Fundamental Symmetries & Neutrinos
Pre-Town Meeting Summary

Organizers: **H**ertzog, David(U of Washington)
Ito, Takeyasu (LANL)
Poon, Alan (LBNL)

Outline

- Scientific questions
- Major scientific discoveries since 2007
- Compelling and unique science to be done in the next 5 years and through 2020
- Recommendations

Scientific Questions

Fundamental Symmetries and Neutrinos

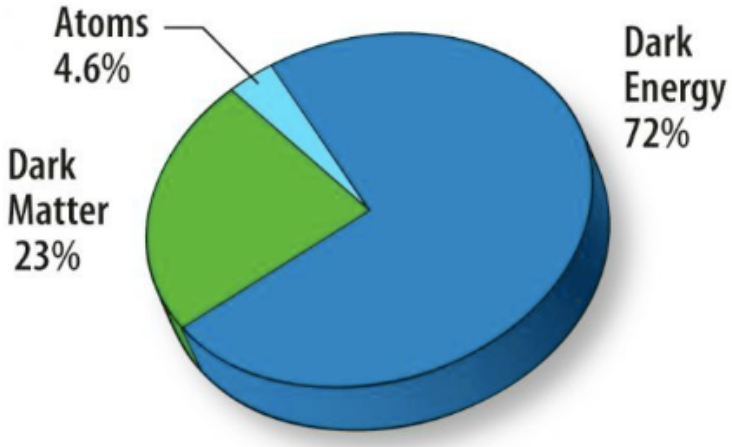
- **What is the nature of the neutrinos, what are their masses, and how have they shaped the evolution of the universe?**
- **Why is there now more visible matter than antimatter in the universe?**
- **What are the unseen forces that were present at the dawn of the universe but disappeared from view as the universe evolved?**

LRP 2007

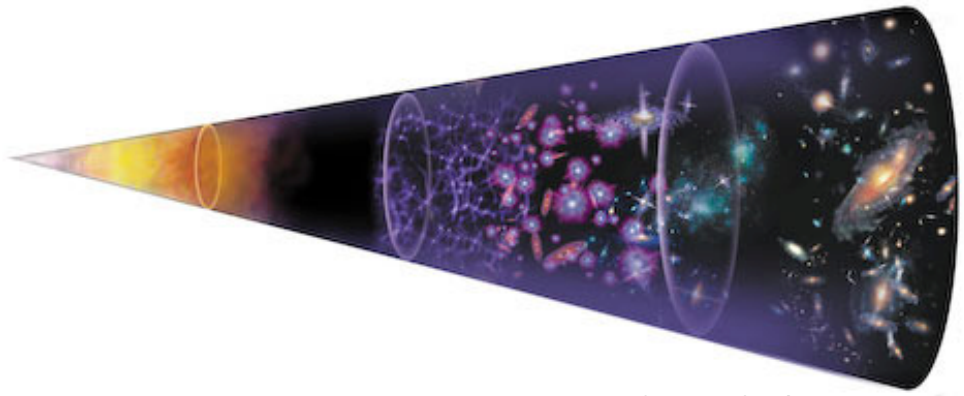
Neutrino mass and hierarchy, lepton mixing, evolution of astrophysical structures...

CP violation, Baryon number violation (EW baryogenesis, leptogenesis)...

SM masses, couplings, structure of interactions, completeness and extensions...



NASA



Scientific America

Four Components

EDM searches: *BSM CPV, Origin of Matter*	***0νββ decay searches:*** *Nature of neutrino, Lepton number violation, Origin of Matter*
Charged leptons: *SM Precision Tests, BSM "diagnostic" probes*	***Other studies:*** *Weak decays, m_ν , "dark photons", non-Newtonian gravity, theory…*

modified from M. Ramsey-Musolf

Major Accomplishments since 2007

- Results on ^{136}Xe $\tau_{2\nu\beta\beta}$ and $\tau_{0\nu\beta\beta}$: **EXO, KamLAND-Zen**
- Determination of θ_{13}: **Daya Bay, RENO, Double Chooz**
- Establishment of **Sanford Underground Research Facility**
- Improved understanding of θ_{12} and Δm_{12}^2 and solar neutrinos: **Borexino, SNO, KamLAND**
- β-asymmetry “Big A” : **UCNA @ LANL**
- Completion and first result of QWeak: **JLab**
- New determination of τ_{μ}, g_p : **MuLan, MuCap @ PSI**
- T-violation limit in neutron beta decay: **emiT**
- Muon Michel parameters: **TWIST @ TRIUMF**
- Results from **MiniBooNE**
- Many advances in theory: **DBD matrix elements, loop corrections...**

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BSM CPV, Origin of Matter

0νββ decay searches:

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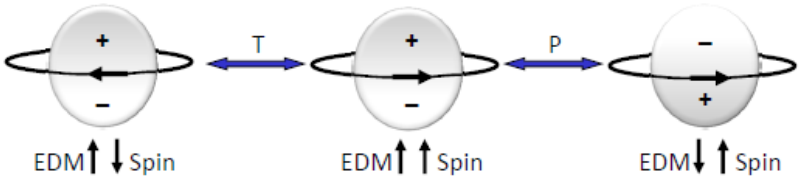
EDM Searches



Zheng-Tian Lu

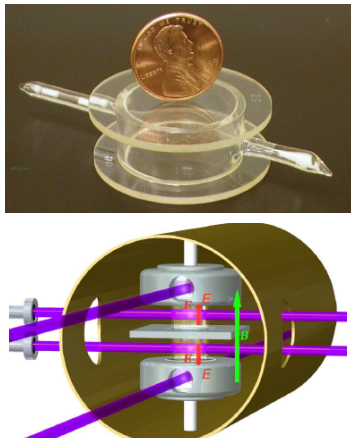
EDM violates T → violates CP

New sources of CP → BAU

Experiments are largely the same:

- Precess spin in B field with parallel and anti-parallel E
- Measure the frequency difference

^{199}Hg @ Seattle

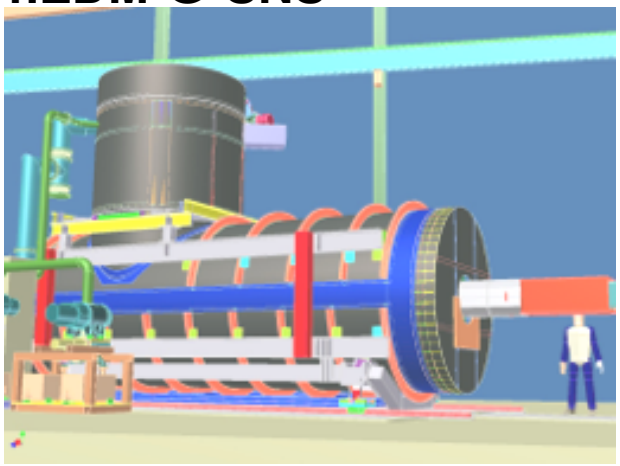


Griffith et al (2009)

Limits and Sensitivities

- Current: < 0.3 x 10^{-28} e-cm
- Next 5 years: 0.03 x 10^{-28} e-cm
- 2020 and beyond: 0.006 x 10^{-28} e-cm

nEDM @ SNS



- R&D in progress
- Construction after with 4 – 5 year timeline
- NSAC neutron subcommittee report 11/2011:
  - **Motivation remains strong**
  - **Sensitivity remains compelling**

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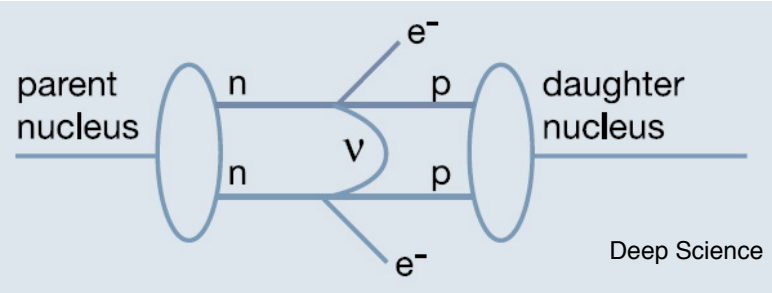
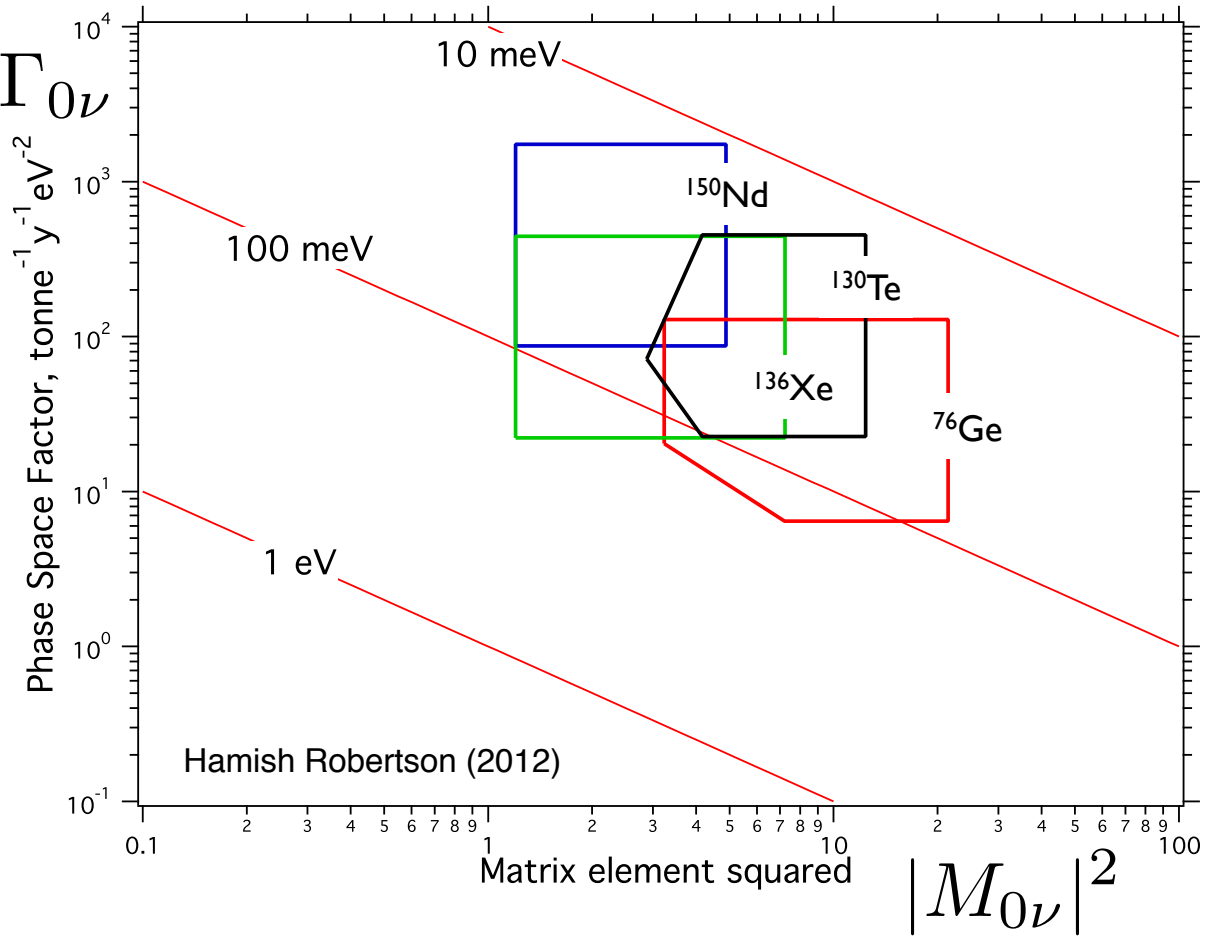
Neutrinoless Double Beta Decays

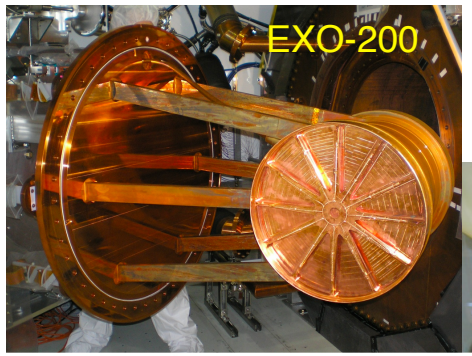


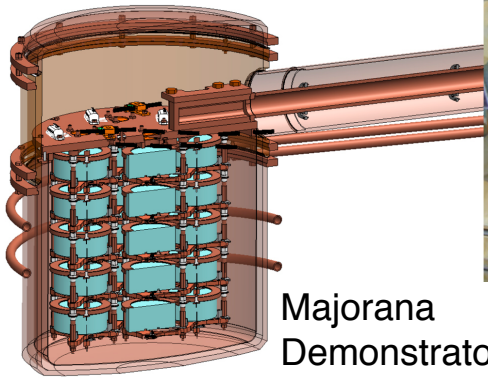
- Lepton number violation: ΔL=2
- Probe neutrino mass hierarchy
- The only known practical technique to determine whether neutrinos are Majorana particles

Decay rate per unit mass: $\Gamma_{0\nu}\ |M_{0\nu}|^2\ |\langle m_{ee}\rangle|^2$



- **Short-term to medium term:** Demonstrate technologies for next generation large-scale experiment



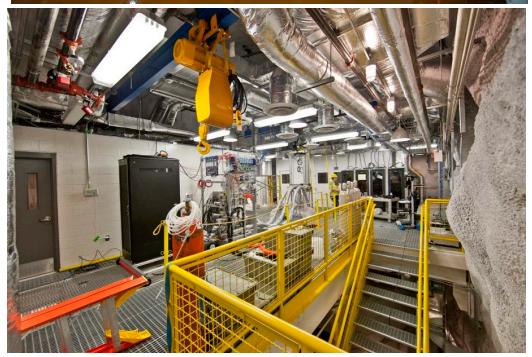


Majorana Demonstrator

Underground Laboratory

Who needs an underground lab?

We do! - Hamish Robertson 2012



- Recommendation from LRP 2007.

- Sanford Underground Research Facility (SURF) is a new asset for the scientific community:
  - Attracted $75M in private funding
  - Hosting Majorana Demonstrator (NP), LUX (HEP), and experiments from other fields

- Other facilities are also playing important roles in the field.

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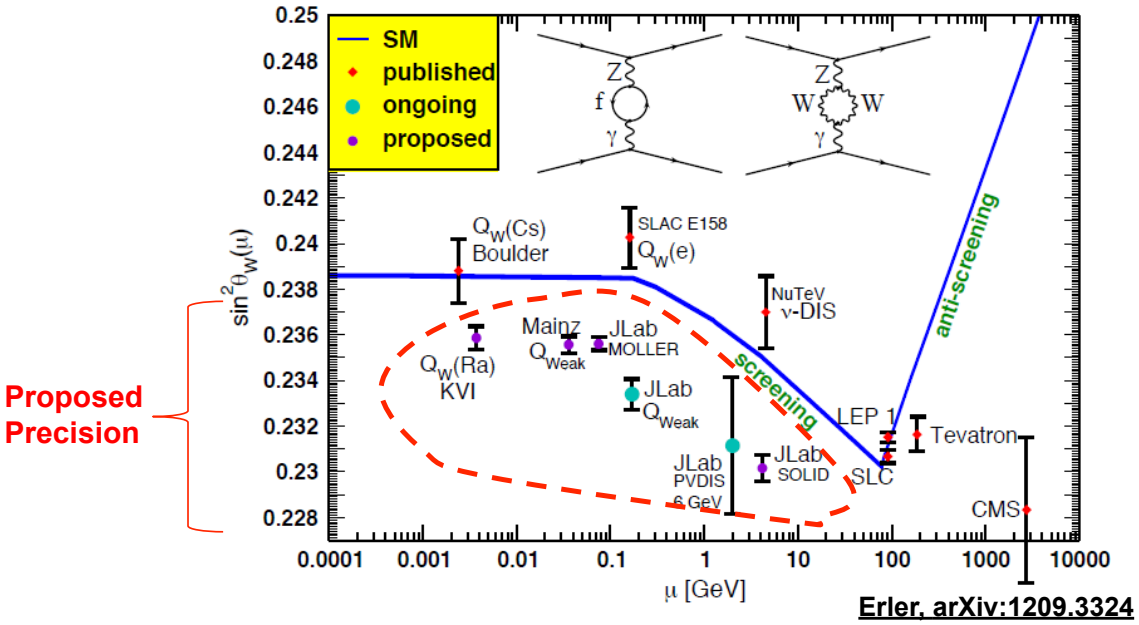
modified from M. Ramsey-Musolf

Charged Leptons

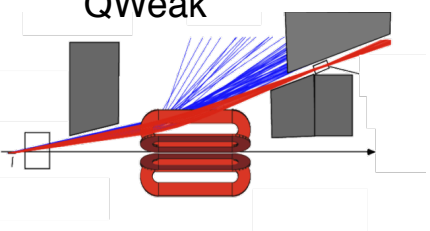
Parity-violating e⁻ scattering

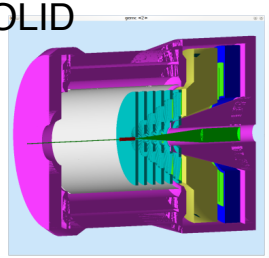
- Higgs mass resolves $\sin^2\theta_W$ tension
- Next generation PVES sensitive to new physics, given firm SM predictions

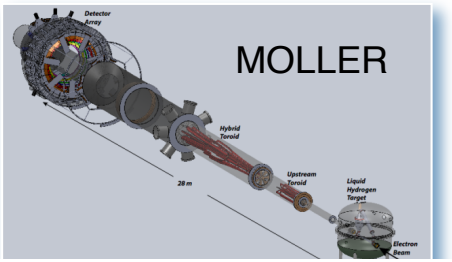


Proposed Precision

Erler, arXiv:1209.3324

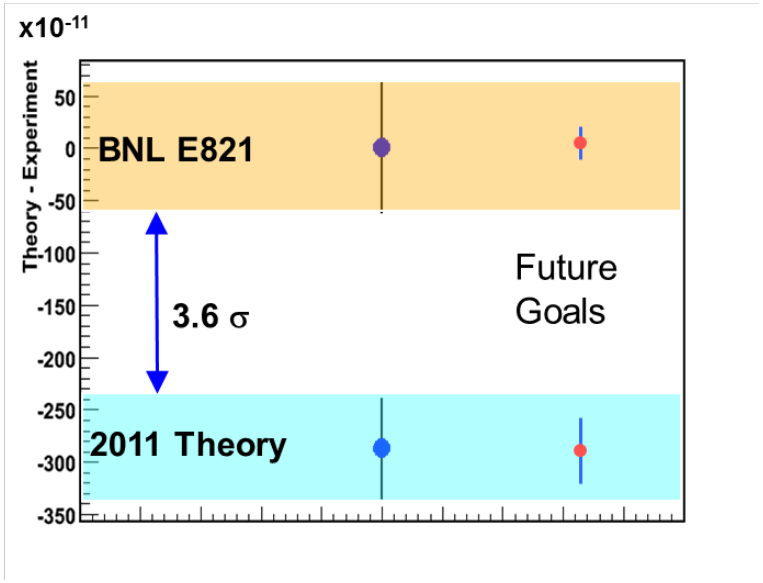


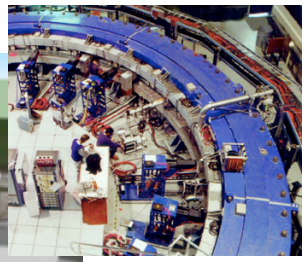




Muons

- New muon campus facility @ FNAL
- Next generation g-2 and mu2e approved





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modified from M. Ramsey-Musolf

Other studies

Example: Neutrons

$$dW \propto \frac{1}{\tau_n} F(E_e)\left[1 + a\frac{p_e \cdot p_\nu}{E_e \cdot E_\nu} + b\frac{m_e}{E_e} + A\frac{\sigma_n \cdot p_e}{E_e} + B\frac{\sigma_n \cdot p_\nu}{E_\nu}\right]$$

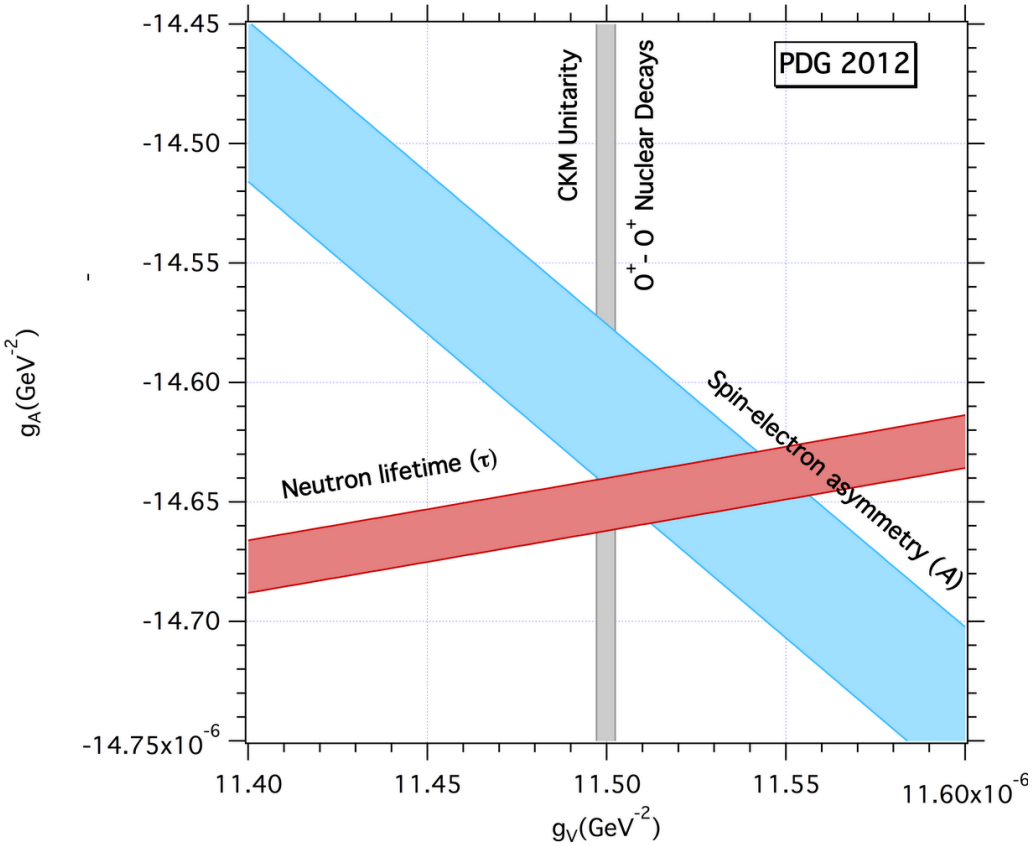
$\tau_n \propto 1/(g_A^2 + 3g_V^2)$

$a = \dfrac{1-\left(\frac{g_A}{g_V}\right)^2}{1-3\left(\frac{g_A}{g_V}\right)^2}$

$b = 0$

$A = -2\dfrac{\left(\frac{g_A}{g_V}\right)^2 + \left(\frac{g_A}{g_V}\right)}{1-3\left(\frac{g_A}{g_V}\right)^2}$

$B = 2\dfrac{\left(\frac{g_A}{g_V}\right)^2 - \left(\frac{g_A}{g_V}\right)}{1+3\left(\frac{g_A}{g_V}\right)^2}$



- **Big A: g_A/g_V**
  - UCNA
  - PERKEO II
- **n Lifetime Update**
  - Important to Big Bang Nucleosynthesis
- Precision of $0^+ \rightarrow 0^+$ **superallowed measurements** for unitarity

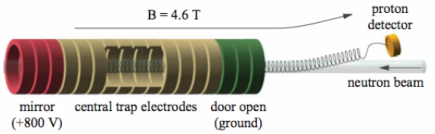
- CVC verified
- V_{ud} = 0.97425(22)

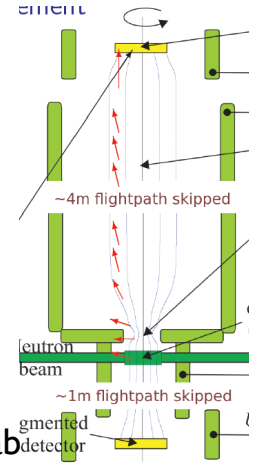
CKM unitarity test:
$V_{ud}^2 + V_{us}^2 + V_{ub}^2 = 0.9999(6)$

Future:

- τ_n from cold neutron beam
- Nab (2015 and beyond) :
  - $\Delta a/a \sim 10^{-3}$
  - $b \sim 3 \times 10^{-3}$

NIST beam method





Nab

Community Inputs

May 15	NSAC Subcommittee meeting #1
June-July	Ad hoc working group formed
August 10-11	Working group meeting in Chicago
September 6-9	NSAC Subcommittee meeting #2 to hear presentations given by community members
October 25, 26	Town meetings at DNP meeting
Nov 29-Dec 2	NSAC Subcommittee meeting #3

Previous FS&N talks posted at http://www.phy.ornl.gov/funsym/

Recommendations

Recommendation 1: **Fundamental Symmetries and Neutrinos figure prominently in the 2007 NSAC Long Range Plan and subsequent assessments of the field, such as the 2012 NAS Nuclear Physics Report, the 2011 NAS Assessment of Science Proposed for DUSEL, and the 2011 NSAC Neutron subcommittee report. The community strongly endorses the recommendation of the 2007 NSAC Long Range Plan: *"We recommend a targeted program of experiments to investigate neutrino properties and fundamental symmetries. These experiments aim to discover the nature of the neutrino, yet-unseen violations of time-reversal symmetry, and other key ingredients of the New Standard Model of fundamental interactions. Construction of a Deep Underground Science and Engineering Laboratory is vital to U.S. leadership in core aspects of this initiative."***

The workshop identified that this subfield is vibrant and continues to address compelling scientific issues with considerable discovery potential. In particular, for the short to medium term timescales, the workshop strongly endorses neutrinoless double β-decay, neutron EDM, parity violating electron scattering, and the g-2 experiment. In addition, we note that progress has been made toward establishing an underground laboratory for science within the U.S.; at the Sanford Underground Research Facility, the Davis Campus at 4,850 feet is operating and being used as a home for the MAJORANA DEMONSTRATOR as well as the (HEP funded) LUX dark matter experiment.

Recommendations

Recommendation 2: **The federal research investment in Fundamental Symmetries and Neutrinos should be commensurate with its tremendous scientific opportunities and discovery potential.**

The second recommendation follows the 2012 NAS Nuclear Physics Report in recognizing the need to balance research funding and construction of new facilities. Fundamental Symmetries and Neutrinos has traditionally not required a large facility operations budget, and therefore represents a cost effective way to obtain tremendously valuable science. However, substantial investments are critical for some of the next-generation experiments needed to maintain scientific momentum and world competitiveness.

Recommendations

Recommendation 3: **In order to ensure the long-term health of Fundamental Symmetries and Neutrinos research, it is necessary to establish and maintain a balance between funding construction of new experiments and facilities with the needs of university and laboratory-based research programs performing existing experiments and developing new ideas and measurements that may have high impact.**

It is important to fund small R&D efforts to establish the feasibility of new ideas. These ideas range from measuring sterile neutrino signals at the Spallation Neutron Source, to small-scale experiments at reactors to understand reactor neutrino flux predictions and spectra, and to measure salient features of neutrino oscillations and investigate coherent neutrino scattering, to initial R&D towards a proton ring for measuring the proton electric dipole moment.

Recommendations

<u>Recommendation 4:</u> The community urges strengthened support for nuclear theory in Fundamental Symmetries and Neutrinos in order to fully exploit, guide, and complement experimental efforts.

Although relatively few in number, nuclear theorists from both universities and national laboratories have historically played a crucial role in developing Fundamental Symmetries and Neutrinos. Their efforts have been especially important in connecting the results of different experiments and providing an intellectual bridge to astrophysics and particle physics. It is crucial to strengthen these efforts to capture the opportunities this field represents. In addition, training the next generation of nuclear theorists starts at universities and we strongly encourage agency incentives to universities (for example, bridge appointments) in this subfield of nuclear theory.

Summary: This field is...

- **Discovery-oriented**
- **Diverse, vibrant and active**
- **Directing larger investments to efforts with significant potential payoff:**
  - $0\nu\beta\beta$
  - nEDM
  - Underground lab
  - MOLLER
  - Equipment request for g-2
- **Incompletely summarized. We omitted a number of proposed and operating experiments.**

LRP 2007

RECOMMENDATION III

We recommend a targeted program of experiments to investigate neutrino properties and fundamental symmetries. These experiments aim to discover the nature of the neutrino, yet-unseen violations of time-reversal symmetry, and other key ingredients of the New Standard Model of fundamental interactions. Construction of a Deep Underground Science and Engineering Laboratory is vital to U.S. leadership in core aspects of this initiative.