Measurement of ν_μ Induced Neutral Current π^0 Production with the NOvA Near Detector

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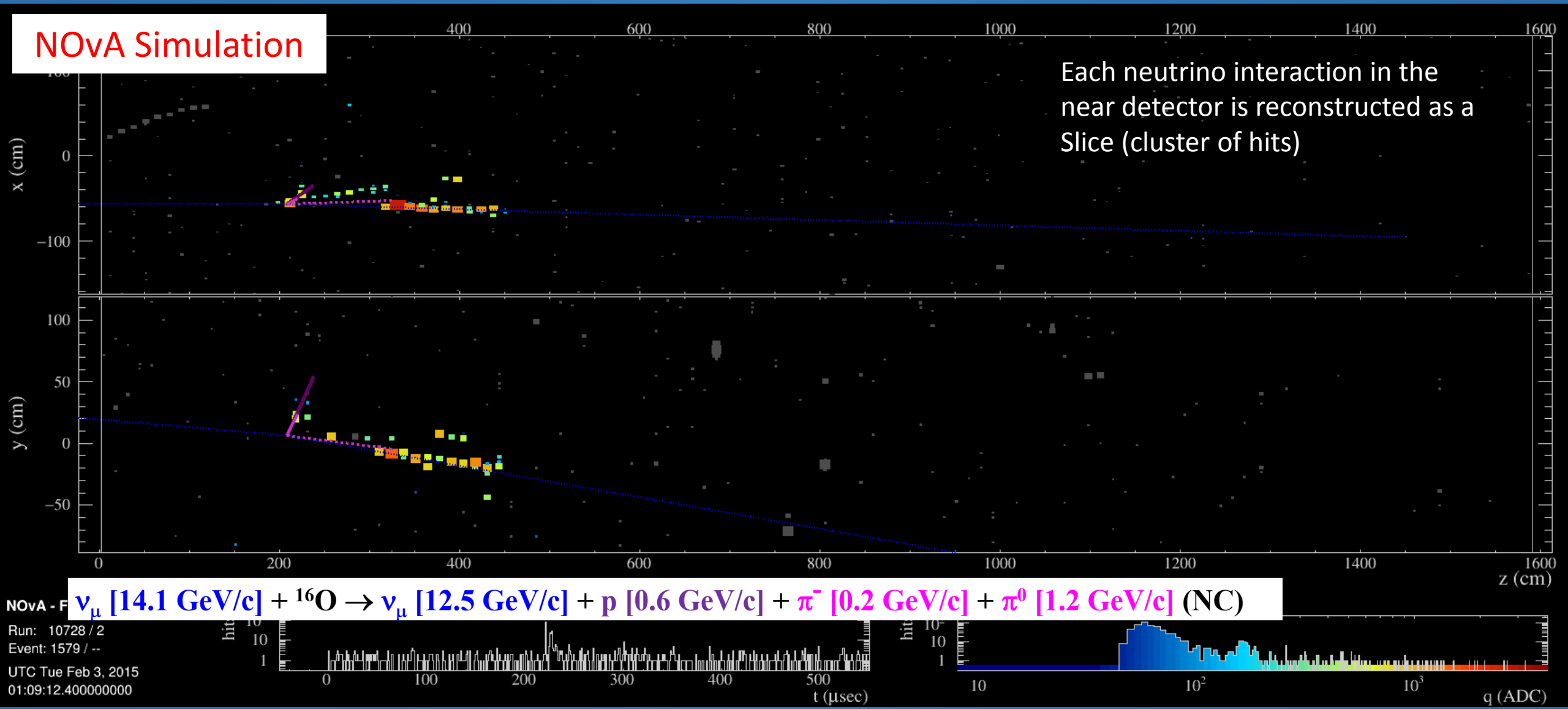
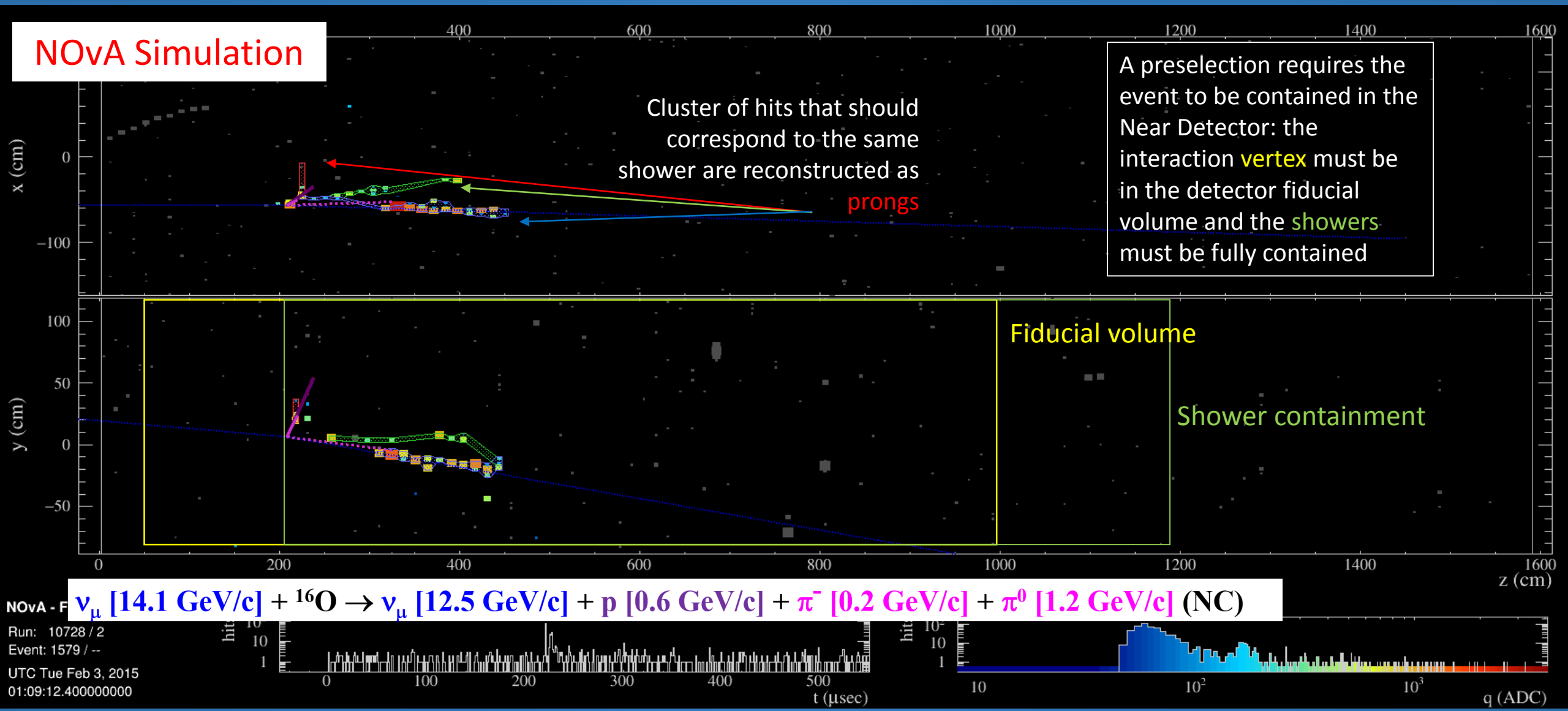
Introduction

- NOvA is a long baseline oscillation experiment to study $\nu_\mu \rightarrow \nu_e$
- The NOvA Near detector is located ~1km from the NuMI target: big ν_μ flux! → high statistics: we can perform a number of neutrino cross-section measurements
- π^0 production from ν_μ NC interactions is NOvA main background because the 2 photons produced by the π^0 decay can fake the ν_e appearance signal → The analysis of the inclusive NC π^0 production has recently started, we present the status of a preliminary Monte Carlo study
- *Our signal*: ν_μ NC interactions with the production of at least one π^0 with kinetic energy above 0.5 GeV. Dominated by inelastic interaction where nuclear recoils are produced, while a small fraction comes from coherent interactions where a forward-scattered π^0 is produced and there are no nuclear recoils.
- The challenge: reconstruct and identify the final states of the interaction to be able to identify the π^0 decay e-m showers
- How do these events look like in the NOvA Near Detector? ⟹

NC ν_μ π^0 in the NOvA Near Detector



NC ν_μ π^0 in the NOvA Near Detector – Reconstructed Prongs

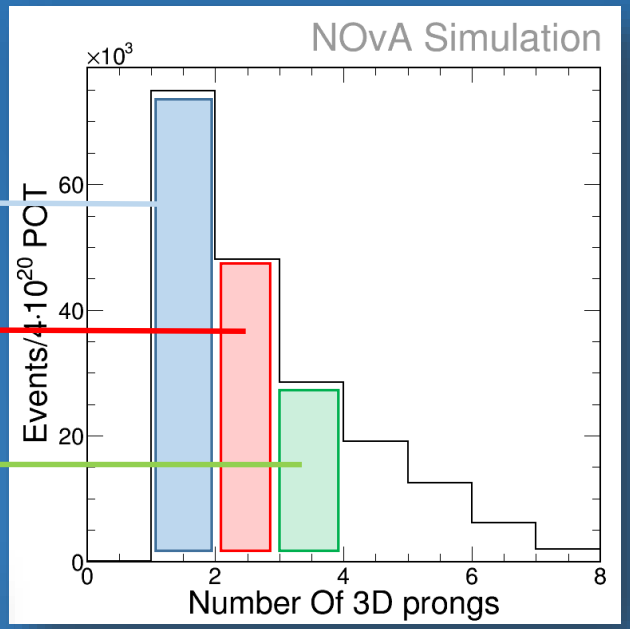


Inclusive NC π^0 in the NOvA Near Detector

- 2 of the reconstructed 3D prongs should be associated with the 2γ of the π^0 decay
- Number of 3D prongs reconstructed for our signal events:

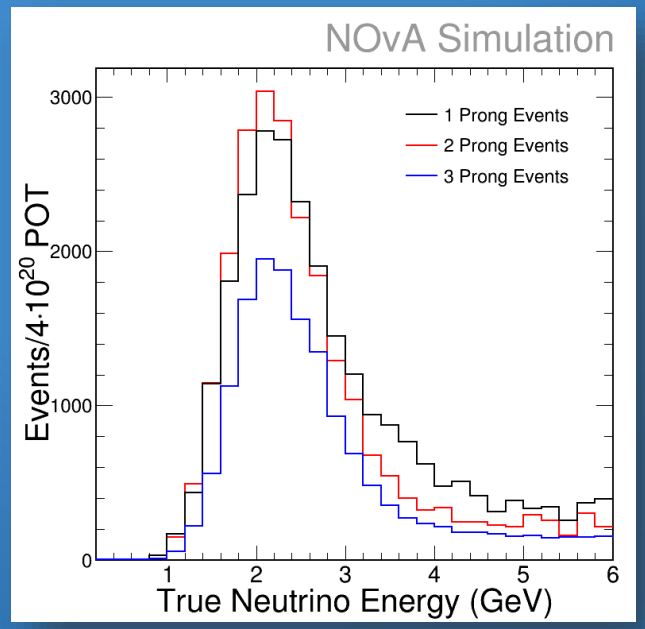
Not considered for the moment ← ~39% 1-prong

Events studied
- ~25% 2-prong
- ~15% 3-prong



- The MC data set considered has high statistics (2.8 10^{21} POT), the distributions will refer to 4 10^{20} POT that reflect our ND data

- True Neutrino Energy for signal for the 1-prong, 2-prong, 3-prong events



The background

- ν_μCC interactions where the outgoing μ is not identified
  - with a π^0 in the final state
  - without a π^0 in the final state
- ν_μ NC interactions without a π^0 in the final state or with a π^0 below energy threshold to be reconstructed
- ν_e : intrinsic contamination in the beam

We can use the NOvA PIDs to make a first rejection of the CC background

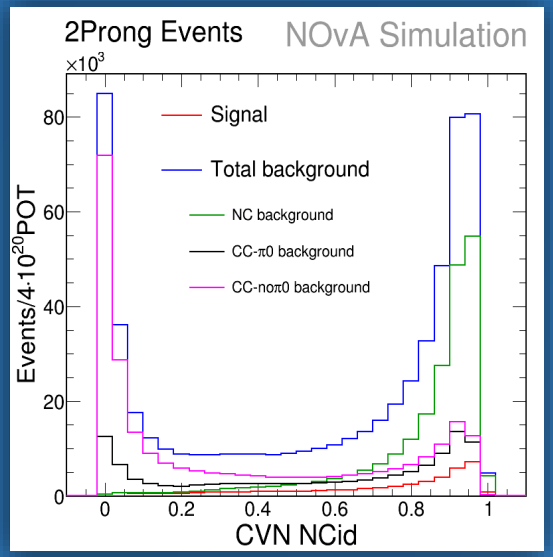
- Reconstructed Muon Identification (REMID) particle identification (PID) algorithm: It's based on muon tracks

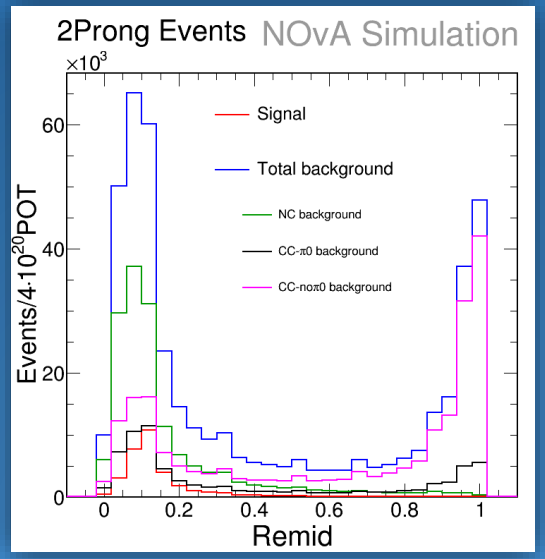
→ It will give to the event a value between 0 and 1 where CC-like events → 1

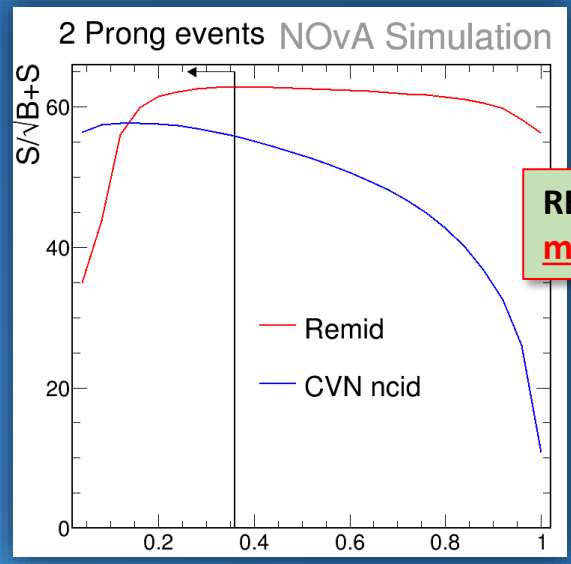
- Convolutional Visual Network (CVN) algorithm is an event selector designed to classify events according to their likely neutrino flavor and interaction type.

→ CVN NCID will give to the event a value between 0 and 1 where NC-like events → 1

REMID & CVN NCid for 2-prong events

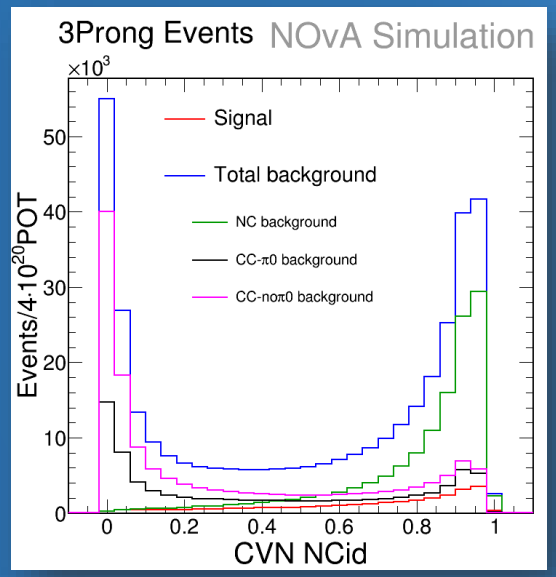


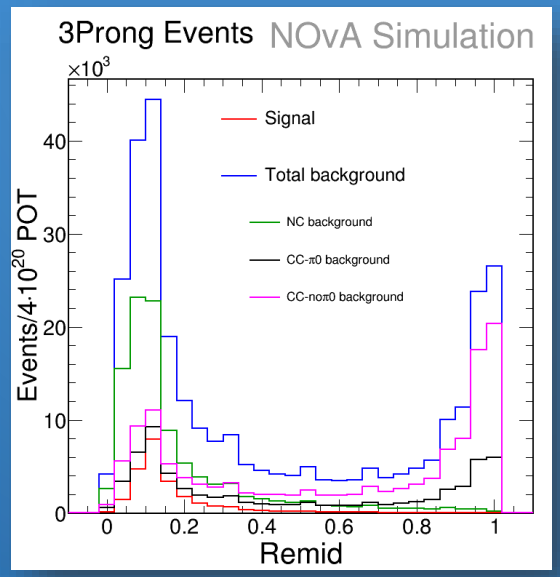


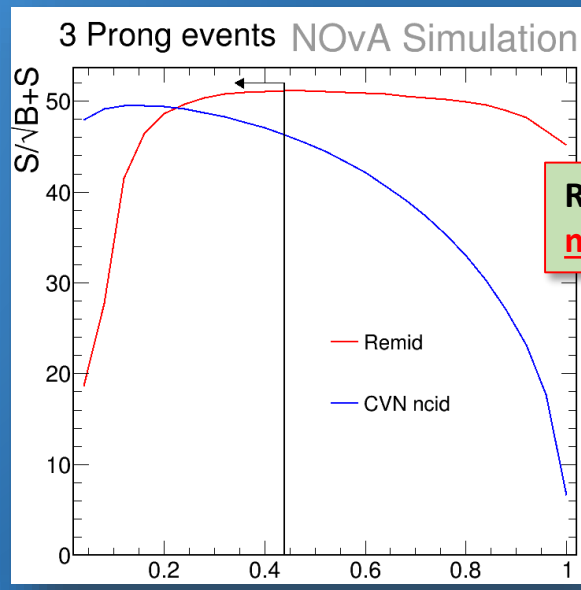


REMID FoM
max at 0.36

REMID & CVN NCid for 3-prong events



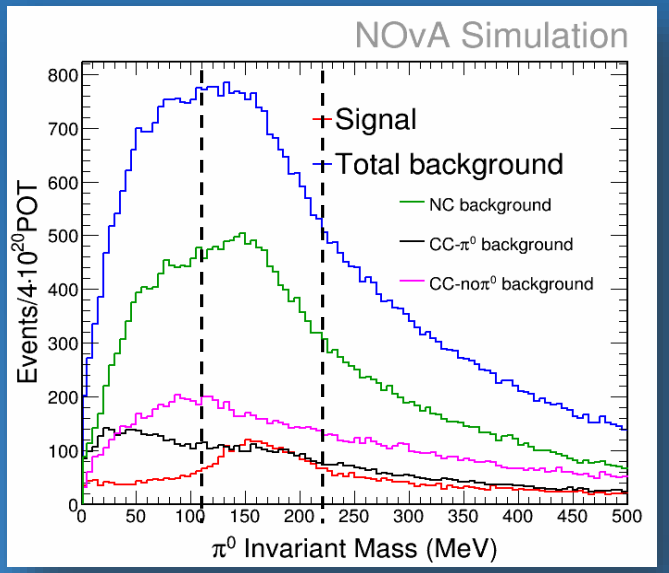


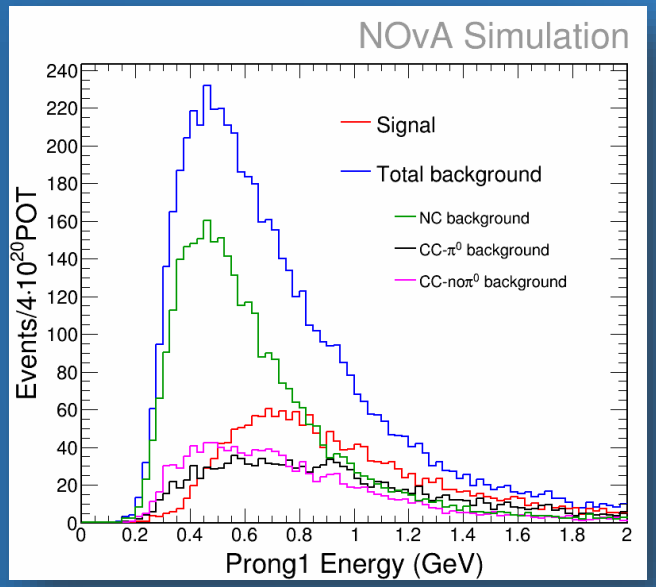


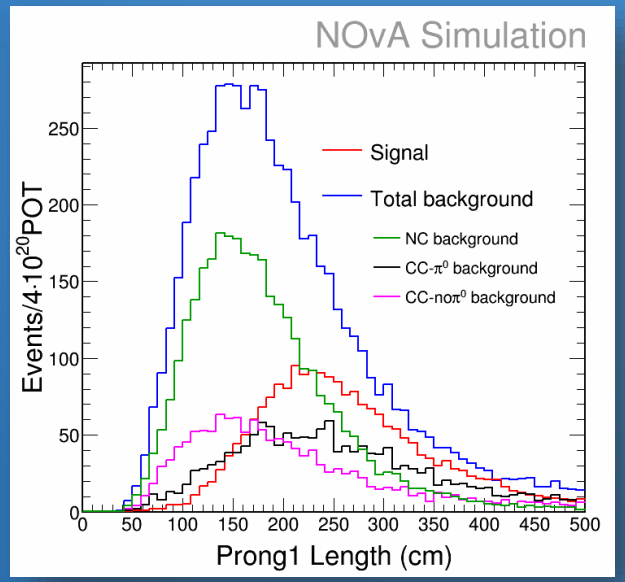
REMID FoM
max at 0.44

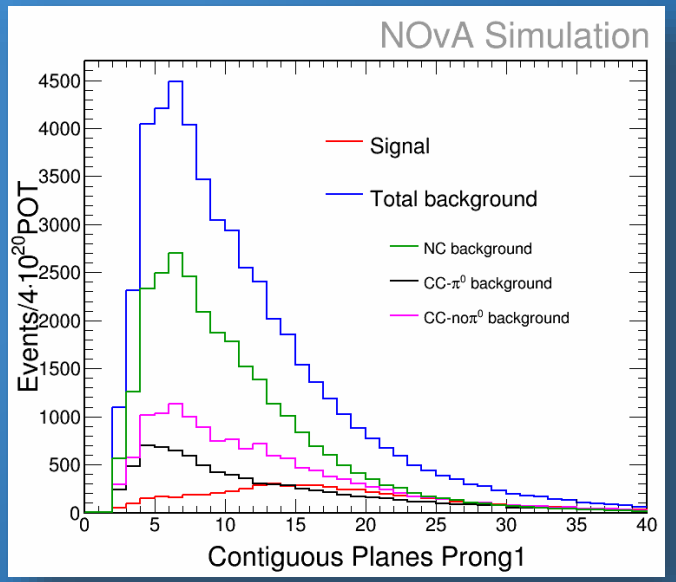
The 2-Prong Events

- Fiducial + Containment + Remid>0.36 → Invariant Mass from the 2 showers
- A look at Slice and Shower variables (energy, number of hits, number of planes *etc*….) to define a series of cuts for signal/background discrimination (Prong1 is the leading shower)









…and several others…

The 2-Prong Events

Cuts	Signal	Background			S/B (%)
		NC	CC π^0	CC noπ^0	
Fidual+Containment & ReMID < 0.36	46467	240092	116382	141488	9.3
Mass Pi0 110 < M < 220	12789	71737	21361	29429	10.4
Slice and Prong Variables Cut (Energy,Missing Planes, Contiguous Planes,dE/dx etc…)	3809	1685	1336	726	101.6

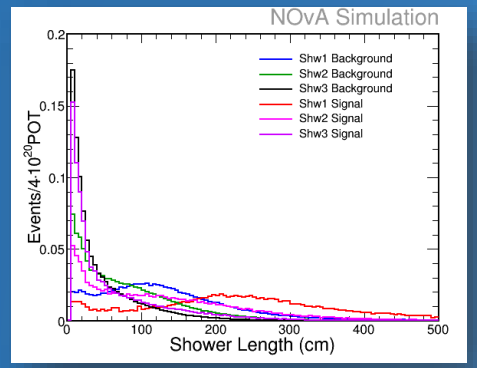
- Background with only fiducial&containment:
  35%NC, 19%CC with π^0, 39%CC without π^0
- After all cuts:
  22% NC, 18%CC with π^0, 10%CC without π^0
- CC background without π^0 goes from being the main background to the least significant one

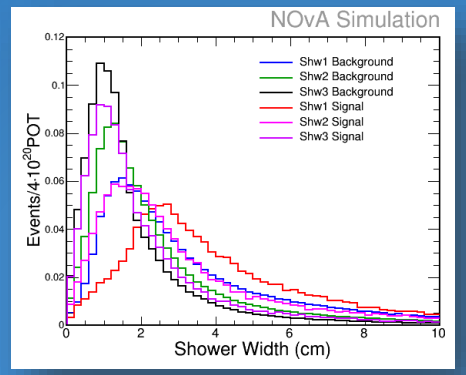
The 3-Prong Events

- Fiducial + Containment + Remid>0.44 → A look at Slice and Shower variables:

The showers are ordered by energy

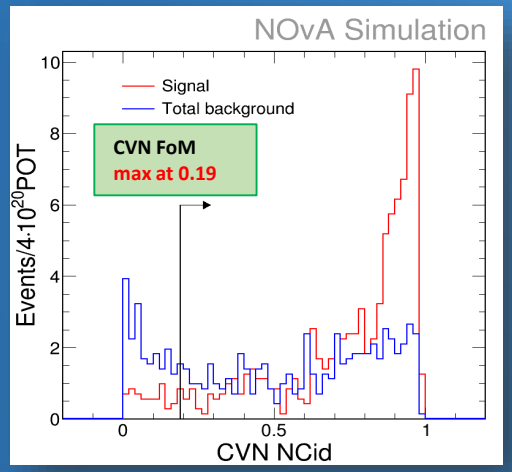
The distributions are area norm.



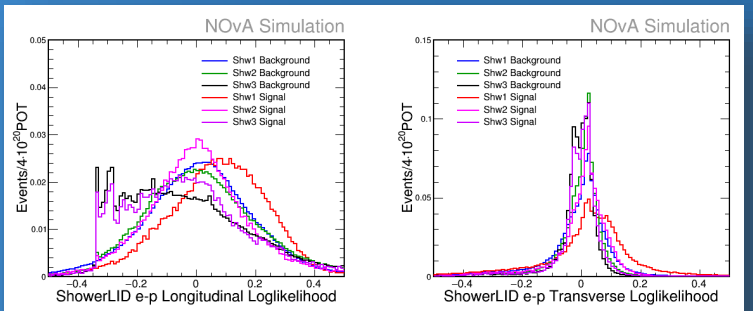


…and many others…

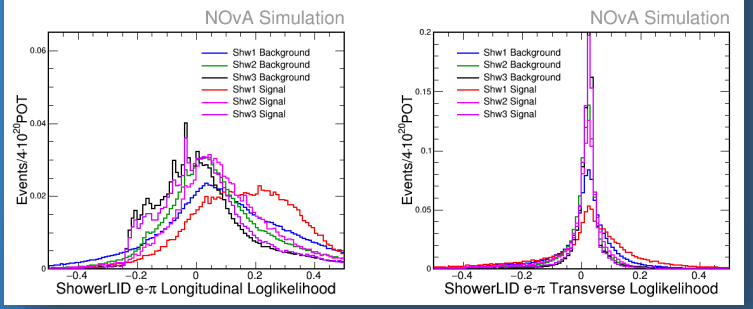
- Fiducial + Containment + Remid>0.44 → A look at the likelihoods:
- The CVN NCID distribution after the cuts on slice and shower variables can help to further reduce the background:



e-p

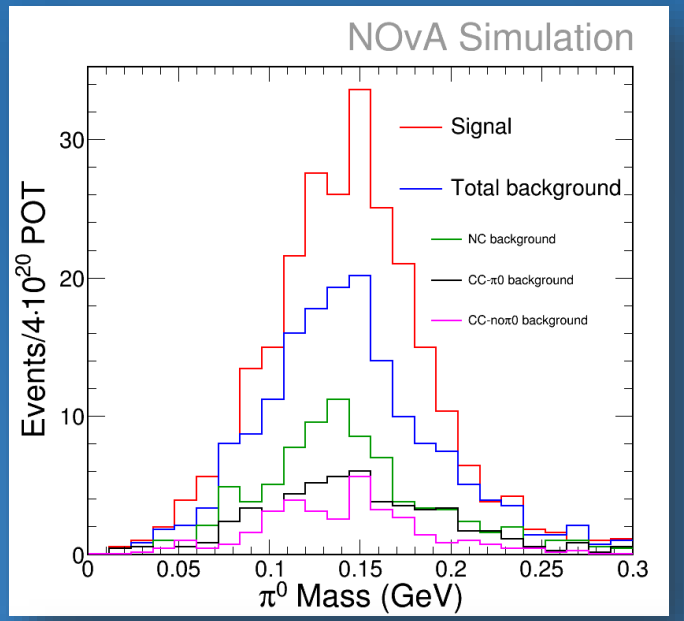


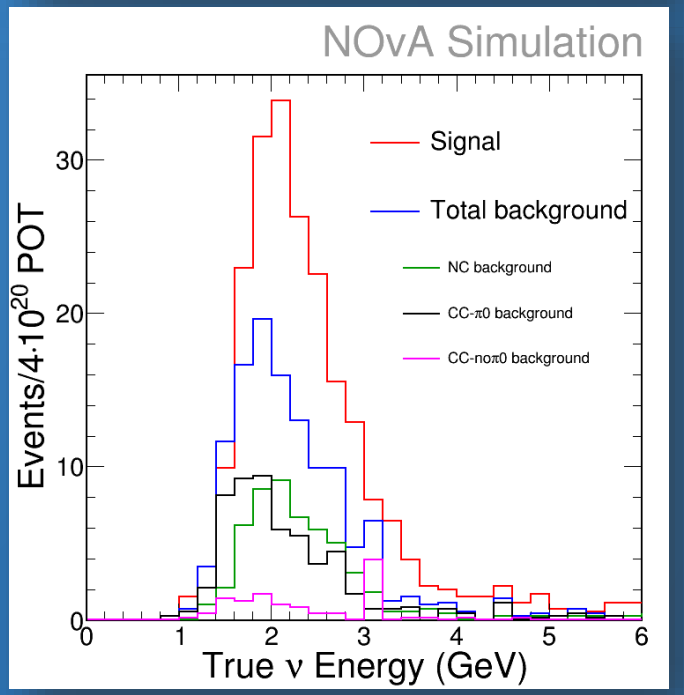
e-π



The 3-Prong Events

	Signal	Tot Bkg	Bkg			% w.r.t. previous cut		S/B %
			NC	CCπ^0	CC noπ^0	Signal	Bkg	
Fiducial&Containment	27717	359484	135057	78992	143429			7%
Remid	26332	13345647	125596	52098	67263	95%	69%	11%
Slice cuts	20742	117033	51417	27944	36133	79%	47%	18%
Shower1 cuts	3904	5193	881	2452	1571	19%	4%	75%
Shower2 cuts	818	748	185	390	116	21%	14%	109%
Shower3 cuts	268	224	64	745	38	33%	30%	119%
CVN NCid	250	168	61	67	21	93%	75%	149%



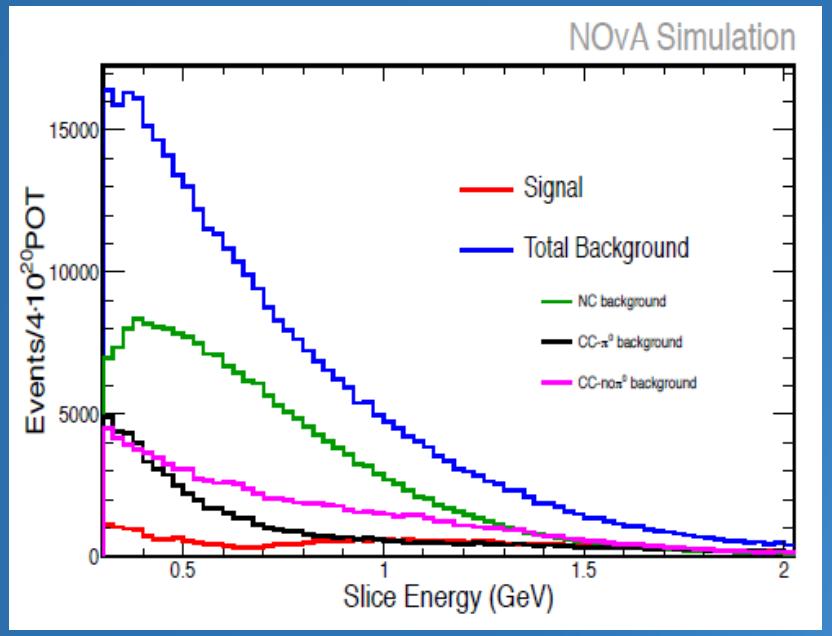


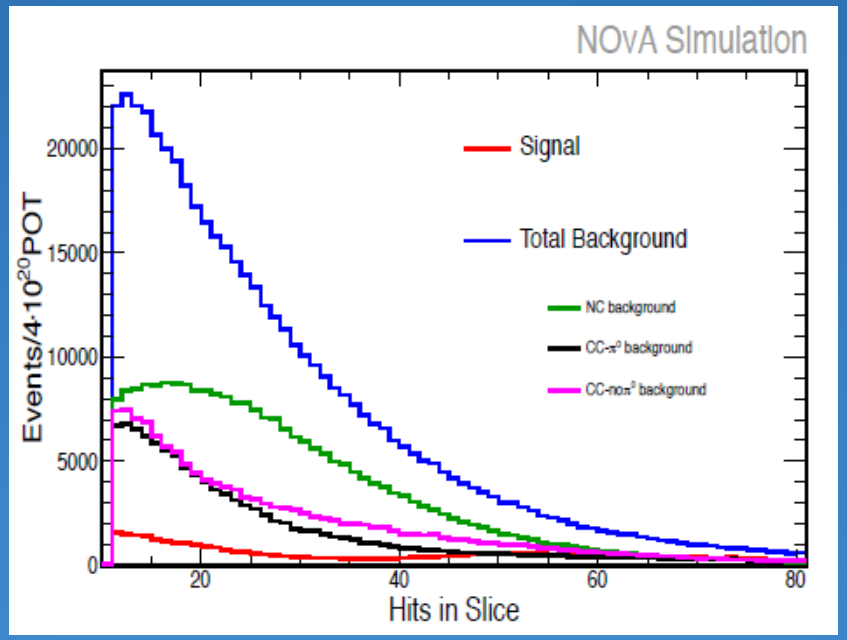
- Background with only fiducial&containment: 38%NC, 22%CC with π^0, 40%CC without π^0
- After all cuts: 37% NC, 37%CC with π^0, 13%CC without π^0
- CC background without π^0 goes from being the main background to the least significant one

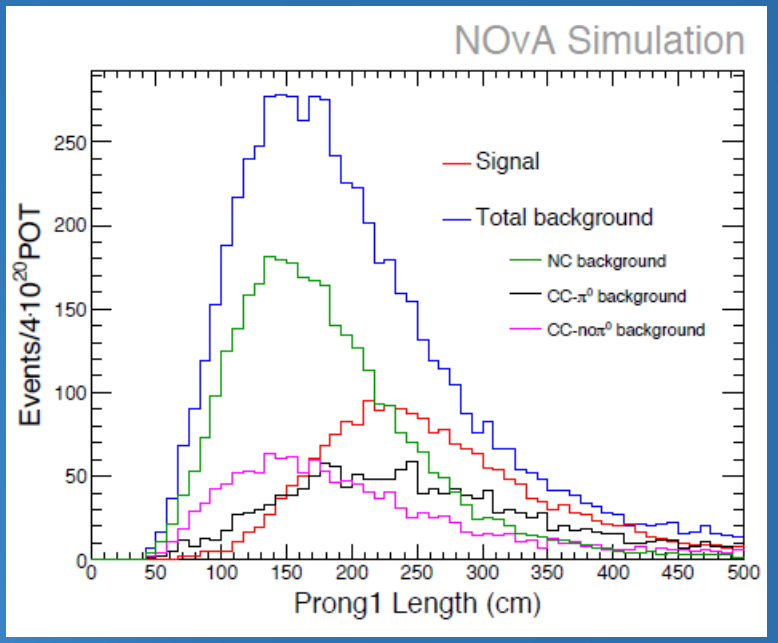
Summary

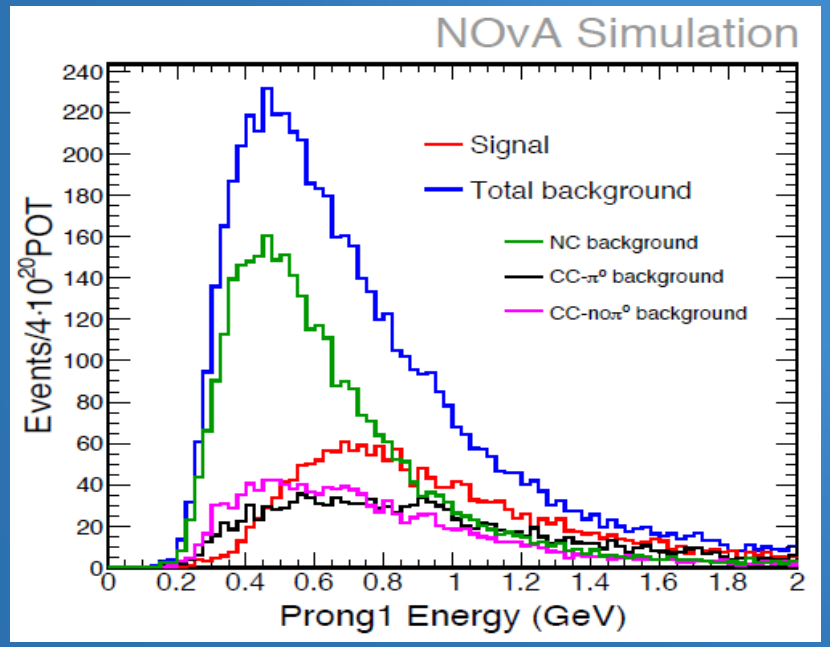
- The NOvA near detector provides an excellent opportunity for the measurement of various neutrino interactions
- Cross section measurements are important for oscillation experiments: π^0 production from ν_μ NC interactions is NOvA main background → we started the analysis of the NC π^0 inclusive measurements
- We have performed a first Monte Carlo study on 2-prong and 3-prong events to discriminate signal from background.
  Now we have to improve our selection efficiency →
- Next steps: multivariate analysis and PID training specific for π0, combine the results on the 2-prong and 3-prong events
- Stay tuned: high-statistics, high-quality data!

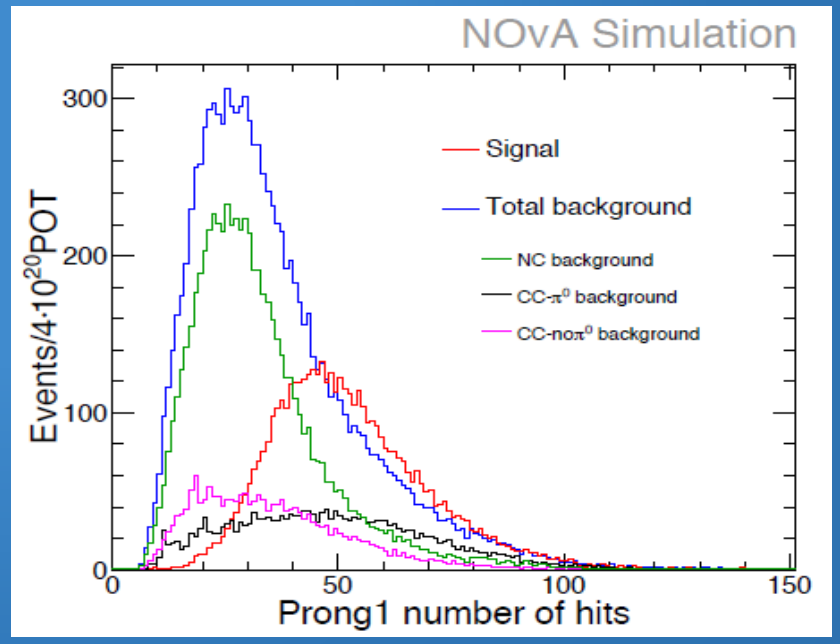
Back-up

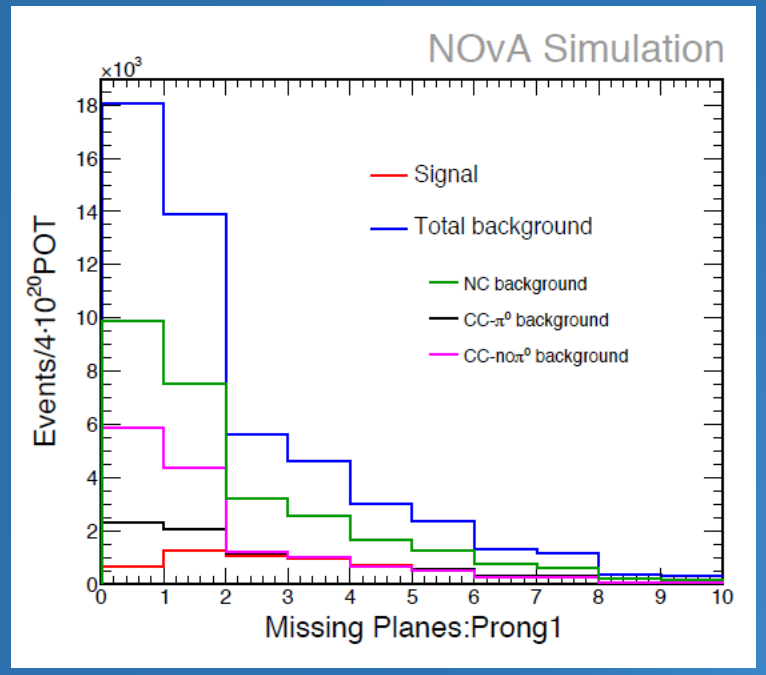

NOvA Simulation
Signal
Total Background
NC background
CC-π⁰ background
CC-noπ⁰ background
Events/4·10²⁰POT
Slice Energy (GeV)

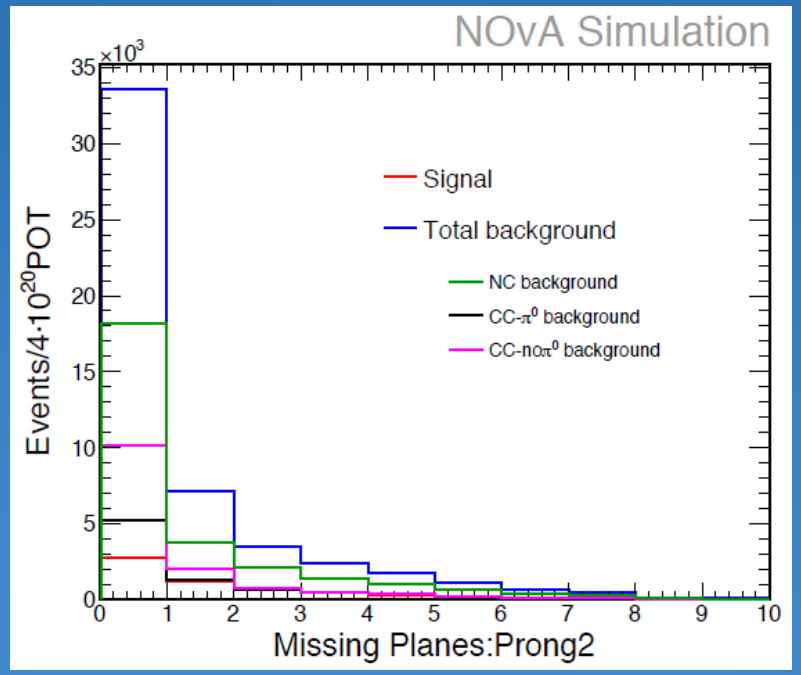

NOvA Simulation
Signal
Total Background
NC background
CC-π⁰ background
CC-noπ⁰ background
Events/4·10²⁰POT
Hits in Slice

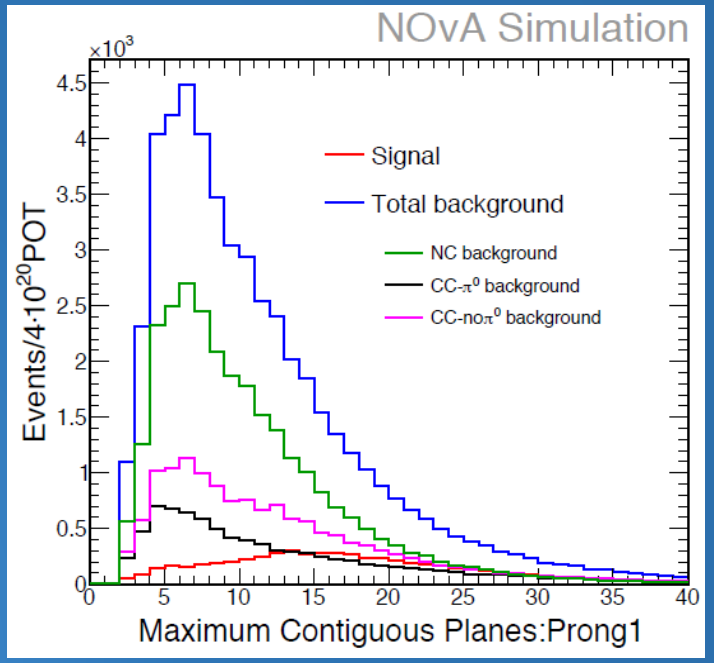

NOvA Simulation
Signal
Total background
NC background
CC-π⁰ background
CC-noπ⁰ background
Events/4·10²⁰POT
Prong1 Length (cm)

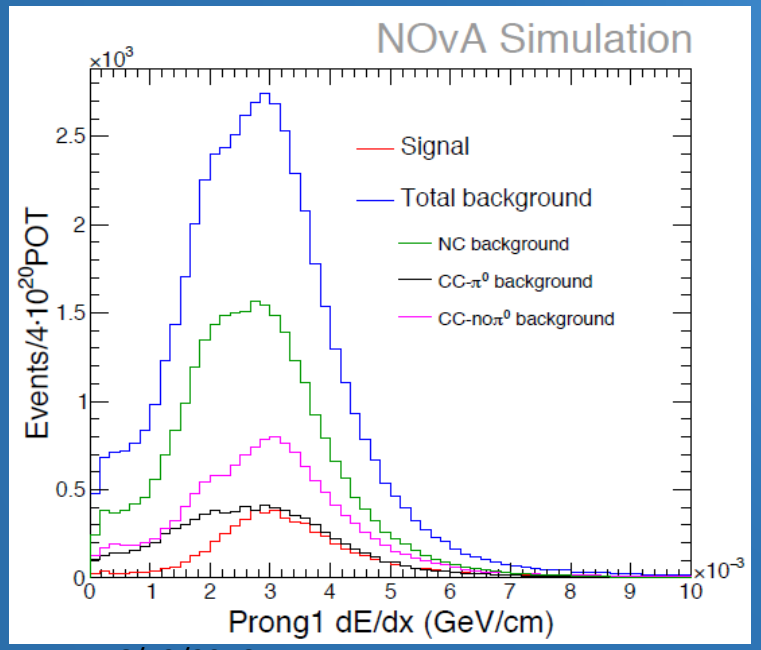

NOvA Simulation
Signal
Total background
NC background
CC-π⁰ background
CC-noπ⁰ background
Events/4·10²⁰POT
Prong1 Energy (GeV)

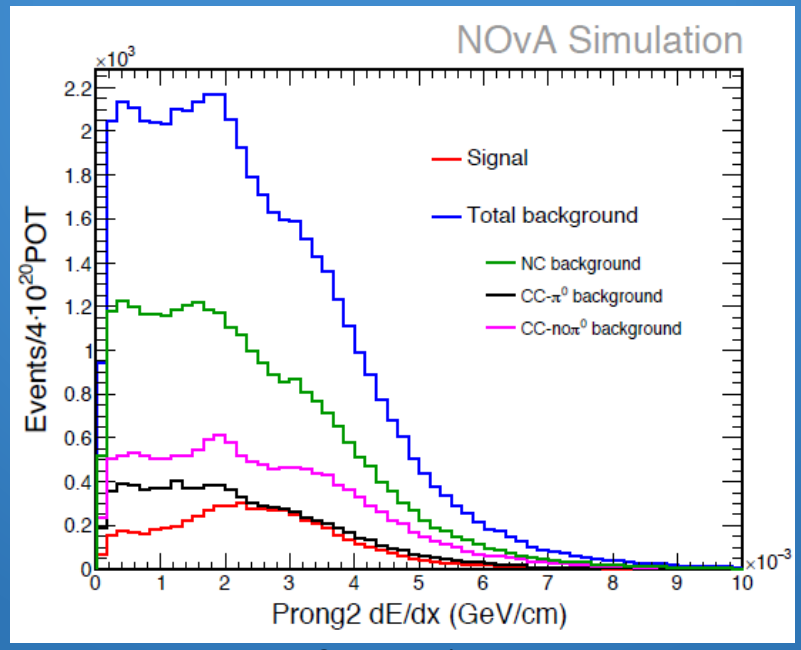

NOvA Simulation
Signal
Total background
NC background
CC-π⁰ background
CC-noπ⁰ background
Events/4·10²⁰POT
Prong1 number of hits

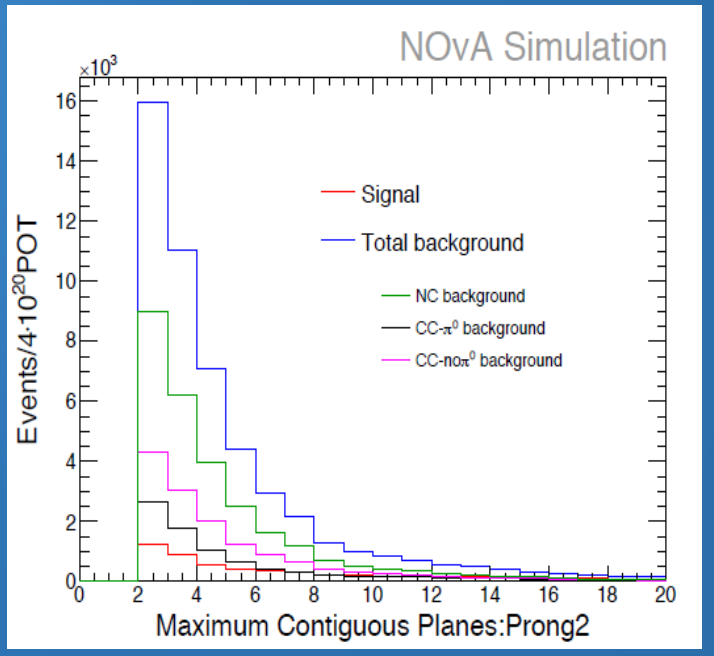

NOvA Simulation
Signal
Total background
NC background
CC-π⁰ background
CC-noπ⁰ background
Events/4·10²⁰POT
Missing Planes:Prong1

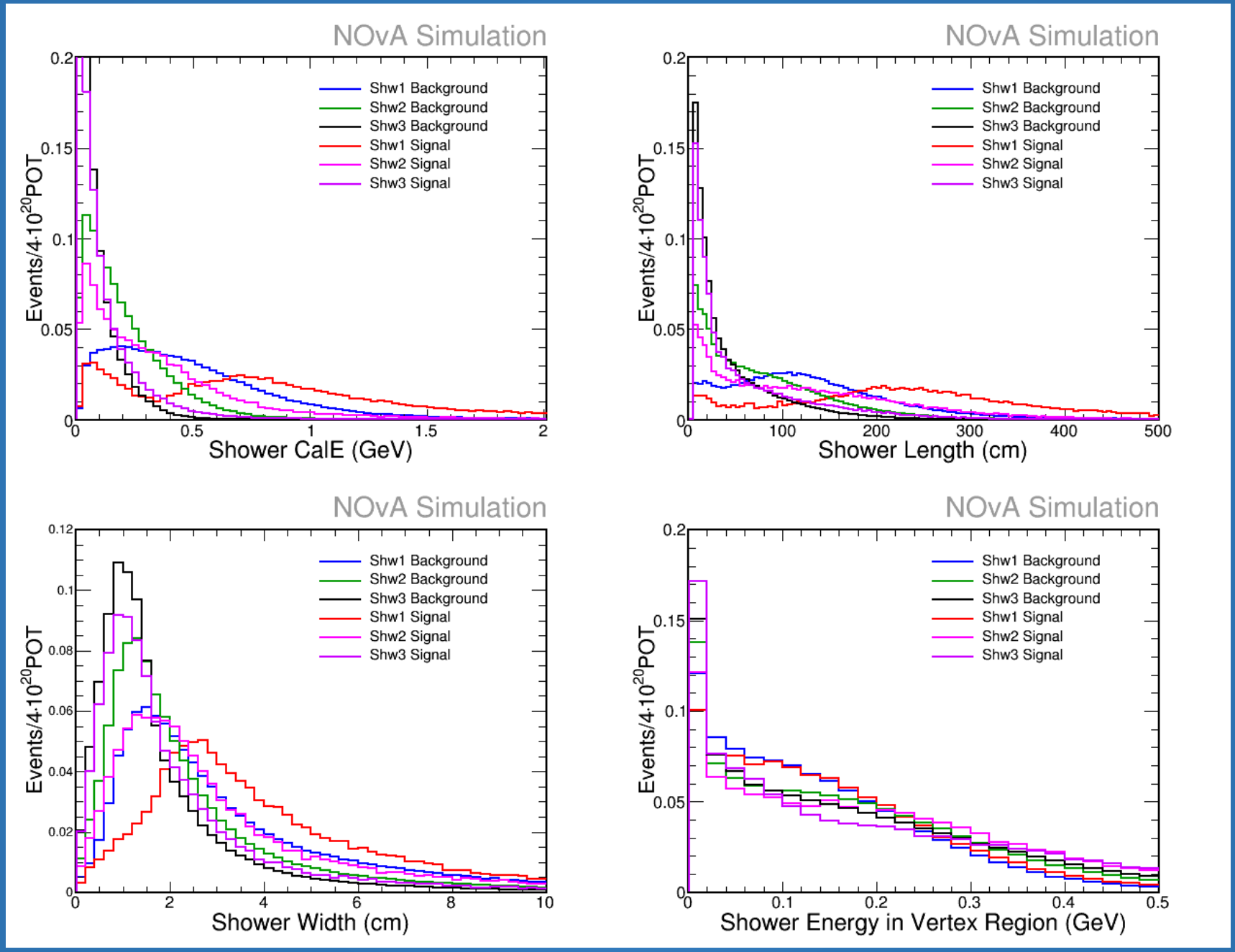

NOvA Simulation
Signal
Total background
NC background
CC-π⁰ background
CC-noπ⁰ background
Events/4·10²⁰POT
Missing Planes:Prong2

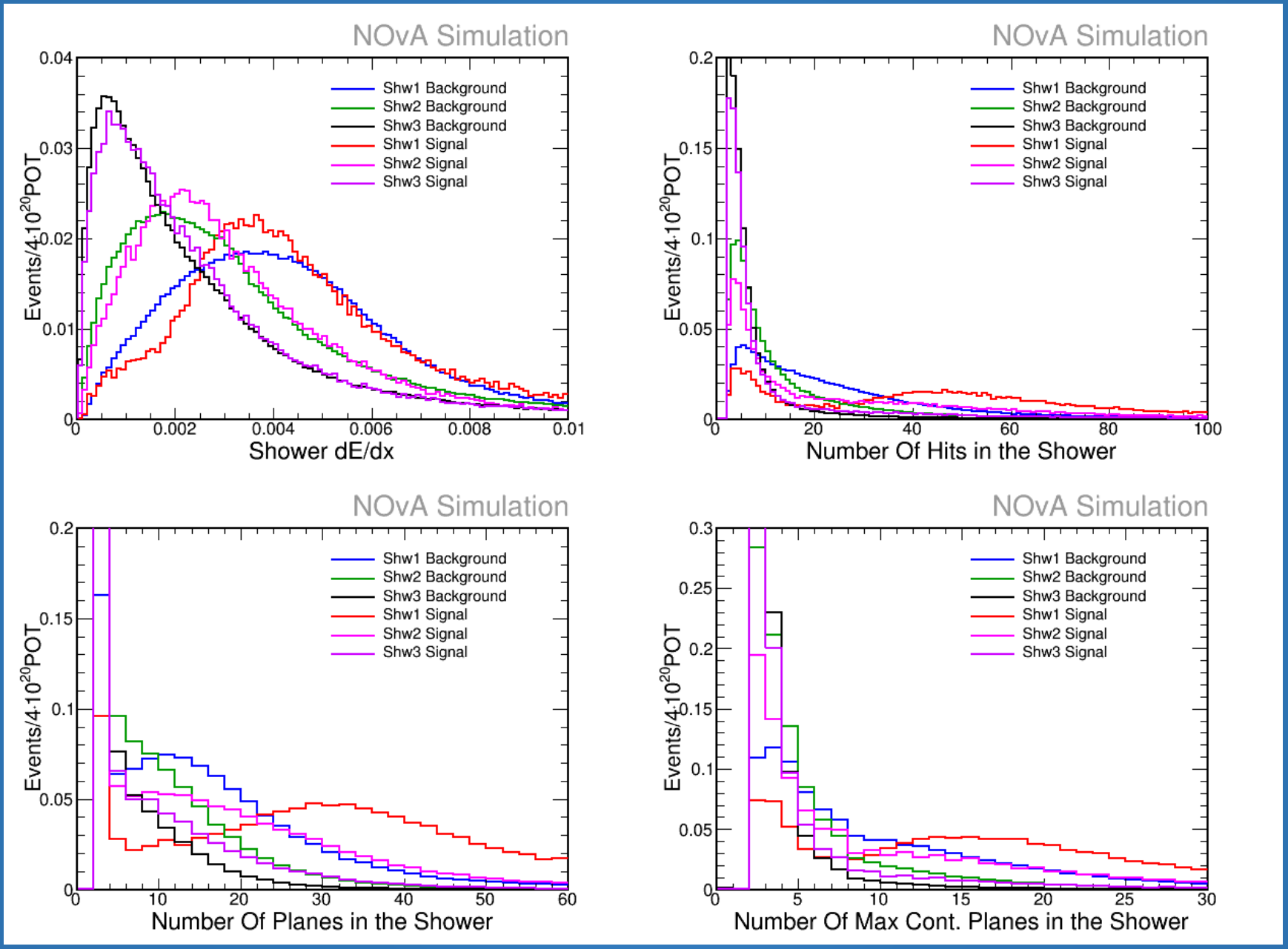

NOvA Simulation
Signal
Total background
NC background
CC-π⁰ background
CC-noπ⁰ background
Events/4·10²⁰POT
Maximum Contiguous Planes:Prong1

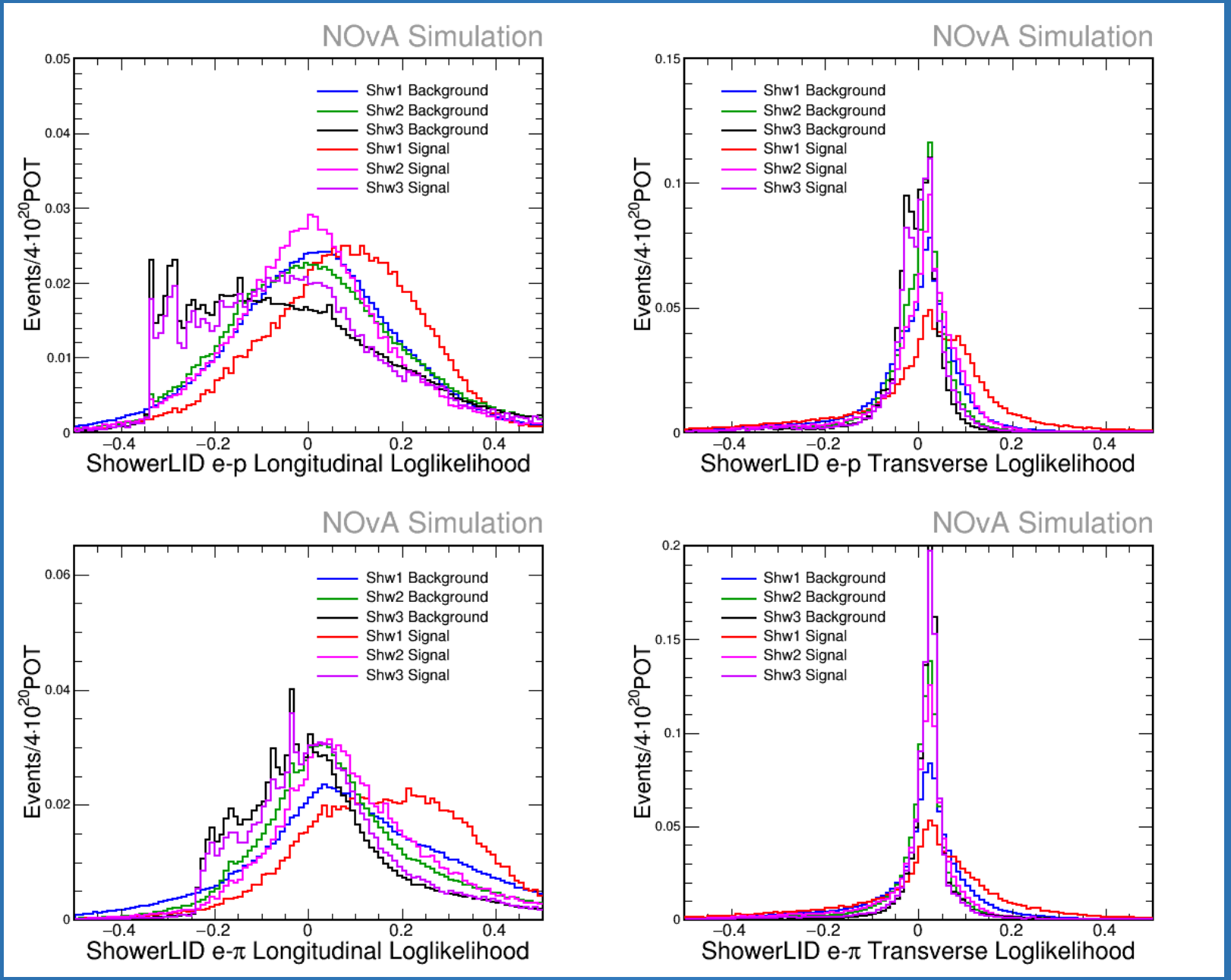

NOvA Simulation
Signal
Total background
NC background
CC-π⁰ background
CC-noπ⁰ background
Events/4·10²⁰POT
Prong1 dE/dx (GeV/cm)

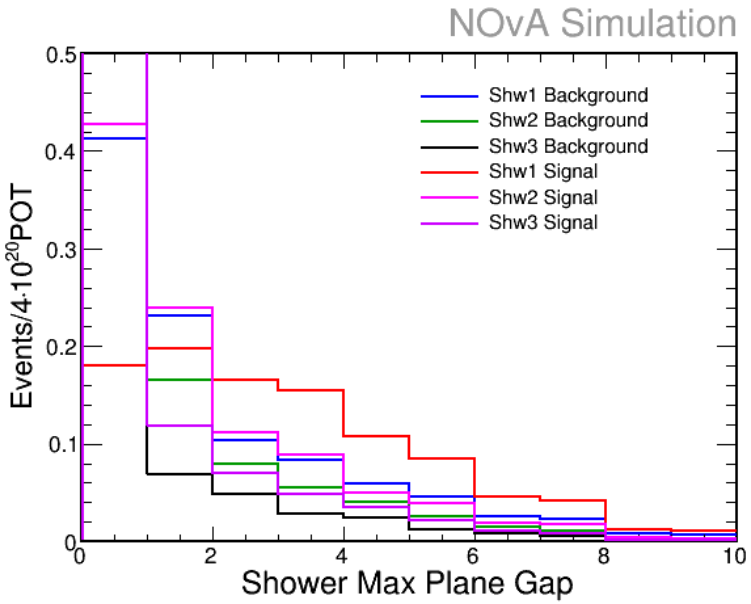

NOvA Simulation
Signal
Total background
NC background
CC-π⁰ background
CC-noπ⁰ background
Events/4·10²⁰POT
Prong2 dE/dx (GeV/cm)

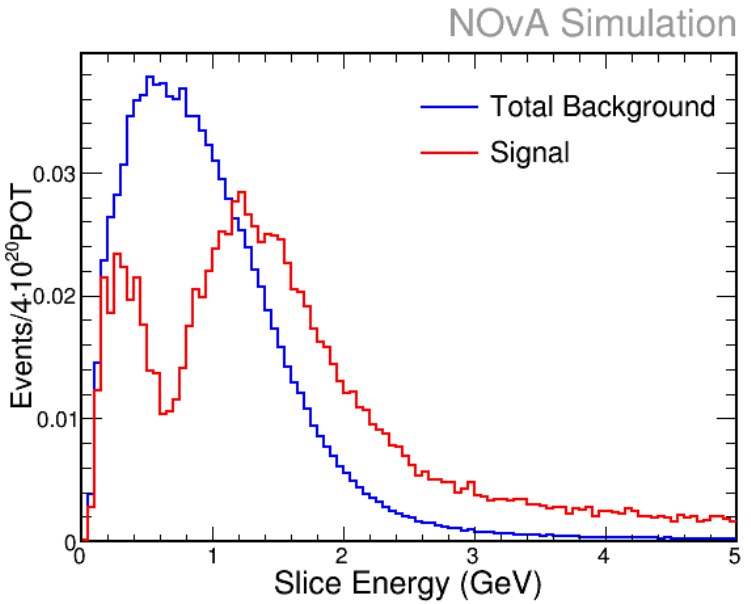

NOvA Simulation
Signal
Total background
NC background
CC-π⁰ background
CC-noπ⁰ background
Events/4·10²⁰POT
Maximum Contiguous Planes:Prong2

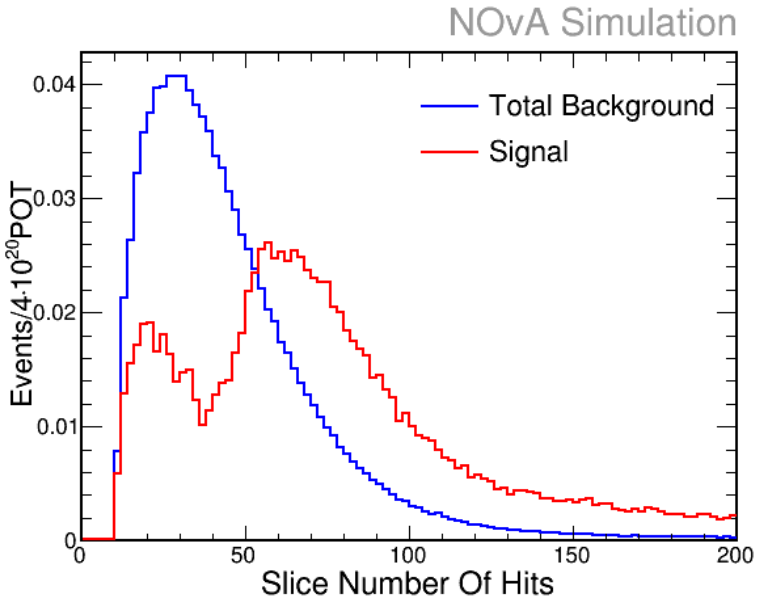

NOvA Simulation
Shw1 Background
Shw2 Background
Shw3 Background
Shw1 Signal
Shw2 Signal
Shw3 Signal
Events/4·10^20POT
Shower CalE (GeV)
NOvA Simulation
Shw1 Background
Shw2 Background
Shw3 Background
Shw1 Signal
Shw2 Signal
Shw3 Signal
Events/4·10^20POT
Shower Length (cm)
NOvA Simulation
Shw1 Background
Shw2 Background
Shw3 Background
Shw1 Signal
Shw2 Signal
Shw3 Signal
Events/4·10^20POT
Shower Width (cm)
NOvA Simulation
Shw1 Background
Shw2 Background
Shw3 Background
Shw1 Signal
Shw2 Signal
Shw3 Signal
Events/4·10^20POT
Shower Energy in Vertex Region (GeV)

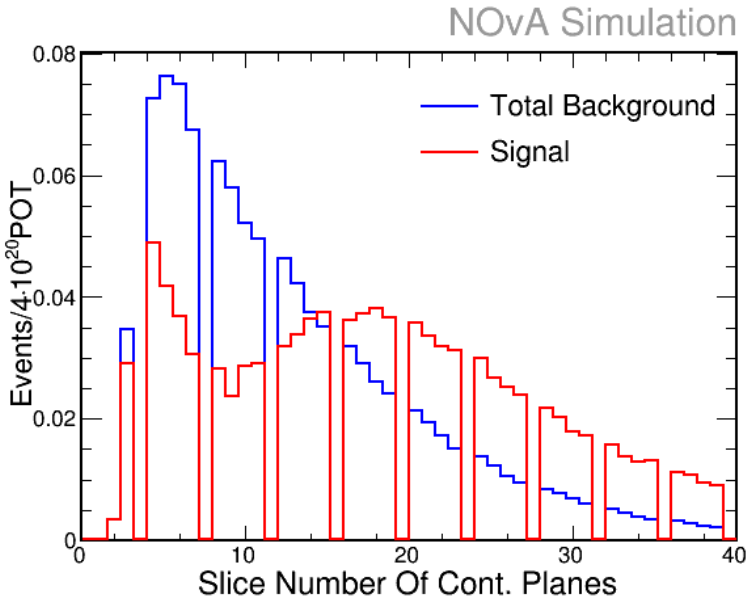

NOvA Simulation
Shw1 Background
Shw2 Background
Shw3 Background
Shw1 Signal
Shw2 Signal
Shw3 Signal
Events/4·10^20POT
Shower dE/dx
NOvA Simulation
Number Of Hits in the Shower
NOvA Simulation
Number Of Planes in the Shower
NOvA Simulation
Number Of Max Cont. Planes in the Shower

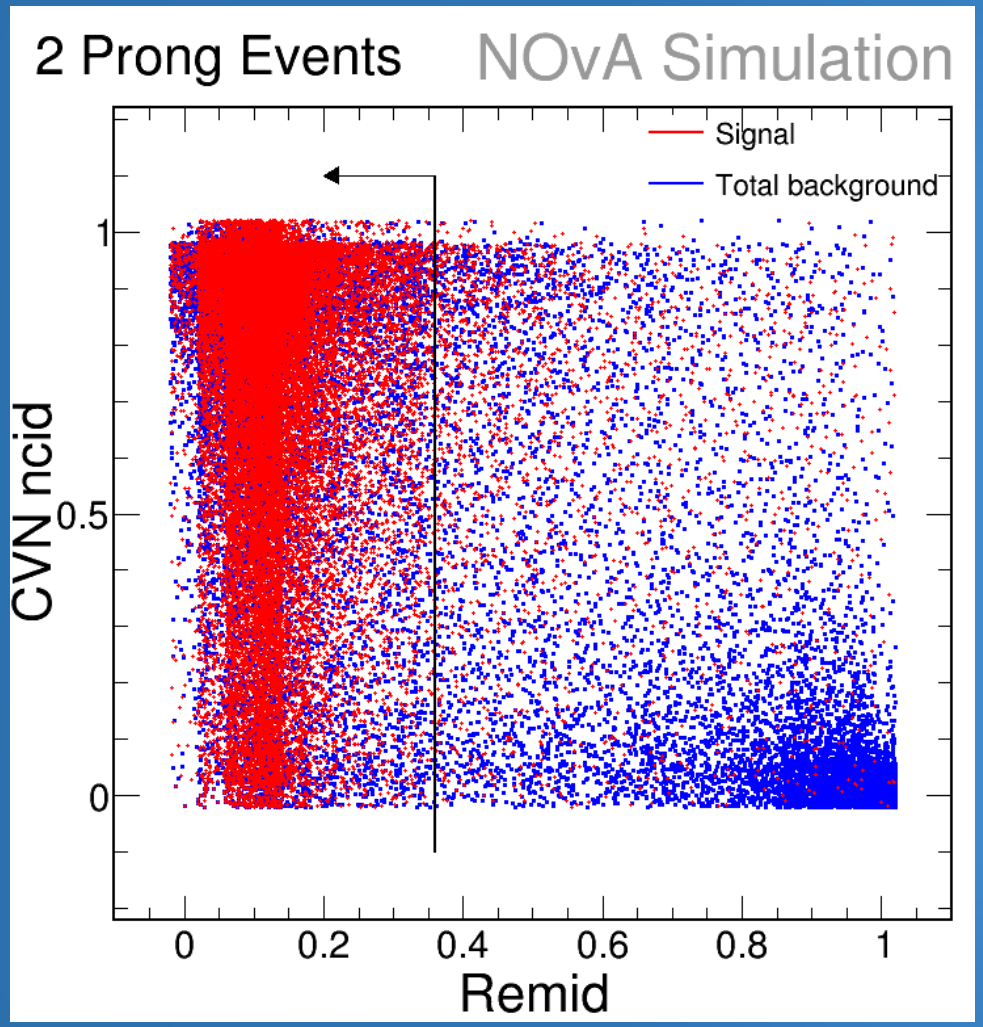

NOvA Simulation
Shw1 Background
Shw2 Background
Shw3 Background
Shw1 Signal
Shw2 Signal
Shw3 Signal
Events/4·10^20POT
ShowerLID e-p Longitudinal Loglikelihood
NOvA Simulation
Shw1 Background
Shw2 Background
Shw3 Background
Shw1 Signal
Shw2 Signal
Shw3 Signal
Events/4·10^20POT
ShowerLID e-p Transverse Loglikelihood
NOvA Simulation
Shw1 Background
Shw2 Background
Shw3 Background
Shw1 Signal
Shw2 Signal
Shw3 Signal
Events/4·10^20POT
ShowerLID e-π Longitudinal Loglikelihood
NOvA Simulation
Shw1 Background
Shw2 Background
Shw3 Background
Shw1 Signal
Shw2 Signal
Shw3 Signal
Events/4·10^20POT
ShowerLID e-π Transverse Loglikelihood

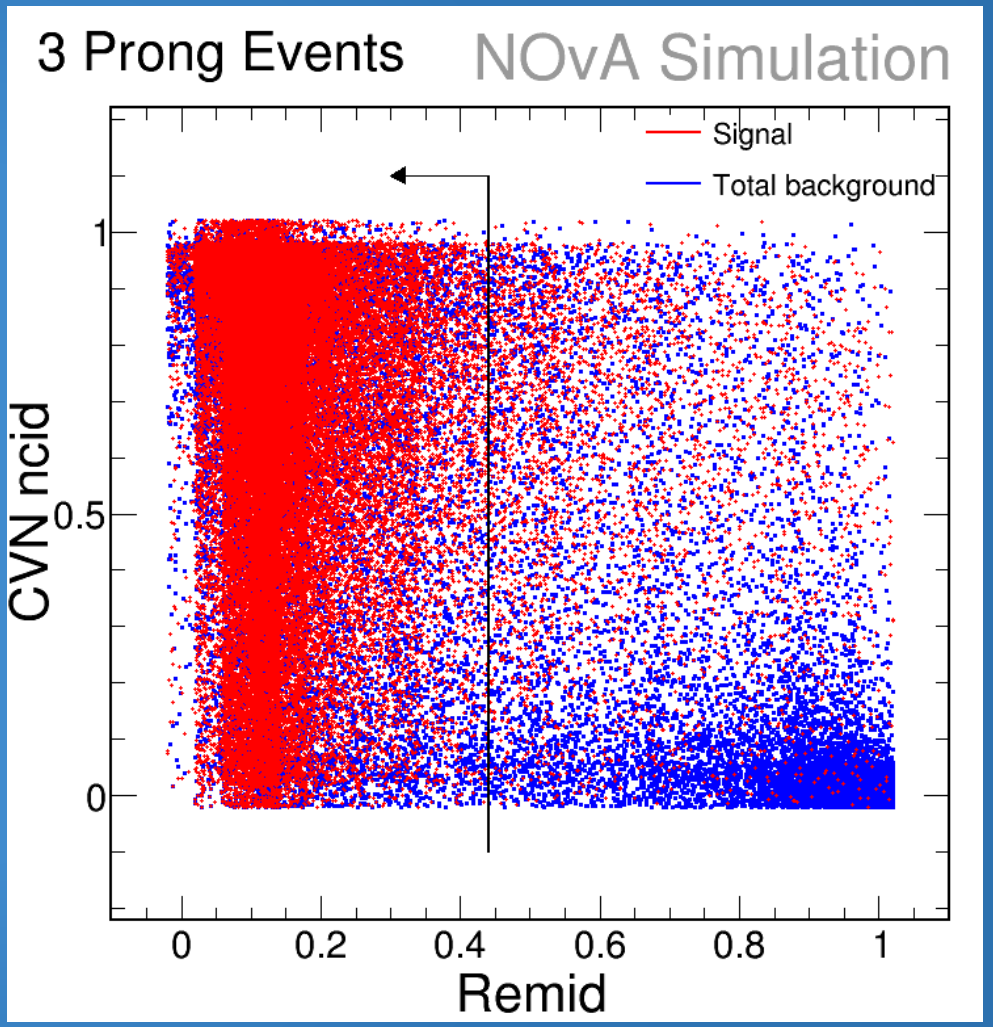

NOvA Simulation
Shw1 Background
Shw2 Background
Shw3 Background
Shw1 Signal
Shw2 Signal
Shw3 Signal
Events/4·10^20POT
Shower Max Plane Gap


NOvA Simulation
Total Background
Signal
Events/4·10^20POT
Slice Energy (GeV)


NOvA Simulation
Total Background
Signal
Events/4·10^20POT
Slice Number Of Hits


NOvA Simulation
Total Background
Signal
Events/4·10^20POT
Slice Number Of Cont. Planes


2 Prong Events
NOvA Simulation
Signal
Total background
CVN ncid
Remid
0
0.5
1
0.2
0.4
0.6
0.8


3 Prong Events
NOvA Simulation
Signal
Total background
CVN ncid
Remid
0
0.5
1
0.2
0.4
0.6
0.8

2Prongs - Cuts	Signal(S)	Background(B)			S/B (%)
		NC Bkg	CC π^0	CC noπ^0	
Fidual+Containment & ReMID < 0.36	46467	240092	116382	141488	9.33
Mass Pi0 110 < M < 220	12789	71737	21361	29429	10.44
Prong Variables Cut (Missing Planes > 1 & Contiguous Planes > 4) for both prongs	5800	12169	3121	3348	31.12
dE/dx > 0.0025 : Prong1 dE/dx < 0.004 : Prong2 Slice CalE (>0.5)	4831	6538	2080	1933	45.78
Leading Prong Variables (Length > 160 , Energy > 0.5, number of hits > 35)	3809	1685	1336	726	101.64

3Prongs- Cuts:

-**Slice**: CalE>0.5 & NbOfHits>40

-**Shower1**:NbOfPlanes>26
MaxPlaneCont>8
MaxPlaneGap>1
Length>180
Width>1
NbOfHits>40
CalE>0.5
VertexEn<0.24
e-p LLL>0 & LLT>-0.05
e-π LLL>0 & LLT>-0.05

Shower2: NbOfPlanes>12
MaxPlaneCont>2
MaxPlaneGap>0
VertexEn<0.24
dE/dx<0.004
e-π LLL>-0.1

Shower3: VertexEn<0.24
dE/dx<0.0025