Detection of Heavy Majorana Neutrinos and Right -Handed Bosons

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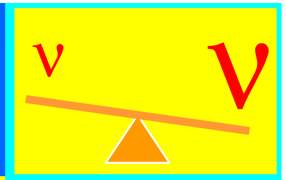
Motivation



- 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!

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):
$M(W_R)=2\,\text{TeV}$, $M(N_e)=500\,\text{GeV}$

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

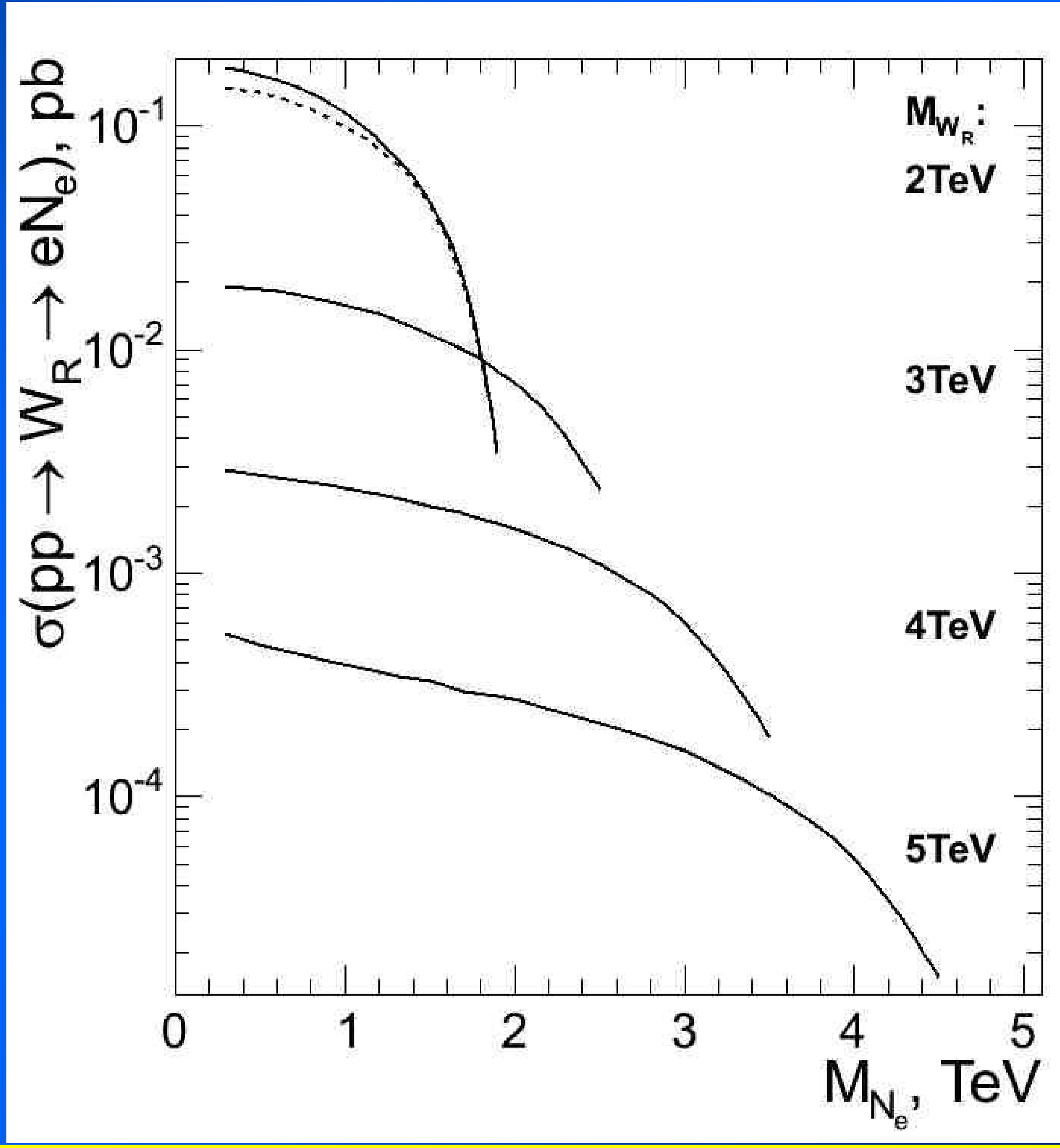
Reconstruction

- Trigger, several possible types.
used electron and electron pair
- Electrons (sometimes high Pt)
- Isolation of electrons 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 or pair required. Efficiency to generator preselected events 100%. Efficiency of similar HLT trigger is 99% (LRRP)

- Two isolated electrons . 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

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

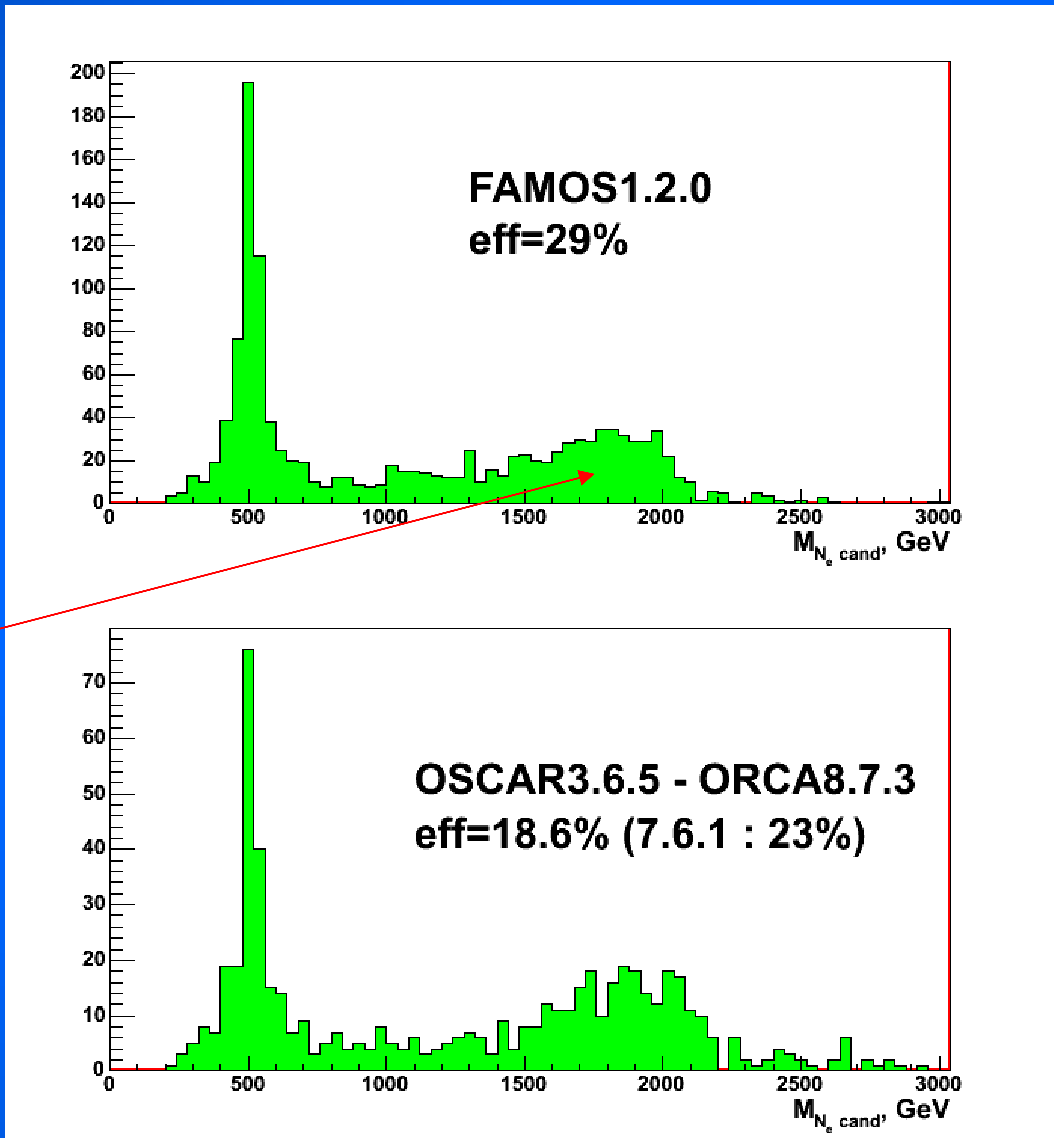
- Minimal invariant mass of all lepton pairs M(ll) > 200 GeV

Typical signal efficiency at LRRP is about 20%.

Signal distributions

Heavy neutrino candidates mass peak

Left-Right Symmetric Model



Combinations with wrong lepton

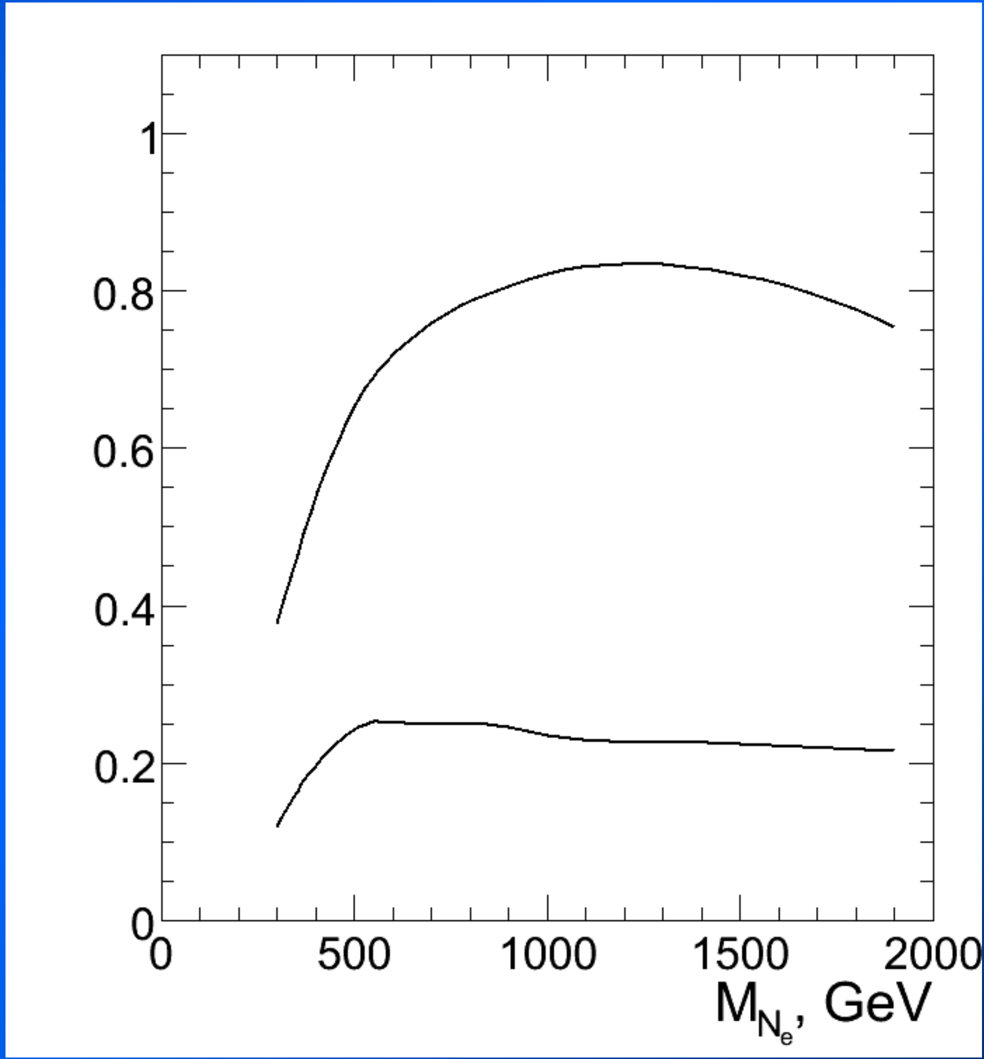
FAMOS 1.4.0 : efficiency 19.6%

Signal reconstruction

Heavy neutrino reconstruction efficiency as a function of heavy neutrino mass. Right-handed boson mass fixed at 2000 GeV

Primary selection →

All reconstructed and matched →



Background sources

- Obvious: WZ $\sigma \approx \sigma_{LRRP}$ Suppressed by M(ll) cut
- Highest: $t\tilde{t}$ $\sigma \approx 1000\sigma_{LRRP}$ (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 $\sigma \approx 100000$ σ_{LRRP} Z → 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 σ small
- WW, ZZ no contribution

Background simulation

By INR Sleptons – heavynu group.

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

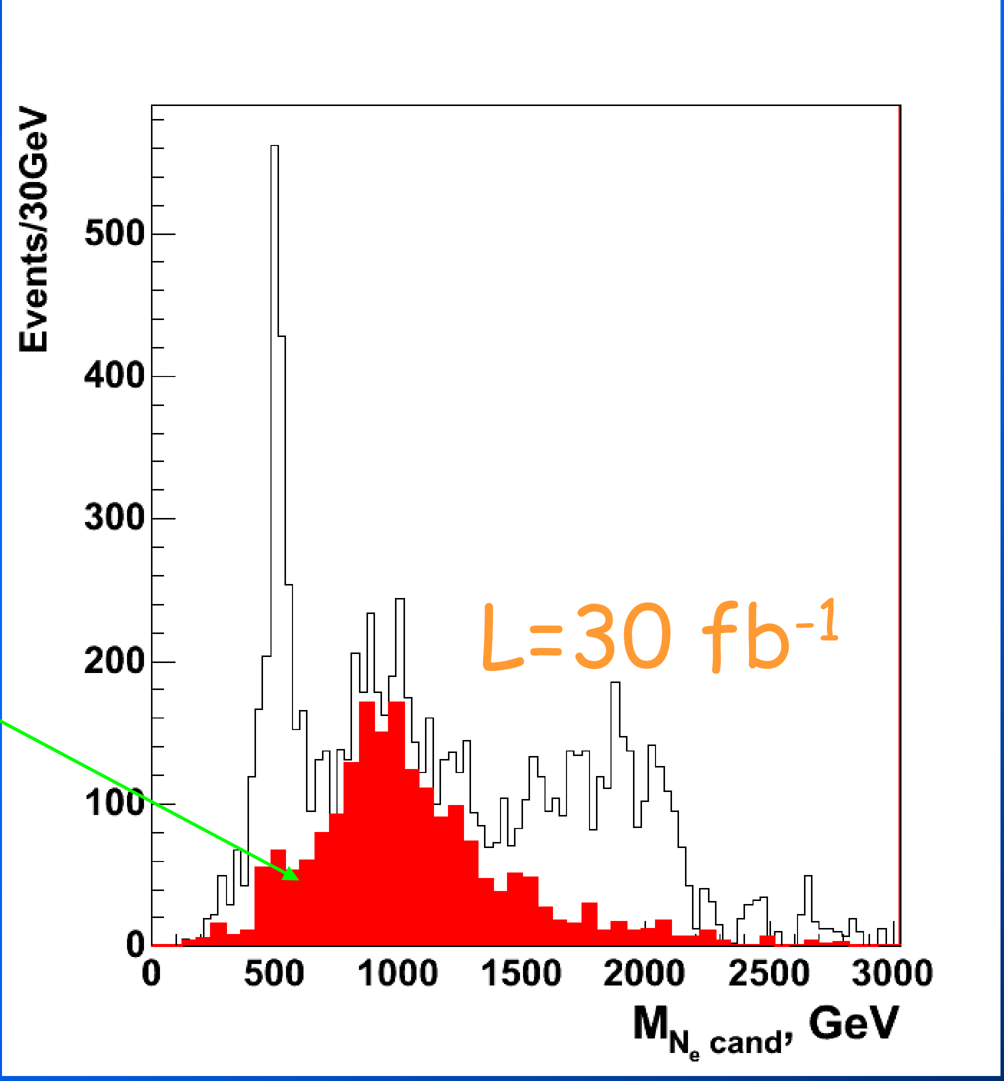
full simulation with of Zg with event generator level pre-selection (factor 2000). 2.2 10^6 events

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

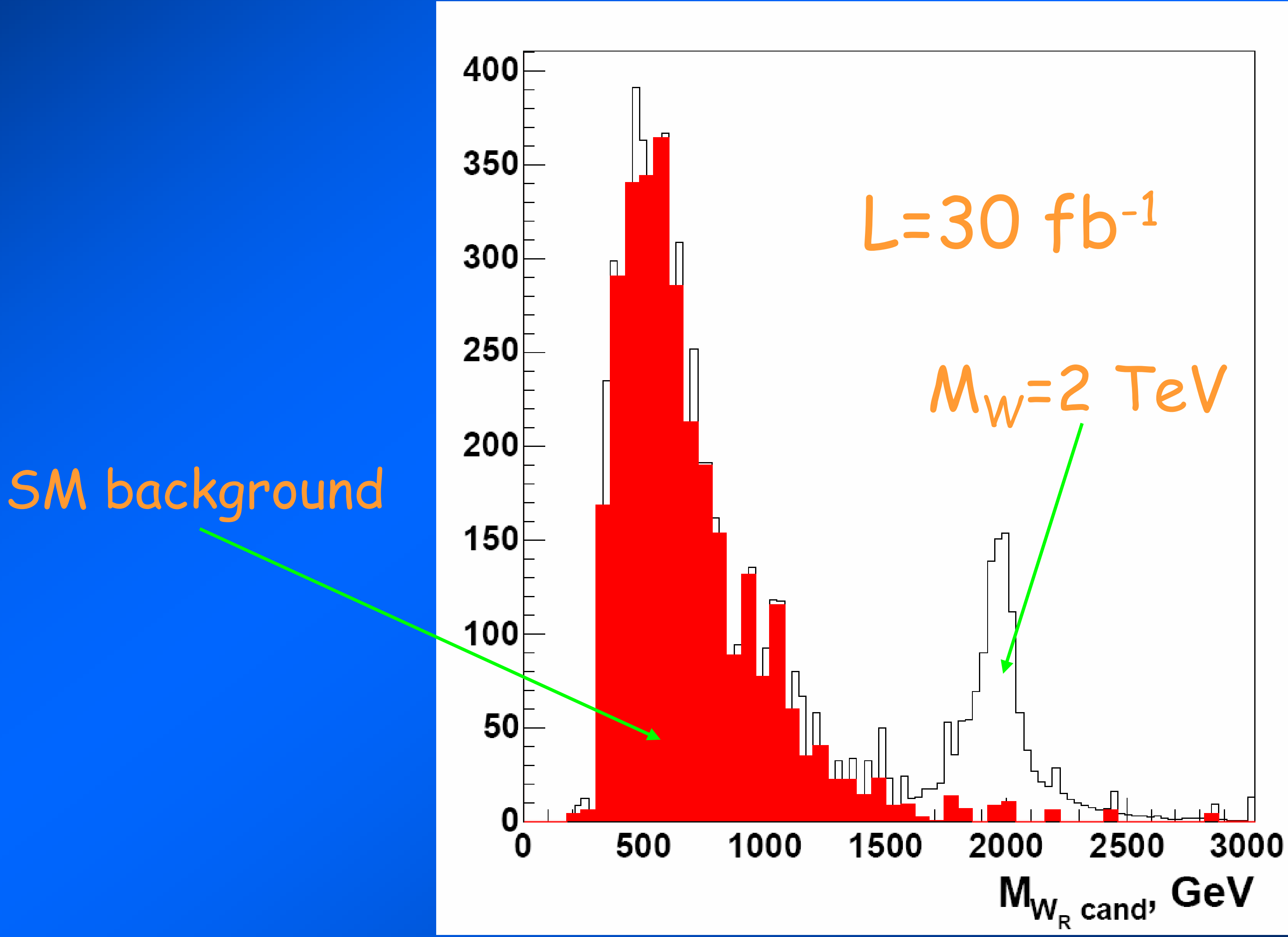
Heavy ν Mass Reconstruction

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

SM background



Right-handed Boson Mass Reconstruction



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 $t\bar{t}$ with all decay modes and B^0 oscillations: small.

• Significant reconstruction background. See in the end.

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

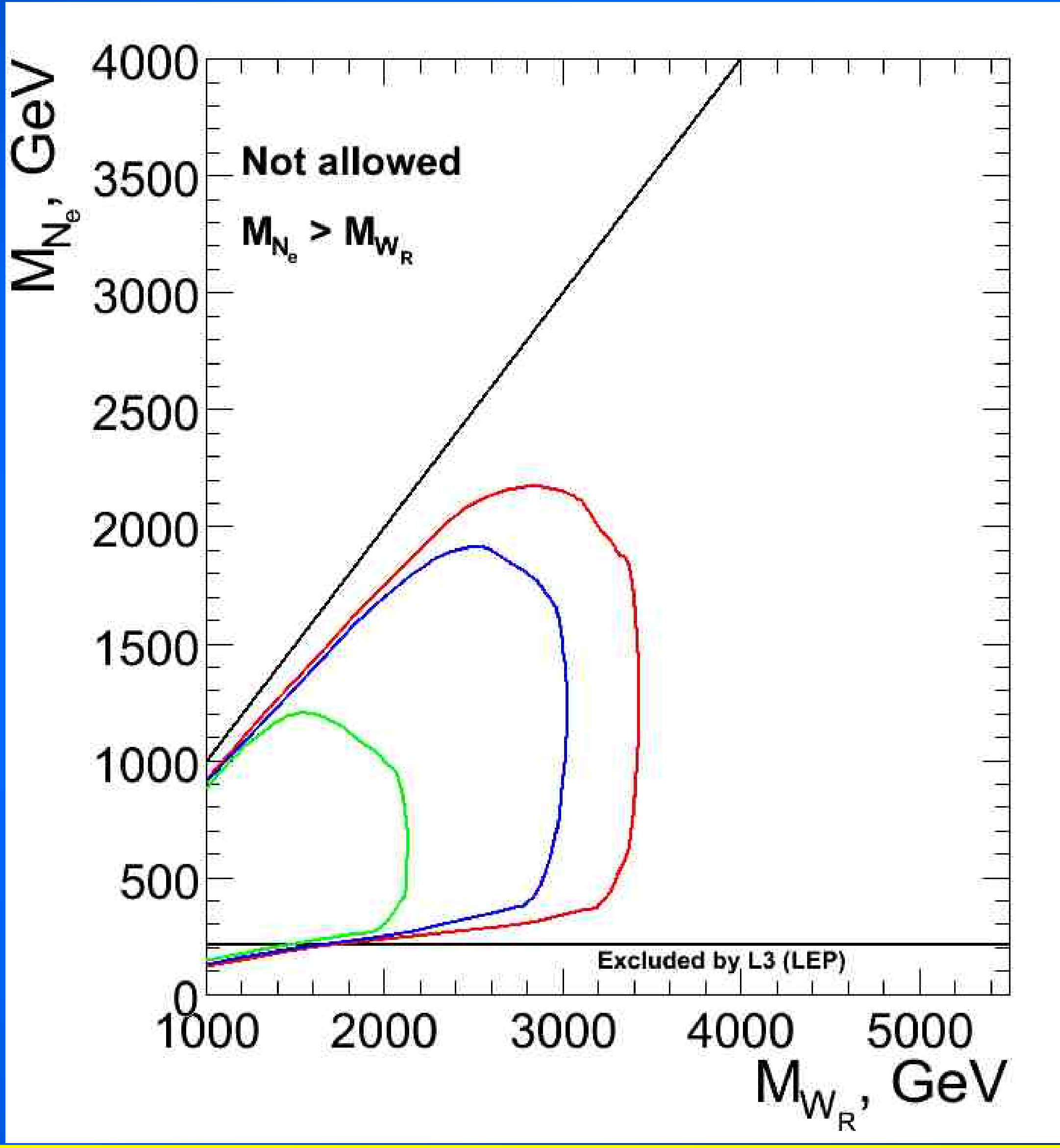
- It is assumed (where relevant) that the uncertainty of the background is 15%

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 stable 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 and plans

- Heavy neutrino and right-handed bosons can be looked for in CMS, already starting from 1 1/fb. The scenario for this small integral luminosity to be studied in more details
- Study in more details the background to same sign, reading anew the production files and using other event generators (CompHEP?)
- Old studies with fast simulation showed that the results in muon channel are very similar. This is to be studied anew, with full simulation and studies of systematics

Background slides

- Read existing $t\tilde{t}$ samples. OK, 700000
- Use missing Et. OK, but so far bad results: disabled
- Isolation in calorimeter for electrons. First variant
- Problem of saturation in ECAL. Effect is small in the discovery region: E < 1.5 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