U.S. DEPARTMENT OF ENERGY | Office of Science

The Neutron Charge to NSAC

DOE/NSF Nuclear Science Advisory Committee Meeting

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Outline

- Science with neutrons
- The 2003 charge to NSAC
- Progress in the U.S. neutron program
- The international context
- Important questions that could be addressed in this decade
- The Neutron Charge to NSAC

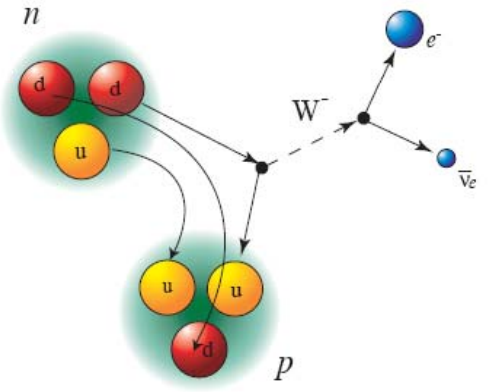
--DOE and NSF--
Fundamental Physics with Neutrons Programs

- The DOE and NSF both have programs in fundamental physics with neutrons
- The two agencies contribute to the joint fabrication of apparatus for several ongoing and planned experiments
- DOE and NSF supported researchers collaborate on experiments, and plan for future experiments

- Among these experiments are:
  - UCN-A
  - $n+p \rightarrow d+\gamma$
  - nEDM

Compelling Science with Neutrons
Fundamental Properties of the Neutron and Hadronic Interactions

- Precision measurements of Fundamental Properties of Neutrons
  - Neutron decay correlation coefficients *a* and *A* provide the best measurement of g_A, one of the fundamental coupling constants of the Standard Model (SM)
  - Neutron lifetime (τ_n) directly enters into verification of Big Bang Nucleosynthesis
  - Together, g_A and τ_n determine V_{ud}, which enters into verification of the unitarity of CKM matrix to test the SM. Other *n* decay correlation coefficients, such as *b* and *D* provide additional tests of SM



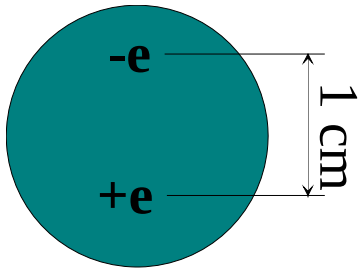
$$\begin{bmatrix} |d'\rangle \\ |s'\rangle \\ |b'\rangle \end{bmatrix} = \begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix} \begin{bmatrix} |d\rangle \\ |s\rangle \\ |b\rangle \end{bmatrix}.$$

$$dW \propto 1 + b\frac{m_e}{E_e} + a\frac{\vec{p}_e \cdot \vec{p}_{\bar{\nu}}}{E_e E_{\bar{\nu}}} + \vec{P}_n\left(A\frac{\vec{p}_e}{E_e} + B\frac{\vec{p}_{\bar{\nu}}}{E_{\bar{\nu}}} + D\frac{\vec{p}_e \times \vec{p}_{\bar{\nu}}}{E_e E_{\bar{\nu}}}\right)$$

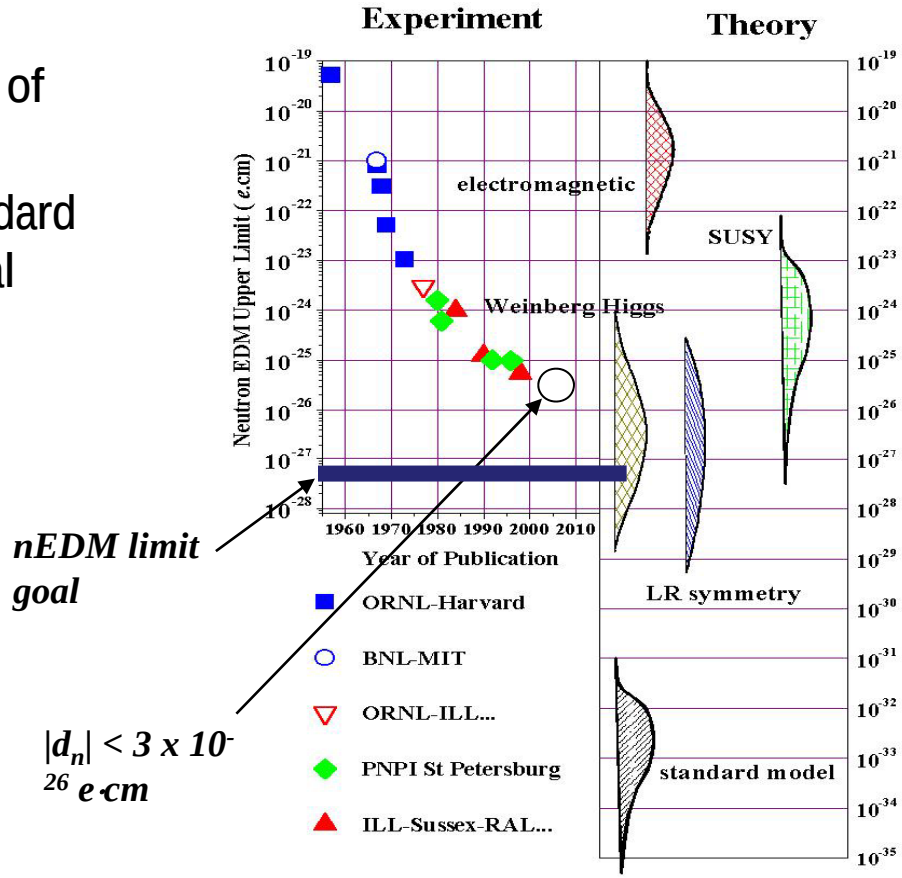
- Precision measurements of the hadronic parity-violating processes—window into strangeness-conserving interactions between quarks

Compelling Science with Neutrons
The neutron Electric Dipole Moment

- A tighter limit on neutron EDM provides clues regarding CP violation and baryogenesis origin of dominance of matter over antimatter
- Constrains extensions of the Standard Model of particles and fundamental interactions

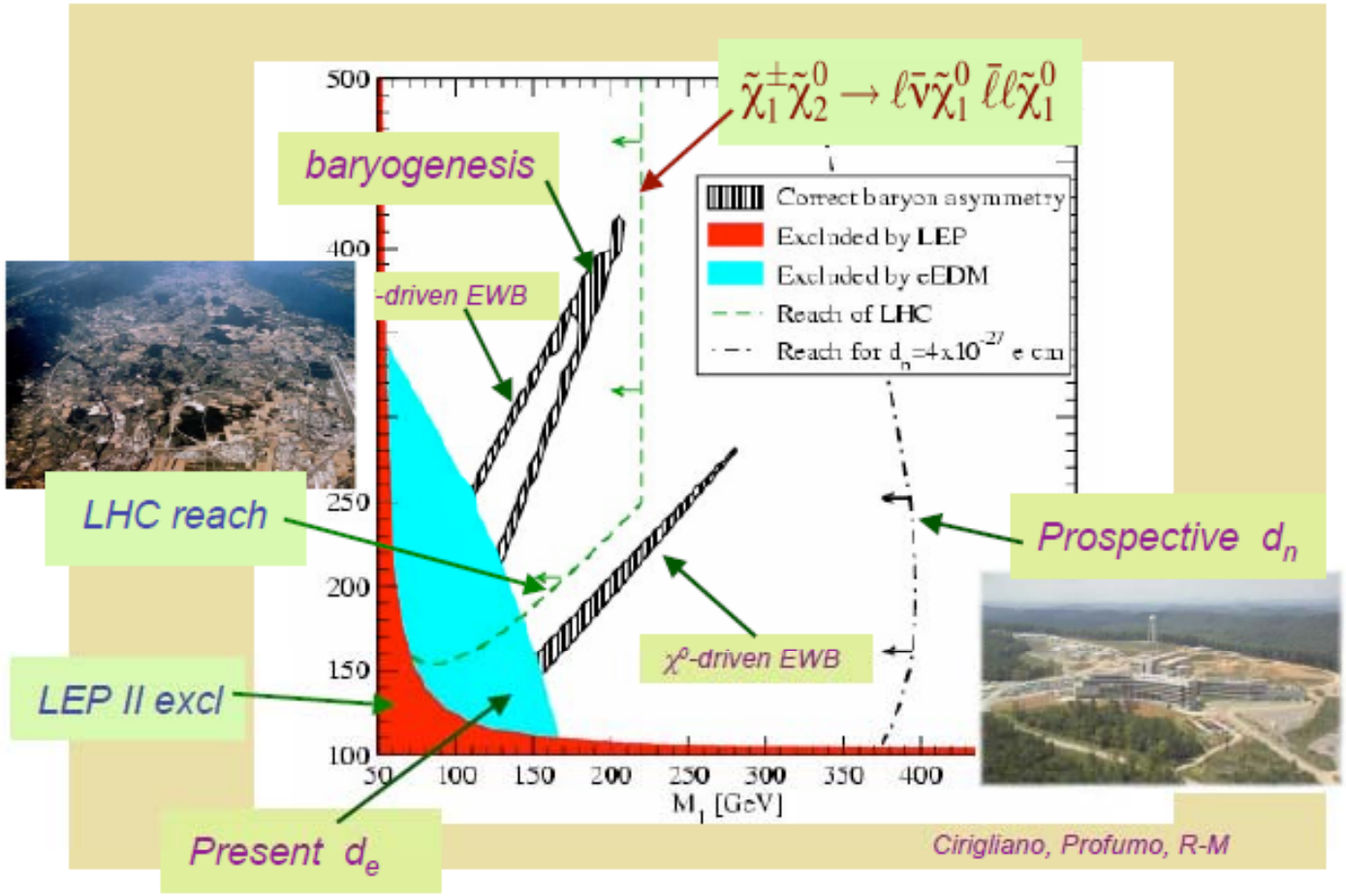


$d_n = 1\ e \cdot cm$



Complementarity of High and Low Energy Approaches to Fundamental Questions

MSSM Baryogenesis: EDMs & LHC



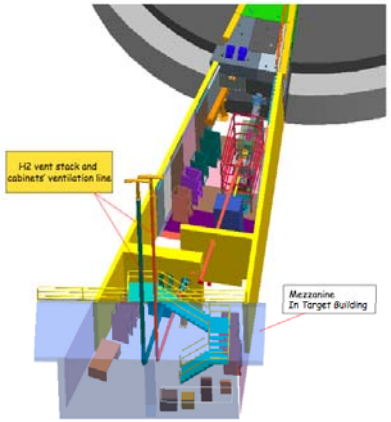
2003 NSAC Report on Physics with Neutrons

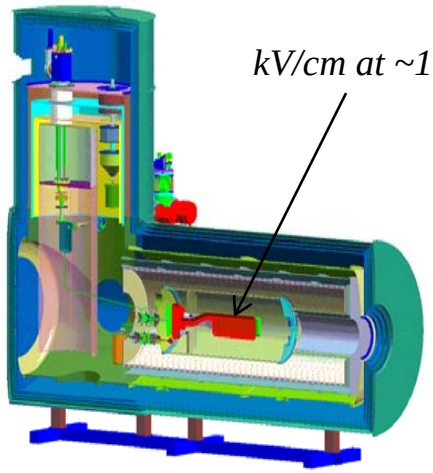
- 2003 study was undertaken by NSAC:
  - The compelling and fundamental nature of the science
  - Interest by the nuclear science community and existing/developing capabilities at LANSCE and NIST
  - Desire for the US to have a strong presence in this important area of research
  - Experiments in progress or being developed to measure τ_n, A, etc.
  - Construction of the SNS that could provide of unique (intense, pulsed) beams of neutrons
- NP needed to receive community advice on how to best utilize this opportunity
- Determinations of the Report
  - U.S. has an active neutron program
  - nEDM has highest discovery potential and is strongly encouraged
  - Construct a cold neutron beamline at the SNS as a capability for a broad neutron physics program
  - Increase the theory effort in the area of physics with neutrons

Implementation of the Recommendations of the 2003 NSAC Report

- Progress toward implementation of the 2003 Report
  - Increased funding for Fundamental Neutron Physics research effort in the US at national laboratories and universities
  - Continued measurements at UNC-A at LANSCE, which have resulted in a new precision measurement of asymmetry parameter *A* , moving us closer to resolve a large discrepancy between previous measurements
  - Construction of the Fundamental Neutron Physics Beamline (FNPB) for research with cold and ultracold neutrons at SNS; initiation of n+p → d+γ experiment for precise determination of A_γ, one of the hadronic parity-violating (PV) nucleon-nucleon interaction parameters
- Investment towards R&D for the next generation neutron EDM experiment at FNPB
- The DOE/NP and NSF jointly support collaborative research with neutrons

FNPB cold line at SNS



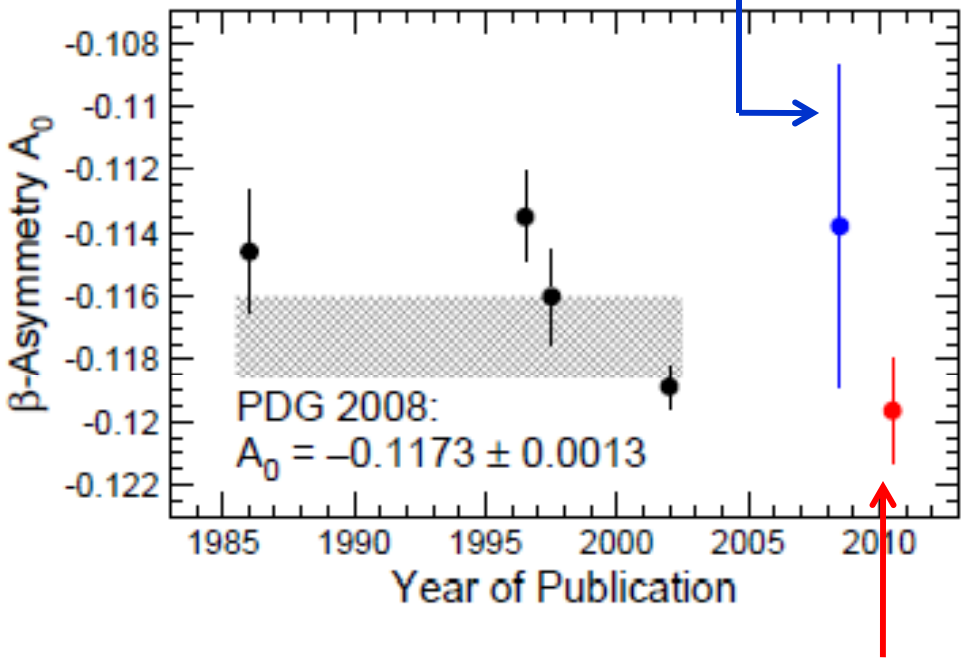


nEDM Apparatus and Detector

Status of beta-asymmetry, A

UCNA Proof-of-Principle

PRL 102, 012301 (2009)



UCNA New Result

Submitted to PRL

Pre-UCNA

expt's	*ΔA/A [%]*
PERKEO I	*1.7*
IAE-PNPI	*1.2*
ILL-TPC	*1.3*
PERKEO II	*0.6*
PDG Average	*1.1*

$\sqrt{\chi^2} = 2.3$

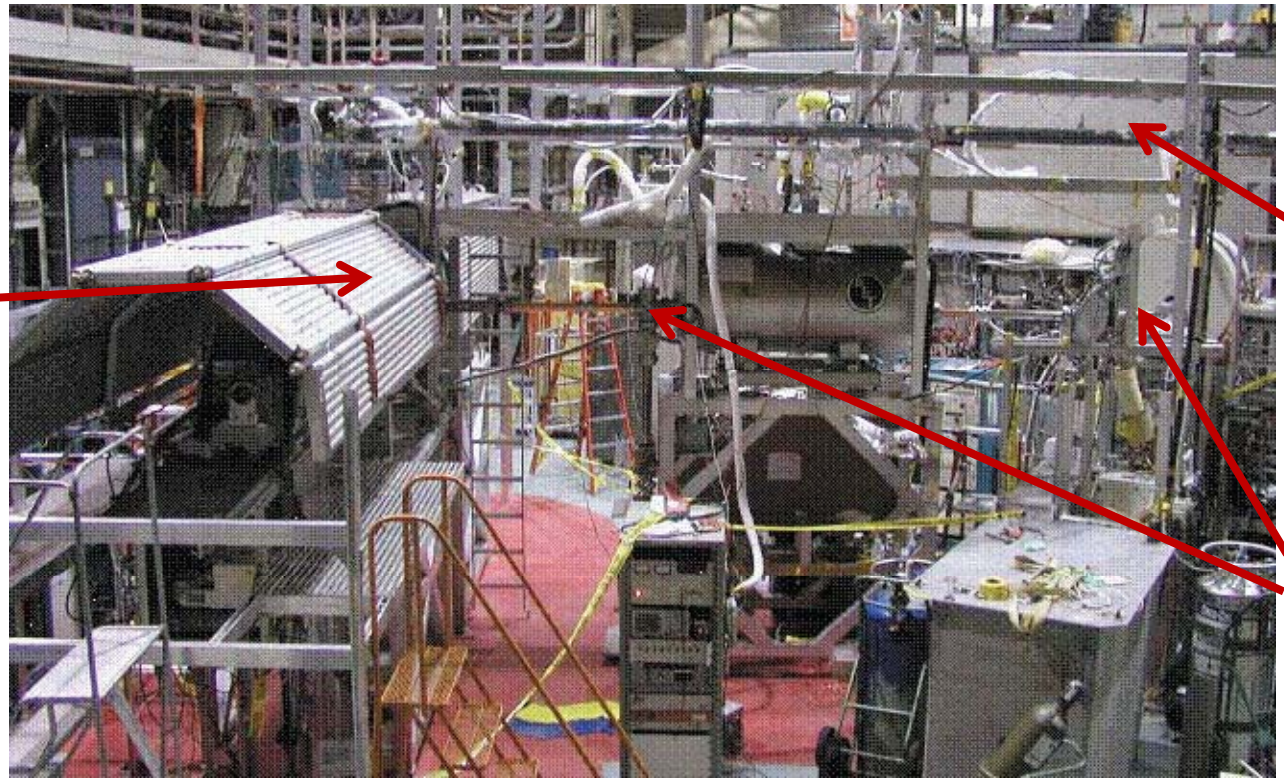
$A_0 = -0.1173 \pm 0.0013$

With-UCNA

$A_0 = -0.1175 \pm 0.0011$

$\sqrt{\chi^2} = 2.1$

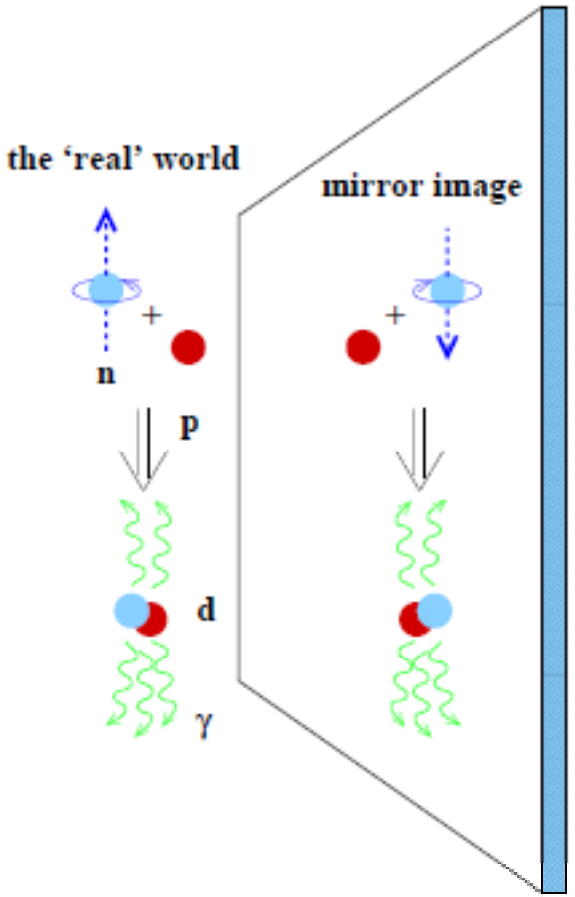
UCN-A Experiment at LANSCE



The UCN-A experiment is poised to significantly improve its recent result during the present LANSCE run

Hadronic Parity-Violation Measuring the Weak Interaction Between Protons and Neutrons via n+p → d+γ

- **Low energy parity violating (PV) potential contains coupling constants for meson exchange (π,ρ,ω).**
- **The weak interactions in strongly interacting systems are not well understood.**
- **The n+p → d+γ experiment will study the flavor-conserving hadronic weak interaction.**
- **If the up/down gamma rates differ, parity is violated, (PV is a signature of the weak interaction).**
- **This experiment will measure cleanly one of the seven weak PV coupling constants, H^1_π.**

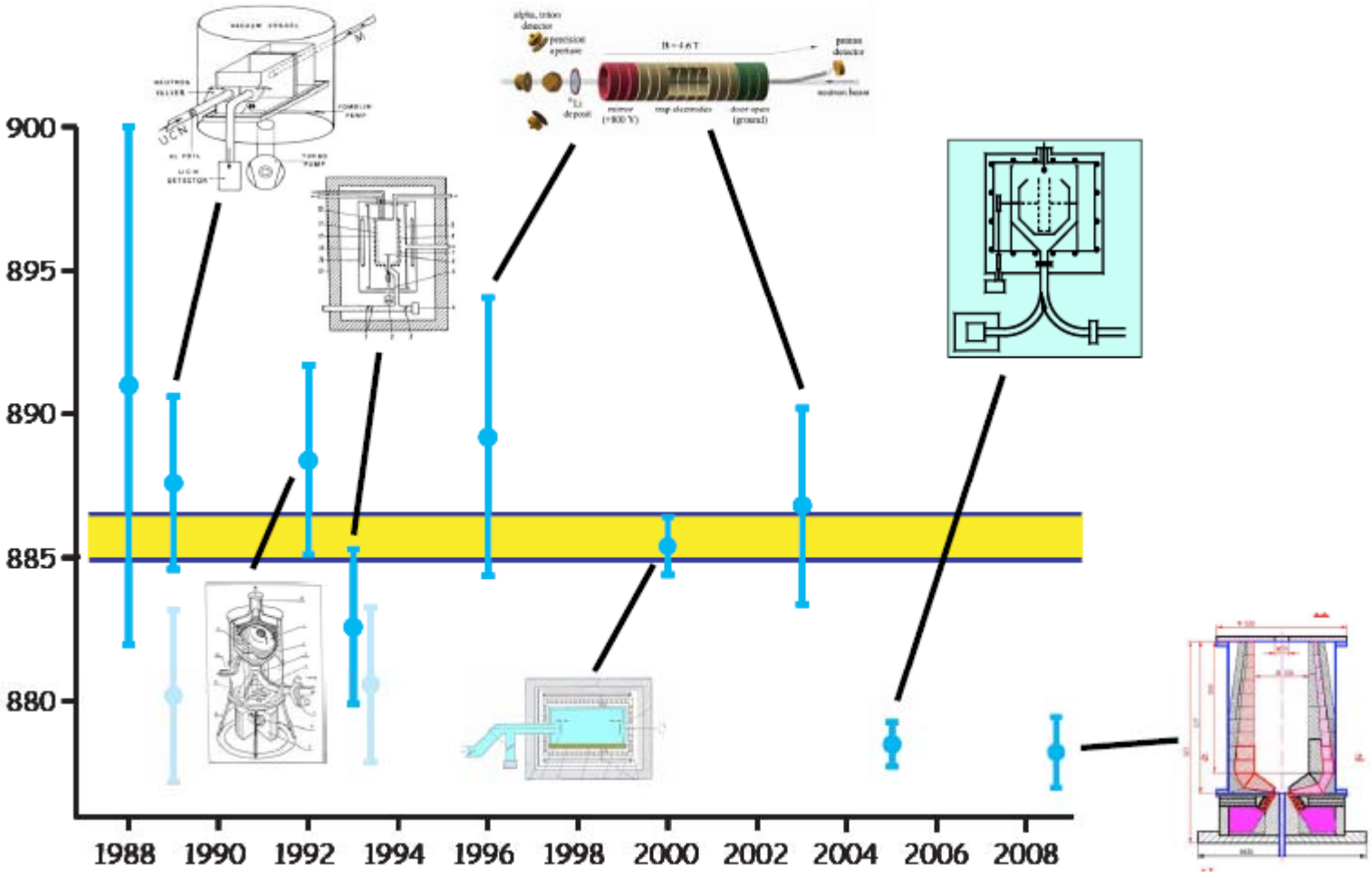


The n+p→d+γ Experiment at the FNPB

The n+p→d+γ experiment was developed and commissioned at LANSCE

The experiment has moved to the SNS and the main components have been installed on the cold neutron beamline at the Fundamental Neutron Physics Beamline

Precision Measurements of the Neutron Lifetime



measurements / error bars incompatible, to be continued...

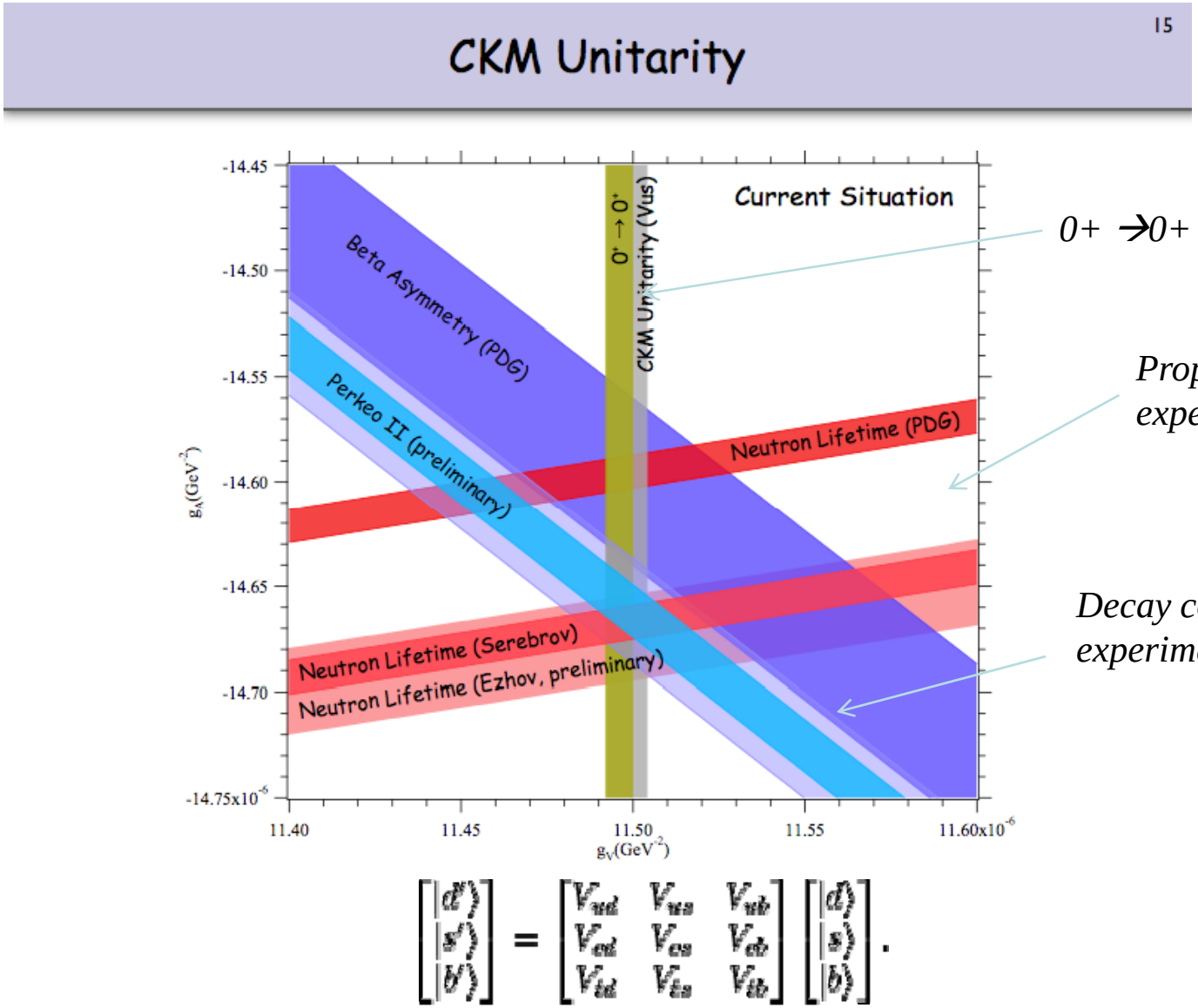
Fundamental physics with neutrons at NIST

A neutron lifetime experiment at NIST

Research in fundamental physics with neutrons is conducted at the NIST reactor:

- Hadronic parity violation with neutron spin rotation in liquid helium
- Radiative decay mode of the neutron
- Neutron lifetime
- Fundamental decay of the neutron—measurement of "*a*" parameter with aCORN
- Development of polarized ^{3}He spin filters for application in research

CKM Matrix Unitarity – Relationship to fundamental properties of the neutron and its decay



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U.S. and International Context

- U.S. Capabilities – SNS/FNPB, NIST (upgrade in progress), LANSCE
- Major International Capabilities – Institut Laue-Langevin, Paul Scherrer Institut, TRIUMF/JPARC (under development)
- U.S. science program
  - Neutron properties; Parity-violating hadronic interactions; Electric Dipole Moment
- International science program
  - Neutron properties; Electric Dipole Moment

- Precision experiments are high risk, high discovery payoff
- Complementarity of methods and approaches
  - The best U.S. and International expected limits for nEDM are similar
  - Early phases of International nEDM experiments are operating or about to begin
  - The U.S. eEDM experiment uses a unique co-magnetometer technique to control systematic errors
  - SNS utilizes a pulsed proton beam, with different experimental conditions than (quasi-) steady-state neutron sources

Challenges for the Next Decade

- Very important questions that make a difference in our understanding of fundamental physics, which could be answered in this decade
  - Improve precision of decay asymmetry parameters to better determine g_A and to test SM:
    - *A* (0.5%) -- UCN-A at LANSCE
    - *a* (0.1%) and *b* (0.3%) -- proposed Nab experiment at FNPB cold neutron beam
  - Neutron lifetime (<1 s) -- two separate magnetic bottle experiments with different systematic uncertainties that may be located at FNPB, NIST, or PULSTAR
  - n+p → d+γ and follow up measurements of hadronic PV interaction parameters -- FNPB cold neutron beam
- Neutron EDM (~ 10^{-28} e cm) – FNPB cold neutron beam
  - Project is under new management
  - Critical R&D underway
  - Rigorous effort underway to understand costs—more expensive than originally anticipated
  - Impact on the rest of the neutron program is being investigated

The Neutron Charge to NSAC

- NSAC Charge—Review and evaluate the current and proposed research program, scientific capabilities, and opportunities for fundamental nuclear physics with neutrons and make recommendations of priorities consistent with projected resources
  - Identify the most compelling scientific opportunities, and the infrastructure and effort required to address them within the context of scientific efforts and capabilities in the United States and elsewhere
  - Establish priorities within a constant effort budget, and recommend priorities for incremental investments beyond this level
  - Assess the current scientific and technical workforce committed to these activities, and the incremental workforce needed for further investments
  - Provide guidance regarding the appropriate mix of facility operations, research, investments in instrumentation and R&D to optimally exploit these opportunities
  - Provide an interim report by June 1, 2011.

The Neutron Charge Letter

The DOE/NSF Nuclear Science Advisory Committee (NSAC) is requested to review and evaluate the current and proposed research program, scientific capabilities, and opportunities for fundamental nuclear physics with neutrons and make recommendations of priorities consistent with projected resources.

In 2003, NSAC provided an assessment of fundamental physics with neutrons in the United States and made recommendations concerning the ongoing program at that time, including an experiment to measure the electric dipole moment of the neutron (nEDM) and the construction of a new neutron beam facility at the Spallation Neutron Source (SNS). The 2007 NSAC Long Range Plan recommended pursuit of a "targeted program to study the symmetries of the New Standard Model and precise measurement of electroweak phenomena." Since 2003, DOE and NSF have made progress towards the implementation of Committee recommendations and advice, including increased base funding for fundamental neutron science research, construction of a Fundamental Neutron Physics Beamline (FNPB) at the SNS, and funding of Research and Development (R&D) that has resulted in better estimates of the experimental sensitivity, and cost and schedule of a nEDM experiment that could be mounted at the FNPB.

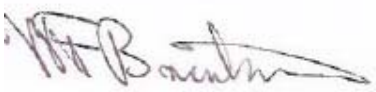
Several precision neutron beta-decay experiments, both in the United States and abroad, have since provided new insight into some of the important questions that were identified in the 2003 report. New experiments are also in the proposal and/or planning stage.

The Neutron Charge Letter cont.

In view of these developments since 2003, NSAC is again requested to examine and evaluate the broad suite of neutron physics research opportunities and how they complement other fundamental symmetry measurements that test the Standard Model, to identify the most compelling opportunities in this field, and make recommendations of priorities consistent with projected resources. It is important that the available resources are directed by NSF and DOE to the optimal investments for a strong national research program in this scientific area for the coming decade.

Your report should identify the most compelling scientific opportunities, and the infrastructure and effort required to address them. Your assessment should be made in the context of existing and planned scientific efforts and capabilities in the United States and elsewhere. It should establish priorities for these opportunities with constant level of effort for neutron science research at the FY 2011 Congressional Request level, and should recommend priorities for incremental investments beyond this level. An assessment of the current scientific and technical workforce committed to these activities is requested, as well as the incremental workforce needed for further investments. In dealing with the proposed activities at the various funding levels, guidance regarding the appropriate mix of facility operations, research, investments in instrumentation and R&D to optimally exploit these opportunities should be provided. We request that an interim report be submitted by June 1, 2011, and a written report responsive to this charge be provided by September 2011.

Sincerely,



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