SO(10) - inspired Leptogenesis and its predictions

Work in progress: P. Di Bari, L. Marzola, S. Huber, S. Peeters

L. Marzola

NExT PhD Workshop
July 2011

SO(10) - inspired Leptogenesis and its predictions

Featuring news from T2K!

Work in progress: P. Di Bari, L. Marzola, S. Huber, S. Peeters

L. Marzola

NExT PhD Workshop
July 2011

Leptogenesis: a short introduction

Two problems:

Leptogenesis: a short introduction

Two problems:

- CMBR: $\eta_B^{CMBR} = \left.\frac{n_B - n_{\bar{B}}}{n_\gamma}\right|_0 \simeq (6.20 \pm 0.15) \times 10^{-10}$
- Neutrino oscillation: $m_{\rm atm}, m_{\rm sol} \neq 0$

??

Leptogenesis: a short introduction

Two problems:

- CMBR: $\eta_B^{CMBR} = \left.\frac{n_B - n_{\bar{B}}}{n_\gamma}\right|_0 \simeq (6.20 \pm 0.15) \times 10^{-10}$
- Neutrino oscillation: $m_{\text{atm}}, m_{\text{sol}} \neq 0$

Leptogenesis!

One solution:

$$\mathscr{L} = \mathscr{L}_{SM} + i\overline{N_{Ri}}\gamma_\mu \partial^\mu N_{Ri} - h_{\alpha i}\overline{\ell_{L\alpha}} N_{Ri}\tilde{\phi} - \frac{1}{2}\overline{N^c_{Ri}} M^R_{ij} N_{Rj} + H.c$$

$(i, j = 1, 2, 3 \quad \alpha = e, \mu, \tau)$

Leptogenesis: a short introduction

Two problems:

- CMBR: $\eta_B^{CMBR} = \left.\frac{n_B - n_{\bar{B}}}{n_\gamma}\right|_0 \simeq (6.20 \pm 0.15) \times 10^{-10}$
- Neutrino oscillation: $m_{\rm atm}, m_{\rm sol} \neq 0$

Leptogenesis!

One solution:

$$\mathscr{L} = \mathscr{L}_{SM} + i\overline{N_{Ri}}\gamma_\mu \partial^\mu N_{Ri} - h_{\alpha i}\overline{\ell_{L\alpha}} N_{Ri}\tilde{\phi} - \frac{1}{2}\overline{N^c_{Ri}} M^R_{ij} N_{Rj} + H.c$$

$(i,j = 1,2,3 \quad \alpha = e,\mu,\tau)$

S.B. + Heavy R.H.N.

$-m^D_{\alpha i}\overline{\nu_{L\alpha}} N_{Ri}$ $\quad [M^R] \gg [m^D]$

Type I Seesaw:

$$M_{\rm light} \simeq -m^D (M^R)^{-1} (m^D)^T$$

$$M_{\rm heavy} \simeq M^R$$

Leptogenesis: a short introduction

Two problems:

- CMBR: $\eta_B^{CMBR} = \left.\frac{n_B - n_{\bar{B}}}{n_\gamma}\right|_0 \simeq (6.20 \pm 0.15) \times 10^{-10}$
- Neutrino oscillation: $m_{\rm atm}, m_{\rm sol} \neq 0$

Leptogenesis!

One solution:

$$\mathscr{L} = \mathscr{L}_{SM} + i\overline{N_{Ri}}\gamma_\mu \partial^\mu N_{Ri} - h_{\alpha i}\overline{\ell_{L\alpha}} N_{Ri}\tilde{\phi} - \frac{1}{2}\overline{N^c_{Ri}} M^R_{ij} N_{Rj} + H.c$$

$(i, j = 1, 2, 3 \quad \alpha = e, \mu, \tau)$

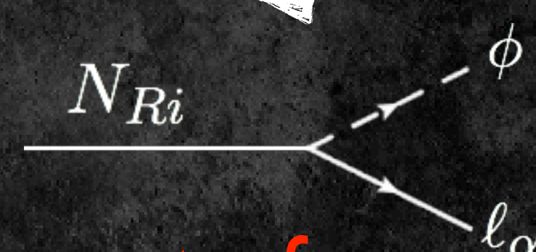
S.B. + Heavy R.H.N.

$-m^D_{\alpha i}\overline{\nu_{L\alpha}} N_{Ri}$ $\quad [M^R] \gg [m^D]$

Type I Seesaw:

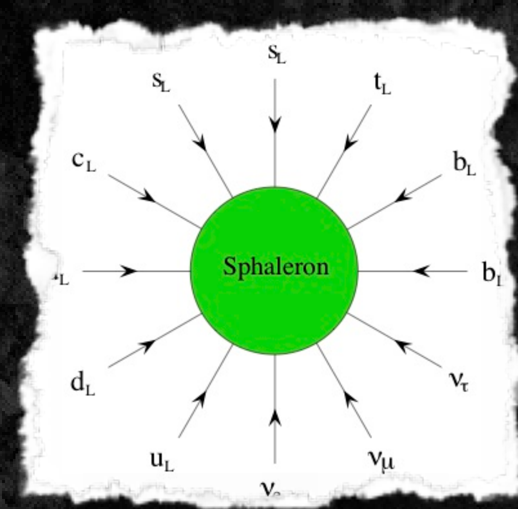
$$M_{\rm light} \simeq -m^D (M^R)^{-1} (m^D)^T$$

$$M_{\rm heavy} \simeq M^R$$



out of eq. ~~CP~~ decays

+



$$\eta_B^{lept} \simeq 9.6 \times 10^{-3} N_{B-L}$$

An example: N_1 Leptogenesis

N_{N_1} evolution:

N_{B-L} evolution:

An example: N_1 Leptogenesis

N_{N_1} evolution:

$$\frac{dN_{N_{R1}}}{dz} = -D_1(N_{N_{R1}} - N_{N_{R1}}^{eq})$$

N_{B-L} evolution:

$$\frac{dN_{\mathrm{B-L}}}{dz} = \epsilon D_1 \left(N_{N_{\mathrm{R1}}} - N_{N_{\mathrm{R1}}}^{\mathrm{eq}}\right) - N_{\mathrm{B-L}} W_1(z)$$

$$D_j(z_j) := \frac{\Gamma_{D,j}}{H\,z} = K_j z_j \frac{\mathcal{K}_1(z_j)}{\mathcal{K}_2(z_j)} \qquad W_j(z_j) := \frac{1}{4} K_j \mathcal{K}_1(z_j) z_j^3$$

$\mathcal{K}_1$, $\mathcal{K}_2$ modified Bessel functions $j = 1, 2, 3$

An example: N_1 Leptogenesis

N_{N_1} evolution:

$$\frac{dN_{N_{R1}}}{dz} = -D_1(N_{N_{R1}} - N^{eq}_{N_{R1}})$$

N_{B-L} evolution:

$$\frac{dN_{\rm B-L}}{dz} = \epsilon D_1 \left(N_{N_{\rm R1}} - N^{\rm eq}_{N_{\rm R1}} \right) - N_{\rm B-L} W_1(z)$$

$$D_j(z_j) := \frac{\Gamma_{D,j}}{H\, z} = K_j z_j \frac{\mathcal{K}_1(z_j)}{\mathcal{K}_2(z_j)} \qquad W_j(z_j) := \frac{1}{4} K_j \mathcal{K}_1(z_j) z_j^3$$

$\mathcal{K}_1, \mathcal{K}_2$ modified Bessel functions $j = 1, 2, 3$

Decay parameter:

$$K_j = \frac{\Gamma^{tot}_{D_j}}{H(z_j = 1)} \equiv \frac{\tilde{m}_j}{m_*}$$

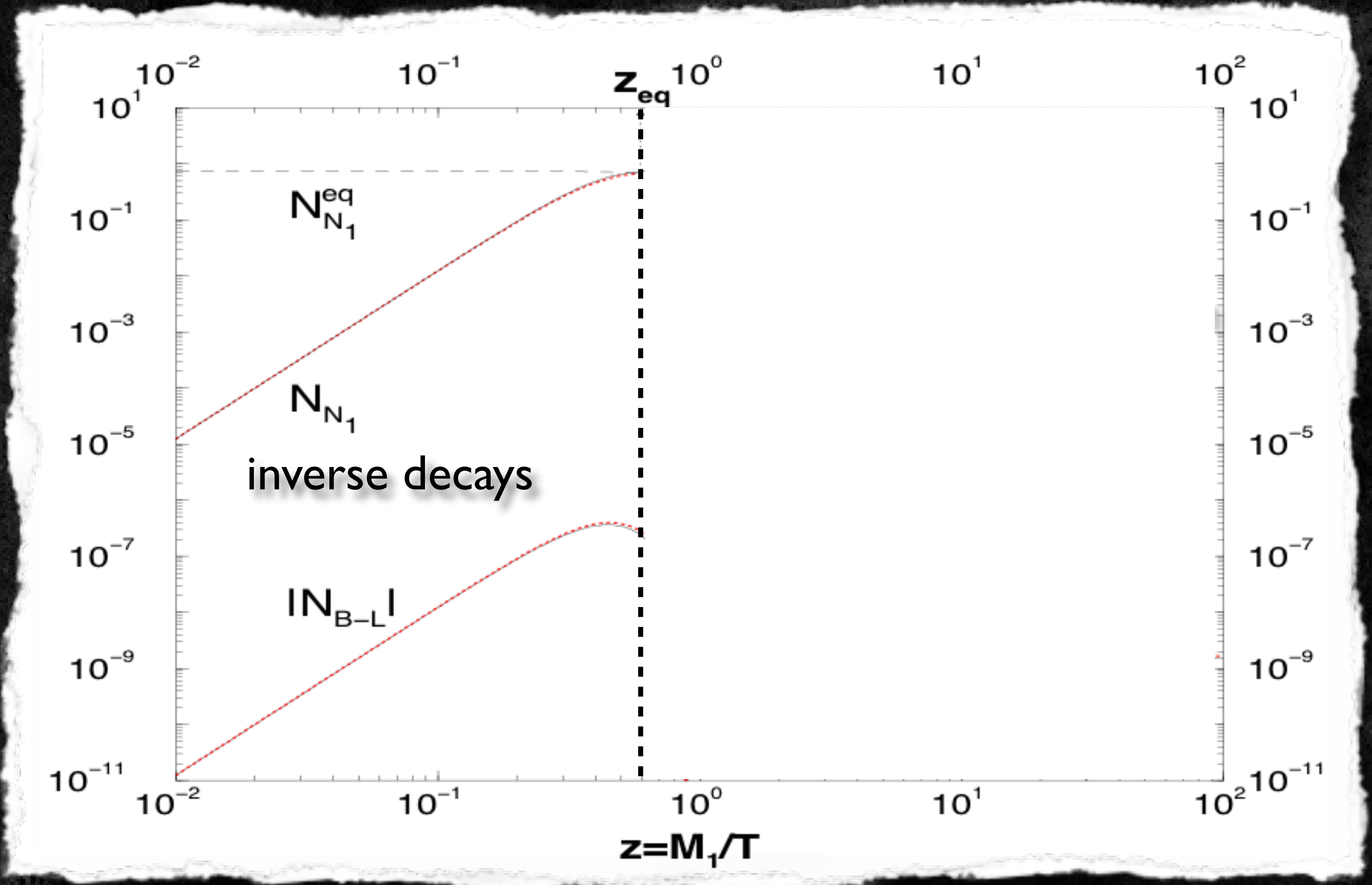
$$\tilde{m}_j := \frac{\left((m^D)^\dagger m^D \right)_{jj}}{M_j} \qquad m_* := \frac{16 \pi^{5/2} \sqrt{g^*}}{3\sqrt{5}} \frac{v^2}{M_{Pl}} \simeq 1.08 \times 10^{-3} \text{ eV}$$

Connection to neutrino oscillations parameters!

An example: N_1 Leptogenesis

N_{N_1} evolution: $$\frac{dN_{N_{R1}}}{dz} = -D_1(N_{N_{R1}} - N^{eq}_{N_{R1}})$$

N_{B-L} evolution: $$\frac{dN_{\rm B-L}}{dz} = \epsilon D_1 \left(N_{\rm N_{R1}} - N^{\rm eq}_{\rm N_{R1}}\right) - N_{\rm B-L} W_1(z)$$

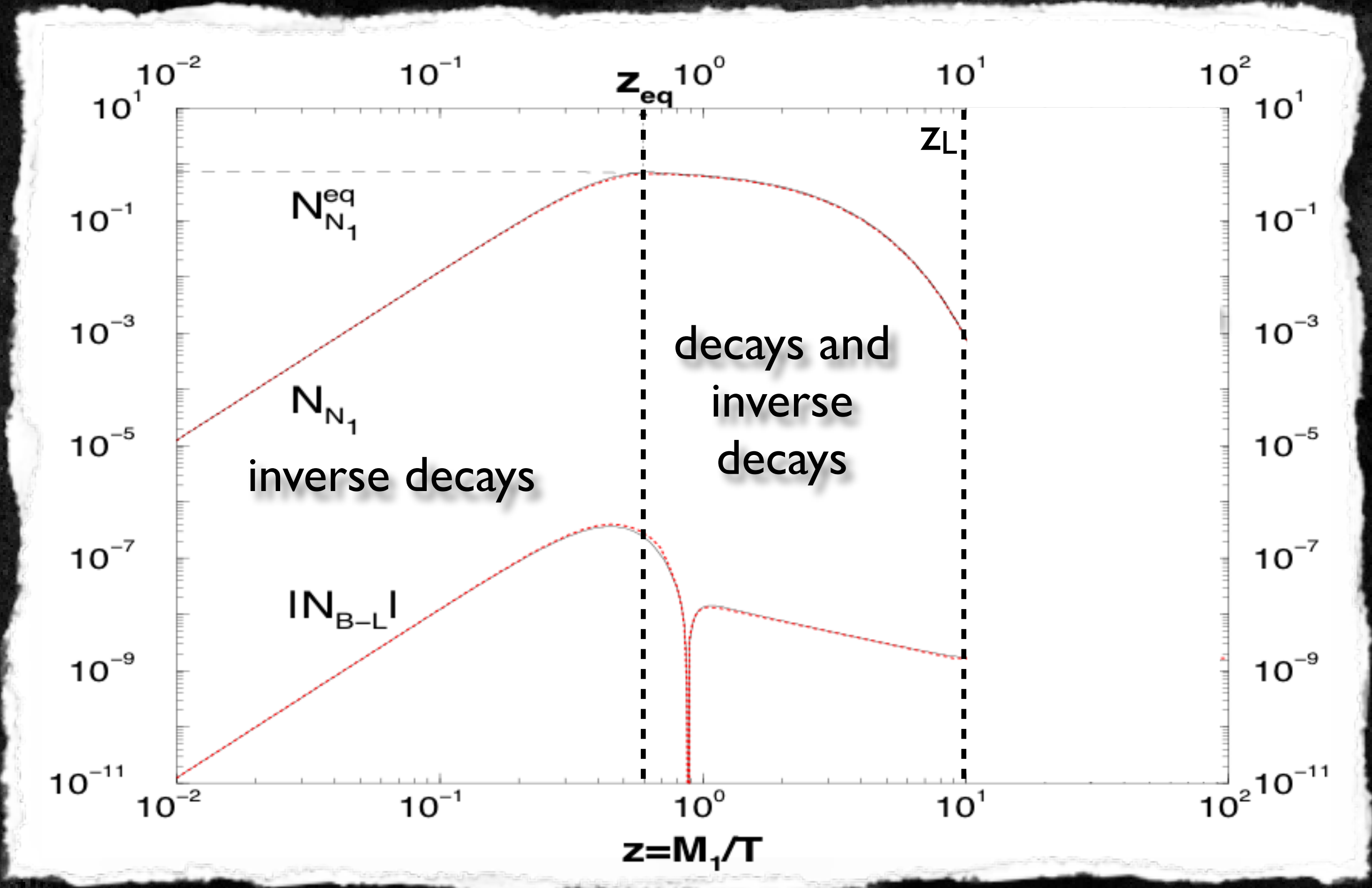


The three stages of N_1 Leptogenesis, strong washout regime: $K_1=100$; $|\epsilon_1|=10^{-6}$

An example: N_1 Leptogenesis

N_{N_1} evolution: $$\frac{dN_{N_{R1}}}{dz} = -D_1(N_{N_{R1}} - N^{eq}_{N_{R1}})$$

N_{B-L} evolution: $$\frac{dN_{\rm B-L}}{dz} = \epsilon D_1 \left(N_{\rm N_{R1}} - N^{\rm eq}_{\rm N_{R1}}\right) - N_{\rm B-L} W_1(z)$$

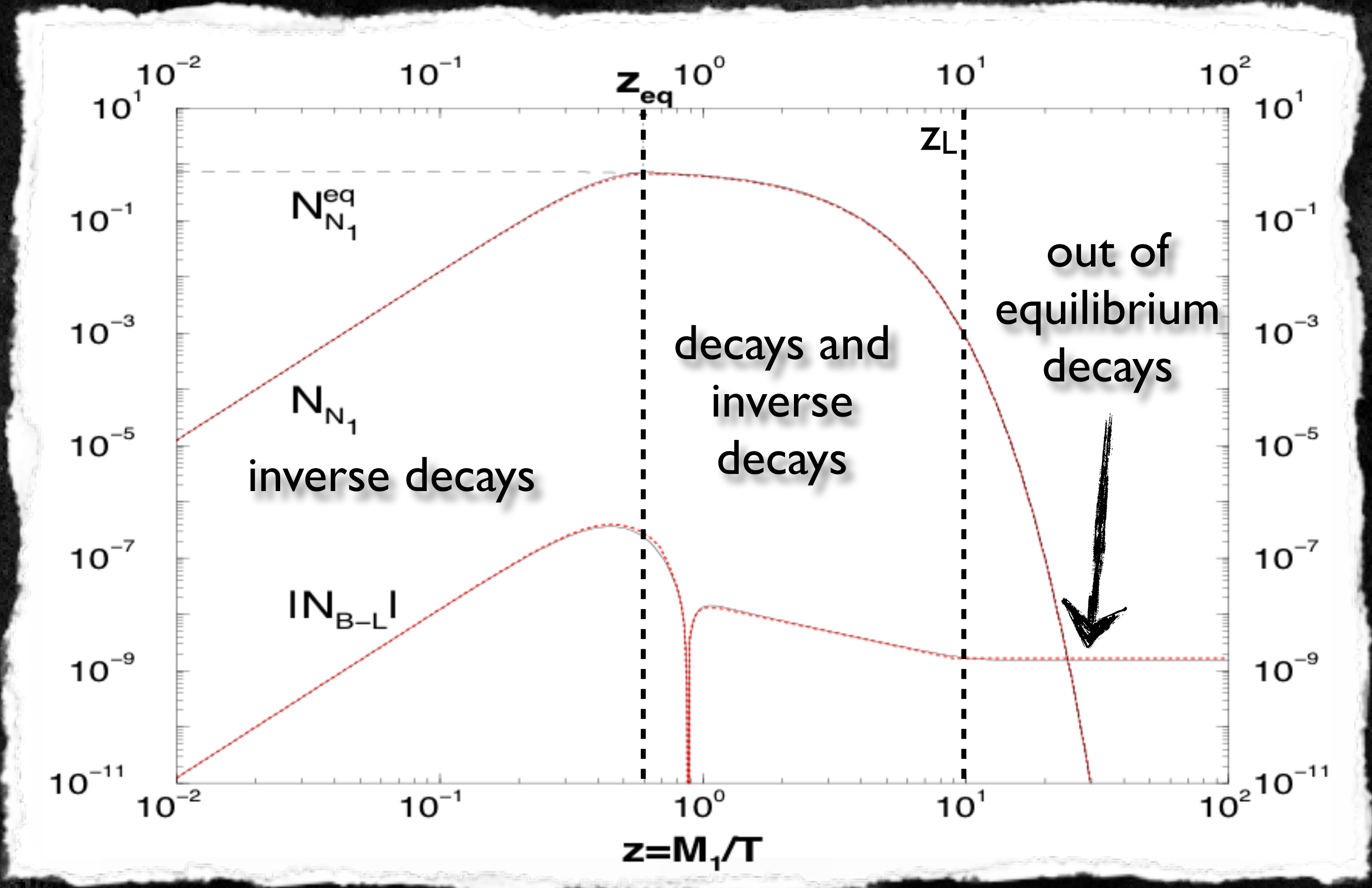


The three stages of N_1 Leptogenesis, strong washout regime: $K_1=100$; $|\epsilon_1|=10^{-6}$

An example: N_1 Leptogenesis

N_{N_1} evolution: $$\frac{dN_{N_{R1}}}{dz} = -D_1(N_{N_{R1}} - N_{N_{R1}}^{eq})$$

N_{B-L} evolution: $$\frac{dN_{\mathrm{B-L}}}{dz} = \epsilon D_1 \left(N_{N_{\mathrm{R1}}} - N_{N_{\mathrm{R1}}}^{\mathrm{eq}}\right) - N_{\mathrm{B-L}} W_1(z)$$



The three stages of N_1 Leptogenesis, strong washout regime: $K_1=100$; $|\epsilon_1|=10^{-6}$

SO(10)-inspired Leptogenesis:

P. Di Bari, A. Riotto
hep-ph: 1012.2343

- Seesaw mechanism:

SO(10)-inspired Leptogenesis:

P. Di Bari, A. Riotto
hep-ph: 1012.2343

- Seesaw mechanism: $m^{\nu} = -m^D D_{M^R}^{-1} (m^D)^T$

SO(10)-inspired Leptogenesis:

P. Di Bari, A. Riotto
hep-ph: 1012.2343

- Seesaw mechanism: $m^\nu = -m^D D_{M^R}^{-1} (m^D)^T$
- Takagi factorisation: $m^\nu = -U D_m U^T \qquad D_m = \begin{pmatrix} m_1 & 0 & 0 \\ 0 & m_2 & 0 \\ 0 & 0 & m_3 \end{pmatrix}$

$$U = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix} \cdot \mathrm{diag}\left(e^{i\rho}, 1, e^{i\sigma}\right)$$

(N.O.)

SO(10)-inspired Leptogenesis:

P. Di Bari, A. Riotto
hep-ph: 1012.2343

- Seesaw mechanism: $m^{\nu} = -m^D D^{-1}_{M^R} (m^D)^T$
- Takagi factorisation: $m^{\nu} = -U D_m U^T \qquad D_m = \begin{pmatrix} m_1 & 0 & 0 \\ 0 & m_2 & 0 \\ 0 & 0 & m_3 \end{pmatrix}$

$$U = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix} \cdot \mathrm{diag}\left(e^{i\rho}, 1, e^{i\sigma}\right)$$

(N.O.)

$$\Rightarrow \quad U D_m U^T = m^D D^{-1}_{M^R} (m^D)^T \qquad D_{m^D} = V_L m^D U_R^{\dagger}$$

$$R := D^{-1}_{m^D} V_L U D_m U^T V_L^T D^{-1}_{m^D} \equiv U_R D^{-1}_{M^R} U_R^T$$

SO(10)-inspired Leptogenesis:

P. Di Bari, A. Riotto
hep-ph: 1012.2343

- Seesaw mechanism: $m^\nu = -m^D D_{M^R}^{-1} (m^D)^T$
- Takagi factorisation: $m^\nu = -U D_m U^T \qquad D_m = \begin{pmatrix} m_1 & 0 & 0 \\ 0 & m_2 & 0 \\ 0 & 0 & m_3 \end{pmatrix}$

$$U = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix} \cdot \mathrm{diag}\left(e^{i\rho}, 1, e^{i\sigma}\right)$$

(N.O.)

→ $U D_m U^T = m^D D_{M^R}^{-1} (m^D)^T \qquad D_{m^D} = V_L m^D U_R^\dagger$

$$R := D_{m^D}^{-1} V_L U D_m U^T V_L^T D_{m^D}^{-1} \equiv U_R D_{M^R}^{-1} U_R^T$$

→ Diagonalising $RR^\dagger$ gives: U_R

$$D_{M^R} = \begin{pmatrix} M_1 & 0 & 0 \\ 0 & M_2 & 0 \\ 0 & 0 & M_3 \end{pmatrix}$$

SO(10)-inspired Leptogenesis:

P. Di Bari, A. Riotto
hep-ph: 1012.2343

- Seesaw mechanism: $m^\nu = -m^D D_{M^R}^{-1} (m^D)^T$
- Takagi factorisation: $m^\nu = -U D_m U^T$ $\quad D_m = \begin{pmatrix} m_1 & 0 & 0 \\ 0 & m_2 & 0 \\ 0 & 0 & m_3 \end{pmatrix}$

⇒ $U D_m U^T = m^D D_{M^R}^{-1} (m^D)^T$ $\quad D_{m^D} = V_L m^D U_R^\dagger$

$$R := D_{m^D}^{-1} V_L U D_m U^T V_L^T D_{m^D}^{-1} \equiv U_R D_{M^R}^{-1} U_R^T$$

⇒ Diagonalising $RR^\dagger$ gives: U_R $\quad D_{M^R} = \begin{pmatrix} M_1 & 0 & 0 \\ 0 & M_2 & 0 \\ 0 & 0 & M_3 \end{pmatrix}$

- Oscillation experiments provide:
  - mixing angles in U
  - light mass differences in D_m
- SO(10)-inspired conditions:
  - V_L between I and CKM.
  - light neutrino Dirac masses $\quad D_{m^D} = \begin{pmatrix} \alpha_1 m_u & 0 & 0 \\ 0 & \alpha_2 m_c & 0 \\ 0 & 0 & \alpha_3 m_t \end{pmatrix}$ $\quad \alpha_i \sim \mathcal{O}(1)$

SO(10)-inspired Leptogenesis II

With this setup the *natural* scenario is *N_2-dominated*

- heavy neutrinos' hierarchical mass spectrum:

SO(10)-inspired Leptogenesis II

With this setup the *natural* scenario is *N_2-dominated*

- heavy neutrinos' hierarchical mass spectrum:

$$M_3 > 10^{12}\,\mathrm{GeV} \gtrsim M_2 > 10^{9}\mathrm{GeV} \gg M_1$$

SO(10)-inspired Leptogenesis II

With this setup the *natural* scenario is *N_2-dominated*

- heavy neutrinos' hierarchical mass spectrum:

$$M_3 > 10^{12}\ \mathrm{GeV} \gtrsim M_2 > 10^9 \mathrm{GeV} \gg M_1$$

- N_{R3} does not contribute to the asymmetry. Furthermore:

$M_3/M_2 > 10$ *no resonant enhancement to ϵ_2*

SO(10)-inspired Leptogenesis II

With this setup the *natural* scenario is *N_2-dominated*

- heavy neutrinos' hierarchical mass spectrum:

$$M_3 > 10^{12}\,\text{GeV} \gtrsim M_2 > 10^9\text{GeV} \gg M_1$$

- N_{R3} does not contribute to the asymmetry. Furthermore:

$$M_3/M_2 > 10$$ *no resonant enhancement to ϵ_2*

- B-L asymmetry produced in a 2-flavours regime for $T \sim M_2$:

$$N_{B-L}(T \sim M_2) \simeq \epsilon_{2\tau}\kappa(K_2, K_{2\tau}) + \epsilon_{2e+\mu}\kappa(K_2, K_{2e+\mu})$$

$$\epsilon_2 := -\frac{\Gamma_2 - \overline{\Gamma}_2}{\Gamma_2 + \overline{\Gamma}_2} \qquad \epsilon_{2\alpha} := p_{2\alpha}\epsilon_2$$

$$K_i = \frac{\tilde{m}_i}{M_i} \qquad K_{i\alpha} := p_{i\alpha}K_i \quad p_{i\alpha} := \frac{\left|(m_D^\dagger m_D)_{i\alpha}\right|^2}{(m_D^\dagger m_D)_{ii}(m_D^\dagger m_D)_{\alpha\alpha}}$$

SO(10)-inspired Leptogenesis II

With this setup the *natural* scenario is *N_2-dominated*

- heavy neutrinos' hierarchical mass spectrum:

$$M_3 > 10^{12}\,\mathrm{GeV} \gtrsim M_2 > 10^9\mathrm{GeV} \gg M_1$$

- N_{R3} does not contribute to the asymmetry. Furthermore:

$$M_3/M_2 > 10$$ *no resonant enhancement to ϵ_2*

- B-L asymmetry produced in a 2-flavours regime for T~M_2:

$$N_{B-L}(T \sim M_2) \simeq \epsilon_{2\tau}\kappa(K_2, K_{2\tau}) + \epsilon_{2e+\mu}\kappa(K_2, K_{2e+\mu})$$

- N_{R1} washout in fully flavoured regime. No B-L production:

$$\eta_B^{N_{R1}} \sim \eta_B^{CMBR} \Leftrightarrow M_1 \gtrsim 10^9\mathrm{GeV}$$

$$N_{B-L}^f \simeq \frac{p_{2e}}{p_{2e+\mu}}\epsilon_{2e+\mu}\kappa(K_{2e+\mu})e^{-\frac{3\pi}{8}K_{1e}} + \frac{p_{2\mu}}{p_{2e+\mu}}\epsilon_{2e+\mu}\kappa(K_{2e+\mu})e^{-\frac{3\pi}{8}K_{1\mu}} + \\ + \epsilon_{2\tau}\kappa(K_{2\tau})e^{-\frac{3\pi}{8}K_{1\tau}}$$

SO(10) inspired predictions:

Unrelated phenomenologies are now *connected*:

SO(10) inspired predictions:

Unrelated phenomenologies are now *connected*:

- ν oscillations:

Parameter:	Δm^2_{12} (10^{-5}eV^2)	$\lvert\Delta m^2_{13}\rvert$ (10^{-3}eV^2)	$\sin^2\theta_{12}$	$\sin^2\theta_{13}$	$\sin^2\theta_{23}$
68% Confidence Interval:	$7.65^{+0.23}_{-0.20}$	$2.40^{+0.12}_{-0.11}$	$0.304^{+0.022}_{-0.016}$	$0.01^{+0.016}_{-0.011}$	$0.50^{+0.07}_{-0.06}$

SO(10) inspired predictions:

Unrelated phenomenologies are now *connected*:

- ν oscillations:

Parameter:	Δm^2_{12} (10^{-5}eV^2)	$\lvert\Delta m^2_{13}\rvert$ (10^{-3}eV^2)	$\sin^2\theta_{12}$	$\sin^2\theta_{13}$	$\sin^2\theta_{23}$
68% Confidence Interval:	$7.65^{+0.23}_{-0.20}$	$2.40^{+0.12}_{-0.11}$	$0.304^{+0.022}_{-0.016}$	$0.01^{+0.016}_{-0.011}$	$0.50^{+0.07}_{-0.06}$

- CMBR:

$$PDF(\eta_B^{CMBR}) \simeq Gauss(6.20 \times 10^{-10}; 0.15 \times 10^{-10})$$

Combine these phenomenologies via i
SO(10)-inspired Leptogenesis!

SO(10) inspired predictions:

Unrelated phenomenologies are now *connected*:

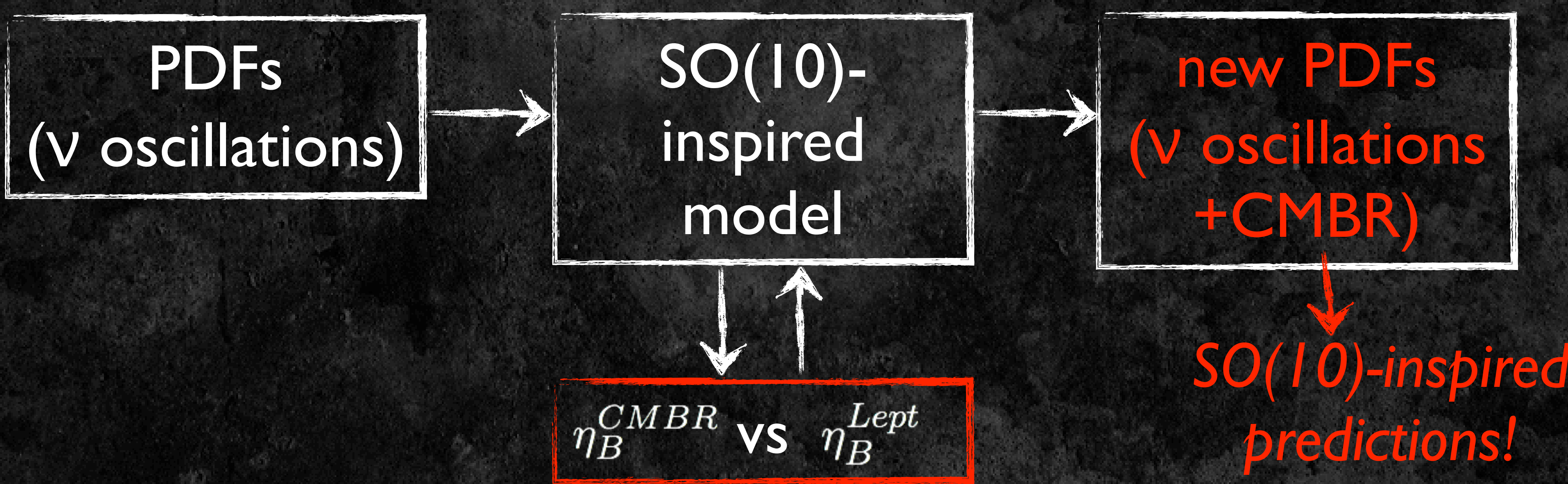
- ν oscillations:

Parameter:	Δm^2_{12} $(10^{-5}\mathrm{eV}^2)$	$\lvert\Delta m^2_{13}\rvert$ $(10^{-3}\mathrm{eV}^2)$	$\sin^2\theta_{12}$	$\sin^2\theta_{13}$	$\sin^2\theta_{23}$
68% Confidence Interval:	$7.65^{+0.23}_{-0.20}$	$2.40^{+0.12}_{-0.11}$	$0.304^{+0.022}_{-0.016}$	$0.01^{+0.016}_{-0.011}$	$0.50^{+0.07}_{-0.06}$

- CMBR:

$$PDF(\eta_B^{CMBR}) \simeq Gauss(6.20\times 10^{-10}; 0.15\times 10^{-10})$$

Combine these phenomenologies via i SO(10)-inspired Leptogenesis!



Implementation:

Our code performs the following tasks:

Implementation:

Our code performs the following tasks:

- populate the sample space:

Parameter:	m_{sol} (eV)	m_{atm} (eV)	$\sin^2\theta_{12}$	θ_{13}	$\sin^2\theta_{23}$
Assumed values:	8.75×10^{-3}	5.0×10^{-2}	$Gauss(0.304;0.019)$	$unif[0°;14°]$	$Gauss(0.50;0.06)$

$m_1:\ uniform[0;10^{-4}]$ eV $\quad \alpha_1=1 \quad \alpha_2=5 \quad \alpha_3=1 \quad \delta,\rho,\sigma : uniform[0;2\pi]$

$V_L=1$ normal ordering only

Implementation:

Our code performs the following tasks:

- populate the sample space:

Parameter:	m_{sol} (eV)	m_{atm} (eV)	$\sin^2\theta_{12}$	θ_{13}	$\sin^2\theta_{23}$
Assumed values:	8.75×10^{-3}	5.0×10^{-2}	$Gauss(0.304; 0.019)$	$unif[0°; 14°]$	$Gauss(0.50; 0.06)$

$m_1 :\ uniform[0; 10^{-4}]$ eV $\quad \alpha_1 = 1 \quad \alpha_2 = 5 \quad \alpha_3 = 1 \quad \delta, \rho, \sigma : uniform[0; 2\pi]$

$V_L = 1$ normal ordering only

- for every point compute: η_B^{Lept} $\quad m_{ee}$

- apply weighted binning:

$$PDF(\bar{\theta}|\eta_B^{CMBR} \equiv \eta_B^{Lept}) \propto PDF_{CMBR}(\eta^{Lept}(\bar{\theta}))\ PDF_0(\bar{\theta})$$

SO(10) inspired predictions

weighting function

initial PDF

First results: phases

Run 0: PDFs for phases have a well defined structure

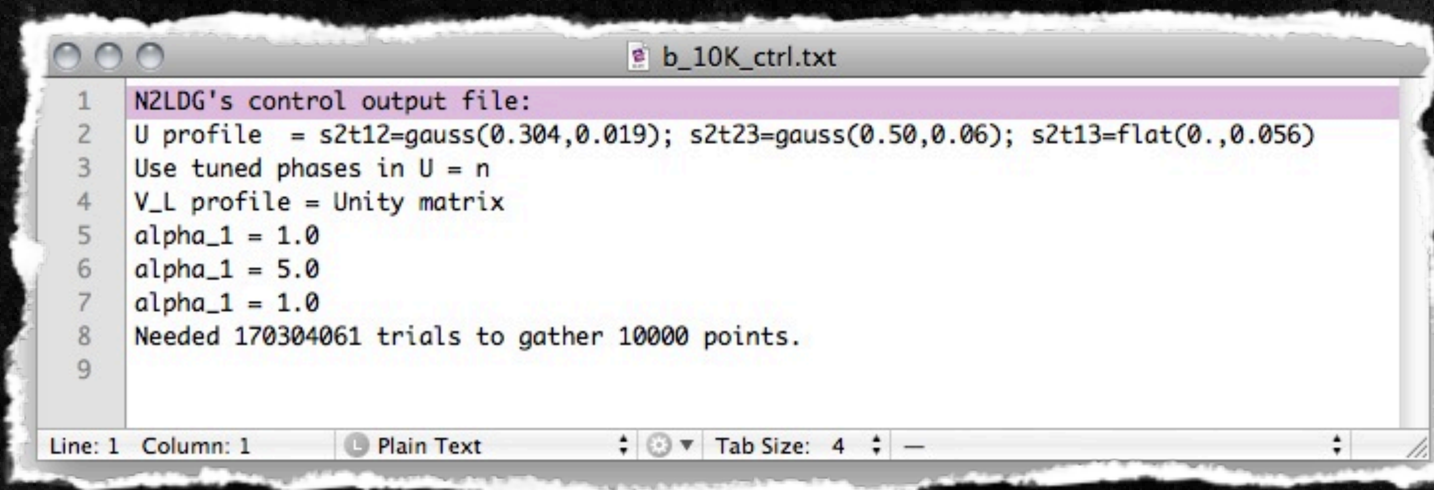
δ/π

ρ/π

σ/π

First results: phases

Run 0: PDFs for phases have a well defined structure

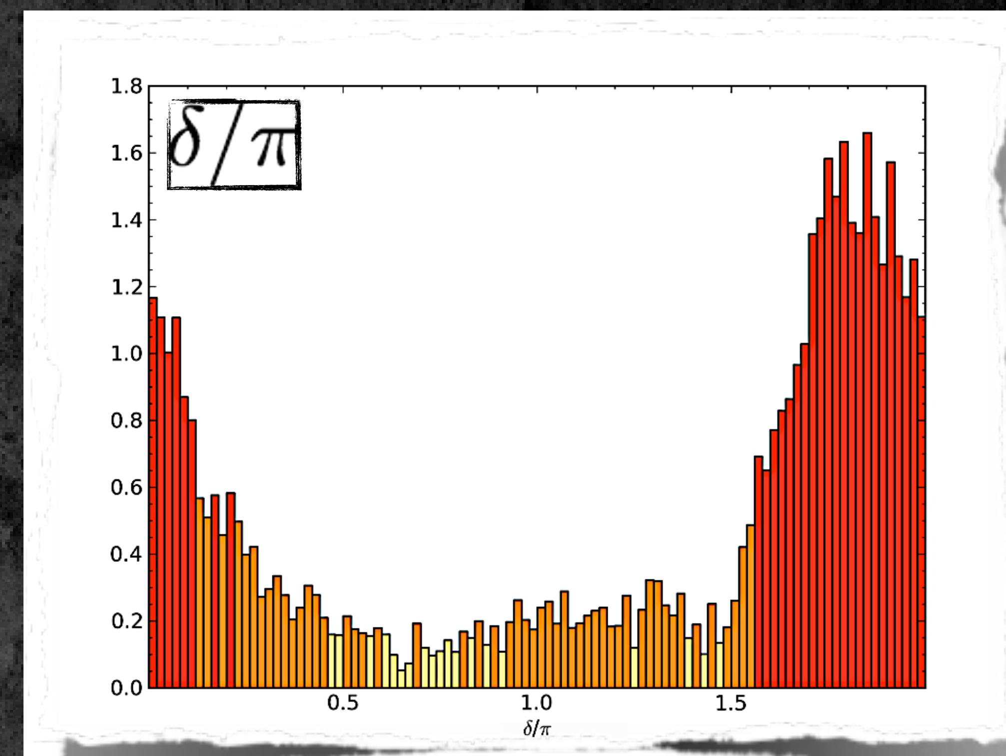

b_10K_ctrl.txt

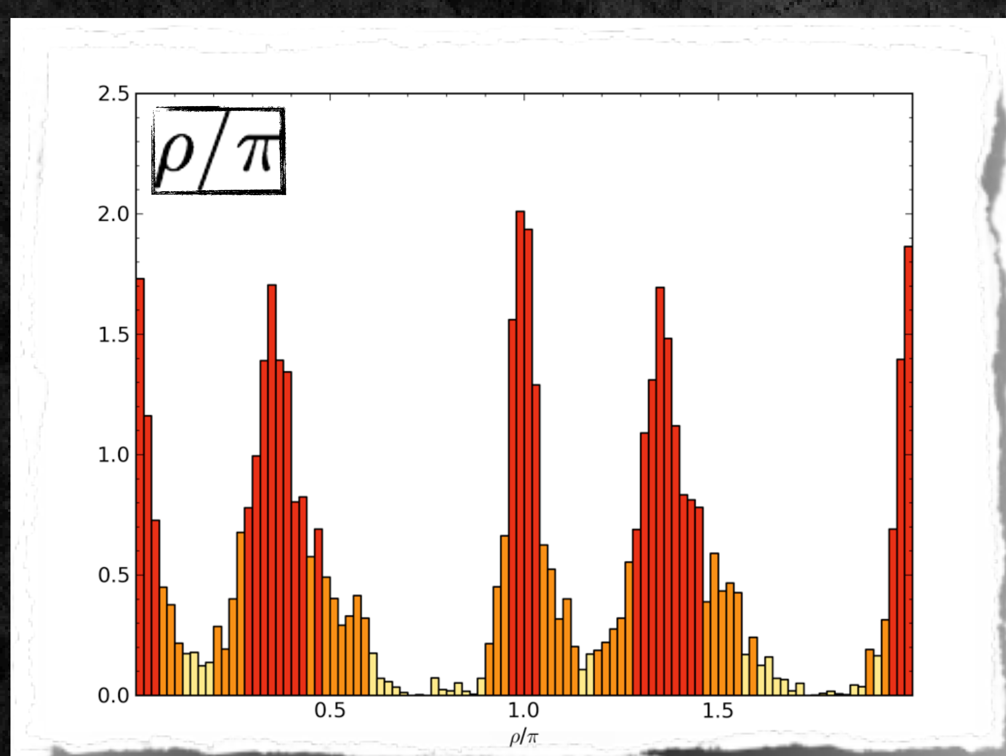
```
N2LDG's control output file:
U profile  = s2t12=gauss(0.304,0.019); s2t23=gauss(0.50,0.06); s2t13=flat(0.,0.056)
Use tuned phases in U = n
V_L profile = Unity matrix
alpha_1 = 1.0
alpha_1 = 5.0
alpha_1 = 1.0
Needed 170304061 trials to gather 10000 points.
```

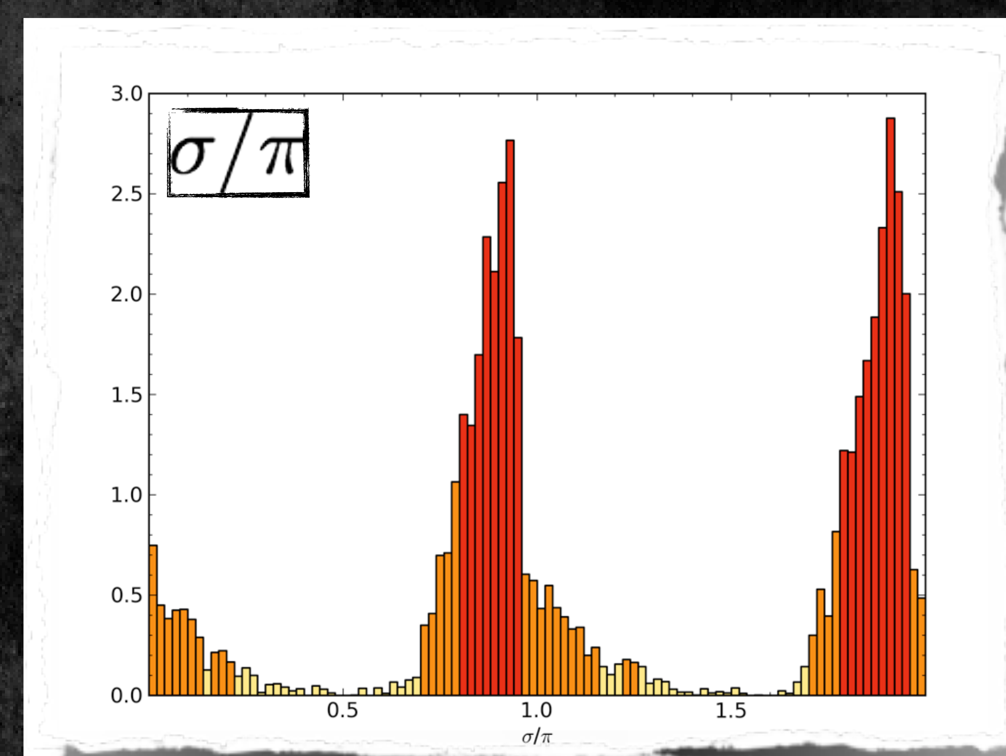
Line: 1 Column: 1 | Plain Text | Tab Size: 4 | —

10K points, 100 bins

68% C.L. 95% C.L.







First results: θ_{12} and θ_{23}

Run 1: PDFs for mixing angles

First results: θ_{12} and θ_{23}

Run 1: PDFs for mixing angles

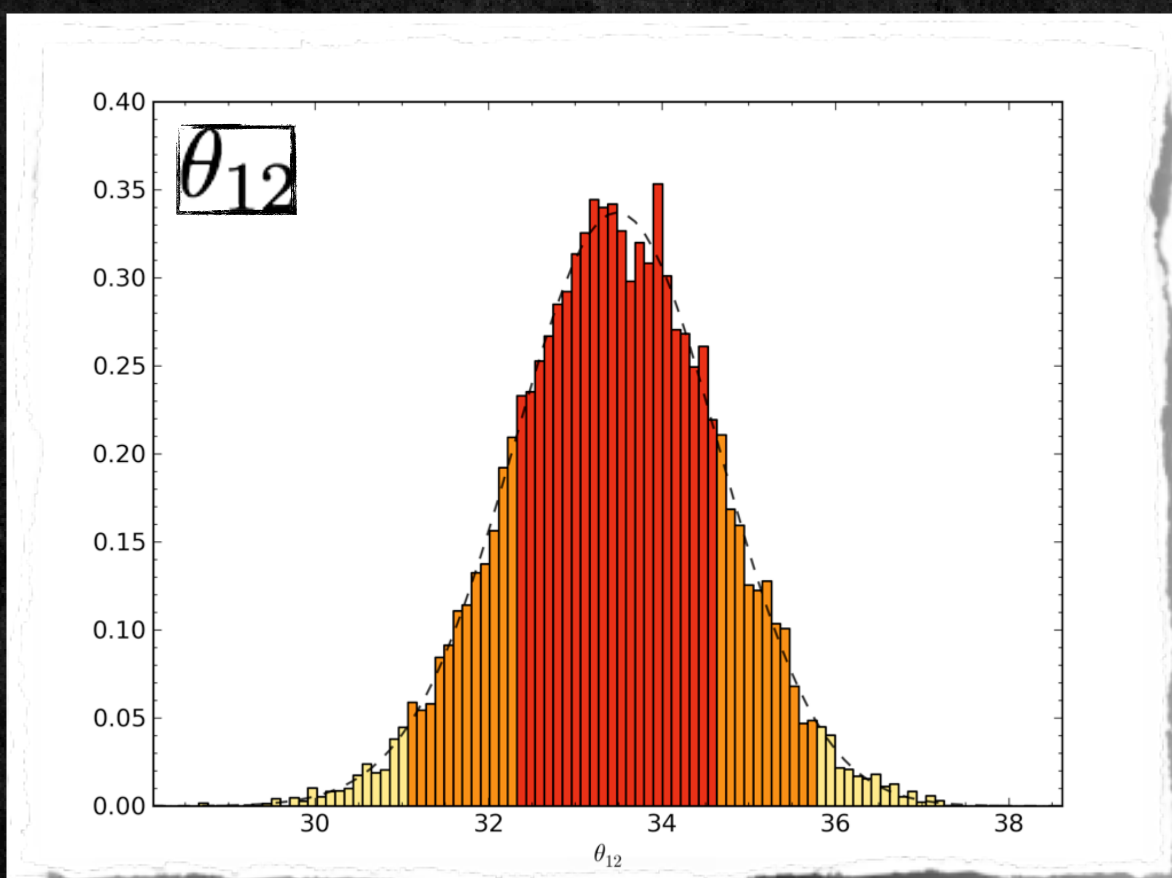
b_20K_ctrl.txt

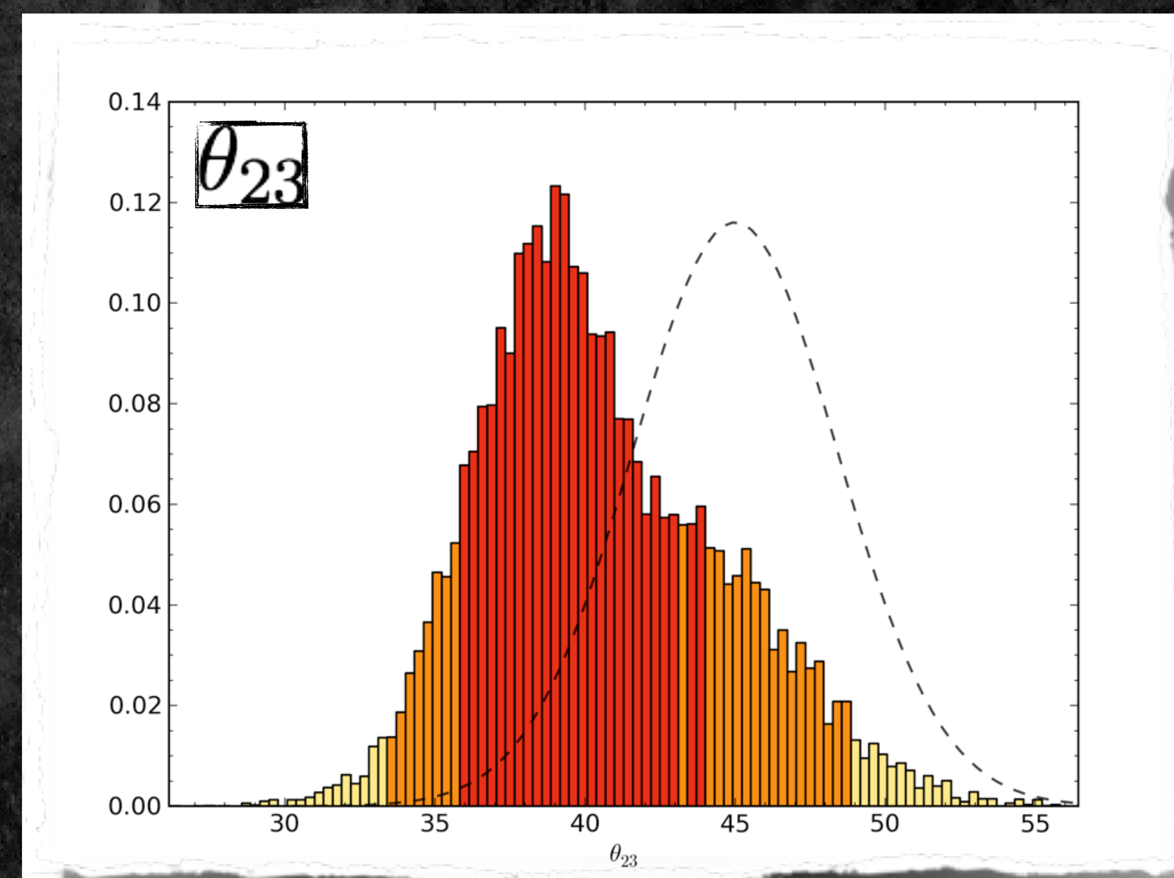
```
N2LDG's control output file:
U profile  = s2t12=gauss(0.304,0.019); s2t23=gauss(0.50,0.06); s2t13=flat(0.,0.056)
Use tuned phases in U = y
V_L profile = Unity matrix
alpha_1 = 1.0
alpha_1 = 5.0
alpha_1 = 1.0
Needed 171043965 trials to gather 20000 points.
```

Line: 1 Column: 1 | Plain Text | Tab Size: 4

20K points, 100 bins

68% C.L. 95% C.L.



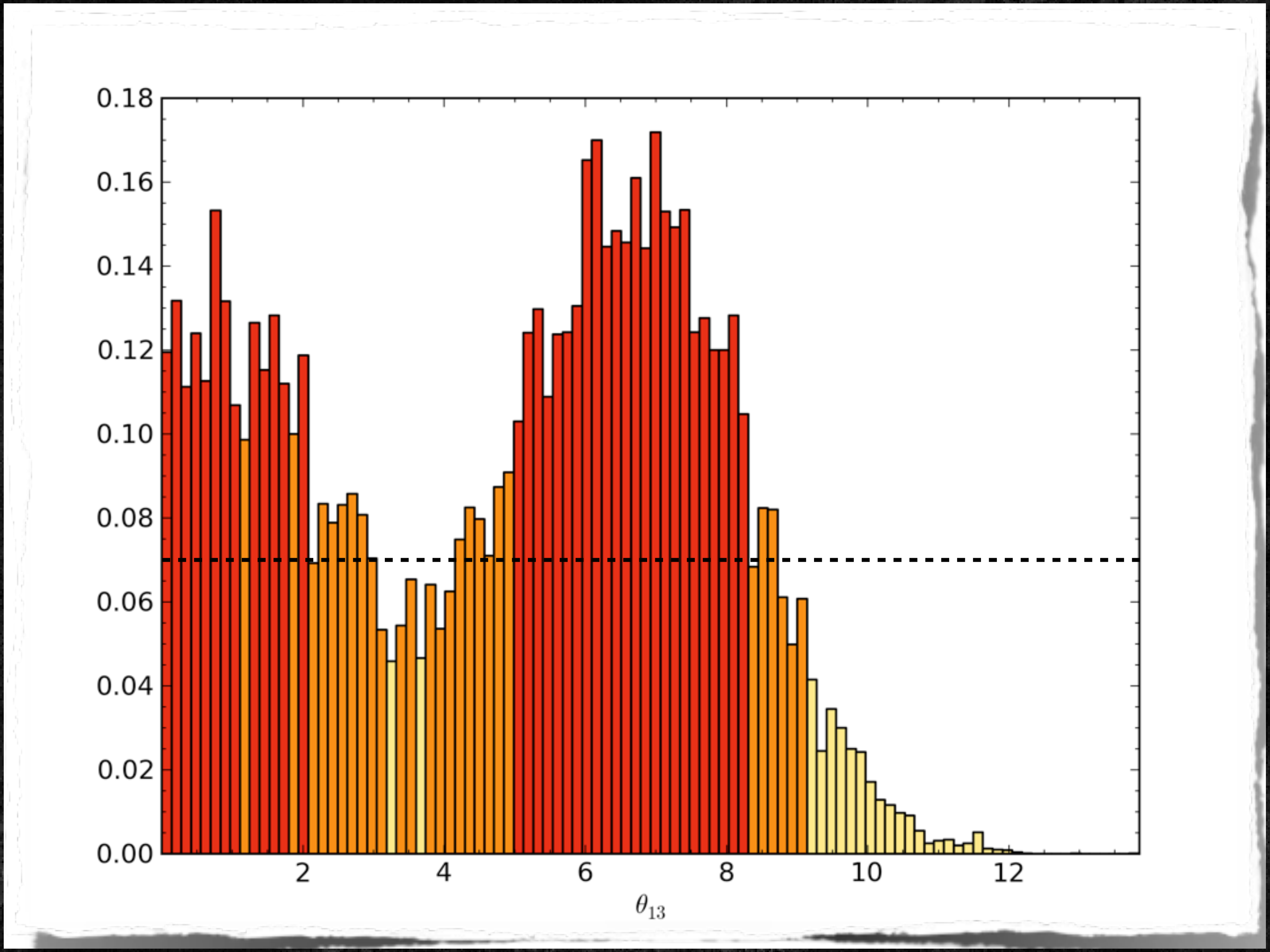


First results: θ_{13}

Input distribution: uniform on [0°,14°]

First results: θ_{13}

Input distribution: uniform on [0°,14°]



First results: θ_{13}

Neutrinos are faster than protons: news from T2K!

arXiv:1106.2822v1 [hep-ex] 14 Jun 2011

Indication of Electron Neutrino Appearance from an Accelerator-produced Off-axis Muon Neutrino Beam

(The T2K Collaboration)

Abstract

The T2K experiment observes indications of $\nu_\mu \to \nu_e$ appearance in data accumulated with 1.43×10^{20} protons on target. Six events pass all selection criteria at the far detector. In a three-flavor neutrino oscillation scenario with $|\Delta m^2_{23}| = 2.4 \times 10^{-3}$ eV^2, $\sin^2 2\theta_{23} = 1$ and $\sin^2 2\theta_{13} = 0$, the expected number of such events is 1.5±0.3(syst.). Under this hypothesis, the probability to observe six or more candidate events is 7×10^{-3}, equivalent to 2.5σ significance. At 90% C.L., the data are consistent with $0.03(0.04) < \sin^2 2\theta_{13} < 0.28(0.34)$ for $\delta_{CP} = 0$ and normal (inverted) hierarchy.

First results: θ_{13}

Neutrinos are faster than protons: news from T2K!

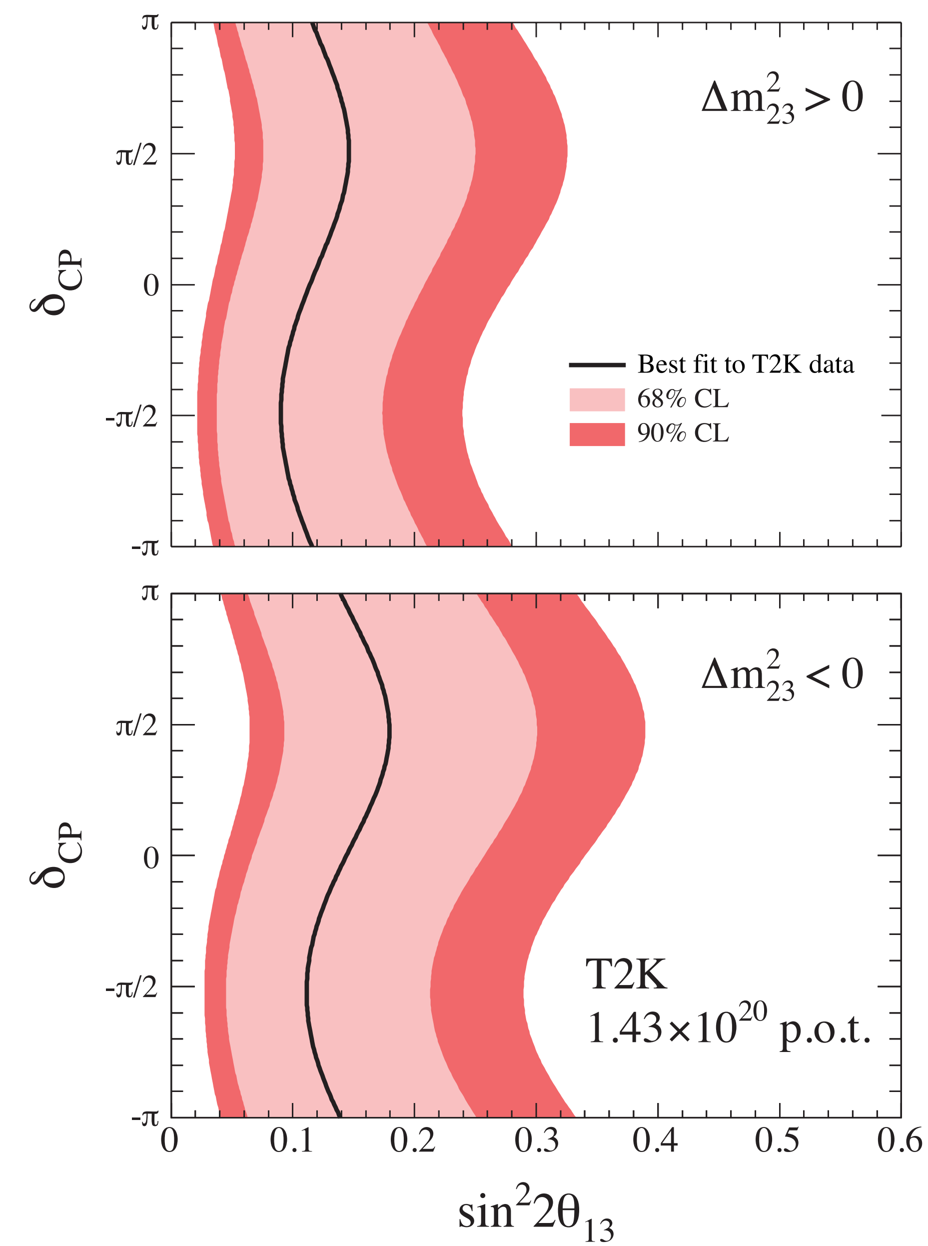
arXiv:1106.2822v1 [hep-ex] 14 Jun 2011

Indication of Electron Neutrino Appearance from an Accelerator-produced Off-axis Muon Neutrino Beam

(The T2K Collaboration)

Abstract

The T2K experiment observes indications of $\nu_\mu \to \nu_e$ appearance in data accumulated with 1.43×10^{20} protons on target. Six events pass all selection criteria at the far detector. In a three-flavor neutrino oscillation scenario with $|\Delta m^2_{23}| = 2.4 \times 10^{-3}$ eV^2, $\sin^2 2\theta_{23} = 1$ and $\sin^2 2\theta_{13} = 0$, the expected number of such events is 1.5±0.3(syst.). Under this hypothesis, the probability to observe six or more candidate events is 7×10^{-3}, equivalent to 2.5σ significance. At 90% C.L., the data are consistent with $0.03(0.04) < \sin^2 2\theta_{13} < 0.28(0.34)$ for $\delta_{CP} = 0$ and normal (inverted) hierarchy.



First results: θ13

Neutrinos are faster than protons: news from T2K!

arXiv:1106.6028v1 [hep-ph] 29 Jun 2011

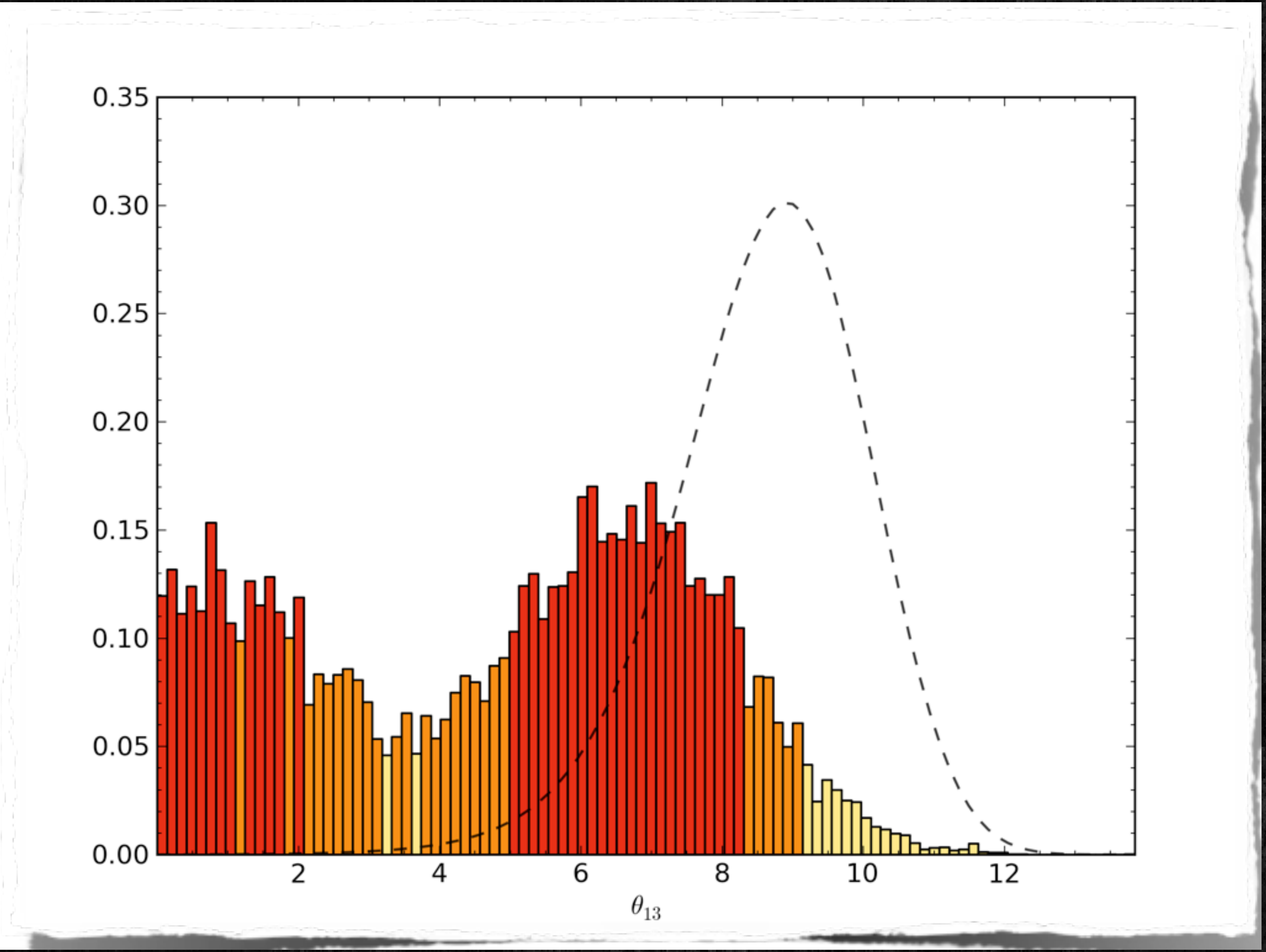
Evidence of $\theta_{13} > 0$ from global neutrino data analysis

G.L. Fogli,[1,2] E. Lisi,[2] A. Marrone,[1,2] A. Palazzo,[3] and A.M. Rotunno[1]

The neutrino mixing angle θ_{13} is at the focus of current neutrino research. From a global analysis of the available oscillation data in a 3ν framework, we previously reported [Phys. Rev. Lett. 101, 141801 (2008)] hints in favor of $\theta_{13} > 0$ at the 90% C.L. Such hints are consistent with the recent indications of $\nu_\mu \to \nu_e$ appearance in the T2K and MINOS long-baseline accelerator experiments. Our global analysis of all the available data currently provides $> 3\sigma$ evidence for nonzero θ_{13}, with 1σ ranges $\sin^2\theta_{13} = 0.021 \pm 0.007$ or 0.025 ± 0.007, depending on reactor neutrino flux systematics. Updated ranges are also reported for the other 3ν oscillation parameters (δm^2, $\sin^2\theta_{12}$) and (Δm^2, $\sin^2\theta_{23}$).

First results: θ_{13}

New profile from global analyses:

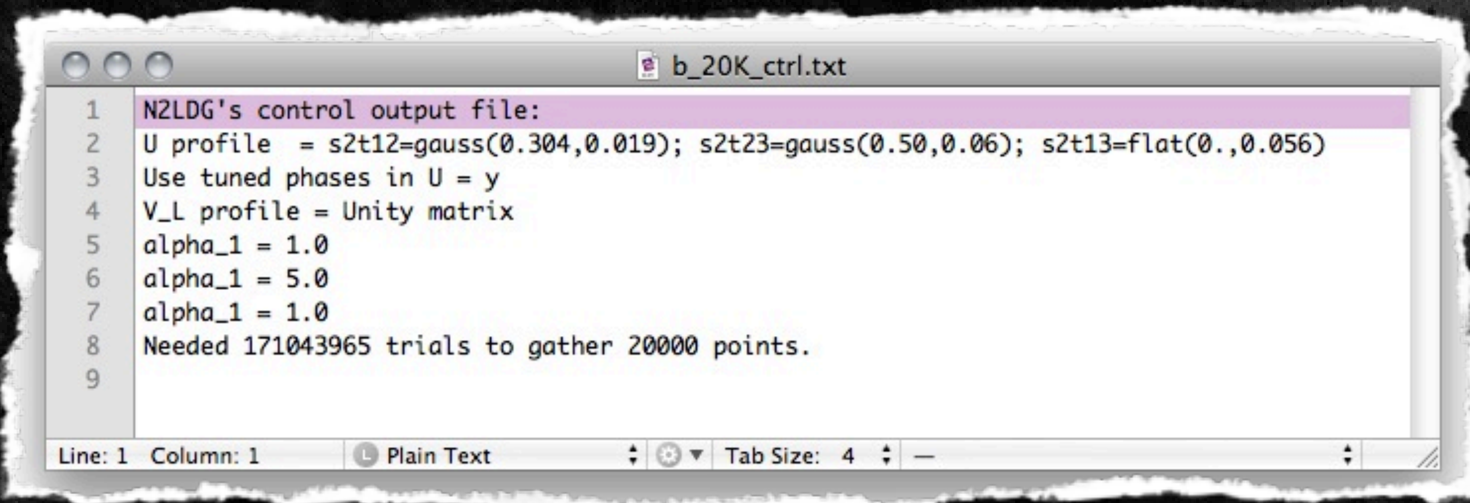


First results: masses

Run 1: PDFs for m_l and m_{ee}

First results: masses

Run 1: PDFs for m_l and m_{ee}



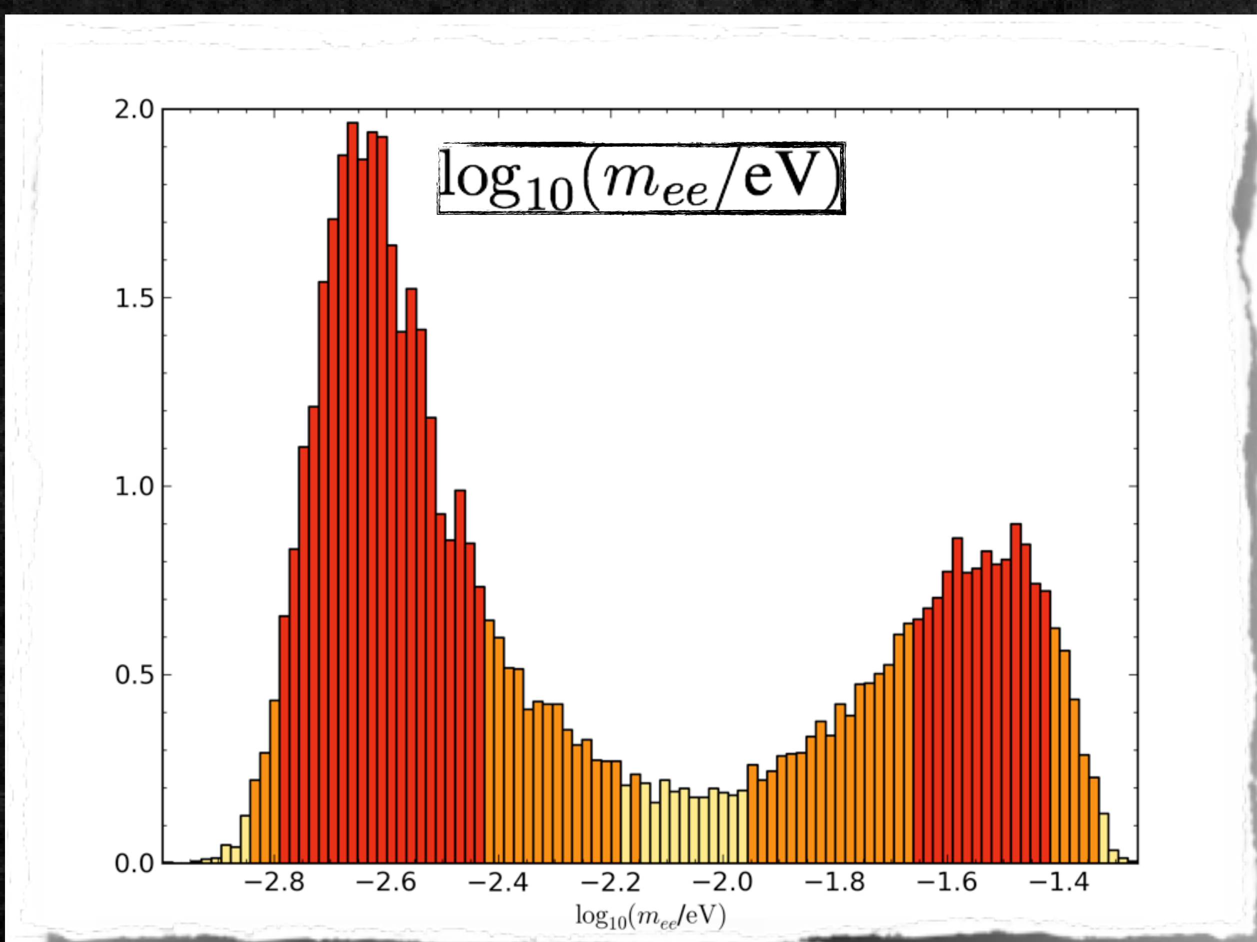
b_20K_ctrl.txt

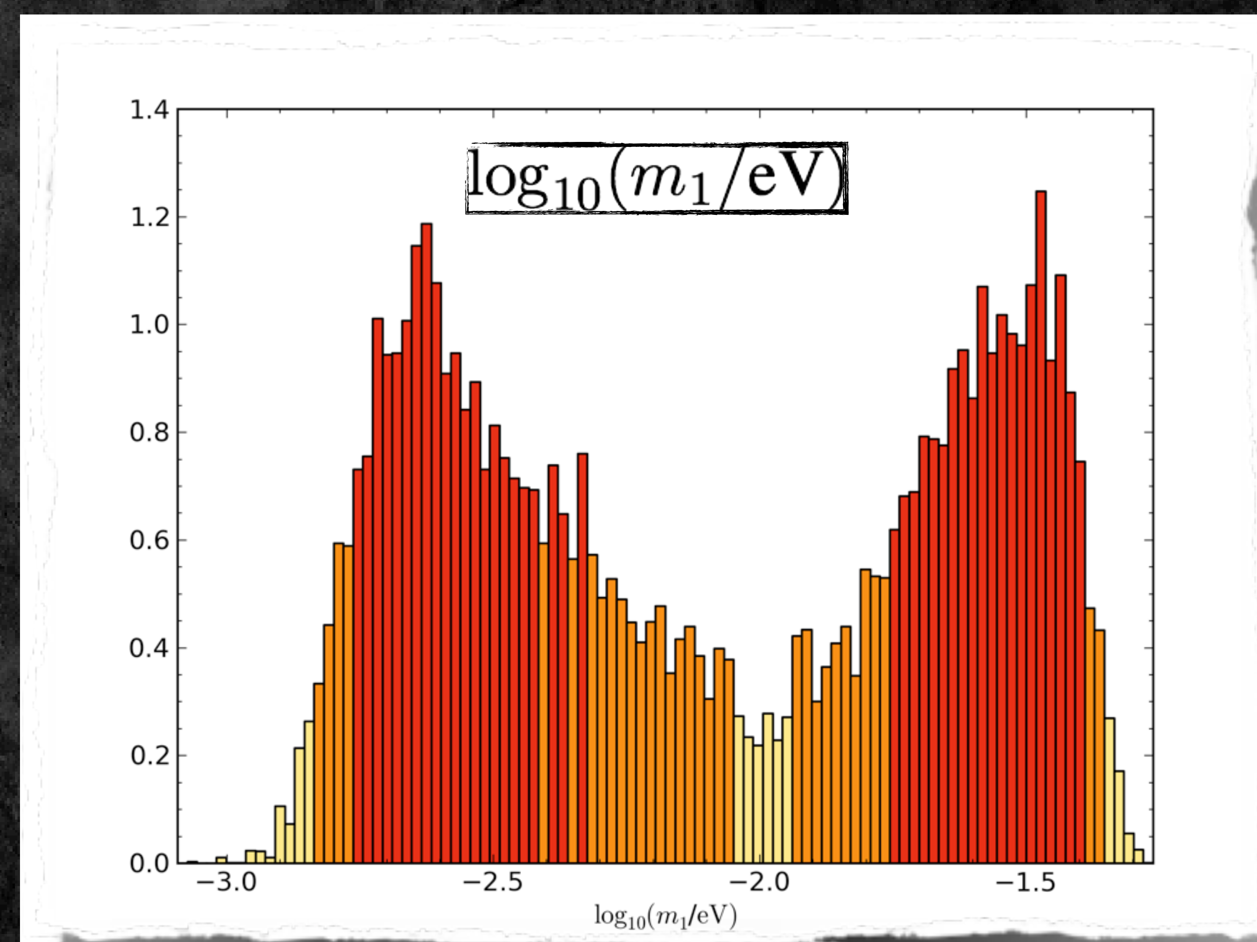
```
N2LDG's control output file:
U profile  = s2t12=gauss(0.304,0.019); s2t23=gauss(0.50,0.06); s2t13=flat(0.,0.056)
Use tuned phases in U = y
V_L profile = Unity matrix
alpha_1 = 1.0
alpha_1 = 5.0
alpha_1 = 1.0
Needed 171043965 trials to gather 20000 points.
```

Line: 1 Column: 1 Plain Text Tab Size: 4

20K points, 100 bins

68% C.L. 95% C.L.





Epilogue and future prospects:

About Leptogenesis and the SO(10)-inspired model:

Future prospects:

Epilogue and future prospects:

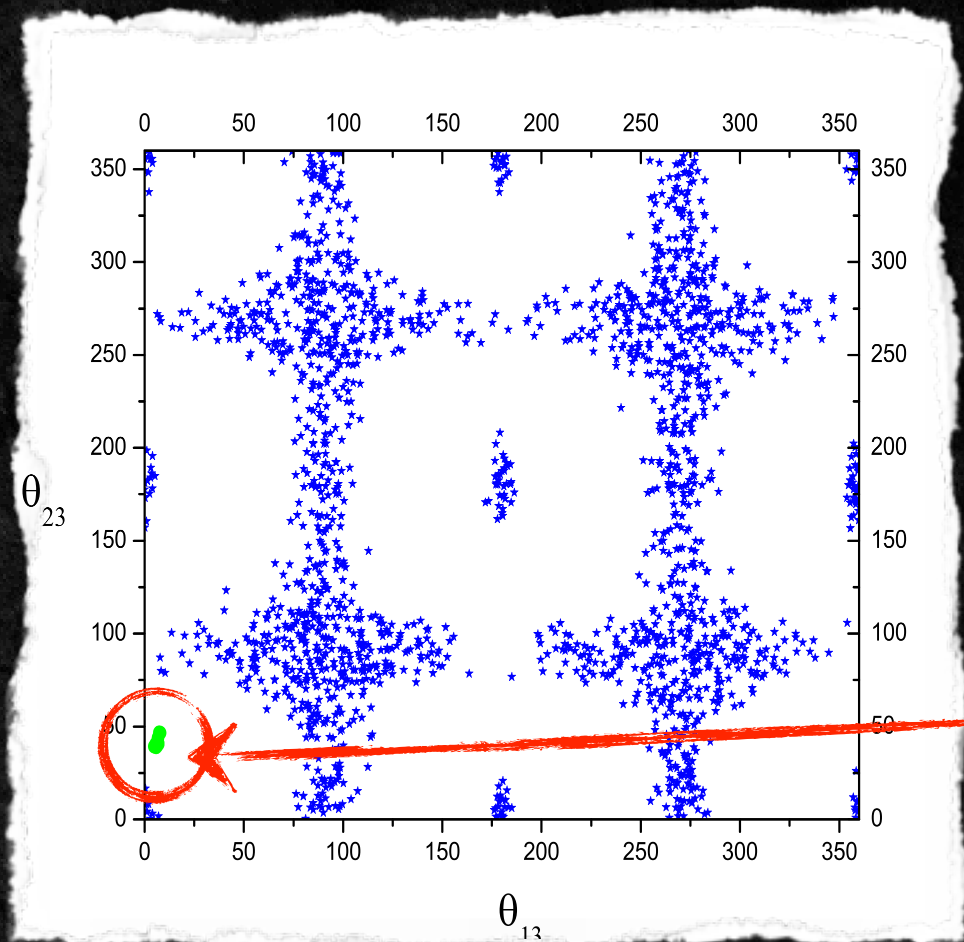
About Leptogenesis and the SO(10)-inspired model:

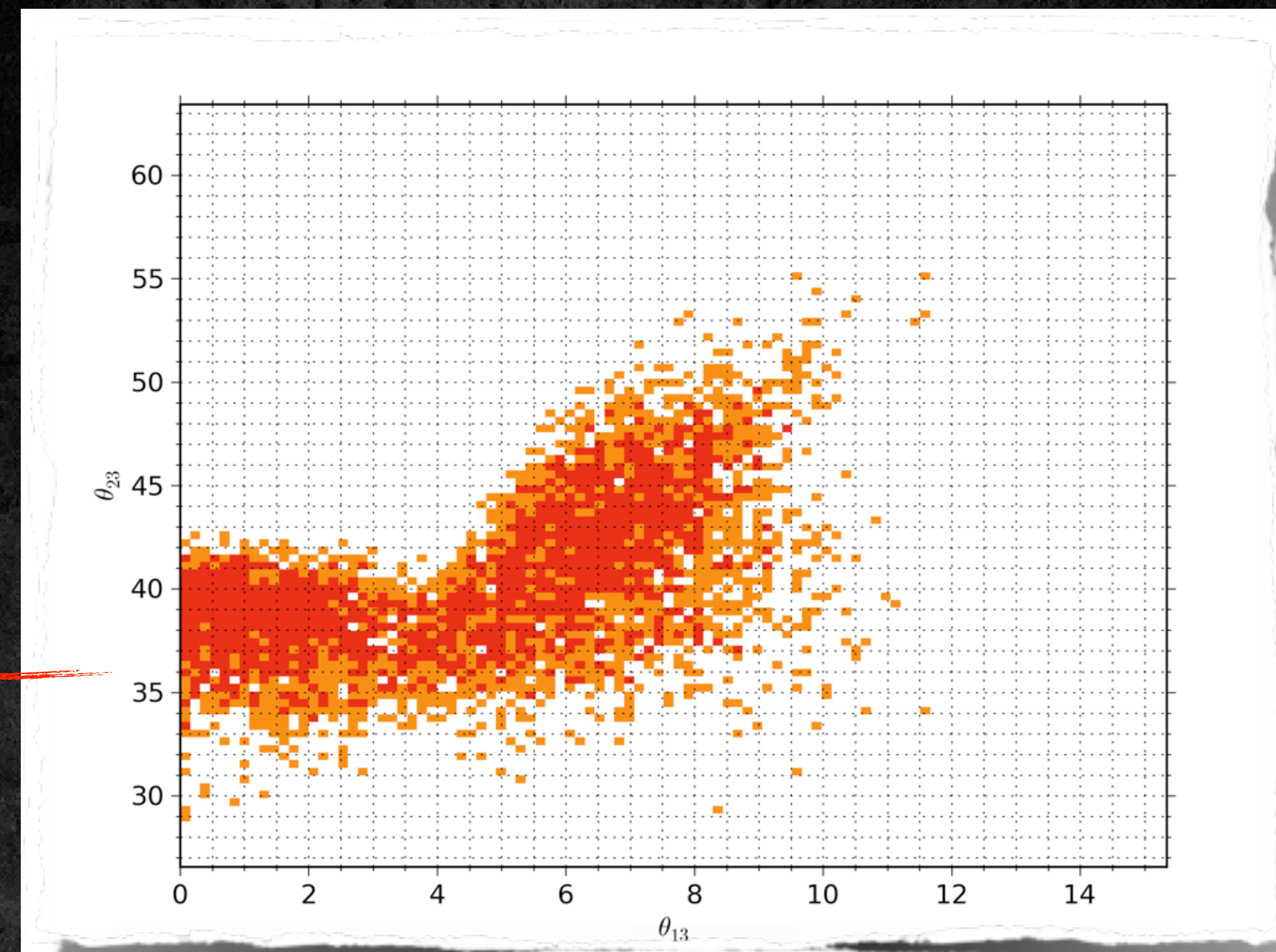
- *Leptogenesis* can explain the *observed BAU* and, via the seesaw mechanism, the *neutrino mass scale* in a natural way
- The *SO(10)-inspired Leptogenesis* model combines different phenomenologies in a *predictive frame*
- Lower bound on m_{ee} and m_1, 95% C.L.: $m_{ee}, m_1 > 1.26 \times 10^{-3}\mathrm{eV}$
- In line with new results on θ_{13}

Future prospects:

- Increase statistics: more precision, *2 parameter joint PDFs*
- more on SO(10)-inspired: inverted order, $V_L \neq 1$ and *possible future scenarios*.

Encore: Correlations θ_{23} - θ_{13}





P. Di Bari, A. Riotto, hep-ph: 1012.2343

For high values of θ_{13} Leptogenesis and the seesaw mechanism select increasing values of θ_{23}