Content

- Current MC tuning status
- Analysis Beam MC and calc efficiency to neutrino event
- Compare Data vs MC.

Current MC

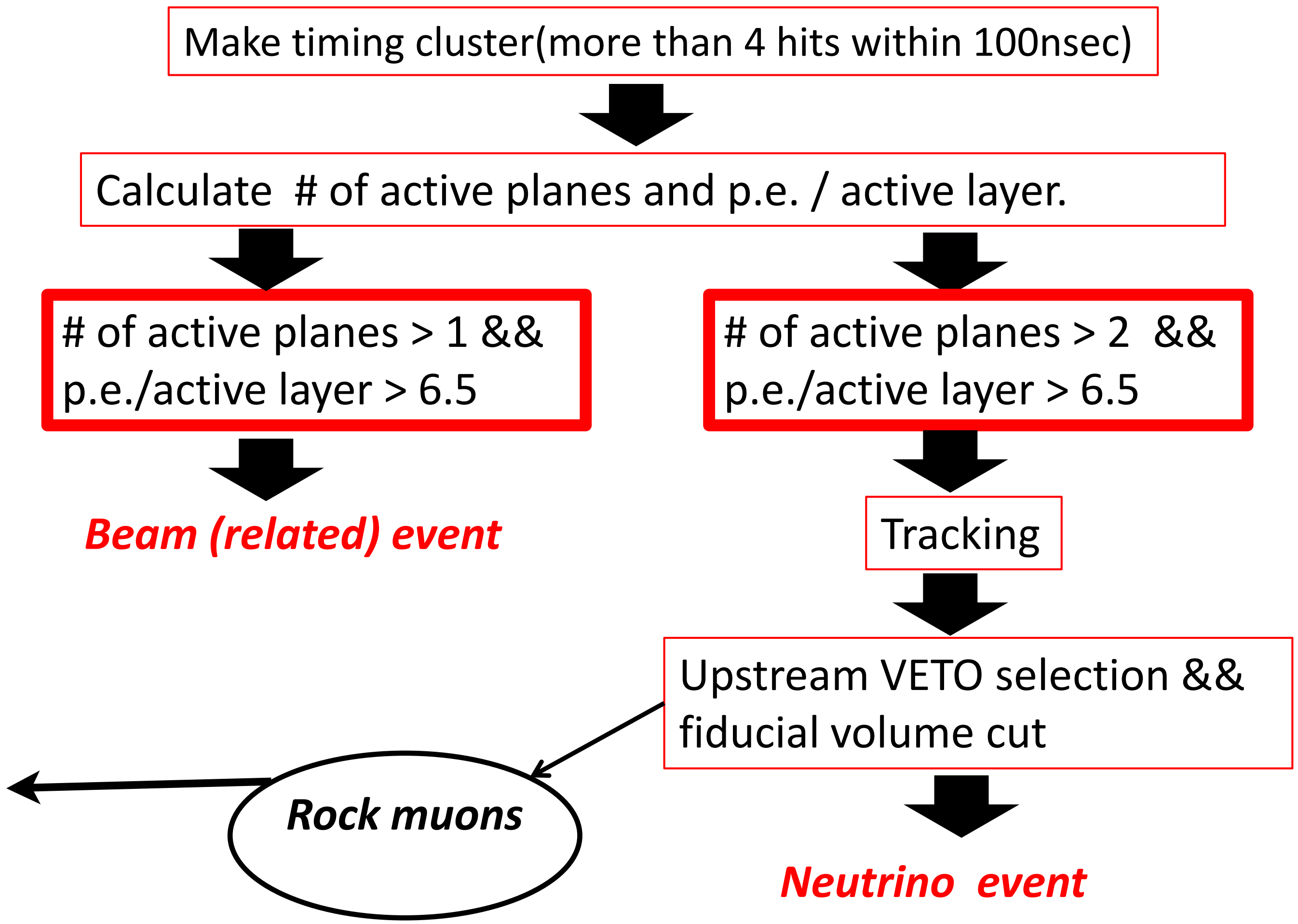
- P.E. of hit is modified from rock muon of Beam data.
- Hit timing from interaction
- Tuning Detector response (response of scintillator, fiber, MPPC).

About energy deposit to P.E.

- I want to simulate MC energy deposit → p.e.
- Calc p.e. of hit by rock muon.
- Calc energy deposit by muon penetrating in one scintillator bar.
- By assuming some detector response, I calc p.e. from MC energy deposit
- I decide some factors of the detector response.

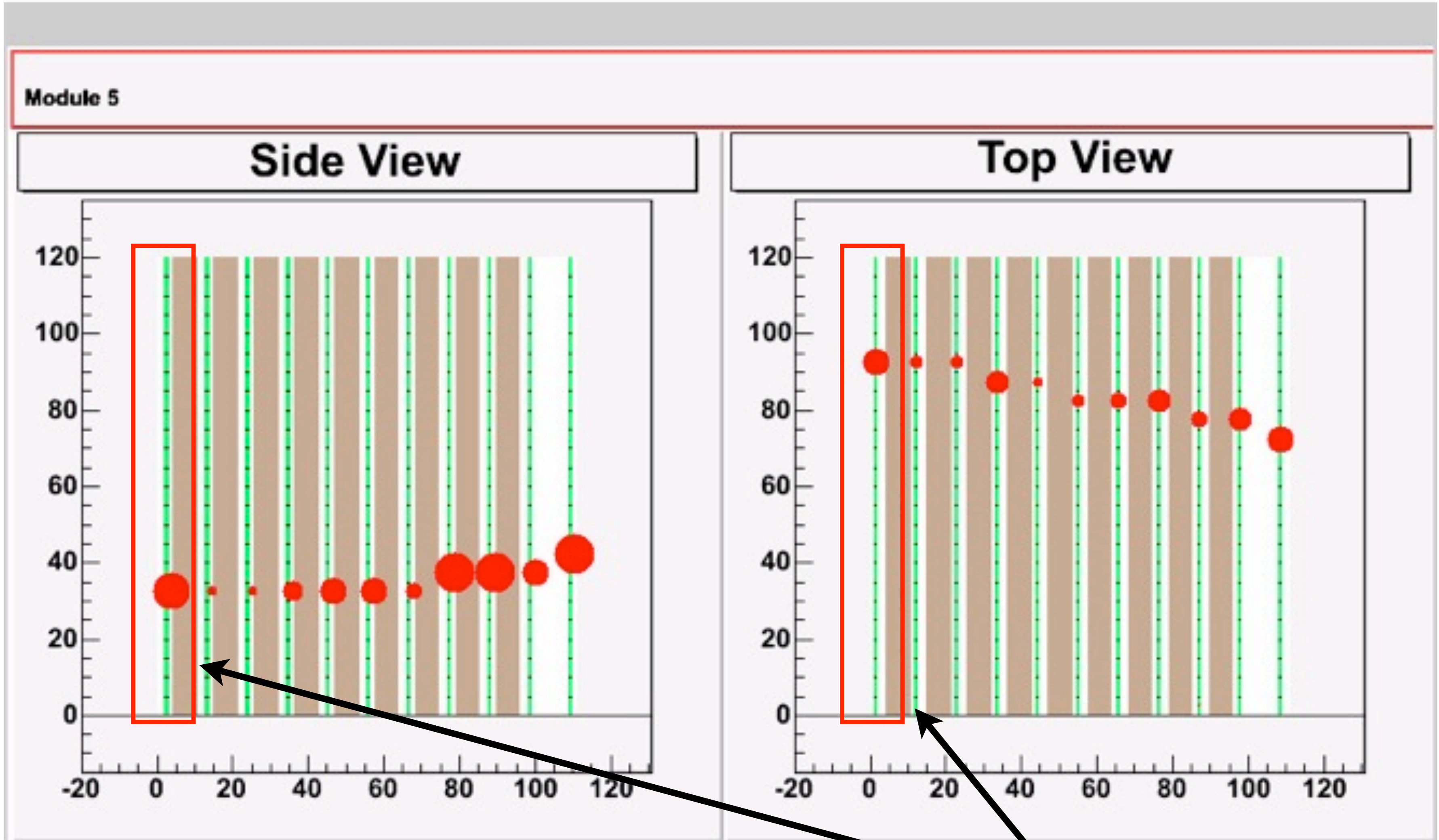
Rock muon select

Use beam data of Run31



\+ # of active plane = 10
\# of track = 1
→ want to select long rock muon track.

Example of selected rock muon event

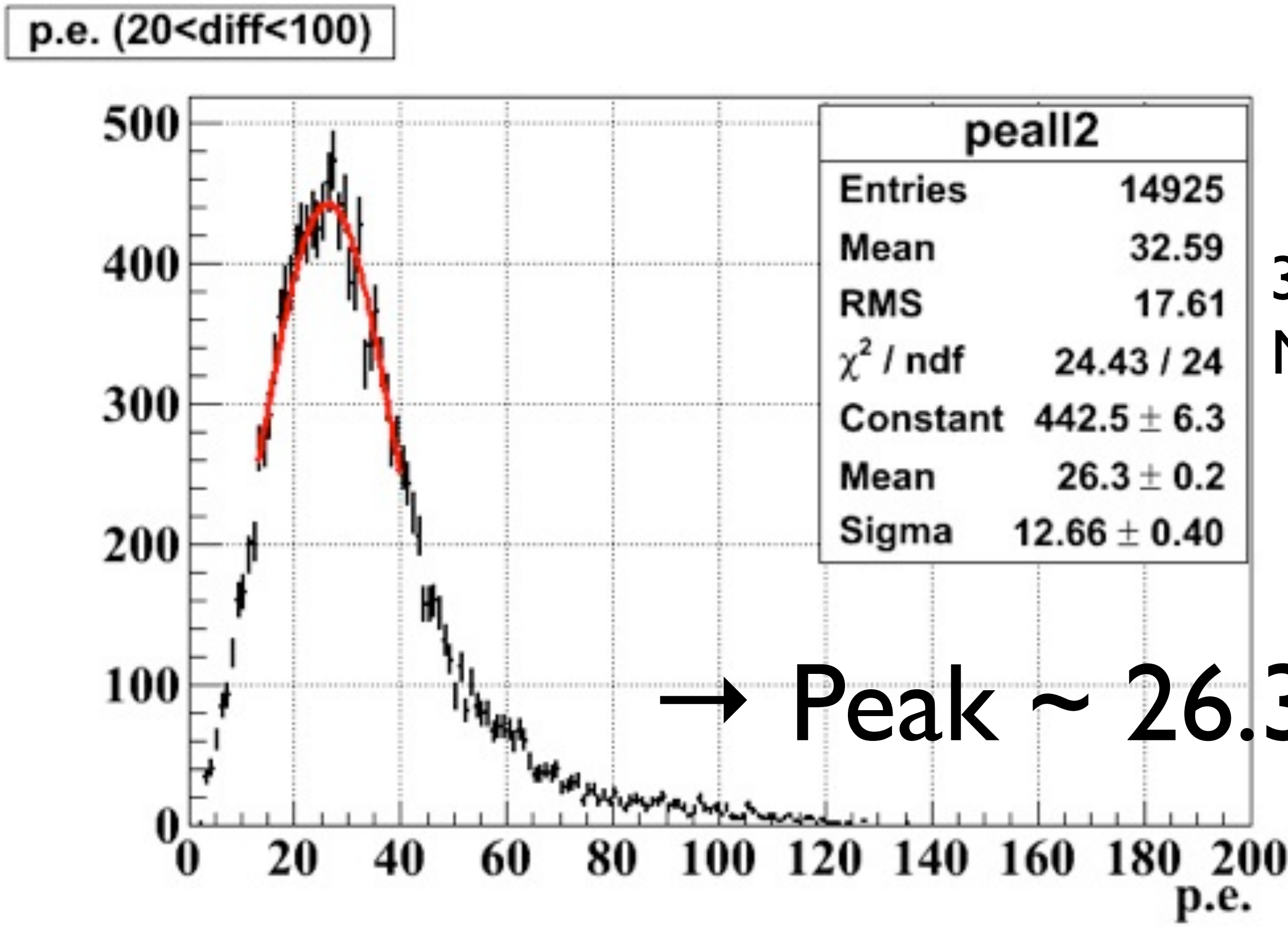


After selection, I use hit at only 1st plane

Correct p.e. of rock muon

- p.e. from rock muon of beam data is attenuated by propagation in fiber and changed by difference of path length in scintillator bar. To use MC tuning, I estimate p.e. before changed.
- I assume these two effect
  - I calc distance from MPPC and path length in scintillator by tracking (tracking method is same as Otani-san) and corrected p.e. (p.e. × (scintillator width)/(path length))
  - I assume p.e. attenuation in fiber is exp (- distance / attenuation length). This attenuation length is 241.1 (calc by Otani-san at beam test).
- This estimation is very rough and need more study for accurate calculation of p.e. of hit.
  - Consider reflective effect at the edge of scintillator, and so on.

After corrected p.e.

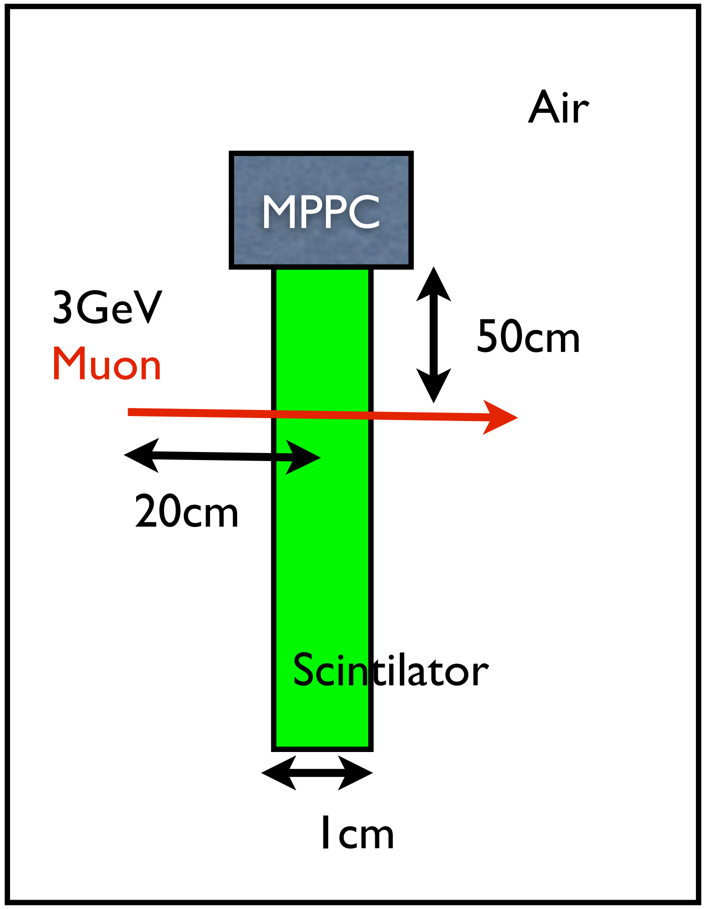


1. Correct path length
2. Correct fiber attenuation
3. Select 20cm < Distance from MPPC < 100cm (for less effect of reflection at edge of the scintillator)

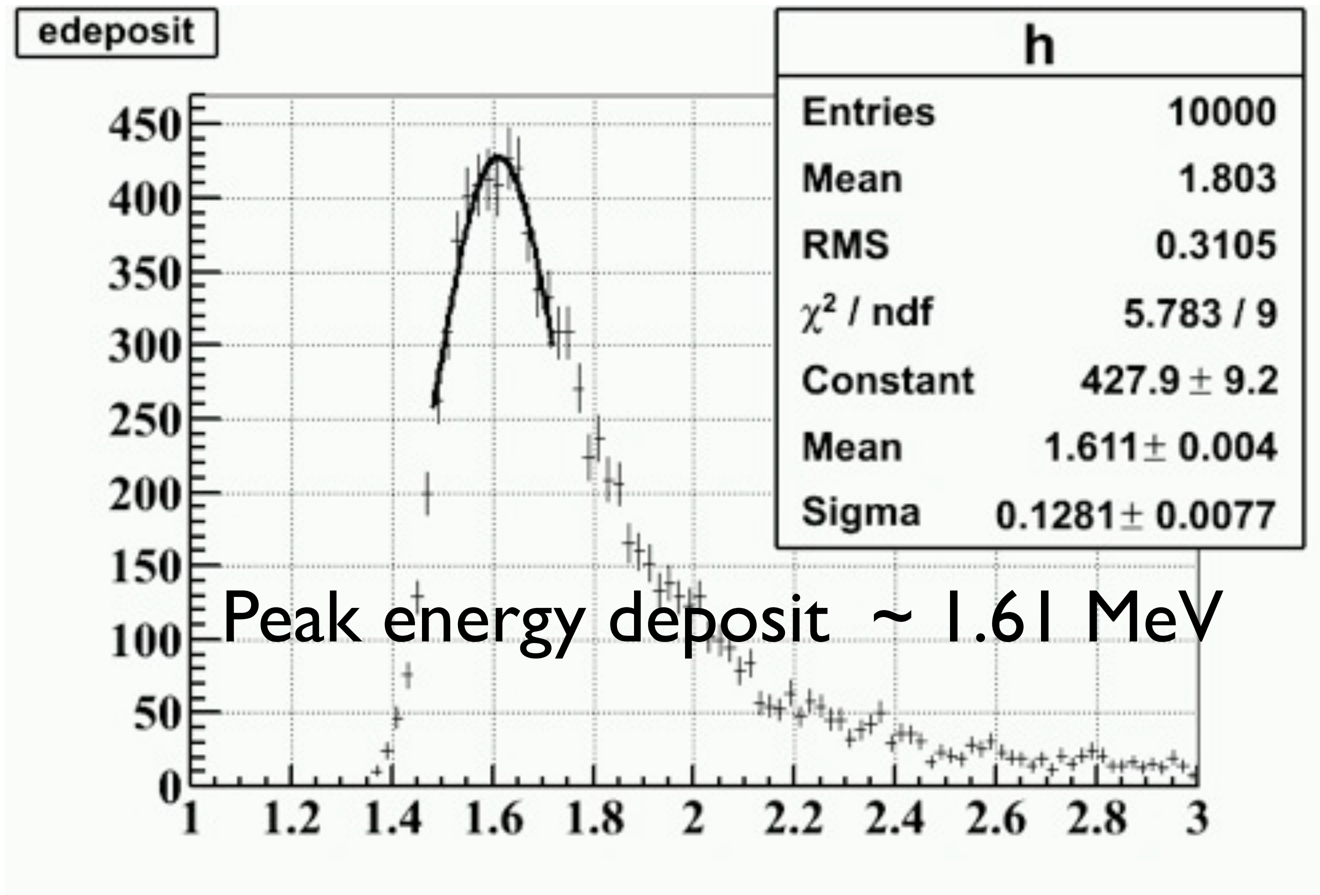
→ Peak ~ 26.3 p.e.

I use this peak p.e. (~26.3) for MC tuning.

1ch Muon MC



Shot muon to one scintillator bar in left condition.
→ calc MC true energy deposit in scintillator
(this value includes quenching effect (birk formula)



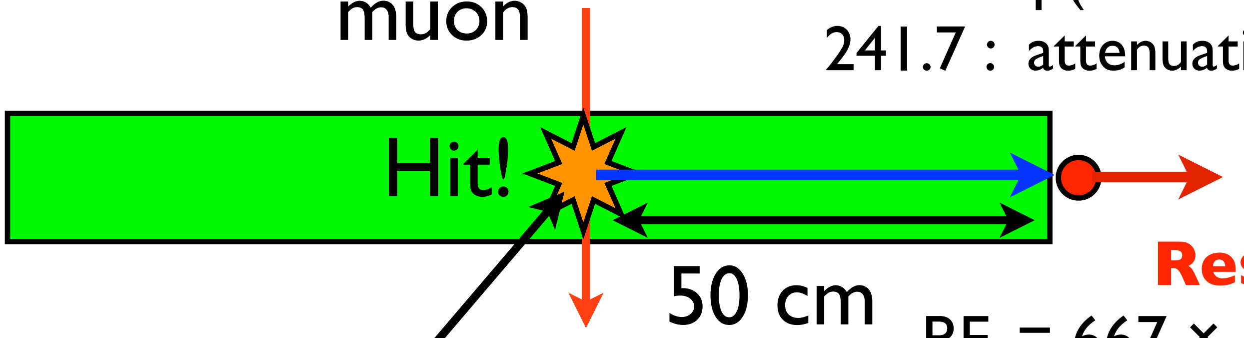
I use this peak energy deposit

Detector response model

Attenuation in fiber

1.61A × exp(-50/241.7) ~ 1.31A

241.7 : attenuation length



Peak energy deposit ~ 1.61 MeV

(including quenching effect)

Assume photons/energy constant : A

→ 1.61A photons

Response of MPPC

P.E. = 667 × (1-exp(- 0.38 × 1.31A) / 667)

667 : # of pixels of MPPC

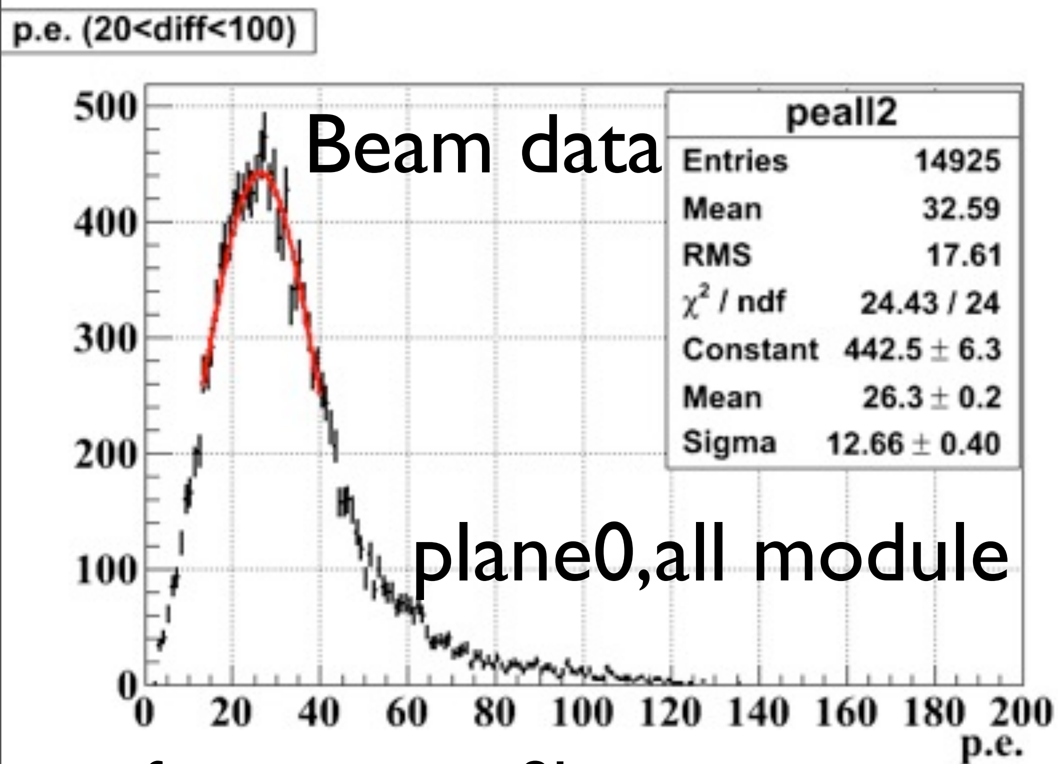
0.275 : constance including PDE and after pulse and cross-talk (ΔV = 1.1)

(detail of this model is http://www.t2k.org/nd280/calib/Meetings/Jan10Workshop/MPPClinearity/at_download/file Page 11)

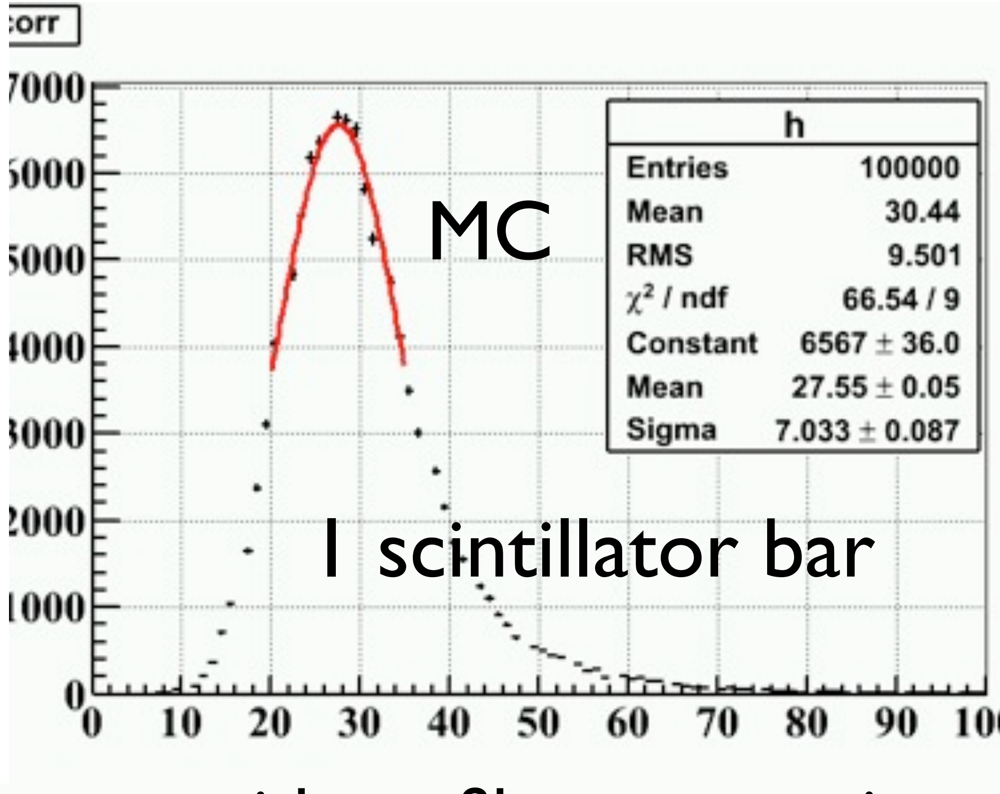
(P.E. from MC) = (P.E. of rock muon in beam data)

→ Decide constance A ~ 60.6

Compare Data vs MC after tuning



after correct fiber-attenuation
after correct path length



p.e. without fiber-attenuation

Peak p.e. ~ 27.6 → MC/Beam ~ 1.05
Sigma ~ MC/Beam ~7 (the difference is # of channels (Beam: at 24ch × 14 module, MC: 1channel)

If more beam data, I can cal p.e. of 1ch and compare to MC

About hit timing

- At current MC, hit timing is time from neutrino interaction + propagation time in fiber.
- Need to consider delay in digitization for accuracy hit timing.

MC tuning

- There are many tuning points in current MC.
- But, I finished tuning temporary and start efficiency of neutrino event at INGRID.
    - At current event select criteria, need not so much accuracy p.e. /hit and hit timing.

Beam MC analysis

- analysis of Beam MC data with the same method as beam data.
    - Use “neutrino event selection”
- Check some distribution of MC data.

Analysis flow chart

Make timing cluster(more than 4 hits within 100nsec)

# of active planes > 1 &&
p.e./active layer > 6.5

On time

Beam related event

# of active planes > 2 &&
p.e./active layer > 6.5

Tracking

Track matching

On time

Upstream VETO

Fiducial volume

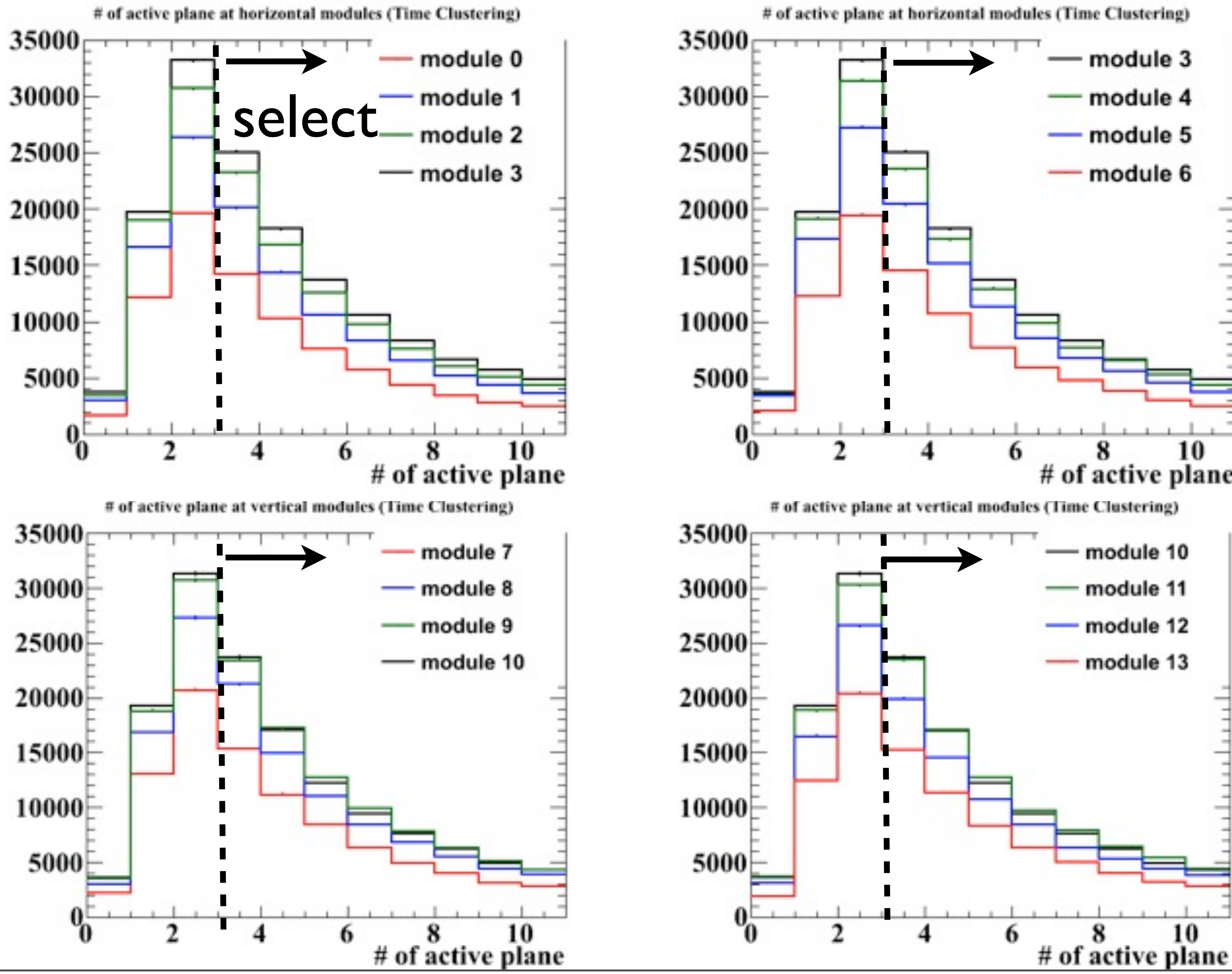
neutrino event

Rock muon enhanced sample

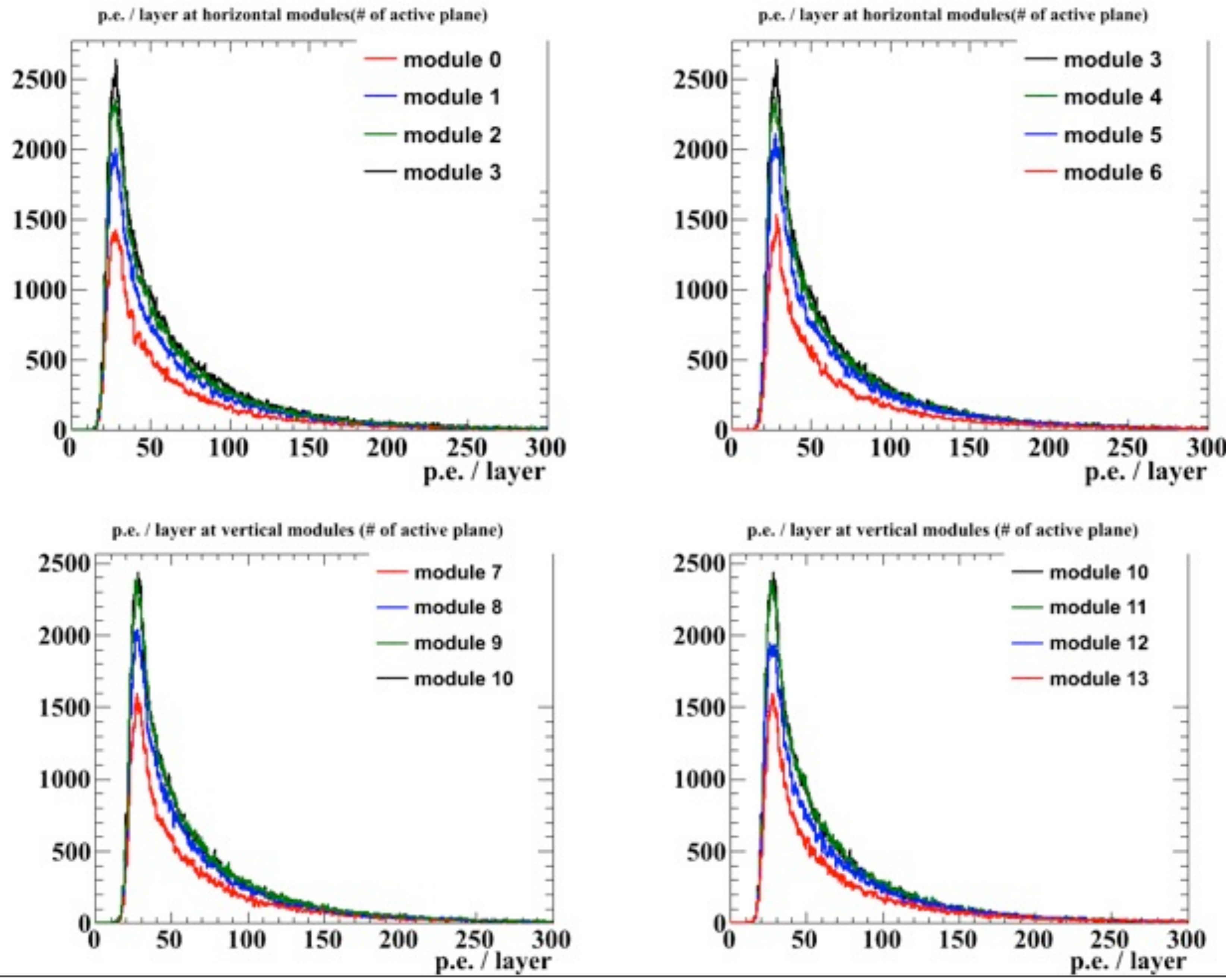
MC data set

- Jnubeam 10a
- NEUT
- Statistics : 1.45×10^6 neutrino interactions.
  - Use only numu interactions.
- INGRID MC was done independently at horizontal and vertical modules.

of active plane
(after Time cluster cut)

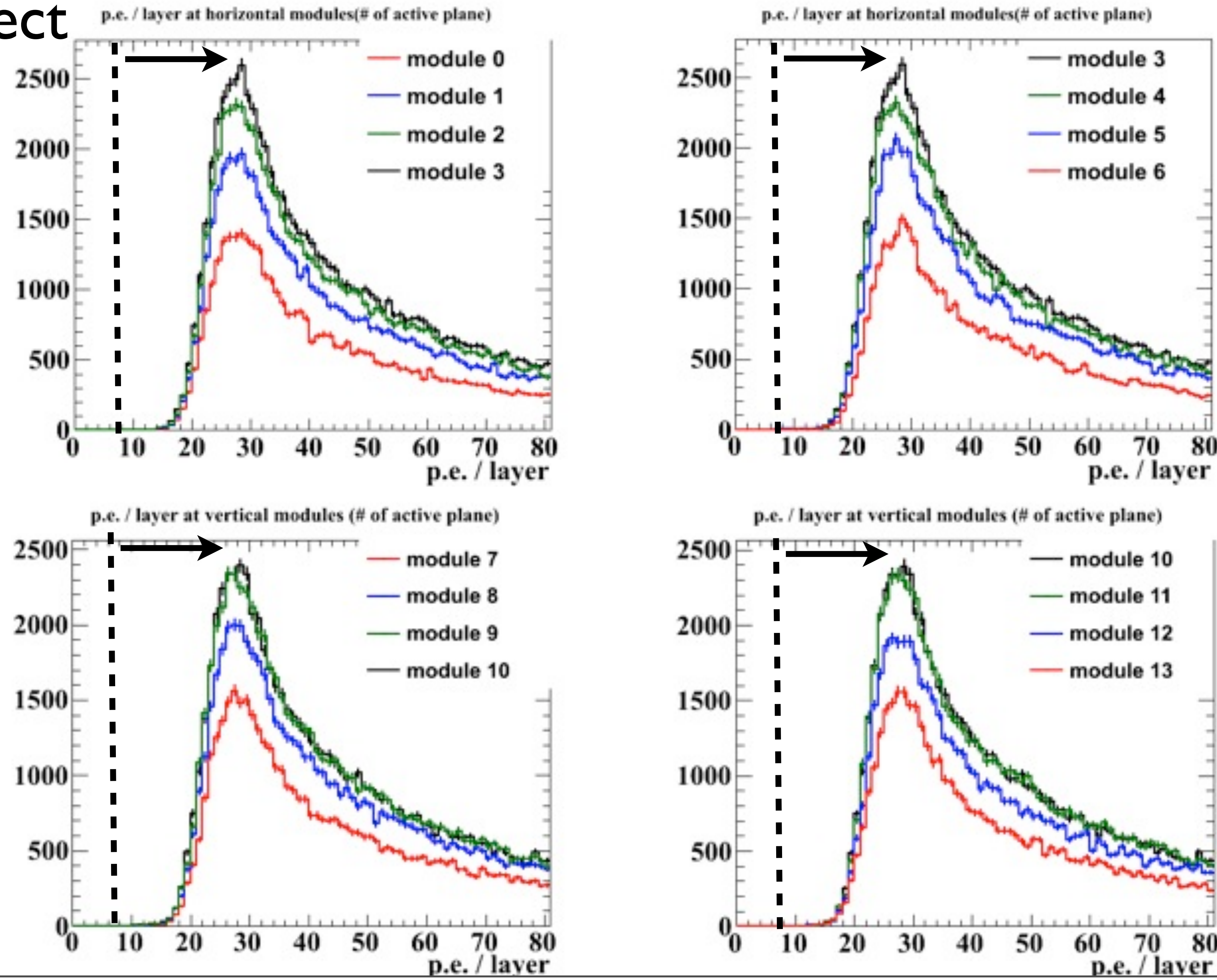


p.e. / active layer
(after # of active plane cut)



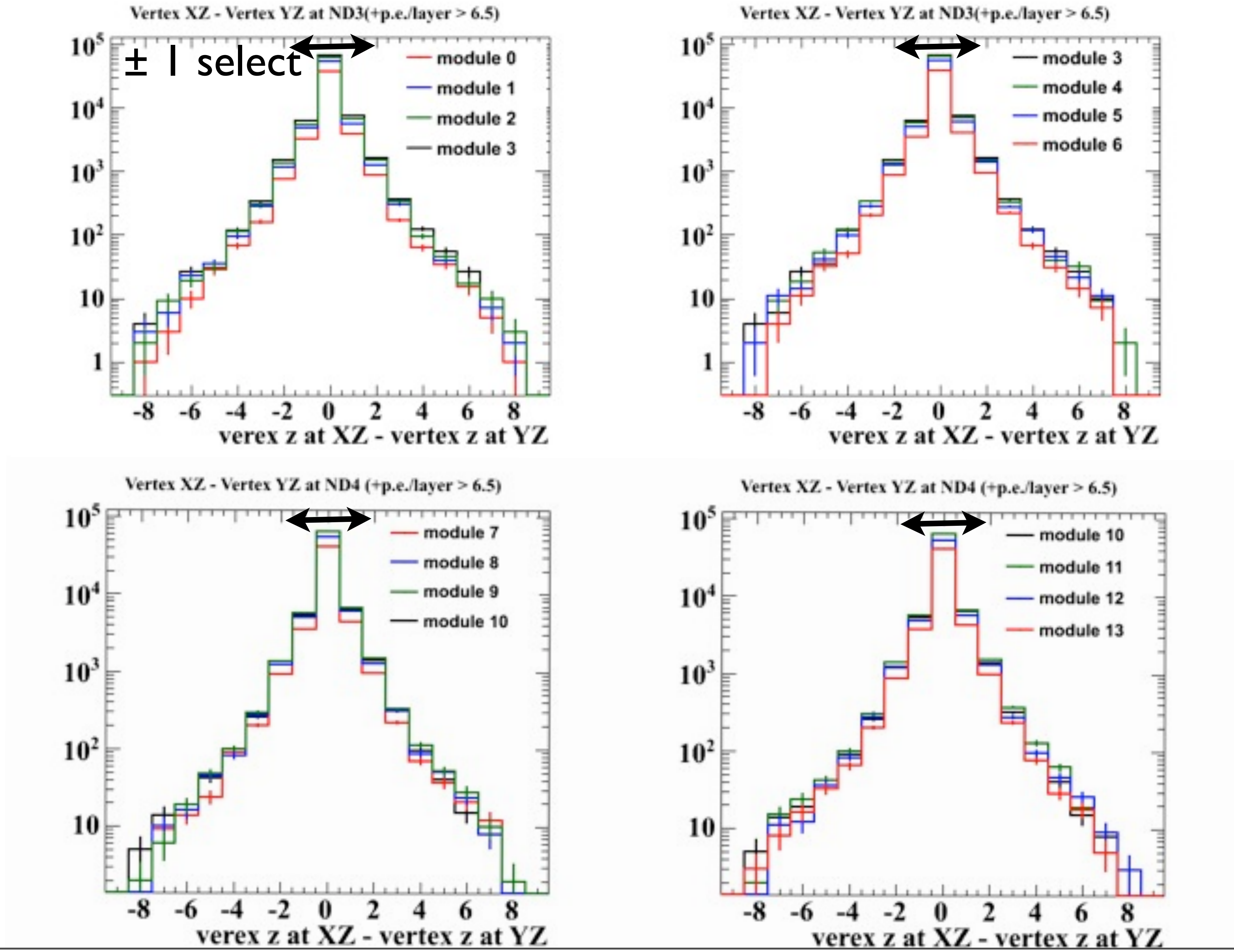
p.e. / active layer at low region
(after # of active plane cut)

select

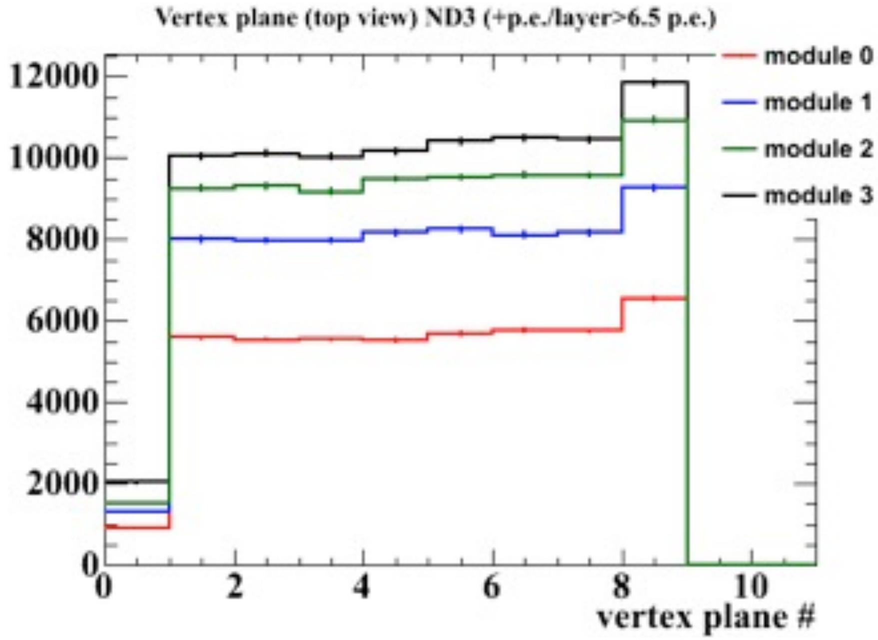


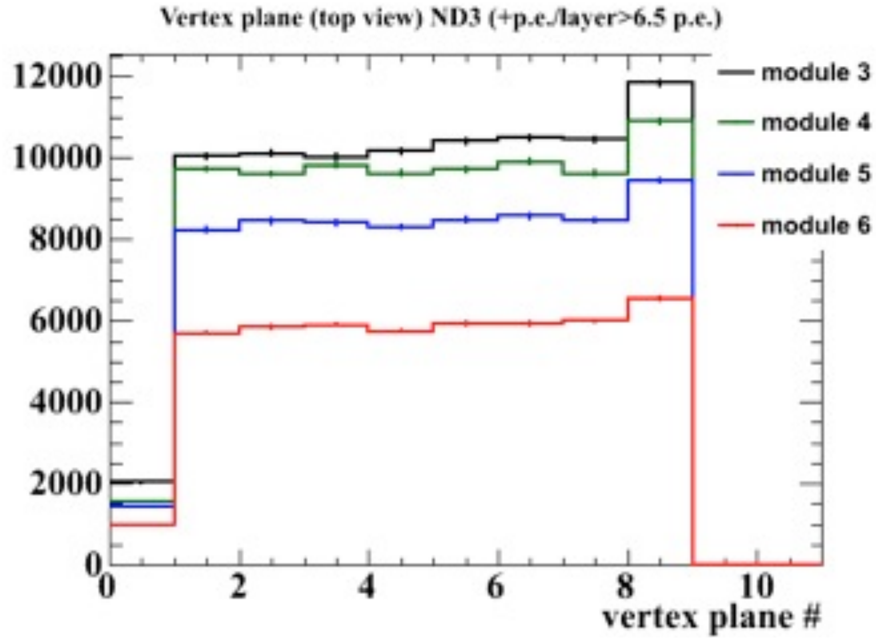
X-Z and Y-Z track matching

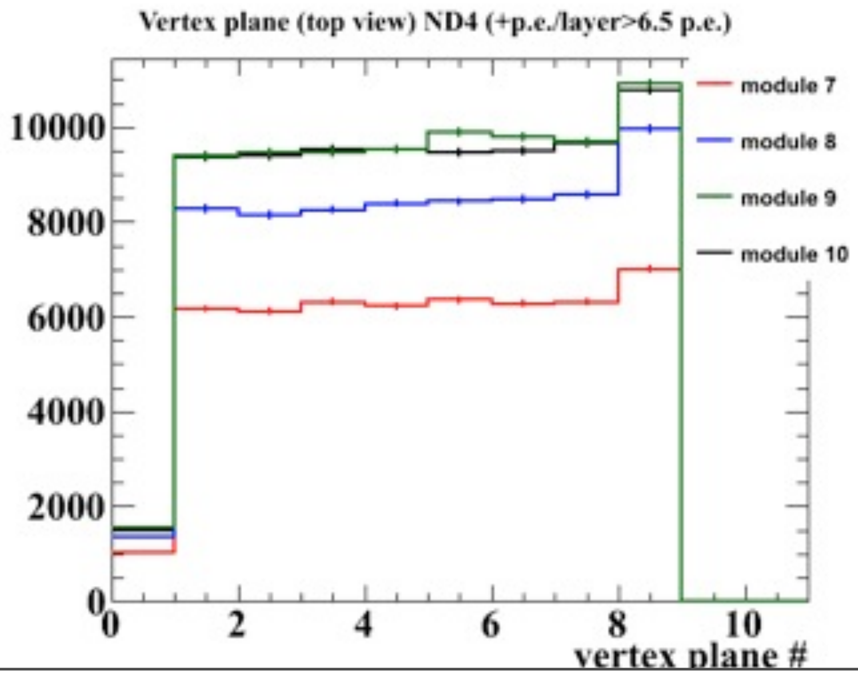
after tracking.

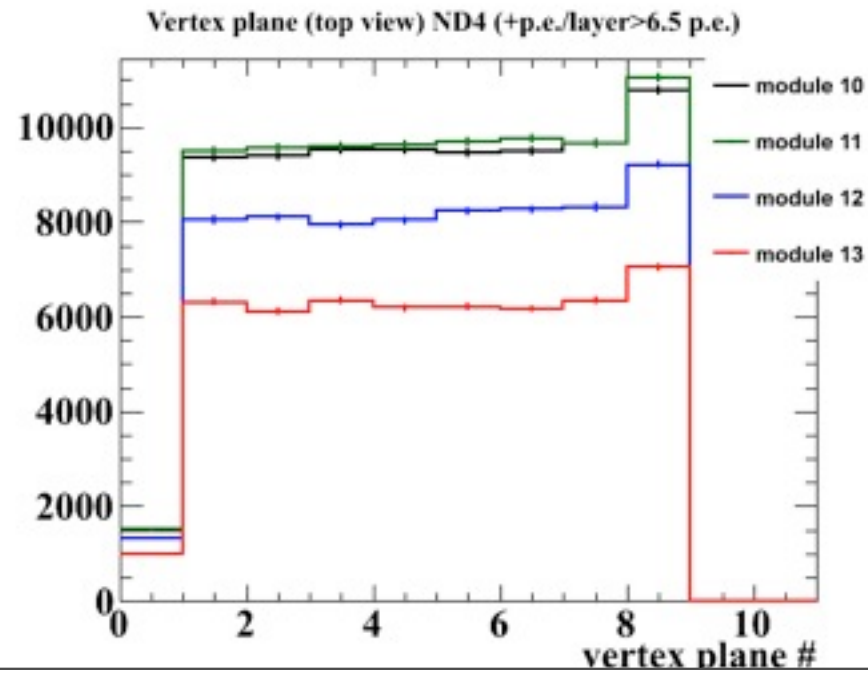


Vertex Z
after track matching

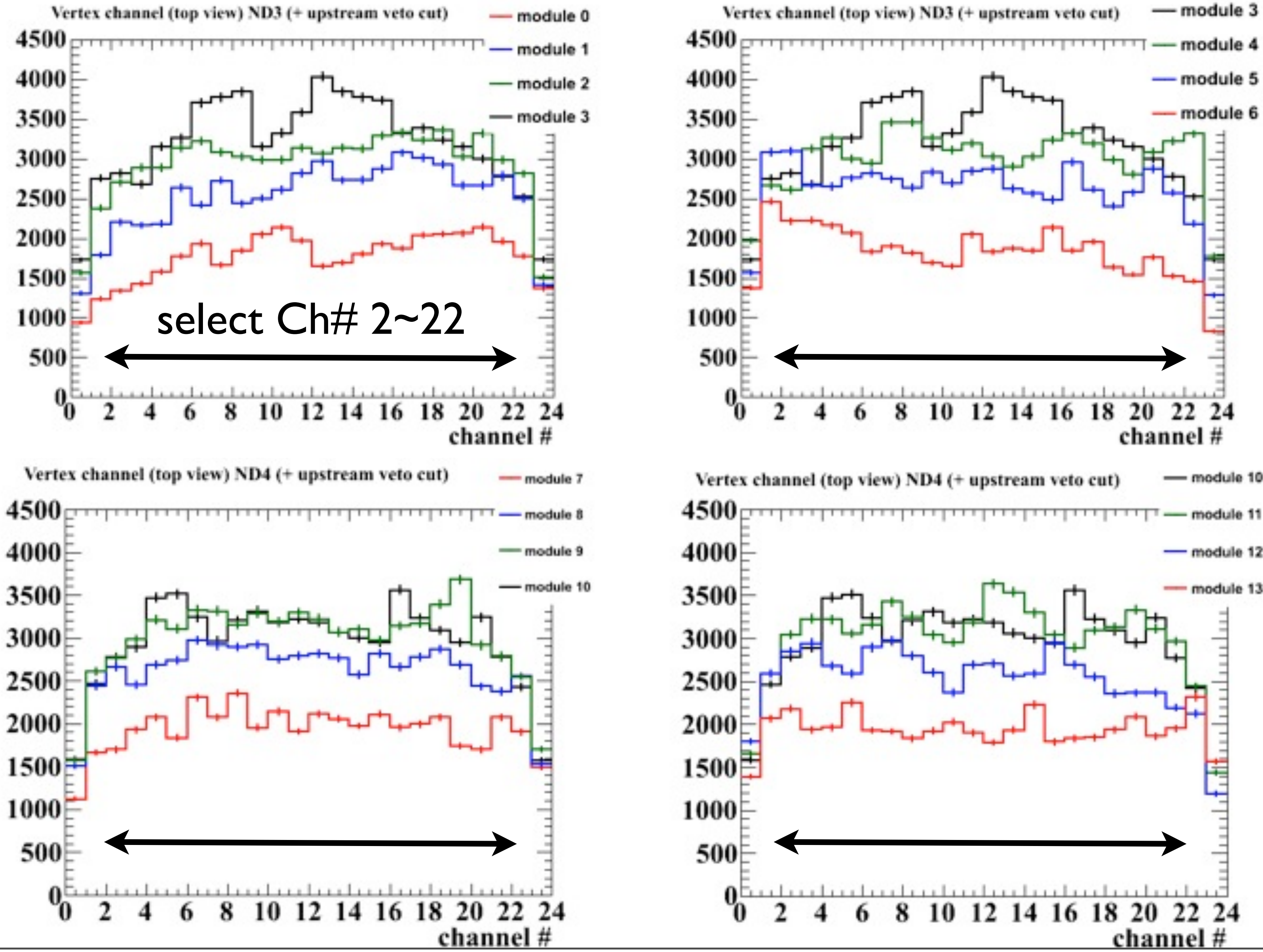








Vertex X
after Upstream VETO cut



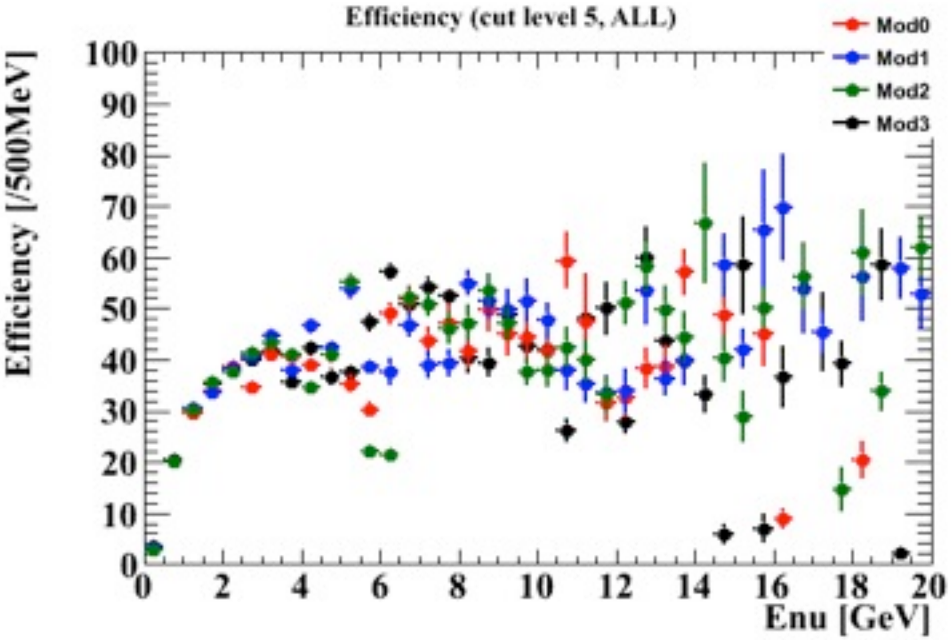
Efficiency of "neutrino event selection"

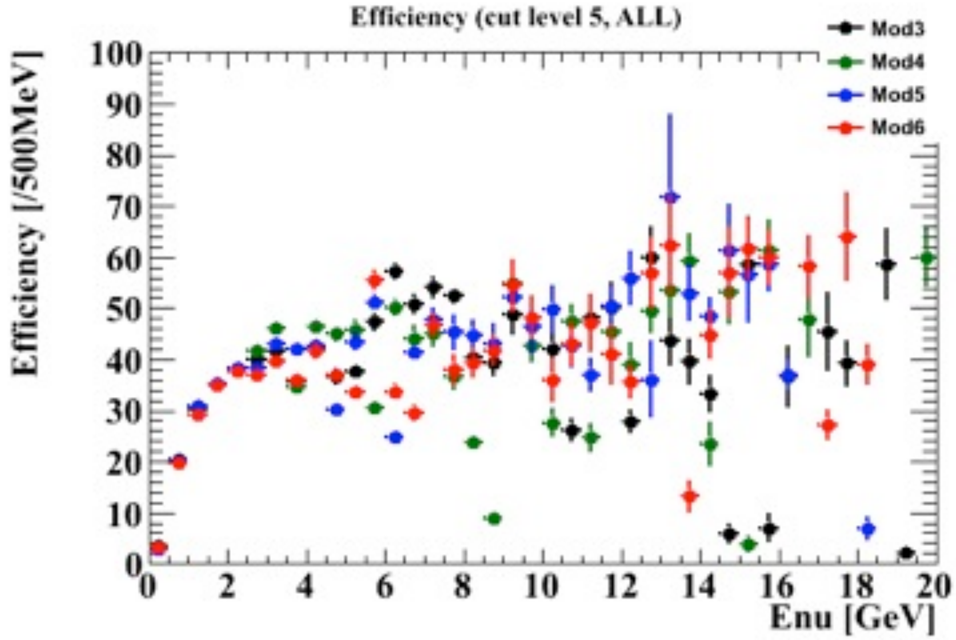
- Event select method is same as analysis of beam data ("neutrino event select" flow chart).

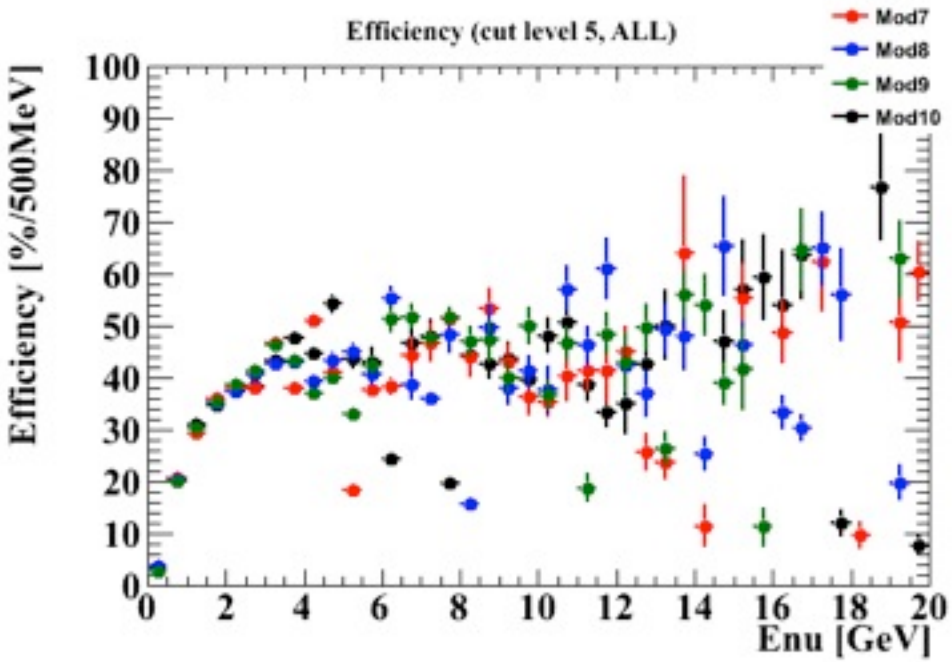
$$\boxed{Efficiency(Enu) = \frac{\phi^{obs}(Enu)}{\phi^{int}(Enu)}}$$

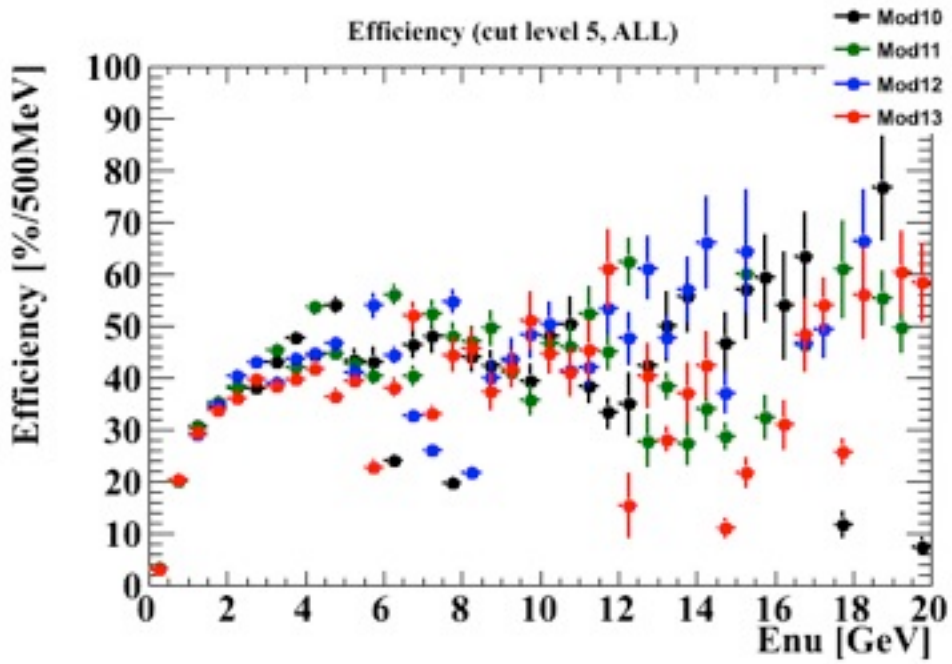
  - Φobs(Enu) = # of events observed after event selection
  - Φint(Enu) = # of interactions inside modules
  - The error bar includes only statistics error.

Efficiency of "neutrino selection"

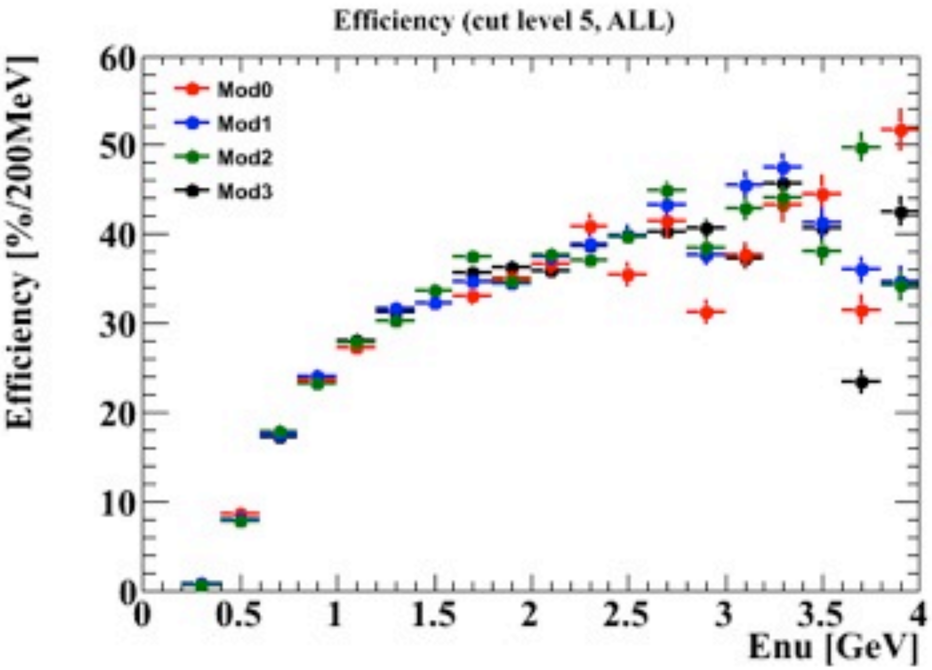


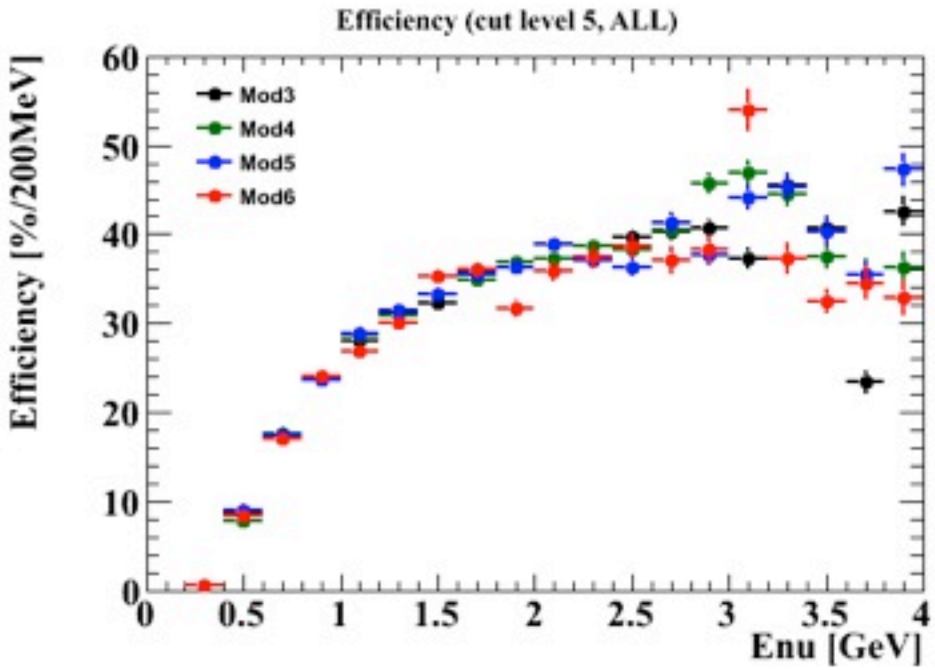


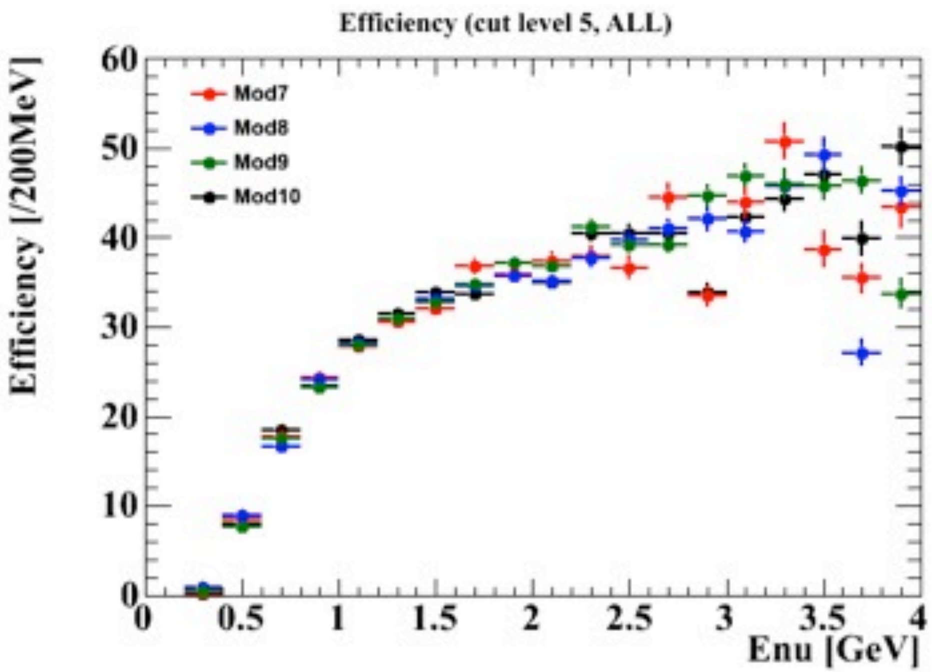


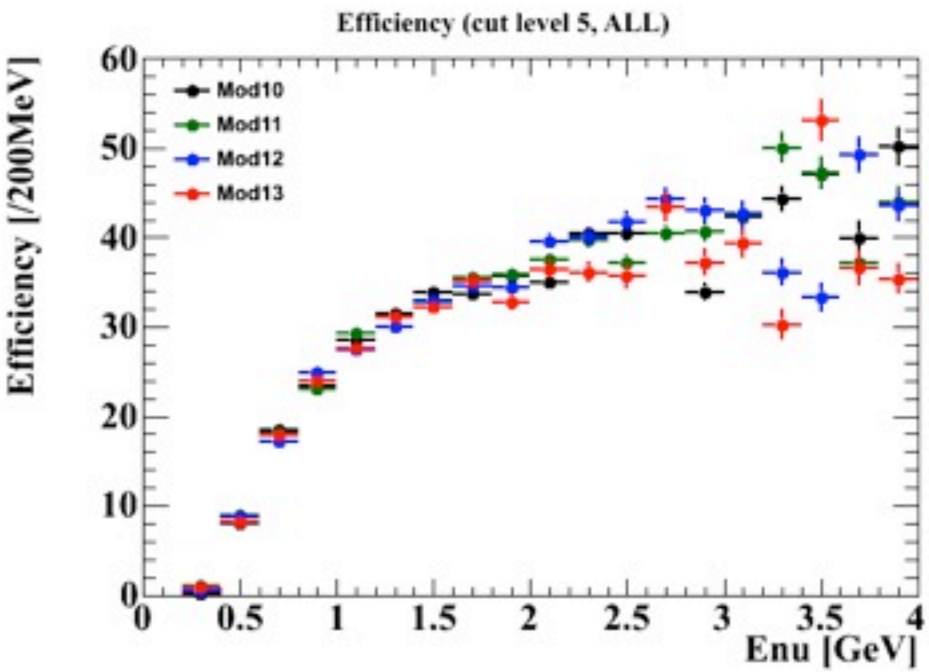


Zoom low Energy









Comment

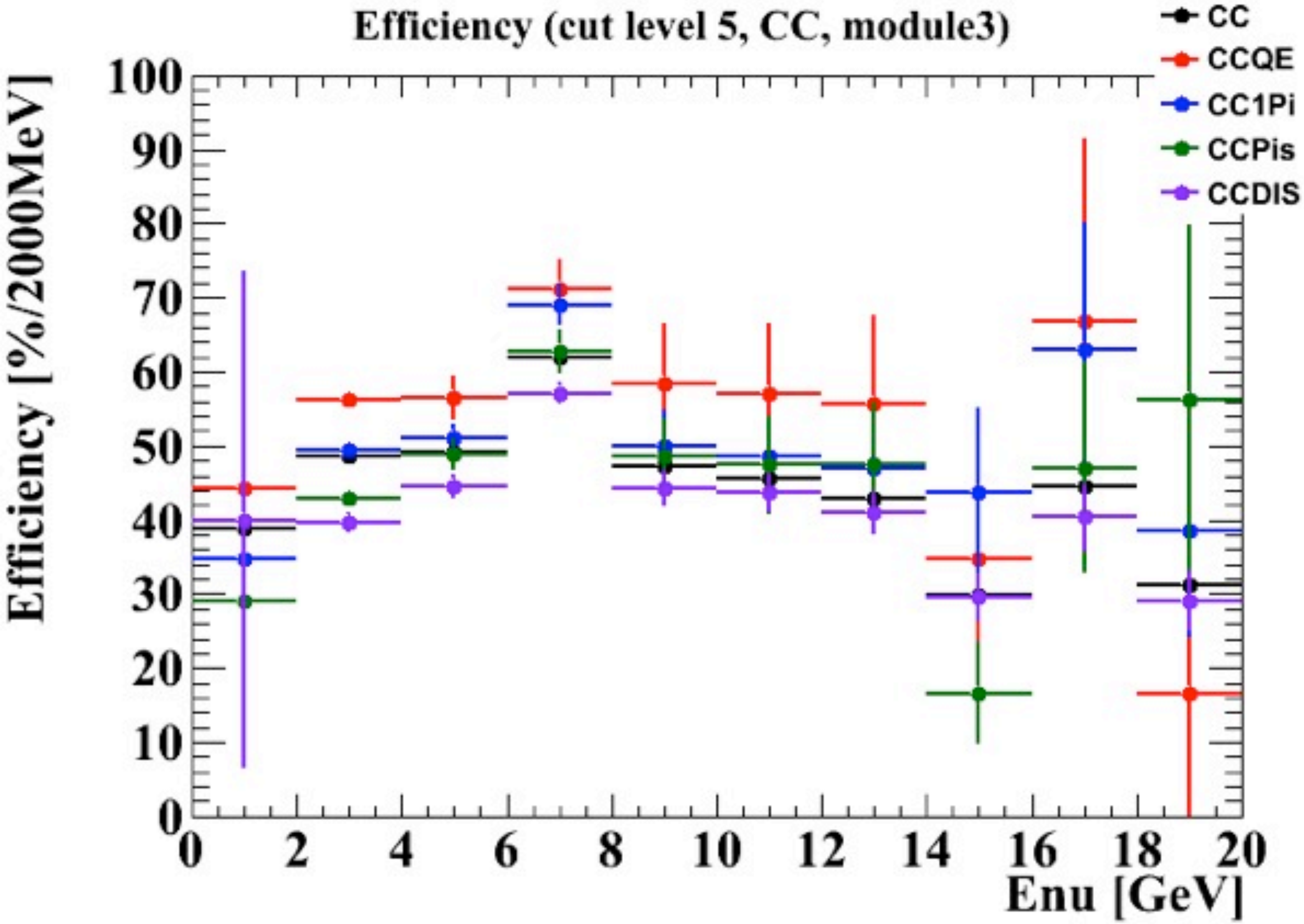
- Efficiency of each module depends mainly on neutrino energy.
  - At low energy region, the efficiency of each module seems to be same.
  - At high energy region, fluctuation of efficiency is large (due to low MC sample ?)

Efficiency to CC or NC interactions

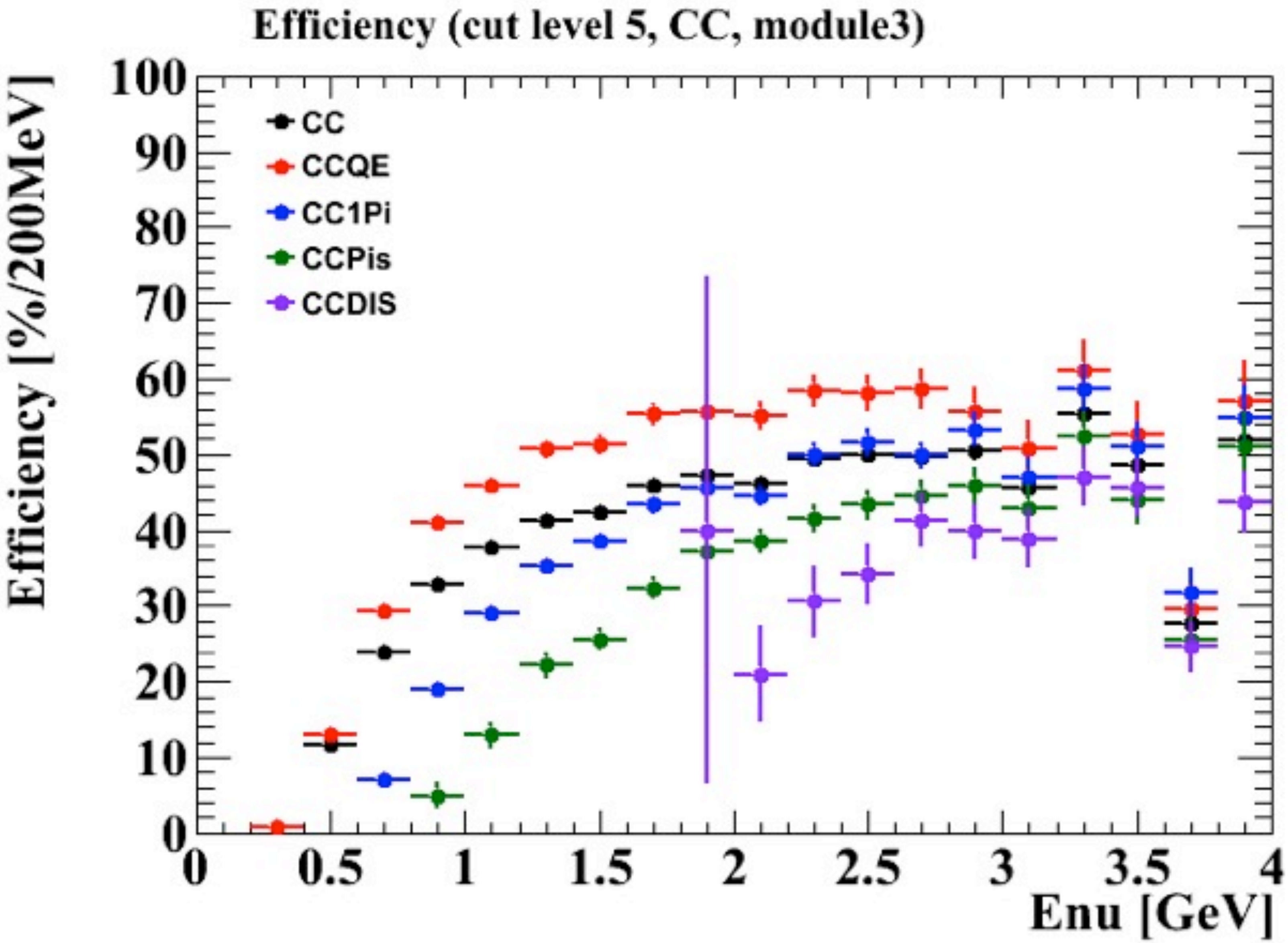
$$Efficiency(Enu) = \frac{\phi^{obs}_{mode}(Enu)}{\phi^{int}_{mode}(Enu)}$$

- Φ^{obs}_{mode}(Enu) = # of events observed after "neutrino event selection"
- Φ^{int}_{mode}(Enu) = # of interactions inside modules
  - calc at each neutrino interaction mode.
- The error bar includes only statistical error.

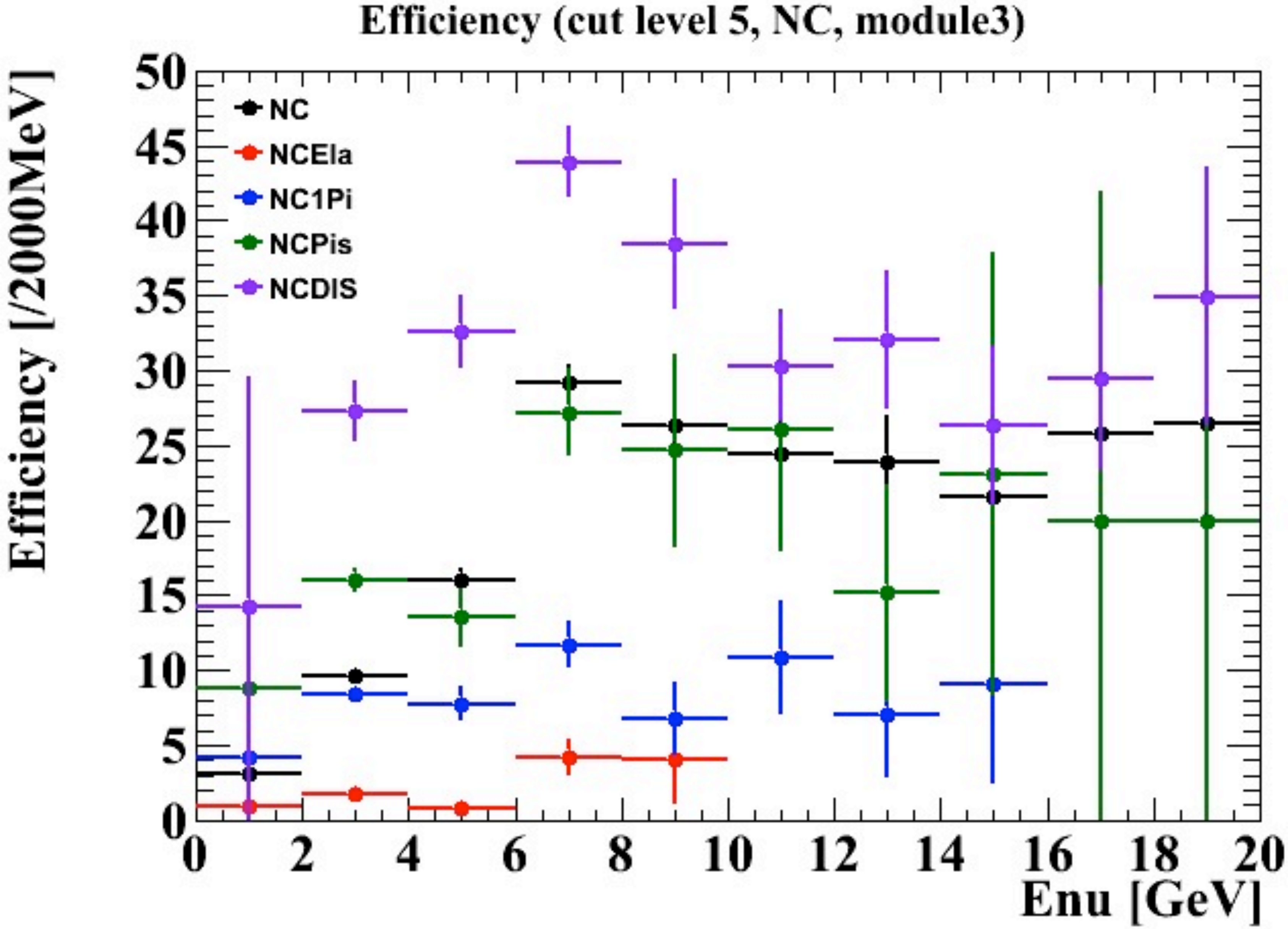
Efficiency to CC



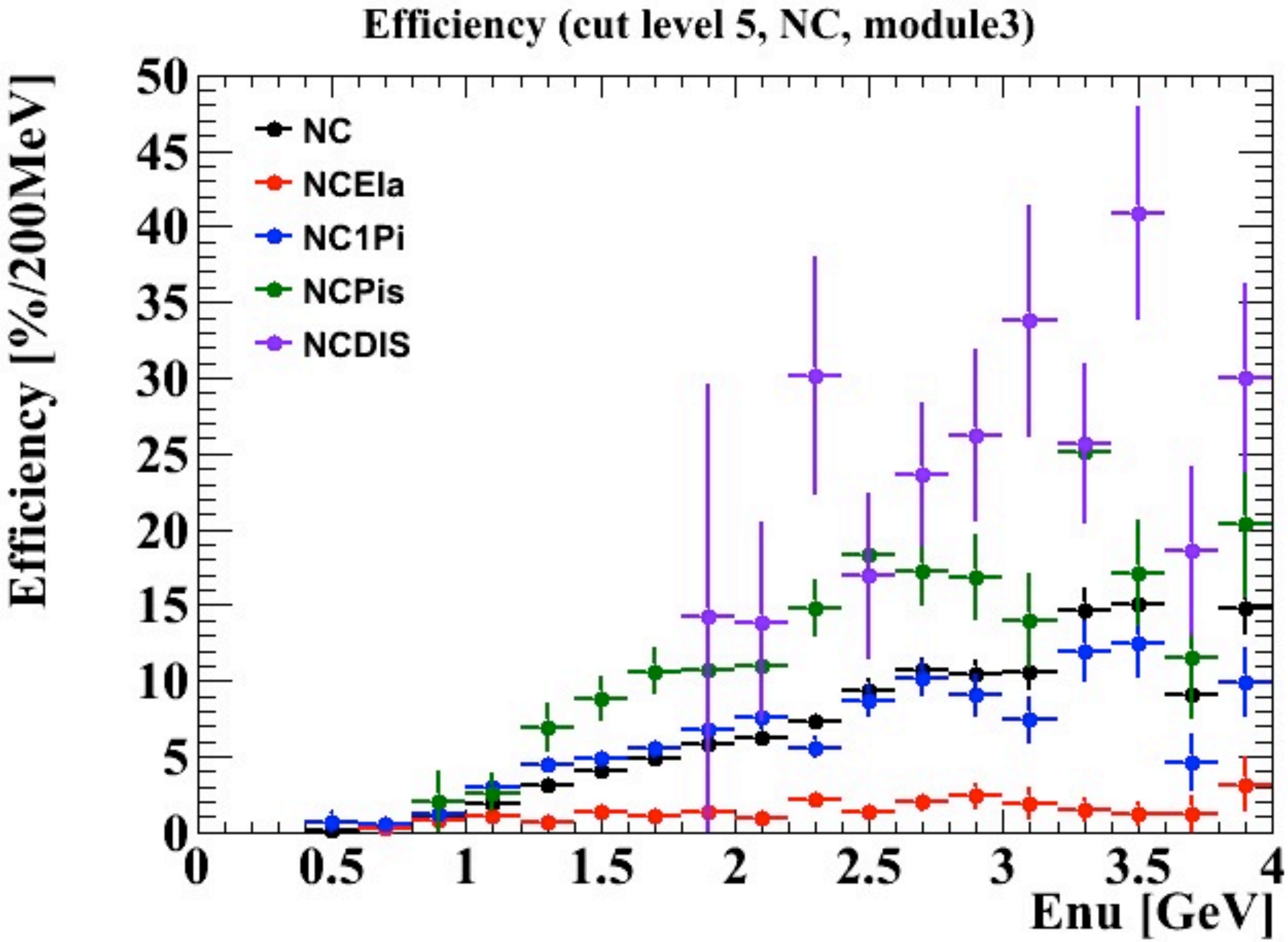
Efficiency to CC (at low energy)



Efficiency to NC

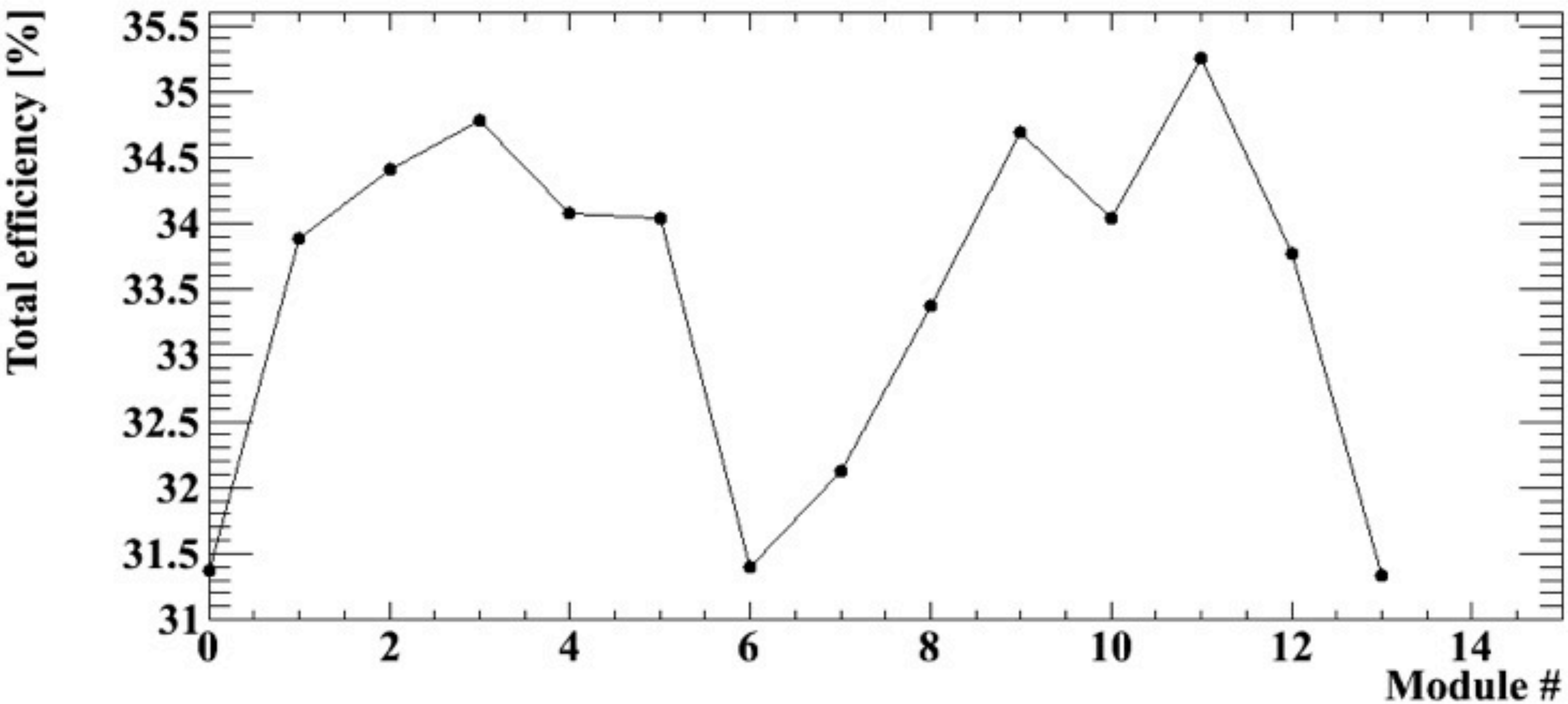


Efficiency to NC (at low energy)



Total efficiency of each modules

$$Total\ efficiency = \frac{\int \phi^{obs}(E)dE}{\int \phi^{int}(E)dE}$$



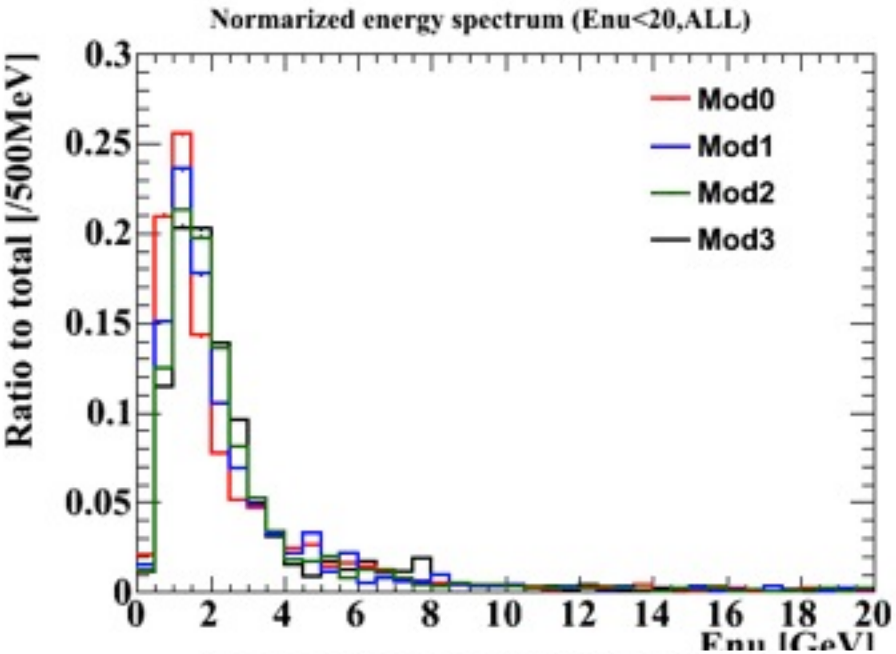
Diff of total efficiency of each modules

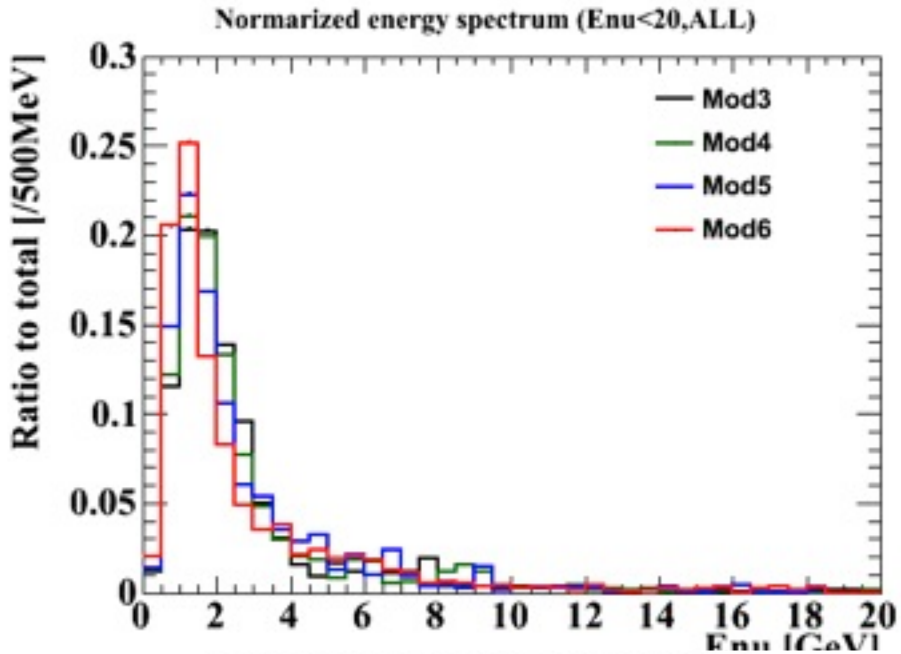
- Diff of total efficiency of each module depends mainly on neutrino energy spectrum at each modules.
  - Efficiency at each energy region depends on neutrino energy, not module.

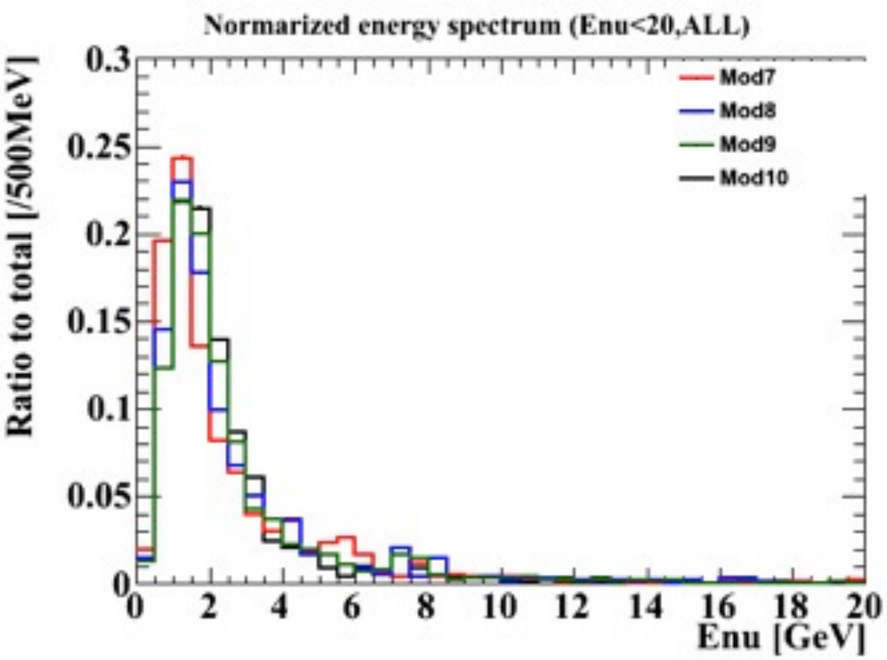
$$Total\ efficiency = \int \phi^{int}_{Norm}(E) \times \varepsilon(E) dE$$

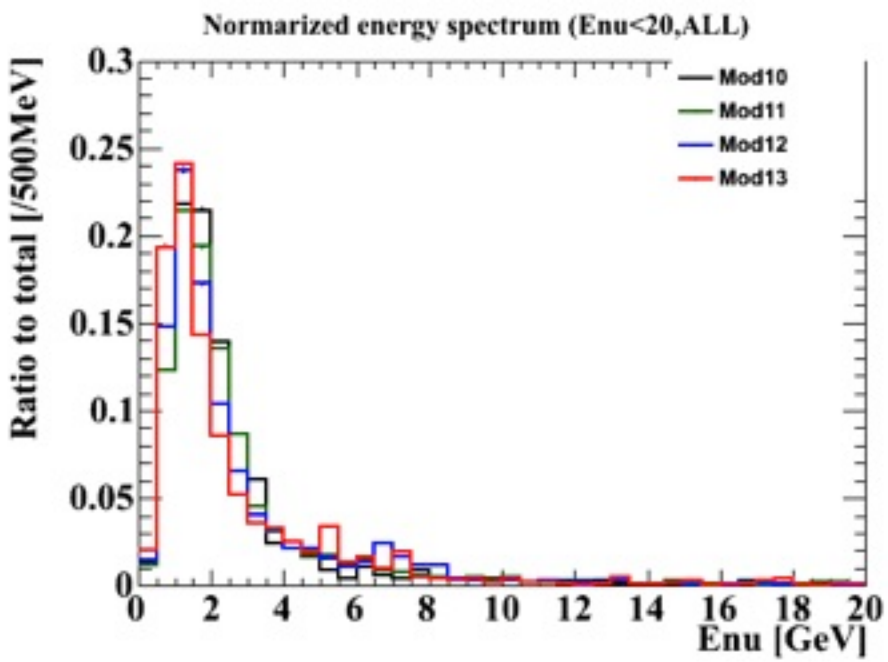
- Φ^{int}_{norm} : Normalized Neutrino energy spectrum by area.
- ε : efficiency at each energy.

Normalized neutrino energy spectrum

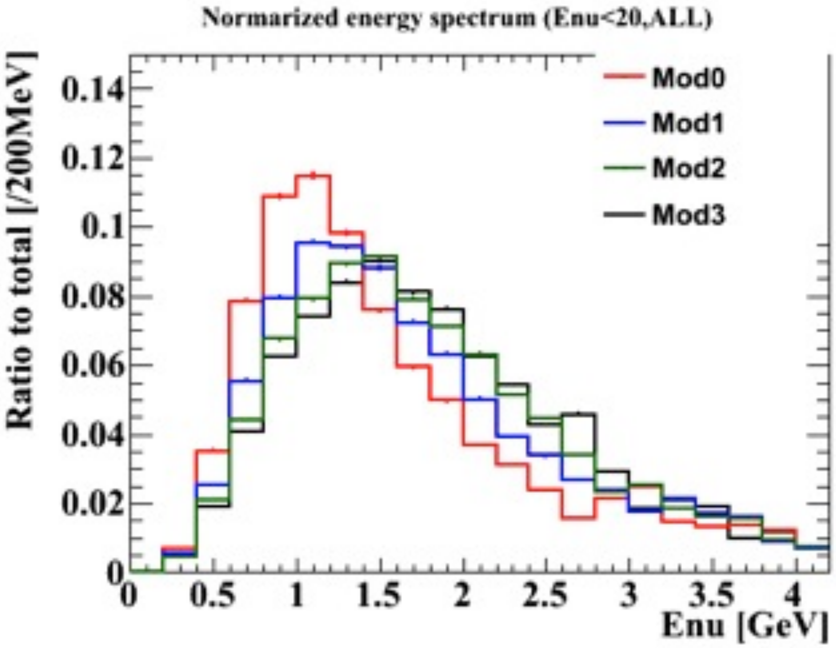


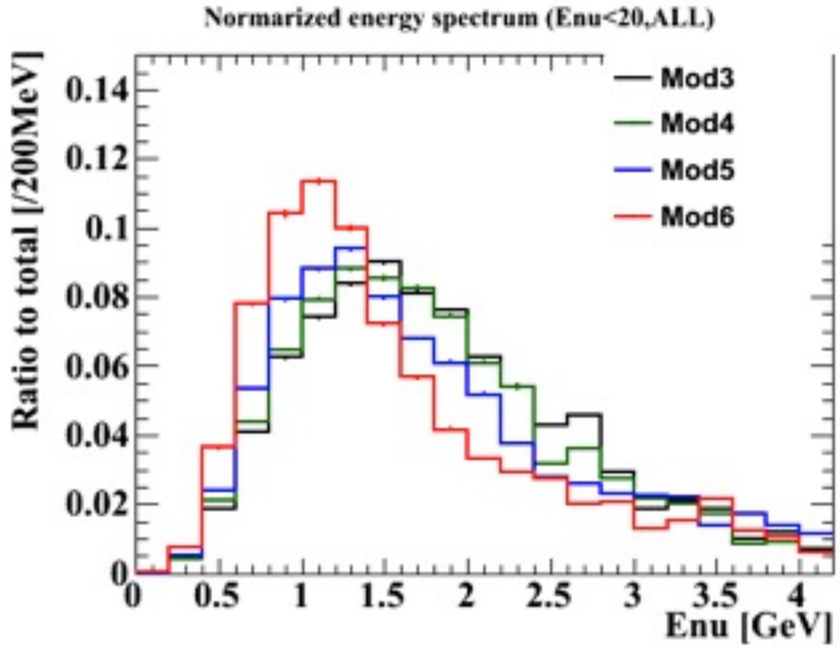


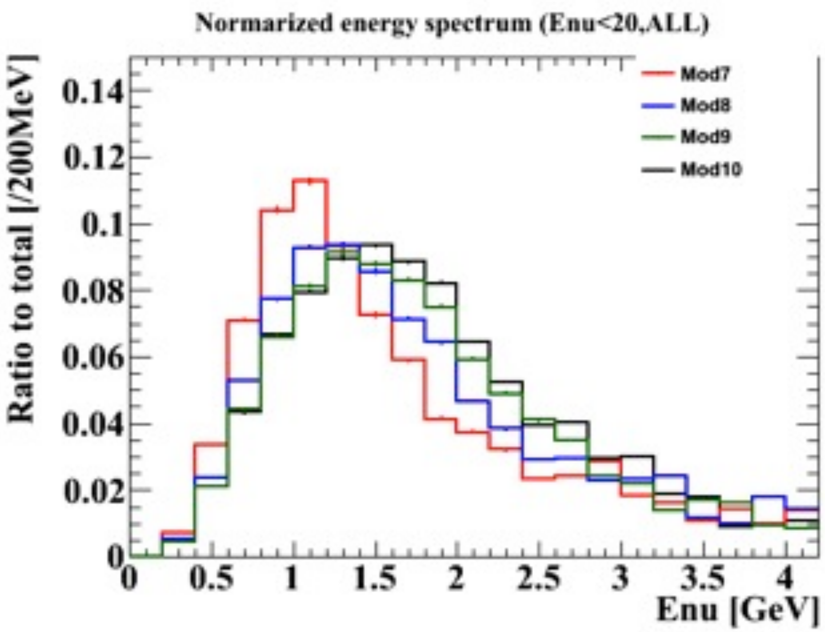


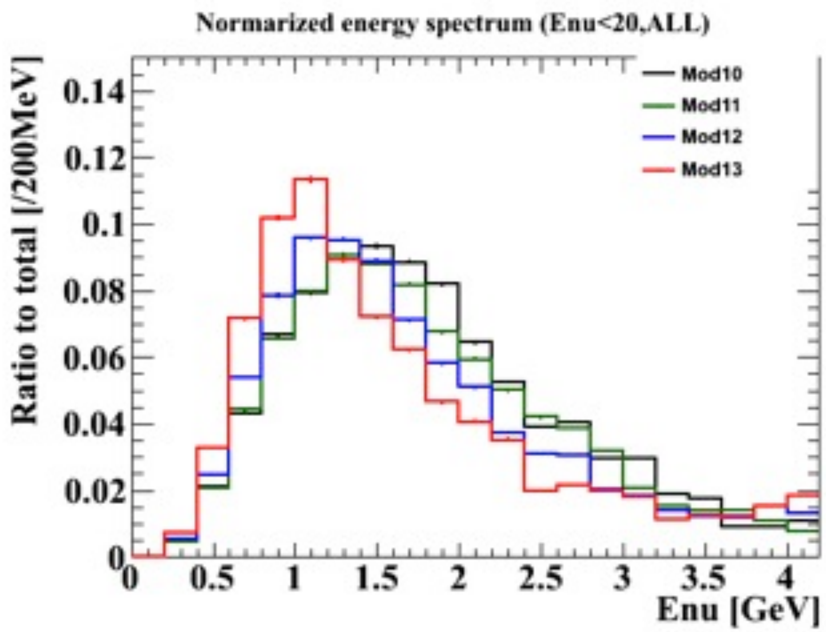


Normalized neutrino energy spectrum (zoom around peak)









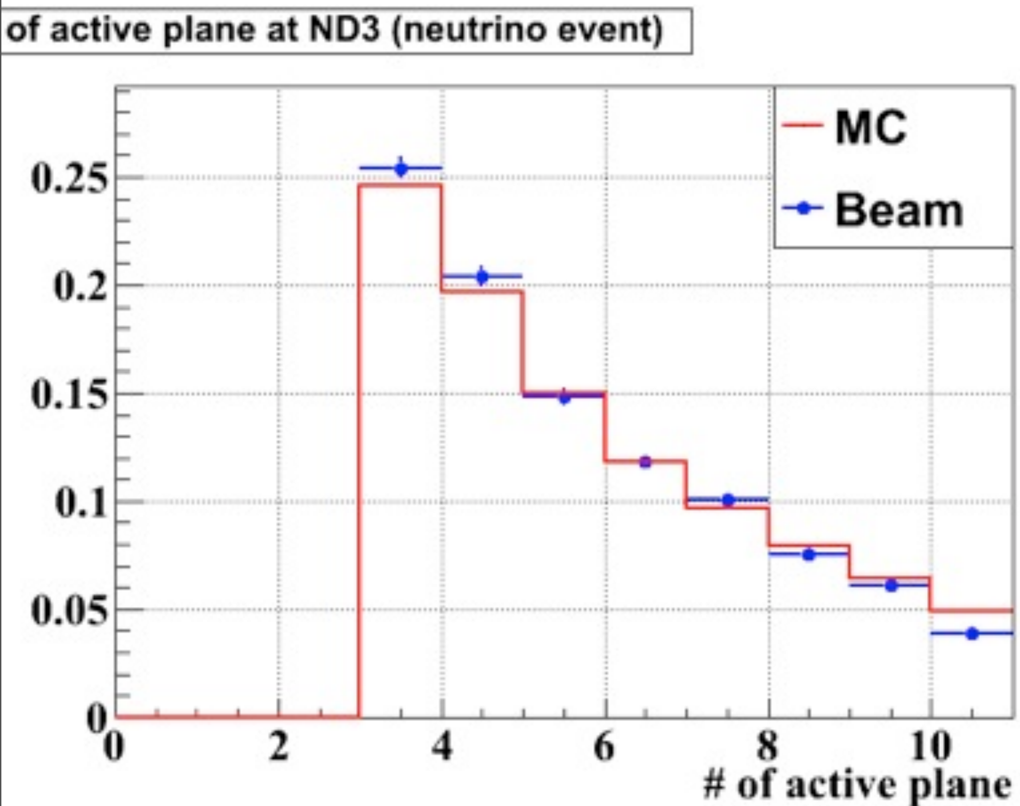
Beam Data vs MC

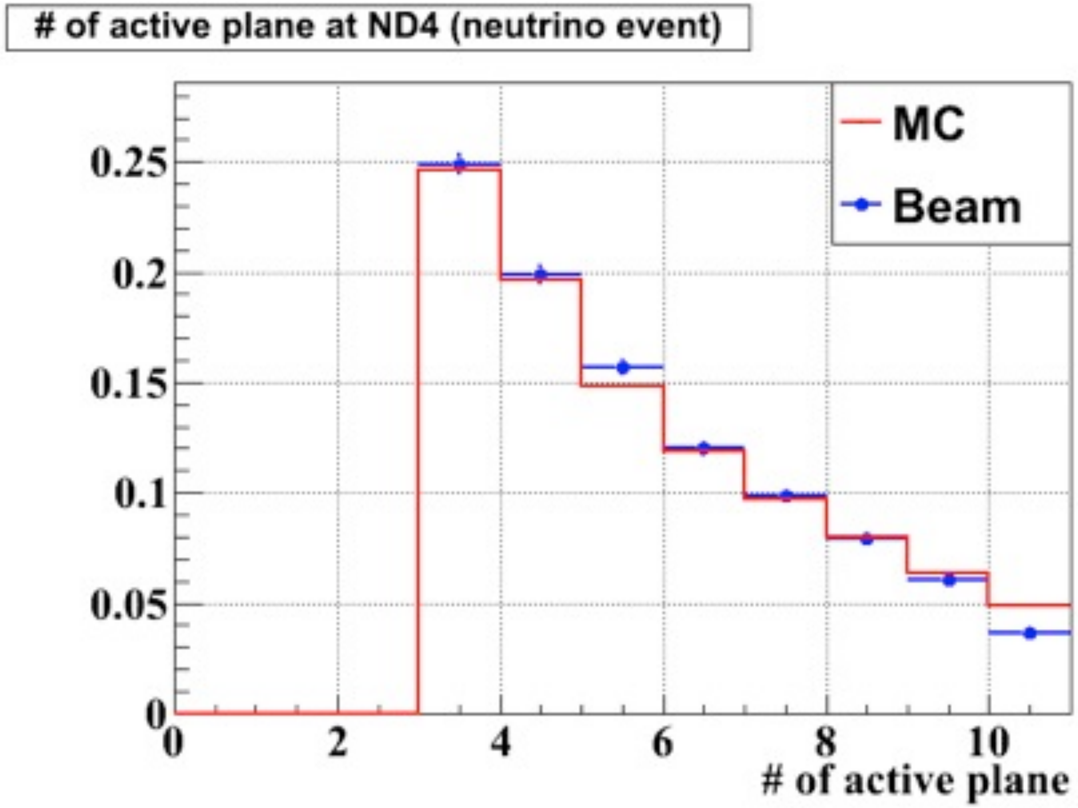
- After "neutrino event selection", compare MC to beam data on some distribution.
  - MC not include background (rock muon event, cosmic event).
- If large difference, current event selection has possibility not to reject these back ground.
- For cancel diff of POT, each distribution is normalized by area.

Data set

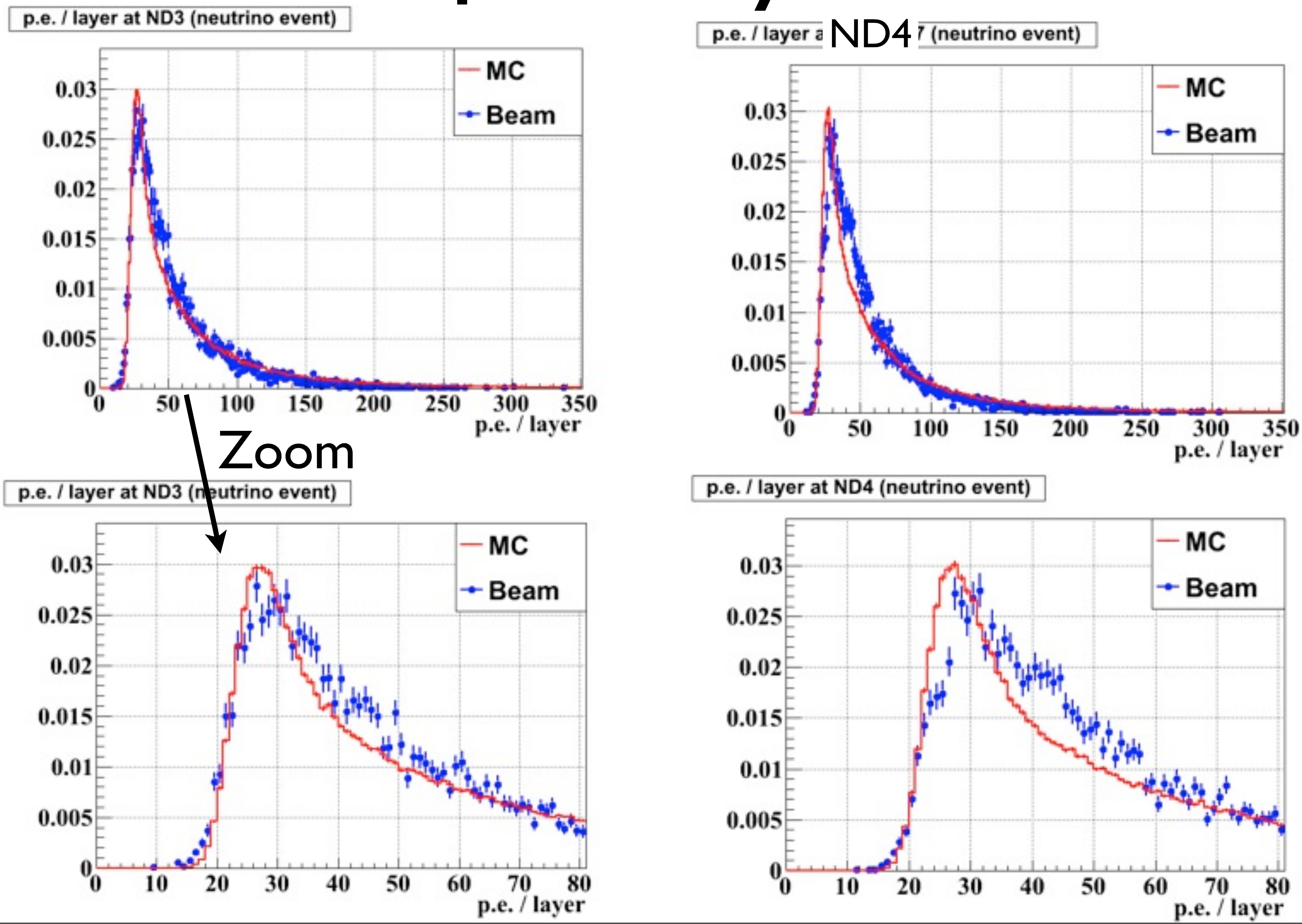
- MC
  - Jnubeam 10a, Neut, 9.5×10^5 interactions
- Beam data
  - Run31
- Show distribution at ND3, ND4.
  - About distribution at each module, put this URL http://www-he.scphys.kyoto-u.ac.jp/~akira.m/ingrid/presen/plot_neutrino_select.pdf.

of active plane

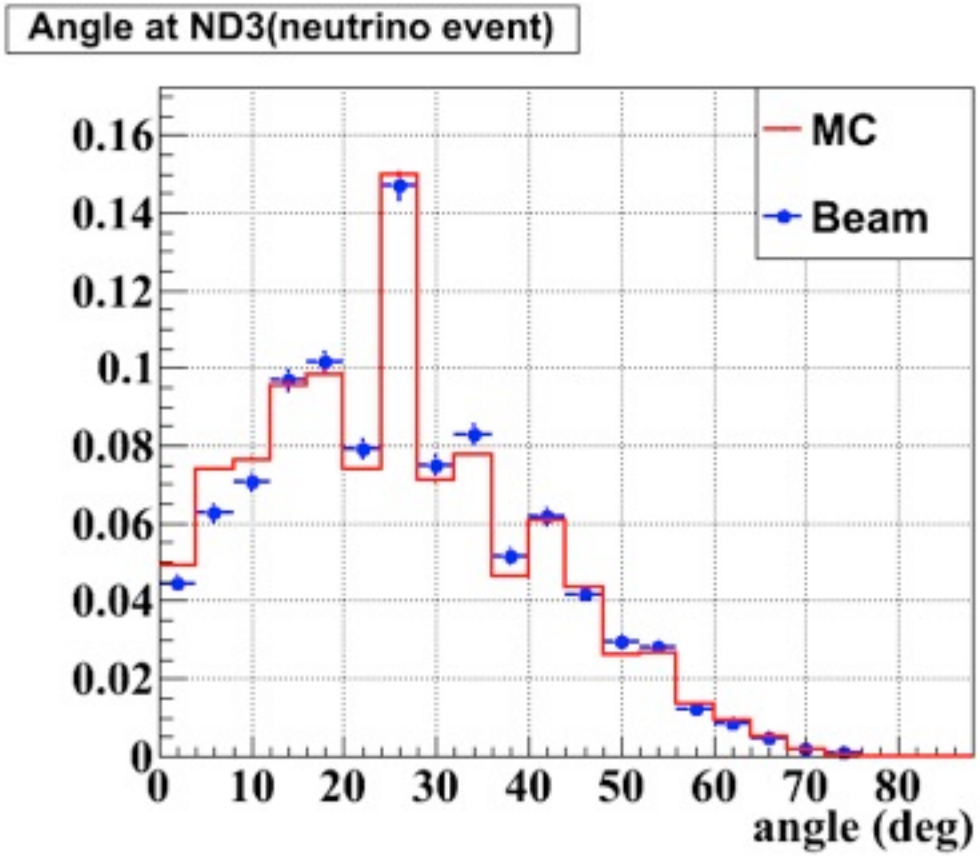


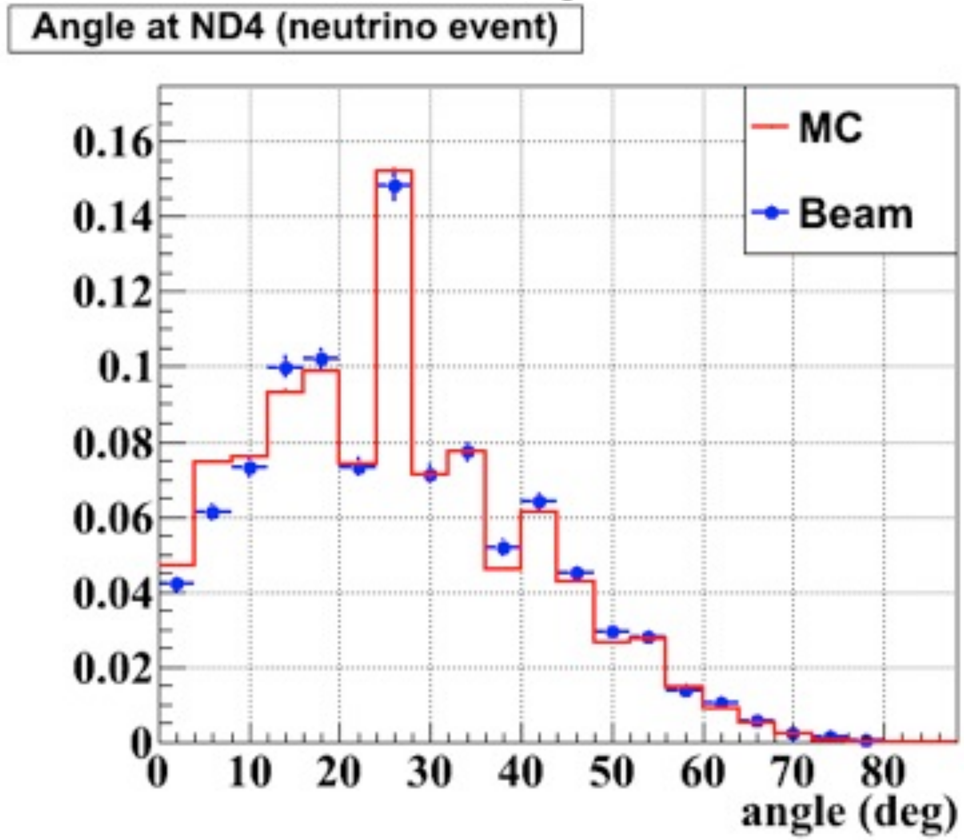


p.e. / layer

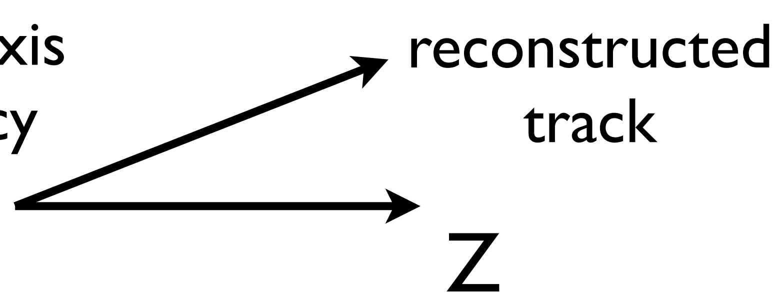

p.e. / layer at ND3 (neutrino event)
ND4
(neutrino event)
p.e. / layer at ND4 (neutrino event)
MC
Beam
p.e. / layer
Zoom
0
0.005
0.01
0.015
0.02
0.025
0.03
50
100
150
200
250
300
350
10
20
30
40
60
70
80

Reconstructed Angle

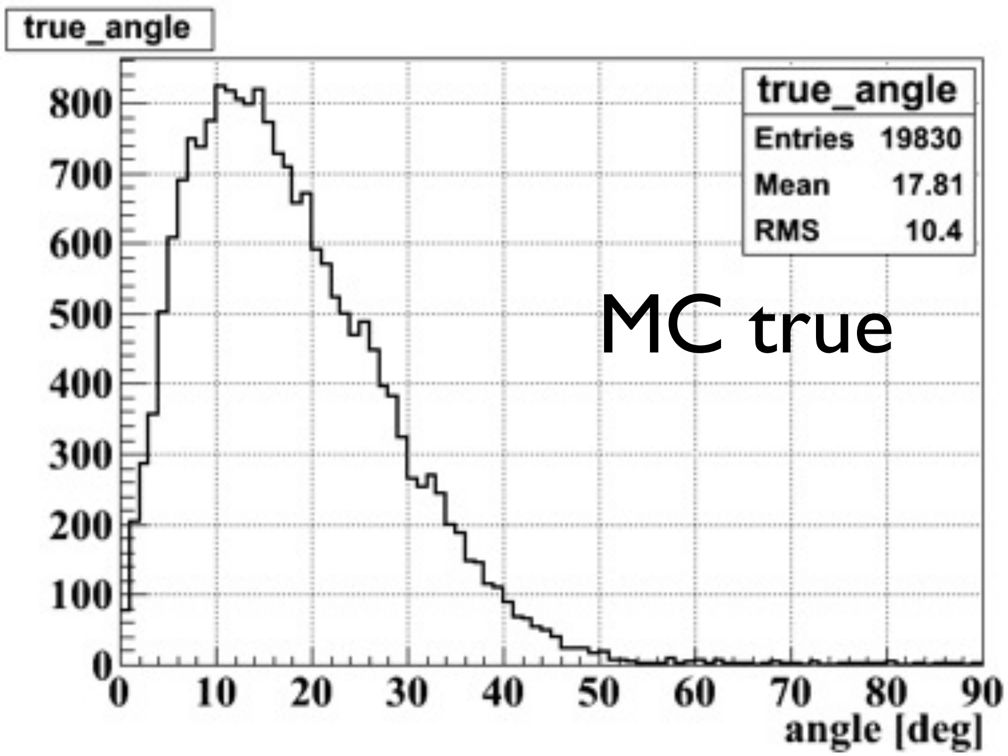


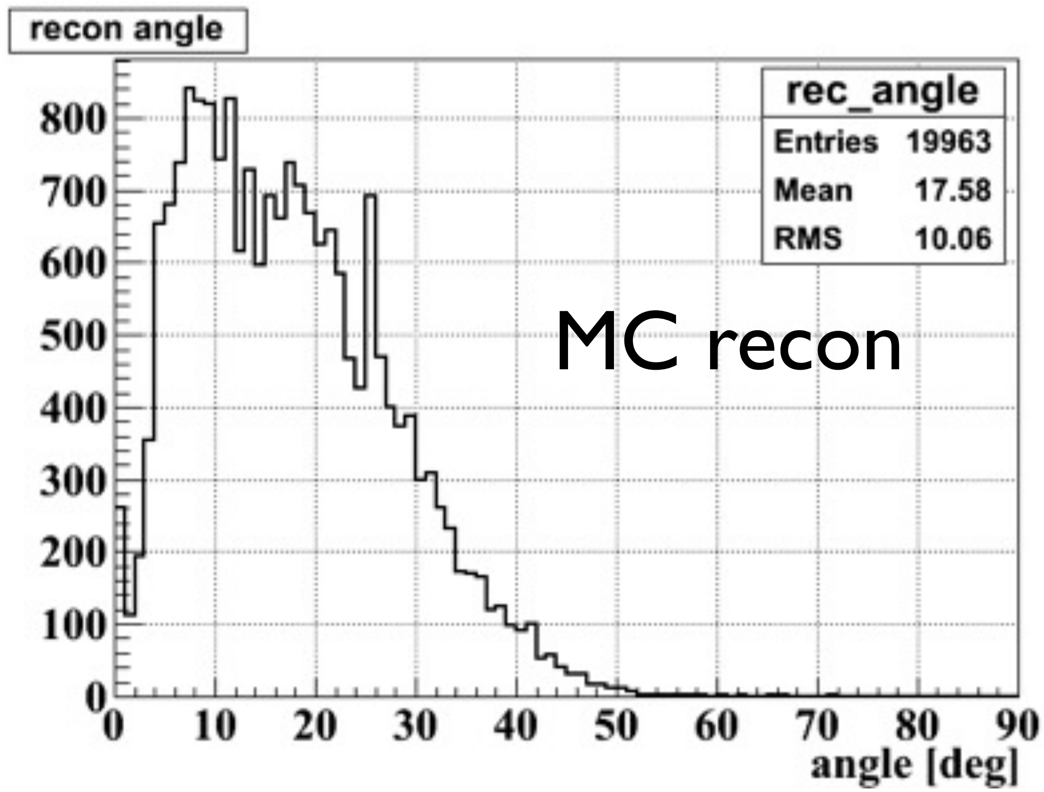


Reconstructed angle is between track and Z-axis
Bin size is decide from reconstructed accuracy
(detail is next page)

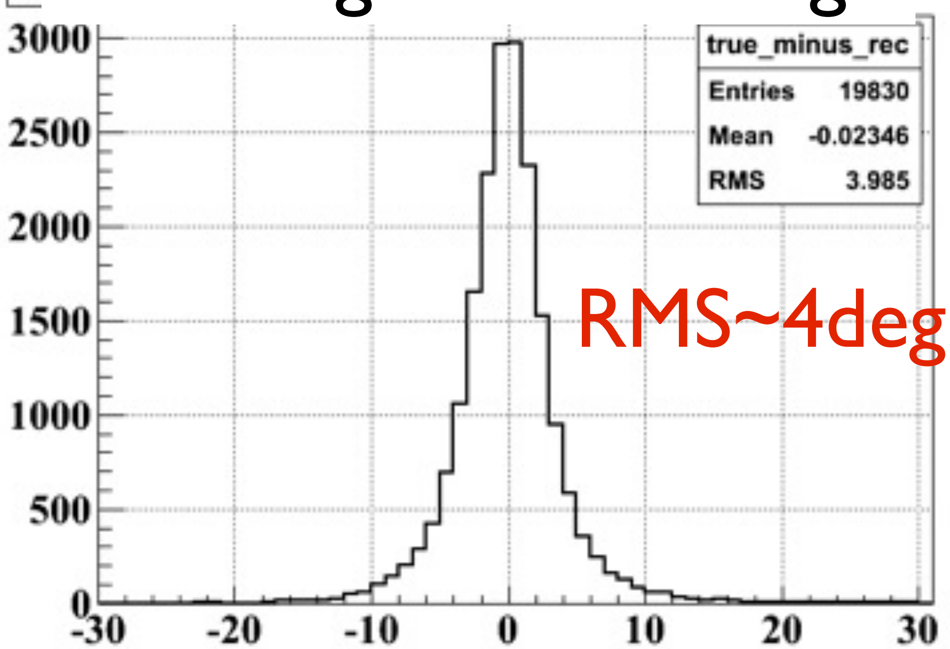


This angle distribution seems to be due to tracking plane structure (need to consider).



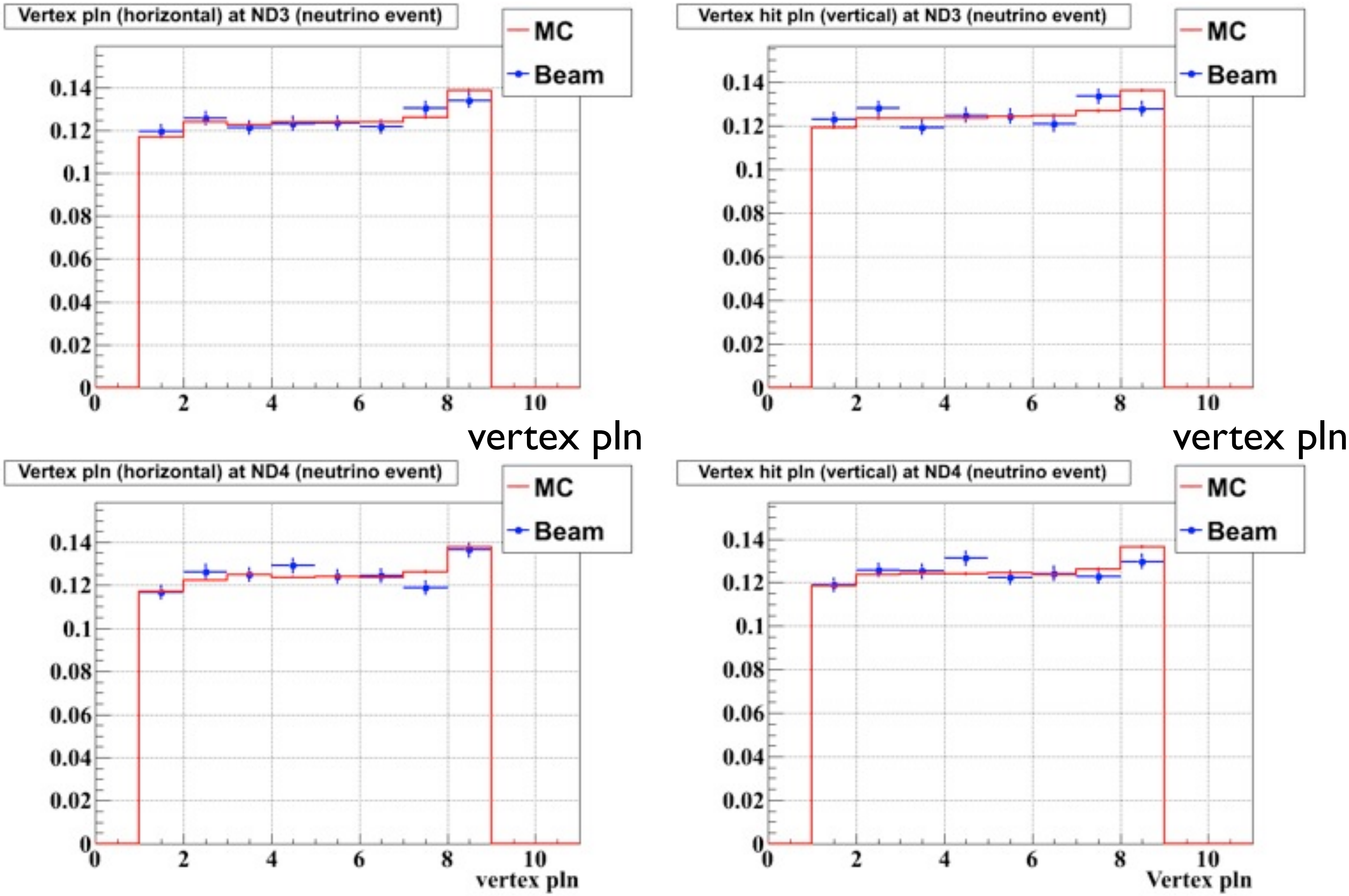


True angle - recon angle



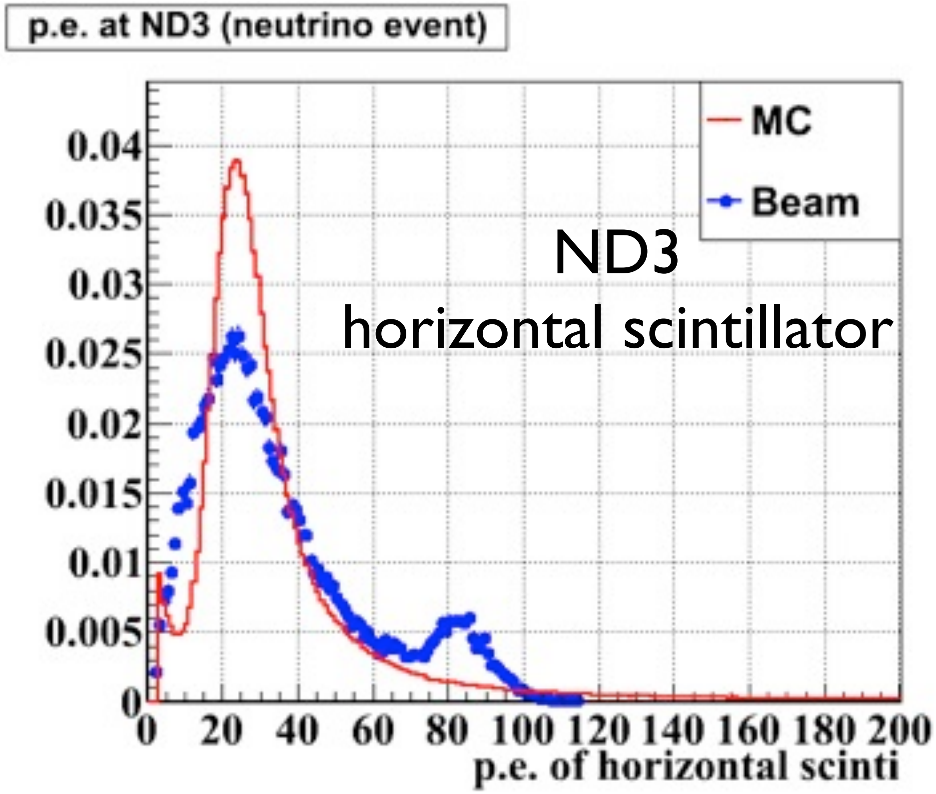
Select long muon track in MC.
→ Tracking & calc recon angle
→ Calc diff between recon angle and true muon angle
→ The RMS of this diff distribution is the accuracy of reconstruction.

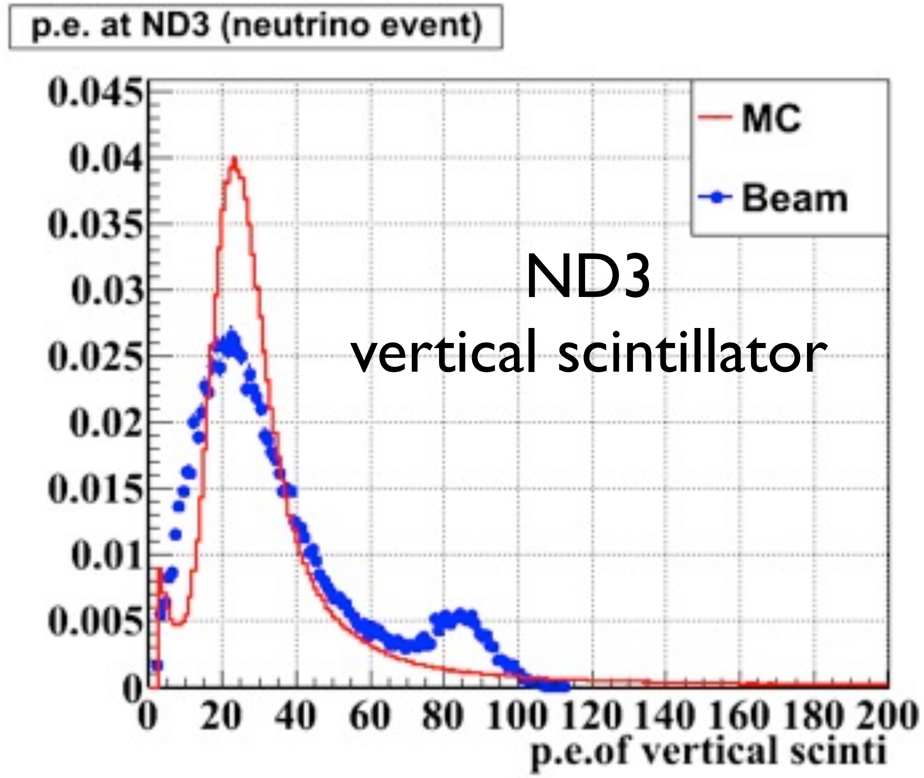
reconstructed vertex z (pln)

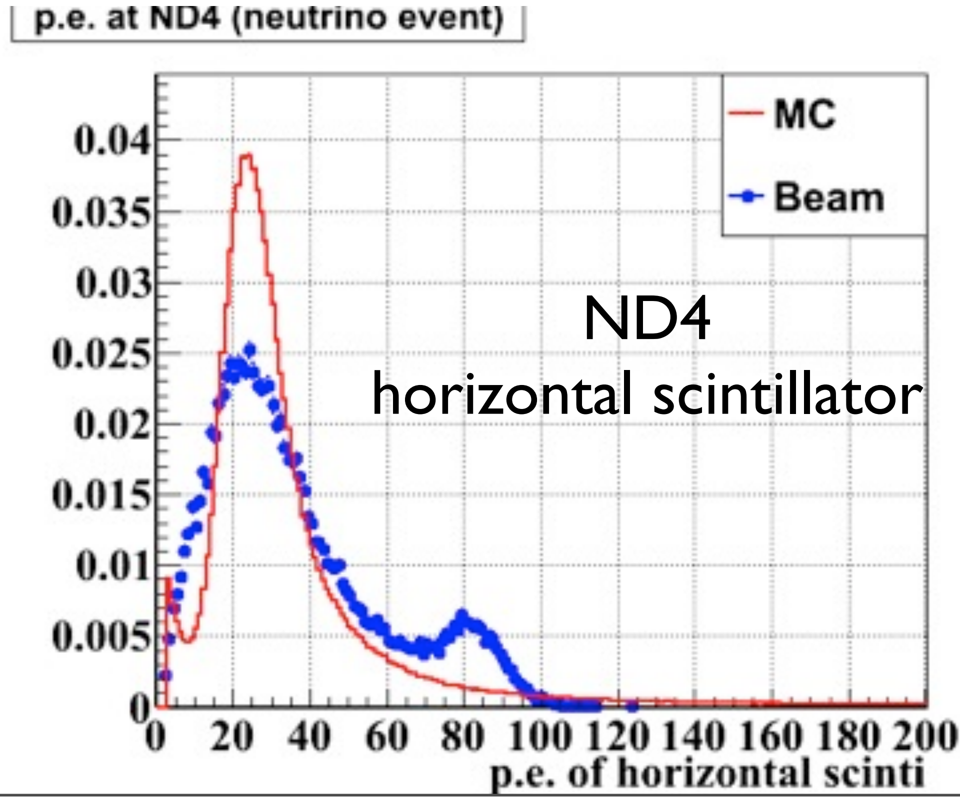


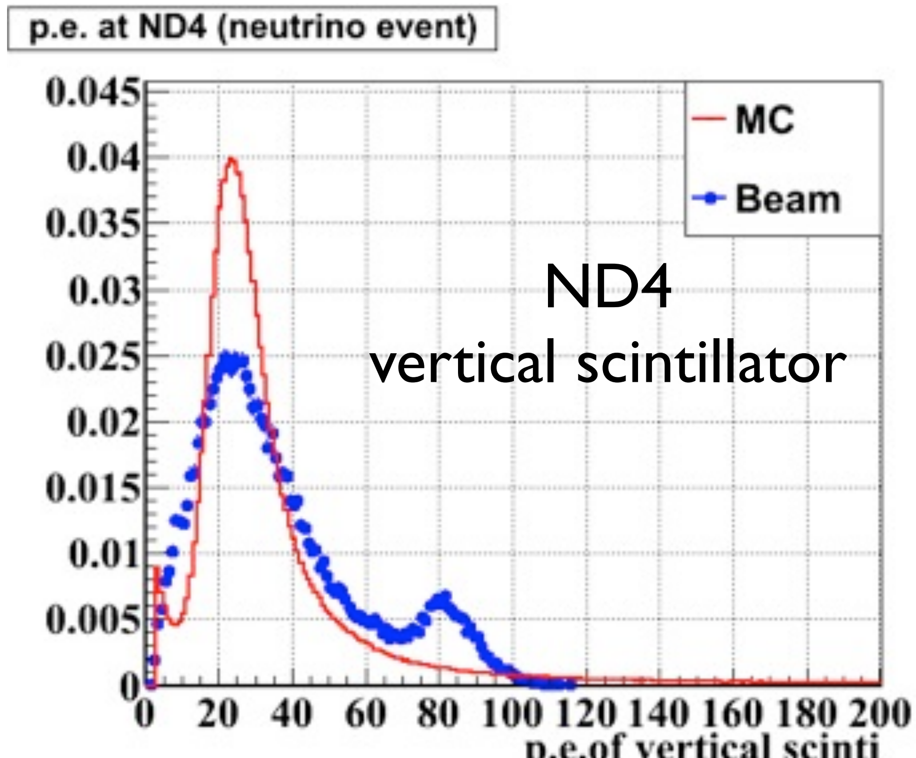
p.e. of track hit

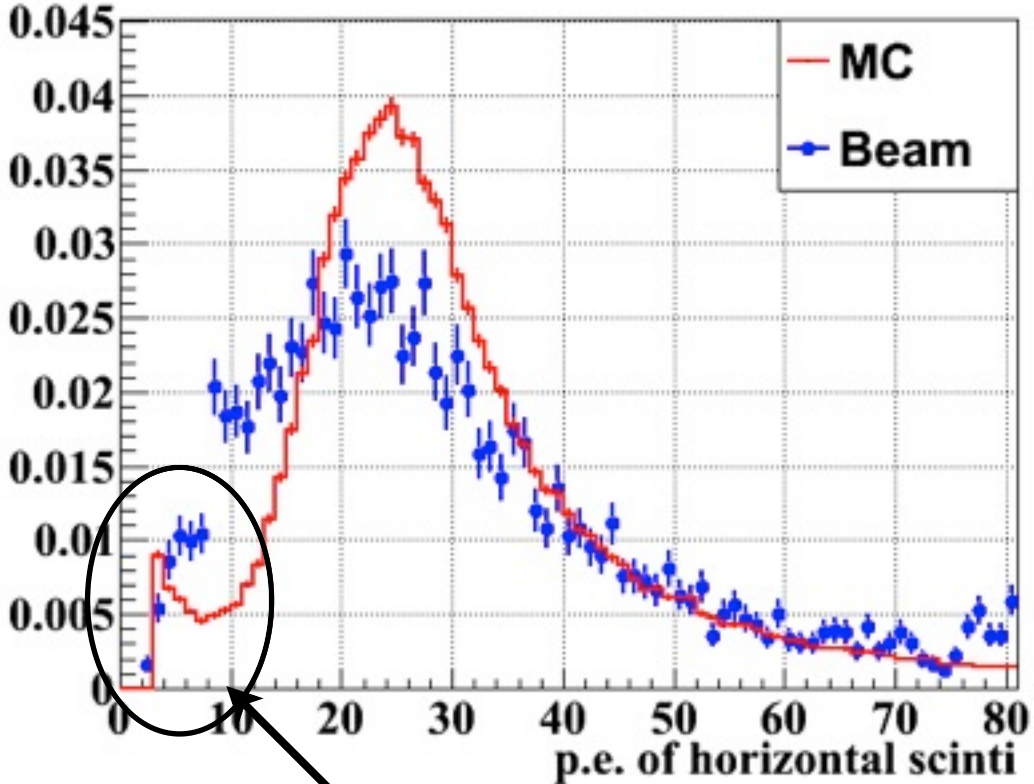
- Distribution of p.e. of hit by reconstructed track
- At used beam data, low gain value is not correct. So, at the high p.e. region (>80p.e.), there are saturation of p.e. of hit.
    - By using resent beam data, this problem has been resolved.


p.e. at ND3 (neutrino event)
MC
Beam
ND3
horizontal scintillator
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
0 20 40 60 80 100 120 140 160 180 200
p.e. of horizontal scinti


p.e. at ND3 (neutrino event)
MC
Beam
ND3
vertical scintillator
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
0 20 40 60 80 100 120 140 160 180 200
p.e.of vertical scinti


p.e. at ND4 (neutrino event)
MC
Beam
ND4
horizontal scintillator
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
0 20 40 60 80 100 120 140 160 180 200
p.e. of horizontal scinti


p.e. at ND4 (neutrino event)
MC
Beam
ND4
vertical scintillator
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
0 20 40 60 80 100 120 140 160 180 200
p.e.of vertical scinti



Zoom around peak

This low p.e. peak is p.e. of hit by electron.

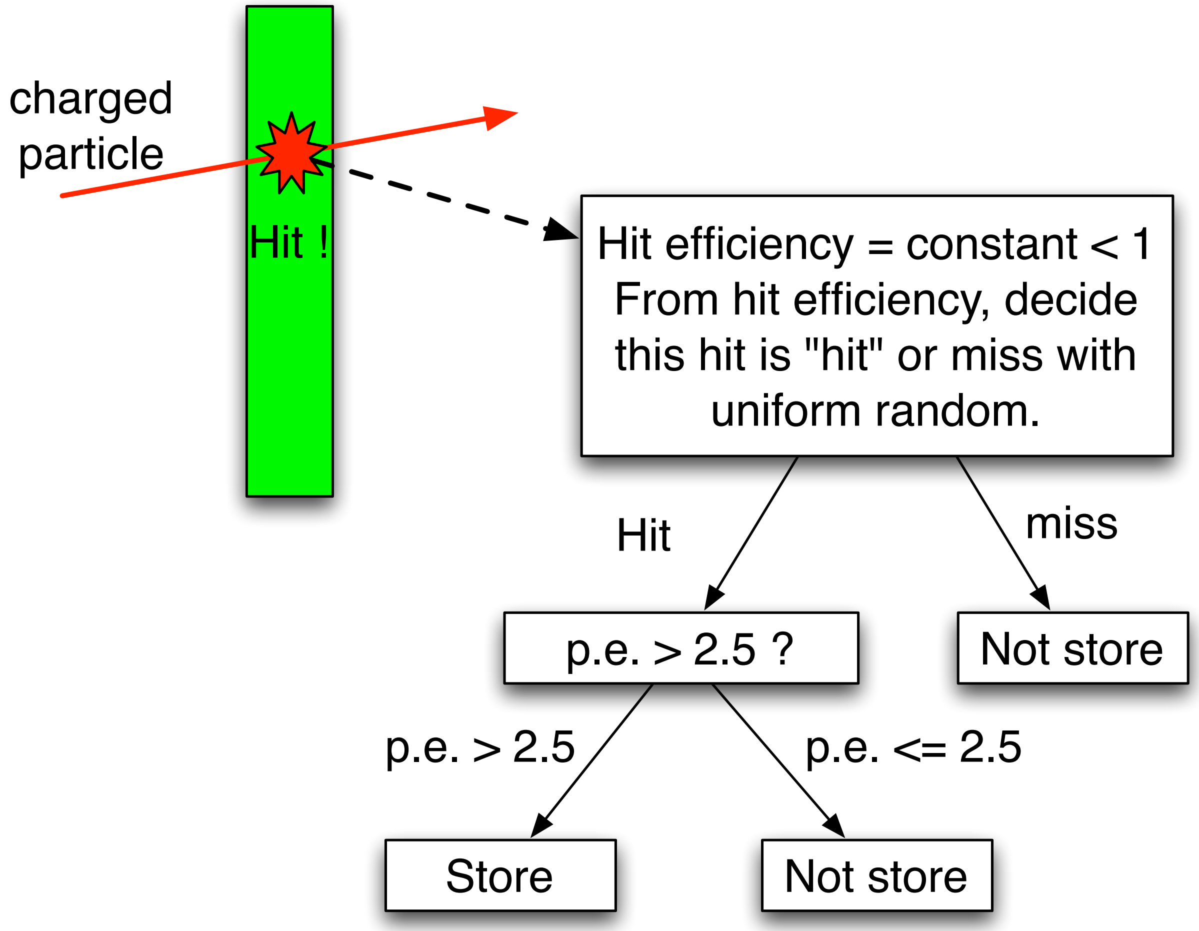
Current study

- Progress in
  - the effect of uncertainty of hit efficiency
  - Event select criteria to enhance low neutrino energy.

About hit efficiency

- Hit efficiency of 1 scintillator is about 99% and has uncertainty.
- Actually, consider the structure of scintillator bar including reflection material and reflect this in MC.
    - But, it seems to need time, I think.
- I want to estimate roughly the uncertainty of efficiency to neutrino event and beam center due to the uncertainty of hit efficiency.

Assume hit efficiency



- At this model, not include angle-dependence of hit efficiency, diff at each channel.
  - But, at fist roughly estimation, it seems to be enough.

Enhance low neutrino energy

- INGRID want to calc the direction of low energy (<3GeV) neutrino beam.
- At current "neutrino event selection", enhance high energy neutrino.
- Need consider new selection.
  - One is "reconstructed angle > 20 cut"
  - This was studied by Kurimoto-san, who designed NGRID.

Neutrino energy vs MC true angle of muon