

TKI, TKI+, and TKI-

– 10 Years of Transverse Kinematic Imbalance with Personal Recollections

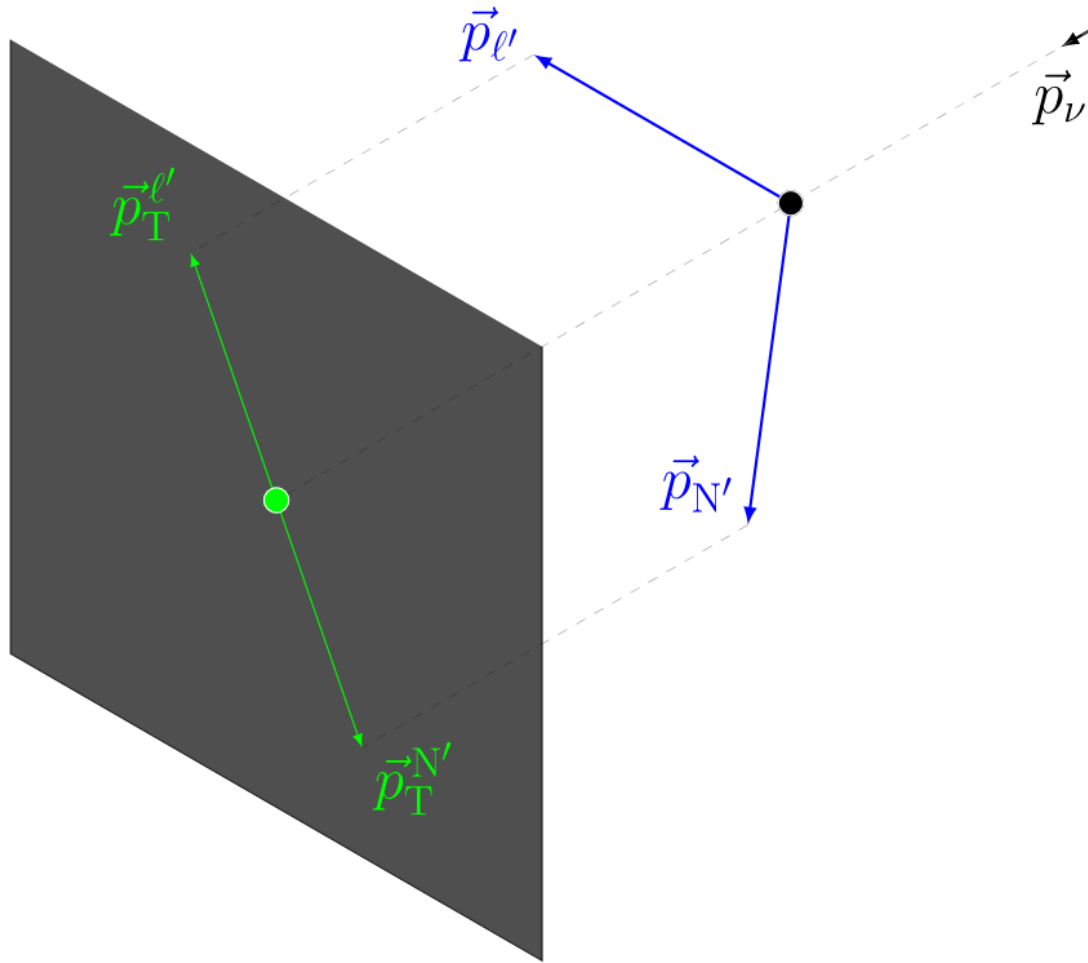
LU Xianguo 卢显国

University of Warwick

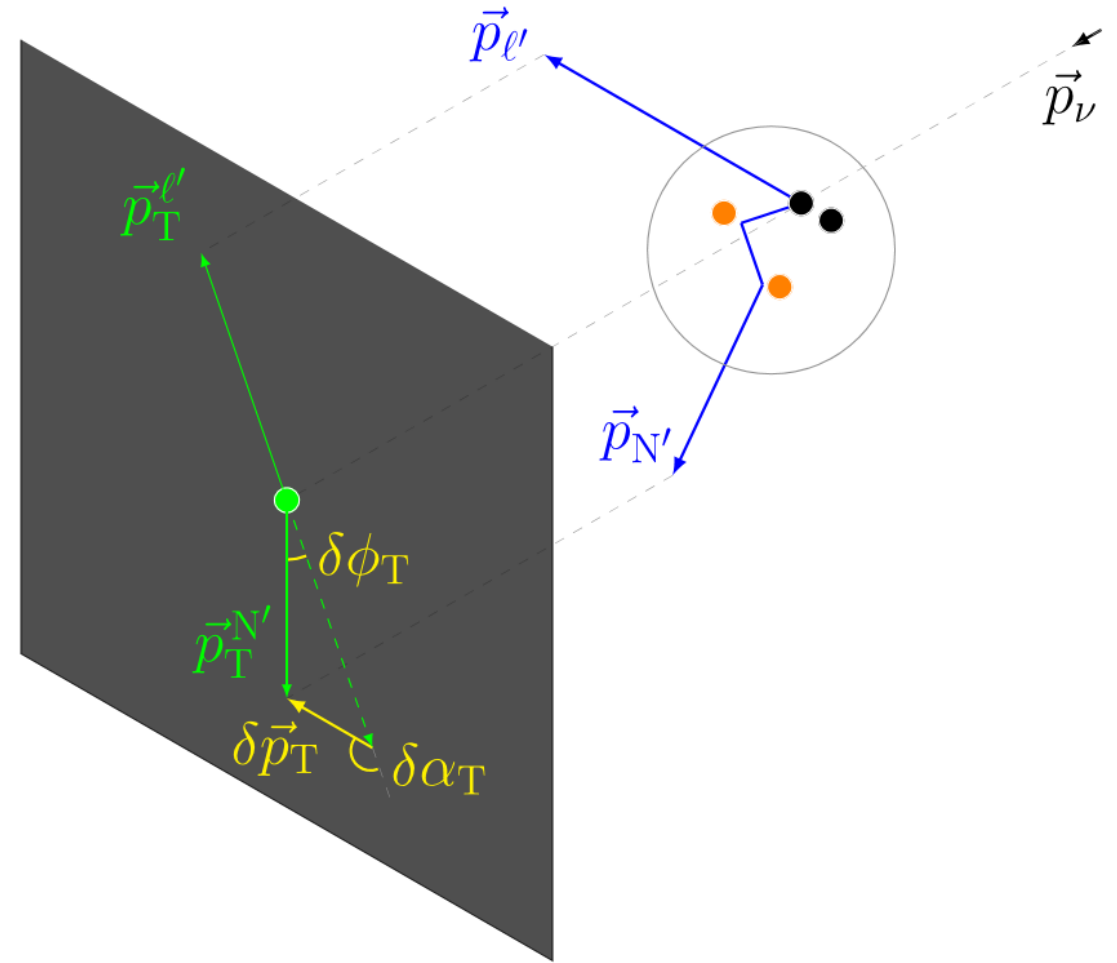
NuWro Workshop

2026 September 16, Wrocław

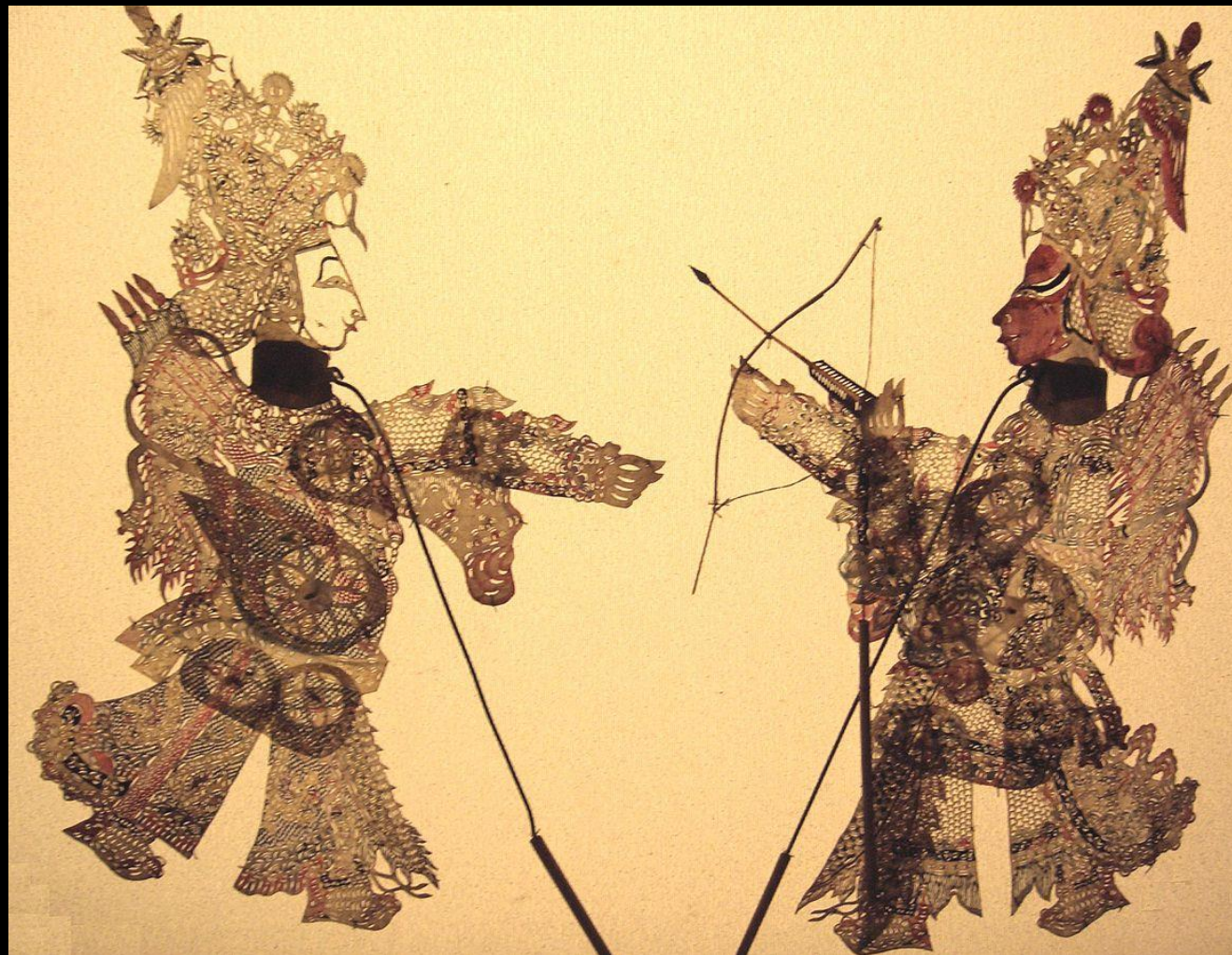
Transverse Kinematic Imbalance (TKI)



No nuclear effect



Complicated nuclear effects



[Wiki](#) 皮影戏 (Shadow Play)

PHYSICAL REVIEW D **92**, 051302(R) (2015)

Reconstruction of energy spectra of neutrino beams independent of nuclear effects

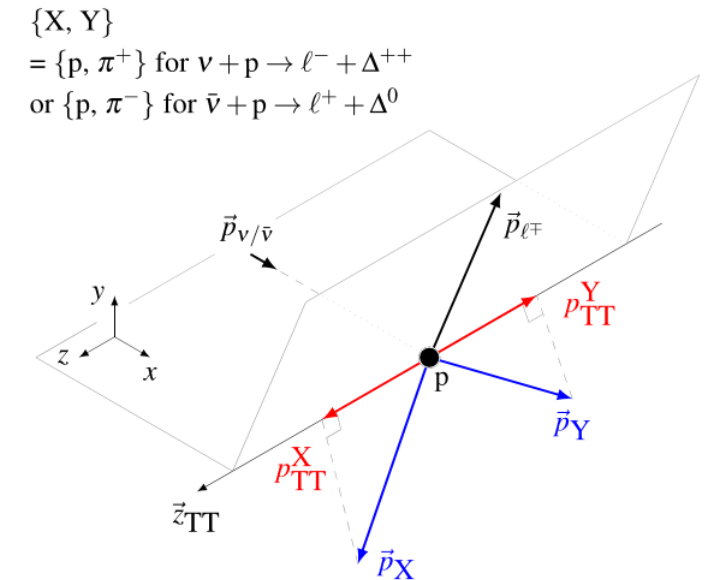
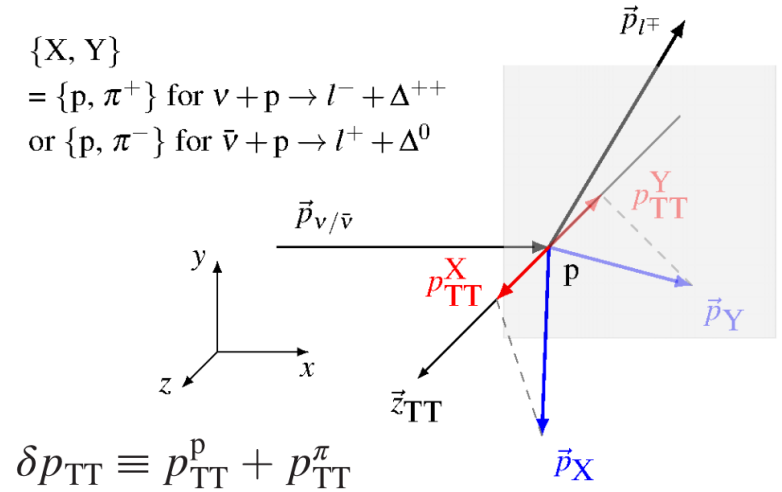
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(Received 3 July 2015; published 21 September 2015)

We propose a new technique that enables an event-by-event selection of neutrino-hydrogen interactions in multinuclear targets and thereby allows application of hydrogen as targets in experiments with neutrino beams without involving cryogenics or high pressure hydrogen gas. This technique could significantly improve the reconstruction of the neutrino energy spectra. Since it allows a separation between hydrogen and the accompanying nuclei, this technique also enables us to measure nuclear effects in neutrino interactions directly.



XL, JPS Conf.Proc. 12, 010034 (2016)

PHYSICAL REVIEW C **94**, 015503 (2016)

Measurement of nuclear effects in neutrino interactions with minimal dependence on neutrino energy

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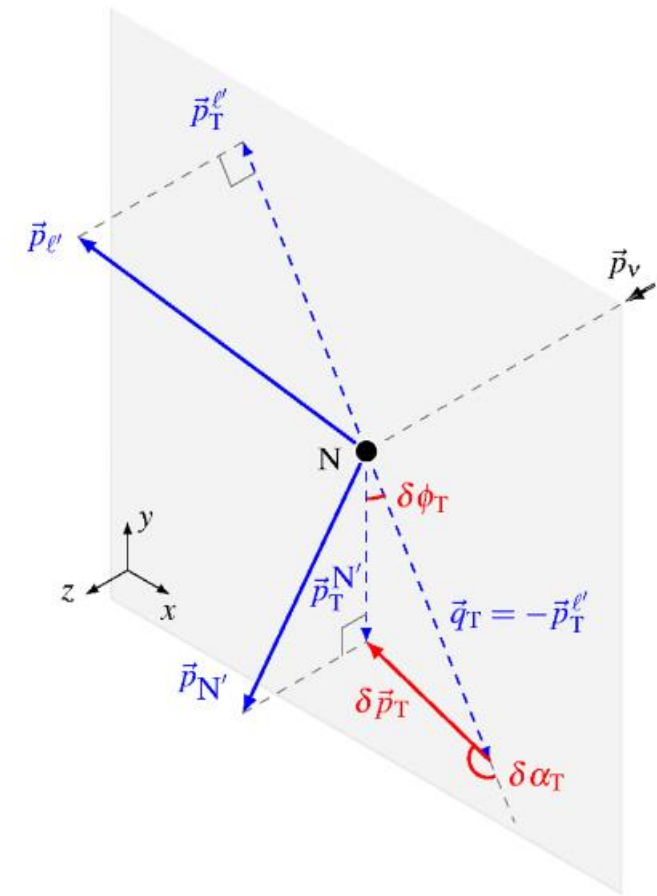
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(Received 17 December 2015; revised manuscript received 27 June 2016; published 28 July 2016)

We present a phenomenological study of nuclear effects in neutrino charged-current interactions, using transverse kinematic imbalances in exclusive measurements. Novel observables with minimal dependence on neutrino energy are proposed to study quasielastic scattering and especially resonance production. They should be able to provide direct constraints on nuclear effects in neutrino- and antineutrino-nucleus interactions.



Every good story has its twists and turns.

So, how did it start?

A huge thanks to Gmail (not Outlook!) which makes this archology possible.

Single-TKI: δp_T and $\delta\phi_T$

Sun, Jan 18, 2015

first study of p_T imbalance in ND280 as a measure for FSI and bound state effects

[...]

during the discussion in our group meeting last Wednesday, I remembered something old from my previous experiments. Now the idea becomes more clear to me. That is, p_T is very interesting in ND280.

Suppose we consider the interaction

$\nu + n \rightarrow \mu + p$

If the neutron were static and free, the p_T of the muon and proton would be balanced. It is however not the case due to Fermi motion, FSI, and some exotic quasi-bound-state effect, which currently limit our E_ν reconstruction precision. It means that the p_T difference is a characteristic of all these effects. By measuring it, we can constrain the theoretical models right at the point where we need them to be improved for the very goal of our experiment. The concept resembles largely what we call " p_T broadening" at HERMES and "jet quenching" at ALICE.

In the attachment is a first study of the p_T imbalance between muon and proton in CCQE using MC.

*The left plot shows **the p_T modification** of the proton and the right plot **the angular** (defined in the perpendicular plane w.r.t. the neutrino beam) **modification**. The simulation quantities are compared to the reconstructed ones (default setting, no QA cuts).*

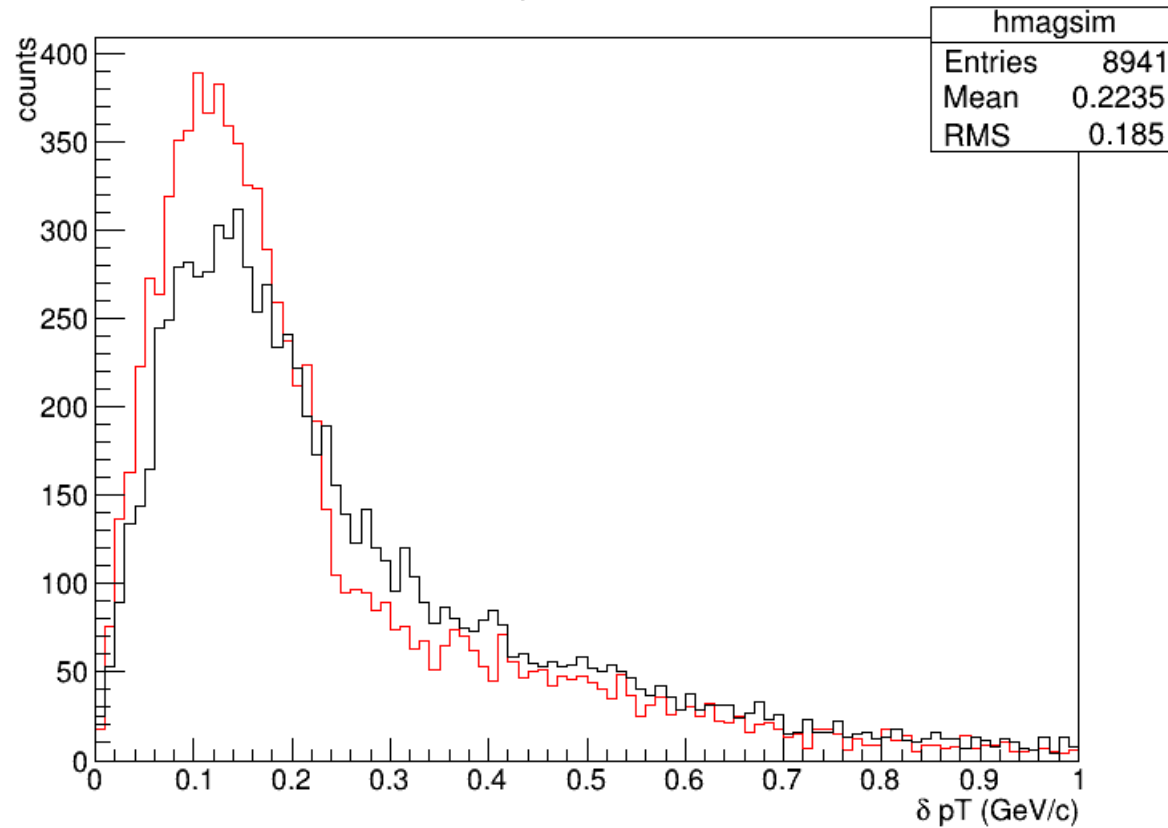
[...]

These two variables had been measured and used in various ways in e.g. NOMAD and T2K, see discussions in the PRC paper.

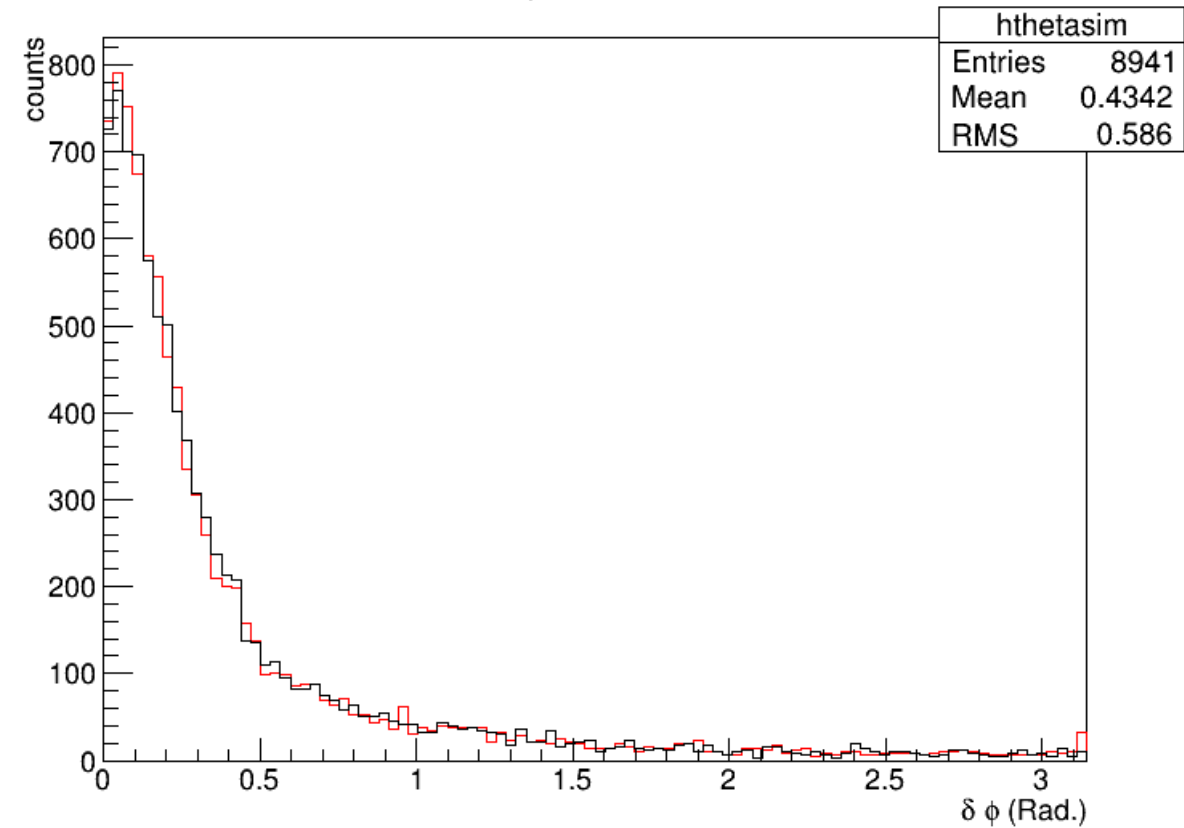
Single-TKL: δp_T and $\delta\phi_T$

Sun, Jan 18, 2015

red: simulation, black: reconstruction



red: simulation, black: reconstruction



Single-TKI: δp_T , $\delta\phi_T$, and $\delta\alpha_T$

Wed, Jan 21, 2015

talk on pT spectrum in x-sec pre-meeting

[...]

in fact my idea here was coming from my HERMES experience. Here is a paper about pt broadening

<http://inspirehep.net/record/823107?ln=en>

The physics is very similar indeed.

However, there the pt is defined w.r.t. the virtual photon direction. Since we don't know about the neutrino energy, we don't know the W-boson direction.

Actually the technical picture I present is more similar to jet quenching from ALICE ...

While you walked down the street, I got another interesting variable -- the force angle. See page 5-6 in the attachment.

[...]

Kinematics Analysis

In the neutrino transverse plane
Static free neutron

$$v + n = \mu + p \Rightarrow \vec{p}_T^\mu = -\vec{p}_T^p \quad - 0 \text{ unknown: independent of } E_\nu$$

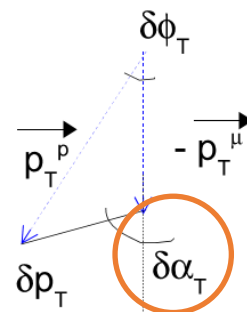
In ND280

$$v + n \neq \mu + p \Rightarrow \vec{p}_T^\mu \neq -\vec{p}_T^p \quad - 1 \text{ unknown: interaction details}$$

The p_T difference between muon and proton points at the very heart of the problem of E_ν calculation, which has uttermost importance in neutrino oscillation experiments.

A planar problem, 2 degree of freedom, 3 correlated variables

1. transverse angular broadening $\delta\phi_T$
2. transverse force angle $\delta\alpha_T$ (drag vs. kick)
3. transverse momentum imbalance δp_T



New variable

Any successful interaction model should be able to describe all quantities simultaneously.

Jan also commented on this early on:
the many variables are over-constraining.

Dynamics Analysis

- 1) Fermi motion: $\vec{p}_F$ isotropic, ~ 200 MeV (221 MeV for ^{12}C [Povh])
 - isotropic non-relativistic ($\beta_{\text{max}} \sim 0.2$) “boost” (consider kinematics from neutron CMS to lab frame)
 - instant effect, simple geometry
- 2) Quasi-bound state effect, e.g. MEC. Big reduction of proton kinematics due to partner's share. Depends on detail like internal motion, life time, emission angle.
- 3) FSI: multiple scattering in nucleus, accumulated along path length, depending on nucleus size and shape (negligible if nuclear polarization can be ignored in ND280 B=? T), and most importantly interaction form between nucleon and nuclear medium. → Initial state effects should be washed out in large nucleus.

$\delta\phi_T$ alone has very clear physics picture!

... but most susceptible to flux uncertainty, see discussions in the PRC paper

First MC Analysis

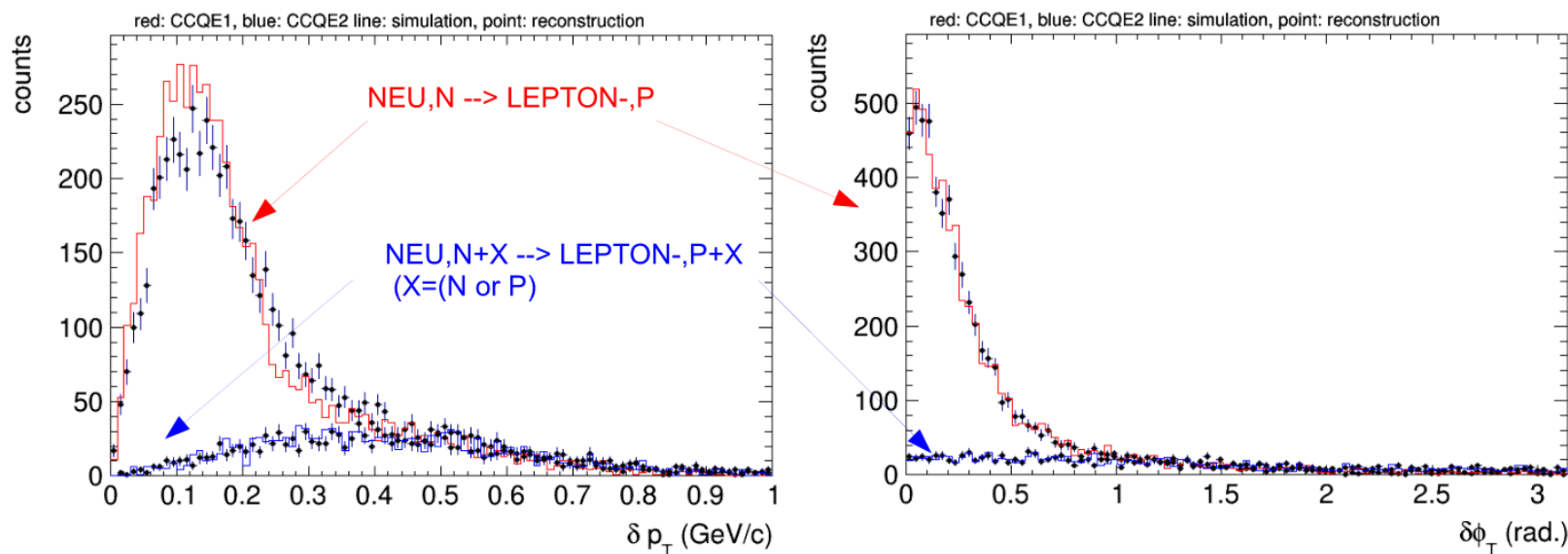
Technical details

1. MC production006/B/mcp/neut/2010-11-water/magnet/run4 (POT: $3.5E21 = 5E17$ POT/files * 7002 files)
2. Highland2 numuCCQEAnalysis output with accum_level[0][1]>=11 (full cuts for 2 TPC tracks, identified as muon- and proton.), cuts see BACKUP.
3. No additional cuts. Same phase space as in standard CCQE analysis.
4. Neutrino direction reconstructed as (mean parent decay point $\rightarrow$ interaction vertex). (see previous talk)

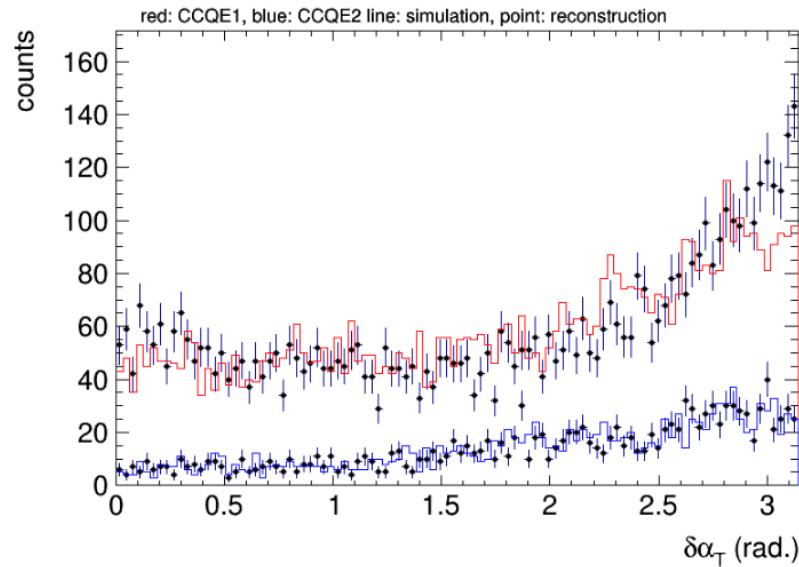
Non-stacked histograms. Comparing samples restricted to be (<http://www.t2k.org/t2ksk/code/neutmodes>)

A) CCQE1 (no quasi-bound state effect): NEU,N $\rightarrow$ LEPTON-,P

B) CCQE2 (quasi-bound state effect): NEU,N+X $\rightarrow$ LEPTON-,P+X (X=(N or P))



First MC Analysis



- Observations:
 - Quasi-bound state effect (e.g. MEC) has very distinct feature: large spread in δp_T and $\delta\phi_T$ due to partner's share $\rightarrow$ a very efficient way to select
 - $\delta\alpha_T$ favor $\pi \rightarrow$ “dragged” other than “kicked”
 - $\delta\phi_T$ has better resolution than δp_T , the latter needing further unfolding or QA cuts $\rightarrow$ resolution already good enough to show interesting physics
- Should be more interesting to separate ISI and FSI!
- Even more interesting to compare to real data!!

Tagged Single-TKI $\rightarrow$ Double-TKI: δp_{TT}

Fri, Feb 6, 2015

No. x-th idea

[...]
[...] In the mean time (this afternoon out of no reason, I don't know how it happened...), another potentially influential measurement came up.

What we discussed today was, in neutrino-scattering, if we measure transverse angular broadening of proton, in addition requiring exactly 1 π^+ in the event, we can probe Δ^{++} -medium effect.

A more general idea is, we can measure transverse angular broadening of proton, in addition requiring certain other particle(s) in the final state. For example, if we require at least one electron/positron track in TPC or gamma/electron/positron clusters in ECal in the final state, we can probe Δ^{+} -medium effect. This is in fact very powerful because we don't need to reconstruct π^0 at all and even don't need 4 legs. 1 is enough. The logic can certainly be carried on.
[...]

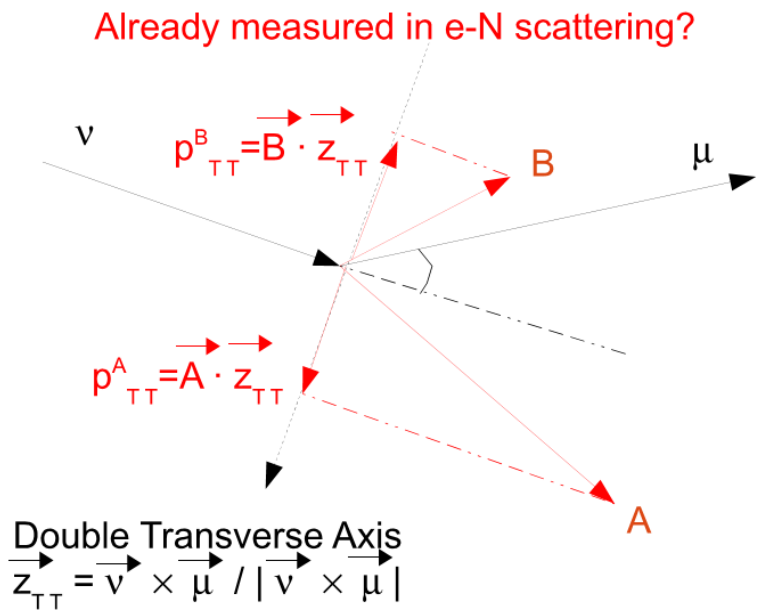
Sat, Feb 7, 2015

recent development

[...]
here is the recent development. Please have a look at the attachment. Sorry for the late briefing. The ideas are really fresh and now seems stable [...]
[...]

Double Transverse Momentum Imbalance

Sat, Feb 7, 2015



$$\delta p_{TT}^{AB} = p_{TT}^A + p_{TT}^B$$

$\nu + N \rightarrow \mu R$
 $R \rightarrow A + B$
N: nucleon
R: resonance
A,B: resonance decay products

If N static and free $\delta p_{TT}^{AB} = 0$.
Otherwise
 $p_{TT}^{A,B}$ subjects to Fermi motion (FM), final state interaction (FSI).
For δp_{TT}^{AB} , FM contributions canceled on the average sense. Only sensitive to FSI.
Iff δp_{TT}^{AB} mean=0 and symmetric shape, FSI of A = FSI of B.

ν	N	R	A	B
neutrino	proton	Δ^{++}	p	π^+
neutrino	neutron	Δ^+	p	$\pi^0 \rightarrow \gamma, e^{\pm}$
anti-neutrino	proton	Δ^0	p	π^-

If FSI is iso-symmetric (no QED correction), $\delta p_{TT}^{p\pi^+}$, $\delta p_{TT}^{p\pi^0}$ and $\delta p_{TT}^{p\pi^-}$, should be consistent (except due to slight mass difference of π^0).

Correlate to combined single TMI to probe path length dependence of FSI (David C.)

A=B= proton $\rightarrow$ MEC new physics? (compare to ArgoNeut <http://arxiv.org/abs/1405.4261>)

nuclear free neutrino energy measurement

[...]

I am sure you still remember the delta function in the distribution of δp_{TT} in s17 of the attachment, which I also showed last week. I though there is something wrong with the MC. But today Giles pointed it out to me that, in case of interaction on Hydrogen target, there won't be nuclear effects and after a check in the analysis, this is indeed the case. So the delta function is indeed physics. In s28 you can see the reconstructed distribution and the distinct peak is seen.

I just realize that we have some potentially very important application from it:

- 1) ν on H target Δ^{++} xsec and anti- ν on H target Δ^0 xsec
- 2) nuclear-free neutrino energy reconstruction using ν on H target.

Currently 2) still suffer from detector resolution, but the results will be of potential impact in the neutrino community because

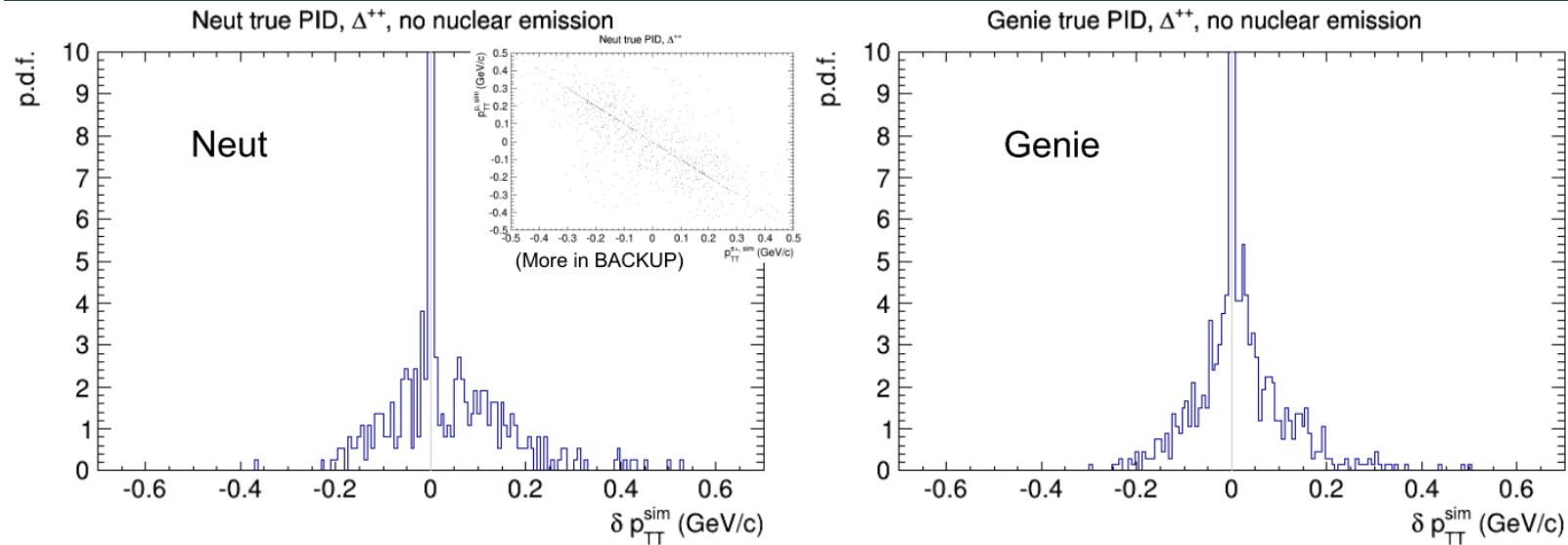
- a) we know how to improve transverse kinematic detector resolution very well
- b) we can use H-enriched material as target material

so if we are considering future experiment, then as long as we have a decent magnetic field, we will be able to measure neutrino energy precisely. The transverse kinematic enables us to select the signal unambiguously. The cross section calculation may be still an issue, but nuclear free $\nu p \rightarrow \mu \Delta^{++}$ doesn't seem very challenging in my impression.

I need to sit down quietly to think about how to update my talk...

[...]

Double-Transverse Imbalance with weak FSI



no nuclear emission (p, n, γ) = weak FSI

(Simulation information:
before GEANT4 propagation)

1) **Exact (!) δ -function in both Neut and Genie $\rightarrow$ 0 FSI:**

Δ^{++} decay inside nucleus $\rightarrow$ no FSI for π and p

Δ^{++} decay outside nucleus $\rightarrow$ no Δ^{++} FSI

$\rightarrow$ either case **unphysical**. Need to get Δ^{++} kinematics directly in future study.

But above all, where is the Fermi motion? The resulting initial transverse momentum should always be there.

2) Different shapes. **The transition between 0 $\rightarrow$ weak FSI is more abrupt in Neut.**

3) Both slightly asymmetric towards positive direction: $p_{\text{TT}}^p > p_{\text{TT}}^\pi$, **more energy loss for pion.**

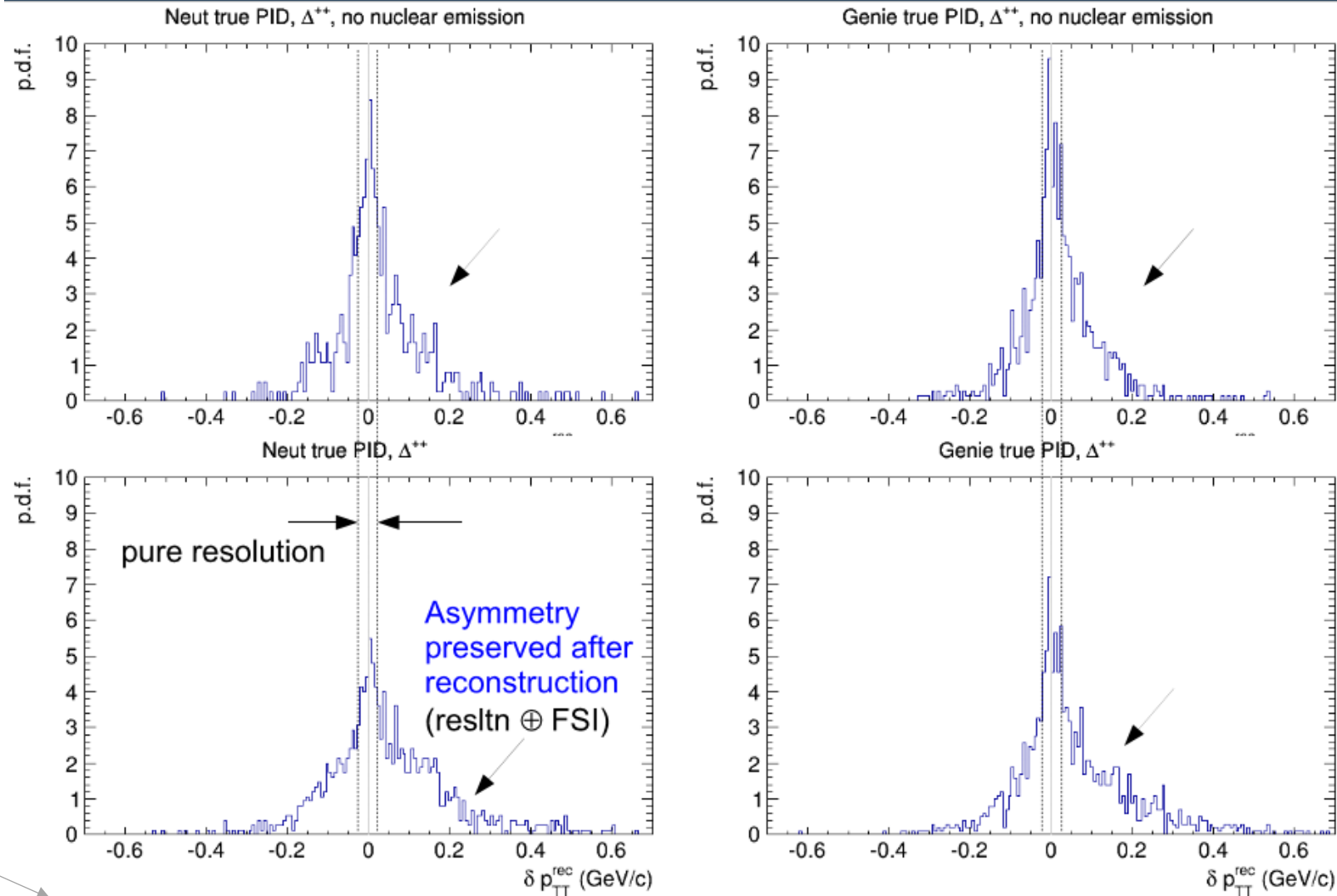
7-April-2025 draft

9-April-2015

X.-G. Lu, Oxford

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Reconstruction Performance



7-April-2025 draft

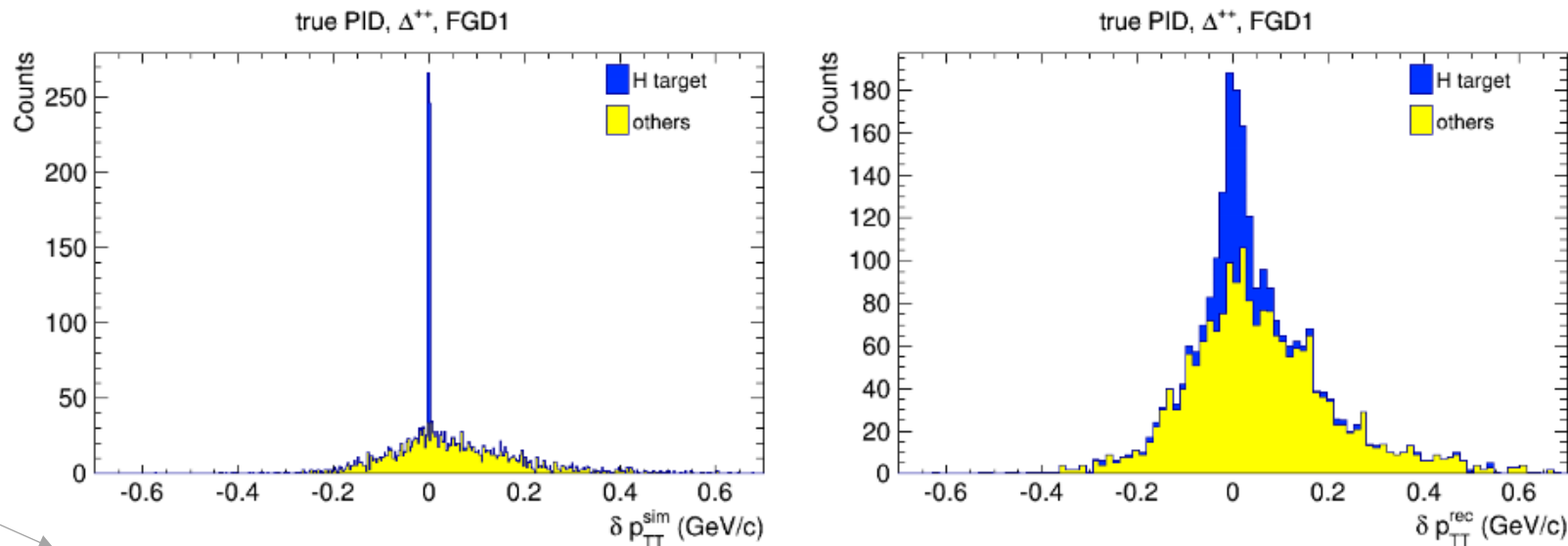
9-April-2015

X.-G. Lu, Oxford

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Application: Resonance Production on Hydrogen

- Double-transverse kinematics (δp_{TT}) provides a distinct signal for Δ^{++} production in neutrino on Hydrogen
 - Signal shape only detector resolution – well known
 - Exactly the same story for anti-nu on $\text{H} \rightarrow \mu^+ \Delta^0, \Delta^0 \rightarrow \text{p} \pi^-$.
- Feasible to perform xsec measurements via sideband subtraction
- With improved resolution, H-target signal can be very clean
(using Neut+Genie unless otherwise stated)



T2KUK presentation

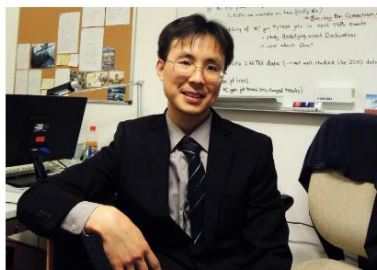
9-April-2015

X.-G. Lu, Oxford

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Proposed TKI Effort in T2K

Proposal of exclusive measurements and
transverse kinematics imbalance
as direct probes of FSI in neutrino interactions



Xianguo Lu
Oxford
T2KUK F2F
9-Apr-2015

Red fonts are questions that I don't have
answers to. Please comment.

9-April-2015

X.-G. Lu, Oxford

1418,3574

1

T2K Activities on Transverse Kinematics

- FSI characteristics
 - FSI model parameters, nucleus dependence with single-transverse kinematics imbalance in CCQE
 - ν -P0D () <http://www.t2k.org/nd280/physics/xsec/subgroup/cc0pi/2015/mar30/p0dsidebands/view>
 - ν -ECal ()
 - FSI particle type dependence and resonance FSI with double-transverse kinematics imbalance in $CC\Delta^{++}/\Delta^0$
 - ν /anti- ν -FGD1 ()
- Cross section measurements
 - CCQE xsec with single-transverse kinematics imbalance
 - ν -P0D () (same like as above)
 - ν -ECal ()
 - CCDIS xsec with muon pT
 - ν -FGD1 () <http://www.t2k.org/nd280/physics/xsec/subgroup/cc/2015/april1/20150401-ccdis-highpt/view>
- Searches
 - $1\mu 1p$ MEC with single-transverse kinematics imbalance
 - ν -FGD1 ()

9-April-2015

X.-G. Lu, Oxford

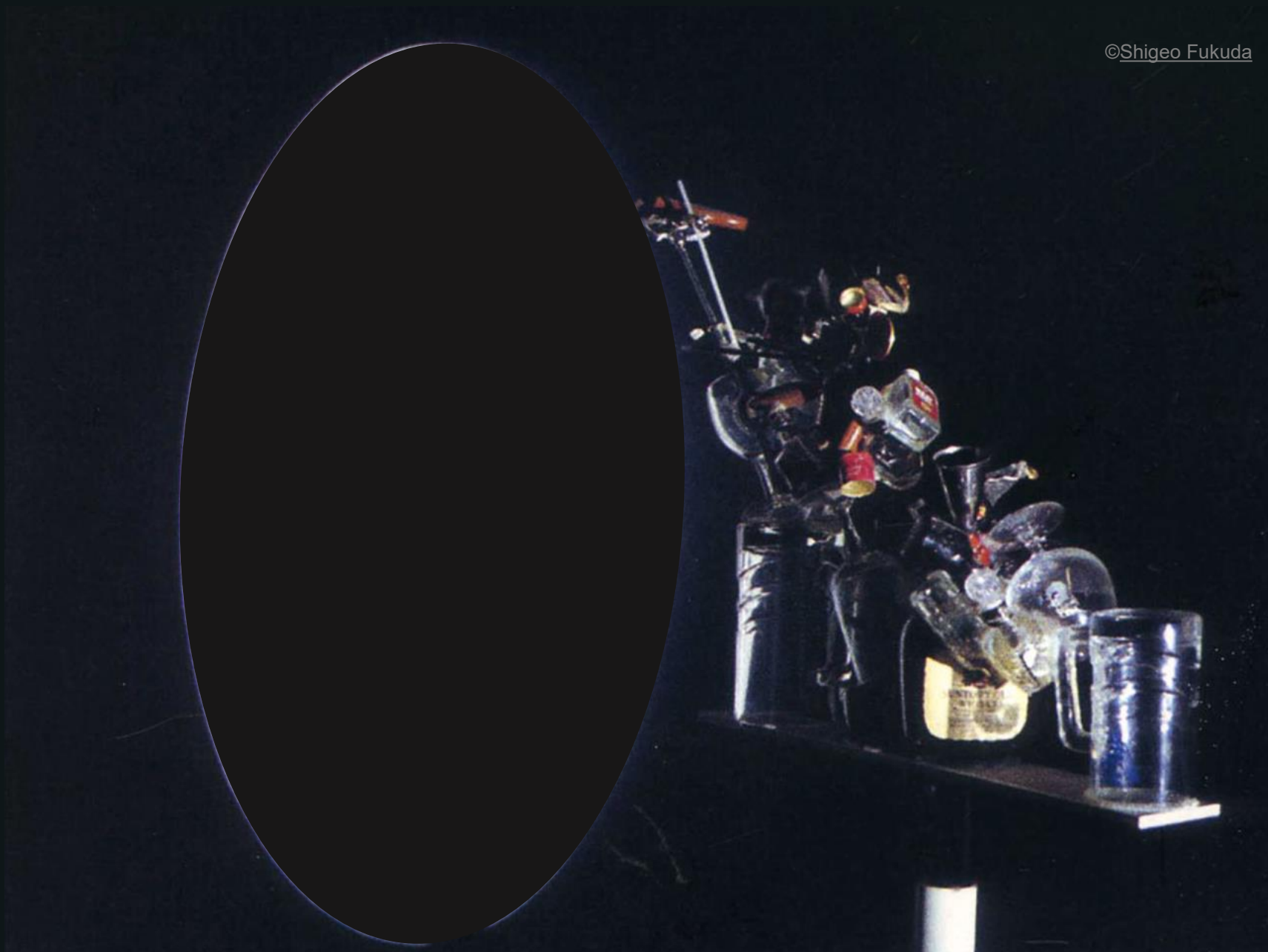
24

TKI Effort in MINERvA

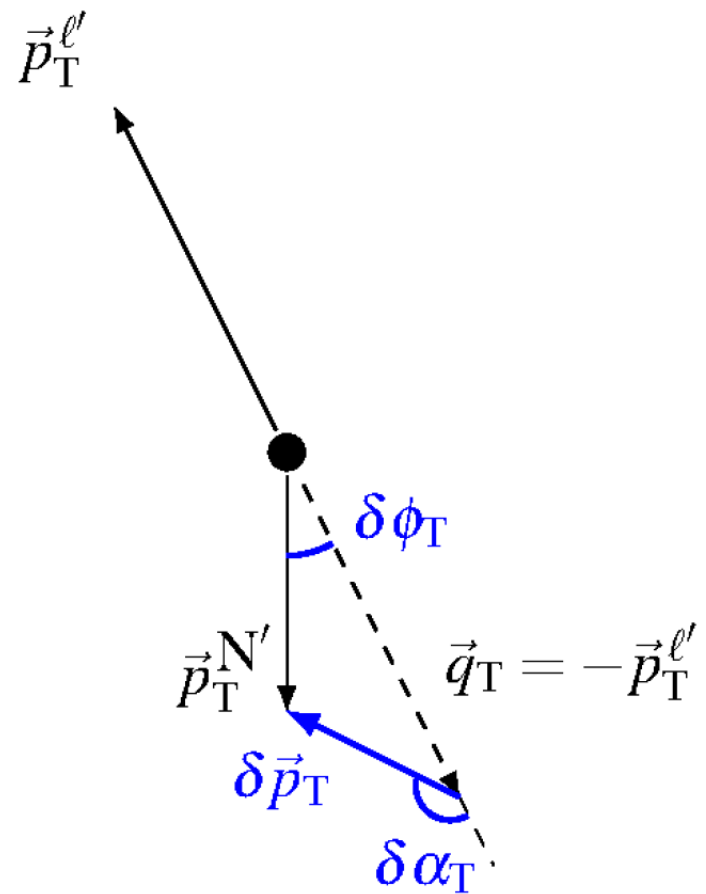
Soon after, informal invitation came on 22 May 2015 to join MINERvA *for contributing to this equivalent analysis*.

Oxford was accepted by MINERvA IB on Feb 6, 2016.

Since then, the first generation of TKI analyses had been carried out in T2K and MINERvA simultaneously.



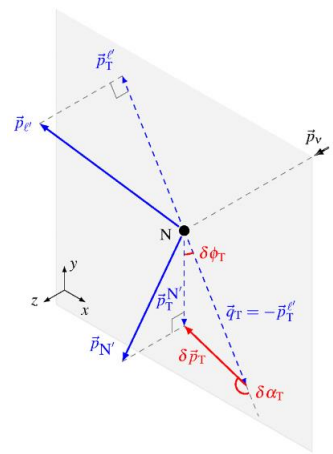
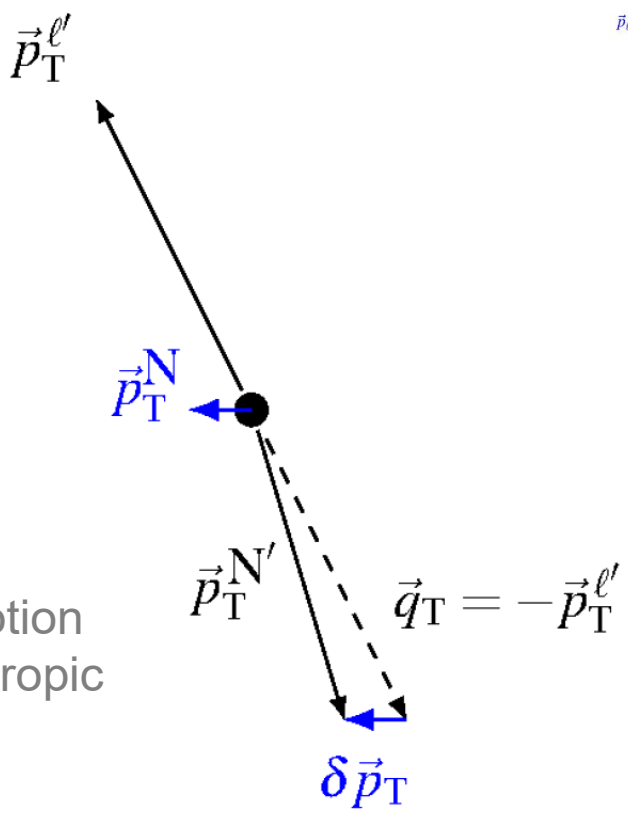
Transverse Boosting Angle $\delta\alpha_T$



if Fermi motion only



$\delta\vec{p}_T = \vec{p}_T^N$
 $\delta\alpha_T$ is Fermi motion
 direction $\rightarrow$ isotropic



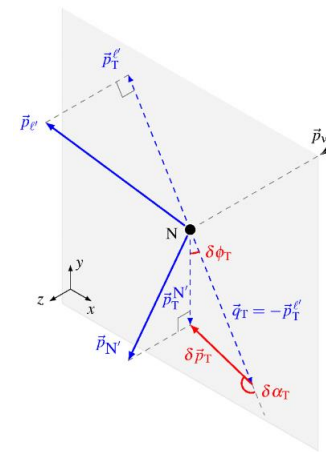
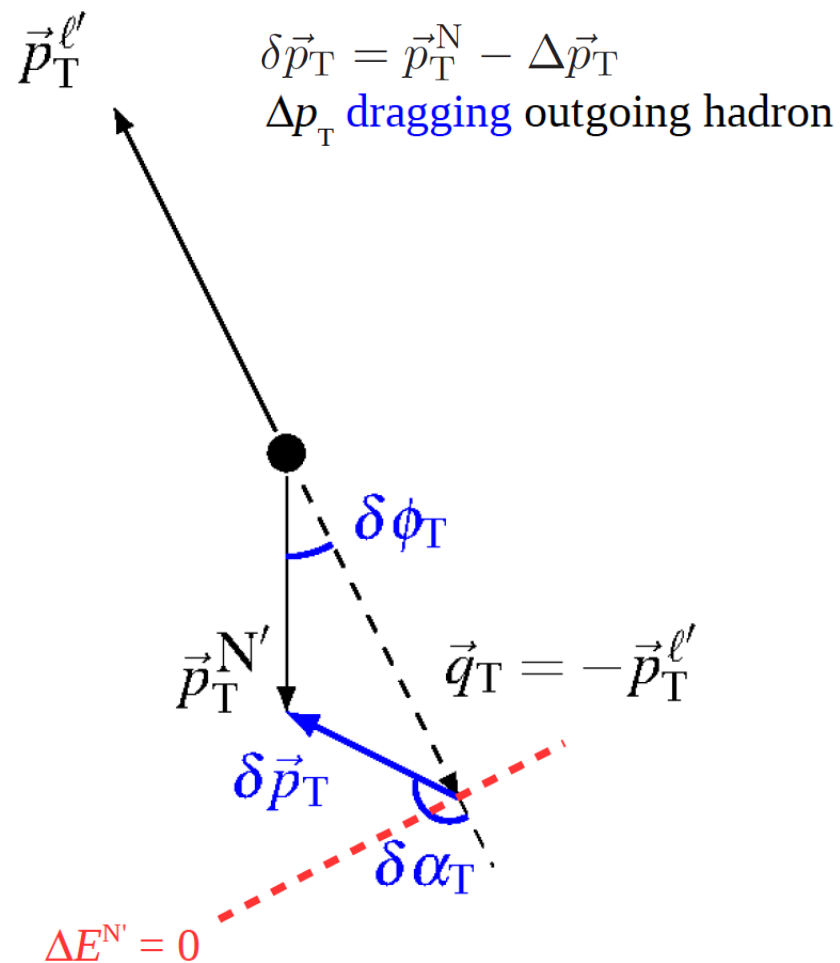
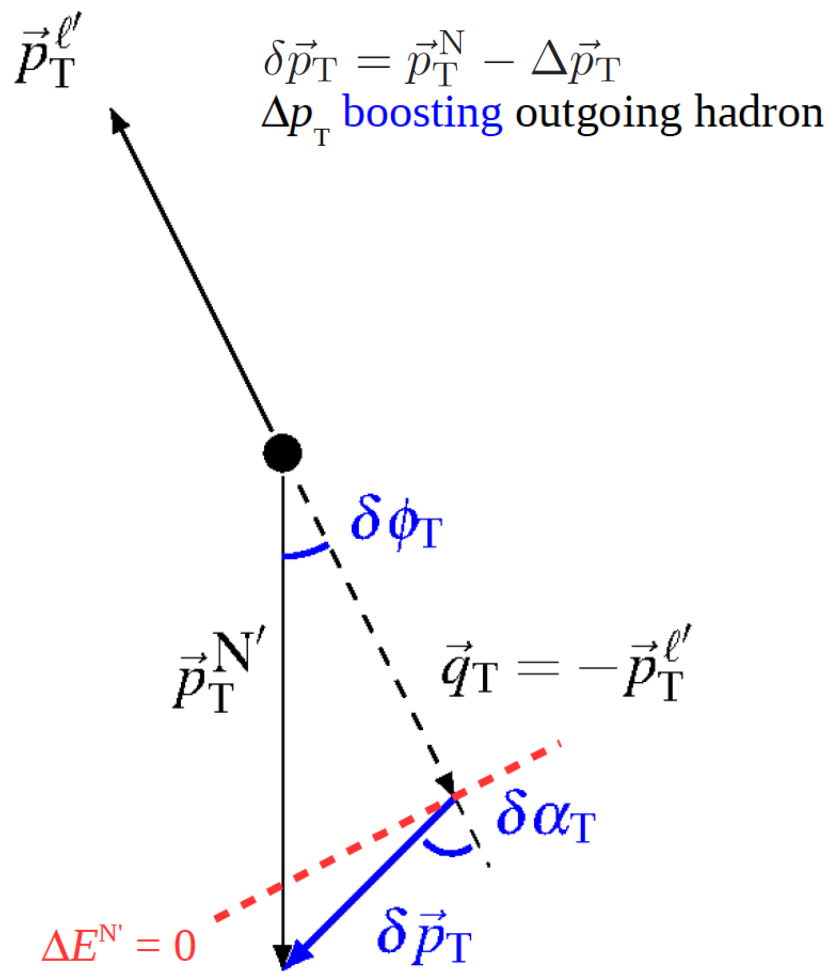
- $\delta\vec{p}_T$
- total transverse momentum
- transverse momentum imbalance
- missing pT
- ...

In full

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

FSI and missing particles

Transverse Boosting Angle $\delta\alpha_T$



FSI and momentum sharing with extra particles

☐ pion absorption

☐ 2p2h

A general analysis of kinematic imbalance

Transverse: $0 = \vec{p}_T^{\ell'} + \vec{p}_T^{N'} - \delta \vec{p}_T$

Longitudinal: $E_\nu = p_L^{\ell'} + p_L^{N'} - \delta p_L$

New variable: $p_n \equiv \sqrt{\delta p_T^2 + \delta p_L^2}$

Neutrino energy is unknown (in the first place),
equations are not closed.

Assuming exclusive ℓ' - N' - A' final states

Use energy conservation to close the equations

$$E_\nu + m_A = E_{\ell'} + E_{N'} + E_{A'}$$

$$E_{A'} = \sqrt{m_{A'}^2 + p_n^2}$$

Final-state interpretation

p_n : recoil momentum of nuclear remnant

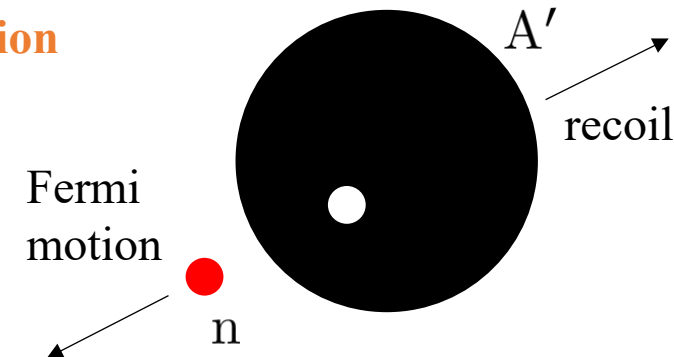
Dual interpretation

Initial-state interpretation

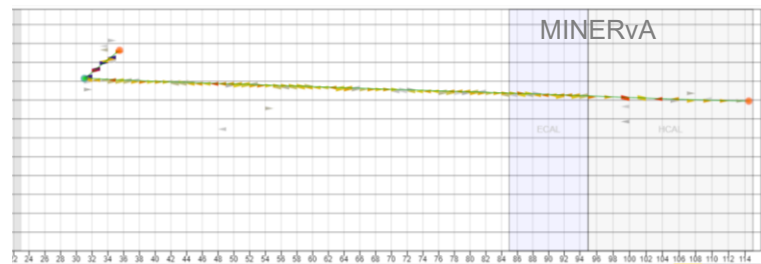
For CCQE, $A' = {}^{11}\text{C}^*$

No more unknowns

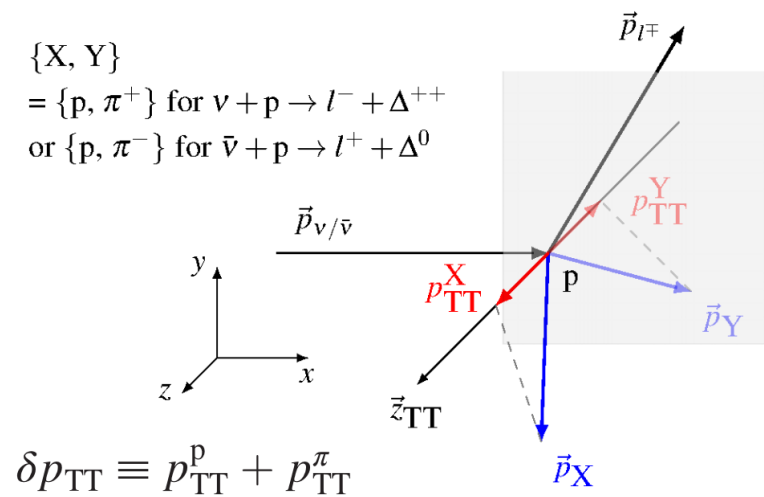
p_n : neutron Fermi motion



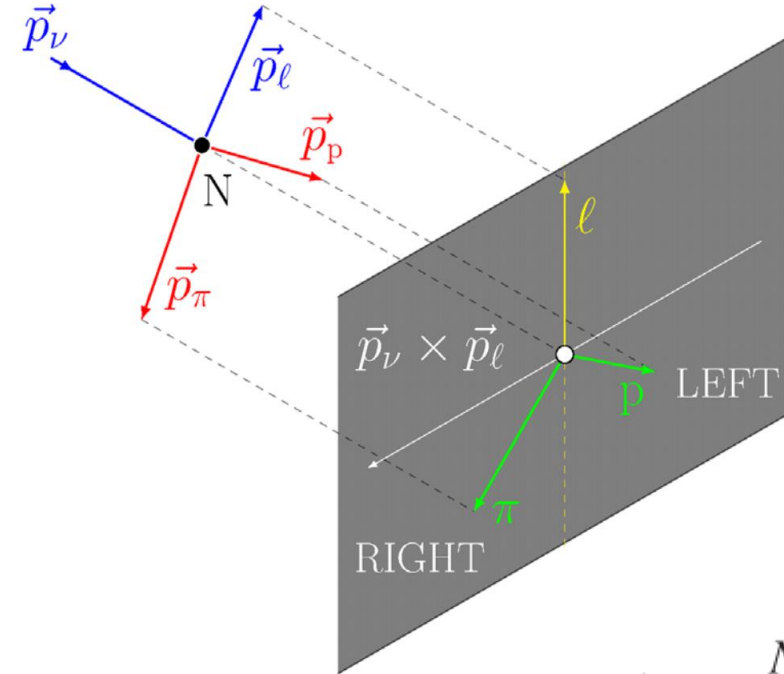
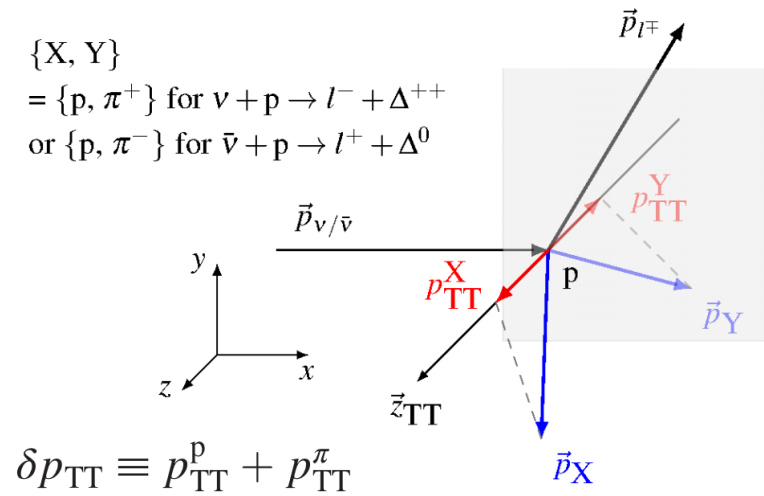
[XL & Sobczyk, PRC 99, 055504 (2019)]



Generalisation #3: $p\pi \rightarrow p$ in Double-TKI


$$\delta p_{Tx} = \delta p_{TT} \text{ when there is no pion in the final state}$$

, Phys.Rev.D 100 (2019) 073010]

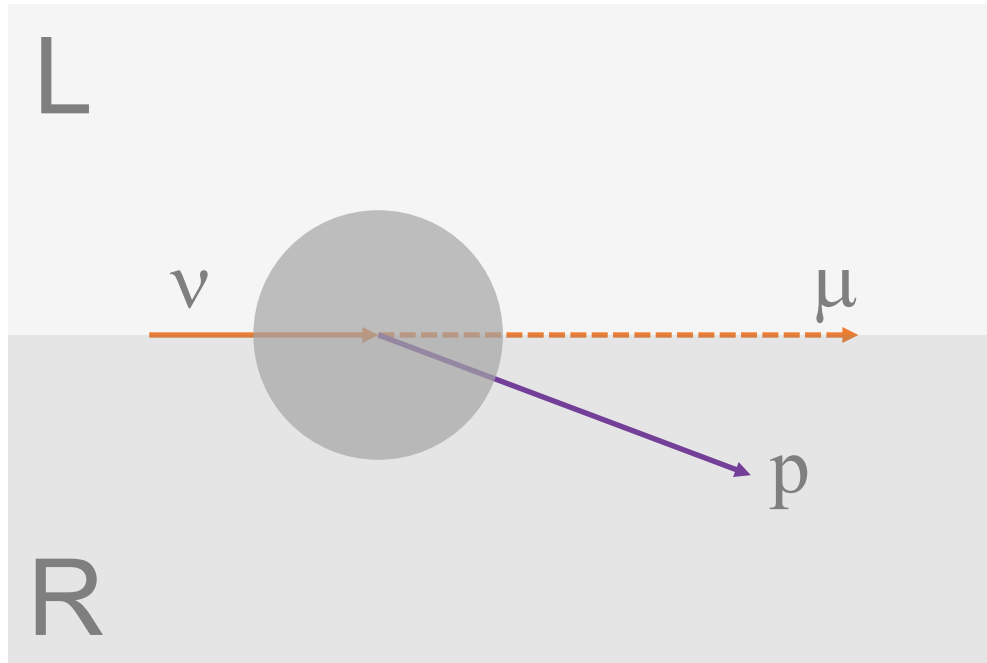


$$\frac{N_- - N_+}{N_- + N_+}$$

Generalisation #4: Double-TKI $\rightarrow$ L-R Asymmetry (TKI-)

[Cai, XL, and Ruterbories, Phys.Rev.D 100 (2019) 073010]

Bird's-eye view—Muon pointing up



0π production contains

- ☐ QE
- ☐ pion absorption (RES)
- ☐ 2p2h

- L-R asymmetry of 0π come from that of each component.
- RES could have L-R asymmetry; QE and 2p2h not.
- Dilution of RES L-R asymmetry tells us how much QE and 2p2h there are, together with TKI separating QE and 2p2h+RES, so we have a way to isolate 2p2h from RES in 0π !

(Detailed analysis in later slides...)

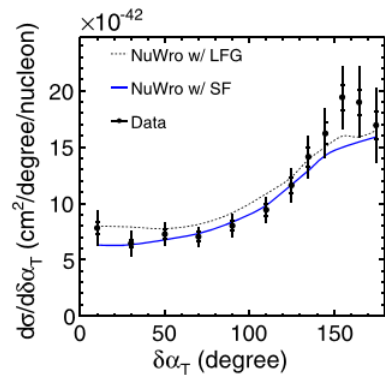
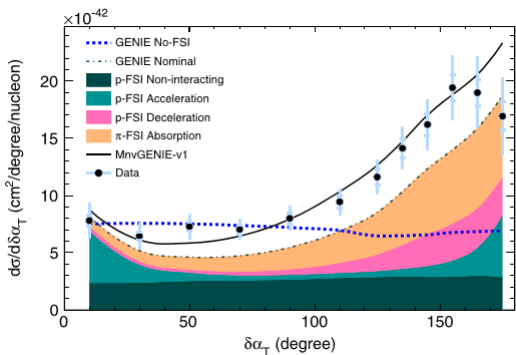


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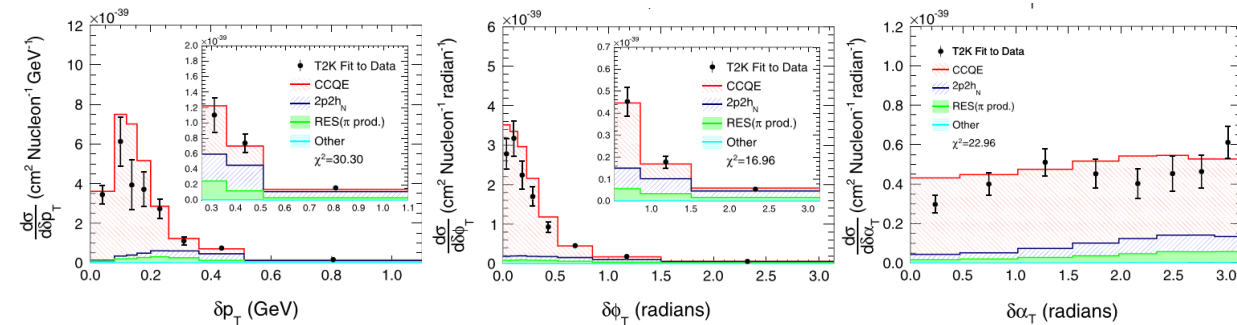
MINERvA/T2K Results: (1) carbon, 0π

TKI

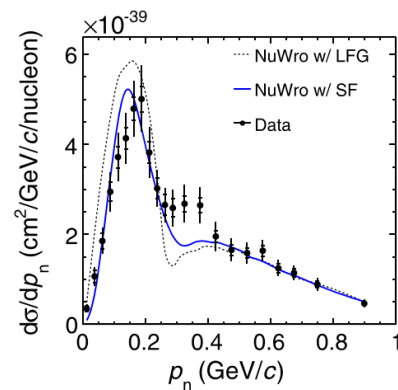
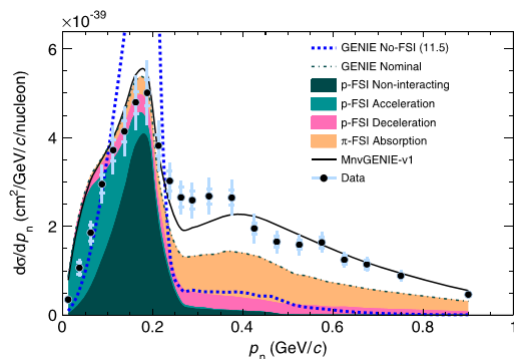
MINERvA, Phys.Rev.Lett. 121, 022504 (2018)



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



TKI+

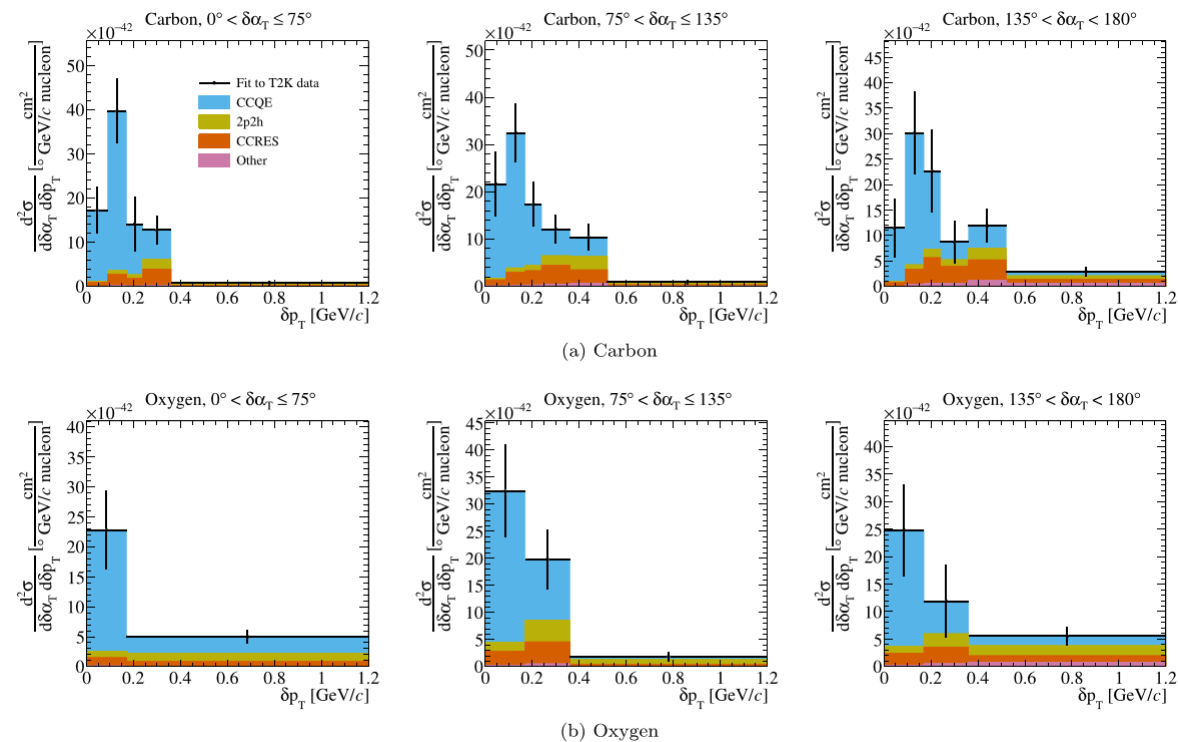
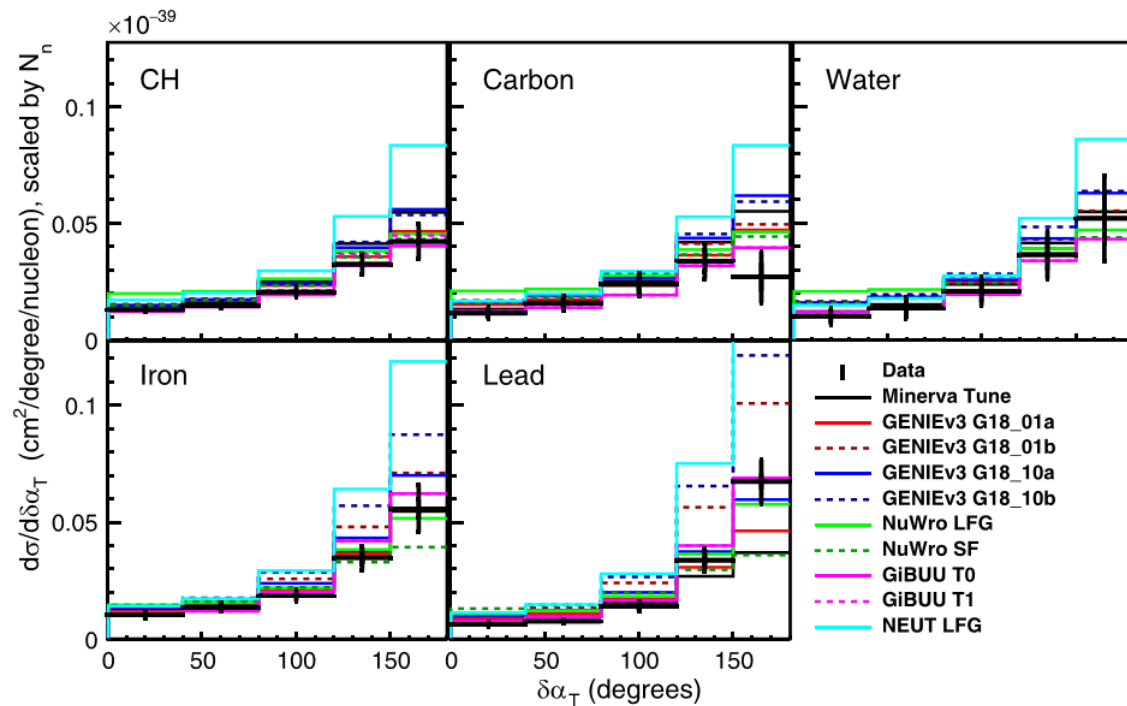


MINERvA/T2K Results: (2a) nuclei, 0π

TKI

MINERvA, Phys.Rev.D 112, 052005 (2025)

T2K, 2607.10638, 2607.10644

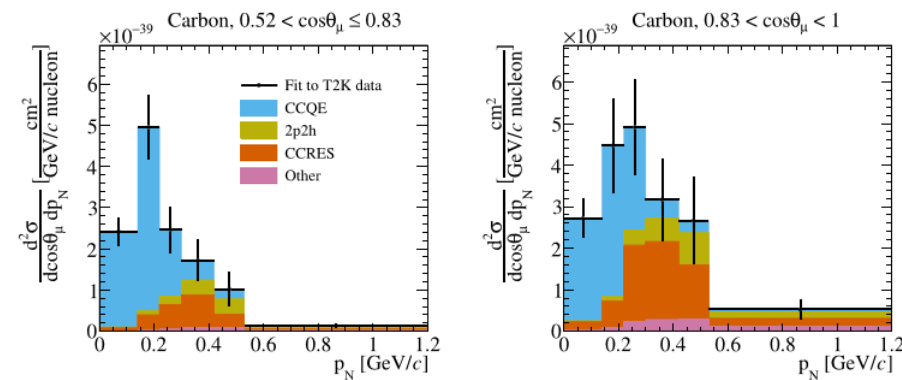
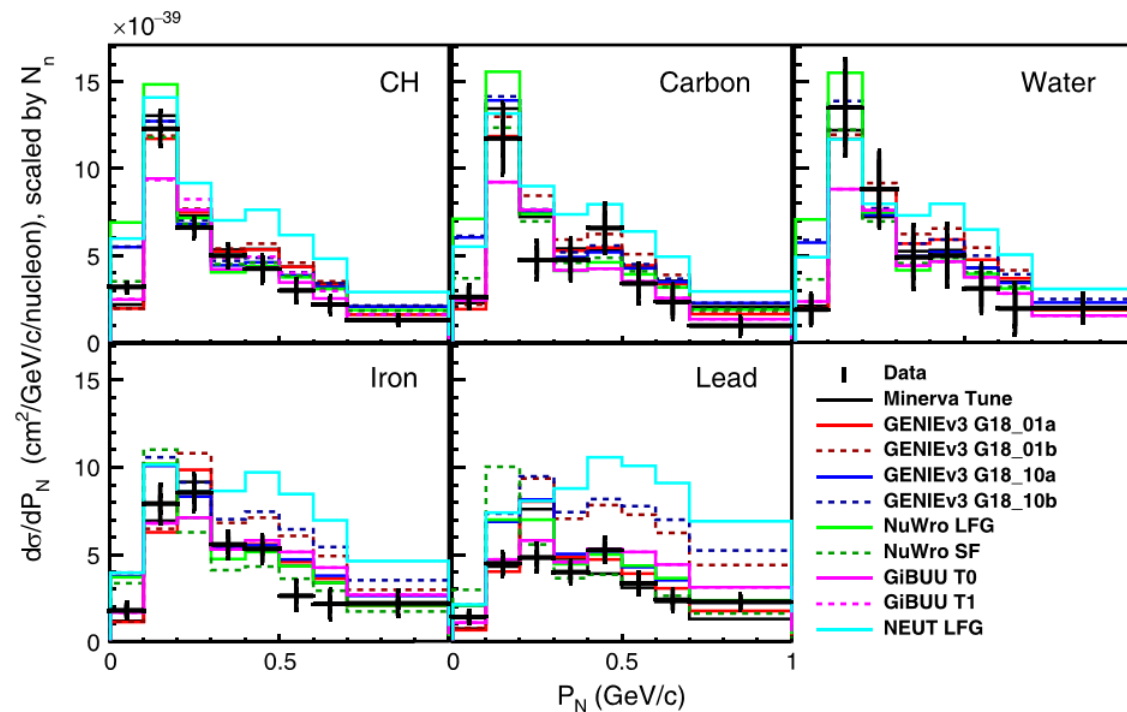


MINERvA/T2K Results: (2b) nuclei, 0π

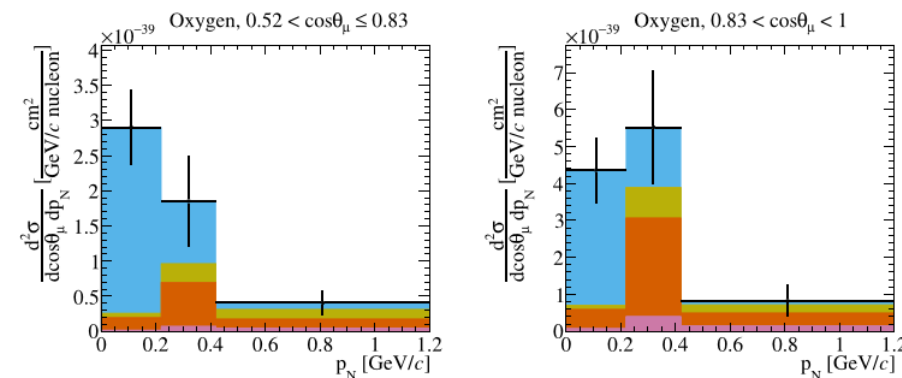
TKI+

MINERvA, Phys.Rev.D 112, 052005 (2025)

T2K, 2607.10638, 2607.10644



(a) Carbon



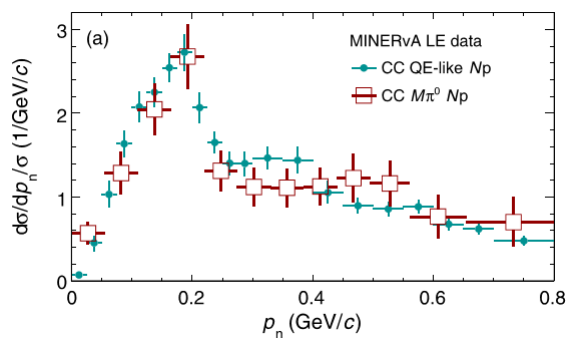
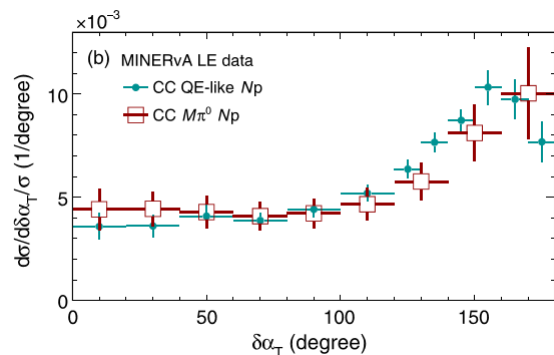
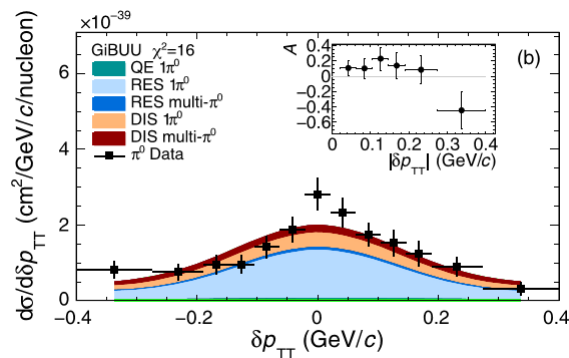
(b) Oxygen

MINERvA/T2K Results: (3) pion production

π^0

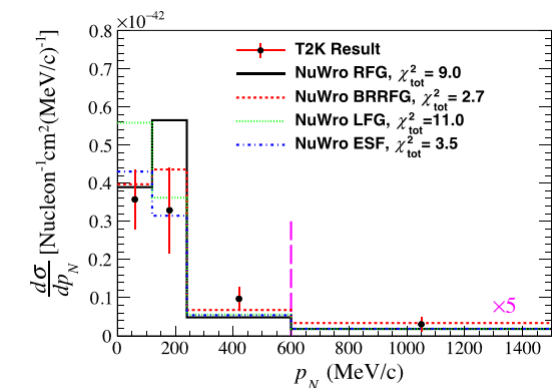
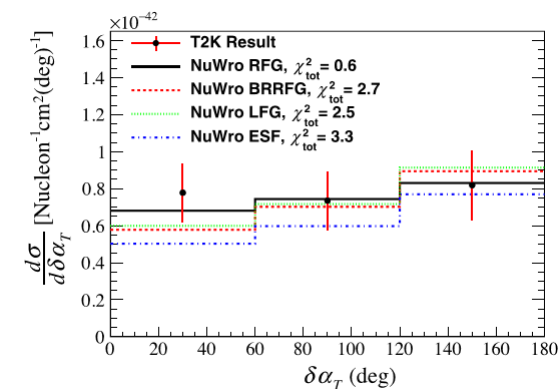
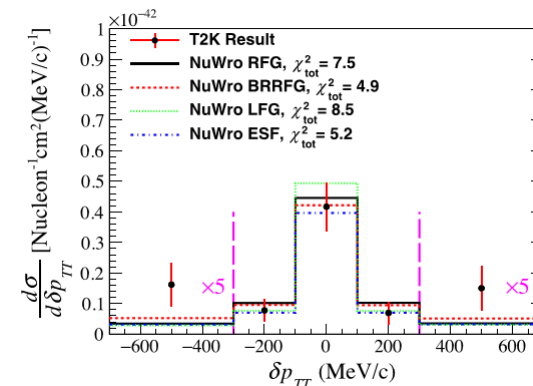
MINERvA, Phys. Rev. D 102, 072007 (2020)

TKI



π^+

T2K, Phys.Rev.D 103, 112009 (2021)

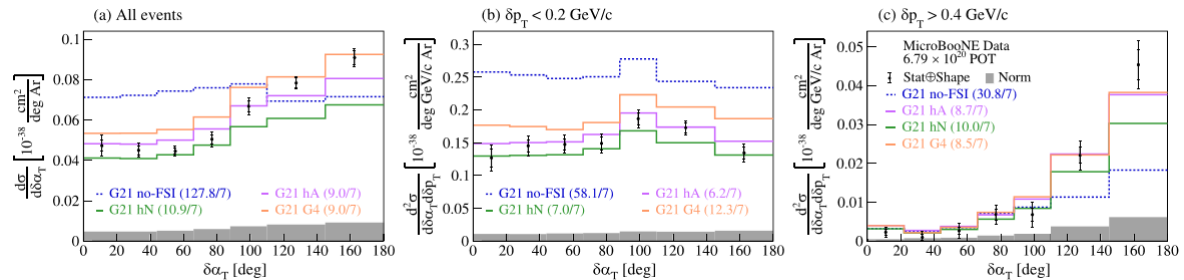


TKI+

MicroBooNE Results

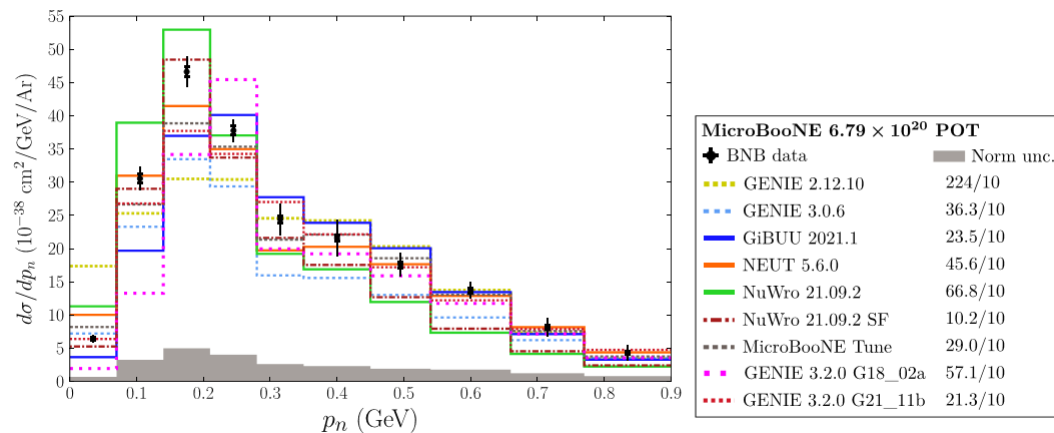
TKI

0π



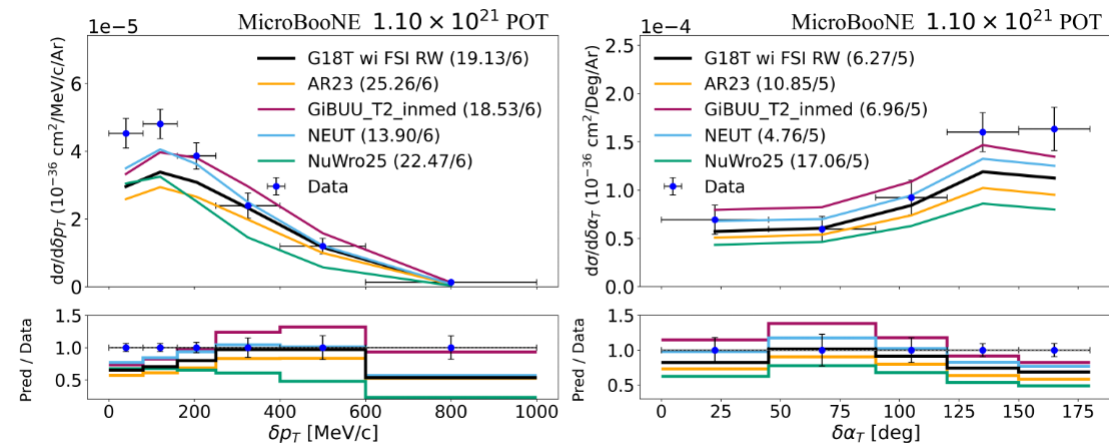
MicroBooNE TKI [Phys.Rev.Lett. 131, 101802 (2023),
Phys.Rev.D 108, 053002 (2023), Phys.Rev.D 112, 112004 (2025)]

TKI+



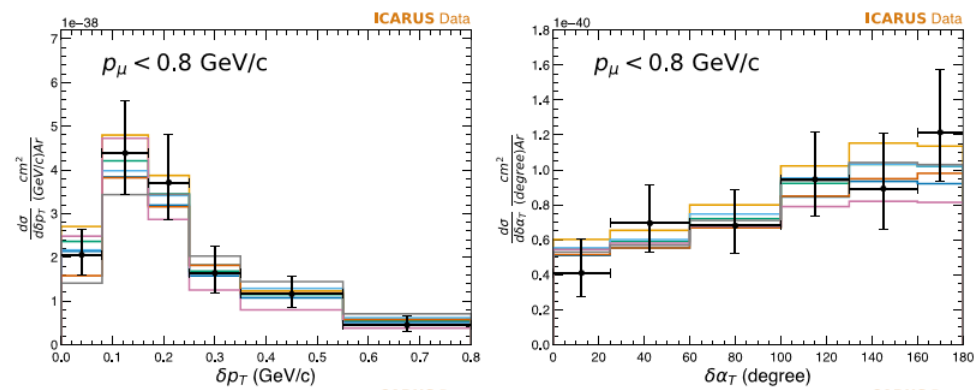
MicroBooNE TKI+ [Phys.Rev.D 112, 112004 (2025)]

π^0



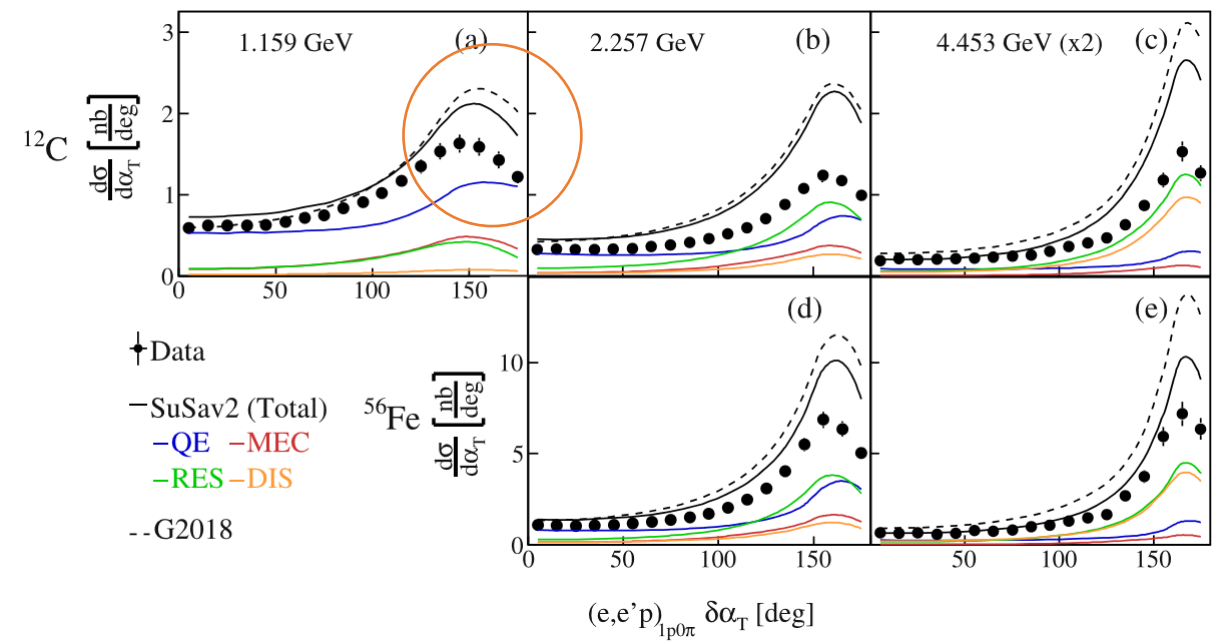
MicroBooNE π^0 TKI [arXiv:2606.23559]

Other TKI Measurements

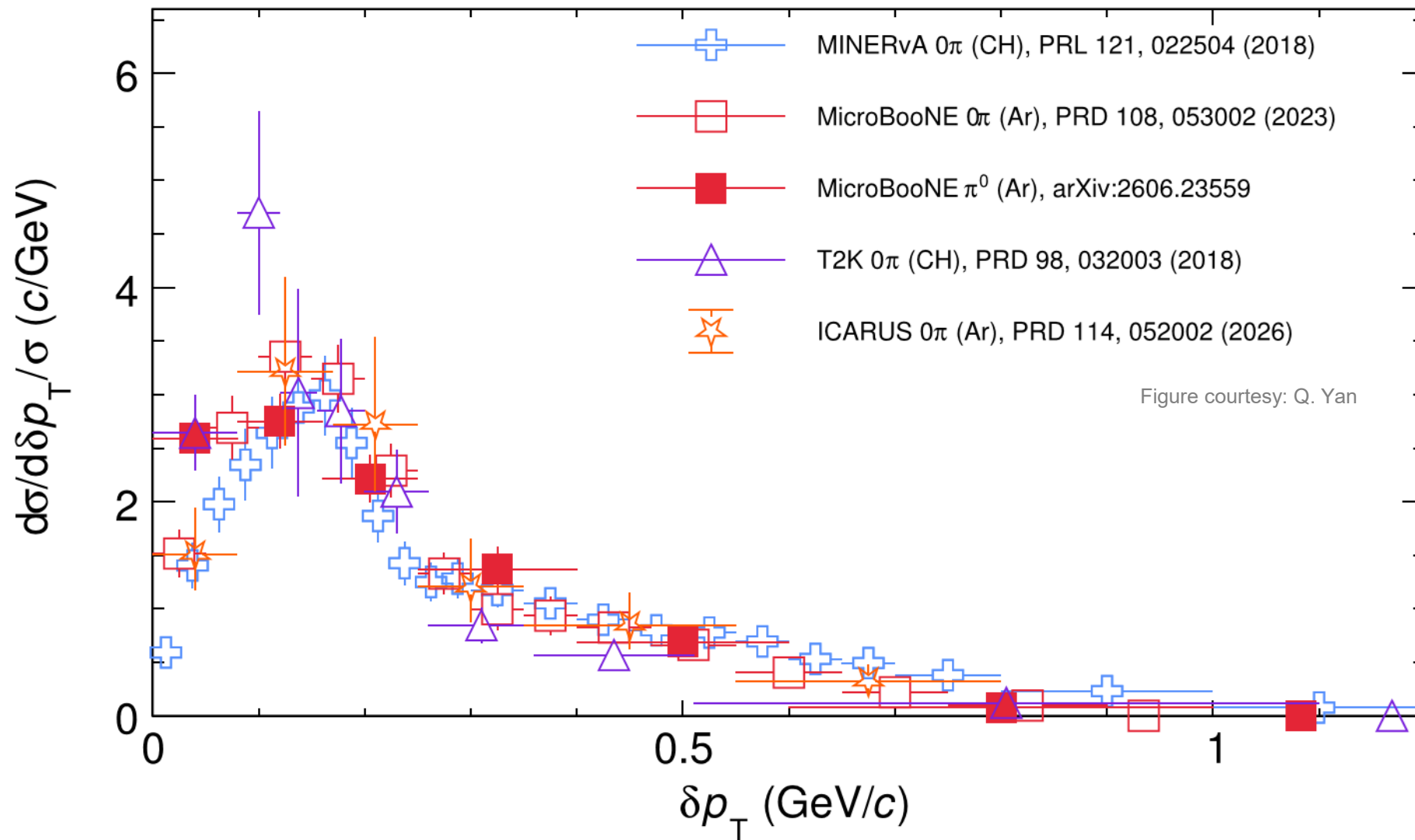


- ✚ Data
- Reference model
- LQCD z-exp F_A^{CCQE}
- MINERvA z-exp F_A^{CCQE}
- hN2018 FSI
- NEUT
- NuWro
- GiBUU

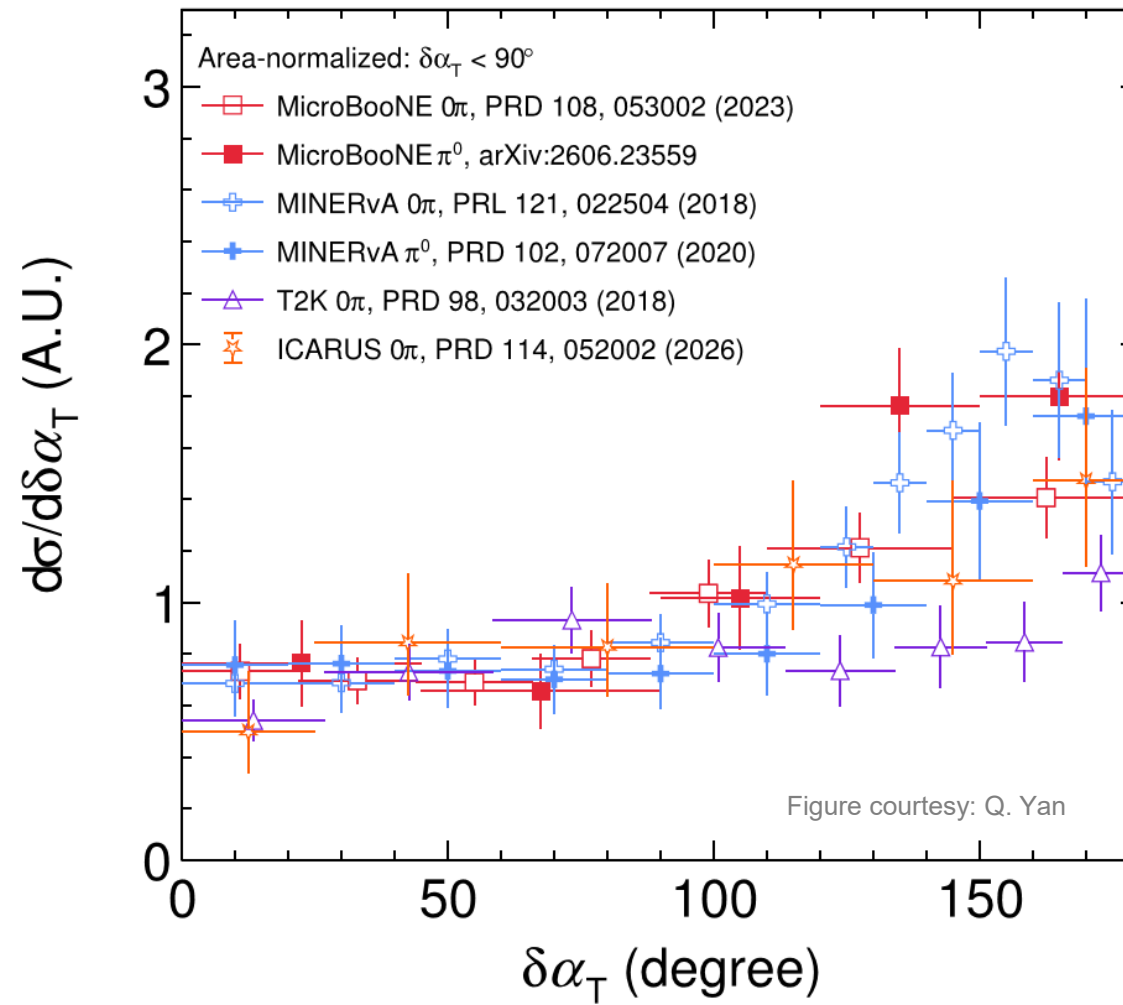
Also a dip at 180°?



A Big Picture



A Big Picture



TKI(+):

- ✓ Same observable for different beam energy, target, topology.
- ✓ Physical insight without referring to any model



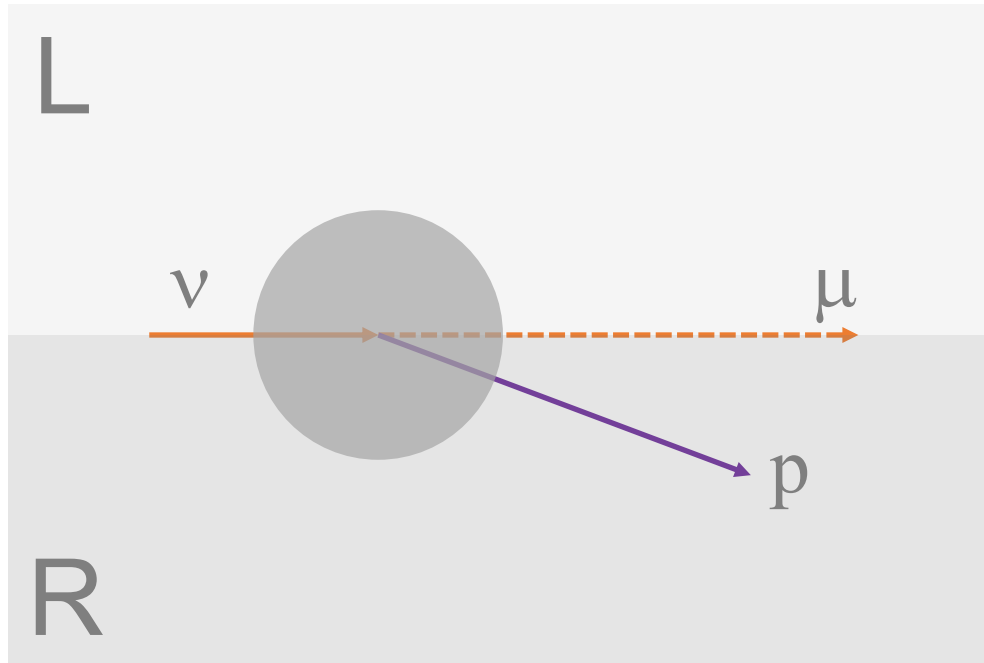
ChatGPT's impression of apple-to-apple comparisons

Cave of Pettakere, Bantimurung district (kecamatan), South Sulawesi, Indonesia. Hand stencils estimated between 35,000-40,000 BP.



[Wiki Cave Painting](#)

Bird's-eye view—Muon pointing up



0π production contains

- ☐ QE
- ☐ pion absorption (RES)
- ☐ 2p2h

- L-R asymmetry of 0π come from that of each component.
- **RES could have L-R asymmetry**; QE and 2p2h not.
- Dilution of RES L-R asymmetry tells us how much QE and 2p2h there are, together with TKI separating QE and 2p2h+RES, so we have a way to **isolate 2p2h from RES in 0π !**

L-R Asymmetry (TKI-)

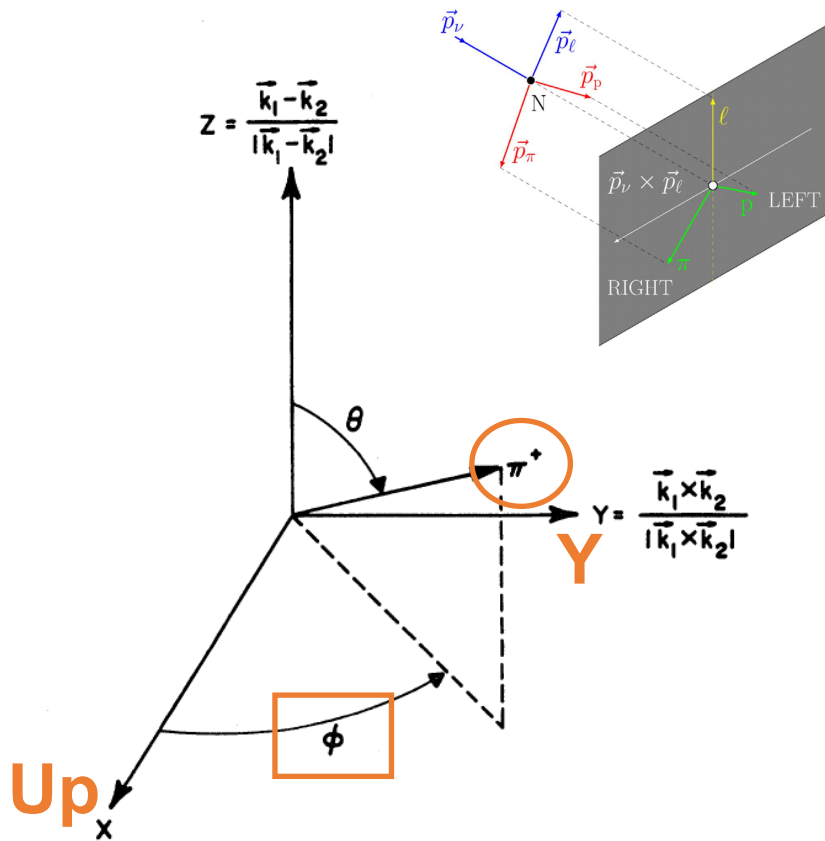


FIG. 14. Definition of the azimuthal ϕ and polar θ angles in the Adler system. $\vec{k}_1$ and $\vec{k}_2$ are vectors along the ν and μ^- directions, respectively, in the $N\pi$ rest system.

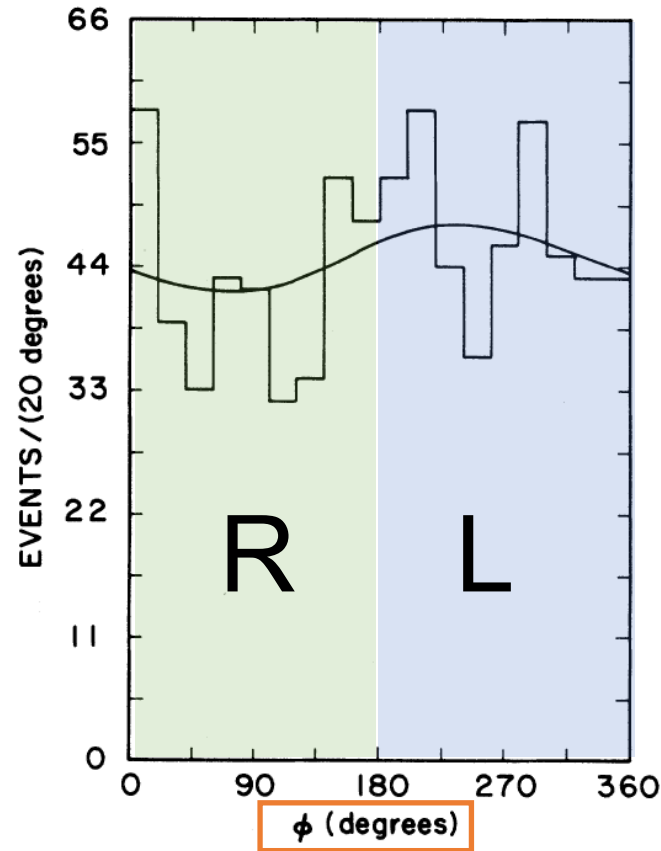


FIG. 16. Distribution of events in the pion azimuthal angle ϕ for the final state $\mu^- p \pi^+$, with $M(p\pi^+) < 1.4$ GeV. The curve is the area-normalized prediction of the Adler model.

Pion prefers one side: L-R asymmetry

- Resonant and nonresonant interference
- Predicted by Adler and more recent models
- Difficult measurements by ANL, MINERvA, T2K, consistent with 0 within error

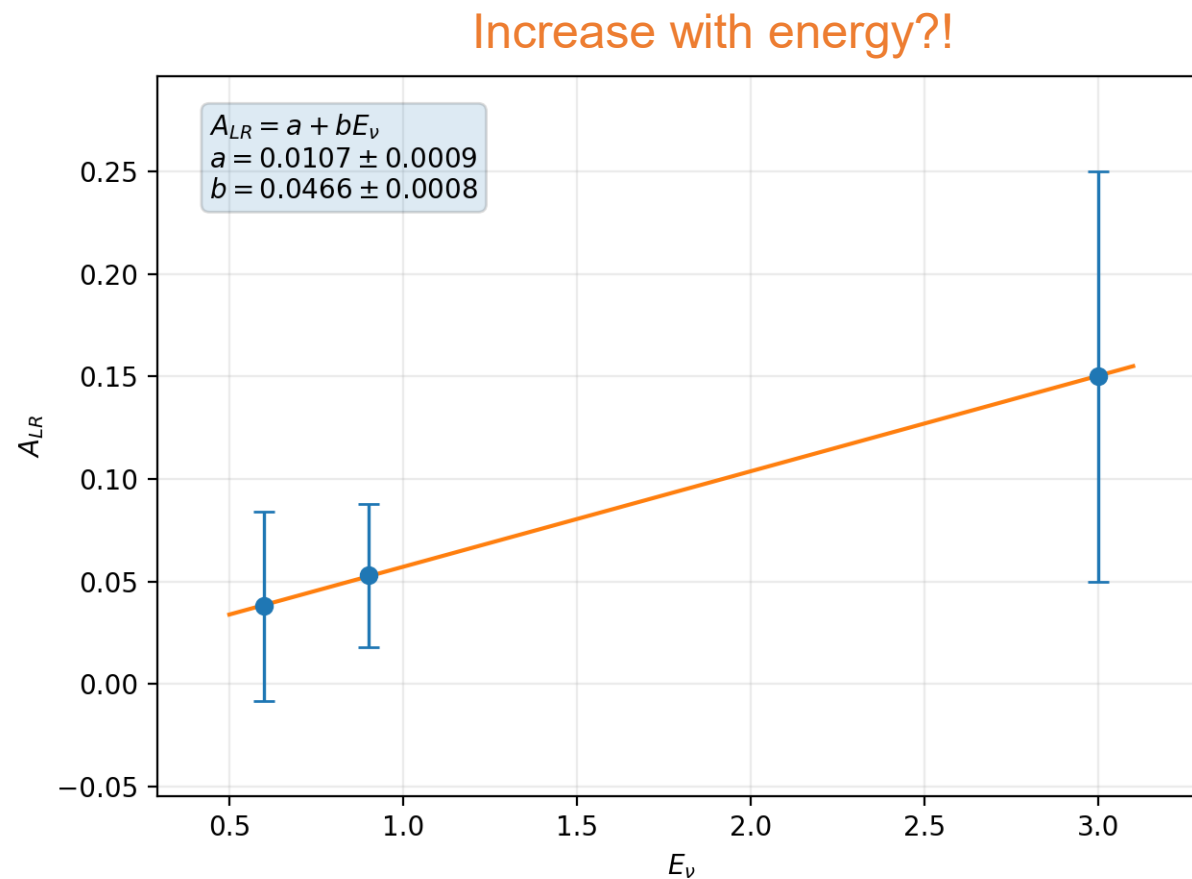
So the first step is to establish the amount of L-R asymmetry experimentally.

ANL data and Adler model [Radecky et al., Phys. Rev. D 25, 1161 (1982)]

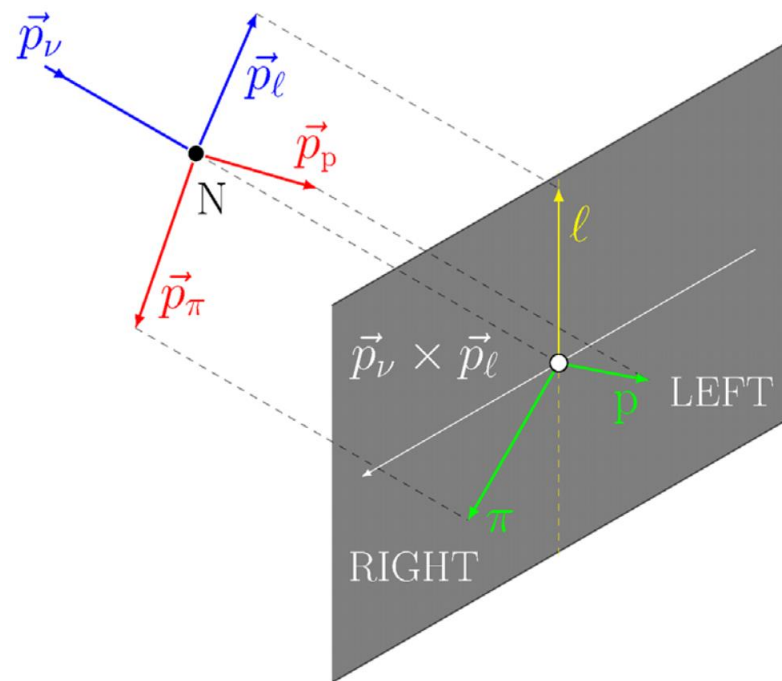
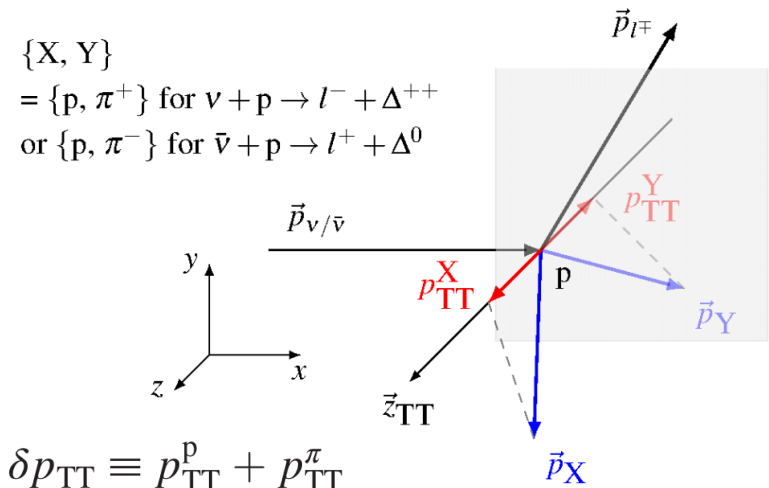
L-R Asymmetry (TKI-)

Exp.	π	Target	$A_{LR} \equiv \frac{N_L - N_R}{N_L + N_R}$ of π	
			E_ν (GeV)	A_{LR}
ANL	π^+	D	0.9	0.053 ± 0.035
MINERvA	π^0	CH	3	0.15 ± 0.10
T2K	π^+	CH	0.6	0.038 ± 0.046

[ANL, Phys. Rev. D 25, 1161 (1982); 26, 3297(E) (1982).
 MINERvA, Phys. Rev. D 96, 072003 (2017).
 T2K, Phys.Rev.D 101, 012007 (2020)]

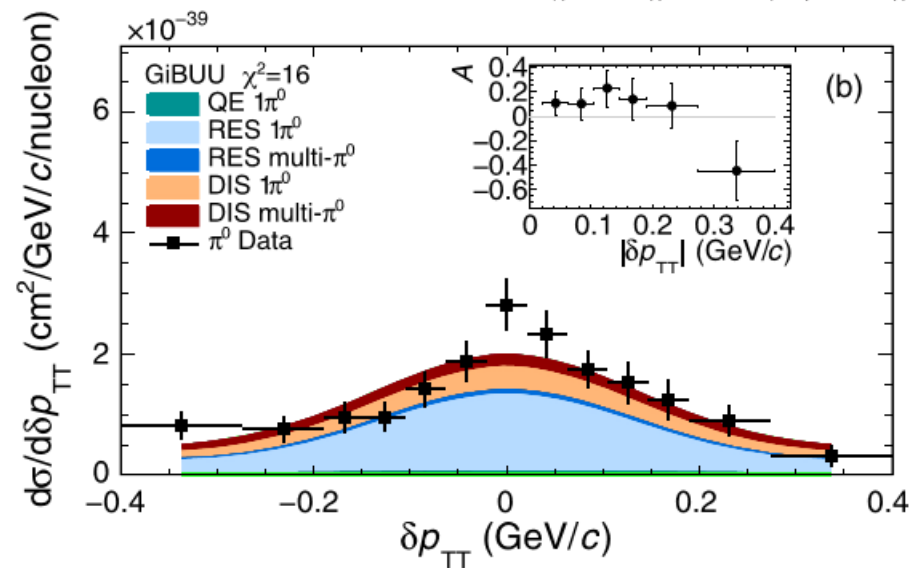


L-R Asymmetry (TKI-)



MINERvA π^0 Double-TKI [Phys. Rev. D 102, 072007 (2020)]

$$A(|\delta p_{TT}|) \equiv \frac{d\sigma(|\delta p_{TT}|) - d\sigma(-|\delta p_{TT}|)}{d\sigma(|\delta p_{TT}|) + d\sigma(-|\delta p_{TT}|)}$$



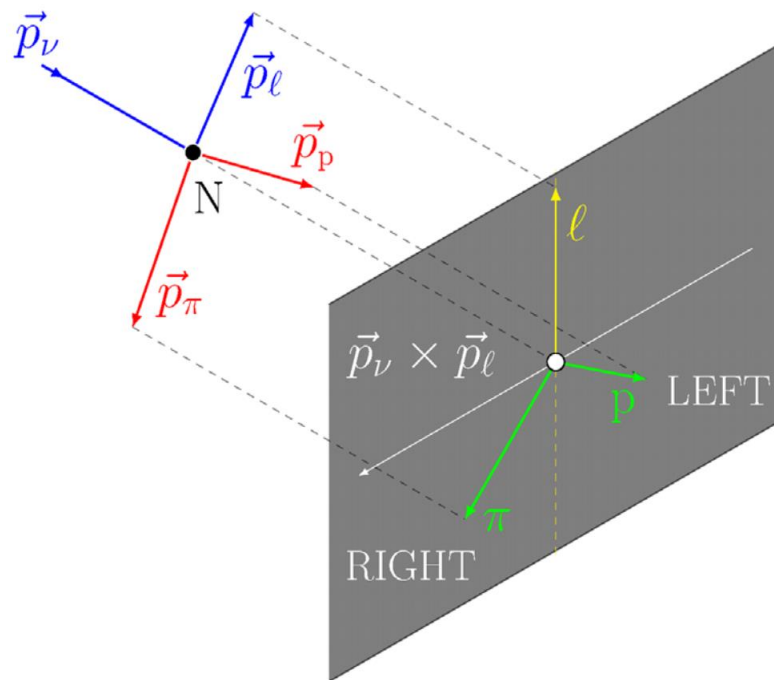
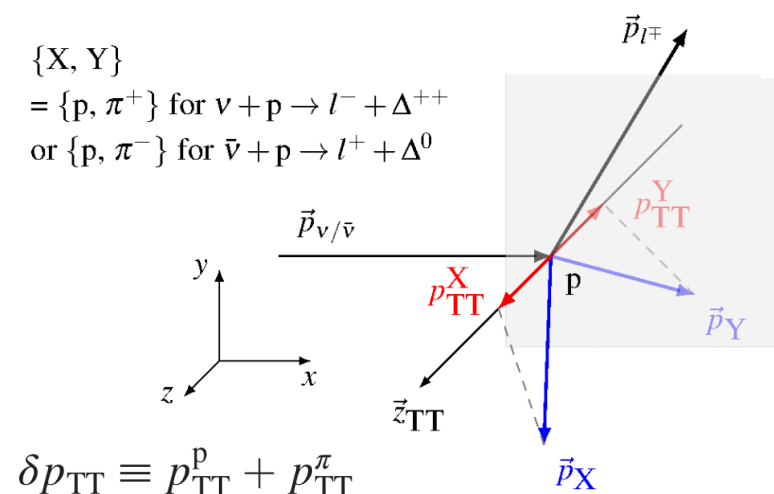
$\delta p_{TT}=0$: symmetric FSI for p and π^0
 Otherwise: L-R asymmetry && FSI asymmetry

T2K Double-TKI: Such an asymmetry is not observed within errors in this study.

[T2K, Phys.Rev.D 103, 112009 (2021)]

L-R Asymmetry (TKI-)

$\{X, Y\}$
 $= \{p, \pi^+\}$ for $\nu + p \rightarrow l^- + \Delta^{++}$
 or $\{p, \pi^-\}$ for $\bar{\nu} + p \rightarrow l^+ + \Delta^0$



$\delta p_{Tx} = \delta p_{TT}$ when there is no pion in the final state

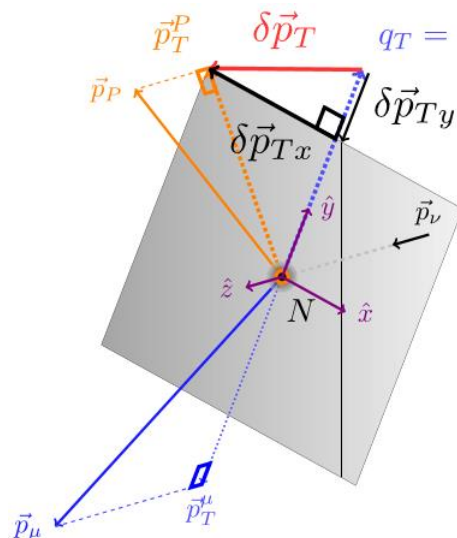
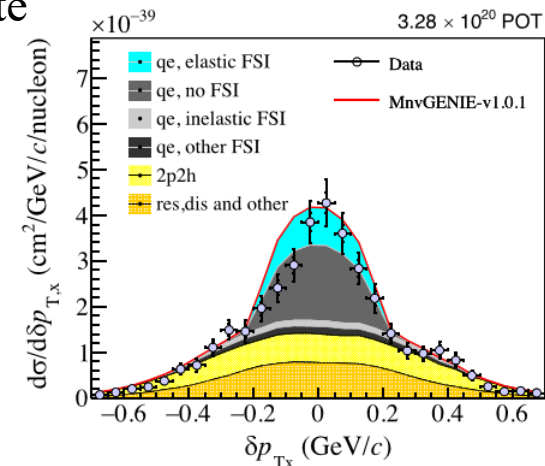


TABLE II. χ^2 of asymmetries (A_{Tx}) against no asymmetry case for regions of δp_{Tx} distributions calculated with the covariance matrix.

δp_{Tx} range (GeV)	χ^2/ndf
0.00–0.40	19.9/8
0.40–0.70	4.95/7
0.00–0.70	21.6/15

$$A_{LR} = \frac{N_- - N_+}{N_- + N_+}$$

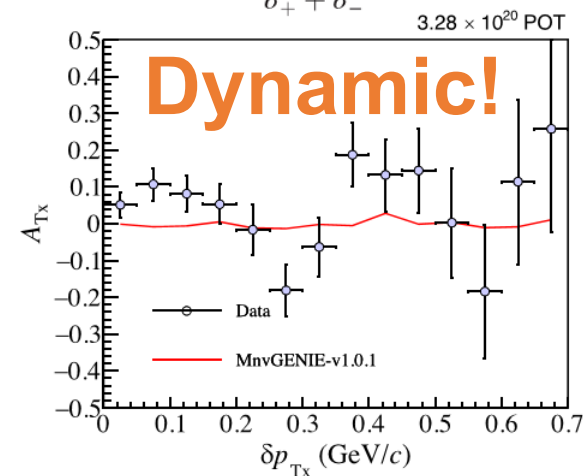
$$A_{LR} = -0.05 \pm 0.02$$



MINERvA 0 π TKI Measurement

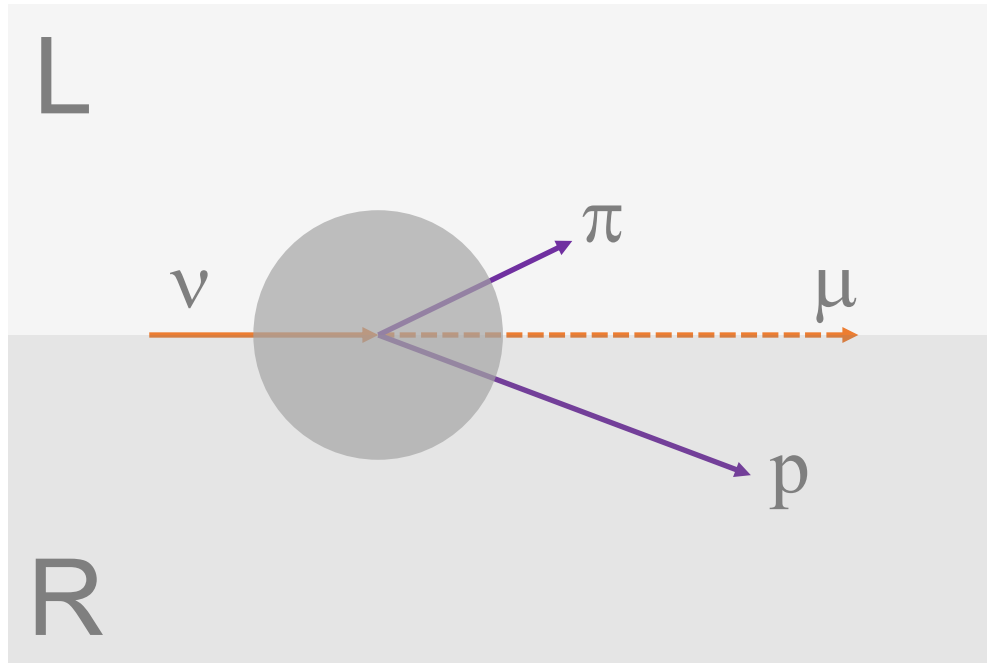
[Phys.Rev.D 101, 092001 (2020)]

$$A_{Tx}(|\delta p_{Tx}|) = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$

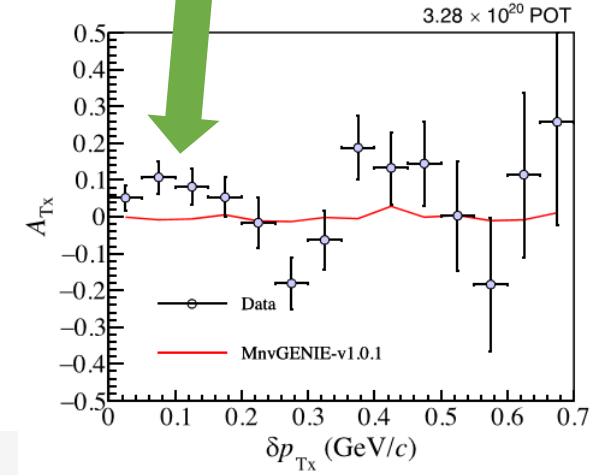
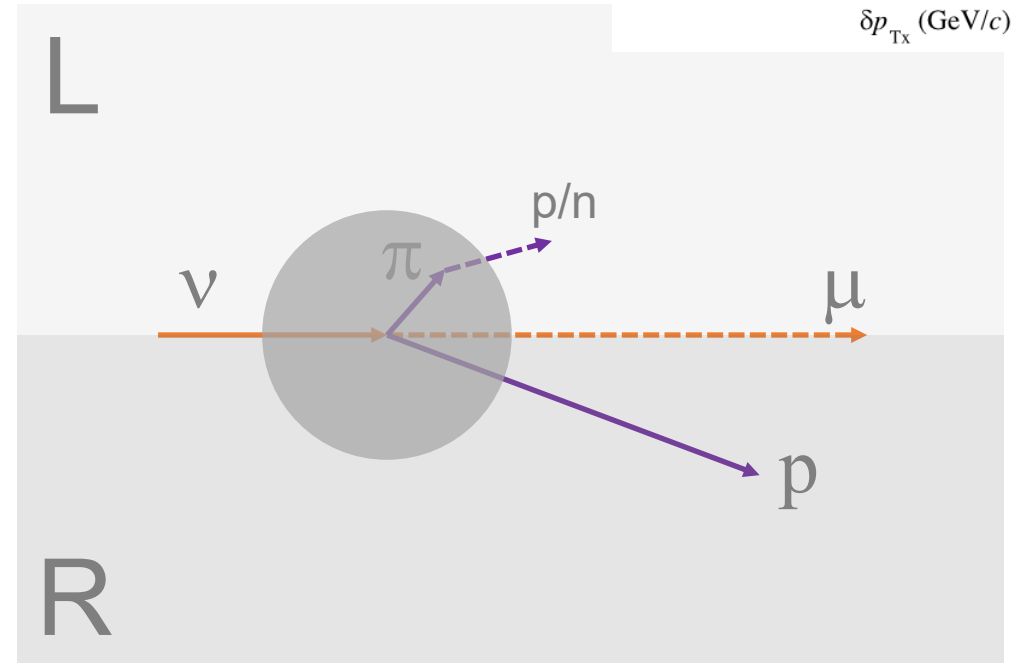


L-R Asymmetry (TKI-)

Bird's-eye view—Muon pointing up

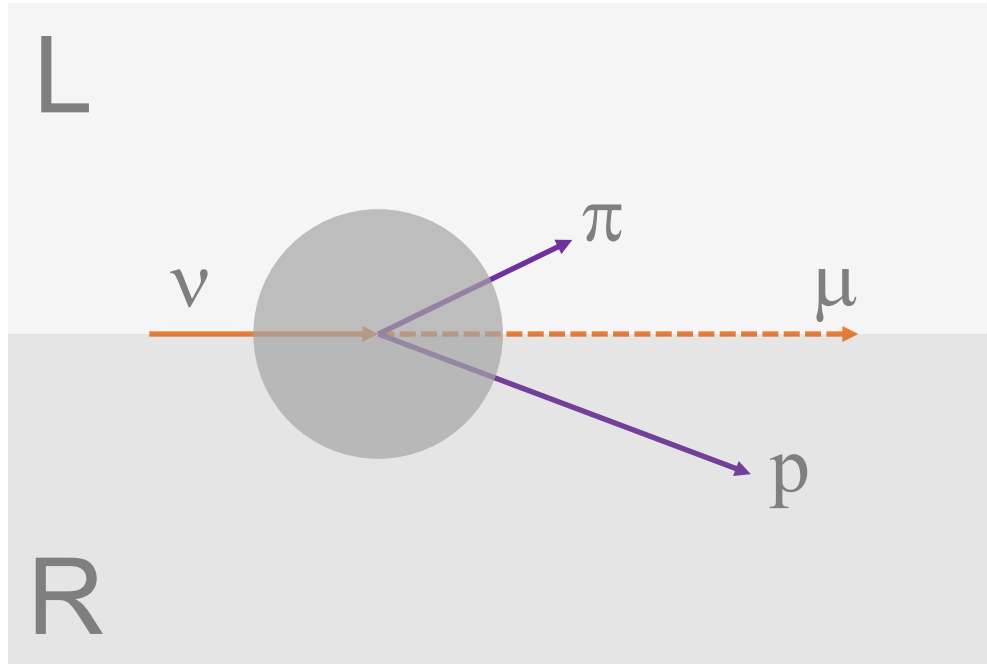


Pion absorption

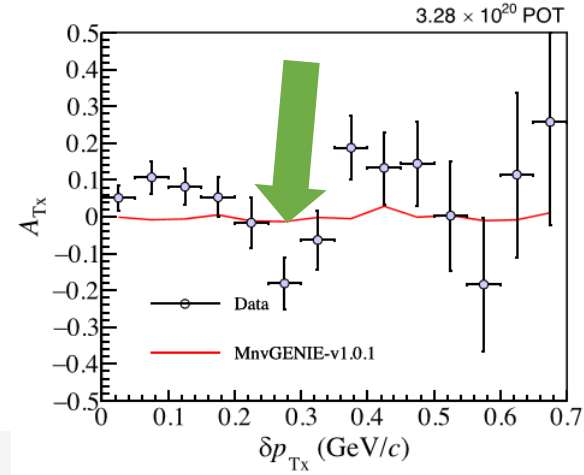
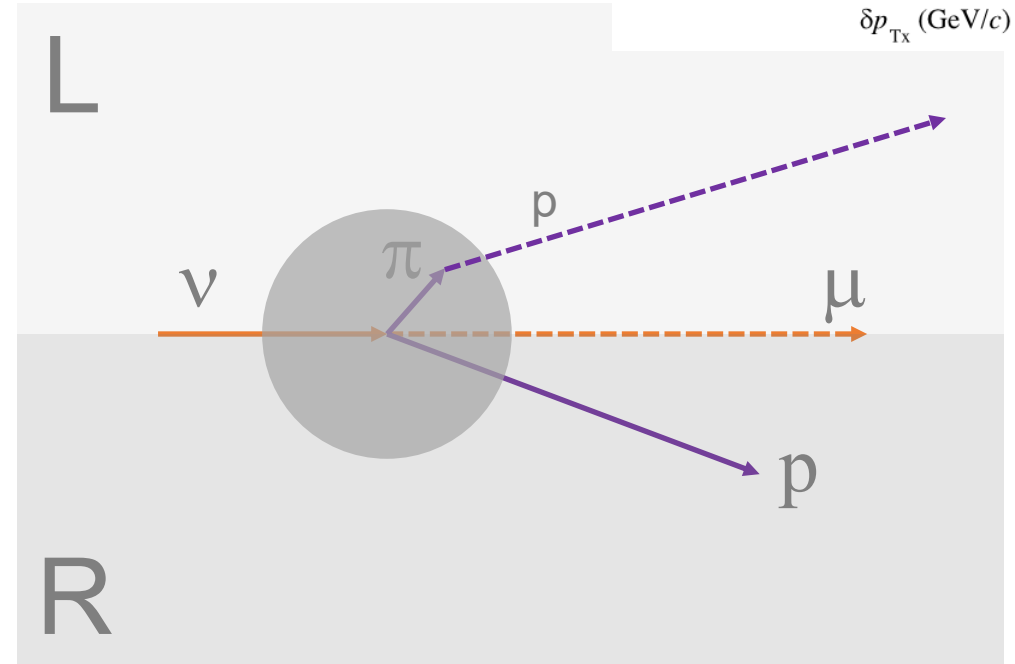


L-R Asymmetry (TKI-)

Bird's-eye view—Muon pointing up



Pion absorption



So, pion is indeed absorbed!

— Or, how do we actually know pions are absorbed in ν interactions?

Summary & Outlook (a)

	MINERvA	T2K	MicroBooNE	ICARUS
		0 π		
TKI	✓✓	✓✓	✓	✓
TKI+	✓✓	✓	✓	
TKI-	✓			
		π		
TKI	✓	✓	✓	
TKI+	✓	✓		
TKI-	✓	✓		

Summary & Outlook (b)

Neutrino interaction measurements are entering precision era.

More information does not necessarily mean better knowledge; organisation matters.

Neutrino energy is unknown; transverse plane factors out this uncertainty, allowing useful correlations.

Full problem = muon flavour + electron flavour

= neutrino + antineutrino

= low E_ν + high E_ν

= carbon + oxygen + argon + ...

= $0\pi + N\pi$

= charged final states + neutral final states

= above tracking threshold + below tracking threshold (calorimetry)

= transverse + longitudinal

= ...

How do you eat an elephant?

One bite at a time...

...and start with an easy bite!

Cueva de las Manos located Perito Moreno, Argentina.
The art in the cave dates between 13,000-9,000 BP



[Wiki Cave Painting](#)

BACKUP