

# Extracting intranuclear dynamics of the argon nucleus with ProtoDUNE

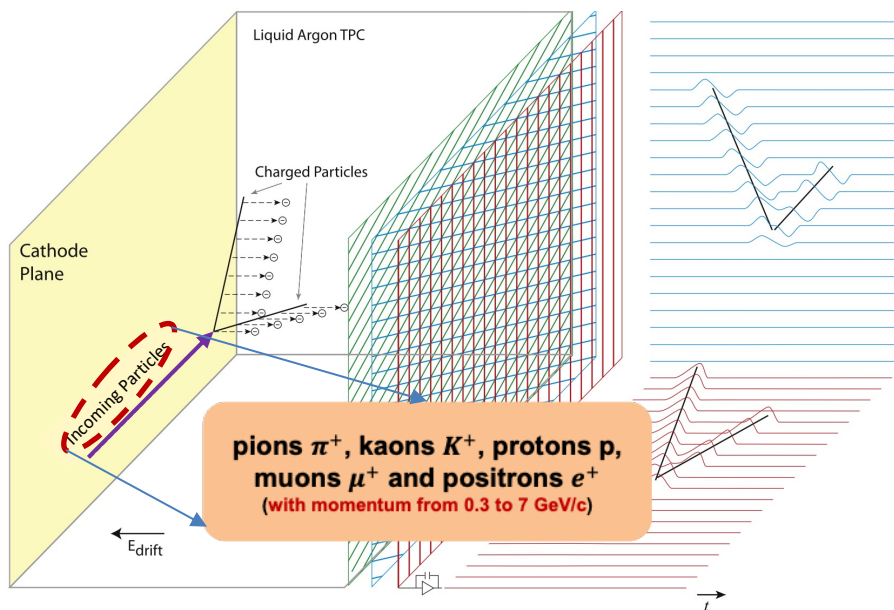
Kang Yang, University of Oxford  
IOP-APP Workshop (OWAN21)  
2021 10<sup>th</sup> Nov. 21

# ProtoDUNE-Single Phase

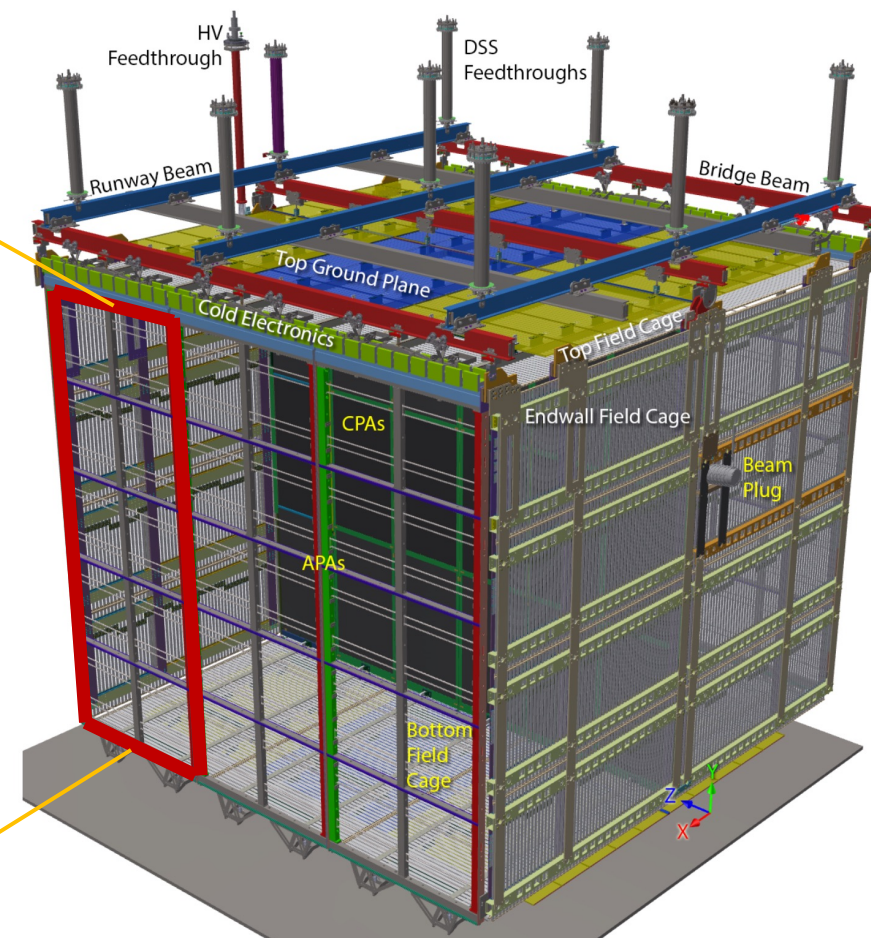
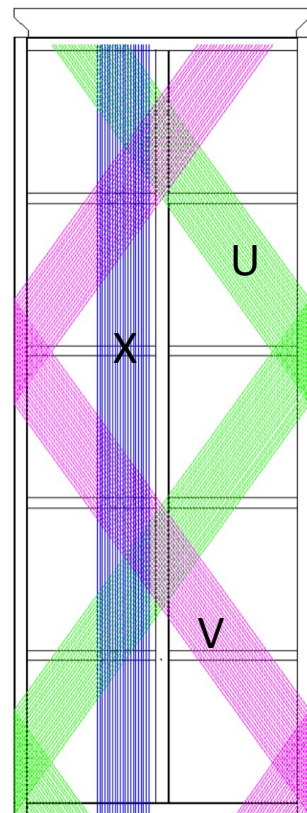
The protoDUNE single-phase apparatus is one of the two large scale prototypes of the far detector module of DUNE.

❖ Several goals:

- Cryostat design validation (electronics, high voltage, LAr purity)
- Data acquisition and storage
- Detector performance characterisation
- Event reconstruction and analysis



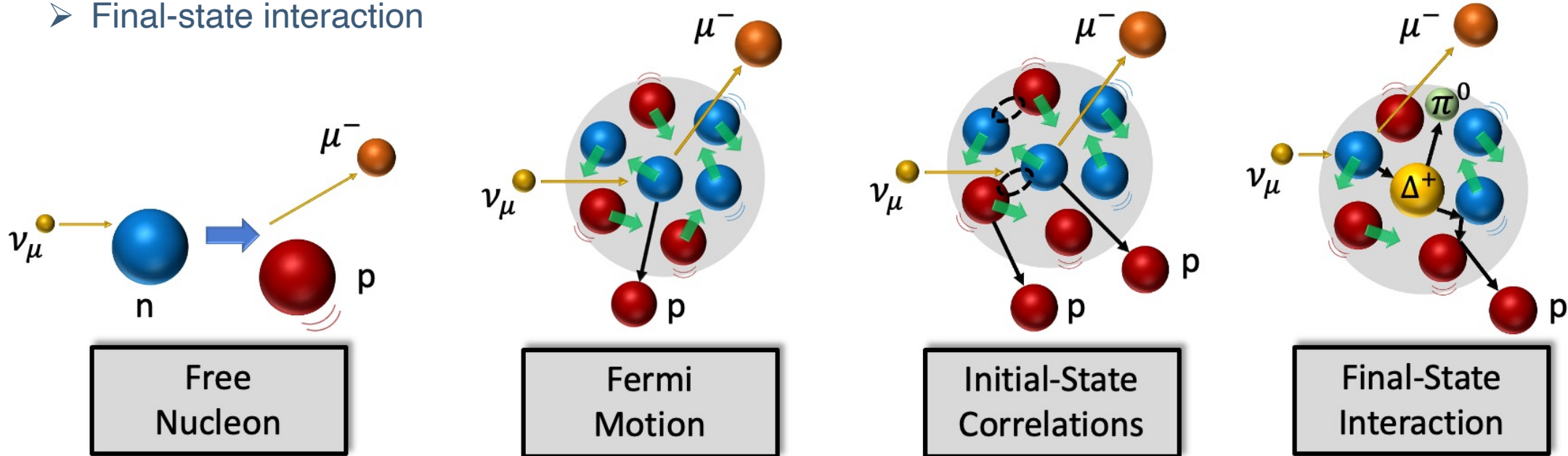
ProtoDUNE-SP APA



# Intranuclear Dynamics

Large systematics uncertainty in  $\nu$ -A interactions

- ❖ Several nuclear effects:
  - Fermi motion
  - 2p2h excitation
  - Final-state interaction

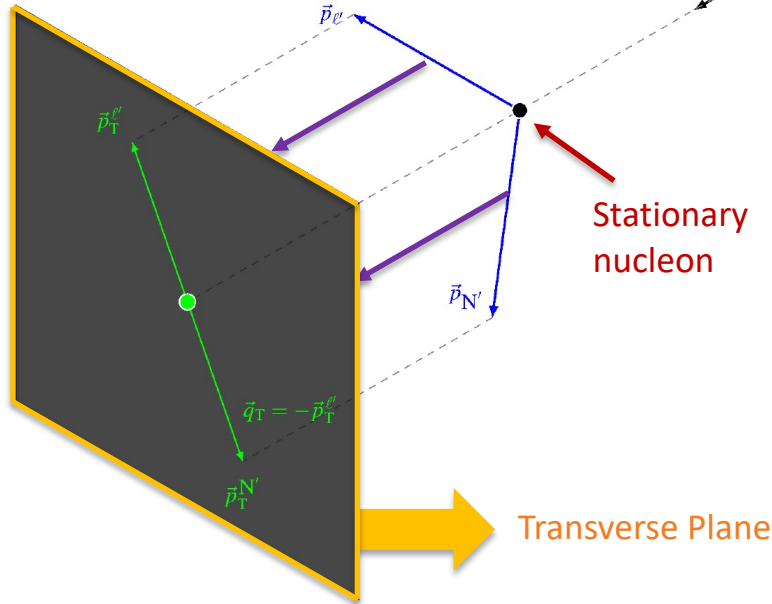


These intranuclear dynamics are all convoluted together in an experimental measurement.

# Transverse Kinematic Imbalance (TKI)

Artwork by Xianguo Lu

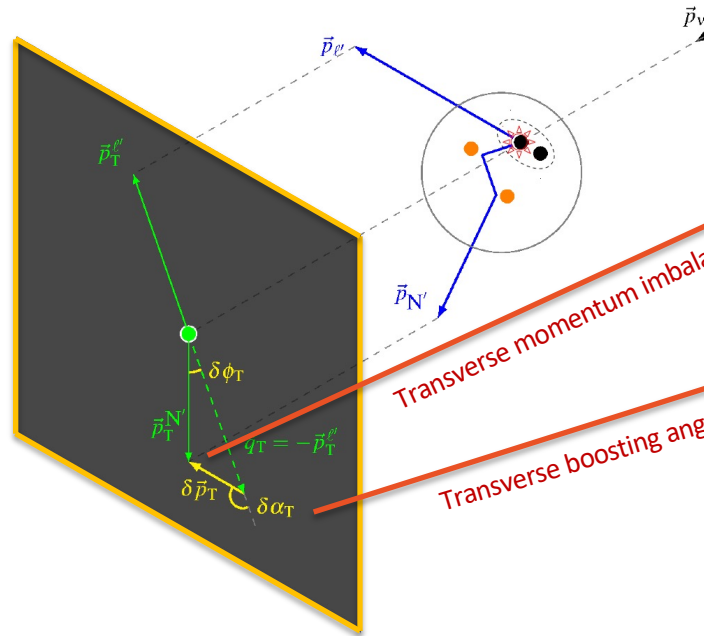
Incoming neutrino



Transverse Plane

Stationary nuclear target

– Precisely identify intranuclear dynamics, or the absence thereof, in interactions between nuclei and GeV-neutrinos from accelerators



We can define several TKI variables:

$$\delta \vec{p}_T \equiv \vec{p}_T^{e'} + \vec{p}_T^{N'}$$

Transverse momentum imbalance

$$\delta \alpha_T \equiv \arccos \frac{-\vec{p}_T^{e'} \cdot \delta \vec{p}_T}{p_T^{e'} \delta p_T}$$

Transverse boosting angle

Struck nucleon momentum  $p_N$ :

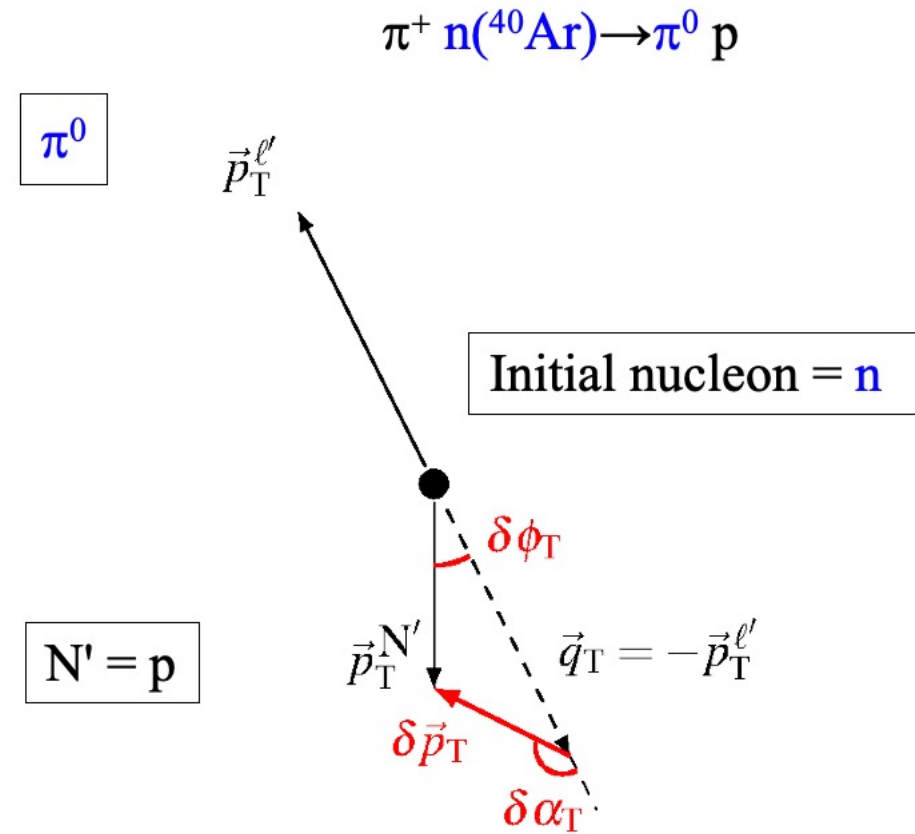
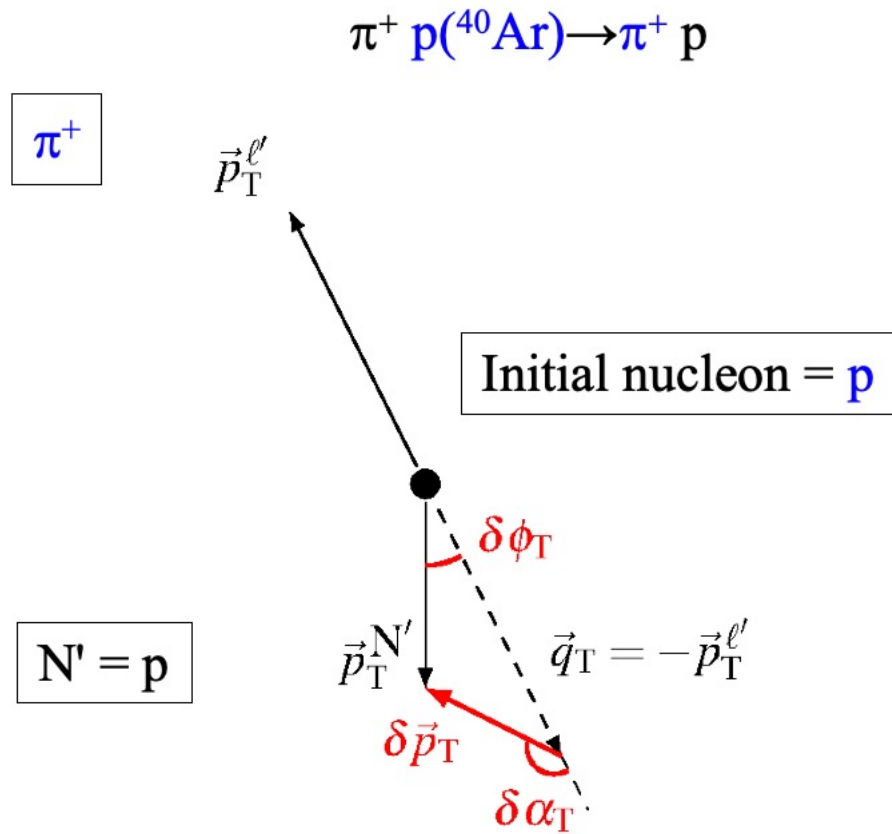
$$p_N = (\delta p_T^2 + \delta p_L^2)^{1/2}$$

[Lu. *et al.* [Phys. Rev. D92, 051302 \(2015\)](#), Lu. *et al.* [Phys. Rev. C94, 015503 \(2016\)](#)]

[Furmanski & Sobczyk, *Phys.Rev.C* 95, 065501 (2017)]

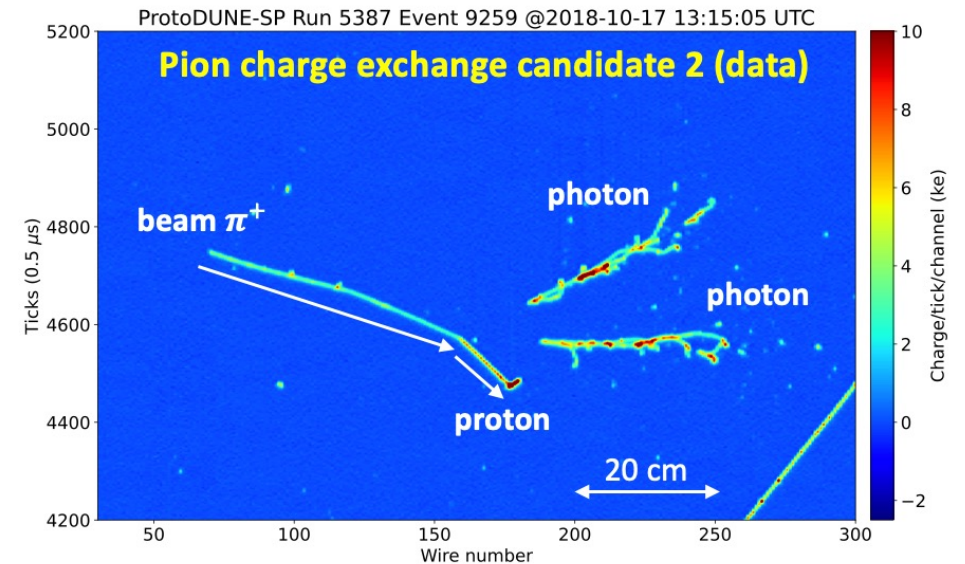
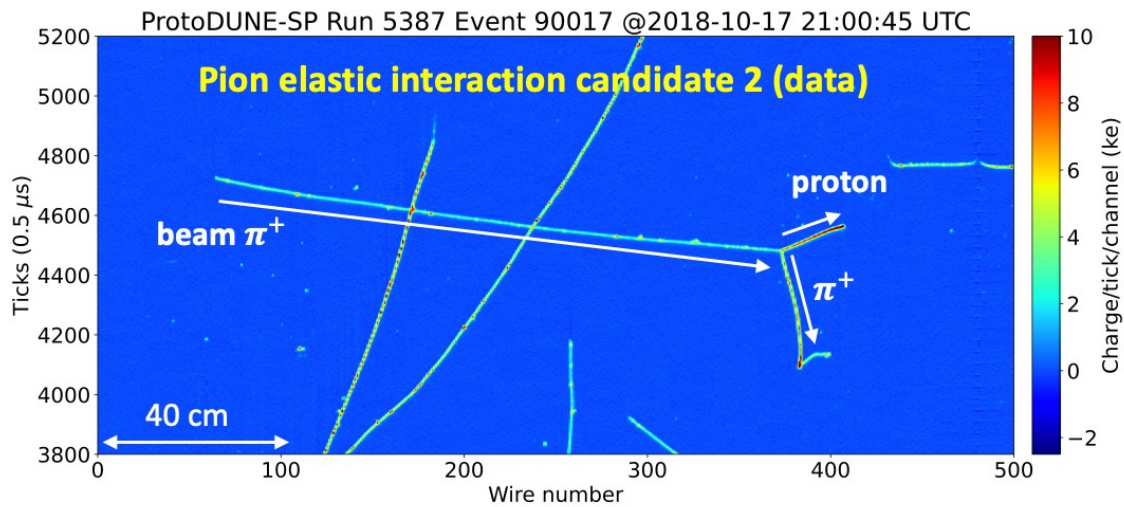
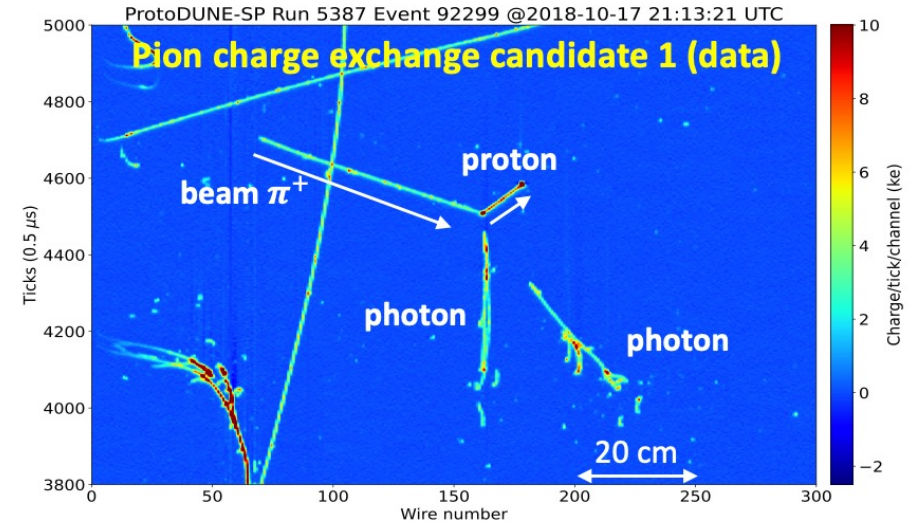
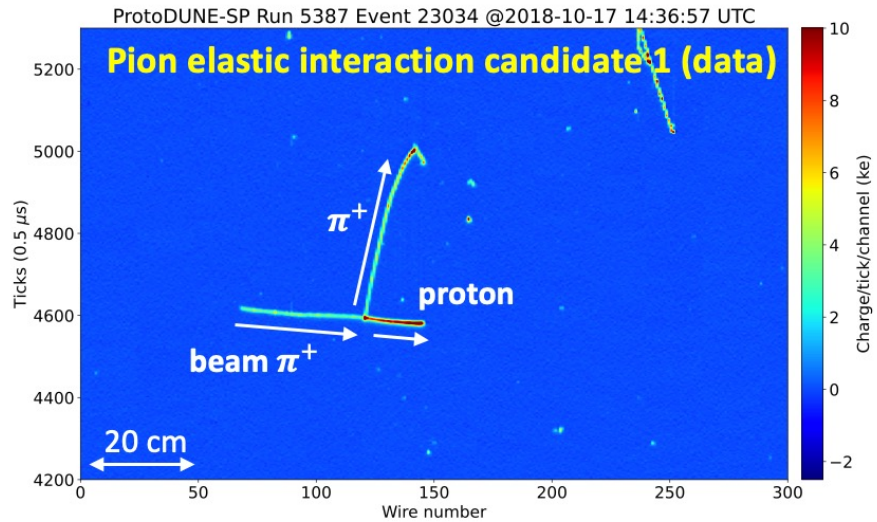
# TKI in protoDUNE

$\pi^+ p(^{40}\text{Ar}) \rightarrow \pi^+ p$  vs.  $\pi^+ n(^{40}\text{Ar}) \rightarrow \pi^0 p$

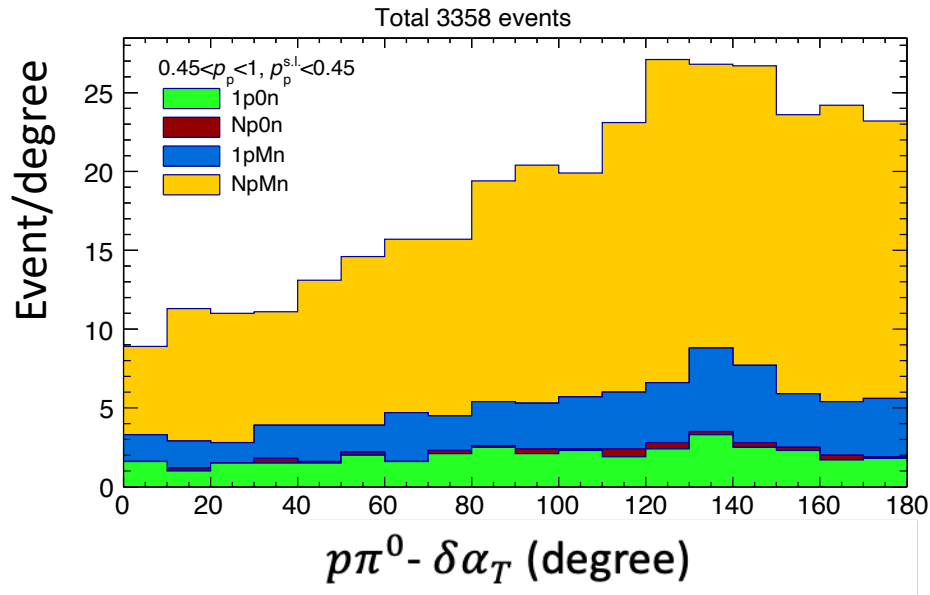


- ❖ The incoming particle is **pion** in protoDUNE with **precisely measured momentum** on an event by event basis.
- ❖ Argon 18 protons, 22 neutrons, previous TKI measurements are on carbon and oxygen (iso-symmetric)
- ❖ Use pion to probe intranuclear dynamics in argon is fun, especially the  $p-\pi^0$  channel.

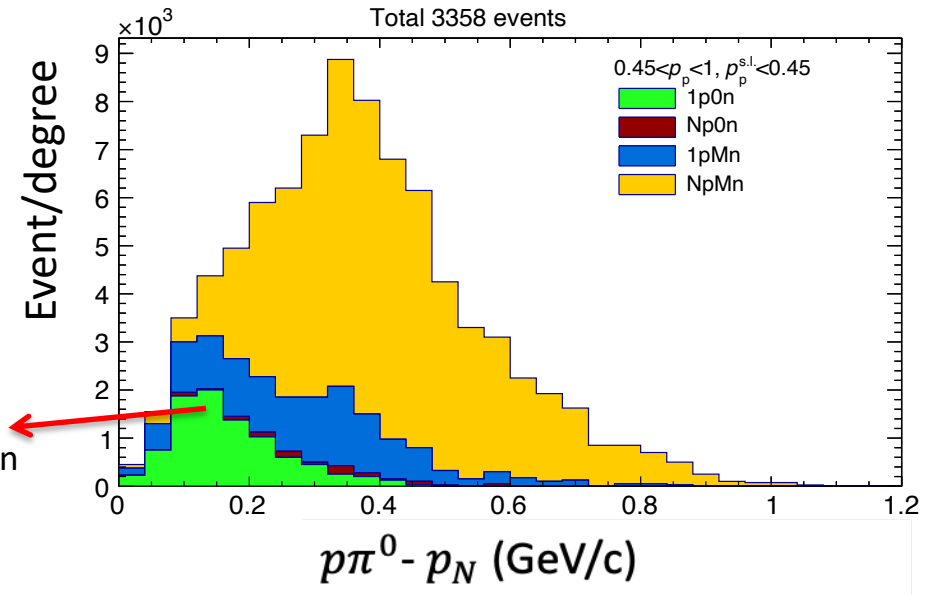
# Event Display ( 1 GeV/c Pion Beam)



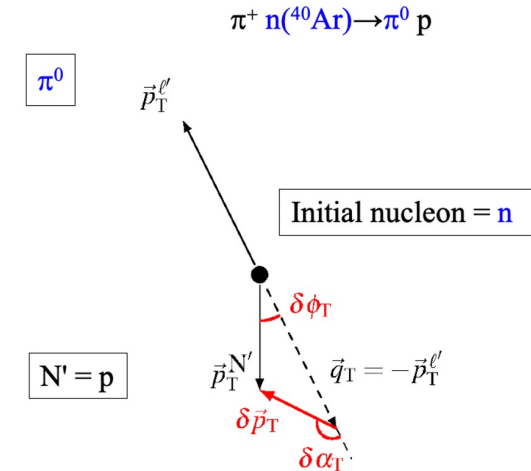
# Truth Signal at protoDUNE



Neutron Fermi motion in argon



- ❖ Since the Fermi motion is isotropic, the distribution of  $\alpha_T$  should be flat if we only consider Fermi motion of the initial nucleon.
- ❖ Large  $\alpha_T$  represents the deceleration of protons in 1p sample.
- ❖ A Fermi motion peak can be found around 0.2 GeV/c.

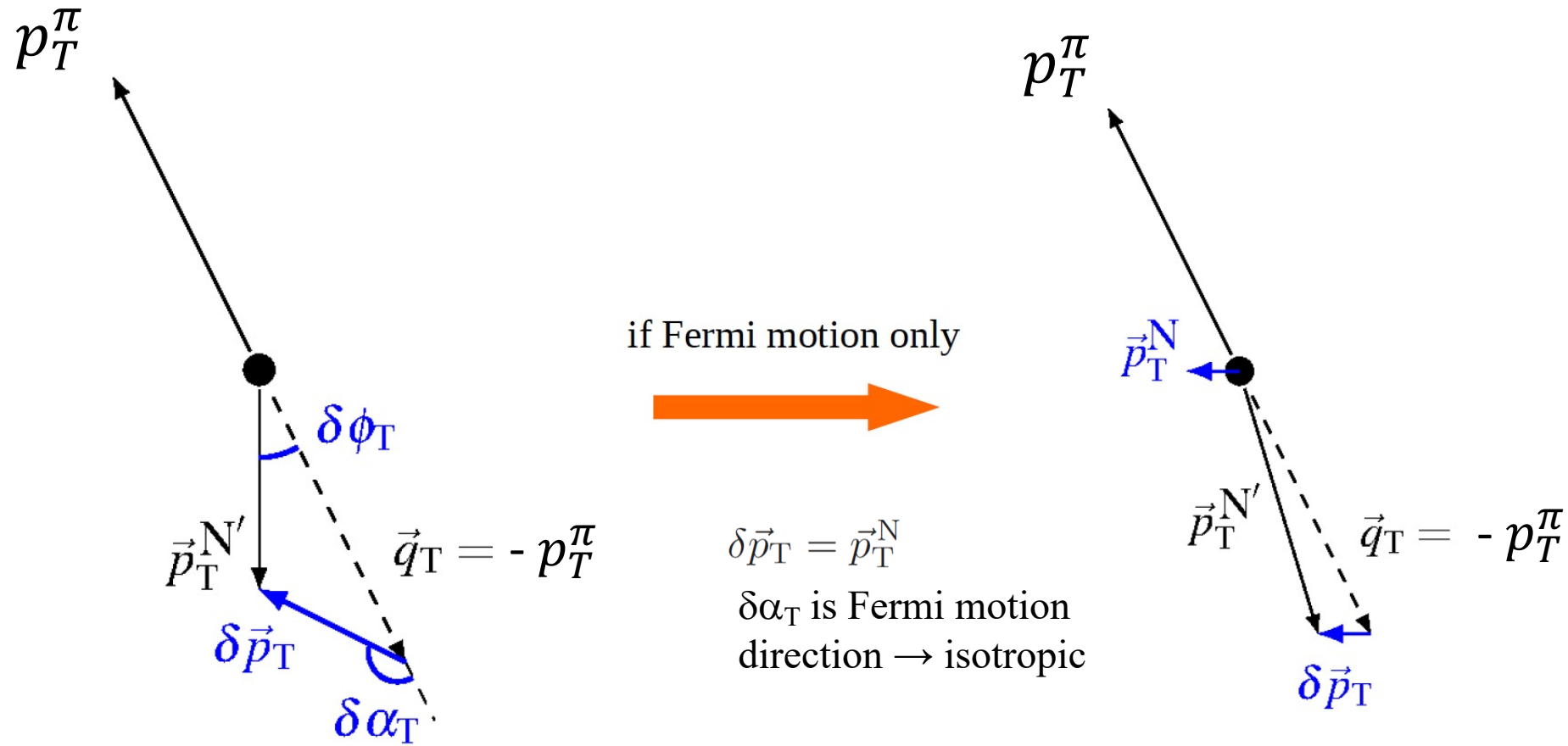


**Thank you for your attention !**



# Backup Slides

# Transverse Momentum Imbalance $\delta p_T$



if Fermi motion only



$$\delta \vec{p}_T = \vec{p}_T^N$$

$\delta \alpha_T$  is Fermi motion  
direction  $\rightarrow$  isotropic

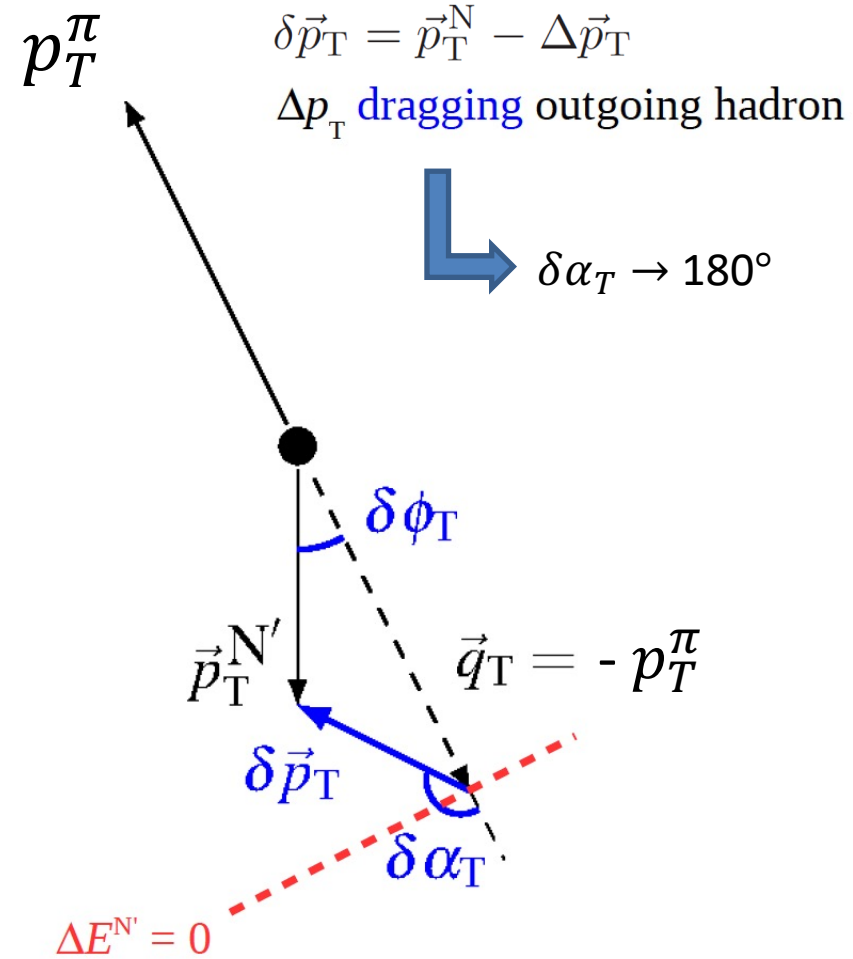
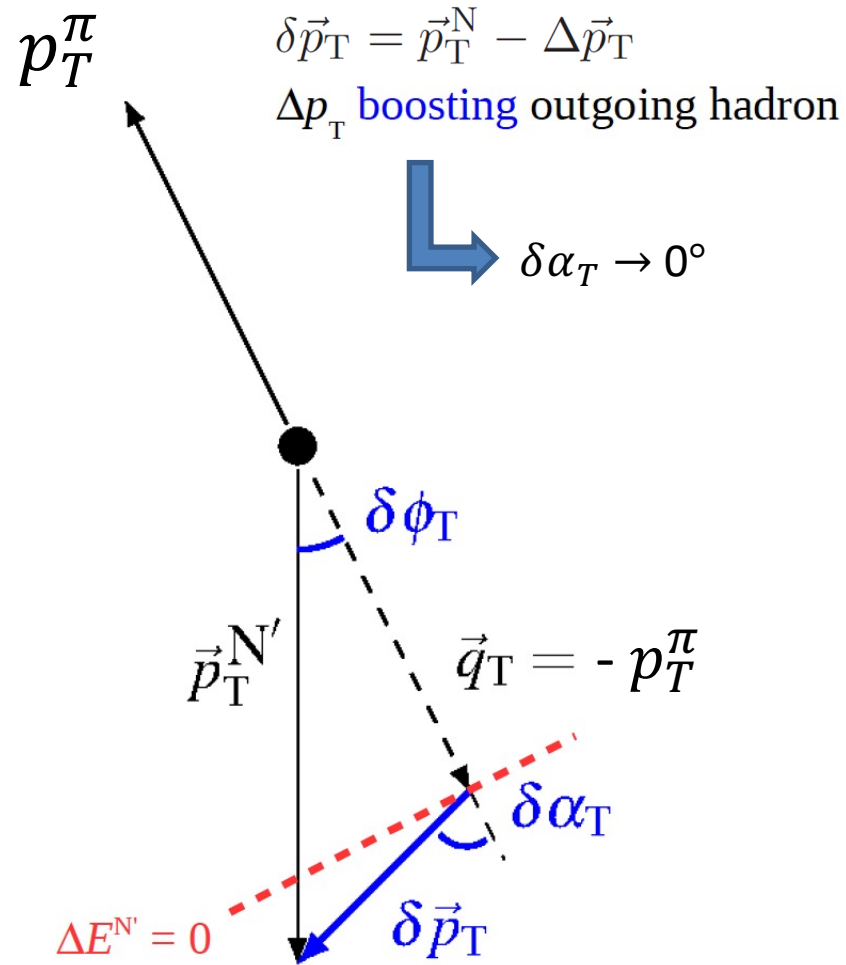
In full

$$\delta \vec{p}_T = \vec{p}_T^N - \Delta \vec{p}_T$$

$\Delta \vec{p}_T$  FSI and missing particles

[XL *et al.*, Phys.Rev.C 94, 015503 (2016)]

# Transverse Boosting Angle $\delta\alpha_T$



[XL *et al.*, Phys.Rev.C 94, 015503 (2016)]