Neutrinos at LHC Results from CMS

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on behalf of CMS Collaboration

Outlines

- Neutrinos parameters
- Seesaw mechanism
- LHC performance
- CMS physics objects
- Type I fermionic isospin singlets
- Type II scalar triplets
- Type III fermionic triplets
- Summary and conclusions

Neutrinos parameters

- Neutrinos oscillate (1998, Super-Kamiokande)
- Neutrinos are massive and mixed
- This is an evidence for physics beyond the standard model (BSM)
- Left-Right-Symmetric extension (LRSM) deploys a **seesaw mechanism** to give a possible explanations for the smallness of the ordinary neutrino masses

LRSM has new particles: $W^{\pm}_R$, Z', N^i_R (mass M)

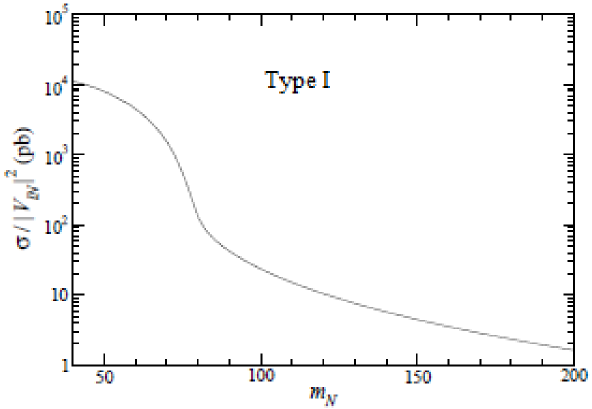
	Standard Model	**Left-Right-Symmetric Extension**
Gauge group	$SU(2)_L \otimes U(1)_Y$	$SU(2)_L \otimes$ **$SU(2)_R$** $\otimes U(1)_{B-L}$
Fermions	LH doublets: $Q_L = (u^i, d^i)_L$; $L_L = (l^i, \nu^i)_L$ RH singlets: $Q_R = u^i_R, d^i_R$; $L_R = l^i_R$	LH doublets: $Q_L = (u^i, d^i)_L$, $L_L = (l^i, \nu^i)_L$ RH doublets: $Q_R = (u^i, d^i)_R$, $L_R = (l^i, N^i)_R$
Neutrinos	ν^i_R do not exist ν^i_L are massless and pure chiral	N^i_R are heavy partners to the ν^i_L N^i_R Majorana in the Minimal LRSM
Gauge bosons	$W^{\pm}_L$, Z^0, g	$W^{\pm}_L$, **$W^{\pm}_R$**, Z^0, **Z´**, g

LHC experiments are investigating seesaw signatures
CMS collaboration results will be shown in this talk

Seesaw mechanism

LHC experiments have discovery potential for seesaw mechanism at electroweak scale.

Fermionic isospin singlets

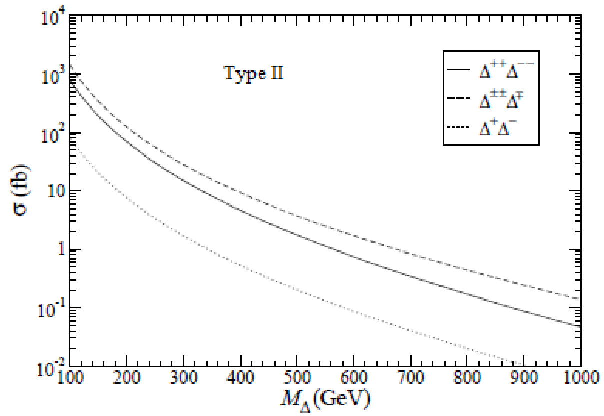


Right-handed neutrino singlets N

$|V_{\ell N}|^2$ = square of the mixing element l,N

$$q\bar{q}' \rightarrow W^* \rightarrow l^{\pm} N$$
$$q\bar{q} \rightarrow Z^* \rightarrow \nu N$$
$$gg \rightarrow H^* \rightarrow \nu N$$

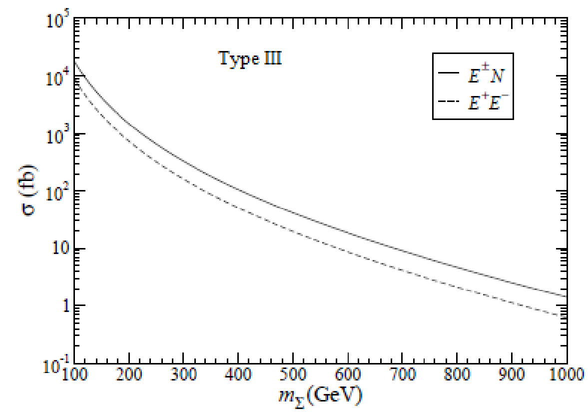
Scalar triplets



Complex scalar triplets Δ with hypercharge Y = 1

$$q\bar{q} \rightarrow Z^* / \gamma^* \rightarrow \Delta^{++}\Delta^{--}$$
$$q\bar{q}' \rightarrow W^* \rightarrow \Delta^{\pm\pm}\Delta^{\mp}$$
$$q\bar{q} \rightarrow Z^* / \gamma^* \rightarrow \Delta^{+}\Delta^{-}$$

Fermionic triplets

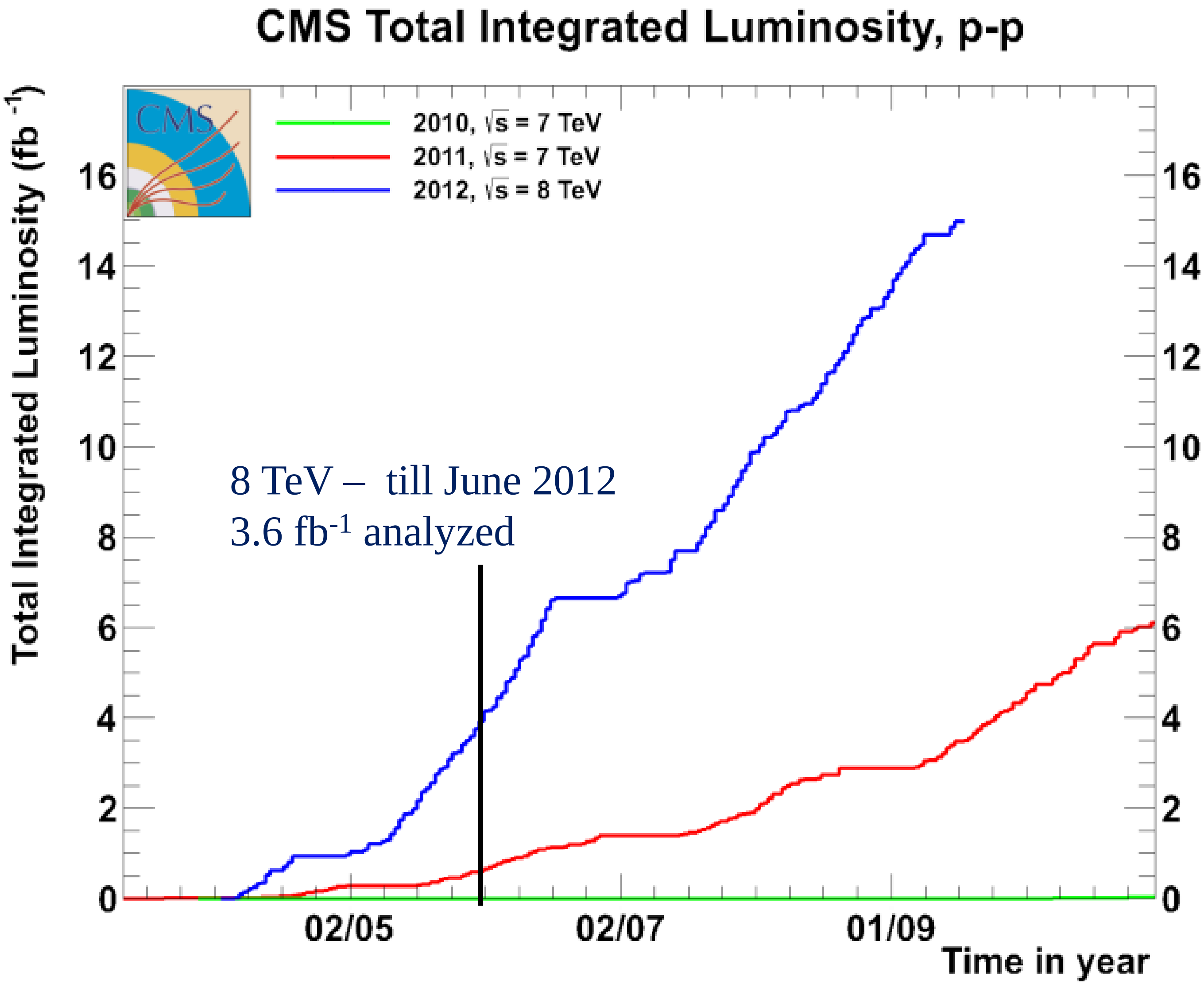


Colourless fermionic triplets Σ with hypercharge Y = 0

$$q\bar{q} \rightarrow Z^* / \gamma^* \rightarrow \Sigma^{+}\Sigma^{-}$$
$$q\bar{q}' \rightarrow W^* \rightarrow \Sigma^{\pm}\Sigma^{0}$$

Final states contain charged leptons (electrons e, muons μ, and taus τ) and jets or E_T^{miss}.

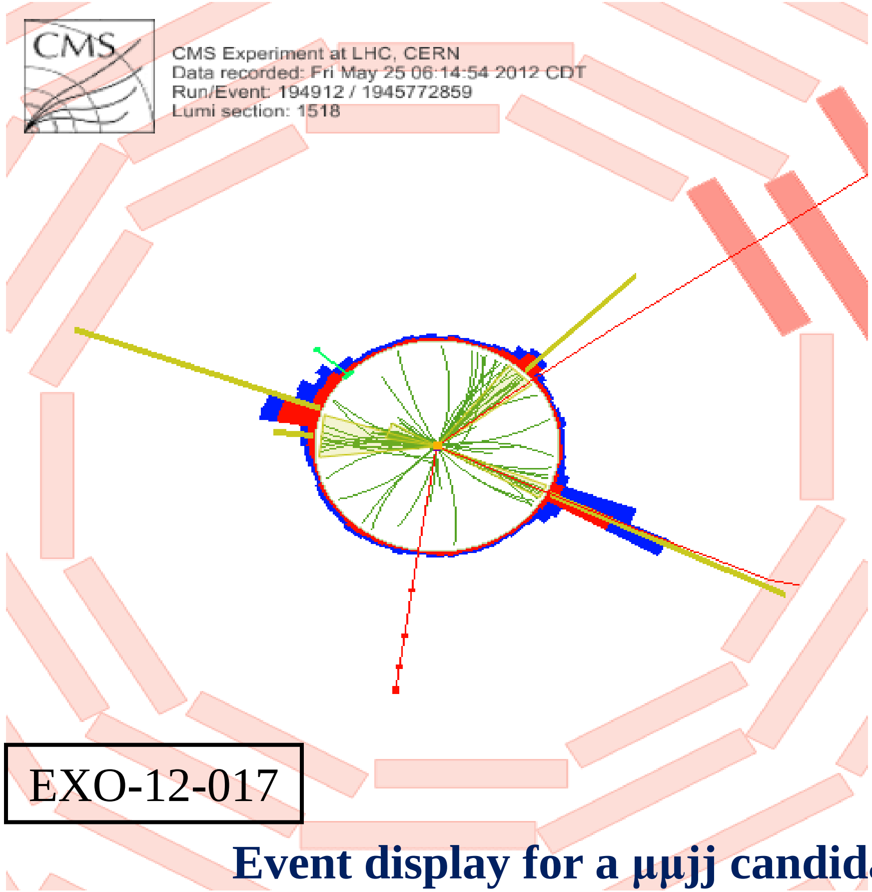
LHC performance



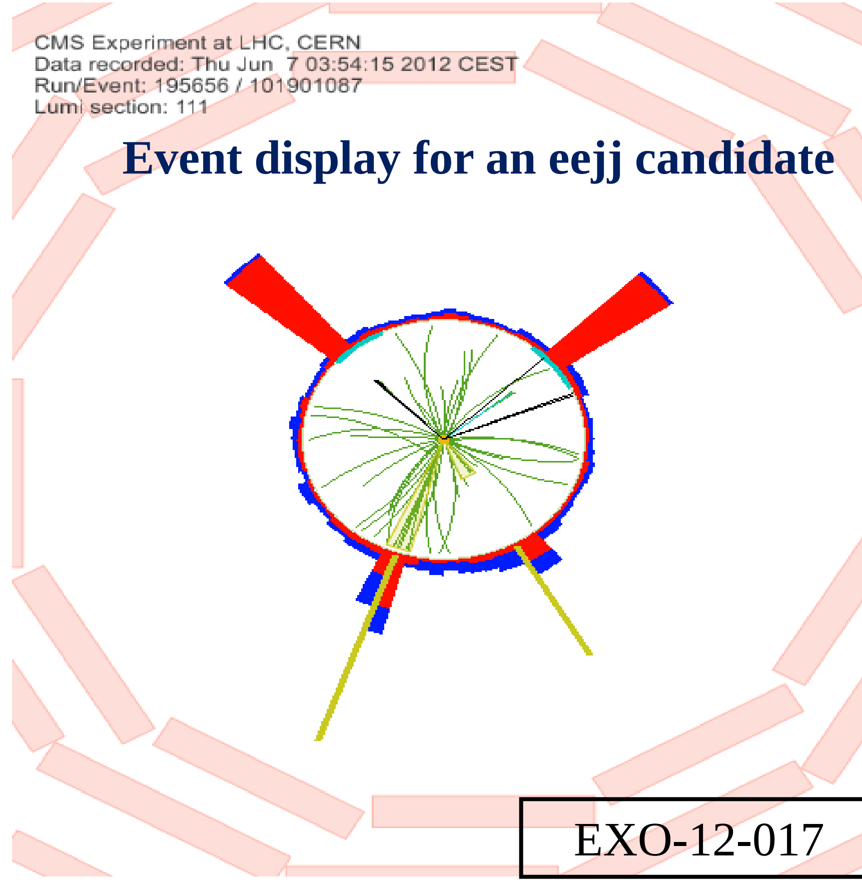
8 TeV –
till September 17th 2012
15.0 fb^{-1} recorded

7 TeV – year 2011
5.0 fb^{-1} analyzed

CMS physics objects



Event display for a μμjj candidate



Event display for an eejj candidate

Electron and Muon candidates, as all objetcs, are recontructed using particle-flow algorithm

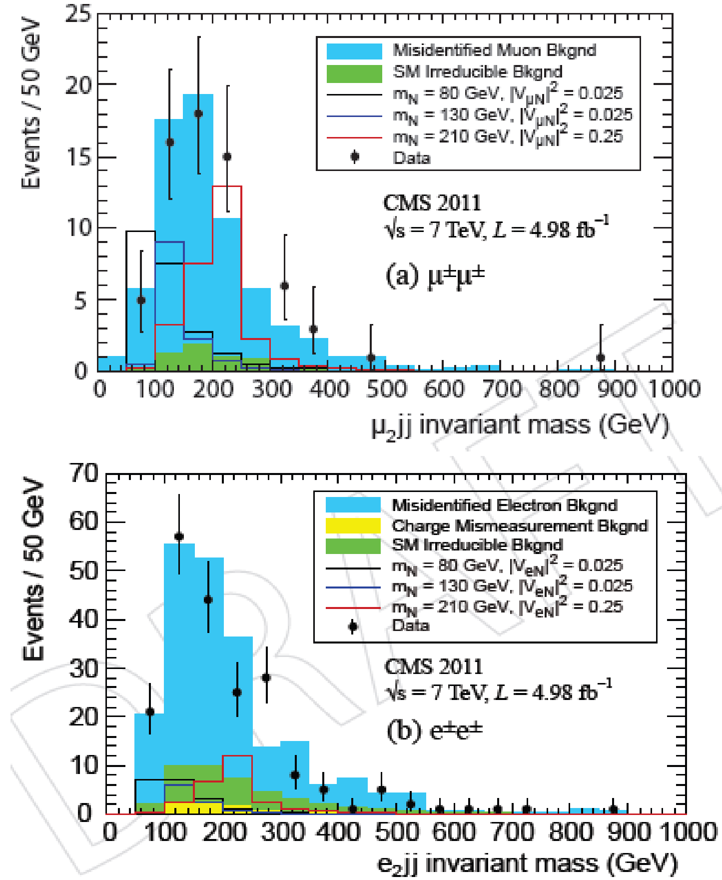
Jets reconstruction uses anti-k_T clustering algorithm with a distance parameter of 0.5

$\mathbf{E_T^{miss}}$ is the magnitude of the vectorial sum of the transverse momenta of all particles

Type I analysis

EXO-11-076
arXiv:1207.6079

Signature: two same charge and flavour leptons and two jets
Chain: pp → Nl^+ → $l^+W^-l^+$ → l^+l^+jj
Trigger: double electron and photon
Backgrounds: Z+jets, ttbar, QCD multijet process



Selections:

* two same-sign μ
* first μ with p_T > 20 GeV, second μ p_T > 10 GeV
* μ in barrel region
* event with third μ opposite-sign excluded if
  76 GeV < $m(\mu^+\mu^-)$ < 106 GeV

* two same-sign e
* first e with with p_T > 20 GeV, second e p_T > 10 GeV
* e in barrel region
* event with any third e opposite-sign excluded

Systematic uncertainties:

jet /e energy scale and resolution, e reconstruction and isolation and identification, trigger efficiency, pileup, background shape and normalization, QCD background estimation

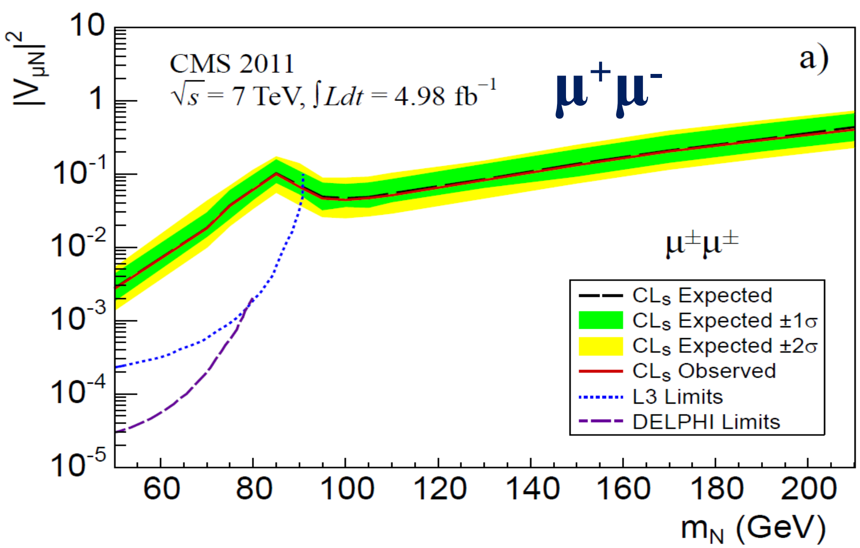
Type I results

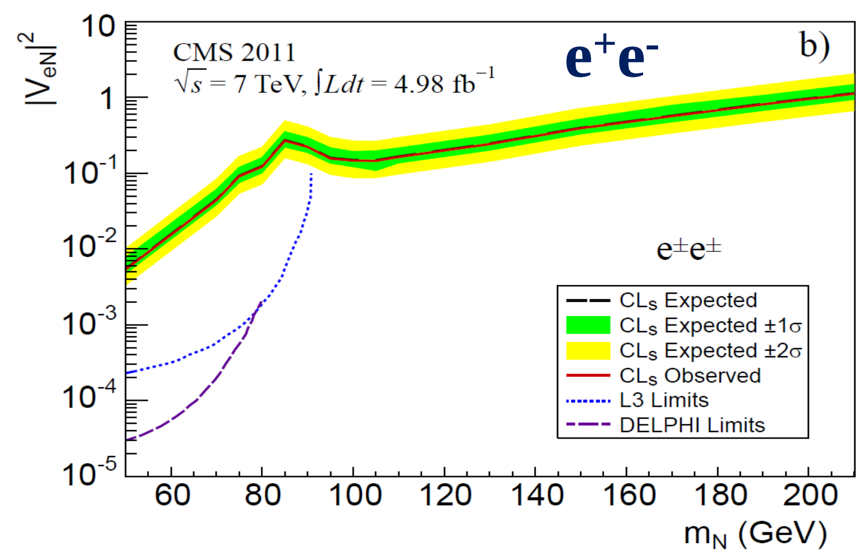
EXO-11-076
arXiv:1207.6079

Data year 2011

Source	$\mu^{\pm}\mu^{\pm}$	$e^{\pm}e^{\pm}$
Total background	$70 \pm 4 \pm 22$	$219 \pm 6 \pm 62$
Data	65	201
Expected signal:		
$m_N = 130$ GeV/c^2, $\|V_{\ell N}\|^2 = 0.1$	$58 \pm 1 \pm 4$	$39 \pm 1 \pm 3$
$m_N = 210$ GeV/c^2, $\|V_{\ell N}\|^2 = 0.1$	$12.0 \pm 0.1 \pm 0.8$	$8.5 \pm 0.1 \pm 0.6$

The data are in agreement with the estimated background.
No evidence for excess in the data beyond the SM background is seen and exclusion limits are setted





First direct upper limits on the heavy Majorana neutrino mixing for mass m_N > 90 GeV

Type II analysis

EXO-12-017
http://cdsweb.cern.ch/record/1460445?ln=en

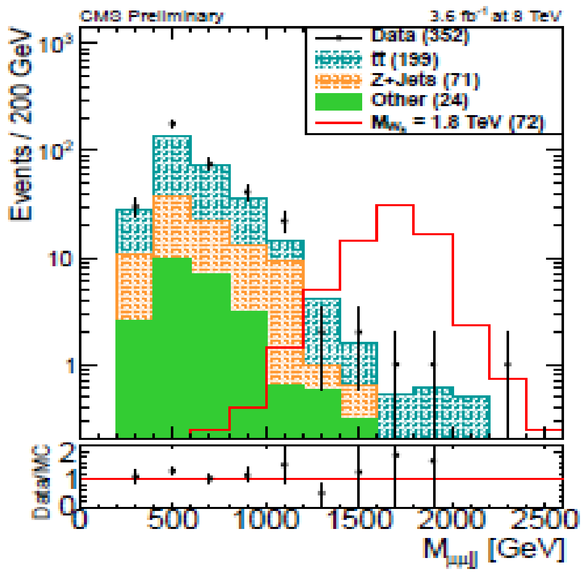
Signature: two leptons and two jets
Trigger: double electron | single muon
Backgrounds: ttbar, Z+jets, QCD multijet processes

Chain:

$$pp \to W_R + X \to N_\ell + \ell + X,$$
$$W_R \to \ell_1 N_\ell \to \ell_1 \ell_2 W_R^* \to \ell_1 \ell_2 q q' \to \ell_1 \ell_2 jj.$$

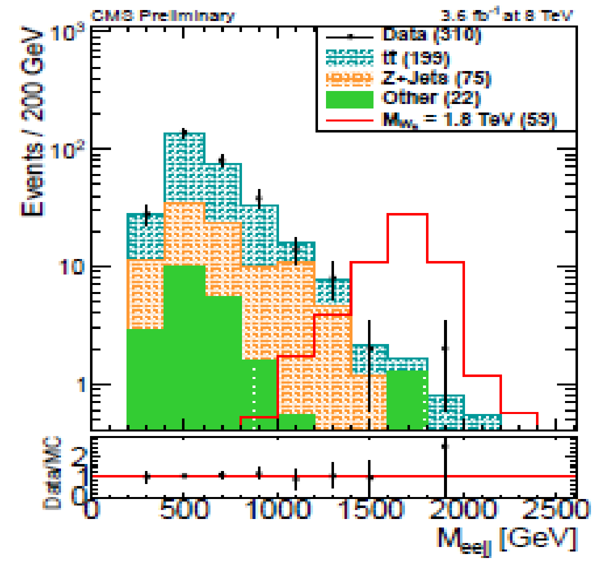
Muon channel

Selection Stage
Two muons, two jets
$\mu_1\ p_T > 60$ GeV
$M_{\mu\mu} > 200$ GeV
$M_{\mu\mu jj} > 600$ GeV



Electron channel

Selection Stage
Two electron, two jets
$e_1\ p_T > 60$ GeV
$M_{ee} > 200$ GeV
$M_{eejj} > 600$ GeV

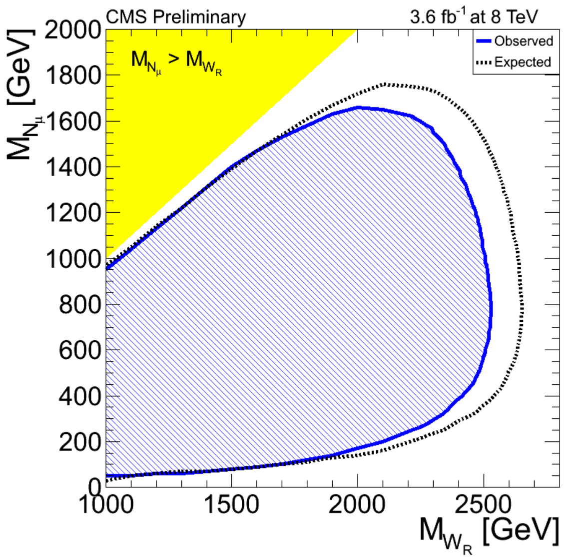


Systematic uncertainties:
uncertainty on the shape of the M_{lljj} background distribution, background normalization, PDF

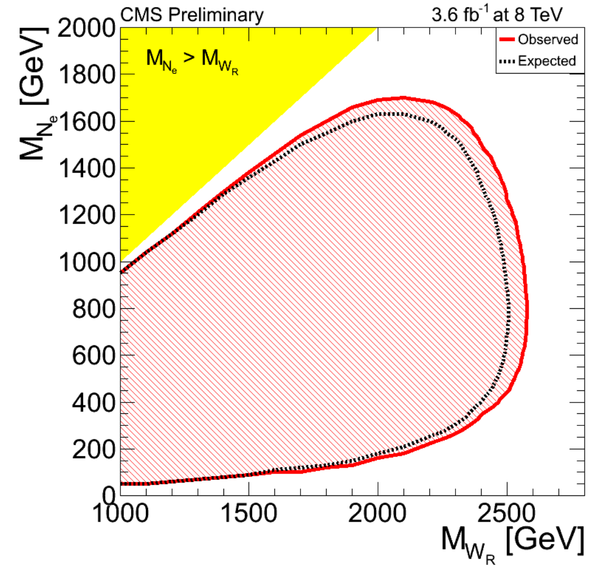
Type II results (1)

EXO-12-017
http://cdsweb.cern.ch/record/1460445?ln=en

μ channel

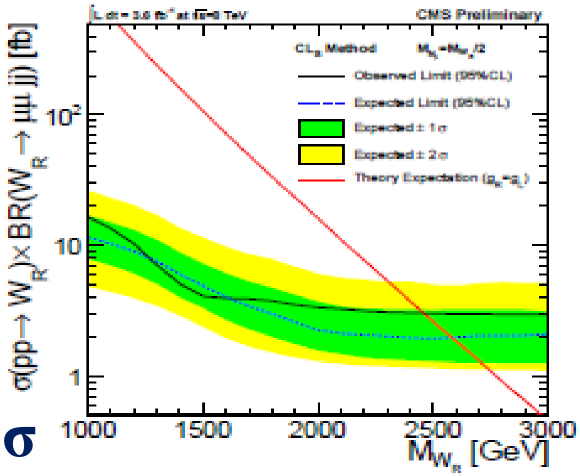


e channel

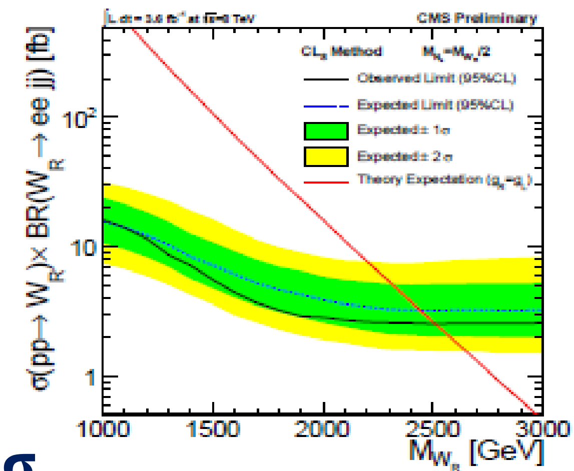


Limits obtain by comparing the observed (expected) upper limit and the expected cross section for each mass point. The limits extend to roughly M_{W_R} = 2.5 TeV and exclude a wide range of heavy neutrino masses.

σ



σ

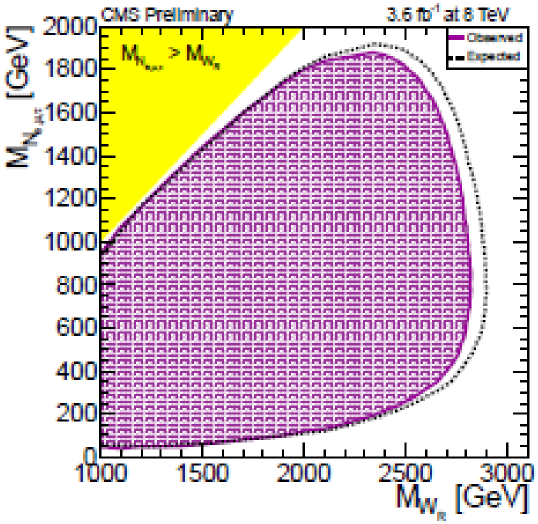


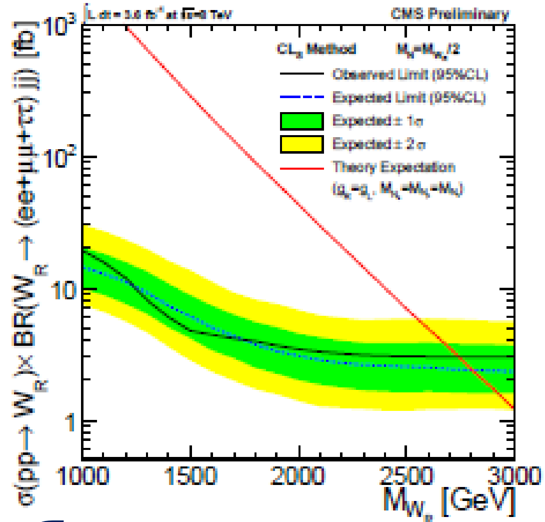
The agreement between the observed and expected limits is good.

Data year 2012

Type II results (2)

EXO-12-017
http://cdsweb.cern.ch/record/1460445?ln=en



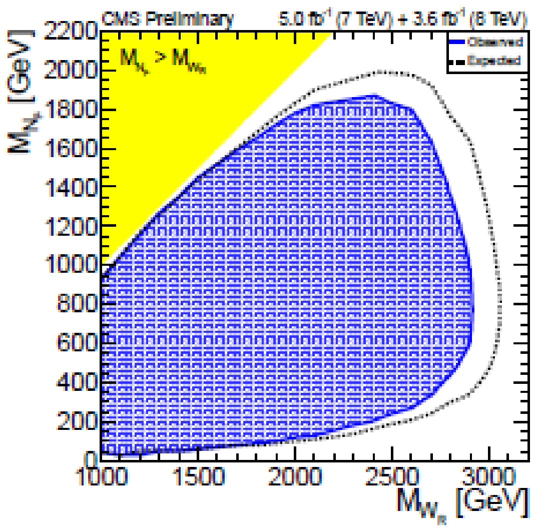


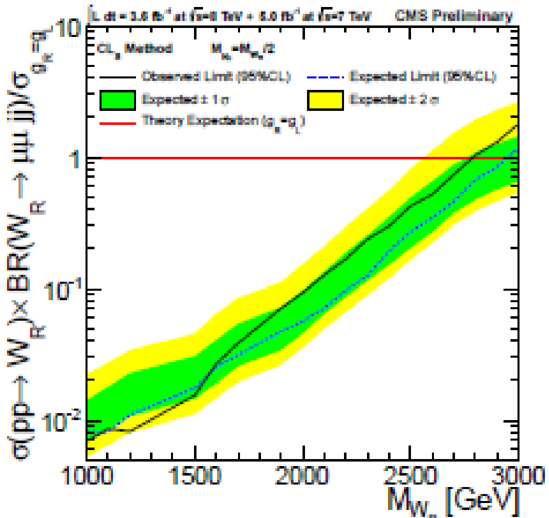
σ

Data year 2012

Combined muon and electron channels

Case of 3 N_l masses are degenerate: results exclude W_R gauge bosons up to a mass of 2.7 TeV.





σ/σ$_{REF}$

Data years 2011 and 2012

Only muon channel

The combined μ channel results exclude W_R gauge bosons up to a mass of 2.9 TeV, depending on the mass of the heavy muon neutrino.

Type III analysis

EXO-11-073
http://cdsweb.cern.ch/record/1470586

Signature: three isolated charged leptons and E_t^{miss}

Chain: pp → $\Sigma^0\Sigma^+$ → $l^\pm W^\pm W^+ \nu$ then W decay l + ν_l

Constraint: at least one mixing matrix element for the heavy and light leptons $V_\alpha > 10^{-6}$

Trigger: two-lepton (two μ or two e or eμ)

Backgrounds: WZ, ZZ, WWW, Zγ, Wγ, Zγ*, Wγ*, ttbar, non-prompt leptons, γ conversion

Selections:

* 3 isolated charged leptons from the same primary vertex
* Sum of the lepton charges = +1
* $E_T^{miss} > 30$ GeV
* $p_T > 18, 15, 10$ GeV
* $H_T < 100$ GeV (H_T scalar sum of central jets p_T, with $p_T > 30$ GeV)

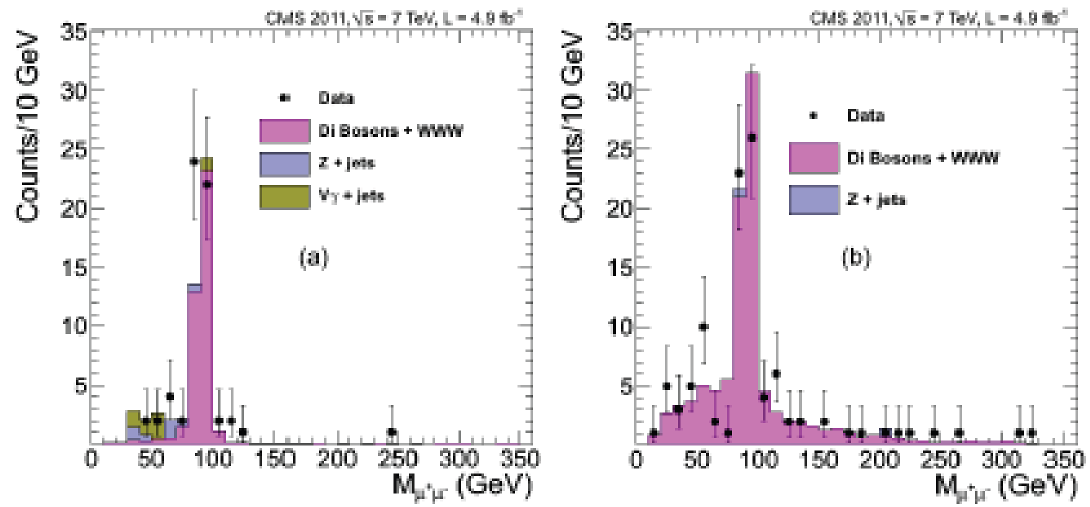
6 categories

$\mu^- e^+ e^+$
$\mu^- e^+ \mu^+$
$\mu^- \mu^+ \mu^+$
$e^- \mu^+ \mu^+$
$e^- e^+ \mu^+$
$e^- e^+ e^+$

Additional request about Z peak
$82 < m_{l+l-} < 102$ GeV rejected

Uncertainties:

trigger selection
physics objects reconstruction
lepton identification
background normalization
integrated luminosity



Type III results

EXO-11-073
http://cdsweb.cern.ch/record/1470586

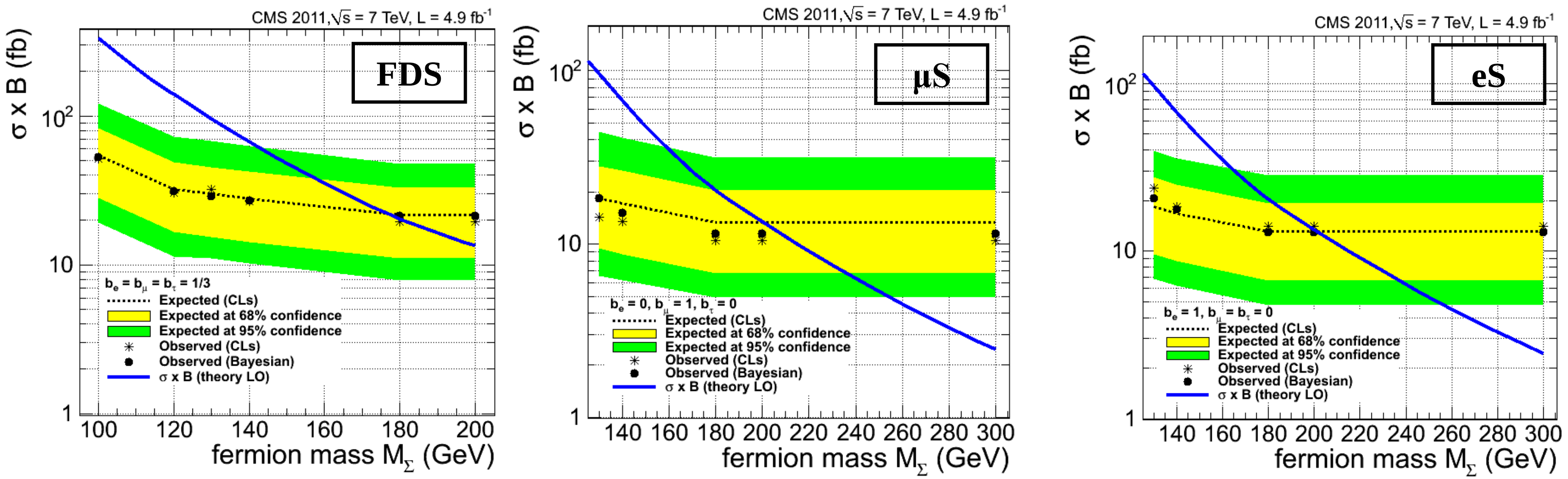
Data year 2011

FDS Category	Expected SM background	Observed in data
$\mu^- e^+ e^+$	0.8±0.4	2
$\mu^- e^+ \mu^+$	7.3±2.1	9
$\mu^- \mu^+ \mu^+$	11.5±3.6	7
$e^- \mu^+ \mu^+$	1.1±0.7	0
$e^- e^+ \mu^+$	8.6±2.2	7
$e^- e^+ e^+$	5.0±1.4	4

No significant excess of events is observed relative to the SM expectations in any of the six analysis categories.

Limits in 3 different scenarios

$$b_\alpha = \frac{|V_\alpha|^2}{|V_e|^2 + |V_\mu|^2 + |V_\tau|^2}$$



First limits on σ x B reported by an experiment at the LHC

Summary and conclusions

LHC experiments can **NOT** study neutrinos parameters, **BUT** they investigate models BSM that give possible explanations for neutrino masses.

NO EXCESS of events is observed above the backgrounds predicted by the SM.

The **CMS results** are interpreted in terms of limits on the cross sections and masses of the new heavy particles expected in the seesaw models.

All three analyses include 2011 data,
and search for a heavy neutrino and right-handed W of the left-right symmetric model (Type II) uses also 2012 data (till June).
The seesaw mechnism could be investigate deeper through all 2012 data
(expected integrated luminosity 20 fb^{-1}), so it is still live and interesting and exciting.

Stay tuned for the LHC experiments results !

OR

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Thank you !!!


LHC Days in Split
1 - 6 October 2012
Diocletian´s Palace / Palazzo Milesi/
Split, Croatia

CMS References

CMS PAS EXO-11-073 Search for heavy lepton partners of neutrinos in proton-proton collisions at $\sqrt{s} = 7$ TeV in the context of the Type III seesaw mechanism.

CMS PAS EXO-11-076 Search for heavy isosinglet Majorana neutrinos in $e^{\pm}e^{\pm}$ and $\mu^{\pm}\mu^{\pm}$ events in pp collisions at $\sqrt{s} = 7$ TeV.

CMS PAS EXO-11-091 Search for heavy neutrinos and WR bosons with right-handed couplings in a left-right symmetric model in pp collisions at $\sqrt{s} = 7$ TeV.

CMS PAS EXO-12-004 Search for a heavy electron neutrino ν_e and right-handed W bosons of the left-right symmetric model in pp collisions $\sqrt{s} = 7$ TeV.

CMS PAS EXO-12-017 Search for a heavy neutrino and right-handed W of the left-right symmetric model in pp collisions at $\sqrt{s} = 8$ TeV.

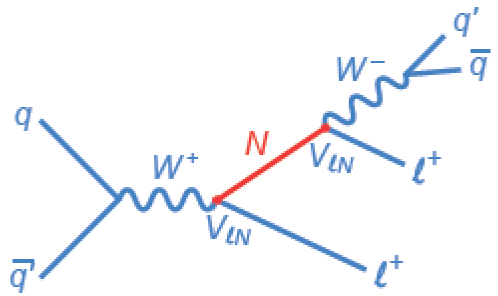
Other references

Y. Fukuda et al, [Super-Kamiokande collaboration], Phys. Rev. Lett. 81, 1562 (1998) arXiv:hep-ex/9807003

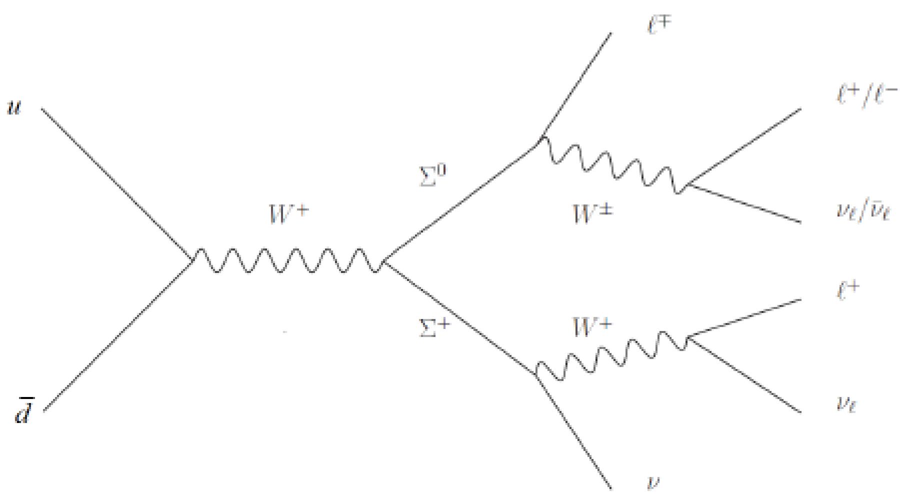
F. del Aguila and J. Aguilar-Saavedra, “Distinguishing seesaw models at LHC with multi-lepton signals”, Nucl. Phys. B813 (2009) 22, doi:10.1016/j.nuclphysb.2008.12.029, arXiv:0808.2468

Back up slides

Feyman diagram

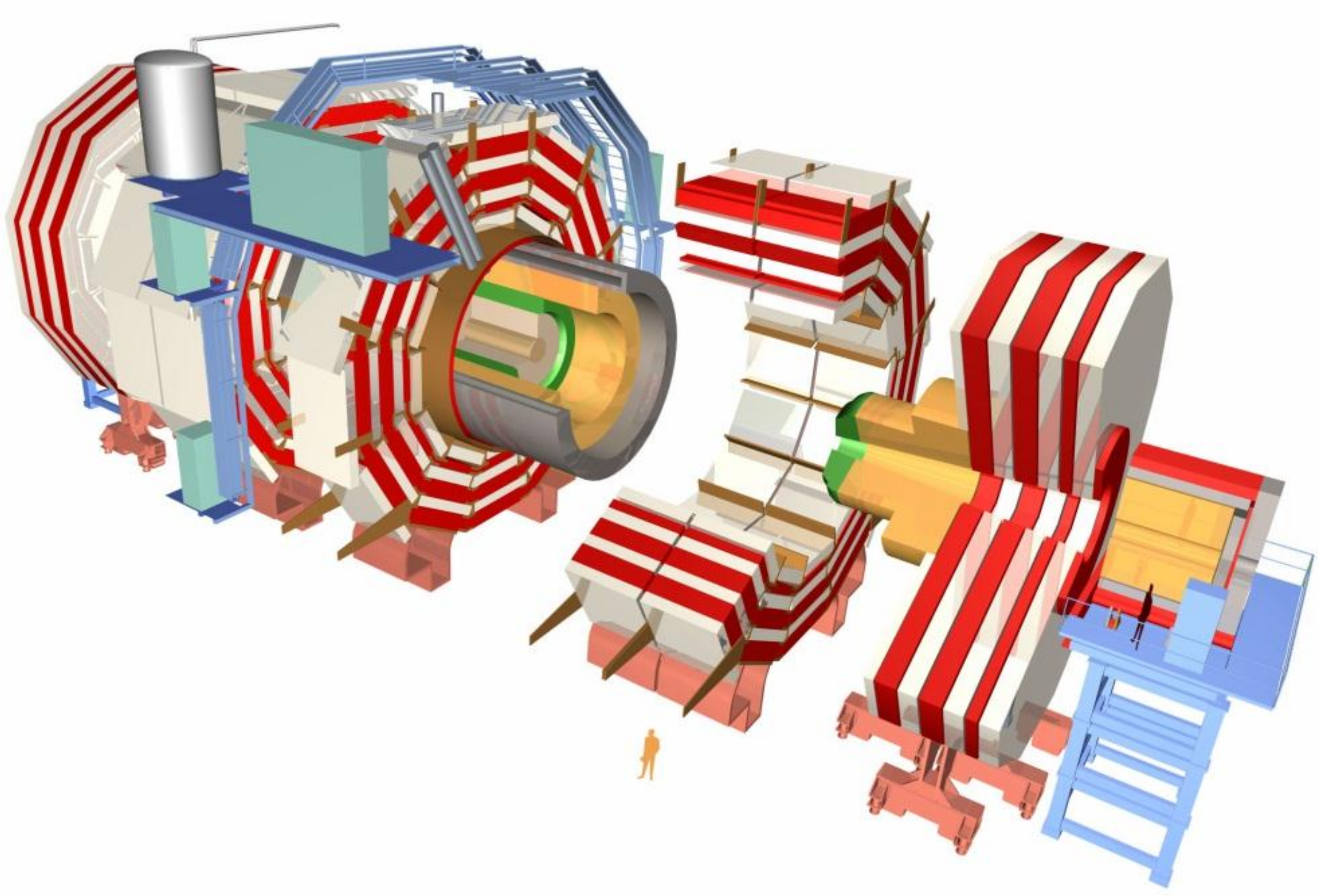


Type I



Type III

CMS experiment



About neutrinos

June 1998: results from measurements of atmospheric neutrinos with the Super-Kamiokande experiment showed that they are massive and mixed.
The masses of neutrinos and their mixing angles as well as their ability to oscillate implies that we have evidence for physics beyond the Standard Model (BSM).

$$\begin{bmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{bmatrix} = \begin{bmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{bmatrix} \begin{bmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{bmatrix}$$

Eigenstates of Pontercorvo Nakagawa Maki Sakata matrix (1969)

$$P(\nu_\alpha \rightarrow \nu_\beta) = 4 \sin^2 \theta \cos^2 \theta \sin^2 \left(\frac{\Delta m^2_{ij} L}{4E} \right)$$

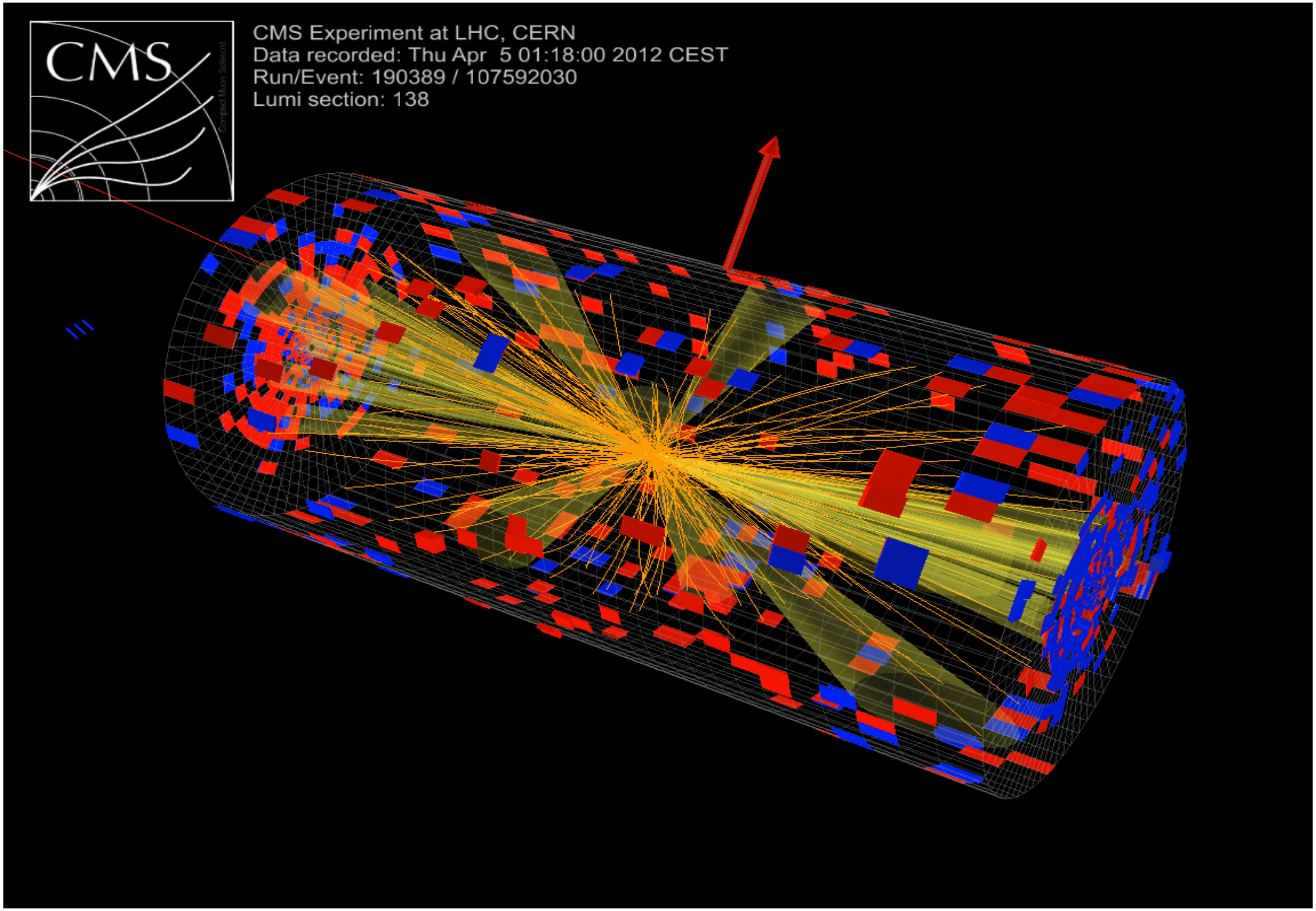
Unitary matrix PMNS = [rotation θ_{12}]X[rotation θ_{13}]X[rotation θ_{23}]

Measurements of mixing angles at reactors or accelerators experiments is done, but they are the beginning of the searches for remaining neutrino parameters.

LHC experiments is studing possible explanations for the smallness of the ordinary neutrino masses through mechanisms BSM.

CMS collaboration is investigating the seesaw mechanism in the exotica field.

CMS event display



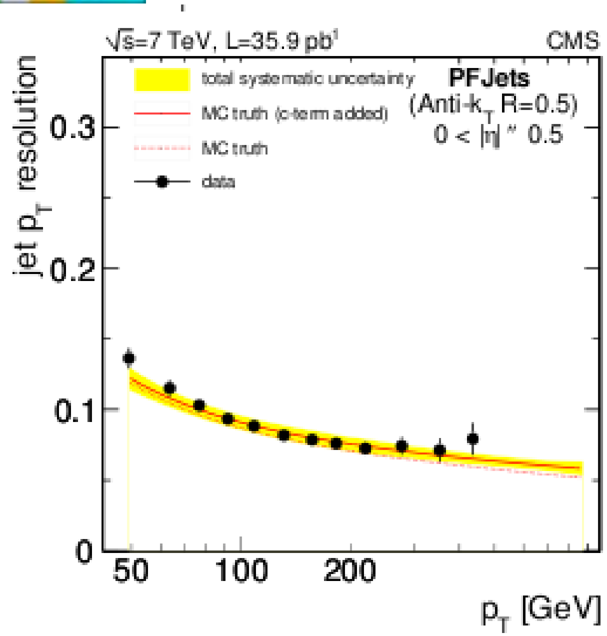
Simulation

Signal event generation: PYTHIA, ALPGEN

Backgrounds event generation: PYTHIA, MADGRAPH, POWHEG, SHERPA

Geometry: Full and Fast CMS detector simulation based on GEANT4

Resolution jets, muons, electrons



- Muons play a very important role in the CMS Physics programme
  - Precision measurements
  - Discoveries
- CMS Detector at the LHC
  - High μ identification efficiency
    (> 95% for tight selection)
  - Good μ resolution for p < 1 TeV
    (< 6 %)
  - Good di-μ mass resolution
    (<1% for 100 GeV)
  - Unambigously μ charge determination for p < 1 TeV
  - Fast μ triggers: unambigous beam crossing identification

Compact
Muon
Solenoid

Trigger

HLT_DoubleMu7_v1,2 or HLT_Mu13_Mu8_v2,3,4,6,7 or HLT_Mu17_Mu8_v10,11
HLT_Ele17_CaloIdL_CaloIsoVL_Ele8_CaloIdL_CaloIsoVL_v1,2,3,4,5,6 or HLT_Ele17_CaloIdT_TrkIdVL_CaloIsoVL_TrkIsoVL_Ele8_CaloIdT_TrkIdVL_CaloIsoVL_TrkIsoVL_v2,3,4,5 or HLT_Ele17_CaloIdT_CaloIsoVL_TrkIdVL_TrkIsoVL_Ele8_CaloIdT_CaloIsoVL_TrkIdVL_TrkIsoVL_v5,6,7,8,9,10
HLT_Mu10_Ele10_CaloIdVL_v2,3,4,or HLT_Mu17_Ele8_CaloIdVL_v1,2,3,4,5,6,8 or HLT_Mu17_Ele8_CaloIdT_CaloIsoVL__v4,7,8 or HLT_Mu8_Ele17_CaloIdL_v1,2,3,4,5,6 or HLT_Mu8_Ele17_CaloIdT_CaloIsoVL_v3,4,7,8

EXO-11-073

Type III

EXO-11-073

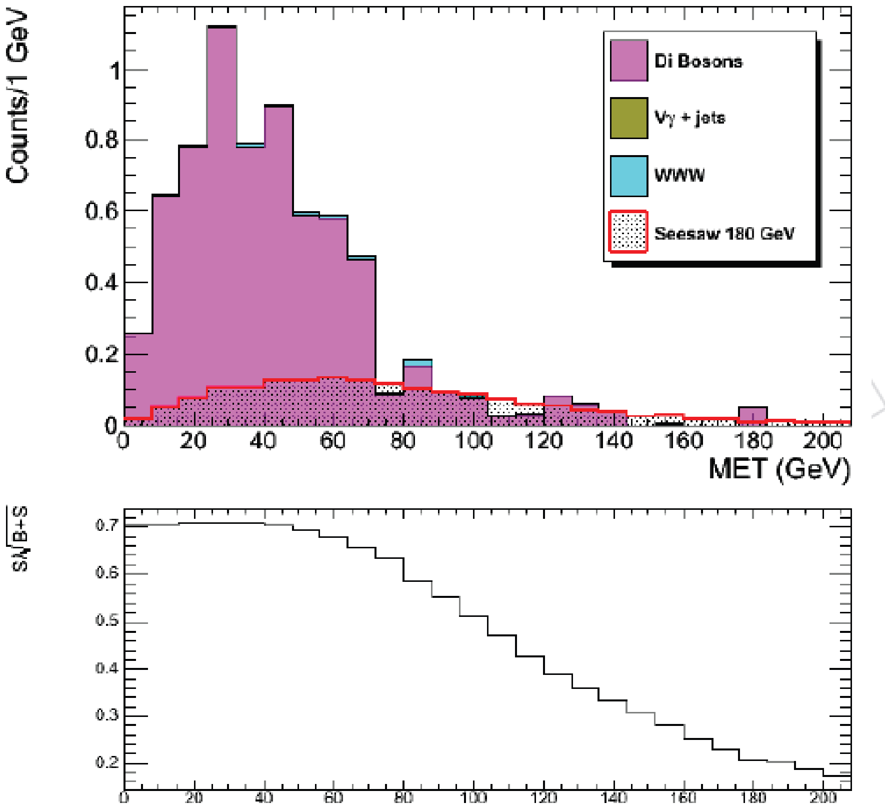


Figure 3: Signal at 180 GeV mass point E_T^{miss}distribution and significance plot for channel $e^-\mu^+\mu^+$ at after all the selection requirements except E_T^{miss}cut.

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