



NOvA Near Detector Physics

EDSU 2022 – La Réunion

Gregory Pawloski

University of Minnesota

What is NOvA

Long-baseline neutrino experiment

$E \approx 1.9$ GeV (off-axis narrow band beam)

$L = 810$ km

Oscillations governed by Δm_{32}^2 (Δm_{31}^2)

NuMI beam produced at Fermilab

ν_μ and $\bar{\nu}_\mu$ beam modes

$(\bar{\nu}_\mu) \rightarrow (\bar{\nu}_\mu)$ and $(\bar{\nu}_\mu) \rightarrow (\bar{\nu}_e)$ oscillations

Two detector experiment

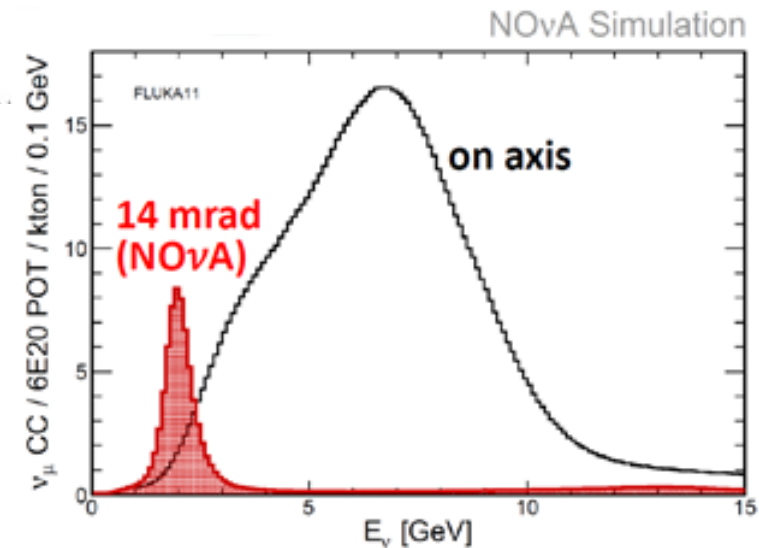
Near detector (Fermilab, IL)

~1km from production target

Measure beam before standard oscillation

Far Detector (Ash River, MN)

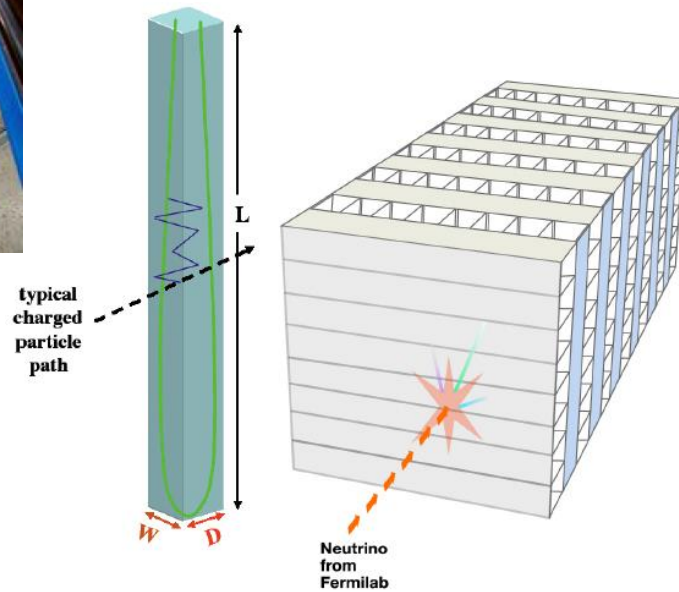
Measure oscillated beam



The NOvA Near Detector

Giant hydrocarbon nuclear targets

67% C, 11% H with 16% Cl, 3% Ti, 3% O

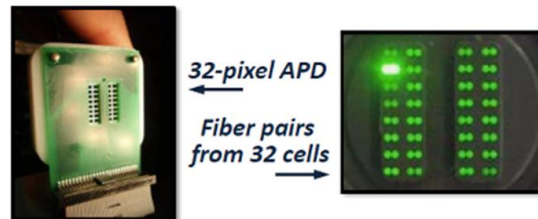


Tracking Calorimeter

- Liquid scintillator filled PVC tubes
- 206 planes
- 18,000 channels

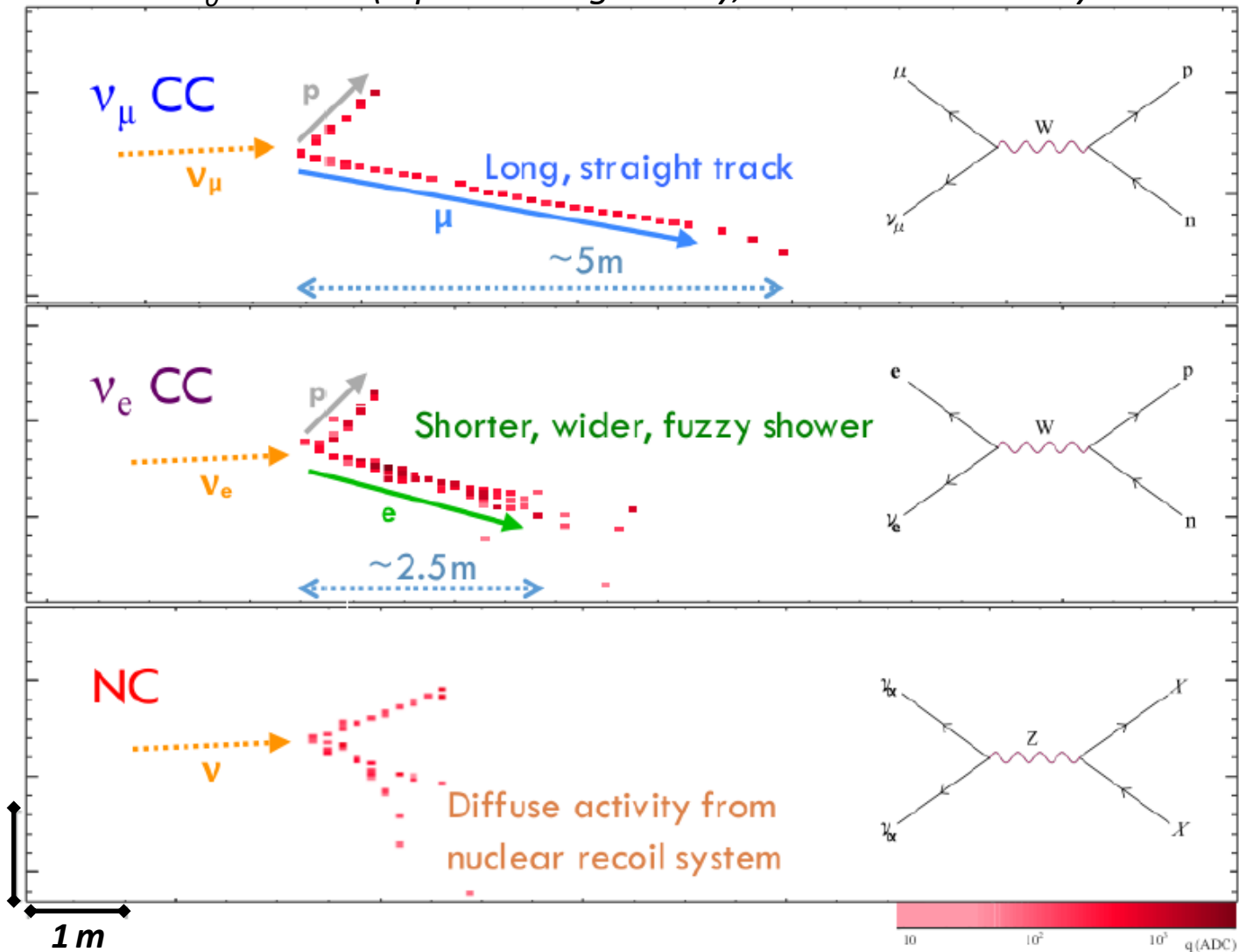
Muon catcher at the end

- 10 steel planes alternating between 11 pairs active
- Stops 3 GeV muons



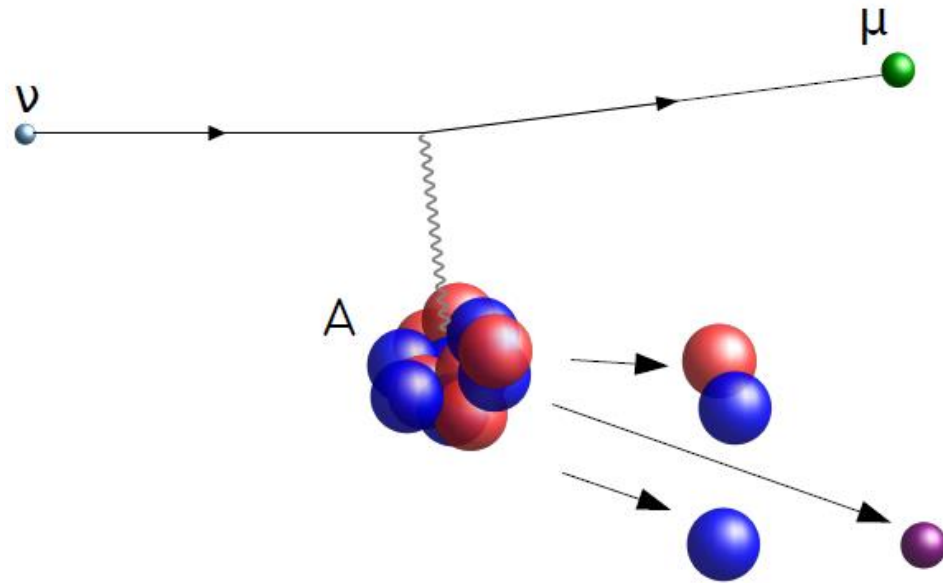
NOvA Event Topologies

$X_0 = 38$ cm (6 planes longitudinally, 10 cells transversely)



Neutrino Interactions

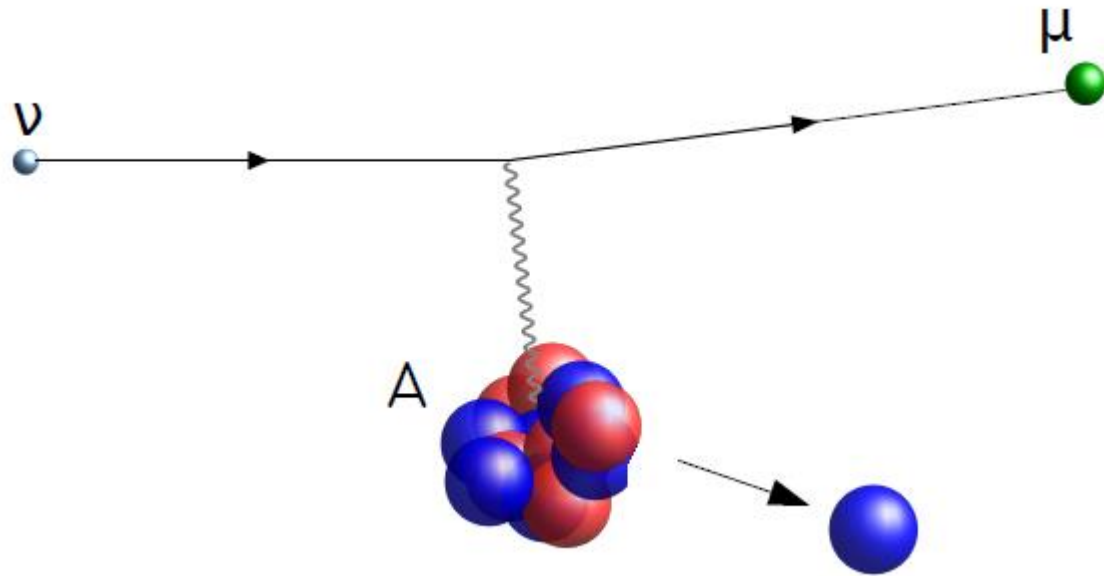
Incoming neutrino interacts with quark in nuclear environment



Nuclear environment muddles theoretical predictions
Impacts selection and energy reconstruction

Neutrino Interactions

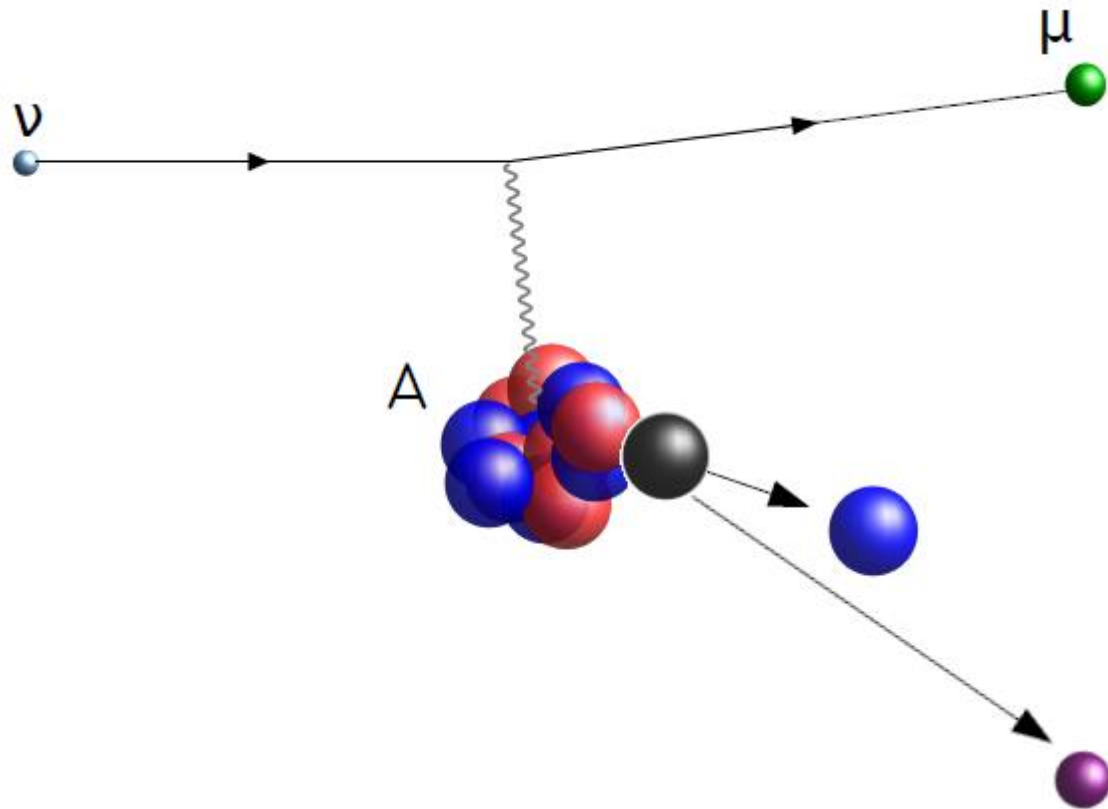
1 - Quasi-elastic event



Approximately a two body collision with a nucleon

Neutrino Interactions

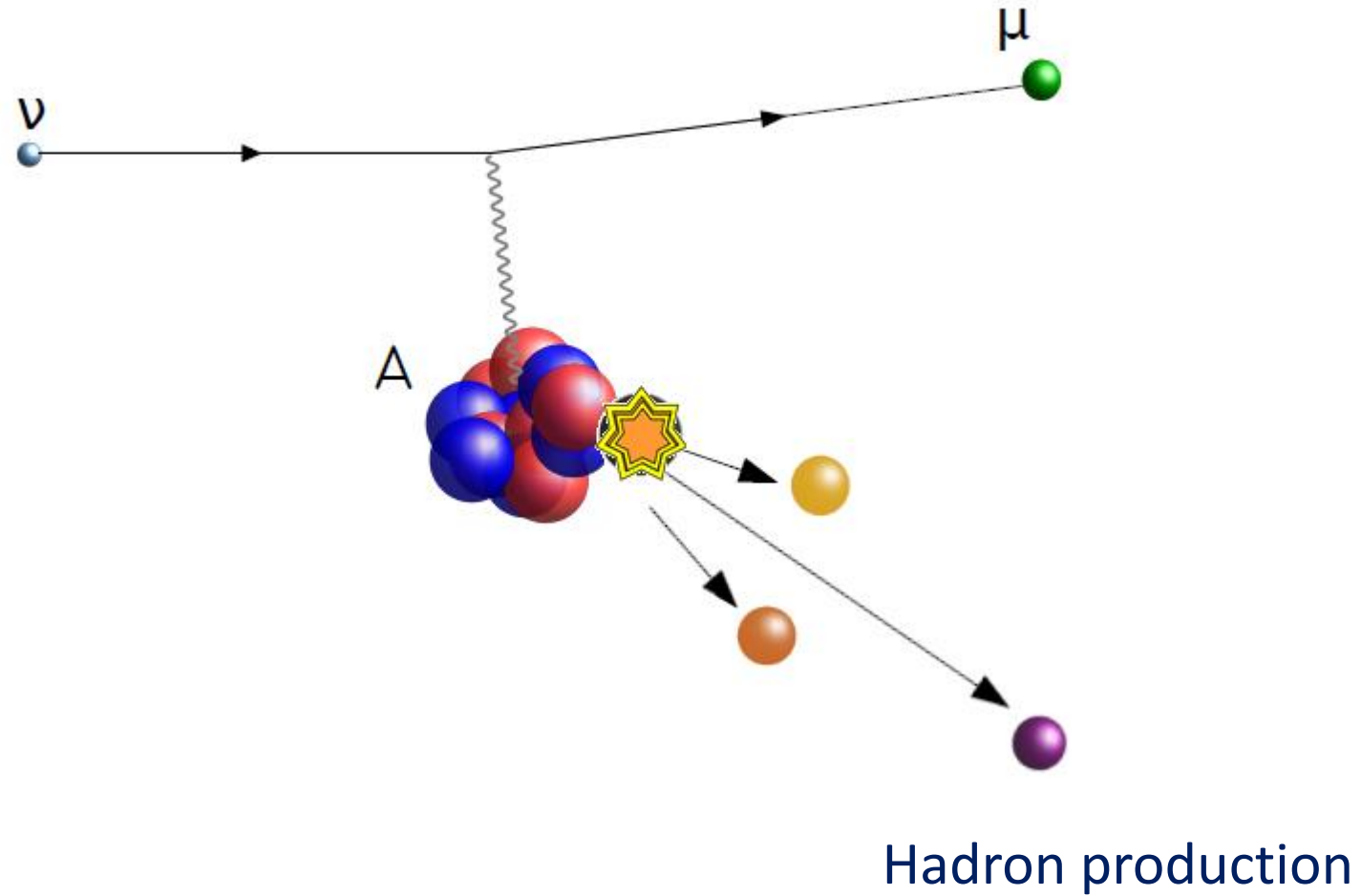
2 - Resonant event



Excite nucleon to Δ resonance state that decays

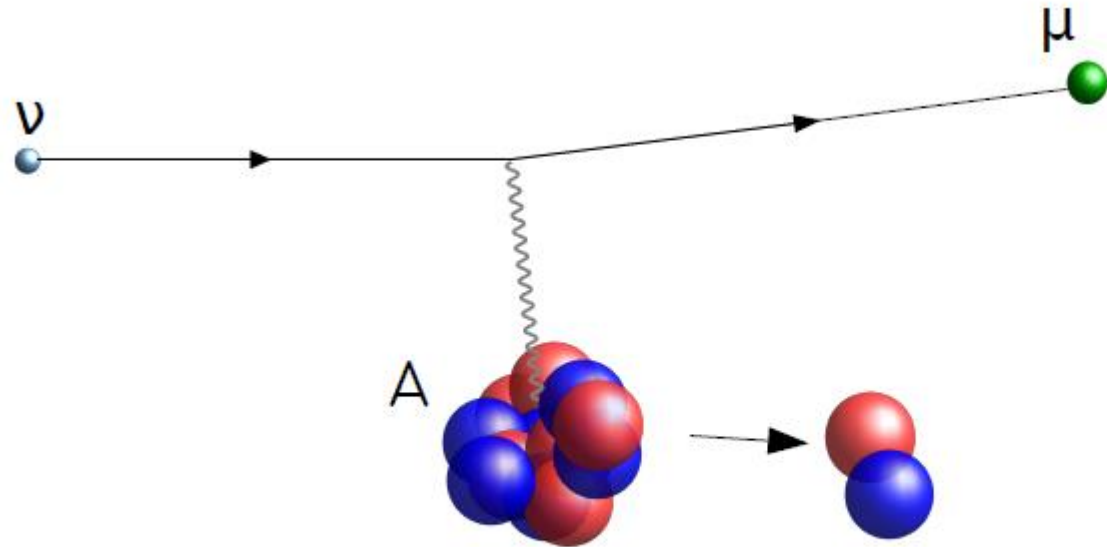
Neutrino Interactions

3 – Shallow or Deep Inelastic Scatter (DIS)



Neutrino Interactions

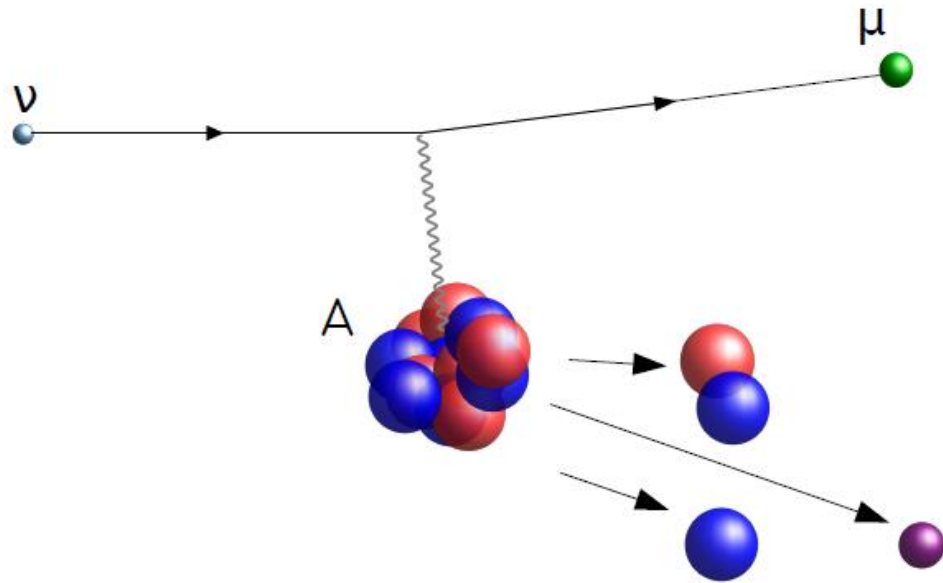
4 – 2 particle, 2 hole (2p2h)



Neutrino interacts with a nucleon pair

Neutrino Interactions

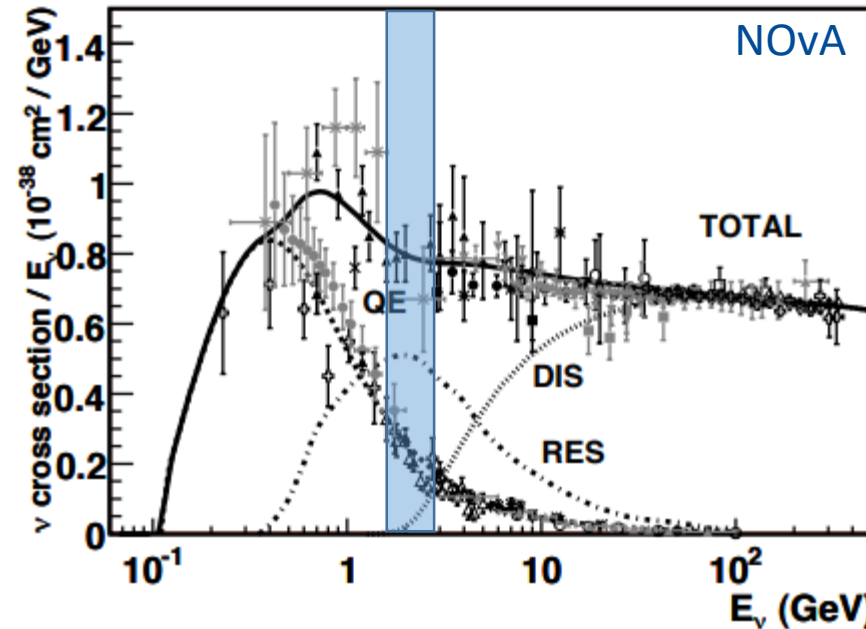
Final State Interactions



Particle from primary interaction has to escape nucleus
Interacts with nuclear medium

Neutrino Interactions

Neutrinos



Rev. Mod. Phys. 84, 1307 (2012)

NOvA at an energy where resonant production is dominant

However the mix of QE, 2p2h, RES, and DIS is important and muddles things

Between T2K and Minerva energy regimes

Recent Cross-section Results

1 – ν_μ CC interactions with low hadronic activity

Enhanced in QE and 2p2h2 events

Compare outgoing lepton kinematics to models

2 – ν_μ CC inclusive double differential cross section in hadronic activity variables

Different production modes tend to occupy different regions of phase space

Compare outgoing hadronic activity to models

1 – Low Hadronic Activity Analysis

Signal Definition

ν_μ CC interaction

No outgoing proton with KE > 200 MeV

No outgoing pion with KE > 175 MeV

Selection Criteria

Muon track

No other reconstructed tracks

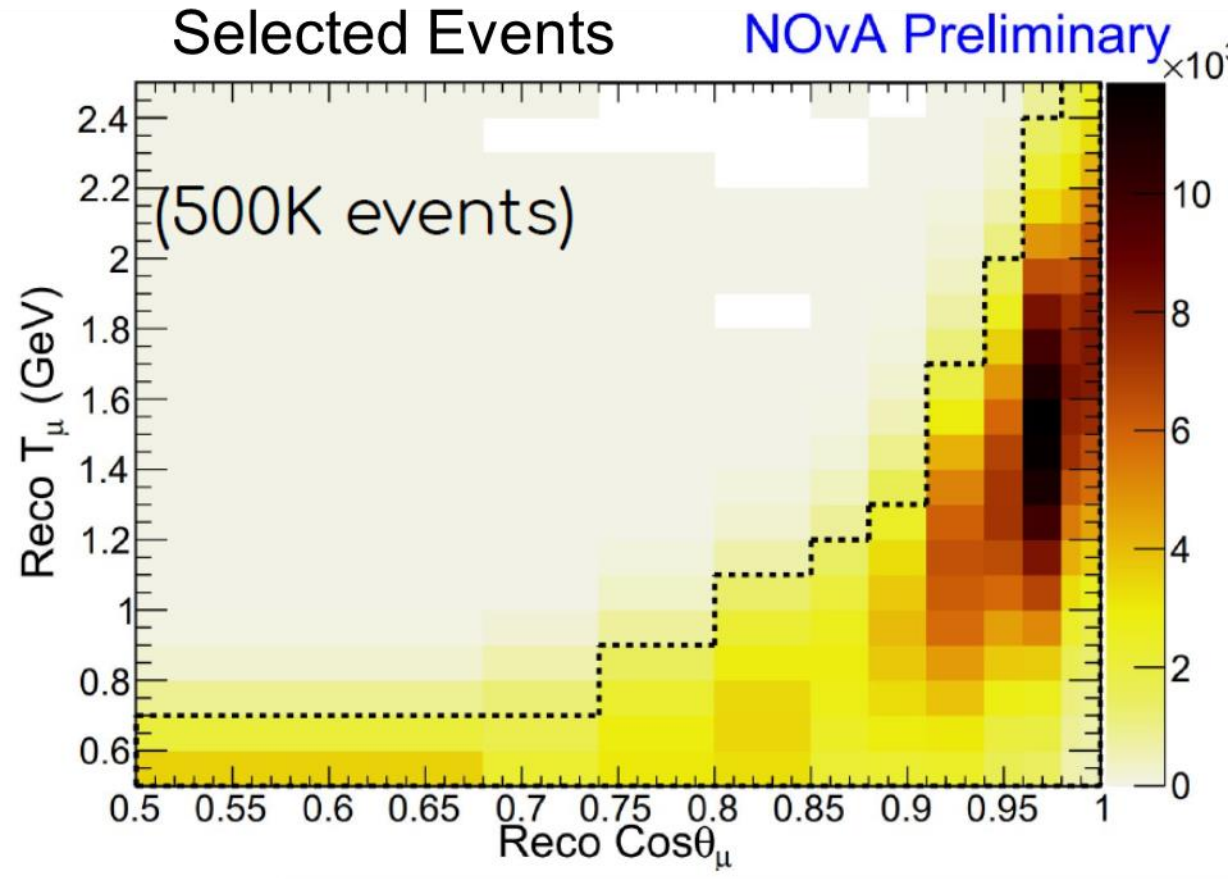
Measurement

Double differential cross section

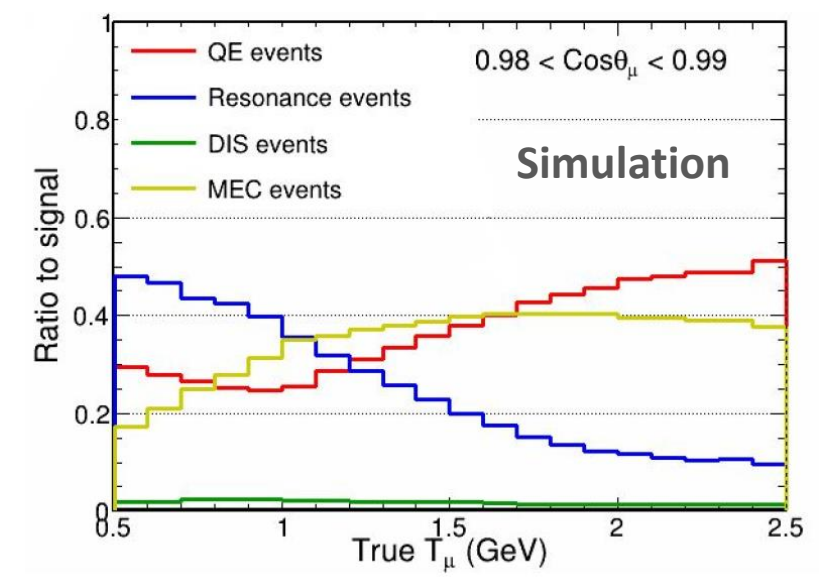
Muon kinetic energy (T)

Muon angle w.r.t. the neutrino beam ($\cos \theta$)

1 – Low Hadronic Activity Analysis



Low Hadronic E → Greater Muon P
Most events forward going
Those events tend to be QE and 2p2h
~50% QE
~40% 2p2h



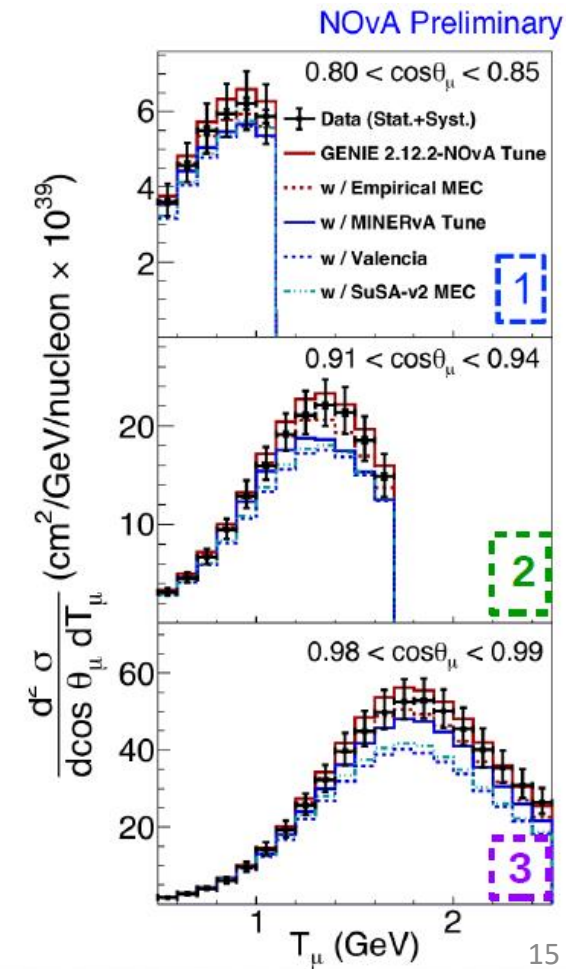
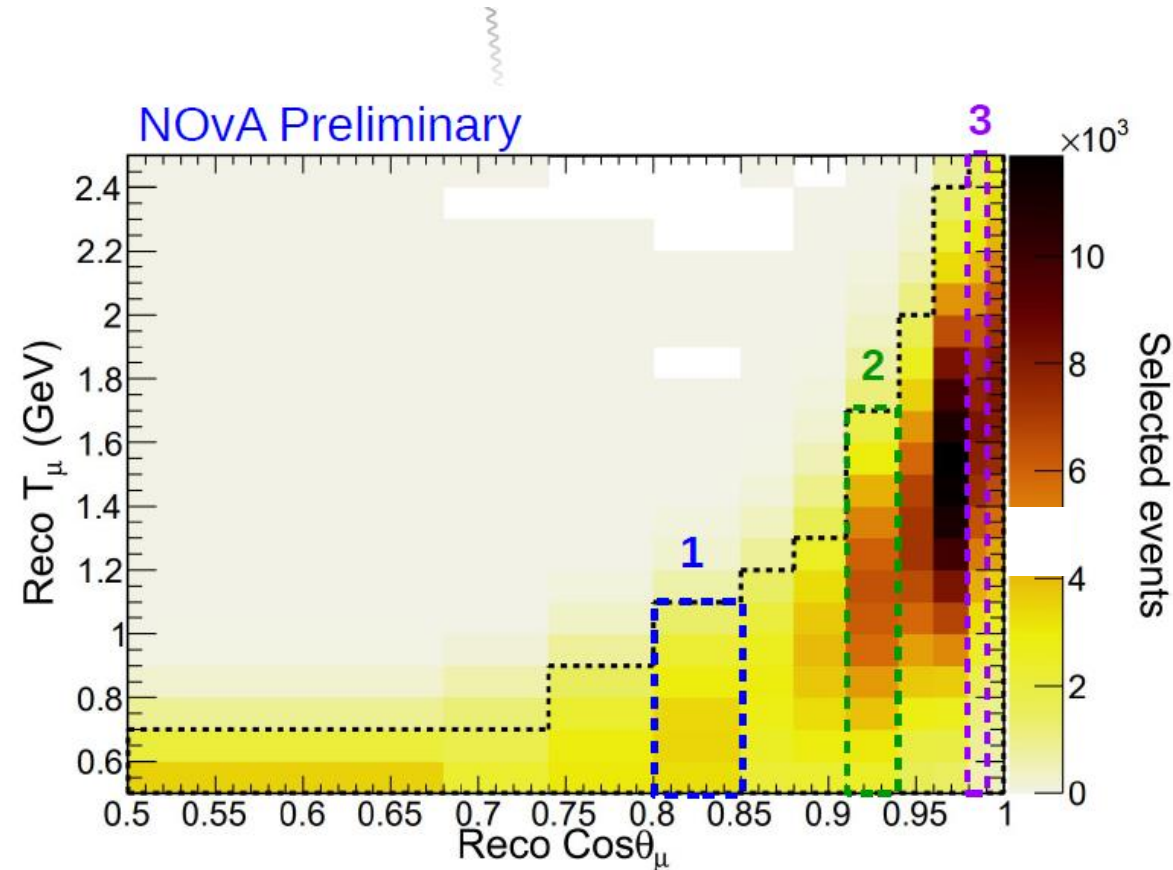
1 – Low Hadronic Activity Analysis

Calculate cross-section for 115 bins and compare to various 2p2h models

2p2h more pronounced in beam direction and larger muon energy

3 representative regions shown to the right

Models tend to under predict 2p2h component



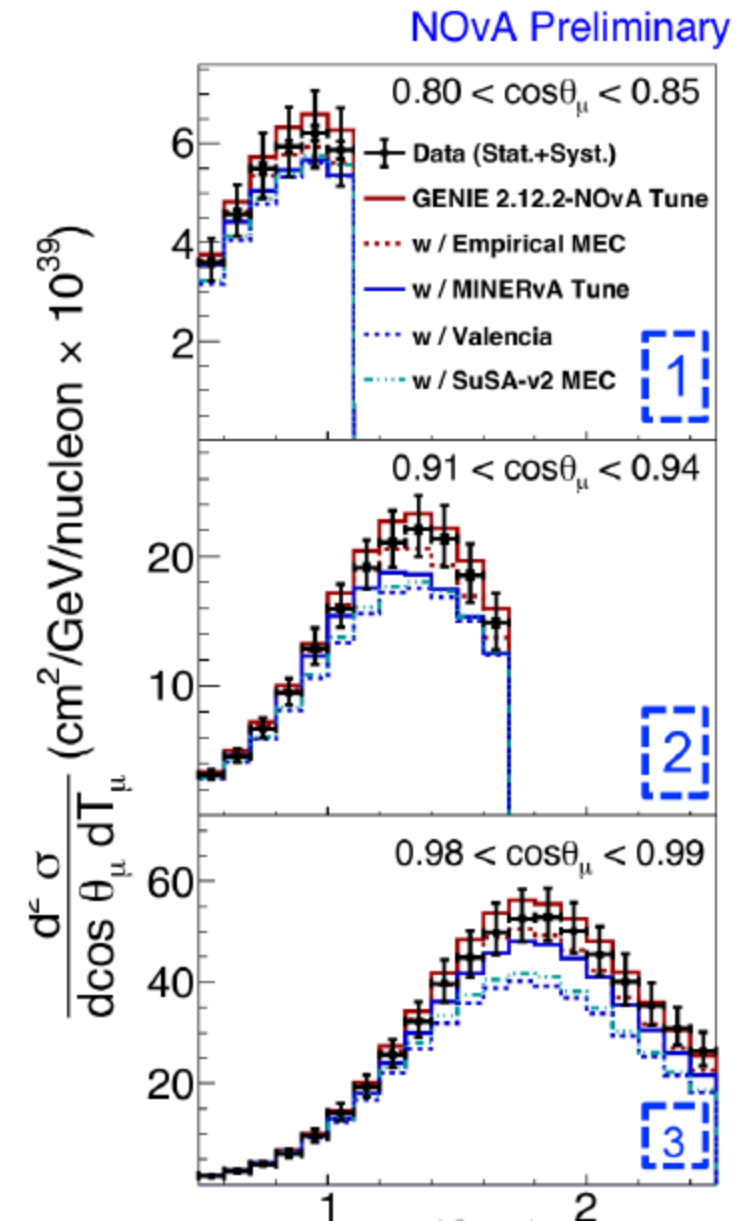
1 – Low Hadronic Activity Analysis

| 2p2h model | χ^2 (115 d.o.f.) (includes 11 $\cos\theta_\mu$ slices) |
|-----------------------------|--|
| València | 630 |
| SuSA v2 | 620 |
| GENIE 2.12.2 + NOvA tune | 200 |
| Empirical MEC | 190 |
| València + MINERvA tune | 340 |

Pure theory

Tuned

All models are lacking
Pure theory has larger deficit



2 – Inclusive Double Differential Analysis

Double differential cross section in hadronic variables

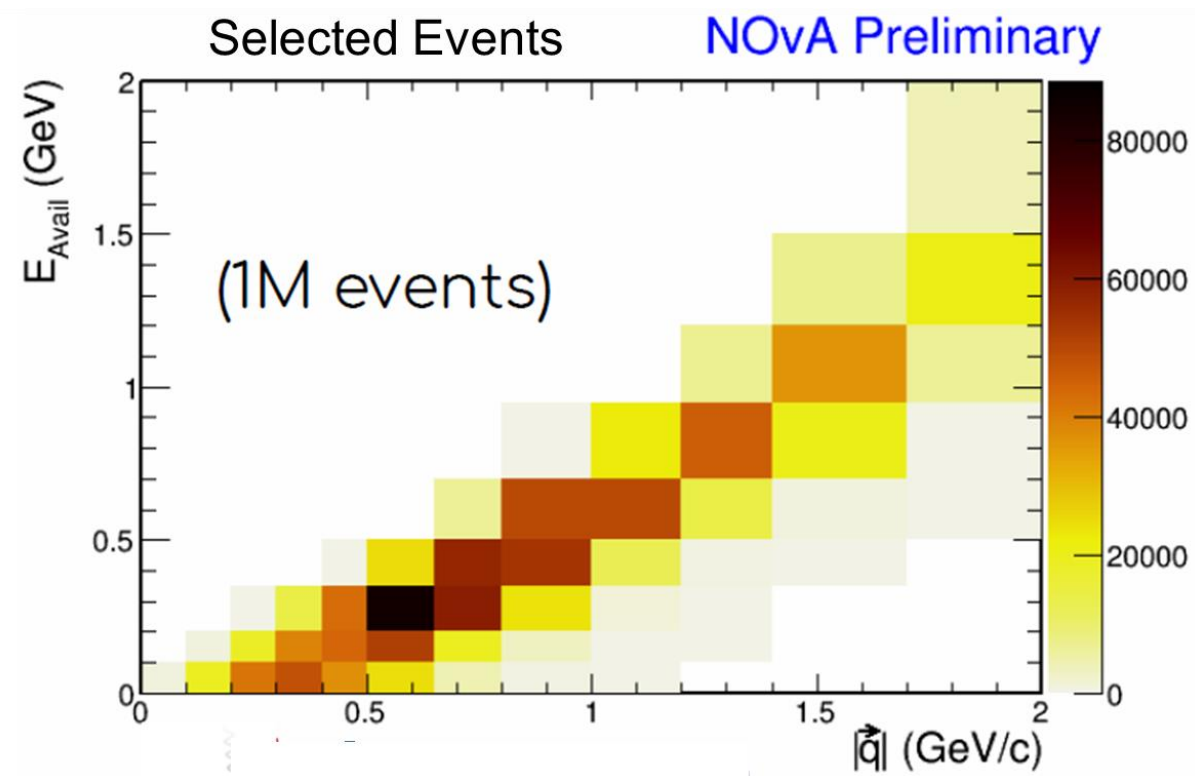
Magnitude of three-momentum transferred to hadronic system ($|\vec{q}|$)

Available Energy (E_{avail})

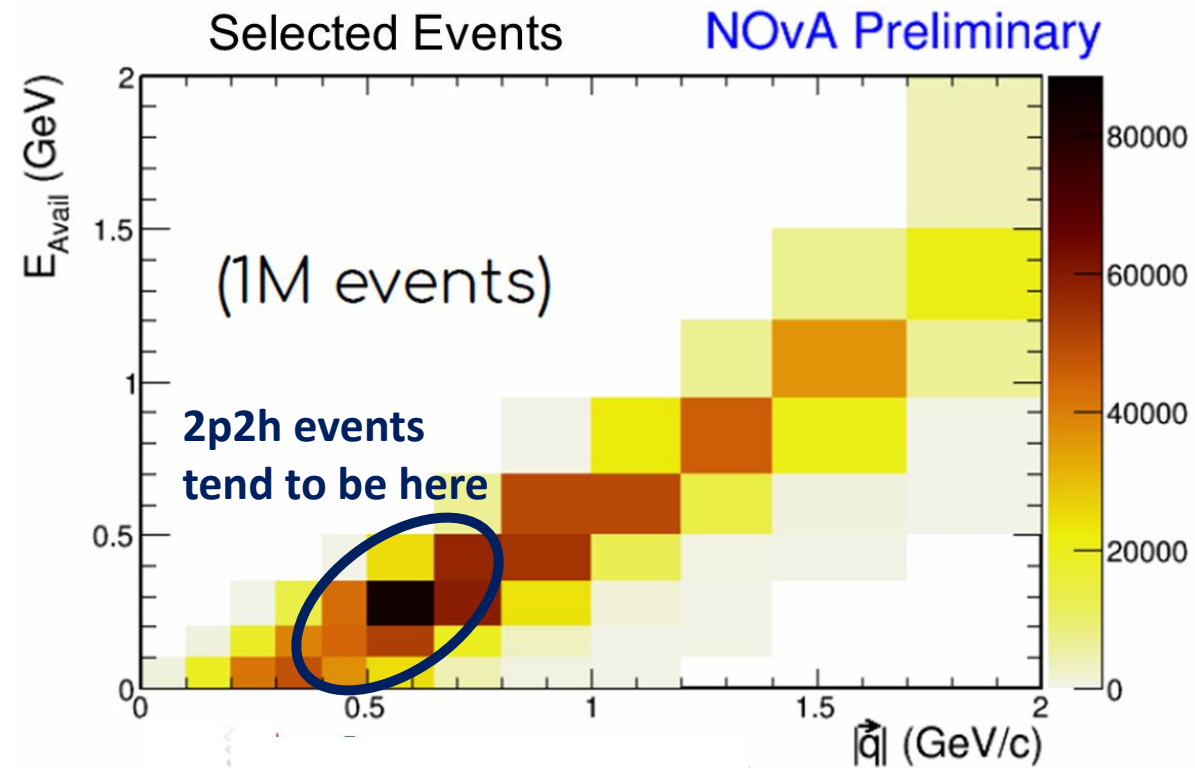
Expected visible hadronic energy (excludes neutrons)

More model independent than visible E and total hadronic E

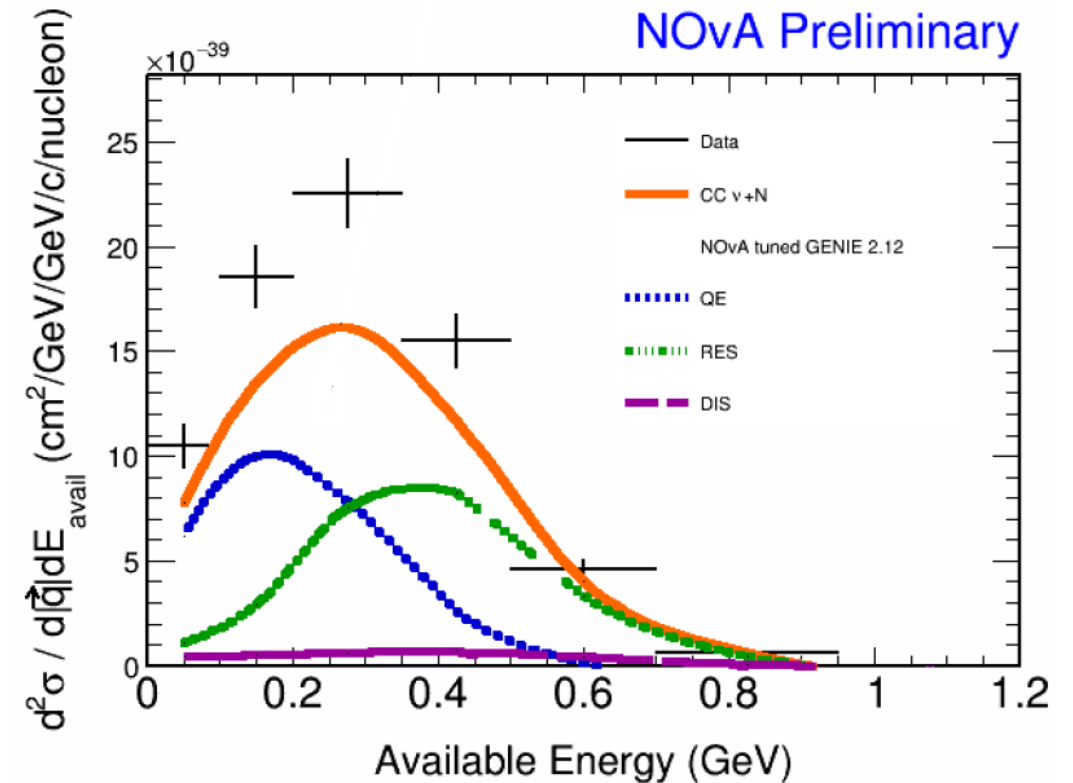
2 – Inclusive Double Differential Analysis



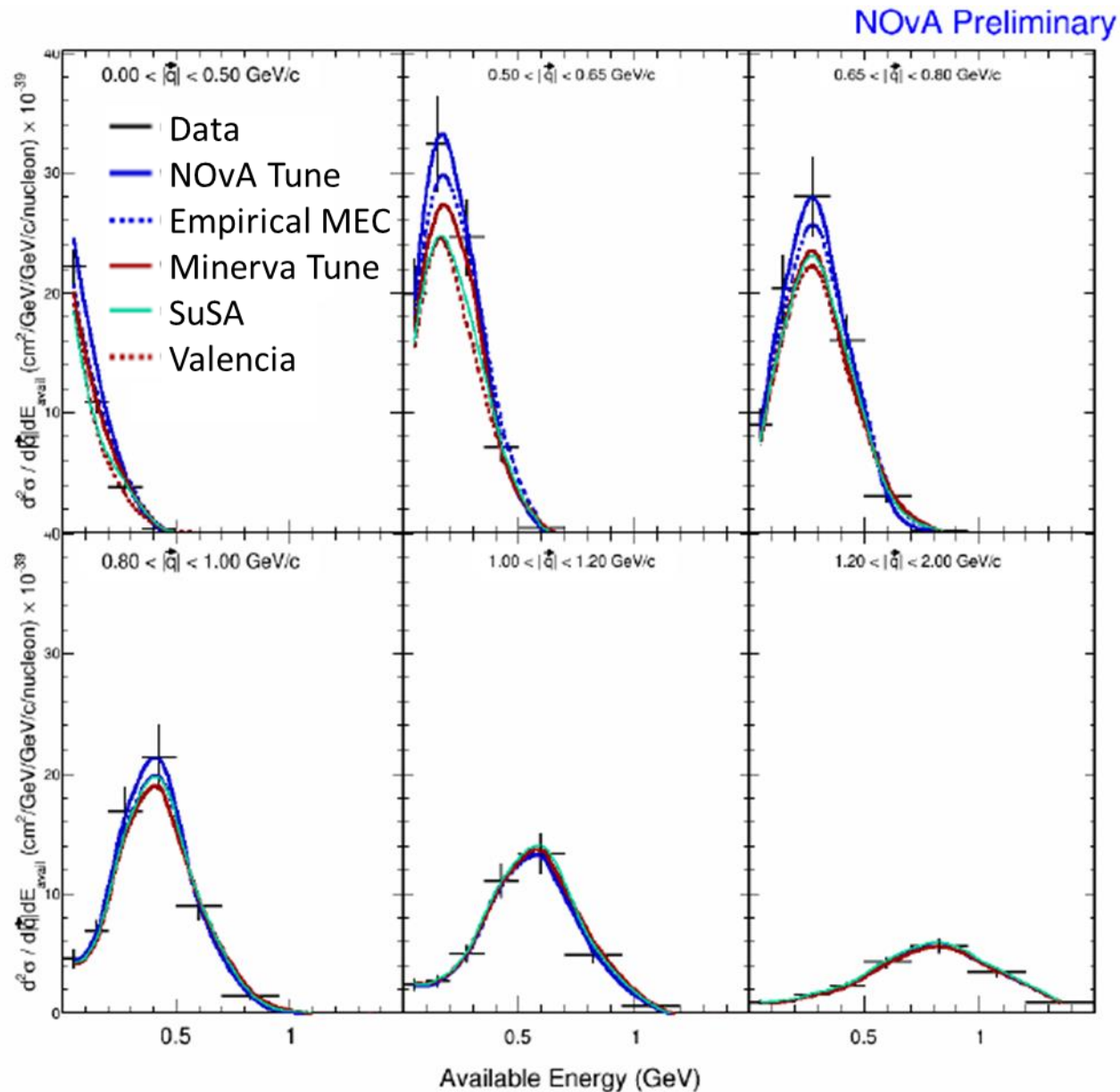
2 – Inclusive Double Differential Analysis



Interaction modes tends to occupy different regions
QE < 2p2h < RES < DIS



2 – Inclusive Double Differential Analysis



Greatest discrepancy between data and simulation in 2p2h region

Similar to Low Had. Activity analysis

Models have deficit

Pure theory under predicts

Better agreement for NOvA tune (tune is related to this variables)

Summary

Significant discrepancies between theory and data for neutrino interactions in nucleus

2p2h models appear to generally under predict

There is ambiguity between quasi-elastic and 2p2h events

There is ambiguity with resonant events

NOvA has to rely on tunes with robust uncertainties

Two recent interaction results with papers to be submitted soon-ish

Interaction model for ND studies

Genie 2.12.2

Global Fermi Gas with high momentum single nucleon tail from short-range correlations

QE: Llewellyn Smith

MEC: Empirical MEC reweighted to ND data

RES: Rein-Sehgal

DIS: Bodek-Yang

FSI: hA (effective model for FSI)