# NEAR DETECTOR SPECTRA AND FAR NEAR RATIOS

Amit Bashyal

August 4, 2015

University of Texas at Arlington

# Introduction

- Near Detector and Near Far Correlation
- DUNE Beamline with near detector position
- Optimized and Reference beamline
- Near and Far detector neutrino fluxes
- Beam Matrix for Near and Far detector
- Beam Matrix Table
- Conclusion and Future works

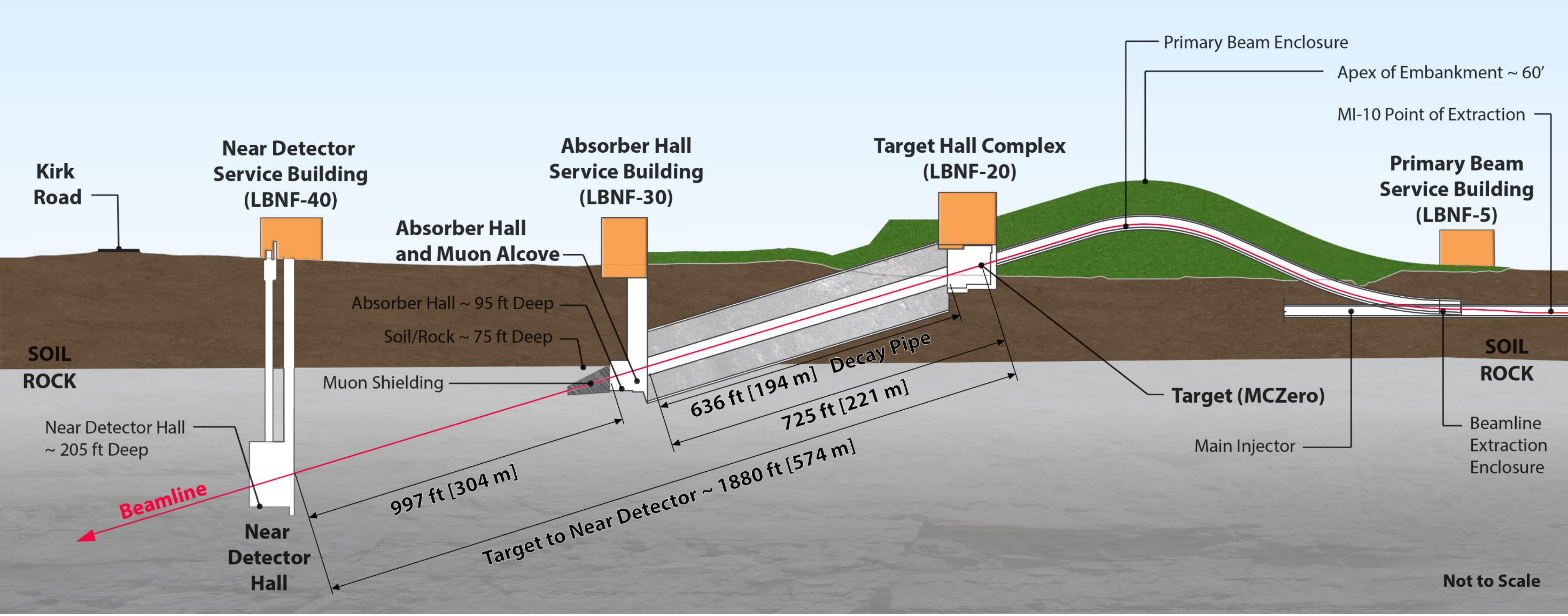
# Near Detector and Near Far Correlation

- DUNE : numu →nue oscillation experiment
- Near Detector to understand the neutrino flux and predict flux at the far detector
- Far Detector to observe the oscillation effect
- **BUT**
- Systematic uncertainties which makes the prediction less accurate
- **SOURCES OF UNCERTAINTIES**
- Hadron Production, material budget, alignments of beamline parts, finite transverse size of decay pipe, target length and so on.

# Continued

- Near and Far Detector sees different neutrino flux due to their location.
- Systematic uncertainties don’t cancel.
- Need to know uncertainties to make the prediction of far detector flux more accurate.
- **Methods**
- Far near ratio
- Beam Matrix

# DUNE Beamline with Near Detector



# Beam Parameters

- Reference Beam
- Proton Beam Energy:80 GeV
- Proton Beam Intensity: 1.2 MW
- Beam spot size: 1.3 mm

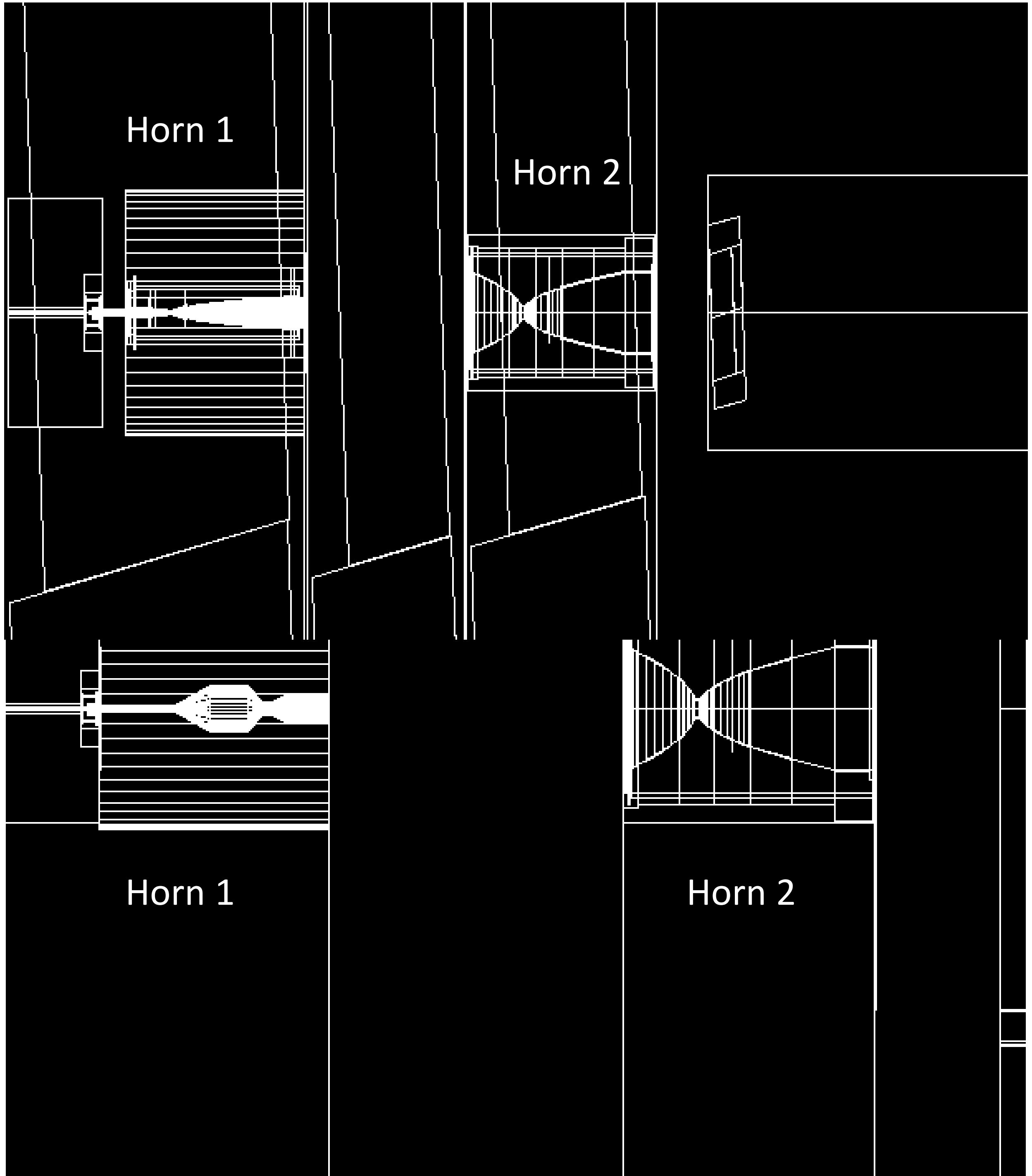
- Optimized Beam(CP_run5_9116)
- Proton Beam Energy: 66 GeV
- Proton Beam Intensity: 1.2 MW
- Beam Spot Size: 1.65 mm

**Parameters used for the Study**

Parameters used for this study are:

- Geant4: geant4.9.6.p3
- Genie: 2.8.4
- G4lbne: v3r3p8

- Total POTS used: 1000X100000

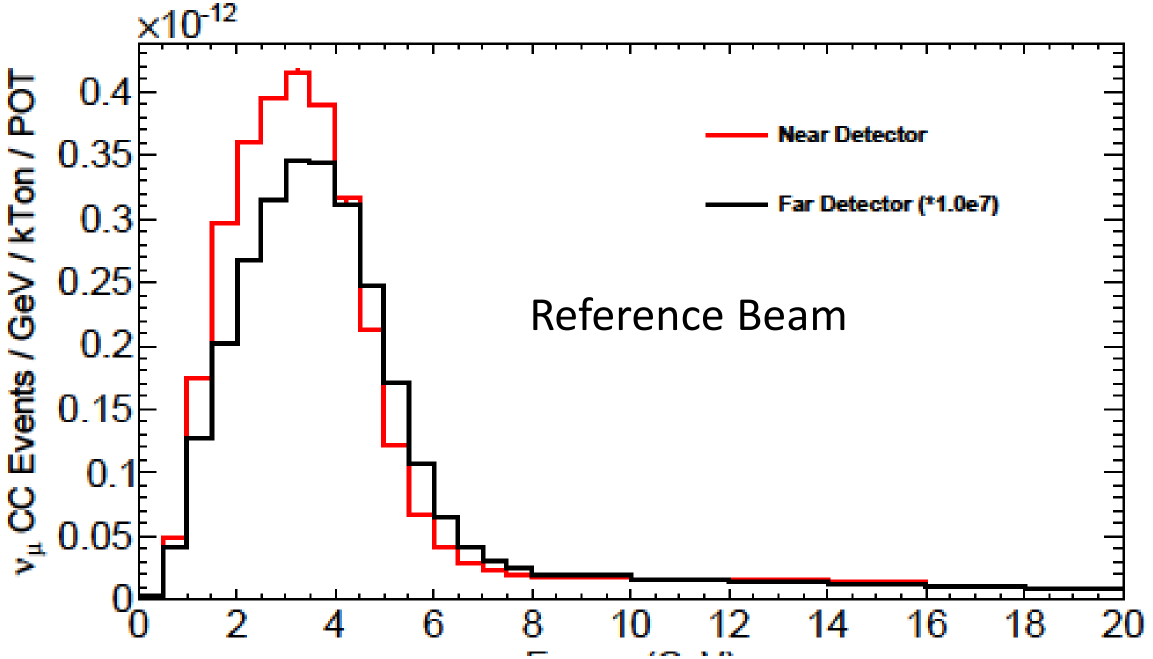


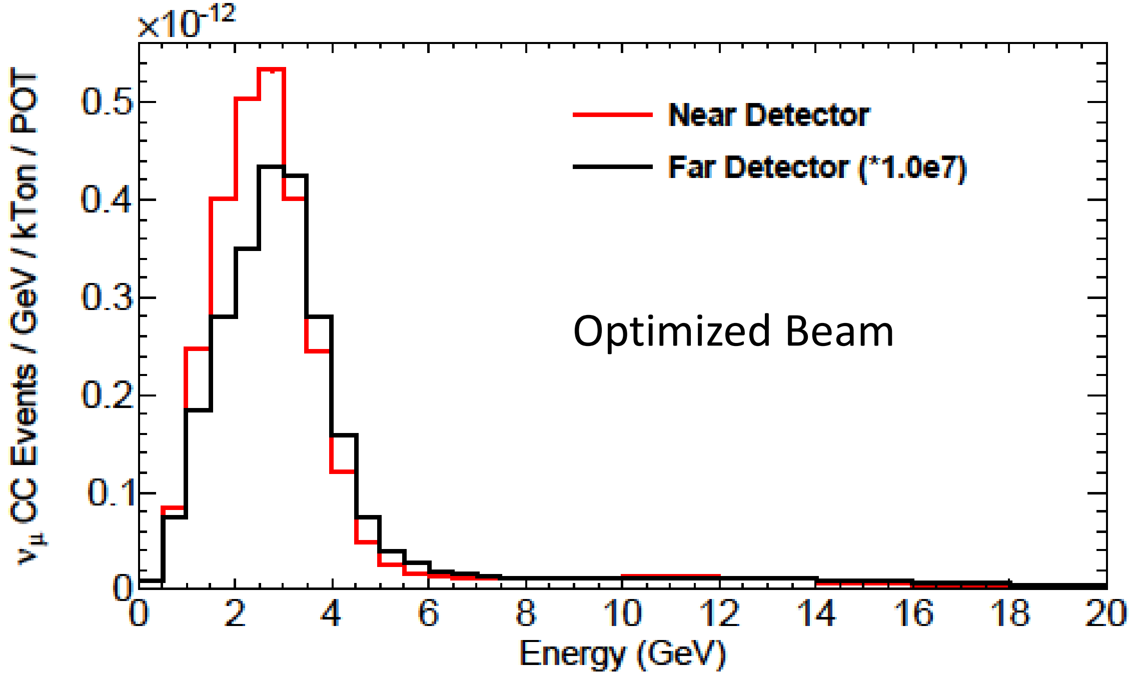

Reference Beam

Relative position of target and focusing system in optimized and reference configuration.
The target is longer and wider in optimized configuration.

Optimized Beam

Horn Current:
Reference: 230 kA.
Optimized: 298 kA.

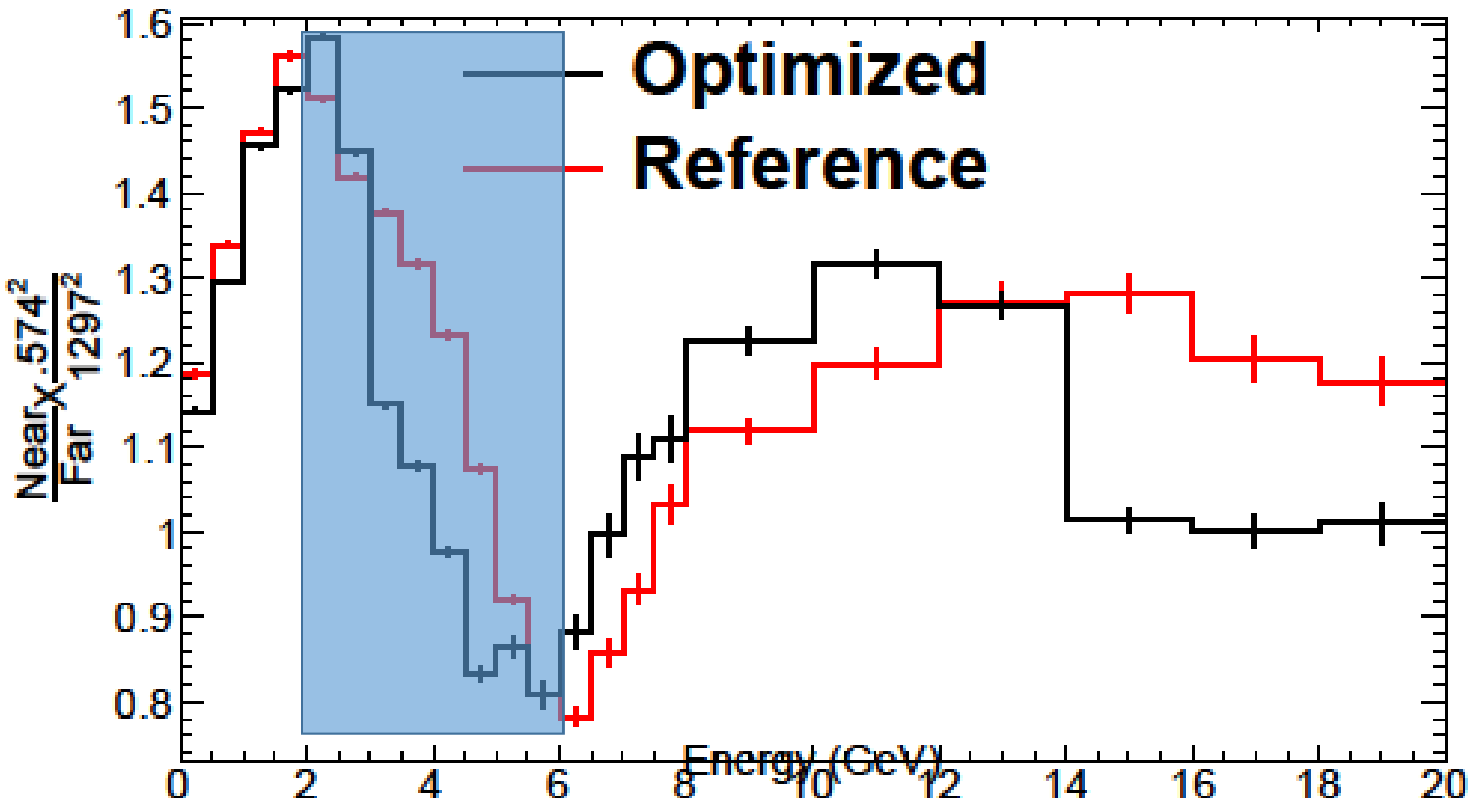



| Proton Beam Energy(GeV) | Protons per Cycle | Cycle Time (sec) | Beam Power(MW) |
|---|---|---|---|
| 60 | 7.50E+13 | 0.7 | 1.03 |
| 80 | 7.50E+13 | 0.9 | 1.07 |
| 120 | 7.50E+13 | 1.2 | 1.2 |

Table 1: Beam parameters and plan

The fluxes are scaled for the cycle time of the accelerator for protons with different proton energy.




- 574 m → Near Detector Location
- 1297 km → Far Detector Location
- Flux Ratio multiplied by R squared ratio (R = detector location).
- 2 to 6 GeV→ Focusing region. Optimized reference has smaller normalization uncertainty (better focusing).
- Highlighted is the focusing region.

# Beam Matrix Method

$$F_i = R_i X N_j \delta_{ij}$$

**Near Far Correlation from Far Near Ratio Method**

Here, $F_i$ = Neutrino event in the far detector

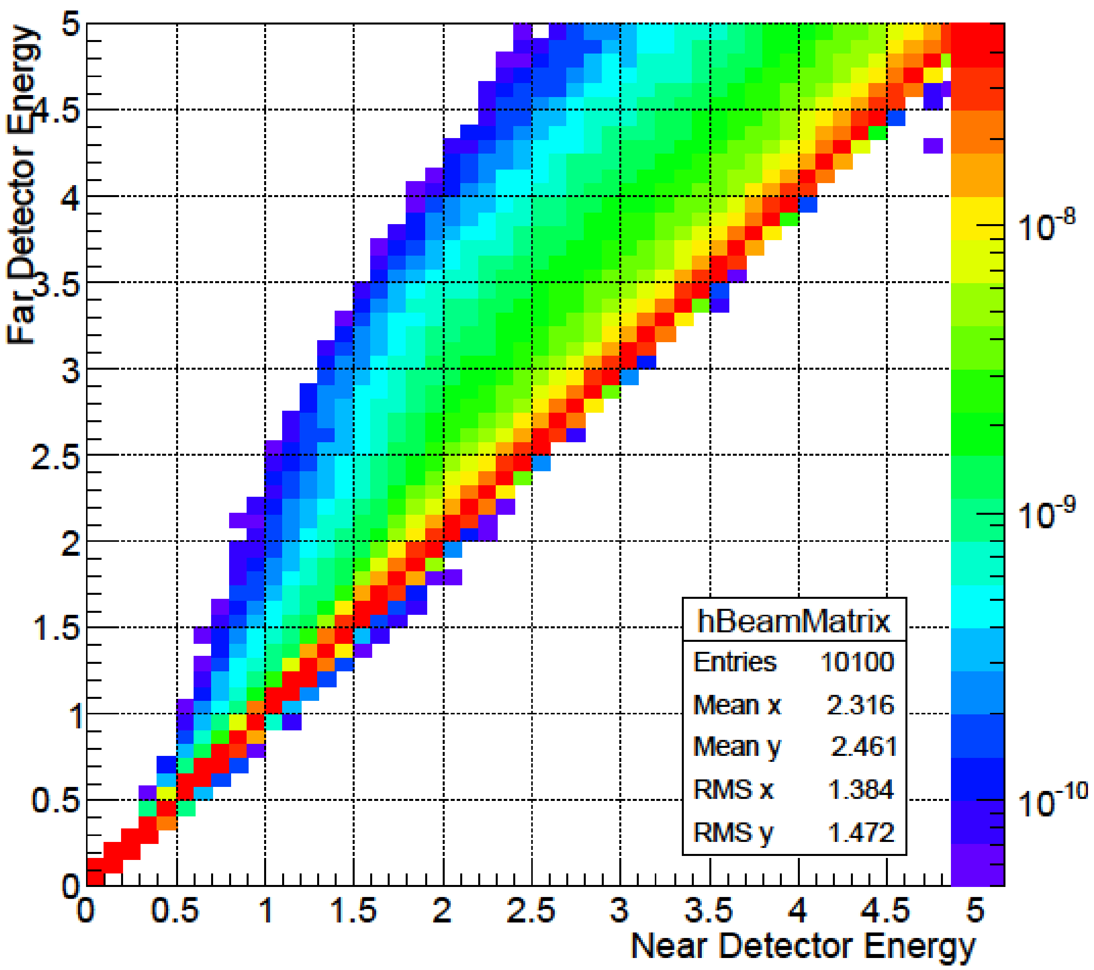
$R_i$ = Near Far Ratio

$N_i$ = Neutrino event in the near detector

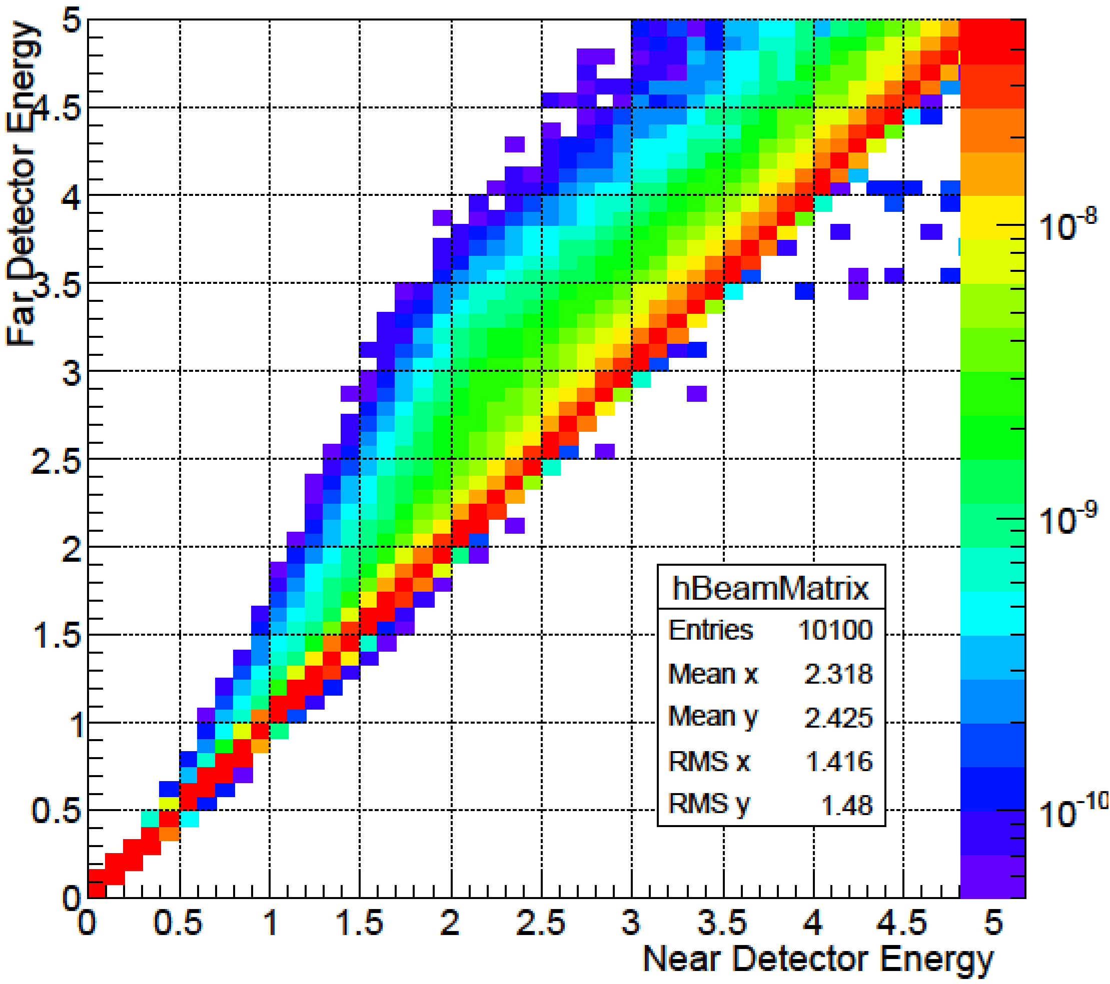
- Limitation of the ratio plot → Near Far correlation only in the given neutrino energy bin
- Each neutrino event at energy $E_n$ implies neutrino spectrum in the far detector.
- Beam Matrix method gives a more accurate near far correlation.

**Near Far Correlation from Beam Matrix Method**

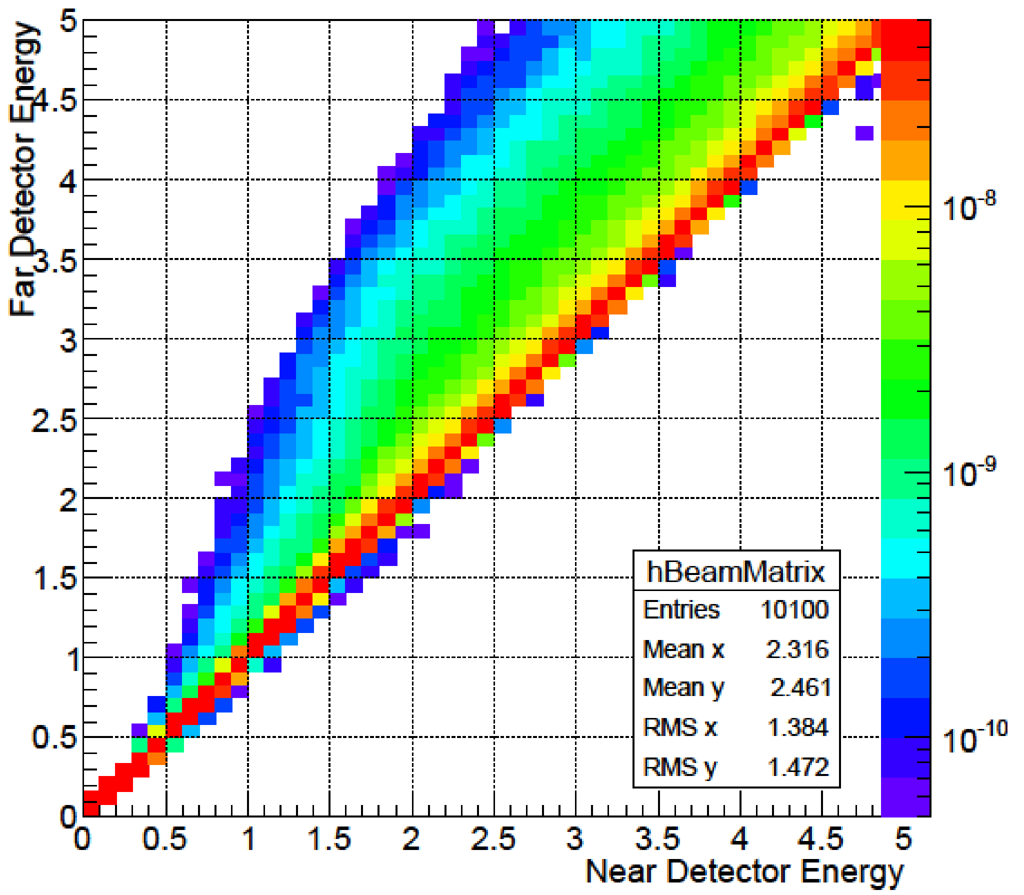
$$(F_1, F_2, \cdots, F_n) = \begin{bmatrix} M_{11} & M_{12} & \dots & M_{1n} \\ M_{21} & M_{22} & \dots & M_{2n} \\ \dots & \dots & \dots & \dots \\ M_{n1} & M_{n2} & \dots & M_{nn} \end{bmatrix} \begin{bmatrix} N_1 \\ N_2 \\ \dots \\ N_n \end{bmatrix}$$

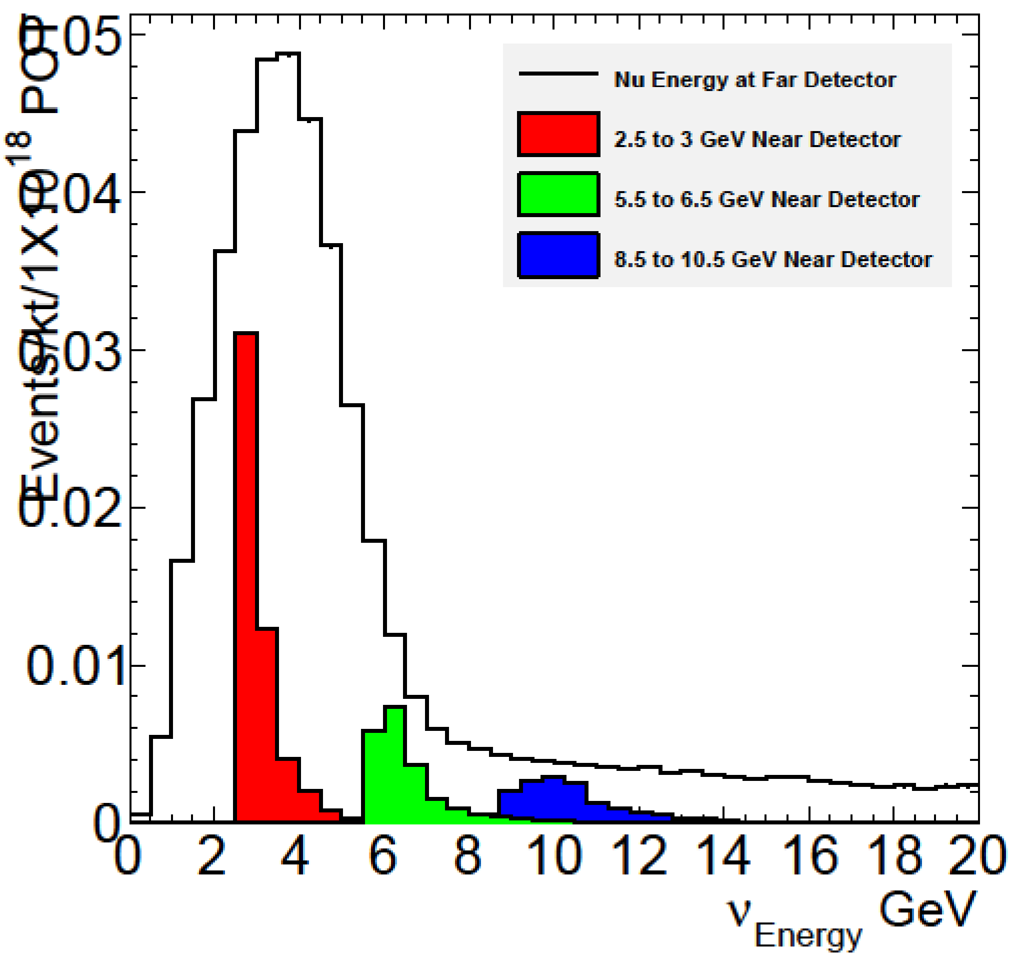



**Reference Beam Matrix**




**Optimized Beam Matrix**

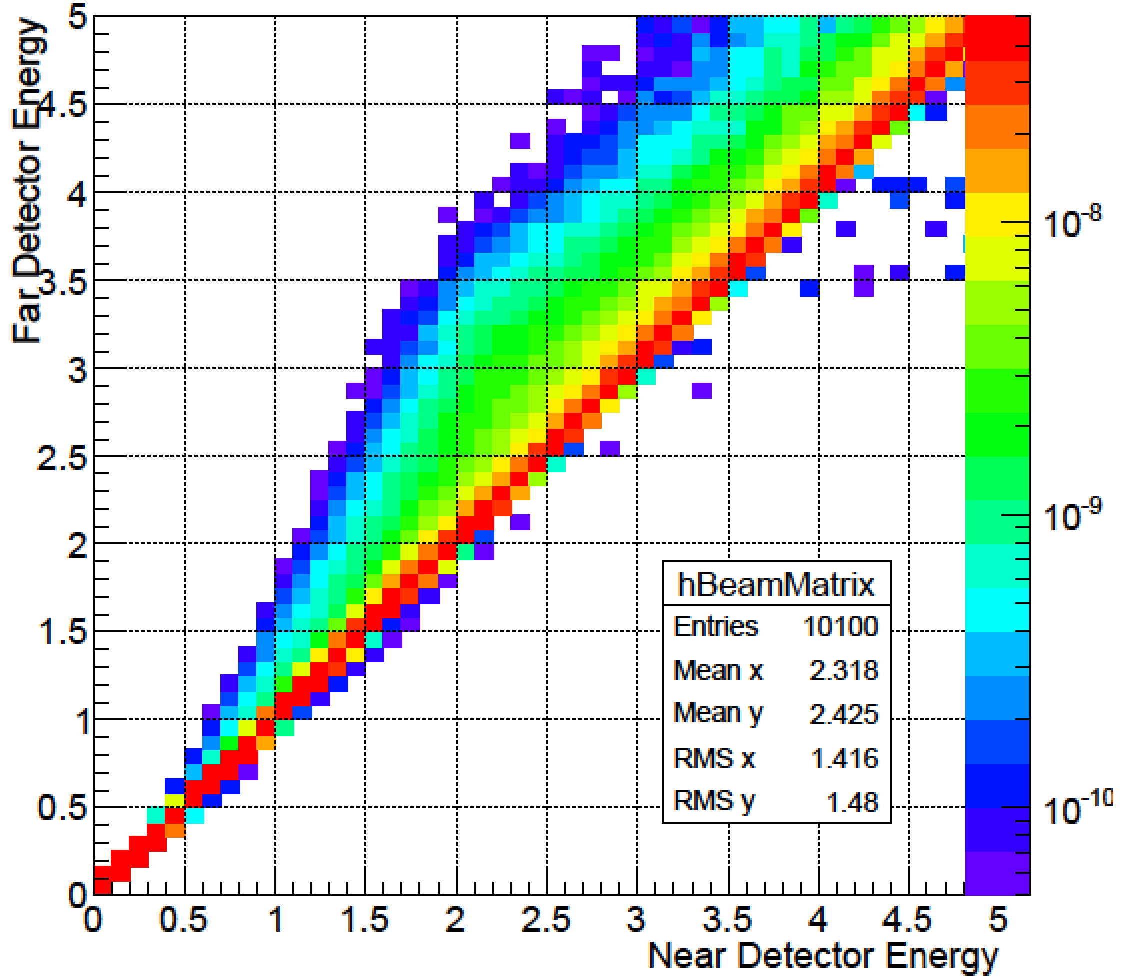


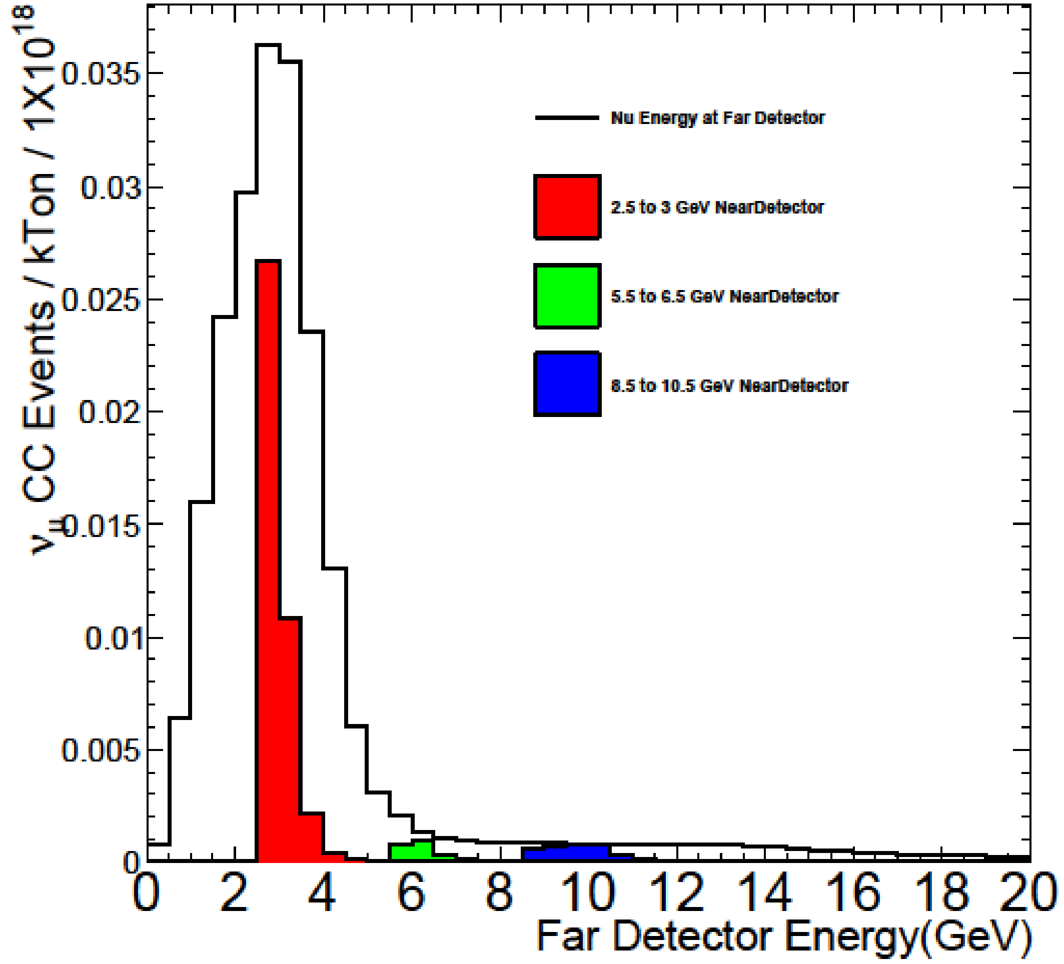

**DUNE Reference Beam Matrix**

The energy smearing becomes more prominent as we go to higher energy neutrino event.

Smearing for 2.5 to 3 GeV (Red), 5.5 to 6.5 GeV (Green) and 8.5 to 10.5 GeV (Blue).




**Optimized Beam Matrix**




Smearing for 2.5 to 3 GeV (Red), 5.5 to 6.5 GeV (Green) and 8.5 to 10.5 GeV (Blue).

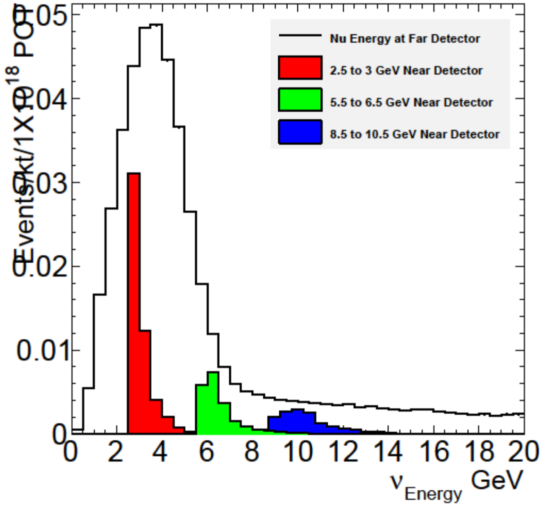
# Beam Matrix Table for Reference Beam

| Near/Far | 0-0.5 | 0.5-1 | 1-1.5 | 1.5-2 | 2-2.5 | 2.5-3 | 3-3.5 | 3.5-4 | 4-4.5 | 4.5-5 |
|---|---|---|---|---|---|---|---|---|---|---|
| **0-0.5** | **98.4538** | 1.55994 | 3.6E-05 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **0.5-1** | 0.05735 | **95.9949** | 3.9274 | 0.05611 | 0.00395 | 0 | 0 | 0 | 0 | 0 |
| **1-1.5** | 0 | 0.11214 | **90.2219** | 8.84246 | 0.69139 | 0.11531 | 0.01634 | 5.3E-05 | 5.1E-05 | 0 |
| **1.5-2** | 0 | 0 | 0.12753 | **81.8734** | 14.3551 | 2.80868 | 0.73643 | 0.09439 | 0.0063 | 0.0002 |
| **2-2.5** | 0 | 0 | 0.00044 | 0.14746 | **71.59** | 21.043 | 5.9952 | 1.04896 | 0.14856 | 0.0238 |
| **2.5-3** | 0 | 0 | 3.5E-05 | 0.00229 | 0.14913 | **69.3683** | 25.1716 | 4.33094 | 0.76174 | 0.1632 |
| **3-3.5** | 0 | 0 | 1.4E-05 | 0.00016 | 0.00716 | 0.16128 | **72.2221** | 23.1204 | 3.49118 | 0.71094 |
| **3.5-4** | 0 | 0 | 0 | 0.00015 | 0.0017 | 0.01846 | 0.1713 | **71.9305** | 23.0349 | 3.34611 |
| **4-4.5** | 0 | 0 | 0 | 0 | 0.00144 | 0.00958 | 0.03381 | 0.15538 | **70.5959** | 22.9954 |
| **4.5-5** | 0 | 0 | 0 | 0 | 0.00056 | 0.00331 | 0.02211 | 0.06401 | 0.23752 | **64.8663** |

Table 2: Beam matrix for DUNE reference beam. Rows- Neutrino events at near detector and Columns- Neutrino events at far detector. The energy is in GeV. The table shows how neutrino events at a given near detector neutrino energy bin spreads over a range of energy bins in far detector.

**Interpretation of Beam Matrix Table**

Neutrino events at, lets say 0-0.5 GeV bin at near detector implies a neutrino spectrum at far detector such that :
98.45% of that event (X $(R_{near}/R_{far})^2$ )is in 0 to 0.5 GeV Far detector neutrino energy bin.
1.559% of that event(X $(R_{near}/R_{far})^2$ ) is in 0.5 to 1 GeV Far detector neutrino energy bin.
And so on……



**Reference Beam**

| Near/Far | 0-0.5 | 0.5-1 | 1-1.5 | 1.5-2 | 2-2.5 | 2.5-3 | 3-3.5 | 3.5-4 | 4-4.5 | 4.5-5 |
|---|---|---|---|---|---|---|---|---|---|---|
| **0-0.5** | **98.4538** | 1.55994 | 3.6E-05 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **0.5-1** | 0.05735 | **95.9949** | 3.9274 | 0.05611 | 0.00395 | 0 | 0 | 0 | 0 | 0 |
| **1-1.5** | 0 | 0.11214 | **90.2219** | 8.84246 | 0.69139 | 0.11531 | 0.01634 | 5.3E-05 | 5.1E-05 | 0 |
| **1.5-2** | 0 | 0 | 0.12753 | **81.8734** | 14.3551 | 2.80868 | 0.73643 | 0.09439 | 0.0063 | 0.0002 |
| **2-2.5** | 0 | 0 | 0.00044 | 0.14746 | **71.59** | 21.043 | 5.9952 | 1.04896 | 0.14856 | 0.0238 |
| **2.5-3** | 0 | 0 | 3.5E-05 | 0.00229 | 0.14913 | **69.3683** | 25.1716 | 4.33094 | 0.76174 | 0.1632 |
| **3-3.5** | 0 | 0 | 1.4E-05 | 0.00016 | 0.00716 | 0.16128 | **72.2221** | 23.1204 | 3.49118 | 0.71094 |
| **3.5-4** | 0 | 0 | 0 | 0.00015 | 0.0017 | 0.01846 | 0.1713 | **71.9305** | 23.0349 | 3.34611 |
| **4-4.5** | 0 | 0 | 0 | 0 | 0.00144 | 0.00958 | 0.03381 | 0.15538 | **70.5959** | 22.9954 |
| **4.5-5** | 0 | 0 | 0 | 0 | 0.00056 | 0.00331 | 0.02211 | 0.06401 | 0.23752 | **64.8663** |

Table 2: Beam matrix for DUNE reference beam. Rows- Neutrino events at near detector and Columns- Neutrino events at far detector. The energy is in GeV. The table shows how neutrino events at a given near detector neutrino energy bin spreads over a range of energy bins in far detector.

**Optimized Beam**

| Near/Far | 0-0.5 | 0.5-1 | 1-1.5 | 1.5-2 | 2-2.5 | 2.5-3 | 3-3.5 | 3.5-4 | 4-4.5 | 4.5-5 |
|---|---|---|---|---|---|---|---|---|---|---|
| **0-0.5** | **99.3319** | 0.78858 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **0.5-1** | 0.33 | **97.5** | 2.514 | 0.0005 | 0 | 0 | 0 | 0 | 0 | 0 |
| **1-1.5** | 0 | 0.05253 | **94.6383** | 5.26657 | 0.06445 | 0 | | 0 | 0 | 0 |
| **1.5-2** | 0 | 0 | 0.05282 | **89.2183** | 10.2718 | 0.45127 | 0.00204 | 0 | 0 | 0 |
| **2-2.5** | 0 | 0 | 0 | 0.0514 | **82.6683** | 15.8891 | 1.3593 | 0.03285 | 0 | 0 |
| **2.5-3** | 0 | 0 | 0 | 0 | 0.05153 | **78.5498** | 18.9763 | 2.30867 | 0.11264 | 0.00135 |
| **3-3.5** | 0 | 0 | 0 | 0 | 0.00025 | 0.05655 | **76.6286** | 20.2937 | 2.7357 | 0.28357 |
| **3.5-4** | 0 | 0 | 0 | 0 | 0 | 0.00254 | 0.03537 | **74.2968** | 21.9502 | 3.21409 |
| **4-4.5** | 0 | 0 | 0 | 0 | 0 | 0 | 0.00499 | 0.04537 | **71.5238** | 23.9466 |
| **4.5-5** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00823 | 0.04501 | **68.1802** |

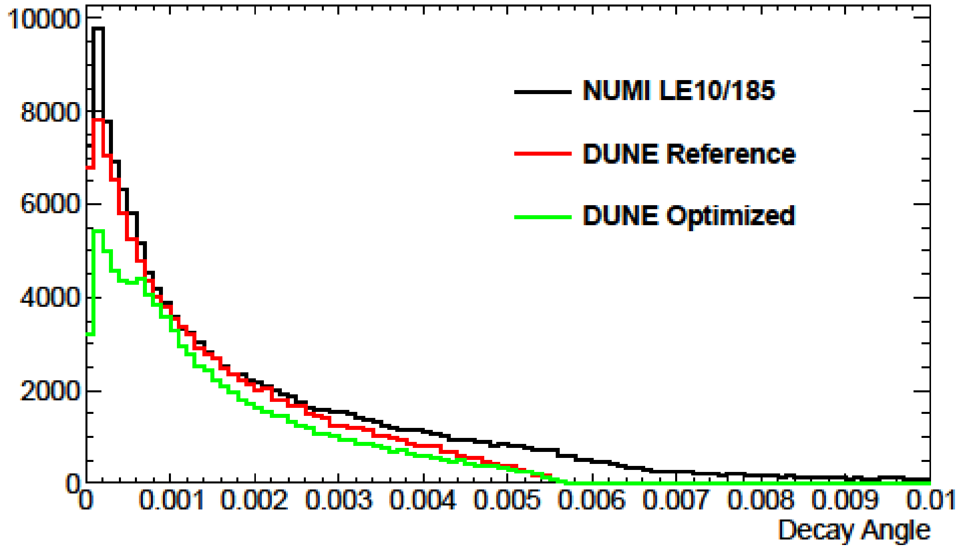
Table 3: Beam matrix for DUNE optimized beam

# Conclusion and Future Work

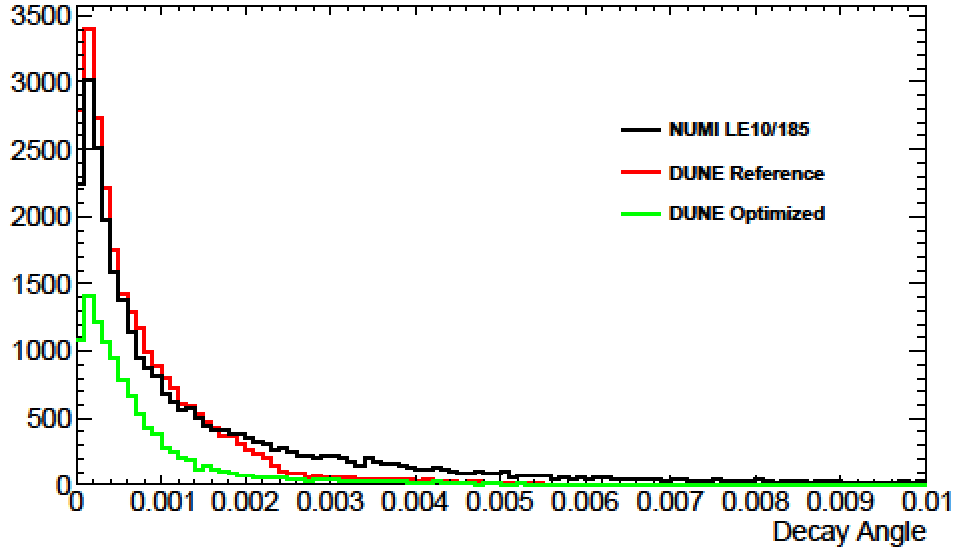
- Near Far Ratio and Beam Matrix → Two method to predict the Far detector spectra from the near detector events.
- Ratio shows that optimized beam configuration performs well in the focusing region.
- Beam Matrix essentially shows the spread of uncertainties at far detector over a range of energy bins. The table shows Optimized beam has less spread than the nominal one.
- Optimized beam shows lesser off diagonal elements (and smaller) than the reference beam. By optimizing the beam, we were able to increase the neutrino flux and decrease the spread of systematic uncertainties at the same time.
- **FUTURE WORKS:**

  Test accuracy of near/far ratio and beam matrix using different physics model.

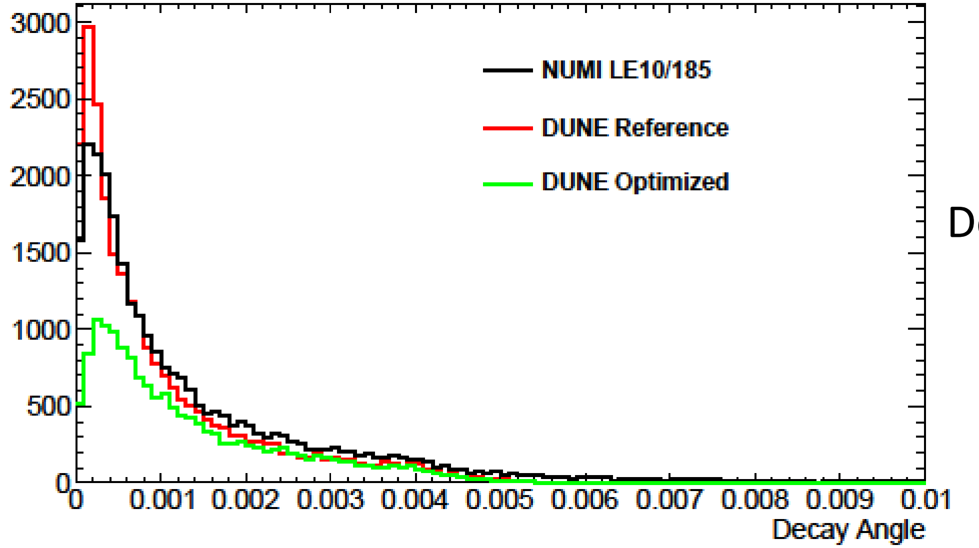
# BACK UP SLIDES



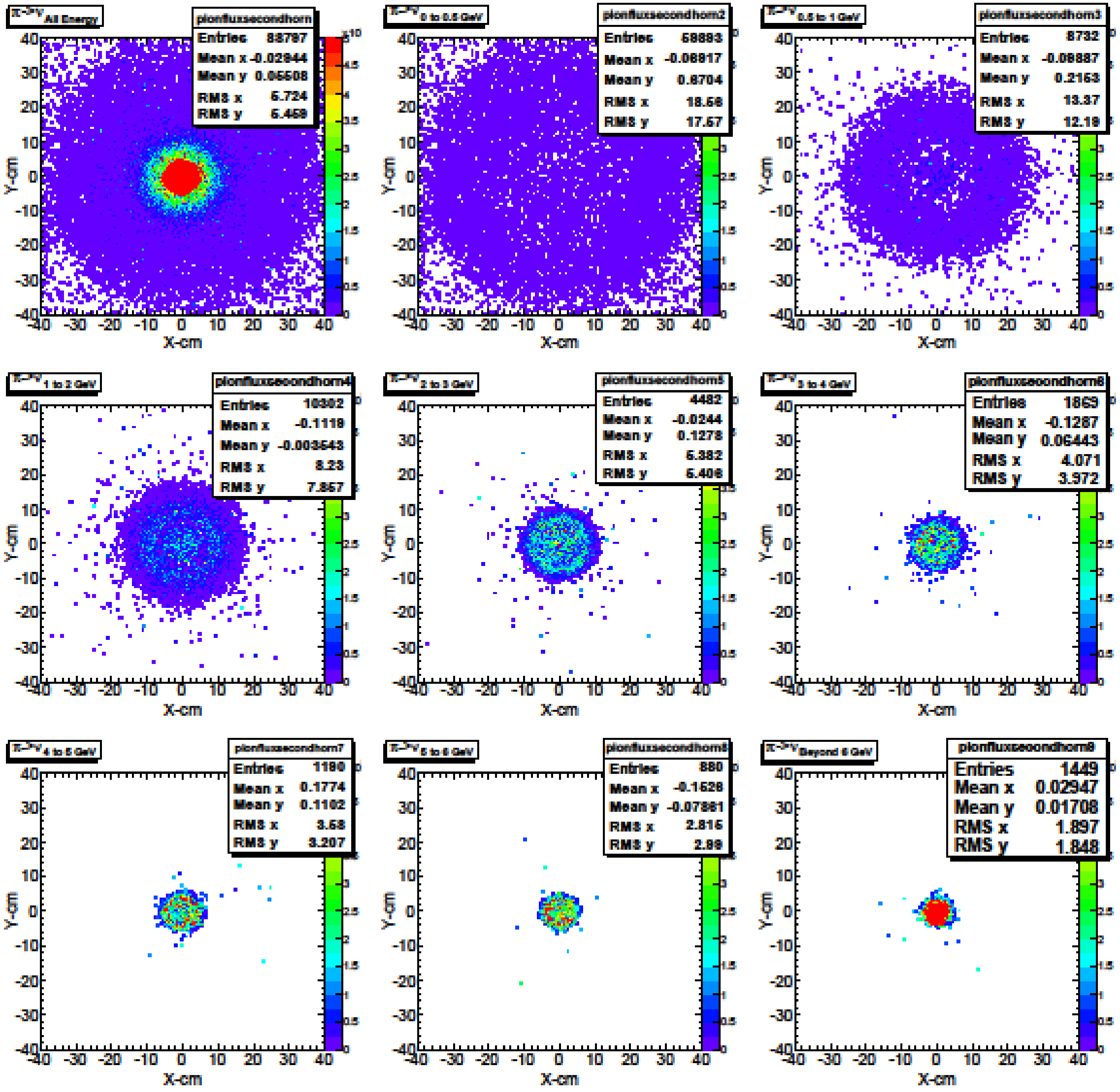

Decay angles for pions (2.5 to 3 GeV)




Decay angles for pions (5.5 to 6.5 GeV)

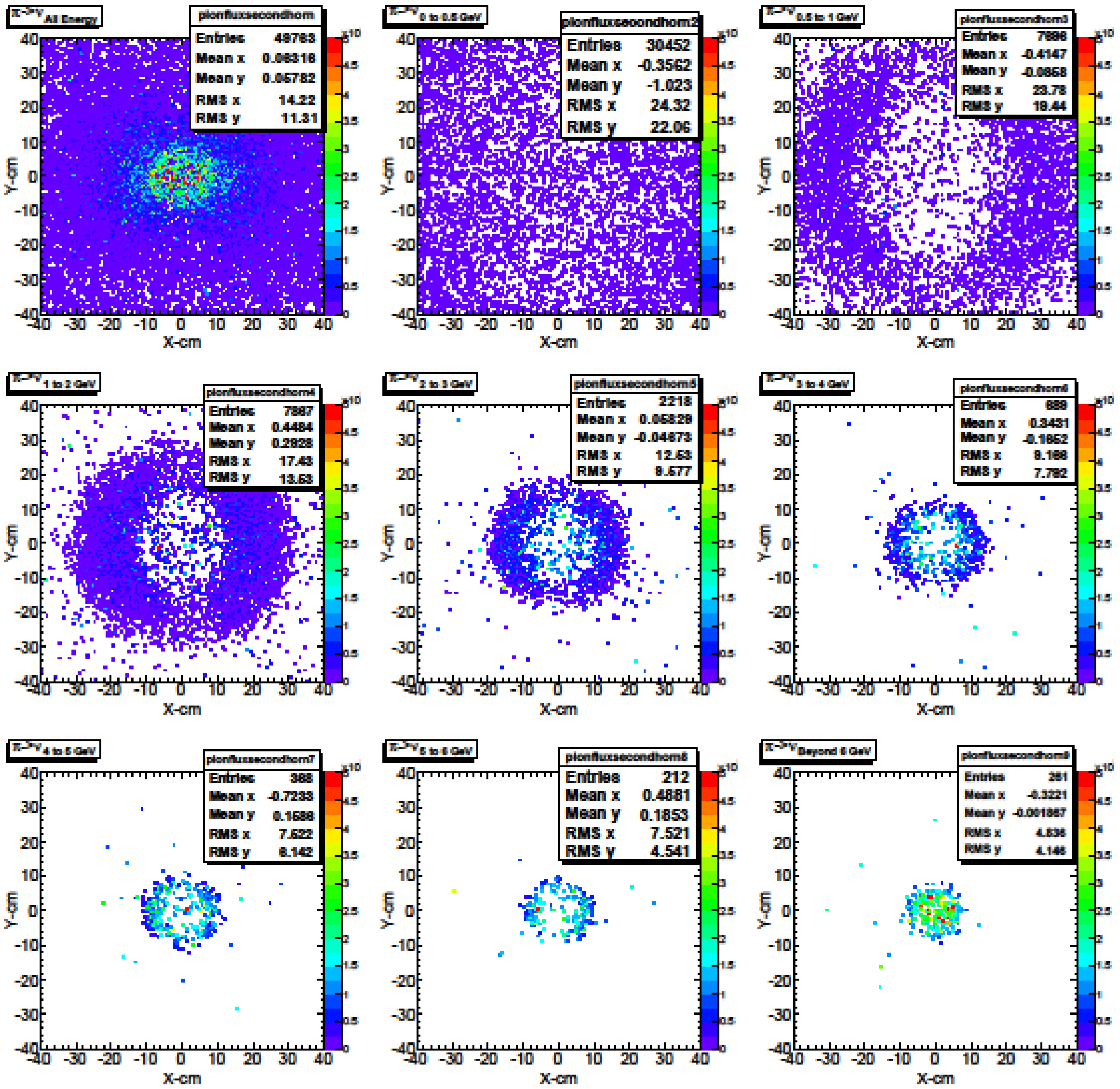



Decay angles for pions (8.5 to 10.5 GeV)




Reference Beam

XY position of pions at the end of second focusing horns giving neutrinos of different energy range at Near Detector




Optimized Beam

XY position of pions at the end of second focusing horn giving neutrinos of different energy range at Near Detector