BEAM MONITORING WITH SAND

via the comparison of the distribution of an observable sensitive to beam anomalies

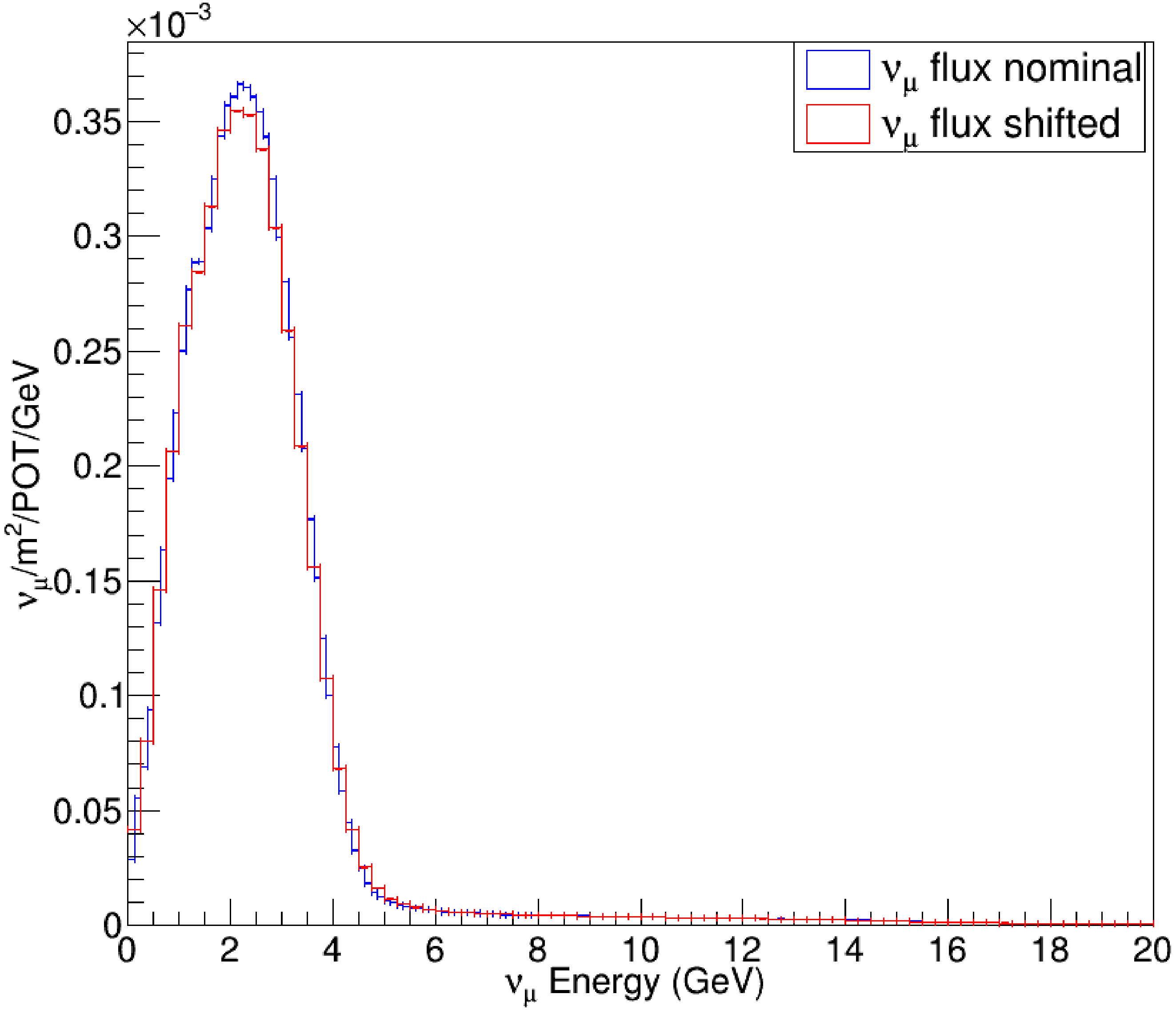
Observable: reconstructed muon momentum

- My thesis studied the beam monitoring capabilities of the SAND detector, ~~via neutrino flux and detector simulations~~
- ~~We compared the reconstructed muon momentum spectra in CC muon neutrino interactions produced with reference beam configuration in a week, with the one produced on the same time span by a displacement of Y +0.5 mm of the first beam horn.~~
- ~~We used a χ^2 two-sample test to distinguish between the two samples~~

bullet: first systematic under study: horn-1 0.5 mm Y shift

test statistic: chi2

SIMULATED SAMPLES



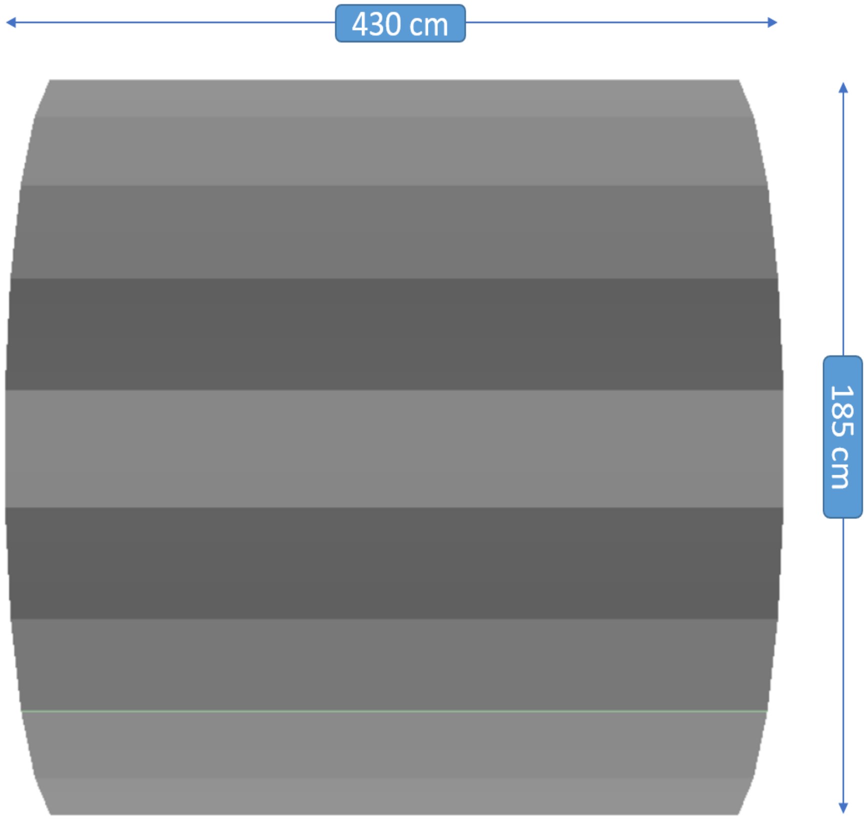
Simulated samples from :

- Nominal neutrino flux
- Shifted neutrino flux
  (Y +0.5mm in the first beam horn)

Note : Histograms retrieved from https://home.fnal.gov/~ljf26/DUNEFluxes

TARGET: FRONT CALORIMETERS

target:



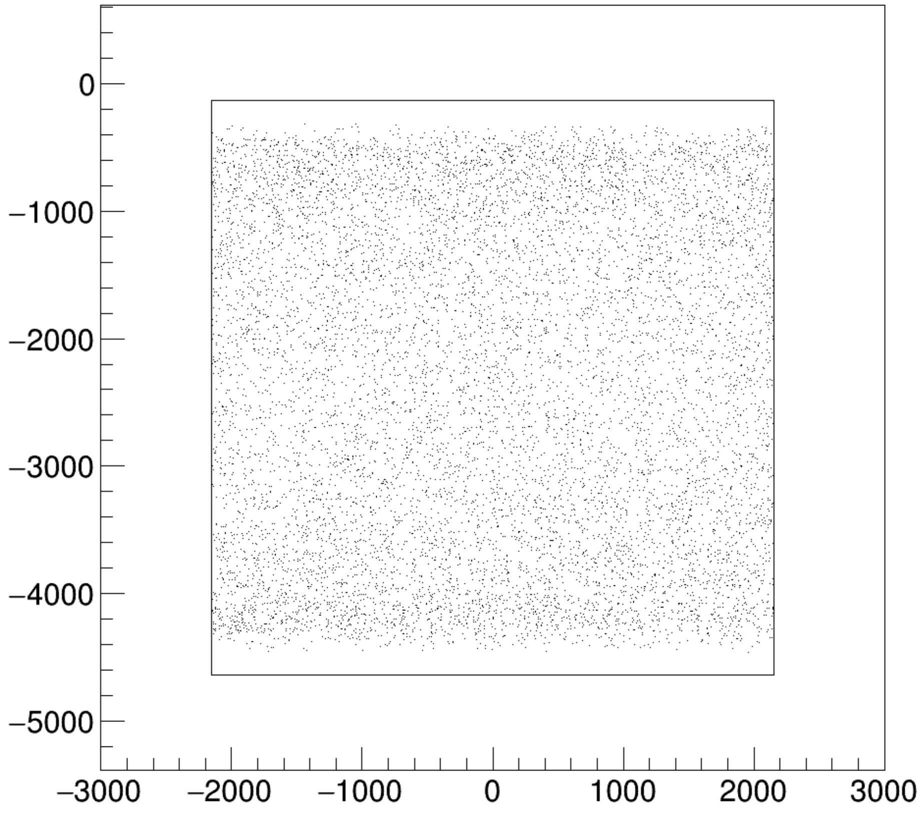
- *Dunendggd* simulated geometry
- 9 front calorimeter barrel modules

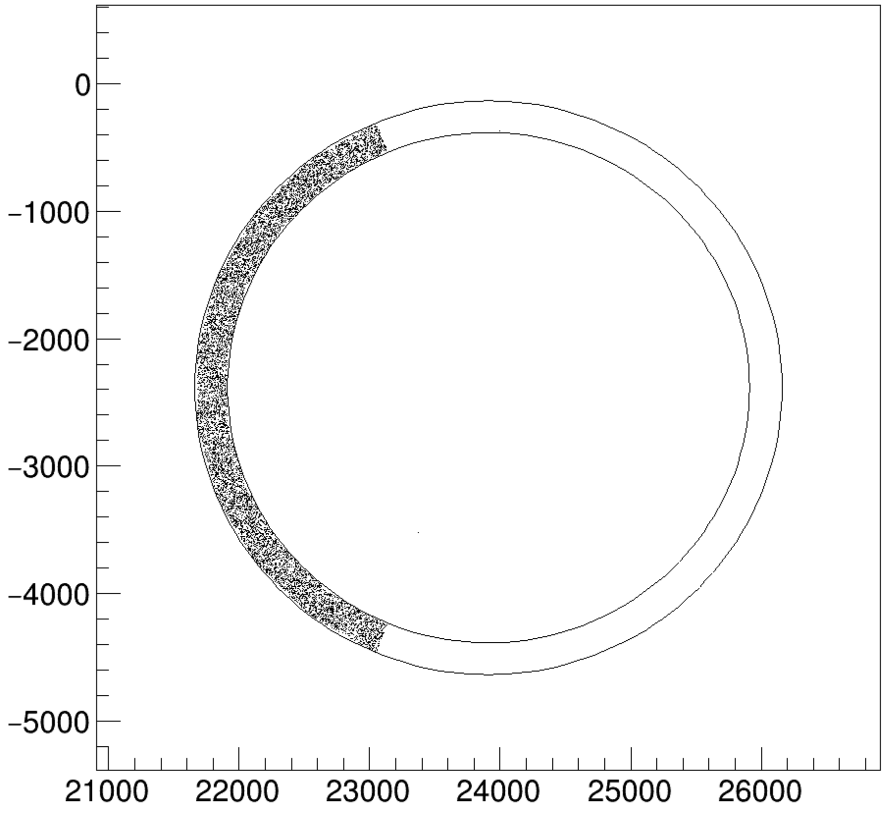
metti anche i numeri

$$N_{week} = r_{CC} \times f_{CC}^{-1} \times m_{mod} \times n_{mod} \simeq 1.74 \times 10^{6}$$

One week's worth of statistics

TARGET: FRONT CALORIMETERS



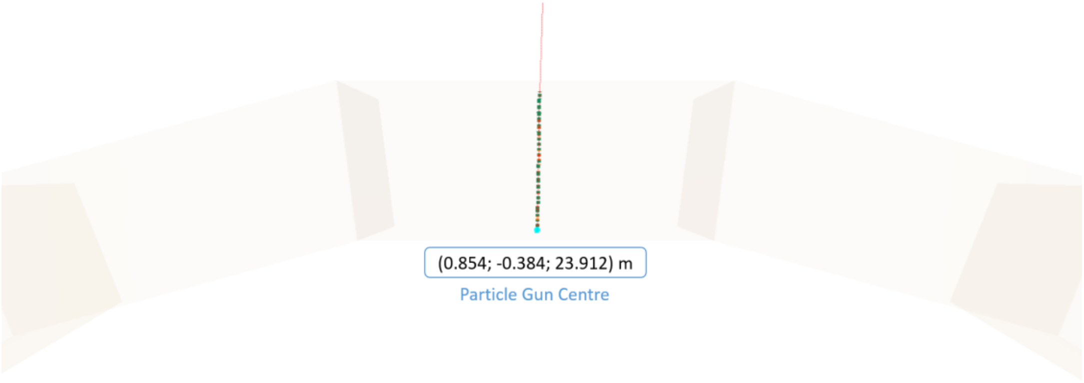


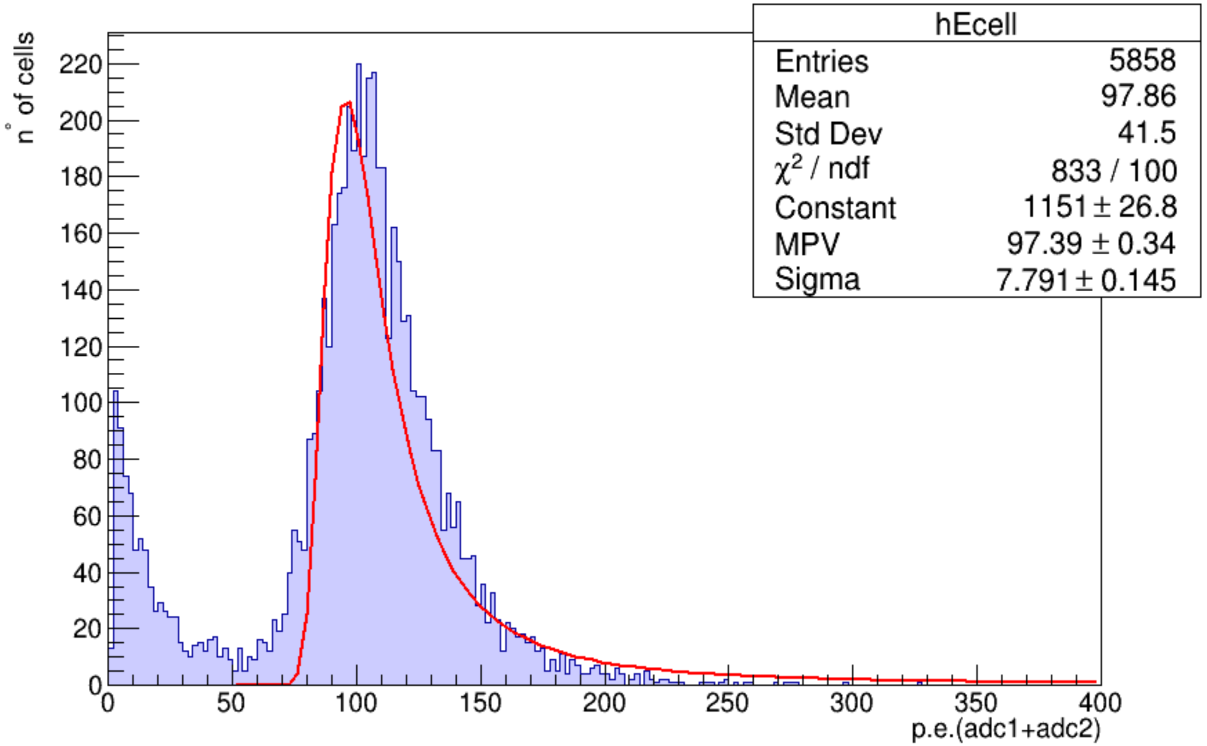
- Interaction vertex distributions on the *xy* and *yz* planes

$$N_{week} = r_{CC} \times f_{CC}^{-1} \times m_{mod} \times n_{mod} \simeq 1.74 \times 10^6$$

One week's worth of statistics

PRELIMINARY MEASUREMENT: LIGHT YIELD





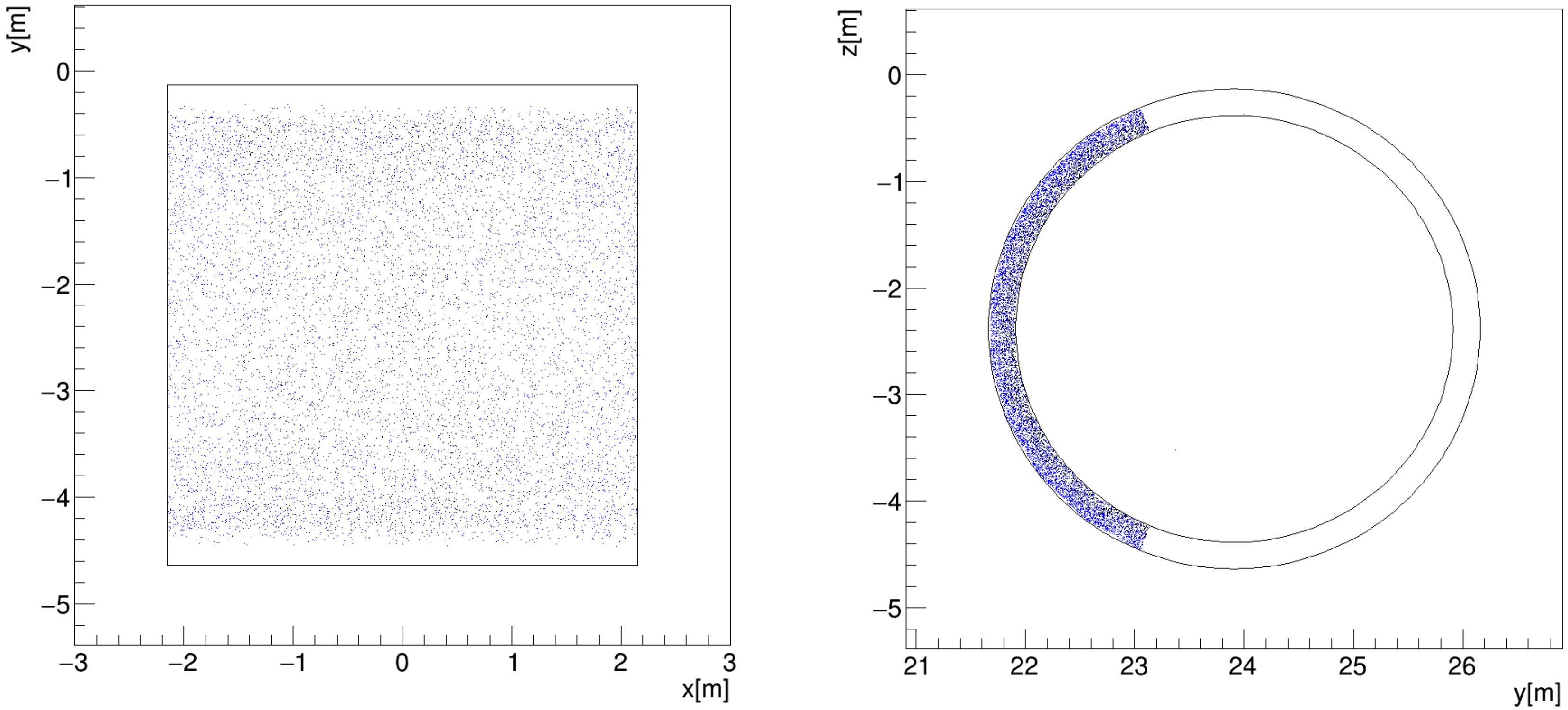
- Simulated 1000 muons at 10 GeV passing through an e.m. calo barrel module

$$\Delta E_{cell} \simeq \left(\frac{dE}{dx}\right)^{MIP} \rho_{Pb}\Delta x_{Pb} + \left(\frac{dE}{dx}\right)^{MIP} \rho_{Sc}\Delta x_{Sc} \simeq 42.22 \text{ MeV}$$

$$N^{cell}_{p.e.} = (97.4 \pm 0.3) \text{ p.e.}$$

$$c = \frac{N^{cell}_{p.e.}}{\Delta E_{cell}} \simeq 2.31 \text{ [p.e./MeV]}$$

FIDUCIAL CUT



Spatial distribution in ND hall global coordinates of the true neutrino interaction vertexes of the events that survive the outer layer cut (black) and those that don't (blue).

selected

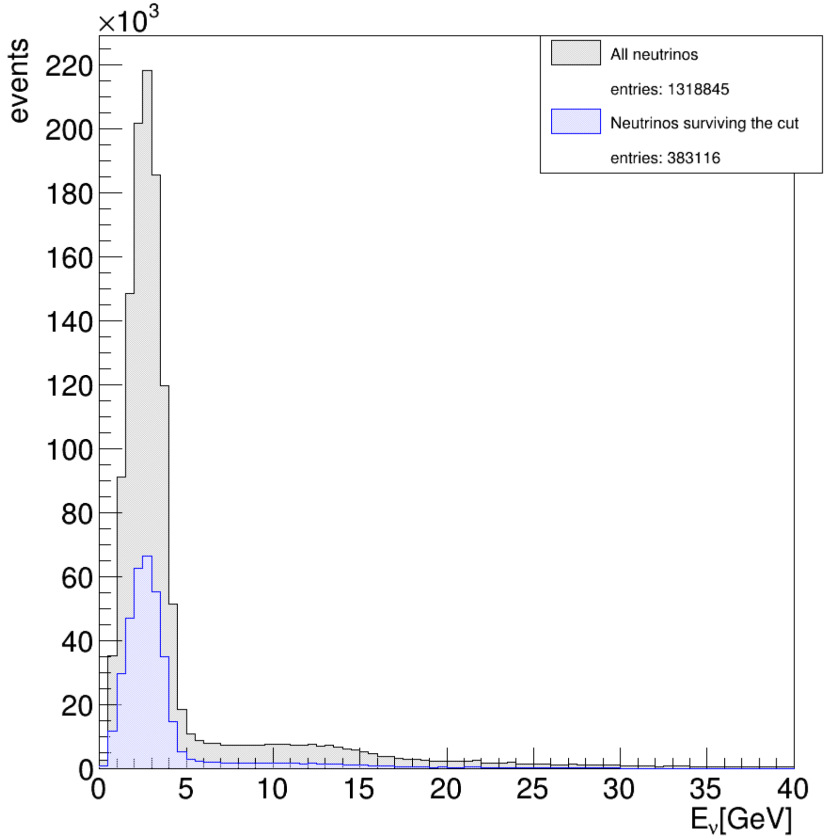
- Threshold on the energy deposition on the outer layer (E < 15MeV):

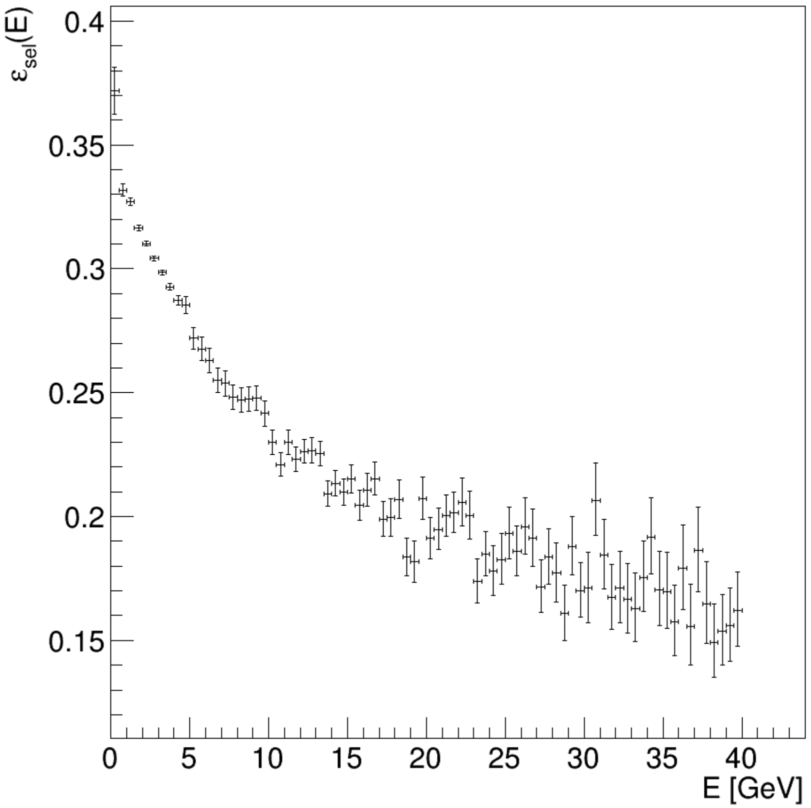
$$N_{p.e.}^{th} = c \times \Delta E_{th} \simeq 35 \text{ p.e.}$$

- X vertex, estimated as a weighted average on the energy deposition on the cells, is selcted as:

$$|x_V| \leq 1.5 \text{ m}$$

FIDUCIAL CUT





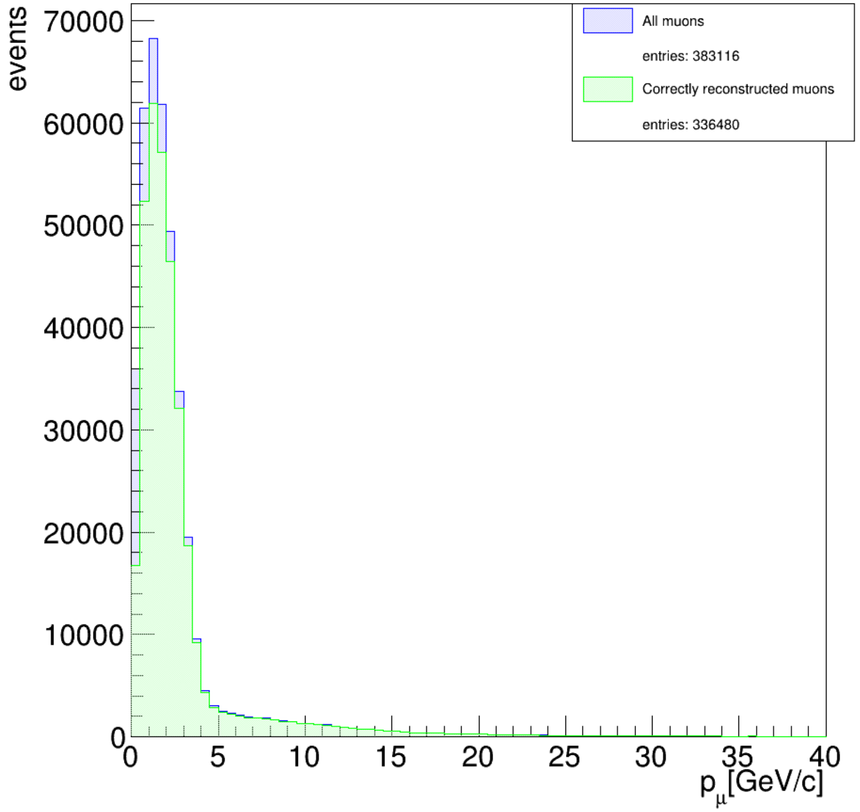
- Selection efficiency:

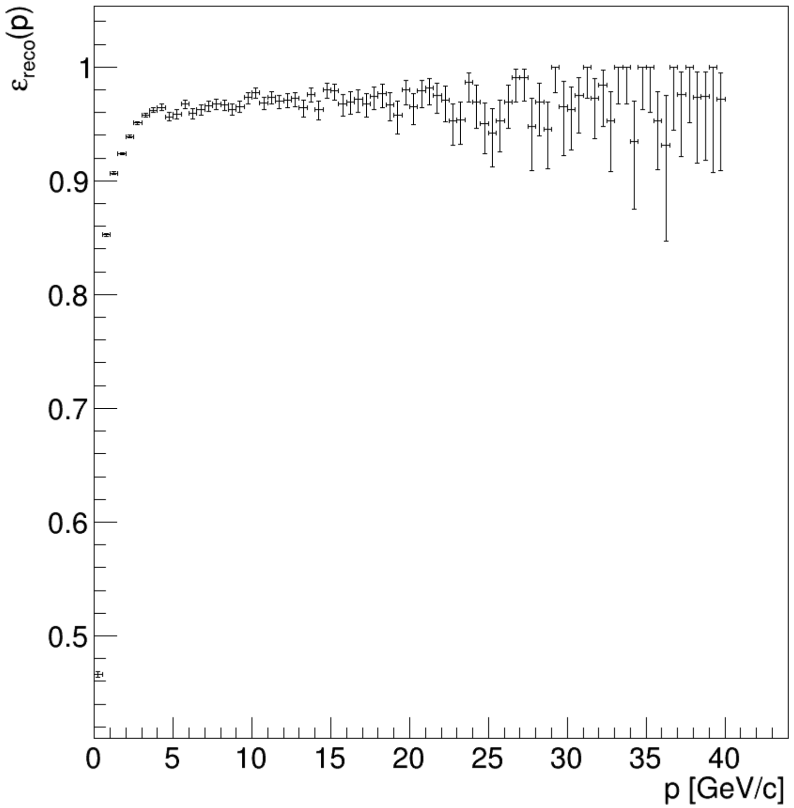
$$\varepsilon_{cut} = \frac{N_{fid}}{N_{CC}} = 0.2905 \pm 0.0004$$

Note: efficiency decreases at higher energy; might be due to nuclei fragmentation in DIS

(*Left*) Energy (Monte Carlo truth) distribution of neutrinos from the CC nominal sample (grey); distribution surviving the fiducial cut (blue).
(*Right*) Selection efficiency as a function of neutrino energy from the Monte Carlo truth.

MOMENTUM RECONSTRUCTION SELECTION





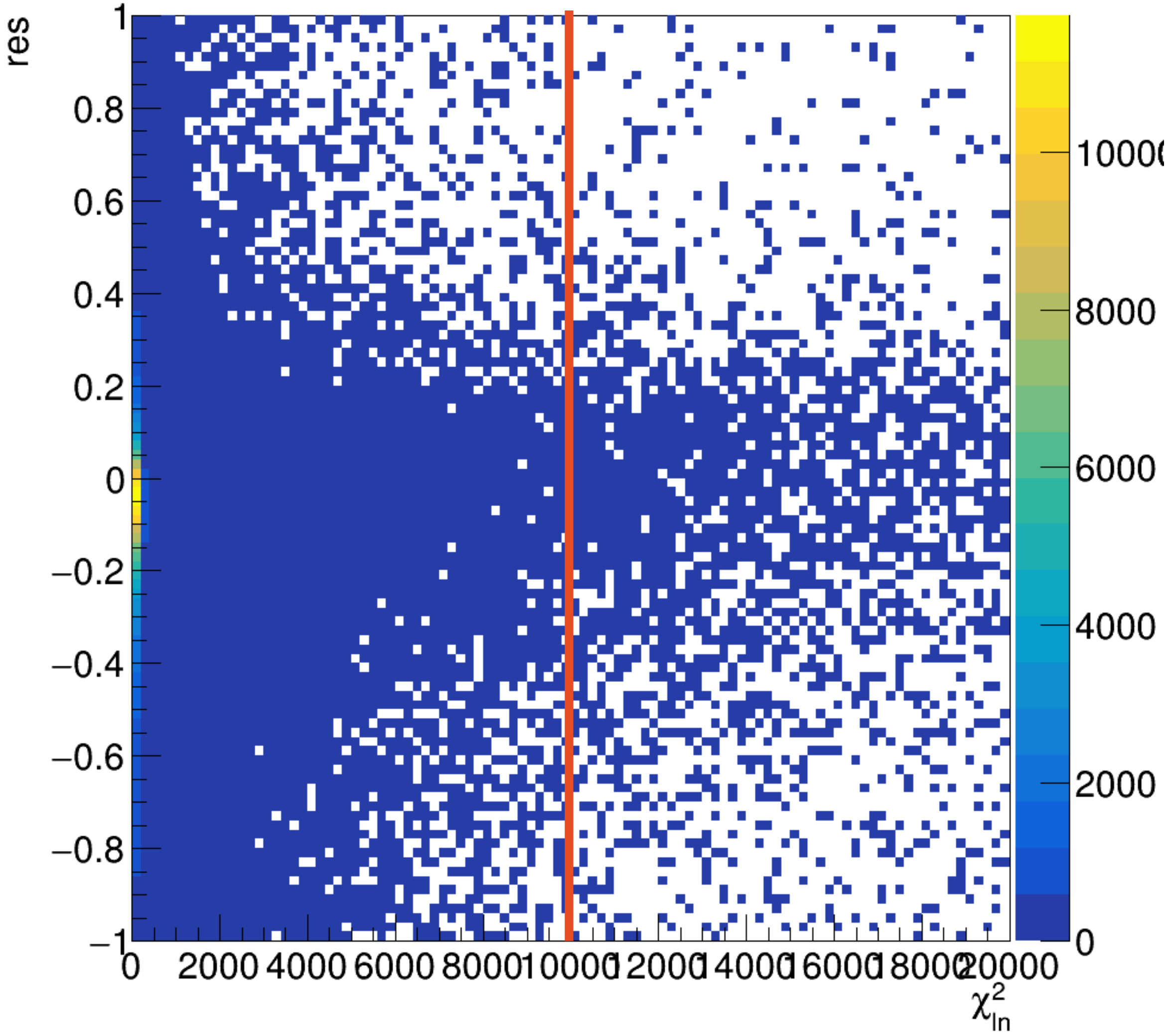
- Momentum reconstruction efficiency:

$$\varepsilon_{reco} = \frac{N_{reco}}{N_{fid}} = 0.9168 \pm 0.0004$$

(*Left*) Distributions of the true Monte Carlo momenta of the muons from the fiducial sample (blue) and only the ones correctly reconstructed (green).
(*Right*) Reconstruction algorithm efficiency as a function of the true Monte Carlo muon momentum

MOMENTUM RECONSTRUCTION QUALITY SELECTION

cambia taglio, grafico e formule



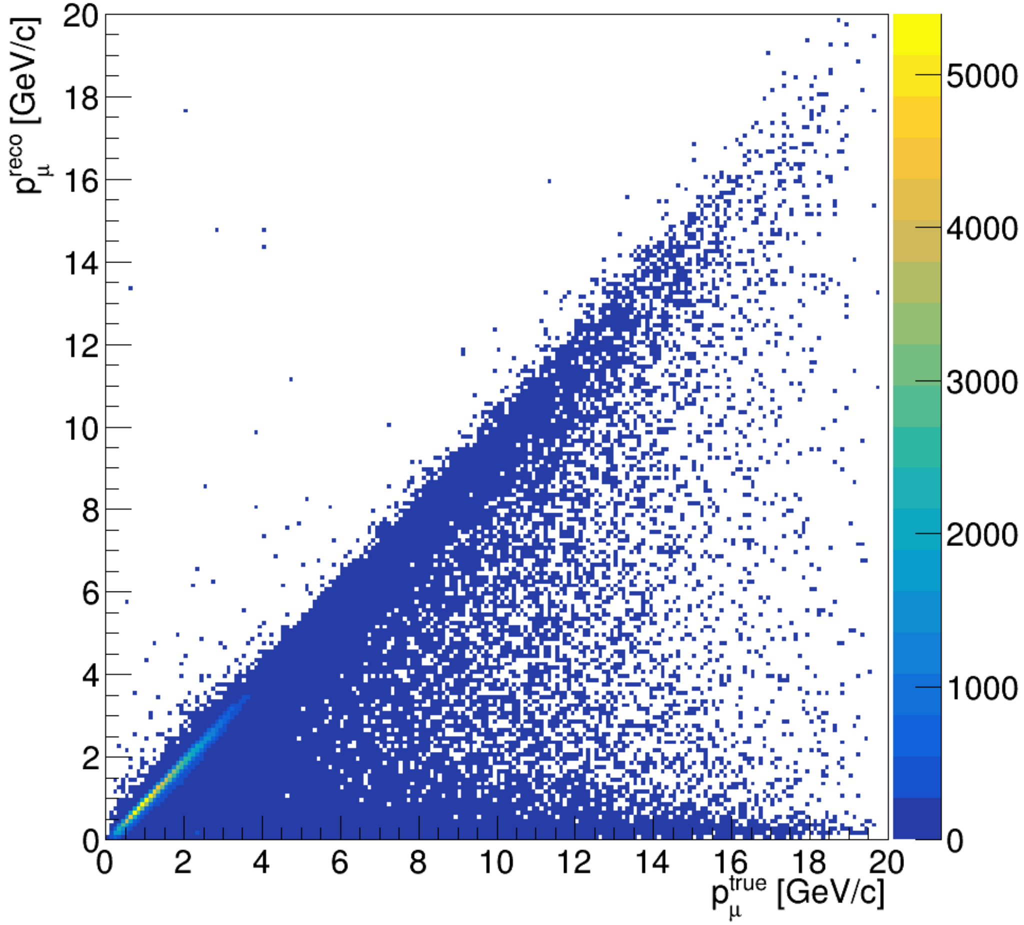
$$\chi^2_{ln} = \frac{1}{N_{hits}} \sum_{i=1}^{N_{hits}} (x_i - x_0 - \rho_i \tan\lambda)^2$$

$$res = 1 - p_\mu^{true} / p_\mu^{reco}$$

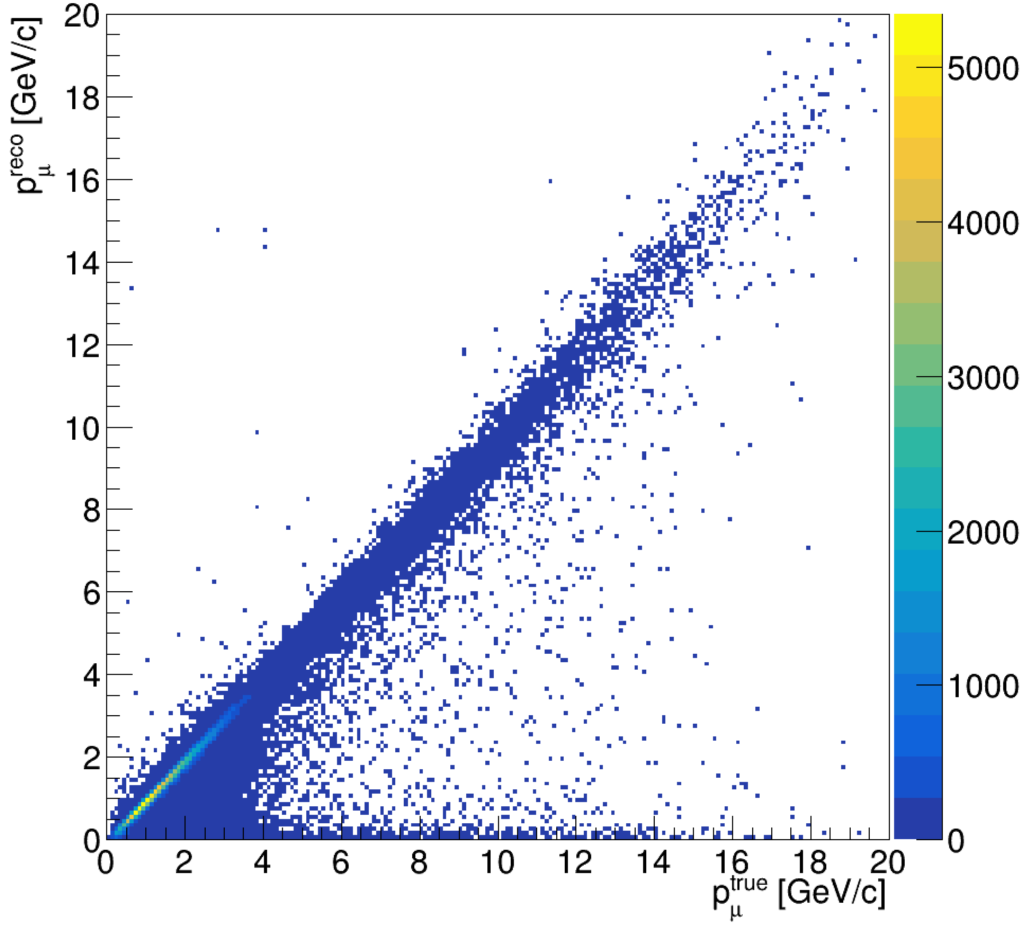
$$\chi^2_{ln} < 10^5$$

$$\varepsilon_{qual} = \frac{N_{qual}}{N_{reco}} = 0.9290 \pm 0.0004$$

MOMENTUM RECONSTRUCTION QUALITY SELECTION



BEFORE CUT



AFTER CUT

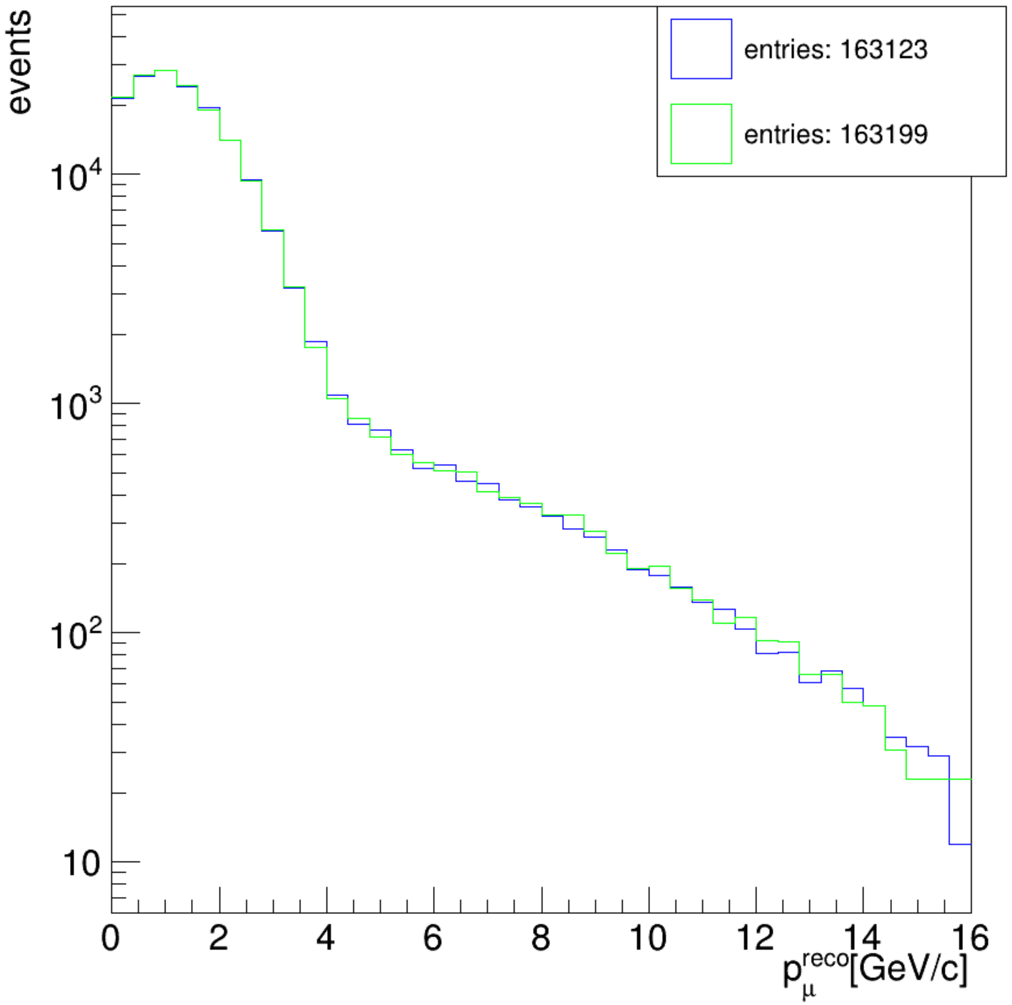
CHI-SQUARED TWO-SAMPLE TEST STATISTICS

- ~~We use a chi-squared two-sample test to distinguish between the reconstructed momenta distribution histograms of the “nominal” and “shifted” sample~~:

$$\boxed{T = \sum_{i=1}^{k} \frac{(u_i - v_i)^2}{u_i + v_i}}$$

- Where k is the number of bins in the histograms and u and v are their contents
- T approximately follows a chi-squared distribution ~~as long as the sample is big enough that the bin contents are distributed following Poisson.~~

CONTROL ANALYSIS: TWO NOMINAL SAMPES



equal

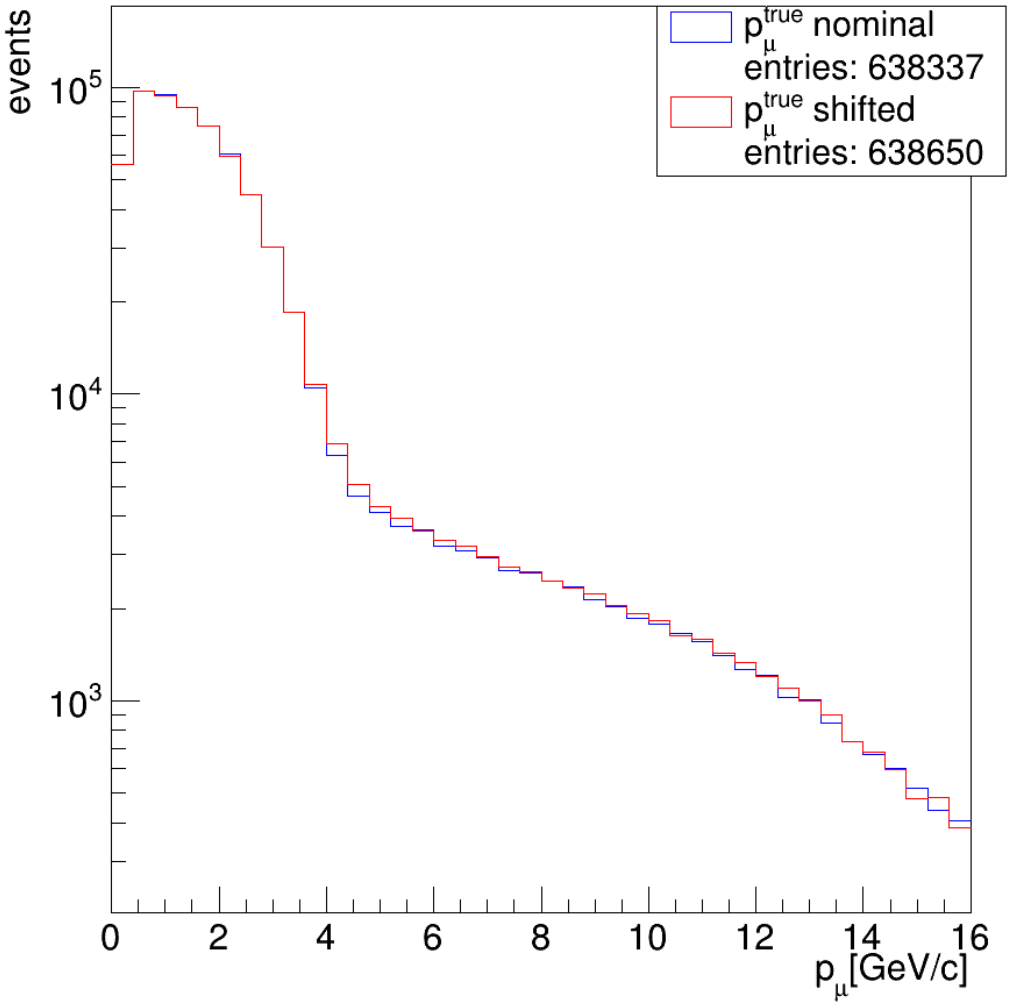
(~ 0.8M events)

- We apply the T to ~~the reconstructed momenta from~~ two nominal samples.
- ~~The fiducial and first reconstruction selection are applied~~
- ~~If the method is capable of distinguishing between the products of two different neutrino beam configurations, we expect to obtain a p-value for two control samples that follow the same distribution that is close to 1:~~

$$p_{control} = 0.527; \quad \sigma_{control} = 0.633 \ (\chi^2)$$

CONTROL ANALYSIS: IDEAL SELECTION

events whose true interaction position was in the fiducial volume

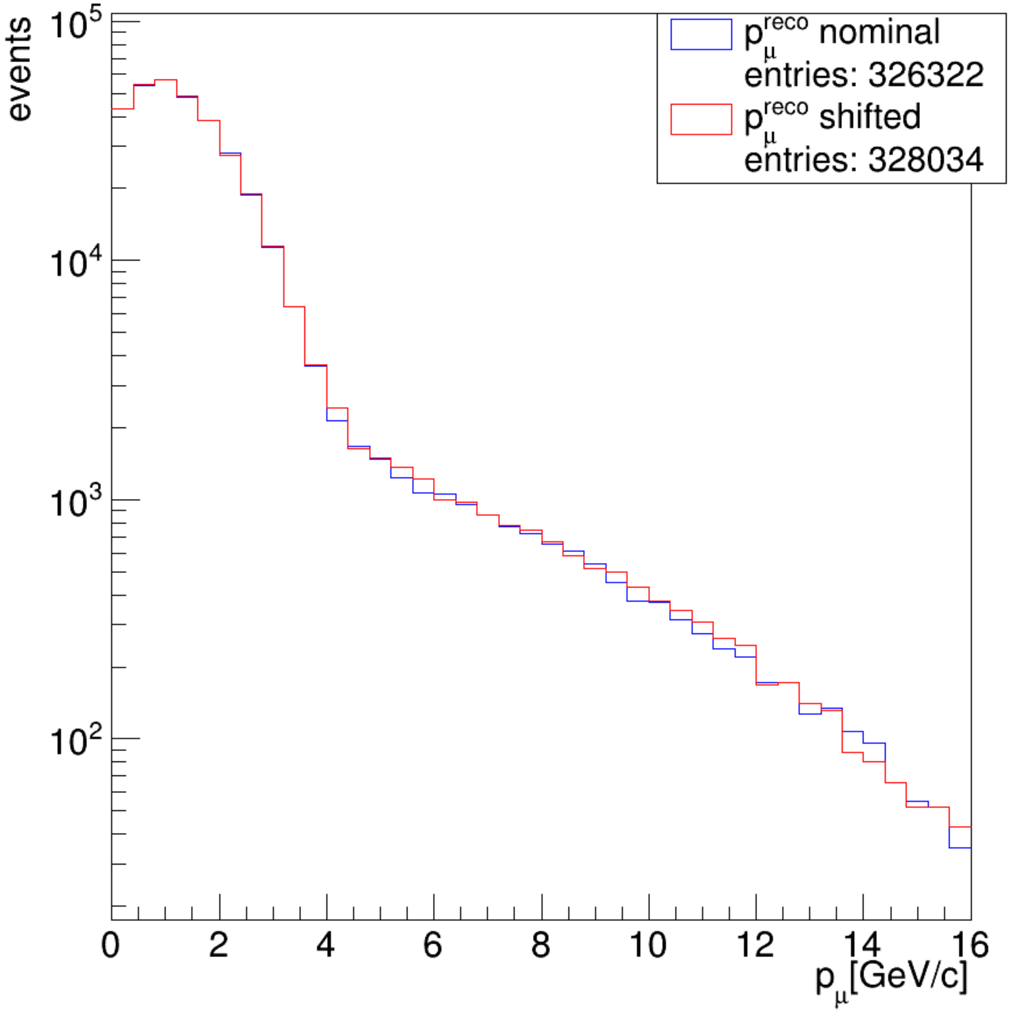


- We applied *T* the test to the true Monte Carlo momenta from the nominal and shifted samples.
- A fiducial cut was applied by selecting only ~~the CC events whose interactions were not on the outer layer of the calorimeter and for which the vertex true x coordinate was <1.5 m~~
- This was done in order to gauge what the best possible p-value (i.e. the smallest and most decisive) might be:

$$p_{truth} = 5.15 \times 10^{-7}; \qquad \sigma_{truth} = 5.02\ (\chi^2)$$

Note: in principle no p-value should be smaller than p_{truth}

RESULTS: FIDUCIAL + RECONSTRUCTION

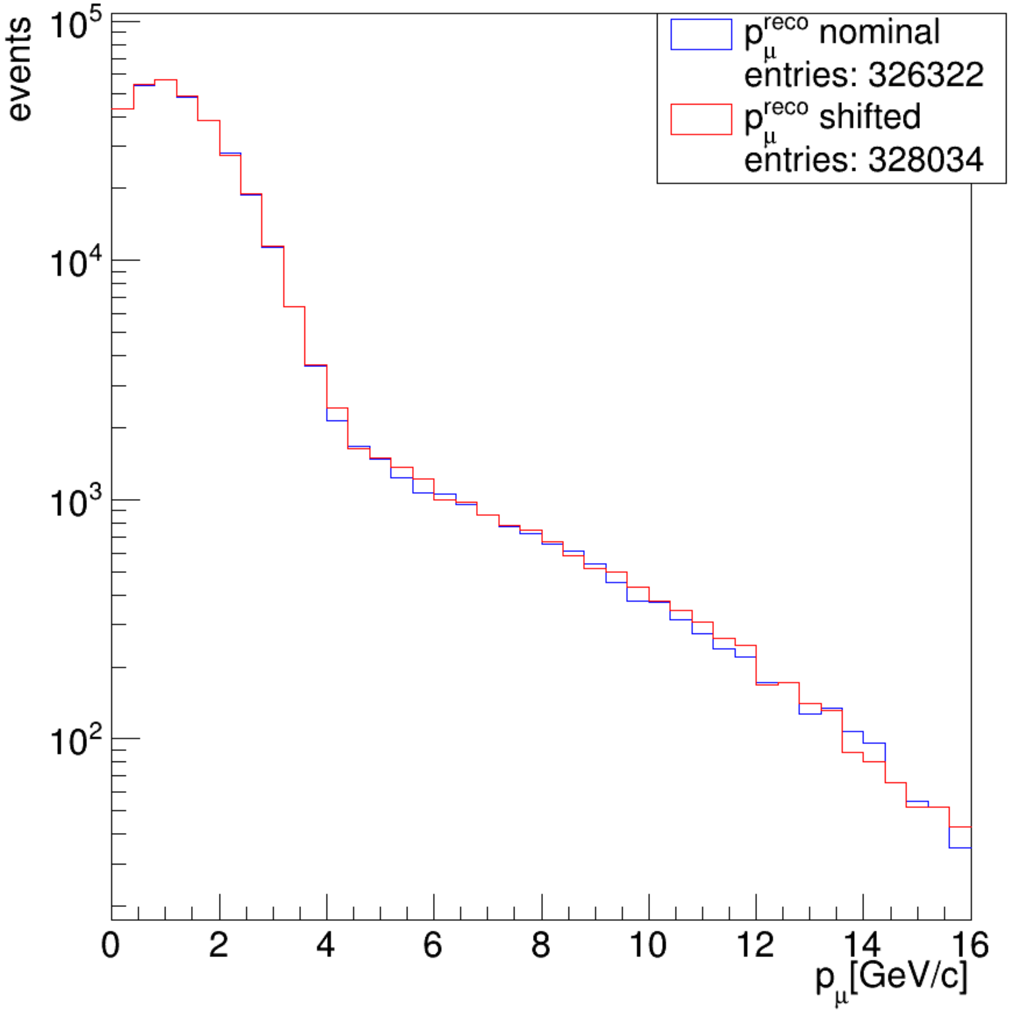


- ~~The first two samples considered for beam monitoring are the muon reconstructed momenta after the fiducial cut and the selection on the successfulness of the muon reconstruction are applied:~~

$$p_{reco} = 1.55 \times 10^{-3};$$

$$\sigma_{reco} = 3.17 \ (\chi^2)$$

RESULTS: FIDUCIAL + RECONSTUCTION + QUALITY

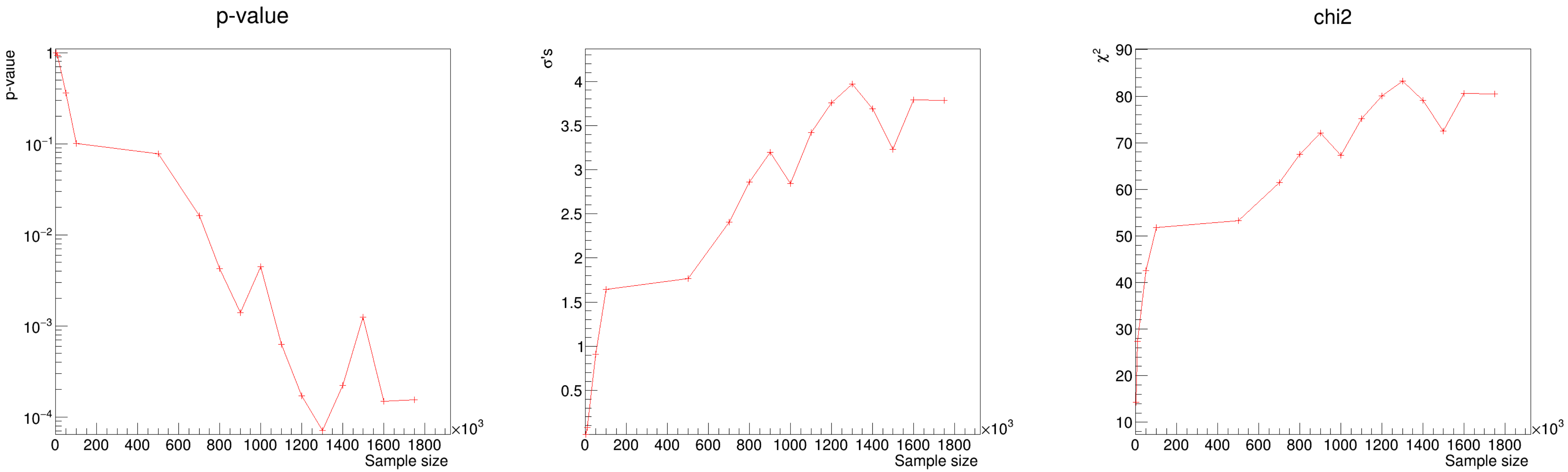


- We repeat the procedure by applying the quality cut to both samples:

$$p_{reco} = 1.55 \times 10^{-4};$$

$$\sigma_{reco} = 3.78$$

P-VALUE EVOLUTION WITH THE SAMPLE



- As we should expect, as the samples become larger the χ^2 and number of σ's increase, while the p-value decreases.
- With a sample grater than 1.2 million events, comparable to (even if smaller) that the one expected during a week of data taking, is possible to identify the beam anomaly with a confidence level corresponding to more than 3σ

CONCLUSIONS

Using reconstructed quantities, fiducial volume and quality selection we reach

- We observed that in the case of a perfect detector with a perfect reconstruction, (i.e. using the Monte Carlo “truth”), the significance of the difference among the nominal and shifted samples does not exceed 5σ
- ~~After a detailed analysis, we found that we are able to distinguish the two reconstructed samples~~ at 3.8σ confidence level
- The result can be improved: for example include neutrinos with interactions in the STT, or consider the reconstructed position on the *xy* plane of the interaction vertexes, both in the front calorimeters and the STT.