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Title: Probing Physics Beyond the Standard Model Using Ultra-Cold Neutrons (LDRD Days)

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Form 836 (7/06)

What is the challenge?

Are there more quarks than we know? Is there an unseen world of Supersymmetric partners to the known particles? There are two ways to think about quarks: by their mass and by the way they interact via the weak nuclear force. The CKM matrix describes the relation between these quark eigenstates. The mathematical properties of the CKM matrix test the **existence of further quark generations** and the possibility of Supersymmetry. These properties can be tested using neutron beta decay, either using **correlations between decay particles** or by using the **lifetime of the neutron**. But both methods have been plagued by substantial discrepancies between experiments.

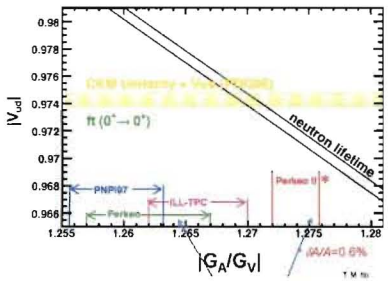
Neutron Decay and CKM Unitarity

Weak eigenstates — Mass eigenstates

$$\begin{pmatrix} d_w \\ s_w \\ b_w \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

$$\begin{pmatrix} d_w \\ s_w \\ b_w \end{pmatrix} = \begin{pmatrix} 0.975 & 0.22 & 0.005 \\ 0.22 & 0.97 & 0.04 \\ 0.005 & 0.04 & 0.99 \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

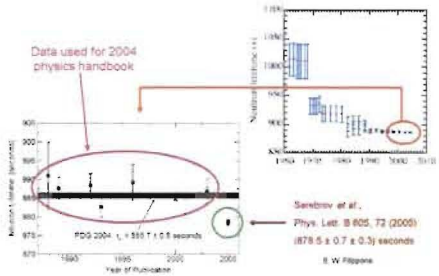
eg. $|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1$



Discrepancy in measurements of the correlation between the proton and electron that emerge from neutron decay

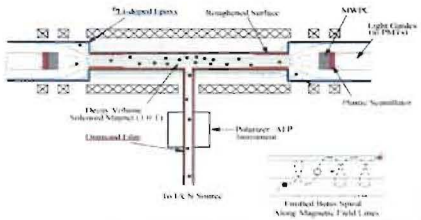
Neutron Lifetime versus Year

Physicists keep doing better, but still disagree on the exact value of the neutron lifetime

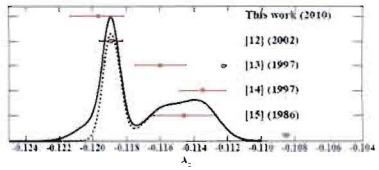


What have we learned so far?

The UCNA experiment has begun to resolve the discrepancy in the correlation of neutron decay particles

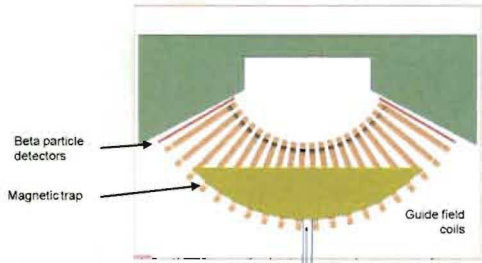


Top view of the UCNA experiment. UCNs from source enter from bottom of page, are polarized by the SC magnet, then decay in a magnetic trap. Decay betas spiral along field lines and are counted at each end.



Interim results of the UCNA experiment, compared with previous measurements of the neutron beta decay asymmetry. The two-peaked probability distribution hints at unrevealed systematic uncertainties in the previous experiments. The solid line is the probability distribution considering all experiments, including the latest UCNA result.

LANL Neutron Lifetime Experiment



UCNs settle at the bottom of the trap like water in a bathtub

UCNs enter from the bottom.

Our experiment under construction is expected to resolve the discrepancy in the neutron lifetime. It uses polarized neutrons in a magnetic trap to reach smaller uncertainties than existing experiments. First data are expected in 2010.

What is our innovation?

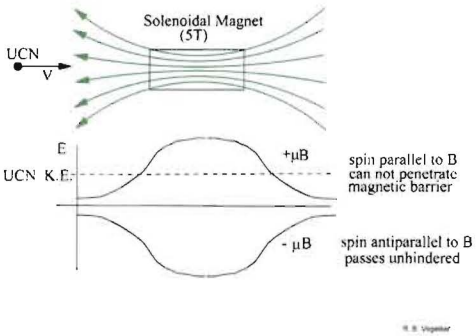
Ultra-cold neutrons (UCN) are a unique tool for improved searches for physics Beyond the Standard Model

UCN are neutrons at a human scale

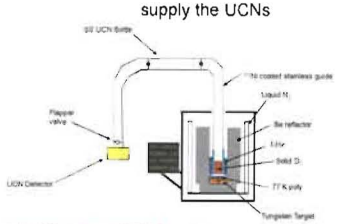
"Man is the Measure of All Things" Protagoras, 480-411 BC

Ultracold neutrons:	
$= \frac{1}{2} m_n v^2 = \frac{1}{2} m_n (8\ m/s)^2$	Move as fast as a runnning human
$= m_n g h = m_n g (3\ m)$	Are handled by human scale equipment
$= h^2/(2 m_n \lambda^2) = h^2/(2 m_n (50\ nm)^2)$	Have the same wavelength as ultraviolet light
$= \mu_n B = \mu_n (3.5\ T)$	Can be 100% polarized
$= k T = k (3\ mK)$	Near absolute zero

UCN can be 100 percent polarized, so they all spin in the same direction, by passing them through a magnetic field, eliminating the leading systematic in previous experiments



A special source, developed at LANL using LDRD funds, is needed to supply the UCNs



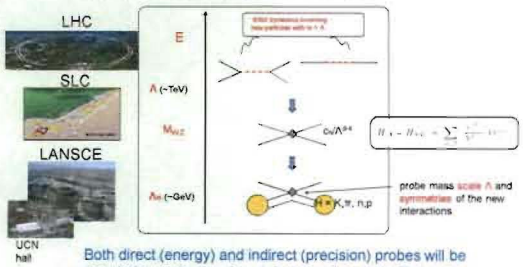
Schematic of Superthermal UCN Source

Protons from the LANSCE accelerator strike the tungsten target and produce spallation neutrons, which are reflected by Be and moderated by CH_2. 5K solid deuterium converts the cold neutrons to UCNs. The UCNs are guided away from the source to detectors or experiments by stainless steel guides.

Why is this important for our nation?

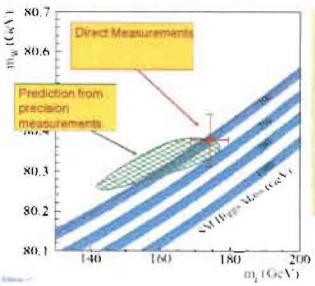
Precision physics measurements using UCN allow us to probe the same physics as the Large Hadron Collider, 15 years and $10B in the making. Our measurements are directly complementary to the LHC. The LHC will directly detect new particles, but precision measurements using UCNs will probe their masses and symmetries.

The big picture: energy vs precision frontier



Both direct (energy) and indirect (precision) probes will be needed to understand particle dynamics at the TeV scale

Precision Electroweak Measurements and Collider Searches are Complementary; They access the same energy regimes



It worked before: precision low energy measurements determined the mass of the W boson and the top quark before they were actually detected.