Direct Searches for New Physics at NuSOnG

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Outline

1. Neutrino properties
2. New physics and possible signatures in the neutrino sector
3. The NuSOnG experiment
4. Direct searches for new physics at NuSOnG
   - **New interactions**
   - **New particles**
   - **New mixing properties**

Neutrino properties

What we know

- non-zero masses
- 3 active (SM) flavors: electron, muon, tau
- mixing
- interact through weak force and gravity

What we don't know

- absolute masses?
- any other 'flavors'?
- $\theta_{13}=0?$ θ_{23} maximal? CP violation?
- any other interactions?

New physics and how they manifest in the neutrino sector

1. Are there new interactions in the neutrino sector?
   Signature: rare neutrino events

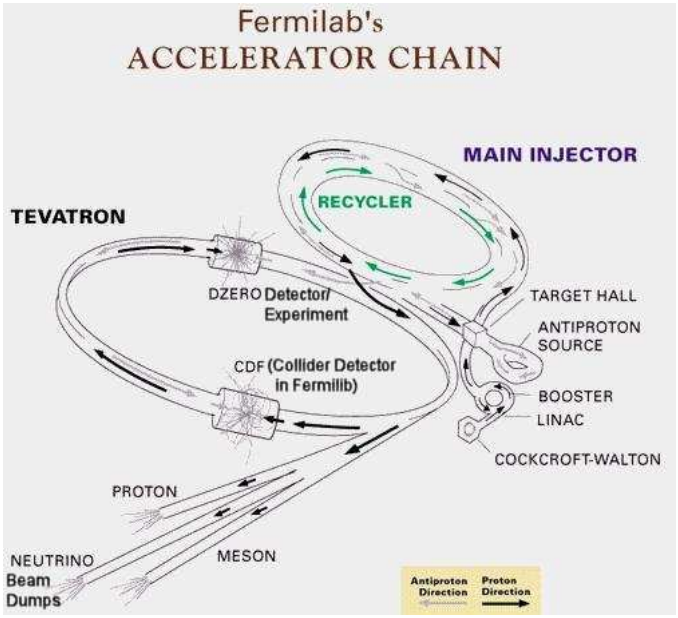
2. Are there new particles?
   Signature: characteristic decay modes

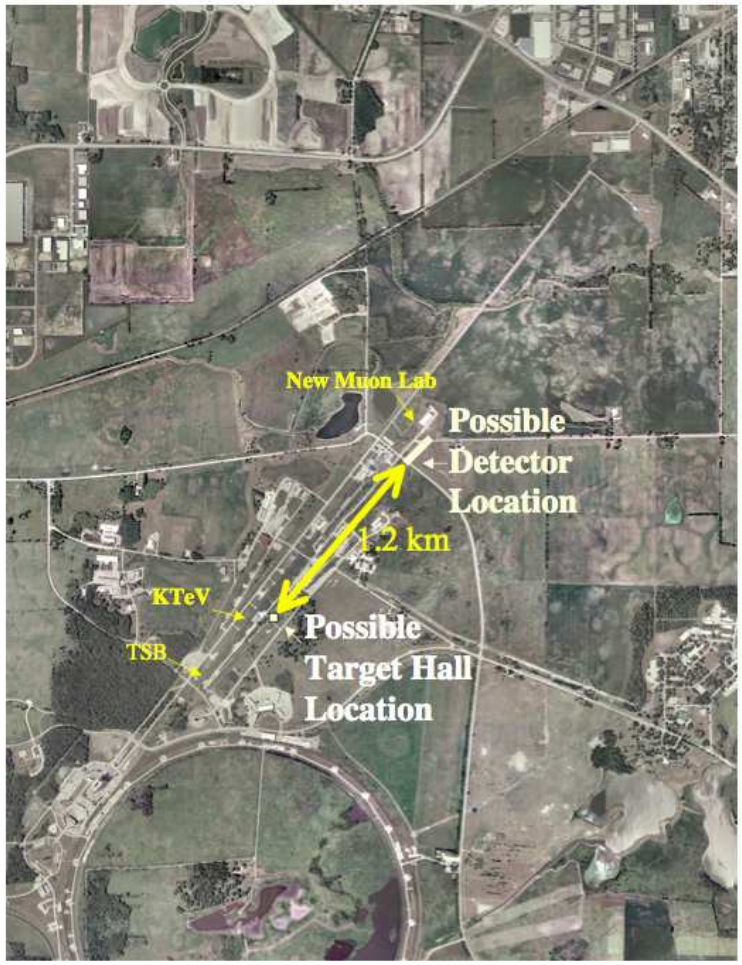
3. Is there new physics (sterile neutrinos, non-standard interactions, etc.) that could manifest through modifications to neutrino mixing?
   Signature: instantaneous flavor transitions, etc.

NuSOnG [**Neu**trino **S**cattering **On G**lass]

… is a high statistics, high-energy
neutrino scattering experiment proposed
to run at the Fermilab Tevatron

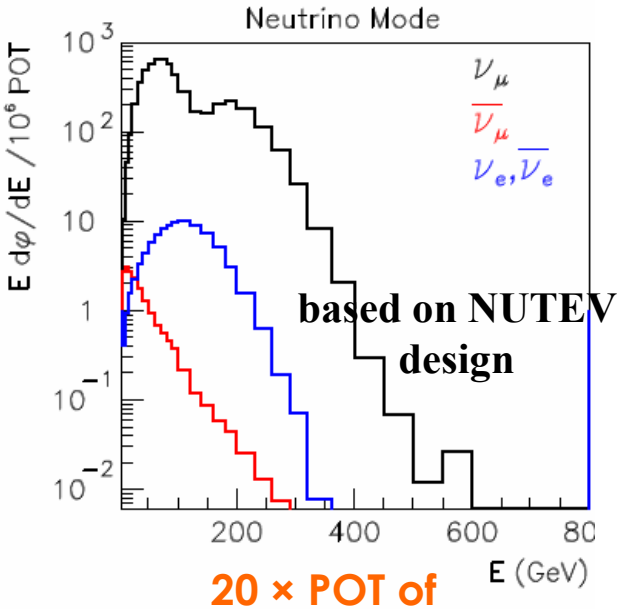
NuSOnG will use 800 GeV protons from Fermilab's Tevatron





Mean neutrino energy ~100 GeV

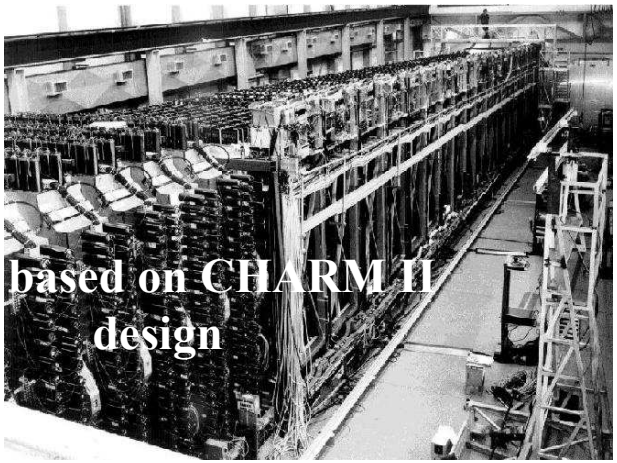
High-energy, very flavor-pure (muon) neutrino beam



20 × POT of NuTeV

×

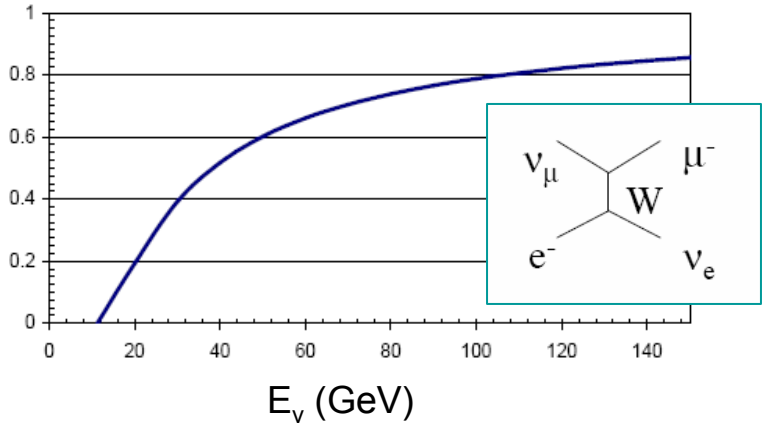
Well-segmented, massive detector



6 × mass of CHARM

High-energy, because we'd like to use IMD events to constrain our flux prediction

IMD Threshold Factor

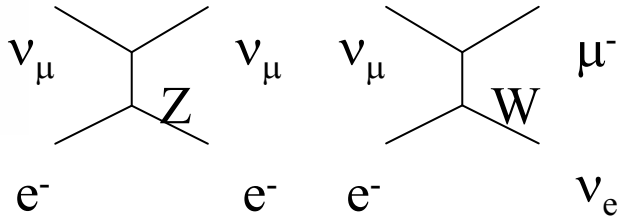


High Statistics & High Precision…

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

Rates assume:
1.5E20 POT in **neutrino mode**
0.5E20 POT in **anti-neutrino mode**.

A unique opportunity for these channels!



NuSOnG will study these interactions to better than 1% precision!

… allows for a lot of new physics search opportunities!

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Terascale Physics Opportunities at a High Statistics, High Energy Neutrino Scattering Experiment: NuSOnG

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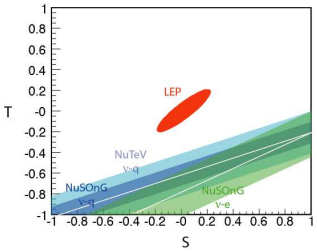
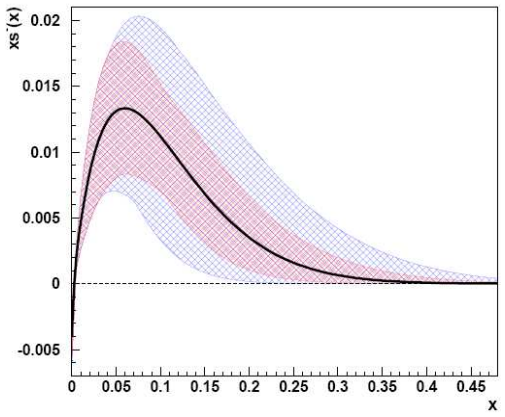
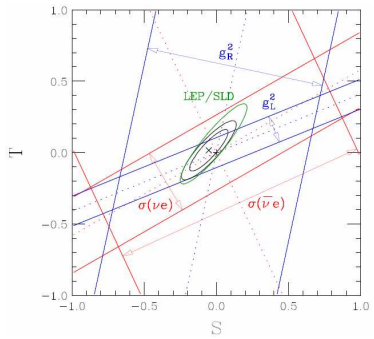
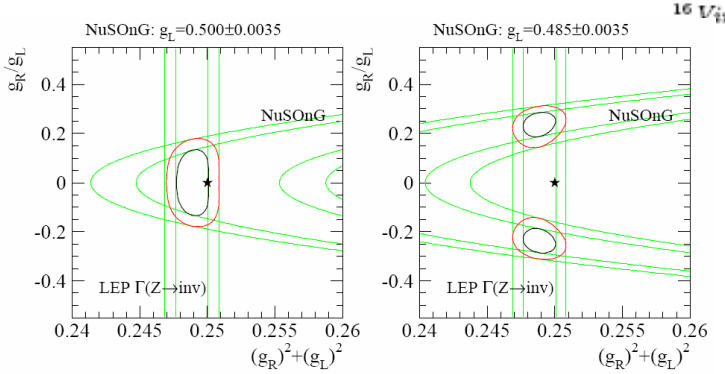
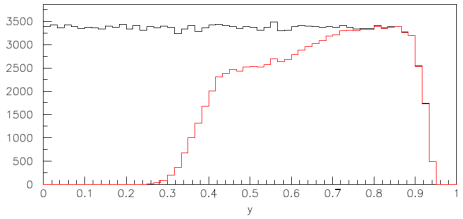
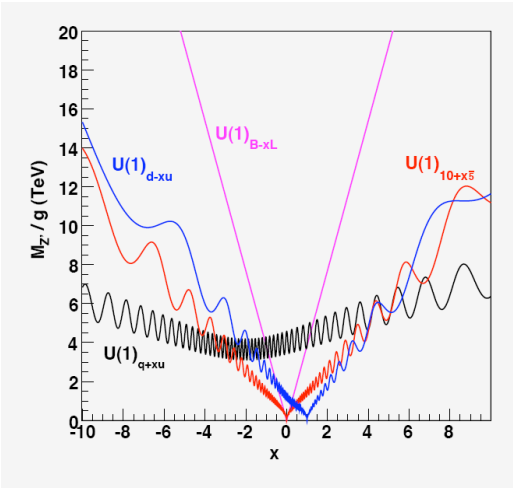












Direct Searches for New Physics

1. New interactions – manifested through rare events

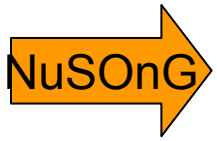
The combination of a **high-intensity and high-purity beam** and an **instrumented detector, optimized to measure IMD with high-accuracy** makes NuSOnG ideal for searching for:

Wrong Sign IMD ($\Delta L_e = -\Delta L_\mu = 2$)

$\bar{\nu}_\mu + e^- \rightarrow \mu^- + \bar{\nu}_e$ …this is forbidden in the SM!

Best limits (90%CL) are from NuTeV
[PRL 87:071803, 2001]

1.7% on V-A couplings
0.6% on the scalar coupling

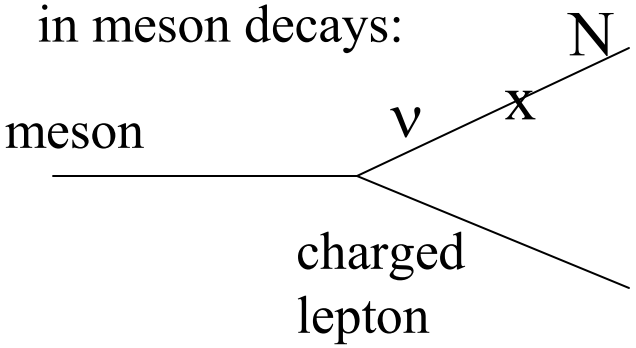


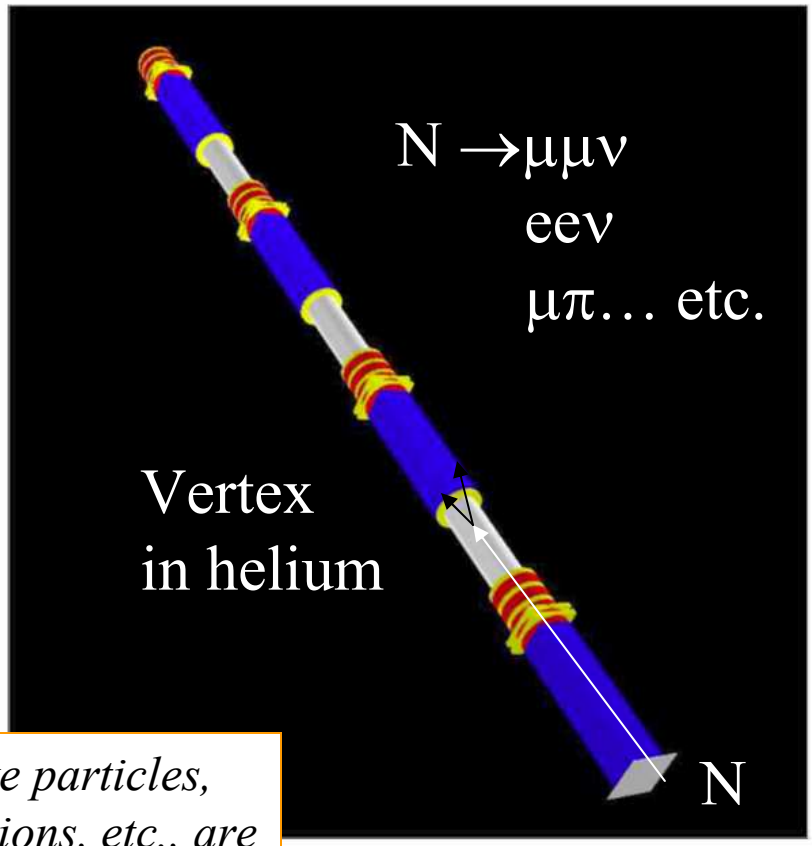
0.6% on V-A
0.2% on scalar

2. New particles –
A direct search for "neutrissimos"

Filling the 15 m region between sub-detectors with helium and looking for neutrissimo decays…

These are produced through mixing in meson decays:





Searches for axion-like particles, dilaton-like particles, light vector bosons, light inflatons, light radions, etc., are also possible.

3. New light neutrino properties – Mixing freedom

Mixing freedom arises when the 3x3 neutrino mixing matrix is non-unitary

$$U = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \qquad \sum_j |U_{\alpha j}|^2 = 1 - X_a$$

Underlying physics:

- sterile neutrinos

- flavor-dependent neutrino couplings

- new particles

- etc.

Modifications to standard oscillation probabilities:

Disappearance:

$$\sum_j |U_{\alpha j}|^2 = 1 - X_\alpha, \qquad \textit{[hep-ph/0705.0107]}$$

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

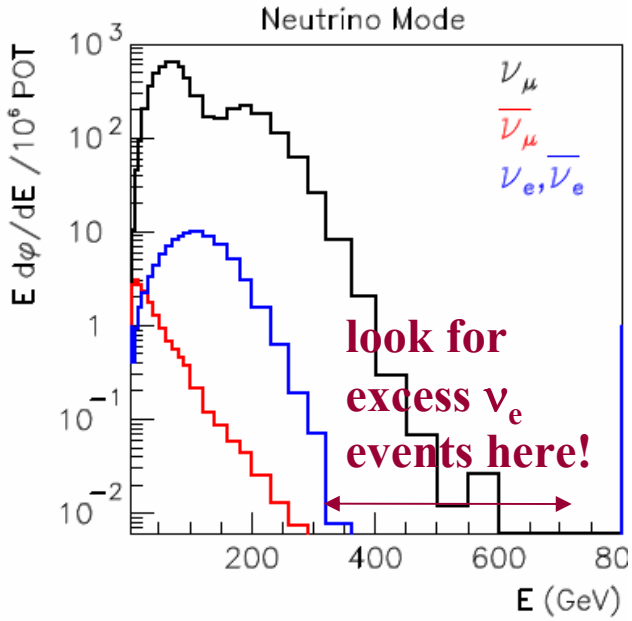
L/E dependent

Not!

Appearance has the same effect!

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

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



To see instantaneous $\nu_\mu \rightarrow \nu_e$
look for an increase
in ν_e rate at $E_\nu \sim 350$ GeV

NuSOnG's reach: 10^{-5} level

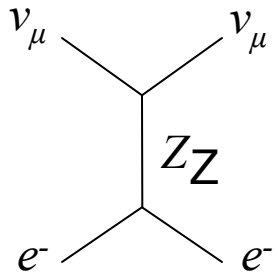
- **Look for "wrong sign" IMD**

If $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$, then $\bar{\nu}_e + e^- \rightarrow \mu^- + \bar{\nu}_\mu$

… same signature as WSIMD!

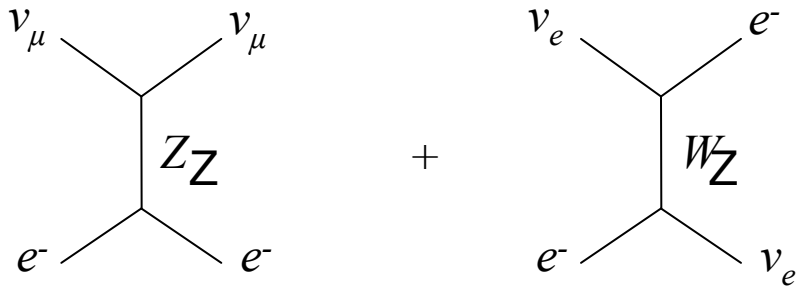
- **Look for increase in ν_μ NC scattering rate**

Without ν_μ transitions, the NC ES rate is just:



With $\nu_\mu \rightarrow \nu_e$ the effective rate becomes:

(to first order)



ν_e cross section is 7x larger

NuSOnG's reach: 10^{-3} level

Seeing all 3 effects would be a striking signature!

Conclusions

With a very pure, high-flux and high-energy neutrino beam one can directly search for new physics in the neutrino sector in unique ways.

Our proposed experiment, NuSOnG, is an ideal tool for such searches.