Status of WP6

A. Donini & P. Hernández

IFT Madrid (UAM/CSIC),

IFIC Valencia (UV/CSIC)

EUROnu Review: 14th April 2011

WP6 work force

CSIC (Spain): Valencia, Madrid, Barcelona
MPG (Germany): Heidelberg, Munich,Würzburg
INFN (Italy): Padua, Rome I, Rome III, Naples, Turin, LNF
University of Durham (UK)
CERN (Switzerland)
Virginia Tech (USA): external member

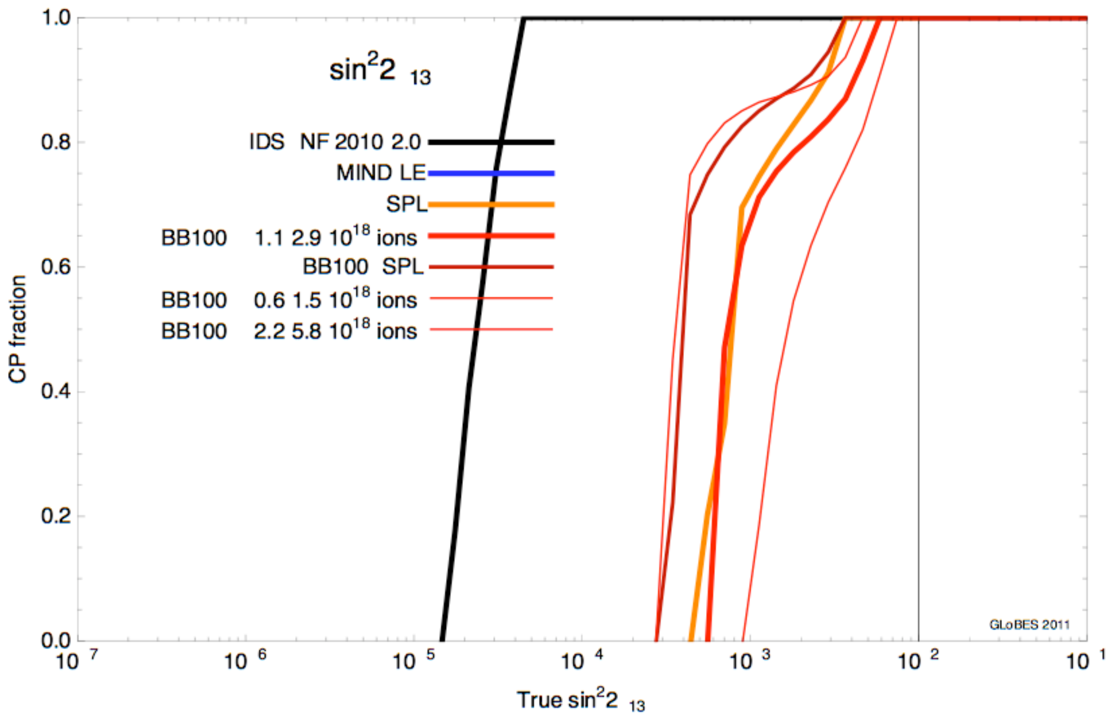
Names: Antusch, Agarwalla, Barenboim, Bernabeu, Blennow, Coloma, Donini, Fernández-Martínez, Gonzalez-García, Giunti, Hernández, Huber, Kopp, Laveder, Li, Lindner, Long, López-Pavón, Maltoni, Mena, Meloni, Mezzetto, Migliozzi, Palomares-Ruiz, Pascoli, Peña-Garay, Ohlsson, Orme, Ota, Rigolin, Rius, Salvado, Schmidt, Schwetz, Scotto-Lavina,Tang, Terranova, Winter, Wong, Zhang …

….. The list includes most of the active researchers in the field….

WP6 Tasks

Our Main Task: Optimization and comparison of facilities in terms of physics performance. Selected observables: θ_{13}, δ and the neutrino mass hierarchy

θ_{13}



P. Huber, preliminary (will be included in the WP6 2010 Yearly report)

TOOLS

- The GLOBES (General LOng Baseline Experiment Simulator) has been developed by members of Euronu and it is now commonly used by all the community
- A Markov Chain MonteCarlo package interfaced with GLOBES has been written by members of Euronu for scanning of large parameter spaces (such as in New Physics models)

TOOLS

- Huber, Lindner, Winter, "Simulation of long-baseline neutrino oscillation experiments with GLoBES"; hep-ph:0407333
- Huber, Kopp, Lindner, Rolinec, Winter, "New features in the simulation of neutrino oscillation experiments with GLoBES 3.0"; hep-ph:0701187
- Blennow, Fernández-Martínez, "Neutrino oscillations parameter sampling with MonteCUBES"; arXiv:0903.3985 (Euronu-WP6-09-03)

WP6 Deliverables

Del. No.	Name	Nature	Delivery Date (proj.month)	Status
D4	Review physics of baseline scenarios and optimization	R	12	✔
D9	Interim report	R	24	✔
D14	Project Review Doc.	R	36	

WP6 Deliverables

Del. No.	Name	Nature	Delivery Date (proj.month)	Status
D4	scenarios and optimization			
D9	Interim report	R	24	✔
D14	Project Review Doc.	R	36	

WP6 EURONU 2009 Yearly Report: arXiv 1005.3146

D9-WP6: WP6 EURONU 2nd year report

Content of the WP6-2010 report

1. Standard Physics
    1. Global fit to neutrino oscillation data
    2. θ_{13}: phenomenology, present status and prospects
    3. Solar fluxes from solar neutrino data
    4. Status and optimization of new facilities:
        1. Neutrino Factory
        2. Beta Beams
        3. Super Beams

2. New Physics
    1. Sterile neutrinos
    2. NSI in neutrino propagation
    3. NSI in neutrino production or detection
    4. Neutrinoless double beta decay
    5. Non-unitarity

2nd year Milestones+ Summary of other activities of WP6

WP6 Milestones

Del. No.	Name	Nature	Delivery Date (proj.month)	Status
6.1	Update Physics Potential	R	12	✔
6.2	Review Systematic Errors. Unified Treatment	R	24	✔
6.3	Scenarios B, Li betabeam	R	24	✔
6.4	Physics performance of all facilities with review of fluxes	R	24	✔
6.5	Theoretical impact of future measurements in physics of flavour and choice of optimal scenario for all facilities	R	36	in progress IV

M 6.2 Systematic errors

1) Detector effects

$$N_\alpha = \int_{E_\alpha}^{E_\alpha+\Delta E} dE_\nu \sigma(E_\nu) P_{osc}(E_\nu, \{\theta_{ij}, \Delta m^2_{ij}\}) \left. \frac{d\Phi}{d\cos\theta}(E_\nu) \right|_{\theta\simeq 0}$$

Energy dependent efficiencies and backg.

$$\text{true energy}(E_\nu) \neq \text{reconstructed energy}(E^r_\nu)$$

M 6.2 Systematic errors

1) Detector effects

$$N_\alpha = \int_{E_\alpha}^{E_\alpha+\Delta E} dE_\nu^r \int_0^\infty dE_\nu M(E_\nu^r, E_\nu)\sigma(E_\nu)P_{osc}(E_\nu, \{\theta_{ij}, \Delta m^2_{ij}\}) \left.\frac{d\Phi}{d\cos\theta}(E_\nu)\right|_{\theta\simeq 0}$$

$$\simeq \sum_{\alpha,\beta} M_{\alpha\beta}\sigma(E_\beta)P_{osc}(E_\beta, \{\theta_{ij}, \Delta m^2_{ij}\}) \left.\frac{d\Phi}{d\cos\theta}(E_\beta)\right|_{\theta\simeq 0}$$

Migration matrices: what we need to know about detector performance…

First introduced for BetaBeam in
Burguet-Castell, et al Nucl. Phys. B695 (2004); B725 (2005)

M 6.2 Systematic errors

Now unified treatment of BB and NF

$$N_\alpha = \int_{E_\alpha}^{E_\alpha+\Delta E} dE_\nu^r \int_0^\infty dE_\nu M(E_\nu^r, E_\nu)\sigma(E_\nu)P_{osc}(E_\nu, \{\theta_{ij}, \Delta m_{ij}^2\}) \left.\frac{d\Phi}{d\cos\theta}(E_\nu)\right|_{\theta\simeq 0}$$

$$\simeq \sum_{\alpha,\beta} M_{\alpha\beta}\sigma(E_\beta)P_{osc}(E_\beta, \{\theta_{ij}, \Delta m_{ij}^2\}) \left.\frac{d\Phi}{d\cos\theta}(E_\beta)\right|_{\theta\simeq 0}$$

WP5 provides MM for signal and background events

$$\epsilon_{\alpha\beta}^{\nu_e}, \epsilon_{\alpha\beta}^{\nu_\mu}, \epsilon_{\alpha\beta}^{\nu_\tau} \quad \alpha, \beta = 1, ..., N_{\rm bin}$$

$$b_{\alpha\beta}^{\nu_e}, b_{\alpha\beta}^{\nu_\mu}, b_{\alpha\beta}^{\nu_\tau} \quad \alpha, \beta = 1, ..., N_{\rm bin}$$

GLOBES modified to include them

Example: MIND MMs (NF)

Signal Efficiency E_ν^{true} A. Laing PhD Thesis

E_ν^{recons}

	0-2.5	2.5-3.5	3.5-4.5	4.5-5.5	5.5-6.5	6.5-7.5	7.5-10	10-15	15-20	20-25	25-30
0-2.5	0	0	0	0	0	0	0	0	0	0	0
2.5-3.5	1.78	1.26	0.01	0	0	0	0	0	0	0	0
3.5-4.5	0.49	5.94	6.54	0.20	0.04	0	0	0	0	0	0
4.5-5.5	0.08	1.71	20.24	16.07	0.68	0.03	0.01	0	0	0	0
5.5-6.5	0.04	0.39	6.04	28.25	20.72	1.59	0.07	0	0	0	0
6.5-7.5	0	0.12	1.18	7.26	31.82	20.23	1.21	0.01	0	0	0
7.5-10	0	0.09	0.70	2.31	11.22	40.36	38.50	1.38	0.01	0.01	0.01
10-15	0	0.06	0.30	0.67	1.18	2.29	26.76	47.64	2.15	0.075	0.032
15-20	0	0	0.14	0.32	0.24	0.35	0.58	19.15	40.25	2.68	0.26
20-25	0	0	0.10	0.07	0.14	0.25	0.17	0.66	24.72	33.40	2.87
25-30	0	0	0	0.12	0.07	0.06	0.12	0.15	1.77	28.15	27.86
overflow	0	0.01	0.04	0.09	0.33	0.40	0.44	0.43	0.62	4.90	37.72

Table A.1: *Signal Efficiency response matrix; All values* $\times 10^{-2}$

M 6.2 Systematic errors

2) Flux uncertainties

$$N_\alpha = \sum_{\alpha\beta} \epsilon_{\alpha\beta}\, \sigma(E_\beta) P_{osc}(E_\beta, \{\theta_{ij}, \Delta m^2_{ij}\}) \left. \frac{d\Phi}{d\cos\theta}(E_\beta) \right|_{\theta\simeq 0}$$

Flux uncertainties for NF & BB

$$\frac{d\Phi}{d\cos\theta}(E_\nu) \to \frac{d\Phi}{d\cos\theta}(E_\nu, \underbrace{N_{\text{ions}}, E_{\mu/\beta}, \delta\phi, Pol}_{\text{4 extra parameters to fit}})$$

4 extra parameters to fit

M 6.2 Systematic errors

Unified treatment:

Example: A = normalization, x = N_{near}/N_{far}

$$\chi^2(\theta_{13}, \delta, ..., A, x) = \sum_i \left(\frac{N_i(\theta_{13}, \delta, ..., A, x) - n_i}{\sigma_i} \right)^2 + \frac{(A-1)^2}{\sigma_A^2} + \frac{(x-1)^2}{\sigma_x^2}$$

Add as many parameters as required by physics/detector.

GLOBES can do this

M 6.2 Systematic errors

2) Probabilities

$$N_\alpha = \sum_{\alpha\beta} \epsilon_{\alpha\beta}\, \sigma(E_\beta) P_{osc}(E_\beta, \{\theta_{ij}, \Delta m^2_{ij}\}) \frac{d\Phi}{d\cos\theta}(E_\beta)\Big|_{\theta\simeq 0}$$

Oscillation probabilities: eg Earth matter density

$$P_{\rm osc}(E_\nu, \{\theta_{ij}, \Delta m^2_{ij}\}) \to P_{\rm osc}(E_\nu, \{\theta_{ij}, \Delta m^2_{ij}\}, \langle N_e \rangle)$$

Taken into account in the fit in phenomenological analyses

M 6.2 Systematic errors

2) Probabilities

$$N_\alpha = \sum_{\alpha\beta} \epsilon_{\alpha\beta}\, \sigma(E_\beta) P_{osc}(E_\beta, \{\theta_{ij}, \Delta m^2_{ij}\}) \left.\frac{d\Phi}{d\cos\theta}(E_\beta)\right|_{\theta\simeq 0}$$

If various channels contribute to the signal…

$$\nu_e \rightarrow \nu_\mu \rightarrow \mu^-$$

$$\nu_e \rightarrow \nu_\tau \rightarrow \tau^- \rightarrow \mu^-$$

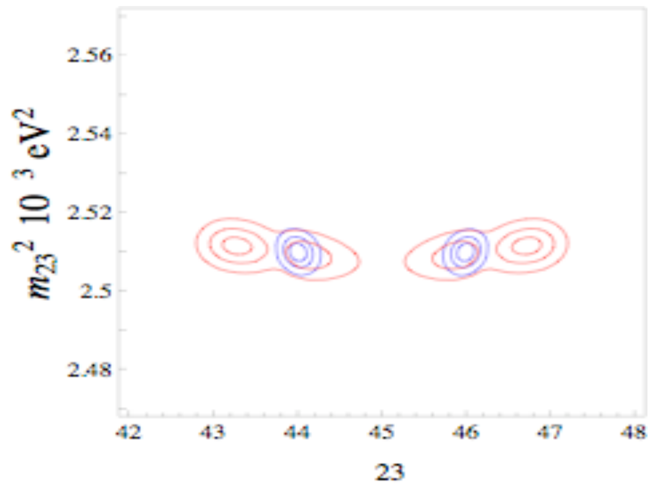
Tau-contamination!

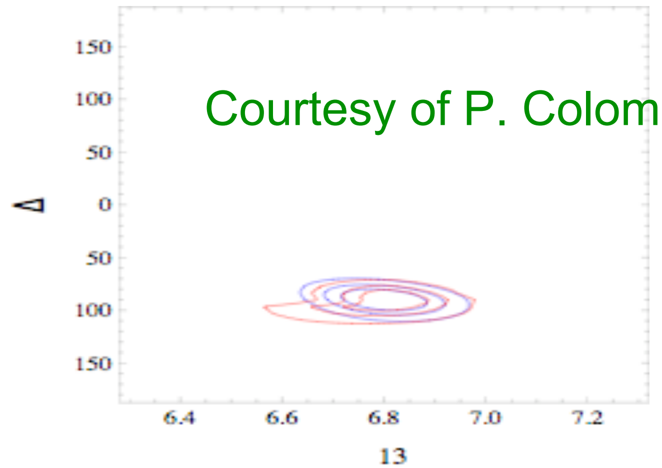
EUROnu-WP6-10-17

M 6.2 Systematic errors

$$N_\alpha = \sum_{\alpha\beta} \epsilon^{\mu}_{\alpha\beta}\, \sigma_{\nu_\mu}(E_\beta) P_{e\mu}(E_\beta, \{\theta_{ij}, \Delta m^2_{ij}\})\, \frac{d\Phi}{d\cos\theta}(E_\beta)\Big|_{\theta\simeq 0}$$

$$+ \sum_{\alpha\beta} \epsilon^{\tau}_{\alpha\beta}\, \sigma_{\nu_\tau}(E_\beta) P_{e\tau}(E_\beta, \{\theta_{ij}, \Delta m^2_{ij}\})\, \frac{d\Phi}{d\cos\theta}(E_\beta)\Big|_{\theta\simeq 0}$$





Courtesy of P. Coloma (CSIC)

Problems in disappearance!
With new MM the problem seems to be solved (to be checked)

M 6.2 Systematic errors

2) Cross-sections & MMs

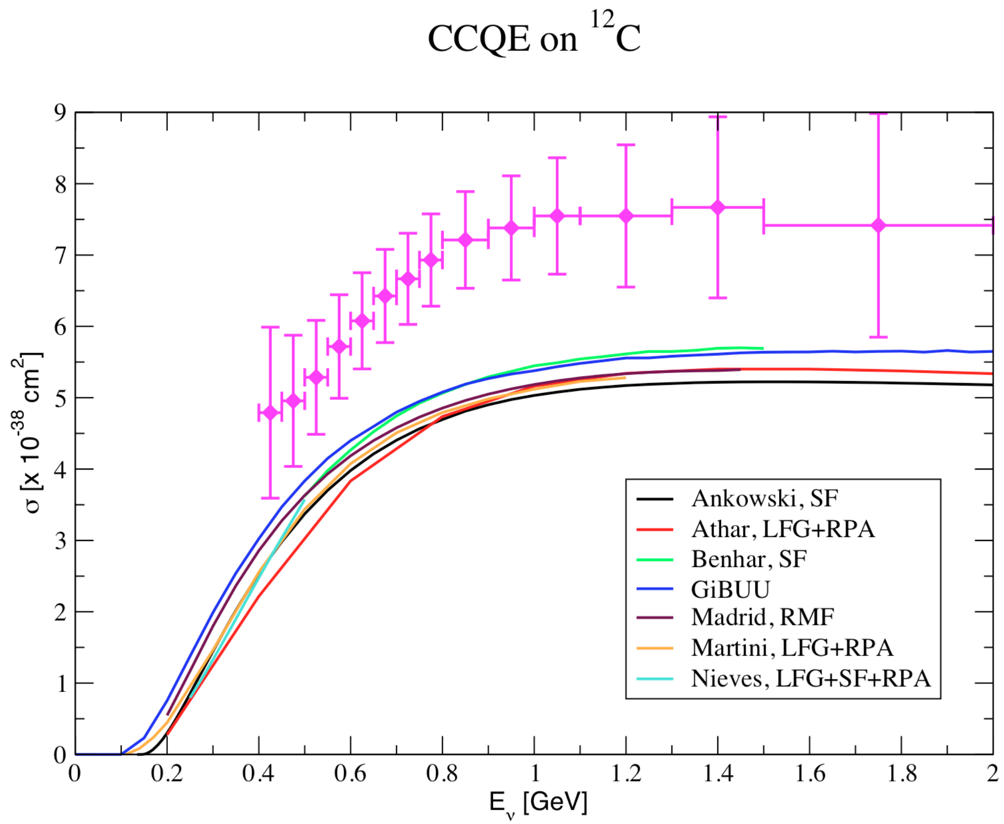
$$N_\alpha = \sum_{\alpha\beta} \epsilon_{\alpha\beta}\ \sigma(E_\beta) P_{osc}(E_\beta, \{\theta_{ij}, \Delta m^2_{ij}\}) \frac{d\Phi}{d\cos\theta}(E_\beta)\Big|_{\theta\simeq 0}$$

Two very different types of errors on MMs

- from cross-section uncertainties
- from detector inefficiencies

Goal is to identify the most relevant parameters of each type

M 6.2 QE Cross Sections



State-of-the-art nuclear models cannot explain MiniBoone data…

M 6.3 Scenarios for betabeams

Li, B vs He/Ne and Low-gamma vs High-gamma

1) Compilation of all physics studies so far (presented at RAL, to be included in WP6 2010 Report)
2) Duty cycle restrictions from atmospheric neutrino background for all scenarios ($\gamma = 100$ done, $\gamma = 350$ in preparation, to be included in WP6 2010 Report)

M 6.3 Scenarios for betabeams

Scenarios for Li, B vs He/Ne betabeam

Ions	Fluxes/10^{18} x years	Minimal θ_{13}		
		Sensitivity	CP-frac at 10^{-3}	Hierarchy
^{6}He ^{18}Ne	2.9 x 5 1.1x 5	5×10^{-4}	~ 50%	NO
^{6}He ^{18}Ne	(2.9 x 2) x 2 (1.1 / 2) x 8	6×10^{-4}	~ 45%	NO
^{8}Li ^{8}B	(2.9 x 5) x 5 (1.1 x 5) x 5	2×10^{-4}	~60%	8×10^{-3}

$\gamma = 100$

M 6.3 Scenarios for betabeams

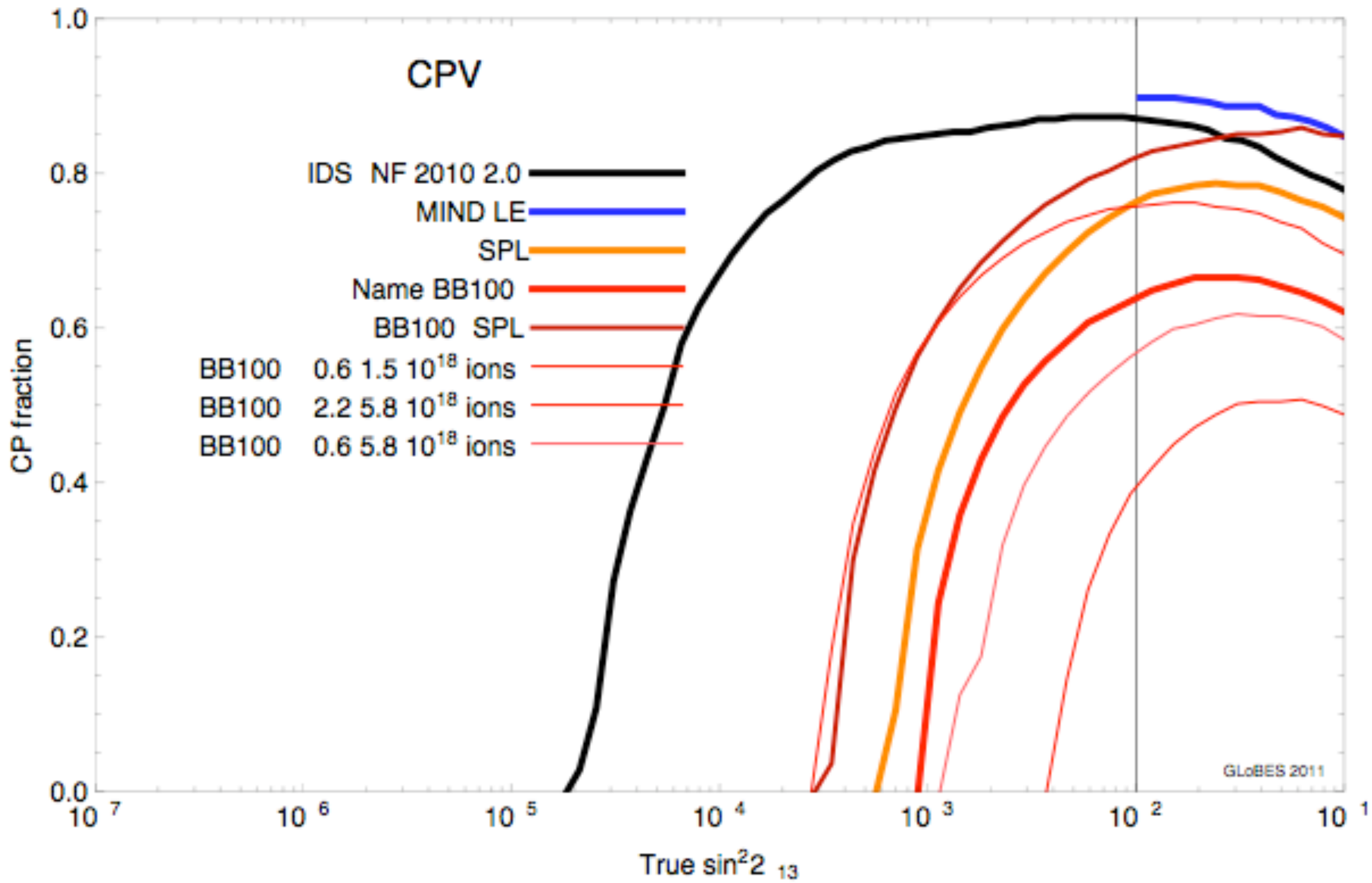
Scenarios for low-gamma vs high-gamma

Ions	Fluxes/10^{18} x years	Minimal θ_{13}		
		Sensitivity	CP-frac at 10^{-3}	Hierarchy
^{6}He ^{18}Ne	2.9 x 5 1.1x 5	5×10^{-4}	~ 50%	NO
^{6}He ^{18}Ne	(2.9 x 2) x 2 (1.1 / 2) x 8	6×10^{-4}	~ 45%	NO
^{6}He ^{18}Ne 500 Kton WC	2.9 x 5 1.1x 5	8×10^{-5}	~75%	2×10^{-3}

$\gamma = 350$

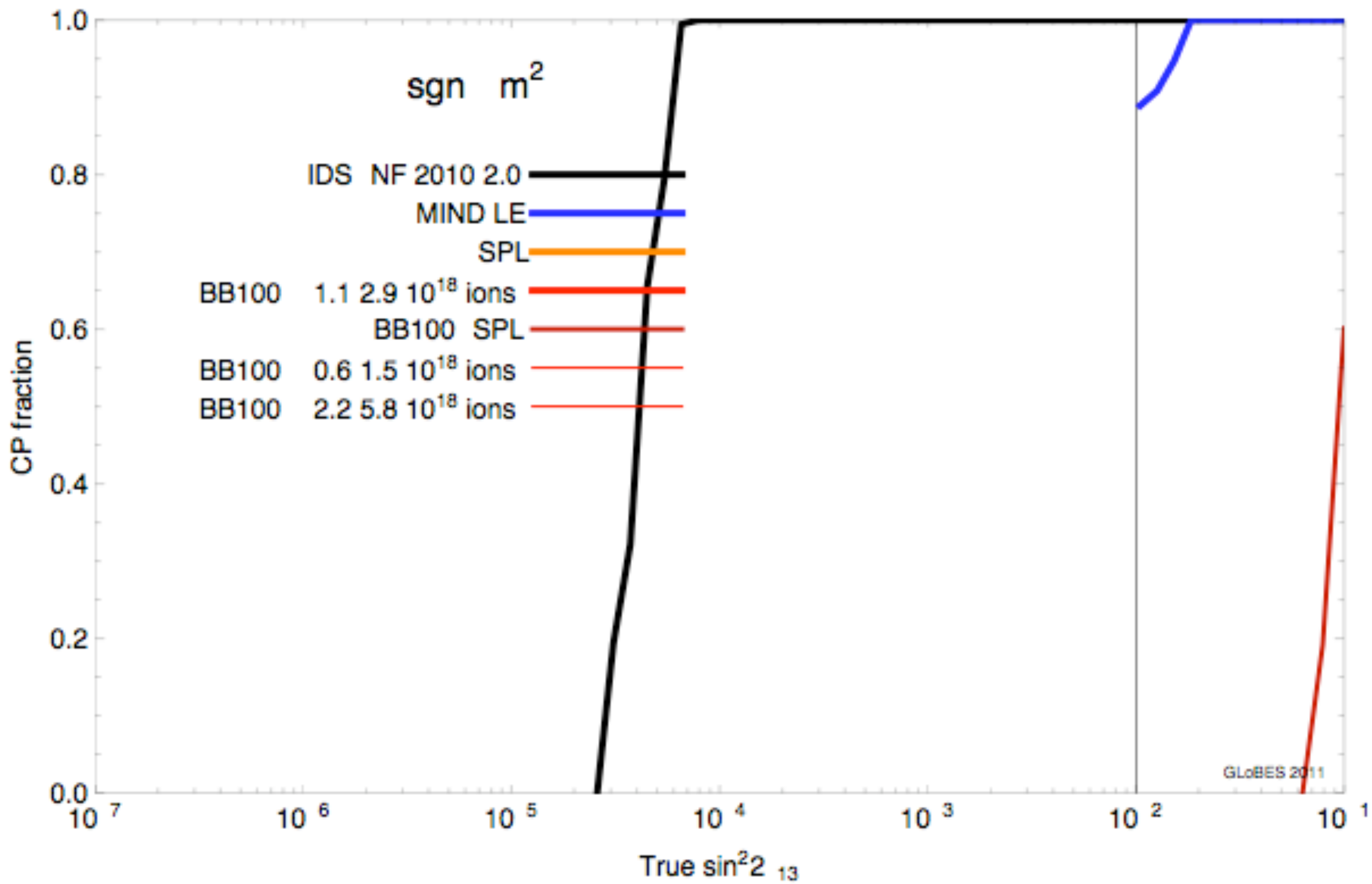
M 6.4 Physics potential

δ



M 6.4 Physics potential

Mass hierarchy



M 6.5

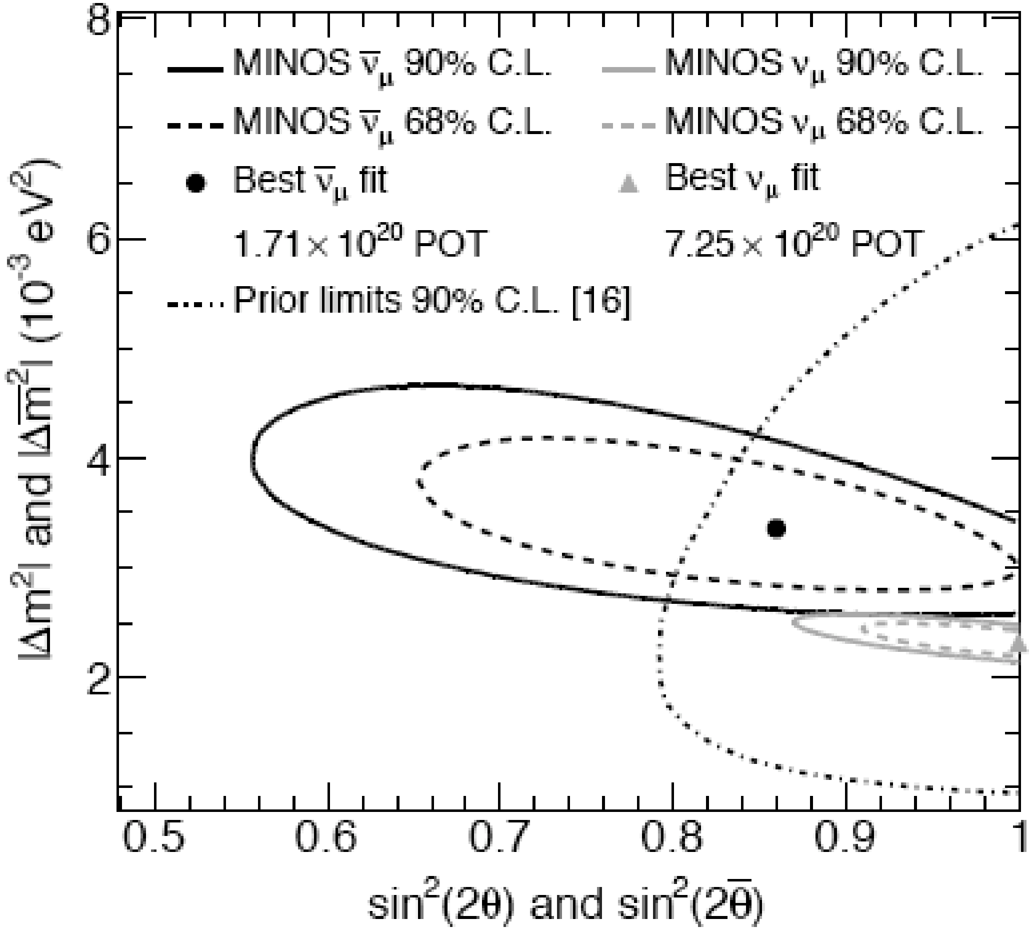
"Theoretical impact of future measurements in physics of flavour and choice of optimal scenario for all facilities."

Present neutrino anomalies:

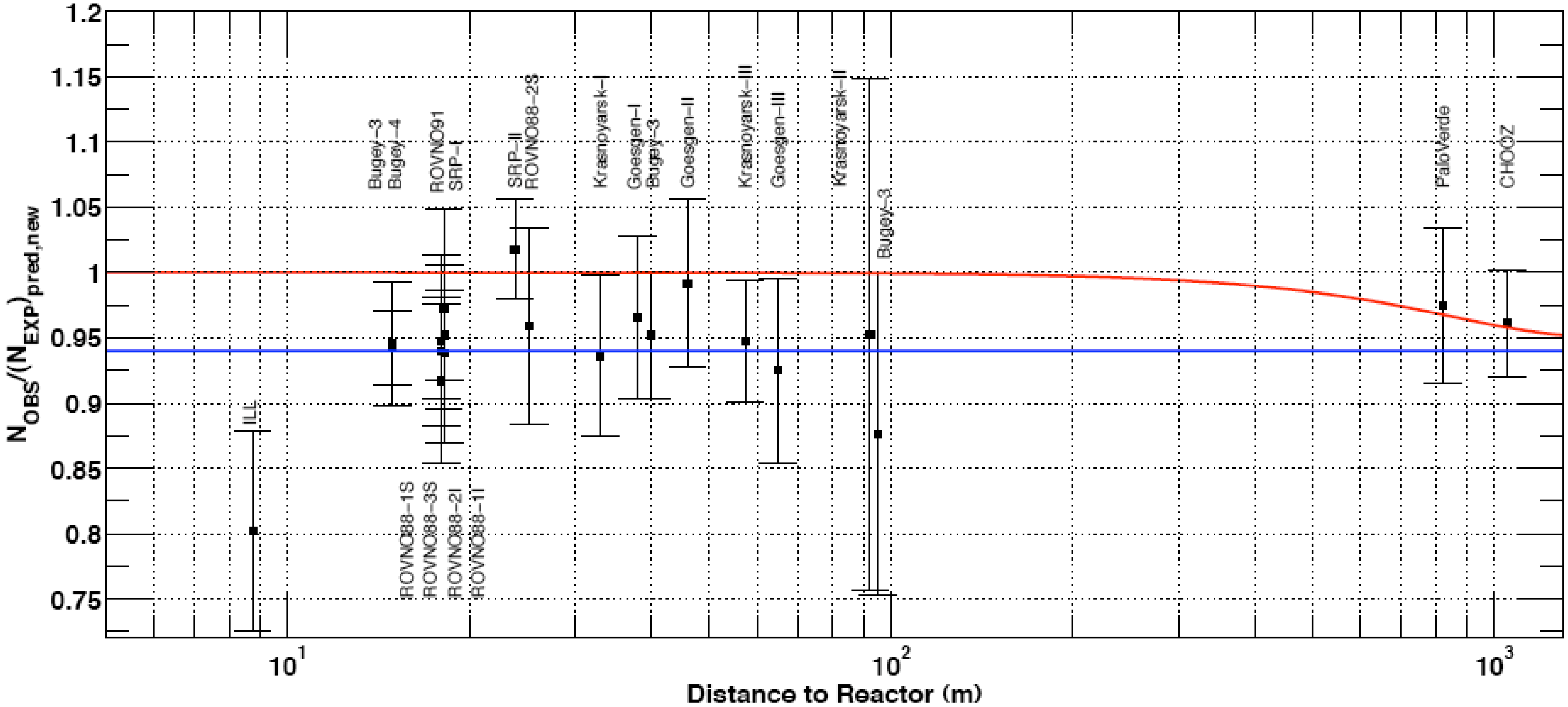
- MINOS neutrino/antineutrino samples
- The "reactor anomaly"
- The LSND/MiniBooNE puzzle
- Cosmology

The MINOS antineutrino data

MINOS Collaboration, arXiv:1104.0344



The reactor anomaly



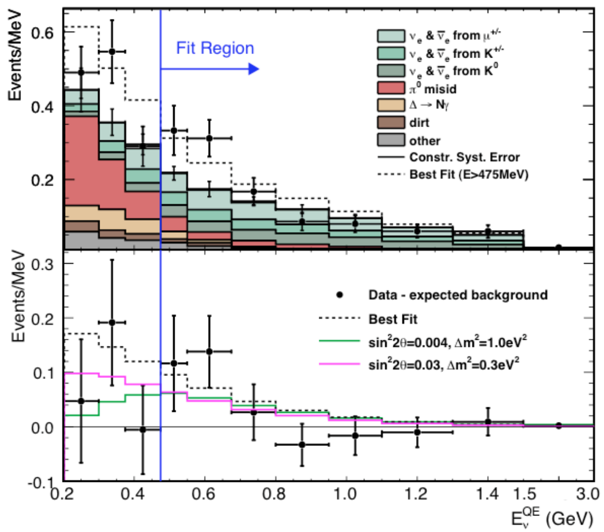
G. Mention et al., arXiv:1101.2755

Revival of LSND by MiniBooNE

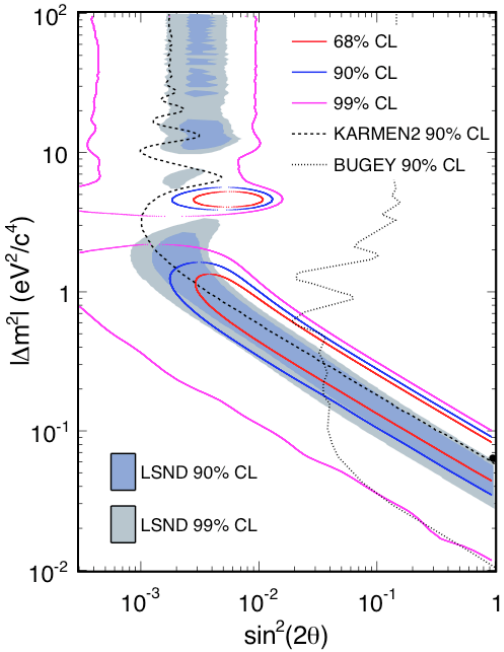
MiniBooNE Antineutrinos

[PRL 103 (2009) 111801; PRL 105 (2010) 181801]

$\bar{\nu}_\mu \to \bar{\nu}_e$ $L \simeq 541\,\text{m}$ $475\,\text{MeV} \leq E \lesssim 3\,\text{GeV}$



[MiniBooNE, PRL 105 (2010) 181801, arXiv:1007.1150]



Agreement with LSND $\bar{\nu}_\mu \to \bar{\nu}_e$ signal!

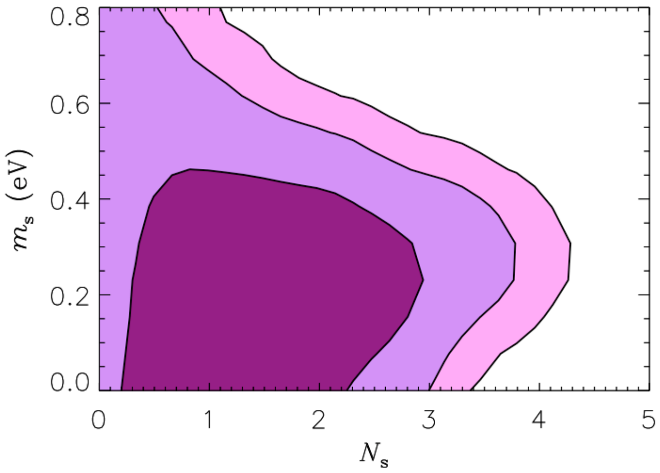
Similar L/E but different L and E $\Longrightarrow$ Oscillations!

C. Giunti — SBL $\bar{\nu}_\mu \to \bar{\nu}_e$ Oscillations — EUROnu 2011, RAL, 19 Jan 2011 — 19

Cosmology

Cosmology

- CMB and LSS in ΛCDM: [Hamann, Hannestad, Raffelt, Tamborra, Wong, arXiv:1006.5276]



- BBN: $N_s = 0.68^{+0.80}_{-0.70}$ [Izotov, Thuan, ApJL 710 (2010) L67, arXiv:1001.4440]

C. Giunti – SBL $\bar{\nu}_\mu \to \bar{\nu}_e$ Oscillations – EUROnu 2011, RAL, 19 Jan 2011 – 8

Also M. C. González-García, M. Maltoni, J. Salvado, EURONU-WP6-10-22

NSI/Steriles ?

- NSI for MINOS ? not easy to fit the data given other constraints
- Steriles for LSND/MiniBooNe? tension between appearance vs disappearance, need additional CPT or NSI

Even if the simplest models do not work, they are worth exploring

See, for example, Kopp, Maltoni and Schwetz, arXiv:1103.4570 (EURONU-WP6-11-32) and
EURONU-WP6-10-14; EURONU-WP6-10-23;EURONU-WP6-10-24; EURONU-WP6-10-25

WP6 Activities

- Two theory workshops organized

  (large participation of the neutrino community):

  Flavour physics in the era of precision neutrino experiments, Cosener's House, June 8-10 June, 2009, 60 participants

  Neutrino Theory, Models and Experimental perspectives, CERN's Theory Division, September 13-22 September, 2010, 56 participants

Uncountable talks of WP6 members (~ 100 talks) in Europe, US, India, Japan, New Zealand, Colombia,…

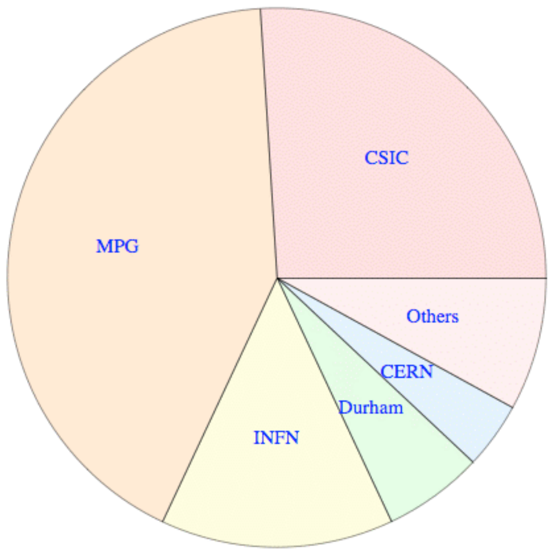
Strong overlap with IDS and LAGUNA EU project

WP6 Activities

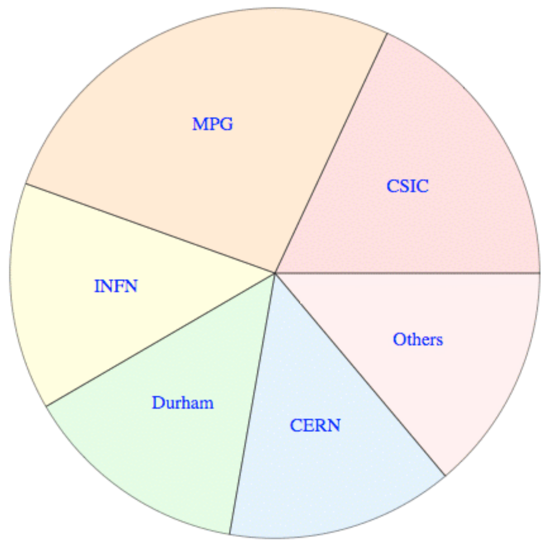
32 EURONU-WP6 papers (all published or in arXiv)

2 Reports of the WP Activity (one already on the arXiv)

analysis of present data, optimization/comparison, new physics....



Papers per institution



Normalized to members of the institution

New physics within Euronu

Model independent approach. Mild experimental constraints:

$$|\varepsilon^{\oplus}_{\alpha\beta}| < \begin{pmatrix} 4.2 & 0.33 & 3.0 \\ 0.33 & 0.068 & 0.33 \\ 3.0 & 0.33 & 21 \end{pmatrix} \qquad |\varepsilon^{\odot}_{\alpha\beta}| < \begin{pmatrix} 2.5 & 0.21 & 1.7 \\ 0.21 & 0.046 & 0.21 \\ 1.7 & 0.21 & 9.0 \end{pmatrix}$$

@NF

$$\epsilon_{ee} - \epsilon_{\tau\tau} \leq 0.1$$

$$\epsilon_{\mu\mu} - \epsilon_{\tau\tau} \leq 0.01$$

$$\epsilon_{\alpha\beta} < 0.001$$