MICROBOONE-NOTE-1095-PUB

Search for Electron-like Low Energy Excess using Wire-Cell Event Reconstruction at MicroBooNE

Hanyu Wei, Brookhaven National Lab
on behalf of the MicroBooNE collaboration

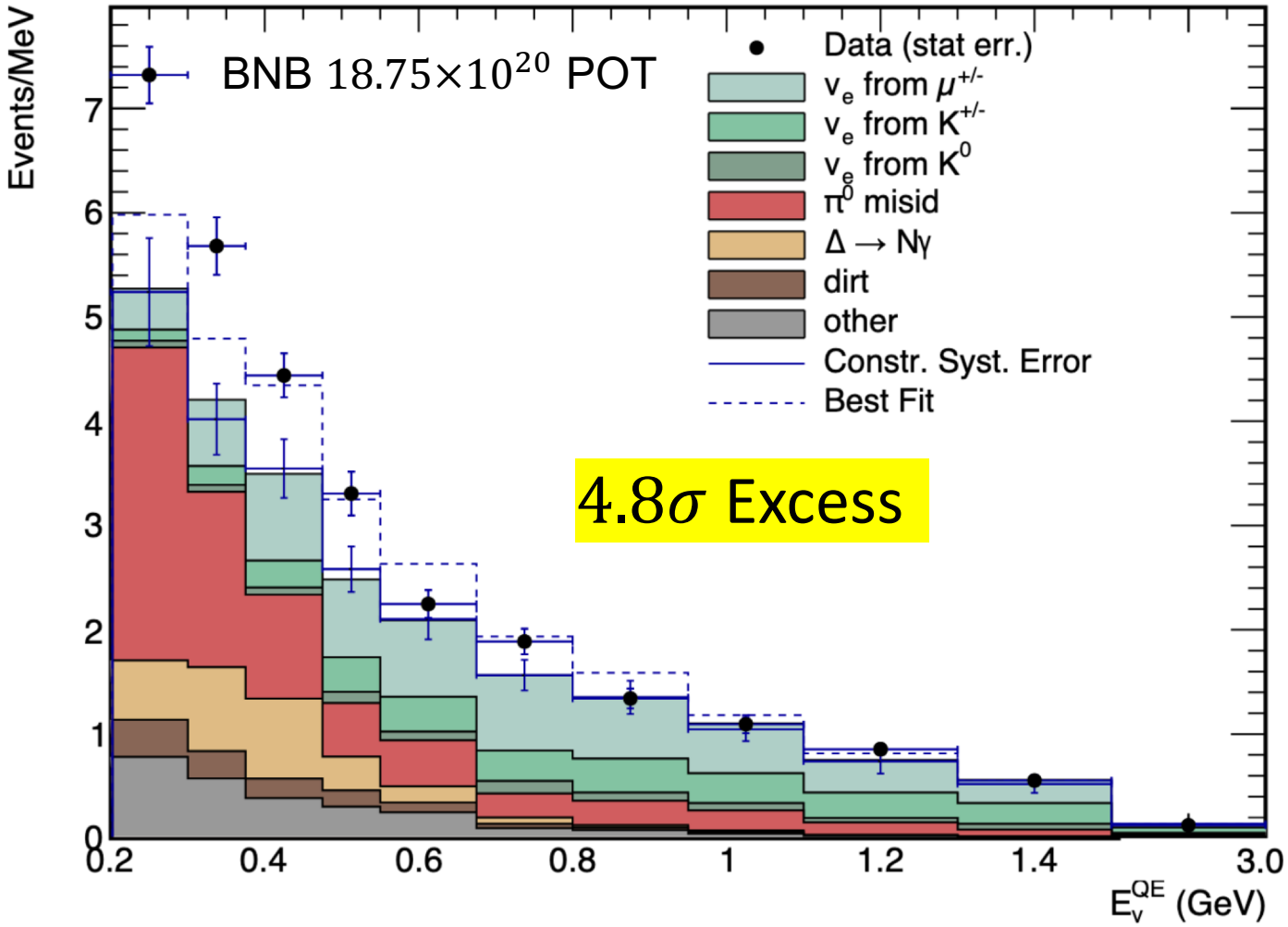
Feb. 23rd, 2021

The XIX International Workshop on Neutrino Telescopes

Contact: hwei@bnl.gov

MiniBooNE low energy excess

arXiv: 2006.16883



- Sterile neutrinos (e from ν_e)
- Excess $\Delta \rightarrow N\gamma$ [M. Ross-Lonergan's talk]
- Dark neutrino portal $Z_D \rightarrow e^+e^-$ [P. Guzowski's talk]
- Other generic photon (γ) background
- …

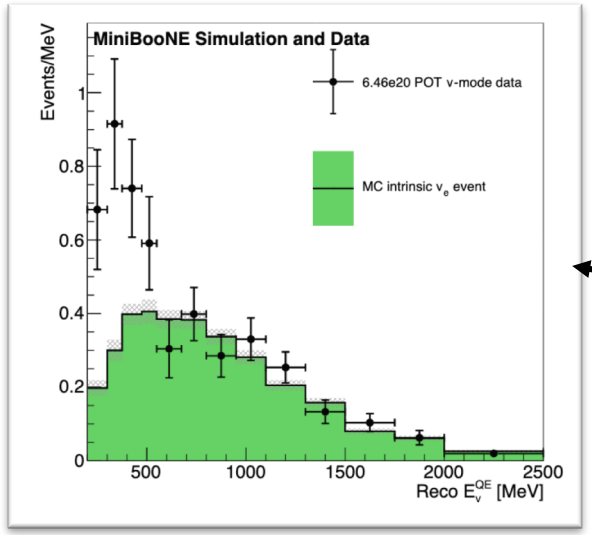
e/γ separation →

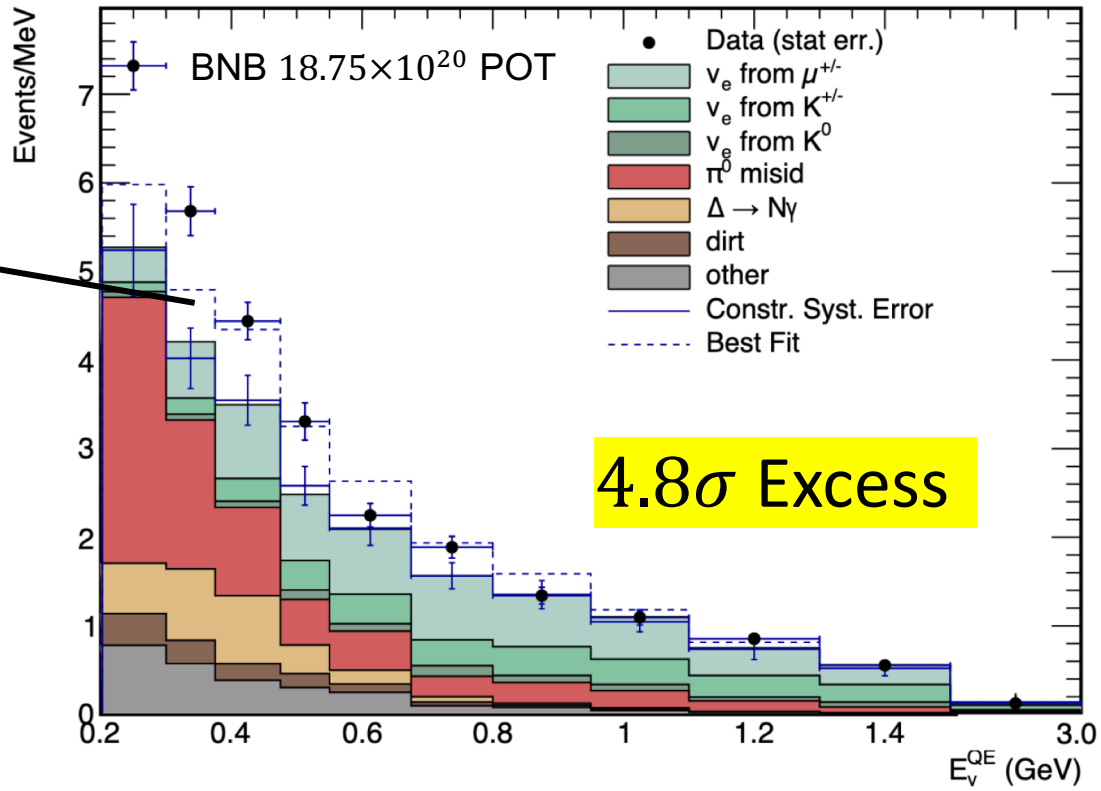
- electron-like (ν_e CC) excess? [eLEE]
- photon-like excess? [gLEE] M. Ross-Lonergan's talk

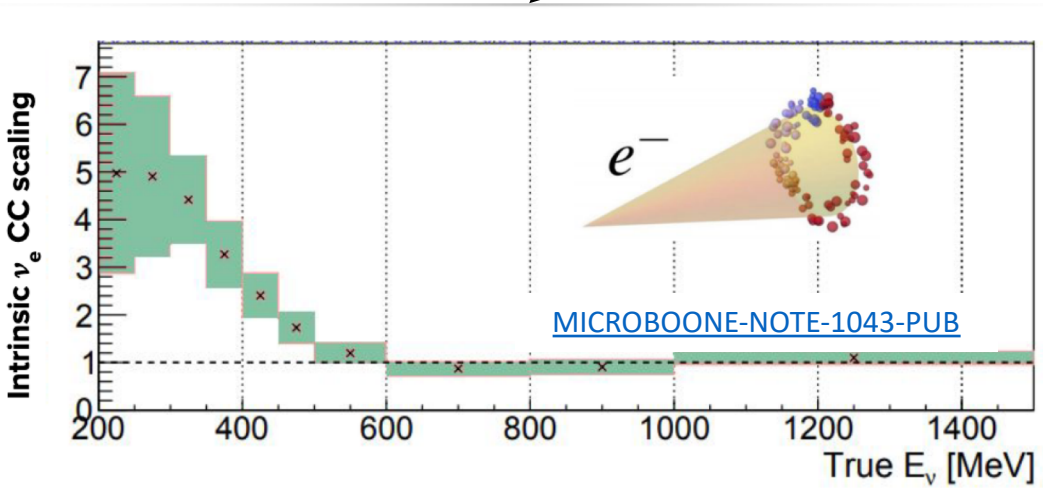
MicroBooNE electron-like LEE prediction

arXiv: 2006.16883

MiniBooNE electron-like excess unfolding





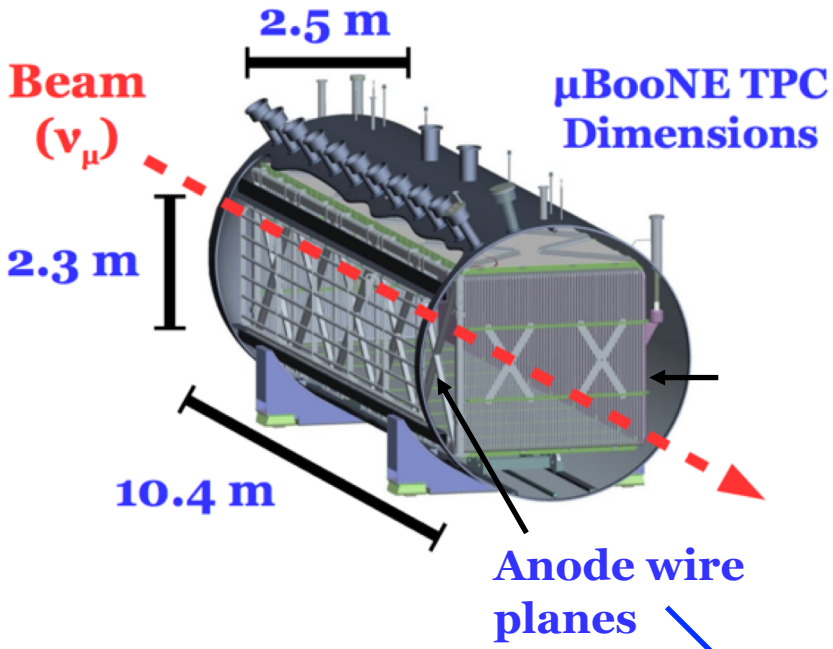


Applying this low-energy excess / beam intrinsic ν_e CC ratio to MicroBooNE → eLEE prediction

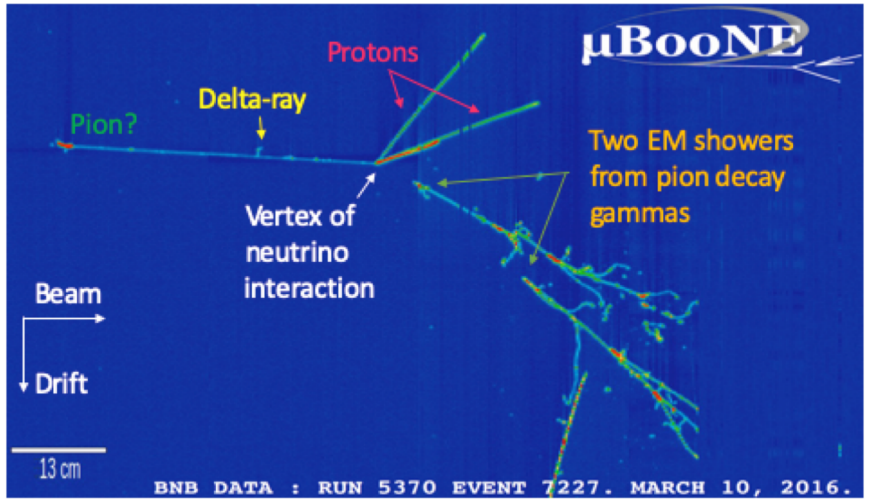
MicroBooNE

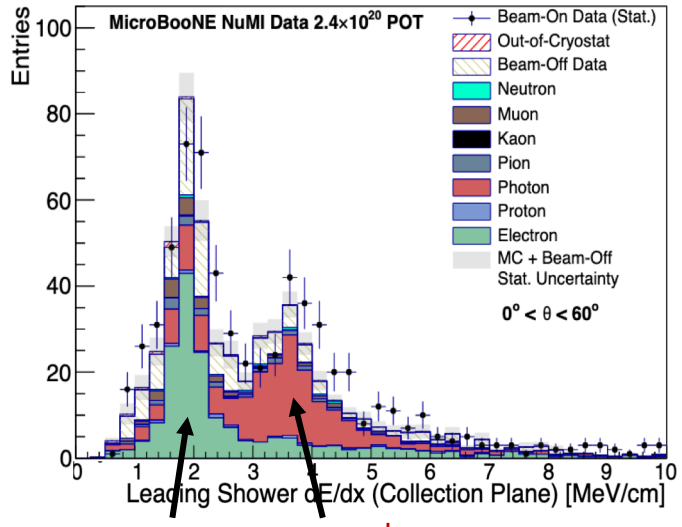
arXiv: 2101.04228

85 ton liquid argon

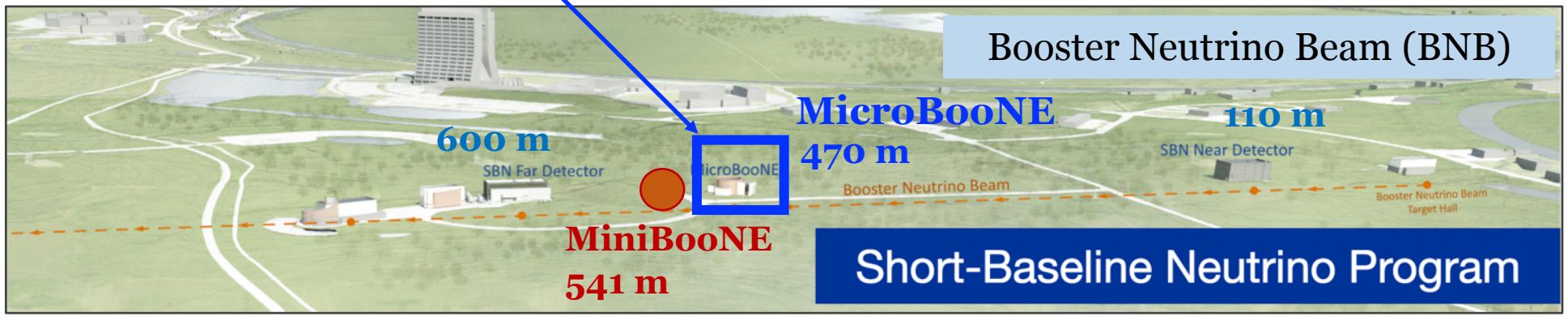


Liquid Argon TPC





e shower γ (e^+e^-) shower



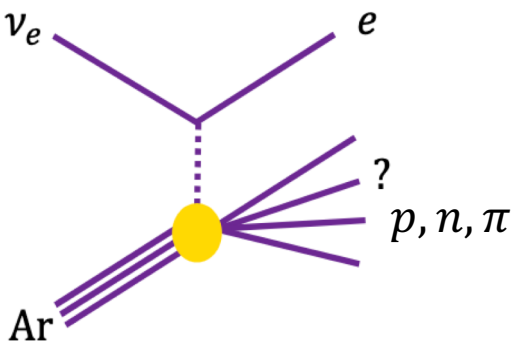
NeuTel 2021 talks:

W. Gu
M. Reggiani-Guzzo
K. Mistry
M. Ross-Lonergan
H. Wei (this talk)
P. Guzowski
M. Wospakrik
A. Mogan

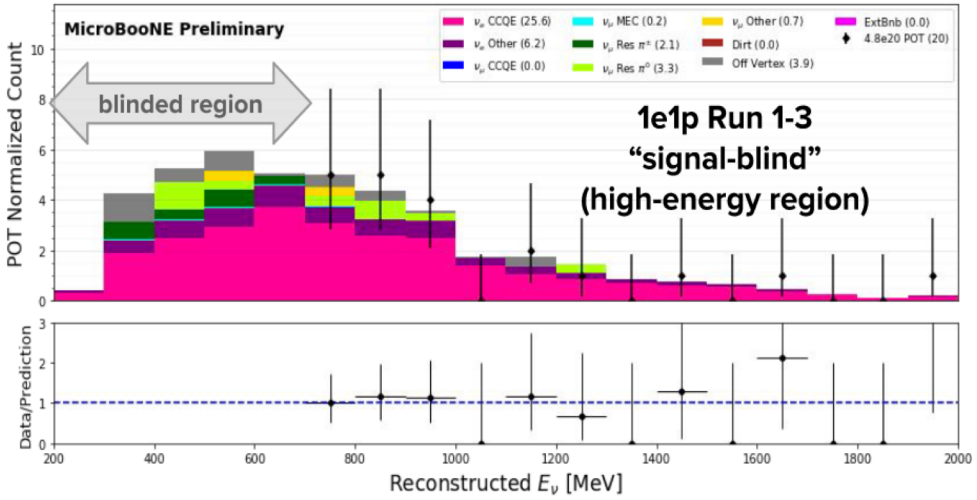
Multiple eLEE searches at MicroBooNE

Various reconstruction methods looking for different final states

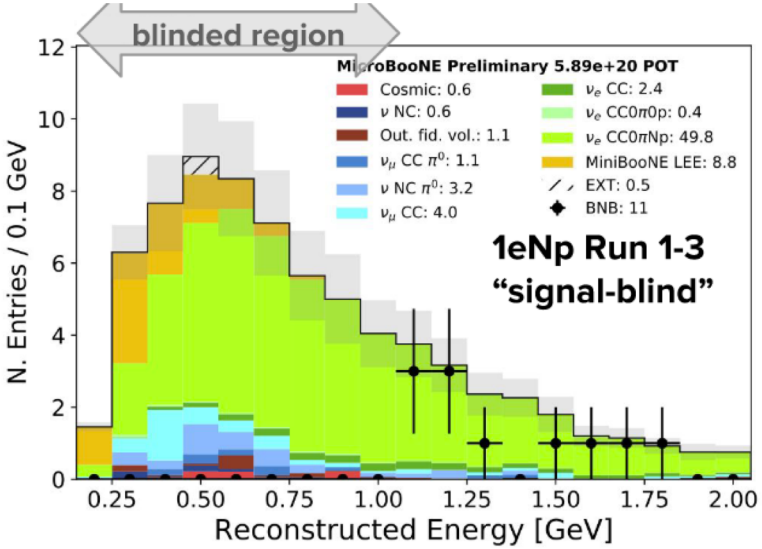
- Deep-learning → $1e1p0\pi$
- Pandora → $1e0p0\pi$ + $1eNp0\pi$
- Wire-Cell → $1e$ + anything (inclusive)

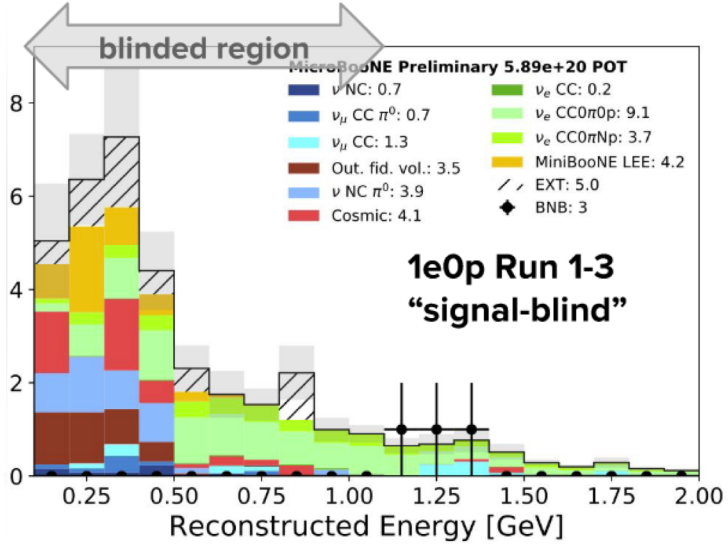


MICROBOONE-NOTE-1086-PUB, Deep-learning



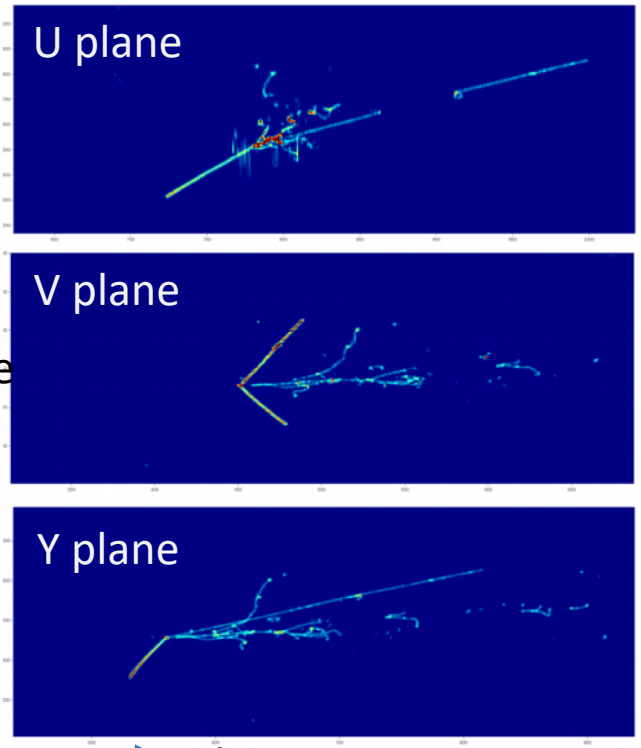
MICROBOONE-NOTE-1085-PUB, Pandora



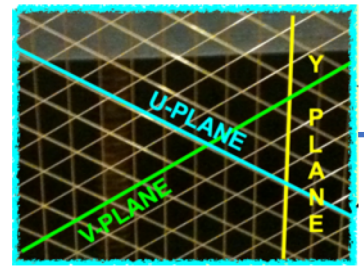


Wire-Cell Event Reconstruction

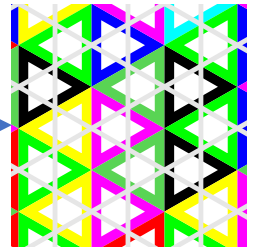
Three time-versus-wire views



Wires



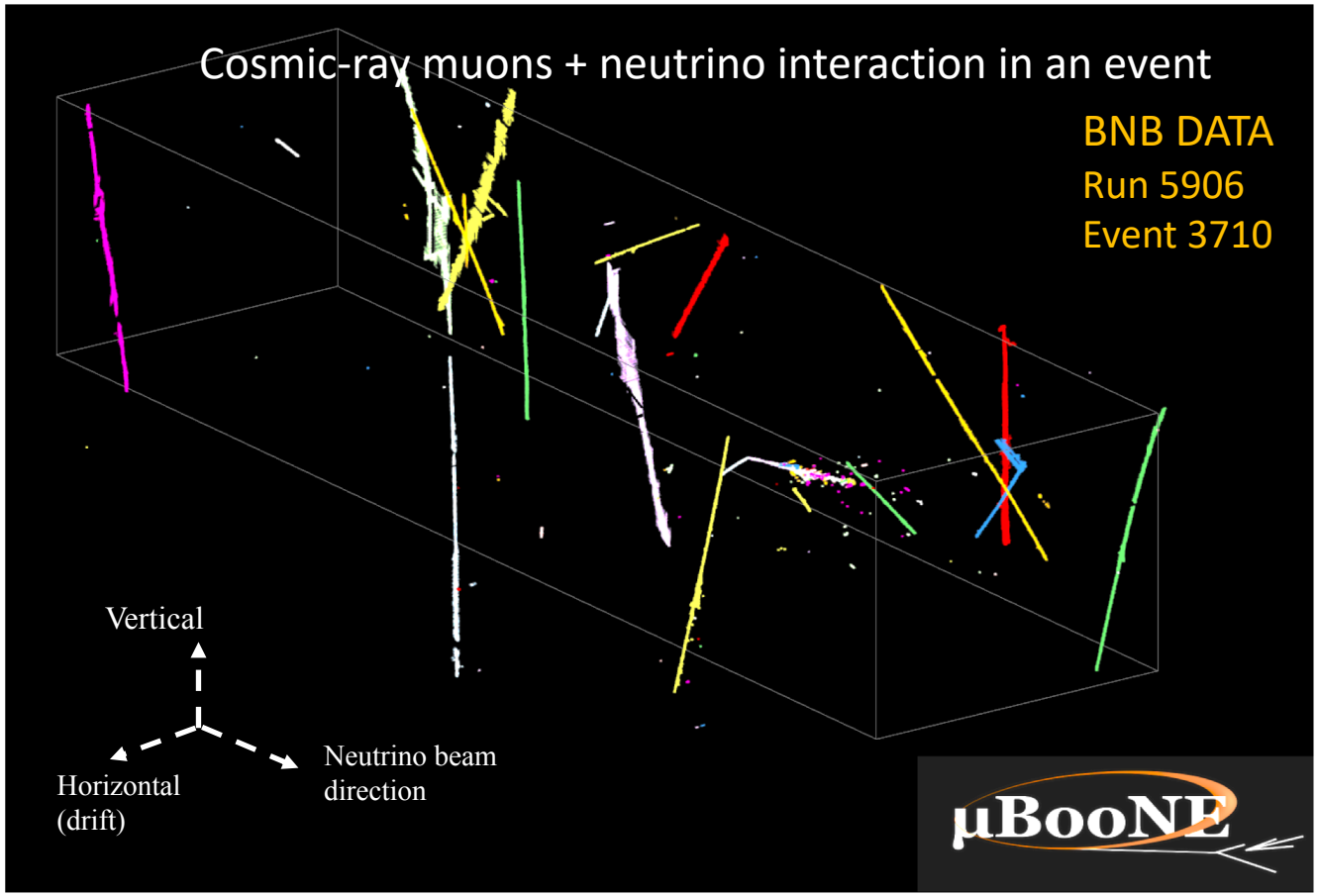
Cells



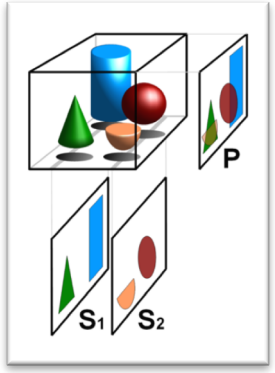
Grey lines: wires

JINST 13 P05032

3D imaging, clustering

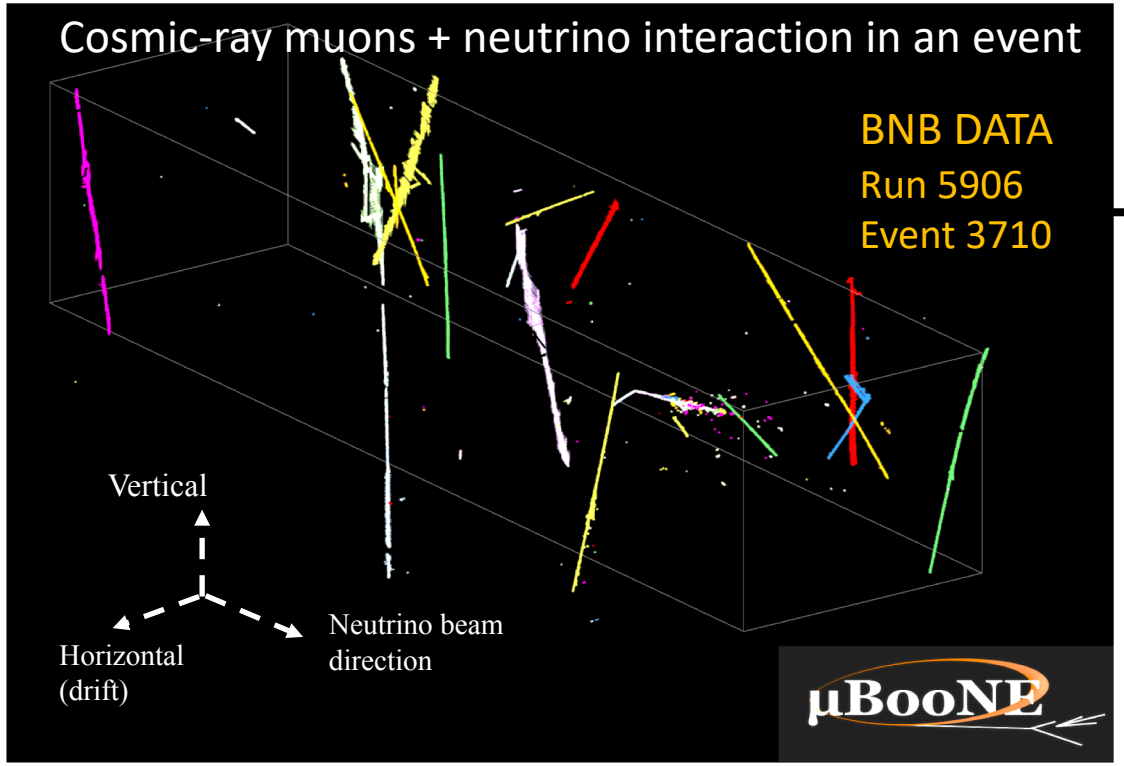


Tomography

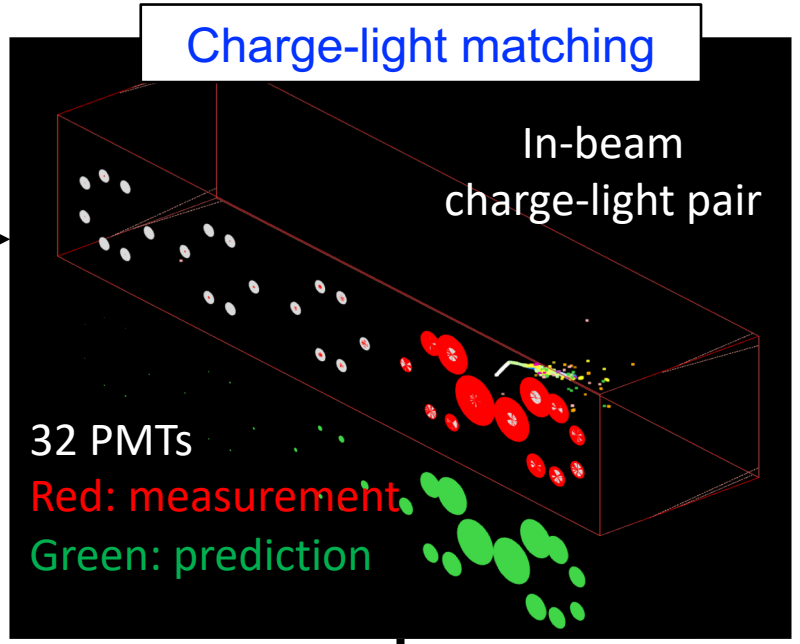


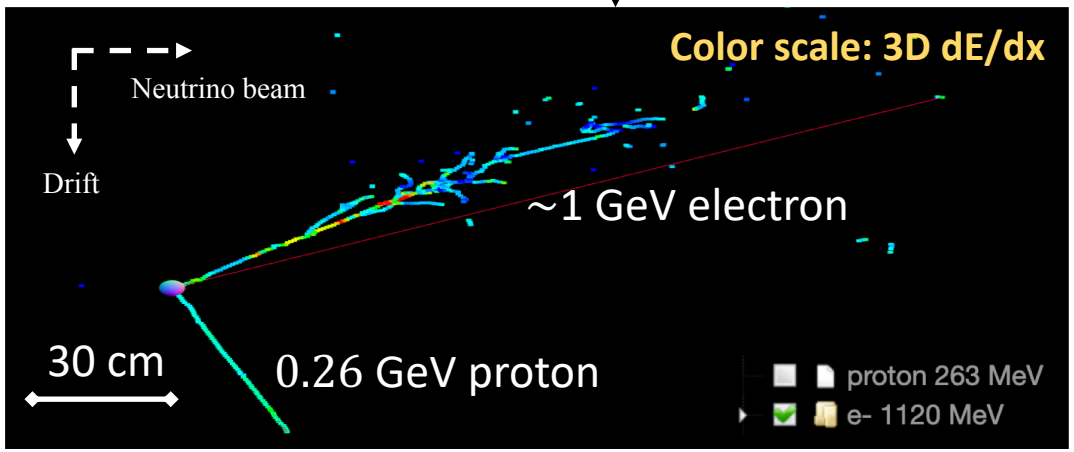
Wire-Cell Event Reconstruction

arXiv: 2011.01375



3D imaging, clustering





3D pattern recognition

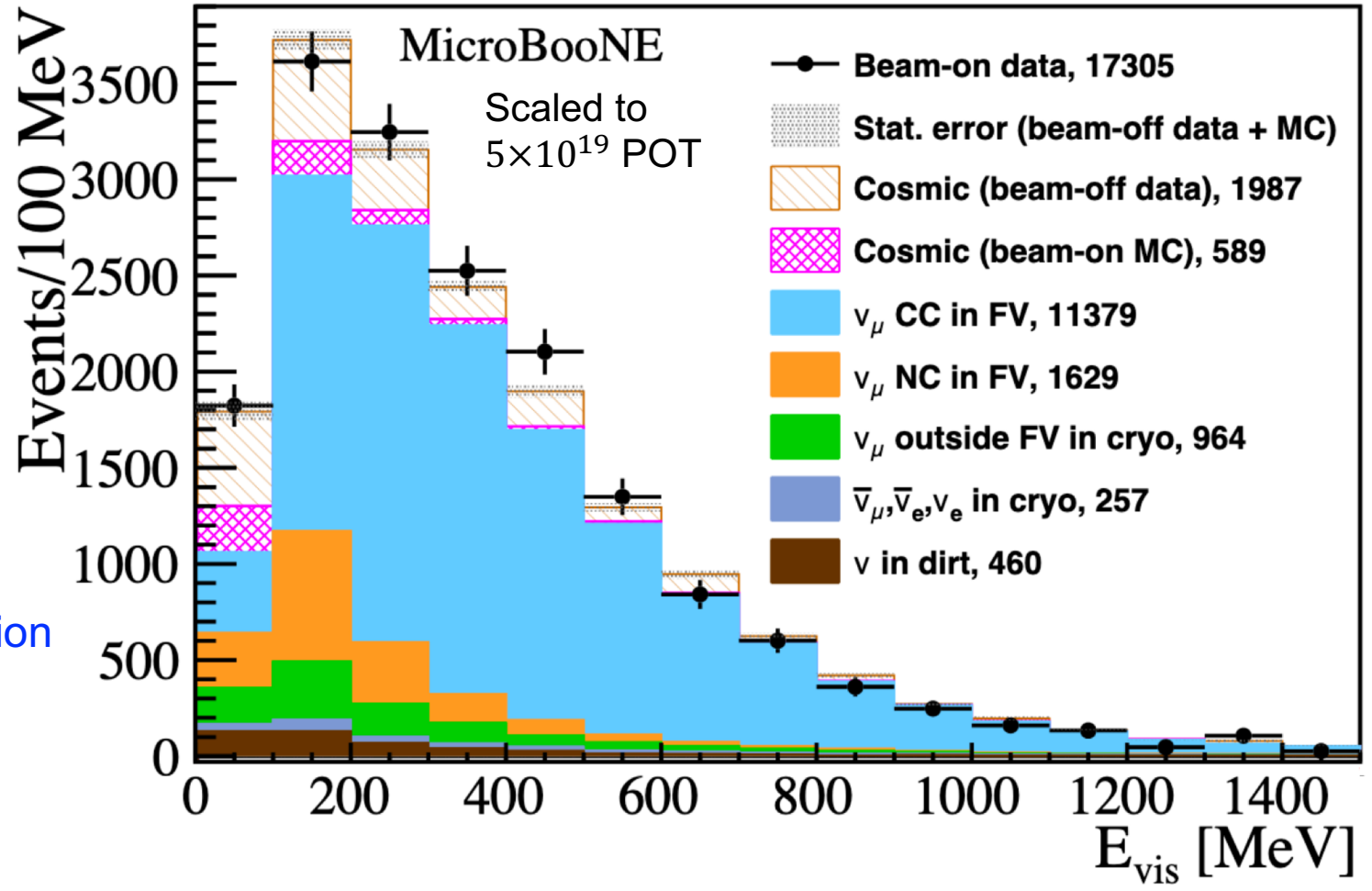
Generic ν selection (pre-selection)

arXiv: 2012.07928, arXiv: 2101.05076

Selection	ν_μ:cosmic-ray
Hardware trigger	1:20k
In-beam light signal	1:210
Generic ν selection	5.2:1

surface detector

99.98% cosmic-ray background rejected

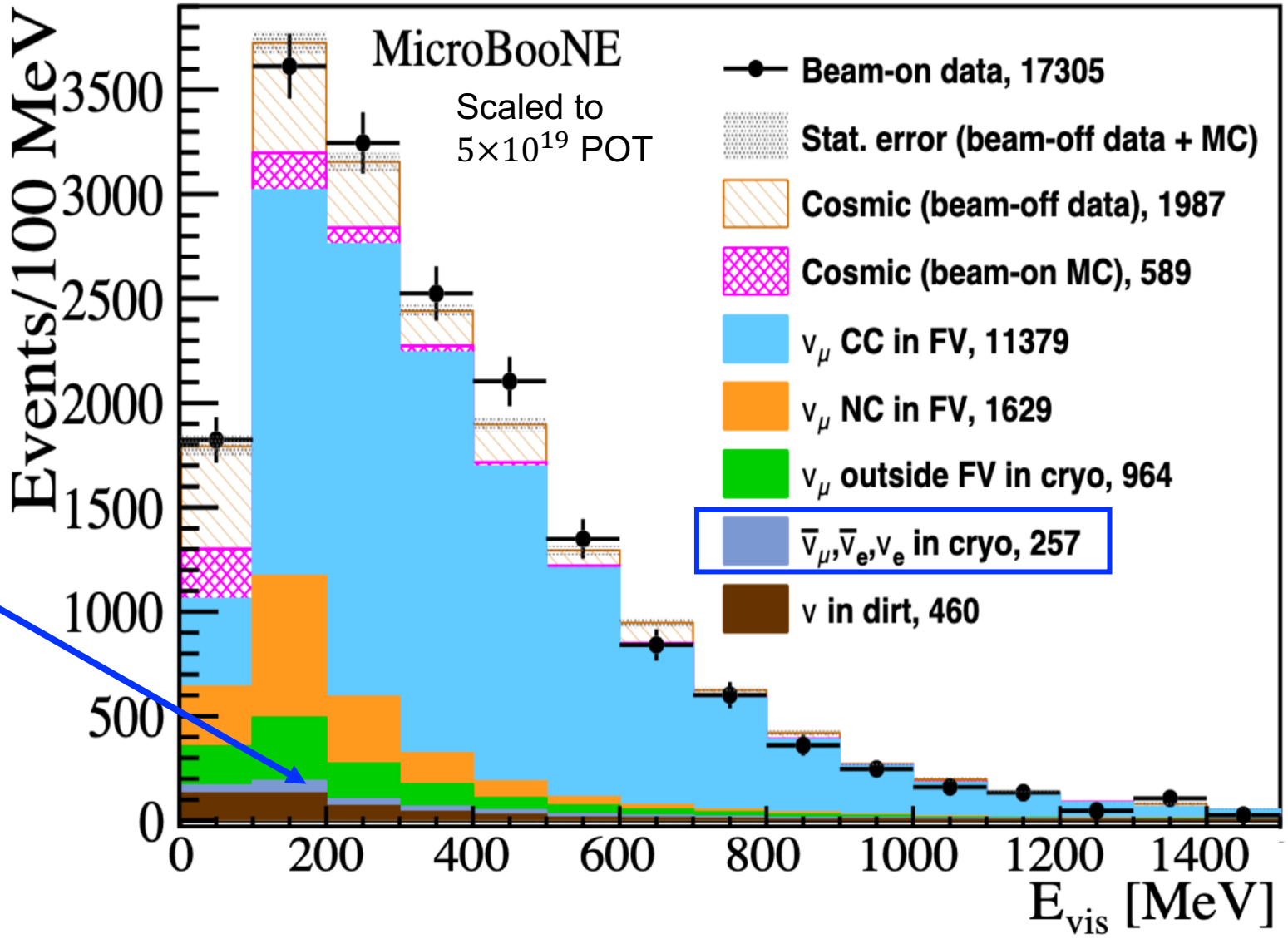


- 15% cosmic-ray background contamination
- ν_μ charged-current (CC) efficiency: **80%**
- ν_e CC efficiency: **90%**

Low energy ν_e CC selection is very tough

- ν_e CC rate **~0.5%** of all neutrino interactions
- High-energy to low-energy feed-down
- Neutral-current (NC) interactions with π^0 decay gammas

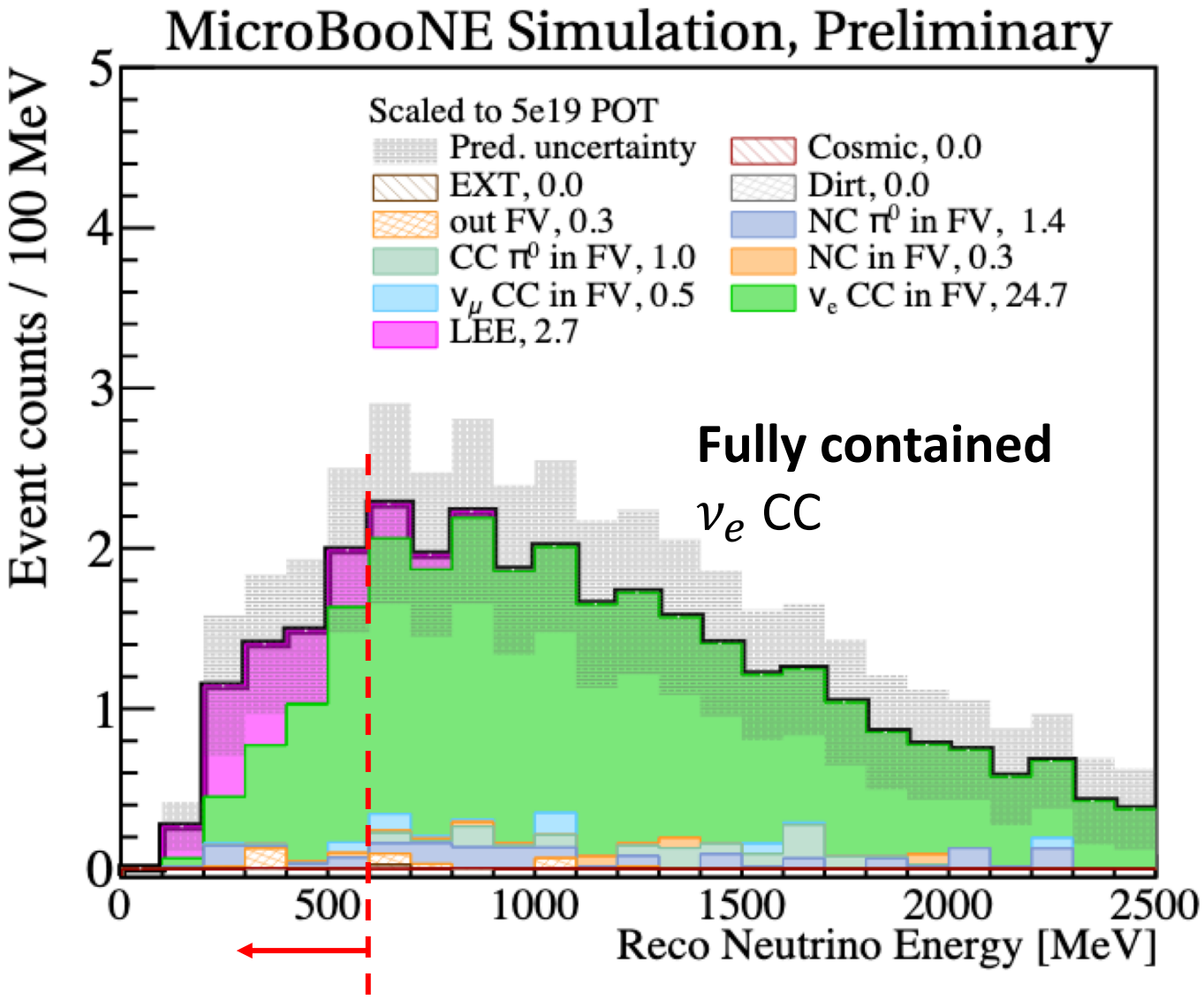
arXiv: 2012.07928, arXiv: 2101.05076



Inclusive ν_e CC selection

- ✓ Background categorization
- ✓ Utilization of advanced booster decision tree

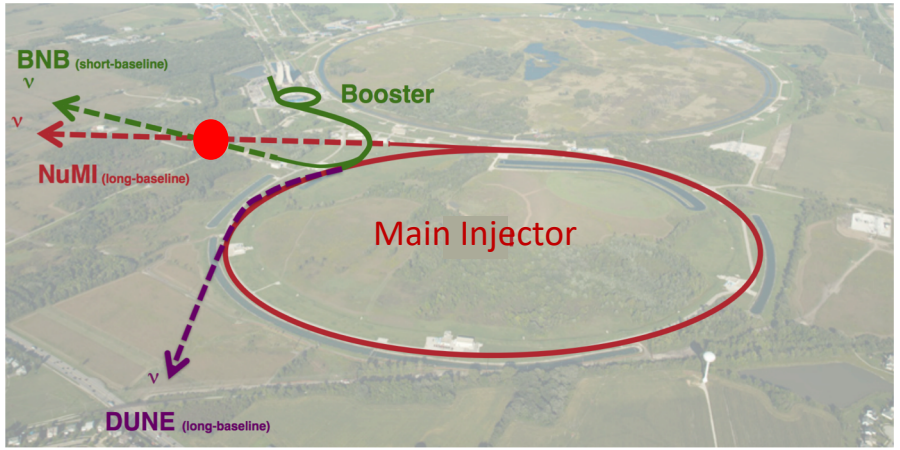
Relative to generic ν selection,
- Background rejection >99.9%
- 49% efficiency, and 84% purity



Enu < 600 MeV
LEE : intrinsic ν_eCC : others
= 0.71 : 1 : 0.15

Validation of ν_e CC selection using NuMI data

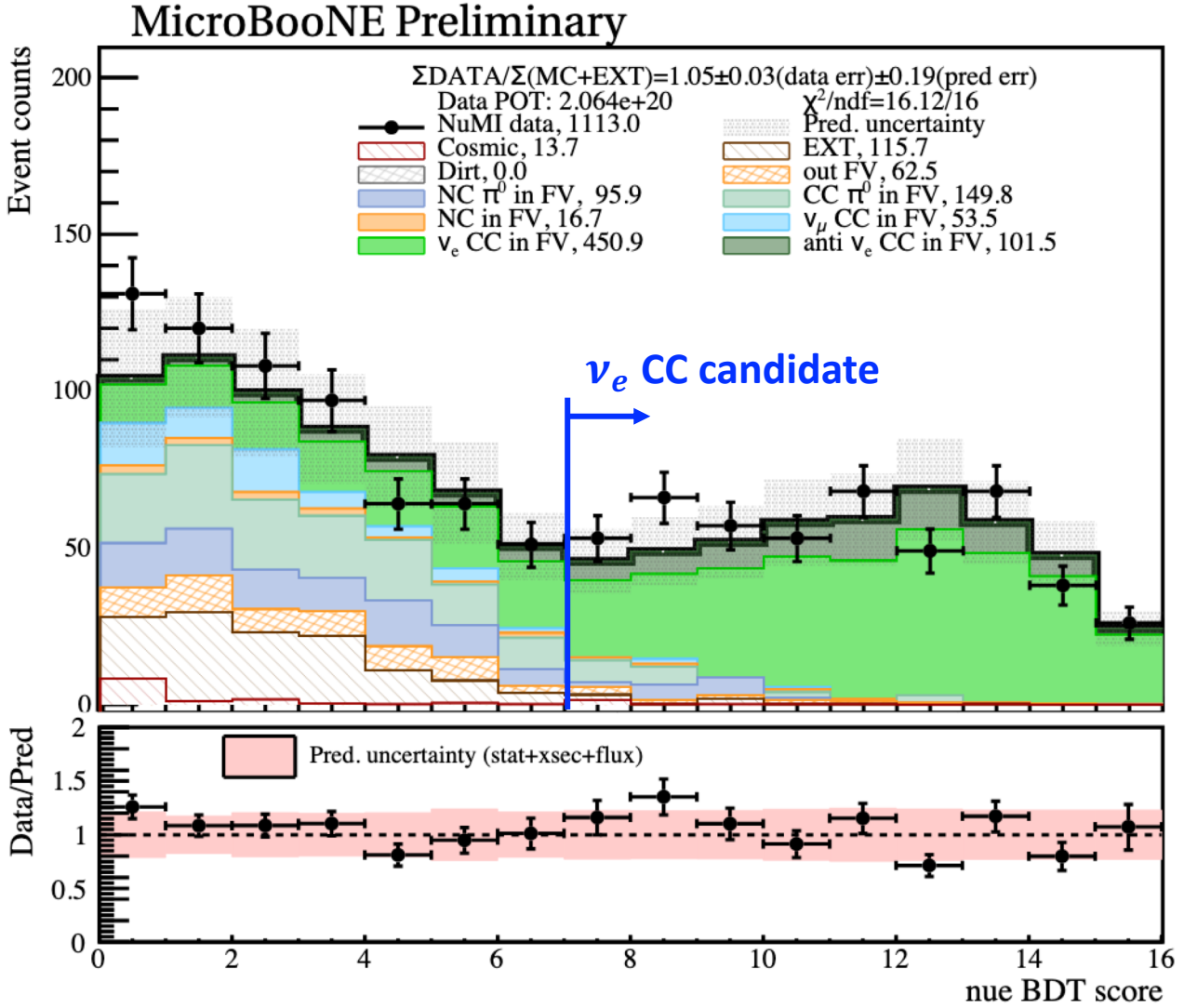
NuMI cross section measurement NeuTel talks:
M. Reggiani-Guzzo and K. Mistry



MicroBooNE ≈700m off-axis to NuMI target

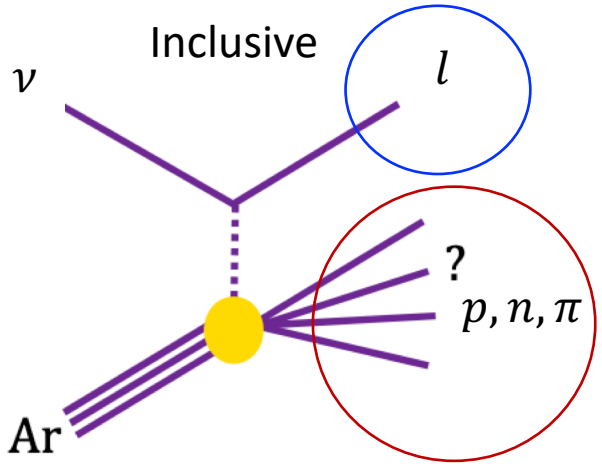
MicroBooNE Preliminary

	BNB	NuMI
ν_e CC abs. efficiency	42%	37%
Purity	84%	91%



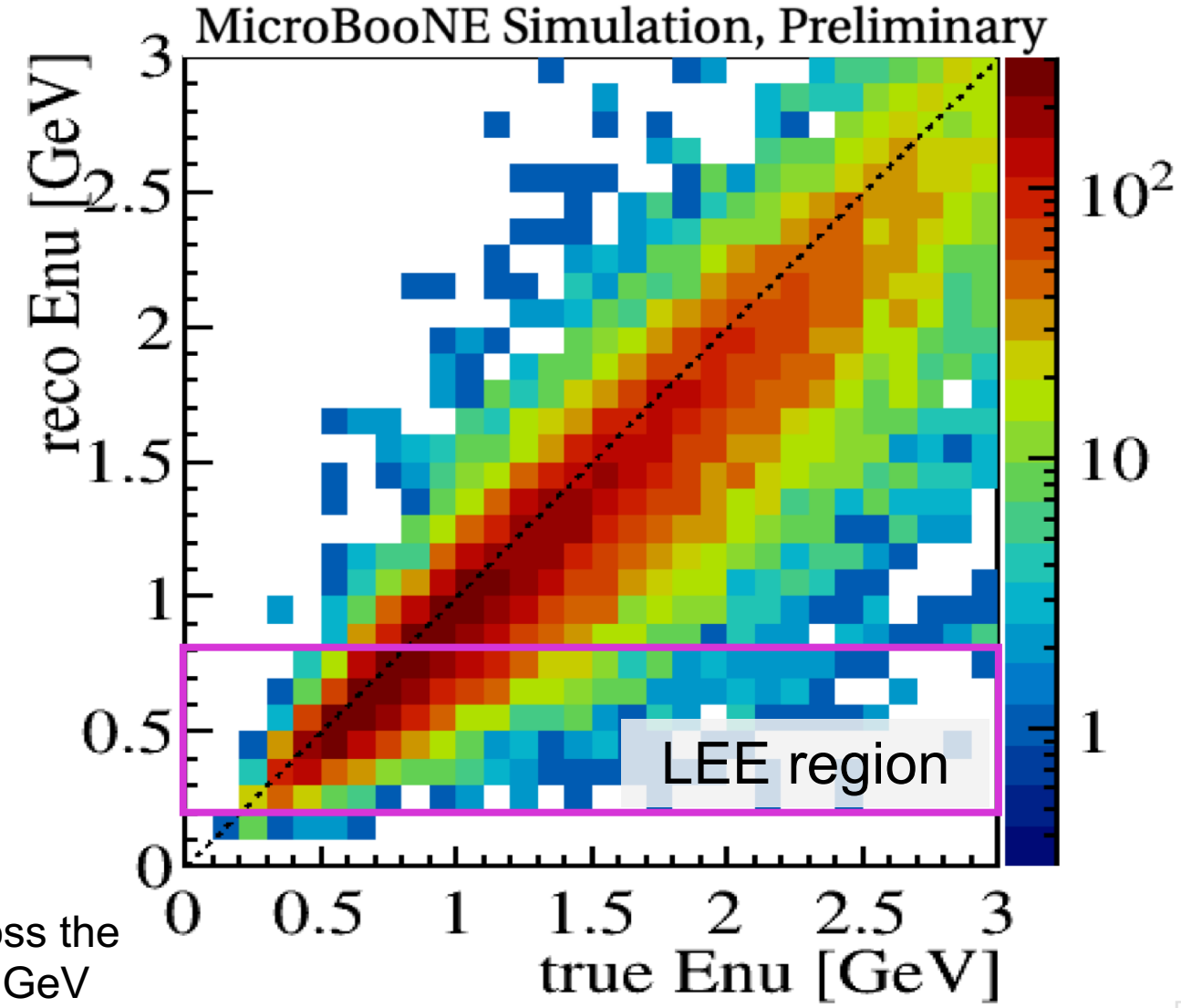
Good agreement between data and Monte-Carlo

Validation of neutrino energy reconstruction



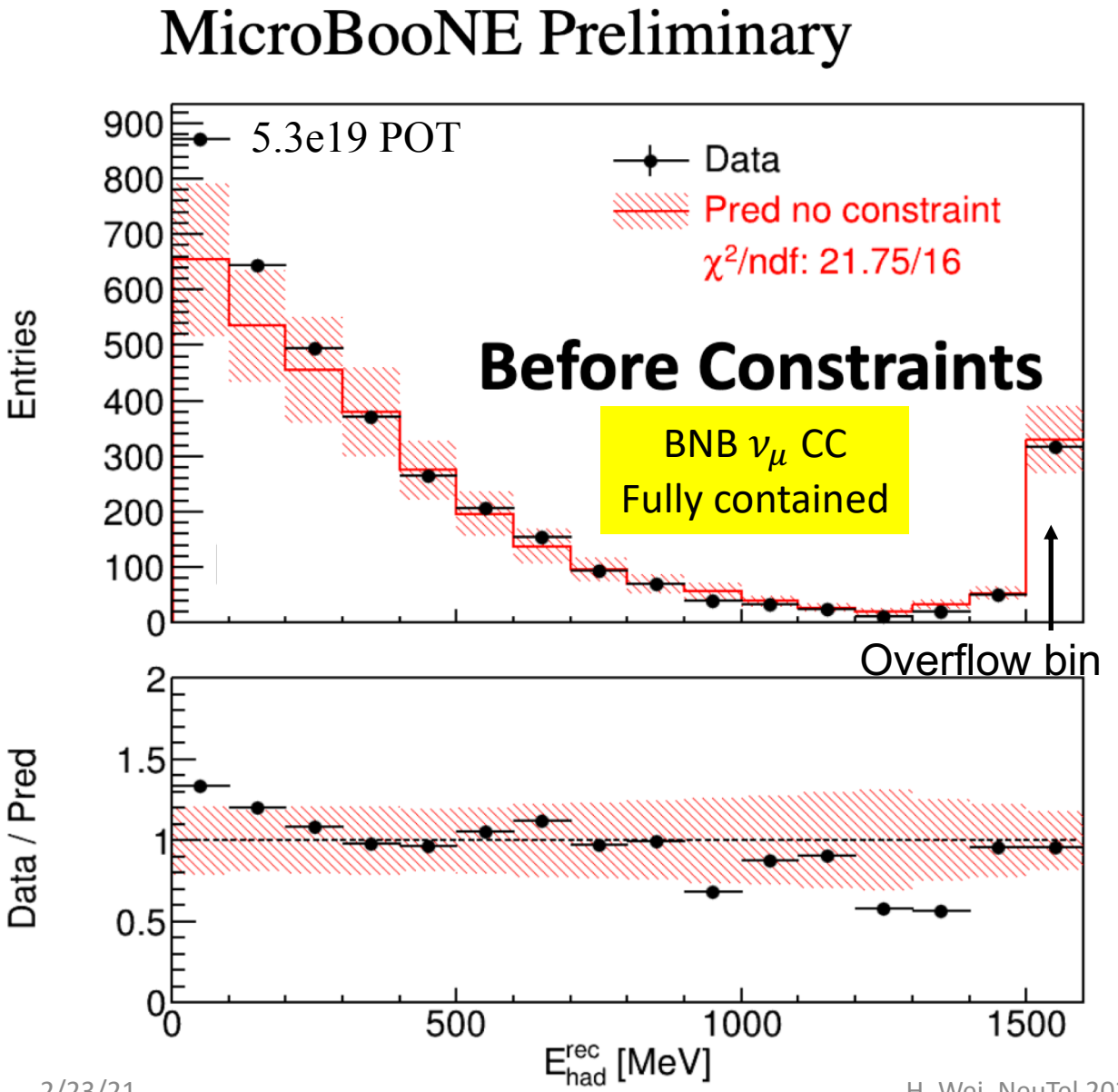
$$E_{\nu}^{rec} = E_{\text{lepton}}^{reco} + E_{hadron}^{reco}$$

- Muon and EM shower energy reconstruction have been validated using data (see backup slides)
- Data vs Monte-Carlo for E_{hadron}^{reco}, missing energy beyond systematics?



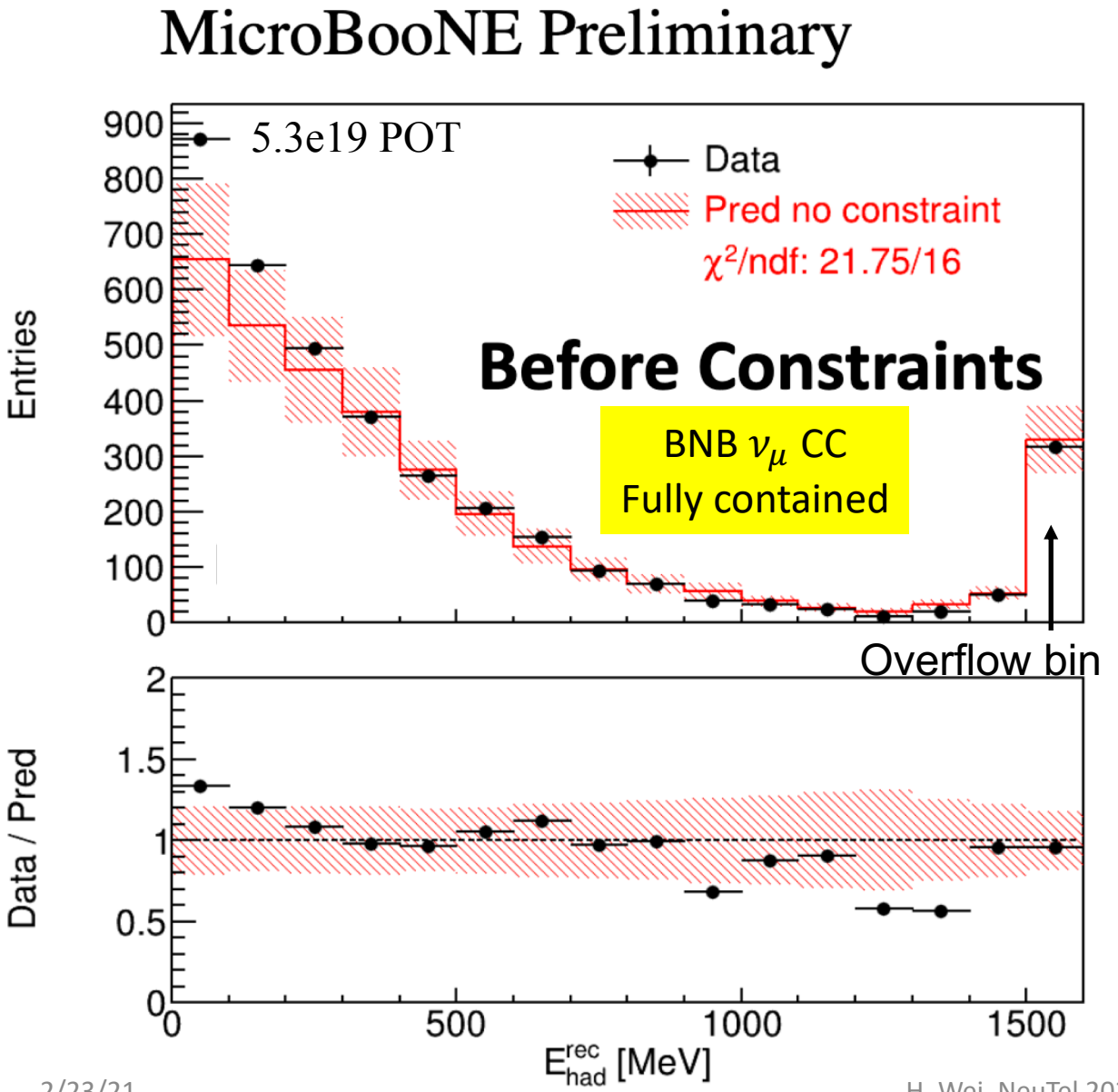
Resolution ~15% across the energy region 0.2-2.5 GeV

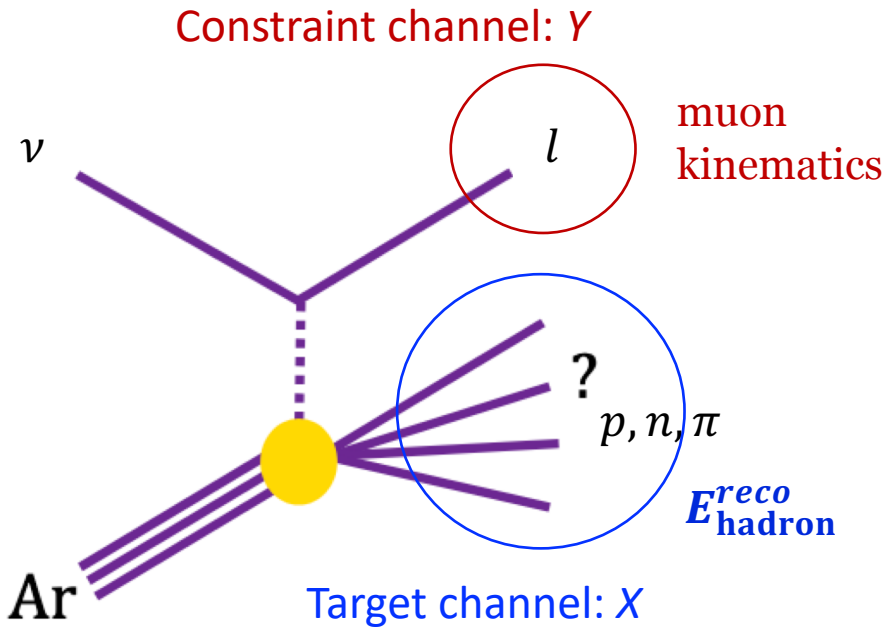
Validation of hadronic energy reconstruction



Missing energy vs. other systematic effects, e.g. GENIE cross section, Geant4 pion/proton reinteraction, and flux (hadron production, horn focusing)?

Validation of hadronic energy reconstruction

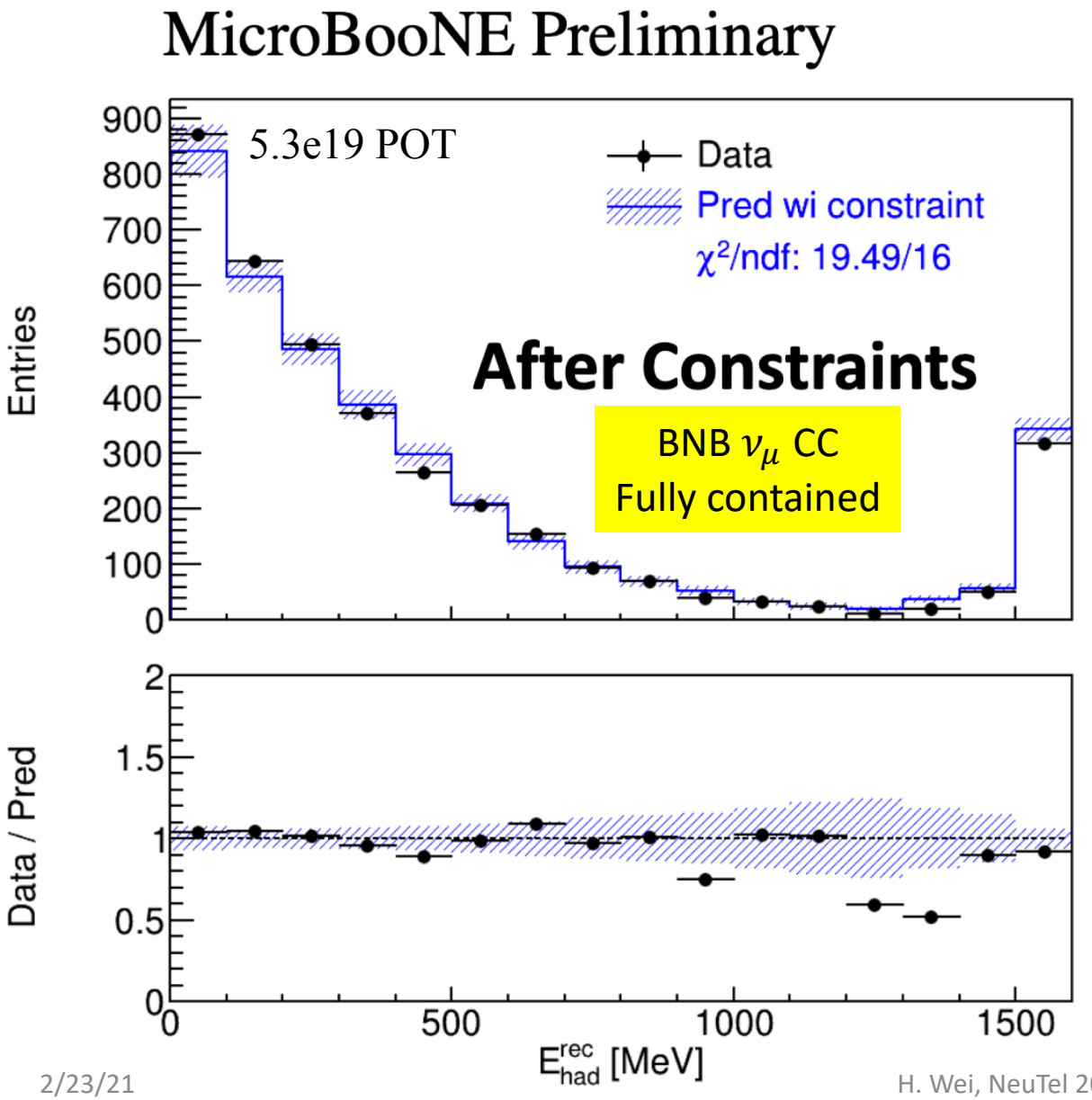




$$\mu^{X,constrained} = \mu^X + \Sigma^{XY} \cdot (\Sigma^{YY})^{-1} \cdot (n^Y - \mu^Y),$$
$$\Sigma^{XX,constrained} = \Sigma^{XX} - \Sigma^{XY} \cdot (\Sigma^{YY})^{-1} \cdot \Sigma^{YX}.$$

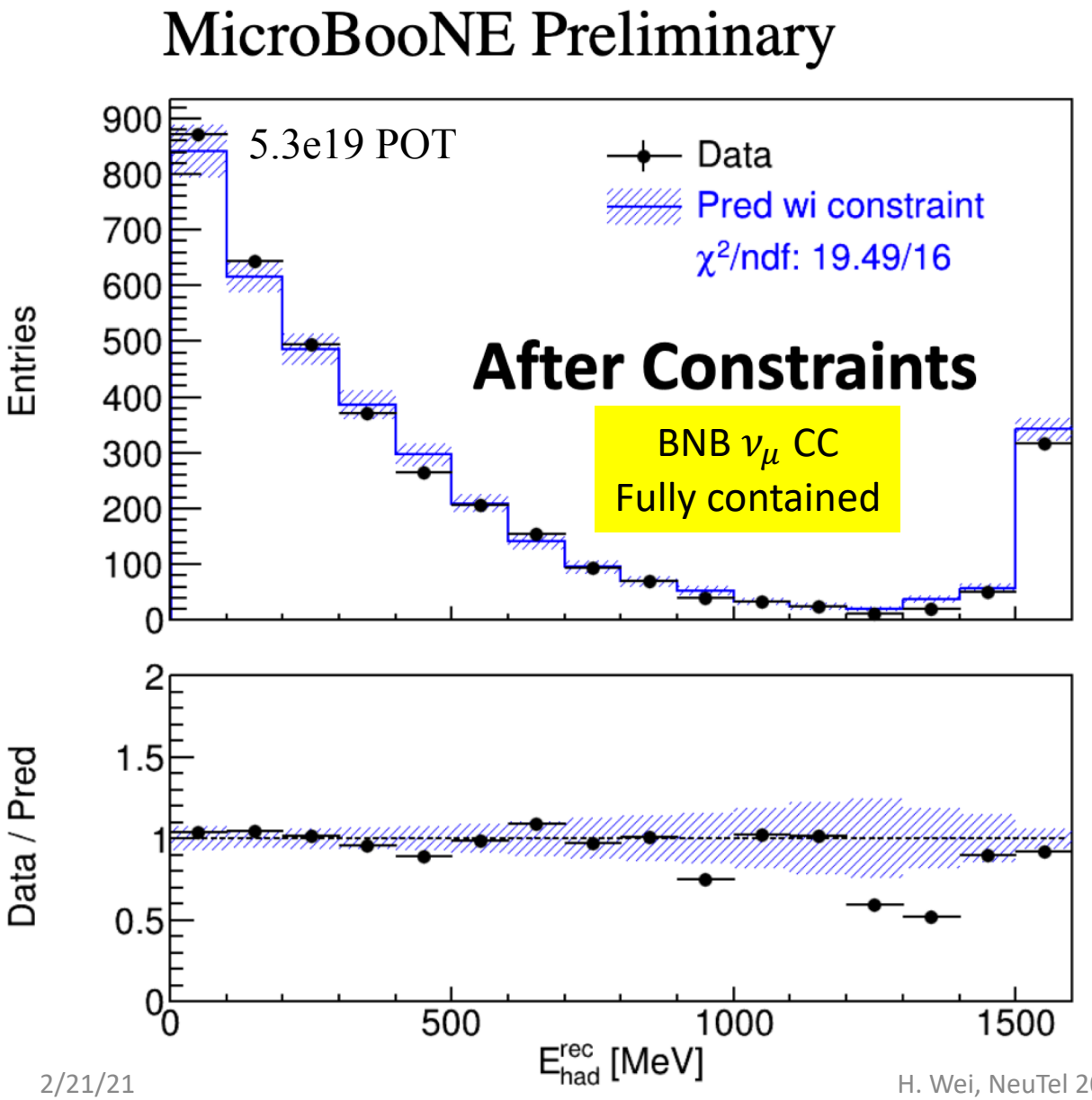
Data-driven correction on Monte-Carlo.

Validation of hadronic energy reconstruction



- Good agreement between data and MC within the residual systematic uncertainties after ***constraint*** from muon kinematics (E_μ and $cos\theta$)

Validation of hadronic energy reconstruction

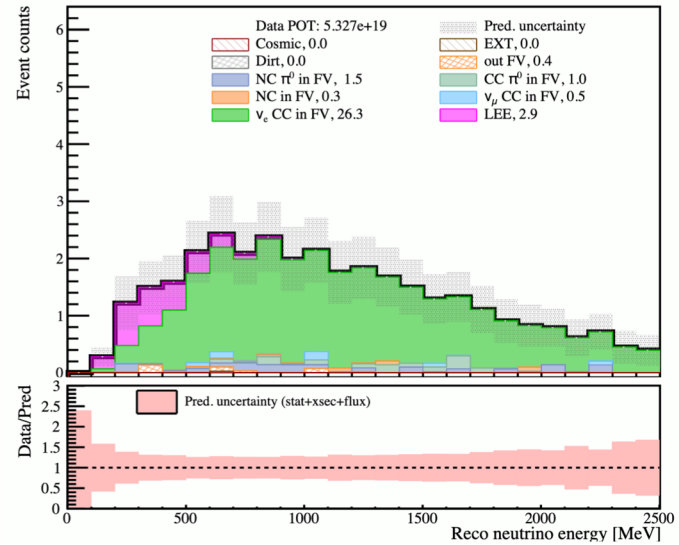


- Good agreement between data and MC within the residual systematic uncertainties after ***constraint*** from muon kinematics (E_μ and $cos\theta$)
- No missing energy beyond the Monte-Carlo systematics
- The current MicroBooNE Monte-Carlo prediction and its uncertainty be able to describe the discrepancy (before constraint)

MicroBooNE Preliminary

Search for eLEE

ν_e CC contained



Reco neutrino energy

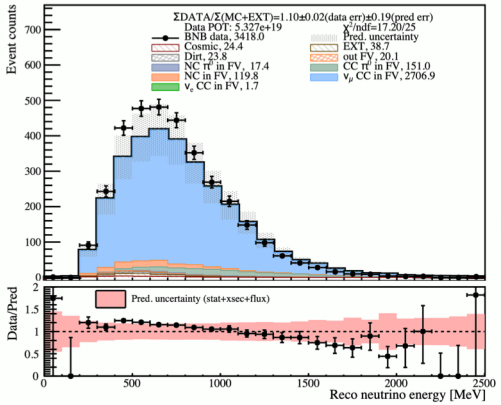
Signal Constraints

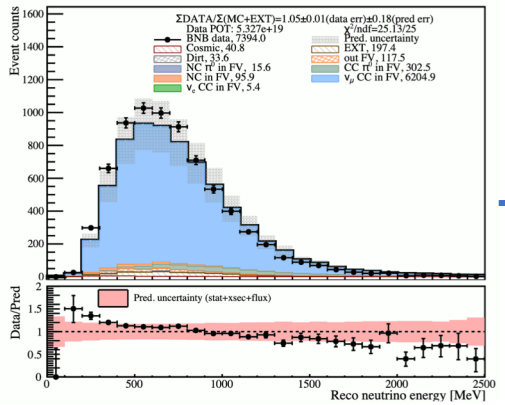
ν_μCC, fully contained

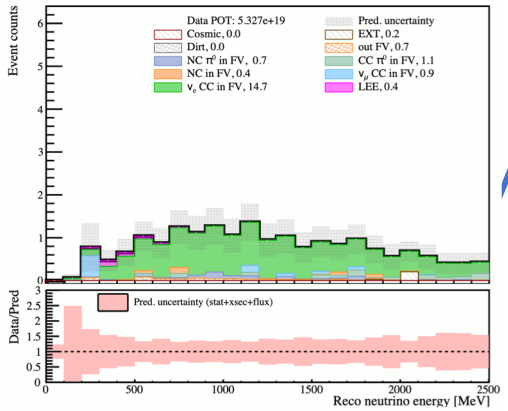
W. Gu's talk

ν_μCC, partially contained

ν_eCC partially, contained





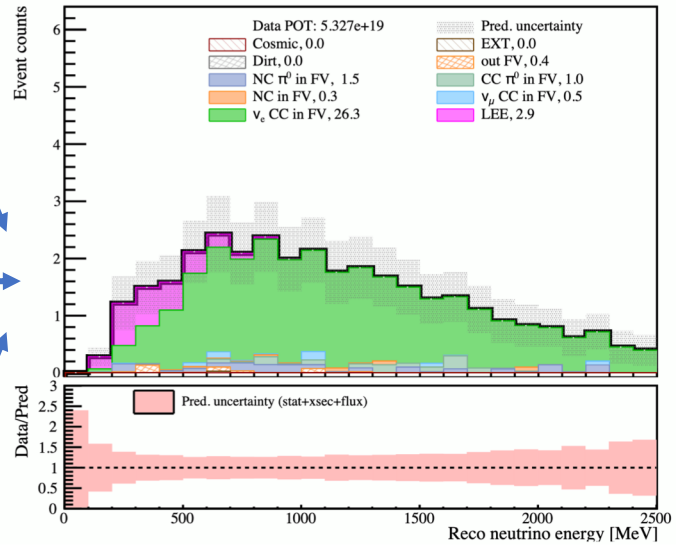


Reco neutrino energy

MicroBooNE Preliminary

Search for eLEE

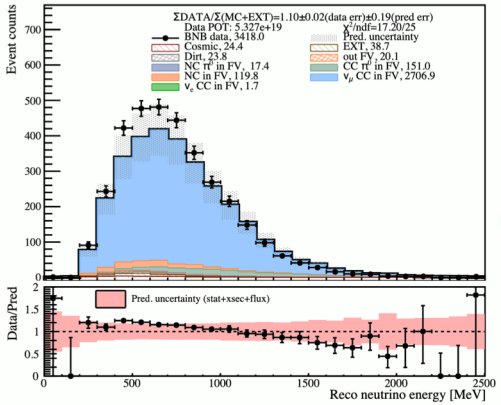
ν_e CC contained



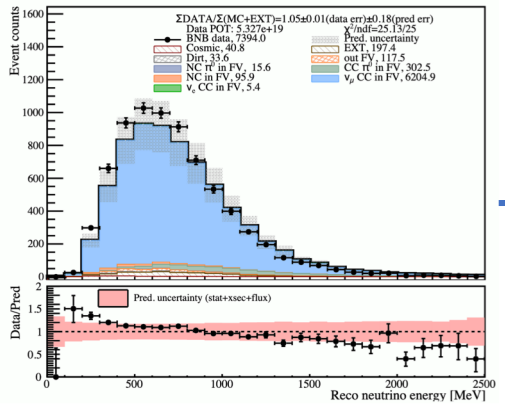
Reco neutrino energy

Signal Constraints

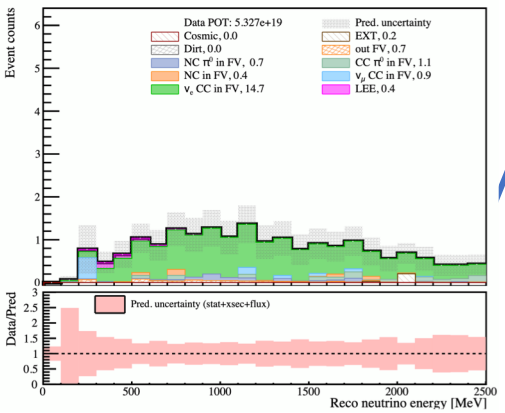
ν_μCC, fully contained



ν_μCC, partially contained



ν_eCC partially, contained

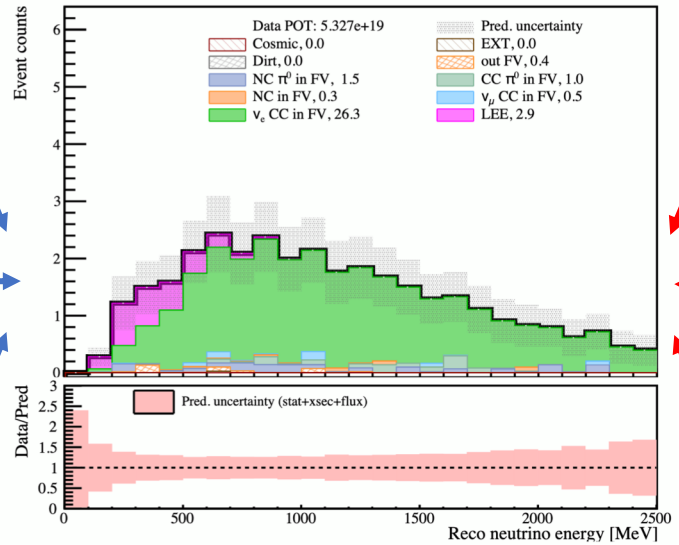


Reco neutrino energy

MicroBooNE Preliminary

Search for eLEE

ν_e CC contained

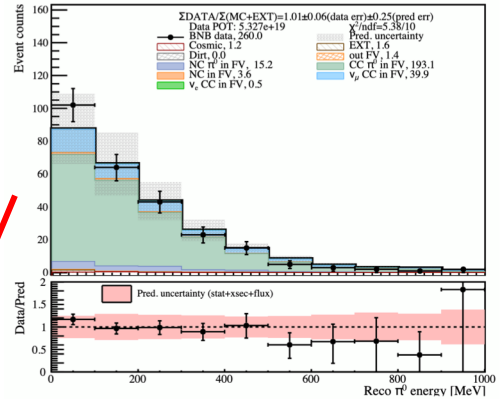


Reco neutrino energy

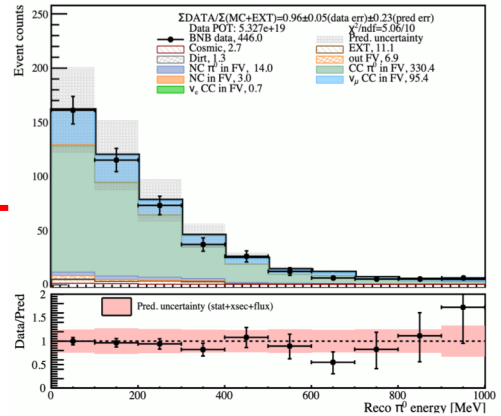
- Perform goodness-of-fit tests on our MC prediction
- Increase the MC accuracy for eLEE search after constraints

Background Constraints

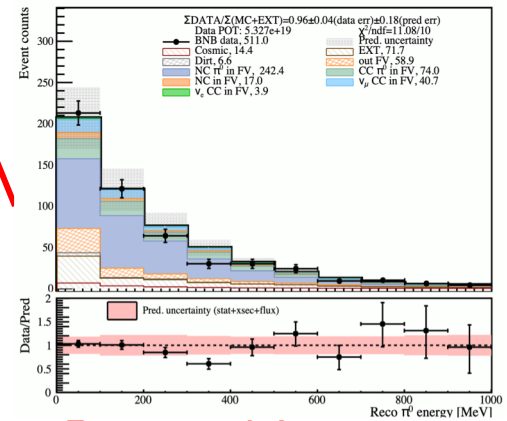
$CC\pi^0$, fully Contained



$CC\pi^0$ partially, contained



$NC\pi^0$

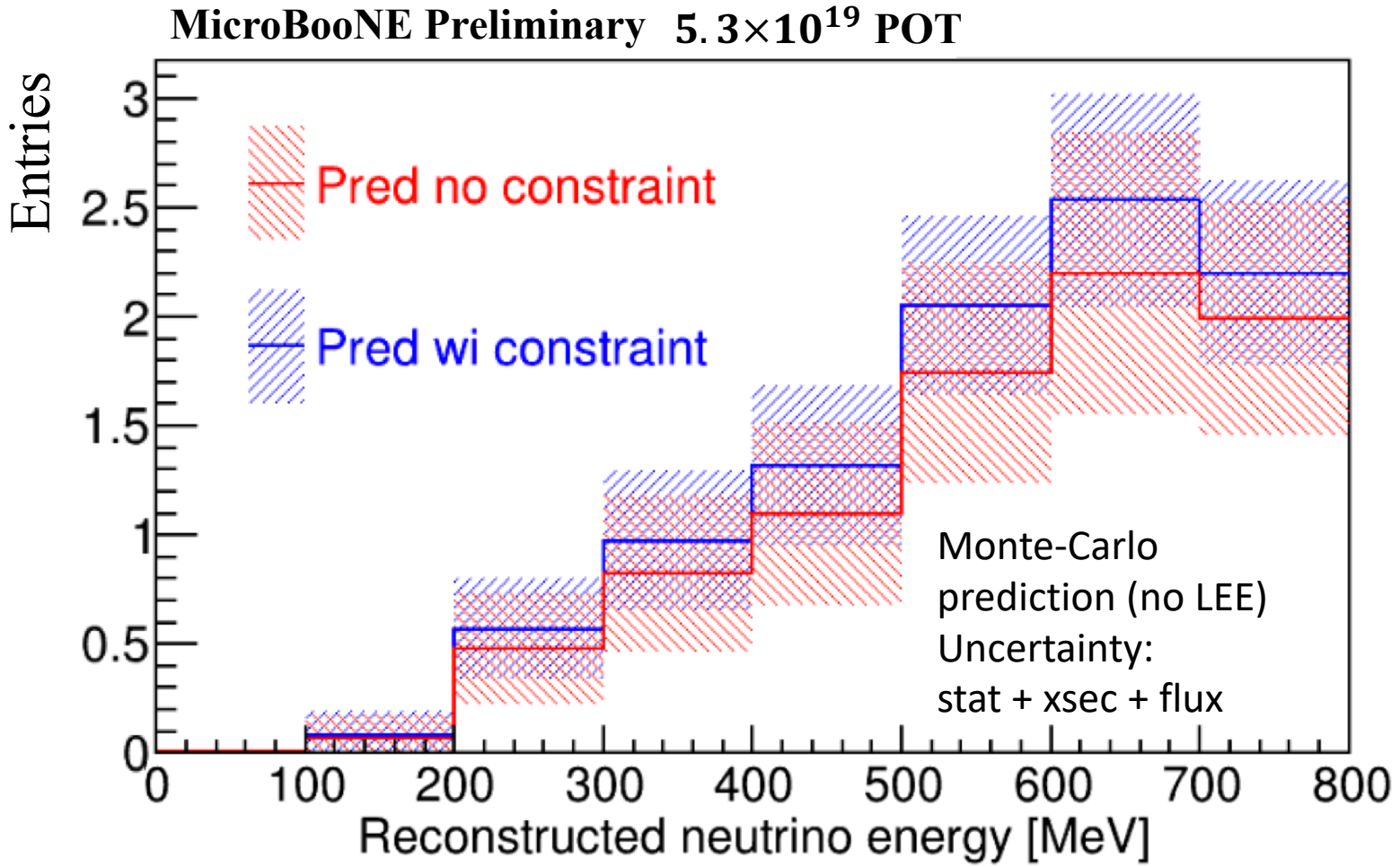


Reco neutrino energy

Search for eLEE

LEE-sensitive region
Fully contained ν_e CC events <800 MeV

Monte-Carlo (no LEE) prediction is increased by 10-20% with constraints, driven by ν_μ CC measurements.

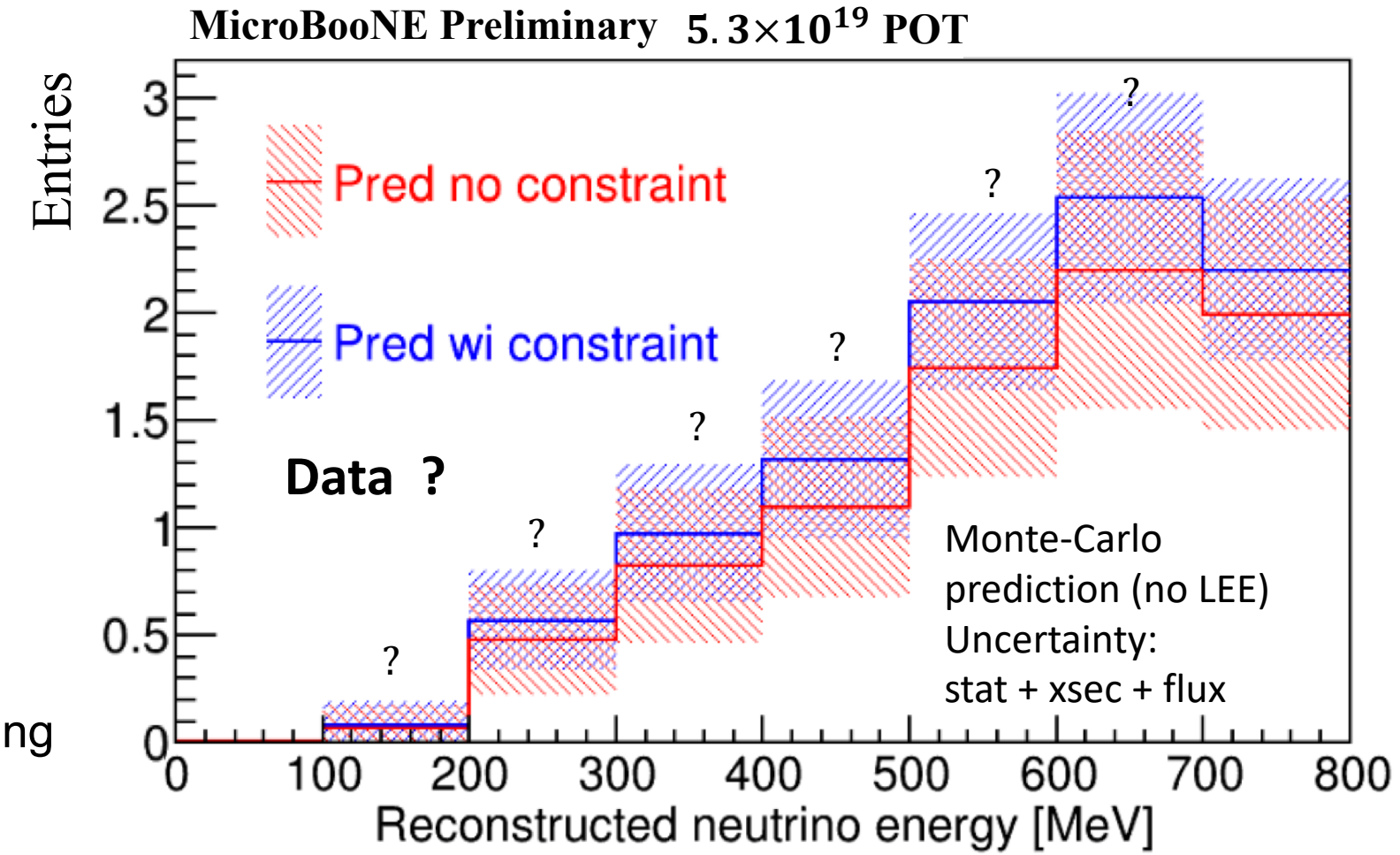


Search for eLEE

LEE-sensitive region
Fully contained ν_e CC events <800 MeV

Monte-Carlo (no LEE) prediction is increased by 10-20% with constraints, driven by ν_μ CC measurements.

Expecting ν_e CC results with 6.9×10^{20} POT data after box opening



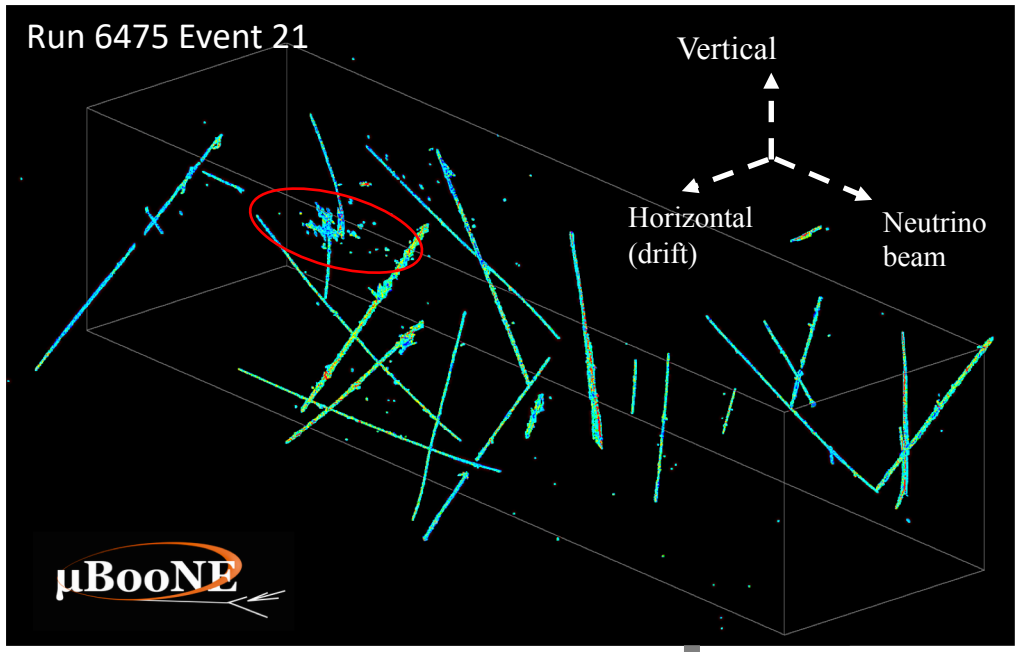
LEE : intrinsic ν_eCC : others = 0.71 : 1 : 0.15 (<600 MeV)

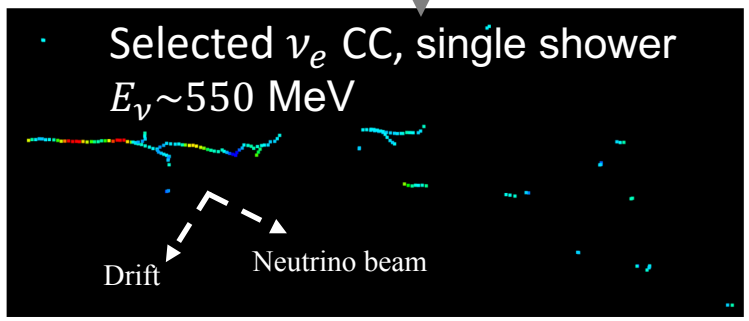
Summary

- The Wire-Cell end-to-end LArTPC reconstruction and neutrino selection chain has been established at MicroBooNE
- A high-performance inclusive ν_e CC selection has been achieved with **42%** efficiency and **84%** purity, validated on NuMI data.
- The strategy of Wire-Cell eLEE search has been finalized.
  - Complementary to 1e1p (Deep Learning) and 1e0p + 1eNp (Pandora) eLEE searches
- First LEE results from MicroBooNE using the first three years' data are imminent.
  - Results will be released in phases as we complete the various analyses
- Next-generation reconstruction tools and additional stats from the analysis of the full 13×10^{20} POT dataset will enable MicroBooNE to reach the ultimate sensitivity on the LEE search.

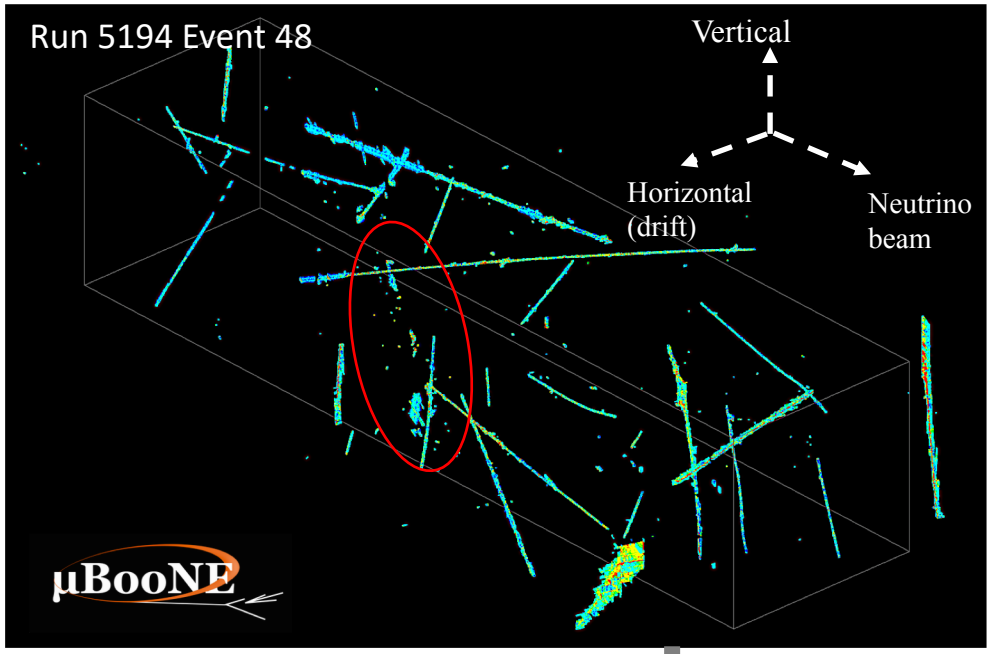
Backup slides

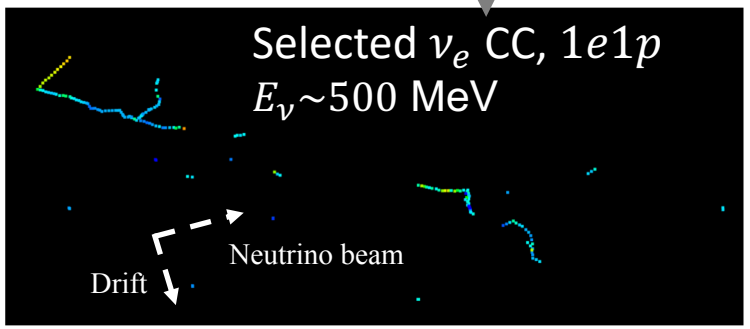
Low energy ν_e CC from NuMI data stream



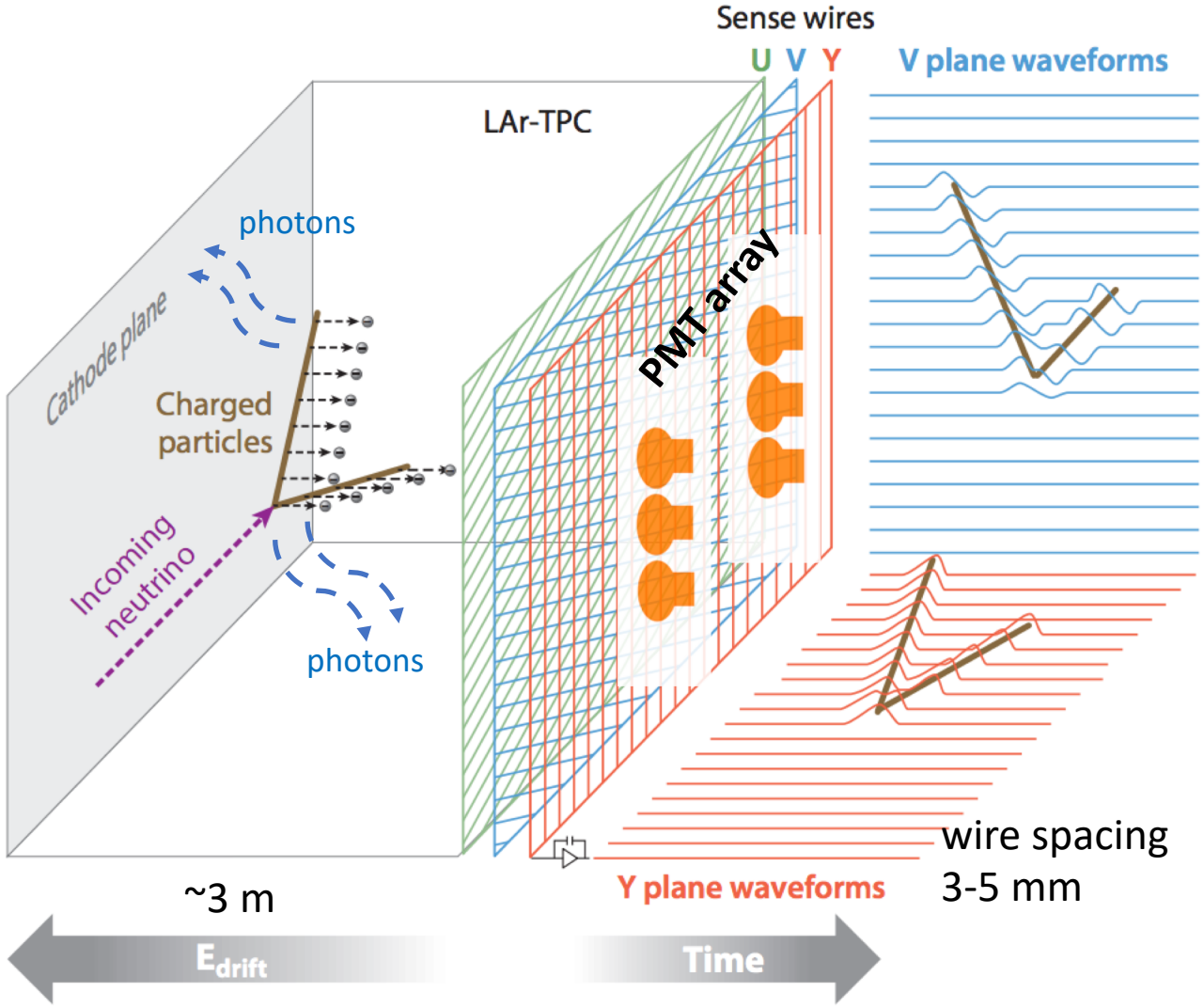


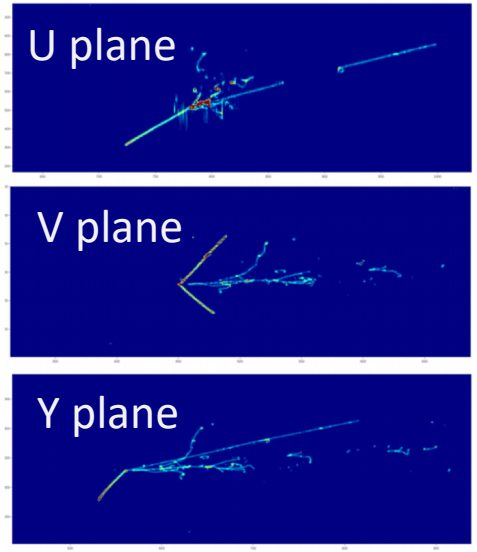
3D space point
per 6 mm

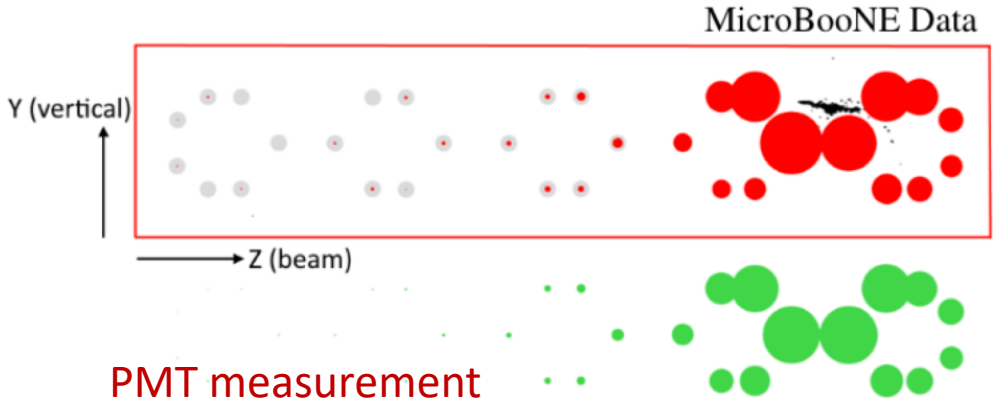




Single-Phase Liquid Argon TPC







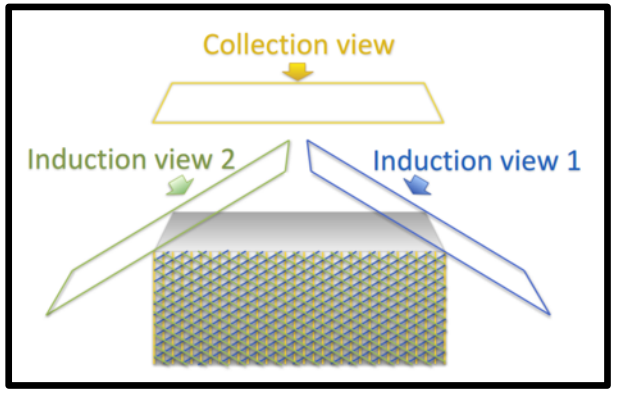
PMT measurement
Prediction from TPC measurement

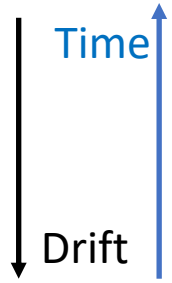
Event Reconstruction in LArTPC

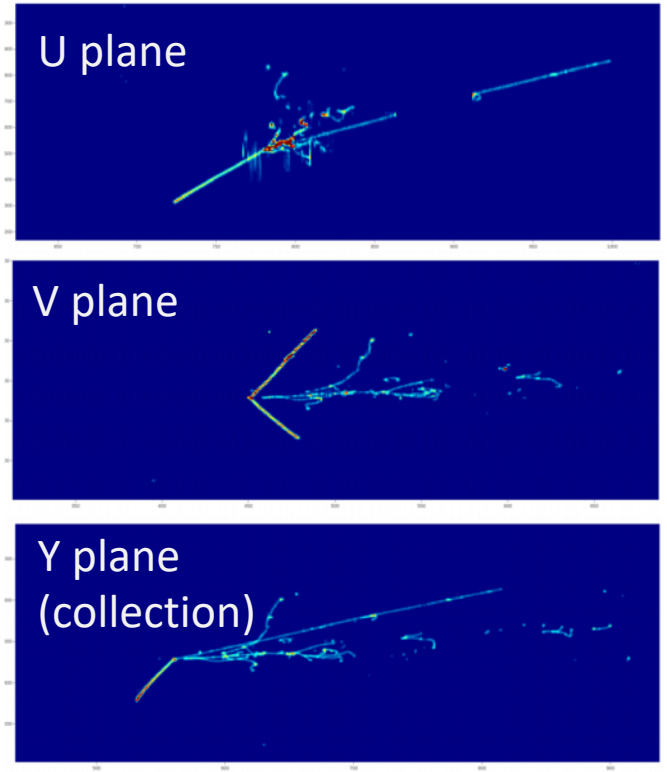
TPC: 2D image + 1D drift

LArTPC (typical single-phase**):**

- Integrated charge along the wire → THREE wire planes ($3\times n$) ≠ 2D pixel readout (n^2)
- Unknown vertex, wiggled tracks, delta-rays, EM showers, etc. in Lar
- Reconstruction is still an open question in many aspects

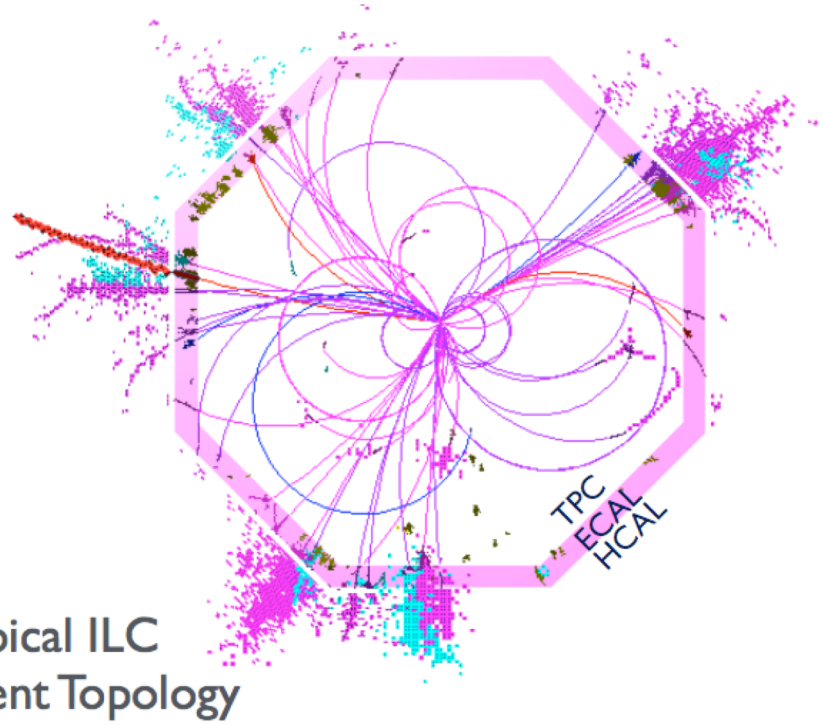






Wire no. (1D projection position)

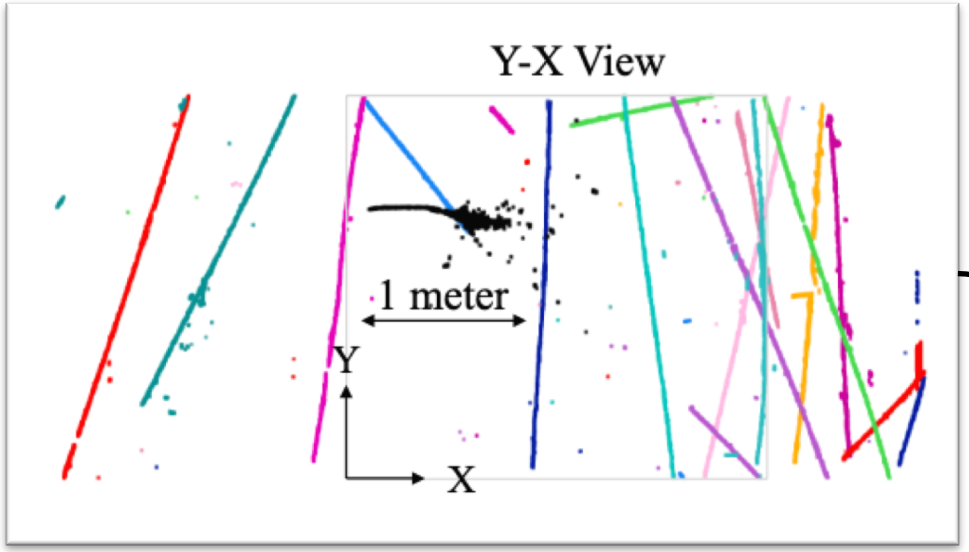
VS.



Wire-Cell Event Reconstruction

arXiv: 2011.01375

Many-to-many charge-light matching

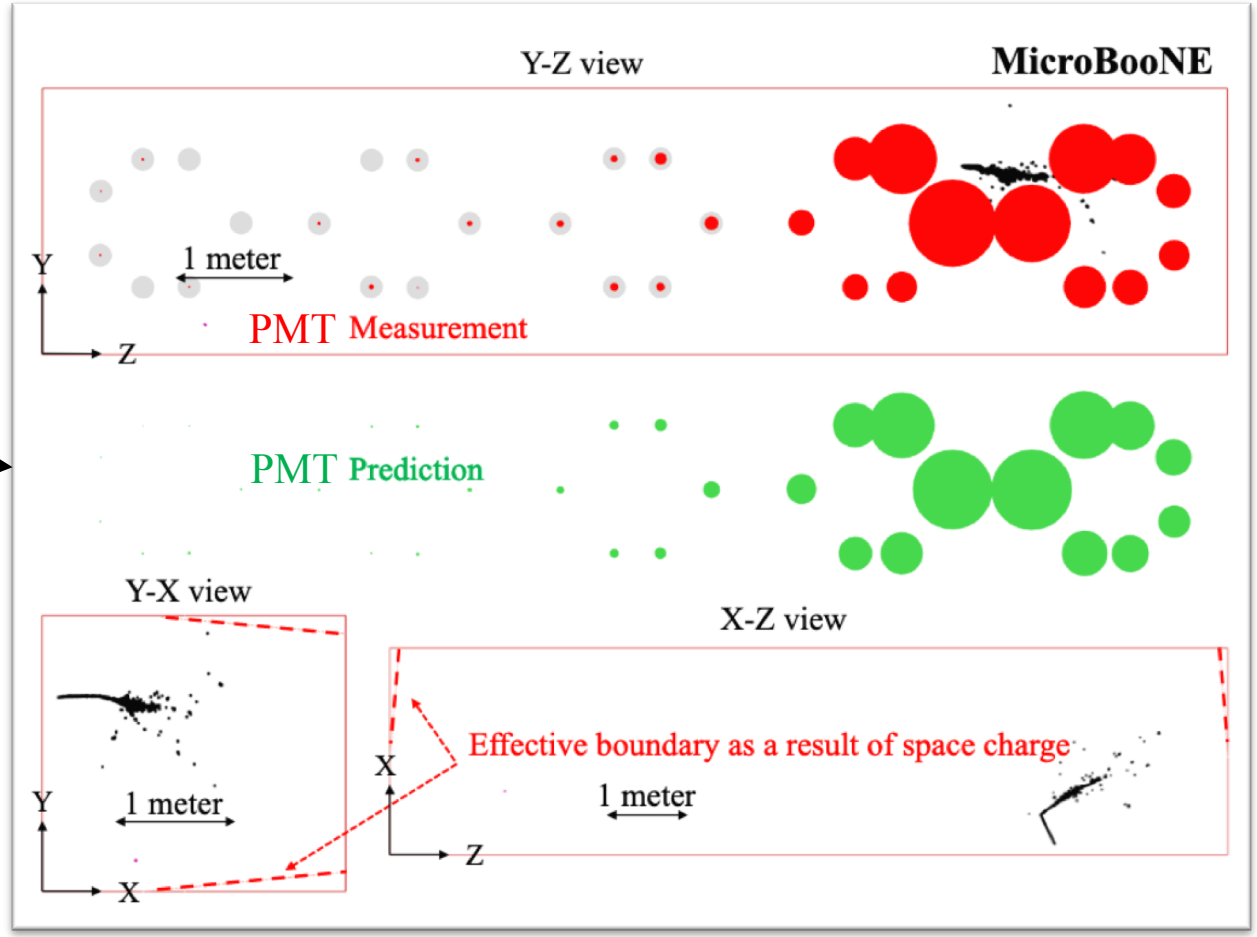


X: opposite drift direction from anode to cathode

Y: vertical up

Z: beam direction

TPC charges match to in-beam light signal

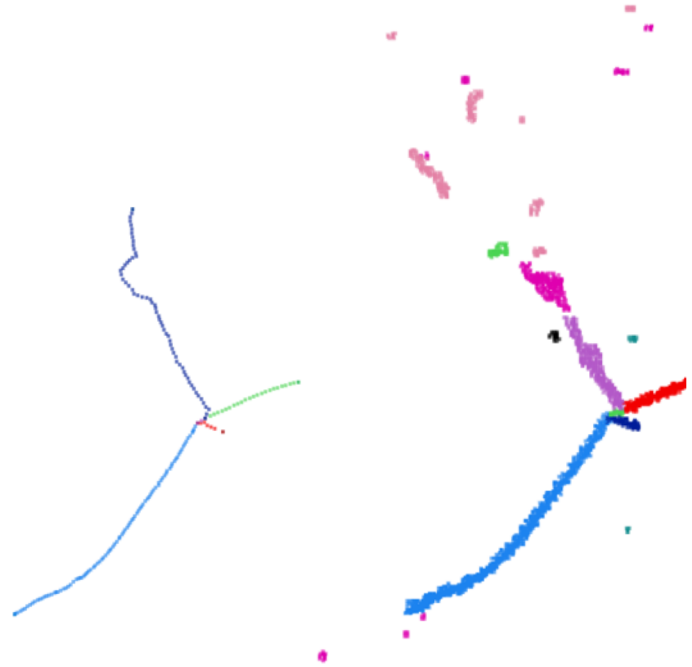


Wire-Cell Event Reconstruction

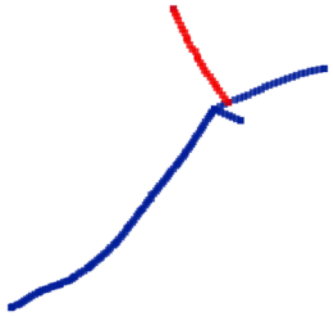
3D pattern recognition
(traditional + deep-learning)

3D image
(2D snapshot)

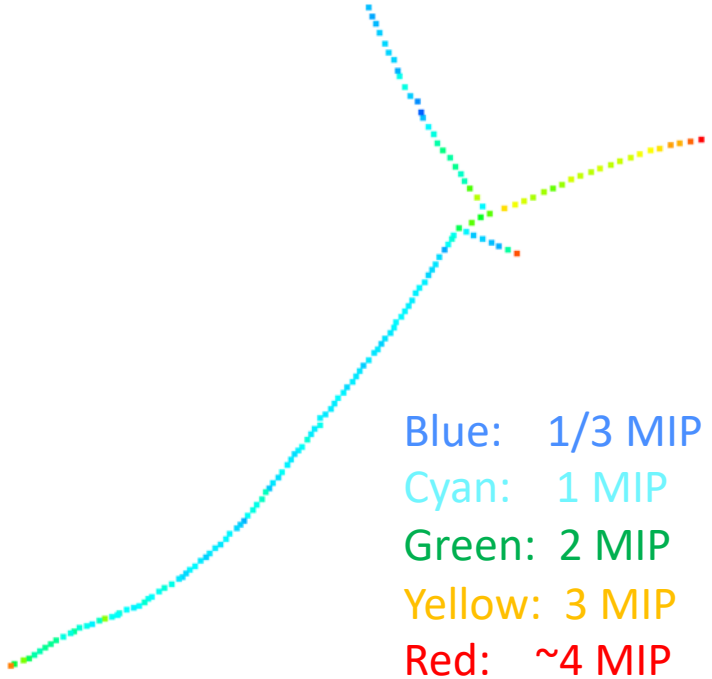
Trajectories and
particle-level clustering



Track/shower (stem)
identification

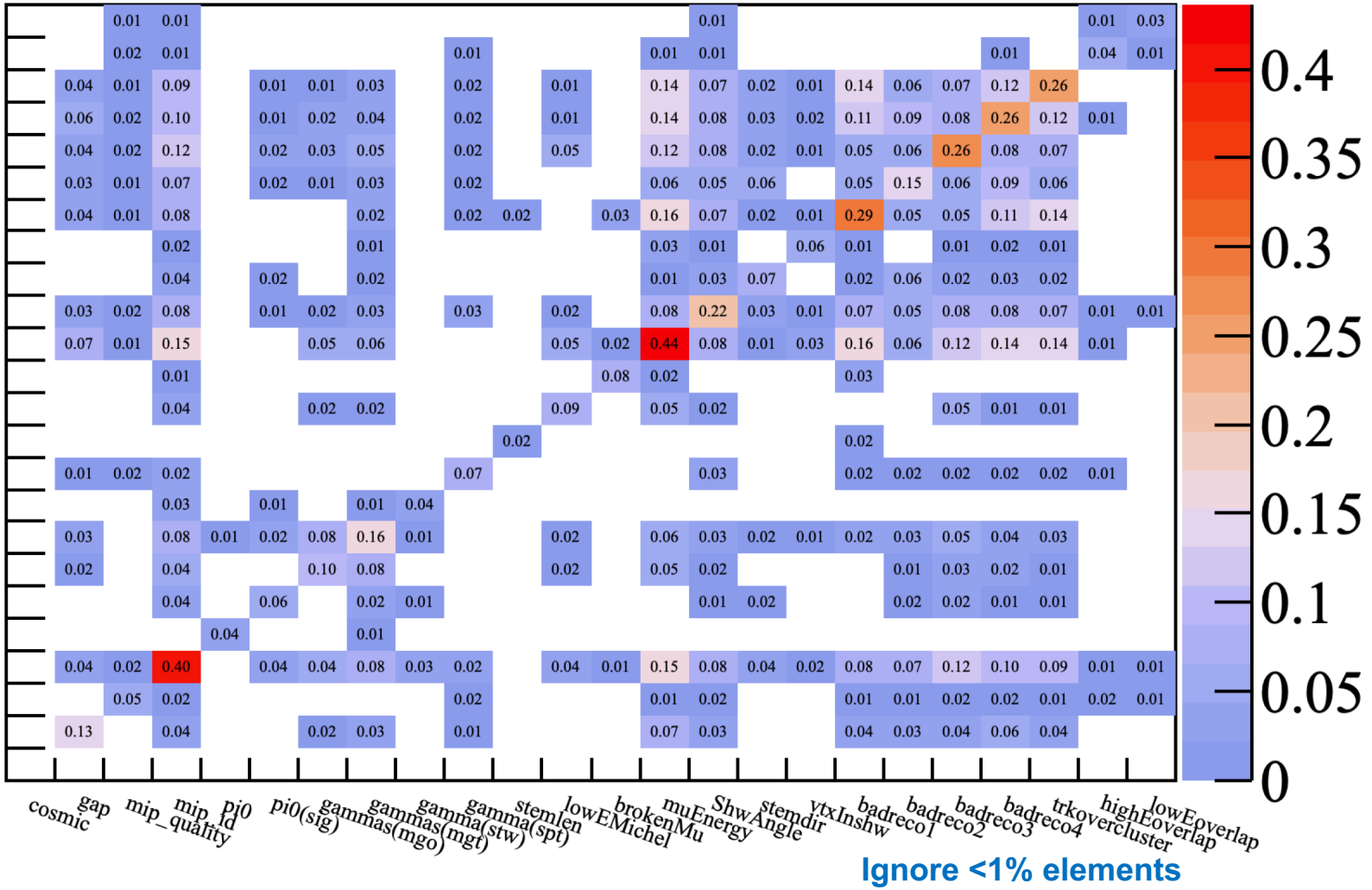


dE/dx (3D) fitting



Background categorization

Rejection rate of background events with reco EM shower(s)



Unreliable pattern recognition

Kinematic

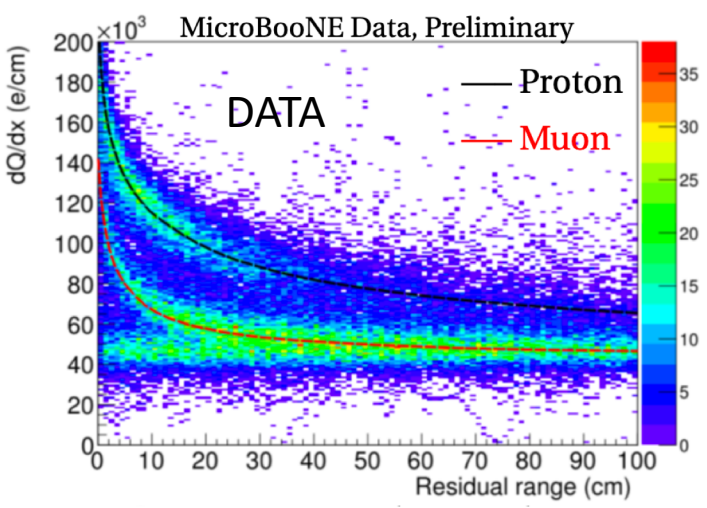
Muon-related misid

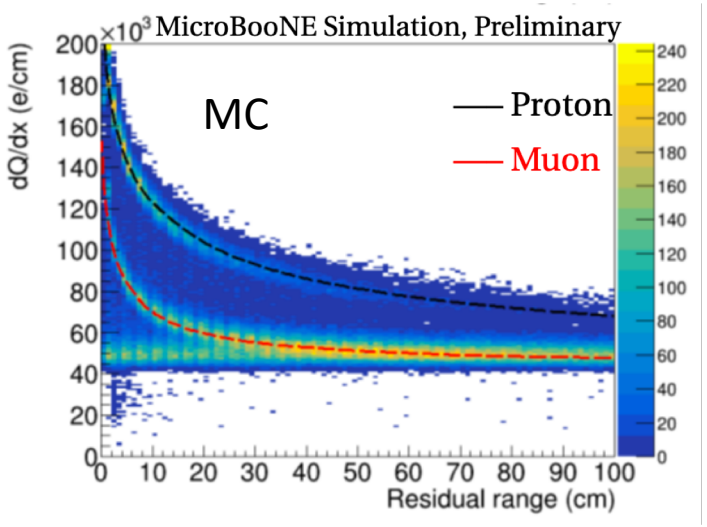
pi0 or gamma

Primary electron id

Ignore <1% elements

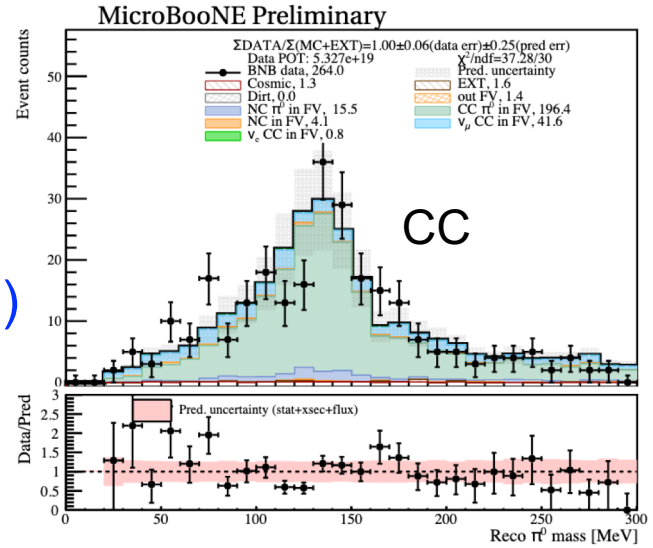
Validation of energy reconstruction

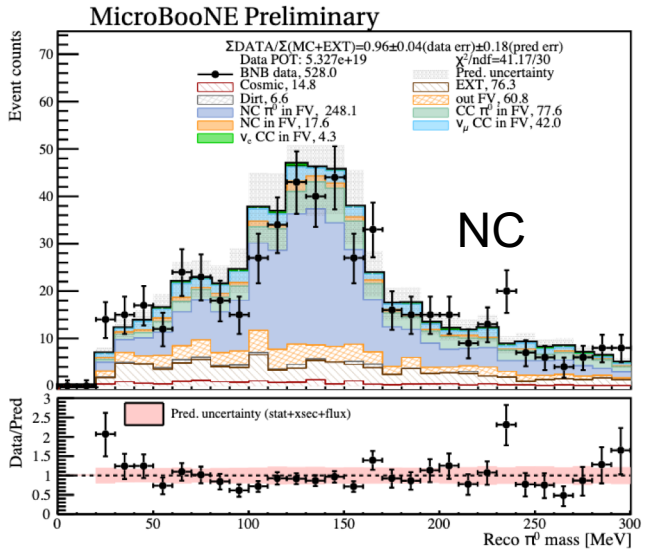




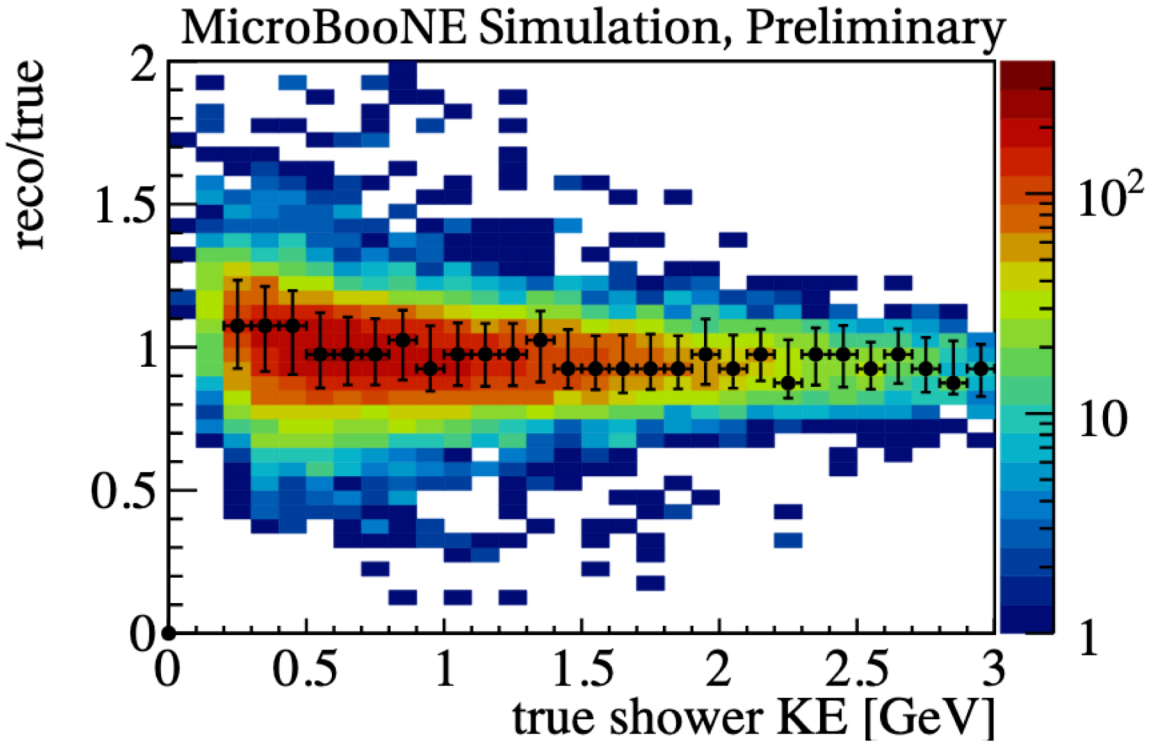
minimal/highly ionizing particle dE/dx

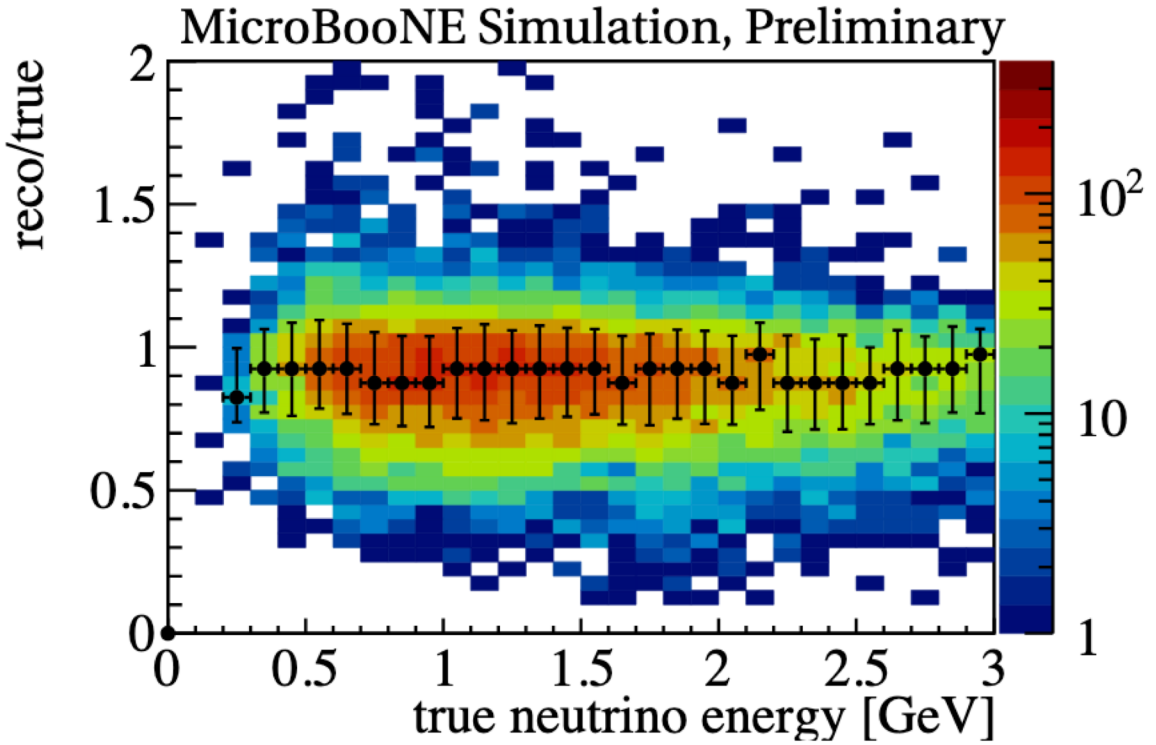
pi0 invariant mass (from decay γ showers)



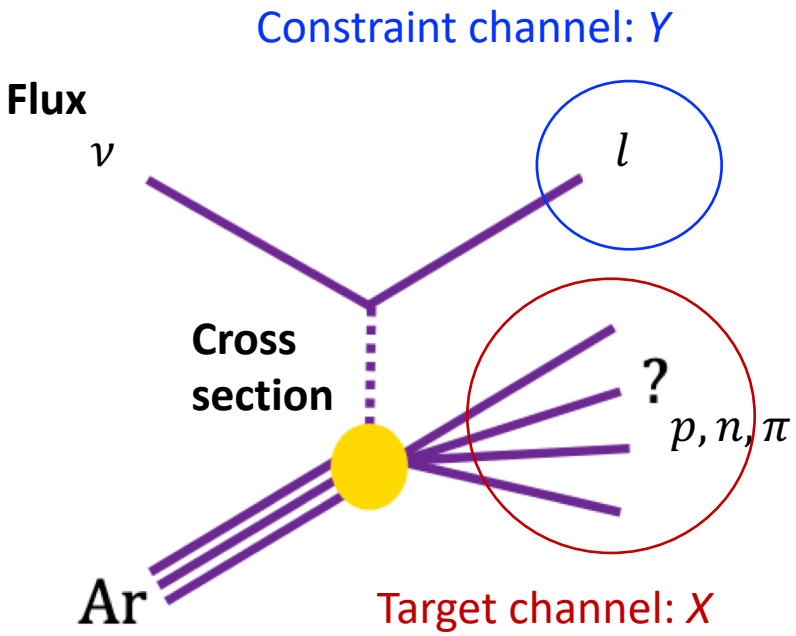


BNB ν_e CC selection: energy resolution





Validation of hadronic energy reconstruction



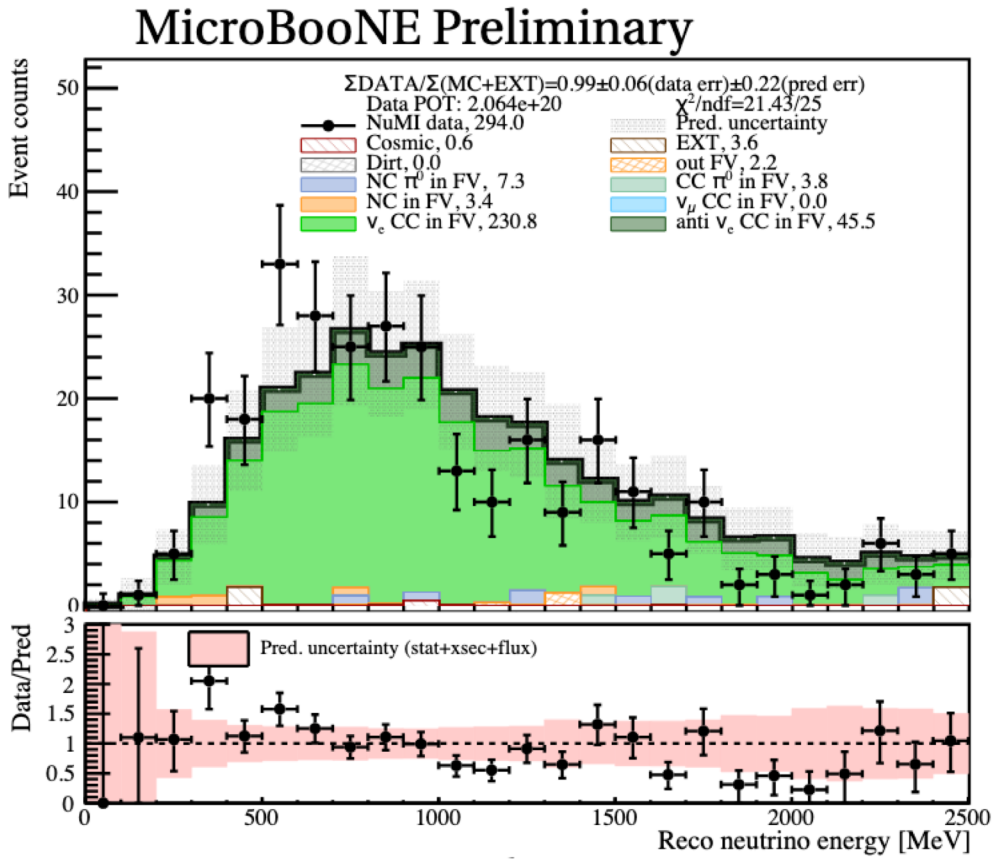
X: target channel
Y: constraint channel
n: measurement
μ: mean of model
Σ: covariance matrix of model

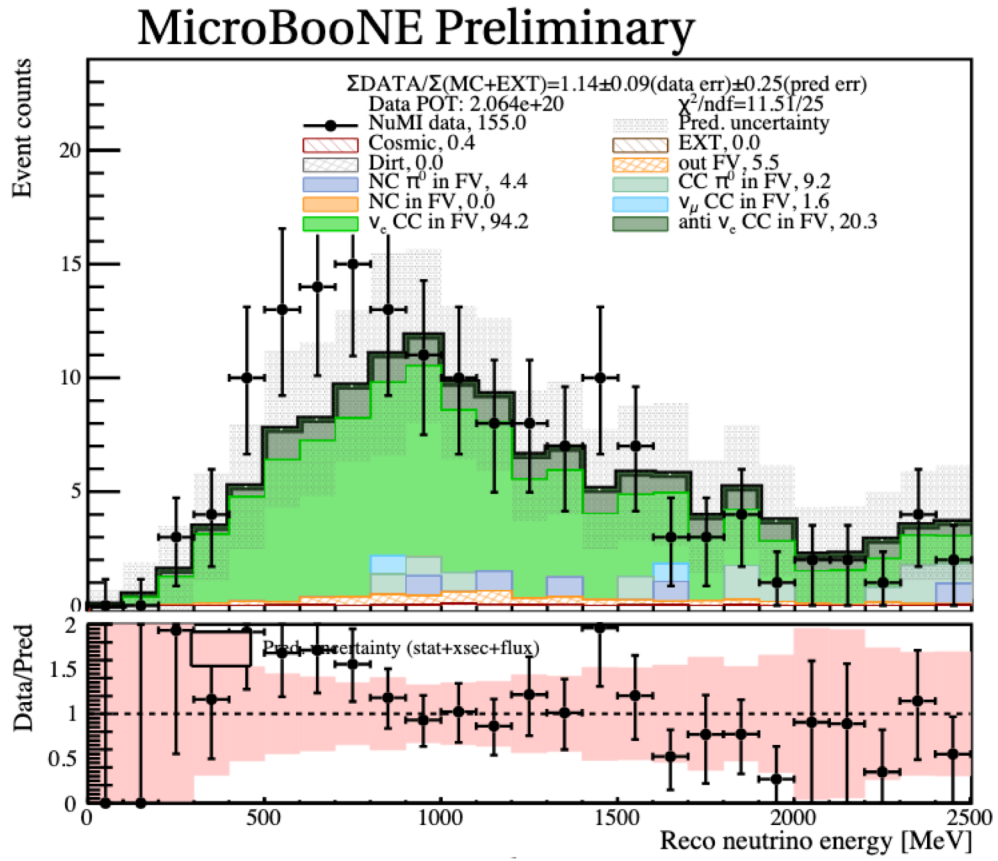
Constraint:
conditional mean and conditional covariance

$$\mu^{X,constrained} = \mu^X + \Sigma^{XY} \cdot (\Sigma^{YY})^{-1} \cdot (n^Y - \mu^Y),$$
$$\Sigma^{XX,constrained} = \Sigma^{XX} - \Sigma^{XY} \cdot (\Sigma^{YY})^{-1} \cdot \Sigma^{YX}.$$

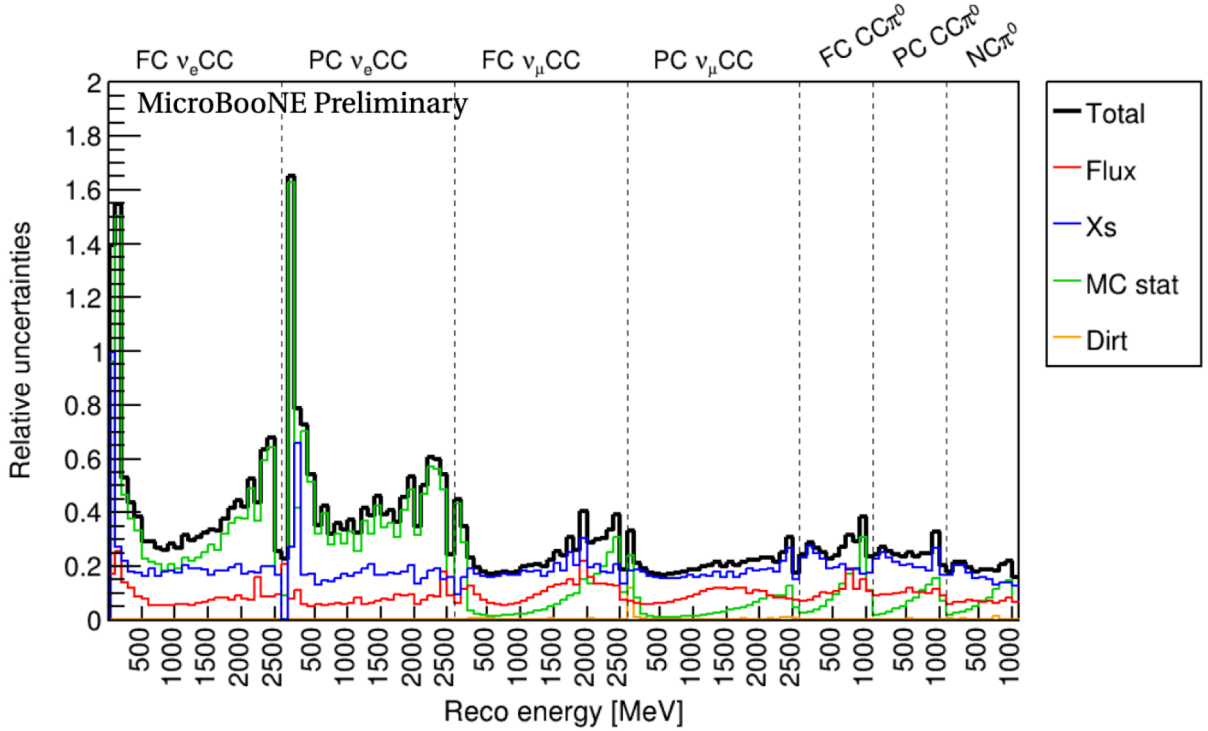
- **Monte-Carlo prediction** is ***corrected*** based on the data/MC discrepancy in the constraint channel.
- **Systematic uncertainty** is ***reduced***
- Constraint respects the allowed error ranges in the cross section, flux, and detector systematics

NuMI preliminary ν_e CC selection

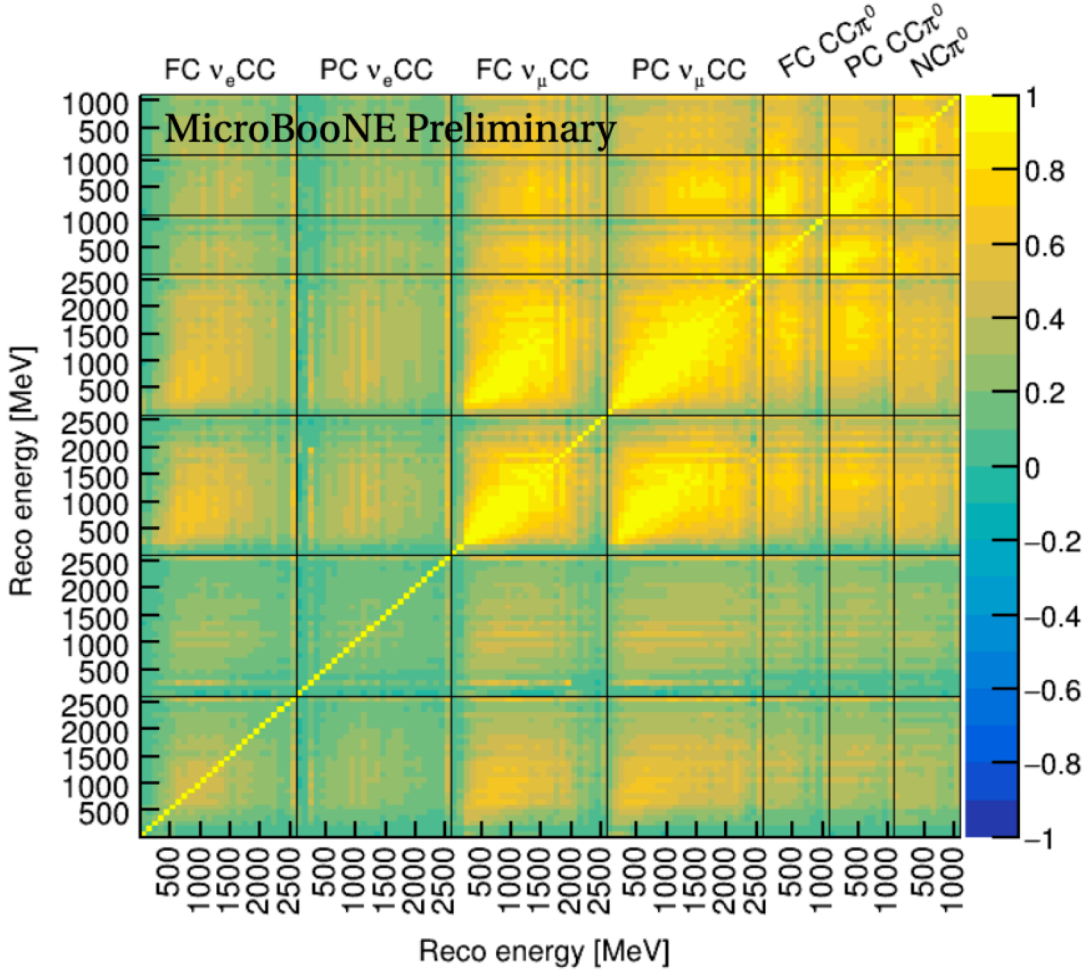




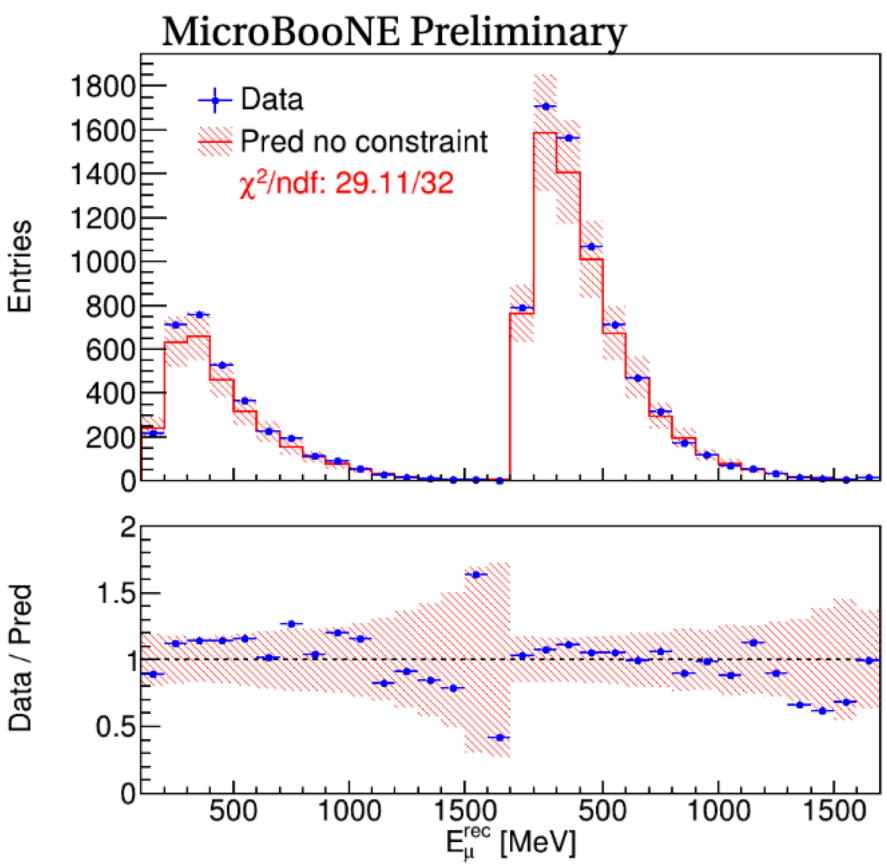
Search for eLEE

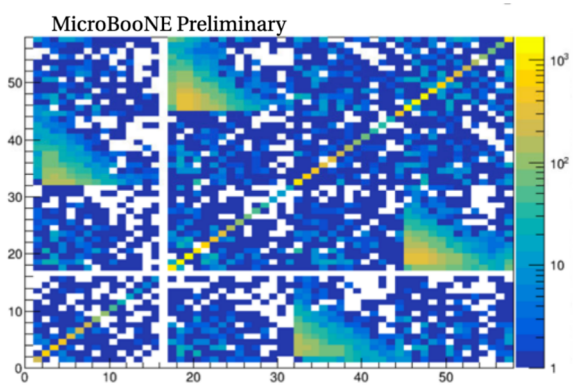


- GENIE and flux reweights
- Bayesian statistical uncertainty
- Detector systematic to be added
  - Bootstrapping method to take into account statistical effect in Monte-Carlo samples

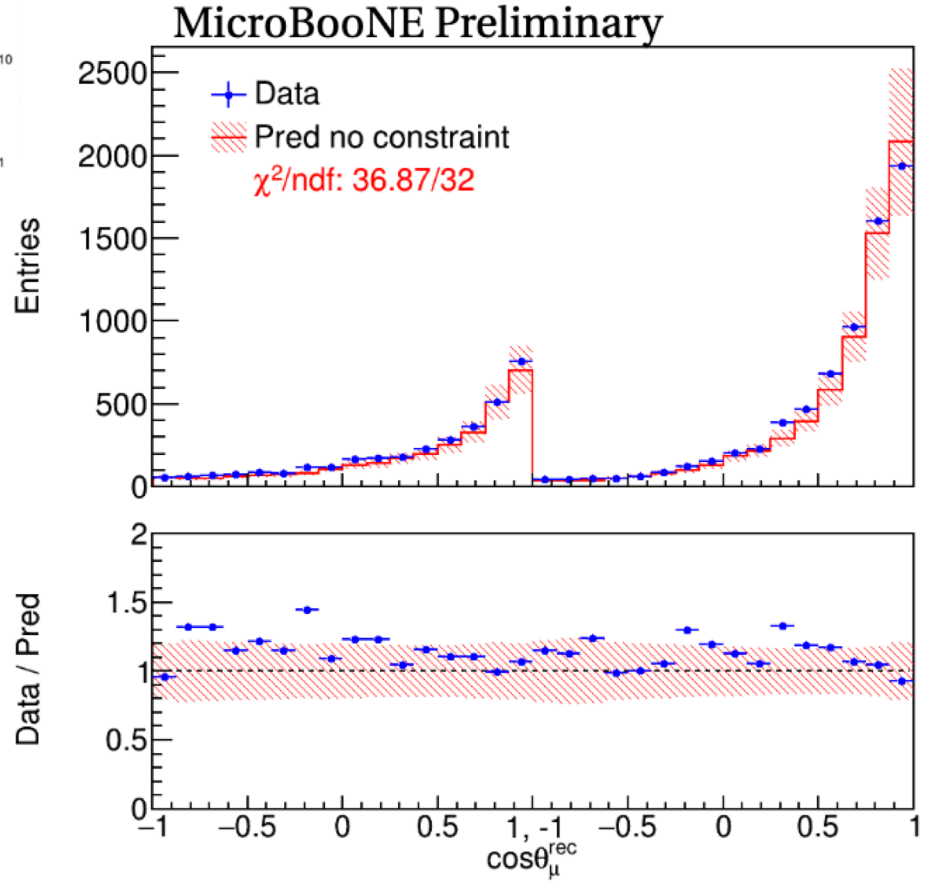


Total uncertainty (no detector systematic) correlation matrix





Statistical correlation



PRD 102,011101(R) (2020) JHEP10 (2020) 114 L. Cremonesi, Neutrino 2020 talk

Intrinsic ν_e CC	MicroBooNE this work		ArgonNeuT	T2K near detector	NOvA near detector
Beam line and distance to beam target	BNB @470 m	NuMI (FHC) off-axis	NuMI @1 km	J-PARC (FHC) @280 m, off-axis	NuMI @1 km, off-axis
Purity	84%	91%	79%	53%	N/A
Efficiency	42%	37%	10%	27%	N/A
# of ν_e CC /1e20 POT	84 (85 tons)	190 (85 tons)	10 (120 kg)	36 (1 ton)	1200 (300 tons)