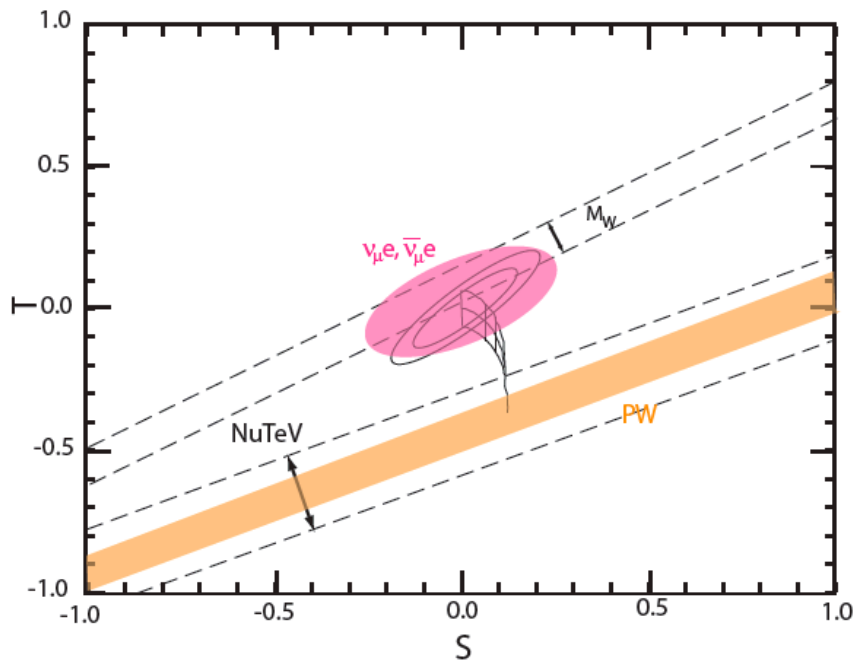
The physics case for...

An ultra-high statistics ν_μ scattering experiment at the TeVatron



May 22, 2007

Janet Conrad (Columbia) and Peter Fisher (MIT),

with input from

Jon Rosner -- Chicago
Mike Shaevitz, Bill Seligman, Sam Zeller -- Columbia
Mike Syphers -- Fermilab

This is an idea under development.

At present, we are settling on the physics goals,
which are ambitious ,
but are back-of-envelope achievable.

Simulations are just beginning...

Sketch of the experiment

The Physics:

- Discovery Potential for
  Precision Electroweak Measurements
  - using $\nu,\bar{\nu}$ -- electron elastic scatters
  - using $\nu,\bar{\nu}$ -- quark scatters ("Paschos-Wolfenstein Method")
- Cross sections and parton distributions
- Searches

We propose to build an experiment with....

Ultra-high event statistics:

100M deep inelastic scattering ν events

500k inverse muon decay events ($\nu_\mu + e \rightarrow \mu + \nu_e$)

50k elastics scatters ($\nu_\mu + e \rightarrow \nu_\mu + e$)

Similar statistics in $\bar{\nu}$ for elastic scatters ($\times 2$ running)

Very low "wrong-sign background"

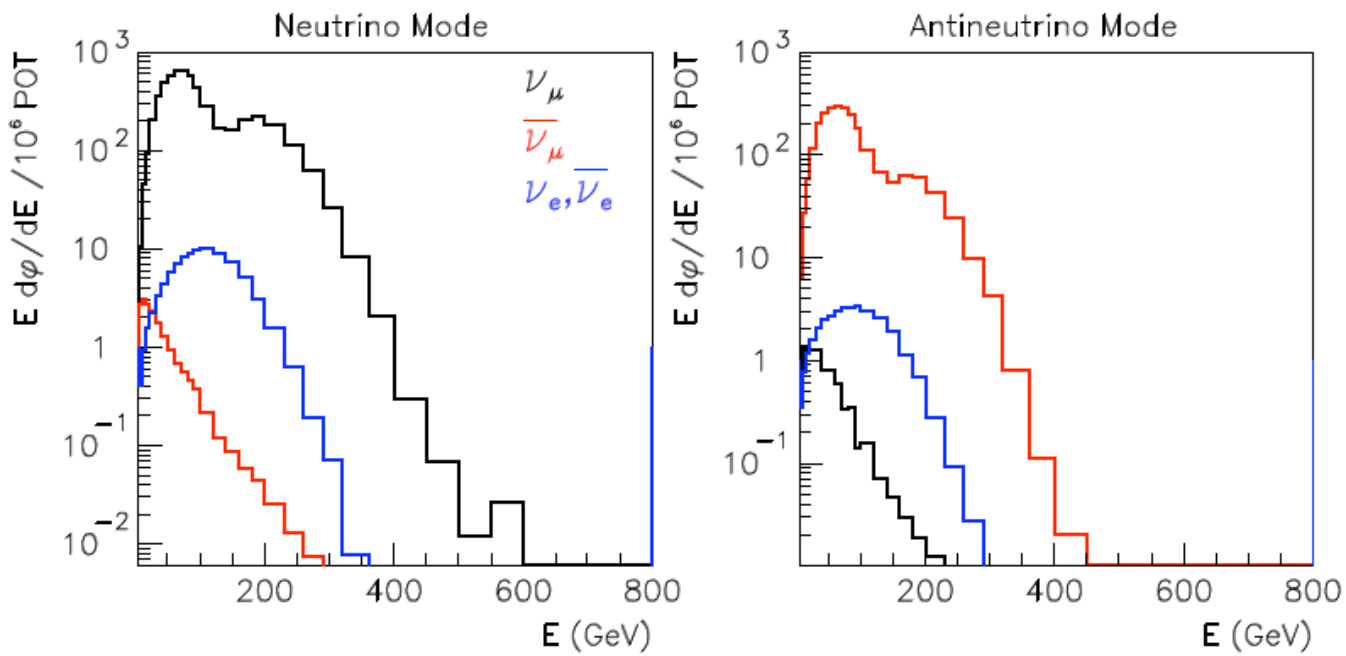
Very low ν_e contamination

Excellent identification of and energy resolution for electromagnetic & hadronic showers and muon tracks

The Beam (based on NuTeV design):

A sign-selected quad train (SSQT) beam from the Tevatron

High energy
Very pure "right-sign"
Low, understandable ν_e contamination

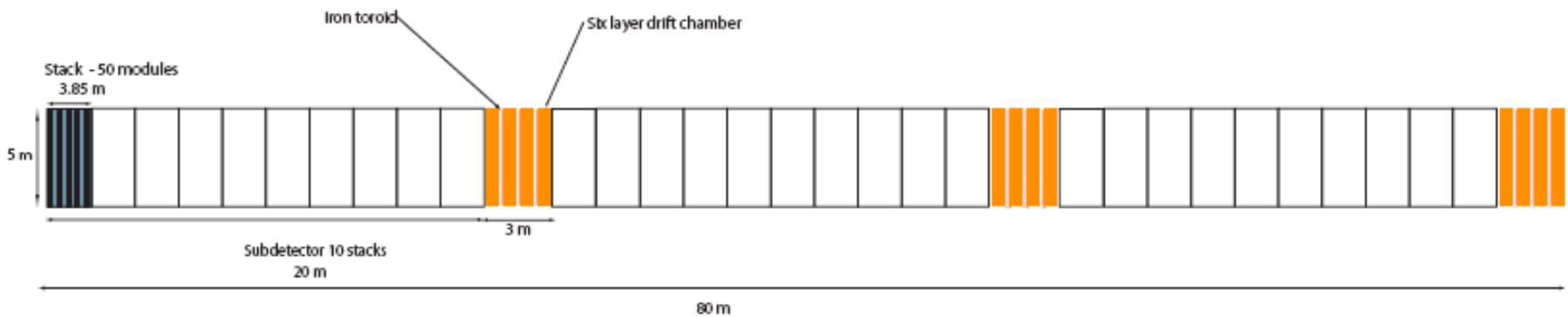


NuTeV beam

The Detector (based on CHARM II design):

A segmented detector

2 kton glass target, with 1/4 λ_0 segmentation
Drift chambers
Three toroids, interspersed
Calibration via testbeam and NCπ^0 (20k) and J/$\varphi \rightarrow \mu\mu$ (50k)



Back of envelope sources of factors

We need:

3×	Fiducial Volume of NuTeV
20×	POT/year (*i.e.*, 5×10^{19})
2 ×	running period (*i.e.*, 3 years)

More than 100× the NuTeV rate
25× the CHARM II elastic scattering rate

The main motivation

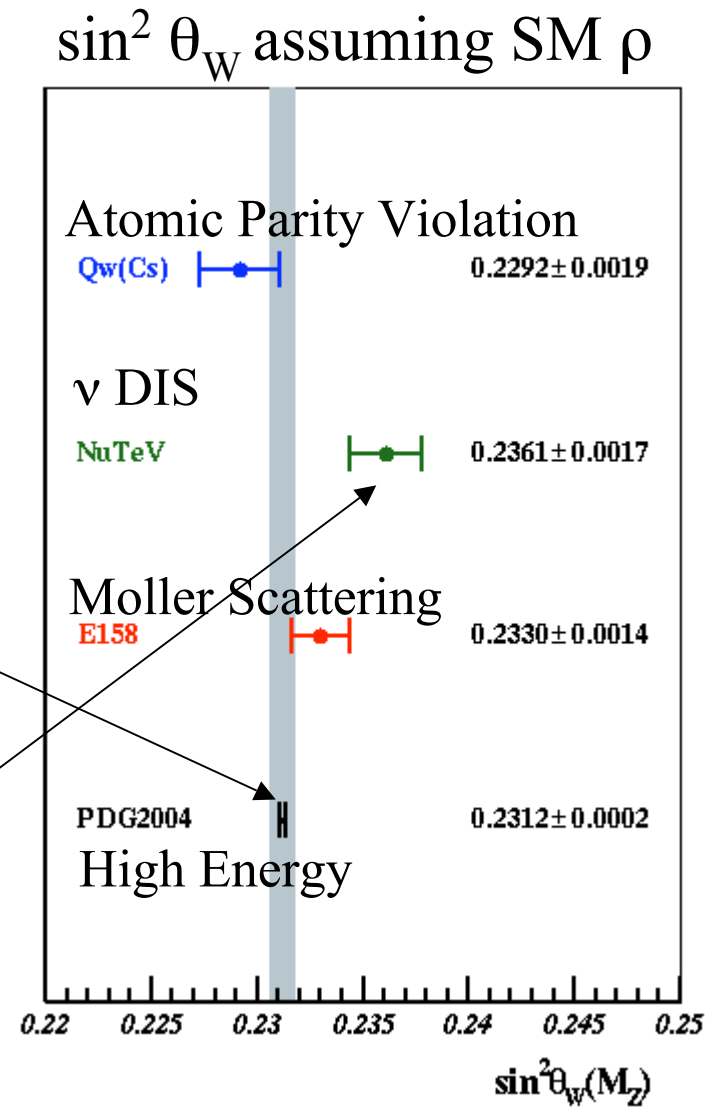
Physics Discovery through Precision Electroweak Measurements

Electroweak measurements are described by two parameters,
e.g. $\sin^2 \theta_W$ and ρ

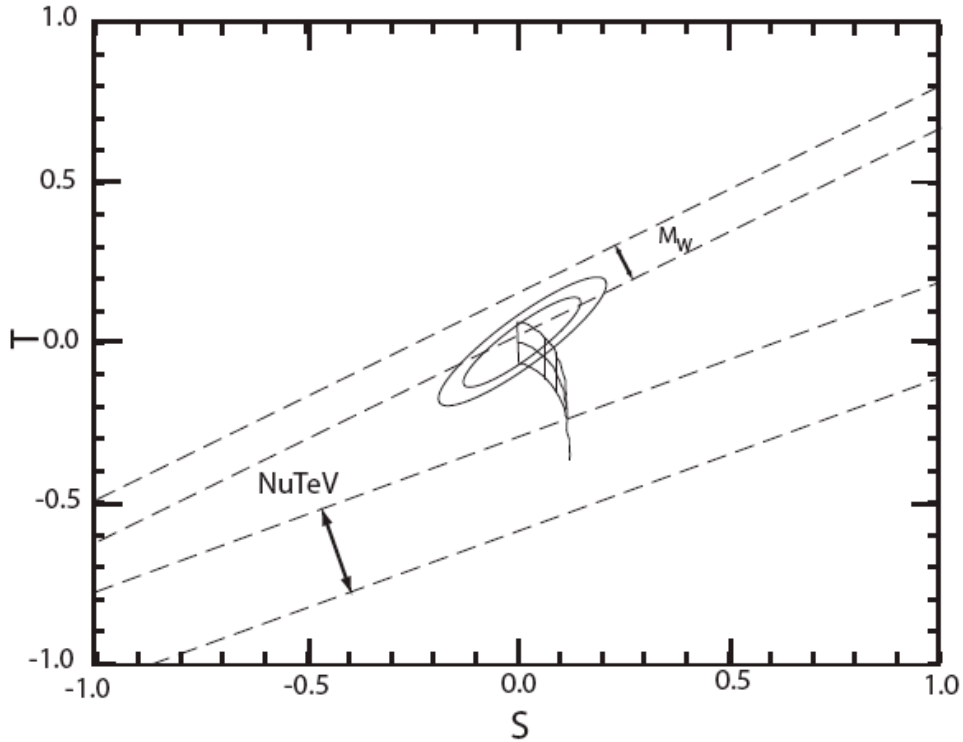
Cross-comparing measurements using many processes...

Agreement constrains the SM...
e.g. the many beautiful measurements from LEP, SLD & TeVatron

Disagreement may open a window on new physics



Present status describe in terms of S & T



Parameterizing beyond SM physics:

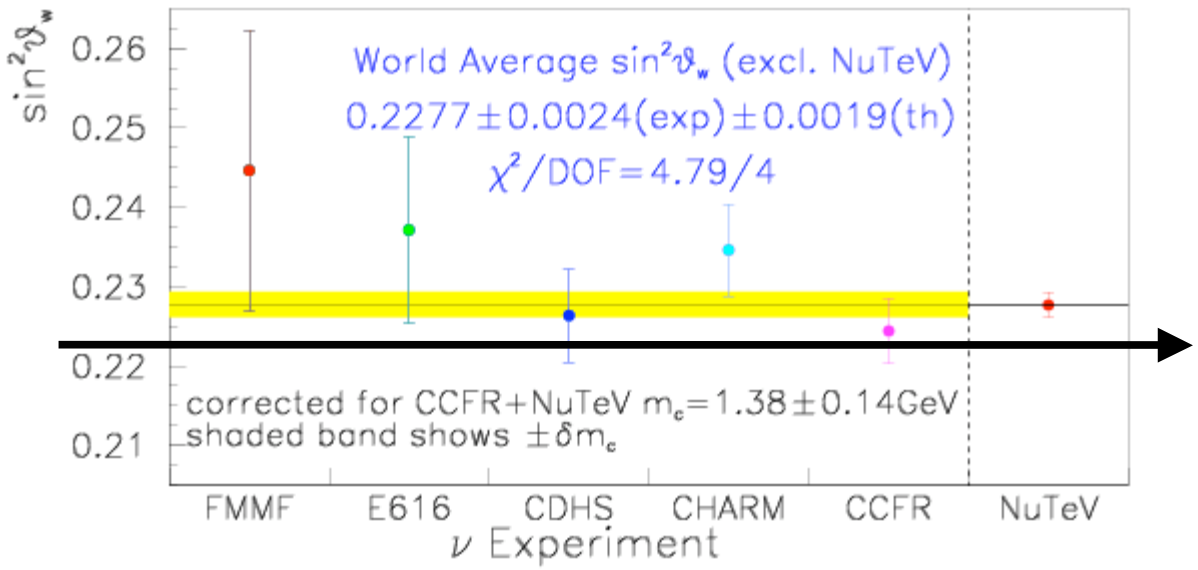
S = weak isospin conserving

T = weak isospin violating

scales such that an effect ~1 corresponds to a correction ~α

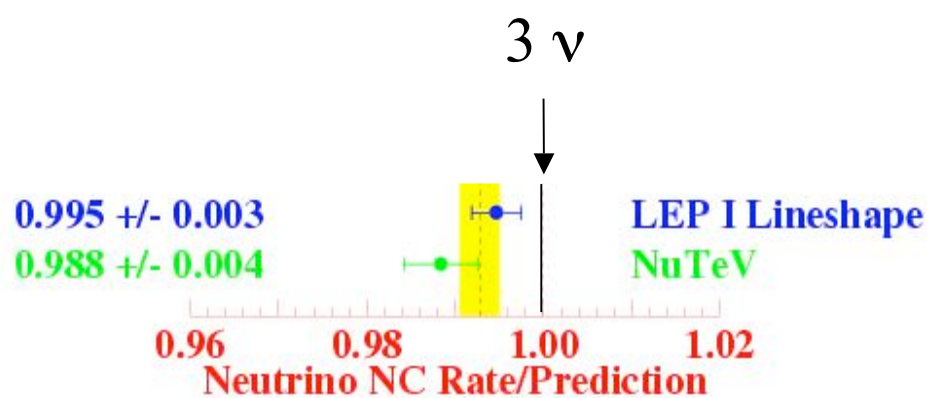
(0,0) is fixed by convention at m_t=175 GeV, m_H=100 GeV

Is there an anomaly in the neutrino sector?



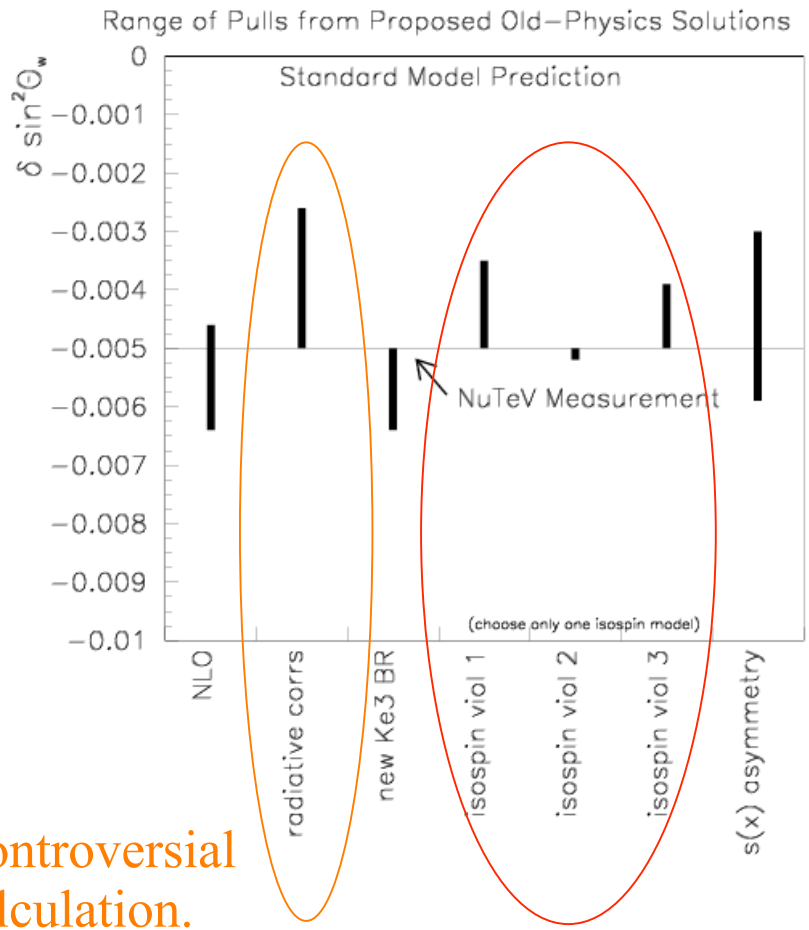
PDG "SM" =0.2227

Number of neutrinos assuming SM coupling:
LEP I is 2σ low
NuTeV is 3σ low



"Standard Model Explanations"

- Upgrade to a full NLO analysis
- Improve radiative corrections
- Update old Ke3 branching ratio based on KTeV result
- Isospin symmetry is violated? ($u^p \neq d^n$ and $u^n \neq d^p$)
- An s vs $\bar{s}$ sea quark asymmetry?



Controversial calculation.

These 3 models are mutually exclusive

Some pull one way, some the other...
No "smoking gun"

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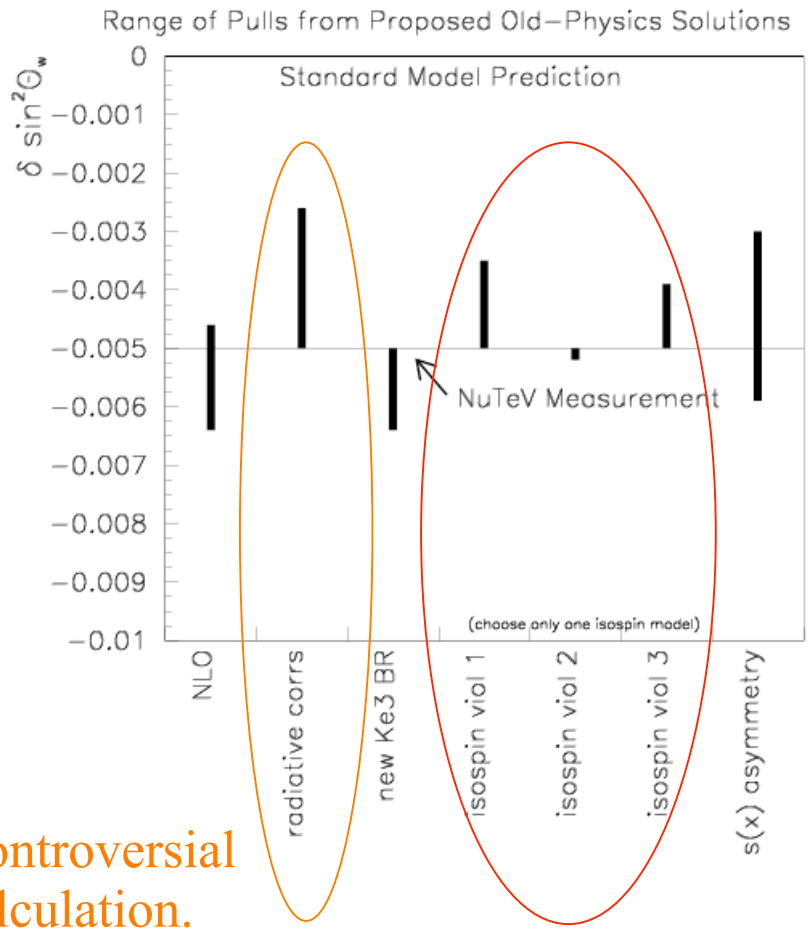
Can be directly addressed by this experiment's SF measurements!



Controversial calculation.

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Beyond the Standard Model Explanations

- Extended SUSY Models

  S. Babu and J. Pati hep-ph/0203029

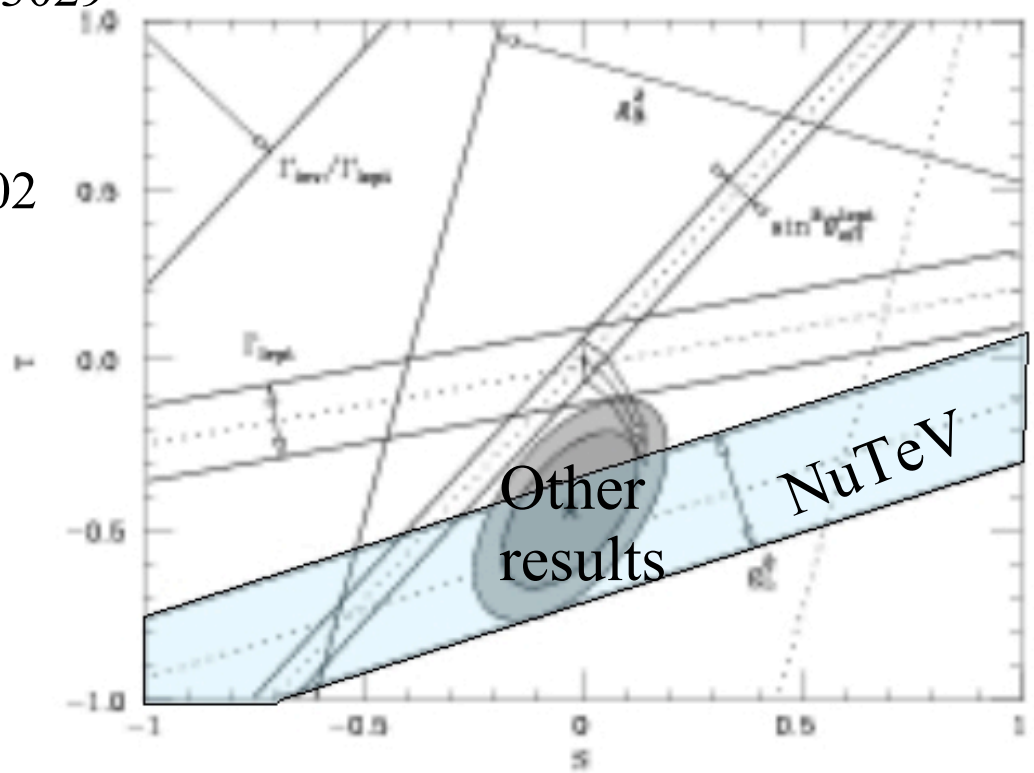
- Designer Heavy "Z" Bosons

  Davidson, et al, hep-ph/0112302

- Allow neutrino non-standard couplings (adjusted by $\varepsilon \sim 0.3\%$, $M_H \approx 500$ GeV)

  Loinaz, et al, hep-ph/0210193

  $Z\nu\nu \leftrightarrow (1-\varepsilon)$
  $Wl\nu \leftrightarrow (1-\varepsilon/2)$



There is a lot of interest!

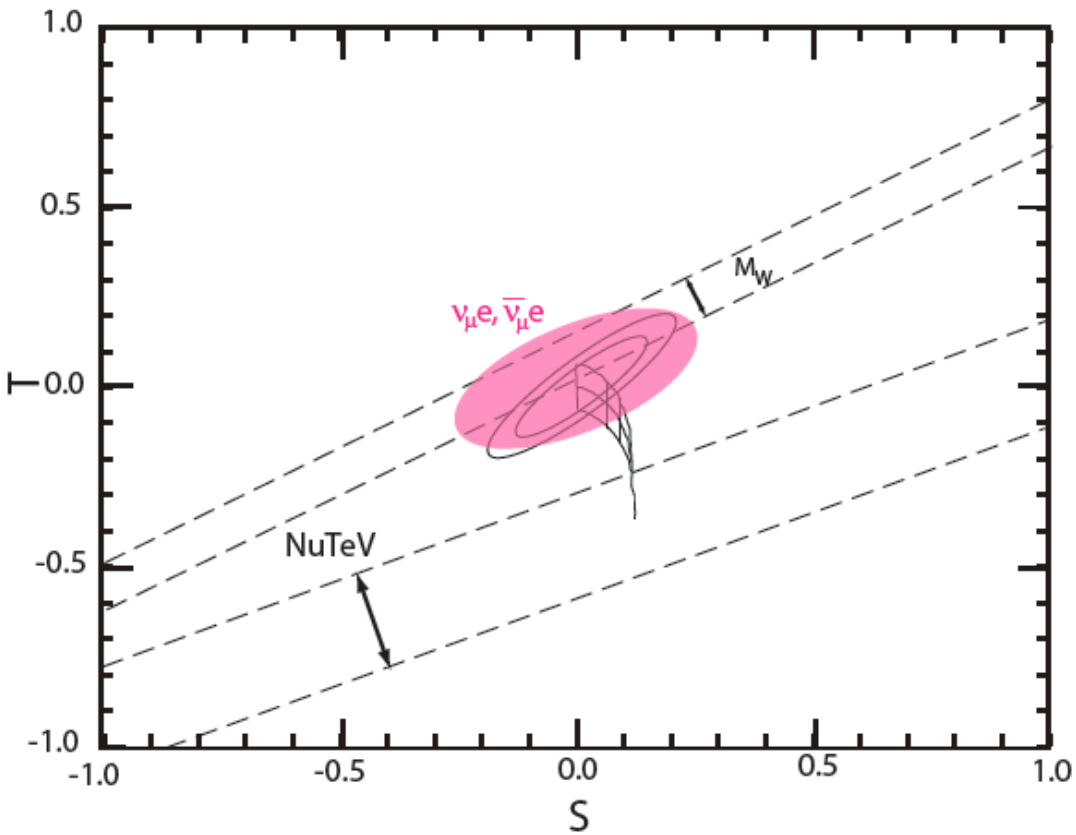
322 citations for the NuTeV paper

"A Precise determination of electroweak parameters in neutrino nucleon scattering".
By NuTeV Collaboration (G.P. Zeller et al.). Oct 2001. 5pp.
Published in Phys.Rev.Lett.88:091802,2002

The APS Neutrino Study noted the need to address this
(See "Neutrinos and the Unexpected")

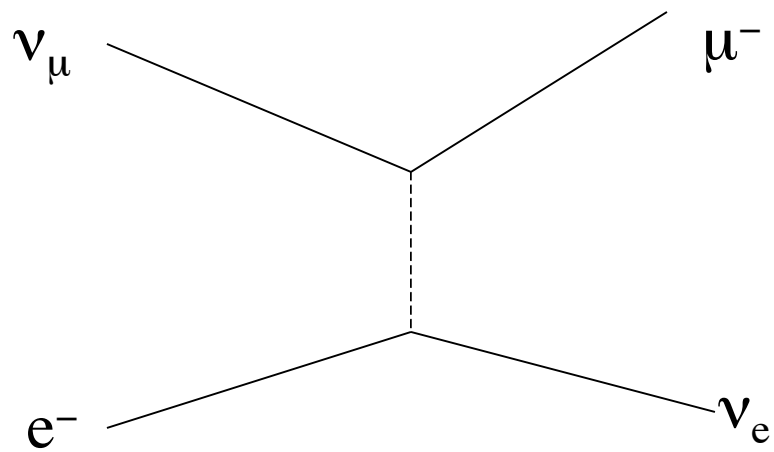
The APS Neutrino Study Theory Whitepaper devotes
a chapter to " NuTeV Physics"

If we could measure the ν and $\bar{\nu}$-electron cross sections to 0.5% (*i.e.*, to level of stats only)



No quark model issues!

A trick to reach small systematic errors in neutrino mode:
Use IMD events to measure the flux



Threshold:
11 GeV

This cross section is precisely known.

Neutrino energy can be reconstructed,
assuming the the neutrinos enter along the z-axis

Getting the antineutrino flux is trickier....

Our initial idea:

IMD events

↓

Adjust SSQT and normalization of π^{+},K^{+} secondaries

↓

Use the π^{-}/π^{+} and K^{-}/K^{+} secondary measured ratio

↓

antineutrino flux prediction

How well could we do a Paschos-Wolfenstein style (i.e. quark target) measurement?

SOURCE OF UNCERTAINTY	$\delta \sin^2\theta_W$	$\delta R^{\nu}_{\rm exp}$	$\delta R^{\overline{\nu}}_{\rm exp}$
Data Statistics	0.00135	0.00069	0.00159
Monte Carlo Statistics	0.00010	0.00006	0.00010
TOTAL STATISTICS	0.00135	0.00069	0.00159
$\nu_e, \overline{\nu}_e$ Flux	0.00039	0.00025	0.00044
Interaction Vertex	0.00030	0.00022	0.00017
Shower Length Model	0.00027	0.00021	0.00020
Counter Efficiency, Noise, Size	0.00023	0.00014	0.00006
Energy Measurement	0.00018	0.00015	0.00024
TOTAL EXPERIMENTAL	0.00063	0.00044	0.00057
Charm Production, $s(x)$	0.00047	0.00089	0.00184
R_L	0.00032	0.00045	0.00101
$\sigma^{\overline{\nu}}/\sigma^{\nu}$	0.00022	0.00007	0.00026
Higher Twist	0.00014	0.00012	0.00013
Radiative Corrections	0.00011	0.00005	0.00006
Charm Sea	0.00010	0.00005	0.00004
Non-Isoscalar Target	0.00005	0.00004	0.00004
TOTAL MODEL	0.00064	0.00101	0.00212
TOTAL UNCERTAINTY	0.00162	0.00130	0.00272

Becomes Negligible

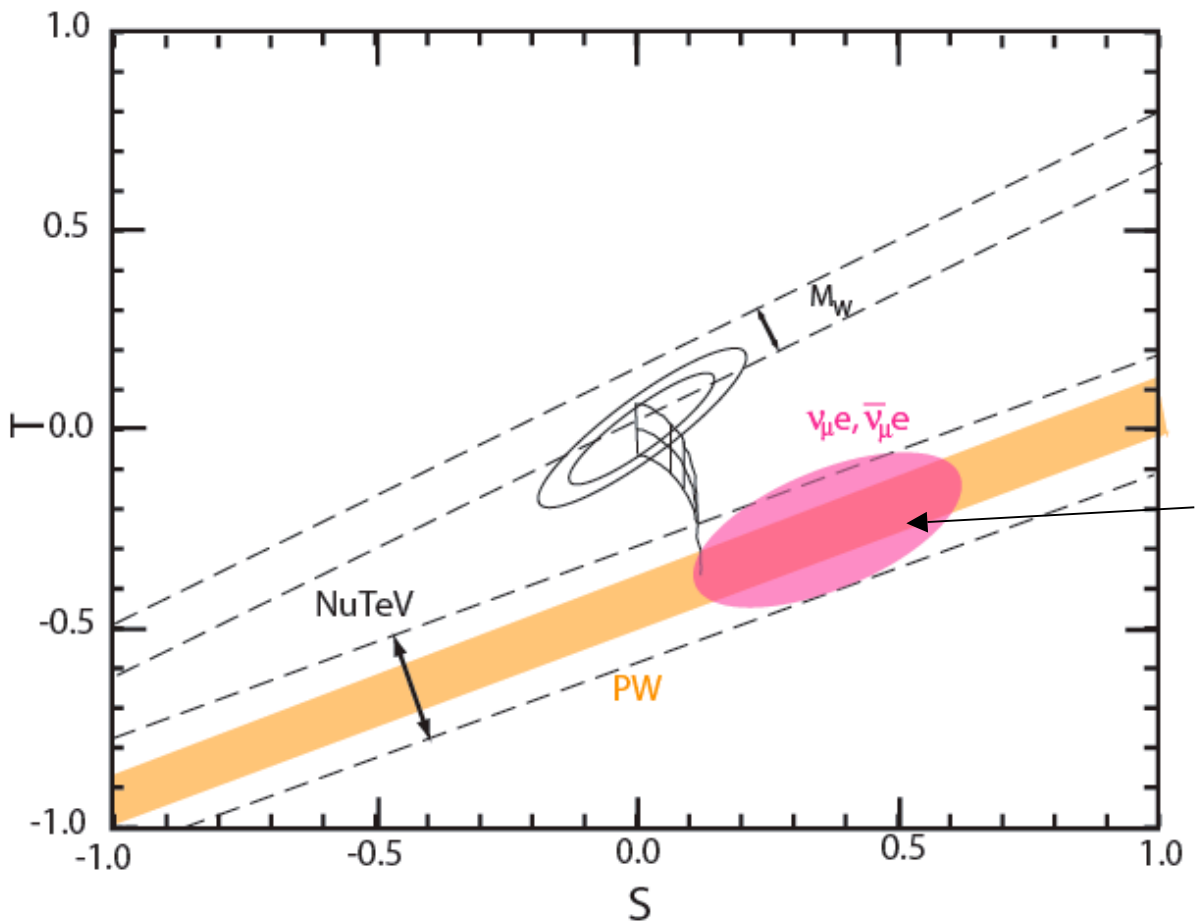
Improved by finer sampling detector

Substantially improved by this expt

May be improved? (under investigation)

Target is isoscalar

Orange band:
if total error is ×2 less than NuTeV



Searching for New Physics:

If elastic scattering agrees with PW result and disagrees with LEP...

This experiment plays well with LHC!

Depending on the result, this experiment could...

Point to new physics if there is disagreement with LEP/LHC
or

Narrow the allowed Higgs range if M_H>500 GeV
or

Help sort out BSM physics signatures observed at LHC

Other Physics:

Cross sections and Parton Distributions

Beyond Standard Model Searches

Cross Section Measurements:

Three which are important for the Paschos-Wolfenstein Errors, as well as being interesting on their own...

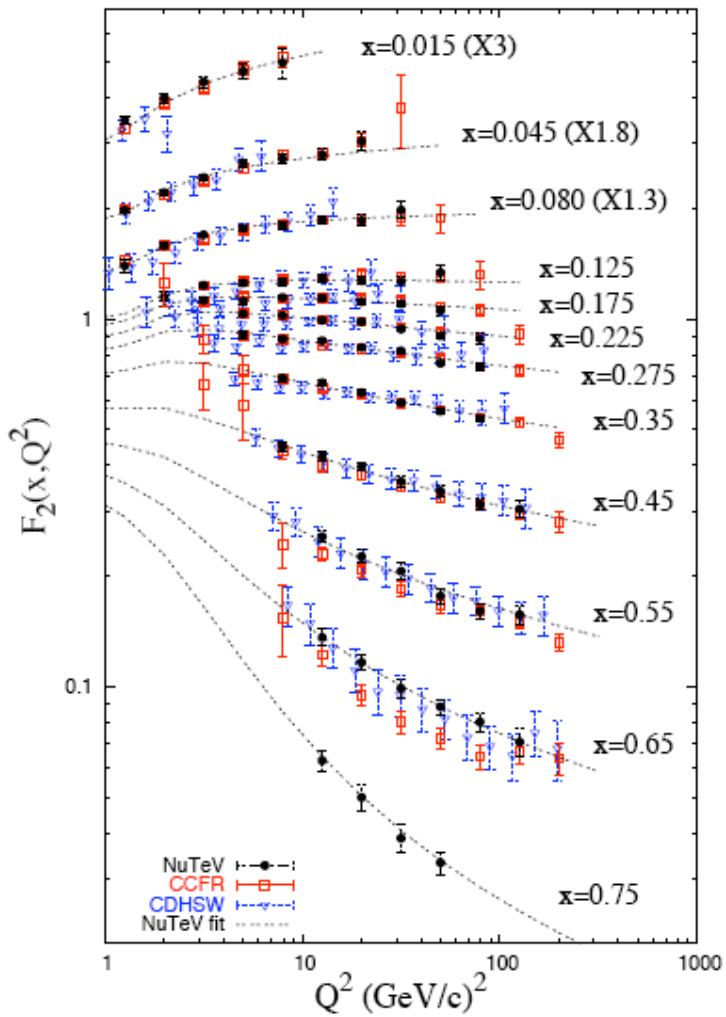
1) A precise determination of $\sigma^{\bar{\nu}}/\sigma^{\nu}$:

Need to understand how well the flux can be measured for antineutrinos to kn if this error can be reduced.

2) A precise determination of Structure Functions:

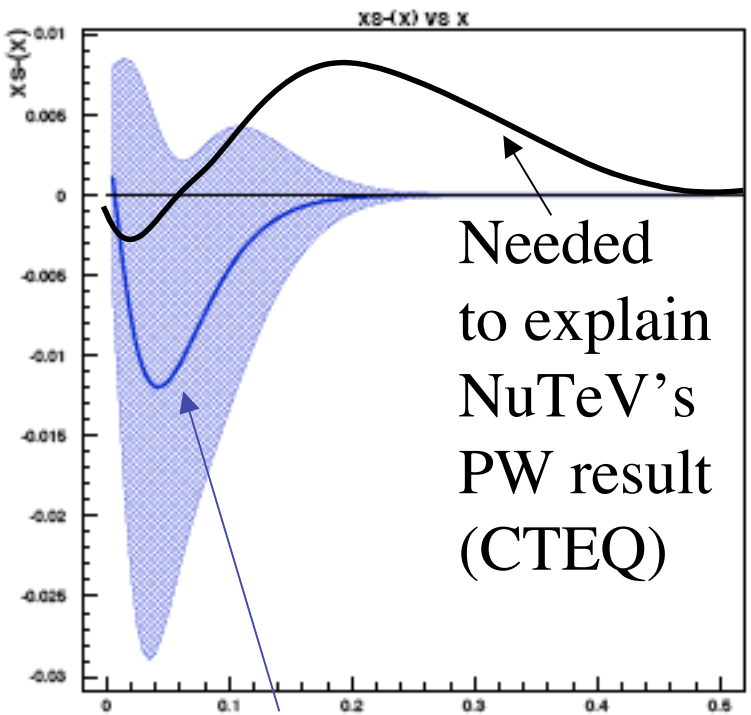
Expect 2-3 lower errors due to precise knowledge of flux.

Improved input to "5/18th rule" analysis addresses isospin violation questions



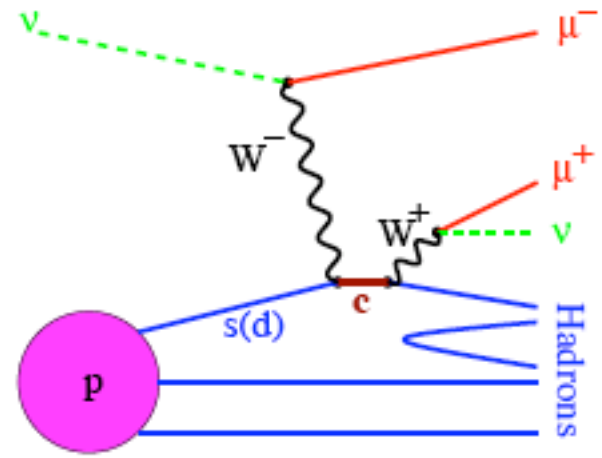
3) The strange sea asymmetry:

$$xs^- = xs - x\bar{s}$$



NuTeV

$$\int xs^-(x)dx = -0.0009 \pm 0.0014$$



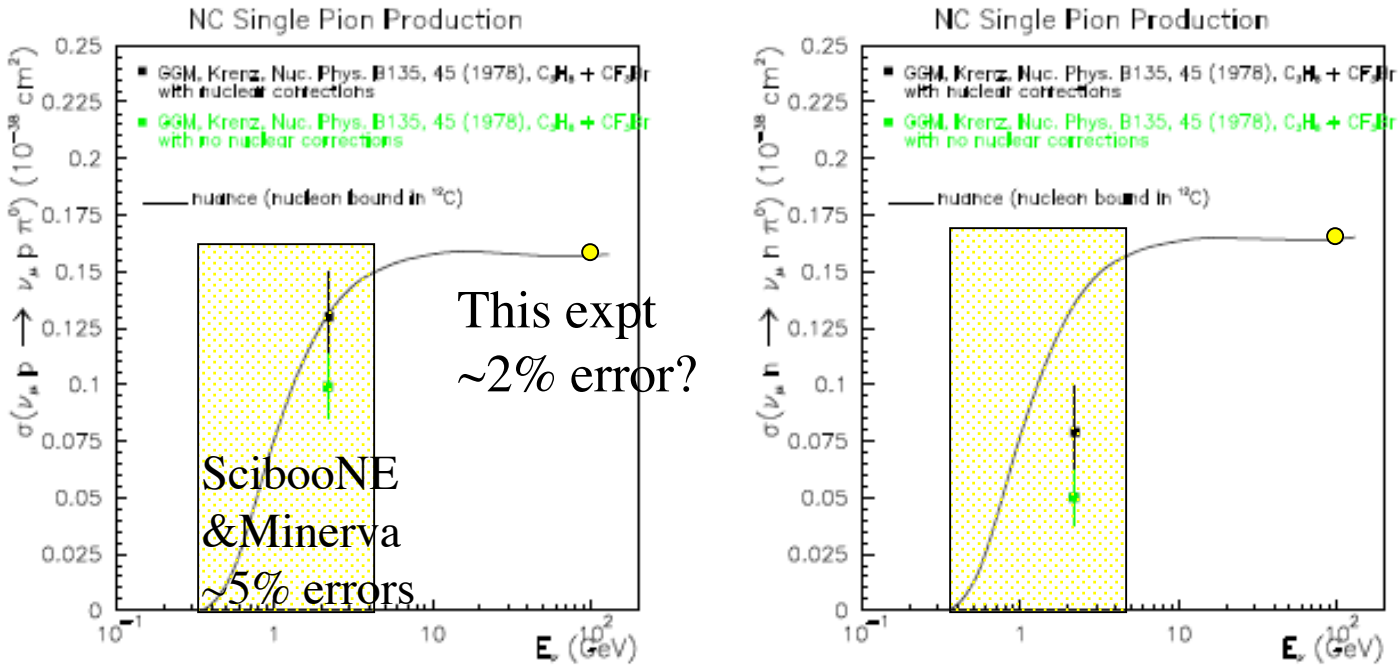
Our measurement will have:

- ×10 smaller statistical errors
- higher reach in x

We should be able to make a definitive statement.

Other interesting quark-model related measurements:

- CCQE high energy measurement (500k events)
- NCπ^0 at high energies with a well-understood flux



- Low x structure functions on SiO_2
- Understanding cascading from higher charm resonance to J/φ

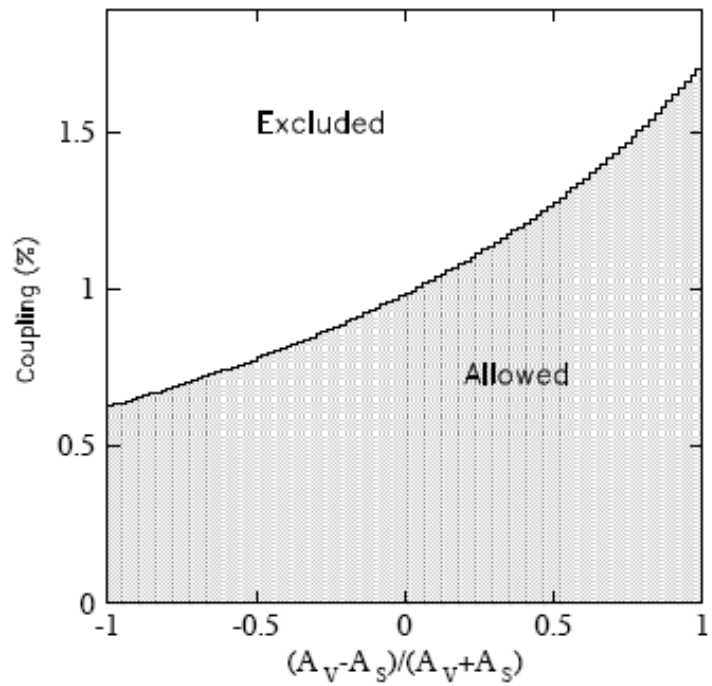
(Chorus saw a factor of 2 more events than expected)

Searches

Lepton Flavor Violation:

$$\frac{\sigma(\overline{\nu}_\mu e^- \to \mu^- \overline{\nu}_e)}{\sigma(\nu_\mu e^- \to \mu^- \nu_e)} = \lambda \cdot [A_V \cdot (\frac{1 + r/2}{3}) + A_S]$$

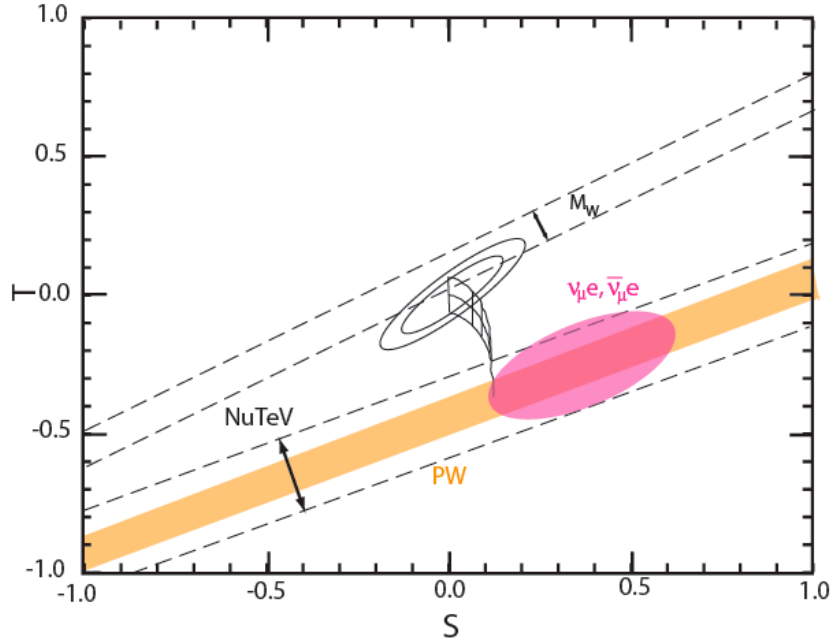
From NuTeV:
present best limit as a function
of Scalar & Vector couplings



Considering statistics only, we can do order of magnitude better

Other examples: Neutral Heavy Leptons
Sterile Neutrino Oscillations at $\Delta m^2 \sim 20$ eV^2

In Conclusion



An ultra-high statistics, high energy
ν experiment
has great discovery potential

We ask for your support of a
TeVatron-based Neutrino Program