Physics potential of the ESSνSB

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KTH VETENSKAP OCH KONST

ESS NEUTRINO SUPER BEAM

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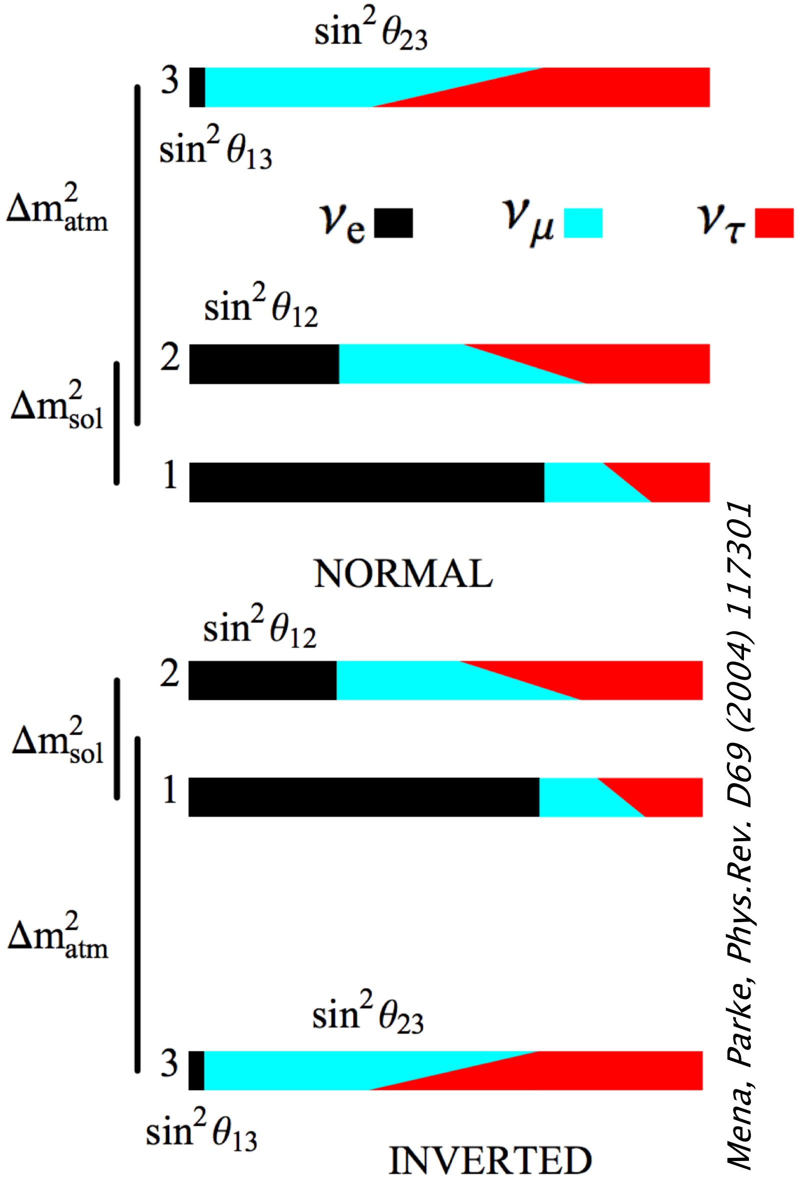
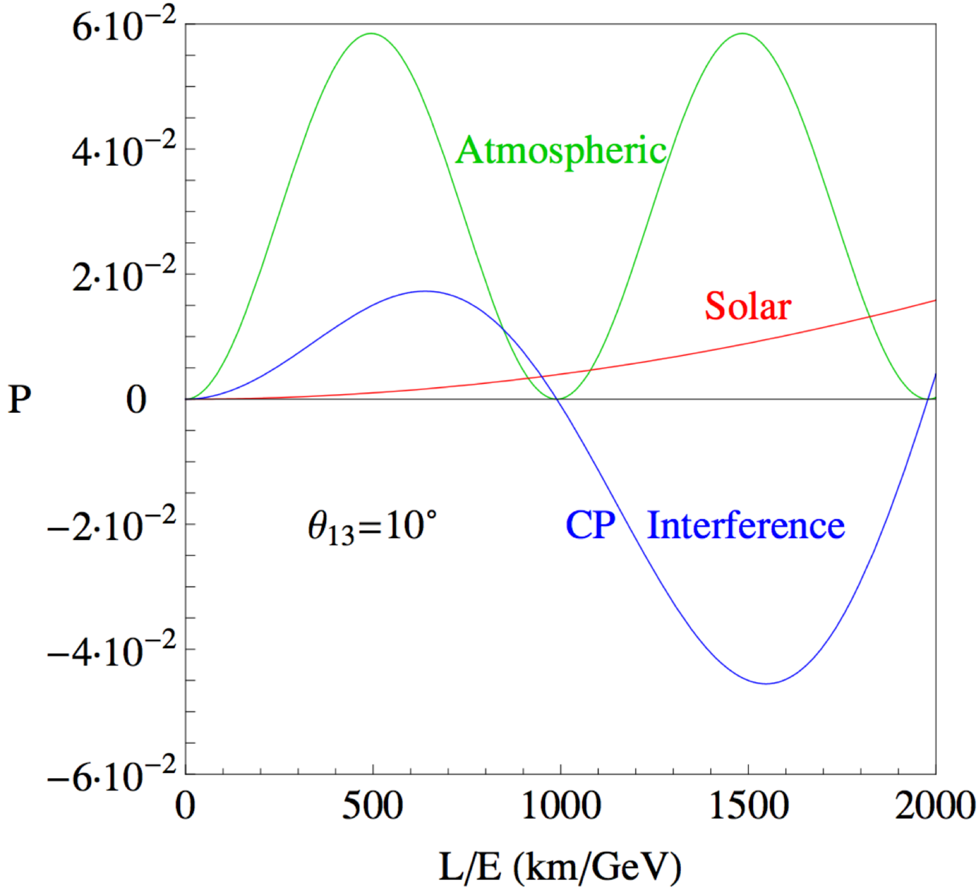
Physics goals

- Establish (bounds on) CP violation in the lepton sector
- Neutrino mass hierarchy
- Investigate new physics in the neutrino sector
- Other goals



Mena, Parke, Phys.Rev. D69 (2004) 117301

Physics of CP violation in $P_{\mu e}$



Coloma, Fernandez Martinez, JHEP 1204 (2012) 089

- CP violation mainly through interference
- Requires similar amplitude of different frequency oscillations

$$P_{\mu e} = \left|A_{sol} + e^{i\varphi} A_{atm}\right|^2$$

- Atmospheric

$$A_{atm} = s_{23} \sin(2\theta_{13}) \sin\left(\frac{\Delta m_{31}^2 L}{4E}\right)$$

- Solar

$$A_{sol} = c_{23} \sin(2\theta_{12}) \sin\left(\frac{\Delta m_{21}^2 L}{4E}\right)$$

$$\varphi = \pm\delta - \frac{\Delta m_{31}^2 L}{4E}$$

Base setup and assumptions

1. Equipment	Parameter	Nominal value	Minimal value	Maximal value	Units	Comments
Detector	Fiducial mass	507			kton	Updated with latest assumptions from WP5
Beam	Proton energy	2.5	2	3.0	GeV	FFlux from Ref. [3]
Location	Baseline	540	100	1000	Km	To optimize
Beam	Total running time	10			yrs	$1.7\cdot10^7$ s per year assumed
Beam	Neutrino/Antineutrino runs	2/8	1/9	9/1	yrs	To optimize
Detector	Expected performance for signal and background components					Migration matrices and efficiencies from Ref. [4]
Detector	Systematic uncertainty on near detector fiducial volume	0.5%	0.2%	1%		See Ref [5]
Detector	Systematic uncertainty on far detector fiducial volume	2.5%	1%	5%		See Ref [5]
Beam	Systematic uncertainty signal neutrino component	7.5%	5%	10%		See Ref [5]
Beam	Systematic uncertainty background neutrino component	15%	10%	20%		See Ref [5]
Detector	Systematic uncertainty on QE cross section	15%	10%	20%		See Ref [5]
Detector	Systematic uncertainty on electron to muon neutrino ratio of QE cross	11%	3.5%	Free		See Ref [5]
Location	Systematic uncertainty on matter density along neutrino beam	2%	1%	5%		See Ref [5]

Table 1.1 Initial set of parameters for the simulation performance.

ESSnuSB WP6, Deliverable 6.1

[4] L. Agostino et al. [MEMPHYS Collaboration], JCAP 1301 (2013) 024 [arXiv:1206.6665 [hep-ex]].

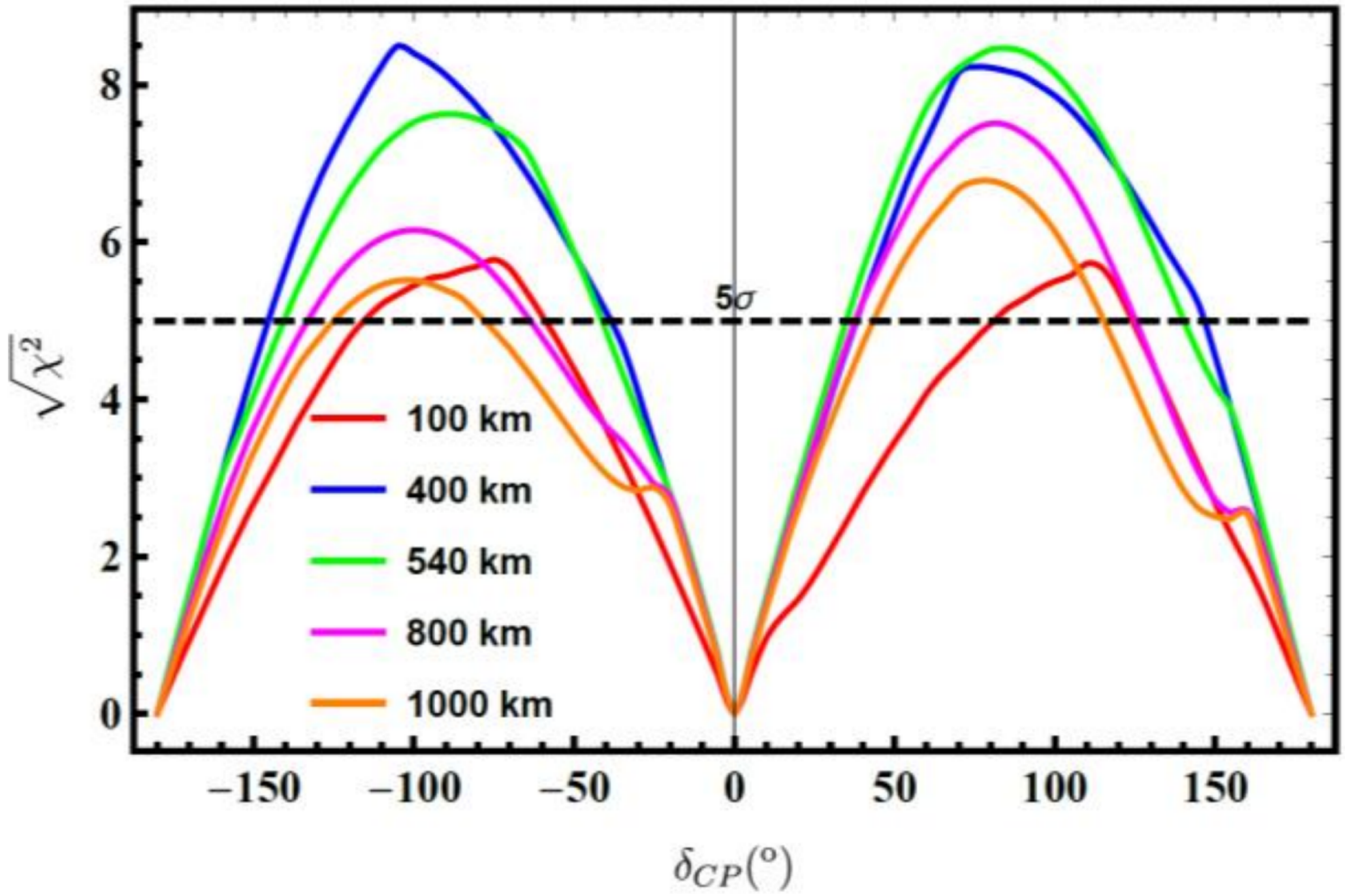
[5] P. Coloma, P. Huber, J. Kopp and W. Winter, Phys. Rev. D 87 (2013) 3, 033004 [arXiv:1209.5973 [hep-ph]].

[6] P. Coloma and E. Fernandez-Martinez, Optimization of neutrino oscillation facilities for large θ_{13}, JHEP 1204 (2012) 089, [arXiv:1110.4583]

Performance of the beam experiment

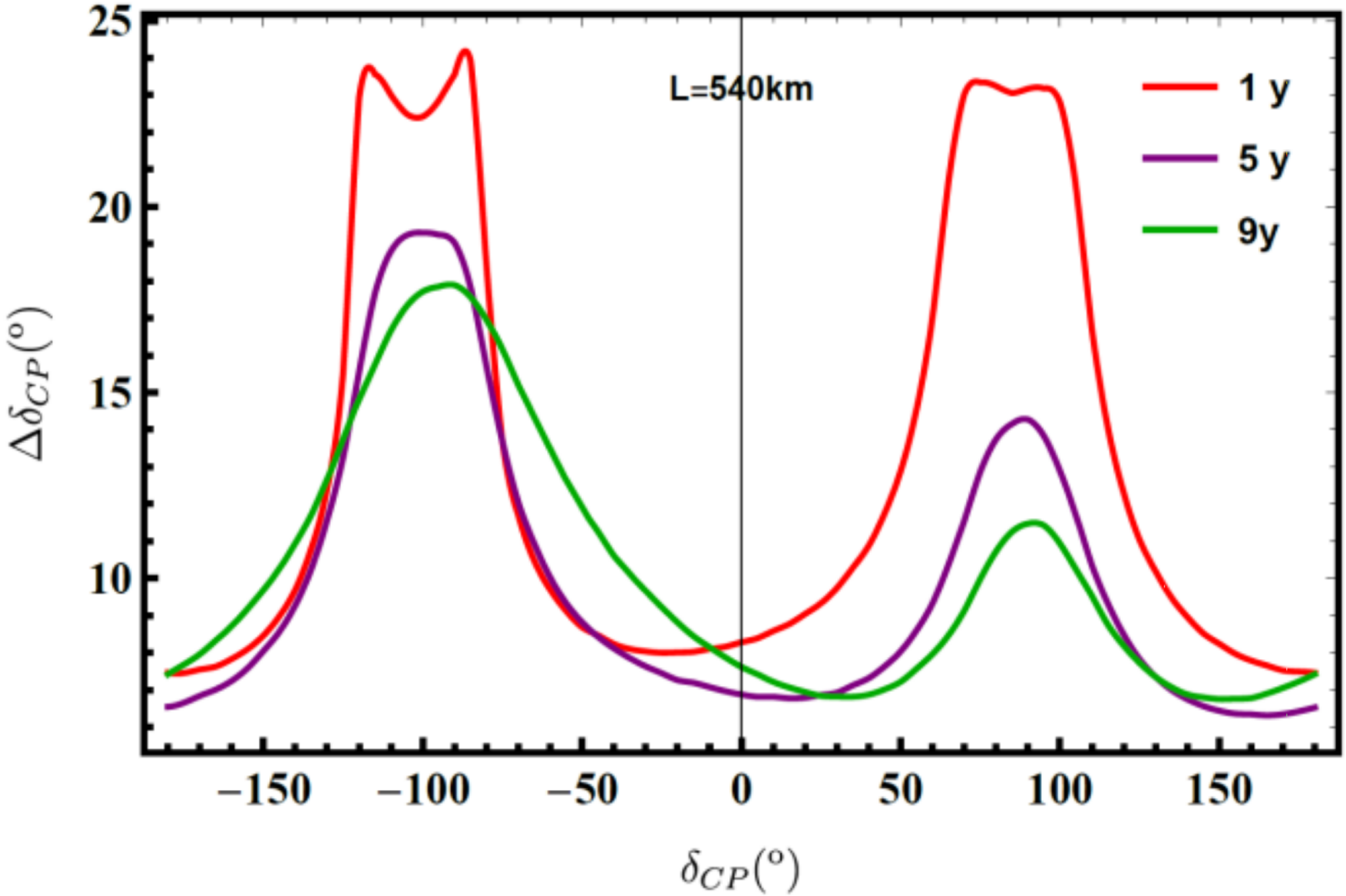
- What is the expected sensitivity to CP violoation?
- What is the expected precision on δ?
- What is the expected sensitivity to the neutrino mass hierarchy?
- What is the impact of degeneracies in the oscillation parameter space?

CP violation



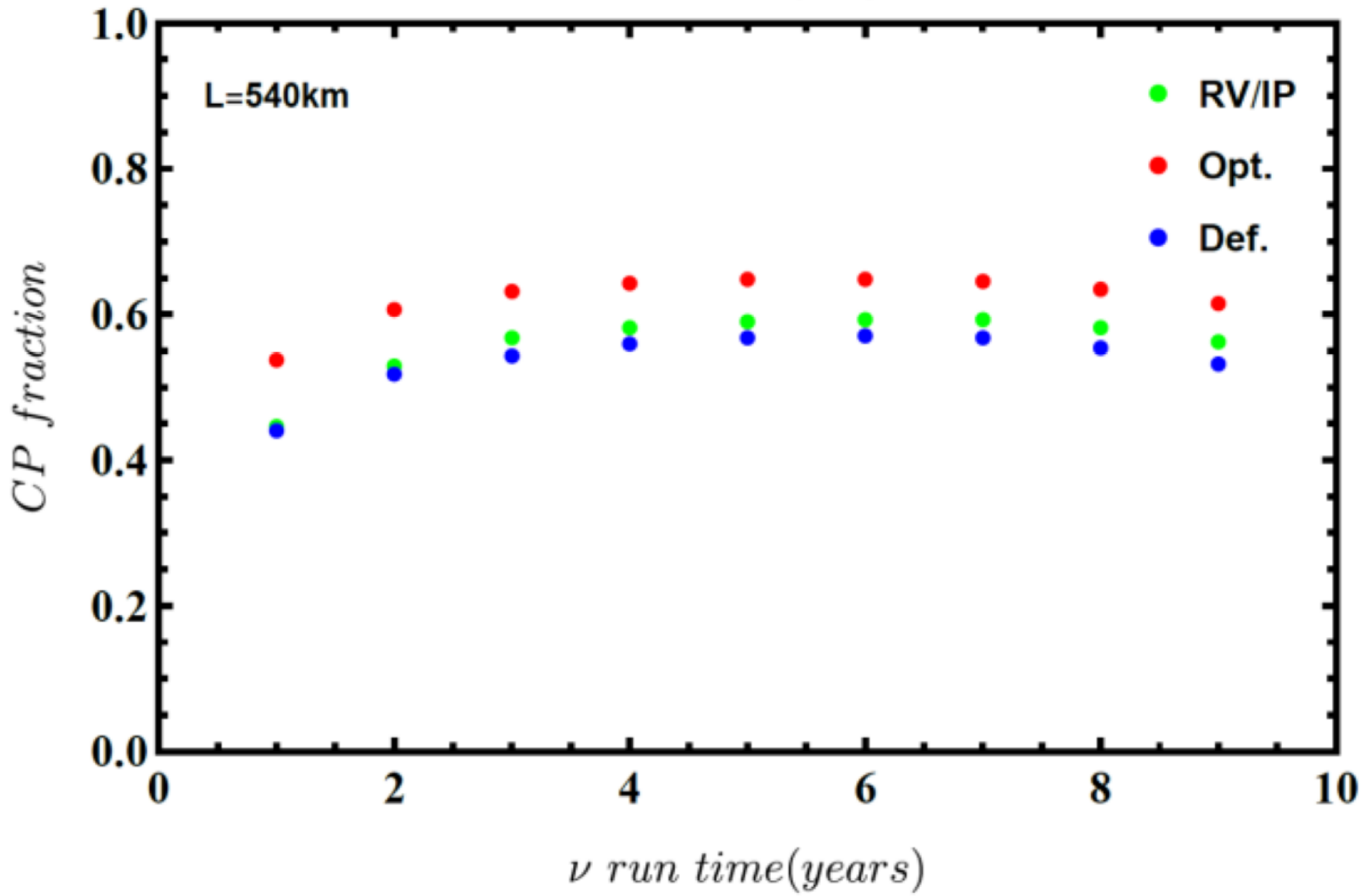
ESSnuSB WP6, Deliverable 6.1

CP precision



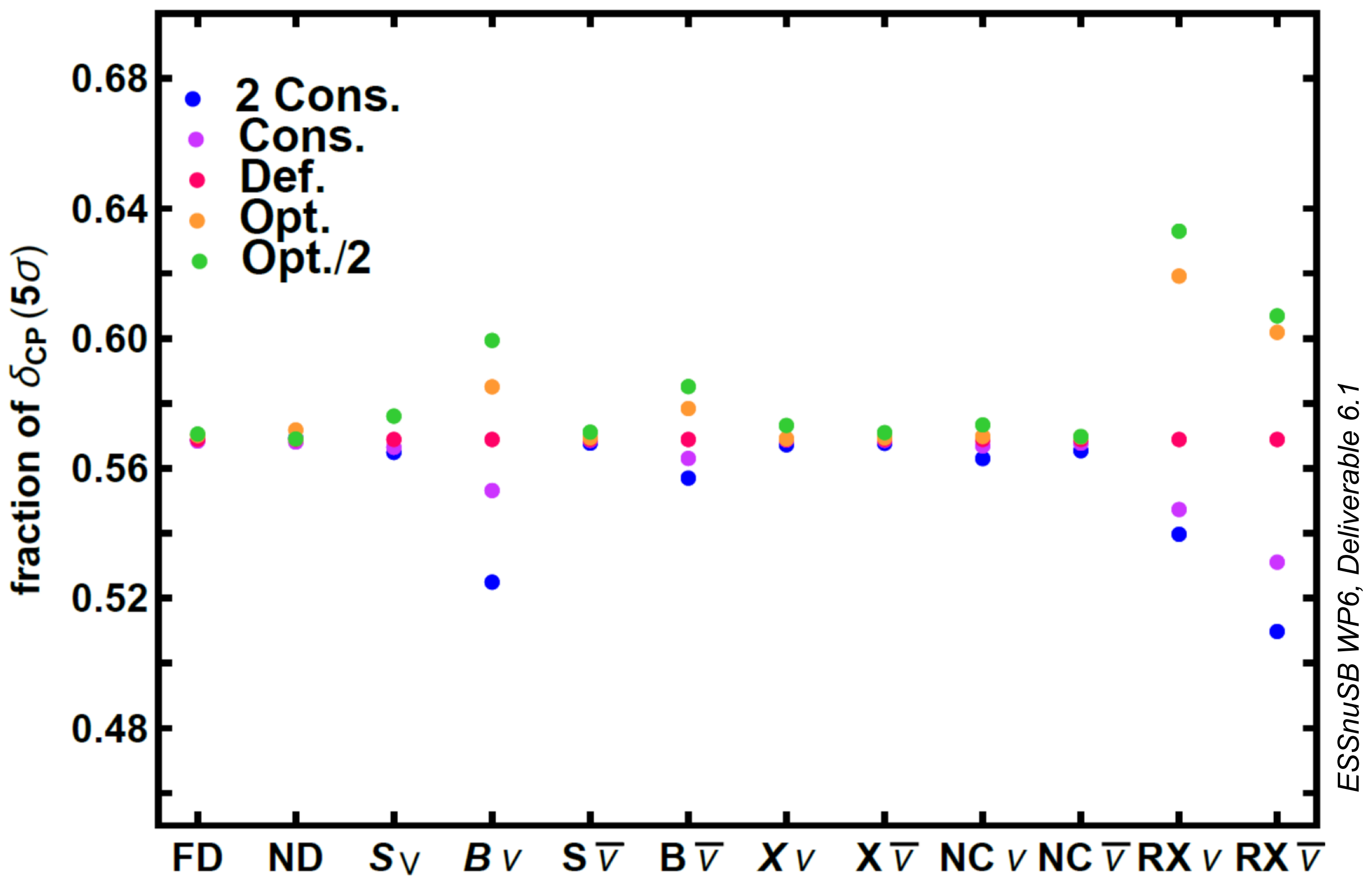
ESSnuSB WP6, Deliverable 6.1

Effects of changing $\nu/\bar{\nu}$ running times

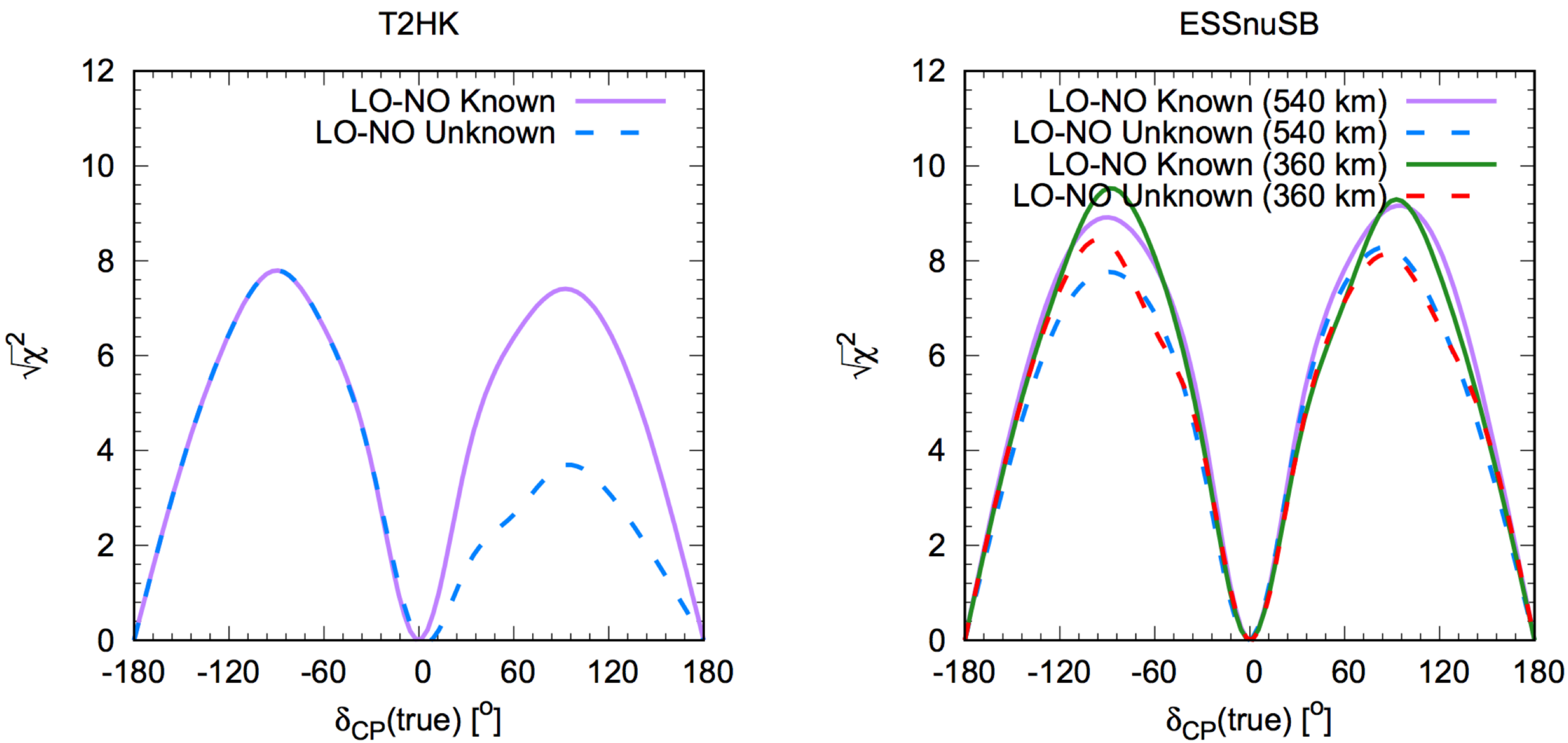


ESSnuSB WP6, Deliverable 6.1

The impact of systematic errors

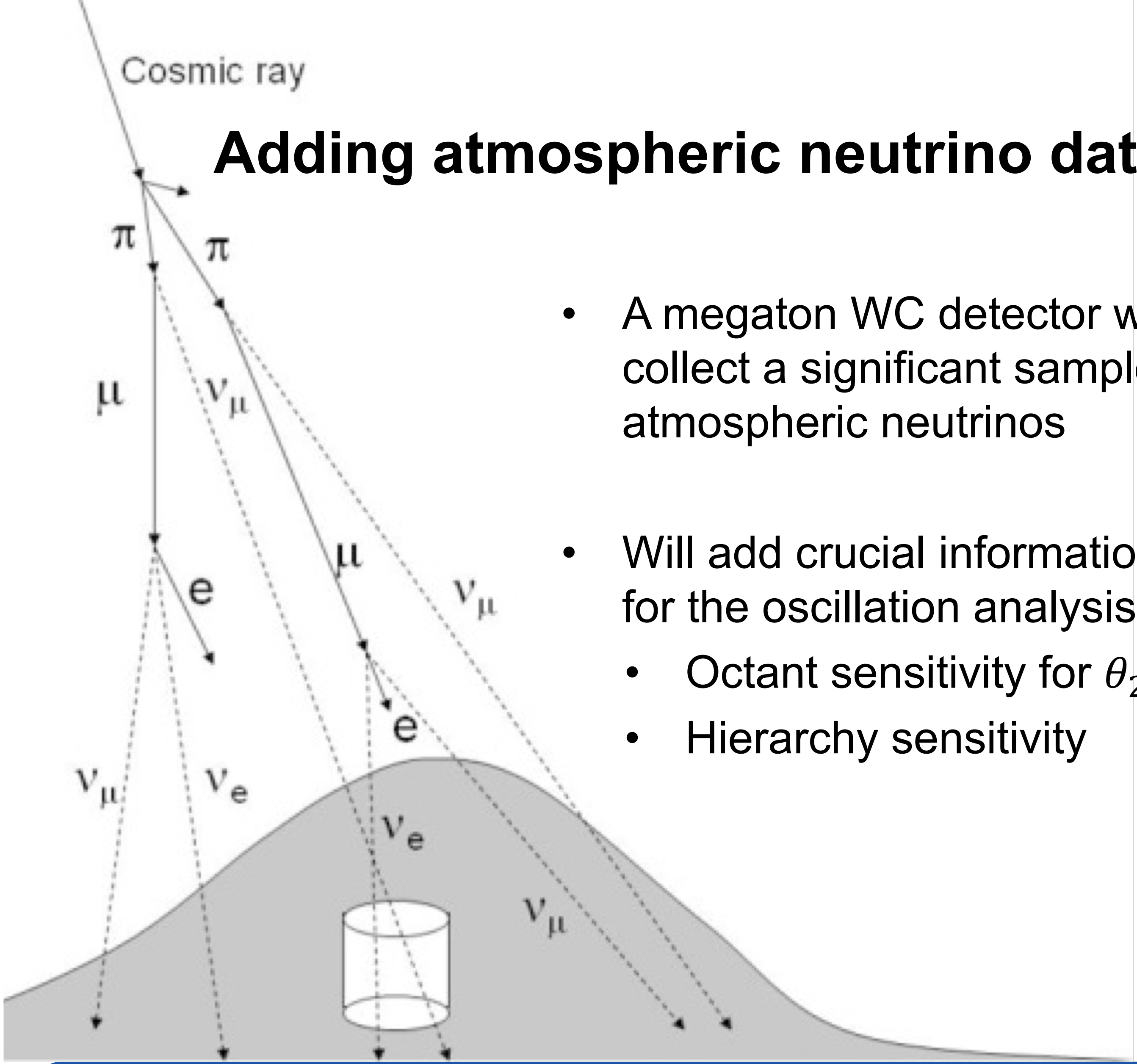


Comparisons to T2HK



Ghosh, Ohlsson, arXiv:1906.05779

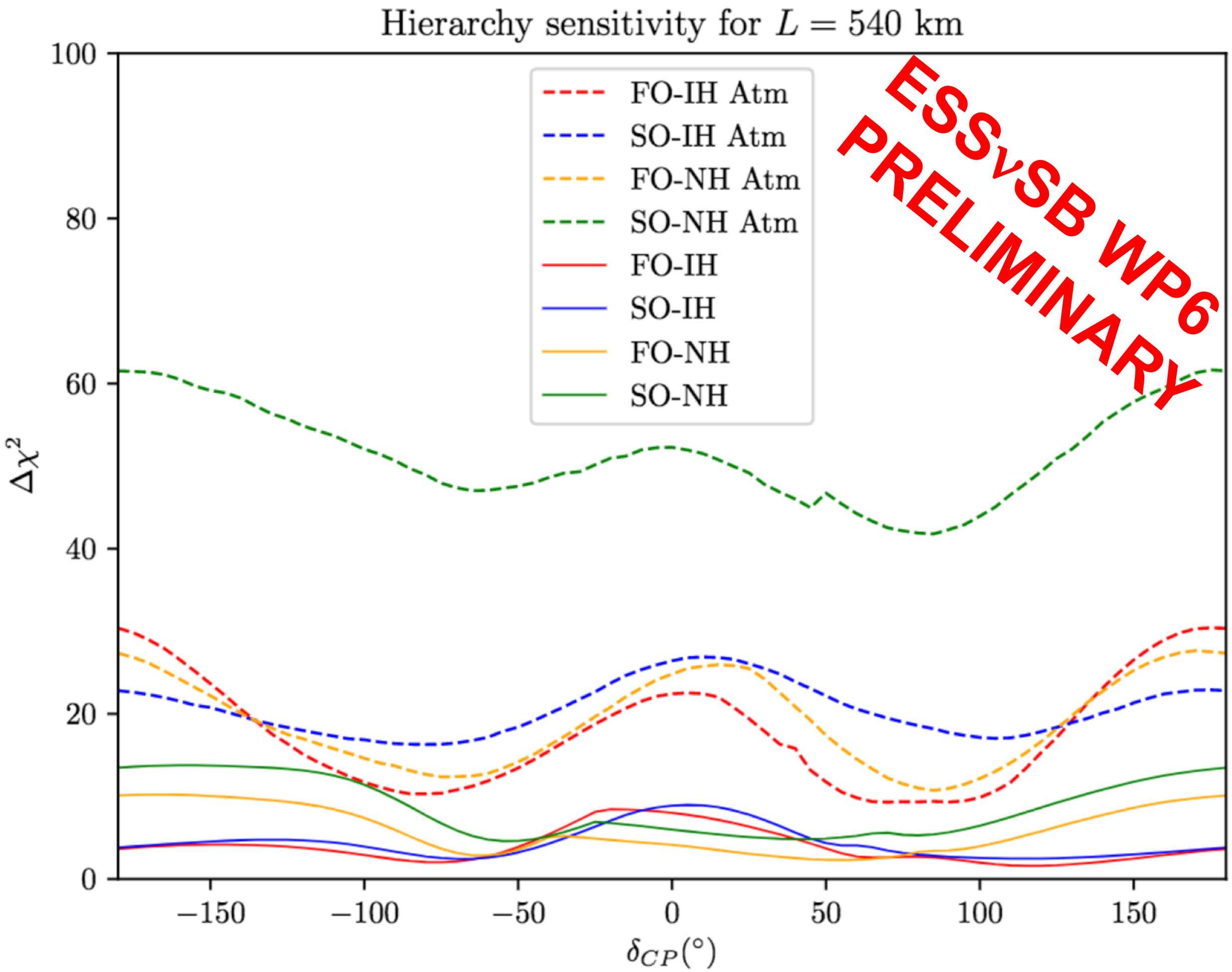
Adding atmospheric neutrino data



Kajita, Proceedings of the Japan Academy, Series B

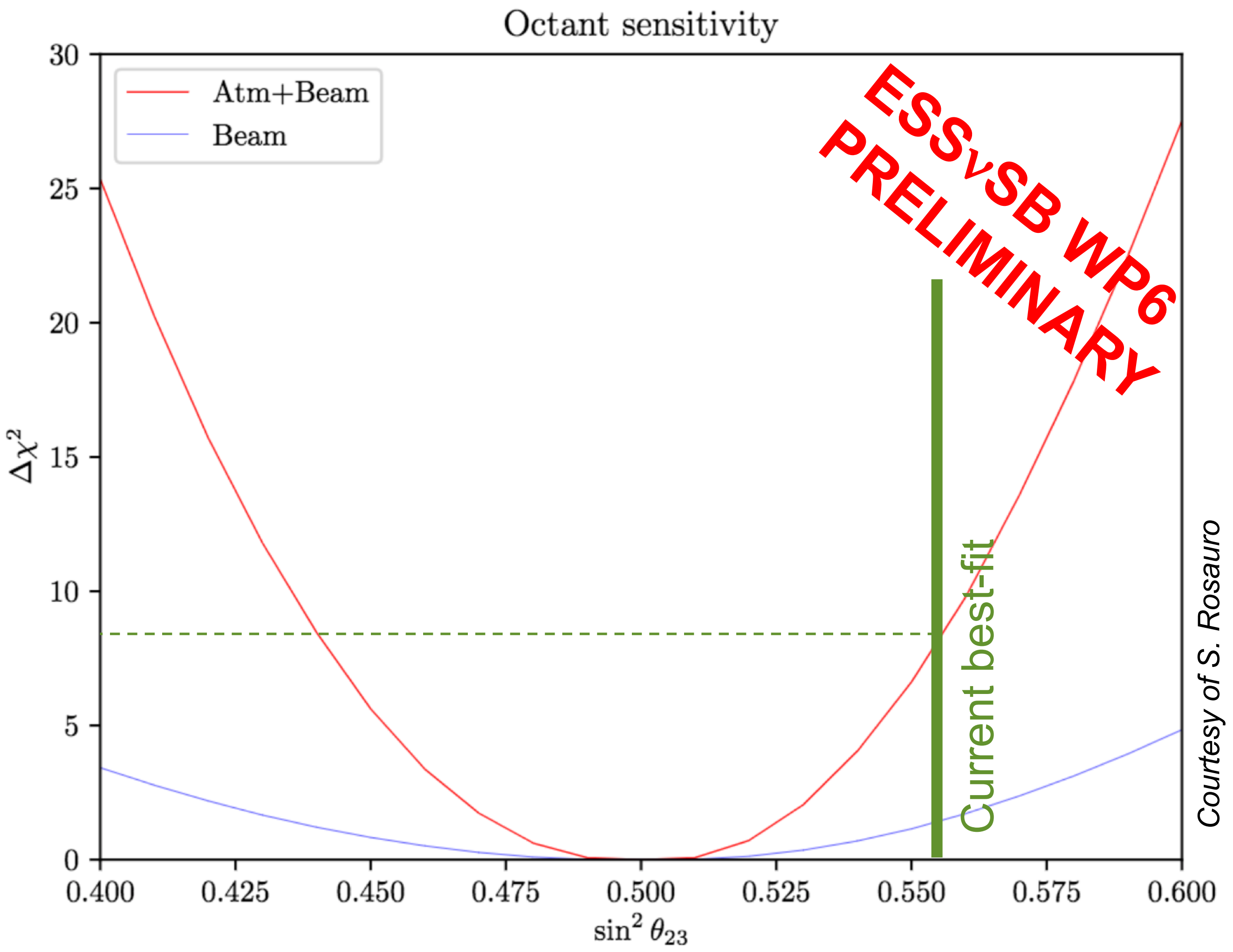
- A megaton WC detector will collect a significant sample of atmospheric neutrinos
- Will add crucial information for the oscillation analysis
  - Octant sensitivity for θ_{23}
  - Hierarchy sensitivity

Mass hierarchy

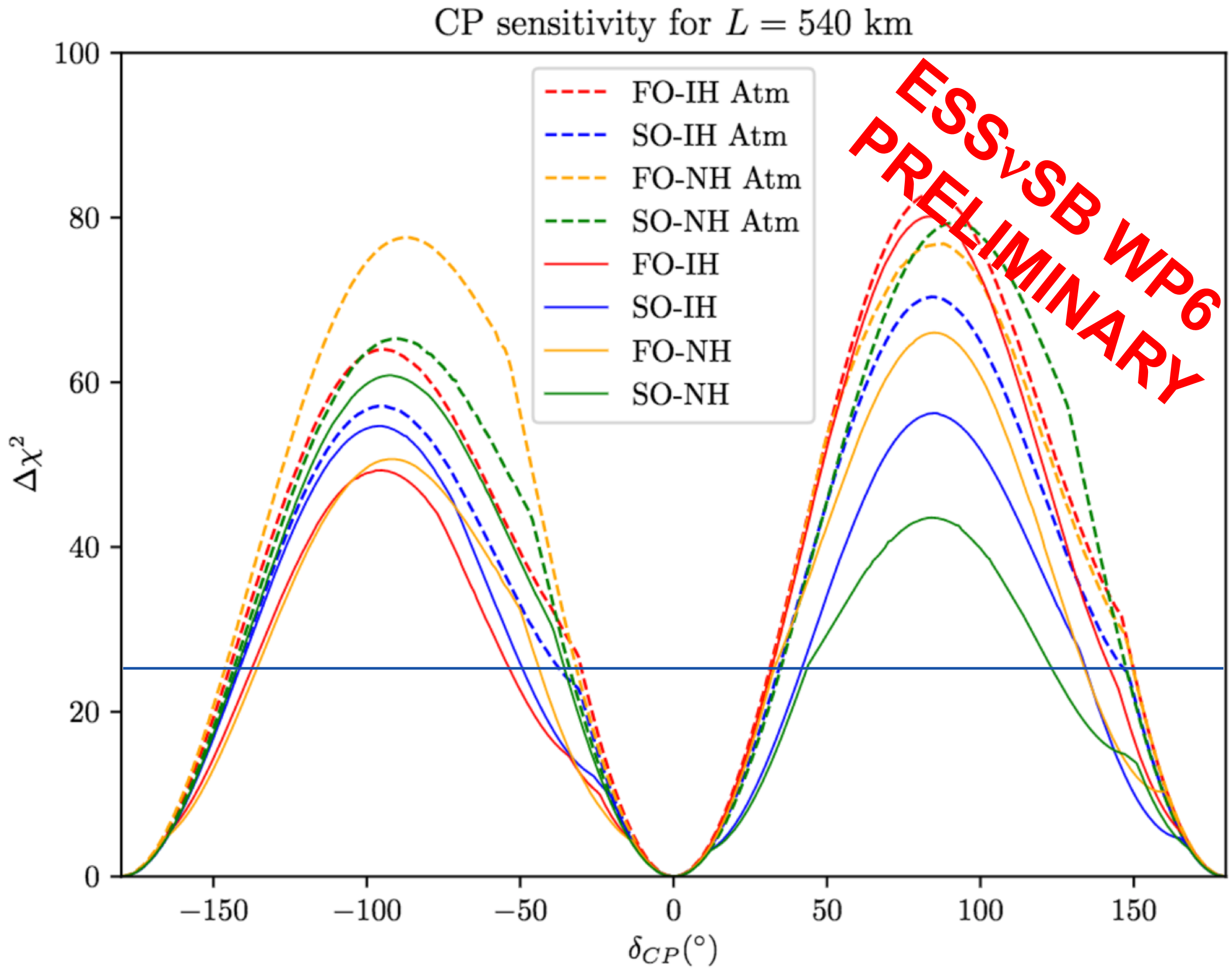


Courtesy of S. Rosauro

Octant sensitivity

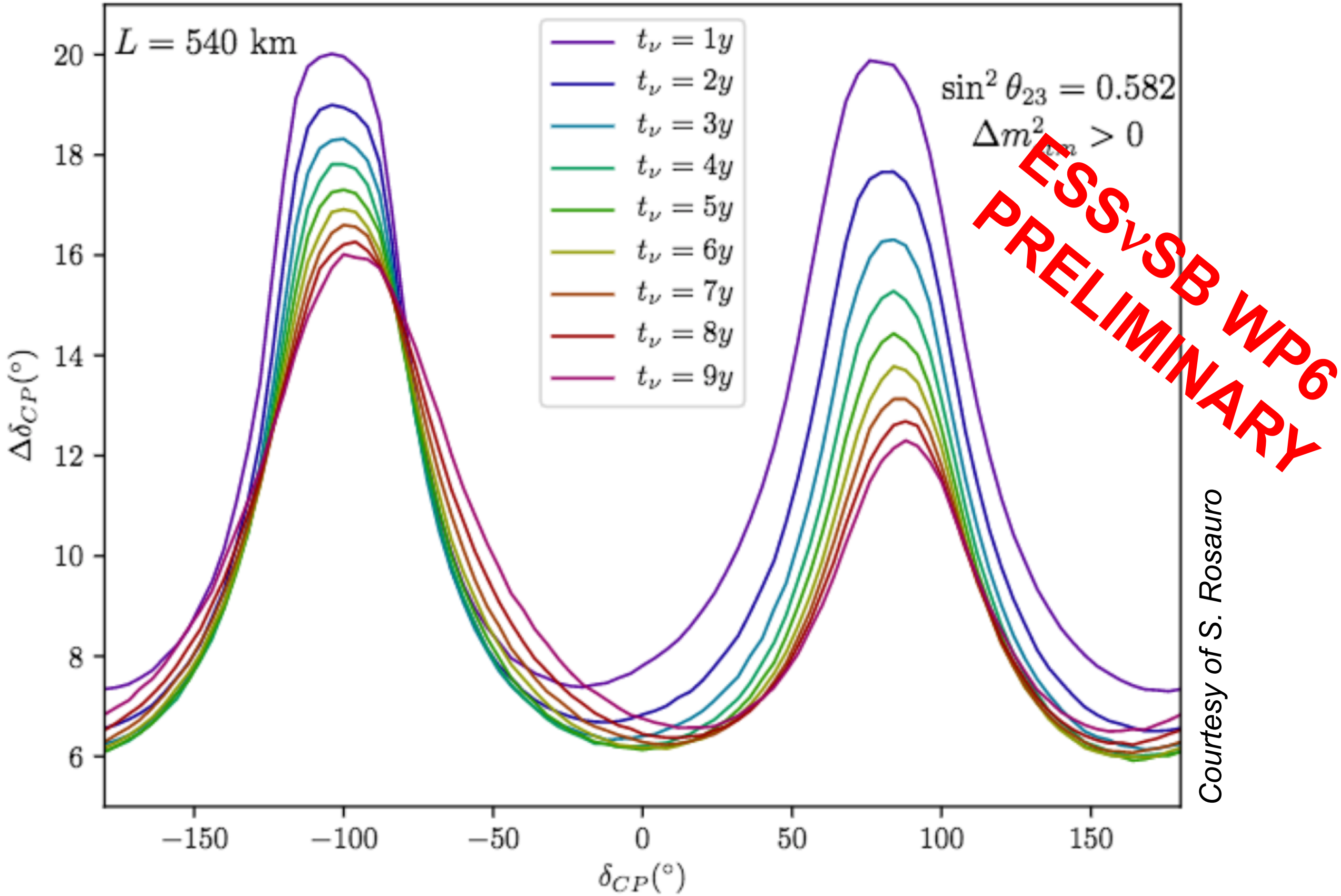


CP sensitivity

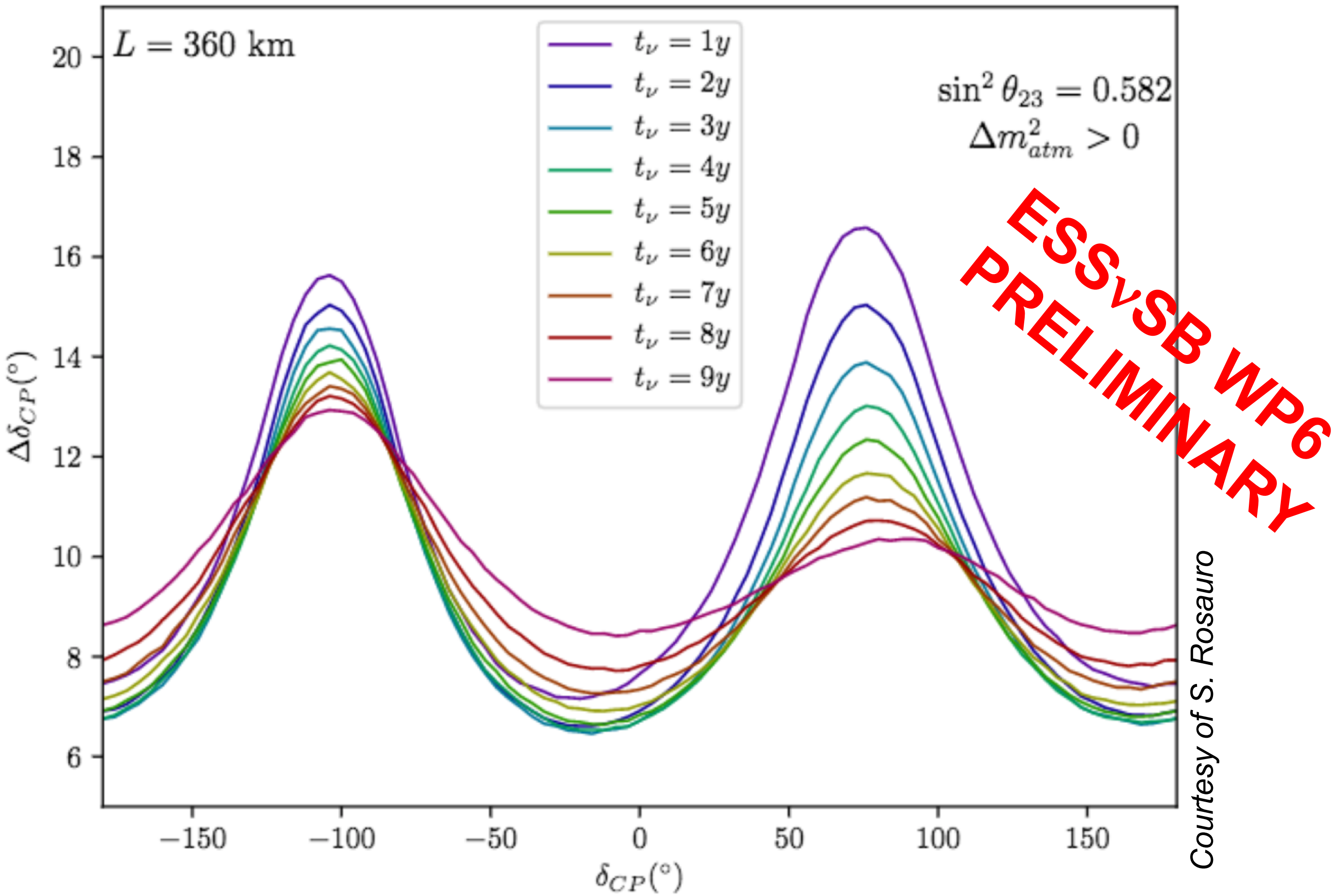


Courtesy of S. Rosauro

CP precision @ 540 km



CP precision @ 360 km

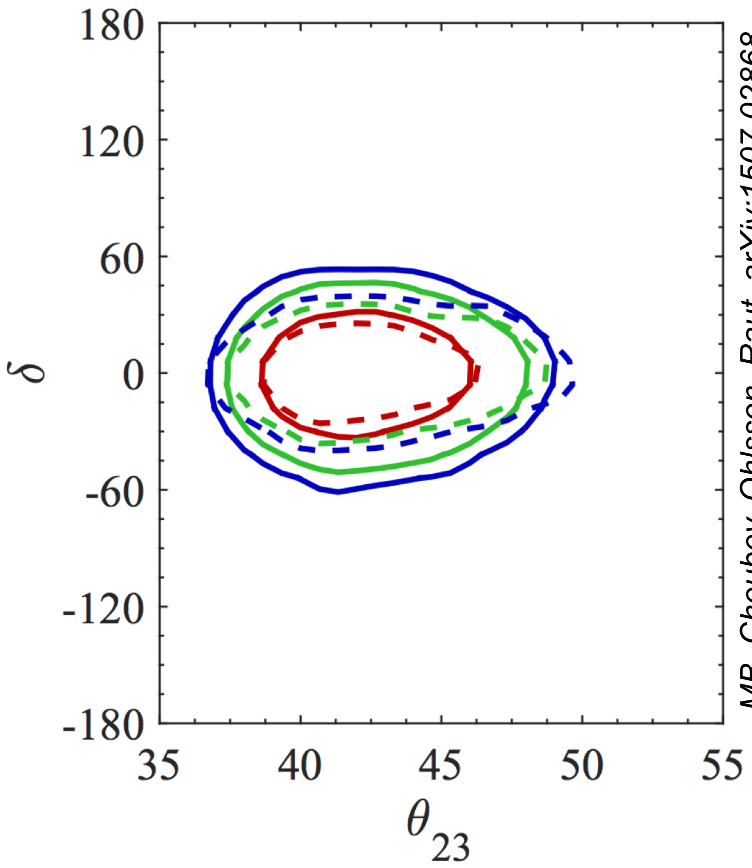


New physics scenarios

- A number of new physics scenarios are being/will be investigated
  - Non-standard neutrino interactions (NSI)
  - Light sterile neutrinos
  - Neutrino mass model discrimination

Non-standard neutrino interactions (NSI)

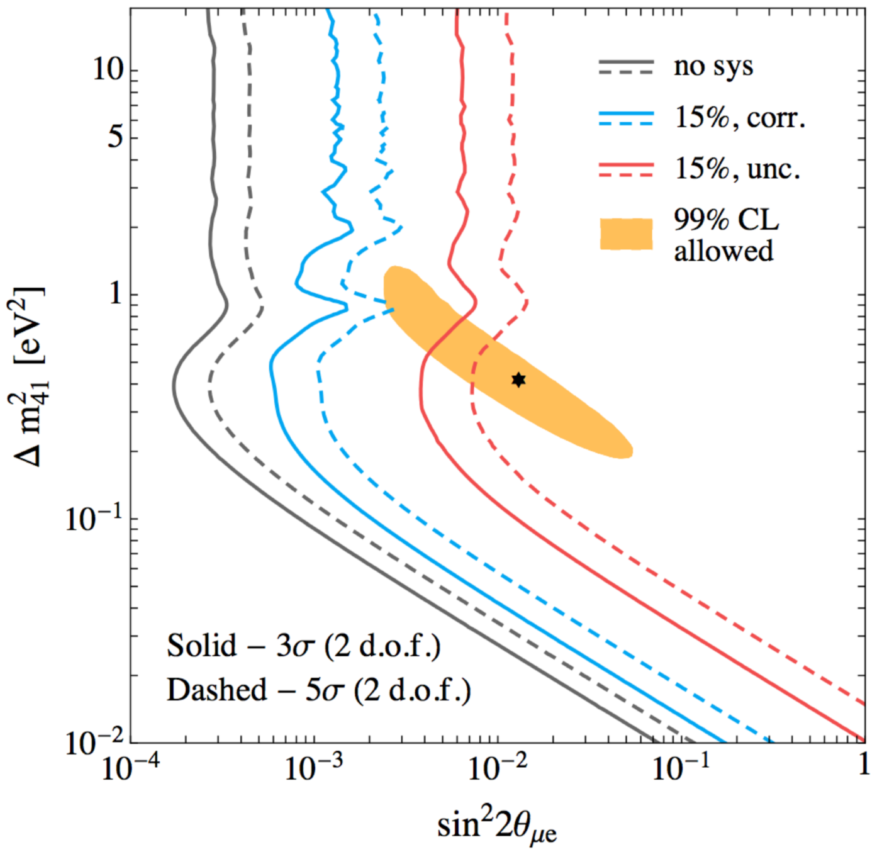
- Effects of NSI on standard measurements
- Sensitivity to NSI
- Current bounds on NSI strong enough to limit impact



MB, Choubey, Ohlsson, Raut, arXiv:1507.02868

Sterile neutrinos

- A sterile neutrino with mass splitting of order 1 eV^2
  - Oscillation pattern in near detector around 1 km
- Currently under investigation by the physics reach WP (WP6)



MB, Coloma, Fernandez-Martinez, arXiv:1407.1317

Other physics

- All of the typical (beam independent) capabilities of a megaton WC detector remain
  - Proton decay ($\sim 2 \cdot 10^{34}$ yr @ 5 MT yr)
  - Solar neutrinos
  - Supernova explosions ($\sim 10^{5}$ events, Milky Way – ~ 20, Andromeda)
  - Diffuse supernova neutrinos
  - Cosmological neutrino sources
  - Geo-neutrinos

Summary

- The ESSnSB aim is to measure the leptonic CP phase with good precision
  - Second oscillation maximum
  - Degeneracies (sufficiently) solved by atmospheric neutrino sample
- Running time in nu/anti-nu can be adapted to hints from earlier experiments without significantly affecting CP-discovery potential
- Robust to systematic errors
- An extensive program related to the far detector possible
- Several avenues for investigating new physics