DEEP UNDERGROUND NEUTRINO EXPERIMENT

PHYSICS POTENTIAL WITH DUNE’S ND-GAR DETECTOR

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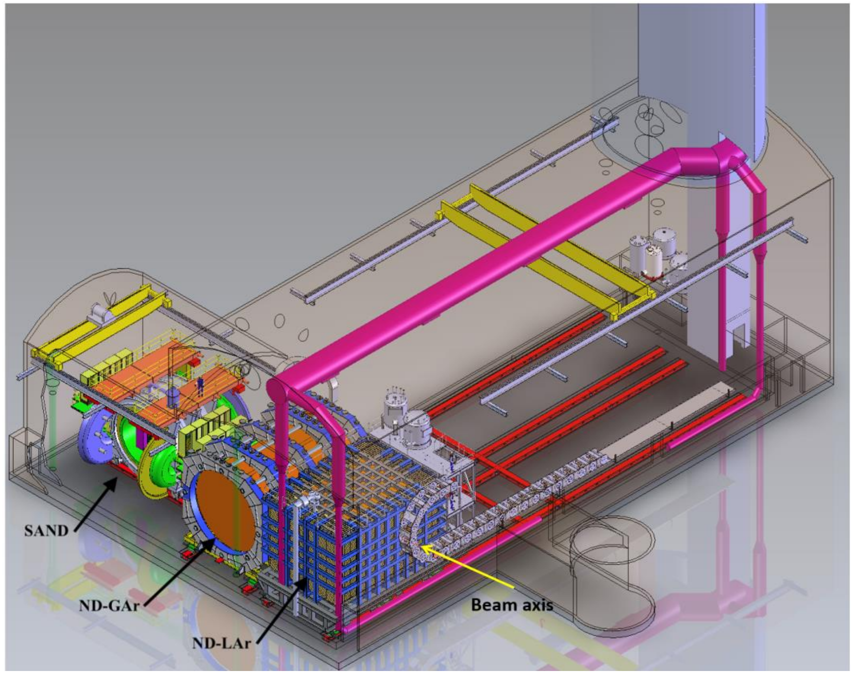
on behalf of the DUNE collaboration

DUNE'S ND: MAIN COMPONENTS AND DESIGN

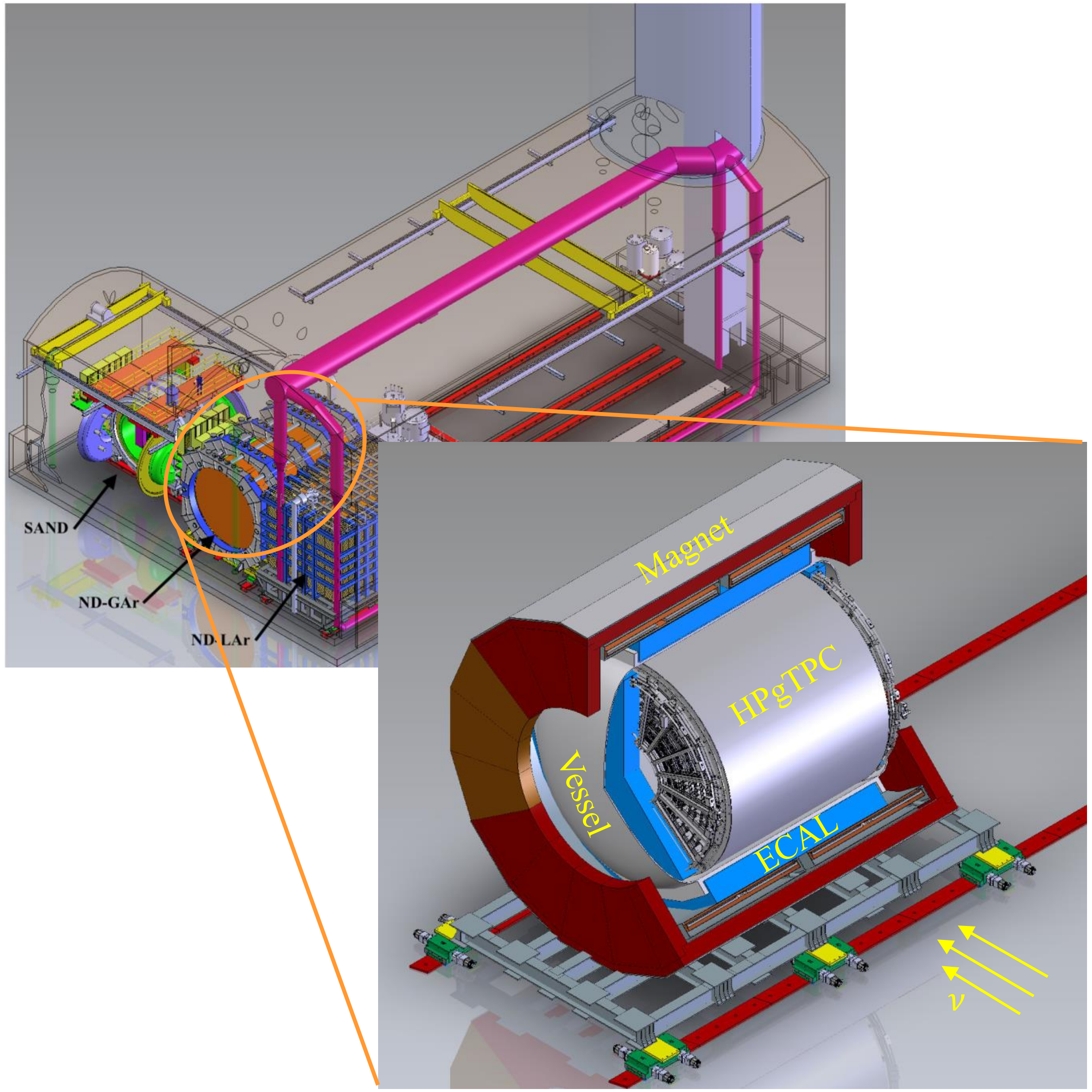


- DUNE neutrino oscillation experiment: FD in South Dakota, 1300 km from a ND in Fermilab hit by 1.2 MW wideband neutrino beam (1.1×10^{21}pot with peak energy for ν_μ is ~2.5 GeV)

- ND serves as the experiment's control:
  - Establishes null hypothesis (i.e., no oscillations)
  - 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



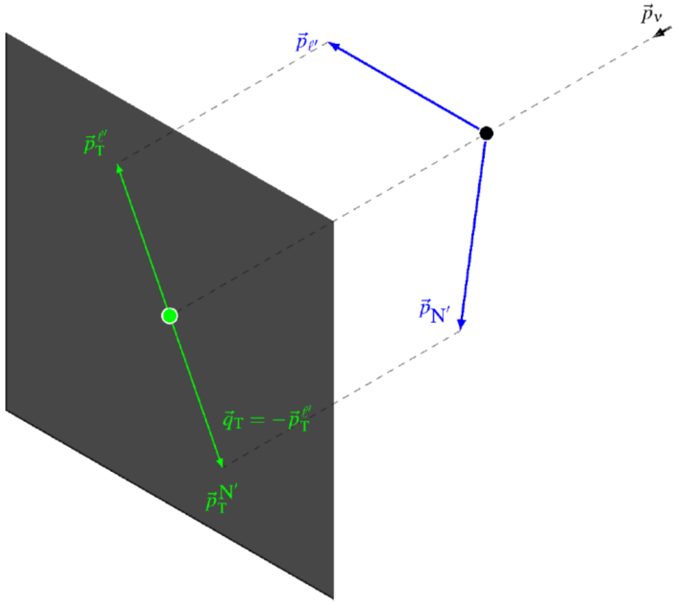
- 3 ND components one of which is ND-GAr : HPgTPC based on ALICE’s filled with Ar-CH4 90-10 gas mixture (97% interactions on Ar) at 10 atm (pressure vessel) surrounded by an ECAL in a 0.5 T super-conducting magnet

- $\mu's$ from ND-LAr detector + ν-Ar interactions on low density medium:
    - Very low momentum threshold for charged particle tracking (π, p)
    - Excellent tracking resolution
    - Nearly uniform angular coverage

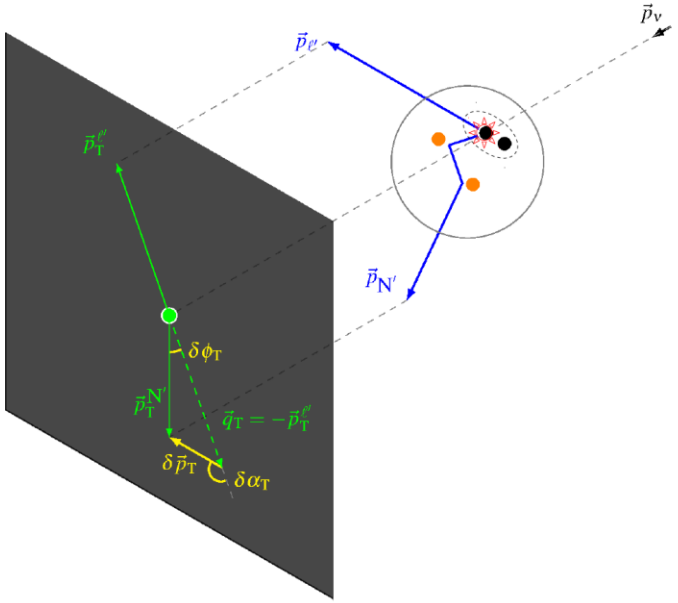
- Reveals discrepancies between different neutrino event generators choosing a more accurate nN interaction model at lower energies

TKI (TRANSVERSE KINEMATIC IMBALANCE)

- TKI: precisely identify intranuclear dynamics or the absence thereof in interactions between nuclei and GeV-neutrinos from accelerators



Stationary nucleon target



Nuclear target ($A > 1$):
Imbalance due nuclear effects
(Fermi motion, FSI, 2p2h)

LHC uses similar technique
to search for BSM particles:

Missing energy

From Wikipedia, the free encyclopedia

In experimental particle physics, **missing energy** refers to energy that is not detected in a particle detector, but is expected due to the laws of conservation of energy and conservation of momentum. Missing energy is carried by particles that do not interact with the electromagnetic or strong forces and thus are not easily detectable, most notably neutrinos.[1] In general, missing energy is used to infer the presence of non-detectable particles and is expected to be a signature of many theories of physics beyond the Standard Model.[2][3][4]

The concept of missing energy is commonly applied in hadron colliders.[5] The initial momentum of the colliding partons along the beam axis is not known — the energy of each hadron is split, and constantly exchanged, between its constituents — so the amount of total missing energy cannot be determined. However, the initial energy in particles traveling transverse to the beam axis is zero, so any net momentum in the transverse direction indicates missing transverse energy, also called missing E_T or MET.

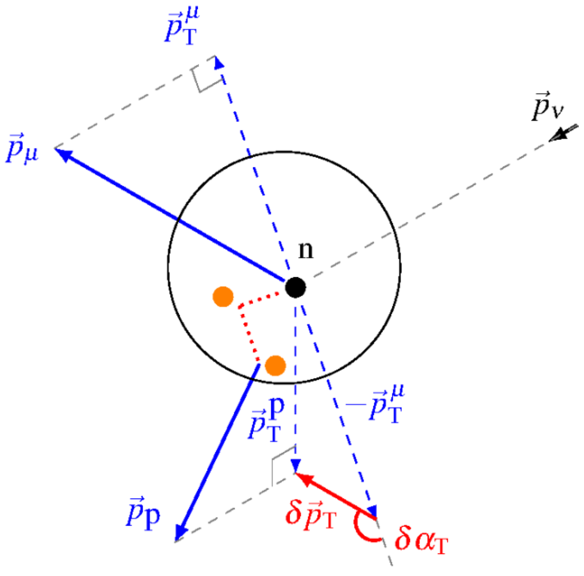
Transverse Kinematic Imbalance
to precisely Identify intra-nuclear dynamics and lack thereof
[Lu et al. Phys. Rev. D92,051302 (2015), Lu et al. Phys. Rev. C94, 015503 (2016)]

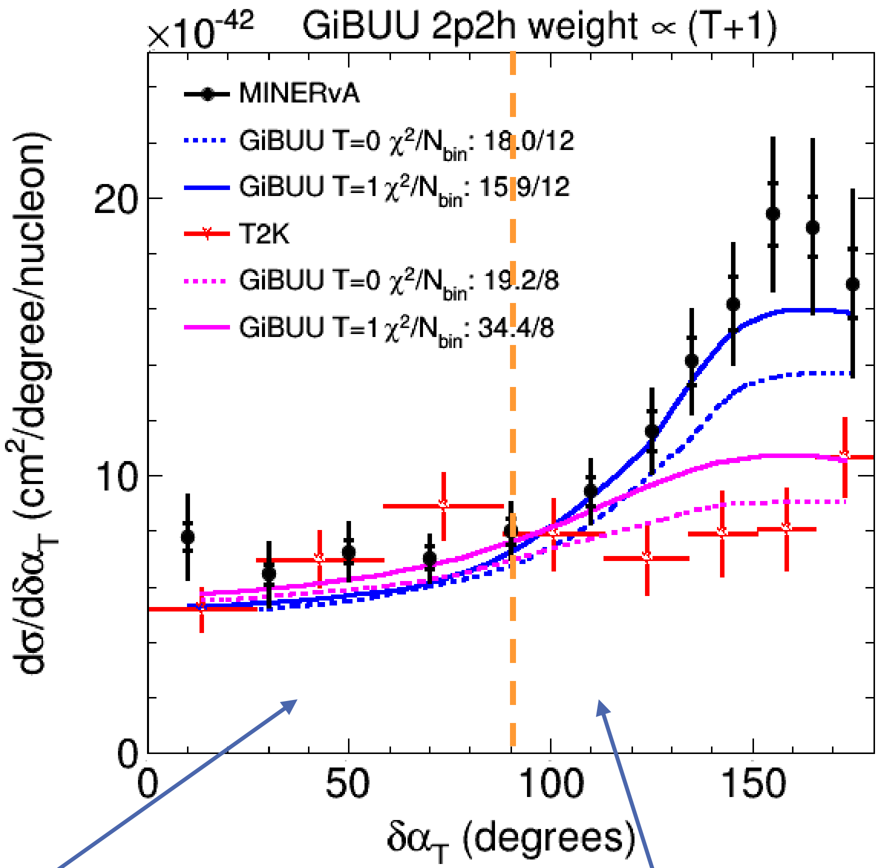
TRANSVERSE BOOSTING ANGLE $\delta\alpha_T$

- Measure intranuclear momentum transfer effects looking at the direction of the imbalance. Use the transverse boosting angle:

$$\delta\alpha_T = \arccos\left(\frac{-\vec{p}_T^{\mu}\cdot\delta\vec{p}_T}{p_T^{\mu}\delta p_T}\right)$$

- Use of TKI techniques proven useful in T2K and MINERνA where energy dependance of nuclear effects has been clearly demonstrated
- Peak Beam Energy: T2K 0.6GeV, MINERvA 3GeV





[MINERvA, Phys.Rev.Lett. 121, 022504 (2018)]

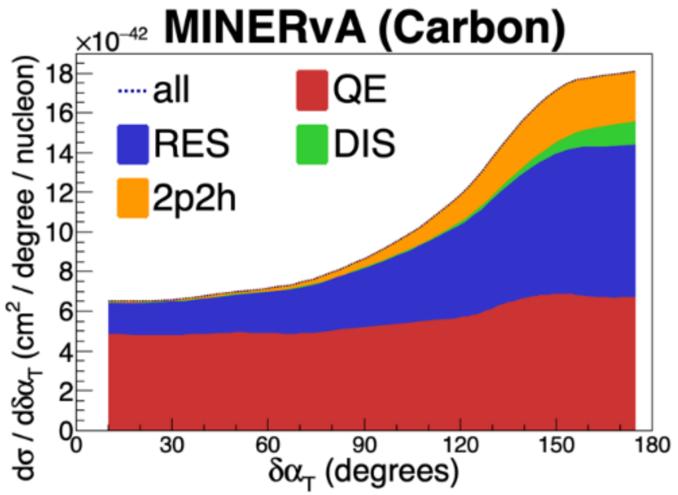
[T2K, Phys. Rev. D 98, 032003 (2018)]

Devoid of (abnormal) FSI acceleration, dominated by pure CCQE events → consistent between MINERνA and T2K

Energy 'dissipation' from FSI deceleration, pion absorption, 2p2h→ increase events in high $\delta\alpha_T$ region

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: $p_\mu > 1.5$ GeV$/c$ and $p_p > 0.45$ GeV$/c$
     - ➢ MINERνA angular acceptance: $\theta_\mu < 20^\circ$ and $\theta_p < 70^\circ$

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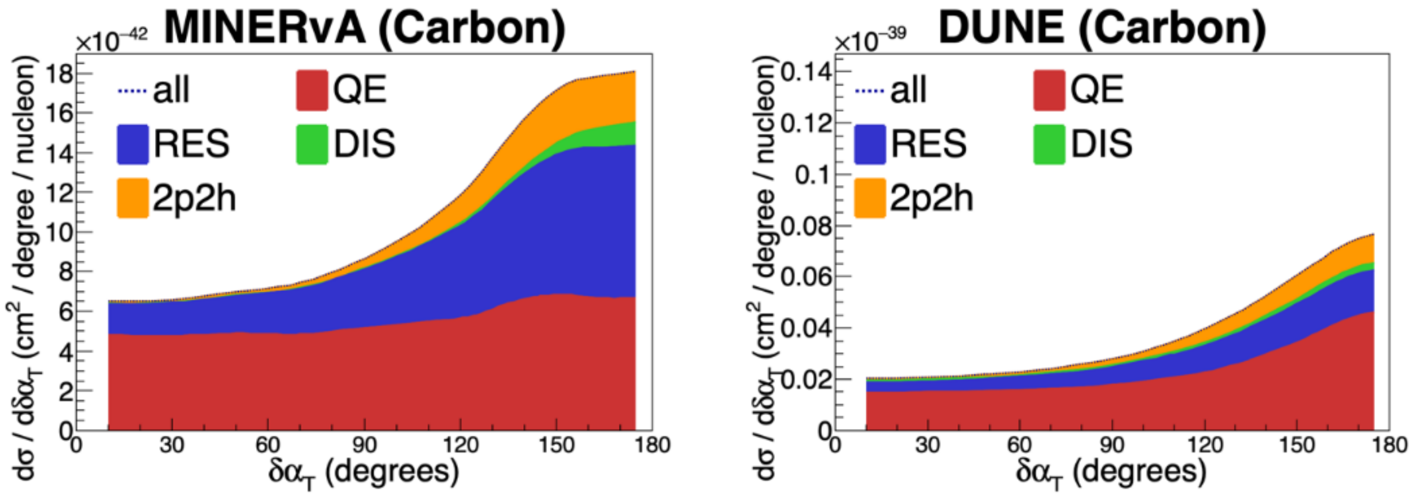

2. Differential cross section as a function of $\delta\alpha_T$ in ND-GAr (test target C):
    - More events with a higher $\delta\alpha_T$ (notice higher scale in 2^{nd} plot 10^{-42} VS 10^{-39})
        - ➢ Lower energy threshold: $p_\mu >$ 0.0254GeV/c and $p_p >$ 0.0751GeV/c
        - ➢ Essentially full 4π angular acceptance

MODEL SIMULATION: ND-GAR ADVANTAGES FOR TKI

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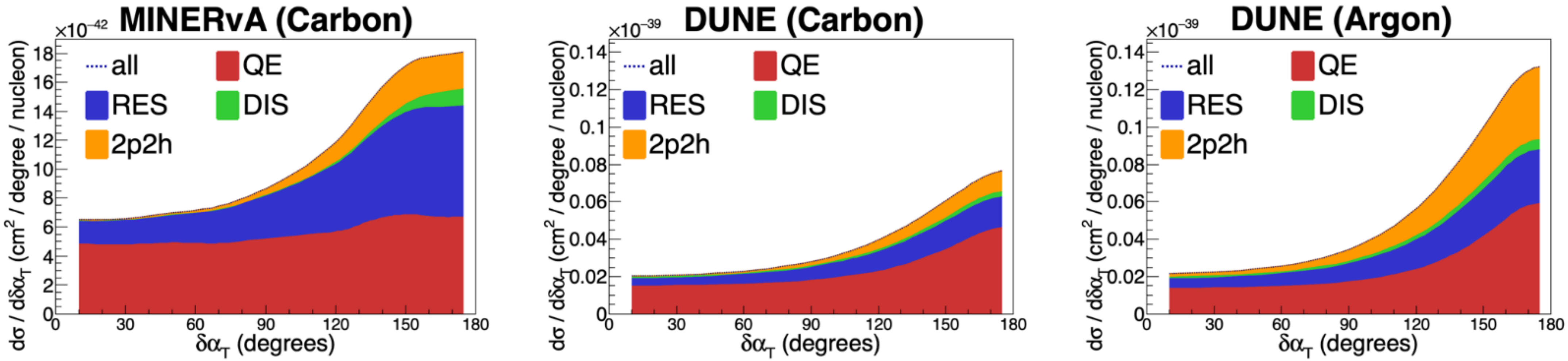
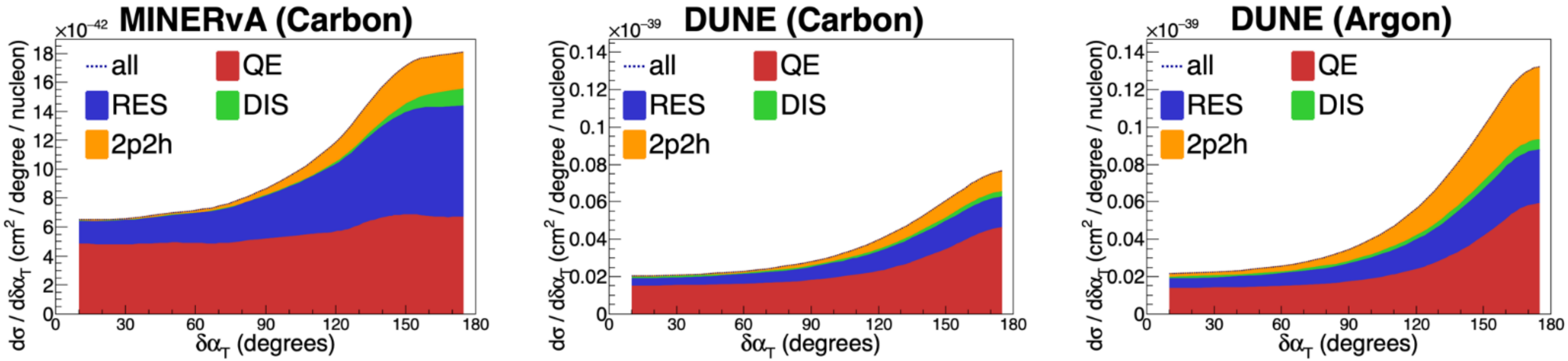


3. Differential cross section as a function of $\delta\alpha_T$ in ND-GAr (Argon target):
   - Increased contribution from FSI effects
     - ➢ Additional strength at high $\delta\alpha_T$
     - ➢ CC0π contribution from RES and DIS events followed by pion absorption
   - Note that model predicts characteristic 2p2h contributions: has to be compared to actual measurement since there is no reliable extrapolation from carbon to argon

MODEL SIMULATION: ND-GAR ADVANTAGES FOR TKI

[DUNE Near-Detector CDR]



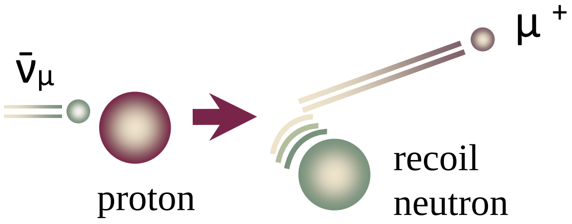
- TKI and other measurements will provide surgical detail about nuclear effects in Argon, removing systematic uncertainties for oscillation analyses in DUNE

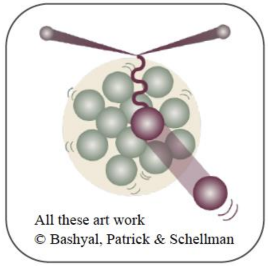
BACK-UP

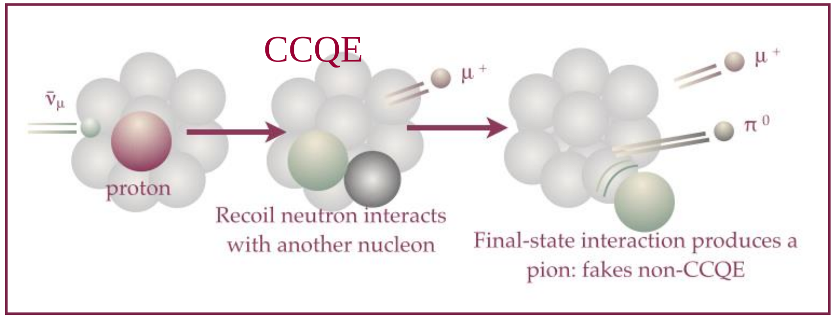
INTRANUCLEAR DYNAMICS

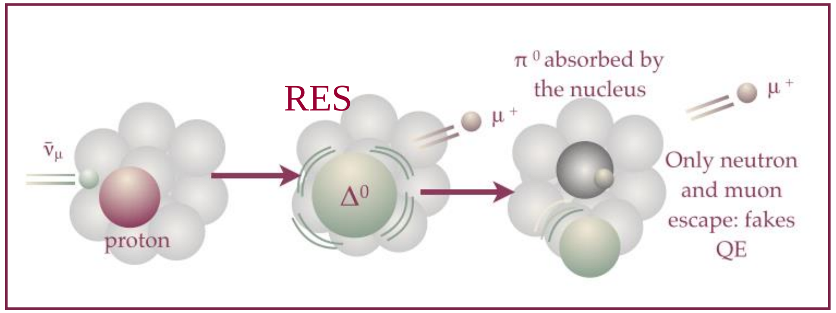
- Nuclear effects in neutrino-nucleus interactions include:
  - ➢ Fermi motion
  - ➢ FSI (Final State Interaction) breaking up nucleus
  - ➢ 2p2h

Charged-current quasielastic (CCQE)









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