GENIE SIMULATIONS WITH NOvA

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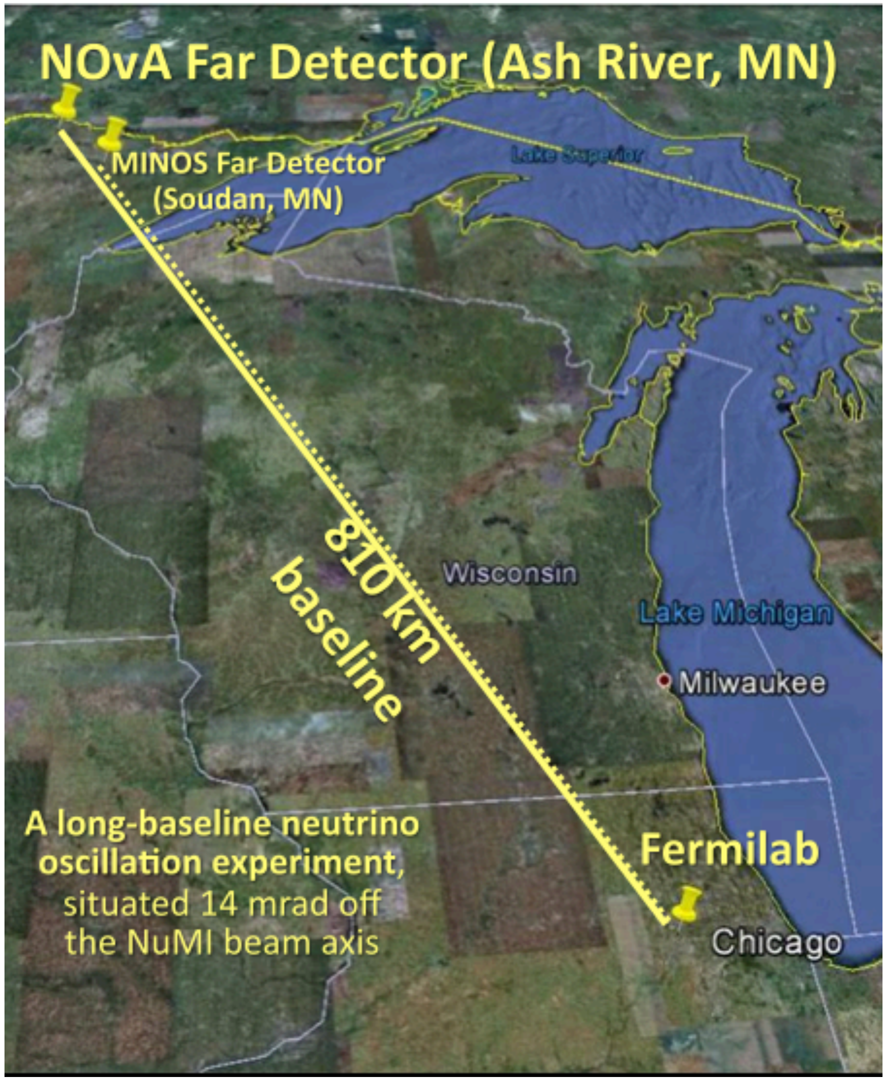
NovA: Overview

Long baseline neutrino oscillation experiment:

- Near and far detector pair
- Energy peak of the neutrino flux at 2 GeV
- 810 km baseline from Fermilab to Ash River, Minnesota

Goals:

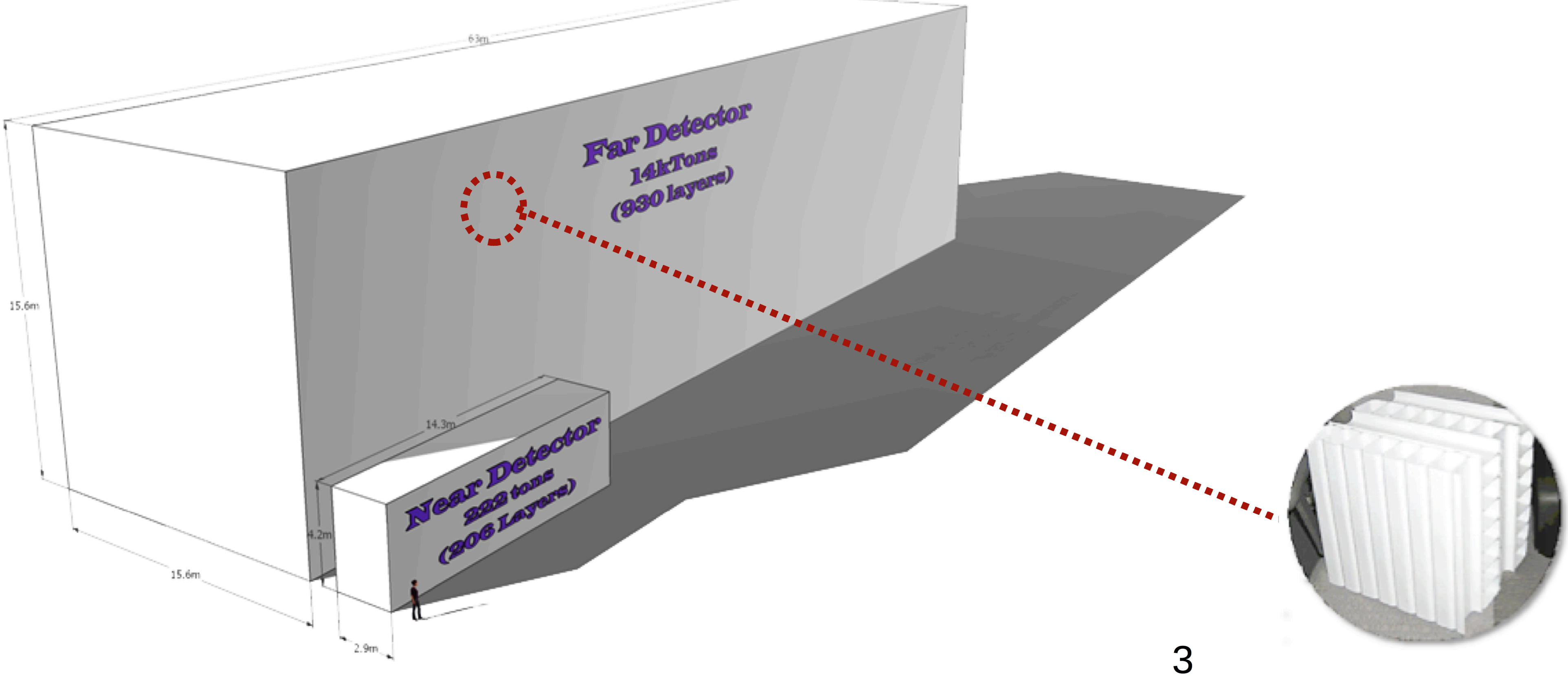
- Measure $\nu_\mu \rightarrow \nu_e$ oscillations.
- Precision measurements of $|\Delta m^2_{13}|$, θ_{23} .
- determine mass hierarchy.
- constrain CP violating phase.



NovA Far Detector

Large 14+ kton optimized to distinguish electrons:

- Highly segmented (alternating X/Y)
- 65% Active Volume
- Low Z materials (PVC and Scintillator)
- Provide radiation lenght of 40 cm



NovA Monte Carlo simulations

Usage of GENIE software for simulations

GENIE neutrino event generator:

- C++
- ROOT based
- Full adaptation of NEUGEN event generator used by MINOS

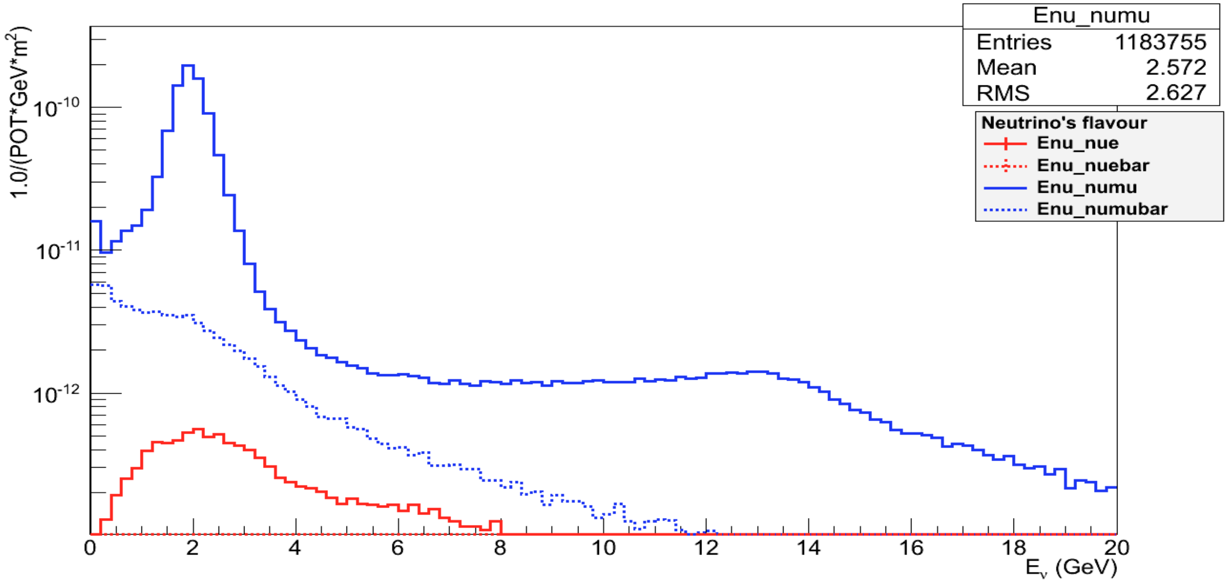
We need to know if GENIE predictions work in NOvA detector

Overview

GENIE Validation:

- Use our NOvA far detector
- Place a known neutrino flux
- Observe event rates
- Calculate cross sections
- Compare the obtained value of cross section with GENIE's ones.

$$F = \frac{(\text{neutrino events passing the square})/(\text{bin width})}{(\text{square area}) * \cos q * \text{POT}}$$



Overview

GENIE Validation:

- Use our NOvA far detector
- Place a known neutrino flux
- Observe event rates
- Calculate cross sections
- Compare the obtained value of cross section with GENIE's ones.

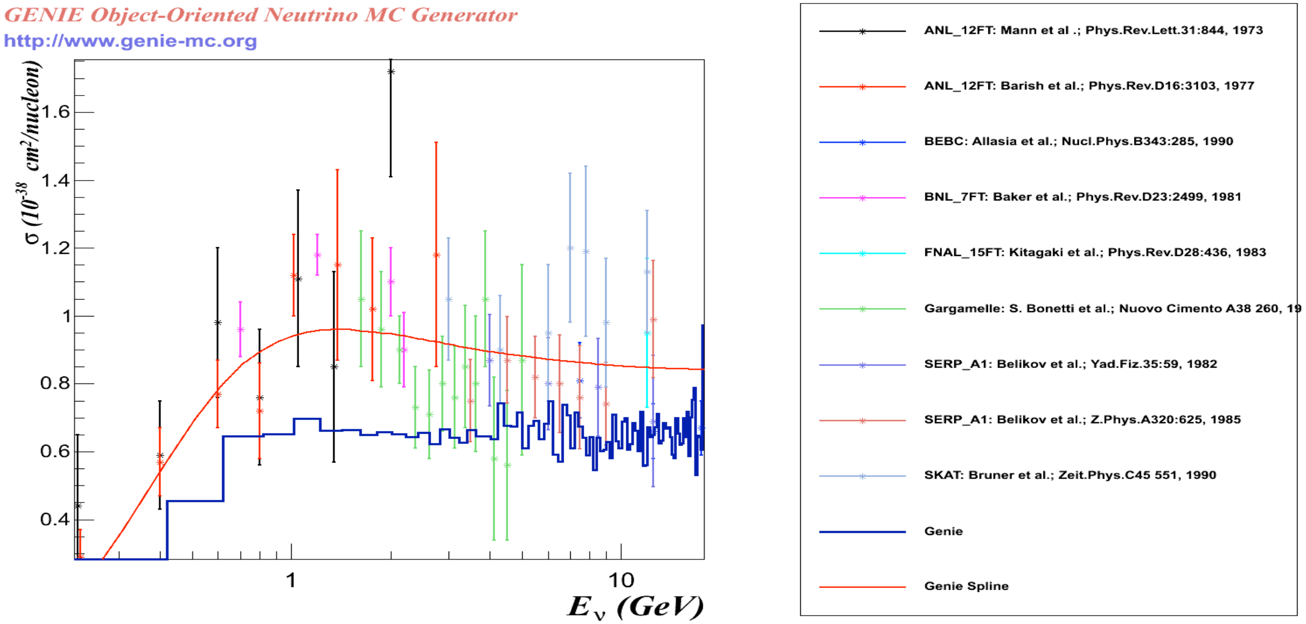
$$\sigma = \frac{(event\ rate\ inside\ the\ detector)}{flux * (number\ of\ targets \in the\ detector)}$$

MC Simulations with Far Detector geometry

- Used NovA far detector geometry
- Used the simple flux

Cross-Section Comparison to Data

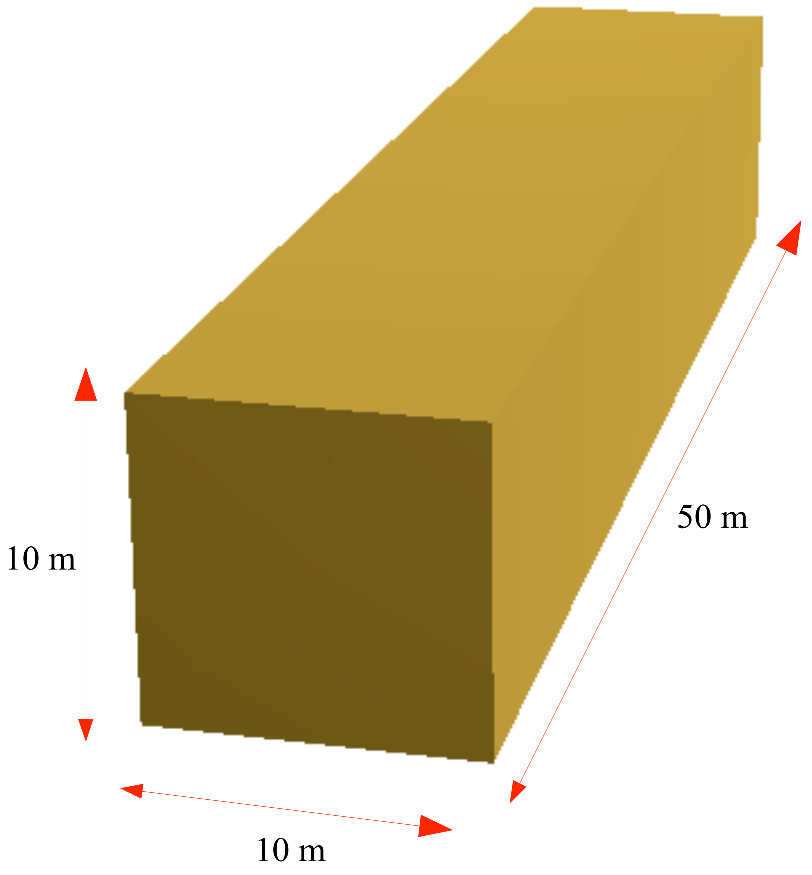
CCQE Cross -Section



Result: the cross section is 30-40% lower of what GENIE claims

MC Simulations with Far Detector geometry

Simplified far detector geometry: 1 block of one material (Carbon)



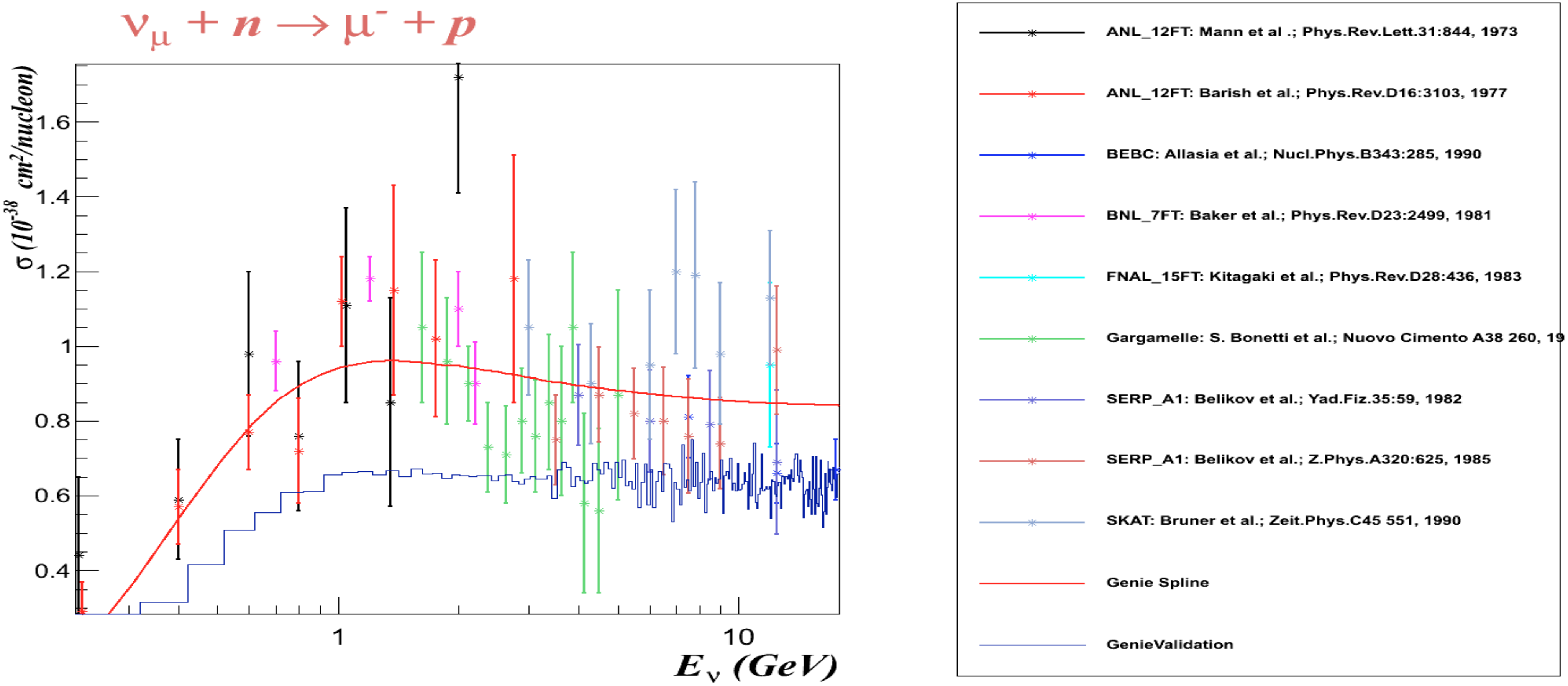
Carbon:
Density=22670 kg/m^3
A=12
Z=6

Proton mass=1.67 x 10^{-27} kg

Neutrino Cross Section calculation

Cross Section comparison to data

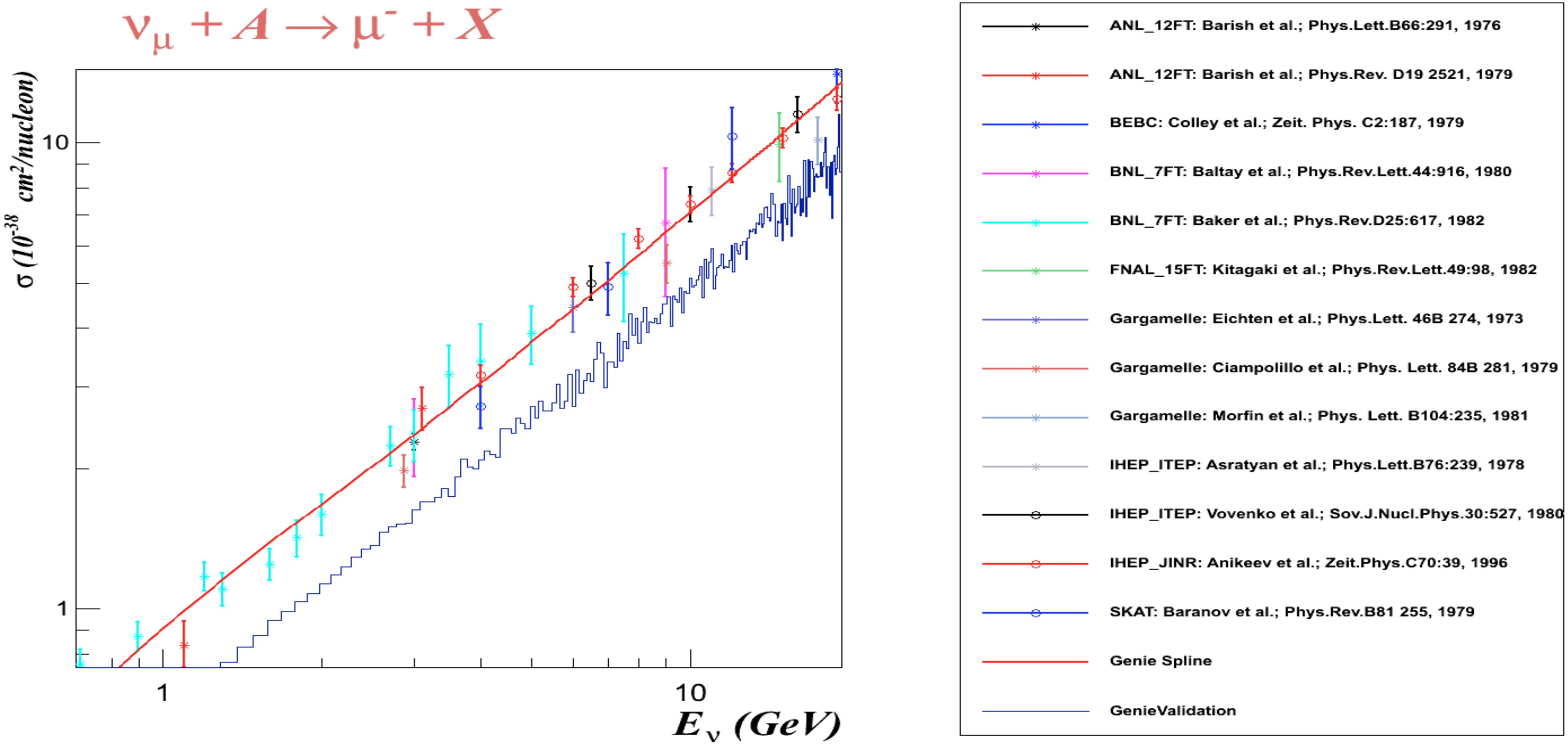
CCQE Cross Section



Neutrino Cross Section calculation

Cross Section comparison to data

CC Cross Section

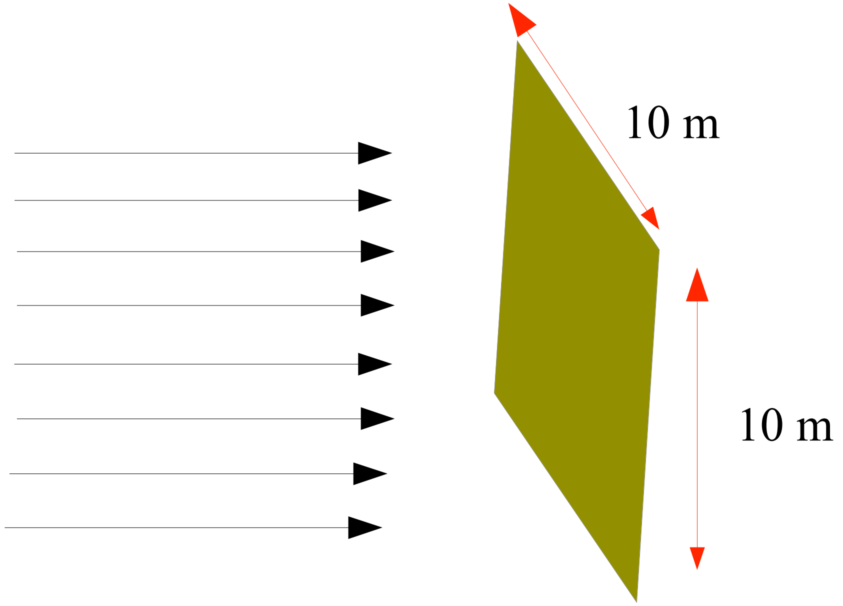


Conclusion: this effect is not due to far detector geometry

Further simplification

A simpler detector geometry still makes GENIE to calculate a lower Cross section

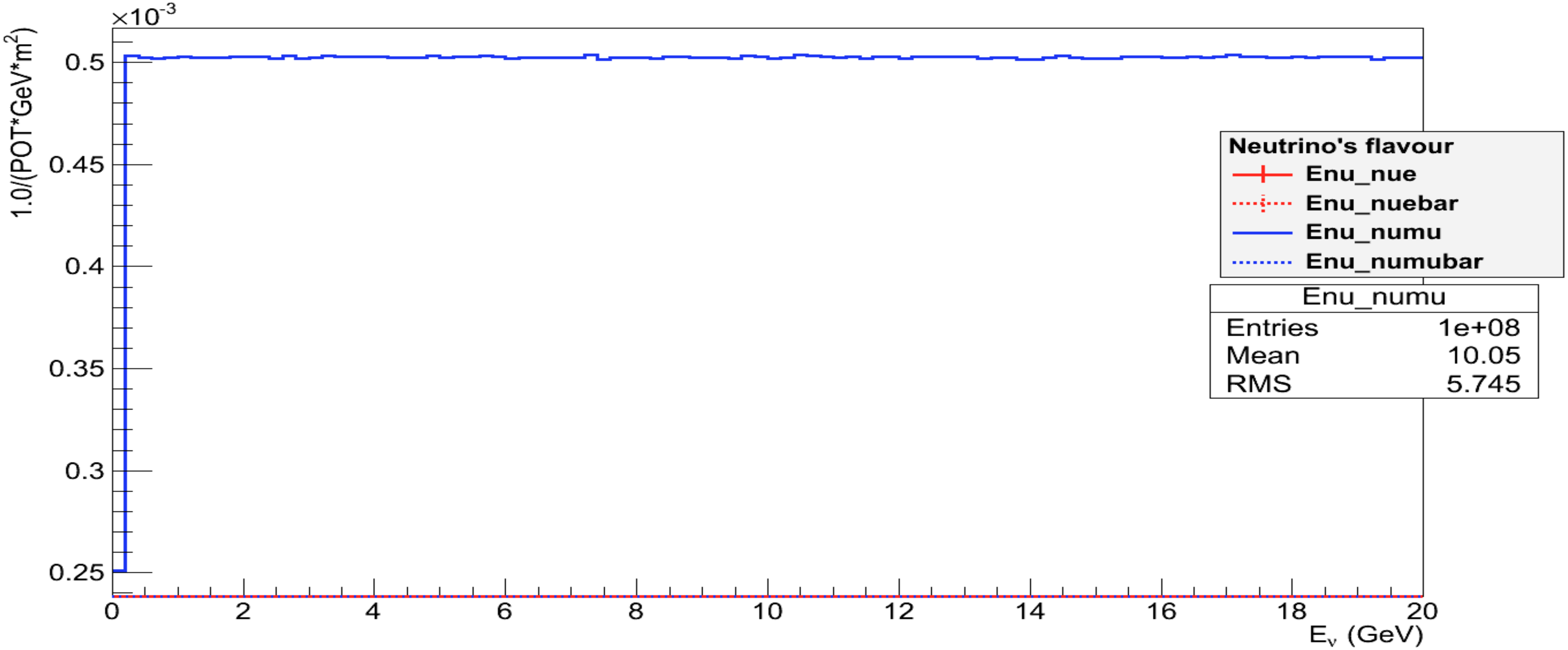
Usage of a flux indipendent by the beam simulations



New simple flux window area=100m^2

Neutrino Fluxes simulations

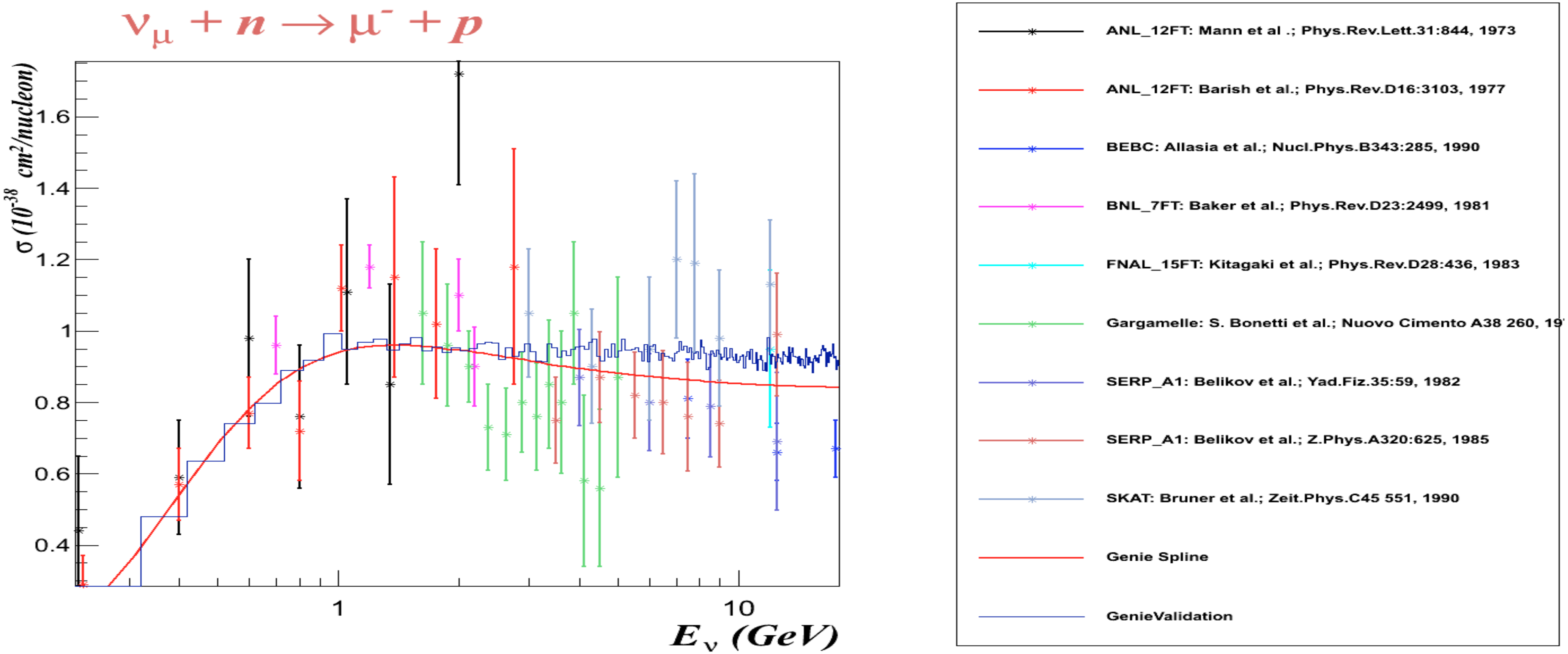
$$F = \frac{(neutrino\ events\ passing\ the\ square)/(bin\ width)}{(square\ area) * POT}$$



Neutrino Cross Section calculation

Cross Section comparison to data

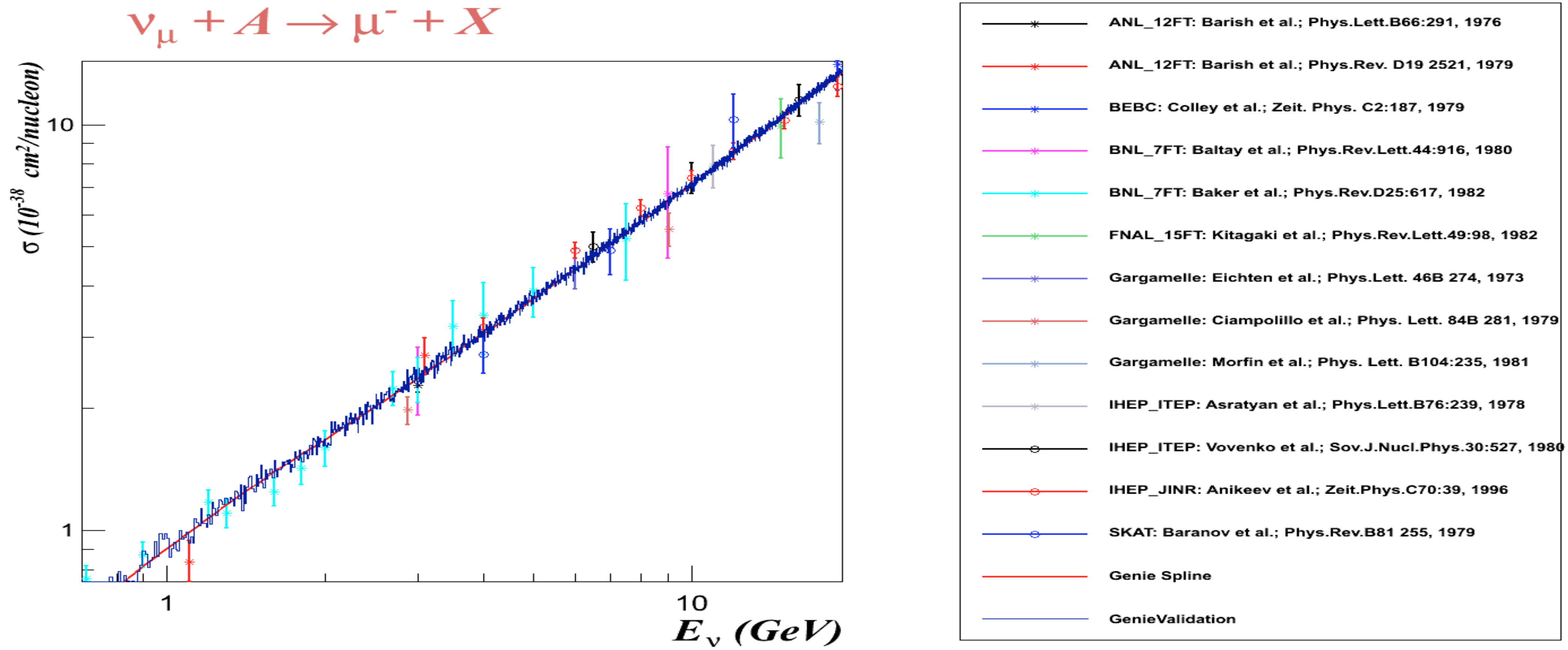
CCQE Cross Section



Neutrino Cross Section calculation

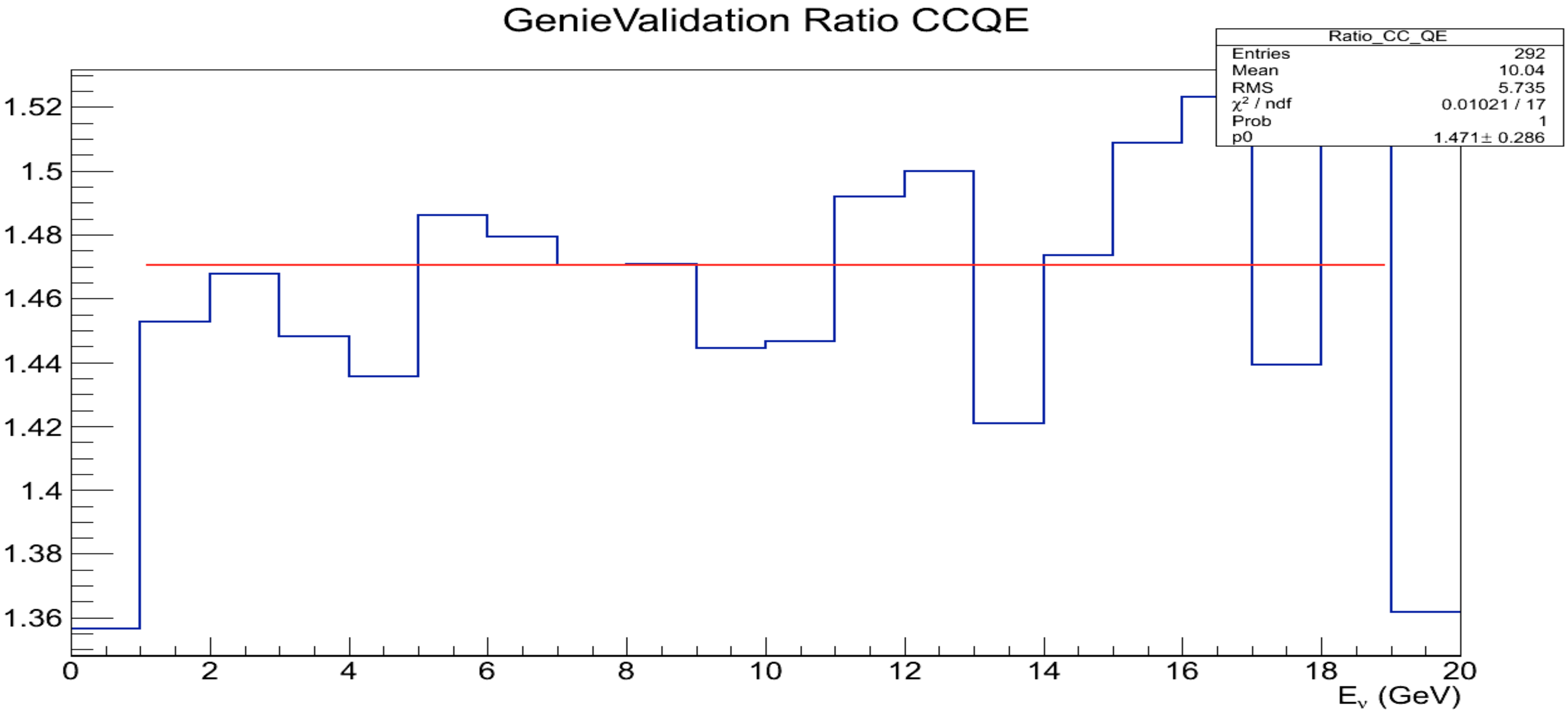
Cross Section comparison to data

CC Cross Section



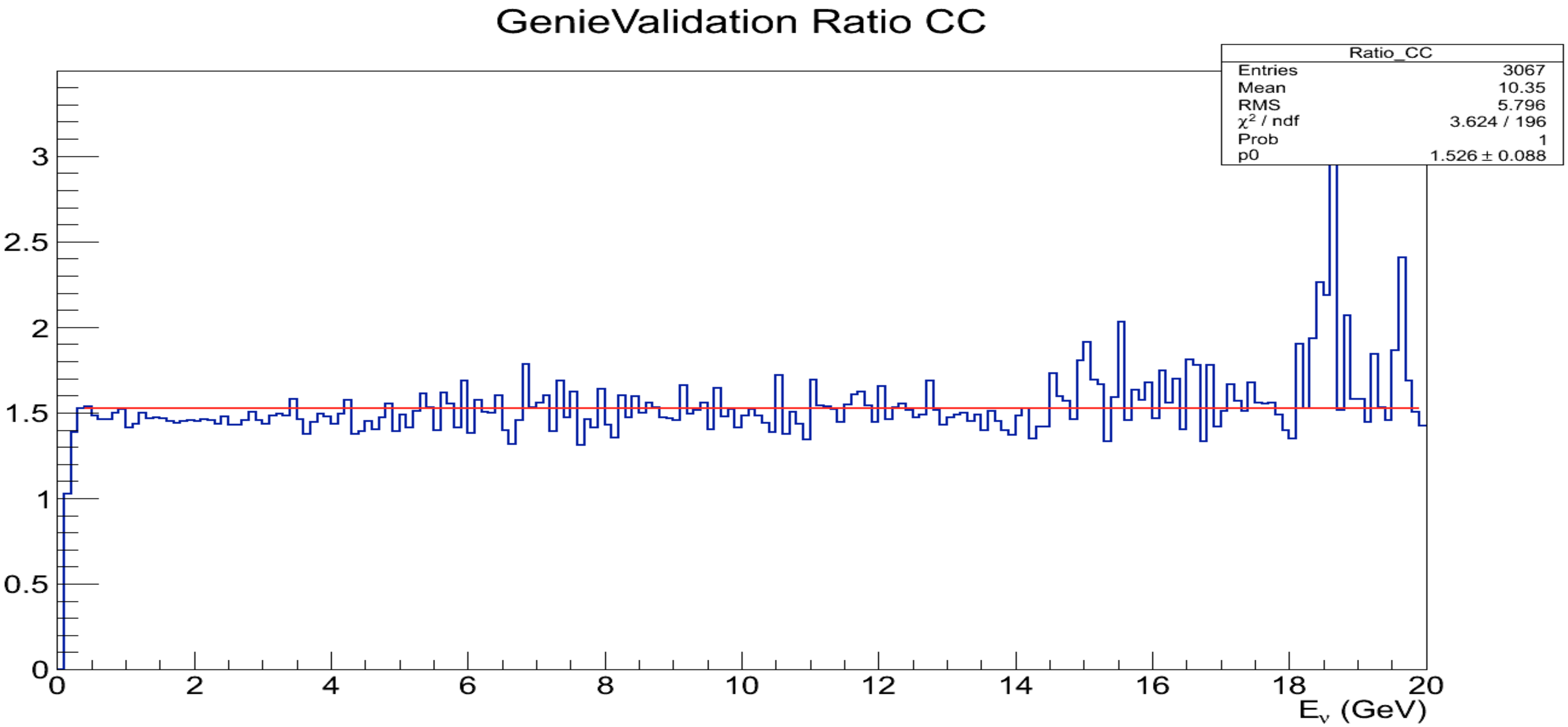
Cross Section Ratio CCQE

$$\frac{\text{Calculated cross section}(\text{flat flux})}{\text{Calculated cross section}(\text{standard flux})}$$



Cross Section Ratio CC

$$\frac{\text{Calculated cross section}\left(\text{flat flux}\right)}{\text{Calculated cross section}\left(\text{standard flux}\right)}$$



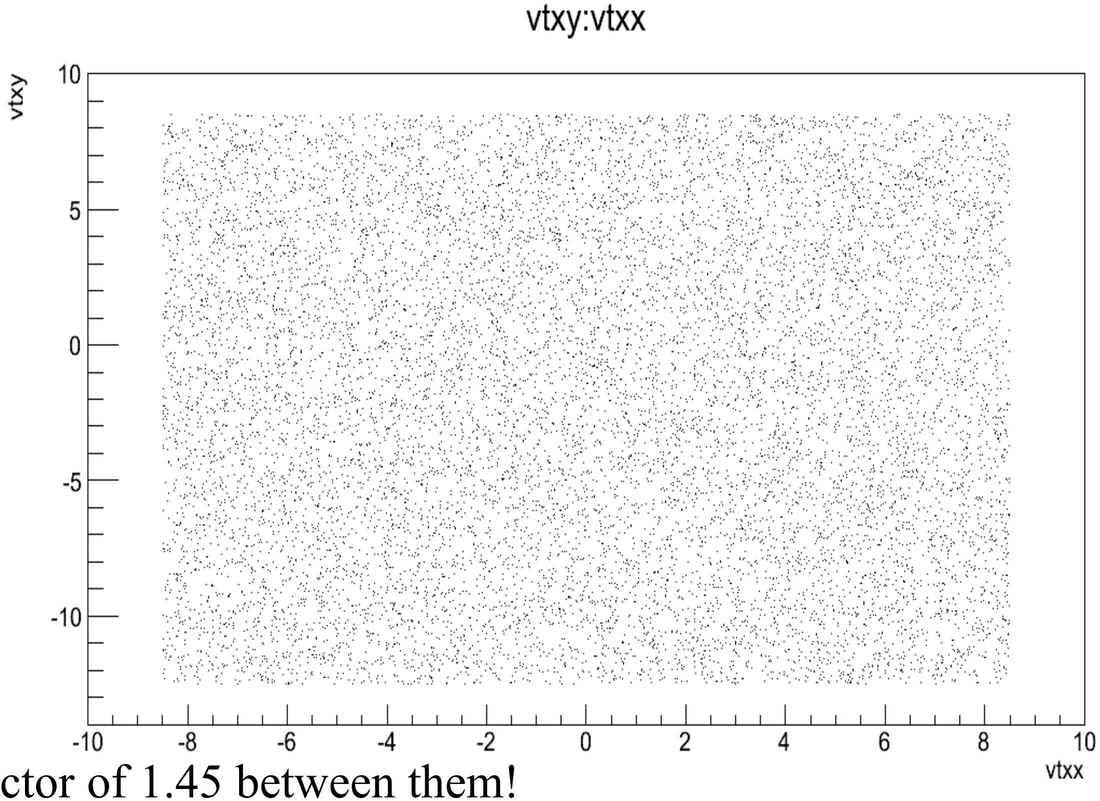
Problem finding

The results show a costant factor of 1.5 between the two cross sections

Looked at one of the simple flux files

Area from the flux file ~360 m^2

Area used in the flux file= 244m^2



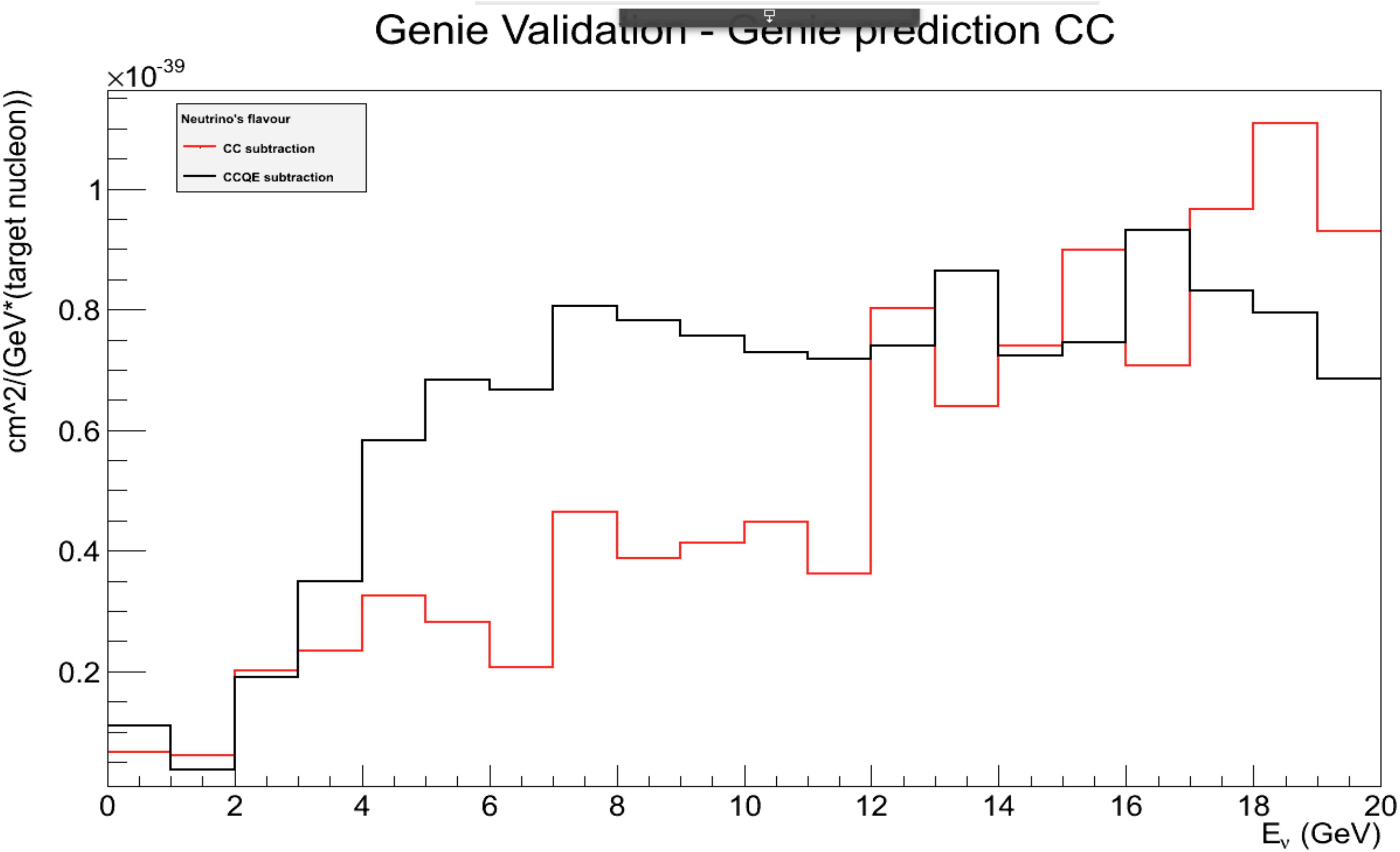
There is a factor of 1.45 between them!

Conclusions

- We performed GENIE validation by calculating cross sections from observed event rates and neutrino fluxes.
- We used simplified detector geometry and simplified flux. The resulting cross section are very close to GENIE Splines.
- We found the problem with previous cross section calculation. It was due to using wrong area for flux window.
- All our code is contained in GenieValidation package. The simplified geometry is contained in file giuseppe_fardet.gdml in Geometry package.

Backup slides

Cross section subtraction



ν_e Appearence

- NovA measures the probability of ν_e appearance in a ν_μ beam:

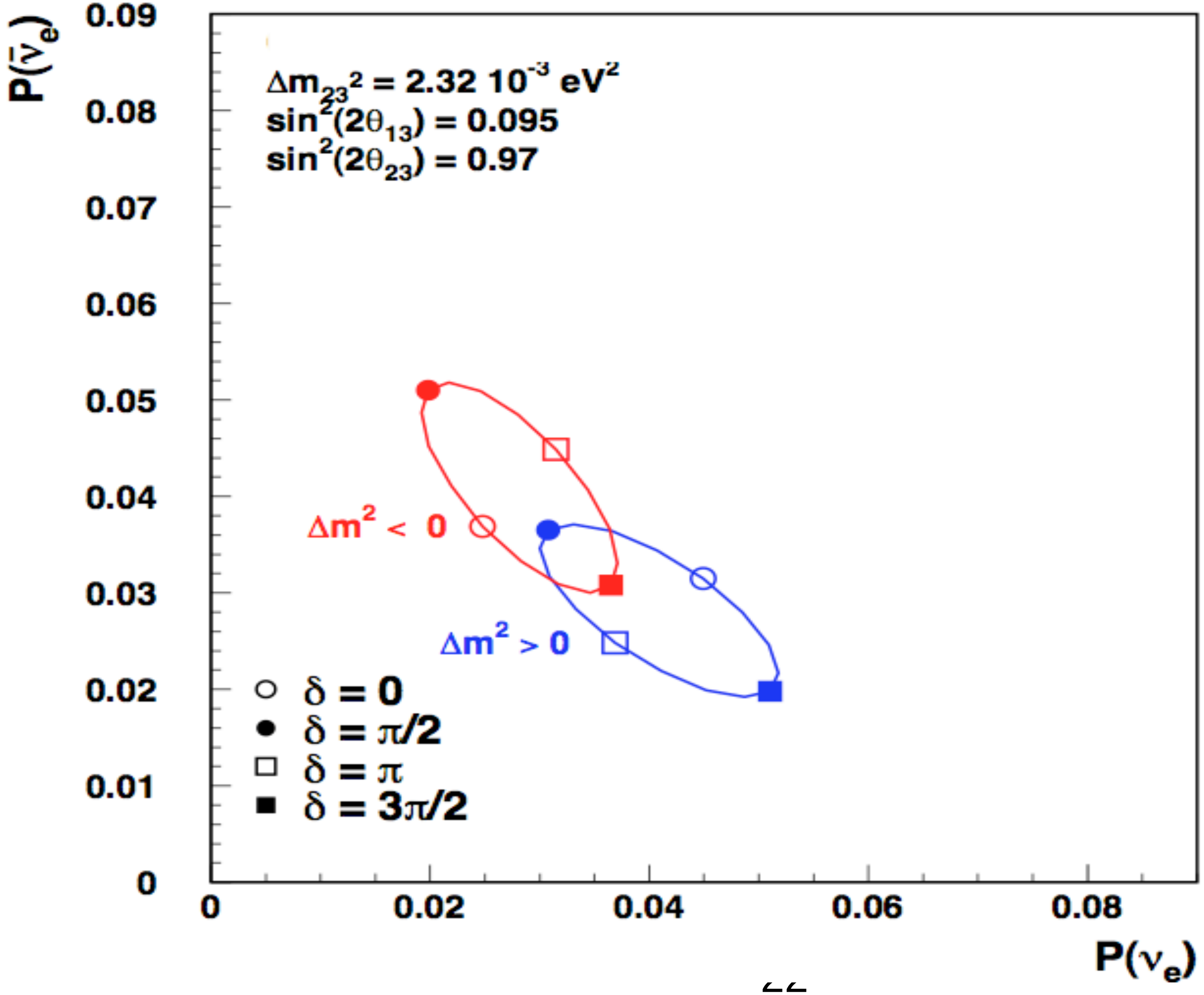
$$
\begin{aligned}
P(\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_e) \approx{}& \sin^2 2\theta_{13} \sin^2\theta_{23} \frac{\sin^2(A-1)\Delta}{(A-1)^2} \\
&\underset{-}{(+)}\, 2\alpha \sin\theta_{13} \sin\delta_{CP} \sin 2\theta_{12} \sin 2\theta_{23} \frac{\sin A\Delta}{A} \frac{\sin(A-1)\Delta}{(A-1)} \sin\Delta \\
&+\, 2\alpha \sin\theta_{13} \cos\delta_{CP} \sin 2\theta_{12} \sin 2\theta_{23} \frac{\sin A\Delta}{A} \frac{\sin(A-1)\Delta}{(A-1)} \cos\Delta
\end{aligned}
$$

$$
\alpha = \Delta m^2{}_{21}/\Delta m^2{}_{31} \qquad \Delta = \Delta m^2{}_{31} L/(4E) \qquad A = \underset{+}{(-)}\, G_f n_e L/(\sqrt{2}\Delta)
$$

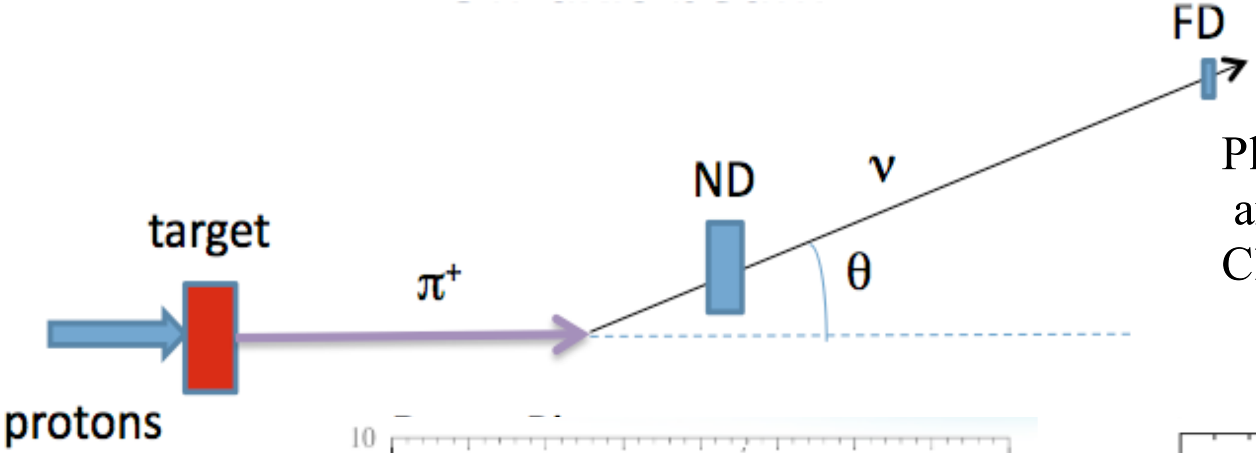
- sin2(2θ_{13}) has been measured which allows us to make measurements of δ_{CP} and mass hierarchy.
- Note that we can improve θ_{23} measurement from $\nu\mu$ disappearence.
- Probability is enhanced or suppressed due to matter effects which depend on the mass hierarchy.

ν_e Appearence

Probability of oscillations for both ν_μ and $\bar{\nu}_\mu$ as a function of δ for normal and inverted mass hierarchy



Off-axis ν_μ beam



Placing detectors 14 mrad off the beam axis results in 2GeV narrow band beam. Close to the oscillation maximum.

$$E_\nu = \frac{\left(1-\frac{m_\mu^2}{m_\pi^2}\right)E_\pi}{1+\gamma^2\theta^2}$$