INGRID Analysis Technical Note

INGRID

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Contents

Chapter 1

Monte Carlo simulation

In this chapter, we explain about Monte Carlo simulation (MC) currently used in INGRID analysis.

- Overview about MC
- Check detector response MC with Beam Data.
- Efficiency to neutrino interaction.
- Expected # of neutrino observation

1.1 Overview about MC

INGRID MC is composed of three parts : Jnubeam, NEUT and Detector response (figure fig:mcoverview).

- Neutrino Flux : Jnubeam (version 10c)
- Neutrino interaction to Target : NEUT (version 5.0.6.)
- Detector response to generated particles from neutrino interaction : Simulator based GEANT4 (Detector response MC)

This INGRID MC is not software of ND280 software packages (nd280mc). Integration of INGRID MC to ND280 packages is on going now. we plan to use nd280mc including INGRID in future.

Jnubeam is T2K neutrino-beam line simulation (based GEANT3). We make neutrino flux (ntuple-based flux), which is called as Jnubeam flux, to INGRID with this simulator. In current INGRID MC (2010.Oct), we use version 10c of Jnubeam mainly.

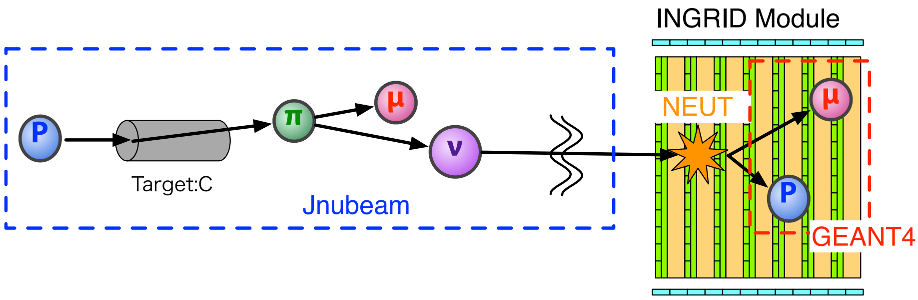

Figure 1.1: INGRID MC overview

Then, we simulate the interaction between the each flavor of neutrino obtained from Jnubeam flux files and target nucleus with NEUT (use 5.0.6. version). This target of INGRID is Iron nucleus(Fe) or scintillator nucleus(CH), but now we use the interaction to Iron mainly. About interaction to CH, we are progress in mass-production and study.

Finally, we simulate detector response to generated particles from neutrino interaction with simulator based GEANT4 which is developed by Japanese of INGRID group. We obtain the neutrino interaction vertex-X and vertex-Y from neutrino vertex of Jnubeam flux file (these variable names are "xnu" and "ynu"). The vertex-Z is uniform in each module, but distribution of the vertex in Iron and scintillator is weighted with the mass ratio of Iron planes (99.54 ton) to scintillator planes (3.74 ton). The detector response MC does not cover the whole detector response of INGRID perfectly, but includes some parts which have an impact to the efficiency to neutrino interaction mainly. Including parts is below,

- Quenting effect of scintillator and attenuation of photon propagating in the fiber.
- MPPC response model (including the effect of cross-talk and after pulse, and the effect of pixel saturation).
- Real geometry of scintillator bar (effect on tracking efficiency).

For MPPC response model, we refer to page 11 of the slide "Characterisation of MPPC linearity response with the TRIP-T electronics " (reported by Calibration group of ND280 working group in 2009. this slide put at t2k.org).

We tuned the scale of exchange from energy to photon of MC with beam related sand muon. We set this scale to adjust the peak p.e. deposit by muon generated in MC to the peak p.e. deposit by sand muon. This tuning of scale factor is just temporary, so need more tuning this scale to refine the estimation of photon generated at MC (but, in currently analysis, the p.e. threshold is not so much critical to the efficiency to neutrino).

1.2 Check detector response MC with Beam data

We compare the detector response to neutrino of MC to one of beam data at some basic distribution (number of active planes, reconstructed vertex, reconstructed tracking angle). The beam data set is Run2010a(from January to June, in 2010). Total number of protons used in analysis is 3.26e19 and total number of good spills is 1005887.

The results of comparison is showed in other section.

1.3 Efficiency to neutrino interaction

We calculate the efficiency to the neutrino interacted Fiducial volume (FV) at each mode (CC+NC, CC, CCQE, CC-nonQE, NC). The error of efficiency is including only MC statistics error (figure1.2, figure1.3).

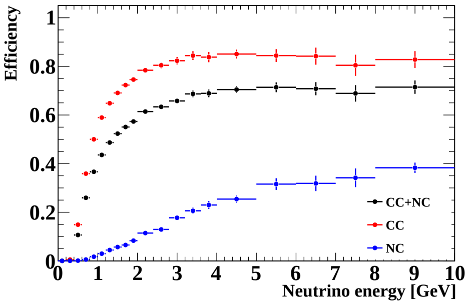

Figure 1.2: Efficiency to ν_μ interacted in FV. Black point show the efficiency to all interaction mode. Red points show one to only CC interaction mode. Blue point show one to only NC interaction mode. The error includes only MC statistics error.

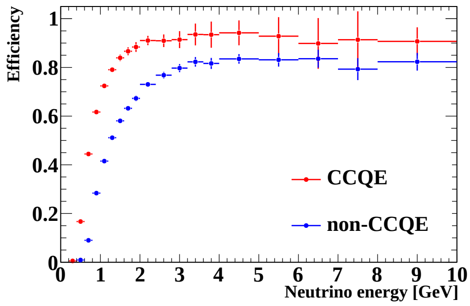

Figure 1.3: Efficiency to ν_μ interacted in FV. Red points show the efficiency to CCQE interaction mode. Blue points show one to CC-nonQE interaction mode. The error includes only MC statistics error.

Now we are creating the efficiency plot to other neutrino flavor ($\bar{\nu_\mu}$, ν_e,$\bar{\nu_e}$) (mass-production of MC was done for ν_μ, $\bar{\nu_\mu}$. About ν_e,$\bar{\nu_e}$, to be prepared).

1.4 Expected number of neutrino observation

We estimate the expected number of neutrino observed at INGRID with this MC.We estimate three value: integrated flux to each modules, the number of interaction in each modules, the number of observation at each modules. And we estimate with other primary hadron production model (FLUKA2008) for collision between proton beam and target carbon at Jnubeam. The default hadron production model of Jnubeam(10c) is GCALOR/GFLUKA. We check the effect of the hadron production difference on the each number. We show the number of integrated flux, interaction, observation at each module (from table tab:fluxnumu to table tab:obsnumubar). We summarize the total number of neutrino observed at INGRID to table tab:sumexp and compare the total number of MC to one of Data (Run2010a). Now, we use the ν_μ and $\bar{\nu_\mu}$ to calculate the expectation. About ν_e and $\bar{\nu_e}$, we are progress in mass-production. ν_e and $\bar{\nu_e}$ contribution to total observation is less than 1% at flux.

Table 1.1: Integrated ν_μ flux at each modules [$\times 10^{17}/10^{21} POT$]

module	0	1	2	3	4	5	6
1.GCALOR/GFLUKA	5.21	6.18	6.87	7.12	6.88	6.18	5.12
2.FLUKA2008	4.84	5.64	6.19	6.39	6.17	5.60	4.82
Ratio (2./1.) [%]	92.8	91.2	90.0	89.7	89.7	90.6	92.5

module	7	8	9	10	11	12	13
1.GCALOR/GFLUKA	5.44	6.40	7.11	7.36	7.14	6.44	5.50
2.FLUKA2008	5.08	5.86	6.45	6.66	6.41	5.81	5.05
Ratio (2./1.) [%]	93.4	91.6	90.8	90.5	89.8	90.1	91.7

Table 1.2: Integrated $\bar{\nu_\mu}$ flux at each modules [$\times 10^{17}/10^{21} POT$]

module	0	1	2	3	4	5	6
1.GCALOR/GFLUKA	0.342	0.395	0.436	0.455	0.438	0.395	0.342
2.FLUKA2008	0.234	0.254	0.274	0.284	0.274	0.254	0.235
Ratio (2./1.) [%]	68.4	64.1	62.7	62.3	62.7	64.4	68.7

module	7	8	9	10	11	12	13
1.GCALOR/GFLUKA	0.371	0.415	0.452	0.474	0.454	0.417	0.375
2.FLUKA2008	0.251	0.271	0.284	0.286	0.282	0.270	0.253
Ratio (2./1.) [%]	67.6	65.4	62.9	60.3	62.1	64.8	67.6

Table 1.3: number of ν_μ interacted at each modules [$\times 10^6/10^{21} POT$]

module	0	1	2	3	4	5	6
1.GCALOR/GFLUKA	2.73	3.55	4.13	4.33	4.19	3.58	2.71
2.FLUKA2008	2.25	2.86	3.29	3.46	3.31	2.84	2.23
Ratio (2./1.) [%]	82.3	80.4	79.6	79.8	79.0	79.3	82.3

module	7	8	9	10	11	12	13
1.GCALOR/GFLUKA	2.89	3.73	4.29	4.48	4.32	3.76	2.93
2.FLUKA2008	2.40	3.01	3.45	3.62	3.43	2.97	2.37
Ratio (2./1.) [%]	83.0	80.7	80.5	80.9	79.5	79.1	80.6

Table 1.4: number of $\bar{\nu_\mu}$ interacted at each modules [$\times 10^4/10^{21} POT$]

module	0	1	2	3	4	5	6
1.GCALOR/GFLUKA	8.36	10.9	13.0	14.2	13.1	10.4	7.95
2.FLUKA2008	3.89	4.55	5.44	5.92	5.42	4.55	3.79
Ratio (2./1.) [%]	46.5	41.7	41.9	41.6	41.2	43.7	47.7

module	7	8	9	10	11	12	13
1.GCALOR/GFLUKA	9.58	11.1	14.1	14.7	13.3	11.7	9.34
2.FLUKA2008	4.37	4.91	5.61	5.58	5.40	5.19	4.47
Ratio (2./1.) [%]	45.6	44.1	39.7	37.9	40.5	44.5	47.8

Table 1.5: number of ν_μ observed at each modules [$\times 10^6/10^{21} POT$]

module	0	1	2	3	4	5	6
1.GCALOR/GFLUKA	0.863	1.19	1.43	1.48	1.45	1.21	0.870
2.FLUKA2008	0.665	0.901	1.08	1.12	1.08	0.898	0.671
Ratio (2./1.) [%]	77.1	75.5	75.2	75.6	74.6	73.9	77.1

module	7	8	9	10	11	12	13
1.GCALOR/GFLUKA	0.936	1.27	1.48	1.54	1.48	1.27	0.951
2.FLUKA2008	0.729	0.961	1.13	1.19	1.11	0.945	0.716
Ratio (2./1.) [%]	77.9	75.9	76.1	76.9	75.3	74.1	75.3

Table 1.6: number of $\bar{\nu_\mu}$ observed at each modules [$\times 10^4/10^{21} POT$]

module	0	1	2	3	4	5	6
1.GCALOR/GFLUKA	3.09	4.09	4.93	5.23	4.91	3.88	2.87
2.FLUKA2008	1.38	1.63	1.99	2.11	1.96	1.61	1.35
Ratio (2./1.) [%]	44.7	39.9	40.4	40.4	39.8	41.5	46.9

module	7	8	9	10	11	12	13
1.GCALOR/GFLUKA	3.54	4.11	5.22	5.77	4.78	4.49	3.46
2.FLUKA2008	1.48	1.81	1.99	2.03	1.89	1.99	1.62
Ratio (2./1.) [%]	41.7	44.1	38.1	35.1	39.6	44.3	46.8

Table 1.7: Expected total number of neutrino observation at INGRID [$/10^{14} POT$]

	ν_μ	$\bar{\nu_\mu}$	ν_μ
GCALOR/GFLUKA	1.72	0.0559	1.78
FLUKA2008	1.38	0.0263	1.41

Table 1.8: Comparison of total number of neutrino observation between Data and MC. This MC includes only ν_μ and $\bar{\nu_\mu}$ data. MC of ν_e and $\bar{\nu_e}$ is to be prepared.

	Observation [$/10^{14} POT$]	Ratio to Data
Data	1.52	1
GCALOR/GFLUKA	1.78	1.17
FLUKA2008	1.41	0.88