Physics potential of the ESSνSB facility

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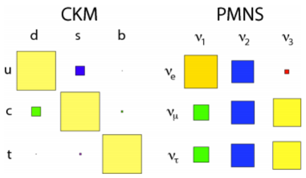
Introduction

In the **SM neutrinos** $\rightarrow$ **massless**
Neutrino oscillations $\rightarrow$ **Physics BSM**

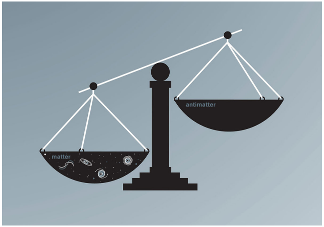
Flavour puzzle

- Why are fermion masses so different in the SM?
- Mixing for quarks very different from leptons



Baryon asymmetry

- Not enough CP violation in quark sector
- ν's could be the answer through leptogenesis



What do we know?

$$U = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix} \mathrm{diag}(1, e^{i\alpha_{21}}, e^{i\alpha_{31}})$$

I. Esteban, M. Gonzalez-Garcia, M. Maltoni, I. Martinez-Soler, T. Schwtetz hep-ph/1611.01514

Best fit values (1σ)

- $\Delta m^2_{21} = 7.50^{+0.19}_{-0.17} \cdot 10^{-5}\mathrm{eV}^2$
- $\sin^2\theta_{12} = 0.306^{+0.012}_{-0.012}$
- $|\Delta m^2_{31}| = 2.524^{+0.039}_{-0.040} \cdot 10^{-3}\mathrm{eV}^2$
- $\sin^2\theta_{23} = 0.441^{+0.027}_{-0.021}$
- $\sin^2\theta_{13} = 0.02166^{+0.00075}_{-0.0075}$

Still unknown

- $\delta \rightarrow$ Leptonic CP violation
- *Sign*(Δm^2_{31})
- Octant of θ_{23}
- ν's Dirac or Majorana?
  Not testable with ν oscillations

The interference term

In matter

A. Cervera *et al.* hep-ph/0002108

$$P^{\pm}_{\mu\to e} = s^2_{23}\sin^2 2\theta_{13}\left(\frac{\Delta_{atm}}{\tilde{B}_{\mp}}\right)^2 \sin^2\left(\frac{\tilde{B}_{\mp}L}{2}\right) \quad \textit{Atmospheric}$$

$$+\, c^2_{23}\sin^2 2\theta_{12}\left(\frac{\Delta_{sol}}{A}\right)^2 \sin^2\left(\frac{AL}{2}\right) \quad \textit{Solar}$$

$$\textit{Interference} + J\frac{\Delta_{sol}}{A}\frac{\Delta_{atm}}{\tilde{B}_{\mp}}\sin\left(\frac{AL}{2}\right)\sin\left(\frac{\tilde{B}_{\mp}L}{2}\right)\cos\left(\pm\delta - \frac{\Delta_{atm}L}{2}\right)$$

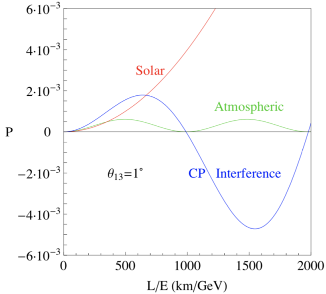
$$J = \cos\theta_{13}\sin 2\theta_{13}\sin 2\theta_{12}\sin 2\theta_{23} \quad \Delta_{atm} = \frac{\Delta m^2_{31}}{2E} \quad \Delta_{sol} = \frac{\Delta m^2_{12}}{2E}$$

$$A = \sqrt{2}G_F n_e \quad \tilde{B}_{\mp} = |A \mp \Delta_{atm}|$$

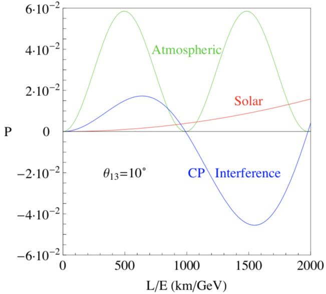
Impact of large θ_{13}

P. Coloma, E. Fernandez-Martinez hep-ph/1110.4583

θ_{13} small



θ_{13} large



First maximum:

- Large statistics
- Systematic error as bottleneck

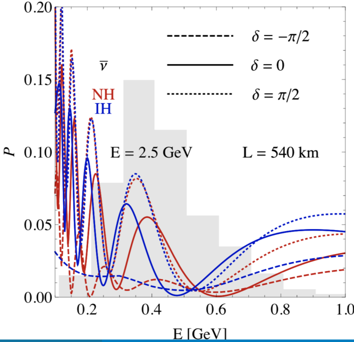
Second maximum:

- Systematic error not a problem
- Statistics as bottleneck

The ESSνSB

E. Baussan *et al.* hep-ex/1309.7022

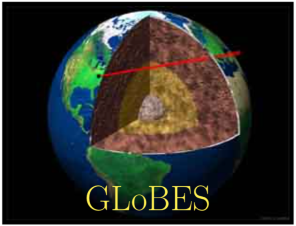
- Modification of the ESS linac to produce neutrinos 14Hz $\rightarrow$ 28Hz
- 5 MW at 2.5GeV proton beam
- MEMPHYS-like WC detector
  - 500 kt fiducial volume
  - Best locations at **540** and 360 km



Simulation framework

P. Huber *et al.* hep-ph/0701187

- Implemented in GLoBES
- Simulation with a ND
- 2.5 GeV proton beam



P. Coloma *et al.* hep-ph/1209.5973

Systematic errors

	SB		
Systematics	Opt.	Def.	Cons.
Fiducial volume ND	0.2%	0.5%	1%
Fiducial volume FD	1%	2.5%	5%
(incl. near-far extrap.)			
Flux error signal ν	5%	7.5%	10%
Flux error background ν	10%	15%	20%
Flux error signal $\bar{\nu}$	10%	15%	20%
Flux error background $\bar{\nu}$	20%	30%	40%
Background uncertainty	5%	7.5%	10%
Cross secs × eff. QE†	10%	15%	20%
Cross secs × eff. RES†	10%	15%	20%
Cross secs × eff. DIS†	5%	7.5%	10%
Effec. ratio ν_e/ν_μ QE*	3.5%	11%	–
Effec. ratio ν_e/ν_μ RES*	2.7%	5.4%	–
Effec. ratio ν_e/ν_μ DIS*	2.5%	5.1%	–
Matter density	1%	2%	5%

Sensitivity to mass hierarchy

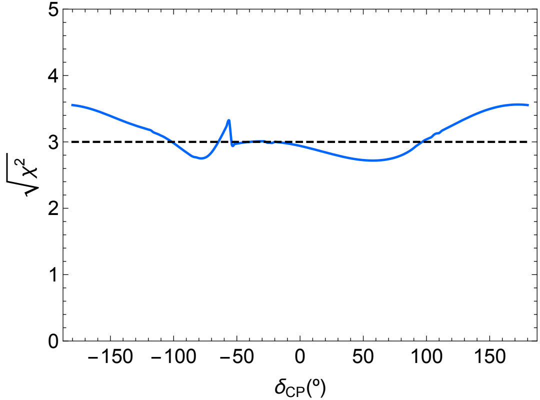
Matter effects relevant when

- High energy ν
  $E_\nu \sim 6$ GeV

ESSνSB

- $L \sim 500km$
- $E_\nu \sim \mathcal{O}(300\text{MeV})$

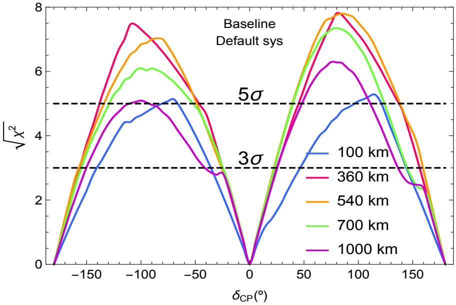
Sensitivity around **3σ**

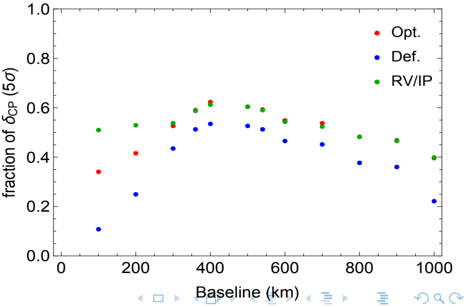


Sensitivity to CP violation

Comparison between

- "Default" systematics
- "Optimistic" systematics
- *T2HK* $\mathcal{O}(3\%)$ systematics with 374 kt (reduced volume and improved photocoverage) K. Abe *et al.* 1805.04163

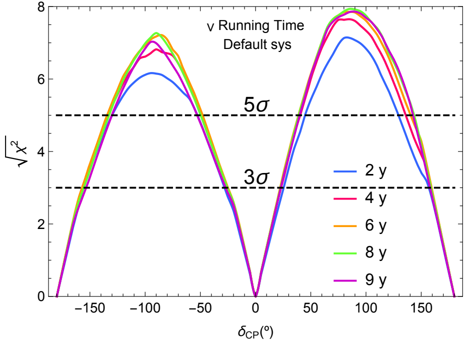


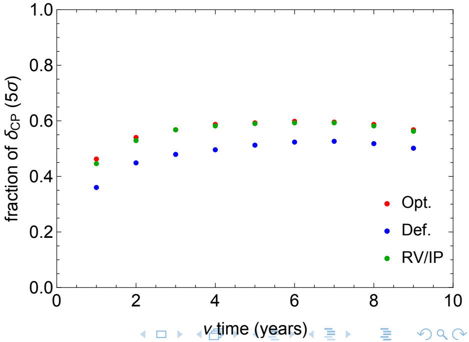


Sensitivity to CP violation

Impact of ν mode running time

- Up to now studies with 2+8 years
- Preference for 5+5 years





Sensitivity to CP violation

Impact of each systematic error

For different values of the systematics

- 2×Cons.
- Cons.
- Def.
- Opt.
- Opt./2

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Systematics	Opt.	Def.	Cons.
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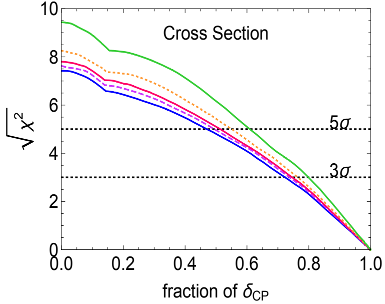
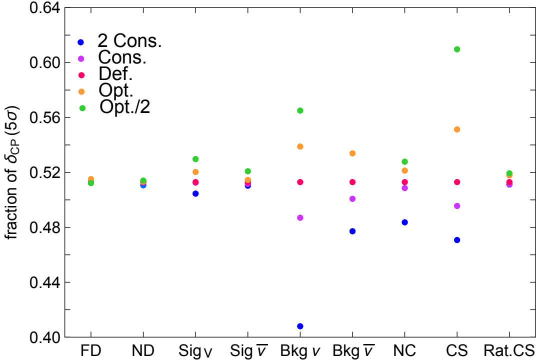
Sensitivity to CP violation

Most important systematics

- ν background
- Cross section uncertainties





Conclusions

- **ESSνSB**
  Complementarity with *DUNE*. **Lower energy ν.**
- Mass hierarchy
  It could exclude the wrong hierarchy at $\sim \mathbf{3\sigma}$
- ν mode running time
  Better a symmetric **5+5 setup**
- Baseline
  - $L < 300$km systematics relevant$\rightarrow$ RV/IP better as $\mathcal{O}(3\%)$ sys.
  - $L_{optimal} \sim$ **400km** for $\mathbf{5+5}$ yrs running
- Impact of systematic errors
  ν **background** and **cross section**

$L = 540$ km and $5 + 5$ yrs

CP violation could be discovered above $\mathbf{5\sigma}$ for a $\mathbf{51.2 - 59.2}\%$ of values of δ depending on the systematics