Status of the ν_μ Charged-Current (CC) Zero Mesons Cross-Section Measurement in the NOvA Near Detector

Sebastian Sanchez-Falero,

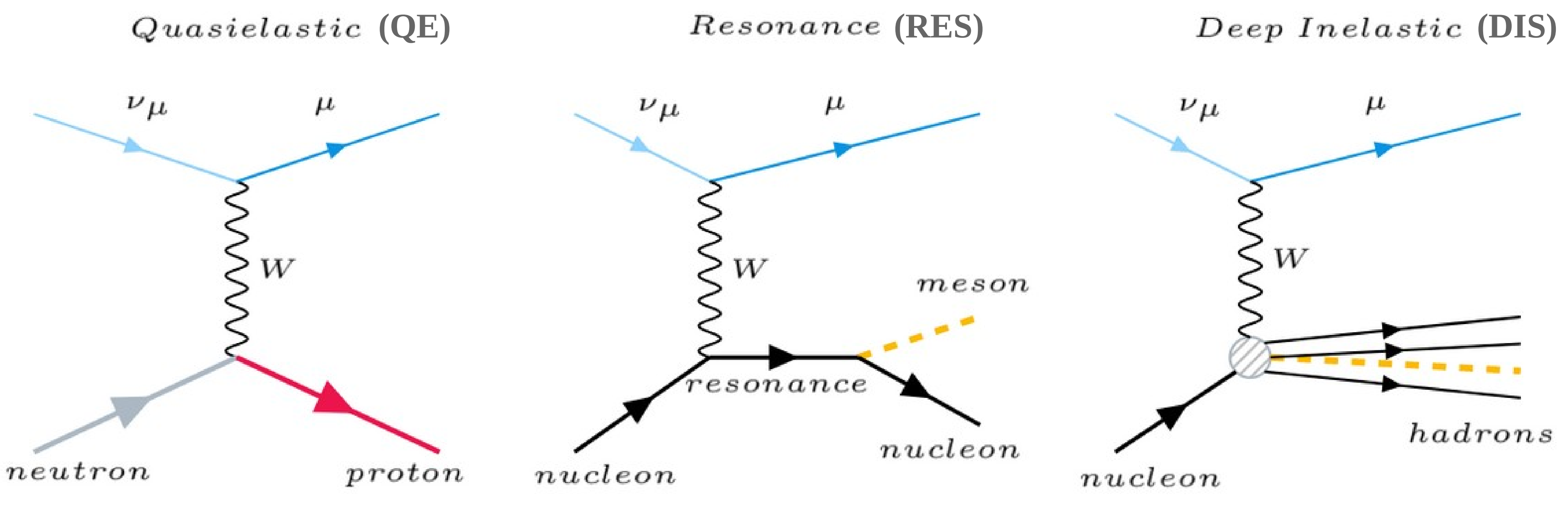
on behalf of the NOvA collaboration

New Perspectives 2021

August 19th, 2021

Why ν_μ CC Zero Mesons?

Solving **open questions in neutrino physics** requires that we understand their **interactions**



More inelastic
Higher energy
Smaller scale

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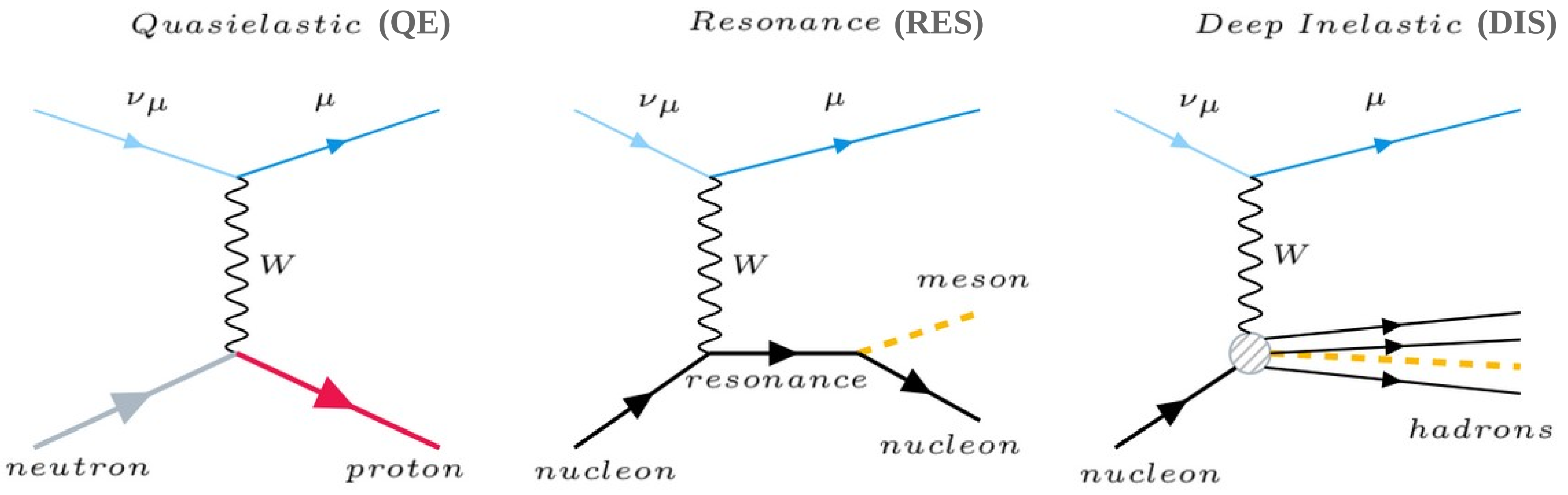
More *elastic* interactions are **easier to fully reconstruct**



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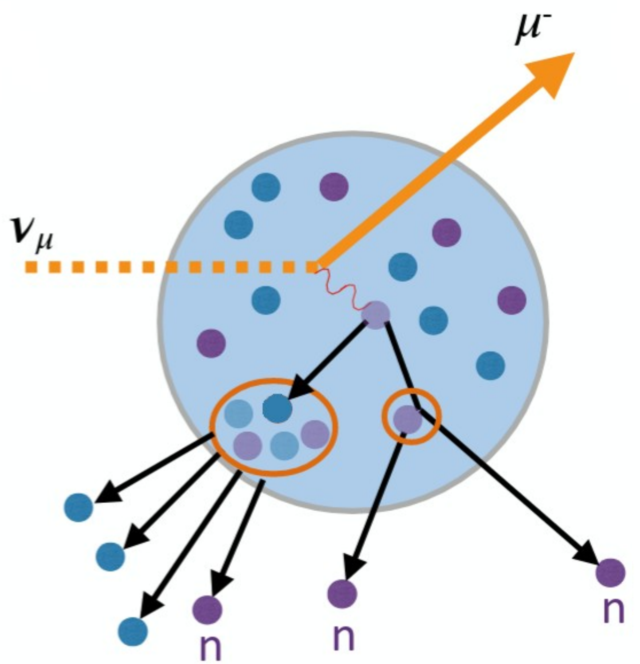

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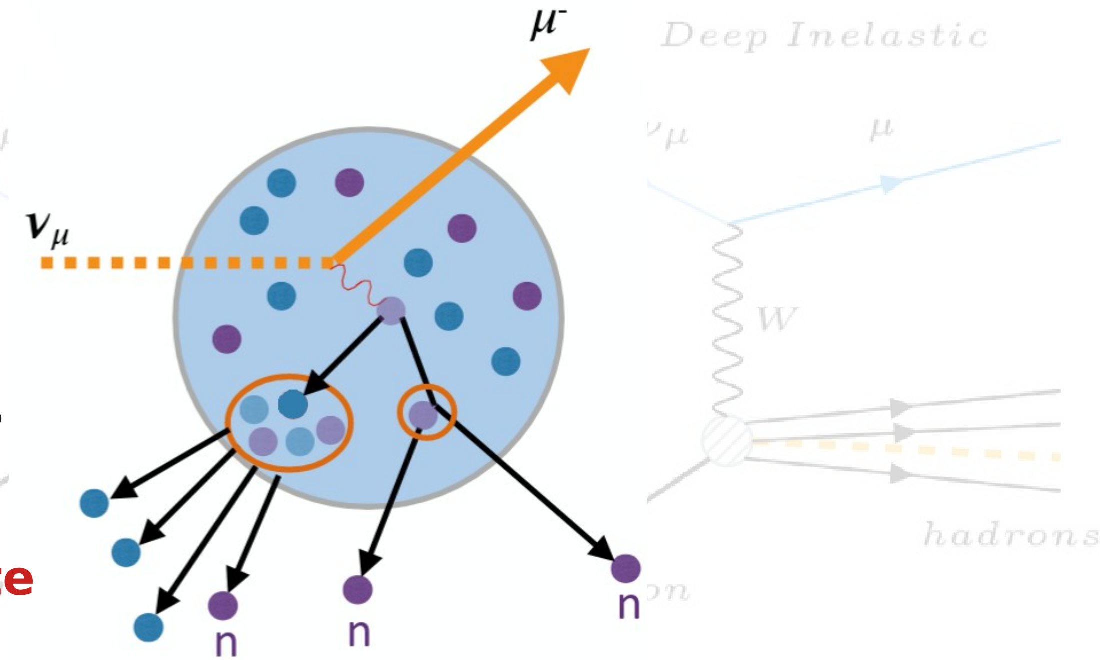

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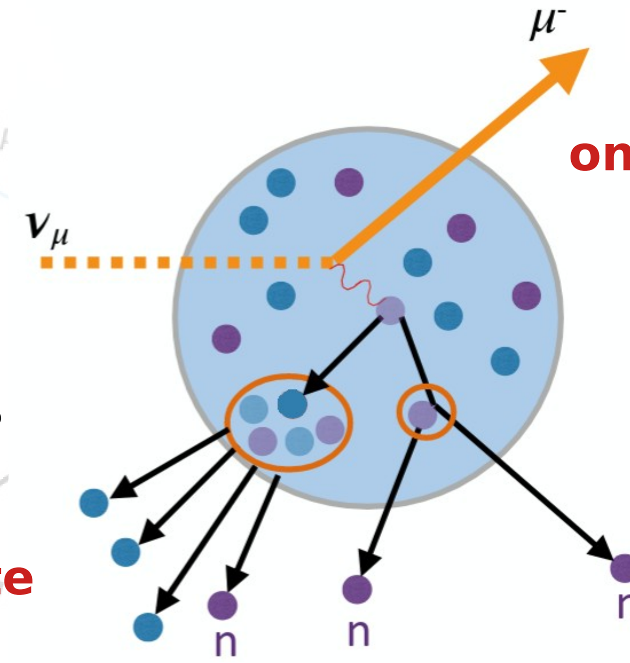

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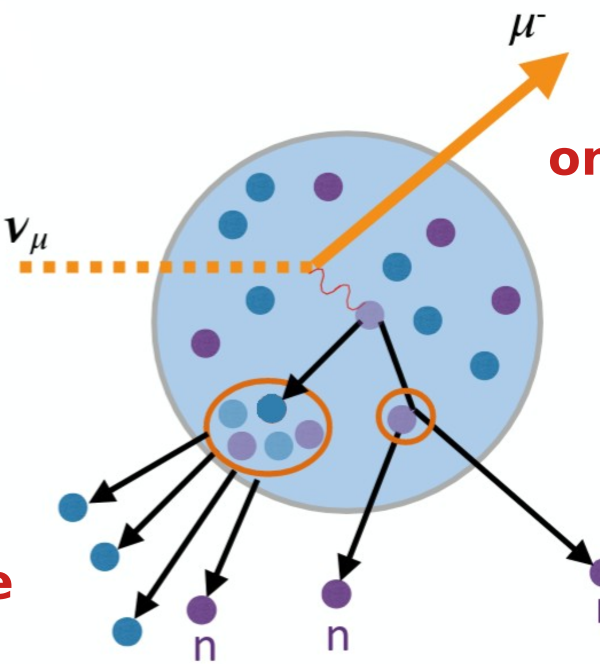

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zero mesons ≈ enhanced fraction of close-to-elastic modes (QE, MEC)

Why ν_μ CC Zero Mesons?

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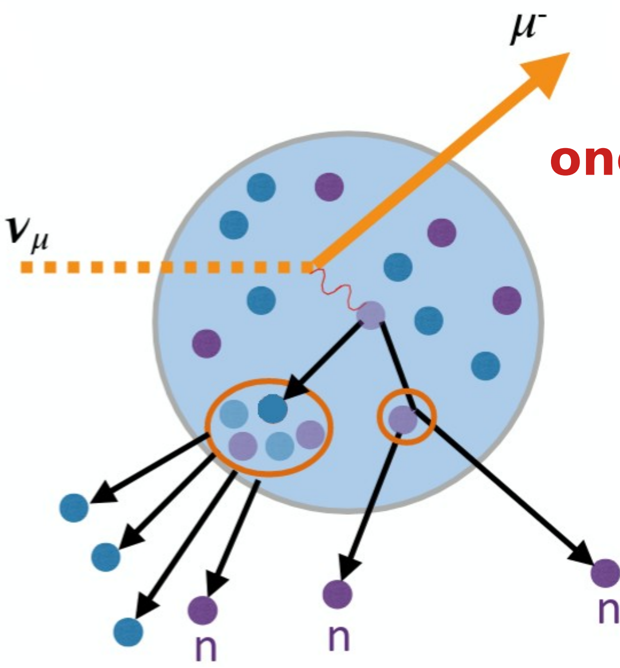
More *elastic* interactions are **easier to fully reconstruct**

This channel also provides windows to:

- Probe **weak-interaction structure** of nucleons
- Constrain **nuclear** and **Final State Interaction** models

Stepping stone for more **exclusive analyses**

Important **signal process** for **oscillation experiments**



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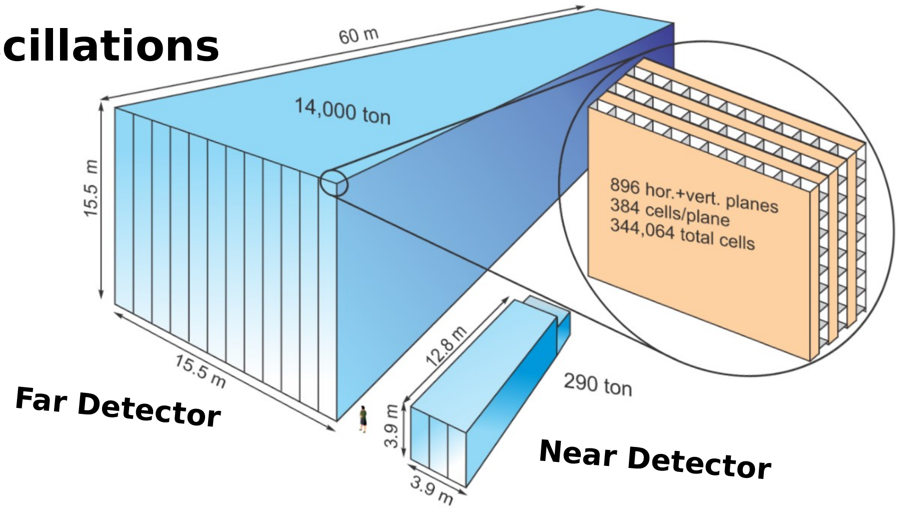
Why at the NOvA Near Detector?

- **Long-baseline** accelerator neutrino experiment at Fermilab
- **Two detectors** (functionally identical) to measure **oscillations**
- Liquid scintillator **tracking calorimeters**
- **77% hydrocarbon**, 16% Chlorine, 6% TiO_2



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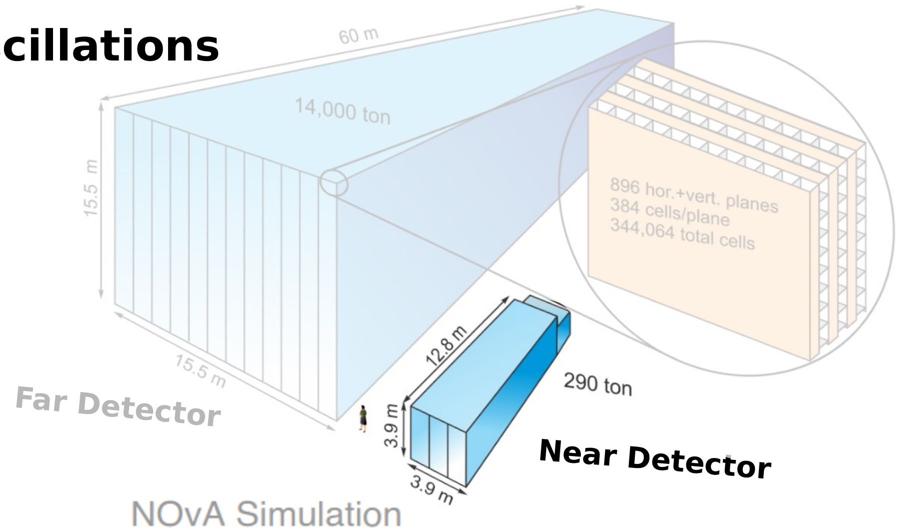
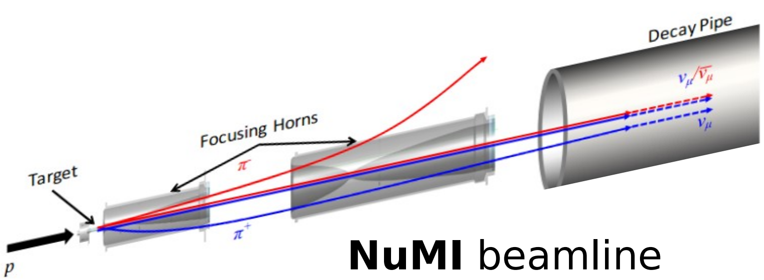
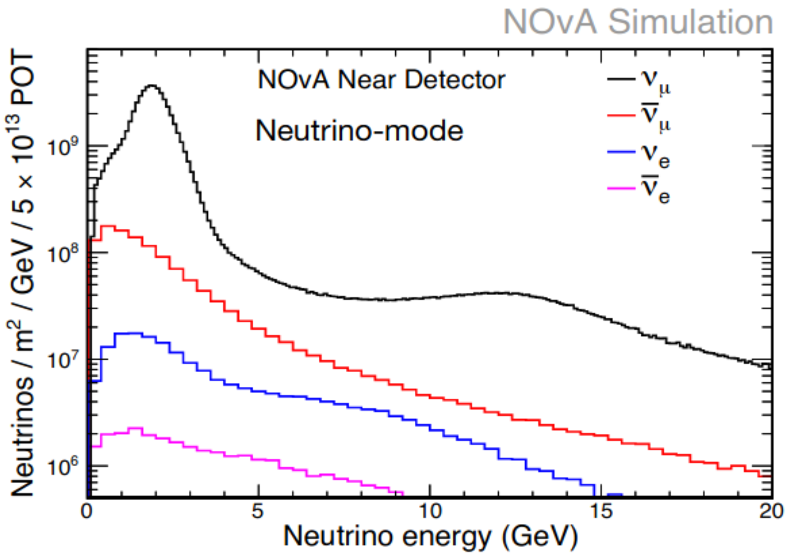




NuMI beamline



Flux at the **Near Detector**

96% νμ

⟨E⟩~2 GeV

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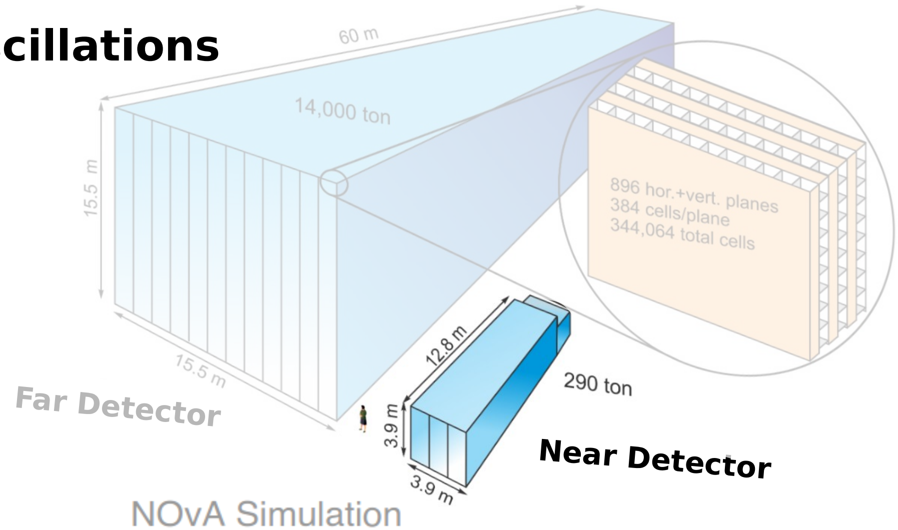
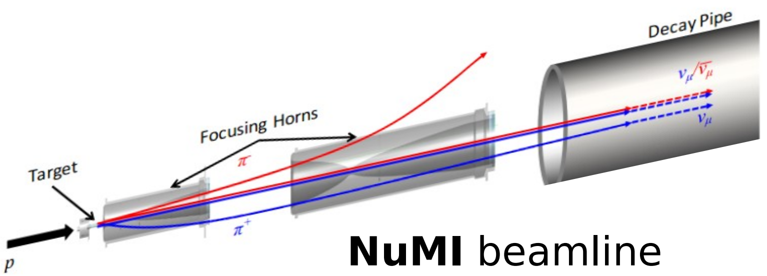


The **Near Detector** receives a

- high **intensity**, high **purity** beam



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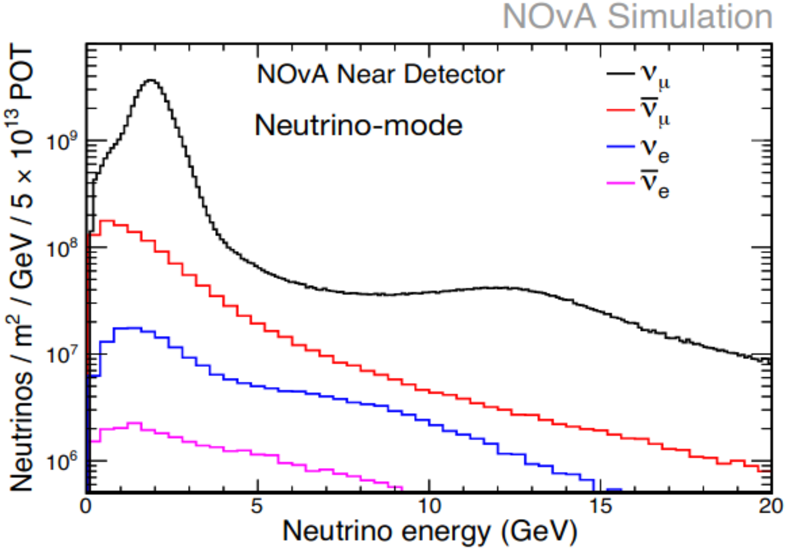

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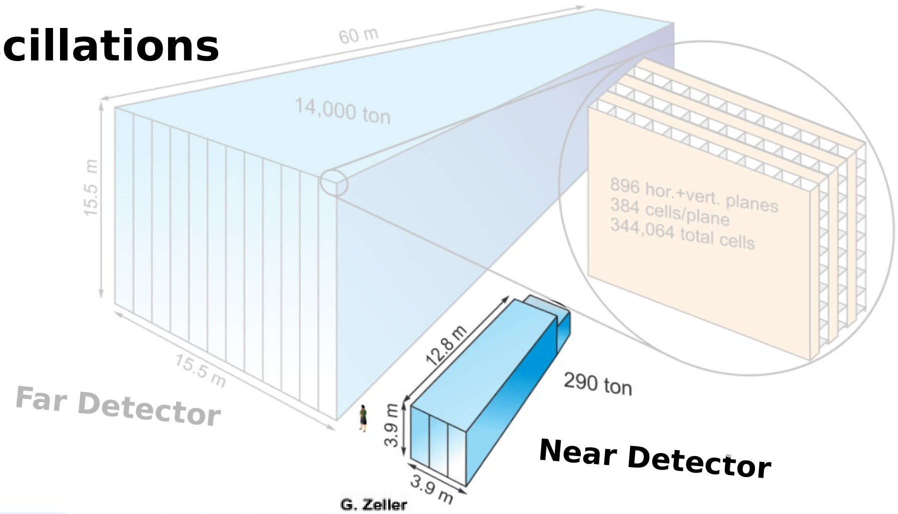
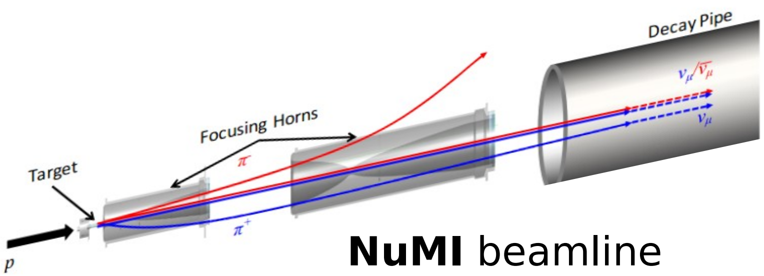


The **Near Detector** receives a

- high **intensity**, high **purity** beam
- in a **dynamic** energy region (interaction modes)

making it an excellent lab for neutrino interactions!



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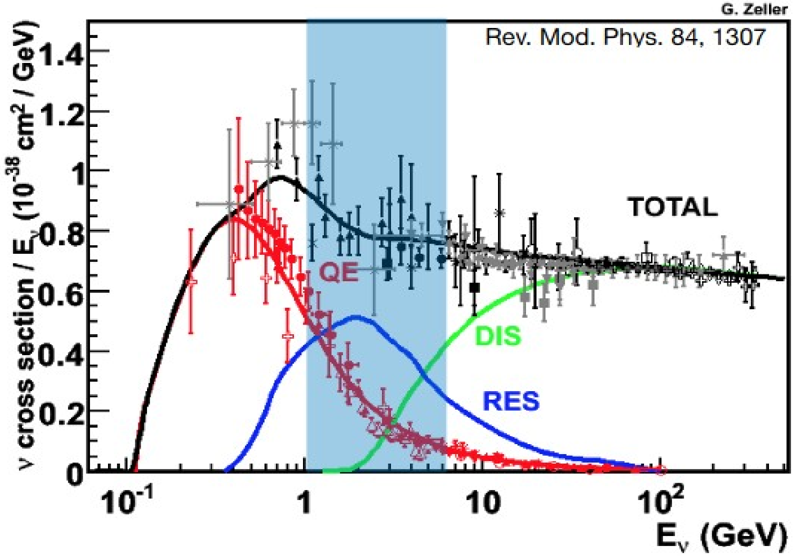

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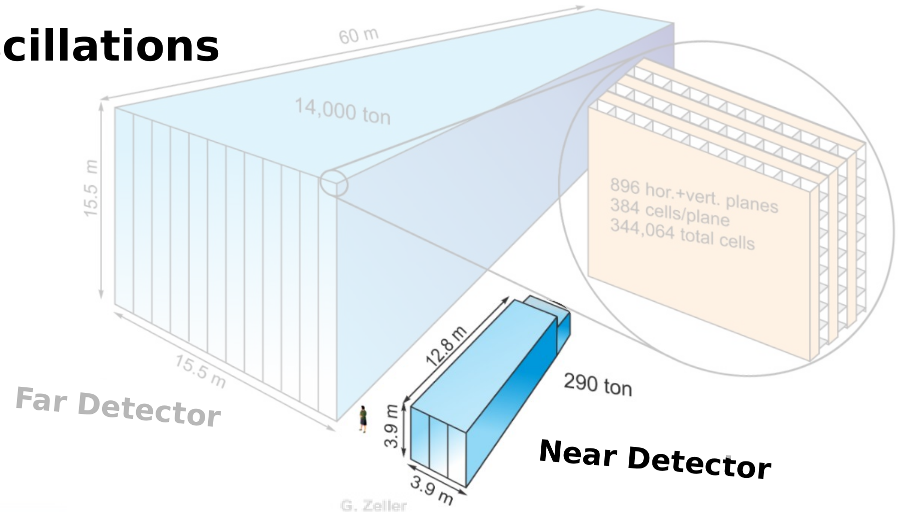

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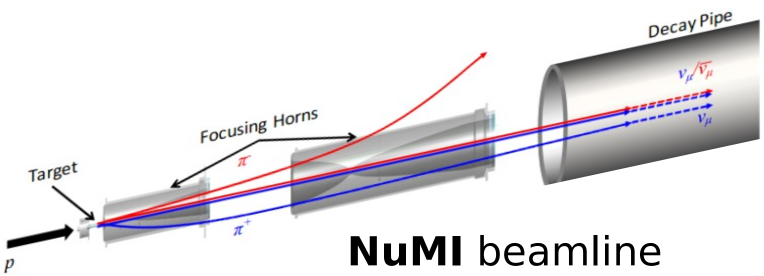

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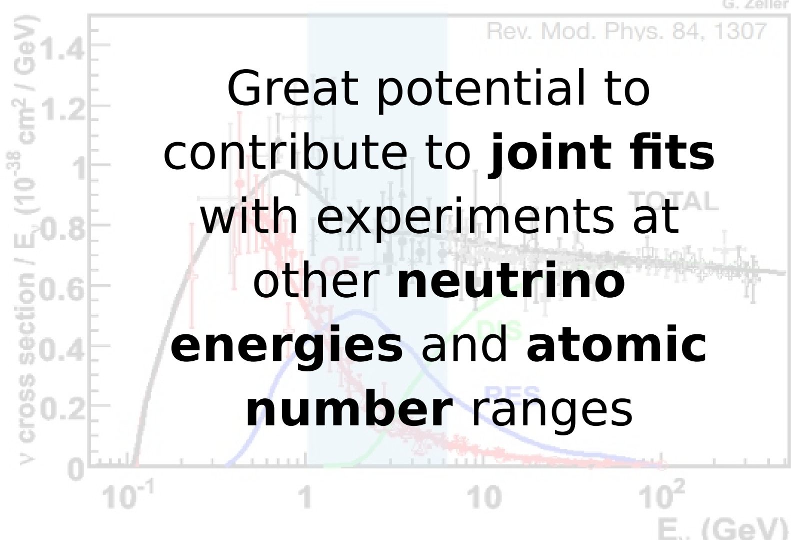


Great potential to contribute to **joint fits** with experiments at other **neutrino energies** and **atomic number** ranges

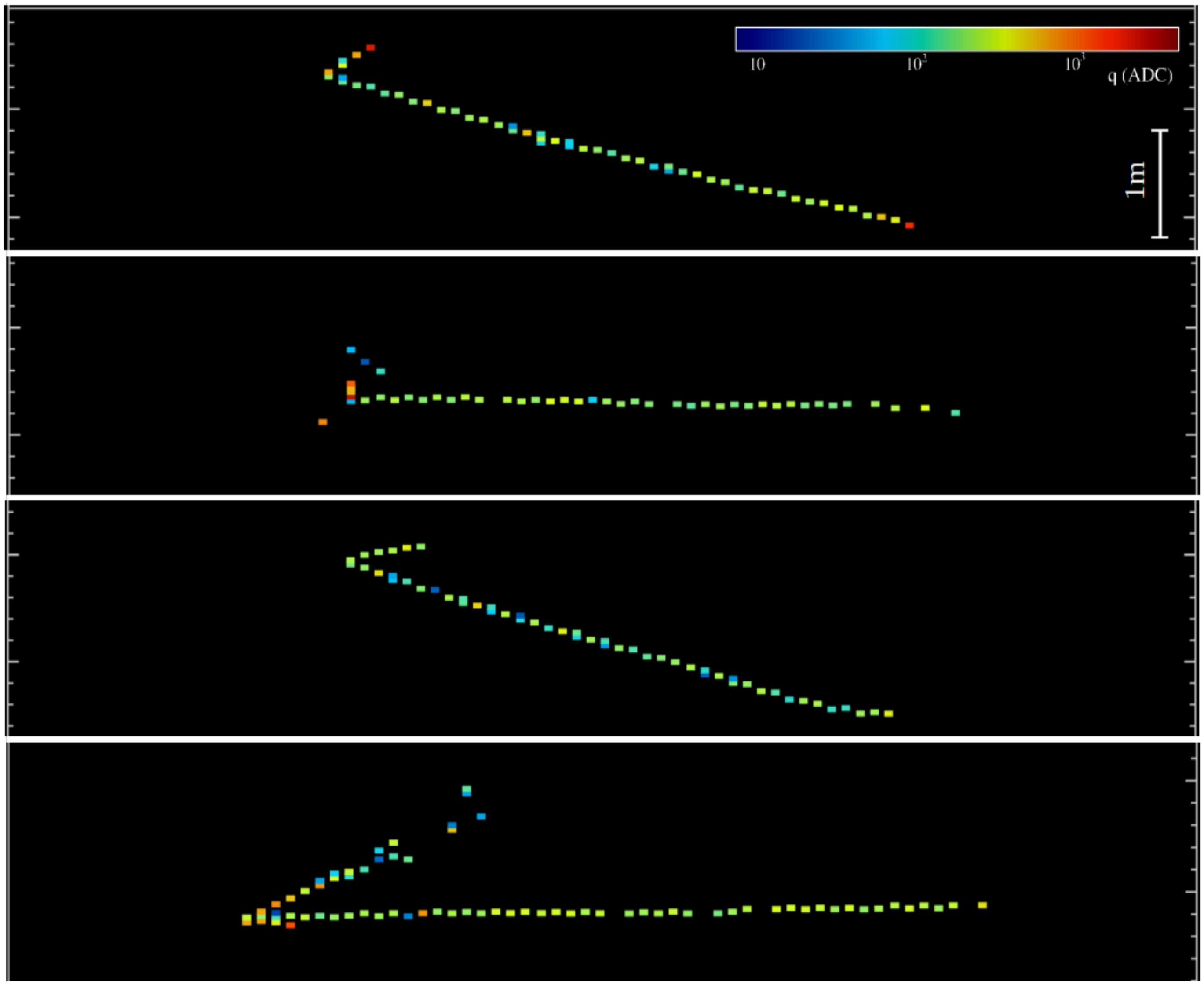
Flux at the **Near Detector**

96% $\nu\mu$

$\langle E \rangle \sim 2$ GeV

Thanks to fellow novans for nicely introducing the experiment!

How do ν_μ CC Zero Mesons look at NOvA?



Prong = a trackable energy deposit

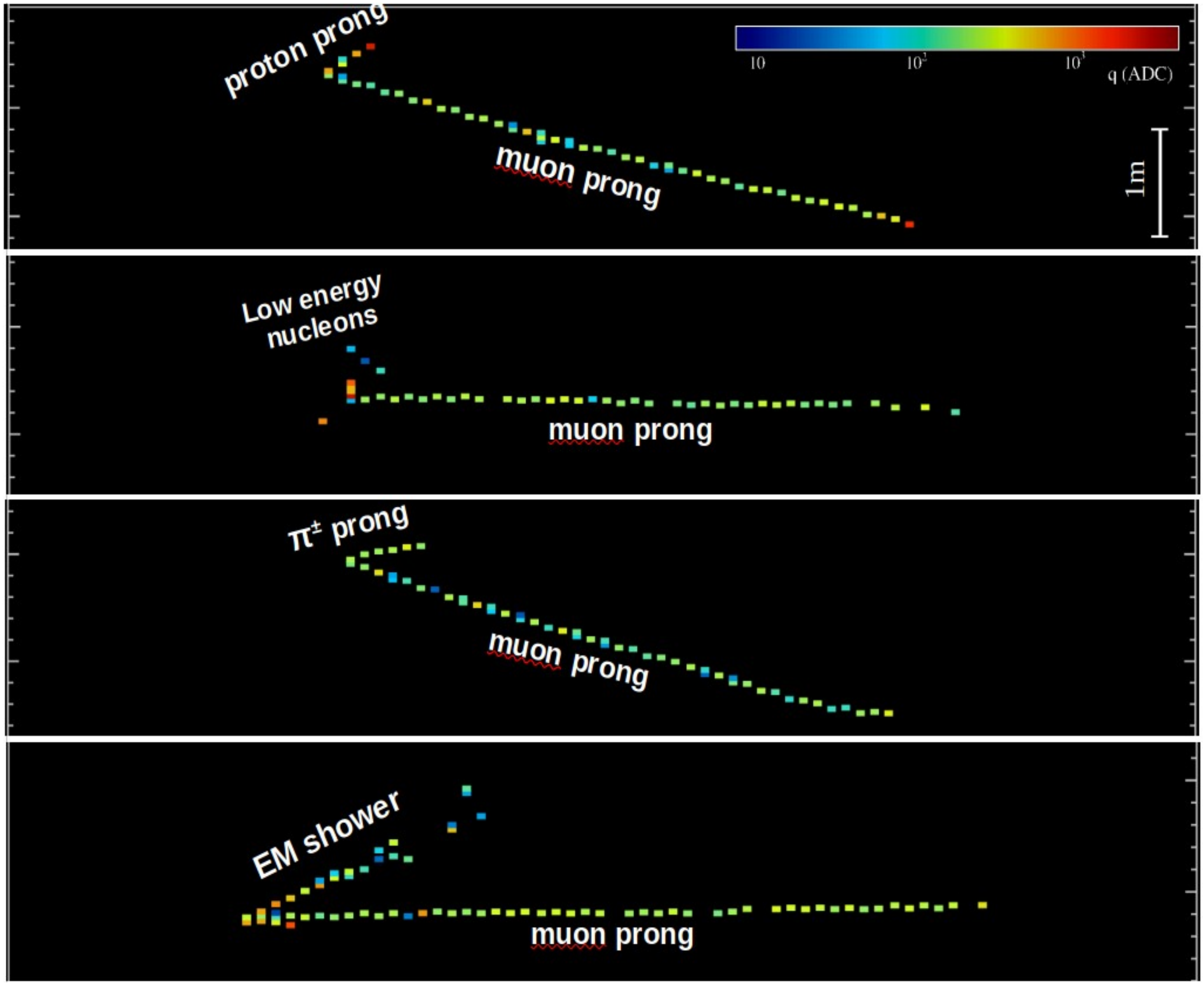
How do ν_μ CC Zero Mesons look at NOvA?

Zero Mesons

Zero Mesons (also)

Meson: Charged pion

Meson: Neutral pion



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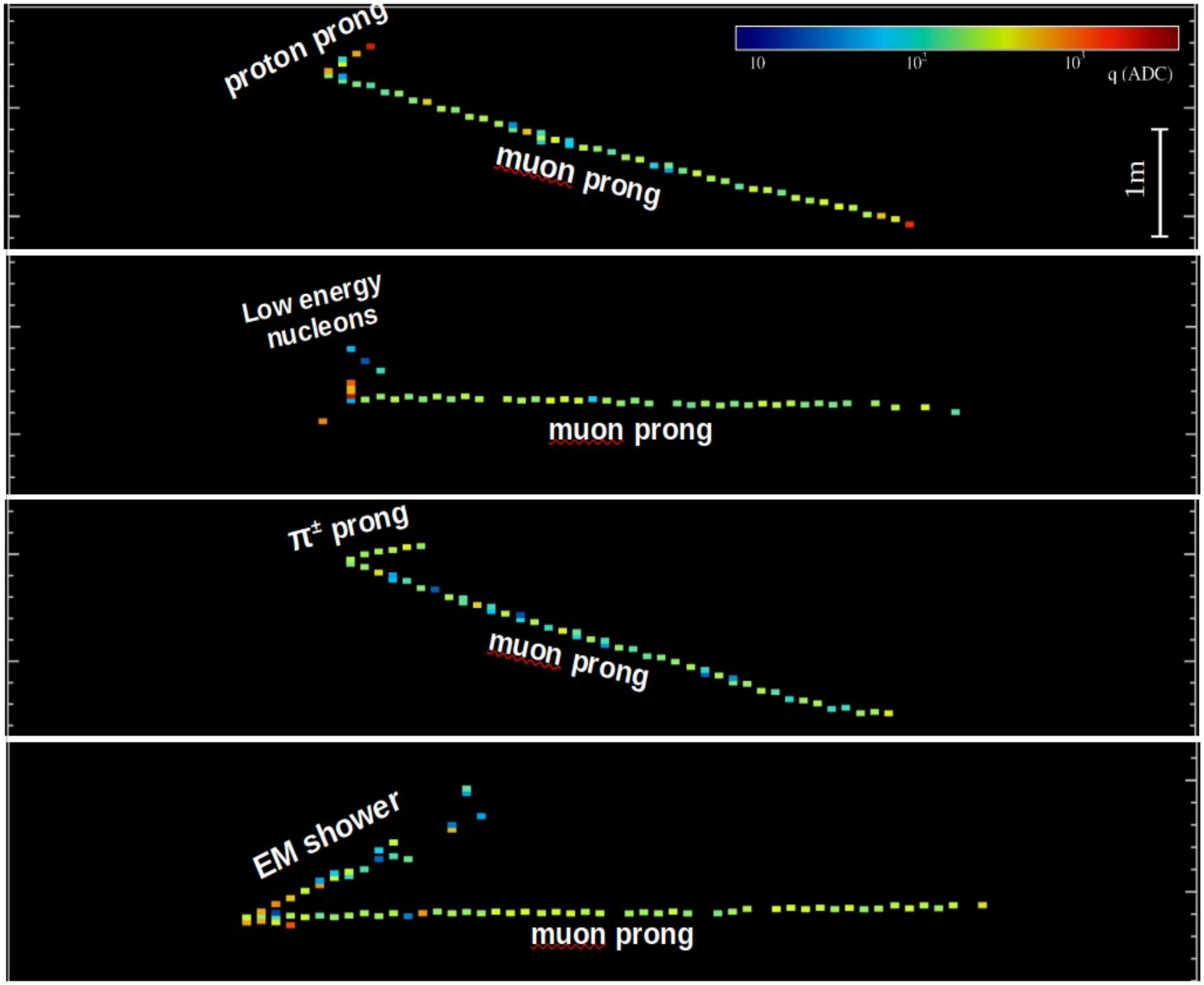
How to select ν_μ CC Zero Mesons events?

Need a tool to **identify individual prongs** by **how to how they look** in the detector



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How to select ν_μ CC Zero Mesons events?

The 5-label Single Particle Prong CVN

- **Convolutional Visual Network**

  Takes pictures of the detector => applies convolutions to extract features

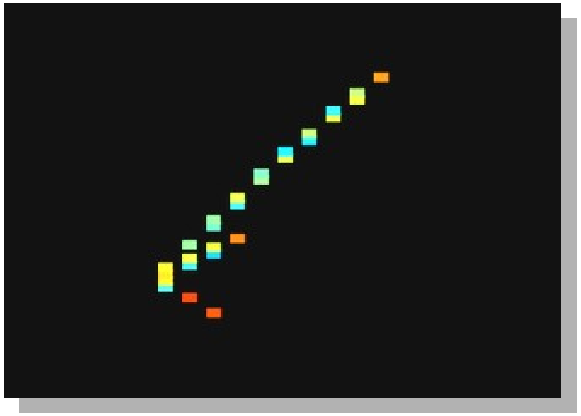
- **Training**

  individual uniformly simulated particles of 5 classes: muon, proton, pion, electron and photon

- **Application**

  Takes a prong => provides five particle ID scores, for each class of particle

Detector picture



- The **CNN** in Akhsay's talk acts at the **event-level** (used in NOvA oscillation analysis)
- This **CVN** acts at the **prong-level (sub-event)**

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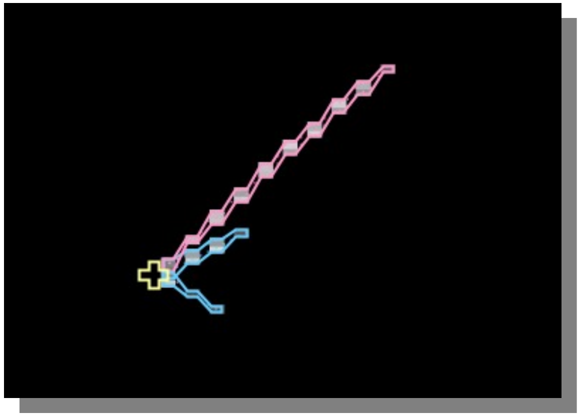
Prong reconstruction



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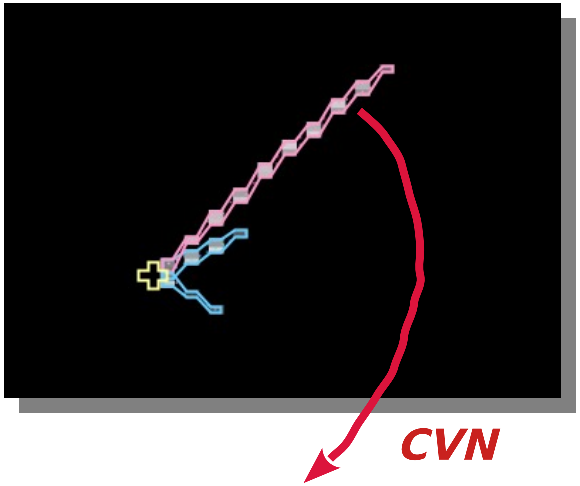

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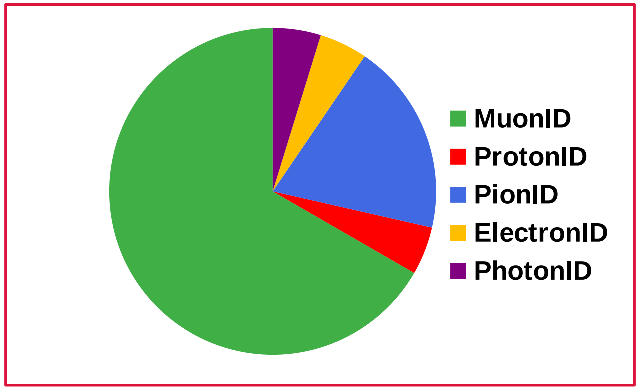

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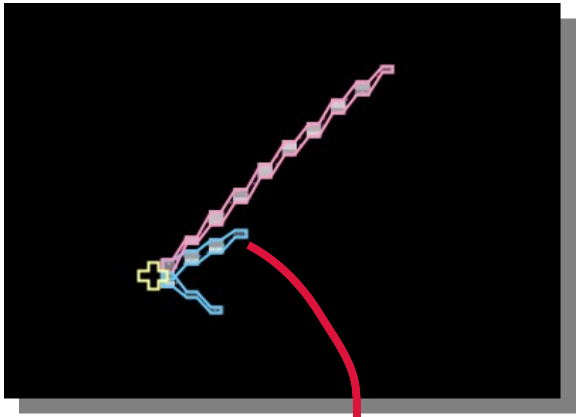

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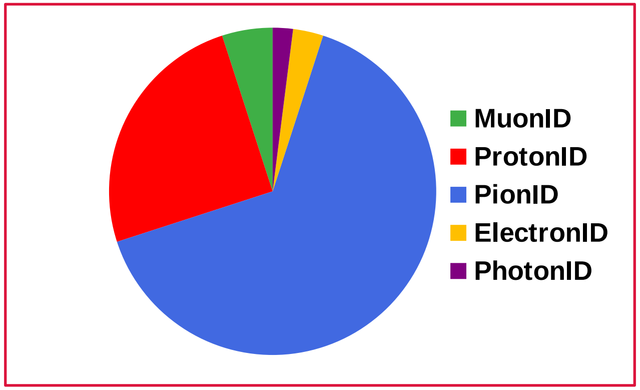

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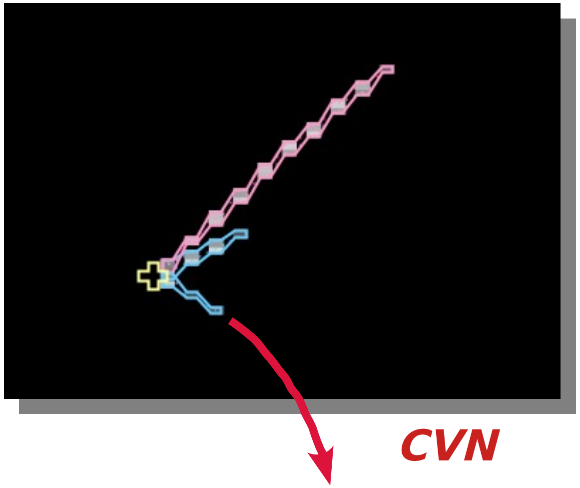

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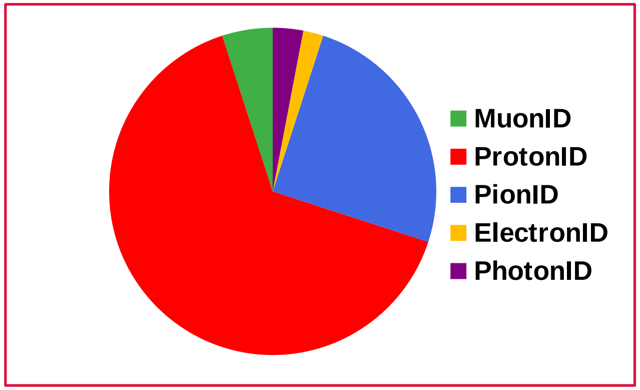

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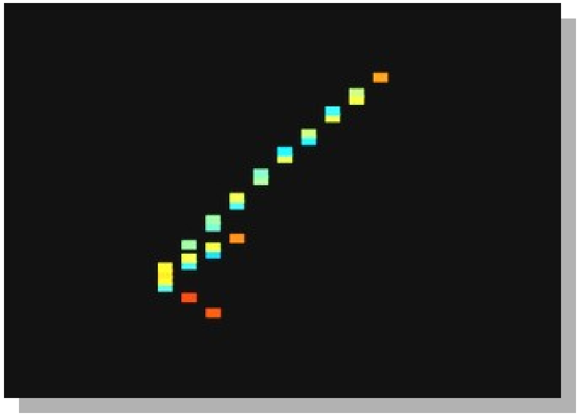
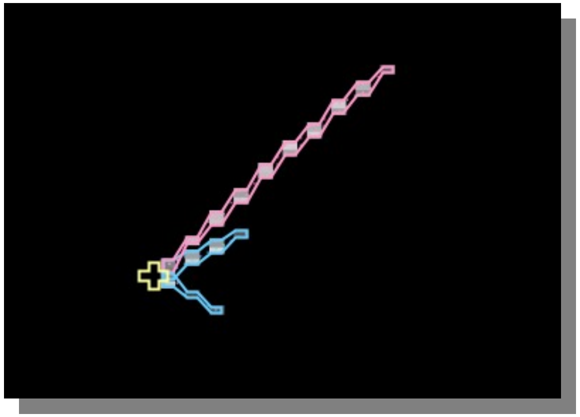
Detector picture



How to select ν_μ CC Zero Mesons events?

Event with CVN ID



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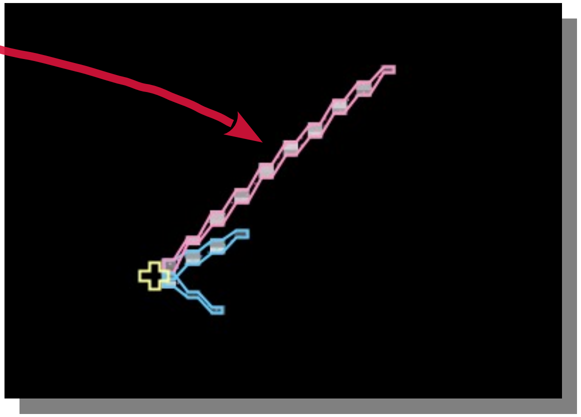

Find a muon

- The longest prong longer than 5 m

OR, if none

- The prong with highest MuonID

Separate this prong from further selection

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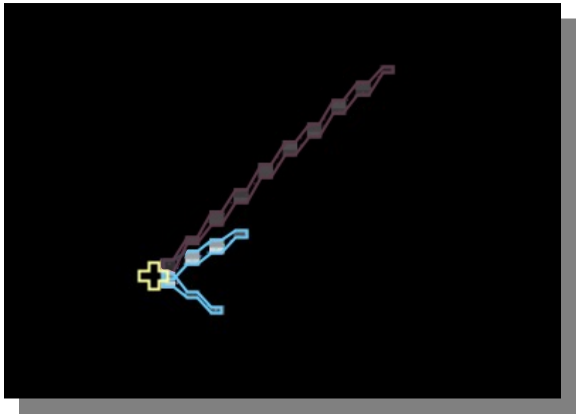

Reject events with Mesons

- Tag **neutral pions**

Reject event if any prong has high *EMID = ElectronID + PhotonID*

- Tag **charged pions**

Rank prongs by PionID:

(1st) Leading pion candidate

2nd Leading pion candidate

3rd Leading pion candidate

...

Use *ProtonID, MuonID and PionID* to reject background events

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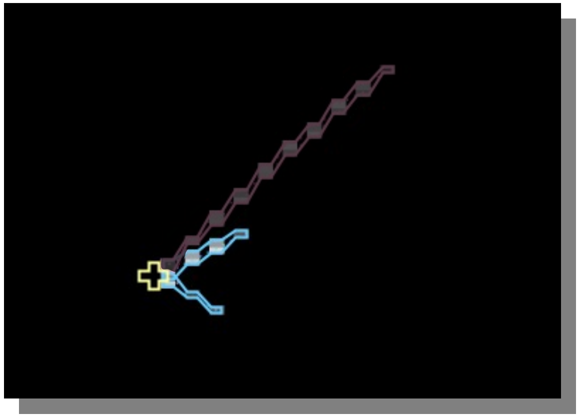

Backgrounds

- **Wrong sign: Anti-ν_μ CC**
- **ν_μ CC N-Mesons (most likely pions)**
- **ν_e or Anti-ν_e CC events**
- **NC events**
- **Others**

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Use *ProtonID, MuonID and PionID* to reject background events

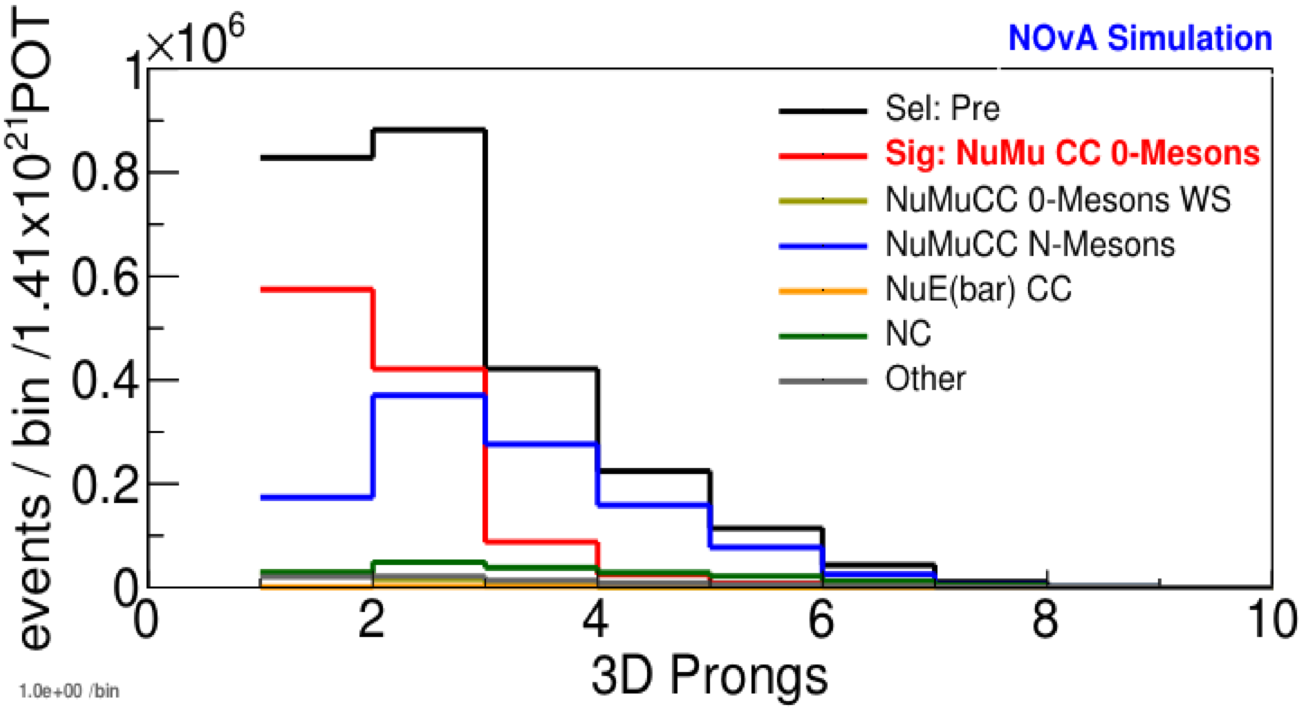
ν_μ CC Zero Mesons Selection: Summary

(1) Preselection

Based on parent **ν_μ CC Inclusive analysis**:

- Reconstruction **quality**
- **Containment** of tracks and showers
- Interaction vertex in a **fiducial** volume
- **MuonID**: Find a muon using a Boosted Decision Tree taking dE/dX and scattering likelihood of tracks as inputs

ν_μ CC Zero Mesons Selection: Number of Prongs



- Very few signal events have five or more prongs
- Interactions that tend to produce less particles

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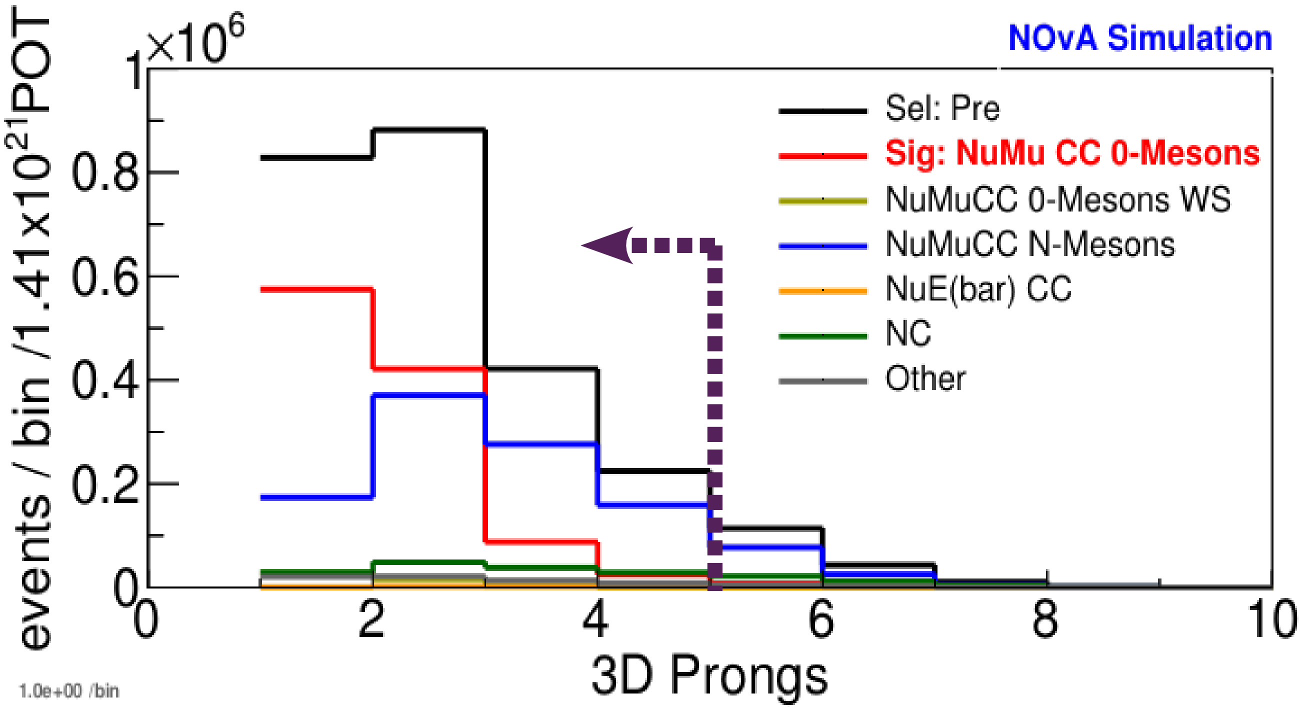
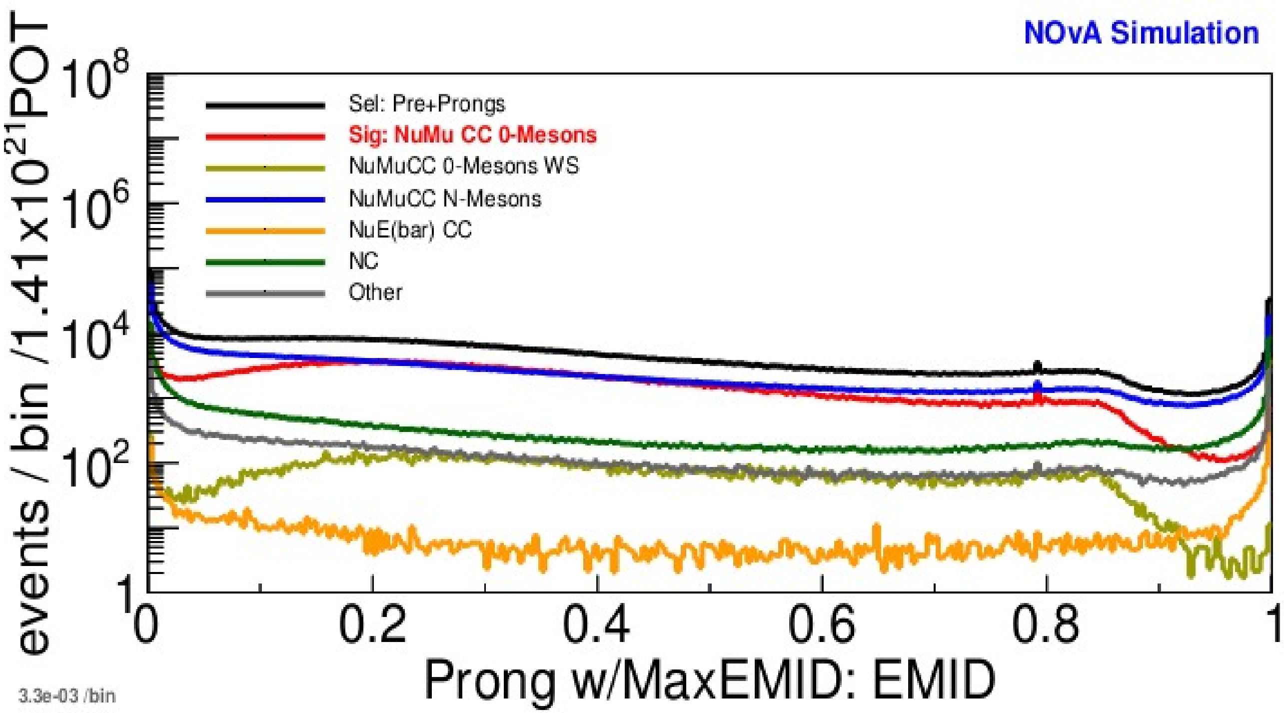


- Very few signal events have five or more prongs
- Interactions that tend to produce less particles
- Select events up to **four prongs**:

  Purity: 42% → 47%

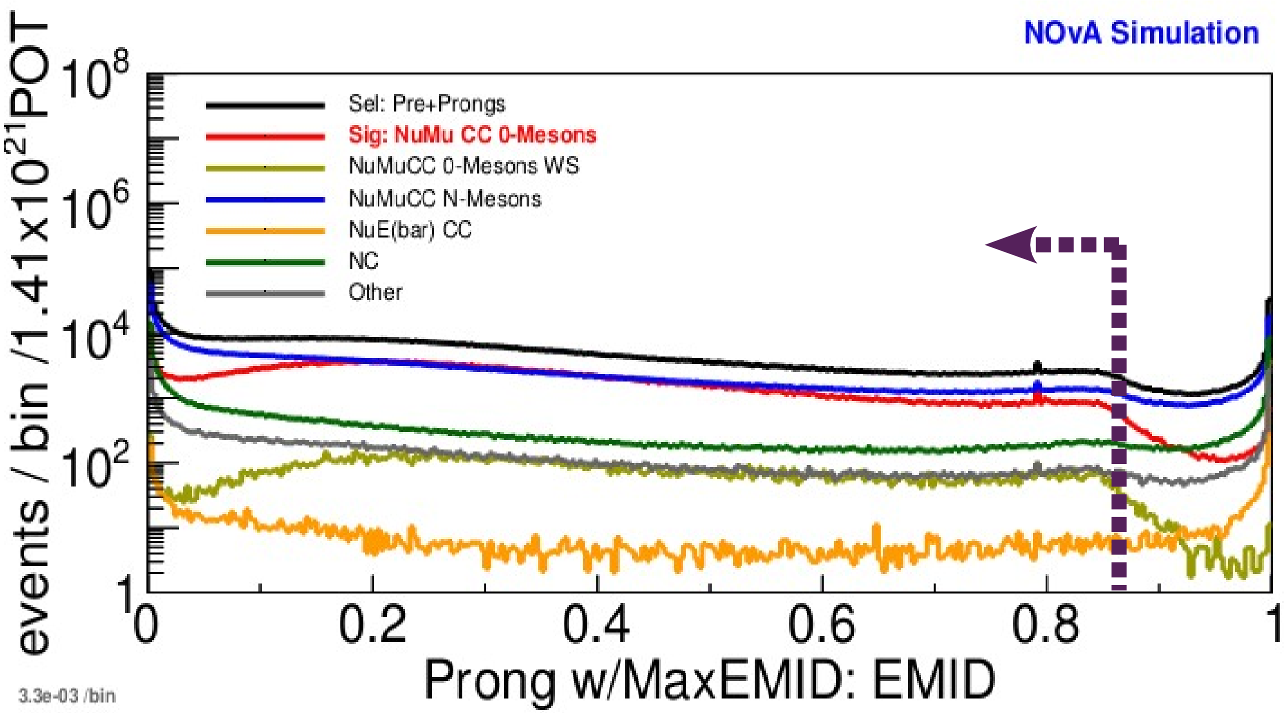
  Efficiency: drops by <1%

ν_μ CC Zero Mesons Selection: Highest EMID in the event



- Events with **2+ prongs** (at least one prong other than the muon)
- Zero Mesons (**signal** and **Wrong Sign**) fall at high EMID

ν_μ CC Zero Mesons Selection: Highest EMID in the event

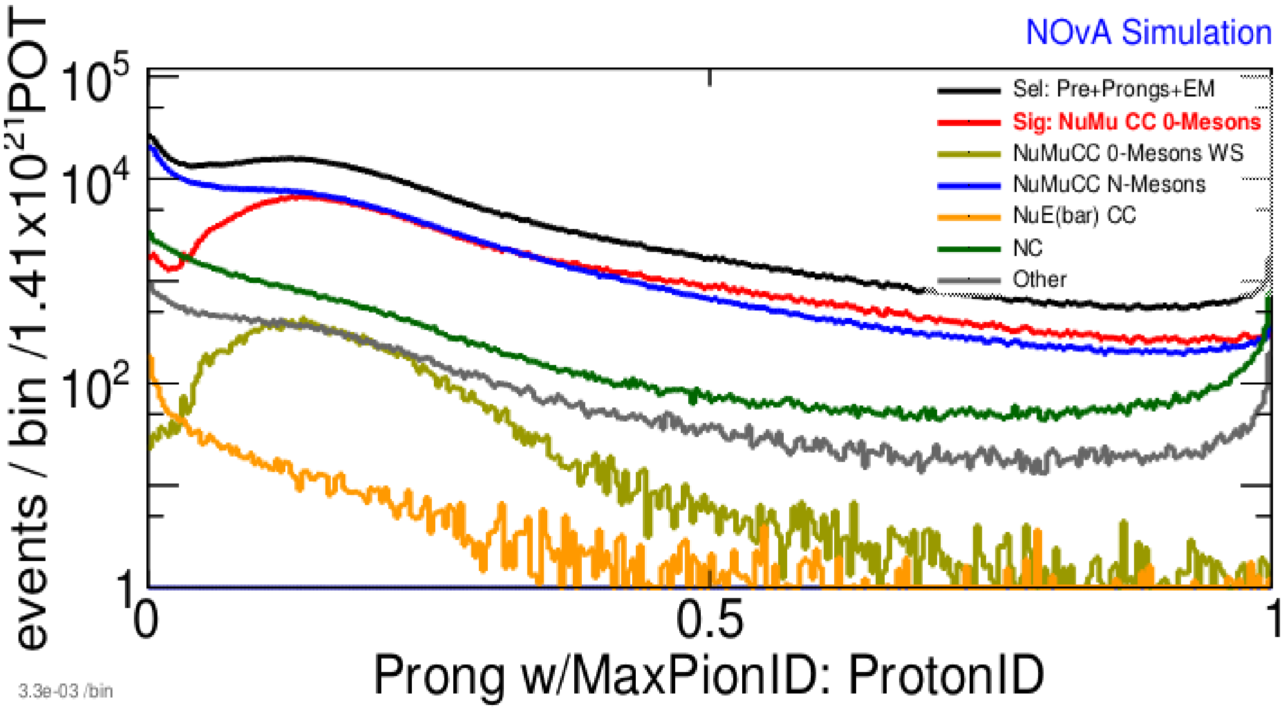


- Events with **2+ prongs** (at least one prong other than the muon)
- Zero Mesons (**signal** and **Wrong Sign**) fall at high EMID
- **Cut where Efficiency x Purity is maximum, EMID <= 0.872**

  Purity 47% → 49%

  Efficiency drops by <1%

ν_μ CC Zero Mesons Selection: 1st Pion Candidate: ProtonID



- Events with **2+ prongs** (at least one prong other than the muon)
- Zero Mesons (**signal** and **Wrong Sign**) fall at very low ProtonID

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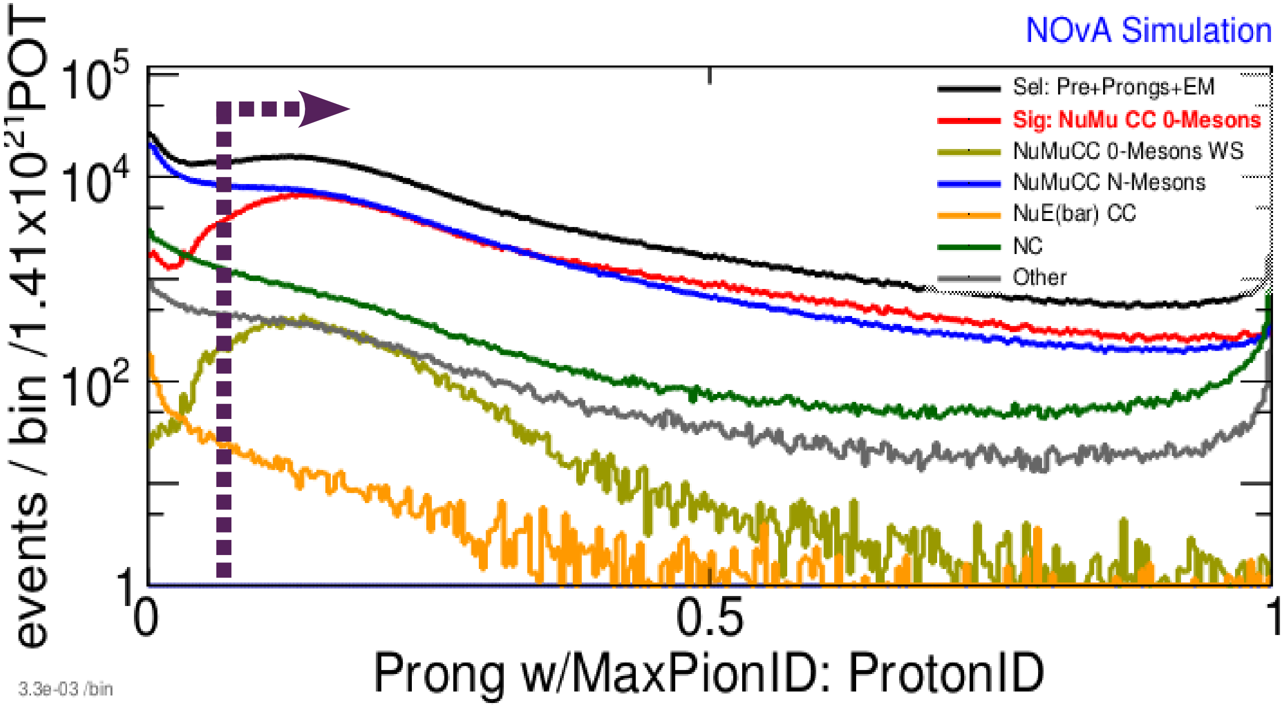
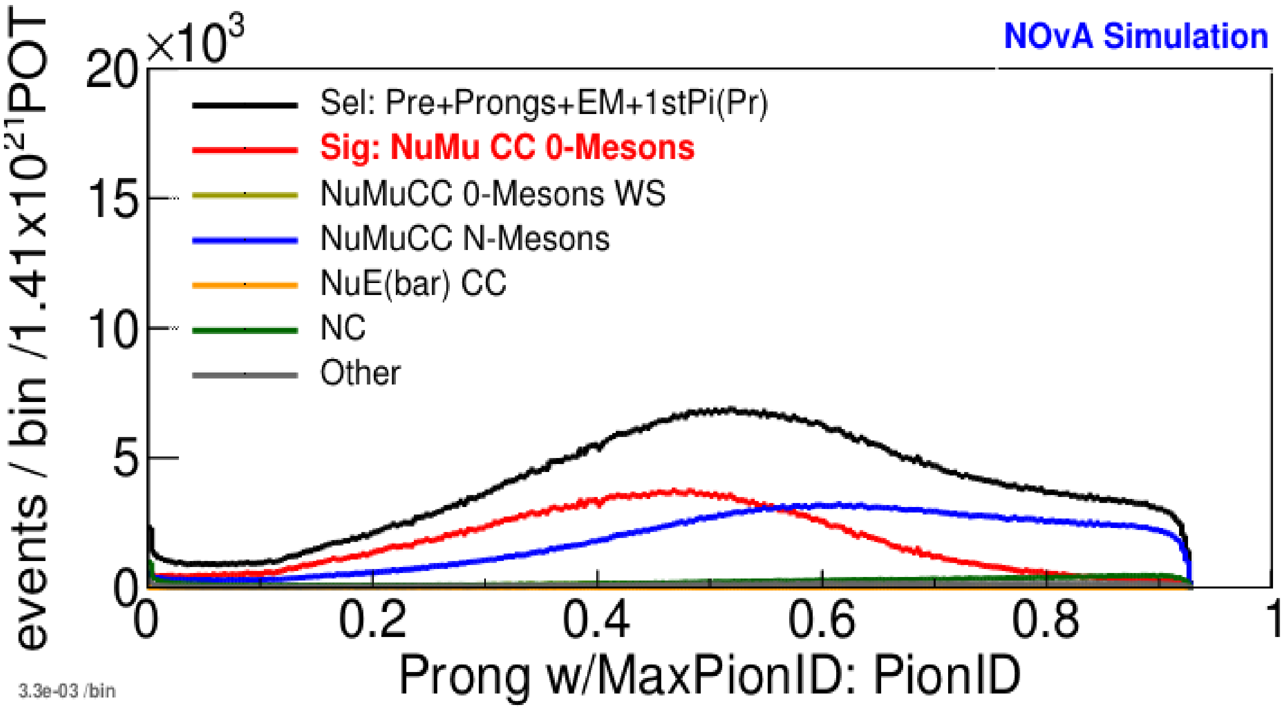


- Events with **2+ prongs** (at least one prong other than the muon)
- Zero Mesons (**signal** and **Wrong Sign**) fall at very low ProtonID
- **Cut where Efficiency x Purity is maximum ProtonID > 0.072**

  Purity 47% → 55%

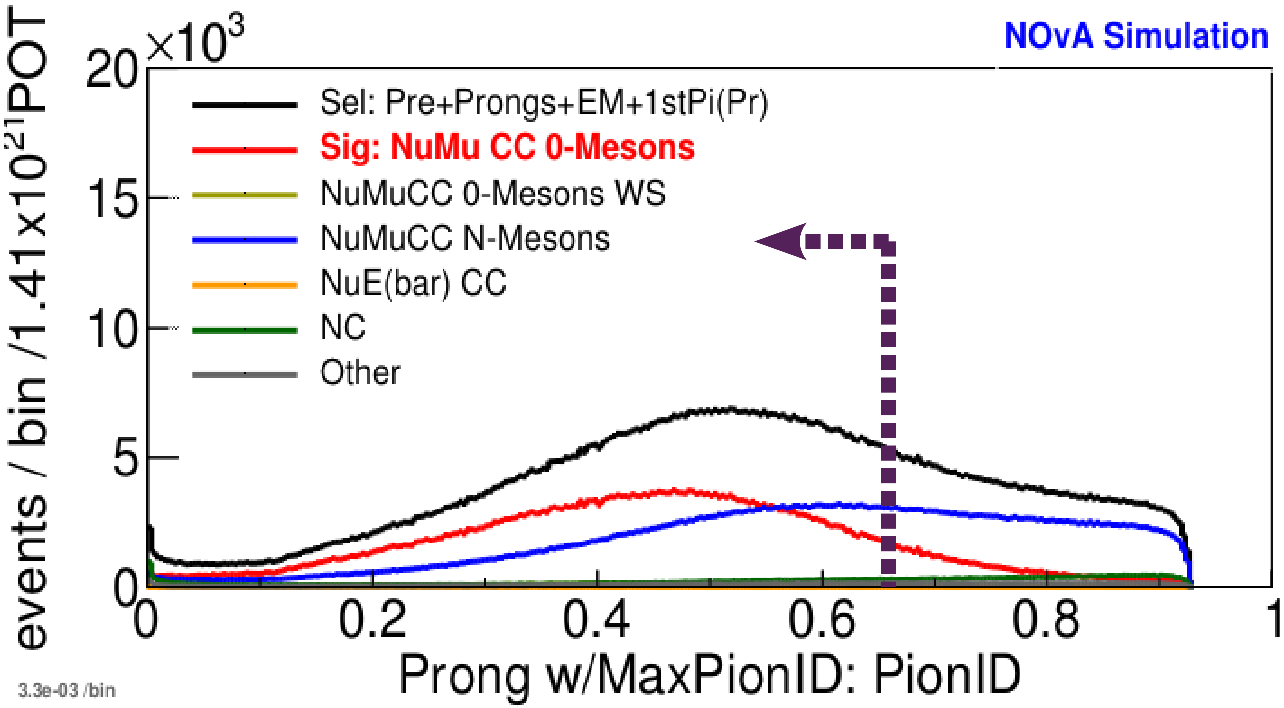
  Efficiency drops by 4%

ν_μ CC Zero Mesons Selection: 1st Pion Candidate: PionID



- Events with **2+ prongs** (at least one prong other than the muon)
- Yields important additional purity gains

ν_μ CC Zero Mesons Selection: 1st Pion Candidate: PionID

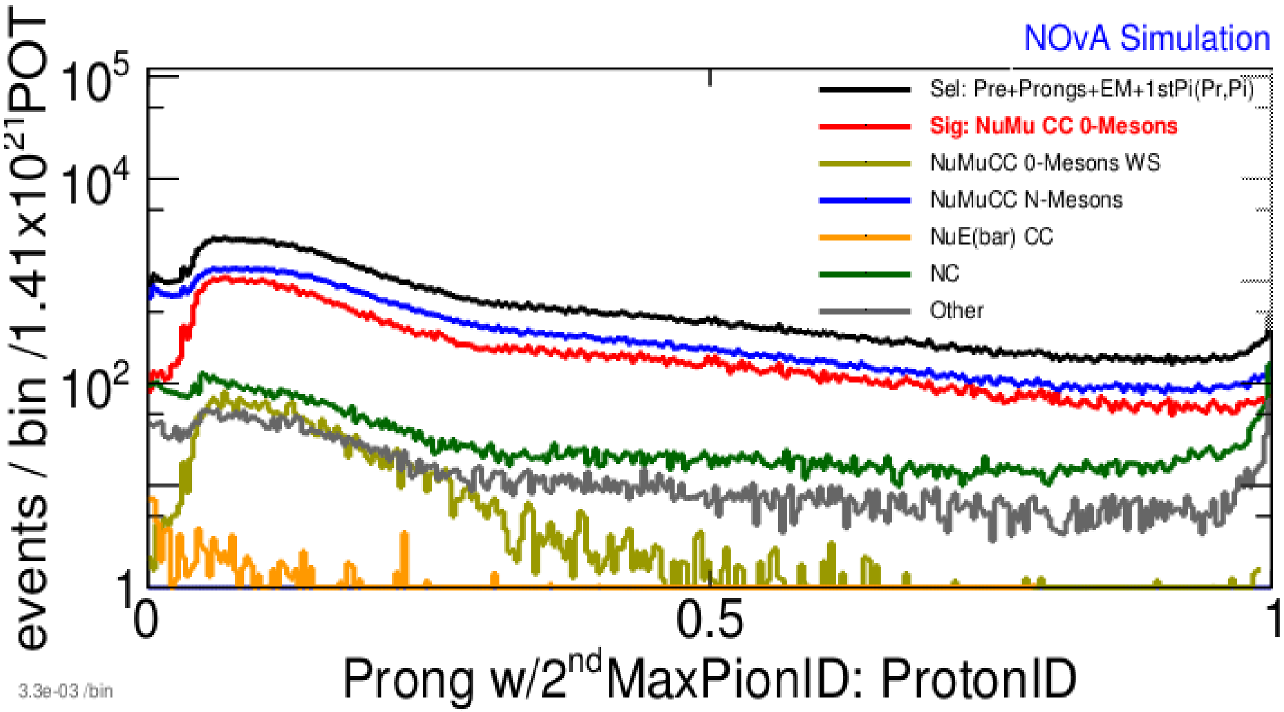


- Events with **2+ prongs** (at least one prong other than the muon)
- Yields important additional purity gains
- **Cut where Efficiency x Purity is maximum PionID<=0.662**

  Purity 55% → 62%

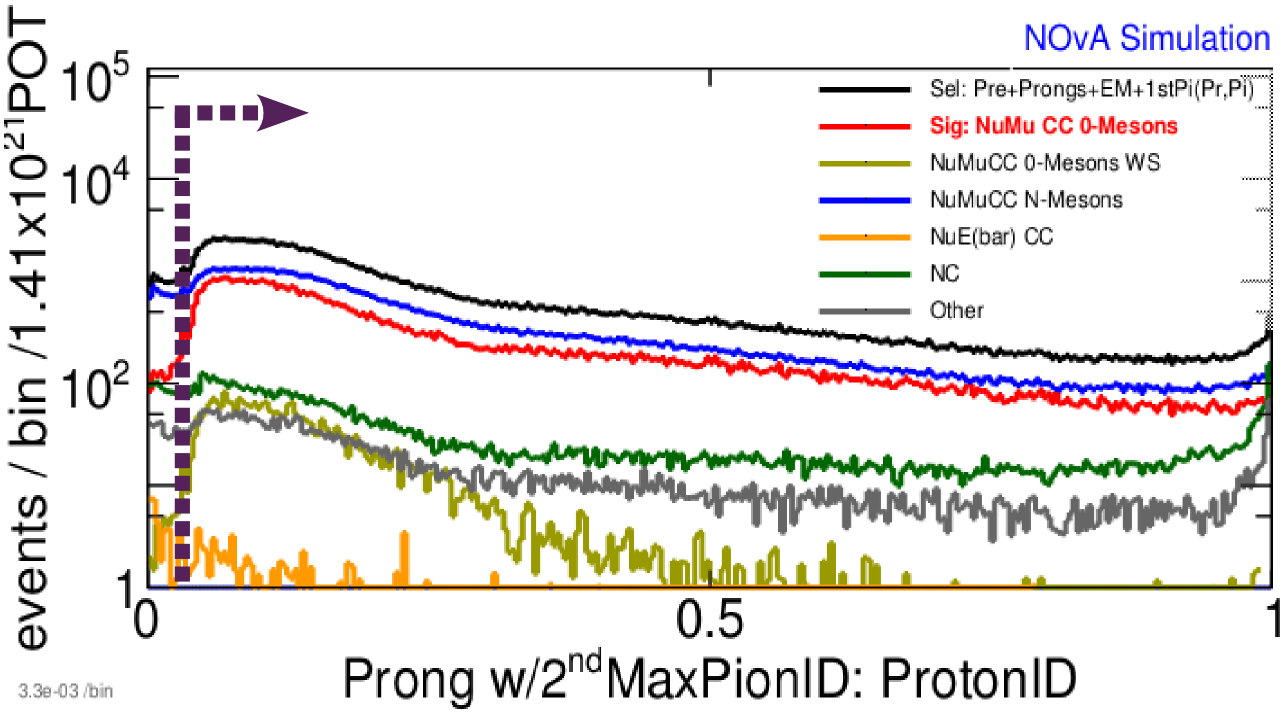
  Efficiency drops by 5%

ν_μ CC Zero Mesons Selection: 2st Pion Candidate: ProtonID



- Events with **3+ prongs** (at least two prongs other than the muon)
- Zero Mesons (**signal** and **Wrong Sign**) fall at very low ProtonID
- Yields ~0.2% purity gain

ν_μ CC Zero Mesons Selection: 2^{st} Pion Candidate: ProtonID



- Events with **3+ prongs** (at least two prongs other than the muon)
- Zero Mesons (**signal** and **Wrong Sign**) fall at very low ProtonID
- Yields ~0.2% purity gain
- **Cut where Efficiency x Purity is maximum ProtonID > 0.042**

  Purity 61.6% → 61.8%

  Efficiency drops by 0.5%

ν_μ CC Zero Mesons Selection: Summary

(1) Preselection

Reconstruction quality, **containment** of tracks, interaction vertex in **fiducial** volume and cut on **MuonID**

(2) Number of prongs <=4

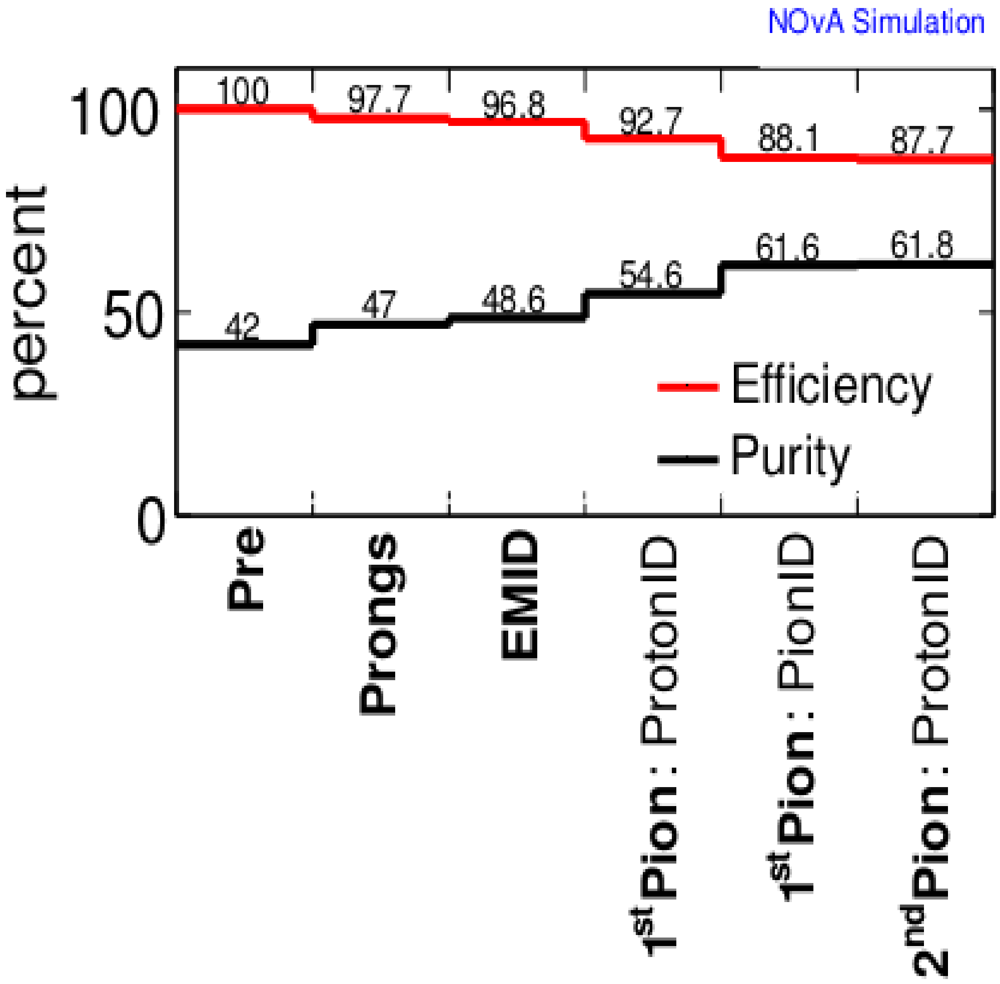
(3) Highest EMID <= 0.872

(4) Leading Pion Candidate (1st Pi)

- ProtonID > 0.072
- PionID <= 0.662

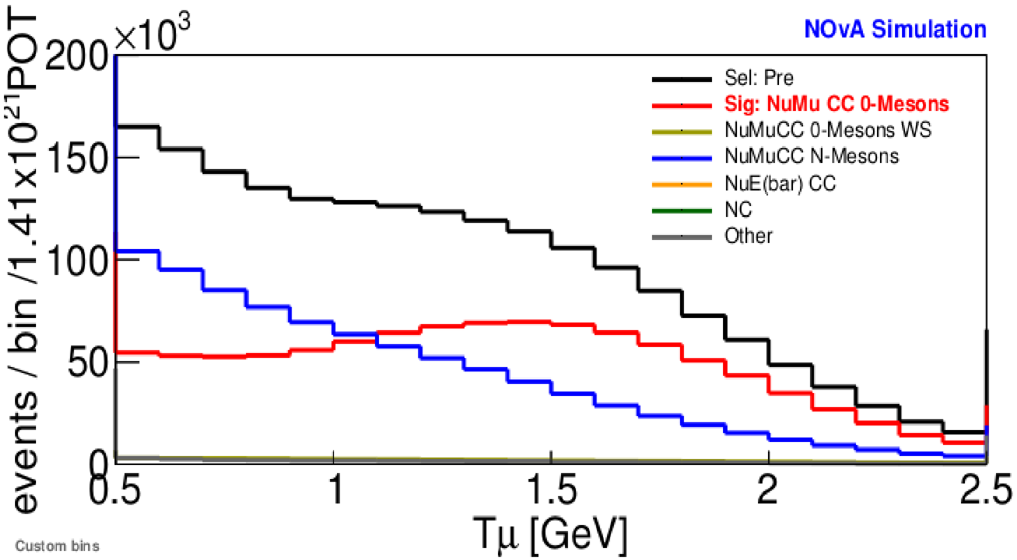
(5) Second Pion Candidate (2nd Pi)

- ProtonID > 0.042

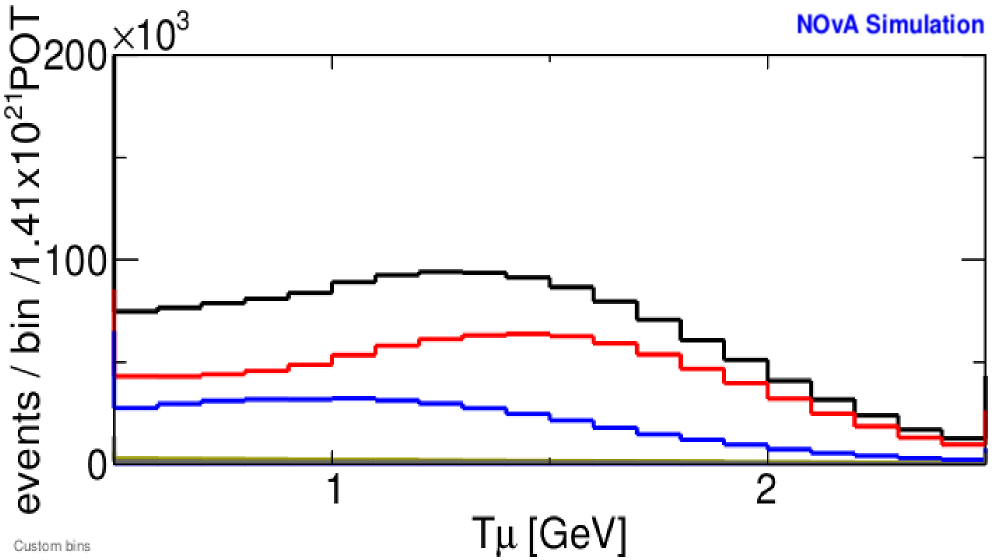


ν_μ CC Zero Mesons Selection:
Preview of Selection: Muon Kinetic Energy

Before Selection



After Selection



Summary

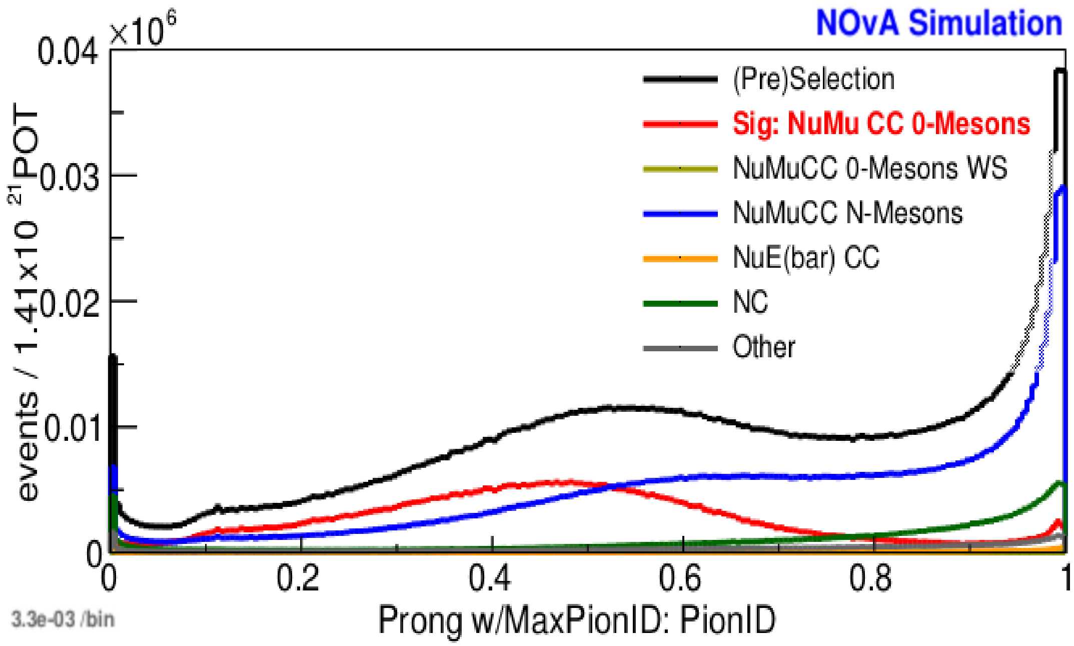
- I have developed a **selection** for a channel defined by a close-to-elastic final state
- This selection currently yields **88% efficiency** (w.r.t. the starting preselected sample) and **62% purity**
- Next steps
  - **Fine tune the signal:** include low energy pions that are not visible in NOvA
  - Evaluate strategies to constrain remaining backgrounds
  - Unfold reconstructed to true variables
  - Efficiency studies and compute cross section
  - Study of systematic uncertainties

Thank you!

MAY 2020

Backup

ν_μ CC Zero Mesons Selection: 1st Pion Candidate: PionID



- Events with 2+ prongs (at least one prong other than the muon)
- Plain PionID distributions before applying EMID cut.