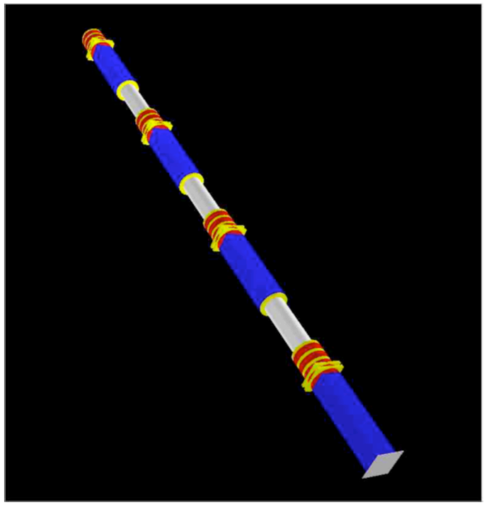
NuSOnG:
Neutrino Scattering on Glass



Janet Conrad, Peter Fisher
Autumn 2007 PAC Meeting
Nov 2, 2007

EOI Authors

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9 Universities • 2 Undergraduate Colleges • 2 National Labs

Outline:

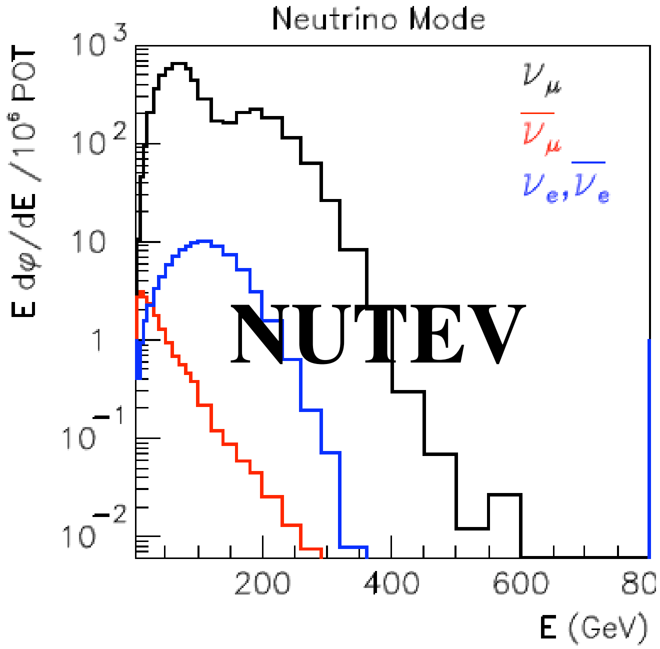
Janet:

1. Intro
2. Physics Opportunities

Peter:

1. Design
2. Future Plans

A high-statistics, high energy neutrino experiment…



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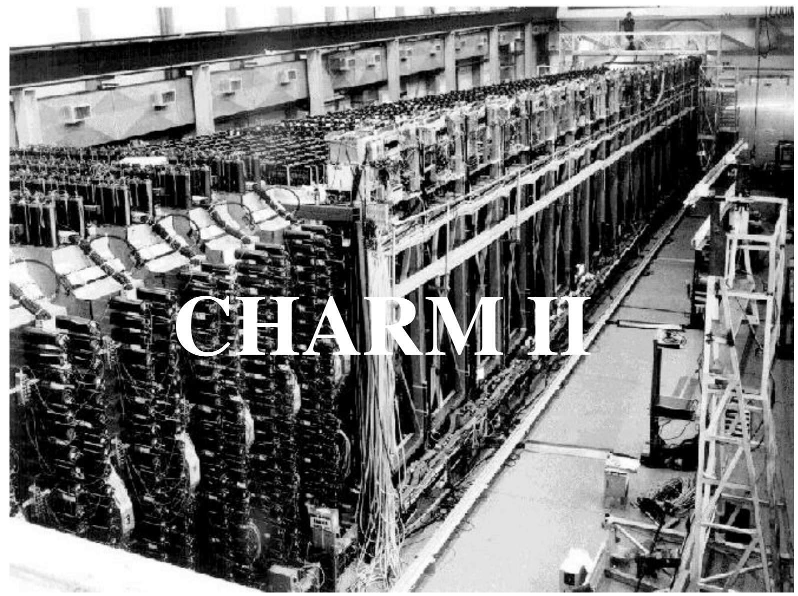


High energy,
very pure beam
(×20 POT)

Fine-grained,
massive detector
(×6 mass)

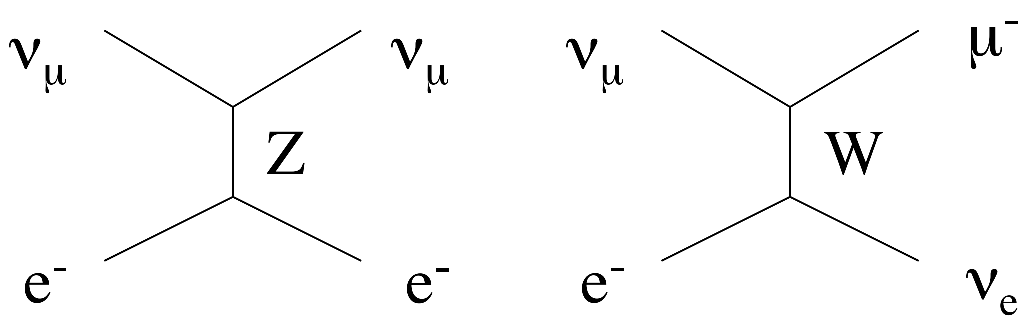
We are in the process of exploring the best run-plan

Physics in this talk assumes 1.5E20 POT in ν , 0.5E20 POT in $\bar{\nu}$

Very high statistics!

600M	ν_μ CC Deep Inelastic Scattering
190M	ν_μ NC Deep Inelastic Scattering
75k	ν_μ electron NC elastic scatters
700k	ν_μ electron CC quasielastic scatters (IMD)
33M	$\bar{\nu}_\mu$ CC Deep Inelastic Scattering
12M	$\bar{\nu}_\mu$ NC Deep Inelastic Scattering
7k	$\bar{\nu}_\mu$ electron NC elastic scatters
0k	$\bar{\nu}_\mu$ electron CC quasielastic scatters

A unique opportunity for these channels!



As many 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**
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Physics Opportunities

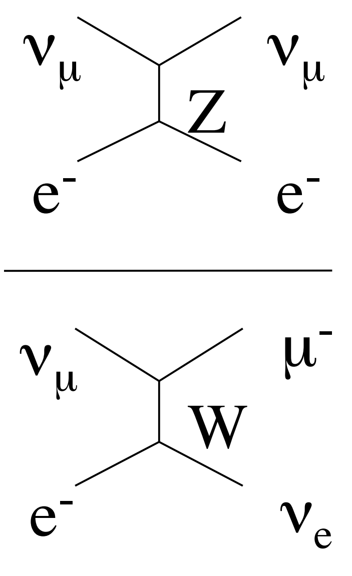
Only a few highlights from three main categories…

1. Indirect Searches for New Physics
2. Direct Searches
3. Parton Distribution Studies

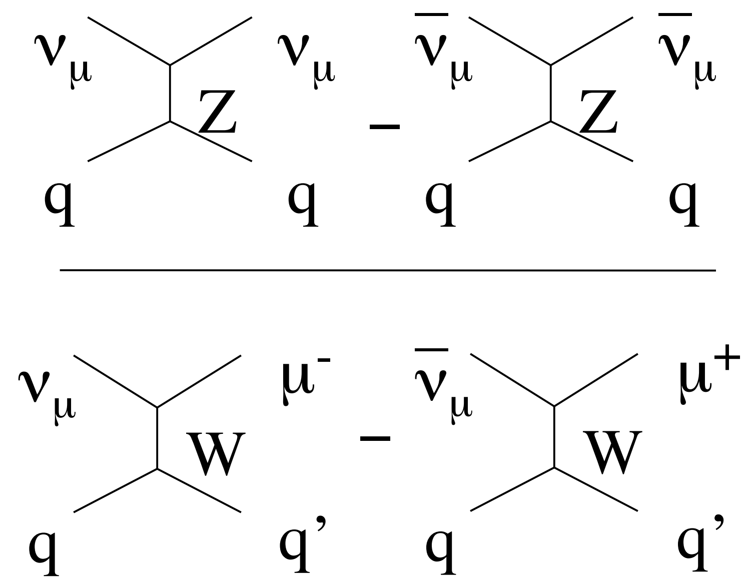
Indirect Searches:
Physics reach of 5.6TeV!

NuSOnG will work with ratios....

New!

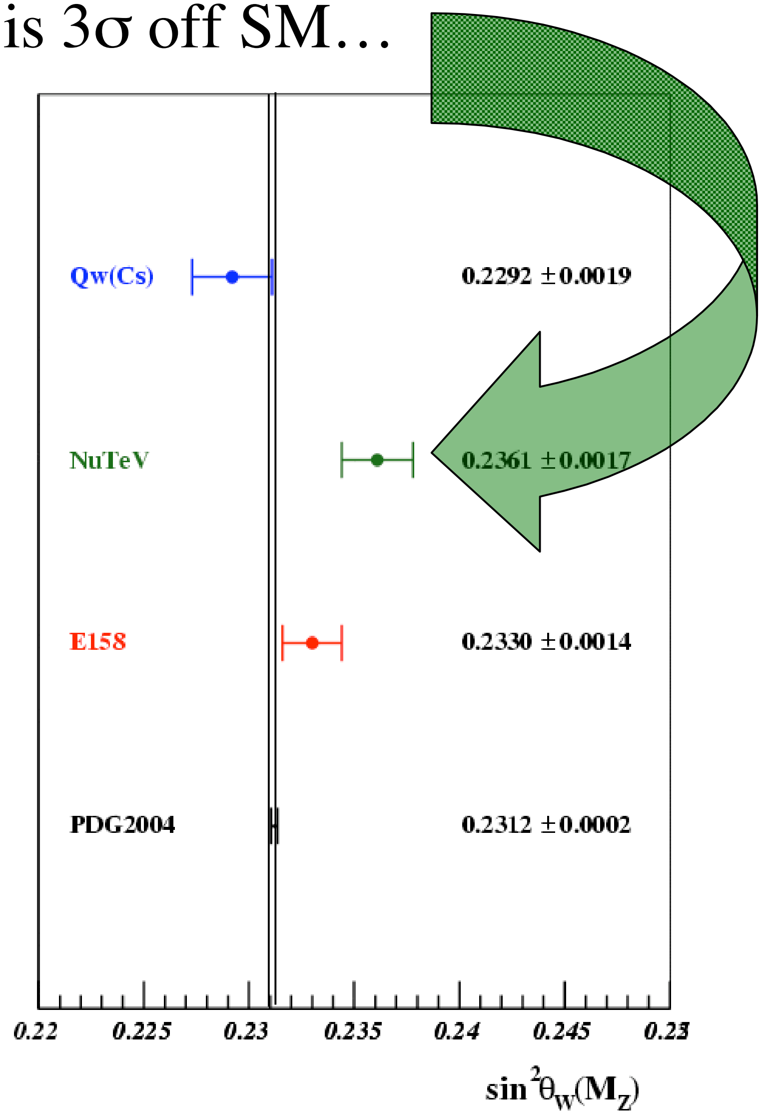


Purely leptonic

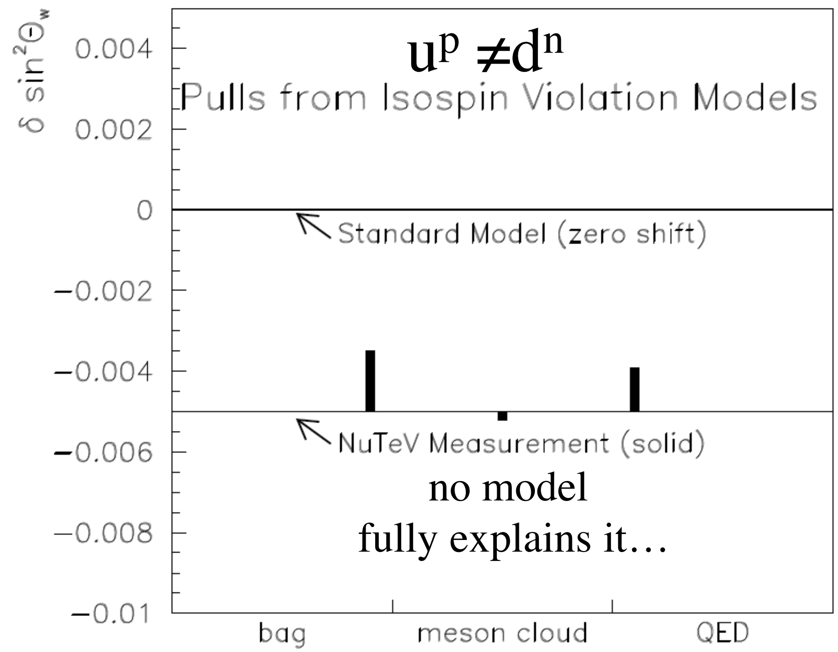


NuTeV-style
“Paschos-Wolfenstein”

NuTeV:
νq scattering (“PW”)
is 3σ off SM…



New Physics
or
“Standard Model”?



no model
fully explains it…

Constrain nuclear isospin violation
through QCD measurements
(specifically: $\Delta xF_3 = xF_3^{\nu} - xF_3^{\bar{\nu}}$)

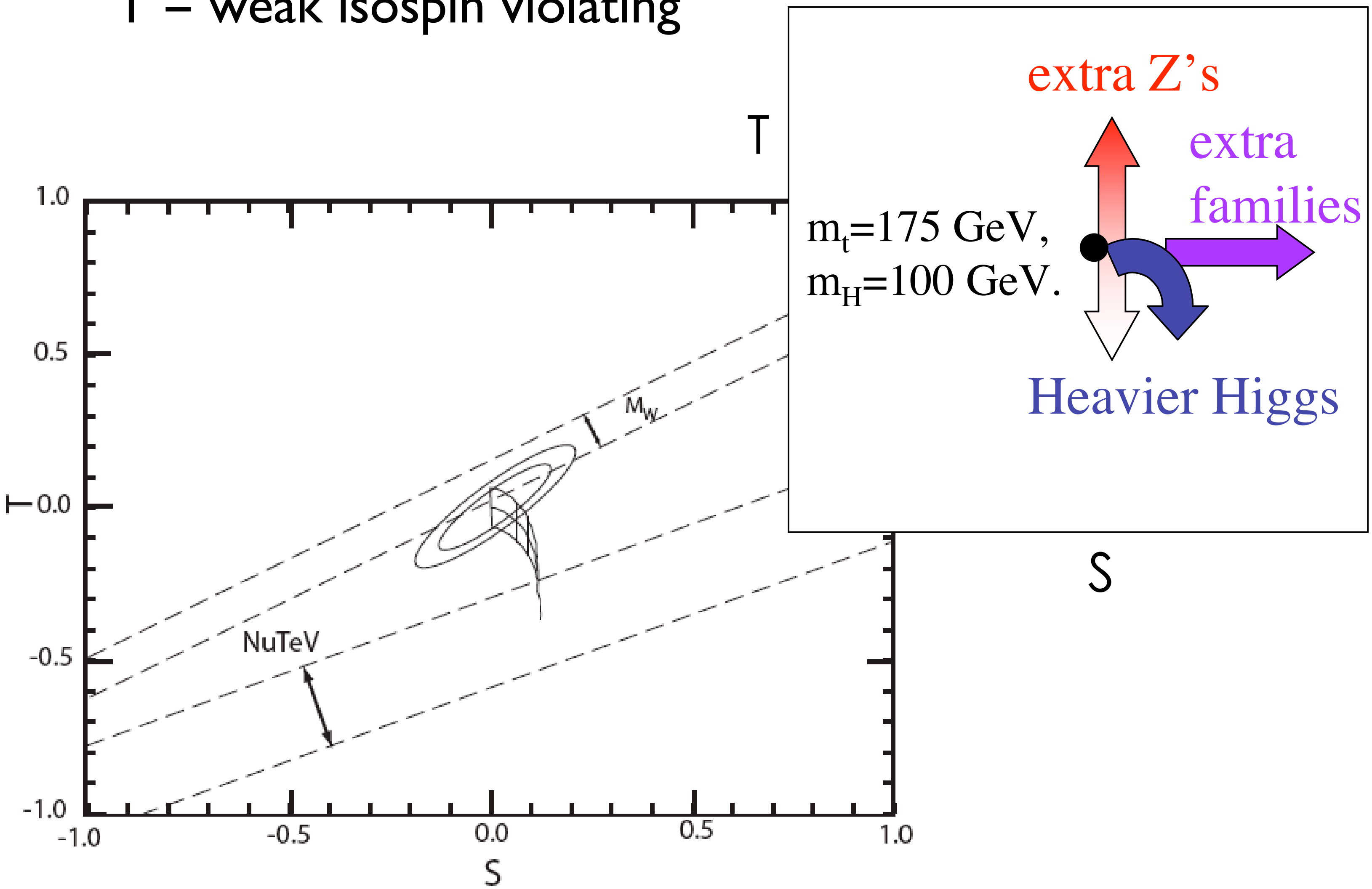
NEW!

Take $\sin^2\theta_W$ and ρ and map them to

S = weak isospin conserving

T = weak isospin violating

very roughly:



Our Expression of Interest provides
a general discussion
of the physics value of this measurement,

both on its own
and within the context of LHC

NEW

Here we show specific models
on how NuSOnG complements LHC
in the case of new physics.

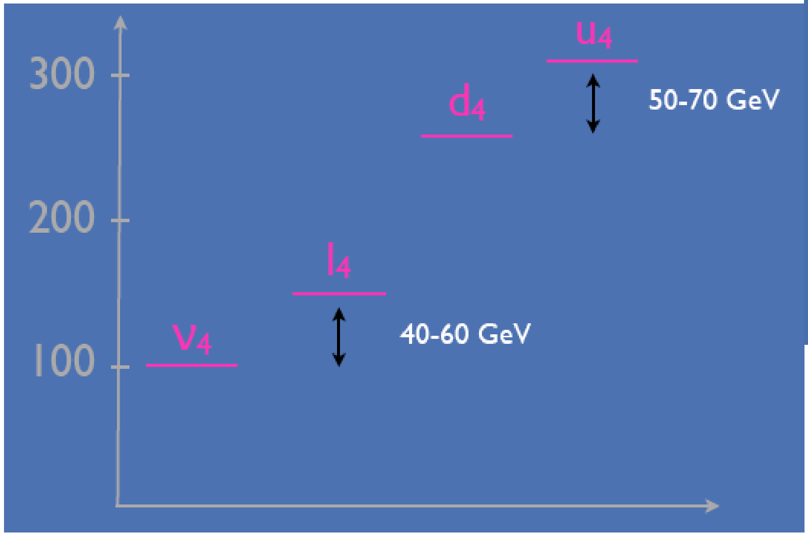
NEW

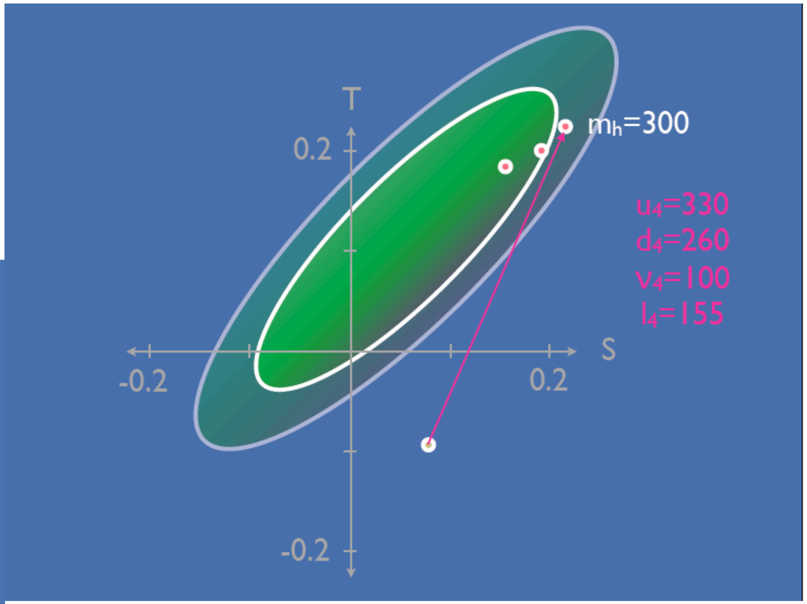
A Chiral 4th Generation Model

see, e.g., Kribs, Plehn, Spannowsky and Tait,hep-ph/0706.3718

Degenerate-mass families are highly constrained.
Families with isospin violation are not!

- Quark mixings < 0.01
- A heavy ν_4 appears which can be dark matter (a "neutrissimo")





•The Higgs can be ~300 GeV

LHC:

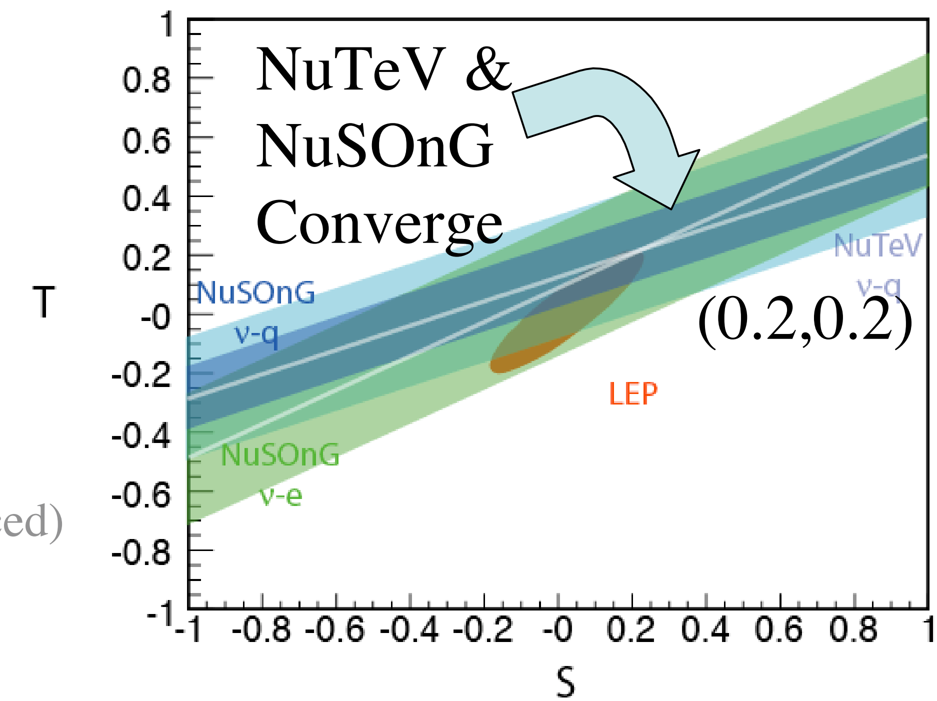
- Highly enhanced H →ZZ
- The Higgs mass,
  lets say 300 GeV
- complex decay modes
  (e.g. 6W's and 2 b's)

And what it doesn't…

- Measure mass of new quarks
- Observe new charged leptons
  (off mass shell Drell-Yan produced)
- Reconstruct the decay modes fully

NuSOnG:

Large isospin violation is measured via ΔxF3, allowing NuTeV to be corrected



A Chiral 4th generation (ΔS=0.2)
with isospin violation (ΔT=0.2)

A Z' Model (B-3L$_\mu$)

for Z' models see, e.g., Carena, Daleo, Dobrescu and Tait, hep-ph/0408098

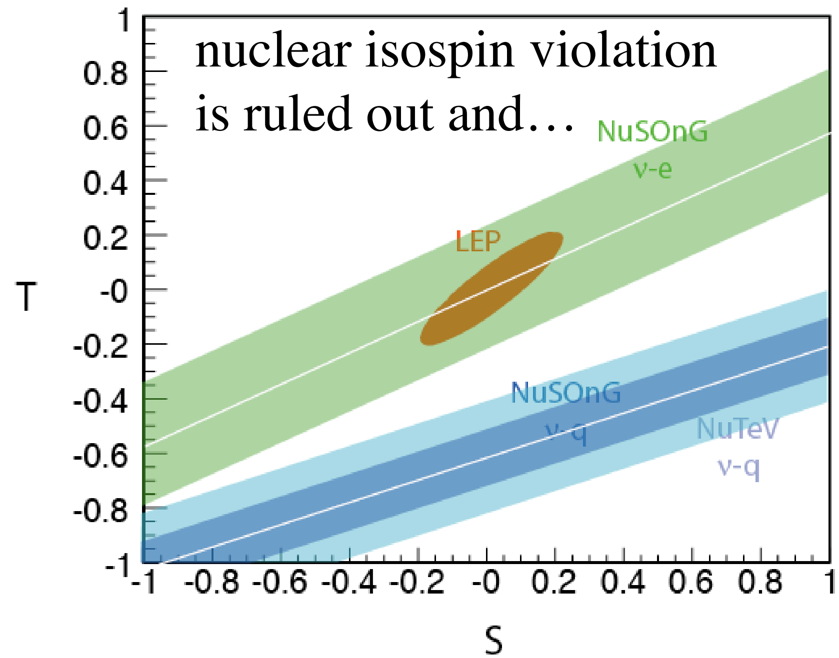
LHC:

- Z' →μμ -- clearly!
- The mass (lets say 3 TeV)
- Missing Z' →ee
- Z' →tt
- Z' →ττ difficult!

...A 3 TeV Z'
with B-3L$_\mu$ coupling

(hep-ph/9903362; 0209316)

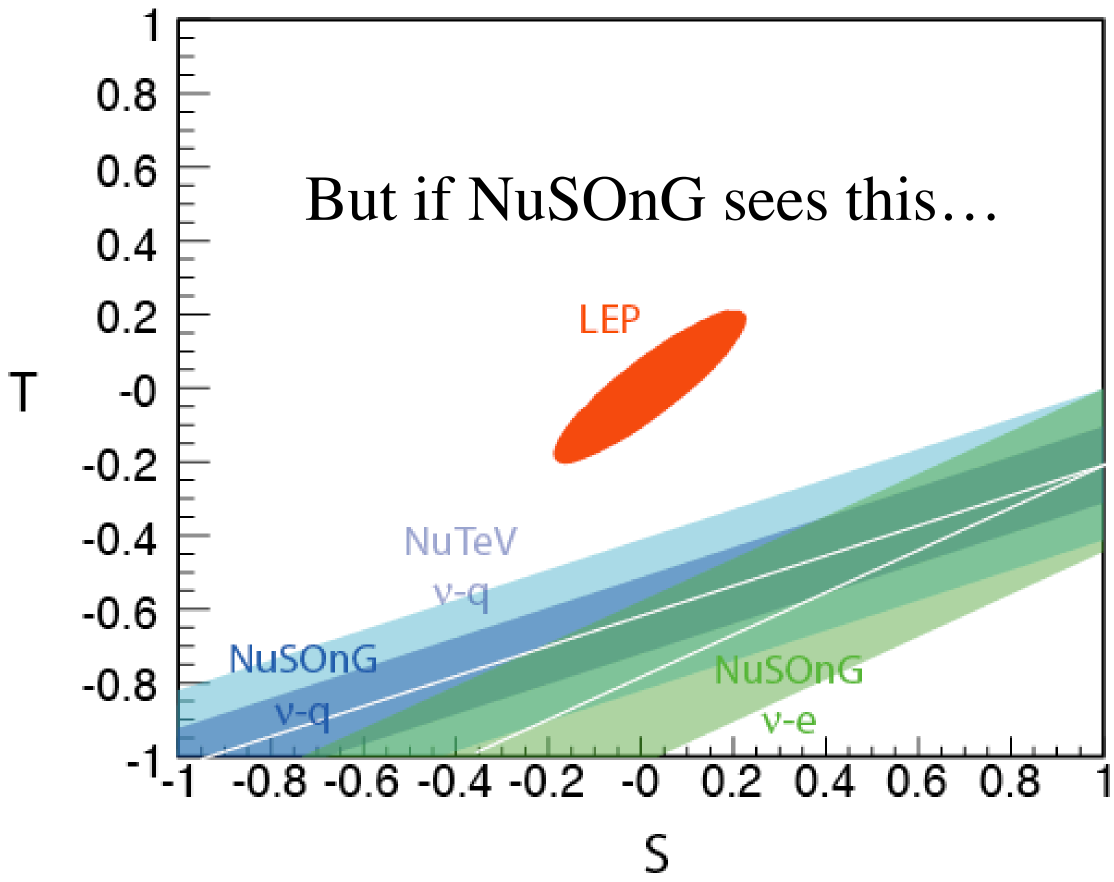
NuSOnG:



- Measure Coupling to light quarks & ν_μ.
- No coupling to e

The "God-forbid" Scenario

LHC sees a standard model Higgs and no signs of new physics



There is new physics in the neutrino sector!

Direct Tests for New Physics
e.g. "Matrix Freedom"

Nonunitarity of the 3 neutrino mixing matrix

$$\sum_j |U_{\alpha j}|^2 = 1 - X_\alpha,$$

hep-ph/0705.0107

$$P_{\alpha\alpha}^{general} = P_{\alpha\alpha}^{unitary} - 2X_\alpha[1 - 2|U_{\alpha 3}|^2 \sin^2 \Delta_{31}] + X_\alpha^2.$$

L/E dependent

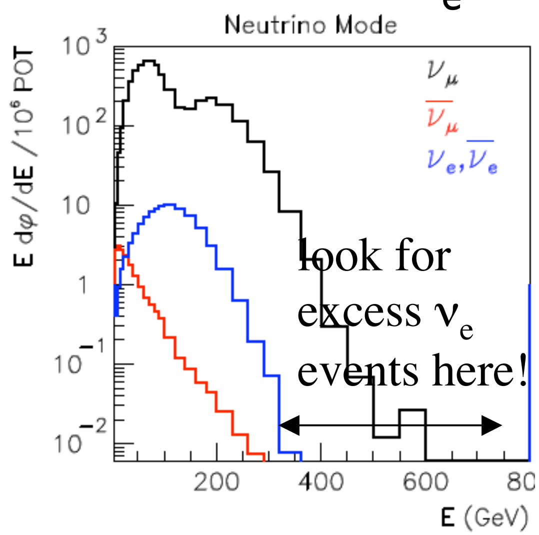
Not!

Appearance has same effect!

At L=0 there will be an instantaneous transition between neutrino species!

Strongest constraints (from rare decays) for instantaneous $\nu_\mu \rightarrow \nu_e$ are at the 1×10^{-4} level

- Look for excess ν_e's in a range not expected



Instantaneous $\nu_\mu \to \nu_e$ at the 1×10^{-4} level gives an ~10% increase in ν_e rate at E_ν~350 GeV

Seeing both would be a striking signature!

- Look for “wrong sign” IMD

$\bar\nu_\mu + e^- \to \mu^- + \bar\nu_e$ -- this should not occur!

But if $\bar\nu_\mu \to \bar\nu_e$, then $\bar\nu_e + e^- \to \mu^- + \bar\nu_\mu$ … same signature!

improve the present limit by a factor of 10, and reach few × 10^{-4} level

Unique Capability!

QCD Studies
e.g. xF_3

- $F_2^{\nu(\overline{\nu})}(x,Q^2) = \Sigma \left[xq^{\nu(\overline{\nu})} + x\overline{q}^{\nu(\overline{\nu})} + 2xk^{\nu(\overline{\nu})} \right]$
- $xF_3^{\nu(\overline{\nu})}(x,Q^2) = \Sigma \left[xq^{\nu(\overline{\nu})} - x\overline{q}^{\nu(\overline{\nu})} \right]$

- xF_3 uniquely determined by νDIS
- Sensitive to valence quarks
- Nonsinglet QCD evolution (theoretically robust)
- $\Delta xF3 = xF_3^{\nu} - xF_3^{\overline{\nu}}$ can be used to constrain isospin violation (1st opportunity!)
- Test if ν, $\overline{\nu}$ nuclear effects are the same.

NuSOnG will have SiO_2, C, Al, Fe and Pb targets,
Kinematic range matches eRHIC and complements Minerva

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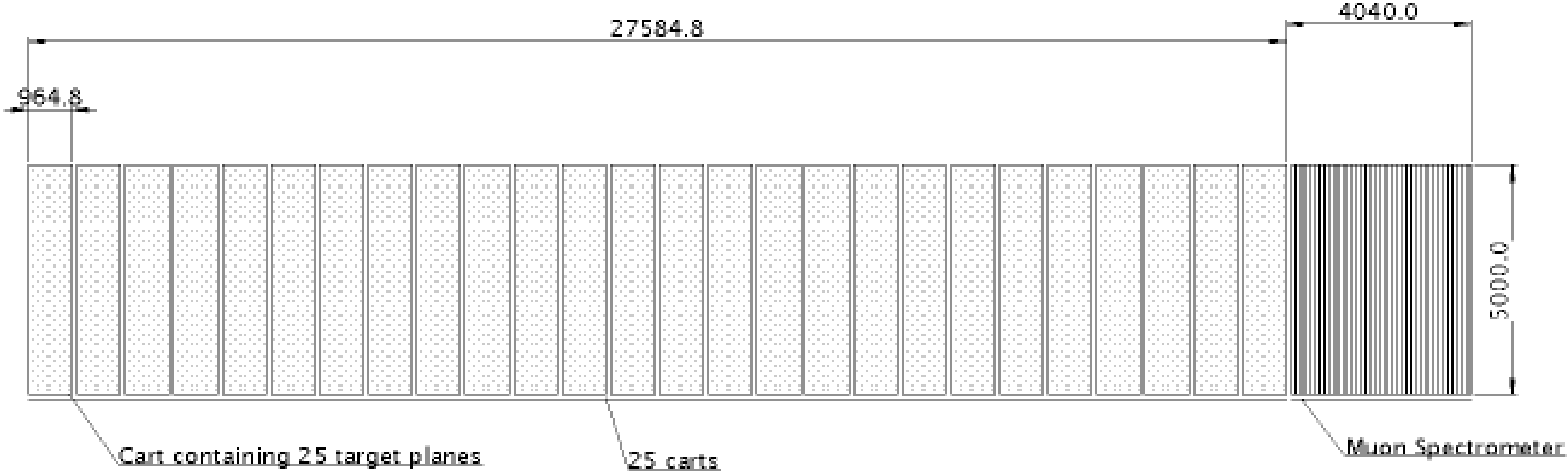
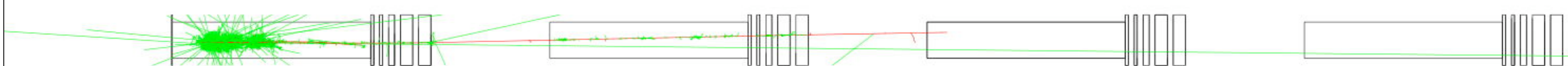
This is a very physics-rich experiment!

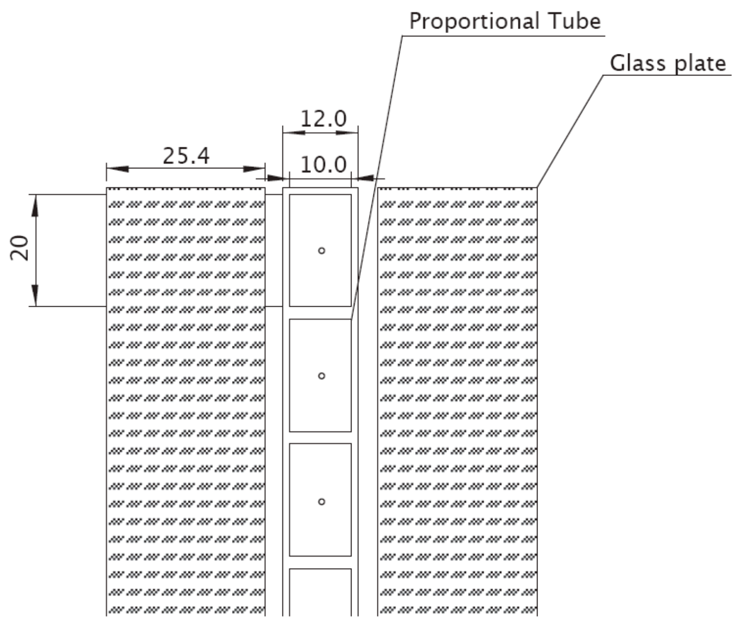
Our detector design draws on the heritage of FMMF, CDHS, CHARM, CCFR and NuTeV.
NuSOnG combines and advances the best ideas of these experiments:

1. High granularity, Xo/4
2. Simple, robust, design
3. Isoscalar target
4. Modularity: active elements could be fabricated at universities for assembly at Fermilab
5. Low risk: well known elements that can be engineered for cost
6. High luminosity, high energy


27584.8
4040.0
964.8
5000.0
Cart containing 25 target planes
25 carts
Muon Spectrometer

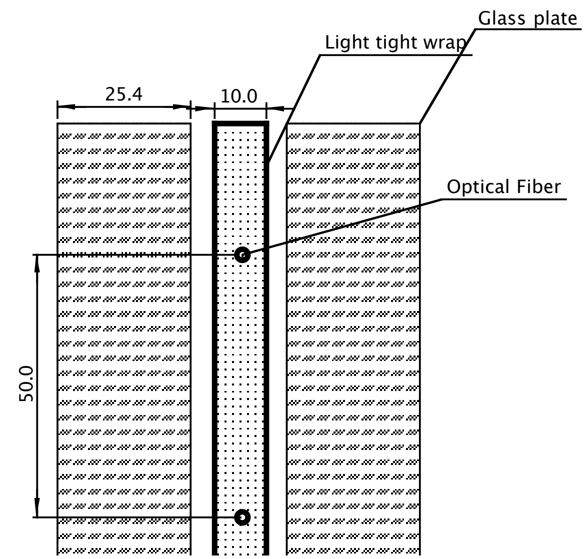


Parameter	Value
Total target mass	3.49 kt
Fiducial mass	2.97 kt
Total length	192 m
Number glass planes	2500
Proportional counter planes	2000
Scintillator planes	500
Toroid washers	96
Drift planes	60



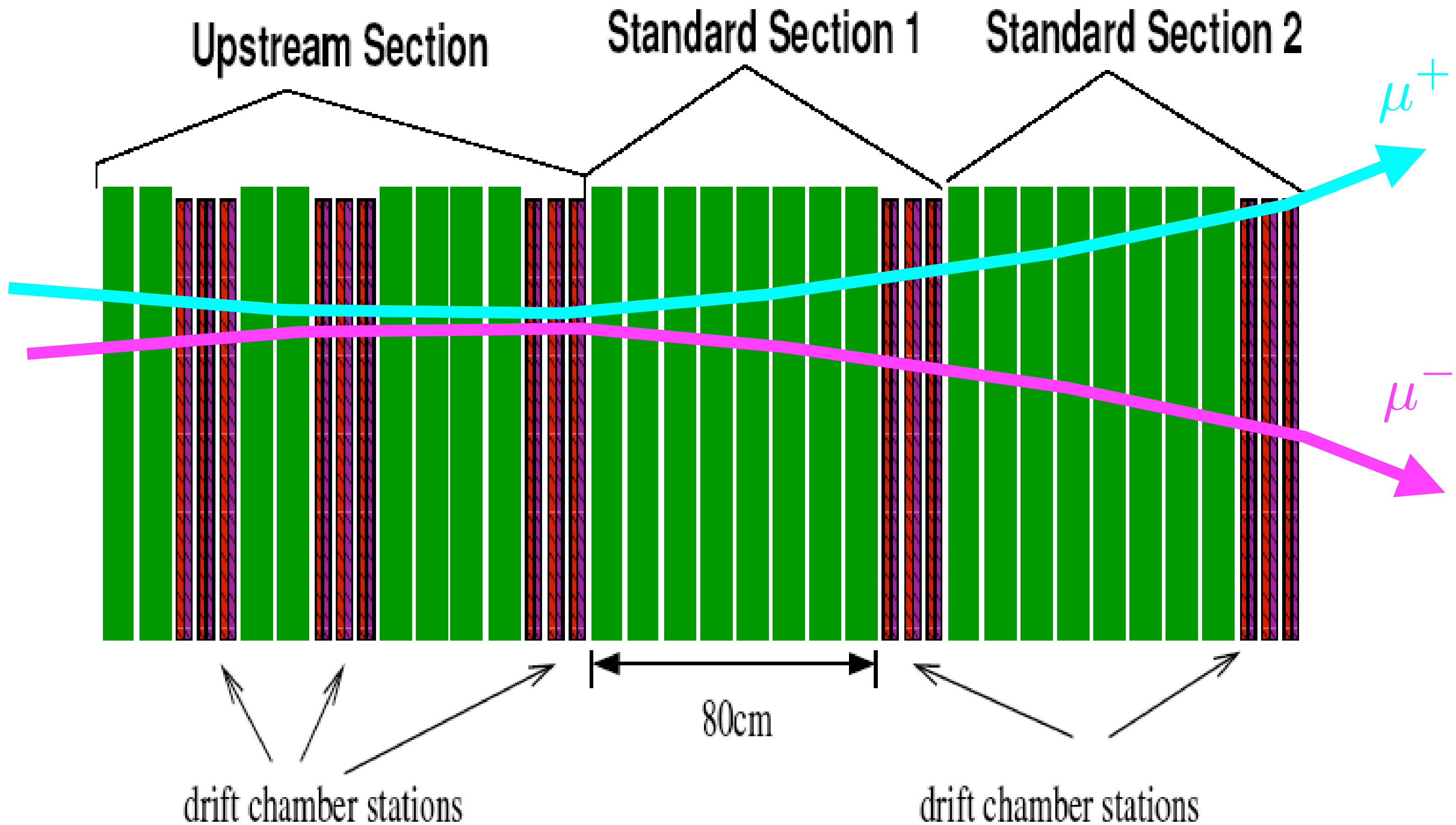
Proportional tubes

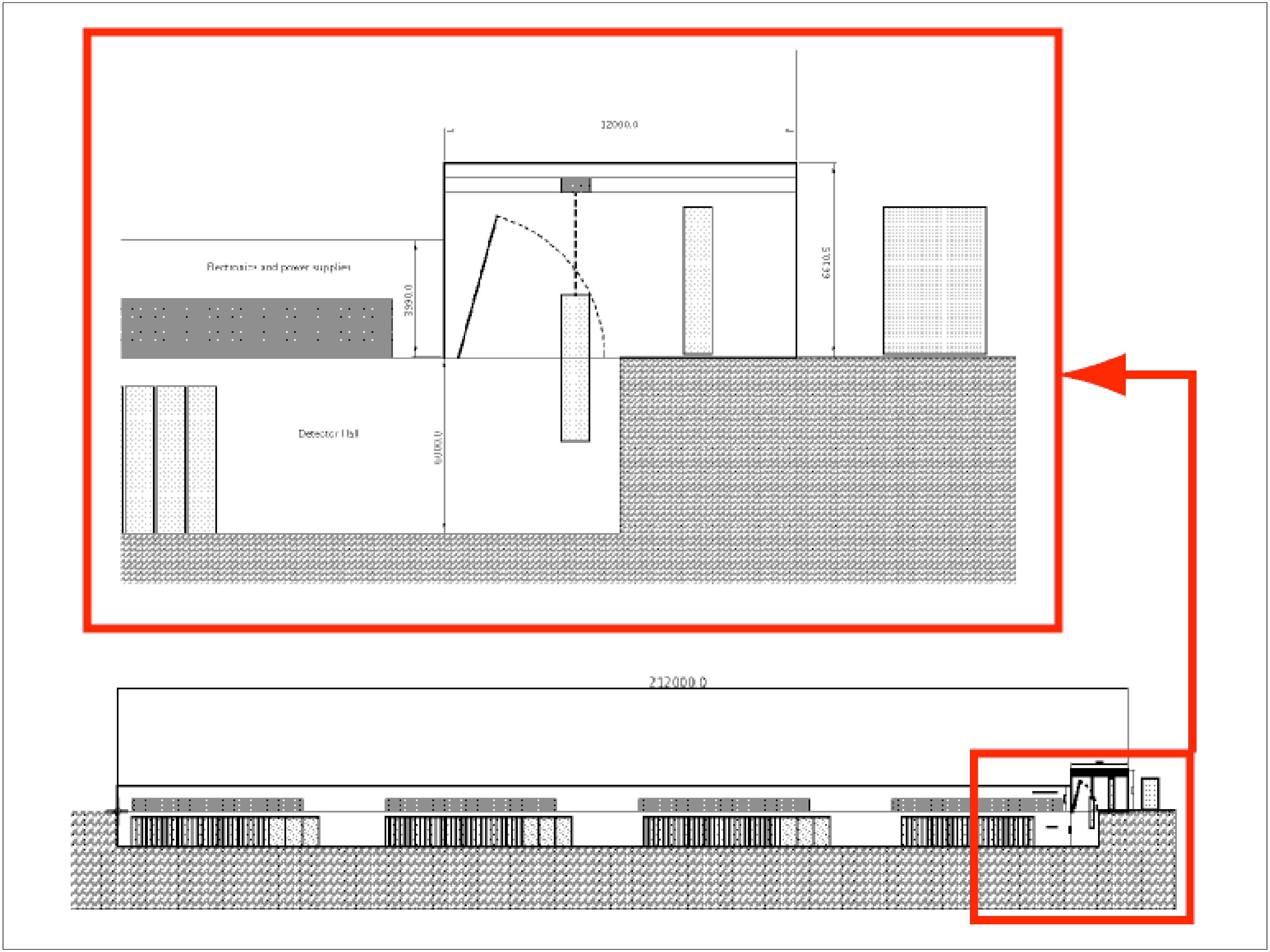
ArCo2 (80:20)
Gain of 3000 gives 52 fC
250 tubes per plane
500k-1000k total channels



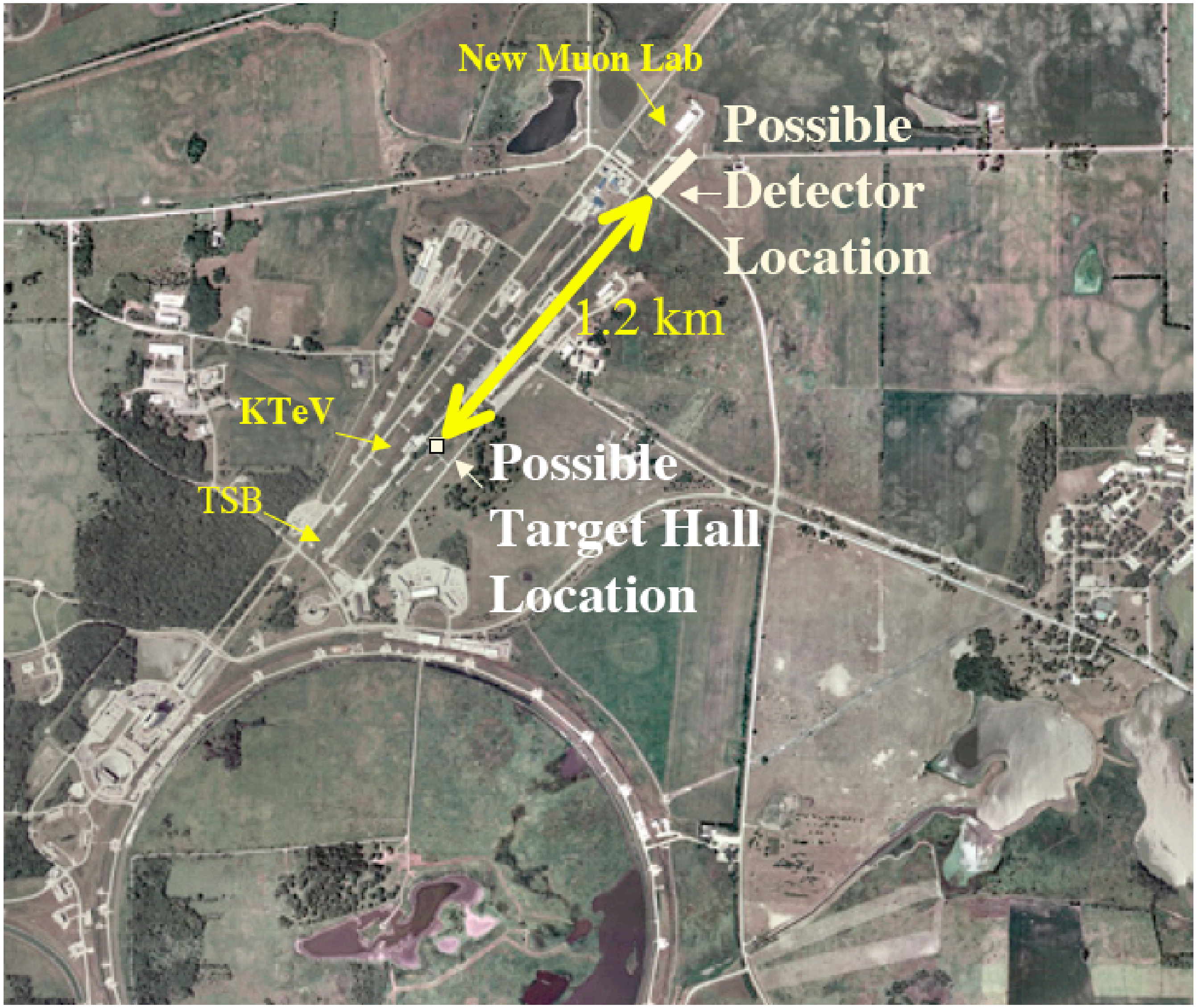
Scintillator planes

18k photons
100 fibers per plane
50k-100k total channels


Upstream Section
Standard Section 1
Standard Section 2
μ^+
μ^-
80cm
drift chamber stations
drift chamber stations



12000.0
Electronics and power supplies
6610.5
Detector Hall
212000.0


New Muon Lab
Possible
Detector
Location
1.2 km
KTeV
TSB
Possible
Target Hall
Location

Key Issues for study in the next few months

- Optimize granularity for good signal efficiency, low background vs. channel count
- Optimize ratio of proportional tubes (good spatial resolution) vs. scintillator (good energy resolution, timing)
- Flux determination using inverse muon decays
- Ability to detect Michel electrons
- Calibration beam requirements
- Shielding and veto requirements
- Cost and schedule

Some Development Projects are just starting

1. Stack of five 1” glass planes with active detectors for cosmic ray studies (Columbia/MIT)
2. Instrumenting the glass targets (Columbia)
3. Liquid scintillator with glass beads to provide high density, isoscalar target - Northwestern
4. Measurement of neutrino cross sections on glass with Minerva
5. Alternatives to toroidal focussing

NuSOnG will provide new measurements in three areas: electroweak measurements of neutrino neutral current couplings, sensitive searches for new neutrino properties and high precision studies of quarks inside the nucleus. The experiment itself is simple, robust and could draw in a large university based community. NuSOnG places modest demands on protons from the accelerator complex and, in return, will provide a very broad physics program.

Backup

What is nuclear isospin violation?

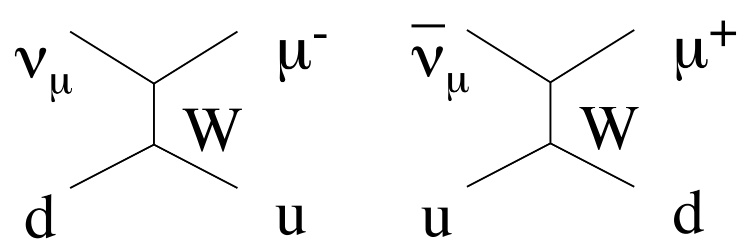
$$\delta u_v(x,Q^2) = u_v^p(x,Q^2) - d_v^n(x,Q^2)$$
$$\delta d_v(x,Q^2) = d_v^p(x,Q^2) - u_v^n(x,Q^2)$$

Why?

- u and d quarks have different masses
  (biggest effect in "bag model")
- Difference in the virtual meson (pion) cloud
- QED corrections (different because u is +2/3, d is -1/3)

Why does it matter?

CC interactions
are flavor-dependent!



Sources of information on nuclear isospin violation:

Past experiments:

F_2 in charged lepton vs neutrino scattering

(comparison will be improved by NuSOnG, which will extend to lower x due to higher stats and less dense target)

W lepton charge asymmetry from the TeVatron

Drell-Yan 866

Proposed Experiments:

NuSOnG ΔxF_3 (1st real opportunity due to high stats!)

Drell-Yan: E906 (approved -- run date?)

Possible Experiments (suggested in hep-ph/0507029)

$\pi^{\pm}D$ scattering

Semi-inclusive deep inelastic scattering

$\Delta xF_3 = x(4(s\text{-}c)\text{+isospin correction})$

Why NuSOnG can do better than CCFR (only previous attempt)?

1. Higher stats
   (stat error determined by the $\bar{\nu}$ events: ~ 33M vs 250k)

2. Better reach in $y=E_{had}/E_{\nu}$
   less material from front face to toroid,
   wider detector (5m vs 3m)

3. Isoscalar target
   (no correction for excess neutrons)

4. Improved measurements of s and c seas

5. Range of nuclear targets to study ν vs $\bar{\nu}$ nuclear effects

A first opportunity for a significant result!

The upcoming NuTeV-reanalysis
(likely available in late winter)

Will include…

The new Ke3 branching ratio which moves $\sin^2\theta_W$ away from the SM

The new strange sea asymmetry which moves $\sin^2\theta_W$ toward the SM

Net expectation: No change,
but small increase in error due to strange sea

Other improvements coming soon…
(but not included in NuTeV re-analysis)

NLO calculations are now available but are awaiting
resolution on nuclear effects in PDFs

Radiative corrections are being recalculated
(available next spring?)

Other experiments measuring $\sin^2\theta_W$

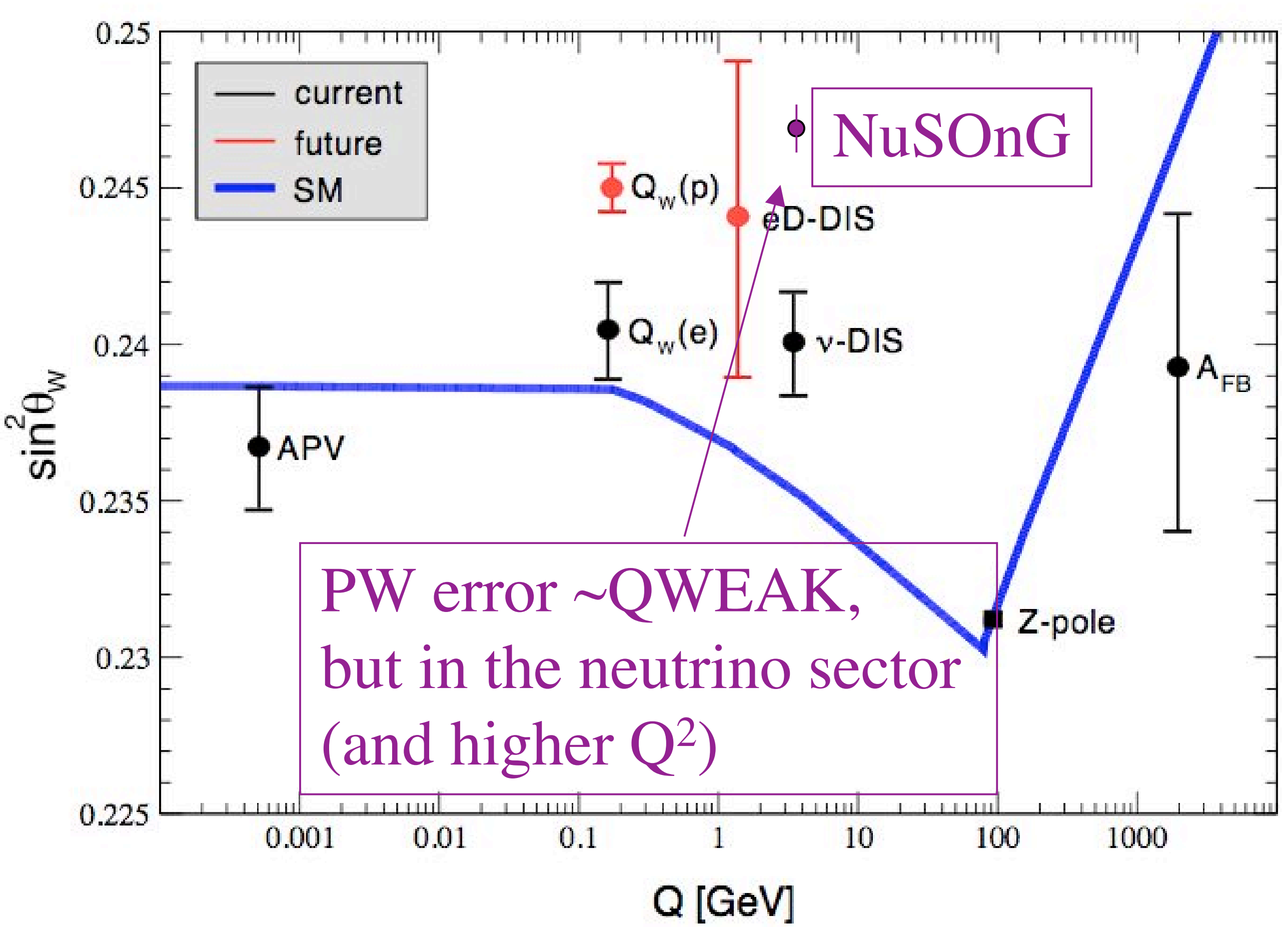
JLAB:

DIS-Parity (needs the 12 GeV upgrade)

QWEAK

Important!

… and complementary



(Figure from QWEAK website)

Challenges for the Tevatron…

1. Instabilities at high luminosity and energy.
2. Repeated ramping.

These questions have to be answered by the Tevatron Dept.

On our experiment, we have expertise:

Ron Moore
Mike Syphers
C.Y. Tan