

# Lepton Number Violation and Scalar Searches at LHC

Francisco del Águila

M. Chala, A. Santamaría and J. Wudka



CENTRO ANDALUZ DE FISICA  
DE PARTICULAS ELEMENTALES



Universidad  
de Granada

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# Outline

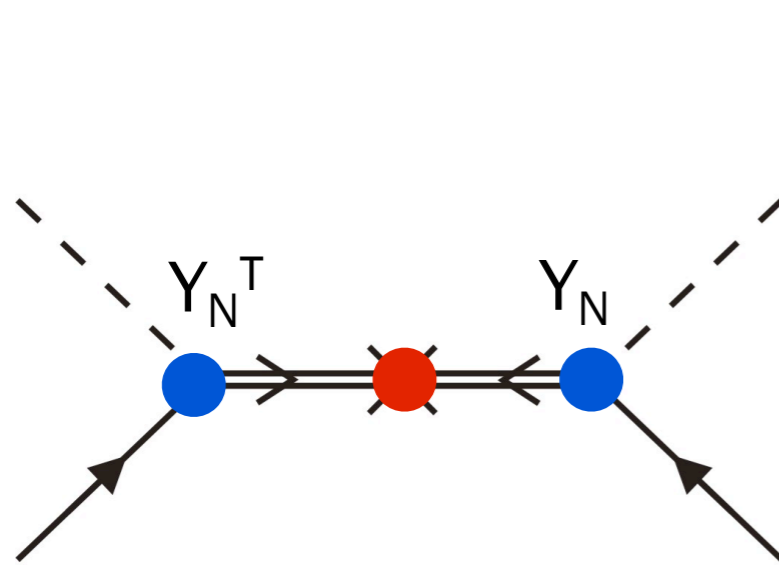
- Introduction: Up to now the tiny neutrino masses are the only direct observation of Lepton Number Violation (LNV), if they are actually Majorana. At the LHC era the question is if LNV is observable at the LHC.
- Present limits on di-lepton decays can be easily extrapolated to LNV processes.
- But  $H^{++}$  can be a component of a generic scalar multiplet, generalizing the see-saw of type II model [with a heavy scalar triplet ( $\Delta^{++}$   $\Delta^+$   $\Delta^0$ ) giving Majorana masses to neutrinos]. What can be determined sampling appropriately 4 and 3 isolated lepton signals because their production rate does depend on  $T$  and  $Y$ .
- Conclusions

$$(m_\nu)_{ij} = x_{ij} v^2 / \Lambda \sim 0.1 \text{ eV}$$

$$\mathcal{O}^{(5)} = (\overline{L}_L^c \tilde{\phi}^*) (\tilde{\phi}^\dagger L_L)$$

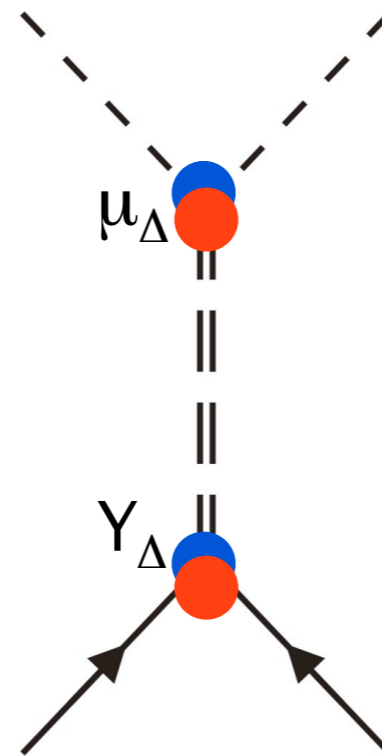
$$\mathcal{L}_{m_\nu}^{(5)} = -x_{ij} \mathcal{O}_{ij}^{(5)} / \Lambda + \text{h.c.} \rightarrow -(x_{ij} v^2 / 2\Lambda) \overline{\nu}_{Li}^c \nu_{Lj} + \text{h.c.}$$

## See-saw mechanisms (messengers of type I, II, III)



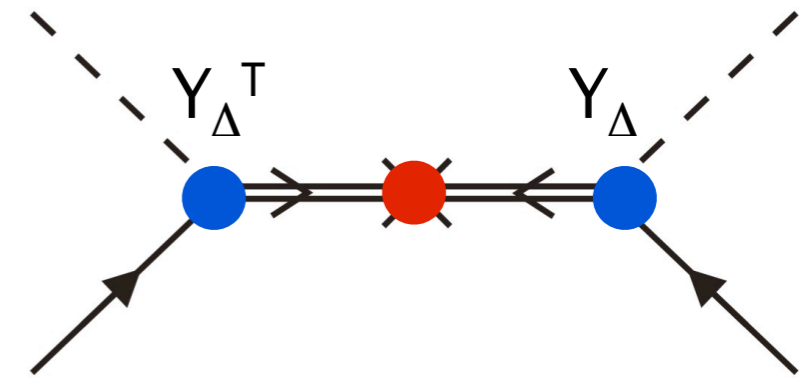
$$1/2 Y_N^T M_N^{-1} Y_N$$

Phase cancellation  
or small couplings



$$-2 Y_\Delta \mu_\Delta M_\Delta^{-2}$$

small coupling(s)

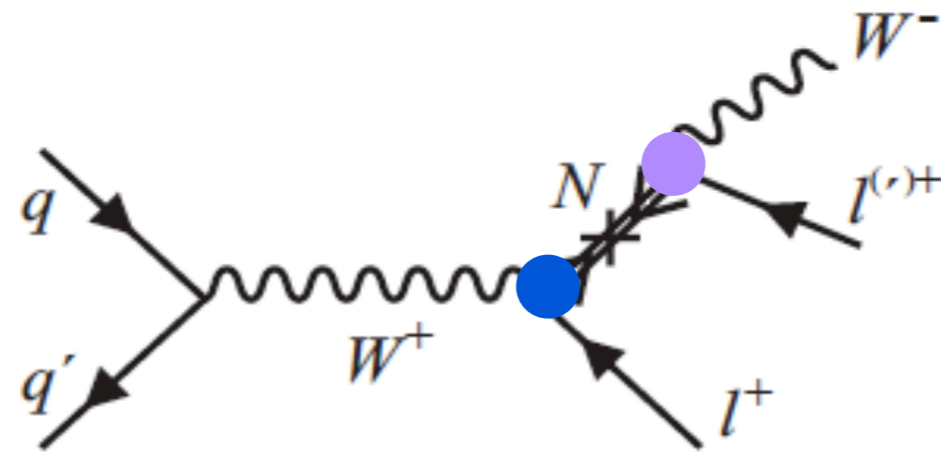


$$1/2 Y_\Sigma^T M_\Sigma^{-1} Y_\Sigma$$

Phase cancellation  
or small couplings

The three mechanisms must violate Lepton Number (LN) for they are assumed to generate Majorana masses. I and III involve fermions: singlets N (I) or triplets  $\Sigma$  (III), and II scalar triplets:  $\Delta$ .

# TeV signatures of see-saw messengers: Multilepton signals

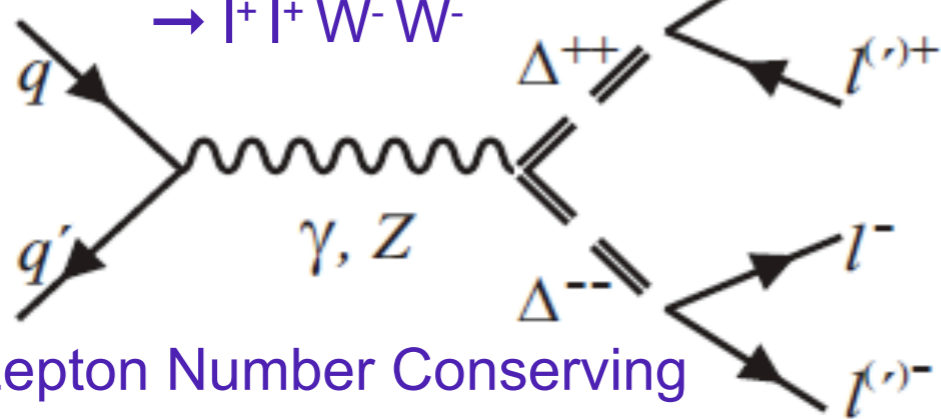


W.Y. Keung and G. Senjanovic,  
Phys. Rev. Lett. 50 (1983) 1427

Lepton Number Violating

$$m_\nu \sim 2 Y_\Delta \mu_\Delta v^2 M_\Delta^{-2}$$

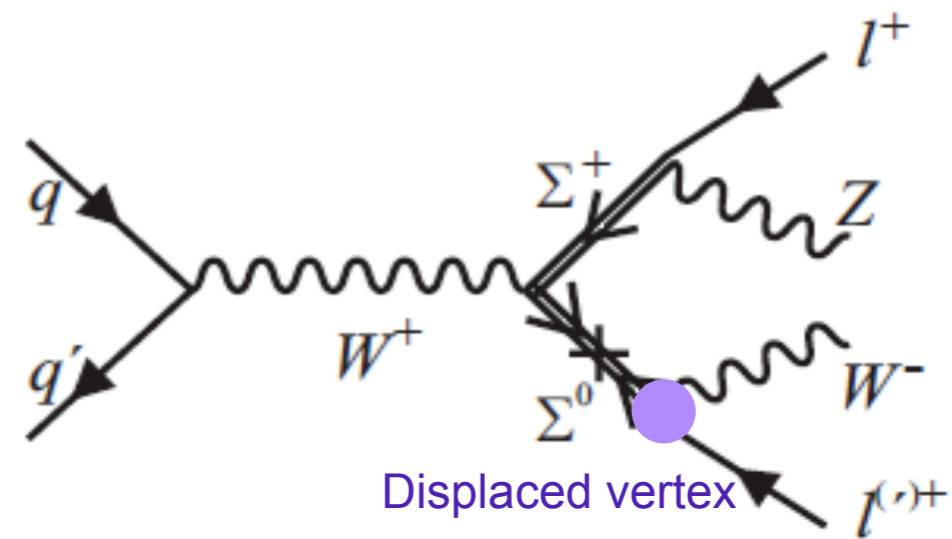
$$\rightarrow l^+ l^+ W^- W^-$$



Lepton Number Conserving

(II)

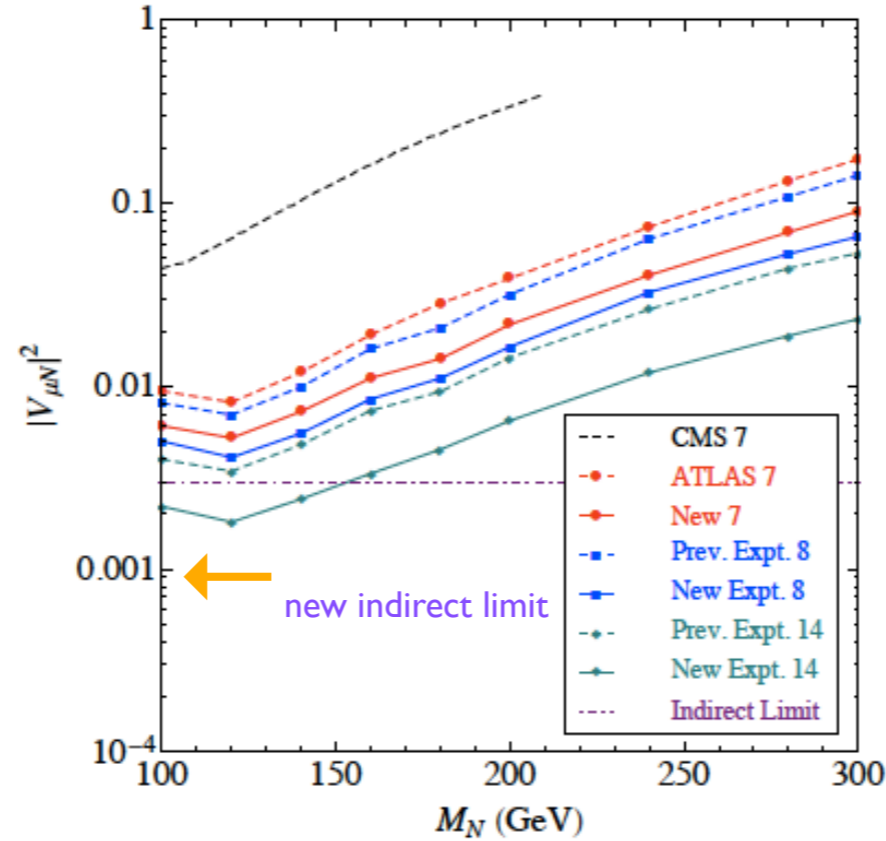
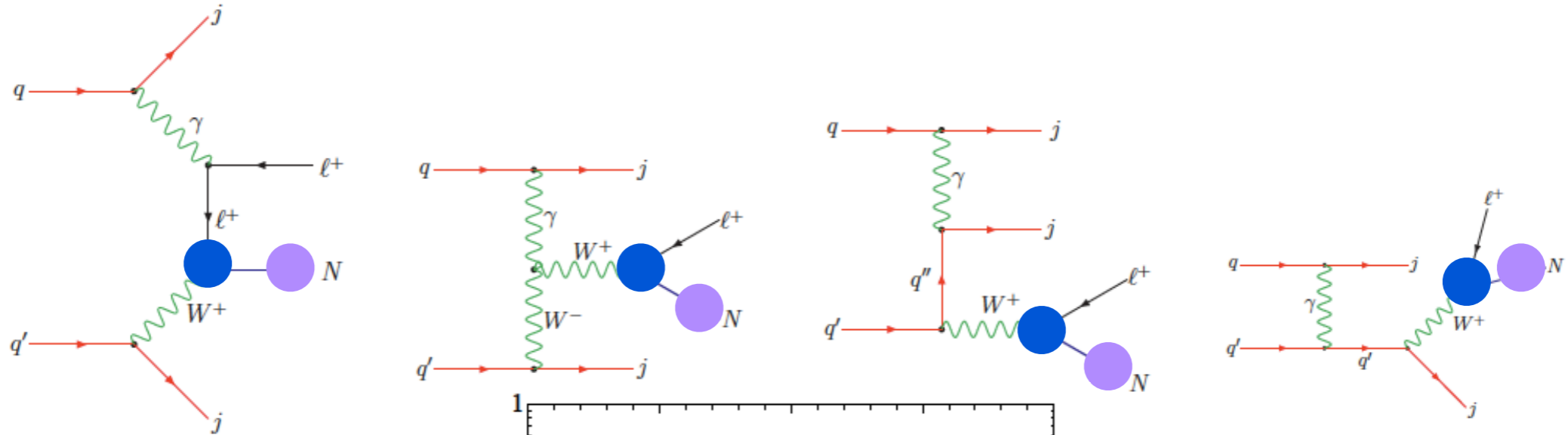
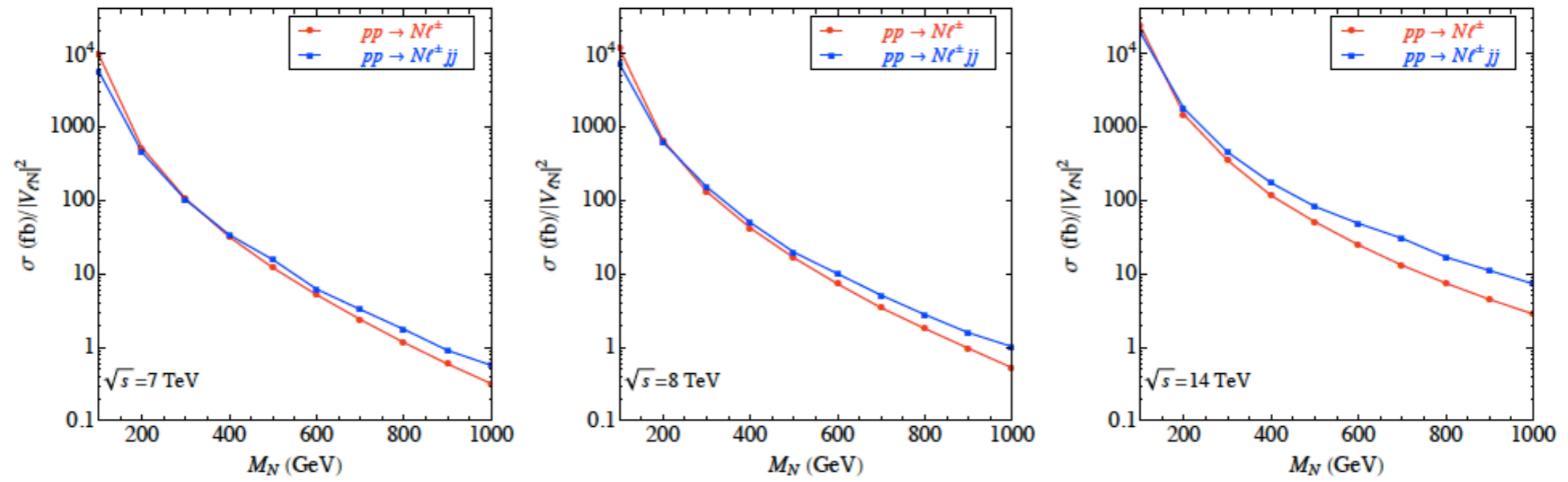
(I)



Displaced vertex

(III)

R. Franceschini, T. Hambye and A. Strumia,  
Phys. Rev. D 78 (2008) 033002 [arXiv:0805.1613 [hep-ph]]



P.S.B. Dev, A. Pilaftsis and U. Yang,  
arXiv:1308.2209 [hep-ph]

J. de Blas  
arXiv:1307.6173 [hep-ph]: 0.0009

CMS and ATLAS have set stringent limits on doubly-charged scalars  $H^{\pm\pm}$  decaying into two same-sign leptons  $\sim 400$  GeV with only  $5 \text{ fb}^{-1}$  at 7 TeV.

But they very much depend on the assumed di-leptonic branching ratios, in particular, into  $T$ s, and especially into gauge bosons. For instance, if the new scalar multiplet has a neutral component getting a v.e.v., through the gauge coupling  $g^2 \langle H^0 \rangle H^{++} W^- W^-$ . On the other hand, if both  $H^{\pm\pm}$  decays are observed,  $pp \rightarrow H^{++} H^{--} \rightarrow l^+ l^+ W^- W^-$ , LN will have been proved to be violated at the LHC.

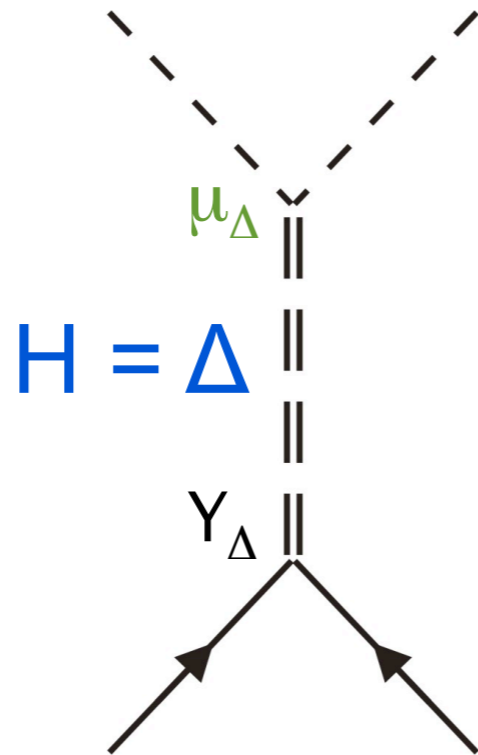
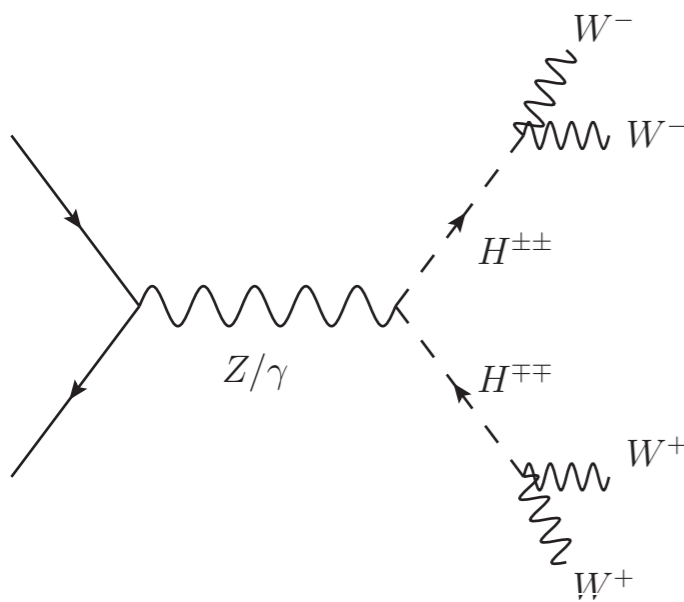
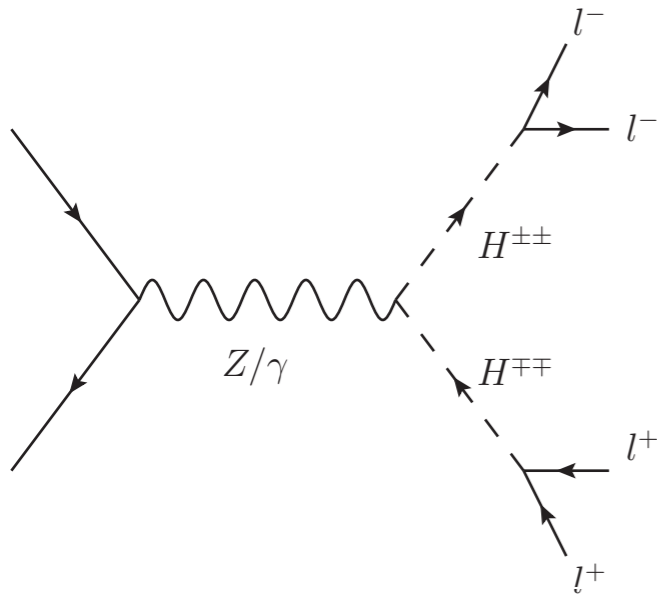
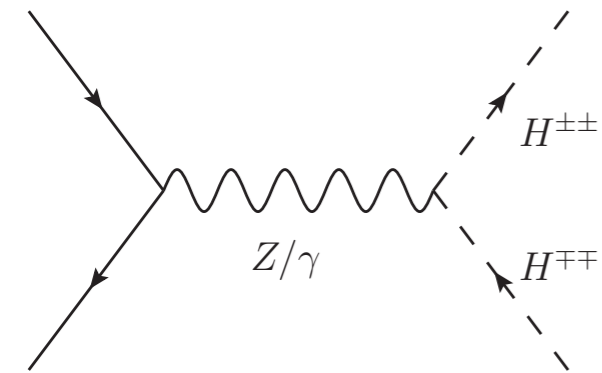
- The most popular Standard Model extension of this class is the see-saw of type II with a heavy scalar triplet  $(\Delta^{++} \Delta^+ \Delta^0)$  giving Majorana masses to neutrinos.

- Present limits on di-lepton decays can be easily extrapolated to LNV processes.

- But  $H^{++}$  can be a component of a generic scalar multiplet with

$$T^H \geq T_3^{H^{++}} = 2 - Y^H$$

- What can be determined sampling appropriately 4 and 3 isolated lepton signals because their production rate does depend on  $T$  and  $Y$ .

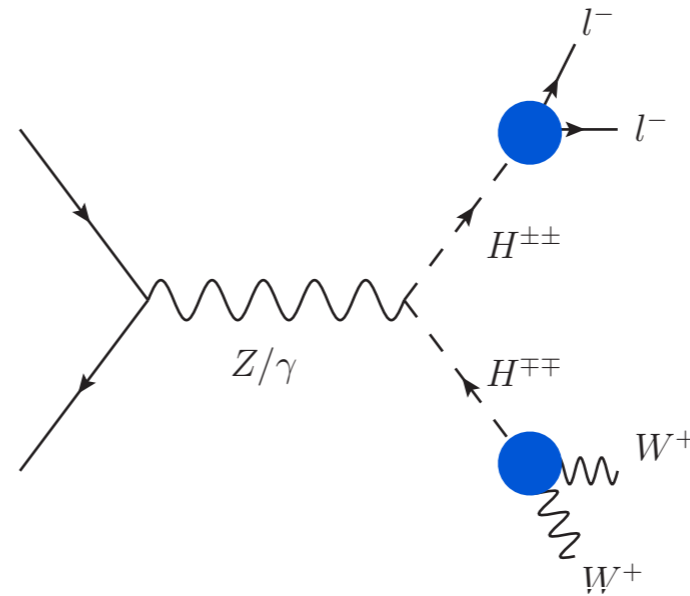


$$g^2 \langle \Delta^0 \rangle W^{\mp\mu} W_{\mu}^{\mp} \Delta^{\pm\pm}$$

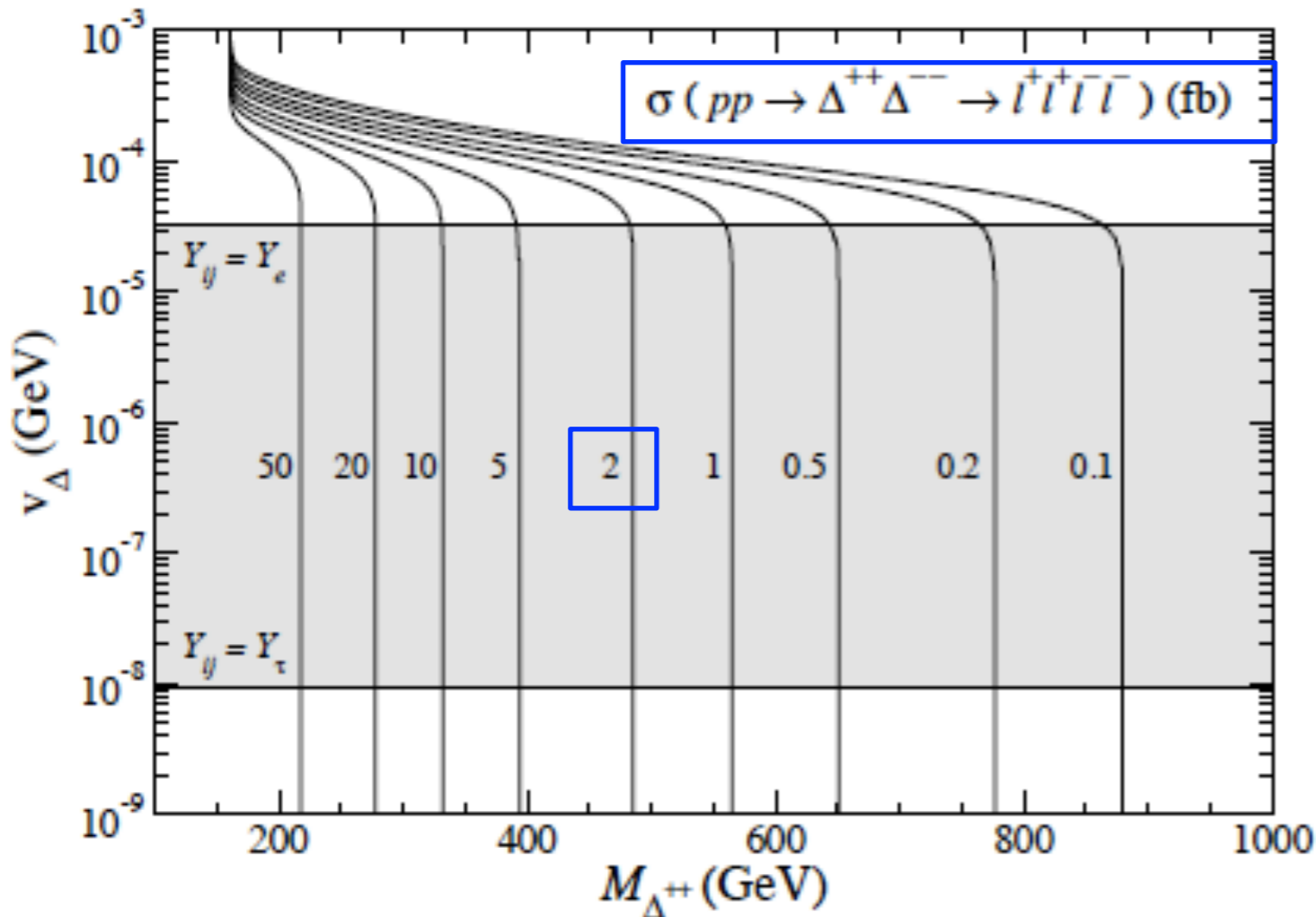
$$(\tilde{L}_L \tau^a L_L) \Delta^{-a}$$

$$-2Y_{\Delta} \mu_{\Delta} v^2 M_{\Delta}^{-2} \sim \text{meV} \text{ with } \sqrt{2} \langle \Delta^0 \rangle = \mu_{\Delta} v^2 M_{\Delta}^{-2}$$

if  $M_{\Delta} \sim \text{TeV}$ :  $Y_{\Delta} \mu_{\Delta} \sim 10^{-11} \text{ GeV}$



$$\left[ \sum_{i,j=e,\mu,\tau} \Gamma(\Delta \rightarrow l_i l_j) \Gamma(\Delta \rightarrow WW) \right]^{-1} \approx 10^{-15} \left[ \sum_{i=1,2,3} m_{\nu_i}^2 \right]^{-1} \frac{m_W^4}{m_{\Delta}^4} > 10^5 \frac{m_W^4}{m_{\Delta}^4} \mu\text{m}^2$$



F.A and J.A. Aguilar-Saavedra,  
Nucl. Phys. B813 (2009) 22 [arXiv:0808.2468 [hep-ph]]

Lepton Number Violating

$$m_\nu \sim 2 Y_\Delta \mu_\Delta v^2 M_\Delta^{-2}$$

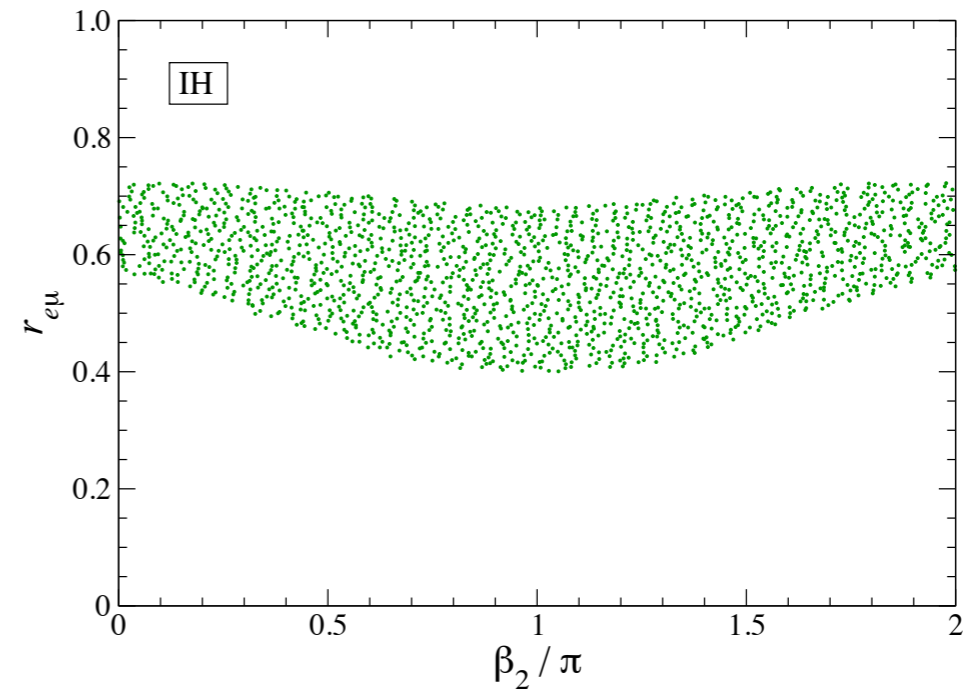
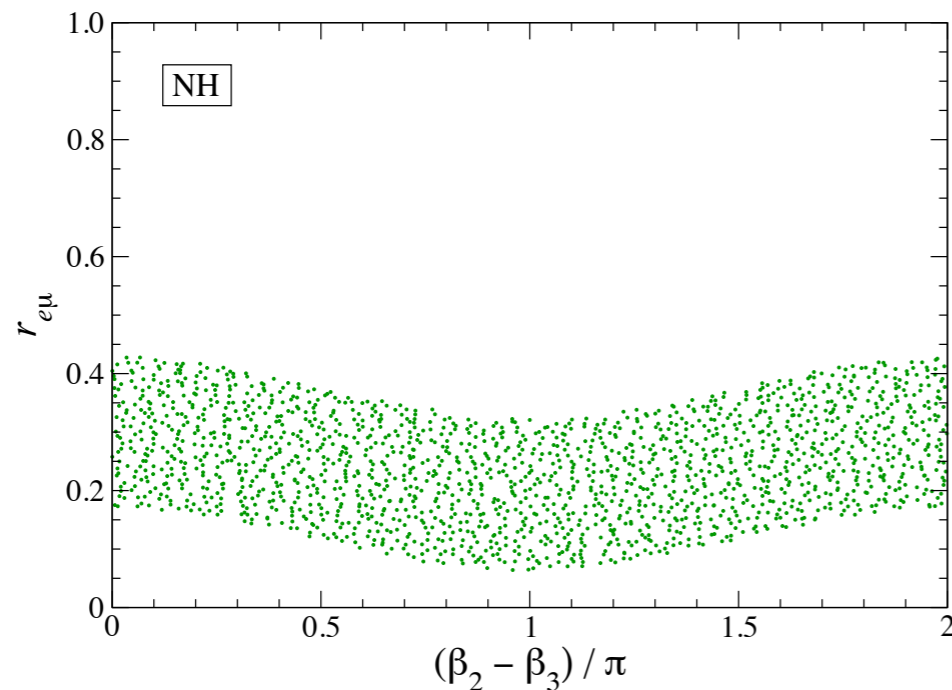
$$\rightarrow l^+ l^+ W^- W^-$$

$$v_\Delta = \frac{v^2 |\mu_\Delta|}{\sqrt{2} M_\Delta^2} < 2 \text{ GeV} \quad \text{EWPD}$$

$\Delta$  BR's into leptons are a high energy window to neutrino masses and mixings, and may even allow for reconstructing the PMNS matrix.

They depend on the neutrino masses and mixings, being the main dependance on  $\alpha_2$  (in the plots  $\beta_2 - \beta_3$  and  $\beta_2$ , respectively).

$$r_{e\mu} \equiv \text{Br}(\Delta^{\pm\pm} \rightarrow e^\pm e^\pm / \mu^\pm \mu^\pm / e^\pm \mu^\pm)$$

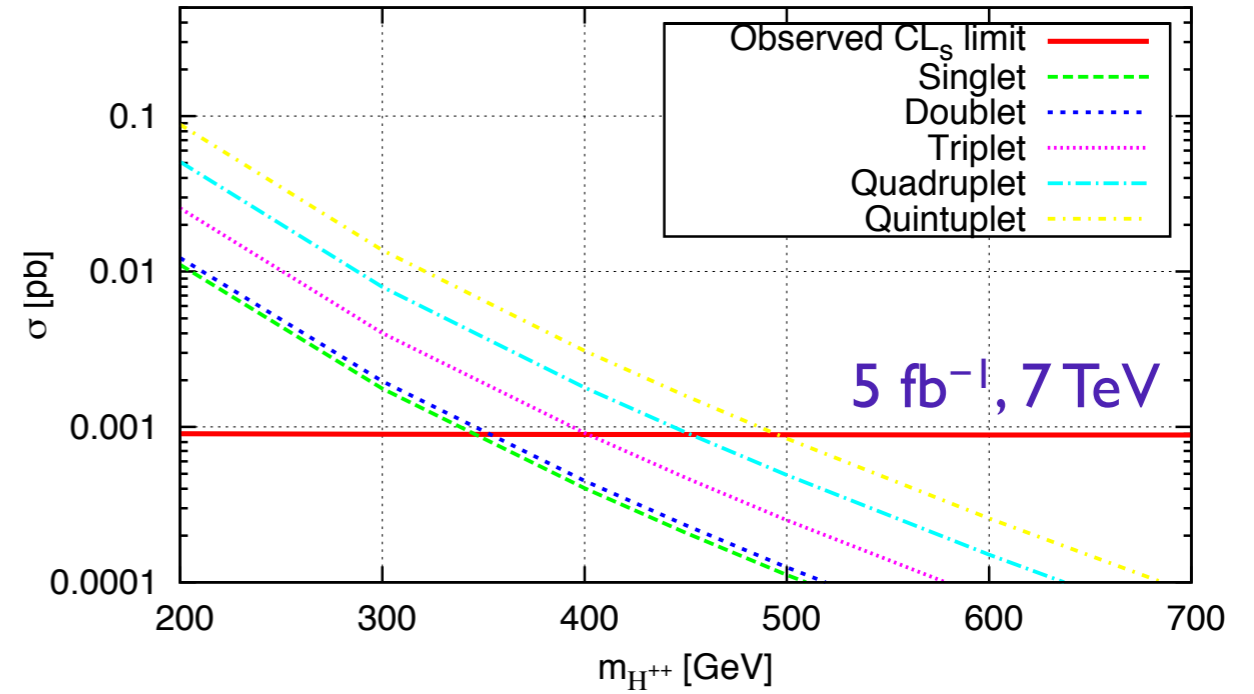
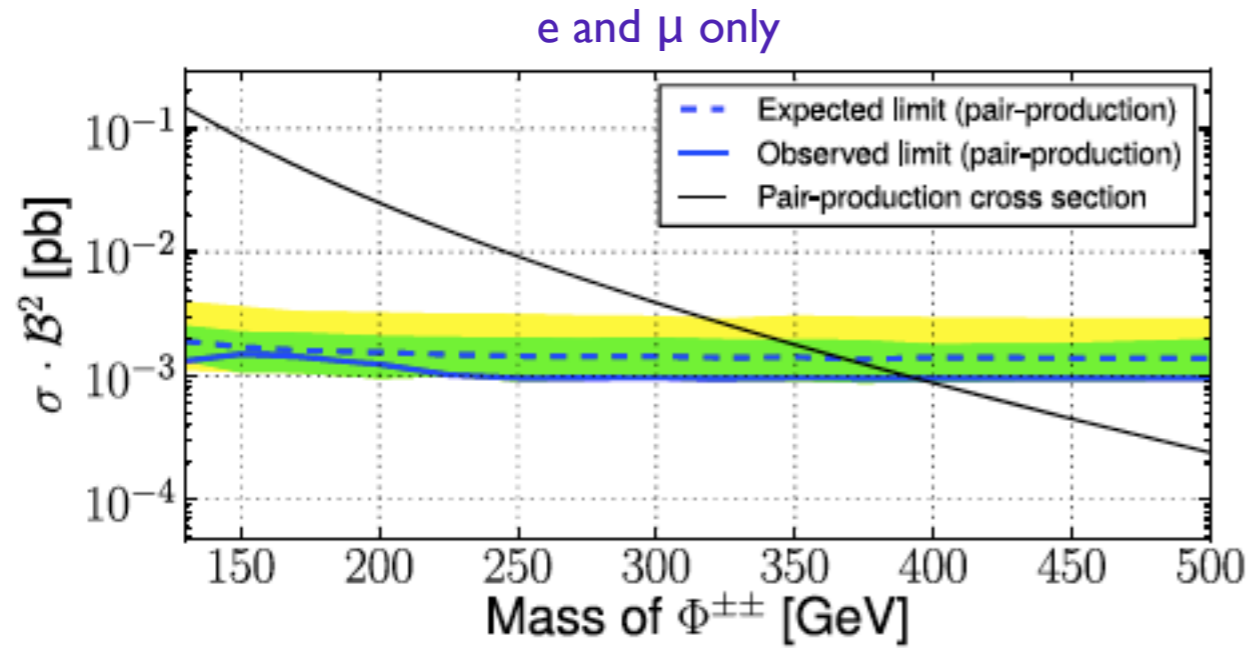




--- K.S. Babu, Phys. Lett. B 203 (1988) 132

--- F.A., A. Aparici, S. Bhattacharya, A. Santamaria and J. Wudka, JHEP 1205 (2012) 133 [arXiv:1111.6960 [hep-ph]]

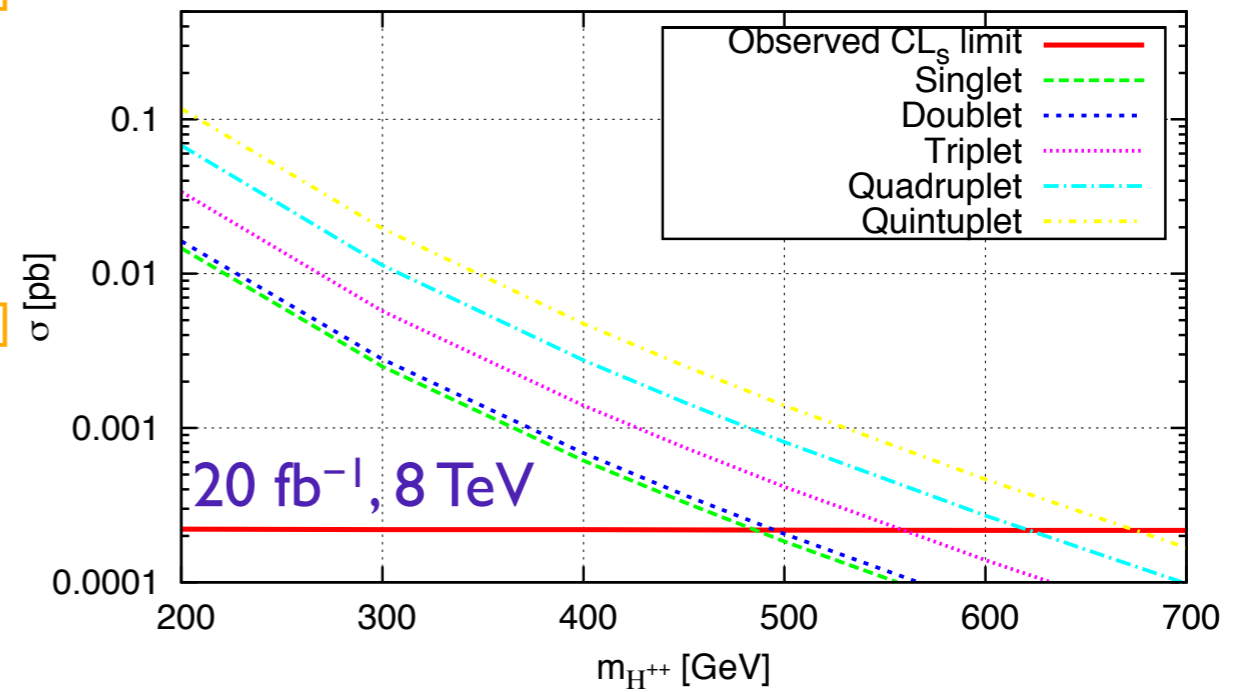
--- K.S. Babu, S. Nandi and Z. Tavartkiladze, Phys. Rev. D 80, 071702 (2009) [arXiv:0905.2710 [hep-ph]]

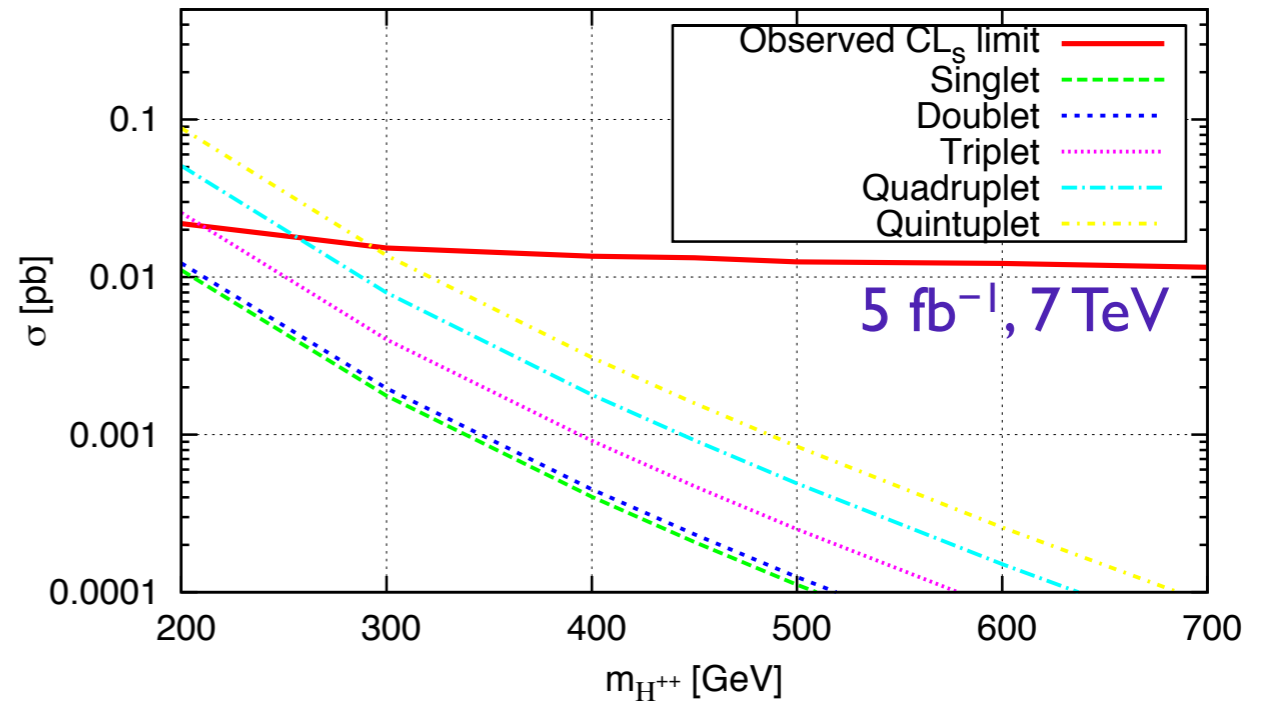
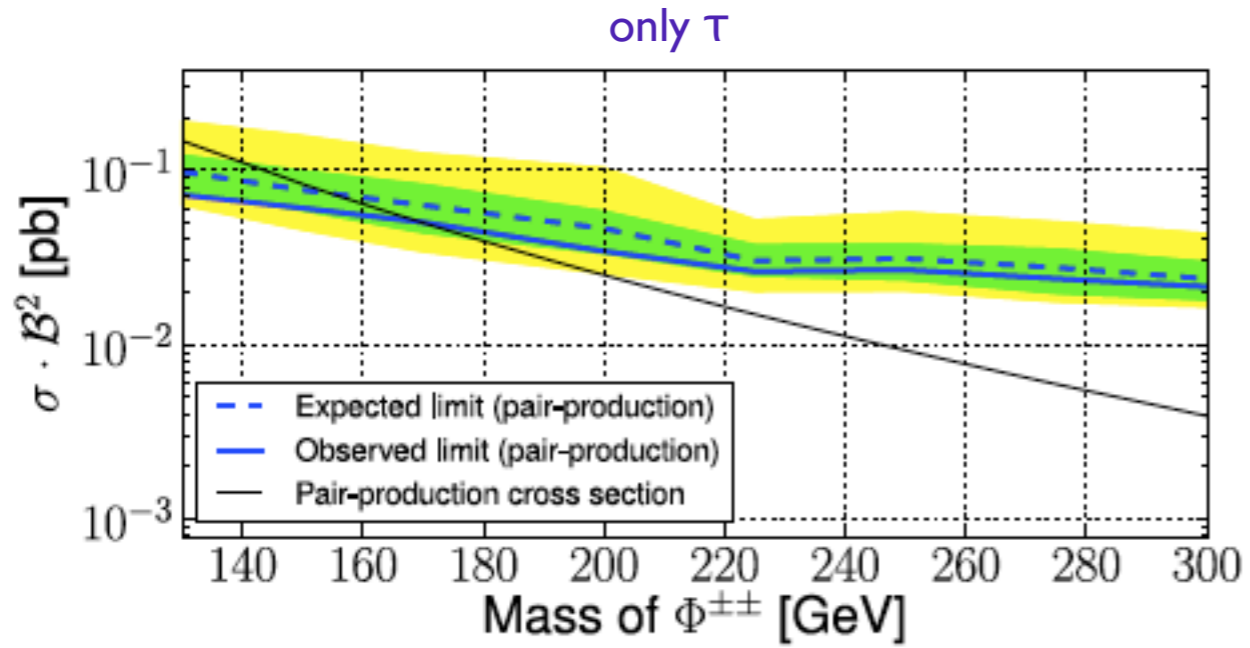


S. Chatrchyan et al. [CMS Collaboration]  
Eur. Phys. J. C 72 (2012) 2189 [arXiv:1207.2666 [hep-ex]]

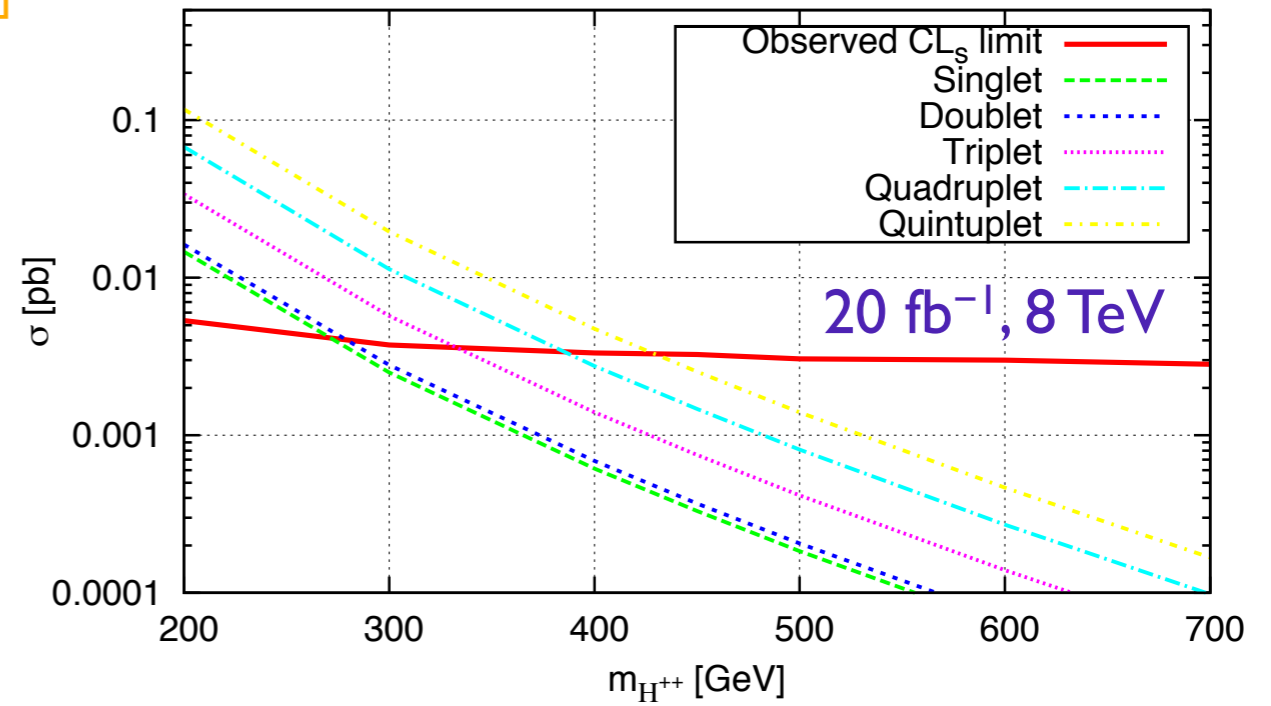
No  $\tau$  decays

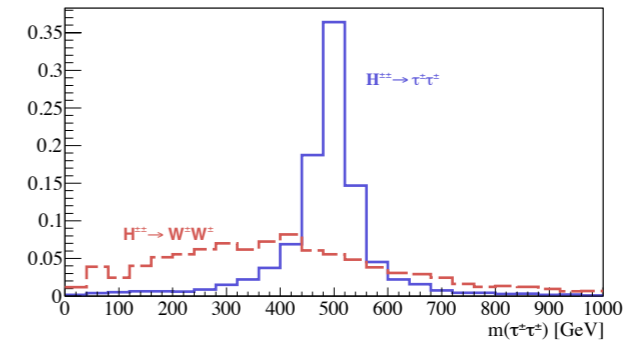
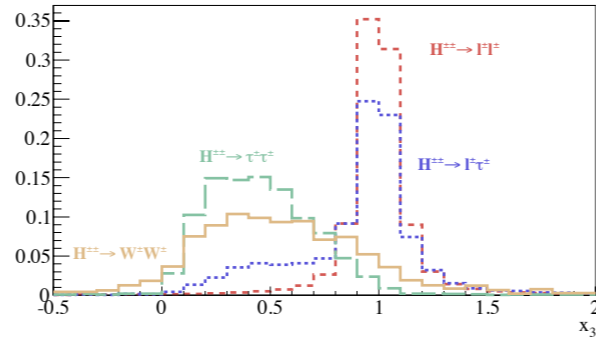
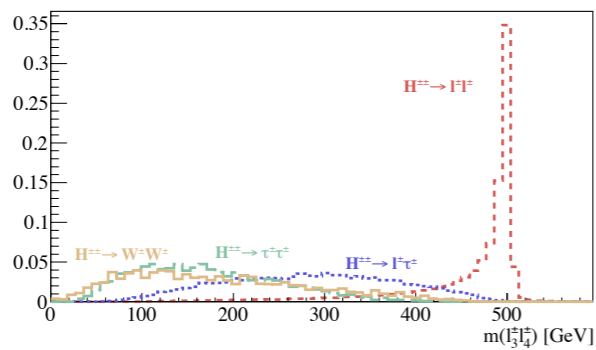
G. Aad et al. [ATLAS Collaboration],  
Eur. Phys. J. C 72 (2012) 2244 [arXiv:1210.5070 [hep-ex]]





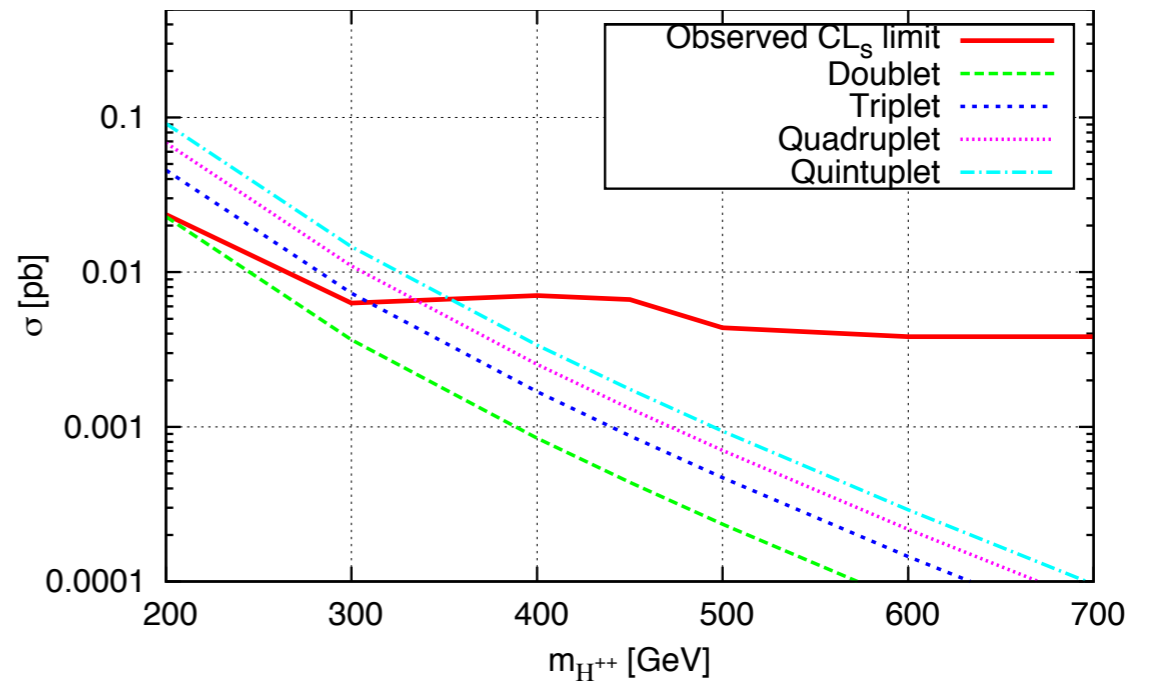
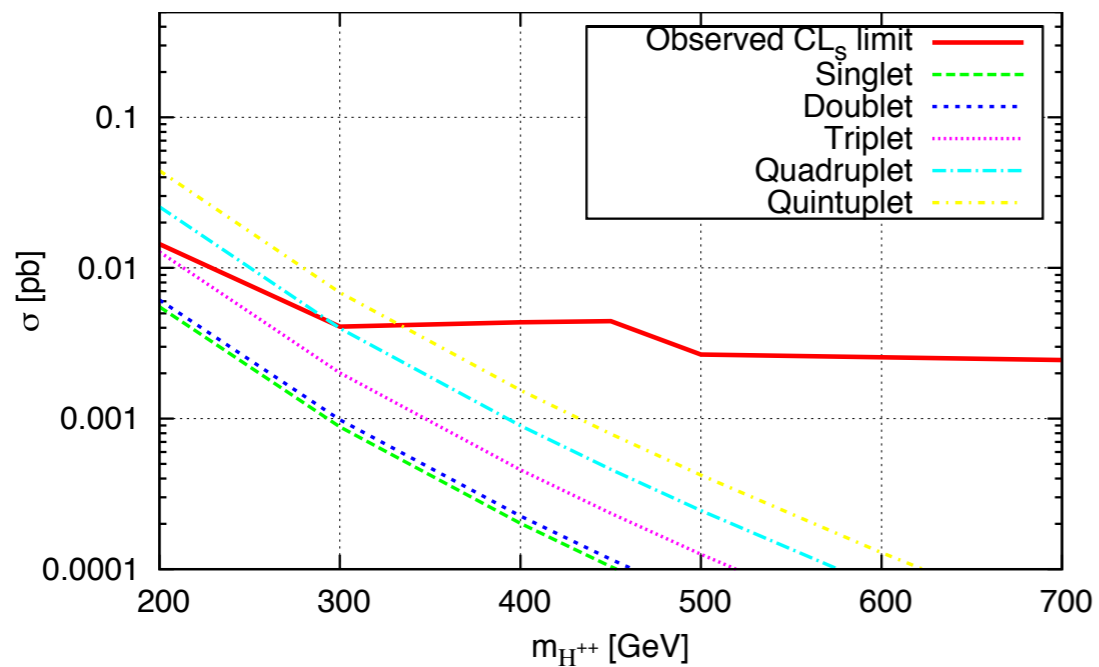
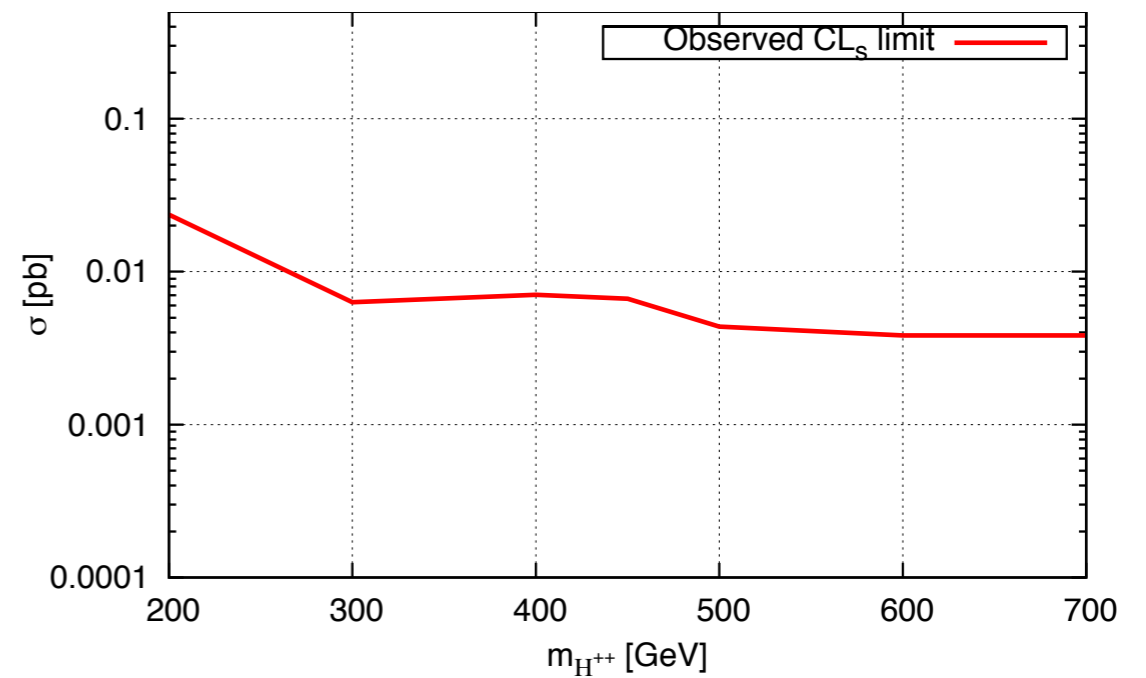
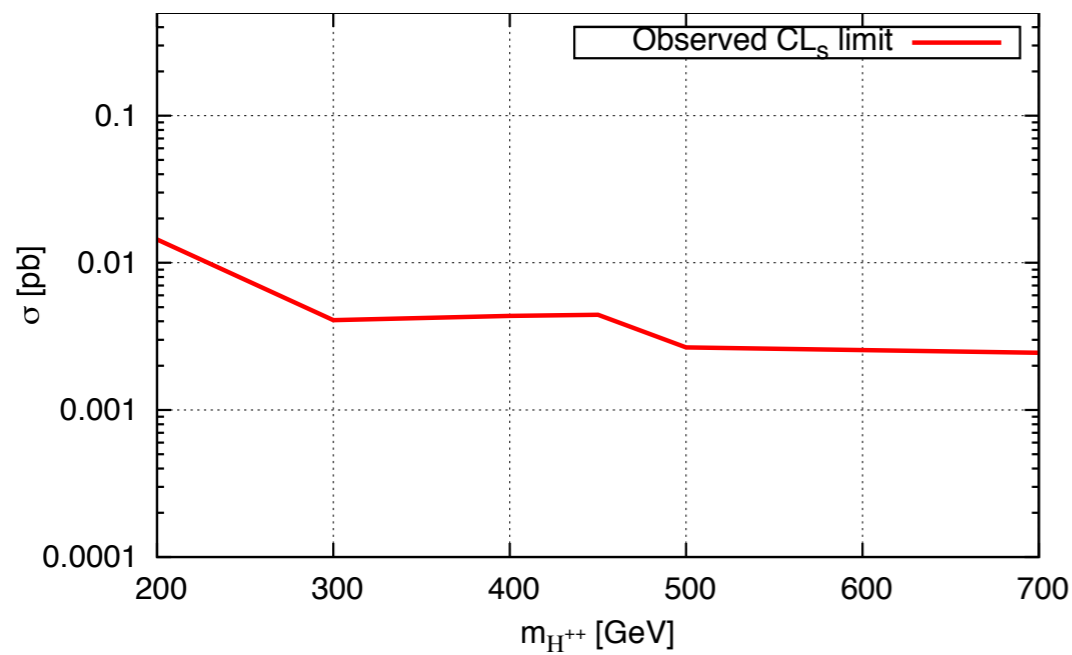
S. Chatrchyan et al. [CMS Collaboration]  
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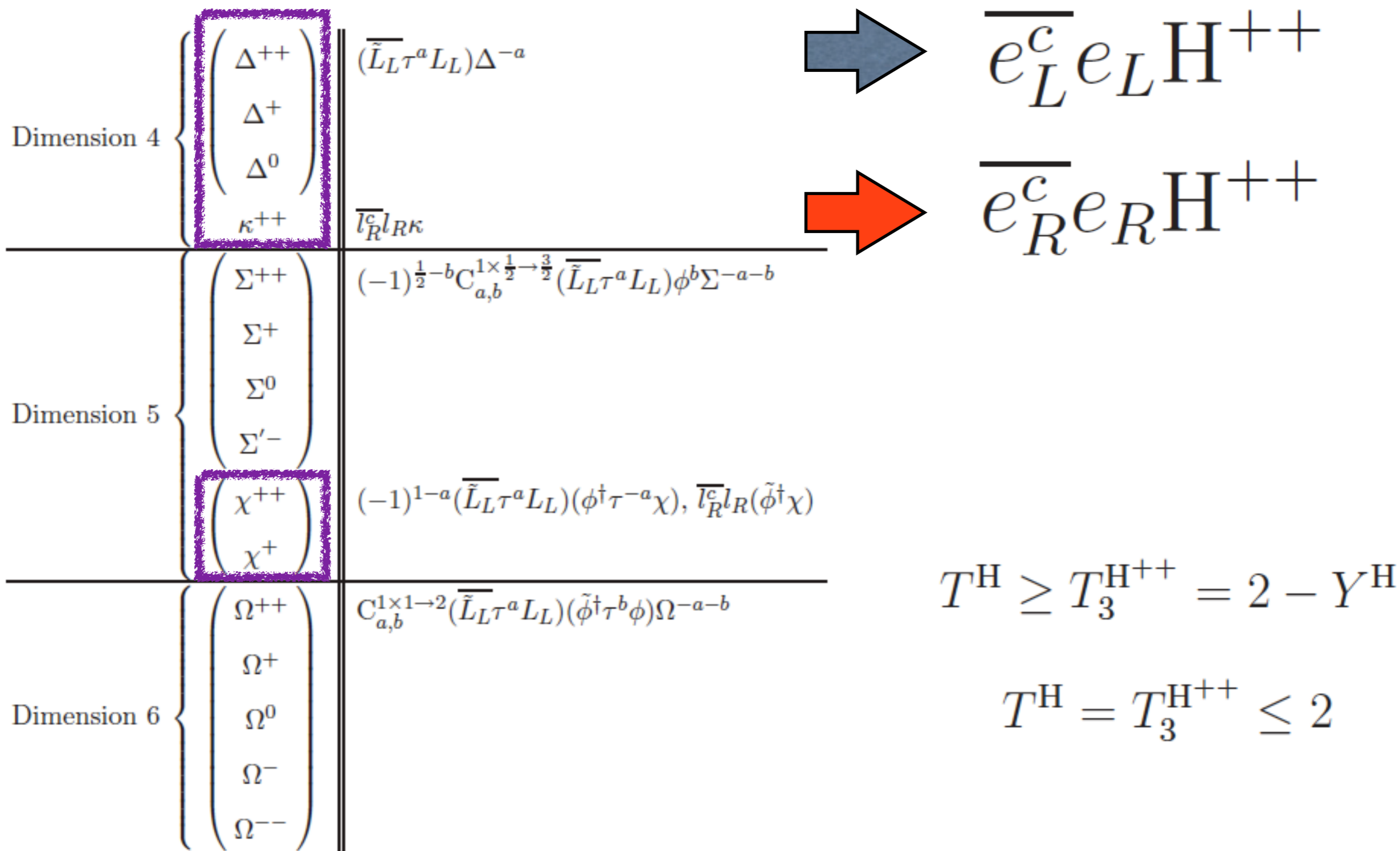


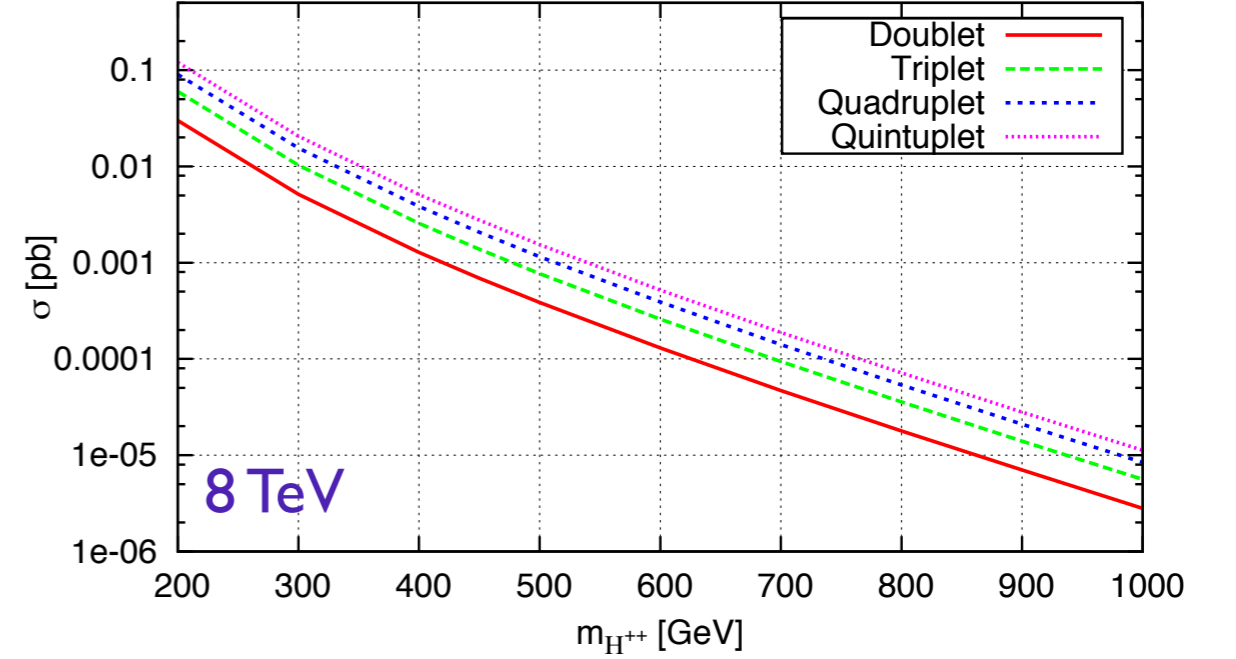
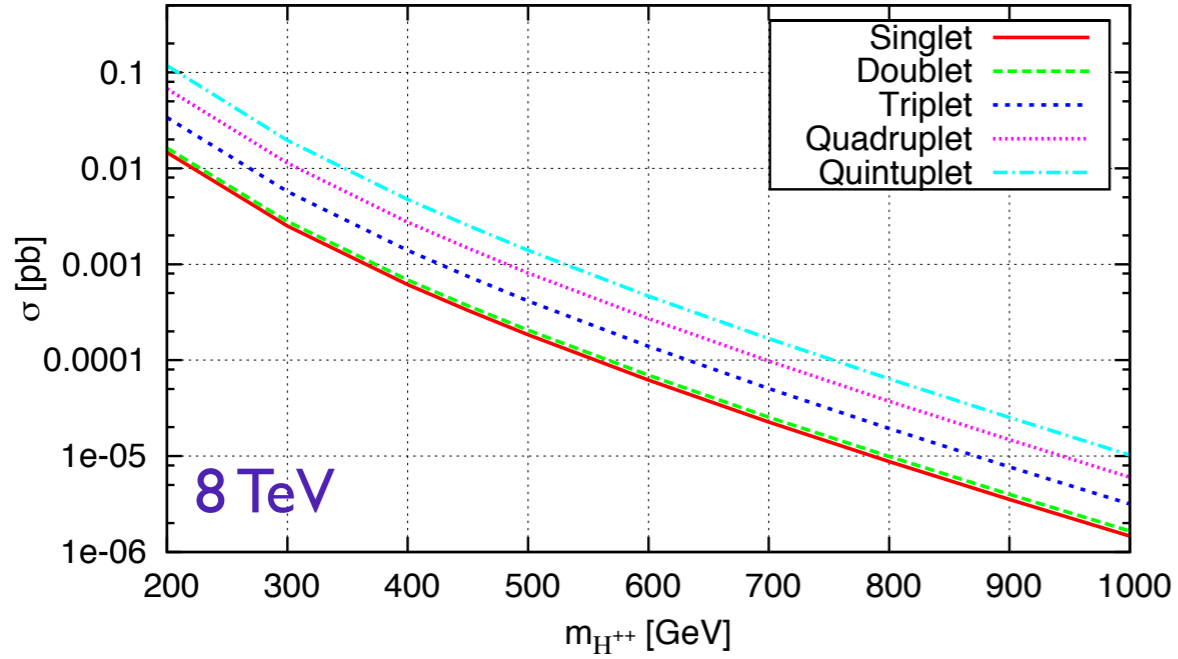
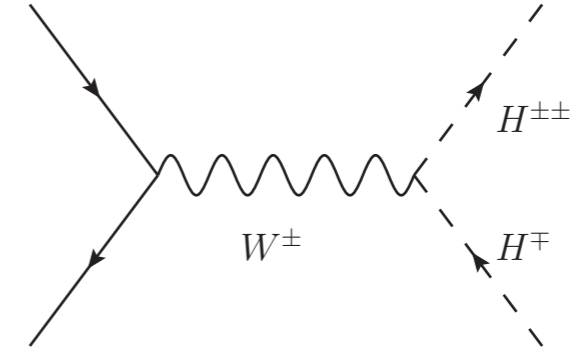
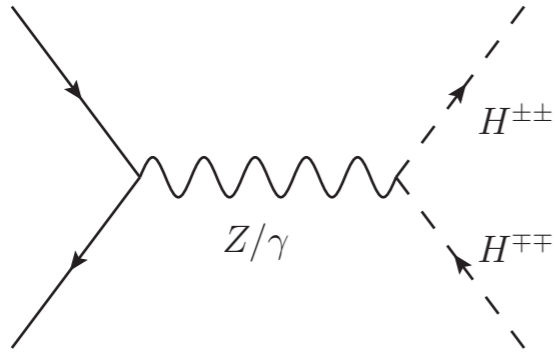


pair production  
 $5 \text{ fb}^{-1}, 7 \text{ TeV}$   
 50 % ll + 50 % WW

associated production  
 $5 \text{ fb}^{-1}, 7 \text{ TeV}$   
 $H^{\pm\pm} \rightarrow l^{\pm}l^{\pm}$  and  $H^{\pm} \rightarrow W^{\pm}Z$



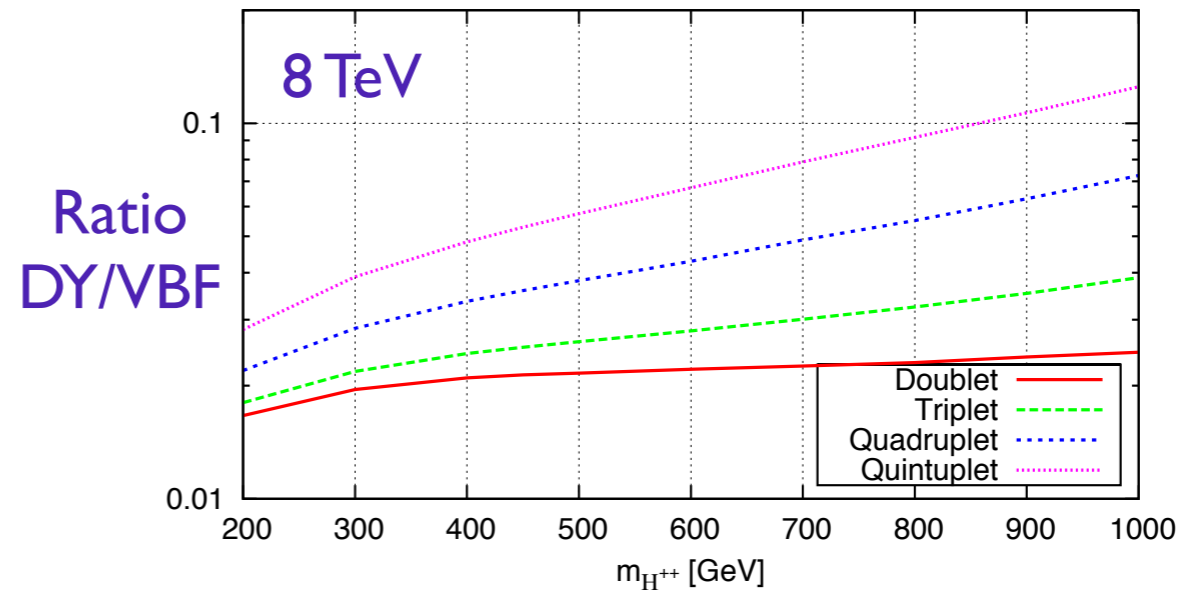
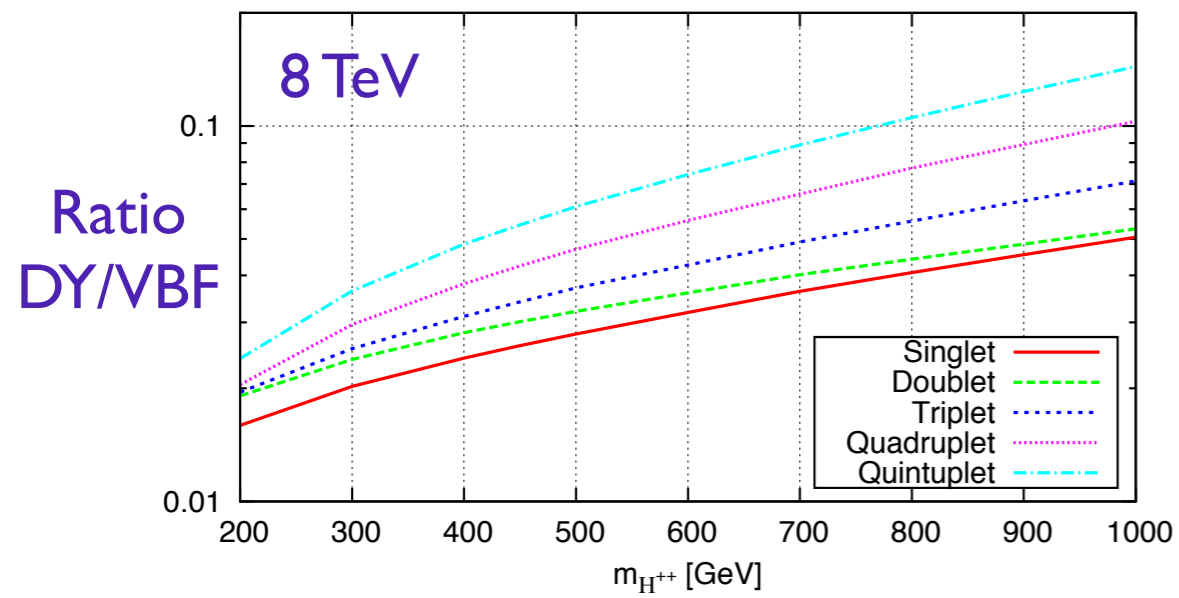
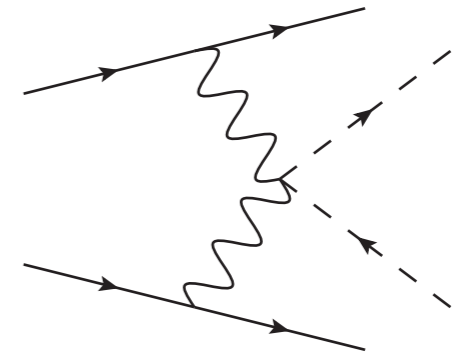
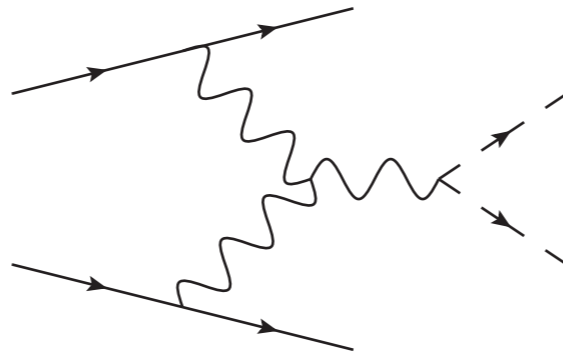
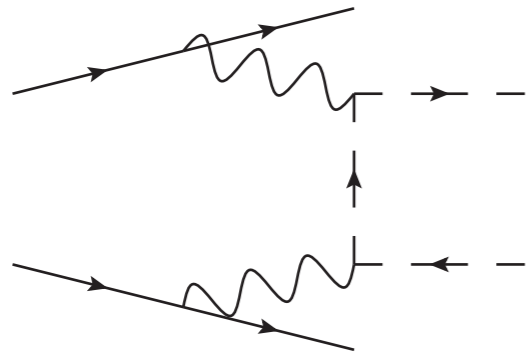




$$\mathcal{L}_\gamma^{\text{H}^{\pm\pm}} = ieQ(\partial^\mu \text{H}^{--})\text{H}^{++}A_\mu + \text{h.c.},$$

$$\mathcal{L}_Z^{\text{H}^{\pm\pm}} = \frac{ig}{c_W}(T_3 - Qs_W^2)(\partial^\mu \text{H}^{--})\text{H}^{++}Z_\mu + \text{h.c.}$$

$$\mathcal{L}_W^{\text{H}^{\pm\pm}} = \frac{ig}{\sqrt{2}}\sqrt{(T - T_3 + 1)(T + T_3)}[\text{H}^{++}(\partial^\mu \text{H}^-) - (\partial^\mu \text{H}^{++})\text{H}^-]W_\mu^- + \text{h.c.}$$



$\gamma\gamma$  contribution

T. Han, B. Mukhopadhyaya, Z. Si and K. Wang,  
 Phys. Rev. D76 (2007) 075013 [arXiv:0706.0441]

		(1, 0, 0)	$(\frac{1}{2}, \frac{1}{2}, 0)$	$(\frac{1}{2}, 0, \frac{1}{2})$	$(\frac{1}{3}, \frac{1}{3}, \frac{1}{3})$
Quintuplet	$(l^\pm l^\pm) l^\mp l^\mp p_T^{miss}$	$1307 \pm 38$	$501 \pm 25$	$362 \pm 22$	$238 \pm 19$
	$(l^\pm l^\pm) (l^\mp l^\mp)$	$1046 \pm 32$	$261 \pm 16$	$261 \pm 16$	$116 \pm 11$
Quadruplet	$(l^\pm l^\pm) l^\mp l^\mp p_T^{miss}$	$765 \pm 30$	$293 \pm 20$	$212 \pm 18$	$139 \pm 16$
	$(l^\pm l^\pm) (l^\mp l^\mp)$	$612 \pm 24$	$153 \pm 12$	$153 \pm 12$	$68 \pm 8$
Triplet	$(l^\pm l^\pm) l^\mp l^\mp p_T^{miss}$	$383 \pm 22$	$147 \pm 16$	$106 \pm 15$	$70 \pm 13$
	$(l^\pm l^\pm) (l^\mp l^\mp)$	$306 \pm 18$	$77 \pm 9$	$77 \pm 9$	$34 \pm 6$
Doublet	$(l^\pm l^\pm) l^\mp l^\mp p_T^{miss}$	$189 \pm 17$	$73 \pm 14$	$53 \pm 13$	$35 \pm 12$
	$(l^\pm l^\pm) (l^\mp l^\mp)$	$151 \pm 12$	$38 \pm 6$	$38 \pm 6$	$17 \pm 4$
Singlet	$(l^\pm l^\pm) l^\mp l^\mp p_T^{miss}$	$168 \pm 17$	$64 \pm 13$	$47 \pm 13$	$31 \pm 12$
	$(l^\pm l^\pm) (l^\mp l^\mp)$	$135 \pm 12$	$34 \pm 6$	$34 \pm 6$	$15 \pm 4$

$(l^\pm l^\pm) (l^\mp p_T^{miss})$	(1, 0, 0)	$(\frac{1}{2}, \frac{1}{2}, 0)$	$(\frac{1}{2}, 0, \frac{1}{2})$	$(\frac{1}{3}, \frac{1}{3}, \frac{1}{3})$
Quintuplet	$1011 \pm 34$	$283 \pm 21$	$261 \pm 20$	$130 \pm 17$
Quadruplet	$592 \pm 27$	$166 \pm 18$	$153 \pm 17$	$76 \pm 15$
Triplet	$296 \pm 21$	$83 \pm 15$	$77 \pm 15$	$38 \pm 14$
Doublet	$146 \pm 17$	$41 \pm 13$	$38 \pm 14$	$19 \pm 13$
Singlet	$0 \pm 12$	$0 \pm 12$	$0 \pm 12$	$0 \pm 12$

$$\sigma_{lla} \equiv 2\sigma z_{ll} z_a, a \neq ll$$

$$\sigma_{lll p_T^{miss}} = \sigma_{lll} + 2 \sum_{a=l\tau, \tau\tau, WW} \sigma z_{ll} z_a Br(a \rightarrow ll + p_T^{miss})$$

How well can we measure  
the total cross-section ?

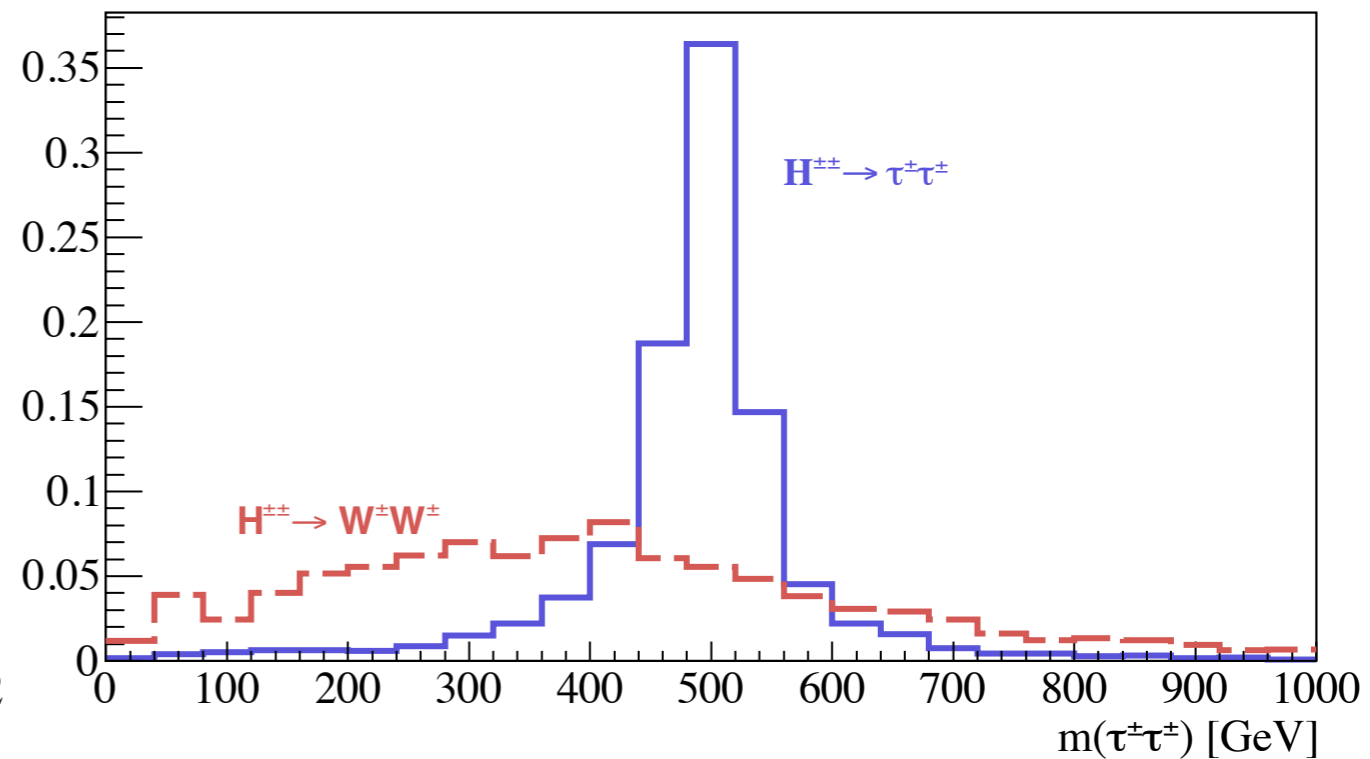
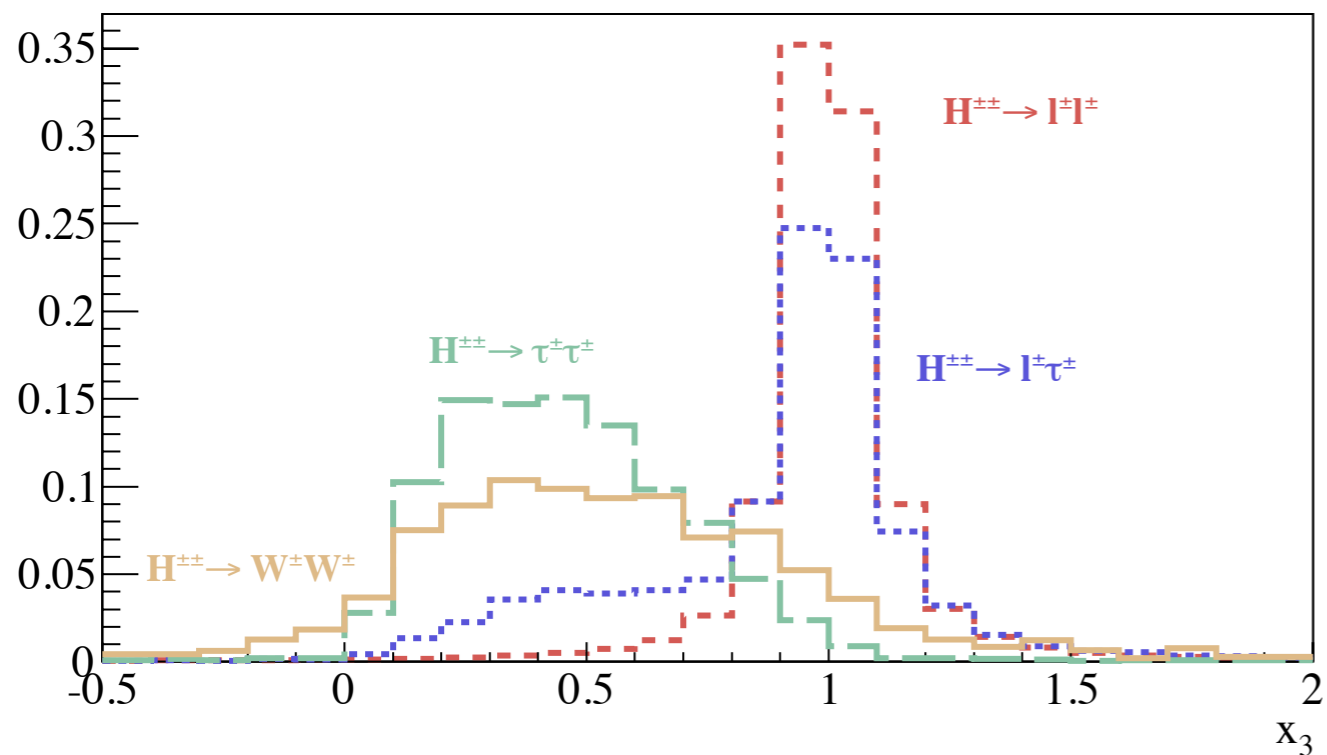
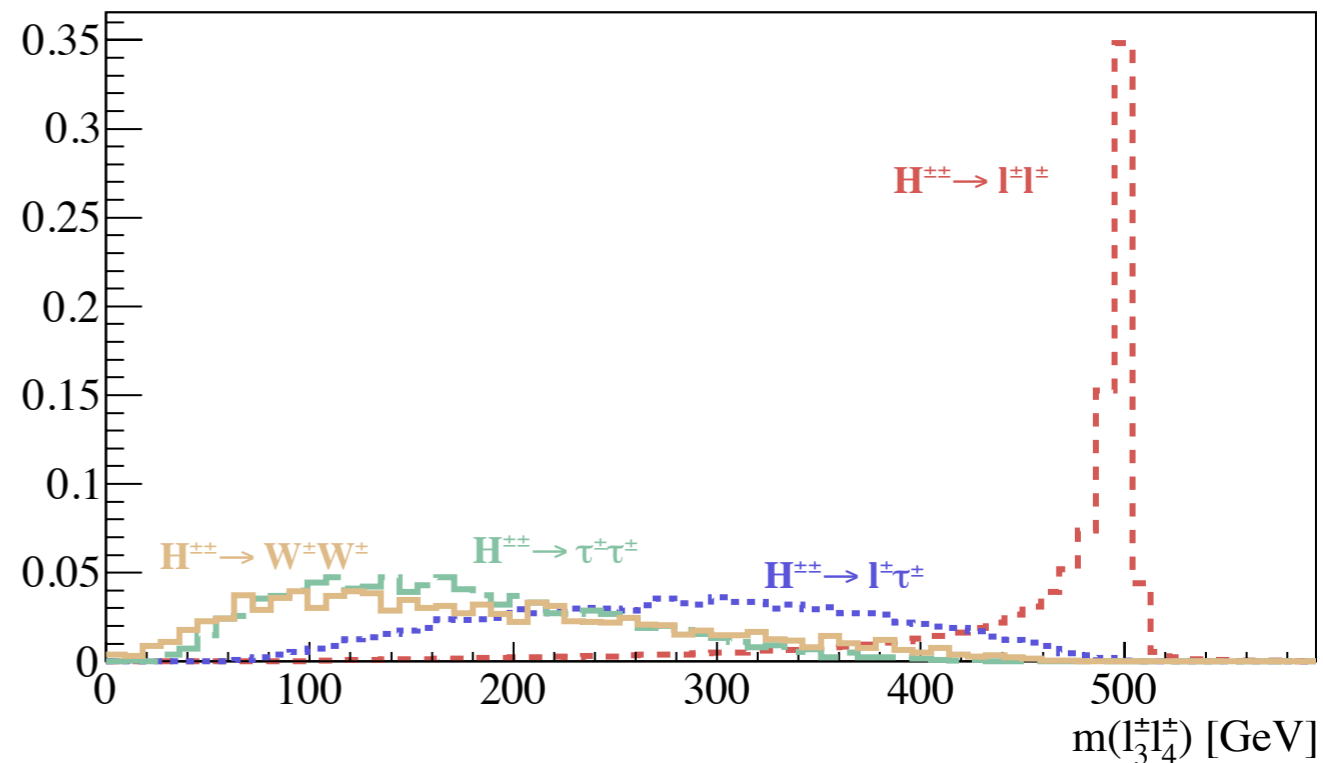
$$\sigma = \left( \sigma_{lll} + \frac{1}{2} \sum_{a \neq ll} \sigma_{lla} \right)^2 / \sigma_{lll}$$

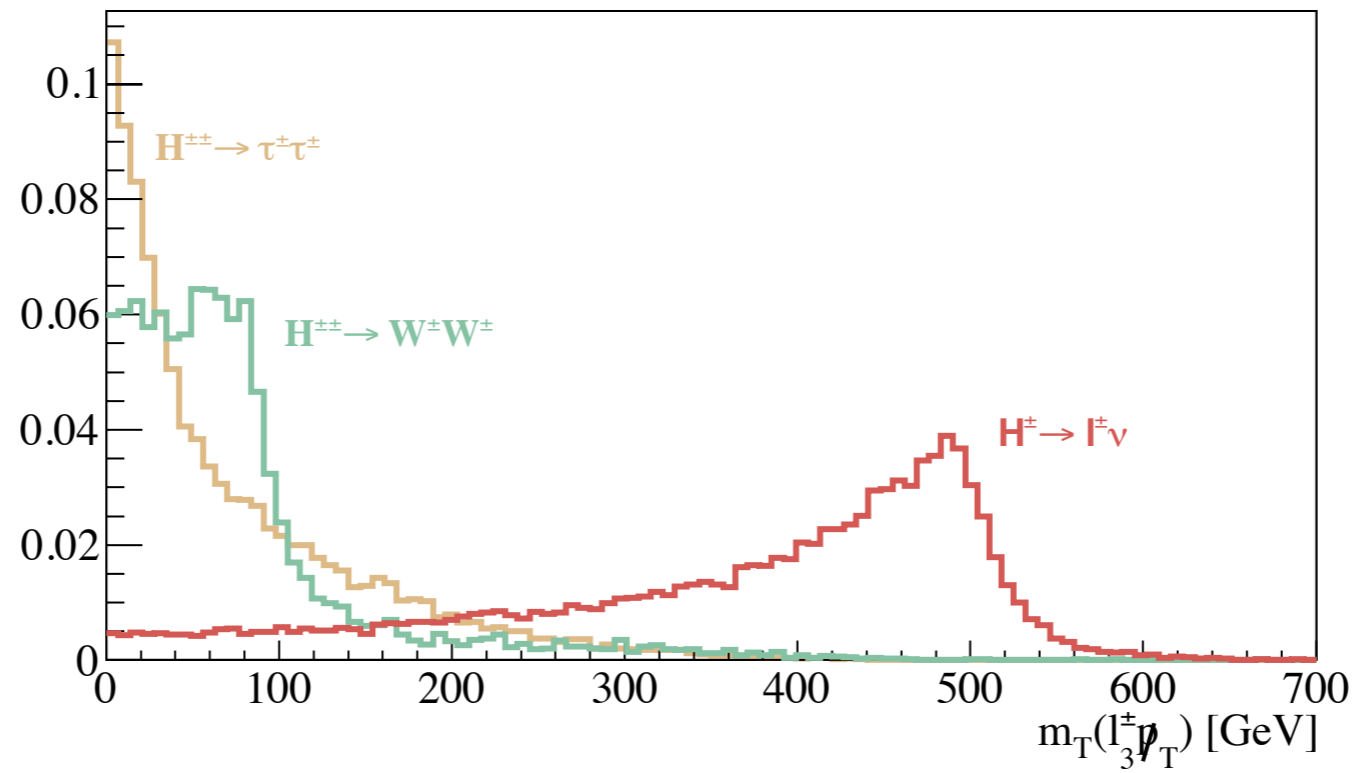
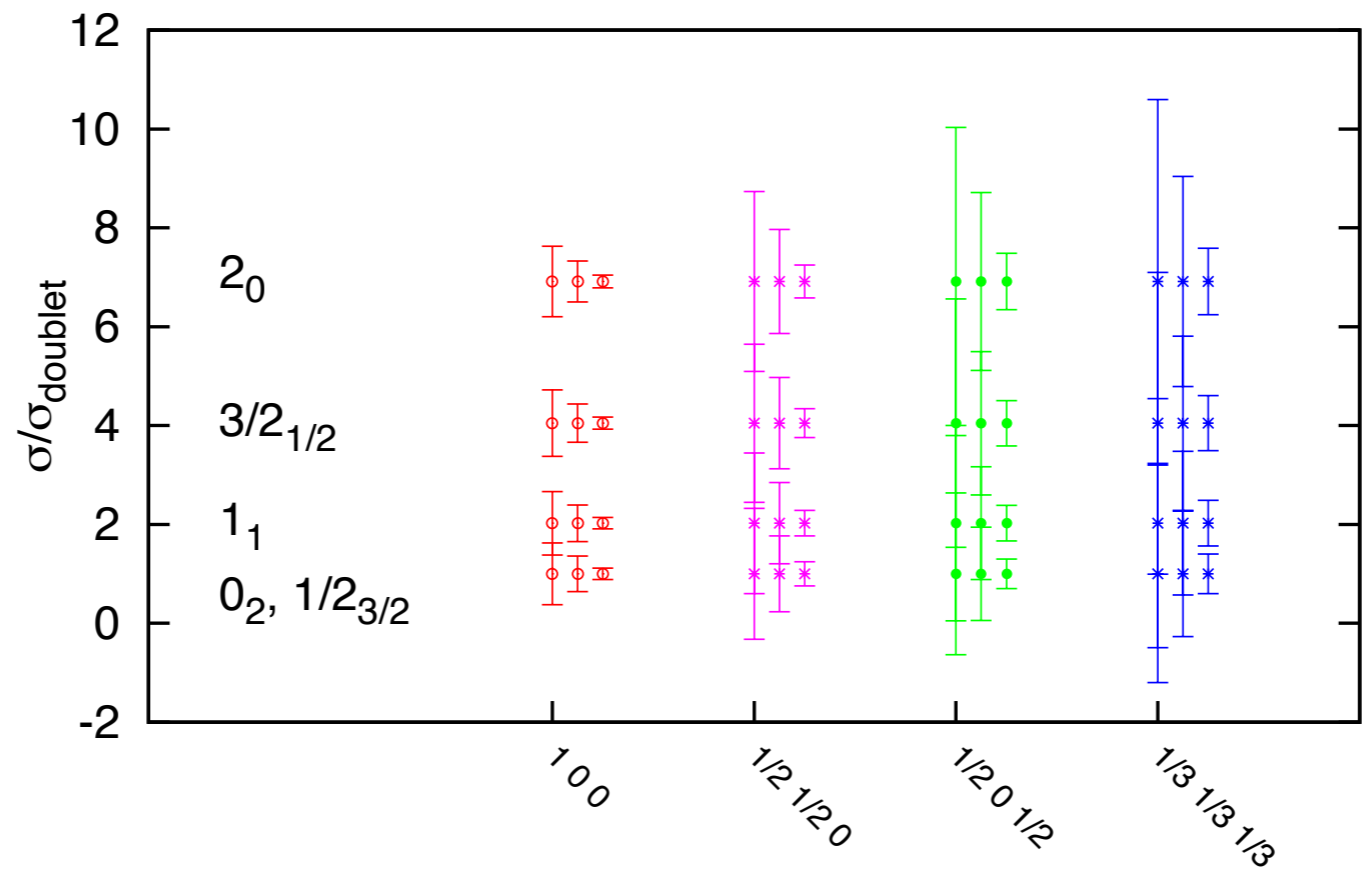
$$1 = \sum_{a=ll, l\tau, \tau\tau, WW} z_a, z_a \equiv Br(H \rightarrow a)$$



It is enough to group the sample with four charged leptons in **three sub-sets**:

$$(z_{ll}, z_{l\tau}, z_{\tau\tau} + z_{WW})$$





# Summary

arXiv:1305.3904 [hep-ph]

arXiv:1307.0510 [hep-ph]

arXiv:1309.xxxx [hep-ph]

- LNV processes are rare ( $m_\nu \sim 0$ ) and require a physical enhancement (cancelling contributions to  $m_\nu$  or rather slow decays) and an efficient reconstruction to be observable at the LHC.
- Present limits on doubly-charged scalar masses mediating the seesaw of type II (triplet) and decaying into leptons only **can be extended to more general multiplets and decays.**
- **If observed in the same-sign charged di-lepton channel, the type of multiplet can be determined using events with four and three isolated leptons, independently of the size of LNV.**

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attention



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