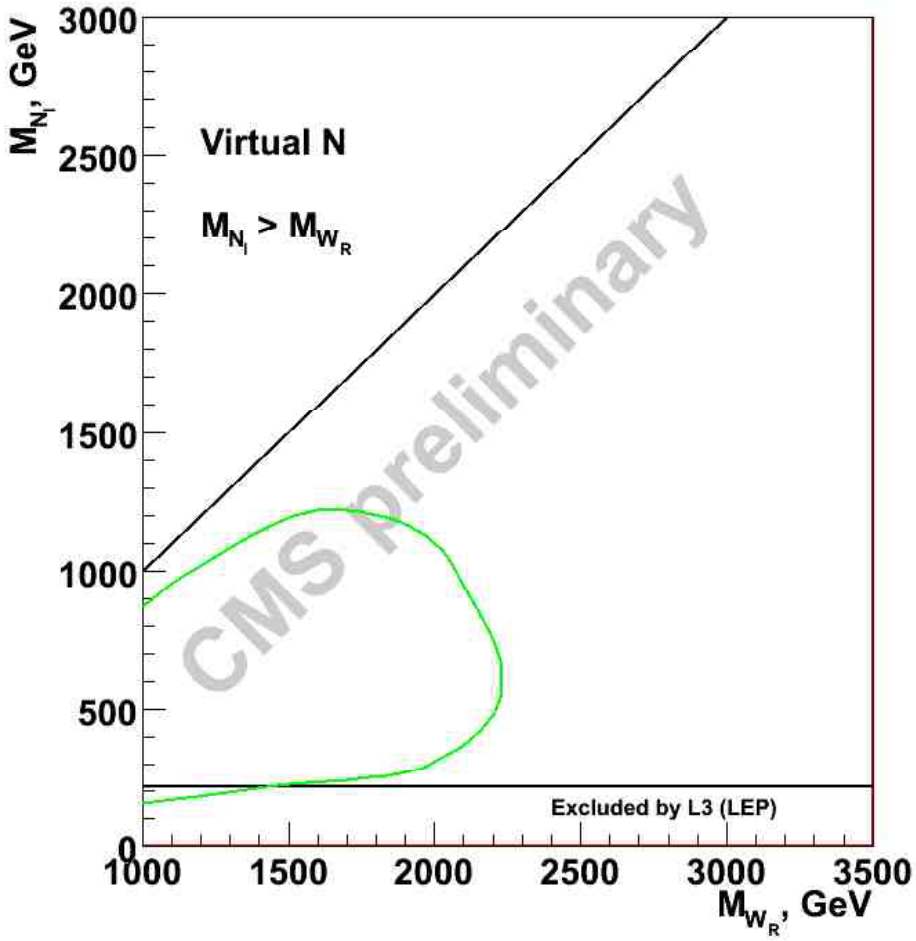


CMS discovery potential of the W_R boson and right-handed heavy neutrino for luminosity 100 pb^{-1}.

Exclusion plot calculation

- The same points in the parameter space
- Packages RooFit and RooStat.
- Find representative likelihood ratio S0 as a median value of S for BG only preudoexperiments
- Simulate bg + signal(NCL) pseudoexperiments, find NCL so that S < S0 in 95% of them
- If NCL < N0 (N0 – number of signal events corresponding to cross section and luminosity), this point of the parameter space can be excluded at 95% C.L.
- Extrapolate masses to N0=NCL
- Systematics 15% for the moment taken into account pessimistically by NCL = NCL/0.85

95% C.L. Exclusion plot



CMS 95% C.L. exclusion plot of the W_R boson and right-handed heavy neutrino for luminosity 100 pb^{-1}.

Summary

- W_R and Heavy right-handed neutrino N (Majorana or a mixture) of the minimal Left-Right symmetric model can be discovered at 100 1/pb for the masses of W_R up to 2100 GeV and masses of N from 300 to 1200 GeV (collision energy 14 TeV)
- At the collision energy of 10 TeV the maximal W_R mass reach drops to 1500 GeV
- With sufficient statistics we can check if it is a Majorana neutrino