

# CP-violation measurement in DUNE with Sub-GeV Atmospheric Neutrinos

K.J. Kelly, P.A.N. Machado, I. Martinez-Soler, S.J. Parke and Y.F. Perez-Gonzalez

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## Abstract

In this work, we study the **DUNE** sensitivity to the **CP-violation** phase using **sub-GeV atmospheric neutrinos**. LarTPCs would reconstruct with high accuracy the direction and the energy of incoming neutrinos. Combining the sensitivity of events with 0,1 and 2 observable protons in the final state, the results indicate that DUNE would be able to exclude several  $\delta_{CP}$  values at more than  $3\sigma$  of CL using only atmospheric neutrinos.

## Atmospheric Neutrinos:

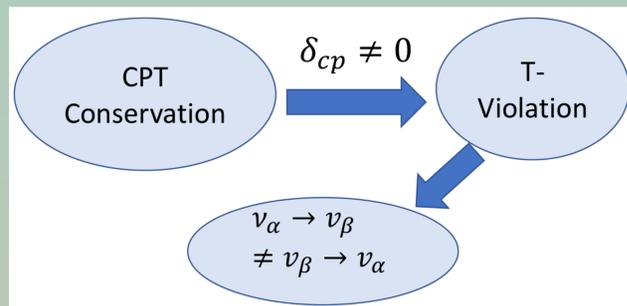
We consider the atmospheric flux in the energy range ( $0.1 \leq E \leq 1$ ) GeV. The flux is parameterized as

$$\phi(E, c_\theta) = \phi_0 f(E, c_\theta) (E/E_0)^\gamma$$

The energy and zenith dependence ( $f(E, c_\theta)$ ) is given by the Honda's table [1].  $\phi_0$  and  $\gamma$  account for the systematic uncertainties.

For the neutrinos **crossing the Earth** with  $E \sim 0.1$  GeV, the flavor oscillation is enhanced due to an **MSW resonance** in the solar sector.

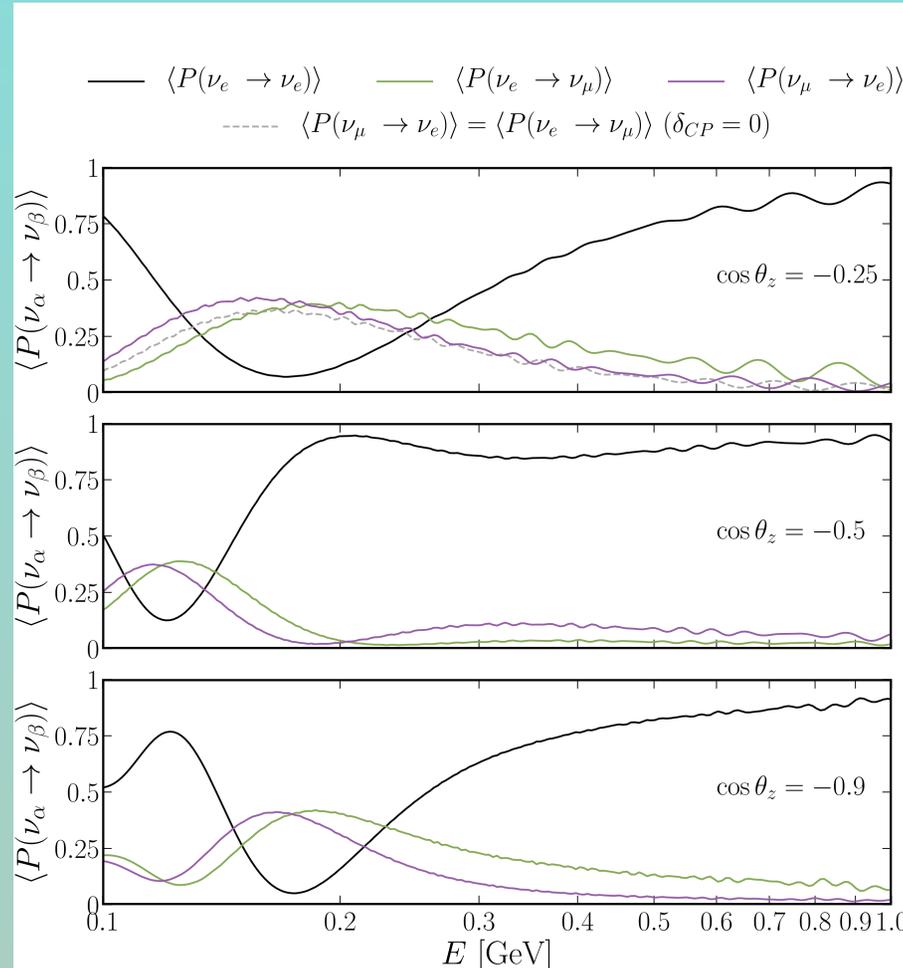
**Can be measured  $\delta_{cp}$  without a  $\nu/\bar{\nu}$  discrimination?**



The CP-violation term in the oscillation probability is

$$P_{CP} = -8J_r \sin \delta_{CP} \sin \Delta_{21} \sin \Delta_{31} \sin \Delta_{32}$$

At the sub-GeV scale,  $P_{CP}$  is enhanced due to the development of  $\Delta_{21}$ .



## DUNE Sensitivity

- LarTPCs reconstruct the incoming neutrino energy and direction from the full event topology.
- We consider CC events with up to two outgoing protons and no pions CC- $Np0\pi$

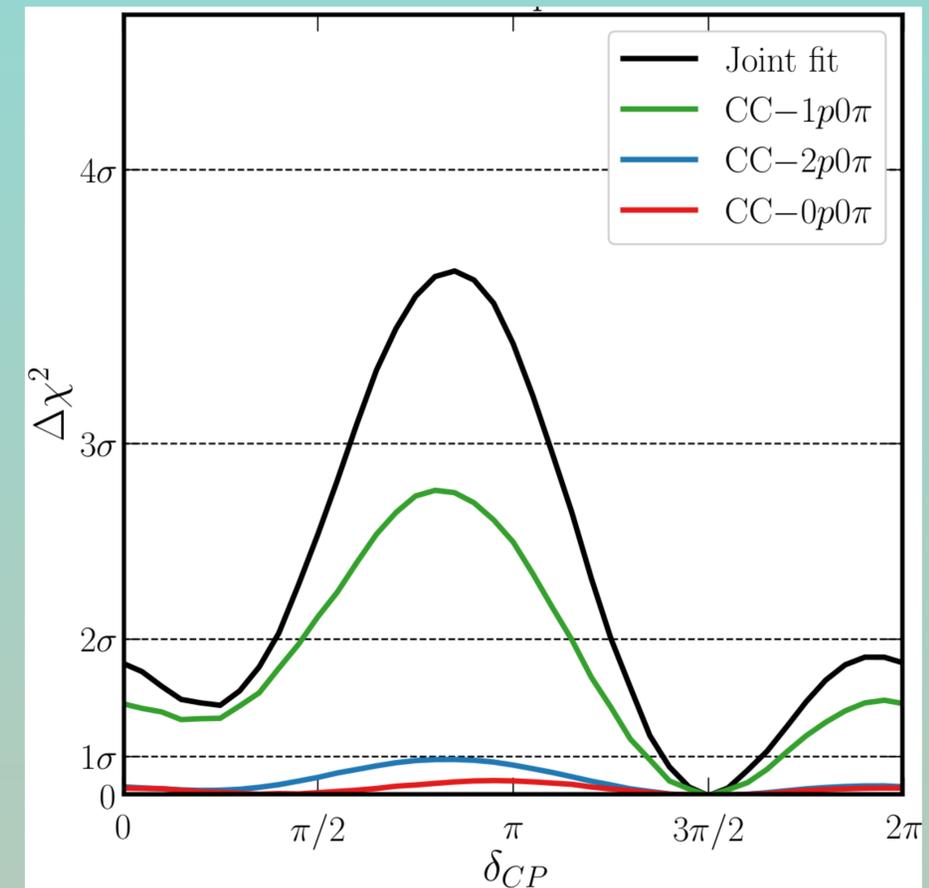
Np	Events/400 kton-year
CC-0p0 $\pi$	$\sim 5000$
CC-1p0 $\pi$	$\sim 9000$
CC-2p0 $\pi$	$\sim 250$

- Each event sample is dominated by a neutrino type.
- Combining all samples, the impact of the systematics ( $\phi_0, \gamma, \nu/\bar{\nu}, \nu_\mu/\nu_e$ ) is reduced to the percent level.

CC-1p0 $\pi$ ( $\nu$ -dominated)  
CC-0p0 $\pi$ ( $\bar{\nu}$ -dominated)

$\phi_0 \sim 2\%$   $\gamma \sim 0.02$   
 $\nu_\mu/\nu_e \sim 2\%$   $\bar{\nu}/\nu \sim 1\%$

- Fixing all the oscillation parameters and marginalizing over the flux systematics, we get the following sensitivity



## Conclusions

- The **CP-violation** has a sizable impact on the **sub-GeV atmospheric neutrino** flux.
- Sub-GeV neutrinos can be reconstructed with a unique capability by **LarTPCs**.
- **DUNE's** sensitivity can rule out regions of allowed  $\delta_{cp}$  parameter space at more than  $3\sigma$  **CL**.

## References

[1] M. Honda et al. *Phys. Rev. D*, 92(2):023004, 2015.