NuSOnG: Neutrinos Scattering on Glass

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The Neutrino Scattering on Glass (NuSOnG) experiment consists of four detector modules, each composed of a finely segmented calorimeter followed by a muon spectrometer. The detector will be illuminated by a neutrino or antineutrino beam from the Tevatron at a rate corresponding to 5×10^{19} protons on target per year. Over five years, NuSOnG will make precise measurements of both neutrino-quark and neutrino-electron scattering and will accumulate the world's largest sample of neutrino-electron events. These data will provide unique opportunities for discovering physics beyond the Standard Model (including lepton flavor violation and new particles) as well as determine structure functions over a wide range of x and Q^2. The breadth of anticipated measurements makes NuSOnG a program rather than an experiment. The design heritage ensures that the approach is low-risk and cost-effective. A neutrino flux a factor of twenty higher than the flux delivered to NuTeV and a target mass a factor of six higher than NuTeV give an overall increase in neutrino data sample more than a factor of one hundred over previous experiments.

The NuSOnG program has three physics components: electroweak physics, searches for new particles and interactions, and precise studies of QCD. In the era of the ILC and LHC, these studies are important because neutrinos appear in the final state at colliders making it impossible to determine their flavor. At NuSOnG, the initial beam determines the neutrino flavor allowing for studies of neutrino universality and unitarity not possible at collider experiments.

The NuSOnG electroweak program arises from our view that an experiment probing the high-energy interactions of neutrinos is a necessary complement to the LHC and an important lead-in to the ILC. In the next few years, the LHC will reveal the nature of electroweak symmetry breaking; the Higgs mass will cease being a prediction of the electroweak theory and will become an input to the theory. With a known Higgs mass as an input parameter, precision electroweak data, including neutrino scattering data, will be much more powerful as a tool for constraining physics beyond the Standard Model that directly influences the electroweak sector. Since NuSOnG probes neutrino interactions in two different ways with a sensitivity comparable to that of the LEP experiments, NuSOnG measurements will provide access to models of new interactions that cannot be probed at LHC or ILC. Figures 1 and 2 show two examples of how NuSOnG measurements would shed light on different scenarios of physics beyond the standard model.

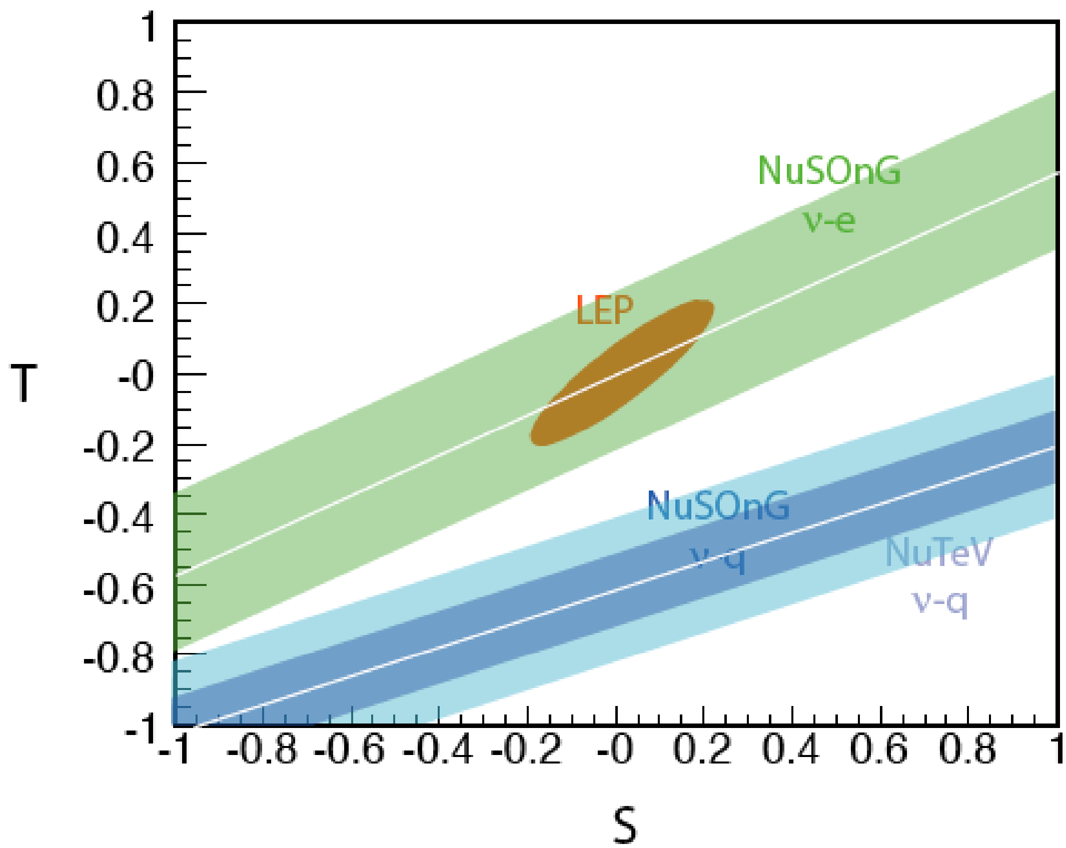

Figure 1 - Three projected electroweak measurements from NuSOnG in the S-T plane. NuSOnG is sensitive to new physics in the neutirno sector which will manifest itself as disagreement withother measurements. Here, the neutrino-electron (green) and deep inelastic (dark) 68% CL EW measurements from NuSOnG projected onto the S and T plane, are compared to the LEP e^+e^- 68% Cl measurements (red) which are blind to new physics manifested in the neutrino couplings and the NuTeV measurement (light blue). By tradition, the LEP results define (0,0) on this plot.

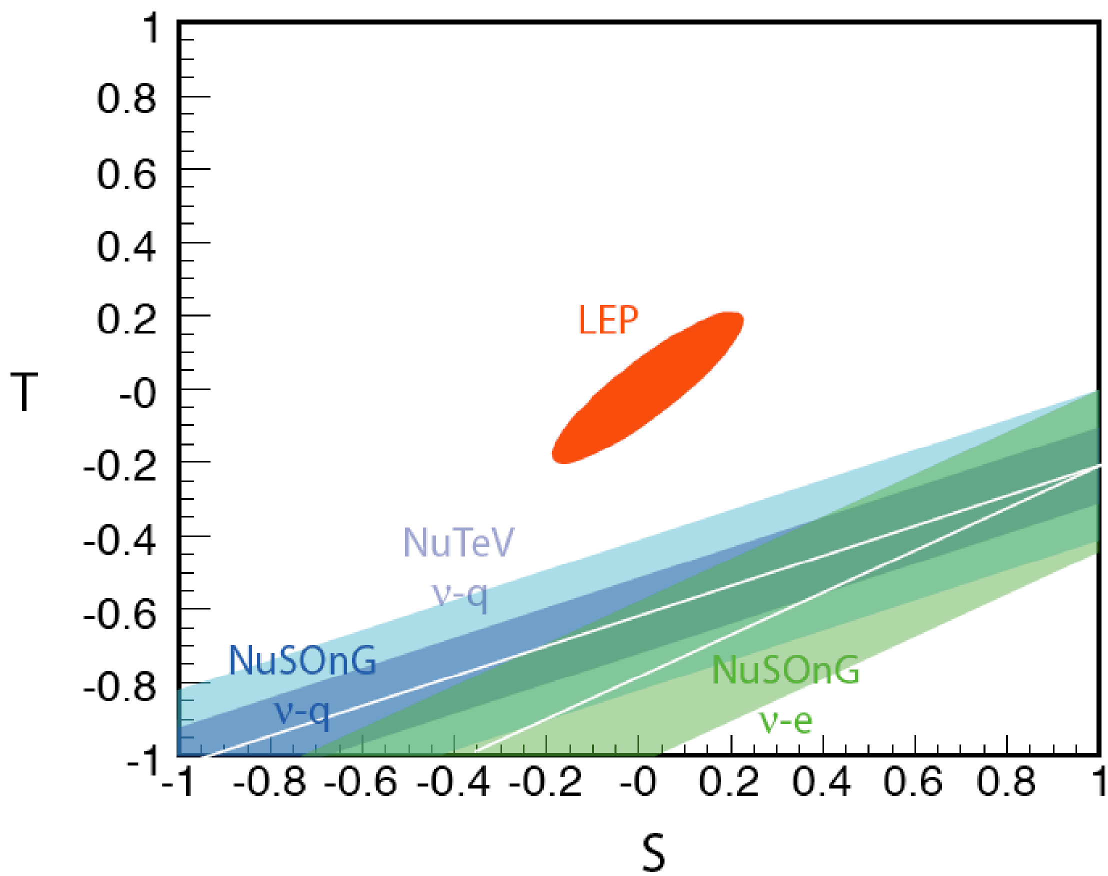

Figure 2 - Three projected electroweak measurements from NuSOnG in the S-T plane for a model with a heavy Higgs inspired by the NuTeV measurement. The labeling is as in Fig. 1.

NuSOnG can also carry out direct searches for new physics in a number of different ways. A search for "matrix freedom" or "nonunitarity" provides a very general example. The presence of a fourth generation neutrino can result in an apparently instantaneous ν_μ to ν_e transition. There is of course ν_e contamination in the incident neutrino beam, but the contamination at high energies ($E_\nu > 250$ GeV) is quite low allowing a sensitive search in high energy region. A sensitivity of 10^{-4} for the transition probability will be possible with the full NuSOnG data set. A search for lepton number violation gives a second important search channel. Here again the large data sample allows a search for the lepton number violating process $\bar{\nu}_\mu + e^- \rightarrow \mu^- + \bar{\nu}_e$. The current limit for this process is surprisingly high, 1.7% (at 90% c.l.) of the inverse muon decay (IMD) rate NuSOnG should have at least an order of magnitude more sensitivity. Measurement of the IMD rate, $\nu_\mu + e^- \rightarrow \mu^- + \nu_e$ gives access to the study of scalar currents in weak charged current interactions. The current lower limit on the standard model coupling is $g_{LL}^V > 0.96$, which allows scalar interactions at the percent level. NuSOnG should be able to improve this limit by a factor of four to better than $g_{LL}^V > 0.99$. NuSOnG will also carry out searches for long-lived, light neutral heavy leptons ("neutralissimos"), muonic photons and sterile neutrino oscillations.

An important aspect of NuSOnG is that new physics can be probed through both elastic and Deeply Inelastic Scattering (DIS) scattering. The elastic scattering measurement is a theoretically robust, purely leptonic measurement. On the other hand, as discussed above, the DIS measurement requires knowledge of Parton Distribution Functions (PDFs) which describe the momentum distribution of quarks as a function of Q^2. This can bring in theoretical uncertainties from sources such as nuclear effects and nuclear isospin violation. The strength of NuSOnG is that these questions can be directly addressed using our own data. At the same time these QCD studies produce interesting results in their own right. The experiment will generate an unprecedented sample of hundreds of millions of DIS events. This can be used to measure six structure functions (xF_3, F_2 and R) on neutrinos and antineutrinos separately. This measurement will be the first of its kind, since past attempts have been limited by statistics. The dimuon data also allows measurement of the strange and antistrange parton distributions to more than an order of magnitude higher precision than the past. This allows us to address the important question of the the strange versus antistrange sea asymmetry. The highest precision QCD measurements from NuSOnG will be made on the SiO_2 target. However, we also plan to intersperse alternative target materials: C, Al, Fe, and Pb. Based on the above flux, we anticipate 202k neutrino-induced and 11.3k anti-neutrino-induced CC DIS events per ton of material. This will provide results that are complementary in kinematic range to the Minerva experiments, and which overlap in kinematic range, but are complementary in lepton scatter, to eRHIC. As a result, NuSOnG will produce interesting measurements to the nuclear as well as the particle physics community.

NuSOnG is a discovery experiment aimed at the terrain not covered by the collider experiments. The detector draws on the heritage of FMMF, CDHS, CHARM and CCFR/NuTeV. The design uses an SiO_2 target in one-quarter radiation length panels interleaved with active detector elements (proportional tubes and/or scintillator), Figure 3. This will provide the very high segmentation needed to ensure good separation between different classes of events. The total detector mass is 3.5 kt, which gives a fiducial mass of 3 kt, Table 1. A group of twenty-seven physicists have worked on developing NuSOnG and submitted an Expression of Interest to Fermilab in September, 2007. We plan to complete a *Physical Review D* article in Spring 2008 and submit a Letter of Intent to the Fermilab Program Advisory Committee in the coming months.

In terms of time scale, we would anticipate two or three years to move the detector through the approval process, during which time prototyping and costing would take place. Construction would take roughly three or four years, followed by a year of commissioning. Data taking would take five years and would start in 2015, assuming construction starts in 2010. Our request for $5x10^{19}$ protons on target per year requires that the Tevatron run at 20 times past intensities. Initial studies indicate that this is challenging but possible at a modest cost. Studies indicate the upgrade can be completed by 2015.

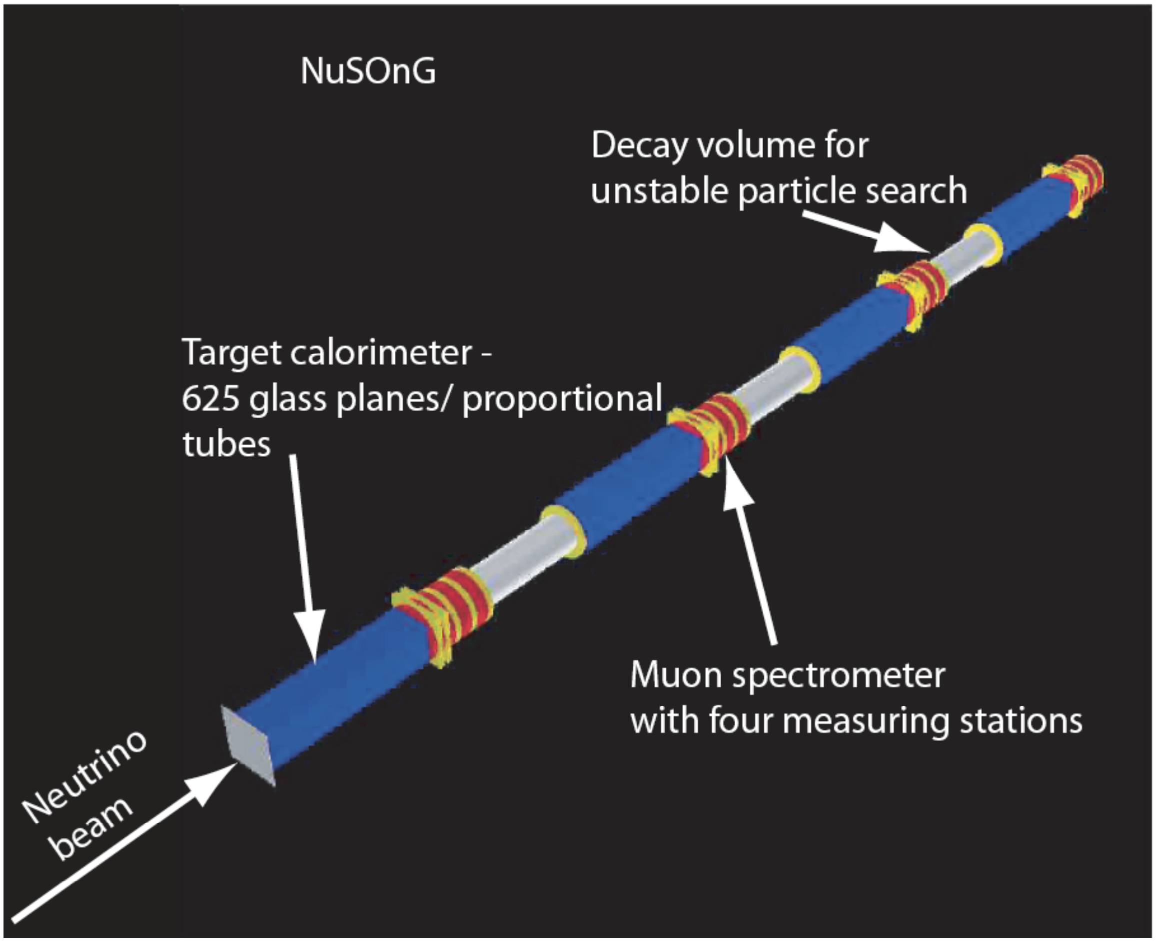

Figure 3 - Conceptual layout of the NuSOnG detector.

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

Table 1 - Summary of NuSOnG parameters for full detector shown in Fig. 3.