ID - #332

EXPLORING EARTH'S MATTER EFFECT IN HIGH - PRECISION LONG - BASELINE EPERIMENTS

Masoom Singh[1,2], **Sanjib Kumar Agarwalla**[1,3,4]

[1] IOP, Bhubaneswar, India, [2] Utkal University, Bhubaneswar, India [3] HBNI, Mumbai, India [4] ICTP, Trieste, Italy

EPS-HEP 2021 Workshop

masoom@iopb.res.in

1. MOTIVATION

DUNE has substantial matter effect because of 1300 km baseline. In this work, we explore :

- **capability of DUNE in establishing matter effect** by excluding vacuum hypothesis
- **precision in the measurement of** line-averaged constant Earth matter density (ρ_{avg})
- **new degeneracies in** ($\rho_{\text{avg}}-\delta_{\text{CP}}$) and ($\rho_{\text{avg}}-\theta_{23}$) **planes**

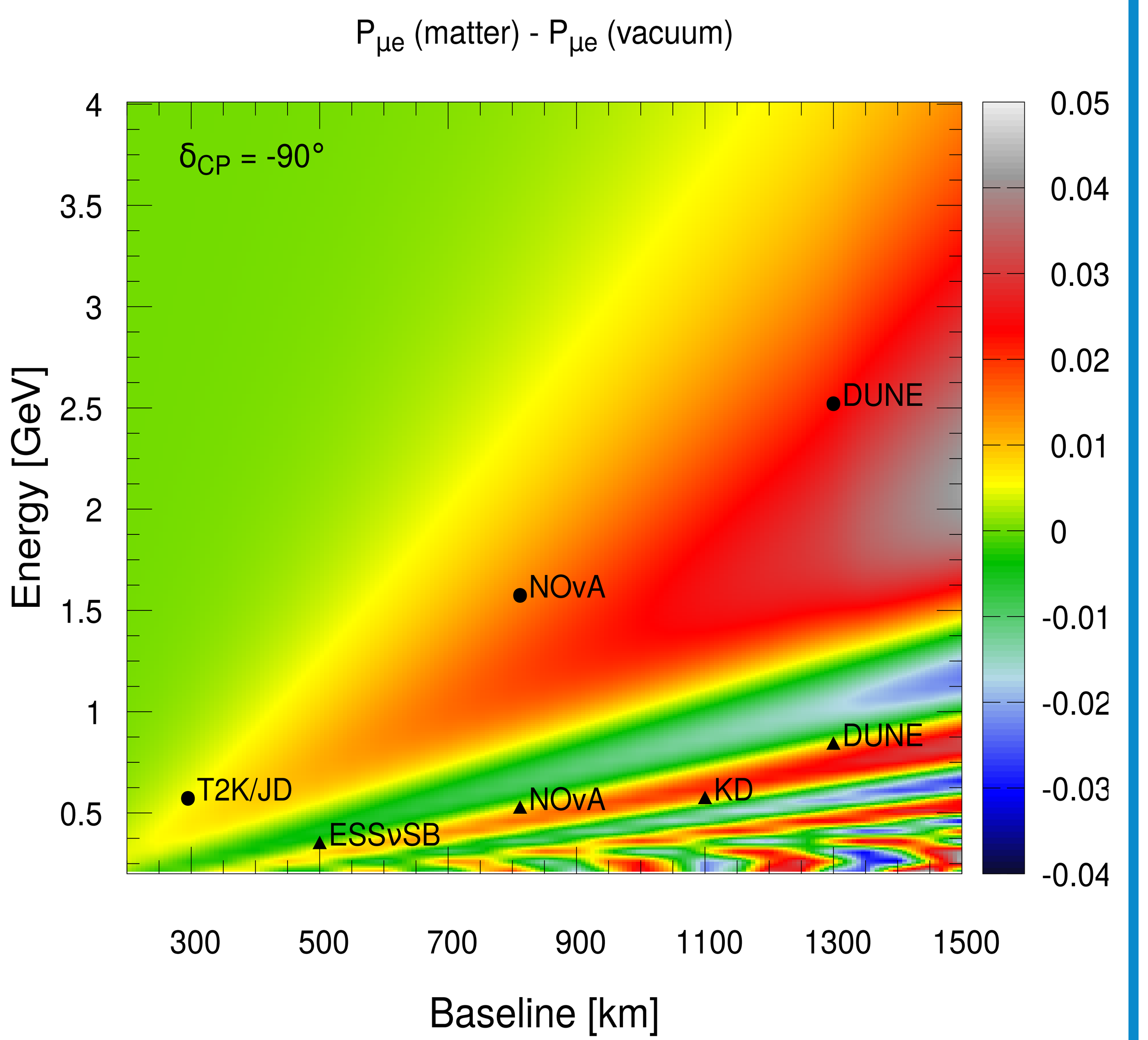
To lift these degeneracies, data from the upcoming T2HK (JD) and T2HKK (KD) are incorporated.

2. MATTER VS. VACUUM

- $\Delta P \approx [P^{\text{mat}}_{\nu_\mu\to\nu_e} - P^{\text{vac}}_{\nu_\mu\to\nu_e}]$ leading term
- Expanding $(1-\hat{A})^{-2}$ and considering terms upto second order in $\hat{A}$:

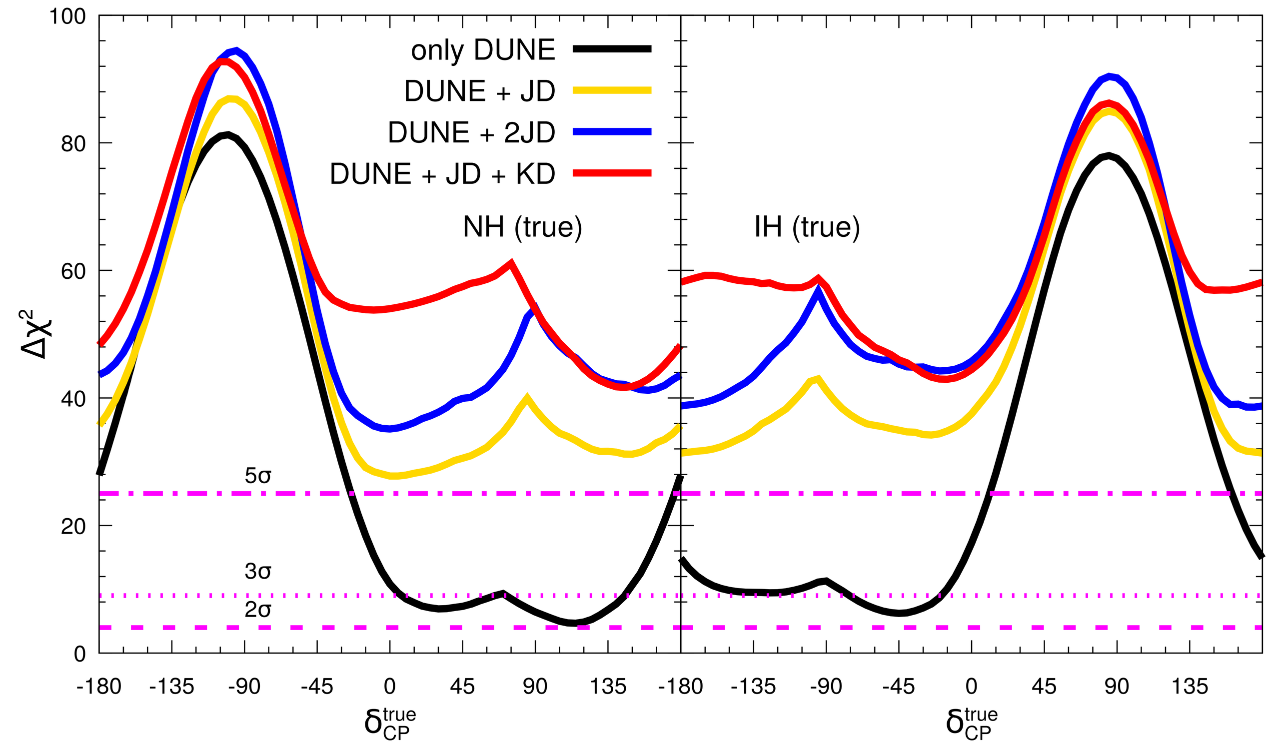
$$\Delta P = \frac{1}{2}\sin^2\theta_{23}\sin^2 2\theta_{13}\Big[(3\hat{A}^2+2\hat{A}-1) + \cos[(2n+1)\pi\hat{A}](3\hat{A}^2+2\hat{A}+1)\Big],$$

$$\hat{A} = \left(\frac{0.76\times10^{-4}(\text{eV}^2)}{\Delta m^2_{31}}\right)\times\left(\frac{\rho_{\text{avg}}}{\text{g/cm}^3}\right)\times\left(\frac{\text{E}}{\text{GeV}}\right).$$

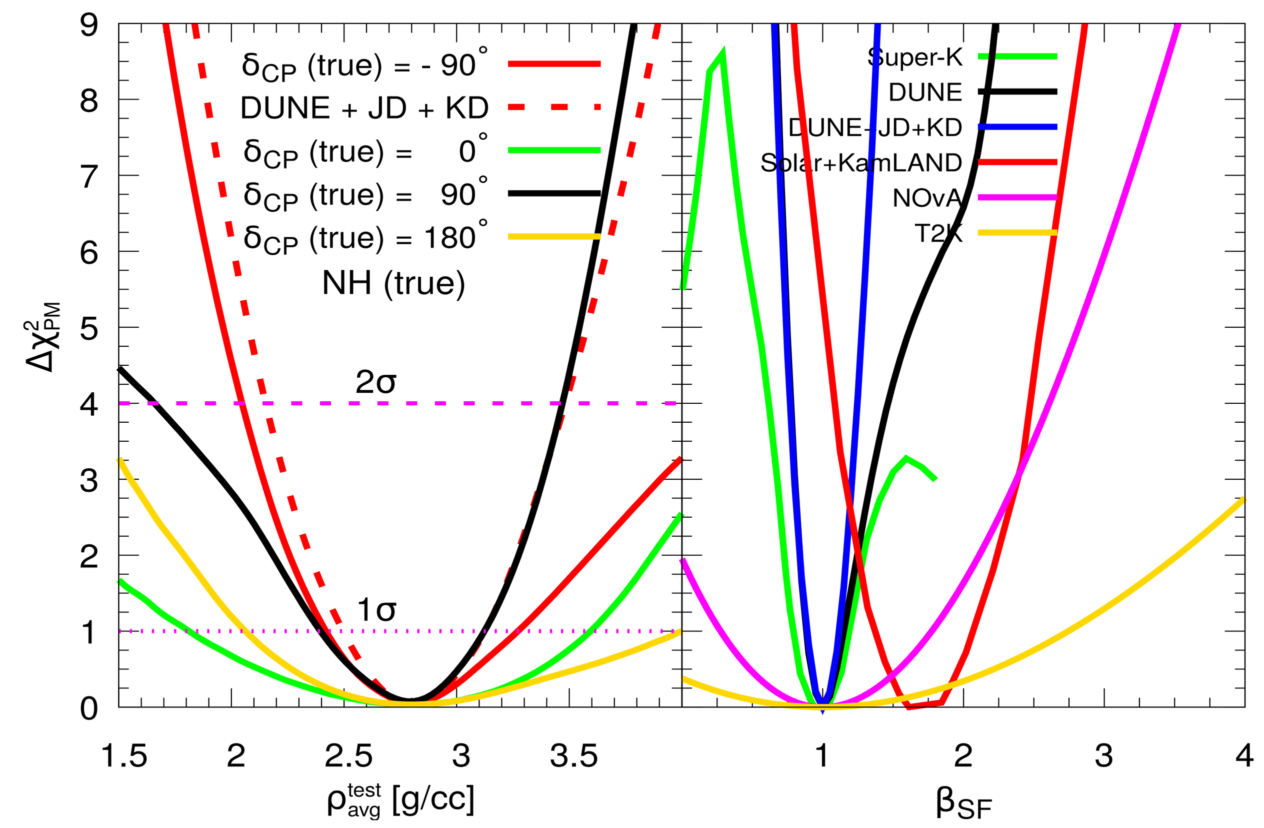


ΔP as a function of baseline and neutrino energy [?]. Solid circle (triangle) shows ΔP at first (second) oscillation maxima.

3. OUR FINDINGS

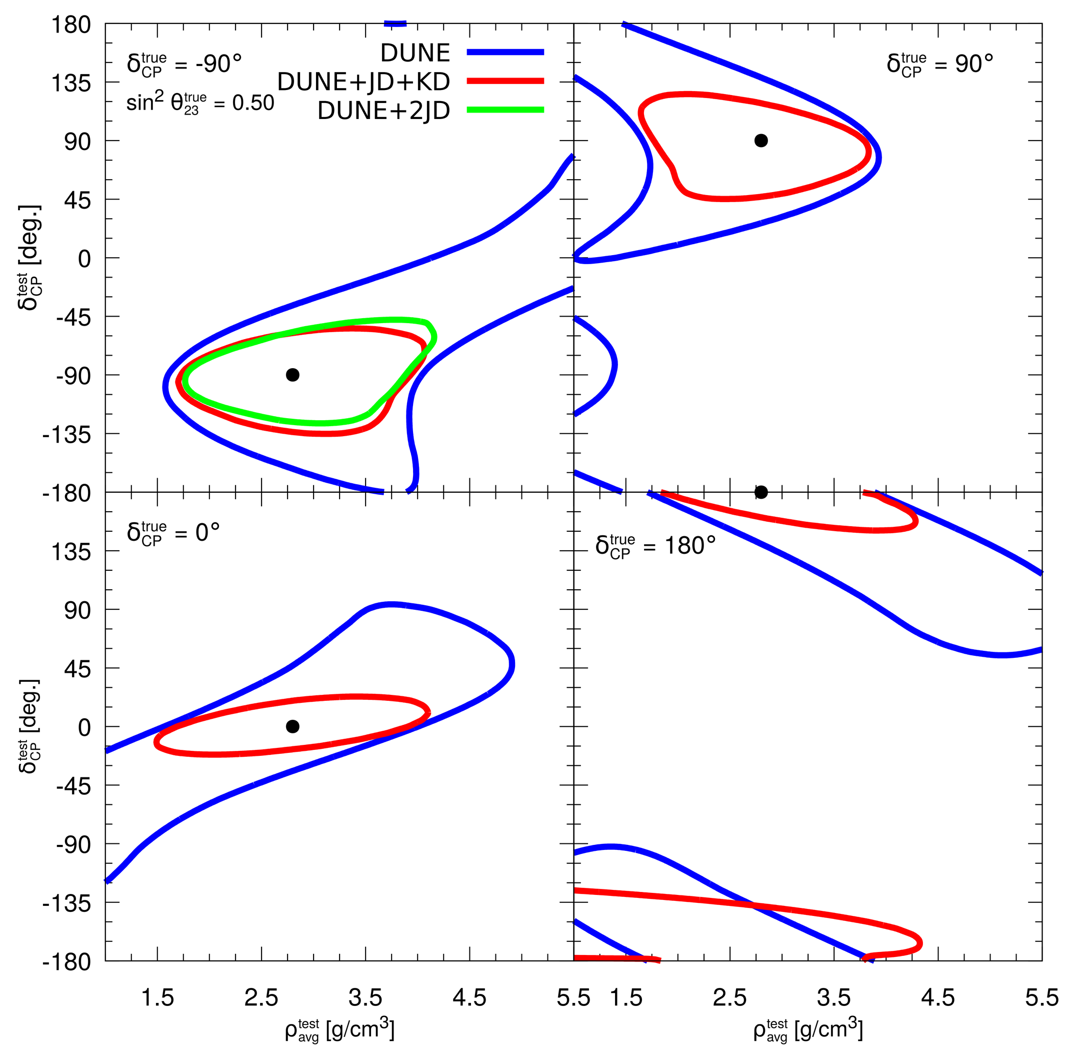


- **Establishing Earth matter effect**
- Capability of different set-ups to exclude vacuum solution as a function of $\delta_{\text{CP}}^{\text{true}}$ at maximal $\theta_{23}^{\text{true}}$. True NH (IH) in left (right) panel.
- At 5σ C.L. : vacuum is excluded $\sim$ **46%** for CP phases in DUNE, while $\sim$ **100%** in combined set-ups.

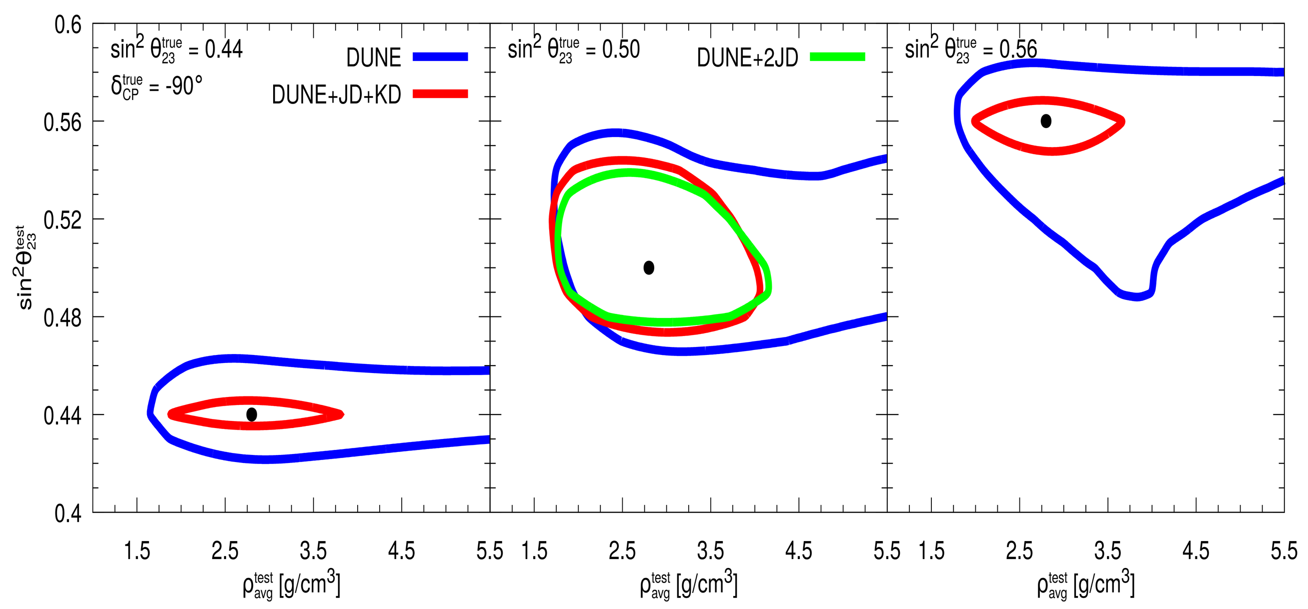


- **Precision in ρ_{avg}**
- Left panel : Relative 1σ precision in ρ_{avg} in DUNE is 15% (13%) for $\delta_{\text{CP}}^{\text{true}}$ = -90° (90°) while in DUNE + JD + KD, it is 23% for $\delta_{\text{CP}}^{\text{true}}$ = -90° with true NH.
- Right panel : If $\delta_{\text{CP}}^{\text{true}}$ = -90° /90°, DUNE is better than Solar + KamLAND [?], Super-K [?], and ongoing T2K, NOνA.
- Combined data from DUNE and T2HKK achieves the best precision.

- **Exploring the degeneracies**



Allowed region in $\rho_{\text{avg}}^{\text{test}} - \delta_{\text{CP}}^{\text{test}}$ plane at 3σ (1 d.o.f.) for four different choices of $\delta_{\text{CP}}^{\text{true}}$ in DUNE (blue), DUNE+JD+KD(red).



- Allowed region in $\rho_{\text{avg}}^{\text{test}} - \theta_{23}^{\text{test}}$ plane at 3σ (1 d.o.f.) for $\delta_{\text{CP}}^{\text{true}}$ = -90°
- Uncertainty in $\rho_{\text{avg}}^{\text{test}}$ is not much affected by choices of $\sin^2\theta_{23}$, but is significantly dependent on the uncertainty in δ_{CP}.
- Complementarity between DUNE and T2HKK helps in incredibly reducing the degenracies in both the planes.

4. KEY TAKEAWAYS

- **Irrespective of the values of oscillation parameters, DUNE establishes Earth's matter at more than 2σ C.L.**
- **Combined data from DUNE and T2HKK enhances** this measure to **more than 5σ C.L. no matter what the choices of mass ordering, δ_{CP}, and θ_{23}.**
- If in Nature, $\delta_{\text{CP}}^{\text{true}}$ = **-90°/90°**, **DUNE + T2HKK followed by DUNE outperforms Super-K, solar+KamLAND and other long-baseline (T2K and NOνA) experiments in measuring ρ_{avg}**
- **Understanding the degeneracies in ($\rho_{\text{avg}} - \delta_{\text{CP}}$) and ($\rho_{\text{avg}} - \theta_{23}$) planes are crucial to correctly assess the outcome of DUNE.**
- **Complementarity between DUNE and T2HKK data significantly minimizes dependency of ρ_{avg} on the uncertainties of δ_{CP} and θ_{23}.**

5. REFERENCES

[1] Masoom Singh *et al.* Matter effect and associated degeneracies in DUNE. *IP/BBSR/2021-1* (2021).

[2] M.Maltoni and A.Yu.Smirnov. EPJ.,A52(4):87, 2016.

[3] K.Abe *et al.* Phys.Rev., D97(7):072001, 2018

6. ACKNOWLEDGEMENT

- DST/INSPIRE Fellowship/2018/IF180059.
- SAMKHYA HPC at IOP, Bhubaneswar.
- Prof. S.Mahapatra from Utkal University for useful discussions.

European Physical Society
Conference on High Energy Physics
26-30 July, 2021