Overview of the Transverse-Kinematic Imbalance Analyses at MINERvA

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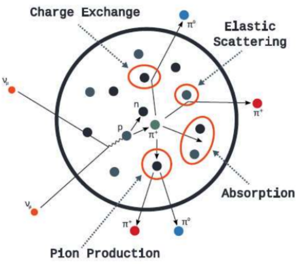
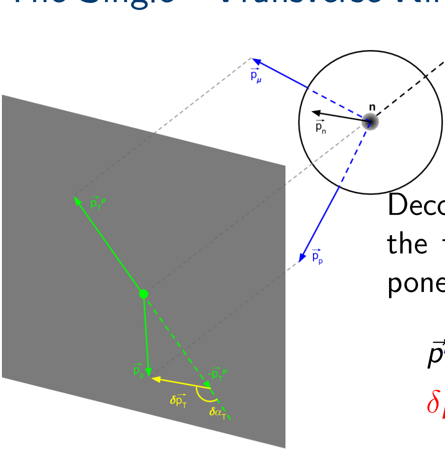
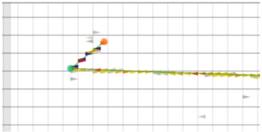


MINERvA aims to

- measure nuclear effects, and
- show areas for improving generators.

The **S**ingle - **T**ransverse **K**inematic **I**mbalance





Decomposes final state momenta into the transverse and longitudinal components

$$\vec{p}^{\mu,P} = (\vec{p}_T^{\mu,P}, \vec{p}_L^{\mu,P})$$

$$\delta\vec{p}_T = \vec{p}_T^{\mu} + \vec{p}_T^{P}$$

$$\delta p_L = \frac{1}{2}R - \frac{m_{A'}^2 + \delta p_T^2}{2R}$$

$$R \equiv m_A + p_L^{\mu} + P_L^{P} - E^{\mu} - E^{P}$$

$$p_{\mathrm{n}} = |\delta\vec{p}_T + \delta\vec{p}_L|$$

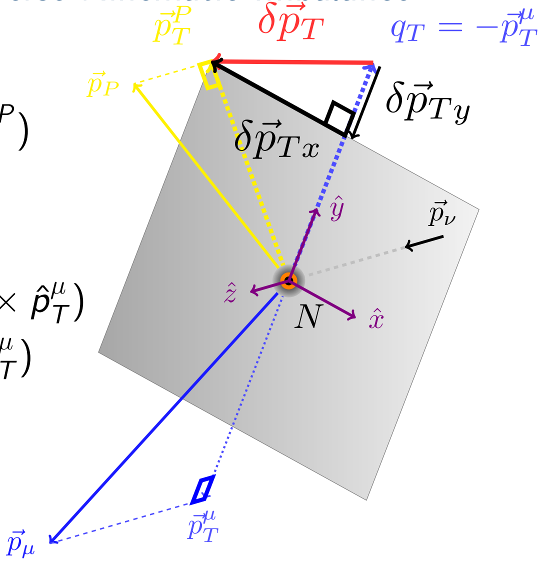
The **S**ingle - **T**ransverse **K**inematic **I**mbalance

$$\vec{p}^{\mu,P} = (\vec{p}_T^{\mu,P}, \vec{p}_L^{\mu,P})$$

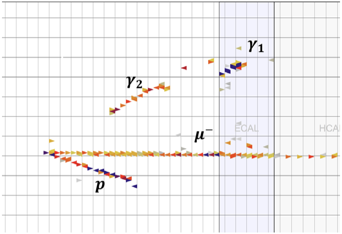
$$\delta\vec{p}_T = \vec{p}_T^{\mu} + \vec{p}_T^{P}$$

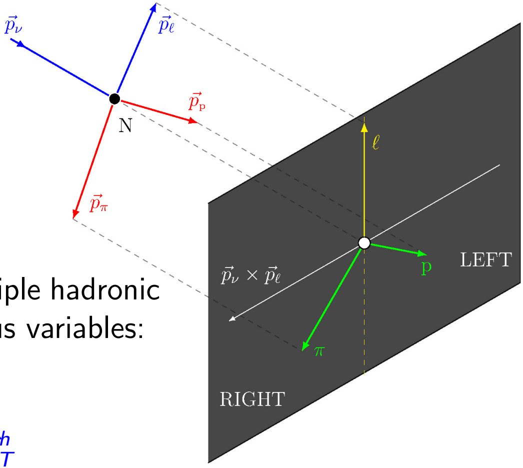
$$\delta p_{\mathrm{Tx}} = \vec{p}_T \cdot (\hat{p}_\nu \times \hat{p}_T^{\mu})$$

$$\delta p_{\mathrm{Ty}} = \vec{p}_T \cdot (-\hat{p}_T^{\mu})$$



The Generalized **T**ransverse **K**inematic **I**mbalance



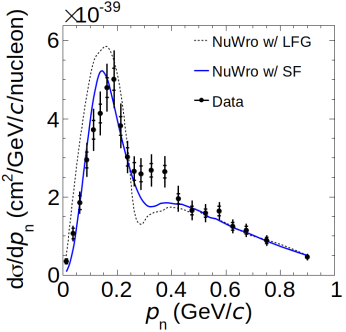


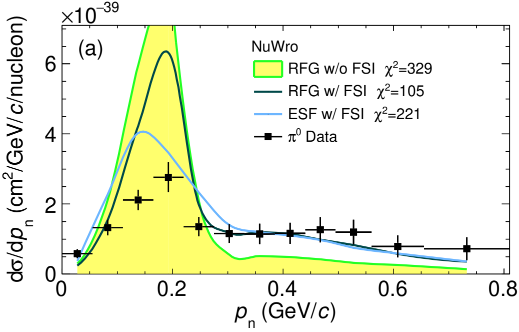
Generalizes STKI to multiple hadronic final states with analogous variables:

$$\vec{p}_T^{\,h} = \vec{p}_T^{\,\pi} + \vec{p}_T^{\,P}$$

$$\delta \vec{p}_T = \vec{p}_T^{\,\mu} + \vec{p}_T^{\,h}$$

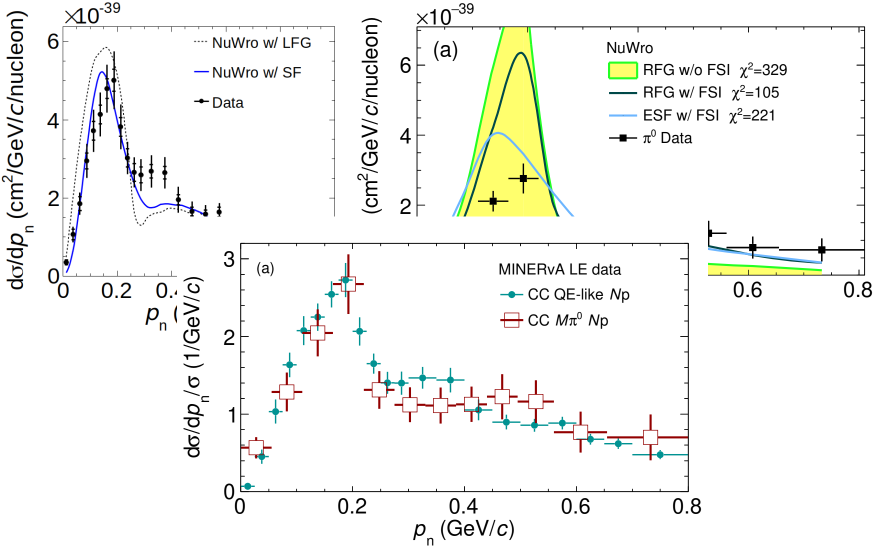
Left: $CC0\pi$, Right: $CC\pi^0$



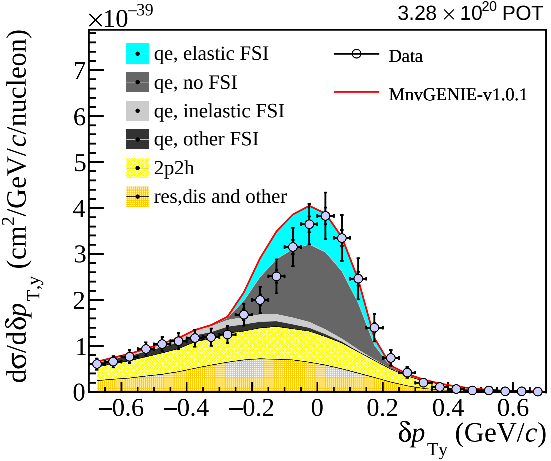


- Initial state models:
  - Relativistic Fermi gas (RFG)
  - Local Fermi gas (LFG)
  - Spectral function (SF) and effective spectral function (ESF)
  - Decent agreement for $\nu n \to \mu p$ but not for $\nu n \to \mu p \pi$.

Left: $CC0\pi$, Right: $CC\pi^0$



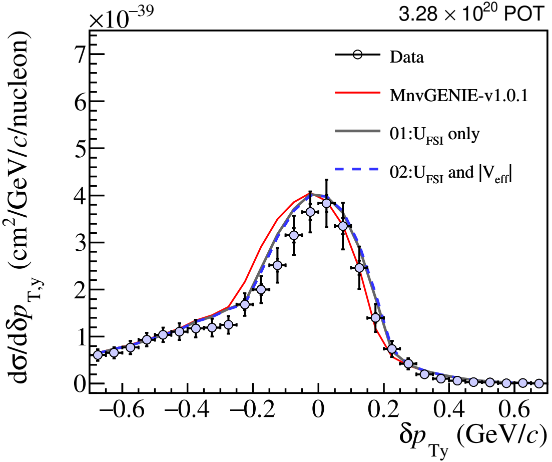
δp_{Ty}



δp_{Ty}:

- Expected asymmetry in non-QE contribution due to momentum conservation.
- Shifts in peak position associated with GENIE's treatment of binding energy.

δp_{Ty}



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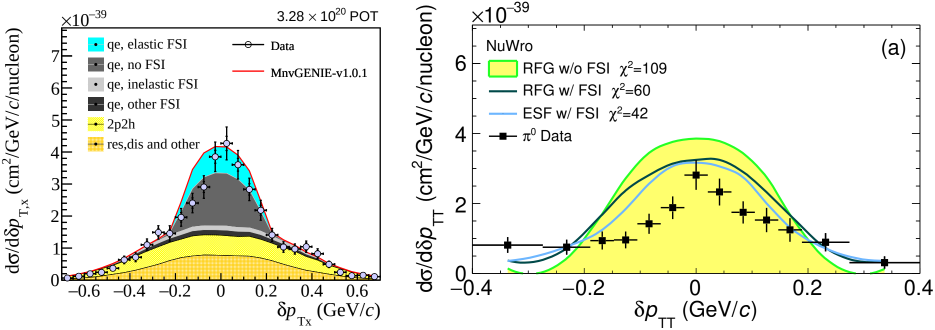
δp_{Tx} and δp_{TT}

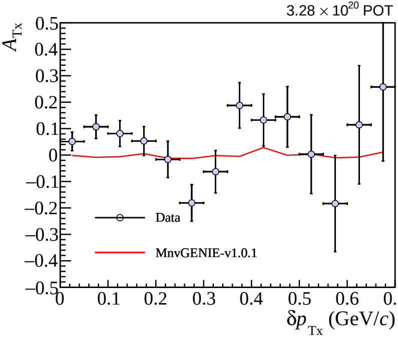


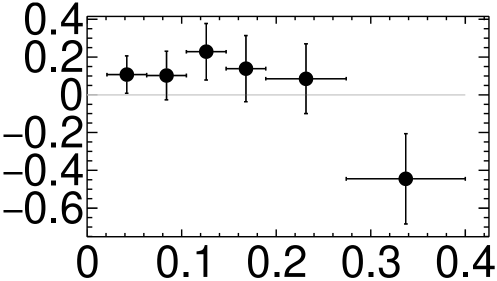
δp_{TT} generalizes δp_{Tx} to multiple hadronic final states.

- Spread in QE due to Fermi motion.
- Slight asymmetry in δp_{Tx} and δp_{TT} where models predict symmetry.

δp_{Tx} and δp_{TT}

$$A(|\delta p_{\mathrm{Tx}}|) = \frac{R-L}{R+L}(|\delta p_{\mathrm{Tx}}|)$$





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Summary and Future Prospects

The TKI variables are powerful tools to observe the nuclear effects.

MINERvA poineered TKI studies using its LE data with 3 publications.

MINERvA's ME dataset contains significantly more statistics and we are looking at TKI in the nuclear targets as well as higher dimensional results on carbon.

Thank you!