Summery

- using electroweak oblique parameters allows to assess the effect of a NP model in the electroweak sector without the need for a “full” analysis
- EWPO constrain the plain SM4 in several ways
  - strong limits on the *maximal* mass splitting of quark (~ 85 GeV for $M_H = 120$ GeV) and leptons (~ 140 GeV for $M_H = 120$ GeV) for a given reference Higgs mass
  - CKM mixing of the 4th generation with the first three
    $\rightarrow$ most important for the $3-4$ mixing
    $\rightarrow$ *higher* masses lead to *lower* a upper bound on the mixing

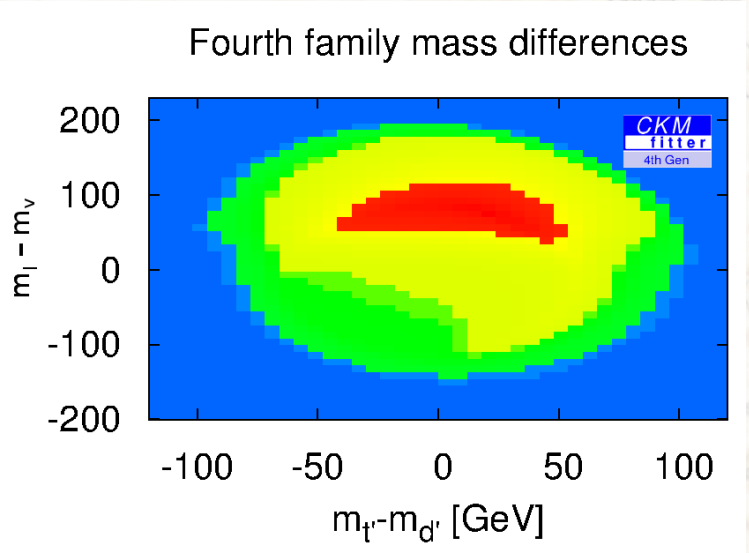


Figure: 68%-,95% and 99% CL contours for the mass splittings in case of a general CKM matrix and free Higgs mass.

- non-oblique effects in R_B (and to a lesser extend in Γ_{had}) are sizable
- for a precision fit of SM4 non-oblique effects should be taken into account

4G Neutrino summary

Large ν_4 mass + Majorana ν's
(theoretical prejudice + better EW precision fit)

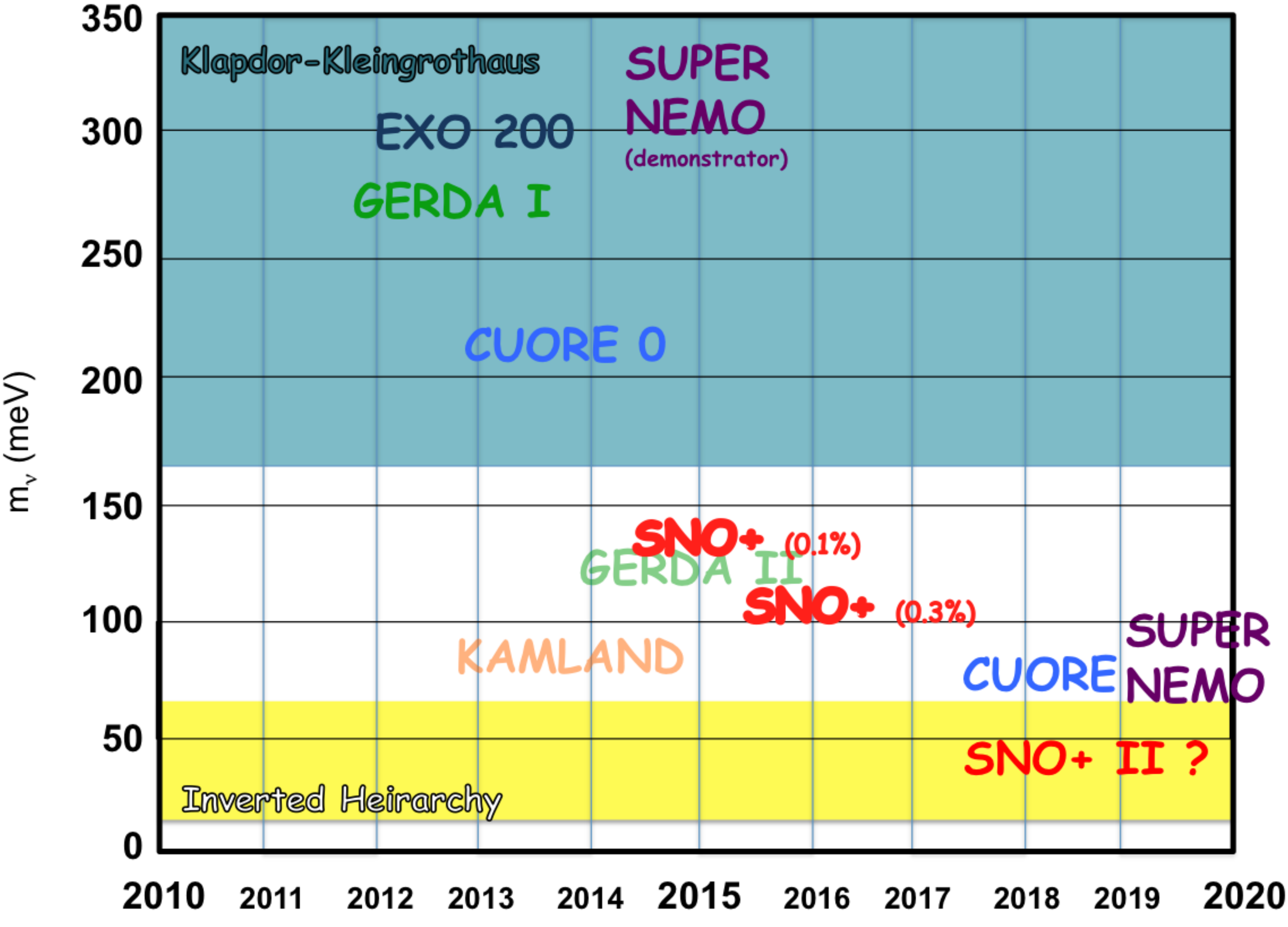
BUT:

- dangerous LNV in 0νBB decay (for finite U_{e4})
- dangerous washout of baryon asymmetry (unless flavor protection or EW baryogenesis)
- dangerous radiative mass contributions for 3G ν masses from ν_4 (Talk by A. Aperici)

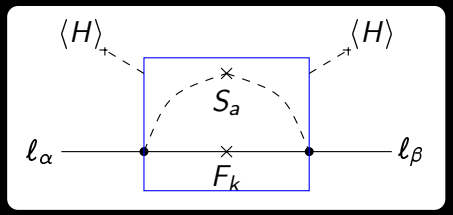
$\Rightarrow$ ν_4 is Dirac or Pseudo-Dirac

$\Rightarrow$ Challenge for model builders

(xtraD? Flavor symmetry? → M. Schmidt)


350
300
250
200
150
100
50
0
m_ν (meV)
Klapdor-Kleingrothaus
EXO 200
GERDA I
SUPER NEMO
(demonstrator)
CUORE 0
SNO+ (0.1%)
GERDA II
SNO+ (0.3%)
KAMLAND
CUORE
SUPER NEMO
SNO+ II ?
Inverted Heirarchy
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020

Experimental Tests of Radiative Neutrino Masses



1. LFV processes
   - At one loop level unless there is flavour symmetry
   - Strongest bound today from $\mu \to e\gamma$
   - What are the experimental prospects for further constraints?
   - What about other LFV processes like τ decays?
2. DM experiments
   - Direct detection experiments: future prospects? Can the current low mass DM hints be explained?
   - In future: constraints from indirect detection experiments
   - High-energy neutrino flux from sun. Further improvements?
3. Collider searches:
   - What branching fraction is acceptable for invisible Higgs decay?
   - New particles couple to EW gauge bosons
   - Decay channels: directly into leptons plus missing energy or via EW gauge bosons
   - What is the potential reach of the LHC for these particles?
   - Can the LHC exclude these models in combination with the other experiments?

B and L violating couplings are flavor couplings.

They may be directly related to the known flavor structures,
i.e. to the fermion masses and mixings.

With three generations:

In general allowed, but *very small because of the Yukawa hierarchies and of the small neutrino masses*

Though bounds are ok, the proton does ultimately decay.

With four generations:

Baryon number can be violated in steps of four only because:

- *Mismatch between the number of color and flavors*,
- *Flavor indices come in even numbers*.

In the absence of new flavor structures, the proton is absolutely stable.

(caution: GUT interactions do introduce new flavor structures.)

Comparison between 3G and 4G

Spurions		Three families		Four families	
		Dim.	$\pm(\Delta\mathcal{B},\Delta\mathcal{L})$	Dim.	$\pm(\Delta\mathcal{B},\Delta\mathcal{L})$
SM gauge	–	27	$(6,0)$, $(0,6)$, $(3,9)$, $(3,\pm3)$	24	$(4,4)$ $\supset$ *anom.*
	–	18	$(3,3)$ $\supset$ *anom.*	18	$(4,0)$, $(0,4)$
Yukawas	$Y_{u,d,e,(\nu)}$	9	$(1,3)$, $(2,0)$	10	$(0,4)$
Seesaw	$Y_{u,d,e,\nu}$, Υ_ν	6	$(1,1)$	7	$(0,2)$
MSSM	$Y_{u,d,e,\nu}$, Υ_ν	4	$(1,1)$	5	$(0,4)$
	$Y_{u,d,e,\nu}$, Υ_ν	3	$(1,0)$, $(0,1)$	4	$(0,2)$
SUSY GUT	$Y_{\bar{5},10}$	3	$(1,0)$, $(0,1)$	3	–

Summary

- It is possible, in an extra-generation context, to generate small masses for the first three generations' neutrinos. For this aim one needs: mixing between the first three and the extra generations, and Majorana masses for the extra generations' neutrinos. The lepton number violation induced by this mass is translated into small Majorana masses for the first three neutrinos through a 2-loop diagram.

- One doesn't have to rely necessarily on this mechanism to generate neutrino masses in this context. But indeed we should bear in mind that the mechanism is there, and could even screw the light neutrino masses, depending on the values of the parameters of our model.

Questions/Comments

- Do extra generations models usually implement lepton number violation? If the answer is yes, how is it implemented?

- As we don't know yet if neutrinos are Dirac or Majorana particles, it could be interesting to consider a 4G analysis (for example, of the EW precision tests) with completely general neutrino masses, i.e., with both Dirac and Majorana mass terms. One would need 4 ν_R's, and we could implement Dirac masses through the Higgs mechanism and Majorana masses through the Weinberg operator (for the ν_L's) and the usual Majorana mass term for the ν_R's:

$$M_\nu = \begin{pmatrix} m_L & m_D \\ m_D & m_R \end{pmatrix}$$

From this setup we could recover any particular scenario just by adjusting the different blocks of the mass matrix.