DUNE'S SENSITIVITY TO SOLAR NEUTRINOS

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Outline

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- Solar Neutrino Analysis:
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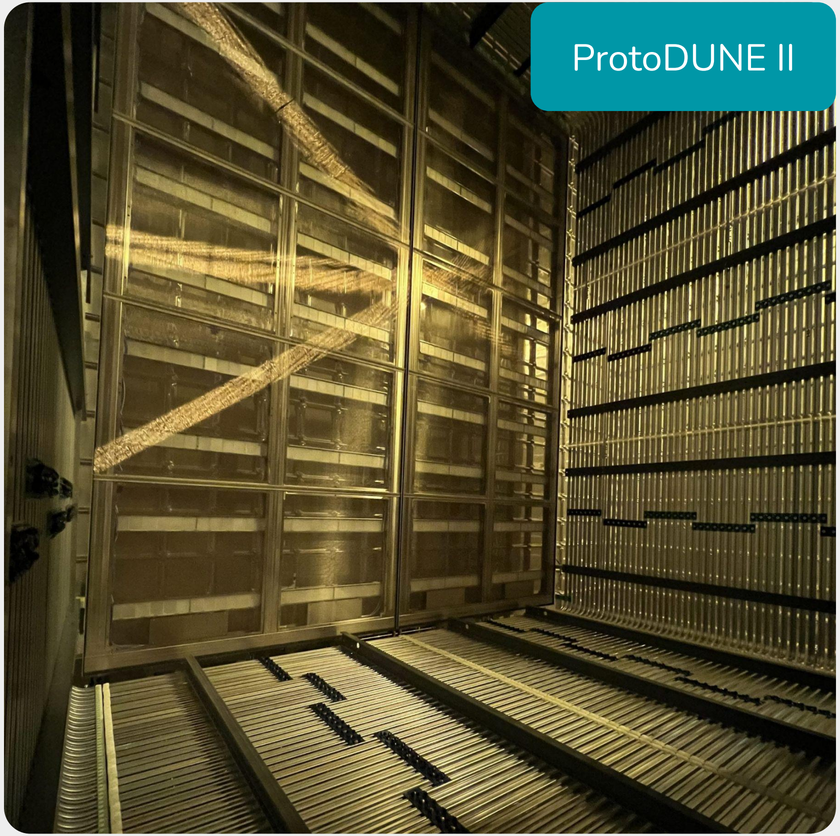
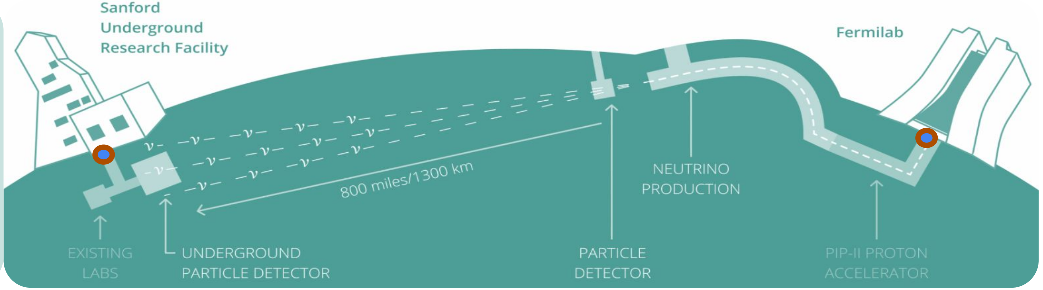
  - Theoretical Computation
  - Experimental Reconstruction
  - Sensitivity
- Summary



DUNE (Deep Underground Neutrino Experiment)

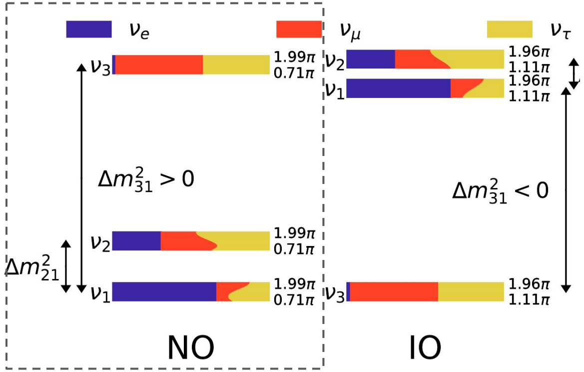


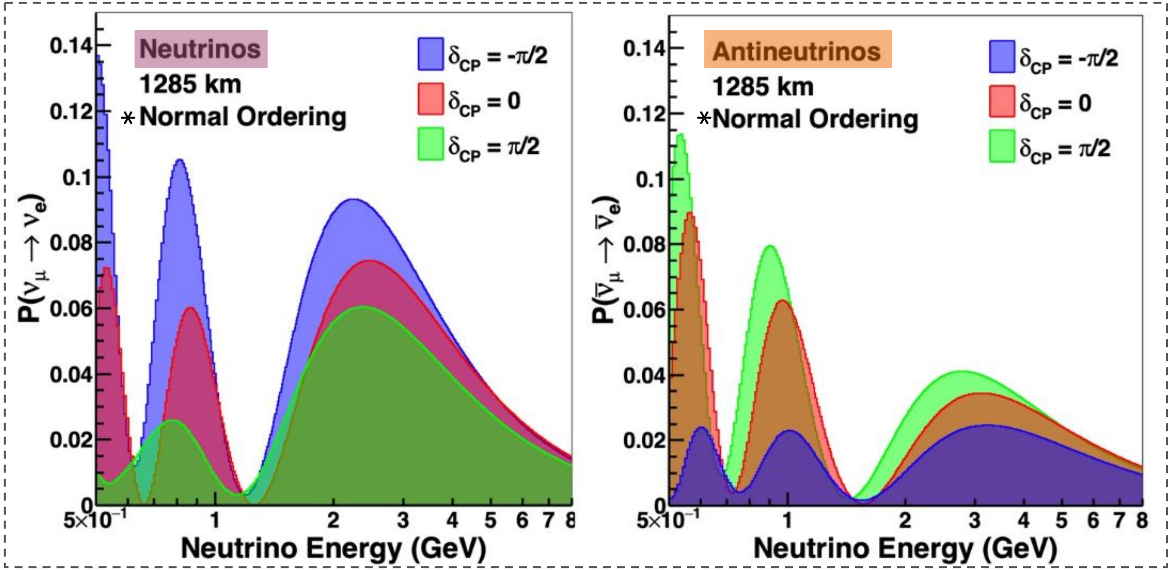
- High purity $\nu_\mu/\bar{\nu}_\mu$ beam (0.5 – 7GeV): ~1.2MW (upgradable to 2.4MW).
- Dual-site experiment with main focus on precise ν oscillation measurement (including CP violation & mass hierarchy determination).
- Near Site Facility: multi-technology to measure unoscillated neutrino flux.
- 4 Far Detectors: total mass of ~ 70 kT.
- Additionally, DUNE aims to explore: BSM physics, supernova detection, Solar Neutrinos…

DUNE Main Analysis

- 3 Flavor paradigm? → Measure **neutrino** and **antineutrino** oscillation as a function of L/E.

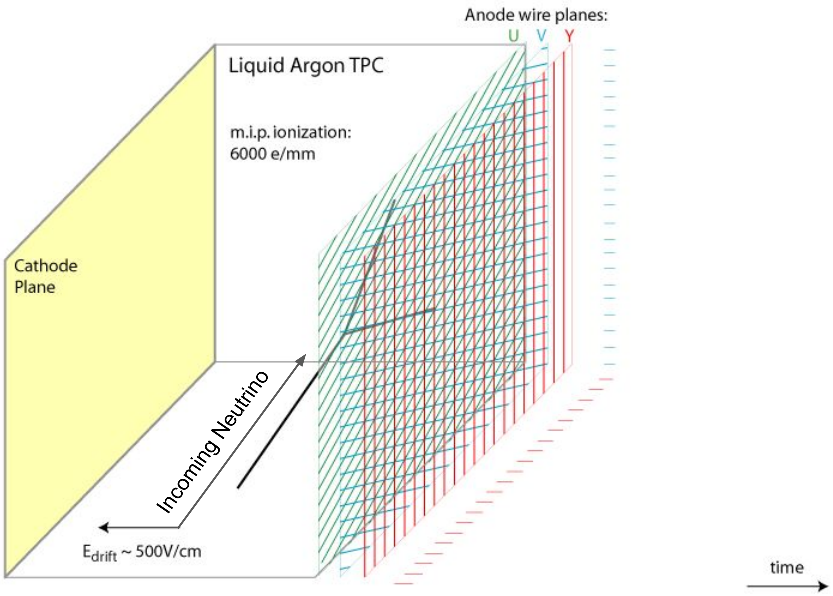
2 Possible scenarios:



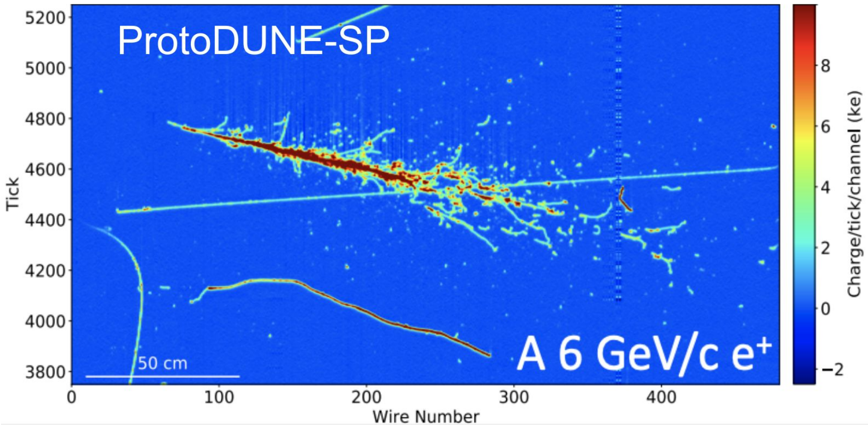


*Equivalent analysis can be performed for the inverted hierarchy scenario.

Liquid Argon Time Projection Chambers (LArTPC)



- 1.4 · water density: ionization yield (**42k e⁻/MeV**).
- Electrons drift (~m/ms) to anode wire planes (APA)
- Argon scintillation light (**40k γ/MeV**) @128nm collected by PDS, providing t_0 for non-beam physics.
- **Excellent 3D reconstruction**, dE/dx & particle id.

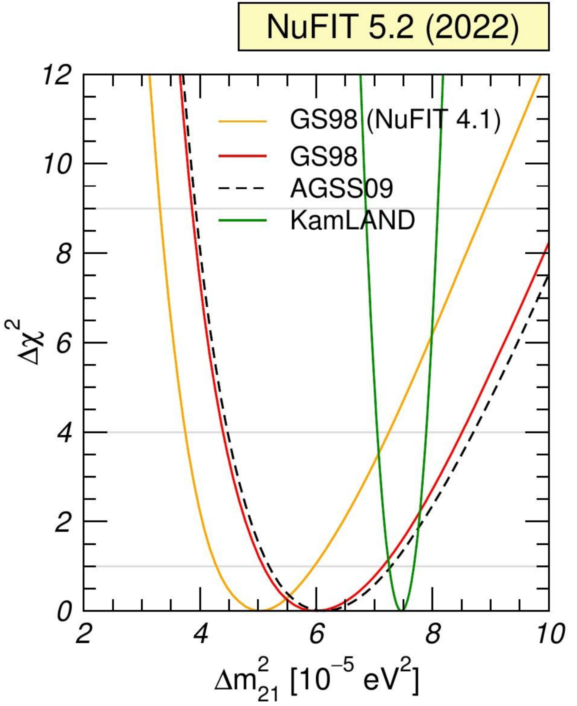


- In DUNE additional PDS integrated for t_0, improved trigger, calorimetry & event reconstruction.

Solar Neutrino Analysis

Motivation

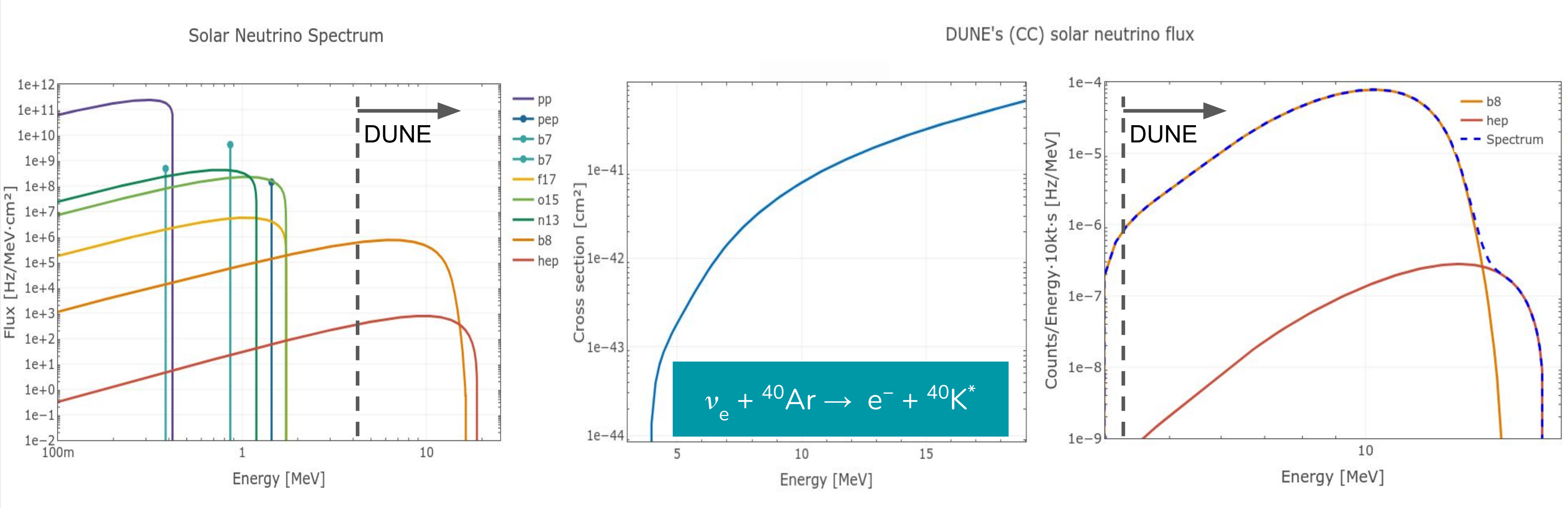
- Due to its **high mass**, great exposure to CC solar neutrinos ~170k per 70 kT · year.
- From **solar neutrinos** measure oscillation parameters (e.g. $\sin^2\Theta_{12}$) best constrained by its differential flux.
- Currently, existing tension between measurement of Δm^2_{21} wrt. nuclear reactor experiments.
- DUNE has the potential of **measuring Δm^2_{21}** from "wiggles" in the oscillation probability of detected C.C. neutrinos.
- DUNE will measure the **hep component** of the solar spectrum (first time), providing valuable contribution to solar modeling.



Theoretical Computation

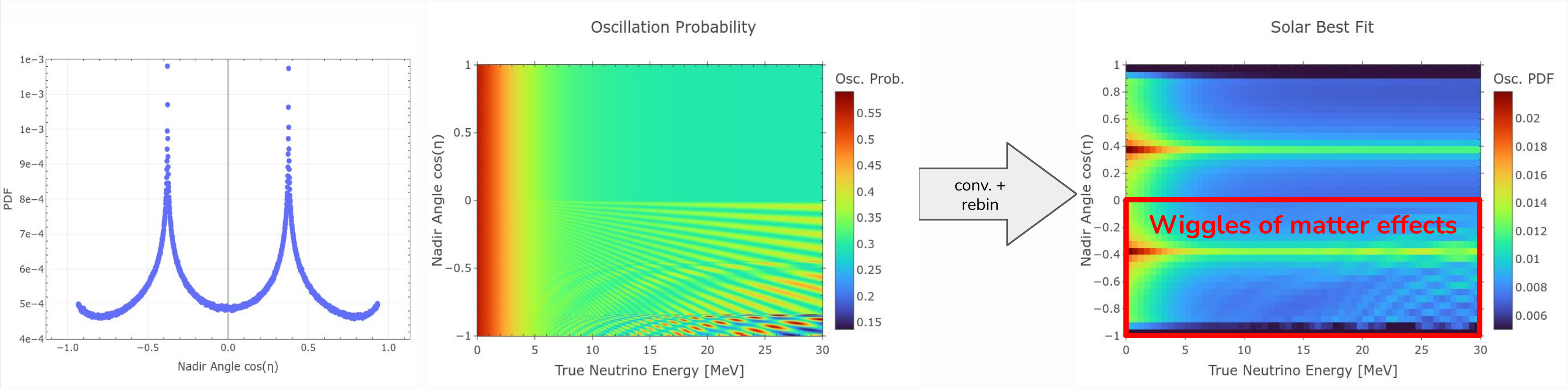
Solar NuE Analysis: Solar Neutrino Flux

- Calculated from BS2005 model and **X-Section** (Marley) → **DUNE's solar neutrino interactions**



- Solar analysis requires good background estimation around **10 MeV**, energy **resolution > 10%** & adequate preselection and **trigger conditions**.

Solar NuE Analysis: Neutrino Oscillations



- **Oscillation probability:**
  ν_e oscillate (main channel for solar C.C. $\nu_e + {}^{40}Ar$).
- Convolve SURF's geographical solar incidence angle & ν_e oscillation probability from [theo. calculation.]()
  → **Wiggles produced by matter effects** clearly detectable in 2D space representing ideal oscillation signal.

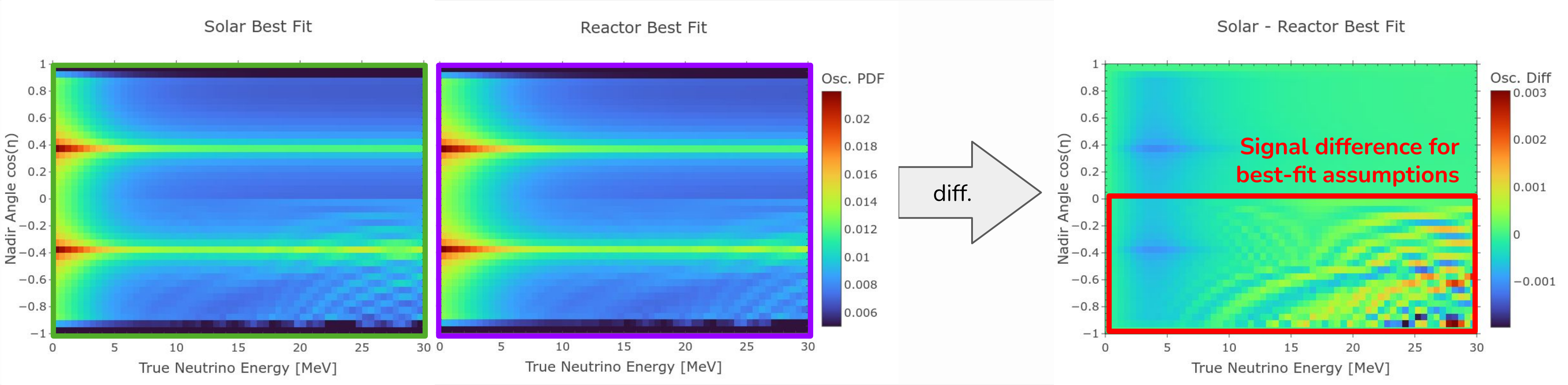
Accounting for oscillations:

- **170k Counts / 70 kT · year**
- 8B → 169k.
- hep → 840.

Expected > 20 years exposure.

Solar NuE Analysis: Neutrino Sensitivity

Goal → Compute DUNE's sensitivity to oscillation parameters from fake data accounting for backgrounds and event reconstruction capabilities:



Log-likelihood computation provides best fitting potential between theoretical assumptions.

- Solar (SNO): Δm^2_{21} = 6.0e^{-5}eV^2, $\sin^2\Theta_{12}$= 3,03e-1, $\sin^2\Theta_{13}$= 2,1e-2
- Reactor (KamLAND): Δm^2_{21} = 7.4e^{-5}eV^2, $\sin^2\Theta_{12}$= 3,03e-1, $\sin^2\Theta_{13}$= 2,1e-2

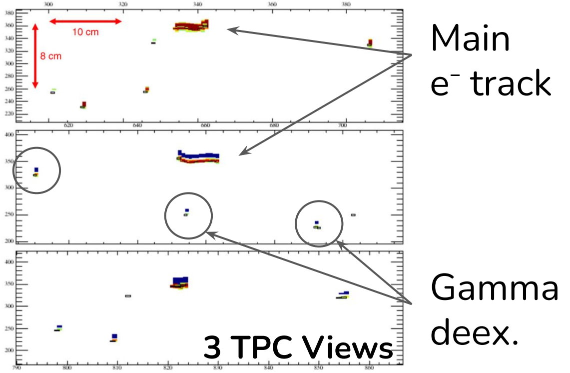
Experimental Reconstruction

Solar Neutrino Signal

$\nu_e + {}^{40}\text{Ar} \rightarrow e^- + {}^{40}\text{K}^* \rightarrow {}^{40}\text{K} + \gamma\ (+ \text{N}^*\gamma)$

- LARSOFT simulation → Solar Neutrino Spectrum (4 - 30MeV).
- **PDS Hits** (photons) collected into flashes → vertex reco (X).
- **TPC Hits** (collected io. electrons) @ APA → vertex (Y, Z).
- Hits **grouped in Clusters** according to time & wire proximity
- **Event definition:**
  → **Clusters (+3 hits)** from **collection + induction plane coincidence & PDS flash-matching**.

ν_eCC event (20.25 MeV)



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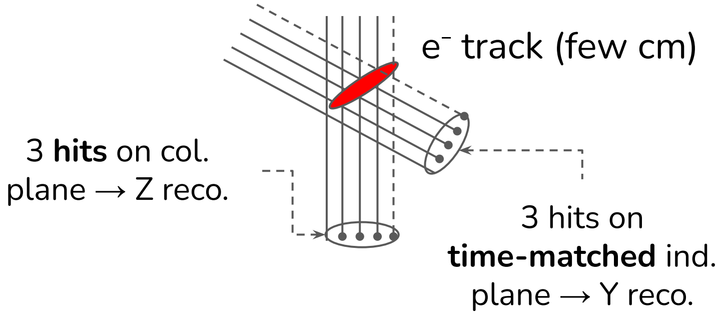


3D Event Topology

Adj. cluster info for event reco and bkg rejection:

- Collect adjacent clusters (**gamma blip** candidates).
- Collect PDS **flashes** for additional particle id.

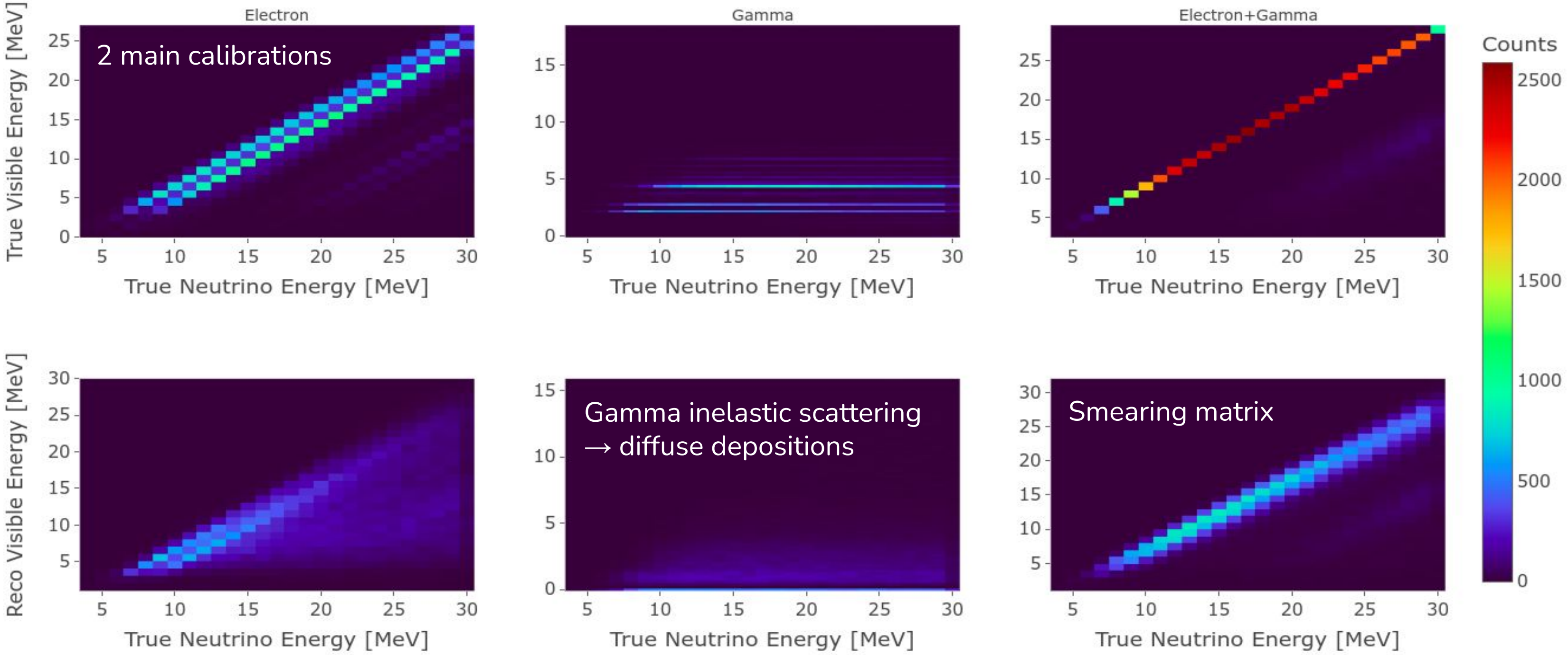
Energy Reconstruction

$\nu_e + {}^{40}Ar \rightarrow e^- + {}^{40}K^* \rightarrow {}^{40}K + \gamma \ (+ N^*\gamma)$

- Basic strategy: **MainCl + AdjCl energy.** Alternatively, **reco ν_e Energy** from e^- + offset.

Truth

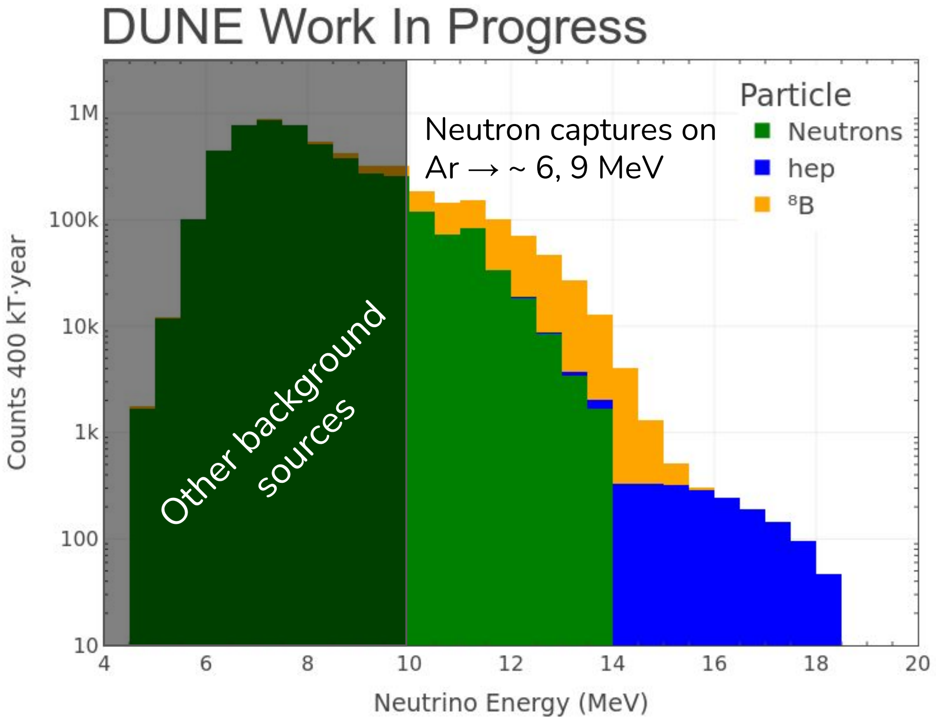
Reco



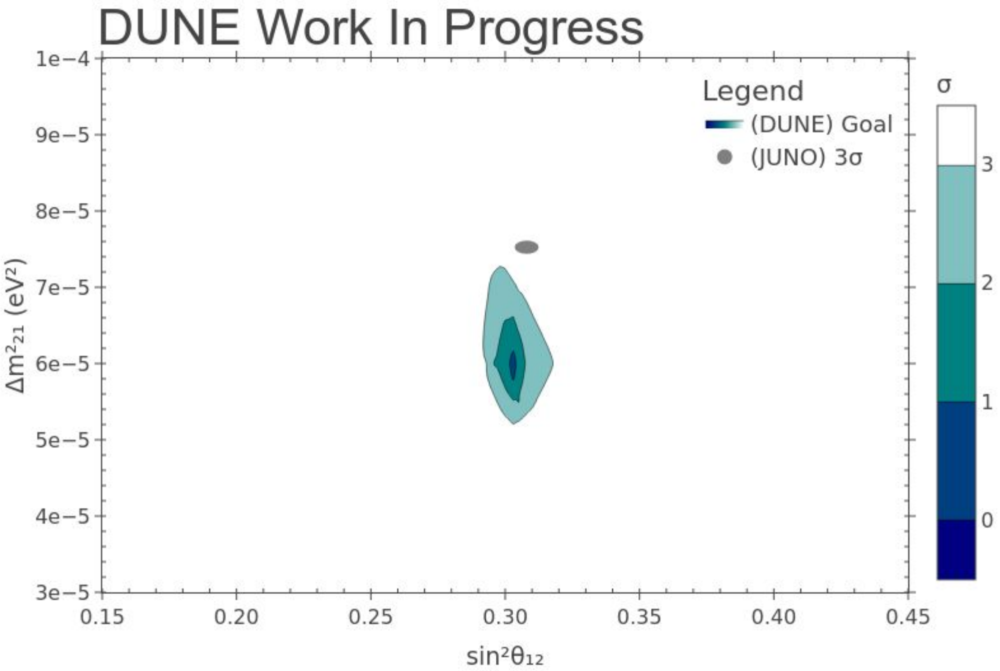
Sensitivity

Reconstructed Energy Spectrum

- Event candidates filtered to achieve **clean neutrino sample**.
- Select primary clusters (charge > adj. cluster charge) & **fidutialize to remove cavern-bkg** contamination.
- Requiring **associated signal-like optical flash** ensures reconstruction accuracy.



Sensitivity Curves



- Estimated using ideal PDS and TPC matching for charge reconstruction.
- Floating uncertainty values of 4 and 2% for signal and background respectively.
- If the **tension** previously presented reveals true physics, DUNE and JUNO (next gen) would show **> 3 σ separation**.

Summary

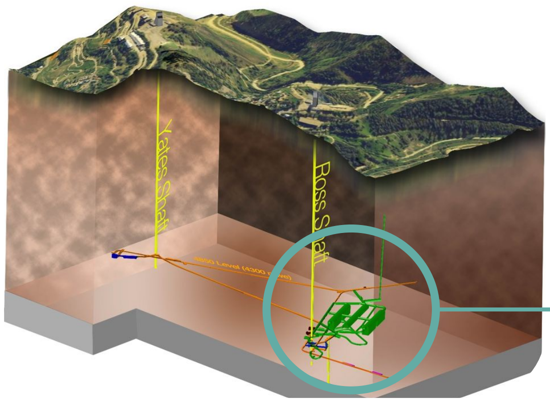
Summary

- DUNE will have great exposure to solar neutrinos, **measuring Δm^2_{21}** from wiggles in the oscillation map and the hep flux.
- Preliminary analysis shows DUNE's energy **reconstruction capabilities** and background rejection in the ROI for solar neutrinos.
- Currently, working on updated bkg rejection and flash-matching.
- **Stay tuned for new data & analyses!**

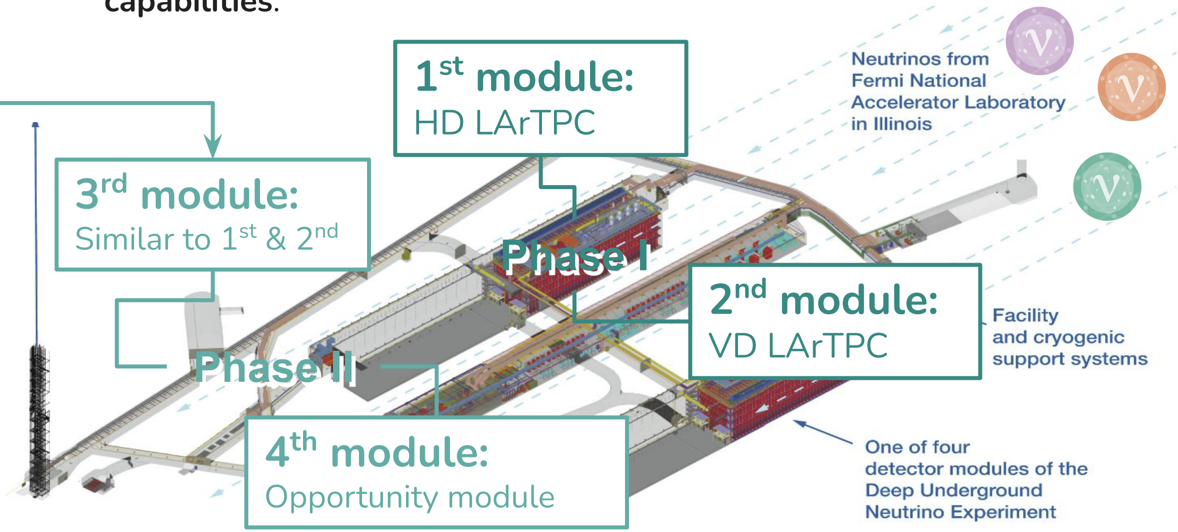
Stay tuned!
Upcoming data.

Thank you for your attention!

DUNE Far Detector Facilities



- Far detectors located 1.5 km underground at SURF.
- Phase I (**first data late 2020s!**):
  FD-1 horizontal drift (HD) / FD-2 vertical drift (VD).
- Phase II: Possibility of a module for low energy with **enhanced physics capabilities**.



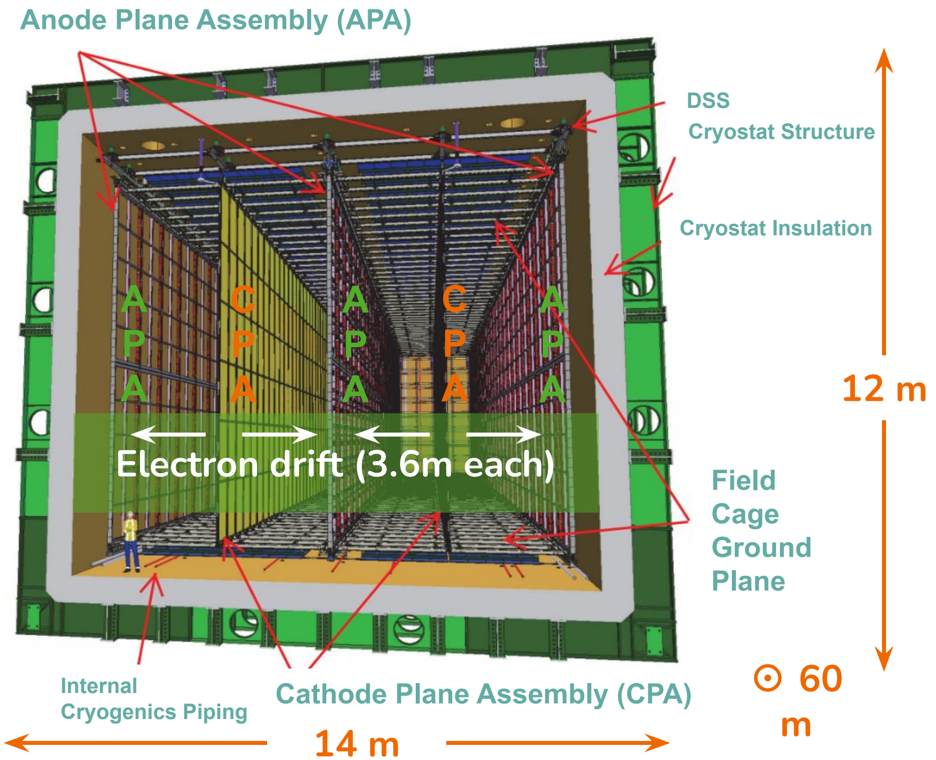
1st Module: HD LArTPC

- **Cryogenic** system (-184°C) for 17kt LAr.

- TPC **charge readout system**:
    - Electric field (~500V/cm) for 3.6m drift.
    - 150 APAs (6x2.3m²), 200 CPAs.
    - 3 view charge collection (pitch 5mm).
    - 384000 readout channels.

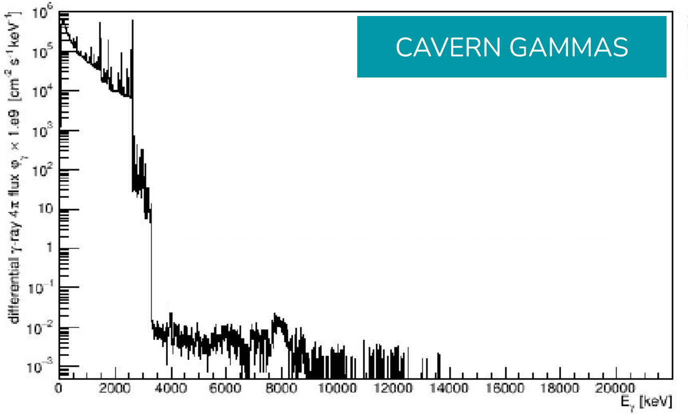
- PDS (**Photon Detection System**) Integrated in the APAs.

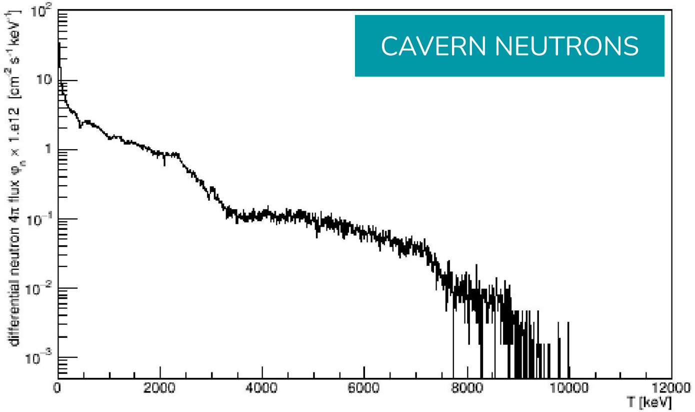
- Technology tested at CERN with **ProtoDUNE** (~8x8x8m³) with full size components.



Background Model

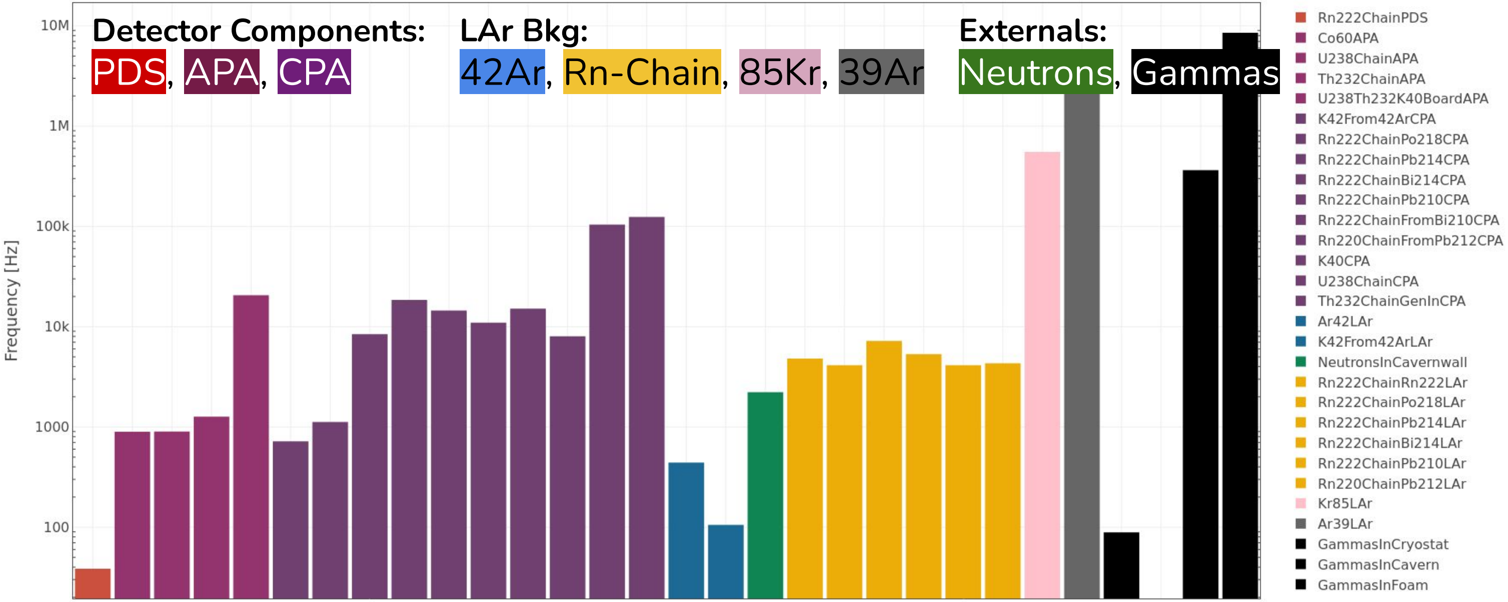
- **Updated** bkg. from **radioassays**.
- LAr:
  - **^{39}Ar & ^{85}Kr (10 MHz, ~500 keV)**
  - ^{42}Ar, ^{42}K, ^{222}Rn chain ($^{214/212/210}$Pb, ^{214}Bi, ^{218}Bi).
- HD internal contributions (inside cryostat).
  - **CPA:** ^{42}K, ^{40}K, ^{238}U chain, ^{232}Th chain, ^{222}Rn chain and ^{222}Rn chain (from ^{212}Pb, ^{210}Bi).
  - APA: ^{60}Co, ^{40}K (boards), ^{238}U chain, ^{232}Th chain.
  - PDS: ^{222}Rn chain.
- External contributions (standalone propagation):
  - **Gammas (cavern, cavernwall, foam, cryostat):** 20 MHz, peak at 2.6 with tail < 14 MeV)
  - **Neutrons:** much less frequent (~ 1 kHz) but high penetration and energy.



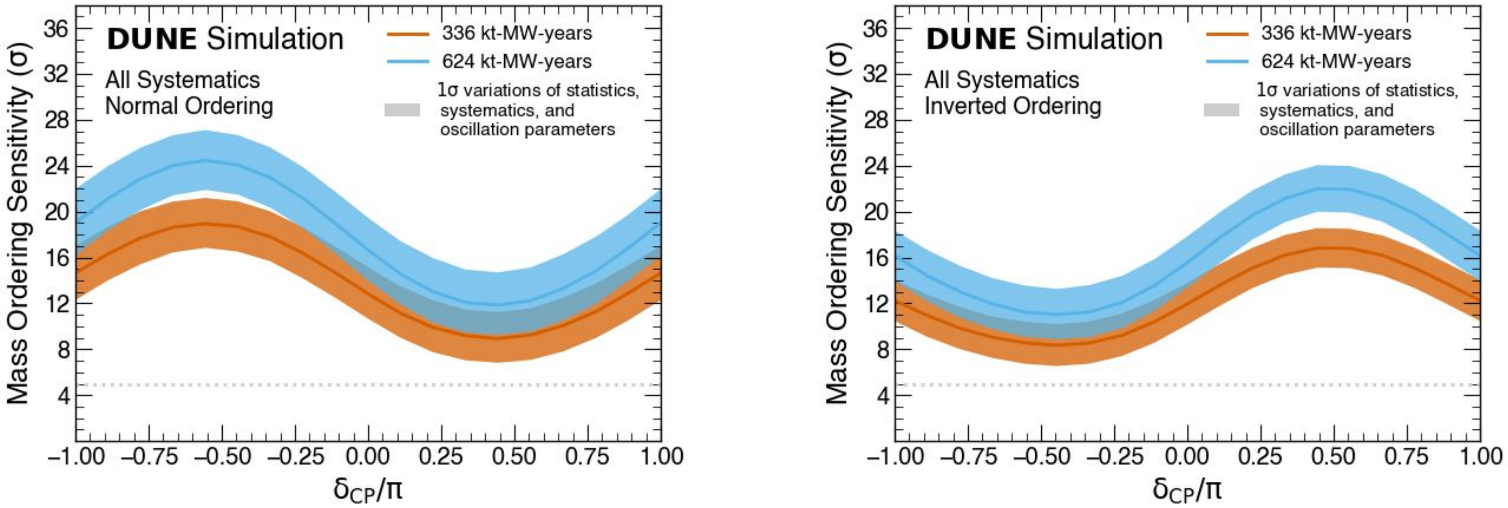


Background Model

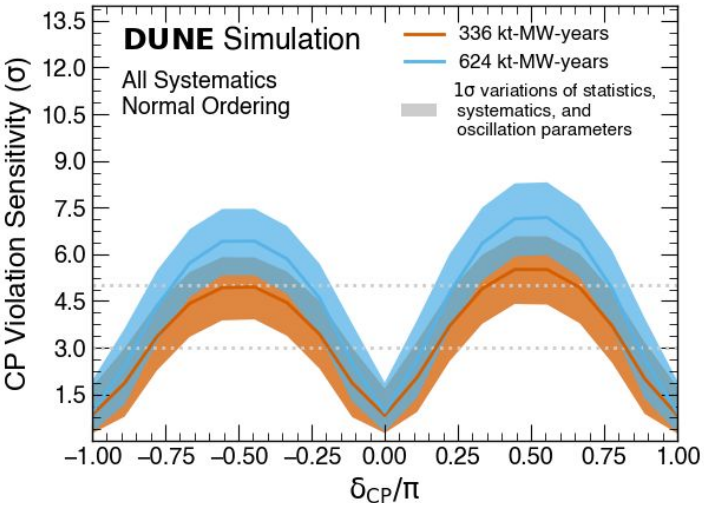
- Preliminary bkg study and contamination in preselection signal.
- Currently updating expected bkg from detector components and LAr with radioassays.

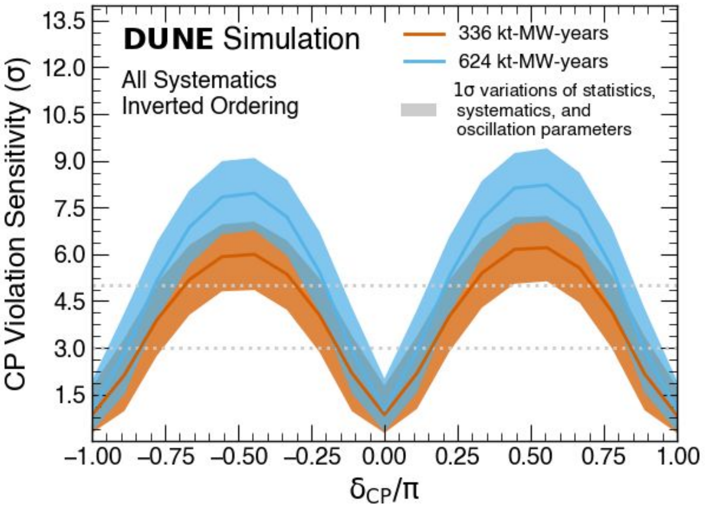


DUNE: Mass ordering vs true δ



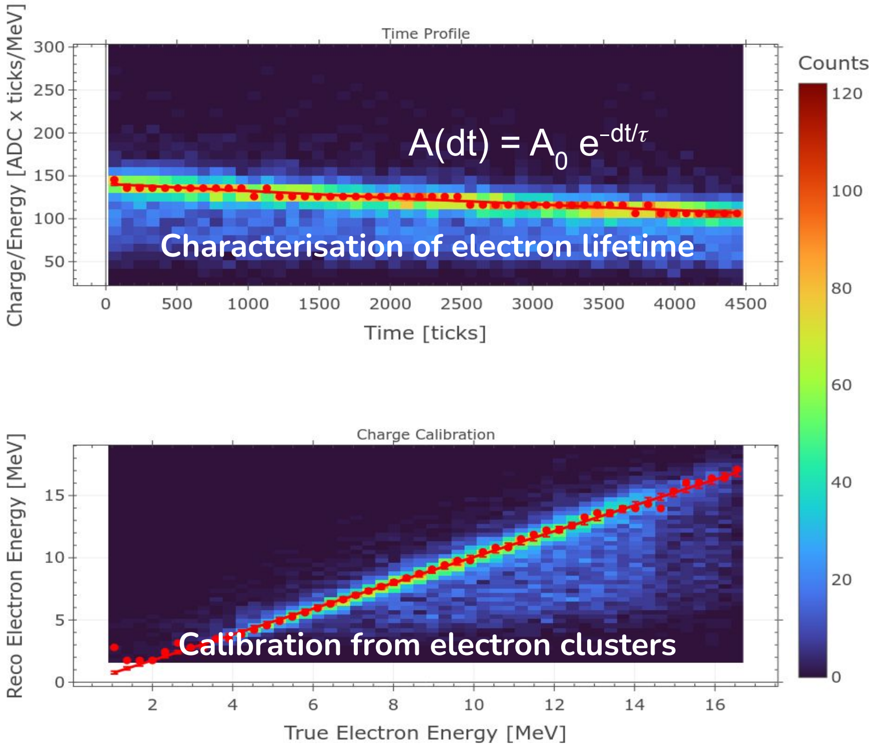
DUNE: CPV significance vs true δ





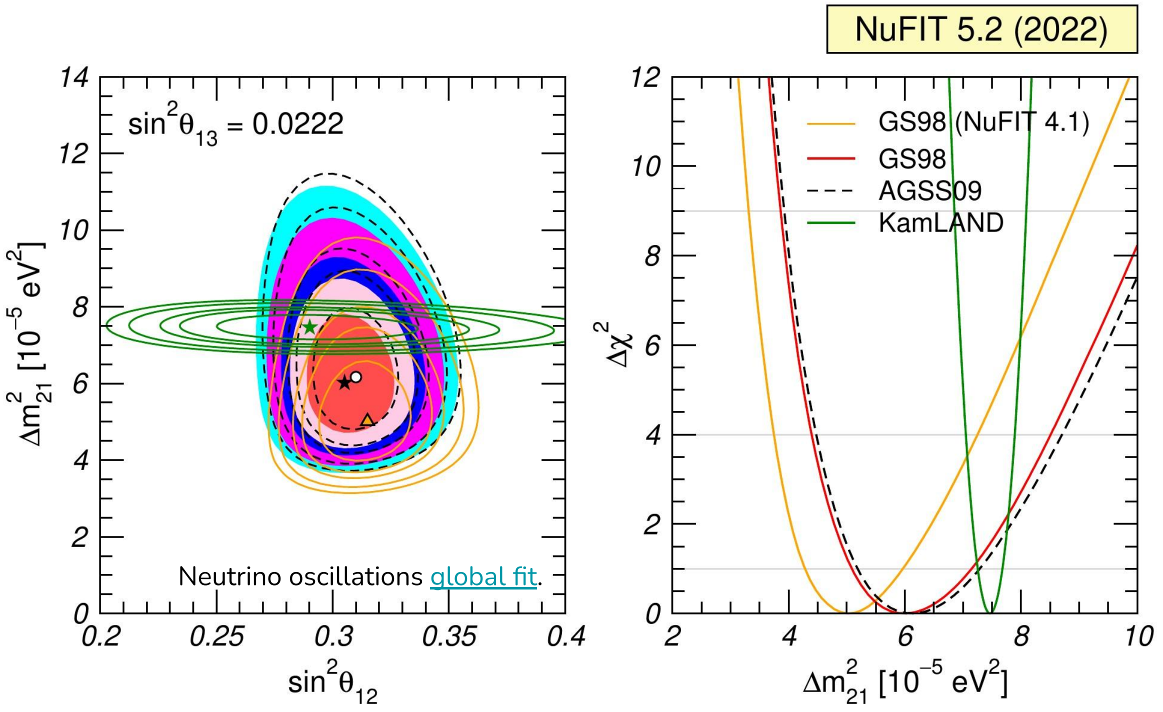
Charge Calibration

$\nu_e + {}^{40}Ar \rightarrow e^- + {}^{40}K^* \rightarrow {}^{40}K + \gamma \; (+ N^*\gamma)$



- Drifting e^- in LAr → lifetime (τ ~30ms).
- Full detector simulation of ν_e interactions provides drift time (dt) profile.
- Assuming a matched PDS flash a **cluster's energy** reconstruction yields ~**10% res.**

Best-Fit For Current Neutrino Experiments



Neutrino oscillations global fit.