The Third NuSAG Report and the Steering Group

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(Most slides from HEPAP talk of Peter Meyers on July 13, 2007)
http://www.science.doe.gov/hep/HEPAPJuly2007Agenda.htm

From NuSAG's second charge letter:

"Assuming a megawatt class proton accelerator as a neutrino source, please answer the following questions for accelerator-detector configurations including those needed for a multi-phase off-axis program and a very-long-baseline broad-band program."

The questions:

- Scientific potential
- Associated detector options, including rough cost
- Optimal timeline, including international context
- What other scientific inputs are needed?
- What additional physics can be addressed?

"Phase 1": currently approved or planned – primary goal is to determine $\sin^2 2\theta_{13}$

Reactor experiments

- Double Chooz: 3σ sens $\sin^2 2\theta_{13} \sim 0.05$ by late 2012
- Daya Bay: 3σ sens $\sin^2 2\theta_{13} \sim 0.02$ by 2013

Accelerator experiments (with currently planned beam power)

- T2K: 90%CL sens $P(\nu_\mu \rightarrow \nu_e) \sim 0.01$ by late 2012
- NOvA: 3σ sens $\sin^2 2\theta_{13} \sim 0.02$ by 2014; ~0.01 by late 2017
- NOvA+T2K: some sensitivity to mass hierarchy at the highest currently allowed θ_{13}'s

"Phase 2": NuSAG's current charge

- Next round of accelerator experiments to **extend mass-hierarchy and CP violation sensitivity** to $\sin^2 2\theta_{13} \sim 0.01$ – seems to be about the max reach with conventional beams

Goals of the next phases of the worldwide experimental program in neutrino oscillations

Fill out our understanding of 3-neutrino mixing and oscillations:

- What are the orderings and splittings of the neutrino mass states?
- What are the mixing angles?
- Is there CP violation in neutrino mixing?

A world-wide effort has laid out an ambitious program that can do ***all*** of this – subject to the values of the unknown parameters.

Goals of the next phases of the worldwide experimental program in neutrino oscillations

These are difficult experiments, requiring huge detectors and high-power beams:

100-500 kton detectors (Super-K: 22.5 kton)

1 MW beam (NuMI: 170 kW average)

Optimistic timescales run to 2030

Costs: $n \times \$100\text{M}$, with $n >$ (>>?) 3

U.S. experimental scenarios using these approaches

All start with Fermilab Main Injector

- Max achieved beam power: 315 kW @ 120 GeV
- Initial upgrade plan to 700 kW – part of NOvA project
- Possible longer-term upgrade to 1.2 MW (or even 2 MW)
- Less beam power at lower energies

Off-axis

- ~100 kton of Liquid Argon TPC
- Use existing/upgraded NuMI beam
- Deploy all at NOvA site, or split with "2nd max", or other

Wide-band beam, very long baseline

- ~300-500 kton of water Cherenkov (or ~100 kton LArTPC)
- In DUSEL
- New neutrino beam

Other Physics – No Accelerator Needed

Nucleon decay

- Water Cherenkov detector 15 times Super-K fiducial volume
  excellent general purpose detector
- Liquid argon TPC – excellent for SUSY preferred decay $p \rightarrow K^+ \nu_\tau$ due to good tracking
- Could become high priority if Super-K sees candidates

Low energy neutrino astrophysics

- Neutrino burst from galactic supernova
- Diffuse supernova neutrino background
- Some solar neutrino physics

Other physics may increase costs (e.g. more PMT's for Low E)

Sensitivity calculations by BNL/FNAL Study Group

Options presented by NuSAG (many others looked at):

1. Off axis, 100 kton LAr at NOvA site
2. Off axis, 50 kton LAr at NOvA site + 50 kton LAr at 2^{nd} max
3. Wide-band, 300 kton Water Cherenkov at Homestake
4. Wide-band, 100 kton LAr at Homestake

Note: rule of thumb was LAr ~ 3×WaterC, hence

300 kton WaterC ←→ 100 kton LAr

but under the assumptions developed for the calculations, the factor is more like ×4-5

All benefit from more intense proton source

Sensitivity calculations by BNL/FNAL Study Group

NuSAG's criteria:

- Establish $\theta_{13}\neq 0$: At what $\sin^2 2\theta_{13}$ is $\sin^2 2\theta_{13}=0$ rejected at 5σ for all values of δ_{CP}?
- Determine the mass hierarchy: At what $\sin^2 2\theta_{13}$ is the wrong mass hierarchy rejected at 5σ for all values of δ_{CP}?
- Find CP violation: At what $\sin^2 2\theta_{13}$ are $\delta_{CP}=0$ and π rejected at 5σ for 50% of the values of δ_{CP}?

The cost, effort, and time required demand that the program's discovery potential be held to high standards.

Option	$\sin^2 2\theta_{13}$ 5σ, all δ_{CP}	CPV 5σ,50% δ_{CP}	$\mathrm{sgn}(\Delta m^2_{13})$ 5σ, all δ_{CP}
1) NuMI-ME 0.9° 100 kt LAr,1st max	0.008	0.08	0.18
2) NuMI-LE 0.9°/3.3° 50/50 kt LAr,1st/2nd max	0.011	>0.10	0.15
2A) 100/100 kt LAr	0.009	0.08	0.08
3) WBB 0.5° 300 kt H_2O Ch,1300 km	0.015	>0.10	0.032
3A) 60×10^{20} p.o.t. each	0.012	0.08	0.022
4) WBB 0.5° 100 kt LAr,1300 km	0.008	0.035	0.019

Timeline

A. Decision/approval

NuSAG advocates learning size of $\sin^2 2\theta_{13}$ from Phase 1 experiments before proceeding with Phase 2

- Double Chooz: 3σ sens $\sin^2 2\theta_{13} \sim 0.05$ by late 2012
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NuSAG conclusion: 2012 at earliest

Project approval process: 3-4 years

Timeline – 2

B. Construction

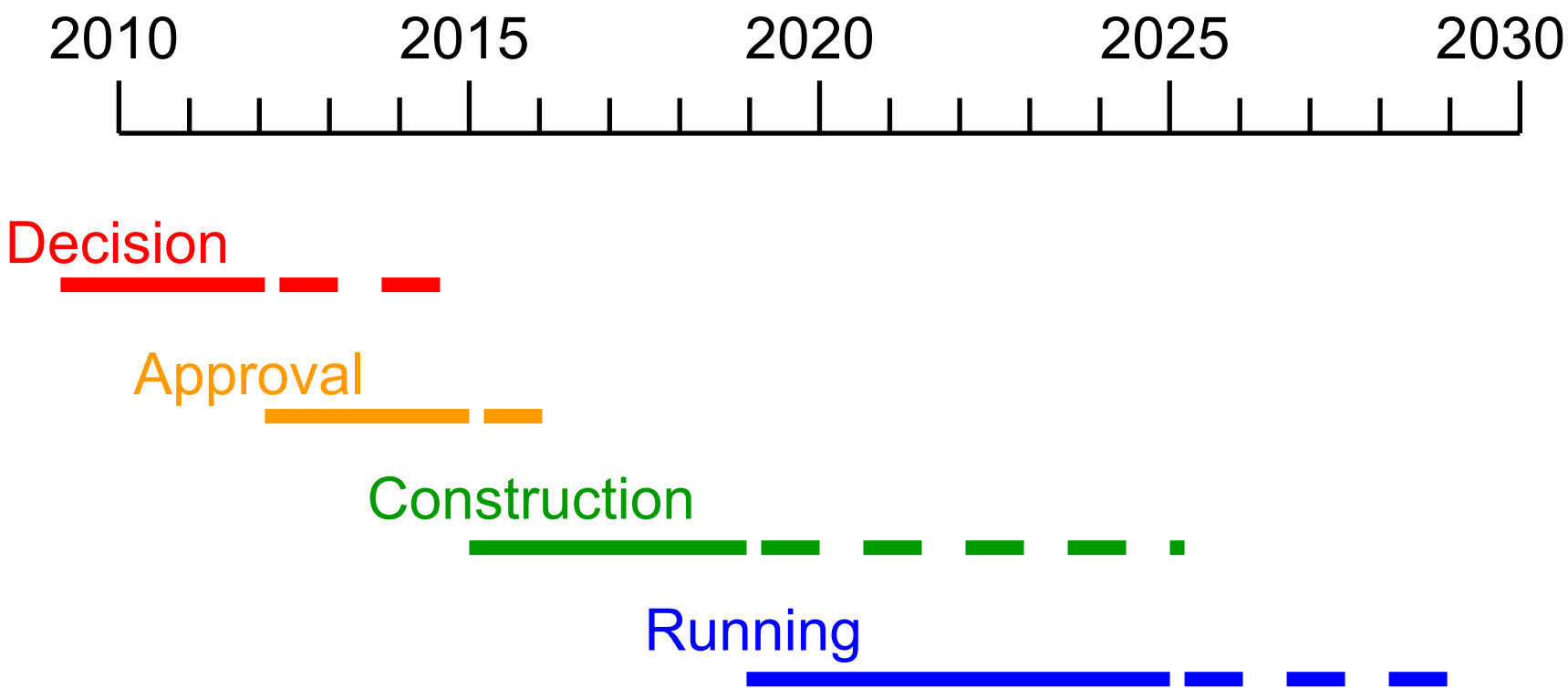
Water Cherenkov: 7-10 years, limited by PMT production – decrease by more suppliers? (cash flow issue)

LArTPC: not known – guess 4-6 years??

If in DUSEL, ready for occupancy when?

C. Running

Sensitivity plots assumed 6-10 years @ 1 MW


2010
2015
2020
2025
2030
Decision
Approval
Construction
Running

Summary

- Plausible extrapolations of existing technology will allow 5σ searches for CP violation in the neutrino sector and 5σ determinations of the mass hierarchy down to $\sin^2 2\theta_{13} \sim 0.03$, with substantial sensitivity to ~ 0.01.

  These are important physics goals!

- The large detectors needed for such measurements can also extend the sensitivity of searches for proton decay and neutrinos from astrophysical sources.

NuSAG Recommendations

1. US should prepare to proceed with next generation neutrino oscillation program
2. Support R&D on intense beams – both NuMI and new beam to DUSEL
3. Support R&D on large water Cherenkov detectors
4. Support R&D on liquid argon TPC