Neutrino Mass Sum Rules: Realistically Probing Flavour Models with near-future Experiments

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King, **AM**, Stuart: JHEP **1312** (2013) 005
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Agostini, **AM**, Zuber: *work in progress*
Gehrlein, **AM**, Spinrath: *work in progress*

WIN 2015, Heidelberg, 10-06-2015

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NJP Highlight 2014

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1. Introduction

- **BASIC PROBLEM FOR FLAVOUR MODELS**:

  if the mixing angles are not correctly predicted, we classify a model as “excluded“

  ➔ ***thus: mixing angles are not well suited to distinguish models without precision***

- **WE NEED TO LOOK FOR FURTHER OBSERVABLES**:

  single β decay ➔ m_β^2: ***not competitive for theorists***

  cosmology ➔ sum Σ: ***may suffer from systematics***

  0νββ ➔ $|m_{ee}|$: ***suffers from nuclear physics***

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  cosmolo… ➔ sum Σ: *may suffer from systematics*

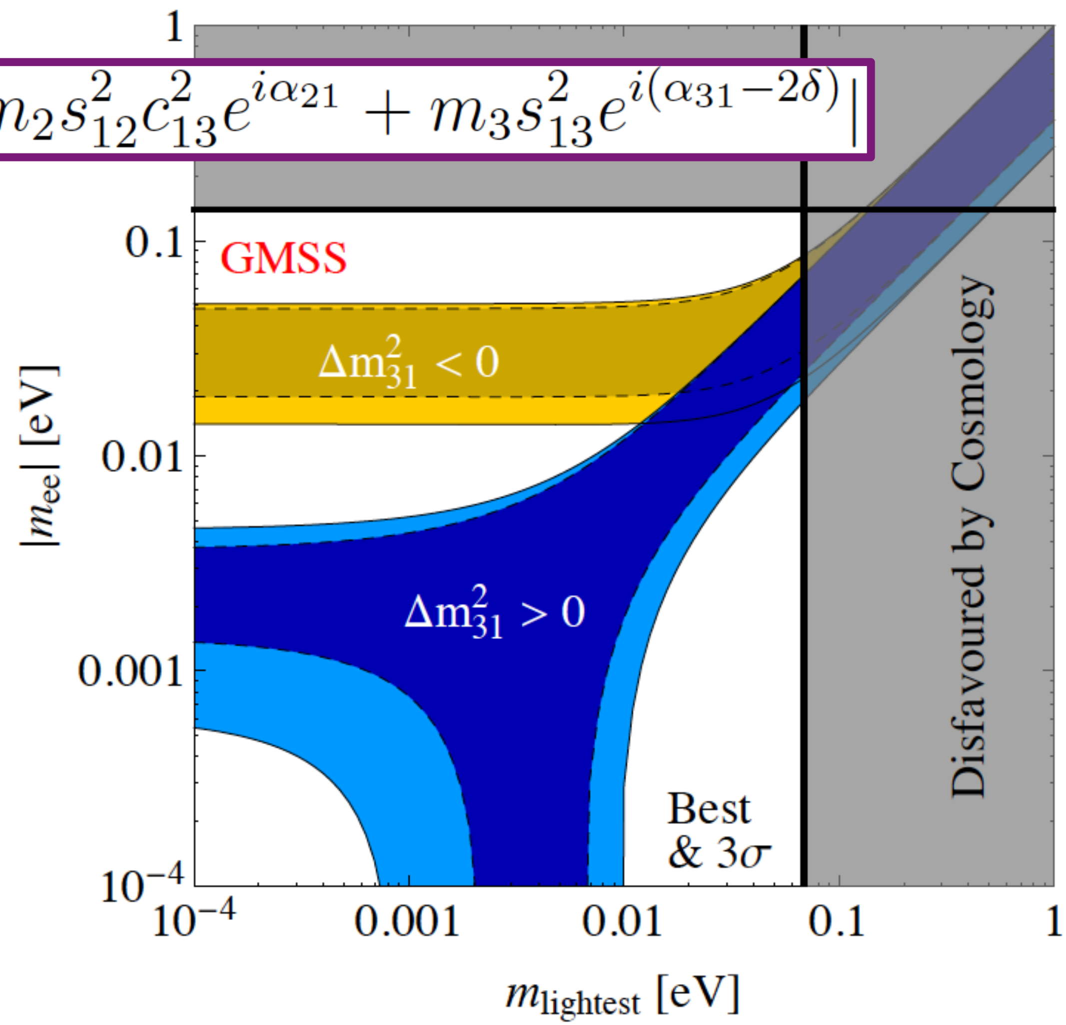
  0νββ ➔ $|m_{ee}|$: *suffers from nuclear physics*

➔ Our observable of choice.

2. Predictions for 0νββ

- **STANDARD PLOT FOR $|m_{ee}|$:**

$$|m_{ee}|_{\mathrm{PDG}} = \left|m_1 c_{12}^2 c_{13}^2 + m_2 s_{12}^2 c_{13}^2 e^{i\alpha_{21}} + m_3 s_{13}^2 e^{i(\alpha_{31}-2\delta)}\right|$$



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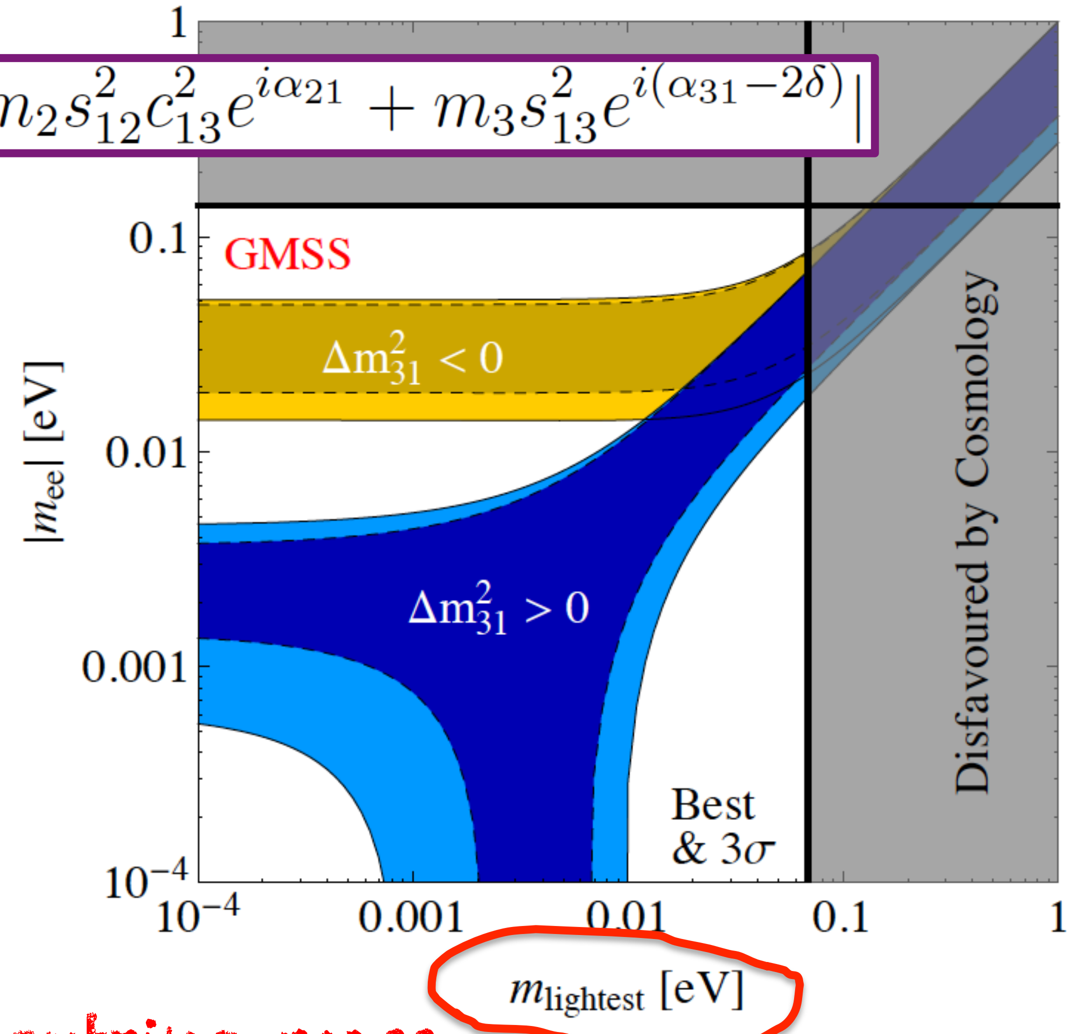

lightest neutrino mass

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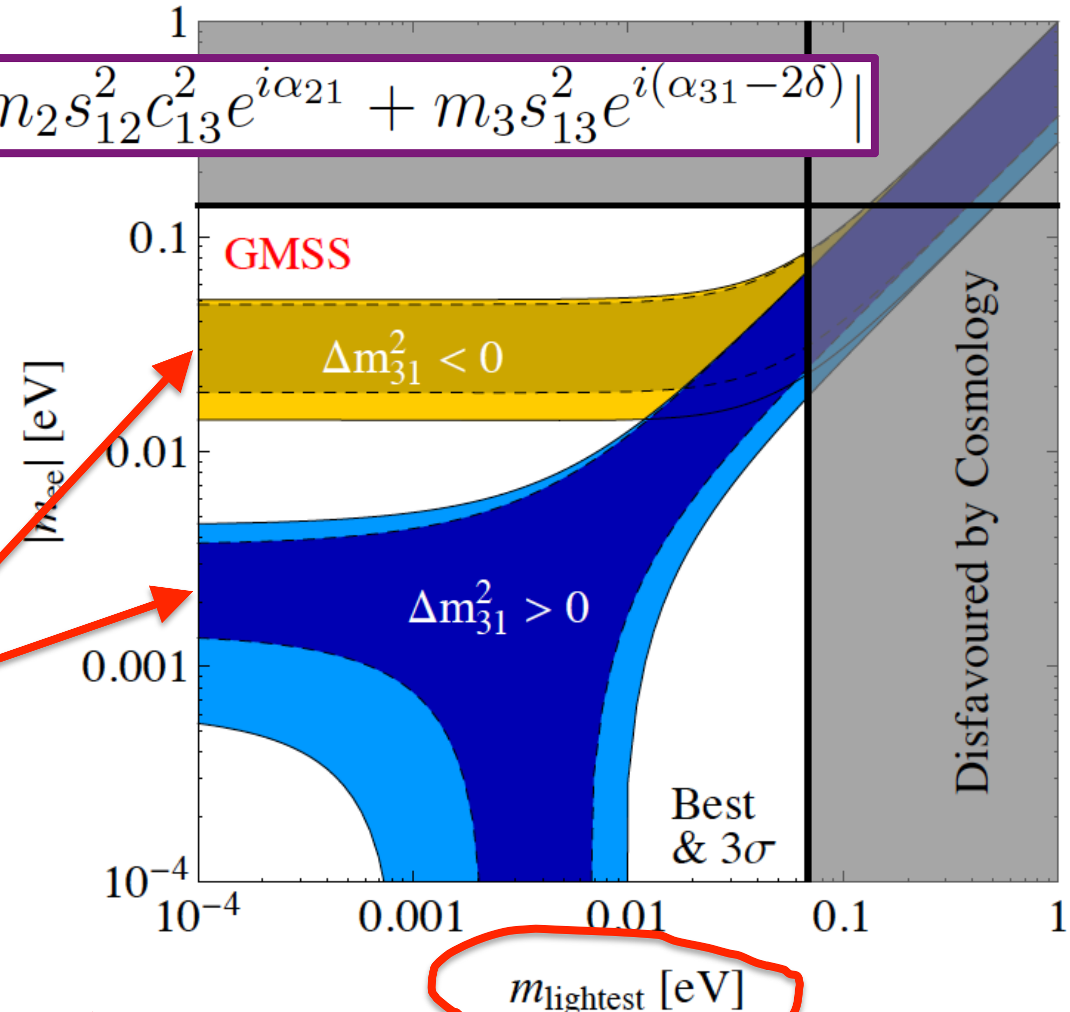


broadening mainly from varying the phases

lightest neutrino mass

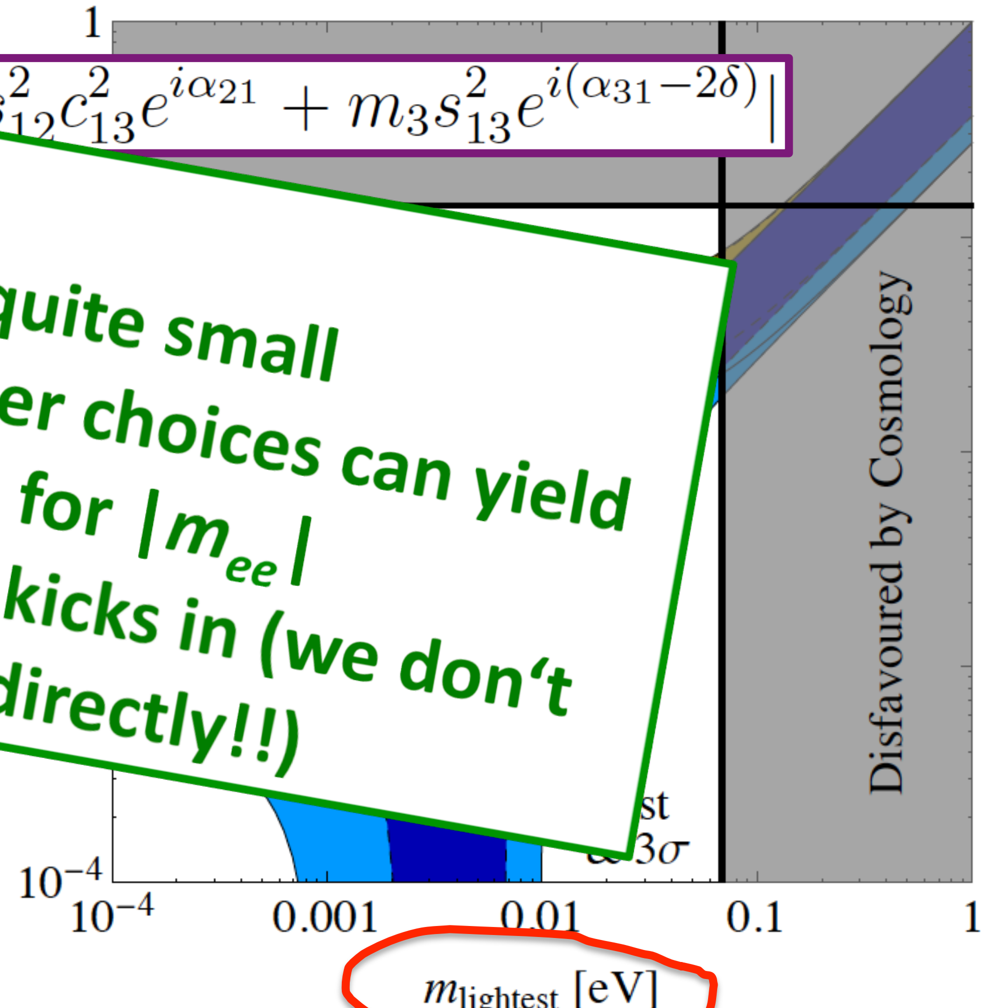
2. Predictions for 0νββ

- **STANDARD PLOT FOR |*m*$_{ee}$|:**

$$|m_{ee}|_{\mathrm{PDG}} \quad \ldots \quad + m_2 s_{12}^2 c_{13}^2 e^{i\alpha_{21}} + m_3 s_{13}^2 e^{i(\alpha_{31}-2\delta)}|$$

PROBLEMS:

- **|*m*$_{ee}$| can be quite small**
- **many parameter choices can yield the same value for |*m*$_{ee}$|**
- **nuclear physics kicks in (we don't measure |*m*$_{ee}$| directly!!)**



broaden...
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2. Predictions for 0νββ

- **STANDARD PLOT FOR |m_{ee}|:**

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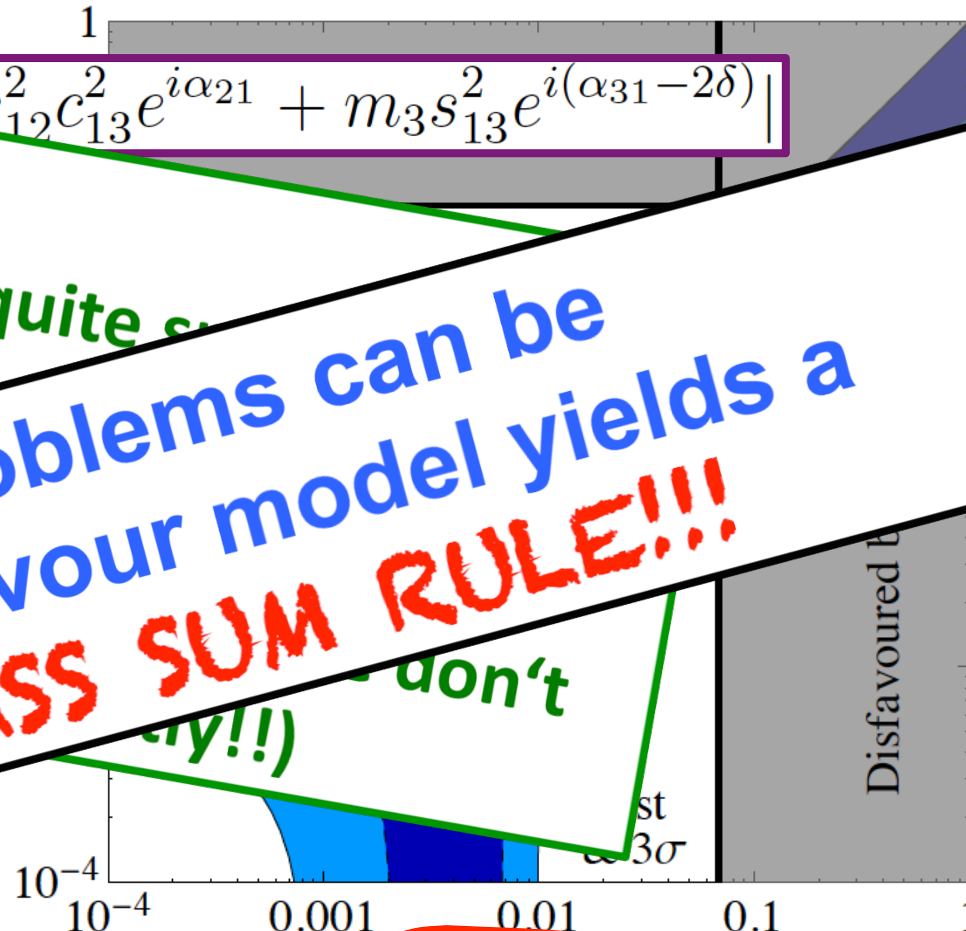


PROBLEMS:

- |m_{ee}| can be quite s…
- many paramet… the sam…
- n… …e don't …ly!!)

Many of these problems can be overcome if a flavour model yields a NEUTRINO MASS SUM RULE!!!

lightest neutrino mass

3. Mass sum rules

- example mass sum rules (*tilde*=complex mass):

$$\tilde{m}_1 + \tilde{m}_2 = \tilde{m}_3$$

$$\frac{2}{\tilde{m}_2} = \frac{1}{\tilde{m}_1} + \frac{1}{\tilde{m}_3}$$

$$\tilde{m}_1 = 2\tilde{m}_2 + \tilde{m}_3$$

$$\frac{1}{\tilde{m}_1} - \frac{2}{\tilde{m}_2} - \frac{1}{\tilde{m}_3} = 0$$

$$\frac{1}{\sqrt{\tilde{m}_1}} + \frac{1}{\sqrt{\tilde{m}_2}} = \frac{2}{\sqrt{\tilde{m}_3}}$$

$$2\sqrt{\tilde{m}_2} + \sqrt{\tilde{m}_3} = \sqrt{\tilde{m}_1}$$

$$\tilde{m}_1 - \frac{\sqrt{3}-1}{2}\tilde{m}_2 + \frac{\sqrt{3}+1}{2}\tilde{m}_3 = 0$$

$$\frac{1}{\tilde{m}_3} + \frac{2i(-1)^\eta}{\tilde{m}_2} - \frac{1}{\tilde{m}_1} = 0$$

$$\frac{1}{\tilde{m}_1} + \frac{1}{\tilde{m}_2} = \frac{1}{\tilde{m}_3}$$

3. Mass sum rules

- any mass sum rule can be written as follows:

$$m_1^p + B_2 \left(m_2 e^{i\alpha_{21}}\right)^p e^{i\Delta\chi_{21}} + B_3 \left(m_3 e^{i\alpha_{31}}\right)^p e^{i\Delta\chi_{31}} = 0$$

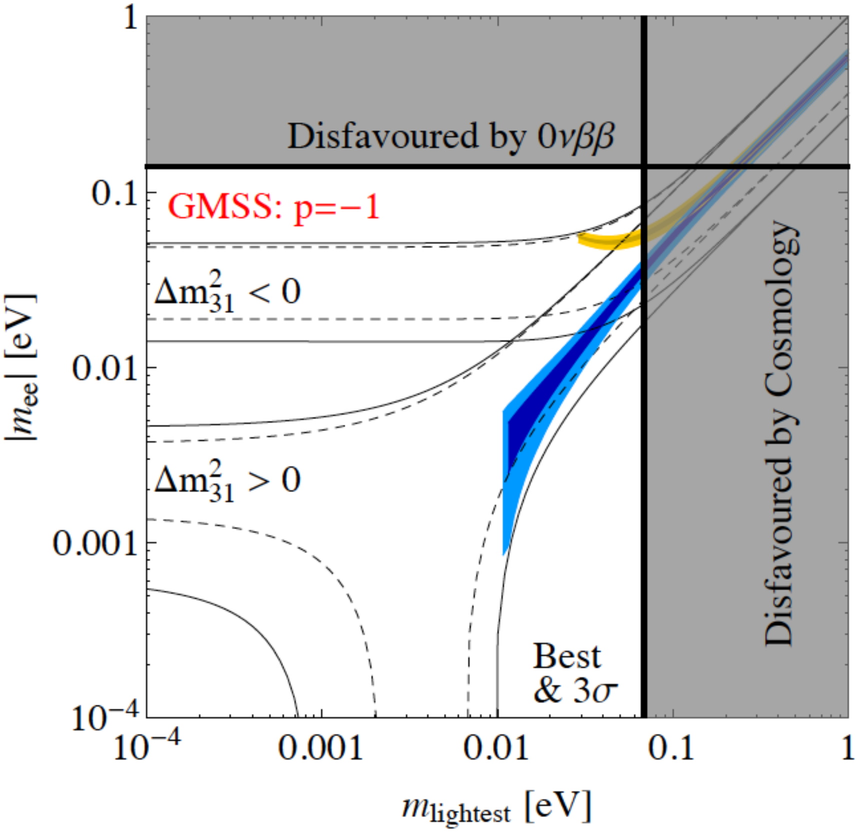
➔ each sum rule can be characterised by **FIVE** parameters:

(p, B_2, B_3, $\Delta\chi_{21}$, $\Delta\chi_{31}$)

➔ each sum rule yields **TWO** pieces of information (**complex equation!!!**)

3. Mass sum rules

- general features: $$\frac{1}{\tilde{m}_1} + \frac{1}{\tilde{m}_2} = \frac{1}{\tilde{m}_3}$$



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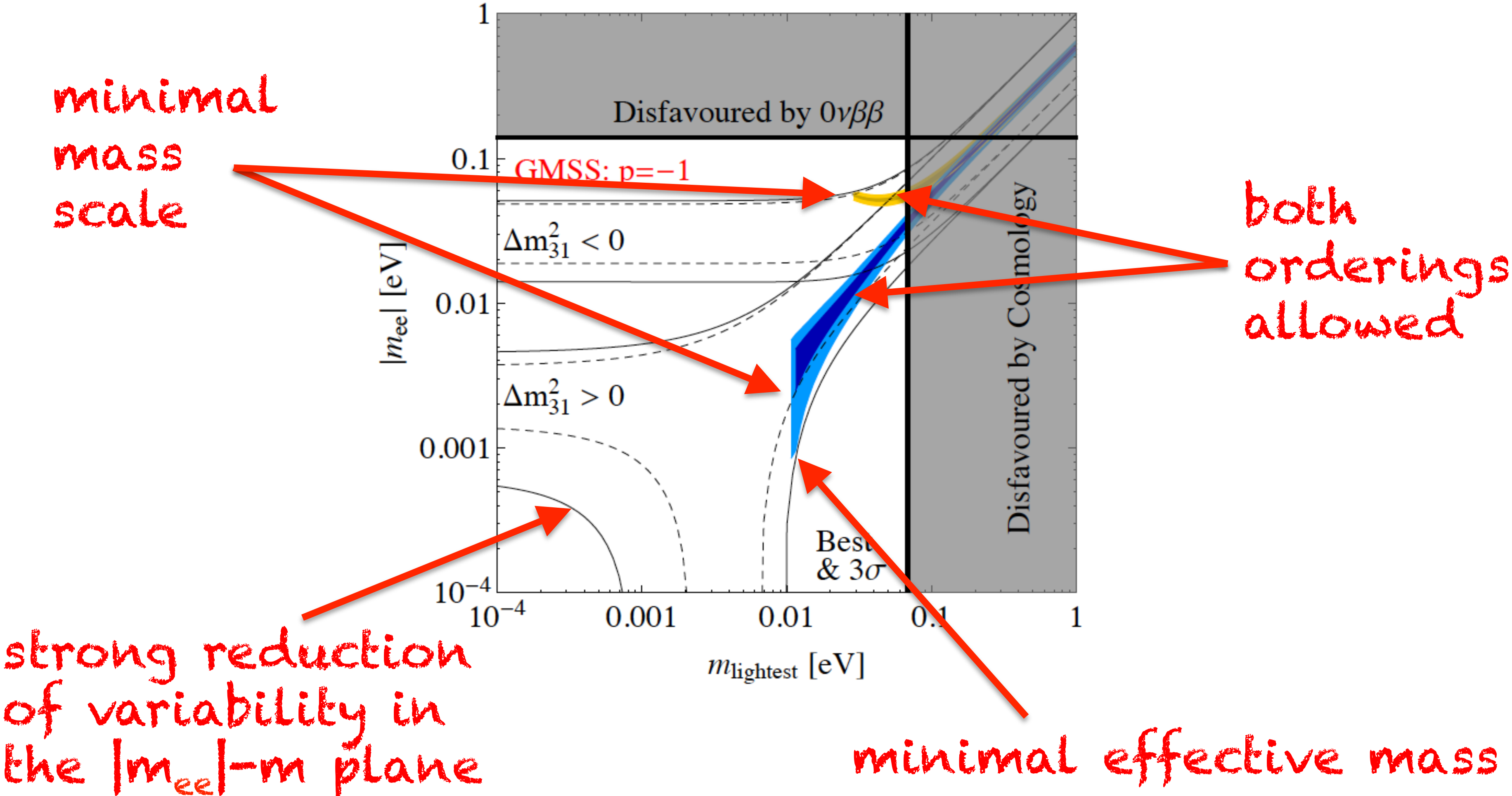

3. Mass sum rules

- general features: $\frac{1}{\tilde{m}_1} + \frac{1}{\tilde{m}} = \frac{1}{\ldots}$

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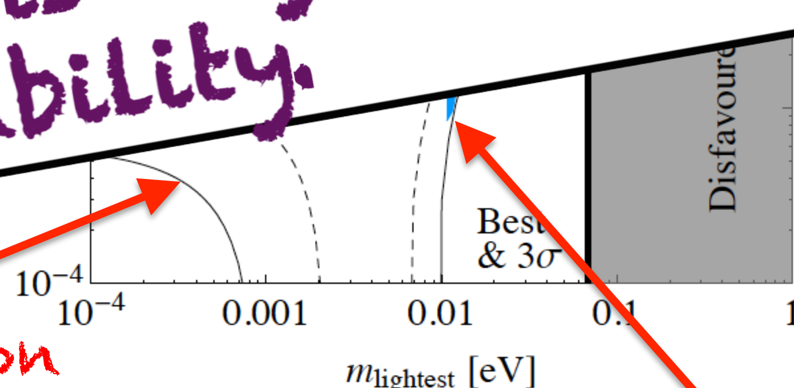
Indeed, a mass sum rule can drastically reduce the available parameter space.

This is key to allow for testability.

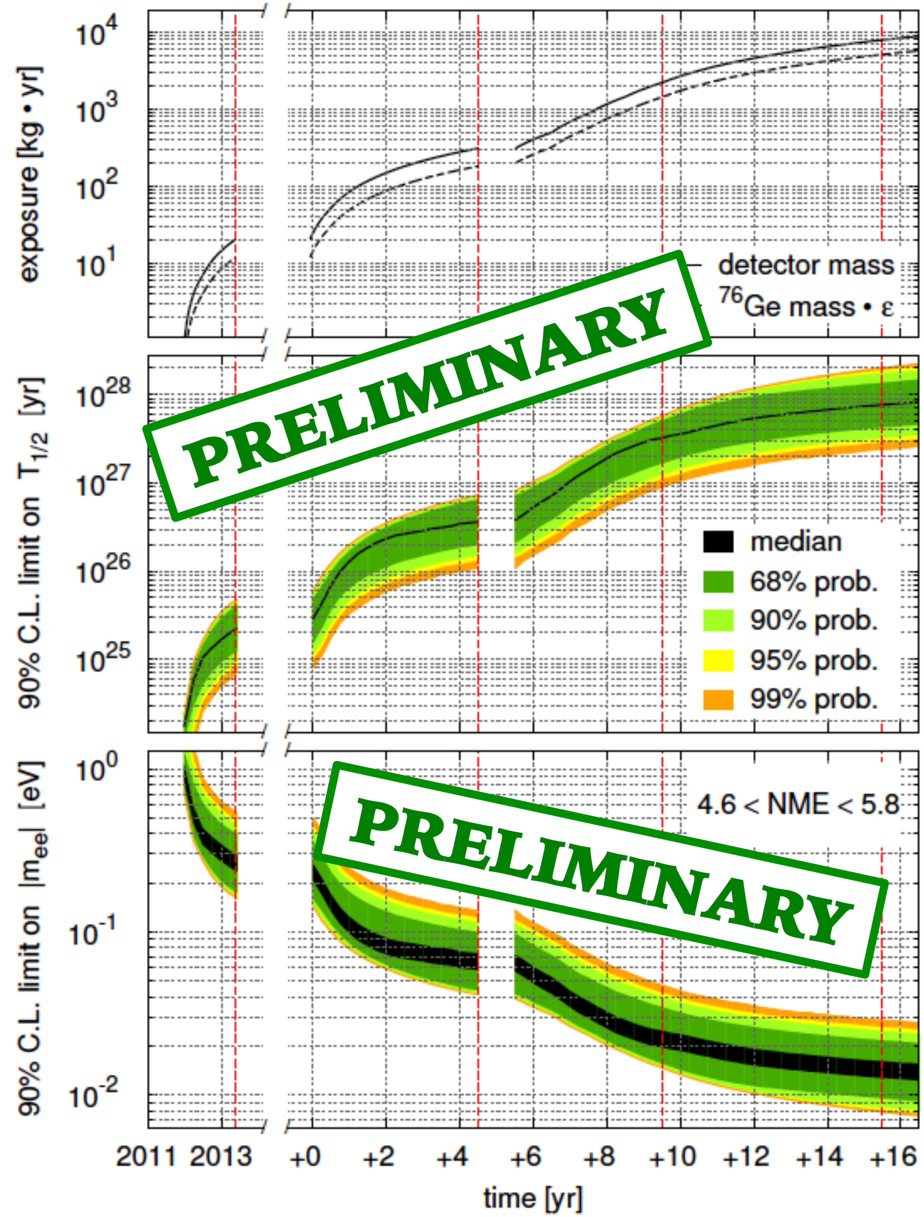


strong reduction of variability in the $|m_{ee}|$–m plane

minimal effective mass

4. Future experiments

- future experiments on neutrinoless double beta decay may gradually approach an $|m_{ee}|$ of about 0.01eV
- with predictions as explicit as those obtained from neutrino mass sum rules, we can extract valuable physics results already on the way to the ultimate sensitivity



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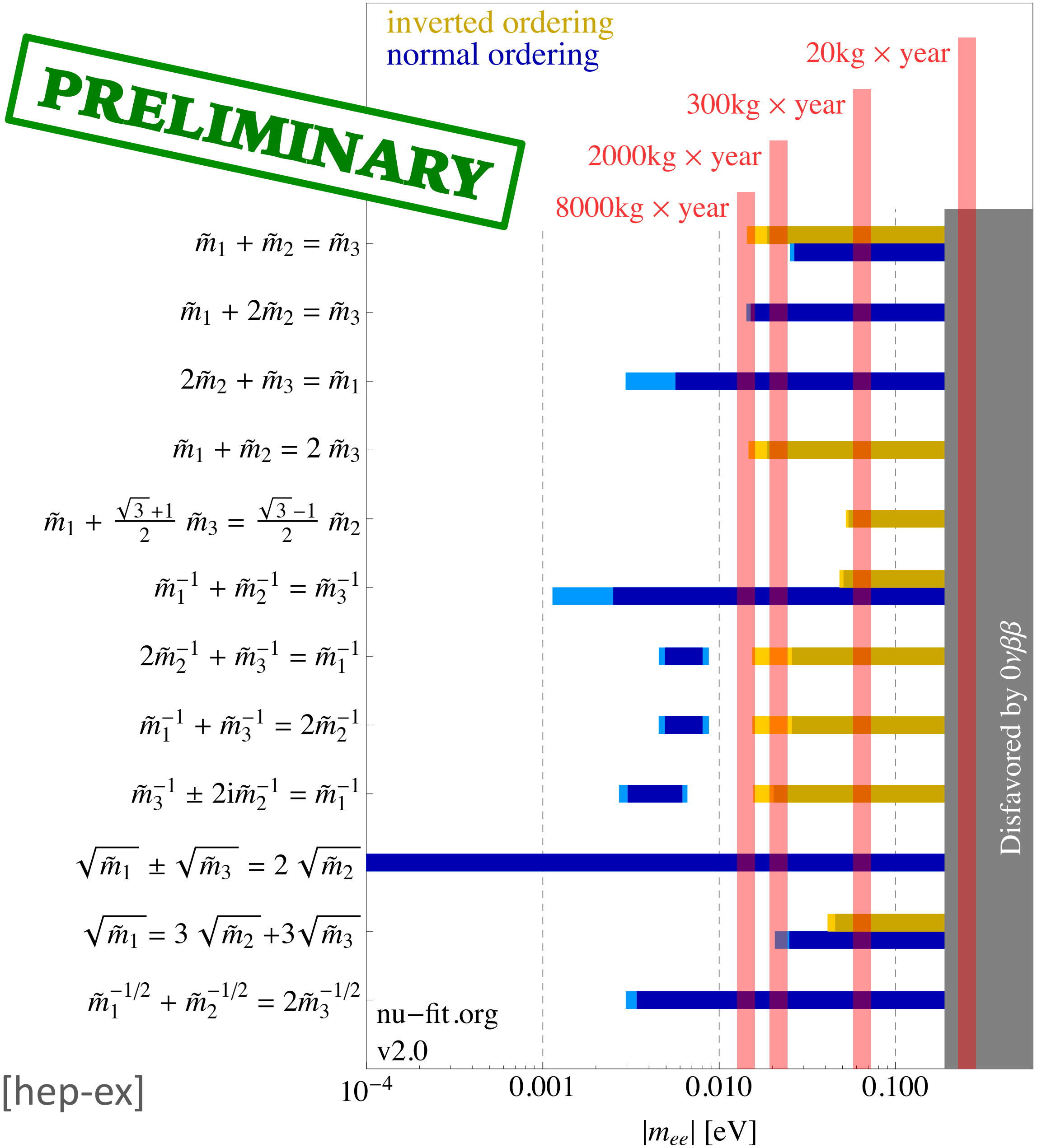
4. Future experiments

- depending on the size of future experiments, they may probe certain groups of models quite soon

- identification of mass ordering would help a lot

- ultimate sensitivity of next generation experiments does not leave much room



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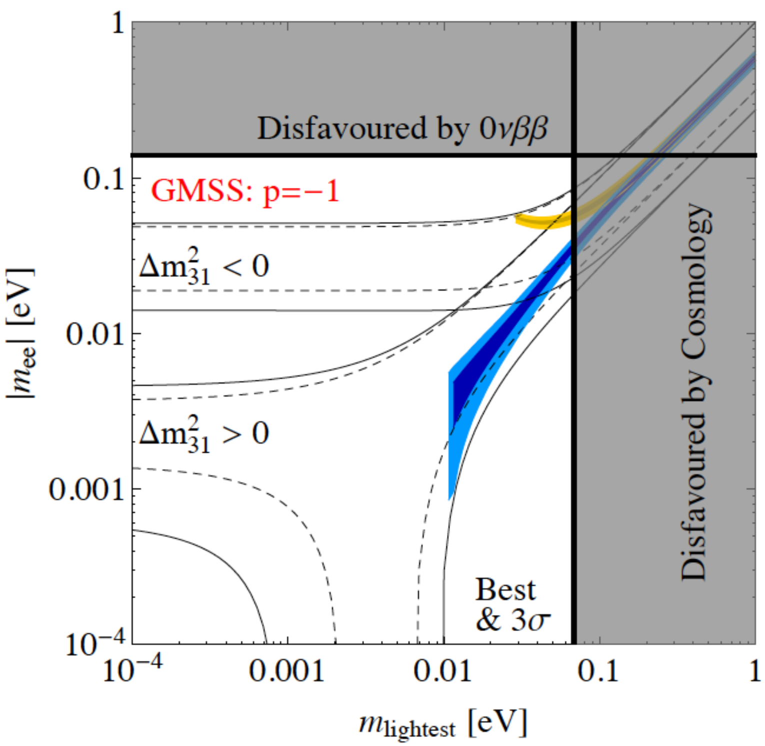
5. Theoretical advances

- **sum rules are not know with infinite precision**

...we need to take into account corrections!!!

- **corrections from RENORMALISATION GROUP RUNNING:**



$$\frac{1}{\tilde{m}_1} + \frac{1}{\tilde{m}_2} = \frac{1}{\tilde{m}_3}$$

This plot may change when including RGE...

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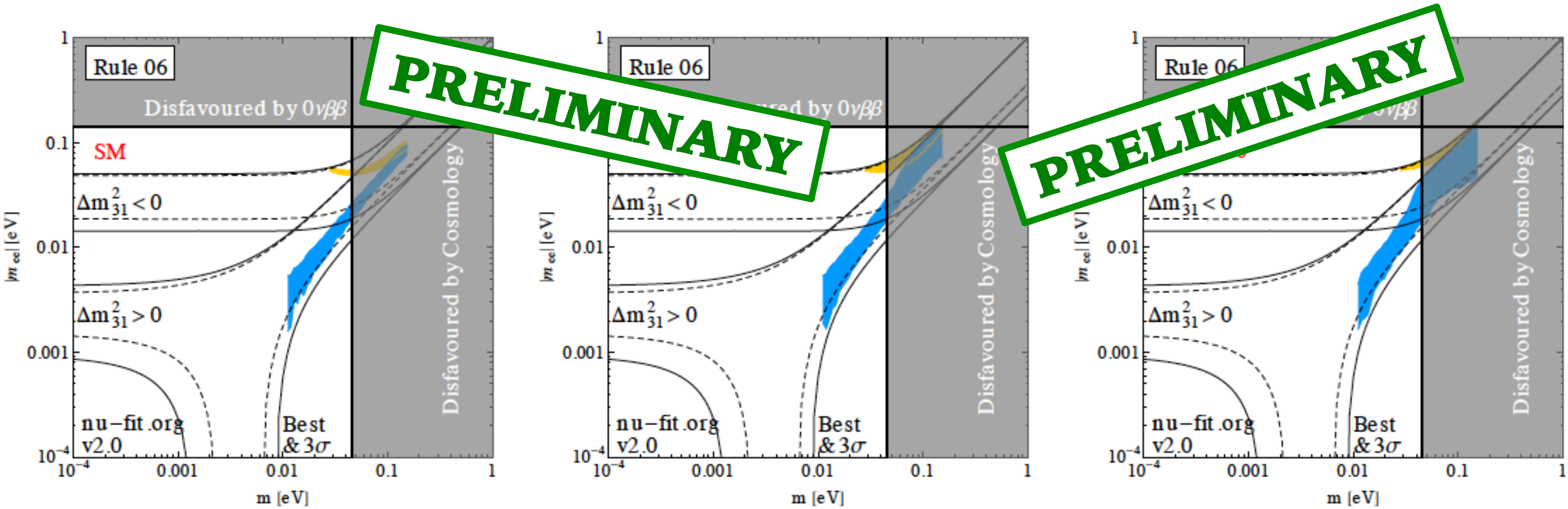
5. Theoretical advances

- **changes visible for large tanβ in SUSY models:**



SM-like **tanβ=30** **tanβ=50**

- SURPRISING: **if a certain mass ordering is forbidden by an exact sum rule, it does NOT open up by RGE corrections!!!**

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5. Conclusions

- *often not sufficiently appreciated*: neutrino mass sum rules are among the **most important tools to distinguish flavour models** (in the absence of precision measurements of mixings & phases)
- we did the most comprehensive classification:
  - ***more than 50 models leading to 12 sum rules***
  - ***all three global fits***
  - ***most recent experimental bounds & NME uncertainties***
- new advances out **this month**:
  - **experimental study with realistic numbers**
  - **effect of renormalisation group running**


THANK YOU!!!