Comparing the physics capabilities of a liquid argon detector and a water based liquid scintillator at DUNE

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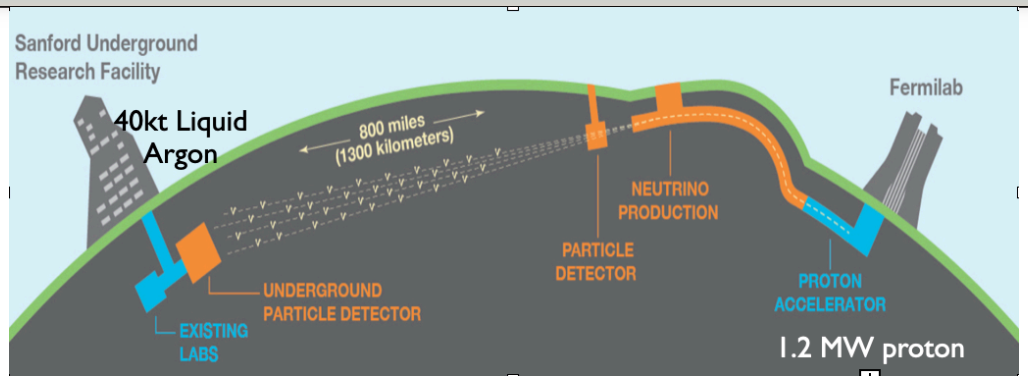
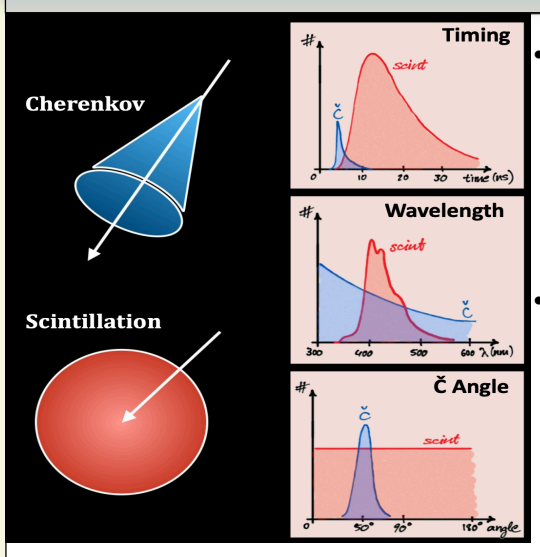
Introduction



- DUNE FD will have 4 modules of which module 1,2,3 are LArTPC
- Module 4 is under discussion, - maybe a water-based liquid scintillator (WbLS), also known as THEIA

Advantage of WbLS (THEIA)



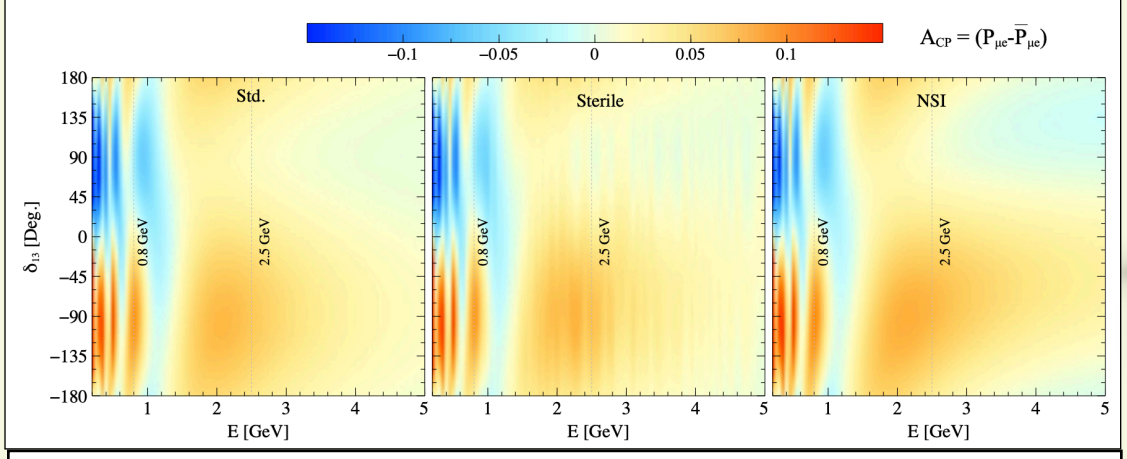
- Angular resolution due to Cherencov radiation : can identify ν from astrophysical sources and reduce background.
- Scintillation offers superior energy resolution ($\gtrsim 3\,\%/\sqrt{E}$) compared to LArTPC ($\gtrsim 15\,\%/\sqrt{E}$) : Can detect more than one oscillation cycles and probe parameters more precisely.

Probability Analysis

- $P_{\mu e} \simeq \sin\Delta\left[\sin^2 2\theta_{13}\sin^2\theta_{23}\sin\Delta + \alpha\Delta\sin 2\theta_{13}\sin 2\theta_{23}\sin 2\theta_{12}\cos(\delta_{13}+\Delta)\right]$
- Oscillation maxima: $\Delta = 1.27 \times \dfrac{\Delta m^2_{31}[\mathrm{eV}^2]L[\mathrm{km}]}{E_n^{\mathrm{OM}}[\mathrm{GeV}]} \simeq (2n-1)\dfrac{\pi}{2} \qquad (n = 1, 2..)$
- First oscillation maximum OM_1 : $E_1^{\mathrm{OM}} \simeq 2.5$ GeV

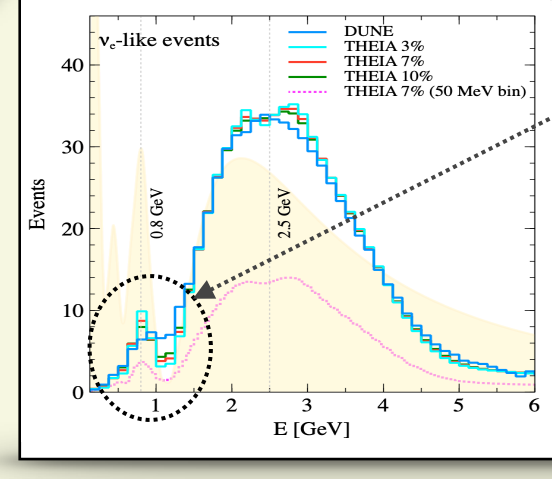
  Second oscillation maximum OM_2 : $E_2^{\mathrm{OM}} \simeq \dfrac{1}{3}E_1^{\mathrm{OM}} \simeq 0.8$ GeV
- CP asymmetry $A_{CP} = P_{\mu e} - \bar{P}_{\mu e} \simeq -2\alpha\sin 2\theta_{13}\sin 2\theta_{23}\sin 2\theta_{12}\Delta\sin^2\Delta\sin\delta_{13}$
- $A_{CP}(\mathrm{OM}_2) \simeq 3 \times A_{CP}(\mathrm{OM}_1)$

Probability asymmetry A_{CP}



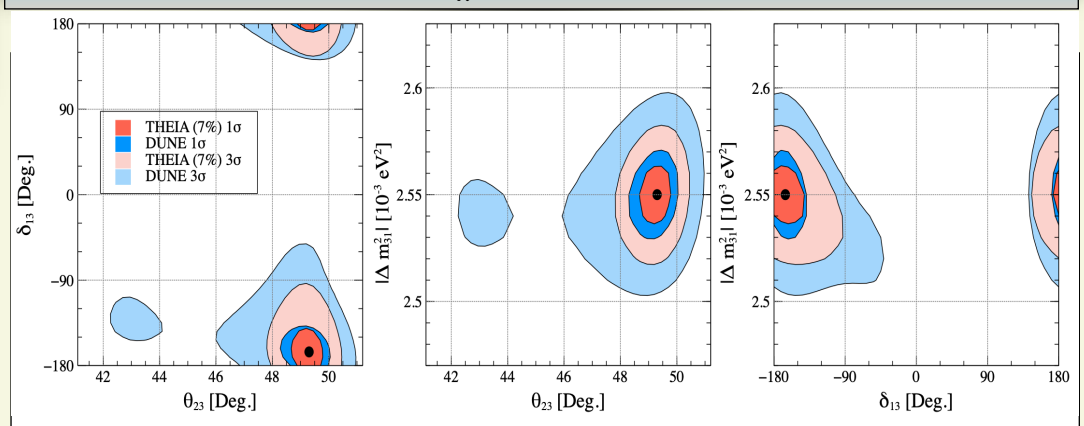
- High asymmetry at oscillation maxima
- Sterile neutrino introduces small rapid oscillations
- NSI increases the magnitude of asymmetry at higher energies

Event spectra



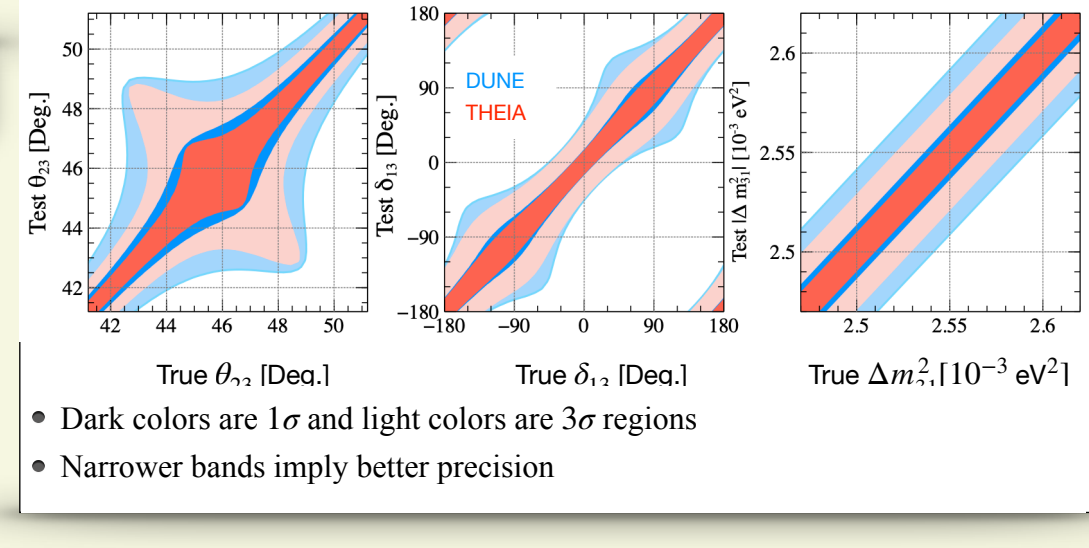
- THEIA is able to distinguish the first and second oscillation maxima more efficiently
- A smaller bin size (50 MeV, as compared to 125 MeV) can probe more substructures

$\Delta\chi^2$ contours



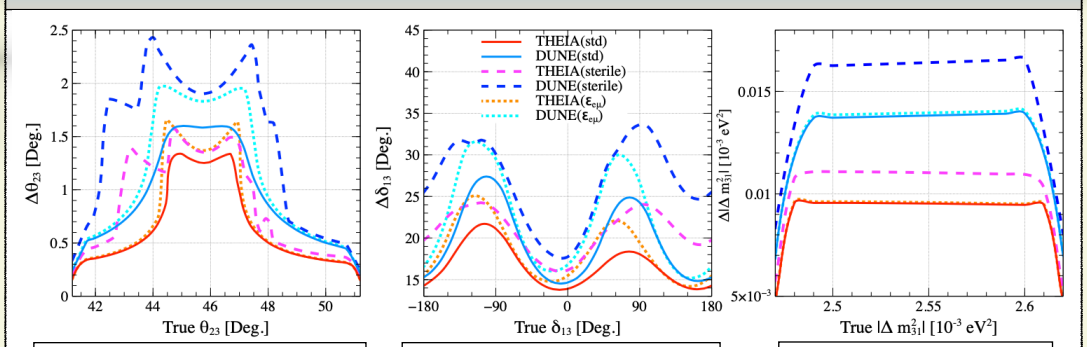
- THEIA offers significant improvement , especially at 3σ
- Lifting of θ_{23} octant degeneracy at 3σ

Parameter reconstruction



- Dark colors are 1σ and light colors are 3σ regions
- Narrower bands imply better precision

Precision (half of 1σ reconstructed interval)



- Difficult to reconstruct values close to $\theta_{23} \simeq \pi/4$
- Better precision for CP conserving values of δ_{13}
- Uniform precision for $|\Delta m^2_{31}|$

Summary

- One WbLS FD module (THEIA) can significantly exclude more parameter space than one LArTPC FD module (DUNE) due to better energy resolution and reach to second oscillation maximum
- The precision in reconstructing the oscillation parameters gets improved for THEIA
- Finally, there is less distortion in parameter precision at THEIA with new physics