Physics Potential with DUNE's Argon Gas TPC

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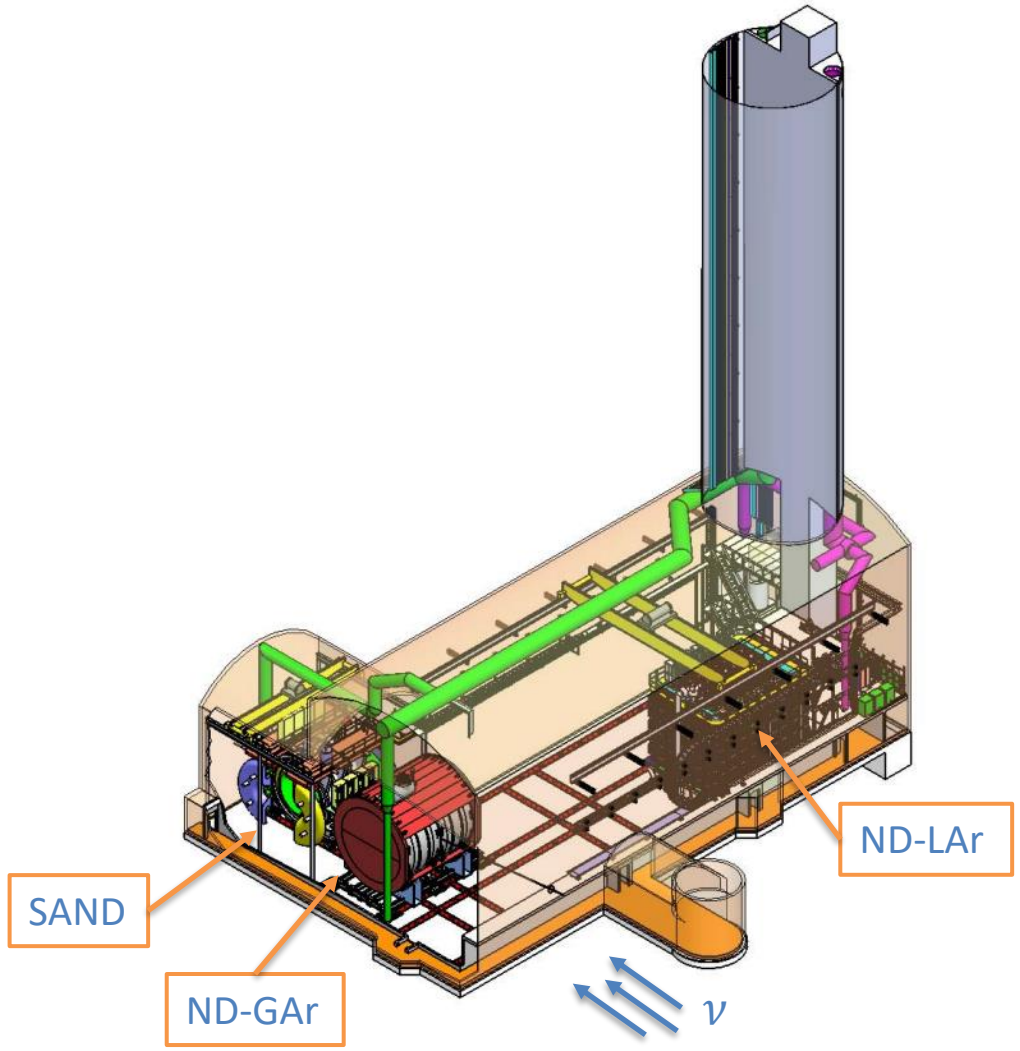
on behalf of the DUNE collaboration

NeuTel Flash Talk

26/02/2021

DUNE's ND: Main components and design

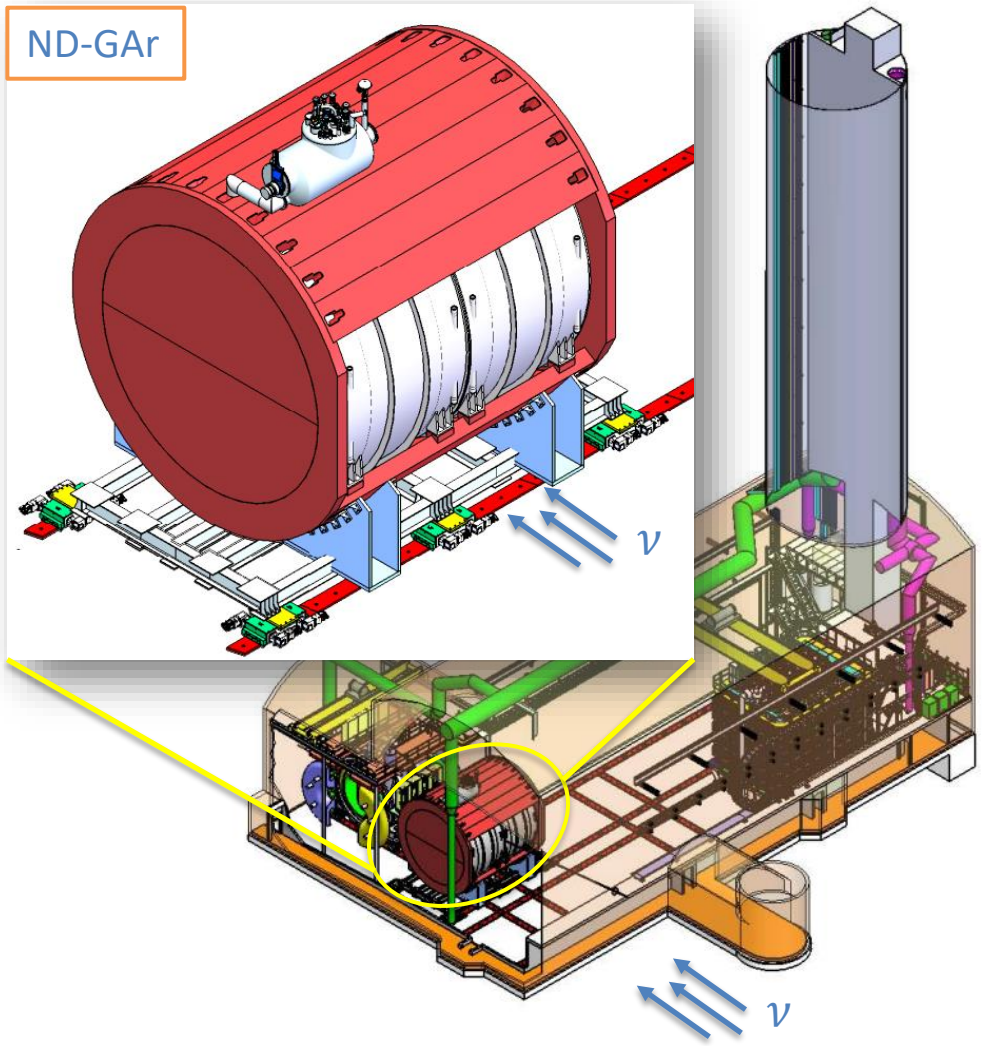


- DUNE neutrino oscillation experiment: Far Detector in South Dakota, 1300 km from a Near Detector in Fermilab hit by 1.2 MW wideband neutrino beam (1.1×10^{21}pot with peak energy for ν_μ is ~2.5 GeV)

- Near Detector (ND) serves as the experiment's control:
  - Measures and monitors the beam
  - Constrains systematic uncertainties
  - Provides input for neutrino interaction model

Dr Tanaz Angelina Mohayai, Parallel Contributed Talk, 22/02/2021
https://agenda.infn.it/event/24250/contributions/130075/

DUNE's ND: Main components and design

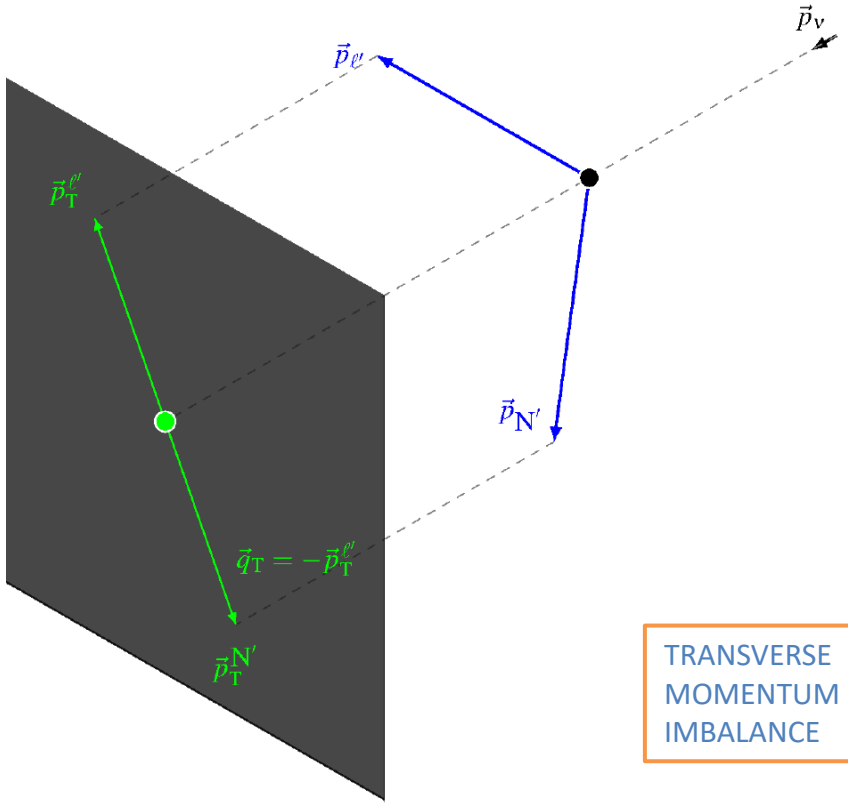


- 3 ND components one of which is ND-GAr (Gas argon) : HPgTPC (High Pressure Gas TPC) based on ALICE's filled with Ar-CH_4 90-10 gas mixture (97% interactions on Ar) at 10 atm (pressure vessel) surrounded by an ECAL in a 0.5 T super-conducting magnet

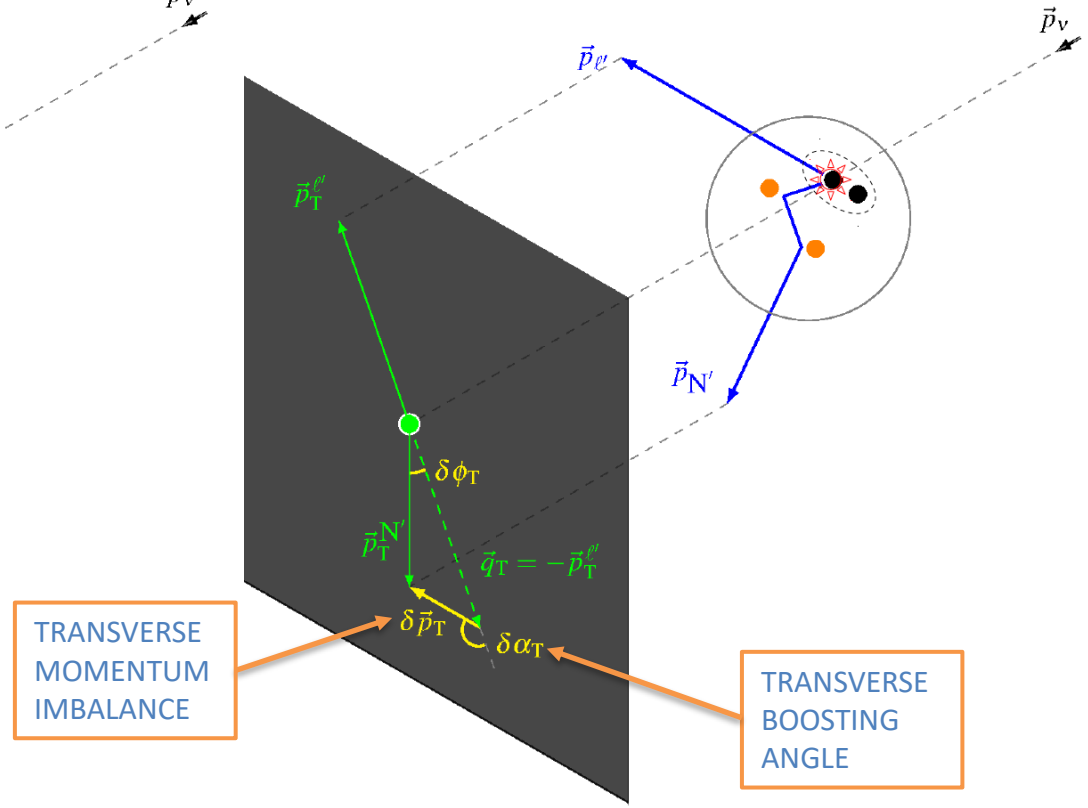
- ν-Ar interactions on low density medium:
  - Very low momentum threshold for charged particle tracking (π, p)
  - Excellent tracking resolution
  - Nearly uniform angular coverage

- Crucial Objective: improve ν-n interaction model at lower energies where MC neutrino generators struggle

TKI: Transverse Kinematic Imbalance



Stationary nucleon target: balanced final state

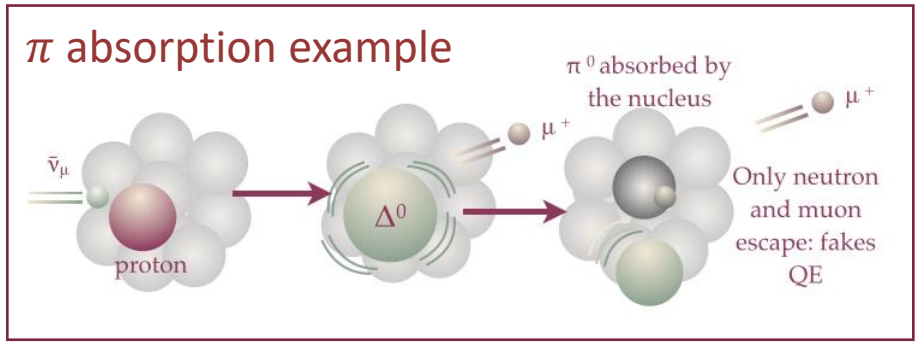


Nuclear target ($A > 1$): interactions in the nuclear matter cause imbalance

- TKI: precisely identify intranuclear dynamics or the absence thereof (Lu et al. Phys. Rev. D92,051302 (2015), Lu et al. Phys. Rev. C94, 015503 (2016))
- Transverse boosting angle $\delta\alpha_T$:
  - Small angle: acceleration
  - Large angle: deceleration
- LHC uses similar technique to search for BSM particles (parton ↔ neutrino)

TKI: Transverse Kinematic Imbalance

- Low $\delta\alpha_T$: Devoid of (abnormal) FSI acceleration, dominated by pure CCQE events
- High $\delta\alpha_T$: Energy 'dissipation' from nuclear effects (FSI deceleration, pion absorption, 2p2h) → increase events in high $\delta\alpha_T$ region



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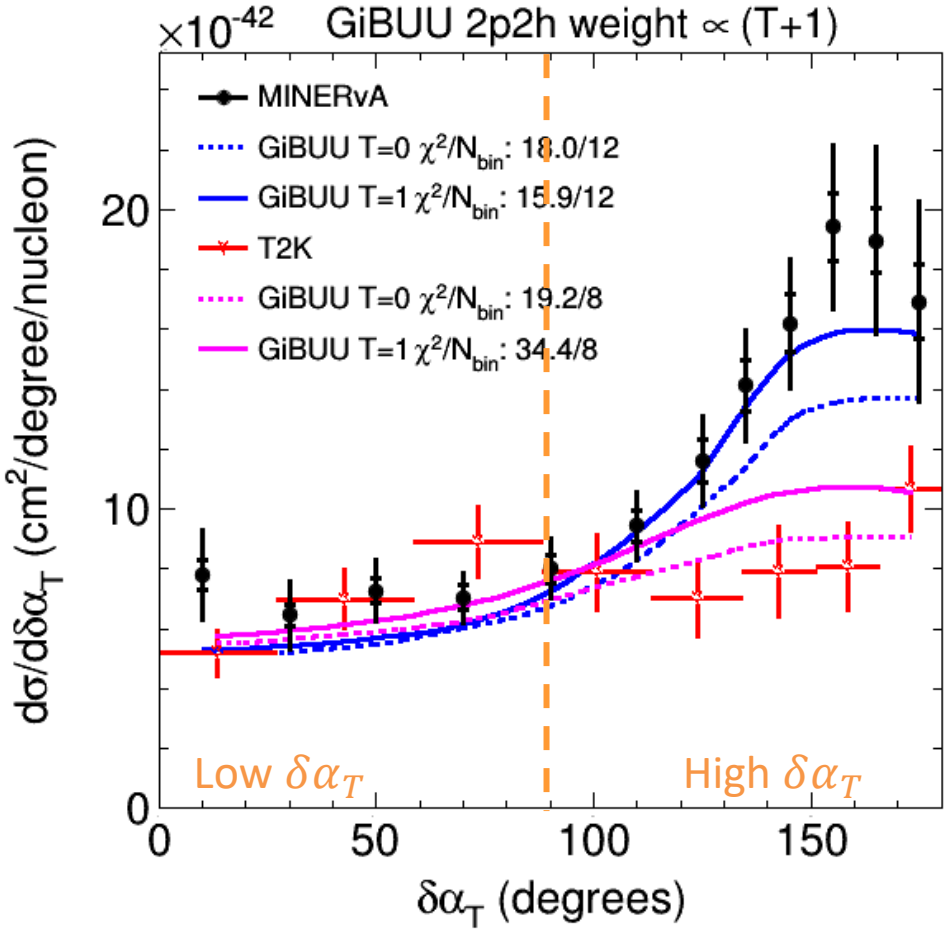
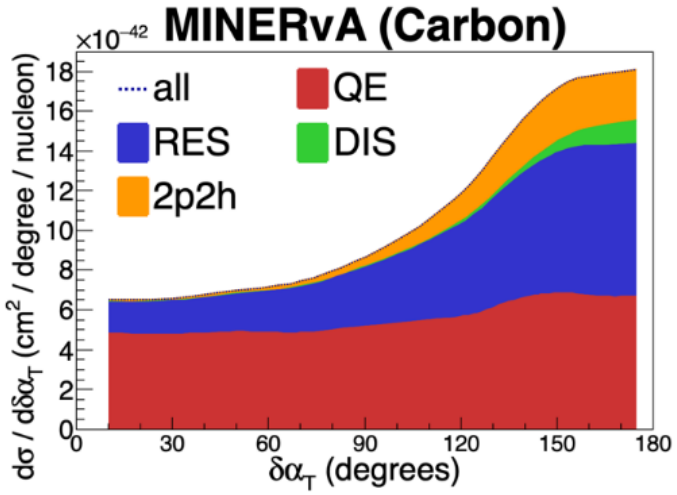


[MINERvA, Phys.Rev.Lett. 121, 022504 (2018)]
[T2K, Phys. Rev. D 98, 032003 (2018]

Model Simulation: ND-GAr advantages for TKI

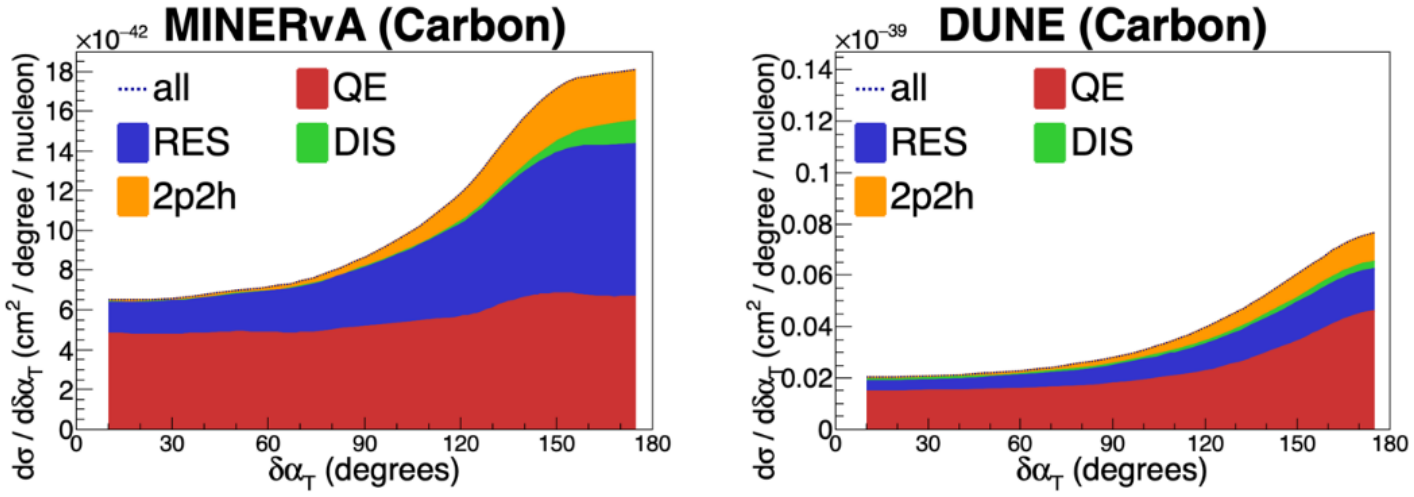
[DUNE Near-Detector CDR]



1. Differential cross section model (GiBUU) calculation as a function of $\delta\alpha_T$ in MINERνA:
   - Consider MINERνA detector as baseline for comparison with ND-GAr:
     - Carbon target
     - Energy thresholds: $KE_\mu > 1.4$ GeV and $KE_p > 0.1$ GeV
     - MINERνA angular acceptance: $\theta_\mu < 20°$ and $\theta_p < 70°$
   - Note: in the calculation only CCQE-like events are considered

Model Simulation: ND-GAr advantages for TKI

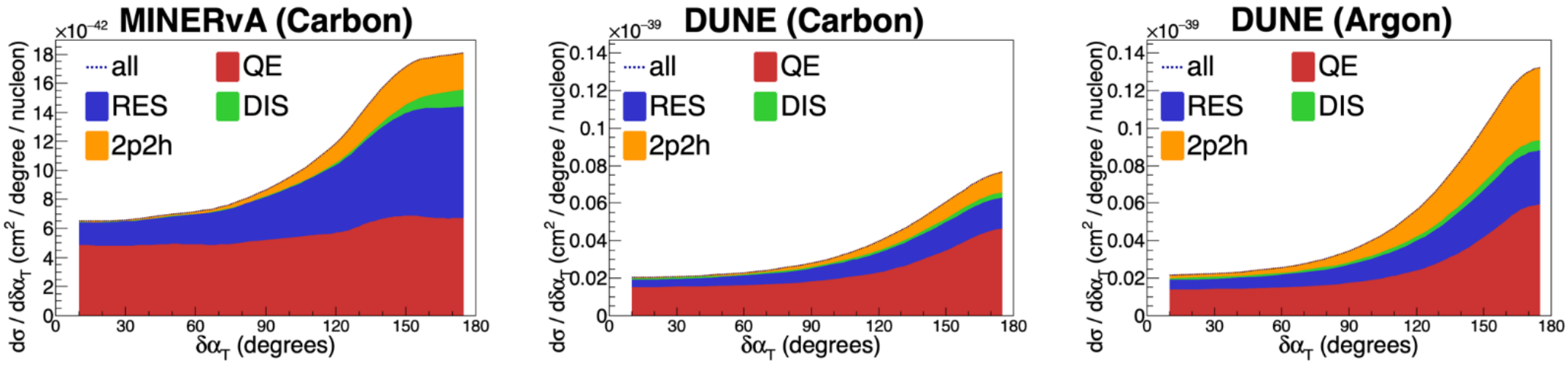
[DUNE Near-Detector CDR]



2. Differential cross section as a function of $\delta\alpha_T$ in ND-GAr (test target C):
   - More events with a higher $\delta\alpha_T$ (notice higher scale in 2^{nd} plot 10^{-42} VS 10^{-39})
     - Lower energy threshold: $KE_\mu > 0.003$ GeV and $KE_p > 0.05$ GeV
     - Essentially full 4π angular acceptance

Model Simulation: ND-GAr advantages for TKI

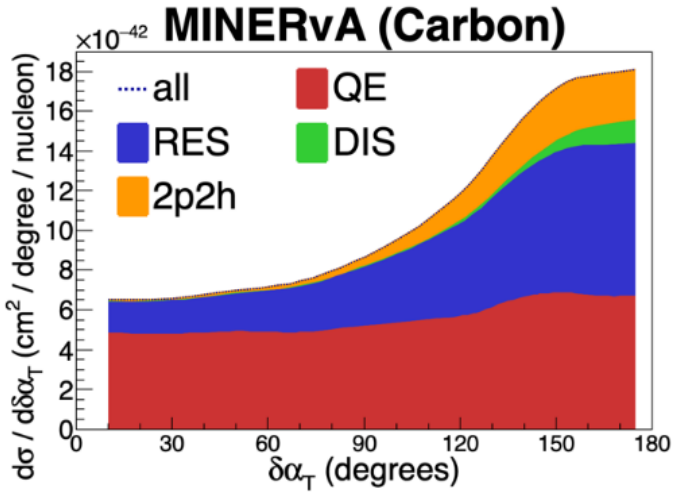
[DUNE Near-Detector CDR]

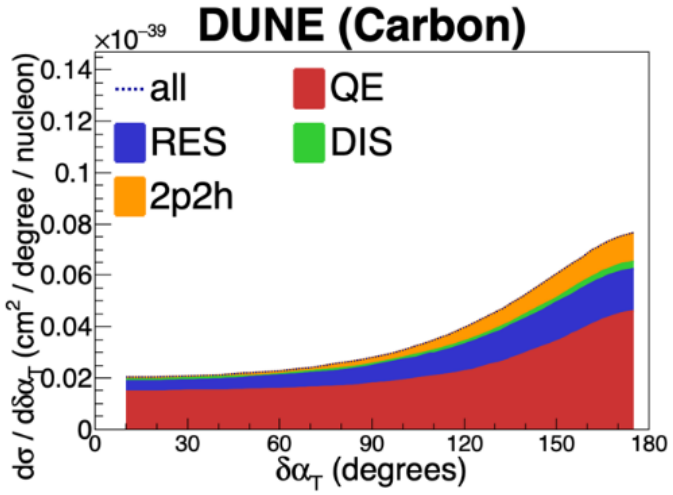


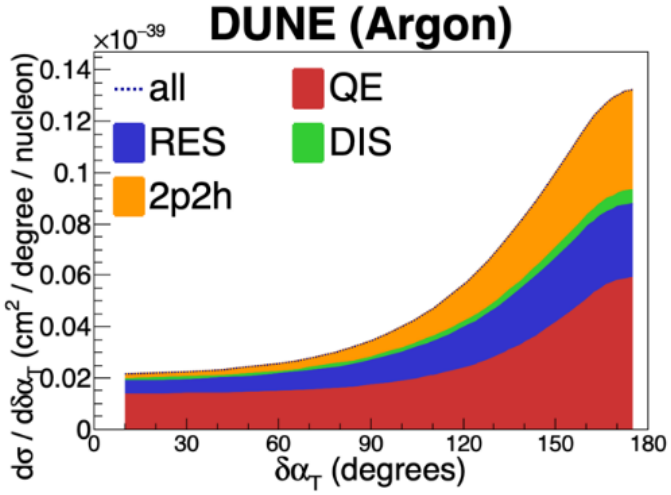
3. Differential cross section as a function of $\delta\alpha_T$ in ND-GAr (argon target):
   - Increased contribution from FSI effects
     - Additional strength at high $\delta\alpha_T$
     - CC0π contribution from RES and DIS events followed by pion absorption
   - 2p2h contributions: compared to actual measurement; no reliable extrapolation from carbon to argon

Model Simulation: ND-GAr advantages for TKI

[DUNE Near-Detector CDR]







MAIN TAKEAWAY

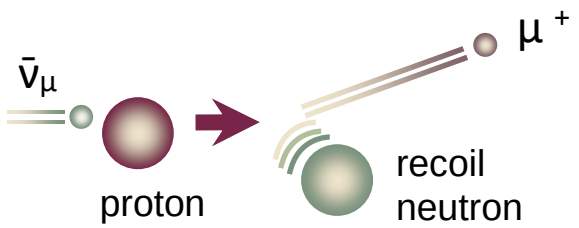
- ND-GAr, using TKI and other measurements, will provide surgical detail about nuclear effects in argon, leading to a greater understanding of systematic uncertainties relevant to oscillation analyses in DUNE and their underlying theoretical motivations

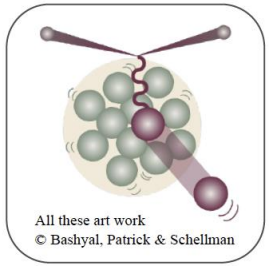
THANK YOU!

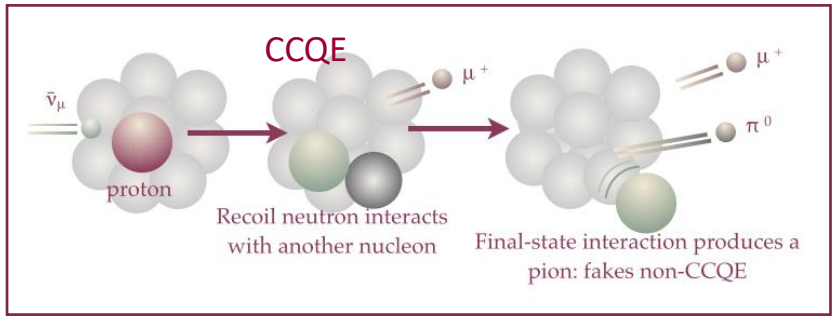
Intra-nuclear Dynamics

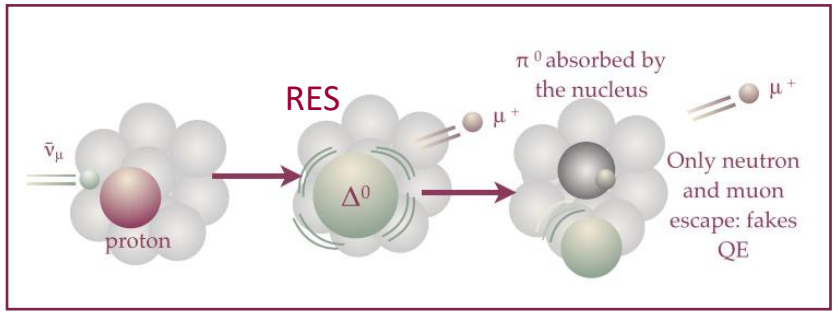
- Nuclear effects in neutrino-nucleus interactions include:
  - Fermi motion
  - FSI (Final State Interaction) breaking up nucleus
  - 2p2h

Charged-current quasielastic (CCQE)

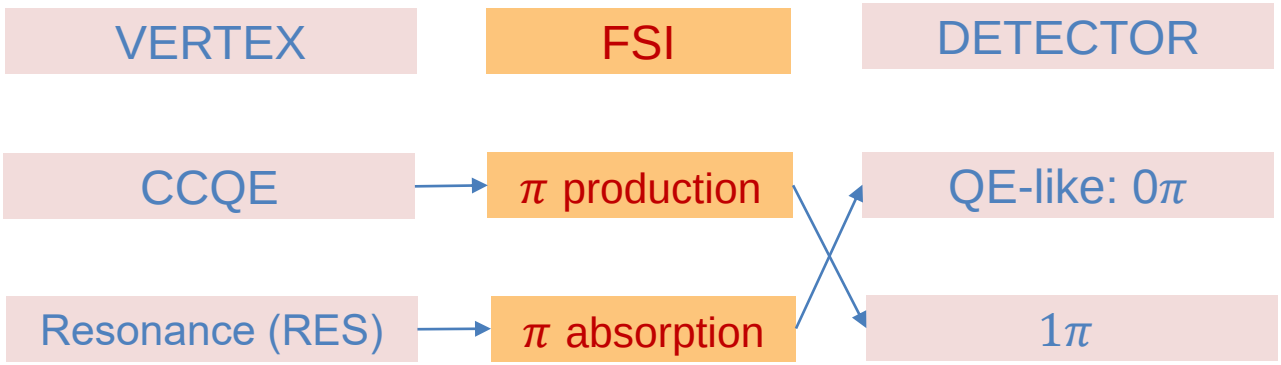






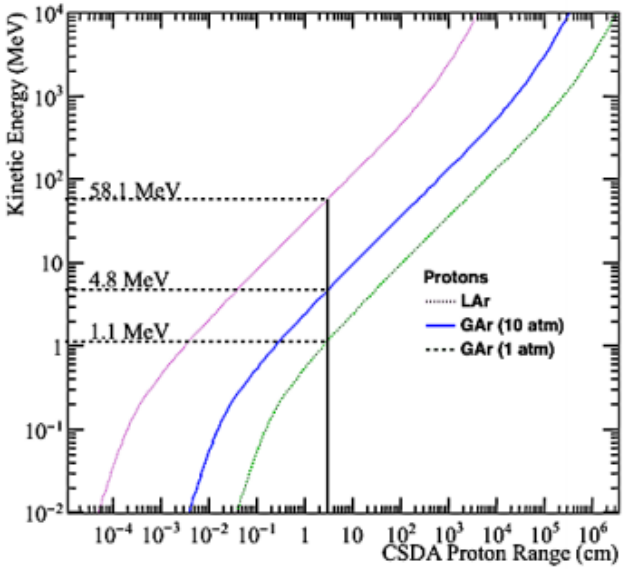


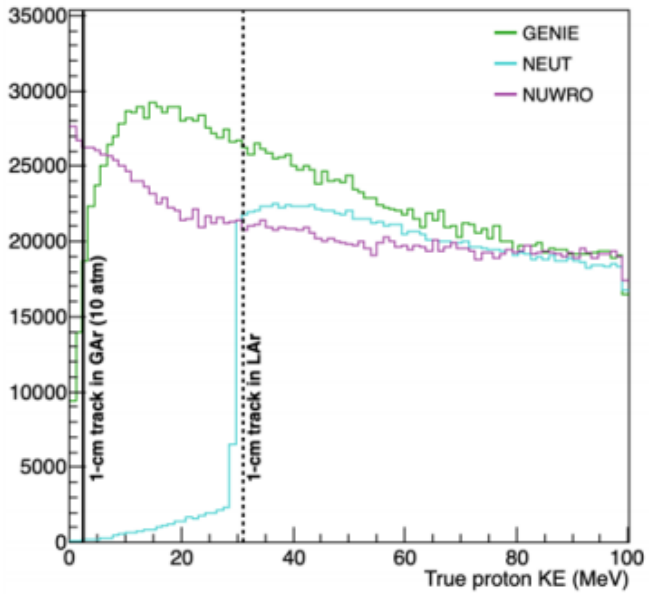
- FSI can (among other things) modify final-state topology creating mix-ups and confusion in cross section measurements



ND-GAr – Capabilities

- Key capabilities:
  - ★ Lower density ($\rho_{LAr}/\rho_{GAr} \approx 85$ for 10 atm GAr) compared with ND-LAr, more sensitivity to lower energy charged particles that may not be seen in ND-LAr
  - ★ Reveals discrepancies between different neutrino event generators for choosing a more accurate ν-N interaction model @ lower energies





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