WP6 Status and plans

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(reduced) IAP recommendations to WP6

- Follow the developments in low-E cross section physics. Recent data suggest a revision of the relativistic Fermi gas model and of the neutrino/antineutrino cross section ratios at low E. Study how much these or similar changes of the cross-sections would affect the central value of δ at the ESSnuSB.

- We implemented the same up-to-date GENIE tune as WP5 recommended by Marco Roda for the ESSnuSB energy range in all our new simulations (G18_10a_00_000).

- Work in progress: generate events with this tune but fit with different models also recommended by Marco Roda to asses the change in the central value of δ.

(reduced) IAP recommendations to WP6

- Since the ND will likely use combination of tracker and water-Cherenkov, seek experts' advice to: (a) define the relation between the low-E cross sections on Carbon and Oxygen, and (b) constrain the poorly known 1-pion NC background

- (a) In our analysis we have implemented a systematic uncertainty of 3.5% (optimistic) or 11% (conservative) to account for the potential difference between the ND cross section on ν_μ and the FD cross section on ν_e. Discussing with Marco Roda he believes these numbers are reasonable.

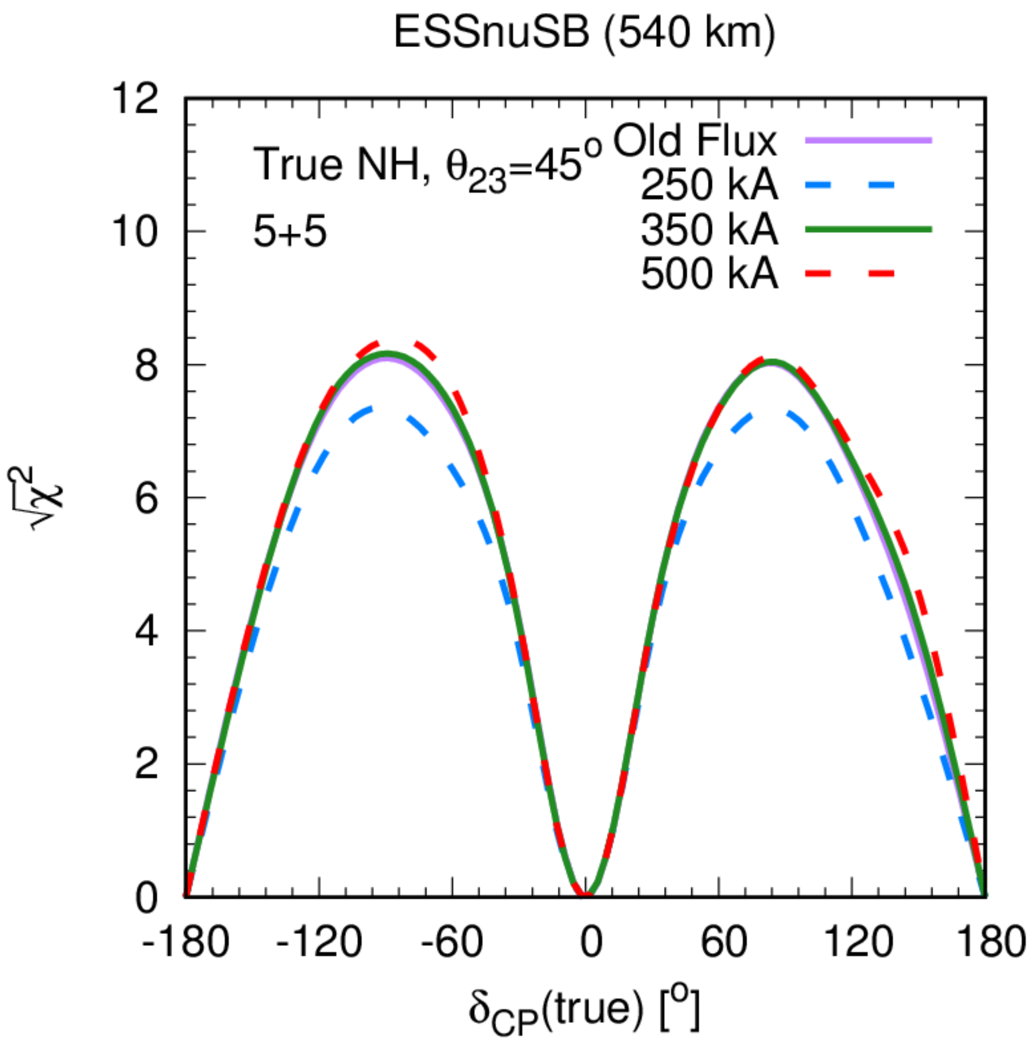
- (b) Since the beam is very low E the NC background is subdominant wrt the beam contamination itself and statistics is more of an issue at the second peak but will discuss with WP5 too.

(reduced) IAP recommendations to WP6

- Uses reliable and updated inputs for cross sections, fluxes, migration matrices for the near and far detectors and for the associated uncertainties (e.g. for the achievable flavor-identification accuracy).

- So far implemented same updated cross section as WP5 from GENIE. Just recieved updated fluxes and started to incorporate them.

Fluxes for different horn currents



Fluxes from Loris D'Alessi

Figure from Monojit Ghosh

PRELIMINARY

Plot by S. Rosauro

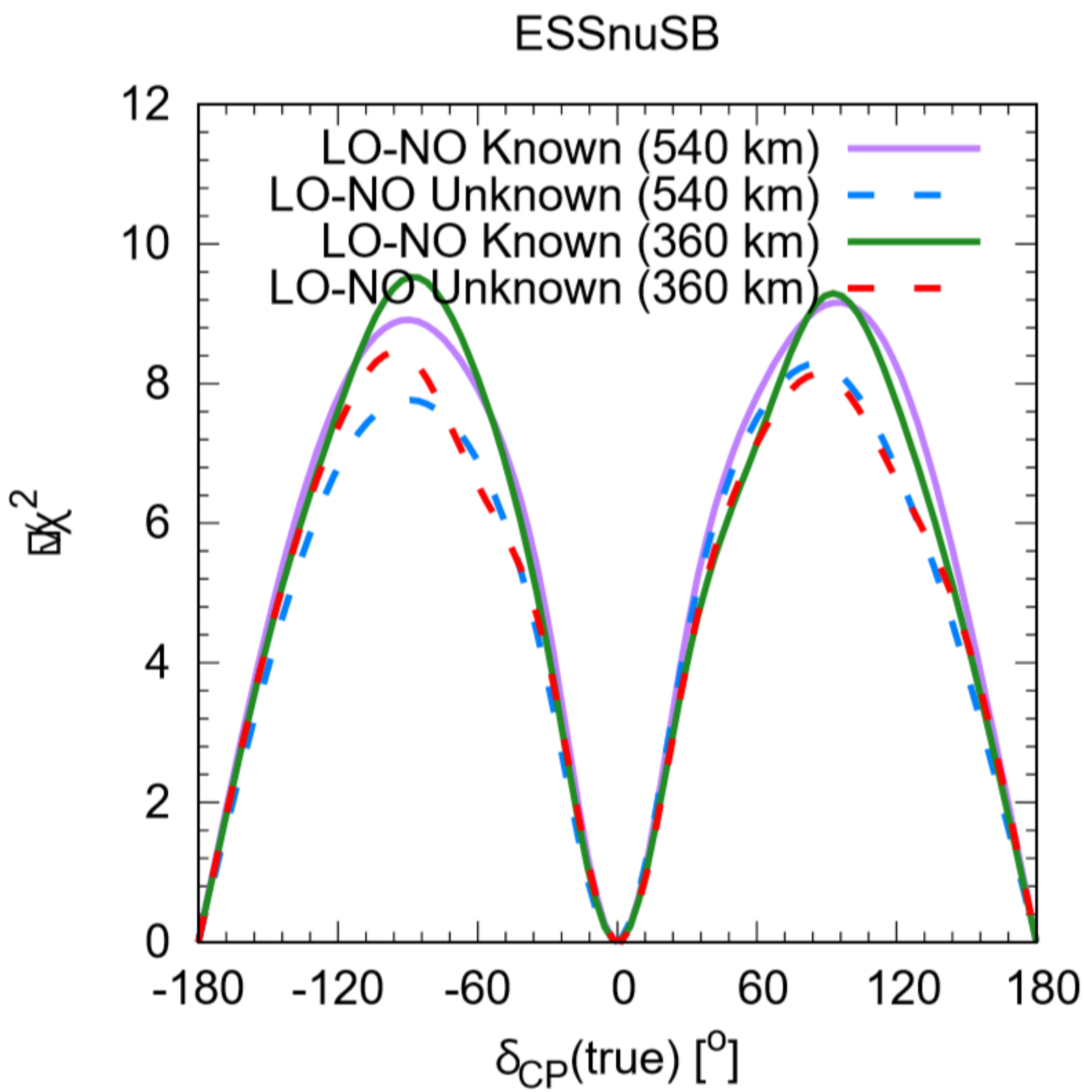
(reduced) IAP recommendations to WP6

- If the current T2K(+NOvA) hints in favour of nearly-maximal CPV are corroborated in the next 1-2 years, one might focus the optimization efforts towards reaching the smallest error on δ in the favoured range, so as to show the "ultimate" ESSnuSB accuracy on this important parameter.

- Will cover in the talk

- Work in progress: Possible new neutrino physics, e.g., a 4th sterile neutrino or non-standard interactions.

Octant degneracy can affect CPV search



The main disavantage of observing at the second peak is the low statistics (especially for antinu) which can lead to octant degeneracies compromising the measurement

M. Ghosh and T. Ohlsson arXiv:1906.05779

Combine with atmospheric neutrinos

Appart from the beam signal, a Mton water Cerenkov detector will also collect a huge atmospheric neutrino sample.

The atmospheric neutrinos can alleviate the main drawbacks of the ESSnuSB setup. In particular increase the statistics, especially for ν_μ disappearance, close the first peak and:

1) Improve the determination of θ_{23} and Δm^2_{31}

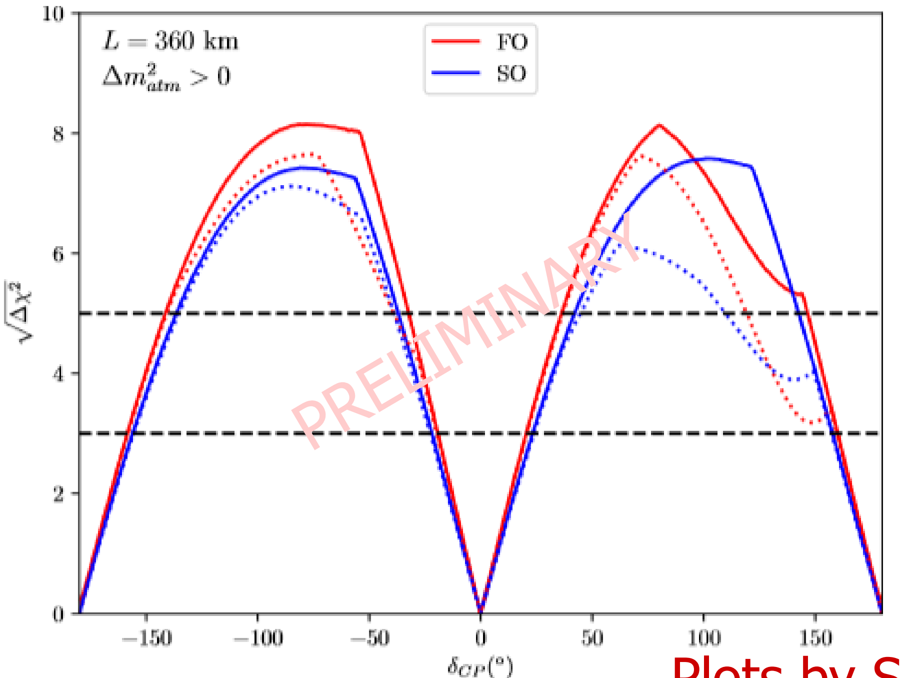
2) Improve the sensitivity to the mass hierarchy

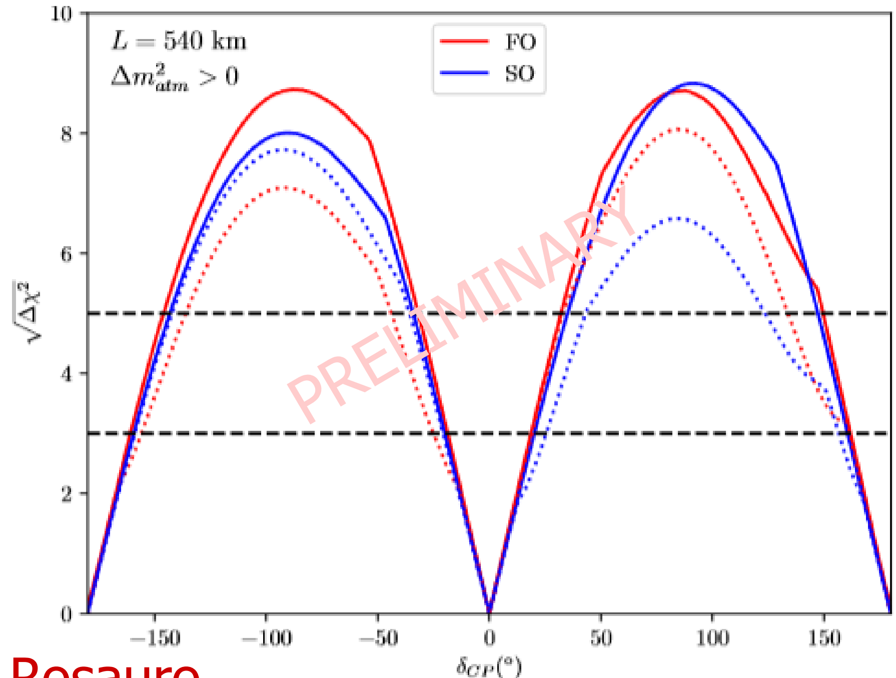
3) Solve octant degeneracies

Combine with atmospheric neutrinos

We combined the beam information with the atmospheric neutrino sample expected at a MEMPHYS-type detector from

J.-E. Campagne, M. Maltoni, M. Mezzetto, T. Schwetz JHEP04 (2007) 003 hep-ph/0603172



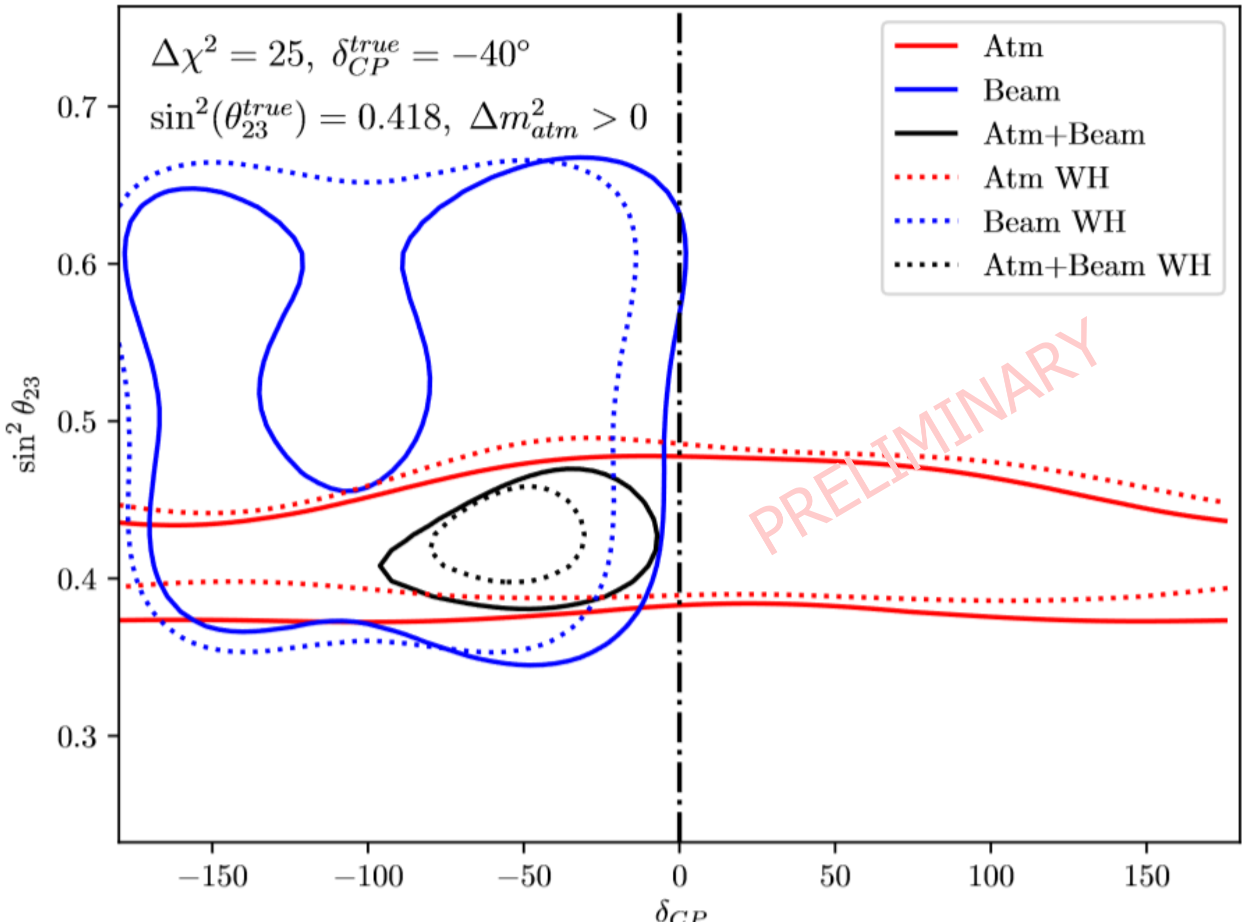


Plots by S. Rosauro

Dashed for beam only, solid beam+atmo. Significant improvement particularly for the longer baseline even though atmo data is not sensitive to δ

Combine with atmospheric neutrinos

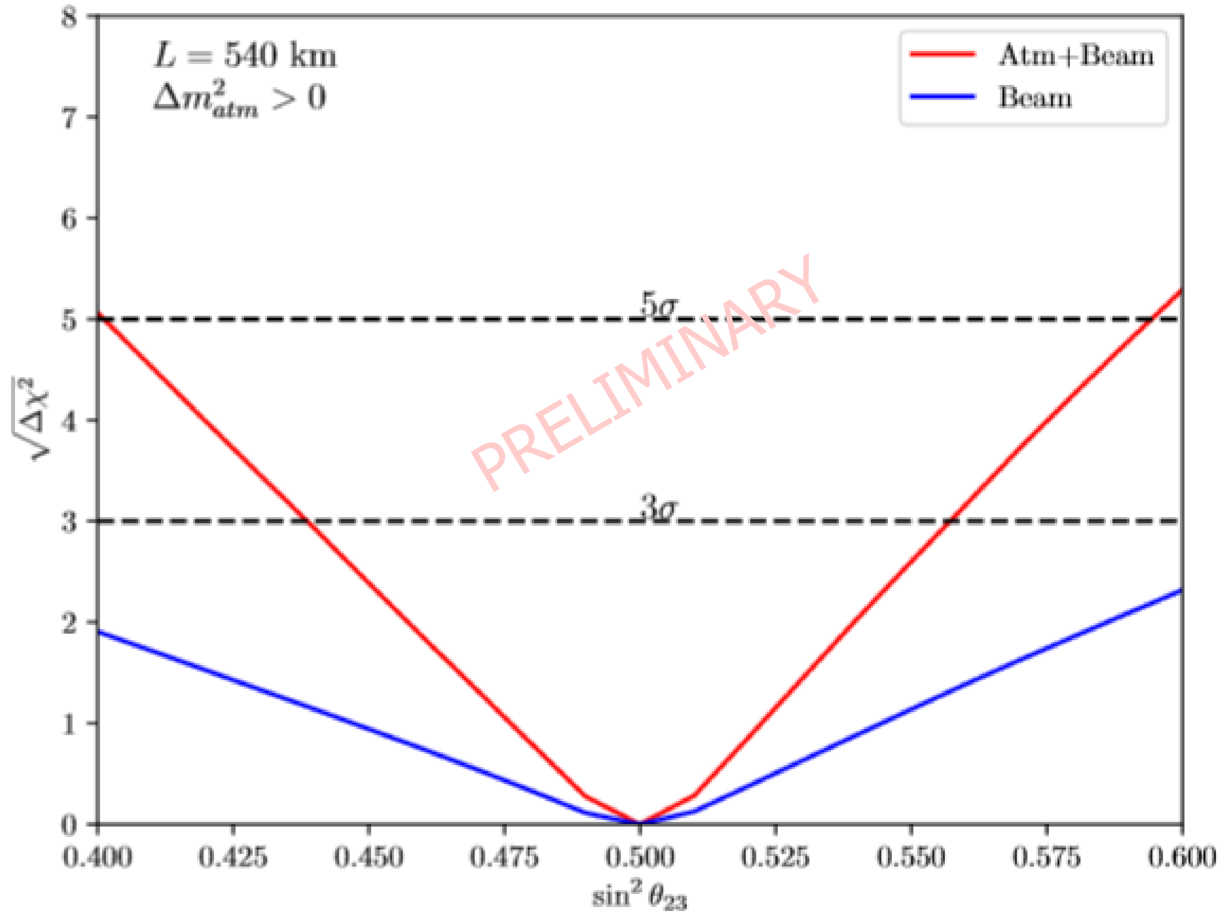
The extra sensitivity comes from solving the octant degeneracy with atmospheric neutrino data:



Plot by S. Rosauro

Combine with atmospheric neutrinos

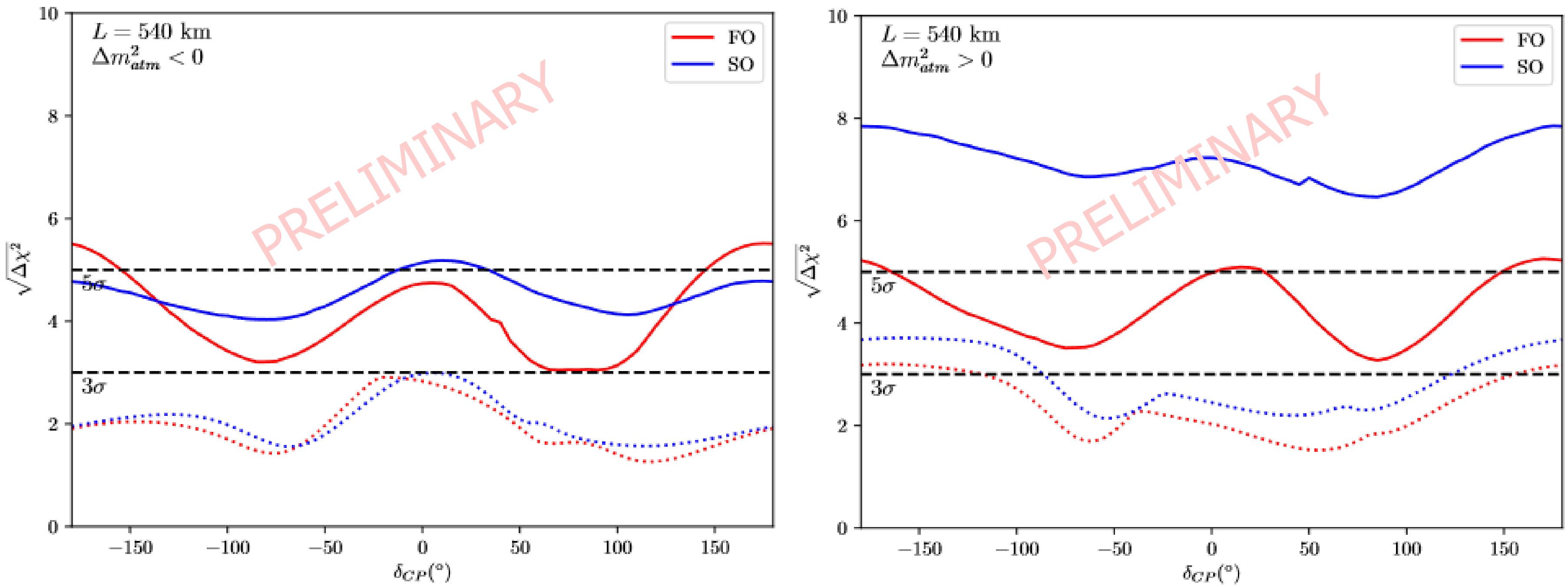
The octant sensitivity significantly improves:



Plot by S. Rosauro

Combine with atmospheric neutrinos

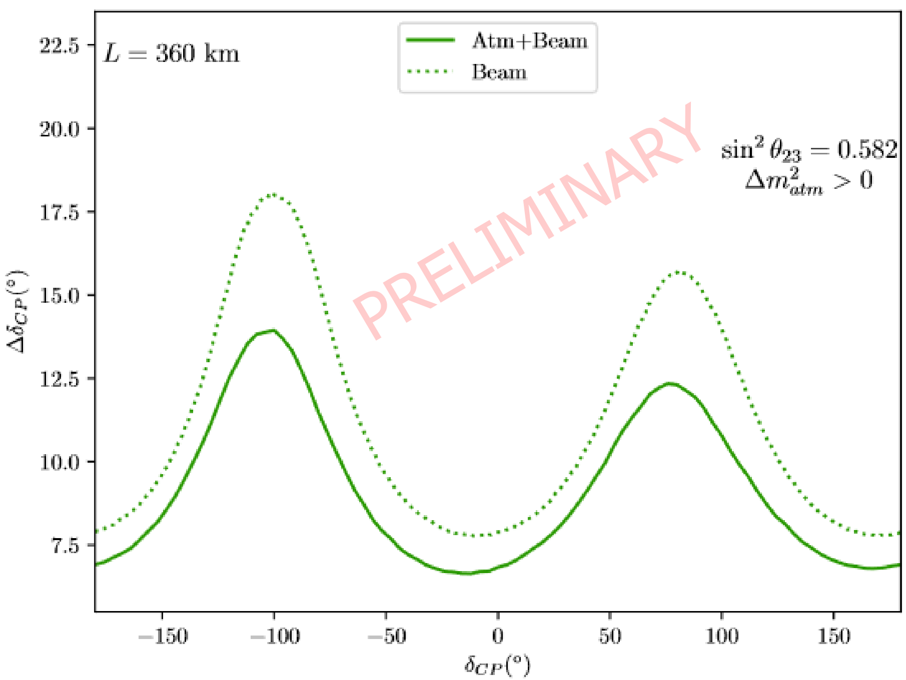
The sensitivity to the wrong hierarchy also improves:

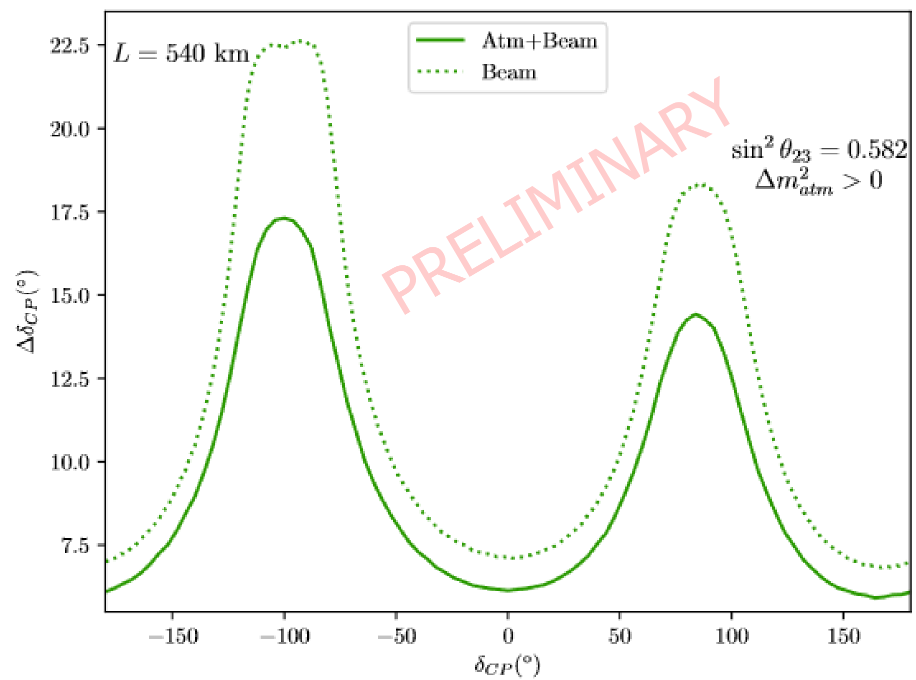


Plots by S. Rosauro

Combine with atmospheric neutrinos

The precision in the measurement of δ for values close to ±90º is particularly challenging since a measurement of cos δ needs events away from the oscillation peak and degeneracies may appear. Atmospheric neutrinos also alleviate this situation:

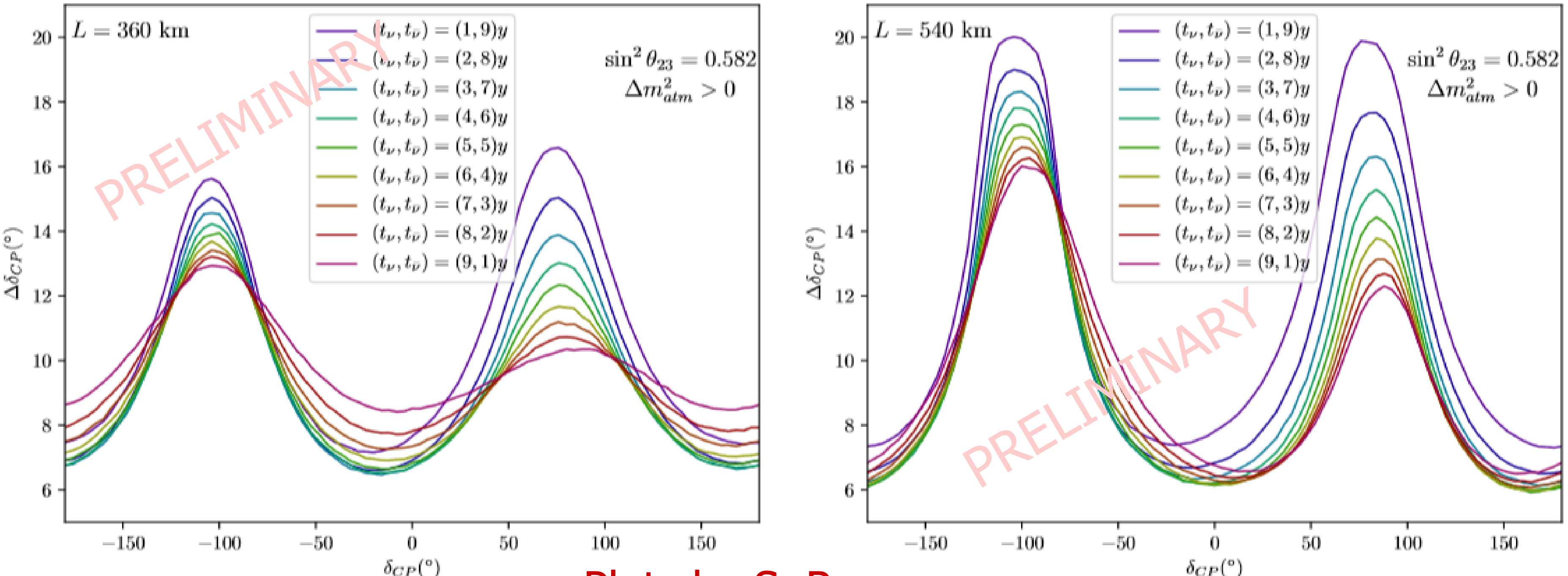




Plots by S. Rosauro

Combine with atmospheric neutrinos

In order to increase the number of events away from the peak better to increase the neutrino vs antineutrino running time:

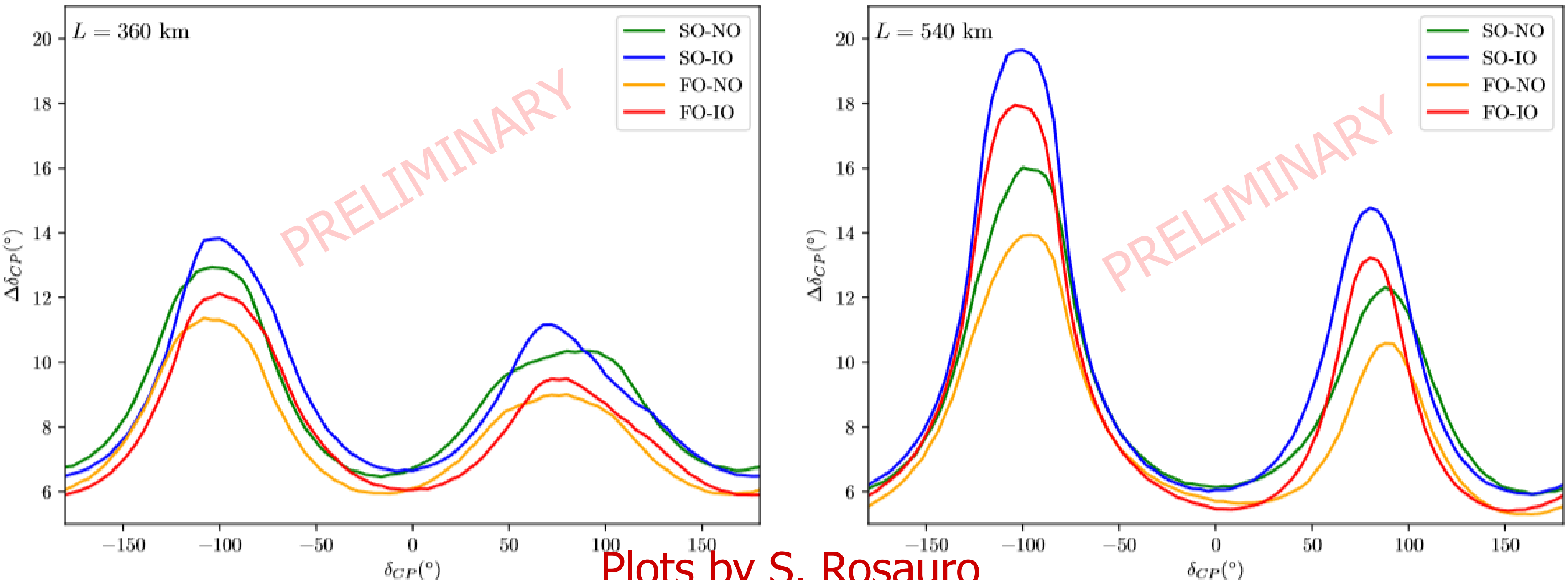


Plots by S. Rosauro

As suggested by the IAP the optimal splitting between neutrino and antineutrino runs can be adapted to the value of δ.

Combine with atmospheric neutrinos

As suggested by the IAP the optimal splitting between neutrino and antineutrino runs can be adapted to the value of δ:

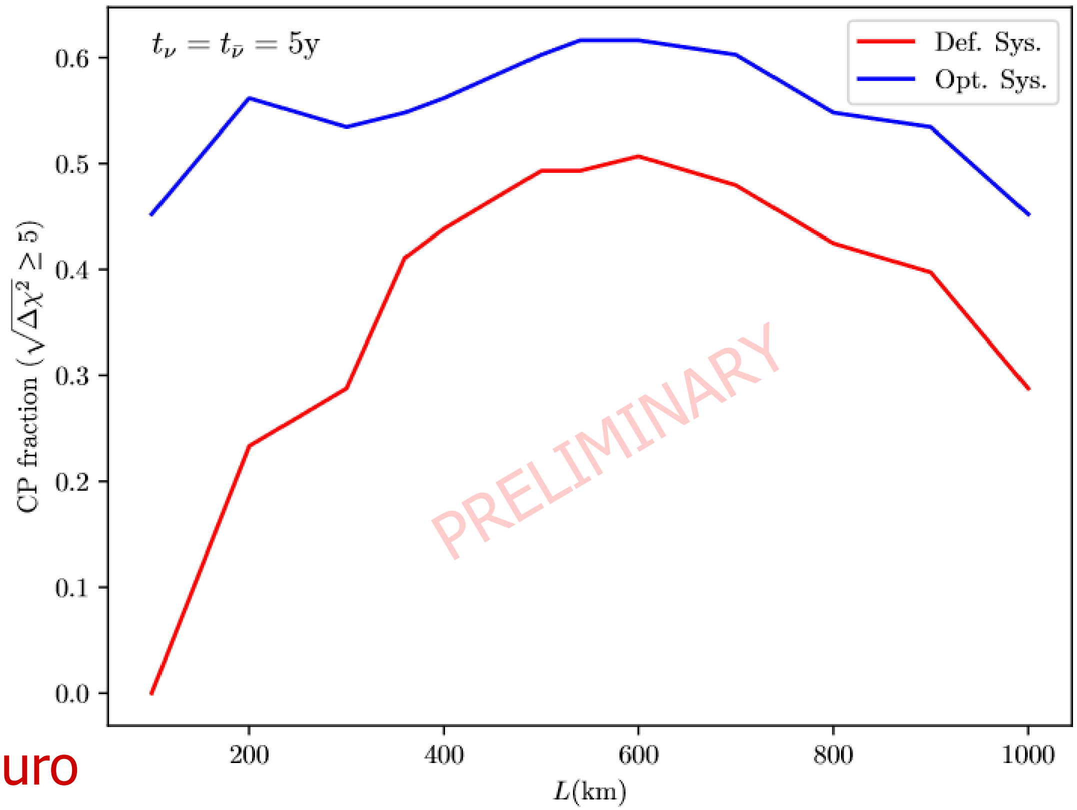


Plots by S. Rosauro

If present and near future experiments discover CPV and its close to maximal, the best option for ESSnuSB is 360 km and running most of the time in neutrino mode to increase precision.

Combine with atmospheric neutrinos

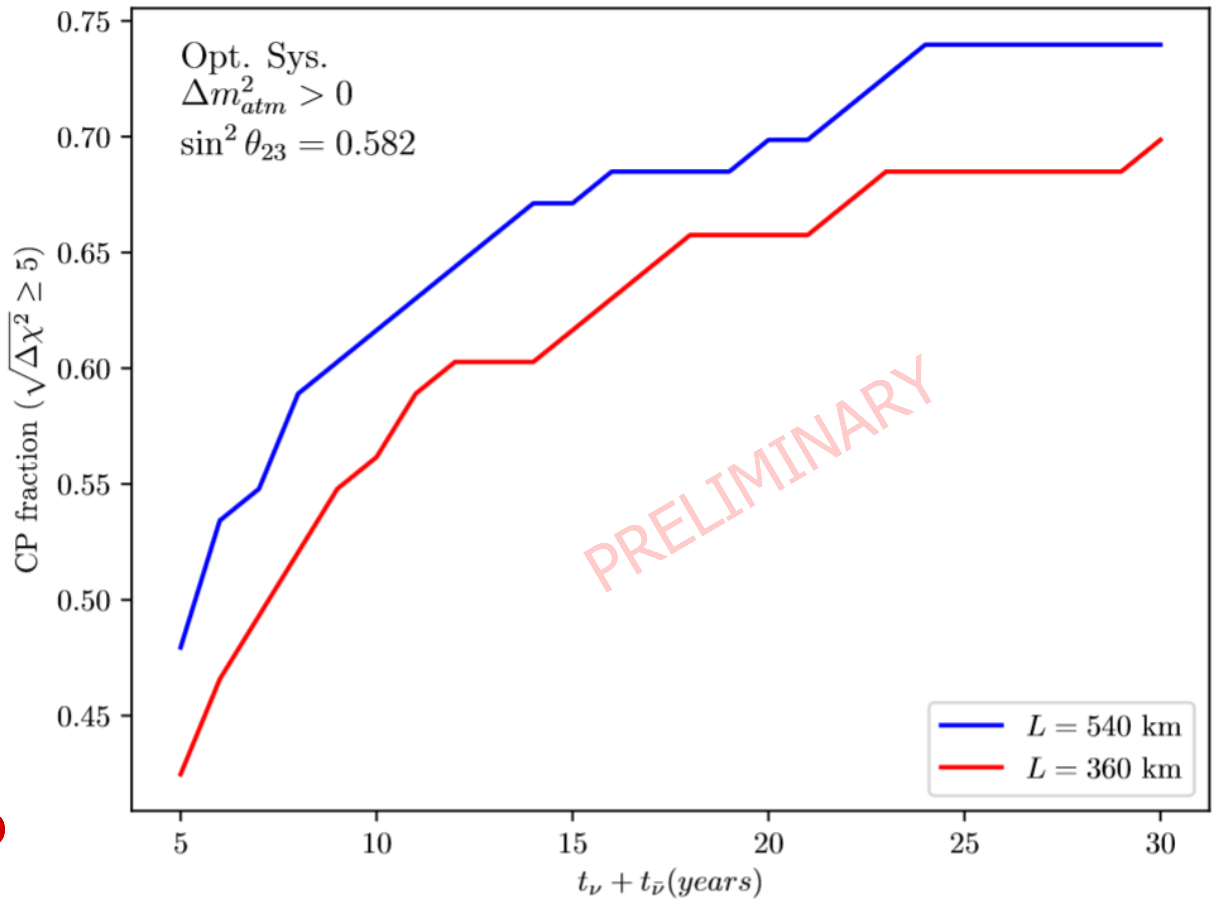
If CPV has not been discovered the best option for ESSnuSB is longer baselines about 500-600 km are prefered. If the systematics are small (Opt.) shorter baselines are less penalized but for larger values (Def.) the longer baselines are better since they maximize the CP dependance at the second maximum.



Plot by S. Rosauro

Combine with atmospheric neutrinos

Statistics is the main bottleneck for the ESSnuSb sensitivity at the second peak and the fraction of values of δ for which a 5σ discovery of CPV would be possible only starts to saturate around 15 years of data taking.



Plot by
S. Rosauro

Summary and future plans

- The combination of atmospheric neutrinos with ESSnuSB beam information is very complementary and allows to improve the measurement of θ_{23} and Δm^2_{31}, increase the senstivity to the mass hierarchy and the octant and indirectly increase the CP discovery potential.

- The ESSnuSB would be able to discover CPV at 5σ for a 62% (56%) of the values of δ for 540 km (360 km)

- A precision measurement of δ with 6º (7º) for the most favourable values or 19º (14º) for the less favourable for 540 km (360 km).

- New physics studies ongoing on the sensitivity to sterile neutrinos of the ESSnuSB as well as its capabilities to discriminate among different models of neutrino masses.

The Golden channel in matter

$$P\left(\overset{(-)}{\nu}_e \to \overset{(-)}{\nu}_\mu\right) = s_{23}^2 \sin^2 2\theta_{13} \left(\frac{\Delta_{atm}}{\tilde{B}_\mp}\right)^2 \sin\left(\frac{\tilde{B}_\mp L}{2}\right)^2$$ "atmospheric"

$$+ c_{23}^2 \sin^2 2\theta_{12} \left(\frac{\Delta_{sol}}{A}\right)^2 \sin^2\left(\frac{AL}{2}\right)$$ "solar"

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

Expanded in

$$\sin 2\theta_{13} \sim 0.3 \qquad \left(\frac{\Delta_{sol} L}{2}\right) \cong 0.05$$

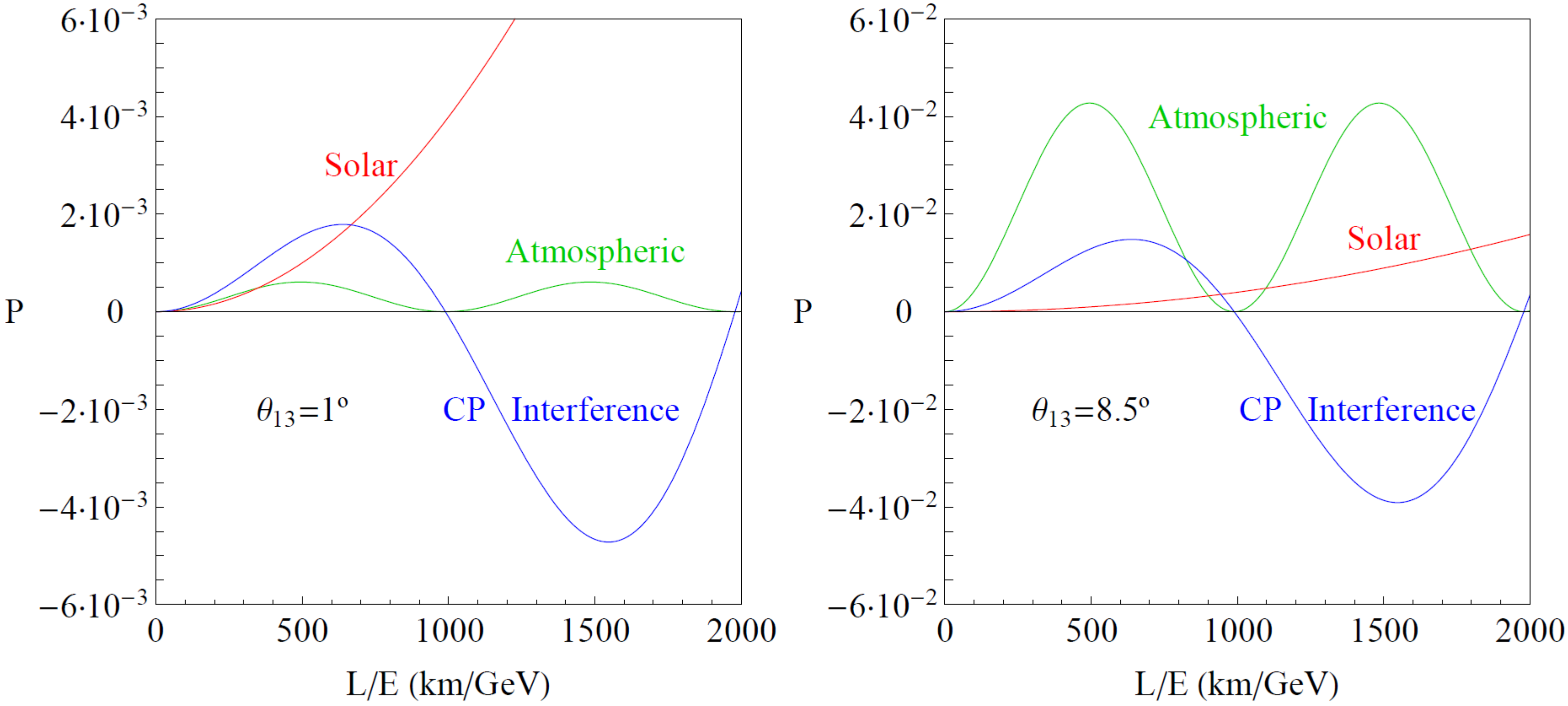
where

$$\tilde{J} = \cos\theta_{13} \sin 2\theta_{13} \sin 2\theta_{12} \sin 2\theta_{23} \qquad \Delta_{atm} = \frac{\Delta m_{23}^2}{2E} \qquad \Delta_{sol} = \frac{\Delta m_{12}^2}{2E}$$

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

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

Optimization of facilities for large θ_{13}



Signal systematics and not stats becomes the bottleneck for large θ_{13}, explore second peak? P. Coloma and EFM 1110.4583

Systematics assumed

Systematics	Opt.	Def.
Fiducial volume ND	0.2%	0.5%
Fiducial volume FD	1%	2.5%
Flux error ν	5%	7.5%
Flux error $\bar{\nu}$	10%	15%
Neutral current background	5%	7.5%
Cross section $\times$ eff. QE	10%	15%
Ratio ν_e/ν_μ QE	3.5%	11%

P. Coloma et al 1209.5973