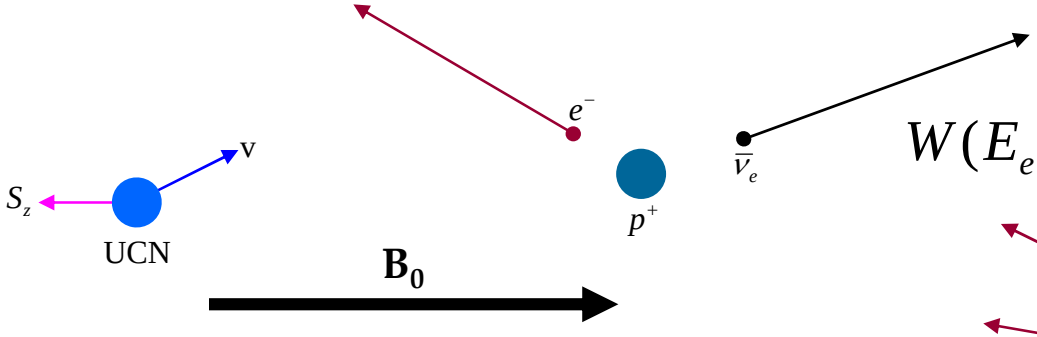
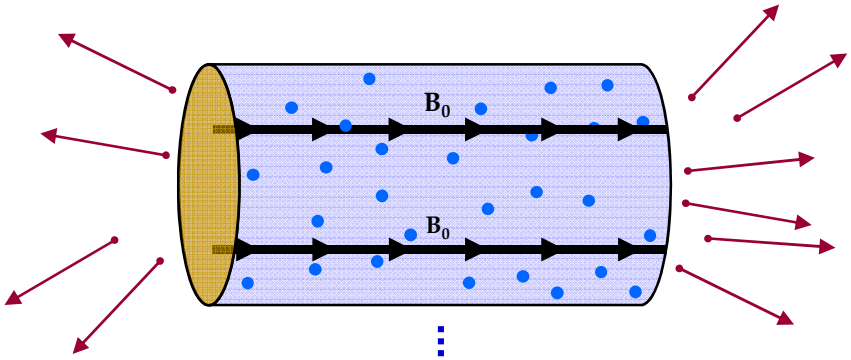
Progress Towards a <1% Measurement of the Neutron Beta Asymmetry using Ultracold Neutrons

A. T. Holley for the UCNA Collaboration

The β Asymmetry



$$W(E_e,\theta) = F(E_e)\left(1 + A(E_e)\langle P\rangle \beta\cos\theta\right)$$



$$\tau = \frac{2\pi^3\hbar^7}{m_e^5 c^4 f^R (1+\Delta_R) G_F^2 U_{ud}^2} \frac{1}{1+3\lambda^2}$$

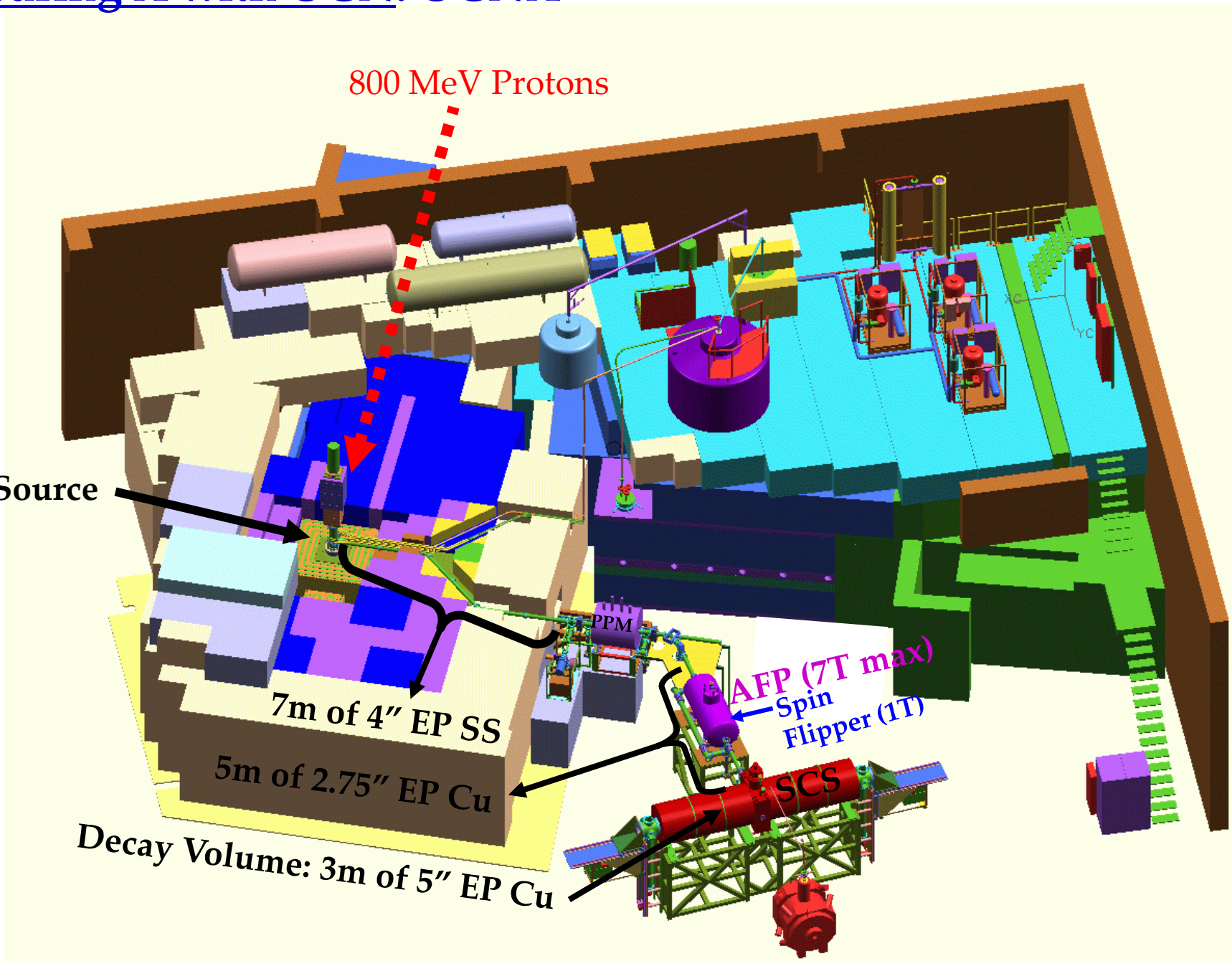
- Polarization
  - Initial Polarization
  - Spin-Flip Efficiency
  - Depolarization
- Backgrounds
  - Beam Related/Environmental
  - Neutron Induced
- Beta Detectors
  - Detector Response (calibration, linearity, response function)
  - Angle-Dependent Energy Loss
- Backscattering
  - Backscatter Reconstruction
  - Missed Backscatters

$$S \equiv \frac{R_E^{\uparrow} R_W^{\downarrow}}{R_E^{\downarrow} R_W^{\uparrow}}$$

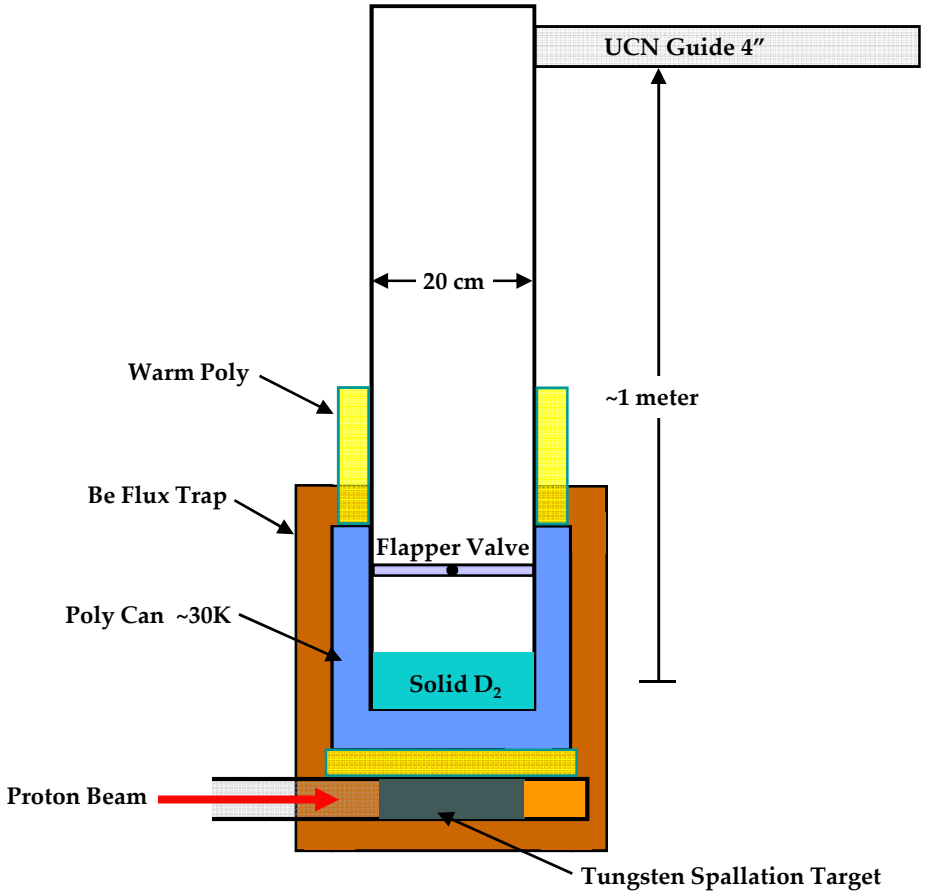
$$A = \frac{1-\sqrt{S}}{1+\sqrt{S}} = \frac{-2\lambda(1+\lambda)}{1+3\lambda^2}$$

with $\lambda = \frac{g_A}{g_V}$

Measuring A with UCN: UCNA



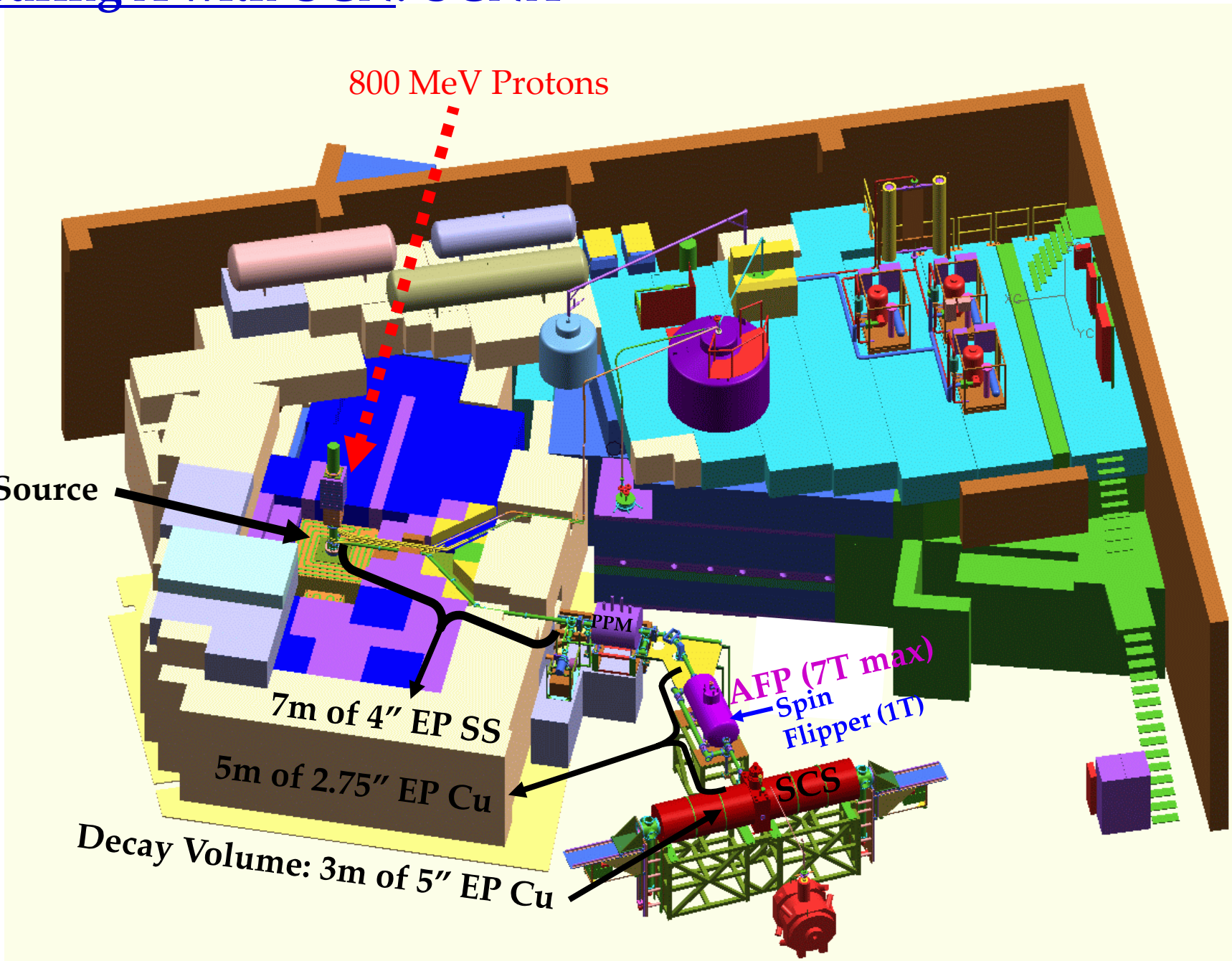
UCN Source



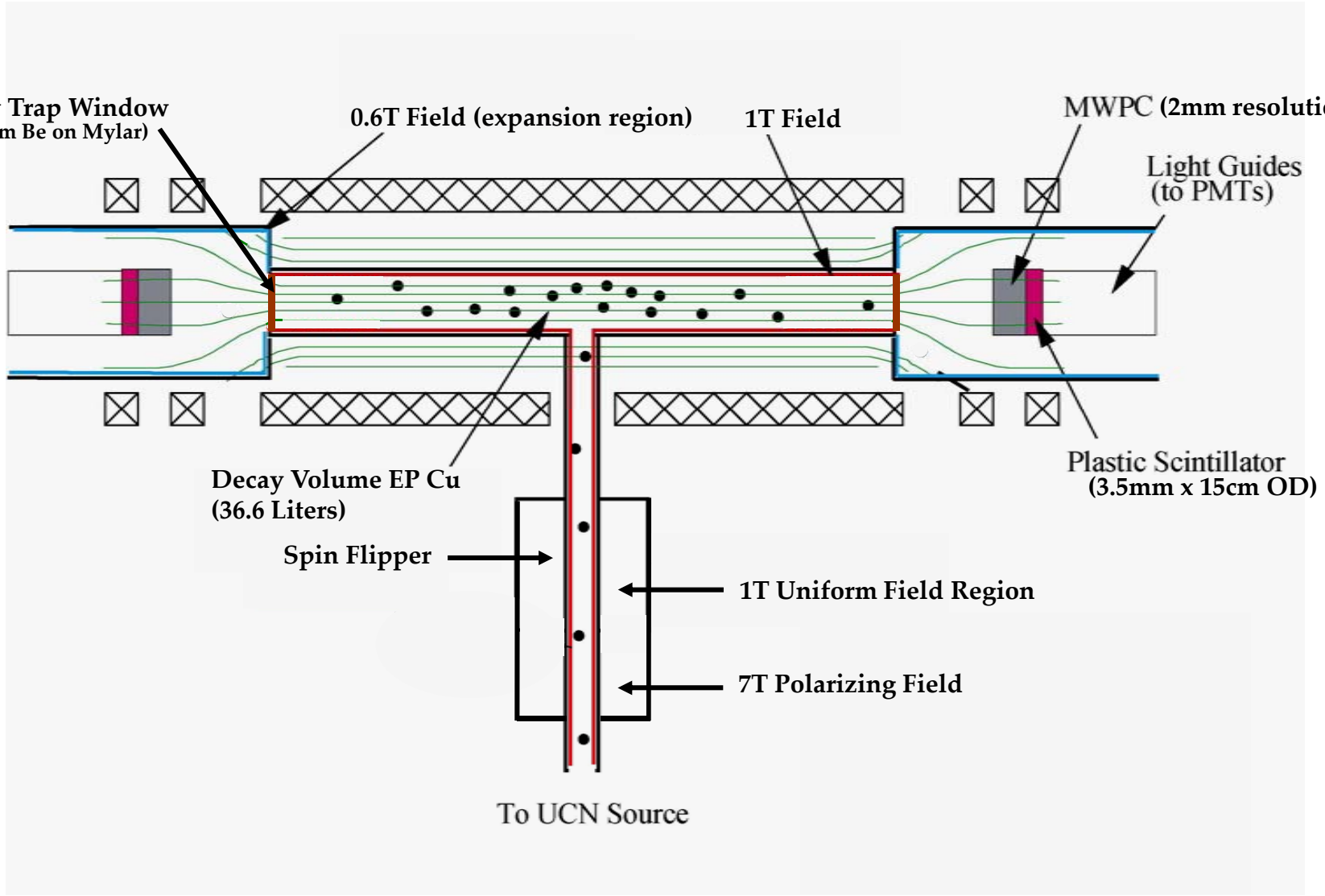
- 4μA limit (designed for 10μA operation)
- 1000cm^3 - 2000cm^3 SD_2 capacity
- 20 L/hr. LHe consumption

- 10 UCN/cm^3 at shield wall (7m from source)
- >0.5 UCN/cm^3 in decay volume
- 25 Hz total decay rate

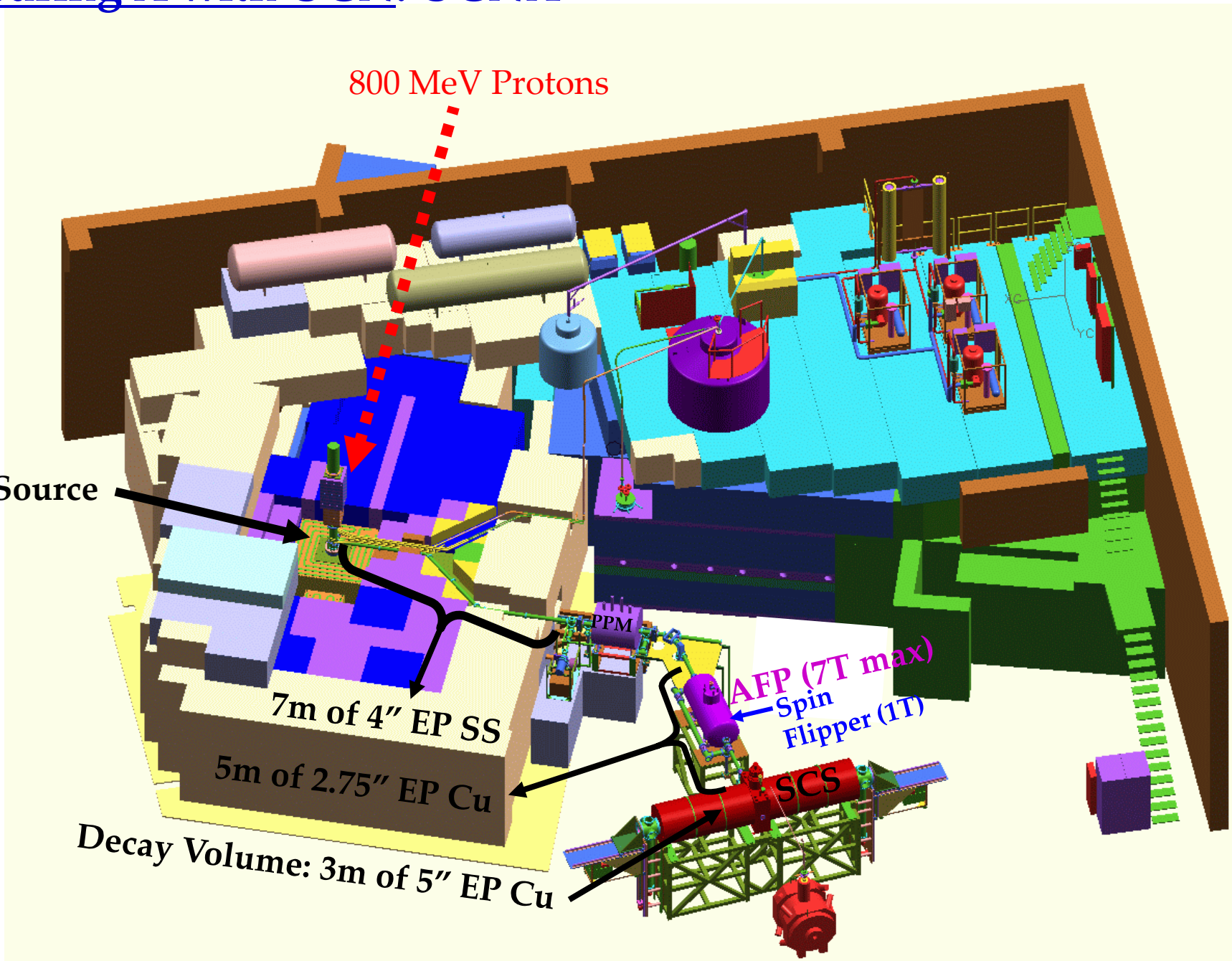
Measuring A with UCN: UCNA



Beta Spectrometer



Measuring A with UCN: UCNA



Measuring A with UCN: UCNA

UCN Polarization

Sources of Depolarized UCN:

- Initial Polarization < 1
- Spin-Flip Efficiency < 1
- Material Depolarization
- Gradient Depolarization

Measurements:

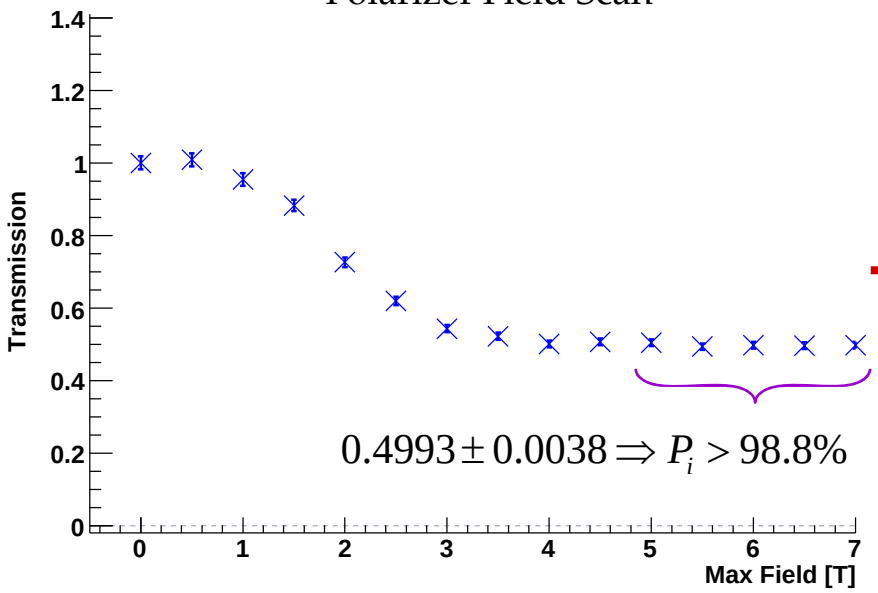
- Initial Polarization > 98.8% (2007) → Essentially equivalent to a spectrum measurement. <100% primarily due to high-energy UCN.
- Spin-Flip Efficiency > 99.6% (2007) → Flipper ON Polarization > 99.1%
- Measured Equilibrium Depolarization > 99.6% (2008)

↓

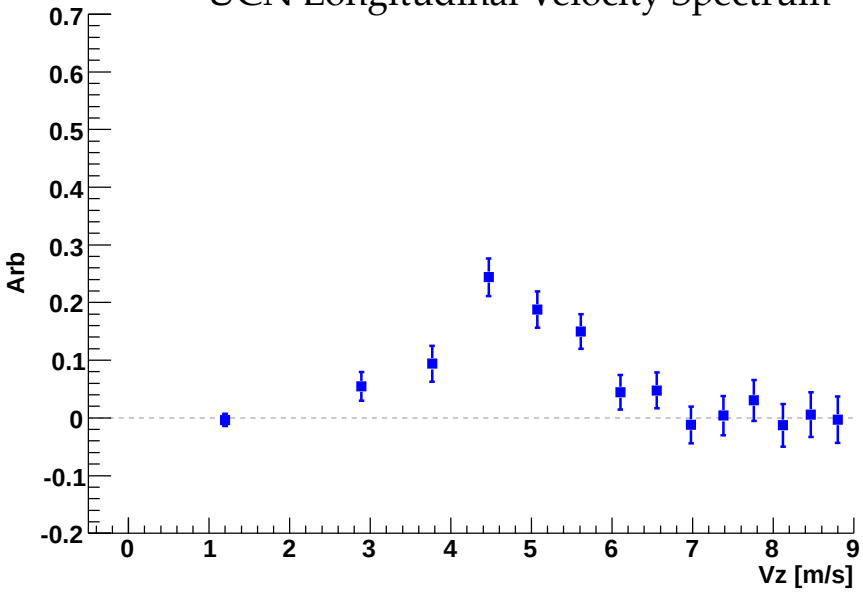
Measures depolarization from **all** sources.
Only sensitive to populations with $\tau \sim \tau_{meas}$.

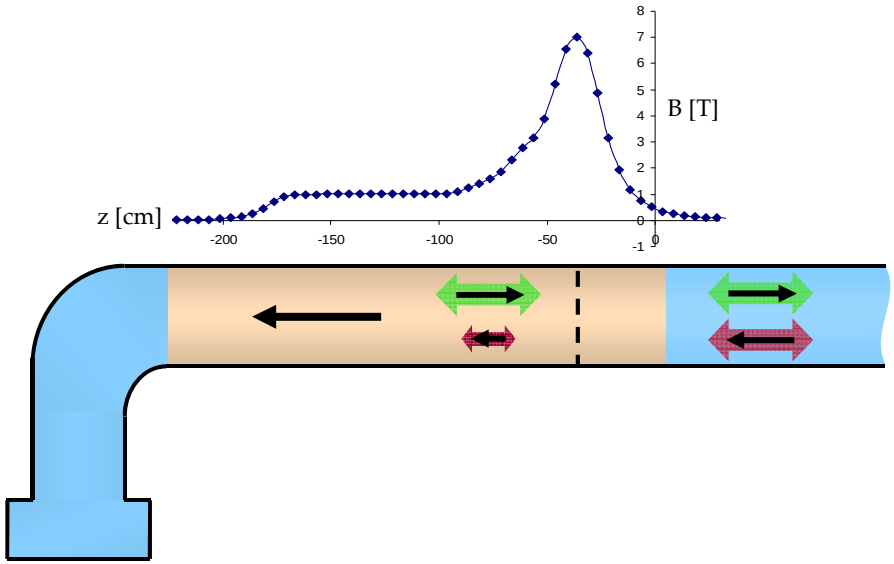
UCN Polarization: Initial Polarization

Polarizer Field Scan



UCN Longitudinal Velocity Spectrum





2007 Run Cycle

UCN Polarization

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UCN Polarization: Spin-Flip Efficiency

2007 Run Cycle

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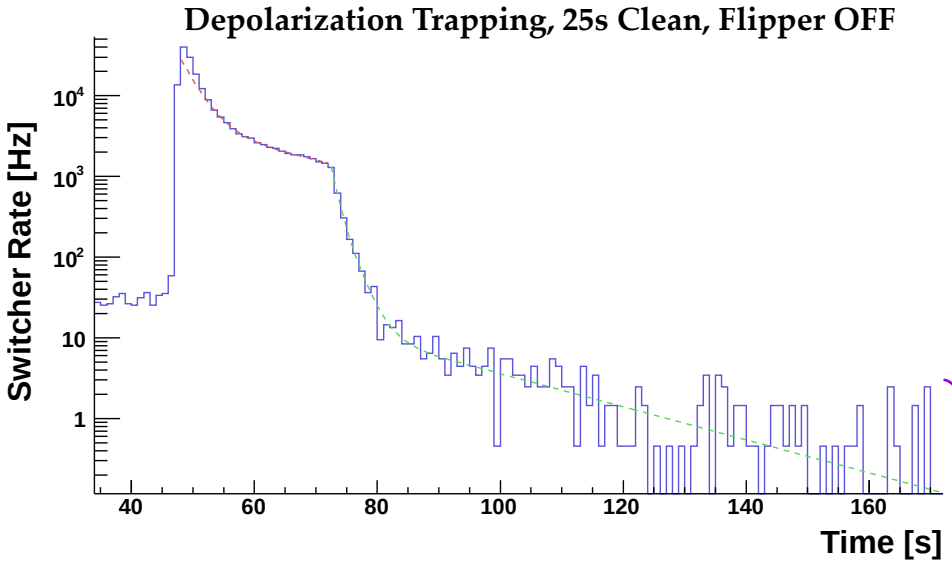
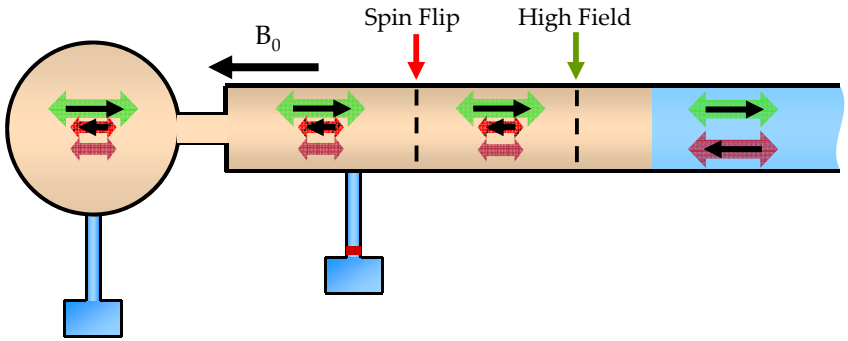
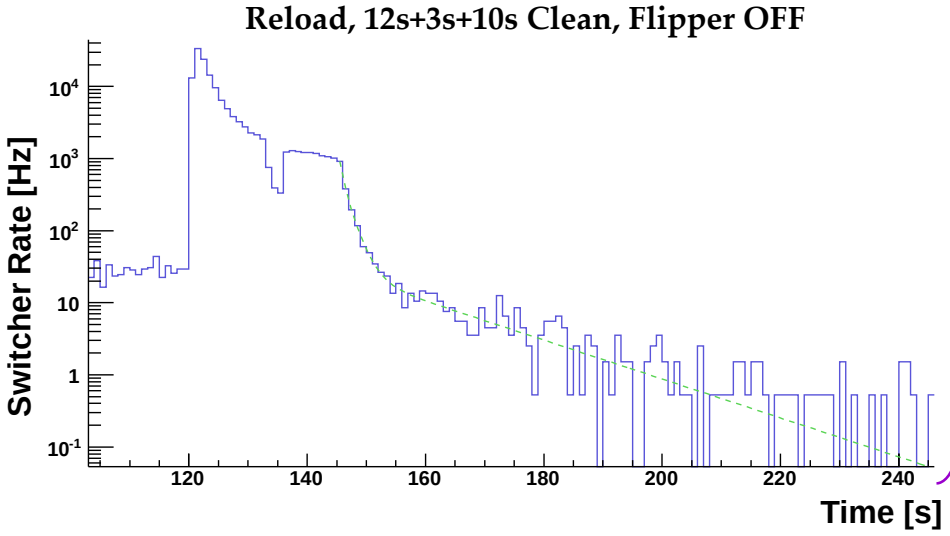
↓

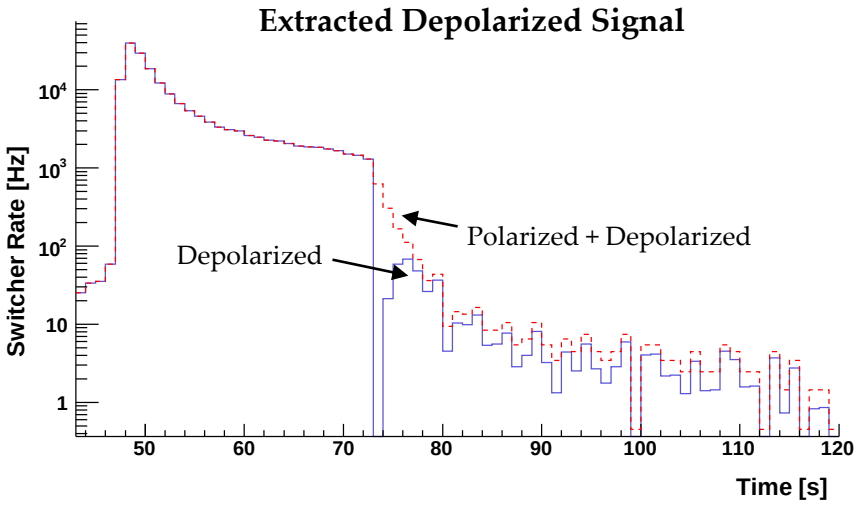
Measures depolarization from **all** sources.
Only sensitive to populations with $\tau \sim \tau_{meas}$.

UCN Polarization: *In Situ* Polarimetry







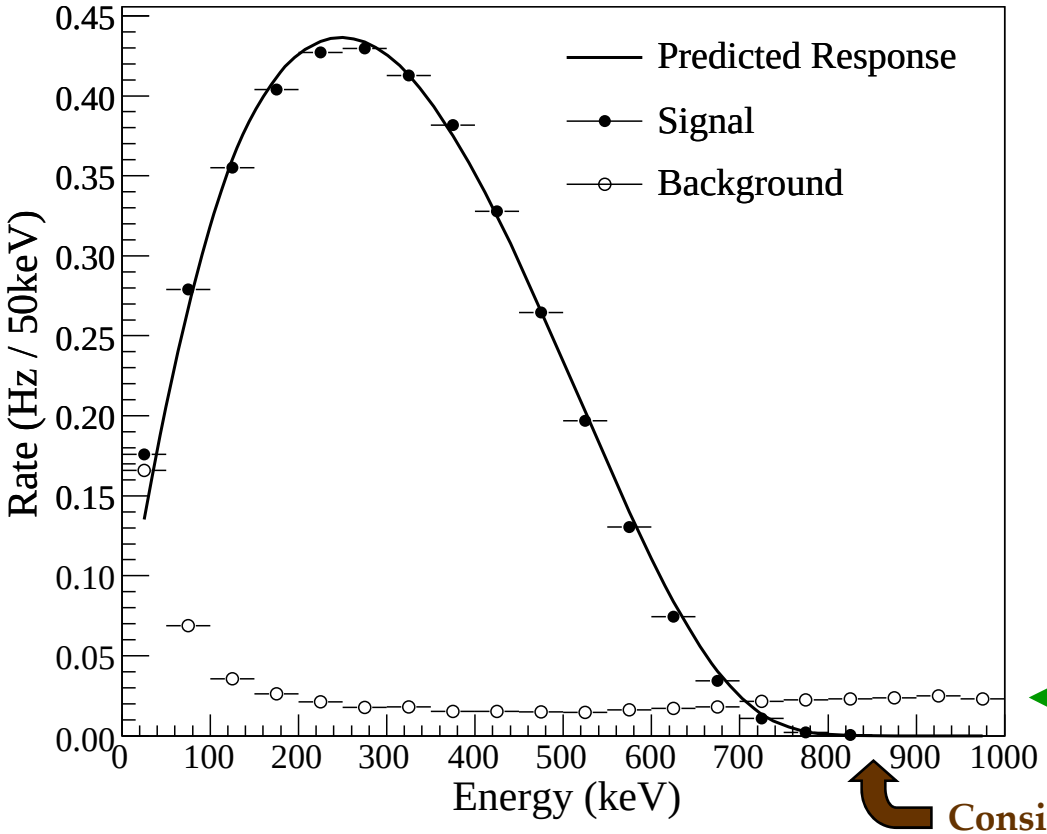


$P_{eq} > 99.6\%$

Includes all sources of depolarized UCN:
- Material Depolarization
- Gradient Depolarization
- Spin-Flipper Inefficiency
- Initial Polarization < 1

Sensitive to populations with $\tau \sim \tau_{meas}$.

Backgrounds



40 Hz

↓ MWPC/Scintillator Coincidence

1 Hz

↓ Beam Pulse Cuts
μ-veto

0.2 Hz (ambient background)

Consistent with zero... negligible UCN-induced BG.

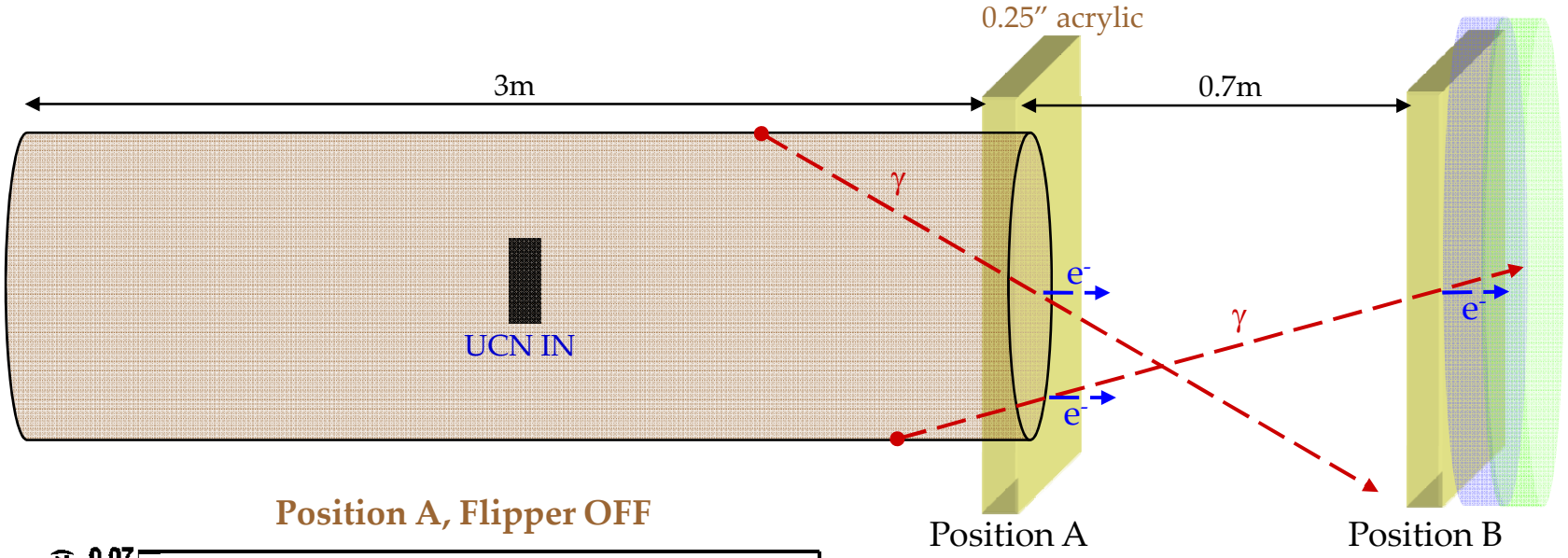
β decay: ~1 hour

Background: ~12 min.

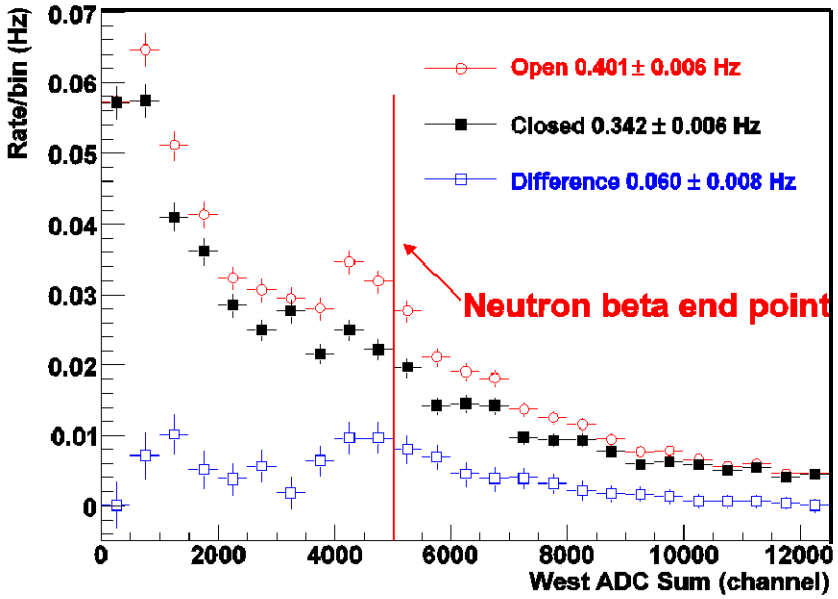
Depol: ~4 min.

$$\begin{cases} B^{on}\,\beta^{on}\,D \rightarrow B^{off}\,\beta^{off}\,D \rightarrow \beta^{off}\,DB^{off} \rightarrow \beta^{on}\,DB^{on} \\ B^{off}\,\beta^{off}\,D \rightarrow B^{on}\,\beta^{on}\,D \rightarrow \beta^{on}\,DB^{on} \rightarrow \beta^{off}\,DB^{off} \end{cases}$$

Cross-checking UCN Generated Backgrounds



Position A, Flipper OFF



"Closed" : No UCN in decay volume

"Open" : UCN admitted to decay volume, β's stopped in acrylic.

Acrylic generates Compton electrons in response to UCN capture gammas.

A → B : Solid angle for gammas decreases. UCN-generated signal consistent with zero.

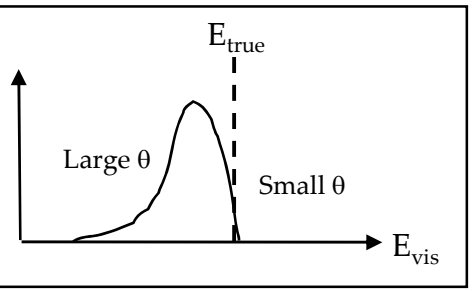
UCN-induced BG/Total Rate < 0.2%

Detector Response

Detector Response → (event type dependent) E_{vis} → (Isotropic MC Correction) E_{true} → (angle effect) A

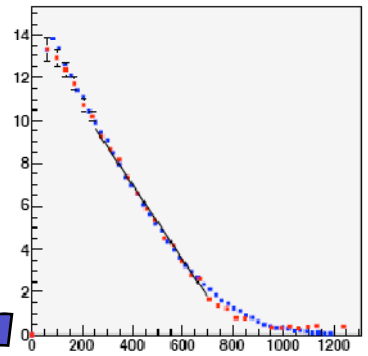
Energy Calibration/Linearity

Gain Maps

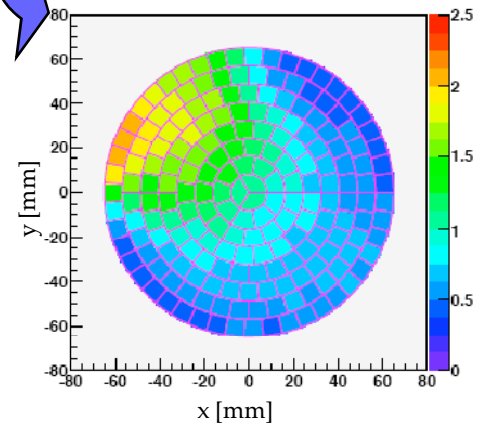


$$\langle \beta \cos\theta \rangle \neq 0.5 \langle \beta \rangle$$

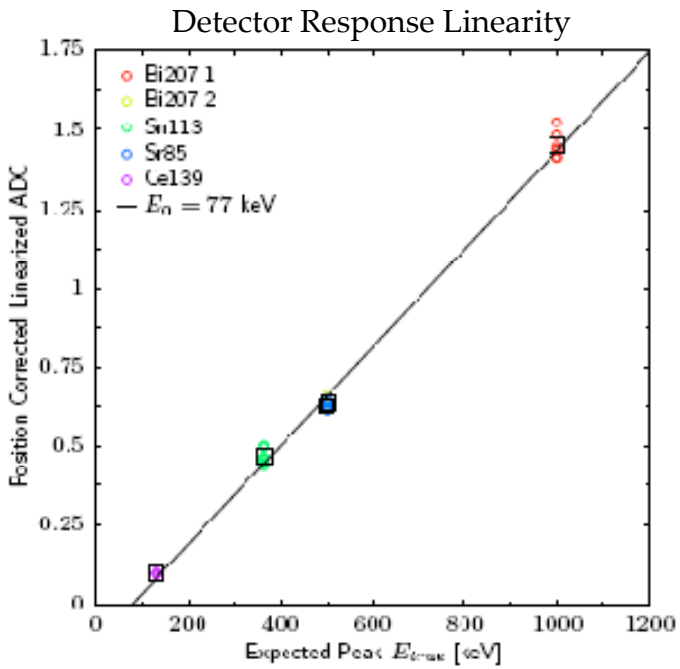
Correct for anisotropy induced by angle-dependent energy loss.



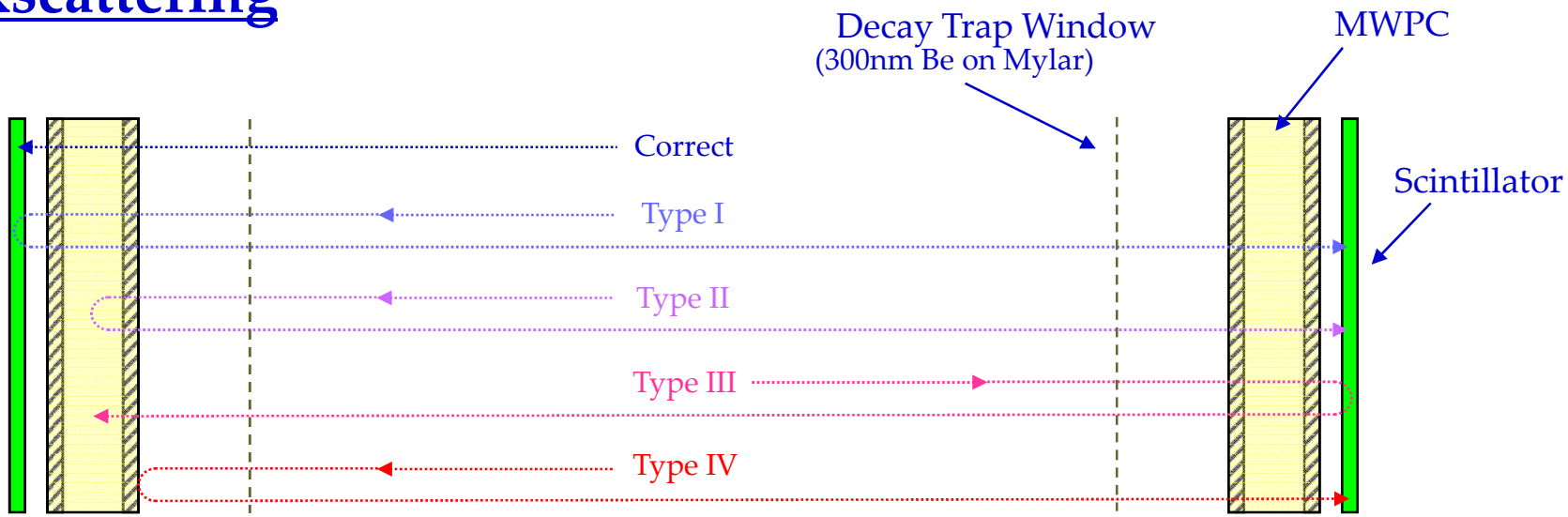
End point energy variations determine relative position-dependence of response.



+ LED Scans + Calibration Sources



Backscattering

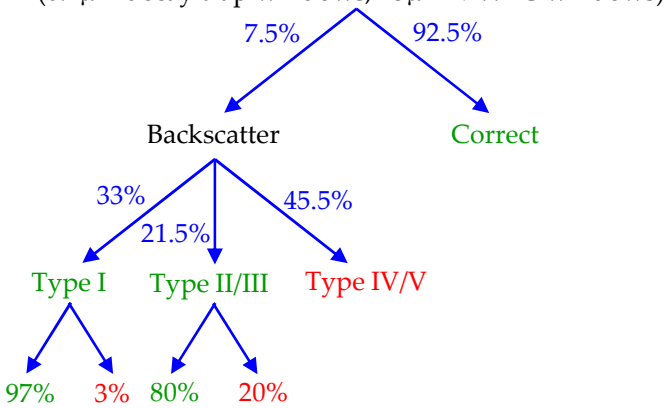


Decay Trap Window Thicknesses: 0.7μm, 2.5μm, 13.4μm
MWPC Front and Back Window Thicknesses: 25μm, 6μm

- 0.7μm decay trap, 25μm MWPC windows → 10M Events, 3.90% Observed BS/Detected
- 13.4μm decay trap, 25μm MWPC windows → 10M Events, 2.87% Observed BS/Detected
- 0.7μm decay trap, 6μm MWPC windows → 4M Events, 4.62% Observed BS/Detected

Helps to characterize/constrain angle-dependent energy loss and backscattering.

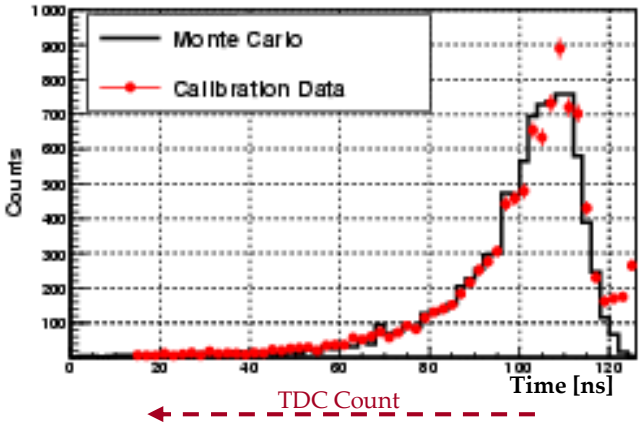
Simulated Detected β-decay Rate
(0.7μm decay trap windows, 25μm MWPC windows)



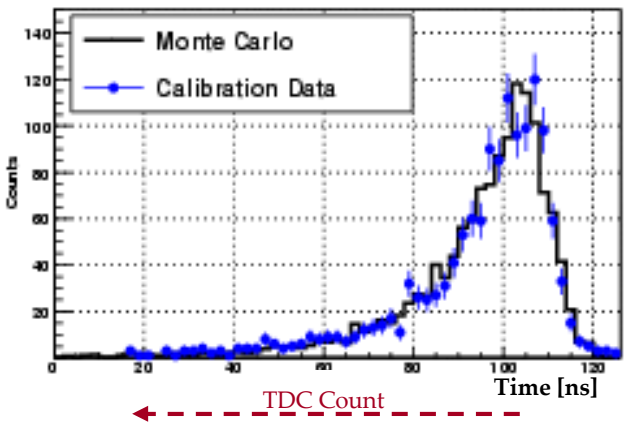
Gives a +0.84% correction to A due to backscatter reconstruction.

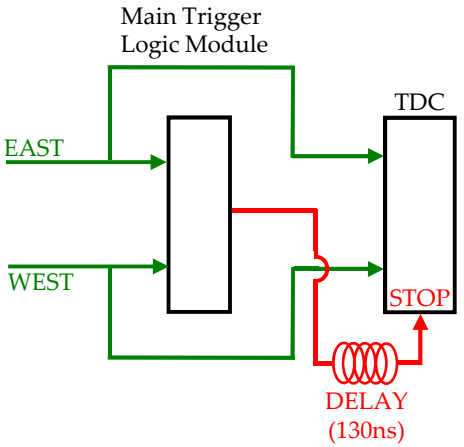
Backscattering

^{207}Bi Timing



^{113}Sn Timing





Decay Trap Window Thicknesses: 0.7µm, 2.5µm, 13.4µm
MWPC Front and Back Window Thicknesses: 25µm, 6µm

Monte Carlo Prediction

0.7µm decay trap 25µm MWPC windows	10M Events 3.90% Observed BS/Detected	4.08% Observed BS/Detected
13.4µm decay trap 25µm MWPC windows	10M Events 2.87% Observed BS/Detected	3.03% Observed BS/Detected
0.7µm decay trap 6µm MWPC windows	4M Events 4.62% Observed BS/Detected	4.80% Observed BS/Detected

Helps to characterize/constrain angle-dependent energy loss and backscattering.

Systematics to Date

	2007		2008	
	Correction	Uncertainty	Correction	Uncertainty
Statistics		4%	--	< 0.8%
Polarization	0	1.3%	0	< 0.7%
Detector Response	0	1.5%	0	< 0.5%
Angle Effect	-1.6%	0.5%	-0.8%	< 0.3%
Backscattering	1.1%	0.4%	0.5%	0.2%
Total		4.5%		<1.2%

0.8M Total Events

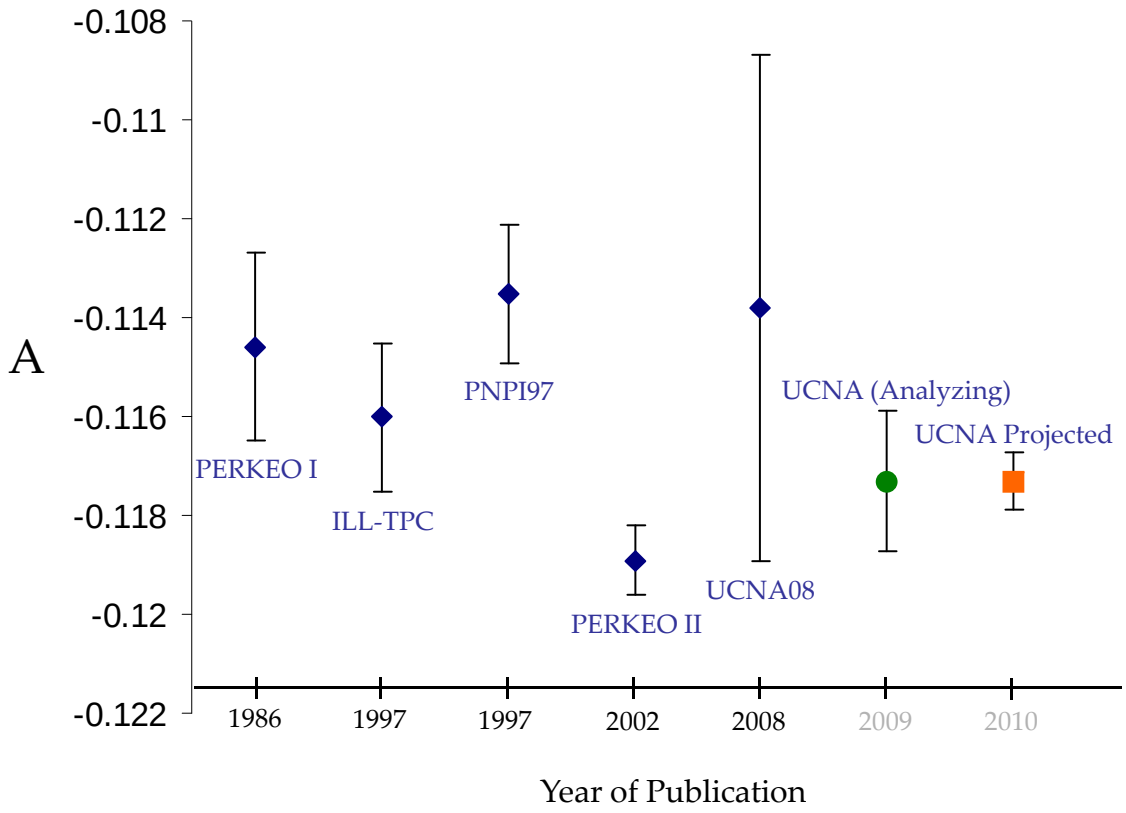
24M Total Events

Improvements 2007 to 2008:

- Quieter UCN detectors for polarimetry.
- More complete UCN transport characterization.
- Improved array of calibration sources (^{113}Sn, ^{85}Sr, ^{207}Bi, ^{114}In, ^{109}Cd, ^{139}Ce).
- Significant statistics for three different window geometries.

This year…

- All Cu surfaces coated with DLC.
- Focus on ideal geometry.
- Area of decay volume feed guide increased.
- Significant improvement to the sensitivity of polarimetry measurements via the addition of a shutter at the entrance to the decay volume.



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