INGRID CC Inclusive

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Update

- Consider detector systematic error, which is common error among modules

χ2 including detector syst.

$$\chi^2 = \boxed{\sum_m^{module} log(N_m^{MC}) + \frac{(N_m^{DATA} - N_m^{MC})^2}{N_m^{MC}}} + \boxed{\left(\frac{f_{det}}{\sigma_{det}}\right)^2}$$

stat. term

syst. term

$$N_m^{MC} = (1 + f_{det}) \sum_i^{E_{bin}} \int_i \phi_m(E)(1 + f_i)\sigma(E)\epsilon(E)dE$$

f_i = fitting parameter of normalization for each energy region.
f_det = fitting parameter of common detector systematic error
σ_det = common detector systematic error

- Current INGRID detector systematic error, σ_det = 0.037
- Fitting parameters for minimum χ2 are normalization parameter (f_i) at each energy region, and f_det.
  - These parameter is not limited at fitting.

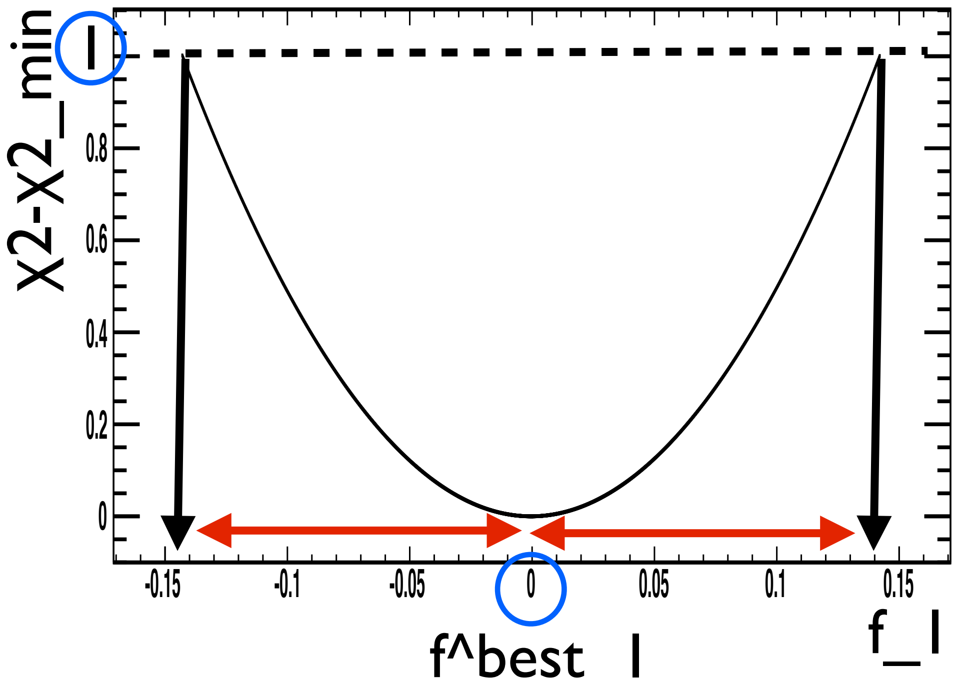
Fitting error calculation

- Search the limit of each parameter in the condition that Δχ2(=χ-χ_min) is one.
- Difference of parameter from best fit value is assigned as error.
  - Change one parameter (for example f_1) by a little bit.
  - Minimize χ2 with other parameters (f_2,3,f_det). f_1 is fixed. And calculate Δχ2.
  - Repeat the above calculation by changing f_1 value until Δχ2 becomes one.
  - When Δχ2 becomes one, f^limit_1 - f^best_1 is assigned as error.

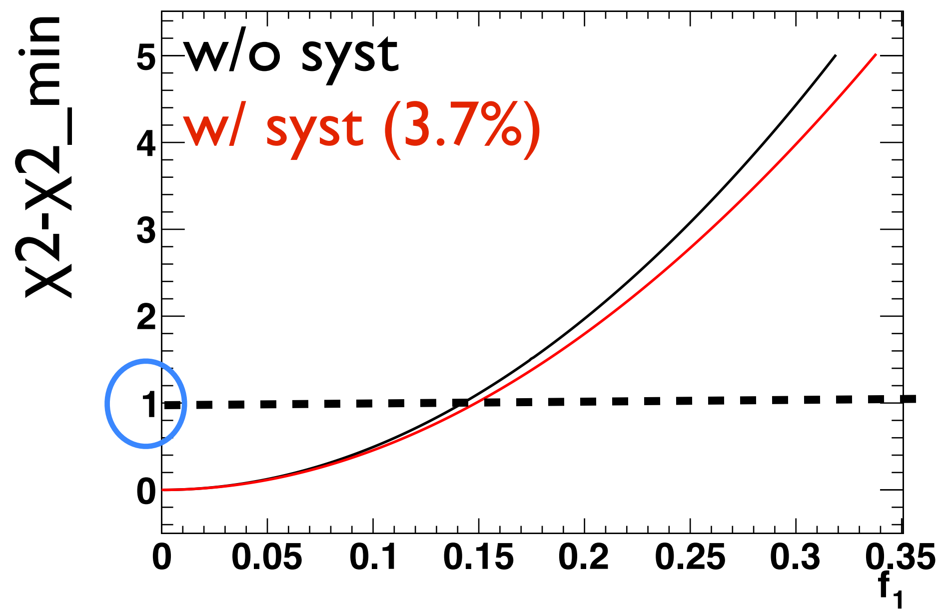
In next page,demonstrate it.

Calculate the fitting error

Δχ2 distribution (w/o syst error) dependent with f_I



Δχ2 difference of w/o syst and w/ syst.



- The demonstrate of error calculation for f_I
- The red arrows are assigned as f_I fitting error.
  - If χ2 is parabolic, the two red arrows (+/- direction) is same size.

Fit setting

- Fitting
  - binning : 3bins = 0~1(#1), 1~3(#2), 3~(#3) (want to determine normalization of bin#2)
- Data
  - p.o.t. stat. is equivalent to run1 & 2
  - Use toy MC sample as input Data
- MC
  - flux : 10d-v2, neut : 5.0.6
  - Detector MC : current INGRID MC (Geant4, not nd280 software)

```
INPUT Toy MC
  f0 = 0
  f1 = 0.1
  f2 = 0.2
```

Fitting results

Fitting results (w/o syst.)

```
f1 : 0.0003 +0.1422/-0.1428
f2 : 0.1000 +0.0234/-0.0234
f3 : 0.1997 +0.1434/-0.1428
```

```
=== INPUT Toy MC ===
     f0 = 0
     f1 = 0.1
     f2 = 0.2
```

Fitting results (w/ 3.7% syst)

```
f1 : -0.0002 +0.1490/-0.1458
f2 : 0.1000 +0.0486/-0.0456
f3 : 0.2001 +0.1514/-0.1484
fdet : 0.0000 +0.0370/-0.0372
```

```
=== INPUT Toy MC ===
     f0 = 0
     f1 = 0.1
     f2 = 0.2
    fdet = 0.0
```

Fitting results (w/ 10% syst)

```
f1 : -0.0002 +0.1856/-0.1650
f2 : 0.0999 +0.1248/-0.1024
f3 : 0.2000 +0.2002/-0.1760
fdet : 0.0001 +0.1000/-0.1002
```

```
=== INPUT Toy MC ===
     f0 = 0
     f1 = 0.1
     f2 = 0.2
    fdet = 0.0
```

- Common detector systematic error is expected to change overall normalization of each bin.
- The fitting error with detector systematic term increases by about detector systematic error .
    - Treatment of detector systematic error seems to be valid.
- Next, other main systematic, flux error is included.

Estimation of CC inclusive σ

$$\sigma_i^{CC} = (1+f_i)\times < \sigma_{CC}^{MC} >_i = (1+f_i) \times \frac{N_i^{MC} \times P_i}{\epsilon_i \times T \times \Phi_i}$$

$$N_i^{MC} = \sum_m^{modules} n_{m,i}^{MC}, \ \Phi_i = \sum_m^{modules} \int_i \phi^m(E_i)dE_i$$

- f = normalization parameter
- P = Purity of CC inclusive sample
- ε = Efficiency
- T = Total # of target nucleons
- n^{MC}_m = MC expectation at the module #m

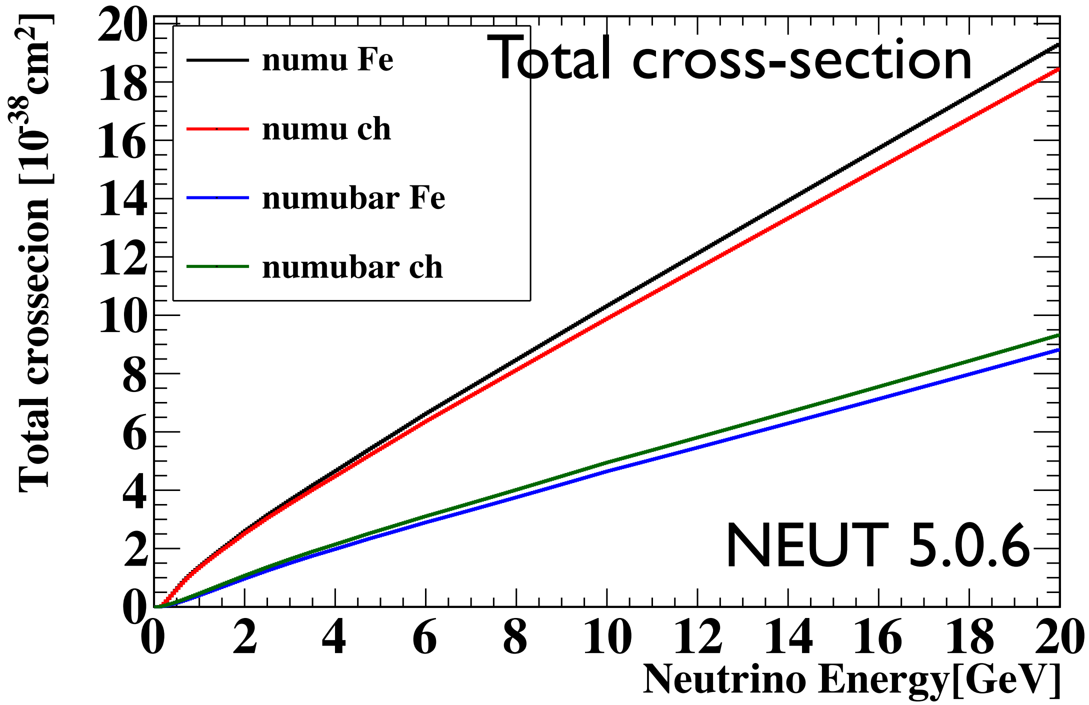
sub-i shows the true energy bin#.

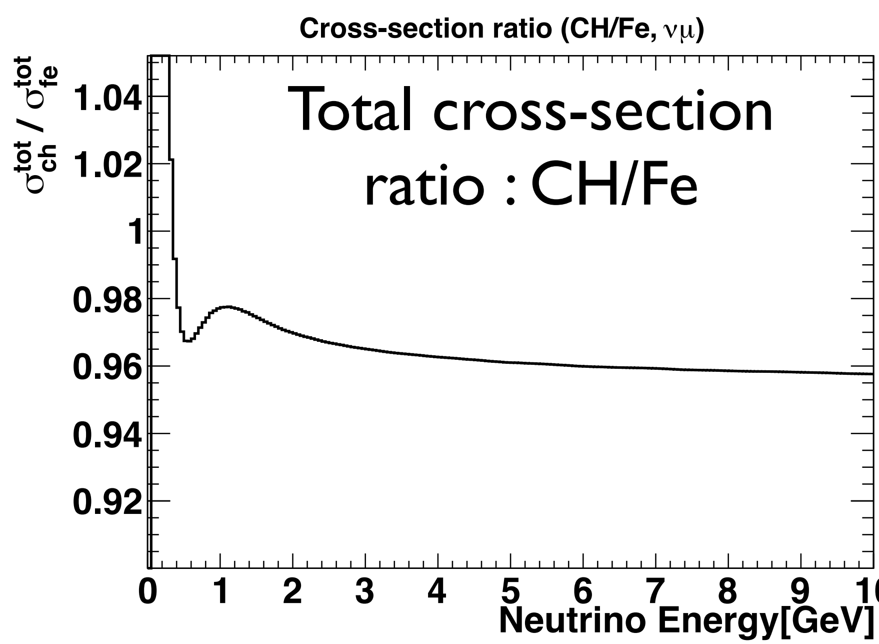
- Φ, P, ε, n and these errors are estimated by MC (Φ:Jnubeam, P:NEUT(or GIENE), ε:Detector MC, n:Full MC).
- T and these errors can be estimated by survey (Iron mass is measured with 0.1% accuracy.)

This formula estimates σ for Fe&CH, not only for Fe.

Iron/Scintillator difference

- In the current INGRID MC, use only neutrino cross section of Fe, even for events happened in scintillators. The difference of cross section of Fe and CH is neglected.
  - For # of expectation, consider Iron&scintillator mass.





The difference is ~3% and not flat in low energy region. For precise measurement, need to consider this difference, and also check the difference of systematic error for Fe and CH.

Estimation of CC inclusive σ of Fe

Total MC expectation is expressed as the following:

$$N^{total} = \int_i \phi_i(E) \cdot (T_{FE} \cdot \sigma_{FE}(E) + T_{CH} \cdot \sigma_{CH}(E)) \cdot \epsilon(E) dE$$
$$= \int_i \phi_i \cdot (1 + R_T(E) \cdot R_\sigma(E)) \cdot T_{FE} \cdot \sigma_{FE}(E) \cdot \epsilon(E) dE$$

So, cc inclusive cross-section of Fe can be estimated with this formula:

$$\sigma_i^{CC(FE)} = \frac{(1 + f_i) \cdot N_i^{MC} \cdot P_i^{FE}}{\Phi_i \cdot (1 + R_T \cdot R_i^\sigma) \cdot T_{FE} \cdot \epsilon_i}$$

$$N_i^{MC} = \sum_m^{module} \left(n_{m,i}^{MC(FE)} + n_{m,i}^{MC(CH)} \right) \;,\; R_T = T_{CH}/T_{FE} \;,\; R_i^\sigma = \sigma_i^{CH}/\sigma_i^{FE}$$

- Assume the efficiency to events in scintillators is same as iron.
- About some variables, it may be not needed to identify Fe/CH. Need to check study of neutrino interaction (or start to study).
- In this formula, neutrino cross-section model is discontinuous at each boundary of energy bin.

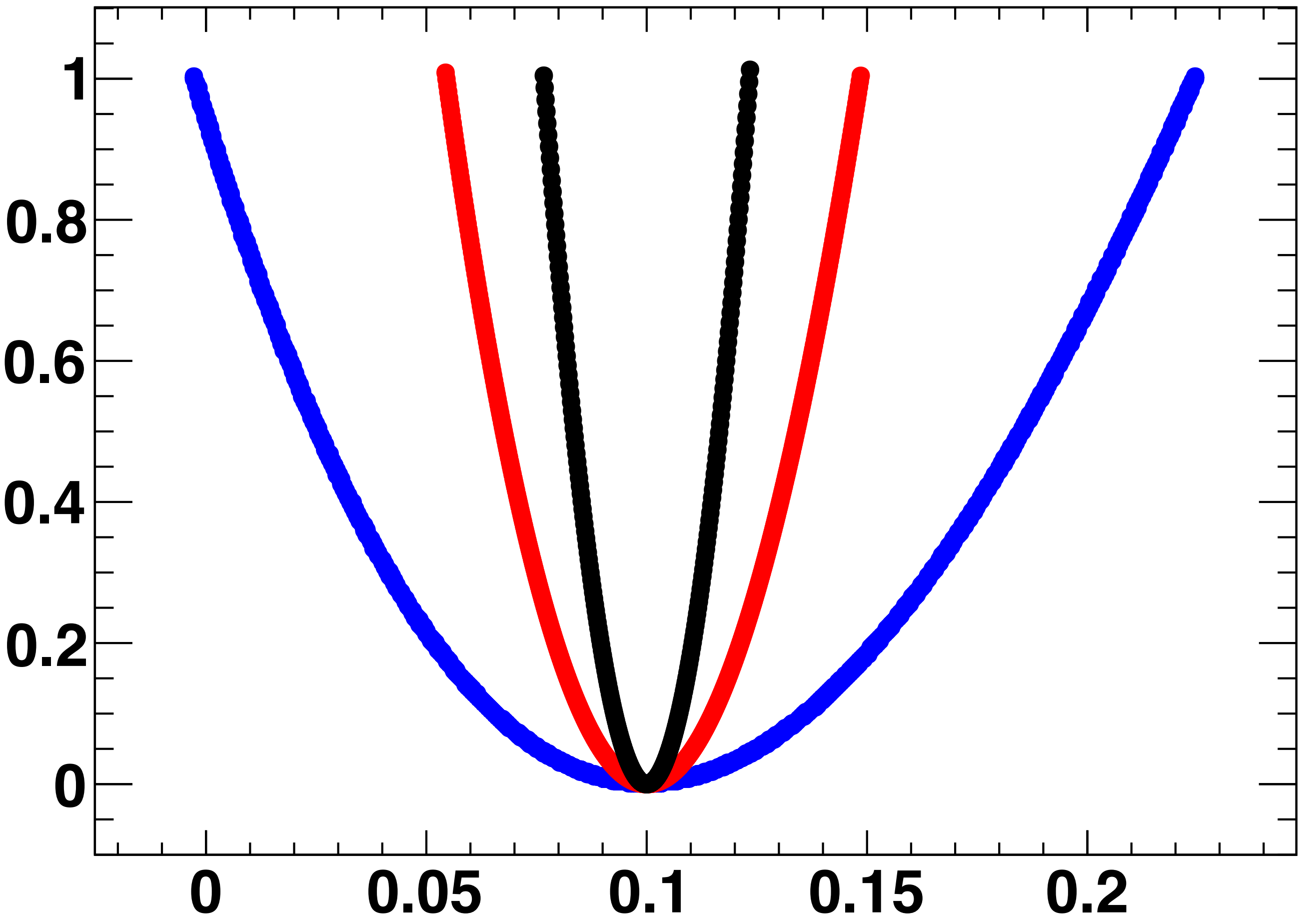
Next

- Treat other systematic error
  - First, due to flux
- Consider another neutrino cross-section model and try it.
  - Simply, linear-connected between center of each energy bin.

Back up

Δχ2 distribution of each case

Only for normalization parameter of bin#2 (f_2)



- w/o syst.
- w/ 3.7% det syst.
- w/ 10% det syst.

Purity

- Calculate the mean purity of all modules
  - Jnubeam 10d, NEUT5.0.6.
    - Neutrino target : Fe
  - Use only numu sample.