Summary of

NuFlavour workshop:
Flavour physics in the era of precision neutrino experiments

Cosener's house, Abingdon (UK), June 8-10 2009
A EUROnu, IPPP and STFC's CfFP workshop

NuFact 09
IIT Chicago - July 21 2009

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1 - The observation of neutrino masses and mixing implies new physics BSM!

Now we want to identify this new physics:

- **open window on the physics BSM** (possibly at scales not accessible directly)

- **complementary window on the flavour problem**

- neutrinos are **critical ingredients in understanding the evolution of the Universe**

Neutrinos provide **indirect information** on this physics. **What is the role of neutrino experiments?**

The NuFlavour meeting focussed on a critical review of the physics case for neutrino physics and long baseline neutrino oscillations from a theoretical perspective.

Aim: to start a discussion on the physics case and to summarise it in a short document, which can constitute a basis on which to develop a **more in focus physics case** for neutrino physics.

- **LFV from GUT see-saw models and from TeV see-saw models** (G. Ross, E. Ma – M. Frigerio)

- **Neutrino physics and cosmology** (S. Hannestad – P. di Bari)

- **LF physics at the TeV scale beyond the standard model** (S. Khalil, F. del Aguila – A. Santamaria)

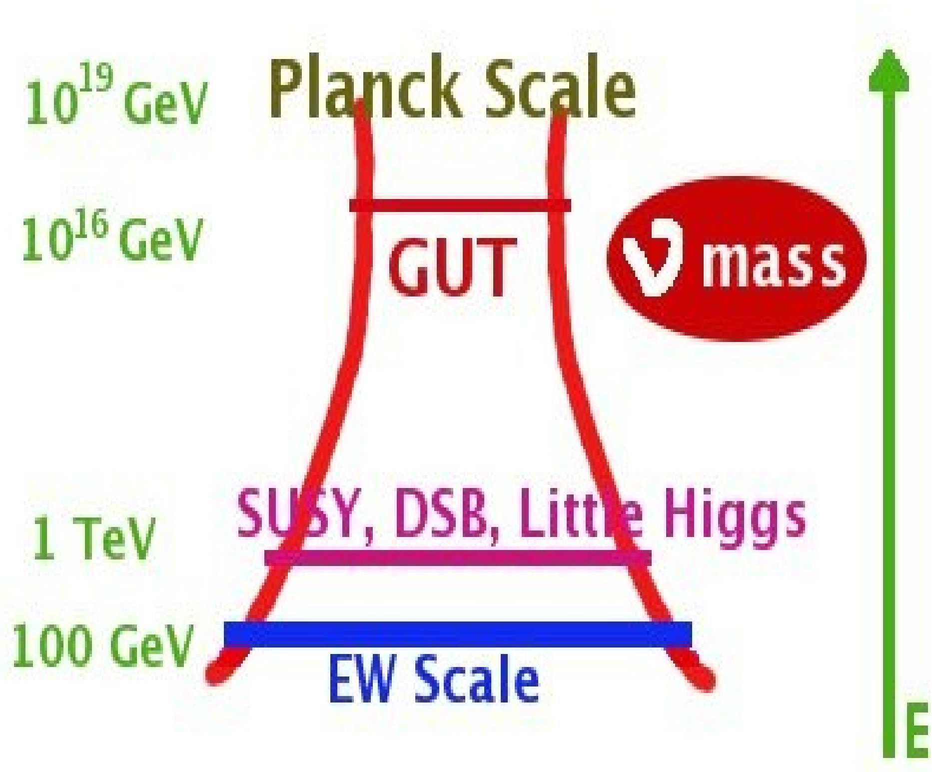
- **Leptogenesis: model-dependent and independent considerations** (A. Abada – E. Nardi)

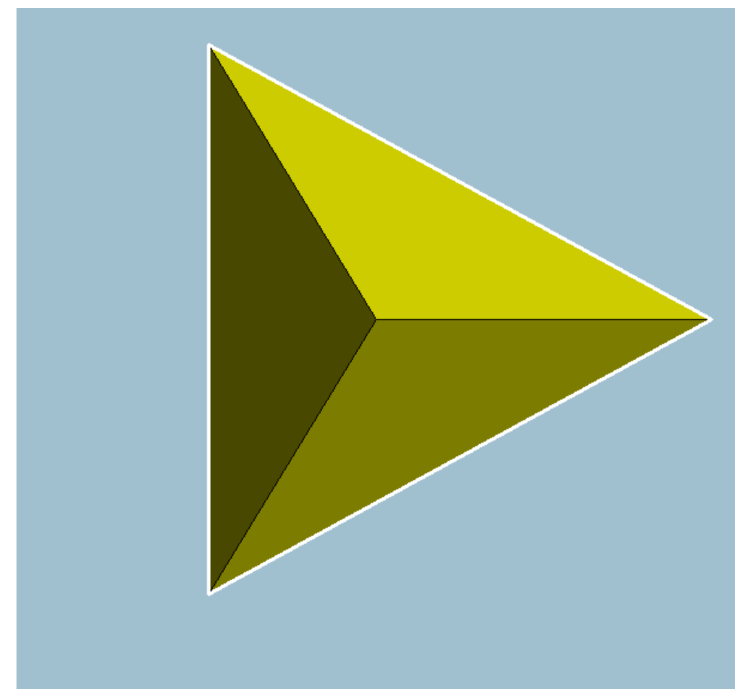
- **Interplay between neutrino masses and other phenomenological signatures** (T. Schwetz, A. de Gouvea, E. Hernandez-Martinez – T. Ohlsson)

- **Performance indicators in long baseline experiments** (Round table, K. Long)

Open window on Physics beyond the SM

Neutrino physics gives a new perspective on physics BSM.





This information is **complementary** with the one which comes from flavour physics experiments and from colliders.

Neutrino masses in the sub-eV range cannot be explained naturally within the SM. It is possible to introduce right-handed neutrinos and a Dirac mass term:

$$y_\nu = \frac{m_\nu}{v} = \frac{0.1\,\mathrm{eV}}{250\,\mathrm{GeV}} = 4 \times 10^{-13}$$

Many theorists consider this explanation of neutrino masses unnatural.

If neutrino are Majorana particles (neutrinos and antineutrinos are indistinguishable), a different type of neutrino mass can be generated (**Majorana mass**):

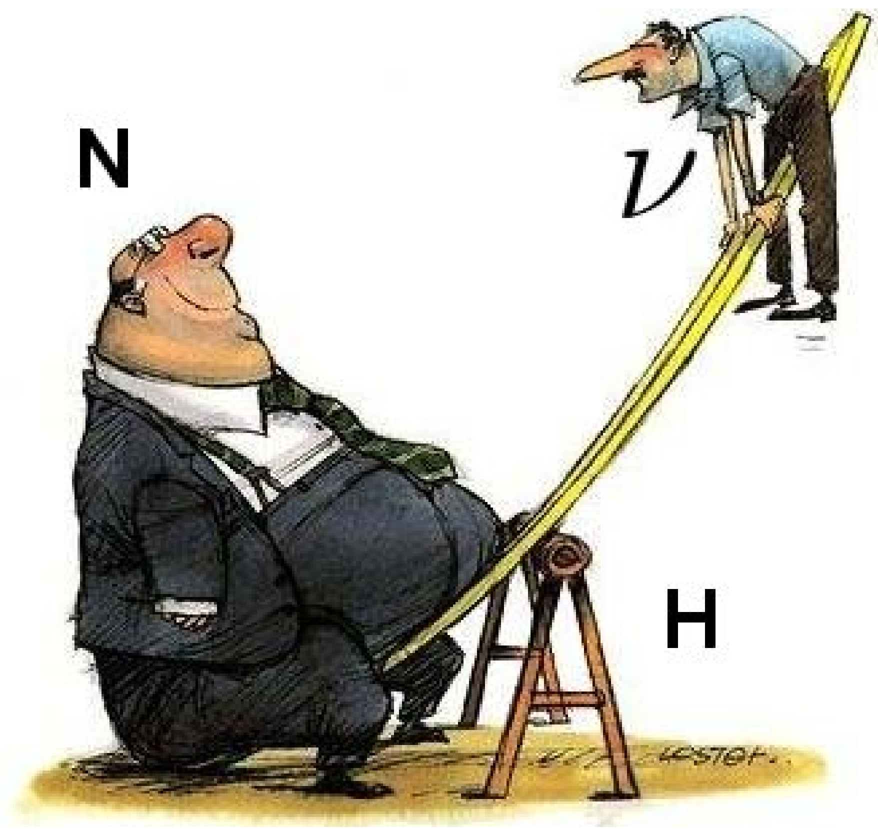
$$-\mathcal{L} = \lambda \frac{\nu_L H\, \nu_L H}{M} = \frac{\lambda v^2}{M} \nu_L^T C \nu_L$$

The Majorana mass term can arise as the **low energy realisation of a higher energy theory**.

$$\boxed{m_\nu = \frac{\lambda^2 v^2}{M} \longrightarrow M \sim 10^{14}\ \mathrm{GeV}}$$

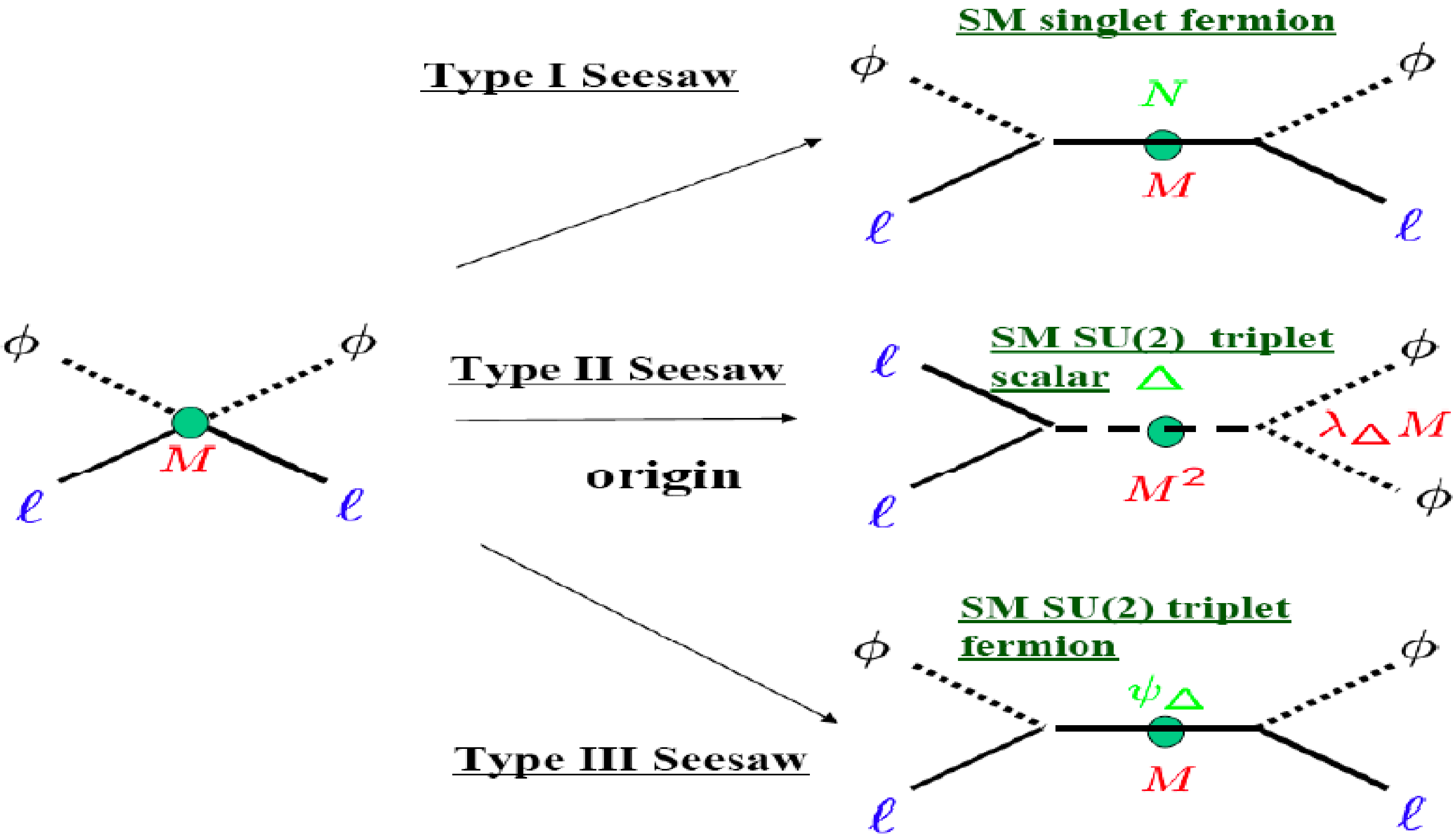
The see saw mechanism

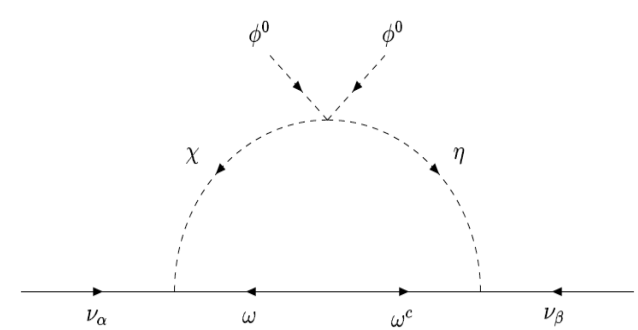
In the **see-saw mechanism**, neutrinos acquire a very small mass due to their interactions. Minkowski; Yanagida; Gell-Mann, Ramond, Slansky.



- Introduce a right handed neutrino **N**
- Couple it to the Higgs and left handed neutrinos

$$m_{light} \simeq \frac{m_D^2}{M_R} \sim \frac{100\,\mathrm{GeV}^2}{10^{14}\,\mathrm{GeV}} \sim 0.1\,\mathrm{eV}$$

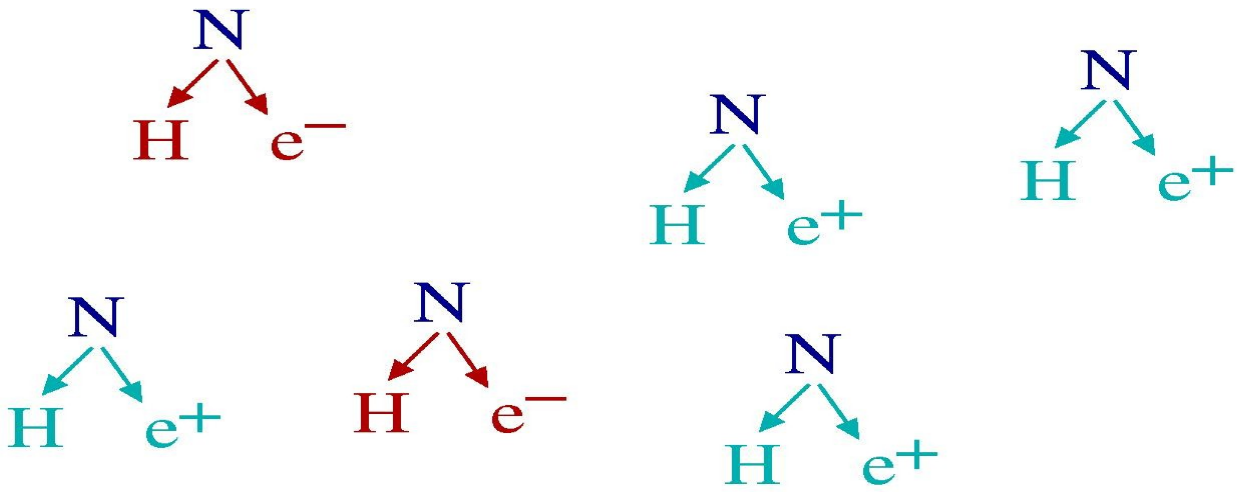




From S. Khalil's and E. Ma talks;
See also G. Ross' and M. Frigerio's talks.

Leptogenesis and the Baryon Asymmetry

The excess of quarks can be explained by **Leptogenesis** (Fukugita, Yanagida): the heavy N responsible for neutrino masses generate a lepton asymmetry.



Excess of $e^+ \longrightarrow$ excess of q over $\overline{q}$

This requires **L violation, CP-violation** and **non-equilibrium** (expansion of the EU). The lepton asymmetry is then converted into the baryon asymmetry.

$$Y_B = \frac{n_B}{n_\gamma} = (6.0 \pm 0.2) \times 10^{-10}$$

The **see-saw mechanism** (type I) might be responsible both for **neutrino masses** and for the **baryon asymmetry**.

Is there a **connection** between the two**?** (i.e. if I measure CP at low energy can we be sure that the baryon asymmetry comes from leptogenesis?)

- In general, there are more parameters at high energy (where leptogenesis happens) w.r.t. the ones we can measure in experiments at low energy.

- The number of parameters is typically reduced in **models of flavour** (symmetries, texture zeros) and a **connection** can be present.

- Due to **flavour effects**, if we **observe CPV at low energy** we know that generically a **baryon asymmetry** was generated (although we cannot predict its magnitude).

- **Observing L violation and CPV** would constitute a **strong hint (circumstantial evidence) in favour of leptogenesis as the origin of the baryon asymmetry**. (A. Abada and E. Nardi's talk)

What is the role of neutrino physics (and LBL experiments in particular) in understanding the physics BSM?

- new **energy scales**

- new window on **the flavour problem**

1. Long baseline neutrino experiments and other new physics searches

2. Neutrino physics and particle physics

Long baseline neutrino experiments and other new physics searches:

- neutrinoless double beta decay

- charged lepton flavour physics (mu-> e gamma ....)

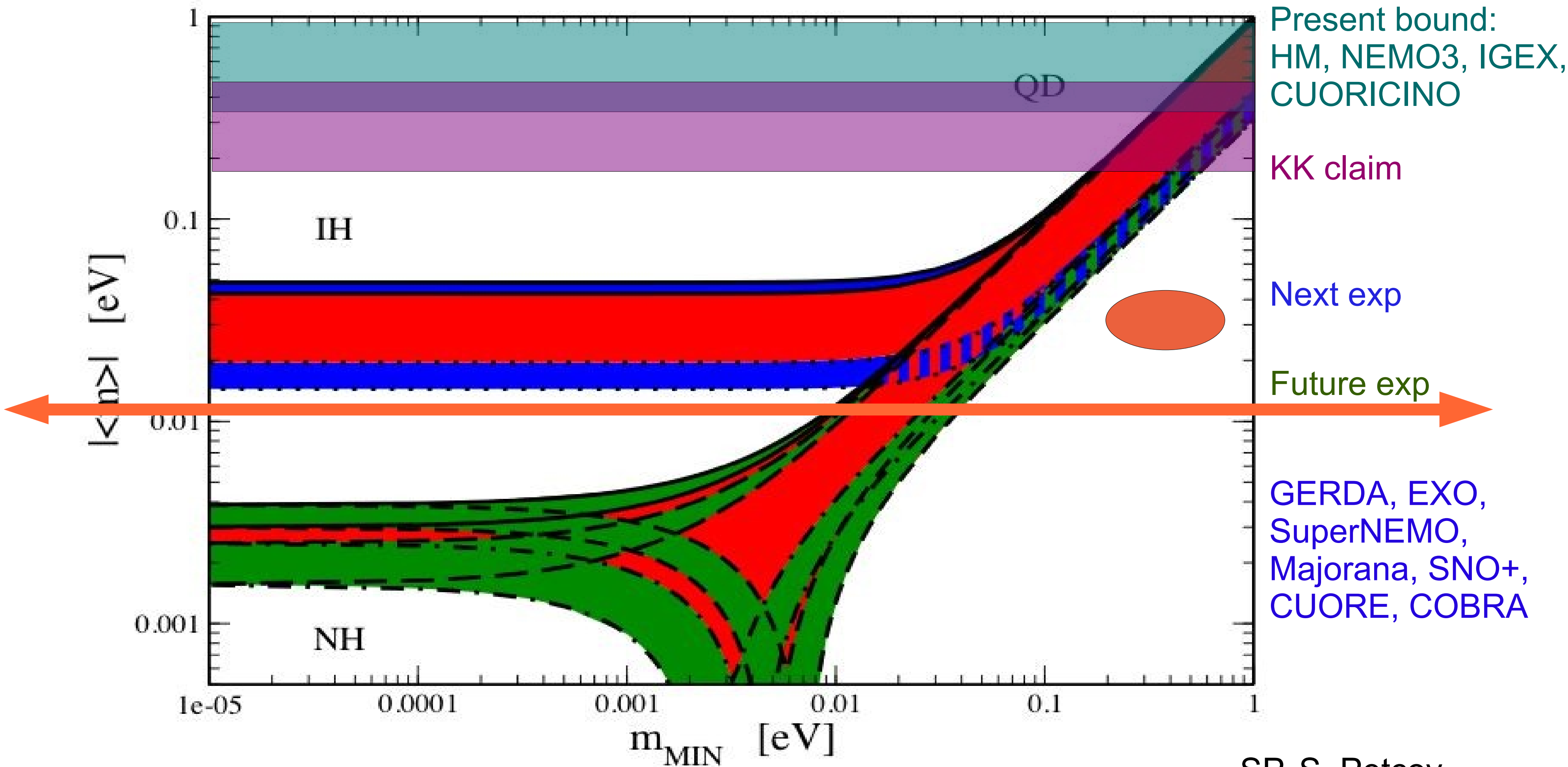
- other oscillation experiments

- direct mass searches

- What is the **complementarity** between these experiments? And what the **synergy**?

- Are there **priorities** between these experiments from a theoretical point of view?

An example: neutrinoless double beta decay + LBL, direct mass searches



SP, S. Petcov

Betabeta-decay (no signal) + LBL (IH) → Dirac neutrinos (?)

Betabeta-decay + direct mass search: new physics (?)

Neutrino physics and particle physics

Neutrino experiments are part of a wide particle physics programme. It is critical to clarify their physics case.

- Is the information we can get from neutrino physics on the physics BSM **unique**?
- Is it **complementary with the energy frontier** (future collider) experiments? If so, how?
- What is the **case for precision** in neutrino physics experiments?

- How can flavour mixing be implemented? Family symmetry

  ...implications of mass hierarchy measurement $\Delta(27)$ model strongly favours normal hierarchy

  ...precision for θ_{13}, δ_{CP} ..

- How do these theories inscribe into a more general theory

- Is it possible to discriminate between GUT and TeV-scale see-saws?

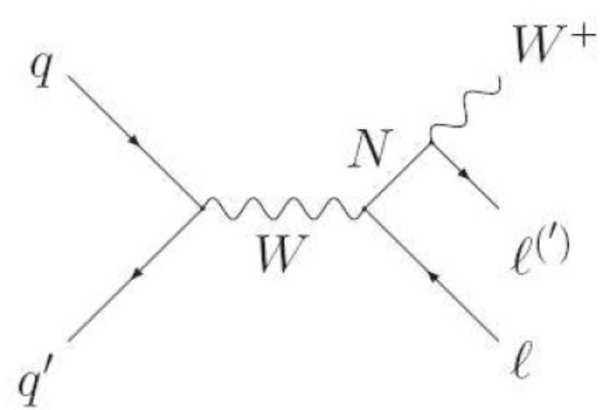
  Predictions for rare lepton decays

  (SUSY) see-saw parameters may be measurable

From G. Ross' talk

Type I seesaw at LHC

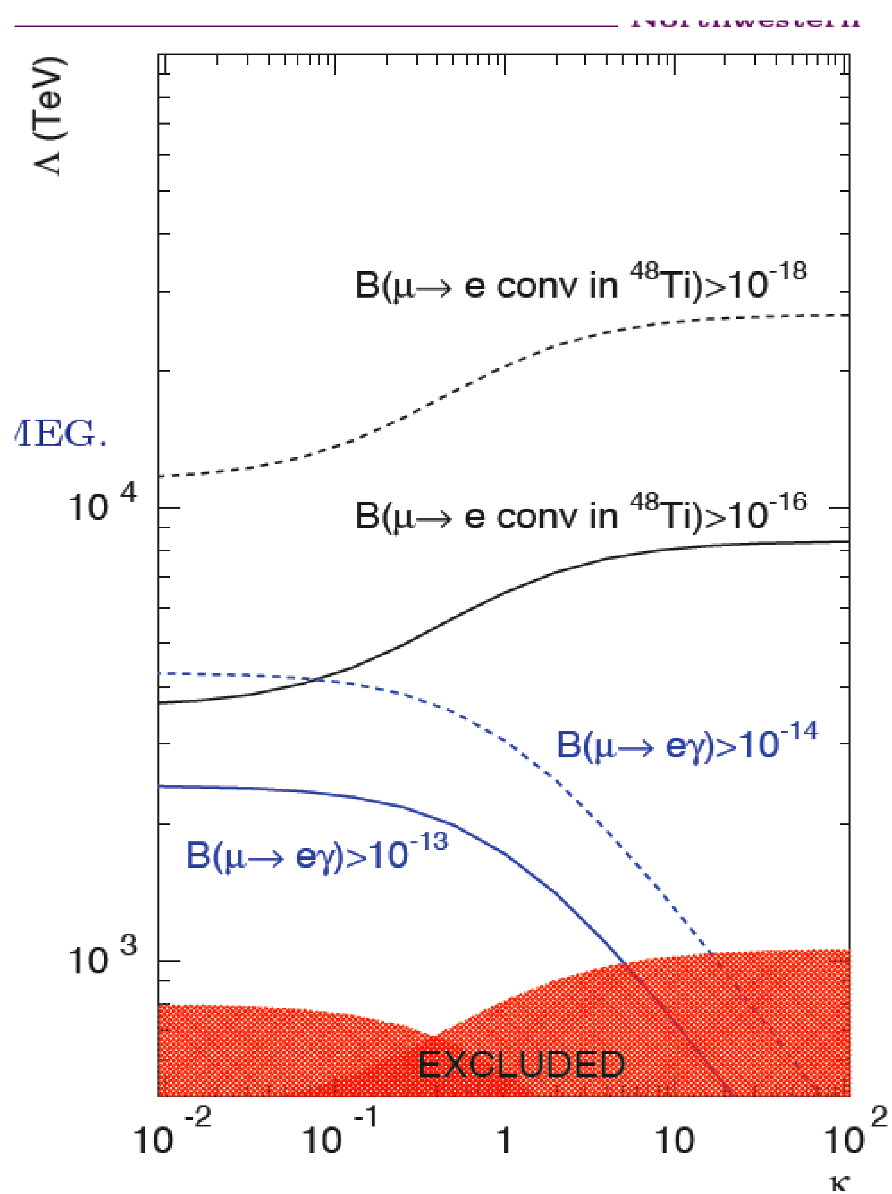
+ new N interactions



From T. Schwetz's talk

LFV processes: $Br(\mu \to e\gamma) = \frac{3\alpha}{32\pi}\left|\sum_{i=2,3} U^*_{\mu i} U_{ei} \frac{\Delta m^2_{1i}}{M^2_W}\right|^2 < 10^{-54}$

LFV process	Present bound	Future sensitivity
$BR(\mu \to e\,\gamma)$	1.2×10^{-11}	1.3×10^{-13}
$BR(\tau \to e\,\gamma)$	1.1×10^{-7}	10^{-8}
$BR(\tau \to \mu\,\gamma)$	6.8×10^{-8}	10^{-8}
$BR(\mu \to 3\,e)$	1.0×10^{-12}	10^{-13}
$BR(\tau \to 3\,e)$	2.0×10^{-7}	10^{-8}
$BR(\tau \to 3\,\mu)$	1.9×10^{-7}	10^{-8}



From S. Khalil's talk and A. de Gouvea's talk

Summary

Neutrino physics provides a new window on the physics at high energy scales and on the problem of flavour.

Many new questions are open:

What is the **complementarity** between these experiments? And what the **synergy**?

Are there **priorities** between these experiments from a theoretical point of view?

Is the information we can get from neutrino physics on the physics BSM **unique**?

Is it **complementary with the energy frontier** (future collider) experiments and other searches? If so, how?

What is the **case for precision** in neutrino physics experiments?

Experiments

- Neutrinoless double beta decay
- Long baseline oscillations
- Direct mass searches
- Other oscillation experiments

Phenomenology

Astroparticles

- Constrain nu properties
- Study evolution of Universe

Theory

- Origin of neutrino masses BSM
- Flavour problem