NuSOnG

- Neutrinos
- Scattering
- On
- Glass

Let’s consider each of these (though not in this order)…
NuSOnG

- Neutrinos
- Scattering
- On
- Glass
Obtaining a neutrino beam

We need a beam of high-energy muon-neutrinos. There’s only one place to get such a beam: the Tevatron at Fermilab.
Protons $\rightarrow$ Neutrinos

From Tevatron
800-GeV Protons

BeO target

particle shower
$(\pi^0, \pi^\pm, K^0, K^\pm, p, \bar{p}, n, \bar{n}, e^-, e^+, \gamma, \text{etc.})$

series of magnets to focus only the particles with the charge we want

$\pi^+, K^+$

Decay Region

give the pions and kaons a chance to decay into neutrinos

Shielding (earth, steel, …)

only the neutrinos pass through the shielding; everything else is stopped

$\pi^+ \rightarrow \mu^+ + \nu_\mu$ (99.99% of the time)

$K^+ \rightarrow \mu^+ + \nu_\mu$ (63.4%)

$\rightarrow \pi^0 + e^+ + \nu_e$ (4.9%; "$K_{e3}^+$")

$\rightarrow \pi^0 + \mu^+ + \nu_\mu$ (3.3%; "$K_{\mu3}^+$")
The $\nu$ beam flux

From my Ph.D. thesis (CCFR 1996; data taken in 1987). In that experiment, we had a combined beam: neutrino (green points) and anti-neutrino (magenta points).
NuSOnG

• Neutrinos
• Scattering
• On
• Glass
The NuSOnG Detector

Total mass of glass targets (green) = 3000 tons

- **v beam**: (to reject $v$ interactions in the material in front of the detector)
- **veto wall**: (to reject $v$ interactions in the material in front of the detector)
- **helium bag**: (decay region for exotic particle searches)
- **Target height and width = 5 meters**

200 meters (about the length of two [American] football fields)

- **a sub-detector module**: (see next slide)
A sub-detector

**Target calorimeter:**
624 layers of inch-thick glass and proportional tubes (in blue); measures shower energy and muon angle (separated into carts for handling)

**Muon spectrometer:**
magnetized steel toroids (in red) ➔ solenoidal field, interspersed with five drift chamber stations (in yellow) to track the muon; measures muon energy

Orthogonal view

~30 meters

~9 meters

Hadron catcher
A typical event: $\nu_\mu$ charged-current deep-inelastic scattering

$\nu_\mu \rightarrow \mu^- \Rightarrow \theta_\mu, E_\mu$

The weak interaction is weak. You have to throw $\sim 10^{12}$ protons at the beam target to see one $\nu$ event in the detector.

The proton (with 3? quarks) undergoes deep-inelastic scattering, producing a muon track and a hadron shower.

The hadron shower energy is $E_H$, the muon angle is $\theta_\mu$, and the muon energy is $E_\mu$. The muon track bends in the magnetic field.
Simulated event: green=neutral particles, red=negatively-charged particles, blue=positively-charged particles.

Process=91, run=0, event=8
Incoming: PDG=14, energy=446276 MeV
vertex=(0.019122,0.0213528,404.54) cm
# primaries=14, total particles=2342
Emu=318897 MeV, theta=18.1429 mr, Etot-Emu=127379 MeV
EmuFF=306724 MeV, theta=18.3256 mr
NuSOnG

• Neutrinos
• Scattering
• On
• Glass
Neutrino-quark scattering

charged-current DIS
charge is exchanged
“deep inelastic scattering”

\[
\begin{align*}
\nu_\mu & \rightarrow \mu^- \\
W^+ & \rightarrow q \rightarrow q'
\end{align*}
\]

\[
\begin{align*}
\bar{\nu}_\mu & \rightarrow \mu^+ \\
W^- & \rightarrow q \rightarrow q'
\end{align*}
\]

What we see:
hadron shower
muon

neutral-current DIS

\[
\begin{align*}
\nu_\mu & \rightarrow \nu_\mu \\
Z^0 & \rightarrow q \rightarrow q
\end{align*}
\]

\[
\begin{align*}
\bar{\nu}_\mu & \rightarrow \nu_\mu \\
Z^0 & \rightarrow q \rightarrow q
\end{align*}
\]

What we see:
hadron shower

Also: elastic, quasi-elastic, and resonance scattering (e.g., just one pion is produced).
**Neutrino-electron scattering**

inverse muon decay
"IMD"

What we see:

\[ \nu_{\mu} \rightarrow \mu^{-} + W^{+} + \nu_{\mu} + \ell^- + \nu_{\ell} \]

Reminder: regular muon decay is

\[ \mu^{-} \rightarrow e^{-} + \nu_{e} + \nu_{\mu} \]

neutral-current electron scattering (ES)

What we see:

\[ e^{-} + \nu_{e} + \nu_{\mu} \]

no positrons in the detector

e-m shower
(shorter than hadron shower with the same energy)
All right, but what do you do with these events?

Quite a lot!
As many NuSOnG thesis topics as I can type in 5 minutes…

1. The weak mixing angle measure from neutrino-electron scattering
2. The weak mixing angle measured from neutrino-quark scattering
3. New physics limits probed through coupling to the Z
4. New physics limits from the inverse muon decay cross section
5. Cross section measurement of neutrino and antineutrino electron scattering
6. A search for $N \rightarrow \mu\nu\nu$ decay in the 5 GeV mass range
7. Searches for light mass neutrinoinos
8. numu disappearance at very high Dm2
9. A search for evidence of nonunitarity of the 3 neutrino matrix
10. A search for neutral heavy leptons in the 5 GeV mass range
11. Constraints on muonic photons
12. Measurement of the CCQE cross section at high energy
13. Measurement of the NCπ0 cross section at high energy
14. A study of the transition from single pion to DIS production at high energy
15. Measurement of $F_2$ and $xF_3$ at very high statistics
16. Comparisons of $F_2$ on nuclear targets from low to high $x$
17. High precision measurement of $R$ from neutrino scattering
18. Extraction of the strange and charm seas from $xF_3$
19. Charm production in the emulsion target and a measure of $B_c$
20. Measurement of the strange sea and $\Delta s$ from dimuon production
21. Measurement of the charm sea from wrong-sign single muon production
22. Search for evidence of anomalously large isospin violation

“I” = Janet Conrad, 2007

… Way more than I can cover here!
Another way to look at these topics

Deep-Inelastic Neutrino Scattering
An Overview of Topics

William Seligman, 1997
I’ve picked two to discuss:

• $\sin^2 \theta_W$
  – This is the “signature” measurement of the experiment; the primary reason it is being proposed.

• Proton structure functions
  – The topic of my doctoral thesis, and my main interest in the experiment.
\[ \sin^2 \theta_W \] What is it?

- The “Weinberg angle” (OK, it’s the square of the sine of the Weinberg angle. Happy now?)

- Parameter in the Standard Model of electroweak interactions.

- Related to the difference in masses between the \( Z^0 \) and \( W^\pm \) bosons.

- Also related to the probability a neutrino will interact in a charged-current or neutral-current interaction:

\[
\begin{align*}
\nu_\mu & \rightarrow \mu^- \\
q & \rightarrow W^+ q'
\end{align*}
\]
\[
\begin{align*}
\nu_\mu & \rightarrow \nu_\mu \\
q & \rightarrow Z^0 q
\end{align*}
\]
How do you measure $\sin^2 \theta_W$?

In a neutrino experiment like NuSOnG, there are two ways:

**electron scattering**

“purely leptonic”

\[
\begin{align*}
\nu_\mu & \to \nu_\mu \\
& \quad \downarrow Z^0 \\
& \quad \quad e \to e \\
\nu_\mu & \to \mu^- \\
& \quad \downarrow W^+ \\
& \quad \quad e \to \nu_e
\end{align*}
\]

used by CHARM

(CHARM = glass detector, lower energy than NuSOnG)

**quark scattering;**

“Paschos-Wolfenstein”

\[
\begin{align*}
\nu_\mu & \to \nu_\mu \\
& \quad \downarrow Z^0 \\
& \quad \quad q \to q \\
\nu_\mu & \to \bar{\nu}_\mu \\
& \quad \downarrow Z^0 \\
& \quad \quad q \to q
\end{align*}
\]

\[
\begin{align*}
\nu_\mu & \to \mu^- \\
& \quad \downarrow W^+ \\
& \quad \quad q \to q'
\end{align*}
\]

\[
\begin{align*}
\bar{\nu}_\mu & \to \mu^+ \\
& \quad \downarrow W^- \\
& \quad \quad q' \to q
\end{align*}
\]

used by NuTeV and CHARM

(NuTeV = iron detector, same energy as NuSOnG)

If you can, always measure ratios instead of absolute values. A ratio can cancel out systematic errors.
The status of $\sin^2 \theta_W$ from past neutrino experiments:

- Neutrino-electron scattering
- Neutrino-quark scattering

All high statistics experiments show the same trend
What is “The Standard Model”? It is the extracted value from the precise LEP measurements.

The highest precision neutrino experiment, led by Mike Shaevitz.

This is $3\sigma$ off.

Emlyn’s past experiment, polarized electron scattering

New physics affects each experiment differently through the radiative corrections.

Janet Conrad, 2007
What’s a “radiative correction”?

Take the following interaction as an example. You want to calculate the probability (cross-section) for this interaction using quantum mechanics.

Then you’ll have to include the effects on the cross-section of diagrams that look like the ones below (and many other diagrams as well).

Here, $f$ is any particle that couples to the $Z^0$, and $g$ is any particle that couples to the $f$. When you do your cross-section calculation, you include all the $f$'s and $g$'s that you know about. If you measure the cross-section, and it differs from your calculation, then the reason might be that there are particles involved that you don’t know about!

Since all these particles are virtual, their masses can be large. In fact, for this particular interaction, they can go up to $\sim5$ TeV and still affect the cross-section for neutrino-electron scattering.
Why did NuTeV’s $\sin^2 \theta_w$ have a $3\sigma$ difference from the Standard-Model value? Some possibilities:

• It was a statistical fluctuation.
• There was a mistake in the NuTeV analysis.
  – The NuTeV data was taken in 1996, and has been analyzed and re-analyzed several times; another re-analysis is still going on. So far, their value of $\sin^2 \theta_w$ has not changed significantly.
• It could be a sign of new physics. Some explanations include:
  – Special features in proton structure functions (next topic)
  – ~100 GeV neutral heavy leptons (“neutralissimos”)
How to resolve this? Take more data! NuSOnG will have higher statistics than any similar previous experiments.

<table>
<thead>
<tr>
<th>Process</th>
<th>Rate</th>
<th>Physics</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\nu_\mu + e^- \rightarrow \mu^- + \nu_e$ [IMD]</td>
<td>700k</td>
<td>“WSIMD”, non-standard interactions</td>
</tr>
<tr>
<td>$\nu_\mu + e^- \rightarrow \nu_\mu + e^-$ [ES]</td>
<td>75k</td>
<td>new “heavy” physics (Z’, $\nu$ mixing with heavy singlets),</td>
</tr>
<tr>
<td></td>
<td></td>
<td>new “light” physics, modified couplings, $\sin^2 \theta_w$, $\rho$, R-parity,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>extended Higgs</td>
</tr>
<tr>
<td>$\nu_\mu + q \rightarrow \nu_\mu + X$ [DIS]</td>
<td>190M</td>
<td>$\nu$-$q$ non-standard interactions, $\sin^2 \theta_w$, $\Delta x F_3$, $x F_2$, isospin violation</td>
</tr>
<tr>
<td>$\overline{\nu}<em>\mu + q \rightarrow \overline{\nu}</em>\mu + X$</td>
<td>33M</td>
<td></td>
</tr>
<tr>
<td>$\nu_\mu + q \rightarrow \mu^- + X$</td>
<td>600M</td>
<td></td>
</tr>
<tr>
<td>$\overline{\nu}_\mu + q \rightarrow \mu^+ + X$</td>
<td>12M</td>
<td></td>
</tr>
<tr>
<td>low-density decay regions</td>
<td>60</td>
<td>new long-lived heavy neutral particles</td>
</tr>
</tbody>
</table>

Rates assume $1.5 \times 10^{20}$ POT (“protons on target”) in neutrino mode; $0.5 \times 10^{20}$ POT in anti-neutrino mode (5 total years of running). The higher statistics come from improved Tevatron luminosity, longer running, and increased detector tonnage.
\[ \sin^2 \theta_W \] and NuSOnG

• NuSOnG will measure \( \sin^2 \theta_W \) to a greater precision than any previous neutrino experiment.

• If the NuTeV measurement difference was a statistical fluctuation, NuSOnG will show it.

• If the NuTeV measurement difference was because neutrino -electron interactions “see” a different \( \sin^2 \theta_W \) than neutrino -quark interactions, NuSOnG will detect it.

• There are other possibilities in electroweak physics that I did not discuss. There’s a great potential for discovery in this measurement.

• In particular, the “scale” of the new physics reaches the 5 TeV energy range. NuSOnG complements the LHC in energy scale and physics!
Proton structure functions

To begin, consider a neutrino (anti-neutrino) charged-current DIS event

\[ \nu_\mu \left( \bar{\nu}_\mu \right) \rightarrow W^+ \left( W^- \right) \]

\[ \mu^- \left( \mu^+ \right) \Rightarrow \theta_\mu, E_\mu \]

proton
(with 3? quarks)

Remember, \( \theta_\mu, E_\mu, \) and \( E_H \) are all quantities that we measure in our detector.
Kinematic variables

The standard variables associated with a DIS event are \( x, y, \) and \( Q^2 \).

If a proton has momentum \( P \), an individual quark has momentum \( xP \); \( x \) is the fractional momentum of the struck quark.

\[ Q^2 \sim \text{the energy transferred from the neutrino to the quark. (If the boson has 4-momentum } q \text{, then } Q^2 = -q^2. \]

\( y \approx \text{the “inelasticity” of the collision; what fraction of the neutrino energy is used to “break up” the proton.} \)

(“Feymann } x \text{” and “Feymann } y \text{” are sometimes used to distinguish from geometric } x \text{ and } y \text{.)} \)
The connection

It’s just arithmetic to go from one set of variables to the other.

\[ \nu_\mu \left( \bar{\nu}_\mu \right) \quad \Rightarrow \quad \mu^- \left( \mu^+ \right) \]

\[ W^+ \left( W^- \right) \]

\[ q \quad q' \]

\[ E_\nu = E_H + E_\mu = \text{neutrino energy} \]

\[ Q^2 = 4 E_\nu E_\mu \sin^2 \left( \frac{\theta_\mu}{2} \right) \]

\[ x = \frac{Q^2}{2 M_P E_\nu} \quad (M_P = \text{mass of proton}) \]

\[ y = \frac{E_H}{E_\nu} \]
The main structure-function equation

Suppose you have lots of CC DIS events (say 600 million of them). How many events do you expect to see as a function of \( x \) and \( Q^2 \)?

Assume you know a lot about quantum mechanics and electroweak interactions. Then this turns out to be the equation:

\[
N^{\nu,\bar{\nu}}(x, Q^2) \propto \int dE \Phi^{\nu,\bar{\nu}}(E) \times
\left[
\left(1 - y - \frac{Mxy}{2E} + \frac{y^2}{2} \frac{1 + 4M^2x^2/Q^2}{1 + R(x, Q^2)}\right)F_2(x, Q^2) \pm y\left(1 - \frac{y}{2}\right)xF_3(x, Q^2)\right]
\]

where \( N^{\nu,\bar{\nu}} \) is the number of neutrino (anti-neutrino) events
\( \Phi^{\nu,\bar{\nu}}(E) \) is the neutrino (anti-neutrino) flux
\( E = E_{\nu} \) is the neutrino energy
\( M = M_P \) is the mass of the proton
The main structure-function equation

Suppose you have lots of CC DIS events (say 600 million of them). How many events do you expect to see as a function of $x$ and $Q^2$?

Assume you know a lot about quantum mechanics and electroweak interactions. Then this turns out to be the equation:

$$N^{\nu,\bar{\nu}}(x,Q^2) \propto \int dE \Phi^{\nu,\bar{\nu}}(E) \times$$

$$\left[\left(1 - y - \frac{Mxy}{2E} + \frac{y^2}{2} \frac{1 + 4M^2x^2/Q^2}{1 + R(x,Q^2)}\right)F_2(x,Q^2) \pm y\left(1 - \frac{y}{2}\right)xF_3(x,Q^2)\right]$$

where $N^{\nu,\bar{\nu}}$ is the number of neutrino (anti-neutrino) events

$\Phi^{\nu,\bar{\nu}}(E)$ is the neutrino (anti-neutrino) flux

$E = E_\nu$ is the neutrino energy

$M = M_p$ is the mass of the proton

DON’T PANIC!
Why you shouldn’t panic

The equation is just math, and you know most of the terms already. \(x, y, Q^2, \text{ and } E\) come from the events; \(M\) you look up in a physics textbook.

You count \(N\), the number of events at a given \(x\) and \(Q^2\). (The flux \(\Phi\) is another story, but I won’t burden you with it in this talk.)

\[
N^{\nu,\overline{\nu}}(x,Q^2) \propto \int dE \Phi^{\nu,\overline{\nu}}(E) \times \\
\left(1 - y - \frac{Mxy}{2E} + \frac{y^2}{2} \left(1 + \frac{4M^2x^2/Q^2}{1 + R(x,Q^2)}\right)\right) F_2(x,Q^2) \pm y \left(1 - \frac{y}{2}\right) x F_3(x,Q^2)
\]

You can calculate or measure these terms; no reason to panic.

Honesty compels me to include this warning: I’m glossing over details to reduce your panic. There are many corrections that must be applied (e.g., detector resolution) in order to use this equation.
The structure functions

\( xF_3, F_2, \) and \( R \) are the “structure functions.” They represent the (for the moment) unknown whatever-it-is that the neutrinos are scattering off of.

At this point in our story, the structure functions (SFs) may be different for neutrinos and anti-neutrinos.

\[
N^{\nu, \bar{\nu}}(x, Q^2) \propto \int dE \Phi^{\nu, \bar{\nu}}(E) \times \left[ \left( 1 - y - \frac{M_{xy}}{2E} \right) + \frac{y^2}{2} \frac{1 + 4 \frac{M^2x^2}{Q^2}}{1 + R(x, Q^2)} \right] F_2(x, Q^2) \pm y \left( 1 - \frac{y}{2} \right) xF_3(x, Q^2)
\]

**The structure functions**

You get the values of the SFs by counting the numbers of events in \( x, y, Q^2, \) and \( E, \) then fitting for the SFs in the above equation.

\( xF_3 \) is unique to neutrino scattering. You also get \( R \) and \( F_2 \) in electron- and muon-scattering experiments, but only neutrinos “see” \( xF_3. \)
What do the structure functions mean?

Up until now, I haven’t mentioned the quark model in connection with the SFs. If we assume the “whatever-it-is” in our target is a proton with quarks, we can interpret what the structure functions mean.

\[
N^{\nu,\bar{\nu}}(x,Q^2) \propto \int dE \Phi^{\nu,\bar{\nu}}(E) \times
\left[
\left(1 - y - \frac{M_{xy}}{2E} + \frac{y^2}{2}\right) \frac{1 + 4M^2x^2/Q^2}{1 + R(x,Q^2)} \right] F_2(x,Q^2) \pm \left(1 - \frac{y}{2}\right) xF_3(x,Q^2)
\]

You start with these \(y\)-coefficients, figure out that \(y \sim \cos\theta_{cm}\), and think about quark and neutrino spins. I’ll spare you the derivation, and just show you the results…
The SFs are related to the quark distributions

\[ xF_3(x) = xq(x) - x\bar{q}(x) = xu_{\text{VAL}}(x) + xd_{\text{VAL}}(x) \]

\[ F_2(x) = xq(x) + x\bar{q}(x) = xq_{\text{VAL}}(x) + xq_{\text{SEA}}(x) \]

\[ R = \sigma_L / \sigma_T \]

“\( xq(x) \)” is the probability that a quark of that type has fractional momentum \( x \) inside a proton. It’s an example of a “parton distribution function” or PDF (nope, nothing to do with Adobe Postscript files).

\( \sigma_L \) and \( \sigma_T \) are (respectively) the cross-section for interacting with a longitudinally- or transversely-polarized boson (either a \( W^\pm \) or a \( Z^0 \) [or a photon in electron- and muon-proton scattering]).
At low $Q^2$, you just see a proton.

At $Q^2 \sim 1 \text{ GeV}^2$, you see signs of quarks; the two up and a down are the “valence” quarks.

At higher $Q^2$, you see additional quark/anti-quark pairs from the gluons; this is the quark “sea.”
Sample Plots

\[ x F_3 = x u_{VAL} + x d_{VAL} \]

\[ F_2 = x q_{VAL} + x q_{SEA} \]
Fun with structure functions

\[ F_2 = xq_{VAL} + xq_{SEA} \]
\[ xF_3 = xu_{VAL} + xd_{VAL} = xq_{VAL} \]
\[ \Rightarrow \]
\[ F_2 - xF_3 = xq_{SEA} \]

and since the sea comes from the gluons,

\[ xq_{SEA} \Rightarrow xG(x), \text{ the gluon distribution in the proton} \]

Honesty compels me to include this warning: I'm glossing over many details (higher-order corrections in the quark model, for example). The “structure-function arithmetic” I’ve presented in this talk is nowhere near this simple!
More fun with structure functions

According to theory, \( R^\nu = R^{\bar{\nu}} \) and \( F_2^\nu = F_2^{\bar{\nu}} \).

But \( xF_3^\nu \neq xF_3^{\bar{\nu}} \):

\[
xF_3 = xu_{VAL} + xd_{VAL} = \left( xF_3^\nu + xF_3^{\bar{\nu}} \right) / 2
\]

\[
xF_3^\nu = xu_{VAL} + xd_{VAL} + 2xs - 2xc
\]

\[
xF_3^{\bar{\nu}} = xu_{VAL} + xd_{VAL} - 2xs + 2xc
\]

\[
xF_3^\nu - xF_3^{\bar{\nu}} \equiv \Delta xF_3 = 4x(s - c)
\]

So \( \Delta xF_3 \) is one method of understanding the strange sea in the proton. (We’ll see another method on the next slide.)
Opposite-sign dimuons \(\rightarrow\) strange sea

The probability of a dimuon event depends on \(s(x)\), the strange sea (and the anti-strange sea for anti-neutrino events).

\[
\nu_\mu \left(\overline{\nu}_\mu\right) \quad \mu^- (\mu^+) \\
W^+ (W^-) \\
s \text{ (or } d) \quad c \\
D\text{-meson} \quad E_H
\]

*What we see:*
- hadron shower
- two muons of opposite sign
Wrong-sign muons may tell us about the charm sea

This has never been reliably observed in neutrino scattering before, but we’ve never had these statistics before.

\[ \nu_\mu \left( \overline{\nu}_\mu \right) \rightarrow Z^0 \rightarrow c \bar{c} \]

\[ \nu_\mu \left( \overline{\nu}_\mu \right) \rightarrow \mu^+ \left( \mu^- \right) \]

What we see:

- hadron shower
- muon with the wrong sign for the neutrino beam

D-meson
SFs in NuSOnG

I’ve mentioned six structure functions:

\[ R^\nu, R^{\bar{\nu}}, F_2^\nu, F_2^{\bar{\nu}}, xF_3^\nu, xF_3^{\bar{\nu}} \]

• NuSOnG will be the first high-energy neutrino experiment with enough statistics to measure these six structure functions independently.\(^\S\)
  • Other experiments have had to make some assumptions or rely on other experiments for one or more of the above SFs to extract the others.
• From these SFs, we get \( xq_{\text{val}}(x), xq_{\text{sea}}(x), xG(x), xs(x), \) and \( xc(x) \) (maybe).
• We can use both dimuon events and \( \Delta xF_3 \) to give us two independent measurements of the strange distribution \( xs(x) \) in the proton.
• We’ll be able to test whether anti-neutrinos “see” a different \( R \) and \( F_2 \) than neutrinos. (If they do, that’s new physics!)

But wait… there’s more!

\(^\S\) This statement has not yet been demonstrated. That’s what I’m working on right now.
Remember $\sin^2 \theta_W$?

Two proposed reasons out of the many possibilities for why $\sin^2 \theta_W$ from NuTeV differs from the Standard Model:

\[ x_s(x) \neq \bar{x}s(x) \]

“Strange sea asymmetry.” If this is the reason, NuSOng will have the precision to see it.

Actually, this asymmetry has already been measured by NuTeV and it looks too small to be responsible for this effect. But NuSOng will make a much more precise measurement of the s and s-bar seas; who knows?

\[ xu^p (x) \neq xd^n (x) \]

Our target is 50% neutrons. To get proton structure functions, we assumed perfect “isospin symmetry,” which means that you can turn a proton into a neutron by swapping the up quarks with the down quarks. If isospin asymmetry is the reason, NuSOng will see it in the difference between the strange distribution $xs(x)$ from dimuon events and $\Delta xF_3$. 
Why I think structure functions are interesting

• They are input to the cross-section calculations used in many experiments, including those at the LHC.

• They are a measurement of something that, as yet, cannot be calculated.
NuSOnG

- Neutrinos
- Scattering
- On
- Glass
When will NuSOnG turn on?

• The NuSOnG collaboration is still in the process of investigating the physics potential of the experiment and designing the detector and beamline.

• We have not yet made a formal proposal to Fermilab.
  – We’ve submitted an “Expression of Interest,” we’re writing a “Letter of Interest,” and we’ve published an article on NuSOnG’s physics potential in *Phys.Rev.D* (and we’ll write at least two more).
  – The approval process is a long one!

• Assuming that everything goes perfectly at this point and with the least possible delay, we’d build the detector and start taking data by 2016.
  – …and then the data analysis wouldn’t start until two years later, with at least three more years of data-taking to follow.

*In the meantime, remember…*
If you want to hear the music of the proton…

“With a good luck charm like you”

“The charm about you, will carry me through”

“Ain’t never gonna give you up”

“Get up, stand up. Don’t give up the fight!”

“Get up, stand up. Stand up for your rights!”

“London Bridge is falling down”

“Strange things are happening”

“People are strange when you’re a stranger”

“Gonna lay down my sword and shield…”

“…down by the riverside”

“When people are the glue”

“Up a lazy river with me”

…you want to listen to NuSOnG

Playing all the quarks, all the time!