INGRID CC inclusive crosssection measurement

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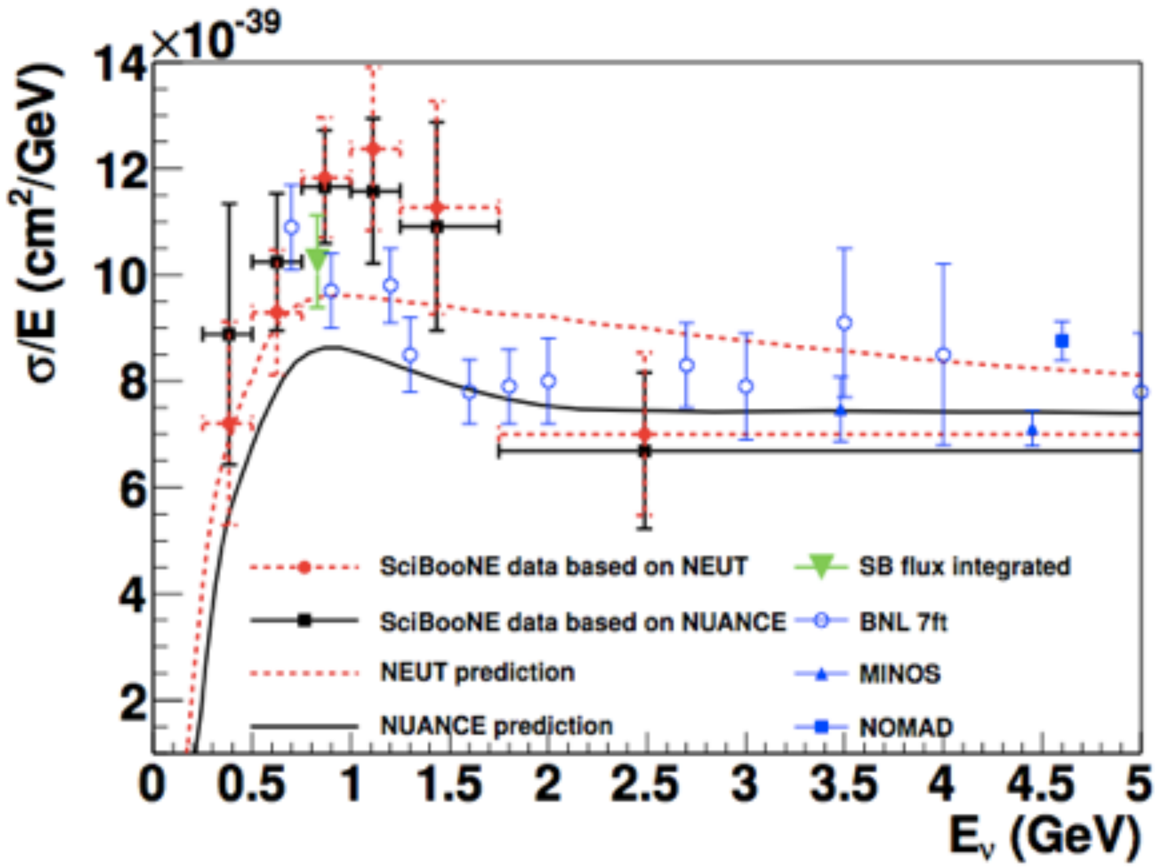
Motivation

- At the current situation of neutrino CC inclusive interaction cross section, there is discrepancy between Data and MC in 1~3 GeV region.

→ Want to measurement the CC inclusive cross section around these region with INGRID.

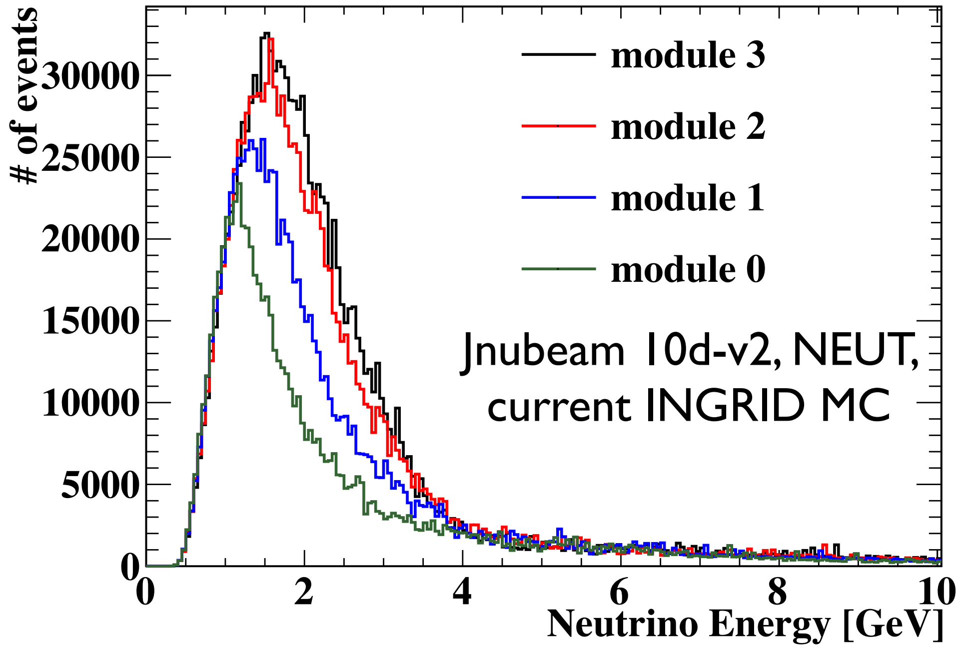
CC inclusive interaction cross sections

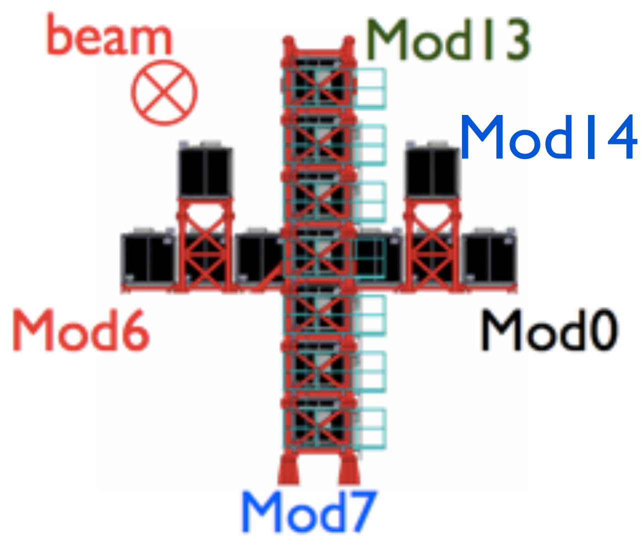


Principle of measurement

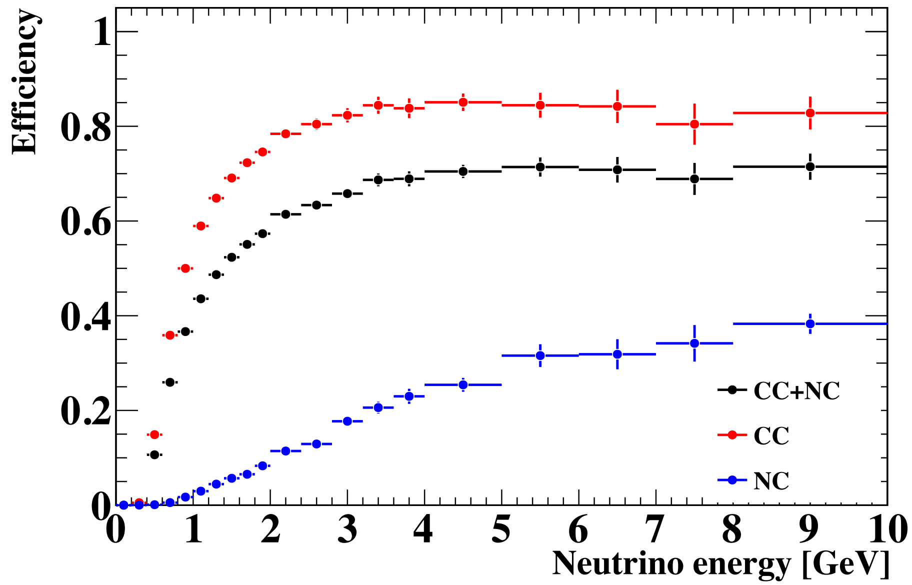
- Neutrino energy distribution is expected to be different at different modules.
  - Because each modules is set at different off-axis angle.
- Flux at each module is almost same for Enu<1GeV and Enu>4GeV, but different at 1<Enu<4GeV
- Try measurement of the inclusive neutrino cross-section at 1~4GeV (or hopefully 1~3GeV) by using the flux difference among modules.

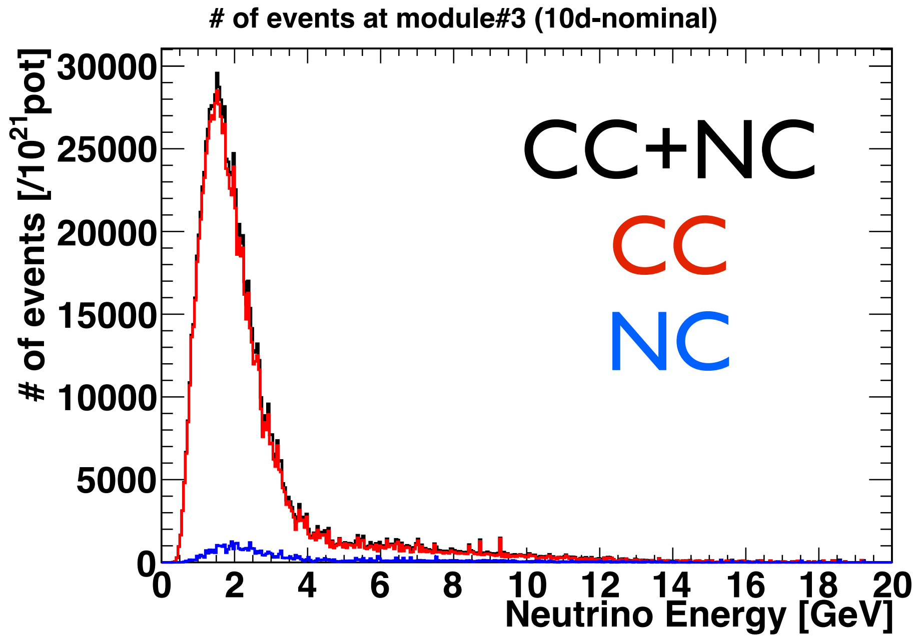
νμ true energy distribution after neutrino selection

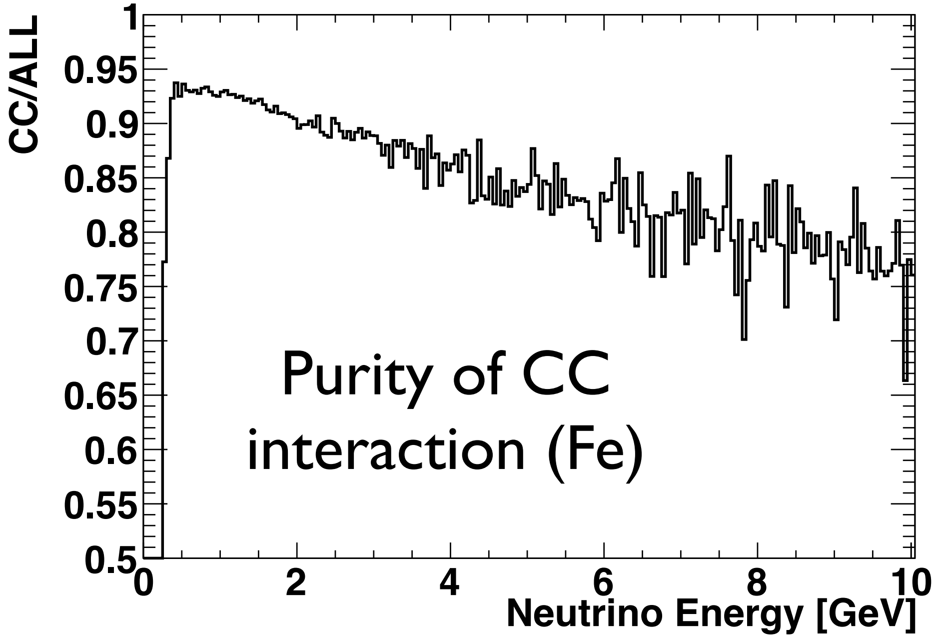




INGRID Efficiency to neutrino interaction in FV



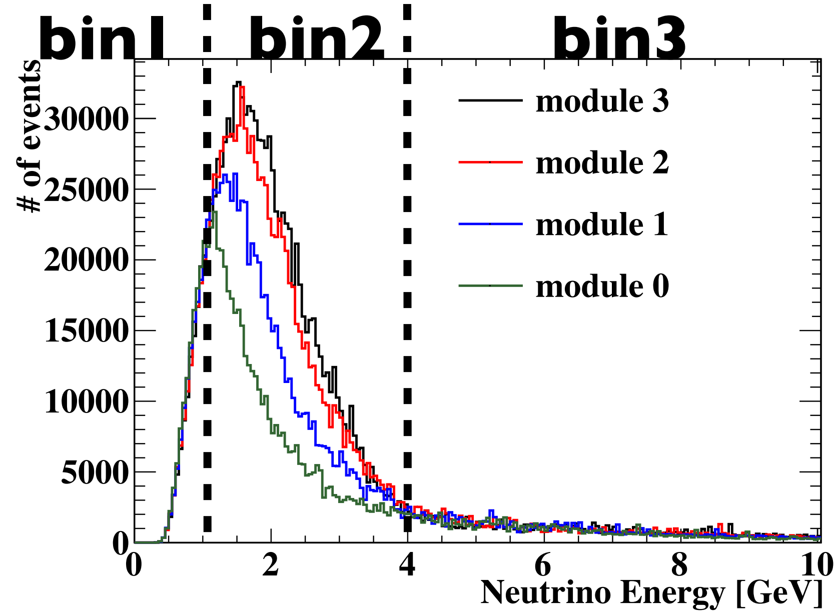


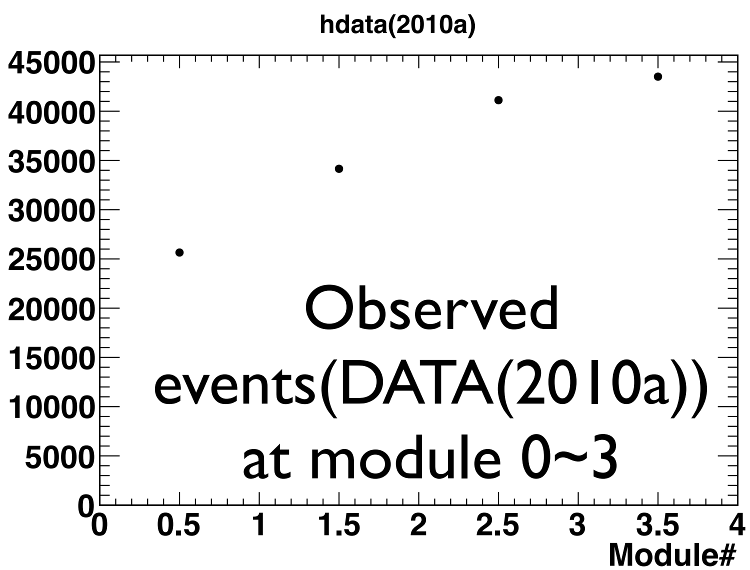


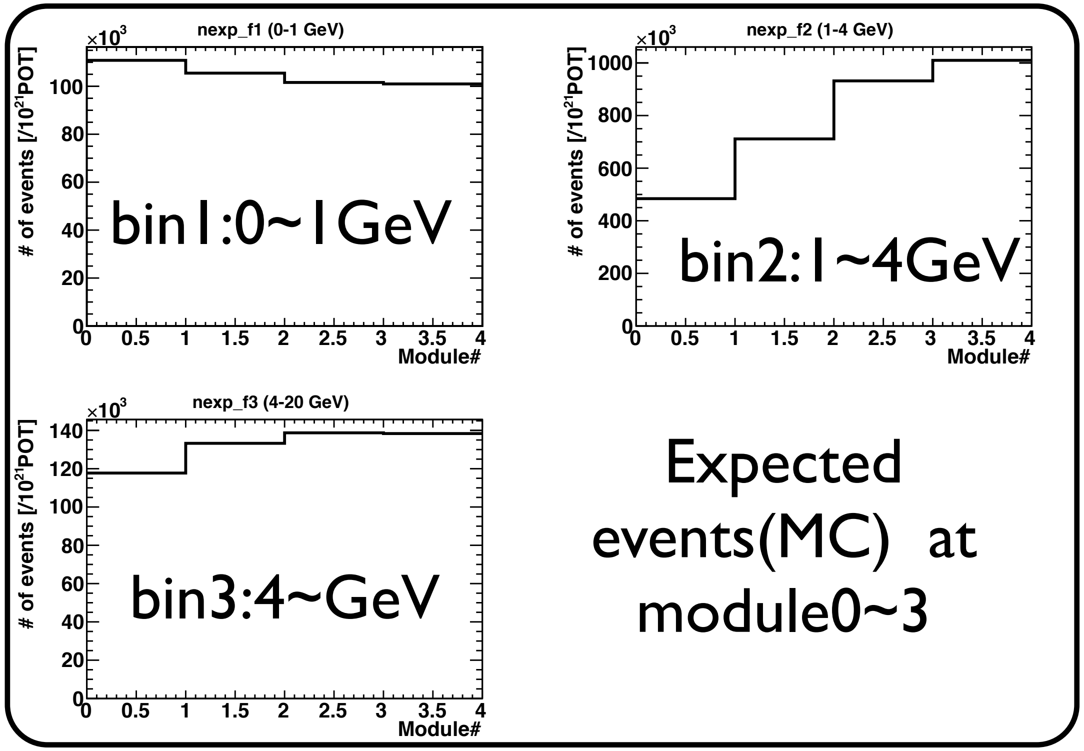
- ~90% of remained events after current neutrino selection is events of CC interaction mode in interested region.

Method

- Divide true neutrino energy into some bins
- Cross section is obtained as the normalization factor(f_i) at each bin(i) which are common to all modules.
- Get f_i's which reproduce Data/MC for all modules.
- Measured Cross section = Cross section(MC) x ($1+f_i$)







Fit function

Maximum the following likelihood:

$$L = \prod_{module} Gauss(N_{mod}^{obs} | N_{mod}^{exp}, \sqrt(N_{mod}^{exp}))$$ **(stat. error)**

$$\times \frac{1}{2\pi^{n/2}\sqrt(det\Sigma_{sys})} exp(-\frac{1}{2}(f_1, f_2, f_3 ...)\Sigma_{sys}^{-1}(f_1, f_2, f_3, ...)^T)$$ **(syst. error)**

$$N_{mod}^{exp} = \Sigma_{bins} \int_{bin\#i} \phi(E)\sigma(E)\epsilon(E) \times (1 + f_i)dE$$

- (f_1,f_2,f_3, ...) are fitting parameters (normalization at each energy bins)
- Fitting parameters is constrained : $1+f_i > 0$.

Fitting demonstration

- Check whether fitting is valid or not by using Toy MC ($N^{exp,toy}$) as N^{obs}.
  - Toy MC is changed from original MC expectation as follows:

$$N_{mod}^{exp,\,toy} = \Sigma_{bins} \int_{bin\#i} \phi_{mod}(E)\sigma(E)\epsilon(E)(1+\delta_i)dE$$

$$\delta_i = 0.1 * i$$

→ Use this $N^{exp,toy}_{mod}$ as N^{obs}_{mod}

- Check if obtained parameters after fitting are consistent to given δ_i .

Analysis configuration

- Used modules for analysis : #0~3, #7~10, #14(Shoulder module)
- MC configuration
  - Flux : Jnubeam 10d-v2 (by weighting based on energy)
  - Neutrino interaction : NEUT 5.0.6
  - Detector MC : current INGRID MC (not nd280 software)
- MC stat. is normalized according to the followings:
  - #0~3, #7~10 : RunI p.o.t. (update RunI & RunII soon)
  - #14 : RunII p.o.t.
- Only stat. error is included this time. Systematic error will be included later

Analysis configuration : binning

- Try two cases for binning as first trial.
  - Case 1 : <1GeV(bin#1), 1~4GeV,(bin#2), >4GeV(bin#3)
  - Case 2 : <1GeV(bin#1), 1~3GeV(bin#2), >3GeV(bin#3)
- In both case, cross section in 2nd bin is the one we want to measure. There would not be sensitivity to dissolve 1st and 3rd bin because fluxes are same for different modules in these two energy region.

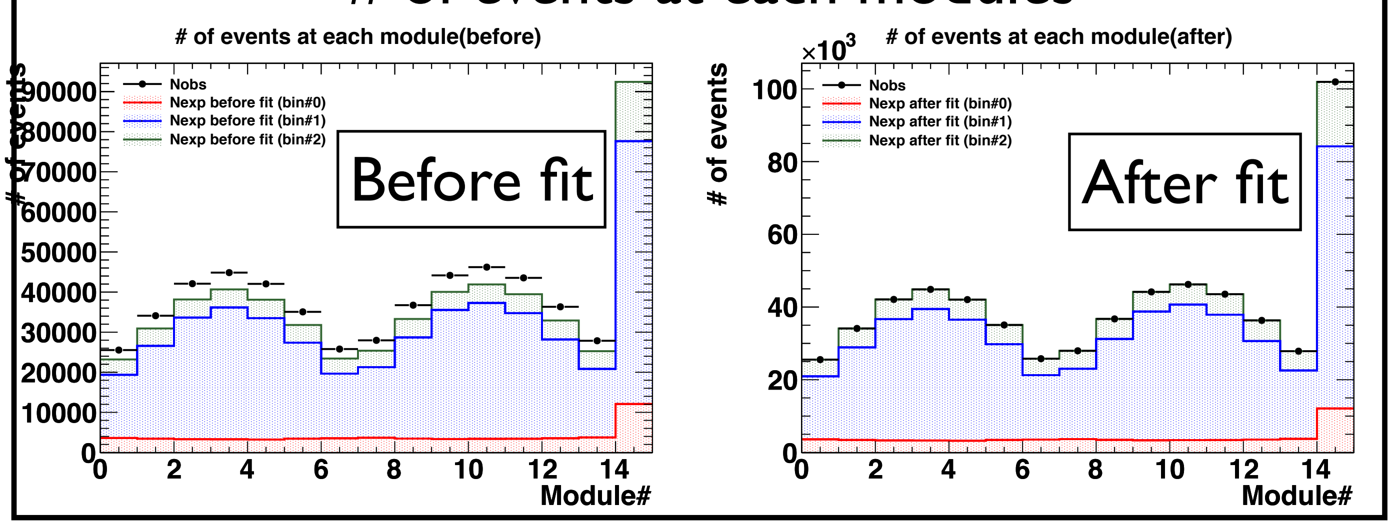
Case 1 :<1GeV(bin#1), 1~4GeV(bin#2), >4GeV(bin#3)

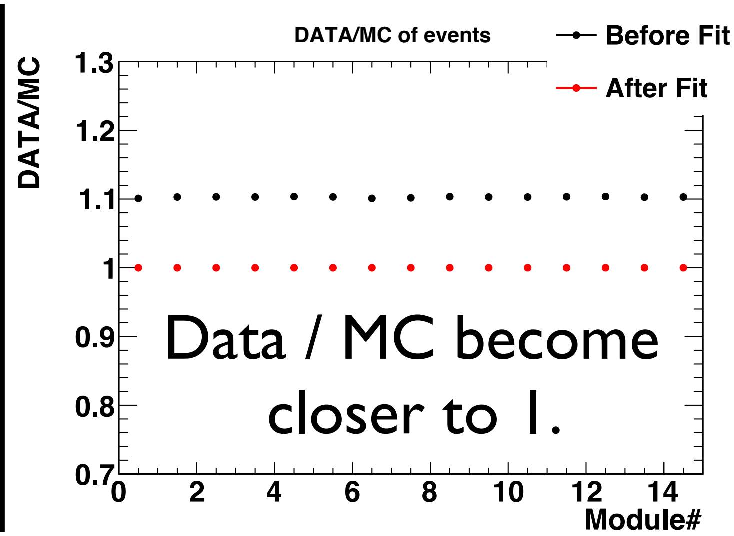
parameter	value	fit error
f1	0.999	0.352
f2	1.100	0.019
f3	1.201	0.370

```
INPUT Fake MC
bin#:0 = 1
bin#:1 = 1.1
bin#:2 = 1.2
```

- Equal to input Toy MC.
- Fitting error of parameter wanted to measure is ~2% → Good

# of events at each modules





This fitting is valid.

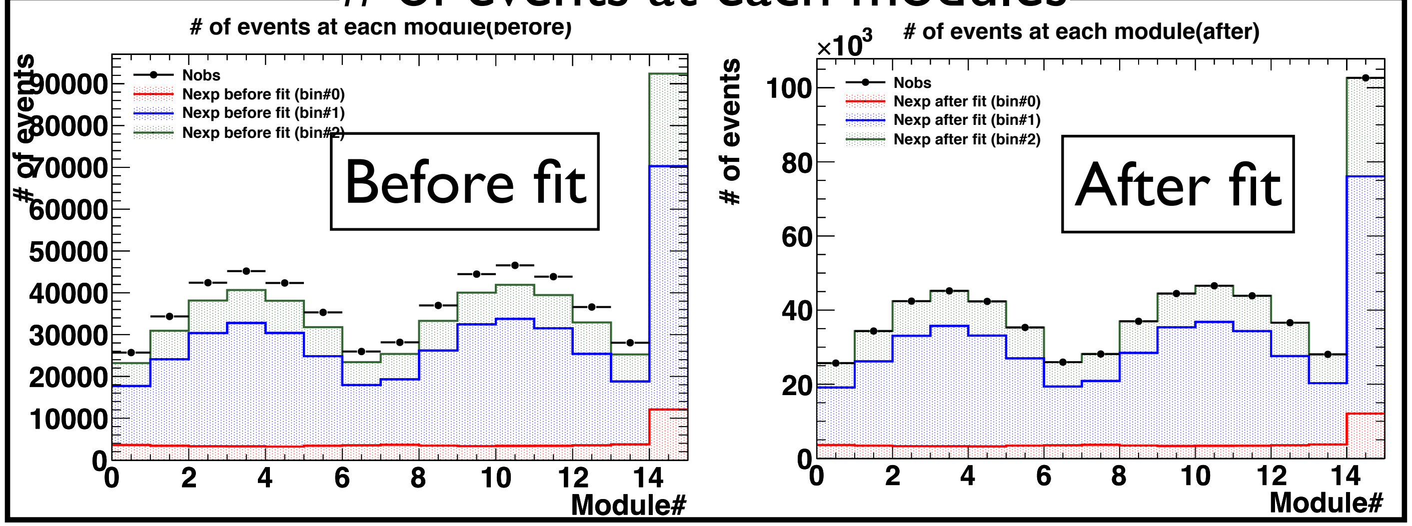
Case 1 :<1GeV(bin#1), 1~3GeV(bin#2), >3GeV(bin#3)

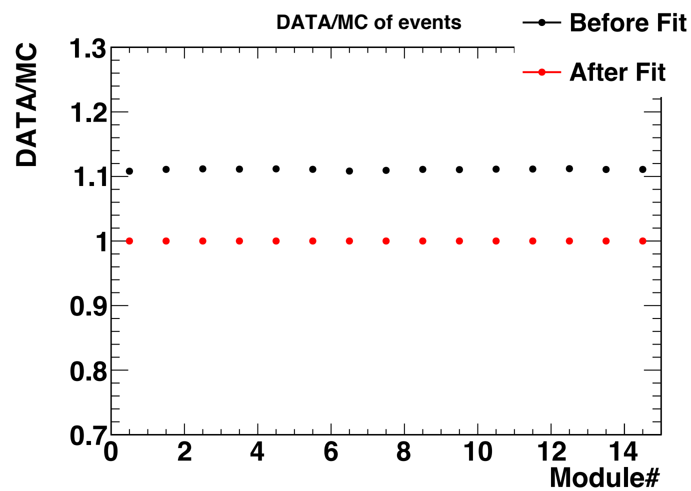
parameter	value	fit error
f1	1.000	0.267
f2	1.100	0.040
f3	1.200	0.252

```
INPUT Fake MC
 bin#:0 = 1
bin#:1 = 1.1
bin#:2 = 1.2
```

- Equal to input Toy MC.
- Fitting error of parameter I want to measure is ~4% → More than first, but small.

# of events at each modules





This fitting is valid.

Systematic uncertainty

- Detector systematic uncertainty : ~ 3.7%
  - Otani-san, Christophe, other people have studied. Need to consider treatment of uncertainty in my analysis.
- Flux uncertainty : typically 15~20%
  - Due to hadron production, proton beam parameter, off-axis, etc.
- Uncertainty of GEANT4 physics models
- Uncertainty related neutrino interaction
  - Events in interacted in scintillator is expected to account for 5% of events in iron. I want to cross section of Fe. Need to identify.
  - Use the current uncertainty studied by NIWG.

I consider the treatment of well-known detector systematic

Detector systematic

- Two kinds of error : detector common / dependent.
- At current study, detector systematic errors are considered as common (according to TN-040)).
  - Deference of each module is estimated to be small against error size.
- At first step, I consider this error as common in all modules. This part of likelihood can be defined as the followings:

$$L^{det.\ syst.} = \prod_{module} Gauss(N^{exp}_{mod} | N^{exp}_{0,mod}, \sigma^{det.}_{N^{exp}_{0,mod}}))$$

$$N^{exp}_{0,mod} = \Sigma_{bins} \int_{bin\#i} \phi(E)\sigma(E)\epsilon(E)dE\ (MC\ init\ prediction)$$

$$N^{exp}_{mod} = \Sigma_{bins} \int_{bin\#i} \phi(E)\sigma(E)\epsilon(E)(1+f_i)dE$$

$$\sigma^{det.}_{N^{exp}_{0,mod}} = N^{exp}_{0,mod}\sigma^{det.},\ \sigma^{det}\ : common\ among\ modules$$

Next step

- Proceed this analysis with Fake MC (to understand fitting).
- Consider treatment of some systematic errors in the analysis.
  - Detector systematic.
  - Flux systematic
- Need to consider the treatment for the purity of CC inclusive sample (and this error).