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**LHC(CMS) Detection of Heavy Majorana Neutrinos and Right Handed Bosons.**

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*RUSSIAN FEDERATION*

# LHC(CMS) Detection of Heavy Majorana Neutrinos and Right – Handed Bosons

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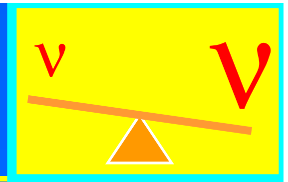
# Introduction and motivation




- SuperK'98 result: neutrinos are massive
  In SM neutrino has no mass : **Direct indication for new physics**

- In many models $m_n$ appears naturally
  Most attractive: Left-Right Symmetric Model:
  - incorporates $W_R$ and Z' and heavy right-handed Majorana neutrino states $N_l$, which can be the partners of light neutrinos, $l=e,\mu,\tau$
  - light neutrino masses are generated via See-Saw mechanism
  - explains parity violation
  - includes SM at ~1 TeV scale
  - in many SM extensions $M_N \sim 0.1$- 1 TeV

**Enhance Motivation to search for these new particles at CMS!**

# Some useful references

- J.C.Pati and A.Salam, Phys.Rev. D10,275(1974)
- R.N.Mohapatra and J.C.Pati, Phys.Rev.D11, 566(1975); Phys.Rev.D11,2558(1975)
- G.Senjanovic and R.N.Mohapatra, Phys.Rev.D12,1502(1975); Phys.Rev.Lett.,44, 912(1980)

# Minimal LR model

- Minimal left-right symmetric model is based on $SU_C(3)\otimes SU_L(2)\otimes SU_R(2)\otimes U(1)_{B-L}$ gauge group
- Each generation of quarks and leptons carry the quantum numbers
- $Q_L \sim(1/2,0,1/3)$, $Q_R \sim(0,1/2,1/3)$,
- $L_L \sim(1/2,0,-1)$, $L_R \sim(0,1/2,-1)$
- Right-handed neutrino $N_R$ should exist

# The minimal Higgs sector

- bi-doublet $\Phi \sim (1/2,1/2,0)$
- Two triplets
  $\Delta_R \sim (1,0,2)$ and $\Delta_L \sim (0,1,2)$
- Nonzero vacuum expectation value $|v_R|$ breaks LR gauge group to the SM gauge group
- Strict LR symmetry leads to $g_L = g_R$

# New gauge bosons

- LR model predict the existence of new
- charged gauge boson $W_R$ and neutral

  Z` gauge boson
- Direct TEVATRON bound $M_{WR}$ >720 GeV
- Indirect bounds are more stringent

  $M_{WR} > (1.6 – 2.5)$ TrV

# Parameters of the Model and Signature

## Parameters:

$M(W_R)$, $M(Z')$, $M(N_L)$

$L=e,\mu,\tau$

## Assumptions:

- mixings are small
- Right-H CKM = Left-H CKM
- g(r) = g(l)
- Only $M(N_e)$ is reachable, others are too heavy

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

## Reactions

$pp \to Z' \to N_e + N_e + X$

$pp \to W_R \to e + N_e + X$

$N_e \to e + j1 + j2$

better sensitivity

## Signature:

- two high Pt electrons
- (muons)
- two high Pt jets
- half of ee pairs have the same sign in case of Majorana neutrino

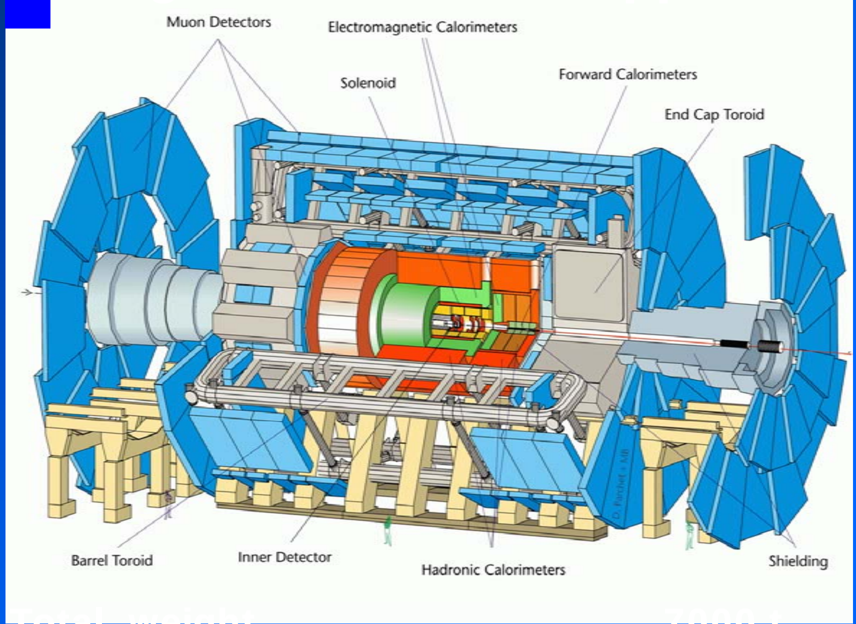
# References

- The results presented in this talk are based on:
- S.N.Gninenko, M.M.Kirsanov, N.V.Krasnikov, V.A.Matveev, CMS NOTE 2006/098(2006) and CMS Physics TDR, v.2
- Similar results have been obtained by ATLAS Collaboration(ATLAS Physics TDR,v.2)

# ATLAS and CMS Experiments

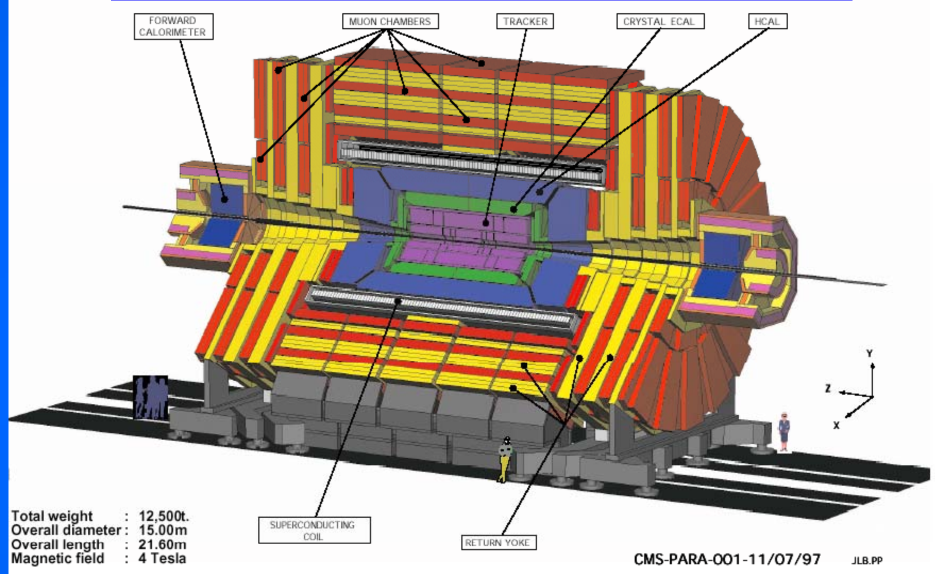
Large general-purpose particle physics detectors

## A Large Toroidal LHC ApparatuS




| | |
|---|---|
| Total weight | 7000 t |
| Overall diameter | 25 m |
| Barrel toroid length | 26 m |
| End-cap end-wall chamber span | 46 m |
| Magnetic field | 2 Tesla |

## Compact Muon Solenoid




| | |
|---|---|
| Total weight | 12 500 t |
| Overall diameter | 15.00 m |
| Overall length | 21.6 m |
| Magnetic field | 4 Tesla |

Detector subsystems are designed to measure:
energy and momentum of $\gamma$ ,e, $\mu$, jets, missing $E_T$ up to a few TeV

# Compact Muon Solenoid (CMS) DETECTOR

EM Calorimeter,

$\sigma/E \approx 3\%/\sqrt{E(GeV)} \oplus 0.5\%$

CALORIMETERS

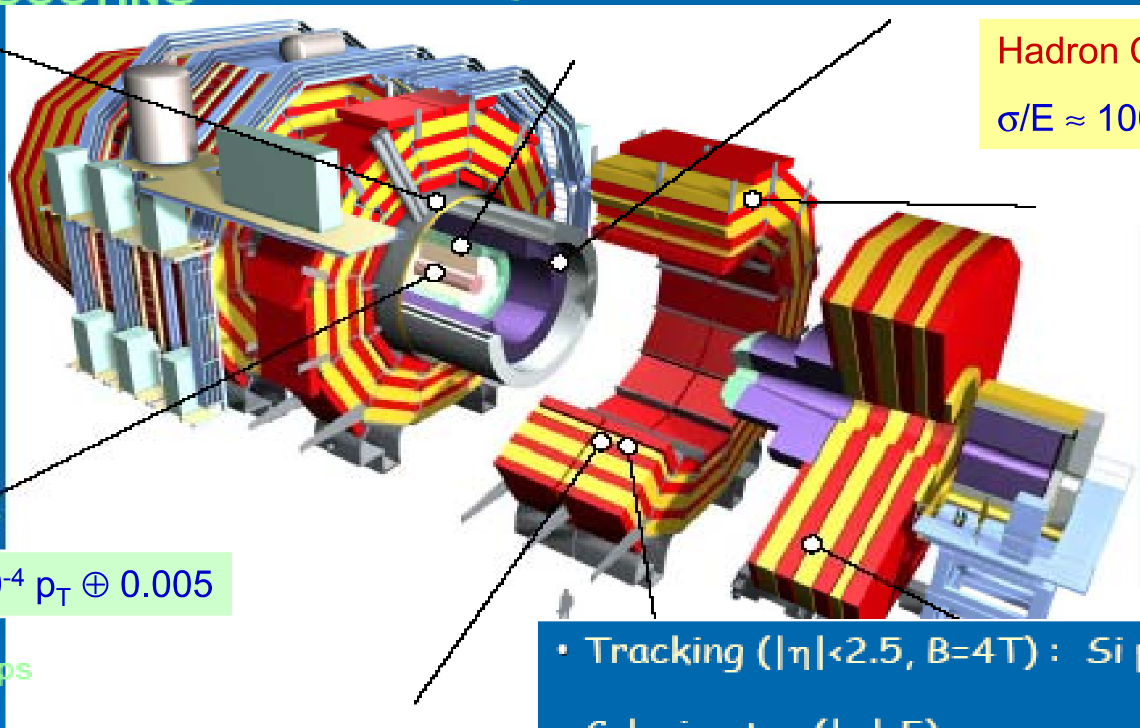
Scintillating PbWO4 crystals | ECAL | HCAL | Plastic scintillator/brass sandwich

SUPERCONDUCTING COIL

Hadron Calorimeter,

$\sigma/E \approx 100\% / \sqrt{E(GeV)} \oplus 5\%$

IRON YOKE



TRACKER

$\sigma/p_T \approx 1.5 \times 10^{-4}\, p_T \oplus 0.005$

Silicon Microstrips
Pixels

Total weight : 12,500 t
Overall diameter : 15 m
Overall length : 21.6 m
Magnetic field : 4 Tesla

MUON E

Drift Tube Chambers

- Tracking ($|\eta|<2.5$, B=4T) : Si pixels and strips
- Calorimetry ($|\eta|<5$) :
  -- EM : $PbWO_4$ crystals
  -- HAD: brass-scintillator (central+ end-cap), Fe-Quartz (fwd)
- Muon Spectrometer ($|\eta|<2.5$) : return yoke of solenoid instrumented with muon chambers

Muon Spectrometer,

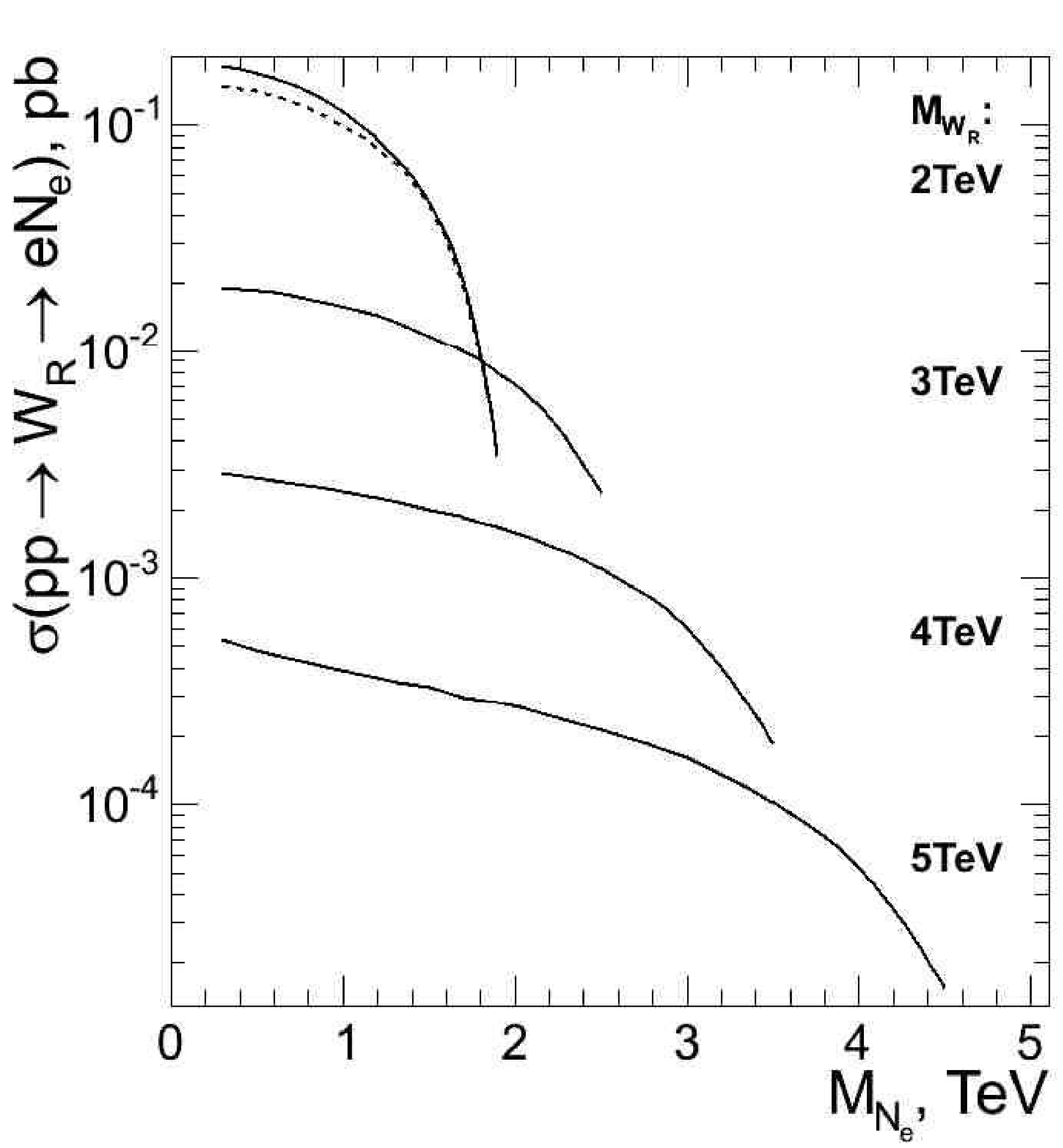
$\sigma/p_T \approx 5\%$ at 1 TeV/c (from Tracker)

# Reconstruction

- Trigger, several possible types. used electron(muon) and electron (muon)pair
- Electrons(muons) (sometimes high Pt)
- Isolation of electrons(muons) in Tracker and Calorimeter
- Jets, in some regions of the parameter space close to each other

# Cross sections

Dashed line: the case with degenerated masses.



# Reconstruction with ORCA

- Electrons. + offline electrons, Et cut 20 GeV
- Double (closer than 0.05 to each other) electrons removed
- Isolation. By INR sleptons – heavynu group
- Tracker isolation: count tracks with Pt > 2 GeV reconstructed in R = 0.3 cone. Cut at 1 (only 1 track allowed).
- Calo isolation is made with towers. Adds little to the tracker isolation ⇨ disabled. Cell based isolation could be needed.
- Isolation cuts efficiency to MC matched electrons 91% (match distance 0.05). Purity of electron sample before isolation cuts 60%, after 90.4%

# Reconstruction with ORCA (2)

- Jets. Iterative Cone algorithm R=0.5
- Seed Et cut 1 GeV, tower Et cut 0.5 GeV
- GammaJet correction
- Et cut 40 GeV

# Analysis and Cuts

L1 single electron(muon) or pair required. Efficiency to generator preselected events 100%. Efficiency of similar HLT trigger is 99% (LRRP)

- Two isolated electrons(muons) . Both same sign and opposite sign.

- At least two jets. From these a pair of jets with highest Pt is chosen (signal jet pair). Signal jet pair + isolated electron

  → M(N) candidate (two combinations). Search for a peak

- Signal jet pair + two isolated electrons(muons)

  → $M(W_R)$ candidate Search for a peak.

- Minimal invariant mass of all lepton pairs M(ll) > 200 GeV

**Typical signal efficiency at LRRP is about 20%.**

# Background sources

- Obvious: WZ $\sigma \approx \sigma_{LRRP}$ Suppressed by M(ll) cut
- Highest: $\widetilde{tt}$ $\sigma \approx 1000\sigma_{LRRP}$ (NLO value 830 pb is taken). Simulated by PYTHIA. Both t decay to jet and leptons. Simulation by TOPREX shows that this is at least not to the optimistic side.
- Zg $\sigma \approx 100000$ $\sigma_{LRRP}$ $Z \rightarrow$ leptons. Simulated with Pt lower limit (CKIN(3) in PYTHIA) = 20 GeV Suppressed to acceptable level by M(ll) cut. Compared with ALPGEN Zjj on the generator level: within 30%
- ZH, WH $\sigma <$ $\sigma_{LRRP}$ (M(H) = 190 GeV). Some contribution, but $\sigma$ small
- WW, ZZ no contribution

# Background simulation

By INR Sleptons – heavynu group.

$t\bar{t}$: read DST with CRAB (together with heavynu – sleptons INR group). Statistics accumulated: 700000. Simulated by Pythia

full simulation with of Zg with event generator level pre-selection (factor 2000). 2.2 $10^6$ events

Other backgrounds (WZ, WH, ZH) are small, no effect on significance. Old fast simulation files used for the background reduction table, compatibility with limited full simulation samples and FAMOS checked: OK

# Invariant mass distributions

- $W_R$ decays into 2 leptons and two hadron jets

  Heavy neutrino decays into lepton and two hadron jets

  So the natural variables for analysis are invariant mass distributions:

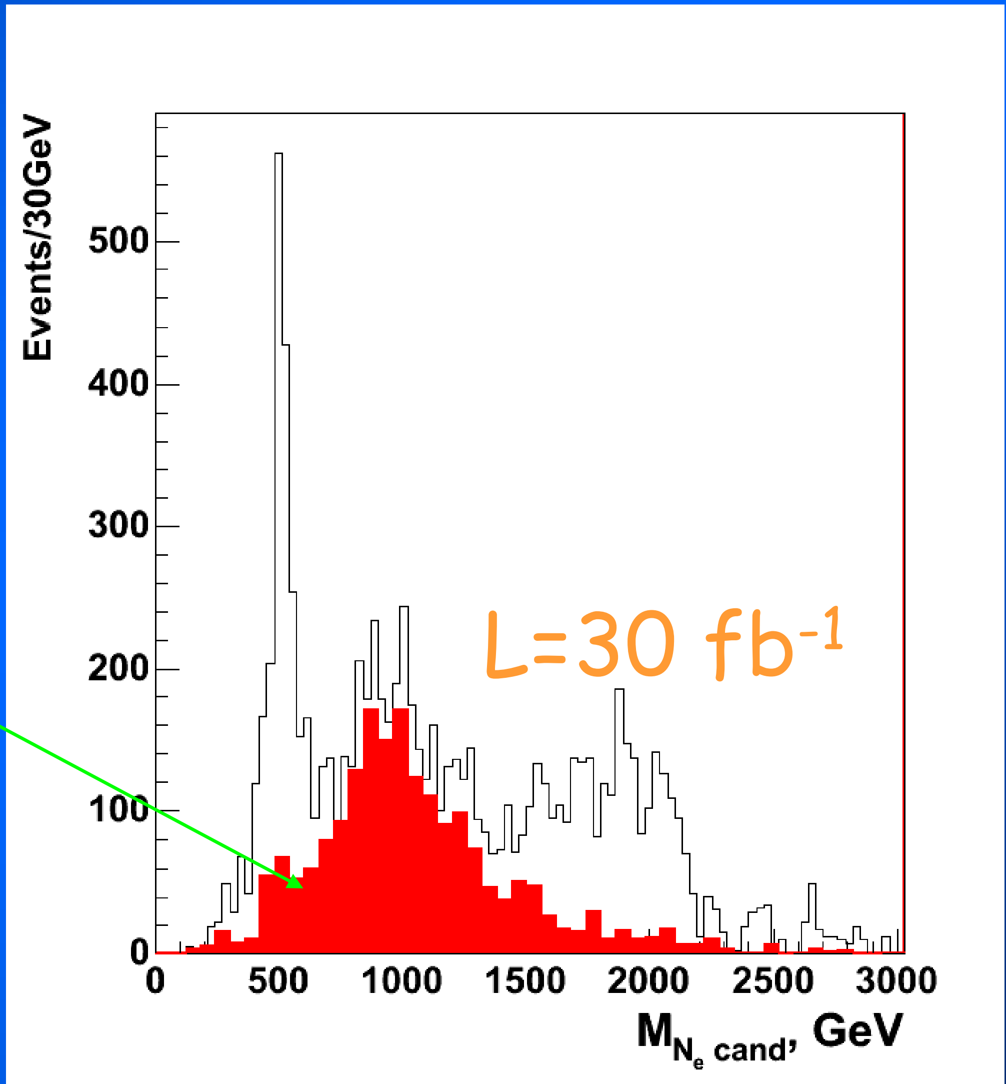
  $M_{inv}(ljj)$- heavy neutrino

  $M_{inv}(lljj)$ - $W_R$ gauge boson

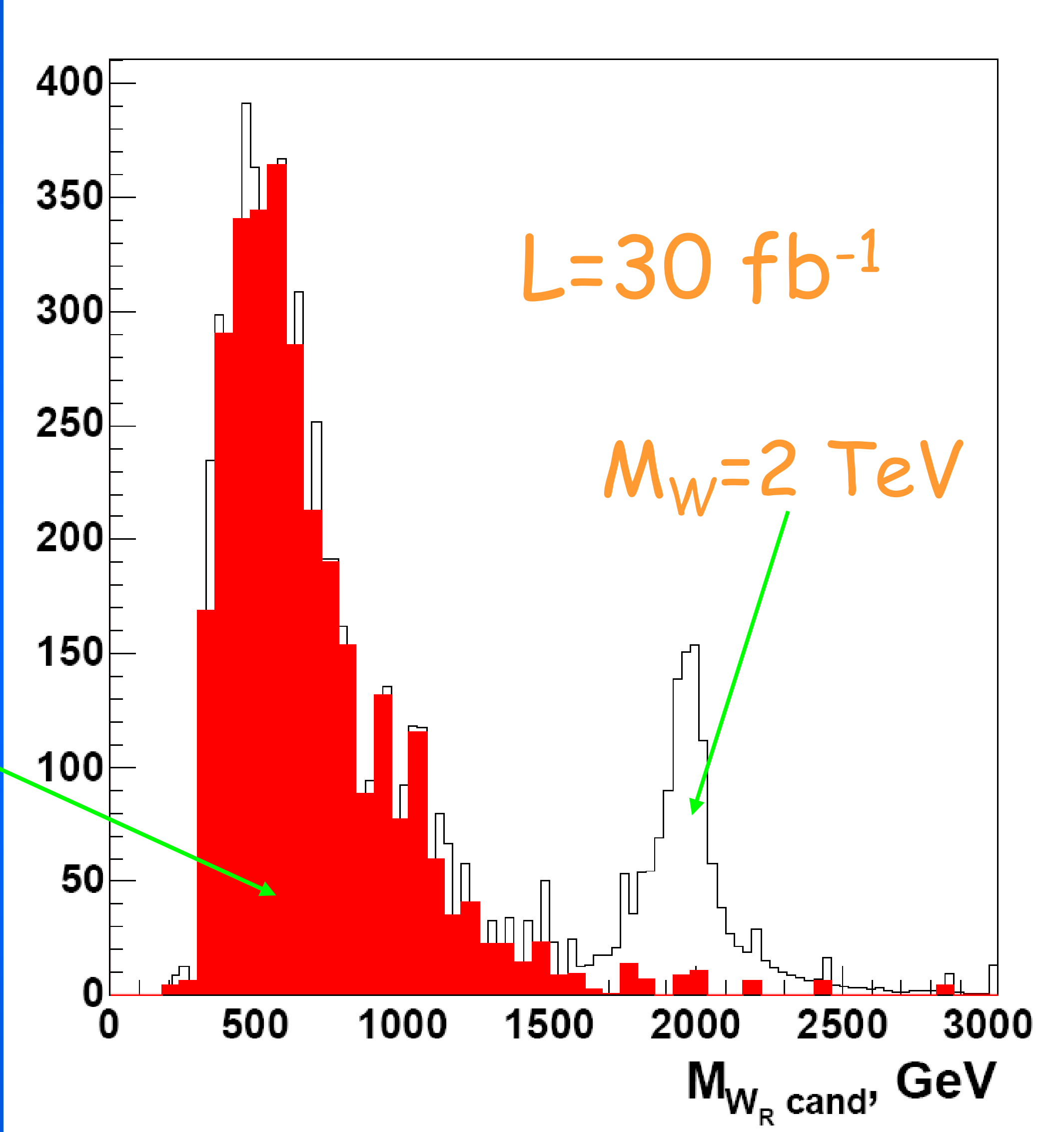
# Heavy ν Mass Reconstruction

additional requirement:
$W_R$ with $M_W$>1 TeV
can be reconstructed in
the event

SM background

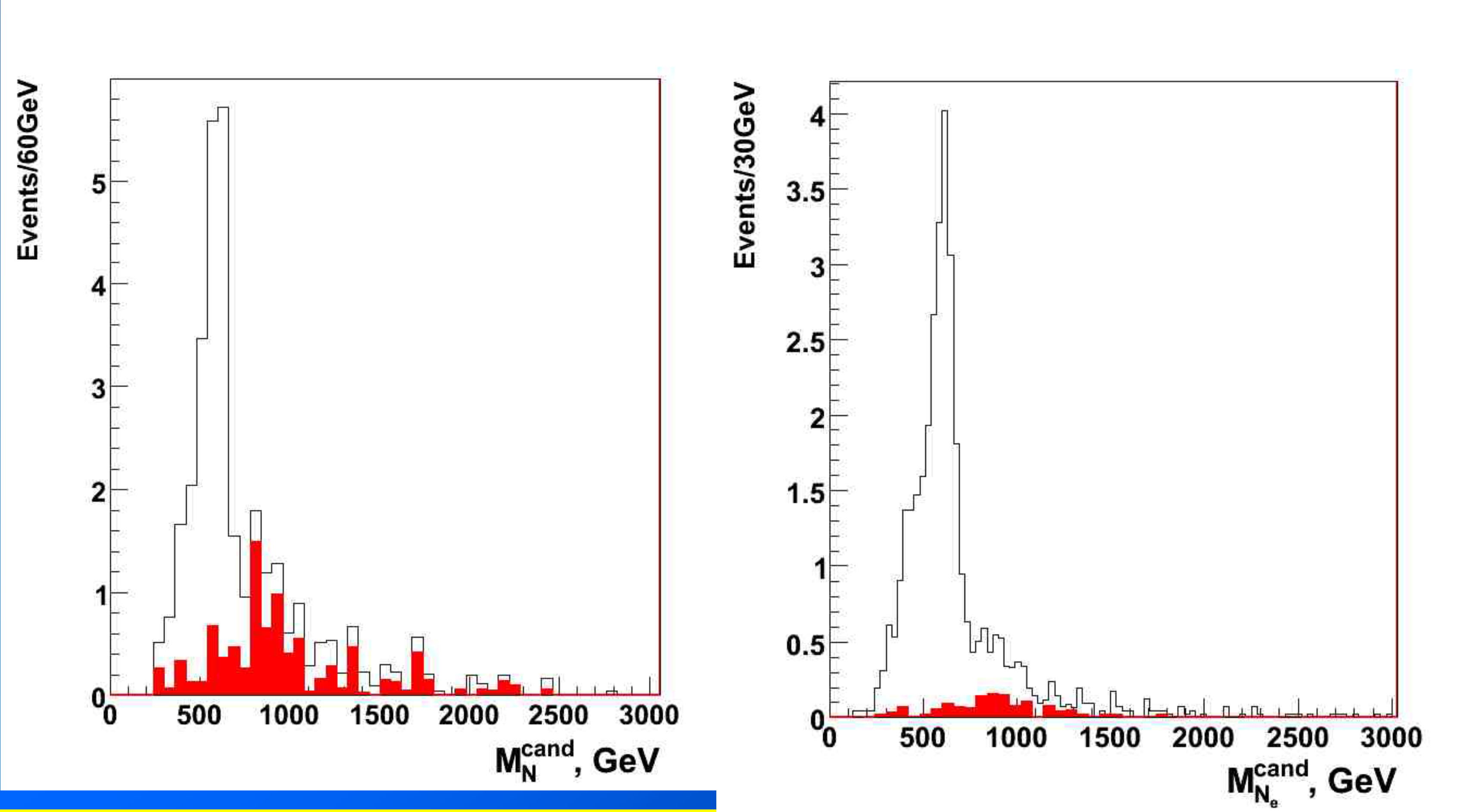


# Right-handed Boson Mass Reconstruction



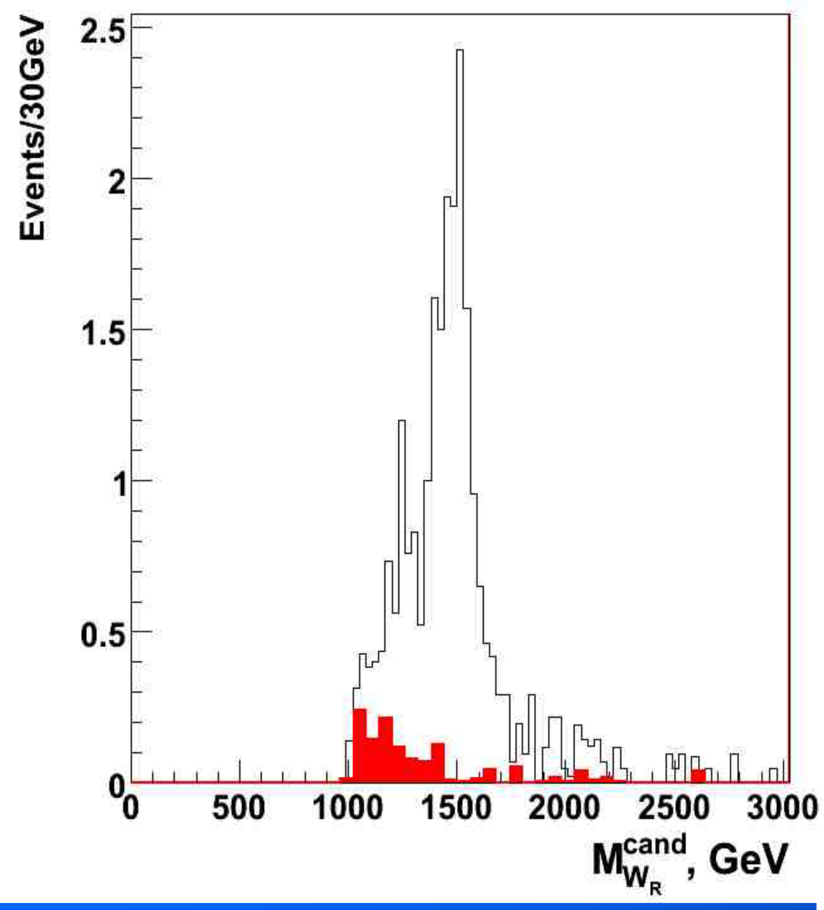

SM background

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

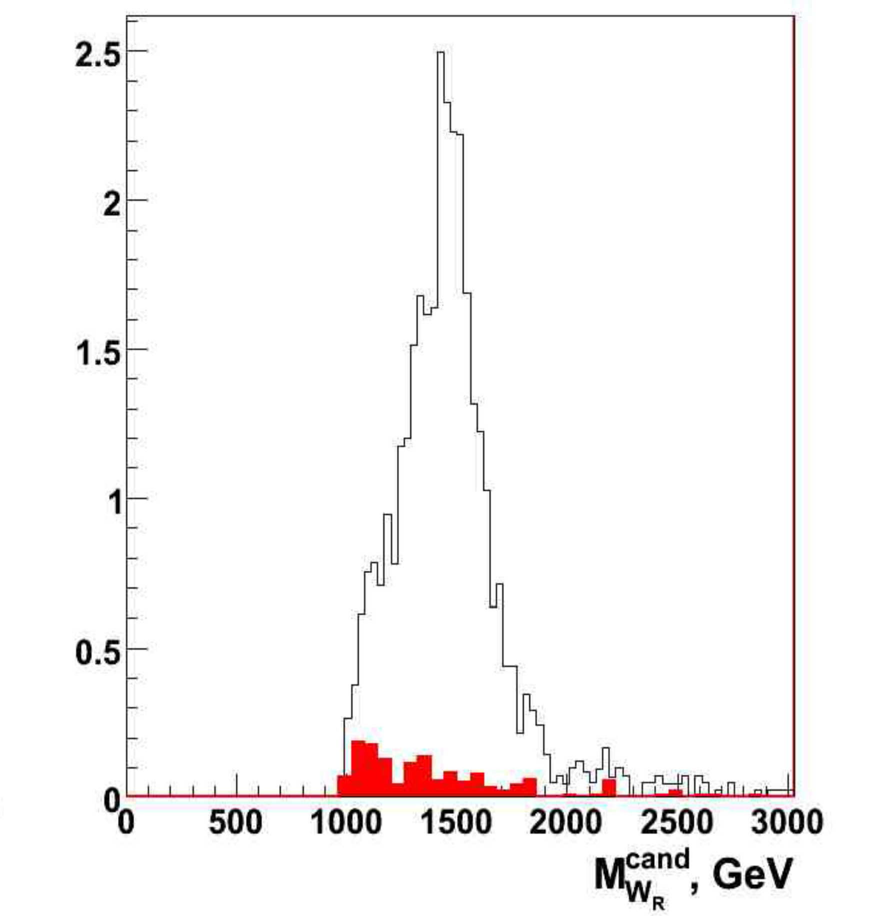


# Signal/background 100 1/pb, MW=1500 GeV

Electron channel

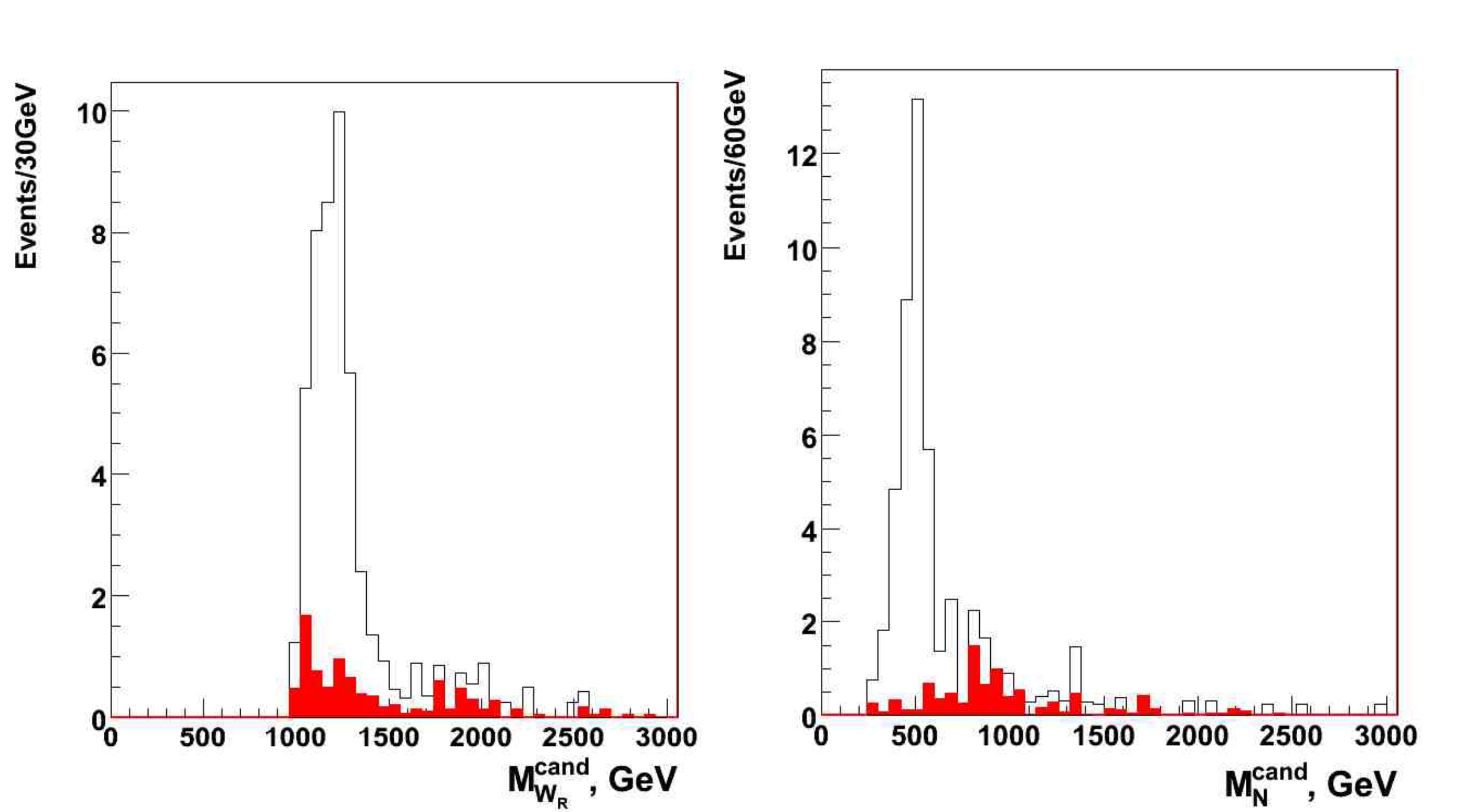



Muon channel



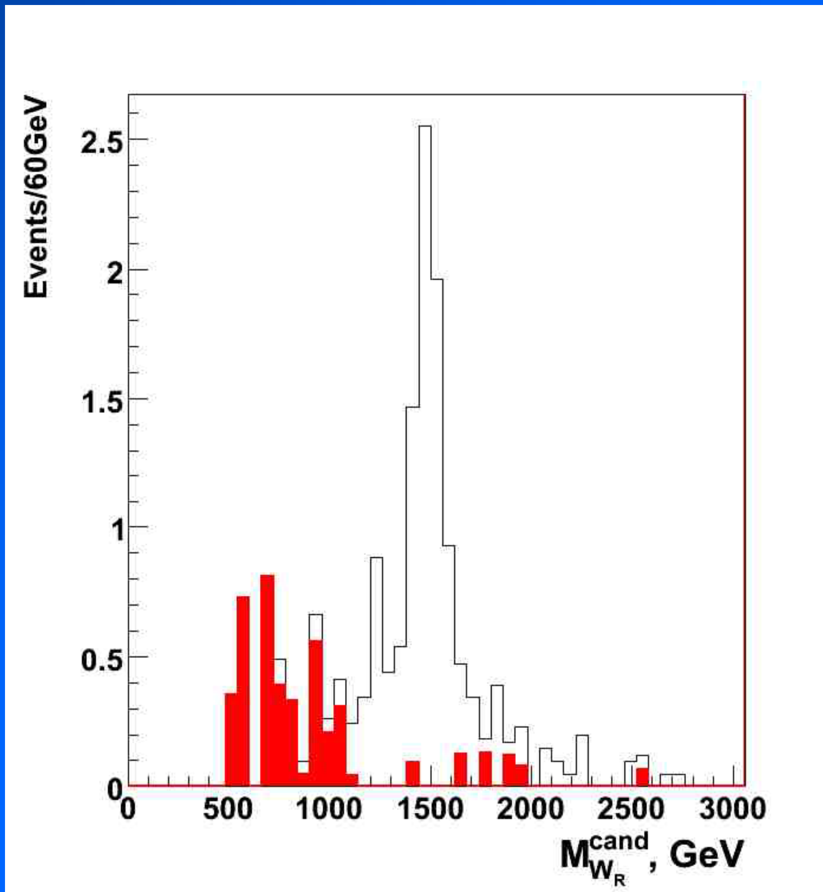
# Signal/background 100 1/pb, MW=1200 GeV, MN=500 GeV. If bg is like this, can still be discovered at 10 TeV and 50 1/pb

Electron channel

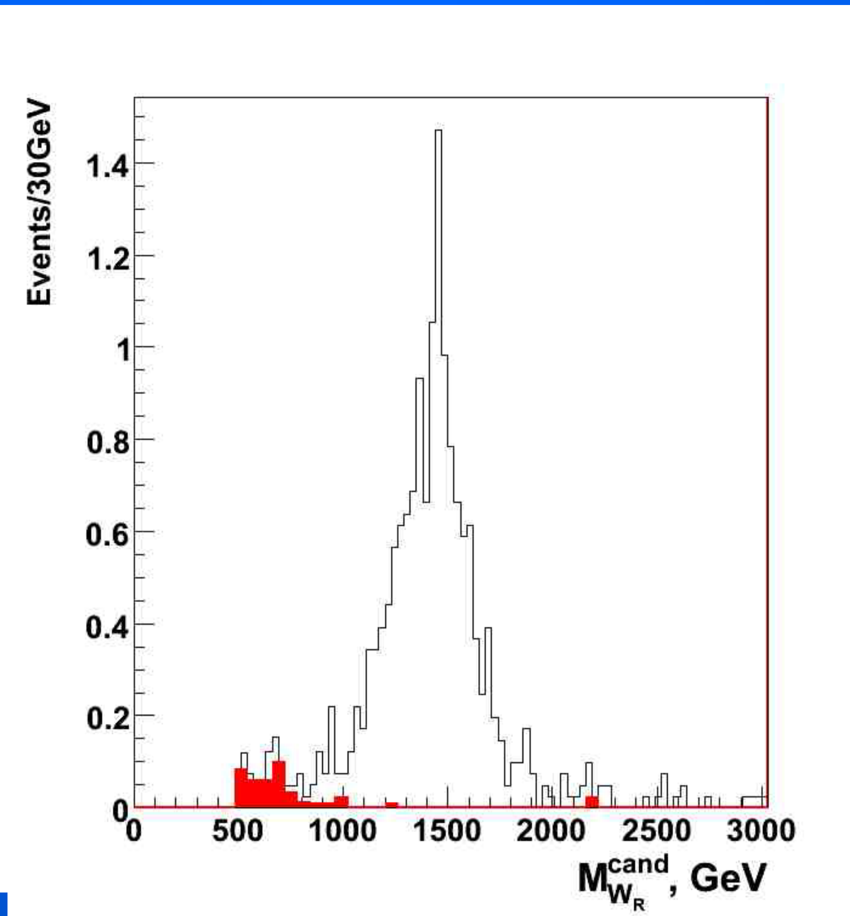


# Same sign leptons. Signal/background 100 1/pb, MW=1500 GeV, MN=600 GeV.

Electron channel




Muon channel



# Different sign and same sign

• Due to the Majorana nature of the heavy neutrino in the LR models, it is always possible to switch to same sign leptons, suppressing dramatically the background.

• Then the only physical background is from ZH, WH: very small. Tried also $t\tilde{t}$ with all decay modes and B° oscillations: small.

• Significant reconstruction background.

• Same sign hardly makes the discovery region wider since 50% of signal is lost and the background is usually not big near the boundary. But if a heavy neutrino is discovered it is a good check of its Majorana nature.

# Sensitivity calculations

- 5σ discovery potential

: $S = 2(\sqrt{N_S + N_B} - \sqrt{N_B})$ is calculated for the integral luminosities of 1, 10 and 30 1/fb

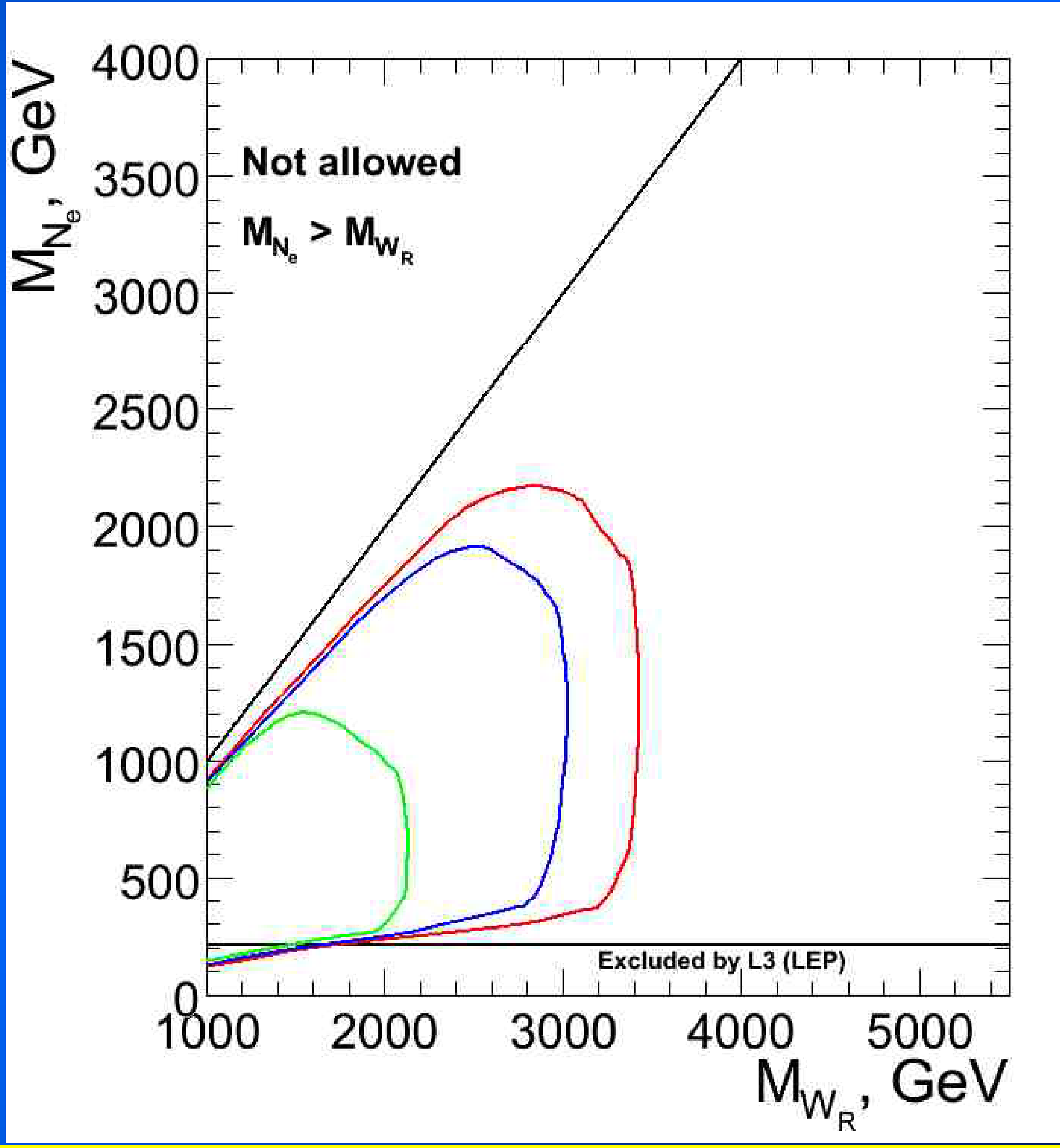
- It is assumed (where relevant) that the uncertainty of the background is 15%

Conclusion: for the integral luminosity 30 1/fb and for M(W) < 3.4 TeV it is possible to discover in CMS an LR model heavy neutrino with a mass up to M(N) ~ 2.2 TeV on the 5σ level

# CMS Discovery Region

Left-Right Symmetric Model

L=30, 10 and 1 $fb^{-1}$



# Uncertainties

General consideration: The shape of the discovery region is rather stble because the significance as a function of masses drops rapidly near the boundaries. This is illustrated on the example of several uncertainties that we studied.

• PDF (parton density functions) in the signal cross sections. We took several different PDF and found that cross section varies by 6%. This is translated in the uncertainty of the upper boundary of 1-2% and lower boundary 2 – 3%

• Jets energy scale. 3% leads to the uncertainty of background of 6 – 10%. This changes significance by 3 – 10%. Upper boundary shifts by 1 – 3%, lower by 2 – 4%.

• Other uncertainties (luminosity, lepton id) are smaller.

# Conclusion

- Heavy neutrino and right-handed bosons can be discovered in CMS, already starting from $L_t$=100/pb.

- For integrated luminosity $L_t$ = 30 fb-1 CMS is able to discover $W_R$ boson with a mass up to 3.4 TeV and heavy neutrino $N_R$ with a mass up to 2.2 TeV.

# Background slides

## Additional questions appeared in process.

- Many wrong sign electrons in full simulation: how to suppress them? OK, most efficient cut is a cut on the number of hits in track: suppression factor ~3 keeping the efficiency to correct sign 90%. Unfortunately, the corresponding info is missing in our Root tree: $t\tilde{t}$ to be reread.

- Mass resolution is now worse. Because of OSCAR? Yes

- Are QED corrections important? PHOTOS cannot be used. Can PYTHIA be used? Checked with 4 TeV Z': QED by PHOTOS does not change the reconstruction efficiency within 6%.

# Background slides

- PYTHIA 6.227 through CMKIN 4.3.1
- FAMOS 1.2.0 – 1.4.0
- OSCAR 3.6.5
- ORCA 8.7.3
- CRAB

# Background slides