Nuclear Science & the New Standard Model:
Neutrinos & Fundamental Symmetries in the Next Decade

The next decade presents NP with a historic opportunity to build on this legacy in developing the “new Standard Model”

The value of our contribution will be broadly recognized outside the field

Fifty years of PV in nuclear physics

Solar vs & the neutrino revolution

Michael Ramsey-Musolf, NSAC March, 2007
Community Input

- **Pre-Town Meetings:**
  - Santa Fe Nov 2006
  - Caltech Dec 2006
- **DNP Town Meeting**
  - Chicago Jan 2007
- **White paper (merging two)**

  Substantial work by the organizing committee
Scientific Questions, Achievements & Challenges
Primary Scientific Questions

- What are the masses of neutrinos and how have they shaped the evolution of the universe? $0\nu\beta\beta$ decay, $\theta_{13}$, $\beta$ decay,…

- Why is there more matter than antimatter in the present universe? EDM, DM, LFV, $0\nu\beta\beta$, $\theta_{13}$ …

- What are the unseen forces that disappeared from view as the universe cooled? Weak decays, PVES, $g_\mu$-2,…
Related Scientific Questions

- **What is the internal landscape of the proton?**  
  PVES, hadronic PV, $\nu$ scattering,…

- **What causes stars to explode?**  
  Large scale supernova simulations, $\nu$ flavor transformation,…

- **What is the origin of the heavy elements from iron to uranium?**  
  Weak interactions and $\nu$ interactions in heavy nuclei,…

*Tribble report*
Scientific Achievements

- *Discovery of flavor oscillations in solar neutrinos; Solution of the solar neutrino problem; 1300+ citations*
- *Discovery of flavor oscillations in reactor neutrinos; Identification of LMA solution; over 1000 citations*
- *World’s most precise measurement of $(g_\mu - 2)$ Possible first indications of supersymmetry; over 1000 citations*
- *Most precise measurement of $\sin^2 \theta_W$ off the $Z^0$ resonance using PV Moller scattering; constrains new physics at the TeV scale ($Z'$, RPV SUSY…)*
Scientific Achievements

• Definitive determinations of strange quark contributions to nucleon EM form factors using PV electron-proton & electron-nucleus scattering; confirmed theoretical estimates of hadronic effects in electroweak radiative corrections

• Quark-lepton universality tested to 0.05% using superallowed nuclear $\beta$-decay, yielding most precise value of any CKM matrix element ($V_{ud}$)

2006 Bonner Prize in Nuclear Physics recognizing work of Towner & Hardy
Scientific Achievements

- Completion of a comprehensive set of computations of supersymmetric effects in low-energy electroweak observables; 2005 Dissertation Award in Nuclear Physics to A. Kurylov
- Reduction in the theoretical hadronic uncertainty in extraction of $V_{ud}$ from neutron and nuclear $\beta$-decay
- New theoretical breakthroughs in simulating neutrino flavor transformation in supernovae; modeling $\nu$ flavor transformation effects nucleosynthesis with SN’s; understanding weak interaction effects in SN shock dynamics
Scientific Achievements

- Development of a EFT treatments of parity violation in the nucleon-nucleon interaction that will guide the future experimental program at the SNS and NIST
- Reduction in theoretical uncertainty in QRPA computations of $0\nu\beta\beta$ decay matrix elements
- Substantial technical developments opening the way for searches for the permanent EDMs of the neutron, neutral atoms, deuteron and electron with 2-4 orders of magnitude greater sensitivity
Technological Achievements & Investments

$\beta$-decay: Neutrino Mass

KATRIN, NexTex, MARE…

Total Lepton Number & Neutrino Mass Term

$0\nu\beta\beta$-decay

Majorana  CUORE  EXO  GERDA
Technological Achievements & Investments

Multi-purpose Facility

DUSEL
Technological Achievements & Investments

Fundamental Neutron Physics Beamline at SNS
1.4 MW, 1 GeV H⁻ beam on L Hg

Also new capabilities at LANSCE, NIST…

CEBAF 12 GeV Up-grade
Muon storage ring at BNL
ISAAC, RIAcino…. 
Challenges: *What role can low energy studies play in the LHC era? (and beyond!)*

Two frontiers in the search for new physics

Collider experiments (pp, $e^+e^-$, etc) at higher energies ($E \gg M_Z$)

Indirect searches at lower energies ($E < M_Z$) but high precision

High energy physics

Particle, nuclear & atomic physics