Adding Hydrogen/Deuterium Target to MINERνA Experiment?

Lingyan Zhu

HAMPTON UNIVERSITY

for

MINERνA Collaboration

at

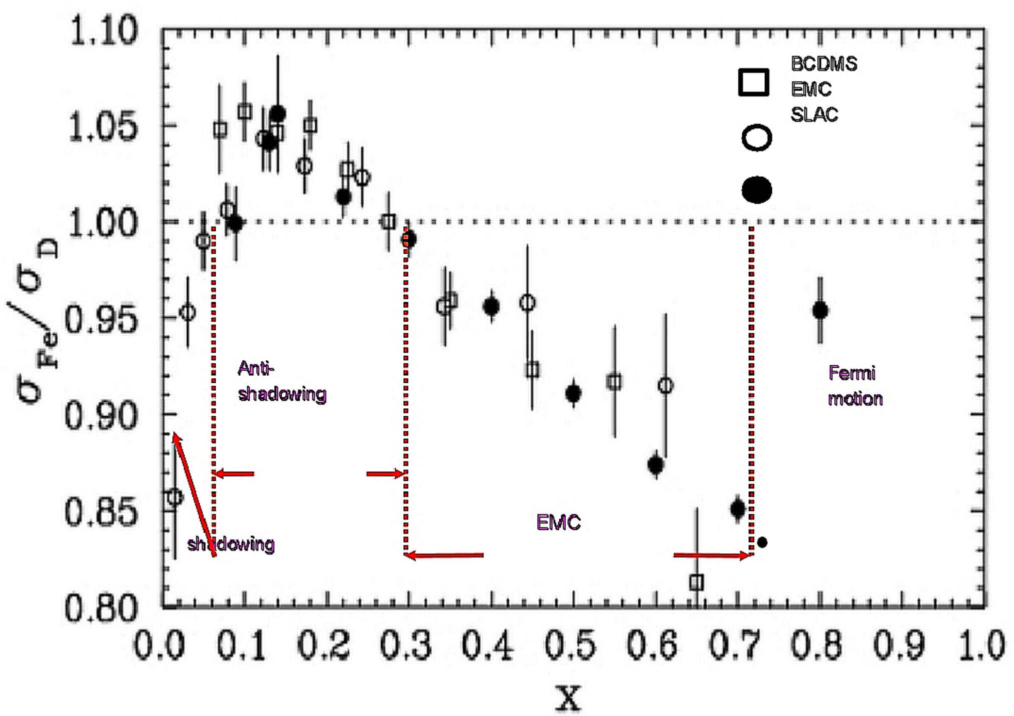
Short Baseline Neutrino Workshop

A continuation of Bari Osmanov's talk on MINERνA present and future.

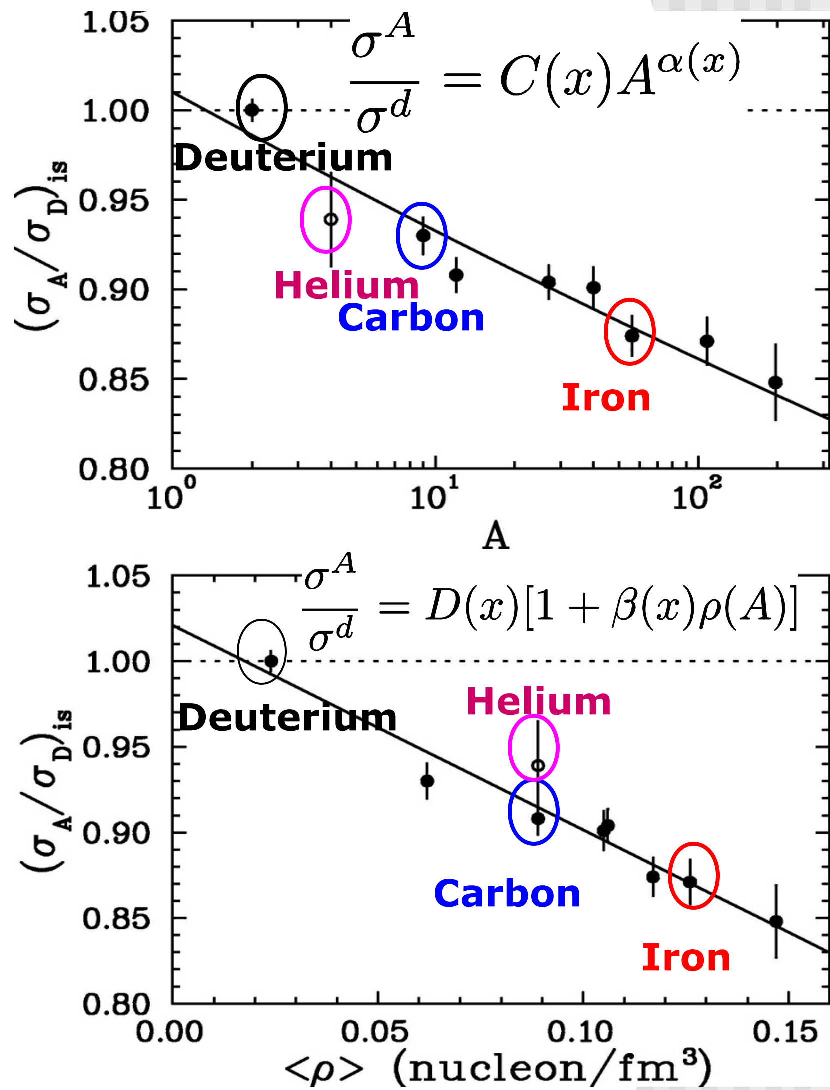
A LOI on deuterium was just submitted.

Nuclear Effects in A/D ratios

The structure functions of a nucleon within a nucleus are different from the structure functions of a free nucleon.



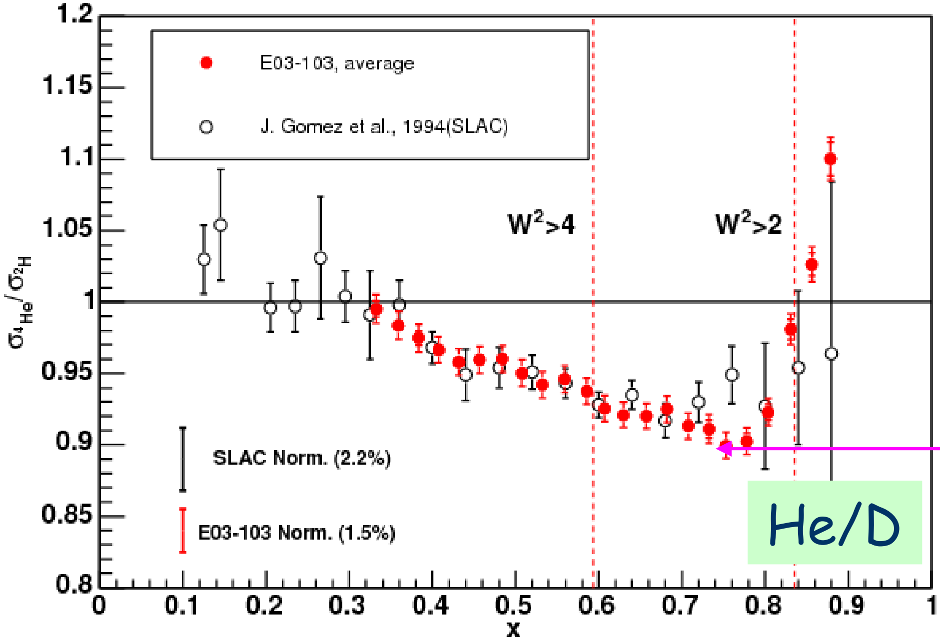
SLAC E139 at x=0.6

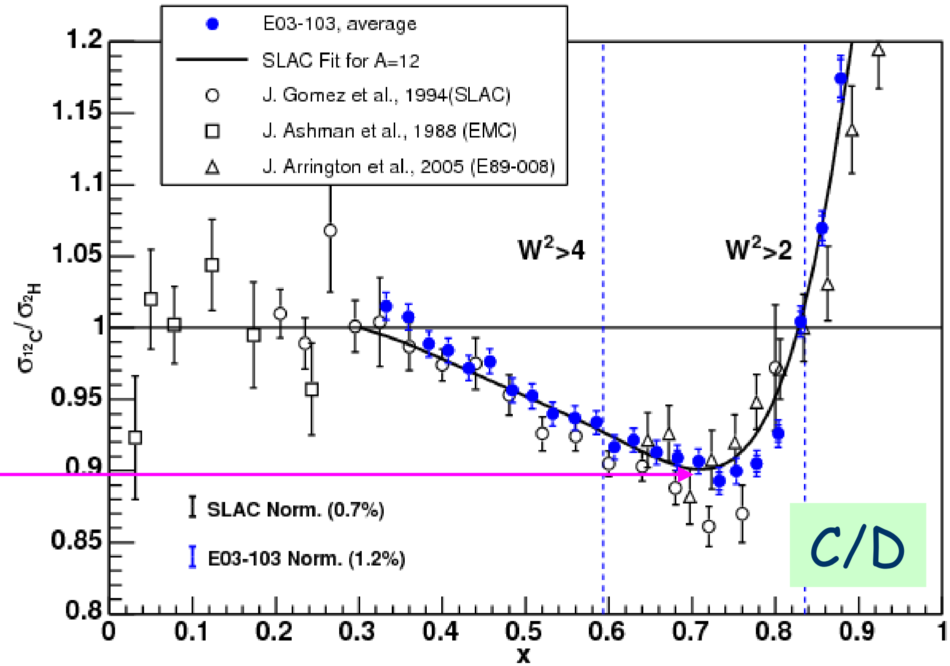


Fe/D cross sections show 13% nuclear effect. Precision neutrino data requires better understandings of nuclear effects.

Helium is Like Carbon

- Jefferson Lab E03-013 data [Ref: J. Arrington, nucl-ex/0701017]

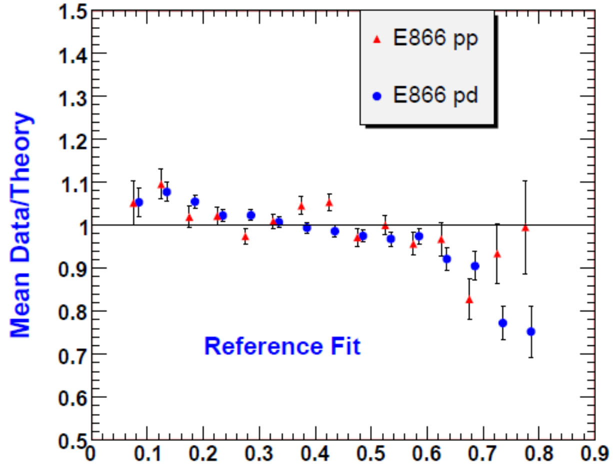


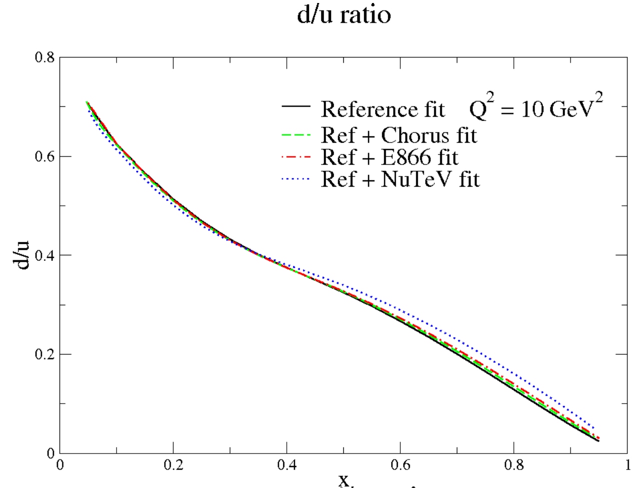


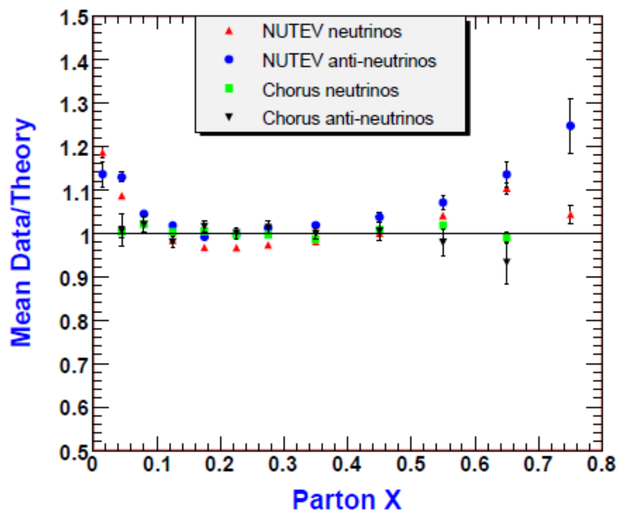
^{4}He show similar nuclear EMC effect as ^{12}C

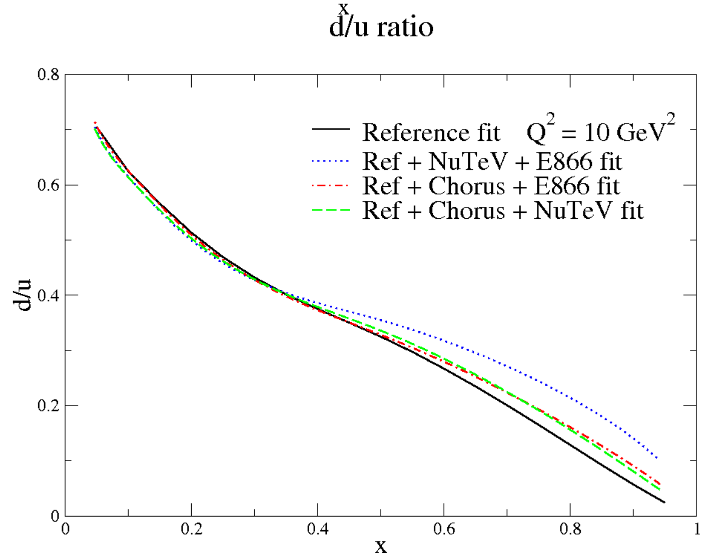
Using Neutrino Data for PDFs

At large x, the neutrino data from NuTeV experiment seem to pull the PDF fits in a different way from the Drell-Yan data. Reducing the nuclear corrections for NuTeV can reduce the tension. [J. F. Owens *et al.,* Phys.Rev.D75(2007)054030]



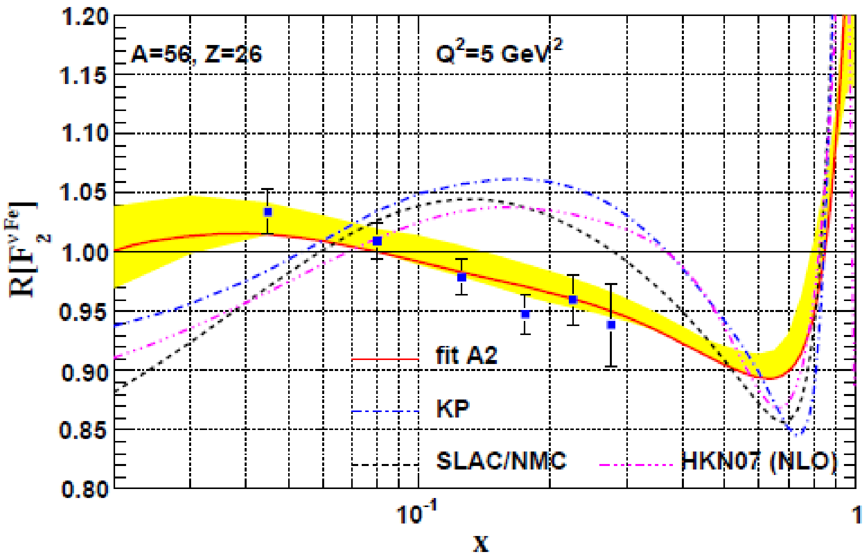


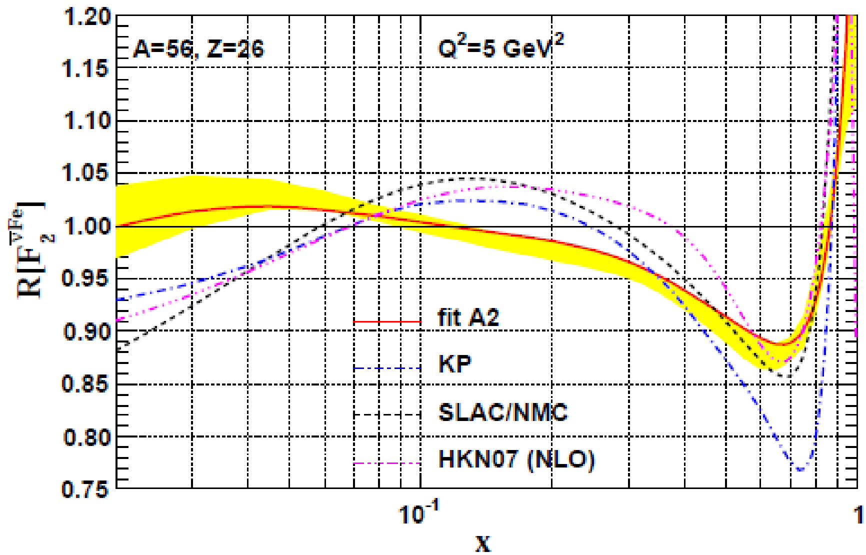




Nuclear Effects for Neutrino Data

The Fe/D ratios extracted from NuTeV data and the free-nucleon PDFs differ in both shape and magnitude from those by using the models and charged lepton DIS data.

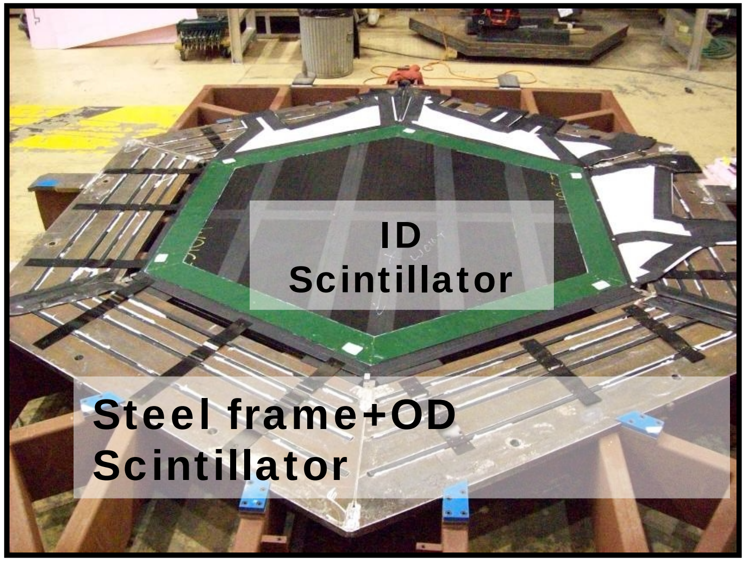


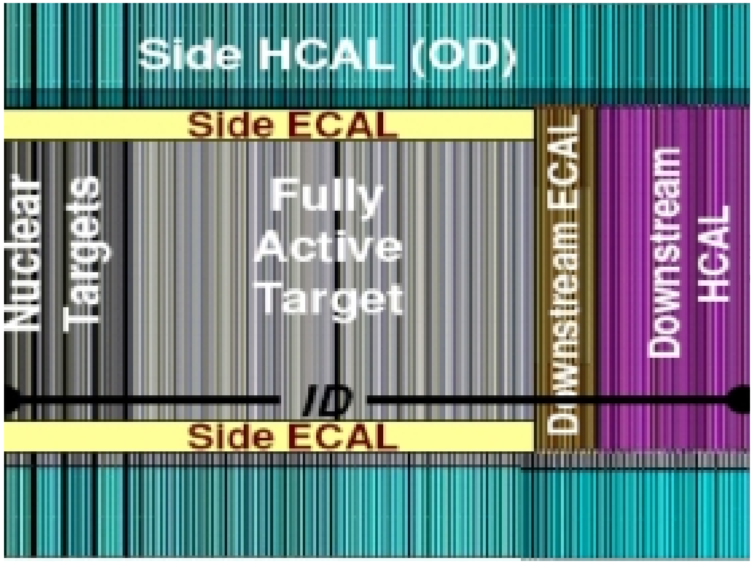


Ingo Schienbein *et al.,* Phys.Rev.D80(2009)094004;PRD77(2008)054013

MINERνA Experiment

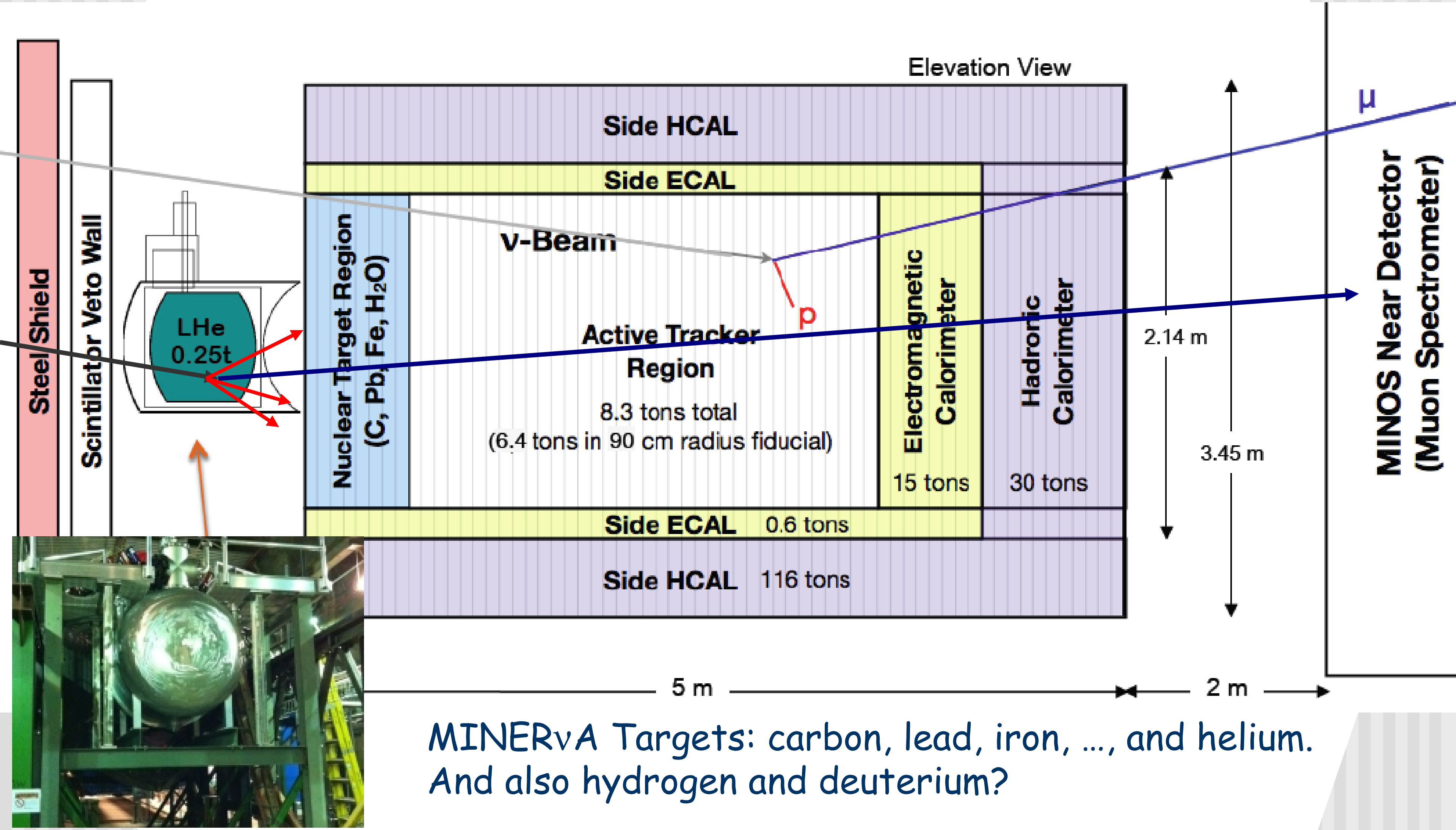
Fine-grained MINERνA Detector
(127 strips per plane)





MINERνA was designed to measure high precision cross section ratios.

MINERνA Cryogenic Target

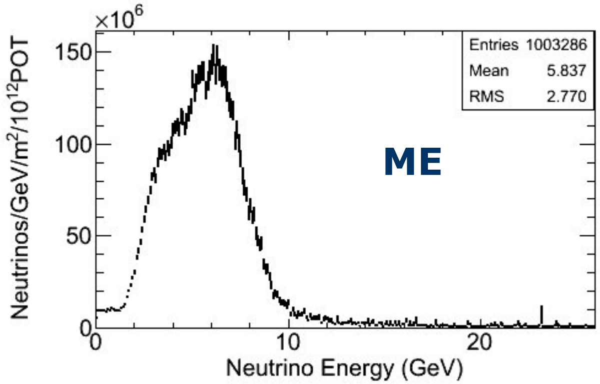


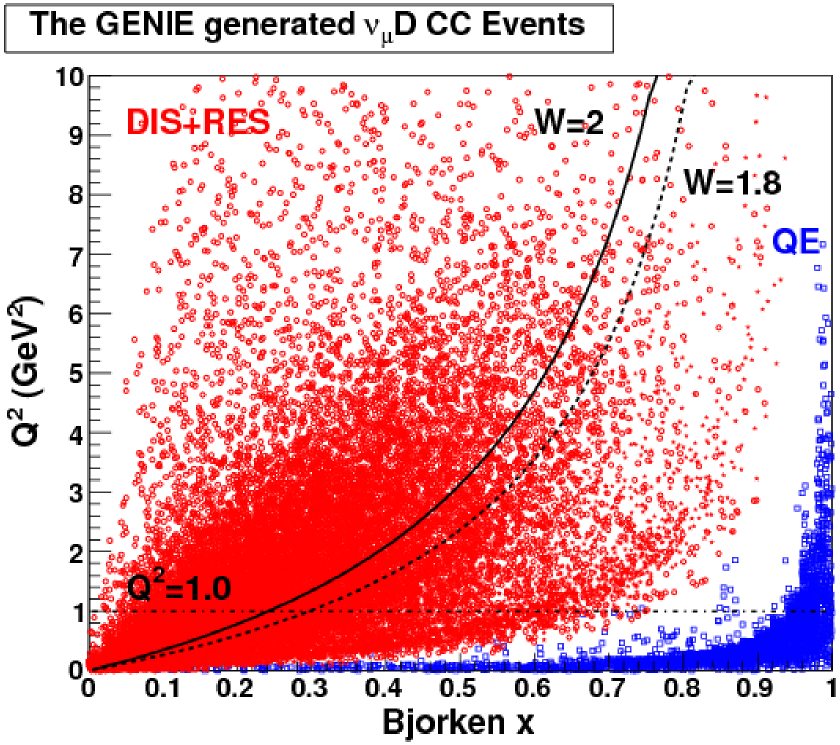
MINERνA Targets: carbon, lead, iron, …, and helium.
And also hydrogen and deuterium?

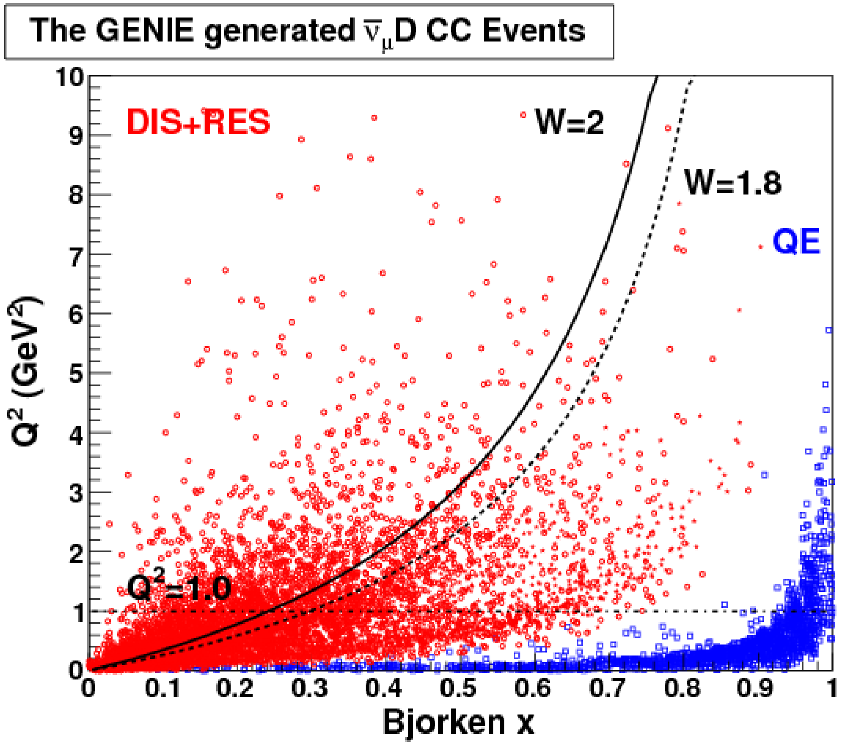
The CC Events from Deuterium Target

Let's fill the cryogenic target with deuterium in simulation

Software: MINERνA simulation (GENIE+GEANT4)
Flux: NOνA neutrino and anti-neutrino ME beam

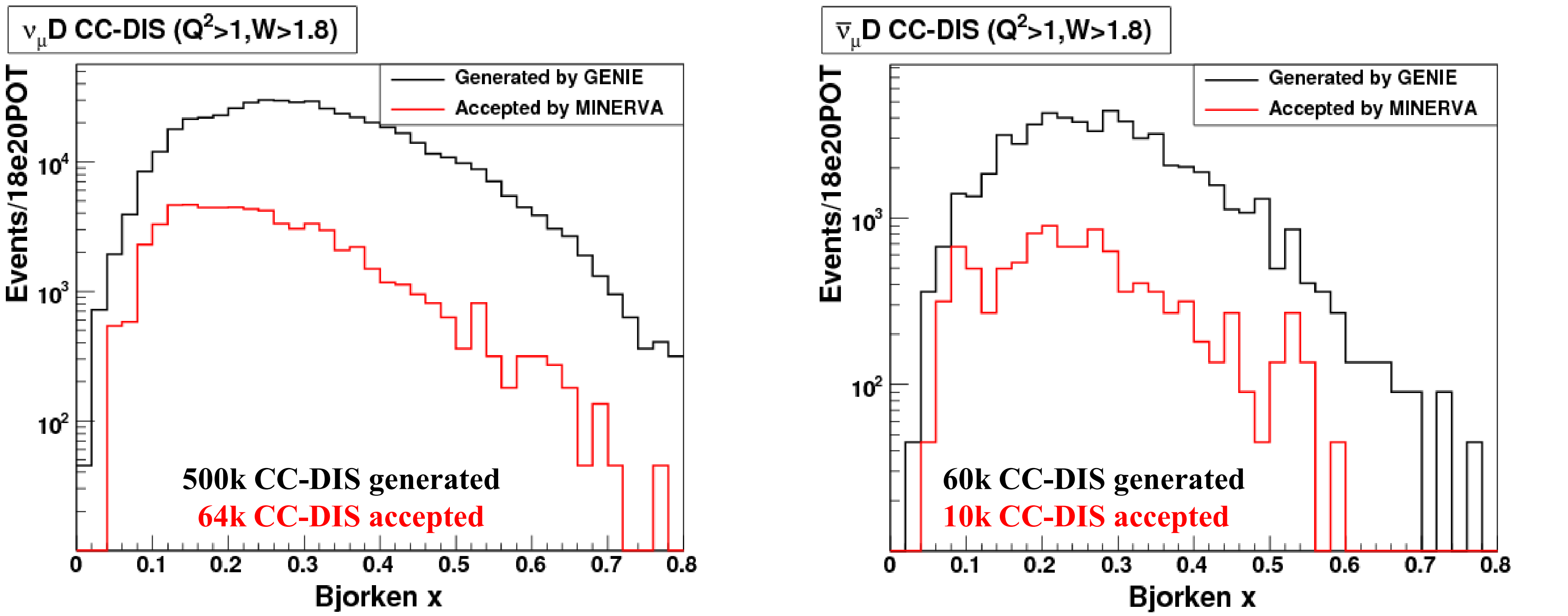






The CC-DIS Events from Deuterium Target

Each scaled to 18*10^20 POT, about 3-years running after NOνA beamline upgrade.

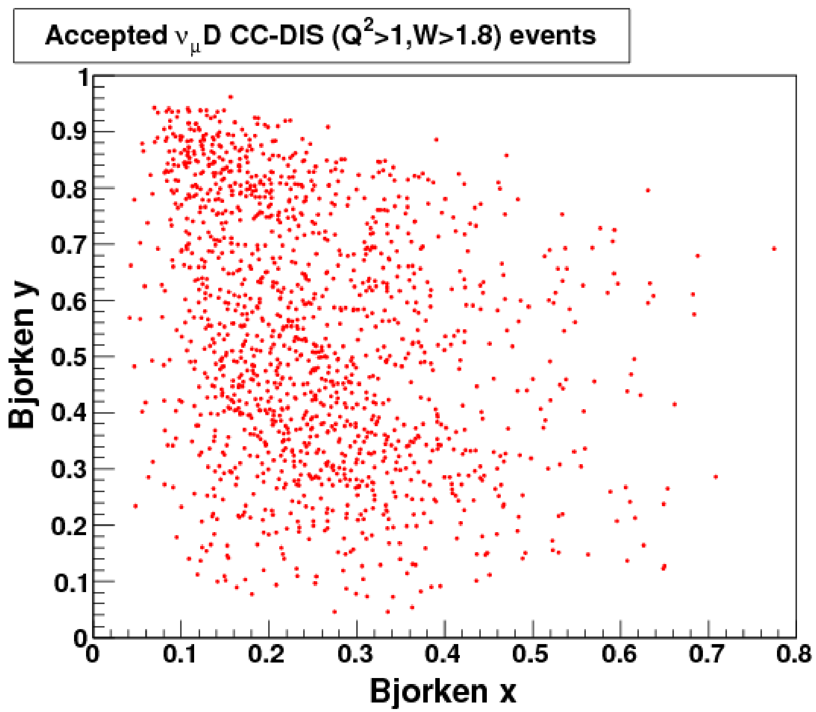


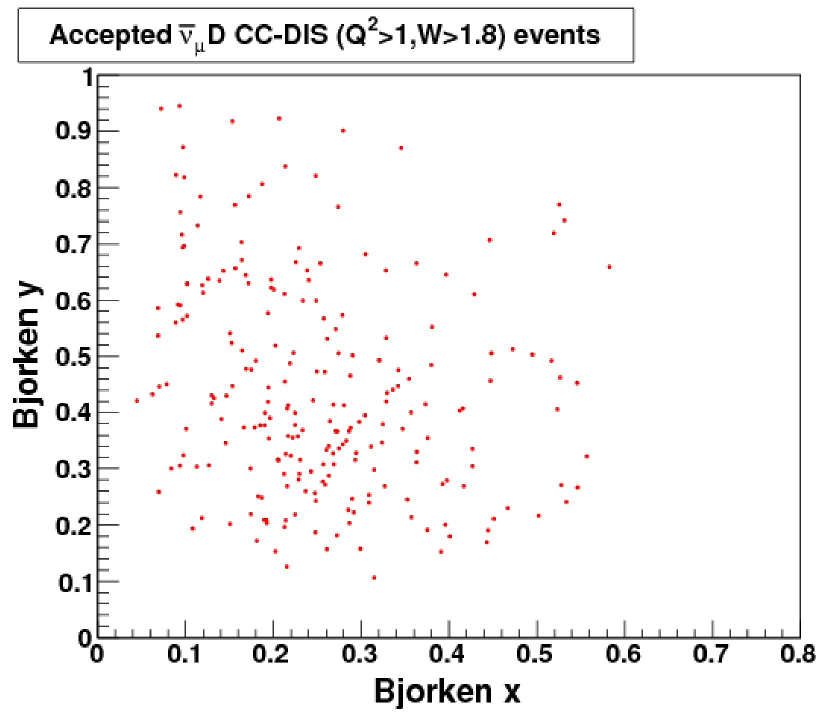
Accepted by MINERVA
means two+ tracks (# of planes>3) including a momentum analyzable muon.

The y Coverage of CC-DIS Events

Accepted

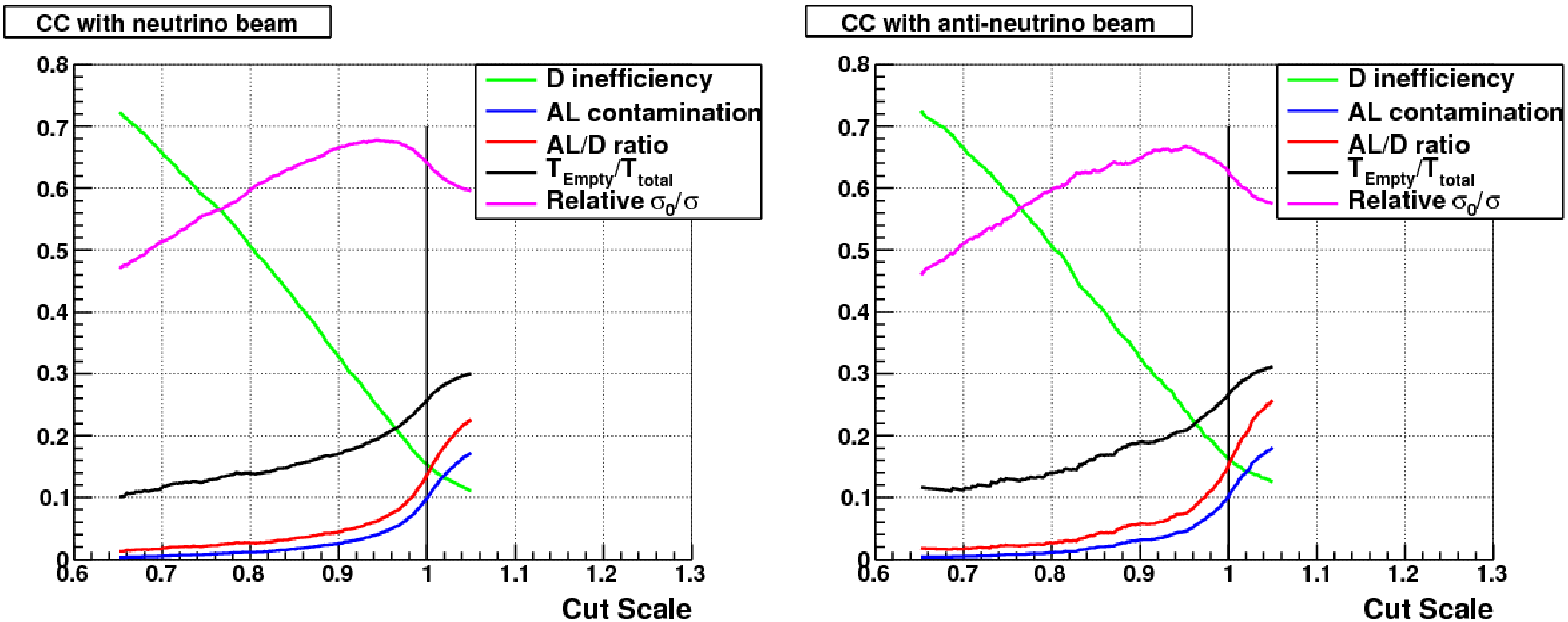
means two+ tracks (# of planes>3) including a momentum analyzable muon in MINERνA.





$$\frac{d^2\sigma^{\nu(\bar{\nu})}}{dxdy} = \frac{G_F^2 M_p E_{\nu(\bar{\nu})}}{\pi}\left(\frac{M_W^2}{M_W^2+Q^2}\right)^2 \Big[xy^2 F_1^{\nu(\bar{\nu})}(x,Q^2)$$
$$+\ (1-y-\frac{M_p xy}{2E_{\nu(\bar{\nu})}})F_2^{\nu(\bar{\nu})}(x,Q^2) \pm y(1-\frac{y}{2})xF_3^{\nu(\bar{\nu})}(x,Q^2)\Big]$$

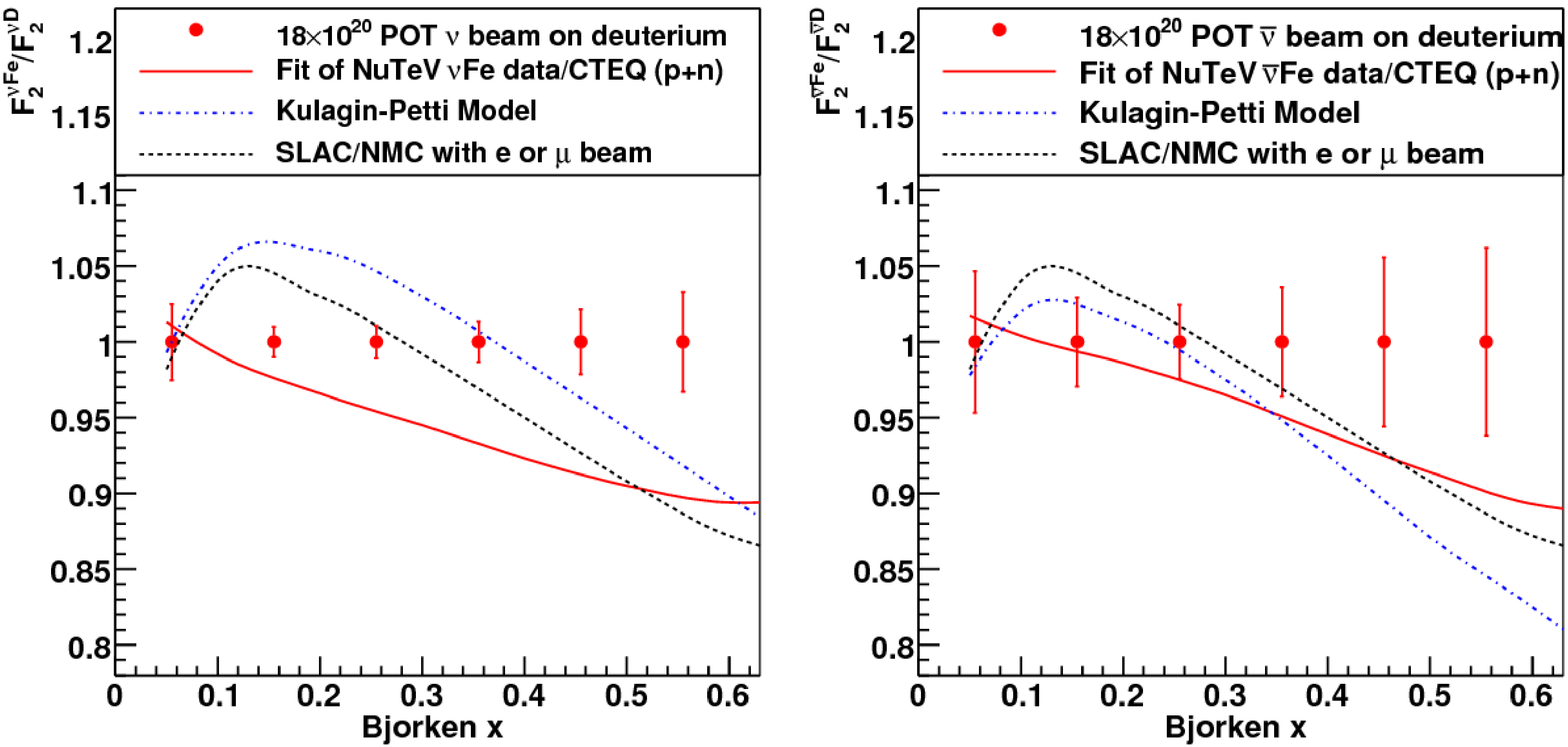
Optimization of the Empty Target Running



The empty target running increases the statistical projections by ~50%. This has been corrected in the projected uncertainties later in this talk.

The Projected A/D CC-DIS Ratio

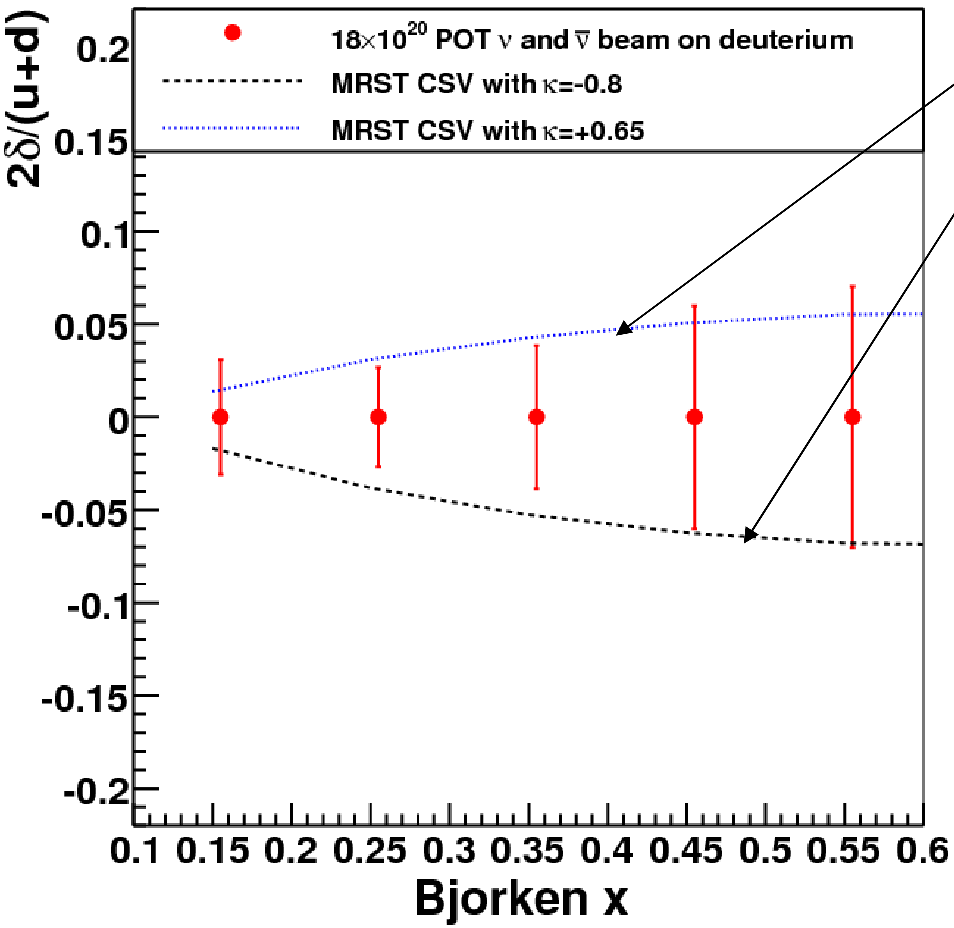
Curves read from: Ingo Schienbein *et al.*, Phys.Rev.D80(2009)094004; PRD77(2008)054013



Other ratios like C/D and Pb/D can be also measured.
The uncertainties of the beam flux will be greatly cancelled in the ratios.

Charge Symmetry Violation Measurement

The neutrino to anti-neutrino ratio on deuterium is a direct measurement of CSV.



The 90% confidence region based on the MRST fit with $\delta=\kappa f(x)$

$$u_p - d_n = -(d_p - u_n) \equiv \delta(x)$$

$$f(x) = (1-x)^4 x^{-0.5}(x - 0.0909)$$

At large x:

$$\frac{d^2\sigma^{\nu D}}{d^2\sigma^{\bar{\nu} D}} \sim \frac{d_p(x)+d_n(x)}{u_p(x)+u_n(x)} \cdot \frac{1}{(1-y)^2}$$

$$2\delta(x)/[u(x)+d(x)] \sim 1 - (1-y)^2 \frac{d^2\sigma^{\nu D}}{d^2\sigma^{\bar{\nu} D}}$$

Deuterium vs. Helium

	Deuterium	Helium
Density	~0.169 g/cm^3 ✓	~0.114 g/cm^3
Temperature	~22K ✓	~5K
Nuclear Effect	A=2,lightest isoscalar ✓	A=4, as dense as A=12 Carbon
Cost	Used Deuterium?	✓
Safety	Flammable+Cryogenic hazard	Only cryogenic hazard ✓

Physics Motivations with Deuterium

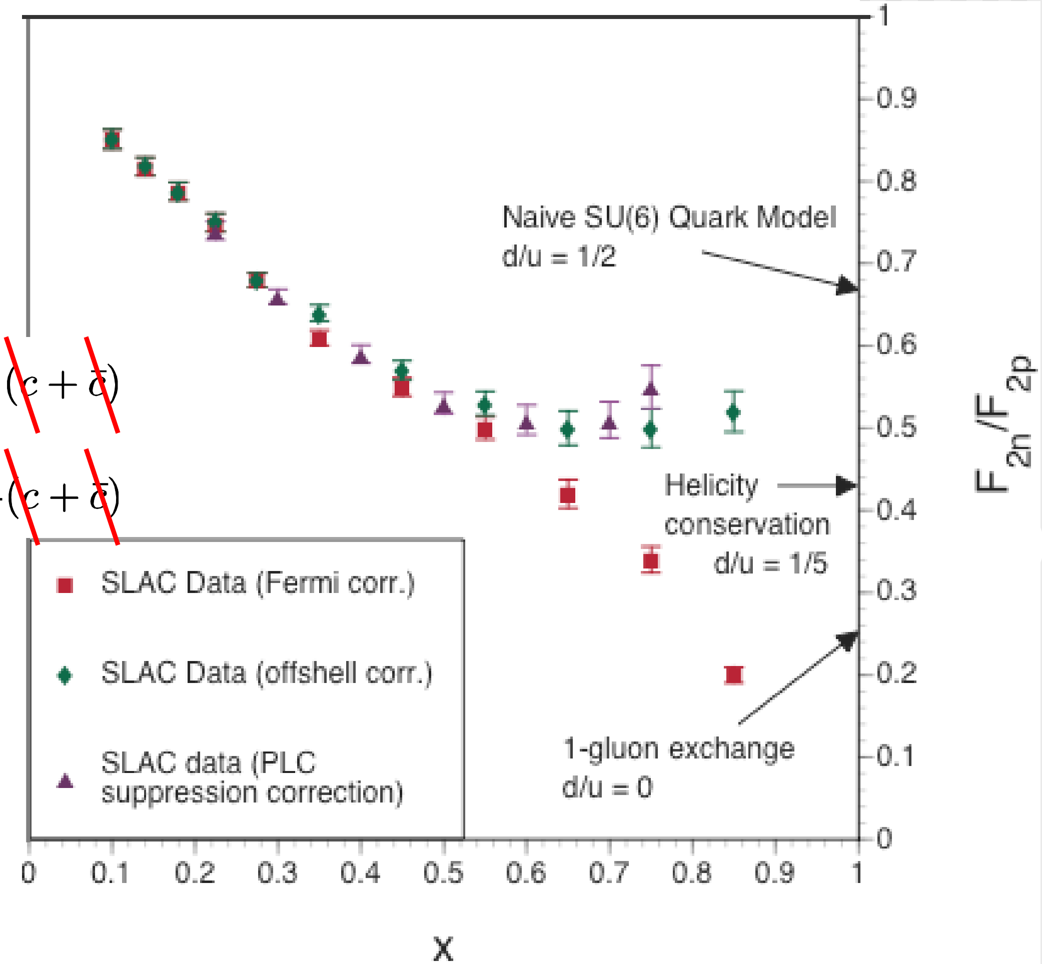
- Deuterium Target
  - A/D ratio with CC-DIS events from neutrino ME beam
  - A/D ratio with CC-DIS events from anti-neutrino ME beam
  - Measurement of charge symmetry violation with CC-DIS from neutrino and anti-neutrino ME beam.
  - …

- How about Hydrogen?

Extraction of d/u at x→1

$$F_{2p}/x = \frac{4}{9}(u + \cancel{\bar{u}}) + \frac{1}{9}(d + \cancel{\bar{d}}) + \frac{1}{9}(\cancel{s} + \cancel{\bar{s}}) + \frac{4}{9}(\cancel{c} + \cancel{\bar{c}})$$

$$F_{2n}/x = \frac{4}{9}(d + \cancel{\bar{d}}) + \frac{1}{9}(u + \cancel{\bar{u}}) + \frac{1}{9}(\cancel{s} + \cancel{\bar{s}}) + \frac{4}{9}(\cancel{c} + \cancel{\bar{c}})$$



The nuclear corrections may shift d/u at x→1 from 0 to 0.5.

List of Experiments to Measure d/u

Electromagnetic Interactions:

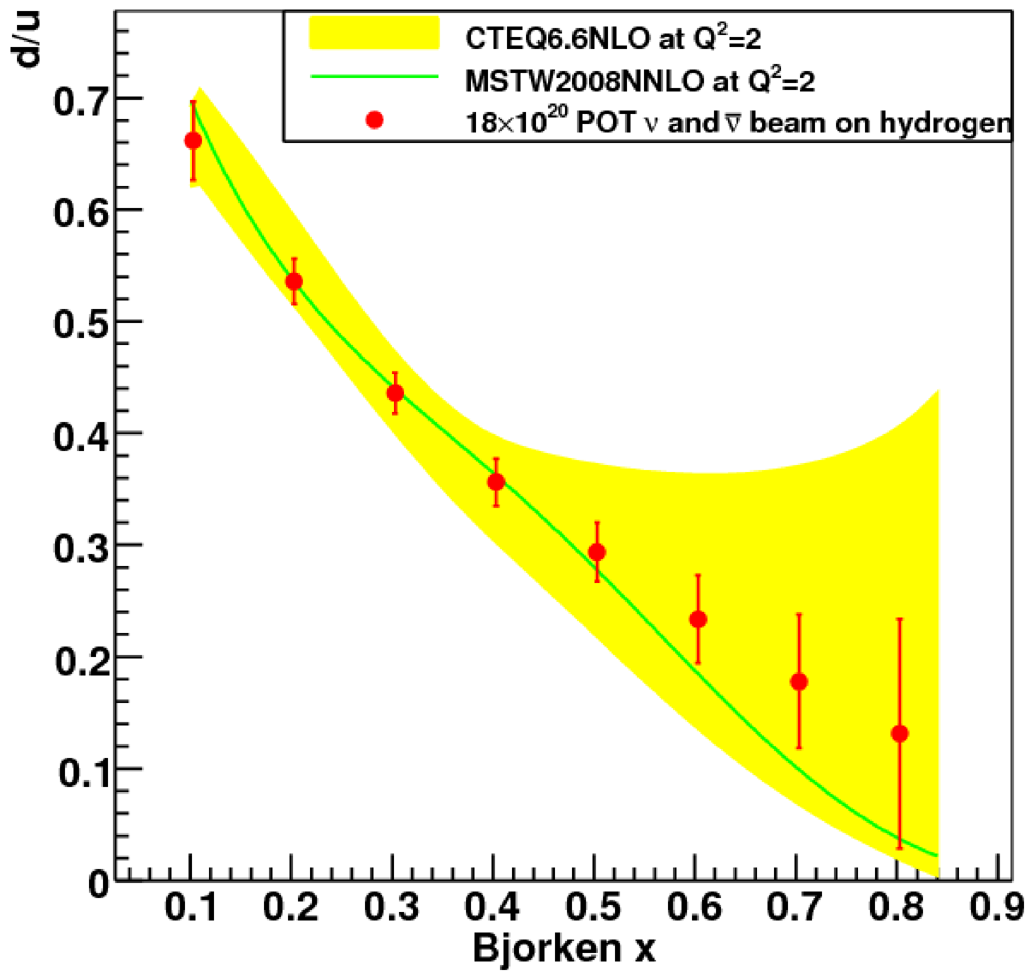
- DIS with electron beam at Jlab with minimized nuclear corrections.
  - Low momentum spectator tagging d(e,e'ps)X: BONUS 6 GeV (2011) and 12 GeV
  - A=3 mirror targets--Helium/Tritium: MARATHON at 12 GeV

Weak Interactions:

- Parity Violating DIS with Jlab 12 GeV upgrade on proton target
- W+/W- (l+/l-) asymmetry with proton and anti-proton collision at Fermilab
  - CDF experiment (2009)
  - D0 experiment
- DIS with neutrino and anti-neutrino beam on proton target
  - Bubble chamber experiment WA21 at CERN (1989)
  - CDHS with a tank of hydrogen at CERN (1984)

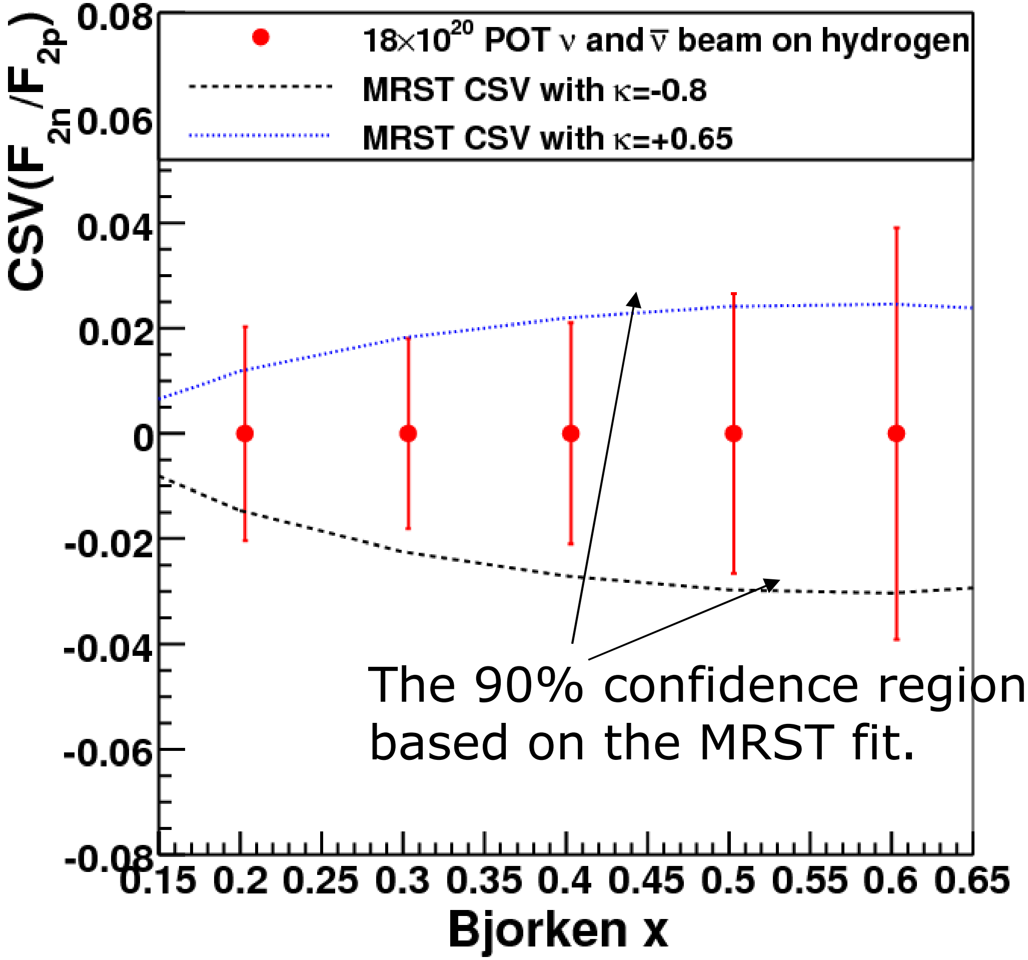
There are quite a few experiments and proposals to measure this most fundamental PDF ratio.

The Projected d/u Measurement



The uncertainties are estimated for MINERνA accepted CC-DIS events including the empty target running.

CSV Measurement with Hydrogen



From charged lepton data:

$[F_{2n}/F_{2p}]_{D/p} = (\sigma_d - \sigma_p)/\sigma_p$

$= (4u_n+d_n)/(4u_p+d_p)$

From neutrino data on hydrogen assuming charge symmetry:

$[F_{2n}/F_{2p}]_p = (4d_p+u_p)/(4u_p+d_p)$

The comparison of the neutrino proton data and charged lepton d/p data can measure CSV.

Summary

- The high intensity neutrino and anti-neutrino beam from NuMI facility at Fermilab makes it possible to perform a statistically significant experiment on the light target.
- The measurement of the A/D ratio is very important for us to be able to include a large amount of nuclear neutrino data into the global fit of PDFs, providing the power of flavor decomposition.
- The deuterium data can be also used to measure the charge symmetry violation, which might be a possible explanation for NuTeV anomaly in the Weinberg angle.
- The challenge to use deuterium is the safety measures to handle the flammable liquid/gas as well as the availability of deuterium at low cost.
- It is technically straightforward to switch from deuterium to hydrogen. The neutrino and anti-neutrino data on hydrogen target can be used to constrain the PDFs (d/u) at high x as well as charge symmetry violation. But the sensitivity at $x \rightarrow 1$ is limited with ME beam.