Neutron β Decay at LANL UCNA, UCNB, and UCNb

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Outline

- Introduction
- Motivation of neutron β decay measurements
- UCNA current status and plans
- UCNB plans and goals
- UCNb
- Summary

- Special Thanks to Alejandro Garcia, Brad Plaster, and Kevin Hickerson

Neutron β decay and V_{ud}

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

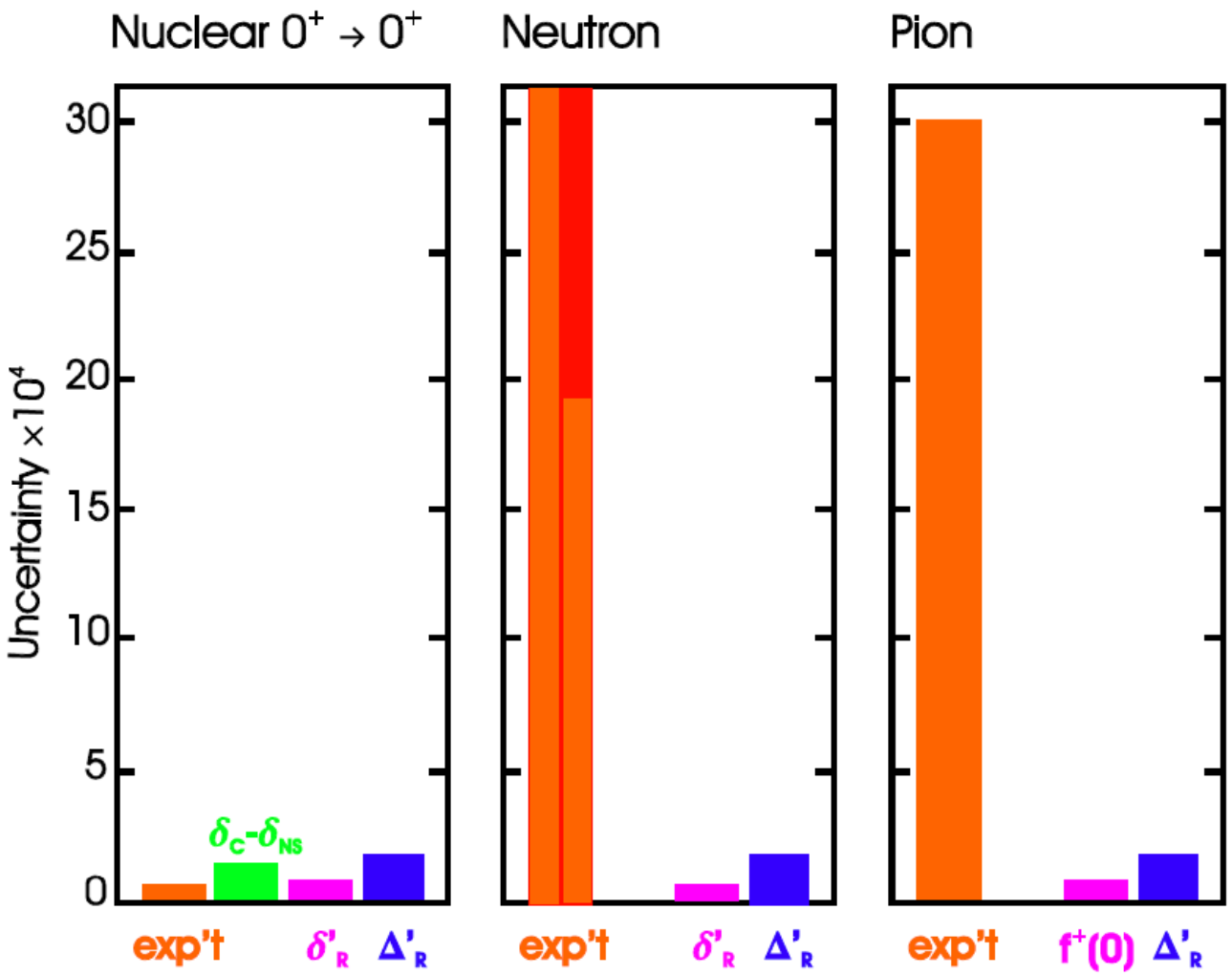
$$d\Gamma = d\Gamma_0 \times \left[1 + a\frac{\overrightarrow{p_e}\cdot\overrightarrow{p_\nu}}{E_e E_\nu} + b\frac{m_e}{E_e} + \left\langle \overrightarrow{\sigma_n} \right\rangle \cdot \left(A\frac{\overrightarrow{p_e}}{E_e} + B\frac{\overrightarrow{p_\nu}}{E_\nu} + D\frac{\vec{p}_e}{E_e} \times \frac{\vec{p}_\nu}{E_\nu}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

$$a = \frac{1-|\lambda|^2}{1+3|\lambda|^2}, \quad A = -2\frac{|\lambda|^2 + \mathrm{Re}(\lambda)}{1+3|\lambda|^2}, \quad B = 2\frac{|\lambda|^2 - \mathrm{Re}(\lambda)}{1+3|\lambda|^2}, \quad b_n = \frac{|b_F| - 3\lambda|b_{GT}|}{1+3\lambda^2}$$

$\delta\lambda/\delta a$ ~ 3.3; a = –0.103 ± 0.004 (PDG2009)
$\delta\lambda/\delta A$ ~ 2.6; A = –0.1173 ± 0.0013 (PDG2009)
$\delta\lambda/\delta B$ ~ 13.4; B = –0.9807 ± 0.003 (PDG2009)

$$\lambda \equiv \frac{G_A}{G_V}$$

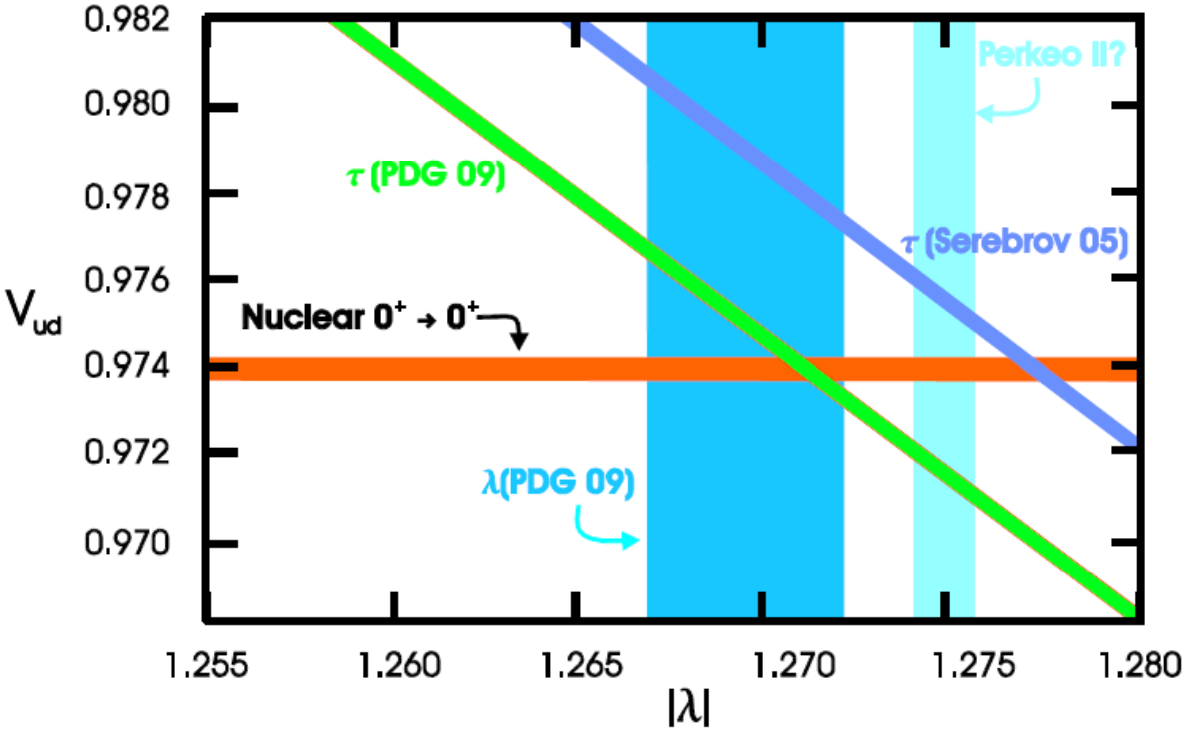
Motivation for A measurement

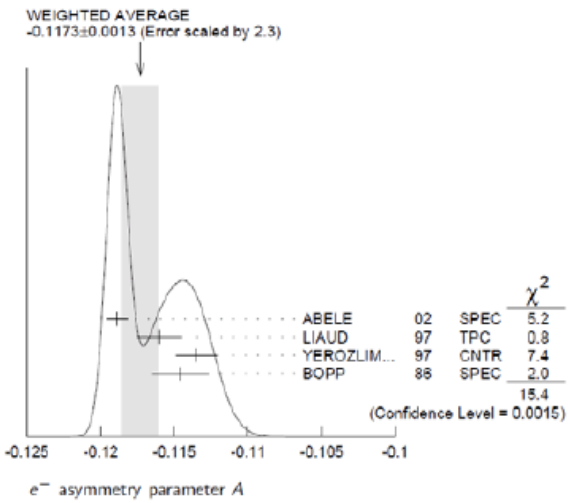


Motivation for A measurement

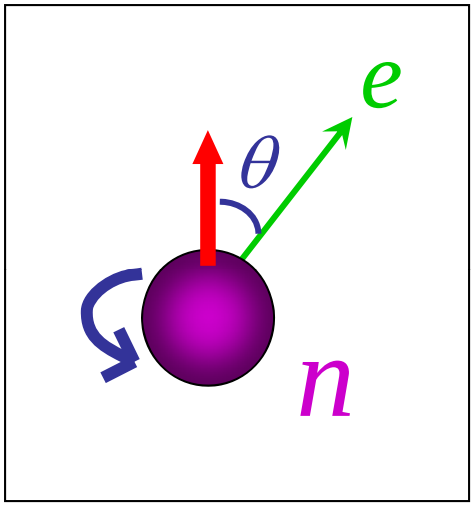
Vud from neutron decay

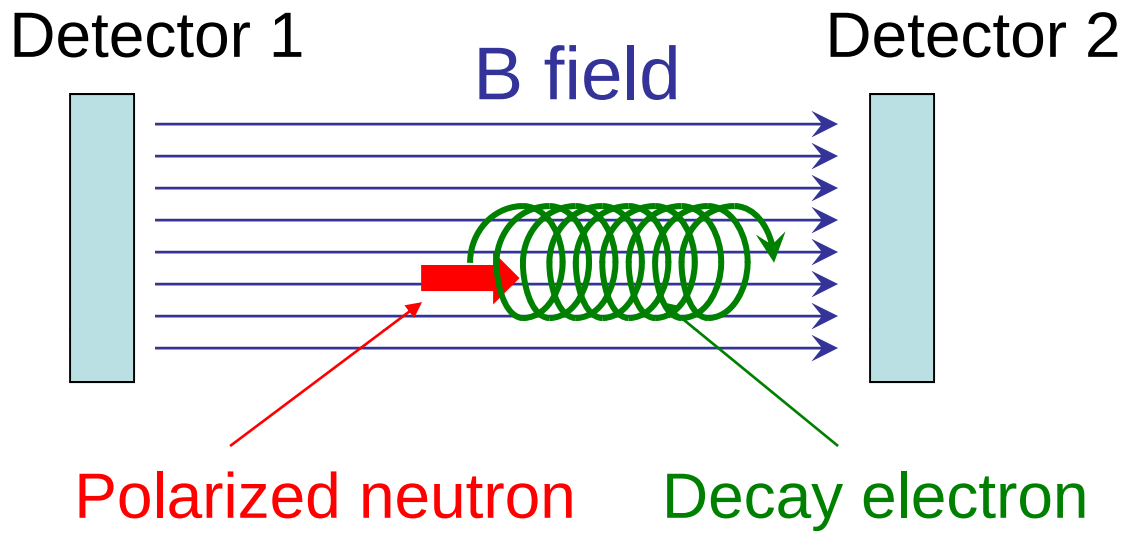
$$\frac{1}{\tau} \approx \frac{C_V^{\ 2}\, m_e^{\ 5}}{2\pi^3\hbar}\left(3|\lambda|^2+1\right) f\left(1+RC\right) \qquad A \approx -2\,\frac{|\lambda|^2+|\lambda|\cos\varphi}{3|\lambda|^2+1}$$





Principle of the *A*-coefficient Measurement





$$dW=[1+\beta PA\cos\theta]d\Gamma(E)$$

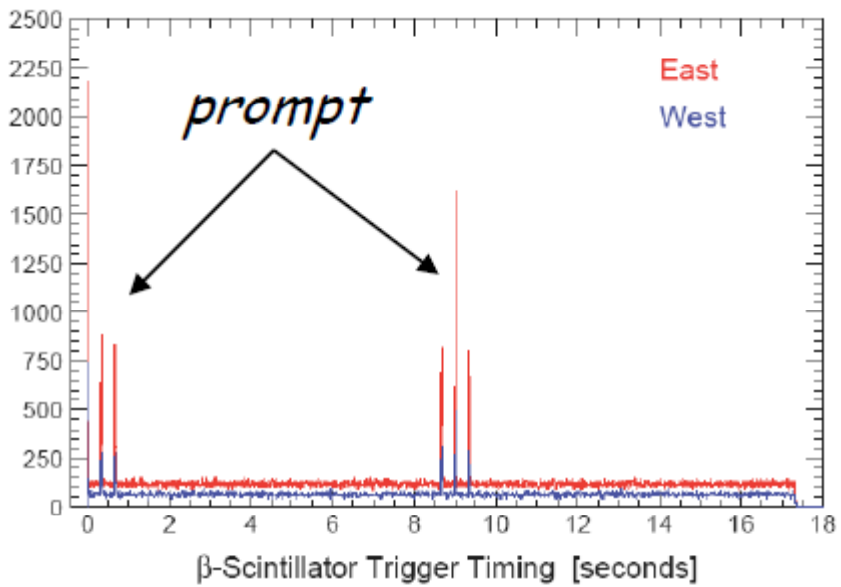
$$A_{\exp}(E)=\frac{N_1(E)-N_2(E)}{N_1(E)+N_2(E)}\approx\langle P\rangle A\beta\langle\cos\theta\rangle$$

(End point energy = 782 keV)

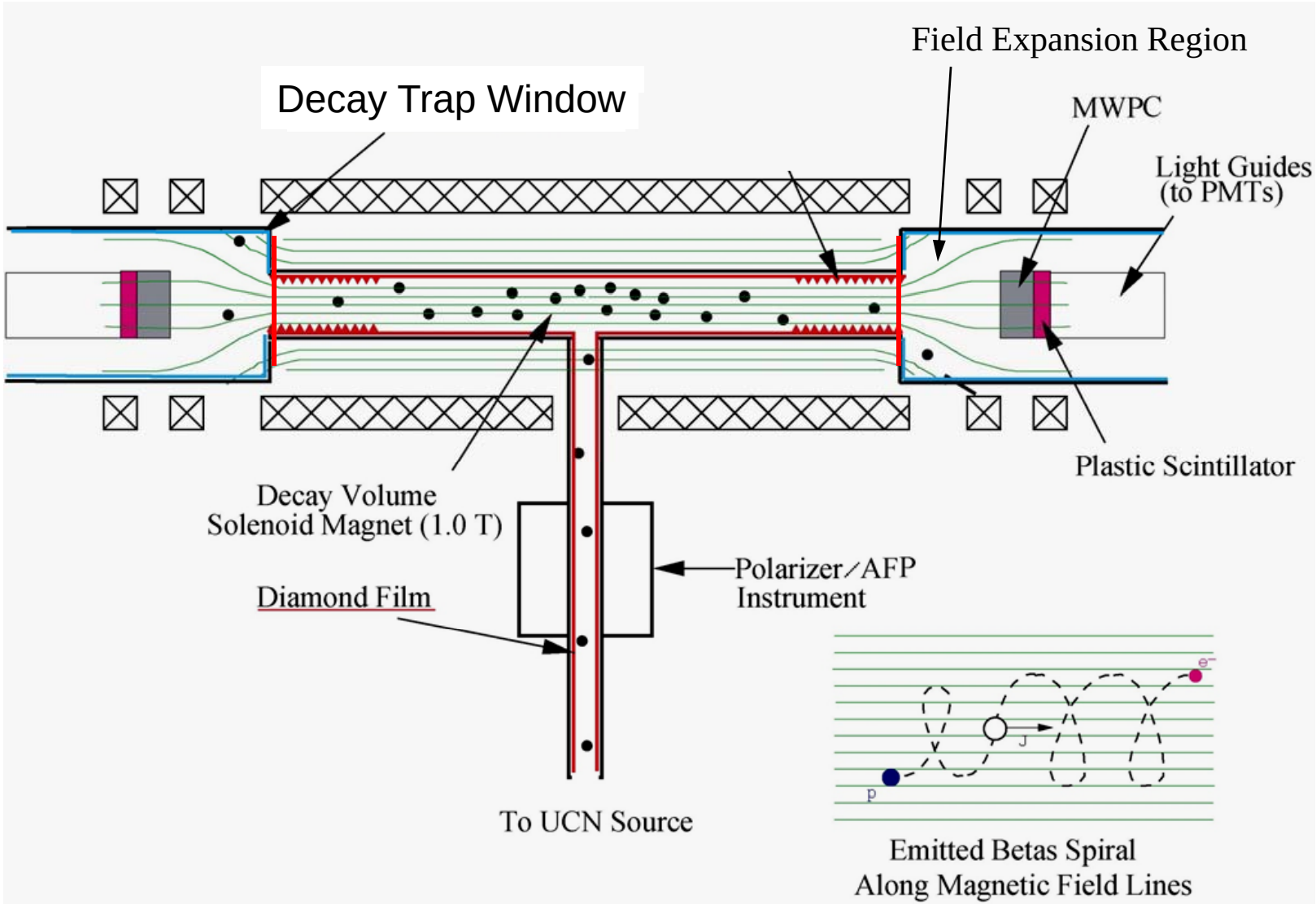
UCNA Experiment — General Approach

Novel features: UCN from pulsed spallation source
MWPC + plastic scintillator as β detector
Ultimate Goal: 0.2% measurement of A ($\delta A/A$ = 0.2%)

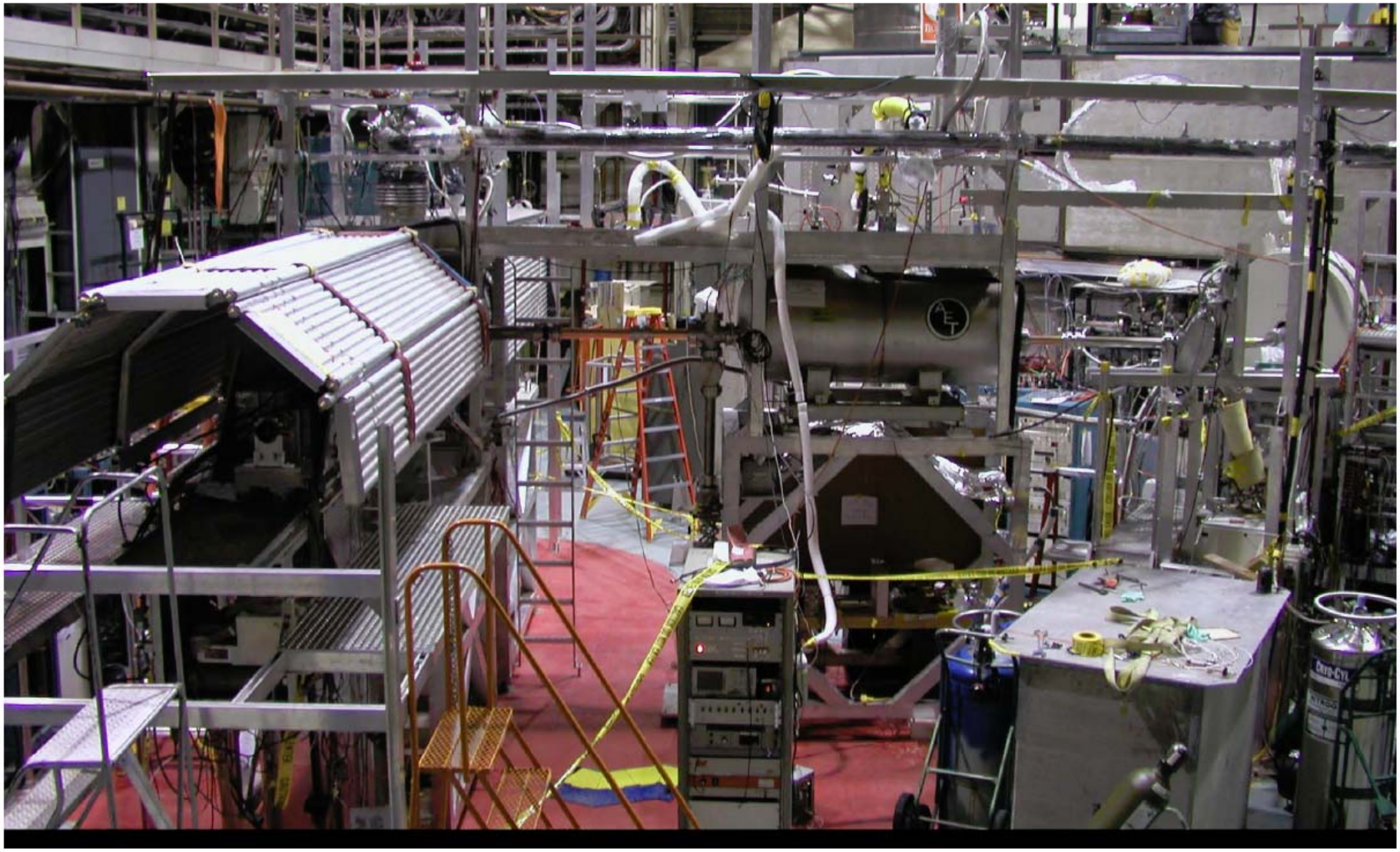
- Neutron Polarization
  - UCN (can produce >99% polarization with 7T magnetic field)
  - Diamond-like carbon coated neutron guide (low depolarization)
- Background
  - Pulsed UCN source
  - MWPC+Plastic scintillator
- Electron backscattering
  - MWPC+Plastic scintillator
- Fiducial volume selection
  - MWPC
- Detector Characterization
  - Off-line calibration system
  - Larger light collection



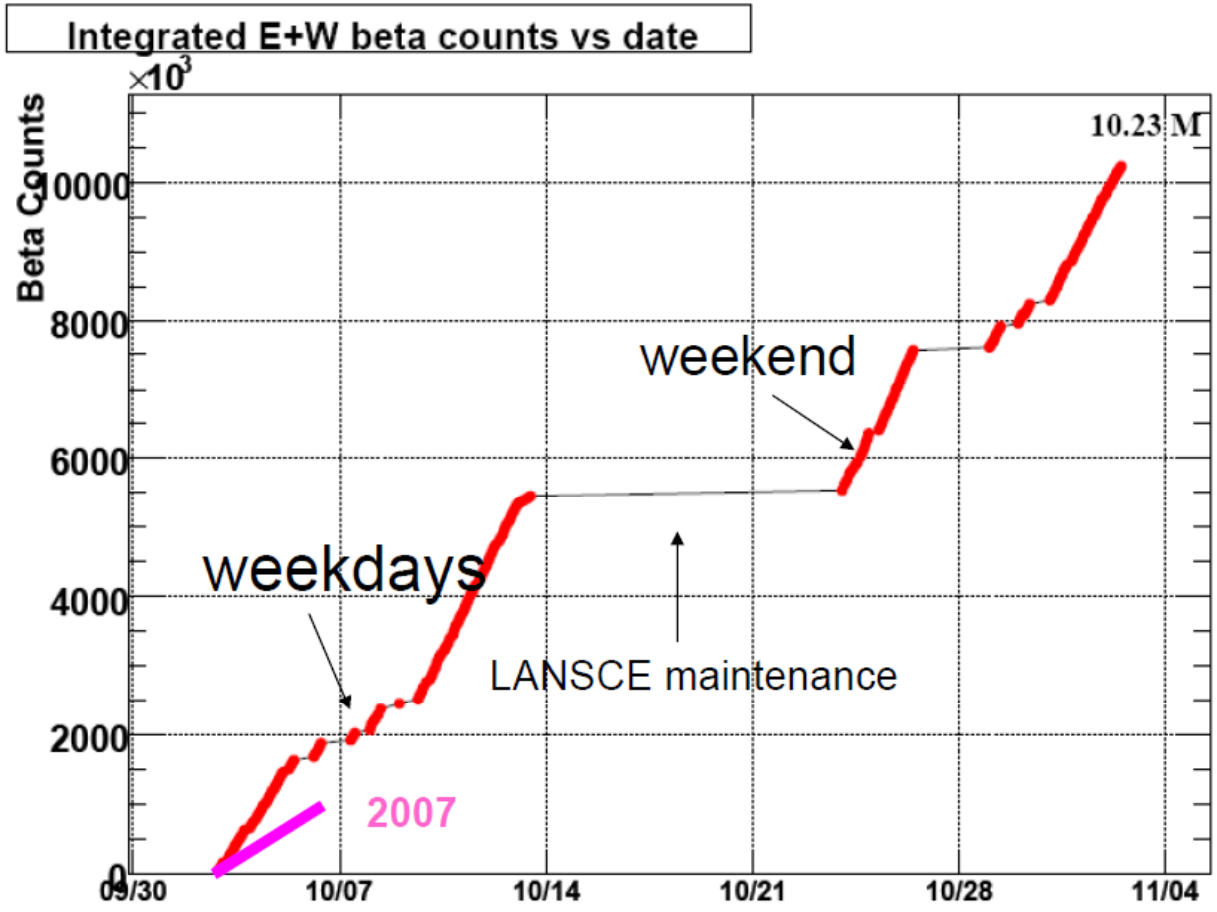
UCNA Experiment — Apparatus



UCNA Apparatus in LANSCE Area B



2008 Data run: 32 M decays

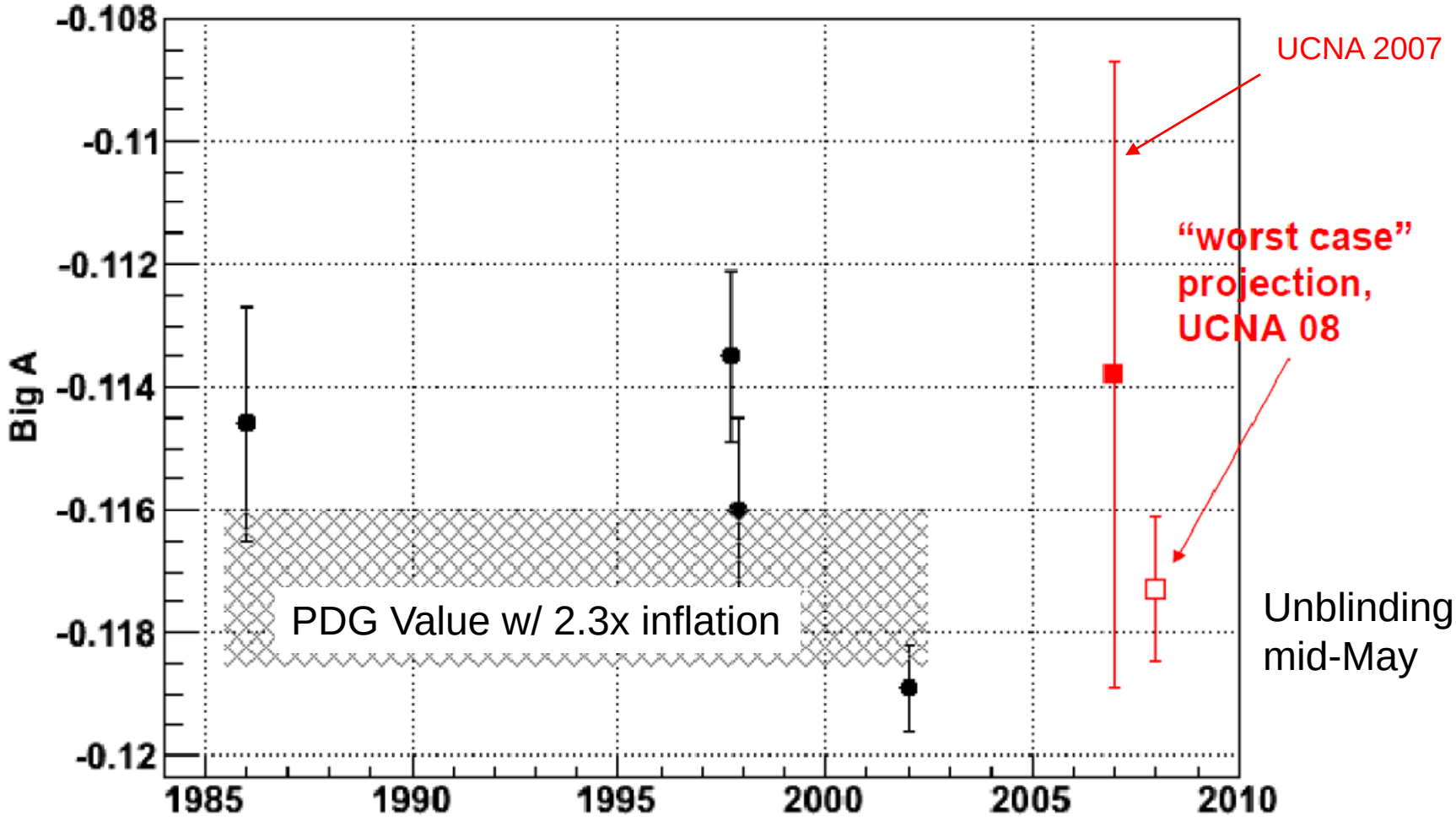


One of three data periods

Preliminary Uncertainty Budget

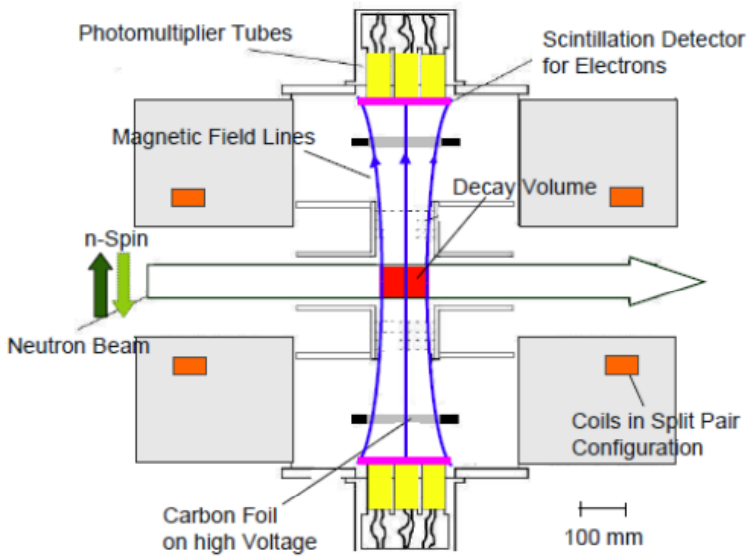
	2007		2008/2009	
	Correction(%)	Uncertainty(%)	Correction (%)	Uncertainty (%)
Statistical	n/a	4	n/a	0.8
Polarization	0	1.3	0	???
Energy Calibration	0	1.5	0	0.6
Angle Effect	-1.6	0.5	-1.4, -2.6, -0.5	<0.3
Backscattering	1.1	0.4	1.7, 5.3, 1.2	0.3%, or 30% of correction
Background	n/a	n/a	0	<0.2
Muon cut			0	0.1
Gamma cut			0	0.3
TDC cut			0	0.24
Fiducial cut			0	0.2
SCS Field dip			0	0.2
Total sys		2.1		0.9 (no pol, 0.3% on bck)
Total		4.5		1.2%

A Correlation history



B History

VALUE	DOCUMENT ID		TECN	COMMENT	P =
0.9807±0.0030 OUR AVERAGE					
0.9802±0.0034±0.0036	SCHUMANN	07	CNTR	Cold *n*, polarized	0.997(1)
0.967 ±0.006 ±0.010	KREUZ	05	CNTR	Cold *n*, polarized	0.987(5)
0.9801±0.0046	SEREBROV	98	CNTR	Cold *n*, polarized	0.975(3)
0.9894±0.0083	KUZNETSOV	95	CNTR	Cold *n*, polarized	0.669(2)
1.00 ±0.05	CHRISTENSEN	70	CNTR	Cold *n*, polarized	0.87(3)
0.995 ±0.034	EROZOLIM...	70C	CNTR	Cold *n*, polarized	0.74(1)



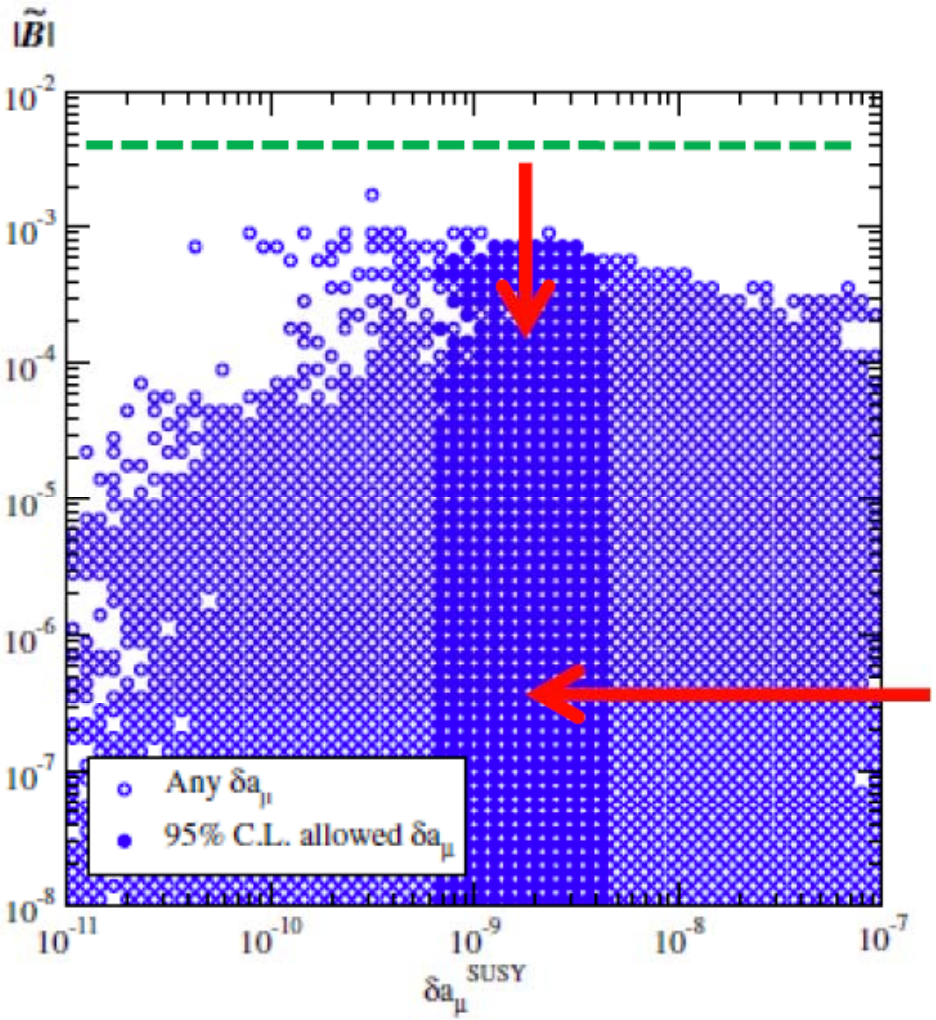
PERKEO IIB

M. Schumann et al., PRL 99, 191803 (2007); and Ph.D. Thesis

$$B_{\exp}(E_e) = \frac{N^{--}(E_e) - N^{++}(E_e)}{N^{--}(E_e) + N^{++}(E_e)}$$

$B_{exp}(E_e)$ related to B via integration of W over the hemispheres

MSSM parameter space



Current 0.3%
Precision on B

Muon g-2 allows these

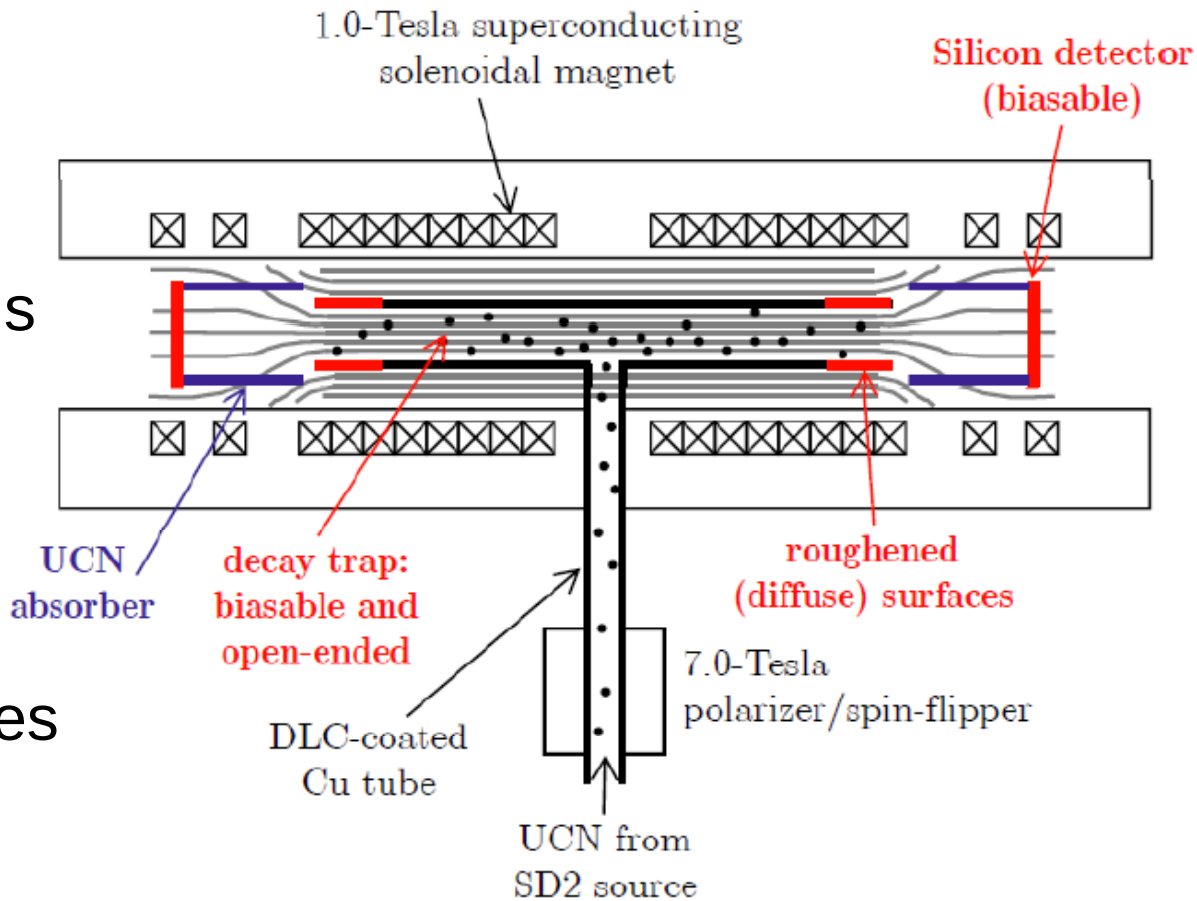
Concept of UCNB Measurement

Detect electrons and protons in coincidence to reduce backgrounds

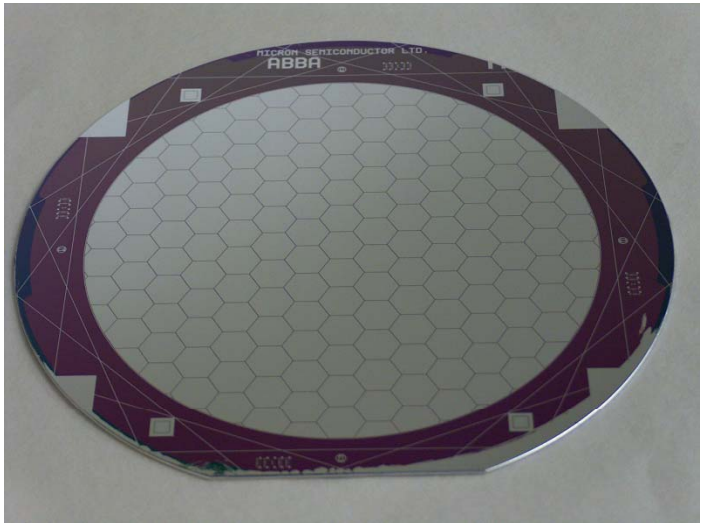
Measure electron energy with Si detectors

Detector bias enables proton detection

Mounted in UCNA spectrometer



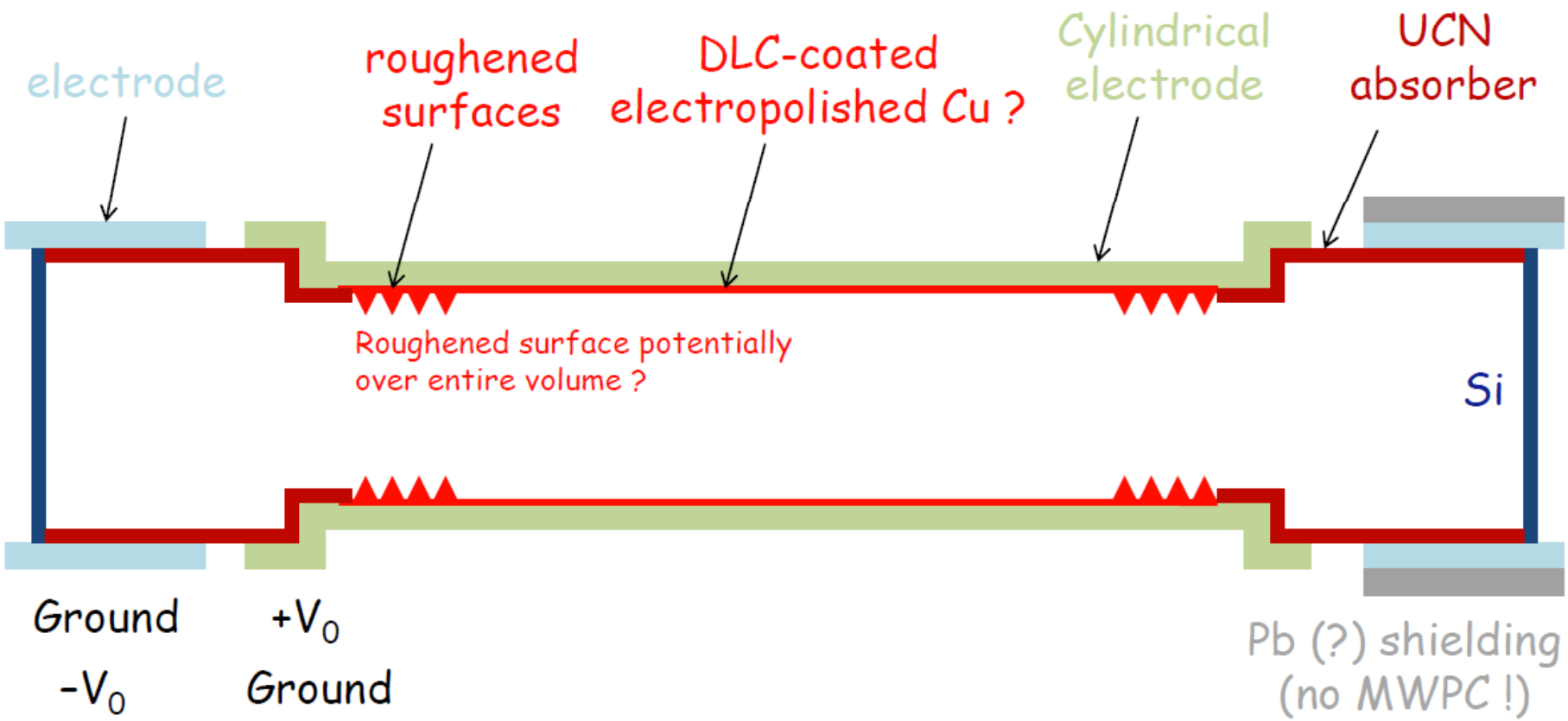
Silicon Detectors



127 hexagonal pixels, 70 mm^2
Up to 2 mm thick in hand

- Electrons
  - 800 keV electrons
    - 1.7 mm
  - Few keV resolution
  - Few ns timing
- Protons
  - 20-30 keV protons
  - 100 nm dead layer (10 keV)

Experiment Layout within 1 T magnet



Symmetric vs. asymmetric configuration

To achieve 0.1% on B, with 10 Hz detected coincidences

Configuration	Symmetric	Asymmetric
Sensitivity	$\sigma_B = 2.6/\sqrt{N}$	$\sigma_B = 5.4/\sqrt{N}$
Required Counts	~1×10^7	~3×10^7
Running Time	2 weeks	6 weeks
Advantage	Better sensitivity; Cancels det. Sens. to higher order	No penning trap of e^-

Preliminary Error Budget for UCNB

Error Source	Correction	Uncertainty	Comment
Statistical	n/a	<0.05%	Weeks of run time at UCNA rates
β backscattering	0.3%	0.06%	No decay trap foils
Missed coincidences	0.1%	<0.03%	1 ms coinc. window
Polarization	0.1%	0.02%	Demonstrated in UCNA
Magnetic Mirror	-0.04%	0.02%	UCN absorbers
β energy calib.	0.1%	<0.01%	Silicon detectors
p backscattering	0.07%	<0.01%	Nico et al. 2005
Accidental coinc.	-0.1%	<0.01%	10 Hz and 1 ms coinc.
Total	0.6%	0.09%	

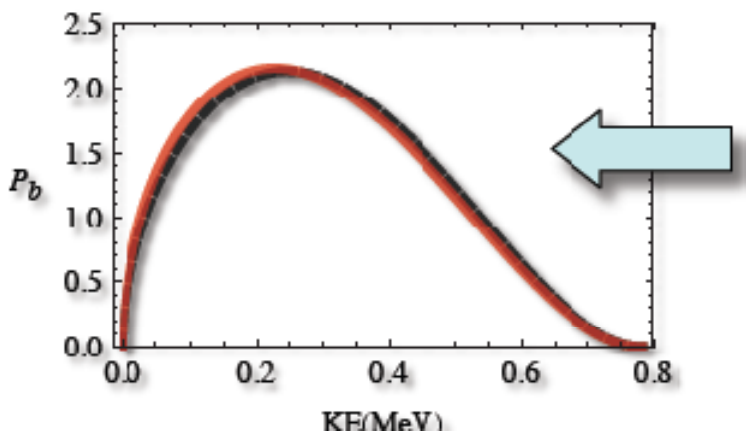
Test run expected 9/2010

UCNb: the Fierz Interference Term

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

$$b_n = \frac{|b_F| - 3\lambda |b_{GT}|}{1 + 3\lambda^2}$$

b_F is measured via super-allowed nuclear beta decay



b_n shifts the electron energy spectrum
And has never been measured…

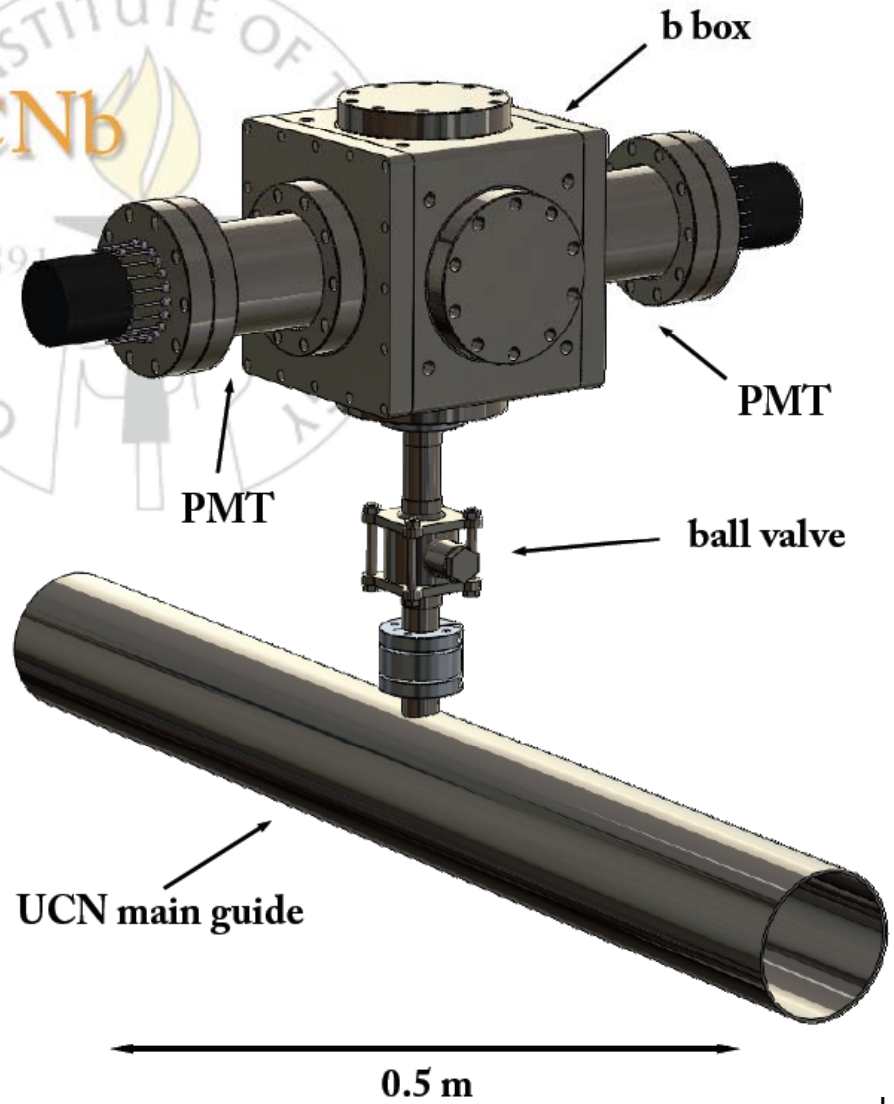
$$\sigma_b = \frac{7.5}{\sqrt{N}}$$

The UCNb experiment

Overview of UCNb

- Compact calorimeter
- Integrating "sphere"
- 2×2" PMT (up to 4)
- Near UCN source
- Sifts off main guide

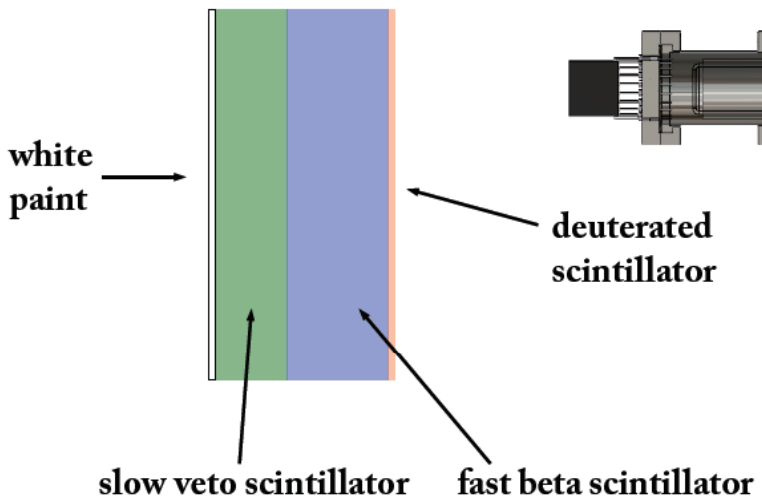
size	12×12×12 cm
volume	1.73 L
area	864 cm^2
density	10 – 30 cm^{-3}
β rate	20 – 60 Hz

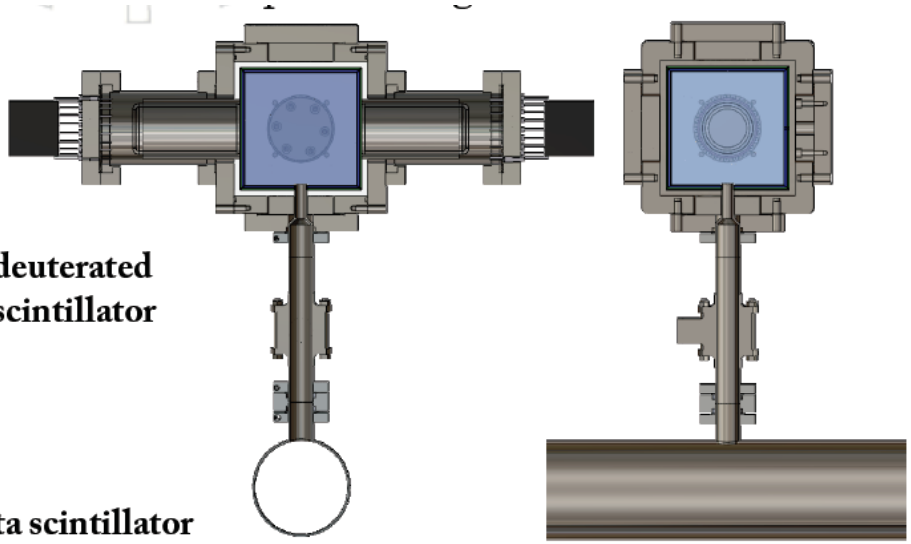


Hickerson

Background Elimination and UCN Bottle

- Scintillator Sandwich
  - Deuterated scintillator traps UCNs
  - Fast scint. (3 mm) detects Betas
  - Slow scint. vetoes backgrounds





UCNb at LANSCE

$$\sigma_b = \frac{7.5}{\sqrt{N}}$$

Weak sensitivity implies 60 days needed for $<10^{-3}$ measurement (at 30 Hz)…
But can run in parallel with other experiments using UCN beam.

Hope to take data summer 2010

UCNA Collaboration

R. W. Pattie, Jr.,[1,2] J. Anaya,[3] H. O. Back,[1,2] J. G. Boissevain,[3] T. J. Bowles,[3] L. J. Broussard,[2,4] R. Carr,[5] D. J. Clark,[3] S. Currie,[3] S. Du,[1] B. W. Filippone,[5] P. Geltenbort,[6] A. García,[7] A. Hawari,[8] K. P. Hickerson,[5] R. Hill,[3] M. Hino,[9] S. A. Hoedl,[7,10] G. E. Hogan,[3] A. T. Holley,[1] T. M. Ito,[3,5] T. Kawai,[9] K. Kirch,[3] S. Kitagaki,[11] S. K. Lamoreaux,[3] C.-Y. Liu,[10] J. Liu,[5] M. Makela,[3,12] R. R. Mammei,[12] J. W. Martin,[5,13] D. Melconian,[7,14] N. Meier,[1] M. P. Mendenhall,[5] C. L. Morris,[3] R. Mortensen,[3] A. Pichlmaier,[3] M. L. Pitt,[12] B. Plaster,[5,15] J. C. Ramsey,[3] R. Rios,[3,16] K. Sabourov,[1] A. L. Sallaska,[7] A. Saunders,[3] R. Schmid,[5] S. Seestrom,[3] C. Servicky,[1] S. K. L. Sjue,[7] D. Smith,[1] W. E. Sondheim,[3] E. Tatar,[16] W. Teasdale,[3] C. Terai,[1] B. Tipton,[5] M. Utsuro,[9] R. B. Vogelaar,[12] B. W. Wehring,[8] Y. P. Xu,[1] A. R. Young,[1,2] and J. Yuan[5]

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UCNB and UCNb Collaborations

"UCNB" Collaboration

R. Alarcon, S. Balascuta, L. Broussard, R. Carr, V. Cirigliano, B. Filippone, A. García, P. Geltenbort, D. Harris, A. Hawari, K. Hickerson, S. Hoedl, A. Holley, G. Hogan, J. Liu, M. Makela, R. Mammei, J. Martin, P. McGaughey, D. Melconian, M. Mendenhall, C. Morris, R. Pattie, A. Pérez-Galván, M. Pitt, B. Plaster, J. Ramsey, R. Rios, A. Salas-Bacci, A. Saunders, S. Seestrom, E. Tatar, R.B. Vogelaar, B. Wehring, W.S. Wilburn, A. Young

"UCNb" Collaboration

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[4]North Carolina State University

Conclusions

- Full suite of neutron beta correlation experiments at Los Alamos
- UCNs give unique advantages
- UCNA producing competitive results
  - Will eventually reach ~0.2%
- UCNB will probe new territory
- UCNb is a brand new measurement