High-energy physics program in THEIA

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Introduction

* The THEIA collaboration
* How does WbLS contribute to the THEIA high energy program?
* Long-baseline physics in THEIA
* THEIA and nucleon decay
* THEIA contributions to atmospheric neutrino measurements

The THEIA collaboration

* A large international effort
* Over 80 collaborators
* 10 countries
* 38 institutions
* Offers an exciting expansion to the high-energy neutrino community

What is WbLS?

* Water-based liquid scintillator (WbLS) is an aggregation of water and oil based liquid scintillator.

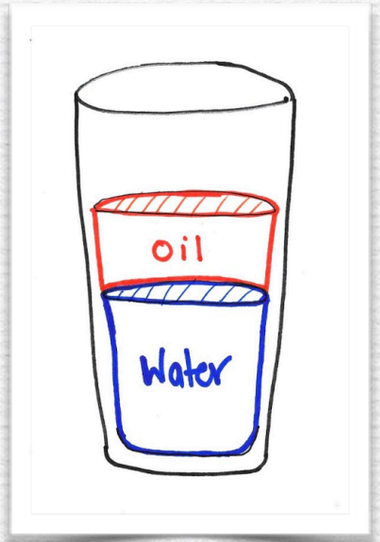
* The idea is to create a novel detector medium which achieves the benefits of both water Cherenkov detection and liquid scintillator detection.

* Produce "micelles" in which the liquid scintillator, such as PPO-doped LAB, droplets are surrounded by a surfactant.

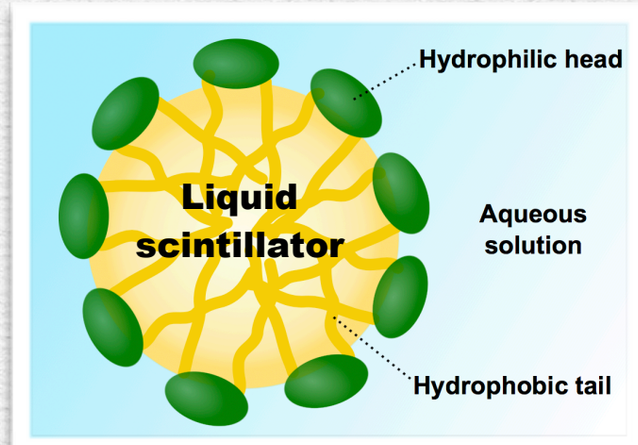
* The surfactant's hydrophilic head acts as a barrier that is "in contact" with the water, whilst its hydrophobic tail is sequestered within the scintillator medium.

* This allows the liquid scintillator micelles to homogenise throughout the water.

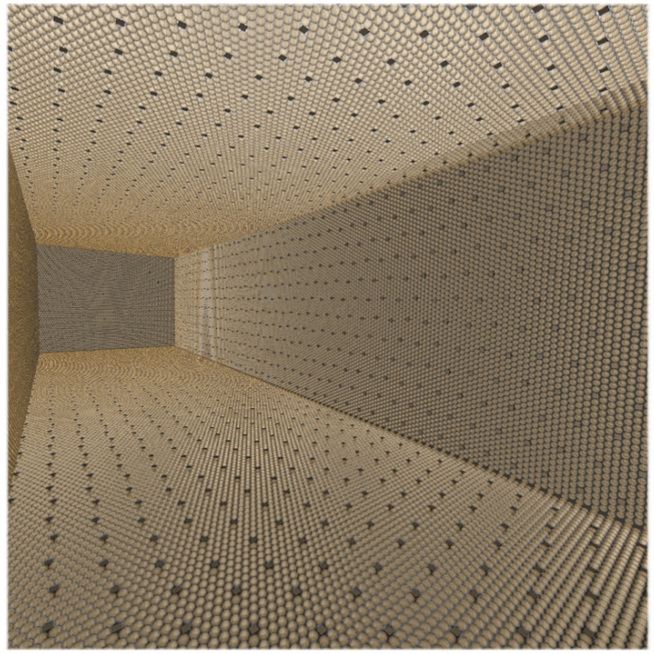
* This innovative detection medium has the capability to further enhance next-generation neutrino experimentation.



Combining liquid scintillators and water is non-trivial, an innovative approach is needed.

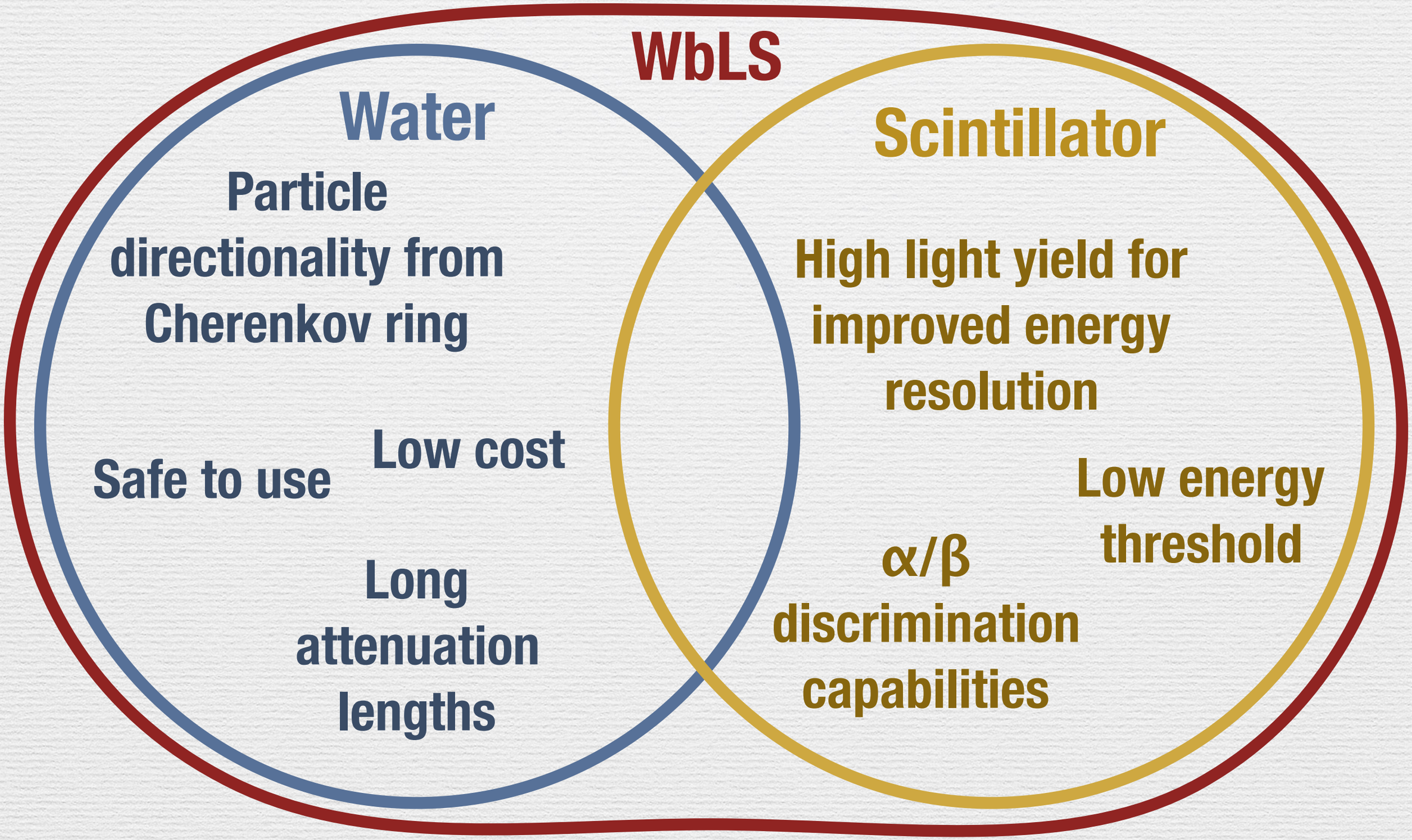


WbLS uses surfactants to form nm-scale micelles of liquid scintillator, such that a suspension can be formed.



THEIA25 visualization using Chroma

How will WbLS help the high-energy neutrino effort?



What is THEIA?

- THEIA25 is a proposed 25kTon experiment designed to fit alongside the DUNE far detectors

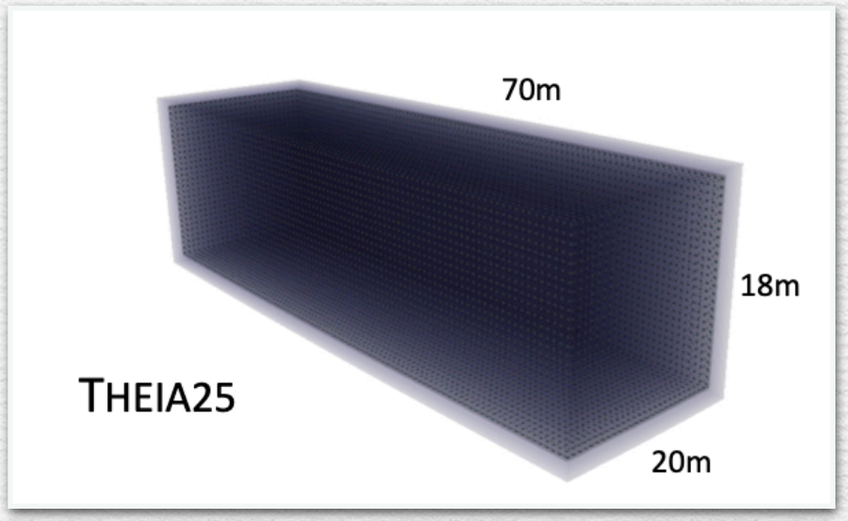
- THEIA is an ambitious 100kTon upgrade to this idea

- Will use novel fast photosensors

- Employ photon sorting techniques

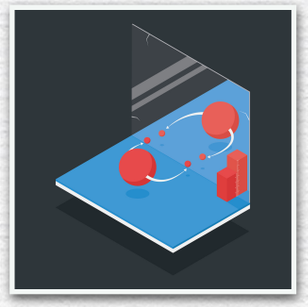
- The unique WbLS nature allows for energies from MeV to GeV to be explored

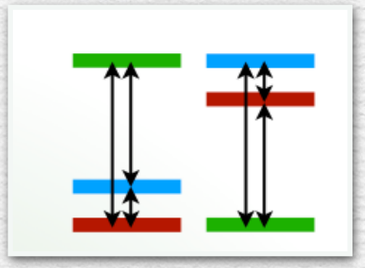
- This will make THEIA arguably the most far-reaching neutrino experiment ever built



The preliminary THEIA design has a 70kTon fiducial volume

Unresolved issues in long-baseline physics





* What value does δ take?
* What is the neutrino mass hierarchy?
* What octant does θ_{23} lie in?
* PMNS parameter degeneracy makes these questions challenging to resolve.

* However, THEIA is well equipped to elucidate the answers.

$$
\begin{aligned}
P(\nu_\mu \to \nu_e) = \; & 4C_{13}^2 S_{13}^2 S_{23}^2 \sin^2\Phi_{31}\left(1 + \frac{2a}{\Delta m_{31}^2}(1 - 2S_{13}^2)\right) \\
& + 8C_{13}^2 S_{12} S_{13} S_{23}(C_{12}C_{23}\cos\delta_{CP} - S_{12}S_{13}S_{23})\cos\Phi_{32}\sin\Phi_{31}\sin\Phi_{21} \\
& - 8C_{13}^2 C_{12} C_{23} S_{12} S_{13} S_{23}\sin\delta_{CP}\sin\Phi_{32}\sin\Phi_{31}\sin\Phi_{21} \\
& + 4S_{12}^2 C_{13}^2 (C_{12}^2 C_{23}^2 + S_{12}^2 S_{23}^2 S_{13}^2 - 2C_{12}C_{23}S_{12}S_{23}S_{13}\cos\delta_{CP})\sin^2\Phi_{21} \\
& - 8C_{13}^2 S_{13}^2 S_{23}^2 (1 - 2S_{13}^2)\frac{aL}{4E_\nu}\cos\Phi_{32}\sin\Phi_{31},
\end{aligned}
$$

Matter effect

CP violating phase

$$\phi_{ji} = \Delta m_{ji}^2 L/4E_\nu$$

$$a \equiv 2\sqrt{2}G_F n_e E_\nu = 7.56 \times 10^{-5}[eV^2]\left(\frac{\rho}{[g/cm^3]}\right)\left(\frac{E_\nu}{[GeV]}\right)$$

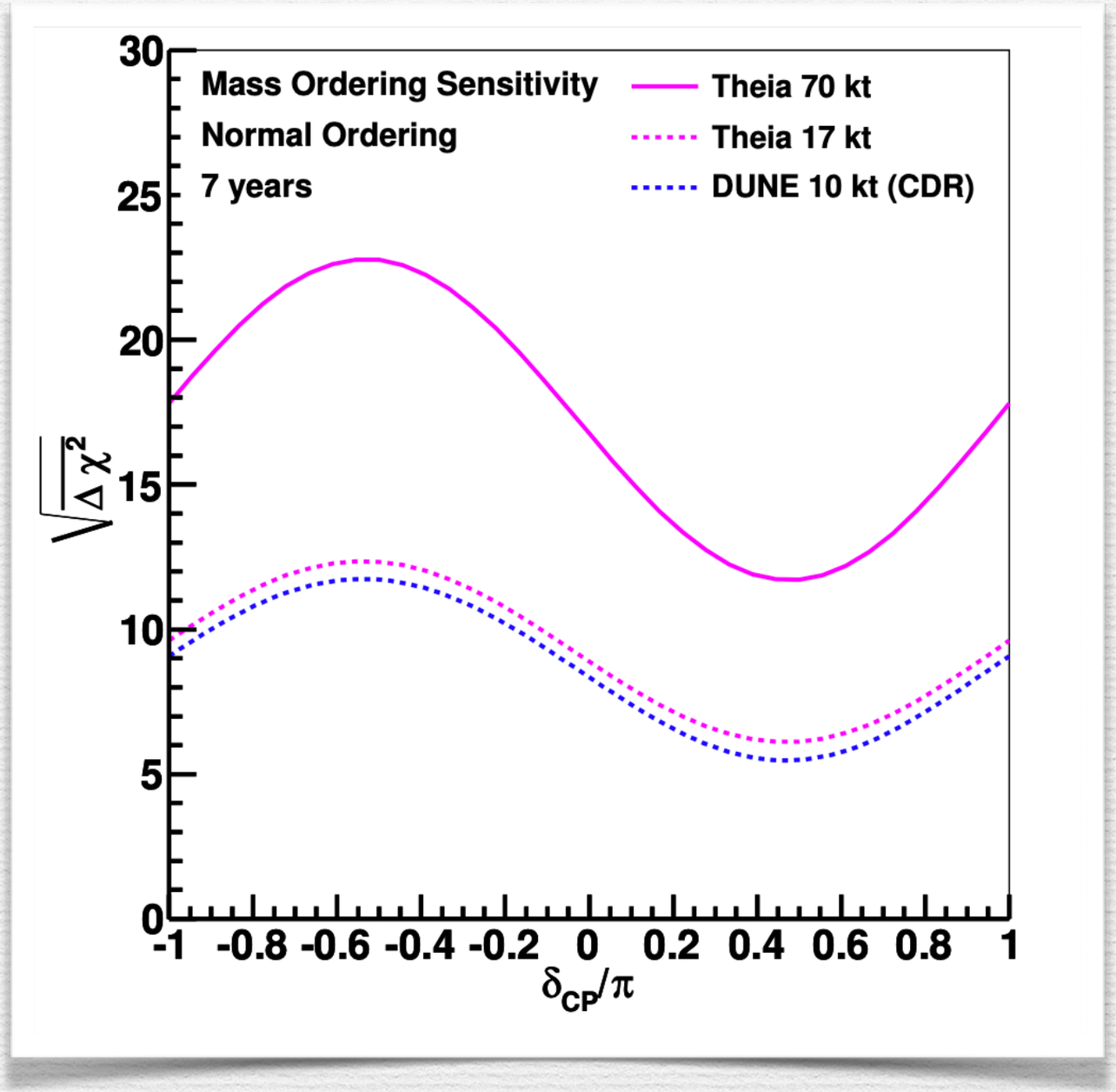
THEIA will achieve a mass hierarchy determination within 7 years

* A simple water target in THEIA, located in the LBNF beam, can achieve a 5σ mass hierarchy determination

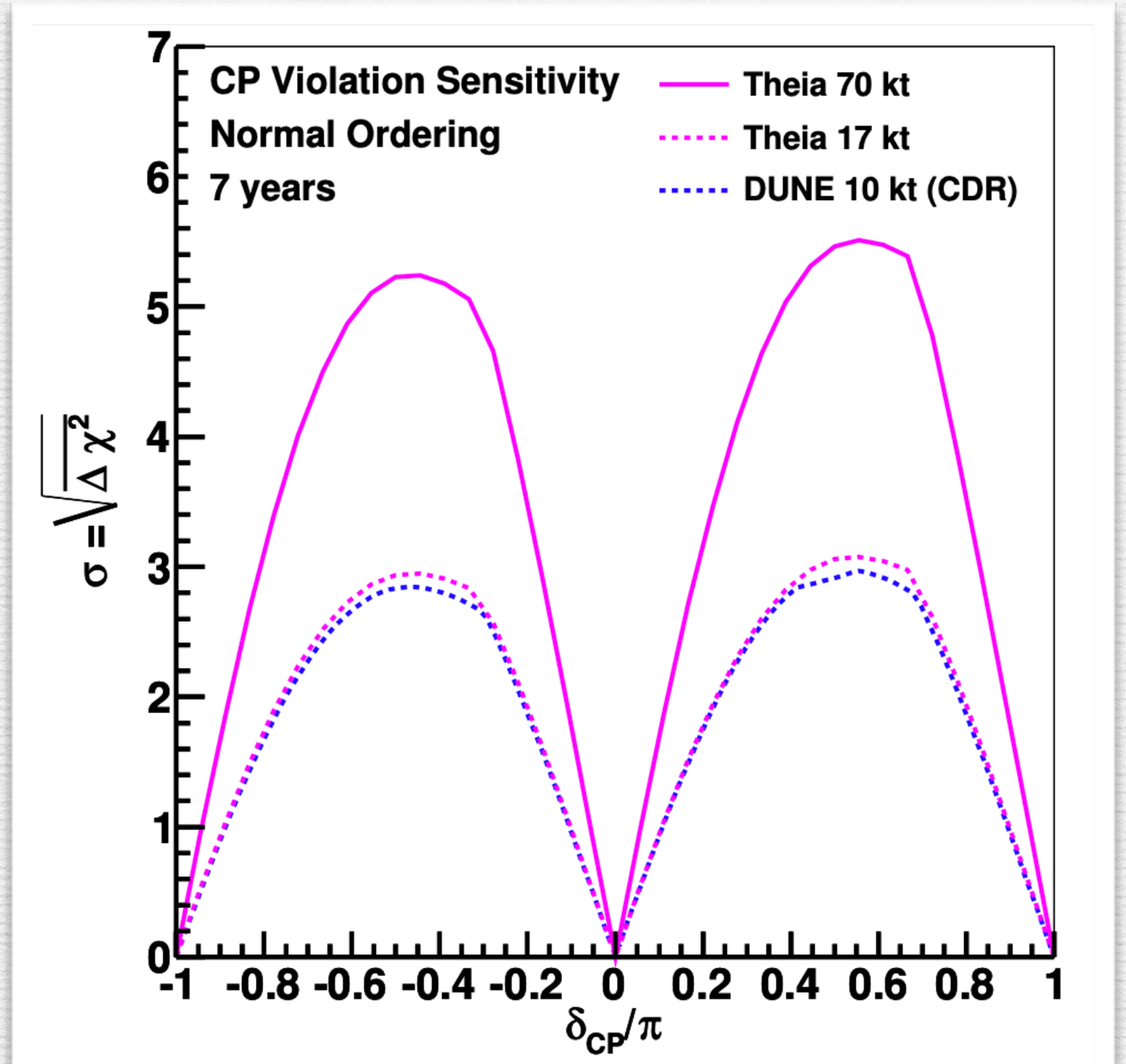
* This is due to recent vast improvements in NC background rejection, e/μ particle identification and multi-ring event utilization.

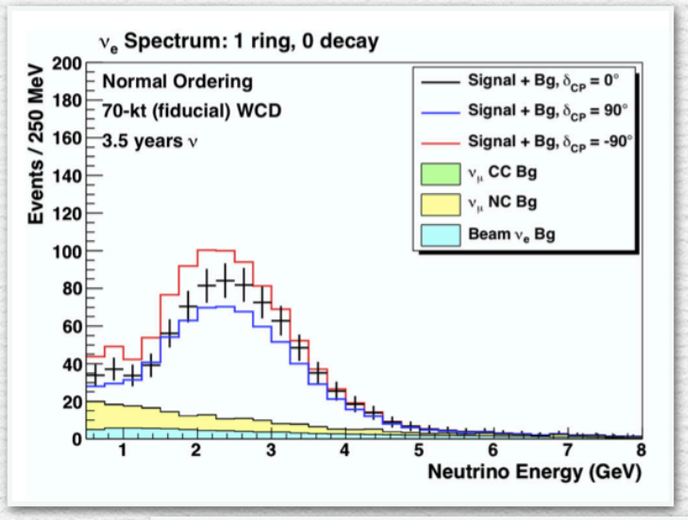
* Analysis here uses a 9-sample likelihood fit with identical beam related systematics as presented in the DUNE CDR.

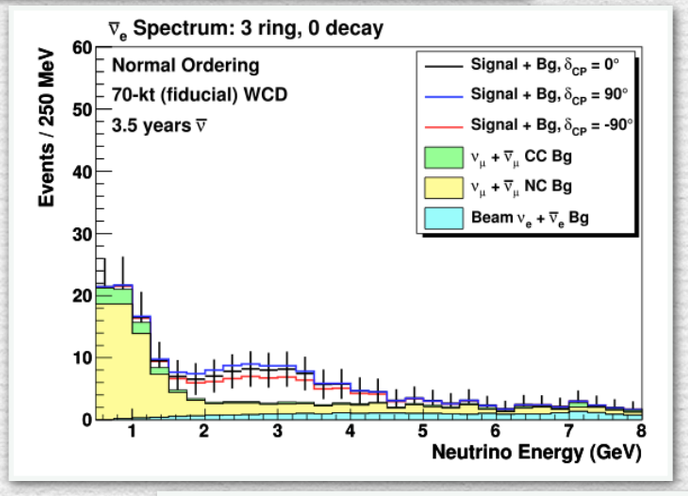
* However, organic loading, with novel photon sorting techniques developed by THEIA collaborators will further improve efficiency, purity and PID!

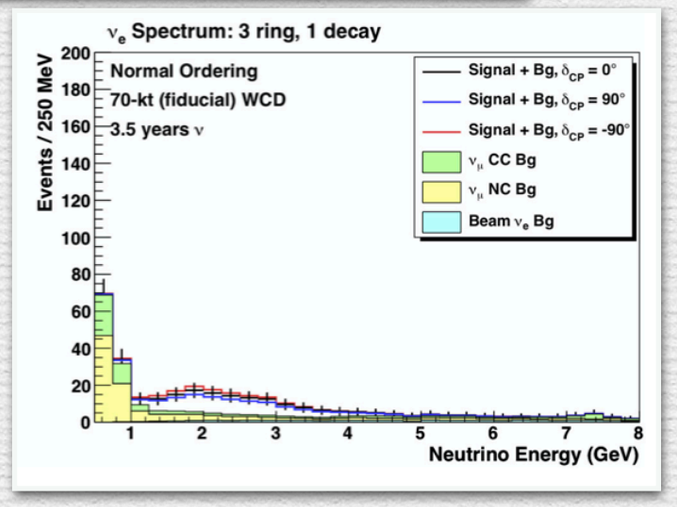


THEIA 100 has the capability to reach a 5σ CPV determination



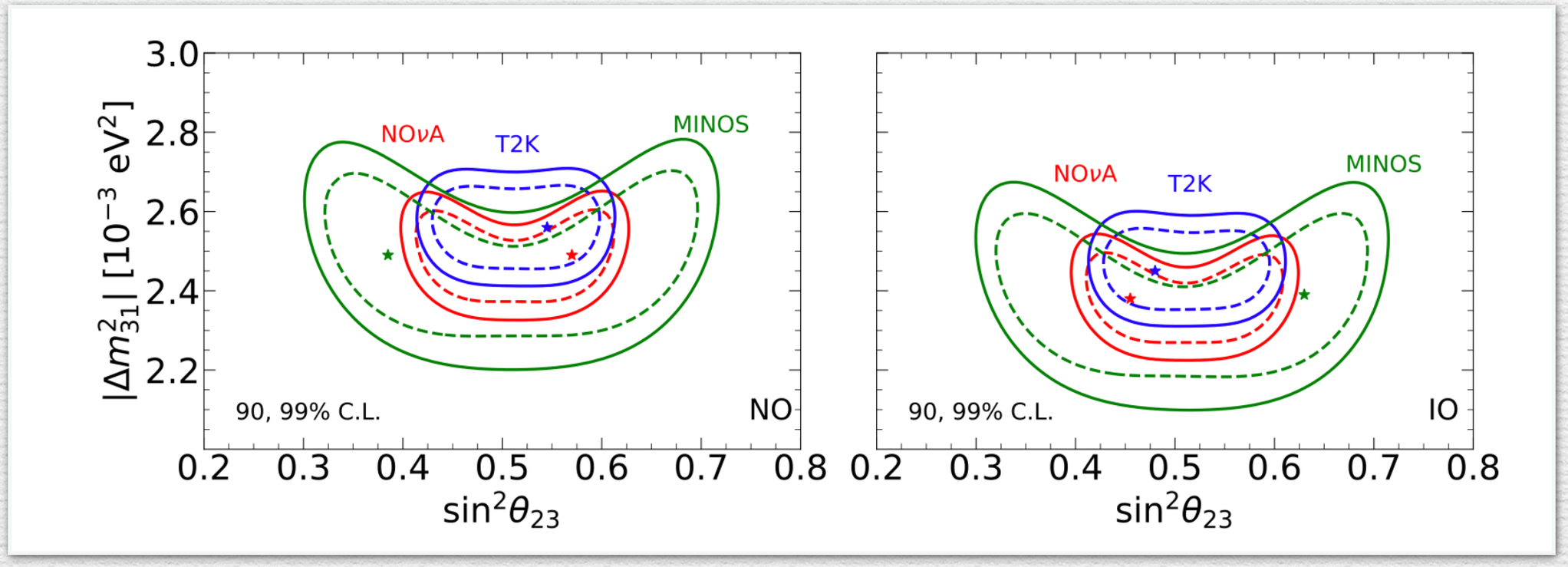






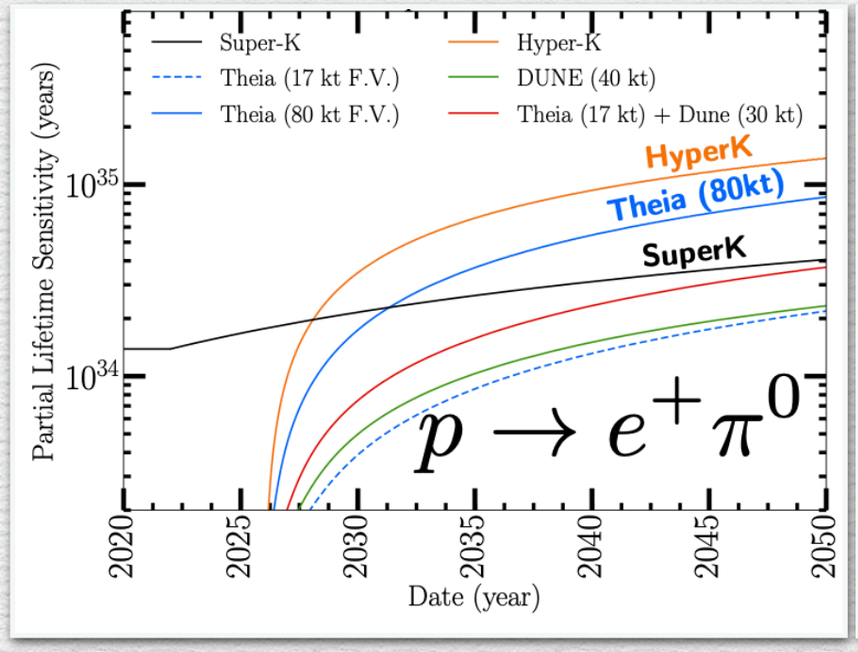
THEIA can add to existing θ_{23} long-baseline data sets

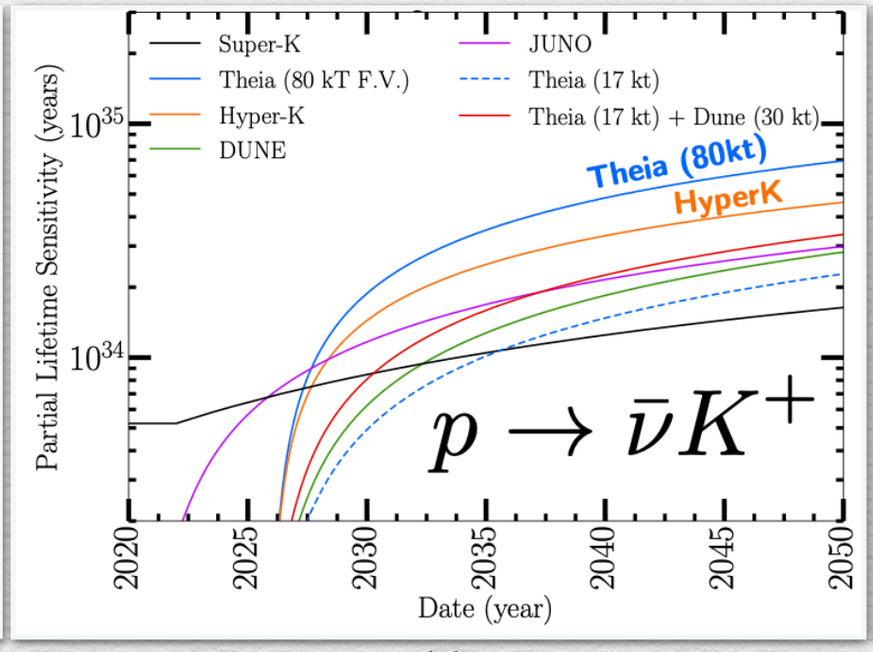
* Using the ν_μ disappearance channel, THEIA will contribute to the global θ_{23} data set
* Will provide different systematic uncertainties to T2K, NOVA and MINOS
* Furthermore, by introducing atmospheric neutrino data into the fit, THEIA can help to break the octant degeneracy associated with long-baseline measurements

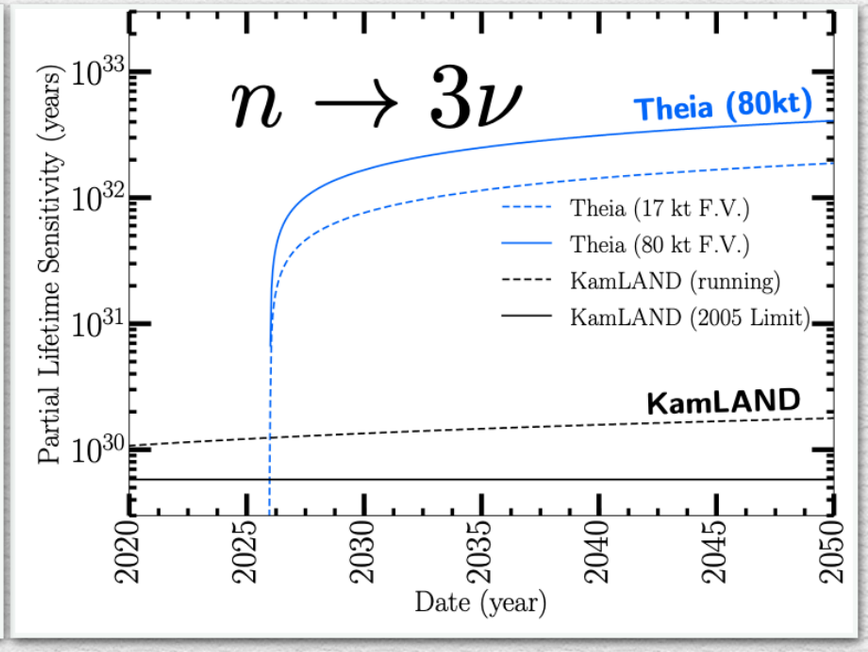


THEIA will be a world leading nucleon decay experiment

- Due to WbLS's scintillation and Cherenkov emission properties, THEIA will have unique advantages compared to existing and future nucleon decay detectors
- For modes in which low-thresholds are not essential, such as $p \rightarrow e^+ + \pi^0$, THEIA will perform comparably to water Cherenkov detectors.
- For modes with below Cherenkov threshold mesons, such as $p \rightarrow \tilde{\nu} + K^+$, THEIA is able to perform coincidence tagging.
- For modes with invisible decays, such as $n \rightarrow 3\nu$, due to its huge volume, low energy threshold, and depth, THEIA will far exceed all other experiments.

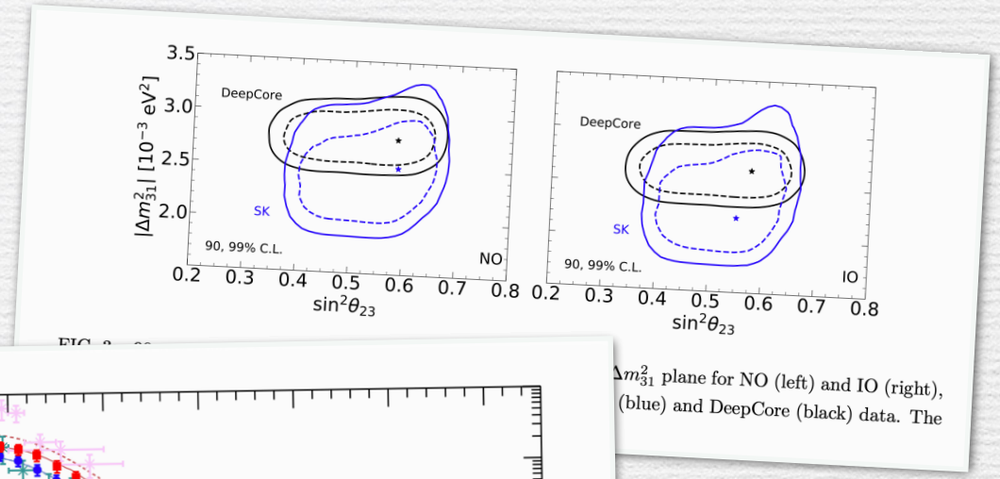


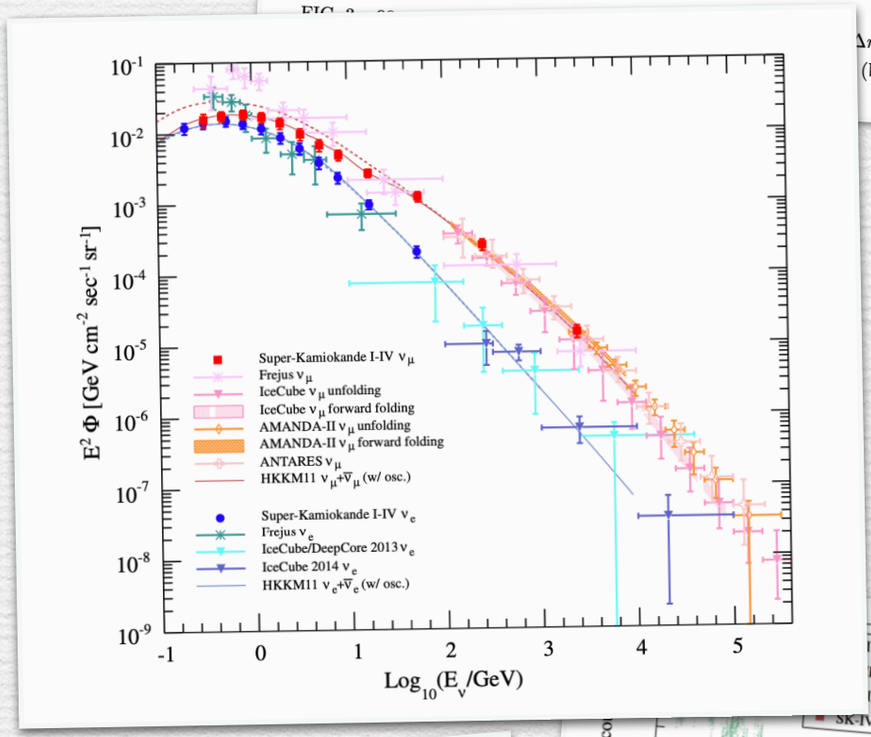


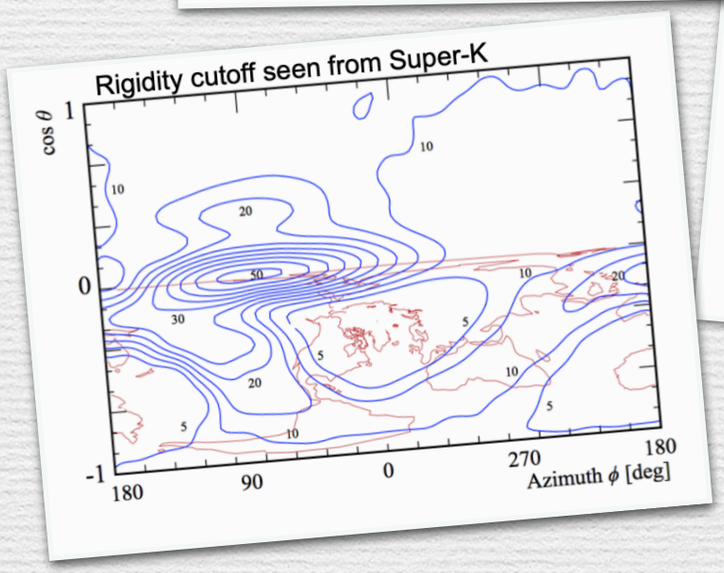


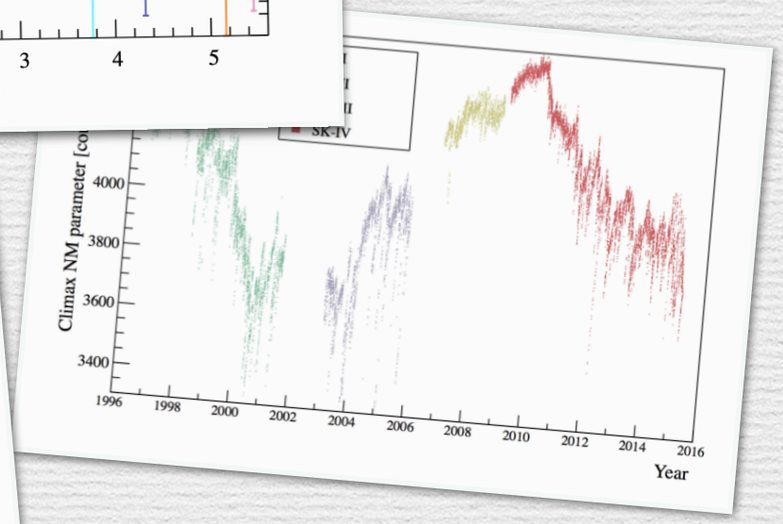
A brief look at atmospheric neutrinos…

- Due to earth matter effects for atmospheric neutrino events, combining with accelerator data helps to break the θ_{23} octant degeneracy
- Many more potential contributions to the field…
- East-west geomagnetic effect?
- Solar wind modulation?
- Absolute flux determination?









Conclusions

- THEIA is a proposed 100kTon experiment with the capability to become the most far-reaching neutrino experiment ever built
- By deploying a novel WbLS volume, THEIA will benefit from both Cherenkov and scintillation emission
- This unique target will greatly benefit the long-baseline effort, culminating in a possible 5σ CPV measurement
- THEIA will also excel as a nucleon decay detector, with the ability to produce world-leading measurements in challenging decay modes
- Furthermore, THEIA can probe atmospheric neutrinos, providing valuable data to the community
- For the extensive low-energy physics program of THEIA, see Zara Bagdasarian's talk!