Minimal Flavour Violation and leptogenesis

hep-ph/0607068 with V.Cirigliano and G.Isidori

Motivation

High energy constraints: leptogenesis

Low energy implications for $\mu \to e\,\gamma$, $\tau \to \mu\,\gamma$

42nd Rencontre de Moriond, La Thuile 15/3/07

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Why Minimal Flavour Violation

New Physics

$$\mathcal{L} = \underbrace{\mathcal{L}^{SM}_{flav.diag.} + \mathcal{L}^{SM}_{Yukawa}}_{\text{Standard Model}} + \sum_{n\geq 5} \frac{c_n}{\Lambda^n} O^{(n)}$$

Standard Model

FCNCs ~ $\frac{m_{ferm}}{M_W}$ x mixing angles

double suppressed → good place to look for NP

If there is NP, why don't we see it in FCNCs ?

1) The NP scale Λ is very high — *hierarchy problem*

2) Also NP is flavour special and hides behind the SM

MFV

Chivukula and Georgi 87, Buras et al. 01, D'Ambrosio et al. 02

In an effective theory format, the MFV method to hide NP behind the SM operators is:

- treat the Yukawa couplings as spurion fields and give them the right transformation properties that make the SM lagrangian formally invariant under U(3) flavour transformations of the fermion fields

- - NP operators are built with the Yukawa couplings and the fermion fields of the SM. Only operators that do not break the $U(3)^N$ flavour symmetry are allowed.

QUARKS

ex: neutral meson oscillations

$$O_{\Delta F=2} = \frac{1}{2} \left[\bar{Q}_L \left(\lambda_u^\dagger \lambda_u\right) \; \gamma_\mu Q_L\right] \; \left[\bar{Q}_L \left(\lambda_u^\dagger \lambda_u\right) \gamma_\mu Q_L\right]$$

the basic FC unit is made up of fermion masses and mixing angles

$$\lambda_u^\dagger \lambda_u = V_{CKM}^\dagger \frac{m_u^2}{v^2} V_{CKM}$$

measurable in low-energy experiments

We expect for new physics FCNCs

$$BR \propto \frac{\left(\lambda_u^\dagger \lambda_u\right)^4}{\Lambda_{FV}^4}$$

Experiments bound the scale Λ_{FV}

Δm_d and ε_K $\rightarrow$ $\Lambda_{FV} \gtrsim 5$ TeV

Reasonably small, ok !

LEPTONS

Could be an exact replica of the quark sector

FC unit $\lambda_\nu^\dagger \lambda_\nu$

but we think that the neutrino mass is not $m_\nu = v\,\lambda_\nu$ but

$$\lambda_\nu^T M_R^{-1} \lambda_\nu = \frac{1}{v^2} U_{MNS}^* m_\nu U_{MNS}^\dagger$$ *see-saw*

two scale problem : $\mathrm{BR} \propto \frac{M_R^2}{\Lambda_{FV}^4}$

impossible to bound the scale of flavour violation Λ_{FV} without info on the scale of lepton number violation $\Lambda_{LNV} \equiv M_R$

MFV in the lepton sector

we assume only Yukawa's break flavour as in the quark sector → the Majorana mass $M_R = 1$

for other definitions see F.Palorini's talk

Linking λ_ν to measurable parameters:

$$\lambda_\nu = \frac{1}{v} M_R^{1/2} \underline{R} \, m_\nu^{1/2} U_{MNS}^\dagger$$

Casas and Ibarra 01

unknown

If $M_R = 1$, M_R is a number and R has 3 real parameters (R=1 if CP conserved)
= 4 (permanent) unknowns, plus Λ_{FV}

[9 if $M_R \neq 1$]

the only unknown in the quark sector

there's also a high energy expt information
the measurement of the baryon asymmetry of the universe

assuming baryogenesis through leptogenesis

leptogenesis depends on

$$\lambda_\nu \lambda_\nu^\dagger = \frac{M_R}{v^2} R m_\nu R^\dagger$$

FCNC rates in MFV on

$$\lambda_\nu^\dagger \lambda_\nu = \frac{M_R}{v^2} U_{MNS} m_\nu^{1/2} R^\dagger R \, m_\nu^{1/2} U_{MNS}^\dagger$$

get info about R and M_R

Leptogenesis in MFV

An issue itself:
can we generate enough asymmetry with MFV spurions
as the only source of flavour breaking

Non-vanishing leptogenesis requires
a **mass splitting** for right-handed neutrinos

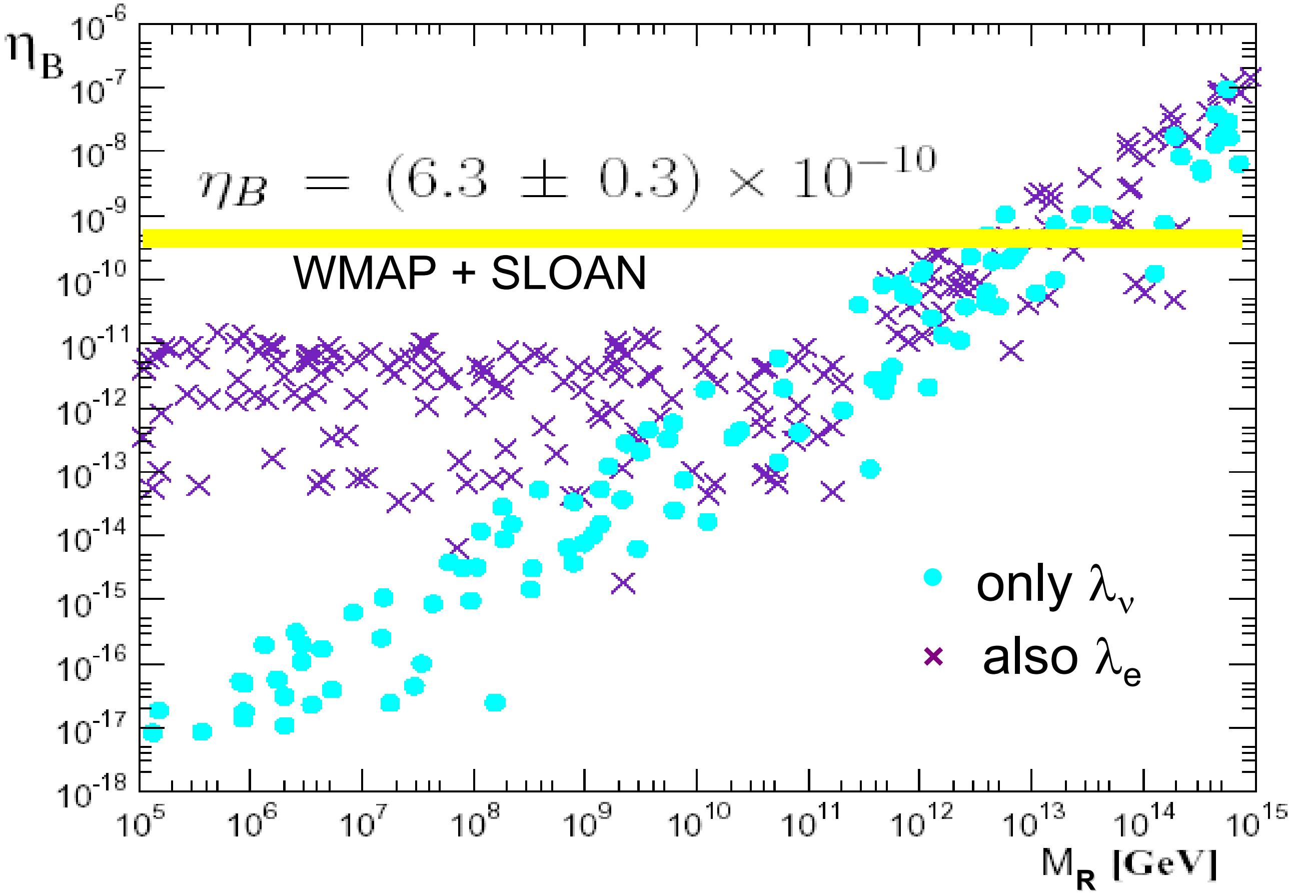
The most general one in lepton **MFV is**

$$\frac{\Delta M_R}{M_R} = a_\nu \left[\lambda_\nu \lambda_\nu^\dagger + \left(\lambda_\nu \lambda_\nu^\dagger\right)^T\right] + \\ + a_{\nu\nu}^{(1)} \left[\lambda_\nu \lambda_\nu^\dagger \lambda_\nu \lambda_\nu^\dagger + \left(\lambda_\nu \lambda_\nu^\dagger \lambda_\nu \lambda_\nu^\dagger\right)^T\right] + a_{\nu\nu}^{(2)} \left[\lambda_\nu \lambda_\nu^\dagger \left(\lambda_\nu \lambda_\nu^\dagger\right)^T\right] + a_{\nu\nu}^{(3)} \left[\left(\lambda_\nu \lambda_\nu^\dagger\right)^T \lambda_\nu \lambda_\nu^\dagger\right] \\ + a_{\nu l} \left[\lambda_\nu \lambda_e^\dagger \lambda_e \lambda_\nu^\dagger + \left(\lambda_\nu \lambda_e^\dagger \lambda_e \lambda_\nu^\dagger\right)^T\right] + \textit{higher order terms}$$

A general analysis in terms of CP invariants shows that

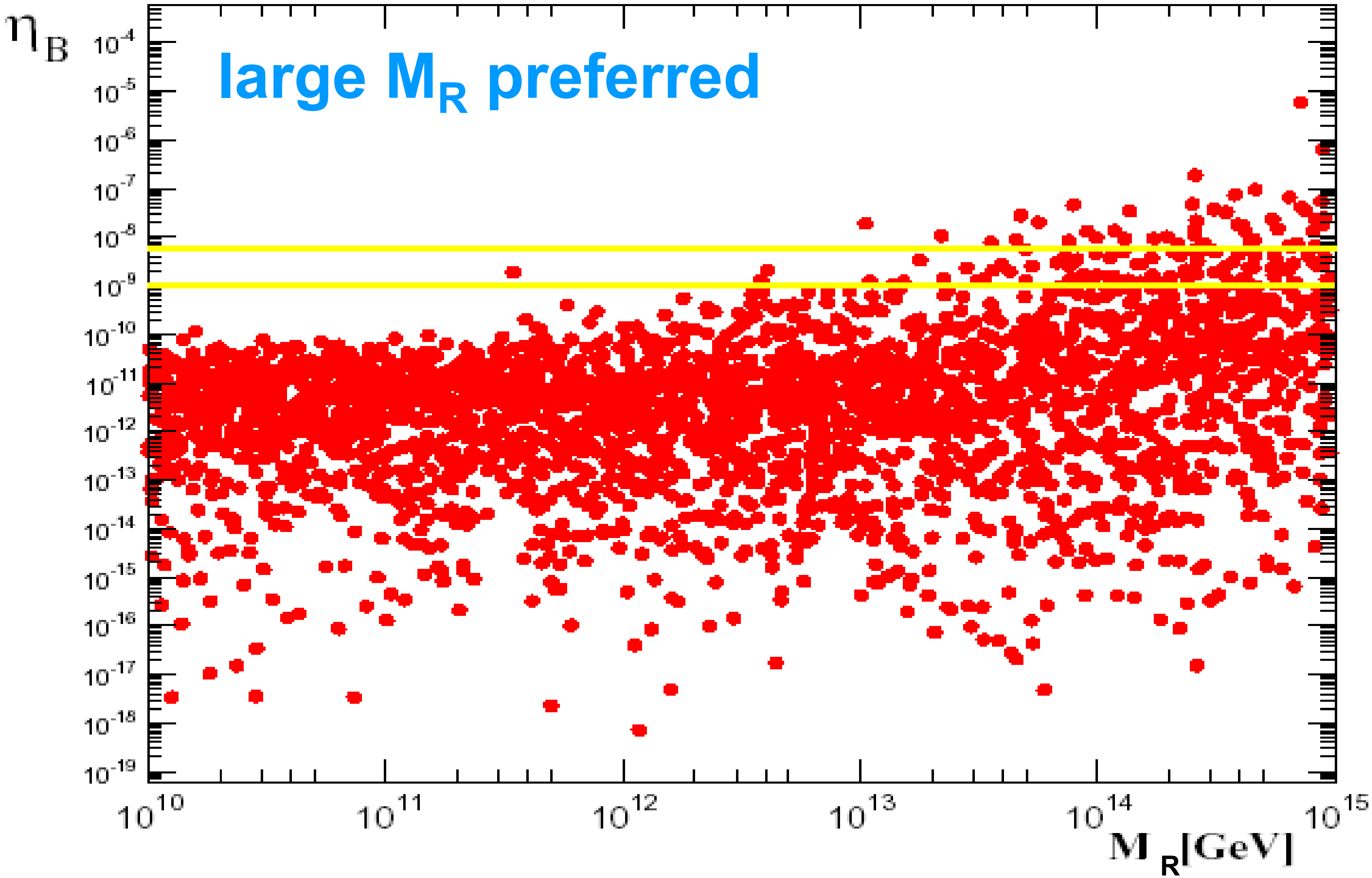
- if only a_ν non-vanishing → zero asymmetry
- if any $a_{\nu\nu}^{(i)}$ non-vanishing → non zero asymmetry,
  enough asymmetry even when λ_ν is the only flavour breaking source

Baryon asymmetry η_B as a function of M_R (I)



- The leading mass-splitting $\sim \lambda_\nu \lambda_\nu^\dagger$ does not contribute to the asymmetry but naturally gives the *resonance condition*
- $\lambda_\nu \sim M_R^{1/2}$ → for large M_R, the mass-splittin $\sim \lambda_\nu^4$ dominates the generation of the asymmetry with respect to the tern $\sim \lambda_\nu^2 \lambda_e^2$ and explains the rising curve.

Baryon asymmetry η_B as a function of M_R (II)



Good news for low energy phenomenlogy:

FCNC enhanced and scale ambiguity M_R^2 / Λ_{FV}^4 broken

This is what we expect in the largest region of the parameter space of MFV models

In particular we assumed:

Standard Model field content

mass-splittings generated perturbatively

one higgs doublet / low tanβ region

subleading flavour effects in the generation of the lepton asymmetry

Branco et al. 06, Uhlig 06 in a MFV-SUSY scenario

General remark: in the lepton sector the MFV hypothesis is forced to much higher energies than in the quark sector, a lot of things can happen in the meanwhile.

LOW ENERGY PREDICTIONS

Effective Lagrangian at the scale Λ_{FV} $\mathcal{L}_{eff} = \frac{1}{\Lambda_{FV}^2} \sum_i c^{(i)} O^{(i)}$

The operators O_i contain the FCNC unit $\lambda_\nu^\dagger \lambda_\nu = \frac{M_R}{v^2} U_{MNS} m_\nu^{1/2} R^\dagger R\, m_\nu^{1/2} U_{MNS}^\dagger$

FCNC observables $\sim \frac{M_R^2}{\Lambda_{FV}^4}$ ***constrain Λ_{FV} only with info on Λ_{LNV}***

- **ratios of the same observables for different lepton families depend on neutrino masses, oscillation parameters, Majorana and R phases, but do not depend on the details of the model.**

- **ratios of observables involving the same lepton families give access to the coefficients of the operators → hints on the specific MFV model behind**

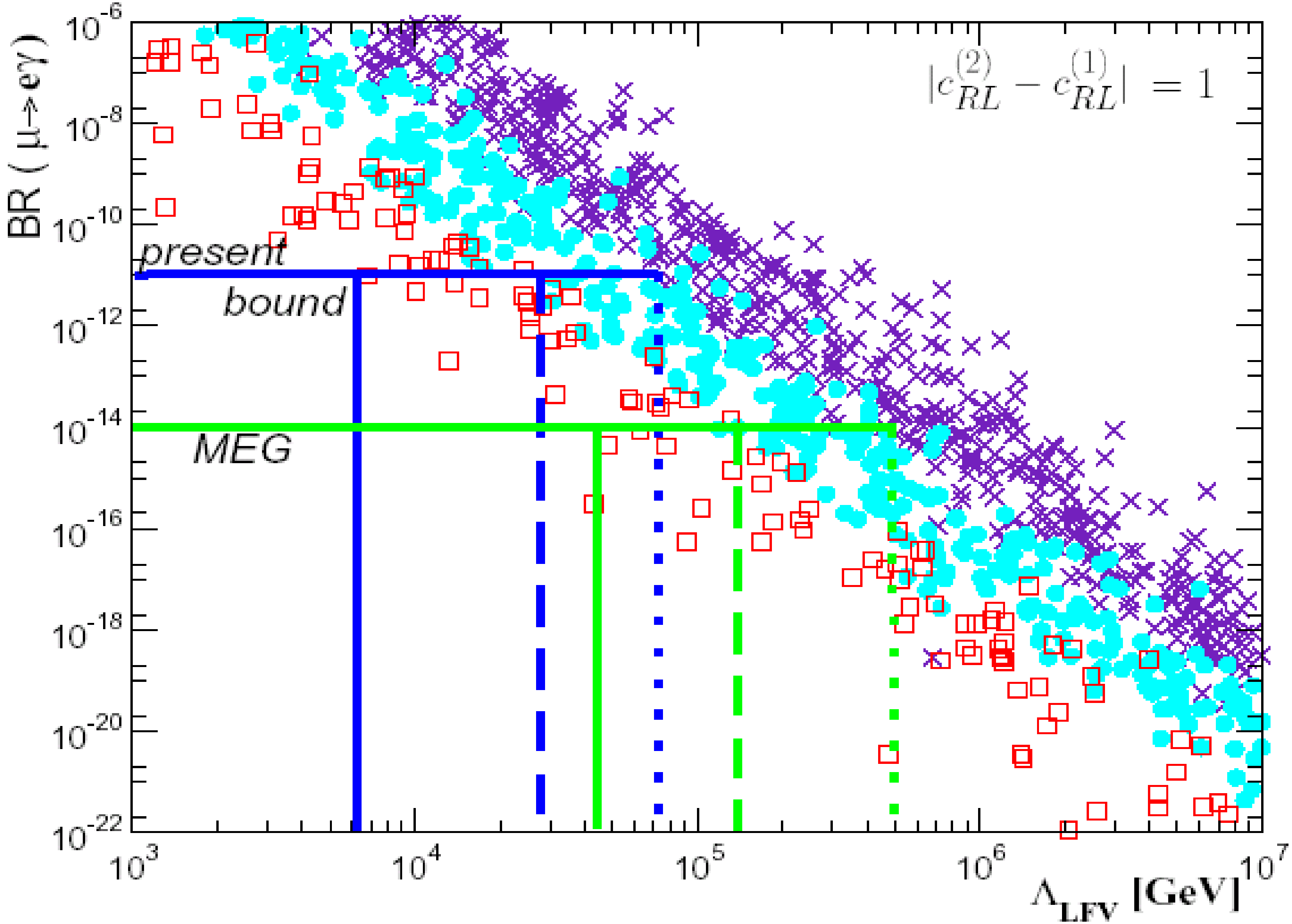
Several patterns can falsify the MFV hypothesis but measurements are needed!

• θ_{13} • δ • ν ***hierarchy*** • $2\beta 0\nu$ • $l_i \to l_j \gamma$ • $\mu \to 3e$ • $\tau \to \mu\pi$
• μ–***e conversion in nuclei*** • $\pi^0 \to \mu e$ • $Y \to \tau\mu$

V.Cirigliano, B.Grinstein 06

What scales of FV are we testing with lepton MFV?

if Λ_{LNV} >, already around 10 Tev ! FV rates should be observed soon

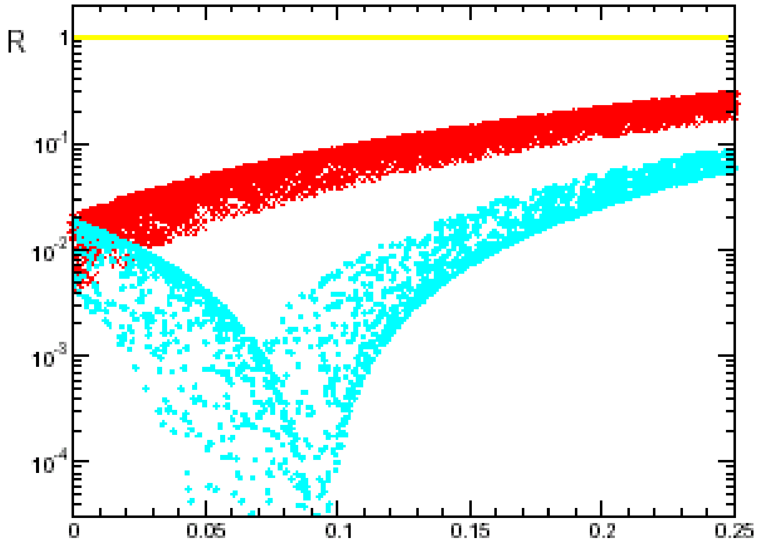


M_R= 10^{13} GeV 10^{14} GeV 10^{15} GeV

Effect of the unknown parameters in the R matrix

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

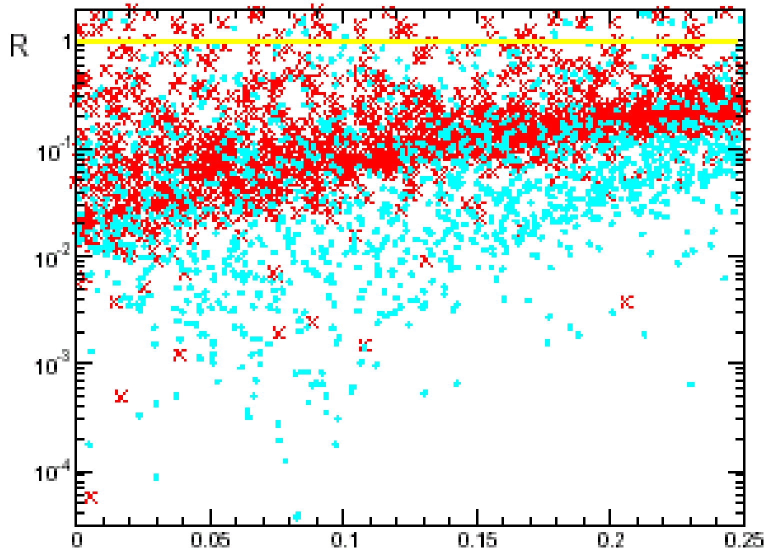
R = I



● $\delta = 0$

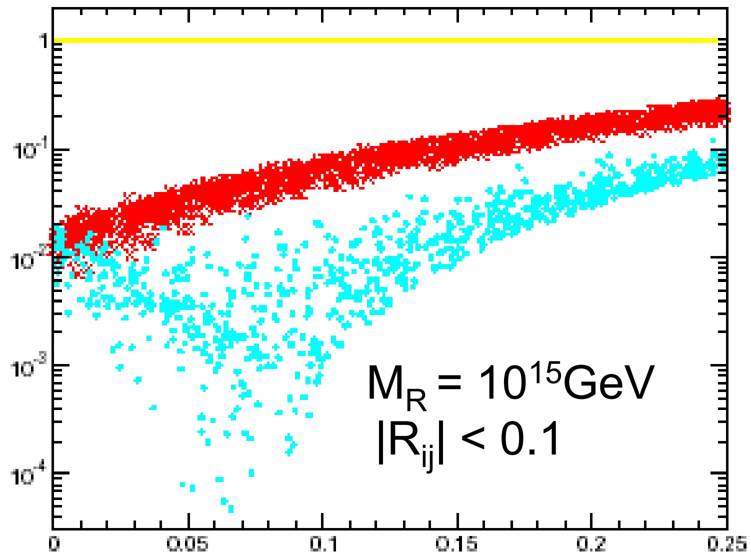
● $\delta = \pi$

lepotg. satisfied



generic case

enhancement
but loss of predictivity



ideal case

for super-heavy ν_R
and small R param's
MFV leptog. viable
&
CP-conserving prediction
valid

We generally expect

$$BR(\mu \to e\gamma) < BR(\tau \to \mu\gamma)$$

SUMMARY

MFV in lepton sector: Yukawa as the only source of flavour breaking + see-saw

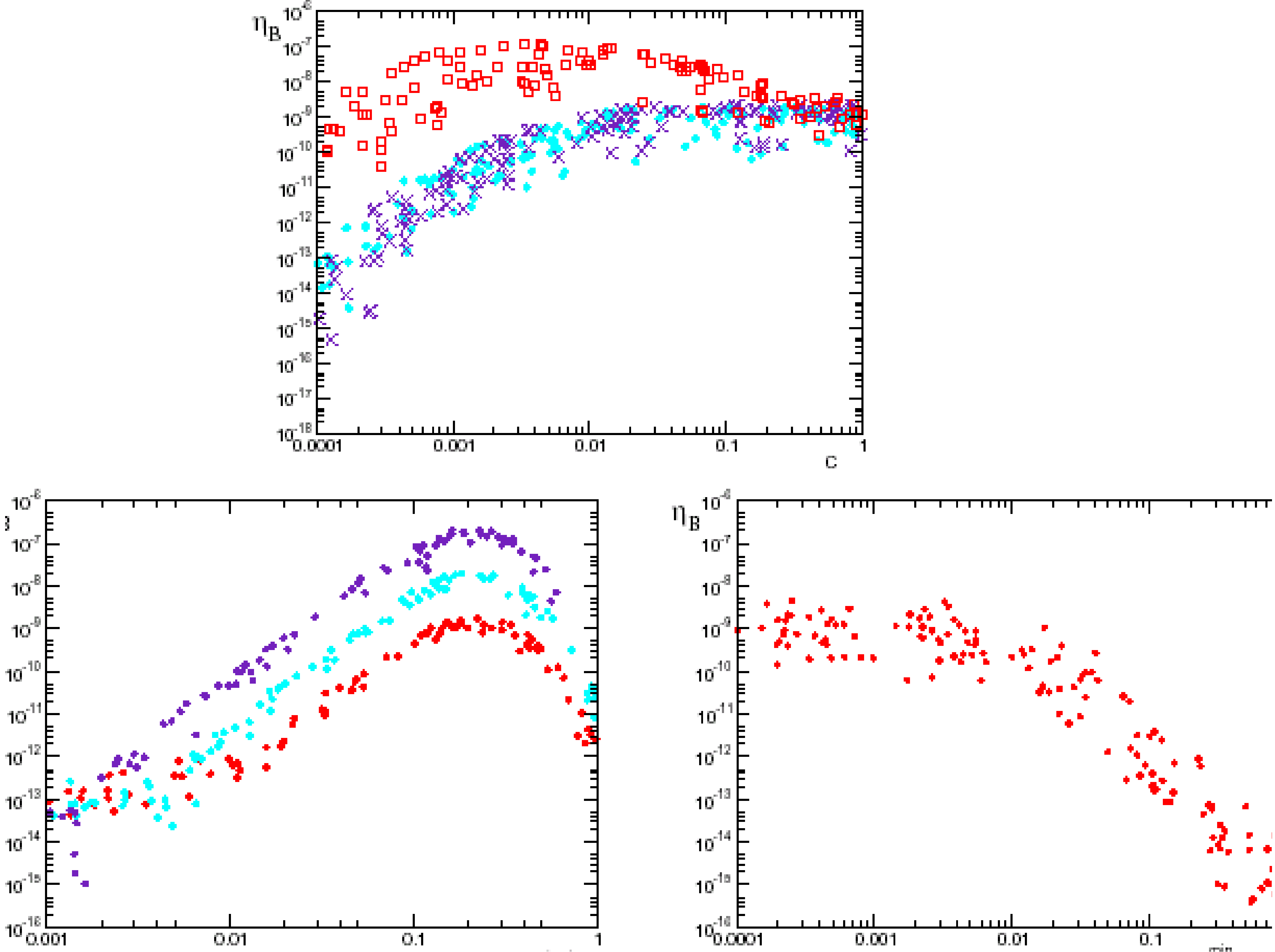
Neutrino Yukawa's are not univocally given by low energy parameters (m_ν, U_{MNS}). Baryogenesis through leptogenesis gives constraints on the high energy sector.

Leptogenesis in MFV is viable and prefers large right-handed neutrino masses

→ enhancement of low energy FCNC rates
→ breaking of the normalization ambiguity of FCNC rates M_R/Λ_{FV}^2

If low energy parameters (PMNS, n masses) are dominant in the see-saw, we expect $BR(\mu \to e\gamma) < BR(\tau \to \mu\gamma)$.

With measurements of m_β, $m_{\beta\beta}$ and four fermion processes, more checks of lepton MFV will be possible.



ηB
10^-6
10^-7
10^-8
10^-9
10^-10
10^-11
10^-12
10^-13
10^-14
10^-15
10^-16
10^-17
10^-18
0.0001
0.001
0.01
0.1
1
C