Measuring a Cross Section in NOvA

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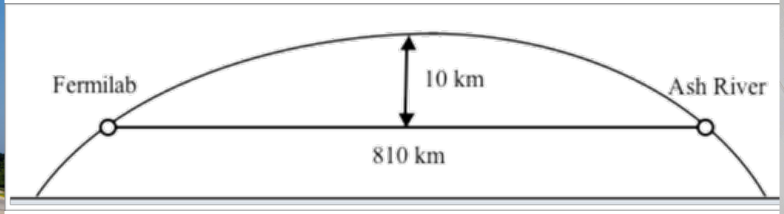
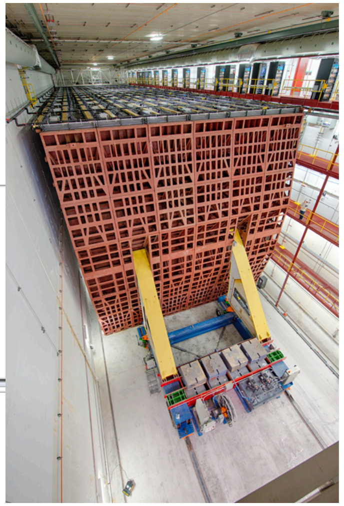
Mathew Muether

State of the Nu-tion 2017 (NuINT)

June 23, 2017

NOvA - NuMI Off-Axis ν_e Appearance Experiment





- Long-baseline neutrino oscillation experiment; 14 mrad Off-axis @ L/E ~ 400 km/GeV
- Near detector to characterize the beam
- Far detector for oscillation study

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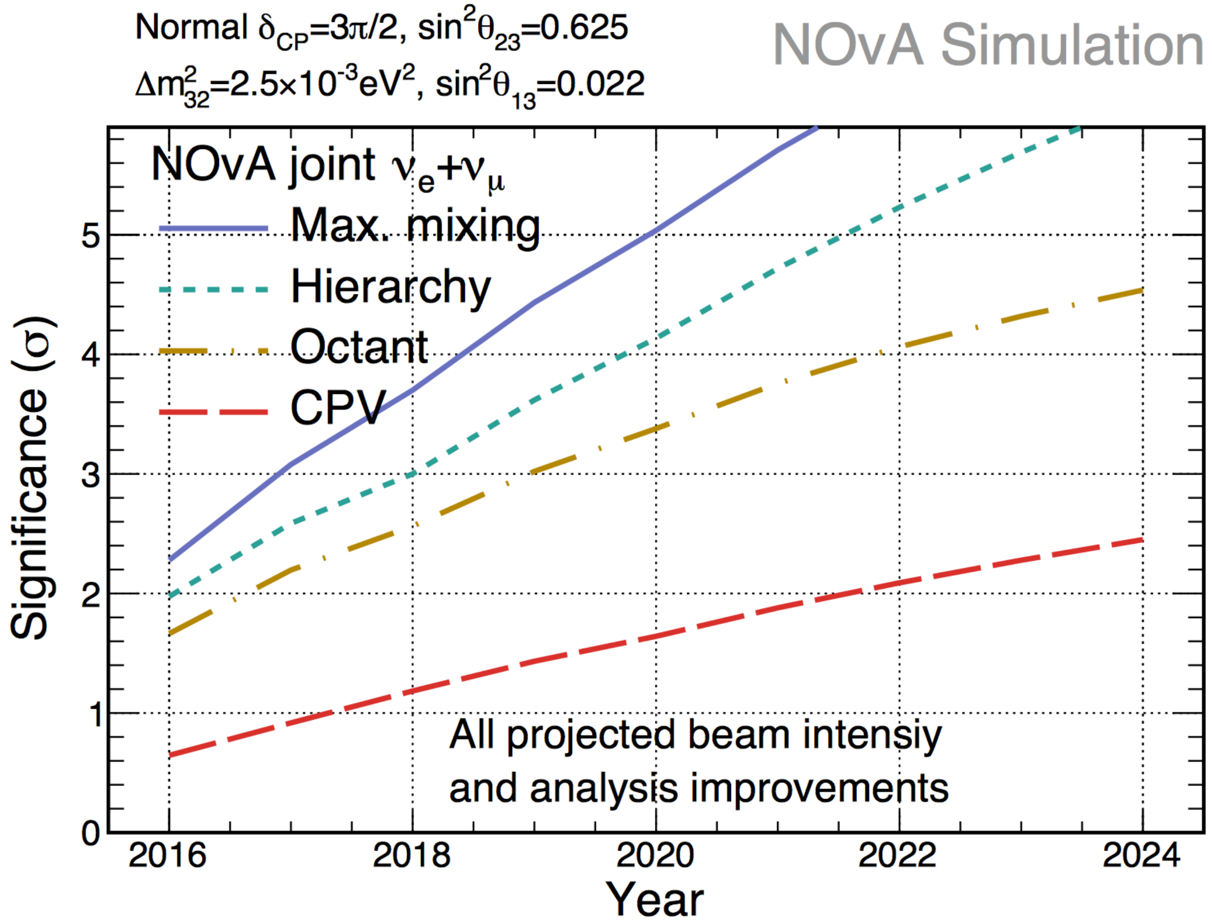
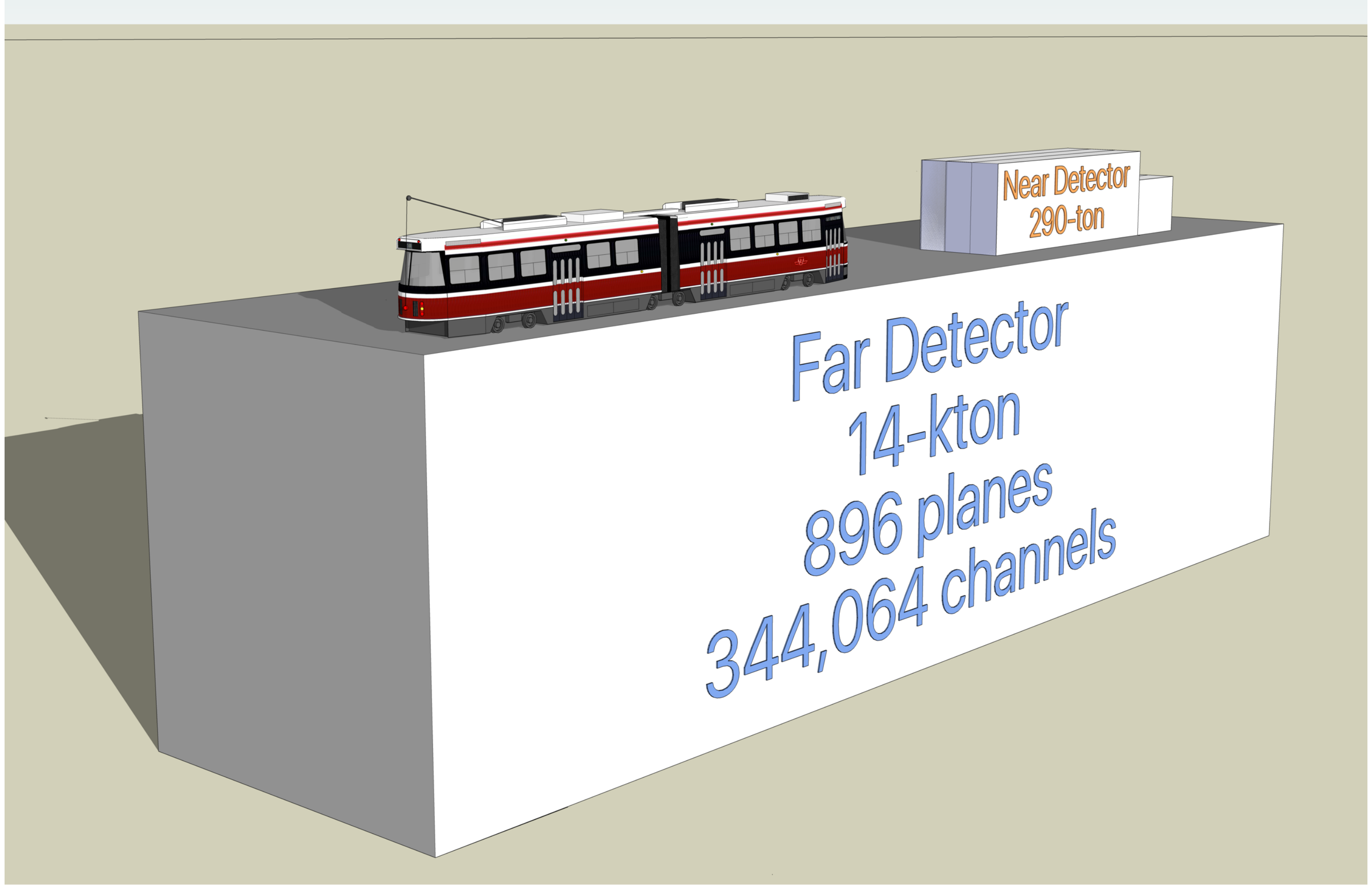
NOvA Physics Goals



- $\nu_\mu \rightarrow \nu_e$ **apperance**
  - Measure θ_{13}
  - ν mass ordering
  - CP violating phase
- $\nu_\mu \rightarrow \nu_\mu$ **disapperance**
  - Precision measurement of θ_{23}, $|\Delta m_{32}{}^2|$
- **Cross-sections from near detector**
- **Other exotics**

NOvA Detectors



Tracking calorimeters for electron ID:

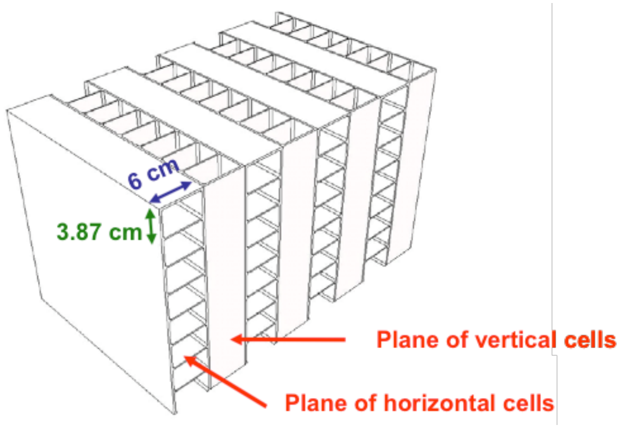
- Segmented (Alternating X/Y)
- Low Z 65% Active Volume

ND: 1 km from NuMI

- 105 m underground

FD: Surface Detector

- Overburden >10 radiation lengths



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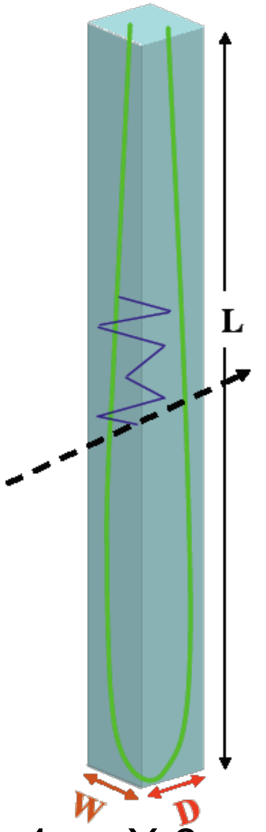
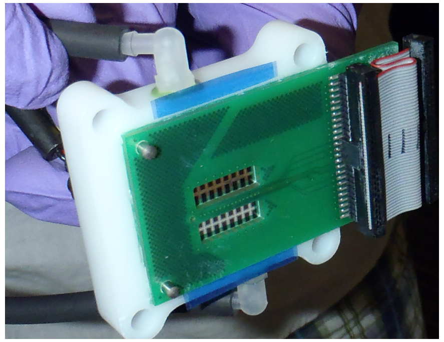
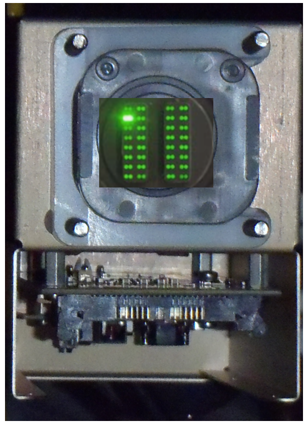
NOvA Detector Technology

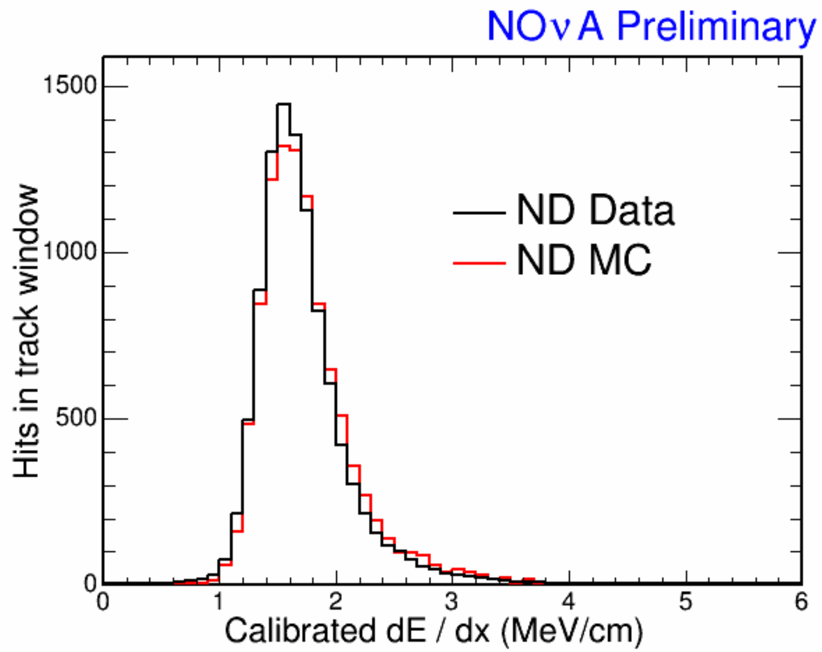


4cm X 6cm

- Extruded PVC cells of liquid scintillator instrumented with WLS fiber
- APD converts photons to charge
- 25 PE for MIP crossing FD far end
- Signal digitized by on module front end electronics (FEBs)







ND Single Hit Timing Resolution: ~5 ns
ND Calorimetric Energy uncertainty: ~3%

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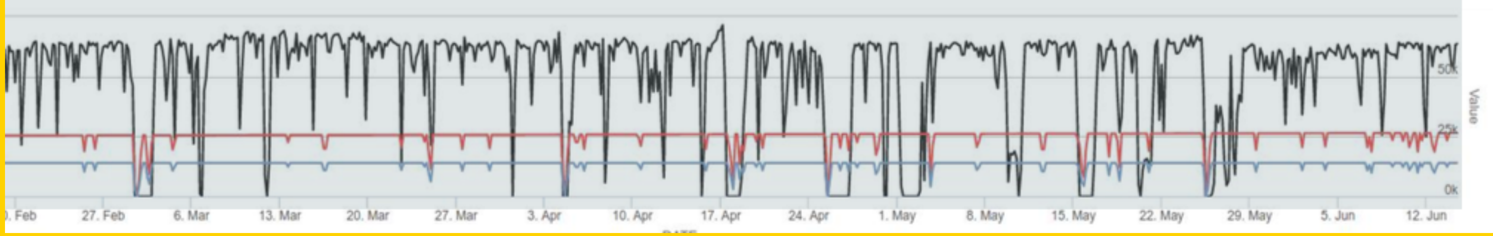
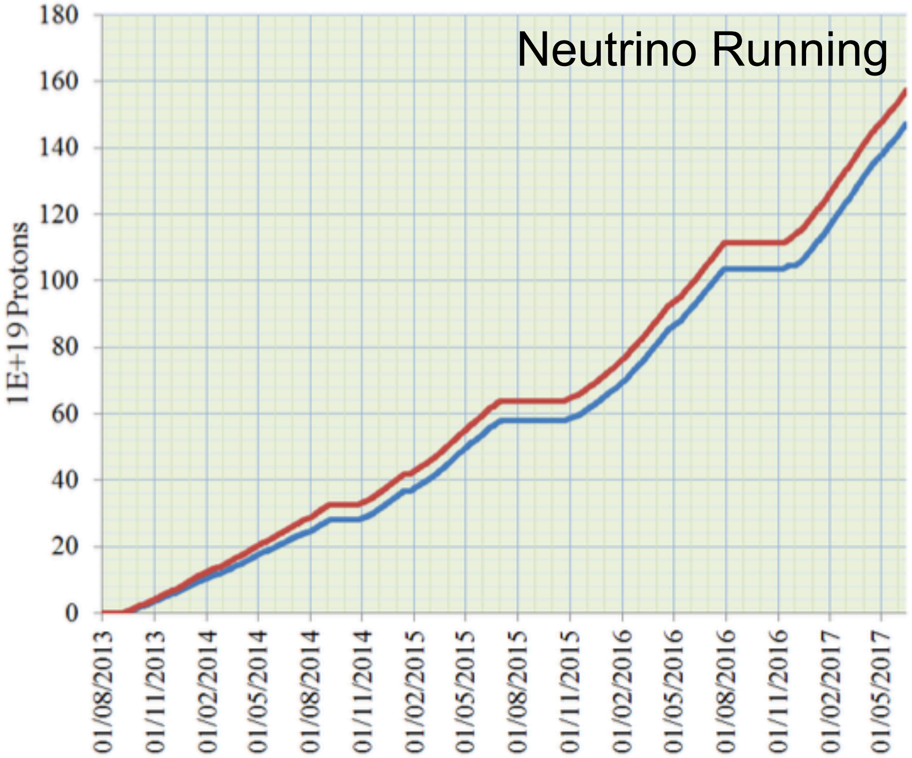
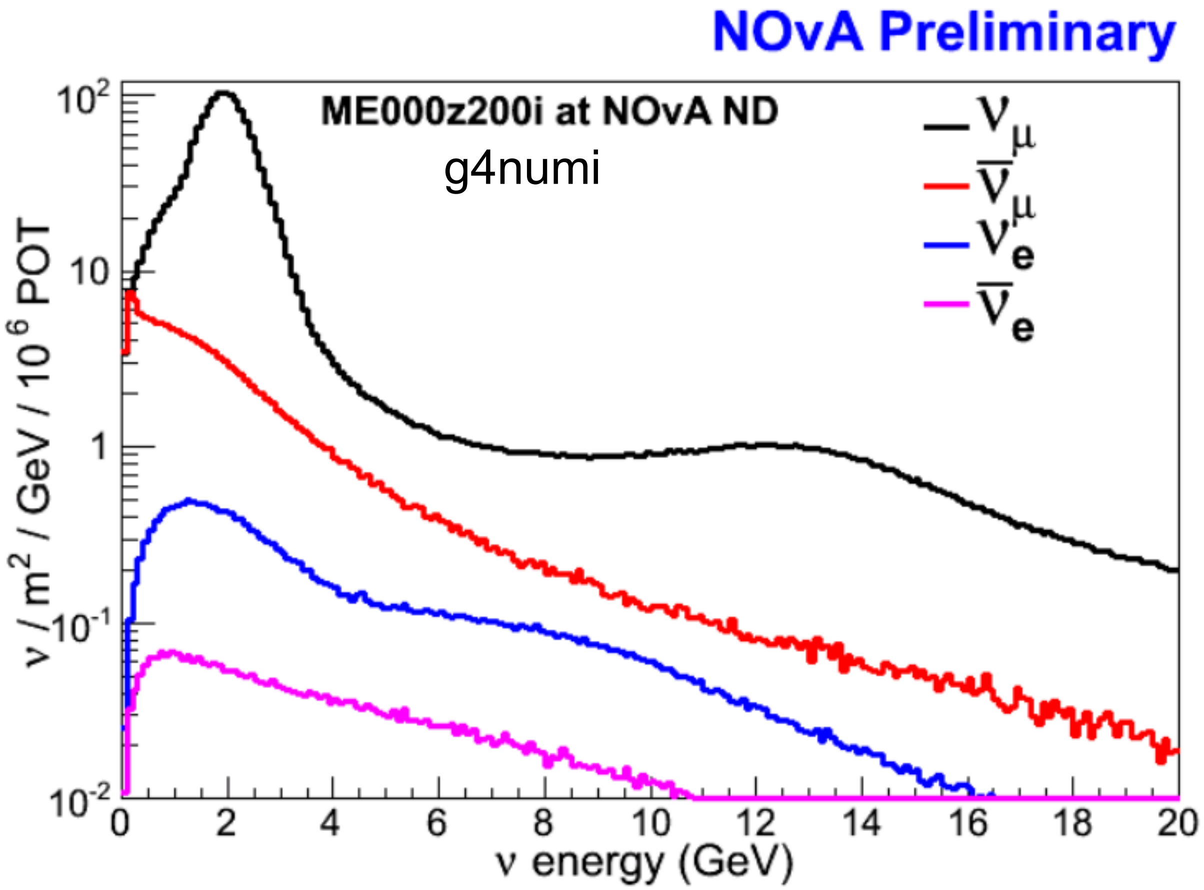
NuMI Beam



650 kW Standard Beam Power

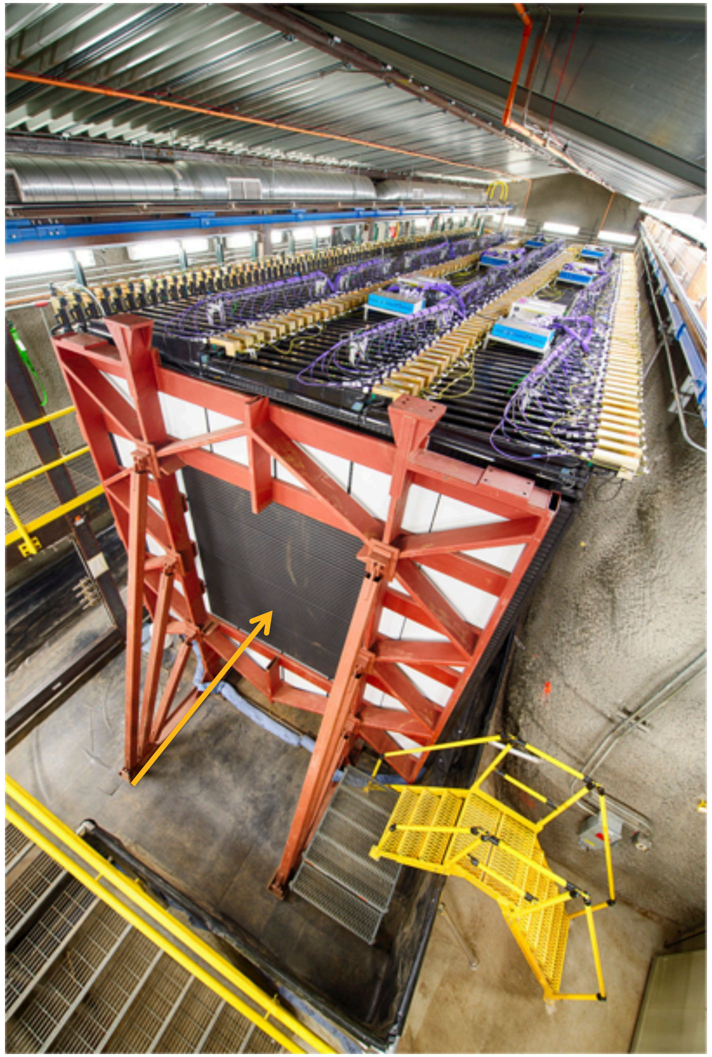


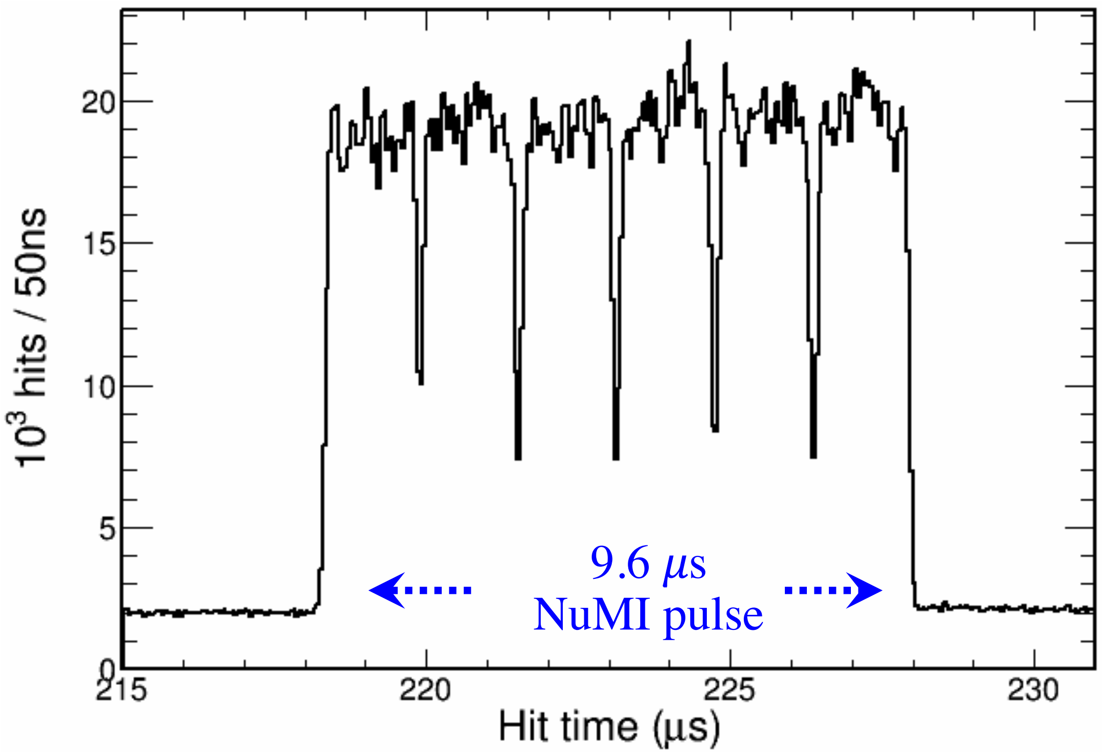


- ~ 8e20 POT in neutrino mode for ND
- ~ 3e20 POT in anti-neutrino mode

NOvA Near Detector

NOvA Near Detector





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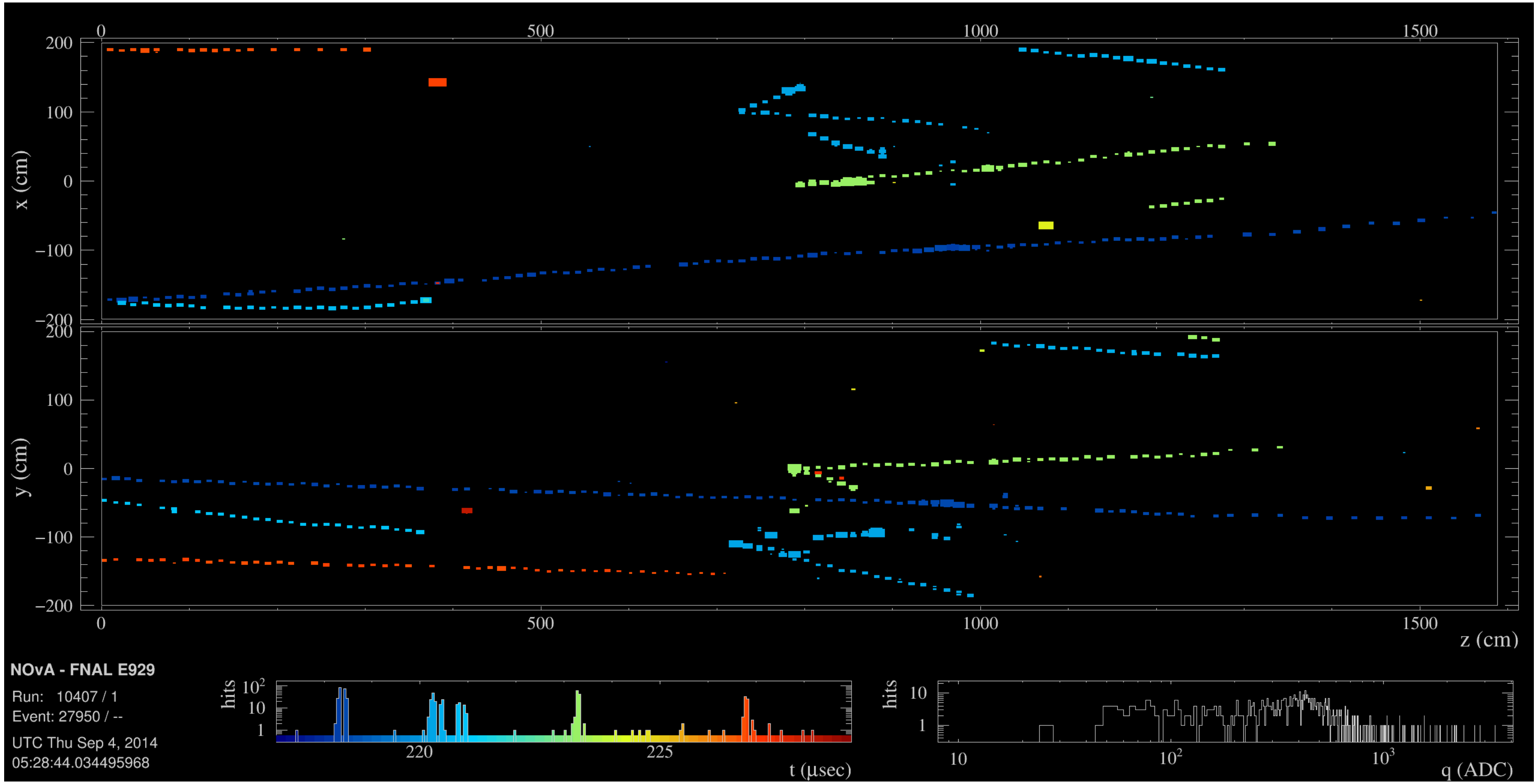
NOvA Near Detector



- Typical ND Event Display
- Events colored by time
- Events are separated by slicing algorithm which accounts for spatial and temporal hit correlations.

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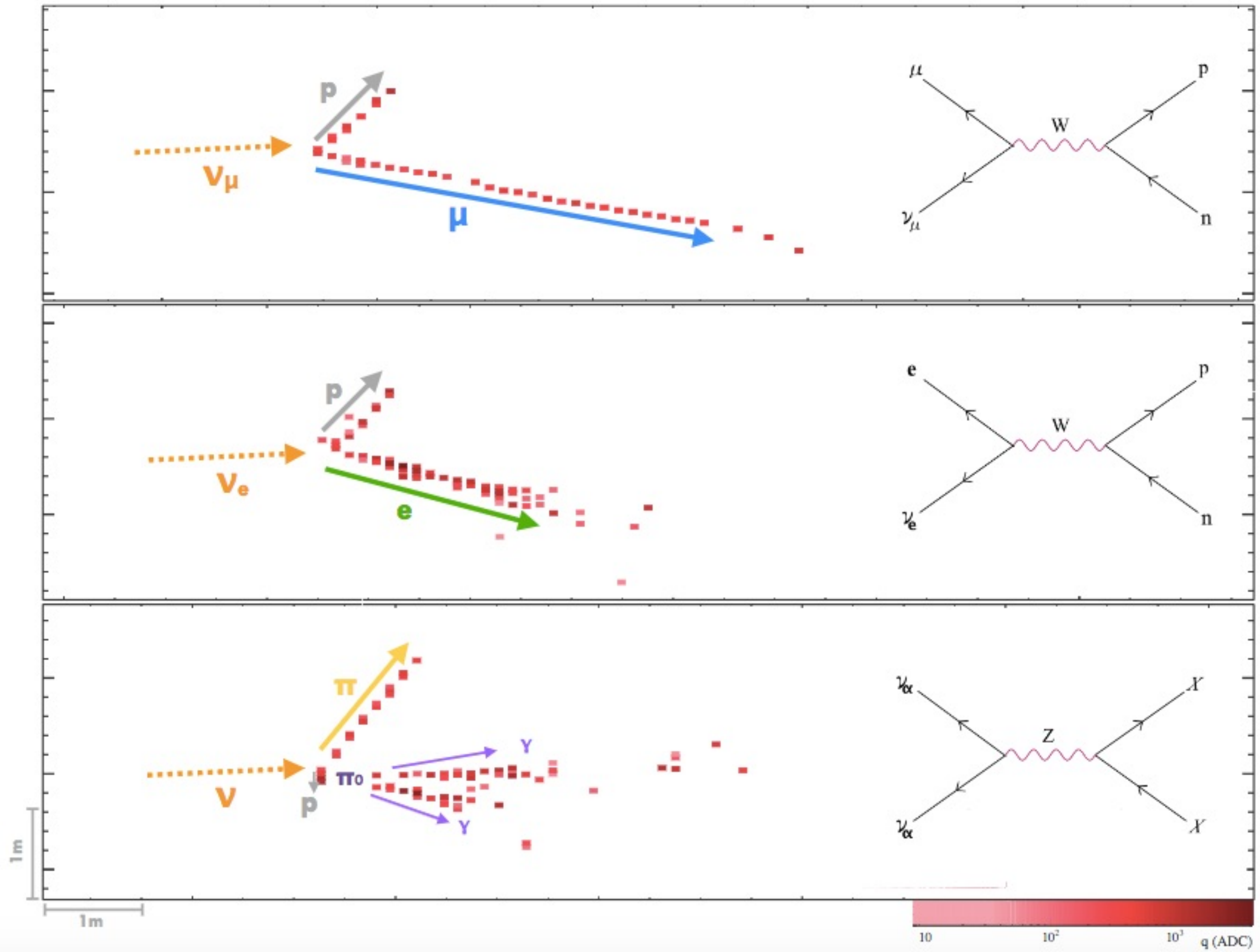
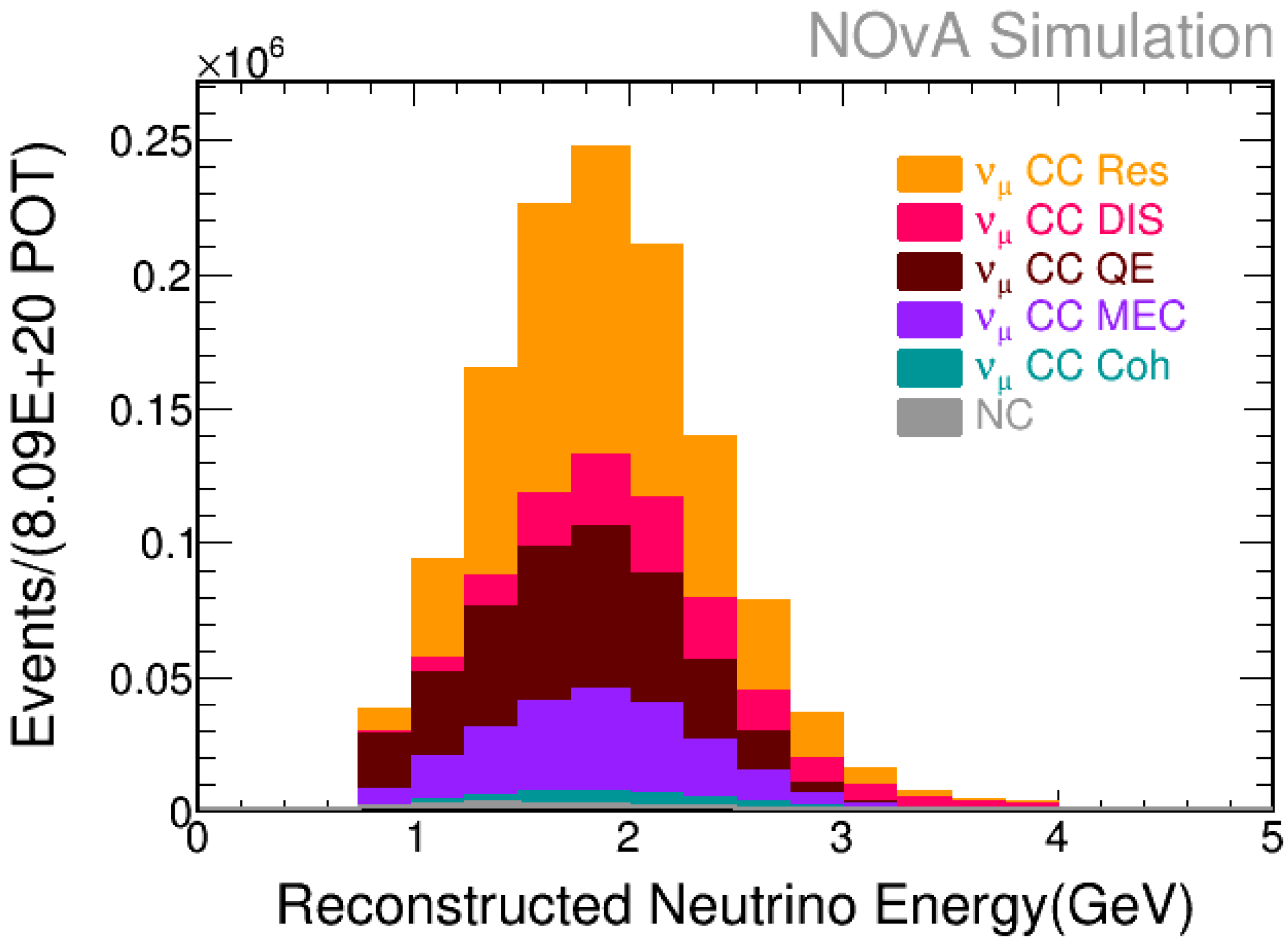
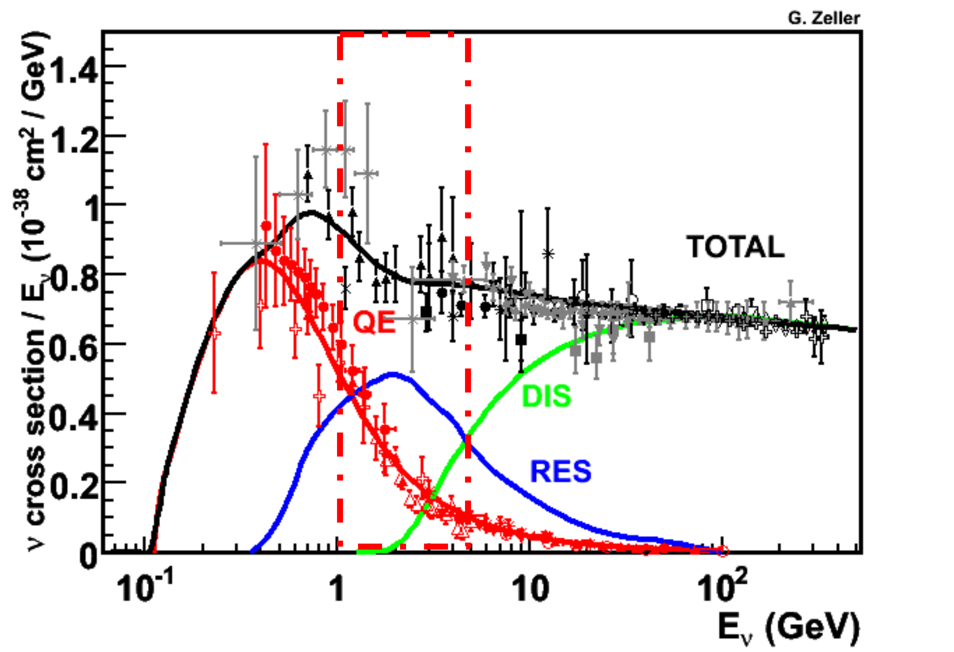
NOvA Event Topologies

Sample of
2 GeV Events



Spectrum and Interaction

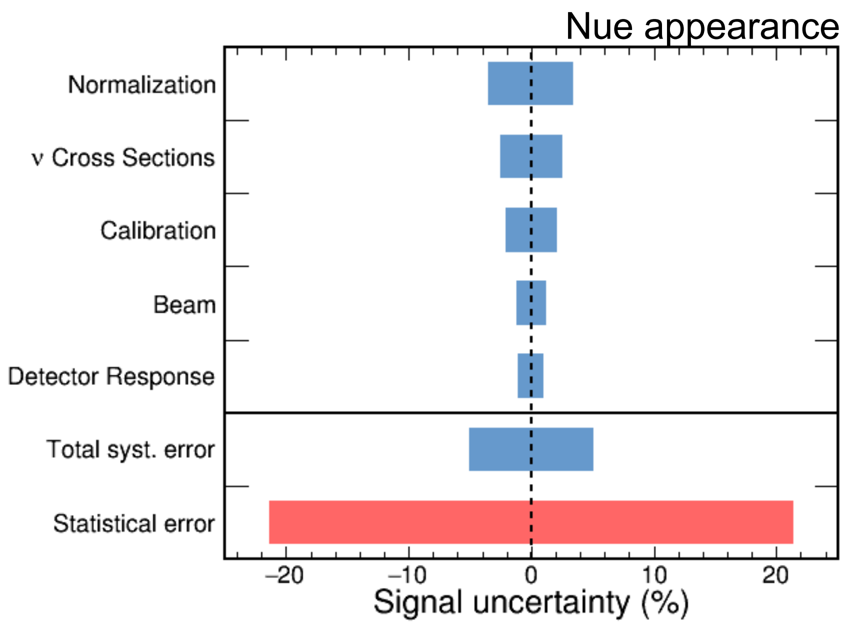


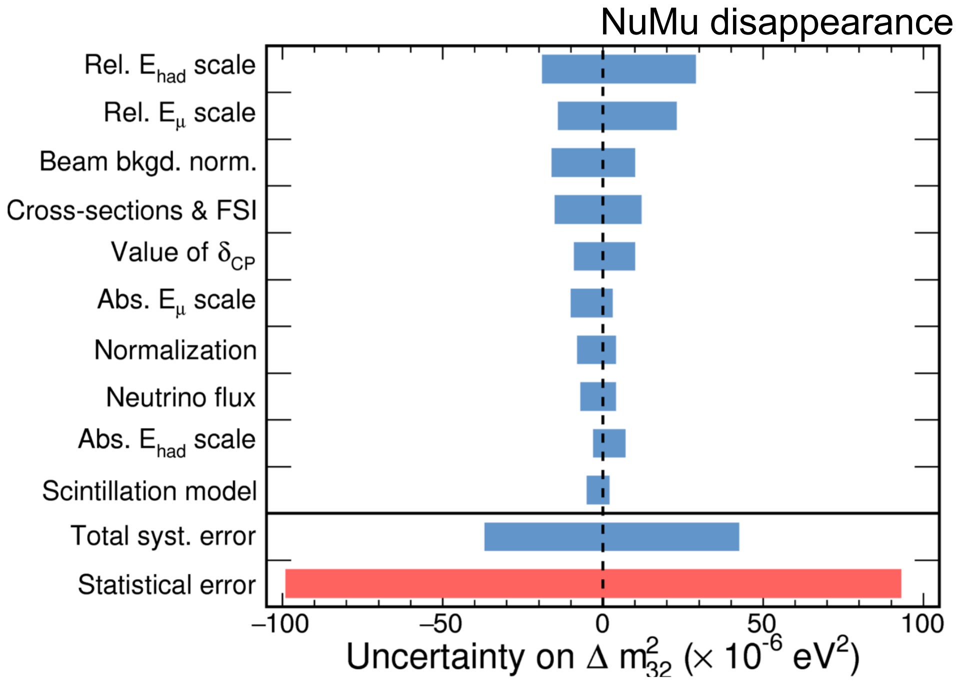


- Quasi-elastic (nominally 26%), resonant (39%), pion-continuum/DIS (34%), and coherent (1%) channels.
- A neutral current sample of one third the size will also be collected.
- Electron neutrino content is about 0.6% of the total flux

Picking the Cross Sections

- Focusing on measurements which will provide an internal XS constraint useful to the osc. analyses
- Trying to pick well defined signals which can reduce model dependency.
- Looking to provided differential cross section as a function of useful kinematics where possible.
- Impactful measurements useful to the community in general.





Active NOvA Cross Section Analysis

- Charged Current
  - ν_μ and ν_e Inclusive
  - ν_u π^0 Inclusive
  - ν_u $\pi^{+/-}$
  - ν_u 2p2h
  - ν on e
  - ν_u 0π
- Neutral Current
  - Coherent π^0 (Results)
  - π^0 Inclusive

Inclusive numu and nue CC measurements at NOvA
Session: Shallow Inelastic, Deep Inelastic and Inclusive Scattering
Presented by **Jon PALEY** on **26 Jun 2017** at **10:20**

NOvA: Impact of cross section uncertainties in the oscillation analysis
Session: Systematic Uncertainties and Impact on Oscillation Measurements
Presented by **Jeremy WOLCOTT** on **25 Jun 2017** at **14:05**

Pion production measurements at NOvA
Session: Neutrino Pion Production and Other Inelastic Interactions
Presented by **Hongyue DUYANG** on **27 Jun 2017** at **16:15**

+ Posters

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Cross Section Measurement in NOvA

Unfolding

$$\sigma_k = \frac{\Sigma_j U_{kj}\left(\overbrace{N_j^{sel}}^{\text{Selection}} - N_j^{bkgrd}\right)}{T\,\phi\,\varepsilon_k}$$

Backgrounds

Target

Flux

Efficiency

The following slide will touch on how we’re handling these components.

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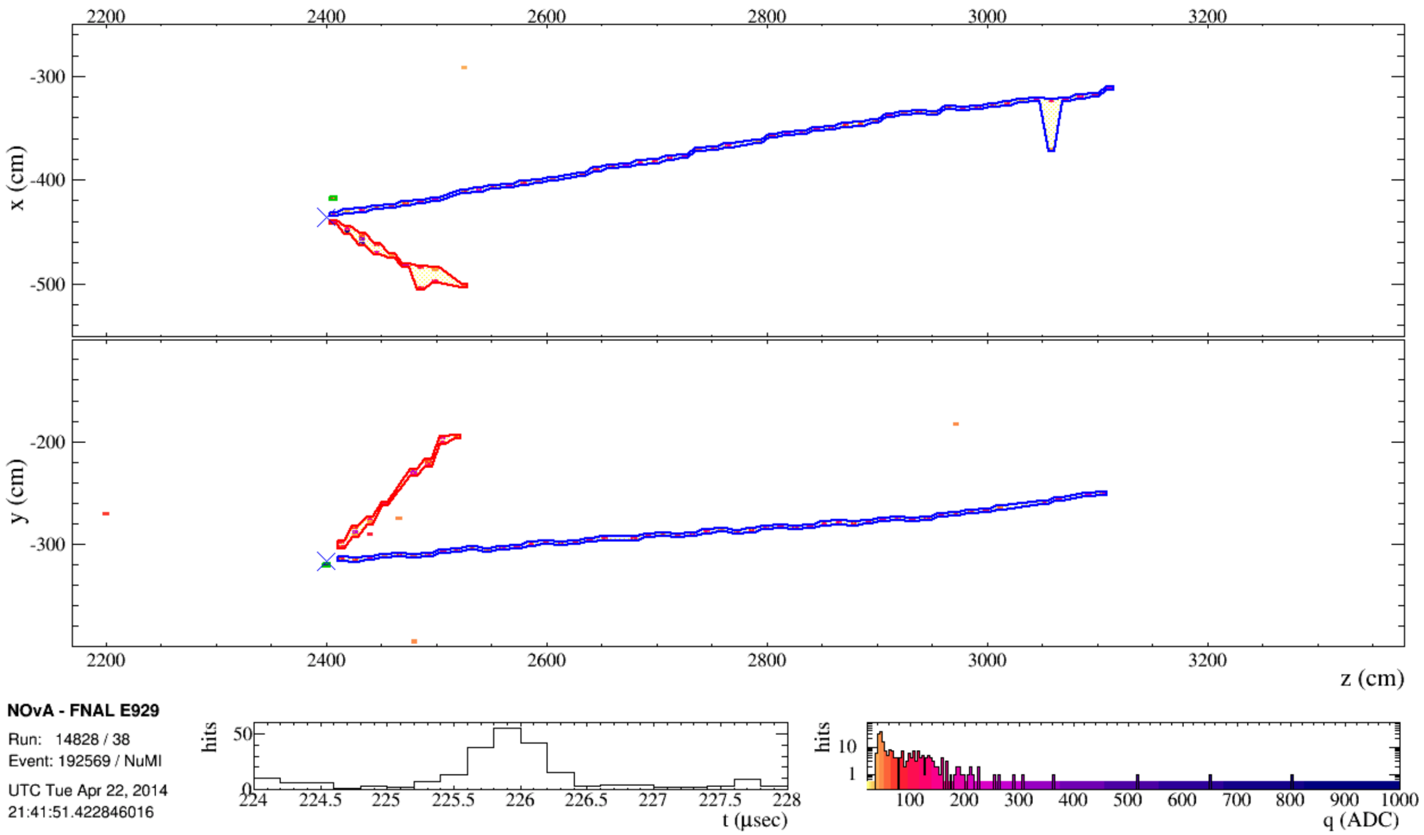
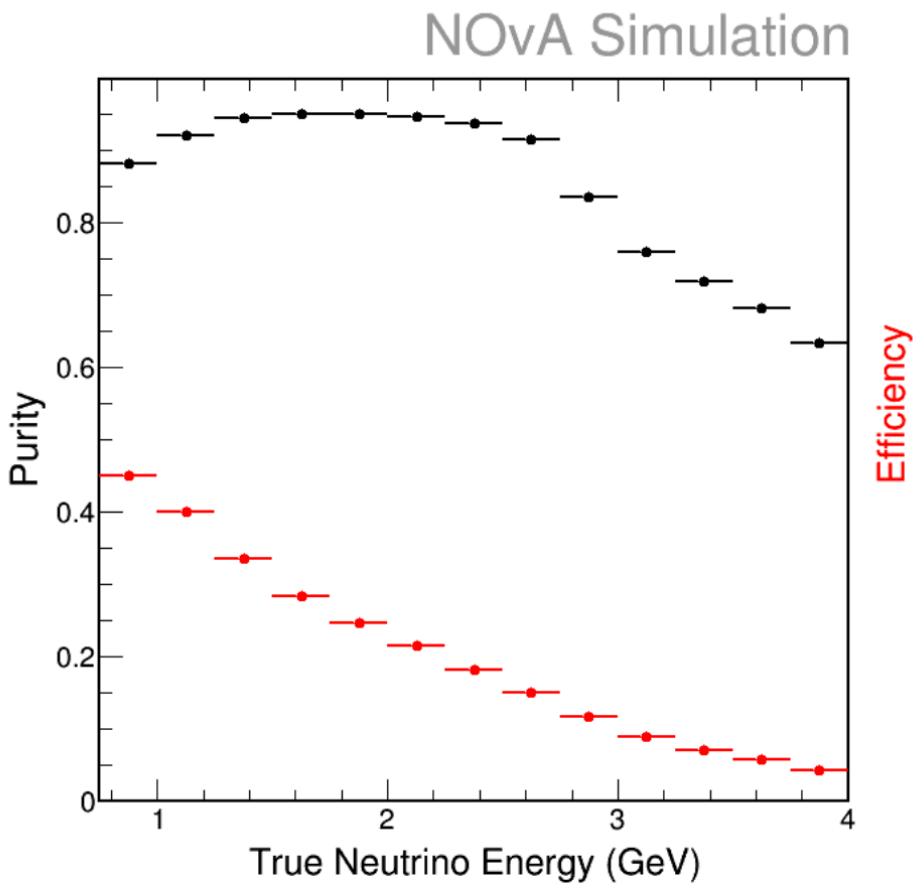
Selection

- Excellent set of reconstruction tools: Space-time Slicing, tracking, prongs (single particles)
- Vertex in fiducial volume.
- Energy deposition contained in volume away from detector edges.
- Numu CC selection from oscillation group (4 variable kNN: Track length, dE/dx along track, scattering along track, track-only plane fraction)

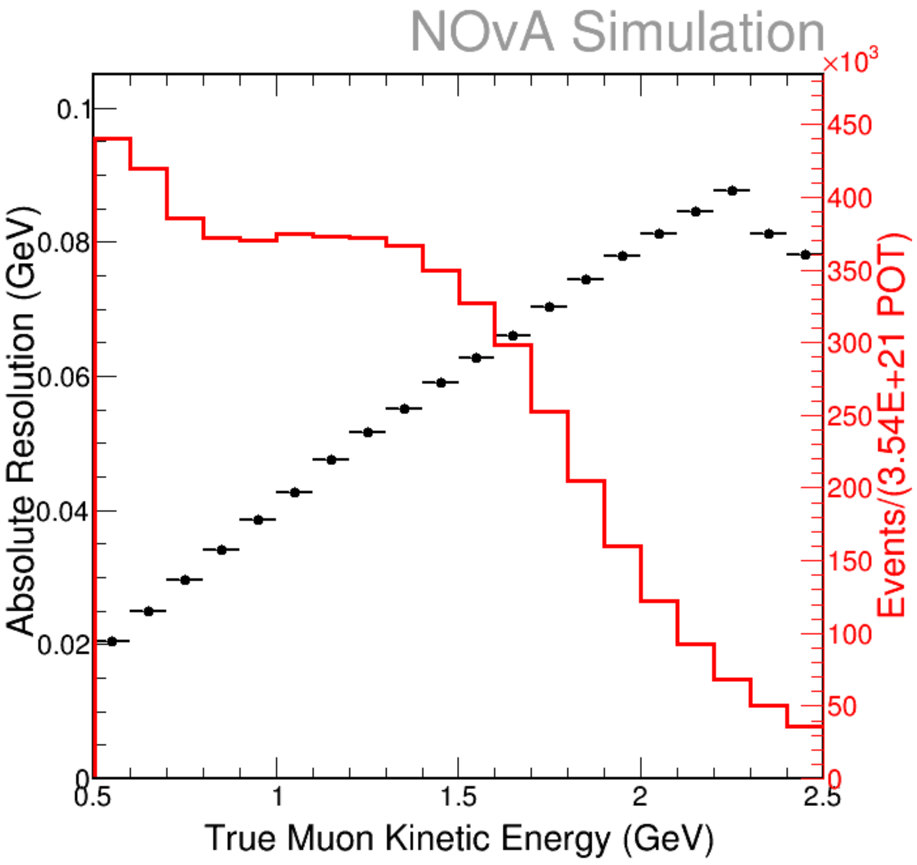


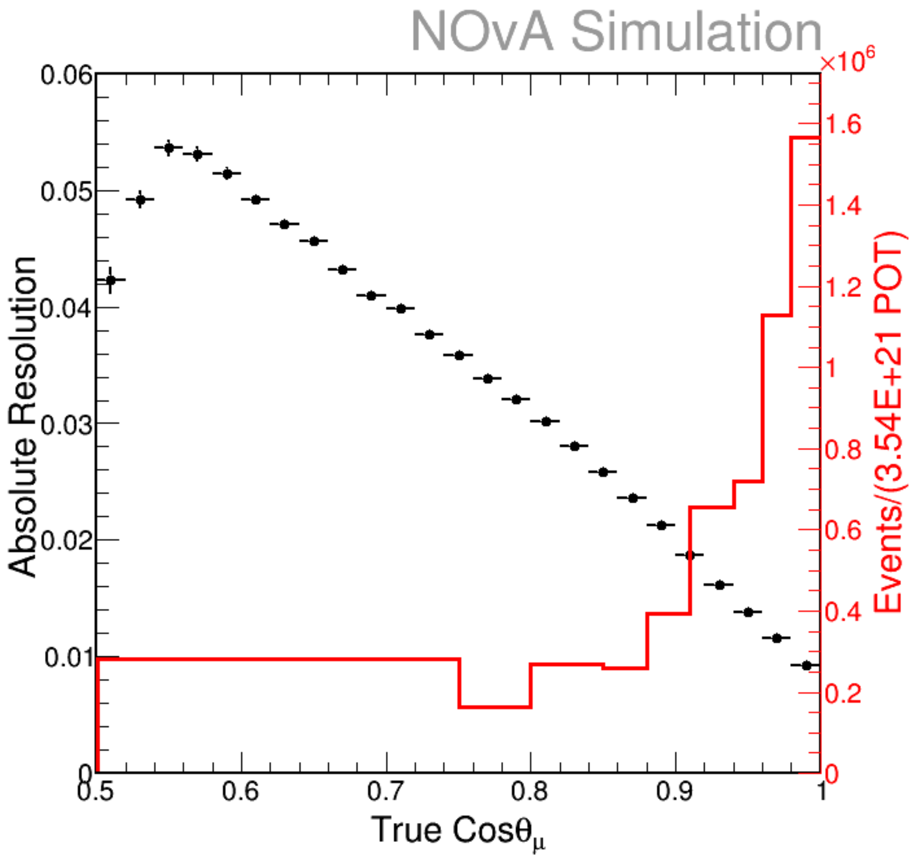
Efficiency and Purity

- Efficiency, calculated by comparing MC truth to reconstructed events for numu CC selected events.
- Use external data constraints where possible to verify or determine correction.
- numu inclusive measurement has studied a data driven efficiency which reweights MC true hadronic energy and muon energy to match data, and then re-computing the efficiency.



Resolution of muon from ν_μ CC selected evetns





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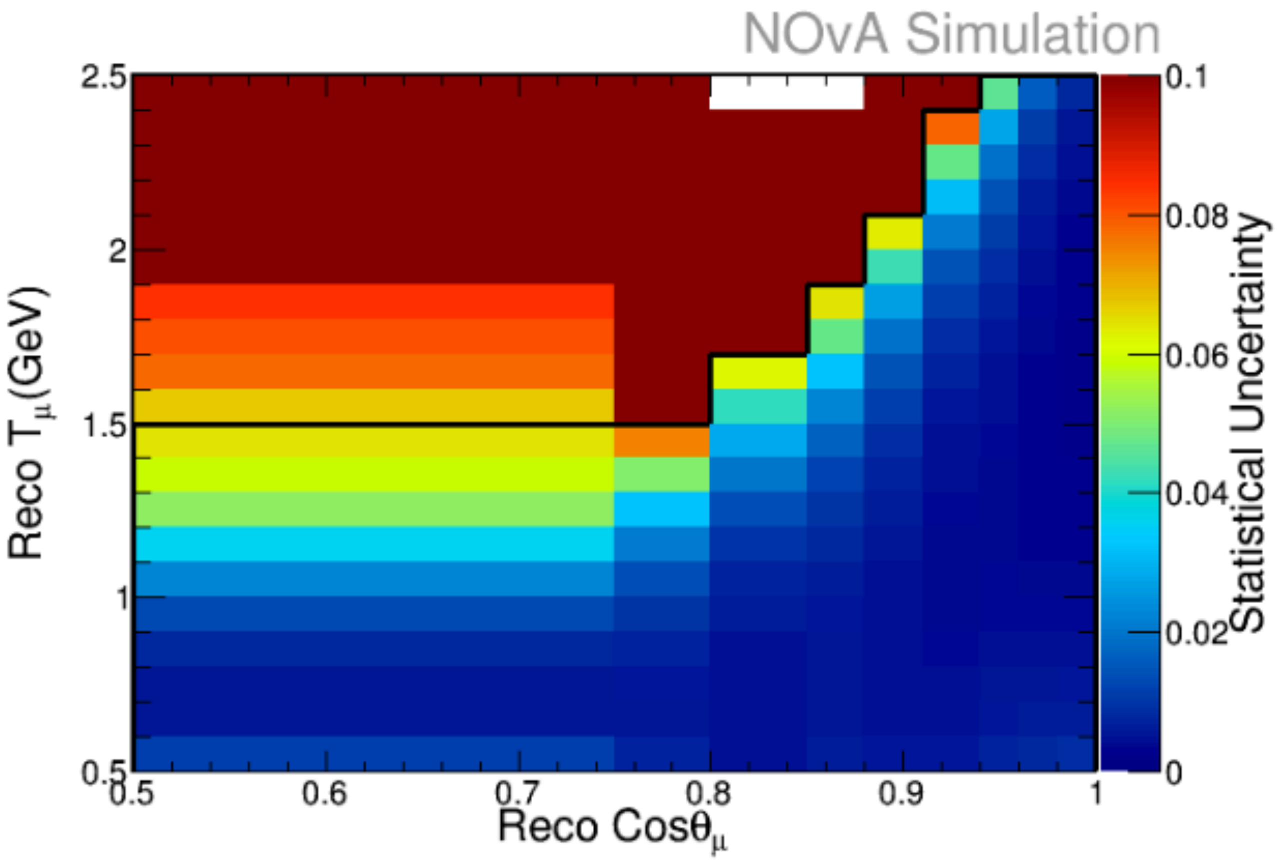
Binning in kinematic variables

- Resolution and statistics are considered to develop a reasonable set of bins for reporting differential cross section.
- The figure to the right show the statistical uncertainty in a set of possible bins after selection.



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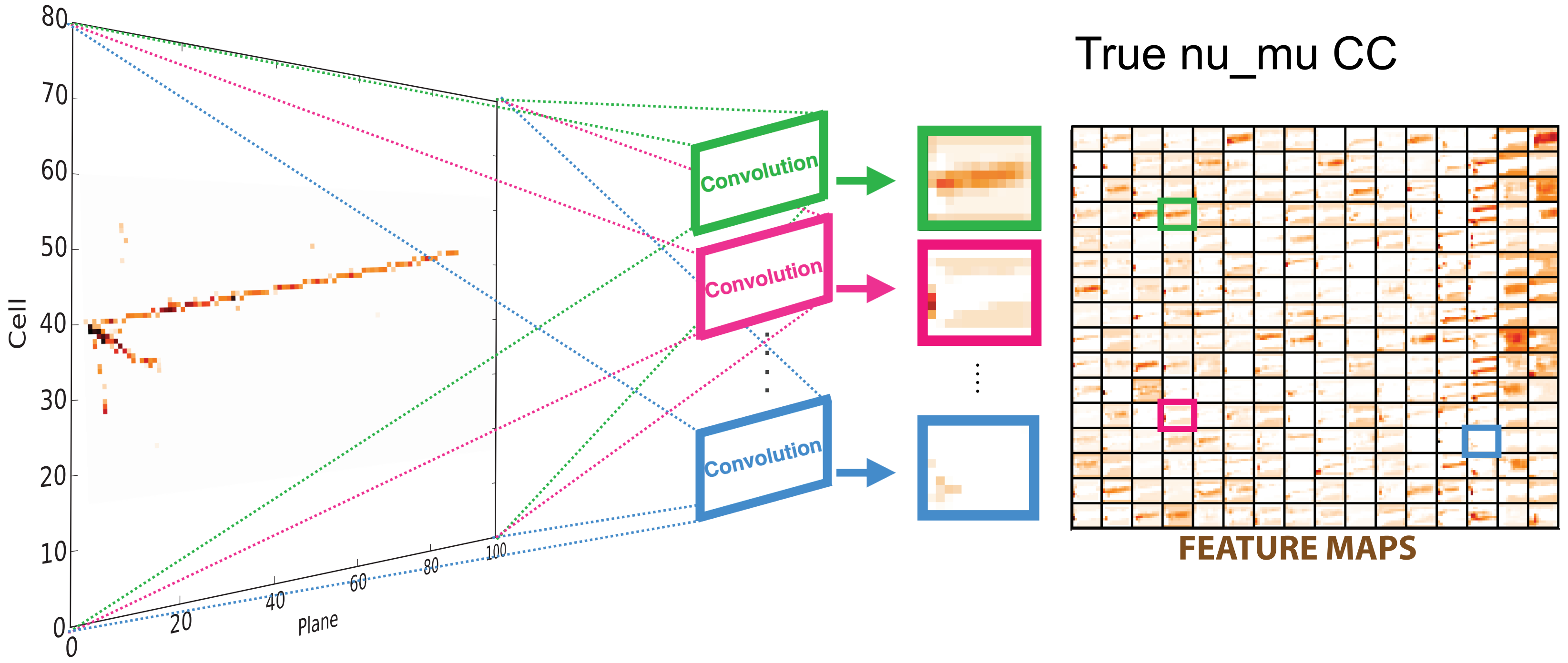
Signal Selection with CVN

- Image representations of our events colored by calibrated hit info are input to Convolutional Visual Network (CVN)
- Kernels, Filters or Convolutional Layers extract features of varying levels of complexity.
- Output – Event Classification score



A. Aurisano et al., arXiv:1604.01444

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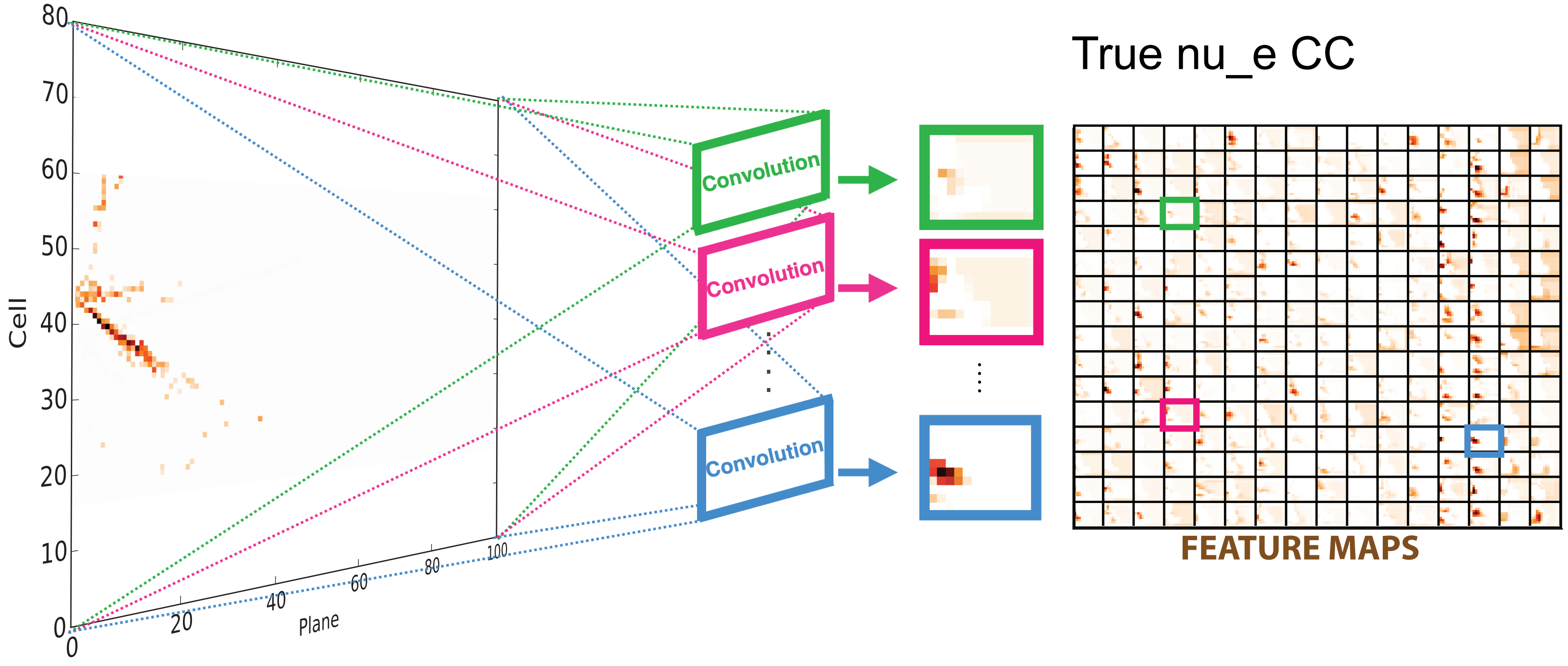

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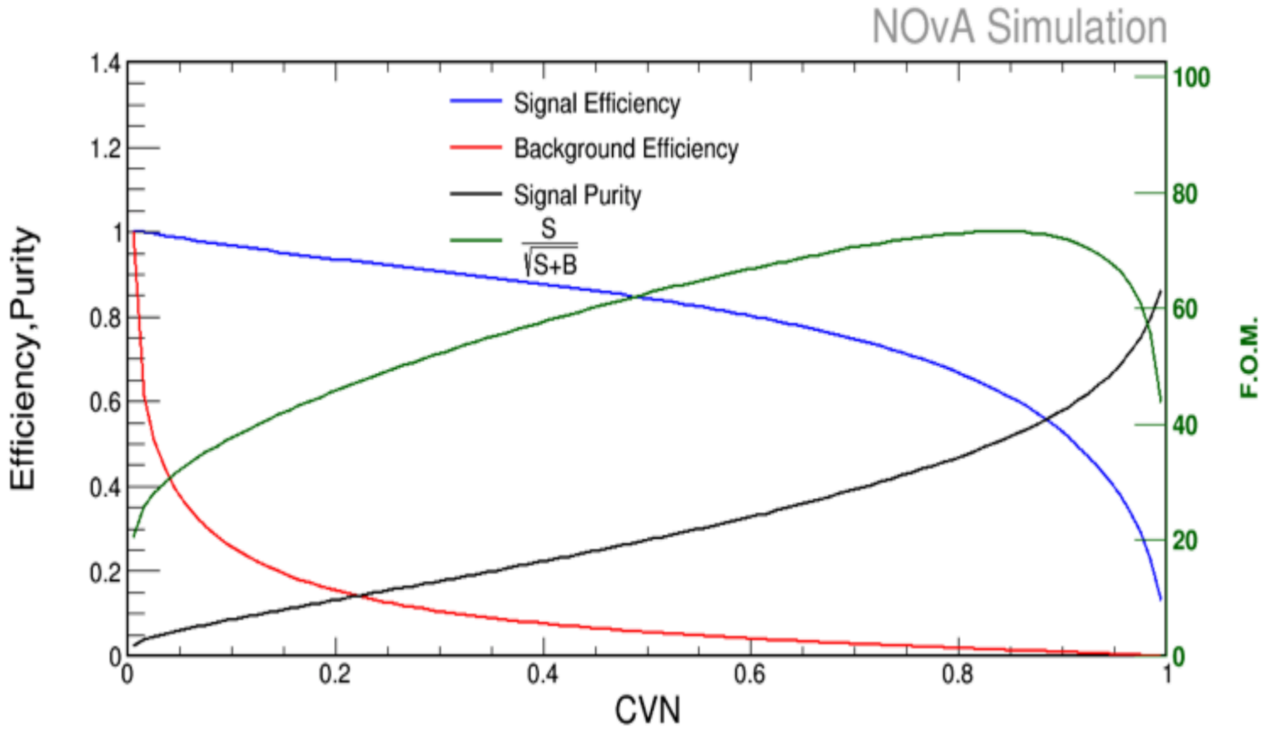
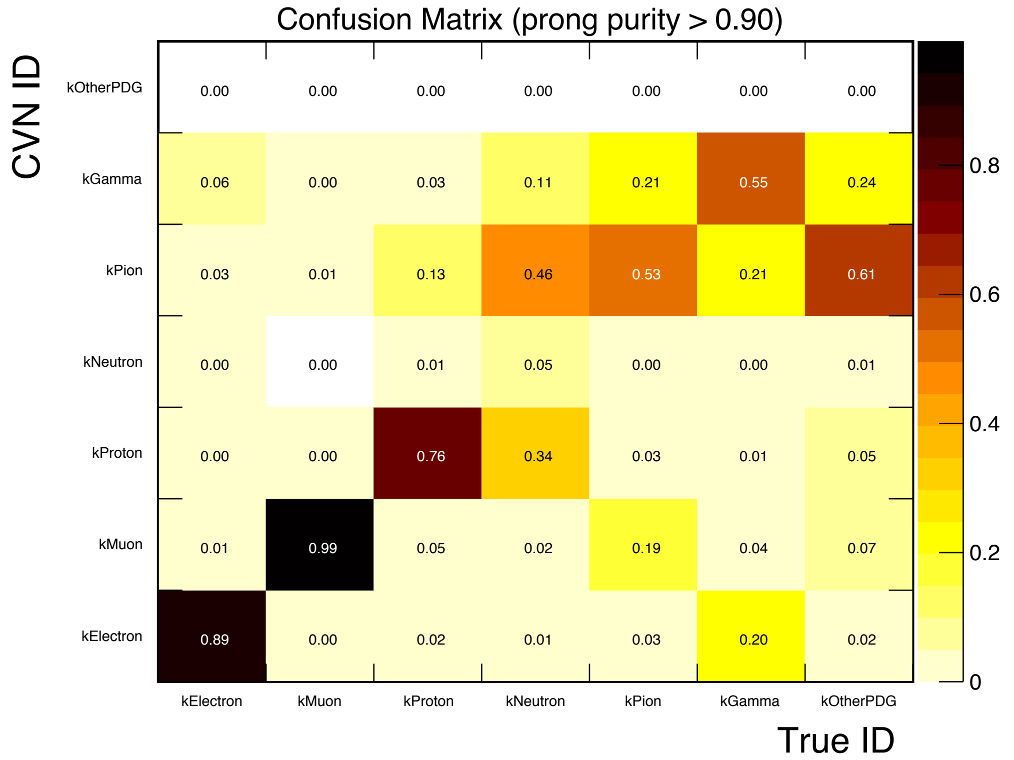
Signal Selection with CVN



nu_e CC inclusive: DQ, fid., containment and ReMID cuts are applied

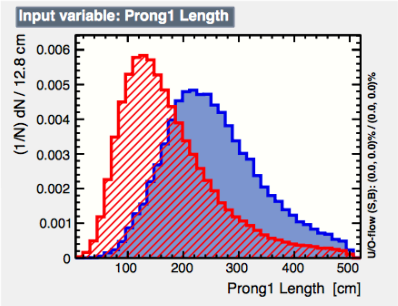
Ongoing effort:

- Prong Based ID
- Reconstruction
- Vertexing
- Energy Estimator
- Add timing info
- Train on TB Data

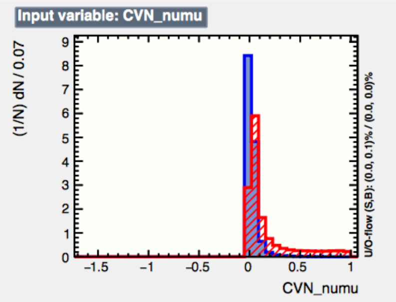


Signal Selection

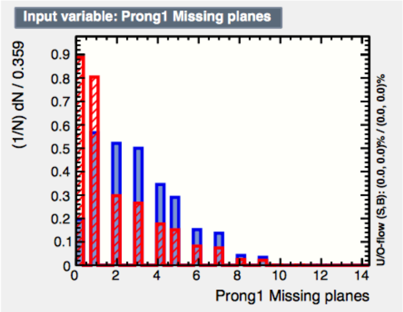
For many analyses additional classifiers are being built on top of CVN.



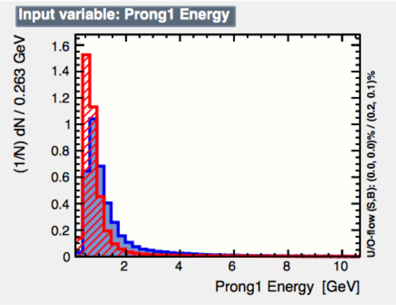
Prong1 (Leading Prong) Length



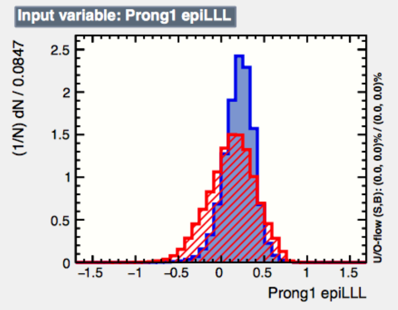
CVN_numu



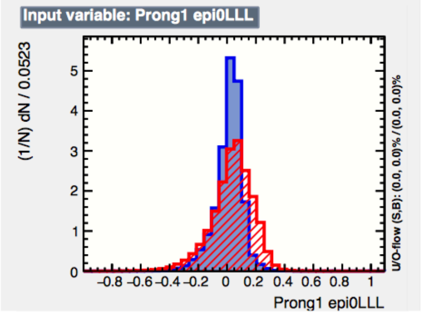
Number of Missing Planes in Prong1: Planes with missing hits



Prong1 Energy: Sum of calorimetric Energy

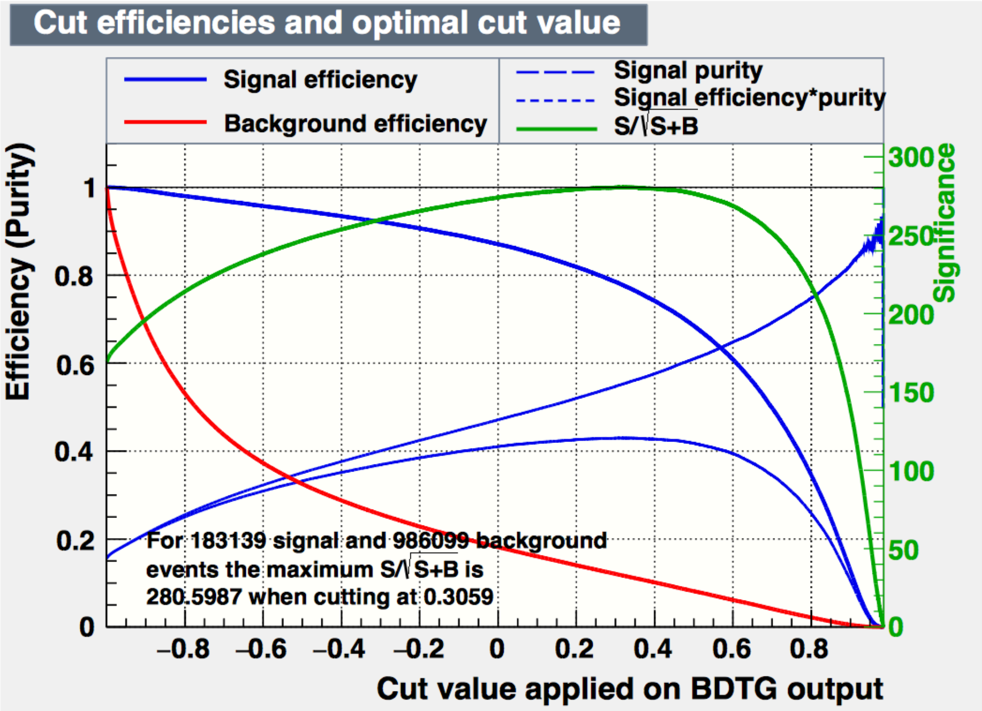


Prong1 epiLLL: Electron-pi for longitudinal shower



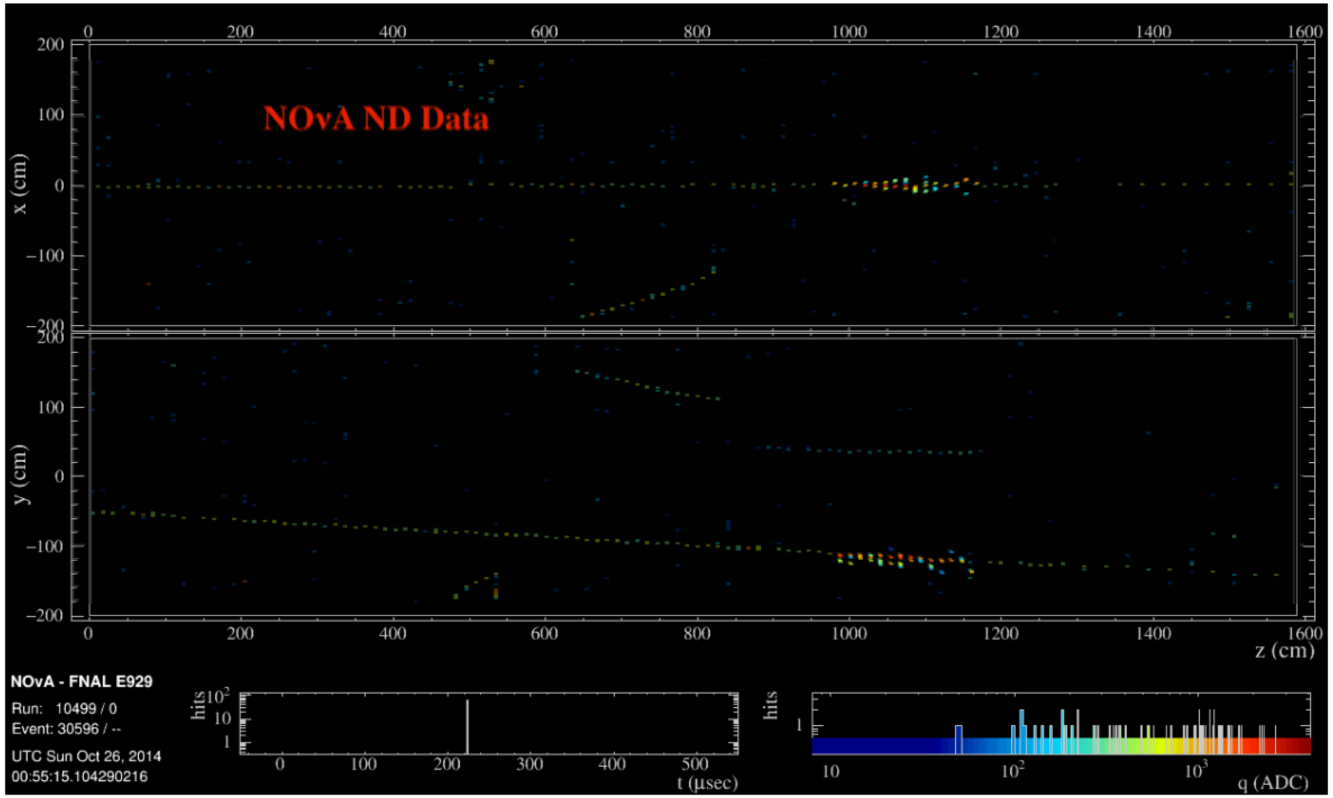
Prong1 epi0LLL: Electron-pi0 for longitudinal shower

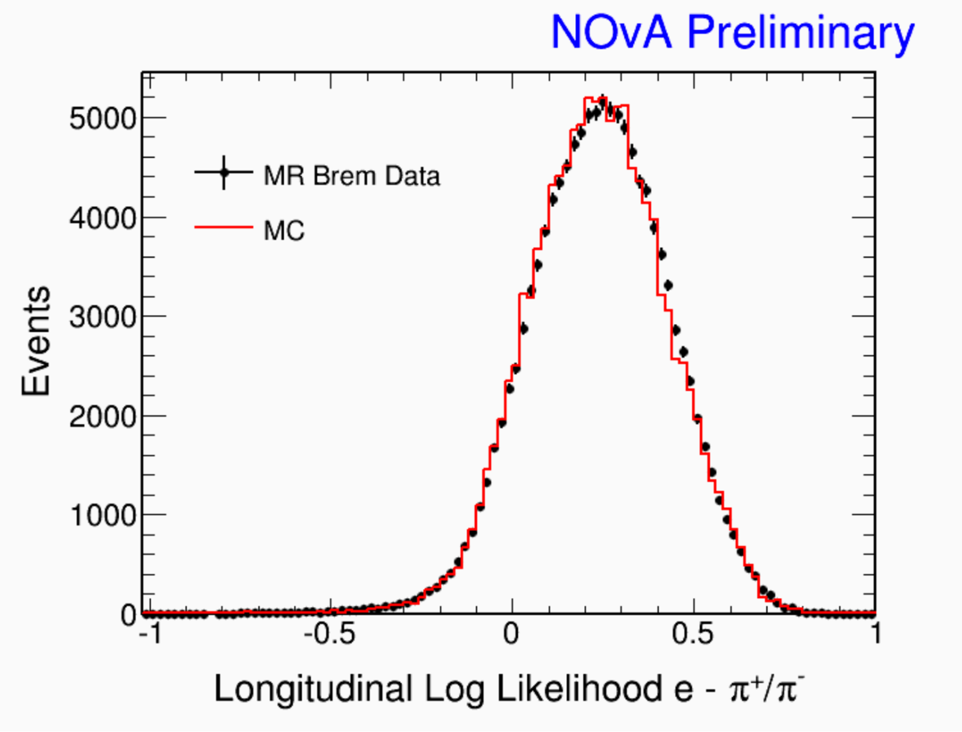
From NC Pi0



Rock muon removed Brems

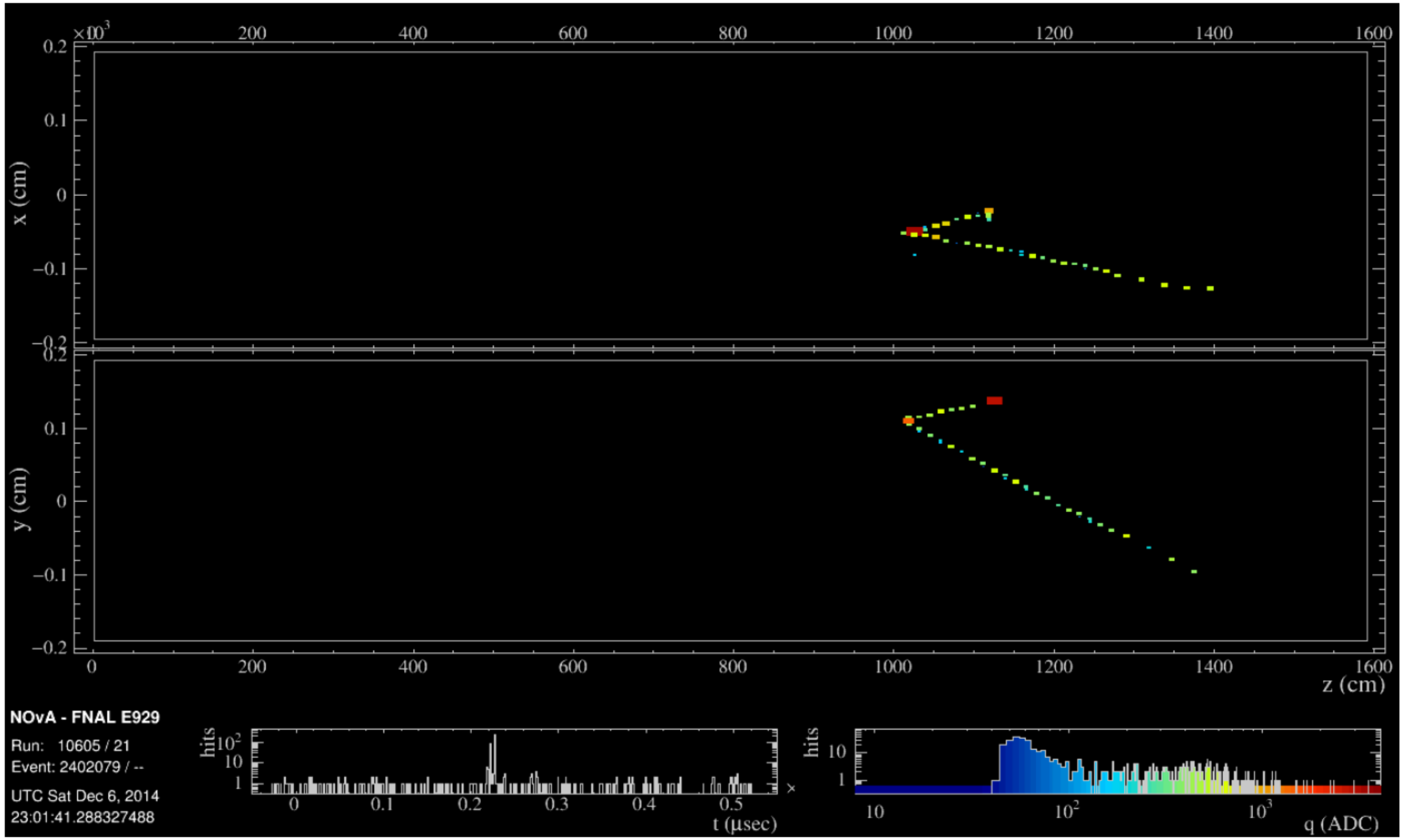
- Bremsstrahlung showers induced by rock muons are used to benchmark the EM shower modeling
- Muons are removed to get pure EM shower samples from data and MC.
- Overall very good data and MC agreement is seen.
- Efficiency diff 1.1% is taken as sys uncertainty on shower modeling.





Muon Removed Electrons

Similarly, we removed the muon from a sample of clean CC events and replace it with a kinematically matched simulated electron to study reconstruction and PID efficiency in both data and MC.



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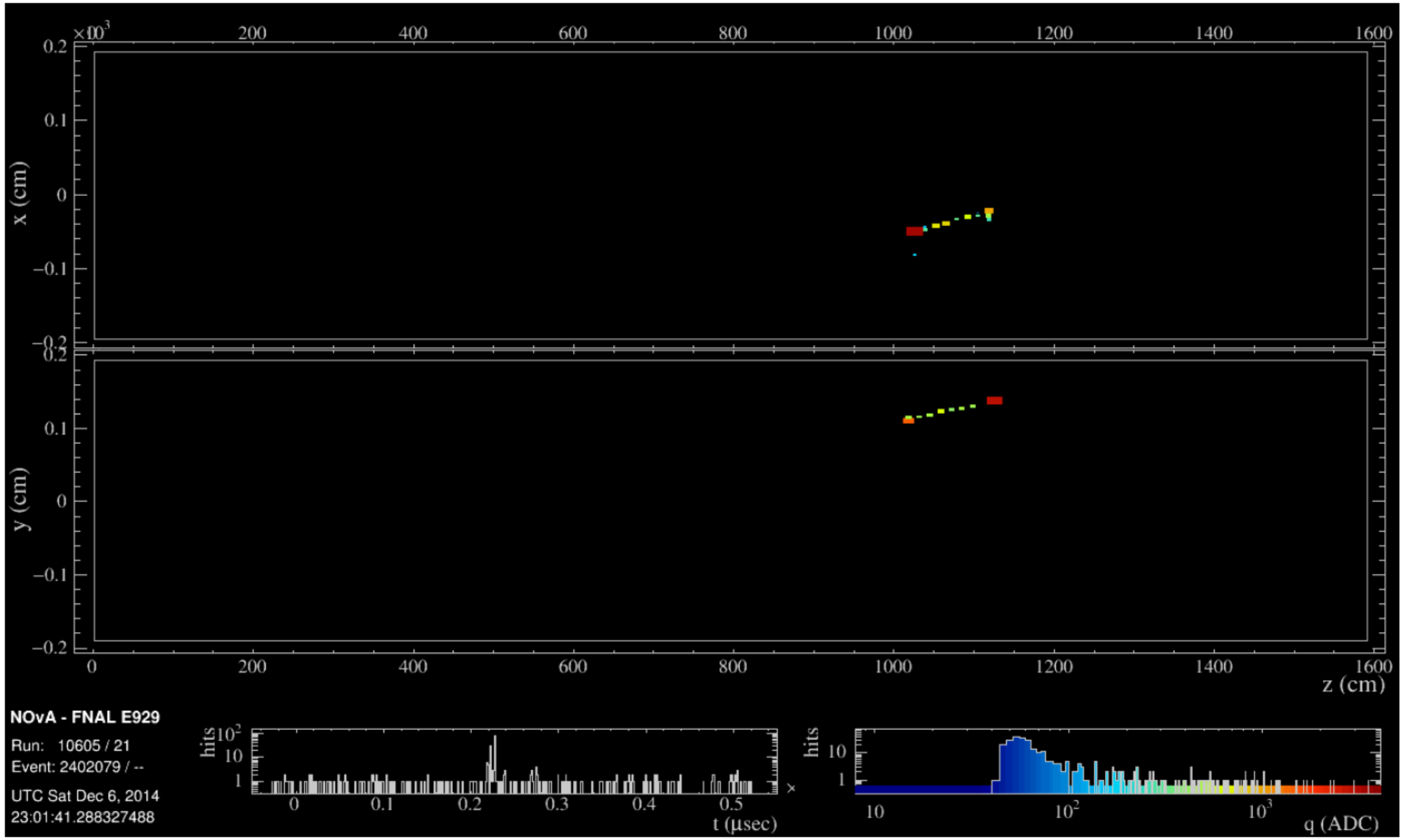
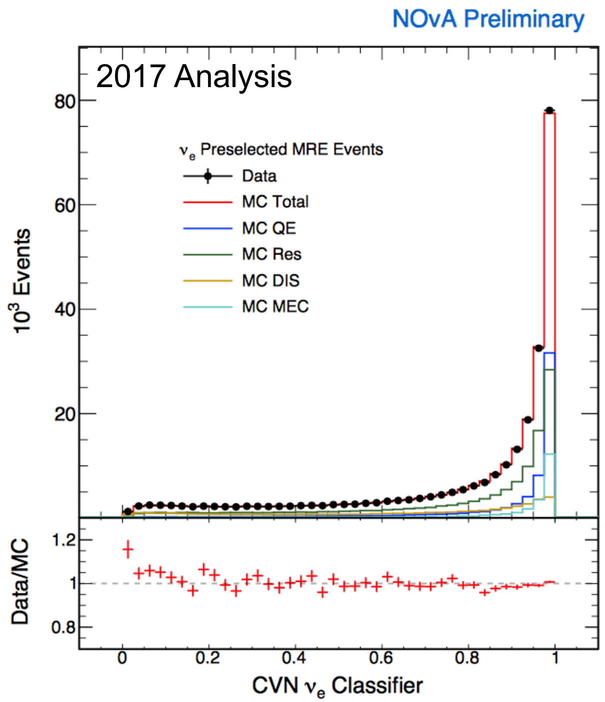
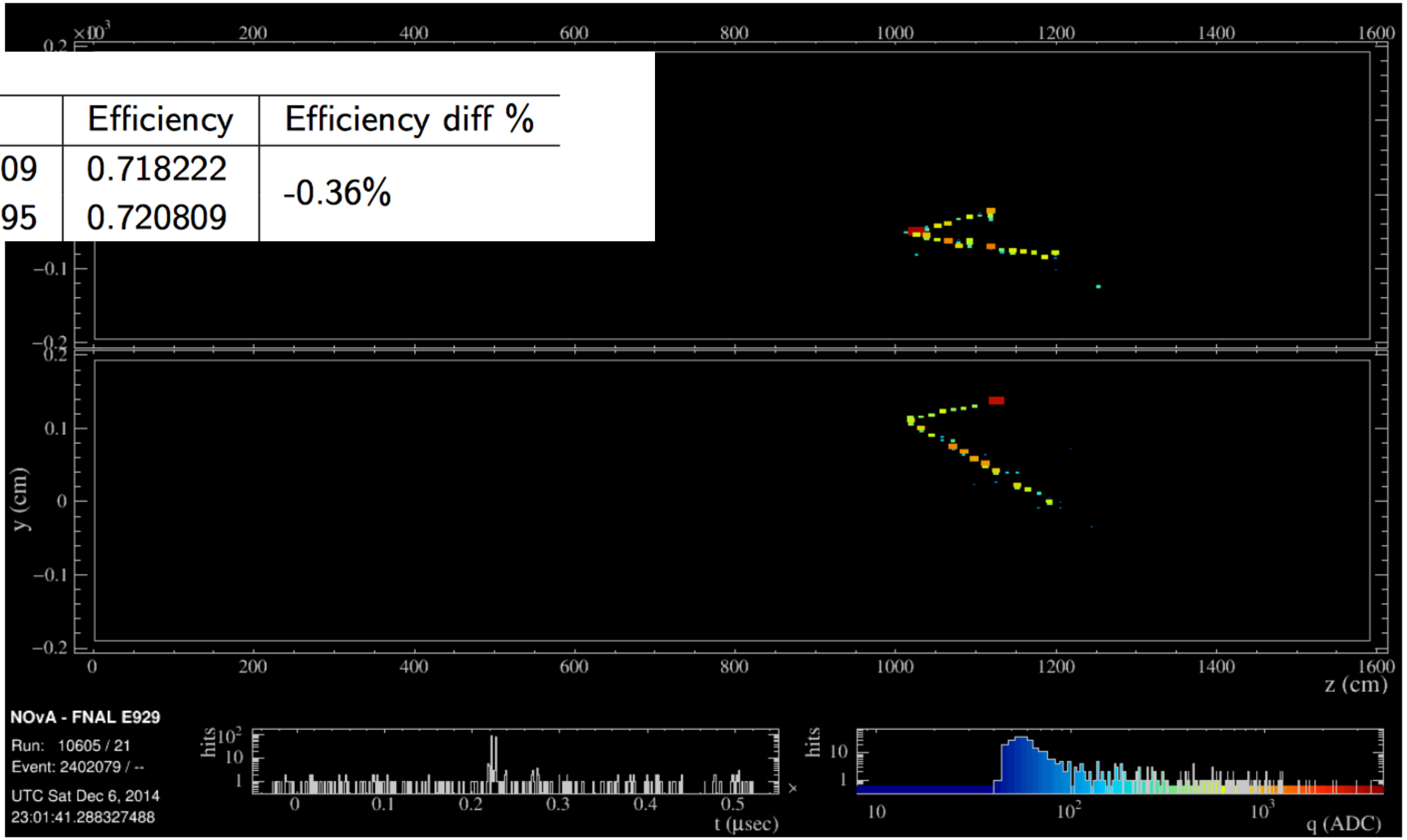


Muon Removed Electrons

PID	Sample	Preselection	PID	Efficiency	Efficiency diff %
CVN	Data	262884	188809	0.718222	-0.36%
	MC	277320	199895	0.720809	





Working to validate for nu_e CC XS analysis.

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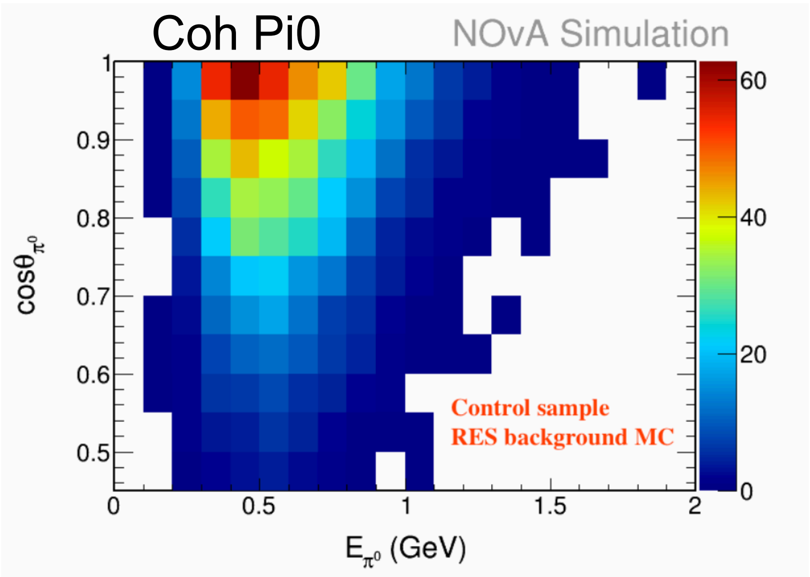
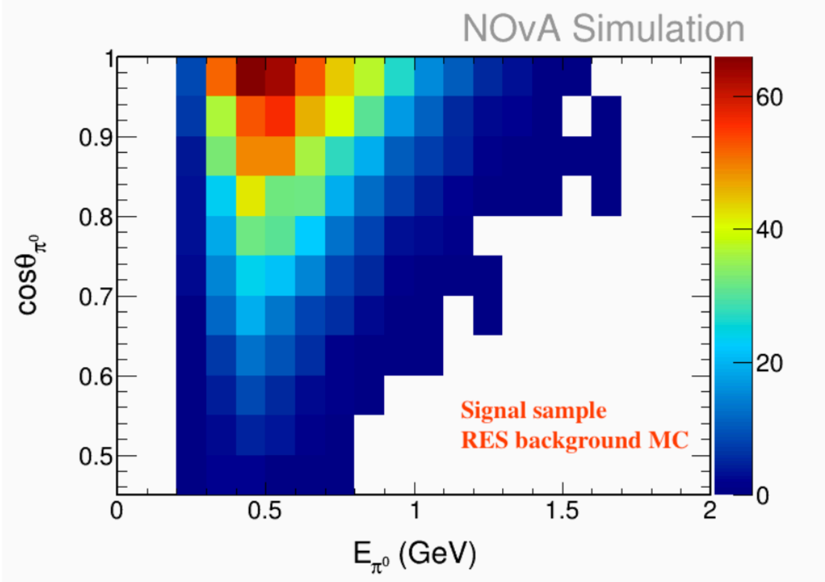
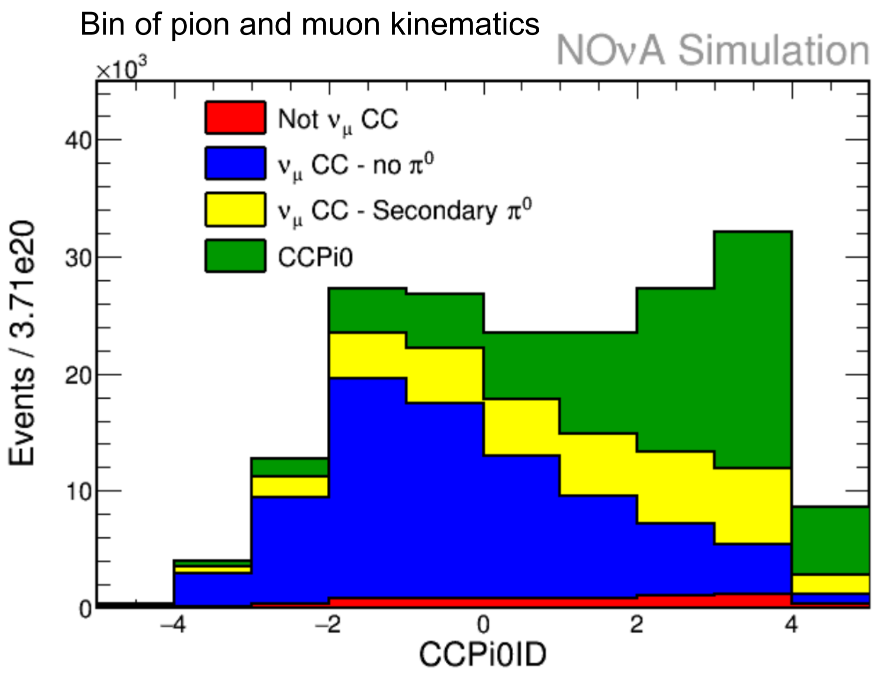
Backgrounds





- For many analyses we identify an independent background dominated control sideband which is kinematically similar to bkgd in signal region.
- Perform background fitting in SB to constrain in signal region.
- For CC pi0 the entire signal and background are fit to template in each analysis bin independently.



The Rest – Common Analysis Framework

NOvA has developed a standard code-set (NDAna) to assure uniform treatment of standard analysis components e.g.:

- Flux: PPFX (**P**ackage to **P**redict the **F**lu**X**)
- Target
  - Using a 3D random-poll algorithm.
  - Return a fiducial mass and elemental composition.
- Unfolding: Multiple techniques available for analyses to assess.

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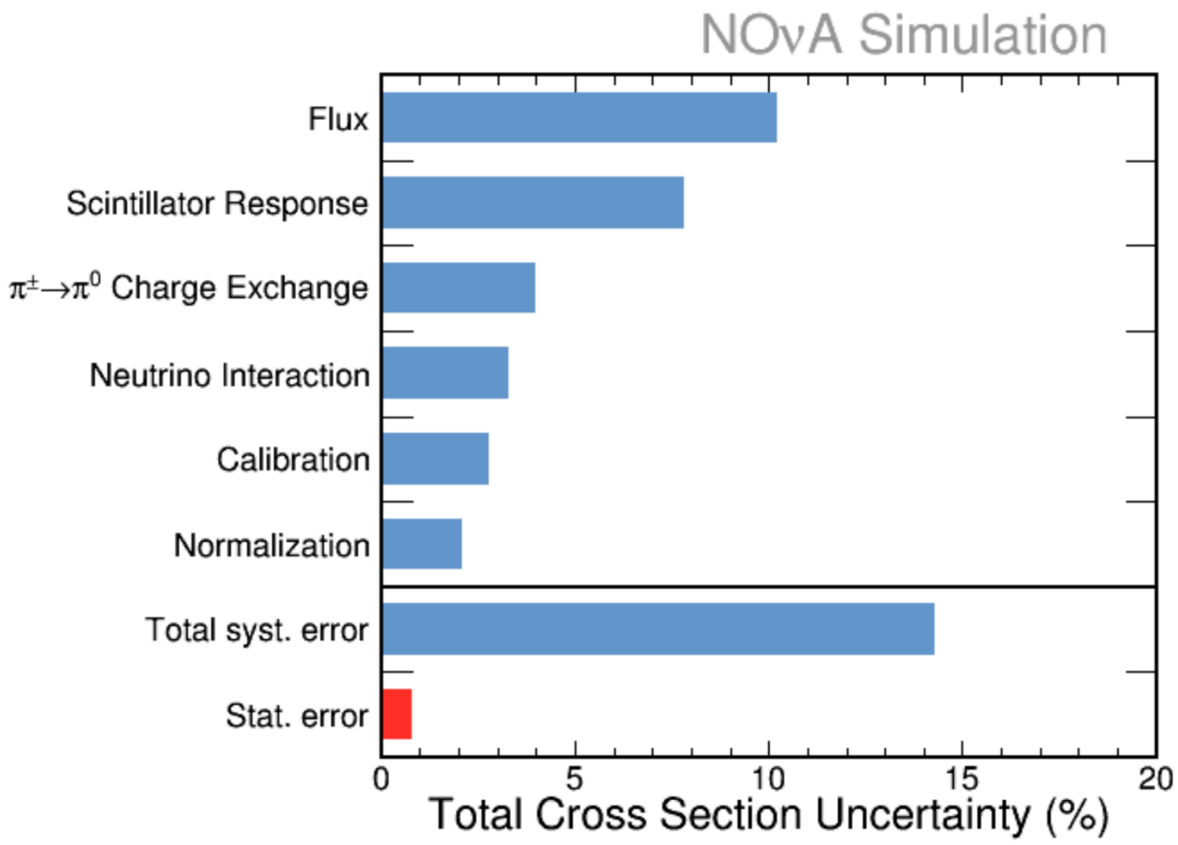
Systematics

- Many of our initial XS analyses will be systematics limited.
- In many cases the beam flux uncertainties dominate.
- Detector response and xs modeling are also important.
- Of course this isn't the full story as the primary result will often be differential in FS kinematics.
- Also for future xs ratio measurement flux uncertainties will be greatly reduced.
- We're working hard to improve…

Est. From CCPi0



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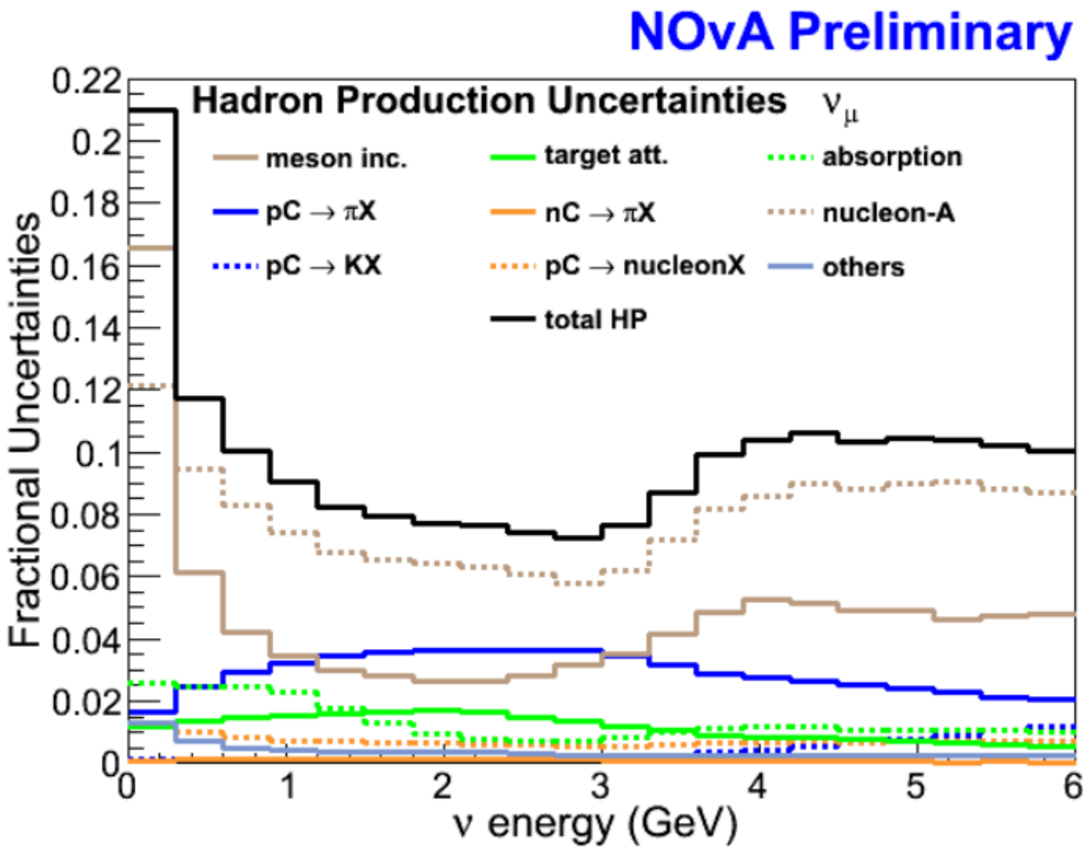
Expected Flux Systematics

PPFX (**P**ackage to **P**redict the **F**lu**X**)

- Pion, kaon and nucleon productions based mainly on NA49 data (thin target by default).
- Corrects HP mis-modeling.
- Uses multi-universe technique for the uncertainty propagation.
- New Hadron Production data?



NuINT 2017

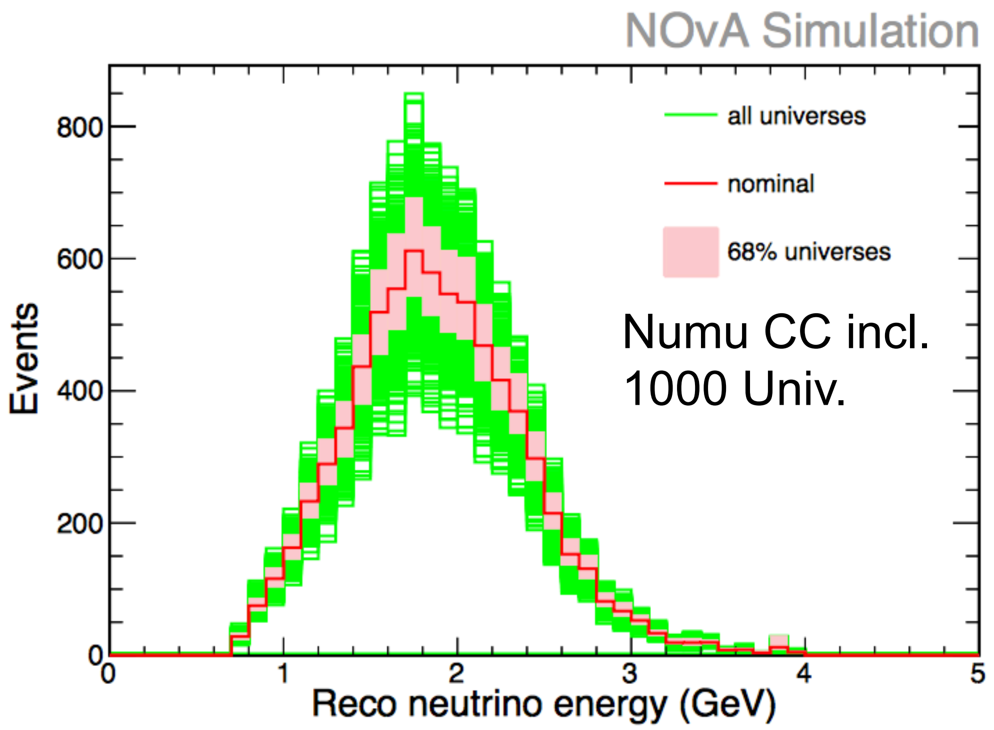
The NuMI Flux Prediction

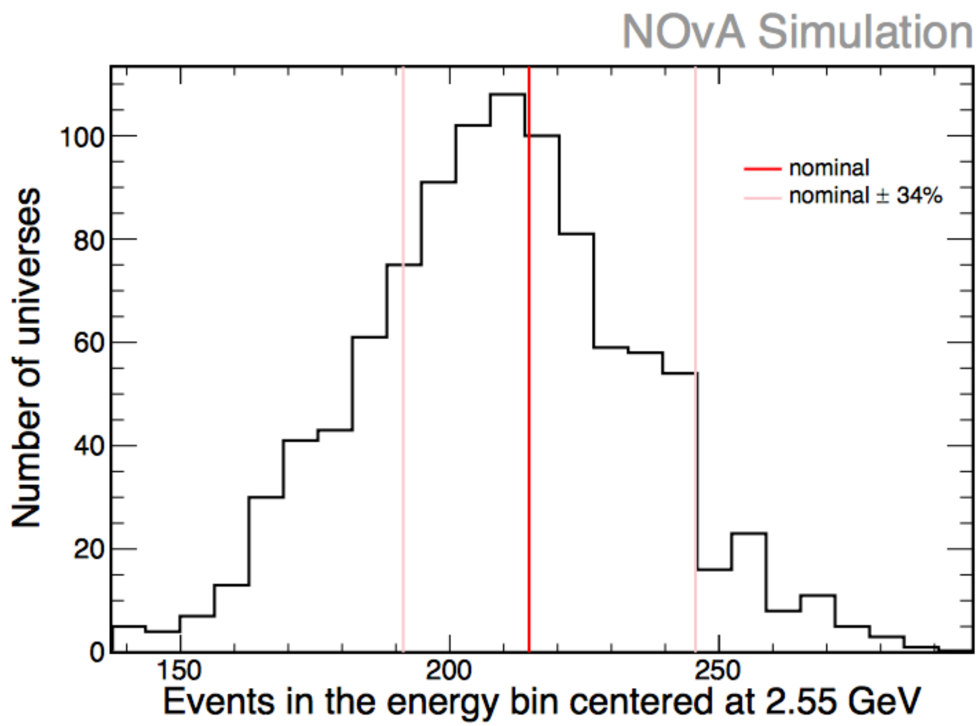
Session: Neutrino Flux Calculations and Measurements

Presented by **Leonidas ALIAGA SOPLIN** on **26 Jun 2017** at **14:20**

Modeling Systematics - Multiverse

- Create an ensemble of universes, each with a different set of relevant GENIE parameters.
- Allows bin-to-bin correlation calculation.
- Easily expandable to include additional systematics.





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Conclusion and Future Work

- NOvA's cross section program is very active (~14 active analyses).
- **First results will be shown at NuINT with more to follow later this year.**
- Working on incorporating additional generators into NOvA framework (NEUT, GiBUU).
- Looking forward to analyzing RHC (3e20 POT available now).
- Improving tools to better reconstruct single particles (p, n, pi, etc).

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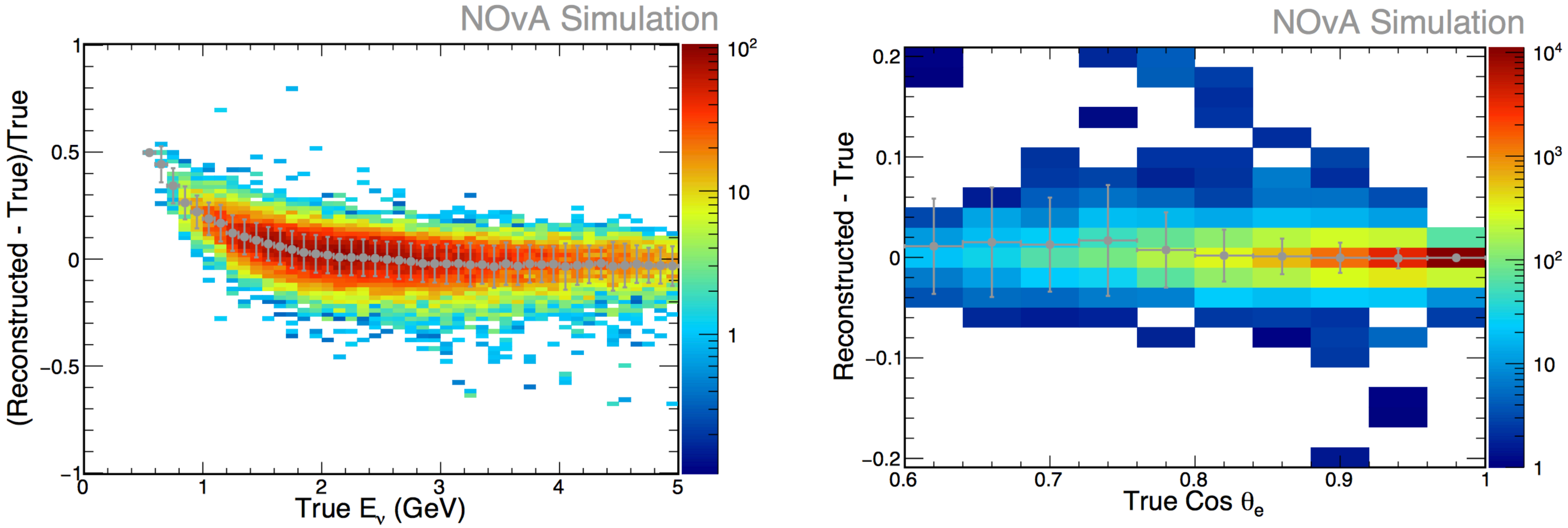
Thanks for your attention.

www-nova.fnal.gov

Resolution ν_e



Energy estimaor bias… new updated estimators.