# Tesing the Left Right Symmetric Models at LHC

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# Problems of the Standard Model

- **Great Puzzle of Parity Violation:**

  **why Nature is left handed ?**
  **why only left handed fermions feel CCWI?**
  **Decays of polarized $^{60}Co \to ^{60}Ni\ e^-\ \nu$**
  **Wu et al.'56.**

- **Neutrinos are massive:**

  **Why $m_\nu$ are small: $m_\nu << m_{q,l}$ ?**
  **Discovery of neutrino mass requires new physics beyond SM which has provided a promising possibility for explaining the matter-antimatter asym.**
  **Results from SuperK , also SAGE,GALEX,SNO,KAMLAND…**
  **while in the SM $m_\nu = 0$.**

# Origin of Parity violation

- Standard model : P,C are broken explicitly in the Lagrangian, no $\nu_R$ ⟶ $m_\nu = 0$
- Left-right model were proposed primarily as a way to understand the origin of P-violation.

  Mohapatra, Pati, Senjanović ‘ 74-75
- Today LRSMs have very large literature, many interesting of its properties were discovered.

# Left-Right symmetric model (LRSM)

- **Gauge group**: $SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L}$
- **Fermion fields** $\begin{pmatrix} u_L \\ d_L \end{pmatrix} \overset{P}{\Leftrightarrow} \begin{pmatrix} u_R \\ d_R \end{pmatrix} \qquad \begin{pmatrix} \nu_L \\ e_L \end{pmatrix} \overset{P}{\Leftrightarrow} \begin{pmatrix} \nu_R \\ e_R \end{pmatrix}$
- **New gauge bosons** $W^{\pm}{}_R,\ Z`$
- **Higgs fields:** $\phi(2,2,0) \quad ; \Delta_R(1,3,+2) \oplus \Delta_L(3,1,+2)$

# Symmetry Breaking

$$SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L}$$

$$< \Delta_R > \neq 0 \quad \Downarrow \quad M_{W_R}, M_{Z'} \neq 0$$

$$SU(2)_L \otimes U(1)_Y$$

$$<\phi> = \begin{pmatrix} \kappa & 0 \\ 0 & \kappa' \end{pmatrix} \quad \Downarrow \quad M_{W_L}, M_Z \neq 0; m_{q,l} \neq 0$$

$$U(1)_{EM}$$

# LRSM is attractive for theorists:

- left – right symmetric lagrangian
- explain P-violation in weak interactions: P is good symm. at high E, but is spontan. broken at low E
- charge quantization: Y/2

  $Q = I_{3L} + I_{3R} + (B - L)/2$

  Y is explained in terms of B and L numbers
- explain lightness of neutrino masses and connect
- neutrino mass to scale of parity restoration
- includes SM at ~TeV scale

# LRSM is attractive for experimentalists:

- new gauge bosons: $W^{\pm}_R$, $Z'$
- right-handed neutrino: $N_R$

} clear signature in high energy exp.

- searches for right-handed currents in precision low energy experiments

# Reconstructing the LRSM Lagrangian

Sensitive searches for all new particles
$W^+_R$, $W^-_R$, $Z'$, $\nu_R$, …

↓

Reconstruction of mass, spin, width, ..

↓

Measurements of coupling constants

# Indirect $W_R$ mass limits

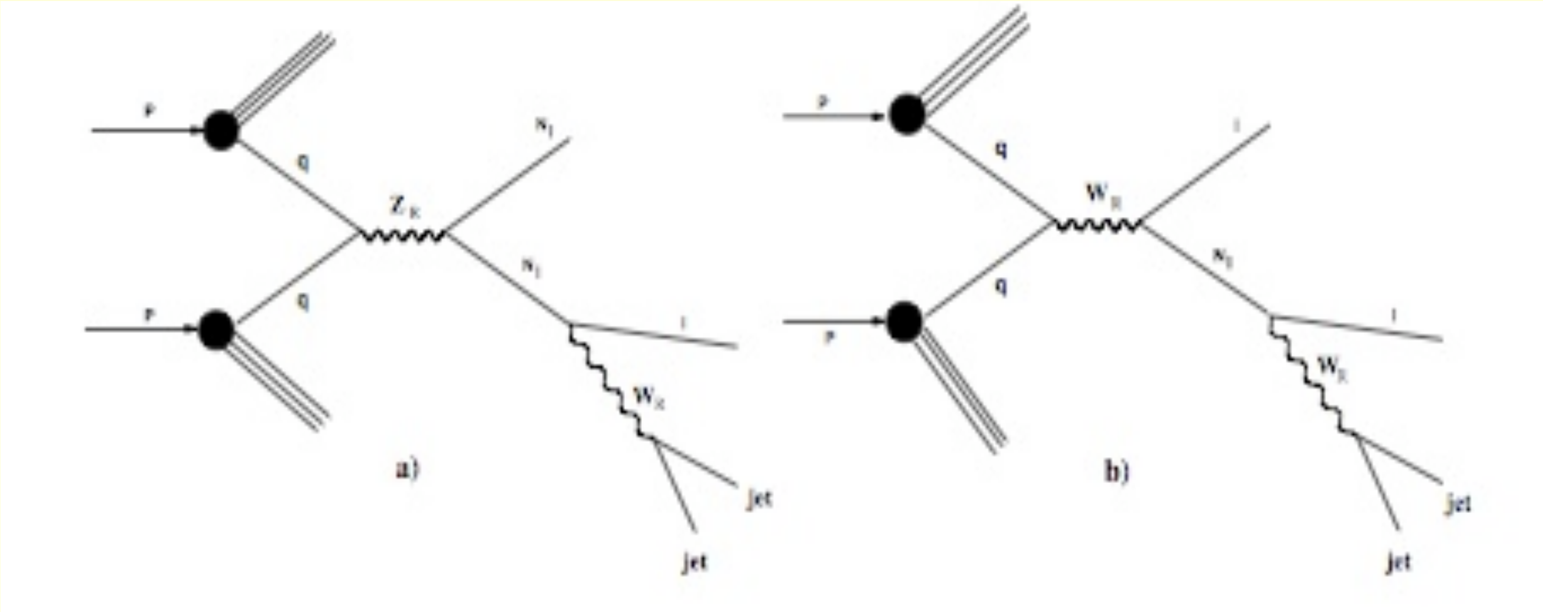
- beta decays: $M(W_R)>230$ GeV J. Deutsch et al.`03
- muon decays: $M(W_R)>325$ GeV TWIST coll.`06
- pol.n decays: $M(W_R)>270$ GeV M.Schuman et al.`07

- K,B mixing, n-EDM: $M(W_R)>2.4$ TeV
- $\Delta M_{K,B}$, ε, ε`, n-EDM: $M(W_R)>2.5–4$ TeV

Y. Zhang et al.`07; `08.

Can these limits can be evaded ?

# Production and signature at pp colliders




Drell-Yan production:

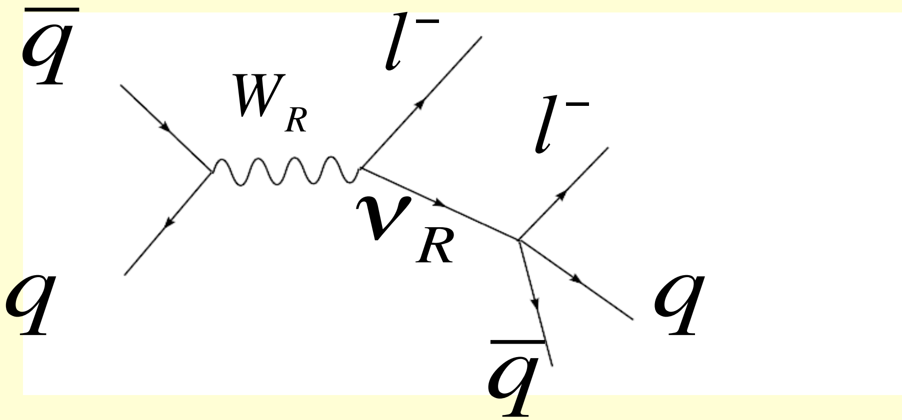
- pp → Z ` → $N_l$ + $N_l$ + X
- pp → $W_R$ → l + $N_l$ + X
- $N_l$ → l + jet + jet

Signatures:

- two high-Pt isolated lept.
- two high-Pt jets
- $M(W_R)$ ,$M(N_l)$ peaks

# Same sign leptons for TeV scale $W_R$,Z`

**Signal:** $pp \rightarrow l^+ l^+ jj + X$




Keung, Senjanović, 83

- ΔL = 2
- small background
- banchmark of the case of Majorana neutrinos

# Direct $W_R$ mass limits from Tevatron

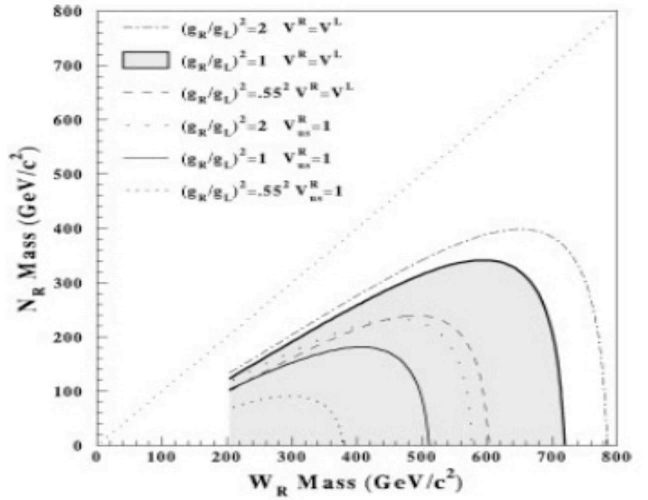



FIG. 3. 95% CL excluded $W_R$ mass region from the *peak search*. The lines represent the contours for different values of the LRM parameters. The diagonal line is the kinematic limit for the $W_R \to eN_R$ decay.

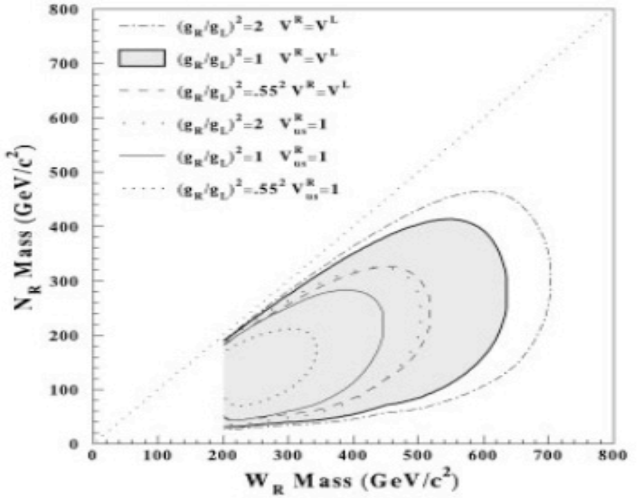



FIG. 4. 95% CL excluded region of $W_R$ mass from the *eejj* search for the no mixing case.

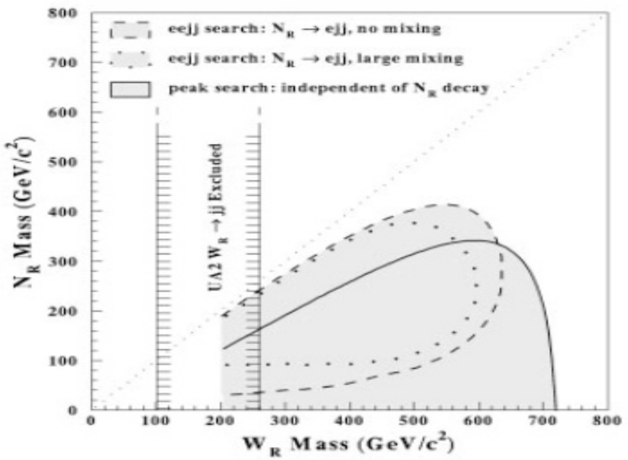



FIG. 5. Excluded regions of $W_R$ mass at the 95% CL assuming $g_R = g_L$ and $V^R = V^L$.

$M(W_R) > 780$ GeV

$M(N) > 400$ GeV

D0/CDF' 97

# The LHC

- 30.03.2010 -> run at 7 TeV

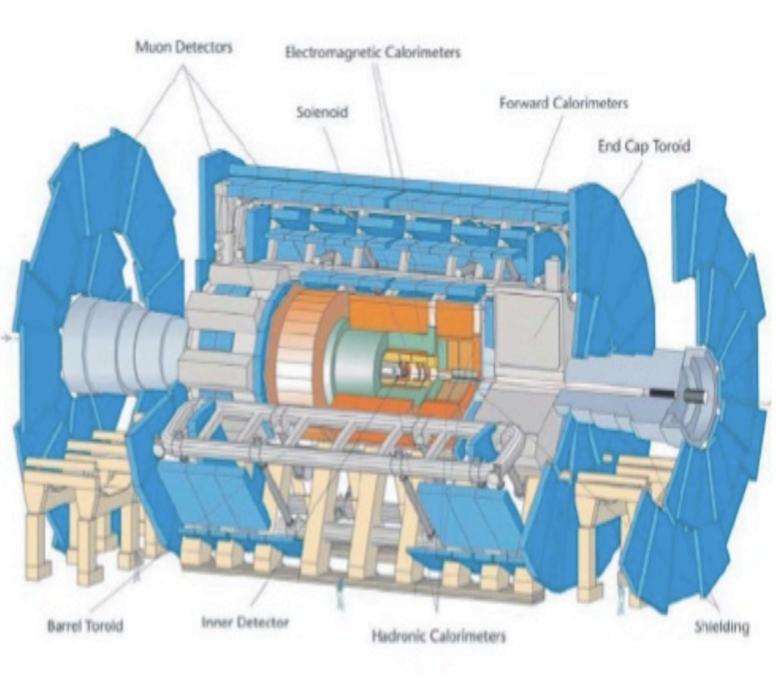
- $\int L dt =$ 1 $fb^{-1}$ by 2012, $R = L\sigma_{int}$

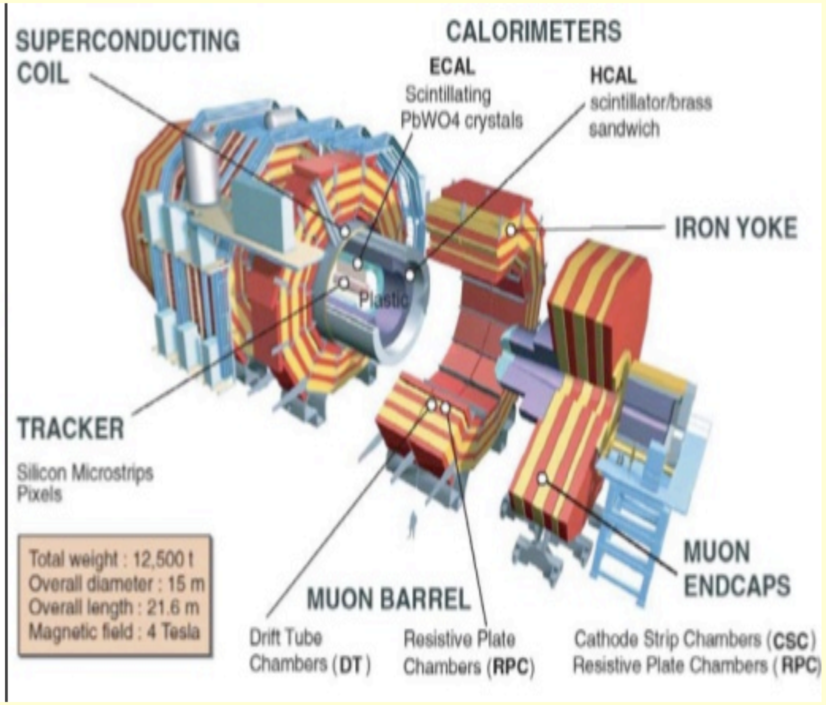
| | | |
|---|---|---|
| 30.03.2010 | 1 bunch/beam | $L=10^{27}$ |
| 22.05.2010 | 13 b./beam | $L=2.10^{29}$ |
| end 2010 | | $L=10^{32}$ |
| future | 2808 b./beam | $L=10^{34}$ |

- 2012 -> shut down / run at 14 TeV

# The LHC Detectors

**ATLAS** | **CMS**




Well equiped to search for New Physics :

- reconstruction: l's, γ's, jets, missing $E_T$
- understanding of the background

# Search for $W_R$ and N

Parameters:

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

reference points

$M(W_R) = 1.5$ TeV,

$M(N_l) = 600$ GeV ;

$M(W_R) = 1.2$ TeV,

$M(N_l) = 500$ GeV

Assumptions:

- small mixings
- $V^L = V^R$
- $g_R = g_L$
- only $M(N_e)$ is reachable
- $N_e$ decays inside detector

S.N.G., M.M. Kirsanov, N.V. Krasnikov, V.A. Matveev, CMS NOTE 2006/098 (2006)

Production and Decay

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

$pp \to W_R \to l_1 + N_e + X$

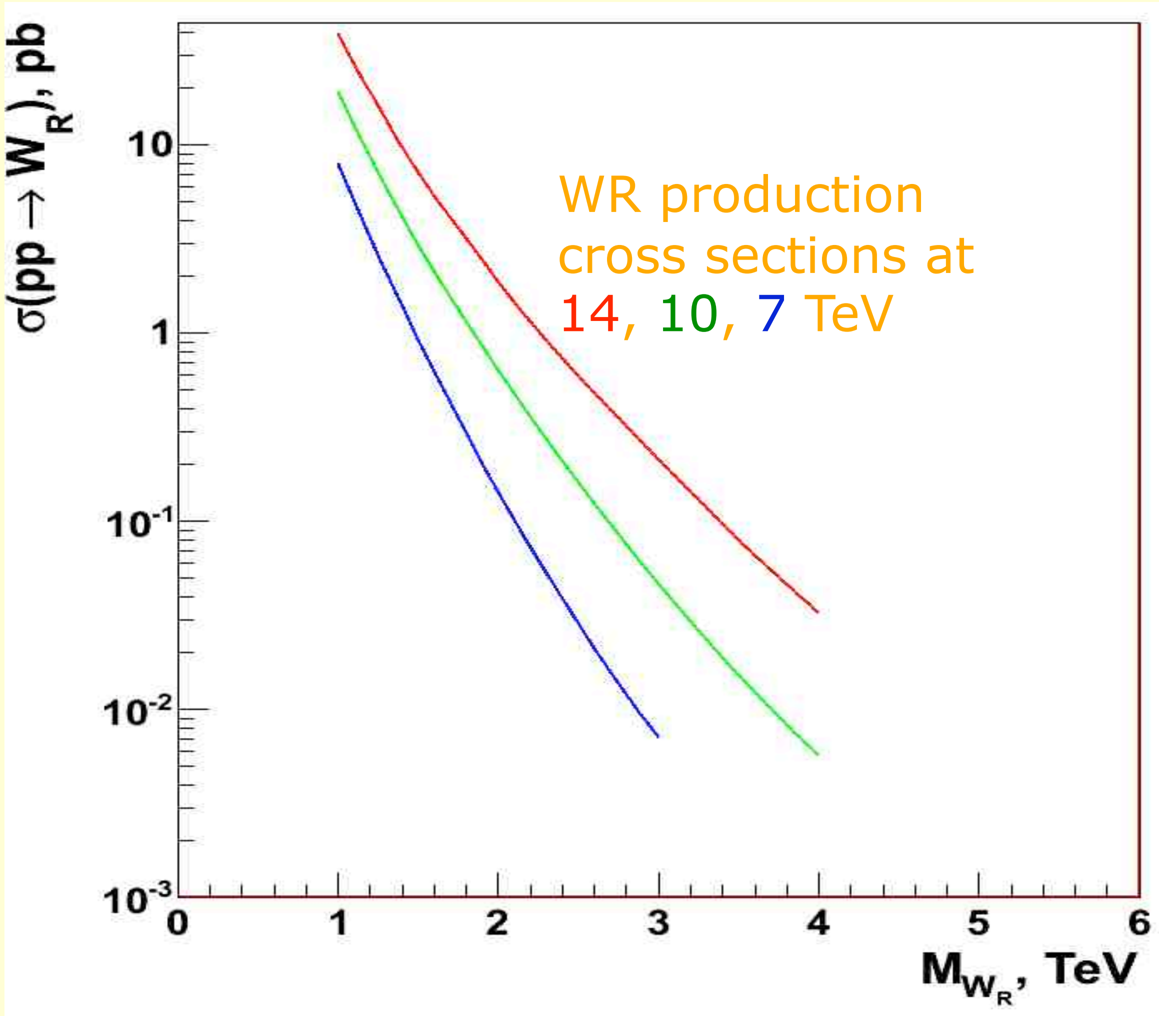
$N_e \to l_2 + j_1 + j_2$

Signature:

- two high Pt leptons
- two high Pt jets
- 50% of l pairs have the same sign in case of Majorana neutrinos

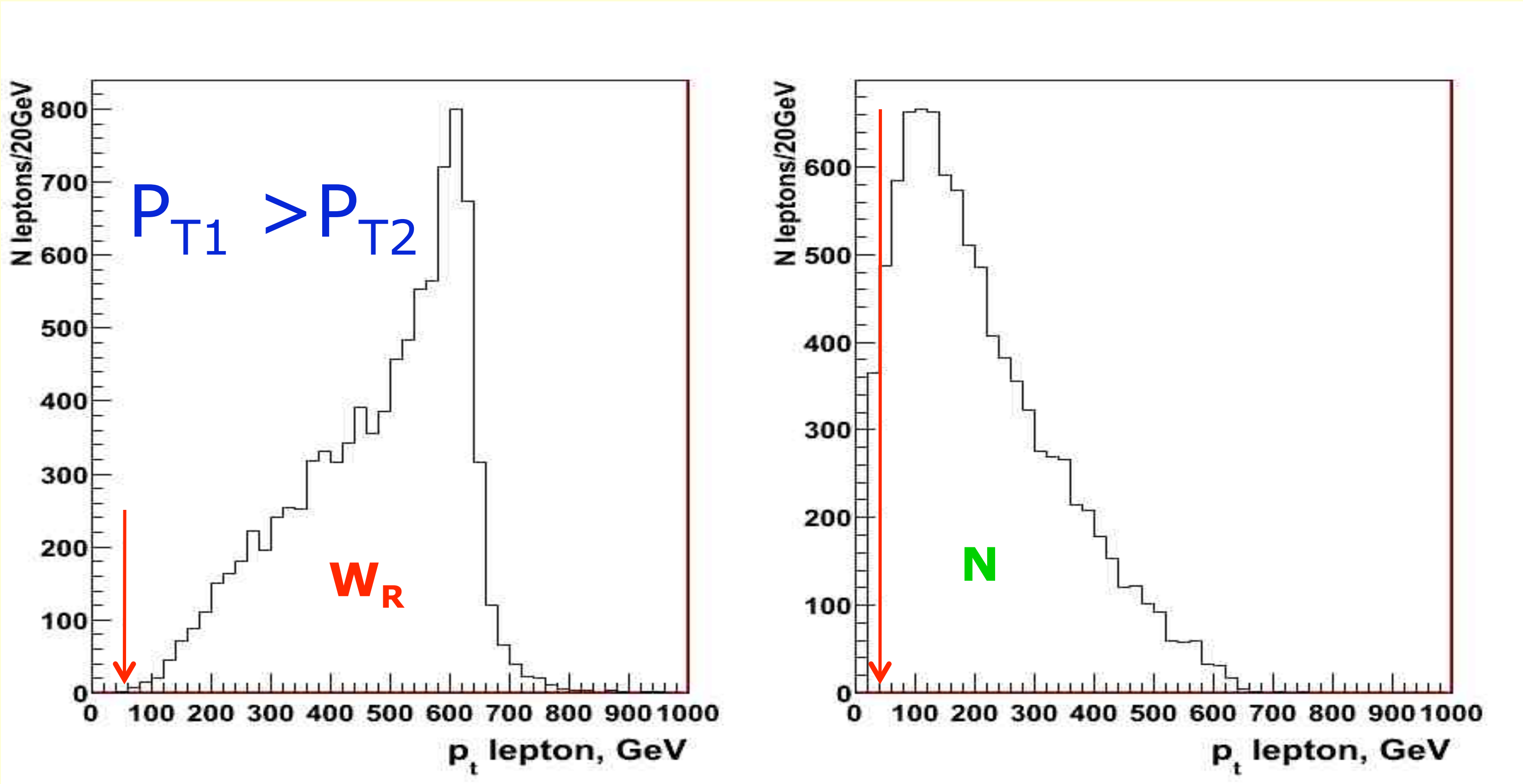
Keung, Senjanović, 83

# cross section pp → $W_R$




difference about factor 2 at 1 TeV

# Leptons momenta




$P_{T1,2} > \sim 40$ GeV

# Events selection

- Preliminary: isolated lept., jet ID, pT > 20 GeV, efficiency check, Z control sample. Typ. : e > 70 %, mu > 80 %

- Primary: at least 2l, pT > 40 GeV (of any flavour and sign) and 2 jets.

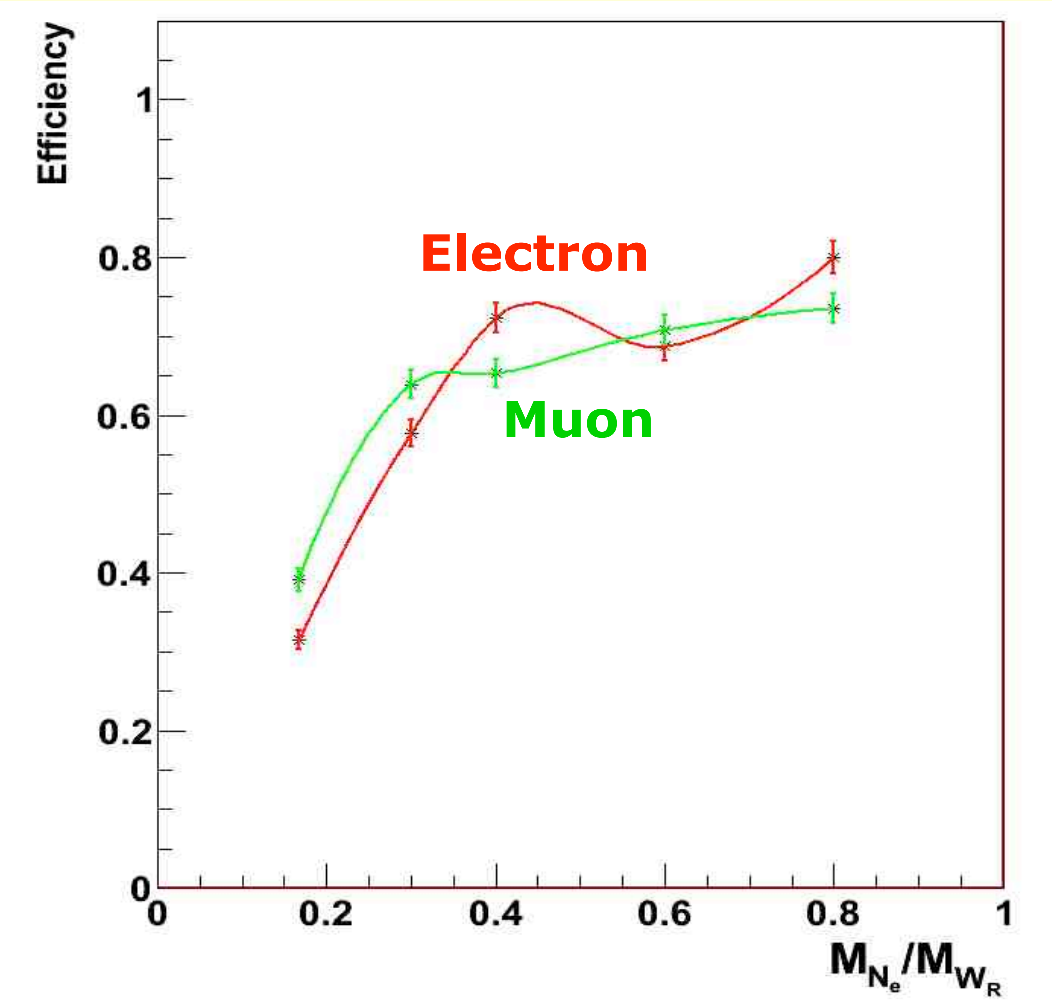
  signal jet pair: 2 highest pT j1, j2, eff. 90%

  signal lepton pair: only 2 high pT l1, l2 to avoid combinatorial bckg.

  $M_N$ = M(l2 j1 j2), 3 – 10 % eff. loss vs $M_N$

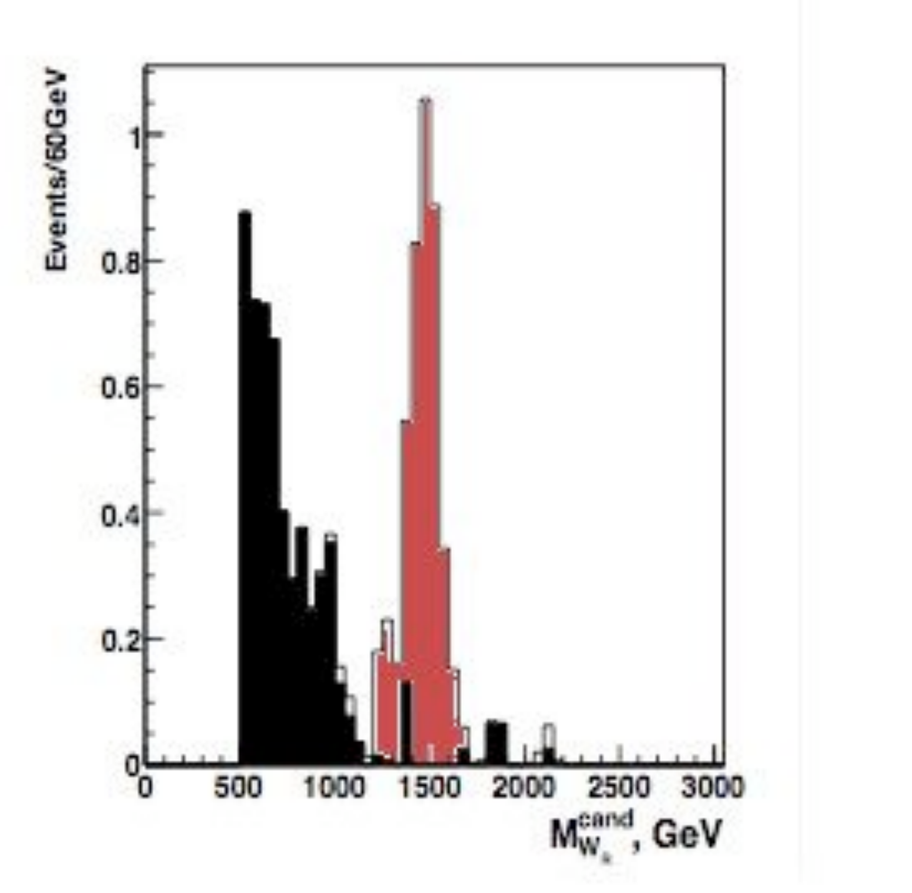
  $M_{WR}$ = M(l1 l2 j1 j2)

# Probability to pass the primary selection $M(W_R) = 1.5$ TeV

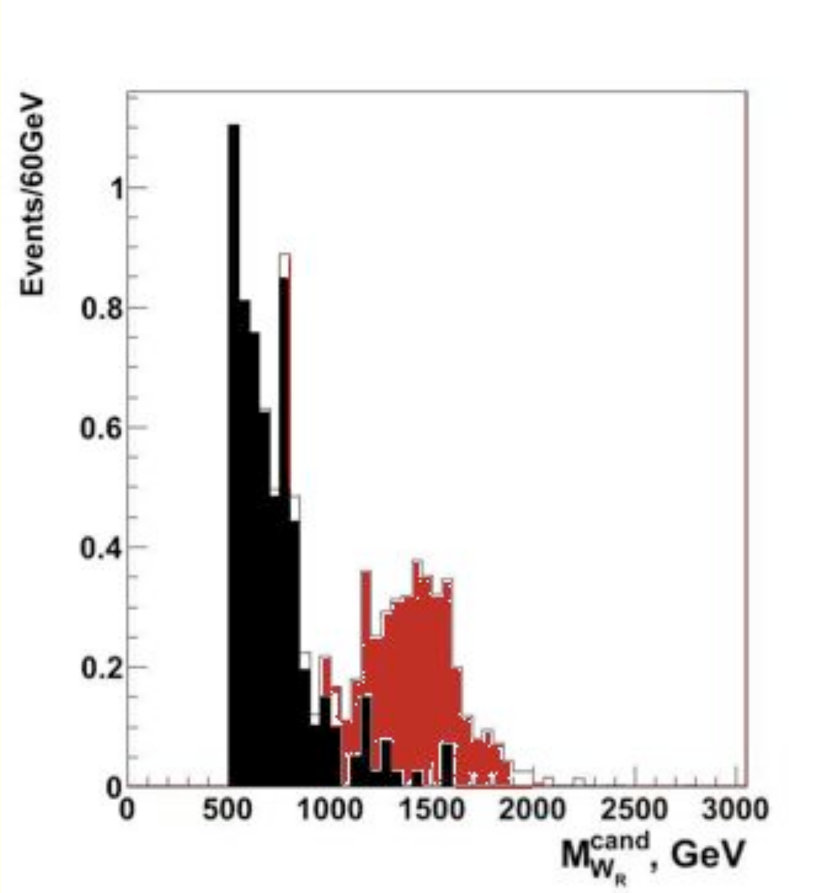


# Signal/background 100 $pb^{-1}$, $M_{WR}$=1.5 TeV

**Electron channel**

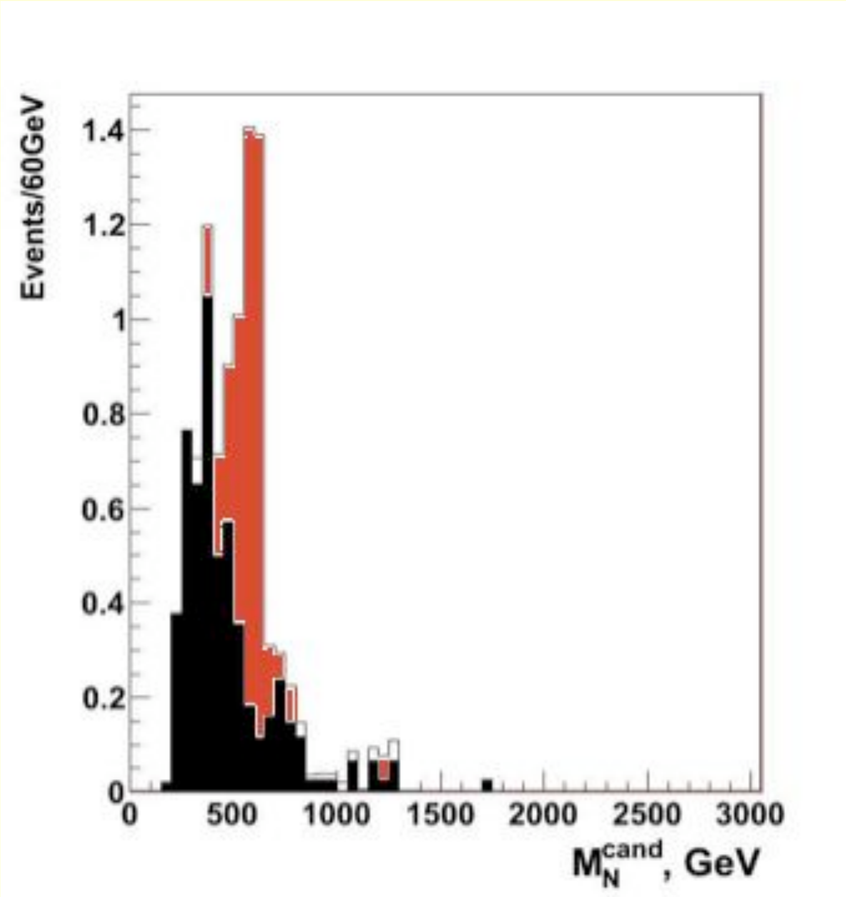



**Muon channel**

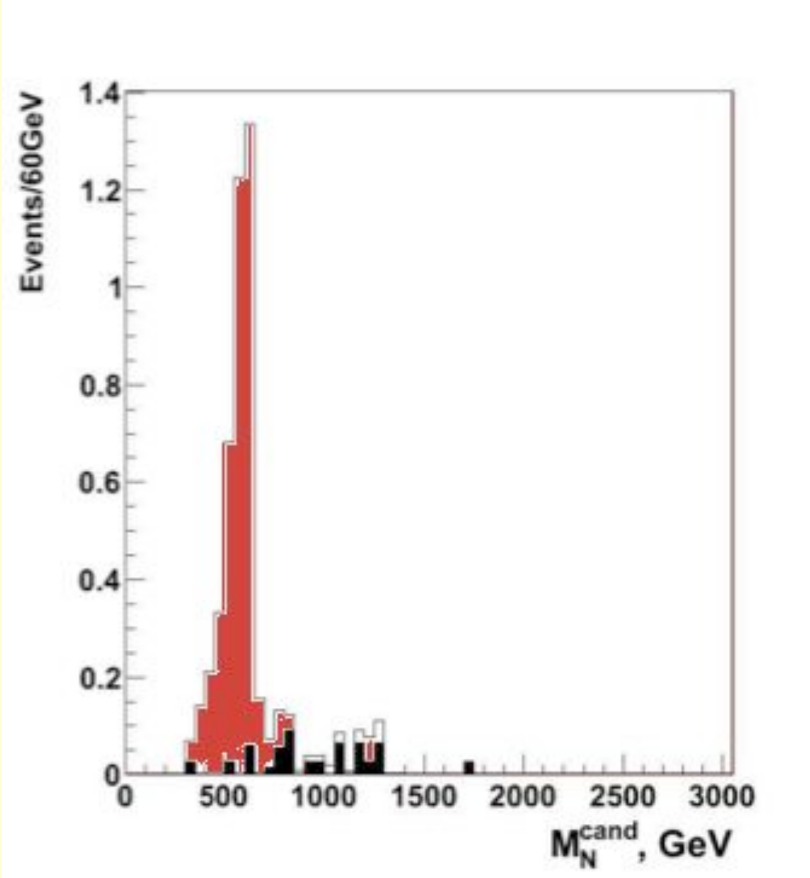


# S/B at 100 $pb^{-1}$, $M_{WR}$=1.5 TeV, $M_N$=0.6 TeV, electrons

$M_{WR}$ > 0.5 TeV




$M_{WR}$> 1 TeV



# Background reduction table, electrons

Table 2: Evolution of the numbers of signal and background events versus selection criteria (electron channel, electron trigger stream used). The window for the 2D peak for LRRP1 are: $1250 < M^c_{W_R} and < 1720$, $480 < M^c_{N_l} and < 710$. The numbers correspond to the statistics collected by the CMS detector for the integrated luminosity of $\mathcal{L}_{int} = 100\ pb^{-1}$

Most dangerous: $t\bar{t}$, Z jets $ee$

| Step | Signal LRRP1 | $t\bar{t}$ | Z jets $ee$ | W jets $e$ | QCD | WW jets | WZ jets | Others |
|---|---|---|---|---|---|---|---|---|
| Events in CMS | 6.72 | 16200 | 167000 | $10^6$ | $2.8 \cdot 10^{10}$ | 4300 | 1800 | 1600 |
| Simulated | 2000 | 627000 | 2539000 | 2078000 | $7.7 \cdot 10^7$ | 120000 | 114000 | 145000 |
| Primary selection | 4.86 | 133 | 413 | 1.5 | 33 | 2.1 | 5.5 | 3.9 |
| Two isolated $e^\pm$ | 4.7 | 44.7 | 360 | 0.5 | 2.5 | 0.7 | 4.4 | 3.25 |
| $M_{ll}$ cut | 4.4 | 5 | 2.7 | 0 | 0 | 0.13 | 0.06 | 0.025 |
| $M^{cand}_{W_R} > 500$ GeV | 4.4 | 3.2 | 2.2 | 0 | 0 | 0.13 | 0.06 | 0.032 |
| Within the 2D peak | 3.28 | 0 | 0 | 0 | 0 | 0 | 0 | 0.004 |

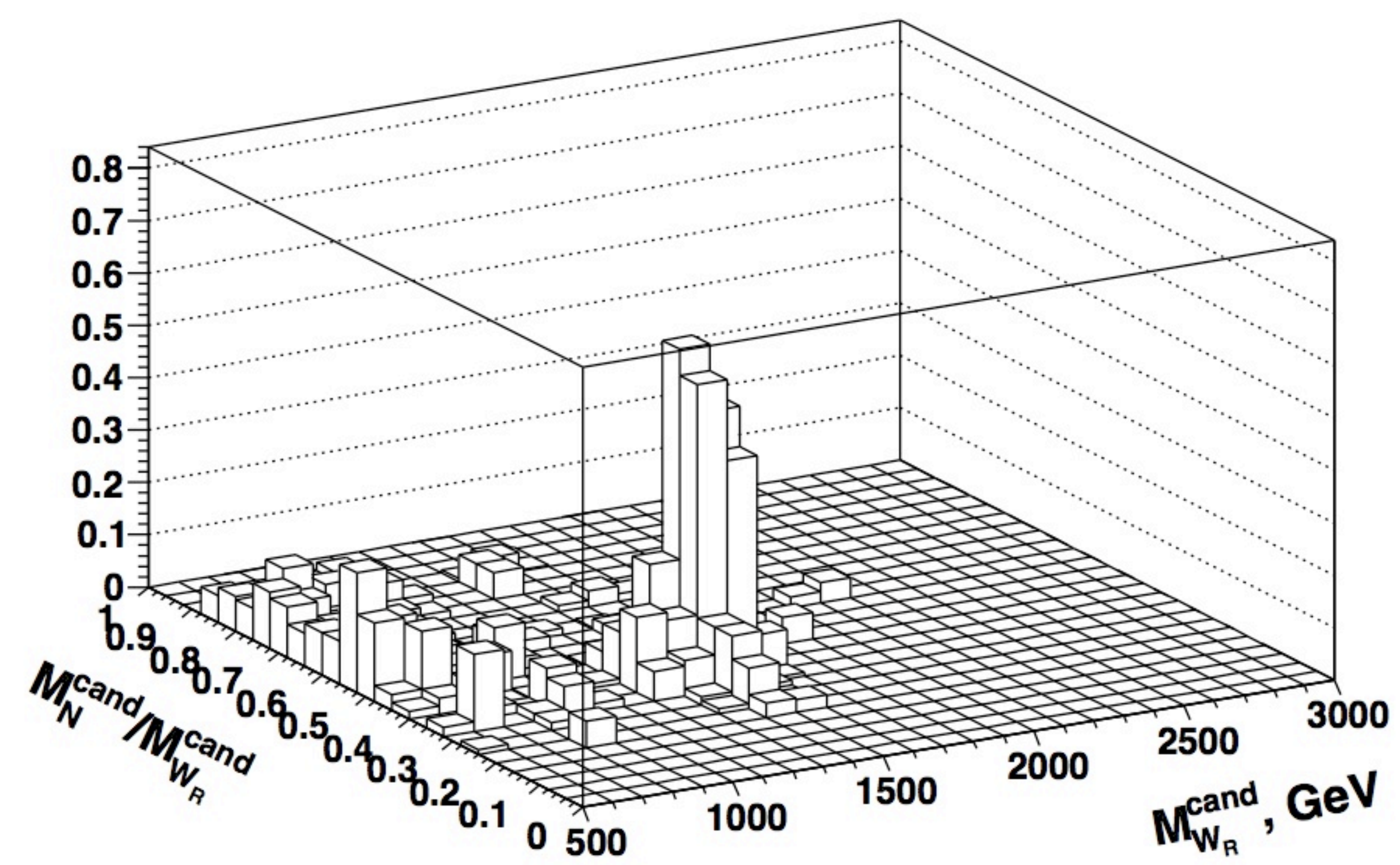
# Backgrouns, muons

Table 3: Evolution of the numbers of signal and background events versus selection criteria (muon channel, muon trigger stream used). The numbers correspond to the statistics collected in the CMS detector for the integrated luminosity of $\mathcal{L}_{int} = 100\ pb^{-1}$.

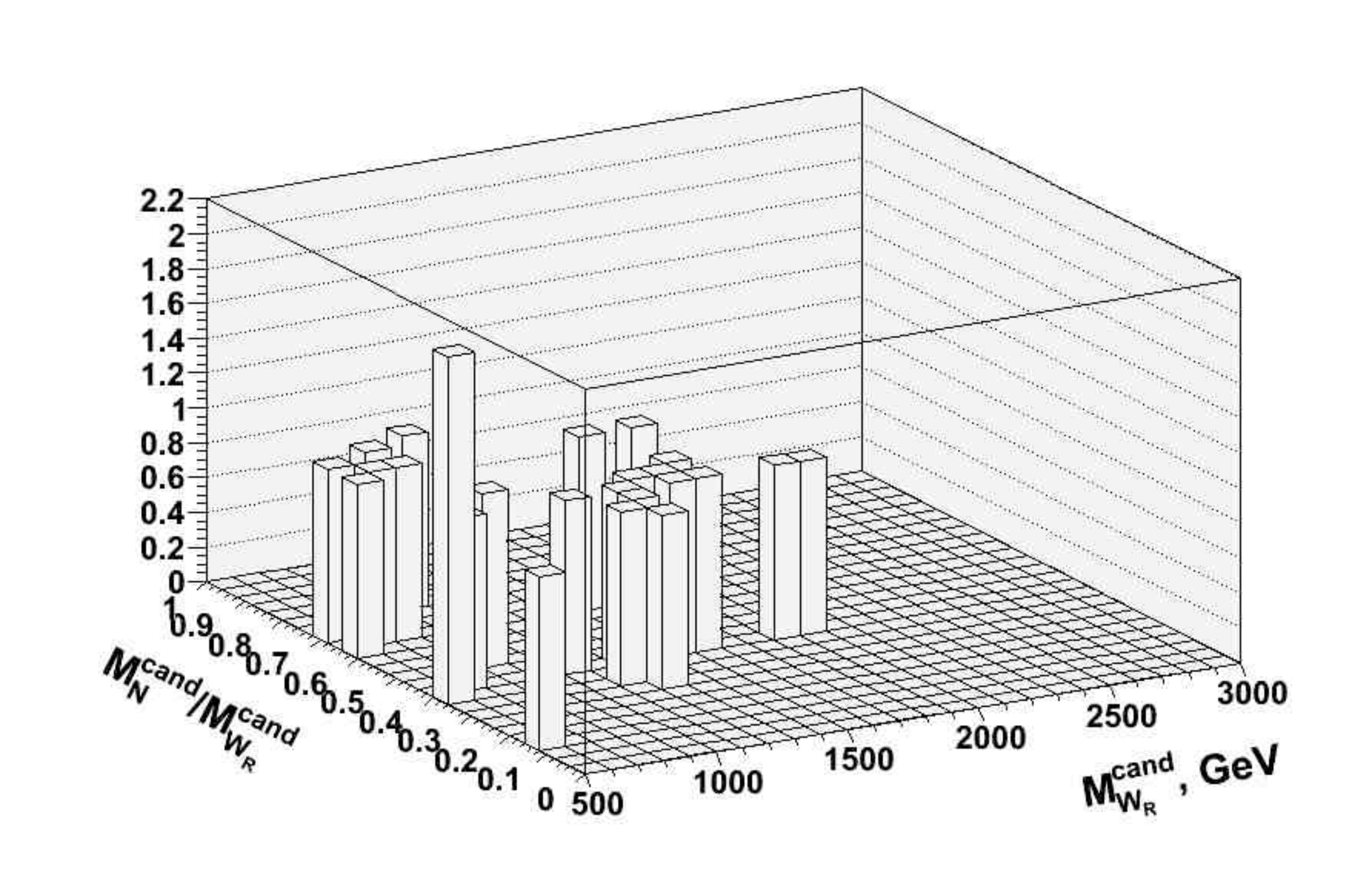
**Most dangerous**

| Step | Signal LRRP1 | $t\bar{t}$ | Z jets $\mu\mu$ | W jets $\mu$ | QCD | WW jets | WZ jets | Others |
|---|---|---|---|---|---|---|---|---|
| Initial | 6.72 | 16200 | 167000 | $10^6$ | $2.8 \cdot 10^{10}$ | 4300 | 1800 | 1600 |
| Simulated | 2000 | 627000 | 2310000 | 2073000 | $2.1 \cdot 10^7$ | 120000 | 114000 | 145000 |
| Primary selection | 4.42 | 138 | 413 | 24 | 40 | 1.9 | 6 | 4.2 |
| Two isolated $\mu^\pm$ | 4 | 50 | 370 | 4.2 | 13 | 0.6 | 4.8 | 3.5 |
| $M_{ll}$ cut | 3.8 | 5 | 2.8 | 0.5 | 0 | 0.12 | 0 | 0.016 |
| $M_{W_R}^{cand} > 500$ GeV | 3.8 | 3 | 2.1 | 0.5 | 0 | 0.07 | 0 | 0.013 |
| Under 2D peak | 1.8 | 0.024 | 0 | 0 | 0 | 0 | 0 | 0 |

# Example of data generated by MC



# Example of "real" data generated by MC



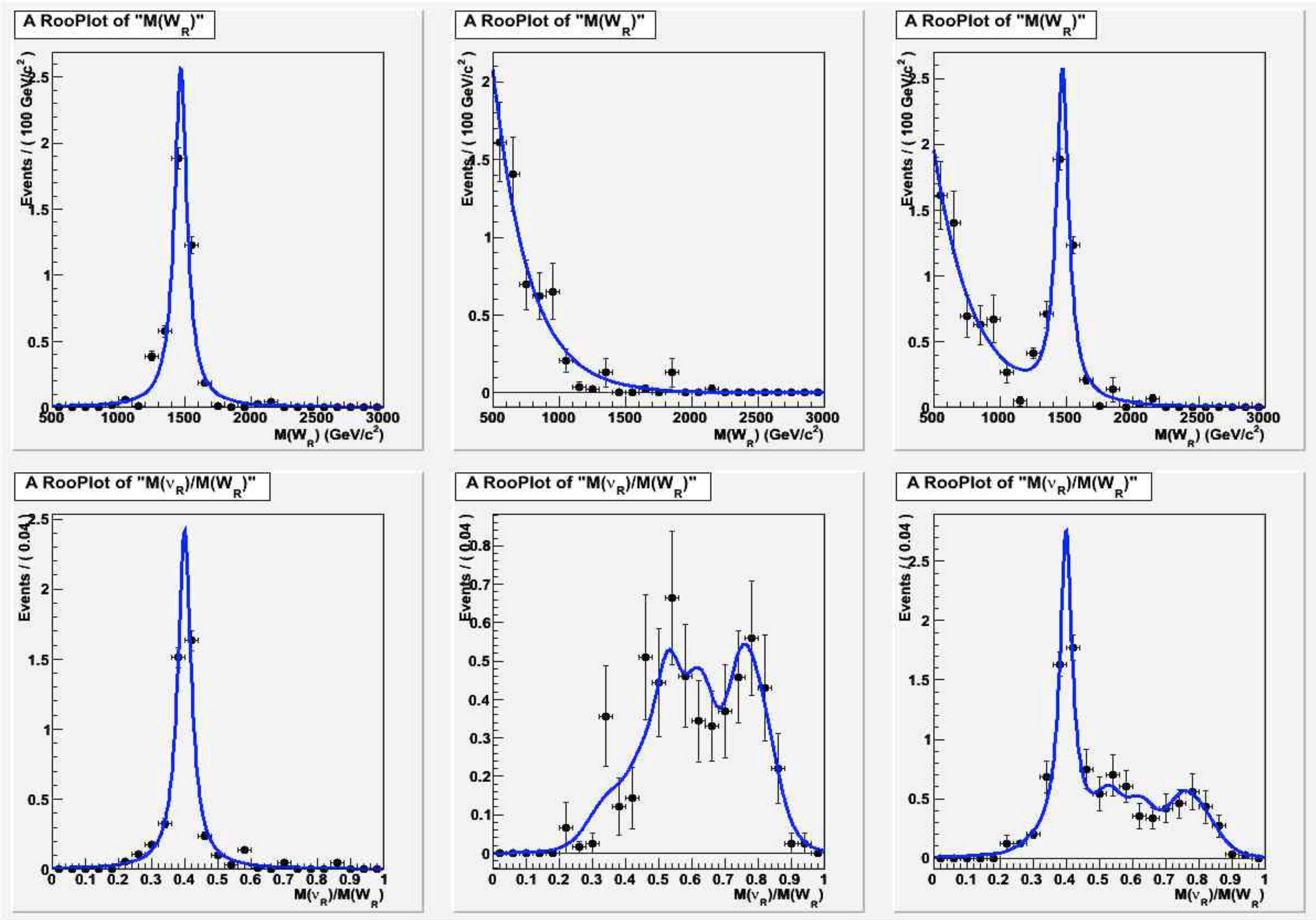
# 2D- Fit

$$F(M_{WR};\frac{M_N}{M_{WR}}) = n_S F(M_{WR};\frac{M_N}{M_{WR}}) + n_B F(M_{WR};\frac{M_N}{M_{WR}})$$

**Free parameters**

- $n_S$ number of signal events
- $n_B$ number of signal events
- $M_{WR}$, $M_N$

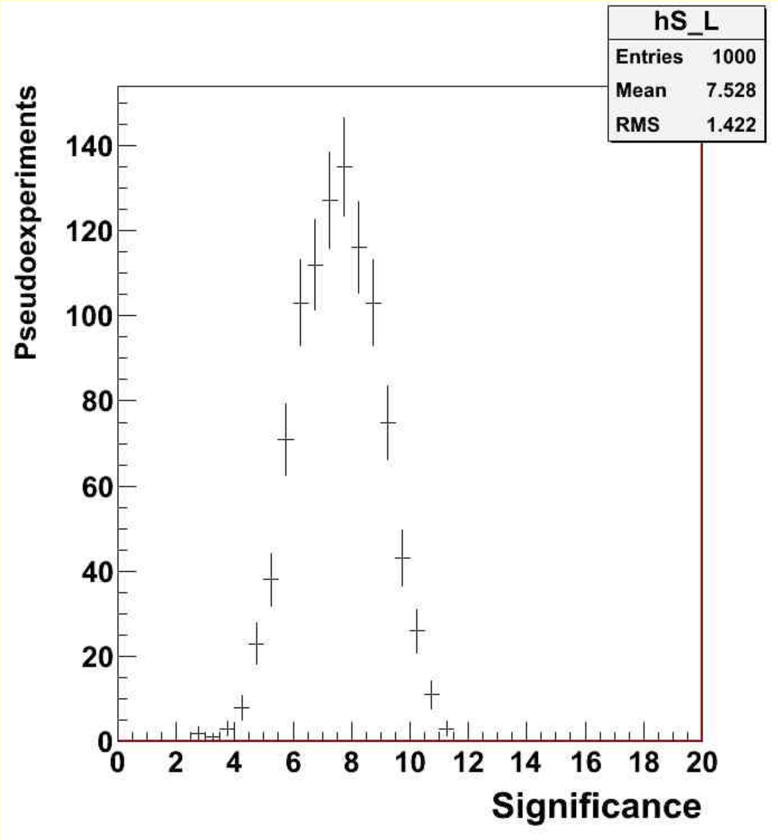
# 2D-fit (2), exampe



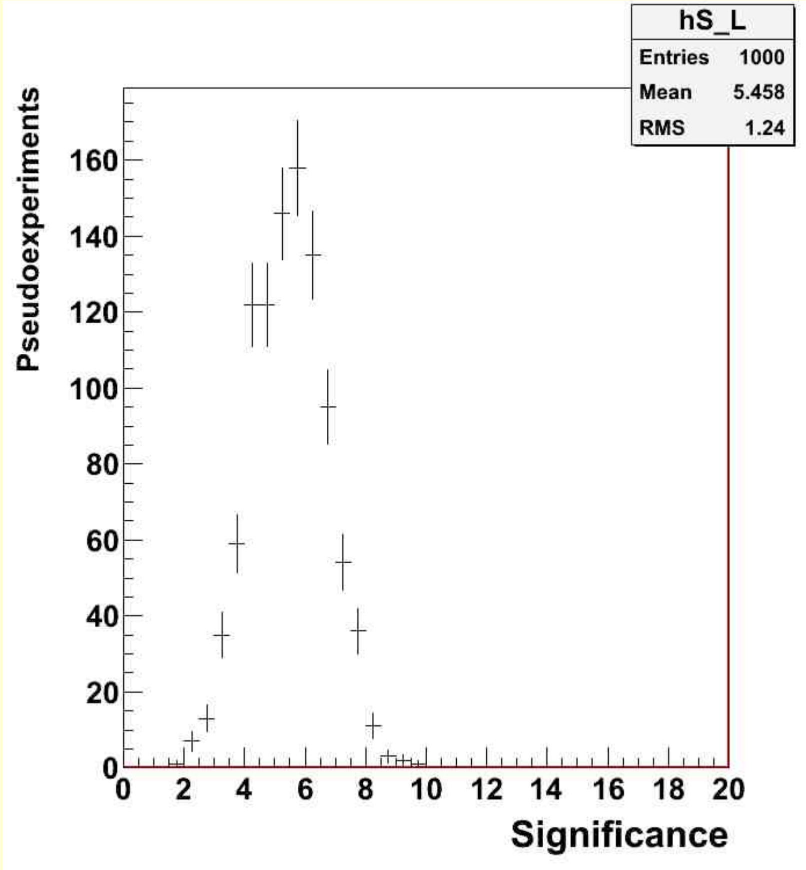
# Significance

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

Electrons

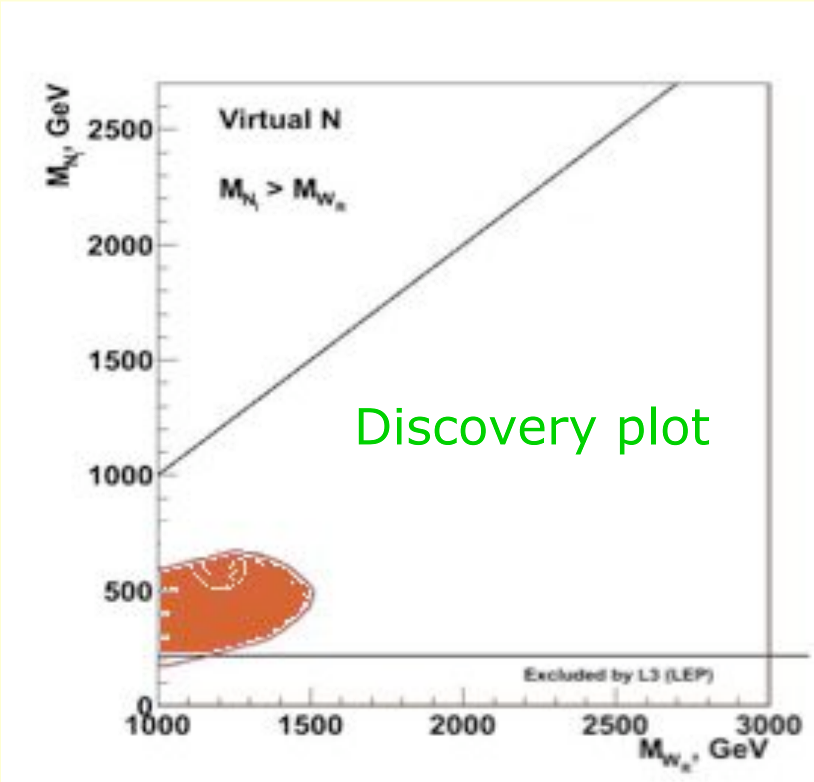


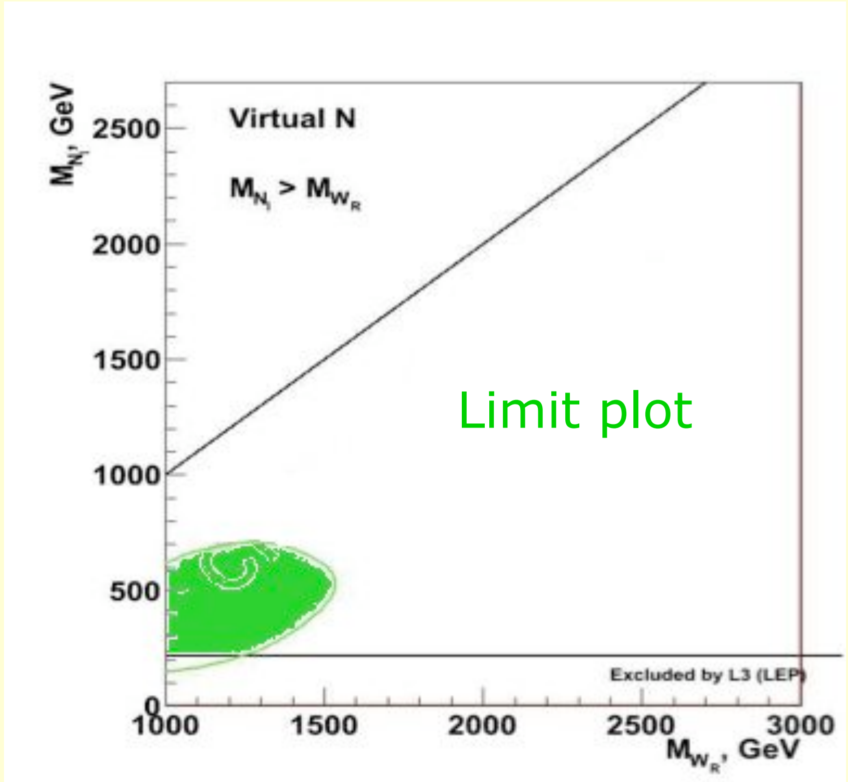

muons



# N vs $W_R$ mass plots at LHC, 7 TeV, 100 $pb^{-1}$

## electron channel



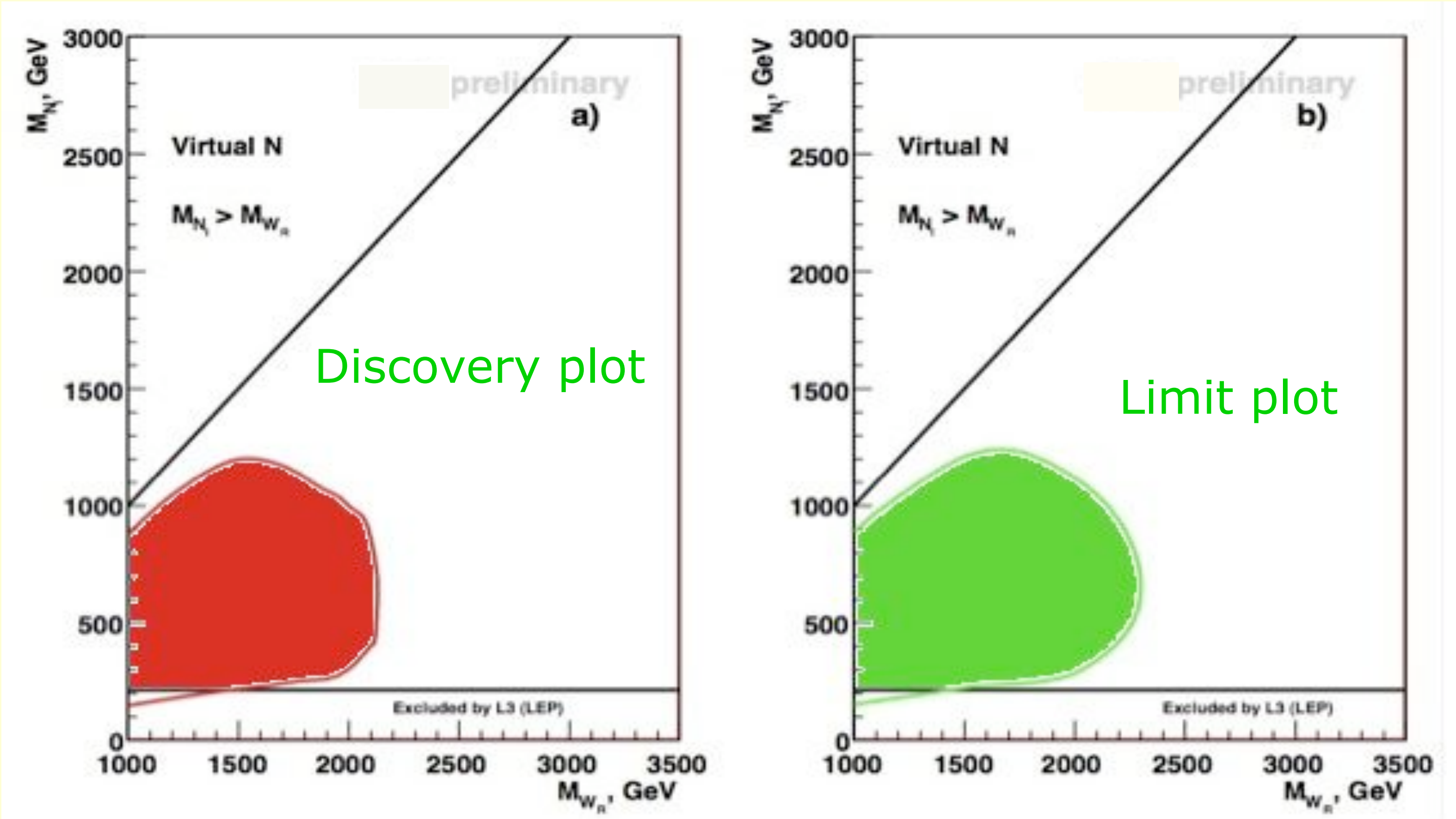




$M_{WR}$ < 1.5 TeV

$M_{WR}$ > 1.55 TeV

# N vs $W_R$ mass plots at LHC , 14 TeV, 1 $fb^{-1}$

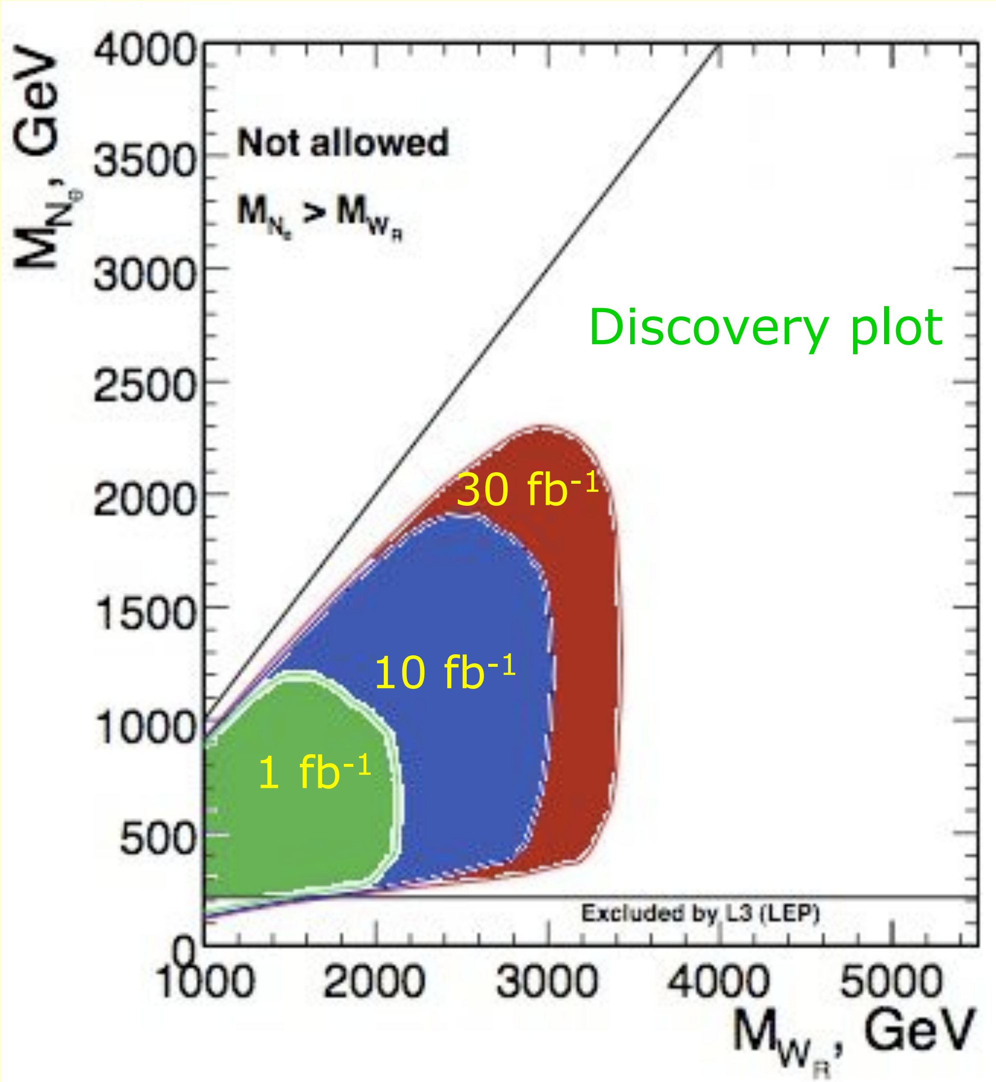
## Electron channel




$M_{WR}$ < 2.1 TeV

$M_{WR}$ > 2.3 TeV

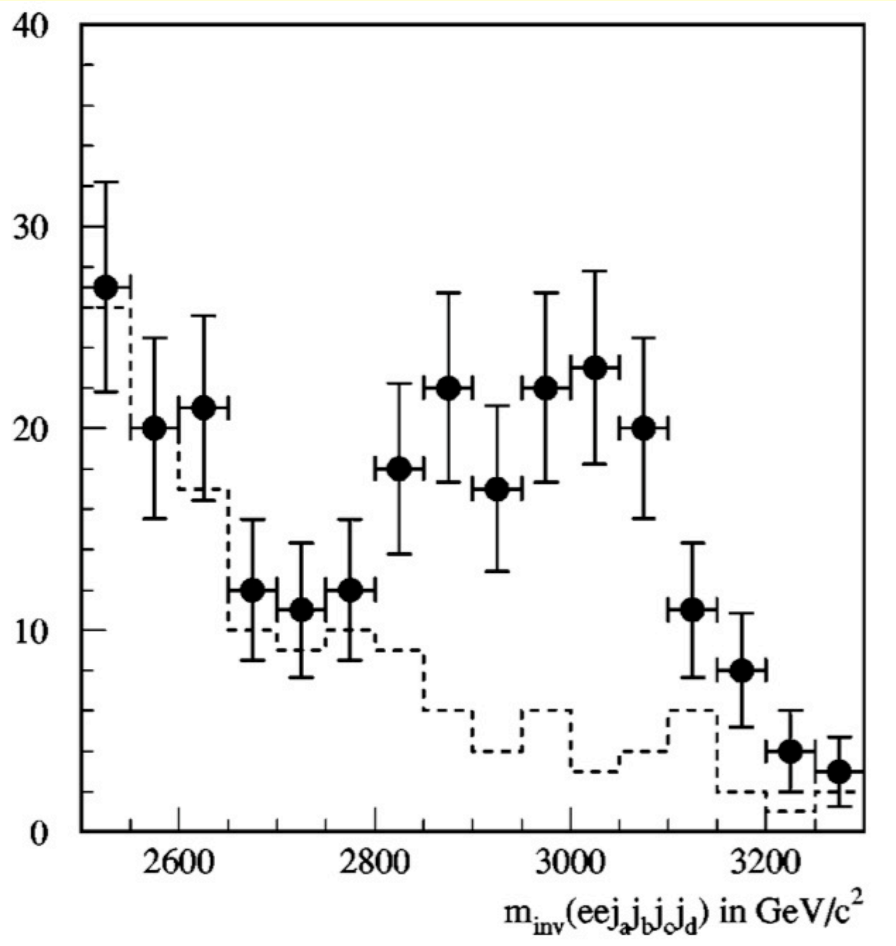
# N vs $W_R$ mass limit at LHC , 14 TeV

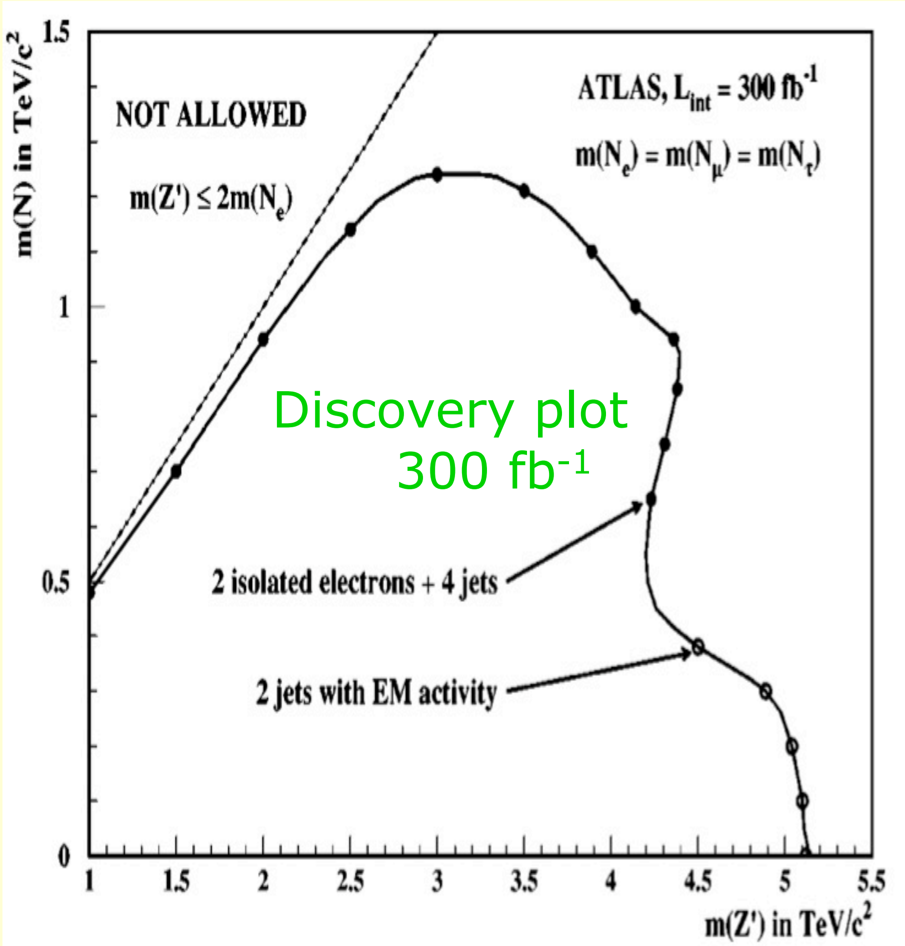



$W_R$ > 3.4 TeV

# Search for Z`

Ferrari’ 02



# Summary

- the **LRSM** can be well probed at the LHC:

  **7 TeV, 100 pb$^{-1}$** ( few months of running)

  $M_{WR} < 1.5$ TeV ; $M_N < 600$ GeV

  can be observed in the ee channel

  **14 TeV, 30 fb$^{-1}$**

  $M_{WR} < 3.5$ TeV ; $M_N < 2.3$ TeV

  can be observed in the ee channel

- next step towards the analysis of real data.

  new results are expected next year