SNS 3X2m WC detector Spectrum

Li-Cheng, FENG

@Online Thursday, 17th Aug, 2023

SNS CC/NC spectrum - Generator

- Generator NEWTON from Baran (for CC events)

  Quasi elastic scattering (QE): Bahcall et al. (1995)

  $\nu_e/\overline{\nu_e}$ - ^{16}O CCQE Cross section: Haxton (1987)

  Oxygen deexcitation: TAYLS package

- Generator NEUT (for NC events)

  Quasi elastic scattering (QE): Nieve1p1h

  $\nu_e/\overline{\nu_e}$ - ^{16}O CCQE Cross section: Nieves et. al (2012)

  NCQE: Benhar Spectral Function (SF)

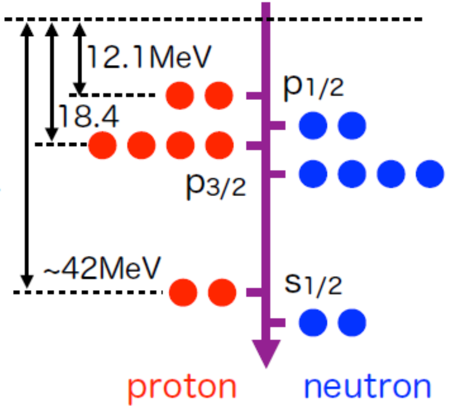
  Nuclear model: Local Fermi Gas

  Oxygen deexcitation: Ankowski et.al., (2012) NEUT

'Others' treatment

- In the simple shell model, the probability of nucleon knock-out is from the number of nucleons in each state;
  $s_{1/2}$: 25%, $p_{3/2}$: 50%, $p_{1/2}$: 25%
- In the recent calculation, the spectral function based on the measurement is used (Ankowski et.al., PRL 108, 052505 (2012)) :
  $s_{1/2}$: 10.55%, $p_{3/2}$: 35.15%, $p_{1/2}$: 15.8%, others : 38.5%
- No particles are emitted when the $p_{1/2}$ nucleon is knocked-out, (g.s. of ^{15}N or ^{15}O) while several particles are emitted in the case of $s_{1/2}$.
- Ueno-san and Huang-san treated 'others' as $p_{1/2}$.
- No one knows how to treat 'others', but most likely the nuclear state should go high. So we decided that 'others' is treated as $s_{1/2}$. This is installed from neut_5.4.0.

	$s_{1/2}$	$p_{3/2}$	$p_{1/2}$
Shell model	25%	50%	25%
- neut 5.3.6	10.55%	35.15%	54.3% (=15.8+38.5)
neut 5.4.0 -	49.05% (=10.55+38.5)	35.15%	15.8%



(The energy level of neutrons is ~3.54MeV deeper than protons.)

Event rate estimation

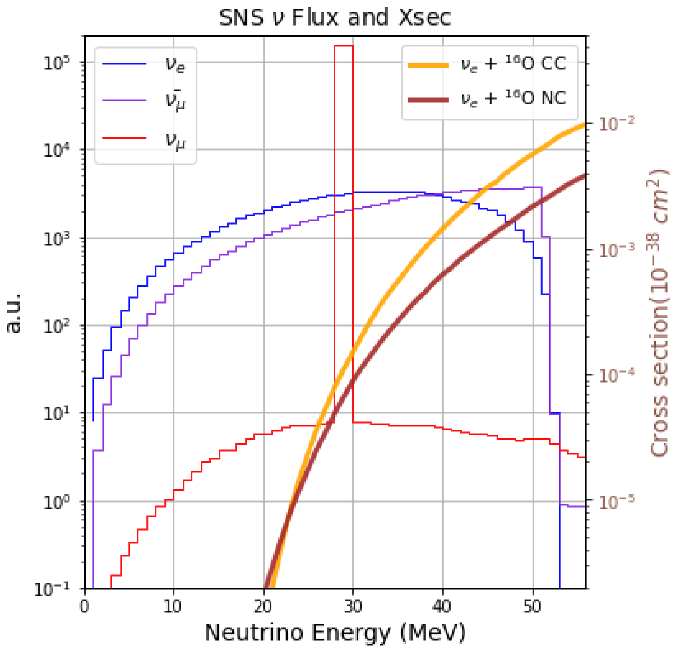
$$\frac{dN(E_{\nu_e})}{dE_{\nu_e}} = \sigma_{CC}(E_{\nu_e}) \cdot \frac{d\phi_{\nu_e - SNS}}{dE_{\nu_e}} \cdot N_{target} \cdot t$$

$$\frac{dN(E_{\nu})}{dE_{\nu}} = \sigma_{NC}(E_{\nu}) \cdot \frac{d\phi_{\nu_e - SNS}}{dE_{\nu}} \cdot N_{target} \cdot t\ ,$$

$$E_{\nu} = E_{\nu_e}, E_{\nu_\mu}, E_{\overline{\nu_\mu}}$$

- Neutrino flux : 4.3 x 10^7 neutrinos cm^{-2} s^{-1} at a distance of 20m.
  arXiv:1803.09183
- SNS-year : 1.8 x 10^7 second (5000 hours)
- N_{target} : ~ 1.98 x 10^{28} of ^{16}O in D2O detector (592kg)

195 evts for 1 SNS-year in D2O detector
arXiv:2104.09605



Input SNS neutrino flux and Xsec.

Scale to 3X2m WC detector

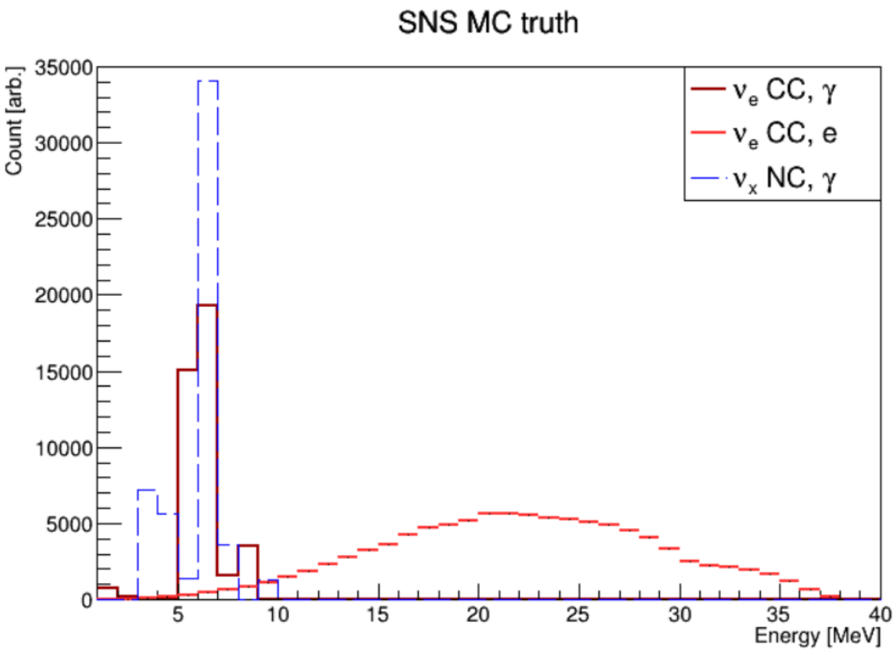
195 evts * $(20m)^2/(12m)^2$ * 14080kg/592kg ~= 12883 evts (CC) for 3X2m WC detector

~= 18664 evts (NC) for 3X2m WC detector

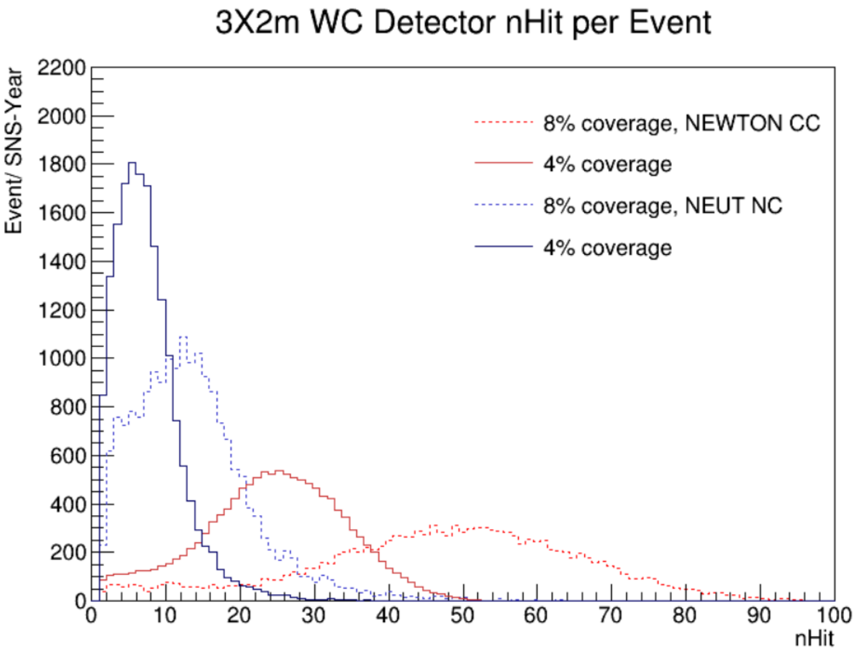
Closer to the source

3mX2m detector,
water density :997 kg/m^3

Estimated Spectrum

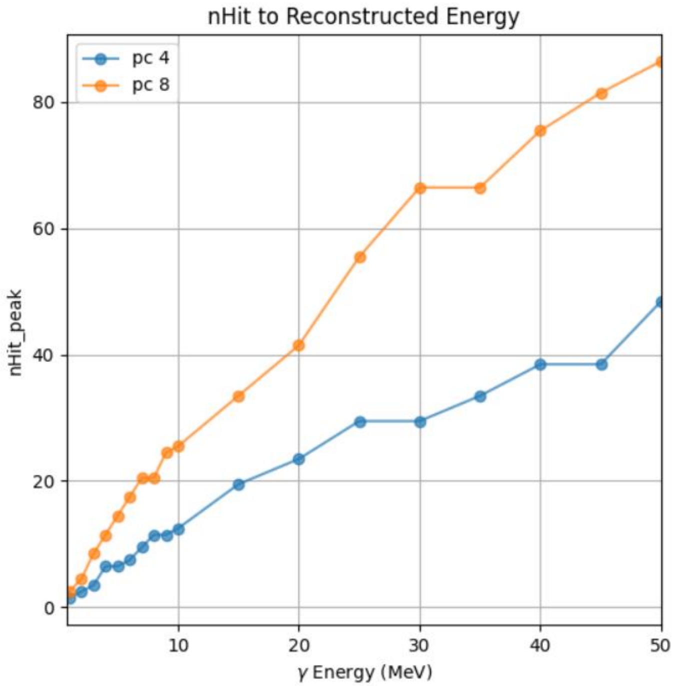


Both 100,000 events are simulated for CC and NC

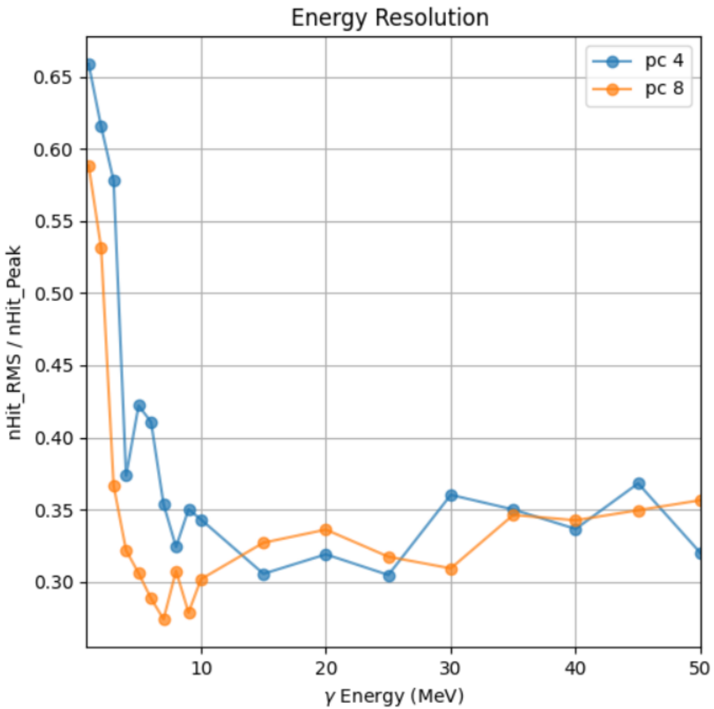


Noted that e & γ that produced within an CC event are contributed together as a final nHit number.

Energy reconstruction and Energy resolution

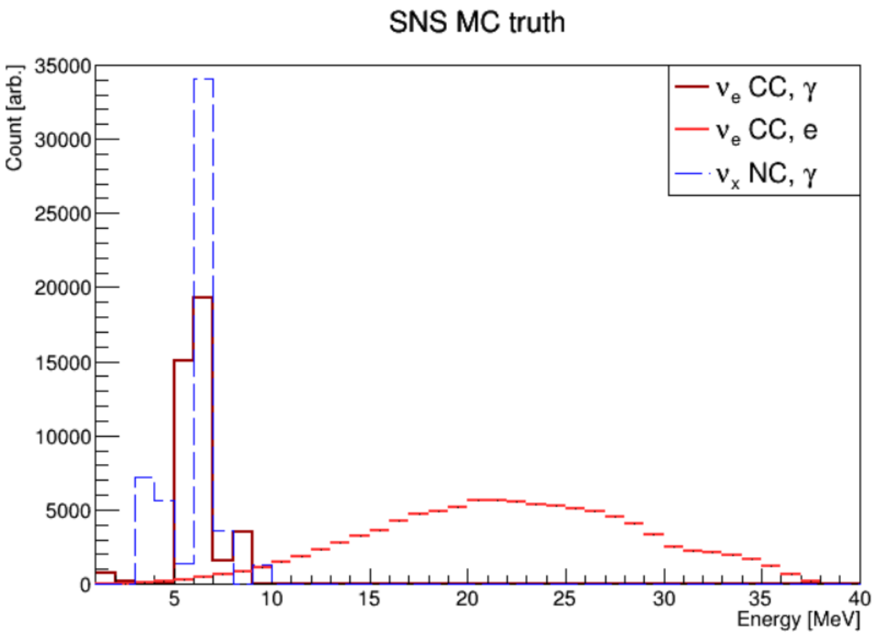


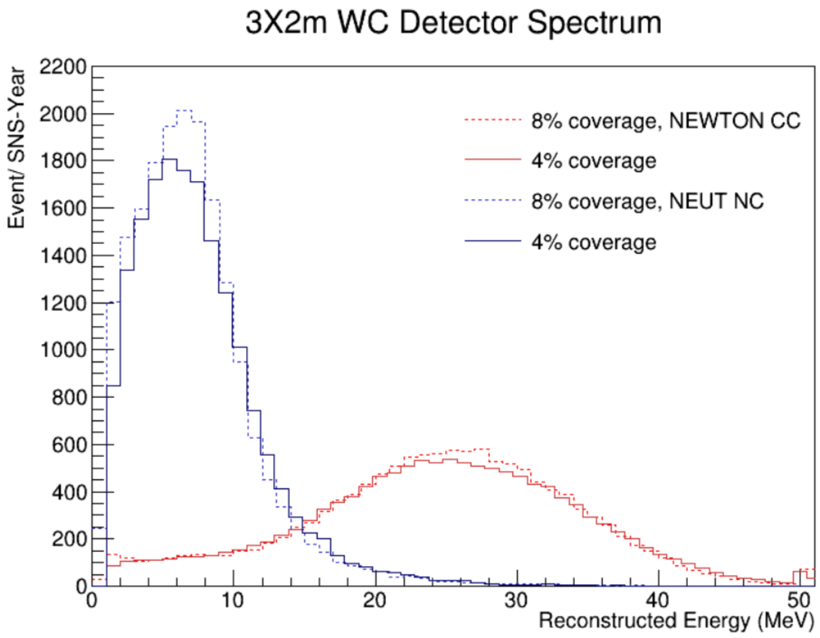
Linear transform for energy reconstruction



For reconstructed energy bin size

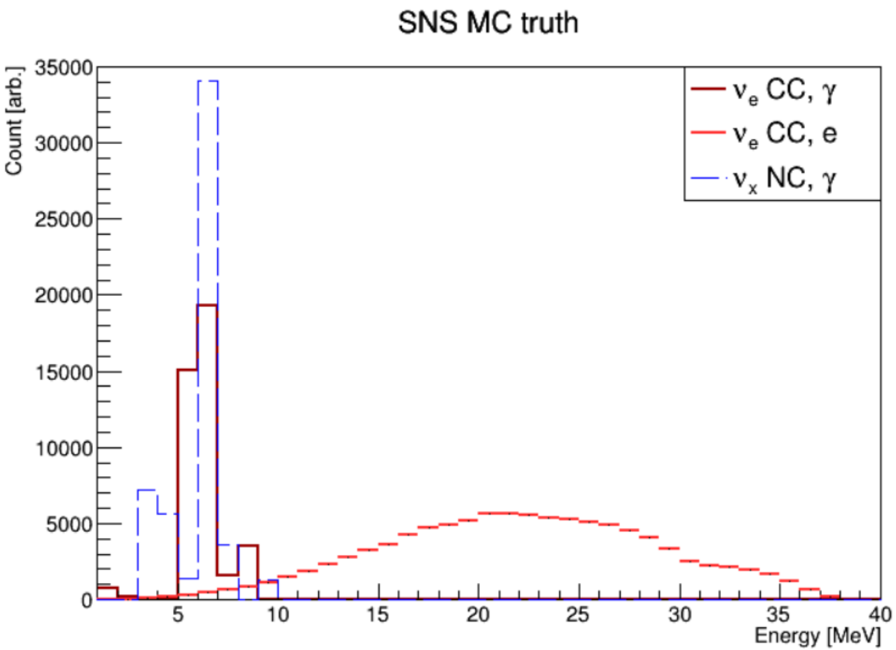
Reconstructed Energy

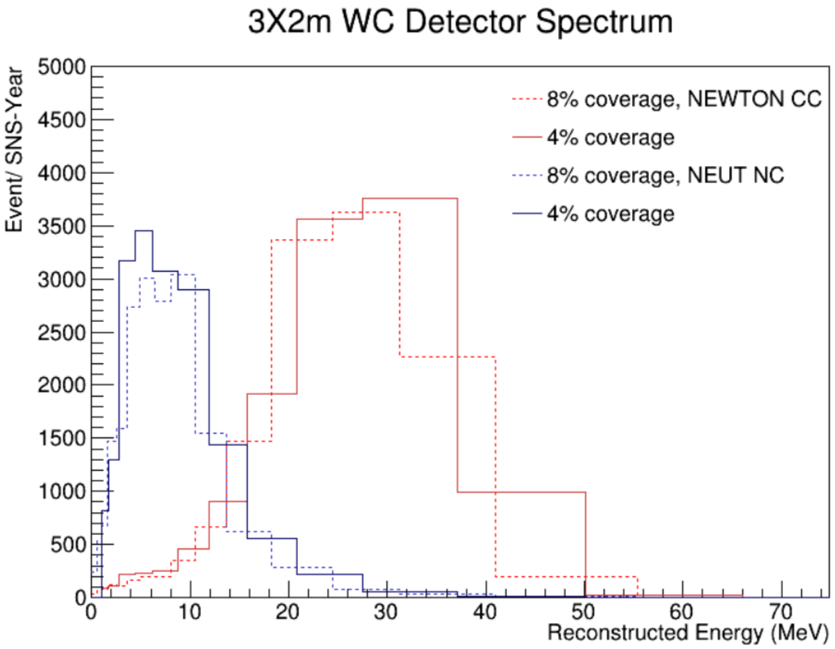




Reconstructed 3X2m WC spectrum

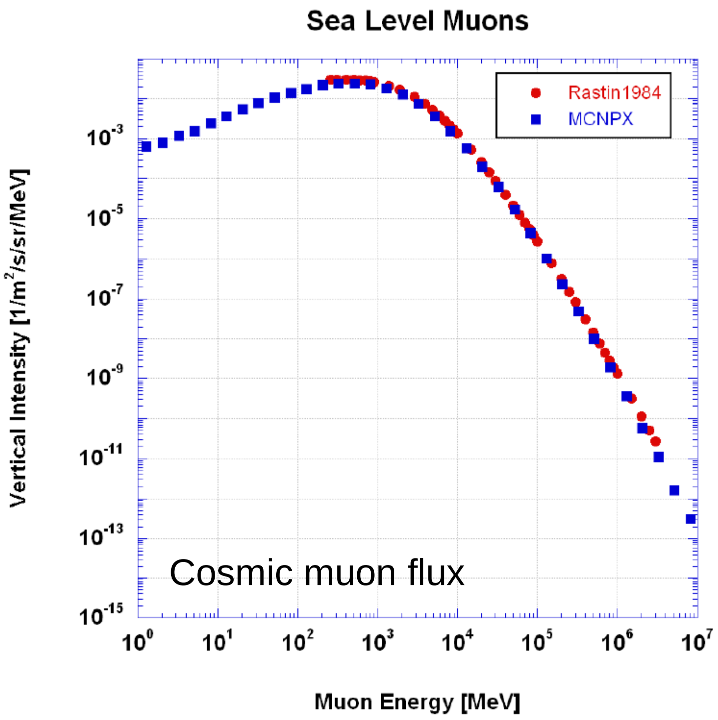
Reconstructed Energy with 8pc detector energy resolution





Reconstructed 3X2m WC spectrum
with realistic energy resolution

Cosmic muons with veto equipment



C. Hagmann et al. IEEE NSSCR. 2 (2007) 1143.

Veto panels from D2O detector design

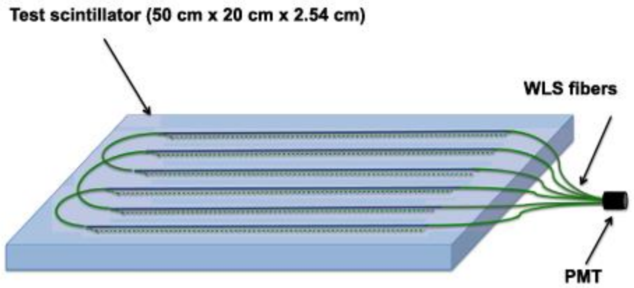


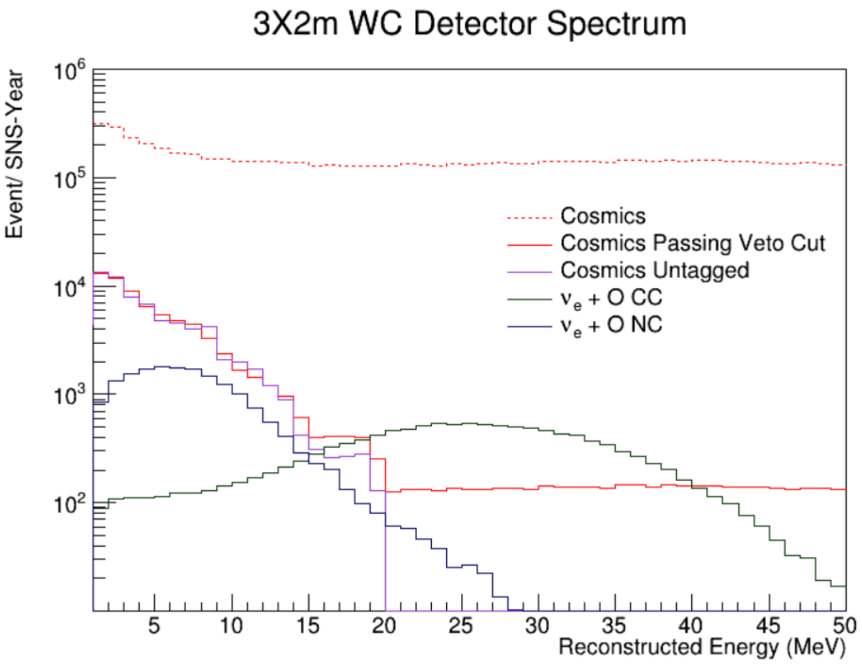
Fig. 1. Test panel.

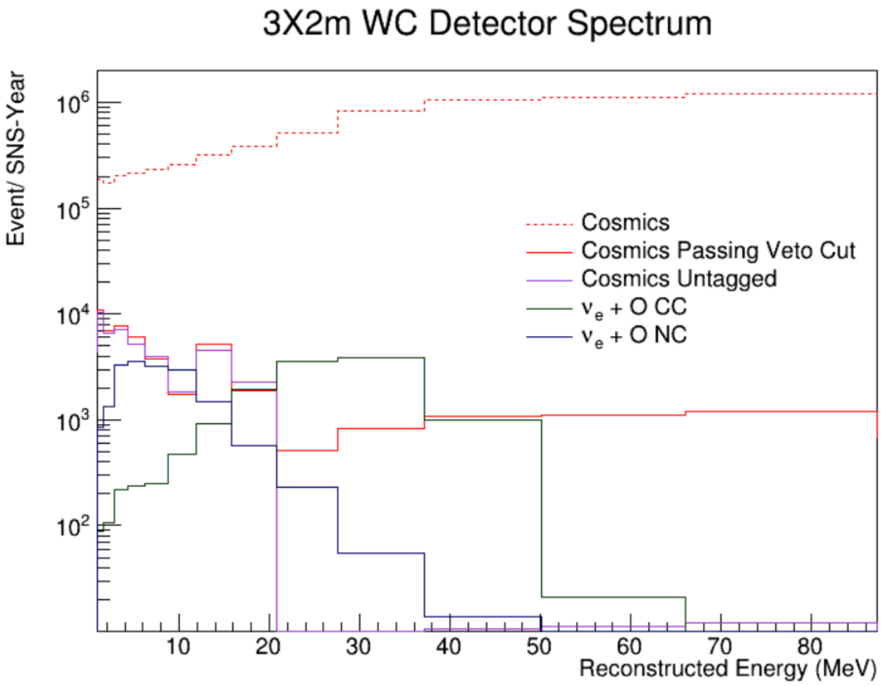
Table 1
Materials studied.

PS	PMT	WLS	REFL
BC-404	R9880U-20	Y-11(150)	TYVEK-1025D
BC-408	R9880U-210	Y-11(200)	TYVEK-1056D
EJ-204A		Y-11(300)	TYVEK HomeWrap
EJ-204B		BCF-91A	VM2000
UPS-923A		BCF-92	ESR
			Aluminum foil
			Aluminized mylar film

W. Bugg et al. NIM-A 758(2014)91–96

Cosmic muons with veto equipment





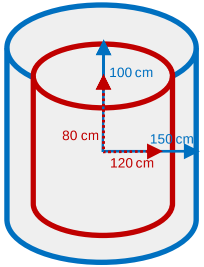
Reconstructed 3X2m WC spectrum with realistic energy resolution

SNS US-Japan Meeting

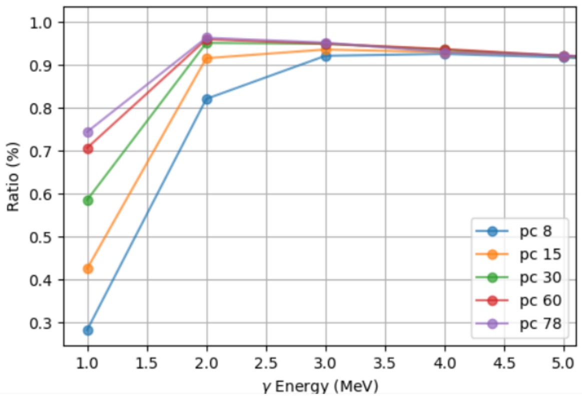
Li-Cheng, FENG

@Online Tuesday, 27th June, 2023

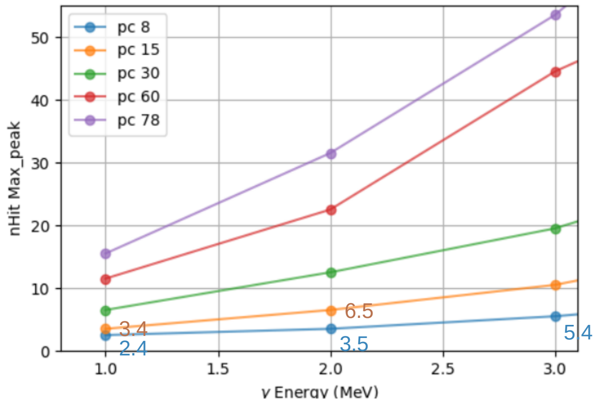
Take aways

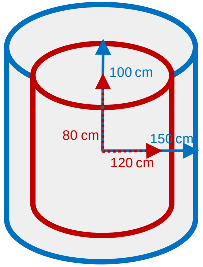


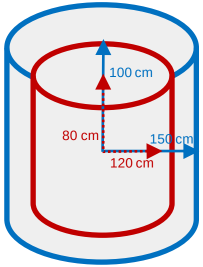
Success full hit ratio



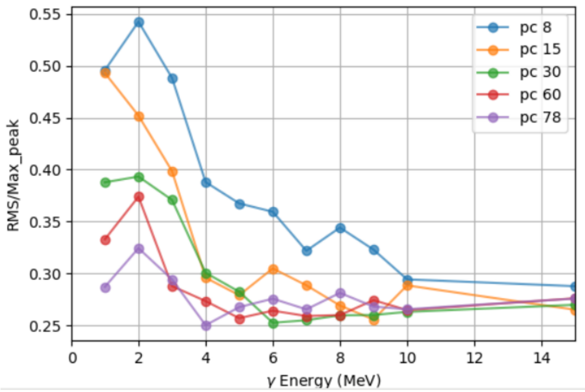
nHit peak distrubution



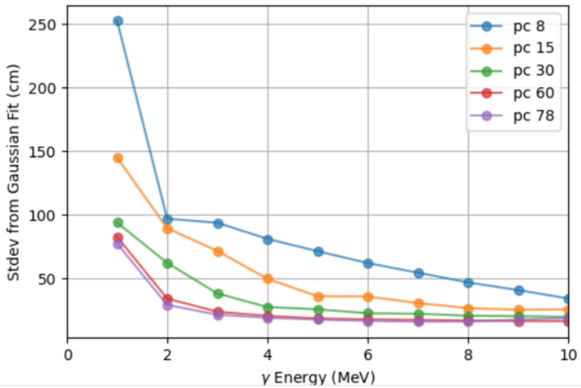


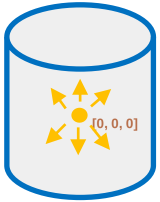


Energy Resolution



Vertex Resolution



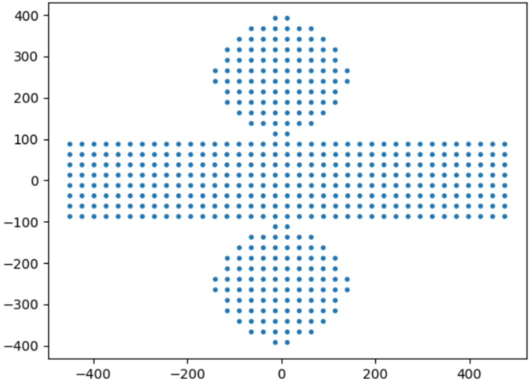


WCSim Simulation

ID Diameter : 3m
IDHeight : 2m
Cathod coverage : [7.5, 15, 30, 60, 78]%
3-inch PMT numbers :[488, 999, 1984, 3956, 5056]
QE: same as 20-inch

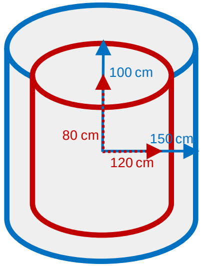
Input particle : gamma
Direction: Uniform
Position : Uniform
MC Statistics: 10,000 event

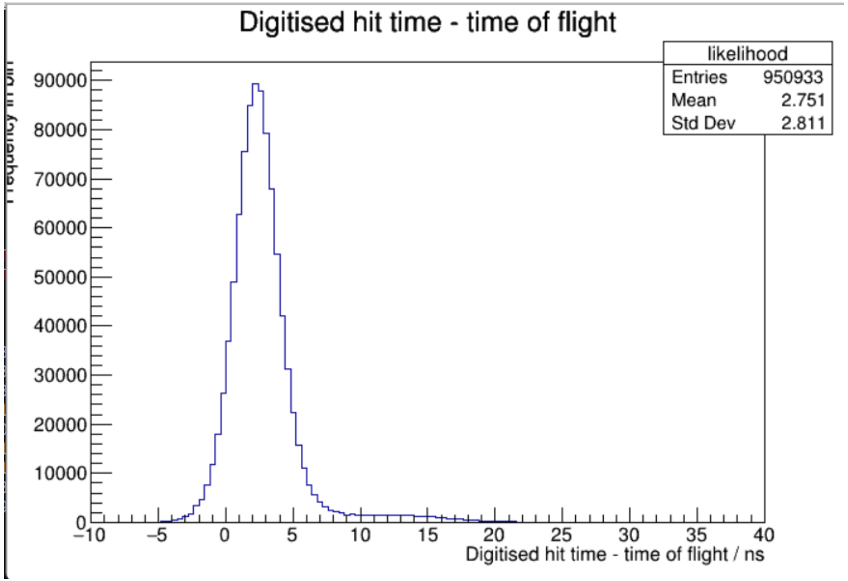
coverage 7.5% #448 PMT

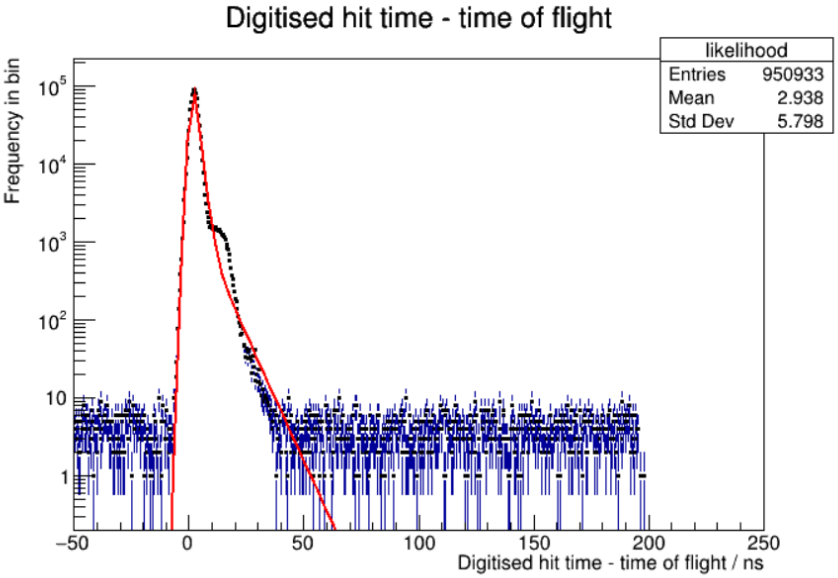


Vertex Reconstruction, WCSim, Bonsai

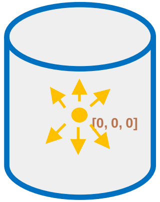
Create T-TOF PDF for the 3m x 2m detector (pc: 78%)



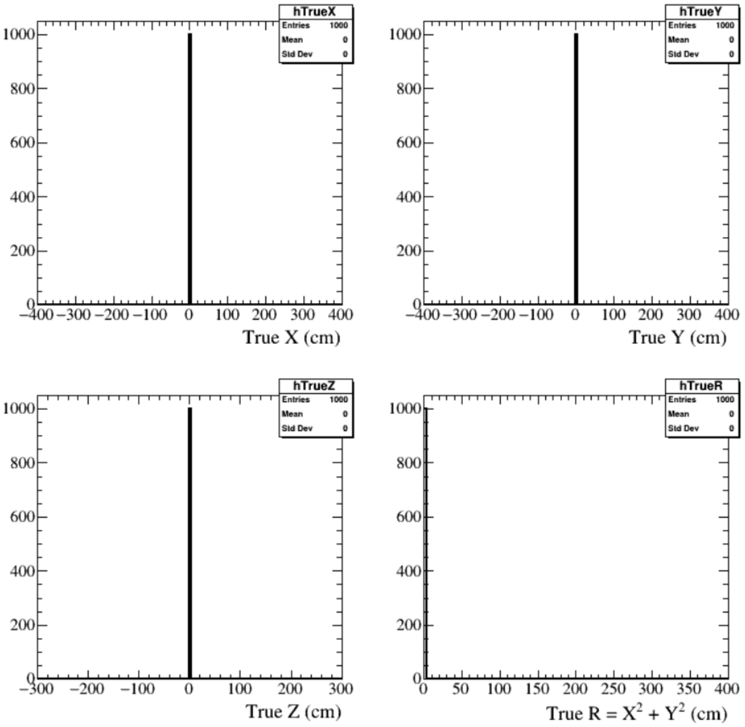




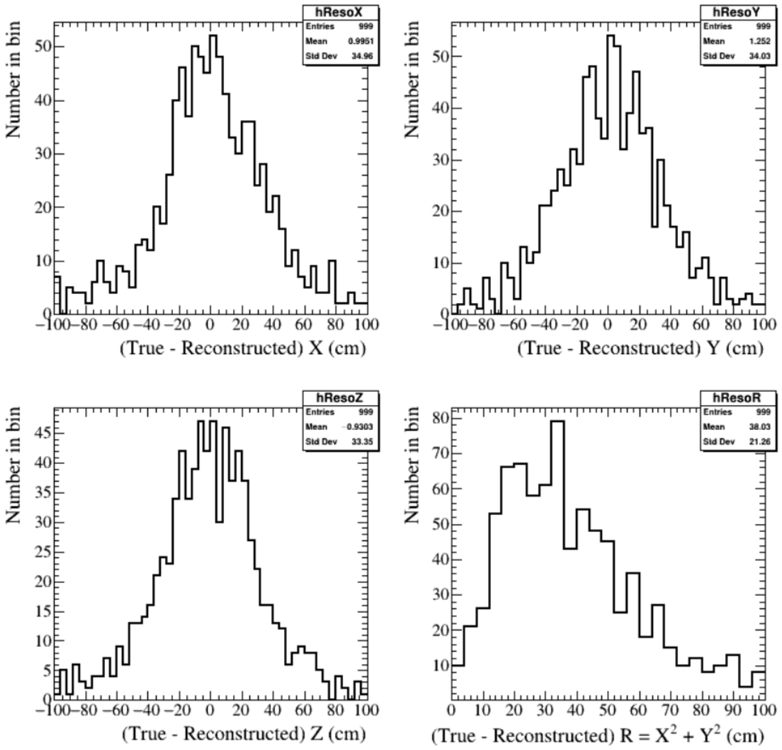
WCSim, Bonsai, e⁻ 10 MeV , Position (0, 0, 0), Direction: Uniform



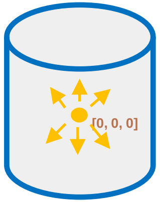
MC Truth

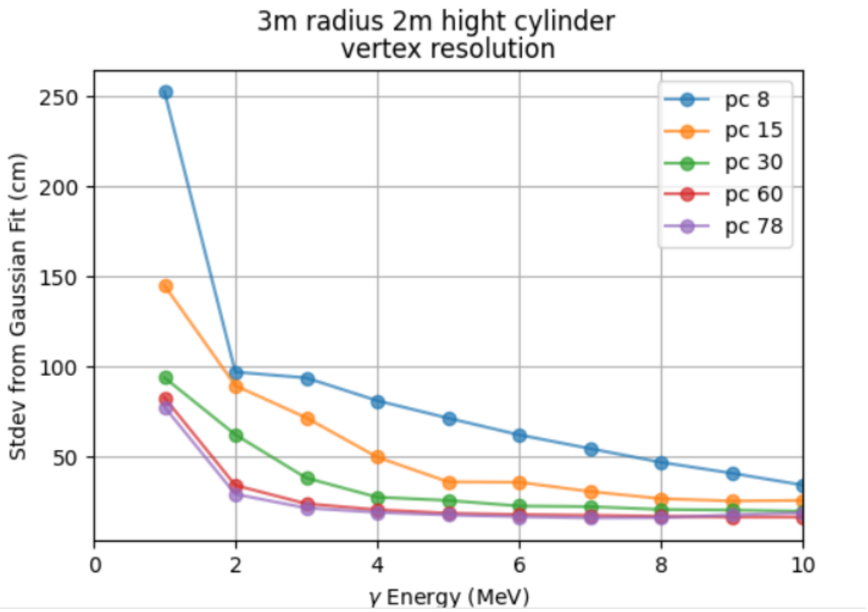


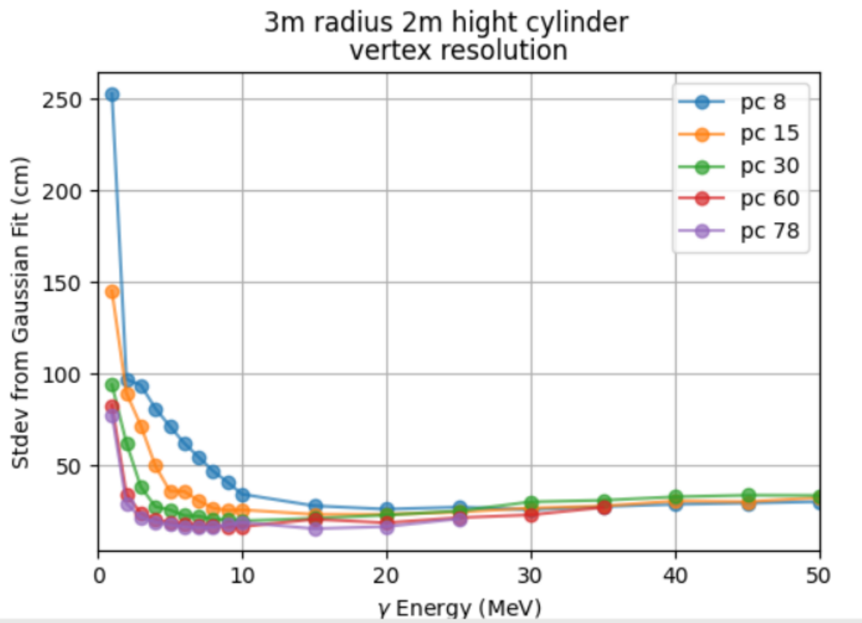
Reconstructed



Vertex Resolution



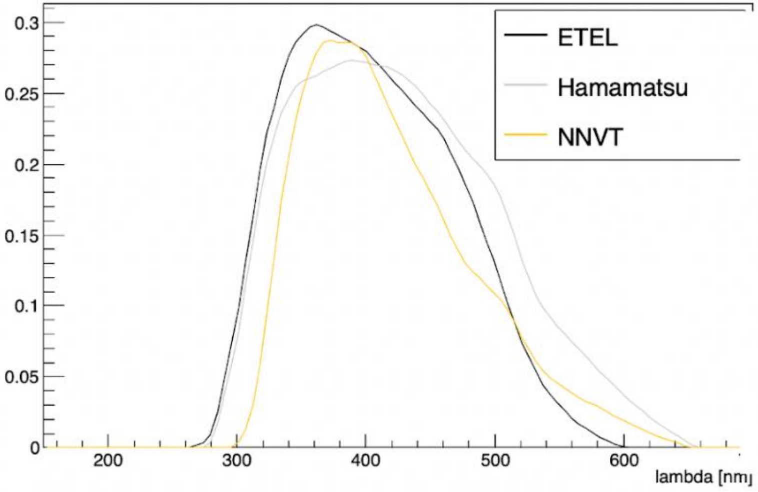


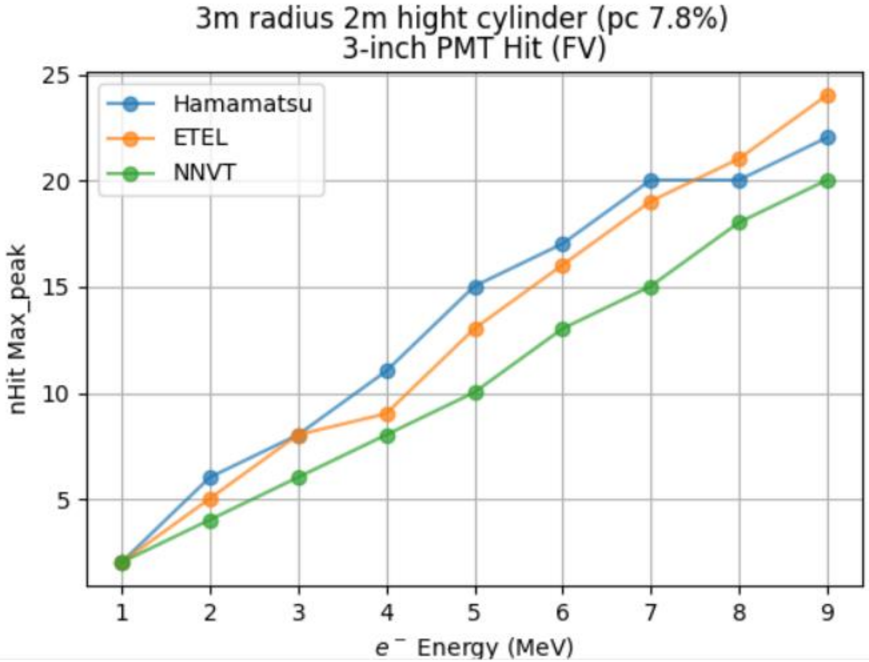


Backup

WCSim Study

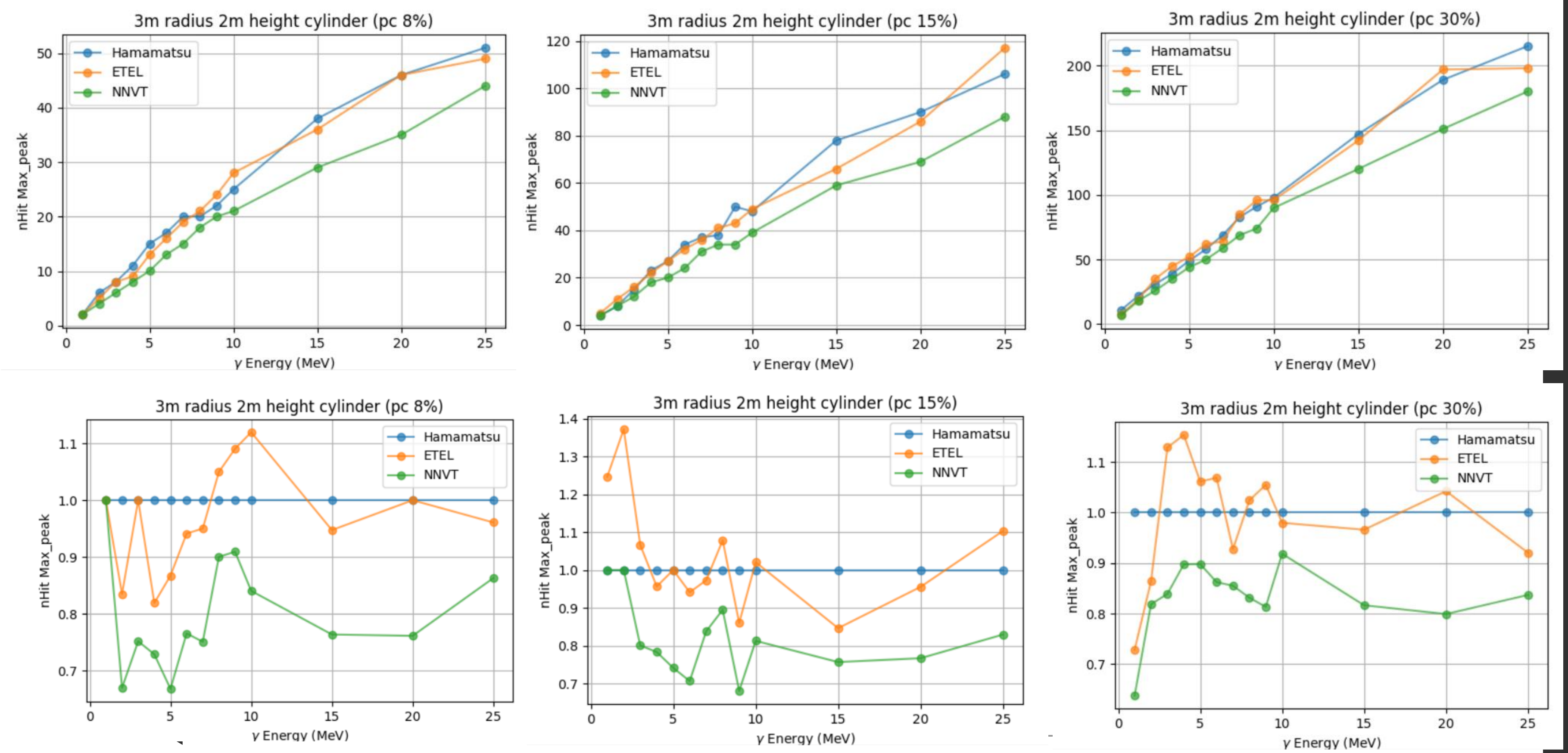
Quantum efficiency of 3-inch PMT



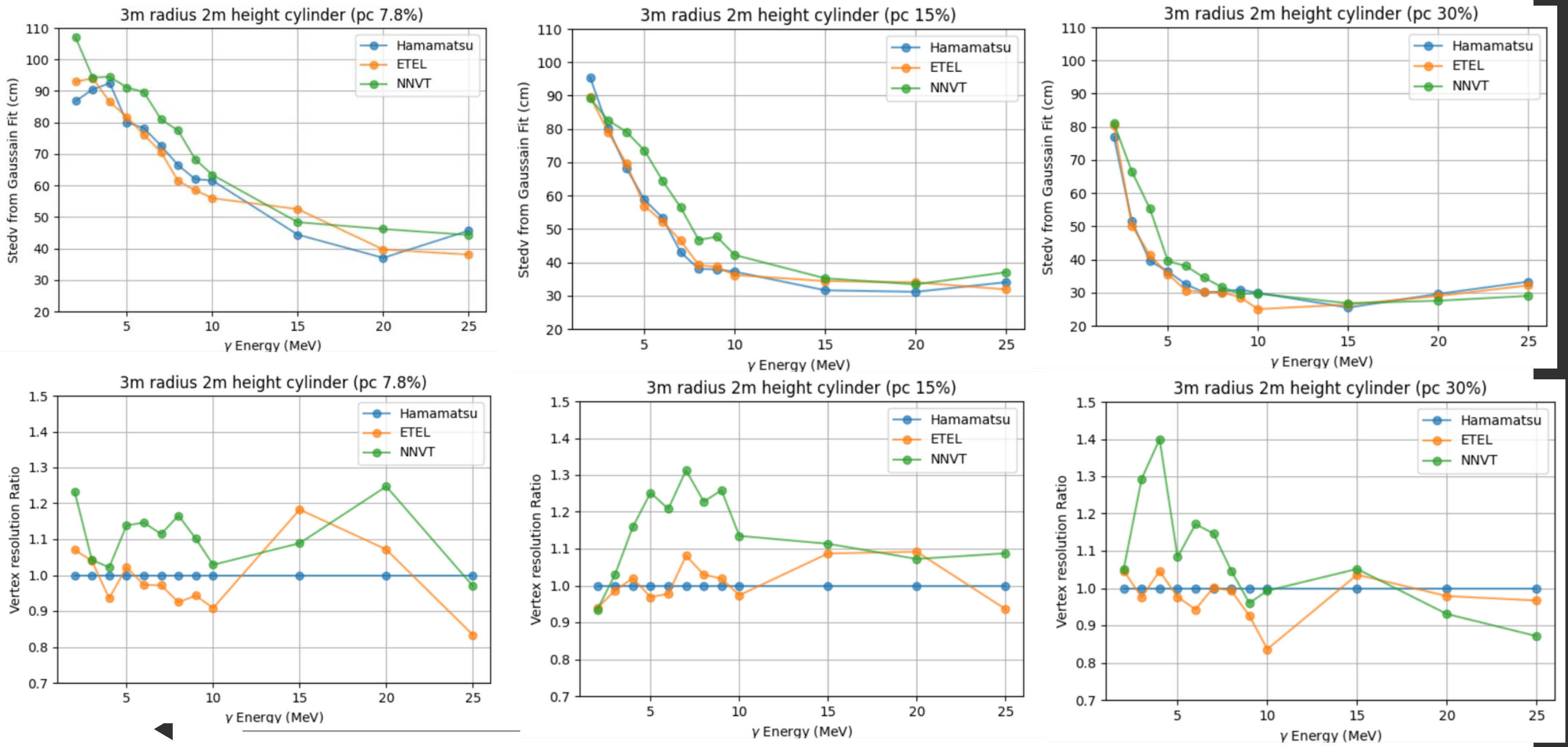


NNVT will have ~20% less hit
compare with Hamamatsu / ETEL PMT

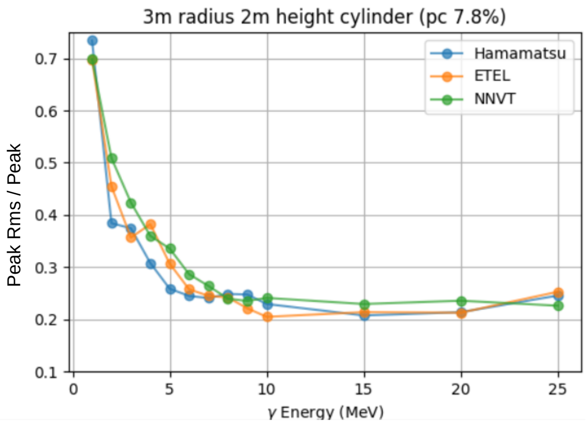
PMT Hit number peak per event

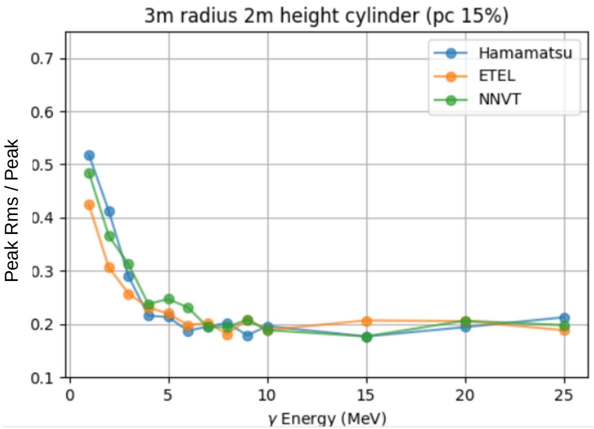


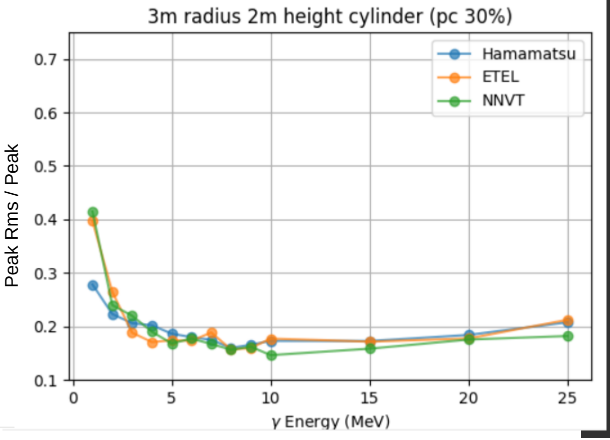
Vertex Resolution

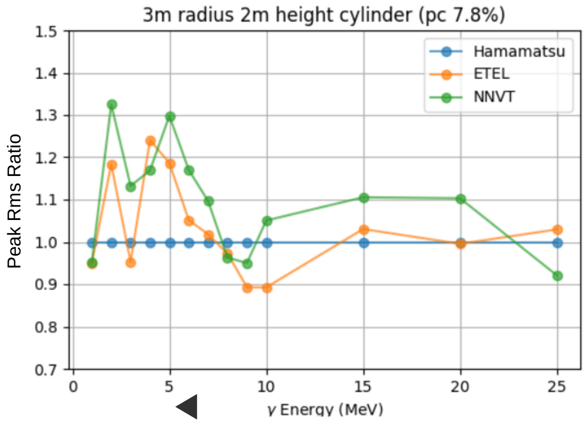


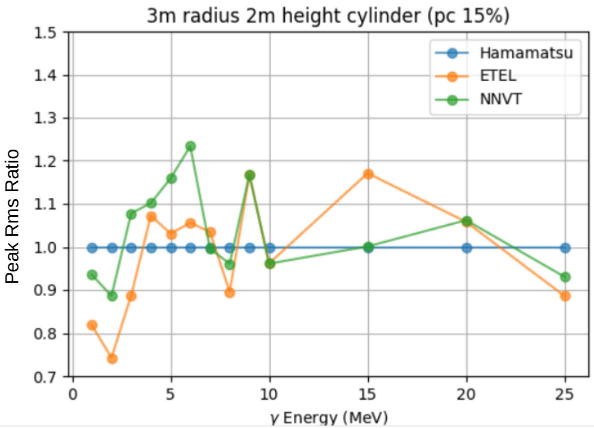
Energy Resolution

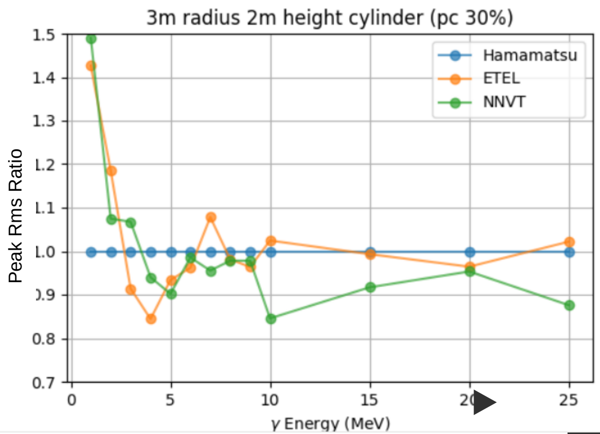








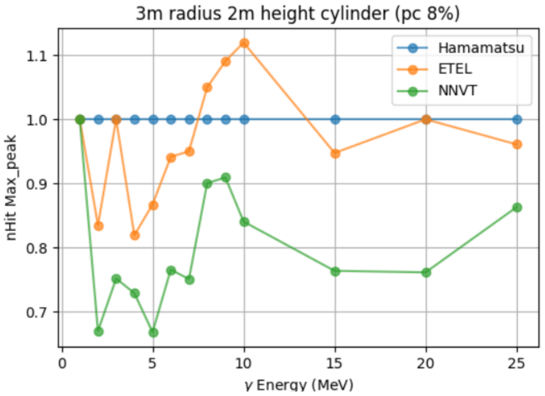




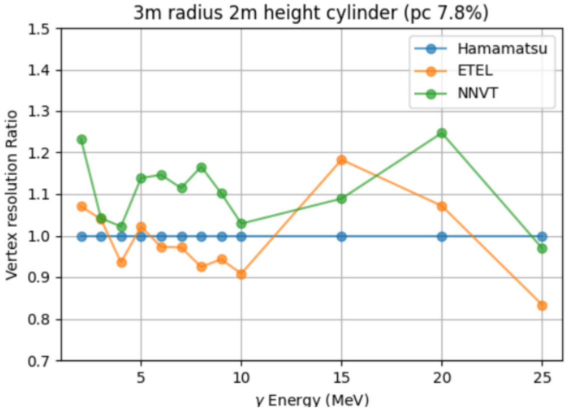
Take away

If we utilize NNVT to control the budget,
we may encounter the following consequences:

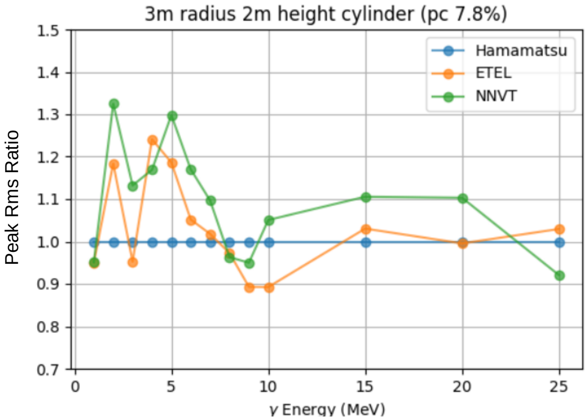
~20% reduction of PMT hits.



~10% degradation in vertex resolution



~10% decrease in energy resolution



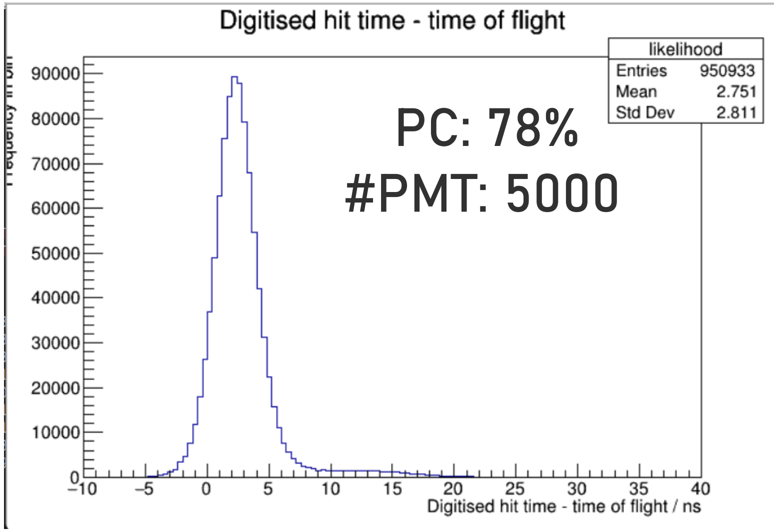
WCSim, Bonsai, e^- 10 MeV , Position (0, 0, 0), Direction: Uniform

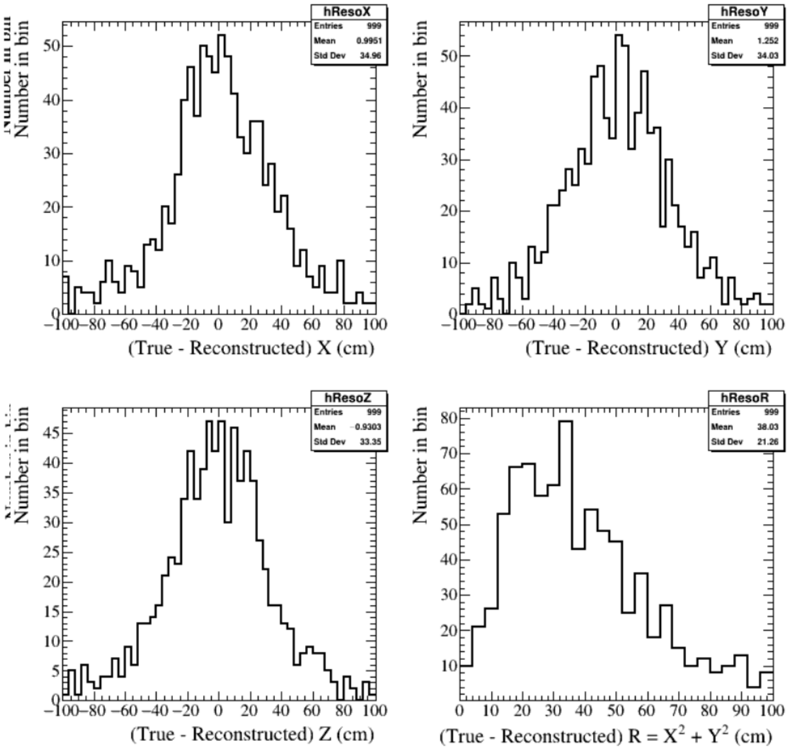
Reconstructed

PDF using

PC: 78%

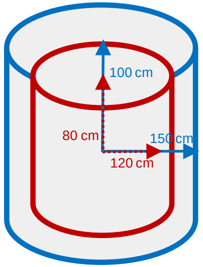
#PMT: 5000

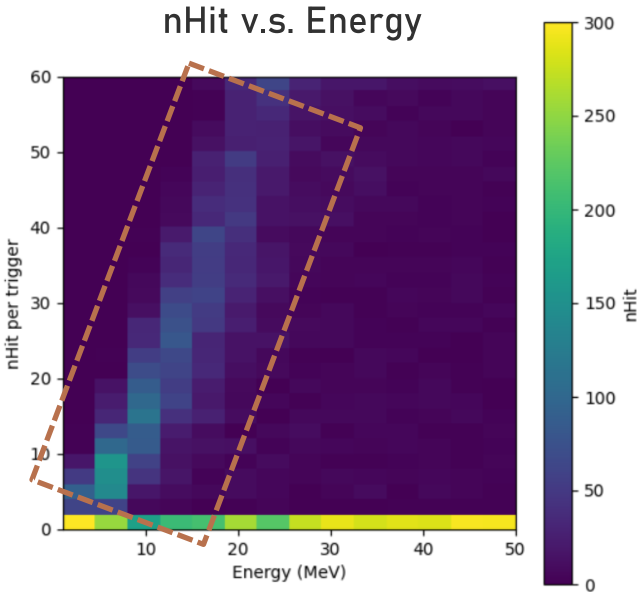


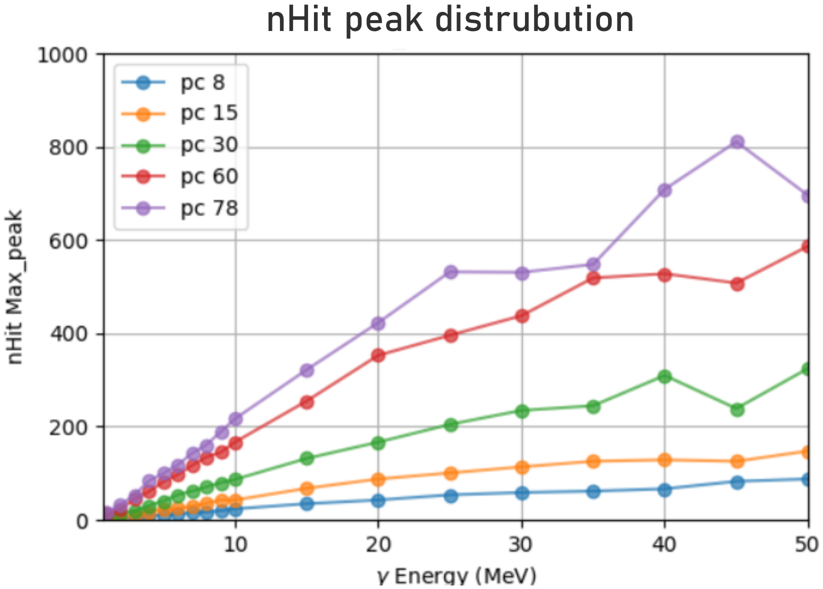


WCSim Simulation

(P.S with fiducial volume cut [radius -30cm, height -20cm]

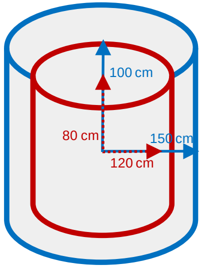




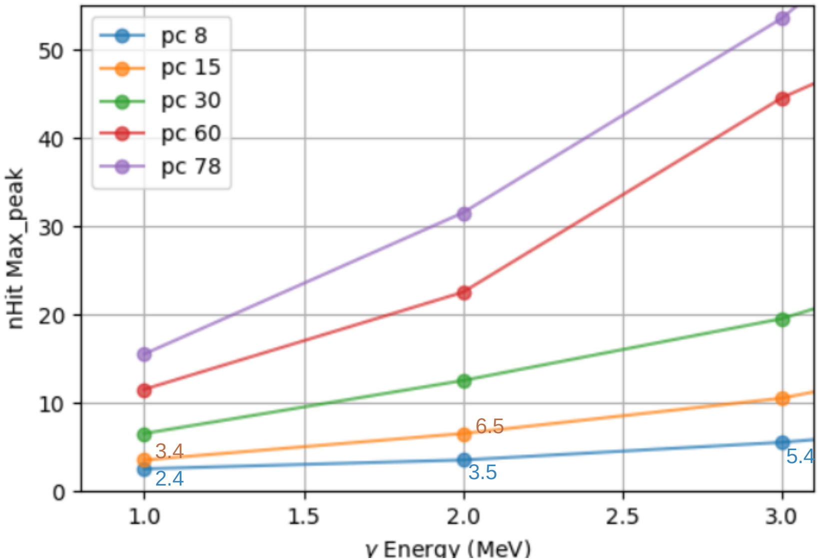


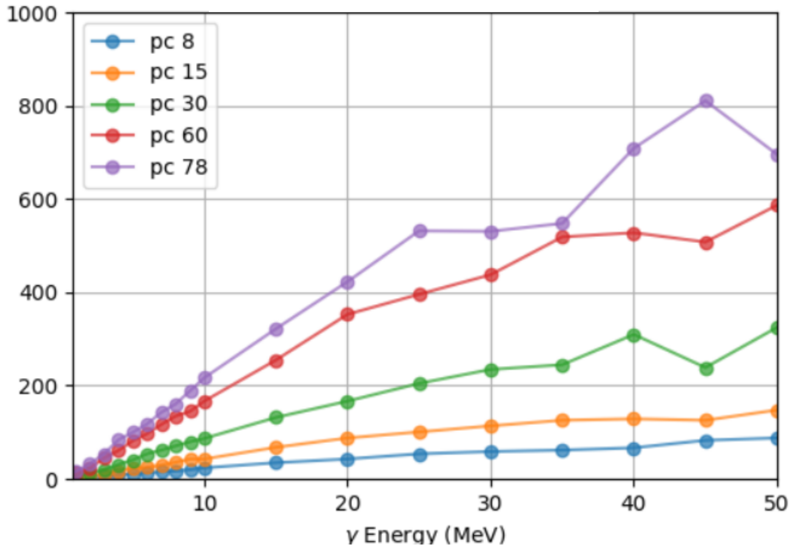
WCSim Simulation

(P.S with fiducial volume cut [radius -30cm, height -20cm]

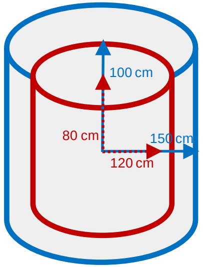


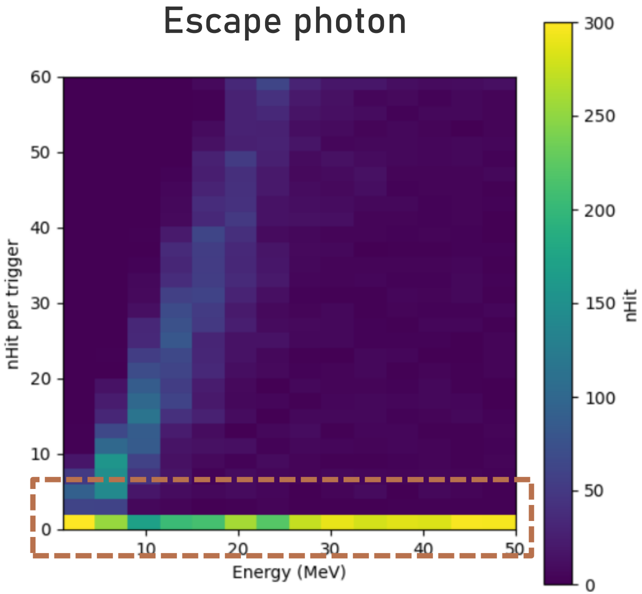
nHit peak distrubution

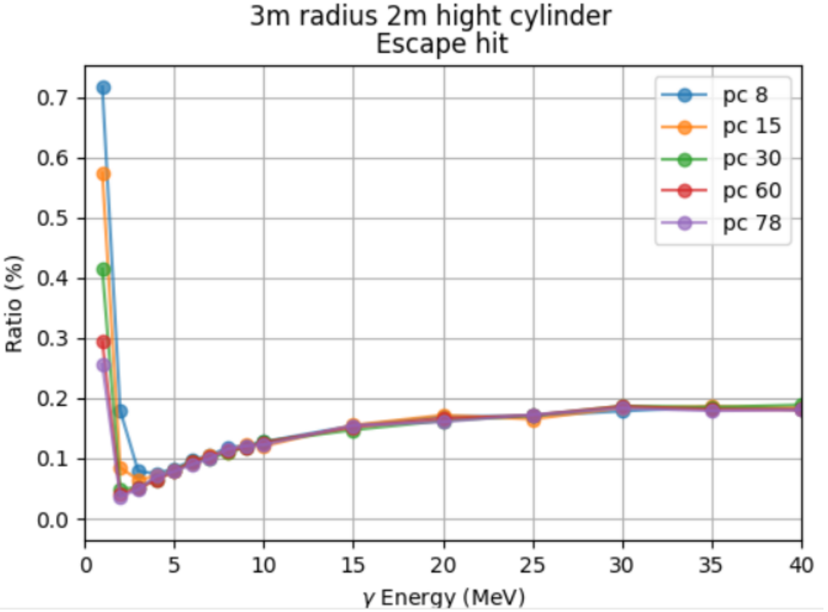




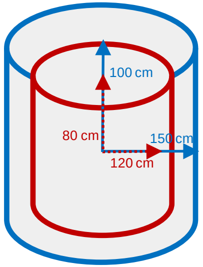
WCSim Simulation

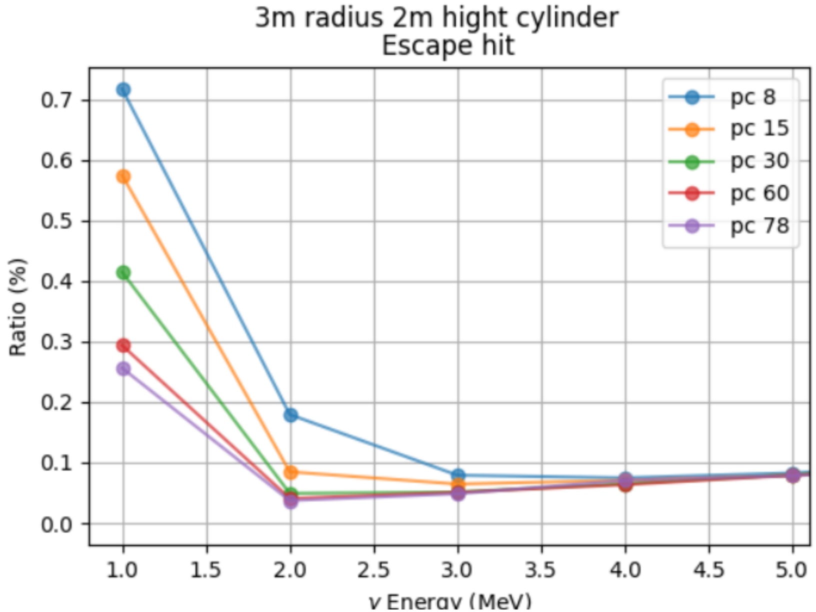


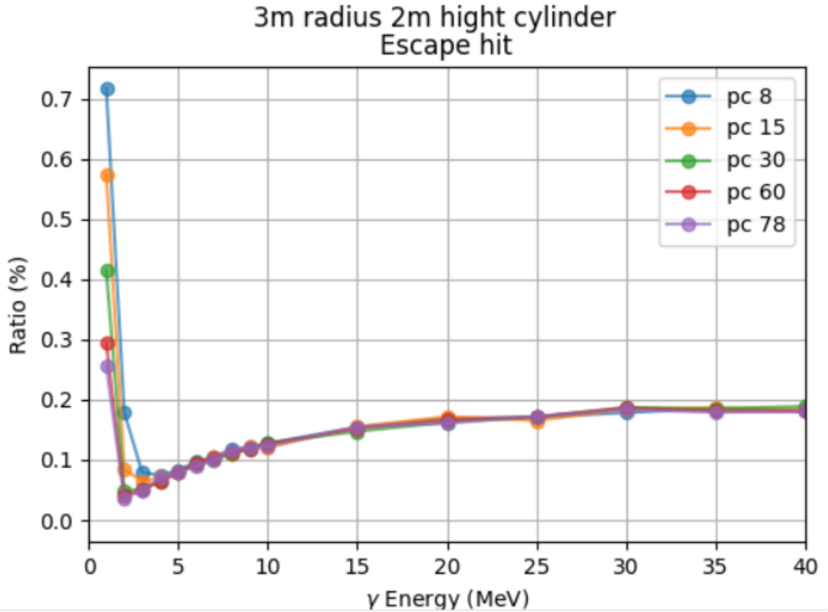




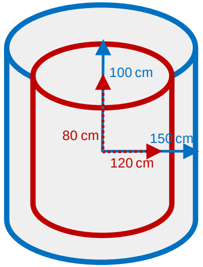
WCSim Simulation

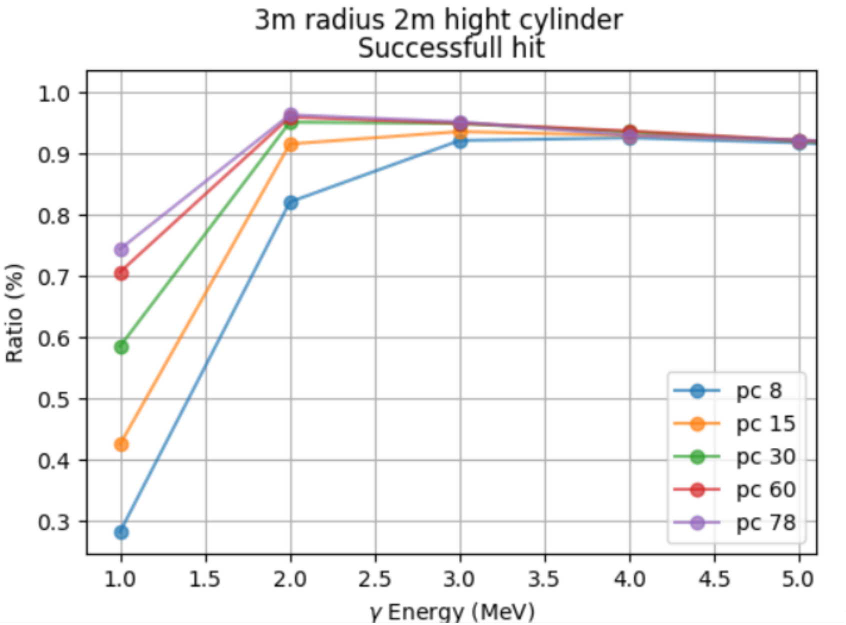


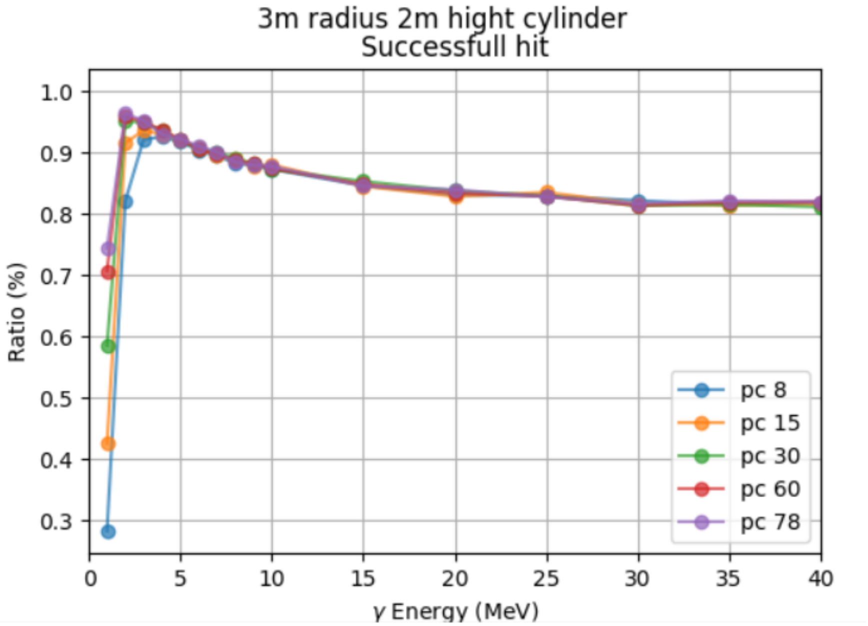




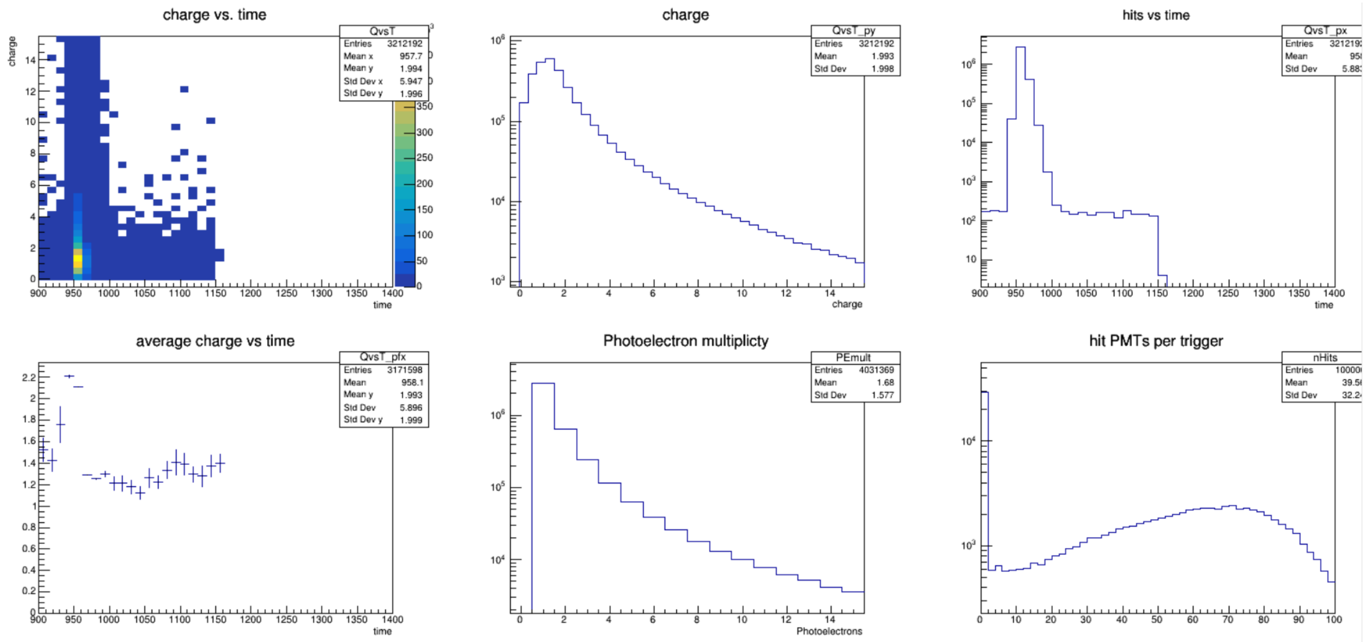
WCSim Simulation

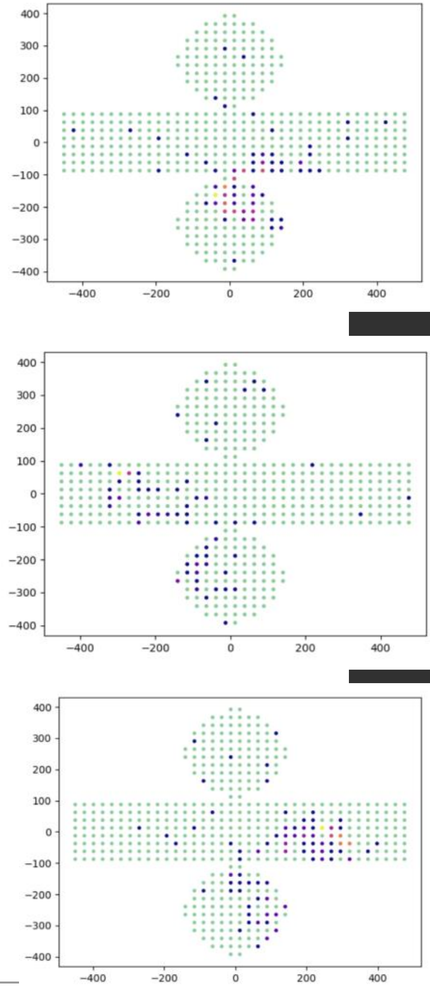




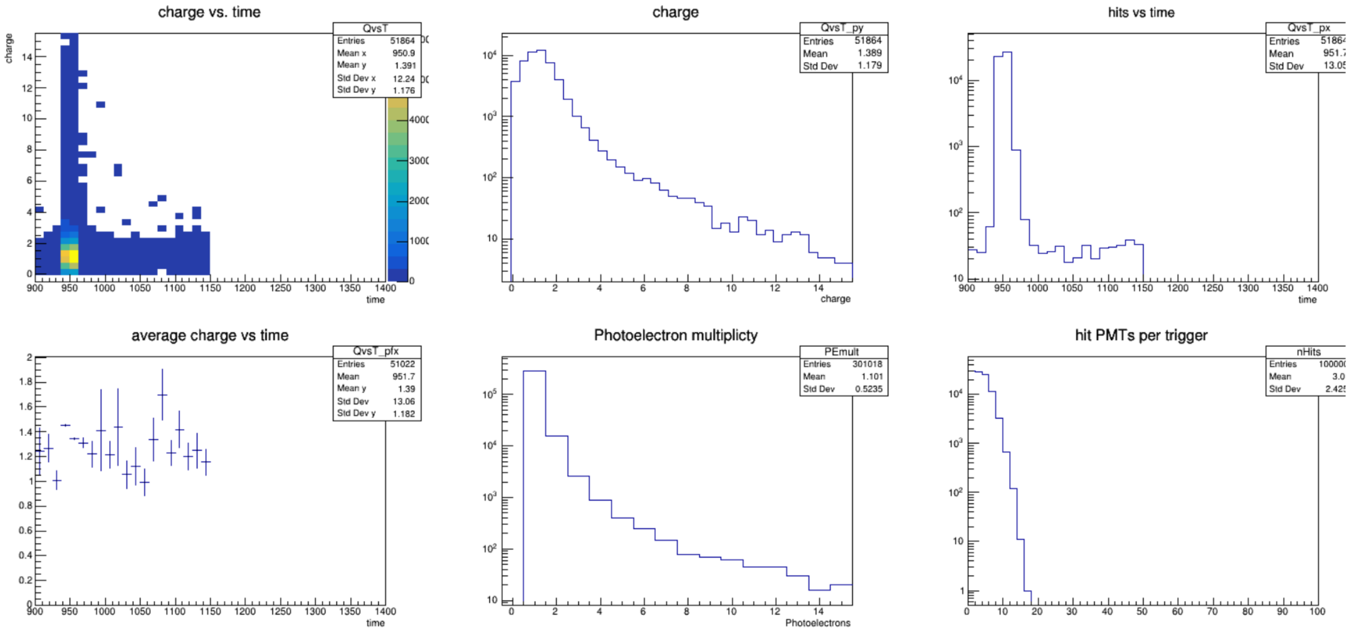


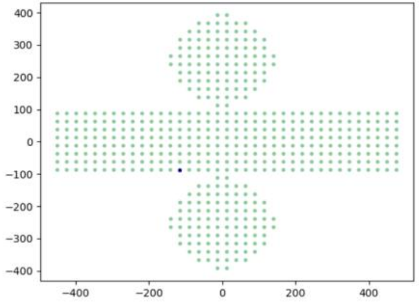
Input gamma energy : 40MeV

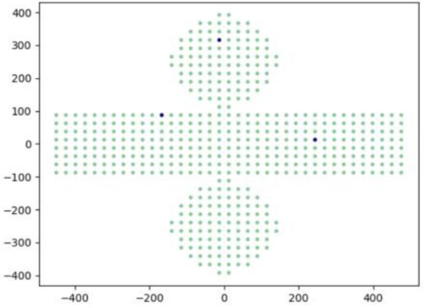


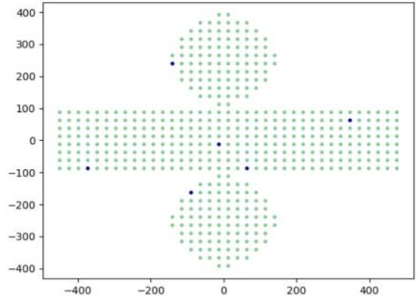


Input gamma energy : 2.2MeV

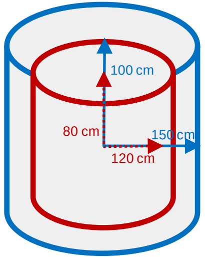


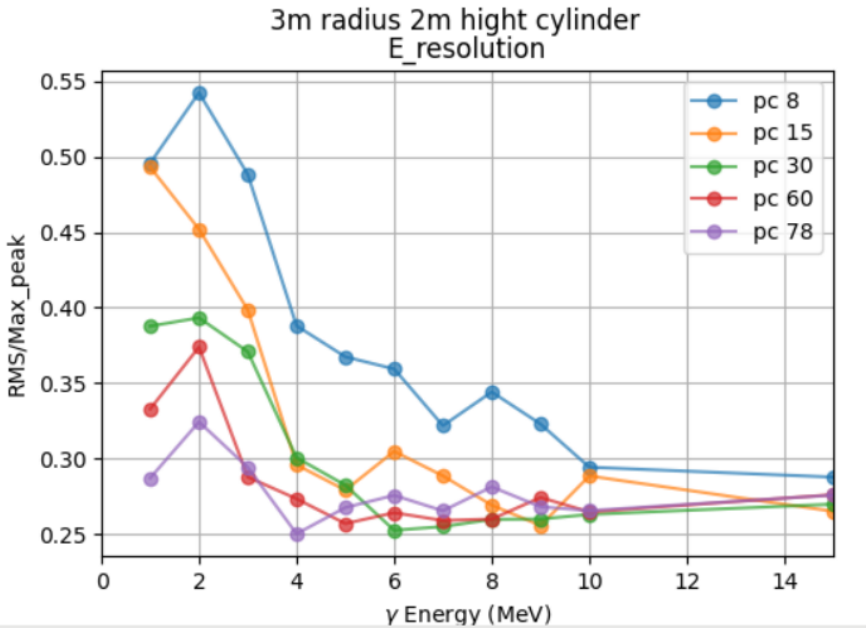


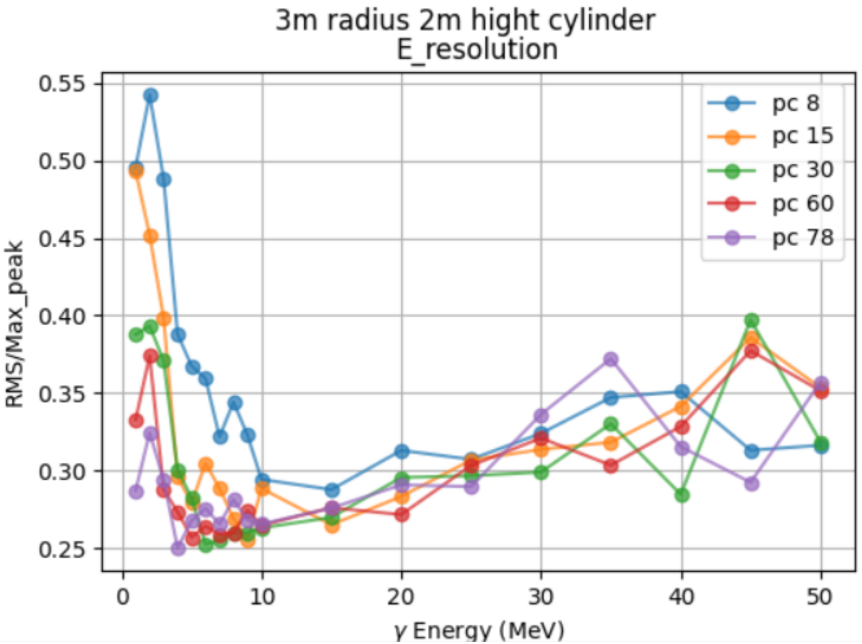




Energy resolution : RMS / nHit Peak

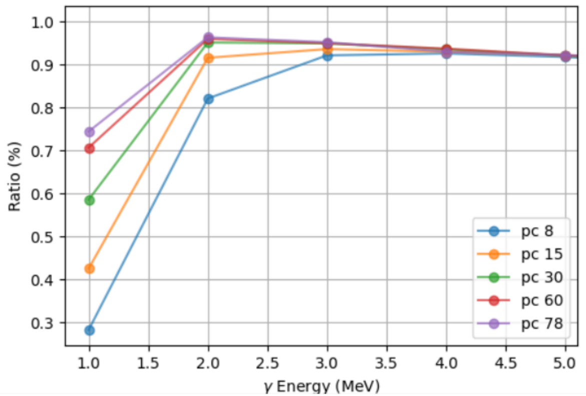




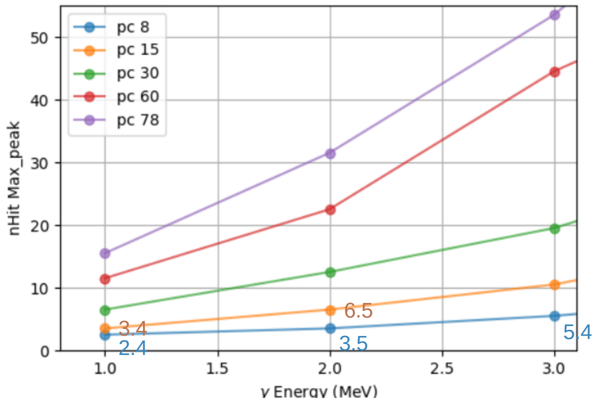


Take aways

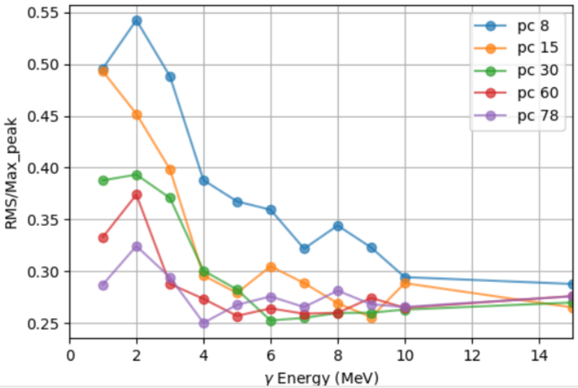
Success full hit ratio



nHit peak distrubution



Energy Resolution



Vertex Resolution