Low nu channel study update

Sunwoo Gwon

Chung-Ang University, Seoul, Korea

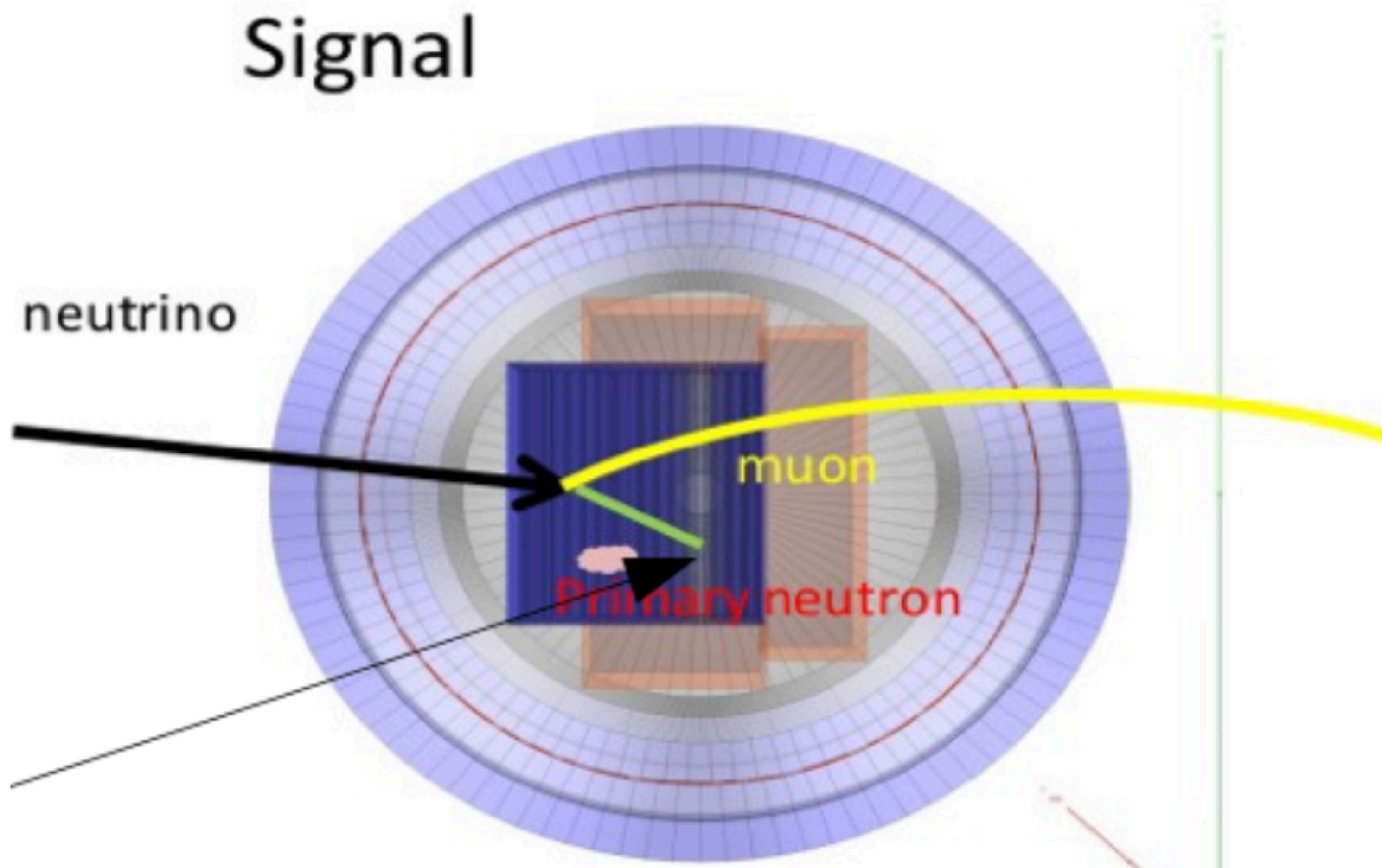
Guang Yang

Stony Brook University, NY, USA

Introduction

- We will use low ν channel to constrain the flux uncertainty due to the relative small uncertainty of low nu cross section.
- A fast version of this work should be done in 2 months (ideally 1 month).
- We have a reconstruction ready by Clark. A more complete description: https://indico.fnal.gov/event/22617/contributions/197701/attachments/135065/167347/software-3dst-tpc-ecal-200924.pdf
- What do we have:
  - reconstructed objects including tracks, clusters, vertices.
  - each object has a list of information such as dedx, track length, energy deposit, position, direction etc.
  - true information are available for each of the reconstructed objects.
- Full simulation chain: GENIE → edep-sim → erep-sim (detector response) → cube reconstruction → higher level analyses
- An event display can be used to understand the reconstructed objects.

Introduction



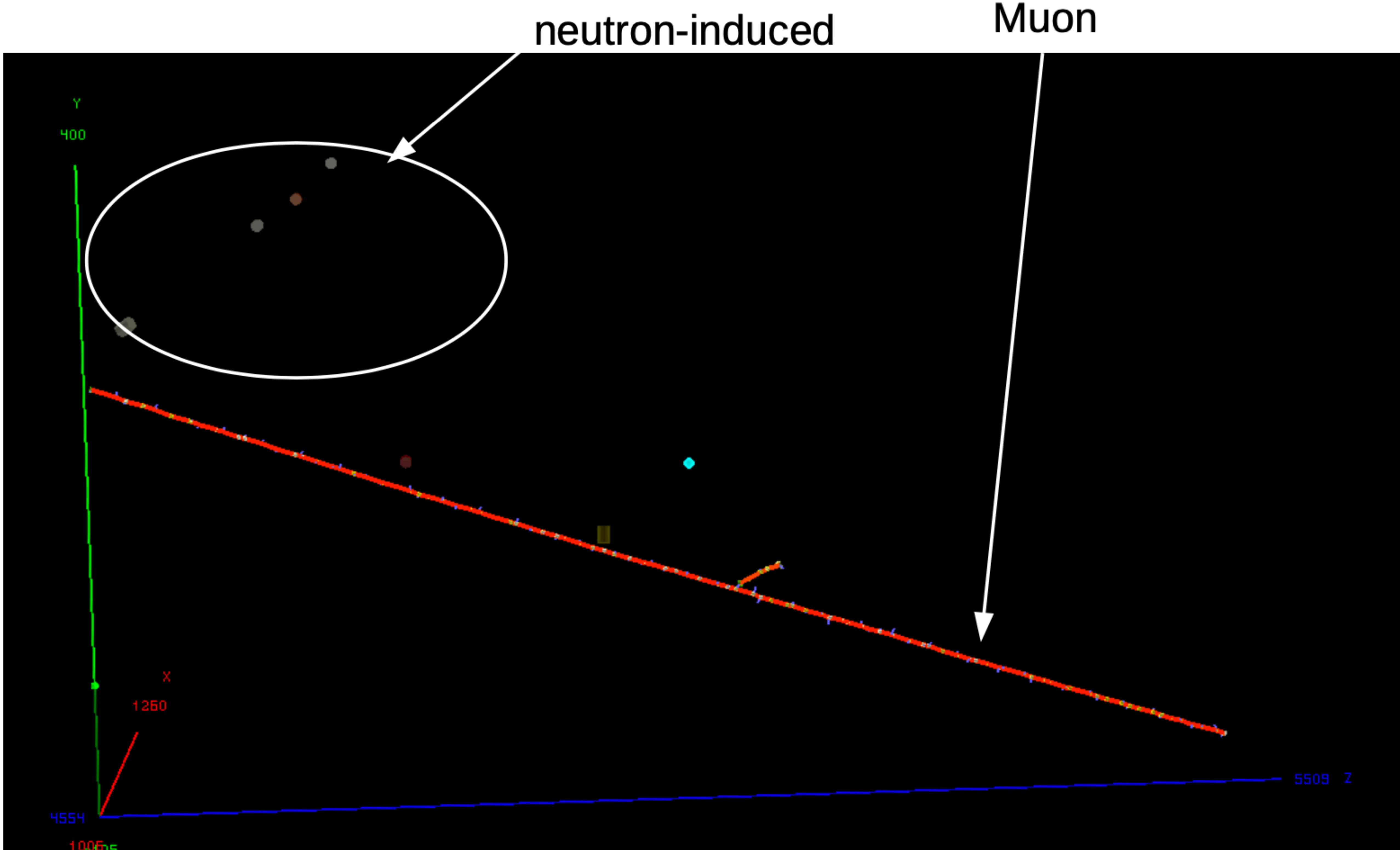
- **We used full reconstruction, we only look at single track events.**

- **Signal is neutron induced isolated object apart from the main muon track (4cm).**

- **For first isolated object**
  - threshold is 20e, sample includes background.
  - we selected cluster.

Neutron-induced signature

Numubar CC

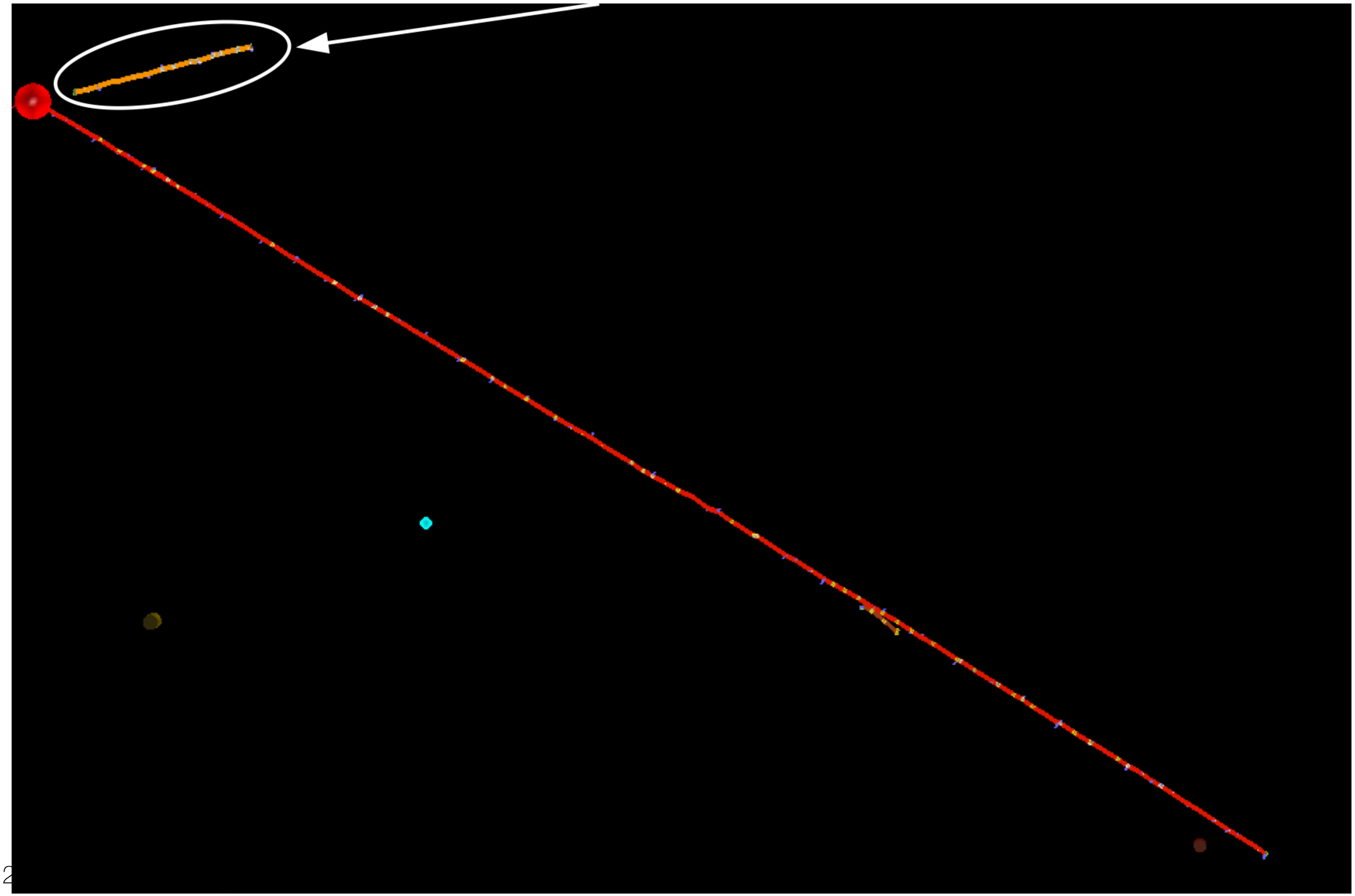


Neutron-induced signature

Numubar CC

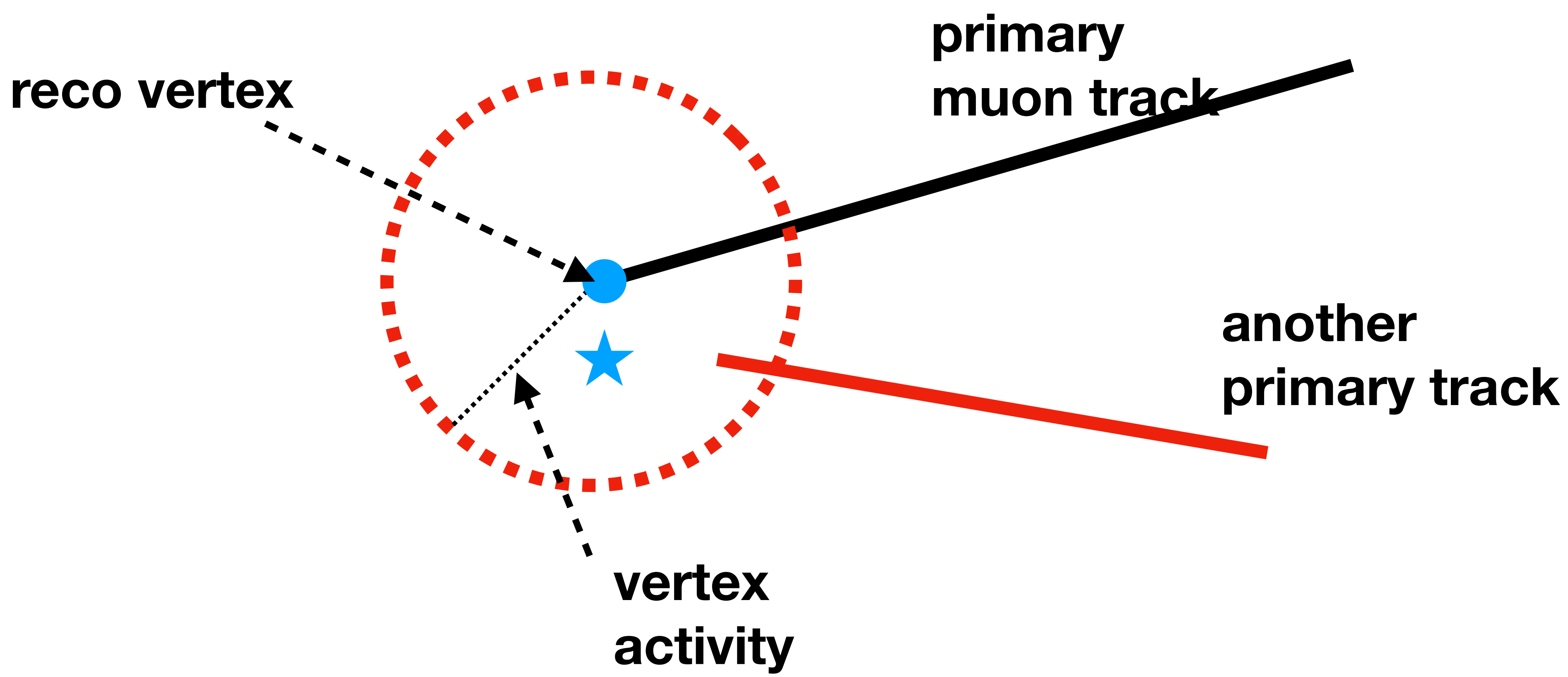
we don’t select these events

neutron-induced



Selection of channel

- **Interaction vertex is the starting point of muon track.**
- **After selecting the vertex, we count how many tracks are inside vertex activity (4cm).**
- **In this analysis, we selected 1 track channel (intended for CC0π).**



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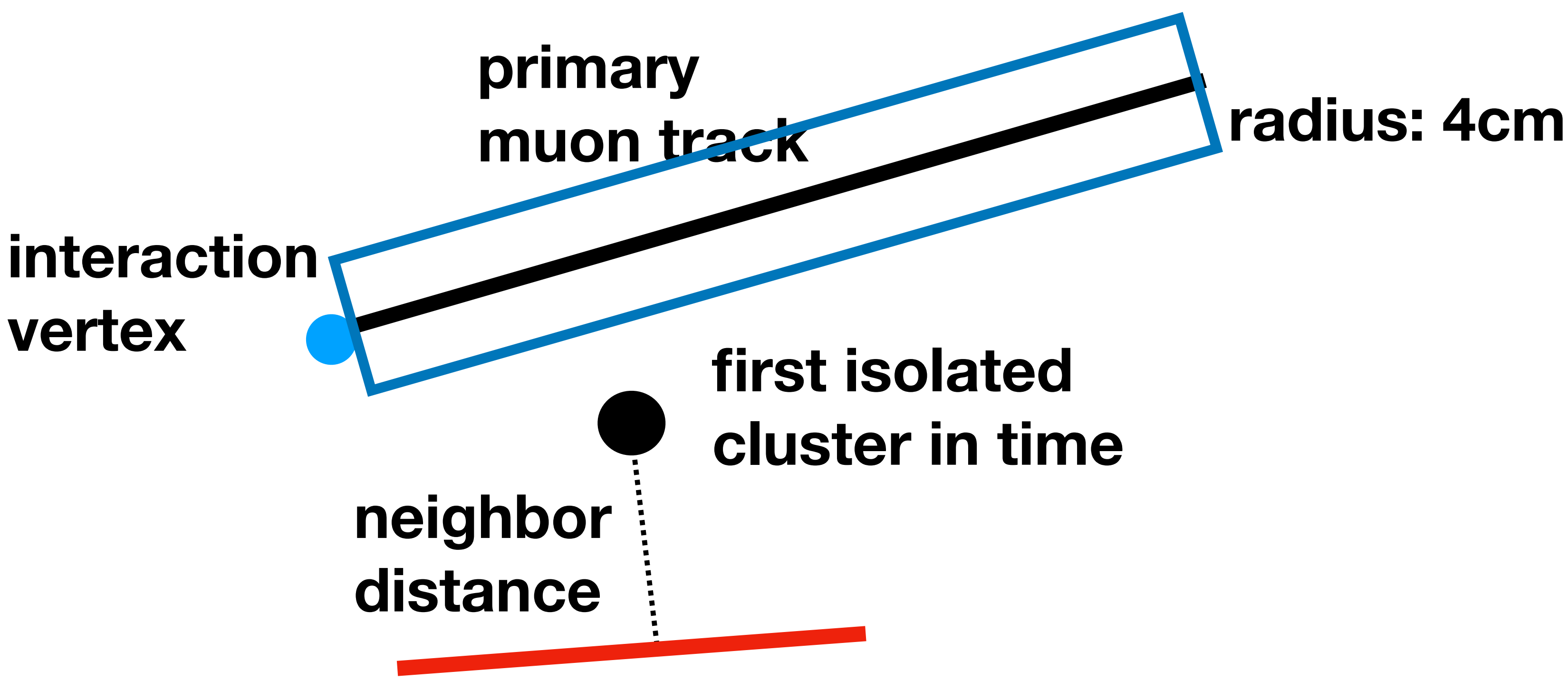
Definition of variable

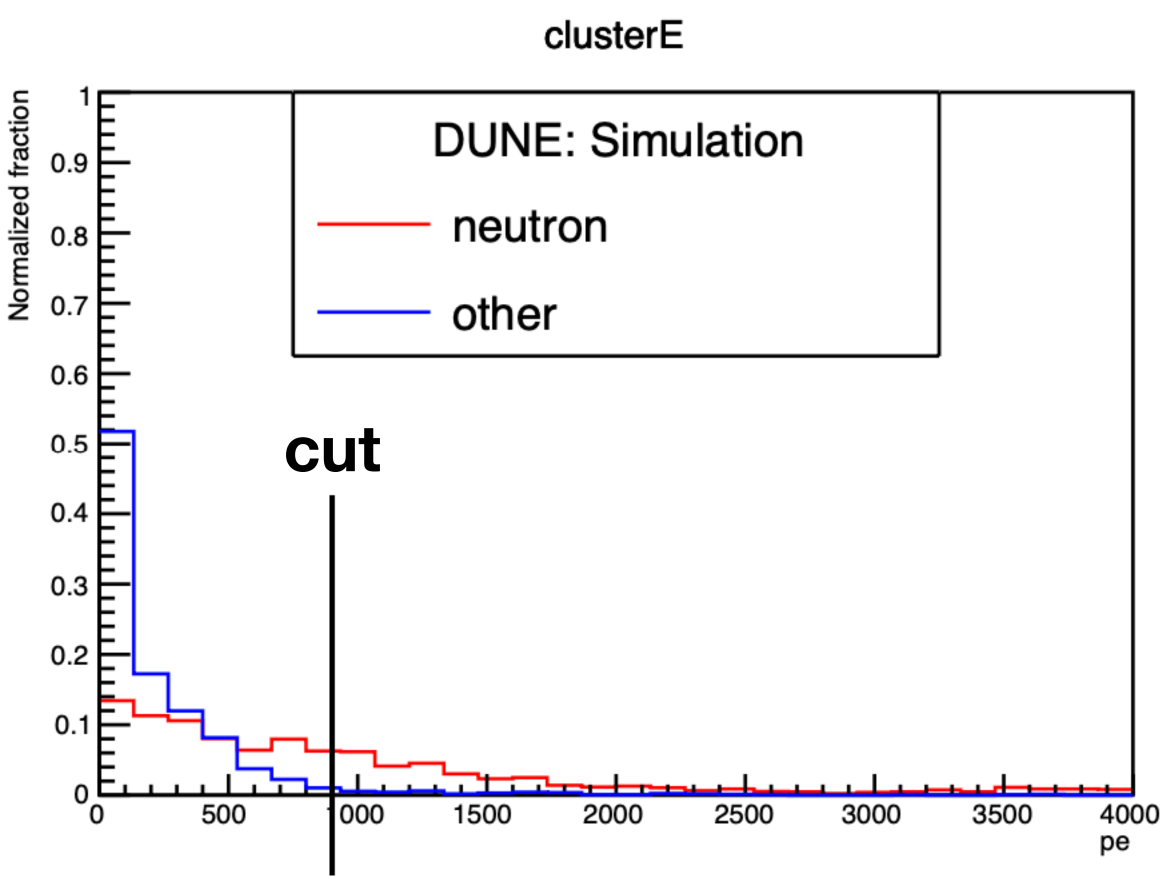
- We look at the first isolated object (either track or cluster) in time and select clusters.

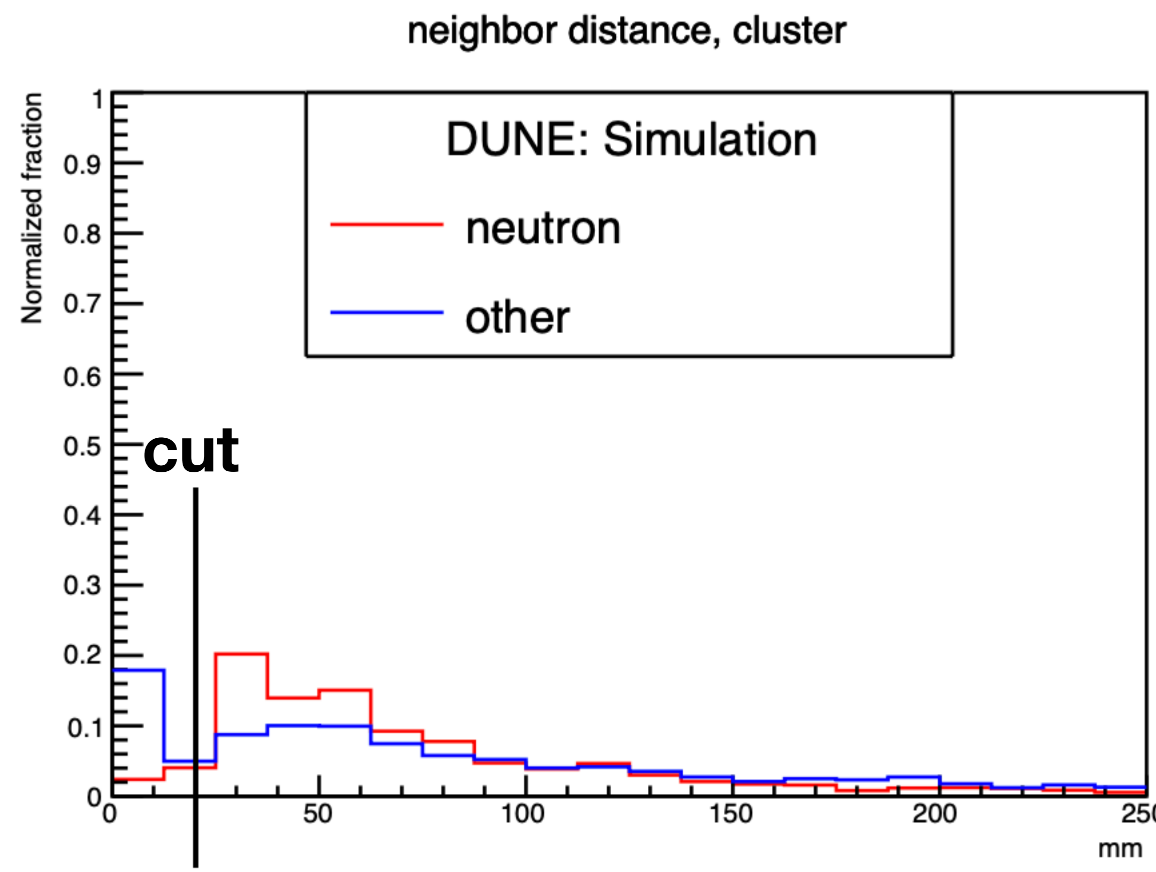
- Isolated object means it has distance > 4cm from muon track.



- We used two variables for sample selection:
  1. clusterE: energy deposited by the cluster.
  2. neighbor distance: closest distance to the neighboring object

Signal sample selection

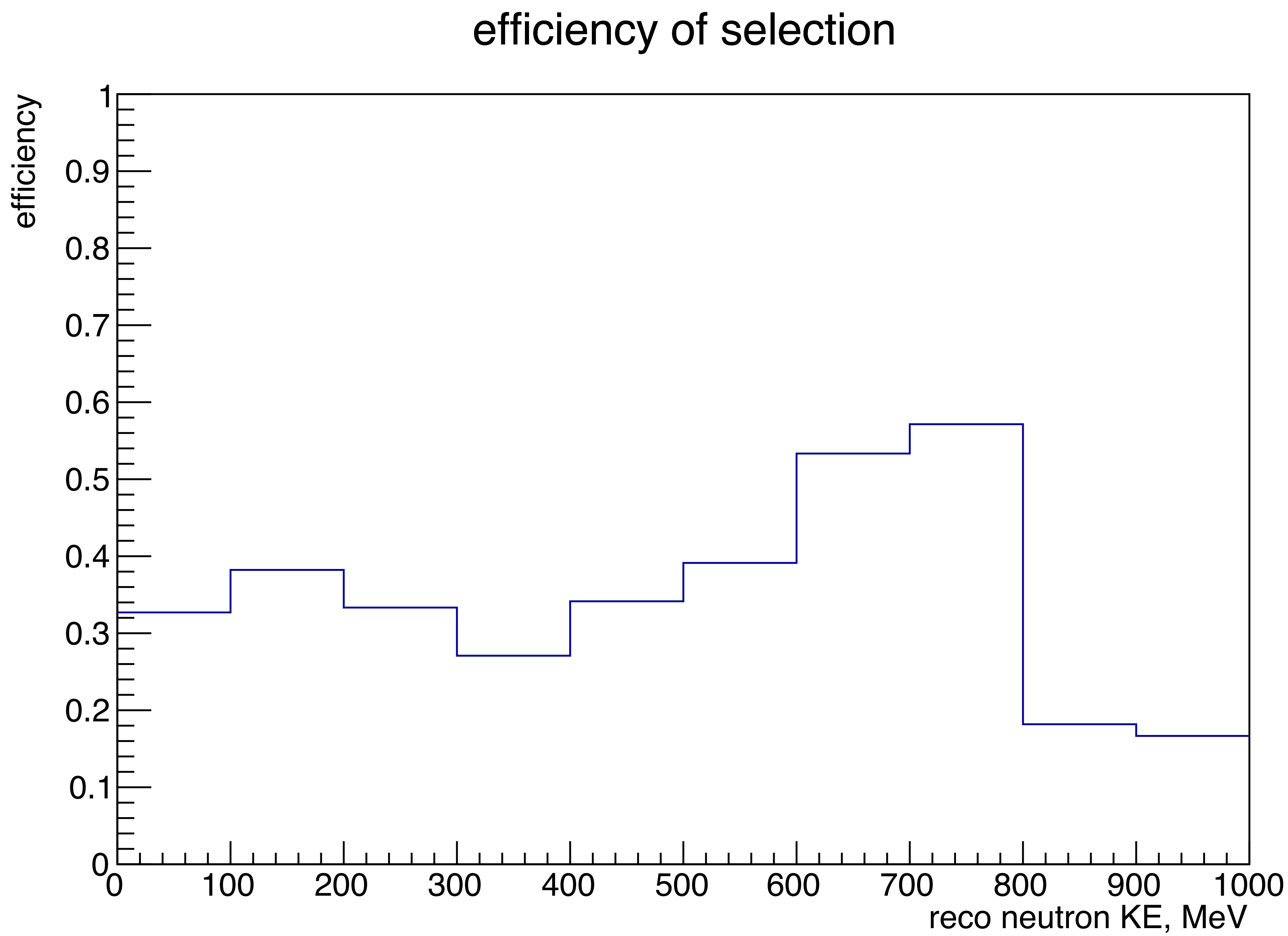




- **We applied combination of simple 2 cuts:**
  ① energy deposit of cluster > 900e (22.5MeV)
  ② neighbor distance > 20mm

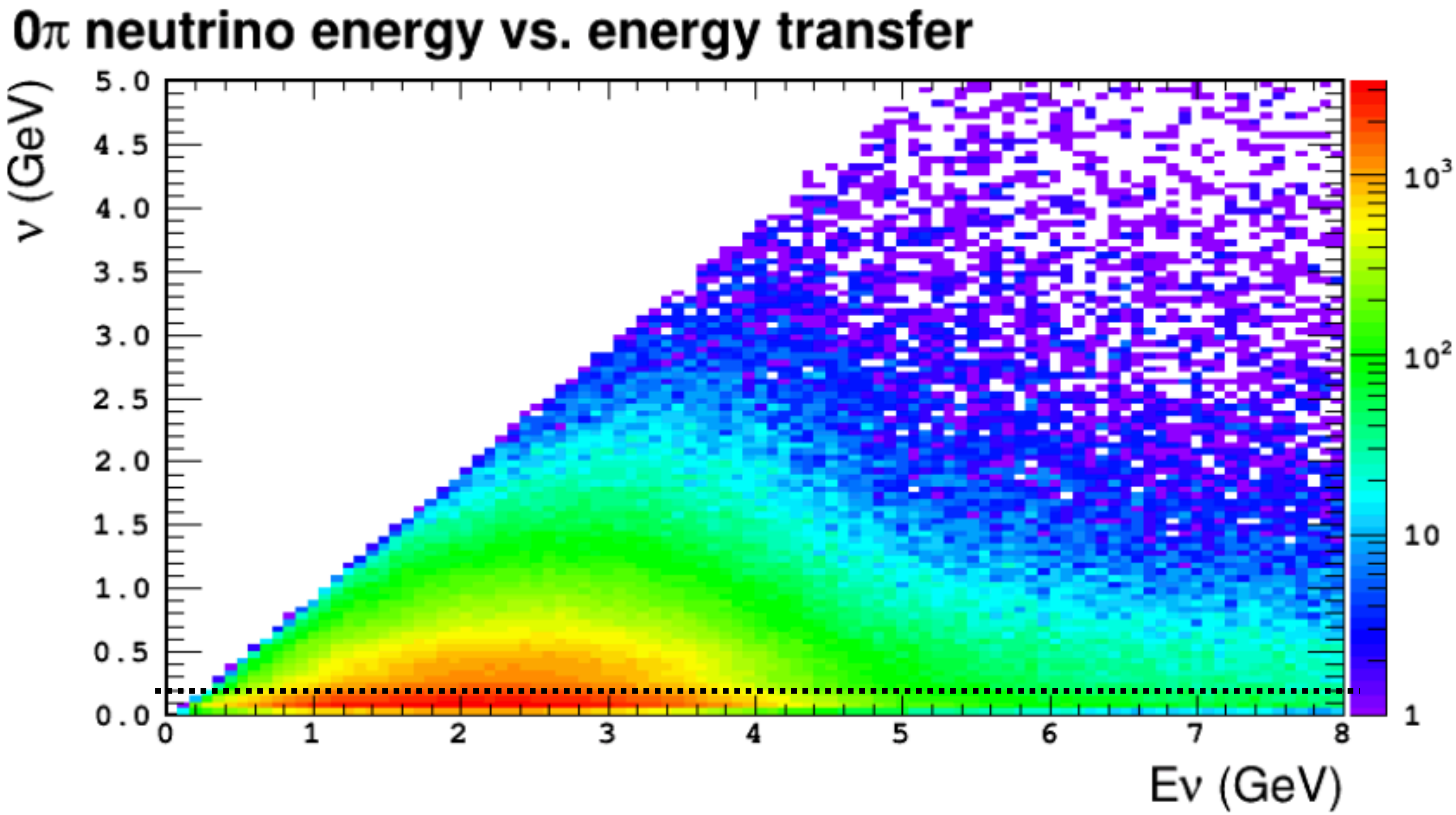
- **The purity after selection is 95% and efficiency is 38%**

Neutron selection efficiency



- **Overall efficiency is 38%**
- **There is no phase space loss in the neutron energy.**

Low ν selection



- **After selection of low ν (ν < 0.2GeV covering entire neutrino spectrum), combined efficiency is 20%**
- **Isolated cluster to track ratio is around 50%**
  → efficiency of selection of cluster low ν sample: 10%

Fitting framework

- We want to see how much selected CC0π low ν sample can constrain the flux uncertainty.

- We have 256 principle component vectors of flux systematic uncertainty from beam line and used the first 10 of them.

- We developed simple χ^2 fitting framework.

- $$\chi^2 = \sum_{i=0}^{N_{E_\nu}} \frac{\left(data_i - \left[p_i(f_0 \ldots f_9) + B\right]\right)^2}{\sigma^2_{i,stat} + \sigma^2_{i,syst}} + \sum_{i=0}^{N_{E_\nu}} \frac{\left(f_{i,CV} - f_i\right)^2}{\sigma_{f_i}} + \frac{(B_{CV} - B)^2}{\sigma_B}$$

  - data : selected CC0π sample, 95% signal + 5% background. (purity: 95%)
  - prediction : with flux systematic uncertainties, 95% (signal $\pm$ Δsignal) + 5% (background $\pm$ Δbackground),
    - $p_i(f_0 \ldots f_9)$: signal prediction with flux systematics (0 ~ 9)
    - B : background prediction, used 100% error
  - σ_{syst} : low ν selection and cross section uncertainties
  - CV : central value

Statistics of selected sample

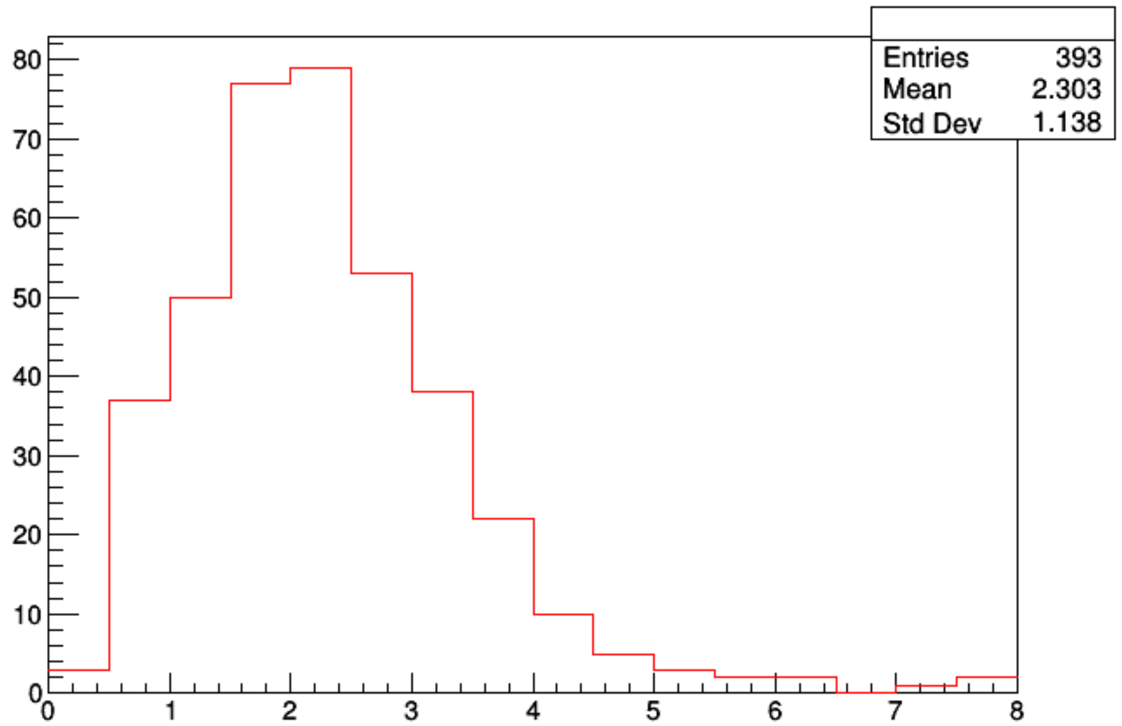
Table 5.1: Projected event rates per year for the 3DST detector, assuming the 120 GeV, three horn, optimized Long-Baseline Neutrino Facility (LBNF) beam. The rates correspond to a fiducial volume of 11.0 tons.

FHC Beam Process	Rate	RHC Beam Process	Rate
All ν_μ-CC	1.5×10^7	All $\bar{\nu}_\mu$-CC	5.5×10^6
CC 0π	4.4×10^6	CC 0π	2.4×10^6
CC $1\pi^\pm$	4.3×10^6	CC $1\pi^\pm$	1.6×10^6
CC $1\pi^0$	1.3×10^6	CC $1\pi^0$	5.4×10^5
CC 2π	1.9×10^6	CC 2π	5.1×10^5
CC 3π	8.3×10^5	CC 3π	1.6×10^5
CC other	1.9×10^6	CC other	3.0×10^5
ν_μ-CC COH π^+	1.3×10^5	$\bar{\nu}_\mu$-CC COH π^-	1.1×10^5
$\bar{\nu}_\mu$-CC COH π^-	1.2×10^4	ν_μ-CC COH π^+	1.6×10^4
ν_μ-CC ($E_{\text{had}} < 250$ MeV)	2.4×10^6	$\bar{\nu}_\mu$-CC ($E_{\text{had}} < 250$ MeV)	1.9×10^6
All $\bar{\nu}_\mu$-CC	7.1×10^5	All ν_μ-CC	2.3×10^6
All NC	5.3×10^6	All NC	2.9×10^6
All $\nu_e + \bar{\nu}_e$-CC	2.6×10^5	All $\bar{\nu}_e + \nu_e$-CC	1.7×10^5
$\nu\ e \to \nu\ e$	2.0×10^3	$\nu\ e \to \nu\ e$	1.1×10^3

3DST event rates, CDR

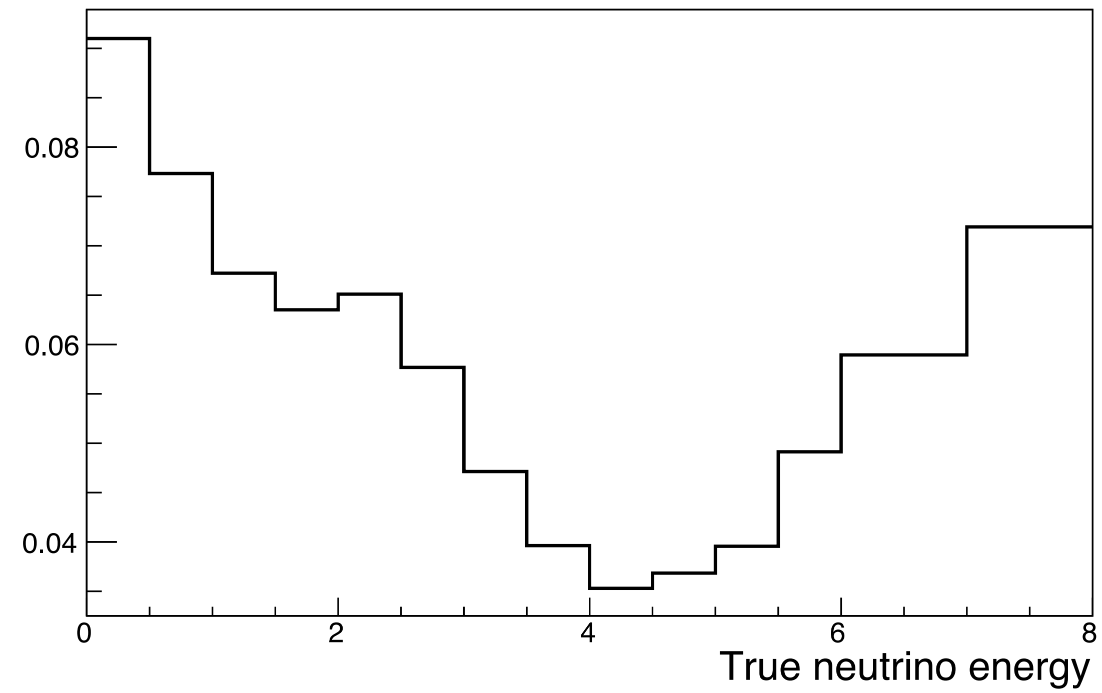
- **Number of anti neutrino CC0π event per year for 3DST is 2.4×10^6**
- **We assume that number of selected CC0π low ν event per year will be around 2.4×10^5 after selection (efficiency: 10%).**

validation of framework

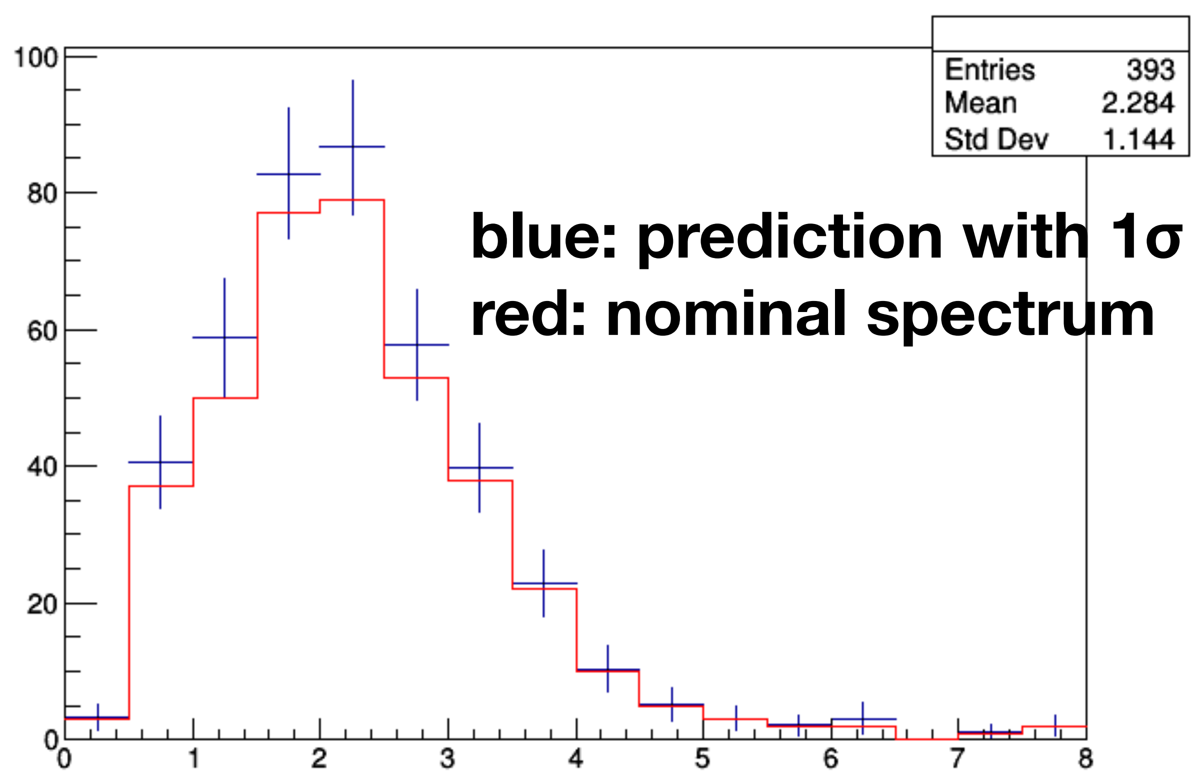


nominal reco E_ν spectrum

+



biggest flux systematic 1σ shift



blue: prediction with 1σ shift of the flux uncertainty
red: nominal spectrum

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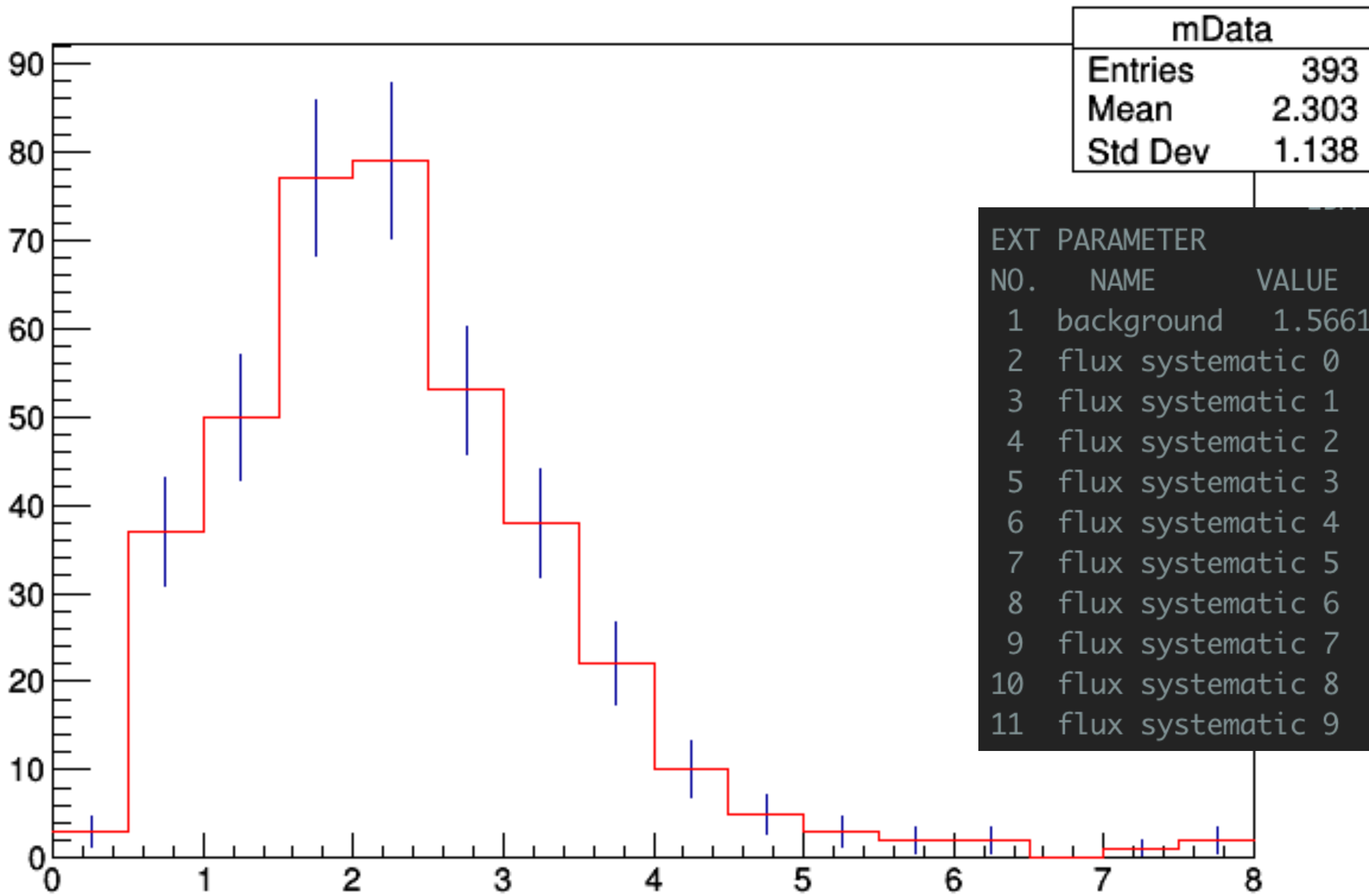
Post fit result



EXT NO.	PARAMETER NAME	VALUE	ERROR	STEP SIZE	FIRST DERIVATIVE
1	background	1.56615e-08	4.33146e-02	1.64026e-07	3.75997e-04
2	flux systematic 0	2.90454e-07	3.26964e-01	1.78604e-07	-2.16577e-04
3	flux systematic 1	-4.43380e-07	3.49190e-01	1.02405e-06	-2.73927e-04
4	flux systematic 2	1.68946e-06	8.71071e-01	6.11504e-07	4.79617e-04
5	flux systematic 3	5.61754e-07	8.76980e-01	4.47822e-07	-5.75719e-05
6	flux systematic 4	8.95475e-08	6.43891e-01	6.19389e-07	-1.94327e-04
7	flux systematic 5	-8.03594e-07	8.48887e-01	2.72966e-06	-1.35971e-04
8	flux systematic 6	-7.85036e-07	6.16075e-01	6.71967e-07	-2.76191e-04
9	flux systematic 7	1.66014e-07	9.73302e-01	2.48139e-06	6.78212e-05
10	flux systematic 8	-2.62349e-07	7.97392e-01	1.78478e-06	-6.78800e-05
11	flux systematic 9	-1.54272e-06	7.68824e-01	9.74488e-07	-2.50480e-04

- **The red line is nominal spectrum and the blue one is post fit.**
- **They are exactly the same.**
  → Fitting frame behaves as expected.
- **Fractional error of the biggest flux uncertainty is 0.35**
  → selected low ν sample can constrain the biggest syst to 1/3

Summary

- We selected CC0π low ν sample based on reconstructed information.
- Fast χ^2 fitting framework has been developed and it can be used to produce the flux constrain by the low nu channel in 1 month scale.
- As a next step, we plan to implement low ν cross section uncertainty.