

# The design of DUNE near detector



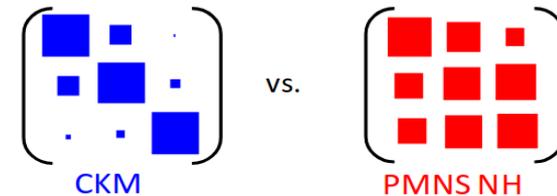
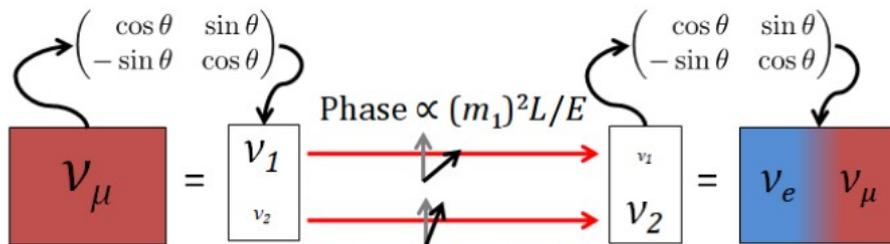
Guang Yang  
On behalf of the DUNE collaboration



# Neutrino Oscillation

- Neutrinos propagate in mass states and interact in flavor states.
- Three generations of neutrino have been found corresponding to lepton flavors.
- Three “Euler” angle has been measured.

- mixing angles 12, 13 and 23 are measured by various neutrino experiments with different sources, Octant of angle 23 is not clear.



$$U_{\text{PMNS}} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu1} & U_{\mu2} & U_{\mu3} \\ U_{\tau1} & U_{\tau2} & U_{\tau3} \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

with  $s_{ij} = \sin \theta_{ij}$ ;  $c_{ij} = \cos \theta_{ij}$



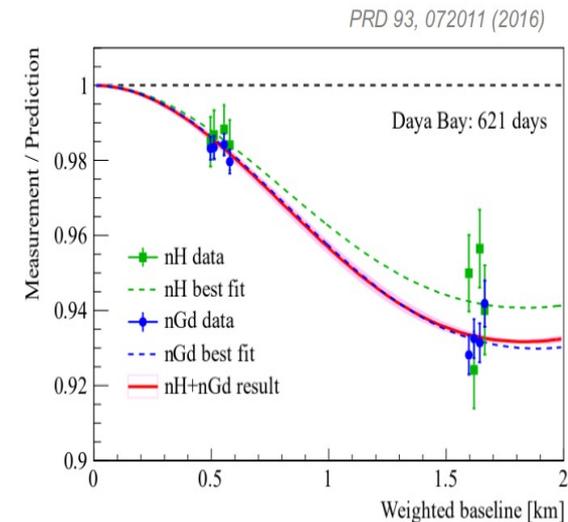
# Neutrino Oscillation

- Non-zero mixing angle 13 measured by Double Chooz, Daya Bay and RENO provides opportunity to measure CP violation phase.
- Matter effect helps on mass hierarchy identification.
- Different appearance probability between neutrino and antineutrino indicates the CP phase. Existing long-baseline experiments are measuring CP phase with a combination of neutrino and antineutrino fluxes.

$$P(\nu_\mu \rightarrow \nu_e) - P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e) =$$

	$\left[ \frac{16A}{\Delta m_{31}^2} \sin^2 \left( \frac{\Delta m_{31}^2 L}{4E} \right) c_{13}^2 s_{13}^2 s_{23}^2 (1 - 2s_{13}^2) \right]$	← What we measure
ME		← Small
ME	$\left[ -\frac{2AL}{E} \sin \left( \frac{\Delta m_{31}^2 L}{4E} \right) c_{13}^2 s_{13}^2 s_{23}^2 (1 - 2s_{13}^2) \right]$	← Proportional to L
CPV	$\left[ -8 \frac{\Delta m_{21}^2 L}{2E} \sin^2 \left( \frac{\Delta m_{31}^2 L}{4E} \right) \sin \delta \right] s_{13} c_{13}^2 c_{23} s_{23} c_{12} s_{12}$	← What we want

with  $A = 2 \sqrt{2} G_{F n_e} E = 7.6 \times 10^{-5} \text{eV}^2 \cdot \frac{\rho}{\text{g cm}^{-3}} \cdot \frac{E}{\text{GeV}}$



# DUNE Collab.



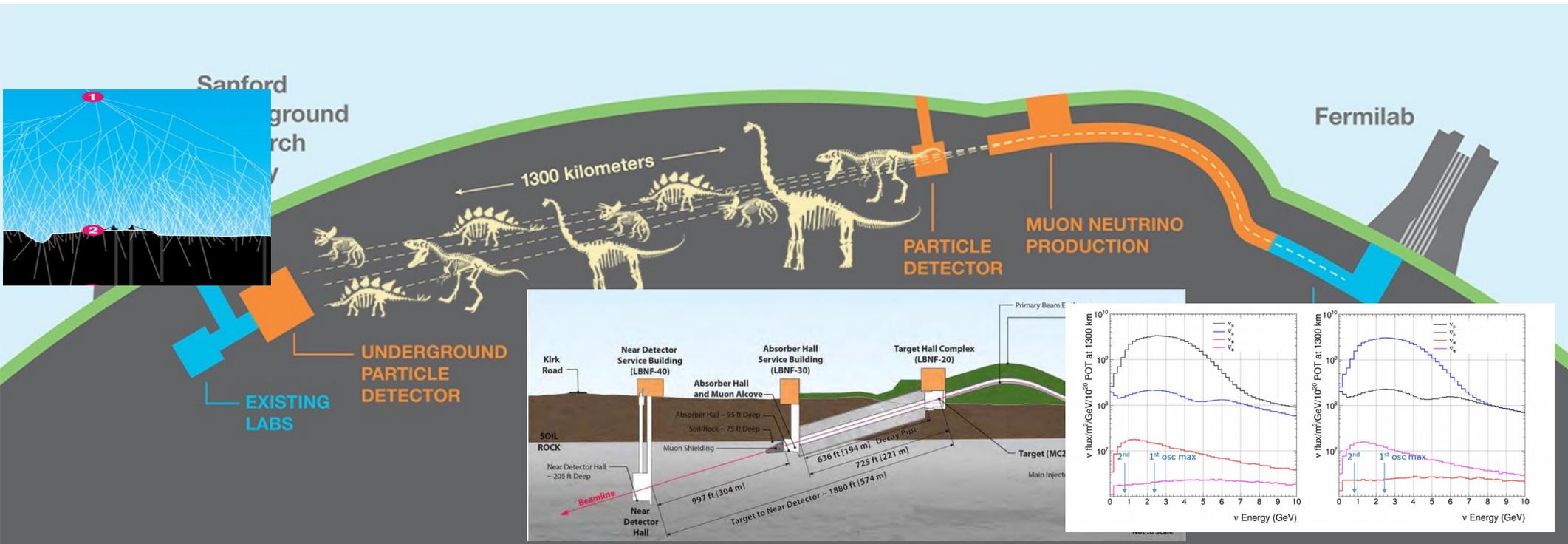
**DUNE** DEEP UNDERGROUND  
NEUTRINO EXPERIMENT





# DUNE experiment

- High-intensity wide-band muon neutrino beam located at Fermilab.
  - Cover at least 2, up to 3 electron neutrino appearance maxima.
  - 1.2 MW proton beam upgradable to 2.4 MW.
- Muon neutrino disappearance and electron neutrino appearance channels will be observed at a high-mass far detector with a baseline of 1300 km.

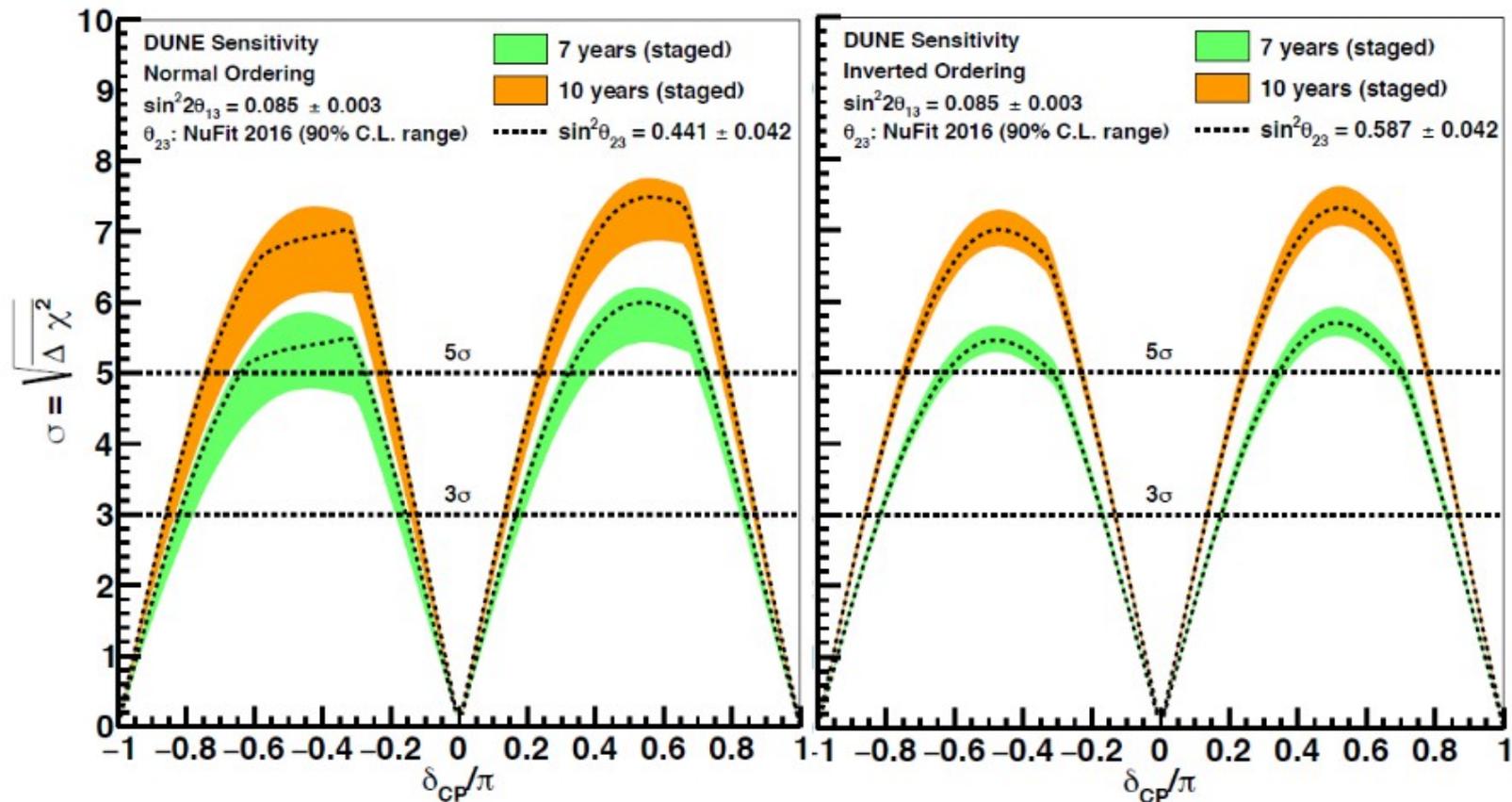




# DUNE Sensitivity

CP (NH)

CP (IH)

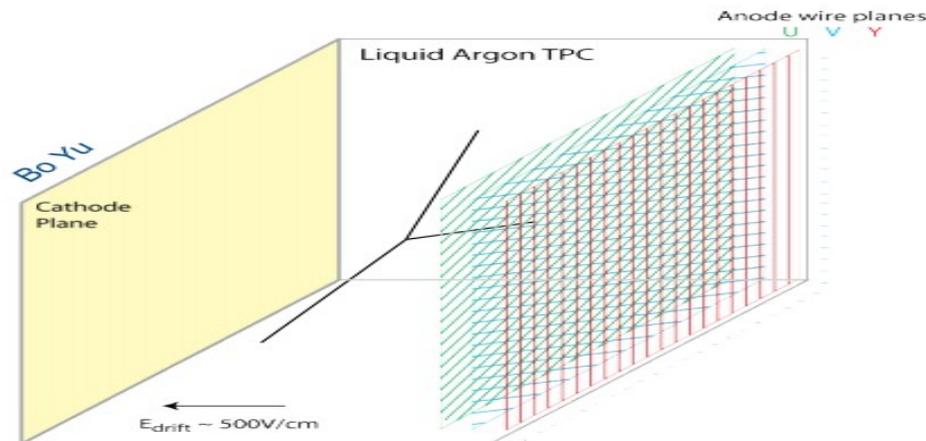
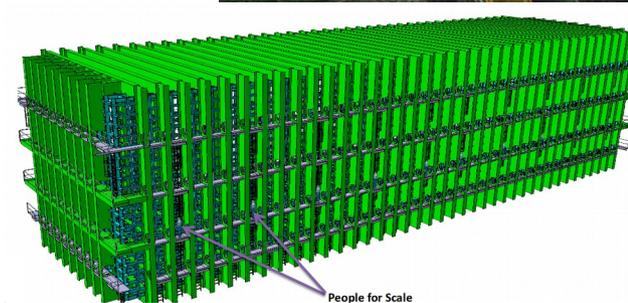
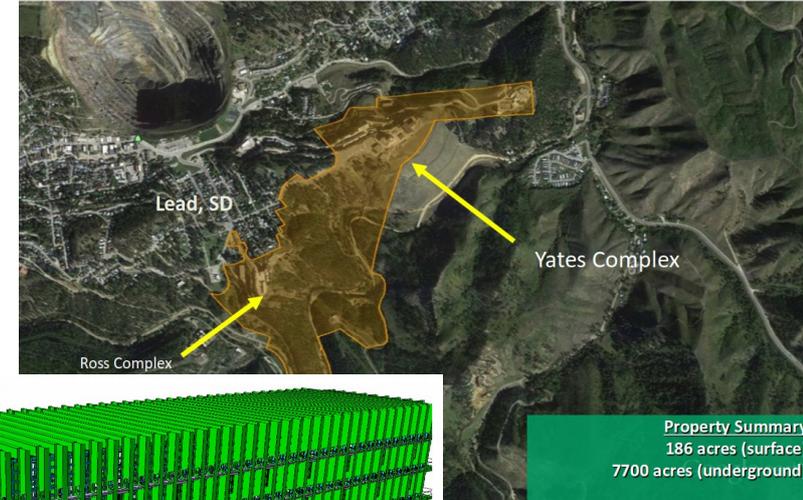


- Aim at 5 sigma CP violation measure after 7 years running of FHC + RHC modes.



# DUNE Far Detector

- FD is located at Homestake in South Dakota with a number of 10 kt liquid argon TPC modules.
- Each module has 3 Anode Plane Assemblies (APA).
  - 384,000 cold electronics channels
- Cathode planes (CPA) operate at 180 kV.
  - 3.6 m max drift length
- Photon detection system to provide T0.





# What ND must do?

Ideally:

$$P_{\nu_{\mu} \rightarrow \nu_e}(E_{\nu}) = \frac{\phi_{\nu_e}^{far}(E_{\nu})}{\phi_{\nu_{\mu}}^{far, no-osc}(E_{\nu})} = \frac{\phi_{\nu_e}^{far}(E_{\nu})}{\phi_{\nu_{\mu}}^{near}(E_{\nu}) * F_{far/near}(E_{\nu})}$$

Event spectrum:

$$\frac{dN_{\nu}^{det}}{dE_{\nu}} = \phi_{\nu_{\mu}}^{det}(E_{\nu}) * \sigma_{\nu_{\mu}}^{Ar}(E_{\nu})$$

However...

$$\frac{dN_{\nu}^{det}}{dE_{rec}} = \int \phi_{\nu}^{det}(E_{\nu}) * \sigma_{\nu}^{target}(E_{\nu}) * T_{\nu_{\mu}}^{det}(E_{\nu}, E_{rec}) dE_{\nu}$$

Just make them  
Canceled??

$$\frac{dN_{\nu_e}^{far}}{dE_{\nu}} \bigg/ \frac{dN_{\nu_{\mu}}^{near}}{dE_{\nu}} = P_{\nu_{\mu} \rightarrow \nu_e}(E_{\nu}) * \frac{\sigma_{\nu_e}^{Ar}(E_{\nu})}{\sigma_{\nu_{\mu}}^{Ar}(E_{\nu})} * F_{far/near}(E_{\nu})$$

$$\frac{\frac{dN_{\nu_e}^{far}}{dE_{rec}}}{\frac{dN_{\nu_{\mu}}^{near}}{dE_{rec}}} = \frac{\int P_{\nu_{\mu} \rightarrow \nu_e}(E_{\nu}) * \phi_{\nu_{\mu}}^{near}(E_{\nu}) * F_{far/near}(E_{\nu}) * \sigma_{\nu_e}^{Ar}(E_{\nu}) * T_{\nu_e}^{far}(E_{\nu}, E_{rec}) dE_{\nu}}{\int \phi_{\nu_{\mu}}^{near}(E_{\nu}) * \sigma_{\nu_{\mu}}^{Ar}(E_{\nu}) * T_{\nu_{\mu}}^{near}(E_{\nu}, E_{rec}) dE_{\nu}}$$

It turns out...

Ambiguities need to be resolved:

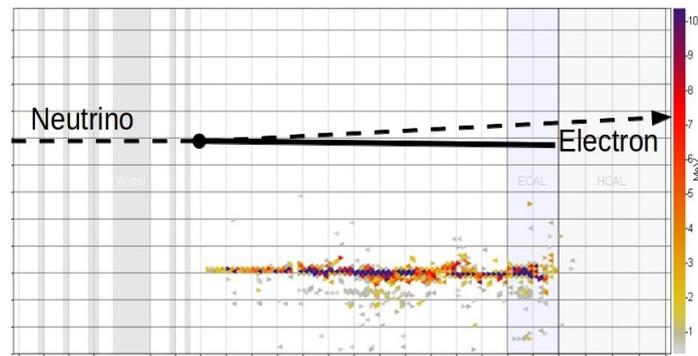
- Detection effects in near and far detector
- Cross section
- Reconstructed energy to true energy mapping
- Near to Far flux extrapolation



# DUNE ND : flux measurement

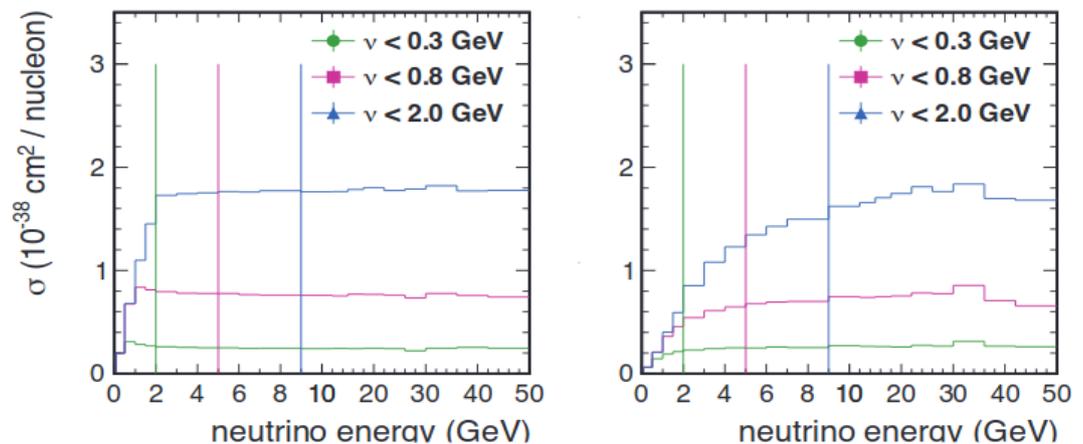
- Target independent
- Better use channels that cross section well known.
  - Neutron-electron scattering: Pure weak interaction; signature is very straightforward electron.
  - low-nu channel: Very low energy transferring from neutrino to nuclear system; Cross section is independent of energy; Cross section depends on ability to measure all hadronic energy including neutrons.

Minerva neutrino-electron scattering event



Phys. Rev. D 93, 112007 (2016)

Minerva low-nu cross section



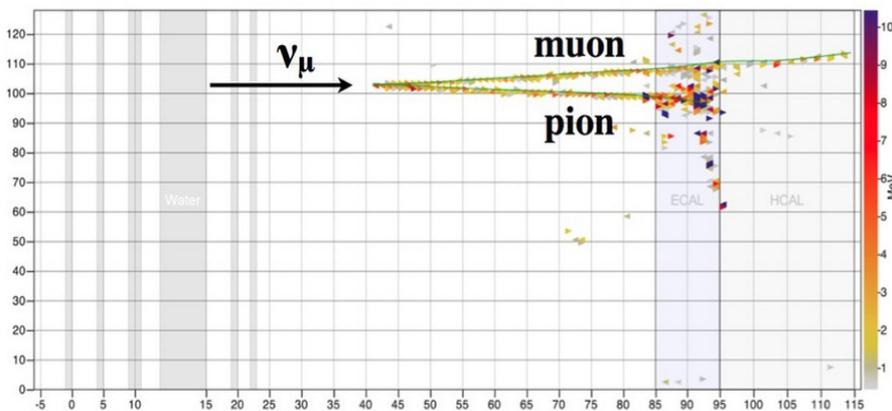
Phys. Rev. D 94, 112007 (2016)



# DUNE ND : flux measurement

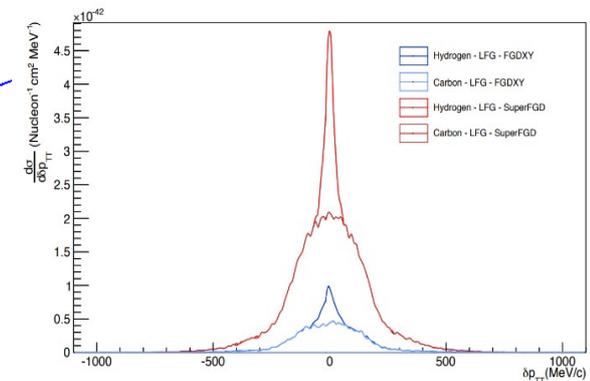
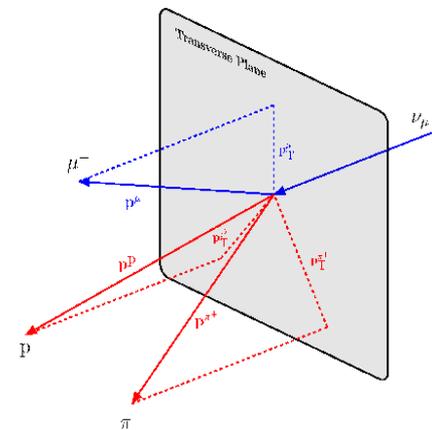
- Coherent channel: No Long/short range correlations and no final state interaction; Cross section not well known; Forward-going lepton and pions.
- Hydrogen interaction: No final state interaction; No initial state transverse momentum → identify by transverse momentum balance;

Minerva Coherent interaction event



Phys. Rev. Lett. 113, 261802 (2014)

T2K transverse momentum  
→ extract hydrogen interaction



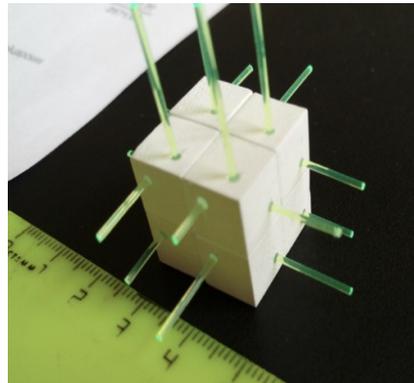
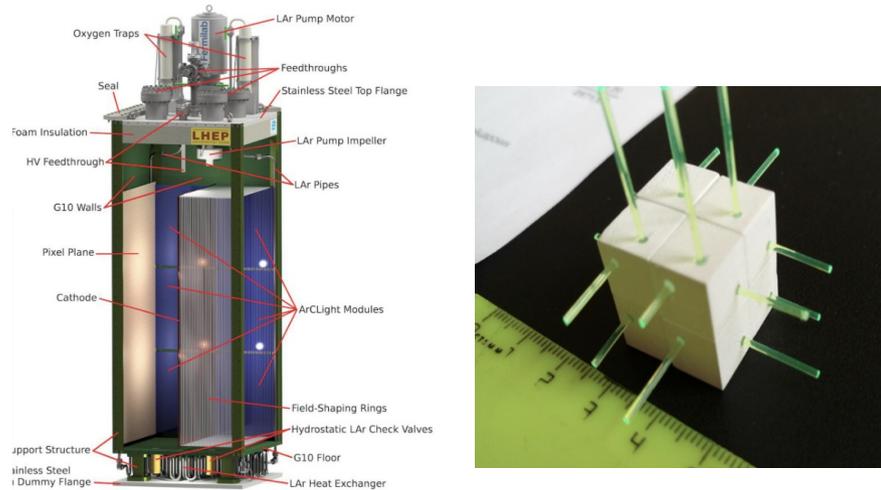
arXiv. 1901.03750s

# DUNE ND : Cross section and smearing

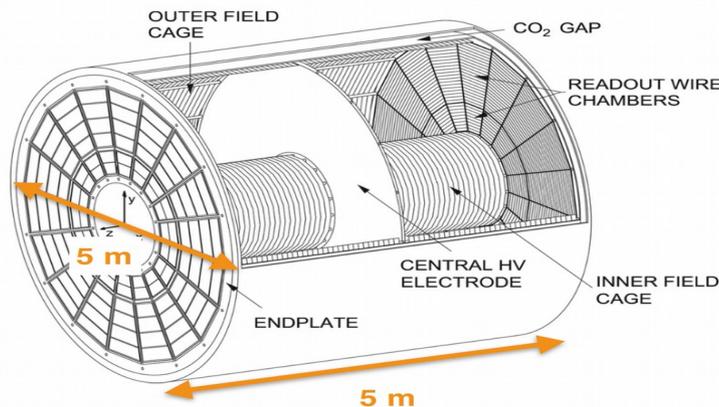
- Unknown initial state: neutrino energy and nucleon momentum
- Unknown final state: Neutron, protons below threshold
- Unknown detector smearing
- Very model dependent
  - ND philosophy:
    - Measure as many exclusive differential cross sections as possible.
    - Tune model.
    - Extract cross section and smearing from simulation.
      - We start to consider detector configuration based on the ideas above.

# Current DUNE ND design

- Each components can take over one specific task and there are redundancies to ensure the success.
- The following talks will describe these components in detail.

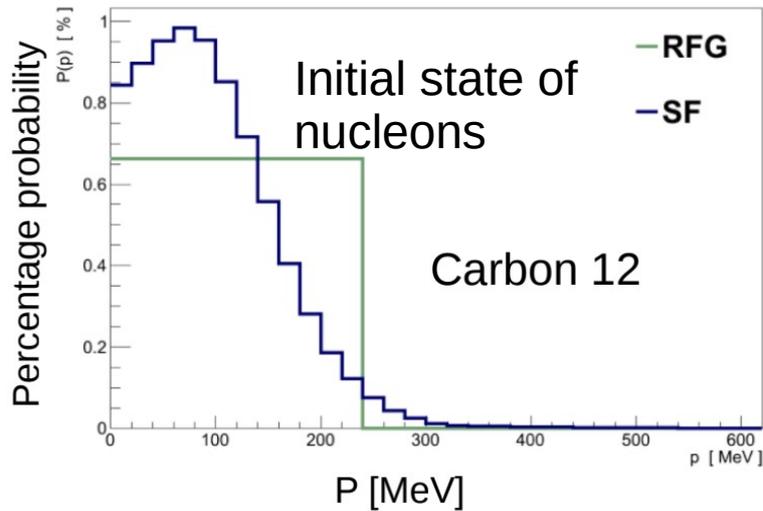


Component	Essential Characteristics	Primary function	Select physics aims
LArTPC (ArgonCube)	Mass	Experimental control for the Far Detector	$\nu_\mu(\bar{\nu}_\mu)$ CC
	Target nucleus Ar	Measure unoscillated $E_\nu$ spectra	$\nu$ - $e^-$ scattering
	Technology FD-like	Flux determination	$\nu_e + \bar{\nu}_e$ CC Interaction model
Multipurpose detector (MPD)	Magnetic field	Experimental control for the LArTPCs	$\nu_\mu(\bar{\nu}_\mu)$ CC
	Target nucleus Ar	Momentum analyze liquid Ar $\mu$	$\nu_e$ CC, $\bar{\nu}_e$
	Low density	Measure exclusive final states with low momentum threshold	Interaction model
3D scintillator tracker spectrometer (3DSTS)	On-axis	Beam flux monitor	On-axis flux stability
	Mass	Neutrons	Interaction model
	Magnetic field CH target		A dependence $\nu$ - $e^-$ scattering

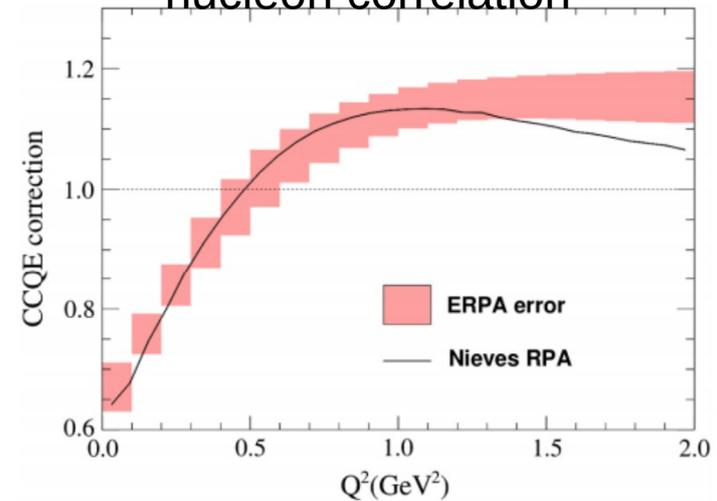


# But, it is hard in reality

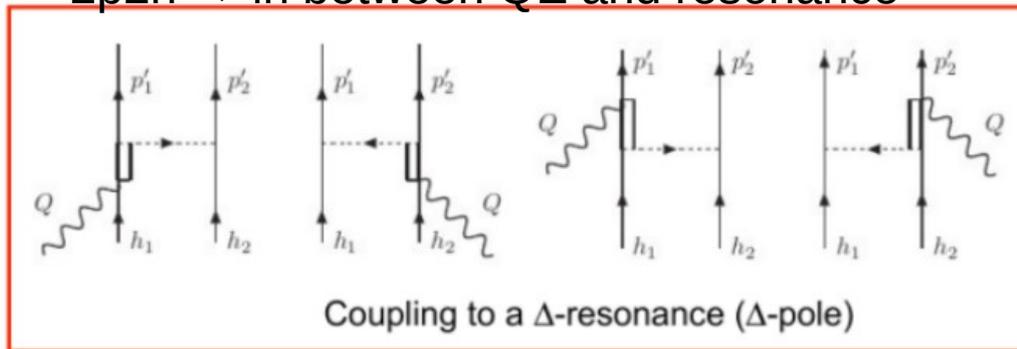
- Following things all need models, we are too model dependent.
  - Parameterizations may be very wrong.



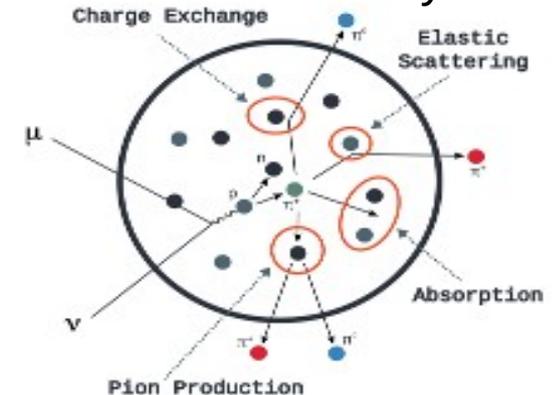
Long-range nucleon-nucleon correlation



2p2h → in between QE and resonance



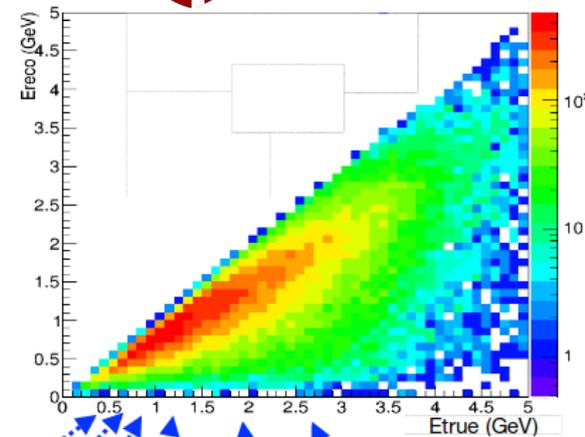
Final state/ secondary interaction





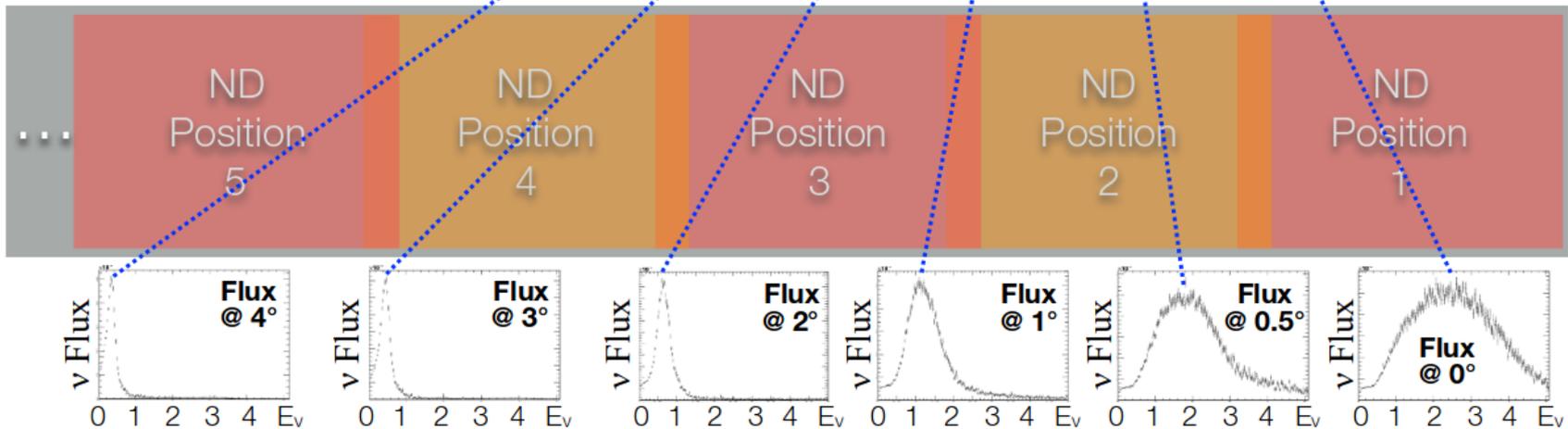
# DUNE-PRISM

- Moving the near detector off-axis the spectrum energy goes lower and lower.
- Linear combination of off-axis spectra provides data-driven reco vs. true mapping.
- ND hall is considered to rotate in order to satisfy the requirement of transverse length.

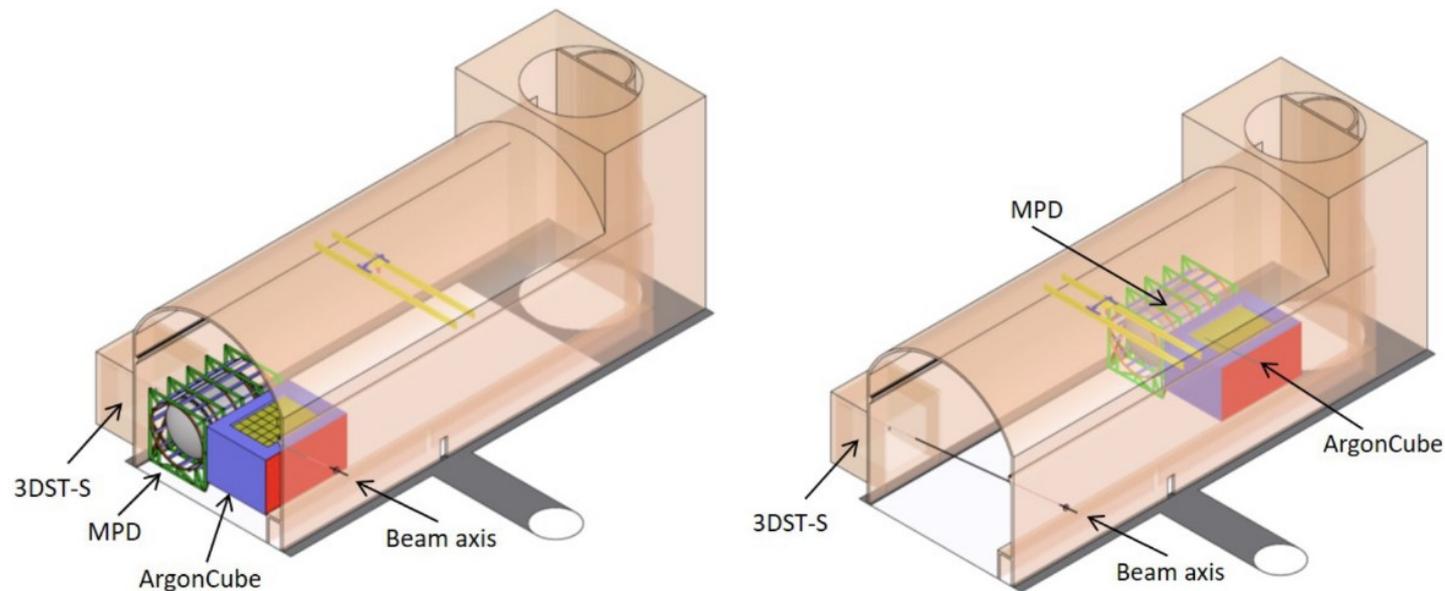


Beam

Increasing Off-axis angle



# DUNE ND hall and conclusion



- DUNE ND will consist of a liquid argon detector, a gas argon TPC system which will be surrounded by ECAL and inside a magnetic volume and a 3D projection scintillator tracker.
- Part of the ND system will be movable.
- DUNE aims at measuring CP violation at five sigma with this wonderful ND system.



# backups