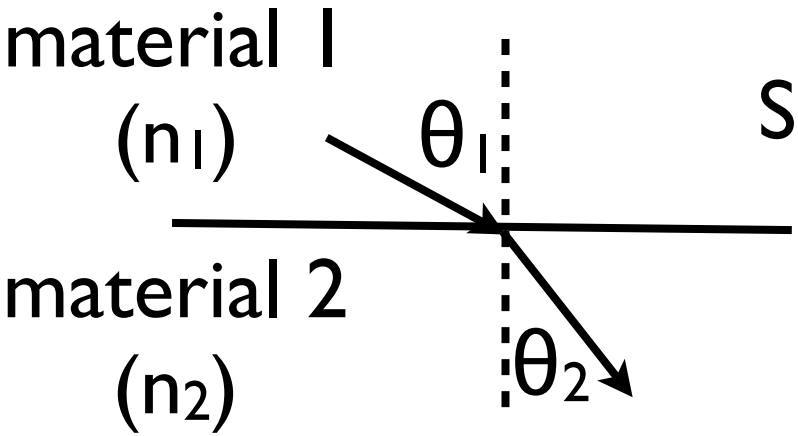
Mizuche MC

A.Murakami

Reflection probability



Snel's low: $\frac{sin\theta_1}{sin\theta_2} = \frac{n_2}{n_1}$

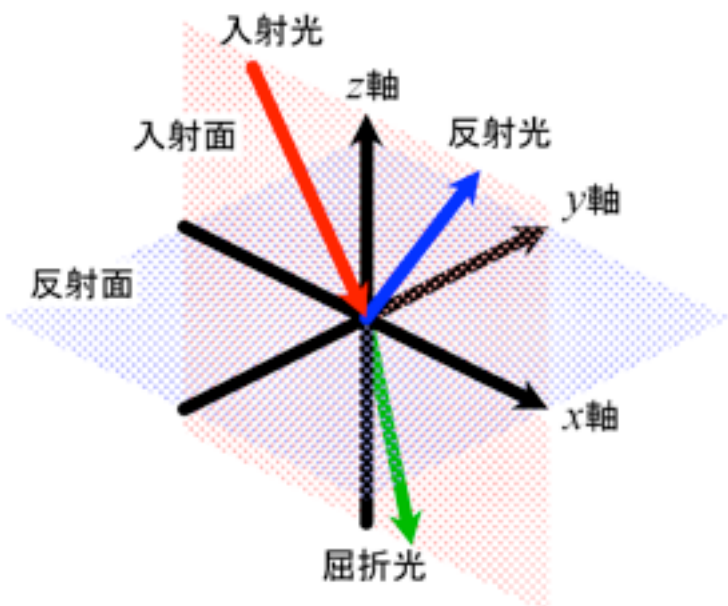
Rs: s波(入射面に垂直) の反射率

Rp: p波(入射面に平行)の反射率

Fresnel equations :

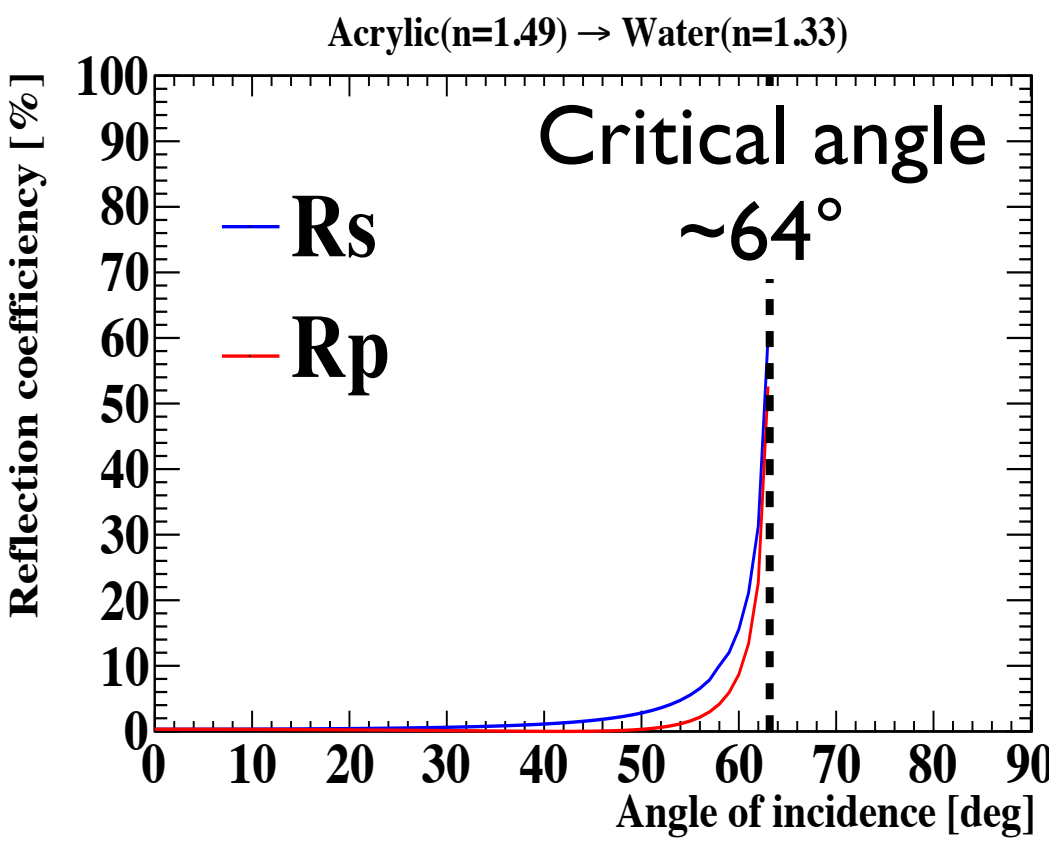
$$R_s = \left(\frac{n_1 cos\theta_1 - n_2 cos\theta_2}{n_1 cos\theta_1 + n_2 cos\theta_2} \right)^2$$

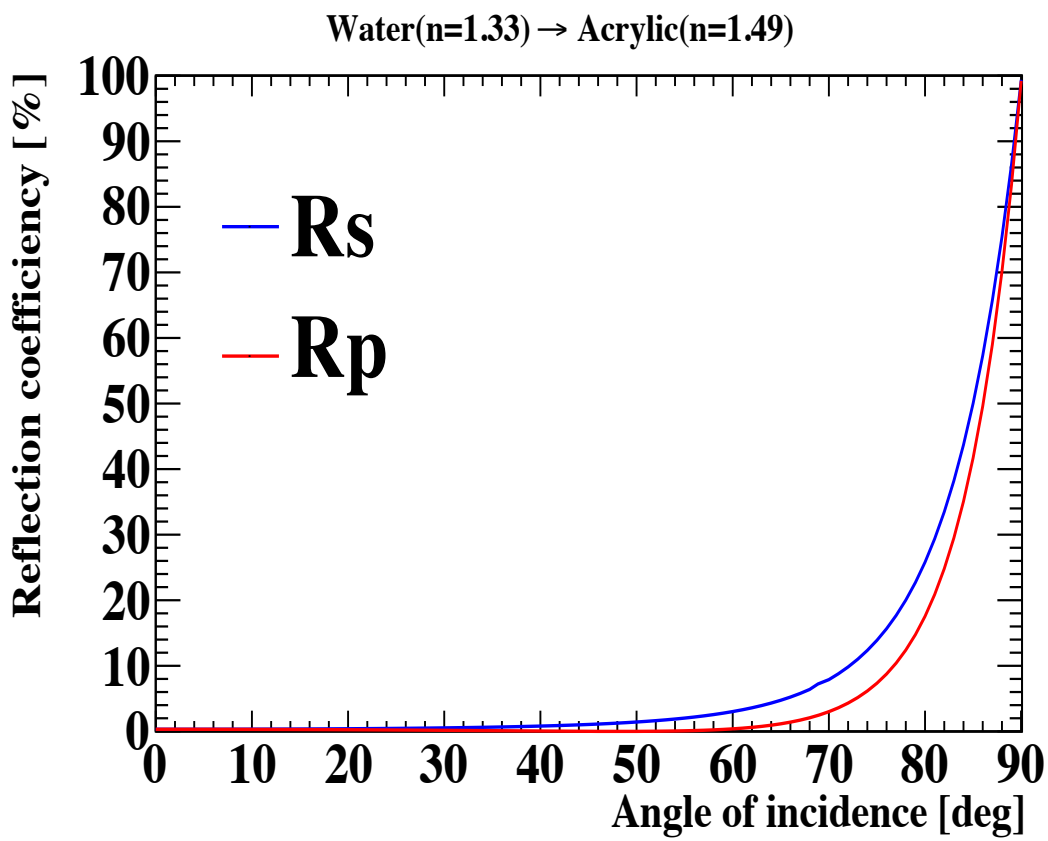
$$R_p = \left(\frac{n_1 cos\theta_2 - n_2 cos\theta_1}{n_1 cos\theta_2 + n_2 cos\theta_1} \right)^2$$



Reflection probability

Water : n=1.33, Acrylic n=1.49

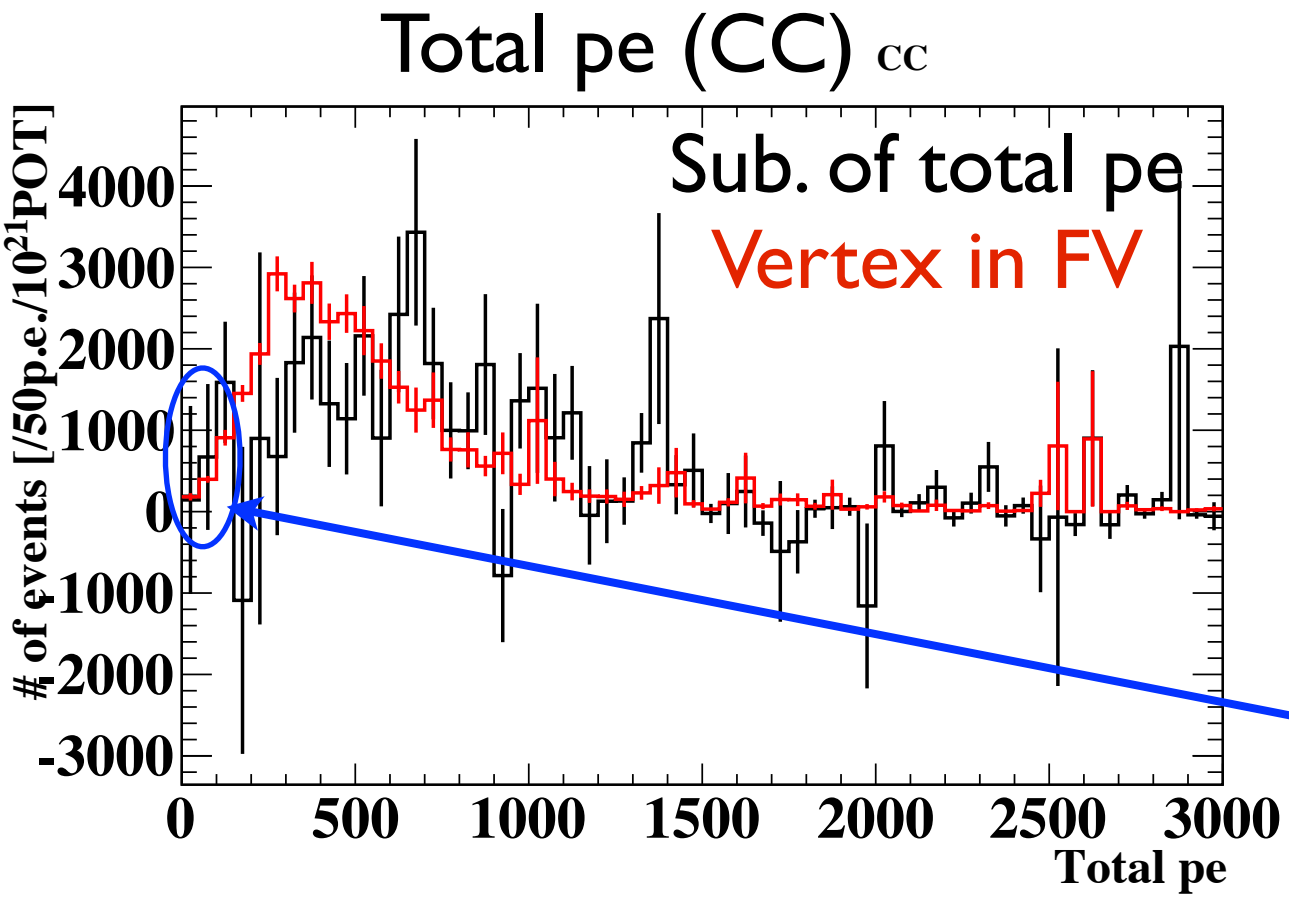




Acrylic→Water : Total internal reflection (angle>64°)

Water→Acrylic : Reflection probability is 80~90%(angle~90°)

Low total pe of CC interaction in FV



Outer area = 30cm
→ Charged particle generated in FV generates enough cherenkov

Check low pe event

Calc # of gen. photons

$$\frac{dN_{photons}}{dL} \simeq 2\pi\alpha z^2 sin^2\theta(\lambda_1^{-1} - \lambda_2^{-1})$$

- μ: Mass = 106MeV/c^2
- λ1, λ2 = 270, 610nm = 2.03, 4.6eV (MC used)
- QE = 0.2 (constant)
- Mean coverage = 6.25% (PMT:164, constant)

Cherenkov threshold (water:n=1.33)

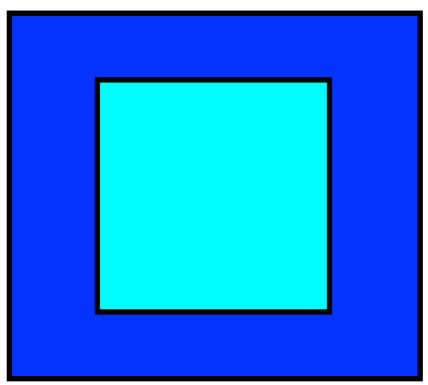
particle	threshold momentum[MeV/c]
muon	**120**
pion	159
electron	0.57
proton	1069

μ mom. [MeV/c]	beta	cosθ	angle [deg]	Gen. photons [/cm]	Gen. pe [/cm]	Measure pe [/cm]
200	0.884	0.851	31.7	261	52.2	3.26
300	0.943	0.797	37.1	345	68.9	4.31
400	0.967	0.778	39.0	374	74.8	4.67
500	0.978	0.769	40.0	387	77.5	4.84
600	0.985	0.764	40.2	395	78.9	4.93
700	0.989	0.760	40.5	399	79.8	4.99
800	0.991	0.758	40.7	402	80.4	5.02

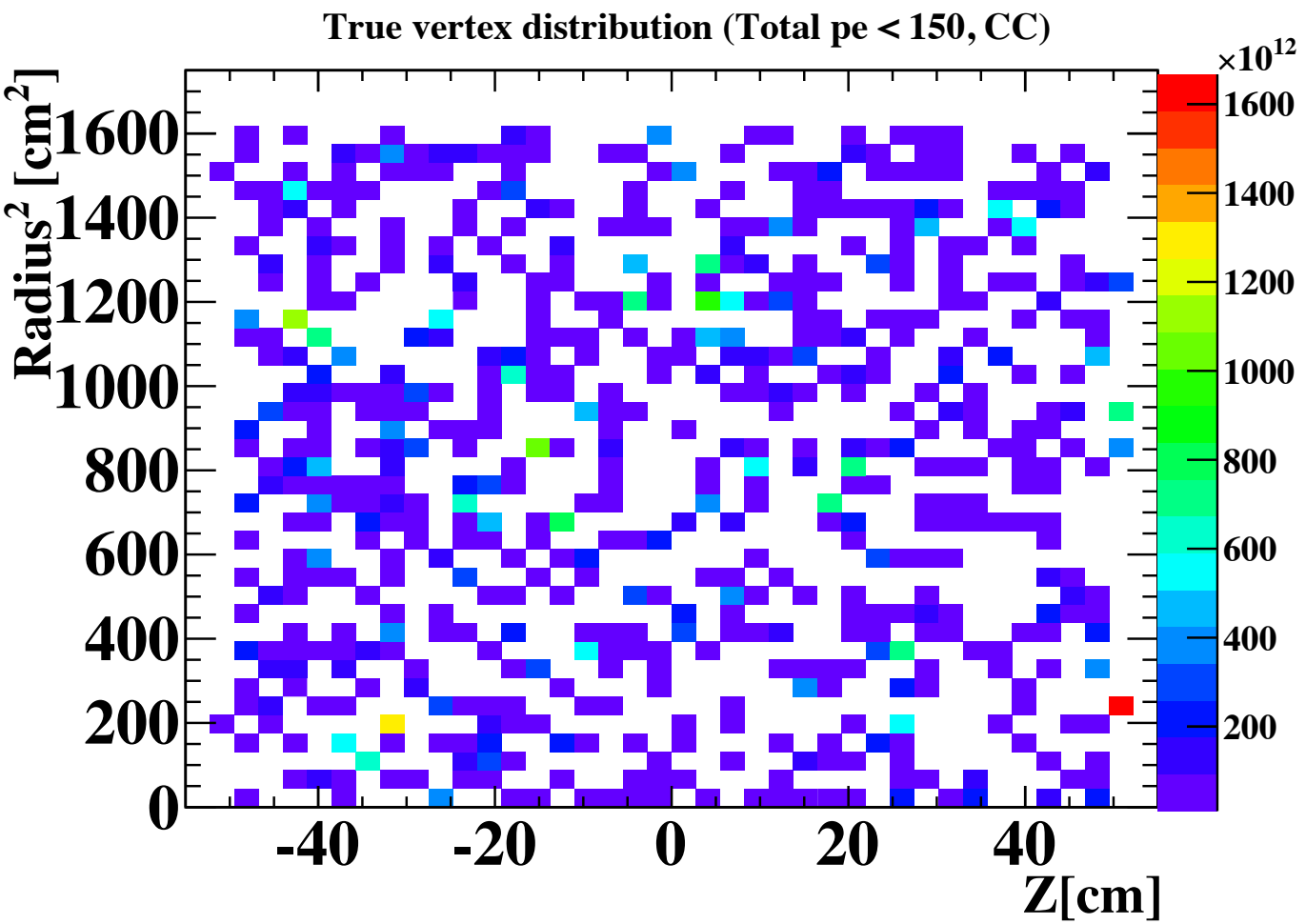
30cm path length → expect to measure 98~150 p.e.

True vertex distribution

Only CC int., Only vertex in FV (with water)
Simple cut : total pe < 150

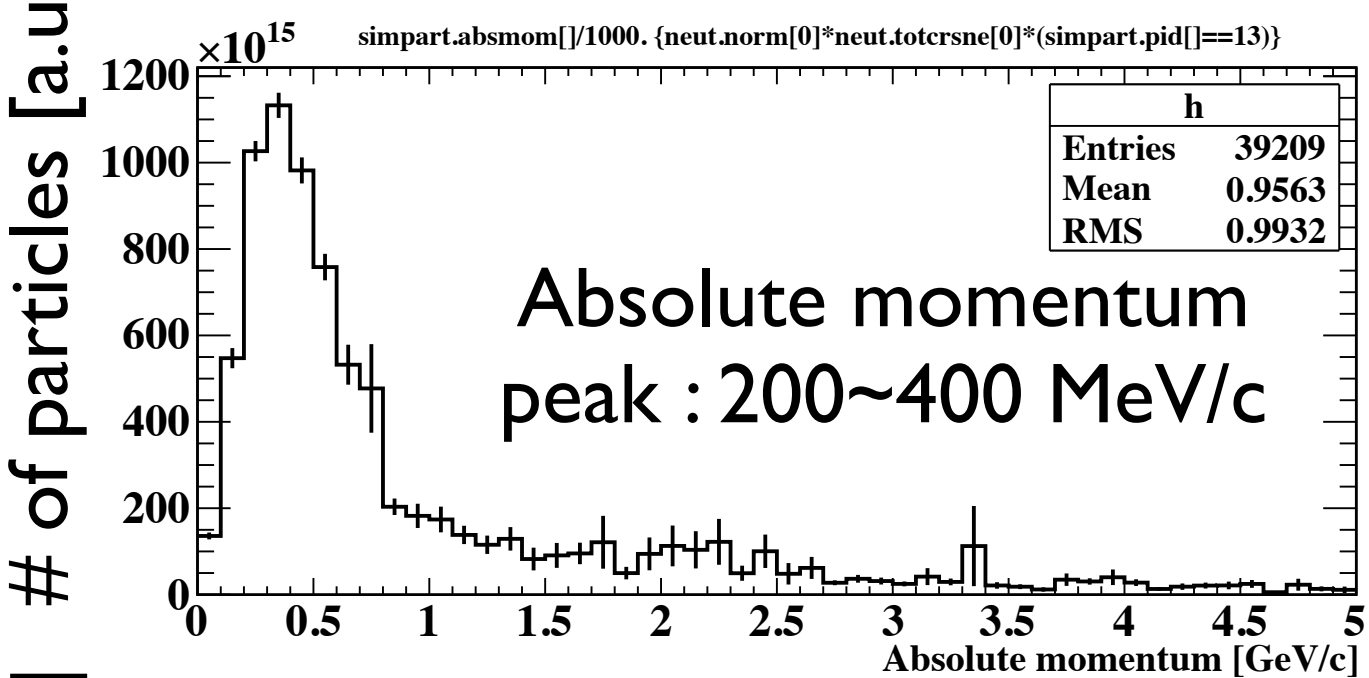


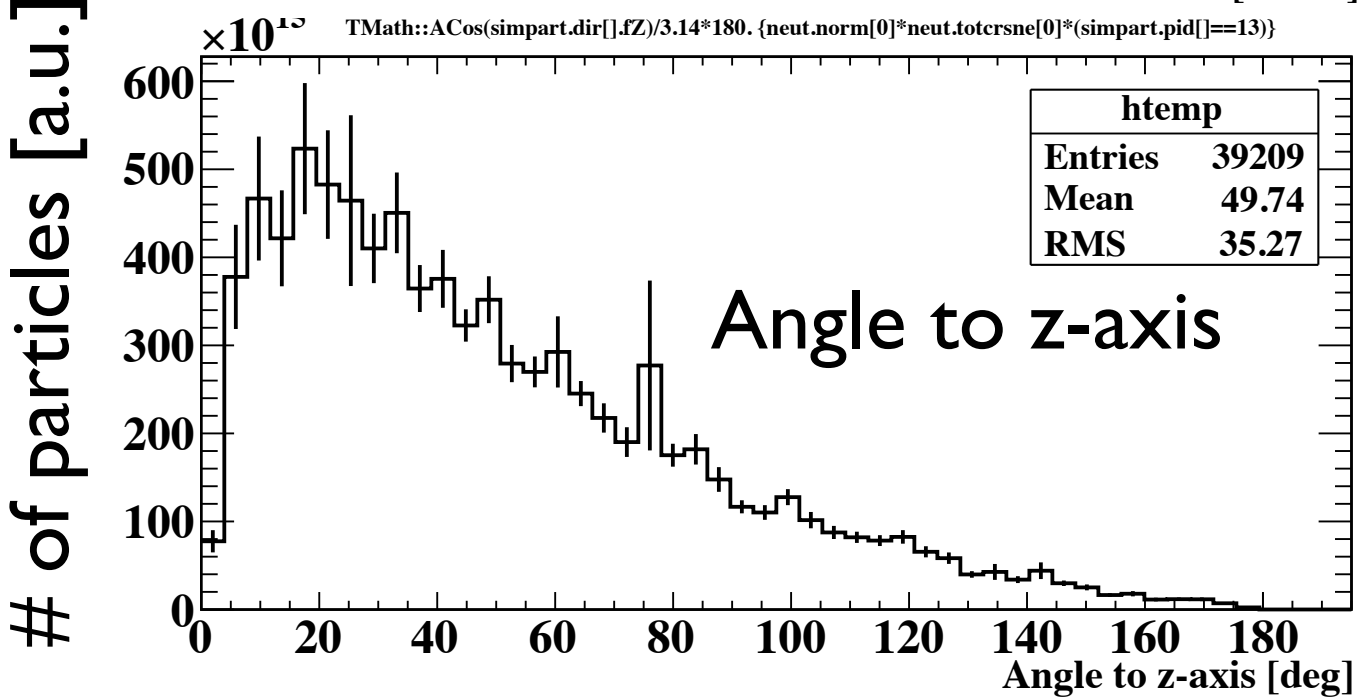
FV spec:
r : 40cm
z : 100cm



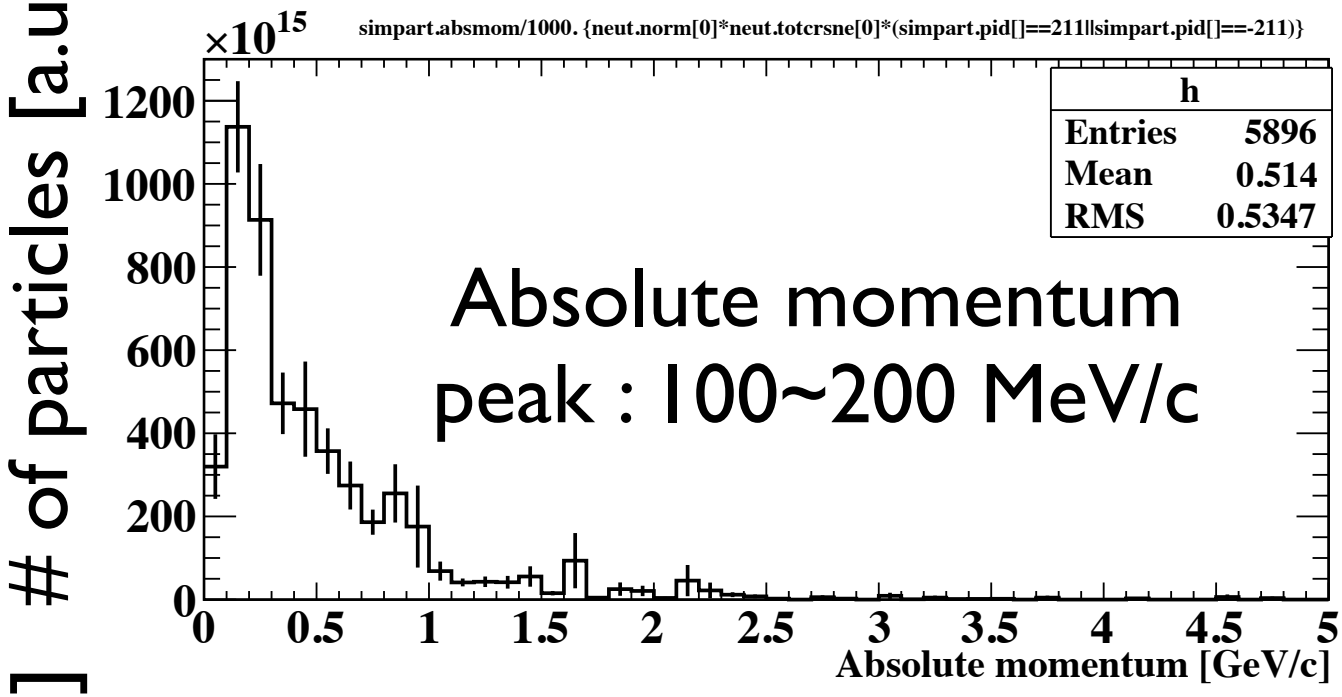
→ Seems to be uniform in FV (but low MC stat.)

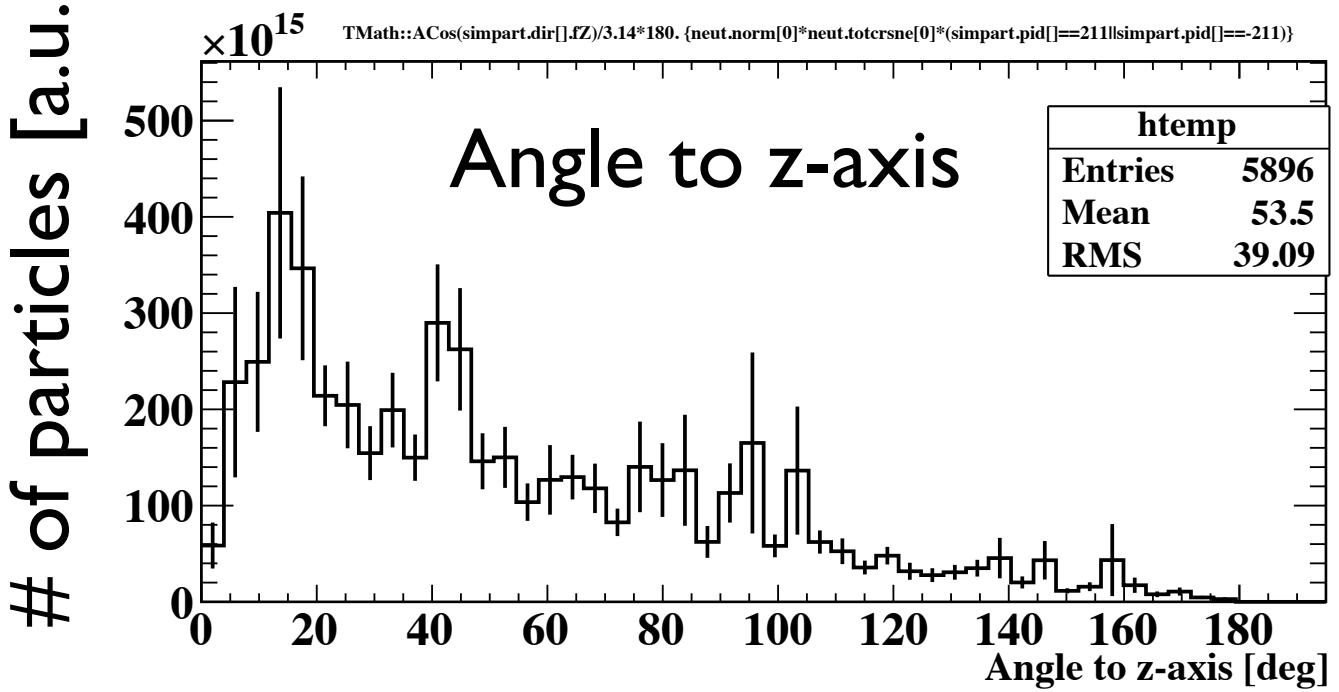
Generated μ info.



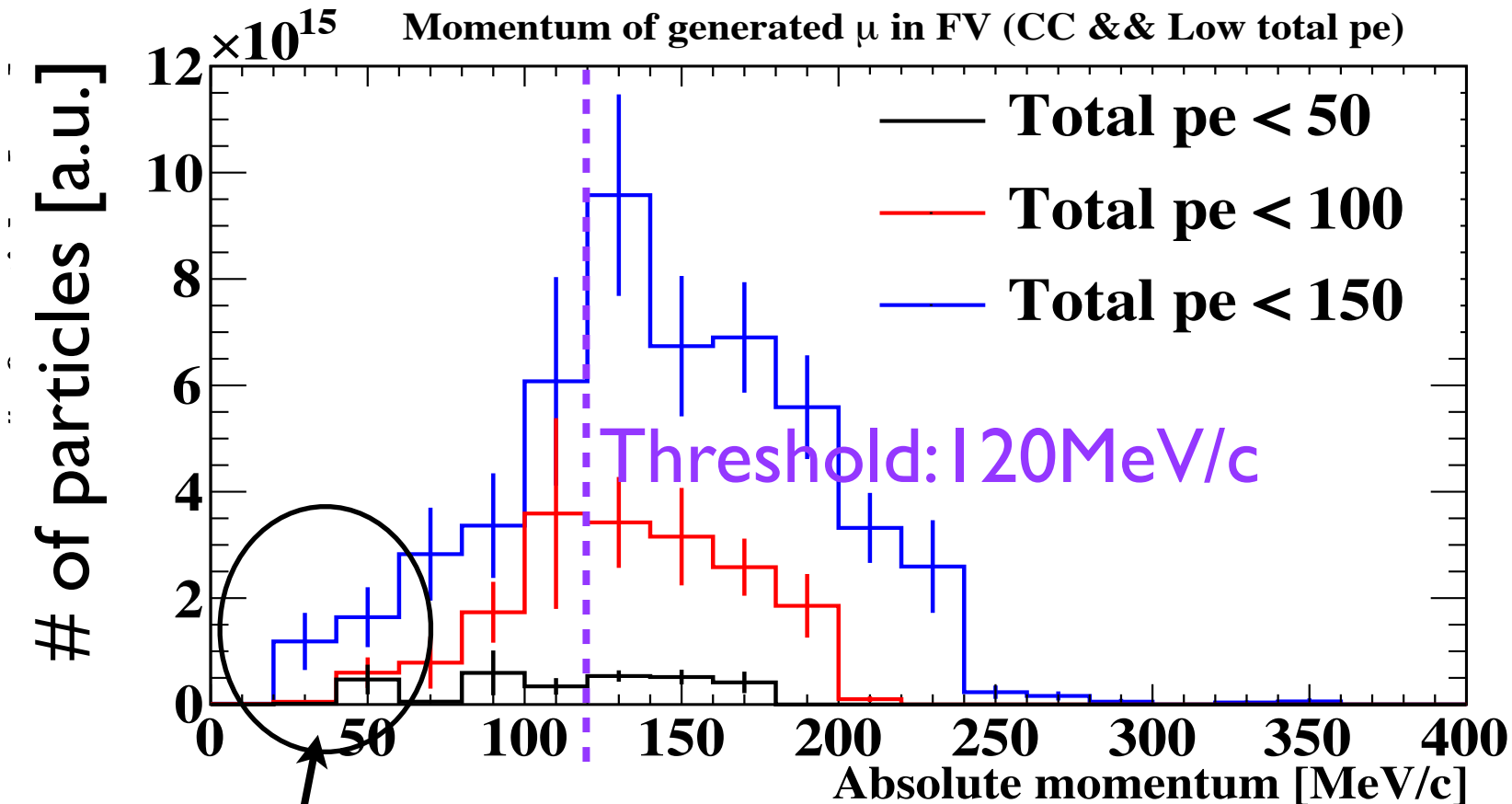


Generated π info.





μ generated in FV (CC)



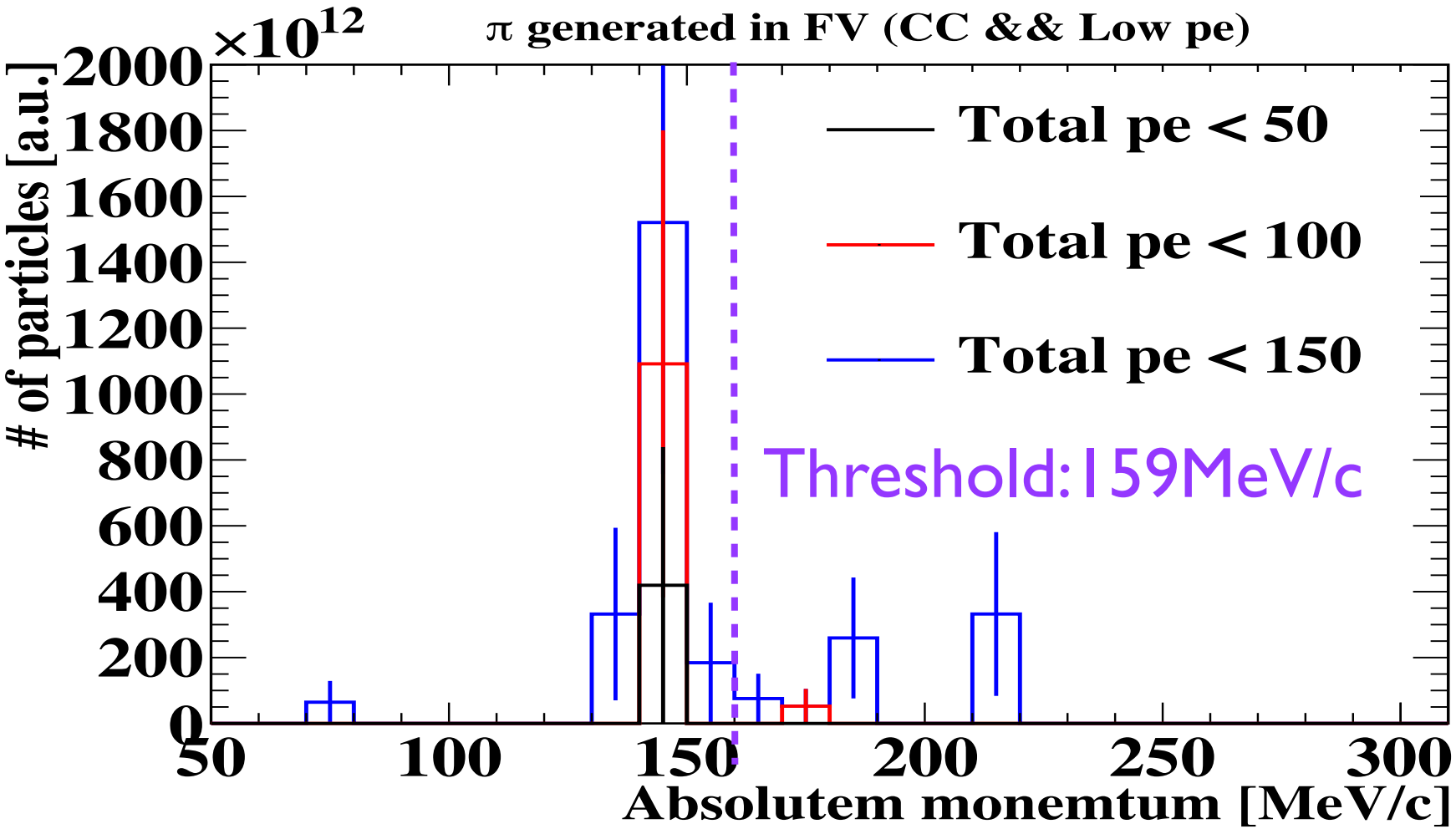
Energy deposit ~ 2MeV/cm

→ 30cm path length ~ 60MeV energy deposit

→ Momentum>**200MeV/c** can generated cherenkov in 30cm

progress in study about low momentum ...

Charged π generated in FV (CC)



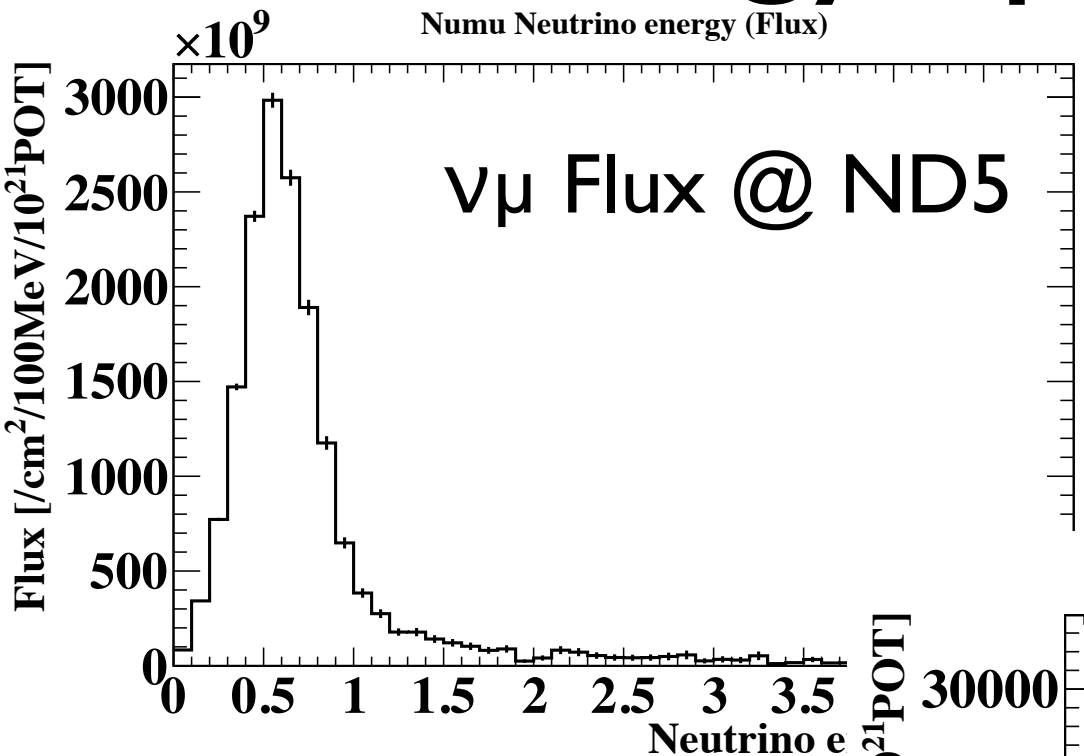
Low MC stat.

Few π can generate cherenkov .

Re-make plot

- Check neutrino interaction ratio NC/CC
- More rough binning of pe distribution
- Data set is same as previous slides.
  - Use Jnubeam 10c @ND5 : 1e6 triggher

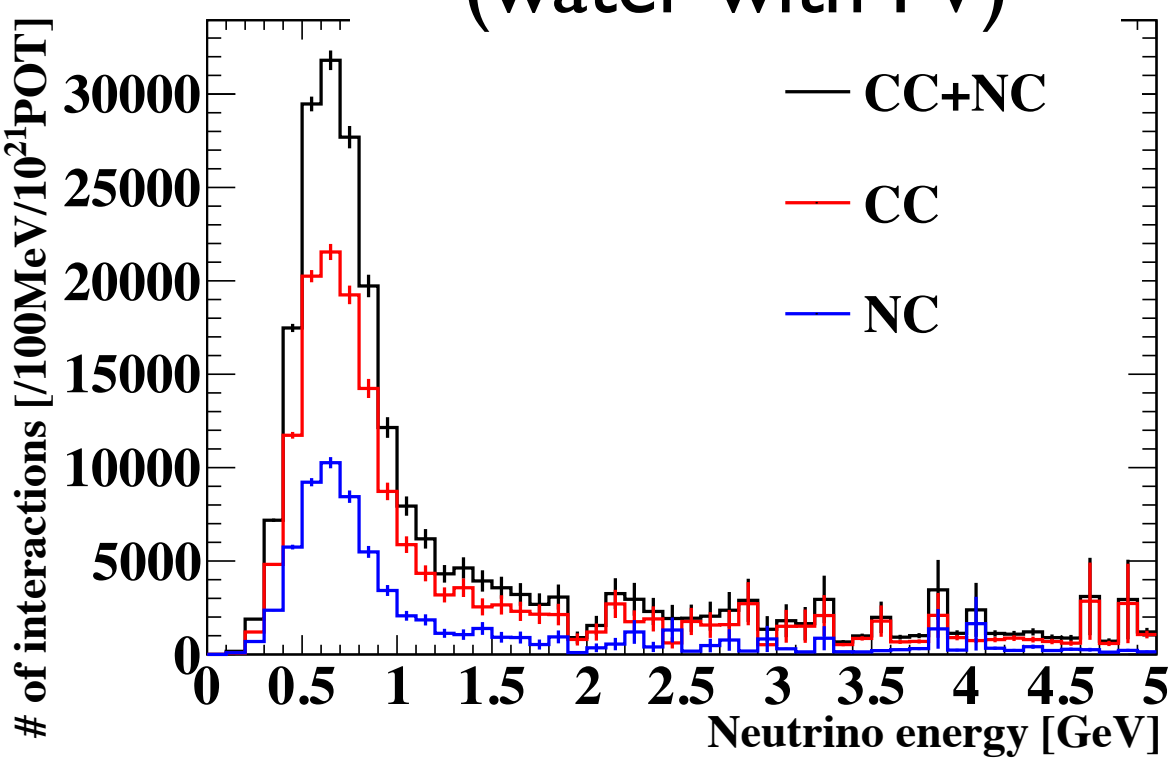
Energy spectrum



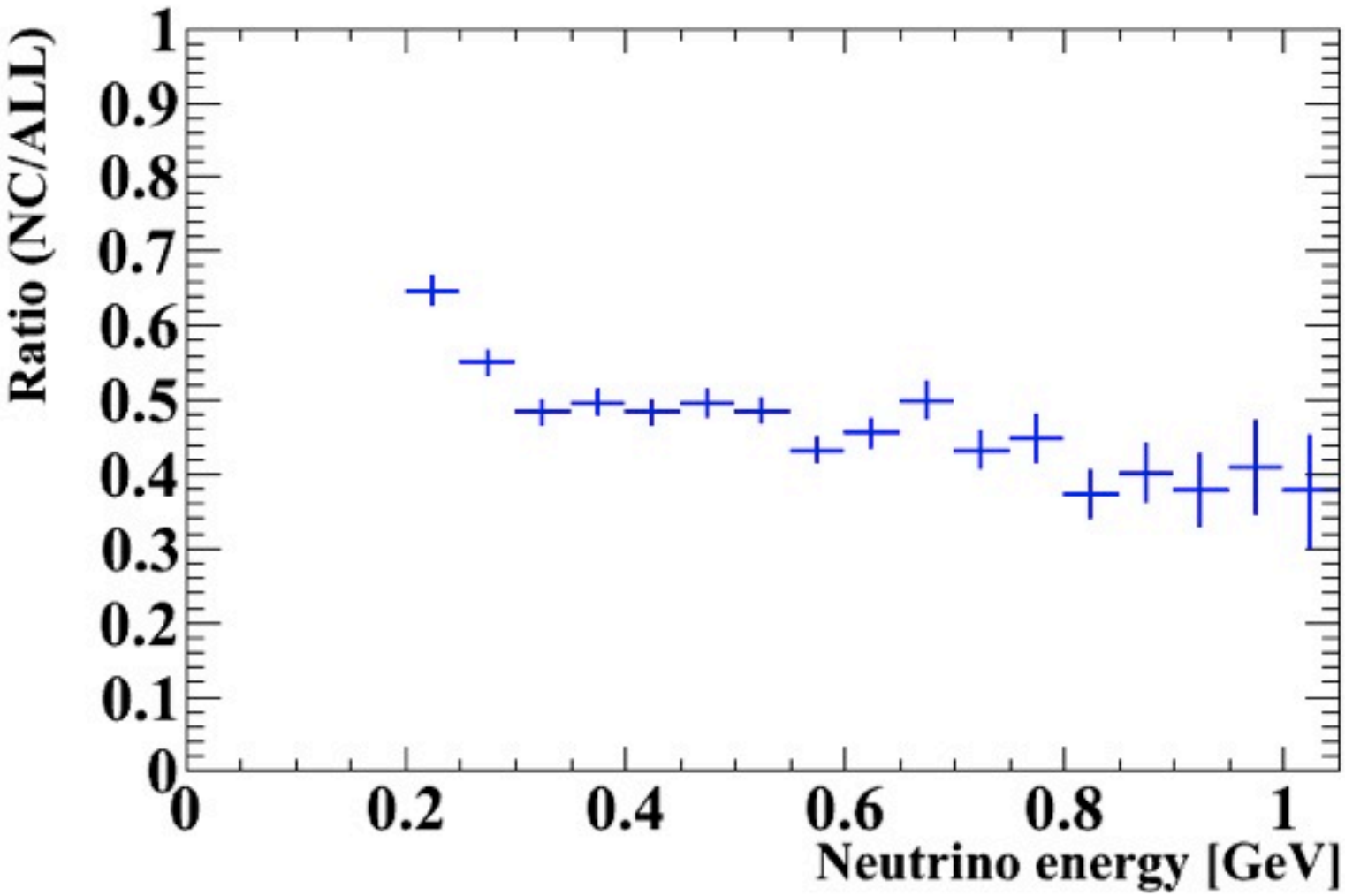
νμ Flux @ ND5

Error : Only MC stat

νμ interacted in Tank (water with FV)



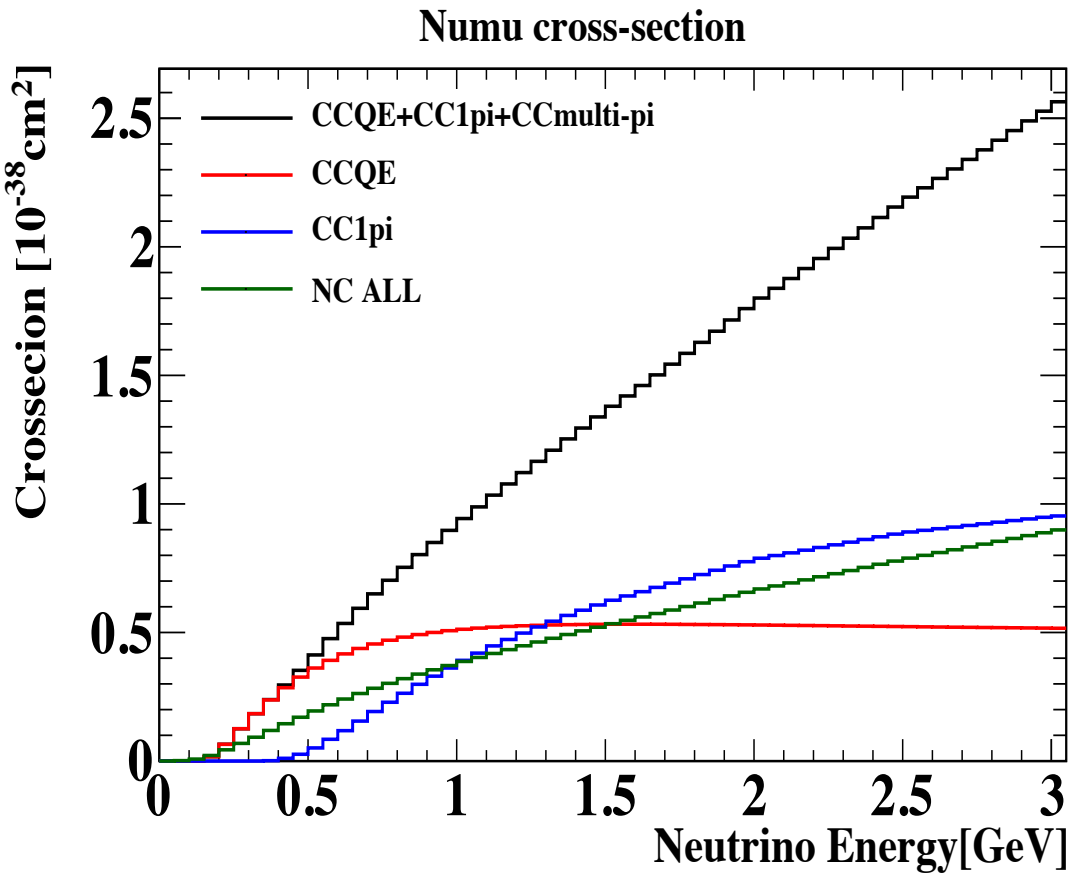
Ratio NC/CC around peak energy region

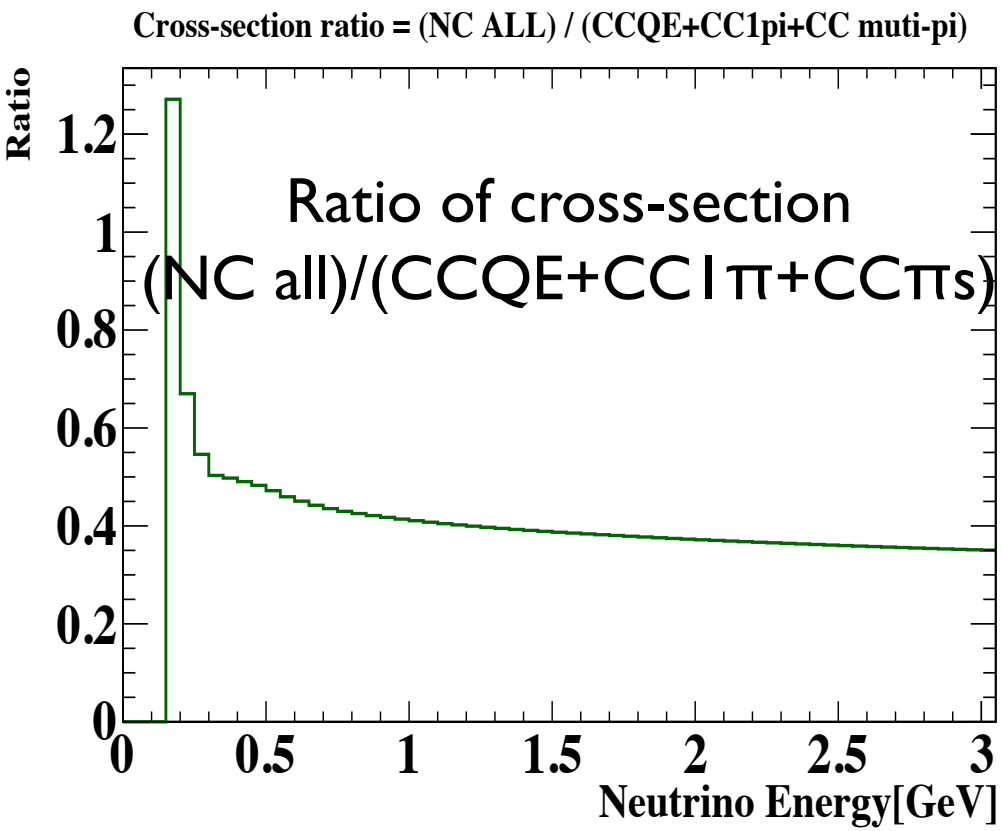


→ Compare with cross-section table

Neutrino cross-section

This cross-section table for water-target was made by Hayato-san (for INGRID study).



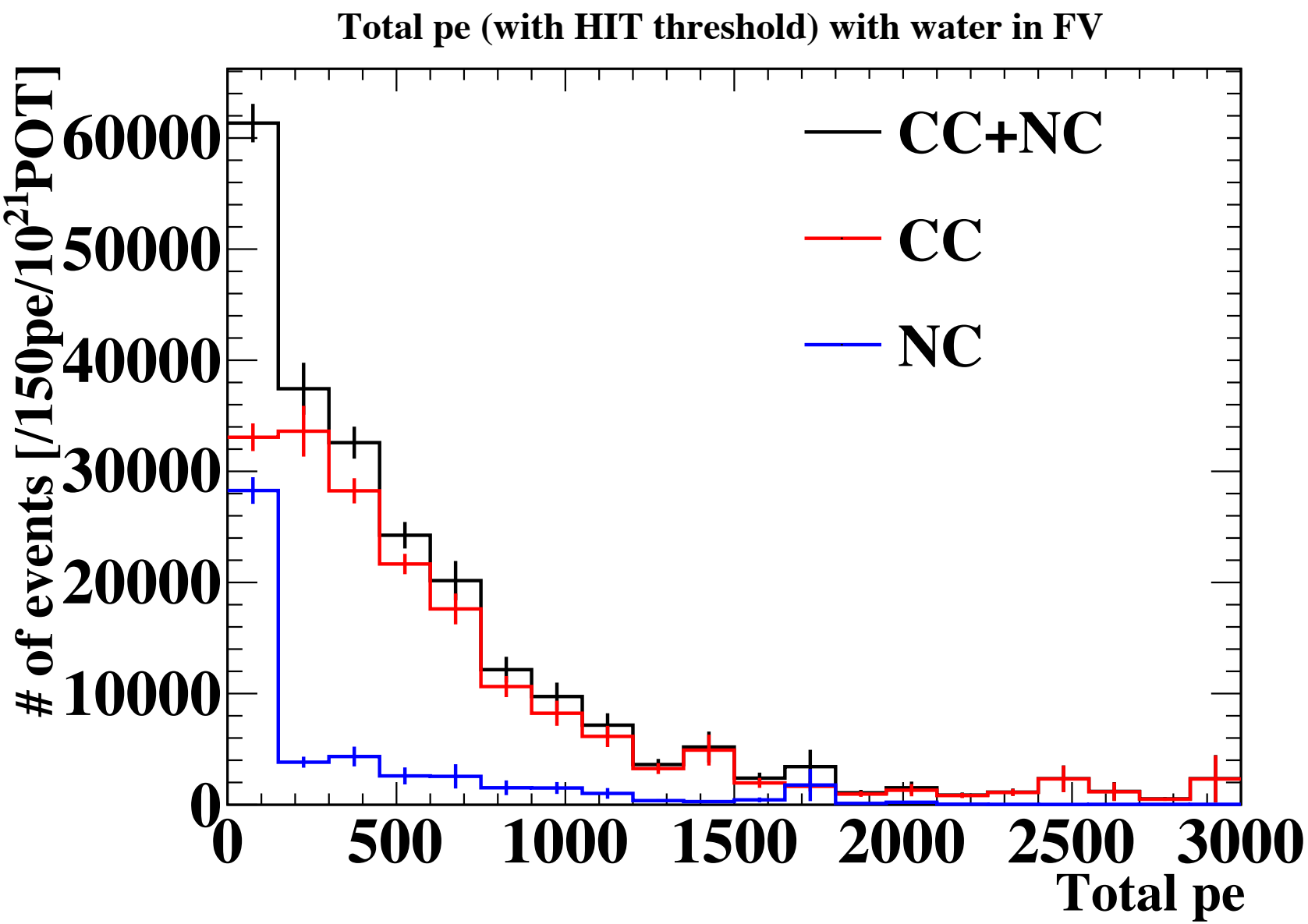


Around 0.6GeV, ratio of interactions : NC/CC ~ 0.5

→ Consistency check is OK

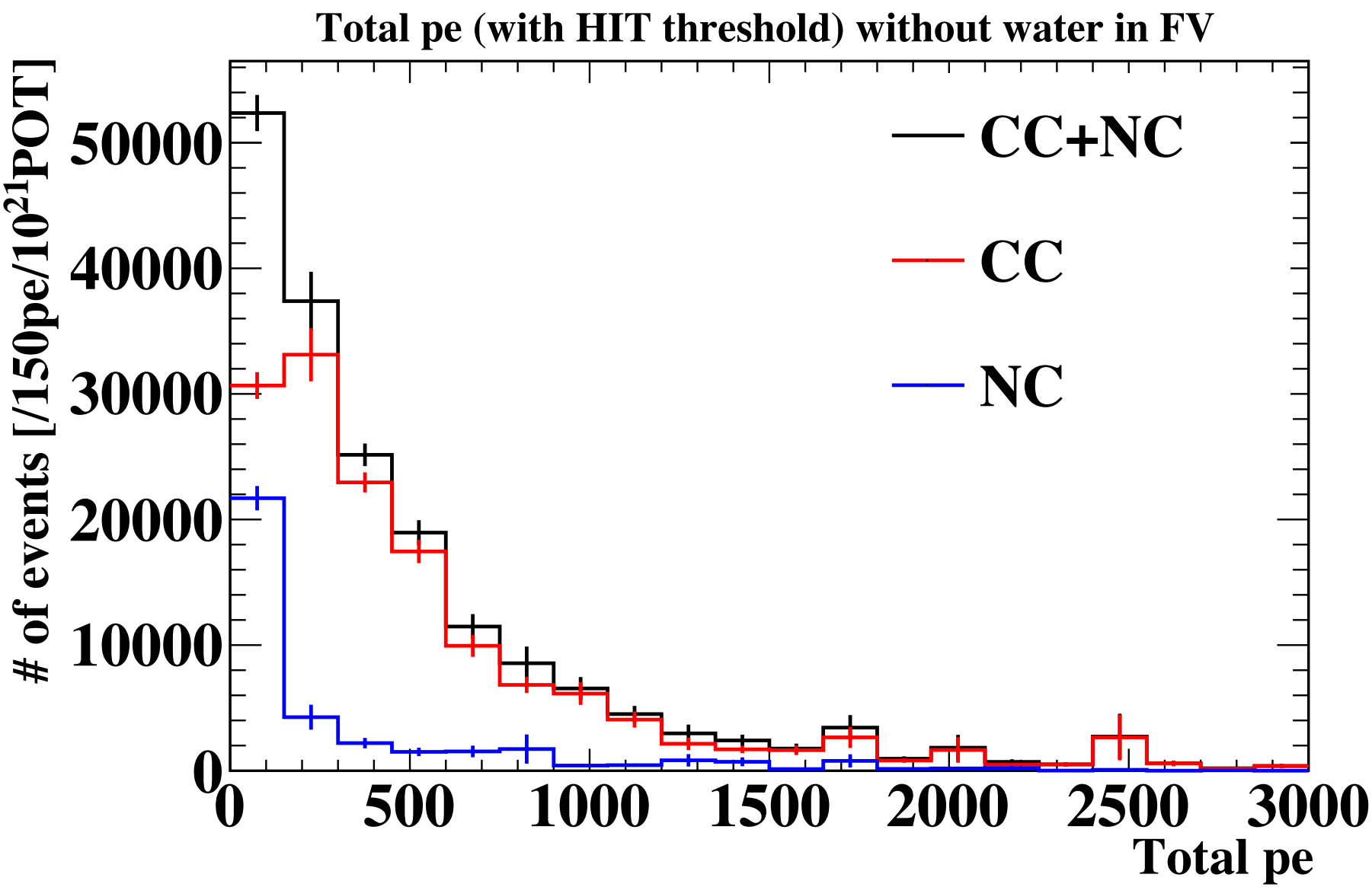
Total p.e. distribution

Vertex in whole Tank, water with FV.



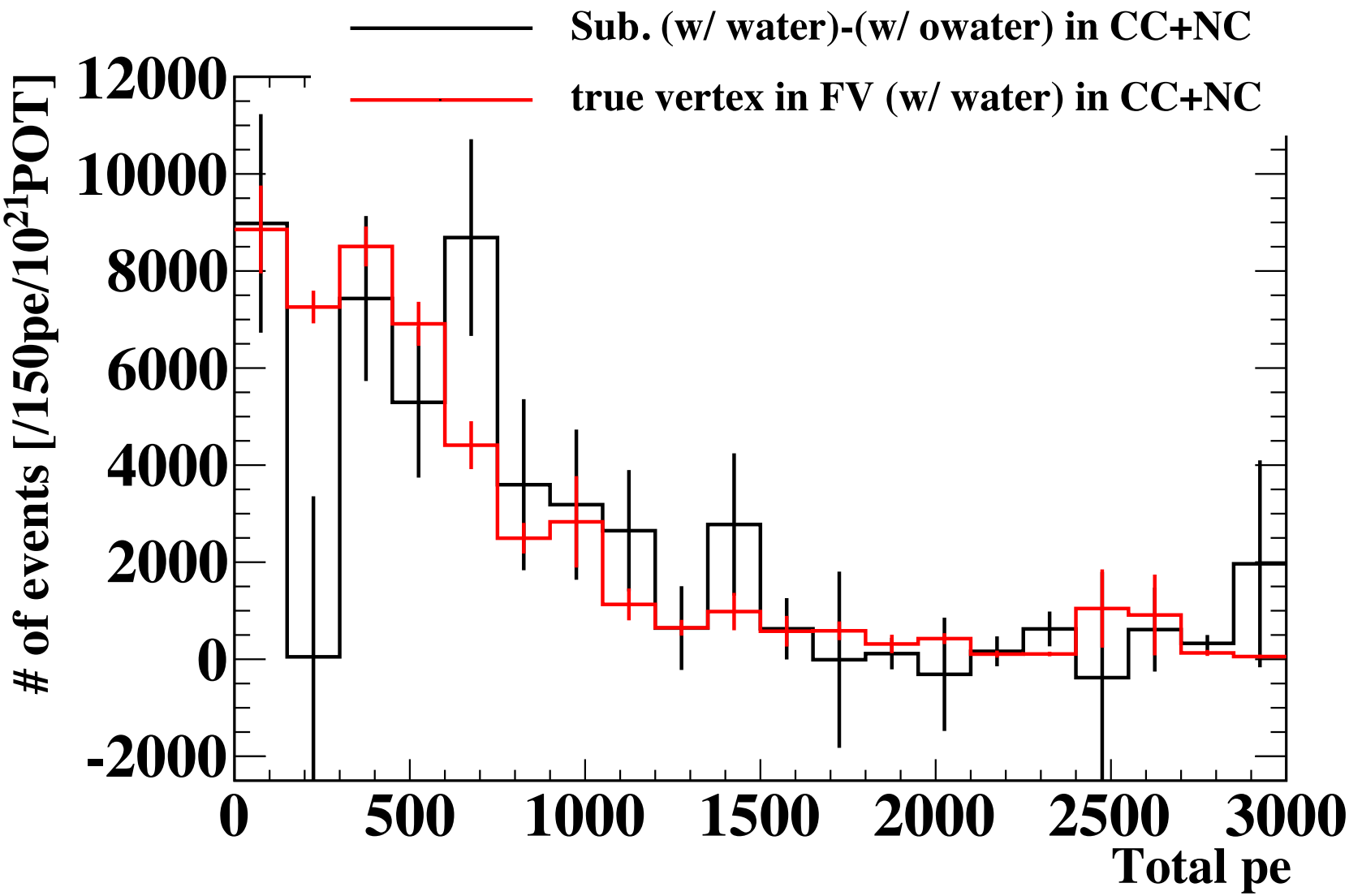
Total p.e. distribution

Vertex outside FV (w/o in FV.)



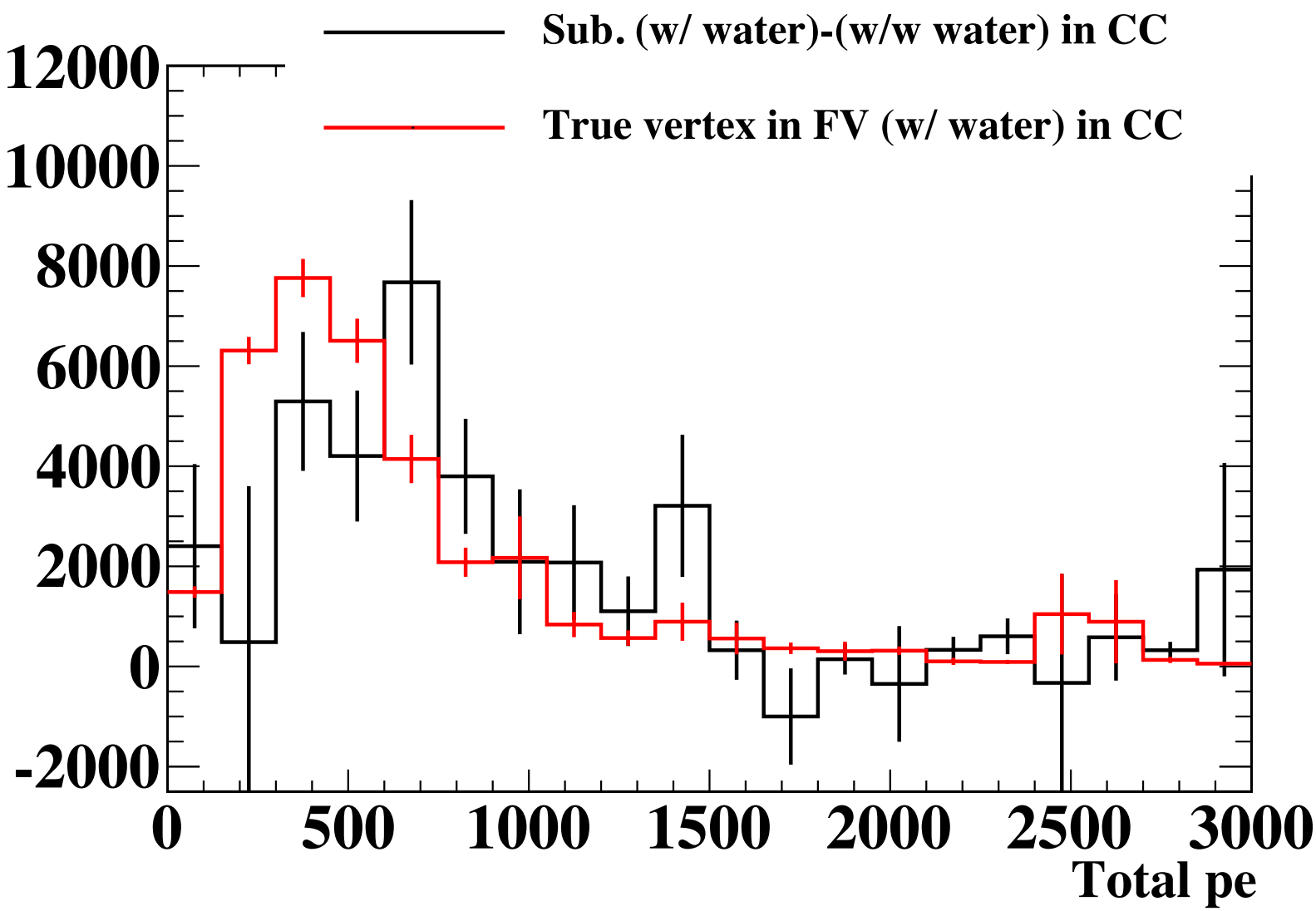
Sub. of total p.e. dist. (CC+NC)

Subtraction of total p.e. : (water w/ FV) - (water w/o FV)
Total p.e. distribution of true vertex in FV.



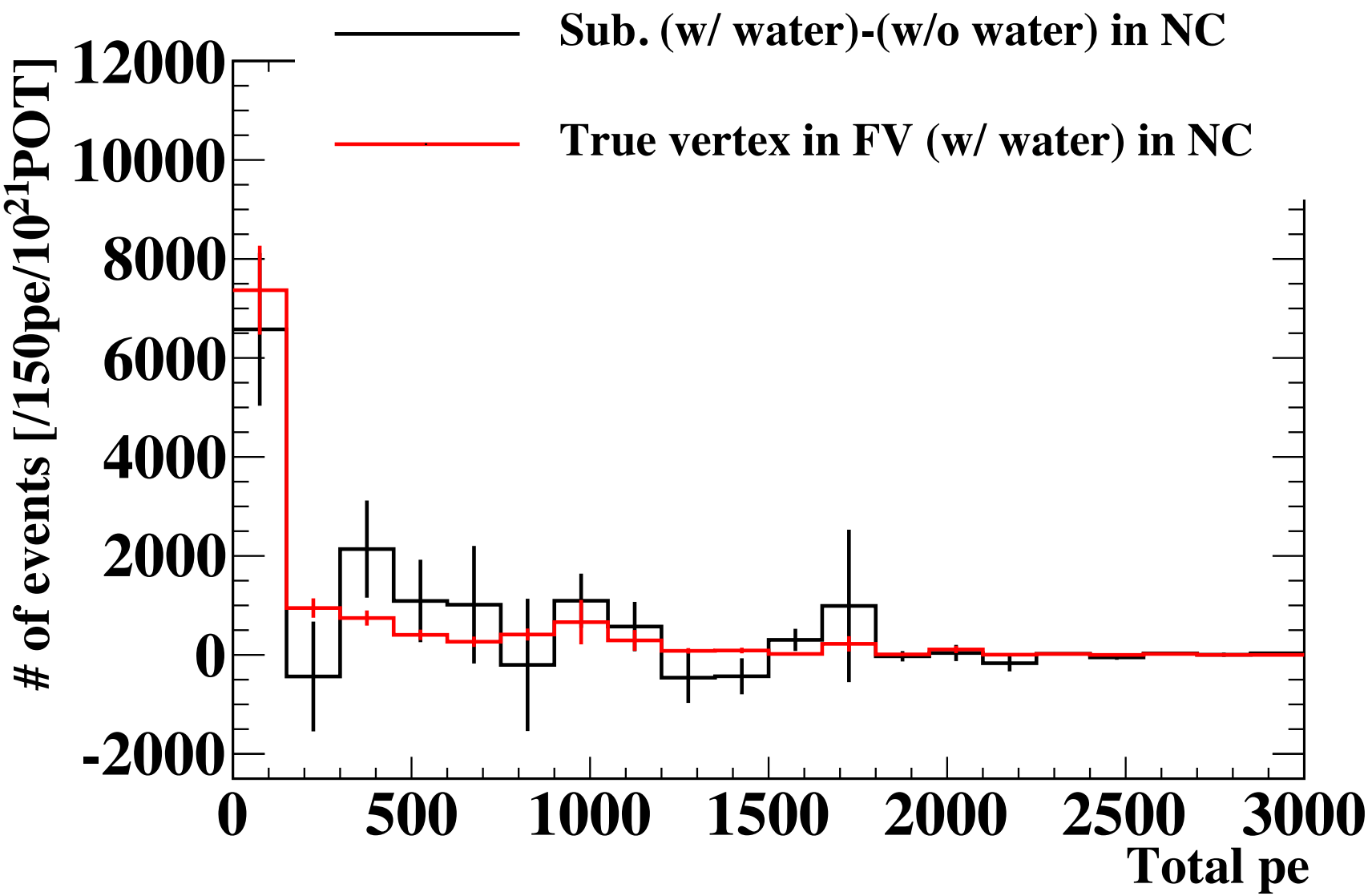
Sub. of total p.e. dist. (CC)

Subtraction of total p.e. : (water w/ FV) - (water w/o FV)
Total p.e. distribution of true vertex in FV.

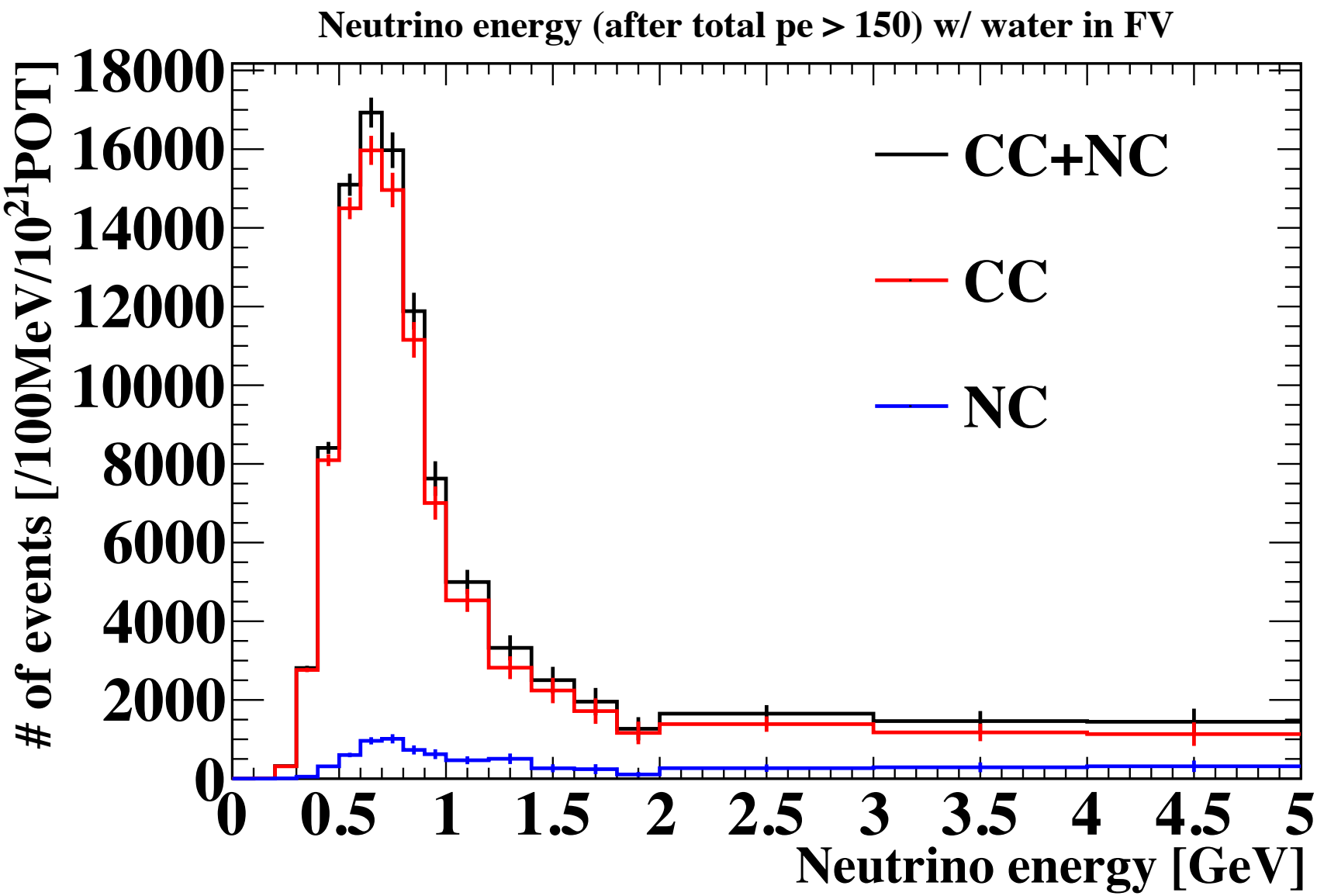


Sub. of total p.e. dist. (NC)

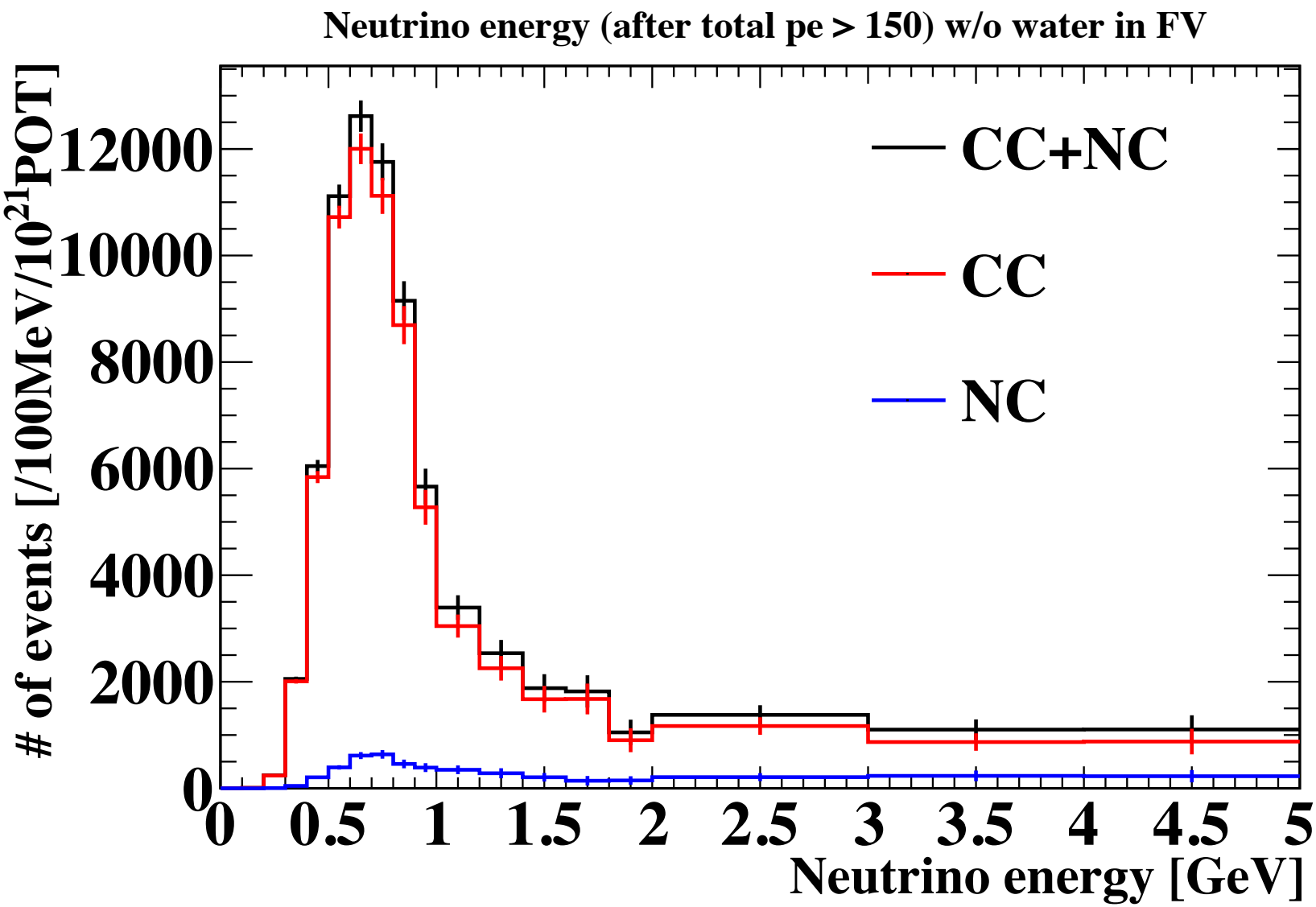
Subtraction of total p.e. : (water w/ FV) - (water w/o FV)
Total p.e. distribution of true vertex in FV.



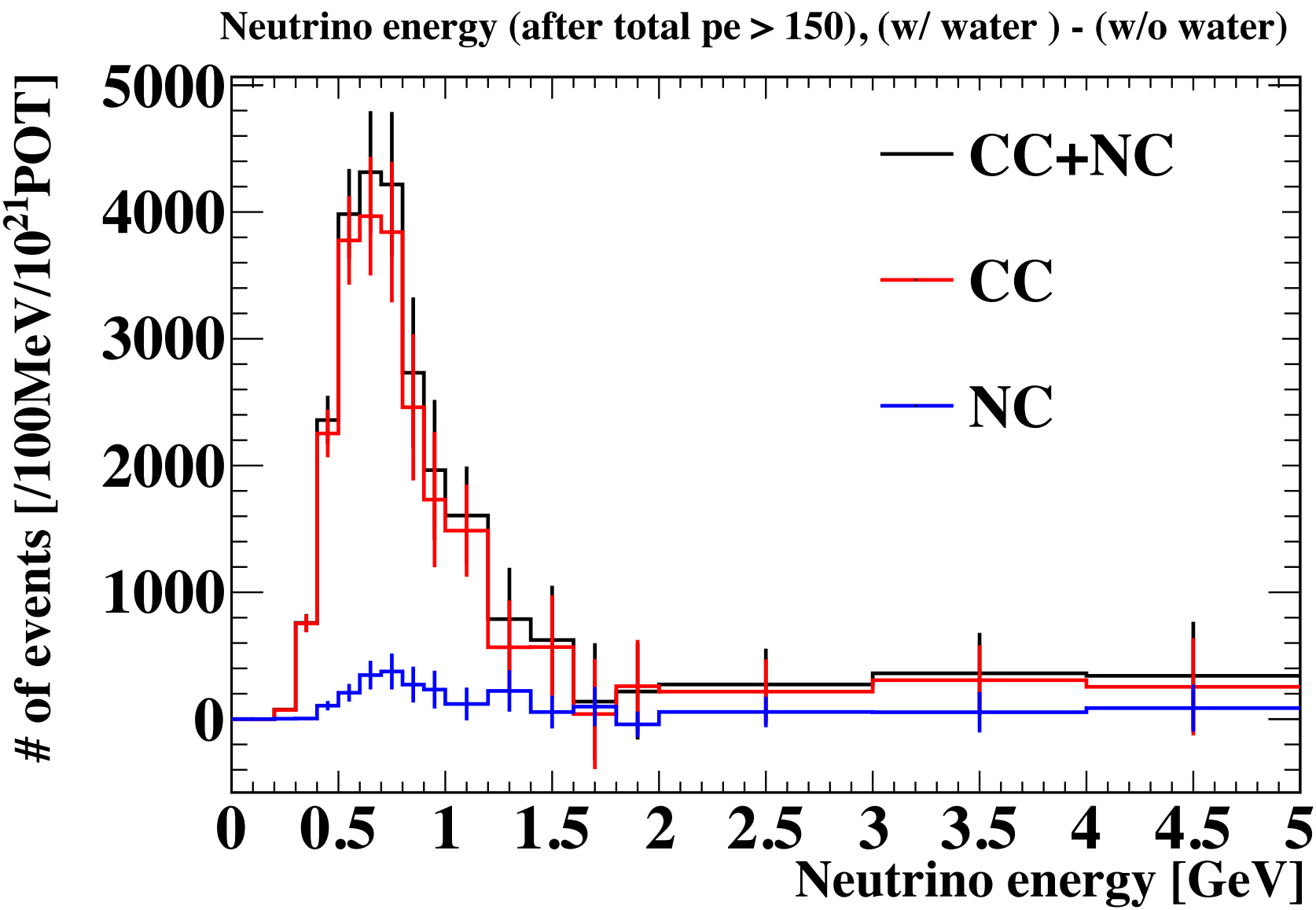
νμ energy w/ water in FV after total p.e. > 150 cut



νμ energy w/o water in FV after total p.e. > 150 cut

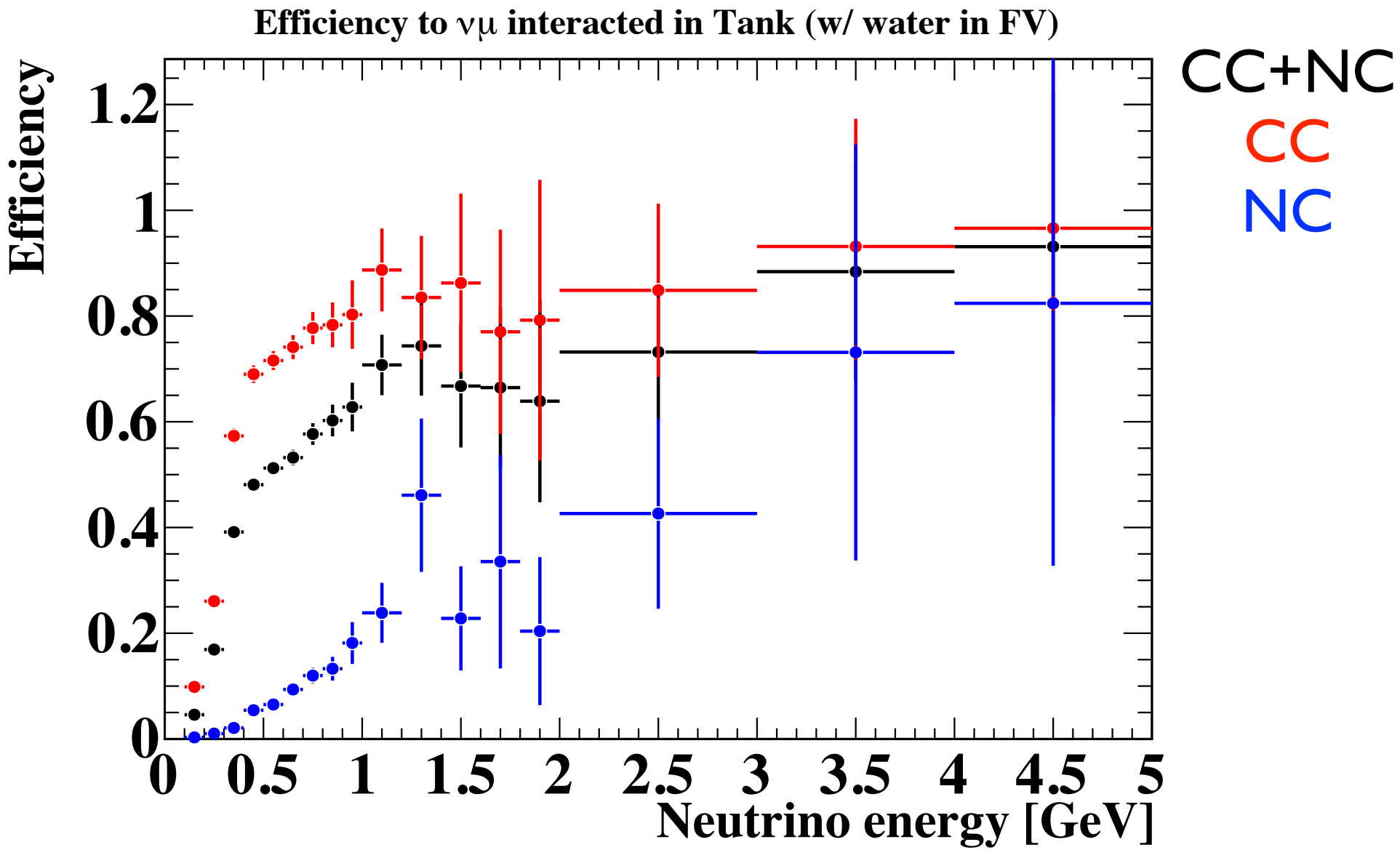


Subtract of νμ energy after total p.e. > 150 cut



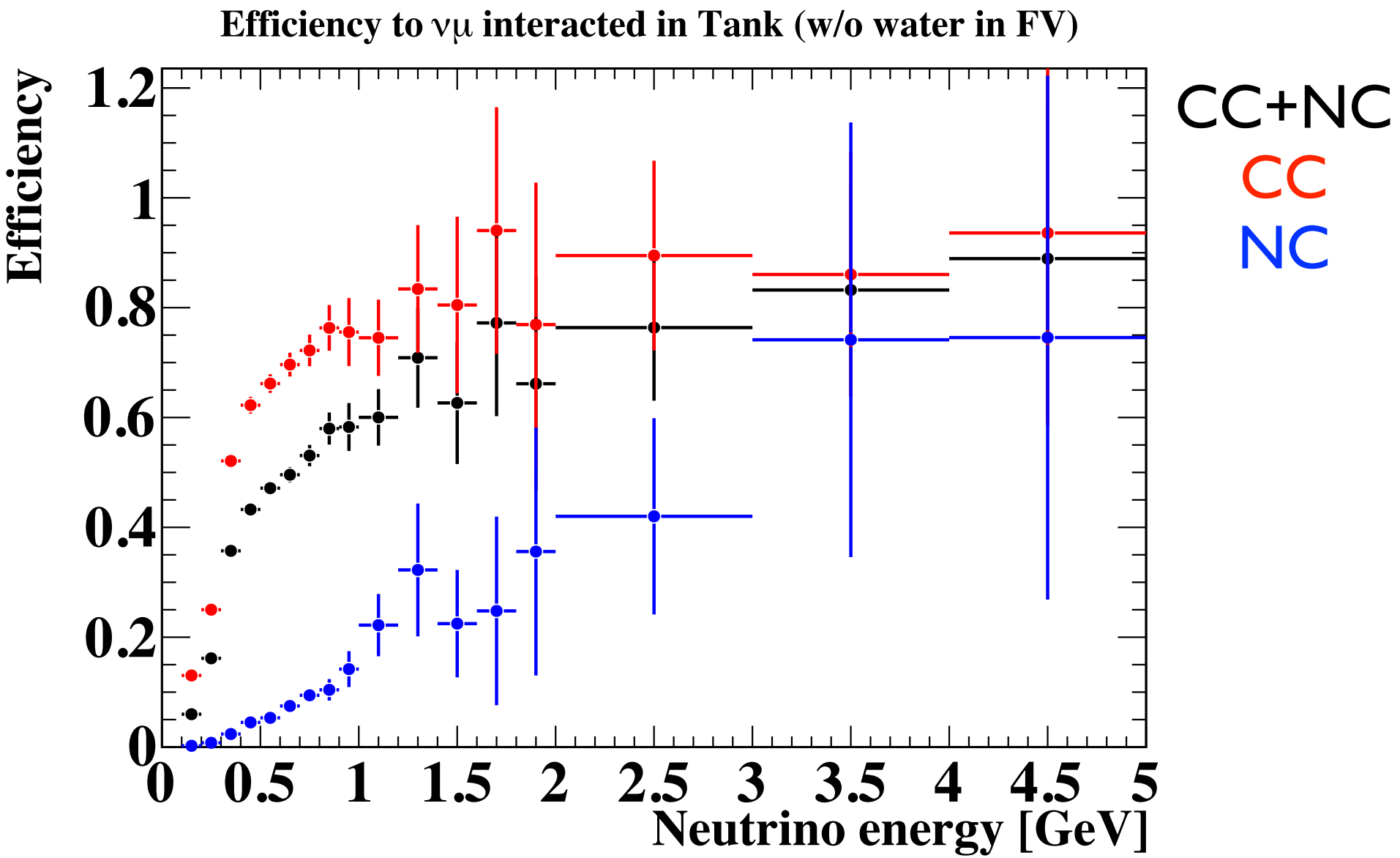
Efficiency (w/ water in FV)

(# of events after total pe>150)/(# of interactions in whole of Tank)



Efficiency (w/o water in FV)

(# of events after total pe>150)/(# of interactions in outside FV)



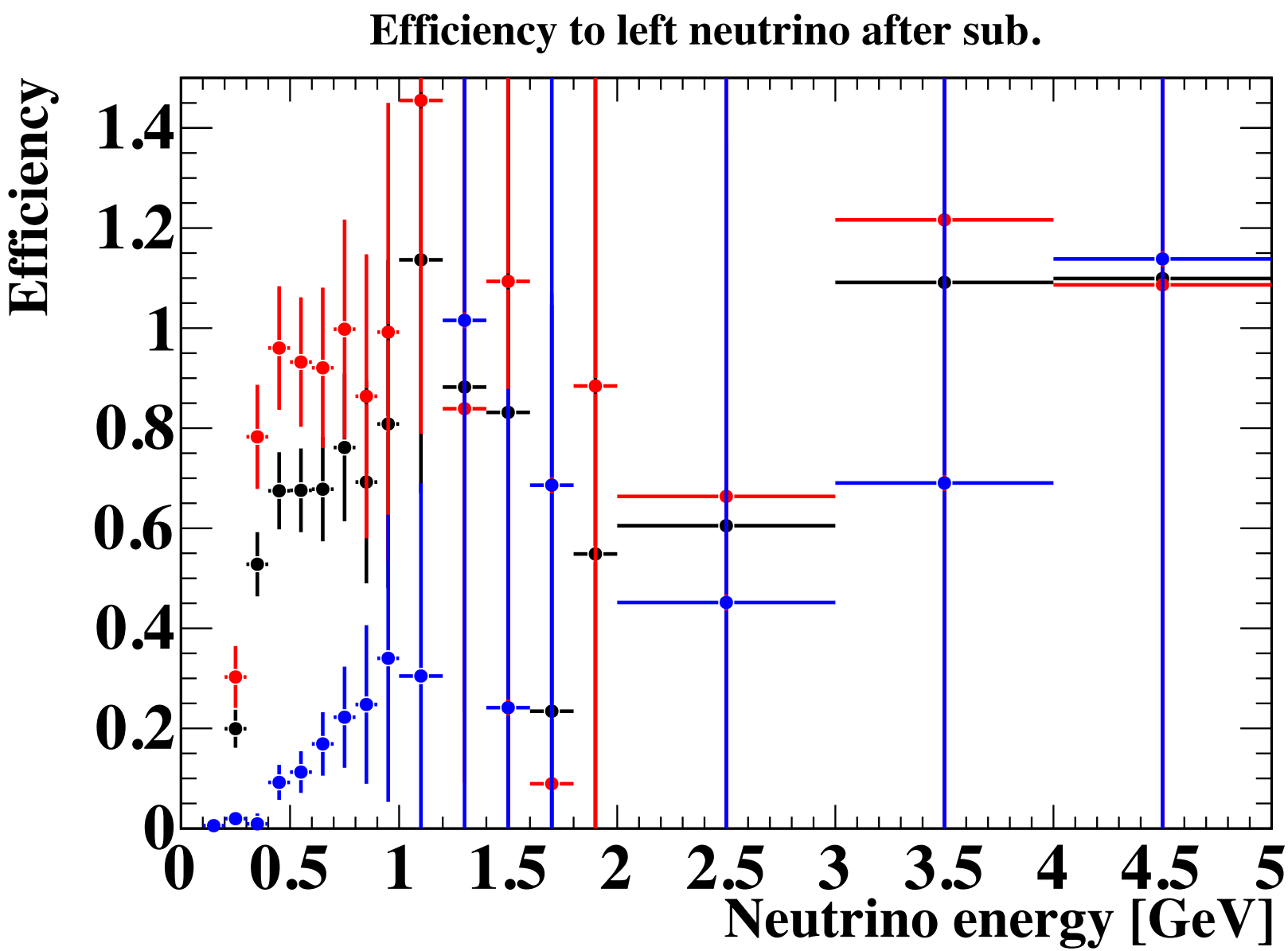
Efficiency (subtraction)

$$Efficiency = \frac{N_{obs,water} - N_{obs,nowater}}{N_{int,water} - N_{int,nowater}}$$

Nint,water : # of interactions in Tank (with water in FV)
Nint,nowater : # of interactions outside FV (without water in FV)

Nobs,water : # of events after total pe > 150 with water in FV
Nobs,nowater : # of events after total pe > 150 without water in FV

Efficiency (subtraction)



CC+NC

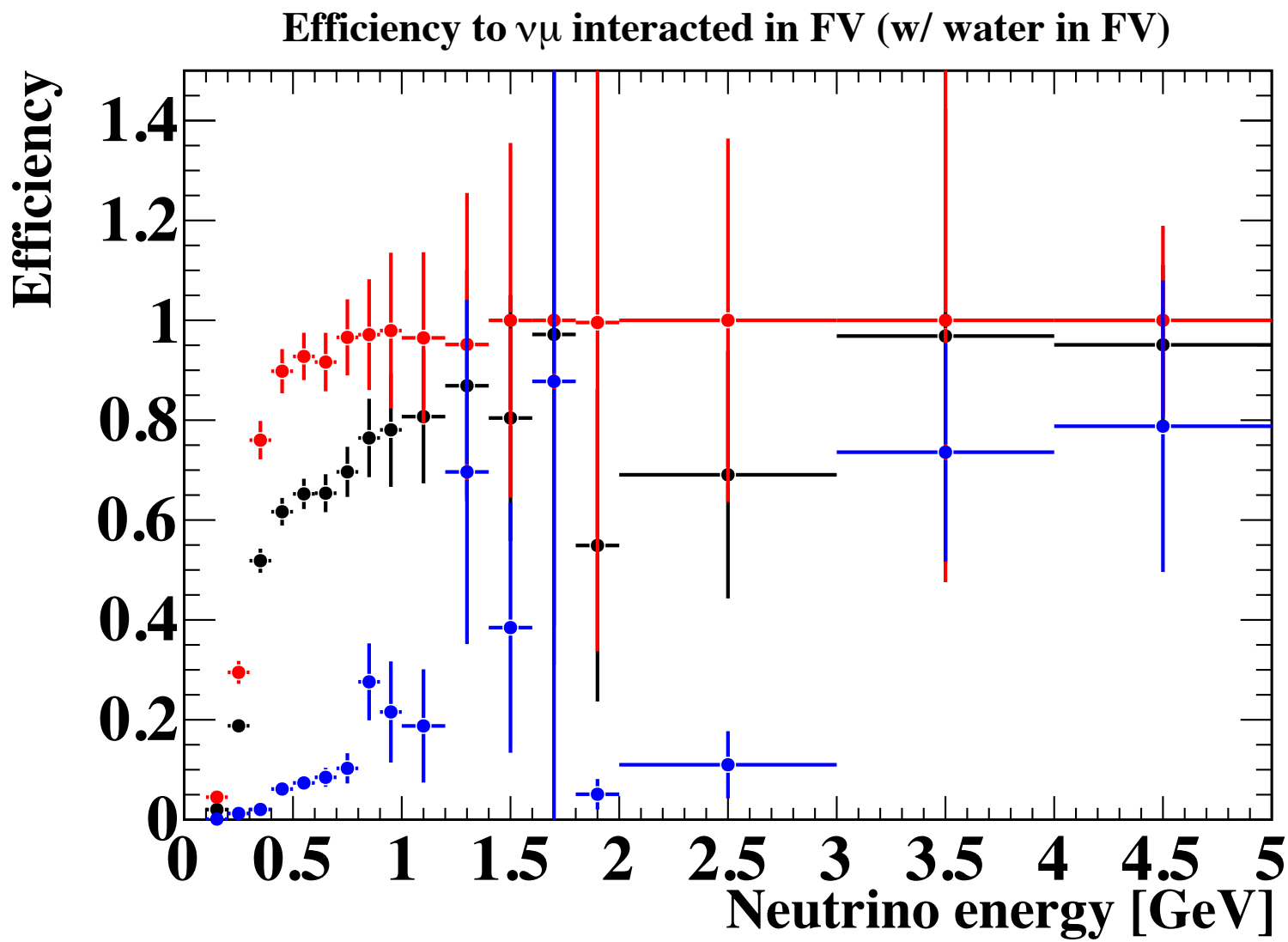
CC

NC

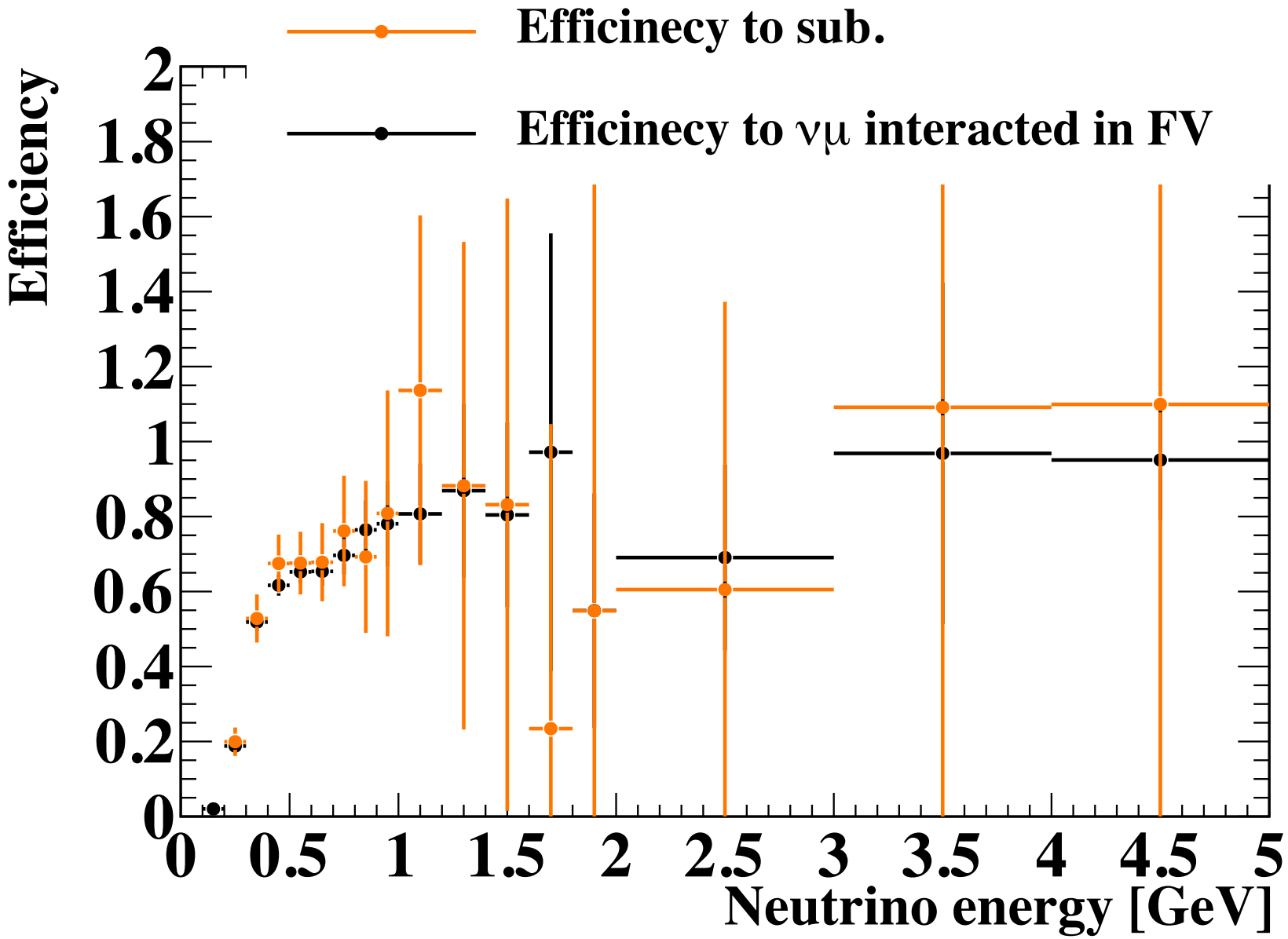
→ Low MC stat...

Efficiency to ν generated in FV

$$Efficiency = \frac{N_{obs,water,vertex\ in\ FV}}{N_{int,water,vertex\ in\ FV}}$$



Efficiency to ν (CC+NC) in FV
Same Draw (sub, vertex in FV)



of events [/10^{21}POT]

CC+NC interaction

	Generate	Total pe > 150	Efficency
# of events w/ water	2.43E+05	1.53E+05	0.63
# of events w/o water	1.94E+05	1.16E+05	0.60
# of events sub.	4.90E+04	3.70E+04	0.76
# of events generated in FV	5.05E+04	3.70E+04	0.73

# of events sub =
(# of events w/ water) - (# of events w/o water)

of events [/10^{21}POT]

Only CC interaction

	Generate	Total pe > 150	Efficency
# of events w/ water	1.72E+05	1.37E+05	0.80
# of events w/o water	1.38E+05	1.04E+05	0.75
# of events sub.	3.40E+04	3.30E+04	0.97
# of events generated in FV	3.57E+04	3.40E+04	0.95

# of events sub =
(# of events w/ water) - (# of events w/o water)

of events [/10^{21}POT]

Only NC interaction

	Generate	Total pe > 150	Efficency
# of events w/ water	7.06E+04	1.61E+04	0.23
# of events w/o water	5.65E+04	1.17E+04	0.21
# of events sub.	1.41E+04	4.40E+03	0.31
# of events generated in FV	1.47E+04	3.02E+03	0.21

# of events sub =
(# of events w/ water) - (# of events w/o water)

Comparison of # of expectation.

- # of interaction in Tank @100kW (previous expect)
  - w/ water in FV : 202 interactions / day
  - w/o water in FV : 127 interactions / day

Assume 100kW ~ 7.2e16 POT/hour (1day=24hours)

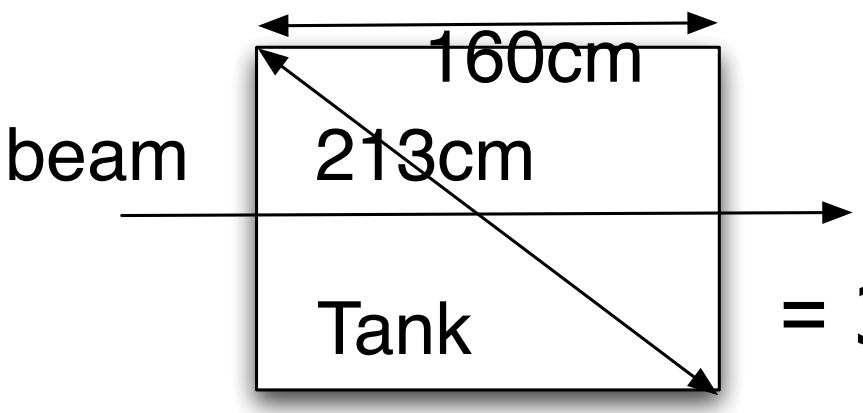
Use this MC	Interactions/day in Tank	Observations/day in Tank
w/ water	420	264
w/o water	335	200

Need data-taking time

- Used event rate:
  - 264 events/day with water in FV
  - 200 events/day without water
- For Stat. error of subtraction < 2% ...
  - 83 days with water in FV
  - 63 days without water in FV
- Total data-taking time : 146 days
  - Stat. error of subtraction ~ 1.9%

Rock muon study

- Expected # of incident rock μ to Tank.
  - Calc from # of measured rock μ at INGRID.
- Selected rock μ
  - penetrate Tank = go through 160~213cm water = go through 3~5 Iron plane of INGRID module.



MIP : 2MeV/cm
→ 160~213cm
= 320~426MeV energy deposit

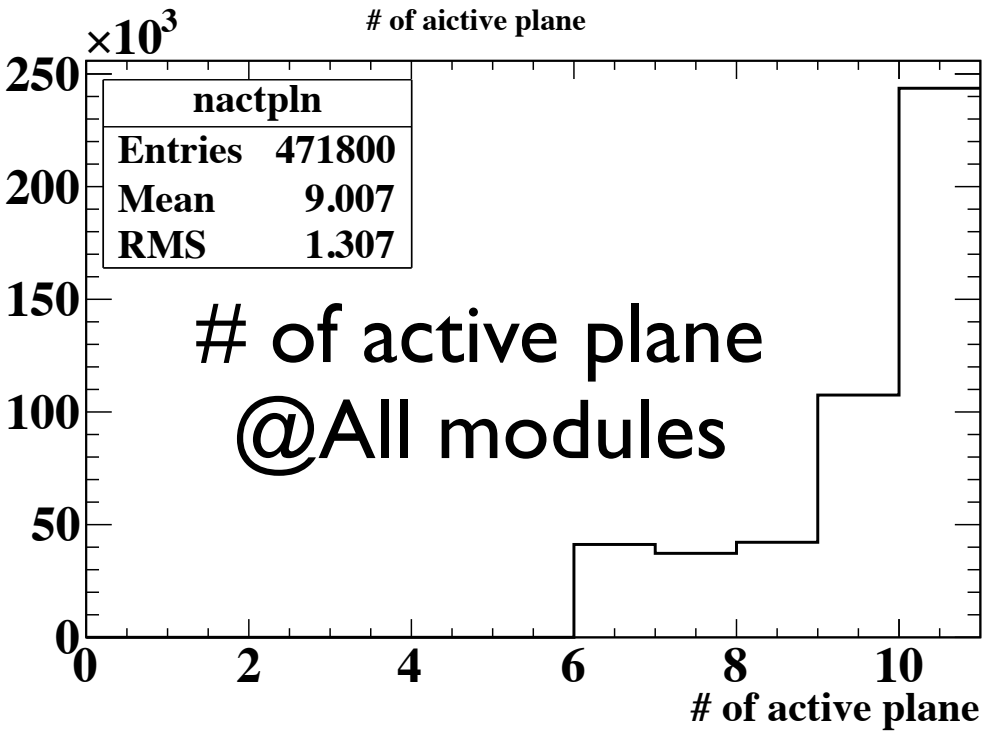
Rock μ selection

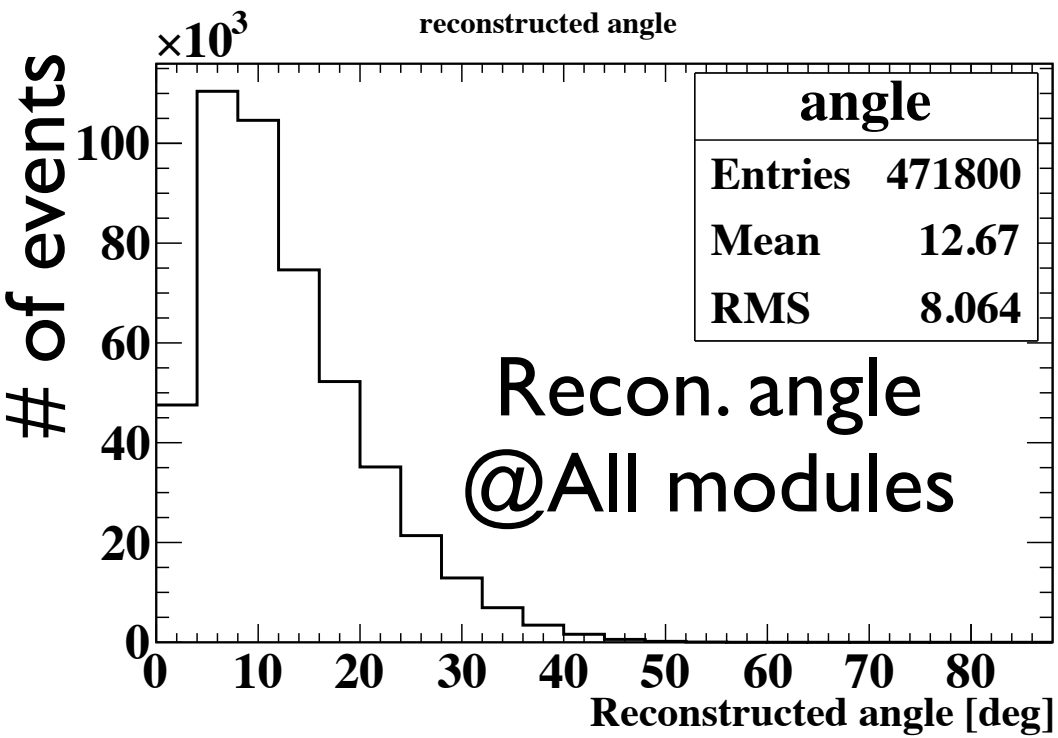
- Analysis INGRID Data Set (Run2010a)
  - Use total # of protons : 3.29 e19
  - Use total # of good spills : 1005887
- Analysis selection :
  - # of active plane >=6 (means to penetrate more 5 Iron planes)
  - p.e. / layer > 6.5 (same as neutrino selection)
  - Reconstructed vertex is in the first plane.
  - Not upstream VETO cut (to select μ from the front)

Analysis results

of detected rock muon : 471800 / 3.26e19 # of protons

The information of this selected rock muon





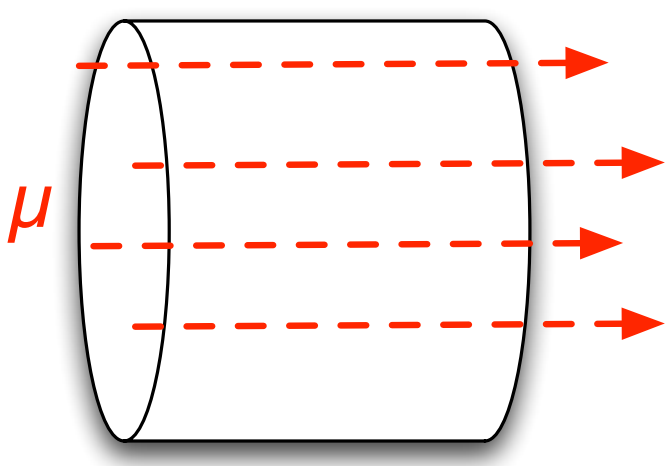
→ in this study, not use this angle distribution...
(more precise estimation, need to use)

Rock muon rate

- Use constant.
  - 100 kW = 7.2 e16 POT / hour
  - Ratio of area (Mizuche)/(INGRID) = 0.089
  - Detection efficiency to rock muon of INGRID ~ 1
- Exp. rock muon rate to Mizuche @ 100kW :
  - 471800×(7.2e16/3.26e19)×0.089 = 92.7 muons/hour

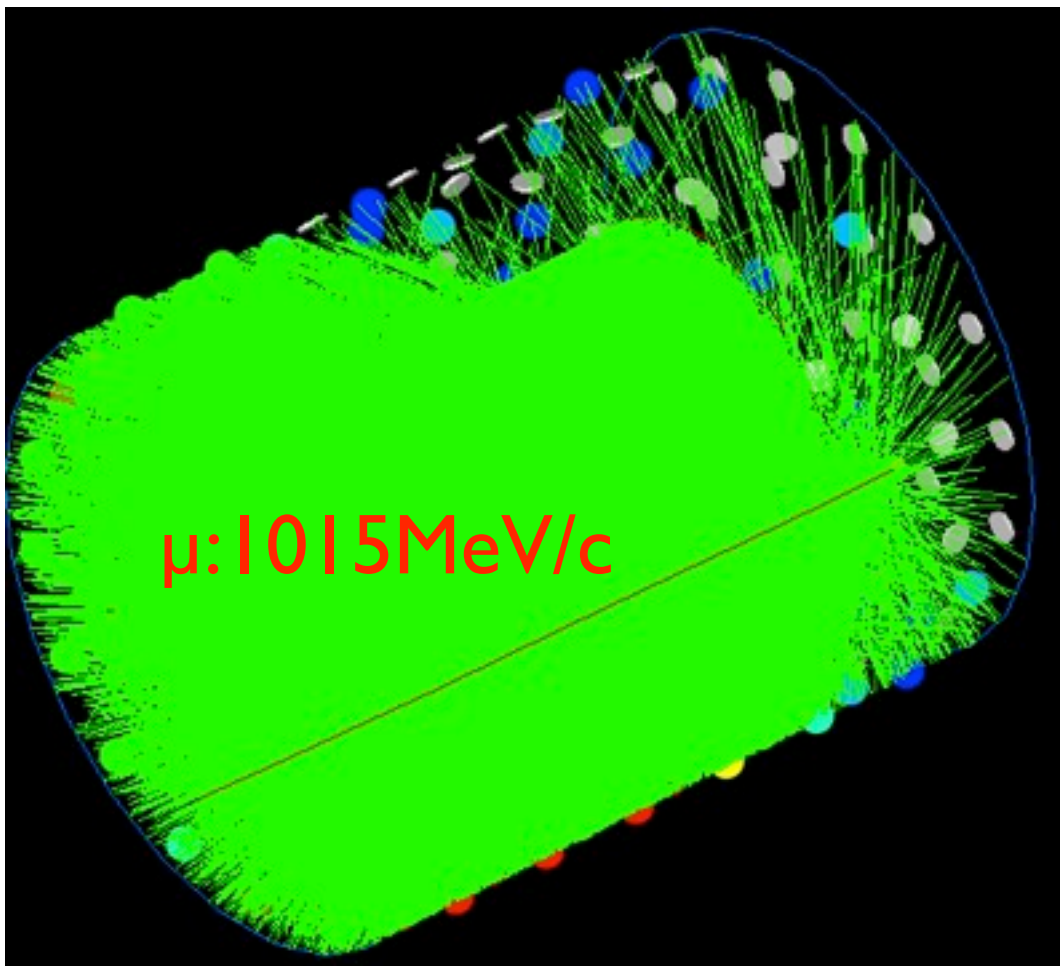
MC setting

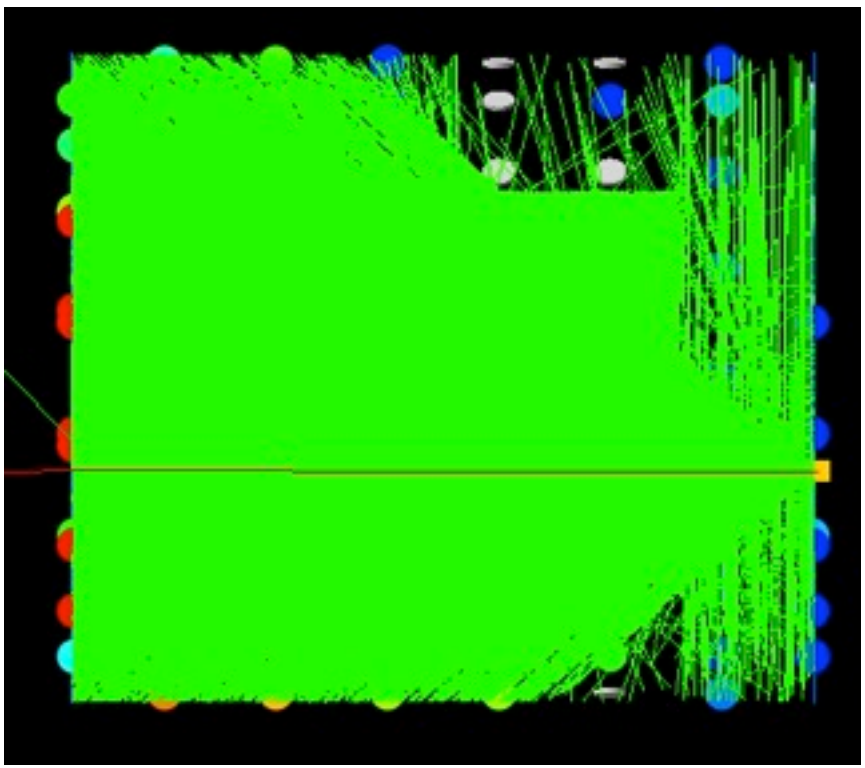
- Generate μ particles
- μ condition is simple
  - Kinetic energy : uniform in 450~1450 MeV
  - Init. direction : (0,0,1) (straight forward)
  - Init. vertex : uniform in the surface of the front of the Tank.



- Generated muon at MC : 3000 particles
- MC normalization : 927 muons (100kW × 10 hour)

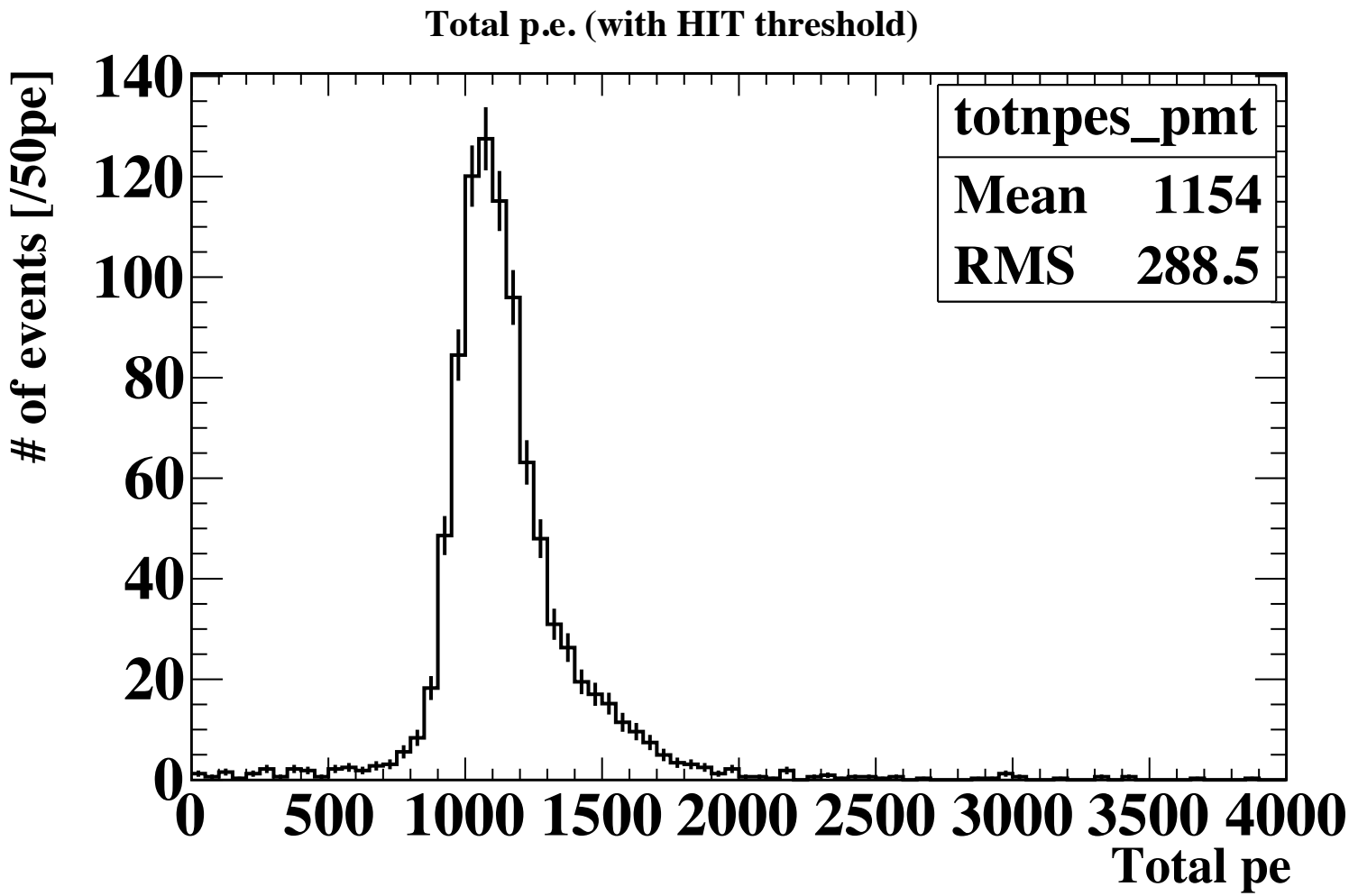
Sample of event





Total # of measured pe = 1148

Total measured p.e.



Peak around 1050 p.e., Mean of total pe : 1154 p.e.

> Expected p.e. ~ 811 p.e. at 160 cm path length

→ progress in study...