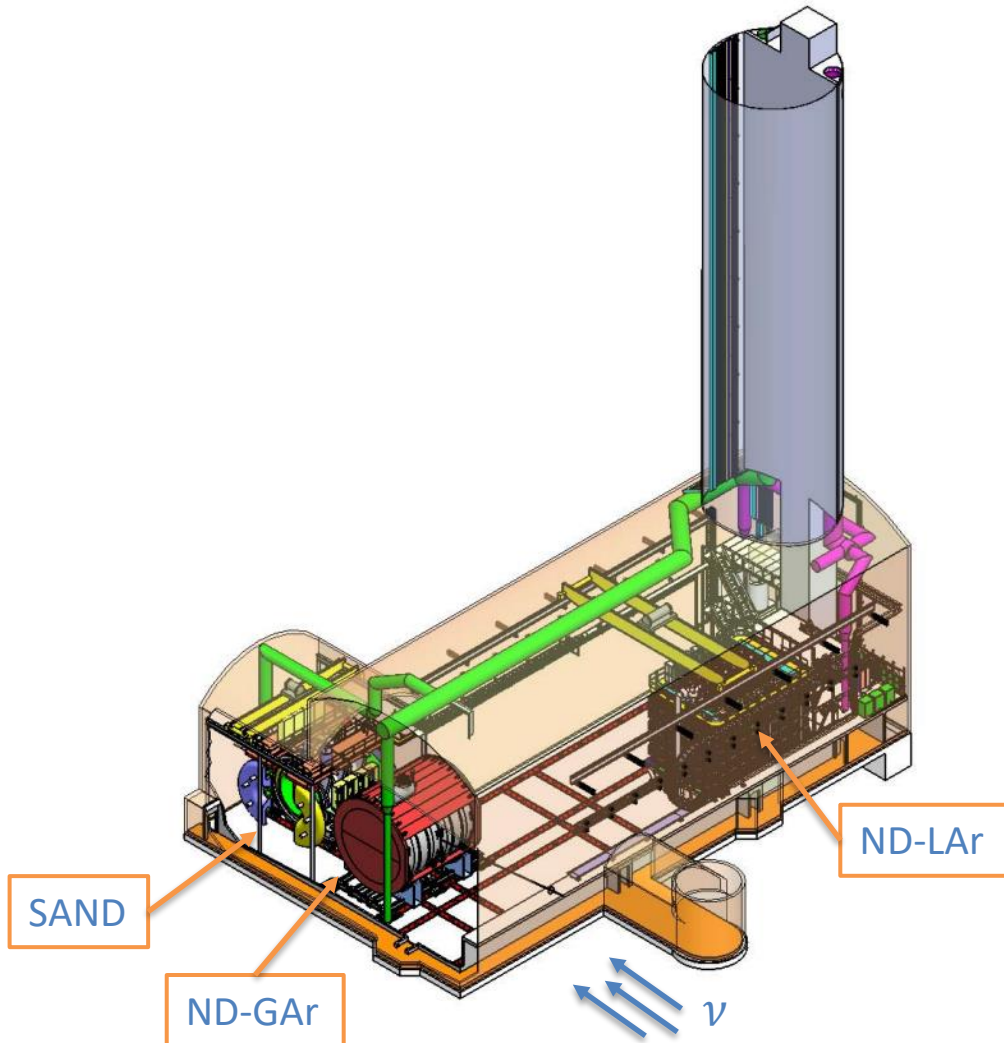


# Physics Potential with DUNE's Argon Gas TPC

Federico Battisti, University of Oxford  
on behalf of the DUNE collaboration  
XIX International Workshop on Neutrino Telescopes  
26/02/2021

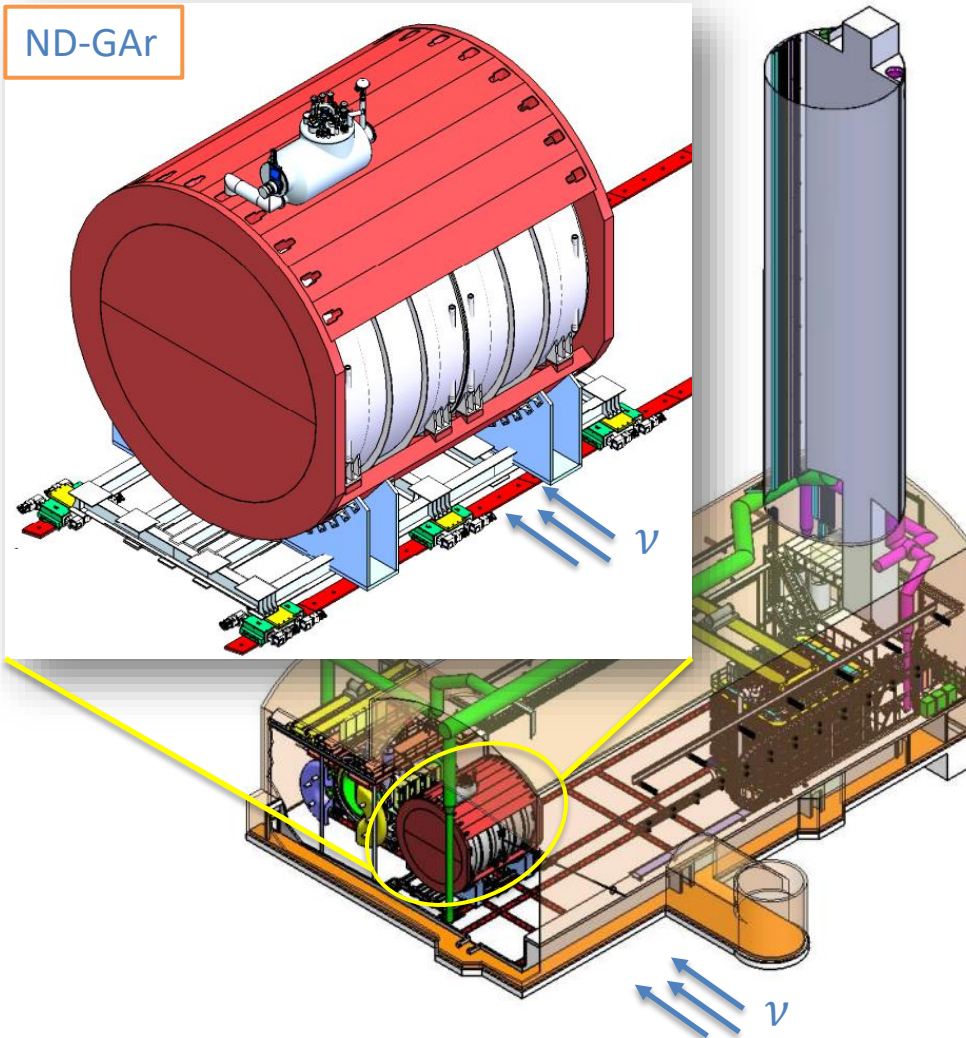
# DUNE's ND: Main components and design



- 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 ( $1.1 \times 10^{21}$  pot with peak energy for  $\nu_\mu$  is  $\sim 2.5$  GeV)
- Near Detector (ND) serves as the experiment's control:
  - Measures and monitors the beam
  - Constrains systematic uncertainties
  - Provides input for neutrino interaction model

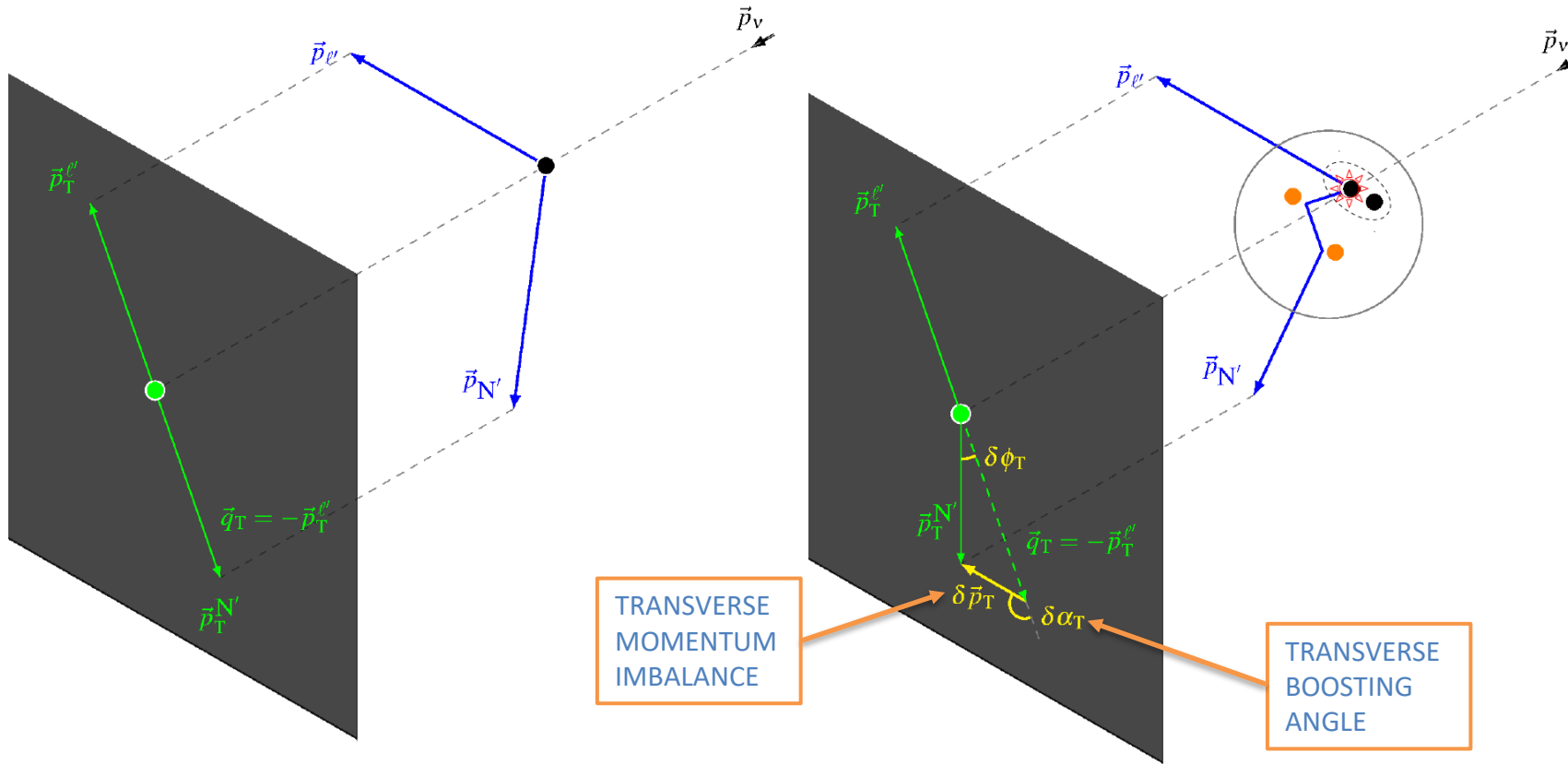
Dr Tanaz Angelina Mohayai, Parallel Contributed Talk, 22/02/2021  
<https://agenda.infn.it/event/24250/contributions/130075/>

# 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<sub>4</sub> 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
- $\nu$ -Ar interactions on low density medium:
  - Very low momentum threshold for charged particle tracking ( $\pi, p$ )
  - Excellent tracking resolution
  - Nearly uniform angular coverage
- **Crucial Objective:** improve  $\nu$ -nucleus interaction model in full phase-space where MC neutrino generators struggle

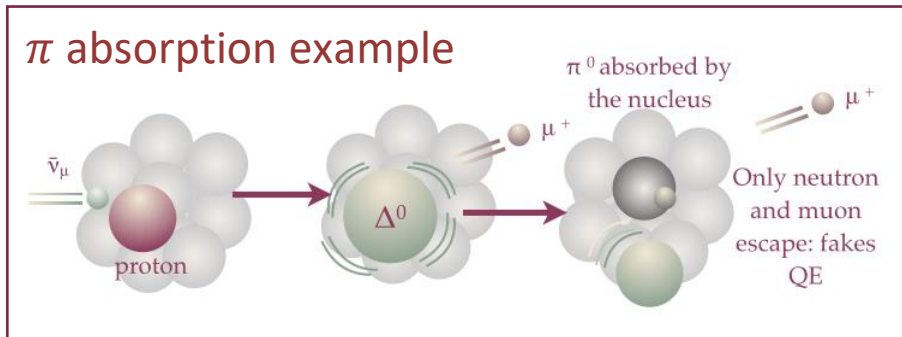
# TKI: Transverse Kinematic Imbalance



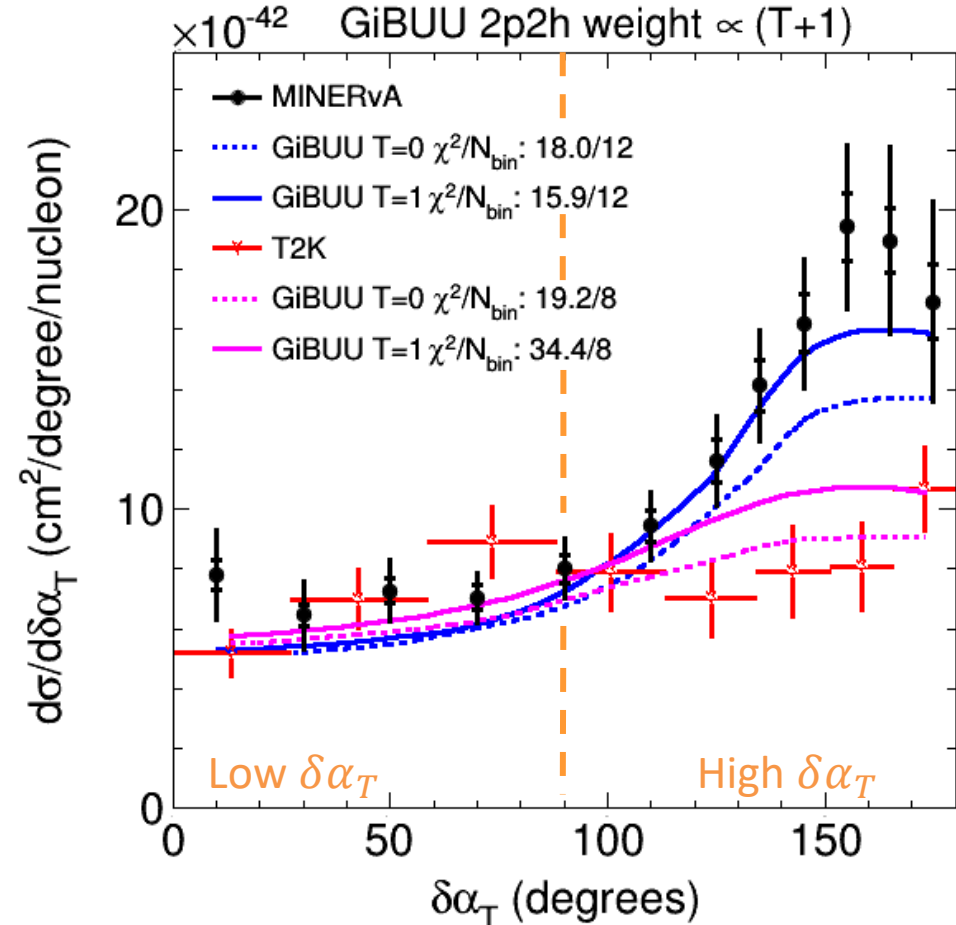
- TKI: precisely identify intranuclear dynamics or the absence thereof  
Lu et al. Phys. Rev. D92,051302 (2015),  
Lu et al. Phys. Rev. C94, 015503 (2016)
- Transverse boosting angle  $\delta\alpha_T$ :
  - Small angle: acceleration
  - Large angle: deceleration
- LHC uses similar technique to search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



© Bashyal, Patrick & Schellman

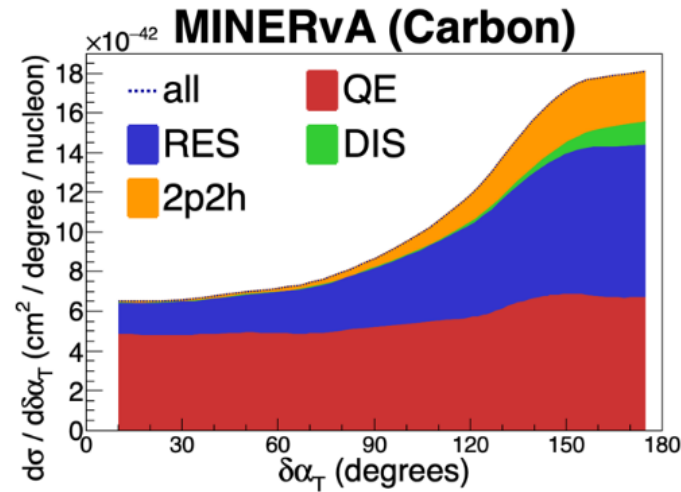


[MINERvA, Phys.Rev.Lett. 121, 022504 (2018)]

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

# Model Predictions: ND-GAr advantages for TKI

[DUNE Near-Detector CDR]



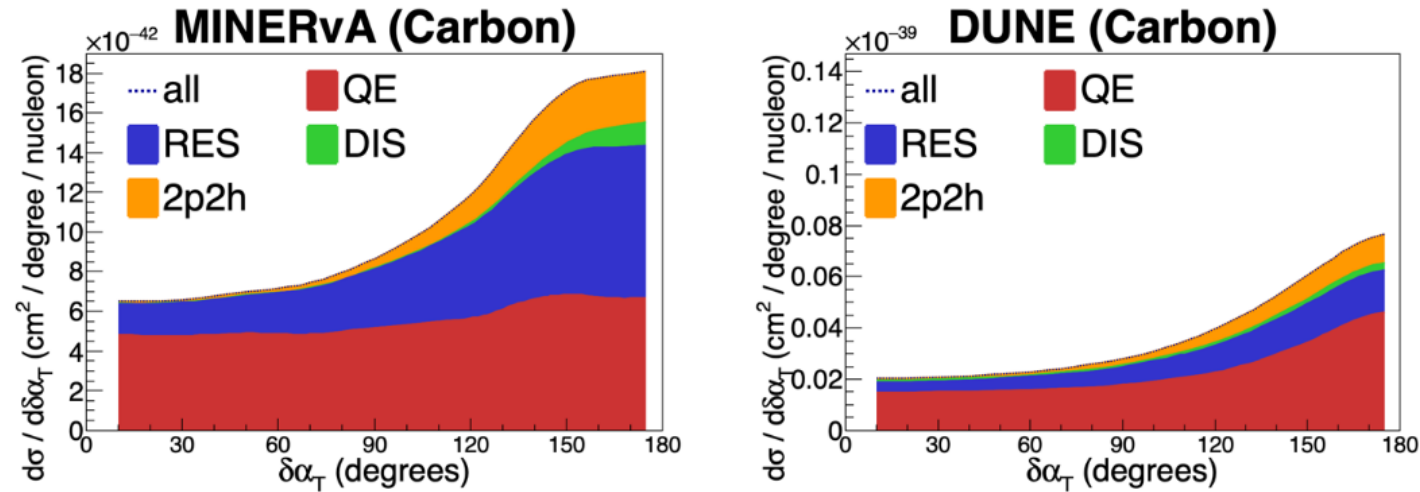
Note: in the calculation only CCQE-like events are considered

## 1. Differential cross section model (GiBUU) calculation as a function of $\delta\alpha_T$ in MINERvA:

- Consider MINERvA detector as baseline for comparison with ND-GAr:
  - Carbon target
  - Energy thresholds:  $T_\mu > 1.4$  GeV and  $T_p > 0.1$  GeV
  - MINERvA angular acceptance:  $\theta_\mu < 20^\circ$  and  $\theta_p < 70^\circ$

# Model Predictions: ND-GAr advantages for TKI

[DUNE Near-Detector CDR]



Note: in the calculation only CCQE-like events are considered

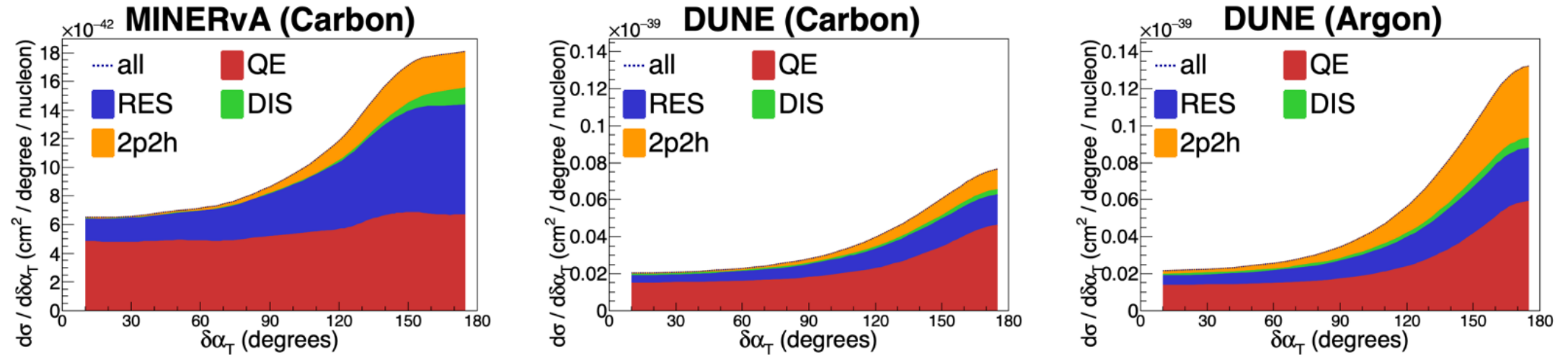
## 2. Differential cross section as a function of $\delta\alpha_T$ in ND-GAr (test target C):

- More events with a higher  $\delta\alpha_T$  (notice higher scale in 2<sup>nd</sup> plot  $10^{-42}$  vs  $10^{-39}$ )
  - Lower energy threshold:  $T_\mu > 3$  MeV and  $T_p > 3$  MeV
  - Essentially full  $4\pi$  angular acceptance



# Model Predictions: ND-GAr advantages for TKI

[DUNE Near-Detector CDR]



Note: in the calculation only CCQE-like events are considered

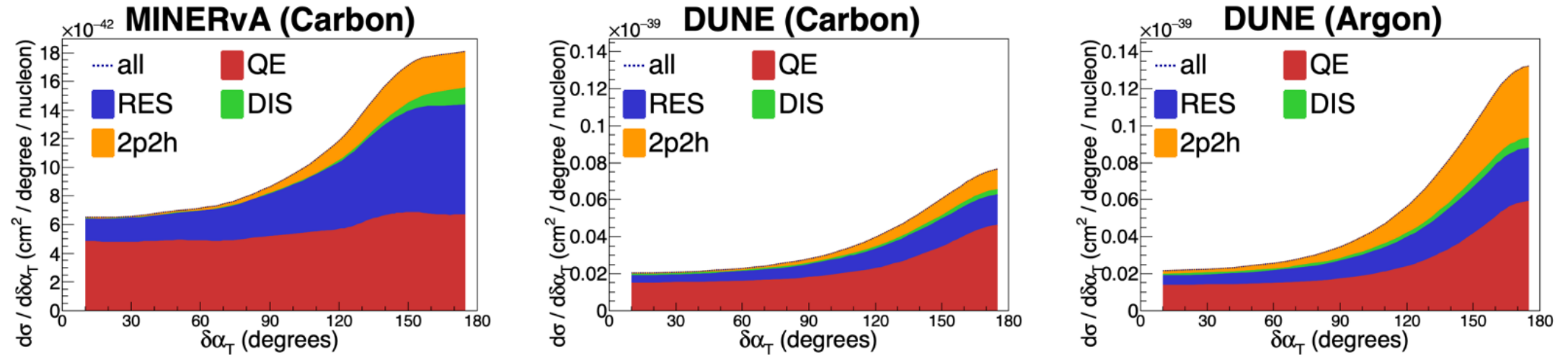
### 3. Differential cross section as a function of $\delta\alpha_T$ in ND-GAr (argon target):

- Increased contribution from FSI effects
  - Additional strength at high  $\delta\alpha_T$
  - CC0 $\pi$  contribution from RES and DIS events followed by pion absorption
- 2p2h contributions: compared to actual measurement; no reliable extrapolation from carbon to argon



# Model Predictions: ND-GAr advantages for TKI

[DUNE Near-Detector CDR]



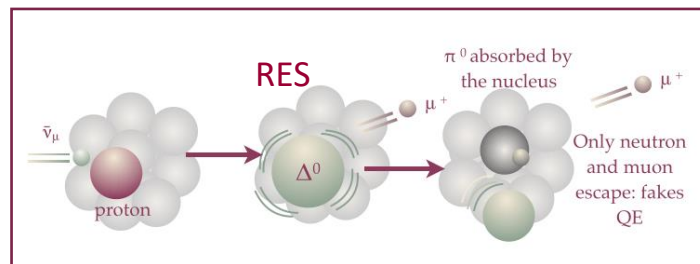
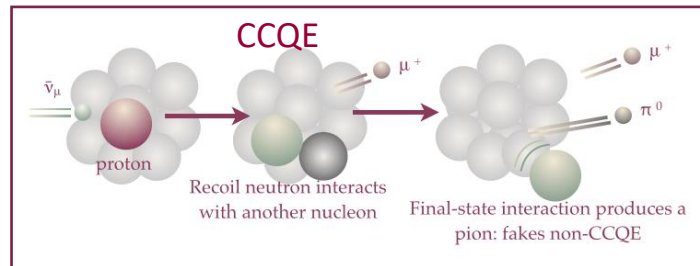
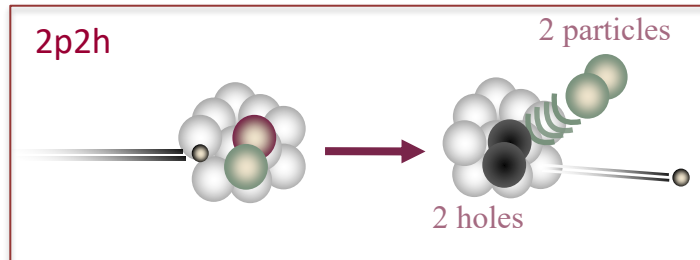
## MAIN TAKEAWAY

- ND-GAr, using TKI and other measurements, will provide surgical detail about nuclear effects in argon, leading to a better understanding of systematic uncertainties for DUNE's oscillation analyses and rare searches

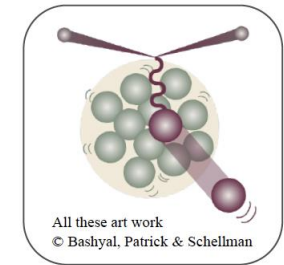
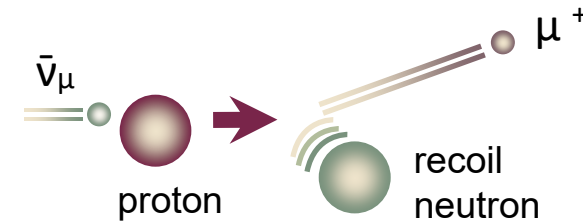
**THANK YOU!**

# Intra-nuclear Dynamics

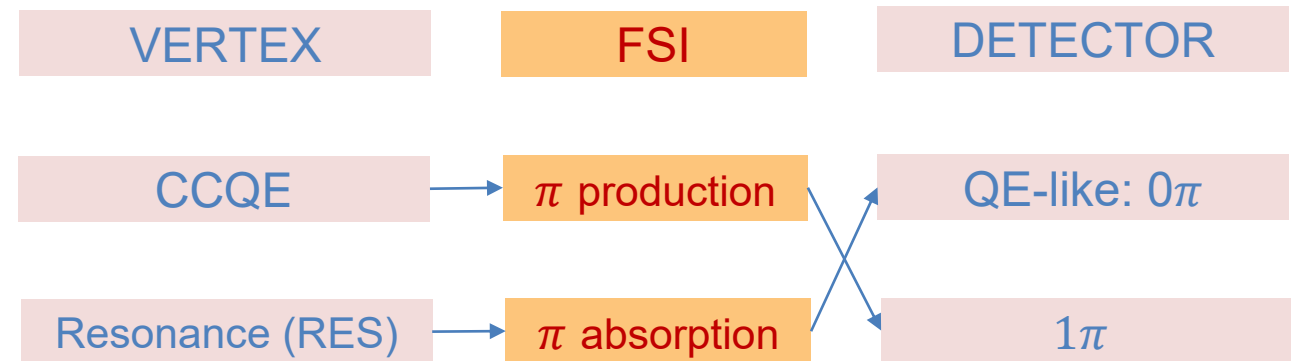
- Nuclear effects in neutrino-nucleus interactions include:
  - Fermi motion
  - FSI (Final State Interaction) breaking up nucleus
  - 2p2h



## Charged-current quasi-elastic (CCQE)



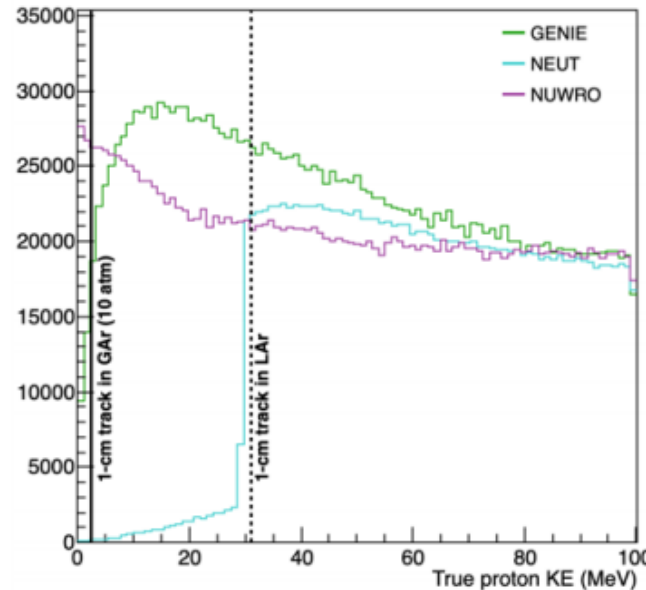
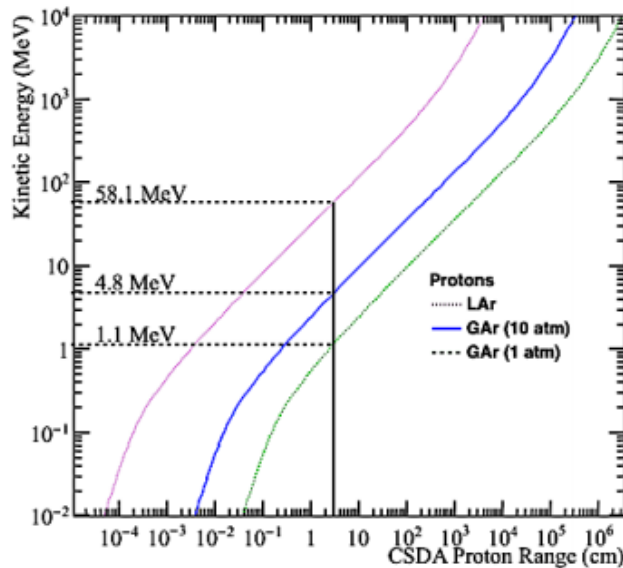
- FSI can (among other things) modify final-state topology creating mix-ups and confusion in cross section measurements



# ND-GAr – Capabilities

- Key capabilities:

- ★ Lower density ( $\rho_{\text{LAr}}/\rho_{\text{GAr}} \approx 85$  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  $\nu$ -N interaction model @ lower energies



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