Progress of the Charged Pion Semi-Inclusive Neutrino Charged-Current Cross Section in NOvA

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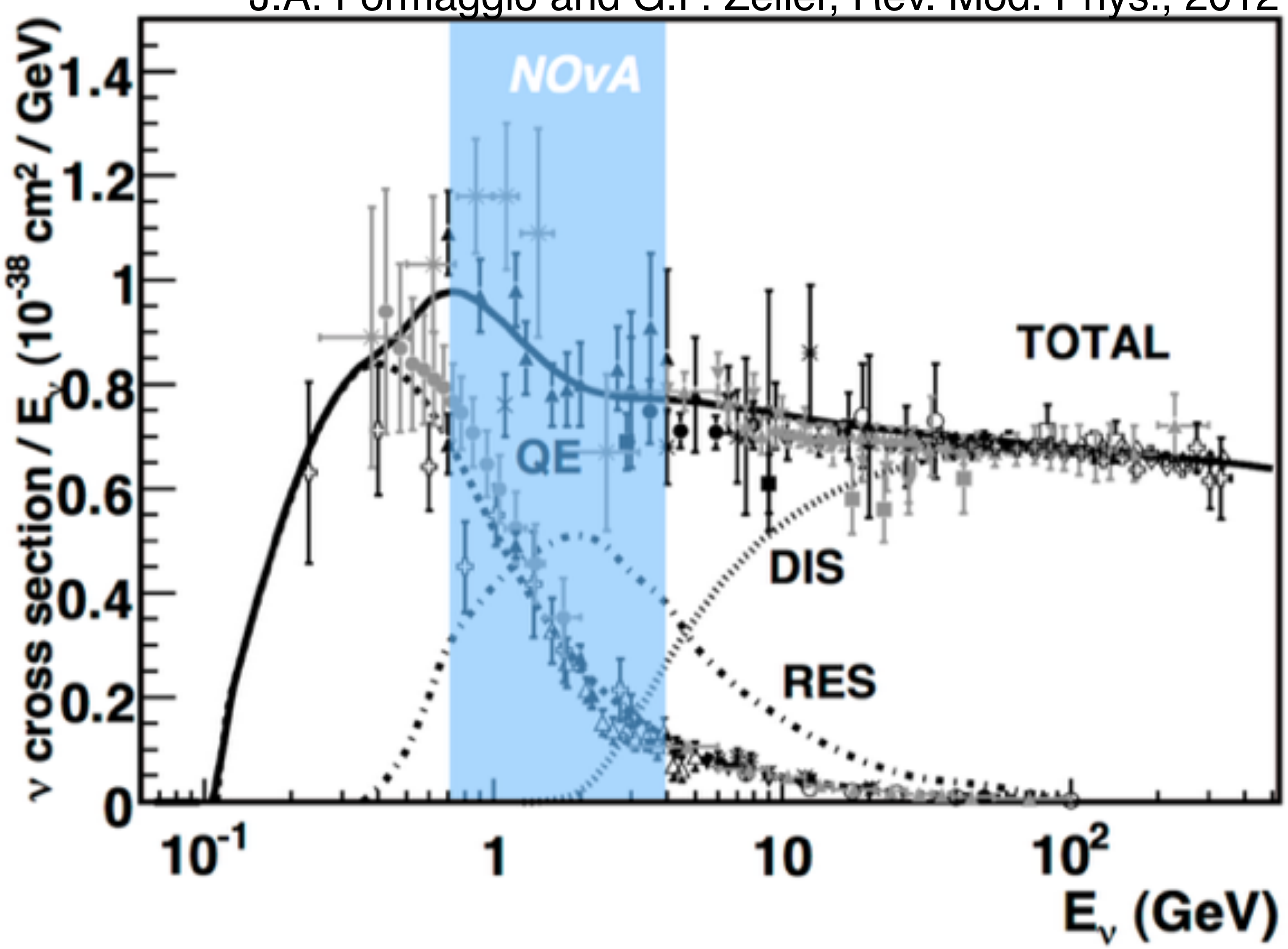
Introduction

Resonant pion production is a dominant interaction channel for the energy range of the oscillation experiments

Thus modeling the nuclear effects for the final state interactions is key for precision neutrino energy measurements.

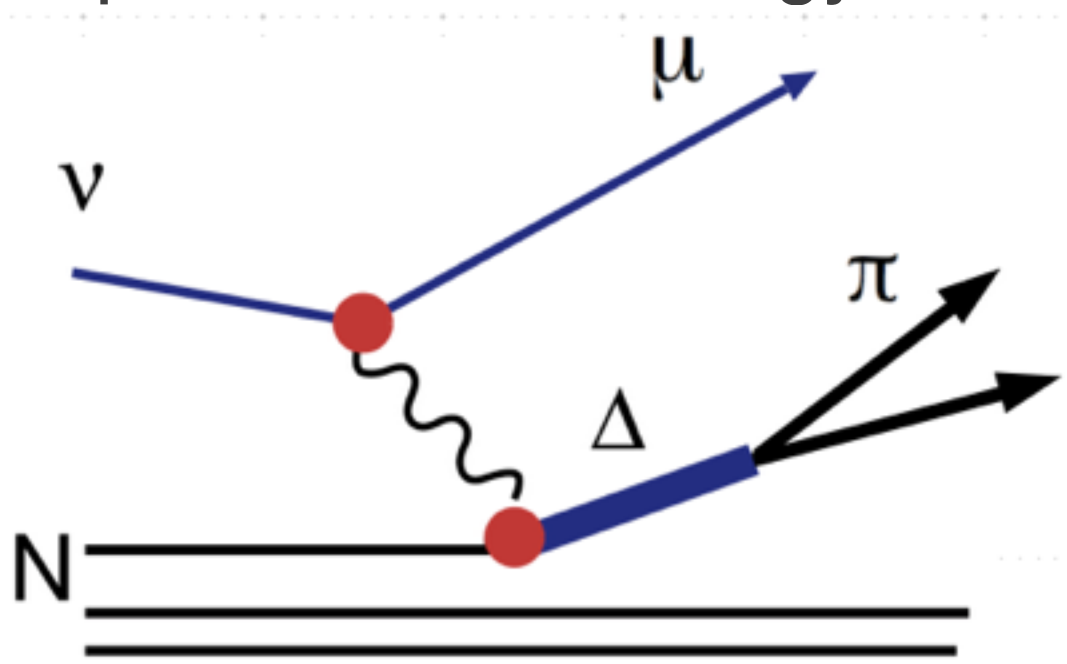
J.A. Formaggio and G.P. Zeller, Rev. Mod. Phys., 2012



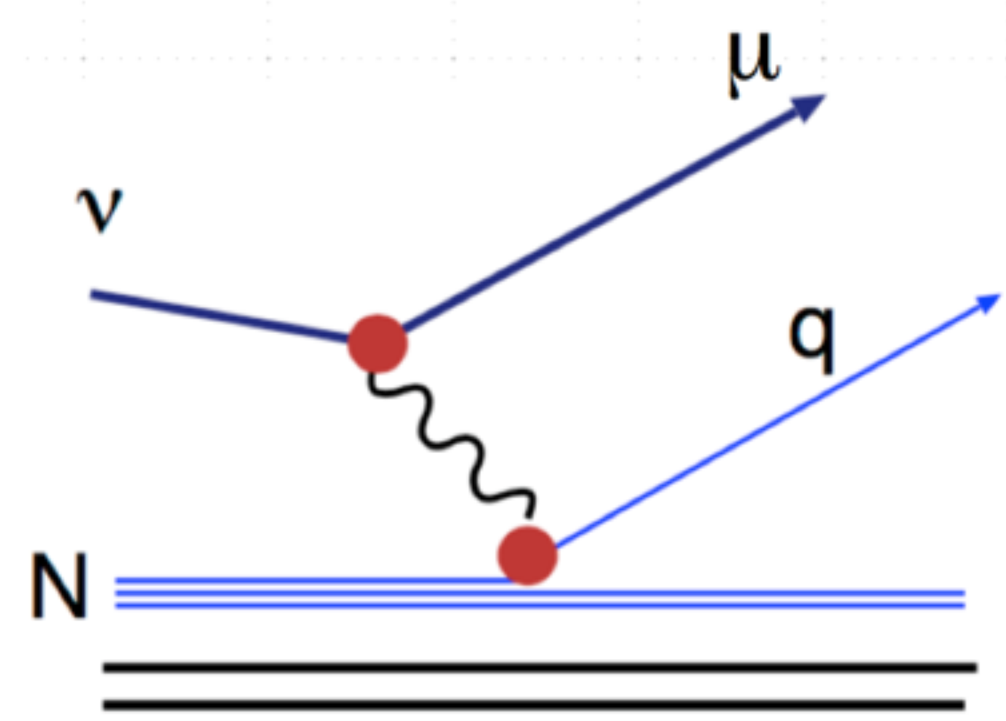
Signal Definition

$$\nu_\mu + N \rightarrow \mu + \pi^{+/-} + X$$

- One muon
- At least one charge pion
- Classify events based on an event id
  - » the selection is sensitive to low energy pions
- Measure the flux integrated double differential cross section with respect to muon energy and angle



Resonance Production: CC1π

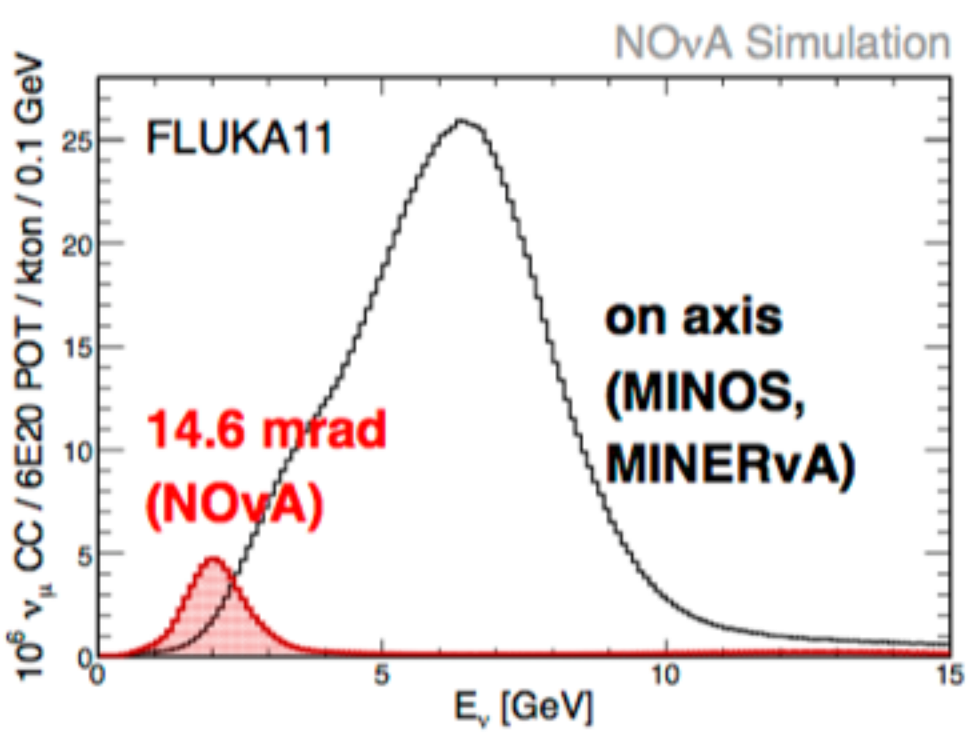


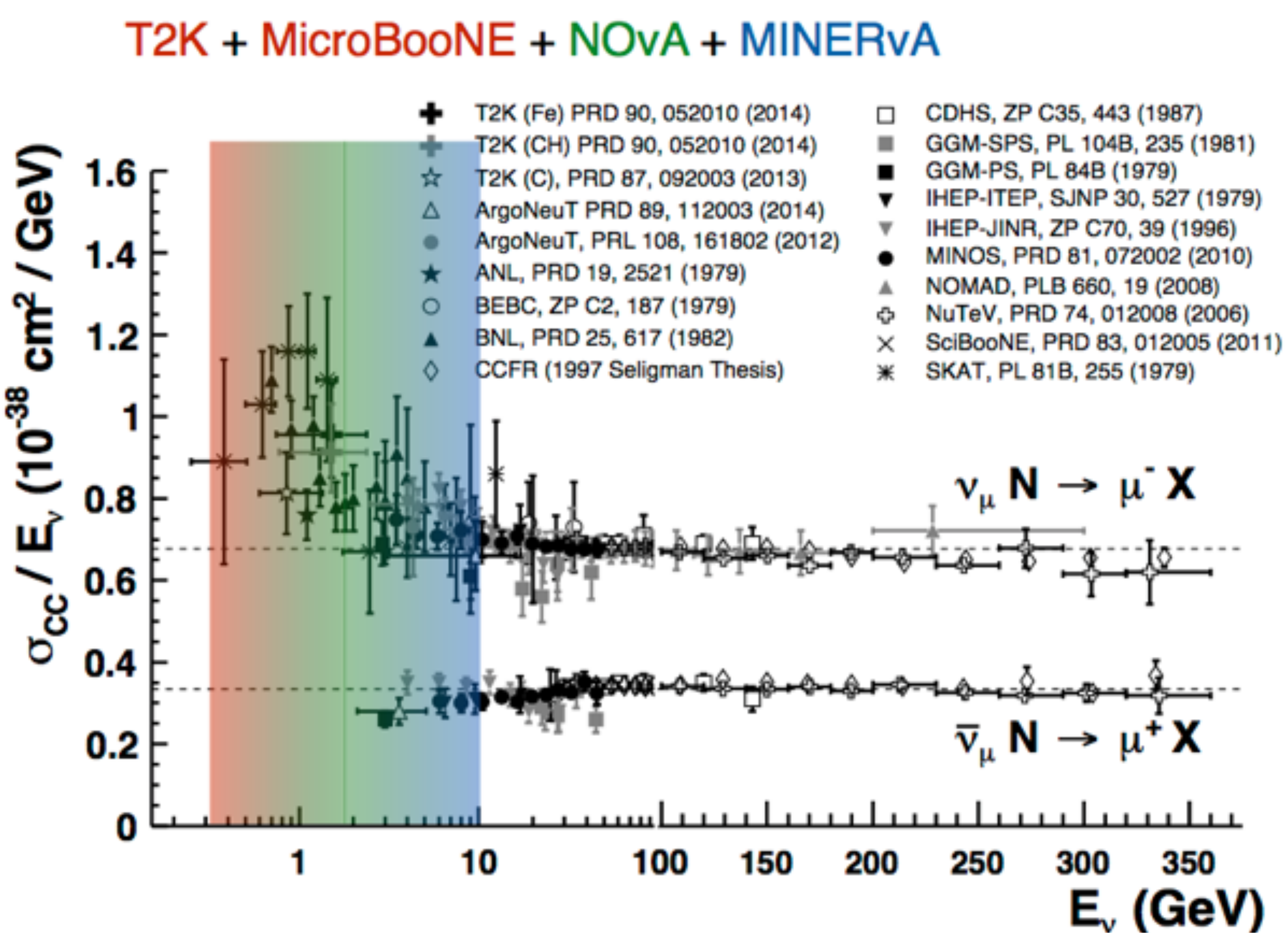
Deep Inelastic Scattering

Beam at NOvA

NOvA has a narrow band beam and it is sensitive to many interaction channels

Nice overlap with other currently running experiments

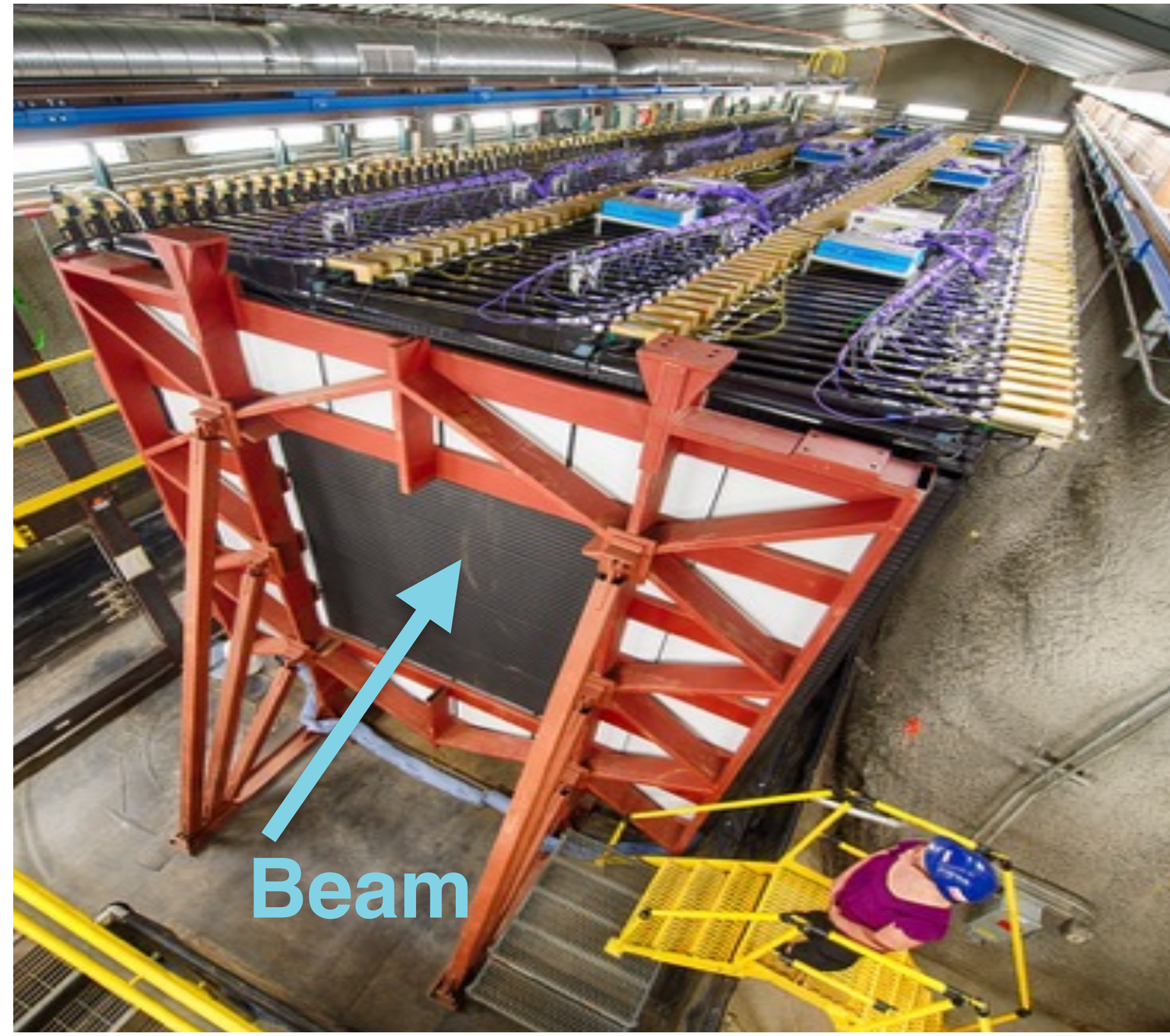


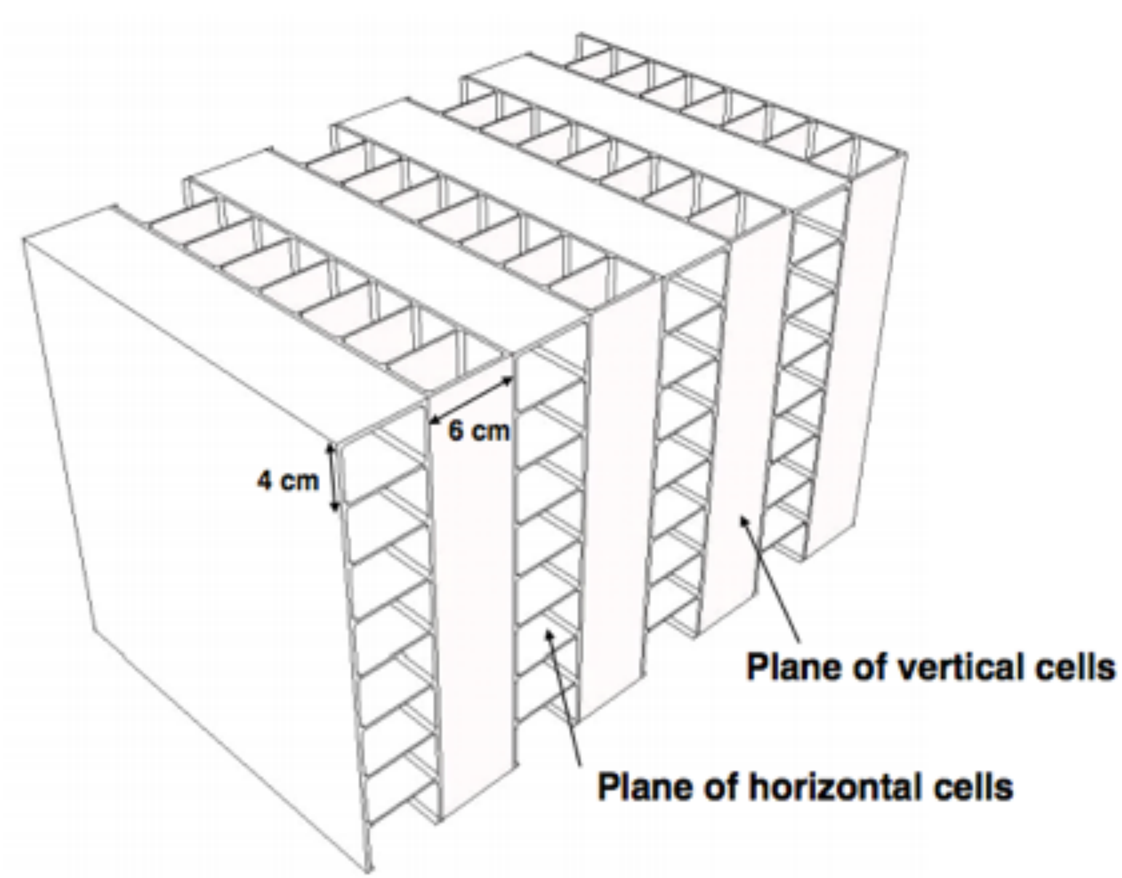


C. Patrignani et al. (Particle Data Group), Chin. Phys. C, 40, 100001 (2016)

The NOvA Near Detector

- 20,193 identical cells constructed into 214 alternating horizontal and vertical planes
- Each plane is 96 cells long





- Cells are filled with liquid scintillator apart from the Muon Catcher which is made from steel to increase efficiency to contain muons (range out ~2 GeV muons)

Cross Section Definition

$$\left(\frac{d\sigma}{dx}\right)_i = \frac{\sum_j U_{ij}\left(N_j^{Sel} - N_j^{Bkg}\right)}{\epsilon_i (\Phi T) \Delta x_i}$$

where

$N_j^{Sel} - N_j^{Bkg}$: data - background = signal

U_{ij} : Unfolding matrix (reco j to truth i)

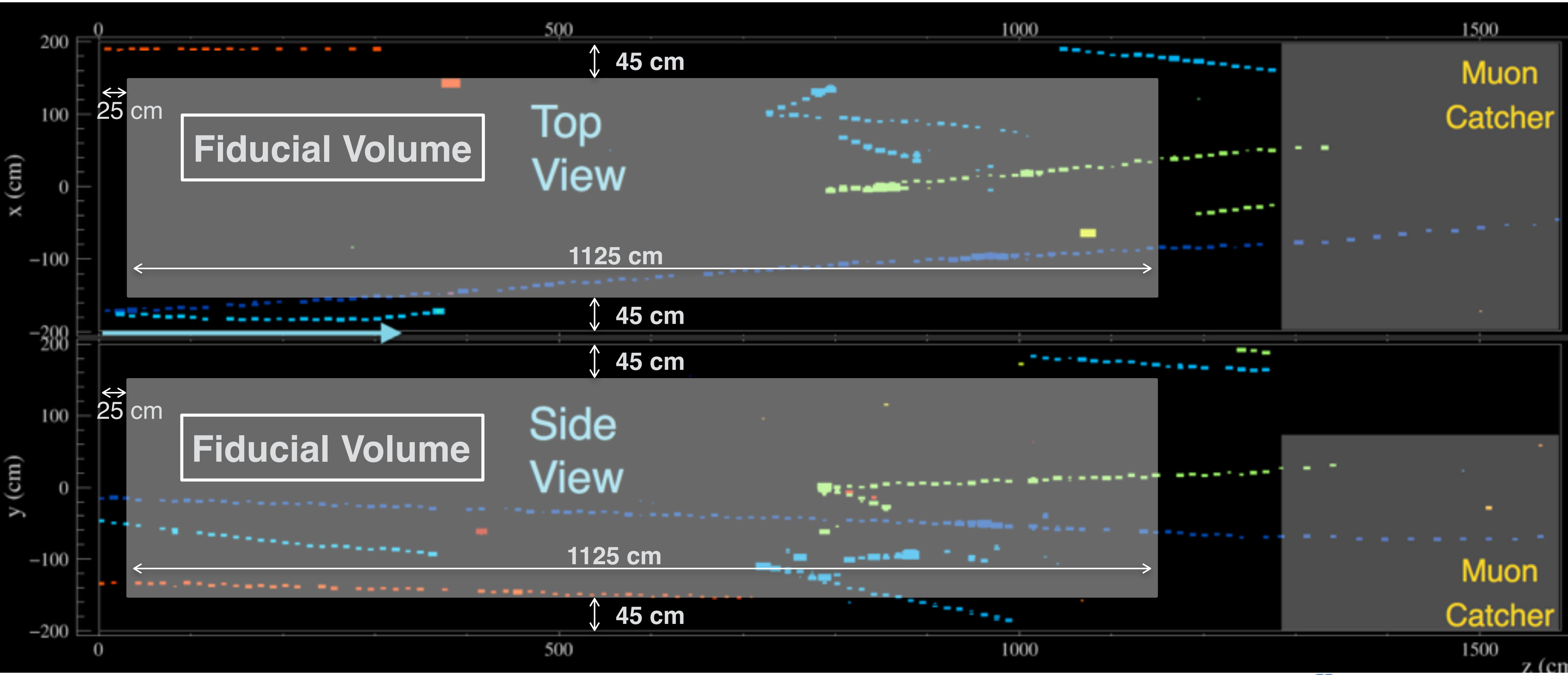
ϵ_i : Efficiency for bin i

ΦT : Flux times target number

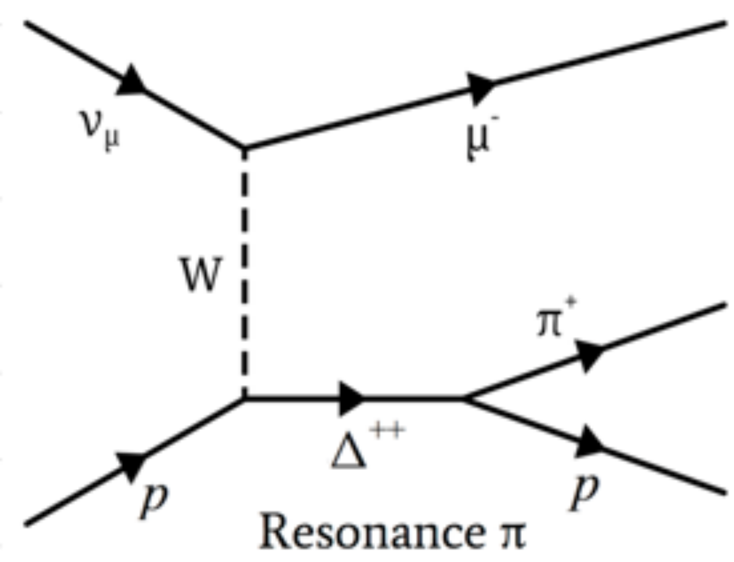
Δx_i : Bin Width

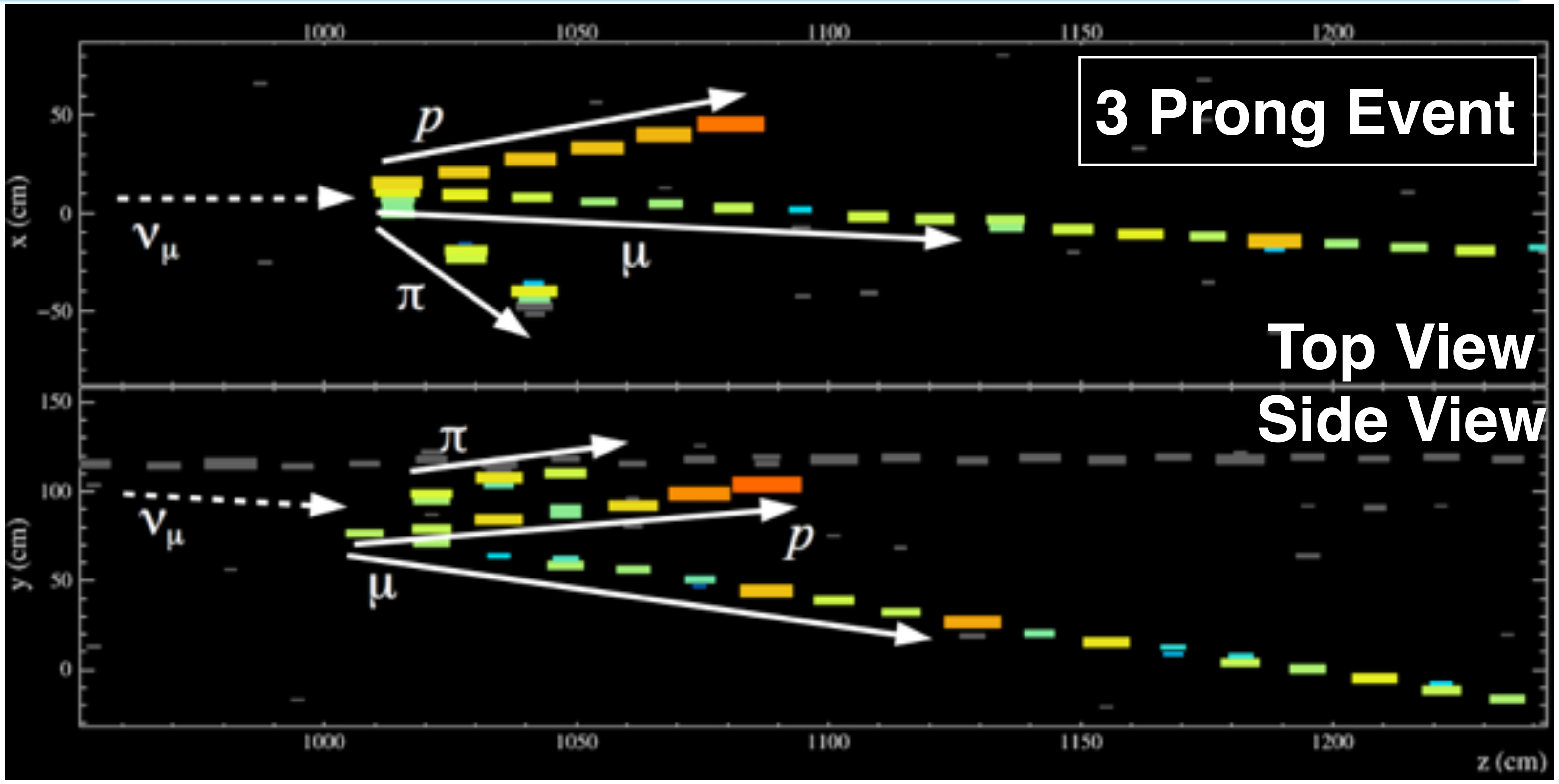
Event Selection

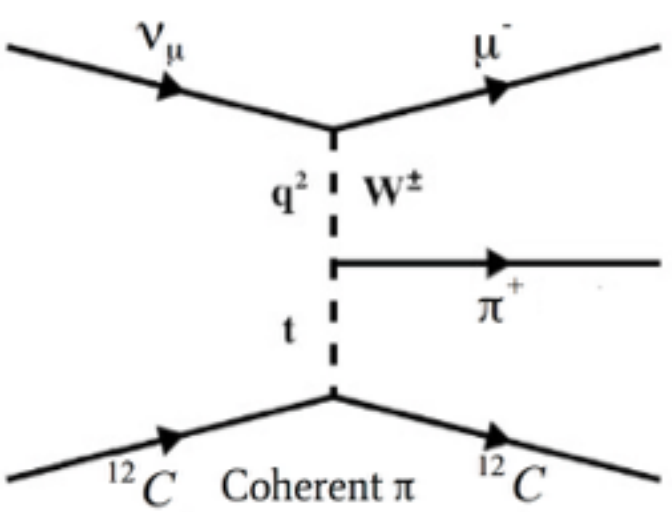
- All track vertices are required to be within the fiducial volume
- To reject neutrino interactions with the surrounding rock, tracks near the edge of the detector are not selected
- Events with hadronic activity near the muon catcher are excluded

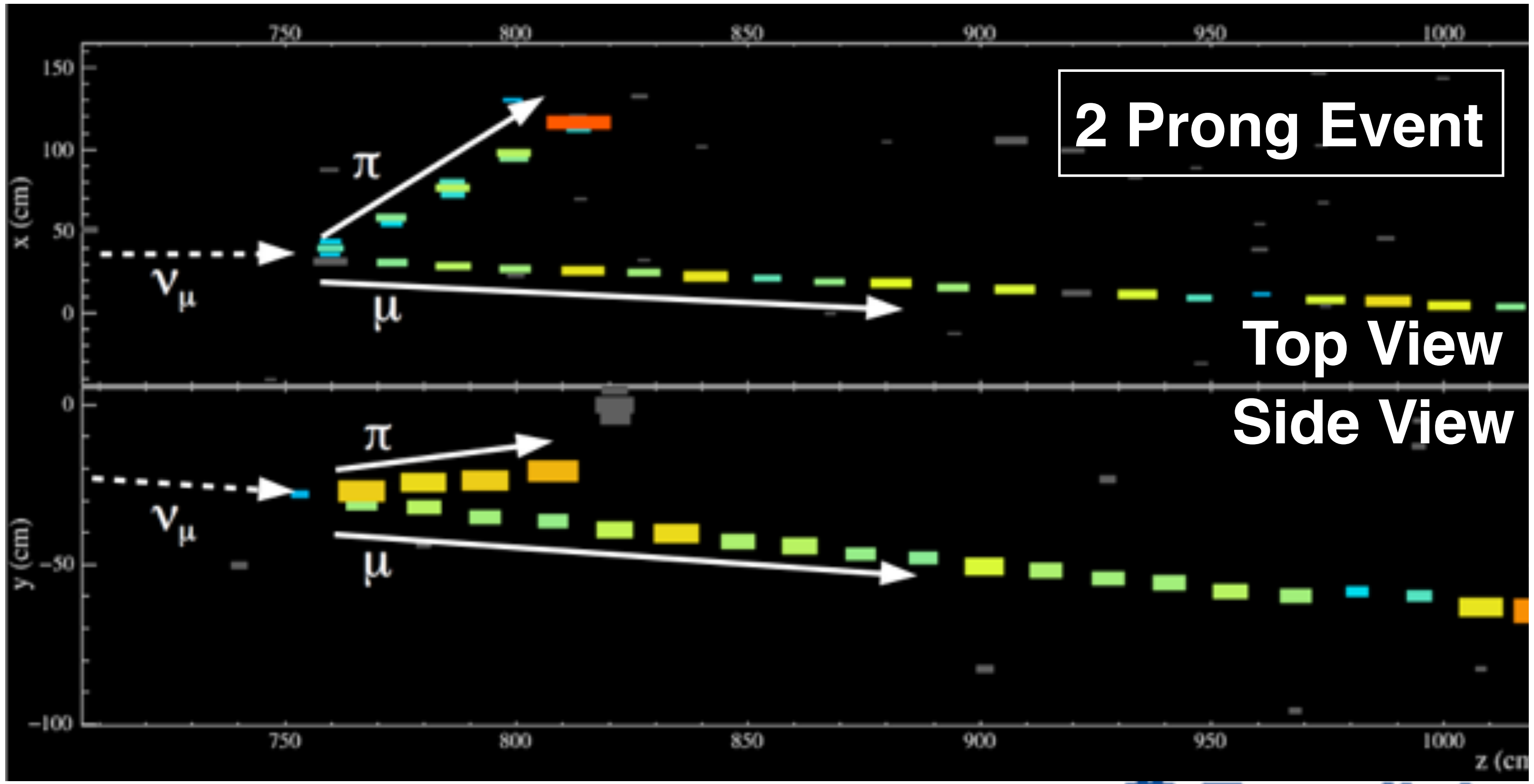


Simulated NOvA Events







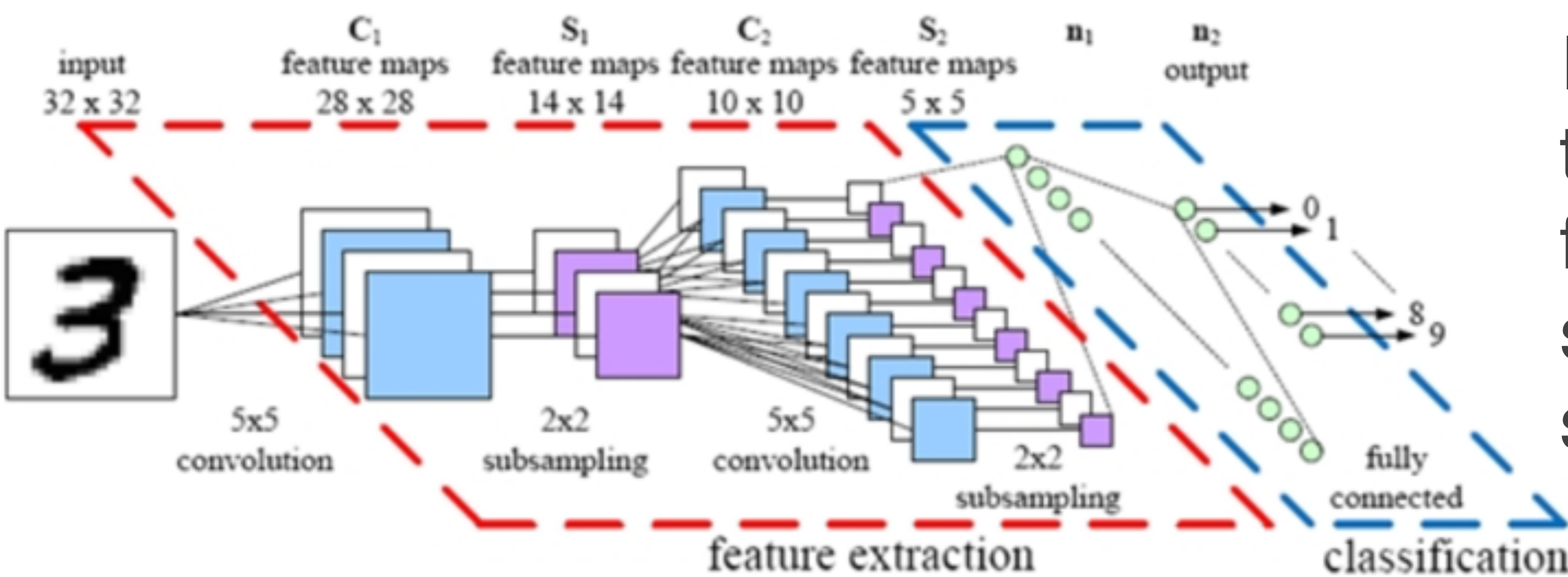


Event Identification

NOvA has successfully used deep learning technique to identify electron neutrino events for the oscillation analysis

» Inspired by GoogLeNet architecture, an Artificial Neural Net was developed (arXiv:1604.01444) to classify neutrino interactions

» An improvement to sensitivity was shown, equivalent to 30% more exposure



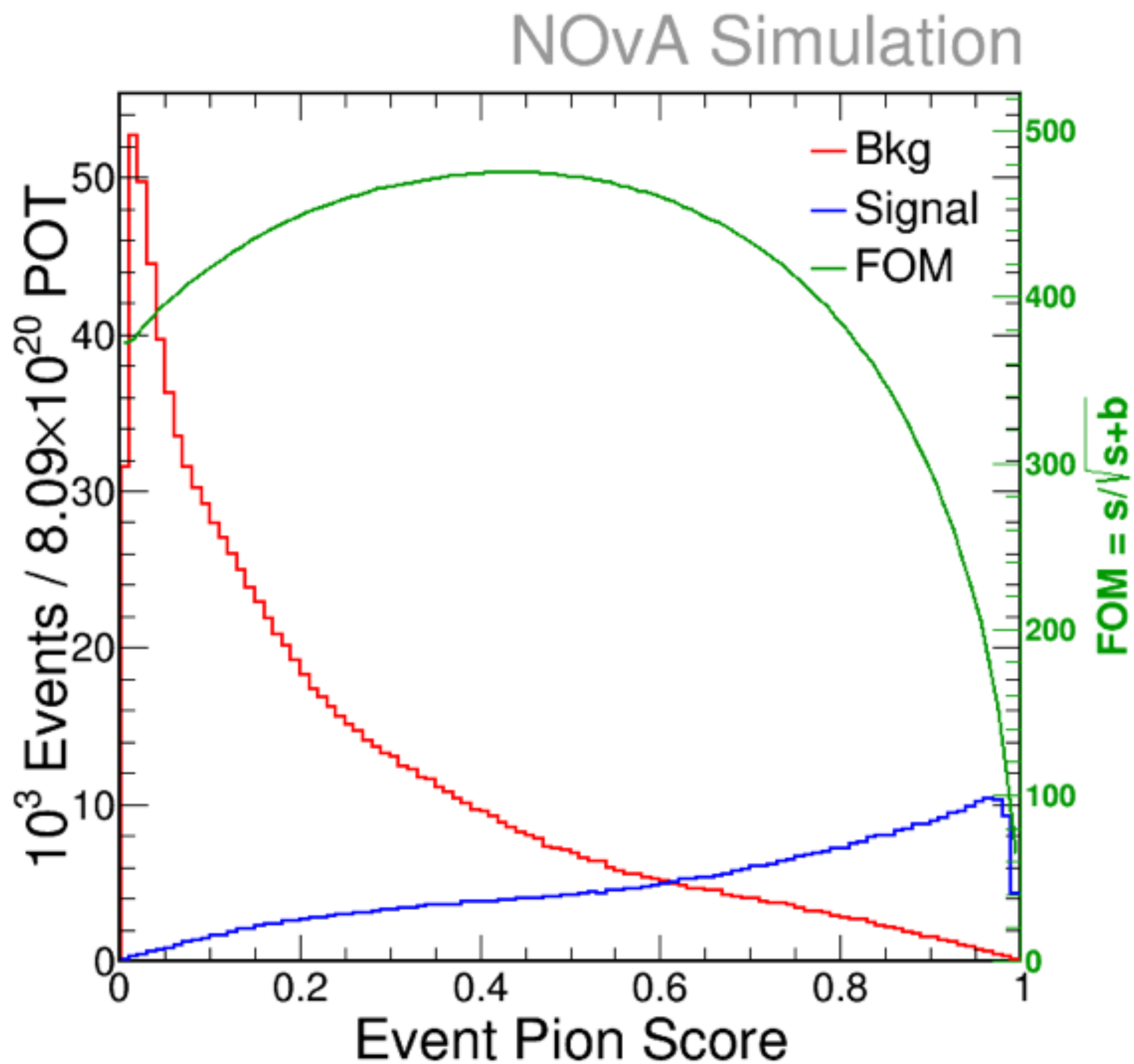
Convolution Neural Network Architecture Model

It learns the topological features of the signal and output a set of weights

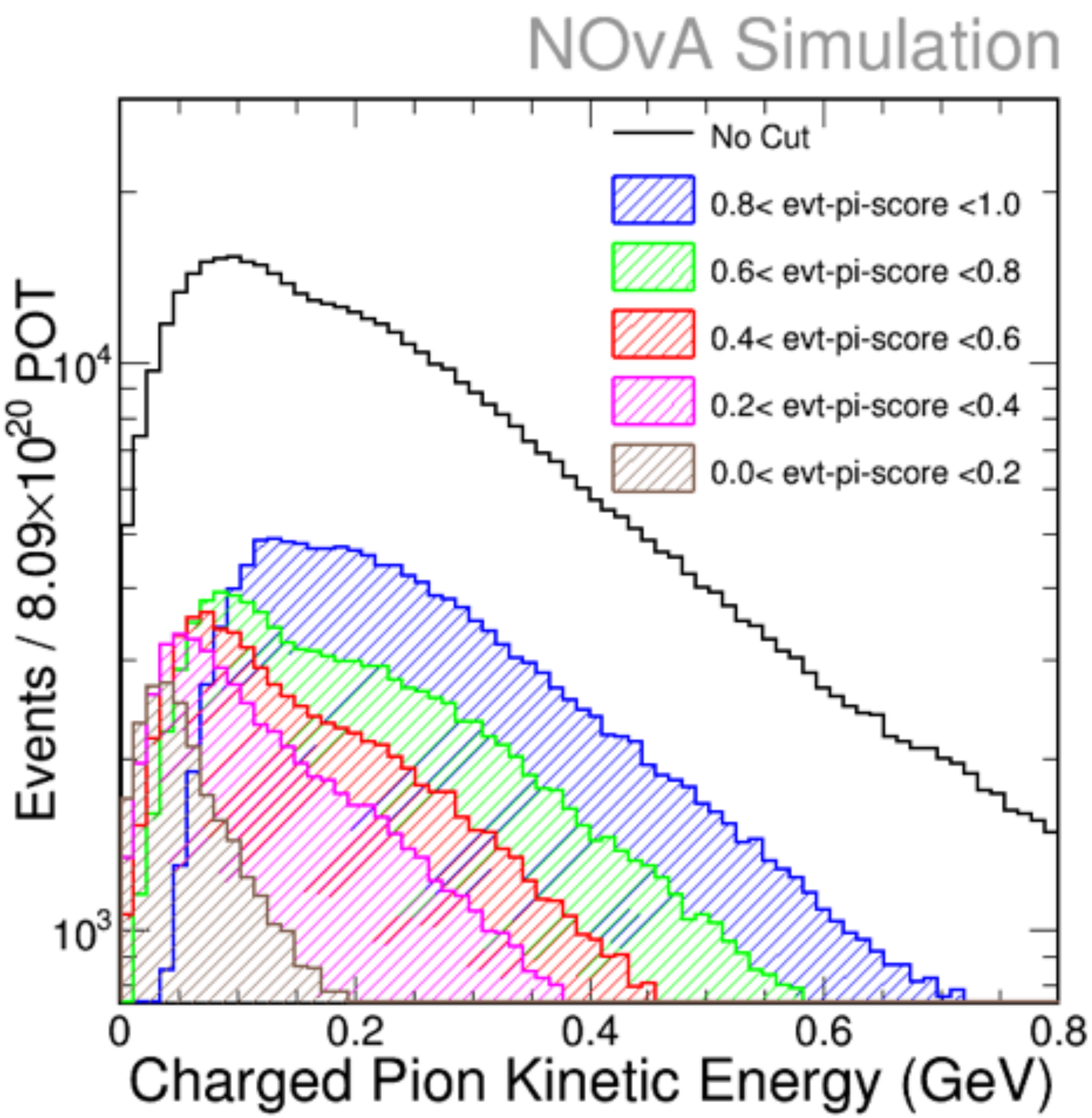
Event Identification

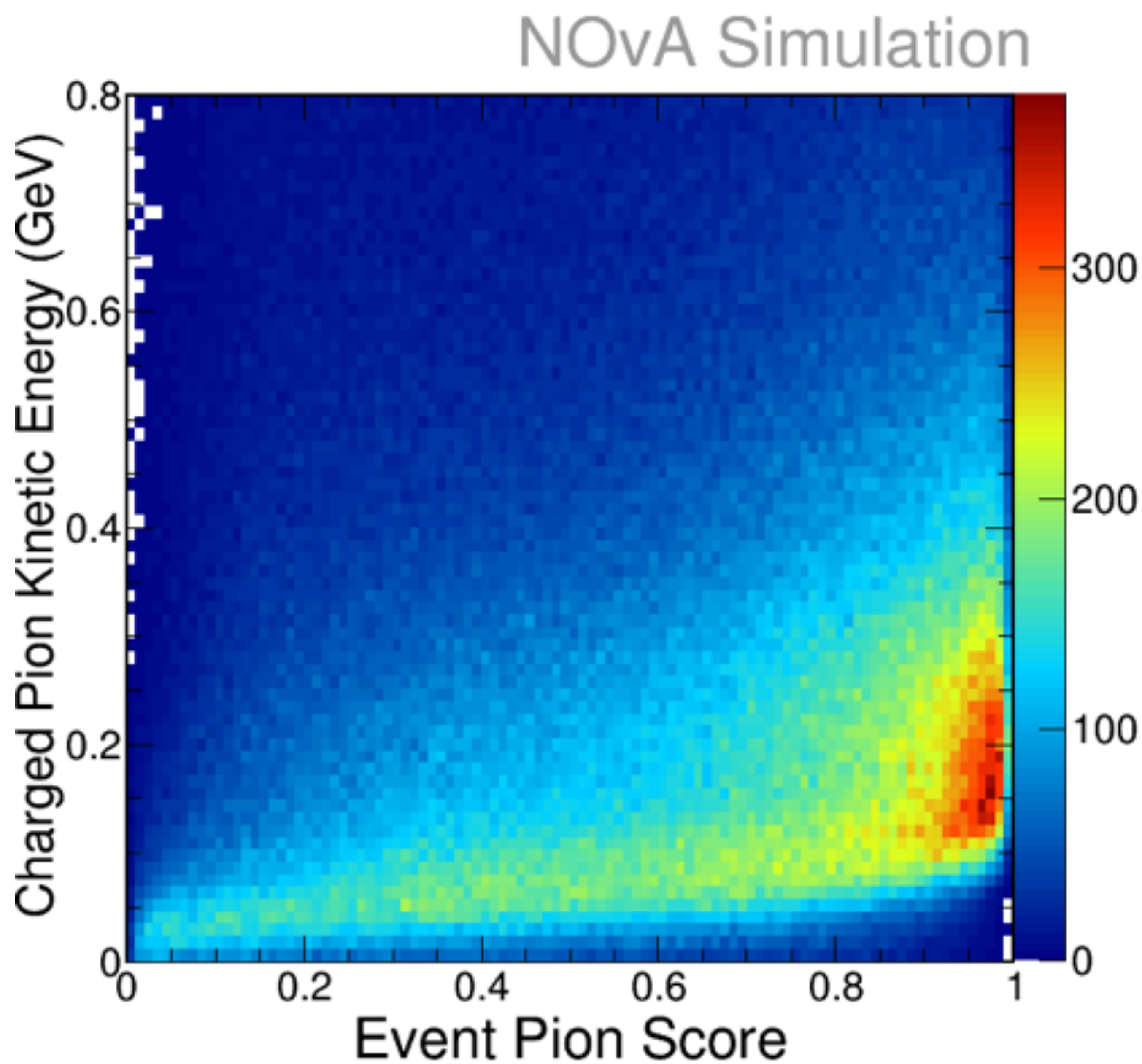
This architecture was used to classify final state interactions

- Having an event id, a semi-inclusive cross section measurement can be made with respect to the lepton kinematics, giving better efficiency to low energy particles than traditional reconstruction
- Potentially on top of classifier techniques can be developed to id the reconstructed objects



Event Identification Energy Dependence



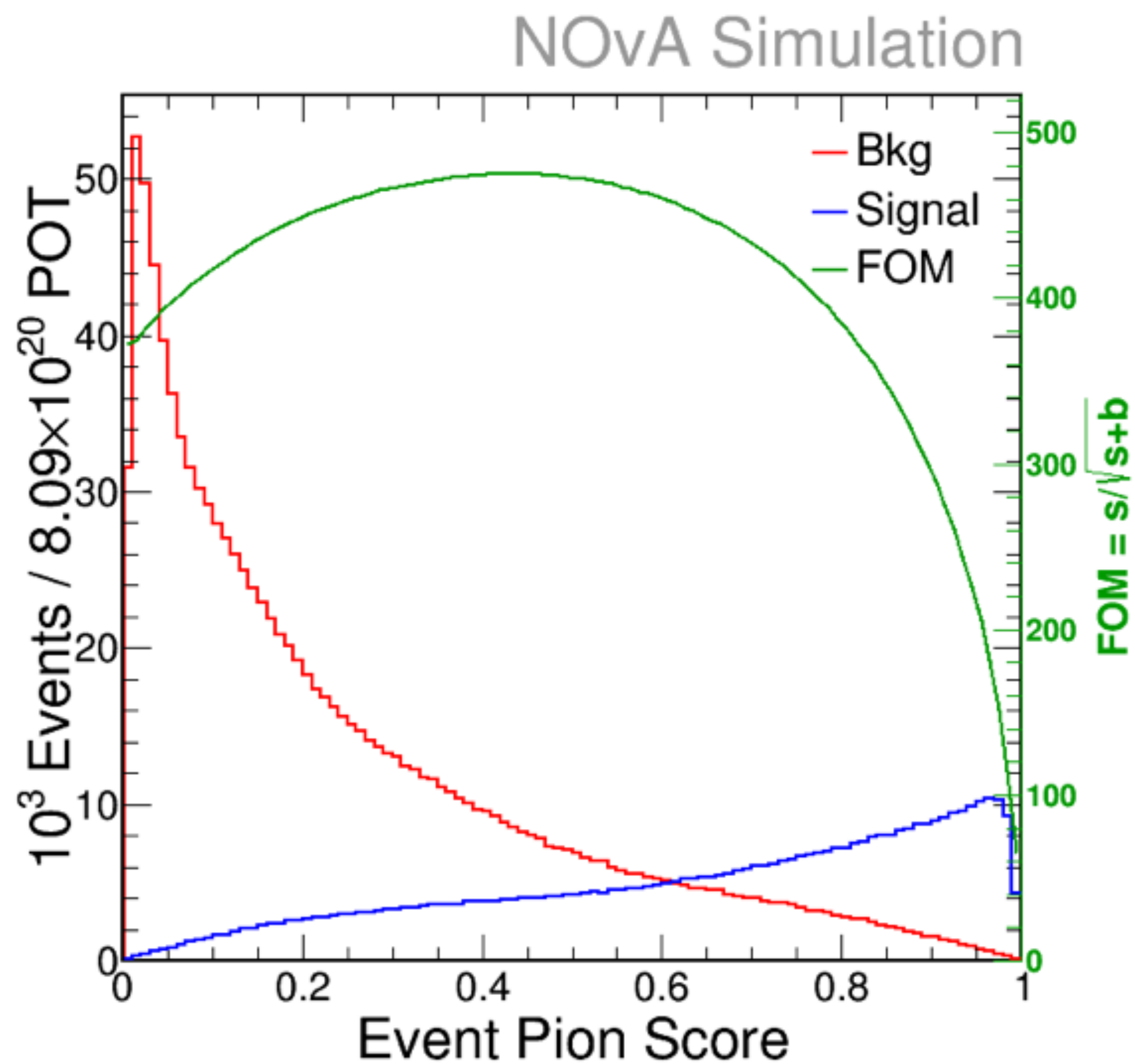


Event ID is better for high energy charge pions

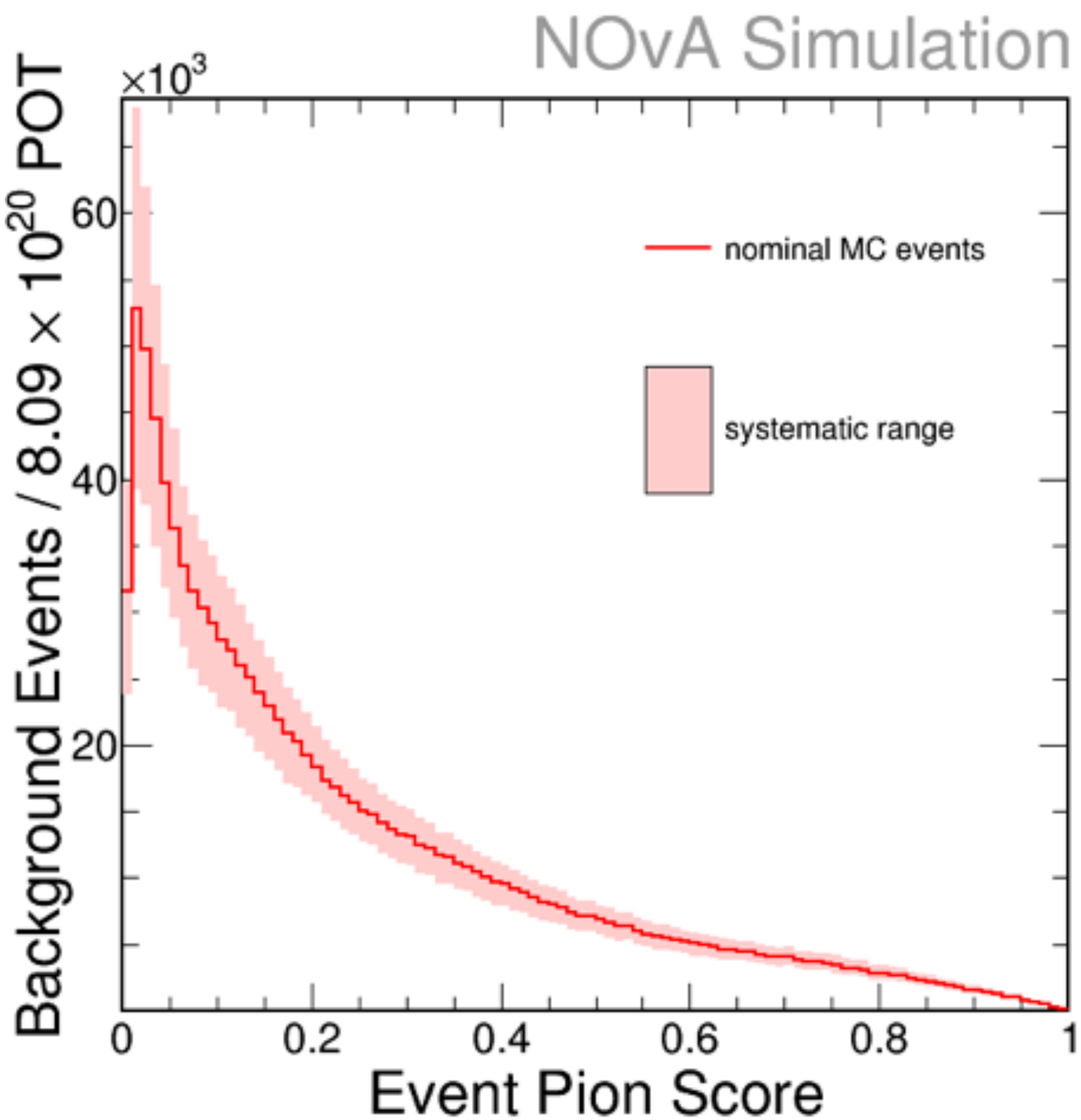
Event Identification

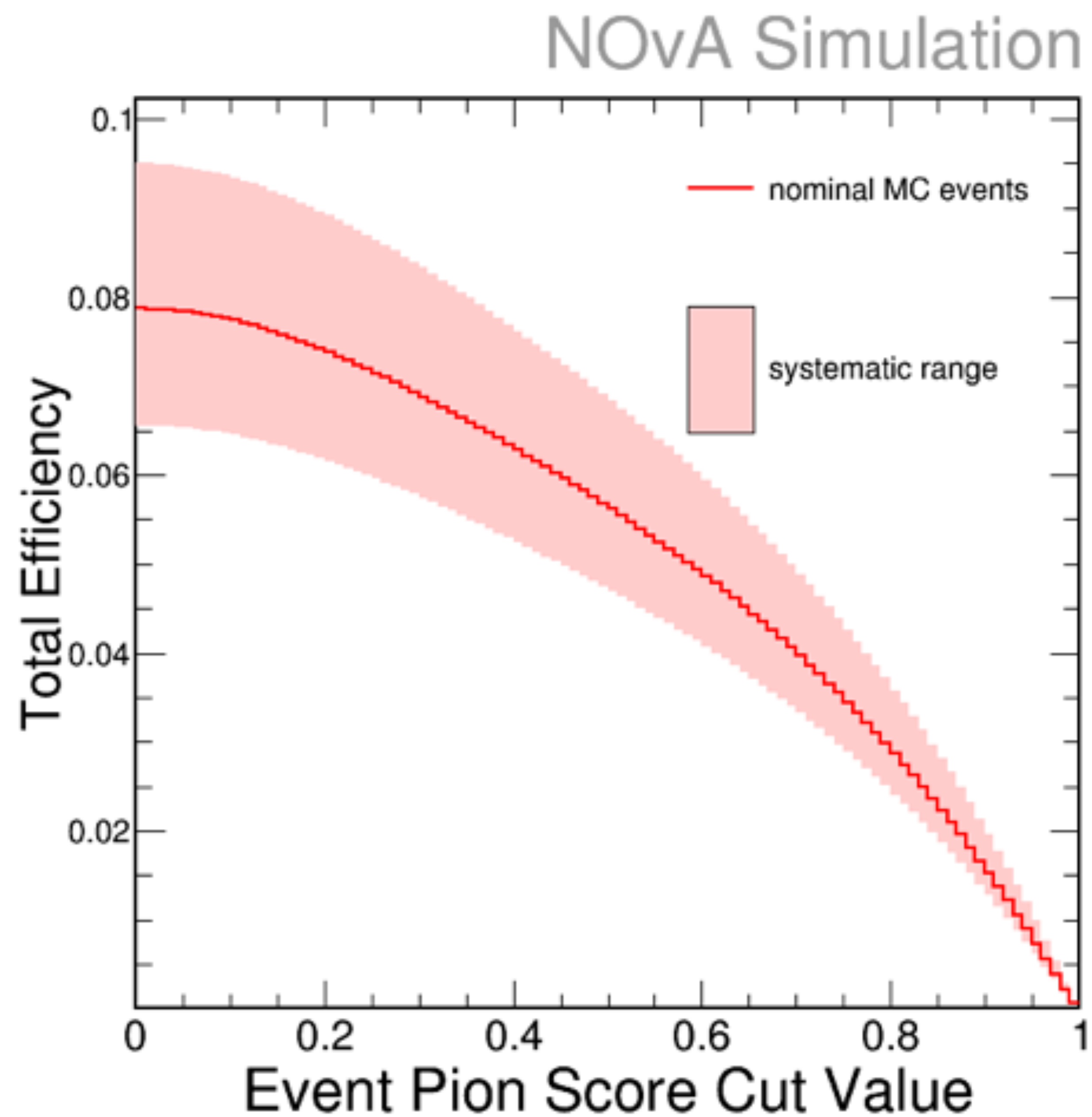
- Since charge pion production has large cross section, find better FOM that statistical to improve the quality of the measurement.
- Quality is being driven by systematics and background events
- Fractional uncertainty of the cross section:

$$\frac{\delta\sigma}{\sigma}=\sqrt{\left(\frac{\delta N_{bkg}^{syst}}{N_{sel}-N_{bkg}}\right)^2+\left(\frac{\delta\epsilon}{\epsilon}\right)^2}$$



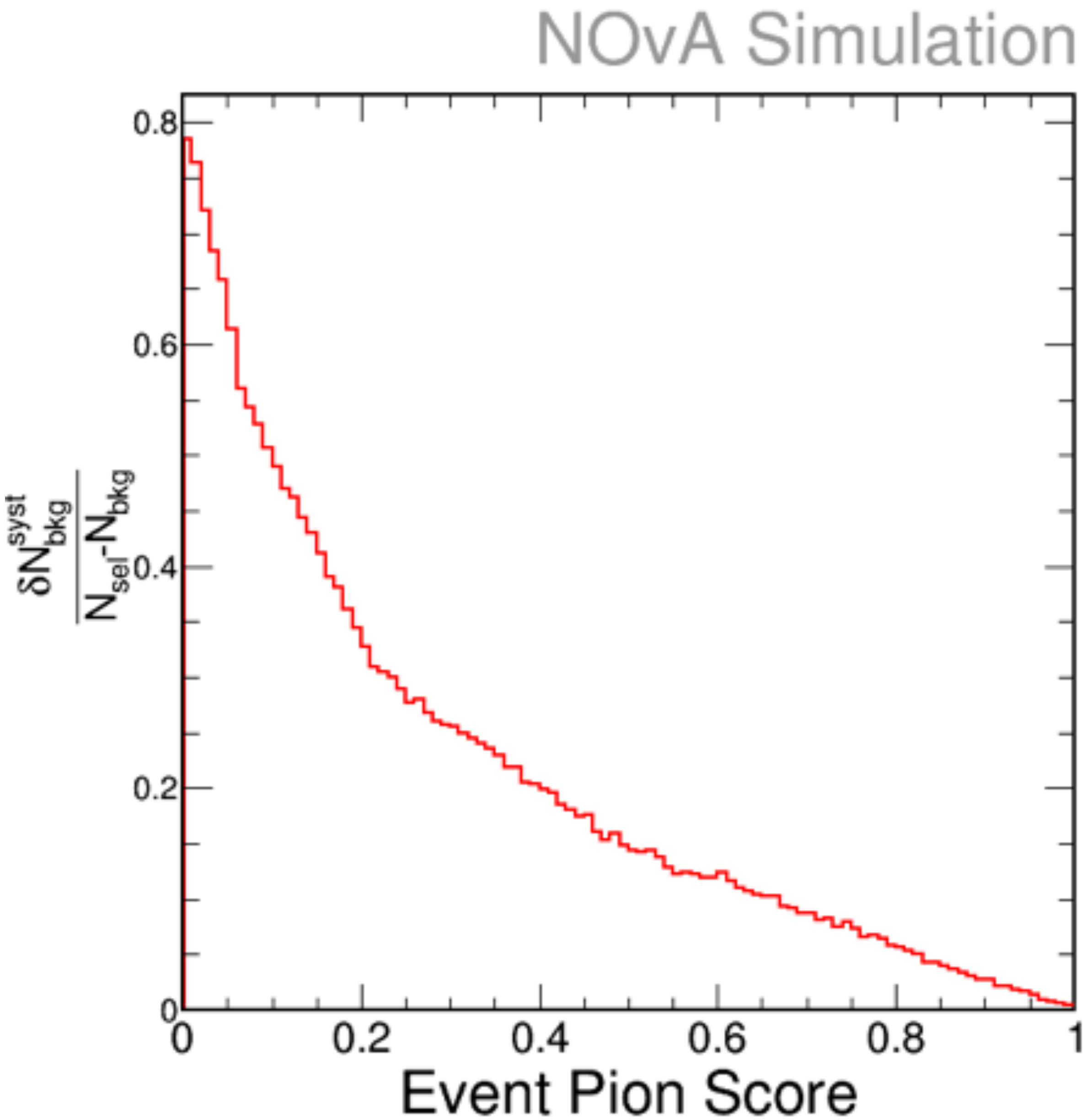
Optimize Event Selection based on Systematics

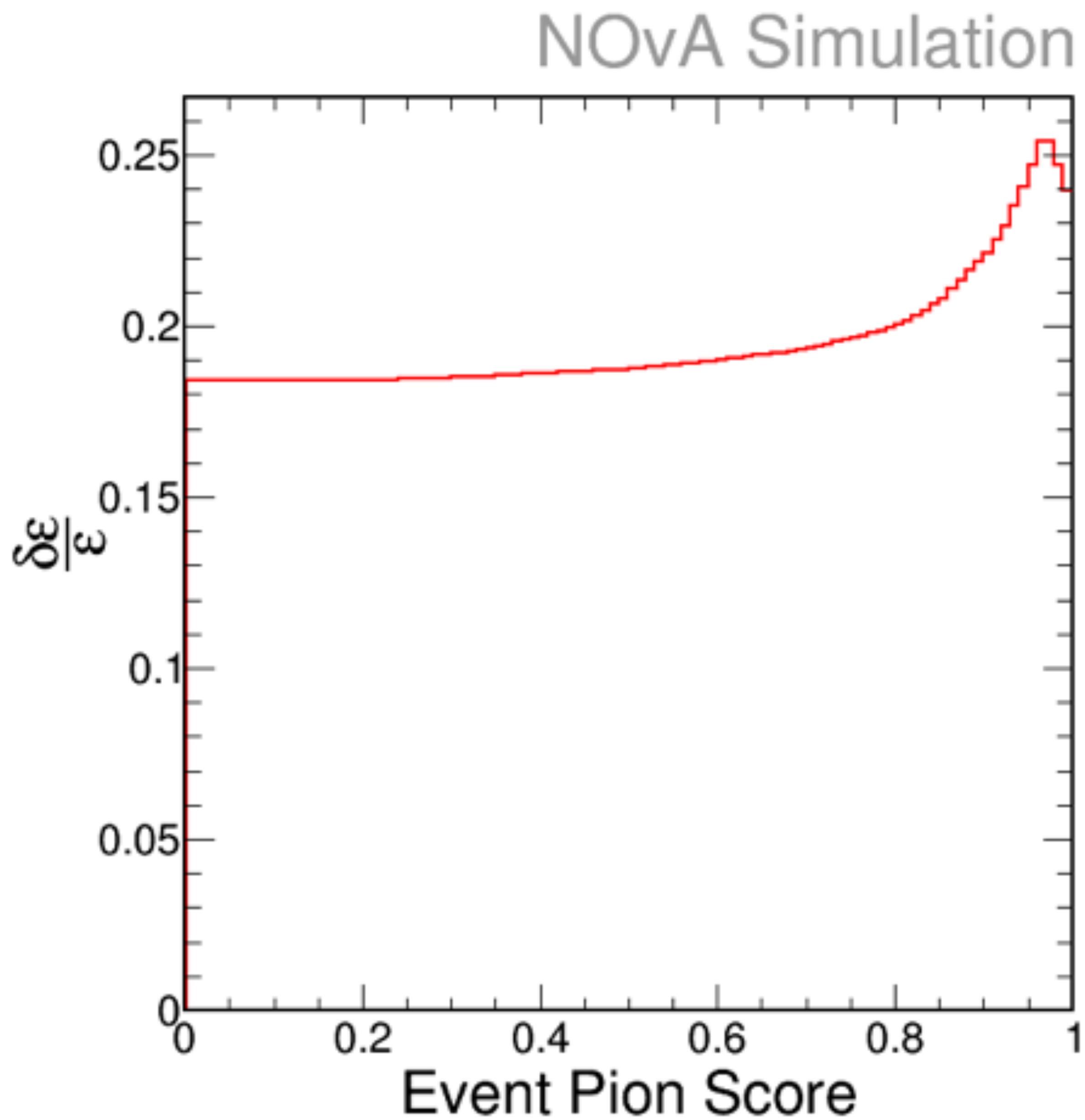




Systematics that were used are: calibration uncertainty, cross section model uncertainty, flux uncertainty

Optimize Event Selection based on Systematics





$$\frac{\delta\sigma}{\sigma} = \sqrt{\left(\frac{\delta N_{bkg}^{syst}}{N_{sel} - N_{bkg}}\right)^2 + \left(\frac{\delta\epsilon}{\epsilon}\right)^2}$$

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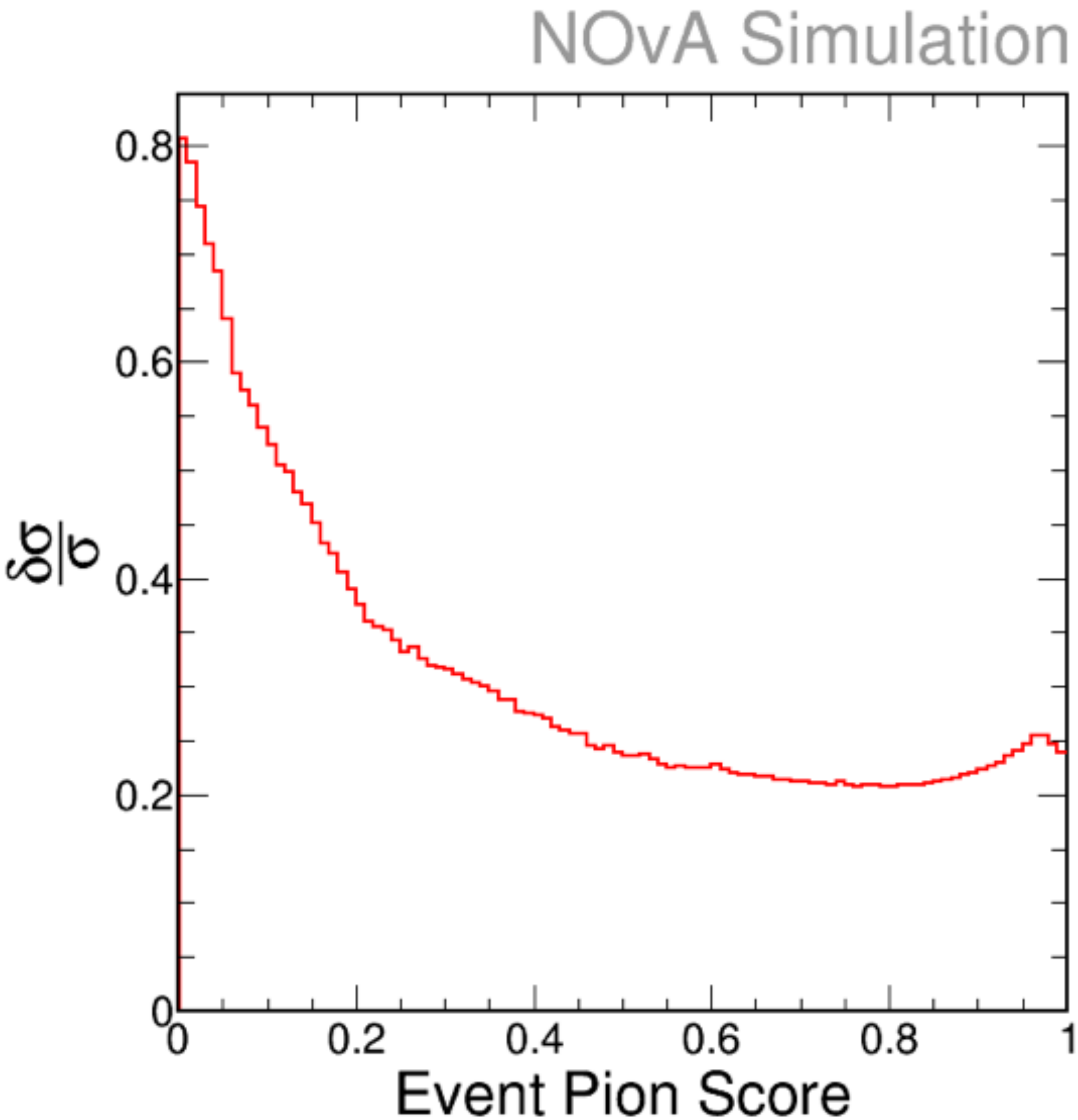

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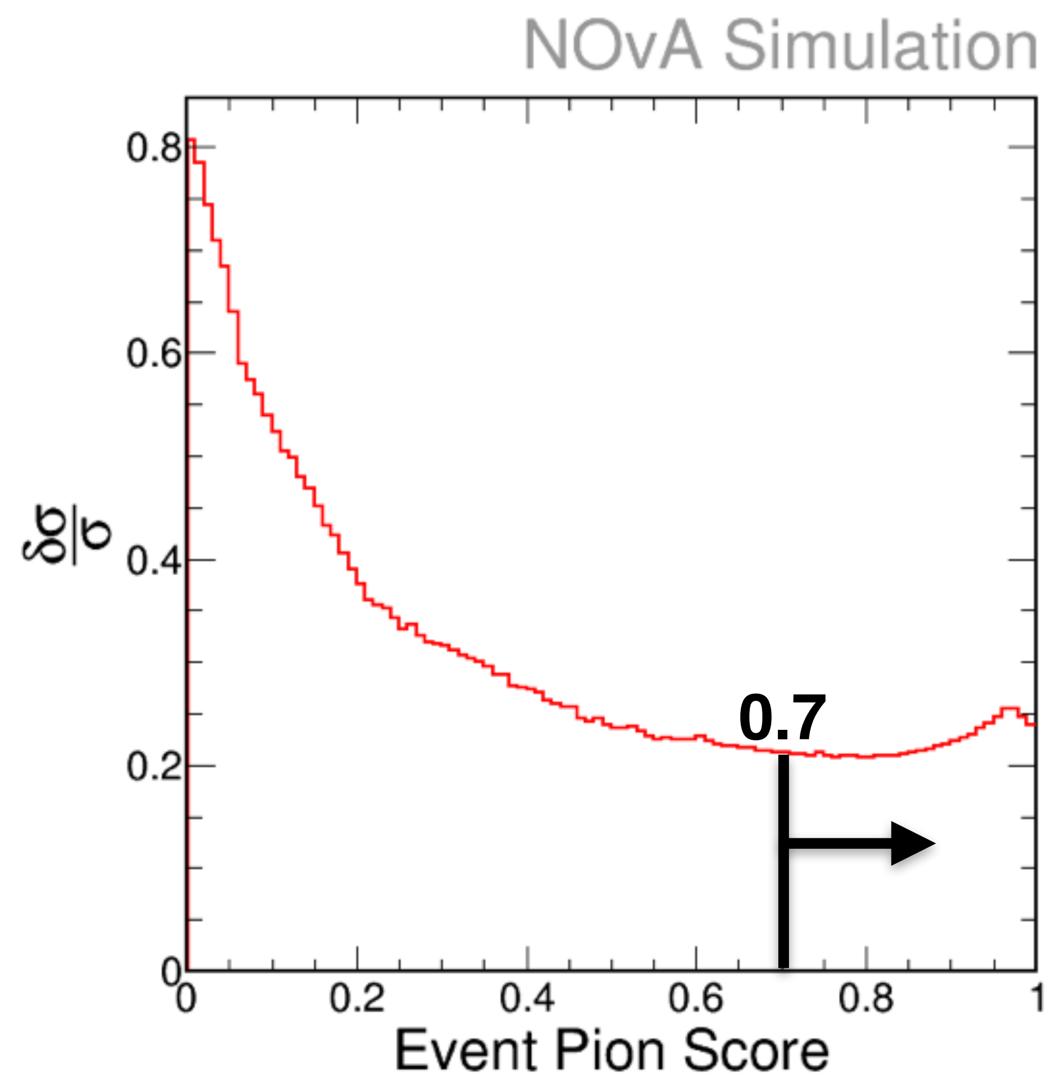
Systematics that were used are:

- calibration uncertainty
- cross section model uncertainty
- flux uncertainty

Optimize Event Selection based on Systematics

- Table shows events selected with event-pion score bigger than 0.7
  - POT exposure corresponds to 8.09 e20
- Main background is CC0π events
- A detailed study is underway for this particular topology



	Cut Value	Selected	Signal	Relative Eff (%)	Purity (%)	NC (%)	CC0Pi (%)	Nue (%)	Other (%)
Presel	—	2,684,460	740,724	12.4	27.6	28.6	33.8	2.0	5.7
CVN-pi	0.7	305,438	237,519	32.1	77.8	2.9	13.3	0.0	5.4

Summary && Future Work

- We are planning to do a measurement of double differential cross section with respect to muon kinematics
  - For the pions that are reconstructable we want to do a measurement with the pion kinematics as well (more related to hadronic interactions)
- Event ID of the charge pion events has been developed
- Framework to make the selection based on optimizing the quality of the measurement
- A multi label ANN is underway which might help us with particular difficult topologies and open more possibilities
- Weight events with different generator trying to quantify model dependence of selection and technique
  - Traditional approaches to id pions