Precise Measurement of the Neutron Beta Decay Parameters "*a*" and "*b*"

The *Nab* Collaboration

- Goals, motivation of experiment
- Basic measurement technique and spectrometer design
- Running requirements
- Projected costs and responsibilities
- Projected schedule

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The Nab Collaboration

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Goals of the Experiment

- Measure the electron-neutrino parameter $\boldsymbol{a}$ with $\sim 10^{-3}$ accuracy

	-0.1054 ± 0.0055	Byrne et al '02
current results:	-0.1017 ± 0.0051	Stratowa et al '78
	-0.091 ± 0.039	Grigorev et al '68

- Measure the Fierz interference term $\boldsymbol{b}$ with sub-percent accuracy

current results: **none**

Neutron Decay Parameters (SM)

$$\frac{dw}{dE_e d\Omega_e d\Omega_\nu} \simeq k_e E_e (E_0 - E_e)^2$$

$$\times \left[1 + a \frac{\vec{k}_e \cdot \vec{k}_\nu}{E_e E_\nu} + b \frac{m}{E_e} + \langle \vec{\sigma}_n \rangle \cdot \left(A \frac{\vec{k}_e}{E_e} + B \frac{\vec{k}_\nu}{E_\nu} + D \frac{\vec{k}_e \times \vec{k}_\nu}{E_e E_\nu} \right) \right]$$

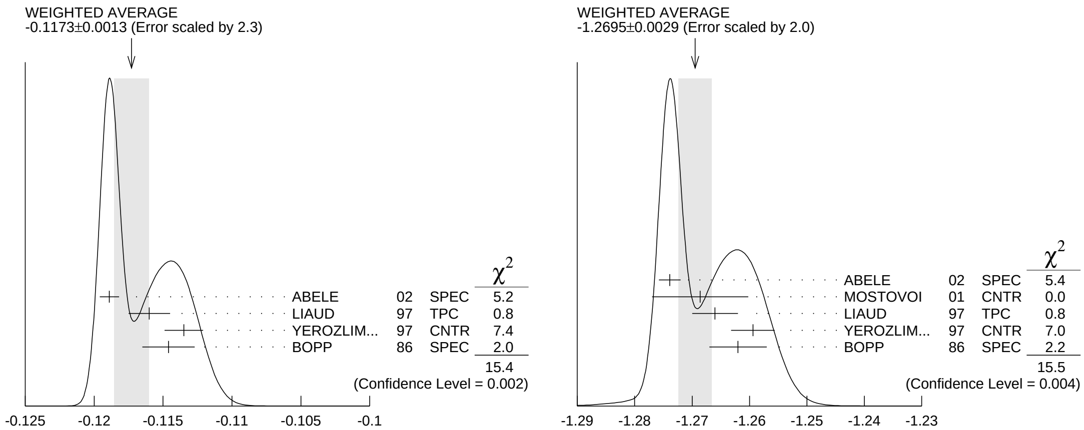
with:

$$a = \frac{1 - |\lambda|^2}{1 + 3|\lambda|^2} \qquad A = -2 \frac{|\lambda|^2 + Re(\lambda)}{1 + 3|\lambda|^2}$$

$$B = 2 \frac{|\lambda|^2 - Re(\lambda)}{1 + 3|\lambda|^2} \qquad D = 2 \frac{Im(\lambda)}{1 + 3|\lambda|^2}$$

$\lambda = \frac{G_A}{G_V}$ ($D \neq 0 \Leftrightarrow T$ invariance violation.)

PROBLEMS WITH A AND λ



(from PDG 2005 compilation)

Note: sensitivity of a to λ comparable to that of A.

FURTHER CONSIDERATIONS

- Beta decay parameters constrain L-R symmetric model extensions to the SM. [Herczeg, Prog. Part. Nucl. Phys. **46**, 413 (2001)].

- Sensitivity of a to L-R model parameters such as $\bar{a}_{RL}$ and $\bar{a}_{RR}$ competitive and complementary to that of A and B. [*ibid*].

- Fierz interference term, never measured for the neutron, offers a unique test of non-$(V-A)$ terms in the weak Lagrangian (S, T).

- A general connections exists between non-SM (e.g., S, T) terms in $d \to u e \bar{\nu}$ and limits on ν masses. [Ito + Prézaeu, PRL **94** (2005)].

Experimental Method

We need to determine dependence of decay rate dw on $\cos\theta_{e\nu}$.

Will measure p_p (TOF) and p_e (Si detector); $\cos\theta_{e\nu}$ follows from

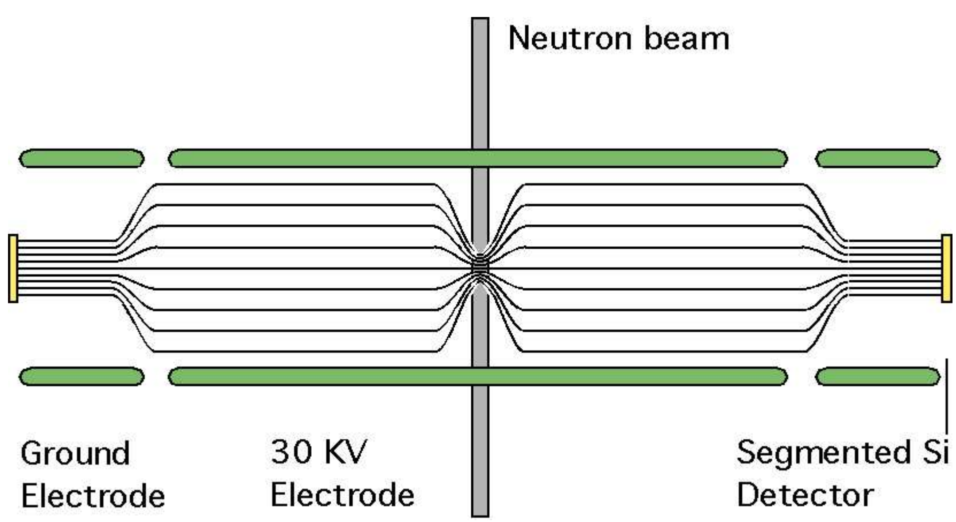
$$p_p^2 = p_e^2 + 2p_e p_\nu \cos\theta_{e\nu} + p_\nu^2\,.$$

No polarization—no need to worry about spin transport!

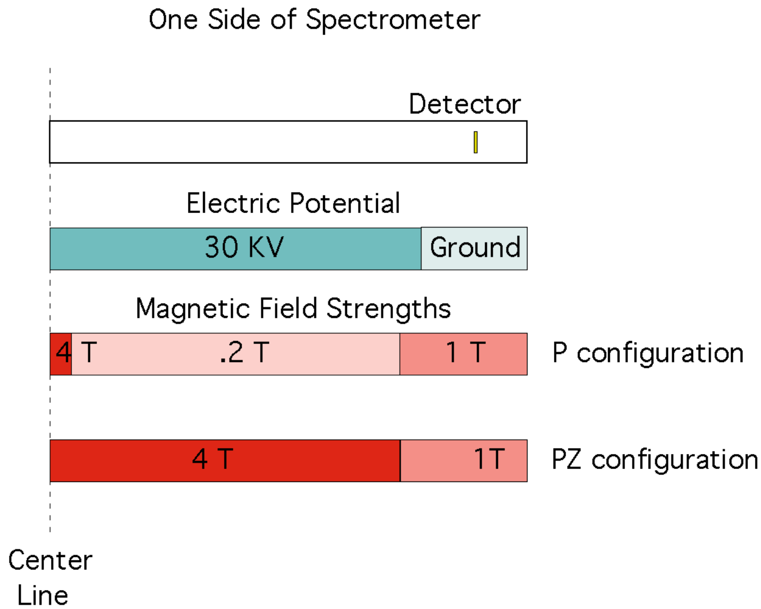
Custom spectrometer with $\vec{\mathcal{B}}$ field expansion, no material windows insures:

- hermeticity: near-4π sr coverage $\Rightarrow$ excellent statistical sensitivity (superior to previous measurements of $\boldsymbol{a}$, and A);
- $\cos\theta_{e\nu}$ reconstructed in kinematically complete way;
- n, p, e interact only with $\vec{\mathcal{E}}$, $\vec{\mathcal{B}}$ fields and detectors;
- magnetic field pinch minimizes backscattered electron events;
- imaging of source n distribution on the face of Si detectors.

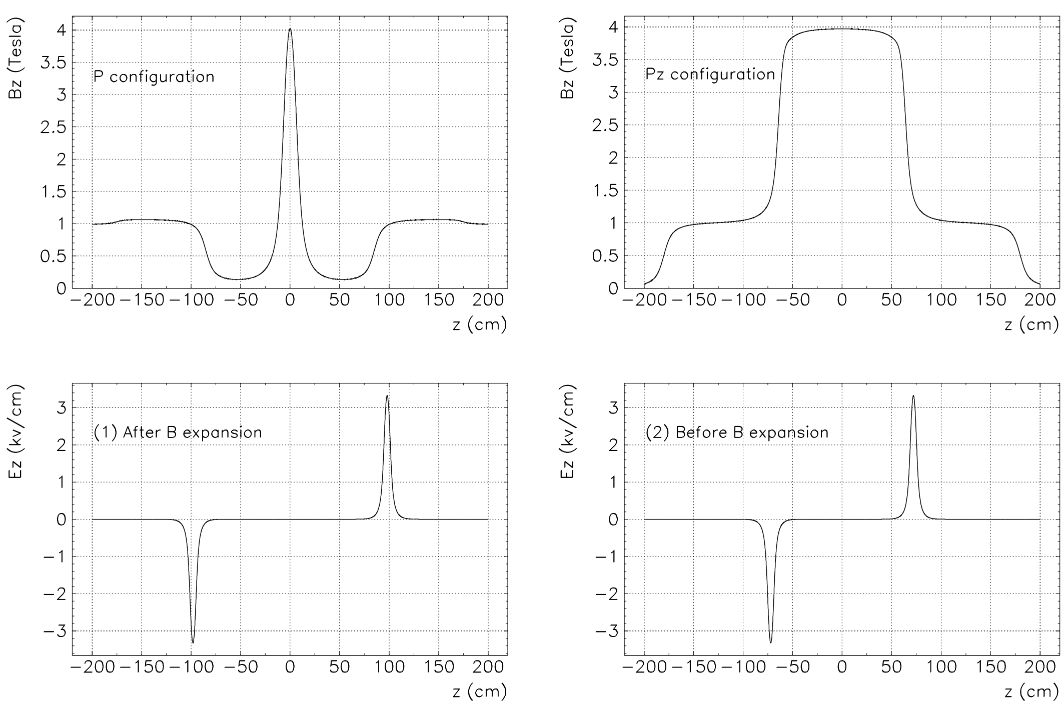
Electromagnetic Spectrometer



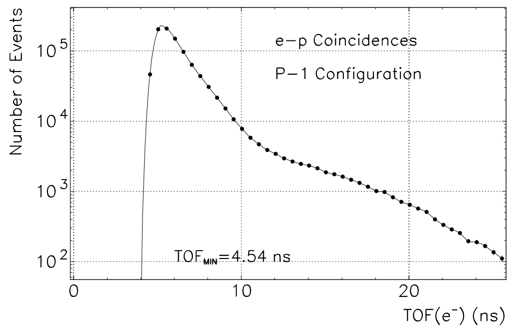
Electromagnetic Field Profiles



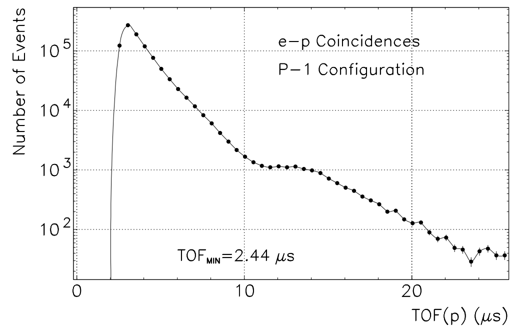
Basic Design Options



Time of Flight Spectra

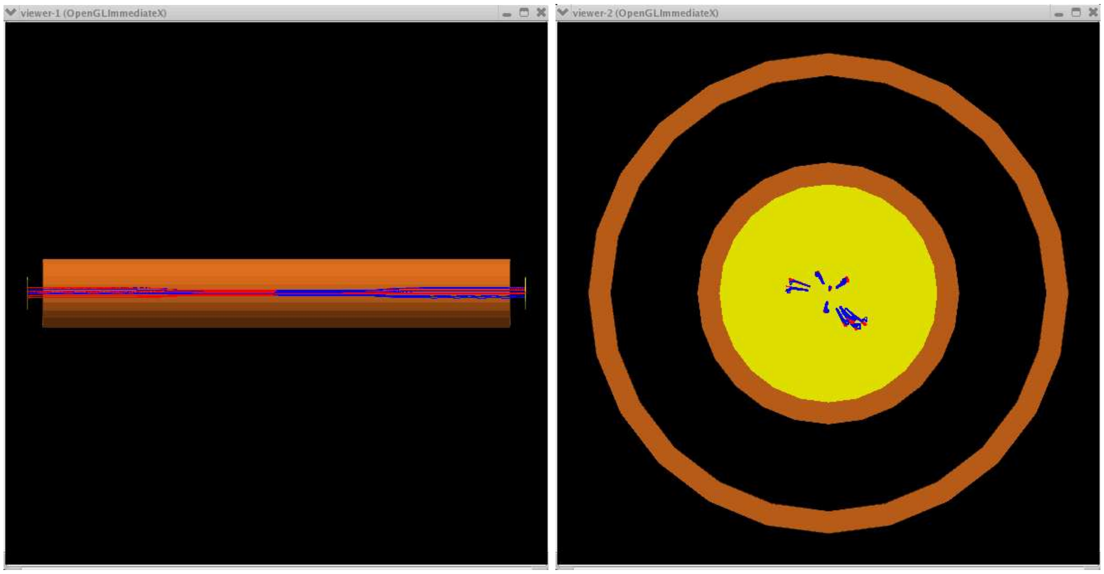


electrons



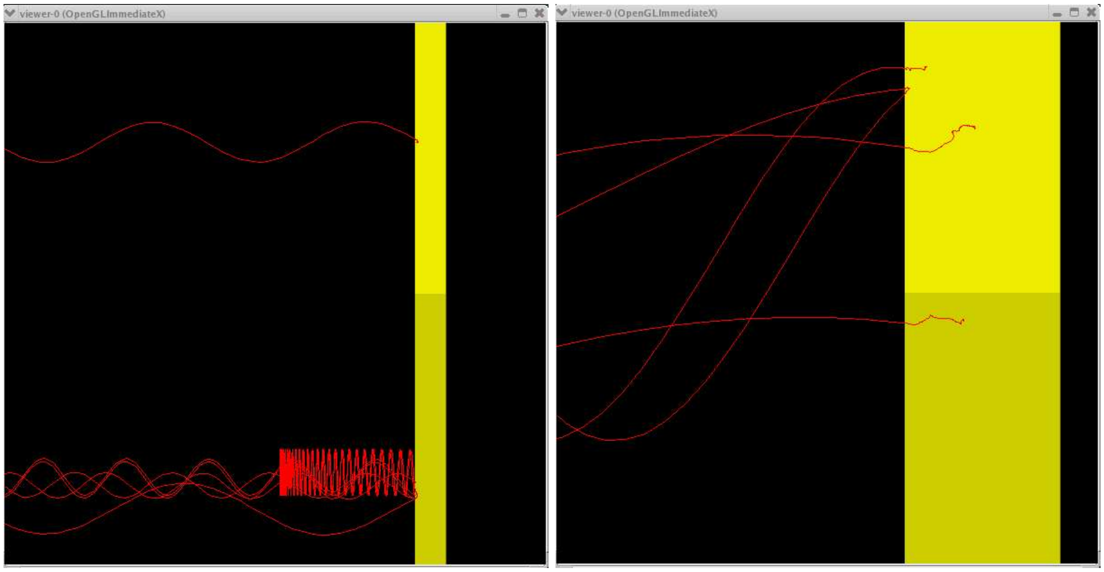
protons

Simulated Data (geant 4)



electrons: red   protons: blue

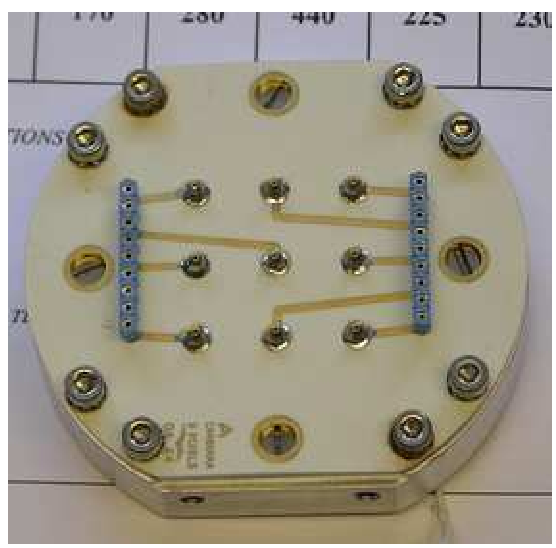
e$^-$ Reflection at Field Pinch (geant 4)



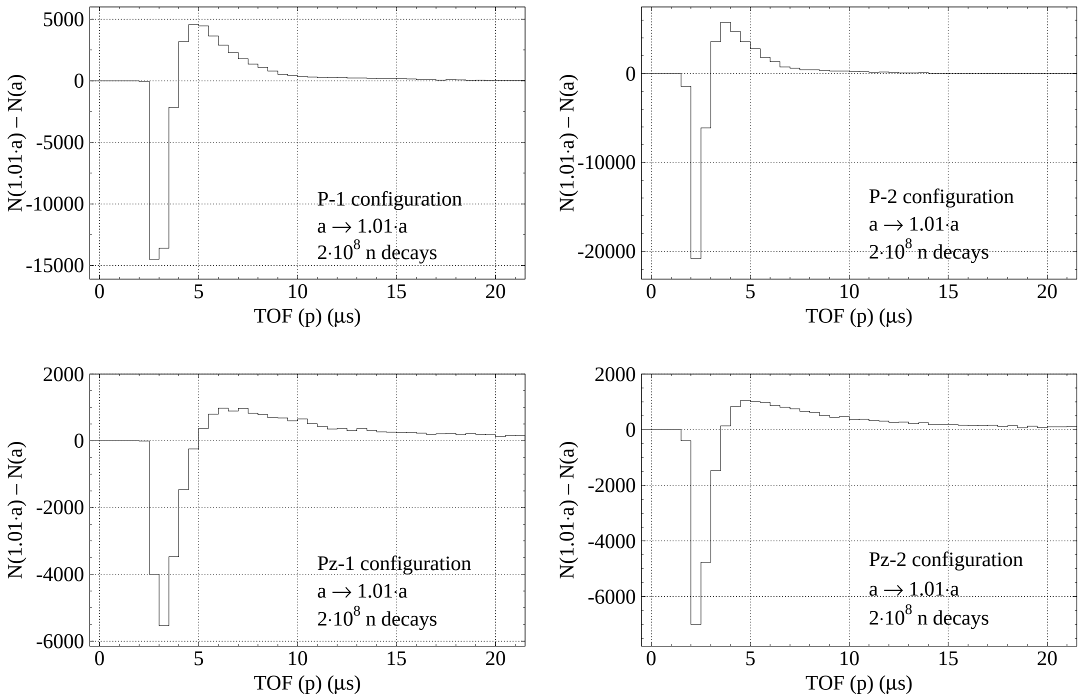
Si thickness: 2 mm

Si Detector Prototypes (1/10 size)

⇓ front ⇓ back ⇒



Expected Physics Signal (geant 4)



Running Requirements

With SNS operating at 1.4 MW, we expect to record 2×10^8 neutron decay events in a standard $\sim$ 10-day run, 7×10^5 s.

Total data sample required will comprise $\sim 5 \times 10^9$ neutron decays collected during about 6-7 months of production beam time spread over $\sim$3 years in several 1-2 month runs.

Statistical uncertainties well under 1 % per standard run in both $\boldsymbol{a}$ and $\boldsymbol{b}$. Current understanding of systematic errors in agreement with 10^{-3} goal (work is ongoing).

We would like to run both "P" and "PZ" configurations because of their significantly different systematics.

Equipment Cost Estimate and Responsibilities

1. Superconducting solenoid and HV electrodes (UVa/NSF)	0.5–1 M$
design: LANL (analytical), UNH+ASU (Tosca), UVa (Monte Carlo)	
2. Si detectors + readout: (ORNL,UT/DoE)	
a. Si detectors (design: LANL+UT)	100 k$
b. waveform digitizer readout+DAQ (design: ORNL+UT)	180 k$
3. Neutron collimation	30 k$
4. Vacuum system	30 k$
5. Supporting mechanical structure	30 k$
Total (est.)	1.5 M$

Additional: ∗ 250 k$/yr. LANL R&D funds starting 10/2006;
∗ will seek UVa matching funds for spectrometer magnet.

(an optimistic) Schedule

2005 finish conceptual design;

2006 1/2: submit proposals to SNS PAC and NSF/DoE for funding;
2/2: freeze design, prepare purchase orders;

2007 (subject to available funding) take delivery of equipment, shake down individual systems, start installing in beam;

2008 initiate test runs; routine data taking by year end;

2009 more data runs, concurrent analysis;

2010 last data runs; data analysis;

“Other” Questions

Outstanding technical issues that must be resolved?	Detector development (close to completion).
Is beam required to address these issues?	No.
Unusual safety issues?	None.
Radioactive waste generated?	Activated beam windows, stop.
Special environmental requirements?	Low backgrounds, similar to other FNPB experiments.
Backgrounds generated by experiment?	Stray magnetic fields.
Ease of removal, installation?	Straightforward, using a crane.
Staging requirements out of beam?	Floor space elsewhere.
Computing, el. power requirements?	Ordinary.
Average users on site? Students in project?	About 5; ∼3 students.
Interactions between Nab and abBA?	Full synergy.

More on Interplay of Nab and abBA

Both Nab and abBA use the same Si detectors and DAQ. Nab builds on existing abBA R&D.

Nab will provide abBA with working Si detectors and DAQ.

Electromagnetic spectrometers for the two experiments have different requirements:

- abBA spectrometer is more complex as it has to accommodate polarization and spin transport with precision polarimetry.
- Nab's is a precision TOF spectrometer with a long drift region.

Nab should run first, abBA second.