Wire-Cell XSec Overview

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Introduction

PRL **128**, 151801 (2022)
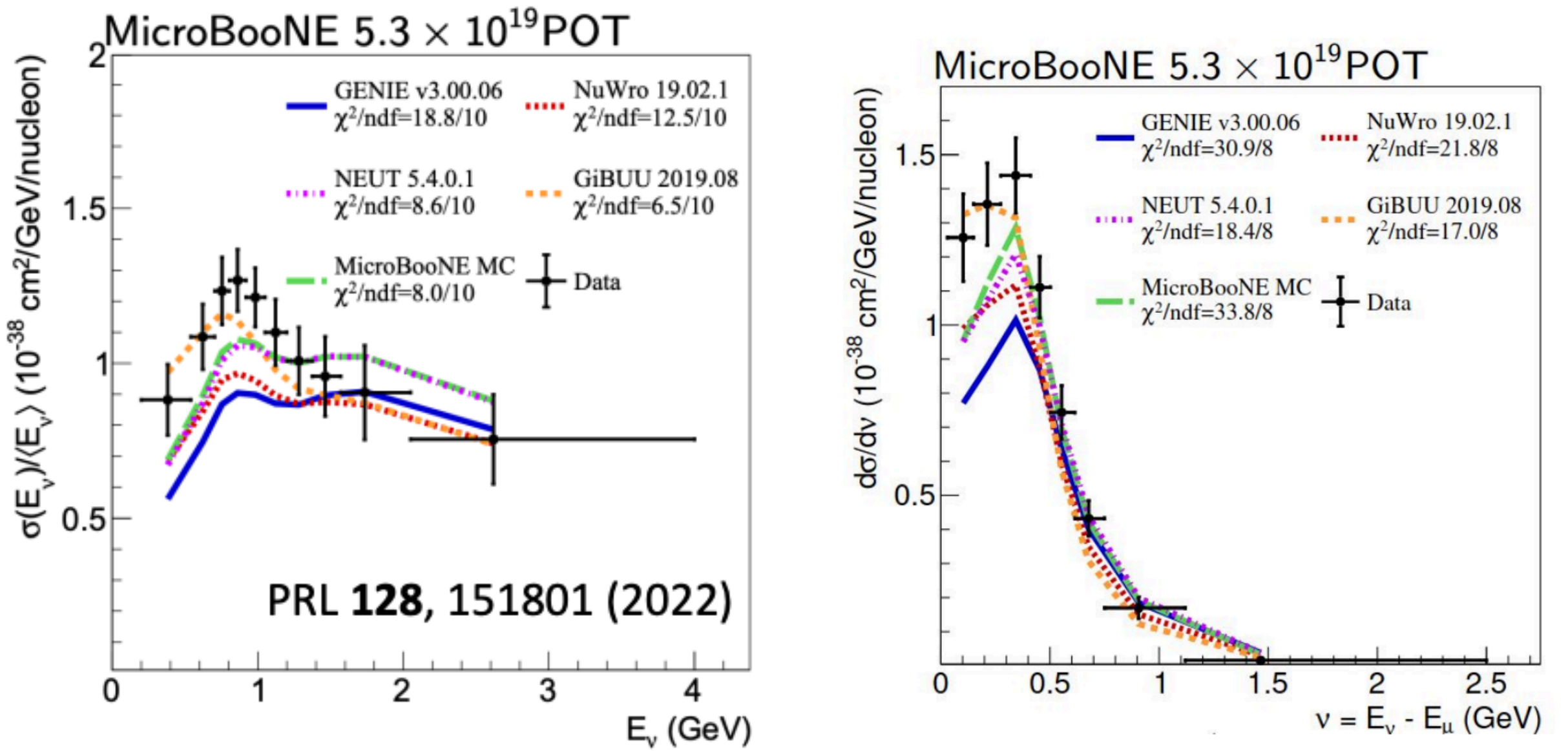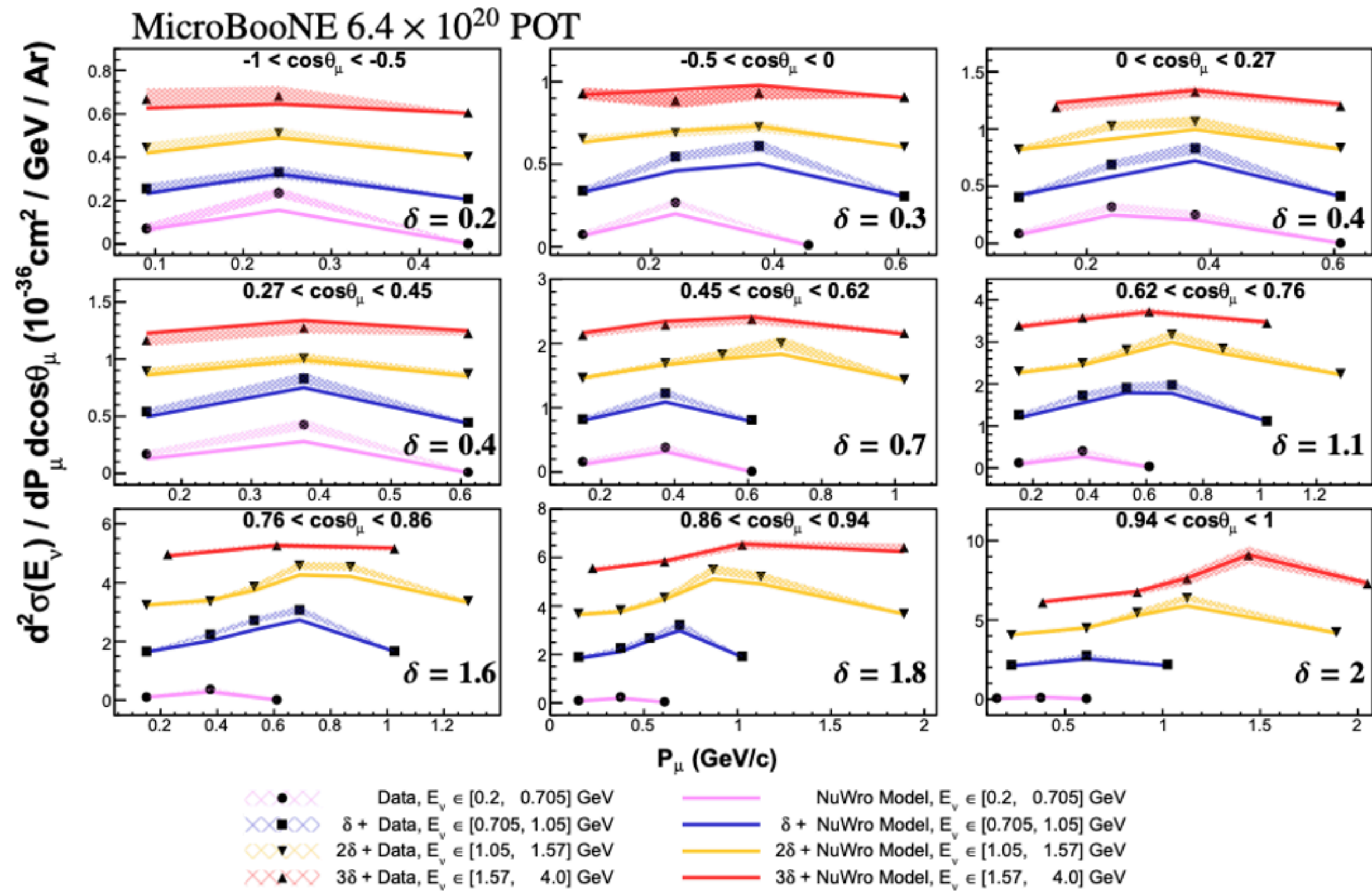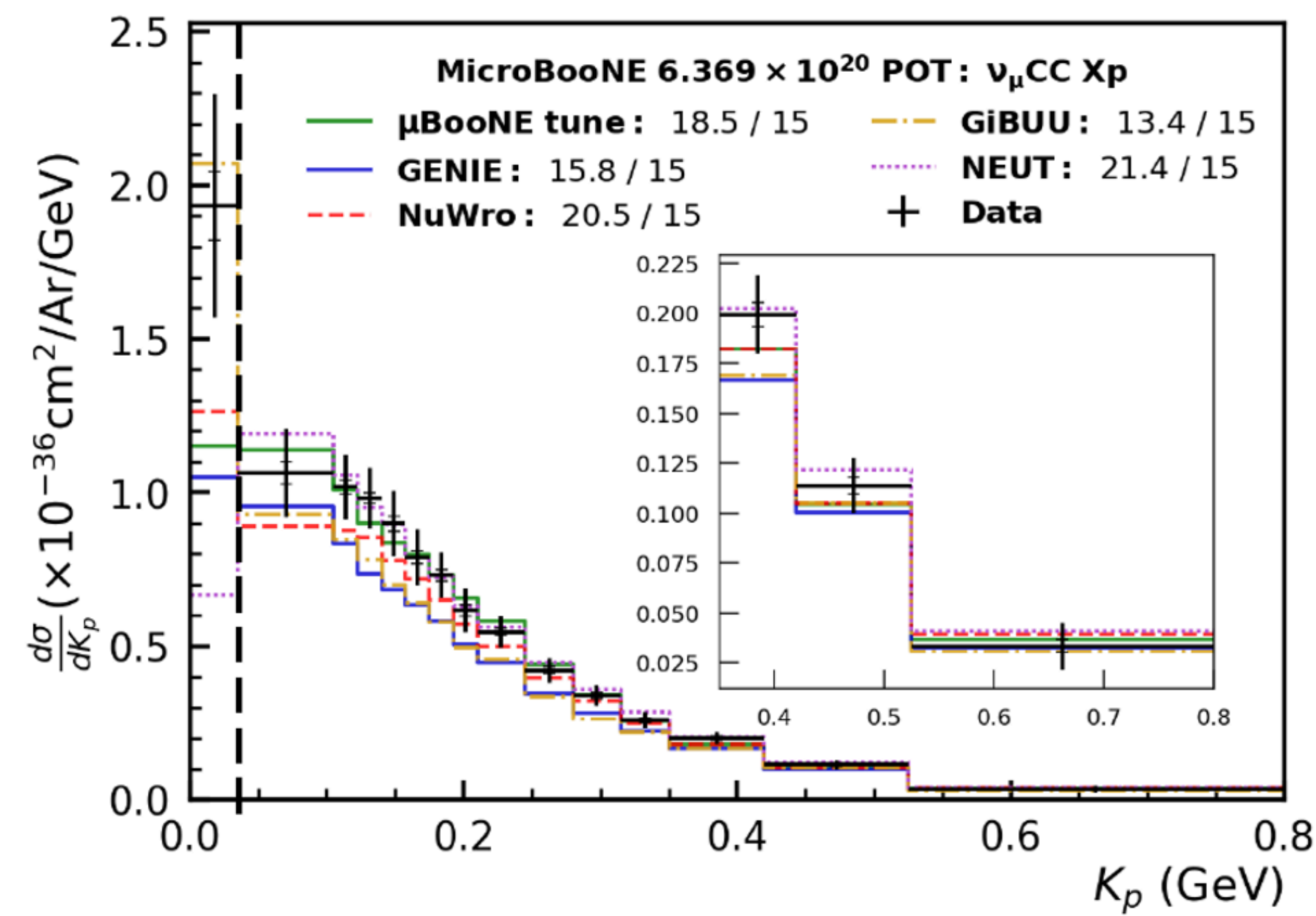

- Evolved from 1D E_ν-based to 3D

- Plenty of new techniques, validation effort to ensure robustness

- Branched out to other analyses, since then
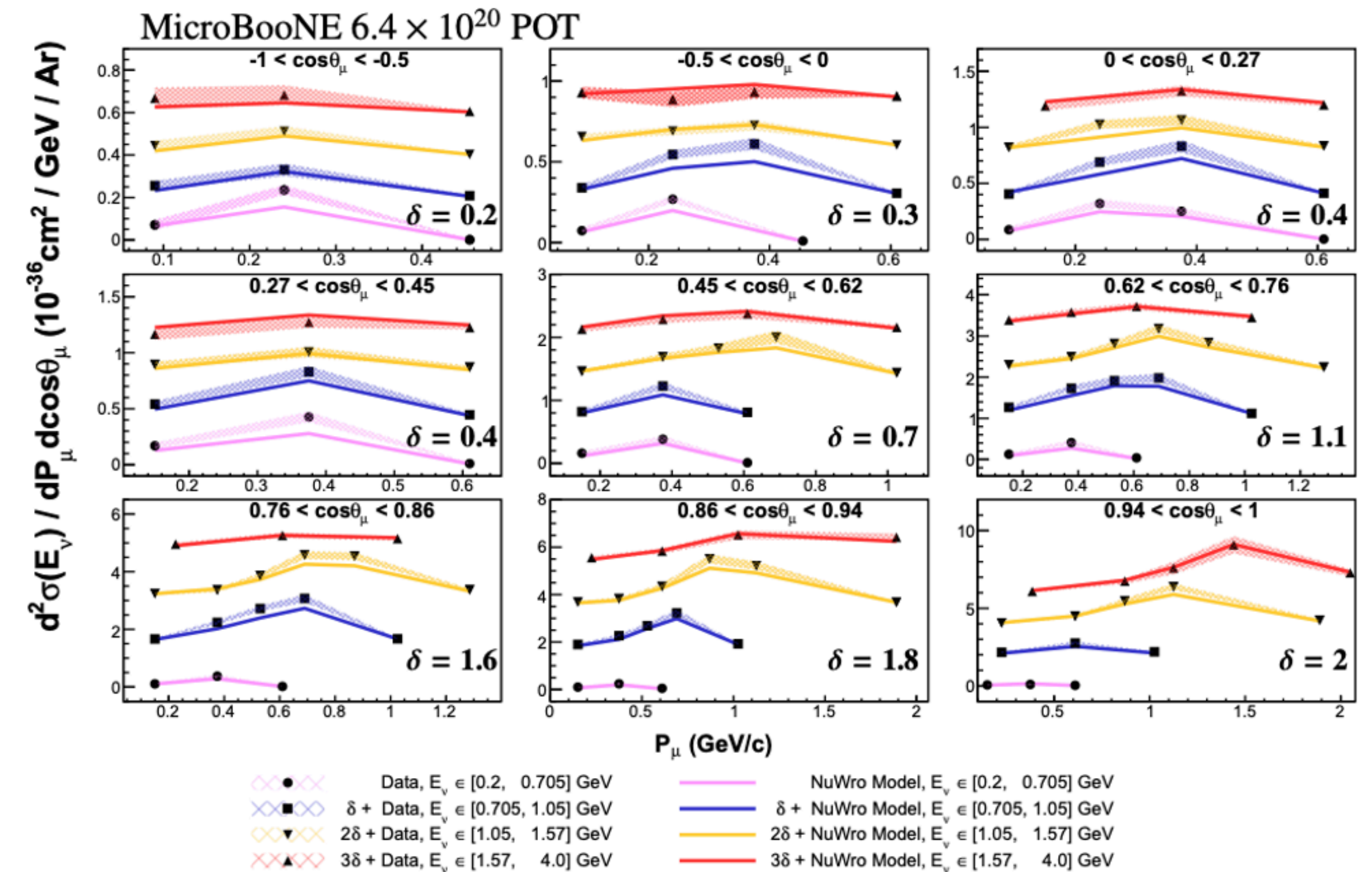
- Active discussion with community

- Conferences, seminars
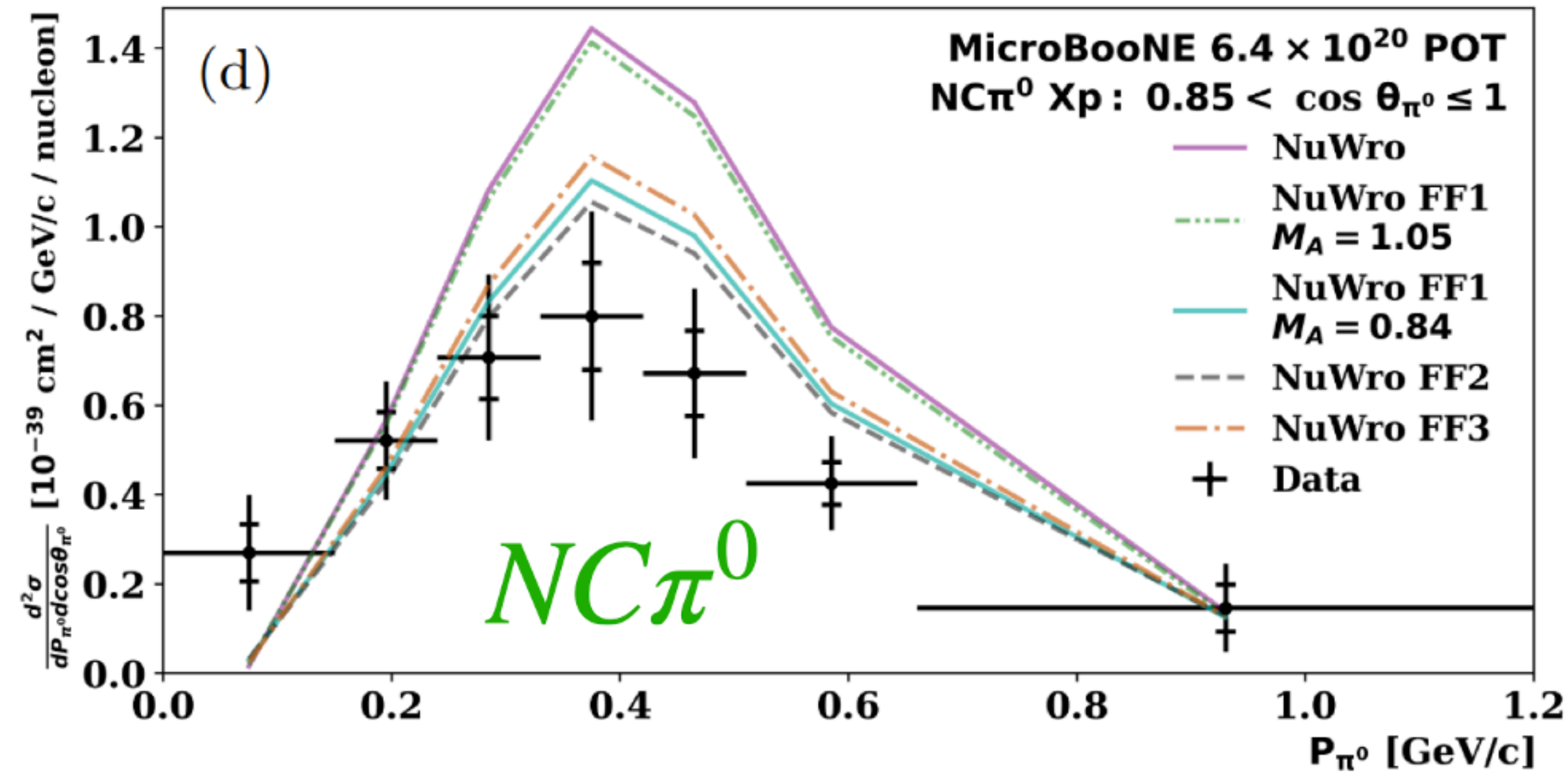
- Publishing Methods Paper

MicroBooNE 6.4×10^{20} POT

- Re-submitted to PLB

- Got single referee comment

  - Opposed to idea of E_ν-based measurements

  - Referee did think model-fits to E_ν-measurement could be useful for osc. Analysis

- Planning to resubmit w/ new strategy :

  - Unfold to 3D but $\sigma(E_{vis}, p_\mu, \theta_\mu)$

  - Provide some fits to E_ν data to ensure its documented

MicroBooNE 6.369×10^{20} POT: ν_μCC Xp

- μBooNE tune: 18.5 / 15
- GENIE: 15.8 / 15
- NuWro: 20.5 / 15
- GiBUU: 13.4 / 15
- NEUT: 21.4 / 15
- + Data

| Measurement	Channel	ndf	μBooNE tune	GENIE	NuWro	NEUT	GiBUU
$\frac{d\sigma}{dE_\mu}$	0p	11	38.3	41.8	29.5	56.2	13.5
	Np	11	16.5	27.2	20.2	13.0	25.3
	0pNp	22	50.8	61.5	46.4	65.7	37.6
$\frac{d\sigma}{d\cos\theta_\mu}$	0p	17	25.6	28.3	13.2	44.7	9.9
	Np	17	34.2	34.2	42.0	19.9	27.3
	0pNp	34	64.3	62.1	55.7	70.3	44.6
$\frac{d\sigma}{d\nu}$	0p	3	37.5	45.1	28.8	91.4	9.2
	Np	6	12.7	24.3	20.6	20.7	26.3
	0pNp	9	63.3	66.2	52.1	153.5	59.0
$\frac{d\sigma}{dE_{avail}}$	0p	5	32.8	39.5	29.9	71.7	0.8
	Np	9	12.7	22.2	13.7	25.7	12.1
	0pNp	14	43.3	56.8	40.4	85.1	14.3
$\sigma(E_\nu)$	0p	10	21.5	29.7	17.5	56.4	15.4
	Np	10	6.4	20.1	13.7	5.5	15.1
	0pNp	20	29.6	41.4	29.2	72.1	43.4
$\frac{d\sigma}{dK_p}$	Xp	15	18.5	15.8	20.5	21.4	13.4
	Np	14	15.4	13.8	13.4	15.8	10.6
$\frac{d\sigma}{d\cos\theta_p}$	Np	20	16.0	22.4	9.9	28.4	48.0
Proton Multiplicity	Xp	4	7.1	19.8	9.9	22.2	10.5
$\frac{d^2\sigma}{d\cos\theta_\mu dE_\mu}$	0p	55	129.8	140.9	109.7	180.3	102.8
	Np	69	203.1	189.7	196.9	192.7	192.1
	0pNp	124	287.5	266.4	263.7	298.8	249.8
	Xp	69	129.6	140.4	169.3	104.7	161.5
$\frac{d^2\sigma}{d\cos\theta_p dK_p}$	Np	96	144.2	138.8	120.3	204.4	274.1
$\frac{d^3\sigma}{dE_{avail}d\cos\theta_\mu dE_\mu}$	Xp	249	274.2	336.9	309.4	330.6	313.9

- Detailed multi-differential 0p/Np measurement

- Lots of concrete insights about model behavior (inclusive vs exclusive, FSI/proton transparency etc)

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- Our first exclusive measurement, important background for $\nu_e CC$

- Learning about Resonance behavior etc, see for eg Ben's paper co-authored with GiBUU team : arXiv: 2405.05921
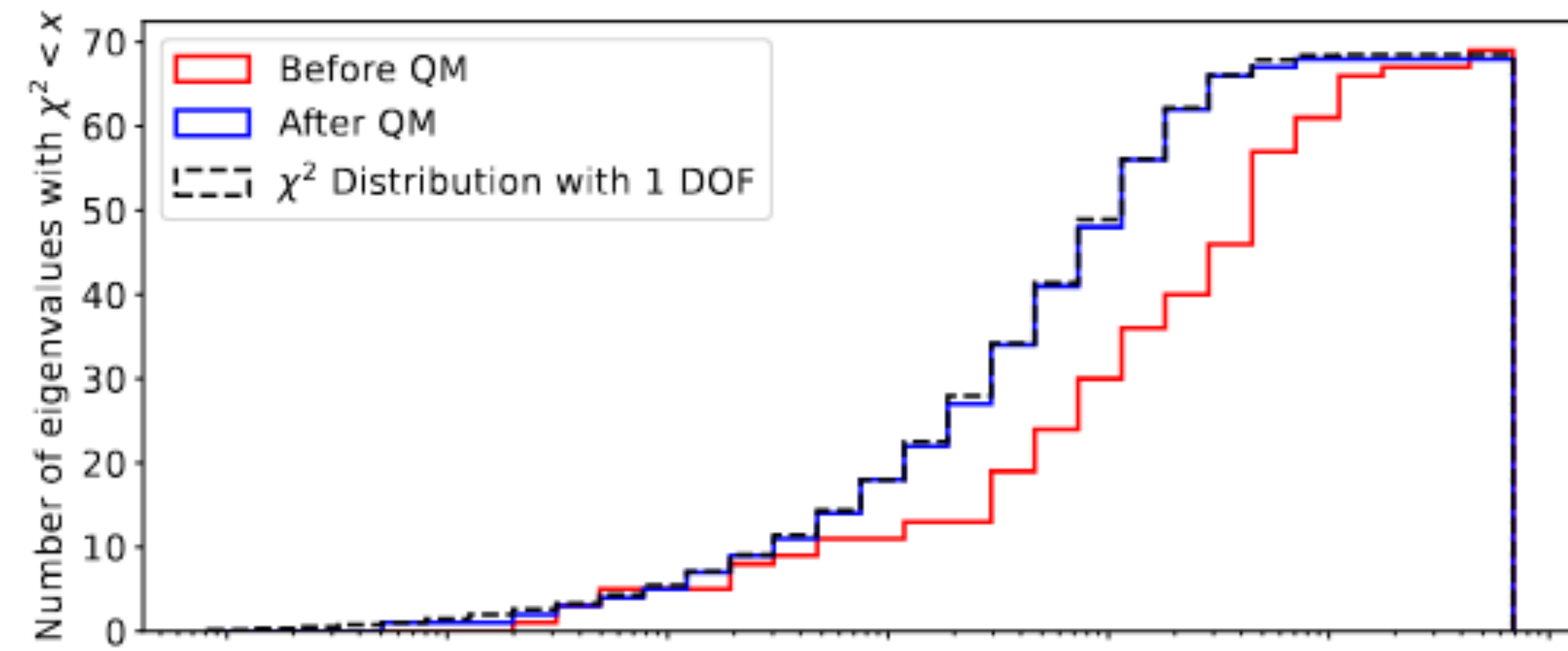
- Recently accepted by PRL!
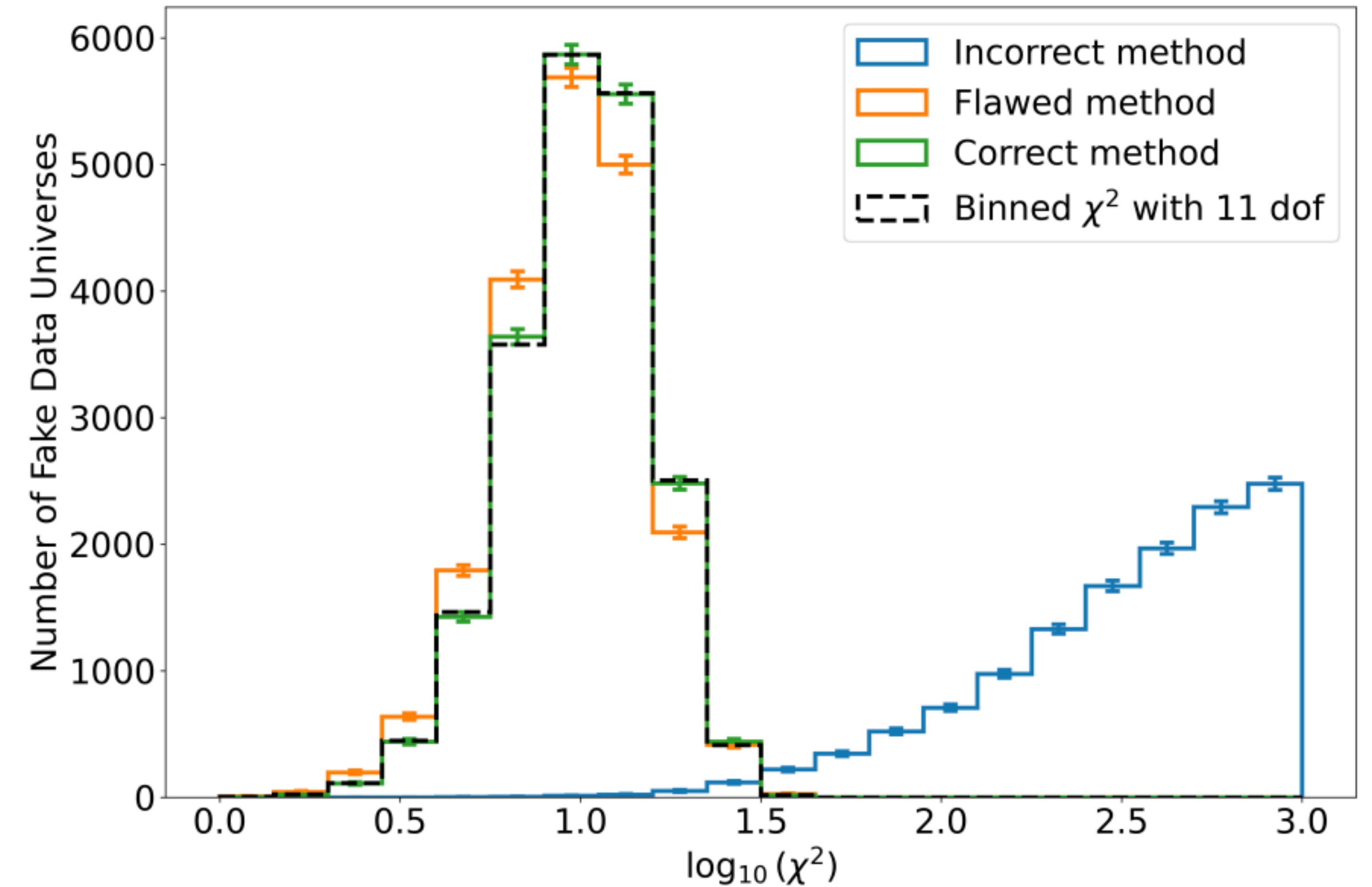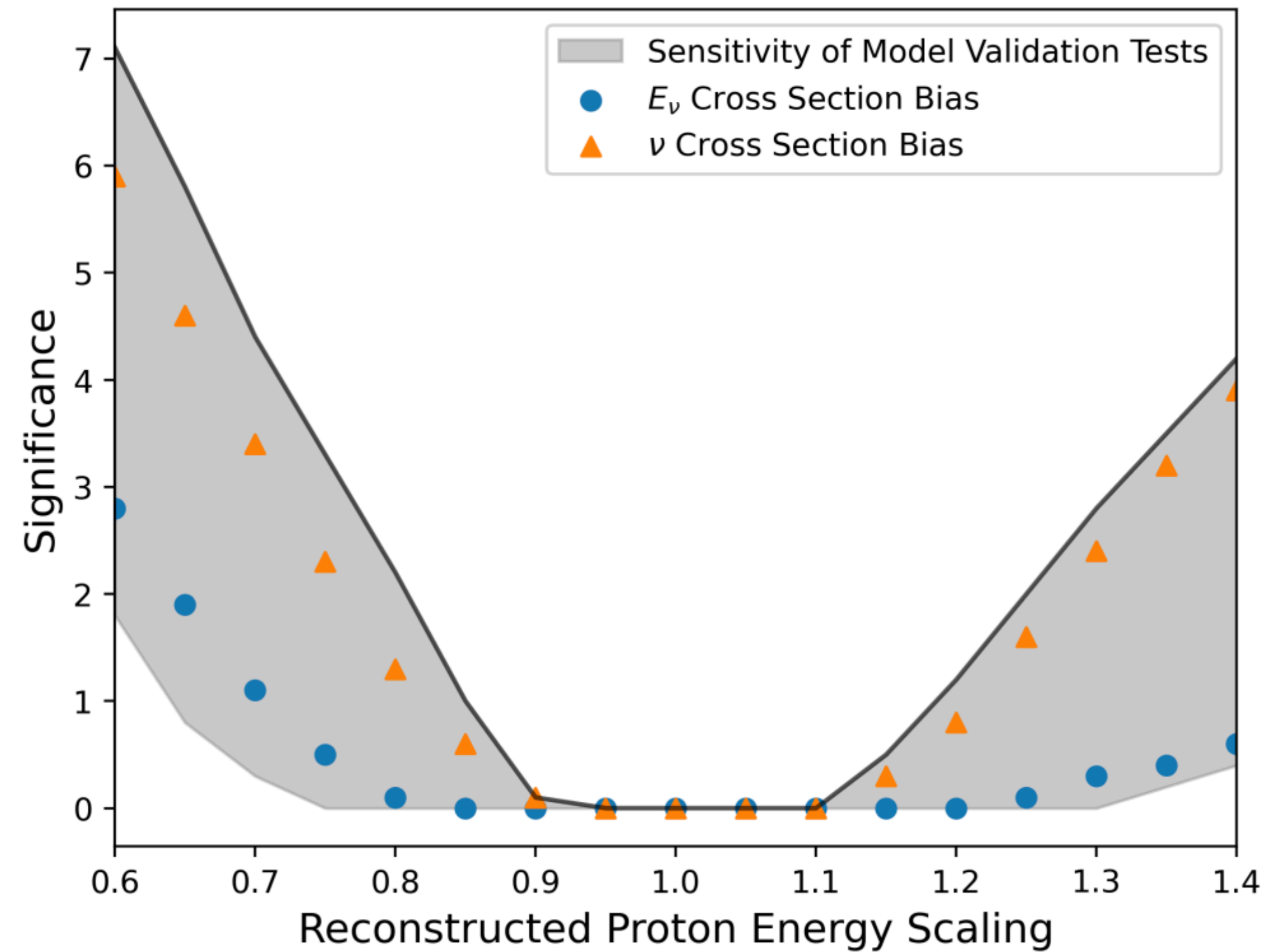
- Exhaustive paper documenting our philosophy/approach for xsec measurements

- Lots of novel techniques and useful discussion

- Based on referee feedback, likely to be accepted into PRD

# Methods (Part 2)
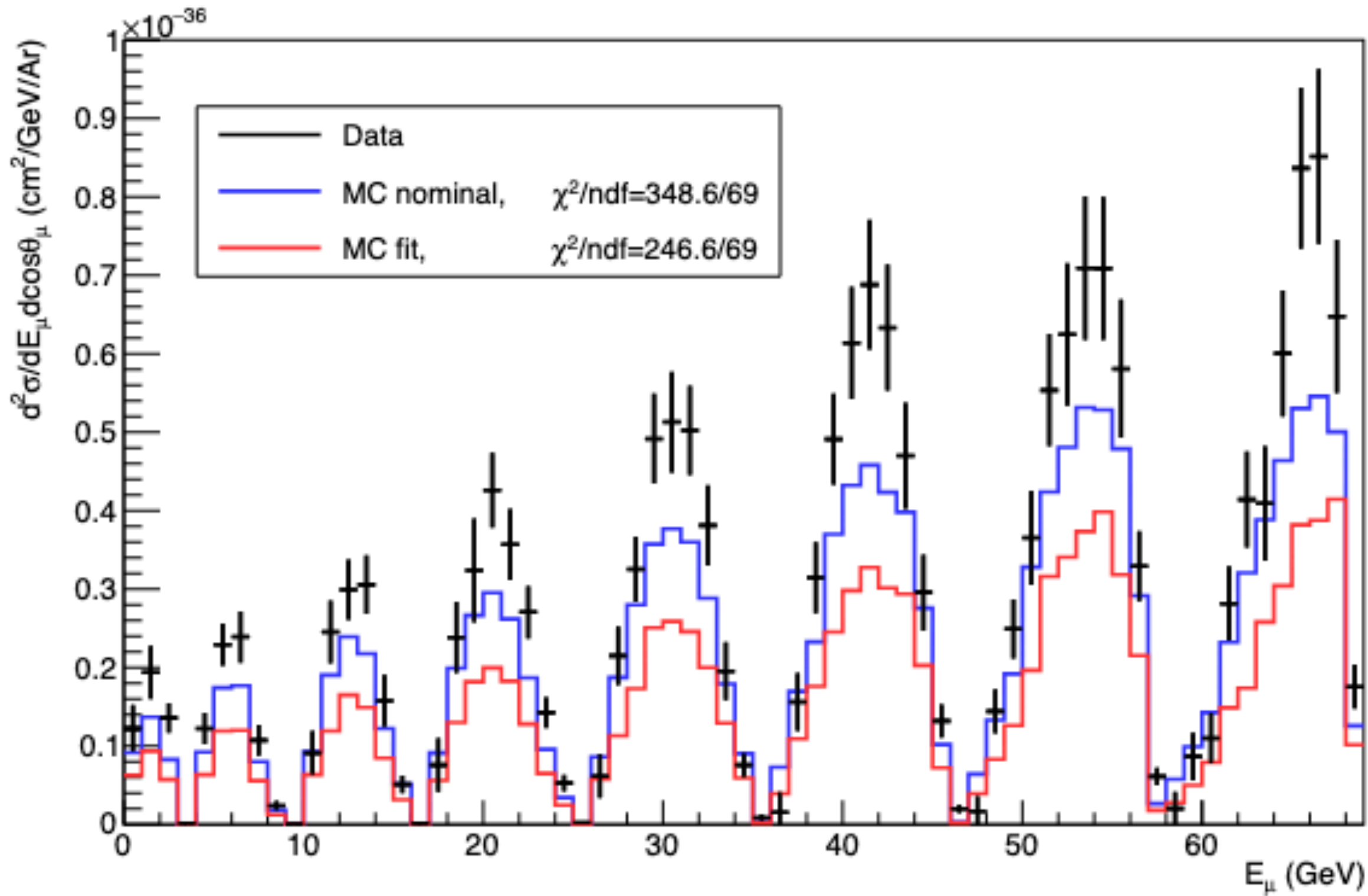
London's Quantile Mapping Method

- Investigation into Peelle's Pertinent Puzzle (issues when fitting to xsec data)

- Survey of possible causes : missing regularization, flux issues, insufficient model parameters etc

  - Strategies for mitigation

- Paper draft is ready for circulation to Pittsburgh TENSIONS group
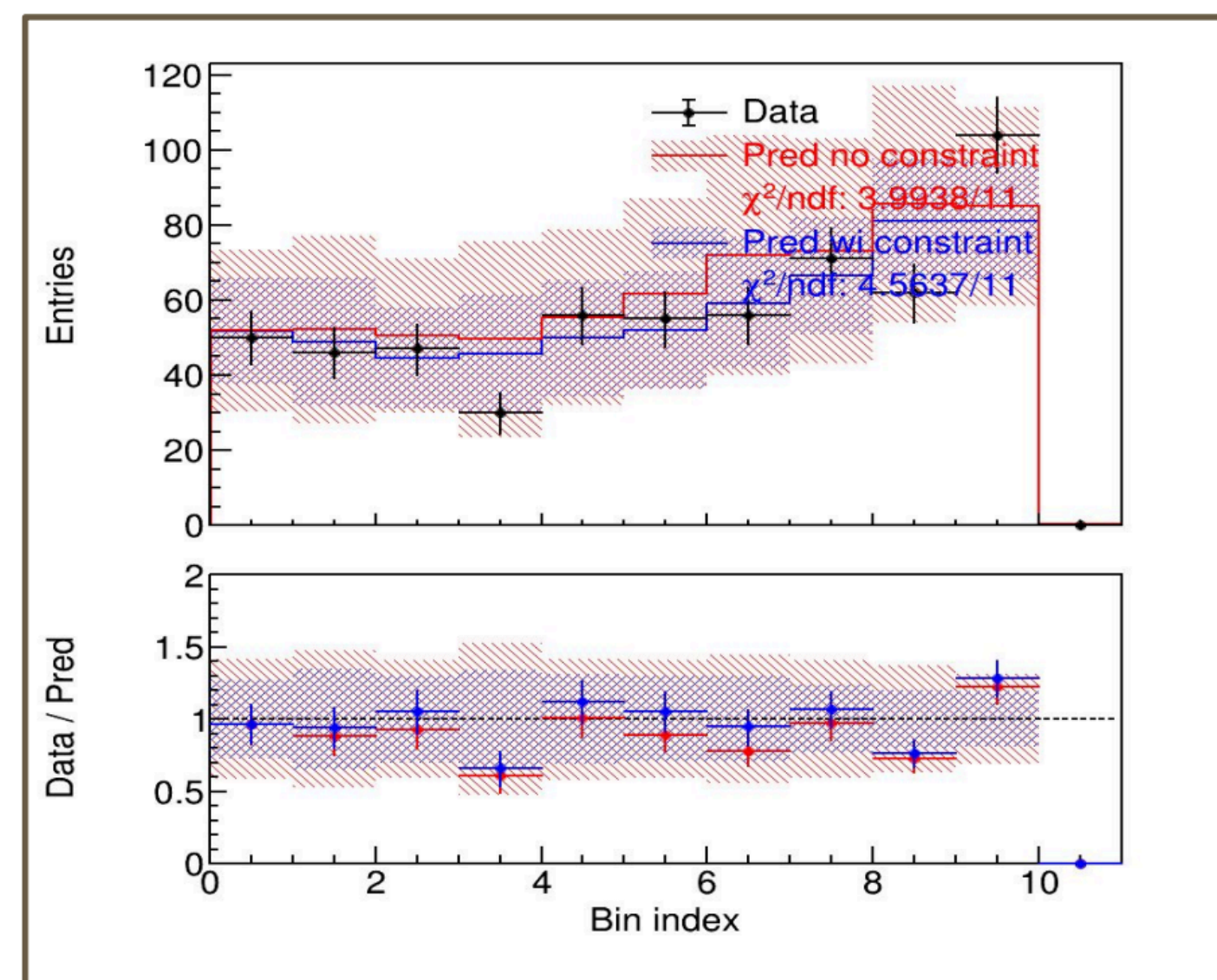
MaCCQE
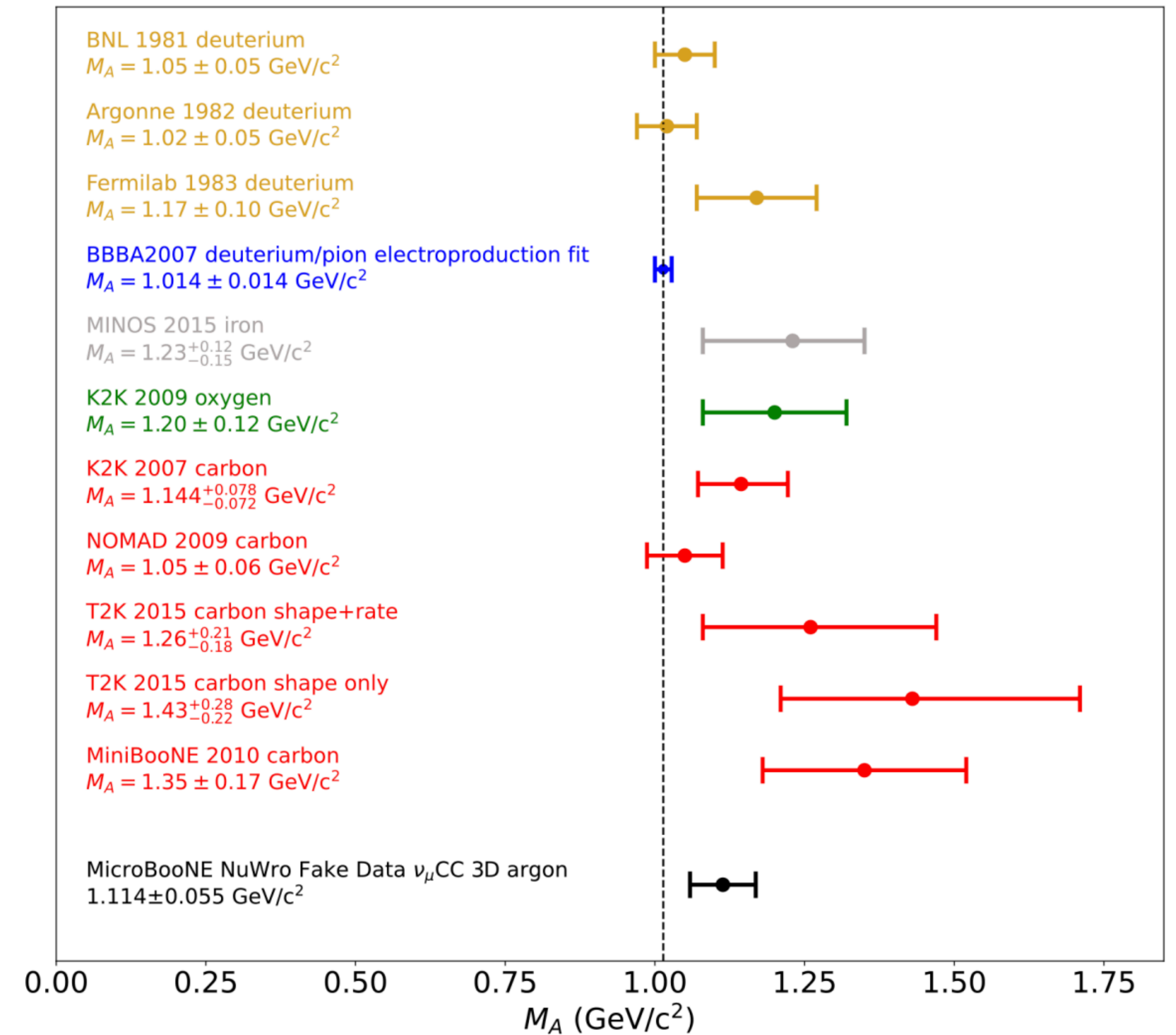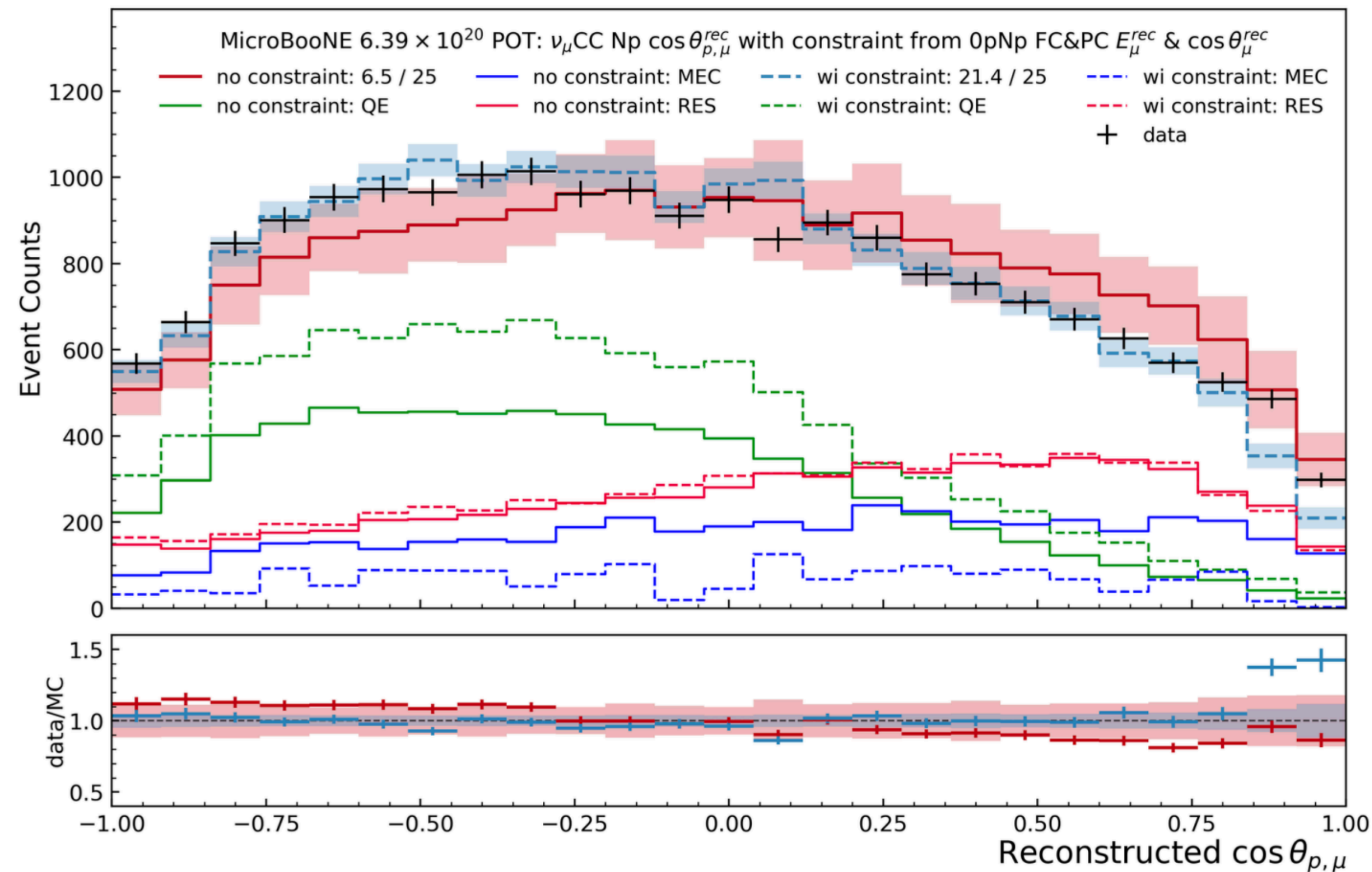
- Further studies on inclusive data

  - QE enhancement, non-QE suppression

  - Suggests effective Ma could be > 1 (consistent with LQCD), lets extract it ourselves like MiniBooNE/MINERvA!

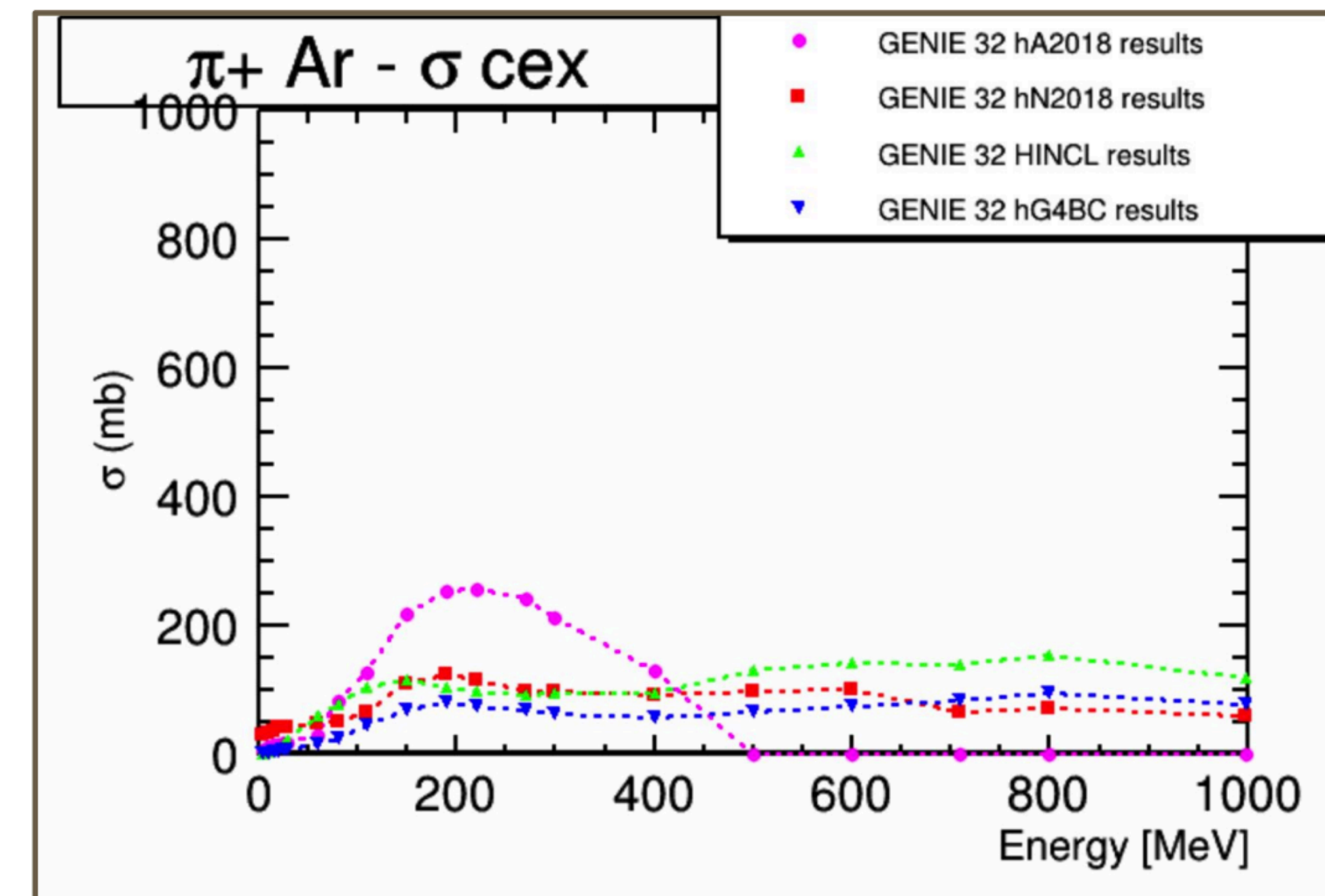- Currently in EB review - Fake Data studies look pretty good overall, want to unblind soon
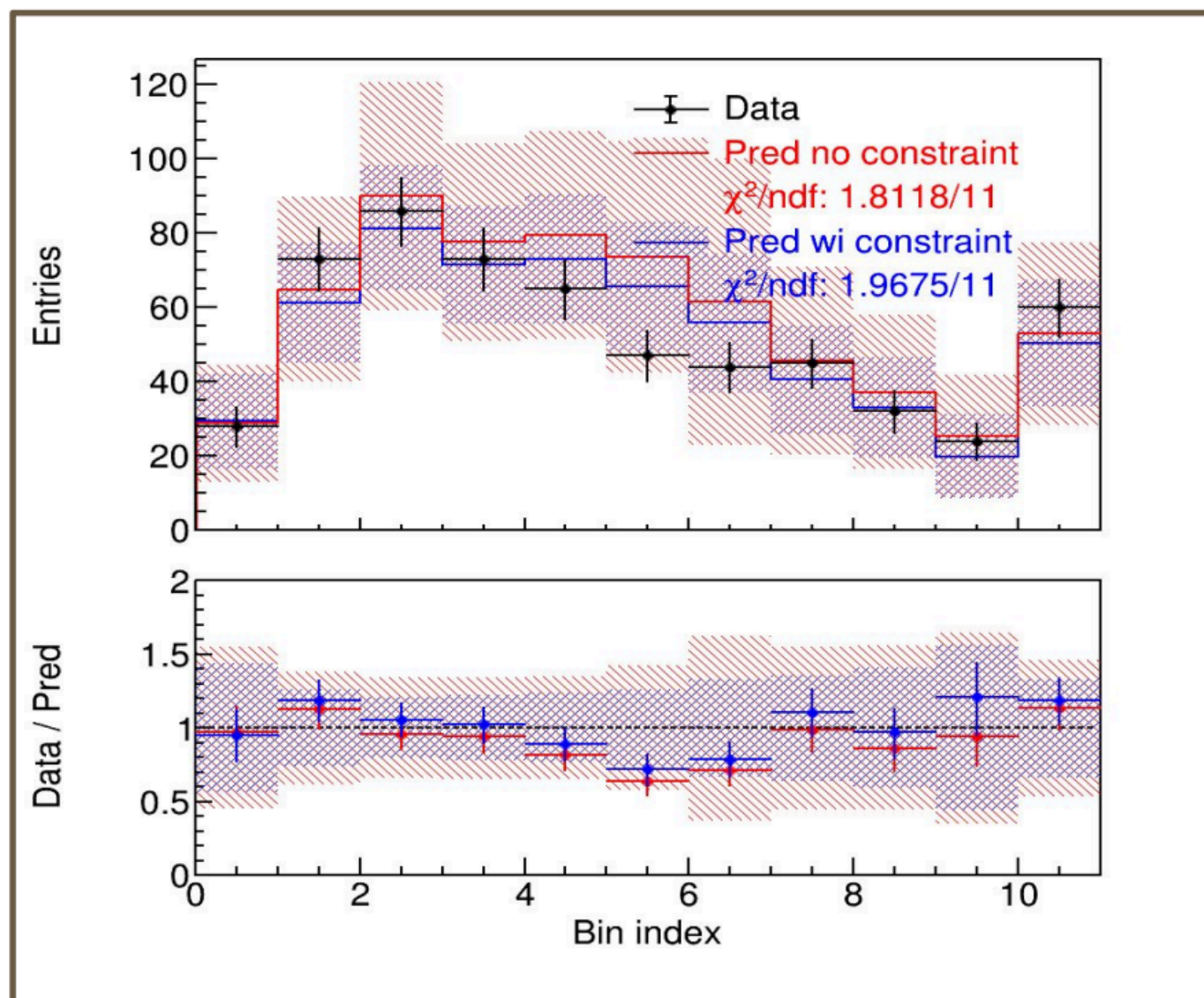
Target: transverse missing momentum (pT) [0,600,10]

Target: Boosting angle (aT)

$$\nu_\mu - CC\pi^0 1p \text{ TKI}$$
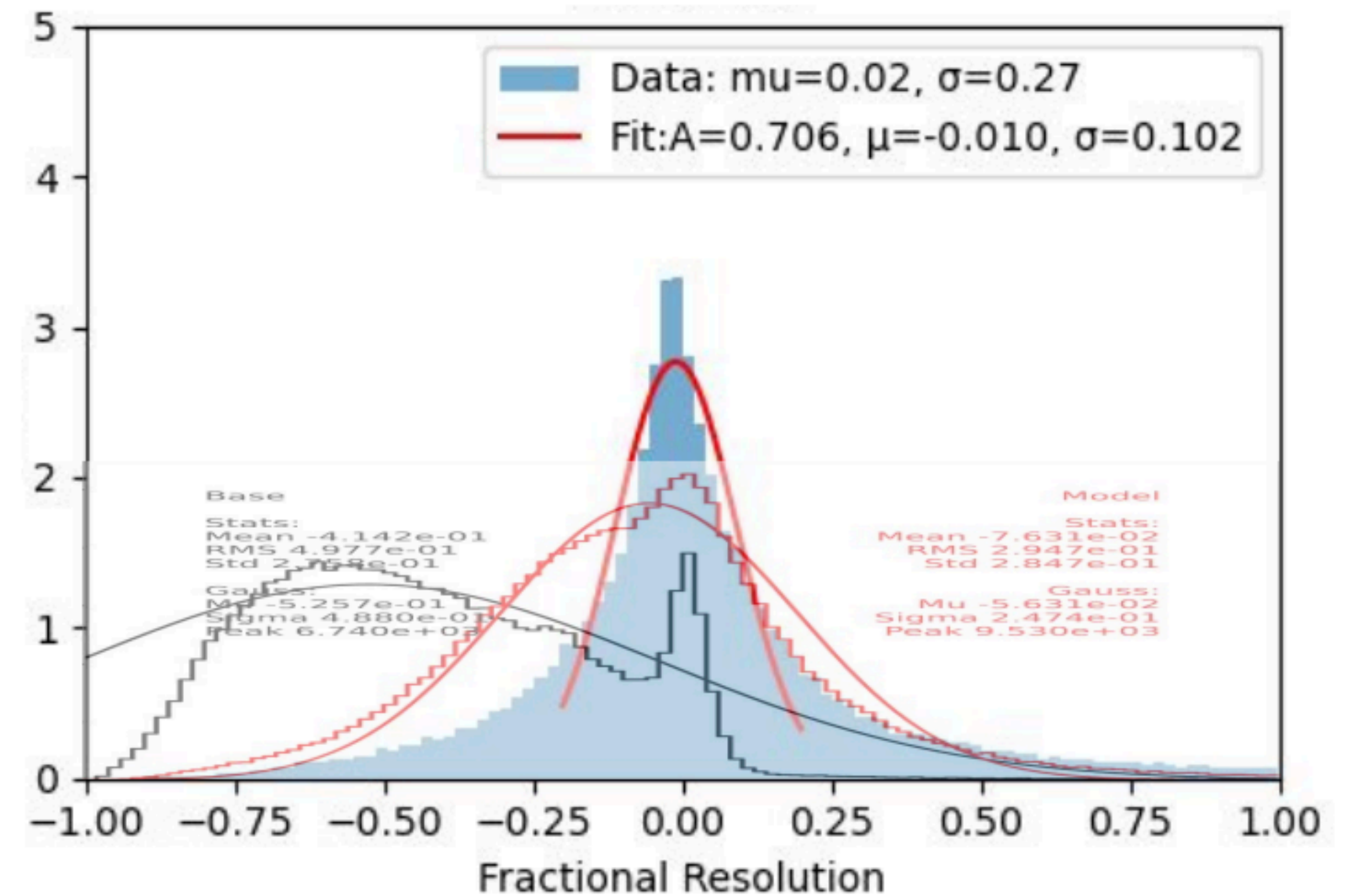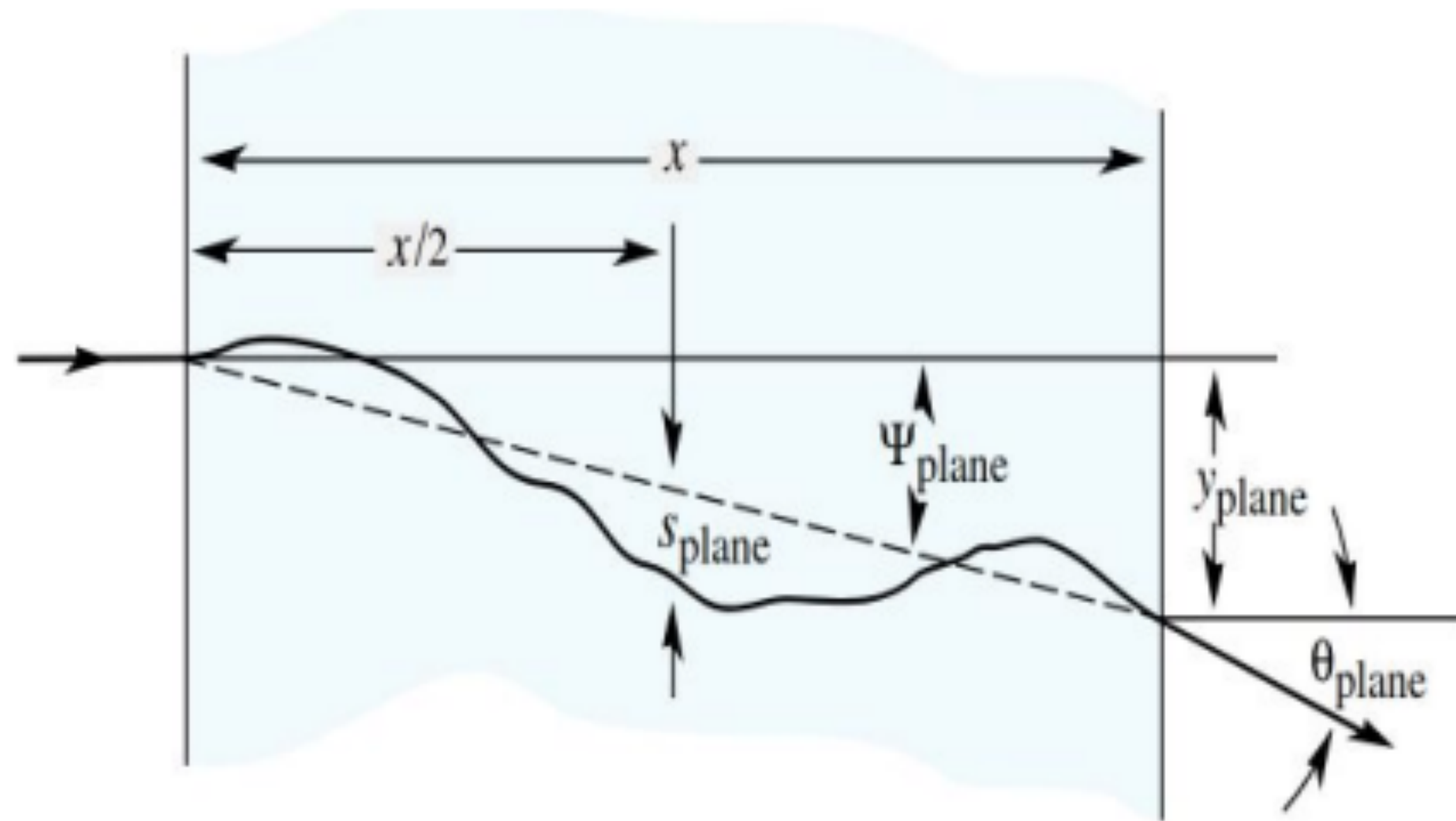

- Looking further into RES hadron kinematics

- Lots of info on π-FSI along with N-FSI

  - Found major bug in GENIE hA2018 FSI model

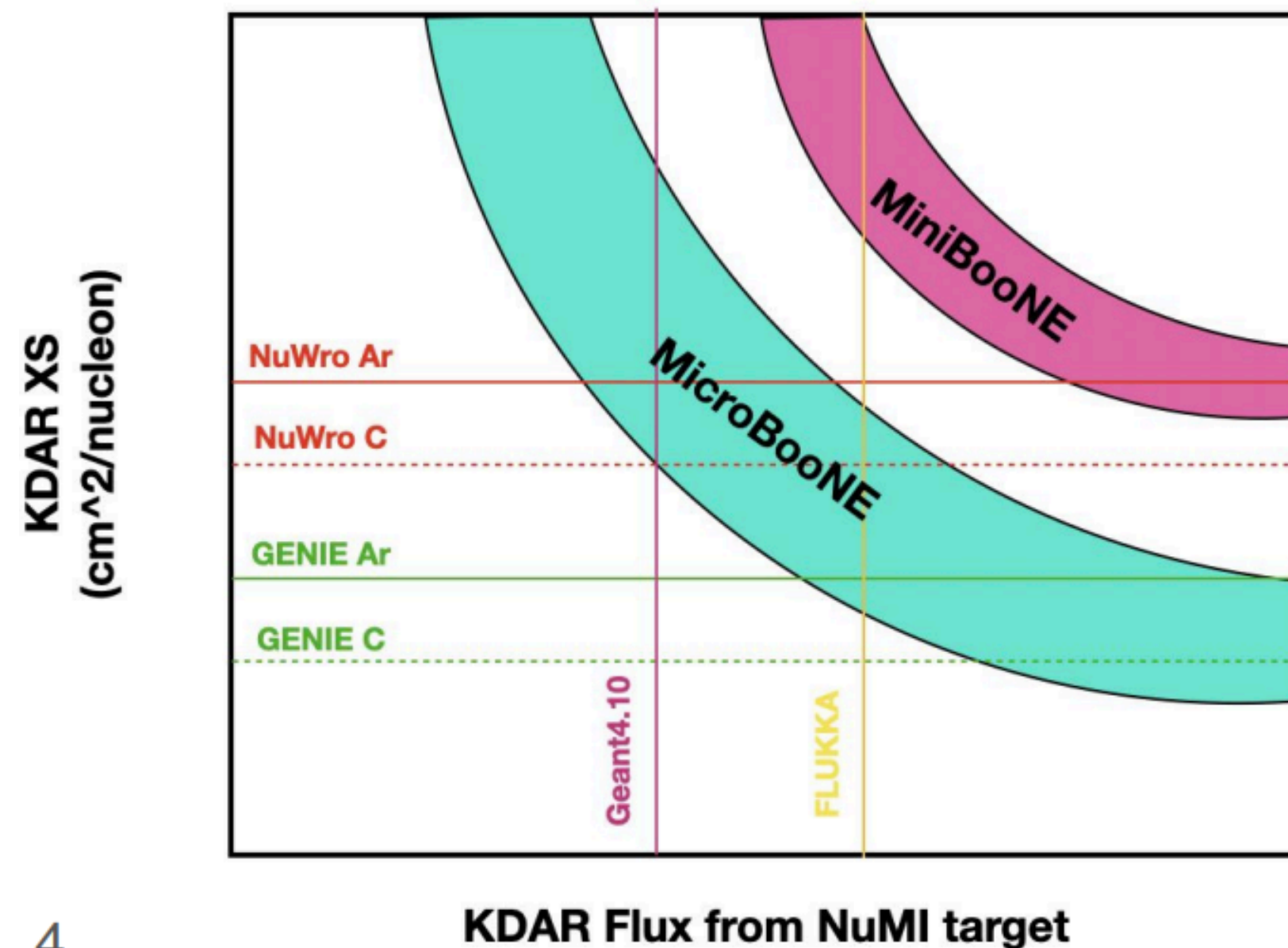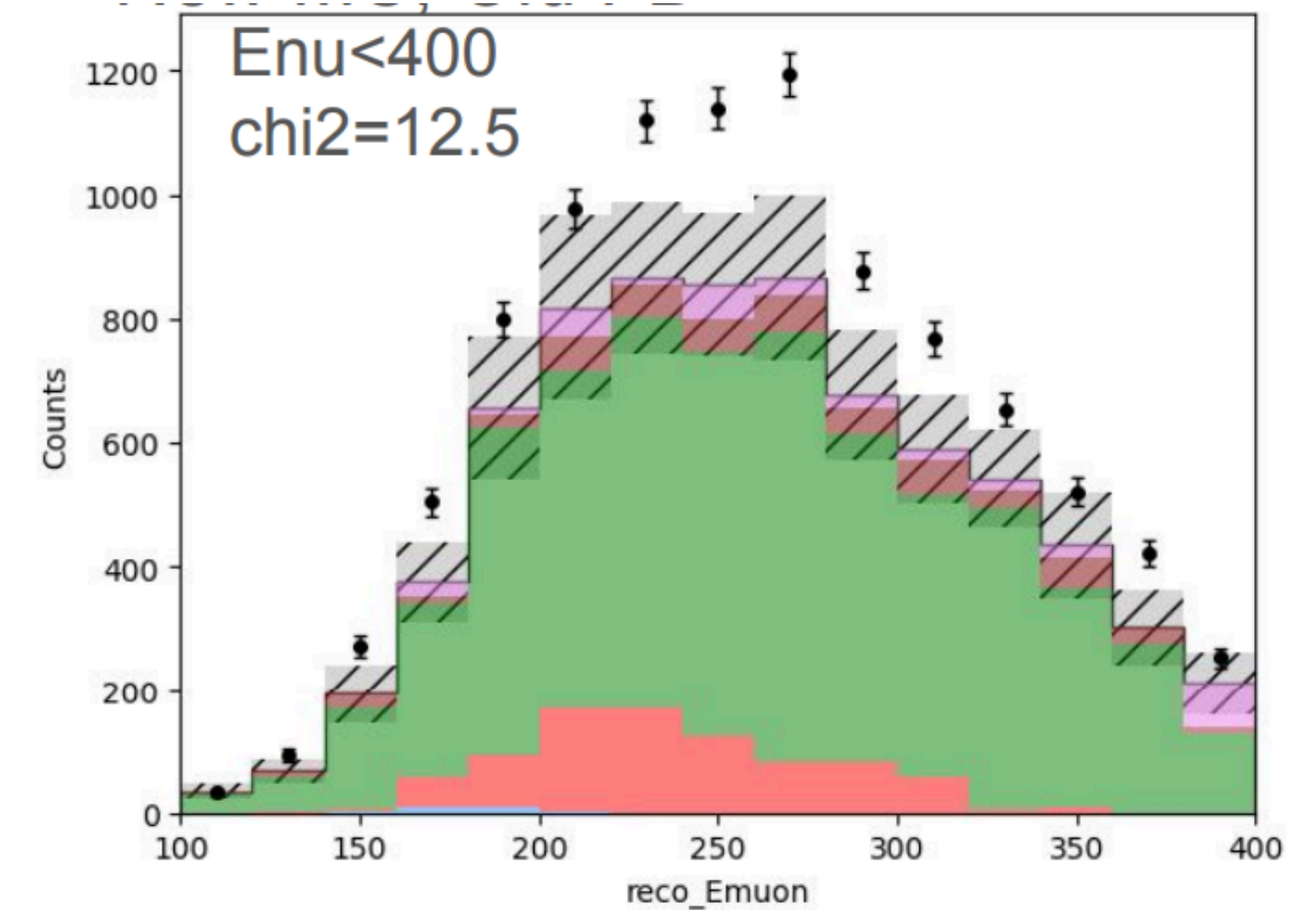- Model validation tests pass => can proceed to measurement
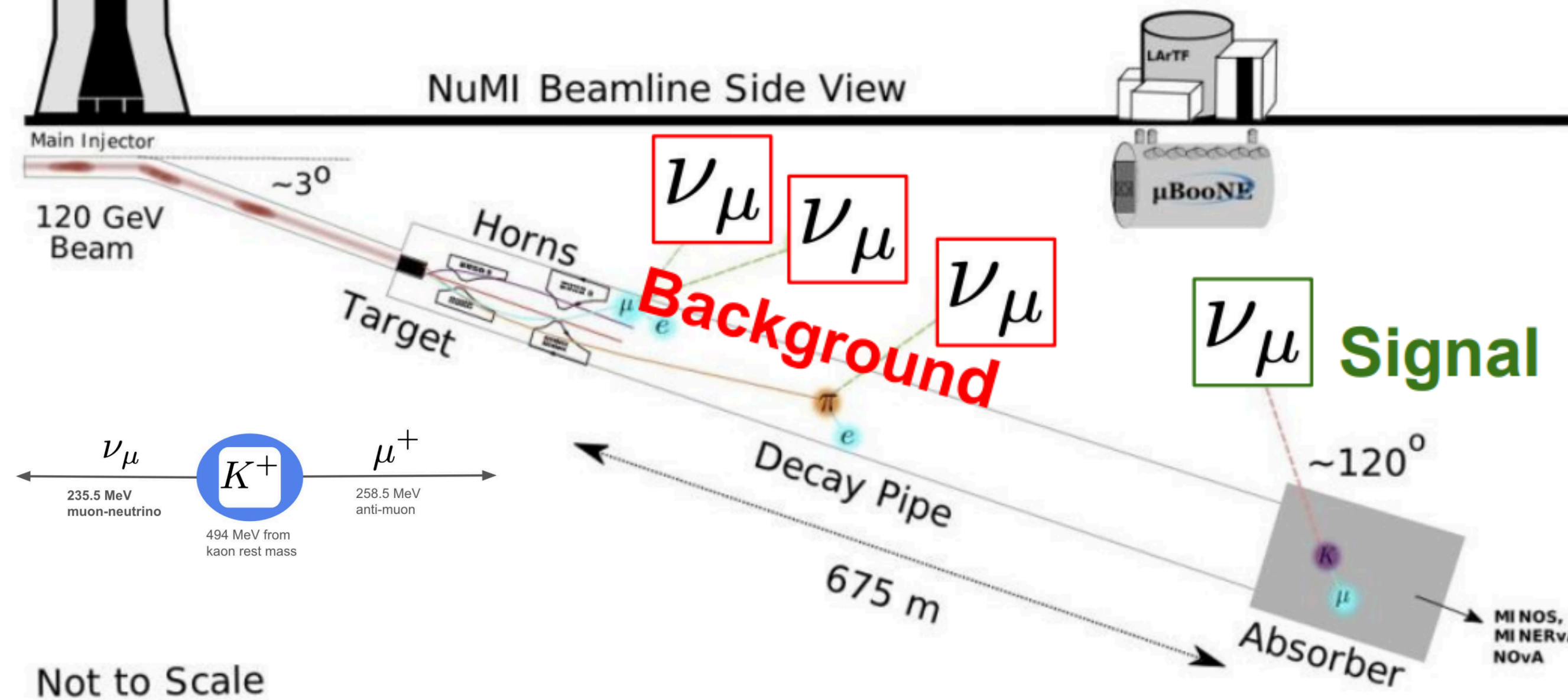
- Wire-Cell MCS method for PC events shows pretty good results

- Incorporated into new Reco workflow => available to next-gen analyses

  - TKI analysis will find it useful, what about other ideas?

- Mono-energetic source at 236 MeV

- Lots of improvements for analysis power

  - Tuned Low-energy Reco, Background-only constraints, NuMI ns-timing

- Lots of technical improvements

  - GiBUU fake data, shape-only measurements

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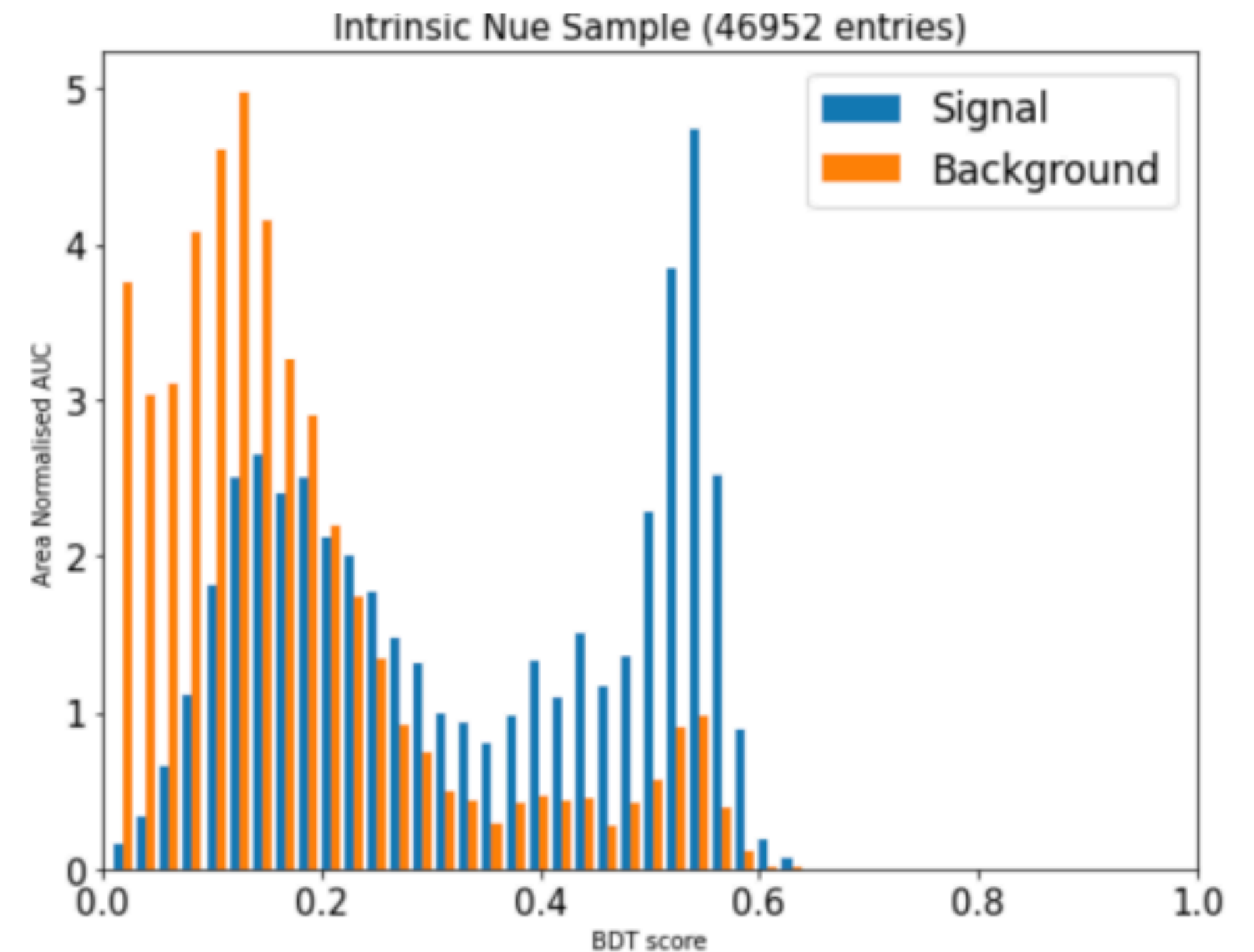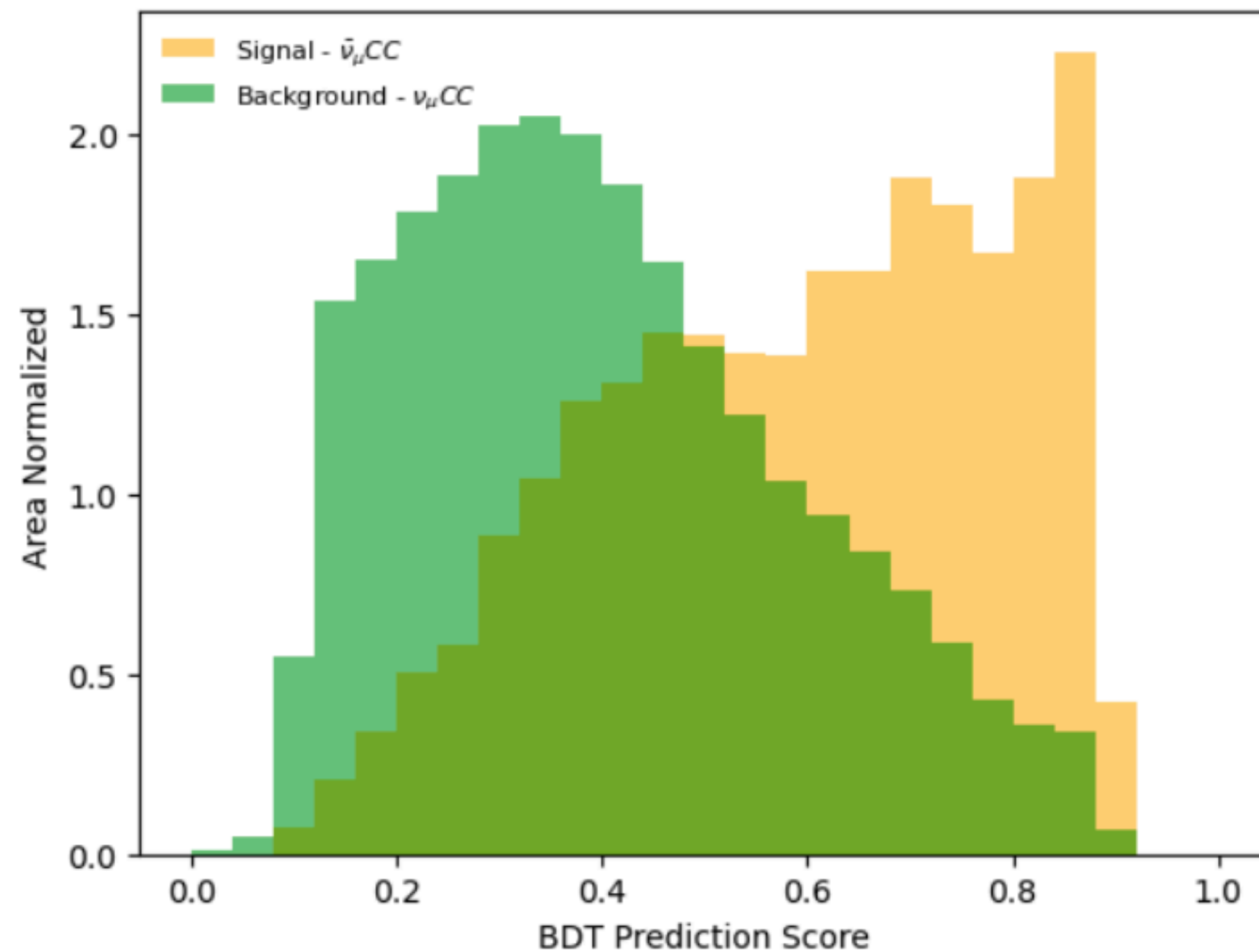
Area normalised: shows two peaks!

- Edinburgh group interested in using WC for anti-neutrino separation ($\bar{\nu}_\mu$, $\bar{\nu}_e$)

  - Potential interest in Reco improvements as well : Michel tagging etc

- Able to separate with BDTs => Measurement as differential xsec or template fit

Summary

- Learning a lot about inclusive channels

  - But also now, RES channels

- Datasets + Model benchmarking, fitting + Wire-Cell methods => concrete improvements for DUNE

- Lots of interesting new channels being explored w/ bonus reco improvements