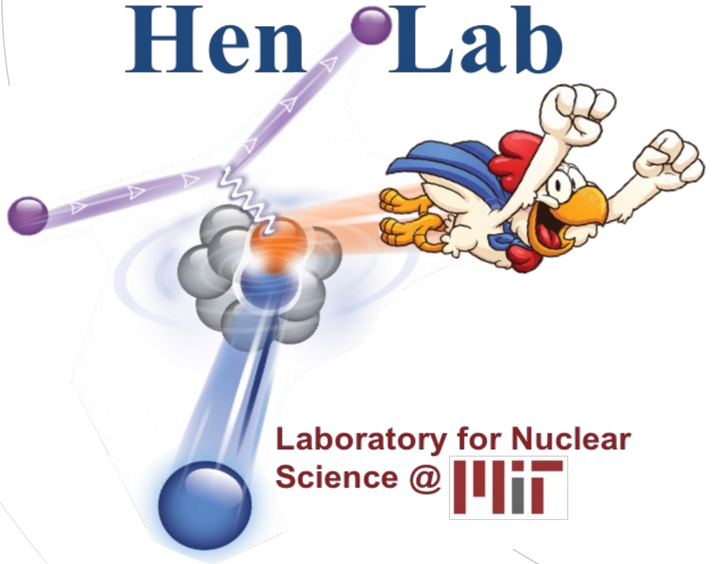
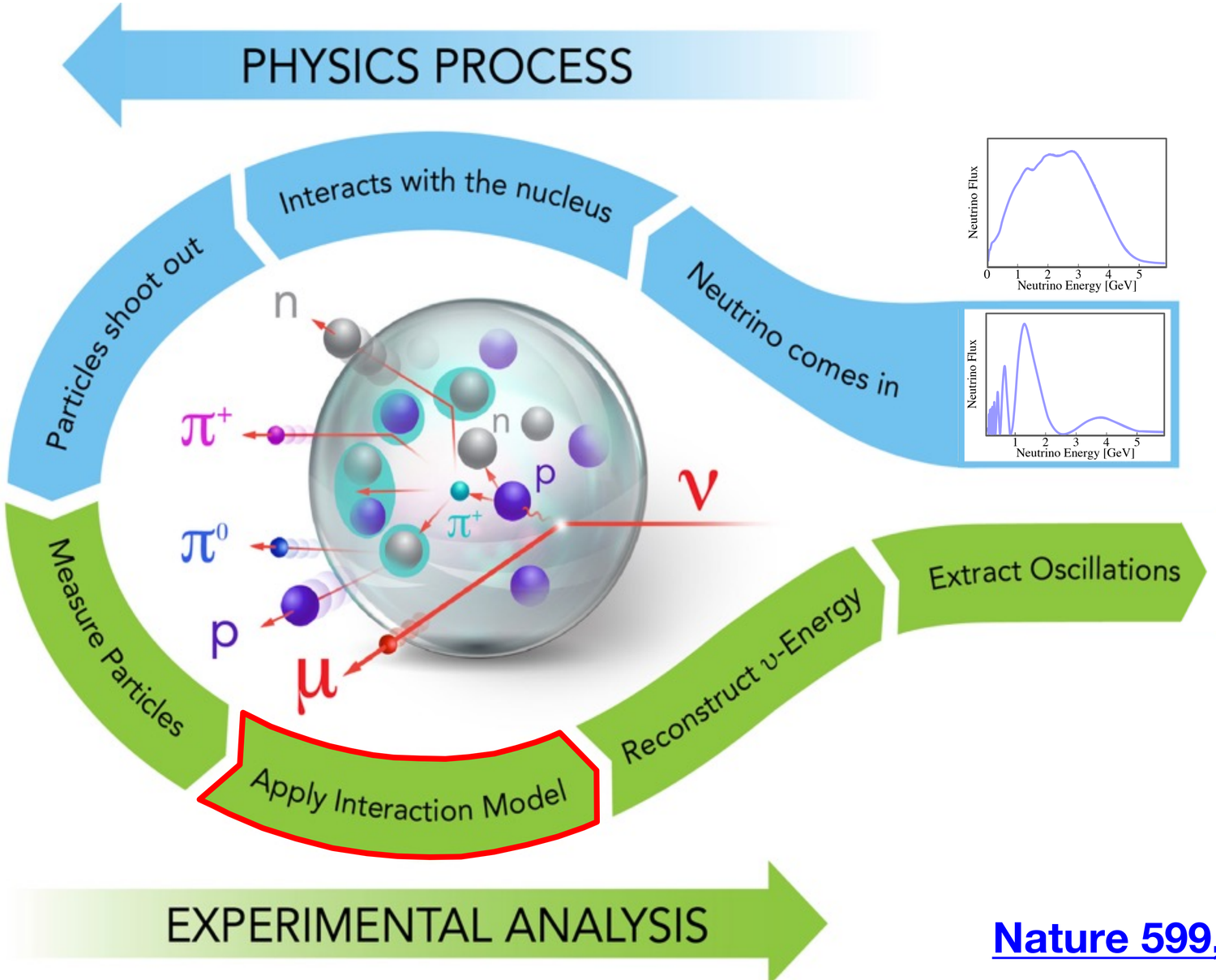
μBooNE Cross-Sections

Or Hen (MIT),
For the MicroBooNE Collaboration



Oscillations Rely on Neutrino Interaction Models



[Nature 599, 565 (2021)]

MicroBooNE is providing much-needed data with Argon

- **Liquid argon time projection chamber** (LArTPC) at Fermilab
  - Low-threshold, fully active tracking calorimeter
  - Detector technology shared by SBN and DUNE

- Largest neutrino-argon data set (~0.5 M events in 5 years)

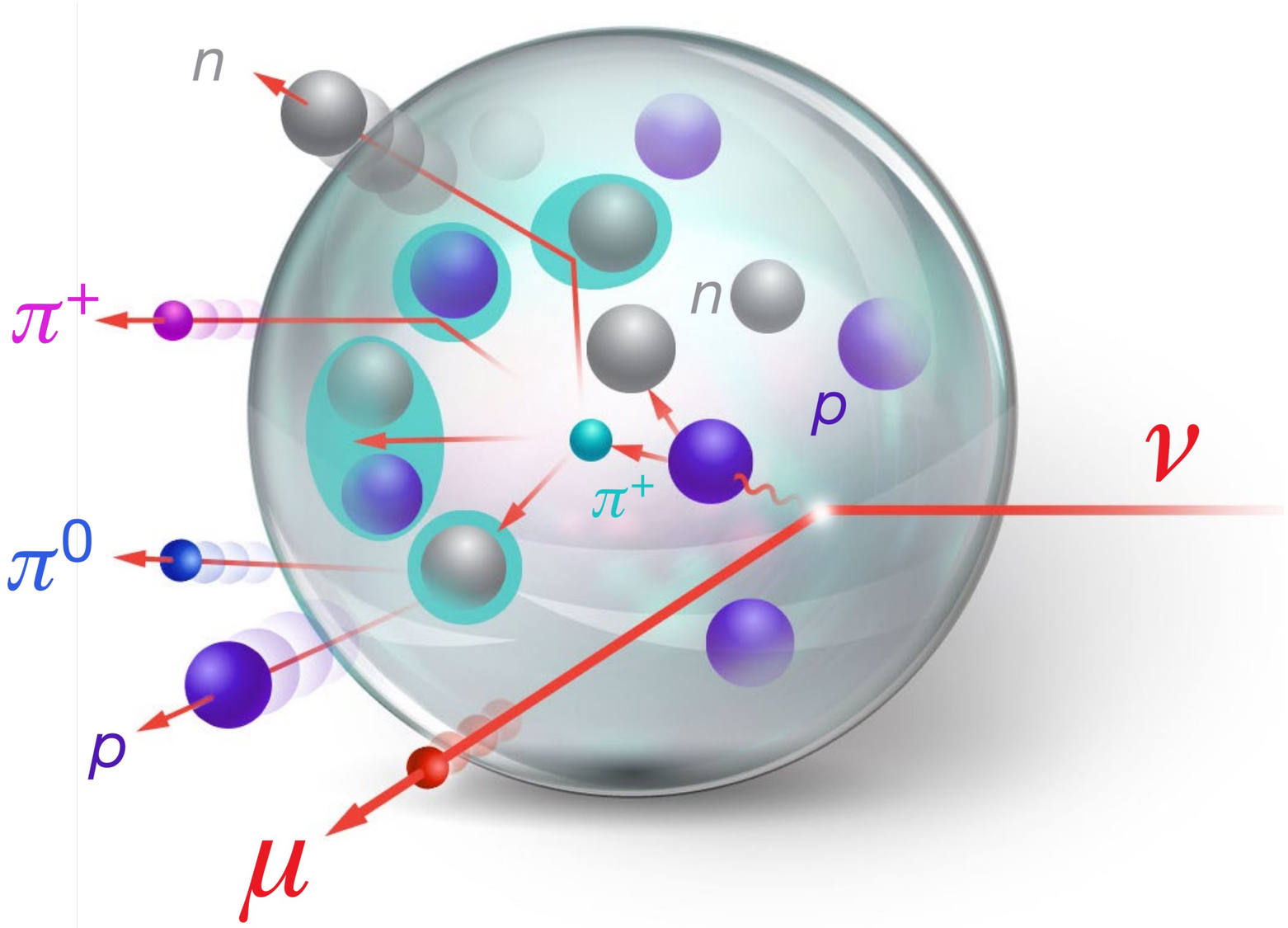
- 30 active cross-section analyses

Today

1. Inclusive + Hadronic Calorimetry

2. Quasielastic-like single-proton knockout

3. Neutral-current (NC) π^0



Nature 599, 565 (2021)

Hadronic energy modeling is crucial for neutrino calorimetry

Oscillations require **energy-dependent event rates:**

$$E_\nu = E_\ell + \omega$$

$$\omega = E_{\text{had}} + E_{\text{miss}}$$

Hadronic energy modeling is crucial for neutrino calorimetry

Oscillations require **energy-dependent event rates:**

"Easy"

$$E_\nu = E_\ell + \omega$$

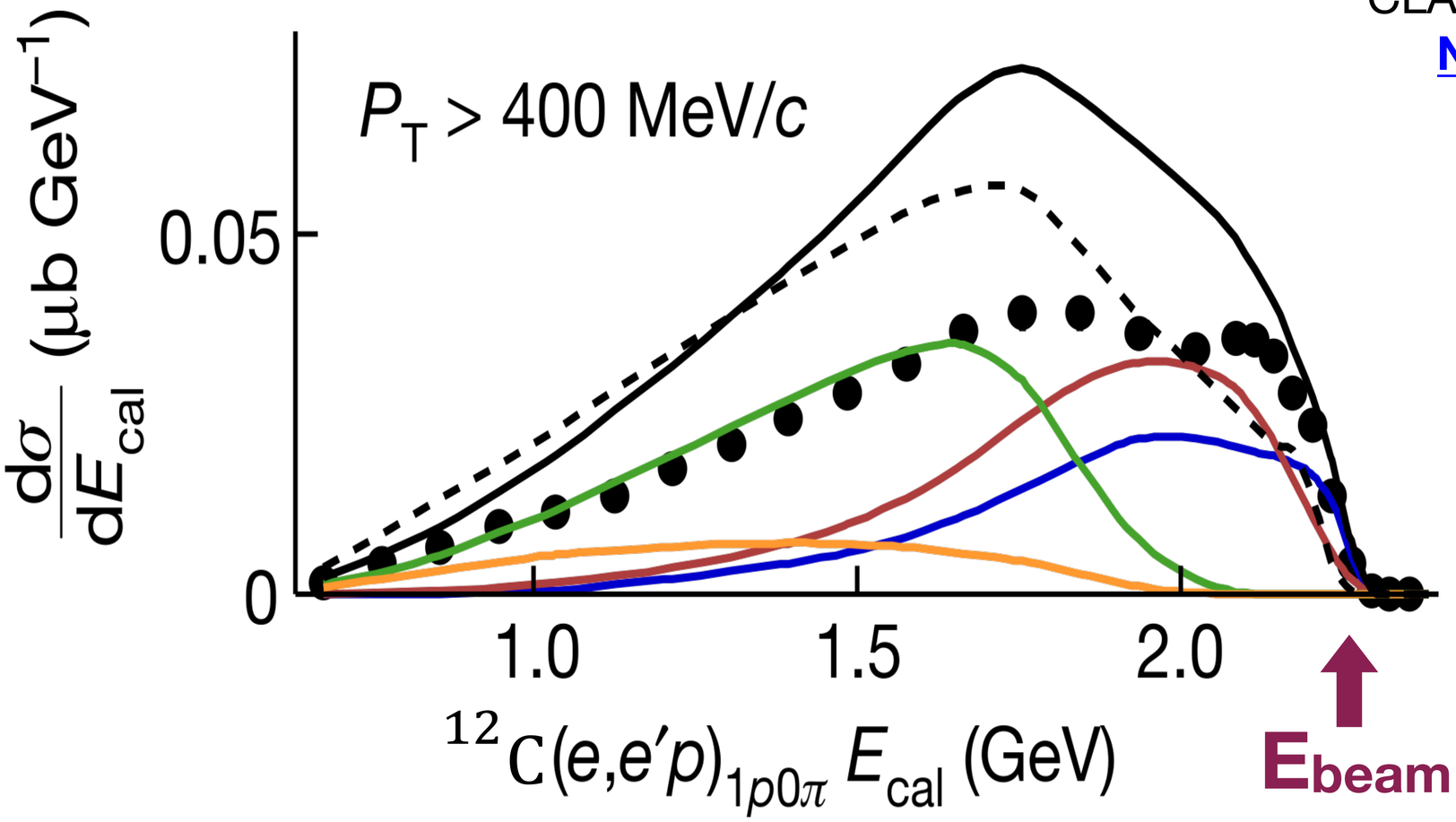
Hard

$$\omega = E_{\mathrm{had}} + E_{\mathrm{miss}}$$

E_{miss} can be a large fraction of the total energy!

We know it doesn't work that well…

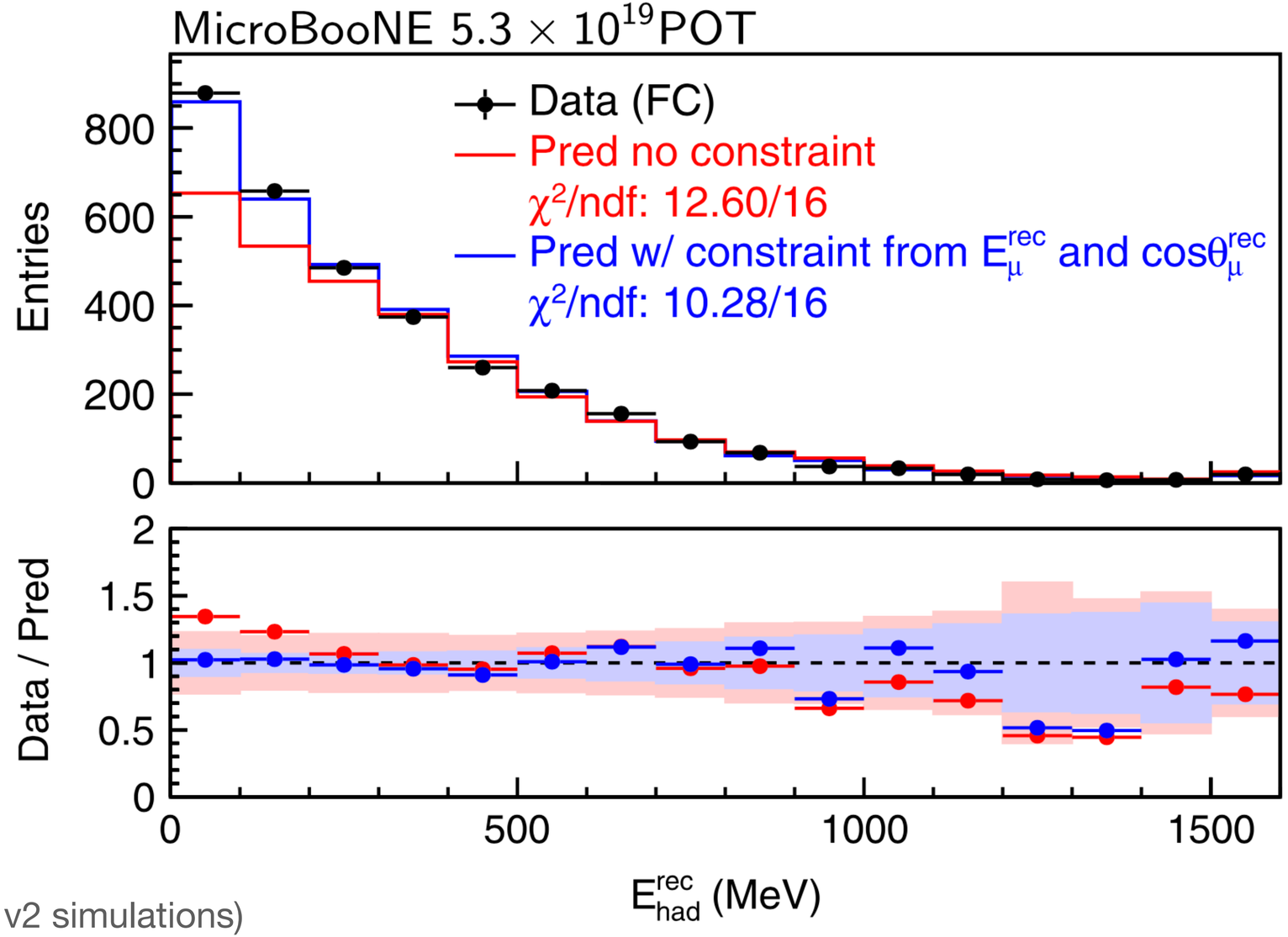
CLAS and e4v Collaborations,
Nature 599, 565 (2021)



Data
SuSAv2 (Total)
QE
MEC
RES
DIS
G2018

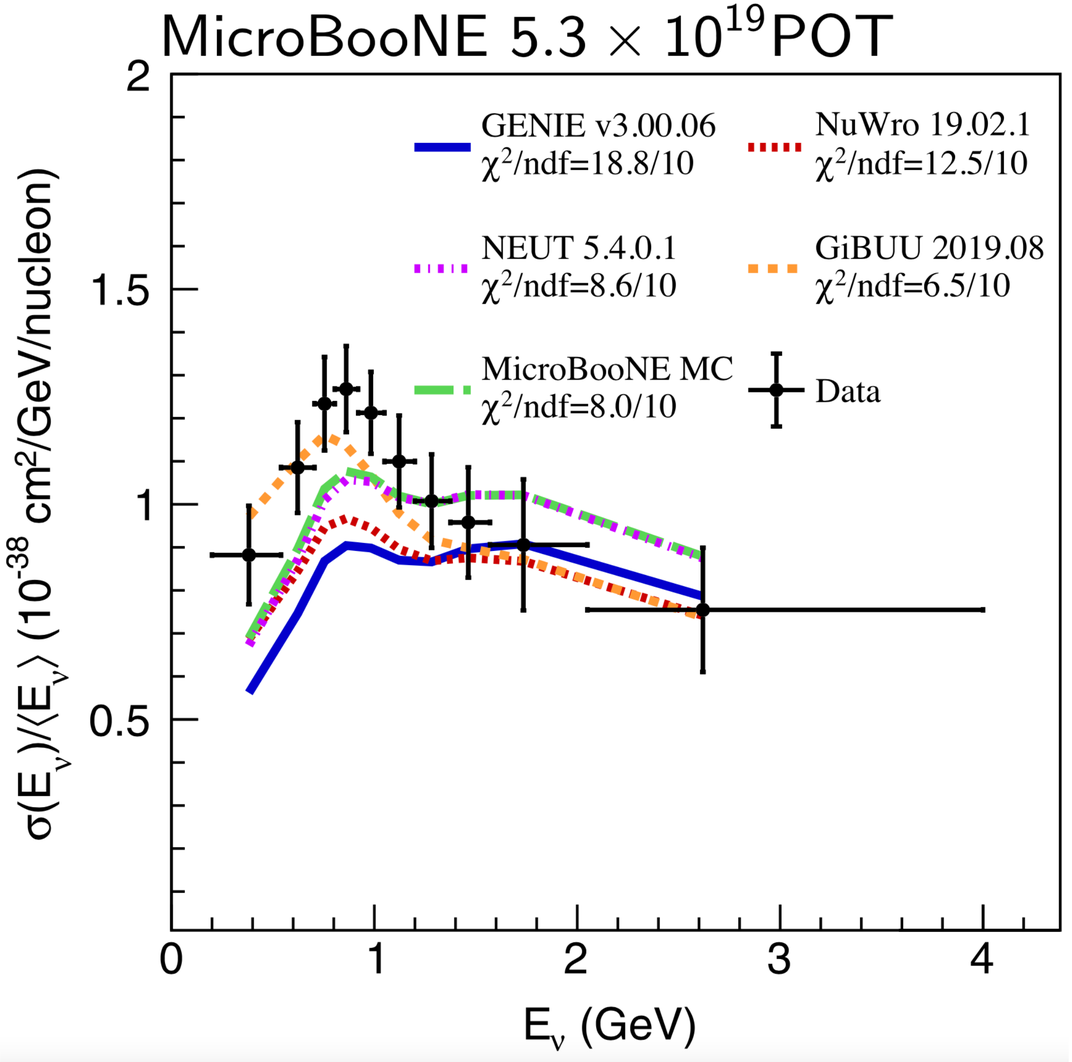
Kinematic Constraints on E_ν and ω

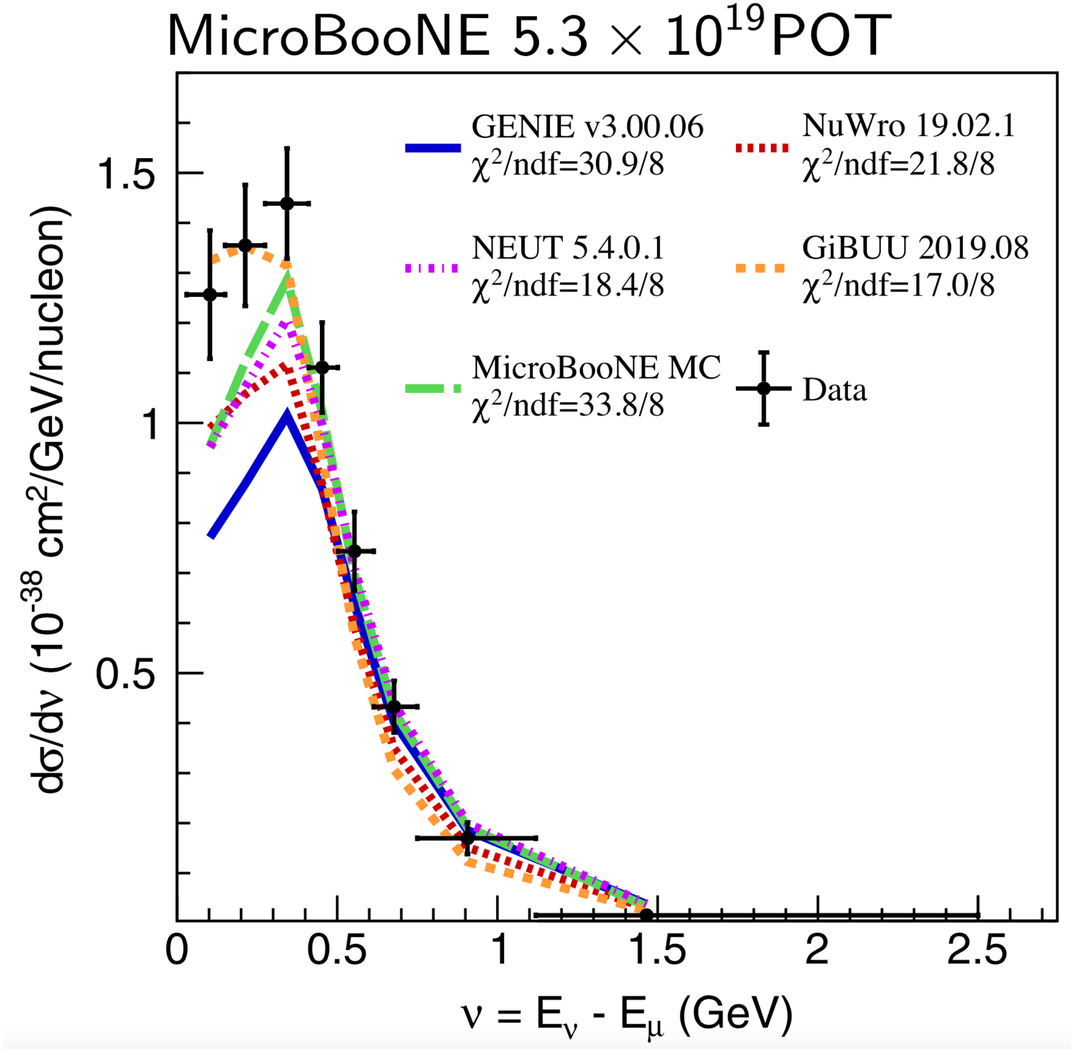
Phys. Rev. Lett. 128, 151801 (2022)



(validated using GENIE v2 simulations)

➔ Cross-sections discriminate between models



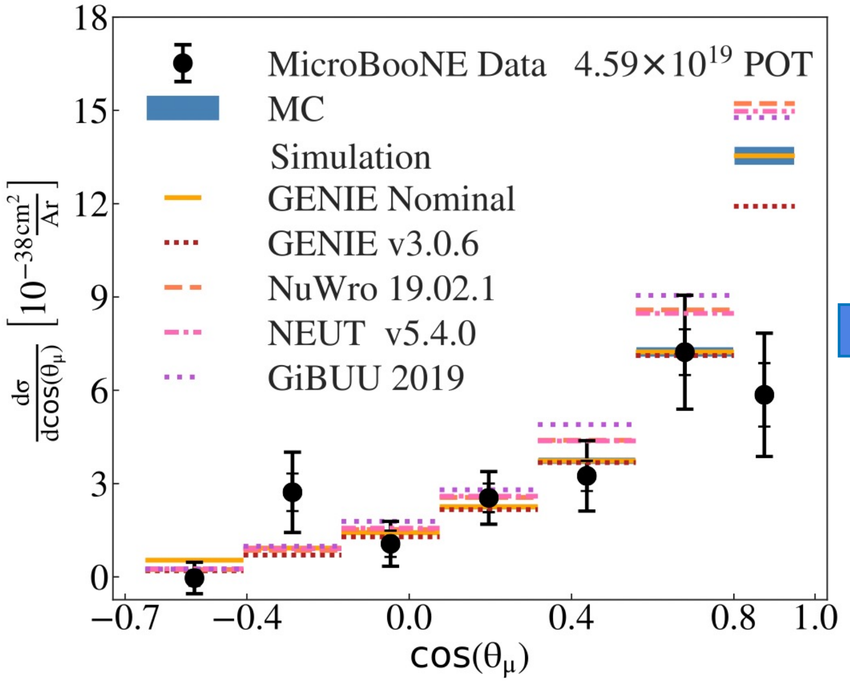


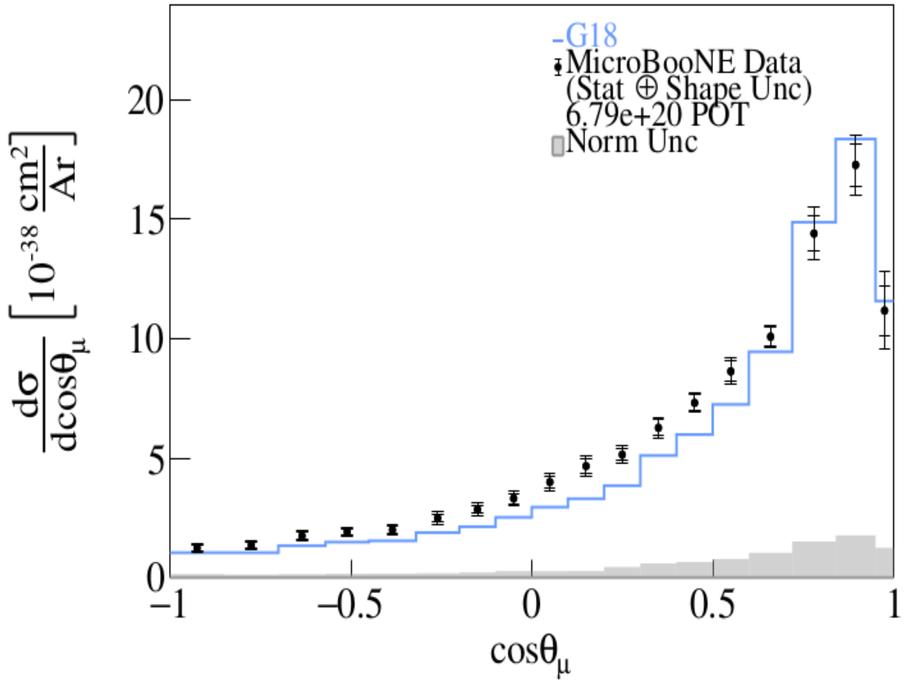
(GiBUU has higher MEC contribution)

Phys. Rev. Lett. 128, 151801 (2022)

1p knockout: clean & simple quasielastic process

New 2022: x30 higher statistics;
Improved systematics

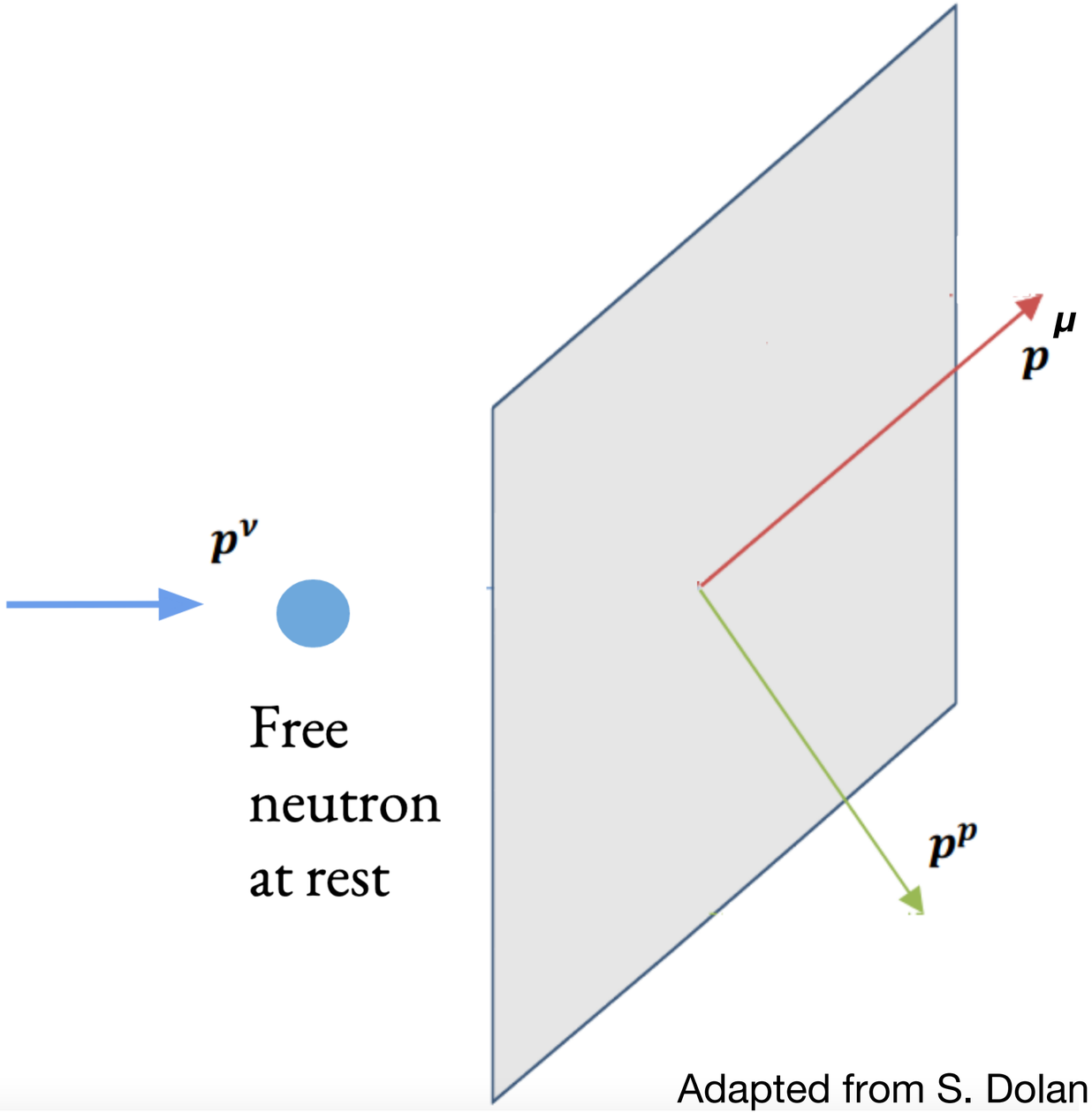




[PRL 125, 201803 (2020)]

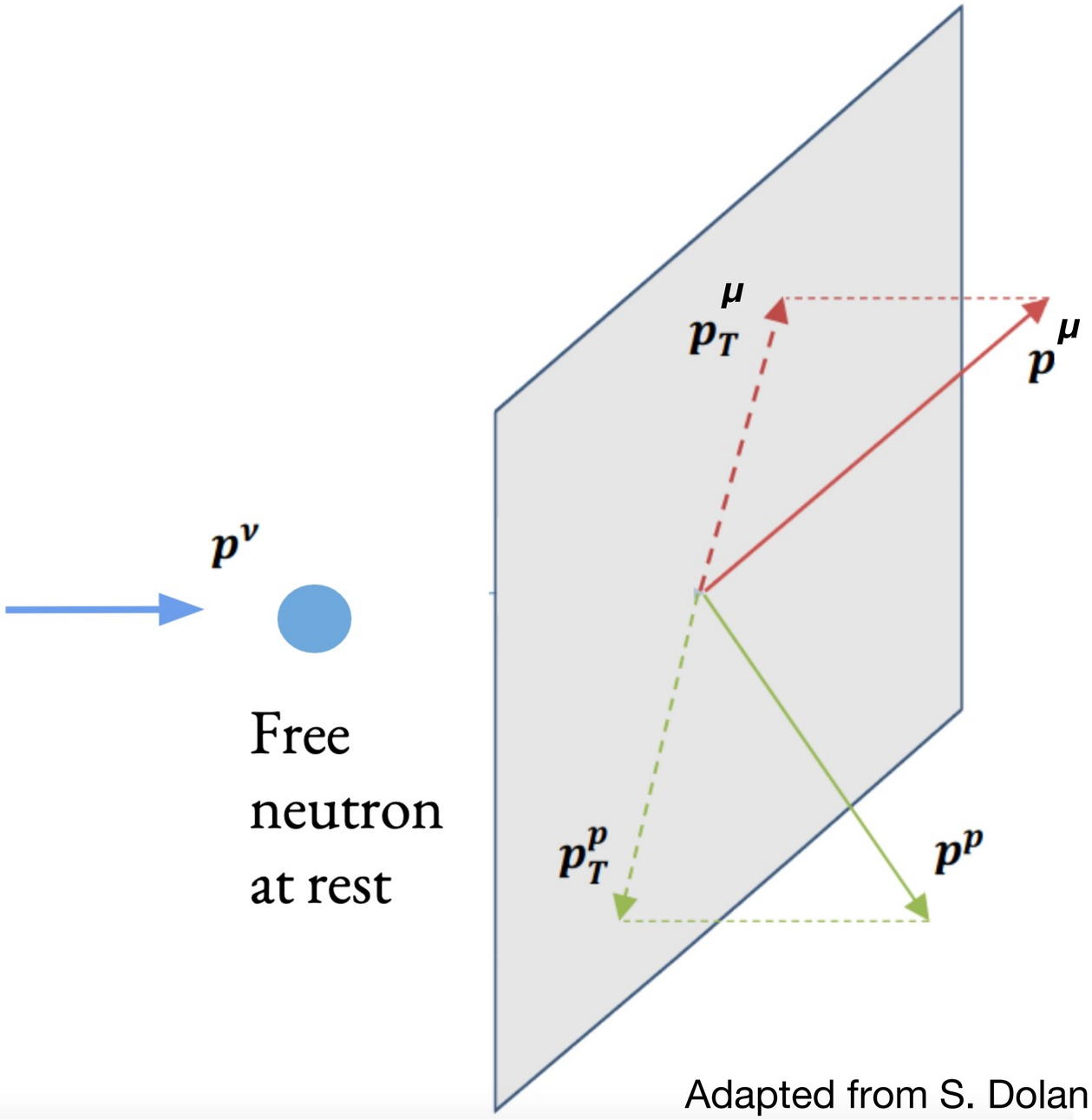
New analysis

Transverse kinematic imbalance (TKI)



Adapted from S. Dolan, "Exploring nuclear effects with transverse imbalances"

Transverse kinematic imbalance (TKI)

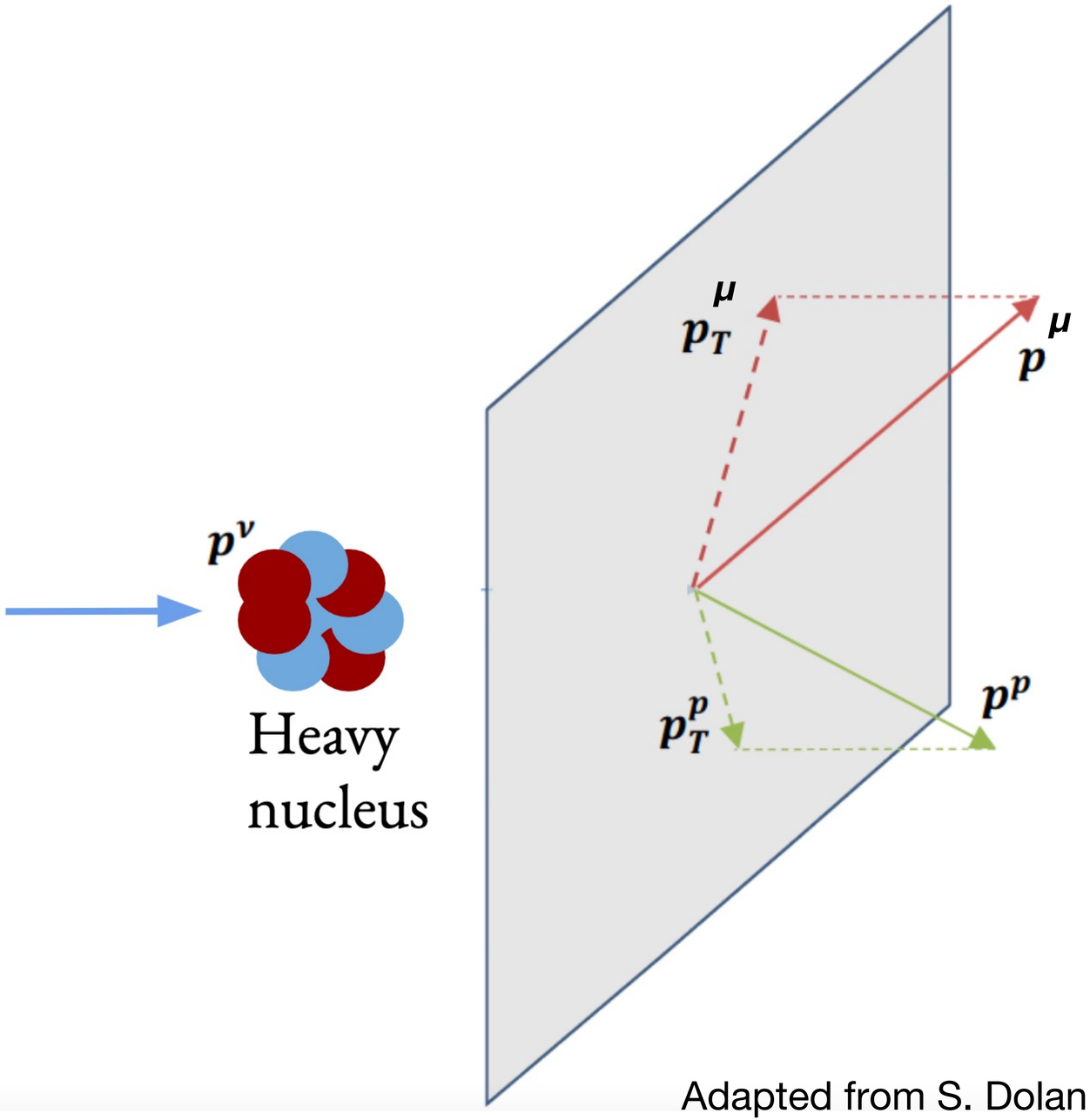


$$\delta p_T = \left| \mathbf{p}_T^{\mu} + \mathbf{p}_T^{p} \right| = 0$$

Transverse projections **trivially equal and opposite** (momentum conservation)

Adapted from S. Dolan, "**Exploring nuclear effects with transverse imbalances**"

Transverse kinematic imbalance (TKI)

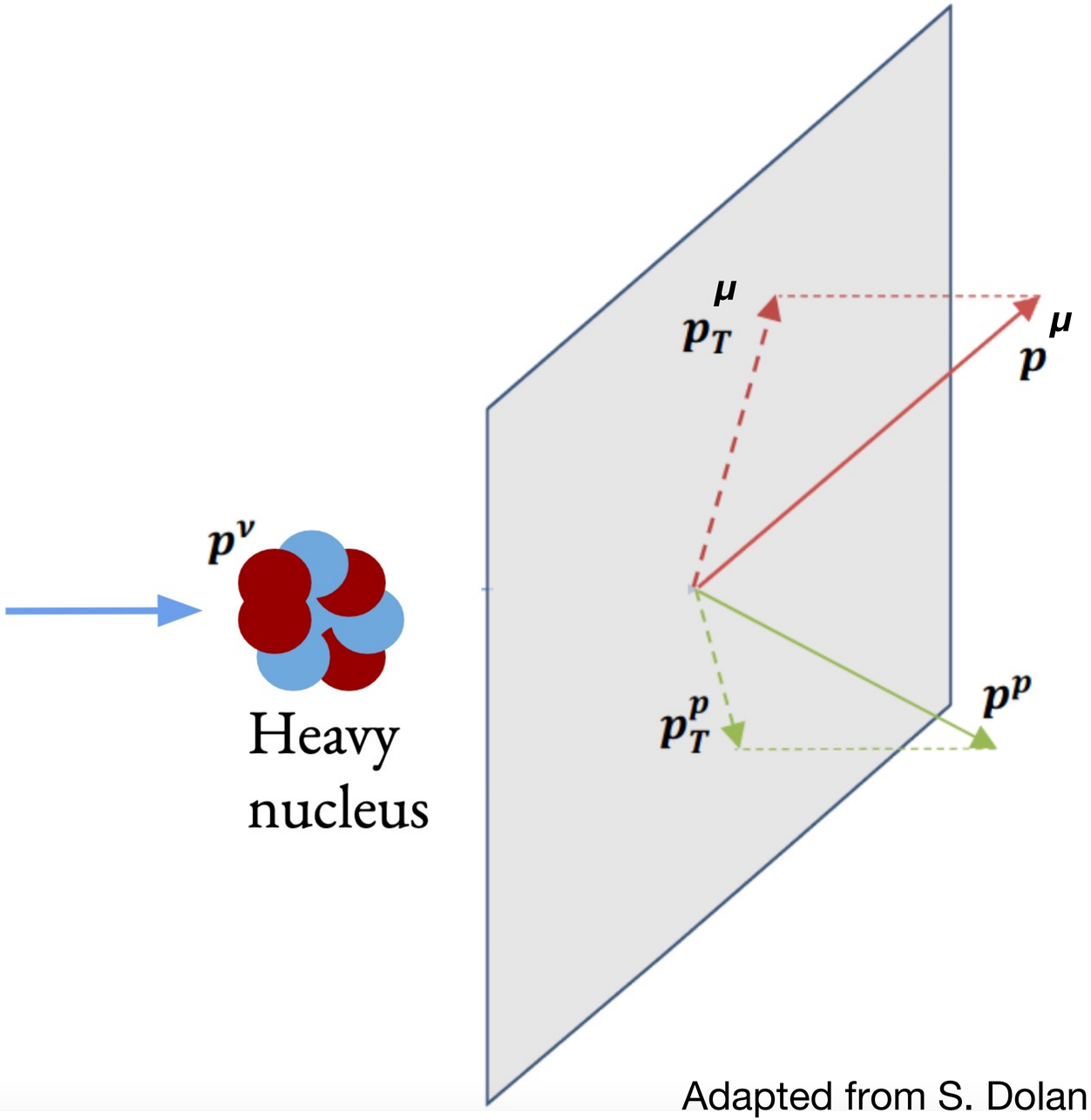


$$\delta p_T = \left| \mathbf{p}_T^{\mu} + \mathbf{p}_T^{p} \right| > 0$$

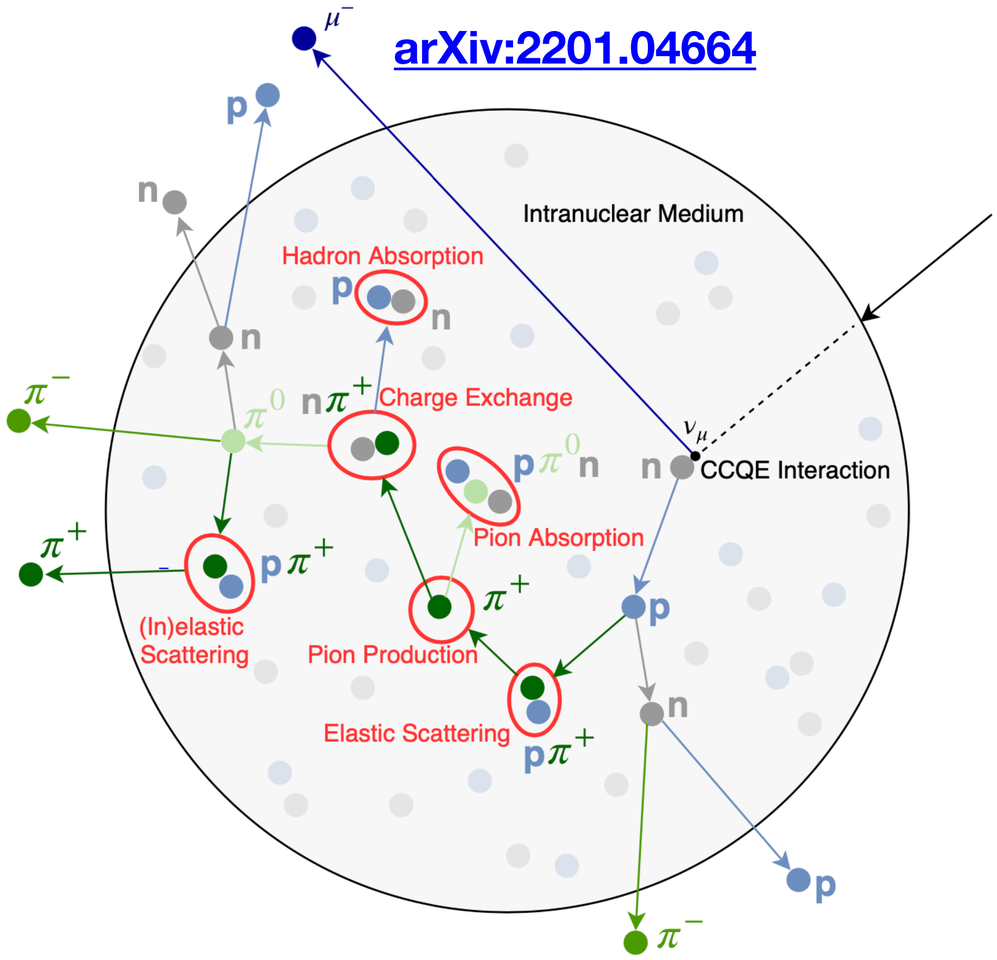
Imbalance due to initial nucleon motion and other nuclear effects

Adapted from S. Dolan, "Exploring nuclear effects with transverse imbalances"

Transverse kinematic imbalance (TKI)

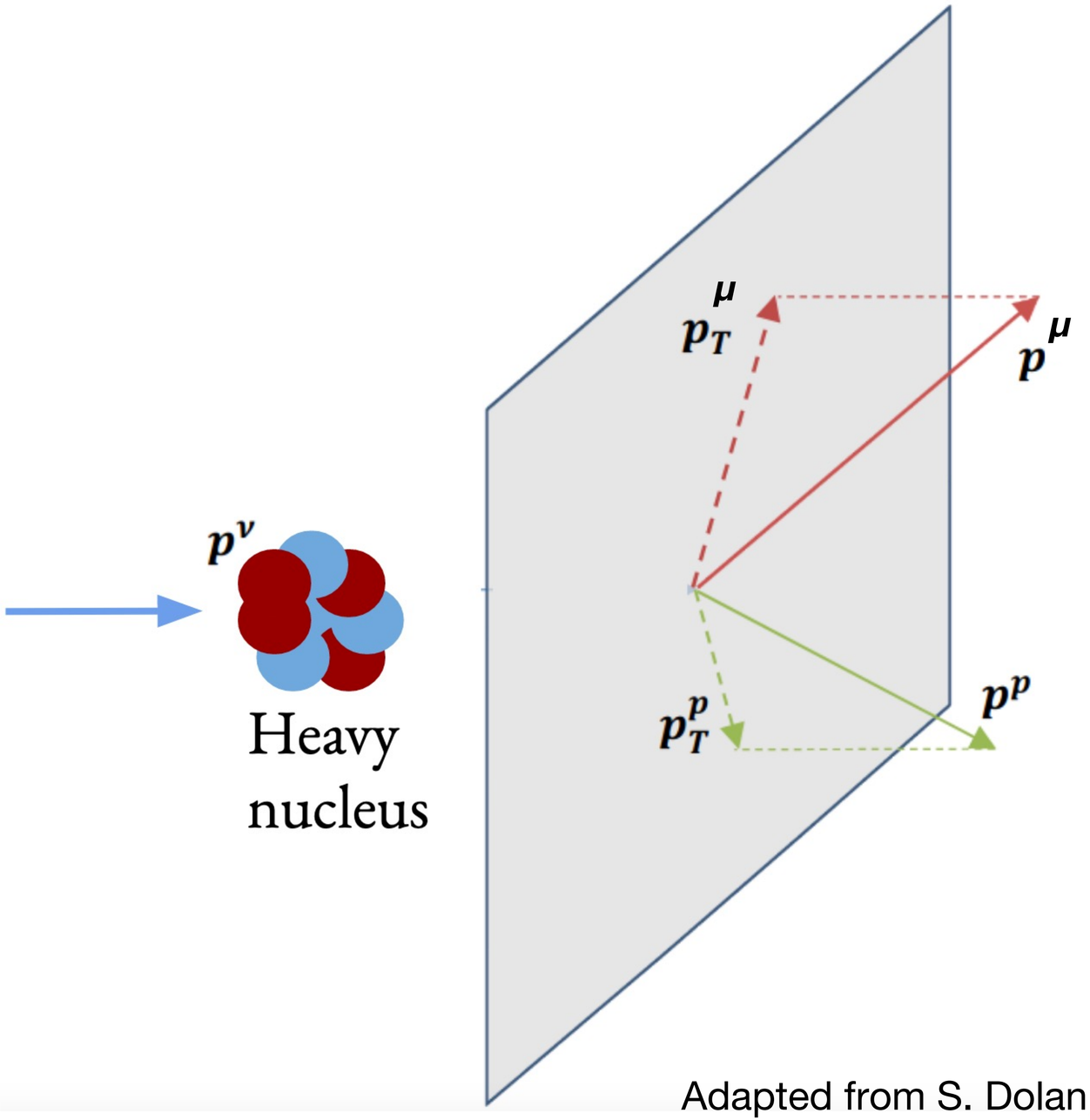


Hadronic final-state interactions (FSI)

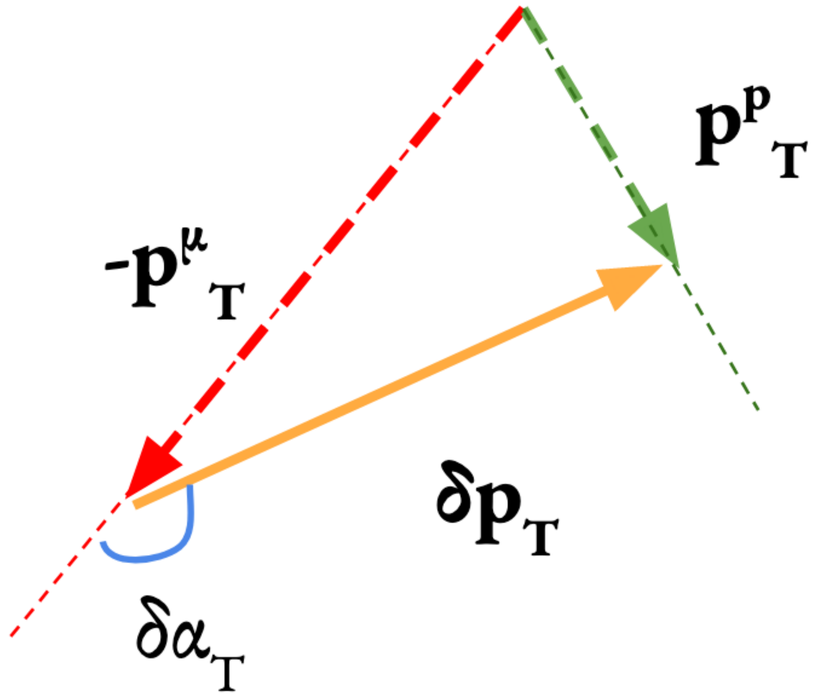


Adapted from S. Dolan, "Exploring nuclear effects with transverse imbalances"

Transverse kinematic imbalance (TKI)

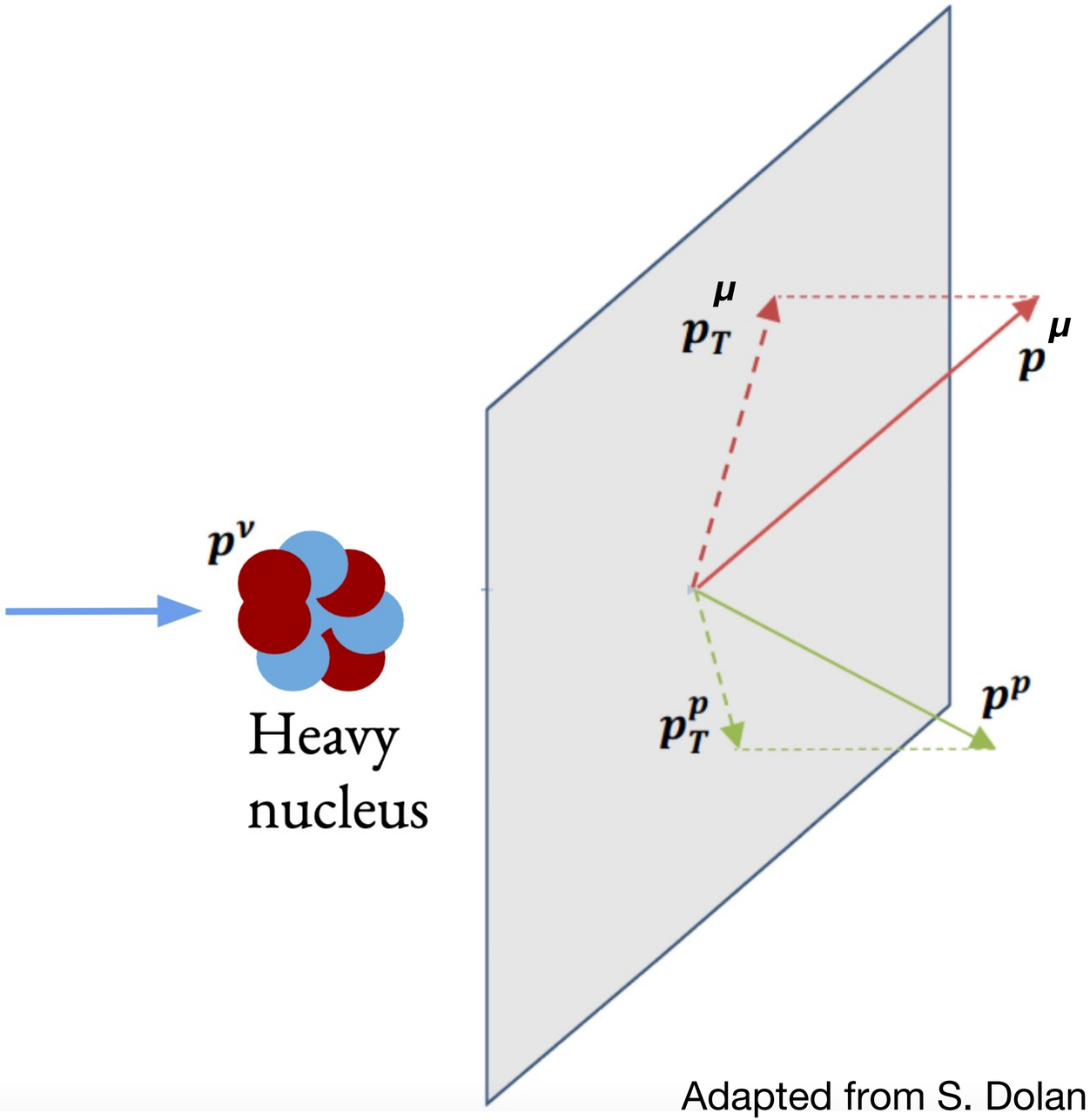


Orientation of the imbalance ($\delta\alpha_T$) also meaningful

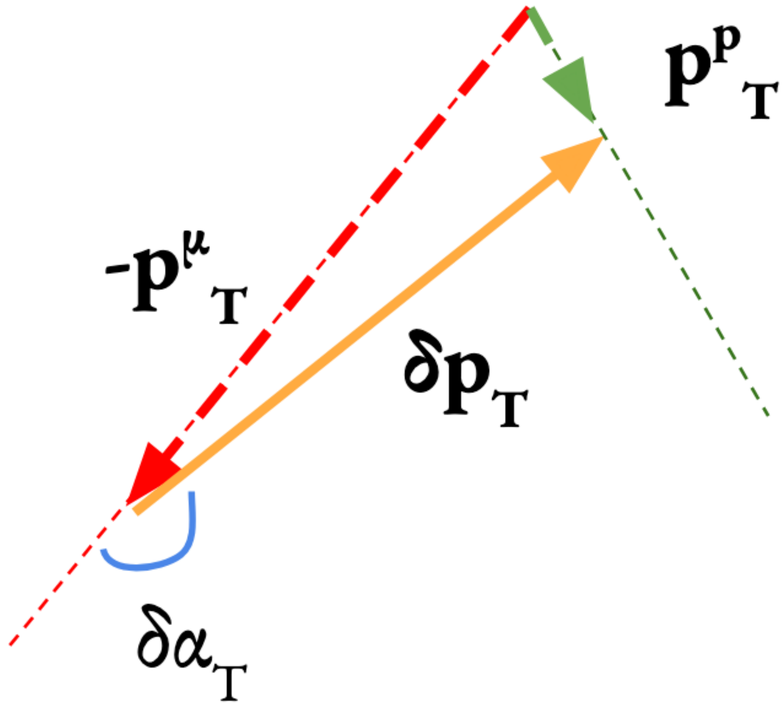


Adapted from S. Dolan, "Exploring nuclear effects with transverse imbalances"

Transverse kinematic imbalance (TKI)

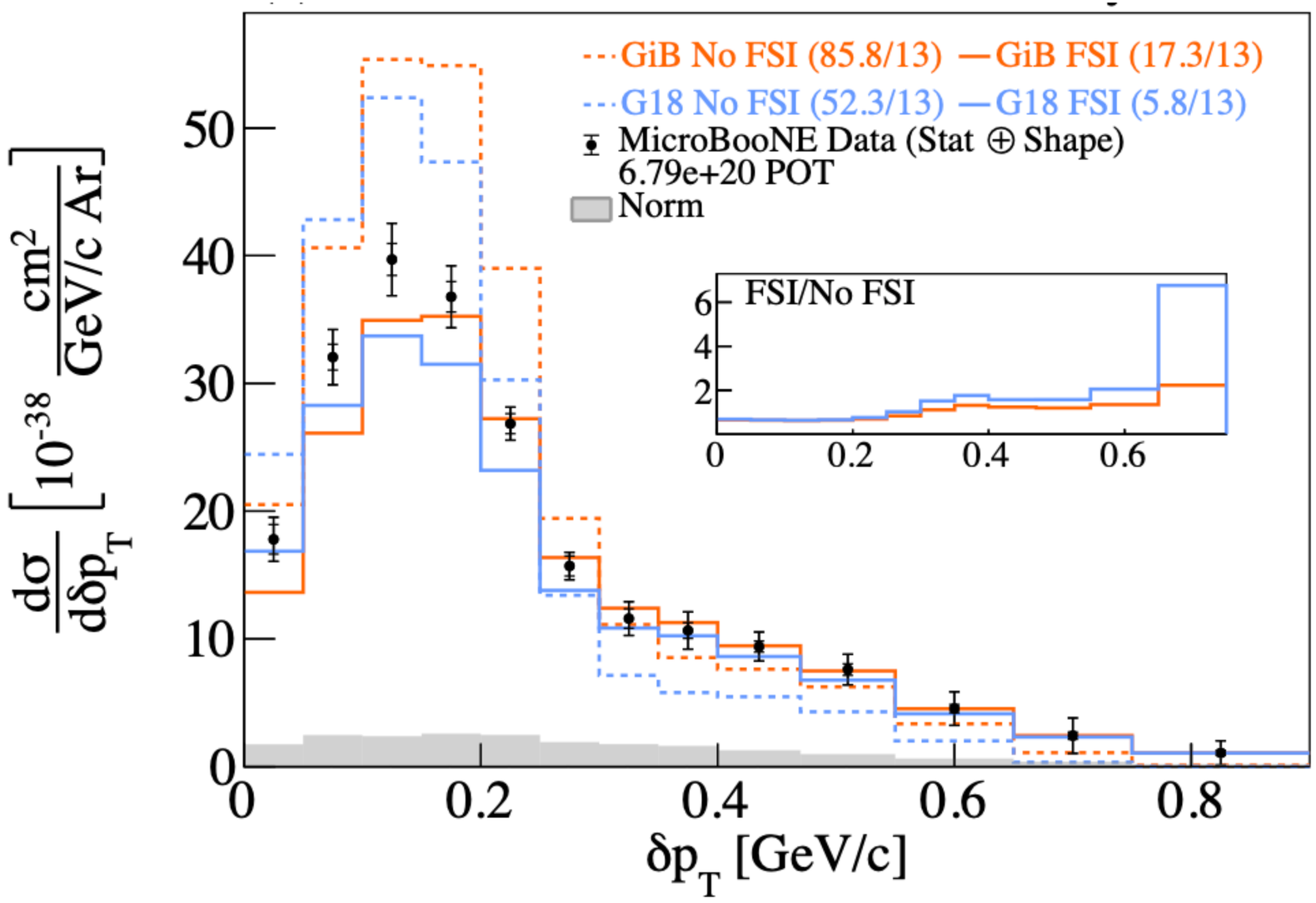


High $\delta\alpha_T$ values correspond to **proton deceleration** due to FSI

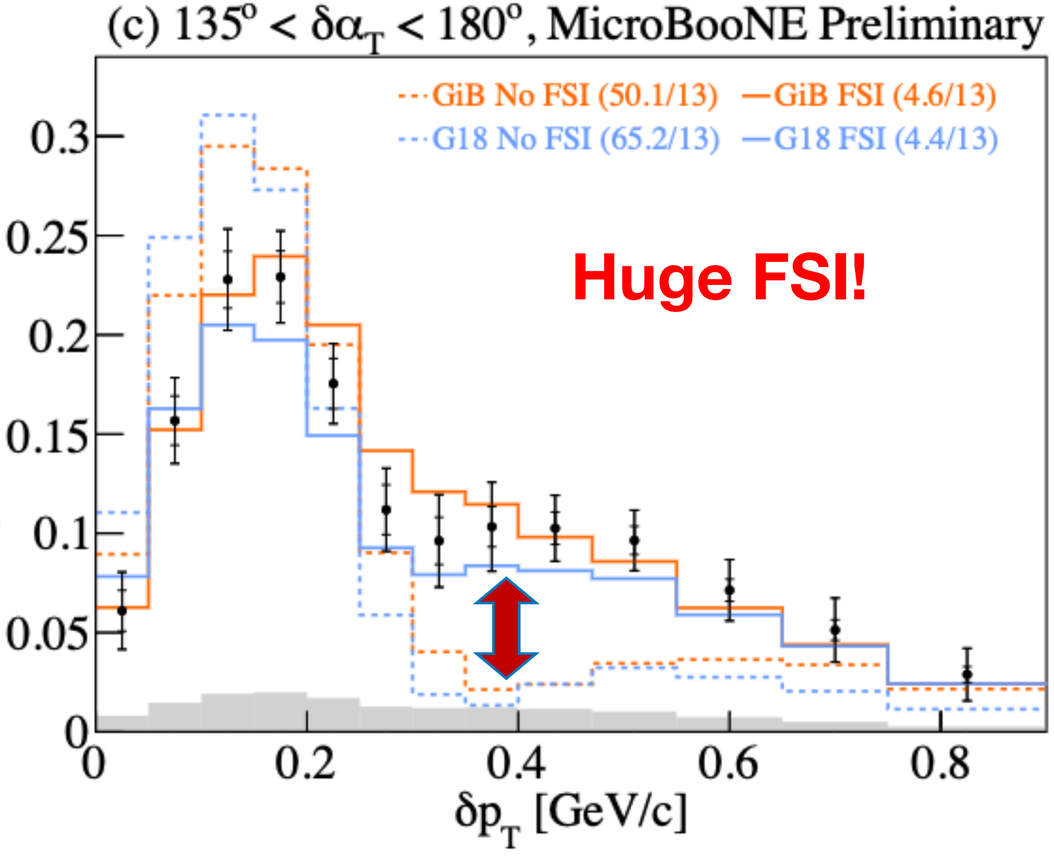


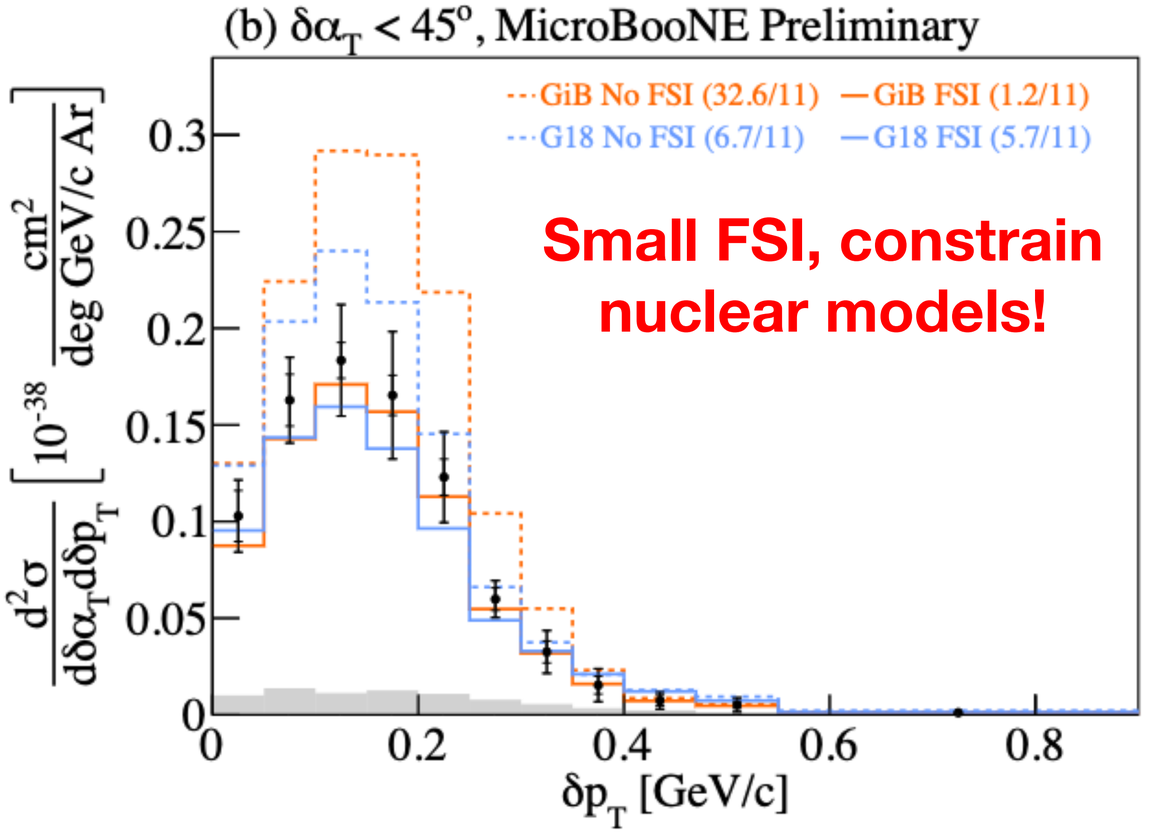
Adapted from S. Dolan, "Exploring nuclear effects with transverse imbalances"

Single differential: Some FSI sensitivity



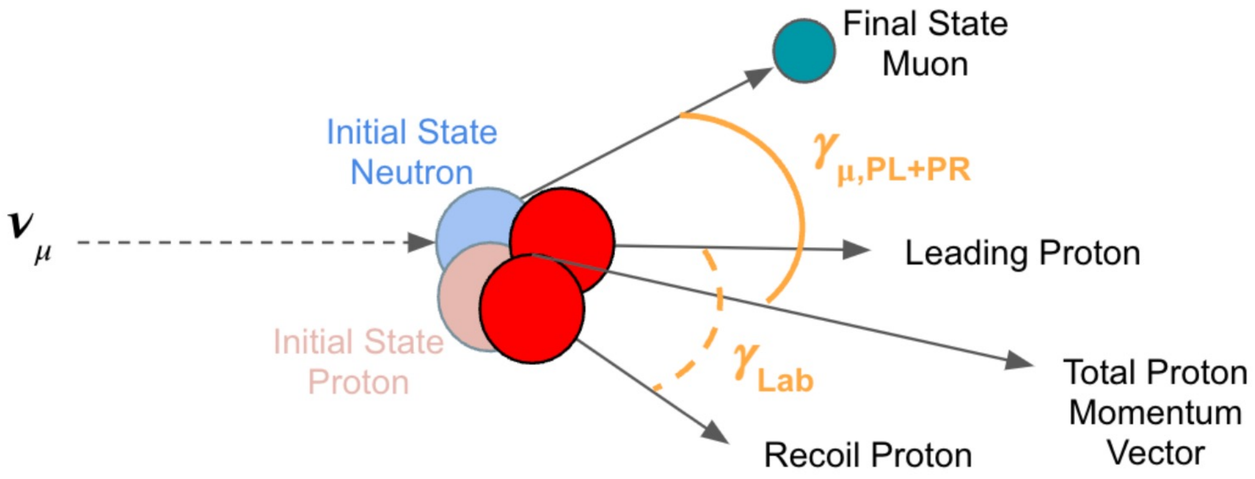
Double differential: Large FSI sensitivity!

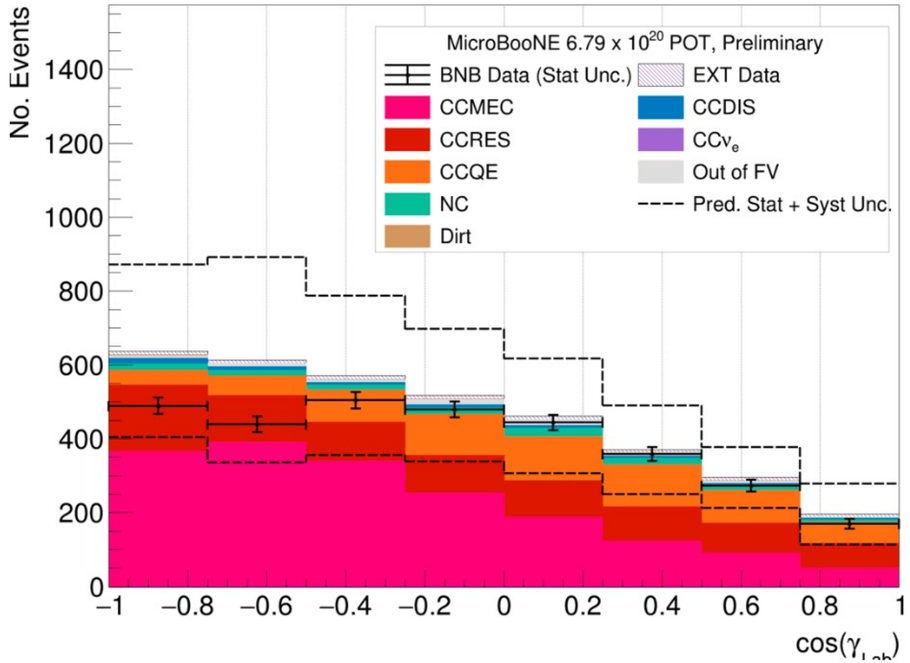


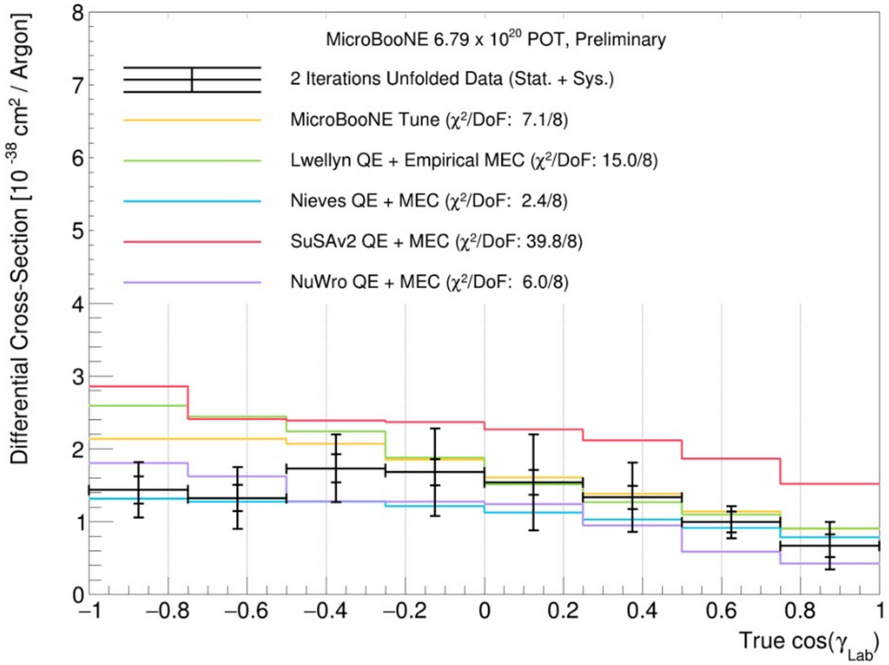


Two-proton knockout: Constraining MECs

- MEC is a key process that has little existing constraint.
- 2p data sensitive to detail MEC kinematics, not only total rate!







ν_e & BSM Background : Neutral-Current π^0 production

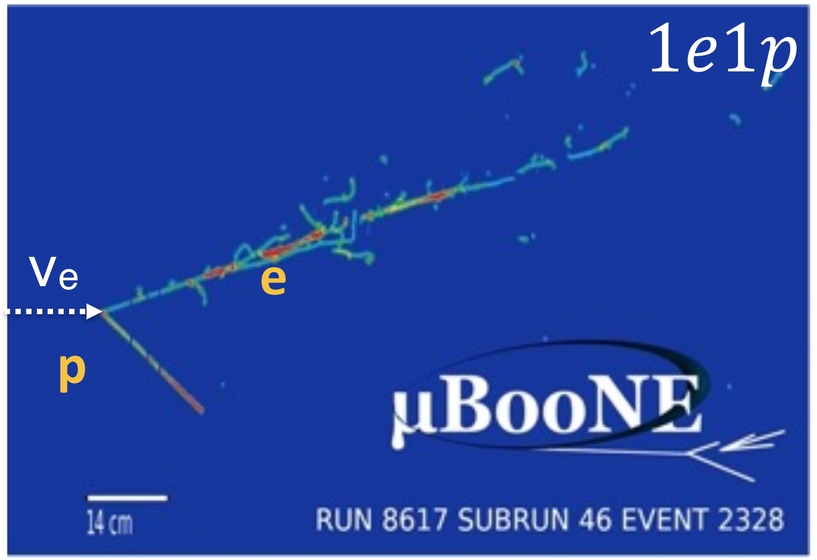
- $\pi^0 \rightarrow \gamma\gamma$ looks like e^- when missing one γ-shower

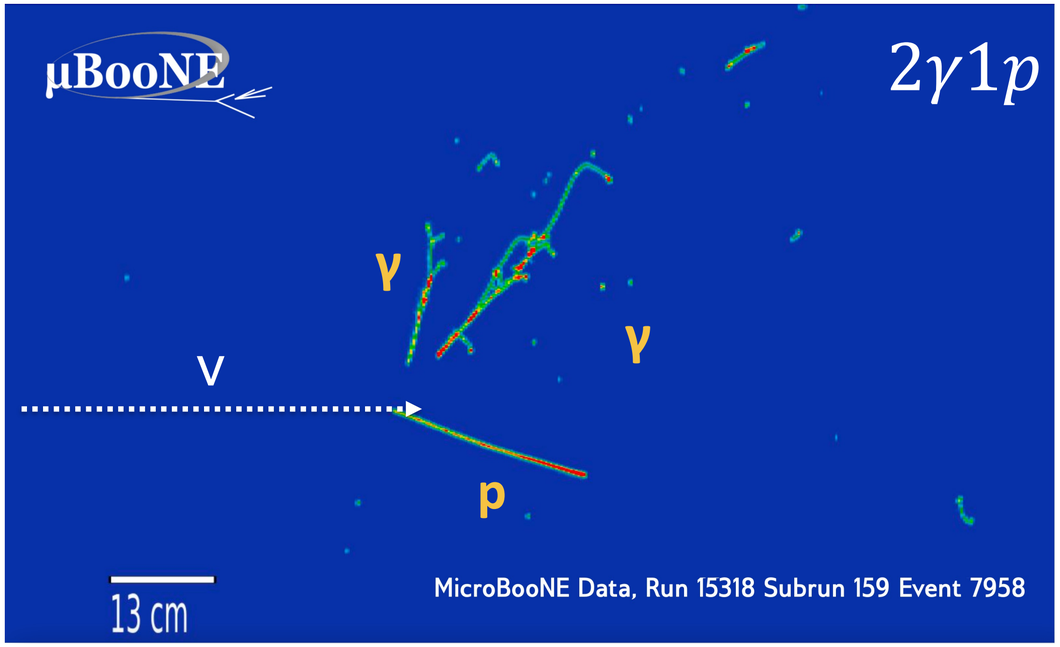
  → Mimics ν_e interaction

- LArTPCs provide powerful, but not perfect, γ/e- discrimination

- Remaining π^0 background must be estimated via simulation

- **How well-modeled are the NC π^0 interactions?**

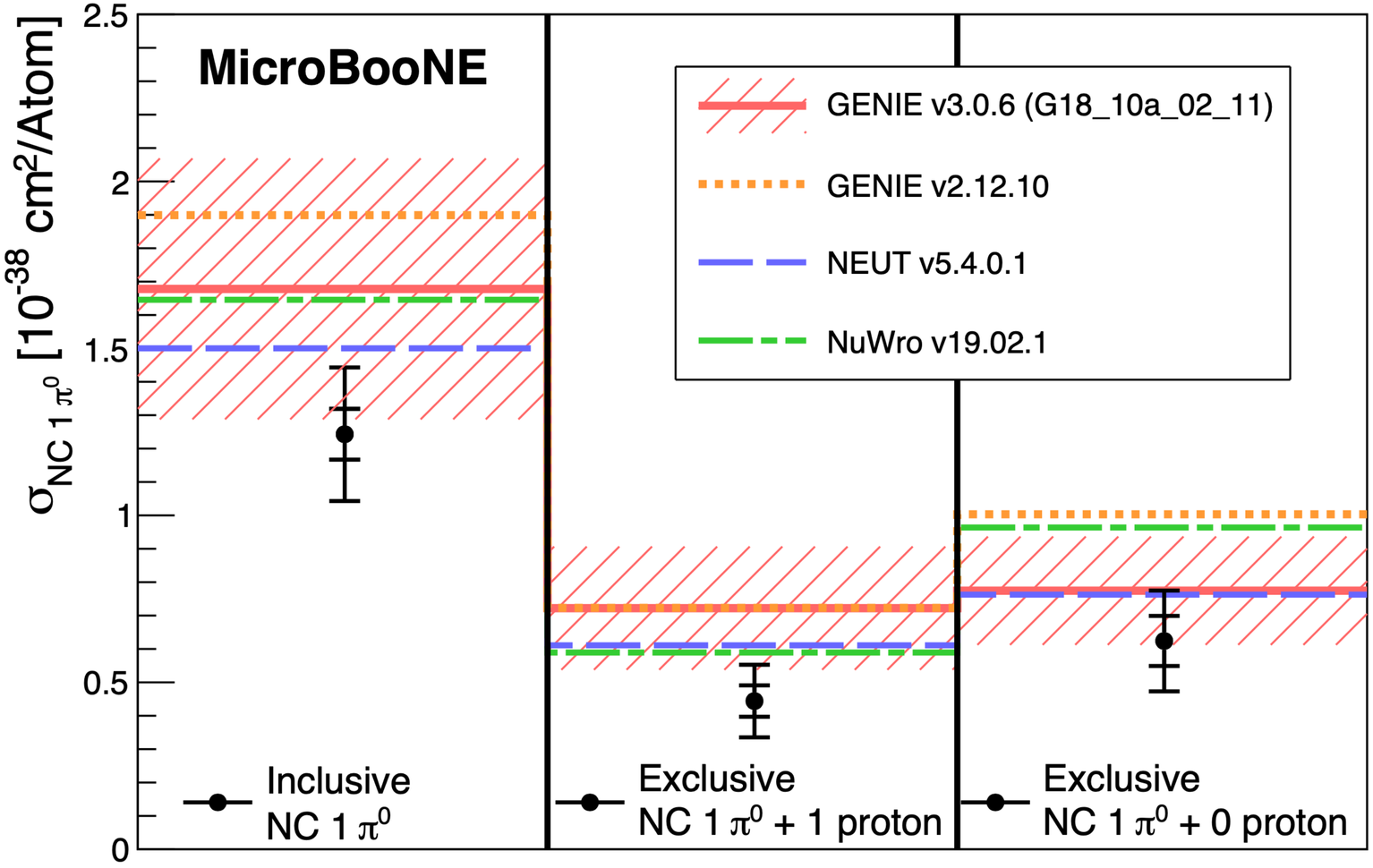




Neutral-Current $1\pi^0$ total cross sections

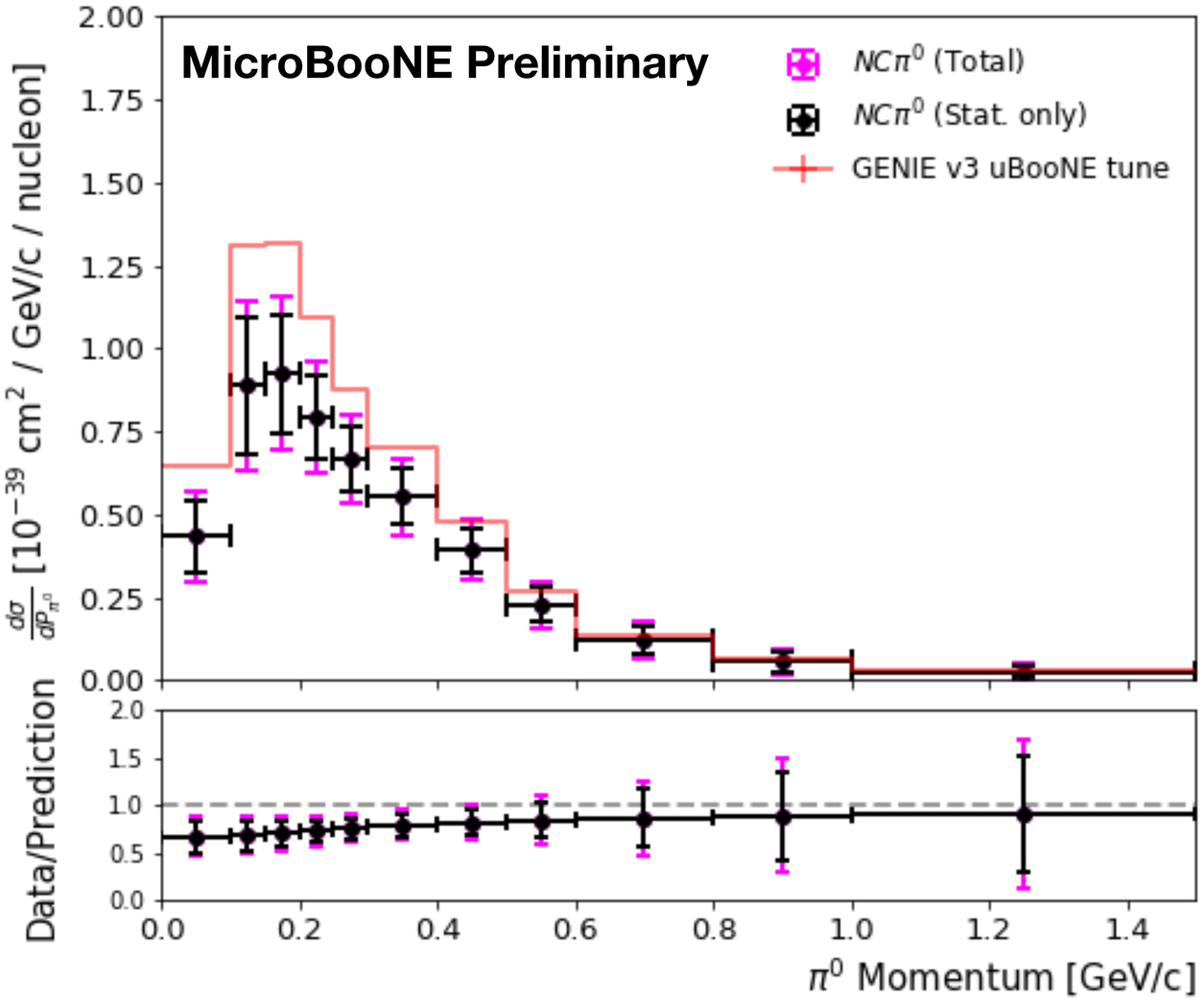
- First NC $1\pi^0$ inclusive on argon with $\langle E_\nu \rangle \approx 1\text{GeV}$
- First exclusive NC $1\pi^0$ measurements in the 0p and 1p channels (any target)
- Data systematically slightly lower than models
- Also useful for non-ν_e BSM searches

arXiv:2205.07943, submitted to PRD



Neutral-Current π^0 differential cross sections

- Analysis for NC ($\geq$1)π^0 well underway
  - ~1σ deficit apparent over much of the phase space
- Preliminary result statistics-limited
  - Few % of available data
- Much more coming soon!



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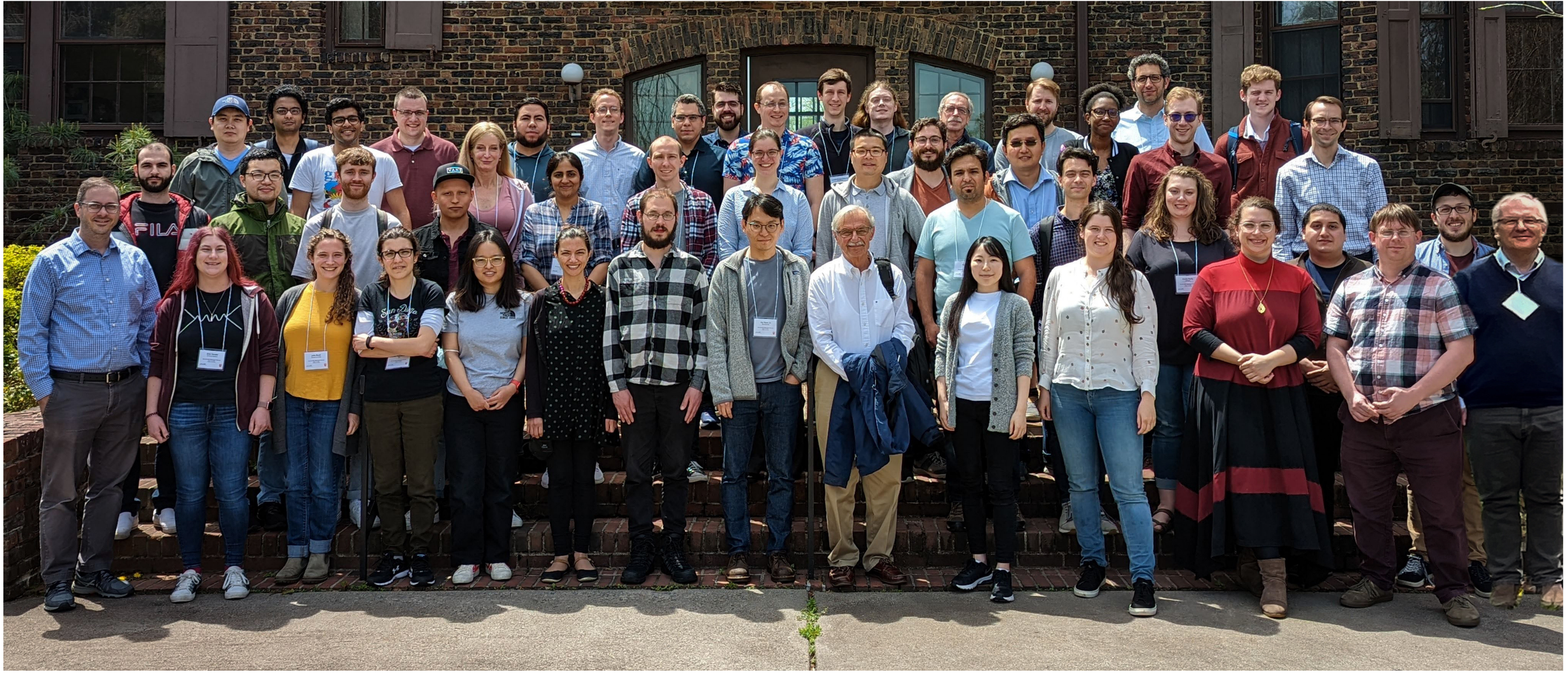

μBooNE

Thank You!

http://microboone.fnal.gov/public-notes/