Technicolor and other Beyond Standard Model alternatives at CMS

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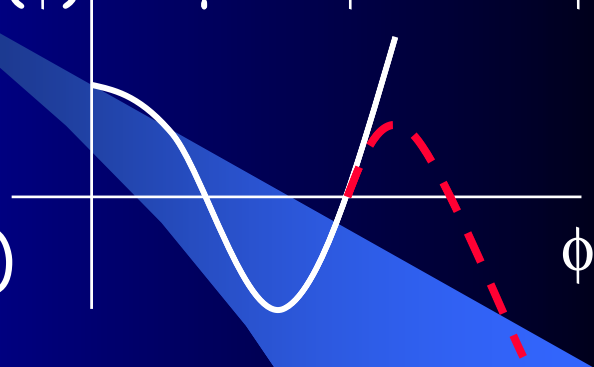
Outline

- Limits on Elementary Higgs Models
- Technicolor: Introduction and Phenomenology
- $\rho_{TC} \rightarrow$ W+Z Discovery Potential at CMS
- Other BSM signal: Heavy Majorana neutrinos

Limits on Elementary Higgs Models

(1) Source of EW Symmetry Breaking ? Why vev = $\upsilon^2 > 0$?

$V(\phi) = -\mu^2/2\phi^2 + \lambda/4\phi^4$



(2) Stability bound:

$\text{vev} \neq 0 \Rightarrow -2\mu^2 = 2\lambda\upsilon^2 = M_H^2$

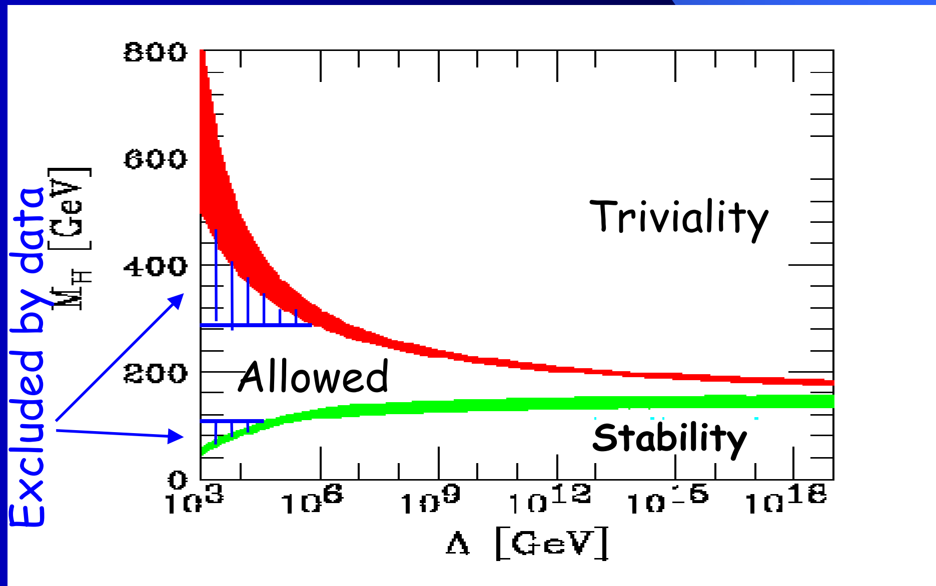
Unstable against rad. corrections:

$\Delta V \sim 1/\upsilon^4 \,(M_H{}^4 - 12m_t{}^4 + 6M_W{}^4 + 3M_Z{}^4)$

$$M_H \gtrsim 130\ \text{GeV}$$

(3) Triviality bound:

$$\Lambda_C = \upsilon \exp\left[\frac{4\pi^2\upsilon^2}{M_H^2}\right]$$



Technicolor Baseline

➔ new strong interaction with N_{TC}^2-1 technigluons
➔ at $\Lambda_{TC} \sim \upsilon_{weak}$, VEV of a technifermion condensate $\langle TT \rangle$
➔ gives dynamical origin to EWSB !

Originally TC built in analogy to QCD:

$\langle TT \rangle \sim \Lambda_{TC}^3$ ⇆ $\langle qq \rangle \sim \Lambda_{QCD}^3$
technipion ⇆ *pion*
$SU(N_{TC})$ ⇆ SU(3)

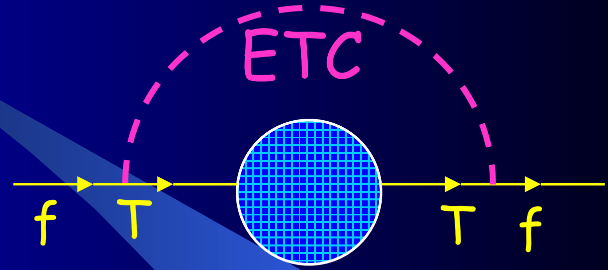
- VEV: chiral symmetry $SU(2)_L \times SU(2)_R$ breaks
- yields technipions π_T (Goldstone bosons)
- π_T become longitudinal components of W and Z

➔ $M_W = M_Z \cos\theta_W = \frac{1}{2} g F_\pi$ ($F\pi$ = 246 GeV)

Technicolor Extensions

Question: how do SM fermions get mass ?

$$m_f \sim \frac{\Lambda_{TC}^3}{M_{ETC}^2}$$



➔ Extended TC (ETC) :

- $SU(N_{TC}) \times SU(3)_C \times SU(2)_L \times U(1)_Y$ broken to technicolor and color at $\Lambda_{ETC} \gg \Lambda_{TC}$

Question: how to incorporate experimental FCNC limits ?

- $\Lambda_{ETC} \sim O(1000\,TeV)$ ➔ m_f are ~ 1000x too small !

solution: $< \bar{T}T >_{ETC} = < \bar{T}T >_{TC} \exp\left(\int_{\Lambda_{TC}}^{M_{ETC}} \frac{d\mu}{\mu} \gamma_m(\mu) \right)$ ⟶ =~1

➔ Walking TC achieved via large nb of technifermions: N_D

Question: how to incorporate experimental top mass ?

➔ Topcolor assisted Technicolor (TC2) (hep-ph/9411426)

Technicolor Phenomenology (I)

➔ Consider in isolation bound-states of the lightest technifermion doublet (T_U, T_D) =

Technicolor Straw Man model (TCSM)

- color-singlet sector:
  technipions π_{TC}, technimesons ρ_{TC}, ω_{TC}
- color-Nonsinglet sector: π_{T8}, π_{LQ}, ρ_{T8}, V_8 (colorons)

➔ Cross-Section parameterization:

$$\rho_{TC} \rightarrow \cos^2\chi(\pi_{TC}\pi_{TC}) + \cos\chi\sin\chi(W_L\,\pi_{TC}) + \sin^2\chi(W_L Z_L)$$

➔ Walking TC: $\sin^2\chi = \dfrac{1}{N_D} << 1$

Technicolor Phenomenology (II)

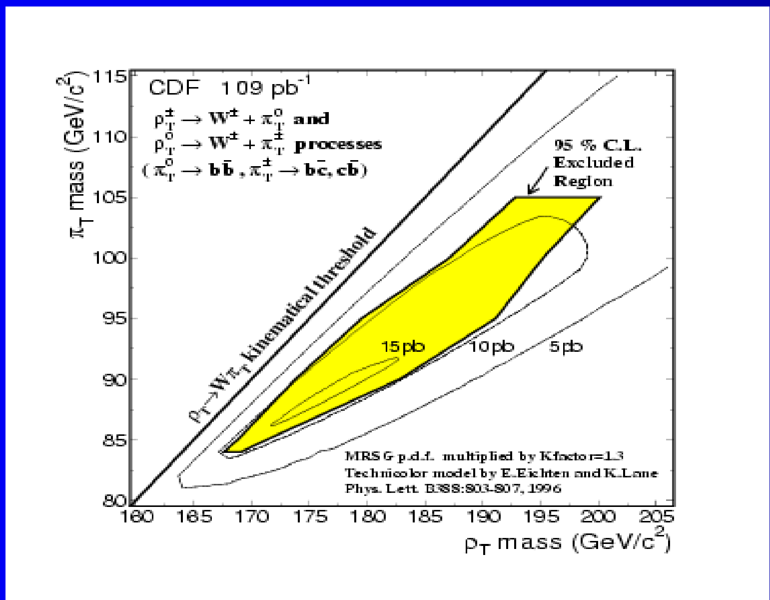
➔ π_{TC} (W_L,Z_L) Drell-Yann produced: $q\bar{q}' \rightarrow W^{+-} \rightarrow \rho^{+-}_{TC} \rightarrow W^{+-}_L \pi^0_{TC}$

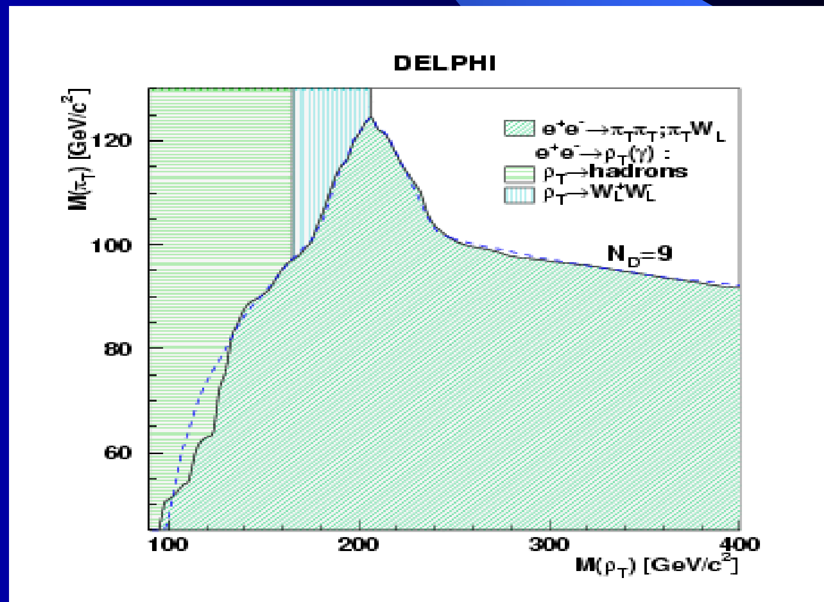
➔ technipions decays: $\pi^{+-}_{TC} \rightarrow t\bar{b}$ or $c\bar{b}$ / $\pi^0_{TC} \rightarrow t\bar{t}$ or $b\bar{b}$

➔ technirho and techniomega decays:

$\rho_{TC} \rightarrow W_L Z_L \,;\, W_L \pi_{TC} \,;\, Z_L \pi_{TC}$ $\qquad \omega_{TC} \xrightarrow[EW]{} W_T \pi_{TC} \,;\, Z_T \pi_{TC} \,;\, \gamma \pi_{TC}$

Existing Limits on ρ_{TC} from data ➔





➔ more: PDG Phys.Lett.B592,1 (2004) and D0 talk by L.Feligioni

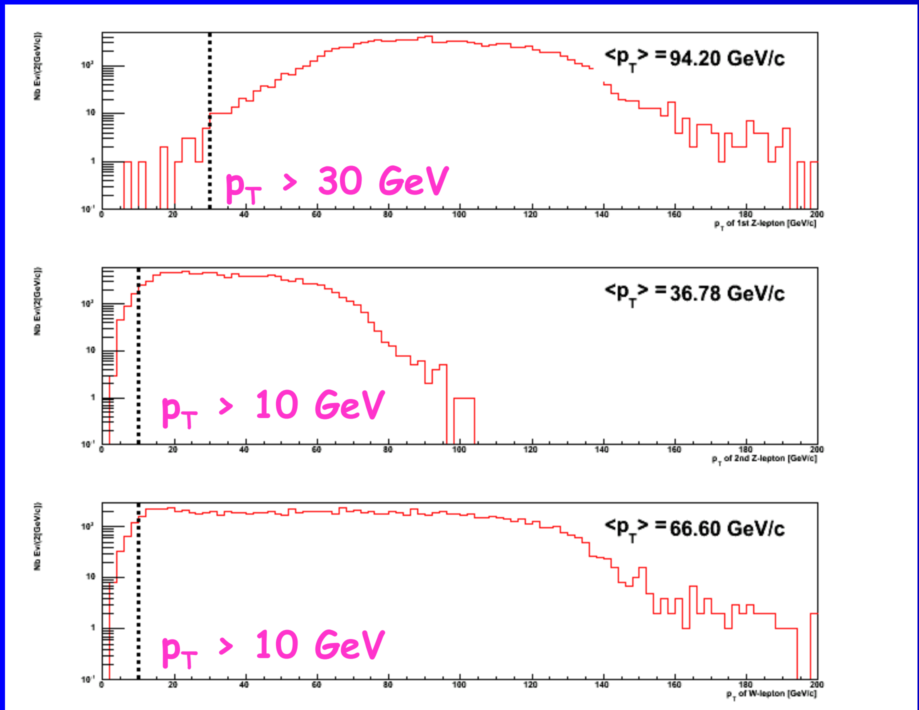
Technicolor potential at CMS

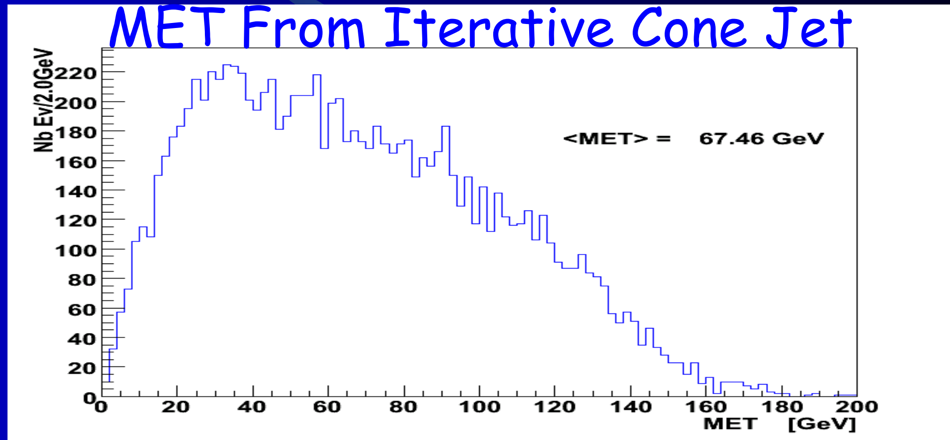
- ➔ main goals of CMS are color-singlet ρ_{TC} and ω_{TC} modes
- ➔ will now show discovery potential of the cleanest channel: $\rho_{TC}^{+-} \rightarrow W+Z \rightarrow 3\ \ell + \upsilon$

  - Signal (TCSM) and Background generation with Pythia 6.2 (CompHEP for Zbb)
  - Dominating background from SM processes: ZW, ZZ, $Zb\bar{b}$ and $t\bar{t}$.
  - Detector simulation + Analysis with CMS Fast Simulation tool "FAMOS"
  - Single- or Two-electron or Muon Trigger
  - Low luminosity scenario $2x10^{33}cm^{-2}s^{-1}$

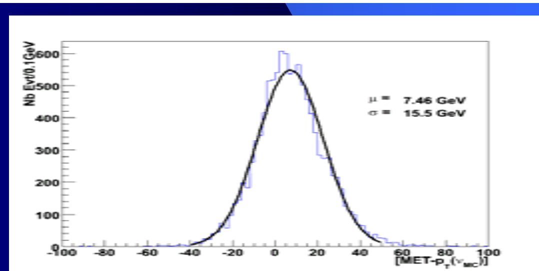
$p_{TC} \rightarrow W + Z \rightarrow 3\ell + \upsilon$ Reconstruction

Main reconstructed objects for this channel are:
Electrons, Muons, Tracks (e/μ Isolation) and Missing E_T (MET)





$$\frac{\sigma_{MET}}{MET} = 23\%$$



➔ Realistic reco quality/efficiency of Leptons and MET included in result as systematic uncertainties: 2% and 7.5%.

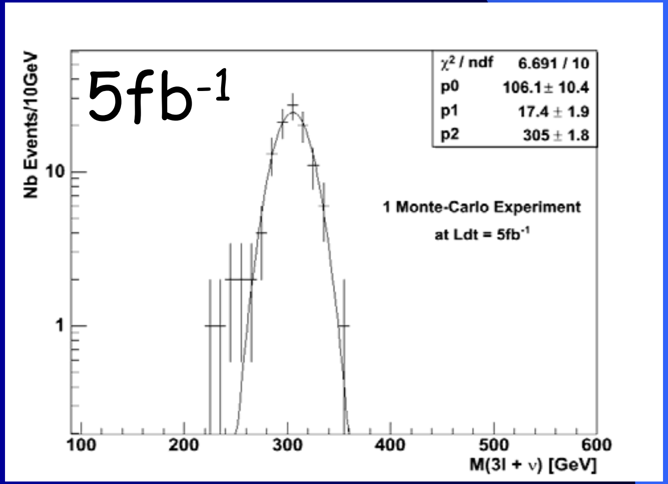
$\rho_{TC} \rightarrow W + Z$ Selection

- ➔ Z Selection: same-flavor and opposite-charge ℓ-pair closest to $M(Z_0)$.

- ➔ W Reconstruction: 3^{rd} ℓ + Missing E_T + M(W)-constraint = 2^{nd} order polynomial in neutrino-p_Z

- ➔ Existing solutions: quadratic ambiguity.
  Minimum-$|p_Z|$ solution correct choice in ~70% of cases
- ➔ Choose minimum-p_Z !

- ➔ Selected ρ_{TC} is admixture of correct/wrong υ-p_Z solutions, but dominated by det. resolution
- ➔ single Gaussian approx. OK !

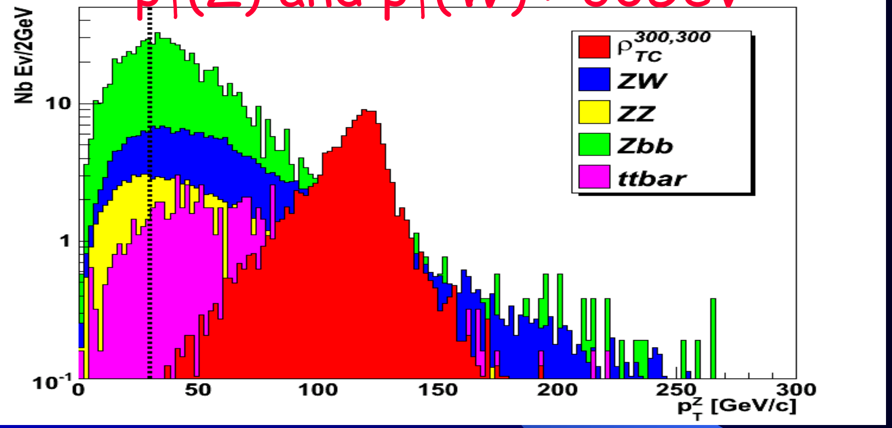


$\rho_{TC} \rightarrow$ W + Z Kinematic cuts

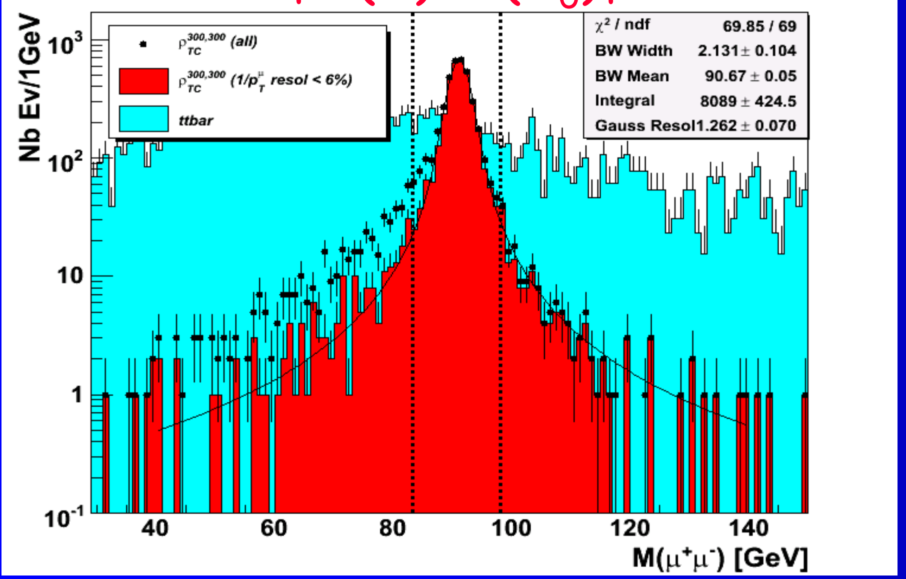
$p_T(Z)$ and $p_T(W)$ cuts ➔
low to preserve exponential
bgd hypothesis in $M(3l+\upsilon)$ fit

➔ All Cuts optimized on S/B

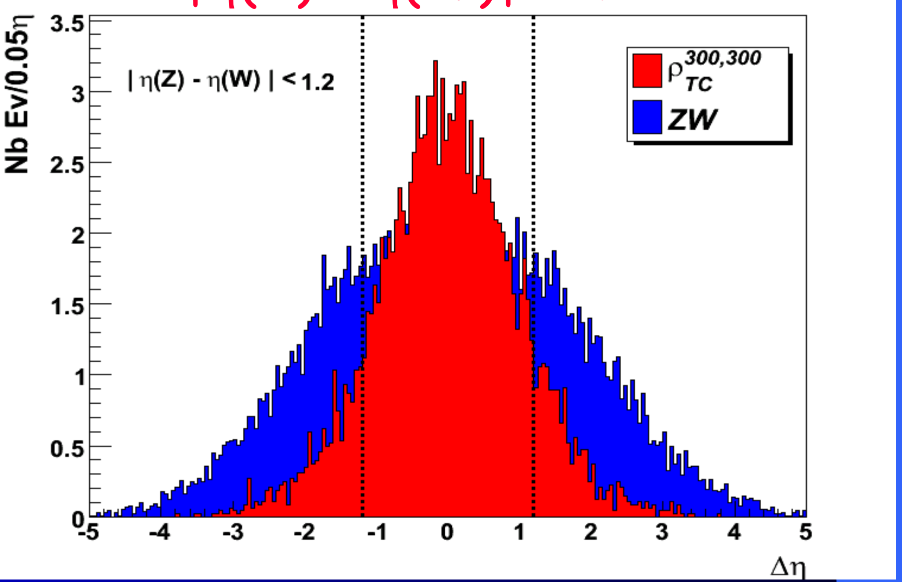
$p_T(Z)$ and $p_T(W)$ > 30GeV



Z Reco + $|M(Z)-M(Z_0)|$<7.8GeV



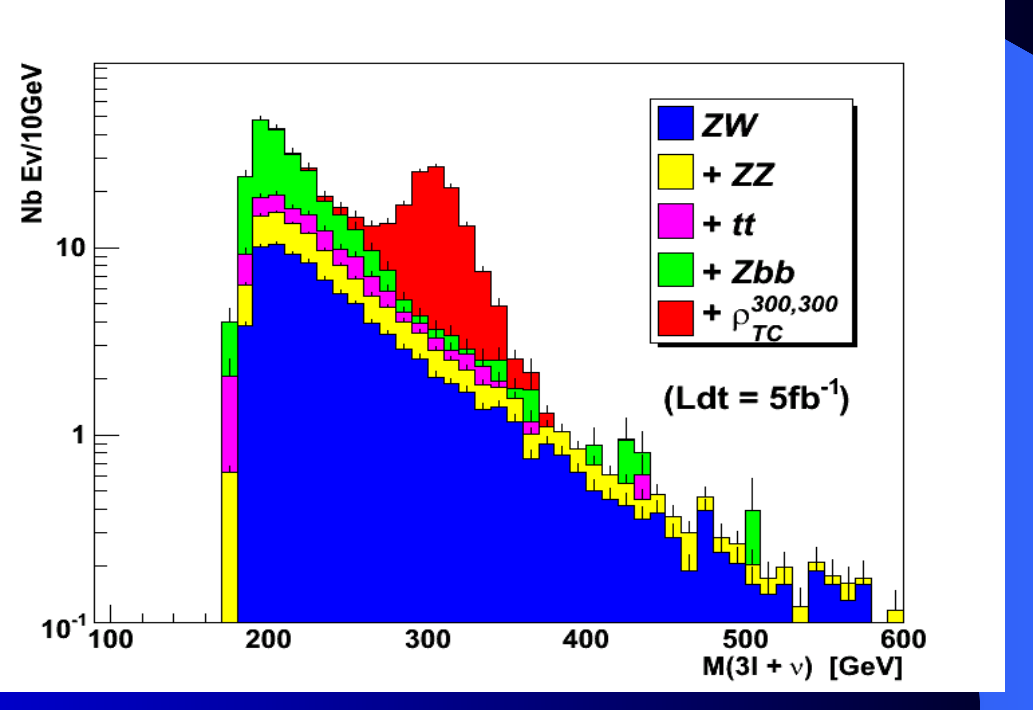
$|\eta(Z) - \eta(W)|$ < 1.2



Invariant Mass Yields $M(3\ell + \nu)$

Sample	σxBR (pb)	$\varepsilon(3\ell)$	ε(Reco)	$Nev(5fb^{-1})$
$\rho_{TC} \to W+Z$	0.13	0.635	25.88 +- 0.40	103
$ZW \to 3\ell+\nu$	0.39	0.471	9.91 +- 0.11	27
$ZZ \to 4\ell$	0.07	0.719	15.80 +- 0.14	10
$Zbb \to 2\ell+X$	332	0.046	0.23 +- 0.01	12
tt	489	0.065	0.019 +- 0.001	8

- ➔ Background dominated by ZW and Zbb
- ➔ Z+jets with fake e/μ included in systematic uncertainties below.



$\rho_{TC} \rightarrow W + Z$ Sensitivity

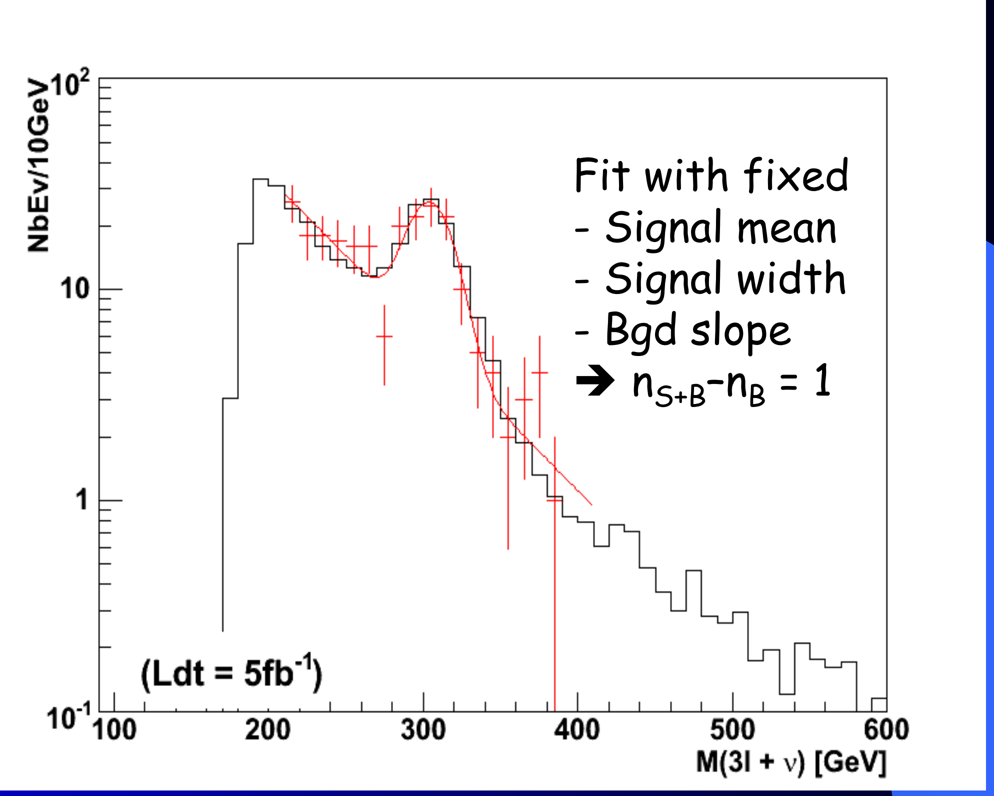
Signal pdf = $\mathcal{P}_S$ =single Gaussian

Background pdf = $\mathcal{P}_B$ = single exponential

Likelihood fit: $\mathcal{L}_{s+b} \sim \Pi\,[\,(n_S\mathcal{P}_S + n_B\mathcal{P}_B)/(n_S + n_B)\,]$

Sensitivity Estimator:

$S_{\mathcal{L}}$ = sqrt[$2\ln(\mathcal{L}_{s+b} / \mathcal{L}_b)$]



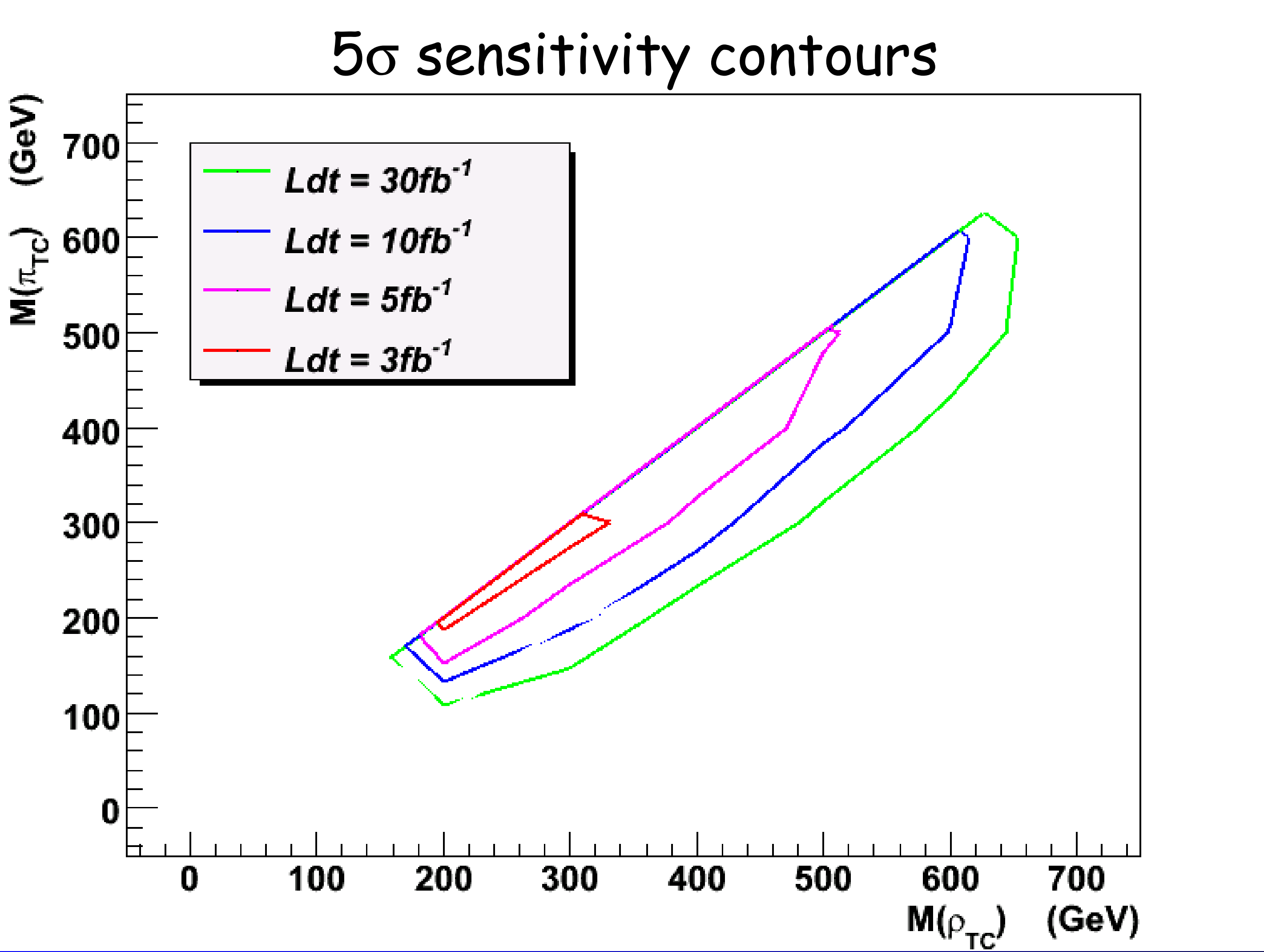
<u>Realistic MC-experiment</u>:

- $M(\rho, p) = (300,300)$GeV
- Ldt = 5fb^{-1}

➔ Sensitivity ~ 7

Repeated for all ρ_{TC} benchmark points

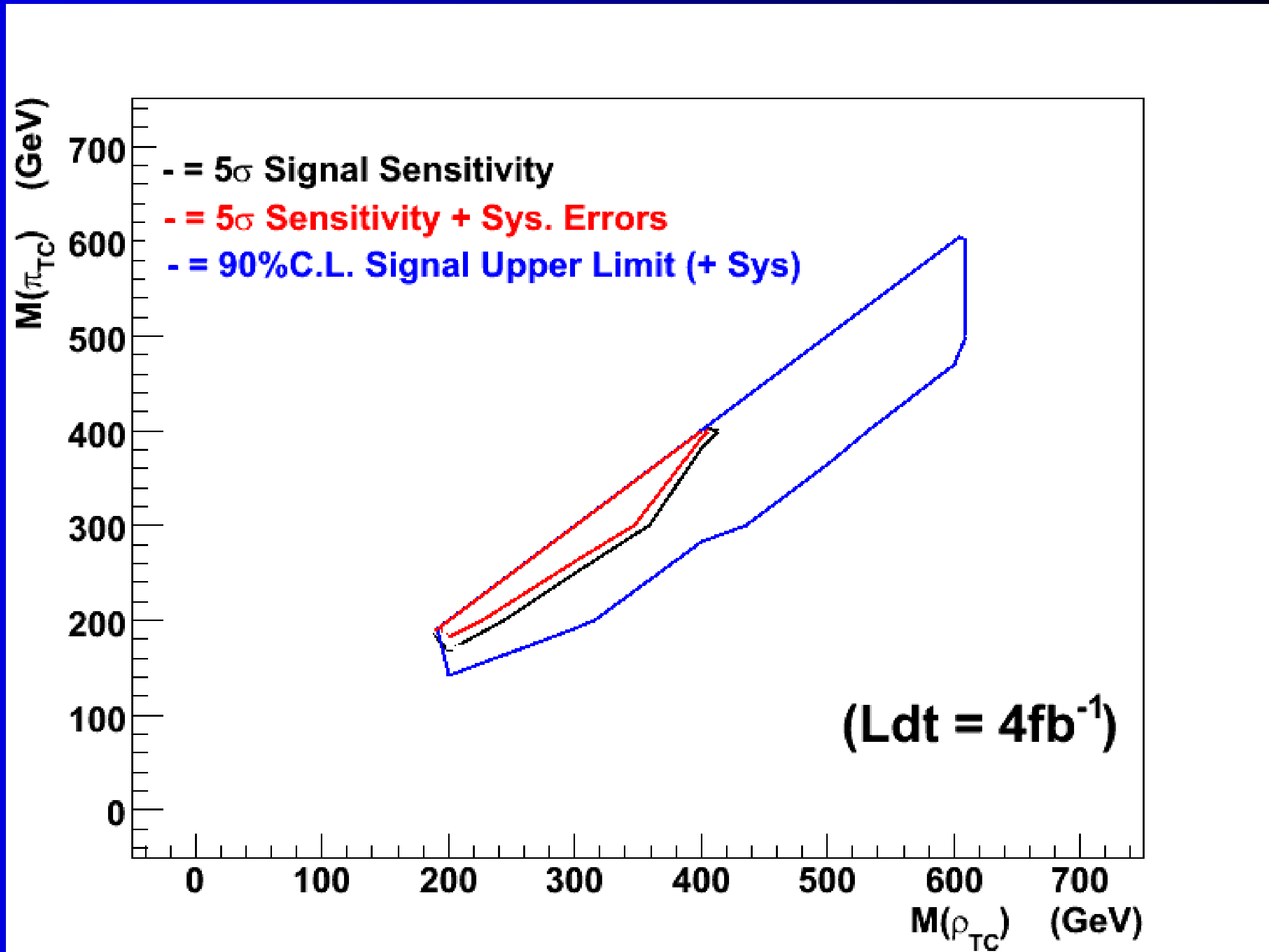
$\rho_{TC} \rightarrow W + Z$ Sensitivity scan



$\rho_{TC} \rightarrow$ W+Z Discovery Potential @ CMS

Expected sensitivity-drop from systematic uncertainties:

- lepton eff	2.7%
- fake leptons	8.5%
- MET	6.6%
total:	11.0%



Heavy Majorana neutrinos

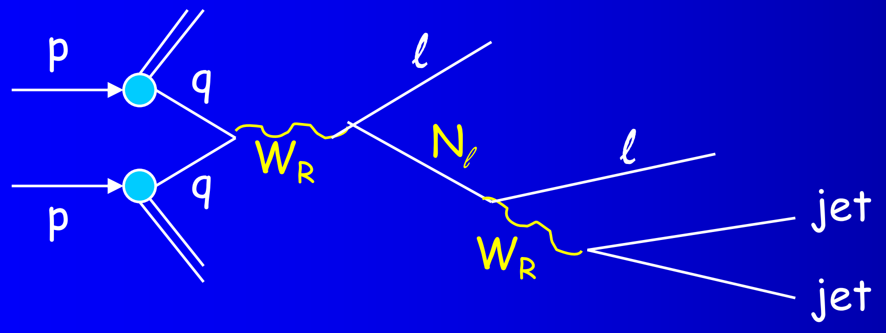
➔ Embedded in the left-right (LR) symmetric model, i.e. extension of the Standard Model which naturally explains parity violation in weak interactions

Gauge Group $SU_C(3) \times SU_L(2) \times SU_R(2) \times U(1)$

➔ theory includes additional gauge bosons W_R, Z' and heavy right-handed Majorana neutrinos N_ℓ

➔ N_ℓ provide ν_ℓ masses through the see-saw mechanism

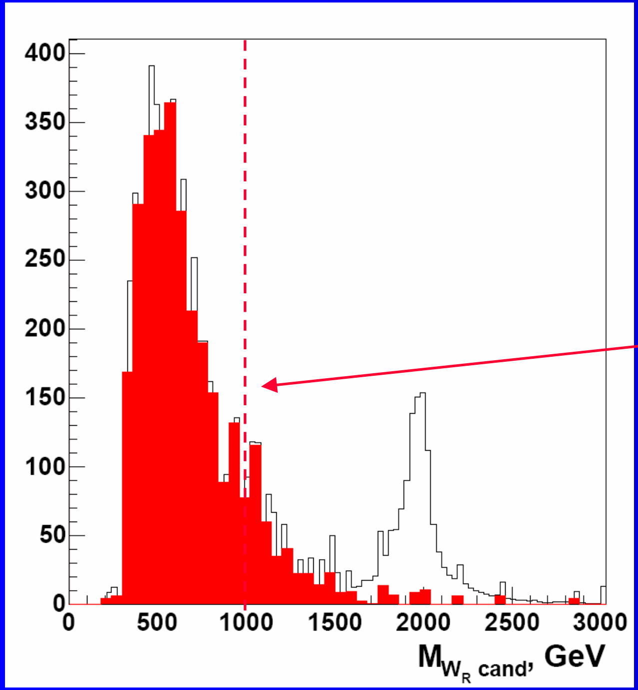
➔ Motivated by latest neutrino oscillation measurements



➔ 2ℓ + 2jet final state

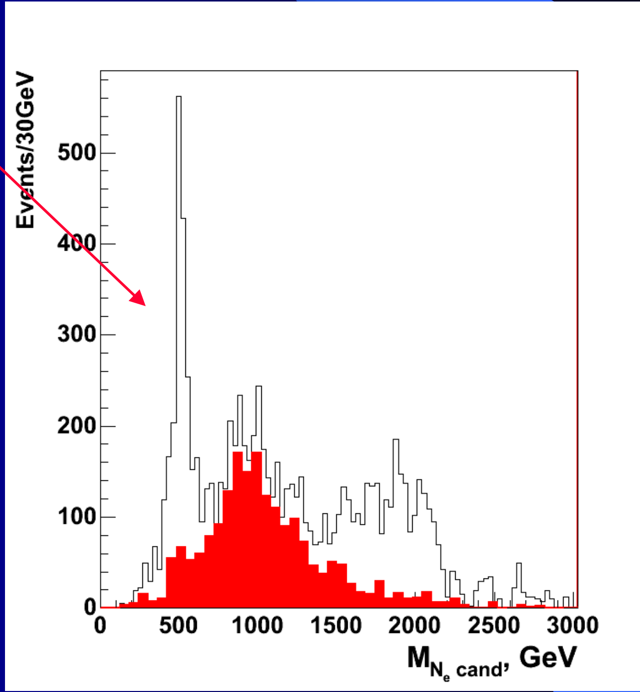
➔ Produced w. Pythia (CMS NOTE 2006/098)

W_R and N_e Selection: 2e + 2jets



<u>Event Selection</u> (full CMS det. Simulation):

- 2 high-p_T isolated e and 2 high-E_T jets
- M_{ee} > 200 GeV
- M(2e+2jets) > 1 TeV
- M(1e+2jets) window (optimized 110 GeV)



➔ Main backgrounds $t\bar{t}$, Z+jets (ZW, WH almost negligible)

➔ Ldt = $30 fb^{-1}$: N_{sig} = 938 evts

N_{bgd} = 294 evts

W_R and N_e Discovery Potential @ CMS

➔ Significance estimator:

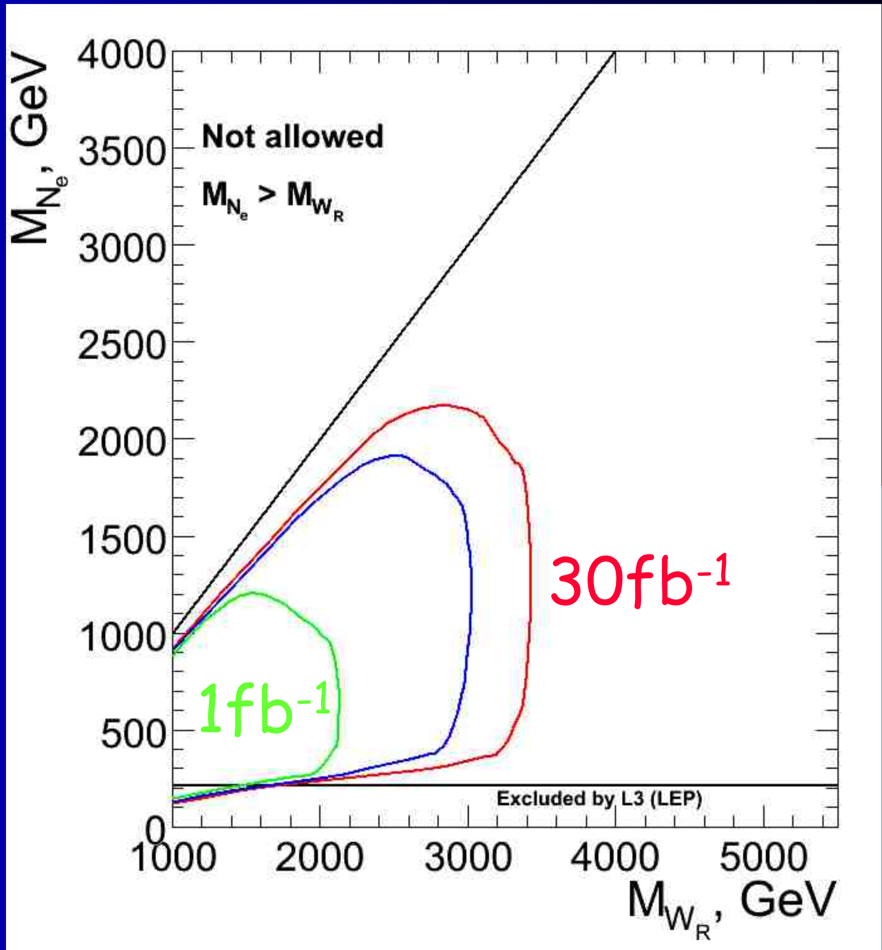
$S = 2(\mathrm{sqrt}[N_S+N_B] - \mathrm{sqrt}[N_B])$

➔ W_R and N_e mass reach at early stage of running !

Systematics uncertainties:

- jet energy scale (3%)
- PDF (6% on X-section)

➔ Discovery contour only affected at few % level



Conclusions

→ The Technicolor Signature $\rho_{TC}^{+-} \rightarrow W + Z$ has been simulated under the color-singlet "Straw Man" Model (TCSM).

→ CMS has the potential for Technicolor discovery at integrated luminosities starting from 3-4 fb^{-1}, i.e. a strong handle for BSM physics @ LHC

(published in CMS PTDR Vol.2 + CMS AN 2006/021
CMS NOTE submitted)

→ The heavy right-handed Majorana neutrino N_e and the heavy gauge boson W_R in the context of the Left-Right symmetric model are reachable at CMS after only ~1 month of running at low luminosity.

(published in CMS PTDR Vol.2 + CMS NOTE 2006/098)