A Tevatron Based Neutrino Program

“ Because there’s likely to be more to neutrinos than just oscillations!”

Janet Conrad
for the
NuSOnG Collaboration

A Tevatron-based neutrino program…

… can do first-rate physics relevant to both the neutrino sector and the EW sector.

This science connects the traditional interests of neutrino physicists to those of the LHC physicists

… explores physics questions that are not explored in the presently-proposed program

… would be unique facility that leverages our existing assets and does not require extensive R&D to be constructed.

This began with NuSOnG,
an experiment under development.

We presented to and were endorsed for further development by the Steering Group.

It has received encouragement from the director:

It is too early to consider a full proposal, but I encourage the plan to submit an LOI to be considered by the PAC. Many things are uncertain in the future HEP program and I can think of circumstances that would make NuSOnG a very attractive option

….is there anything else that you can think of that could be run along NuSOnG…?

from a letter to the collaboration from Pier Oddone

My goal for this talk:

Describe the possibilities to you,
to encourage you to join in the discussion
on the potential of this new facility.

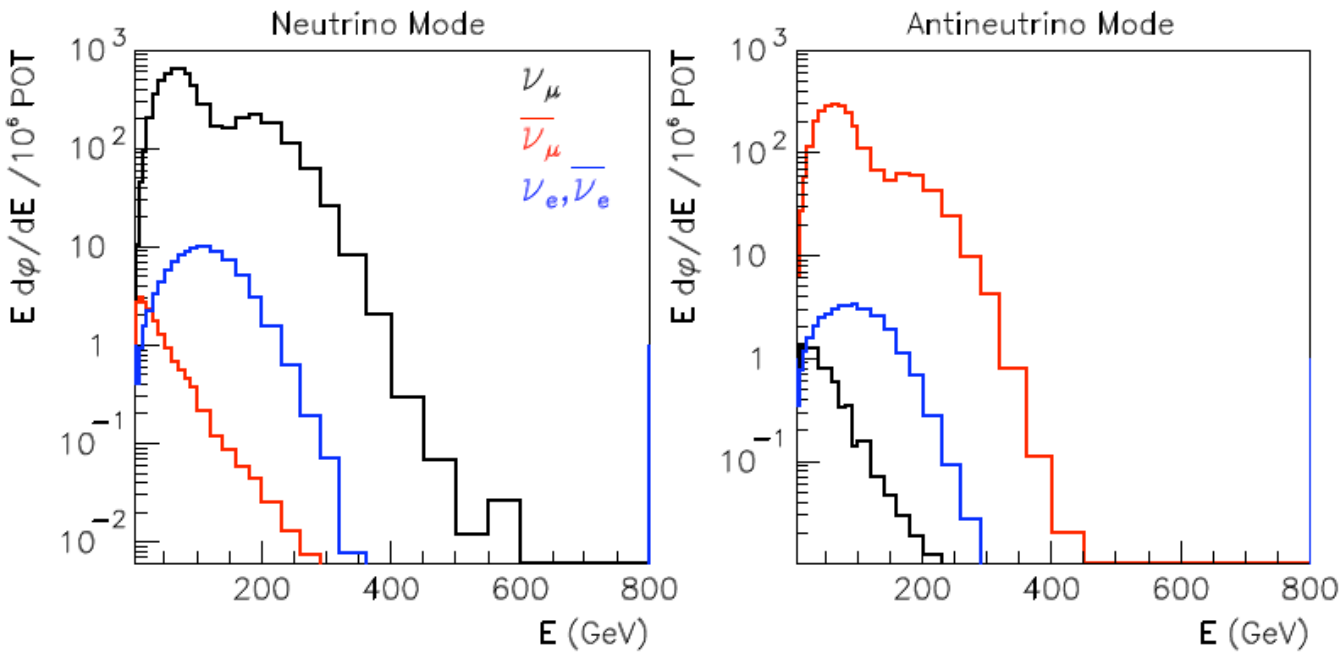
Outline:

- What a Tev-based neutrino beam offers
- Three example experiments (emphasizing new opportunities)
- Especially my favorite…NuSOnG

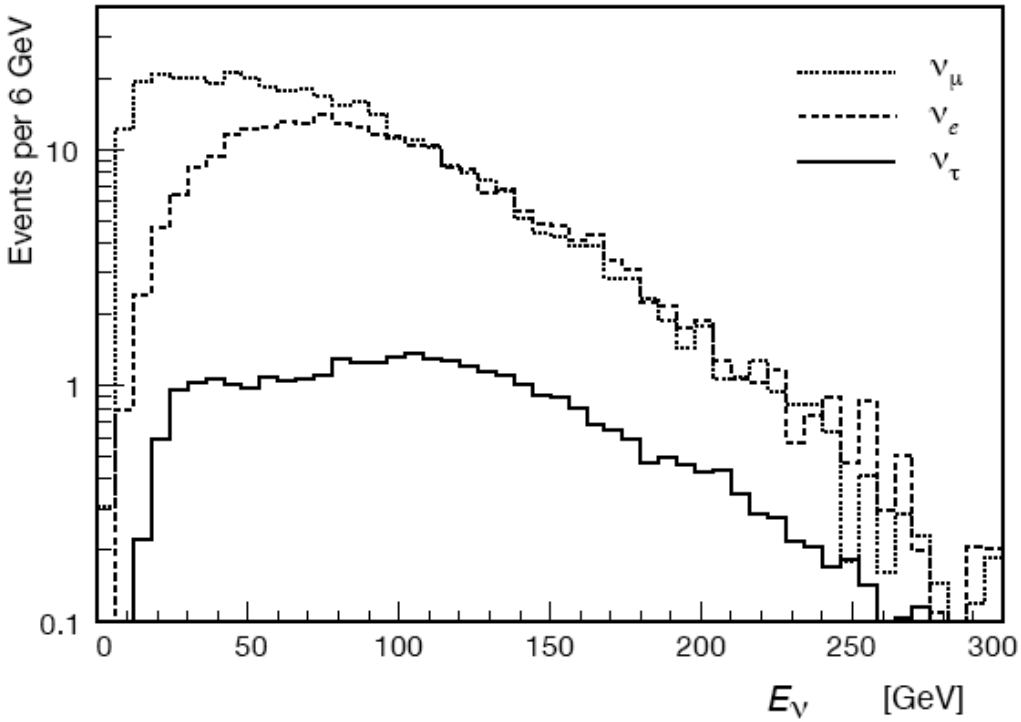
A Tevatron-based beam offers the highest energy neutrino beams in the world.

Example 1: The NuTeV Flux

Uniquely high energy, and low background, produced using a sign-selected quad-train



Example 2: The DoNuT (Discovery of the Nu Tau) Flux



Uniquely enriched in ν_τ's which are above threshold for CCQE

It's all about flavor & energy!

A Tev-based program is the only source of

High purity ν_μ beams at high energies

Enriched ν_τ beams at high energies

Our idea:

Build a combined-beam facility,
providing both a sign-selected beam and a beam dump flux,

with ×20 times the NuTeV POT/year
with ×150 times the total DoNuT POT

5×10^{19} POT/year

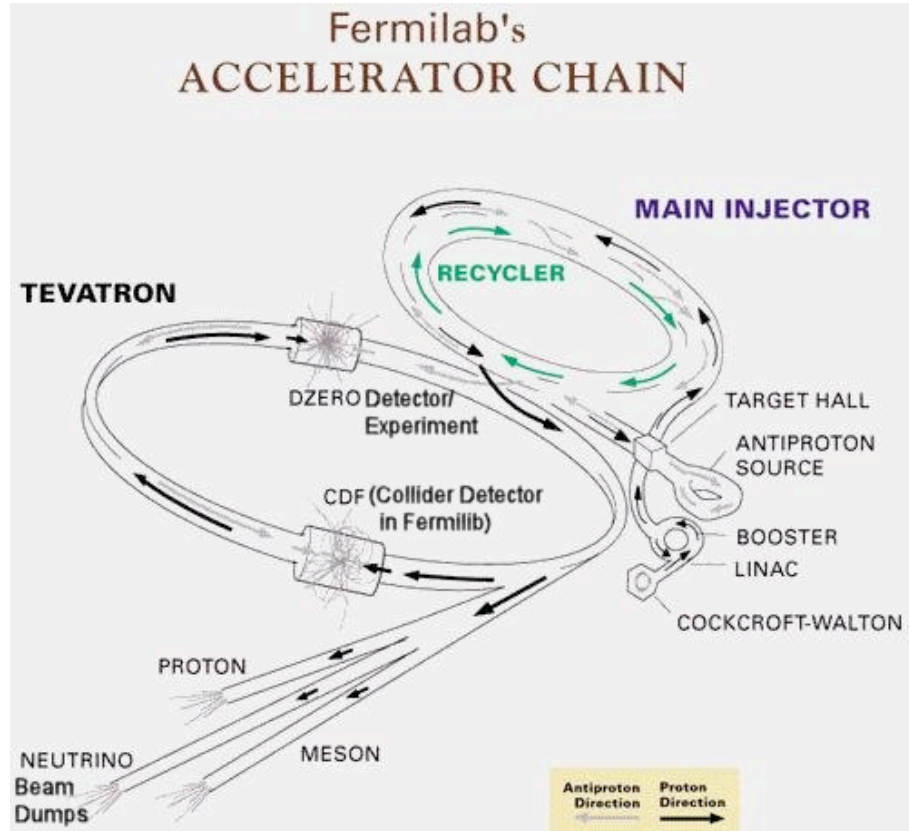
This a small cost to the planned neutrino programs
(cost is mainly in ramp time)

It does not require substantial proton source upgrades

It does require new records of performance from the Tevatron

5× the number of protons per fill,
1.5 × faster cycle time
66% uptime per year

The goals were set in consultation with the Tevatron department to be ambitious but not outrageous.



There are written 2 useful publicly-available memos:

http://beamdocs.fnal.gov/AD-public/DocDB/ShowDocument?docid=2222
http://beamdocs.fnal.gov/AD-public/DocDB/ShowDocument?docid=2849

Discussion of Tevatron Fixed Target Options after Run II

M. J. Syphers

July 30, 2007

DRAFT

Abstract

Following the very successful completion of Run II in the upcoming years, the Tevatron synchrotron will become available for other uses. Assuming that its function as a proton-antiproton collider is no longer supported, several new (and old) options become available. In this report we examine specifically two scenarios, namely the use of the accelerator as a "stretcher ring" for 120-150 GeV fixed target operation to the existing SY120 facilities, or possibly as a high energy (800 GeV) fixed target synchrotron for neutrino experiments. While much more work needs to be done to understand fully the implications of using the Tevatron in these modes, here we attempt to present the major factors which may influence the decisions necessary for going forward with either of these options. Other options, for example the use of the tunnel for electron storage ring or damping ring studies, will be left to other reports.

A first very tentative, highly-preliminary M&S cost est.

$0.65M for implementation (beam only, not target hall)
$18M /year to run

Can be implemented by 2015

What could you do with such a facility?

Three Example Experimental Programs:

1. Study of properties of the ν_τ } very briefly
2. Search for light neutrissimos
3. NuSOnG … my real interest

The first two examples are just sketches
that is our response to Pier's question

The real point: if we build this facility,
there will be lots of good physics to do!

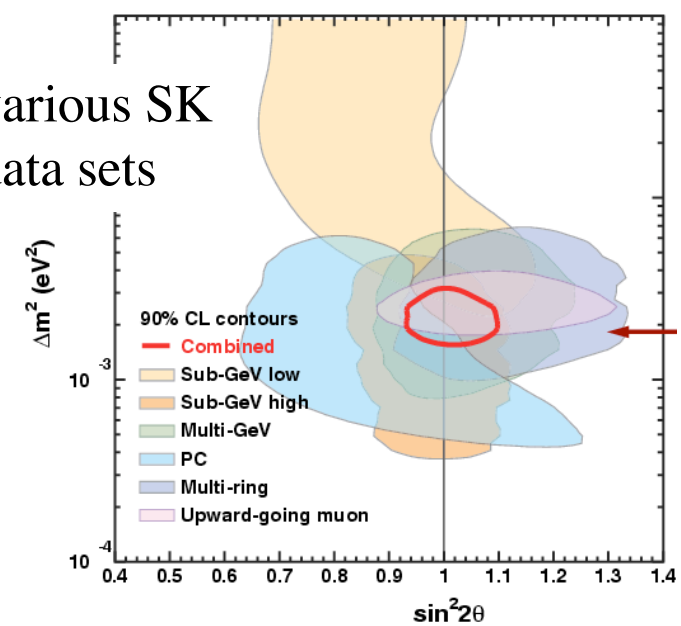
Experiment Example 1: Study of the ν_τ

- This is the least explored part of the neutrino sector.

- Many models favor new physics signals in the third family, showing up as non-universal couplings
  (see e.g., Langacker, Physics of Heavy Z' Gauge Bosons, arXiv:0801.1345)

- Is apparent maximal mixing telling us something about the ν_τ?

various SK data sets



Expt.	best fit	ref.
Minos	1.01	hep-ex/0607088
SK:	1.02	hep-ex/050106
K2K:	1.2	hep-ex/0606031

Very different fluxes, detectors, MCs
Also true for older, lower stats expts

A new beam-dump experiment could potentially…

Obtain 100 to 500 times the DoNuT statistics
(depending on detector and run time)
You can measure the properties of the ν_τ
to high precision for the first time!

As well as searches for new physics via ν_τ,
it can also do:
interesting charm measurements
structure function measurements
valuable to a neutrino factory.

Experiment Example 2: A dedicated search for neutrissimos

(expt idea inspired/drawn from talks by F. Vannucci)

not-so-heavy-neutral-heavy-lepton,
a.k.a. moderately-heavy-sterile-neutrino

These appear in many BSM theories, e.g.

The νMSM model

T. Asaka and M. Shaposhnikov Phys.Lett.B620(2005)17
M.Shaposhnokov Nucl.Phys.B763(2007)49

Three singlet RH neutrissimos: N_1, N_2, N_3

⇒N_1 with very large lifetime, $N_1 \rightarrow 3\nu$, also radiative decay
Best choice : $m(N_1)$ ~10 keV (warm dark matter)

⇒⇒ N_2, N_3 almost degenerate (leptogenesis)
With masses 100 MeV-few GeV

Other light particle to search for… axion-like, dilaton-like, light vector bosons, light inflatons, etc…

Accelerator limits are based on mixing to light ν

Their mass is limited by the parent particle

$\pi \Rightarrow e\,N$	$m(N) < 130$ MeV
$\pi \Rightarrow \mu\,N$	$m(N) < 20$ MeV
$K \Rightarrow e\,N$	$m(N) < 450$ MeV
$K \Rightarrow \mu\,N$	$m(N) < 350$ MeV

Only a Tev-based beam allows you to search in B-decay
you to reach up to ~5 GeV!

A nice, small, inexpensive, dedicated neutrissimo decay search

would be a first -- past experiments have been add-ons

These are two examples I think are nice.
But my personal motivation for proposing this program is…

NuSOnG: Neutrino Scattering On Glass

http://www-nusong.fnal.gov

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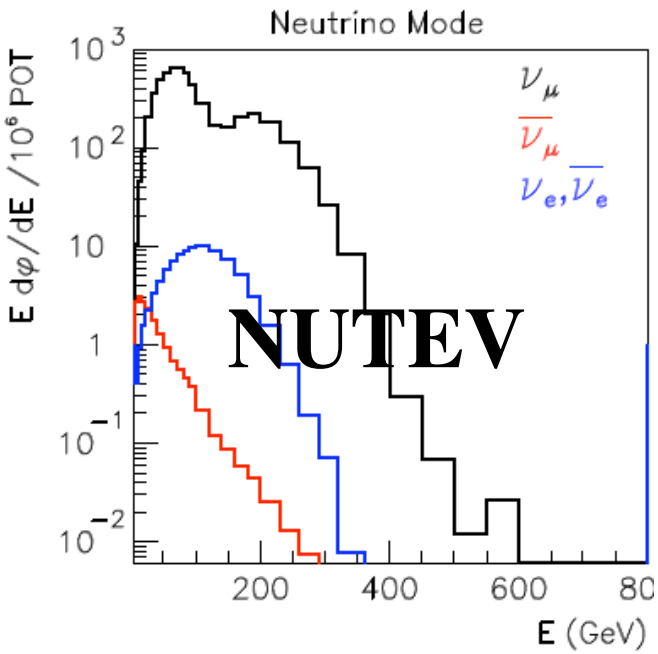
9 Universities • 2 Undergraduate Colleges • 2 National Labs

We have turned in an EOI to the laboratory.
We plan to submit and LOI in the future.

The Experimental Design



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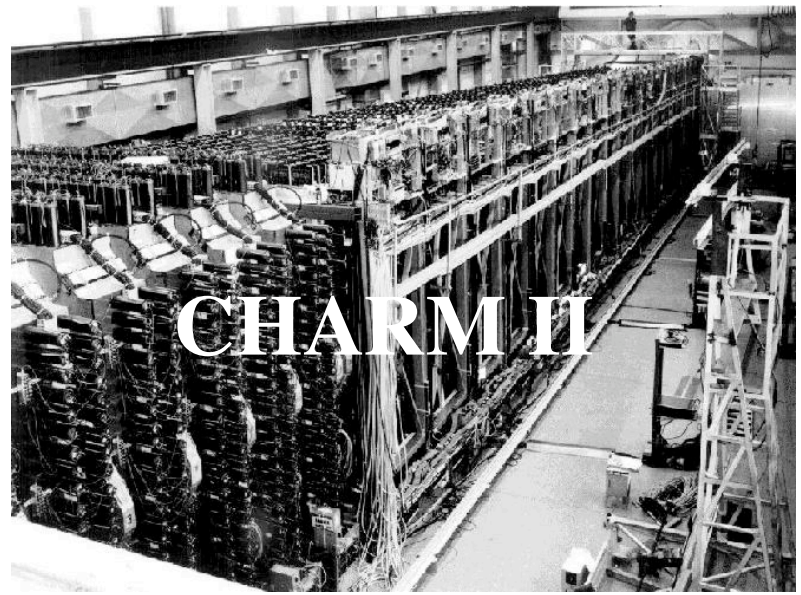


High energy,
very pure beam
(×20 POT)

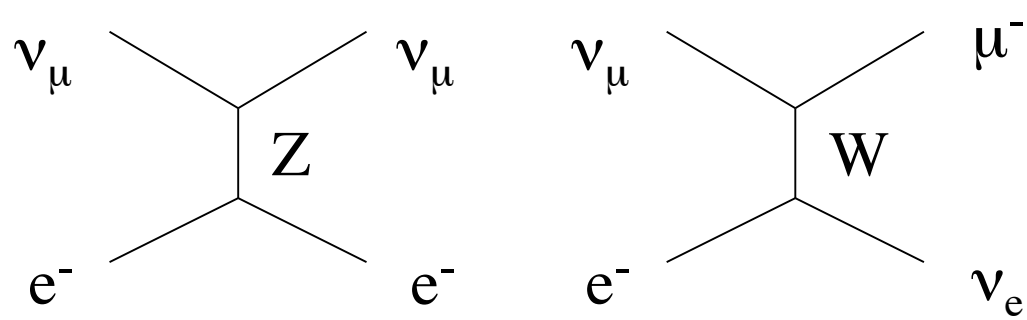
Fine-grained,
massive detector
(×6 mass)

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**
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 $N \rightarrow \mu\mu\nu$ decay in the 5 GeV mass range**
7. **Searches for light mass neutrissimos**
8. **ν_μ disappearance at very high Δm^2**
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. **Constraint on isospin violation from ΔxF_3**
19. **Charm production in the emulsion target and a measure of B_c**
20. **Measurement of the strange sea and Δs from dimuon production**
21. **Measurement of the charm sea from wrong-sign single muon production in DIS**
22. **Neutrino vs antineutrino nuclear effects**

My own personal interest….

New physics at ~1 TeV scales is likely.

Neutrinos are an excellent probe for this.
In fact, they may be the only probe for certain aspects!

This new physics will manifest itself in NuSOnG as…

Nonuniversality and Nonunitarity
Neutrino couplings that don't match expectation,
and may even vary between flavors!

What new physics could do this?

New heavy Z's
New 4th generation families,
100 GeV scale neutrissimos which mix with light neutrinos

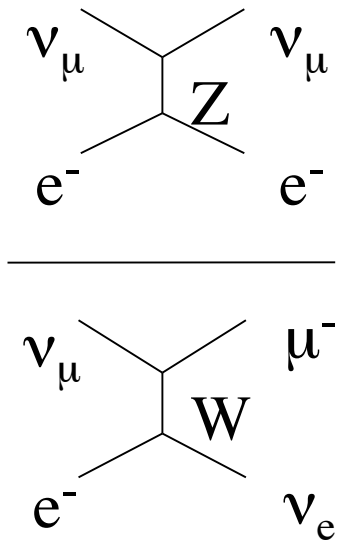
Many things on the menu for LHC,
and even things that LHC cannot see

Recall the question from the last Project X workshop:
How does the future neutrino program tie to LHC?
… NuSOnG is the answer.

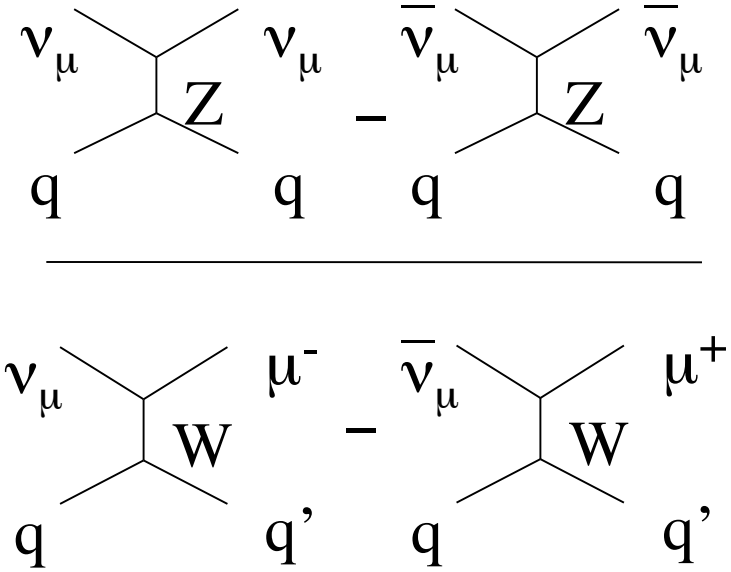
To obtain very high precision…

NuSOnG will work with ratios….

New!



Purely leptonic



NuTeV-style
"Paschos-Wolfenstein"

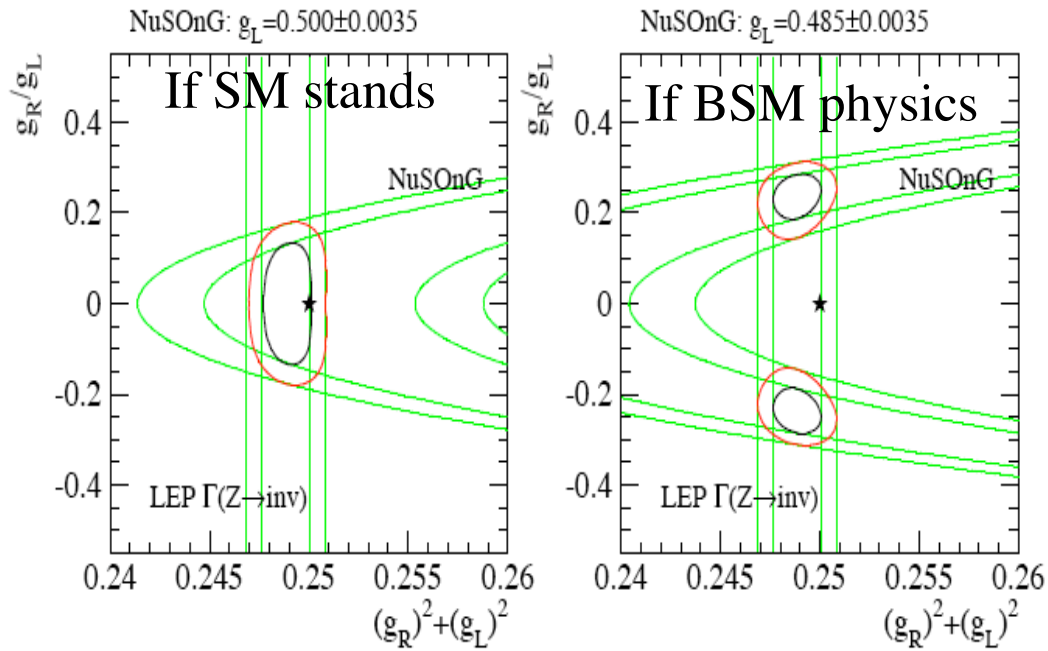
goal: 0.7% error

goal: 0.4% error

Unprecedented measure neutrino couplings!

Orthogonal to the only other precision contributor: LEP inv. Z width

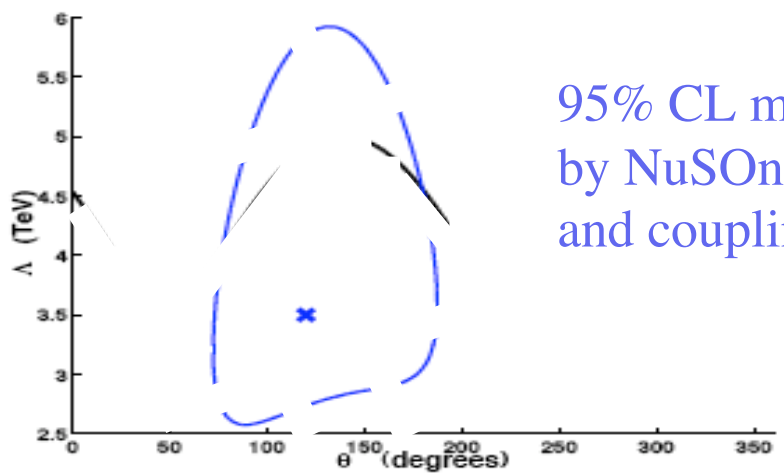
Reaches LHC mass scales (5.6 TeV at 95% CL)…



For a new interaction…

$$\mathcal{L}_{\rm eff} = \frac{\sqrt{2}}{\Lambda^2}\bar{\nu}_{\alpha L}\gamma_\sigma\nu_{\mu L}\left(\cos\theta\bar{e}_L\gamma^\sigma e_L + \sin\theta\bar{e}_R\gamma^\sigma e_R\right) + H.c.,$$

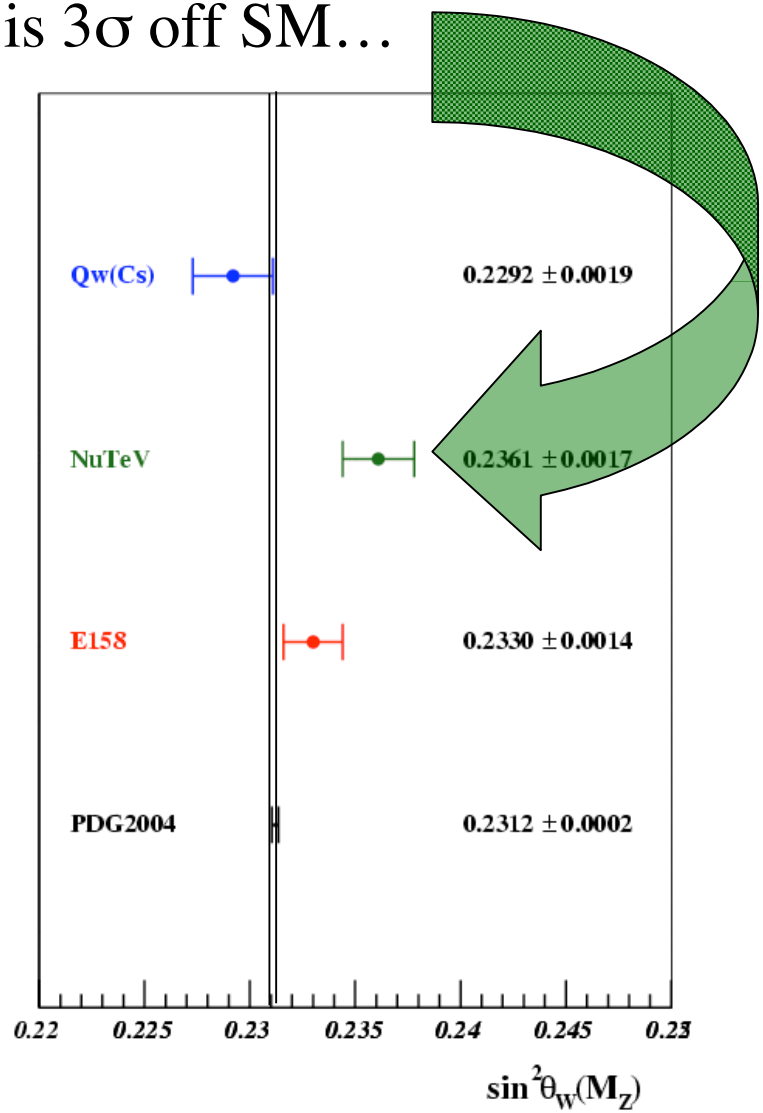
New physics scale



95% CL measurement by NuSOnG if scale is 3.5 TeV and coupling is mixed-handedness (θ=2π/3)

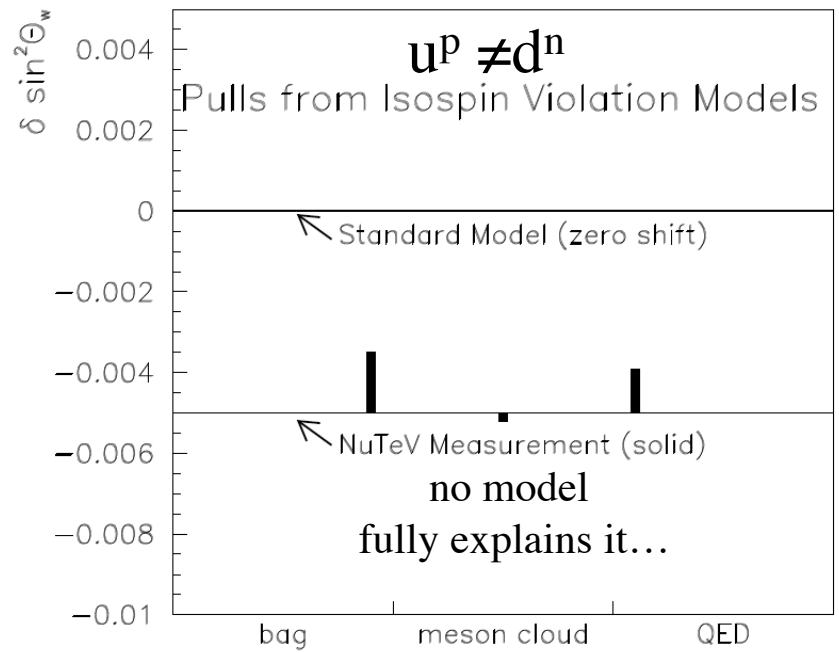
relative left vs right handed coupling

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



(NuSOnG measures $\sin^2\theta_W$ in 2 ways!)

New Physics,
e.g. nonuniversality?
or
"Standard Model"?



Constrain nuclear isospin violation through QCD measurements

(specifically: $\Delta xF_3 = xF_3^{\nu} - xF_3^{\bar{\nu}}$)

NEW!

Which gives me the opportunity to highlight…

QCD Studies
e.g. xF_3

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

Important to the EW studies!

- 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.

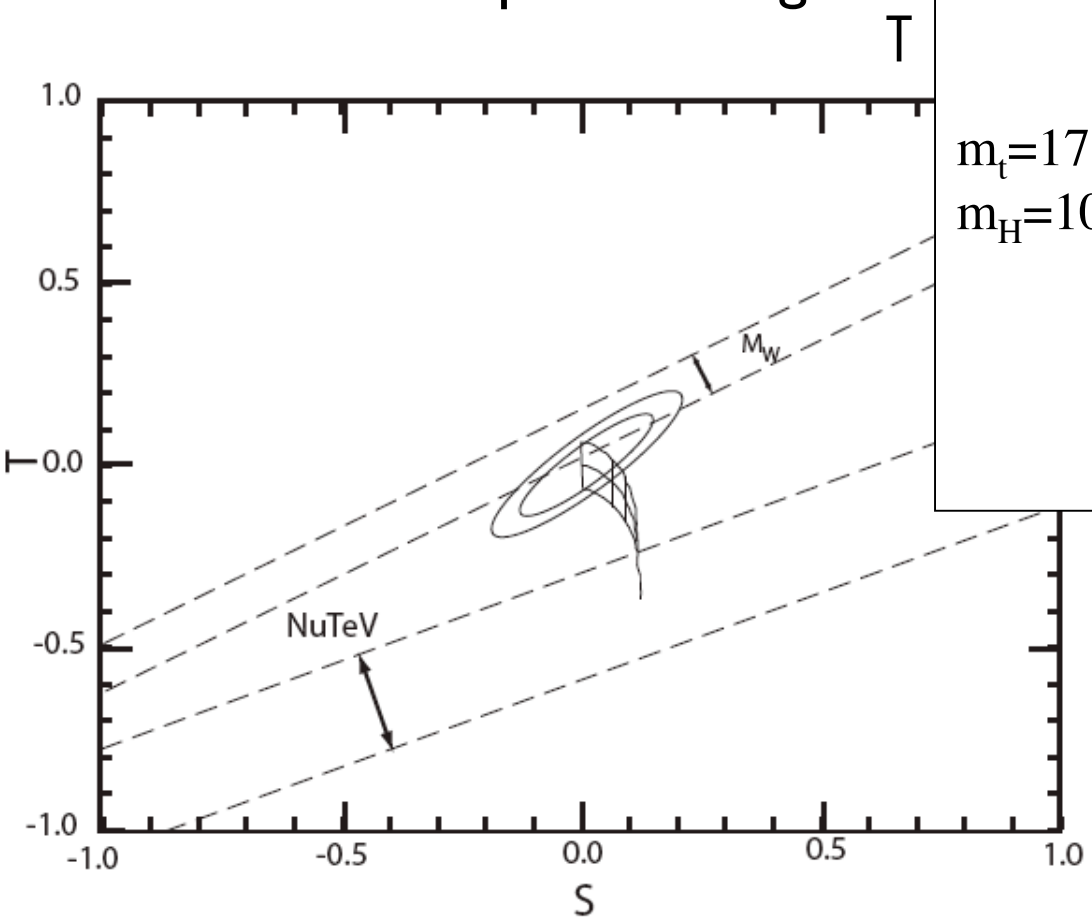
NuSOnG will have SiO_2, C, Al, Fe and Pb targets,
Kinematic range matches eRHIC and complements Minerva

By comparing our measurement to LHC,
we can help sort out new their new physics signatures.

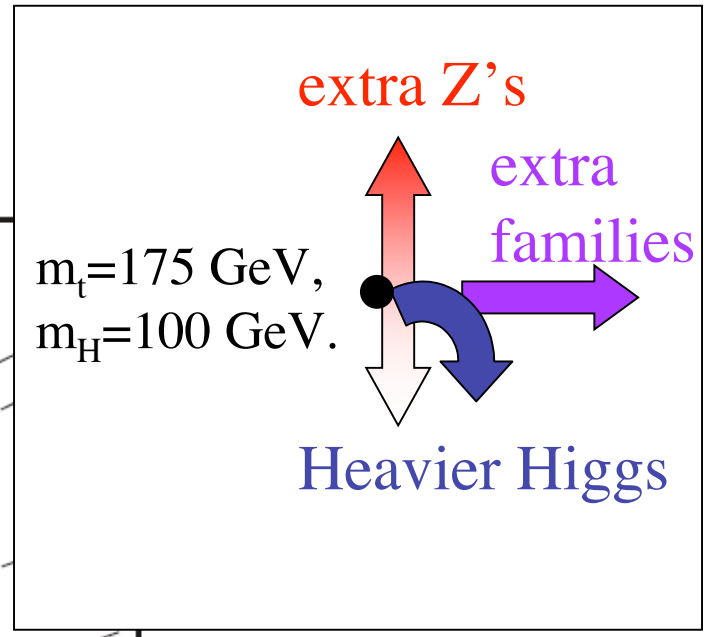
Take $\sin^2 \theta_W$ and ρ and map them to

S = weak isospin conserving

T = weak isospin violating



very roughly:

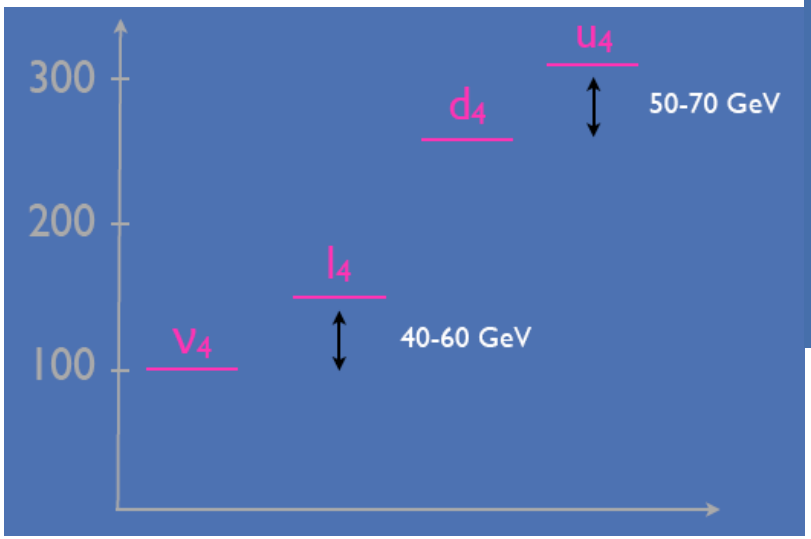


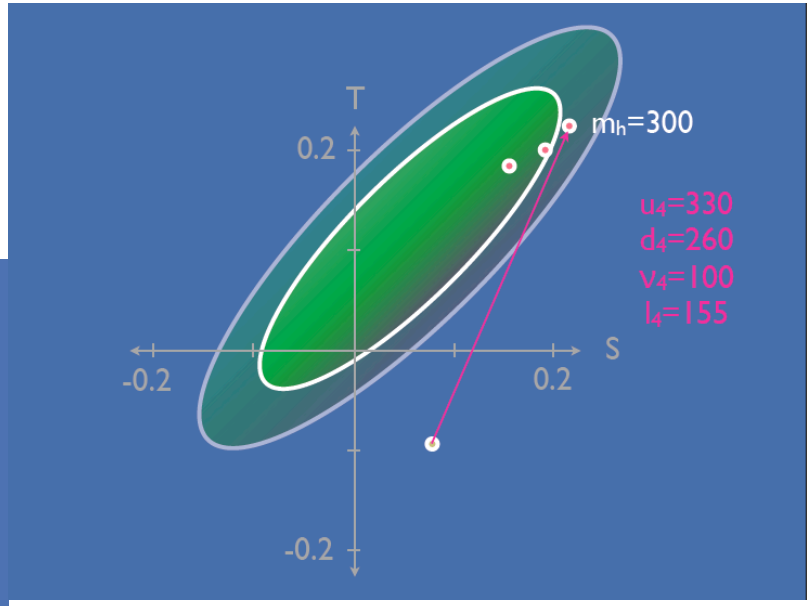
An example: A Chiral 4th Generation Model

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:

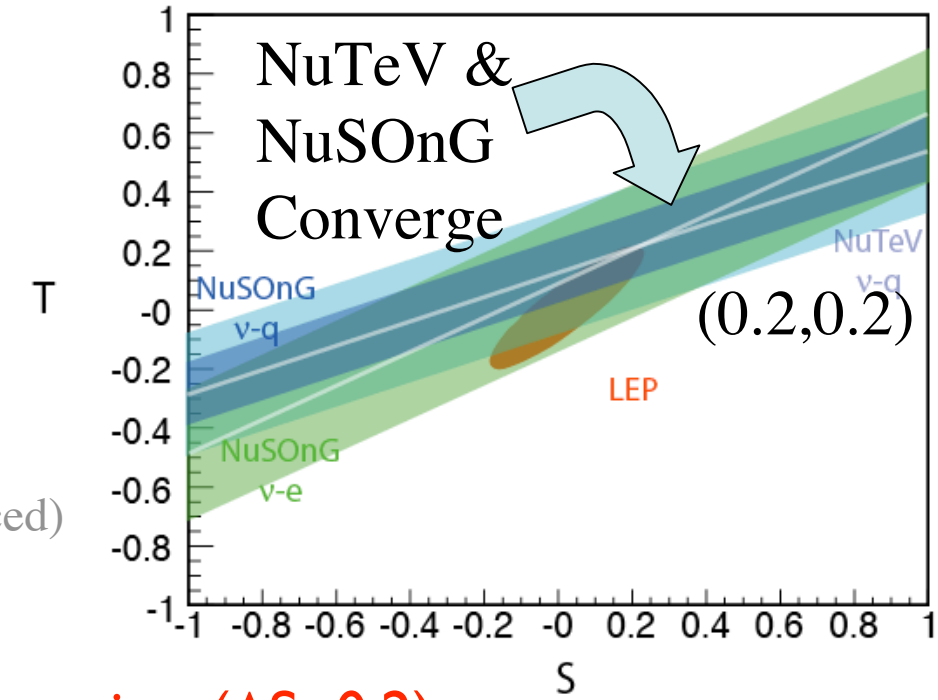
- Highly enhanced H →ZZ
- The Higgs mass,
  lets say 300 GeV
- complex decay modes
  (e.g. 6W's and 2 b's)

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

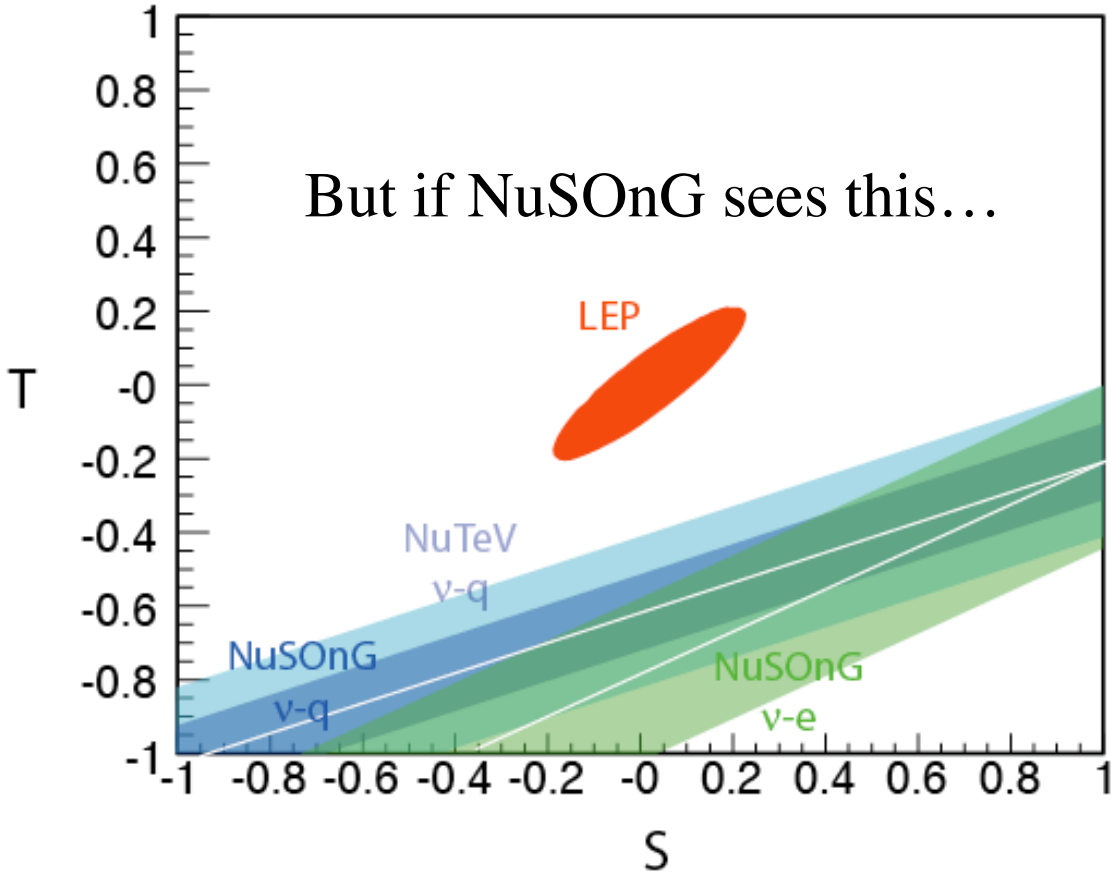


A Chiral 4th generation (ΔS=0.2)
with isospin violation (ΔT=0.2)

Pick your favorite LHC BSM model, I'll show how we help…

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

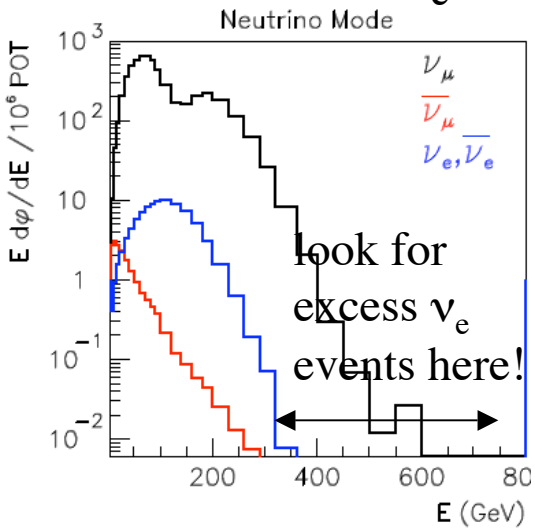
Not!

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 $\nu_\mu \rightarrow \nu_e$
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

$\bar{\nu}_\mu + e^- \rightarrow \mu^- + \bar{\nu}_e$ -- this should not occur!

But if $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$, then $\bar{\nu}_e + e^- \rightarrow \mu^- + \bar{\nu}_\mu$ … same signature!

Unique Capability!

Conclusions:

A new Tevatron Neutrino Program is very physics-rich
with great discovery potential

The physics program is unique in the world
and complements our present neutrino & collider programs.

The facility is challenging, but constructable.

NuSOnG is a versitile and exciting experiment
that can anchor this program.

I hope you have ideas to add!