Carla Biggio
IFAE/UAB

TeV -neutrino implications at the LHC

from Genova,
like me ;)

After one year of LHC data,
the only evidence for physics beyond the SM
comes from neutrinos…
(apart from DM)

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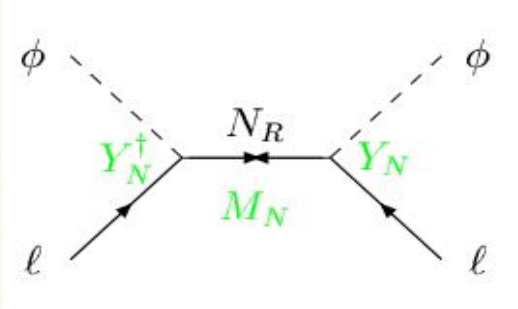
SEESAW MECHANISM: NEW PHYSICS AT HIGH SCALE CAN EXPLAIN THE SMALLNESS OF m_ν

Several possibilities for the seesaw

- **Type I:** 

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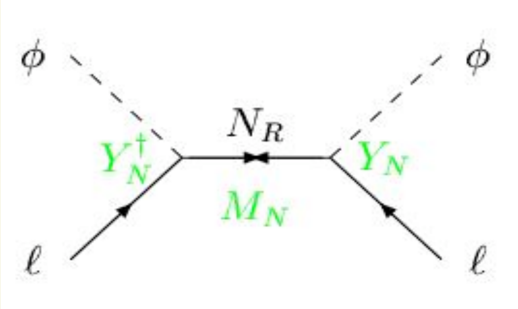
- **Type I:** 

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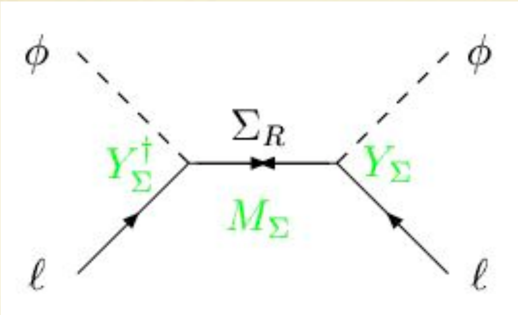
- **Type III:** 

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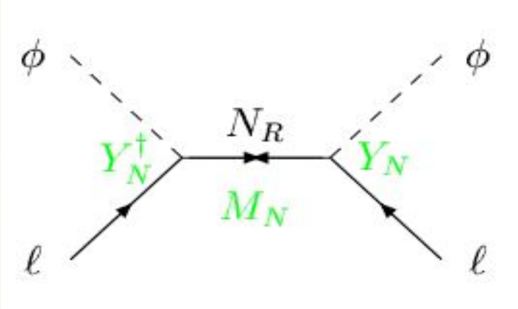
- **Type I:** 

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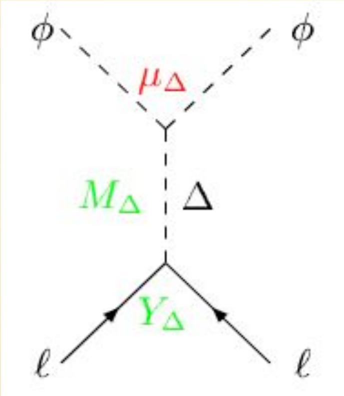
- **Type II:** 

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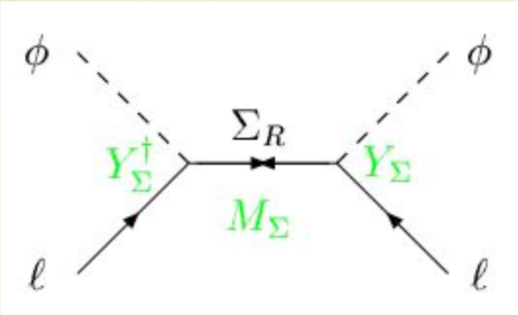
- **Type III:** 

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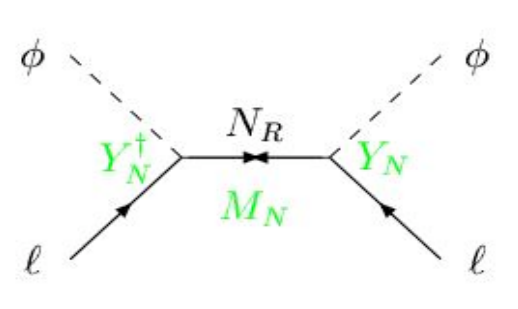
- **Type I:** 

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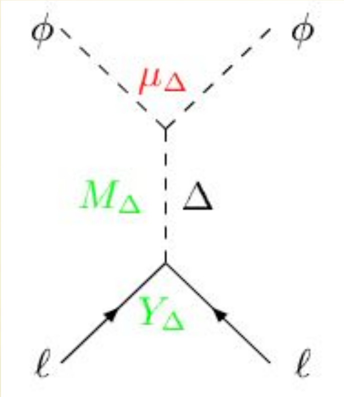
- **Type II:** 

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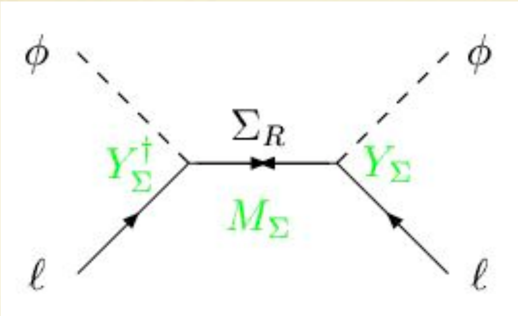
- **Type III:** 

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Alternatives: radiative seesaws, higher dimensional operators, extra dimensions, susy with R-parity violation…

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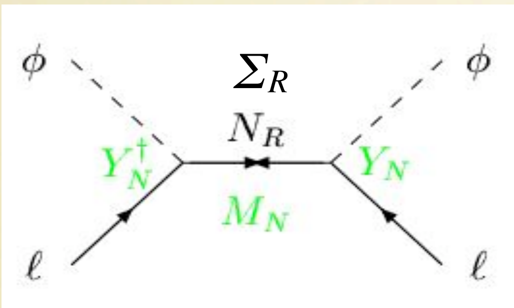

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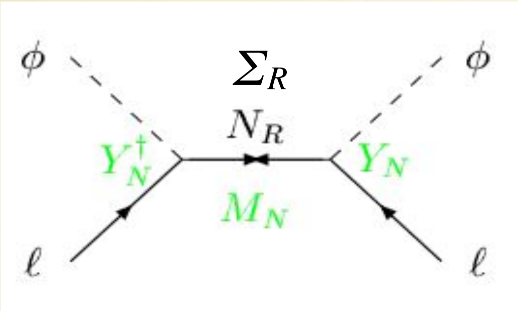

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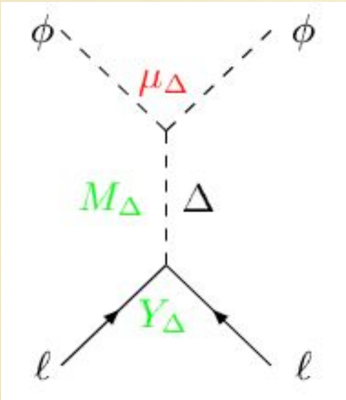

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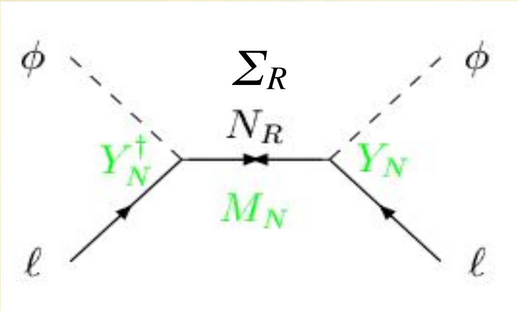

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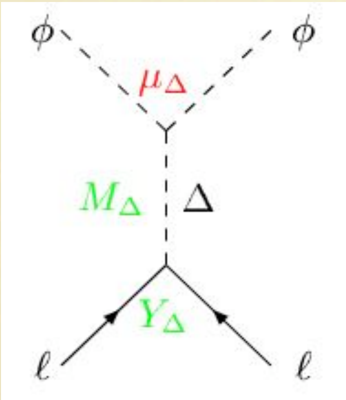

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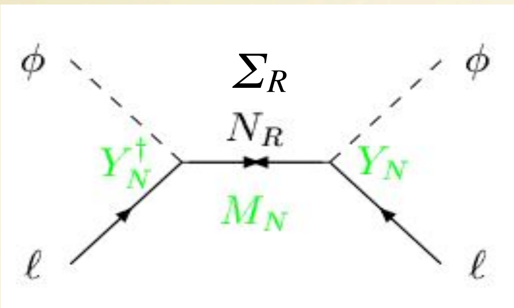

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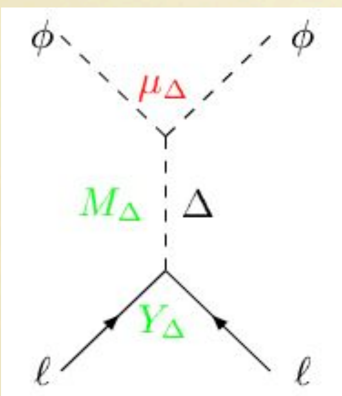

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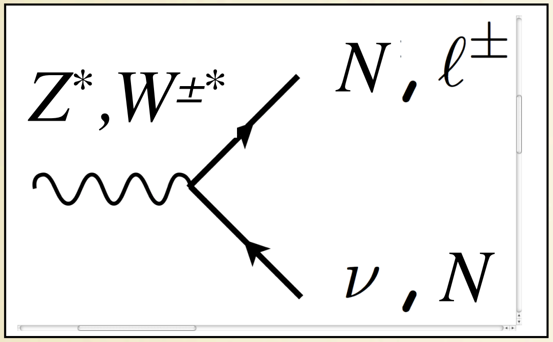
- Low scale seesaw with large Yukawas possible for small μ (type II) or inverse seesaw (both type I and III) -

Production at the LHC

I



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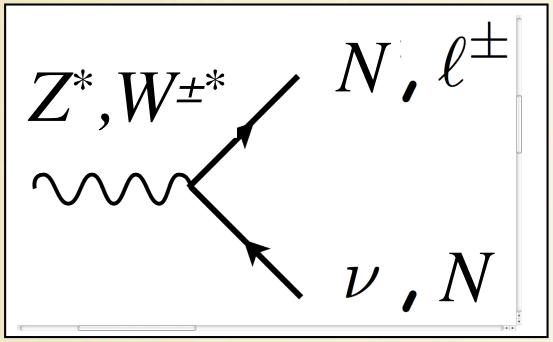

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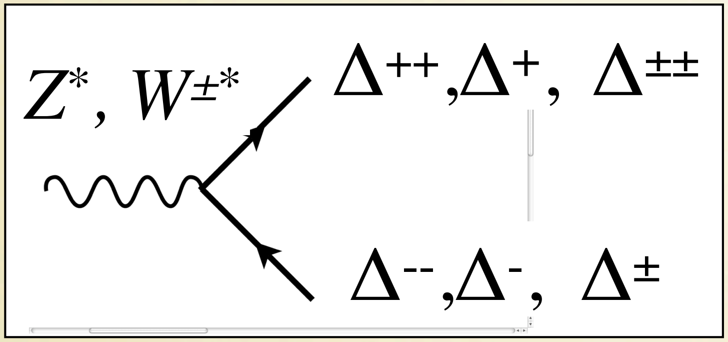

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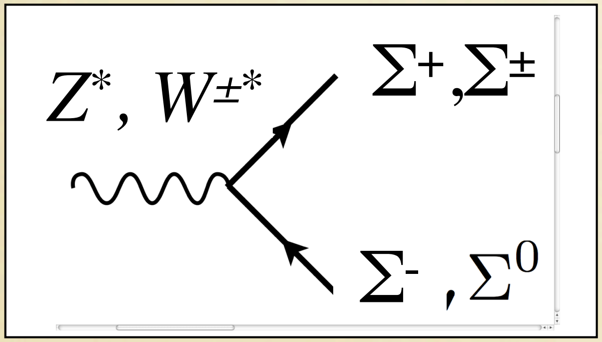

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Gauge production:

σ *not suppressed by small Yukawas*

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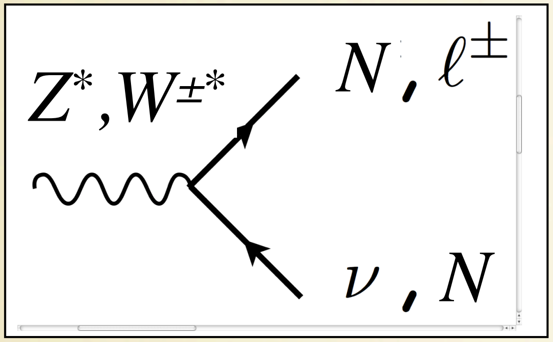

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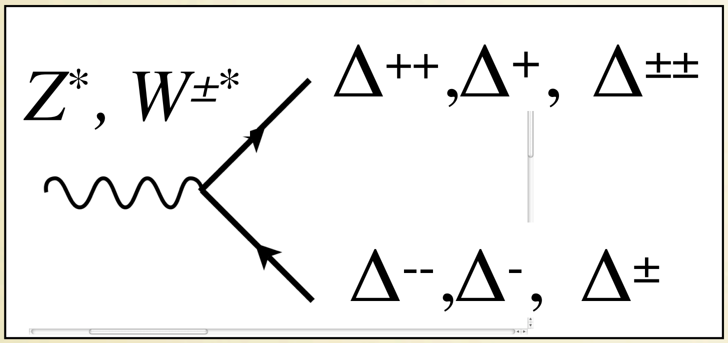

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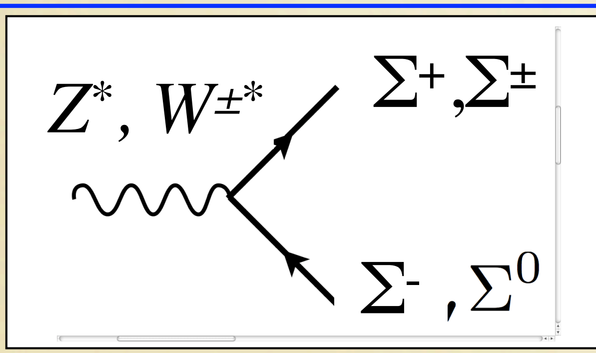

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The type III seesaw

$$\mathcal{L} = Tr[\overline{\Sigma} i \not{D} \Sigma] - \frac{1}{2} Tr[\overline{\Sigma} M_\Sigma \Sigma^c + \overline{\Sigma^c} M_\Sigma^* \Sigma] - \tilde{\phi}^\dagger \overline{\Sigma} \sqrt{2} Y_\Sigma L - \overline{L} \sqrt{2} {Y_\Sigma}^\dagger \Sigma \tilde{\phi}$$

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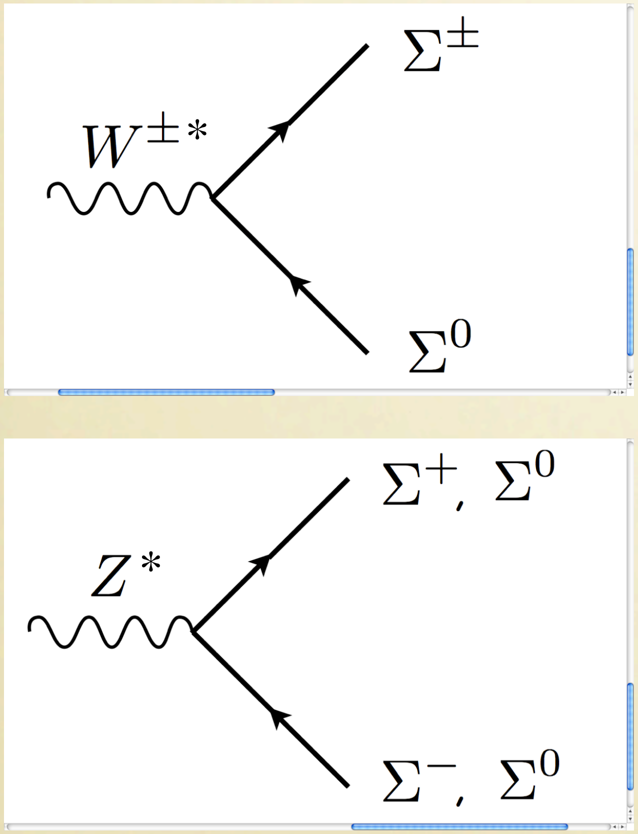
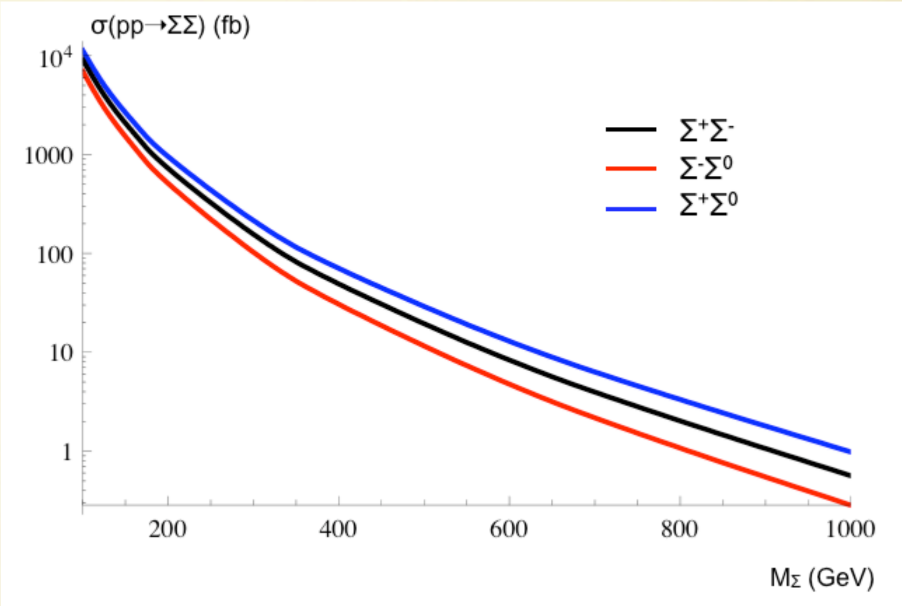
direct gauge coupling



they determine the production at colliders



LHC 14TeV

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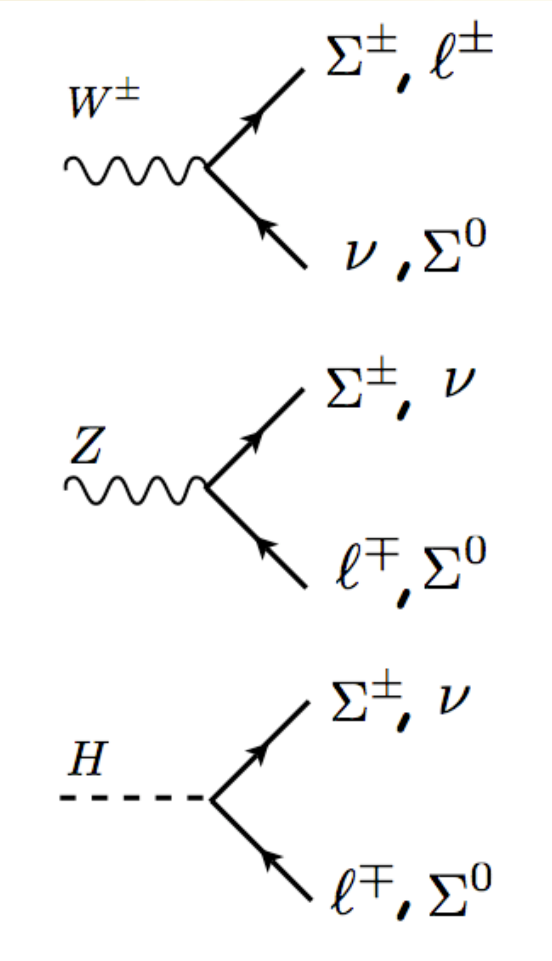
source of mixing with light leptons



they determine the triplet decays

$$\propto V_{\Sigma \alpha\beta} = \left(\frac{Y_\Sigma v}{\sqrt{2} M_\Sigma} \right)_{\alpha\beta}$$

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Abada, CB, Bonnet, Gavela, Hambye 07
Del Aguila, De Blas, Perez-Victoria 08
CB, Bonnet 11

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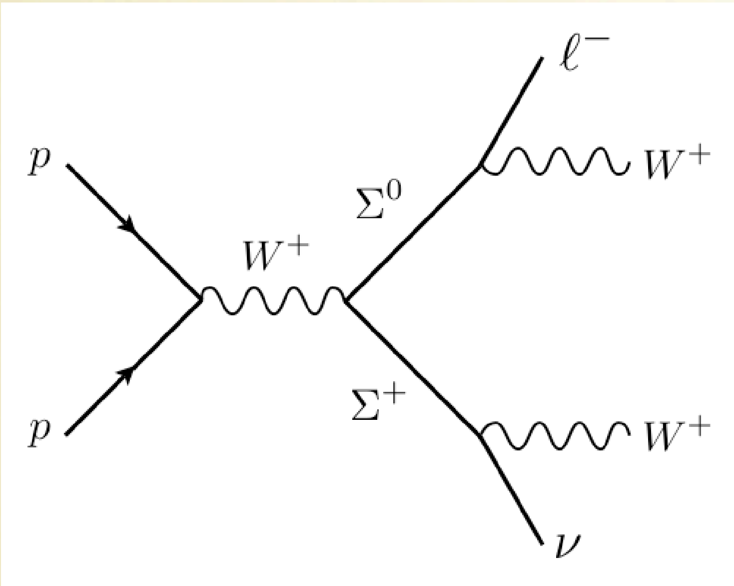
Stringent bounds are not so important...

The type III seesaw at the LHC



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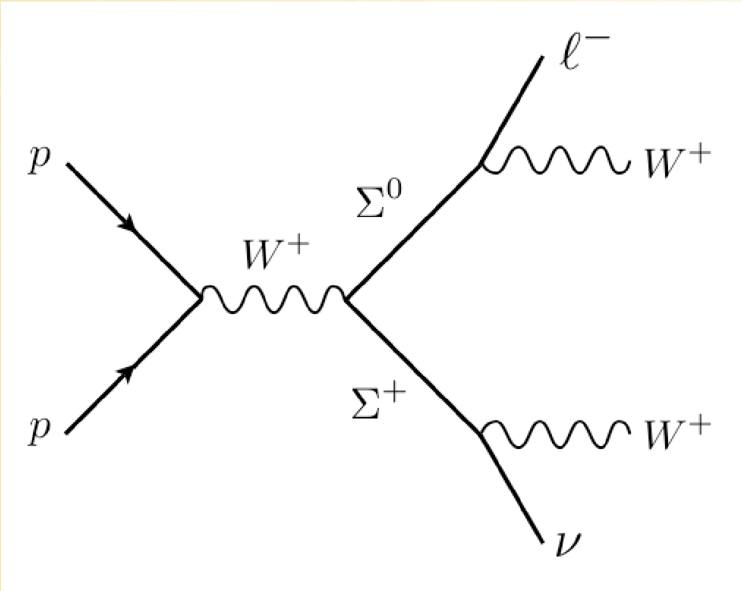

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narrow width approx valid

$$\sigma = \sigma^{prod} \times Br$$

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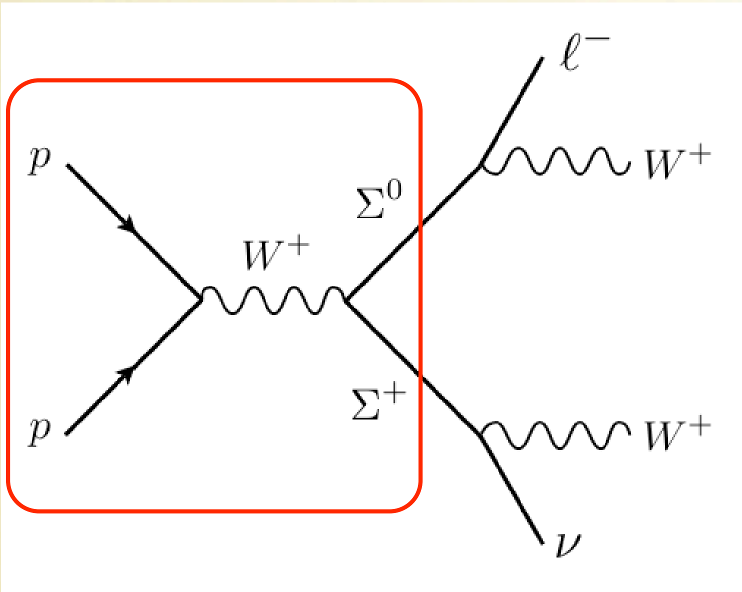

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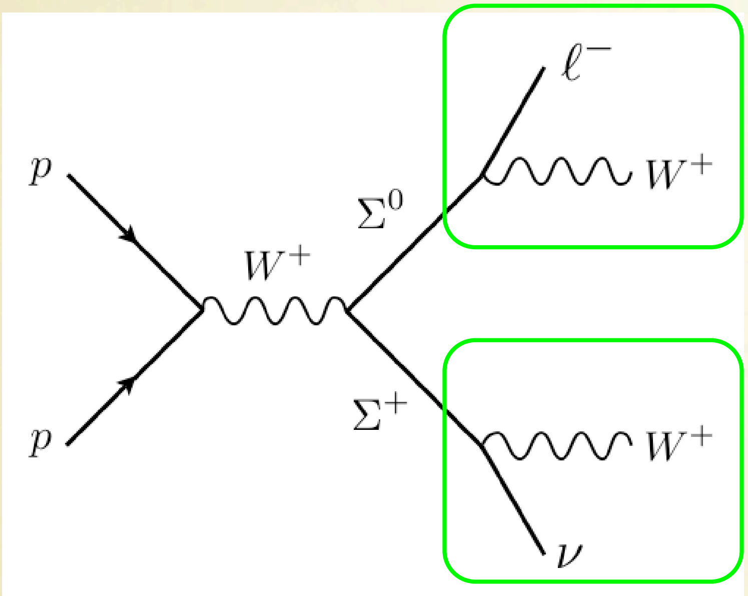

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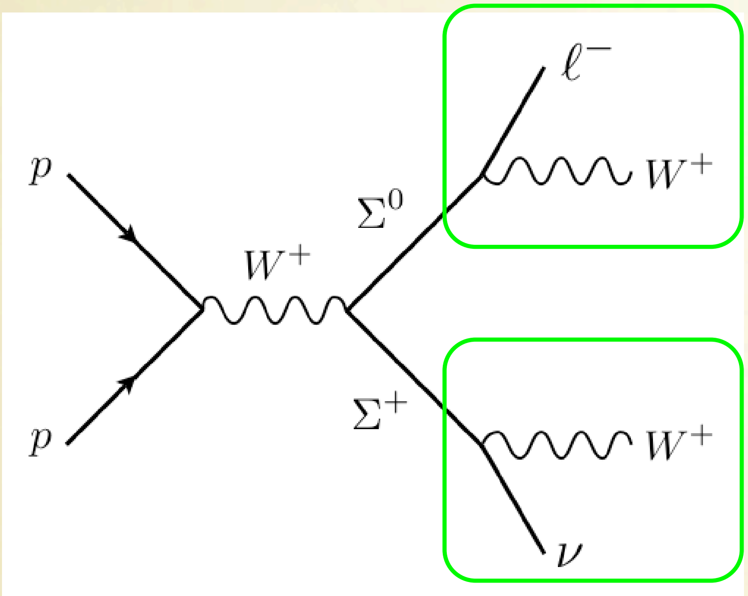

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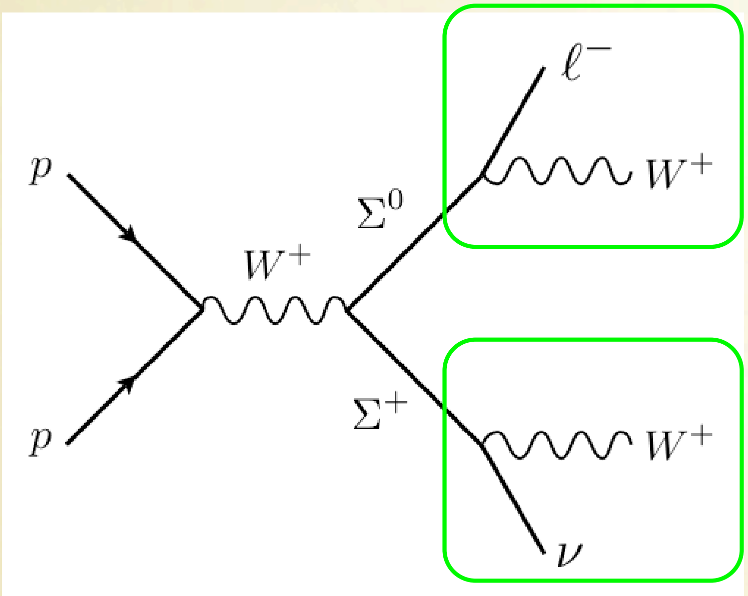

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$\to$ the smallness of V_α affects τ_Σ $\to$ *displaced vertexes?*

Franceschini
Hambye
Strumia 08

but it does not drastically affect the final cross section

The type III seesaw at the LHC

Del Aguila, Aguilar-Saavedra 08

(LHC 14TeV)

- 6 leptons
- 5 leptons
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(eventually + jets)

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} Only in type III; low background but low σ

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Best discovery potential

- $\ell^\pm \ell^\mp$
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(eventually + jets)

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Del Aguila, Aguilar-Saavedra 08

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← *Best discovery potential*

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(eventually + jets)

} High σ but high background; difficult

Which is the situation with the LHC at 7TeV?

The type III seesaw in feynrules/madgraph

CB, Bonnet 11

- We have implemented the simplified model (only 1 triplet) in FeynRules
- It generates the output for MadGraph (and CalcHep)
- Events can be generated!

http://feynrules.irmp.ucl.ac.be/

→ Model database → Simple extensions of the SM

Simple extensions of the SM

This is a collection of models that are simple bottom-up extensions of the SM, obtained by adding a set of new particles and or interations to the Standard Model.

Available models

Model	Short Description	Contact
Higgs effective theory	An add-on for the SM implementation containing the dimension 5 gluon fusion operator.	C. Duhr
4th generation model	A fourth generation model including a t' and a b'	C. Duhr
Standard model + Scalars	The SM, together with a set of singlet scalar particles coupling only to the SM Higgs, and allowing it to decay invisibly into this new scalar sector.	C. Duhr
Hidden Abelian Higgs Model	A Z' model where the Z' interacts with the SM through mixings, leading to very small non-SM like Z' couplings.	C. Duhr
Hill Model	A model with an unusual extension of the SM Higgs sector.	P. de Aquino, C. Duhr
The general 2HDM	The most general 2HDM, including all flavor violation and mixing terms.	C. Duhr, M. Herquet
Triplet diquarks	The SM plus triplet diquark scalars.	J. Alwall, C. Duhr
Sextet diquarks	The SM plus sextet diquark scalars.	J. Alwall, C. Duhr
Monotops	The SM plus monotop effective Lagrangian.	B. Fuks
Type III See-Saw Model	The SM, including neutrino masses coming from a type III See-Saw mechanism.	C. Biggio, F. Bonnet
DY SM extension	The SM plus new spin-0, -1, and -2 bosons that contribute to Drell-Yan production of leptons at the LHC.	N. Christensen

http://feynrules.irmp.ucl.ac.be/wiki/TypeIIISeeSaw

TypeIIISeeSaw - FeynRules

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Type III Seesaw

Authors

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Model Description

This model describes the minimal realisation of the Type III Seesaw. It is an extension of the Standard Model where a fermionic triplet is added to the matter content in order to give mass to mechanism. The fermionic triplet is introduced under the form of a heavy Dirac charged lepton $tr^{+/-}$ and a heavy Majorana neutral lepton tr^{0}. For an exhaustive description of the model, see r

References

- "mu->e gamma and tau->l gamma decays in the fermion triplet seesaw", A. Abada, C. Biggio, F. Bonnet, B. Gavela, T. Hambye, Phys. Rev. D78 (2008) 033007 0803.0481
- "Implementation of the Type III Seesaw model in FeynRules/MadGraph? and prospects for discovery with early LHC data", C. Biggio, F. Bonnet, arxiv:1107.3463

Model Files

- typeIIIseesaw1.0.fr: this is the file containing the model
- For `MadGraph/MadEvent` and BRIDGE users: formats.inc: this is a modified version of the file formats.inc, that can be useful when dealing with small mixing angles (the original file sets t than 10^{-5})
- typeIIIseesaw.nb: this is a Mathematica notebook that loads the model and export it to the `MadGraph` and `CalcHep` format.

The "golden channels" at the LHC7

CB, Bonnet 11

$l^+l^+l^- + \not{E}_T \qquad l^+l^+l^- jj + \not{E}_T$

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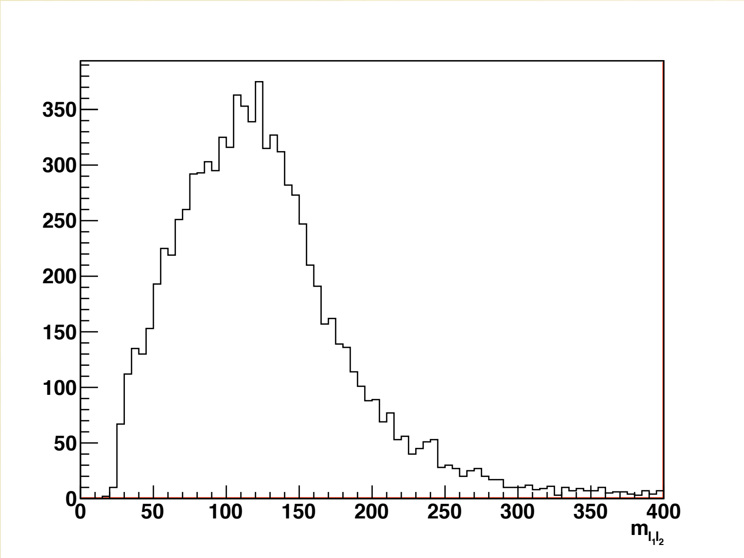
- Best discovery channel: no jets good for background rejection
- Invariant mass of dileptons good to distinguish from other seesaws

Del Aguila, Aguilar-Saavedra 08



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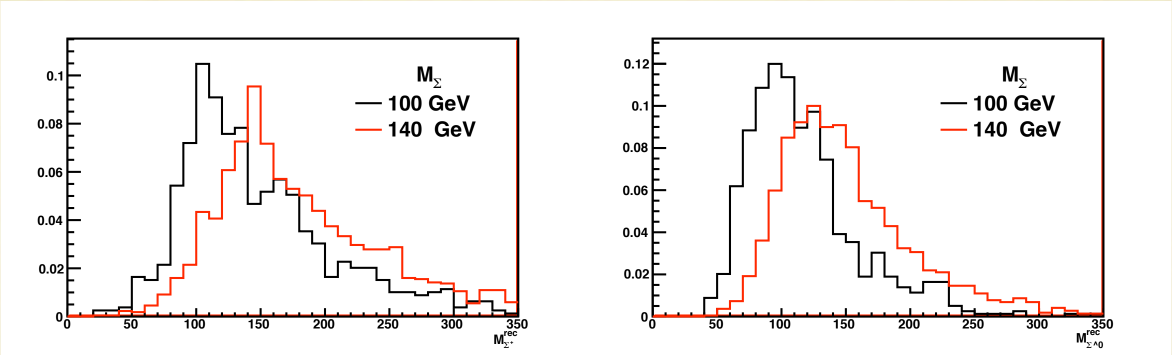
- Best channel to measure the triplet mass

Del Aguila, Aguilar-Saavedra 08

$$pp \to (\Sigma^\pm \to \ell^\pm Z/H)(\Sigma^0 \to \ell^\pm W^\mp) \quad Z/H \to jets$$

jets momenta → *Z*/*H* momenta
+ *l* momenta ⇒ triplet mass



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Process	Cross Sections (fb)			Final State	Final State Cross Section (fb)		
	100 GeV	120 GeV	140 GeV		100 GeV	120 GeV	140 GeV
Final State + + −							
$W^+\mu^-W^+\nu$	1.2e+3	5.1e+2	2.4e+2	$\mu^+\mu^+\mu^-\nu\nu\nu$	14.9	6.3	3.0
$W^+\mu^-Z\mu^+$	6.7e+1	1.4e+2	8.9e+1	$\mu^+\mu^+\mu^-\nu hadr$	5.1	10.8	6.8
				$\mu^+\mu^+\mu^-\nu\nu\nu$	1.5	3.1	2.0
$W^+\mu^-h\mu^+$	9.5e−4	2.1e−3	9.7	$\mu^+\mu^+\mu^-\nu hadr$	–	–	1.0
$W^+\nu Z\nu$	2.3e+2	2.0e+2	1.2+2	$\mu^+\mu^+\mu^-\nu\nu\nu$	0.9	0.8	0.5
$Z\mu^+Z\nu$	2.4e+1	1.1e+2	8.3+2	$\mu^+\mu^+\mu^-\nu hadr$	0.6	2.7	20.1
				$\mu^+\mu^+\mu^-\nu\nu\nu$	0.2	0.8	5.8
$Z\mu^+h\nu$	4.4e−4	5.0e−2	1.9e+1	$\mu^+\mu^+\mu^-\nu hadr$	–	–	0.6
$W^-\nu Z\mu^+$	1.3e+2	2.5e+2	1.5e+2	$\mu^+\mu^+\mu^-\nu hadr$	3.0	5.8	3.5
$W^-\mu^+Z\mu^+$	3.3e+1	7.0e+1	4.6e+1	$\mu^+\mu^+\mu^-\nu hadr$	2.5	5.4	3.5
				$\mu^+\mu^+\mu^-\nu\nu\nu$	0.7	1.6	1.0
$W^-\mu^+h\mu^+$	4.4e−4	1.0e−3	4.9	$\mu^+\mu^+\mu^-\nu hadr$	–	–	0.5
Total Cross Sections $\mu^+\mu^+\mu^-$ + jets + missing E_T					11.2	24.7	36.0
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$V_e = V_\tau = 0$

$V_\mu = 0.063$

Acceptance Cuts		
$p_{T_j} > 20\,\mathrm{GeV}$	$\eta_j < 5$	$\Delta R_{jj} > 0.4$
$p_{T_\ell} > 10\,\mathrm{GeV}$	$\eta_\ell < 2.4$	$\Delta R_{\ell\ell} > 0.2$

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CB, Bonnet 11

$t\bar{t},\ t \to bW,\ b$ decaying leptonically

$t\bar{t}W,\ t \to Wj$

WW

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ZZ

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all +jets

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- High cross sections: *O(1-10³) fb*
- Cuts: - jet veto
  - b-tagging
  - $|m_{ll} - M_Z| > 10 GeV$
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Real analysis $\longrightarrow$ *it will be provided by experimental collaborations*

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