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Title: Ultra-cold Neutron Fundamental Physics Experiments at LANSCE

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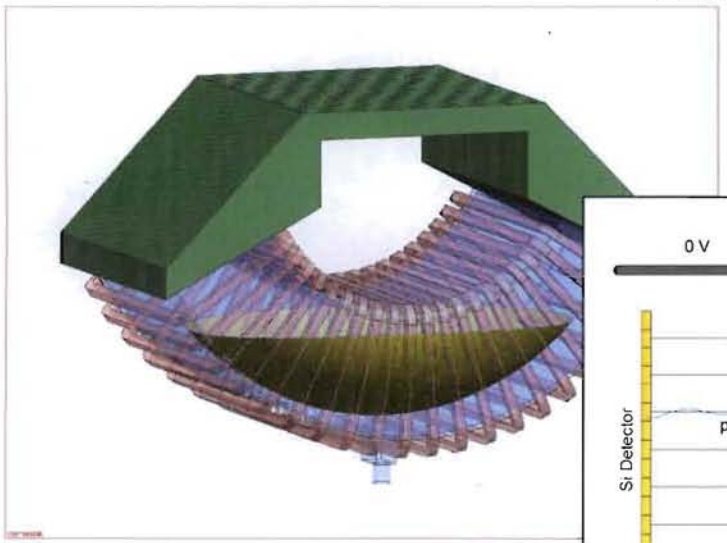
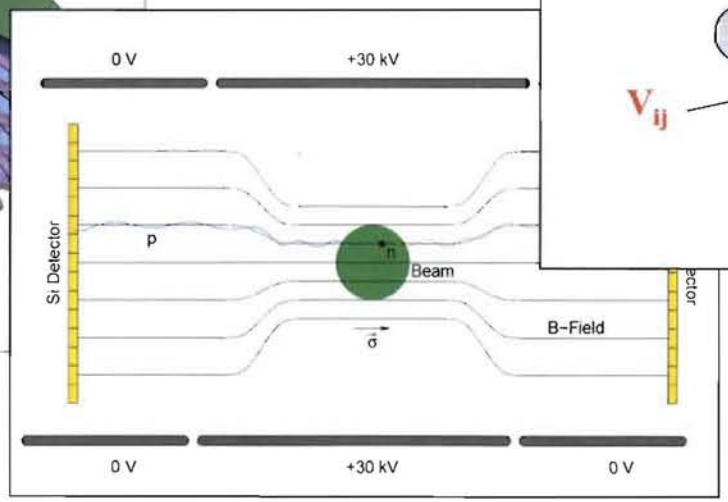
Alexander Saunders

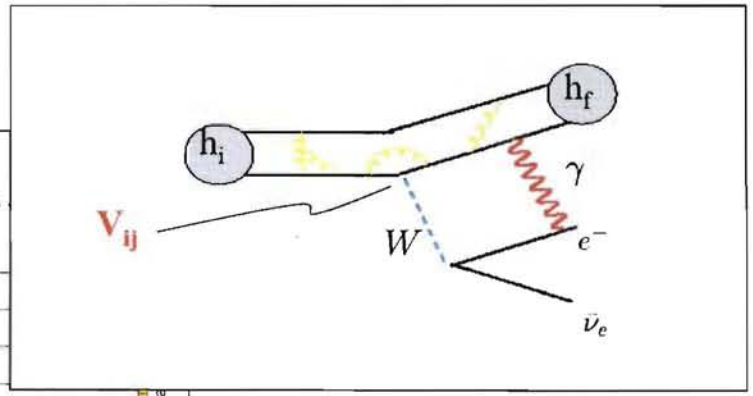
Los Alamos National Laboratory



Neutron Lifetime



Beta Decay Correlations



Beta Decay Theory

UCNA Collaboration

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The future: a UCN User Facility at LANSCE

- Fundamental physics with UCN in the U.S.
  - 1995: about 5 active US faculty and staff
  - 2009: 44 active US faculty and staff
  - 7 current projects (5 based in the US)
- UCN Sources in US
  - Around 1995, only source in world of extracted UCN for experiments – Steyerl rotor at ILL
  - 1995, superthermal LHe source development began at NIST for dedicated lifetime experiment
    - no extracted UCN capability
  - 1998, SD2 source development began at LANL
  - 2004, first tests of production SD2 source at LANL
  - 2005, SD2 source development began at PULSTAR: much smaller than LANL source; first tests expected in 2010
  - 2007, superthermal LHe source development began at SNS for dedicated EDM experiment
    - no extracted UCN capability

2009, LANL source remains the **only**, operational source for extracted UCN in the US

Neutron β decay and V_{ud}

$$|V_{ud}|^2 = \frac{G_V{}^2}{G_F{}^2(1+\Delta_R^V)}$$

Neutron lifetime

$$\tau^{-1} = Kf^R(G_V{}^2 + 3G_A{}^2)$$

(τ = 885.7±0.8 s PDG2006)

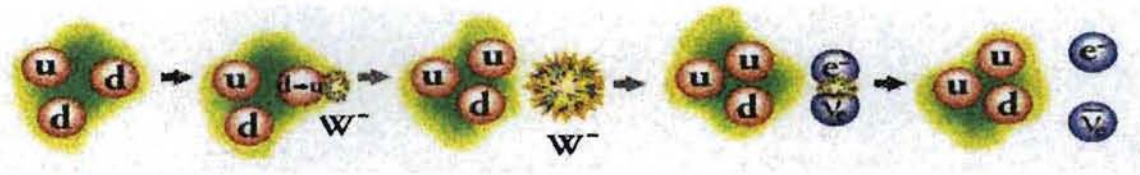
Angular correlation in polarized neutron decay (Jackson *et al* '57)

$$d\Gamma = d\Gamma_0 \times \left[1 + a\frac{\overrightarrow{p_e}\cdot\overrightarrow{p_\nu}}{E_e E_\nu} + \left\langle\overrightarrow{\sigma_n}\right\rangle\cdot\left(A\frac{\overrightarrow{p_e}}{E_e} + B\frac{\overrightarrow{p_\nu}}{E_\nu}\right)\right]$$

$$a = \frac{1-|\lambda|^2}{1+3|\lambda|^2}, \quad A = -2\frac{|\lambda|^2 + \mathrm{Re}(\lambda)}{1+3|\lambda|^2}, \quad B = 2\frac{|\lambda|^2 - \mathrm{Re}(\lambda)}{1+3|\lambda|^2} \qquad \lambda \equiv \frac{G_A}{G_V}$$

$\delta\lambda/\delta a$ ~ 3.3; a = –0.103 ± 0.004 (PDG2006)
$\delta\lambda/\delta A$ ~ 2.6; A = –0.1173 ± 0.0013 (PDG2006)
$\delta\lambda/\delta B$ ~ 13.4; B = –0.981 ± 0.004 (PDG2006)

Neutron β-Decay



$$d^3W(\mathbf{p}_e,\mathbf{p}_\nu|\boldsymbol{\sigma}) = dW(\mathbf{p}_e)d\Omega_e d\Omega_\nu \left[1 + a\frac{\mathbf{p}_e\cdot\mathbf{p}_\nu}{E_eE_\nu} + b\frac{m}{E_e} + \boldsymbol{\sigma}\cdot\left(A\frac{\mathbf{p}_e}{E_e} + B\frac{\mathbf{p}_\nu}{E_\nu} + D\frac{\mathbf{p}_e\times\mathbf{p}_\nu}{E_eE_\nu}\right)\right]$$

Jackson et al

a = electron neutrino correlation
A = beta asymmetry
B = neutrino asymmetry

D = triple correlation (T-violating)
b = Fierz interference term

Measuring A and neutron lifetime

$$A = -2\frac{-G_AG_V + G_A^{\ 2}}{G_V^{\ 2} + 3G_A^{\ 2}}$$

$$ft_n = \frac{constant}{G_V^{\ 2} + 3G_A^{\ 2}}$$

gives G_A and G_V

G_F from muon decay
CKM unitarity

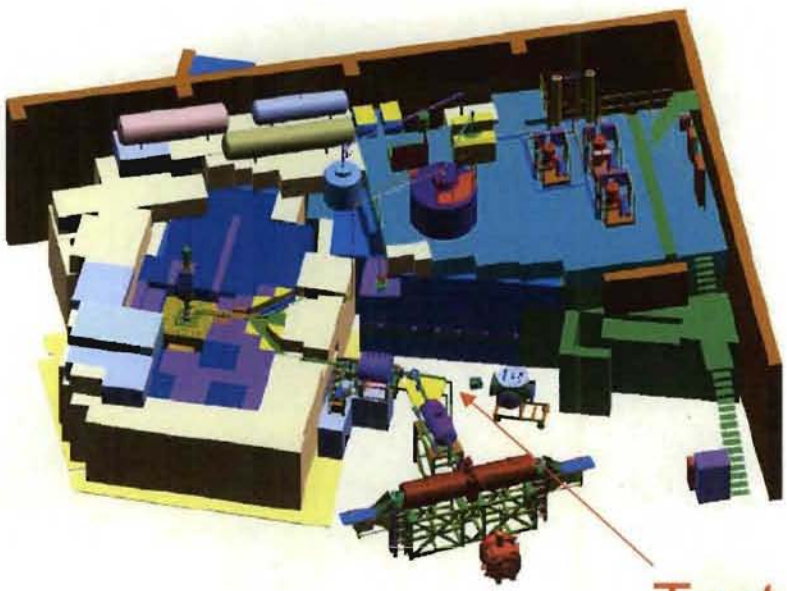
$$\lambda = G_A / G_V$$

$$G_V = G_F V_{ud}$$

$$G_A = G_F V_{ud}\lambda$$

gives V_{ud}

Capabilities of LANSCE UCN Source



Current capabilities:

- Huge floor space, ample cryogenic cooling for high field magnets and cryogenic systems
- ~10 UCN/cm^3 at the shielding wall
- Test port available (nEDM opt, lifetime)
- In spectrometer:
  - 0.6 UCN/cm^3 (measured decays)
  - Greater than 99.8% polarized UCN
  - Negligible UCN-generated backgrounds

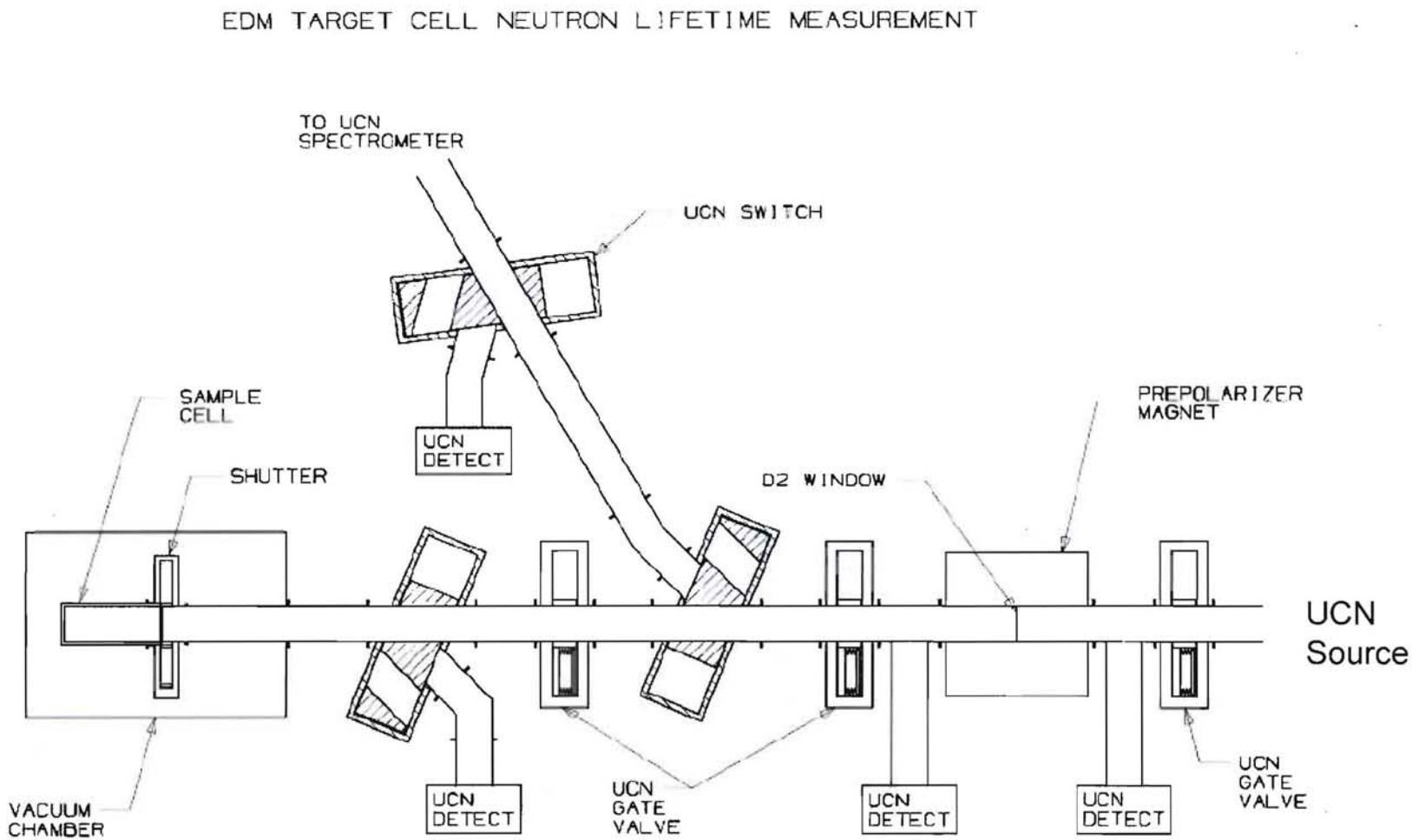
β-decay rates:

2006: less than 2 Hz

2007: 6.5 Hz

2008: 20 Hz

Test beam port available in parallel w/ UCNA

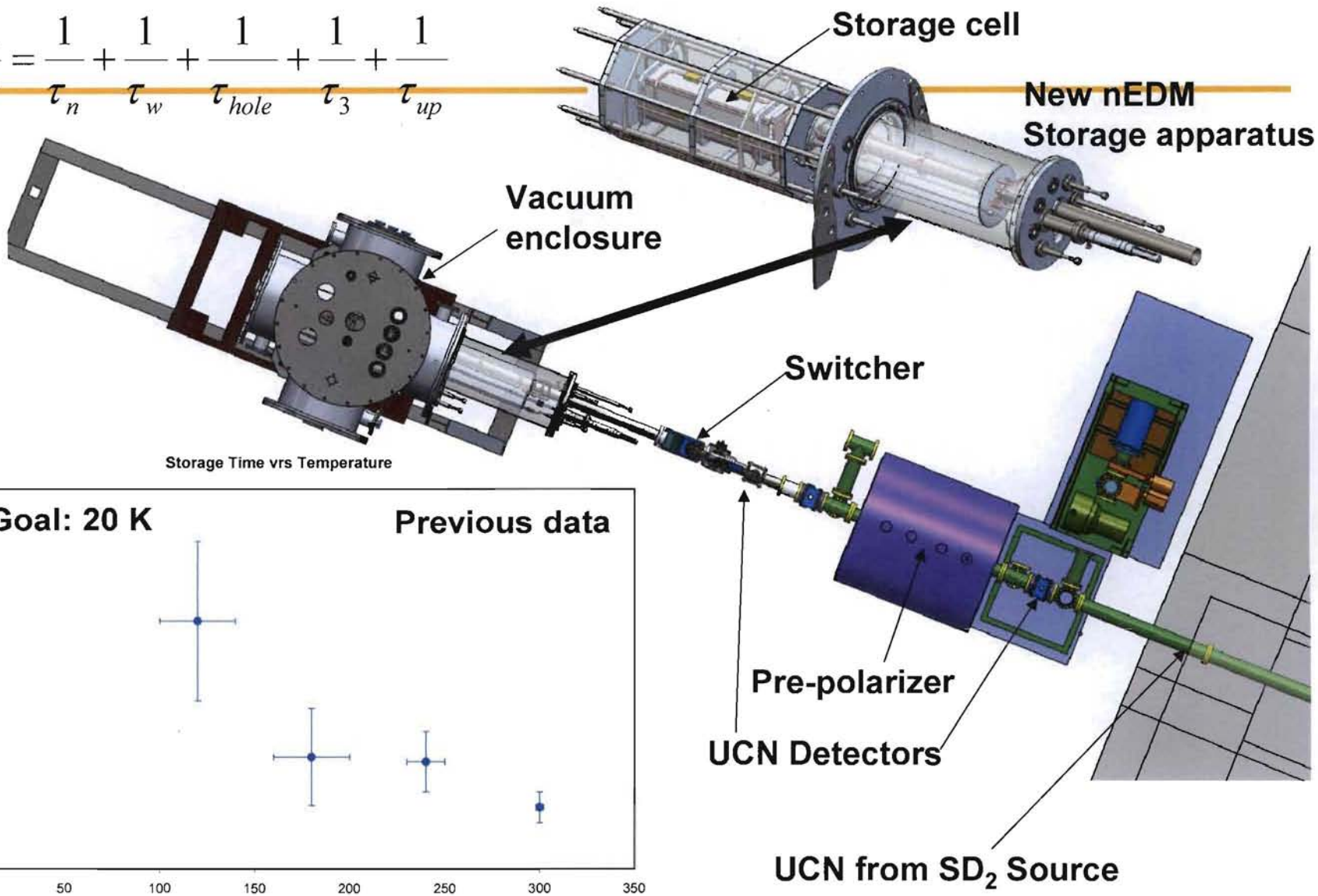


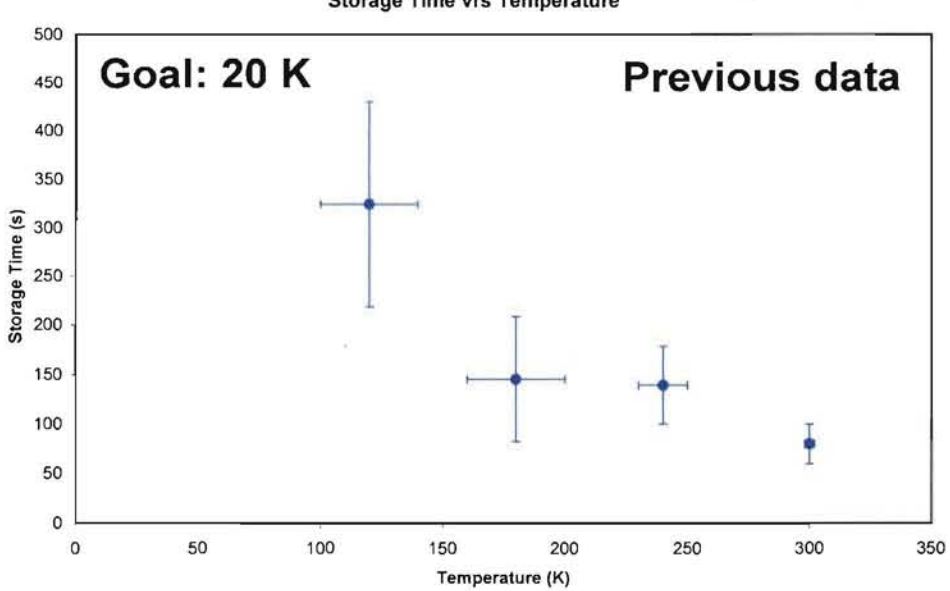
Possible Experiments for User Facility

- Neutron EDM experiment engineering and optimization (nEDM collaboration)
- Neutron beta decay measurements
  - Neutron lifetime (Saunders et al.)
  - Beta asymmetry measurements (UCNb, abBA, UCNB)
- Short ranged forces and quantum gravity (Baessler, NIST)
- Neutron interactions with surfaces and solids (Korobkina)
- NNbar development (NNbar collaboration)
- UCN source technology development (Liu et al.)

nEDM Storage Time at LANSCE Area B

$$\frac{1}{\tau} = \frac{1}{\tau_n} + \frac{1}{\tau_w} + \frac{1}{\tau_{hole}} + \frac{1}{\tau_3} + \frac{1}{\tau_{up}}$$





Summary

- Ultra-cold neutrons provide a unique tool for studying fundamental weak nuclear interactions and searching for physics beyond the standard model
- A UCN user facility at LANSCE will provide a fertile resource for future fundamental physics