Improving the NOvA 3-Flavour Neutrino Oscillation Analysis Selection

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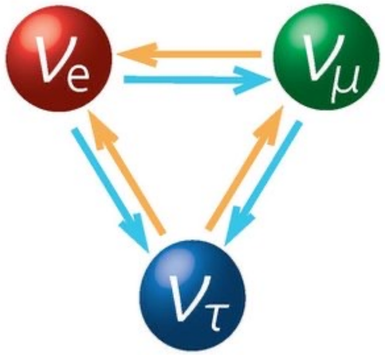
NOvA

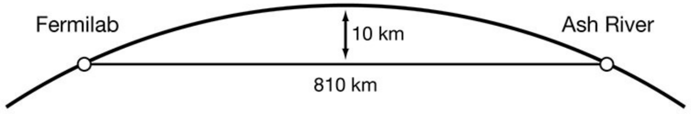
- Long-baseline neutrino experiment studying neutrino oscillations

- Two functionally identical, finely granulated tracking calorimeter detectors 810km apart
  - Neutrinos from the NuMI beam
  - Underground near detector 300 tons
  - Surface far detector 14 ktons

- The detectors are placed 14.6 mrad off the beam axis to obtain a narrow energy peak near where the oscillations are maximal ($\sim 2\ GeV$)

- 4 neutrino oscillation channels
  - **$\boldsymbol{v_\mu}$ disappearance** ($v_\mu \rightarrow v_\mu$)
  - **$\boldsymbol{v_e}$ appearance** ($v_\mu \rightarrow v_e$)
  - **Respective anti-neutrino channels**





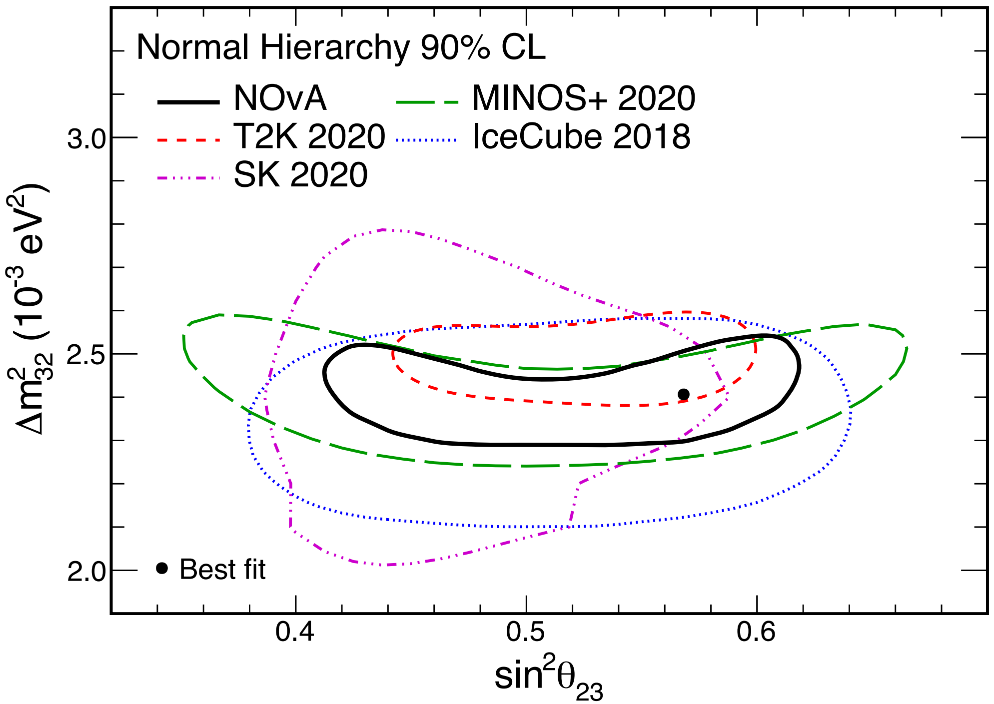
Physics Goals of NOvA

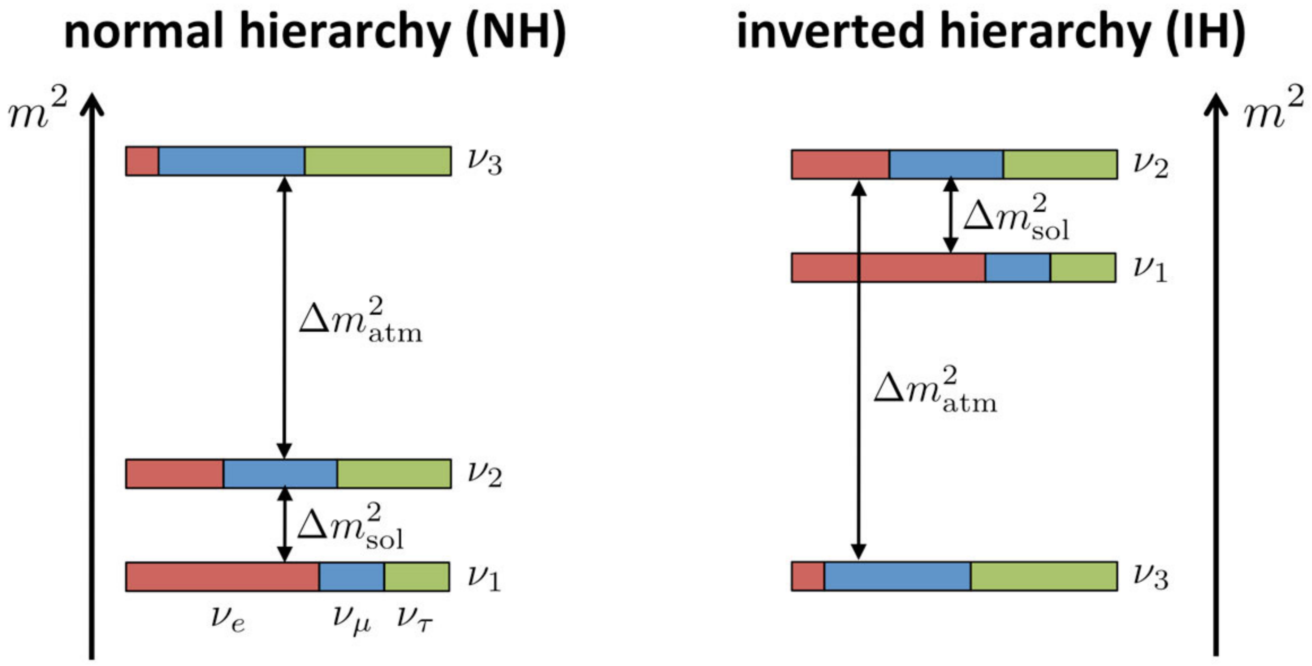
- Measure the neutrino oscillation parameters Δm^2_{32} and $sin^2\theta_{23}$

2-flavour approximation: (L = 810 km)

$$P(v_\mu \rightarrow v_\mu) = 1 - sin^2(2\theta_{23})sin^2(\frac{1.27\Delta m^2_{32}L}{E})$$

- Set limits to mass hierarchy, θ_{23} octant and δ_{CP}

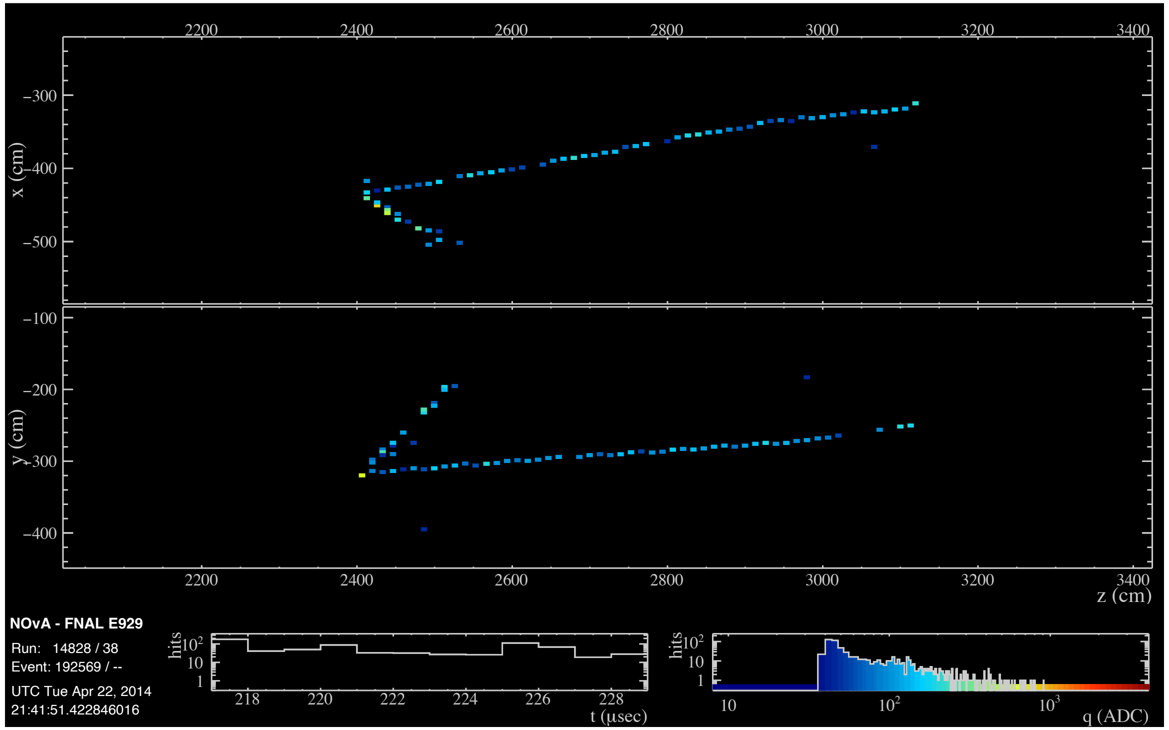




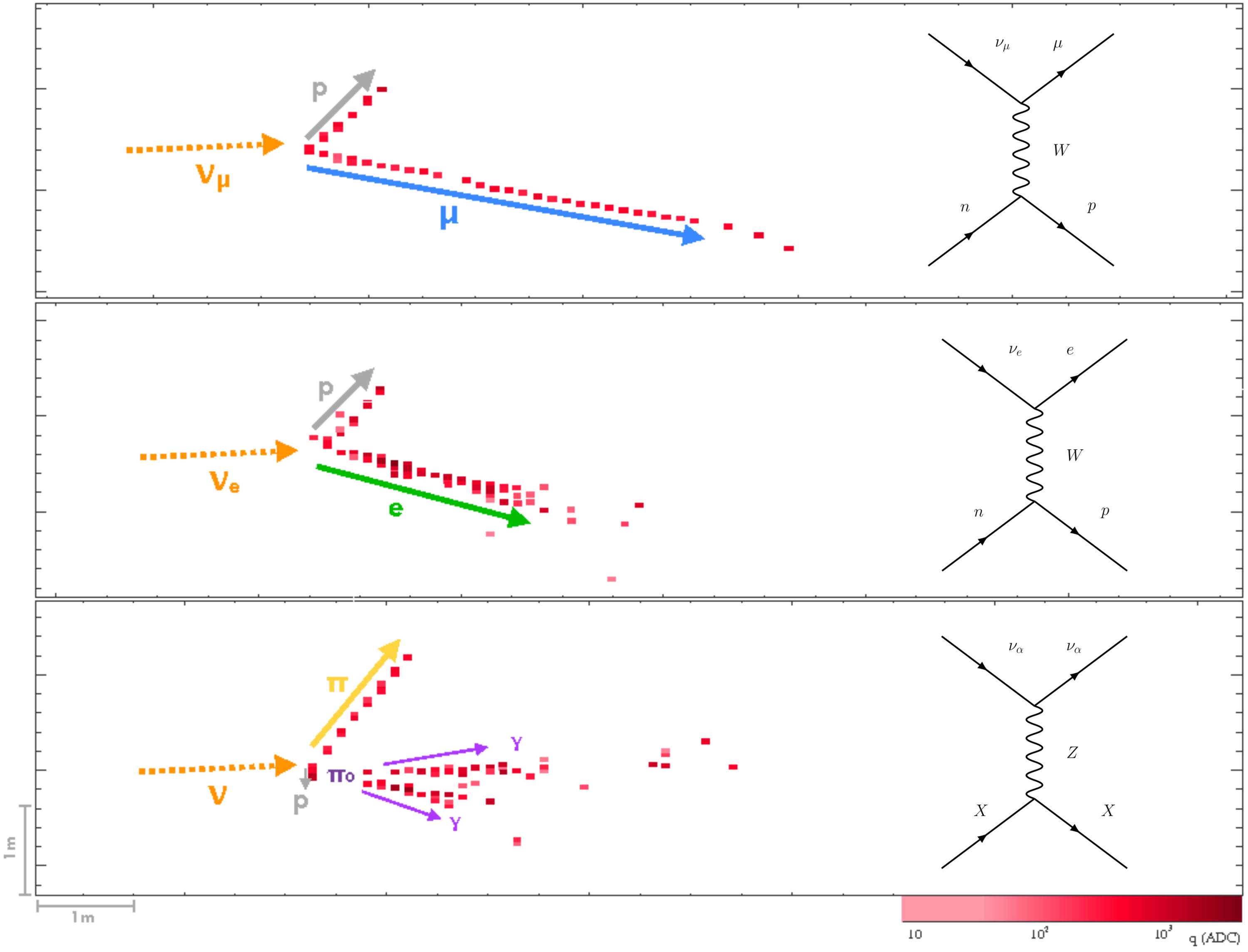
Event selection study

- NOvA is still taking data, but there are other ways to improve the future results:
  - improve uncertainty and systematics
  - better **event selection** and energy estimation

- NOvA signal is the observed charged current (CC) υ_μ neutrino interactions and background is all other neutrino interactions (NC, υ_e and υ_τ)
- Current NOvA 3 flavour analysis does not select all υ_μ CC events
  - Recover these events back to the analysis with a cut based on neural network training
  - Potentially improve the sensitivity



- Example Event from NOvA in two orthogonal views



υ_{μ} CC Event

υ_{e} CC Event

NC Event

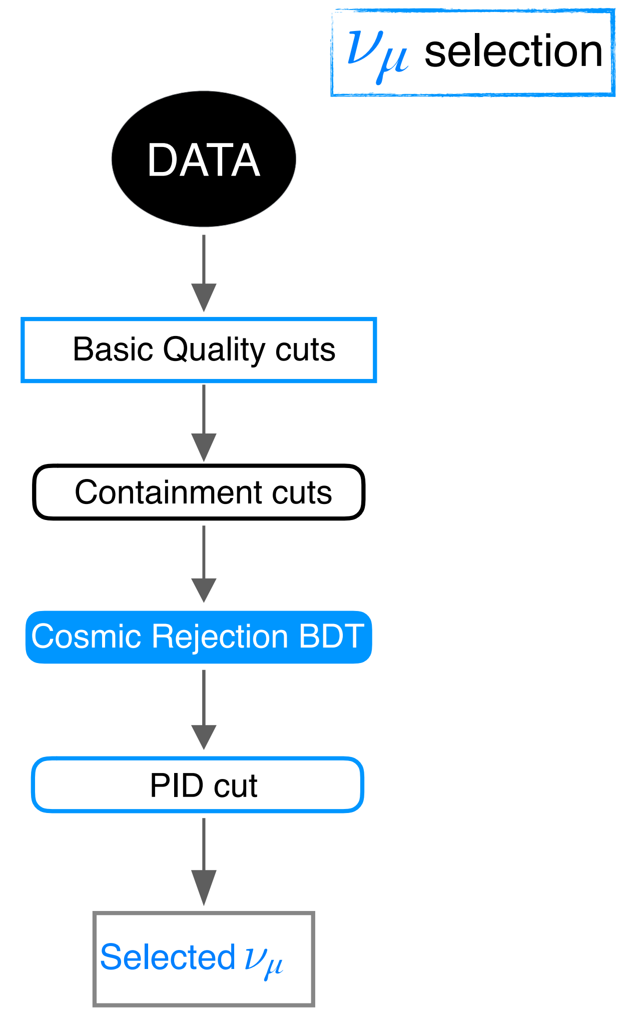
Current NOvA Selection

First basic cuts: energy > 0, sufficient number of hits, track angle (no vertical tracks)

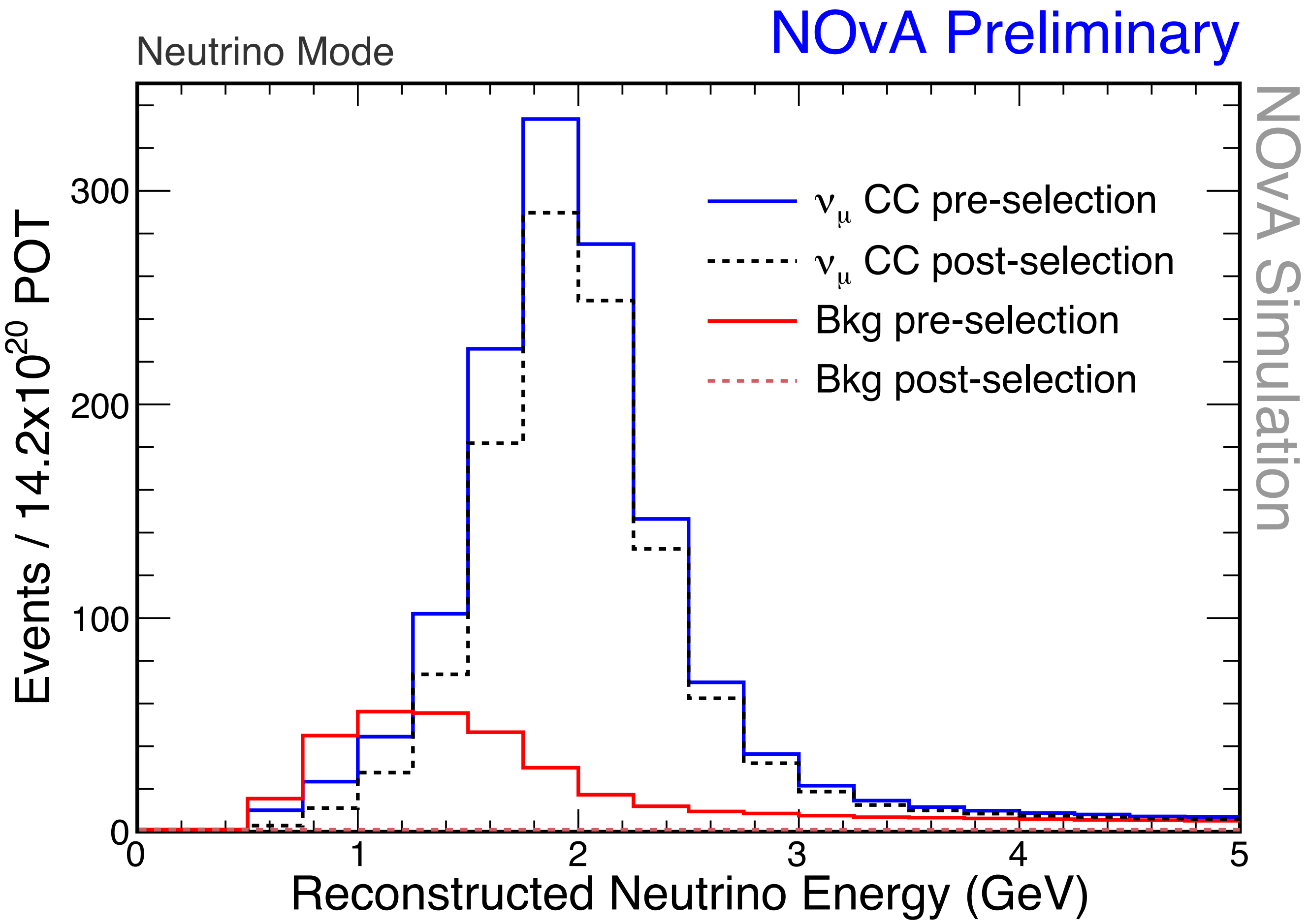
Containment: neutrino energy deposited within the detector

Cosmic Rejection BDT (boosted decision tree): reject cosmic ray events

PID: particle identification using deep learning CNN (convolutional neural network)

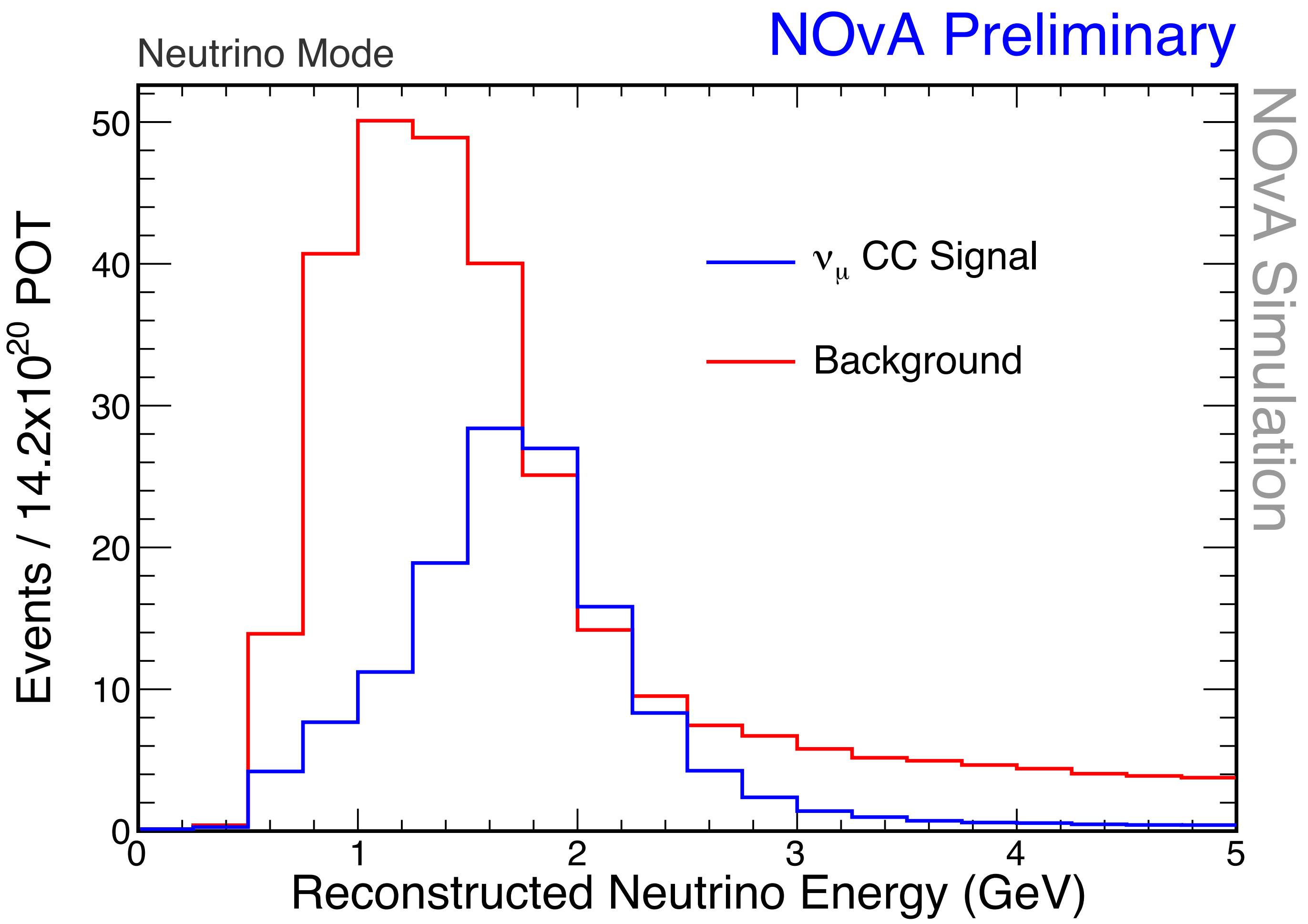


Current NOvA selection



- Data: NOvA simulation
- Far detector
- Scaled to be what is seen in the detector

Events cut from 2020 analysis

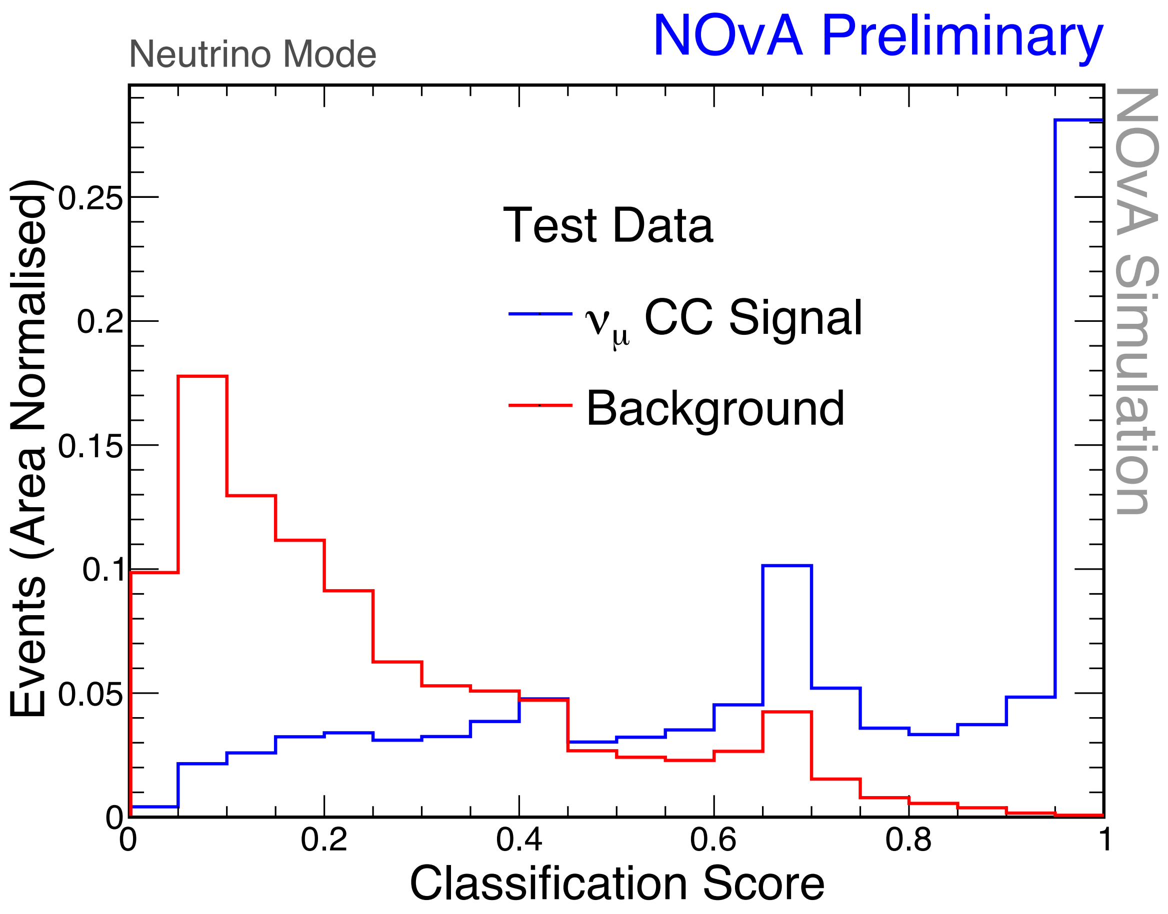


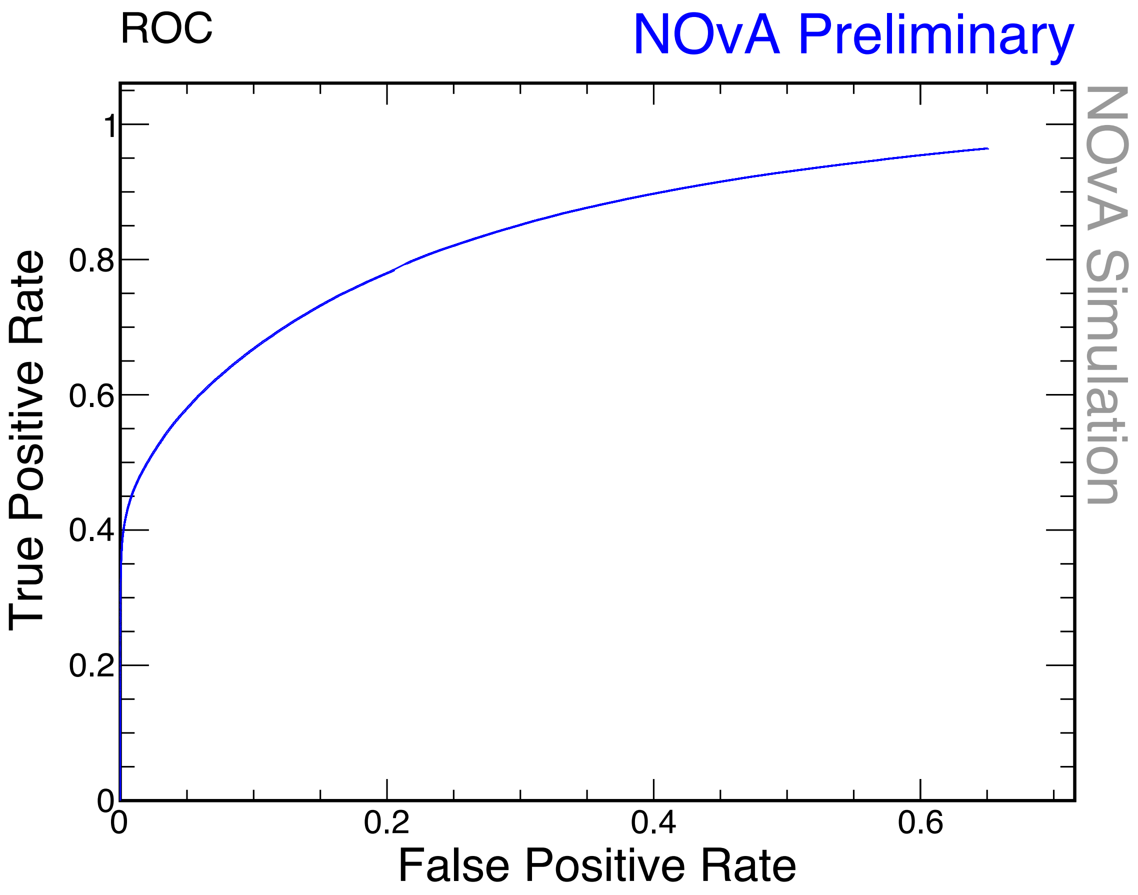
- Pre-selection minus post-selection: events that are currently not selected
- Either failed the cosmic rejection or the particle identification cut

Training the Network

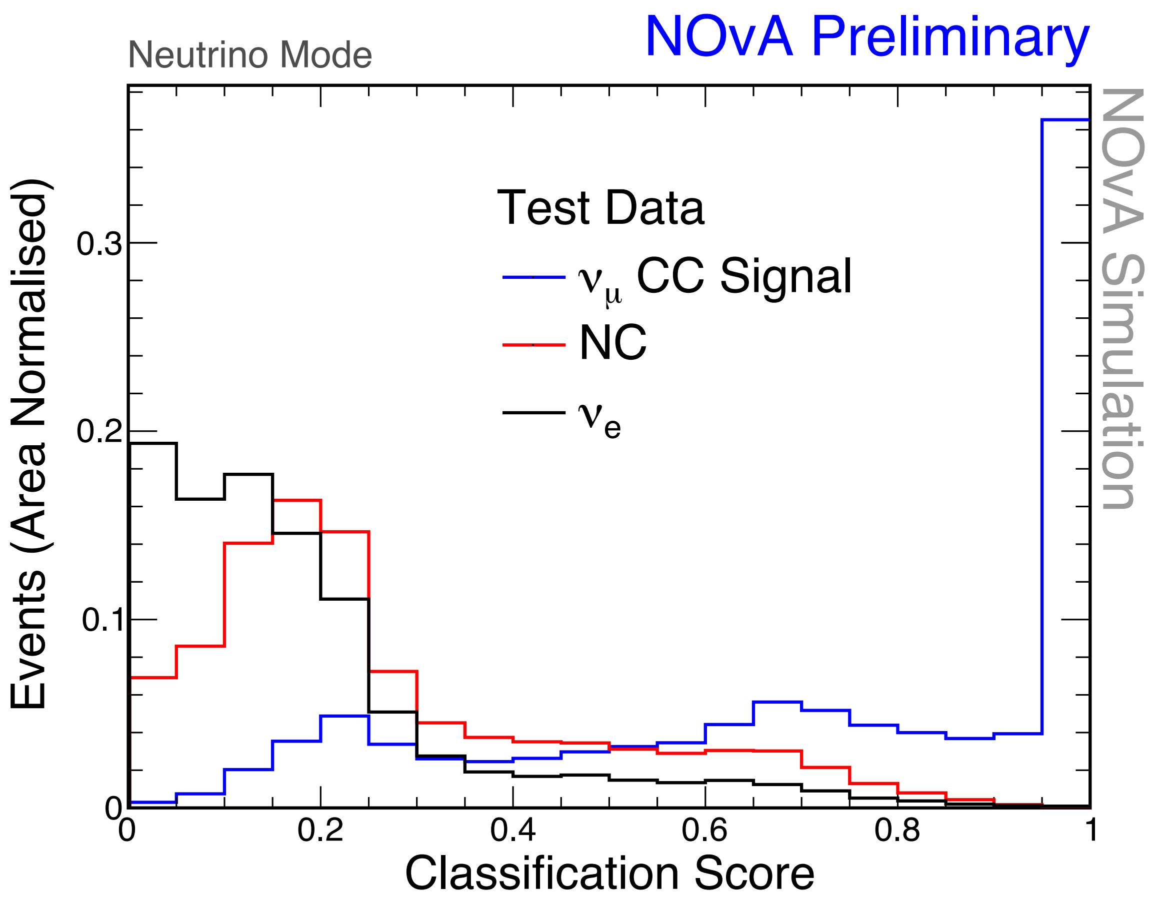
- Two TensorFlow neural networks:
  - signal (υ_μ CC) and background (everything else)
  - signal (υ_μ CC) and two background categories (NC and υ_e)

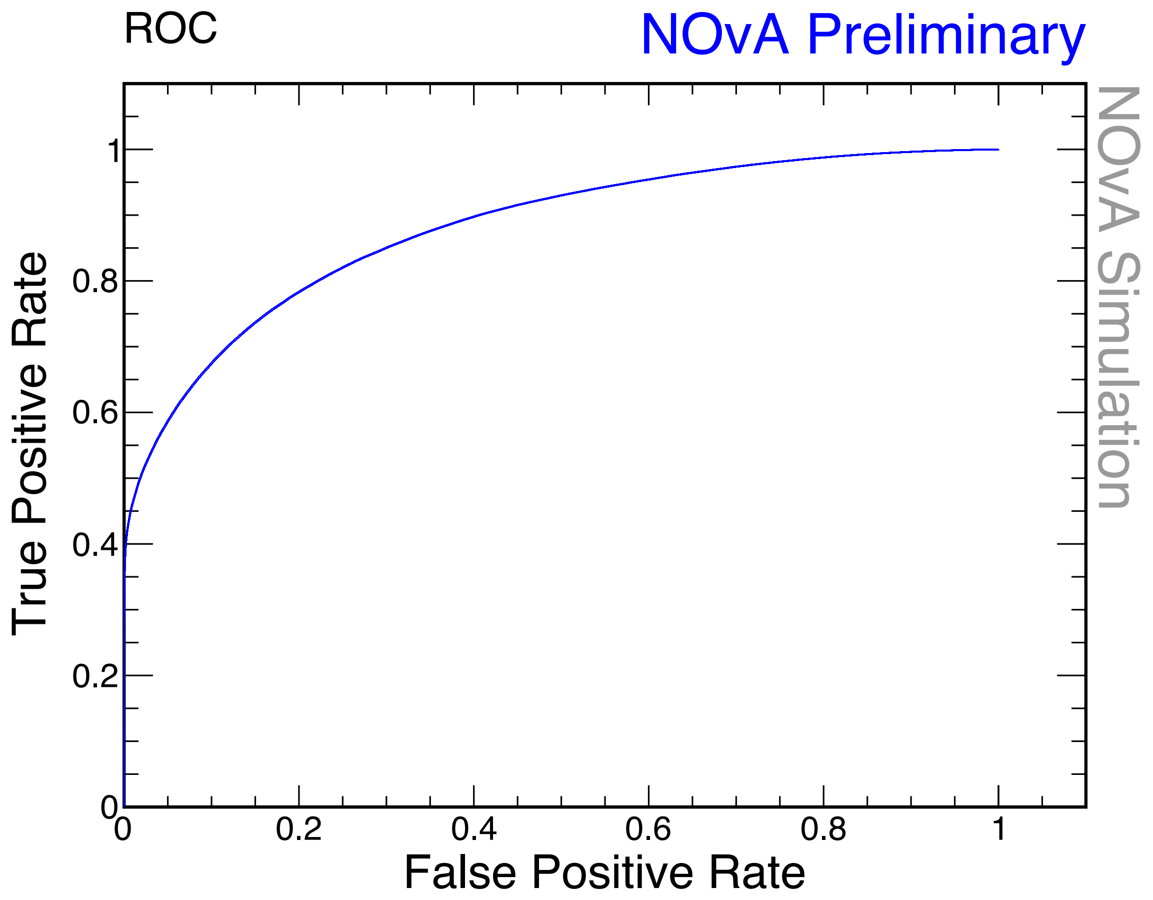
- 14 variables, different information on event energies, momentum, track information etc.



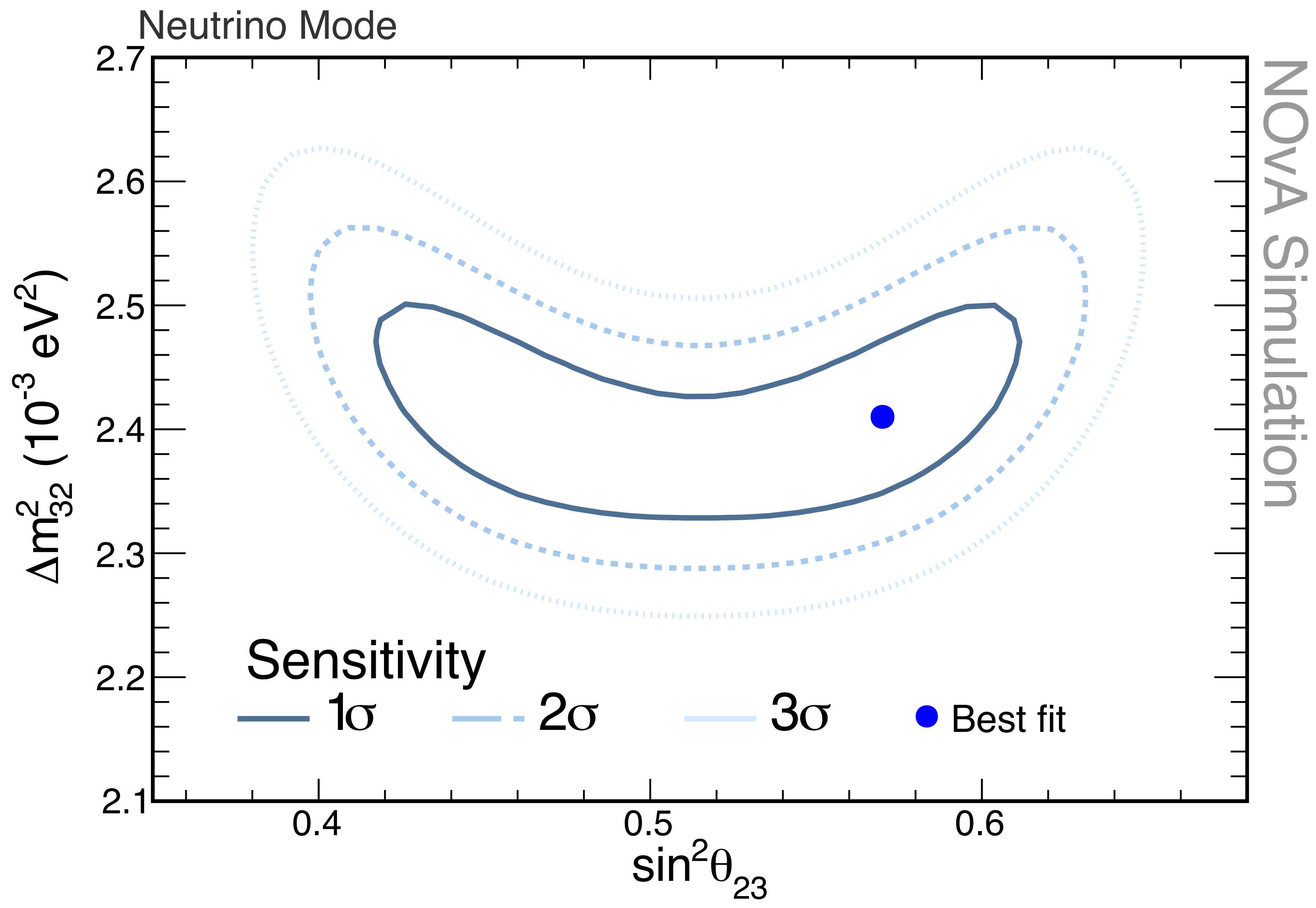


1st model with two categories: υ_μ CC signal, background (everything else)

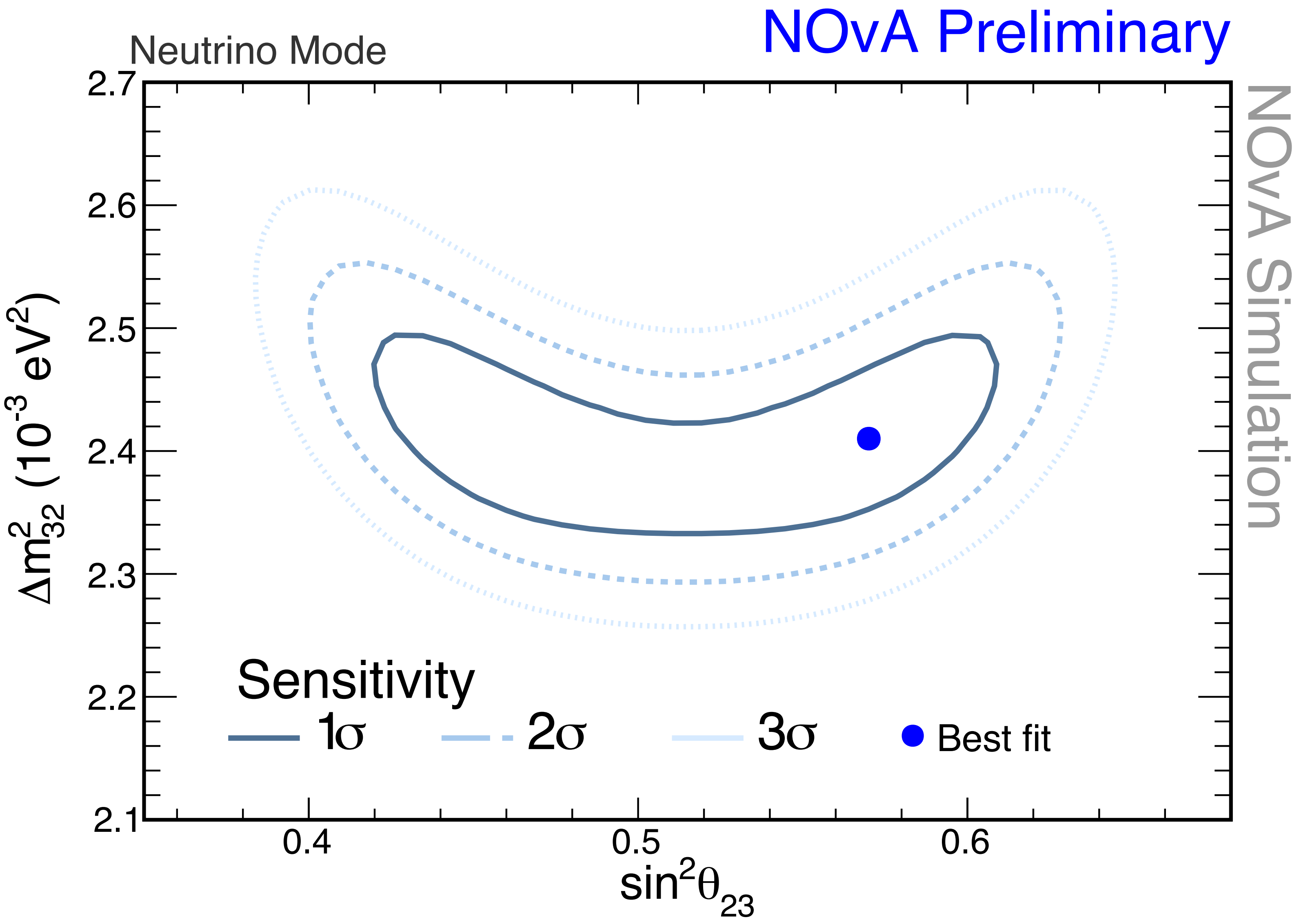




2nd model with three categories: υ_μ CC signal, NC and υ_e



Sensitivity: 2020 selection, normal hierarchy



Sensitivity: Added events excluded from current analysis, normal hierarchy

Conclusions & Future Work:

- Potentially could recover 40% of these events based on the network
  - Equivalent to 5% increase in the number of events

- If 100% of excluded events are recovered the increase in effective POT is 14%
  - In reality the improvement will be less

- There are some questions on the quality of the events since they failed to cut

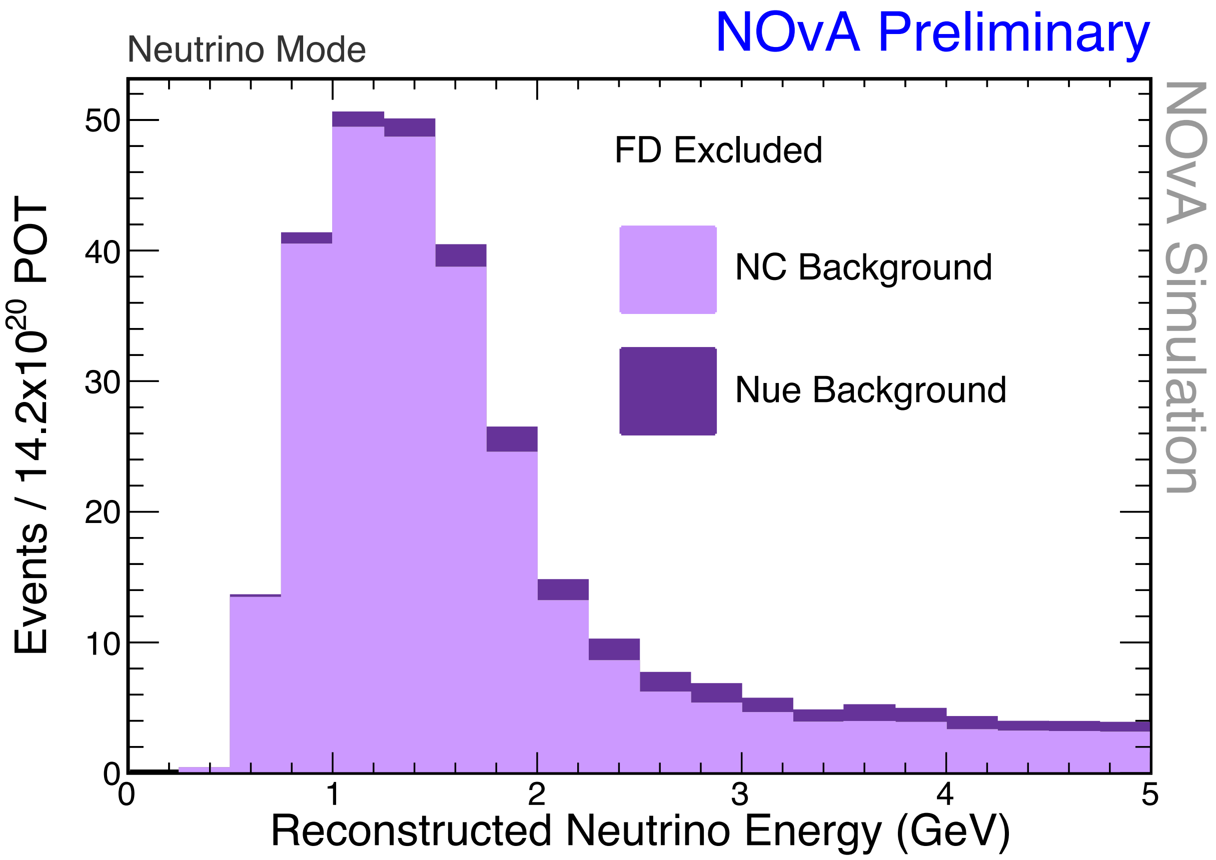
- Training has room for improvement – check variable correlations and susceptibility to systematics

Thank you!

Questions?

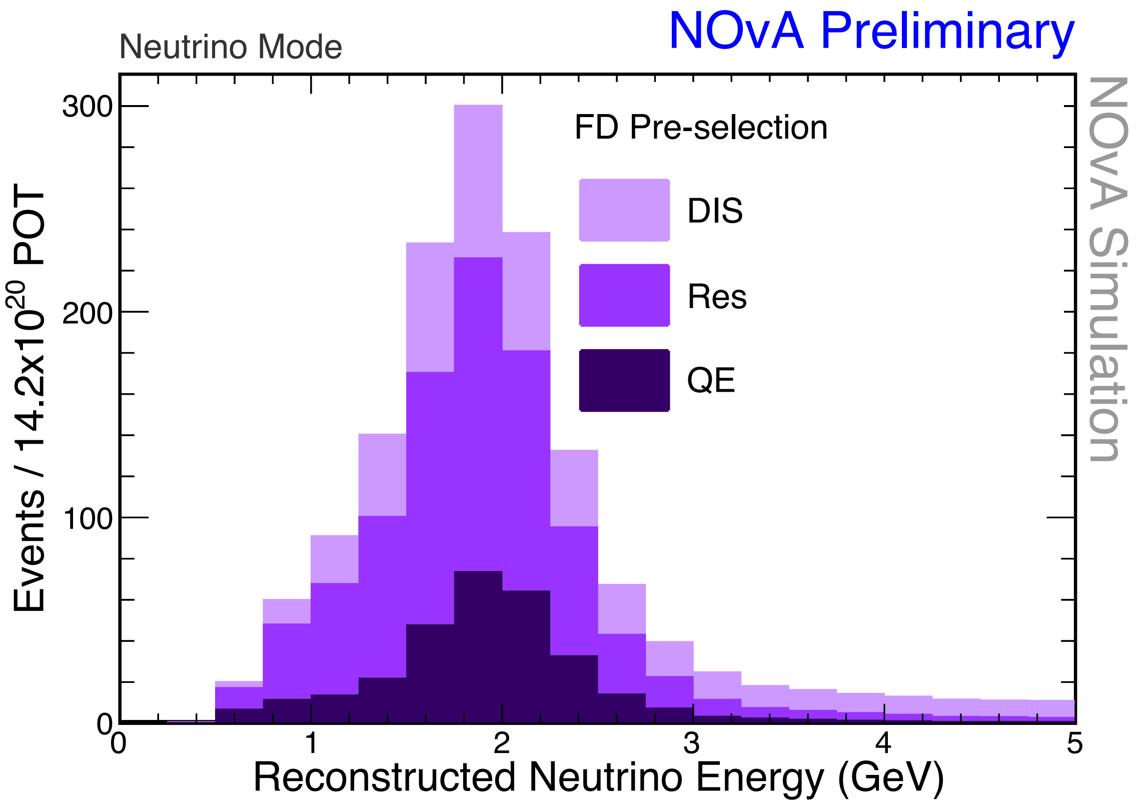
Backup

Events cut from 2020 analysis

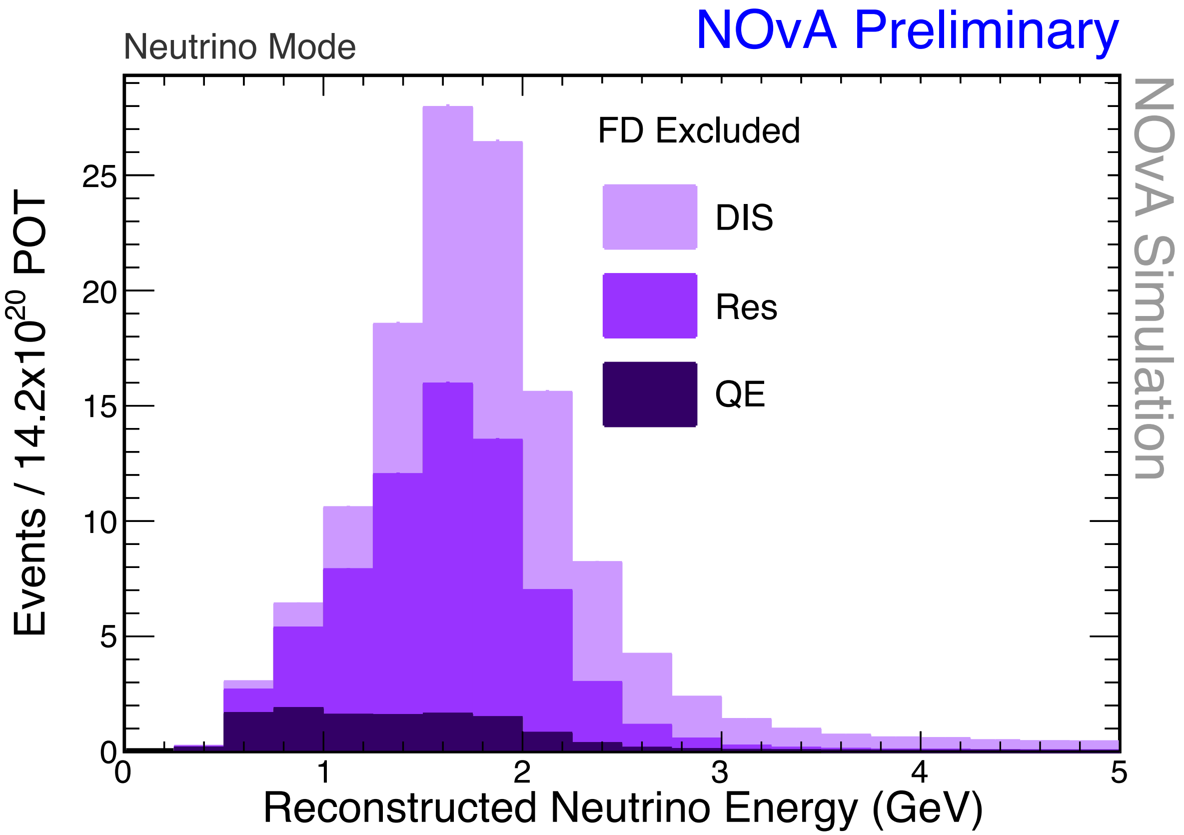


Background by component

NumuCC signal by component



Pre-selection



Events cut from 2020 analysis

Network details:

- Variables trained

Slice:
kNHit (Number of hits)
kCalE (Calorimetric Energy)
kEPerhit (calE per hit)
kHADEperhit

Cosmis Rejection:
Cos Angle of Best Kalman Track (kAngleKal)

CVN:
ProngIndex_muonlike (kCVNMuonIdx)

Track variables:
kRecoThetaMu
kNumuMuonPtP (Reconstructed muon Pt/P)
kNumuMuonPt (Reconstructed muon transverse momentum Pt)
kTrkLenght (Track Length)

Energy/Event:
kHadE (Hadronic energy)
kRecoW (Reconstructed invariant mass)
kHadEFrac (Hadronic energy fraction)
kCCE (Reconstructed neutrino energy)
kRecoEPerHit (NueE per hit)