Searching for LNV scalars at the LHC

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Outline

 $0\nu\beta\beta$ and **neutrino masses**

 **Effective lagrangian** approach

 **LHC phenomenology**

 Conclusions

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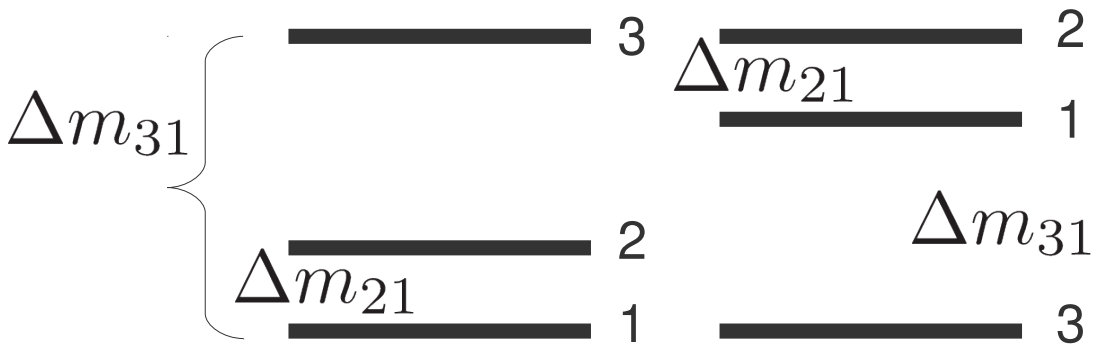
What do we know on neutrino masses?

Neutrino oscillations

$$|\nu_\alpha\rangle = \sum_i U_{\alpha i} |\nu_i\rangle$$

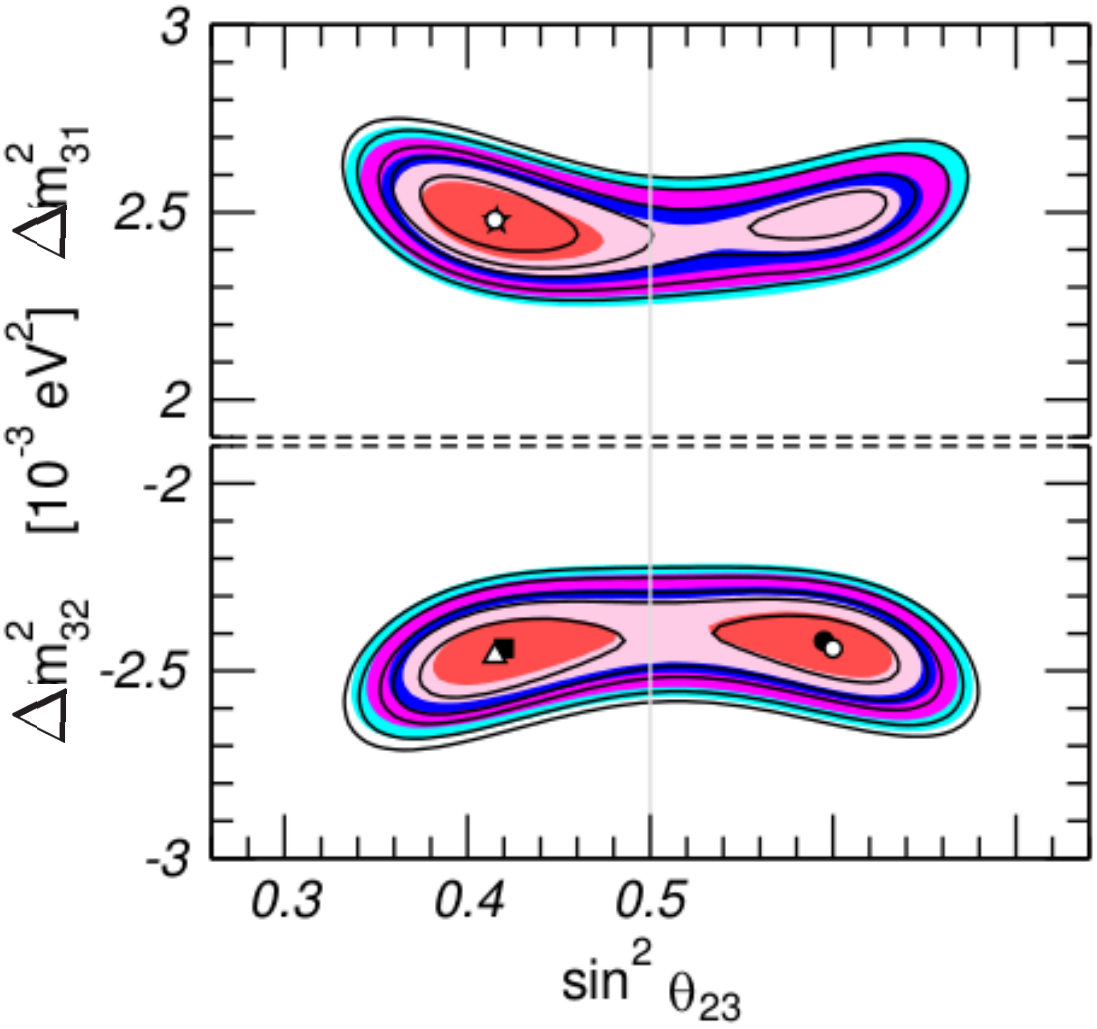


$$P(\nu_\alpha \to \nu_\beta) \propto \sin(2\theta)^2 \sin\left(1.27 \Delta m^2 \frac{L}{E}\right)^2$$

For two families!

- Atmospheric $\sim 10^{-4}$
- Reactor $\sim 10^{-2} - 10^{-3}$
- Solar $\sim 10^{-11}$

eV sensitivity depending on the scales **L**, **E**



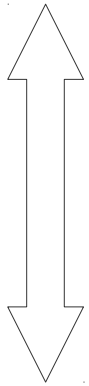
Gonzalez-Garcia et all, arXiv:1209.3023 (2012)

What do we know on neutrino masses?

$SU(3)_c \times U(1)_Q$

Quantum numbers$(1, 0)$

Neutrinos can be **Majorana**



Singlet!

Other fermions are charged, so they can not be self-conjugated

Neutrino oscillations **can not** test the Majorana character

About Lepton Number Violation

$$e^{\pm i\Psi} \Rightarrow \mathcal{L}_{SM} \rightarrow \mathcal{L}_{SM}$$

Majorana neutrinos...

$$\sim m_\nu \bar{\nu}_L \nu_L^c$$

LNV !

Accidental from gauge symmetry

Where to look for LN violation?

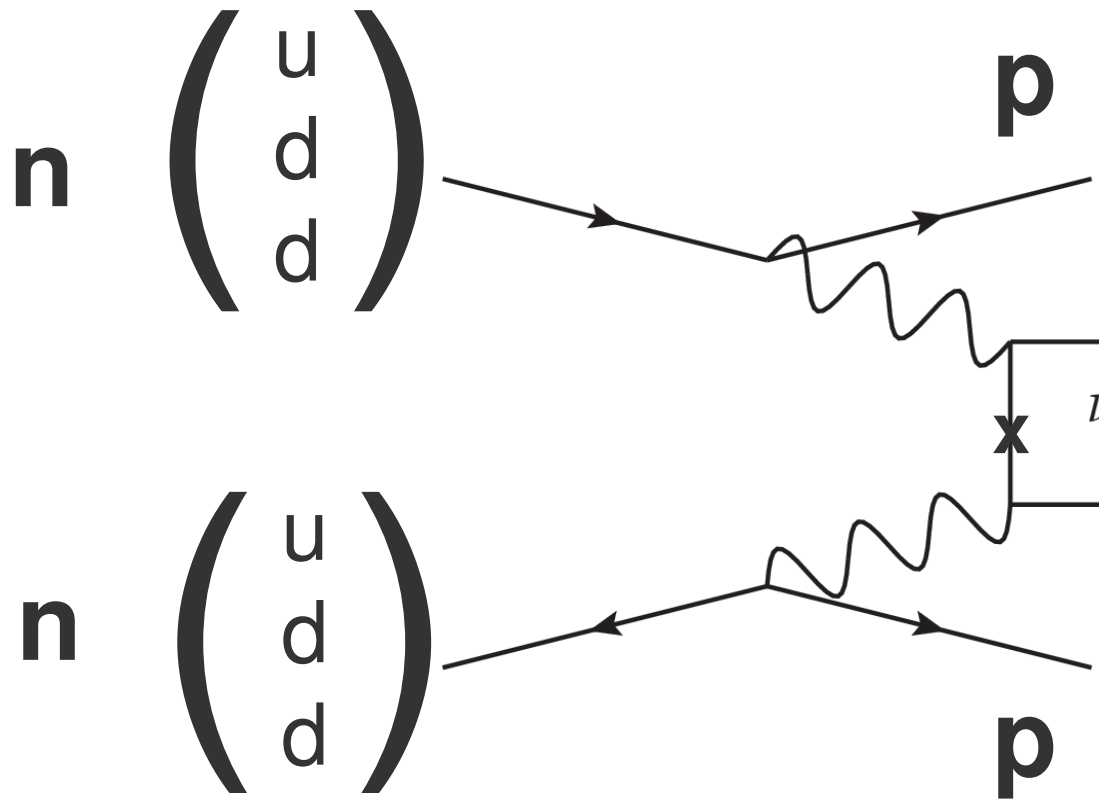
$$\mu^-(A,Z) \rightarrow \mu^+(A,Z-2)$$

$$K^+ \rightarrow \mu^+\mu^+\pi^-$$

$0\nu\beta\beta$ decay

Testable at the LHC

Neutrinoless double beta decay



Majorana neutrino

Weinberg op. $(\bar{\tilde{l}}_L \phi)(\tilde{\phi}^\dagger l_L)$

in the minimal SM extension

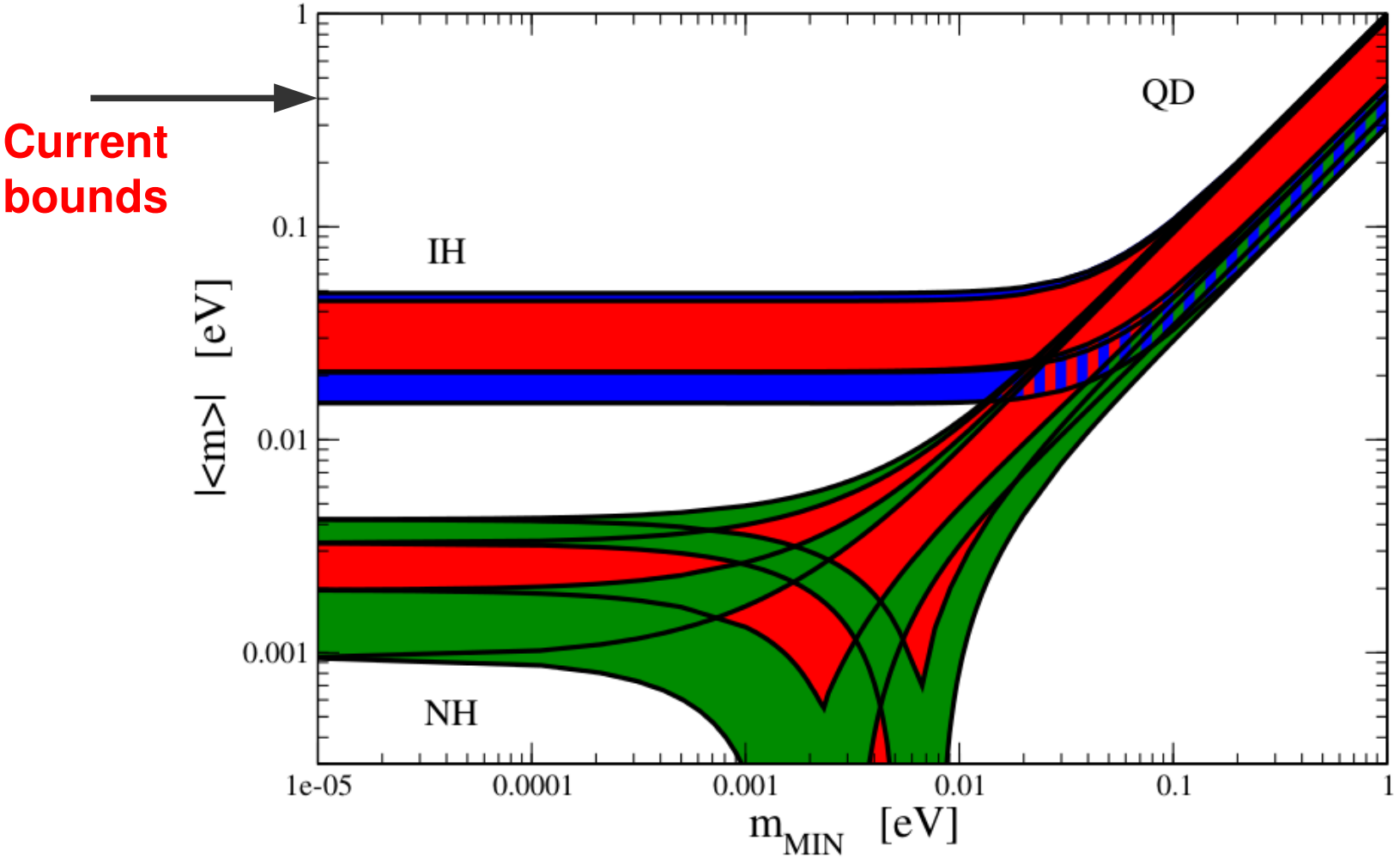
New physics
for $\sim m_\nu \bar{\nu}_L \nu_L$

- Left-Right models
- Sterile neutrinos
- ...

Neutrinoless double beta decay

Decay rate $\propto$ $|\langle m \rangle| = \left| \sum_{\alpha} m_{\alpha} U_{e\alpha}^2 \right|$

J. Beringer et al.
[Particle Data Group]



So, open questions

- Are neutrinos Dirac or Majorana?
- What are the absolute mass and the hierarchy?
- Why so small?
- Is CP violated in the lepton sector?
- **Which is the new physics behind LNV?**
- **Could it be probed at the LHC?**

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Effective approach

Neutrino masses and $0\nu\beta\beta$

Low energy process

E ~ MeV

Effective approach

$$\mathcal{L} = \mathcal{L}_{SM} + \sum_{n=5}^{\infty} \left(\frac{C_i^n}{\Lambda^{n-4}} \mathcal{O}_i^{(n)} + h.c. \right)$$

Respect local symmetries

Involving SM gauge bosons

LNV operators

del Águila et all,
arXiv:1204.5986 (2012)

$$m_\nu \sim \frac{1}{\Lambda}(\cdots)$$

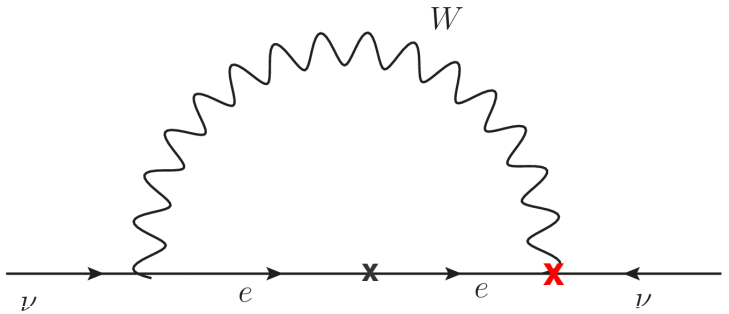
decoupling

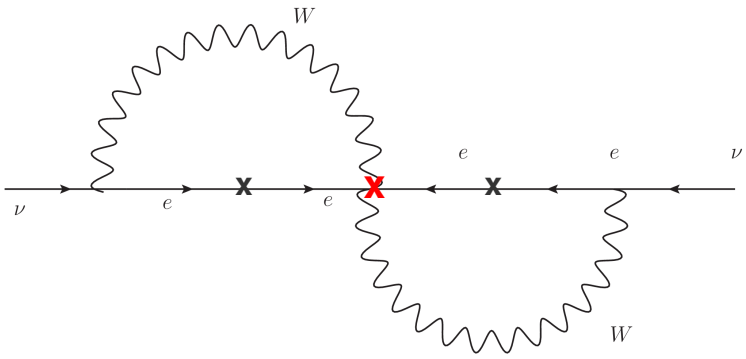
$$\mathcal{O}^{(5)} = (\bar{\tilde{l}}_L \phi)(\tilde{\phi}^\dagger l_L)$$

Tree level
neutrino mass

$$\mathcal{O}^{(7)} = (\phi^\dagger D^\mu \tilde{\phi})(\phi^\dagger \bar{e}_R \gamma_\mu \tilde{l}_L)$$

$$\mathcal{O}^{(9)} = \bar{e}_R e_R^c (\phi^\dagger D^\mu \tilde{\phi})(\phi^\dagger D_\mu \tilde{\phi})$$





LNV operators

del Águila et all,
arXiv:1204.5986 (2012)

From neutrinoless double beta decay **bounds**!

$$\mathcal{O}^{(5)} = (\bar{\tilde{l}}_L \phi)(\tilde{\phi}^\dagger l_L) \longrightarrow \textbf{Triplet} \quad \Lambda >\sim 10^{11}\,\text{TeV}$$

$$\mathcal{O}^{(7)} = (\phi^\dagger D^\mu \tilde{\phi})(\phi^\dagger \bar{e}_R \gamma_\mu \tilde{l}_L) \quad \textbf{Doublet} \quad \Lambda >\sim 10^{2}\,\text{TeV}$$

(at higher order)

$$\mathcal{O}^{(9)} = \bar{e}_R e^c_R (\phi^\dagger D^\mu \tilde{\phi})(\phi^\dagger D_\mu \tilde{\phi}) \quad \textbf{Singlet} \quad \Lambda >\sim \text{TeV}$$

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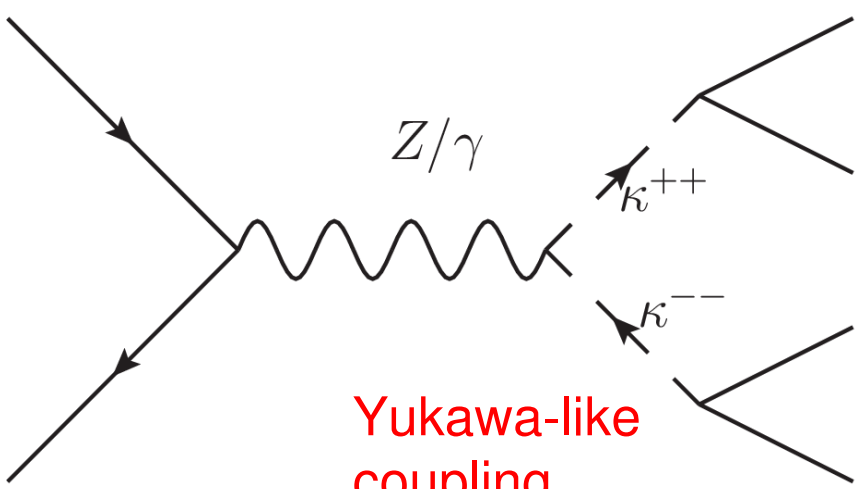
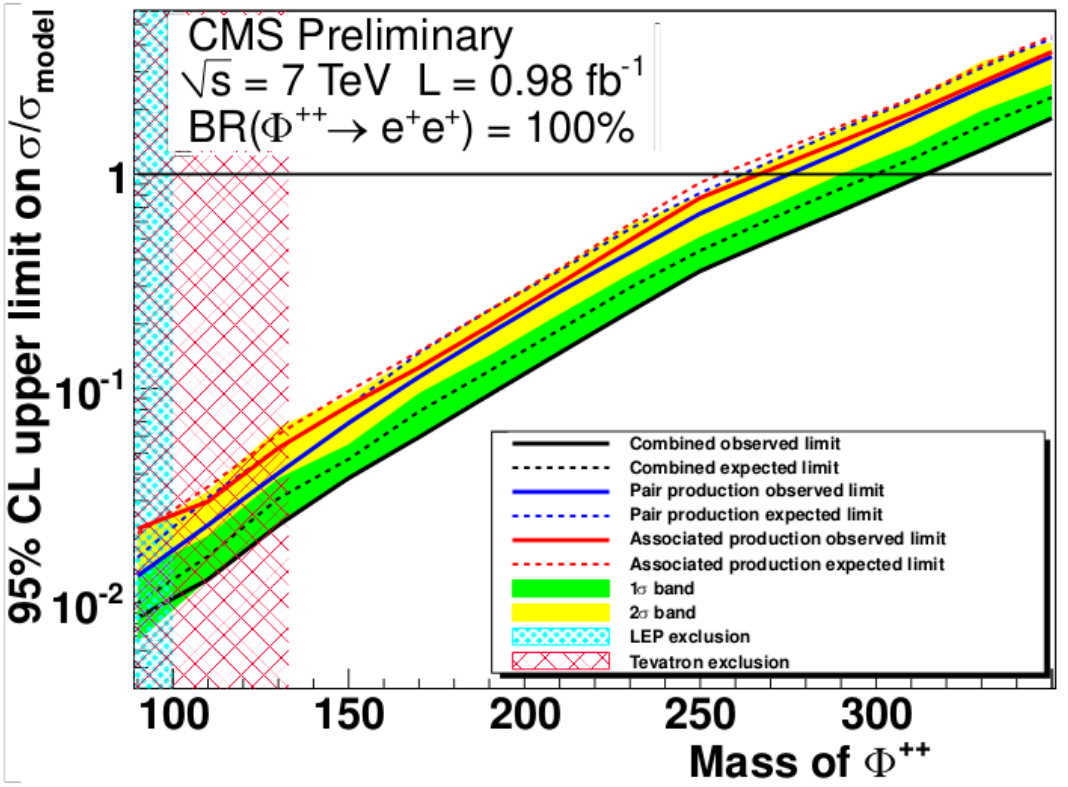
Can we look for a doubly charged singlet? (**Displaced** vertices?)



Same sign leptons!

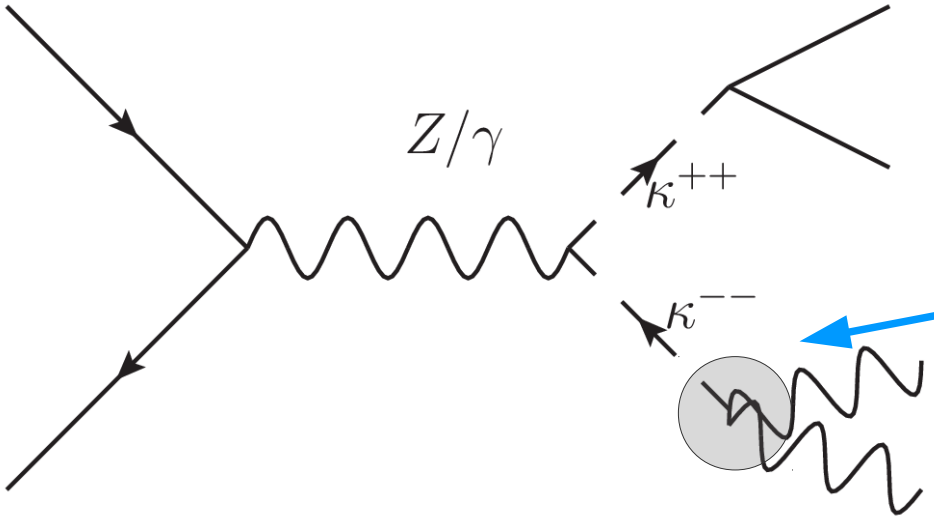
Yukawa-like coupling

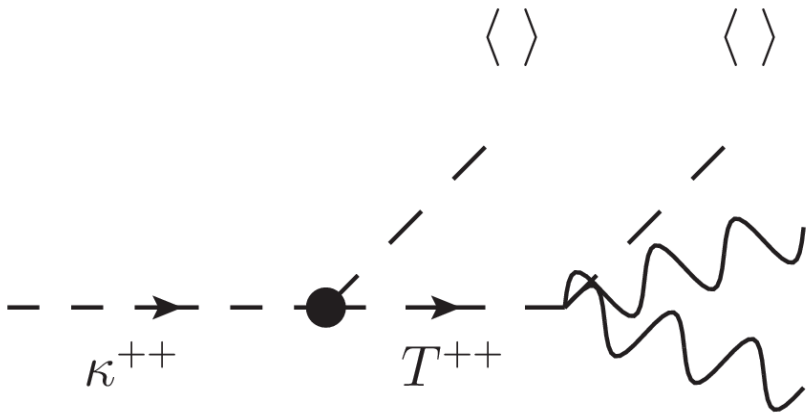
Not a LNV signal



CMS PAS HIG-2011-007
'2011

LNV signal?

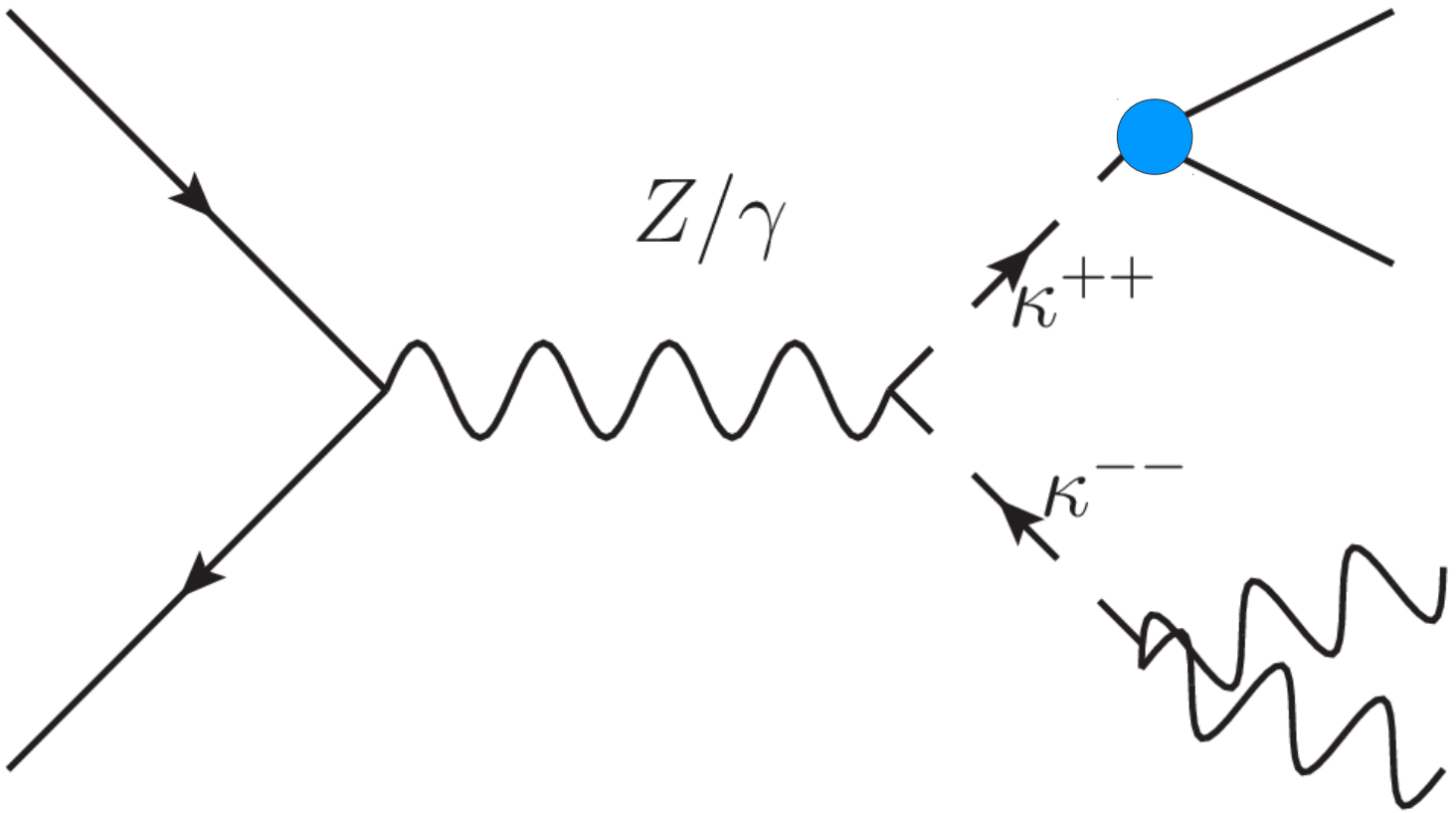




Effective vertex!

$$\propto \frac{v_T^2}{m_T^2}$$

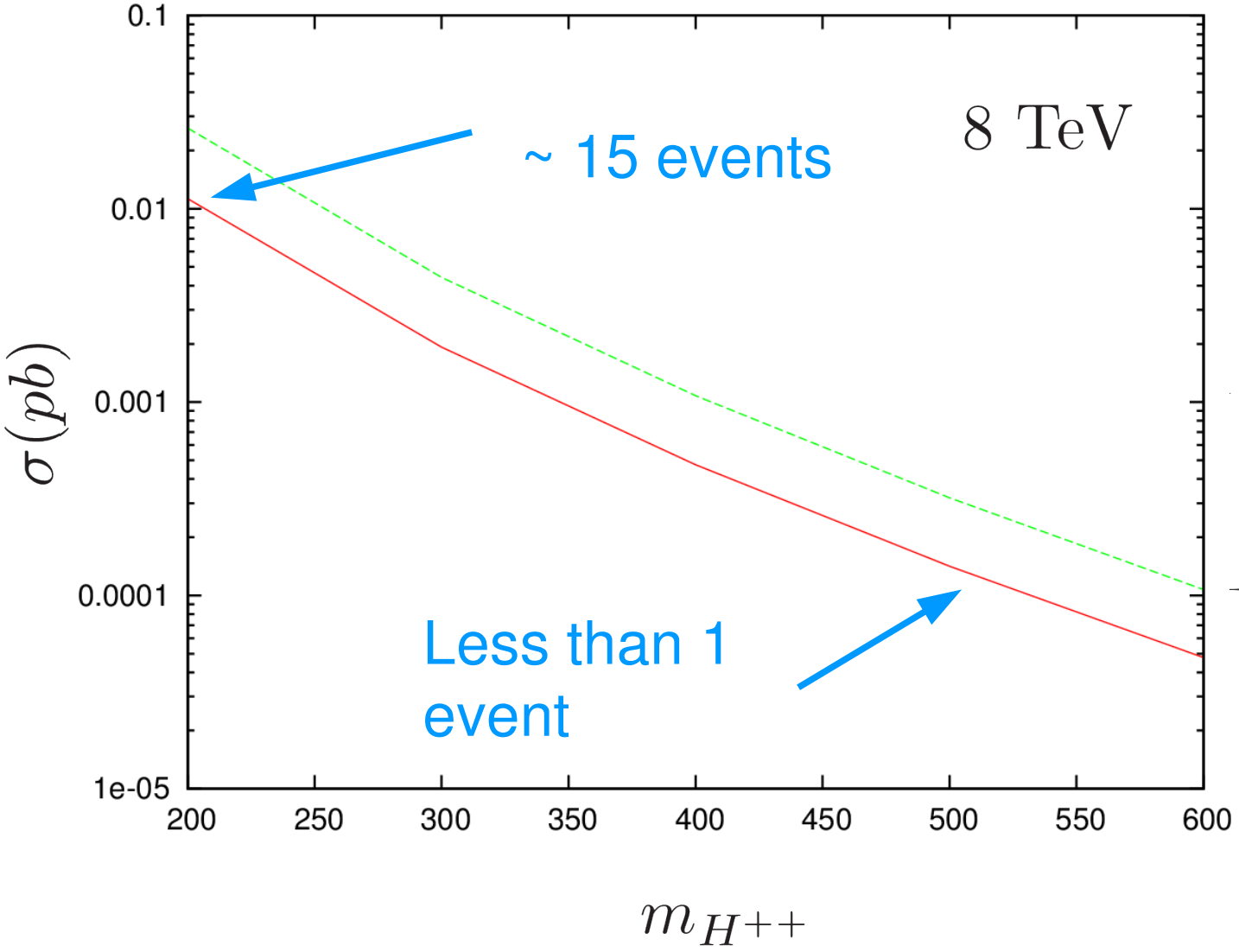
very suppressed!



$$\rho = 1 - \frac{2v_T^2}{v^2 + 4v_T^2} \Rightarrow v_T \sim 0$$

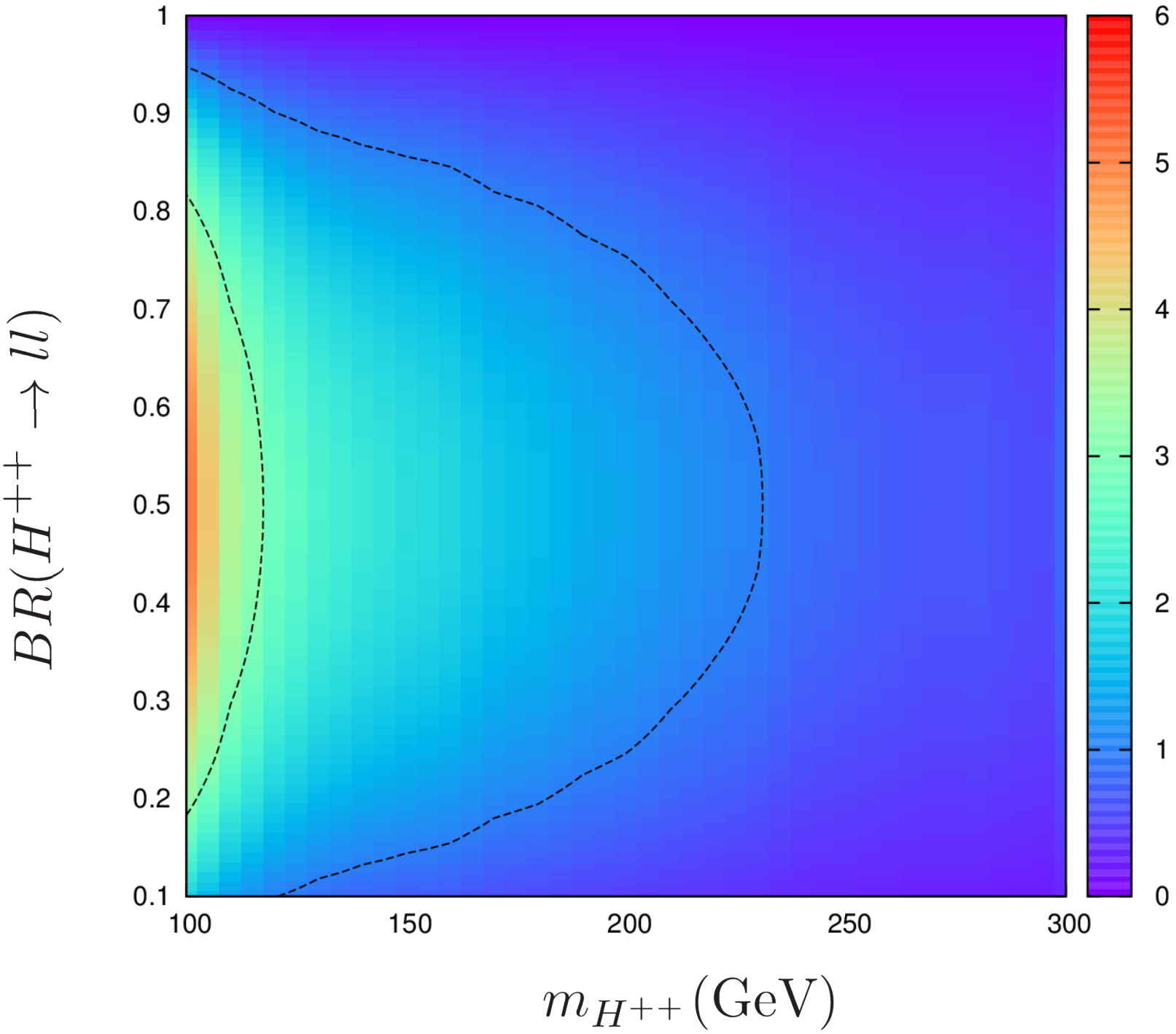
Custodial symmetry

Sizable if the **leptonic coupling** is **small**



Look for **two same sign leptons** and

- 1l 2j $\not{E}_T$
- 4j


$BR(H^{++} \to ll)$
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
100
150
200
250
300
$m_{H++}\,(\mathrm{GeV})$
6
5
4
3
2
1
0

Conclusions

- There are still open questions on **neutrino masses** and **LNV**
- **Effective theory description** of low energy processes
- **LNV** described by just **three effective operators**
- What is the **new physics**?
- Time to **LHC studies**

Thank you for your attention!