CP phase from sub-GeV atmospheric neutrinos in DUNE

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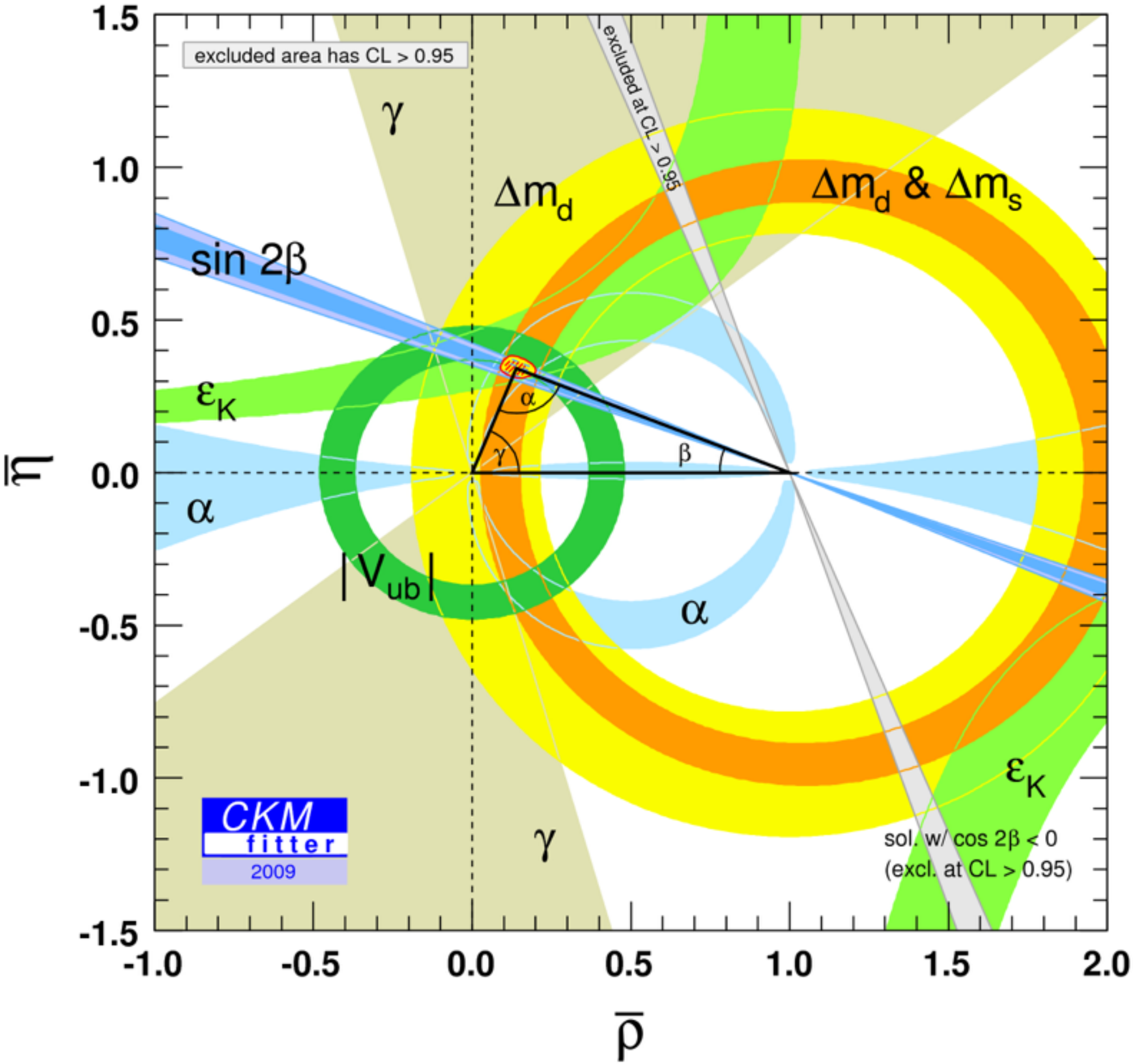
Motivation:

CP violation is the main goal of DUNE

Redundancy



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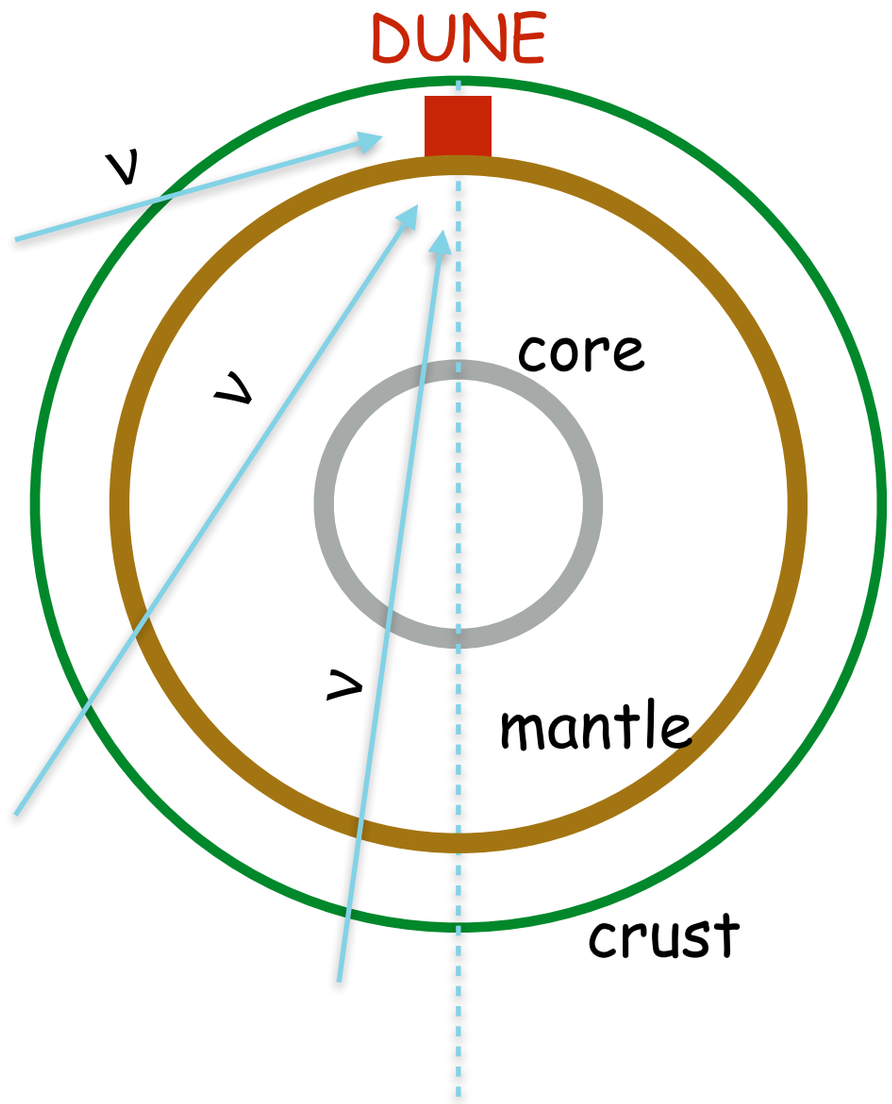
Sub-GeV atmospheric neutrinos are one of the richest neutrino samples we have access to.



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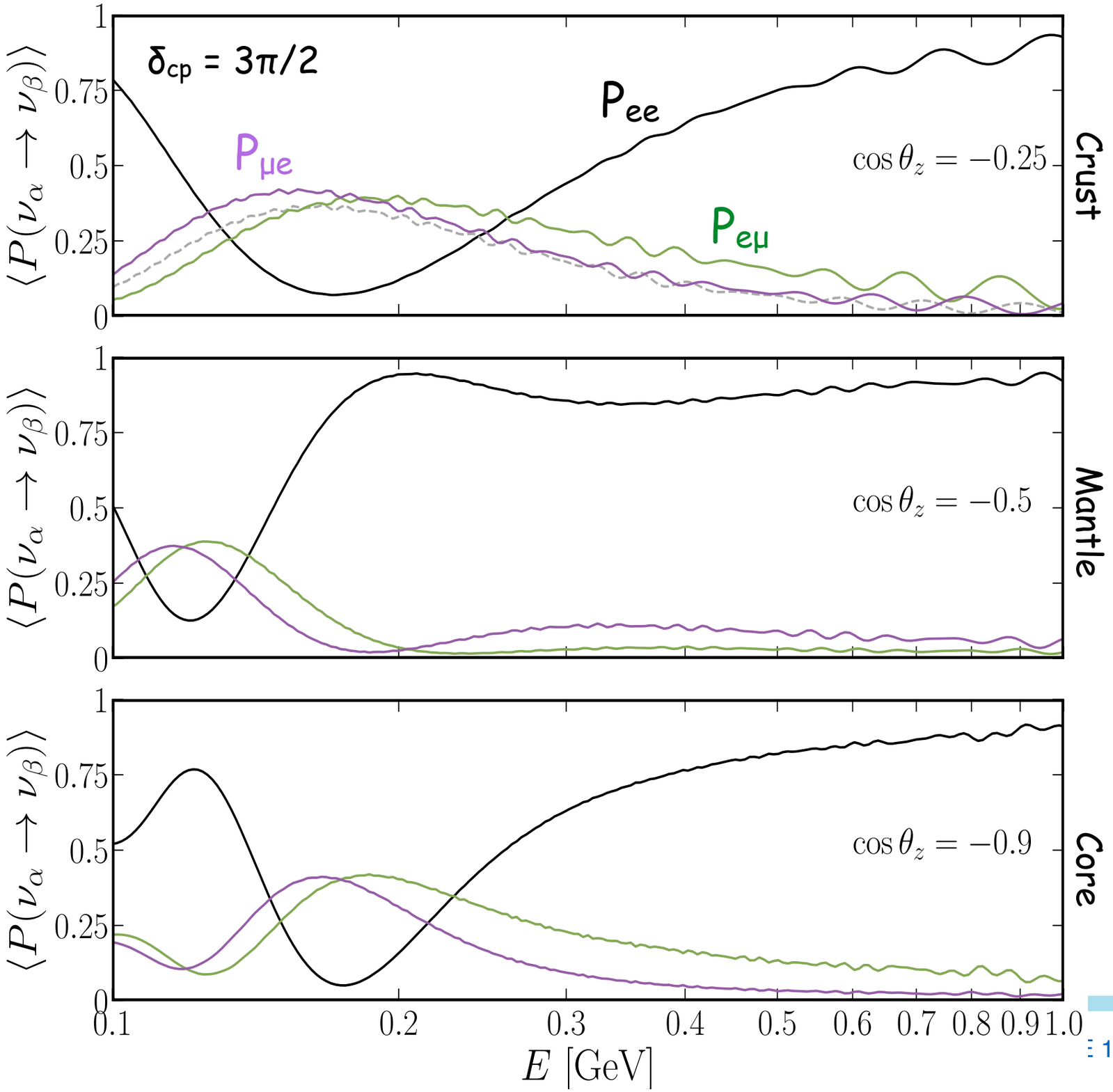

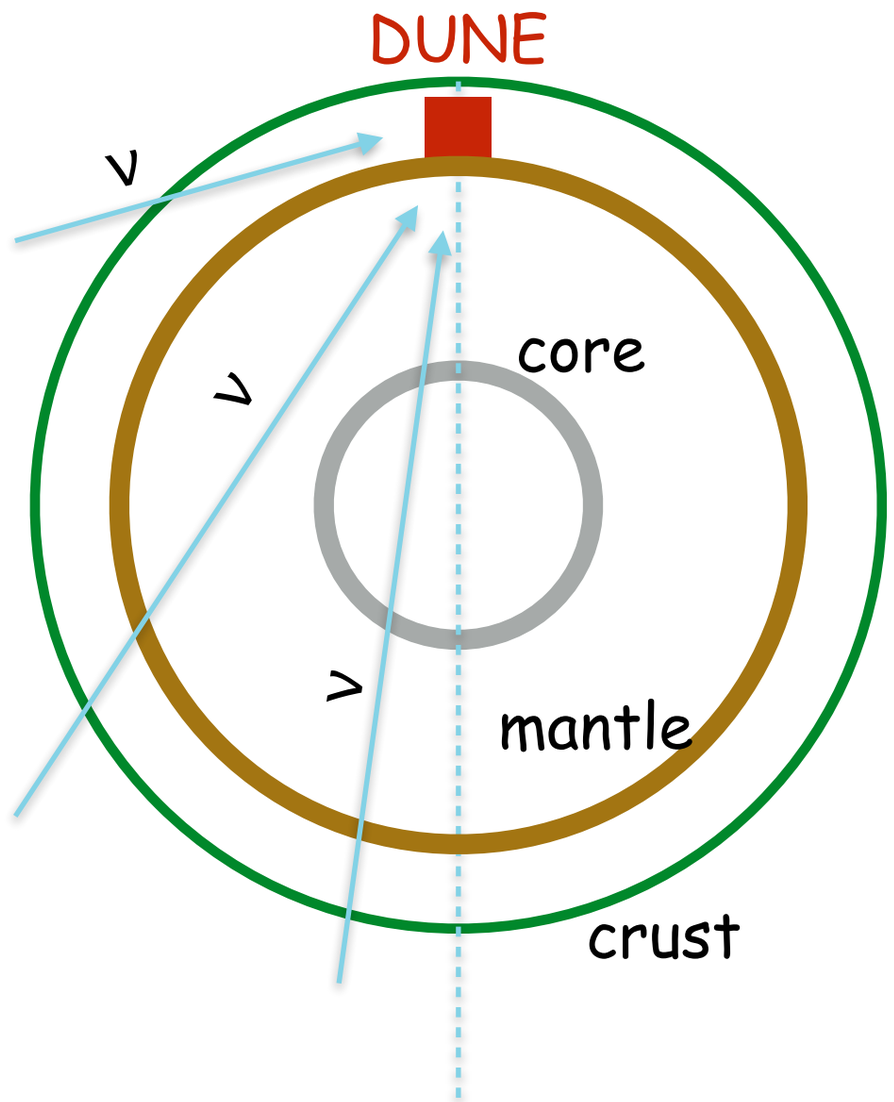

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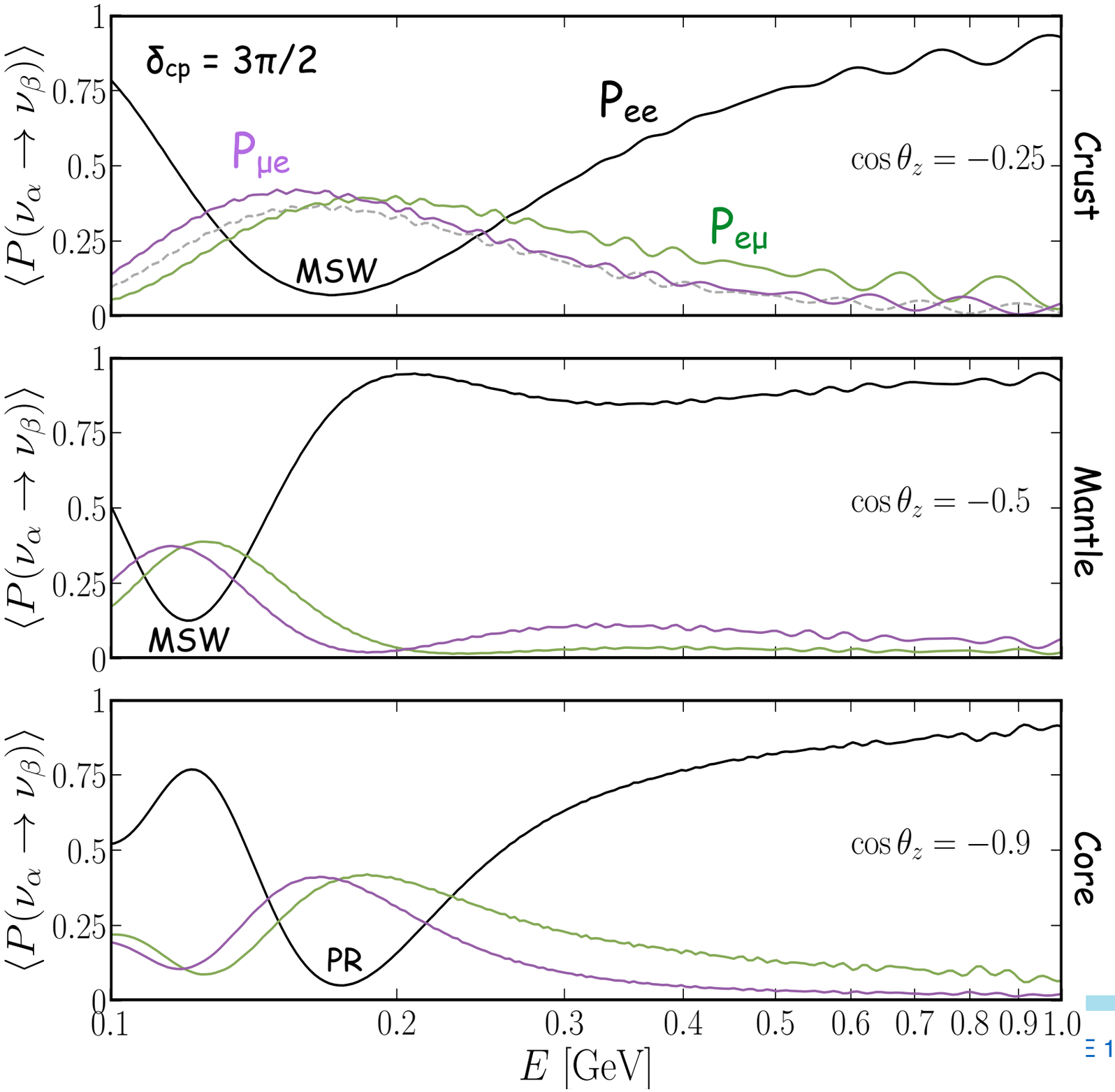

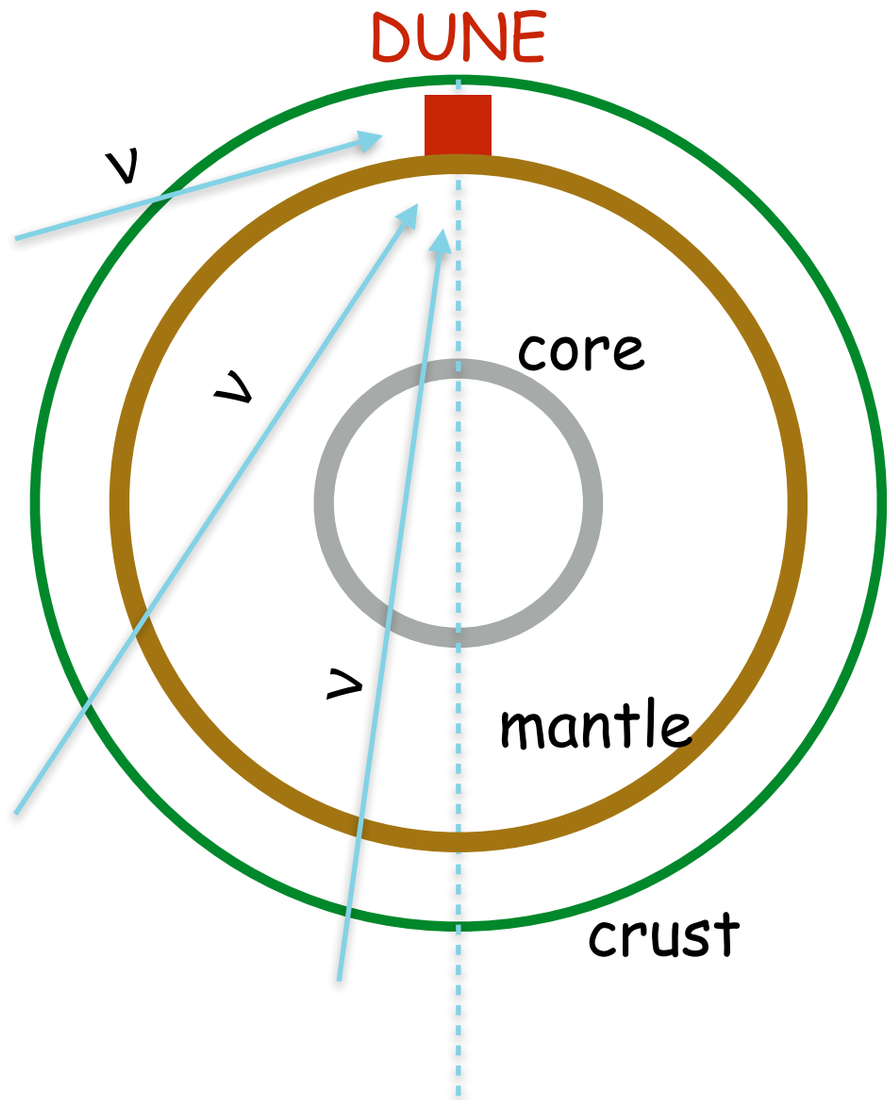

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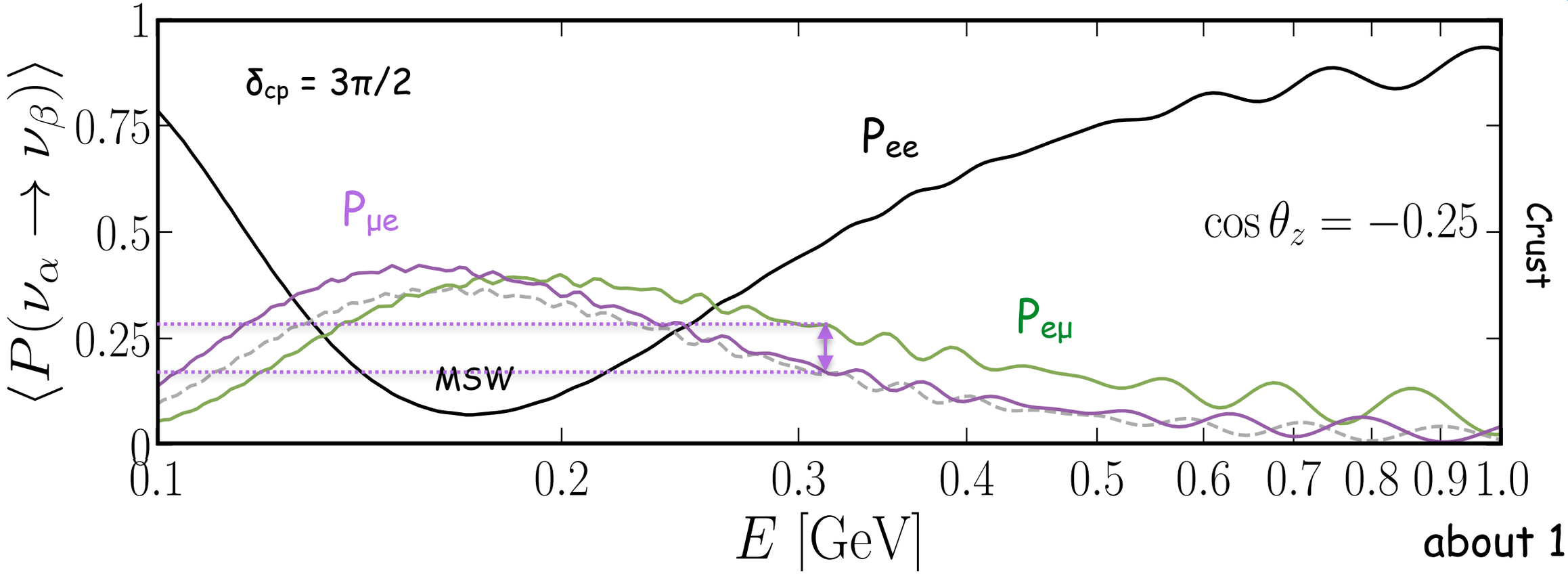
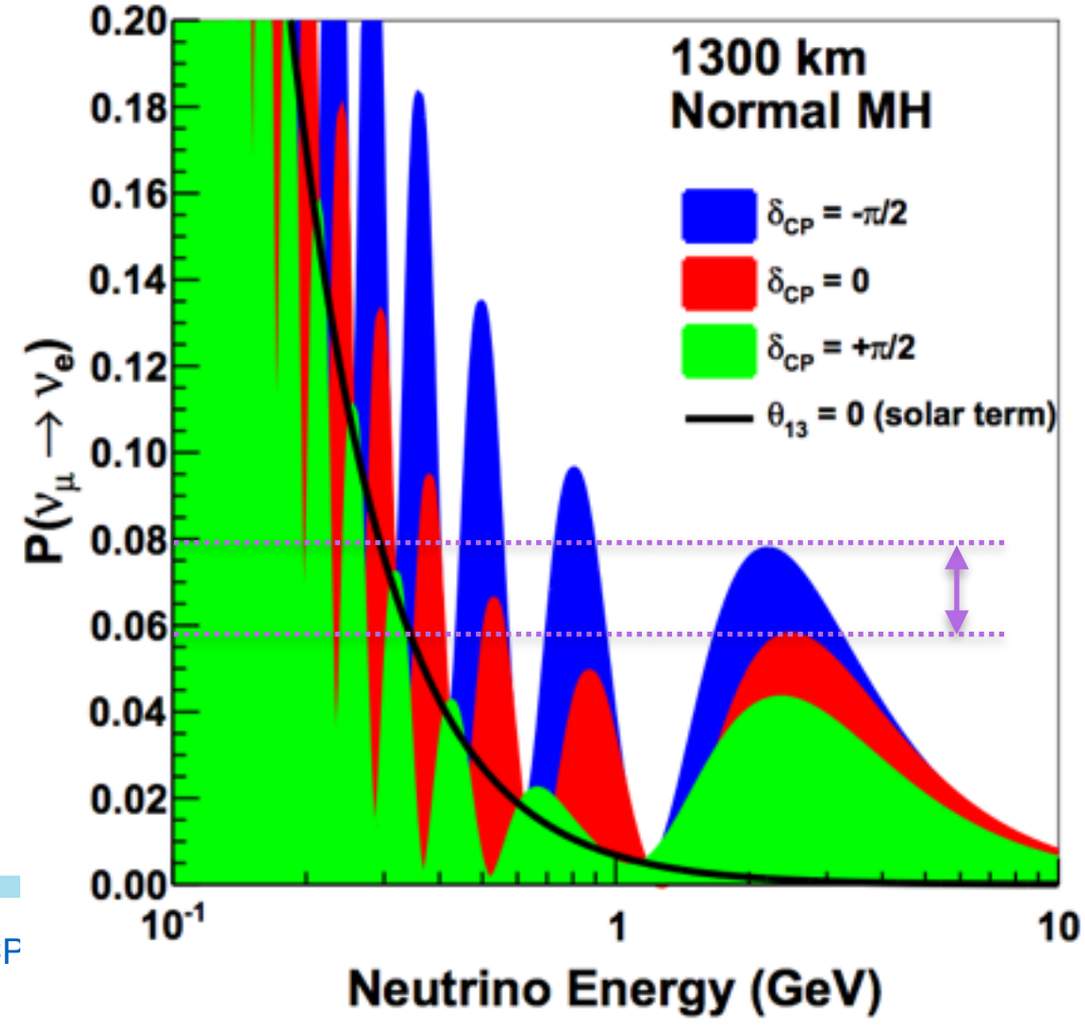
Kelly et al 1904.02751



about 12%



about 2%

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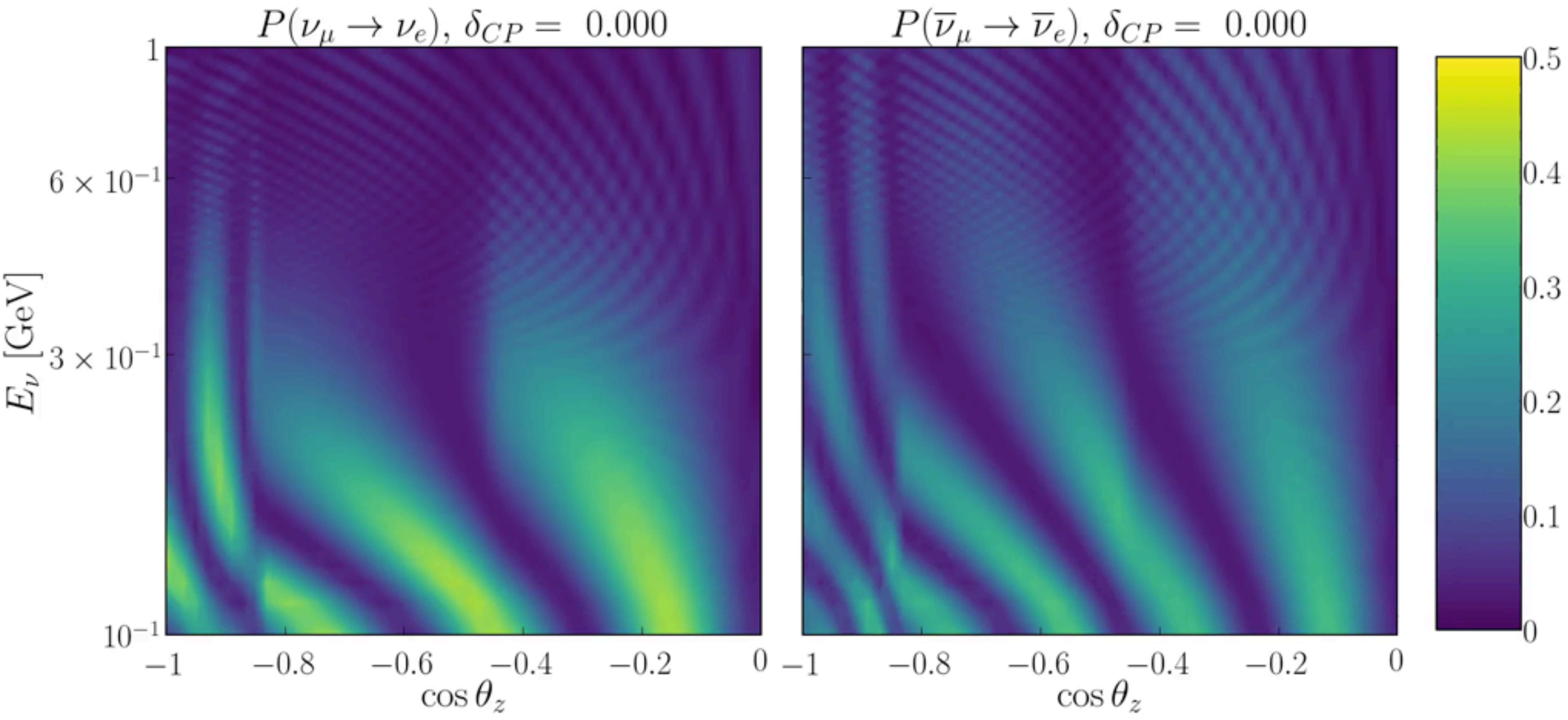

https://imgur.com/HoWUniu

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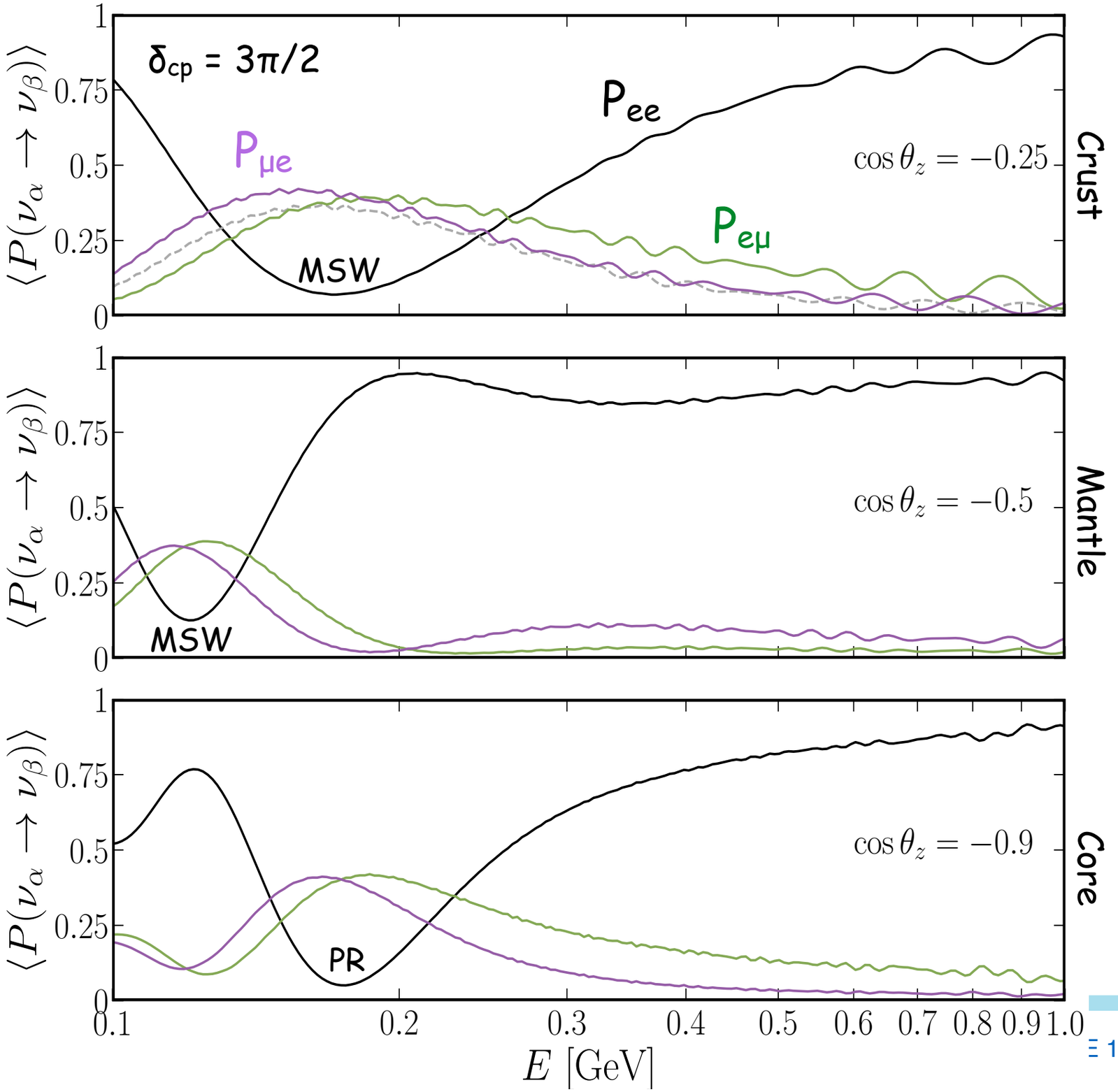

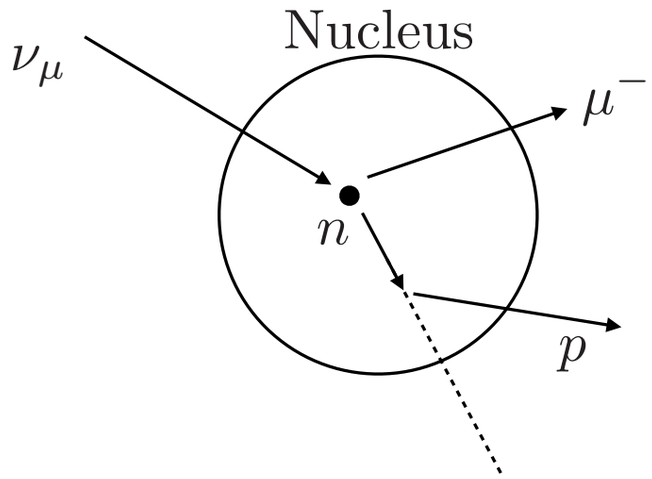

Needs to know neutrino direction

Low E protons are invisible @ Cherenkov detectors

Liquid Argon TPCs can do it!

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Experimental evidence

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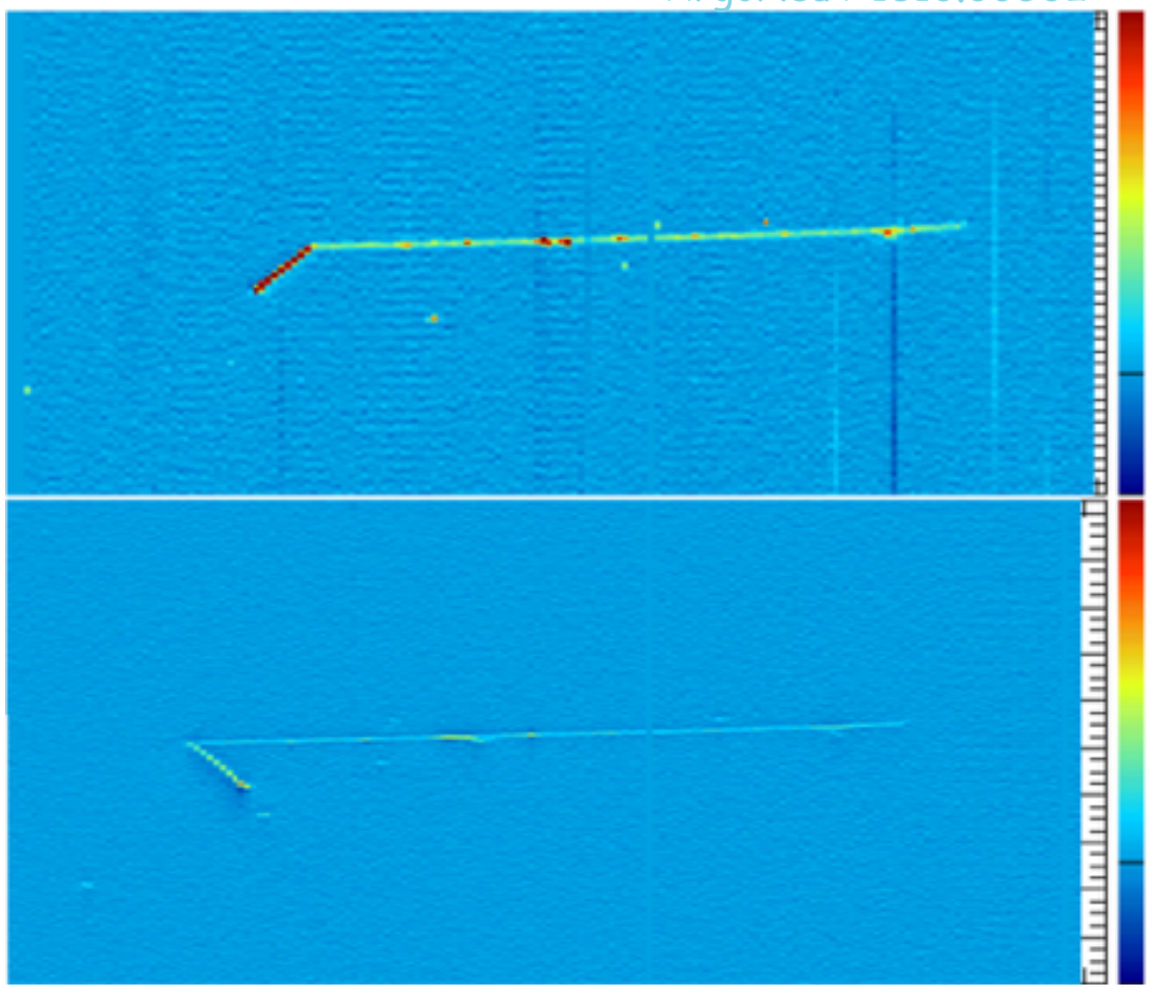
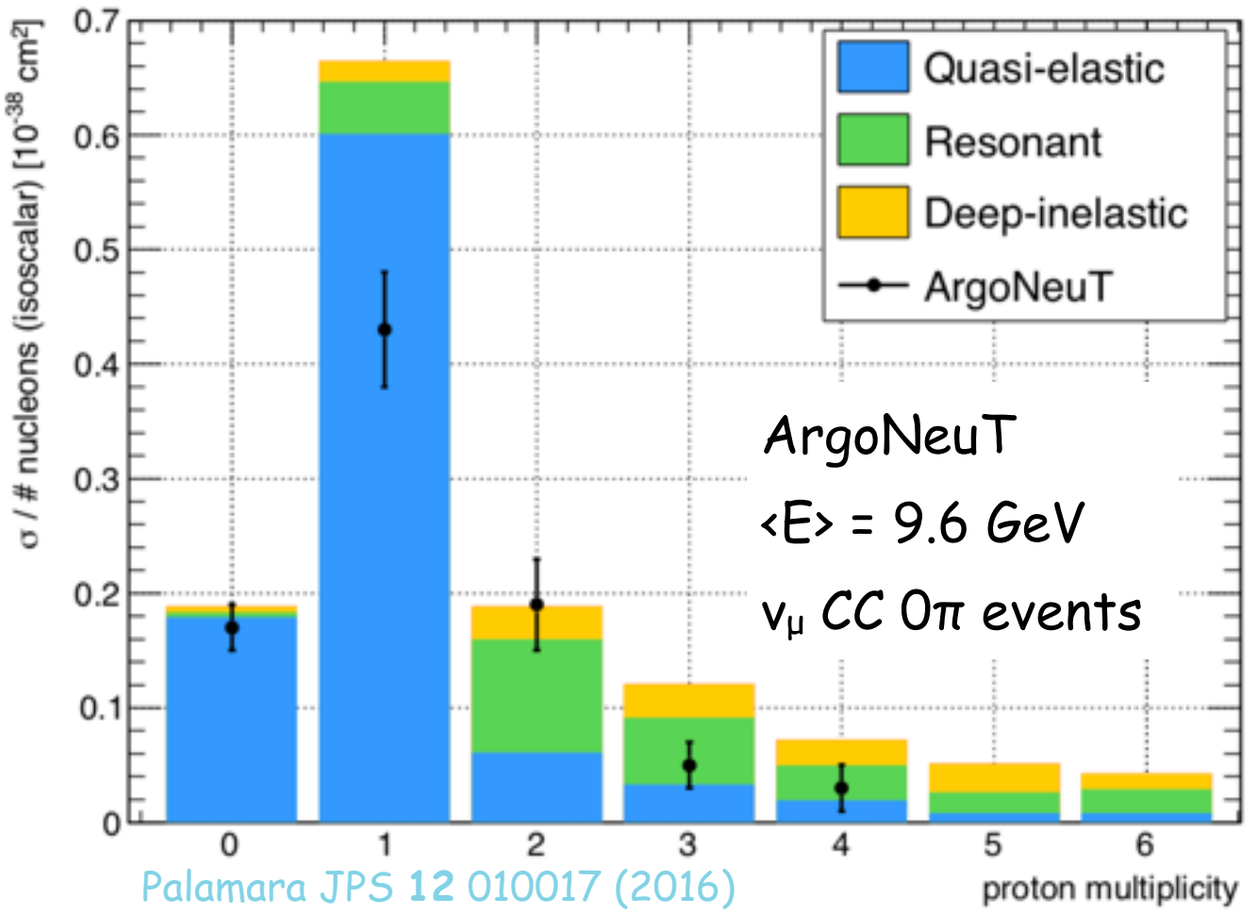
ArgoNeuT 1810.06502



ArgoNeuT demonstrated the LAr capability to detect 21 MeV recoil protons.

Event topology carries extra information



Palamara JPS 12 010017 (2016)

Technical details

Kelly et al 1904.02751

Atmospheric flux from Honda et al 1502.03916

$$\Phi_\alpha(E) = \Phi_{\alpha,0}\, f_\alpha(E) \left(\frac{E}{E_0}\right)^\gamma$$

Uncertainties:

1) overall normalization (40%)
2) e-μ ratio (5%)
3) Neutrino-antineutrino (2%)
4) Spectral distortion γ (±0.2, absolute)

Cross section: NuWro

- Classify events by final state topology: no pions (simplicity); n=0,1,2 protons; use only CC events so we can identify the charged lepton, no charge separation
- K_p > 30 MeV
- Momentum resolution: 5%, 5%, 10% at 100 MeV for e, μ, p
- Angular resolution: 5°, 5°, 10° for e, μ, p

Technical details

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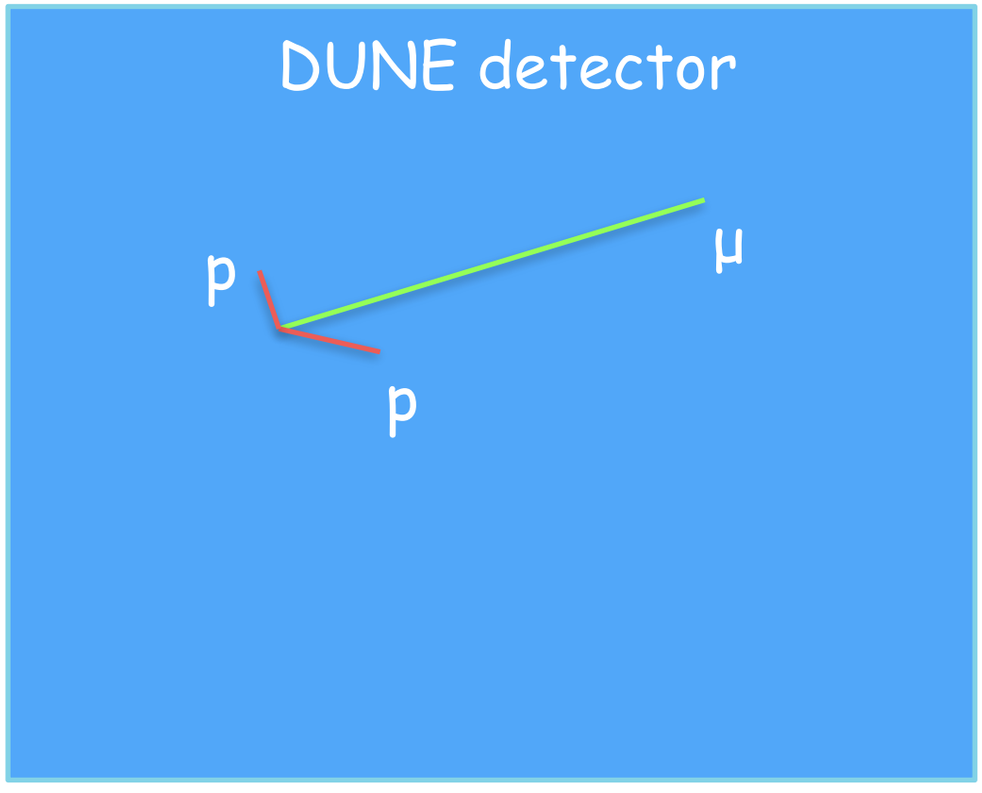
Exposure: 400 kton-year

Observables:

- Deposited energy (E_{dep})
- Zenith direction of deposited momentum (θ_{dep})

Example: muon CC-2p0π



$$E_{\rm dep} = E_\ell + K_p^{(1)} + K_p^{(2)}$$

$$\cos\theta_z = \hat{p}_{out} \cdot \hat{z}$$

$$\vec{p}_{out} = \vec{k}_{p1} + \vec{k}_{p2} + \vec{k}_\mu$$

Sub-GeV atmospheric neutrinos in DUNE

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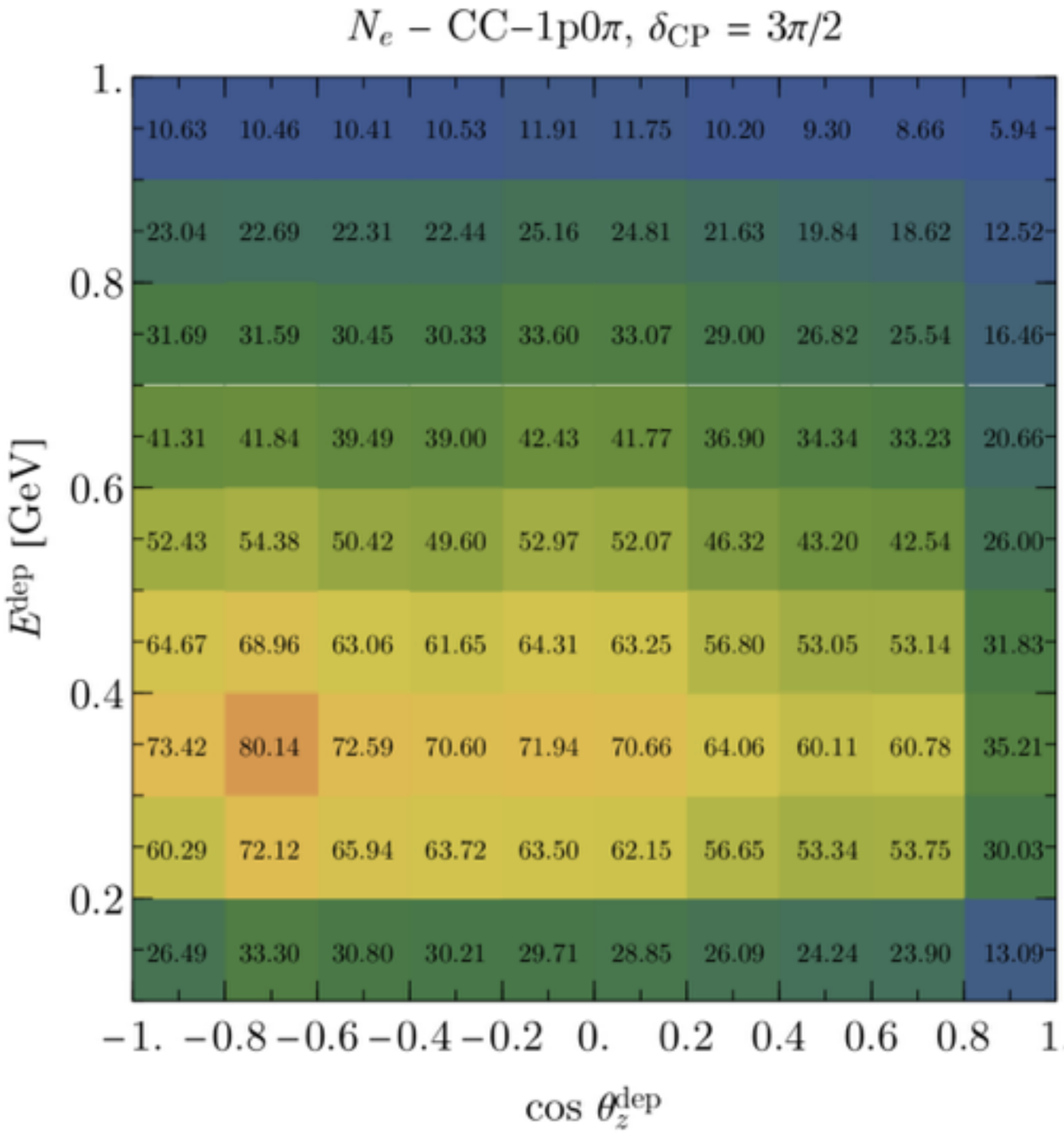

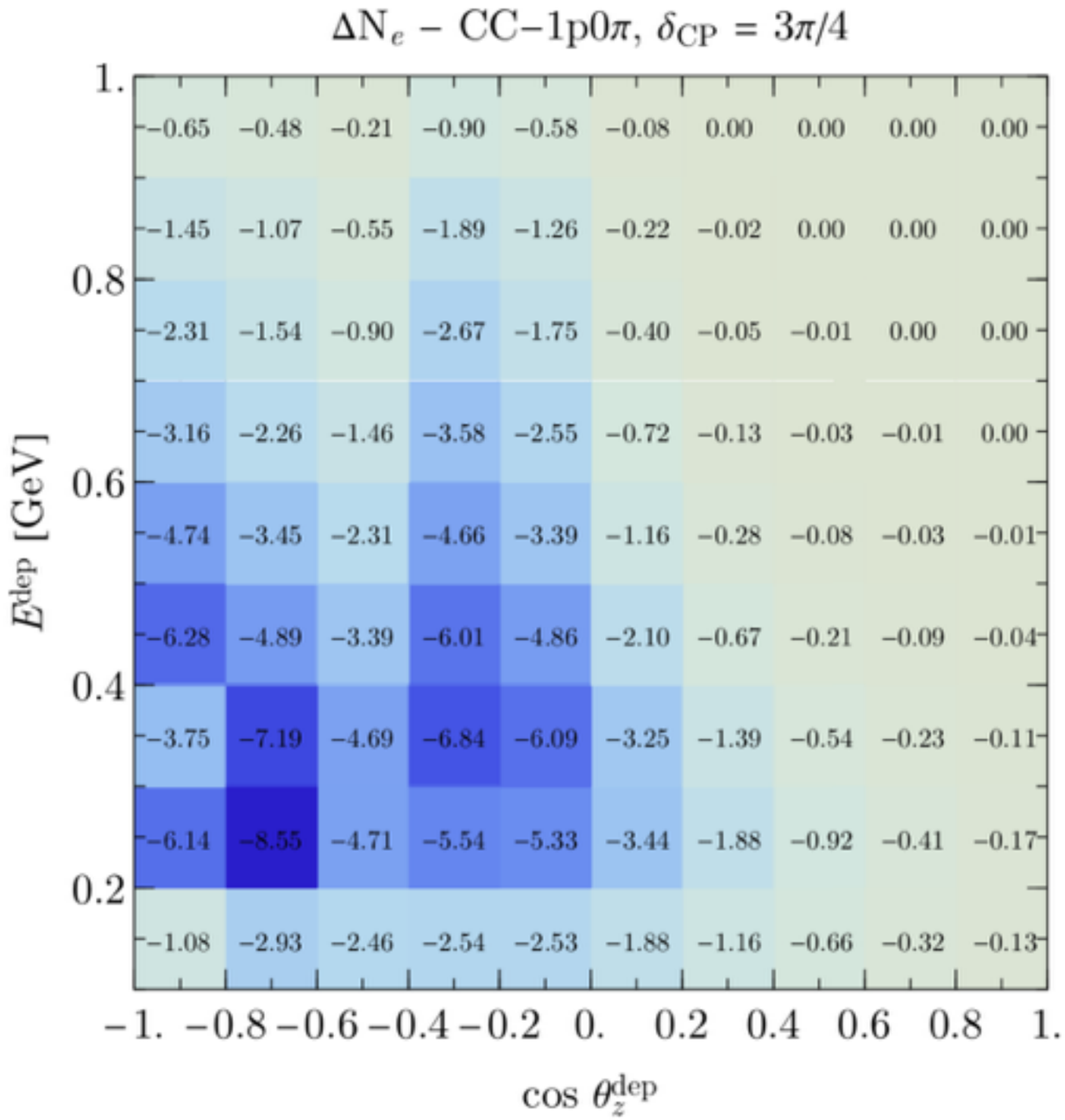

Plus muon events and other topologies (0p, 1p, 2p, …)

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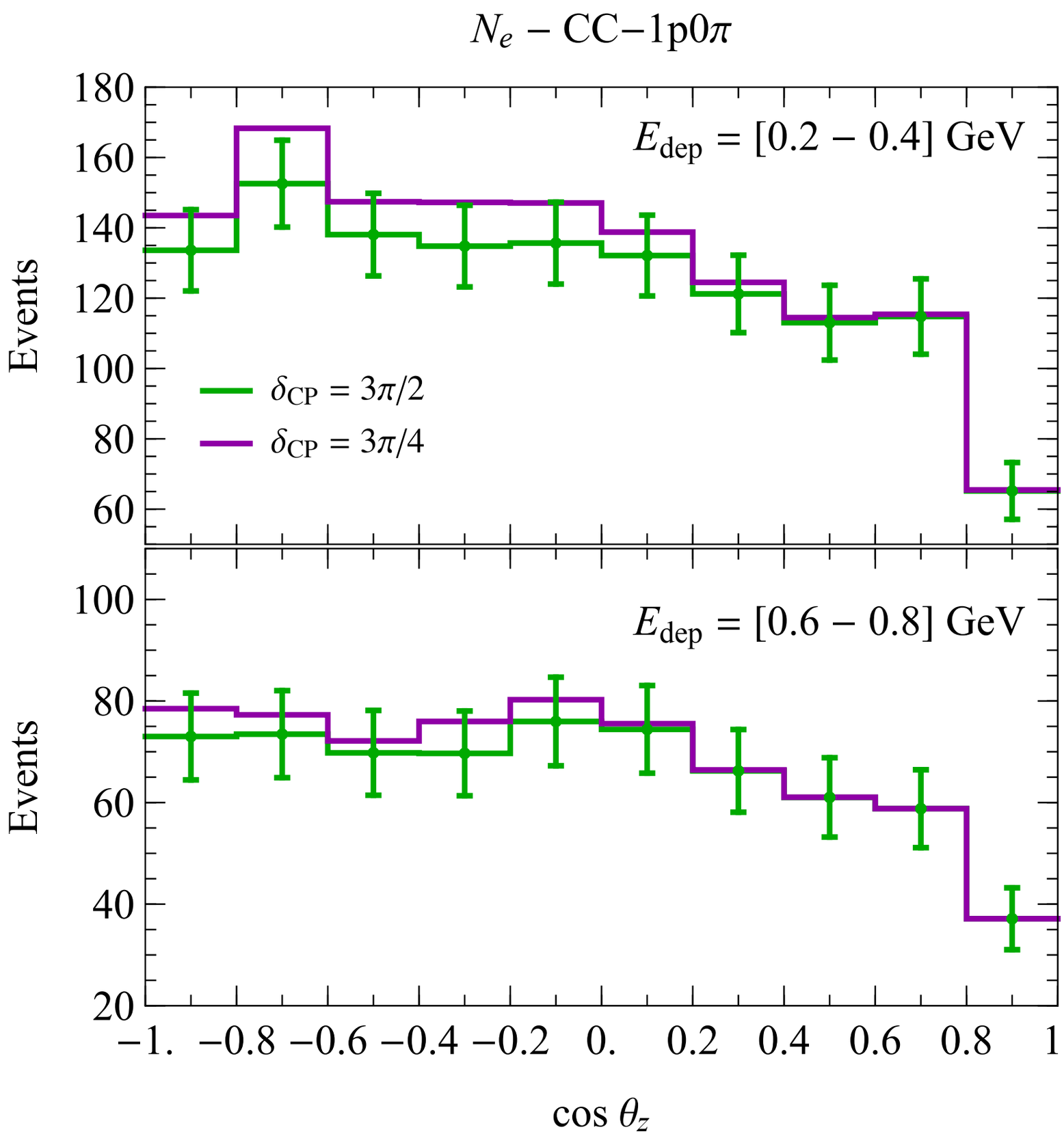

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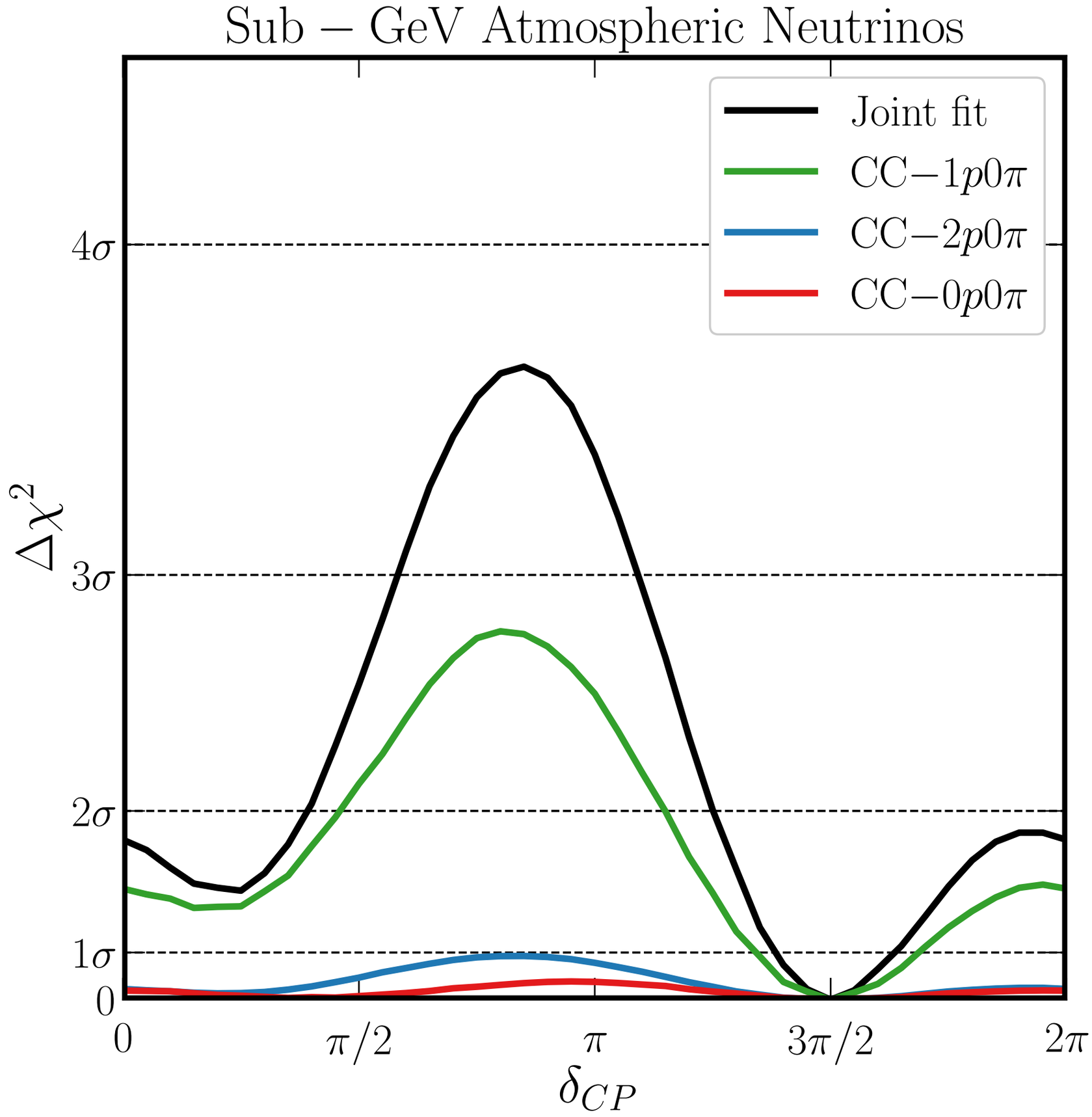


Conclusions and discussion

Sub-GeV atmospheric can yield complementary information on δ_{cp}

Analysis uniquely enabled by LArTPC technology and large mass

Flux uncertainties well under control

Working on generator comparison (FSI model)

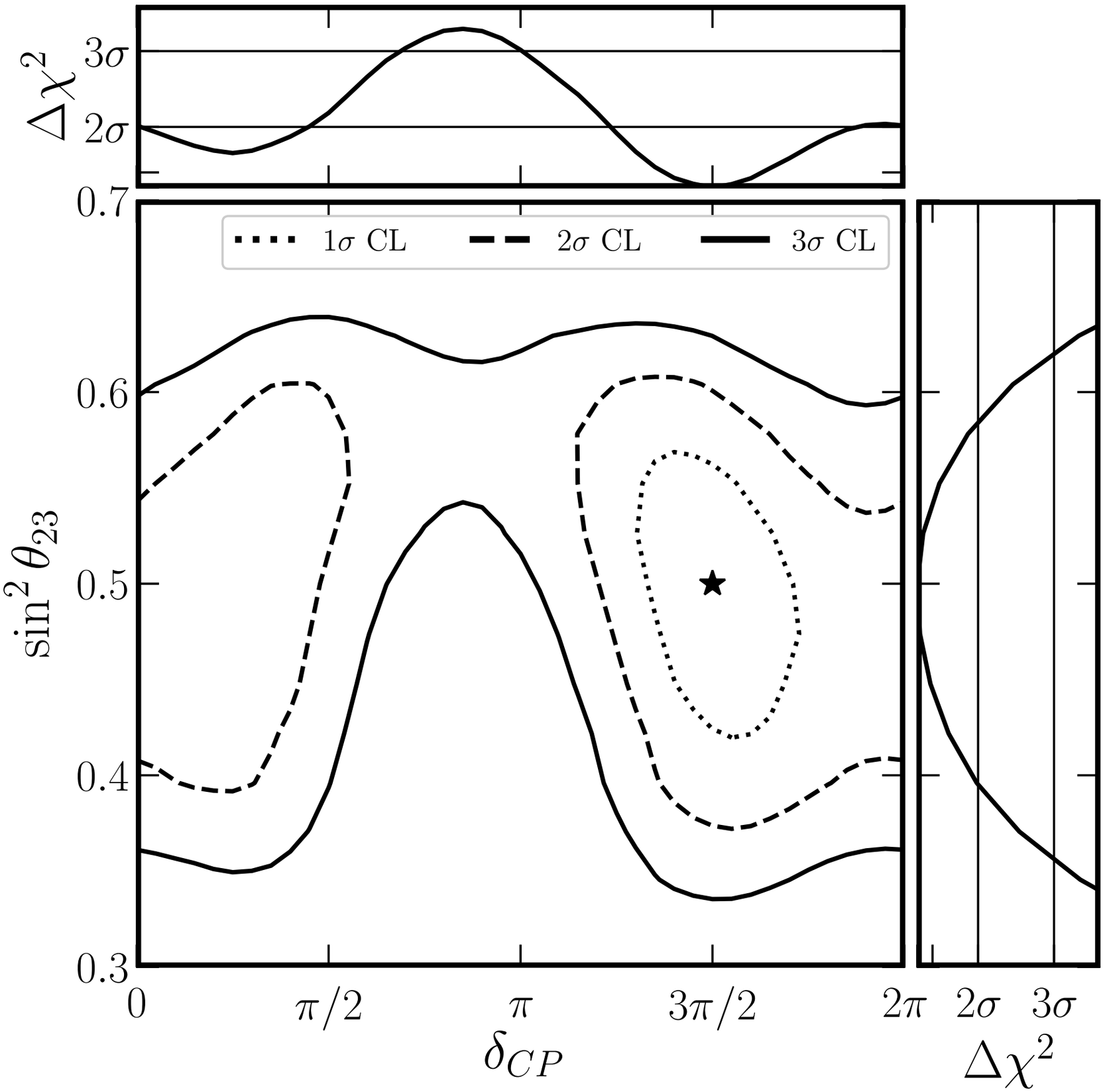
Data-driven study of cross section and directionality?

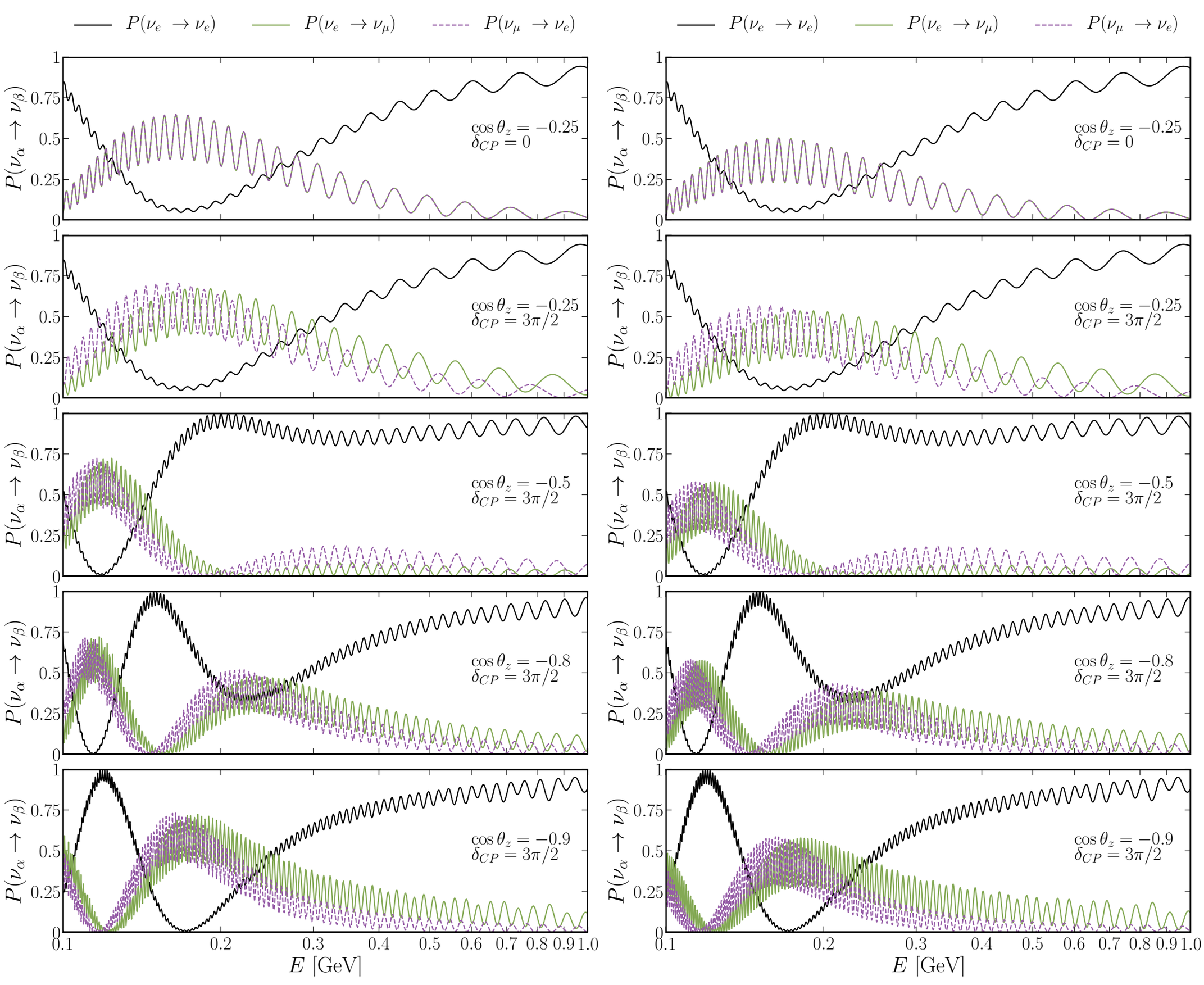
DUNE-PRISM beyond 30m?

Working on discriminators to improve sensitivity (like NOvA's quartiles)

What is the impact of $\mu^{\pm}$ separation by observation of Michel electron?

Working on impact of sub-GeV atm in new physics searches


$\Delta\chi^2$
3σ
2σ
0.7
0.6
0.5
0.4
0.3
$\sin^2\theta_{23}$
1σ CL
2σ CL
3σ CL
0
$\pi/2$
π
$3\pi/2$
2π
δ_{CP}
2σ
3σ
$\Delta\chi^2$



Kelly et al 1904.02751

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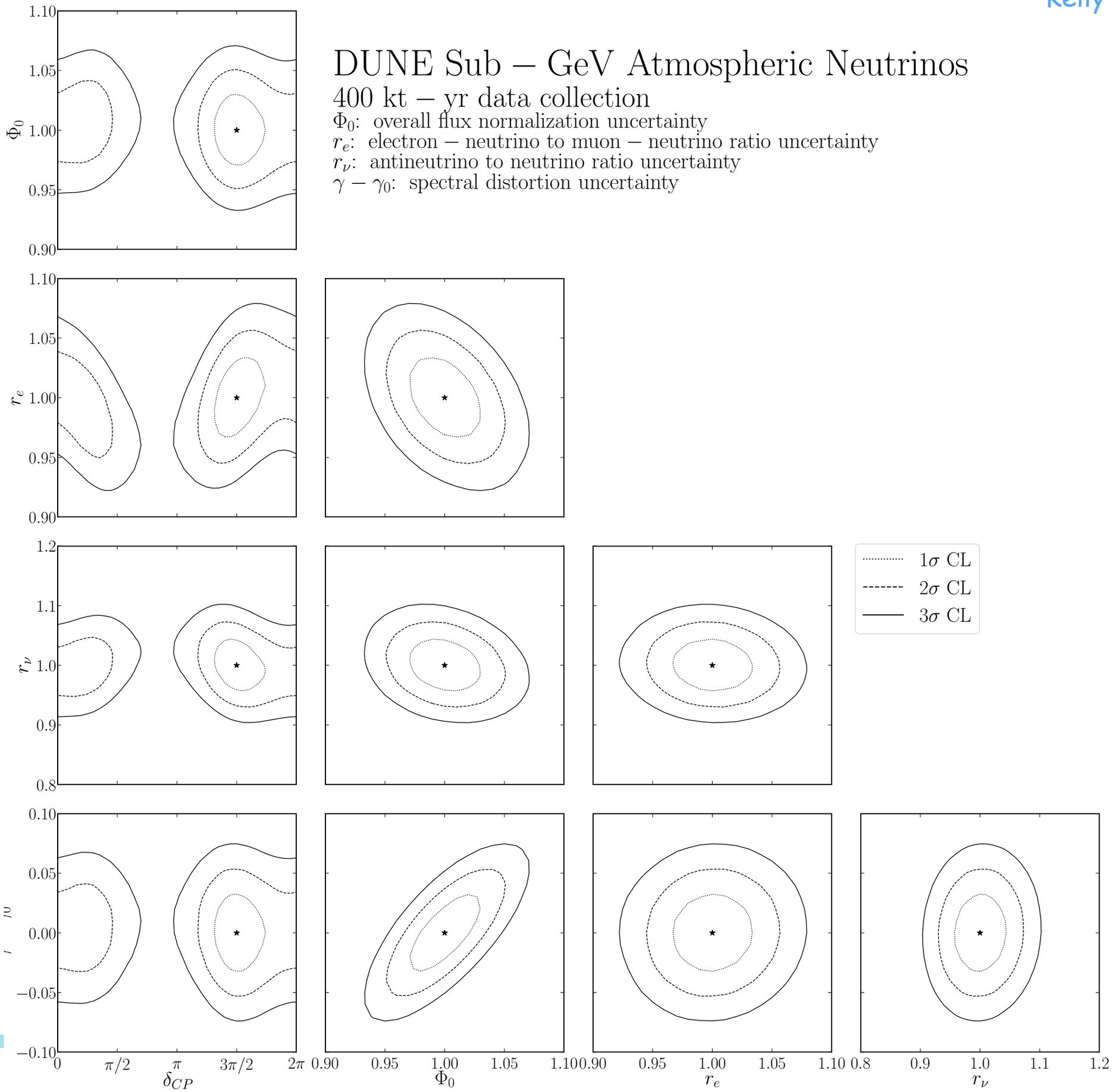
DUNE Sub − GeV Atmospheric Neutrinos

400 kt − yr data collection

Φ_0: overall flux normalization uncertainty
r_e: electron − neutrino to muon − neutrino ratio uncertainty
r_ν: antineutrino to neutrino ratio uncertainty
$\gamma - \gamma_0$: spectral distortion uncertainty



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