Minimal Flavour Violation

The hypothesis that the Yukawas are the only source of flavour violation in SM and Beyond Standard Model

R. S. Chivukula and H. Georgi, Phys. Letters B 188 99 (1987)

Such an assumption is very predictive:

Successful in quark sector

Consistent with not finding
new signals at B factories

Would MINSIS give stronger constraints on the Minimal Flavour Violation Simplest model?

For the quark sector:

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{c^{d=6}}{\Lambda_{fl}^2} O^{d=6} + \dots$$

(D'Ambrosio, Cirigliano, Isidori, Grinstein, Wise….Buras….)

$$O^{d=6}_{\alpha\beta\gamma\delta} \sim \bar{Q}_\alpha Q_\beta \bar{Q}_\gamma Q_\delta \longrightarrow c^{d=6}_{\alpha\beta\gamma\delta} \sim Y^\dagger_{\alpha\beta} Y_{\gamma\delta}$$

Given a dimension 6 Op with flavour structure

MFV tells us the coeficients

AND THIS IS MODEL INDEPENDENT

For the lepton sector majorana neutrino masses induce a dim 5 operator:

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{c^{d=5}}{\Lambda_{LN}} O^{d=5} + \frac{c^{d=6}}{\Lambda_{fl}^2} O^{d=6} + \dots$$

Cirigliano, Isidori, Grinstein, Wise

THIS IS MODEL DEPENDENT

It is possible, and sensible to assume: $TeV \sim \Lambda_{fl} << \Lambda_{LN} \sim 10^{15} GeV (GUT)$

For neutrino masses are known to be very small, but we could have seizable effects of flavour violation.

How do we achieve such a condition with a type I Seesaw?

THE SIMPLEST CASE DOES NOT WORK
simplest type I seesaw

If we try the Standard Seesaw with an added singlet coupled via Yukawas:

$$\mathscr{L} = \cdots - Y_N \bar{N} \phi^\dagger L_L - \Lambda \, \bar{N}^c N \ldots$$

THERE IS ONLY ONE SCALE FOR BOTH OPERATORS!

$$\mathscr{L}_{M_\nu} = \begin{array}{c} \\ \\ \end{array} \begin{array}{cc} \bar{L}_i & \bar{N}^c \\ \left(\begin{array}{c} 0 \\ Y_N v \end{array} \right. & \left. \begin{array}{c} Y_N^T v \\ \Lambda \end{array} \right) \end{array} \begin{array}{c} L_i^c \\ N \end{array}$$

SOLUTION: INVERSE SEESAW

→ **We have to introduce another mediator** $N\overline{N'}$

* Besides the N there are N' , connected by a Dirac-type mass

$$\overline{N'}\Lambda N$$

* Majorana character in the N' mass μ

$$\mathscr{L}_{M_\nu} = \begin{array}{c} \\ \\ \\ \end{array}\begin{array}{ccc} \bar{L}_i & \bar{N}^c & \bar{N}'^c \\ \left(\begin{array}{ccc} & Y_N^T v & 0 \\ Y_N v & 0 & \Lambda^T \\ 0 & \Lambda & \mu \end{array}\right) \end{array}\begin{array}{c} L_i^c \\ N \\ N' \end{array}$$

This achieves scale separation

$\Lambda_{fl} = \Lambda$

$\Lambda_{LN} = \Lambda^2/\ \mu$

Usually $\Lambda \sim GUT$, $\mu \sim GUT$

But we will assume $\Lambda \sim TeV$, $\mu << TeV$

SOLUTION: INVERSE SEESAW

But we can also introduce small parameters in the other entries:

$$\mathscr{L}_{M_\nu} = \begin{array}{c} \\ \left(\begin{array}{ccc} \bar{L}_i & \bar{N}^c & \bar{N}'^c \\ 0 & Y_N^T v & \epsilon Y_N'^T v \\ Y_N v & \mu' & \Lambda \\ \epsilon Y_N' v & \Lambda & \mu \end{array}\right) \end{array} \begin{array}{c} \\ L_i^c \\ N \\ N' \end{array}$$

Wyler,Wolfenstein; Mohapatra,Valle, Branco,Grimus,Lavoura,Malinsky, Romao…

this theory yields the effective lagrangian operators after integrating the heavy fields:

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{c^{d=5}}{\Lambda_{LN}} O^{d=5} + \frac{c^{d=6}}{\Lambda_{fl}^2} O^{d=6} + \ldots$$

$$c_{\alpha\beta}^{d=5} \equiv \epsilon \left({Y_N'}^T \frac{1}{\Lambda^T} Y_N + Y_N^T \frac{1}{\Lambda} Y_N' \right)_{\alpha\beta} - \left(Y_N^T \frac{1}{\Lambda} \mu \frac{1}{\Lambda^T} Y_N \right)_{\alpha\beta}$$

$$c_{\alpha\beta}^{d=6} \equiv \left(Y_N^\dagger \frac{1}{\Lambda^\dagger \Lambda} Y_N \right)_{\alpha\beta} + \mathcal{O}(\epsilon) \,.$$

Now we can contact the low energy parameters and as this is a predictive model...

THE CONCRETE MODEL UNDER STUDY

- We are taking just one singlet N and it's associated N'
- So our yukawas have one index only Y_β

The model parameters are almost determined by the low energy ones

Mixing angles an phases $\approx$ # parameters in the yukawas

Normal hierarchy:

$$r = \frac{|\Delta m^2_{12}|}{|\Delta m^2_{13}|}$$

Up to terms of $\mathcal{O}(\sqrt{r}, s_{13})$, we find

$$Y^T \simeq y \begin{pmatrix} e^{i\delta} s_{13} + e^{-i\alpha} s_{12} r^{1/4} \\ s_{23}\left(1 - \frac{\sqrt{r}}{2}\right) + e^{-i\alpha} r^{1/4} c_{12} c_{23} \\ c_{23}\left(1 - \frac{\sqrt{r}}{2}\right) - e^{-i\alpha} r^{1/4} c_{12} s_{23} \end{pmatrix} .$$

Note the smallness of this element it'll be relevant for MINSIS

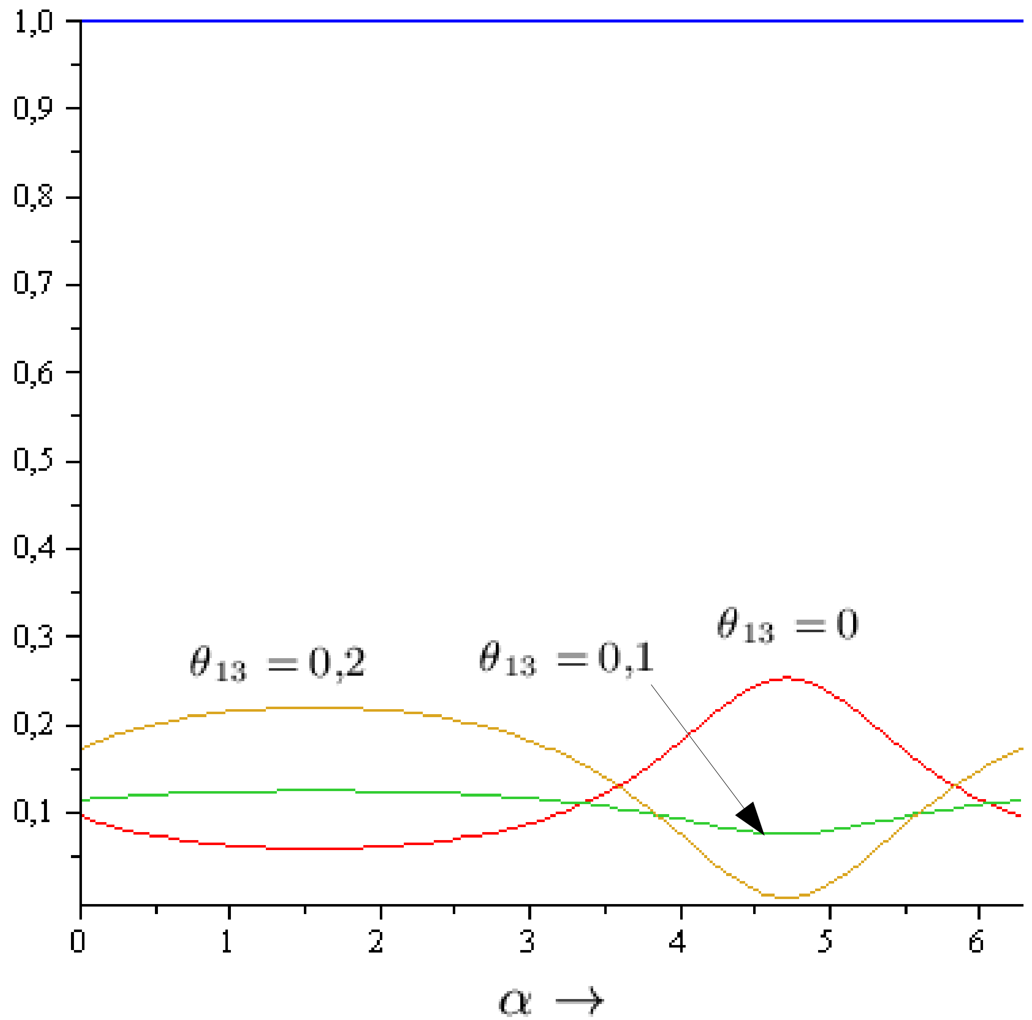
Inverted hierarchy:

$$Y^T \simeq \frac{y}{\sqrt{2}} \begin{pmatrix} c_{12} e^{i\alpha} + s_{12} e^{-i\alpha} \\ c_{12}\left(c_{23} e^{-i\alpha} - s_{23} s_{13} e^{i(\alpha-\delta)}\right) - s_{12}\left(c_{23} e^{i\alpha} + s_{23} s_{13} e^{-i(\alpha+\delta)}\right) \\ -c_{12}\left(s_{23} e^{-i\alpha} + c_{23} s_{13} e^{i(\alpha-\delta)}\right) + s_{12}\left(s_{23} e^{i\alpha} - c_{23} s_{13} e^{-i(\alpha+\delta)}\right) \end{pmatrix}$$

Hambye, Hernandez2, B.G. 09

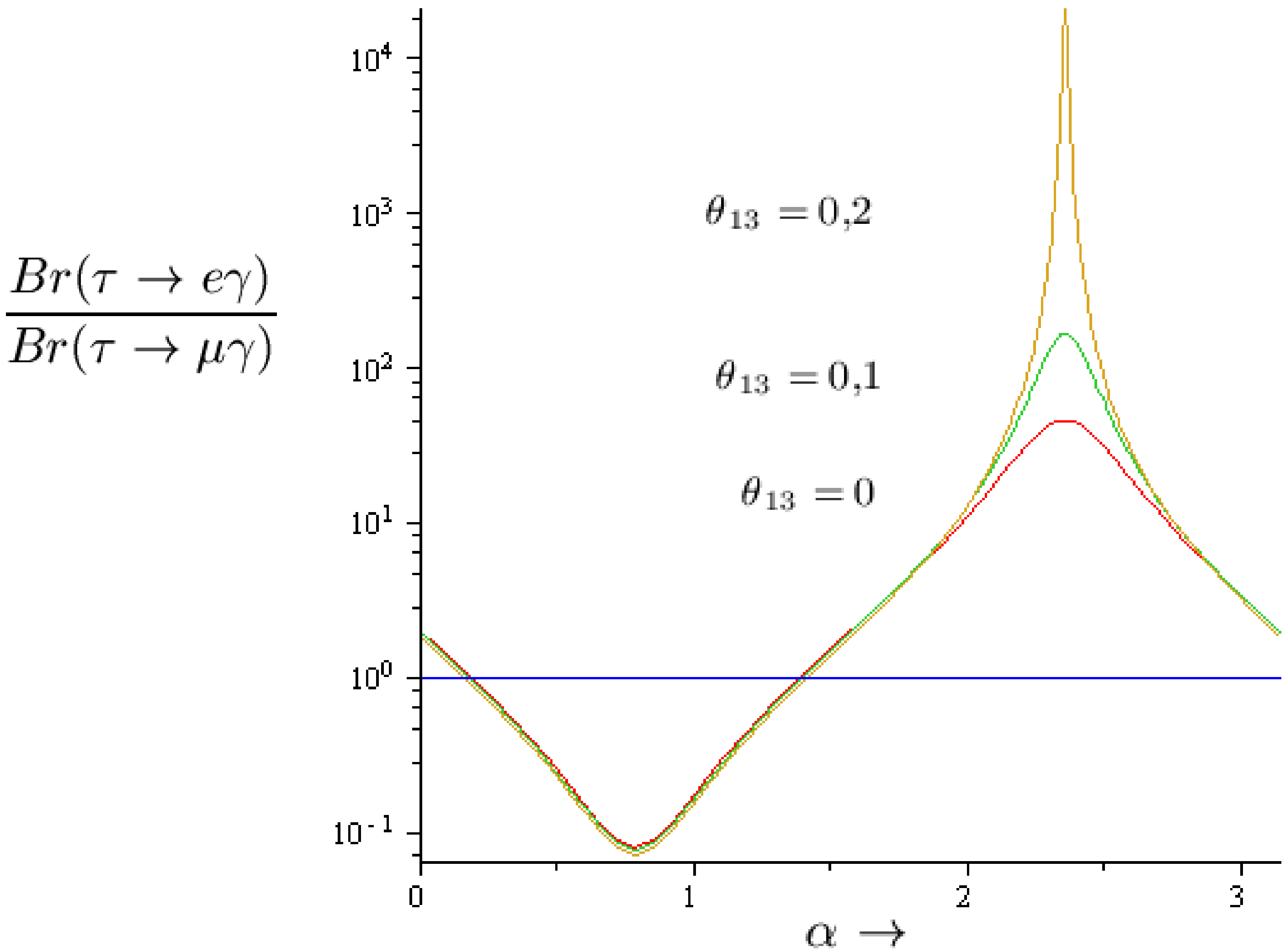
Normal hierarchy:

$$\frac{Br(\tau \to e\gamma)}{Br(\tau \to \mu\gamma)}$$



$$\frac{Br(\tau \to e\gamma)}{Br(\tau \to \mu\gamma)} \sim 10^{-1}$$

Inverted hierarchy:



Strong dependence on the Majorana phase

Dimension 6 Operator

The dimension 6 Operator induces non Unitarity $\nu_\alpha = N_{\alpha i}\nu_i$

$$NN^\dagger_{\alpha\beta} \approx \delta_{\alpha\beta} - \frac{v^2}{\Lambda^2} Y^*_\alpha Y_\beta$$

The bounds on non unitarity restrict our model

we can bound the moduli of $\frac{v^2}{\Lambda^2}$

An example:

$$\frac{10^{-3}}{|Y_\mu Y^*_\tau|} > \frac{\left|(NN^\dagger)_{\mu\tau}\right|}{|Y_\mu Y^*_\tau|} = \frac{v^2}{\Lambda^2}$$

A SMALL VALUE OF $Y^*_\alpha Y_\beta$ WORSENS THE BOUND ON OUR MODEL

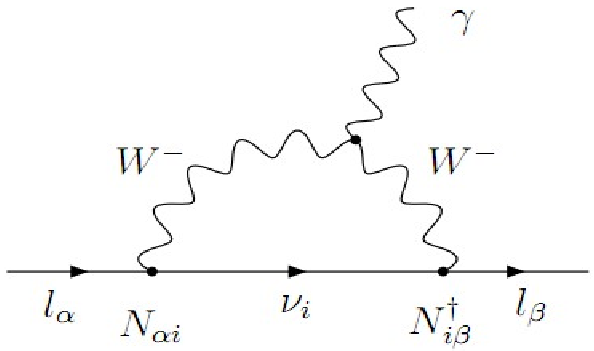
There are bounds on non-unitarity coming from:

Rare decays

Weak decays

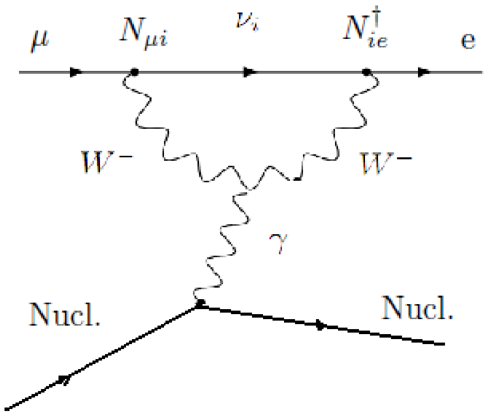
Invisible Z width

Neutrino Oscillations



and others are coming

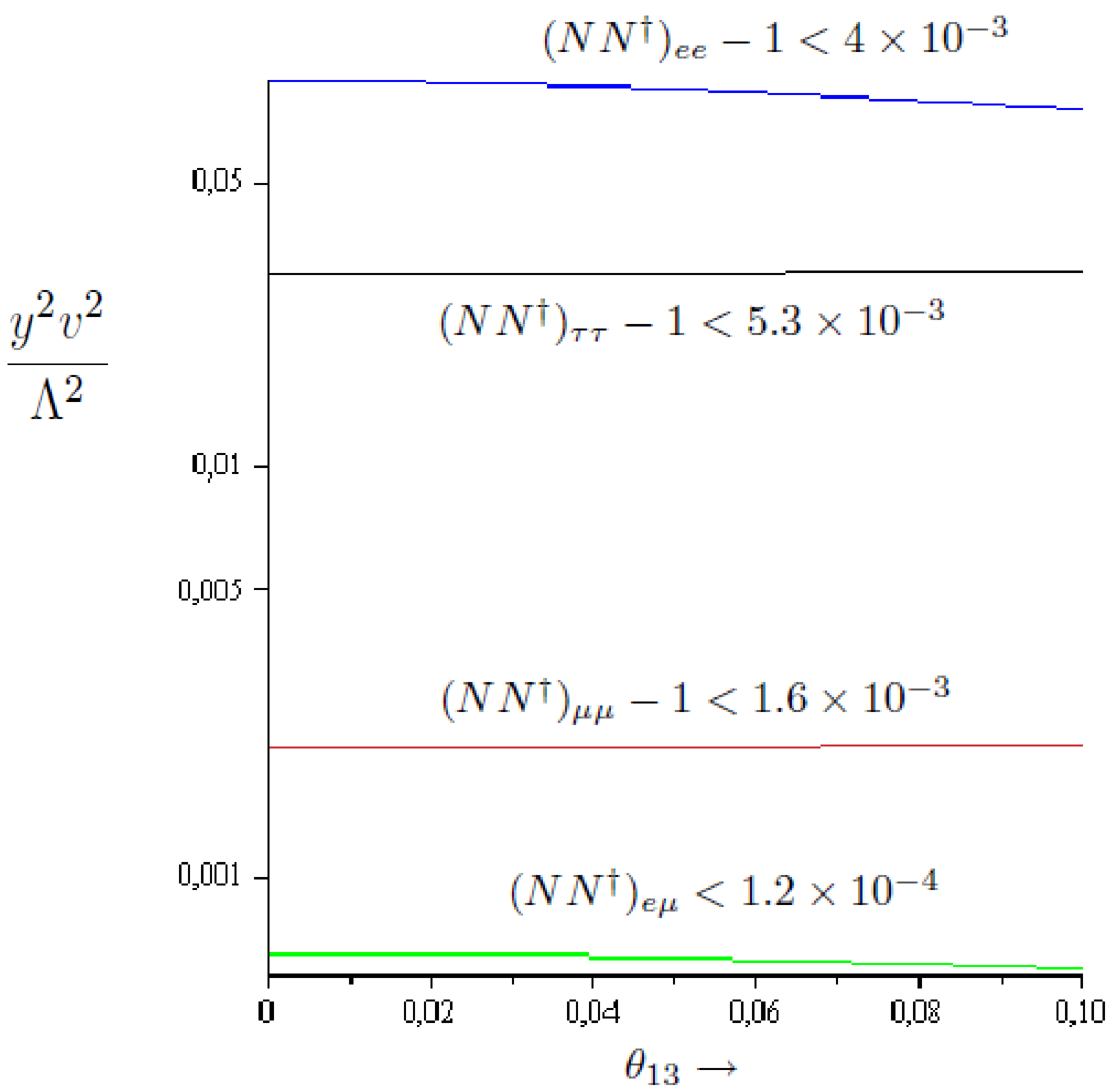
mu to e conversion



that we can use to restrict the parameters in our model:

Normal hierarchy:

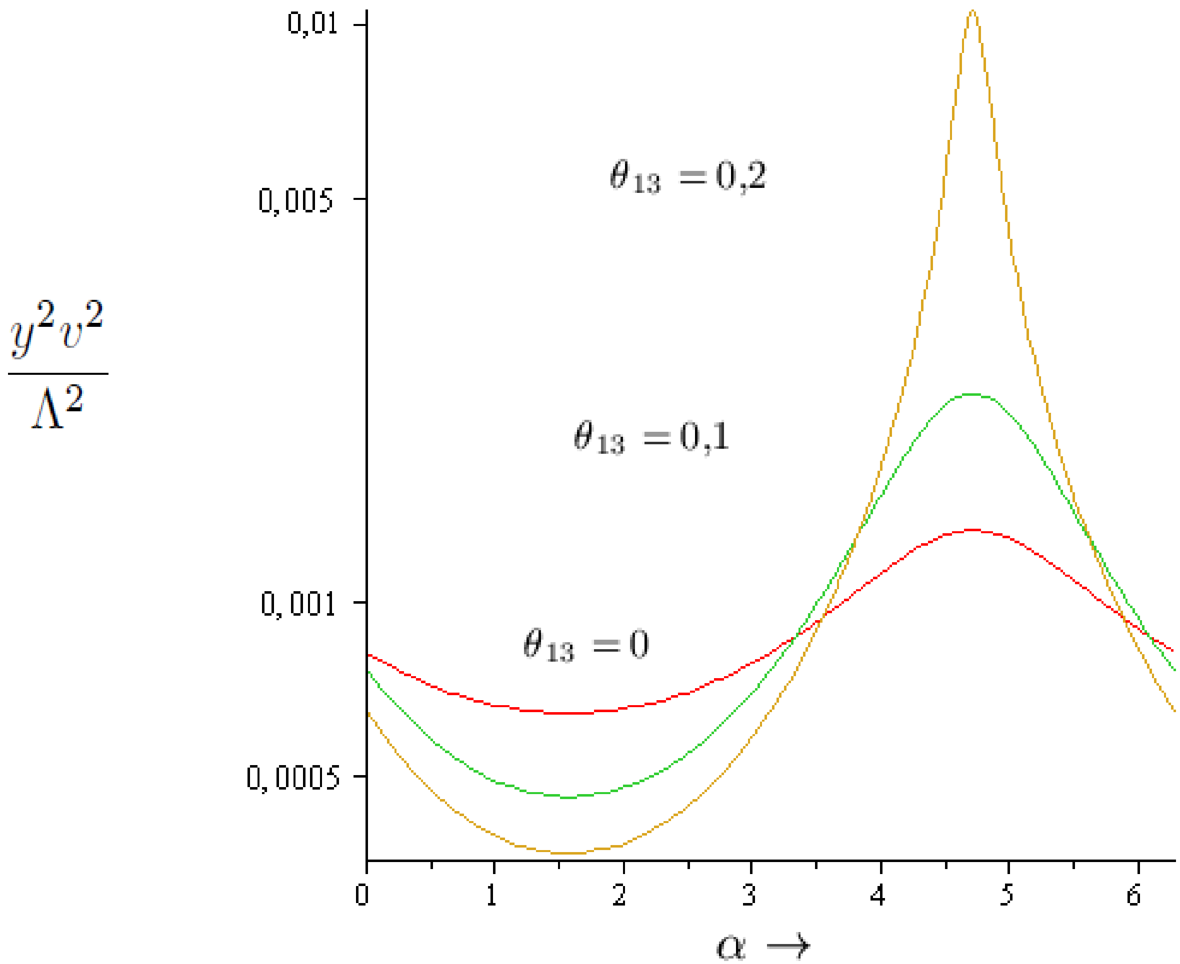
$$\frac{y^2 v^2}{\Lambda^2} \text{ VS } \theta_{13}$$



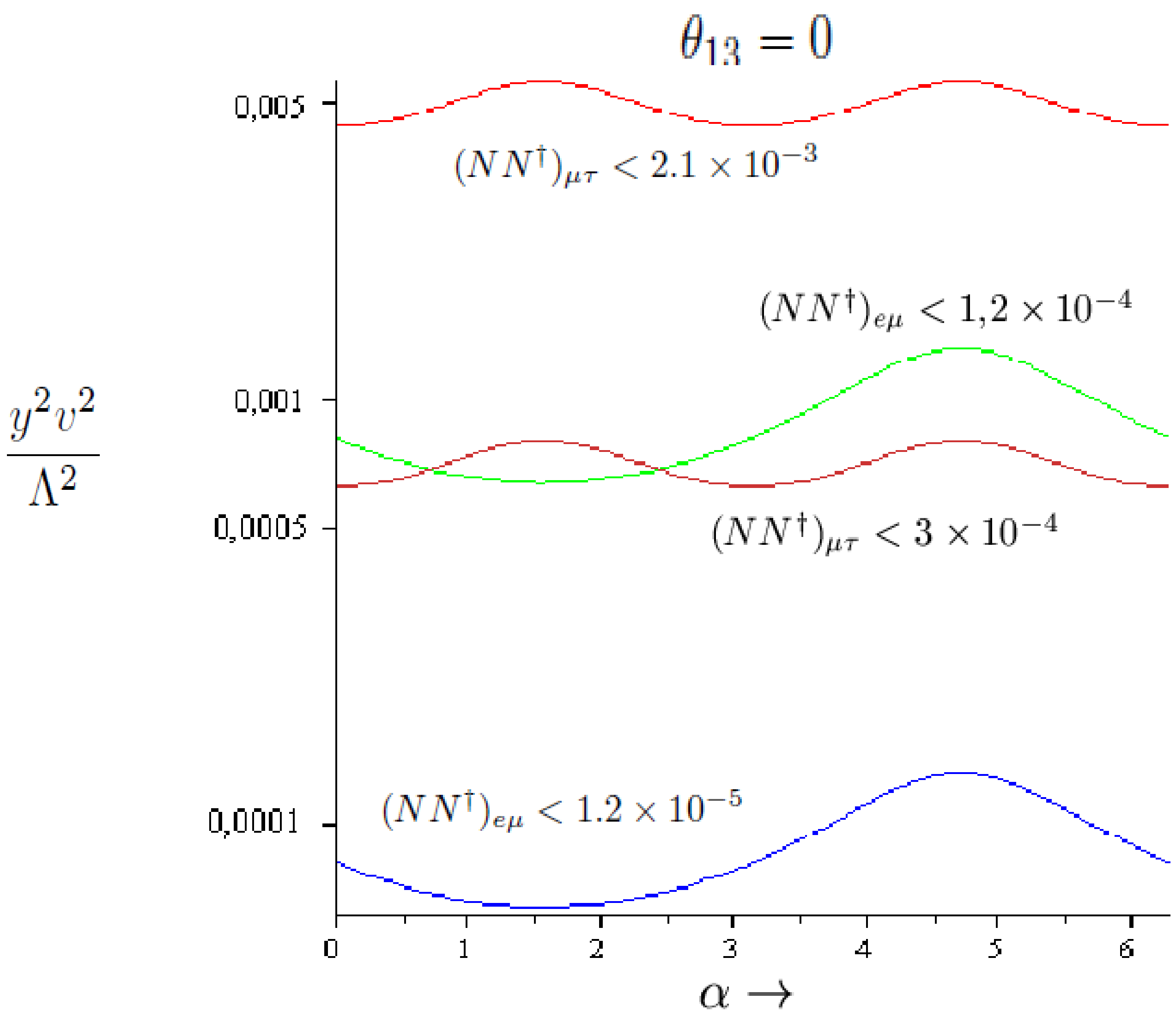
Actual Data

Normal hierarchy:

The best bound for this model to this date is given by the constraint on the rare decay $\mu \to e\gamma$



Normal hierarchy: MINSIS and MFV



Current Diagonal-deduced bound on $(NN^\dagger)_{\mu\tau}$

Current bound on $(NN^\dagger)_{e\mu}$

Expected bound from MINSIS

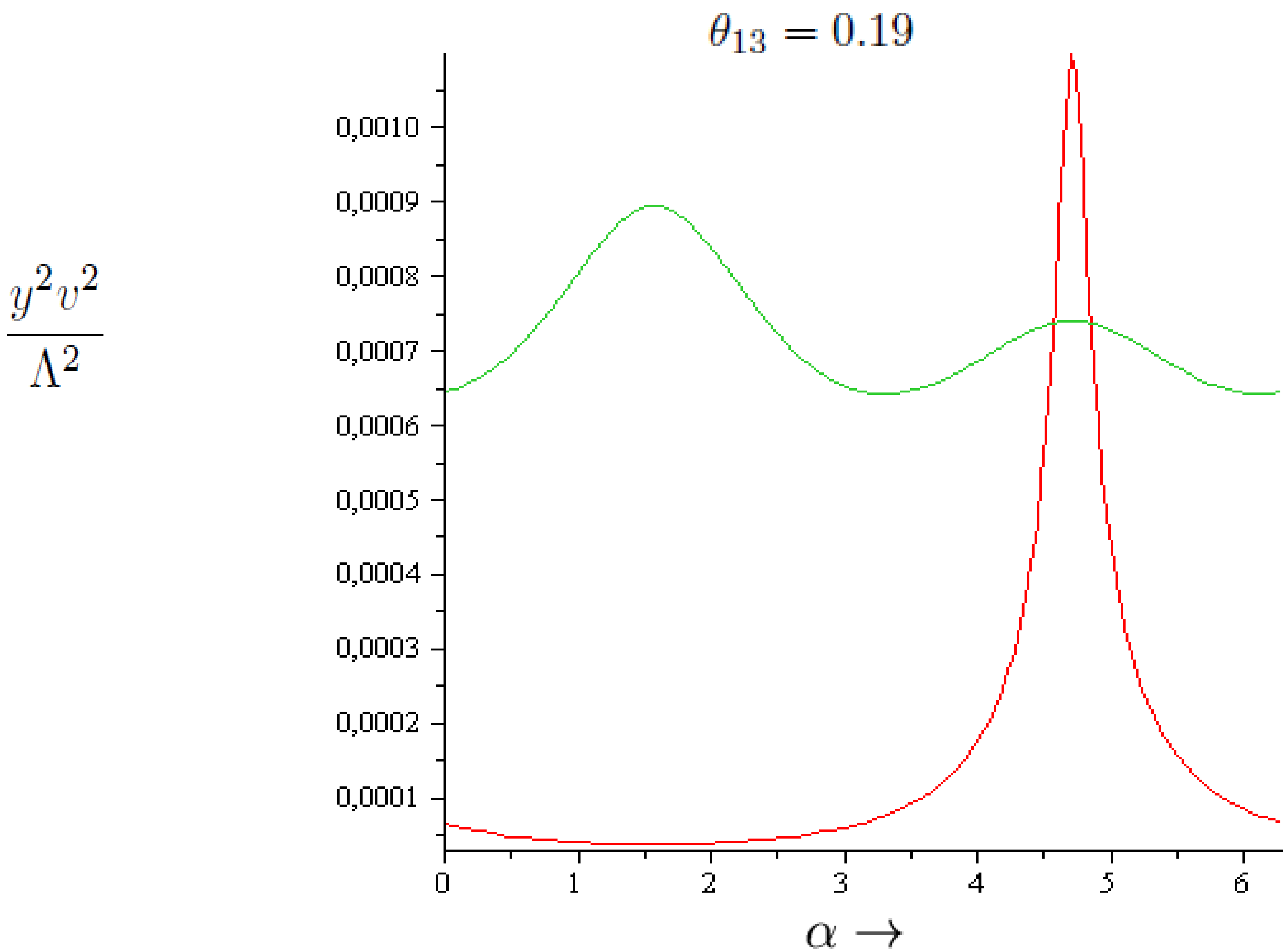
Expected MEG bound

BUT there are regions where:

Normal hierarchy: MINSIS and MFV

MINSIS WOULD DO BETTER THAN MEG

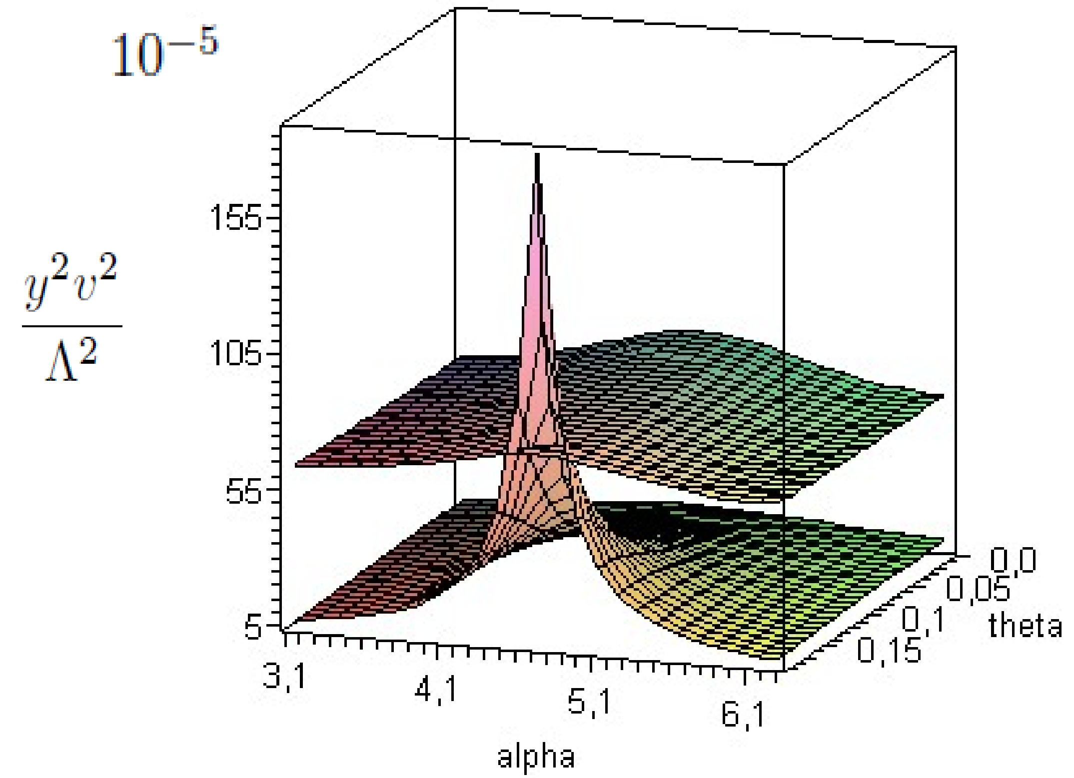
with a 10^-7 sensitivity:



The peak depends on r and theta12

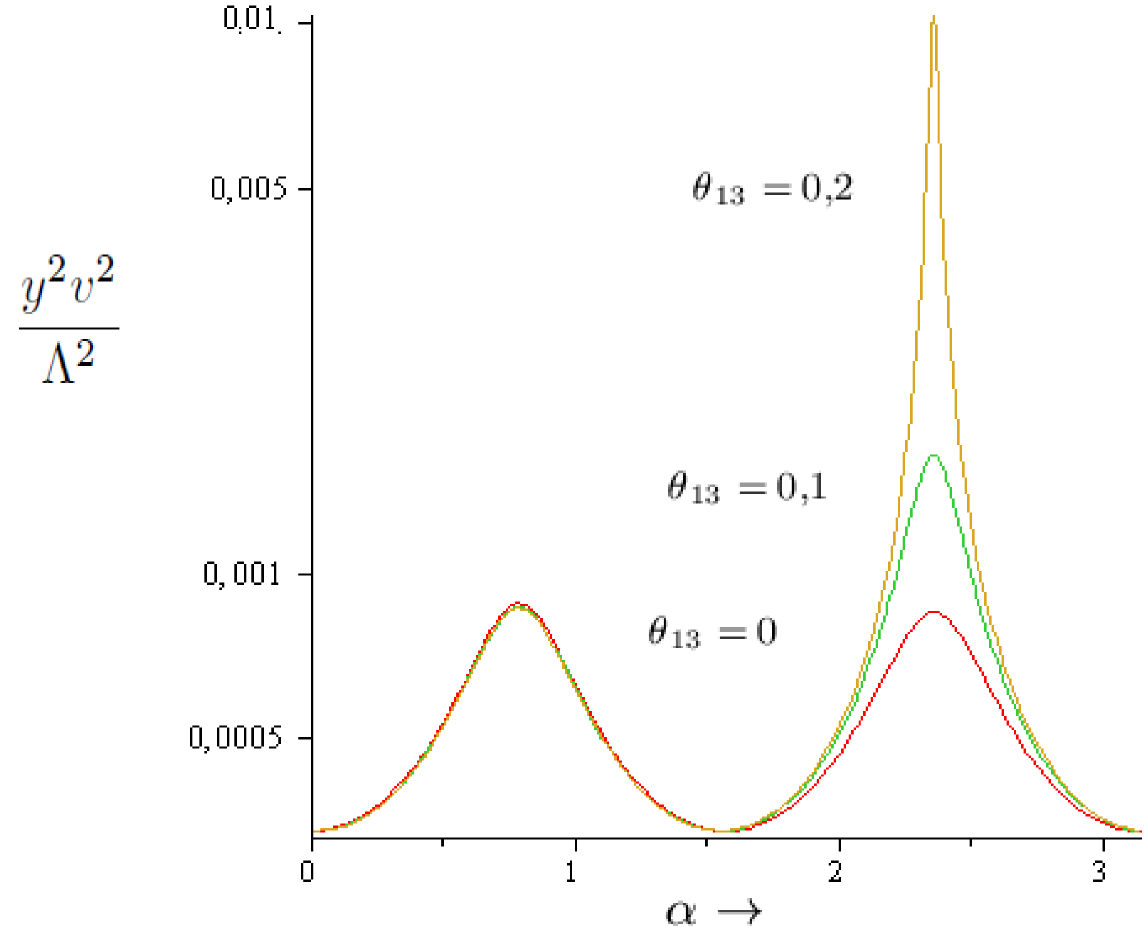
Normal hierarchy: MINSIS and MFV

with a 10^-7 sensitivity:



Inverted hierarchy:

The best bound for inverted Hierachy comes from the mu to e meassure



$$\frac{y^2 v^2}{\Lambda^2} < 10^{-3}$$

CONCLUSION

So with the actual data we can say: $\frac{yv}{\Lambda} < 3 \times 10^{-2}$

MINSIS AND MINIMAL FLAVOUR VIOLATION

MINSIS WOULD IMPROVE ACTUAL BOUNDS ON OUR MFV MODEL

BUT, FURTHERMORE:

IT WOULD EVEN IMPROVE MEG EXPECTED BOUNDS
IN CERTAIN REGIONS OF OUR PARAMETER SPACE

FIN

As we have a predictive model there are physical quantities we can determine without knowing the actual values of our parameters

Normal hierarchy:

To try and see through all the formulae lets make take $\theta_{12} = \theta_{23} = \pi/4$ and expand on r and θ_{13}

$$|Y_e| = \frac{y}{2}\Big(r^{1/4} + \sqrt{2}(1 - \frac{\sqrt{r}}{4}) \sin(\alpha + \delta) \sin\theta_{13} + \dots\Big)$$

$$|Y_\mu| = \frac{y}{\sqrt{2}}\Big(\sqrt{1 - \frac{\sqrt{r}}{4} + r^{1/4}\sin\alpha)} + \dots\Big)$$

$$|Y_\tau| = \frac{y}{\sqrt{2}}\Big(\sqrt{1 - \frac{\sqrt{r}}{4} - r^{1/4}\sin\alpha)} + \dots\Big)$$

Here we clearly see the smallness on Ye

Inverted hierarchy:

$$|Y_e| = \frac{y}{2}\left(\sqrt{1 - \frac{\sqrt{r}}{4} - \sqrt{1 - r/16}\sin 2\alpha} + \ldots\right)$$

$$|Y_\mu| = \frac{y}{2}\left(\sqrt{1 + \frac{\sqrt{r}}{4} + \sqrt{1 - r/16}\sin 2\alpha)} + \ldots\right)$$

$$|Y_\tau| = \frac{y}{2}\left(\sqrt{1 + \frac{\sqrt{r}}{4} + \sqrt{1 - r/16}\sin 2\alpha)} + \ldots\right)$$

Now the values are close but variate differently with alpha

at alpha=Pi/4,3Pi/4 the approximation worsens, for some values approach zero, and it is there also where we find maxima and minima, and the strongest dependance on alpha,theta13

We expect the quotients of branching ratios to variate strongly with alpha
- maximum, minimum on alpha=Pi/4, 3Pi/4