Muon - Charged Current Neutrino Event Selection From The NOvA Prototype Detector's Data

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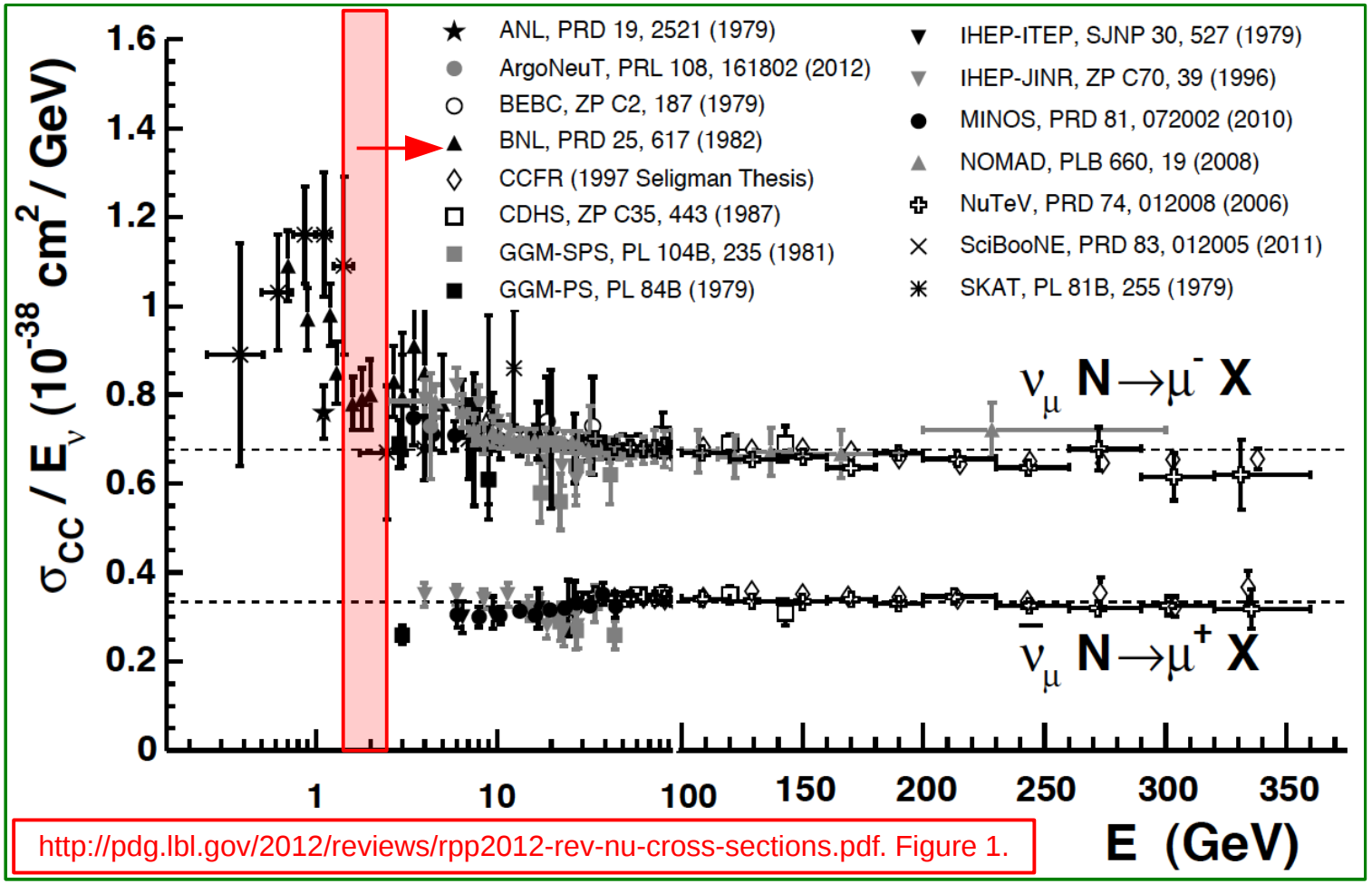
OBJECTIVE

Ph.D. Thesis

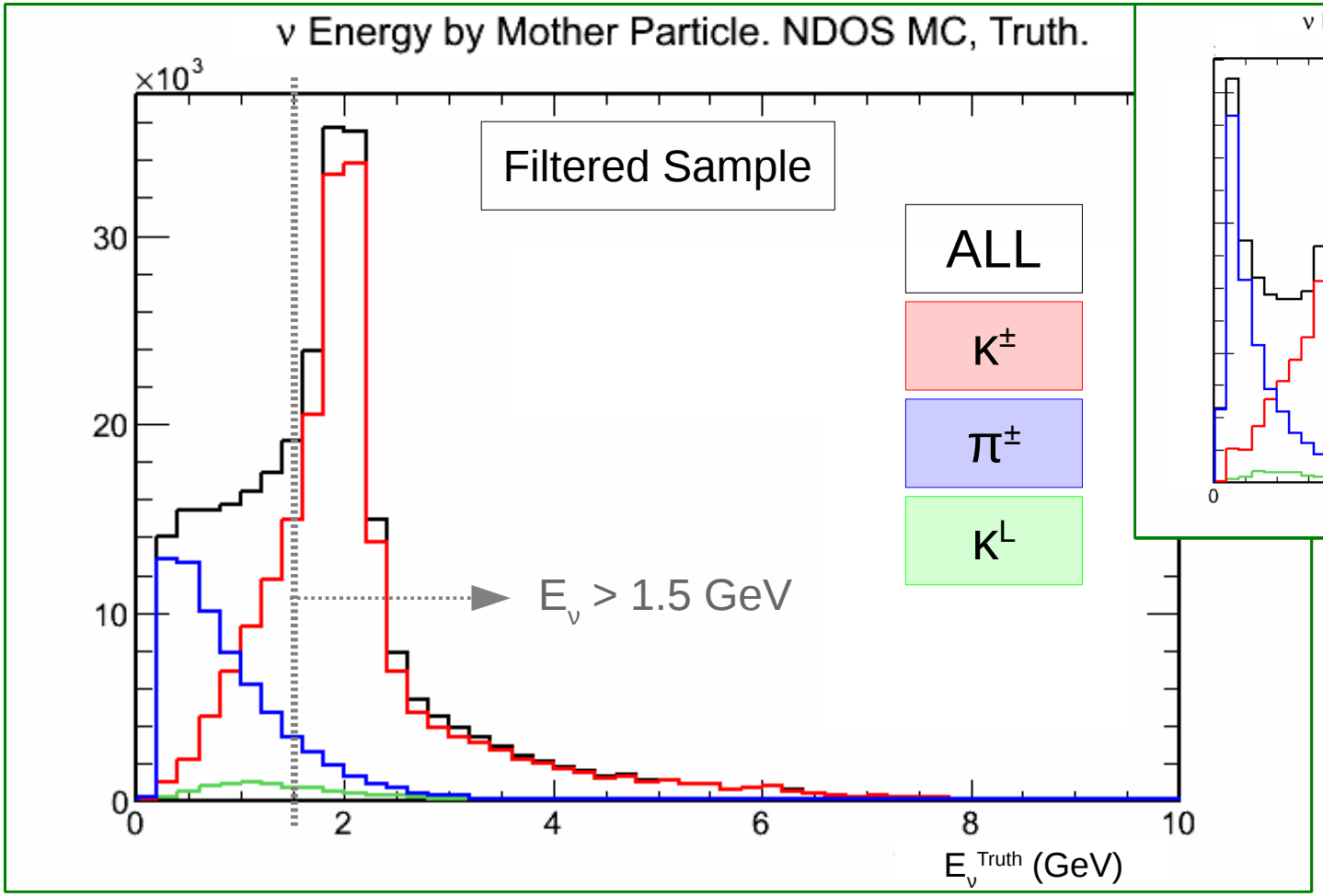


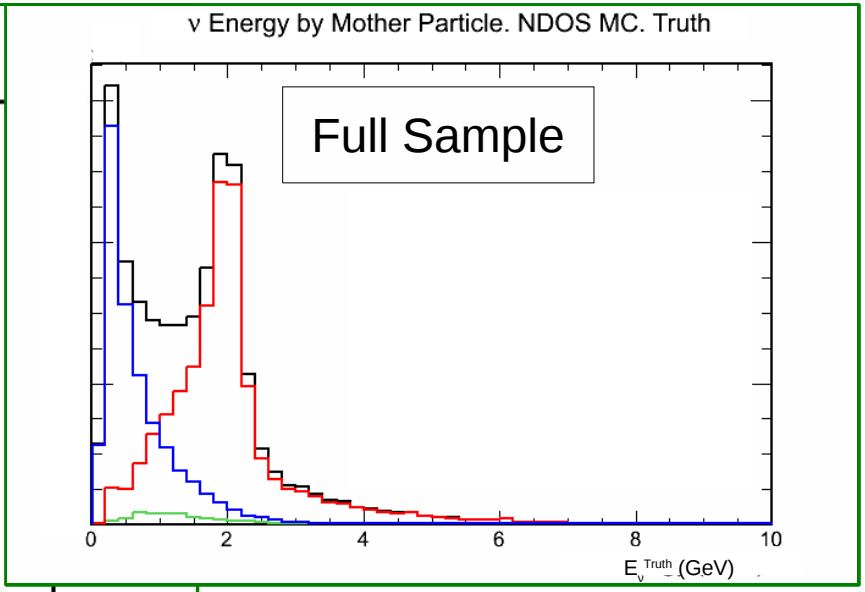
http://pdg.lbl.gov/2012/reviews/rpp2012-rev-nu-cross-sections.pdf. Figure 1.

Measurements of ν_μ *CC* inclusive scattering cross sections divided by neutrino energy as a function of neutrino energy. The red region, ~ 2 *GeV*, is the region of interested for my thesis. Within that region, the only measurements are those from BNL. They used a deuterium bubble chamber exposed to a wide – band neutrino beam with a mean neutrino energy of 1.6 *GeV*. A 29 *GeV/c* proton beam extracted from the AGS struck a sapphire target once every 1.4 *sec* at an intensity of ~ 0.8×10^{13} protons per pulse. I want to use this plot to illustrate the motivation of my thesis. I want to show that this energy region has not been studied in great detail, and that *NDOS* could contribute with a new competitive measurement if an uncertainty of ~ 10% could be achieved.

ν ENERGY

Mother Particle





$$\frac{ALL^{1.5\,GeV\rightarrow}_{part.}}{ALL^{energy}_{part.}} = 0.65$$

$$\frac{\kappa^{1.5\,GeV\rightarrow}}{\kappa^{all}} = 0.82$$

$$\frac{\pi^{1.5\,GeV\rightarrow}}{\pi^{all}} = 0.19$$

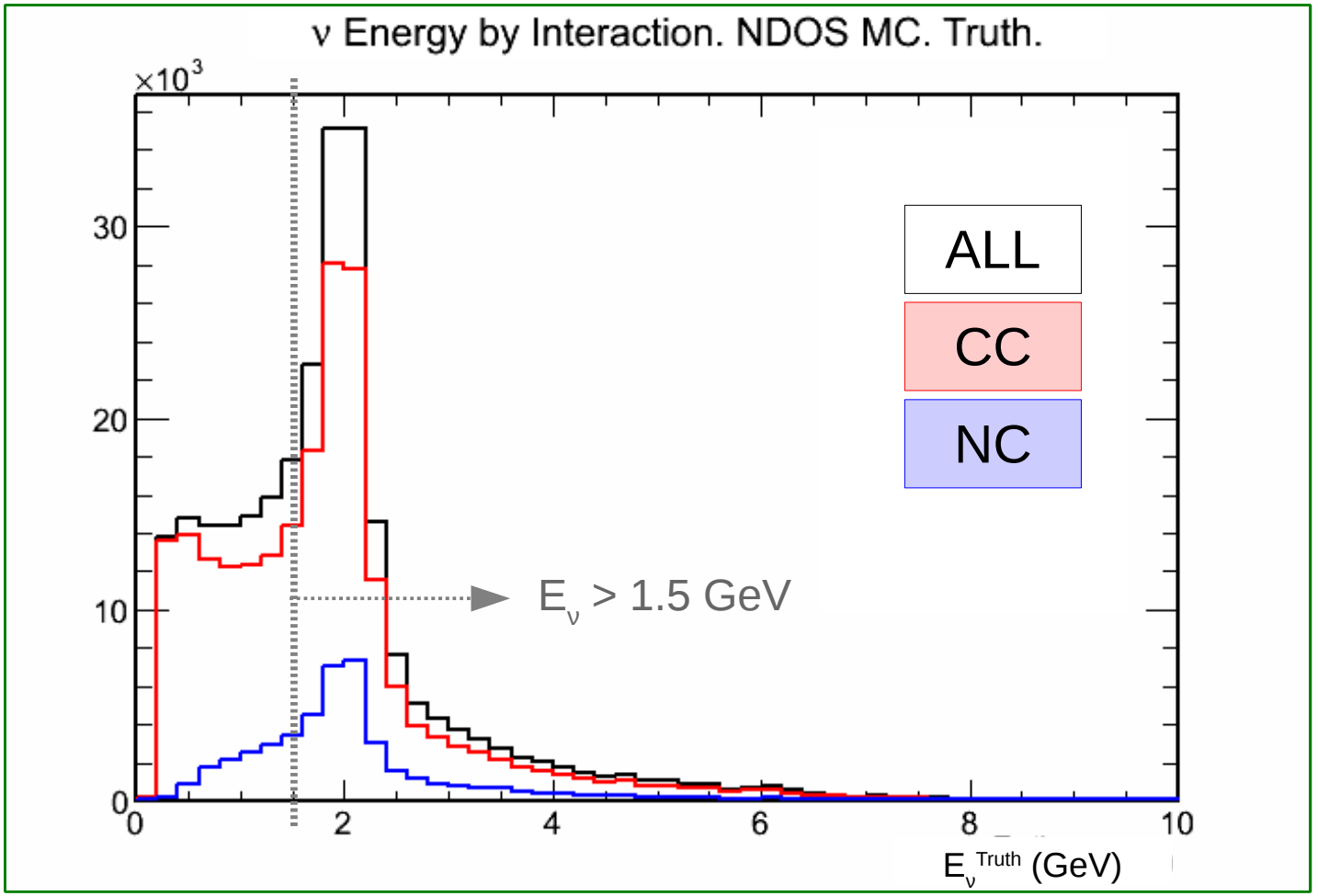
$$\frac{\pi^{1.5\,GeV\rightarrow}}{\kappa^{1.5\,GeV\rightarrow}} = 0.08$$

Filtered Sample: ν energy discriminated by the ν's mother particle. This plot was produced by *MCCheckOut*. The ν events that made it to this plot were selected by means of asking for a *Kalman Track* having its starting coordinates with in the instrumented volume of *NDOS* 2.0. The black histogram is the energy of all simulated ν's for the *NuMI* beam. The red histogram is the energy of simulated ν's produced in κ± decays. The blue histogram is the energy of simulated ν's produced in π± decays. The green histogram is the energy of simulated ν's produced in κL decays. The region with E_ν > 1.5 *GeV* is dominated by ν's from κ± decays, with an 8% π± contamination. In my thesis I want to use this high purity ν events from κ± decay. Because the event selection is based on reconstructed *Tracks*, a good number of low energy events do not make it to this plot just because they do not meet the criteria to make a *Track*. The *MC* files used here are those from the S12-12-12 release that belong to the *NDOS* 2.0 era. Each file has 10^3 events, with one event per spill.

Full Sample: The same description given for the Filtered Sample fits here except for the facts that only *MC* files from 13067 to 13199 Runs were used, and that all neutrinos interacting inside the instrumented volume of *NDOS* 2.0 were taken into account, and not only those with reconstructed *Tracks*.

ν ENERGY

Interaction Type



$$\frac{E^{1.5\,GeV\rightarrow}}{E^{all}} = 0.66$$

$$\frac{NC^{1.5\,GeV\rightarrow}}{NC^{all}} = 0.77$$

$$\frac{CC^{1.5\,GeV\rightarrow}}{CC^{all}} = 0.64$$

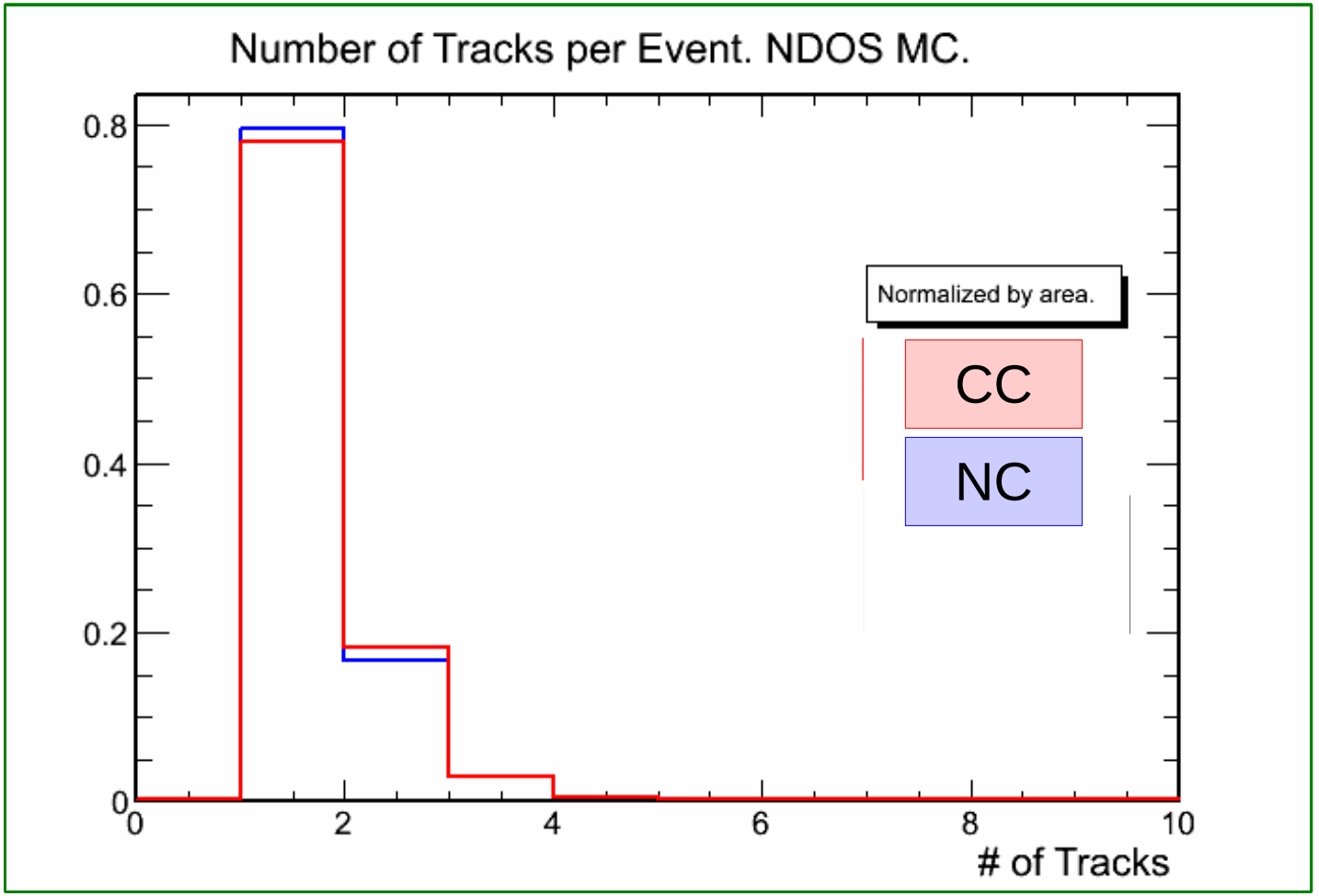
$$\frac{NC^{all}}{CC^{all}} = 0.22$$

$$\frac{NC^{1.5\,GeV\rightarrow}}{CC^{1.5\,GeV\rightarrow}} = 0.26$$

ν energy discriminated by the type of ν's interaction inside the *NDOS*. This plot was produced by *MCCheckOut*. The ν events that made it to this plot were selected by means of asking for a *Kalman Track* having its starting coordinates within the instrumented volume of *NDOS* 2.0. The black histogram is the energy of all simulated ν_μ's for the *NuMI* beam. The red histogram is the energy of simulated ν_μ's produced in *CC* interactions. The blue histogram is the energy of simulated ν_μ's produced in *NC* decays. The region of interest for my thesis is E_ν > 1.5 *GeV*, which has *NC/CC* = 0.26. The *NC* events are background to the sought *CC* signal. The main goal of my APS talk is to illustrate the studies done to separate *BG* from *S*.The *MC* files used here are those from the S12-12-12 release that belong to the *NDOS* 2.0 era. Each file has 10^3 events, with one event per spill.

TRACK MULTIPLICITY

CC & NC



$$\frac{CC^{One\ Trk}}{CC^{All}} = 0.78$$

$$\frac{NC^{One\ Trk}}{NC^{All}} = 0.8$$

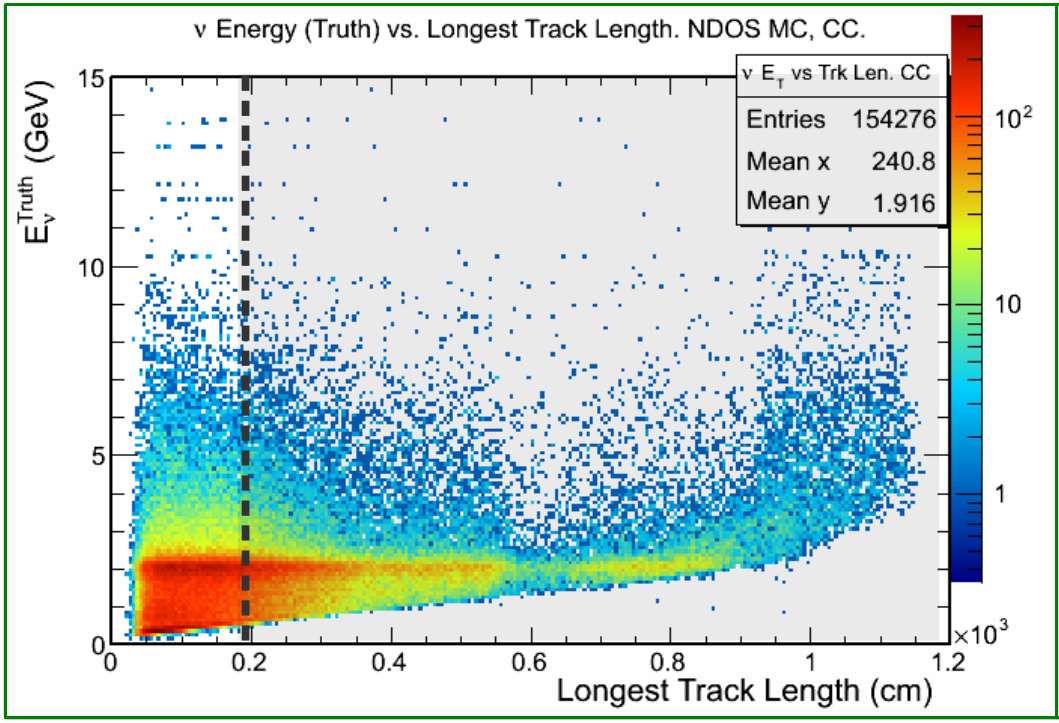
$$\frac{CC^{Two\ Trk}}{CC^{All}} = 0.18$$

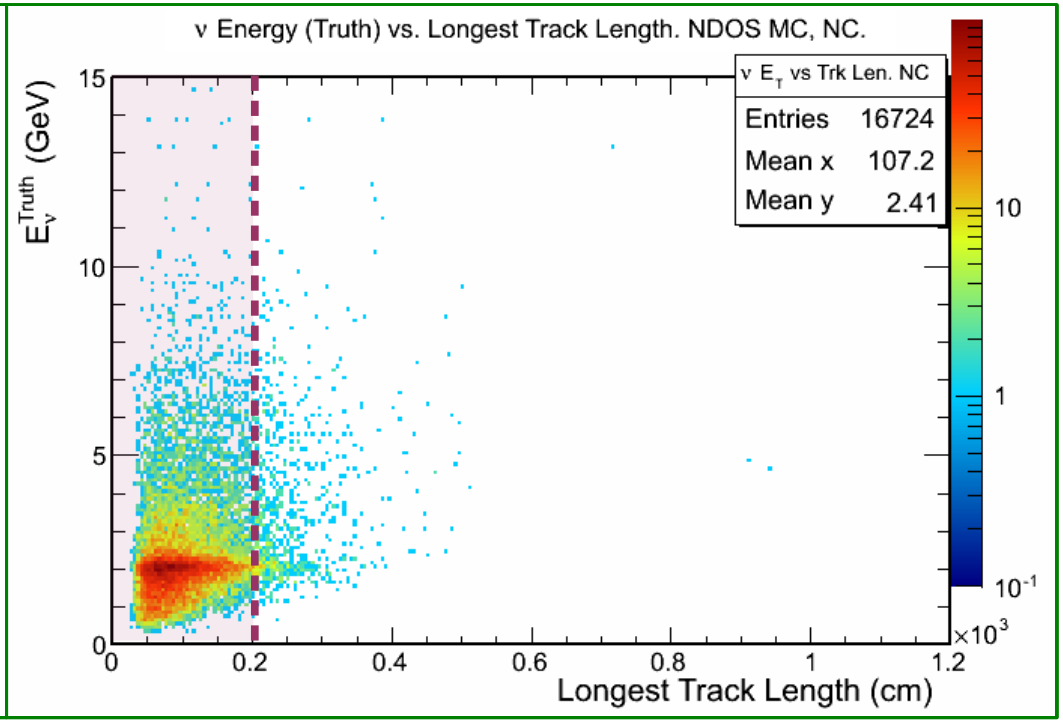
$$\frac{NC^{Two\ Trk}}{NC^{All}} = 0.16$$

Track Multiplicity **discriminated by the type of ν's interaction inside the *NDOS*. The red histogram is the number of reconstructed *Tracks* for *CC* interactions. The blue histogram is the number of reconstructed *Tracks* for *NC* decays. The two histograms are very similar, which means that this variable is not good to separate *CC* from *NC*. However, the fact that ~ 80% of all events have one reconstructed *Track* means that the study can focus on the longest – *Track* – per – event's properties. The *MC* files used here are those from the S12-12-12 release that belong to the *NDOS* 2.0 era. Each file has 10^3 events, with one event per spill.**

ν ENERGY vs TRACK LENGTH

CC & NC





ν energy vs reconstructed *Track* length discriminated by the type of ν's interaction inside the *NDOS*. The scattered plot to the left shows the correlation for *CC* interactions. The scattered plot to the right shows the correlation for *NC* interactions. Using the length of the longest *Track* per event makes it is possible to discriminate between the two interactions. The sample of events with a longest *Track* longer than 200 *cm* has a high purity *CC* component, with only 2% *NC* contamination. This sample, under the grey shadow, needs no further study to call it *CC* signal, and contains 42% of all *CC* interactions. The other sample, under the purple shadow, has a 17% *NC* contamination. Whether or not this is an acceptable background is under investigation. All the efforts so far indicate that this *BG* is irreducible. The *MC* files used here are those from the S12-12-12 release that belong to the *NDOS* 2.0 era. Each file has 10^3 events, with one event per spill.

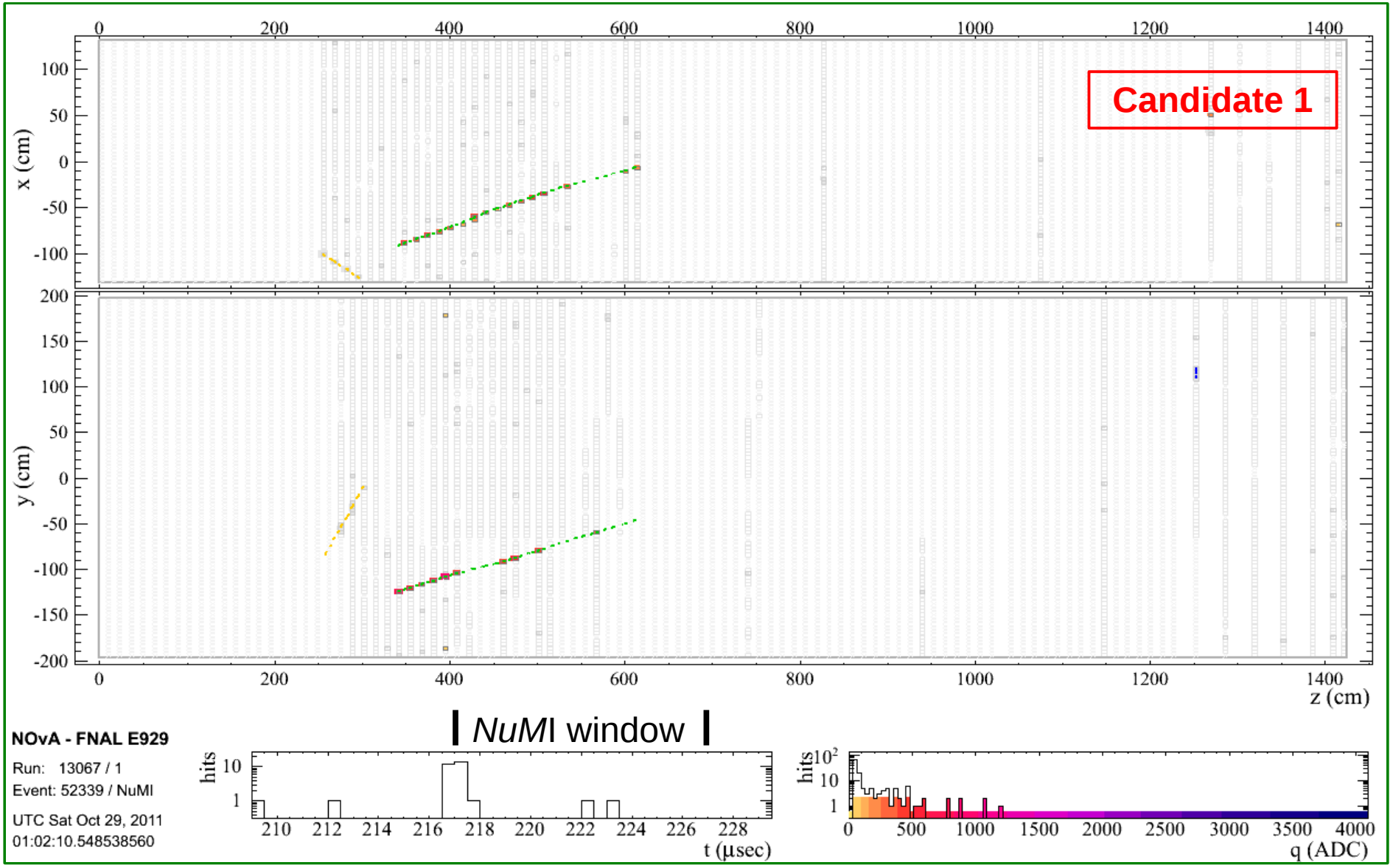
$$\frac{NC_{200\,cm\rightarrow}}{CC_{200\,cm\rightarrow}} = 0.02$$

$$\frac{NC_{\leftarrow 200\,cm}}{CC_{\leftarrow 200\,cm}} = 0.17$$

$$\frac{CC_{200\,cm\rightarrow}}{CC_{All}} = 0.42$$

SAMPLE EVENTS, DATA

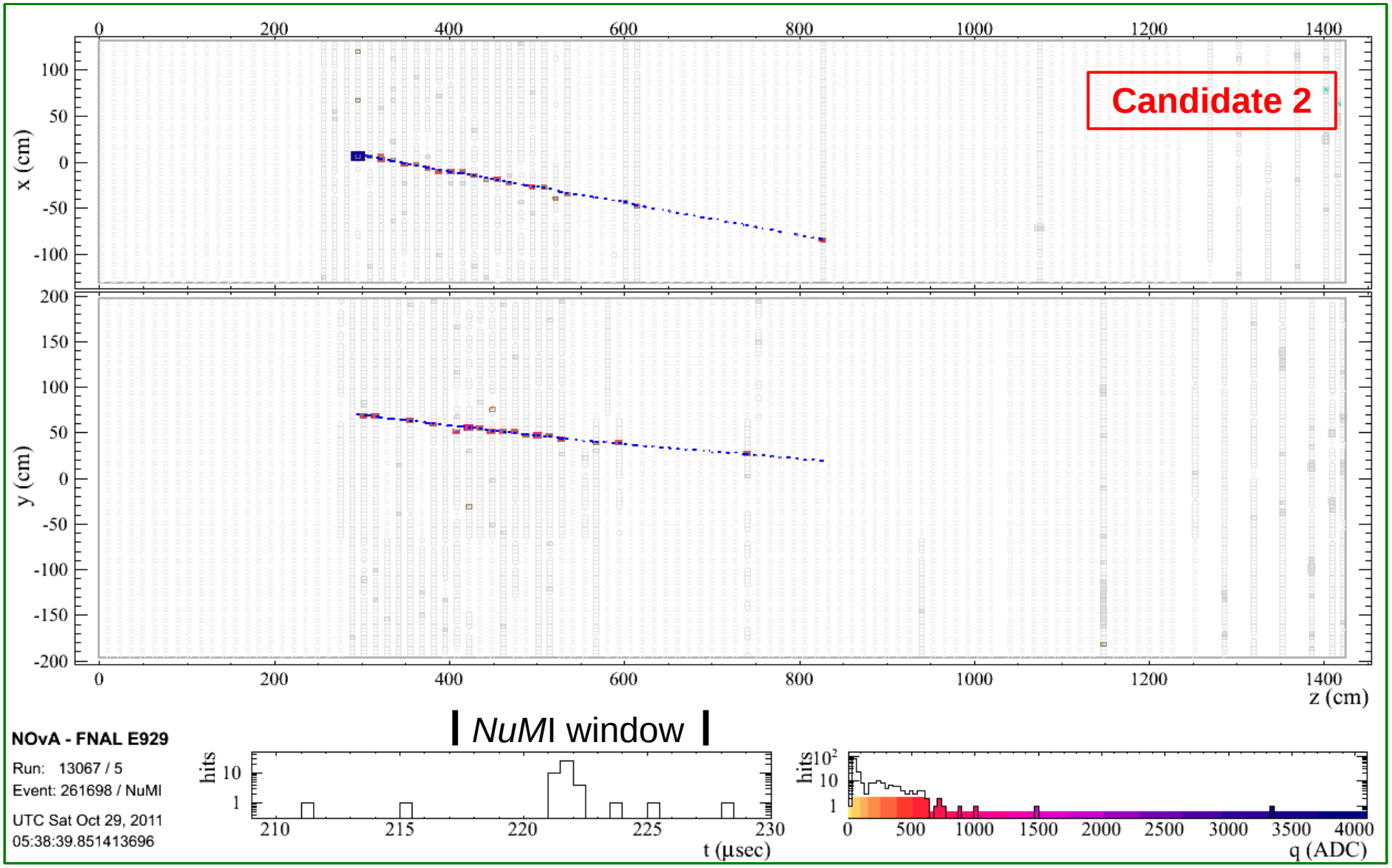
CC



By means of the longest *Track* length cut, this is a *CC* candidate.

SAMPLE EVENTS, DATA

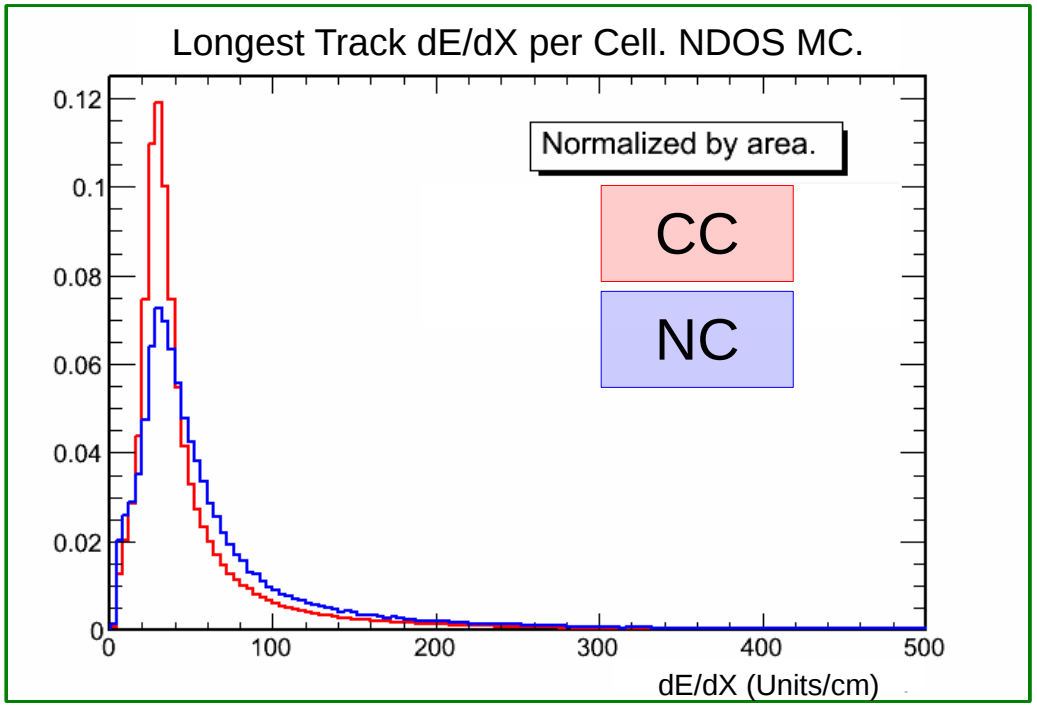
CC



By means of the longest *Track* length cut, this is another *CC* candidate.

dE/dX

CC & NC

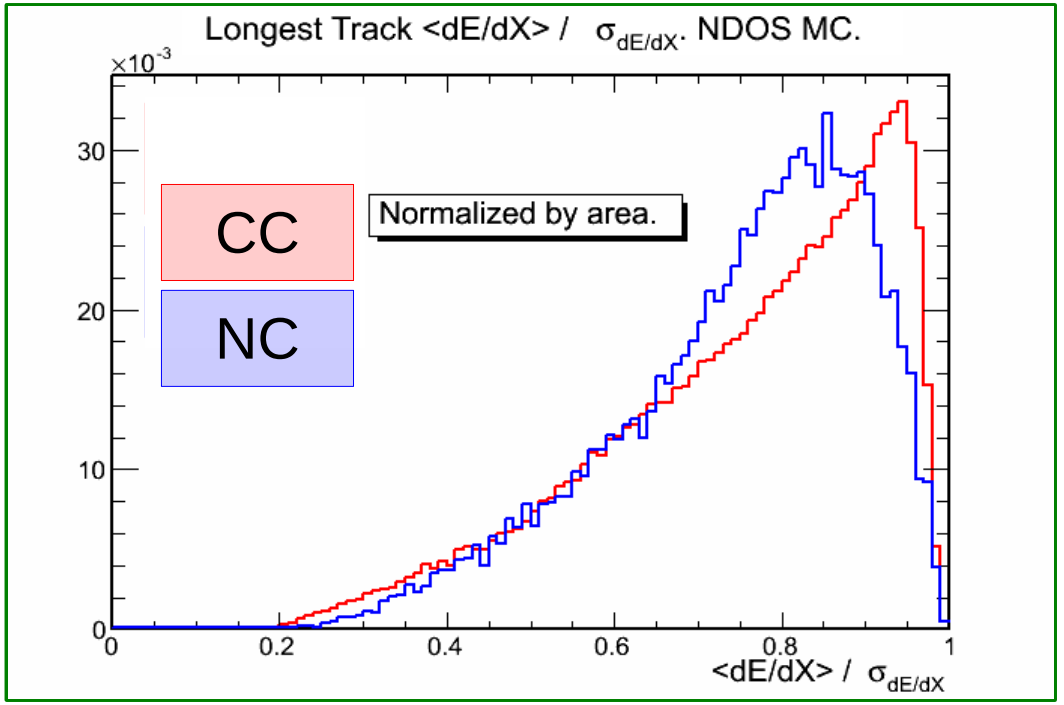


Longest *Track dE/dX* per *Cell* in a reconstructed *Track* discriminated by the type of ν's interaction inside the *NDOS*. To make this plot the path of the particle of interest through each *Cell* in its trajectory is taken into account. In order to know this path, the trajectory points of the studied *Track* are used. The energy used to make this calculation is the reconstructed energy deposited per *Cell*. The units of such energies are: *PECorr*, however, in the plot this units are omitted for the general public. The red histogram is the *dE/dX* per *Cell* of longest reconstructed *Tracks* for *CC* interactions. The blue histogram is the *dE/dX* per *Cell* of longest reconstructed *Tracks* for *NC* interactions. The sample of events with a longest *Track* shorter than 200 *cm* makes it to this plot. *CC Tracks* have a narrower distribution, however, this feature is not enough to separate *CC* from NC. The *MC* files used here are those from the S12-12-12 release that belong to the *NDOS* 2.0 era. Each file has 10^3 events, with one event per spill.

dE/dX (Units/cm)

dE/dX

CC & NC



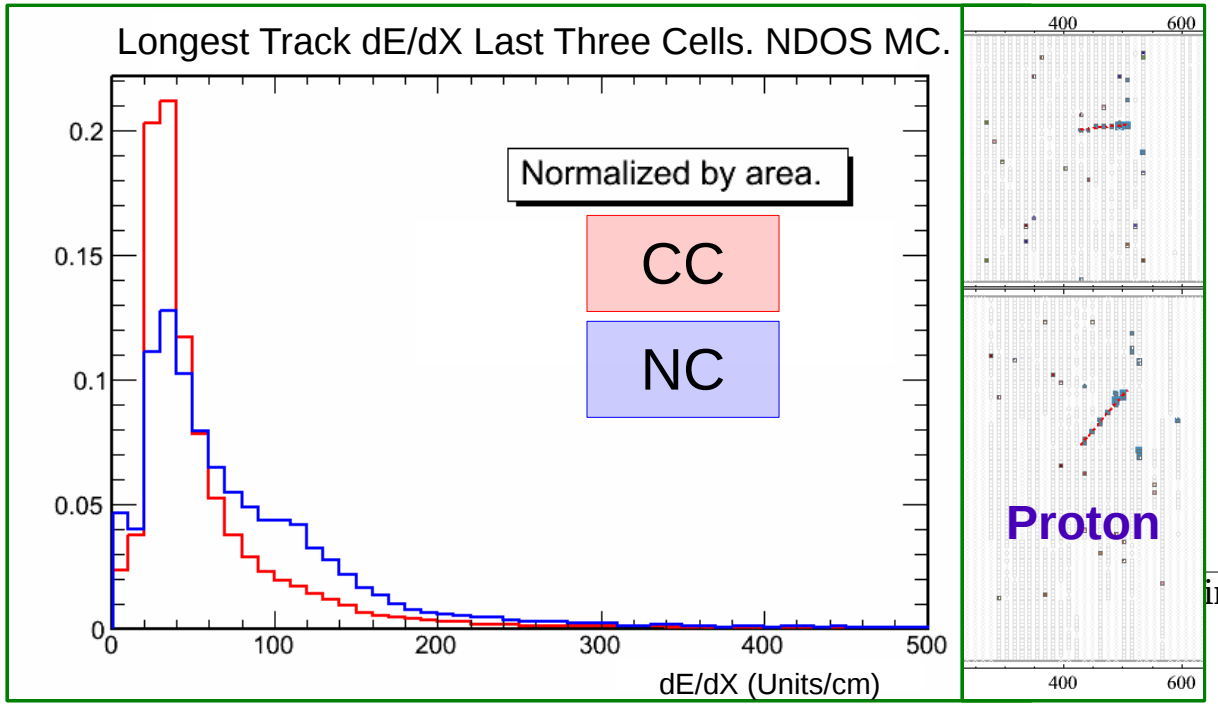
Longest *Track dE/dX* mean over longest *Track dE/dX RMS* discriminated by the type of ν's interaction inside the *NDOS*. To get the mean the *dE/dX* of all *Cells* in the longest *Track* are added and divided by the number of *Cells* in the *Track*. The red histogram is the *dE/dX* mean of the longest reconstructed *Track* over the *dE/dX RMS* for *CC* interactions. The blue histogram is the *dE/dX* mean of the longest reconstructed *Track* over the *dE/dX RMS* for *NC* interactions. μ's should have a ratio ~ 1, on average; other *Tracks* should have large *RMS*, hence ratio < 1, on average. The sample of events with a longest *Track* shorter than 200 *cm* makes it to this plot. *CC Tracks* pile towards 1, whilst *NC Tracks* peak around 0.8, however, this feature is not enough to separate *CC* from NC. The *MC* files used here are those from the S12-12-12 release that belong to the *NDOS* 2.0 era. Each file has 10^3 events, with one event per spill.

dE/dX (Units/cm)

dE/dX

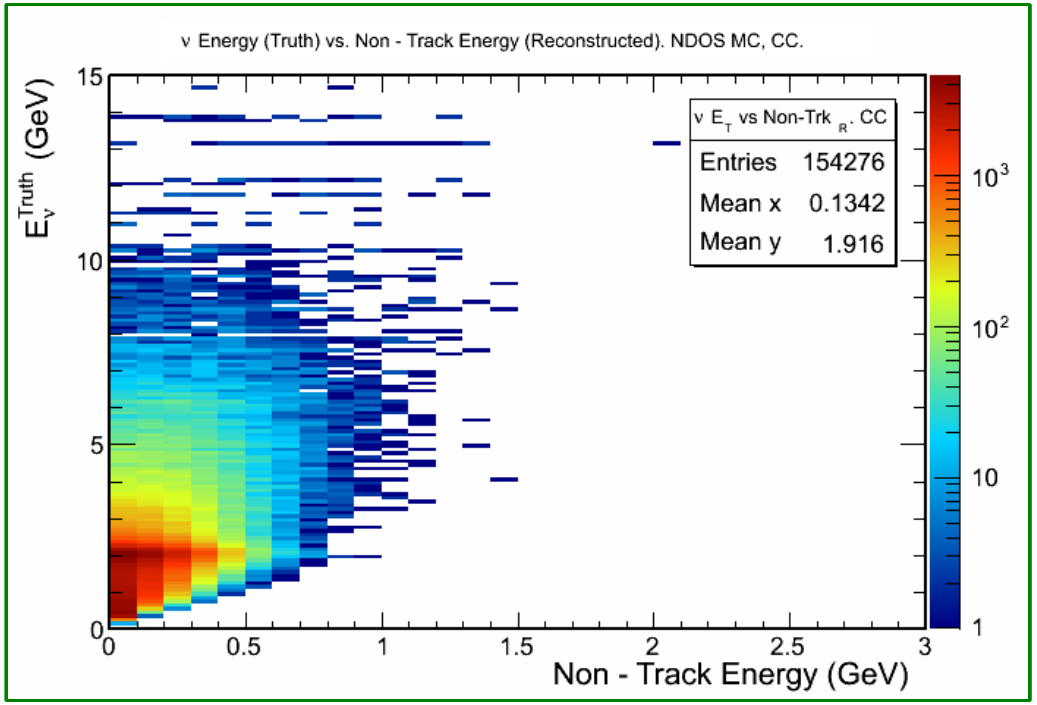
CC & NC

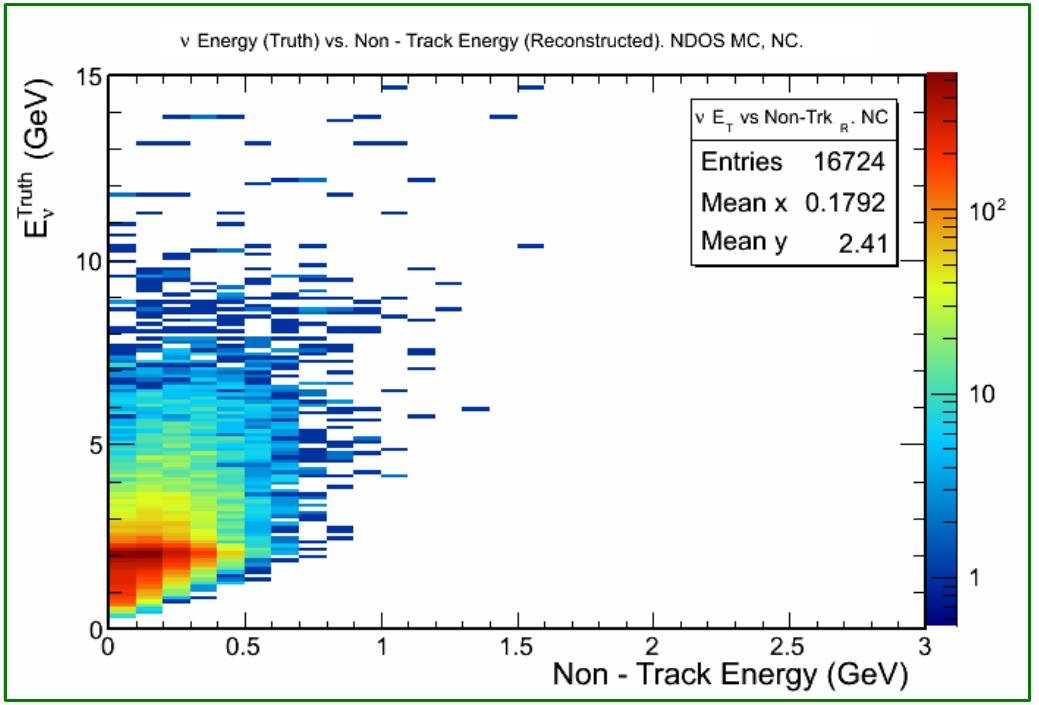
Longest *Track dE/dX* mean of the last three *Cells* discriminated by the type of ν's interaction inside the *NDOS*. Protons, often, deposit more energy in the last few *Cells* of their paths. If this path can be matched to a reconstructed *Track*, then the average *dE/dX* of these *Cells* should be, on average, larger than that of μ's. The energy used to make this calculation is the reconstructed energy deposited per *Cell*. The units of such energies are: *PECorr*, however, in the plot this units are omitted for the general public. The red histogram is the *dE/dX* mean of the last three *Cells* of the longest reconstructed *Tracks* for *CC* interactions. The blue histogram is the *dE/dX* mean of the longest reconstructed *Tracks* for *NC* interactions. The sample of events with a longest *Track* shorter than 200 *cm* makes it to this plot. *CC Tracks* have a narrower distribution, however, this feature is not enough to separate *CC* from NC. The *MC* files used here are those from the S12-12-12 release that belong to the *NDOS* 2.0 era. Each file has 10^3 events, with one event per spill.



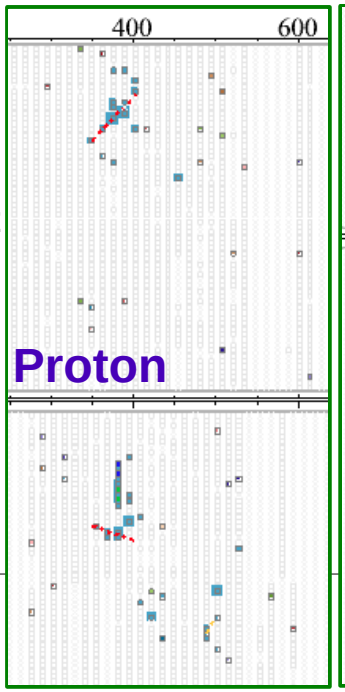
(ν vs NON TRACK) ENERGY

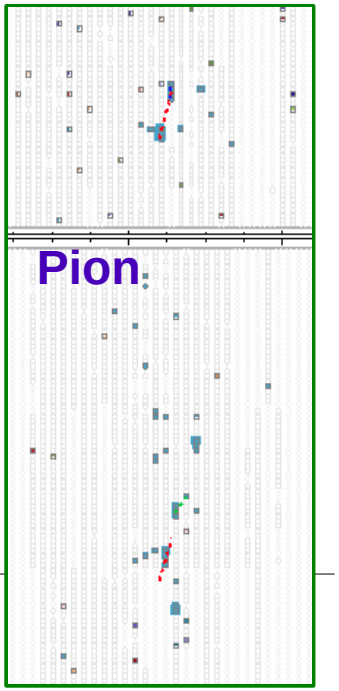
CC & NC





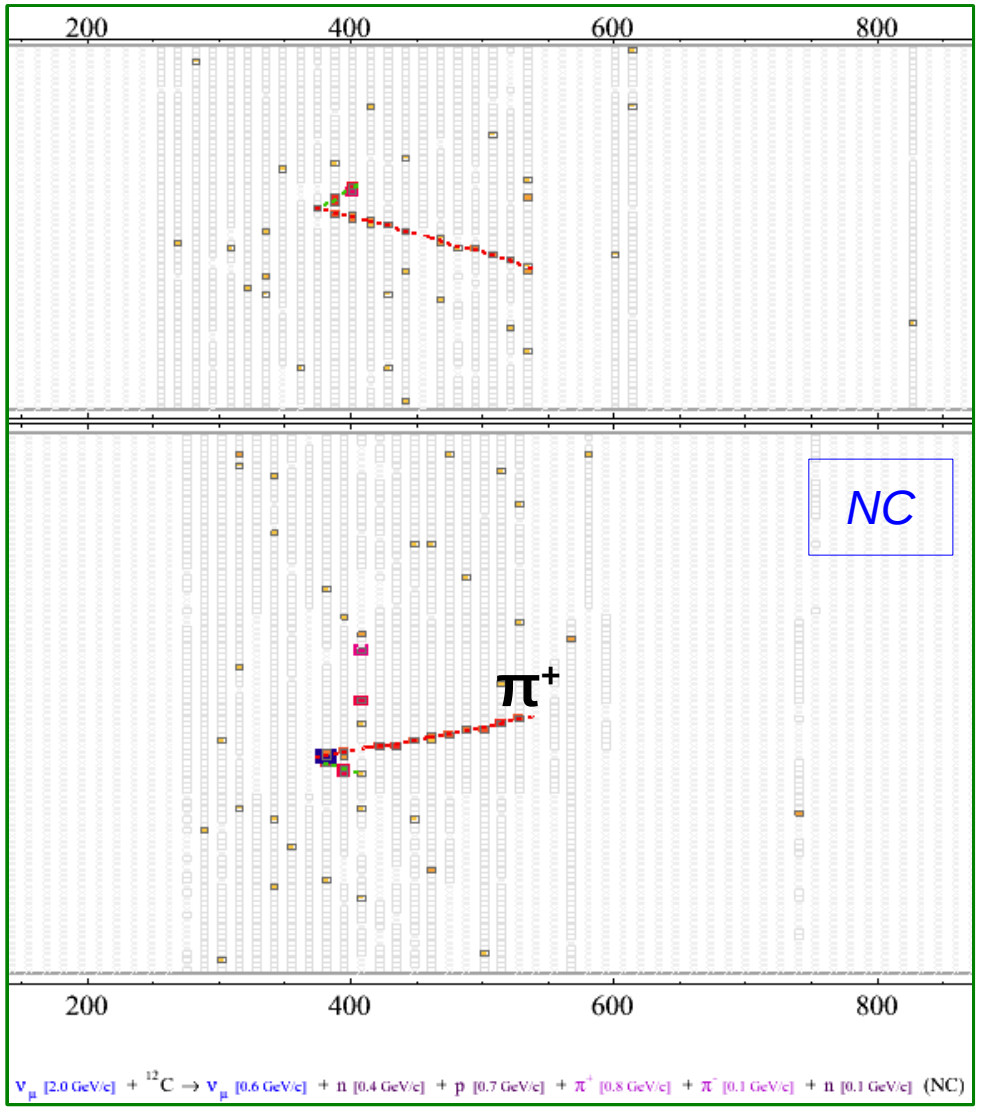
ν energy vs *non – Track* energy discriminated by the type of ν's interaction inside the *NDOS*. The scattered plot to the left shows the correlation for *CC* interactions. The scattered plot to the right shows the correlation for *NC* interactions. In the single – particle events to the right it is seeing that, often, protons and $\pi^{\pm}$ deposit energy inside the *NDOS* not in a *Track – like* pattern, but in a rather showery pattern. Since the reconstruction used for this analysis is *Track* based, this kind of energy deposition is not very well reconstructed into *Tracks*. A good number of *Cells* with deposited energy do not belong to any *Track*, and this is the feature that was the object of study in this plot. Most of the energy deposited by μ's can be grouped into a *Track – like* pattern, so a big difference between *CC* and *NC* was sought. The two scattered plots are very similar, so no information to discriminate *CC* from *NC* events was found here. The sample of events with a longest *Track* shorter than 200 *cm* makes it to this plot. The *MC* files used here are those from the S12-12-12 release that belong to the *NDOS* 2.0 era. Each file has 10^3 events, with one event per spill.

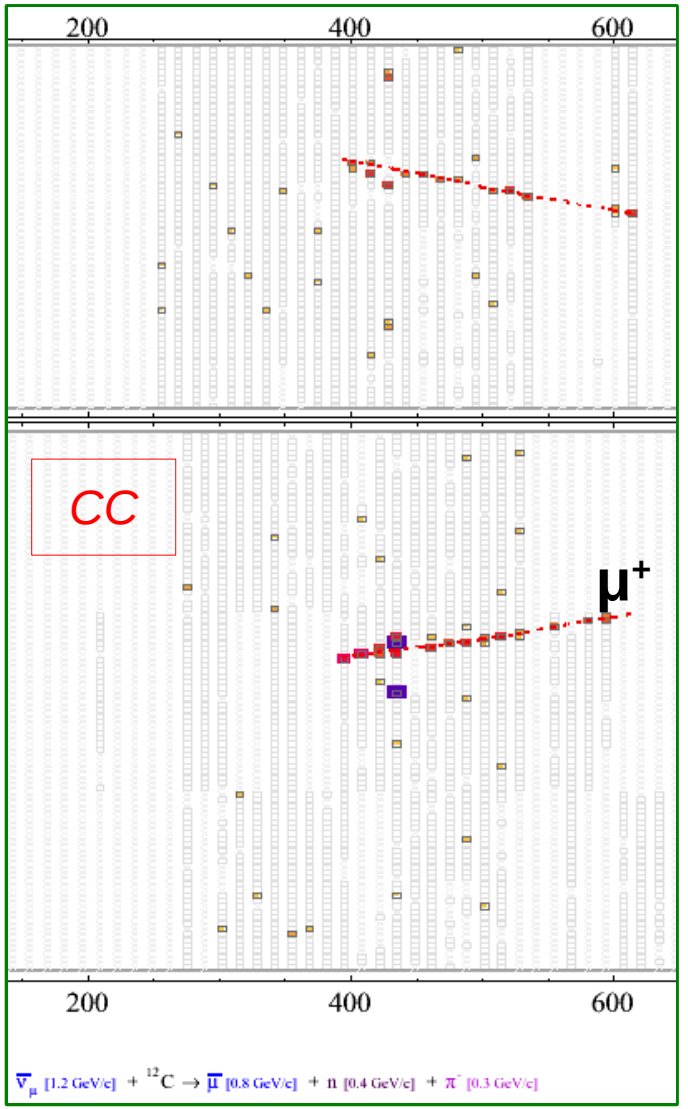




SAMPLE EVENTS, MC

CC & NC





- **The study continues to find ways to differentiate the *NC* background from the *CC* signal, or reduce it to an acceptable minimum.**

TRACK's ORIENTATION

DATA & MC

Tracks' *Cos* θ_{NuMI} for *Data & MC*. This plot is meant to illustrate the fact that *NDOS* did record neutrino events carrying angular information to prove that they came from the *NuMI* beam. The black dots represent *Tracks* with average time outside the *NuMI* time window. The red dots represent *Tracks* with average time inside the *NuMI* time window. The blue dots represent *Tracks* from *MC*. From the in time *Data* it is evident that there is an excess of events with *Cos* $\theta_{NuMI} \approx 1$, which agrees with the trend of the *MC Tracks*. All *Tracks* started inside the *NDOS* 2.0 instrumented volume.

Tracks' average time. This plot is meant to show that *NDOS* saw and excess of events with average time inside the *NuMI* time window.

For both plots, *MC & Data* files (S12-12-12 release) from 13067 to 13199 Runs were used.