Hunting for heavy composite Majorana neutrinos at the LHC

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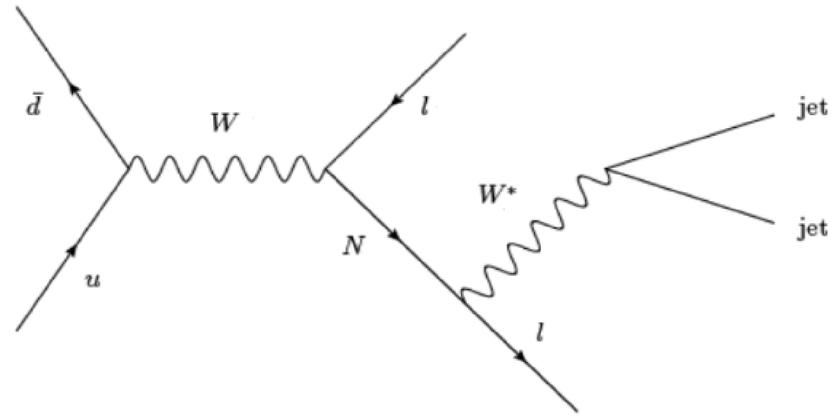
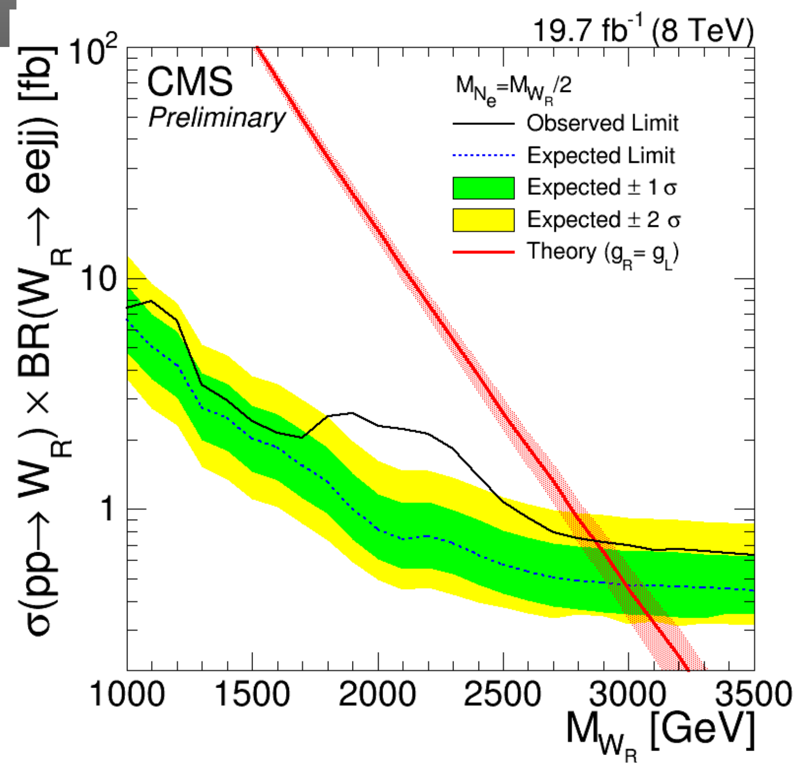
Search of Heavy Neutrinos in CMS





Excess over the SM expectation in the eejj channel.
The Analysis was based on 19.7 fb^{-1} of intagrated luminosity and $\sqrt{s} = 8$ TeV.
It reports a 2.8σ excess in the eejj invariant mass distribution in the interval $1.8TeV < M_{eejj} < 2.2TeV$

Composite models for quarks and leptons

- The proliferation of standard model fermions can suggest a further composition
- If quarks and leptons are composite we expect:
  $\Rightarrow$ Excited leptons and quarks
  $\Rightarrow$ Contact interaction between four fermions: a residual interaction of an interaction between the constituent particles
  - Eichten, Lane e Peskin, Phys. Rev. B 50, 811 (1983)
  - Cabibbo, Maiani e Srivastava, Phys Lett. B 149, 459 (1984)
  - Baur, Spira e Zerwas, Phys. Rev. D 42, 815 (1990)

Extended weak isospin model

Pancheri and Srivastava, Phys. Lett. B 146 (1984).

- Fermions' composition trough the weak isospin symmetry
- It don't refer to the internal dynamics
- analogy with strong isospin $\rightarrow$ prediction of hadronic states before the discovery of quarks and gluons
- SM q,$\ell \in I_W = 0, 1/2$ and $W^{\pm}$, Z^0, $\gamma \in I_W = 0, 1$
  $\Rightarrow$ excited fermions $\in I_W \leq 3/2$

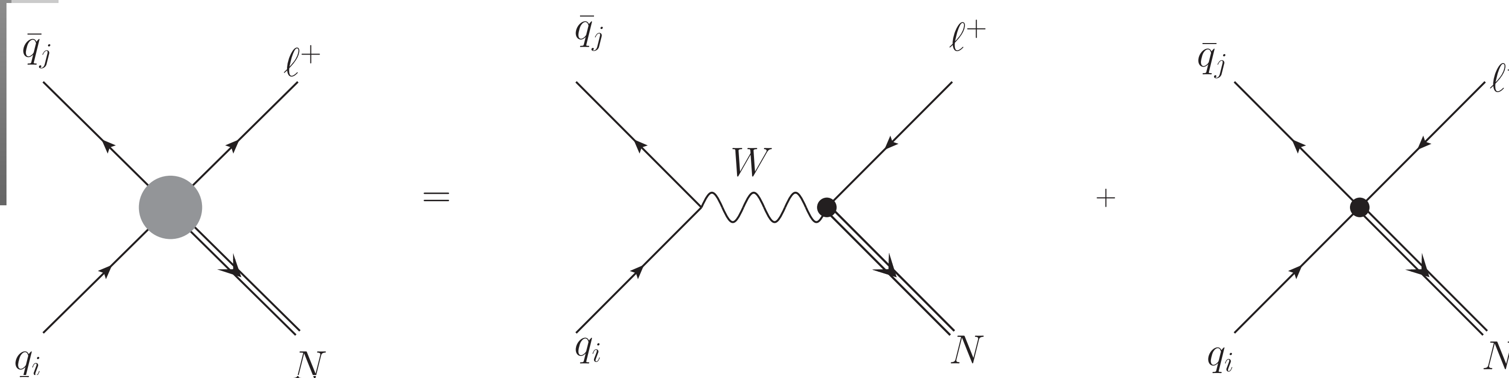
Extended weak isospin model

Multiplets of the model

I_W	Multiplet	Q	Y	Coupled to
0	E^-	-1	-2	e_R through B^μ
1/2	$\epsilon \equiv \begin{pmatrix} E^0 \\ E^- \end{pmatrix}$	$\begin{matrix} 0 \\ -1 \end{matrix}$	-1	$\ell_L = \binom{\nu_e}{e^-}_L$ through W^μ and B^μ
1	$\epsilon \equiv \begin{pmatrix} E^0 \\ E^- \\ E^{--} \end{pmatrix}$	$\begin{matrix} 0 \\ -1 \\ -2 \end{matrix}$	-2	e_R through W
3/2	$\epsilon_M \equiv \begin{pmatrix} E^+ \\ E^0 \\ E^- \\ E^{--} \end{pmatrix}$	$\begin{matrix} 1 \\ 0 \\ -1 \\ -2 \end{matrix}$	-1	$\ell_L = \binom{\nu_e}{e^-}_L$ through W

I_W	Multiplet	Q	Y	Coupled to
0	(i) U	2/3	4/3	u_R through B^μ and G^μ
	(ii) D	$-1/3$	$-2/3$	d_R through B^μ and G^μ
1/2	$\Psi \equiv \begin{pmatrix} U \\ D \end{pmatrix}$	$\begin{matrix} 2/3 \\ -1/3 \end{matrix}$	1/3	$q_L = \binom{u}{d}_L$ through W, B^μ and G^μ
1	(i) $U \equiv \begin{pmatrix} U_+ \\ U \\ D \end{pmatrix}$	$\begin{matrix} 5/3 \\ 2/3 \\ -1/3 \end{matrix}$	$+4/3$	u_R through W
	(ii) $D \equiv \begin{pmatrix} U \\ D \\ D_- \end{pmatrix}$	$\begin{matrix} 2/3 \\ -1/3 \\ -4/3 \end{matrix}$	$-2/3$	d_R through W
3/2	$\Psi_M \equiv \begin{pmatrix} U_+ \\ U \\ D \\ D_- \end{pmatrix}$	$\begin{matrix} 5/3 \\ 2/3 \\ -1/3 \\ -4/3 \end{matrix}$	1/3	$q_L = \binom{u}{d}_L$ through W

Contact and gauge interactions

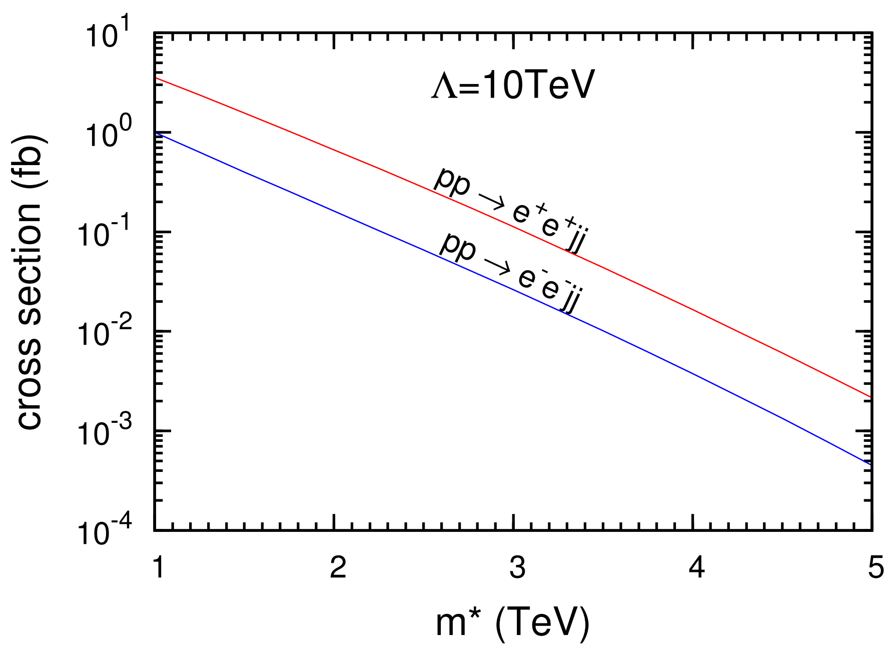


$$\mathcal{L}_{\mathsf{G}} = \frac{gf}{\sqrt{2}\Lambda}\,\bar{N}\,\sigma_{\mu\nu}\,\ell_L\;\partial^{\nu}\,W^{\mu}\;+h.c.$$

$$\mathcal{L}_{\mathsf{CI}} = \frac{g_*^2}{\Lambda^2}\,\bar{q}_L\gamma^{\mu}q'_L\,\bar{N}_L\gamma_{\mu}\ell_L$$

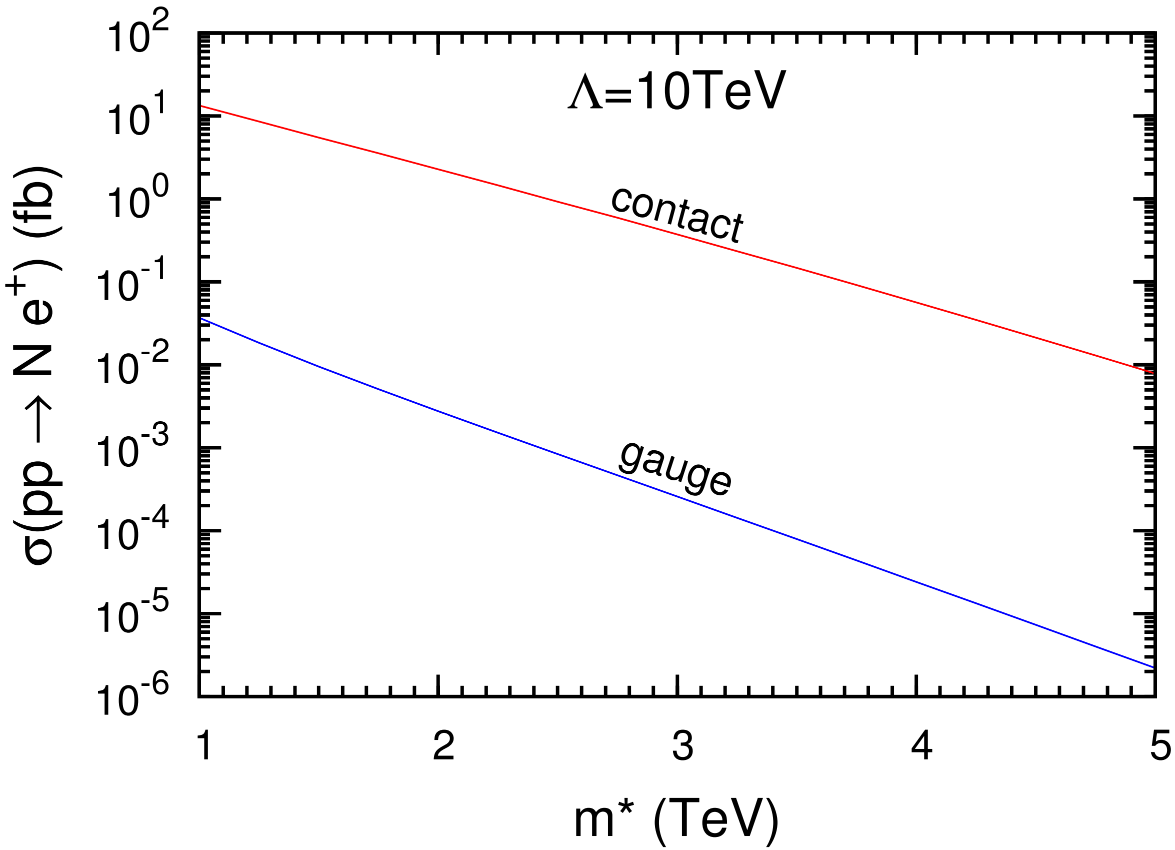
Final state

We consider a Majorana neutrino
The same-sign dilepton is a peculiar final state for Majorana neutrinos
We choose the positive same-sign dilepton due to its larger cross section



Production of the heavy Majorana neutrino

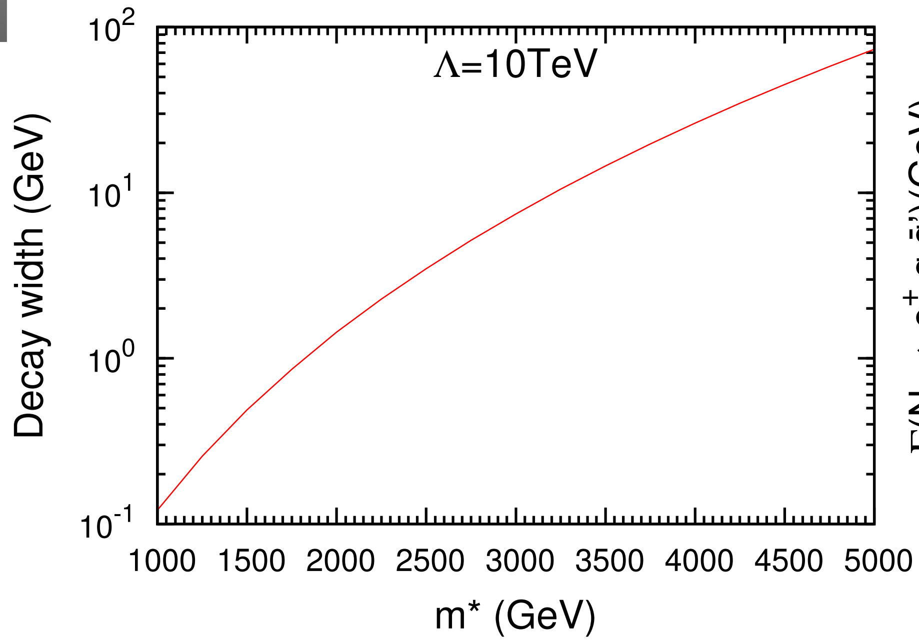
$$pp \to N\ell$$

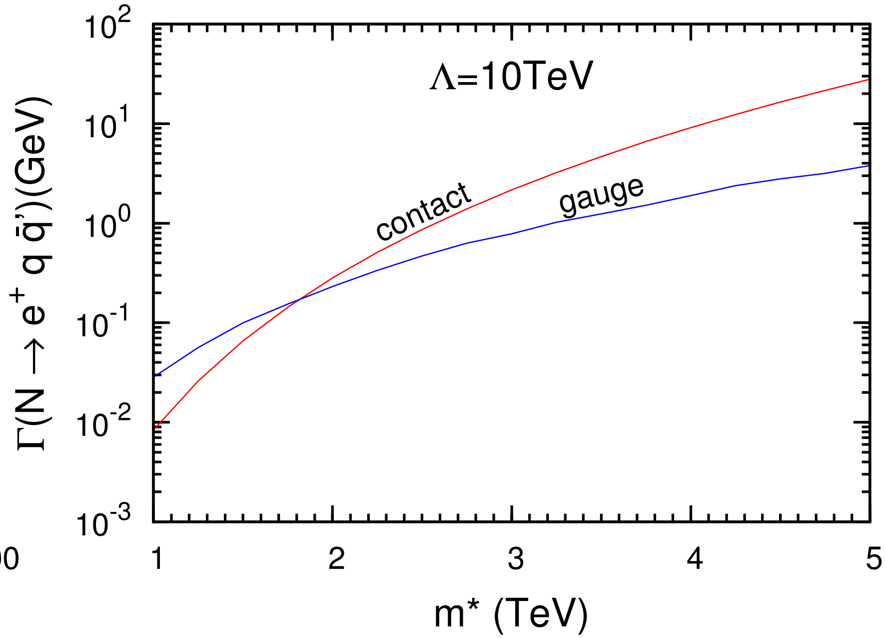


The contact interaction is the dominant one

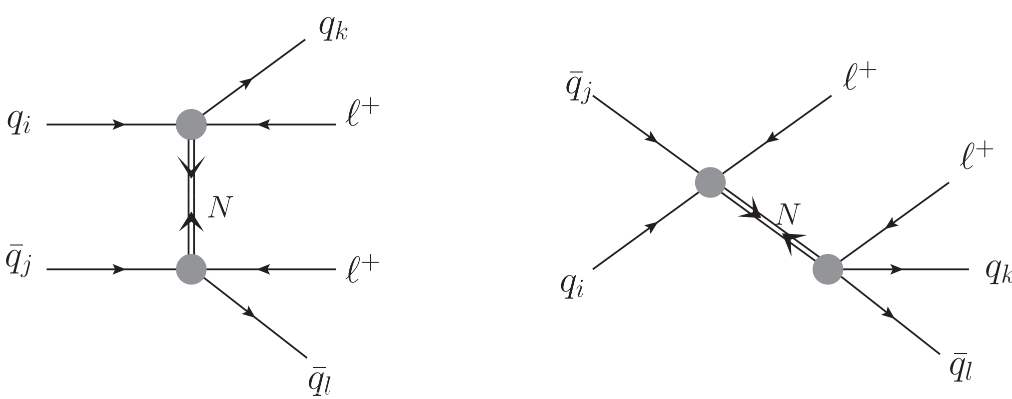
Decays of the heavy Majorana neutrino

$$N \to \ell q \bar{q}' \qquad N \to \ell^+ \ell^- \nu(\bar{\nu}) \qquad N \to \nu(\bar{\nu}) q \bar{q}'$$

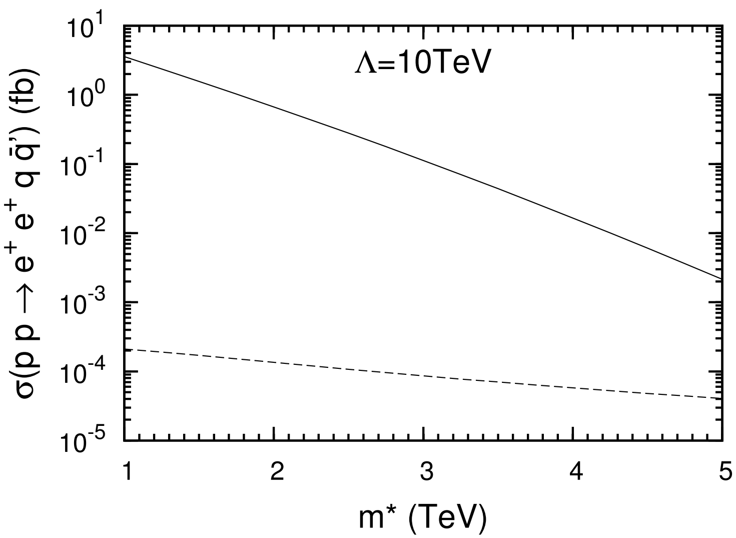




Processes under examination



Exchange of virtual heavy Majorana neutrino (left), resonant production of heavy Majorana neutrino (right)

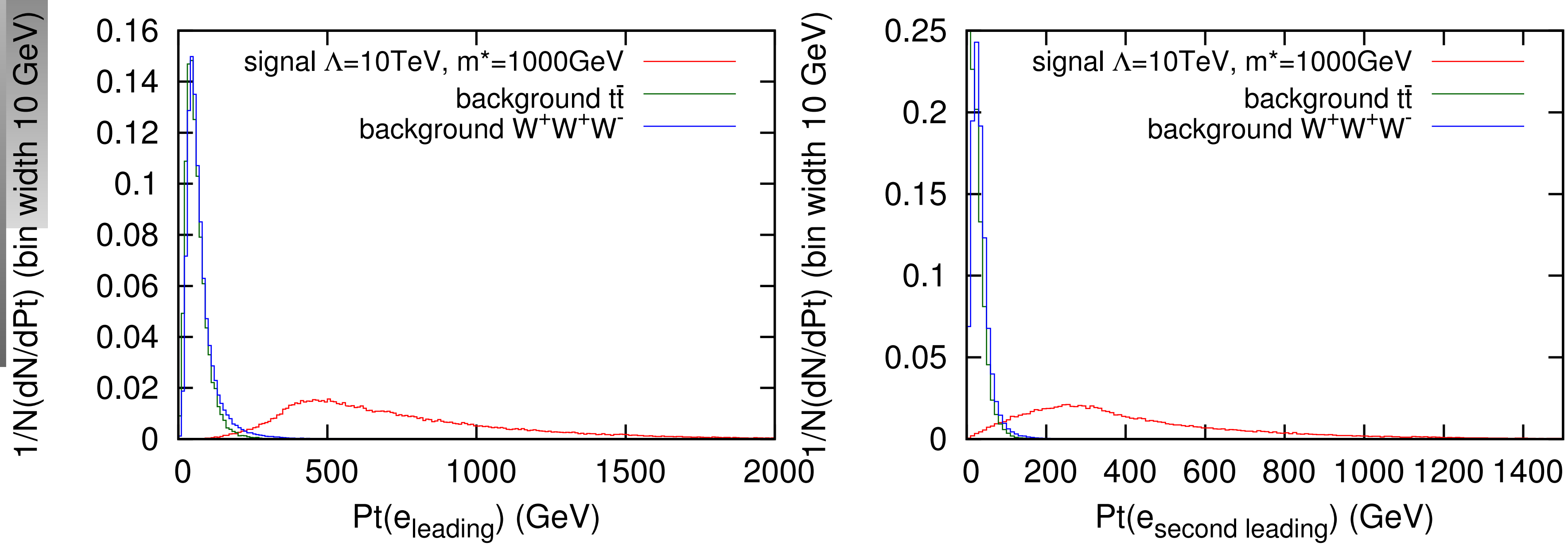


The resonant production is the dominant process

Background

- In SM the lepton number is conserved, so processes like the our ($\Delta L = 2$) are not allowed
- However in the SM there are several processes that can produce same sign leptons in association with jets
- the main backgrounds are:
  - $pp \to t\bar{t} \to \ell^+\ell^+\nu\nu jets$
  - $pp \to W^+W^+W^- \to \ell^+\nu\ell^+\nu jj$

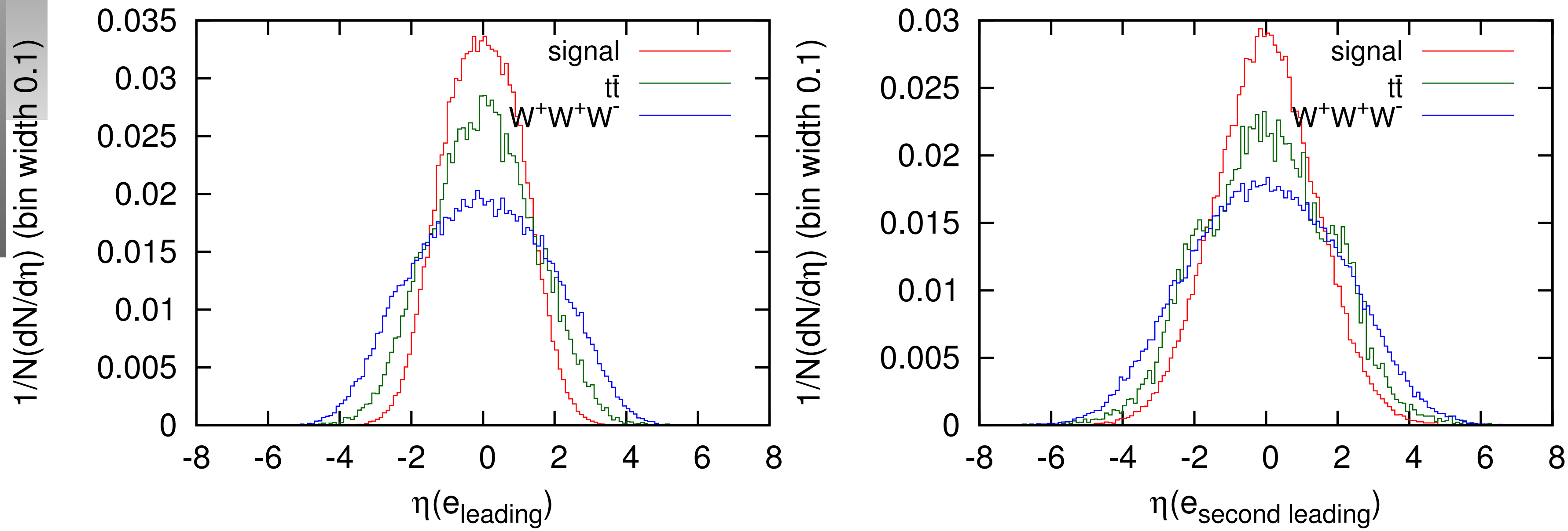
Kinematical distributions: Transverse momentum



We can reduce drastically the background with the cuts:

- $p_T(e^+_{\text{leading}}) \geq 200$ GeV
- $p_T(e^+_{\text{second-leading}}) \geq 100$ GeV

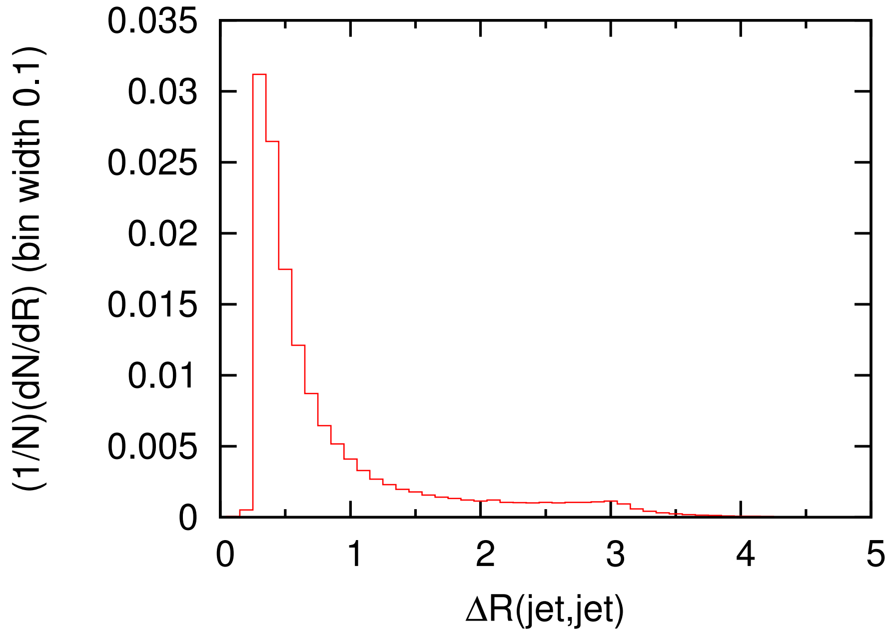
Kinematical distributions: pseudorapidity



The pseudorapidity is not very selective

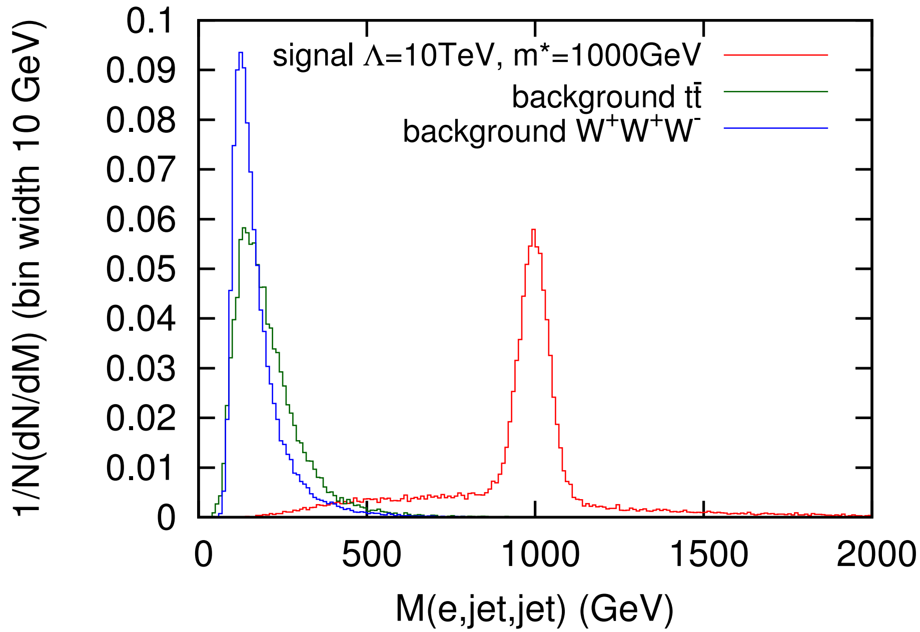
Kinematical distributions:

$\Delta R(jet, jet)$



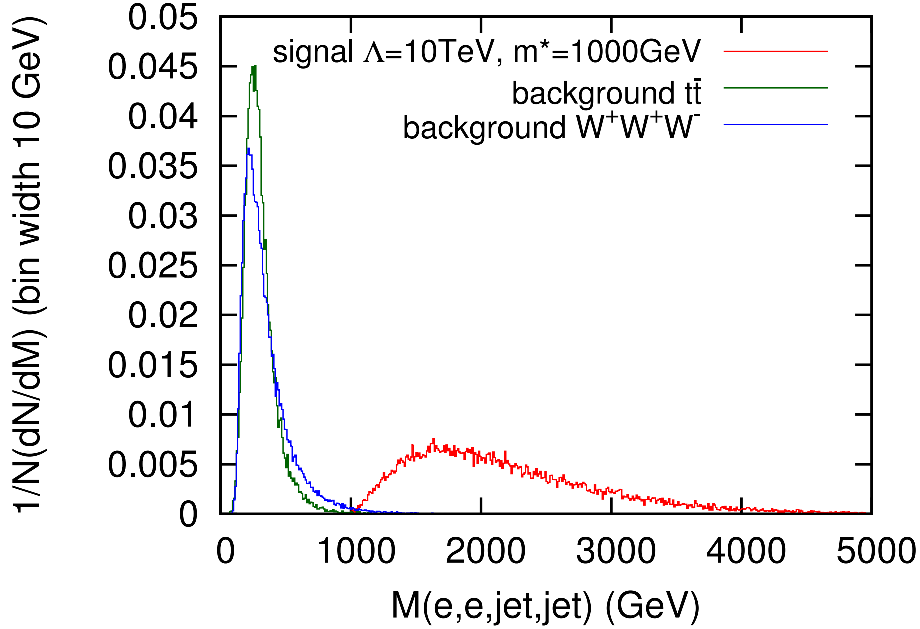
- A large fraction of the events have two jets with very small separation
- In the reconstruction process we will have merging

Kinematical distributions: M(e,j,j)



The invariant mass of the second leading electron plus the two jets give informations about the mass of heavy neutrino

Kinematical distributions: M(e,e,j,j)



The eejj invariant mass can easily accomodate the excess in the interval observed by CMS

Simulations

$\Rightarrow$ LHE files generation by CalcHEP for signal and background

- Scan in parameters space:
  - $\Lambda \in [8, 40]$ TeV with step of 1 TeV
  - $m^* \in [500, 5000]$ GeV with step of 250 GeV
- 100000 events for each LHE file

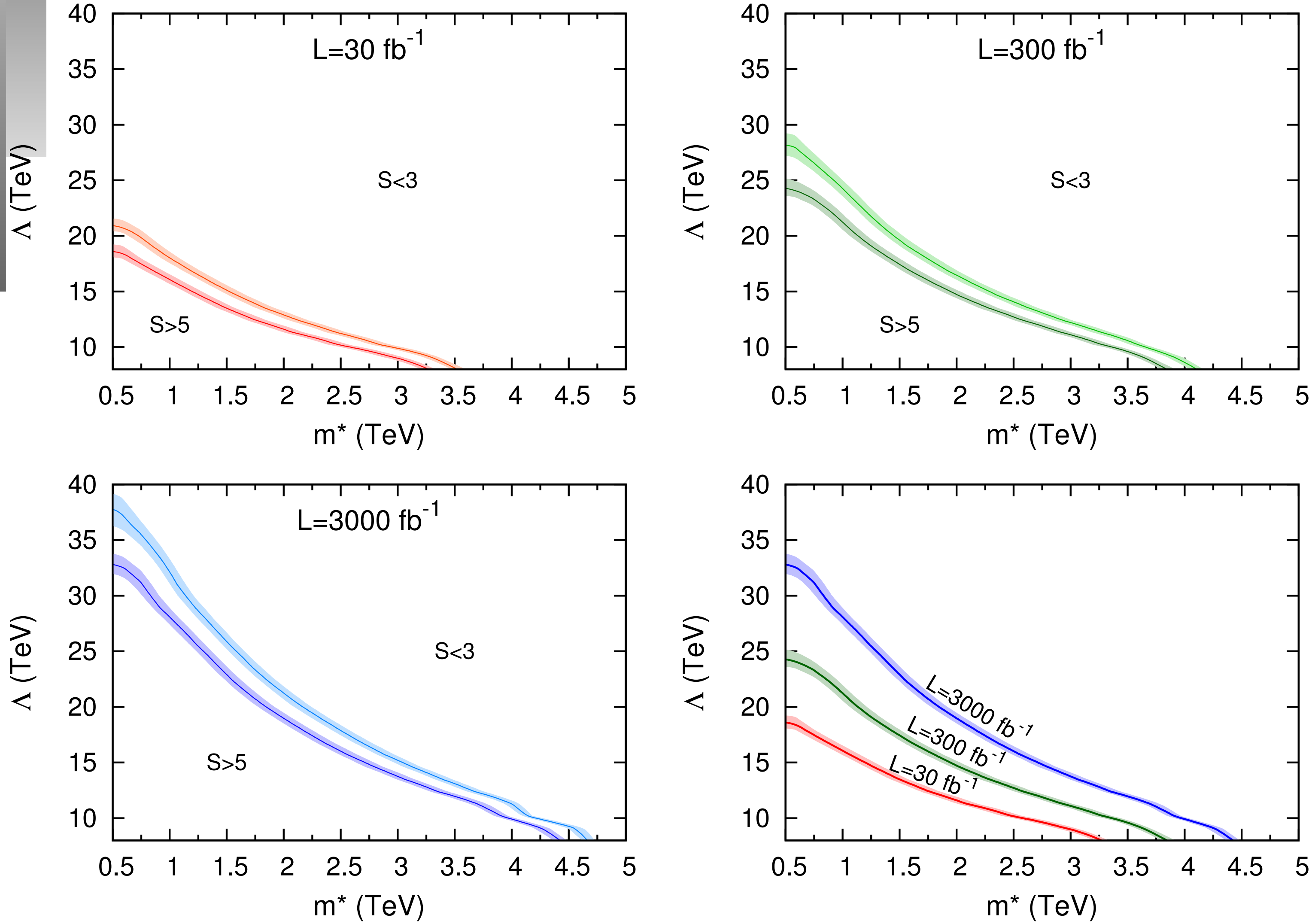
$\Rightarrow$ DELPHES simulates the particles reconstruction by the detector considering

- efficiency
- geometrical acceptance

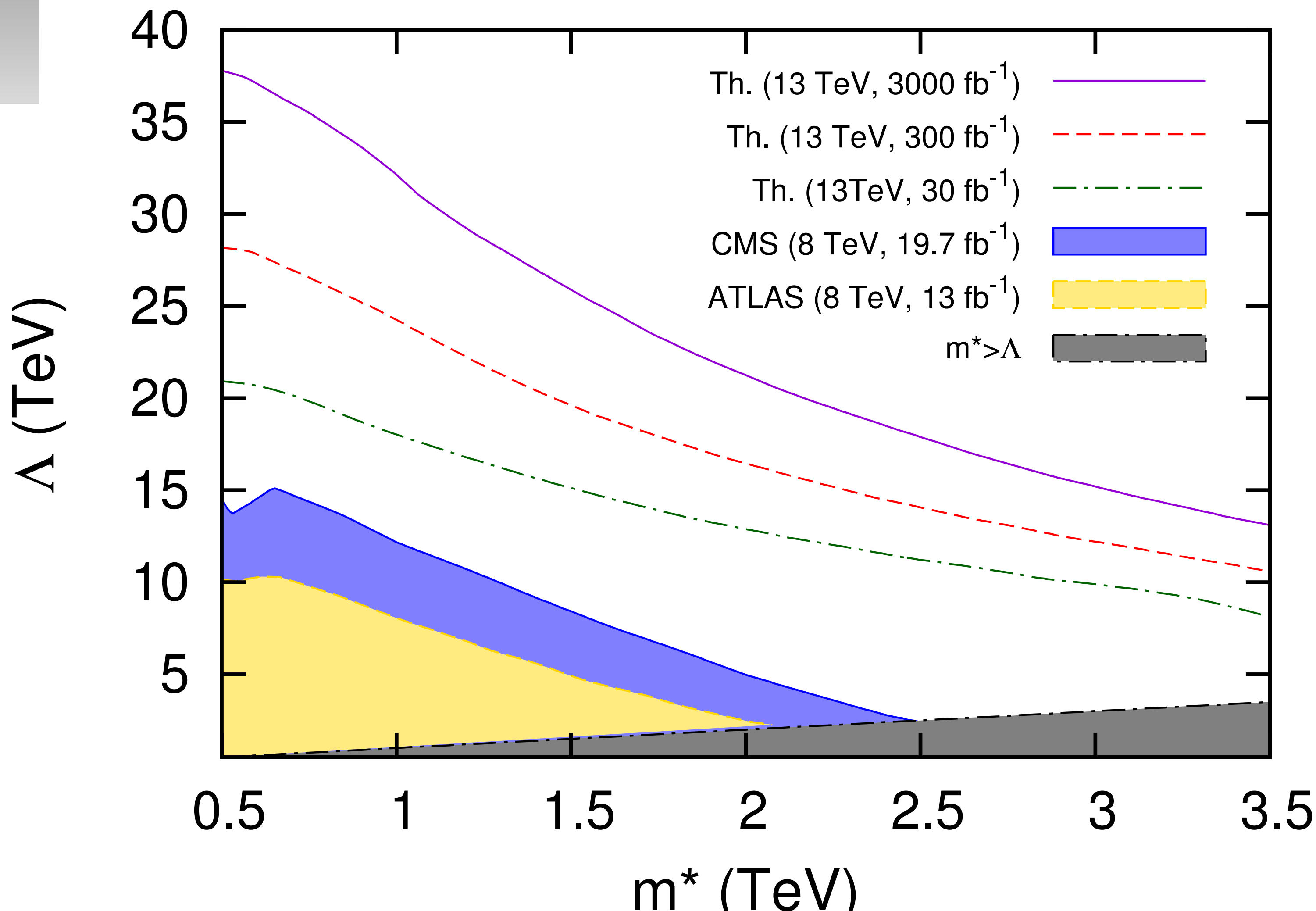
Simulations

- Selection criteria:
  - Presence of two e^+
  - Kinematical cuts:
    $p_T(e^+_{\text{leading}}) \geq 200$ GeV, $p_T(e^+_{\text{second-leading}}) \geq 100$ GeV
- Determination of reconstruction efficiencies
- Determination of expected number of events for signal and background: $N_s = L\sigma_s\epsilon_s$, $N_b = L\sigma_b\epsilon_b$
- Determination of statistical significance: $S = \frac{N_s}{\sqrt{N_b}}$
- Determination of contour plots in the parameter space (Λ, m^*) at $S = 3$ and $S = 5$

Contour plots



Contour plots



Conclusions

- We have performed a phenomenological study about a heavy neutrino in view of the recent observation by CMS of the excess in eejj channel
- We considered the composite model scenario and an excited Neutrino of Majorana type
- We found that the invariant mass distribution of the second leading electron and the two jets is higly correlated to the heavy neutrino mass
- We provide the contour plots of Statistical significance at 3- and 5-sigma and compare them to the experimental data of Run-I, showing a great potential of discovery or improving the current bounds in eejj signature from a heavy composite Majorana neutrino