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PERSPECTIVES ON NEUTRINO TELESCOPES 2009

CHRIS QUIGG
Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510 USA
and
Institut für Theoretische Teilchenphysik
Universität Karlsruhe, D-76128 Karlsruhe, Germany
E-mail: quigg@fnal.gov

ABSTRACT

Remarks at the roundtable on plans for the future at the XIII International Workshop on Neutrino Telescopes.

1. Neutrino Properties and Neutrino Astronomy

I would like to begin by saying in full voice what has been implicit in the presentations by all the other participants in this roundtable: the scientific achievements and scientific promise of neutrino observatories and their companion experiments are glorious.

Concerning neutrino properties, we look forward to addressing many specific questions: Having established the gross features of neutrino oscillations, we want to know what are the subdominant neutrino transitions. How closely does the pattern of neutrino mixing conform to simple symmetry predictions? Is the neutrino mass hierarchy normal or inverted, and what is the absolute scale of neutrino masses? What is the bottom line on the LSND and MiniBooNE observations? Is neutrino mass a sign of nontrivial physics beyond the standard model? Do neutrino masses probe extra dimensions? Can we find evidence for (or against) a sterile neutrino? Can we find evidence for lepton-number violation that demonstrates that neutrinos are Majorana particles? If so, do heavy right-handed "neutrinos" provide information about energy scales far above the electroweak scale? Can we map a detailed connection between neutrino mass and lepton-flavor violation? How could a light sterile neutrino arise? Does the "atmospheric" mixing angle θ_{23} correspond to maximal mixing? If not, is the extreme mass eigenstate ν_3 richer in ν_μ or ν_τ? Is the angle θ_{13} observably large? What would it take for us to detect CP violation in neutrino mixing? Does neutrino mixing respect CPT invariance? What constraints can we place on neutrino lifetime and on electric or magnetic dipole moments of the neutrino? Does leptogenesis explain the excess of matter over antimatter in the universe? How do neutrinos shape the universe? And finally, what will be the best and fastest ways to obtain information we so urgently desire about neutrinos, flavor, and identity?

Such a long list[a] speaks to the richness of flavor physics. We are very good at specifying the quantities that we want to measure—the blanks in tables of numbers that we want to fill in. We have much work to do—I think of it as our homework problem over the next decade—to understand what broad questions we hope to answer by working out the patterns. In contrast to the issues of the 1-TeV scale and electroweak symmetry breaking, which are highly developed and for which we believe the tools are at hand, we have not yet identified what we hope nature is trying to tell us through flavor physics. As an aside, while the seesaw tradition encourages us to think that neutrino properties are linked to physics at a very high scale, it is well possible that neutrino mass is generated nearby—perhaps even on the TeV scale[2)]. The seesaw itself may entail TeV-scale phenomena[3)]. Regular dialogue between neutrino physics and LHC physics should be a continuing strong feature of our research.

While pinning down the properties of neutrinos may well give us indications of physics beyond the standard model, perhaps including nonstandard interactions[4)], there are also many openings for new physics (or new manifestations of old physics) *within the standard model.* I have in mind phenomena implied by the standard model, including those too subtle to have attracted our notice—either theoretical or experimental—until now. A famous example of new physics hiding within the electroweak theory is the nonperturbative violation of baryon number mediated by sphalerons, with its possible implications for baryogenesis.[b] Of current interest is the identification (by theorists) of a $Z\gamma\omega$ anomaly-mediated neutrino-photon interaction in the presence of baryons[7)], which could have implications for low-energy neutrino scattering in the laboratory and in astrophysical settings. It does not appear[8)] that this interaction accounts for the low-energy excess of electromagnetic energy observed by the MiniBooNE experiment[9)]. Looking deeper within the standard model provides added motivation for experiments to measure and understand neutrino cross sections (Minerνa) and hadroproduction (HARP, MIPP, SciBooNE) at low energies[10)]. I expect the search for new physics within the standard model to take us into very rich terrain over the next few years.

Neutrino observatories may well contribute to elaborating neutrino properties, but neutrino astronomy has an independent agenda as well[11)]. An early goal of the next generation of neutrino telescopes will be to detect the flux of cosmic neutrinos that we believe will begin to show itself above the atmospheric-neutrino background at energies of a few TeV. The first interest of the science program is to prospect for cosmic-neutrino sources and characterize the sources. Detecting the diffuse glow of supernova relic neutrinos is a particularly challenging task. In time, we may foresee contributions to the study of neutrino properties and sensitivity to new phenomena in particle physics. I would like to underline the importance of flavor identification

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[a] For some context and pointers to the literature, see my summary talk[1)] at NuFact08.

[b] Electroweak baryogenesis[5)] remains a candidate explanation for the baryon asymmetry of the universe in supersymmetric extensions of the standard model[6)].

for the particle-physics, and astrophysics, capabilities of the neutrino observatories.[c] Combined with our improving knowledge of neutrino mixing, observing the flavor composition of neutrinos arriving at Earth may help us establish the nature of the neutrino sources, and would add an important means of searching for unexpected behavior, including neutrino decays. Should neutrino telescopes be able to identify neutral-current interactions with high efficiency, *and measure the neutrino energy,* a step or bump in the neutral-current to charged-current ratio, measured as a function of energy, would be an excellent flux-independent diagnostic for the onset of new phenomena. New physics typically contributes equally to charged-current and neutral-current cross sections, whereas standard electroweak interactions favor the charged current over neutral current, by a factor of two or three. It is important to push for this capability.

Although it is a highly important quest, I am not highly optimistic about the prospects for indirect detection of dark-matter relics through their annihilation products. If, as straightforward argumentation suggests, dark matter is composed of weakly interacting particles with masses in the few-hundred-GeV range, then the plausible number density—even for cuspy profiles—does not lead to observable annihilation rates. Large "boost factors" may not violate first principles, but they don't seem to arise automatically from the physics we know. If a signal is established, we will learn a great deal.

As Copernicus, Galileo, and Kepler taught us, by observing the universe from Earth, we may learn about our observatory. At this meeting, we have heard about using geoneutrinos to study Earth's interior13) and about observing bioluminescence in an undersea neutrino telescope14). The MINOS experiment has recently published correlations between atmospheric muon (background) rates and sudden atmospheric disturbances15), and Francis Halzen informs me that AMANDA has seen the comings and goings of the ozone hole. The engagement with earth sciences seems to me a promising development. Should we be welcoming researchers and graduate students from other fields into our neutrino observatories on a wider scale? Should we imagine a global network, including the collider detectors at the Tevatron and LHC, to make available environmental data such as downgoing muon rates in real time?

2. Getting the Tools We Need

I was much impressed by the process outlined in Christian Spiering's report16) concerning the European strategy on astroparticle physics, and—as a scientist in an accelerator laboratory—envious of many lines of nonaccelerator projects laid out for development. Time will tell whether there are too many lines to be pursued at an optimal pace, but the contrast with the recent state of accelerator development is dramatic! Faced with budget convulsions and other pressures, the masters of the

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[c] I summarized some of the applications at an earlier Venice meeting12).

accelerator universe have been too timid to advance several promising lines in parallel. Without discounting the excellent work done by our colleagues to develop multiple futures, including neutrino factories, β beams, and superbeams, we should be further along as a community than we are. I was pleased by the emphasis other panelists placed on the need for more vigorous accelerator research and development, and I strongly endorse that sentiment.

3. Our Debt to Galileo

In this quadricentennial of Galileo's telescope, it was inspiring to be reminded in our opening session of the context and reception of Galileo's innovation—using an instrument to extend our human senses and explore the world around us17). In appreciation for all that Galileo has done for us, I would like to propose that each of us, as teachers of physics, do something for his memory.

Our conference program reminds us that Galileo, the icon of the moment when we humans found the courage to reject authority and learned to interrogate nature by doing experiments, expressed his approach in this way18):

> Io stimo più il trovar un vero, benchè di cosa leggiera, ch'l disputar lungamente delle massime questioni senza conseguir verità nissuna.[d]

Indeed, science has advanced over these past four centuries not so much by ruminating on the majestic questions as by examining small questions that we have a chance to answer, and then trying to weave the answers into an understanding that gives us insight into the largest questions.

By focusing on "small things," with an eye to their larger implications, Galileo spoke more powerfully to the "greatest questions" than the Venetian and Florentine philosophers and theologians who, by their authority, asserted answers. A great shame of our race as physics professors is that the elementary mechanics lab often consists in going through Galileo's motions—sliding blocks or rolling cylinders down an inclined plane—*without* an eye to their larger implications. We owe it to our students to explain *why* we require them to reënact Galileo's investigations, how we seek to integrate the answers to small questions into broader understanding. We owe it to Galileo's memory, and to our students, to convey what science really is. We need to propagate this glorious living story to our students and to the public at large.

4. On Data Preservation and Access

The roundtable addressed, in insufficient depth and nuance for my taste, the question of open access to scientific data. Unlike some of the other panelists, I am

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[d] I attach more value to finding a fact, even about the slightest thing, than to lengthy disputations about the greatest questions that fail to lead to any truth whatever.

not persuaded that open availability of all data would advance science or be worth the cost. The campaign to open data in the United States has elements of noble intention, but also entails the desire to discourage conclusions about product liability or climate change that some interests find inconvenient. That is to say, both the desire to broaden scientific inquiry and to inhibit it are at play. We scientists have an obligation to ourselves and to society to seek wise solutions, and not simply to go with the flow. Not all the potential costs are financial.

Two slogans are often invoked. The first is that astronomers make their data public, so everyone should. A couple of points are worth discussing here. One is that observation—of natural events that are here and gone—is not the same as experimentation, which should be broadly reproducible. Another is that the traditional astronomical data—photographic plates—are rather simple forms of primary information, and that much of their content can be extracted by anyone broadly familiar with the technique. Whether that is true for data from neutrino telescopes, or collider experiments, or even the coming generation of astronomical instruments is not so clear. The second slogan is that governments have paid for the data, so it belongs to the public. It is worth considering whether the governments of the world are indeed paying us to take data, or to do science. I do not argue that experimenters or observers should have exclusive rights to their data forever, but that one needs to lay out the projected benefits of some course of action, and ask what the gain to science would be.

A related, highly important, aspect of this topic relates to the persistency of data and analysis tools so that data sets can be interrogated in the future. The challenge is already great, and the data flow from the Large Hadron Collider will make it even greater. Representatives of the leading particle physics laboratories have convened a study group[e] to create a common international vision that carries over many experiments. The effort is just beginning, but it is worth watching (or joining)!

5. On Engagement with the Public

How we involve the public in the adventure of our science is an inexhaustible subject raised in the roundtable. It is fine to say that more is better, but we shouldn't underestimate what our colleagues are doing already[f]! As one example, I would point to the highly appreciated Quarknet organization, which engages teachers and students in research of their own and in conjunction with major experiments, using real analysis tools. A recent innovation is the Quarknet/Grid collaborative learning program, in which students use grid technology and modern software tools (ROOT, for example)

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[e] dphep.org: study group on data preservation and long-term analysis in high-energy physics

[f] I have sketched some of the American efforts in$^{19)}$, which includes many references and links to web sites.

to analyze data. Several *e*-Labs are in production or development[20]. The most elaborate is the cosmic-ray *e*-Lab, which introduces students and teachers not only to cutting-edge tools, but also initiates them into far-flung collaboration and shared data. It is described this way:

> The Cosmic Ray *e*-Lab provides an online environment in which students experience the excitement of scientific collaboration in this series of investigations into high-energy cosmic rays. Schools with cosmic ray detectors upload data to a "virtual data grid" portal where *all* the data resides. This approach allows students to analyze a much larger body of data and to share analysis code. Also, it allows schools that do not have cosmic ray detectors to participate in research by analyzing shared data.
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> Students learn what cosmic rays are, where they come from and how they hit the Earth. While scientists understand cosmic rays with low to moderate energies, some cosmic rays have so much energy that scientists are not sure where they come from. A number of research projects are looking at this question. Students will have a chance to gain their own understanding of cosmic rays and may be fortunate enough to capture a rare highly-energetic cosmic ray shower on their classroom detector and analyze their results with this *e*-Lab.

The ATLAS and CMS experiments at the Large Hadron Collider have established extensive efforts in outreach, education, and engagement. The Sanford Underground Laboratory at Homestake[23], precursor to DUSEL, has launched a vigorous outreach and education project, and even has a twitter presence.

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7. References

1) C. Quigg, "NuFact08 – Closing Talk," in *Proceedings of the Tenth International Workshop on Neutrino Factories, Super Beams, and Beta Beams (NuFact08), PoS(Nufact08)032* [arXiv:0810.1530 [hep-ph]].
2) M. C. Chen, A. de Gouvêa and B. A. Dobrescu, *Phys. Rev. D* **75** (2007) 055009 [arXiv:hep-ph/0612017].
3) B. Bajc, M. Nemevšek and G. Senjanović, *Phys. Rev. D* **76** (2007) 055011 [arXiv:hep-ph/0703080].

4) H. Minakata, "Neutrino's non-standard interactions . . . ," *These Proceedings.*
5) A. G. Cohen, D. B. Kaplan and A. E. Nelson, *Ann. Rev. Nucl. Part. Sci.* **43** (1993) 27 [arXiv:hep-ph/9302210].
6) M. Carena, G. Nardini, M. Quiros and C. E. M. Wagner, *Nucl. Phys. B* **812** (2009) 243 [arXiv:0809.3760 [hep-ph]].
7) J. A. Harvey, C. T. Hill and R. J. Hill, *Phys. Rev. D* **77** (2008) 085017 [arXiv:0712.1230 [hep-th]]; *Phys. Rev. Lett.* **99** (2007) 261601 [arXiv:0708.1281 [hep-ph]].
8) W. C. Louis, "MiniBooNE Results and the OscSNS Neutrino Project," *These Proceedings.*
9) A. A. Aguilar-Arevalo *et al.,* [MiniBooNE Collaboration], "Unexplained excess of electron-like events from a 1-GeV neutrino beam," arXiv:0812.2243 [hep-ex].
10) M. G. Catanesi, "Status and prospects for hadron production experiments," in *Proceedings of the Tenth International Workshop on Neutrino Factories, Super Beams, and Beta Beams (NuFact08), PoS(Nufact08)014.*
11) F. Halzen, "Neutrino Telescopes," *These Proceedings.*
12) C. Quigg, "Extremely high energy cosmic neutrinos and relic neutrinos," in *Proceedings of the Third International Workshop on Neutrino Oscillations in Venice,* edited by M. Baldo Ceolin (Padova, Papergraf, 2006), pp. 309-327 [arXiv:astro-ph/0603372].
13) S. Enomoto, "Using neutrinos to study the Earth," *These Proceedings.*
14) V. Flaminio, "ANTARES, the first undersea telescope," *These Proceedings.*
15) S. Osprey et al., [National Centre for Atmospheric Science Climate Working Group & MINOS Collaboration], Geophys. Res. Lett. **36** (2009) L05809.
16) C. Spiering, "The European Strategy on Astroparticle Physics," *These Proceedings.*
17) A. van Helden, "Galileo and his Telescope," *These Proceedings.* G. Galilei, *Sidereus Nuncius, or, The Sidereal Messenger,* translated with introduction, conclusion, and notes by Albert van Helden (University of Chicago Press, Chicago, 1989).
18) G. Galilei, *Opere* (Ristampa dell'Edizione Nazionale, Firenze, 1968), Vol. IV, p. 738; marginal note in, "Response to Ludovico delle Colombe and Vincenzo di Grazia's criticisms of Galileo Galilei's *Discourse on Bodies on or in Water.*"
19) C. Quigg, "Comunicare Fisica all'americana," in *Comunicare Fisica 2005,* ed. Franco L. Fabbri & Piero Patteri (LNF, Frascati, 2006) pp. 245–262 [arXiv: physics/0511254].
20) A list of *e*-Labs is available at www.i2u2.org/elab/list.html. Distributed cosmic-ray detectors, LIGO, and the CMS detector are represented.
21) ATLAS experiment at the LHC: atlas.ch.
22) Compact Muon Solenoid at the LHC: cms.cern.ch.
23) See sanfordundergroundlaboratoryathomestake.org; twitter.com/SanfordLab.