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# NuInt22

## Overview of Experimental Presentations

Jorge G. Morfín  
Fermilab

# NuInt22

## Seoul National University – Seoul, KOREA

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- ◆ The organizers of this NuInt faced many challenges, stemming from the pandemic, to hold NuInt22 as an in-person workshop.
- ◆ Concern with the **very limited contact** between organizers and the community were expressed.
- ◆ 2 Co-chairs - **Un-ki Yang and Jonghee Yoo** –
  - ▼ along with 2 Administrators and 14 Students Staff.
- ◆ 120 Participants.
- ◆ 73 Physics talks of which
  - ▼ 9 were on-line.
- ◆ 7 Posters.
- ◆ 60 Highschool students at the Public Lecture.

# Very thought-provoking Summaries:

Theory/Phenomenology: Natalie

Experimental: **Callum Wilkinson**

[https://indico.cern.ch/event/881216/contributions/5094434/attachments/2538084/4368569/NuInt\\_summary\\_wilkinson.pdf](https://indico.cern.ch/event/881216/contributions/5094434/attachments/2538084/4368569/NuInt_summary_wilkinson.pdf)

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## Experimental summary

NuInt 2022, Seoul  
29<sup>th</sup> October 2022  
Callum Wilkinson



# Emphasizing considerable new results since last NuInt in 2018!

## NuInt 2022: thought provoking discussion and scenery



Wealth Of Results → Better Understanding of  $\nu$ -Ar Interactions

### T2K cross-section publications (>20 articles in $\approx 10$ years)

#### 6 $\nu_\mu$ or $\bar{\nu}_\mu$ CC inclusive

PRD arXiv: 1302.4908  
 PRD arXiv: 1801.05148  
 PTEP arXiv: 1904.09611  
 PRD arXiv: 1407.4256  
 PRD arXiv: 1509.06940  
 PRD arXiv: 1706.04257

#### 3 $\nu_e$ or $\bar{\nu}_e$ CC inclusive

PRL arXiv: 1407.7389  
 PRD arXiv: 1503.08815  
 JHEP arXiv: 2002.11986

#### 12 $\nu_\mu$ or $\bar{\nu}_\mu$ CC0 $\pi$

PRD arXiv: 1602.03652  
 PRD arXiv: 1708.06771  
 PRD arXiv: 1908.10249  
 PRD arXiv: 2002.09323  
 PRD arXiv: 2004.05434  
 PRD arXiv: 1503.07452

PRD arXiv: 1411.6264  
 PRD arXiv: 1403.3140  
 PRD arXiv: 1910.09439  
 PRD arXiv: 1802.05078  
 PRD arXiv: 2102.03346  
 PTEP arXiv: 2004.13989

#### 4 $\nu_\mu$ or $\bar{\nu}_\mu$ CC1 $\pi$

PRD arXiv: 1605.07964  
 PRL arXiv: 1604.04406  
 PRD arXiv: 1909.03936  
 PRD arXiv: 1704.07467

#### CC inclusive

- $\nu_e$  CC inclusive @ NuMI (Wed.)
- $\nu_\mu$  CC inclusive @ NuMI
- $\nu_\mu$  CC inclusive @ BNB (Wed.)
- $\nu_e/\nu_\mu$  ratios @ NuMI
- $E_\nu, E_\mu$ , hadronic energy @ NuMI & BNB

#### CC0 $\pi$

- $\nu_\mu$  Single Transverse Variables @ BNB (Wed.)
- $\nu_\mu$  CC2p topologies @ BNB (Wed.)
- $\nu_\mu$  CC0 $\pi$  inclusive @ BNB
- $\nu_\mu$  CC0 $\pi$ 0p @ BNB
- $\nu_e$  CC0 $\pi$ Np @ NuMI

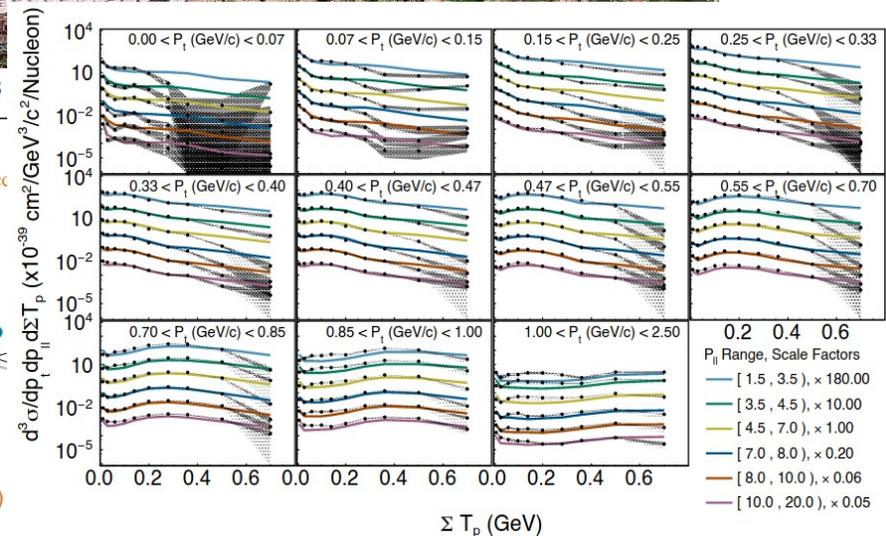
#### Much more coming from 30+ active analyses

#### Pion production

- $\nu_\mu$  CC1 $\pi^+$  @ BNB
- $\nu_\mu$  CC-Coherent @ BNB
- $\nu_\mu$  CC $\pi^0$  @ BNB
- $\nu_\mu$  NC $\pi^0$  @ BNB (Fri.)
- $\nu_\mu$  CC/NC  $\pi^0$  @ BNB

#### Rare channels

- $\nu_\mu$  CC Kaon @ BNB
- $\nu_\mu$  CC Kaon @ NuMI
- $\eta$  production @ BNB
- Hyperon ( $\Lambda, \Sigma$ ) production @ NuMI (Fri.)
- MeV-scale Physics in MicroBooNE

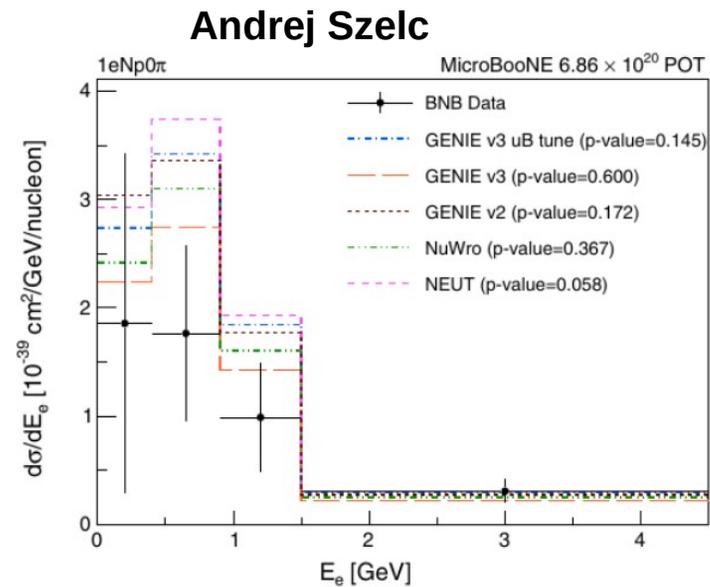
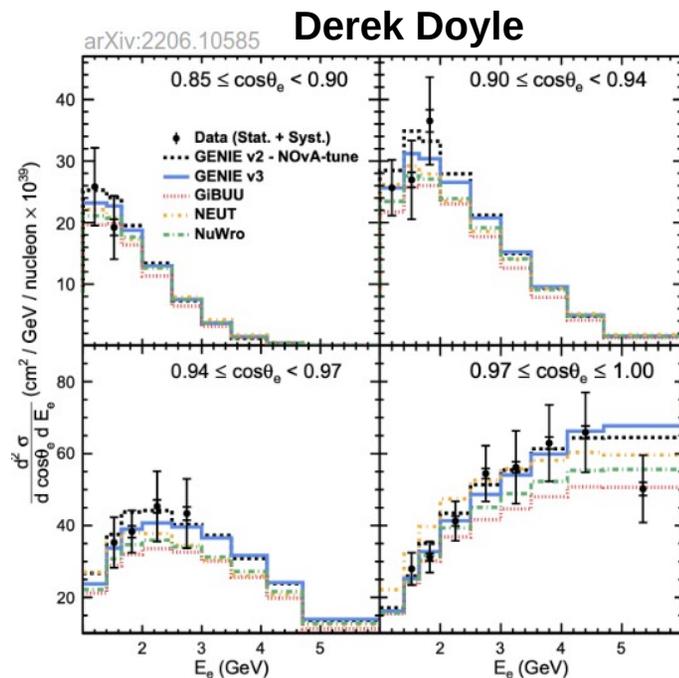


# NOvA and MicroBooNE

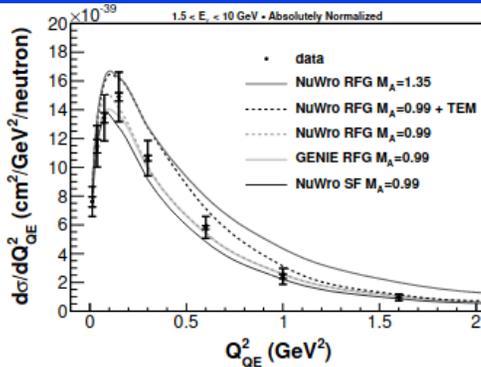
## Measuring the $\nu_e/\nu_\mu$ ratio

### Electron neutrino cross sections

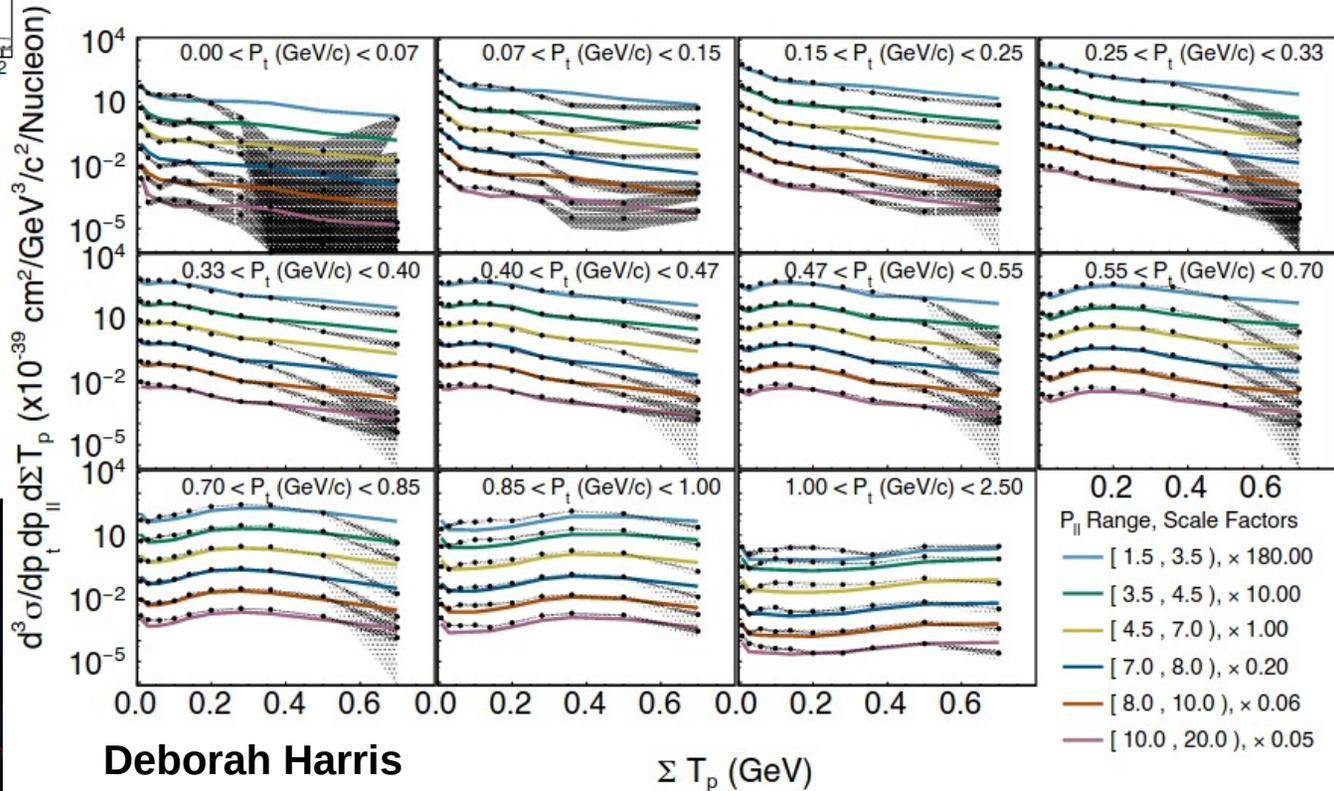
- Potentially vital tests of  $\nu_e/\nu_\mu$  for oscillation measurements
- **NOvA**: double-differential(!)  $\nu_e$  CC inclusive,  $\bar{\nu}_e$  on the way!
- **MicroBooNE**: differential  $\nu_e$  CC inclusive NuMI and  $\nu_e$  CC0 $\pi$  BNB



# MINERvA: high statistics multi-dimensional analyses



A wealth of information about lepton/hadron correlations → hard to believe this is neutrino data!



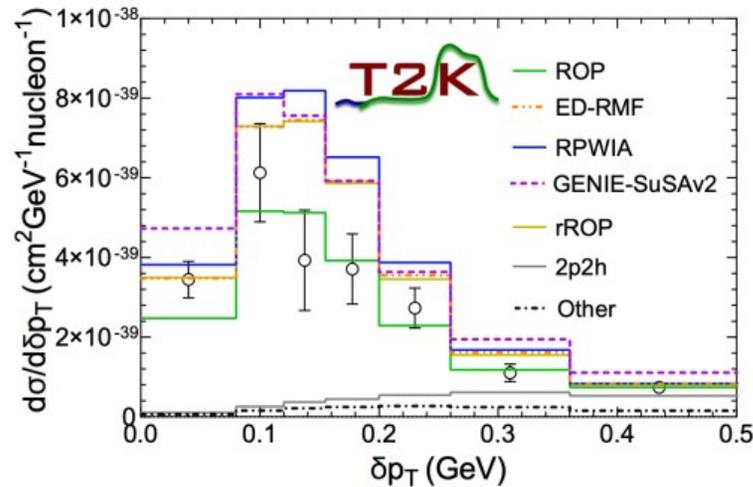
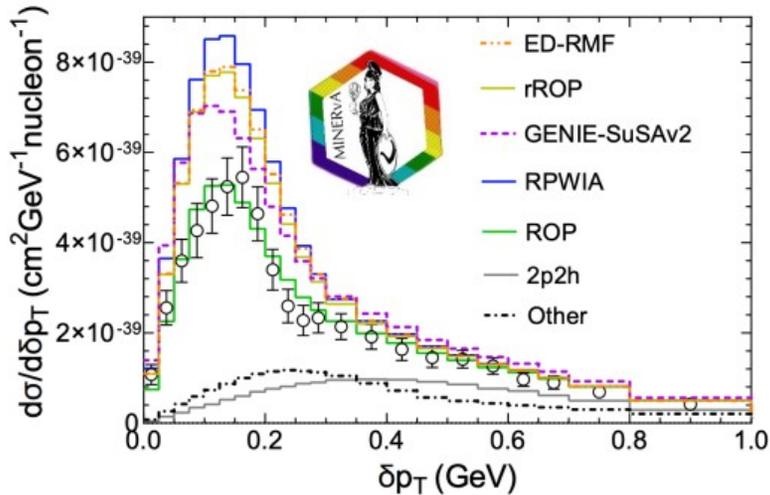
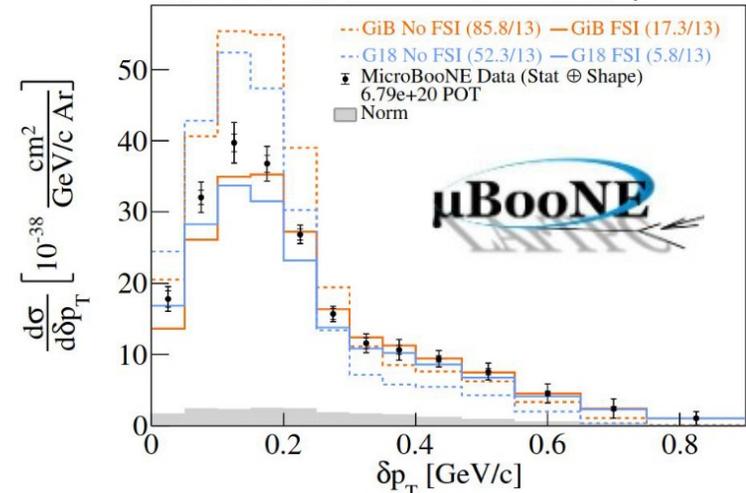
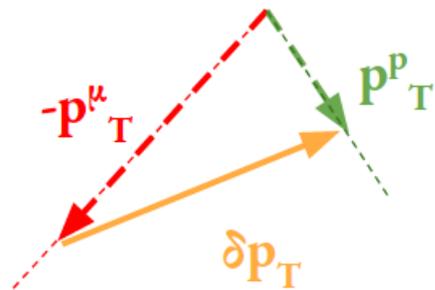
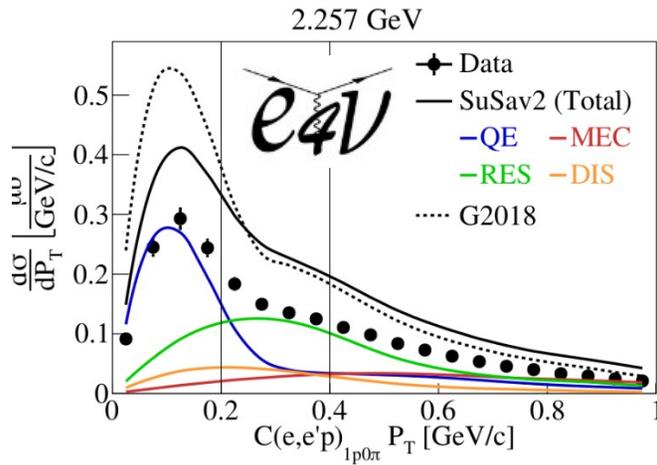
Deborah Harris

PRL 129 (2022) 2, 021803

Lepton-Hadron Correlations in QE-like scattering: MINERvA

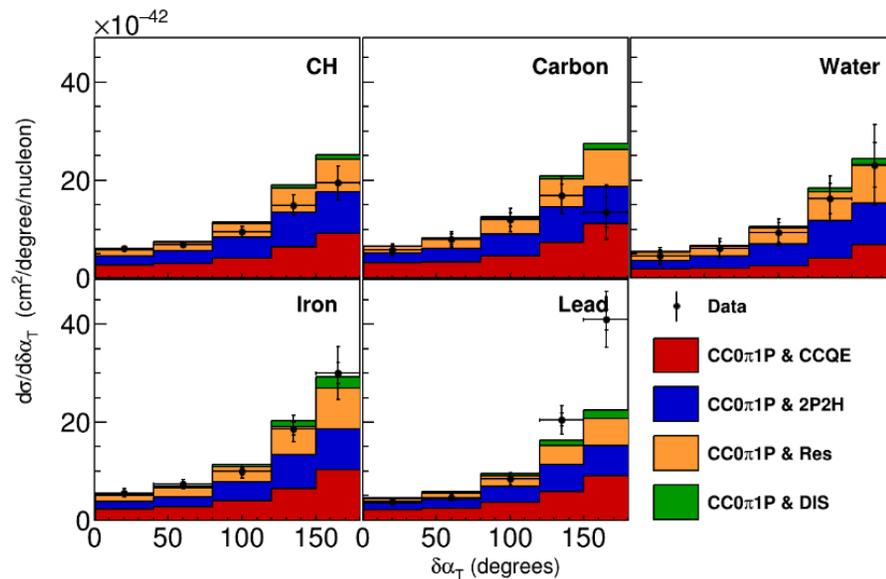
# Lepton-hadron Relationship across Experiments

Also, first multi-differential TKI analysis from MicroBooNE!



# Addressing A-dependent Nuclear Effects

## A-scaling

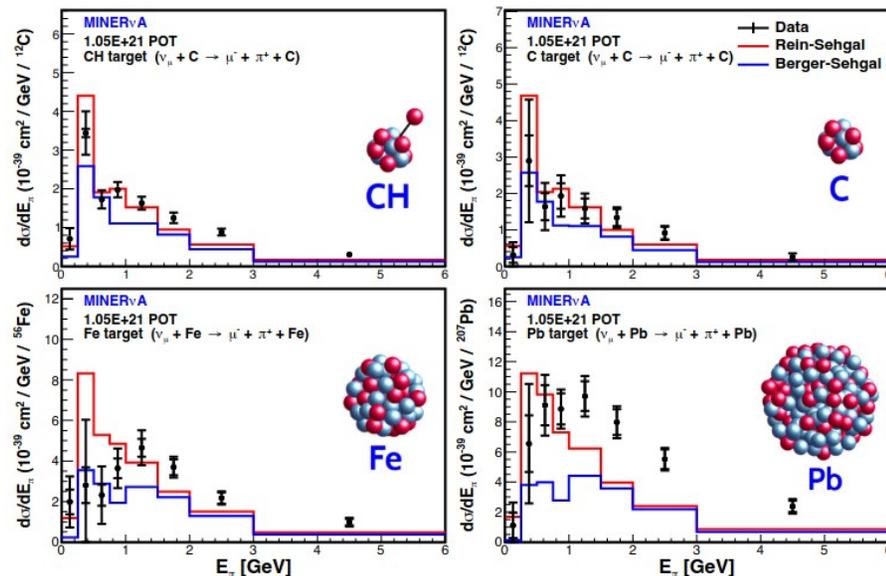


- A-scaling behaviour vital for LAr program as most data on hydrocarbons

• Significant new results from MINERvA exploring this

- TKI variables for different targets – Jeffrey Kleykamp

- Coherent pion production – Kevin McFarland

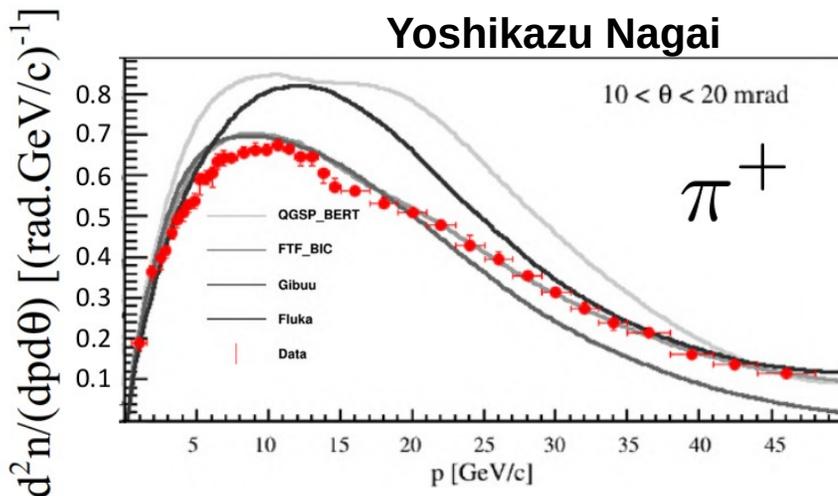


# Improving Neutrino Flux Measurements

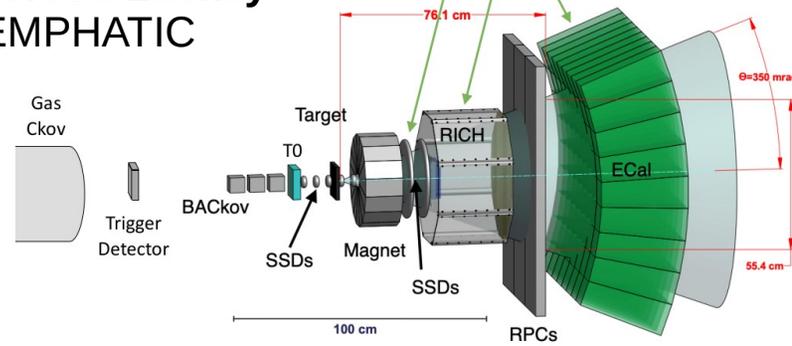
Flux uncertainties critical for precision XSEC or oscillation measurements

$$R(\vec{x}) = \int dE \underbrace{\Phi(E_\nu)}_{\text{Near}} \times \underbrace{\sigma(E_\nu, \vec{x}) \times \epsilon(\vec{x}) \times P(E_\nu; \nu_A \rightarrow \nu_B)}_{\text{Far}}$$

- Ongoing hadron-production efforts can deliver ~5% flux uncertainties through replica target efforts
- ENUBET concept reaching maturation → a potential path to ~1% uncertainties



**Teresa Lackey**  
EMPHATIC



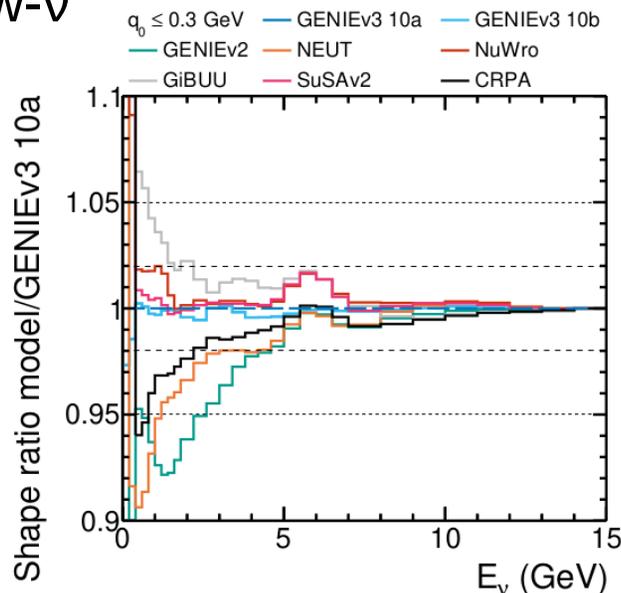
# Neutrino Flux Constraints

- In situ flux constraints are hugely important for next-generation program

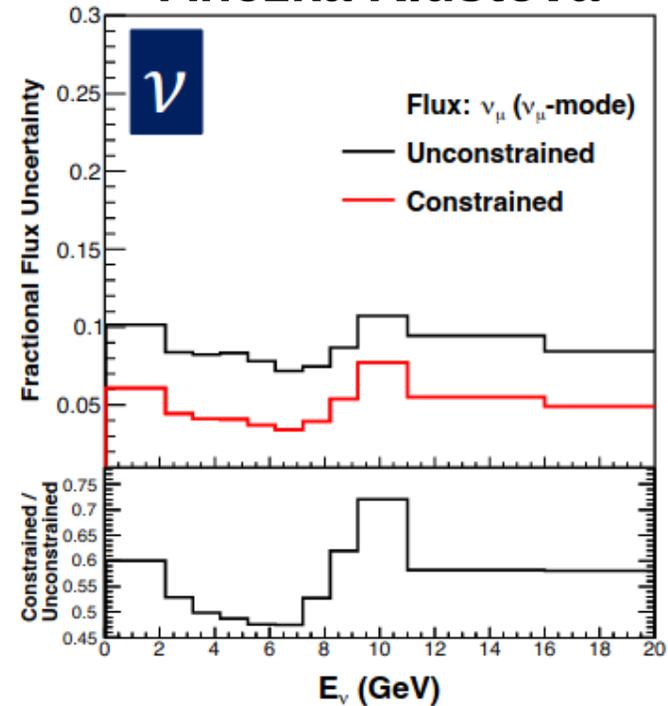
No Bothans died to bring you this information...

- MINERvA is providing blueprints for how to leverage small well-known signals

- Important to explore and understand the utility of different methods
- Some limitations still to be understood for low- $\nu$



## Anežka Klustová



	$\bar{\nu}_\mu$ -mode				$\nu_\mu$ -mode			
	$\bar{\nu}_\mu$	$\bar{\nu}_e$	$\nu_\mu$	$\nu_e$	$\nu_\mu$	$\nu_e$	$\bar{\nu}_\mu$	$\bar{\nu}_e$
<i>a priori</i>	7.76	7.81	11.1	11.9	7.62	7.52	12.2	11.7
$\nu_\mu$ -mode $\nu e^-$	6.11	5.81	6.30	8.50	3.90	3.94	8.37	8.68
$\bar{\nu}_\mu$ -mode $\nu e^-$	4.92	4.98	8.07	9.19	5.88	5.68	8.36	8.64
combined $\nu e^-$	4.68	4.62	5.56	7.80	3.56	3.58	7.15	7.84
<b>combined <math>\nu e^-</math> + IMD</b>	<b>4.66</b>	<b>4.56</b>	<b>5.20</b>	<b>6.08</b>	<b>3.27</b>	<b>3.22</b>	<b>6.98</b>	<b>7.54</b>

# Theory-Generator-Data Comparisons

$$\frac{d^2\sigma}{dT_l d\cos\theta} = \frac{1}{\int \Phi(E_\nu) dE_\nu} \int dE_\nu \left[ \frac{d^2\sigma}{d\omega d\cos\theta} \right]_{\omega=E_\nu-E_l} \Phi(E_\nu)$$

Are flux-averaged XSECs accessible for theorists?

Multiple channels and FSI adds significant burden...

Faster generator implementation cycle, but fast enough?

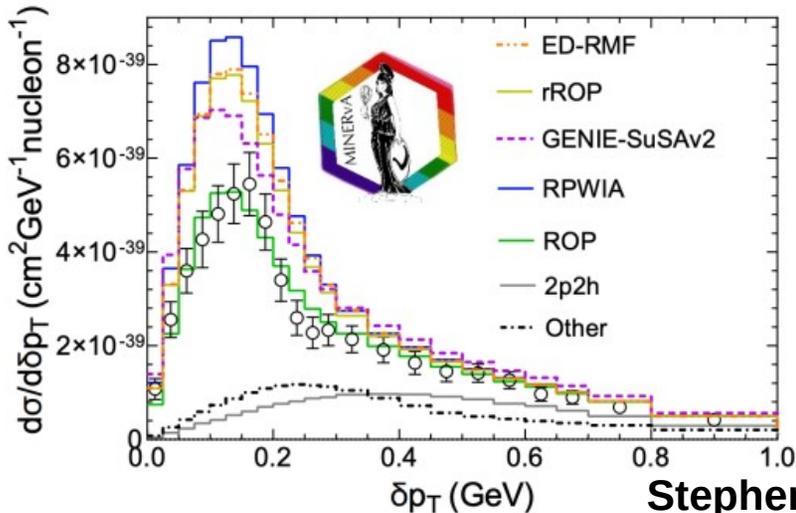
Theorists



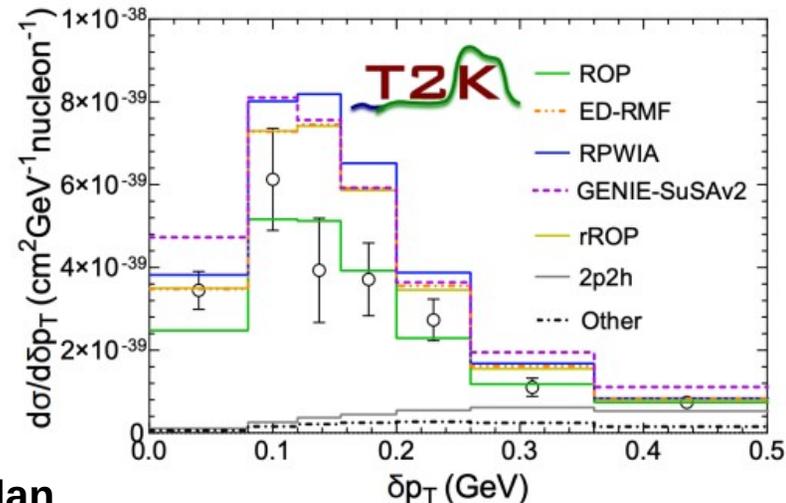
**Teppei Katori**

Experimentalists

$$\frac{d^2\sigma}{dT_l \cos\theta} = \frac{\sum_j U_{ij}(d_j - b_j)}{\Phi \cdot T \cdot \epsilon_i \cdot (\Delta T_l, \Delta \cos\theta)_i}$$



**Stephen Dolan**  
arXiv:2207.02086



# Increasing role of “Model Fitters”

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Prediction: in future NuInts, “global” fitters will have their own summary talk

Experiments and generators are tuning MC to data in increasingly sophisticated ways

**Many examples at this workshop:** GENIE, DUNE, T2K, NUISANCE, uBooNE, ...

Trying to understand the impact of our data on  $\nu$ -A models, and the impact of other data in our analyses



# Generator Support

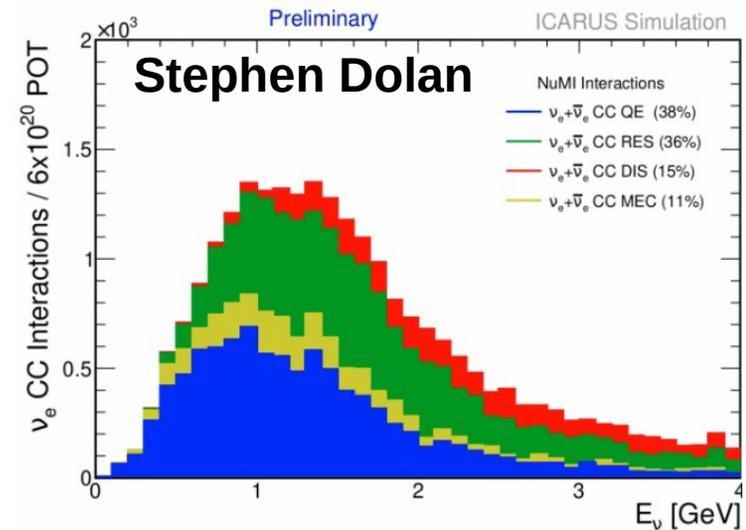
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- Theory → generator → experiment pipeline is improving, but this is a long effort
- Increasingly rely on generators to support more and more complex analysis
- Some progress:
  - New generator on the market – ACHILLES
  - Shared tools (e.g., GENIE flux driver for other events)
  - Ability to propagate custom tunes etc

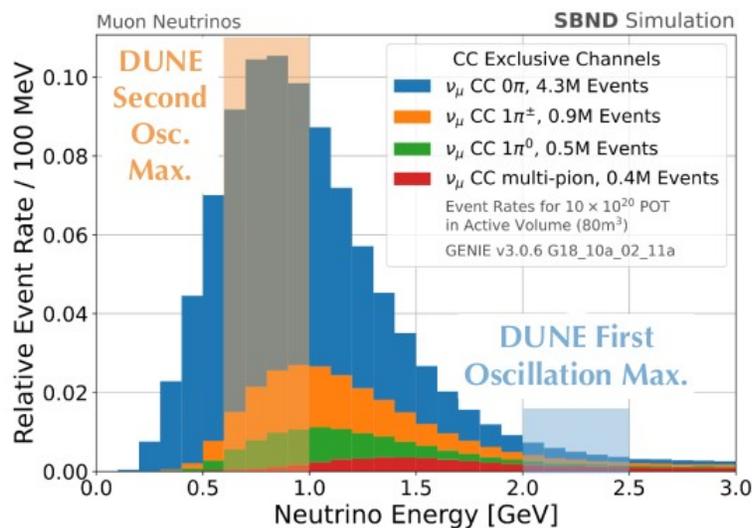
# What can we expect in our $\nu$ -A Scattering Future

## Anticipated Measurements

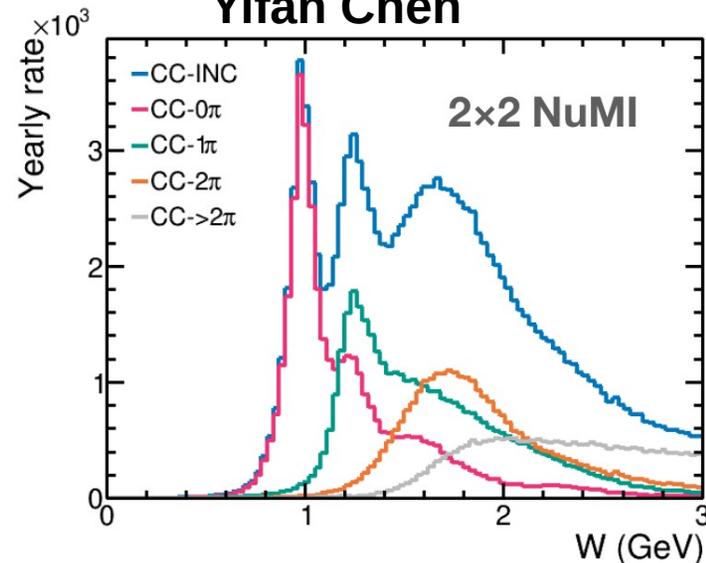
- Anticipate very high statistics results from SBND  $\rightarrow$  **hugely important for DUNE program!**
- Additional great ideas leveraging various detectors and fluxes promises a rich LAr program



### Lauren Yates

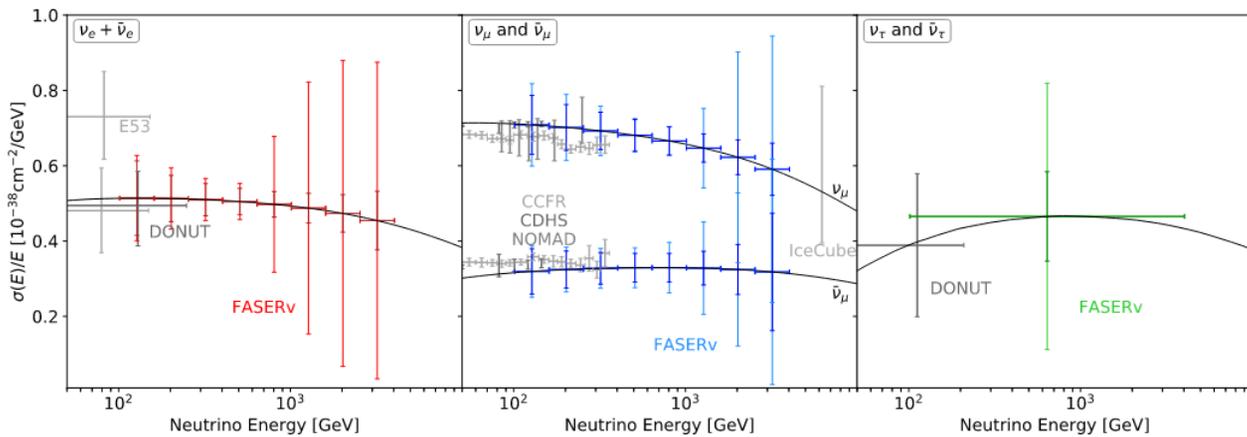


### Yifan Chen

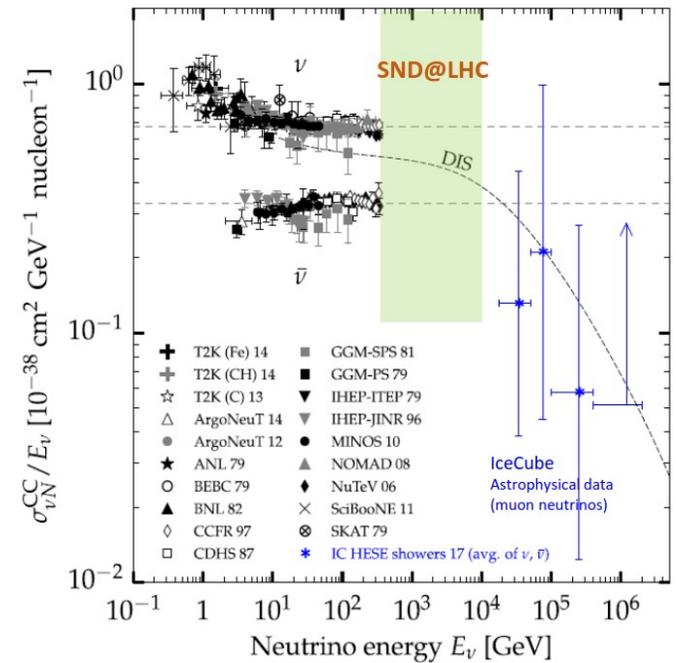


# Future Higher Energy Experiments – BRAVO!

- FASERv and SND → Forward Physics Facility in HL-LHC
- Bridges a gap in our understanding of quite-high<sup>TM</sup> and ultra-high energy neutrinos
- An interesting connection between our community and the energy frontier



Daiki Hayakawa

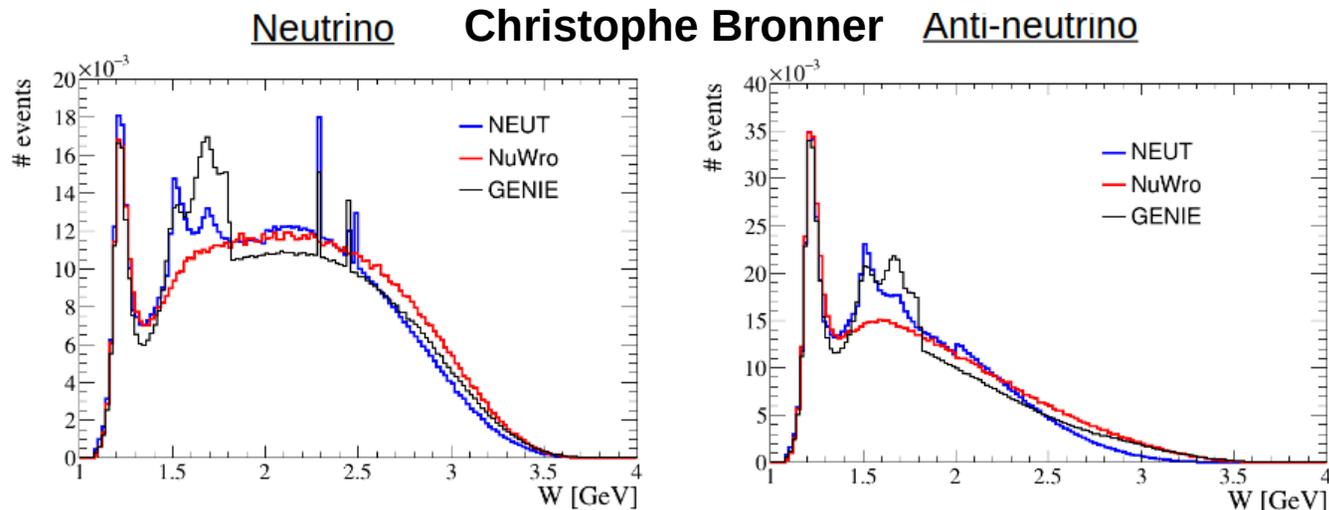


Chun Sil Yoon

# What's Missing

- I worry that DUNE phase space is not adequately covered by existing plans...  
... we may be in for a rocky ride
- Two areas stick out for me (please add your own!):
  1. Lack of  $\bar{\nu}_\mu$  measurements

2. SIS/DIS...

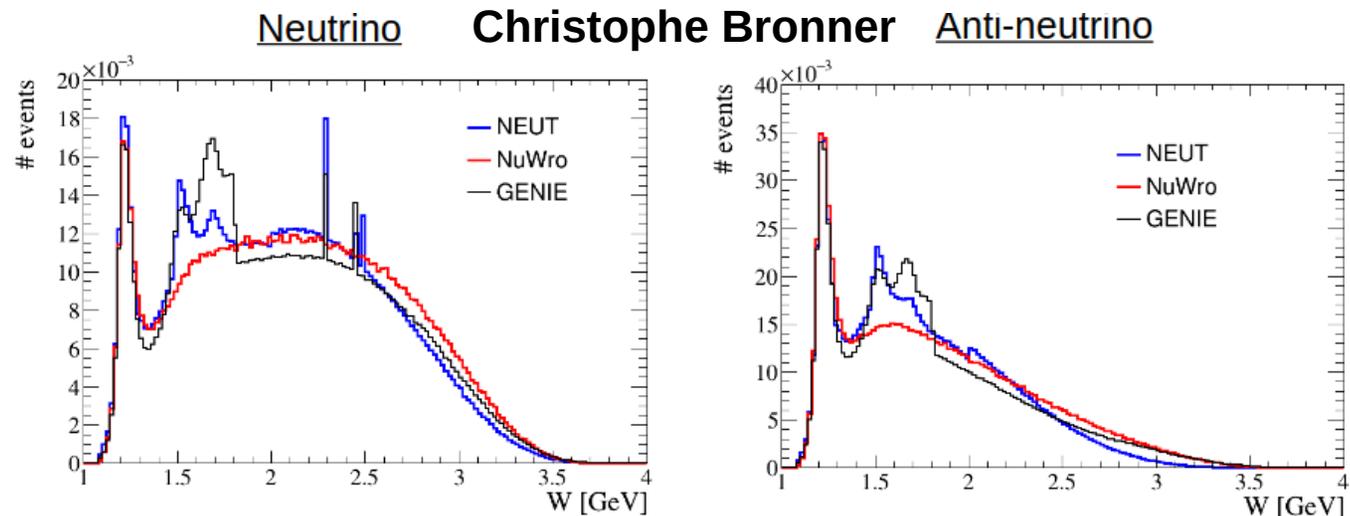


# What's Missing

1) Lack of SBND antineutrino mode plans → something we should encourage as a community

2) Many challenges to making SIS/DIS measurements as discussed:

- Challenging events to reconstruct
- Issues of model dependence in the extraction



# Summary of Summary

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- A wealth of new data has been shown at this meeting!
- High statistics, multiple fluxes and targets, more hadron kinematics... all most of the things we say we need to constrain models
- Models do not do a good job of describing the majority of the data. A major challenge, maybe an opportunity
- We need to continue to support generator work, as the bridge between theory and experiments
- Ad hoc tuning efforts are becoming increasingly important for analysis and more sophisticated – potential for issues



# Future NuInts

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- ◆ Up to and including NuInt22, the venues of NuInts have been chosen by the **International NuInt Commission (INC)** – all the hosts of past NuInts:
  - ▼ Omar Benhar, Sampa Bhadra, Flavio Cavanna, Yoshinari Hayato, Jorge G. Morfín, Helio Da Motta, Federico Sanchez Nieto, Toru Sato, Shri Krishna Singh, Michel Sorel, Hirohisa A. Tanaka, Morgan Wascko, with now Un-ki Yang, Jonghee Yoo.
- ◆ We (INC) offered our help and advise in the organization of the particular NuInt, however the **organization decisions were the responsibility of the host(s)**.
- ◆ This year NuSTEC began a discussion on our relationship with the NuInt workshops leading to discussion with the INC on the organization of future NuInts.
- ◆ Starting with the next NuInt, **NuSTEC is coordinating selection of the hosts/venue and date of the workshops and offering our experience in the organization.**

## The next NuInt

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- ◆ Following the general area sequence of Europe, Asia, Americas - the next NuInt will be in the Americas.
- ◆ We are pleased to announce that the next NuInt will be co-hosted by **Orlando Peres and Hélio da Motta** in **São Paulo, Brazil.**

## The next NuInt

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- ◆ As far as **the date of the next NuInt** is concerned, the hosts currently prefer spring of 2024.
- ◆ They mention that after checking the availability of dates in the venue, contacting the hotel and the funding agencies they might find a way to have the meeting as early as October 2023; **however, this could mean higher registration fee and higher costs leaving little funds to support students and postdocs.**
- ◆ This might be a reasonable time to also open a **discussion (through NuSTEC-news) within the community, of the frequency of NuInts?** Is the current every 18 months still optimal? If we prefer yearly then choosing hosts/venues two years in advance would be reasonable.