Distinguishing LNV scalars at the LHC

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Outline

- Introduction: What can we expect if we (do not) observe a same-sign di-lepton scalar resonance ? a see-saw type II mediator violating Lepton Number (LN), a Little Higgs or Extra Dimensional reminiscence, ... There are many phenomenological papers addressing what we can expect, but discussing in general two alternatives depending if the doubly-charged scalar has a large coupling to WW or not. We will assume that it is observable in the di-lepton channel and may violate LN, generalizing the models of see-saw of type II.

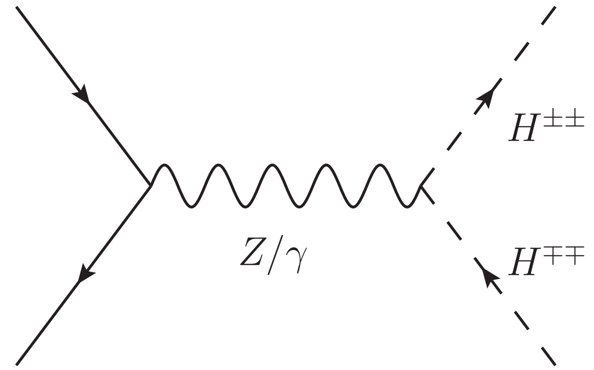
- Discrimination: Their production and decays are then fixed but one has to account for several final modes to characterized the new scalar multiplet.

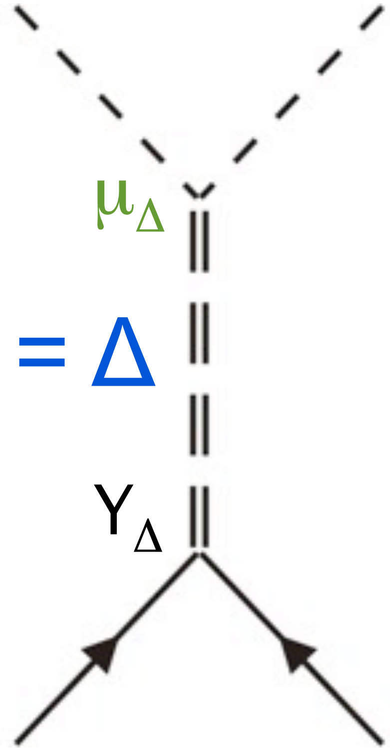
CMS and ATLAS have set stringent limits on doubly-charged scalars $H^{\pm\pm}$ decaying into two same-sign leptons ~ 400 GeV with only 5 fb^{-1} at 7 TeV

Which very much depend on the assumed di-leptonic branching ratios, in particular, into τs, and especially into gauge bosons. For instance, if the new scalar muliplet has a neutral component getting a v.e.v., through the gauge coupling

$g^2 \langle H^0 \rangle H^{++} W^- W^-$

Within this class of models the best studied case is the see-saw of type II with a heavy scalar triplet (Δ^{++} Δ^{+} Δ^{0}) giving Majorana masses to neutrinos





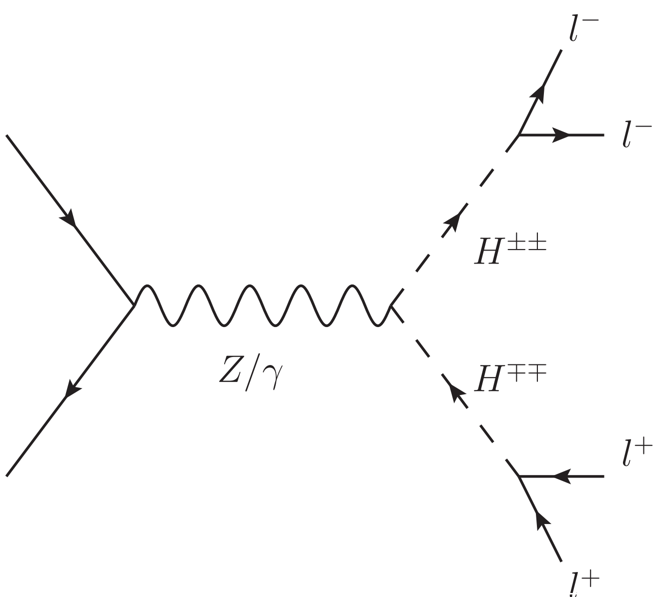
H = Δ

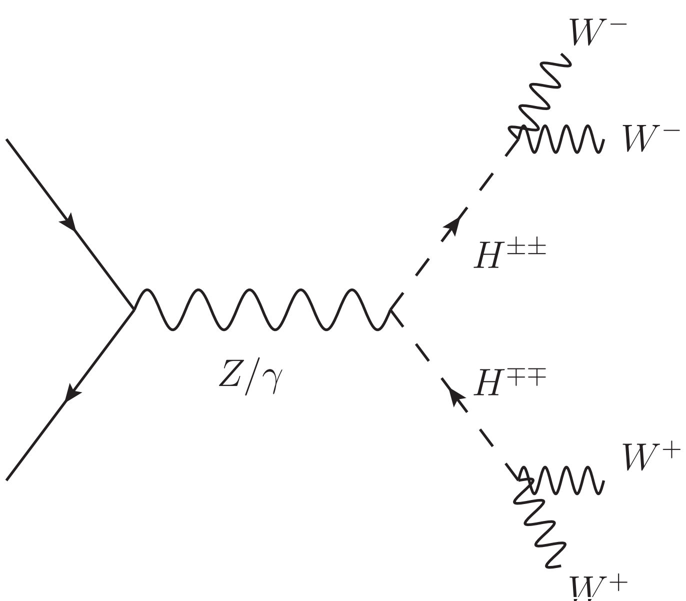
$$g^2 \boxed{< \Delta^0 >} W^{\mp\mu} W^{\mp}_{\mu} \Delta^{\pm\pm}$$

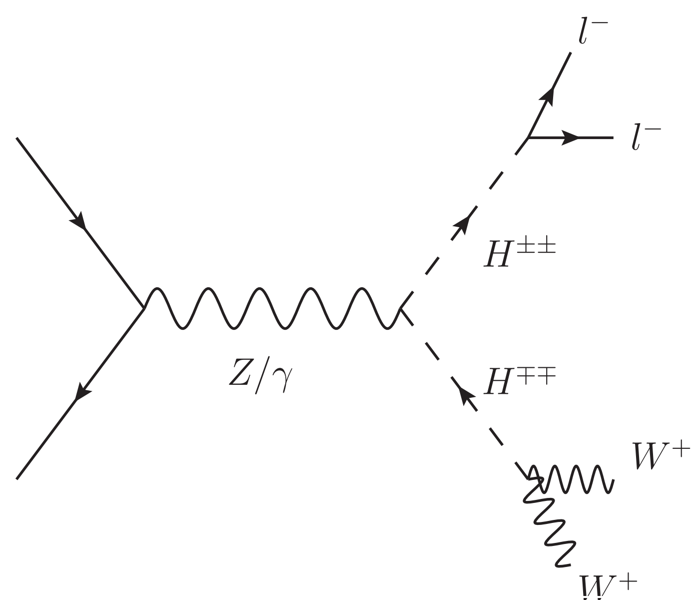
$$(\overline{\tilde{L}_L} \tau^a L_L)\Delta^{-a}$$

$-2Y_\Delta \mu_\Delta v^2 M_\Delta^{-2} \sim$ meV with $\boxed{\sqrt{2} <\Delta^0> = \mu_\Delta v^2 M_\Delta^{-2}}$

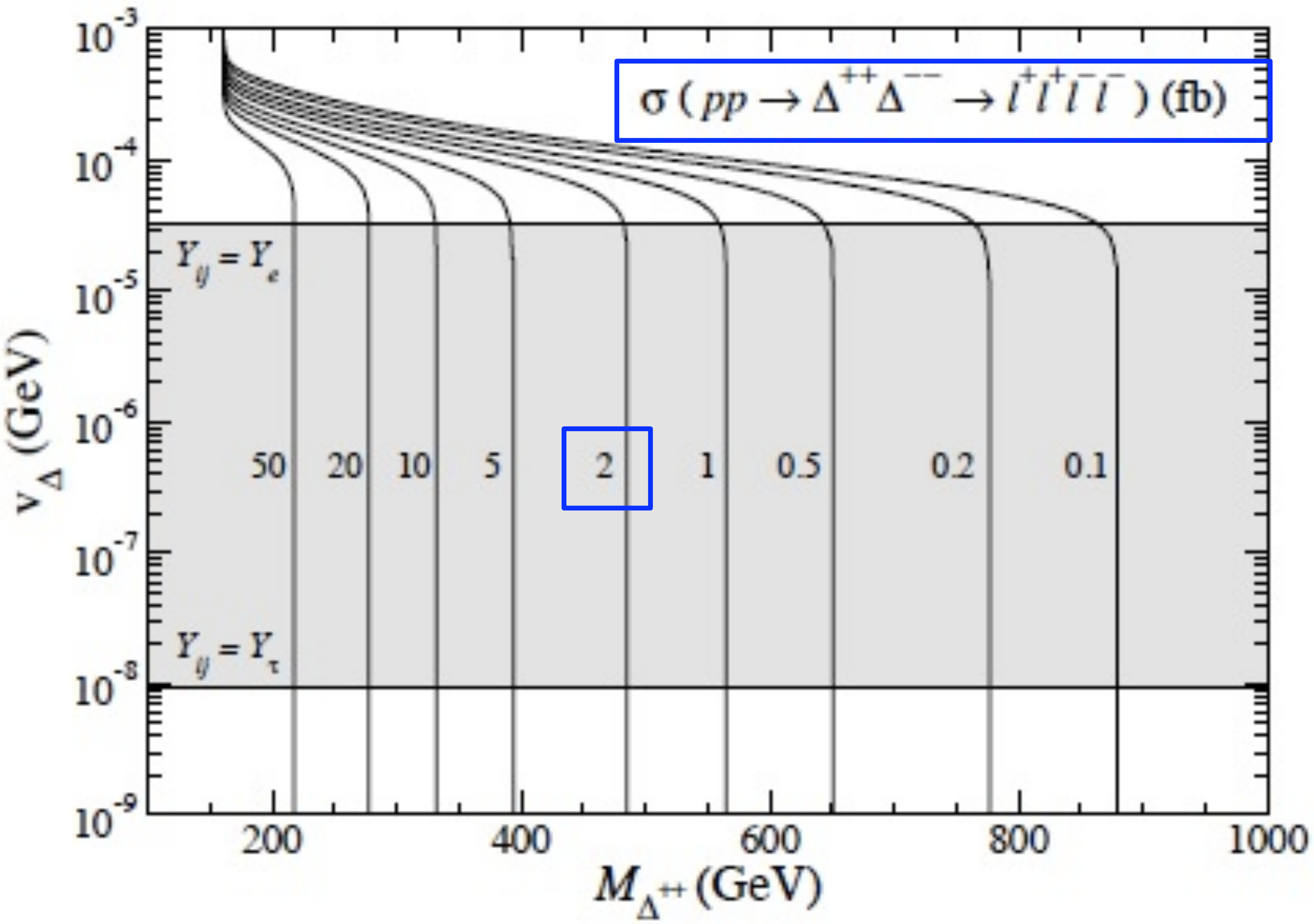
if $M_\Delta \sim$ TeV: $Y_\Delta \mu_\Delta \sim 10^{-11}$ GeV







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



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

Lepton Number Violating

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

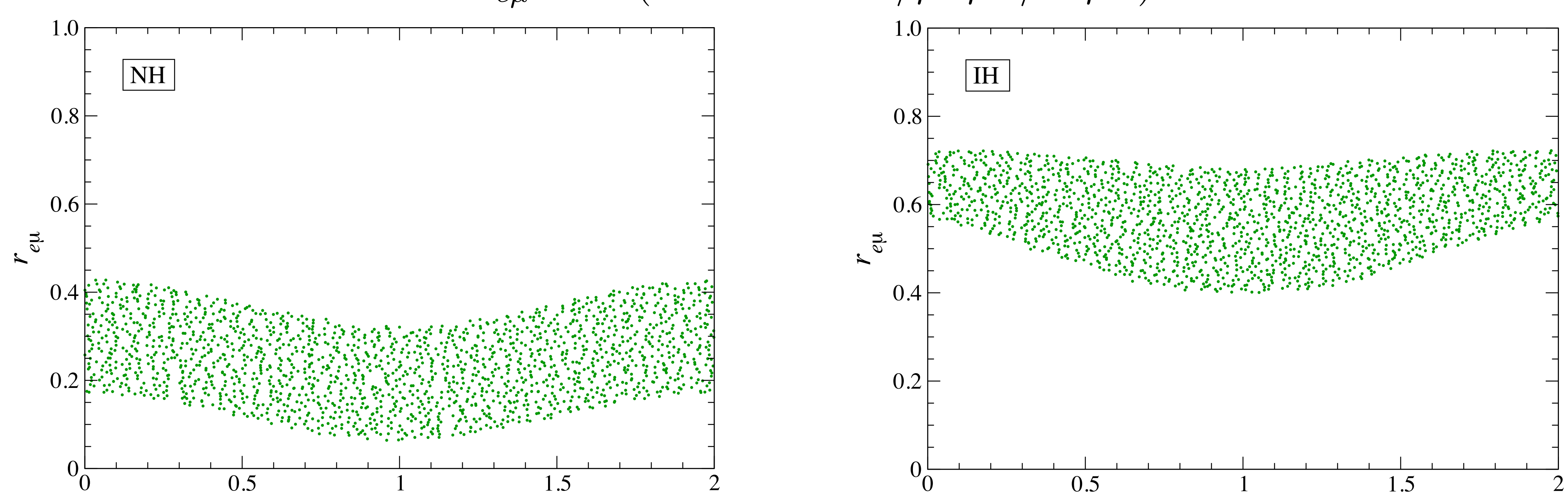
$\to l^+ l^+ W^- W^-$

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

Δ 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 α_2 (in the plots $\beta_2-\beta_3$ and β_2, respectively).

$$r_{e\mu} \equiv \mathrm{Br}(\Delta^{\pm\pm} \to e^\pm e^\pm/\mu^\pm\mu^\pm/e^\pm\mu^\pm)$$



Dimension 4	$\begin{pmatrix} \Delta^{++} \\ \Delta^{+} \\ \Delta^{0} \end{pmatrix}$	$(\overline{\tilde{L}_L}\tau^a L_L)\Delta^{-a}$
	κ^{++}	$\overline{l^c_R} l_R \kappa$
Dimension 5	$\begin{pmatrix} \Sigma^{++} \\ \Sigma^{+} \\ \Sigma^{0} \\ \Sigma'^{-} \end{pmatrix}$	$(-1)^{\frac{1}{2}-b} C^{1\times\frac{1}{2}\to\frac{3}{2}}_{a,b}(\overline{\tilde{L}_L}\tau^a L_L)\phi^b \Sigma^{-a-b}$
	$\begin{pmatrix} \chi^{++} \\ \chi^{+} \end{pmatrix}$	$(-1)^{1-a}(\overline{\tilde{L}_L}\tau^a L_L)(\phi^\dagger \tau^{-a}\chi)$, $\overline{l^c_R} l_R(\tilde{\phi}^\dagger\chi)$
Dimension 6	$\begin{pmatrix} \Omega^{++} \\ \Omega^{+} \\ \Omega^{0} \\ \Omega^{-} \\ \Omega^{--} \end{pmatrix}$	$C^{1\times1\to2}_{a,b}(\overline{\tilde{L}_L}\tau^a L_L)(\tilde{\phi}^\dagger\tau^b\phi)\Omega^{-a-b}$

Dimension 4	$\begin{pmatrix} \Delta^{++} \\ \Delta^{+} \\ \Delta^{0} \end{pmatrix}$	$(\overline{\tilde{L}_L}\tau^a L_L)\Delta^{-a}$
	κ^{++}	$\overline{l^c_R} l_R \kappa$
Dimension 5	$\begin{pmatrix} \Sigma^{++} \\ \Sigma^{+} \\ \Sigma^{0} \\ \Sigma'^{-} \end{pmatrix}$	$(-1)^{\frac{1}{2}-b} C_{a,b}^{1\times\frac{1}{2}\to\frac{3}{2}}(\overline{\tilde{L}_L}\tau^a L_L)\phi^b\Sigma^{-a-b}$
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	$\boxed{\kappa^{++}}$	$\overline{l_R^c} l_R \kappa$
Dimension 5	$\begin{pmatrix} \Sigma^{++} \\ \Sigma^{+} \\ \Sigma^{0} \\ \Sigma'^{-} \end{pmatrix}$	$(-1)^{\frac{1}{2}-b} C_{a,b}^{1\times\frac{1}{2}\to\frac{3}{2}} (\overline{\tilde{L}_L}\tau^a L_L)\phi^b \Sigma^{-a-b}$
	$\boxed{\begin{pmatrix} \chi^{++} \\ \chi^{+} \end{pmatrix}}$	$(-1)^{1-a}(\overline{\tilde{L}_L}\tau^a L_L)(\phi^\dagger \tau^{-a}\chi)$, $\overline{l_R^c} l_R (\tilde{\phi}^\dagger \chi)$
Dimension 6	$\begin{pmatrix} \Omega^{++} \\ \Omega^{+} \\ \Omega^{0} \\ \Omega^{-} \\ \Omega^{--} \end{pmatrix}$	$C_{a,b}^{1\times 1\to 2}(\overline{\tilde{L}_L}\tau^a L_L)(\tilde{\phi}^\dagger \tau^b \phi)\Omega^{-a-b}$

$$\Rightarrow \quad \overline{e_L^c} e_L H^{++}$$

Dimension 4	$\begin{pmatrix} \Delta^{++} \\ \Delta^{+} \\ \Delta^{0} \end{pmatrix}$	$(\overline{\tilde{L}_L}\tau^a L_L)\Delta^{-a}$
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$$\overline{e^c_L} e_L \mathrm{H}^{++}$$

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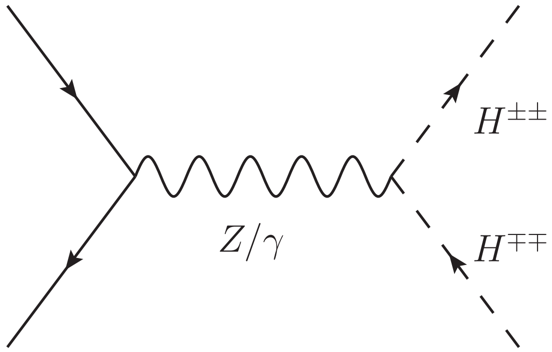
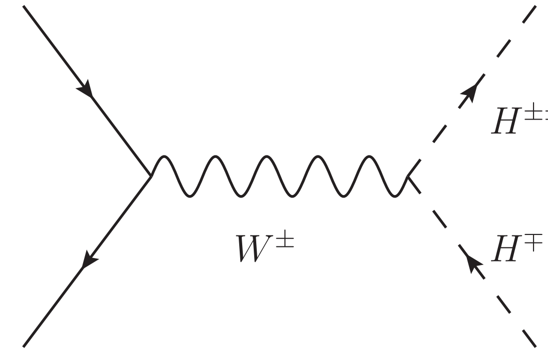
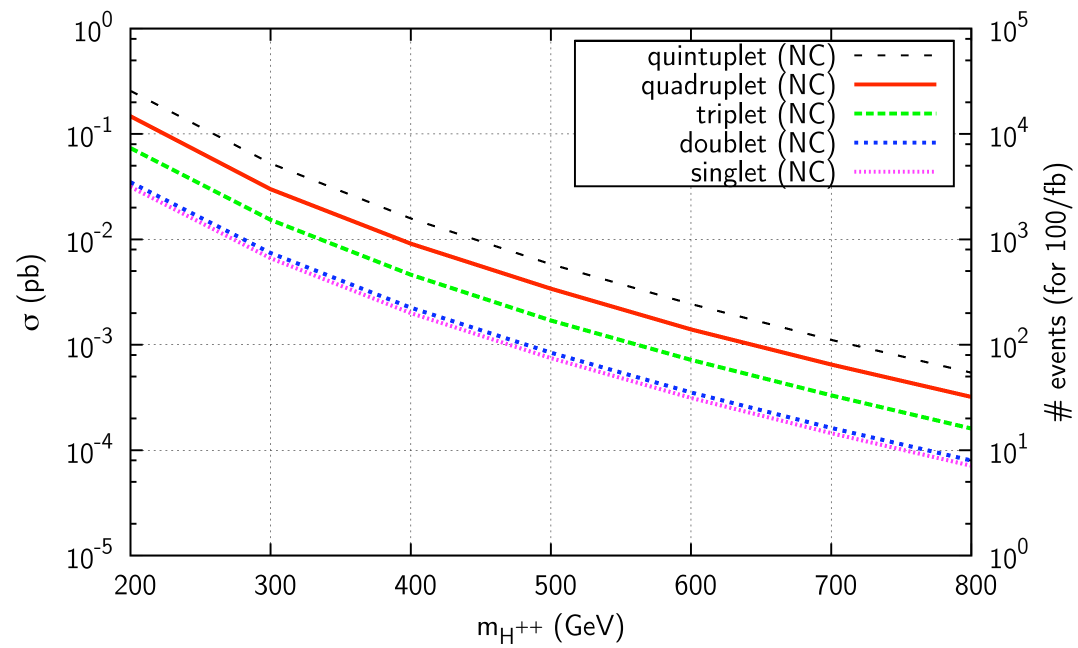
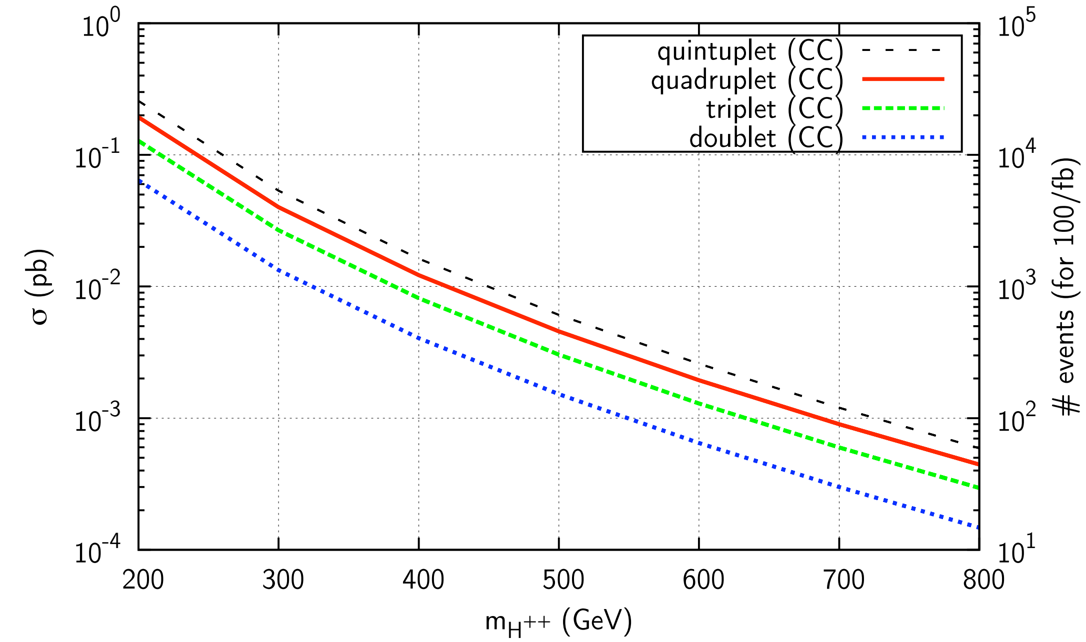
$$\Rightarrow \overline{e^c_L} e_L \mathrm{H}^{++}$$

$$\Rightarrow \overline{e^c_R} e_R \mathrm{H}^{++}$$





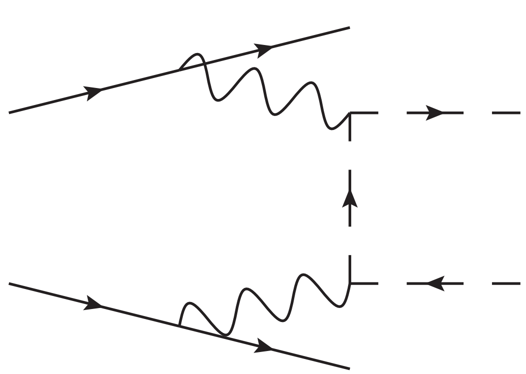


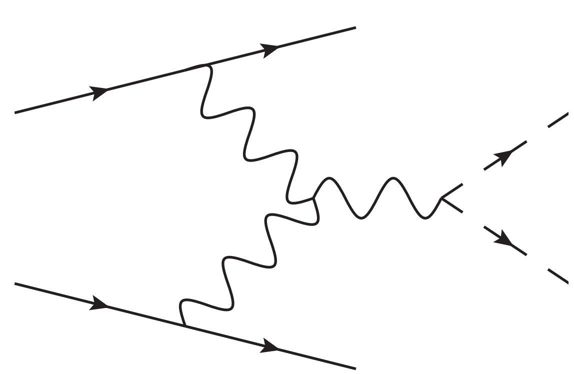


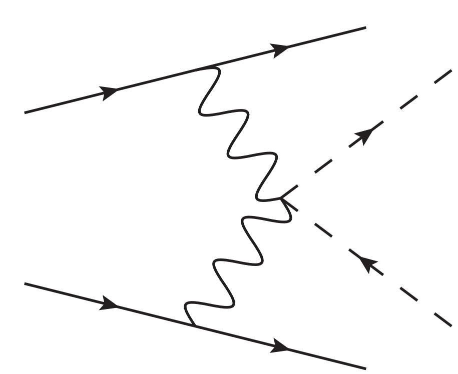
$$\mathcal{L}_\gamma^{\mathrm{H}^{\pm\pm}} = ieQ(\partial^\mu \mathrm{H}^{--})\mathrm{H}^{++}A_\mu + \mathrm{h.c.}\,,$$

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

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







		$(1, 0, 0)$	$(\frac{1}{2}, \frac{1}{2}, 0)$	$(\frac{1}{2}, 0, \frac{1}{2})$	$(\frac{1}{3}, \frac{1}{3}, \frac{1}{3})$
Quintuplet	$(l^{\pm}l^{\pm})l^{\mp}l^{\mp}p_T^{miss}$	1307 ± 38	501 ± 25	362 ± 22	238 ± 19
	$(l^{\pm}l^{\pm})(l^{\mp}l^{\mp})$	1046 ± 32	261 ± 16	261 ± 16	116 ± 11
Quadruplet	$(l^{\pm}l^{\pm})l^{\mp}l^{\mp}p_T^{miss}$	765 ± 30	293 ± 20	212 ± 18	139 ± 16
	$(l^{\pm}l^{\pm})(l^{\mp}l^{\mp})$	612 ± 24	153 ± 12	153 ± 12	68 ± 8
Triplet	$(l^{\pm}l^{\pm})l^{\mp}l^{\mp}p_T^{miss}$	383 ± 22	147 ± 16	106 ± 15	70 ± 13
	$(l^{\pm}l^{\pm})(l^{\mp}l^{\mp})$	306 ± 18	77 ± 9	77 ± 9	34 ± 6
Doublet	$(l^{\pm}l^{\pm})l^{\mp}l^{\mp}p_T^{miss}$	189 ± 17	73 ± 14	53 ± 13	35 ± 12
	$(l^{\pm}l^{\pm})(l^{\mp}l^{\mp})$	151 ± 12	38 ± 6	38 ± 6	17 ± 4
Singlet	$(l^{\pm}l^{\pm})l^{\mp}l^{\mp}p_T^{miss}$	168 ± 17	64 ± 13	47 ± 13	31 ± 12
	$(l^{\pm}l^{\pm})(l^{\mp}l^{\mp})$	135 ± 12	34 ± 6	34 ± 6	15 ± 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 ± 34	283 ± 21	261 ± 20	130 ± 17
Quadruplet	592 ± 27	166 ± 18	153 ± 17	76 ± 15
Triplet	296 ± 21	83 ± 15	77 ± 15	38 ± 14
Doublet	146 ± 17	41 ± 13	38 ± 14	19 ± 13
Singlet	0 ± 12	0 ± 12	0 ± 12	0 ± 12

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

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

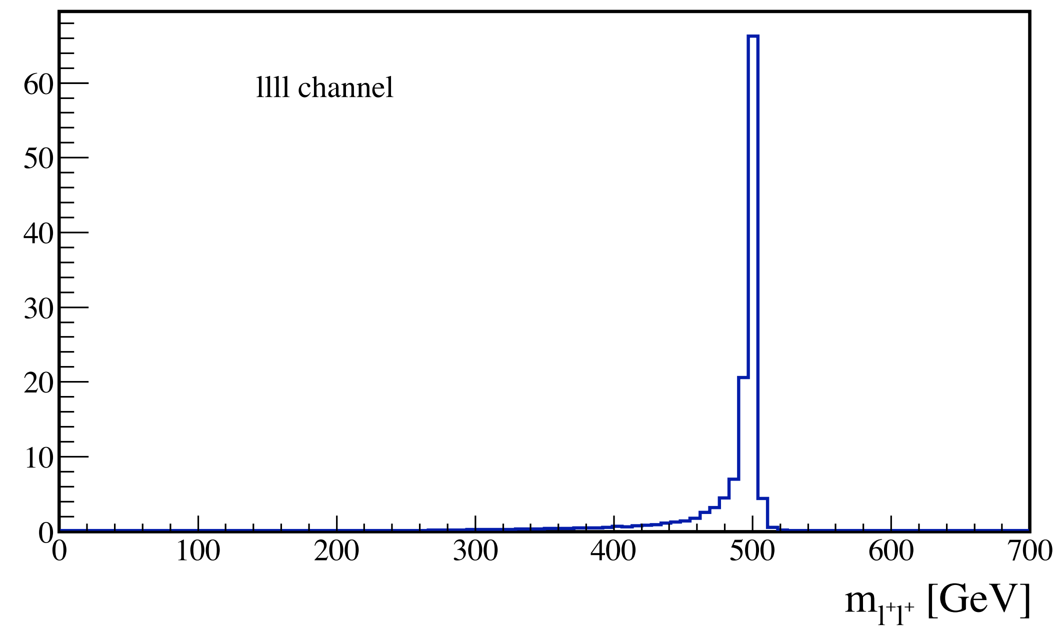
How well can we measured the total cross-section ?

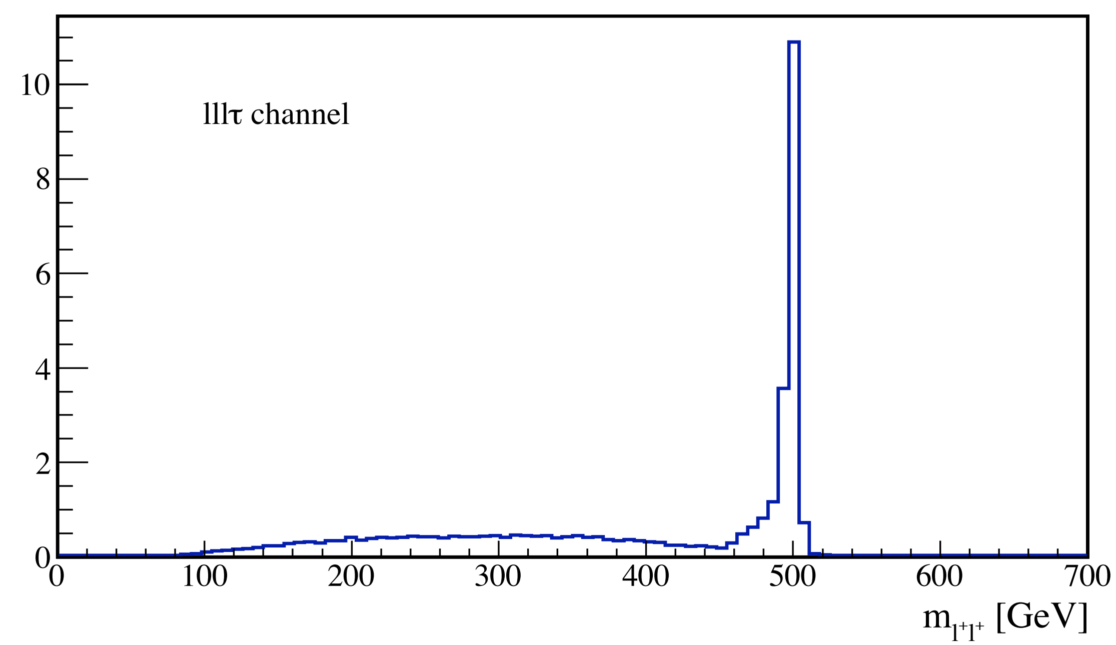
$$\boxed{\sigma = \left(\sigma_{llll} + \frac{1}{2}\sum_{a\neq ll}\sigma_{lla}\right)^2 / \sigma_{llll}}$$

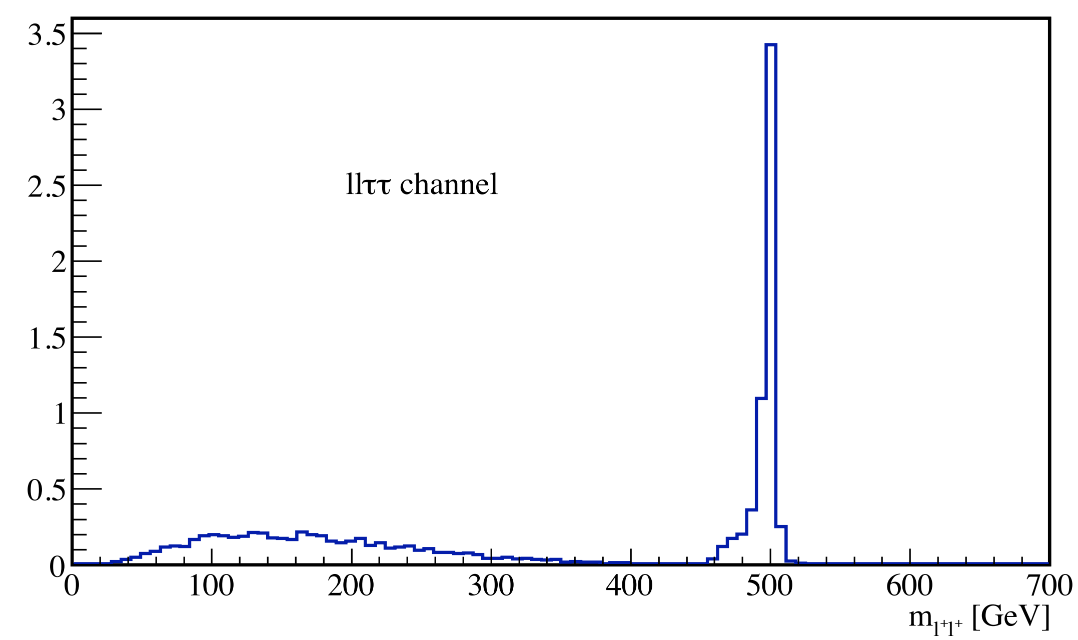
$$1 = \sum_{a=ll,l\tau,\tau\tau,WW} z_a, z_a \equiv Br(H \to a)$$

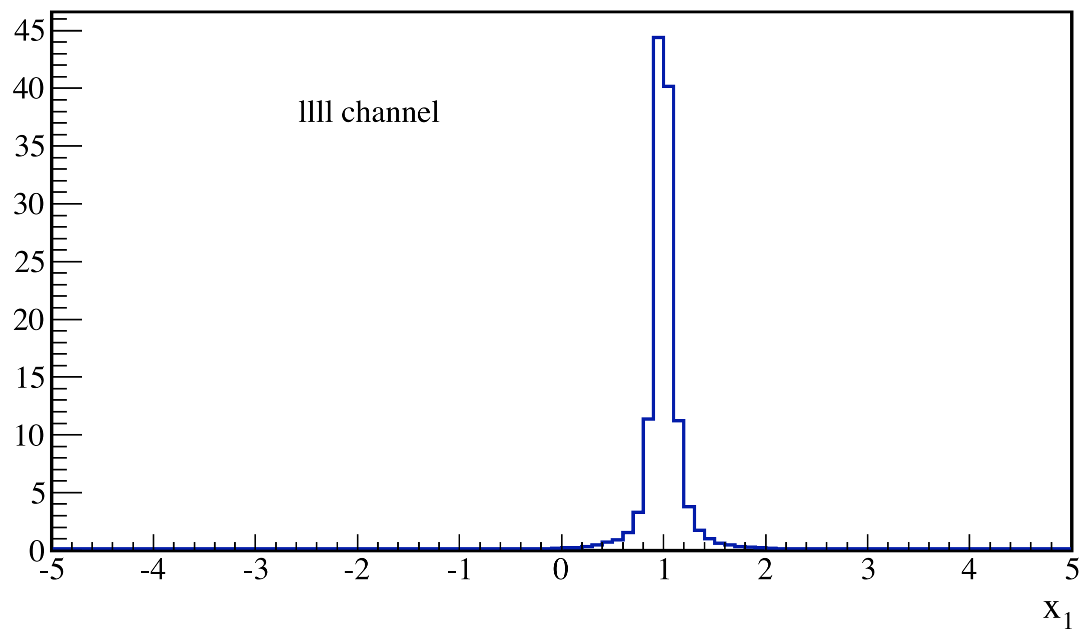
It is enough to group the sample with four charged leptons in three sub-sets:

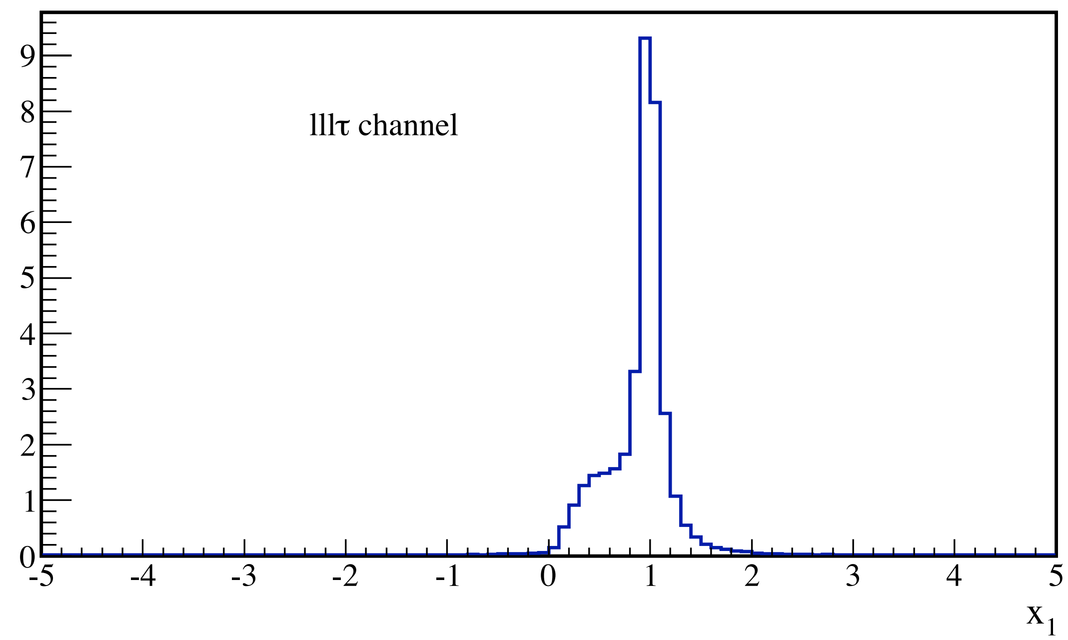
$$\left(z_{ll},\, z_{l\tau},\, z_{\tau\tau} + z_{WW}\right)$$

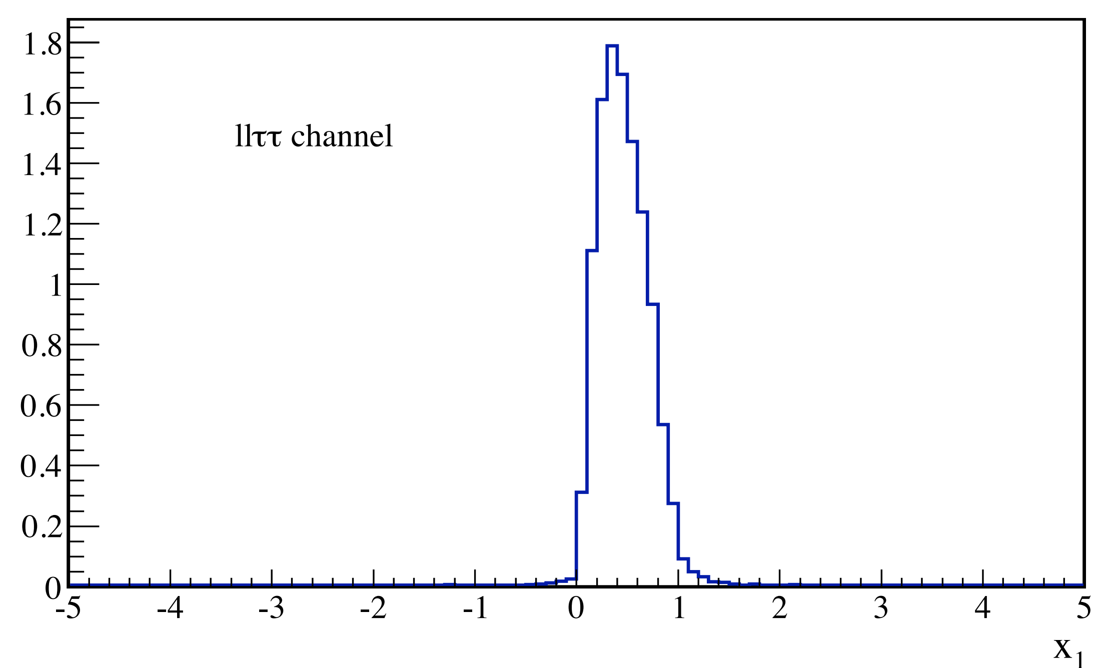


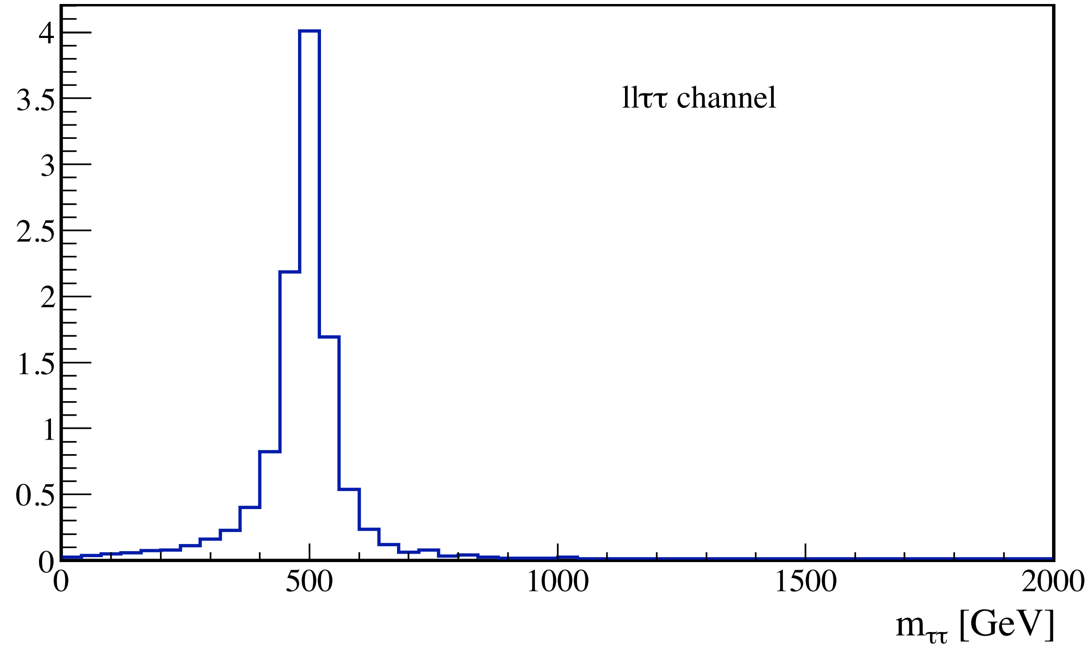


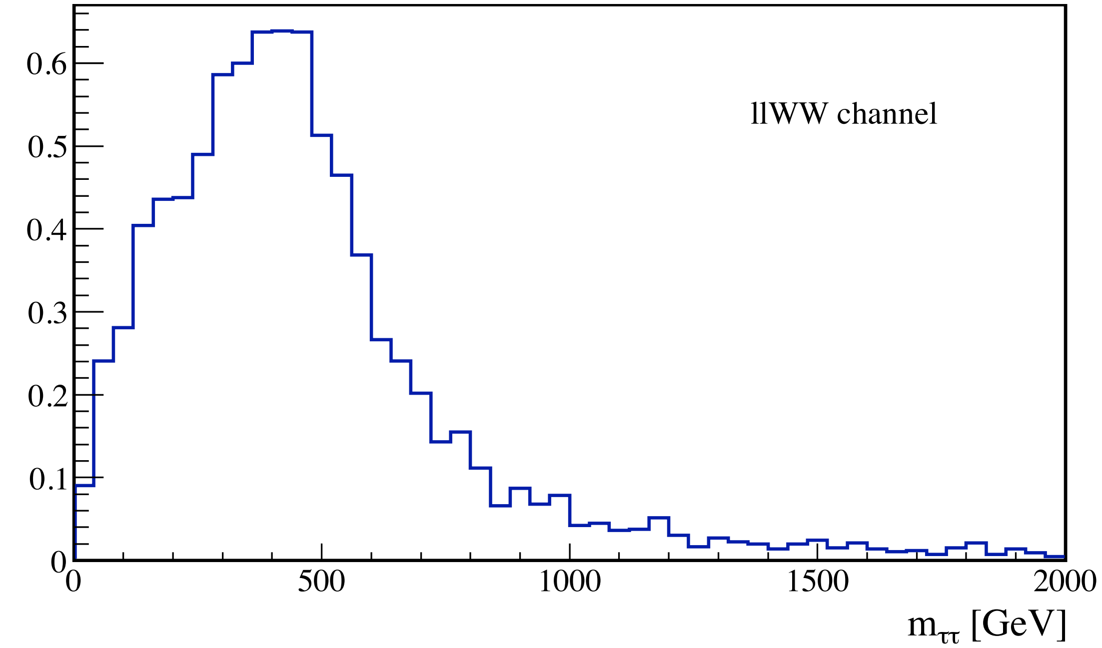


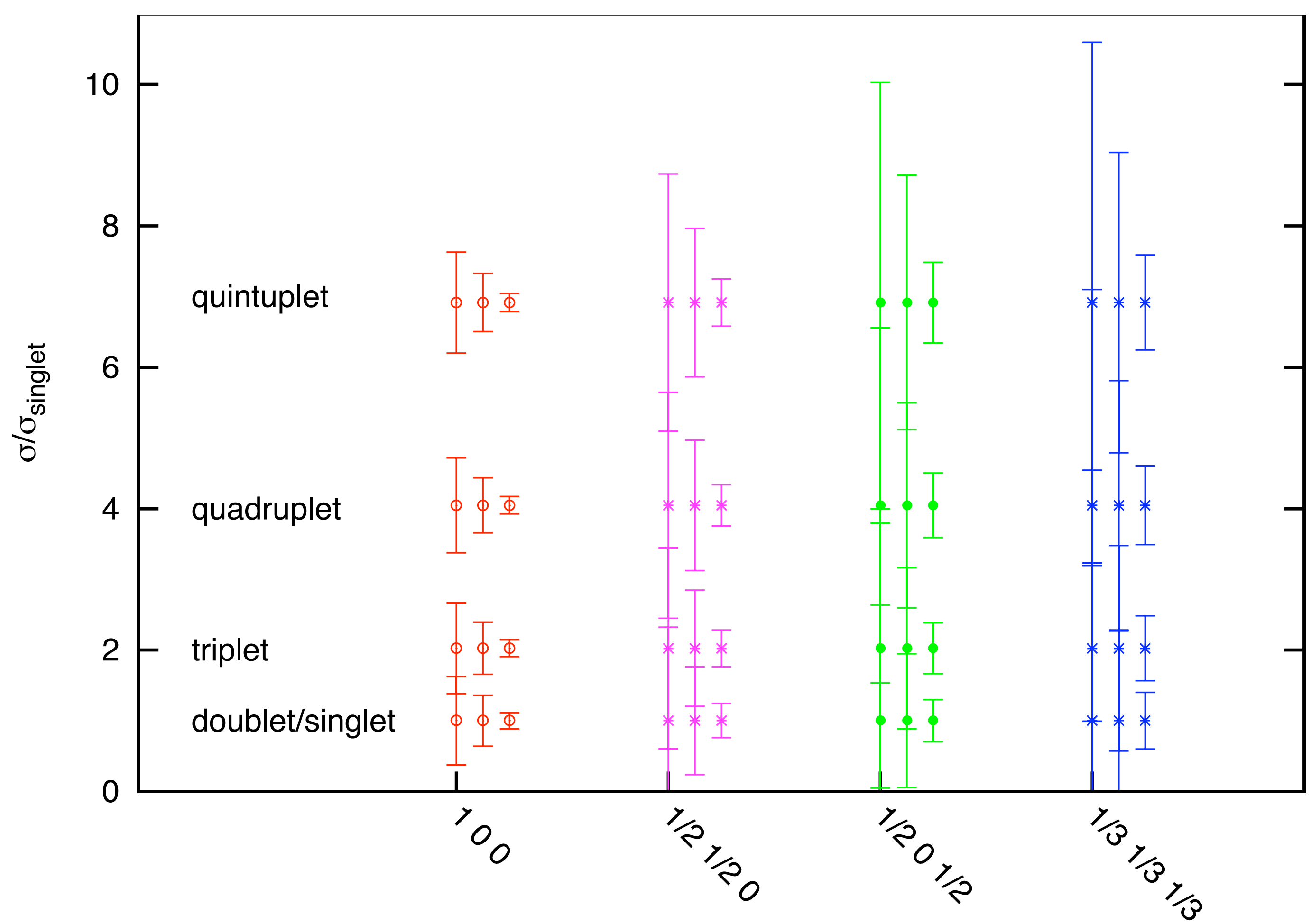

llll channel
x_1


lllτ channel
x_1


llττ channel
x_1


llττ channel
0
0.5
1
1.5
2
2.5
3
3.5
4
0
500
1000
1500
2000
mττ [GeV]


llWW channel
0
0.1
0.2
0.3
0.4
0.5
0.6
0
500
1000
1500
2000
mττ [GeV]


σ/σsinglet
0
2
4
6
8
10
quintuplet
quadruplet
triplet
doublet/singlet
1 0 0
1/2 1/2 0
1/2 0 1/2
1/3 1/3 1/3

Summary

- Doubly-charged resonances in di-leptonic channels have in general sizeable couplings to all leptons flavours, in particular to t leptons, and maybe to gauge bosons W.

- If they are observed, the events with four final leptons alone allow for discriminating among the possible new scalar multiplet additions.

Thanks for your attention

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