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The Science Program at the Los Alamos Ultracold Neutron Source

Alexander Saunders
Los Alamos National Laboratory

PSI Seminar, 2013

Outline

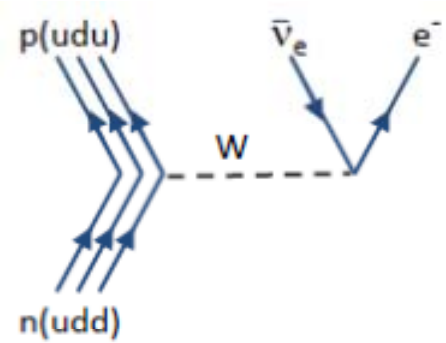
- Introduction
- Motivation of neutron β decay measurements
- UCNA current status and plans
- A new UCN lifetime measurement
- UCNB plans and goals
- The LANSCE UCN source
- Summary

- Special Thanks to Mark Makela, Alejandro Garcia, Brad Plaster, Albert Young, Chen-Yu Liu, Dirk Dubbers, and Kevin Hickerson

Neutron Decay Parameters

- Semi-leptonic decay
  - Lifetime 880 s
  - Endpoint energy 782 keV

- Just two free parameters in SM
  - CKM mixing matrix element
  - Ratio of weak coupling constants
  - Uncertainty comes from radiative corrections



$$n \rightarrow p + e^- + \bar{\nu}_e$$

$$\tau_n = \frac{4908.7 \pm 1.9\ s}{|V_{ud}|^2 \left(1 + 3\lambda^2\right)}$$

$$\lambda = g_A / g_V$$

Neutron β decay and V_{ud}

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

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

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

$$\tau^{-1} = Kf^R(G_V{}^2 + 3G_A{}^2) \qquad B = B_0 + B_1\frac{m_e}{E_e}$$

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

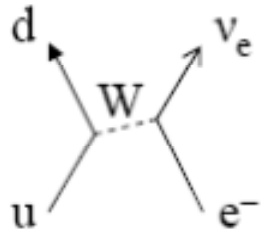
In Standard Model:

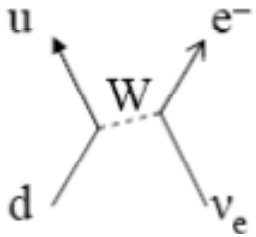
$$B_1 = 0 \qquad b = 0$$

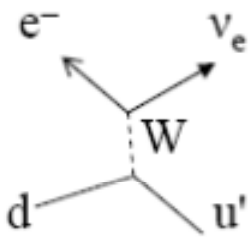
Neutron beta decay can inform many areas of physics

- Many reactions share the same Feynman diagram as neutron beta decay

Primordial element formation	$n + e+ \rightarrow p + \nu'_e$	$\sigma_\nu \sim 1/\tau$
(^{2}H, ^{3}He, ^{4}He, ^{7}Li, …)	$p + e^- \rightarrow n + \nu_e$	$\sigma_\nu \sim 1/\tau$
	$n \rightarrow p + e^- + \nu'_e$	τ
Solar cycle	$p + p \rightarrow {}^2H + e^+ + \nu_e$	
	$p + p + e^- \rightarrow {}^2H + \nu_e$ etc.	$\sim (g_A/g_V)^5$
Neutron star formation	$p + e^- \rightarrow n + \nu_e$	
Pion decay	$\pi^- \rightarrow \pi^0 + e^- + \nu'_e$	
Neutrino detectors	$\nu'_e + p \rightarrow e^+ + n$	
Neutrino forward scattering	$\nu_e + n \rightarrow e^- + p$ etc.	
W and Z production	$u' + d \rightarrow W^- \rightarrow e^- + \nu'_e$ etc.	







Dubbers 2011

Effects of $\lambda = G_A/G_V$

Where does the proton get its spin?

Some comes from the quarks, but how much and which quarks?

$G_A^3 = \Delta u - \Delta d$ Axial-vector weak charge Neutrons *et al.*

$G_A^8 = \Delta u + \Delta d - 2\Delta s$ SU(3) octet weak charge hyperon decay

$G_A^0 = \Delta u + \Delta d + \Delta s$ Flavor singlet weak charge DIS

Bass, 2005

Solar fusion rates and the Standard Solar Model

$$r_{pp} \propto \langle \sigma v \rangle_{pp} \propto \int_0^\infty E\sigma(E) e^{\left(\frac{-E}{kT}\right)} dE$$

$$\sigma(E) = \frac{S(E)}{E} e^{\frac{-2\pi\alpha}{v(E)}} \qquad S_{pp} \propto \left(\frac{G_A}{G_V}\right)^2$$

Adelberger 2010

Effects of $\lambda = G_A/G_V$

- gA is a fundamental parameter for the charged weak current of the nucleon and defines a frontier for our understanding of this interaction
- Lattice calculations of gA are becoming an interesting target for high precision lattice calculations (Yamazaki et al., 2008)
- Reactor antineutrino anomaly: gA affects antineutrino cross sections needed for that work (Mention et al., ArXiv: 1011.2755v4)

Neutron Decay and Unitarity

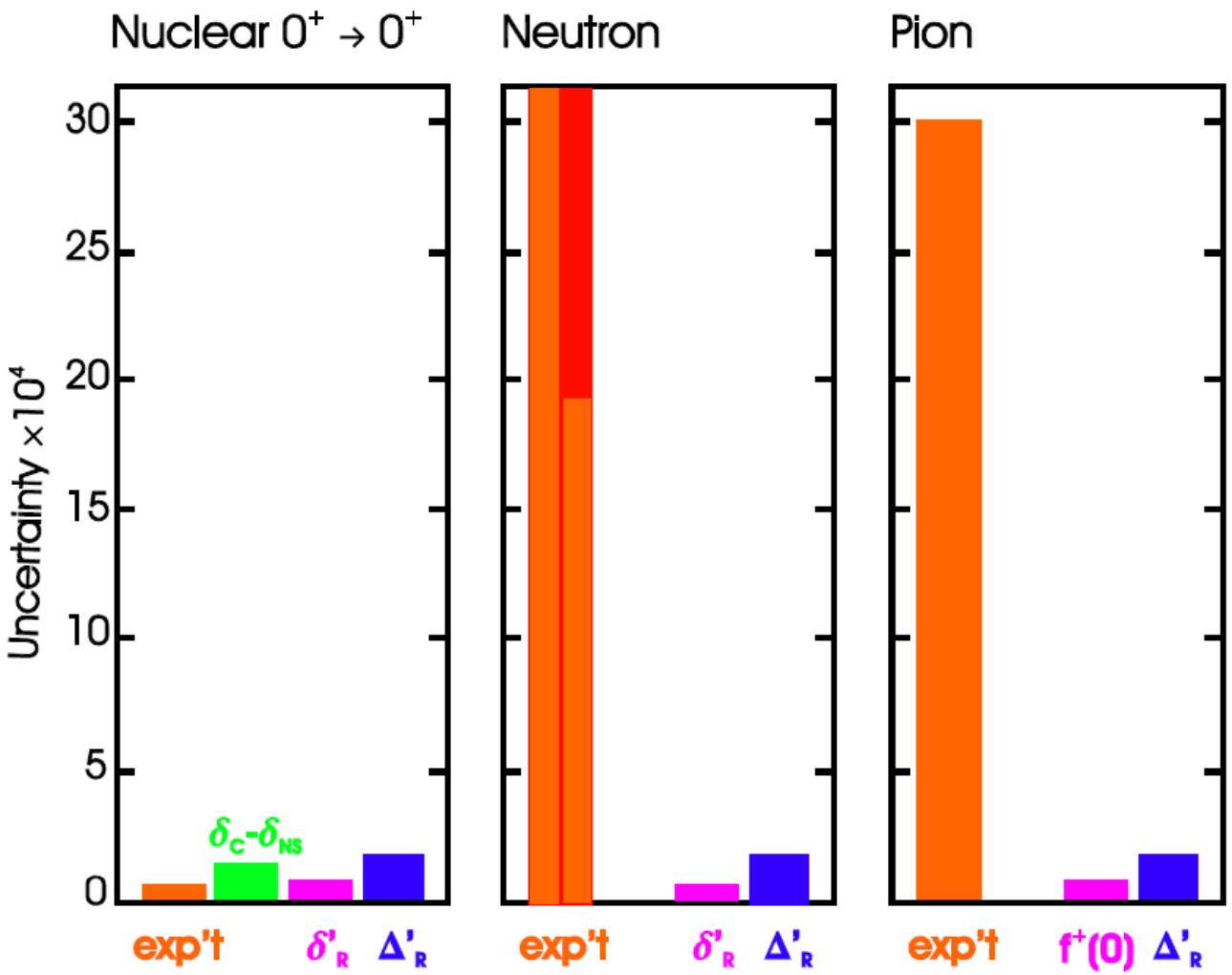
$$\begin{pmatrix} d_w \\ s_w \\ b_w \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cd} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d_m \\ s_m \\ b_m \end{pmatrix}$$

$$\begin{pmatrix} d_w \\ s_w \\ b_w \end{pmatrix} = \begin{pmatrix} 0.975 & 0.22 & 0.005 \\ 0.22 & 0.97 & 0.04 \\ 0.005 & 0.04 & 0.99 \end{pmatrix} \begin{pmatrix} d_m \\ s_m \\ b_m \end{pmatrix}$$

Unitarity, eg. $|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1$, (or lack thereof) of CKM matrix tests existence of further quark generations and possible new physics (eg. Supersymmetry)

B. W. Filippone

Motivation for A measurement: independent determination of V_{ud}



Motivation for b and B measurement: BSM Physics

- ε_s and ε_t are non-(V-A) contributions to the effective Hamiltonian

$$b = f_b\,(\varepsilon_{S,T} * g_{S,T})$$
$$B_1 = f_B\,(\varepsilon_{S,T} * g_{S,T})$$

$g_S \sim \langle p|\bar{u}d|n\rangle$

$g_T \sim \langle p|\bar{u}\sigma_{\mu\nu}d|n\rangle$

Measure these quantities with UCNs

Calculate these hadronic matrix elements in QCD

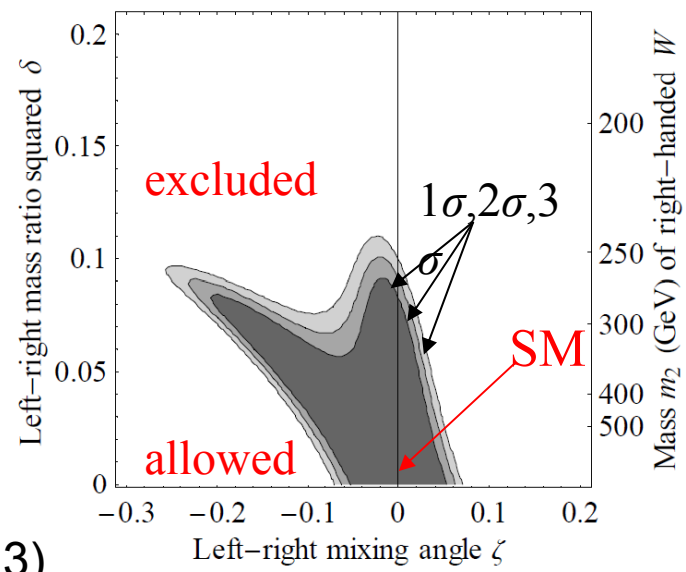
Analyze relation of ε_S and ε_T to other measurements (including LHC signals) within BSM extensions

Search for new physics

- A single parameter yields λ, multiple measurements yield V_{ud} and beyond
- CKM unitarity
  - Do neutrons and superallowed beta decays agree?

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

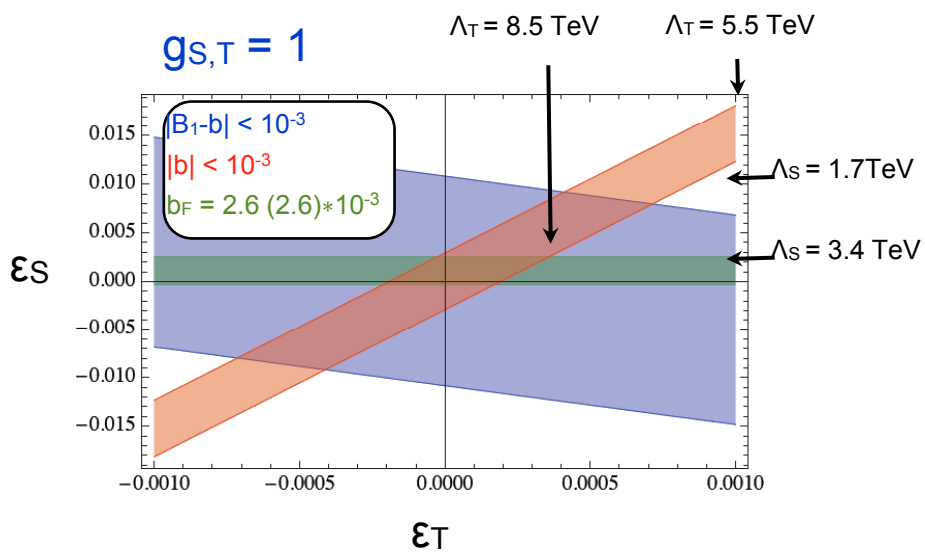
- Search for right-handed currents (250 GeV limit from n decay)
- Scalar and tensor couplings from *B* and *b*
  - Cirigliano 2012

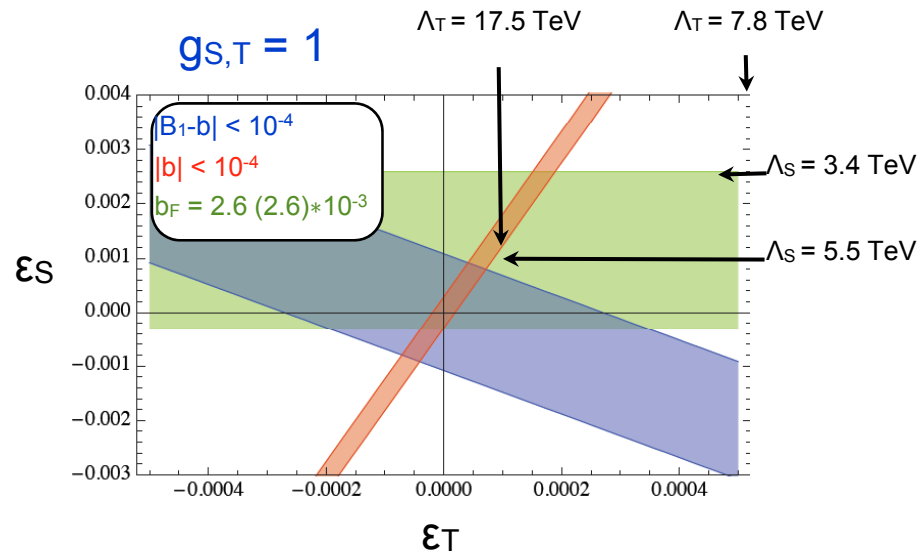


Holeczek *et al*., arxiv 1303.5295 (2013)

Phenomenology: preliminary study

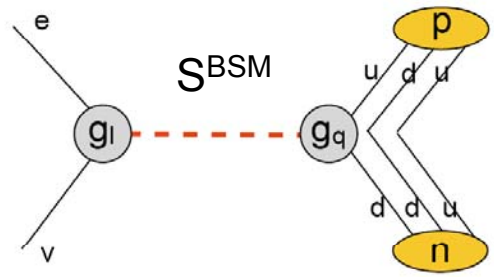
- Constraints on ε_S and ε_T from proposed experiments vs other measurements ($0^+ \rightarrow 0^+$; $\pi \rightarrow e\nu\gamma$ and collider not competitive)





- Already 10^{-3} measurements probe multi-TeV scale; stringent constraint on existence of scalar and tensor BSM interactions

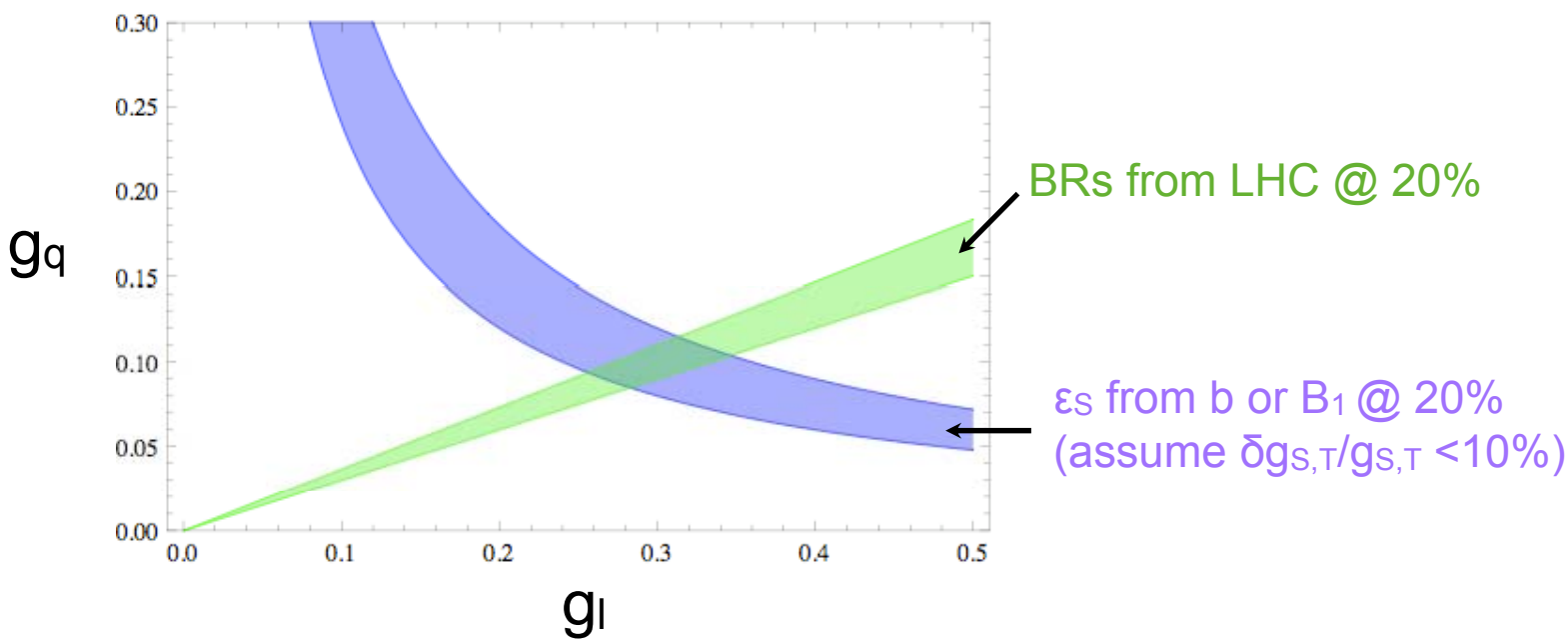
- Example: charged scalar resonance with M_S=1 TeV, g_l=0.3, g_q=0.1



(e.g. 2nd Higgs doublet with non-standard couplings)

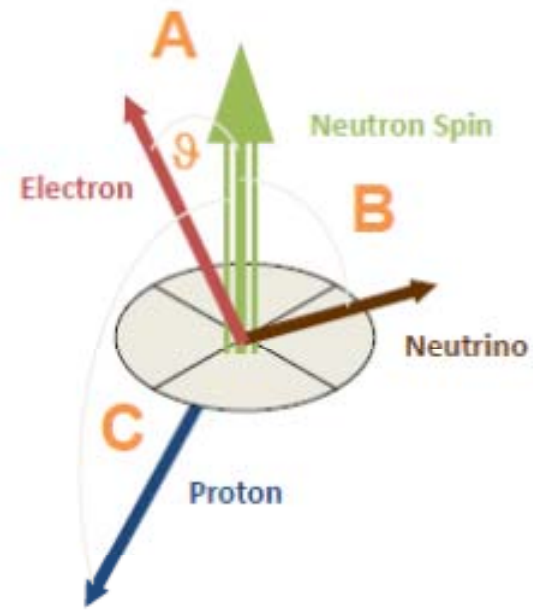
- LHC would measure M_S and $g_q/g_l = [BR(ud)/BR(e\nu)]^{1/2}$

- n decay sensitive to $G_F \cdot \varepsilon_S = g_l\, g_q/M_S^2$ (ε_S=1.8 10^{-3})



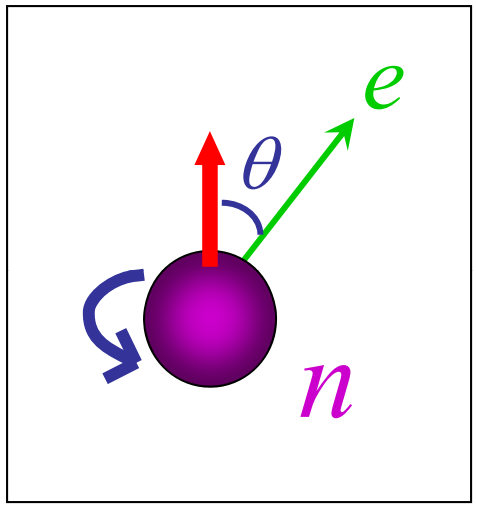
Decay Correlations

- A: electron asymmetry $\vec{\sigma}_n \cdot \vec{p}_e$
  - Perkeo II, Perkeo III, UCNA
- B: neutrino asymmetry $\vec{\sigma}_n \cdot \vec{p}_\nu$
  - Perkeo II
- C: proton asymmetry $\vec{\sigma}_n \cdot \vec{p}_p$
  - Perkeo II
- D: triple correlation $\vec{\sigma}_n \cdot \left(\vec{p}_e \times \vec{p}_\nu\right)$
  - TRINE, emiT
- a: electron-neutrino correlation $\vec{p}_e \cdot \vec{p}_\nu$
  - aSpect, aCORN, Nab

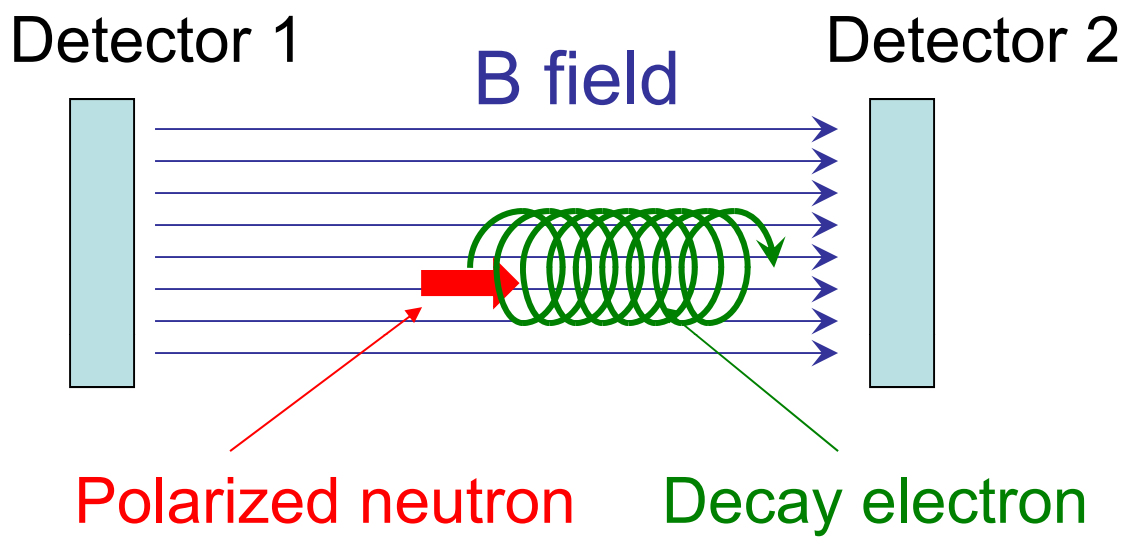


Plus Fierz interference *b*, helicity correlations, etc.

Principle of the *A*-coefficient Measurement



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



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

Systematics:

Polarization

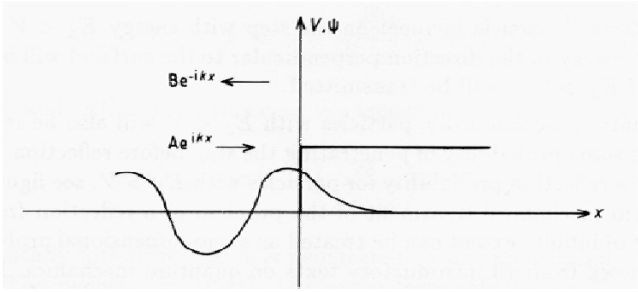
Backgrounds

(End point energy = 782 keV)

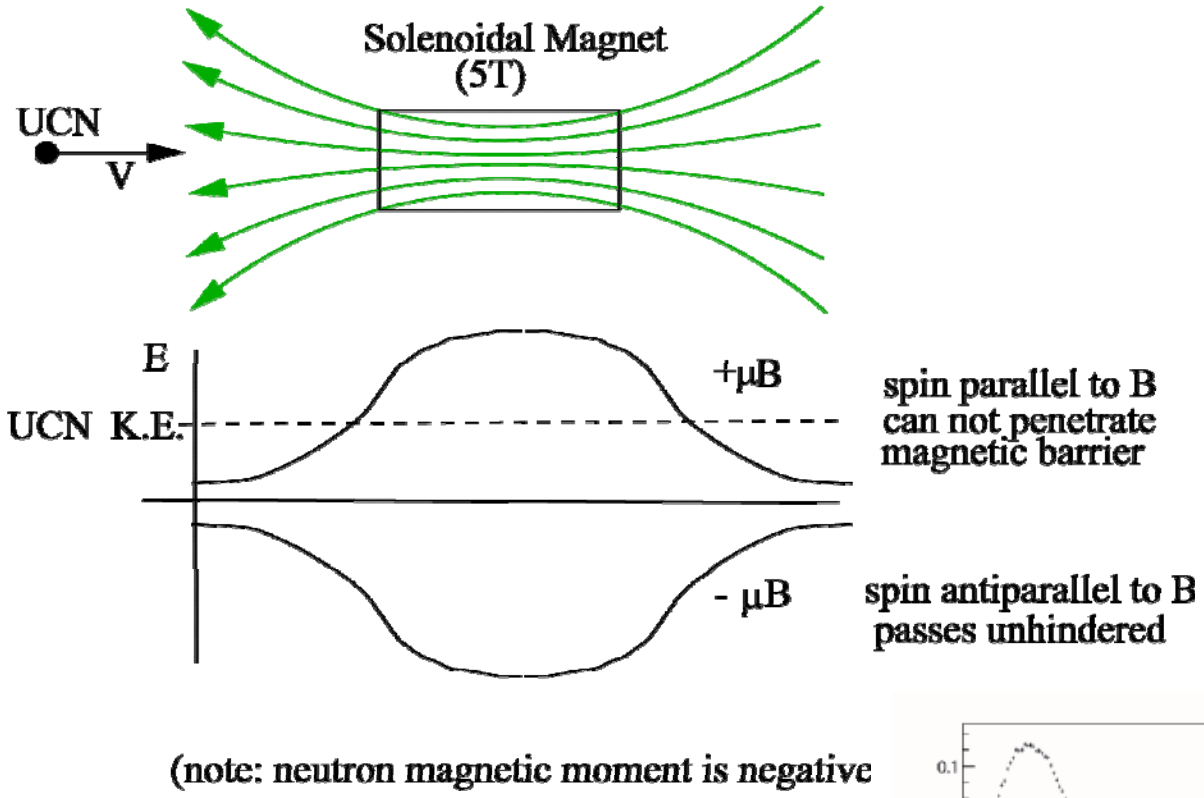
Interlude: Ultra-Cold Neutrons (UCN)

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

- 300 neV = Potential Energy in wall — External reflection
  - $= \frac{1}{2} m_n v^2 = \frac{1}{2} m_n (8\ \mathrm{m/s})^2$ — Running speed
  - $= m_n g h = m_n g (3\ \mathrm{m})$ — Human scale equipment
  - $= h^2/(2 m_n \lambda^2) = h^2/(2 m_n (50\ \mathrm{nm})^2)$ — Ultraviolet
  - $= \mu_n B = \mu_n (3.5\ \mathrm{T})$ — 100% polarization
  - $= k T = k (3\ \mathrm{mK})$ — Ultra-cold!
- Total external reflection allows arbitrary guides and bottles; long lifetime
- Speed implies easy timing
- Installations: centimeters to meters in size
- UCN wavelength: about 0.1 μm
  - *close to visible light*
  - *mirrors for people can be mirrors for UCN*
- 100% polarization is easy to achieve (for a time)

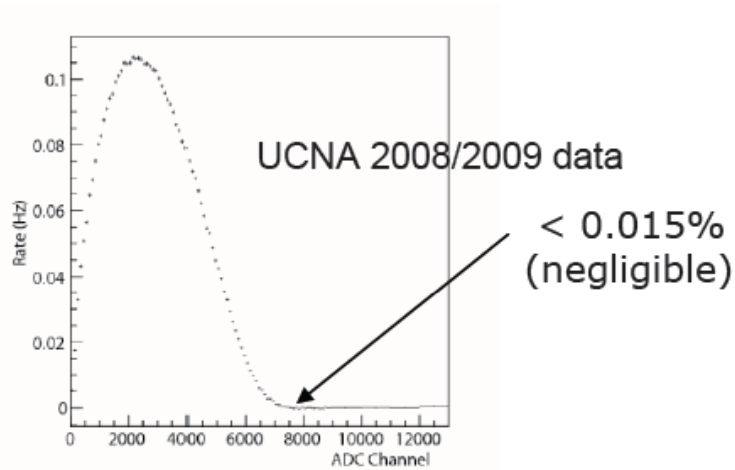


UCN can also be essentially 100 percent polarized



→ ~100% polarization, provided v_{UCN} is low enough

Backgrounds can be reduced relative to cold neutron experiments



UCN for n beta decay measurements

- Reduced background
  - Higher ratio of decays to neutrons
  - No production source background
- 100 % polarization using magnetic fields

$$V_{^{58}Ni} = \frac{2\pi\hbar^2 \rho_n a}{m} = 335\,nV \rightarrow v = 8\,m/\sec$$

$$V = mgh = 102\,nV/m$$

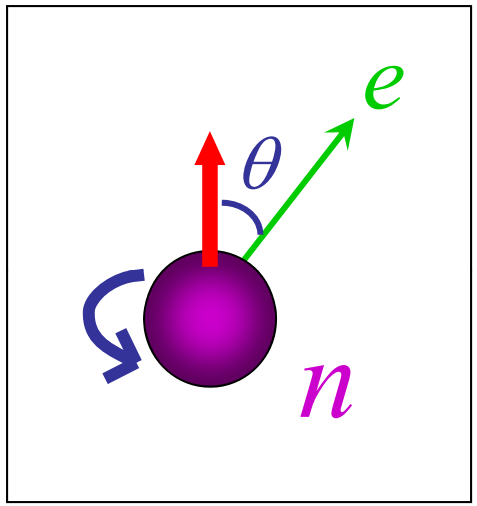
$$V = \vec{\mu} \bullet \vec{B} = 60\ nV/T$$

But…

Production of UCNs is very tricky

Previously existing sources used the low energy tails of thermal neutron spectra from nuclear reactors, sometimes moderated to a low temperature. But this method entails high backgrounds from the reactor in any experiment.

Principle of the *A*-coefficient Measurement



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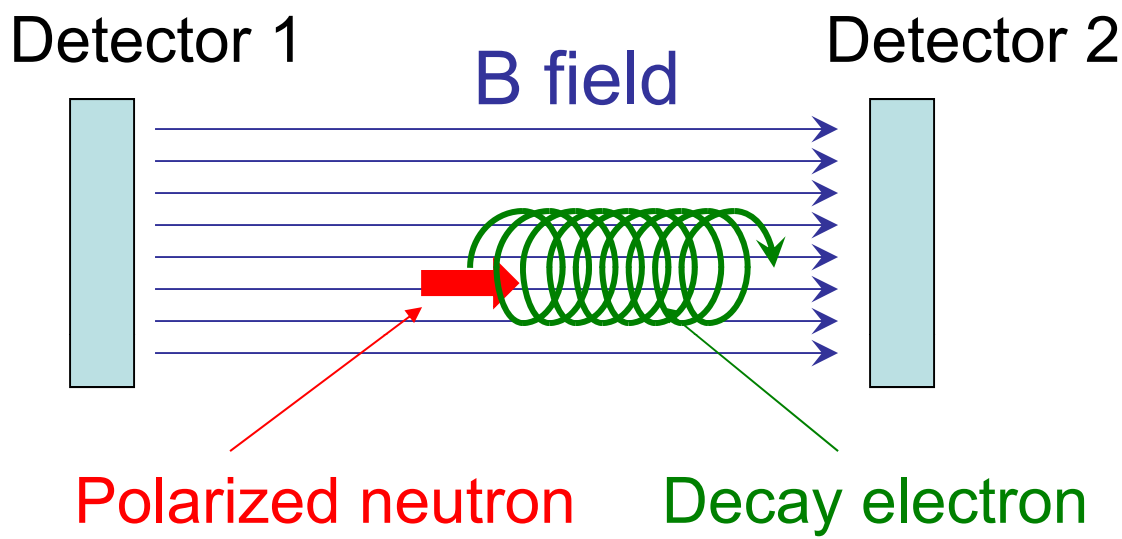


$$A_{\exp}(E) = \frac{N_1(E) - N_2(E)}{N_1(E) + N_2(E)} \approx \langle P \rangle A \beta \langle \cos\theta \rangle$$

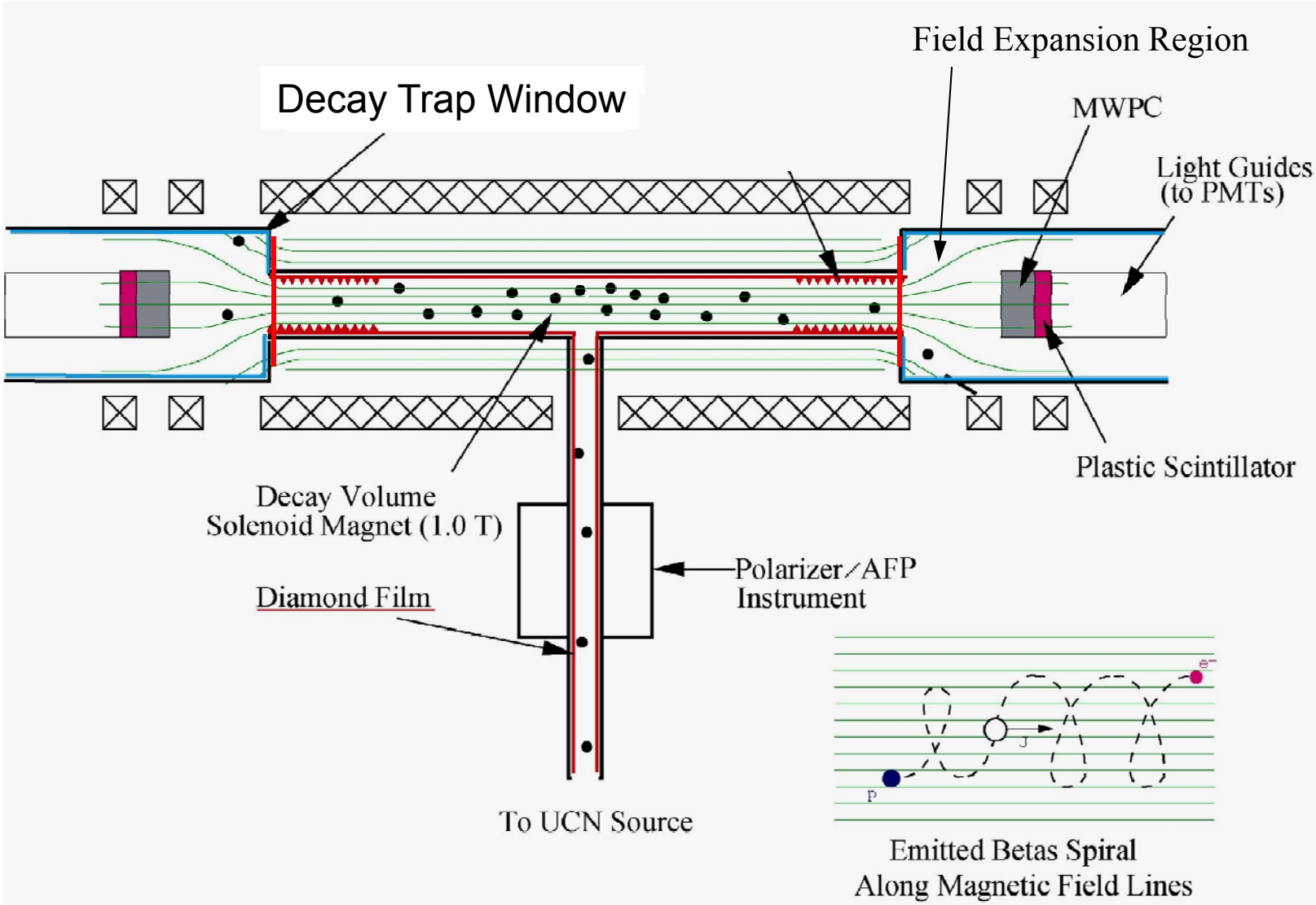
Systematics:

Polarization

Backgrounds

(End point energy = 782 keV)

UCNA Experiment — Apparatus

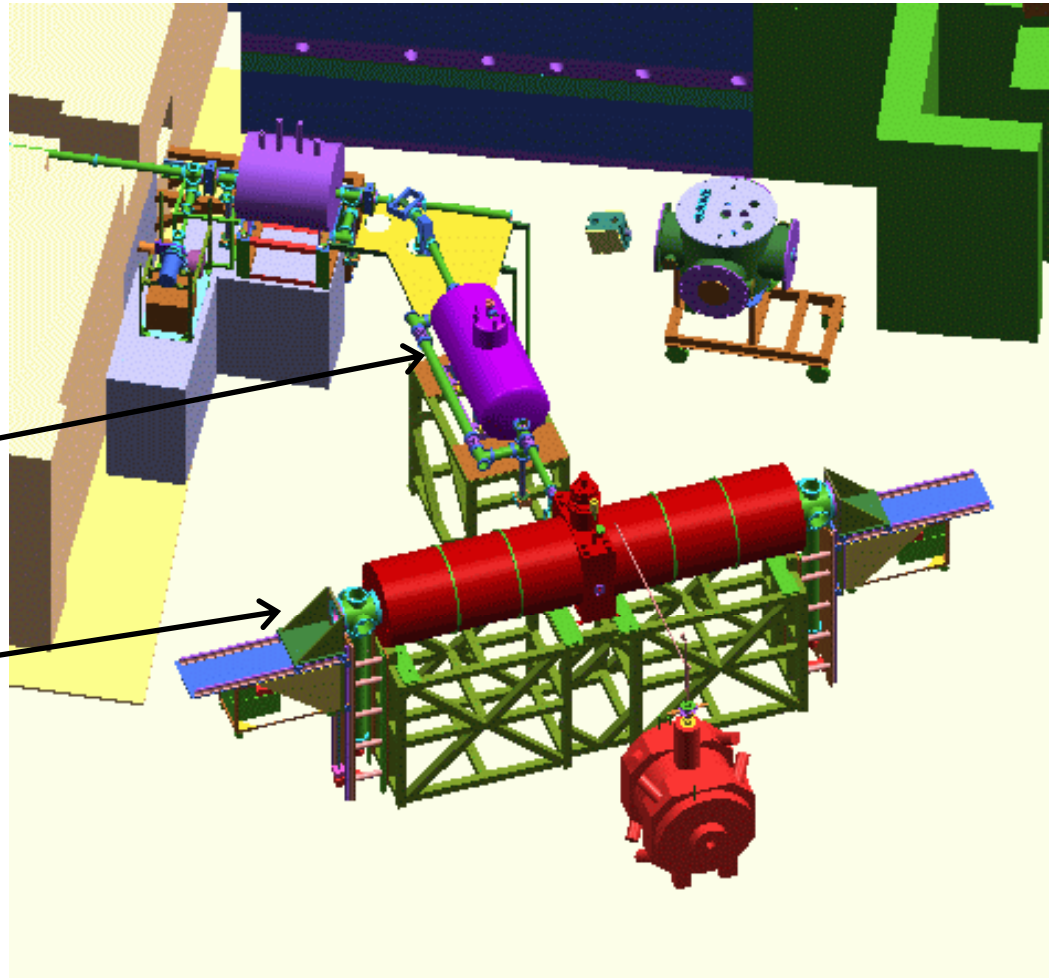


The UCNA Apparatus at LANL

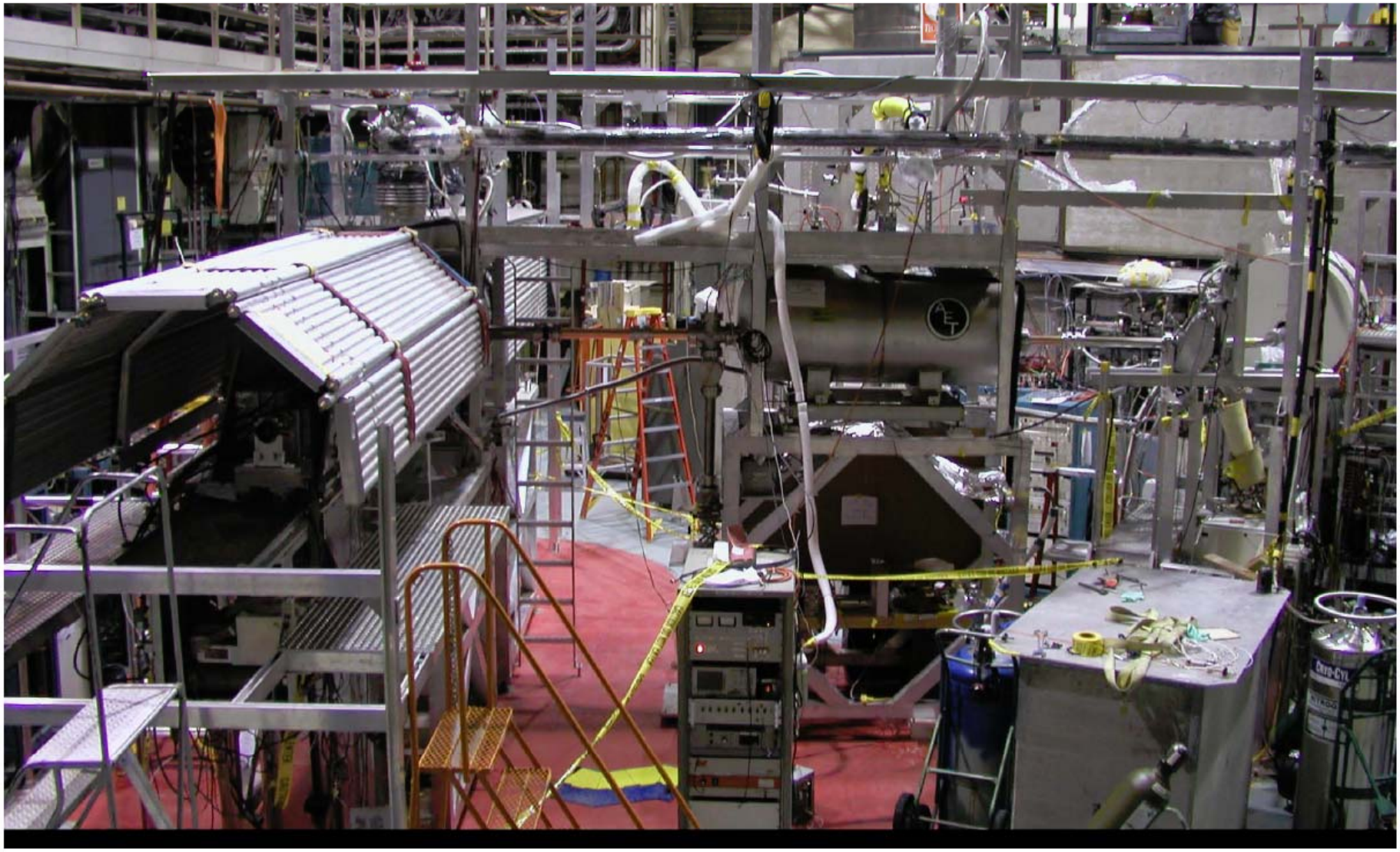
UCN Source

Polarizer magnet
and spin flipper

Spectrometer



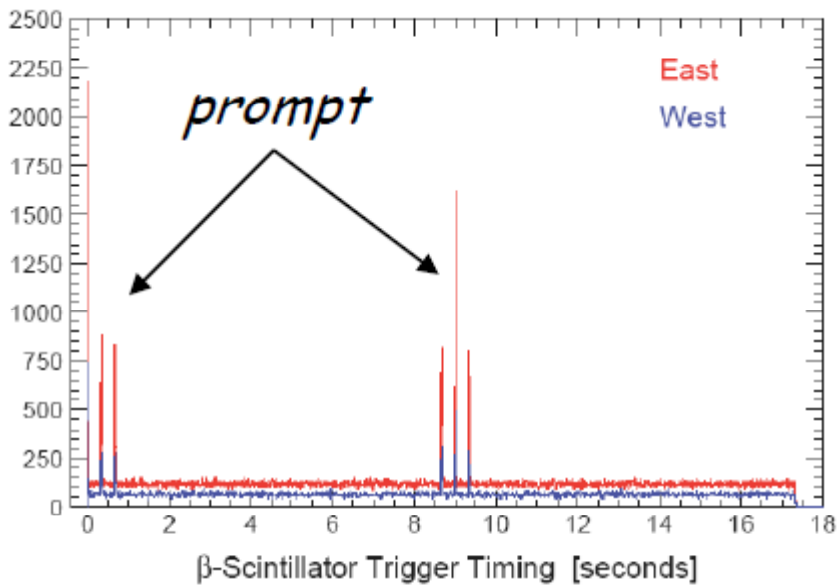
UCNA Apparatus in LANSCE Area B



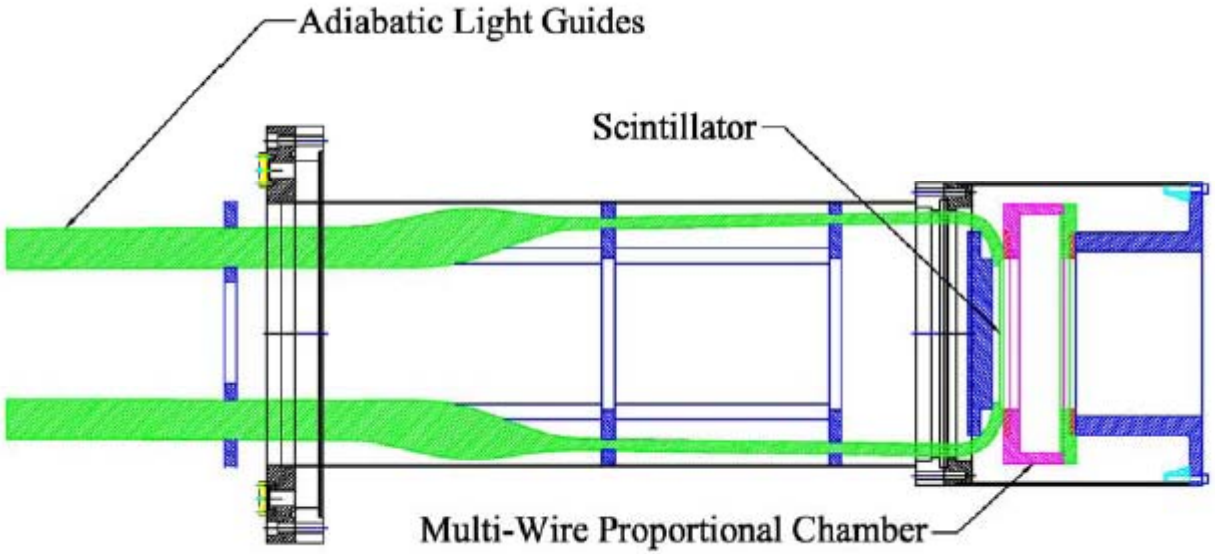
UCNA Experiment — General Approach

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)
  - Copper and diamond-like carbon coated neutron guide (low depolarization)
- Background
  - Pulsed UCN source
  - MWPC+Plastic scintillator
- Electron backscattering
  - MWPC+Plastic scintillator
- Fiducial volume selection
  - MWPC

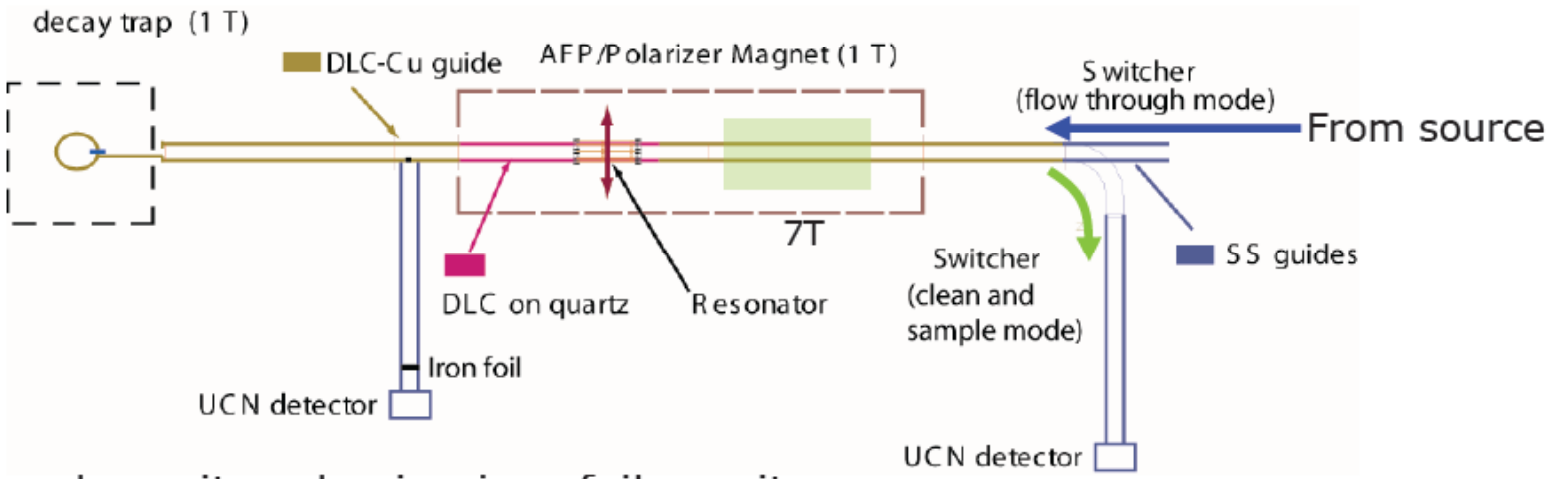


UCNA Experiment Detectors

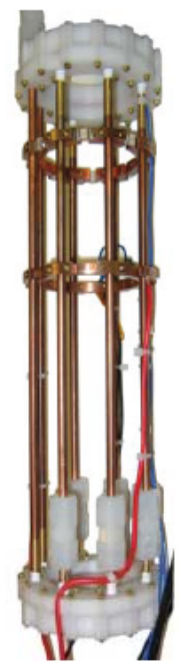


- Reduced backscatters
  - Magnetic pinch
  - Low Z thin detectors
- MWPC and scintillator in coincidence
  - Position-dependent efficiency
  - Apertures and fiducial volume
- Backscatter reconstruction

In situ polarization/polarimetry



- Flipper tuned and monitored using iron foil monitor
- Polarization measured after each ~50 minute run
- In normal running, depolarized UCN trapped, accumulate for storage time about 30s
- Equilibrium depolarized UCN population measured by
    - change switcher to clean out right spin neutrons (not trapped)
    - change spin-flipper state to unload depol neutrons -- expect sensitivity < 0.1%
    - Reloading correction necessary (UCN in guide during spin-flip)



Loading the Decay Volume: SD_2 source facility

- 2005: no decays

  replaced horizontal guides w/ SS
- 2006: 2 s^{-1} (raw rate)

  current: <1μA →2μA, improved flapper
- 2007: 6 s^{-1}

  current: →4μA, source volume 2l
- 2008: 15 s^{-1}

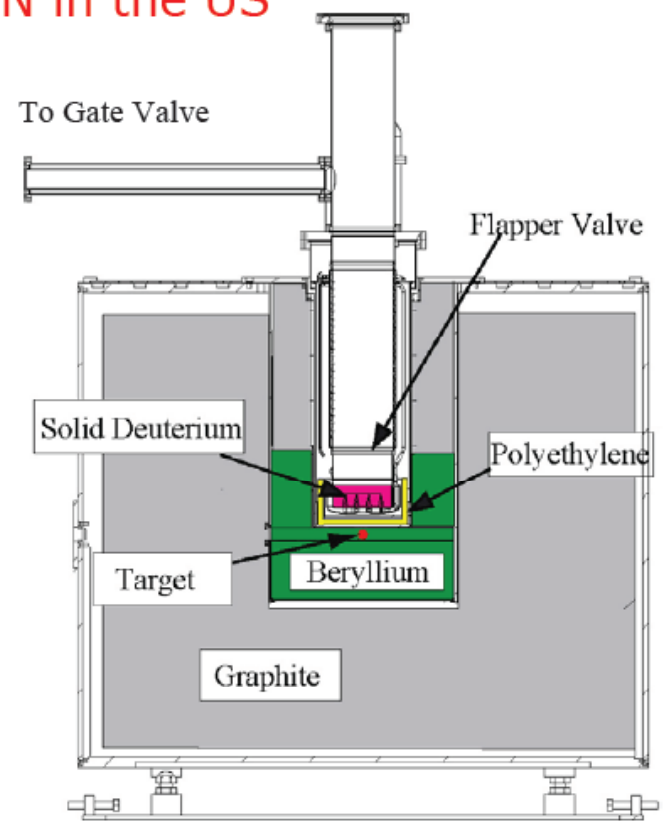
  guides changed to DLC-coated EP Cu, geom C
- 2009: 30 s^{-1}

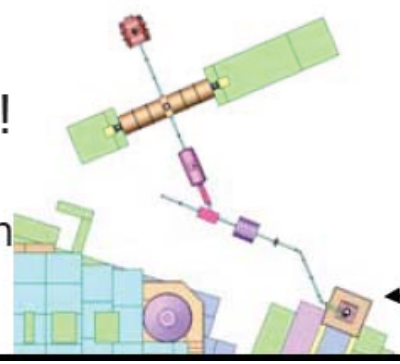
  new target and improved guides before AFP
- 2010: 55 s^{-1} (Nov)

≈2 UCN/cm^3 in decay trap!

At present Area B is best place in world for UCNA

Only source of extracted UCN in the US

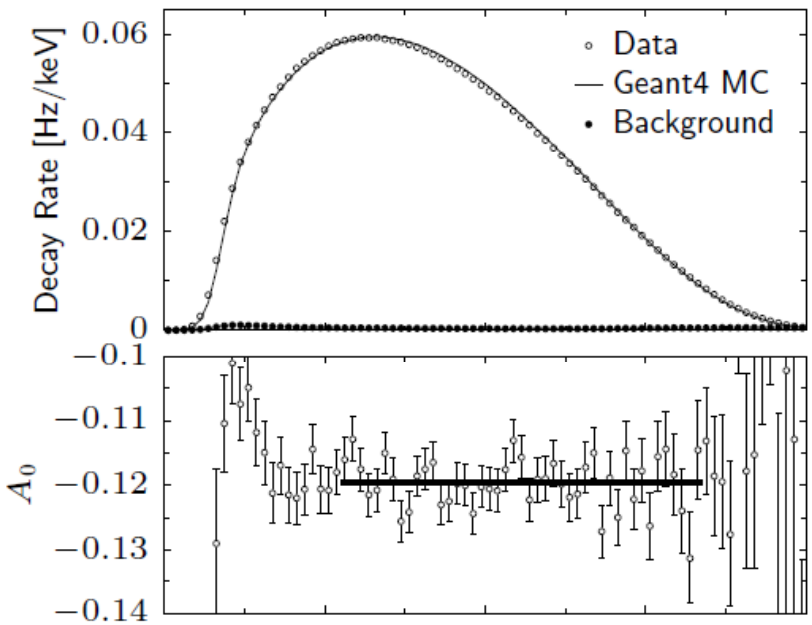


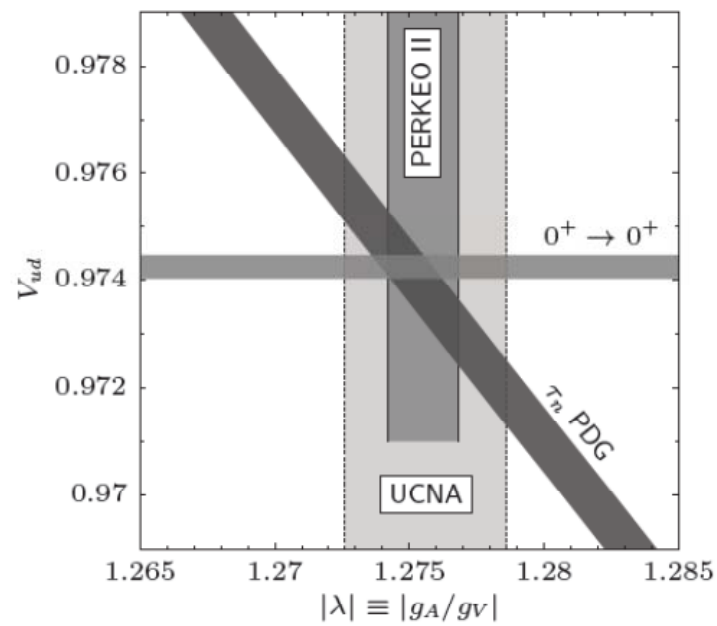


Solid deuterium source

UCNA Status

- Taking production data since 2009 using LANL UCN source
- Latest result: A=-0.11954(112)



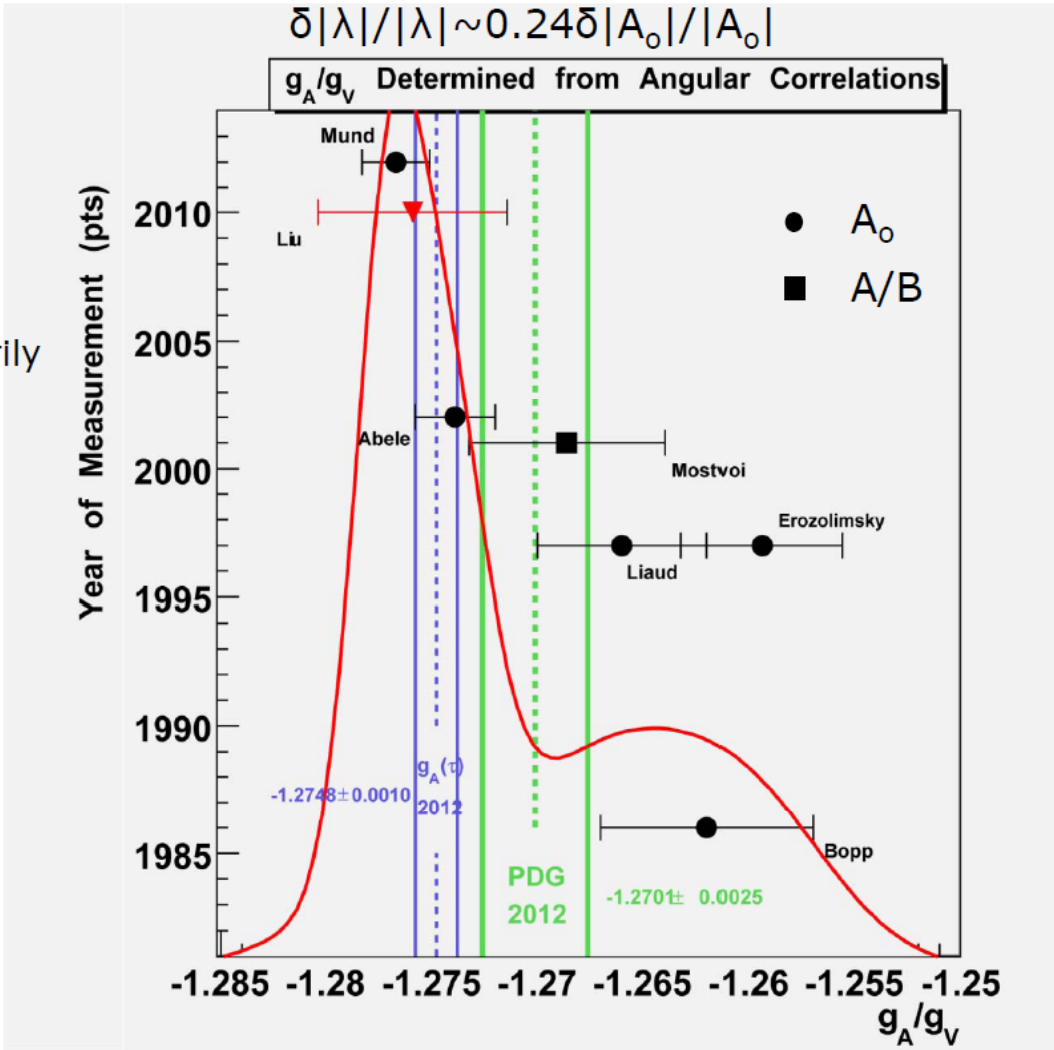


Mendenhall *et al*., arXiv 1210.7048 (2012)

A Correlation history

PDG λ

Derived primarily from A [2]



0.20%

PDG 2012: λ=-1.2701 ± 0.0025, error scaled by 1.9

From PDG2012 τ: λ = -1.2748 ± 0.0010, error scaled by 1.8

agree at 1.75 σ level

Neutron Lifetime affects BBN

Light elements from ^{2}H up to ^{7}Li created in "first three minutes"

Weak reactions between particles:

$$n + e^+ \leftrightarrow p + \bar{\nu}_e, \qquad \sigma_\nu \sim 1/\tau_n$$

$$n + \nu_e \leftrightarrow p + e^-, \qquad \text{(all have same Feynman diagram)}$$

$$n \rightarrow p + e^- + \bar{\nu}_e. \qquad \tau_n$$

At time $\approx$ 1 s, at "freeze-out" temperature $T_f \approx 1$ MeV:

neutron to proton ratio frozen to:

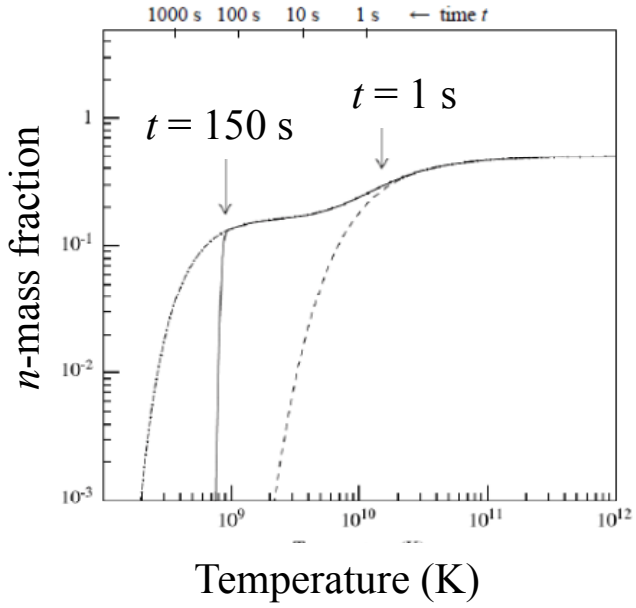
$$n/p = \exp(-\Delta m / kT_f) \approx 1/6.$$

$$\Delta m = m_n - m_p = 1.3 \text{ MeV}$$

After another ≈ 150 s, practically all neutron wind up in ^{4}He,

i.e., He mass fraction $Y_p = 2 \times$ neutron mass fraction $\approx 25\%$.

Primordial nucleosynthesis:

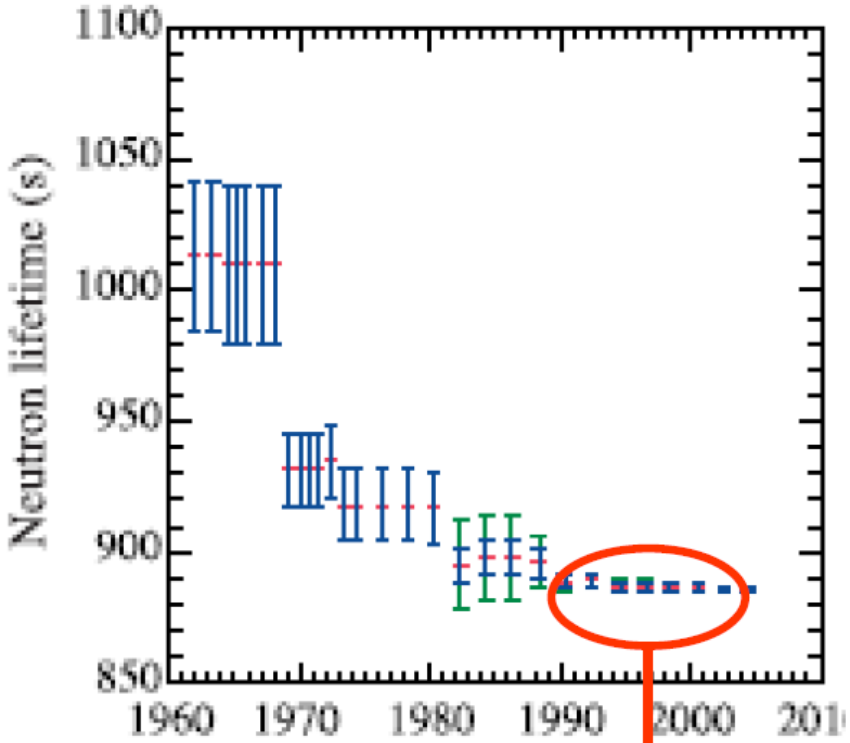


Dubbers 2013

And ratio of He/n depends directly on n lifetime: 1% lifetime uncertainty shifts calculated He fraction of Y=0.2480+/- .0003 by 0.0015, or 5 sigma!

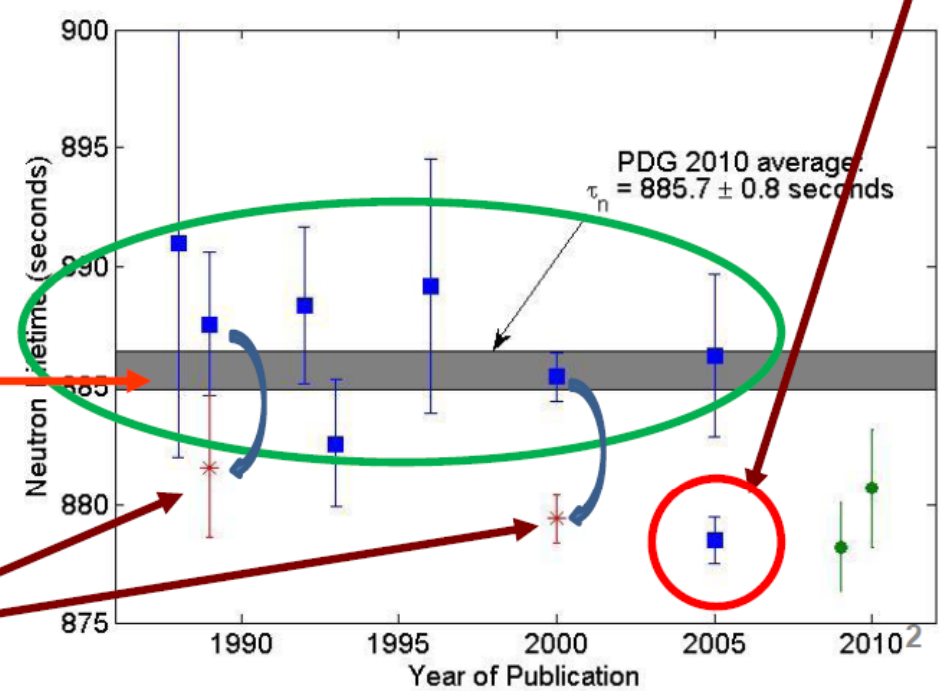
Free Neutron Lifetime

Precision improves over time, but accuracy?



PDG 2010: 885.7 ± 0.8 s
PDG 2011: 881.0 ± 1.5 s
PDG 2012: 880.1 ± 1.1 s

Serebrov et al.,
(878.5 ± 0.7 ± 0.3) seconds



Reanalysis of bottle experiments by Serebrov, et al.

Lifetime uncertainty has grown recently

And central value has shifted by almost 1%!

PDG 2001-2010 $\tau_n = (885.7 \pm 0.8)$ s $(S = 1)$
Serebrov *et al*. 2005 $\tau_n = (878.5 \pm 0.8)$ s
Pichlmaier *et al*. 2010 $\tau_n = (880.7 \pm 1.8)$ s
PDG 2012 $\tau_n = (880.1 \pm 1.1)$ s $(S = 1.8)$

Serebrov *et al.*,
PL B **605**, 72 (2005)

Pichlmaier *et al.*,
PL B **693**, 221 (2010)

Beam Method: Count the dying

PHYSICAL REVIEW C **71**, 055502 (2005)

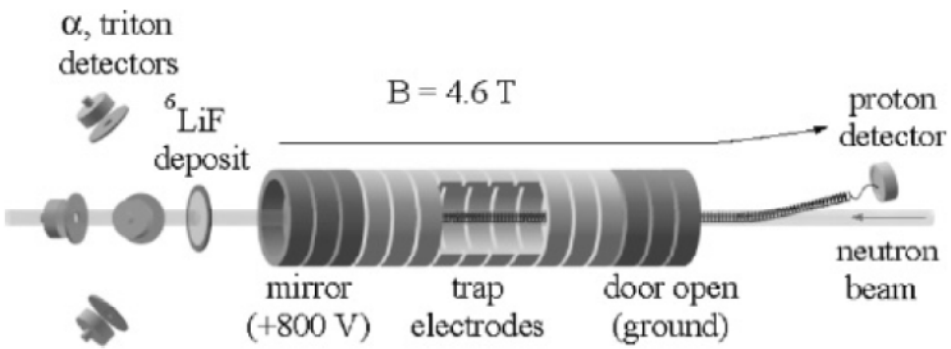
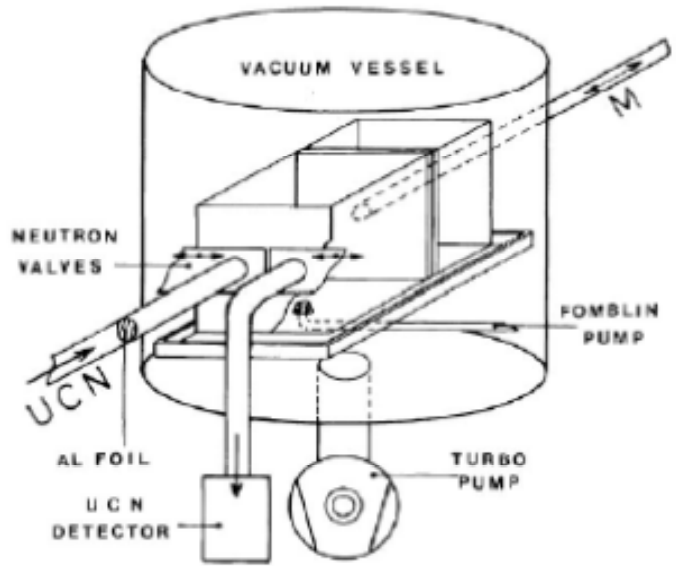


FIG. 2. Experimental method for measuring lifetime by counting neutrons and trapped protons.

Danger: absolute monitor efficiency needed!

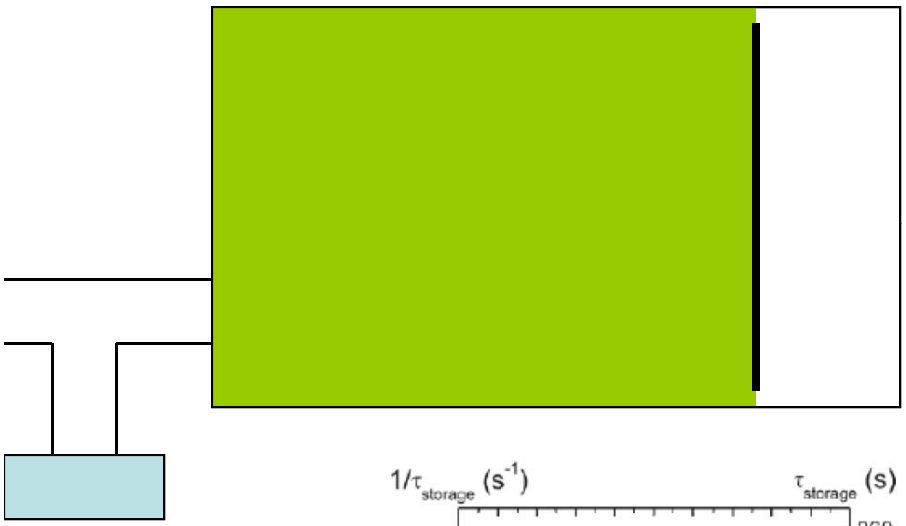
Bottle method: count the survivors

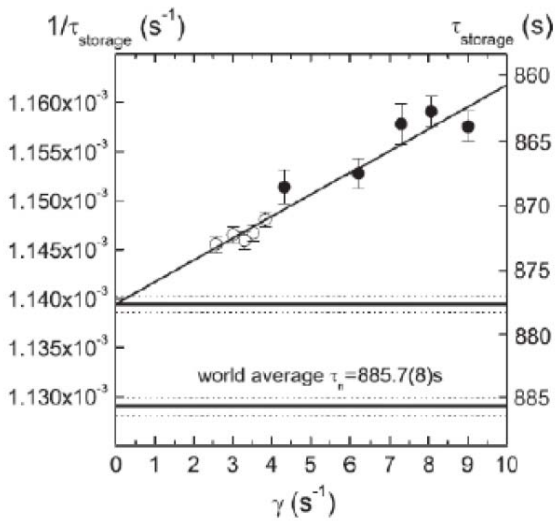


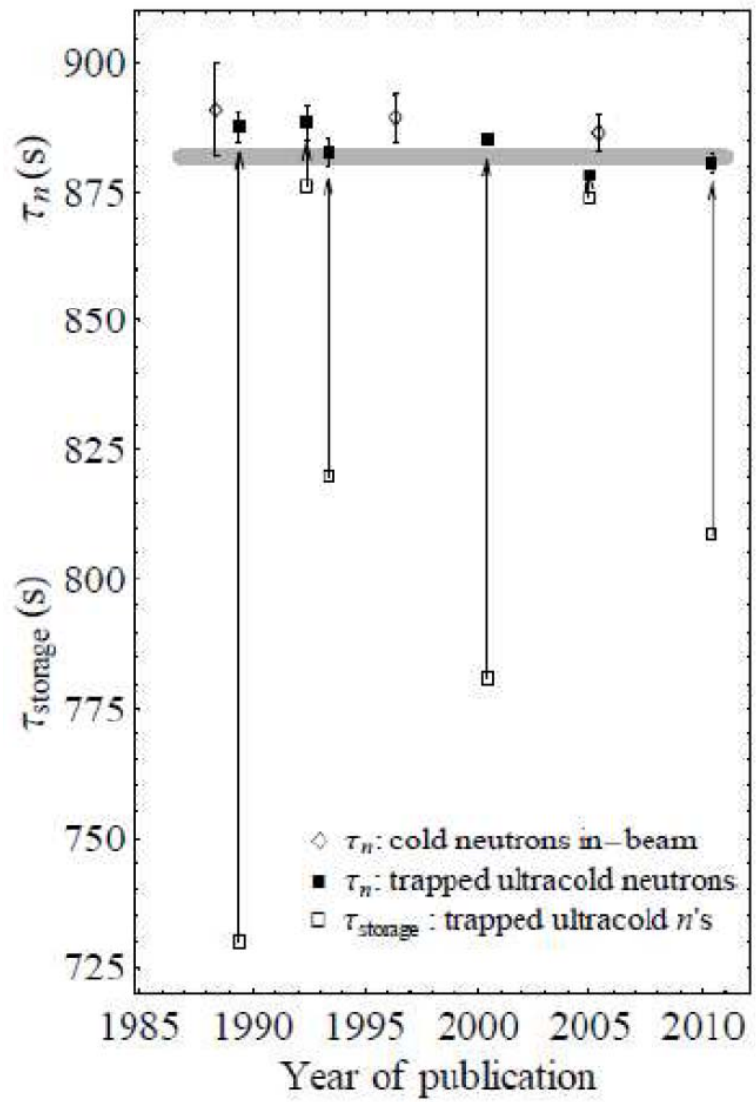
$$1/\tau_{\text{storage}} = 1/\tau_n + 1/\tau_{\text{loss}}$$

Wietfeldt and Greene,
Rev. Mod. Phys. **83**, 1173 (2011)

Material bottle experiments involved 100 s extrapolations due to wall losses

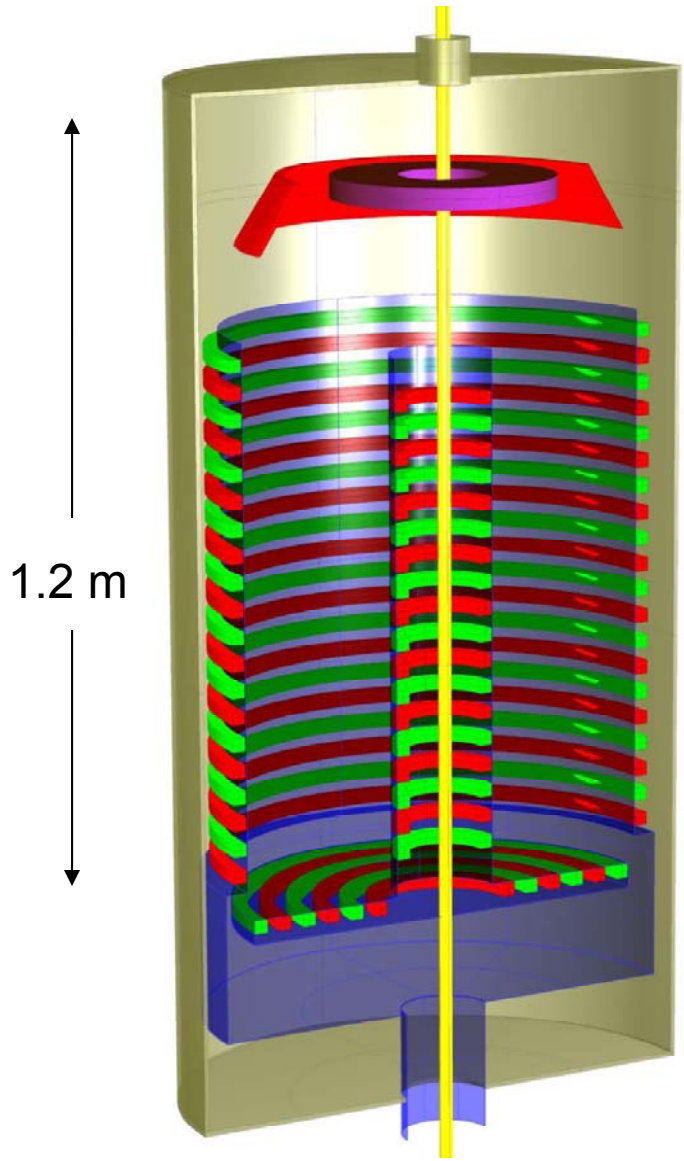






Penelope experiment under development

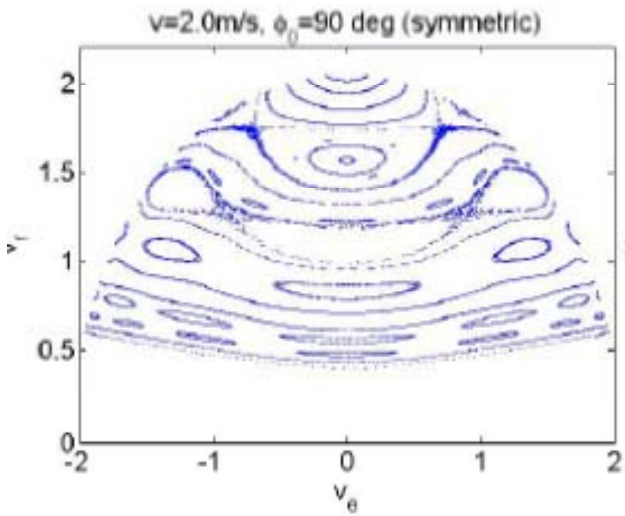
- Superconducting multipole
  - Field zero in center eliminated by inner conductors
- Filled with UCN from FRM-2 through gap in bottom
- Decay products detected at top, guided by field lines
- Spectrum cleaned using absorber lowered from top
- Magnet now under construction



An outstanding problem: phase space evolution

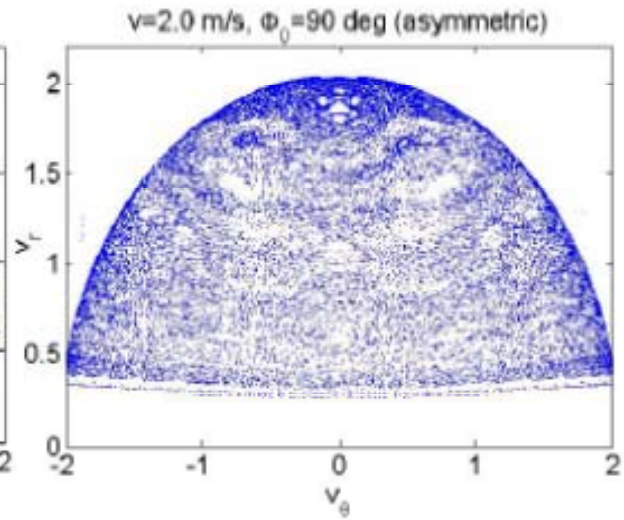
- Neutron losses on scale of neutron lifetime (quasibound orbits)
- Detector efficiency changes with time
- Must fill phase space evenly, quickly: chaos!

Symmetric Trap has stable orbits



Thin stochastic regions bounded by KAM curves.

Asymmetric Trap has chaotic orbits



Strong perturbation, KAM curves are destroyed.

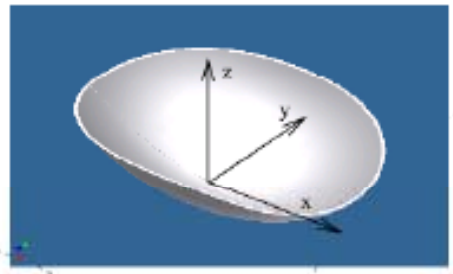
C.-Y. Liu, 2012

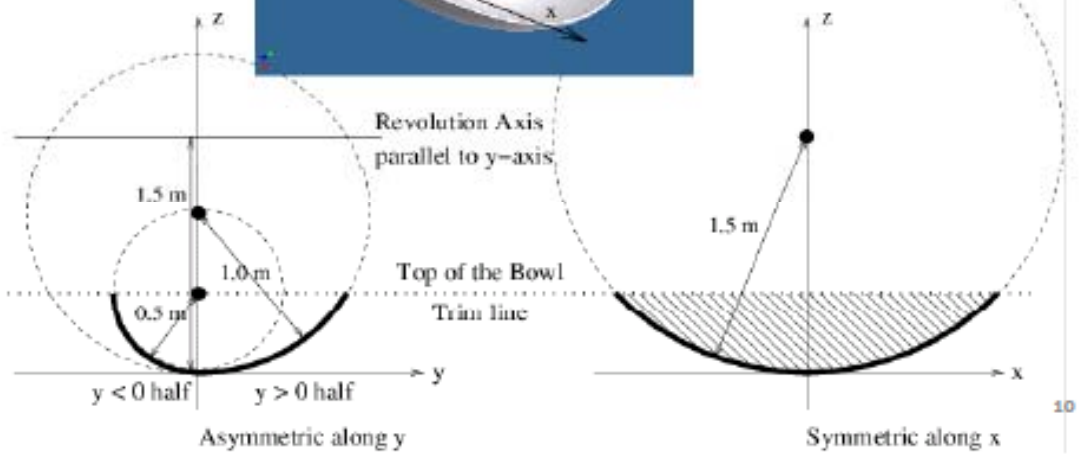
UCNTau experiment designed to overcome phase space issues

Asymmetric Trap → Phase Space Mixing

- **Low symmetry** (together with **field ripples**) induces states mixing between circular orbits, through chaotic motion (or not).

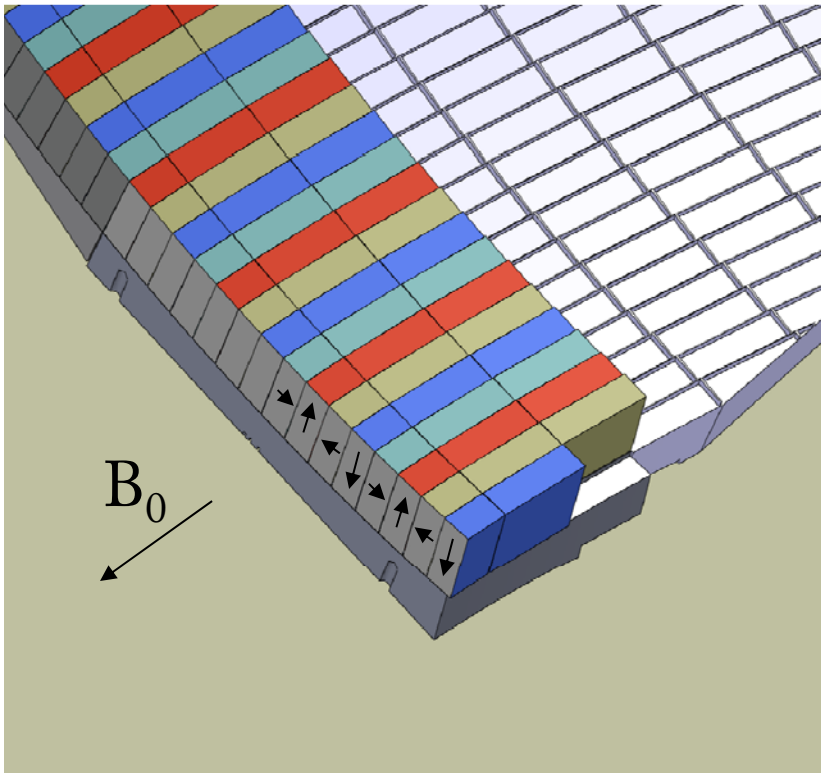
- → **quick cleaning** (~ seconds) of the quasi-bound UCN with large tangential velocities.

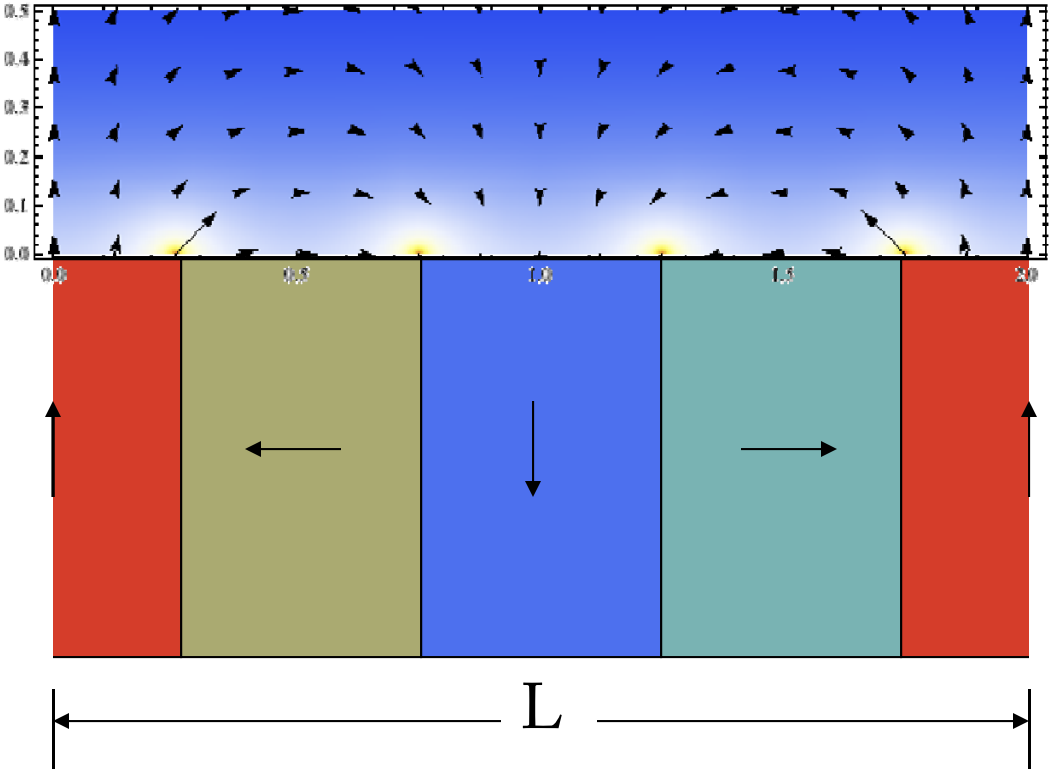


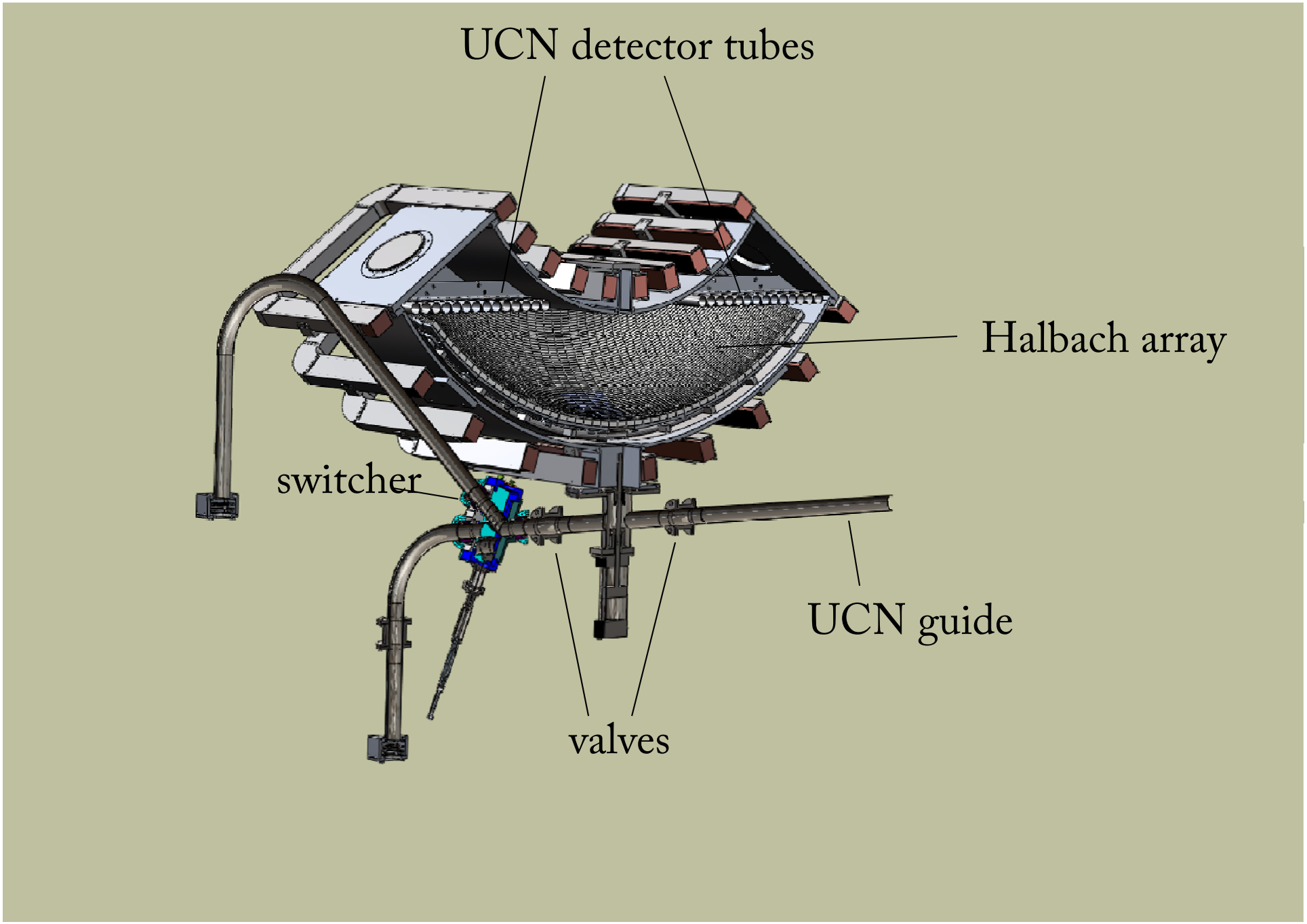


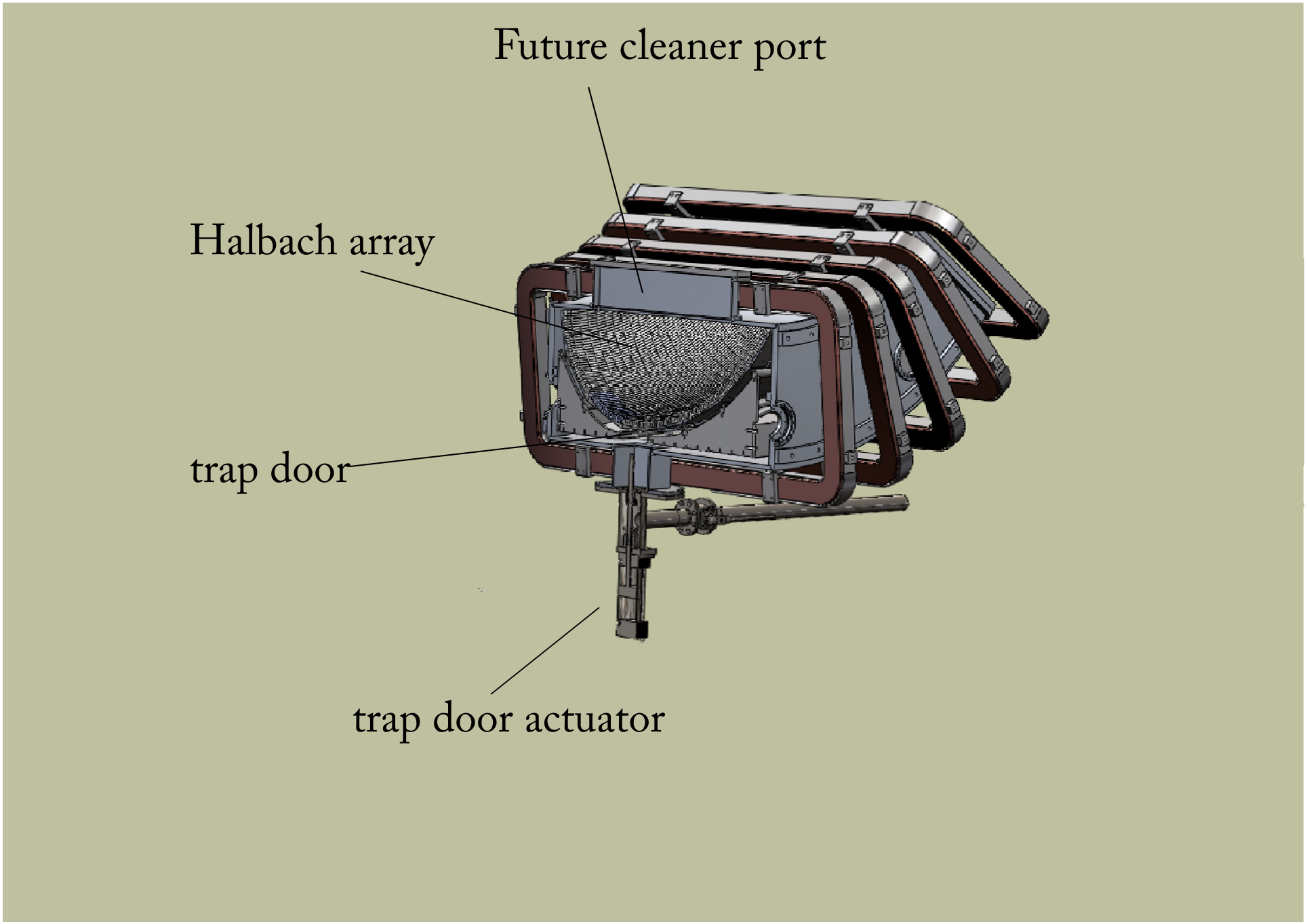
Halbach array

- Each magnet 90º out of phase with its neighbor.
- The array has B field "ripples" of scale L/4 = 0.5 in
- Rotating field is orthogonal to holding field B_0





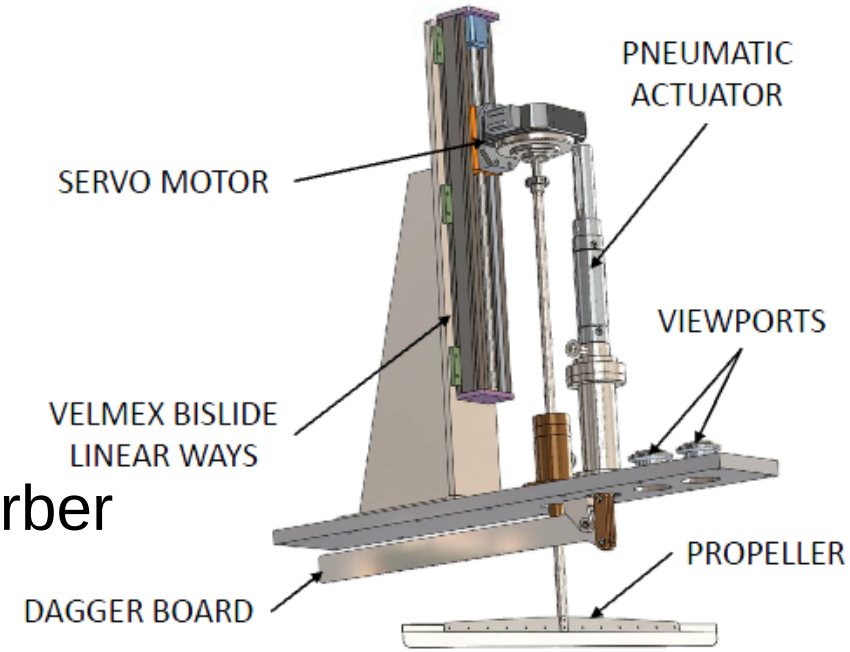

UCN detector tubes
Halbach array
switcher
UCN guide
valves


Future cleaner port
Halbach array
trap door
trap door actuator

R&D: Vanadium solid state detector

Neutron scattering lengths and cross sections							
Isotope	conc	Coh b	Inc b	Coh xs	Inc xs	Scatt xs	Abs xs
V	---	-0.3824	---	0.0184	5.08	5.1	5.08
50V	0.25	7.6	---	7.3(1.1)	0.5	7.8(1.0)	60.(40.)
51V	99.75	-0.402	6.35	0.0203	5.07	5.09	4.9

Negative UCN pote Good UCN absorber



$^{50}V + n \rightarrow {}^{51}V$ (stable)

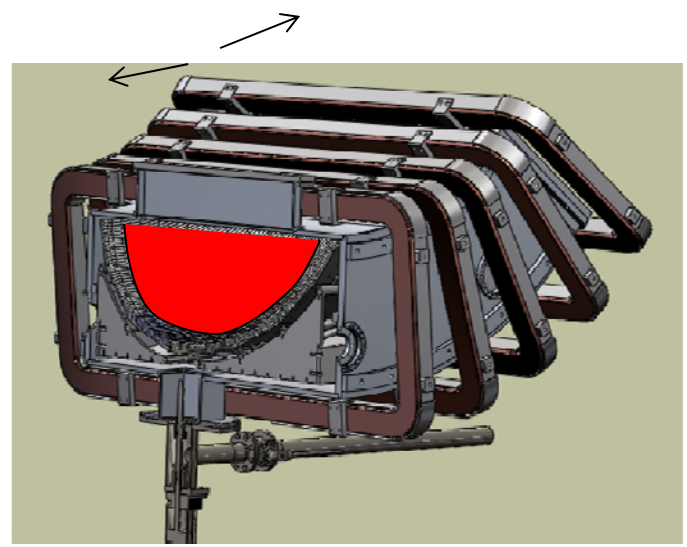
$^{51}V + n \rightarrow {}^{52}V \rightarrow {}^{52}Cr + \beta^- + \gamma$ (100%)

1. Insert vanadium foil to absorb neutrons
2. Extract foil into shielded counter
3. Perform β-γ coincidence measurement.

β : 1.073 MeV , γ : 1.4 MeV

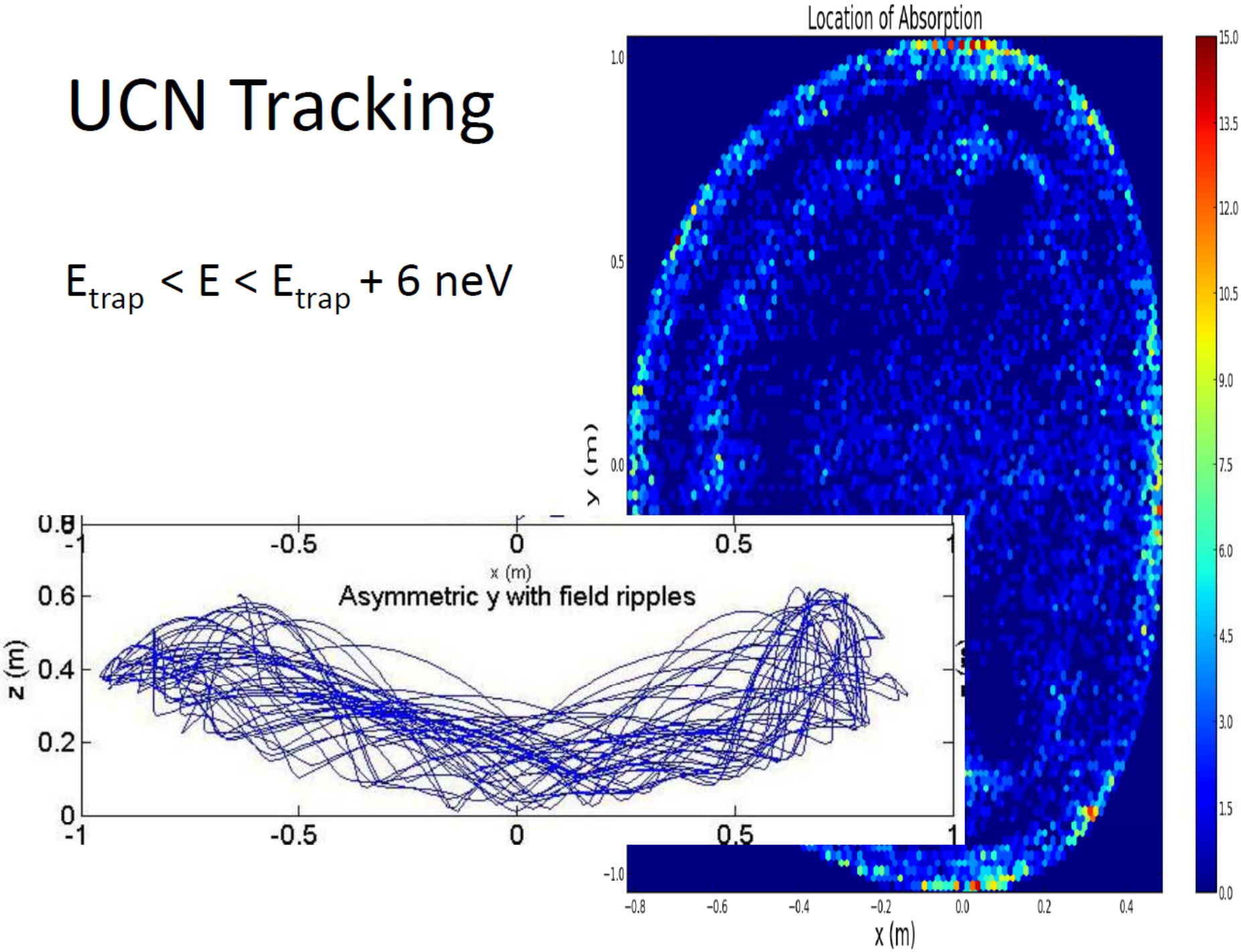
$T^{1/2}$ = 3.743 m

Use several detectors to get position information on UCN distribution inside the trap.



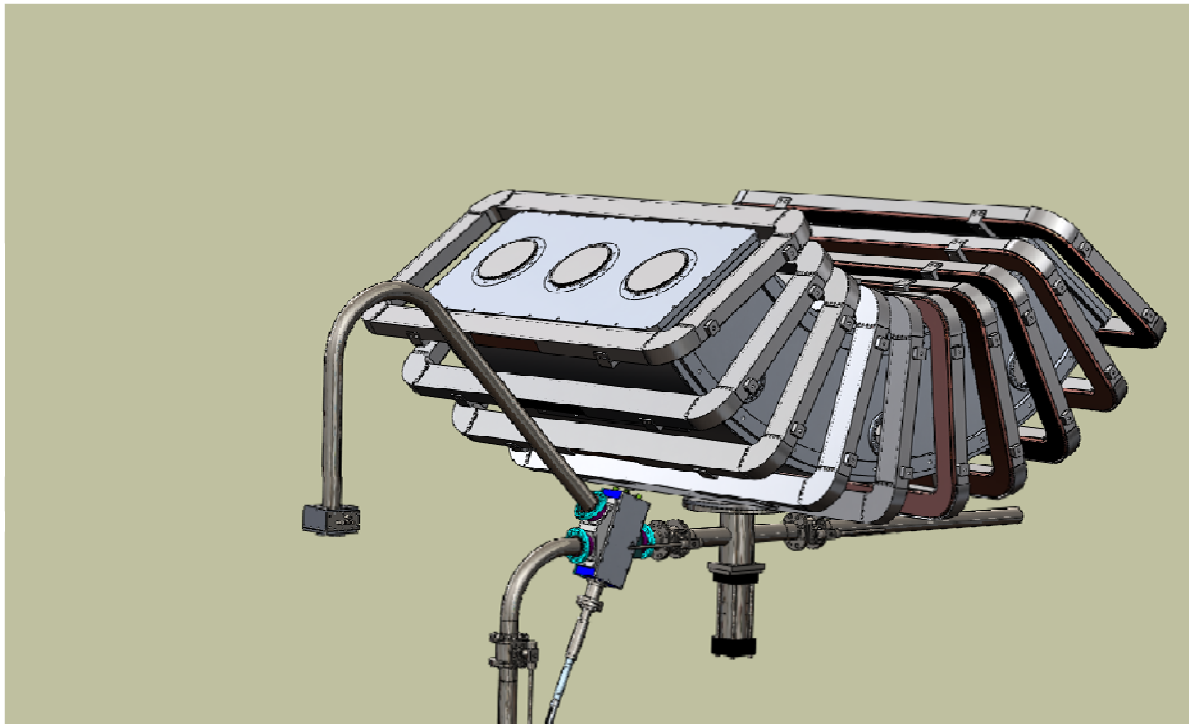
UCN Tracking

$E_{trap} < E < E_{trap} + 6$ neV



Statistical Sensitivity

- Effective trap volume is 0.6 m^3
- UCN may trap up to E = 48 neV
- LANSCE source can produce >10 UCN cm^{-3} at gate valve
- Trap density >1 UCN/cc: 600,000 UCN per fill
- 15 minutes to 1 hour per fill
- 1 s precision in 6 hours

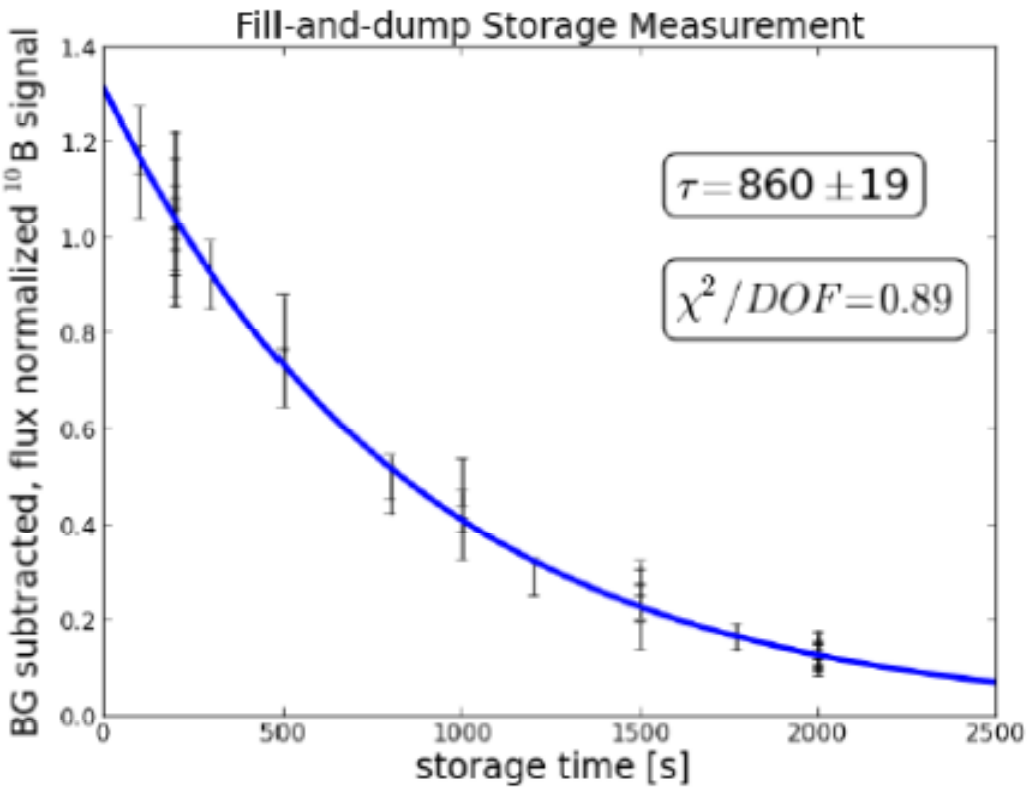


Ultimate goal: a 0.1 s total uncertainty

- Short term goals (2012-2013):
  - Prototype experiment being set up at LANSCE
  - 6 hours of DAQ for 1 s statistics
  - Measure trap lifetime
  - Detector R&D (V and monitor detectors)
  - Investigate systematic effects:
    - Spectrum dependence
    - Loss mechanisms (spin flips, residual gas, …?)
    - Polarization and rate
    - Detector effects: position, dead time, gain
  - Workshop to discuss path to 0.1 s
- Longer term goals (2014 and out):
  - 0.1 s precision
  - 1 month of statistics at present UCN production rate

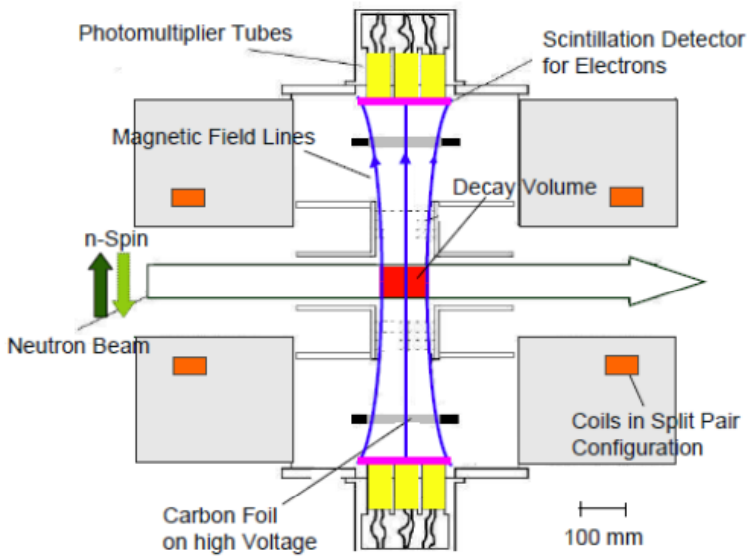
UCNTau Experiment now commissioning

- Asymm
  magnet
- Holding
- UCNs fr
  through
- Neutron
  on vana
  trap, act
- Has sto



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

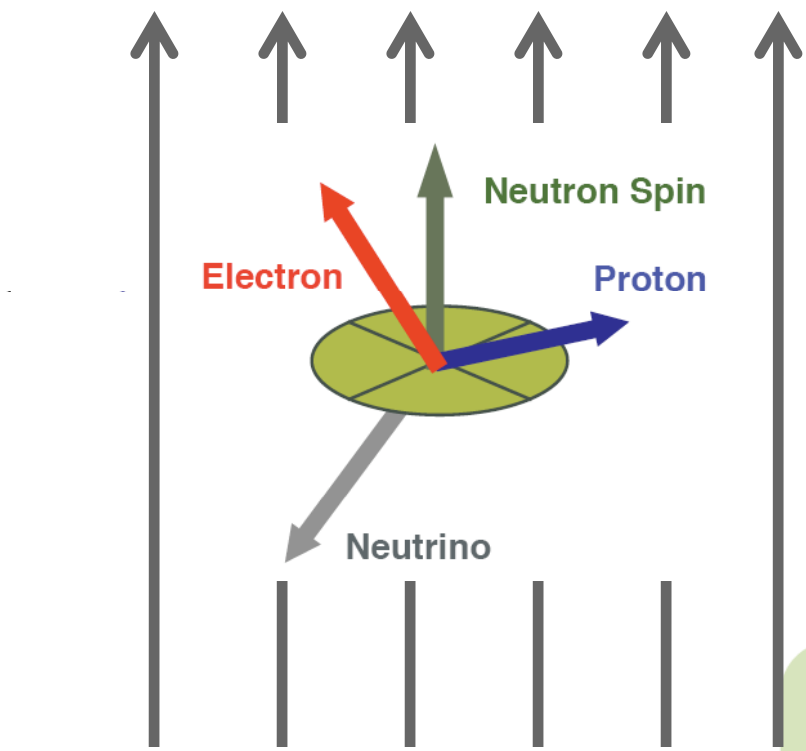
$$B_{\exp}(E_e) = \frac{N^{--}(E_e) - N^{++}(E_e)}{N^{--}(E_e) + N^{++}(E_e)}$$

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

The "UCNB" concept

[W.S. Wilburn et al., submitted to Rev. Mex. Fis.]

1 Tesla, B-Field



Basic Idea: Detect e-p coincidences

e: "start" (prompt)

p: "slow" (~ μs – ms)

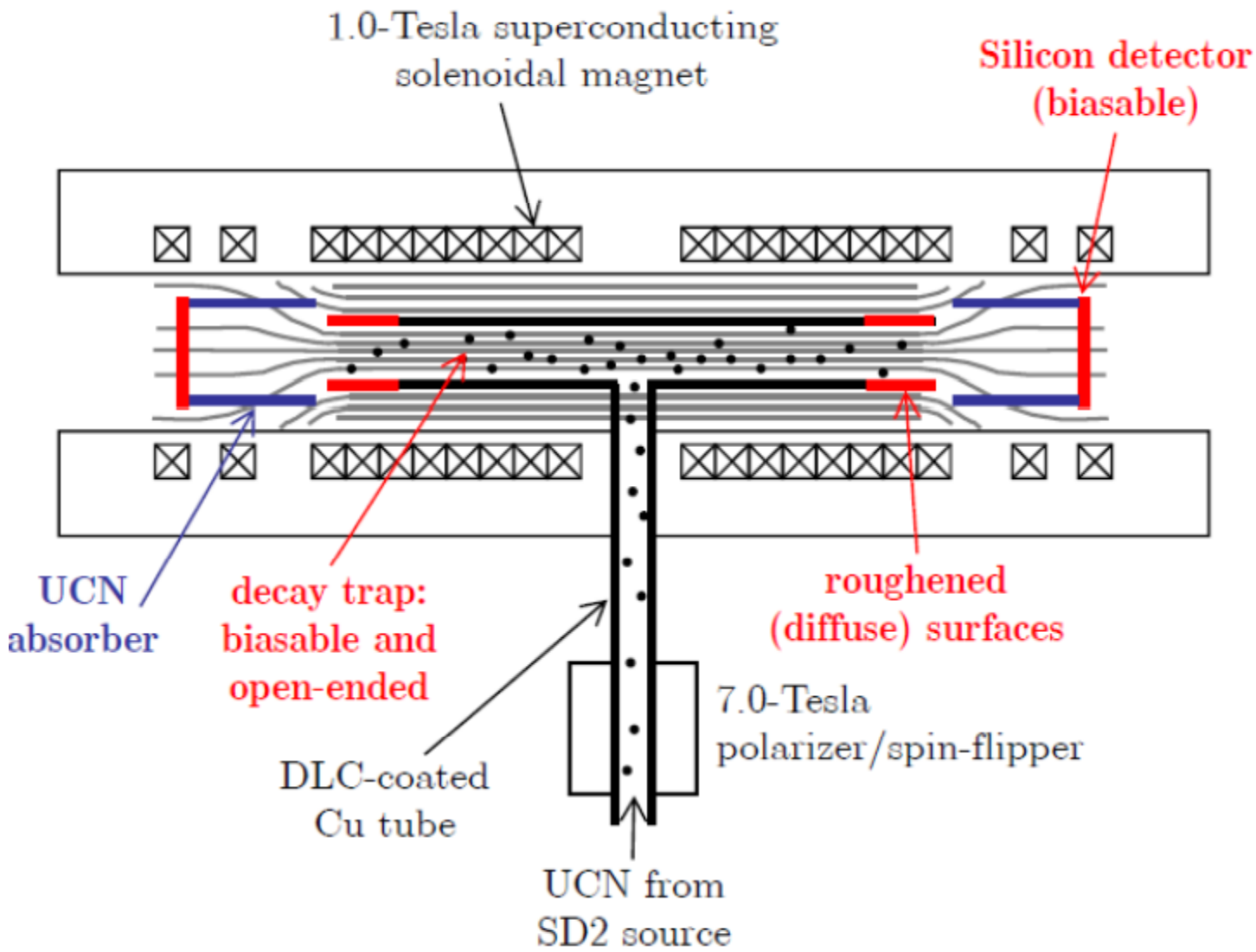
UCNB Observables

Neutron Polarization

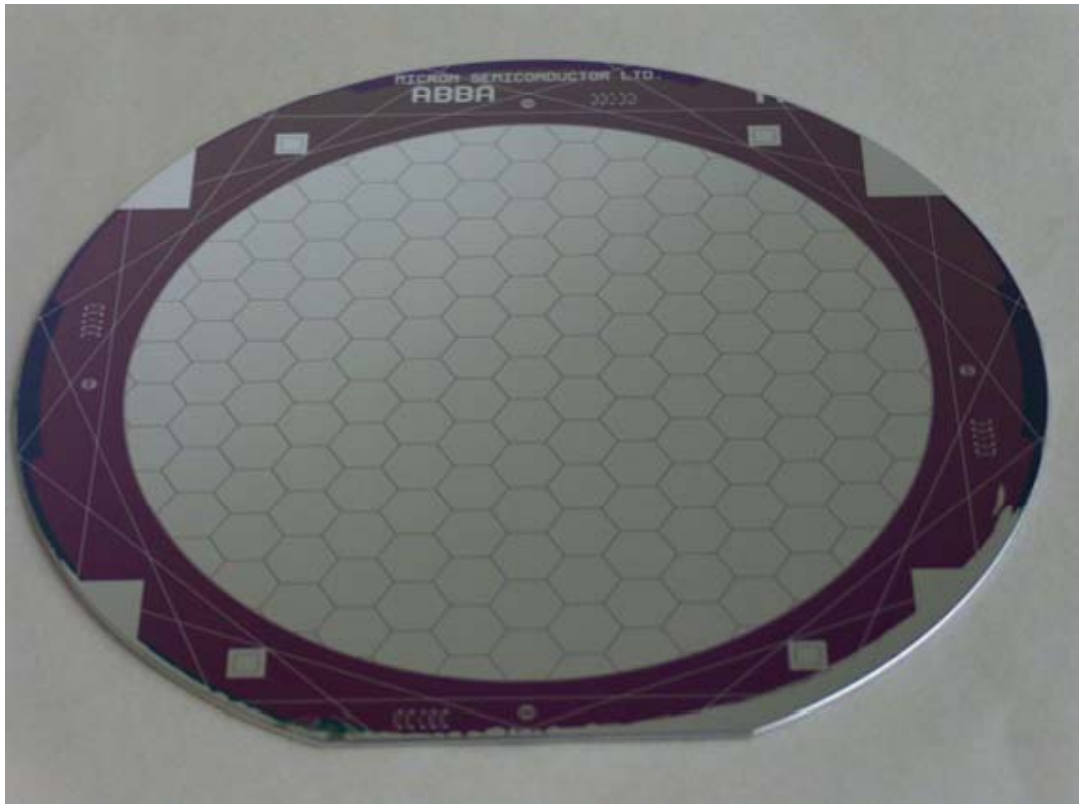
Electron and Proton Directions

Electron Energy

First-Pass Goal: 0.1% on B


1.0-Tesla superconducting
solenoidal magnet
Silicon detector
(biasable)
UCN
absorber
decay trap:
biasable and
open-ended
roughened
(diffuse) surfaces
7.0-Tesla
polarizer/spin-flipper
DLC-coated
Cu tube
UCN from
SD2 source

Highly Segmented Si Detector



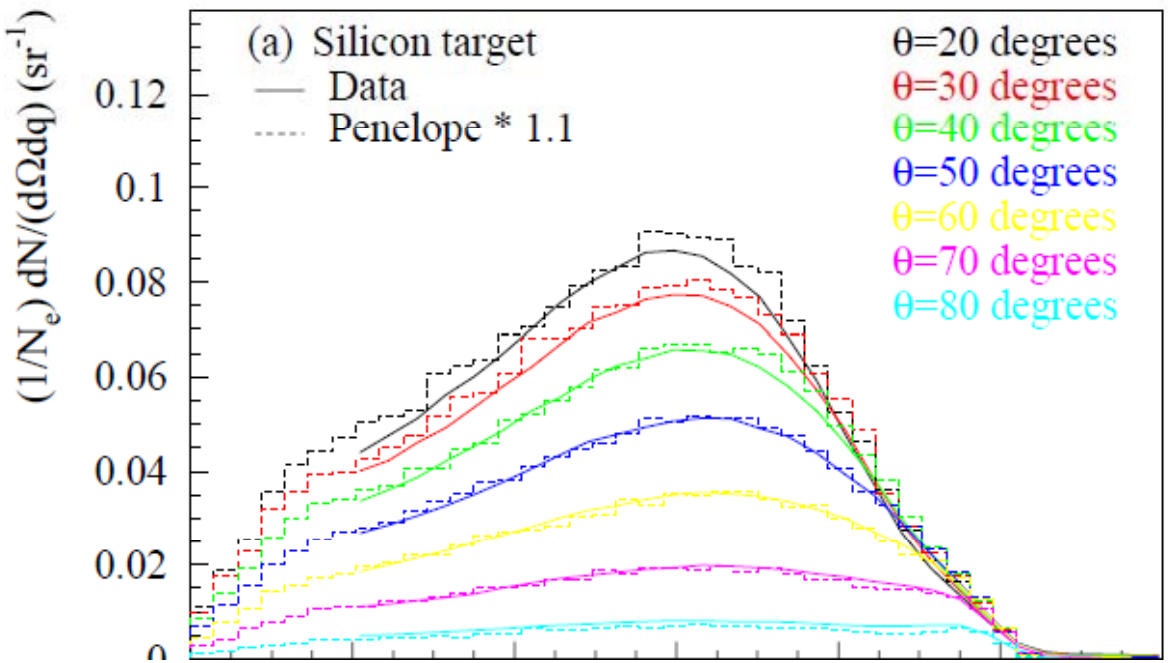
- Developed by LANL with LDRD funding
- .5, 1, 1.5 and 2mm thick
- New level of resolution
- Background reduction with e-p coincidence
- <100nm dead layer, p-gun

Preliminary Systematics + Statistical Error

Table 1: Major corrections and error table for “Bexp (E)”			
Major Systematic	Correction	Error	Source
Statistics	n/a	0.05%	Assuming a year long run
Neutron polarization	<0.1%	0.02%	UCNA experience
Det. calibration, linearity, response	0.10%	<0.01%	Projected silicon detector linearity
Proton backscatter	0.07%	<0.01%	[8]
Electron Backscatter	0.30%	0.06%	[10]
Missed coincidences	0.10%	<0.03%	1 ms window [9]
Accidental coincidences	-0.10%	<0.01%	Rate 10/s ~ 1 ms window [9]
Mirroring effects in B field expansion	-0.04%	0.02%	UCN absorbers
Total	0.30%	<0.07%	“Cexp (E)”

Electron Backscatter Modeled

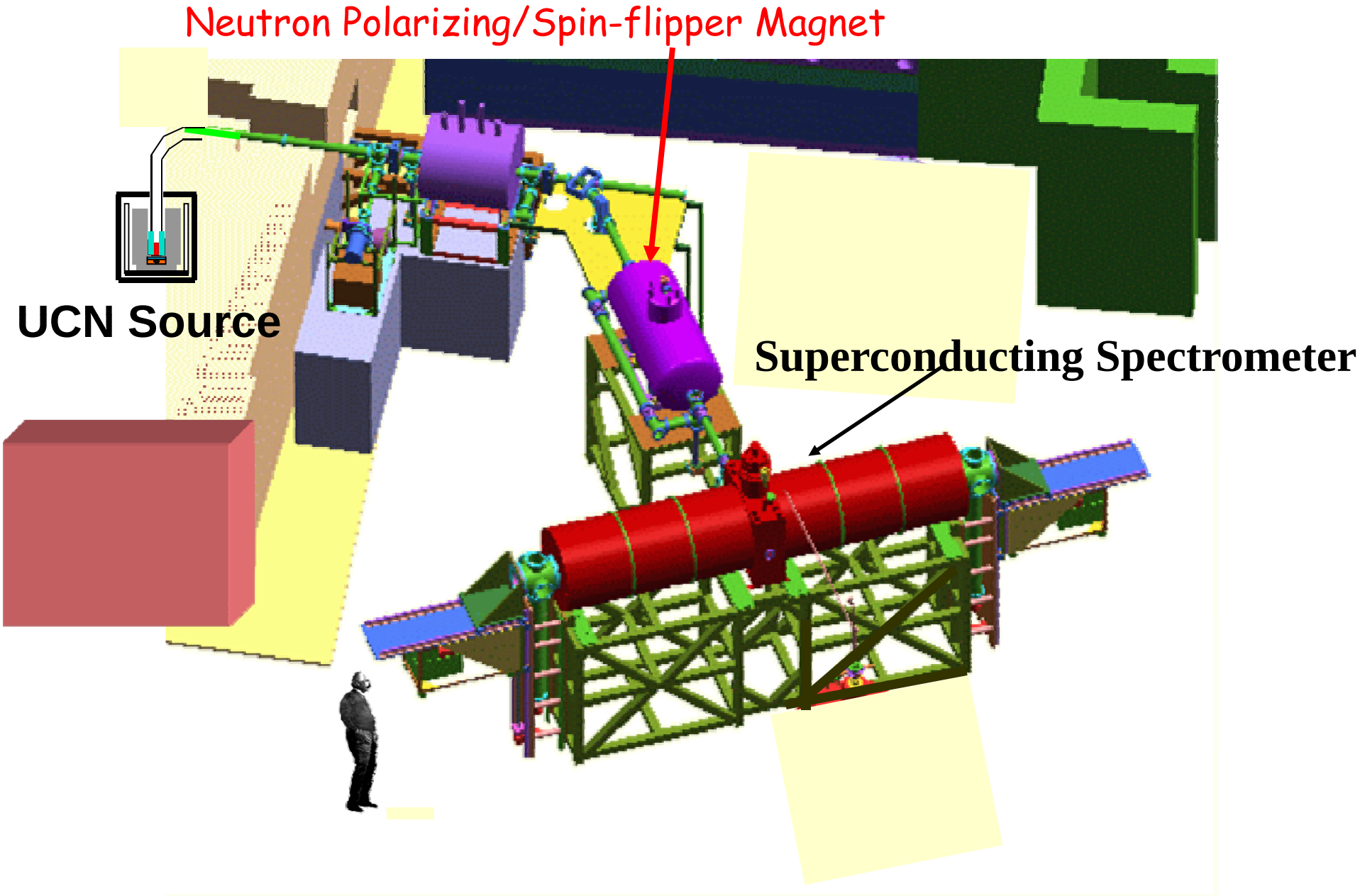
PHYSICAL REVIEW C **68**, 055503 (2003)



- Monte Carlos exist – UCNA
- Only effects energy in “C”
- Can use bias to under stand low energy response

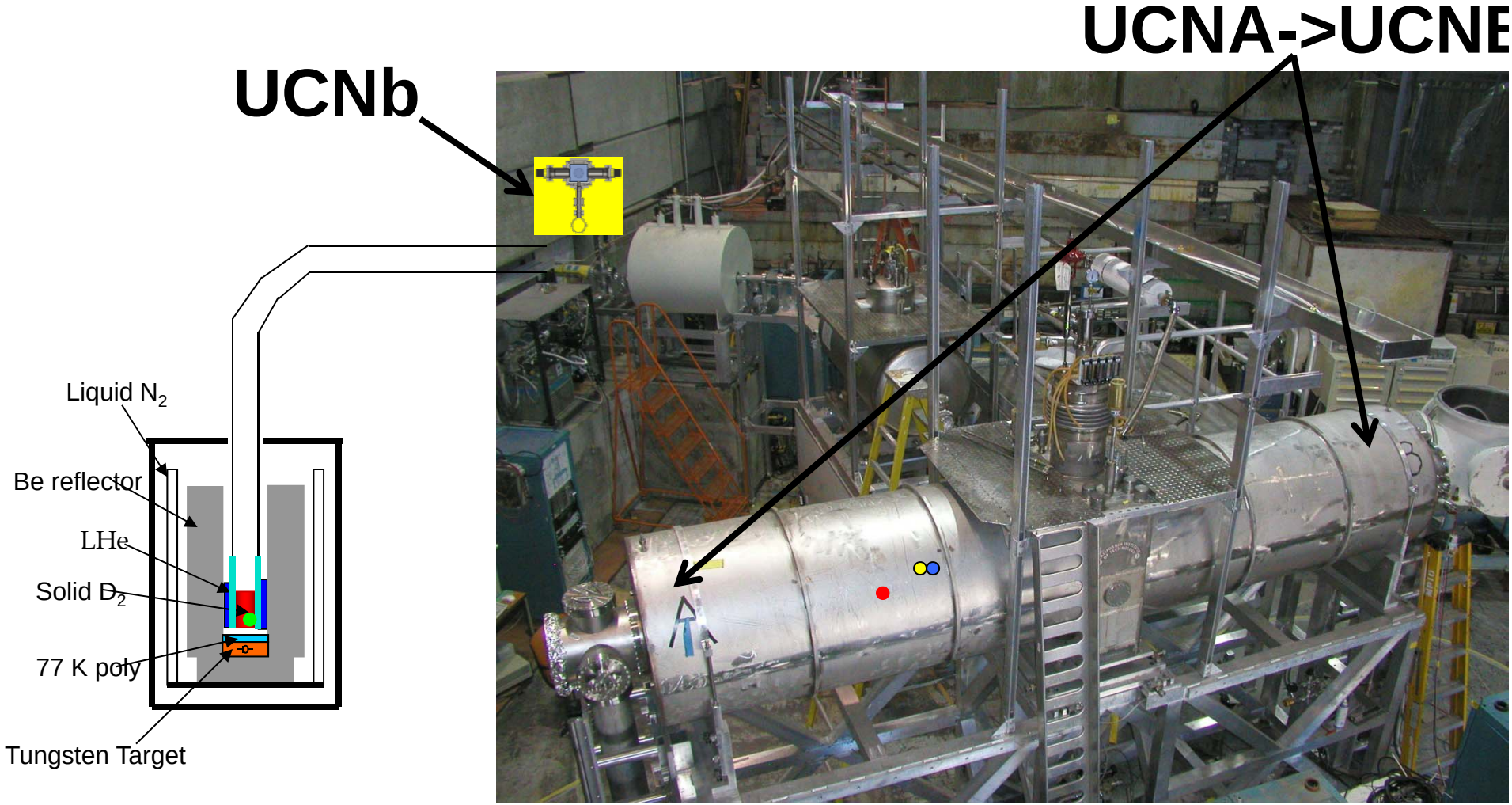
125 KeV data from Caltech e-gun

UCN Hall Layout



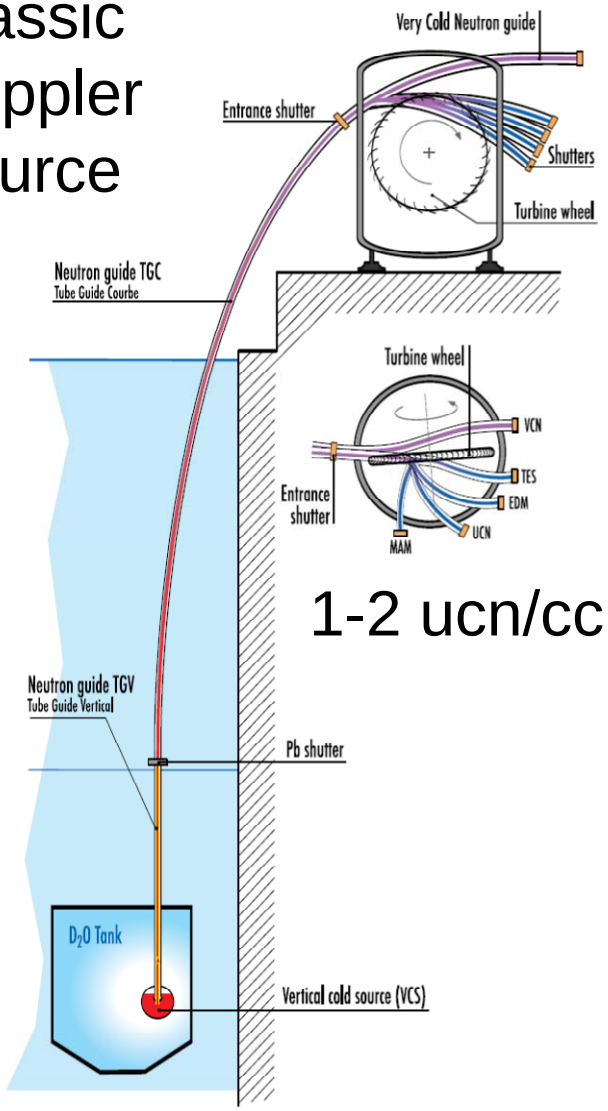
UCNA->UCNb, UCNB

Current facility DOE and NSF funded



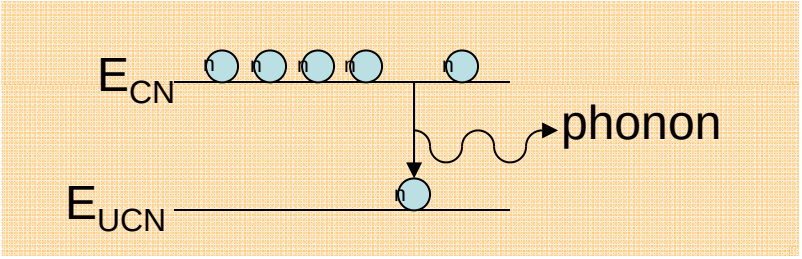
UCN sources, Solid, LHe, Doppler

Classic Doppler Source



1-2 ucn/cc

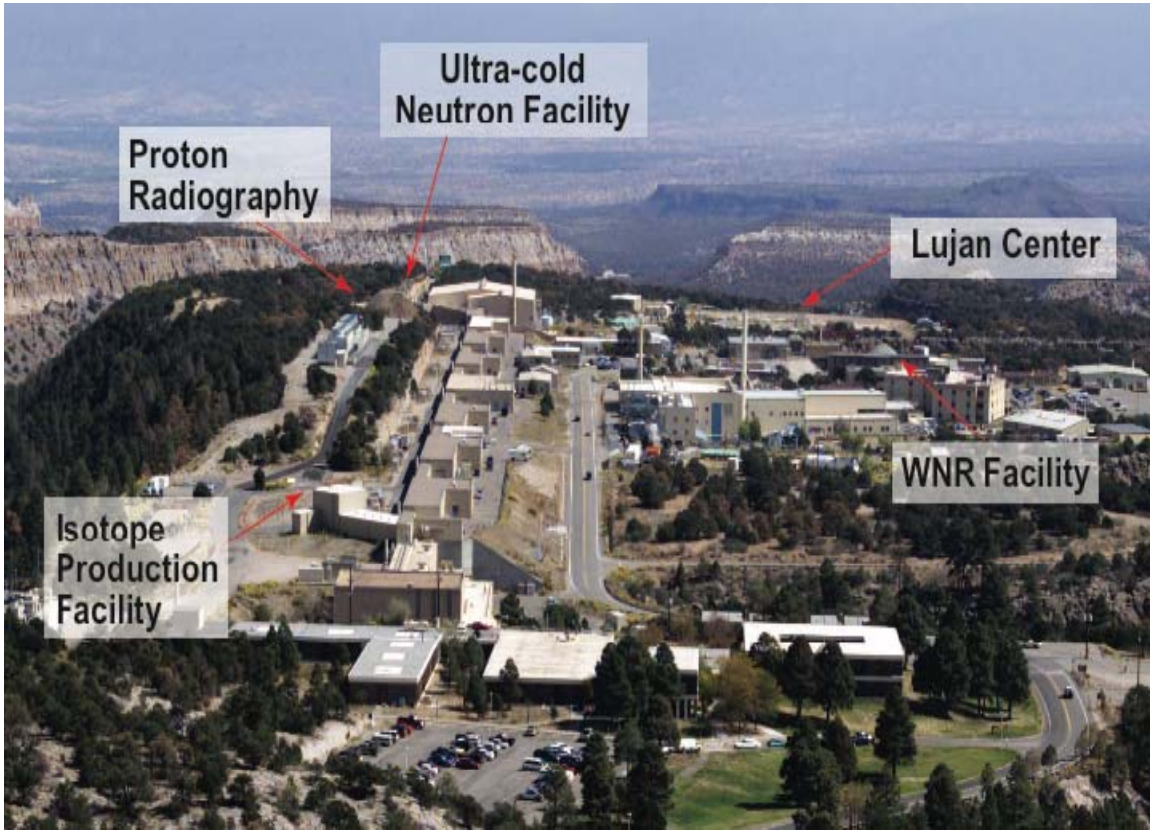
New "Superthermal" UCN sources utilize phonon scattering. Both liquid and solid media are being used.



What makes a good superthermal UCN source?

- Low neutron absorption
- High single phonon energy
  - Light atoms
  - Weak crystal

LANSCE LINAC provides unique, highly-flexible beam delivery to multiple facilities
7 months per yr @ 24/7 with ~1200 user visits



The Los Alamos Neutron Science Center

800 MeV protons, up to 1 mA at 120 Hz and 12% DF

Lujan Center

- *Materials science and condensed matter research*
- *Bio-science*
- *Nuclear physics*
- *BES National User Facility*

WNR

- *Nuclear physics*
- *Semiconductor irradiation*

Proton Radiography

- *HE science, dynamic materials science, hydrodynamics*

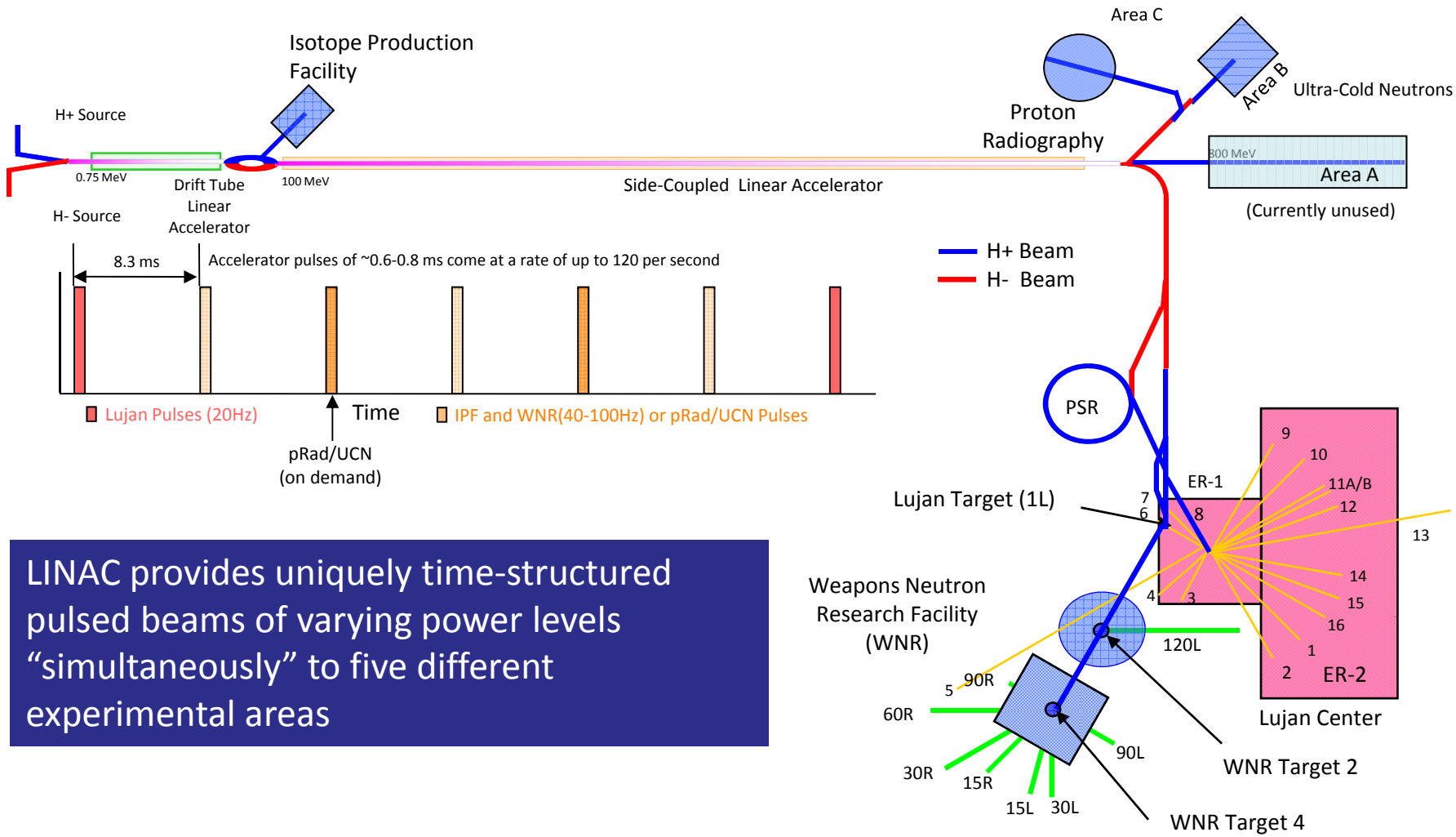
Isotope Production Facility

- *Nuclear medicine*
- *Research isotope production*

Ultracold Neutrons Facility

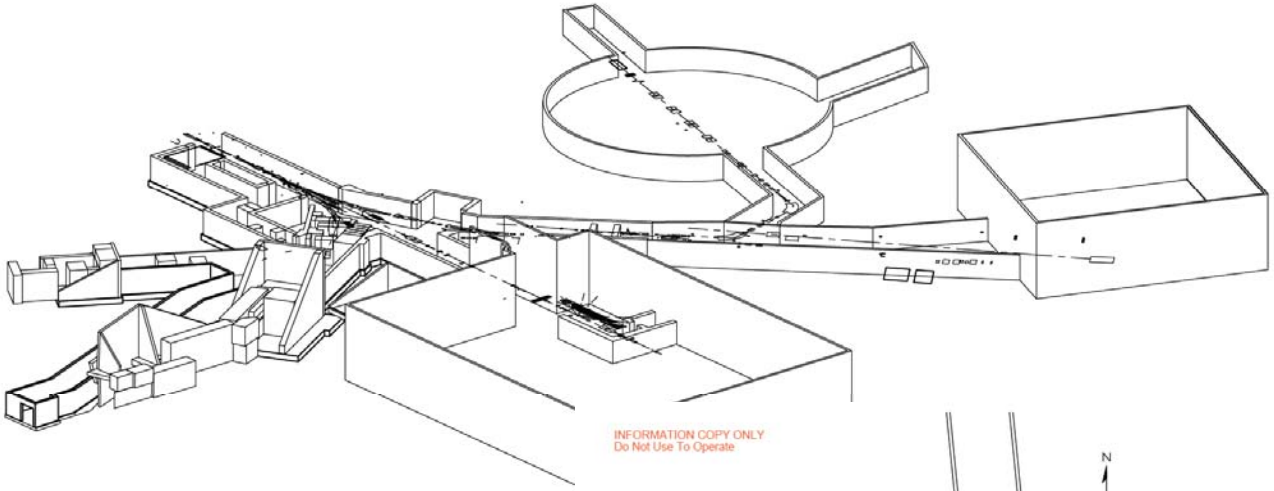
- *Fundamental nuclear physics*

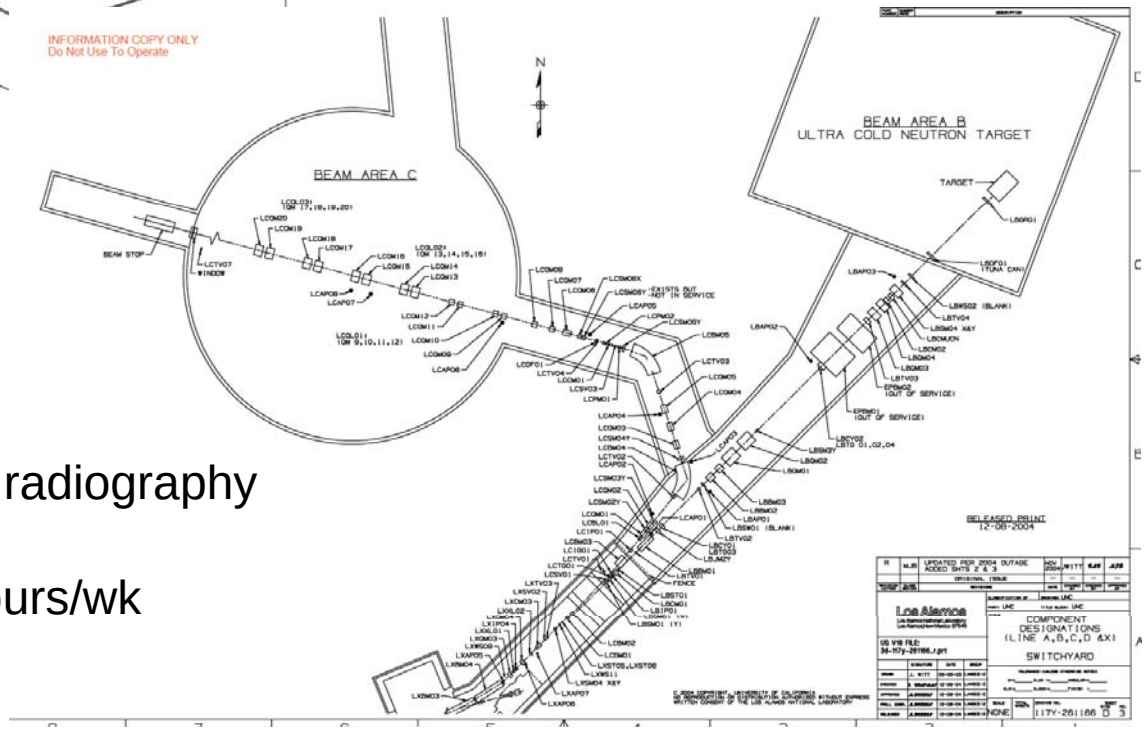
The heart of LANSCE is a very flexible 800-MeV proton linear accelerator (LINAC)--one of the most powerful in the world!



LINAC provides uniquely time-structured pulsed beams of varying power levels "simultaneously" to five different experimental areas

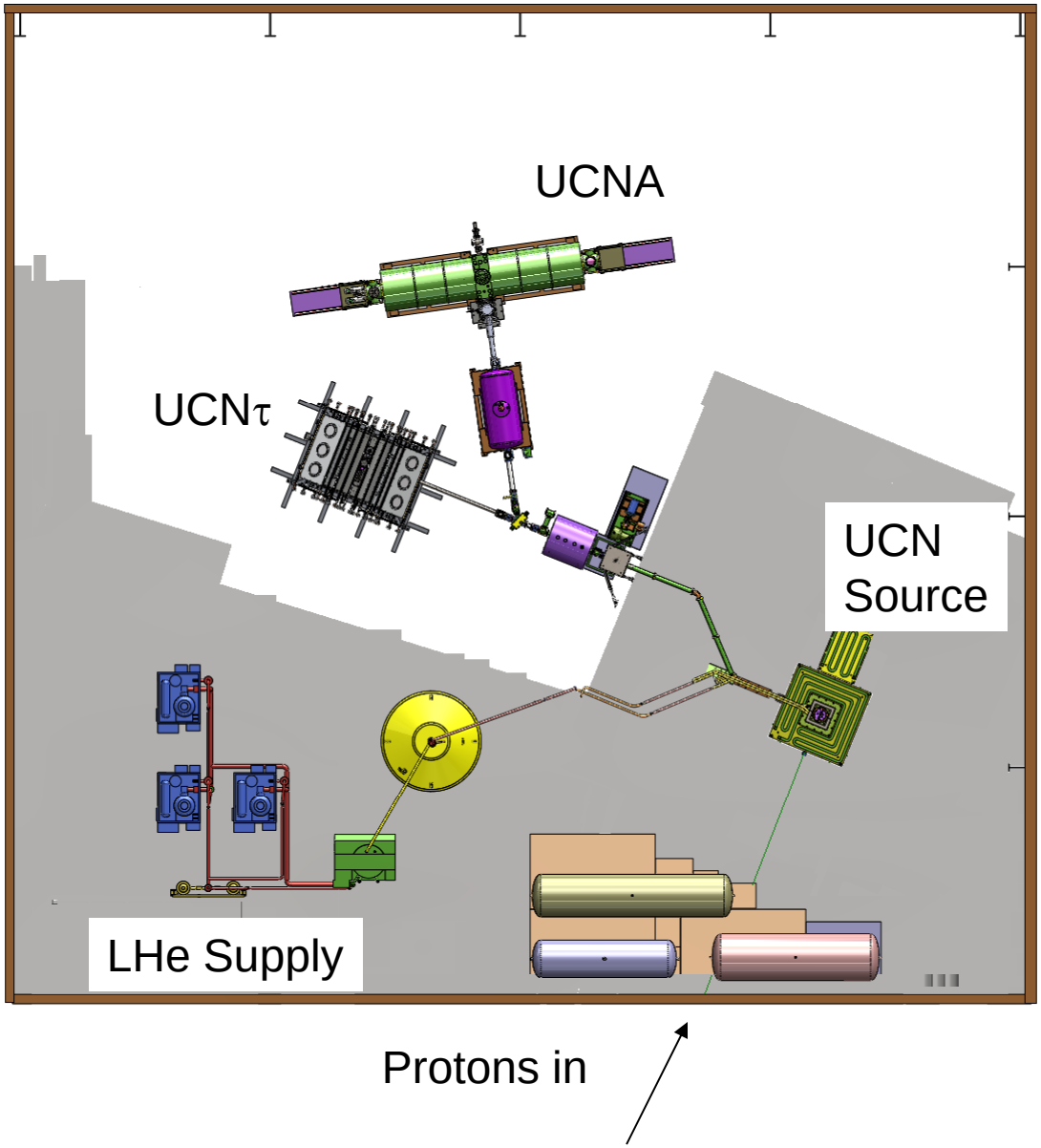
UCN Experiment Hall at LANSCE (Area B)





Dedicated experiment hall
25 x 25 m
Beam line shared with proton radiography
1 hr to switch beams
UCN dedicated beam ~100 hours/wk
(Nights and weekends!)

Top view of experiment hall



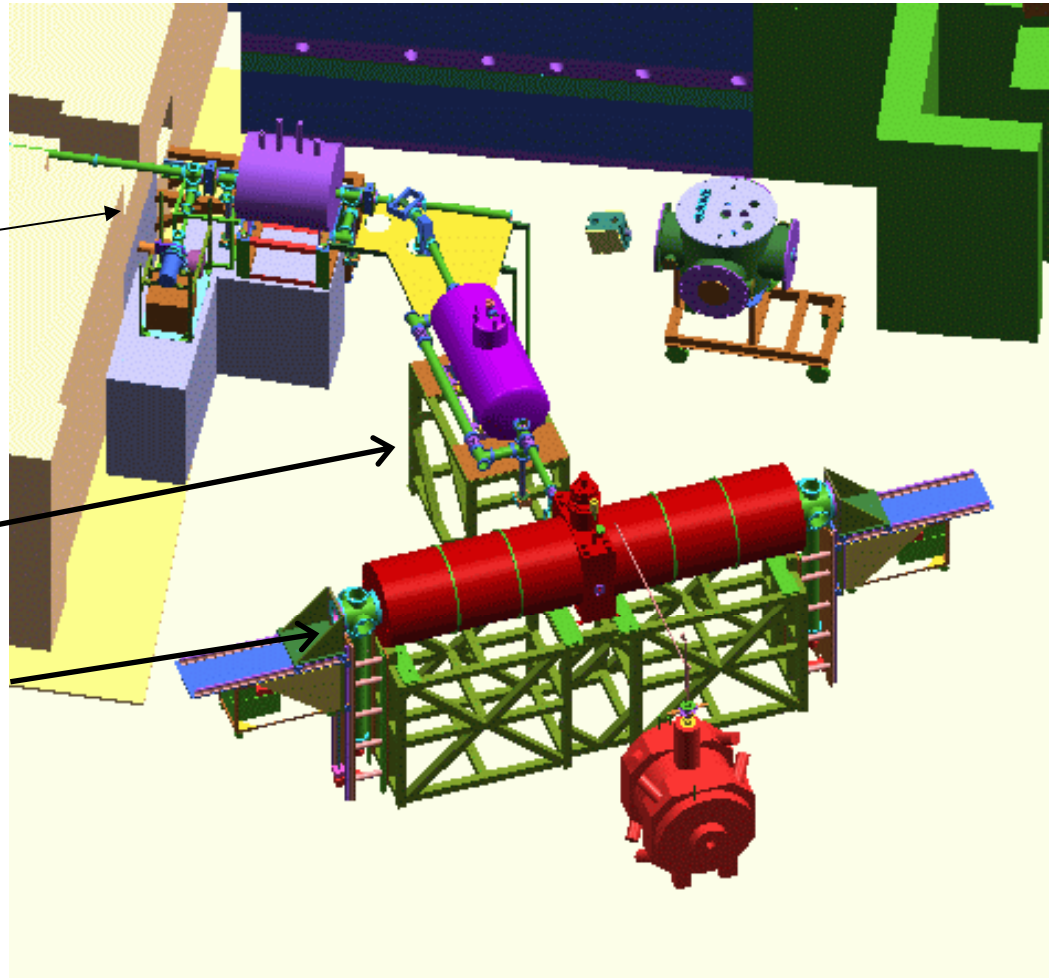
The UCNA Apparatus at LANL

UCN Source

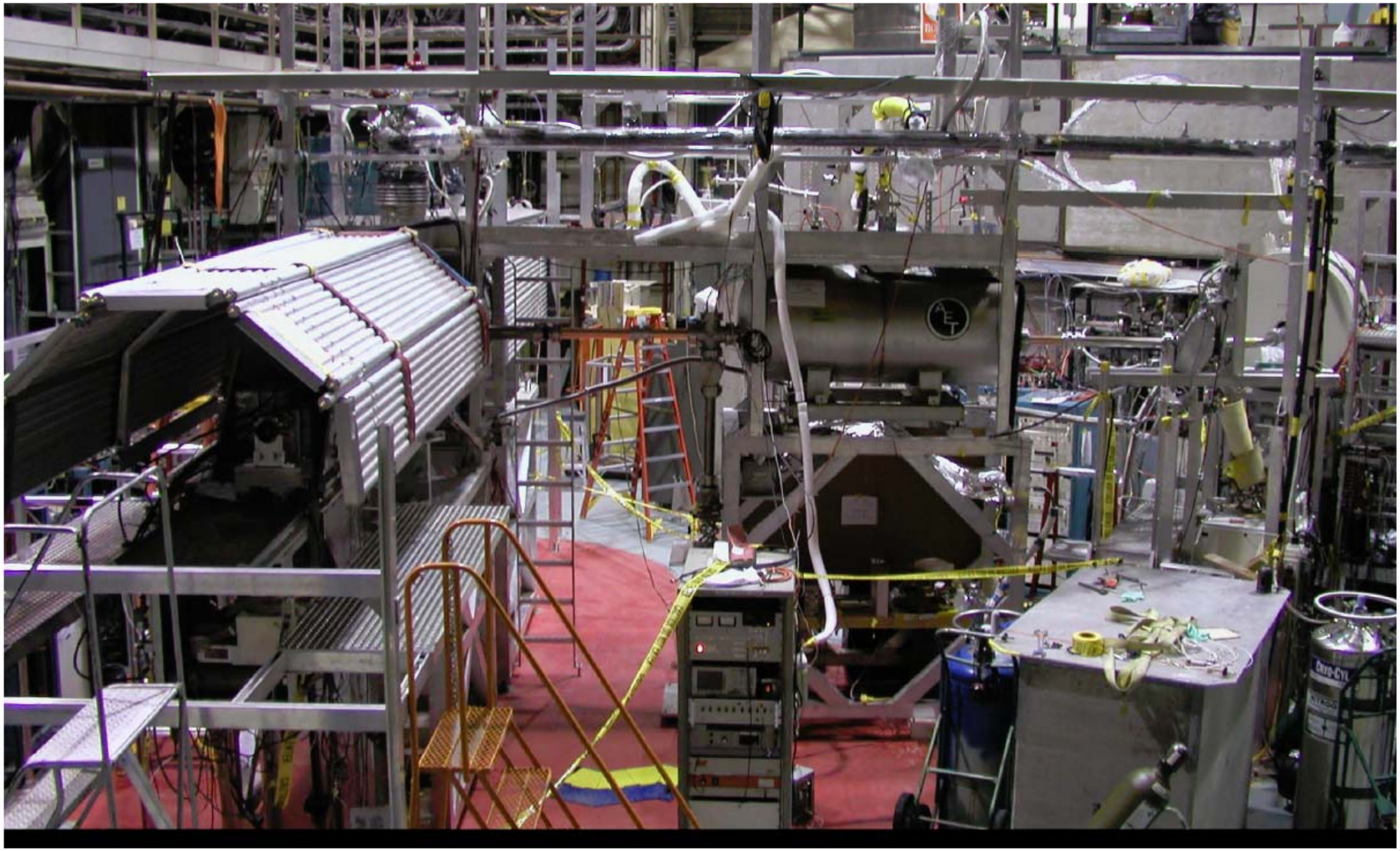
"Prepolarizer" and safety foil

Polarizer magnet and spin flipper

UCNA Spectrometer



UCNA Apparatus in LANSCE Area B

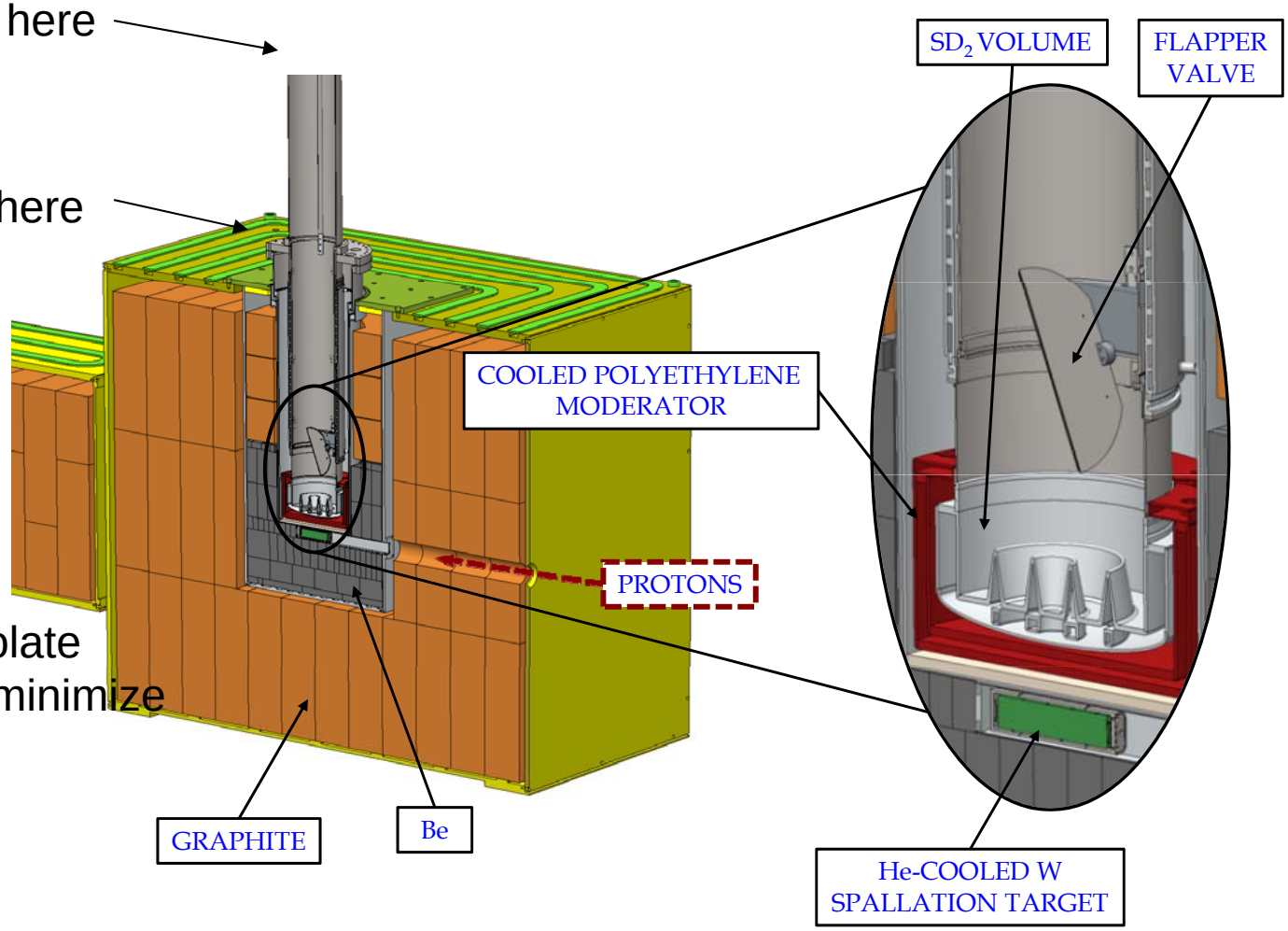


UCN Source Layout

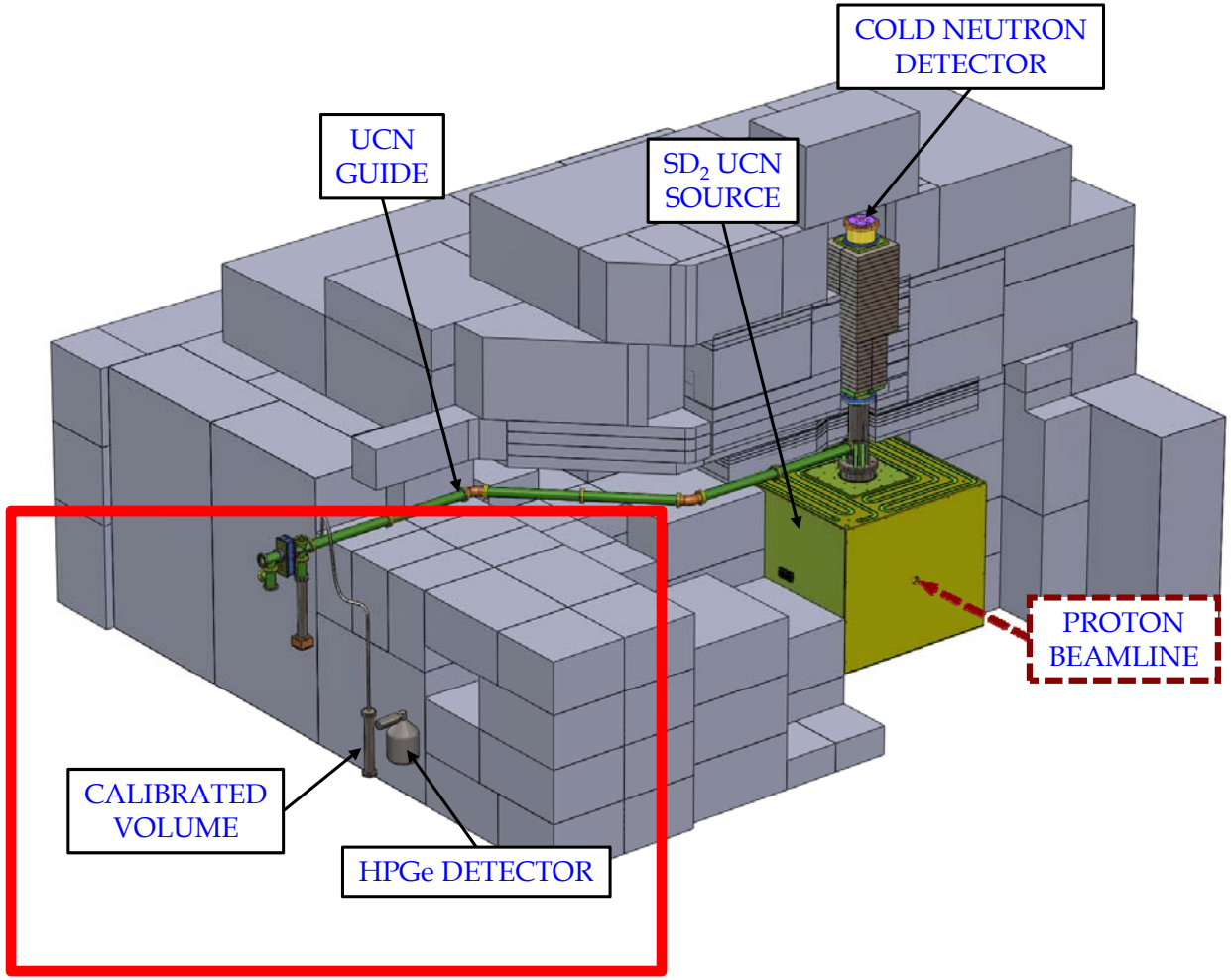
Shield plug starts here

6 m horizontal guide here

W at ~100 C
Be and C at 300 K
CH2 at 40-120 K
Al and Be walls to minimize heating
Coated with 58Ni
Flapper valve to isolate UCN from D2 and minimize radiative heating

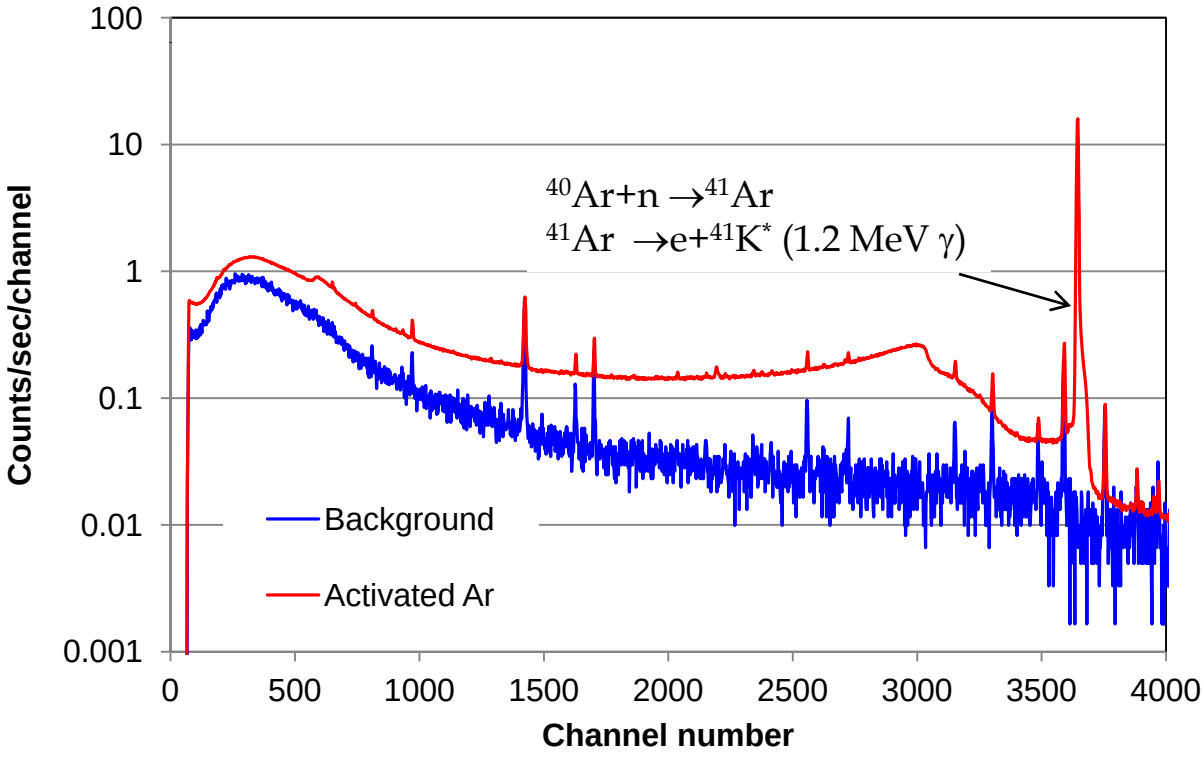


Cold neutron measurements: direct detection and Ar activation

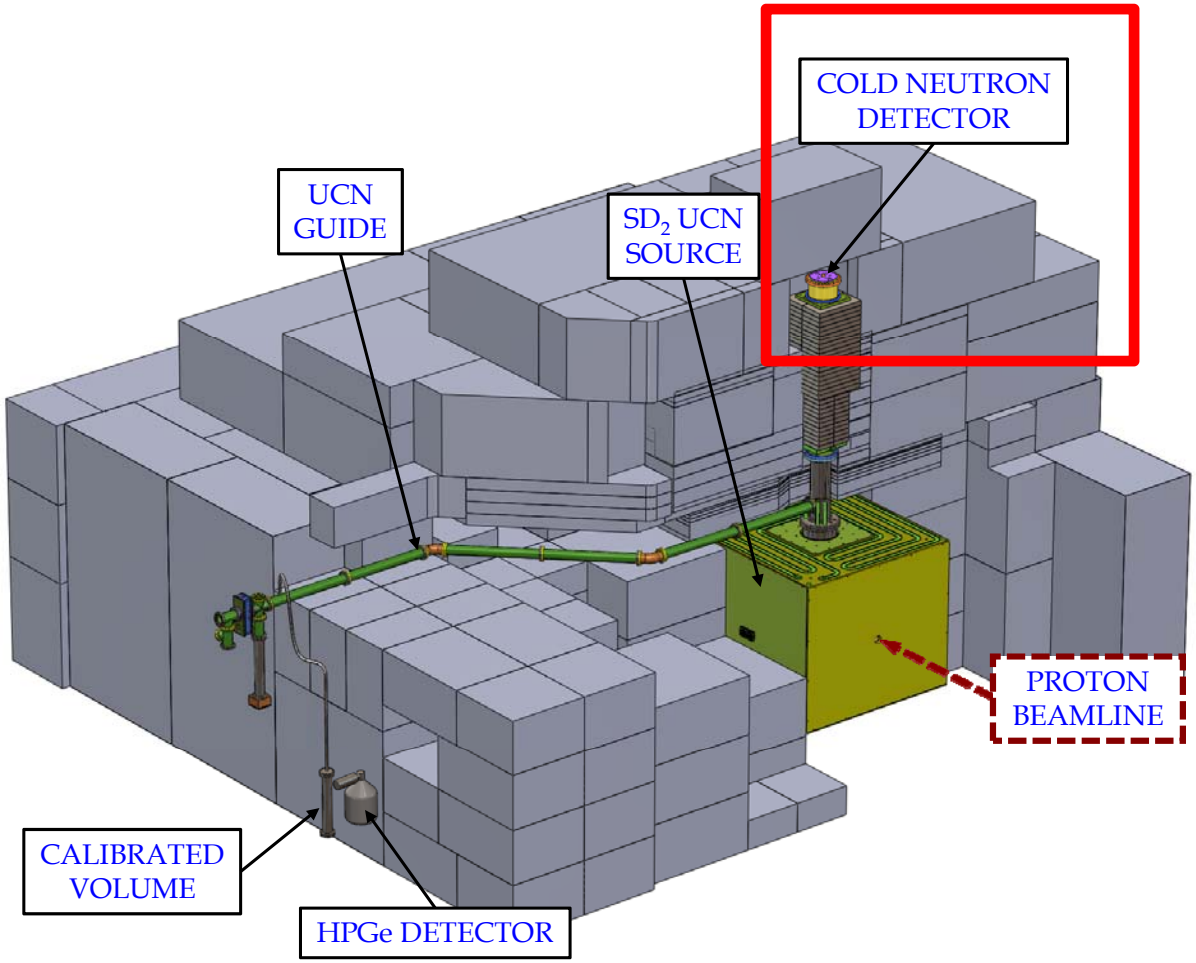


Argon activation cold flux measurements

- Measure background
- Freeze calibrated volume of Ar into cryostat
- Exposed to known proton flux, producing ^{41}Ar
- Boil off into calibrated gas volume
- Count decays with HPGe counter
- Calibrate efficiency and solid angle with ^{60}Co source
- Compare to MCNP prediction
- Extract cold neutron flux: (1.7 +/-0.3)e10 n/cm^2/s/μA (with no deuterium)

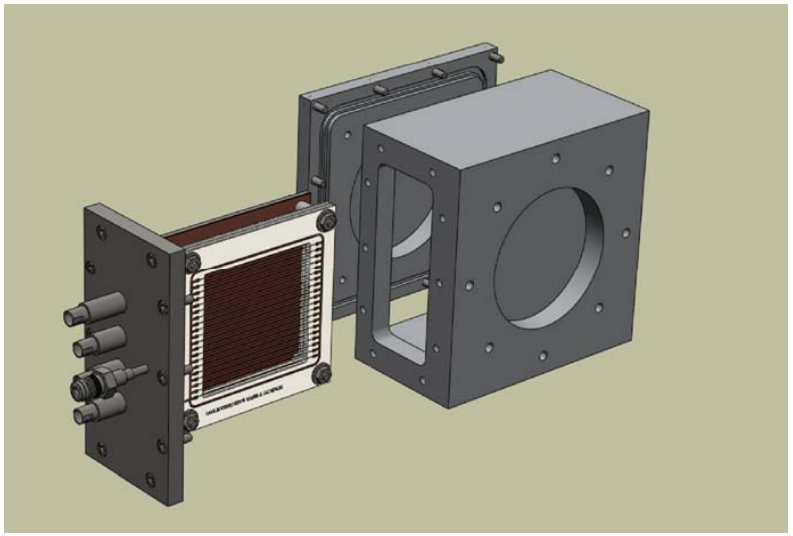


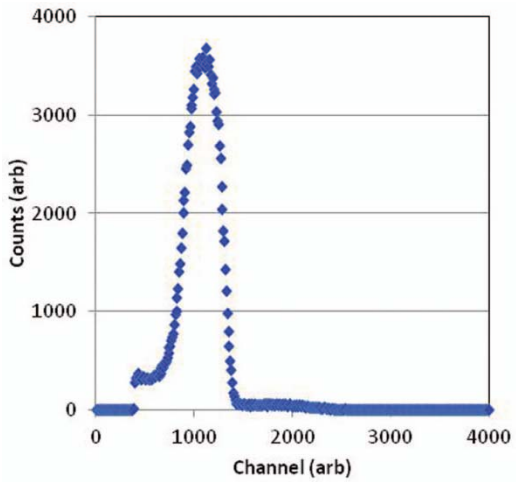
Cold neutron TOF measurement

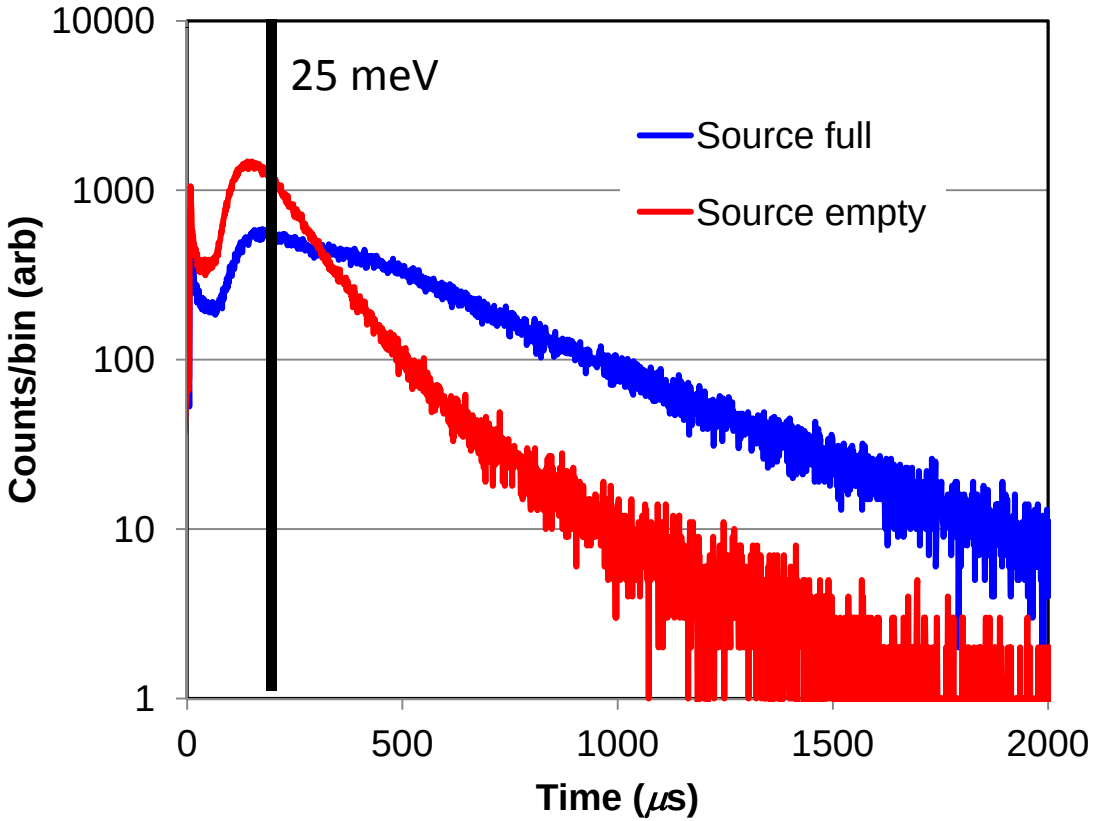


Cold neutron TOF measurement

- Cold neutrons detected after 3.6 m vertical flight through 2 cm diameter hole in shield package
- 1 proton pulse per second, 1.4e10 protons per 250 ns pulse
- Compare to MCNP prediction: 1.56e5 n/μC detected vs 1.70e5 predicted (full); 0.75e5 n/μC detected vs 0.86e5 predicted (empty) (< 25 meV)

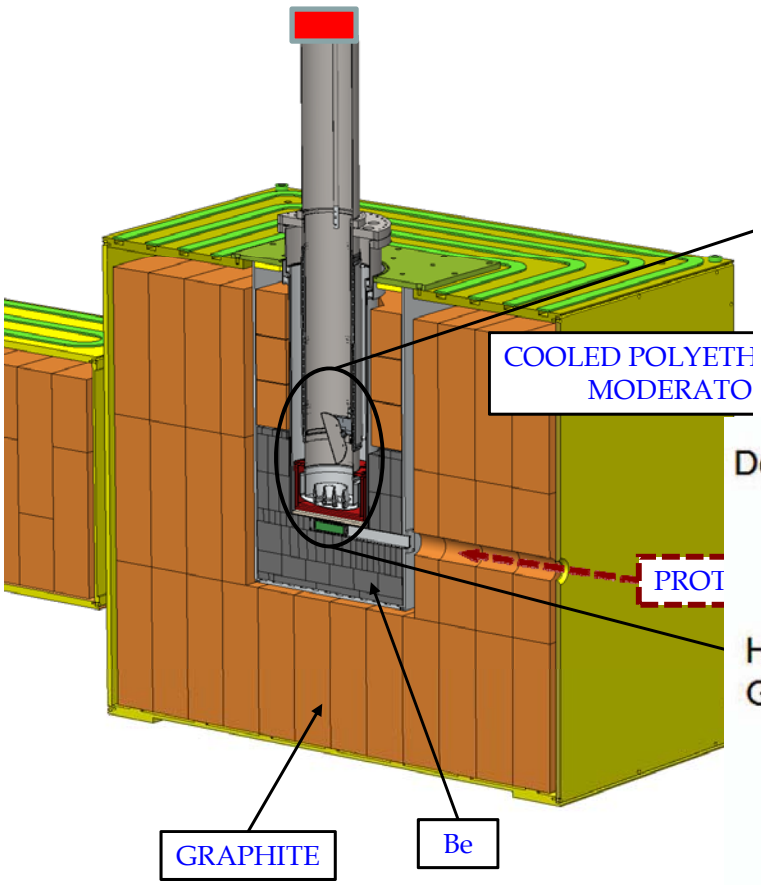




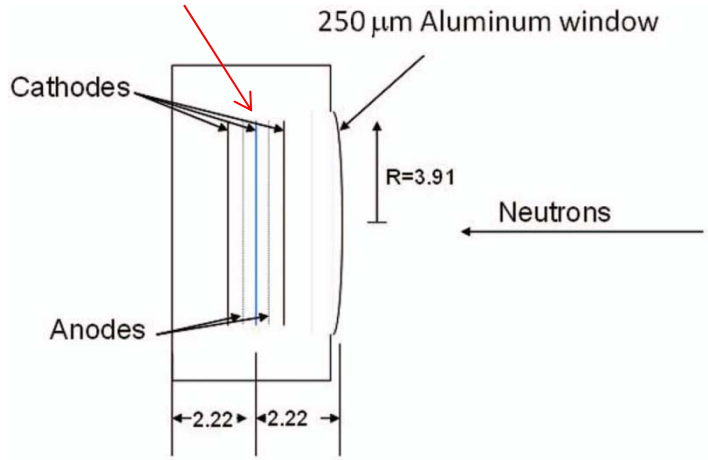


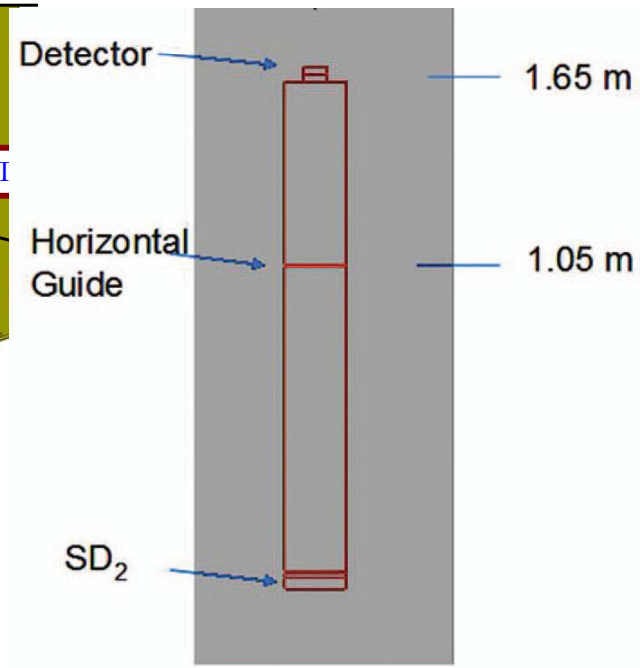
Internal UCN Measurements

UCN Detector



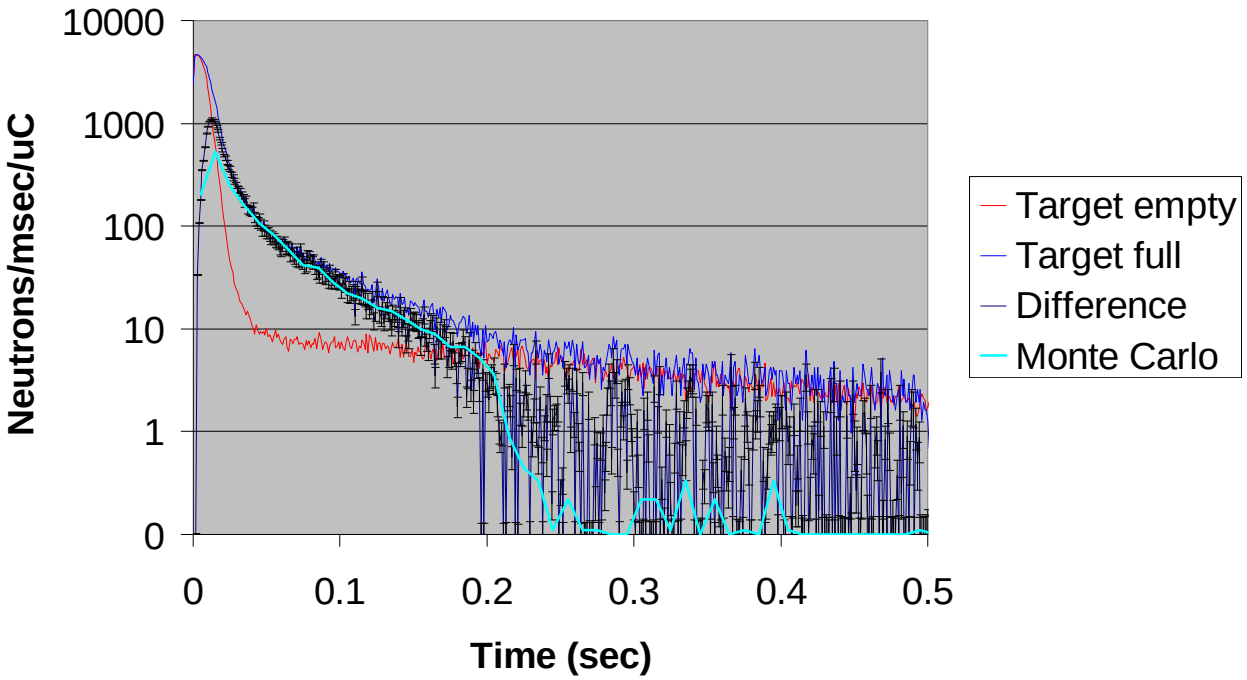
Natural Ni Foil



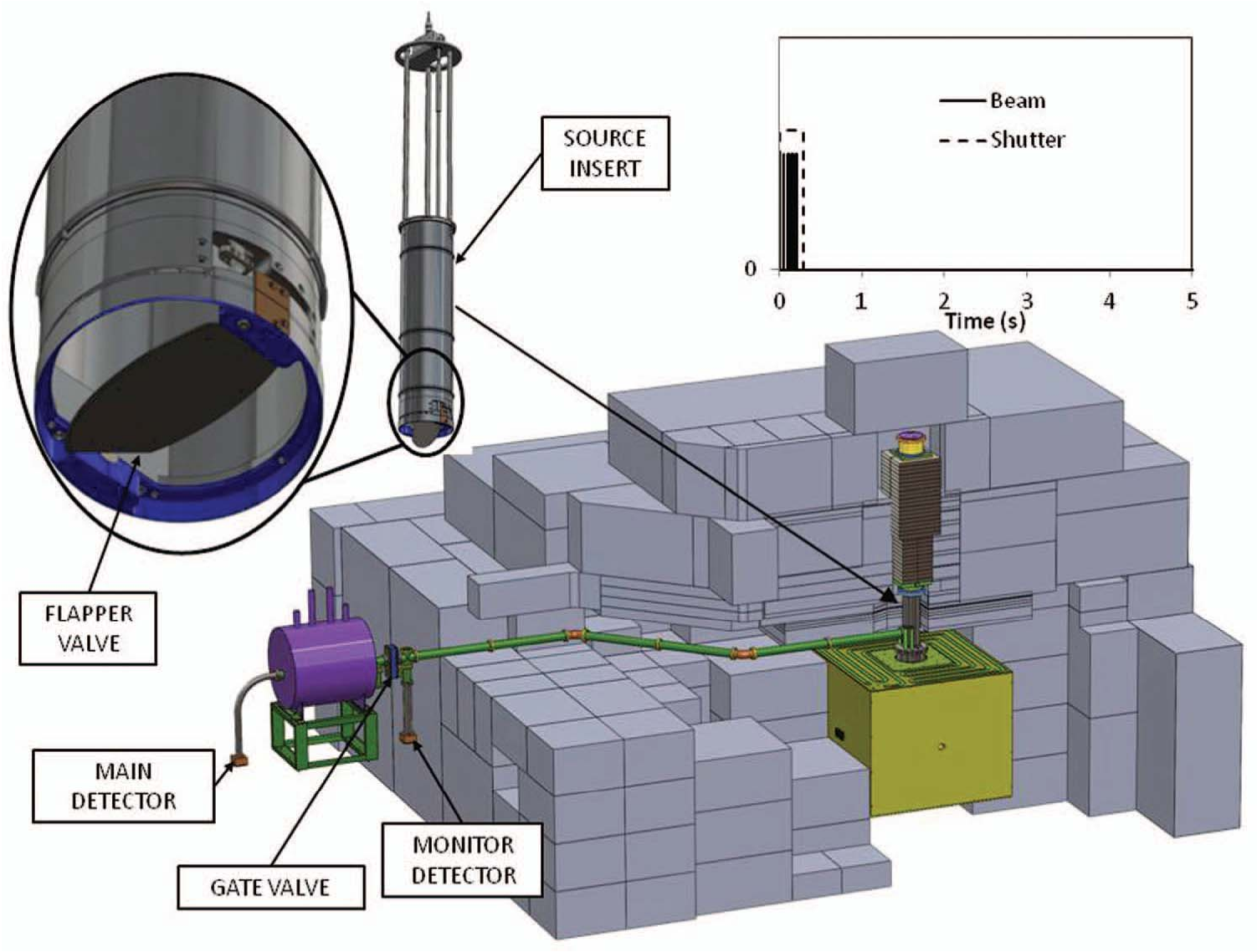


Internal UCN Measurements

- Cut off in MC corresponds to height + Al potential – D2 potential
- UCN transport using custom MC: track back to UCN density in D2 of 85(10) UCN/μC/cm^3
- Use measured CN density + Atchison production cross sections: 107(20) UCN/μC/cm^3
- Compare to prototype:
- 460(90) UCN/μC/cm^3
- @6 μA: 3000 UCN/cm^3

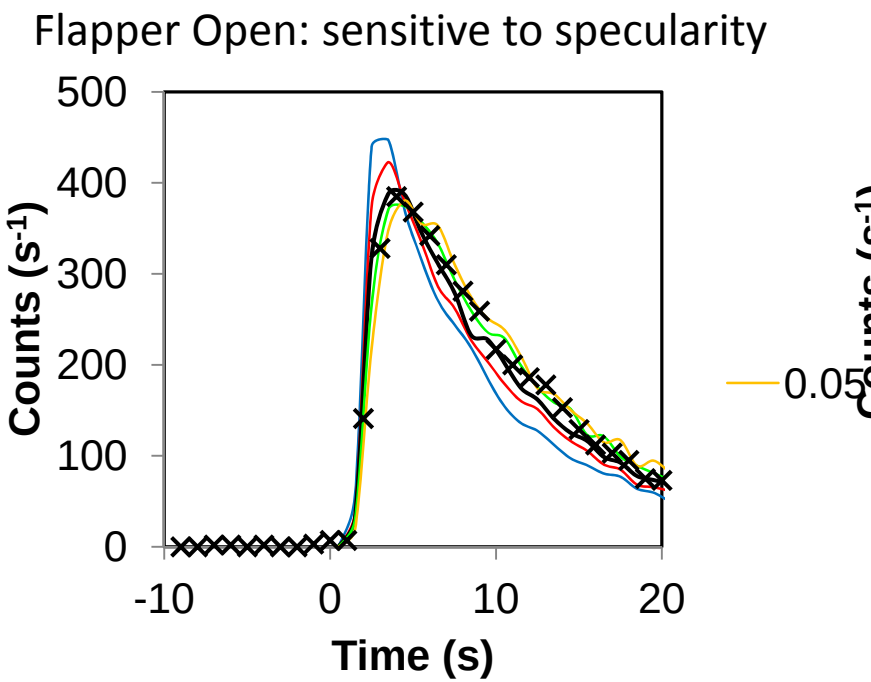


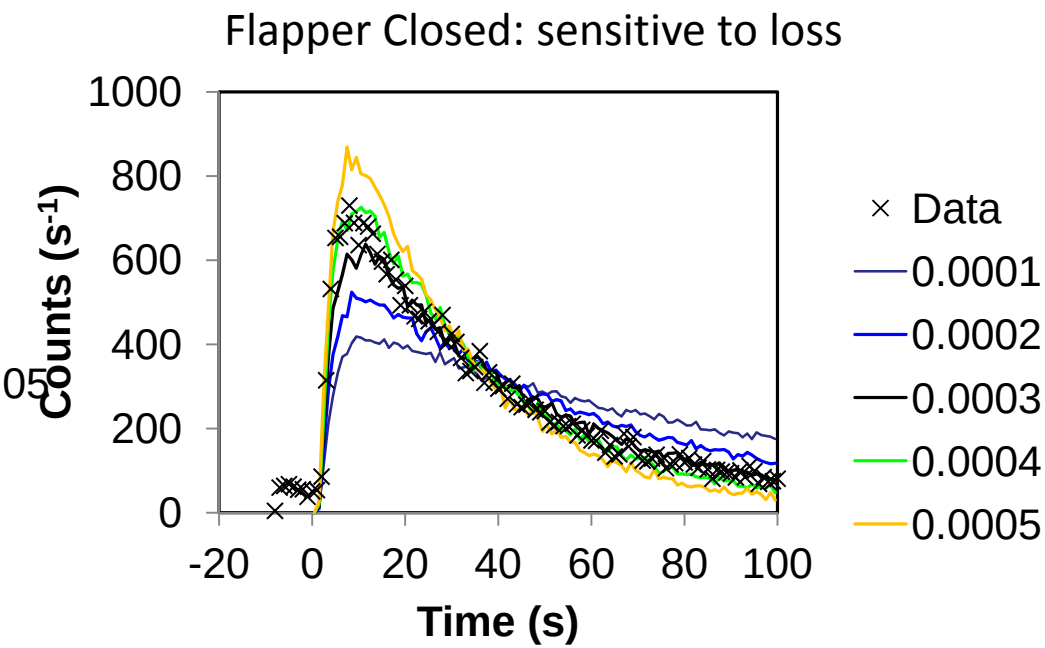
External UCN Measurements: Transport thru shield stack



System lifetime measurements

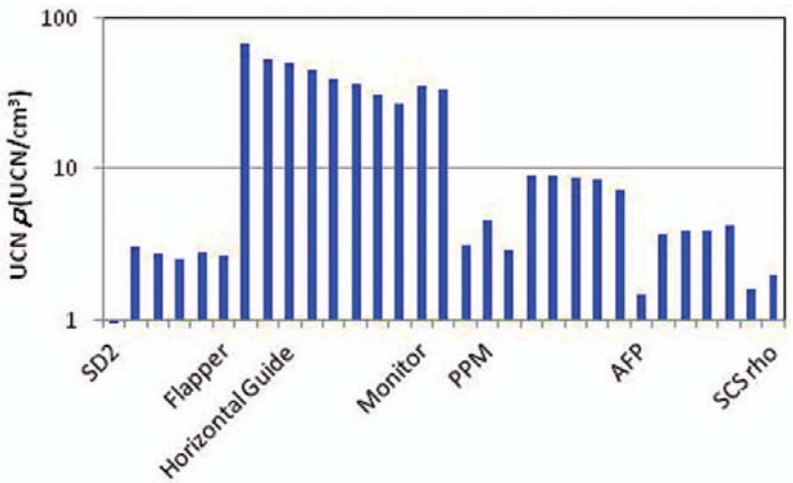
- Simulate transport of UCN through shield wall, detect with GV monitor, Gate valve closed
- Vary specularity and loss per bounce to match measured distributions
- ~10 cm diameter SS guides, butted joints, ~6 m total length to gate valve
- Measure lifetime with flapper open (D2 exposed) and closed (D2 hidden)
- Monitor detector port not well modeled: check normalization with main detector

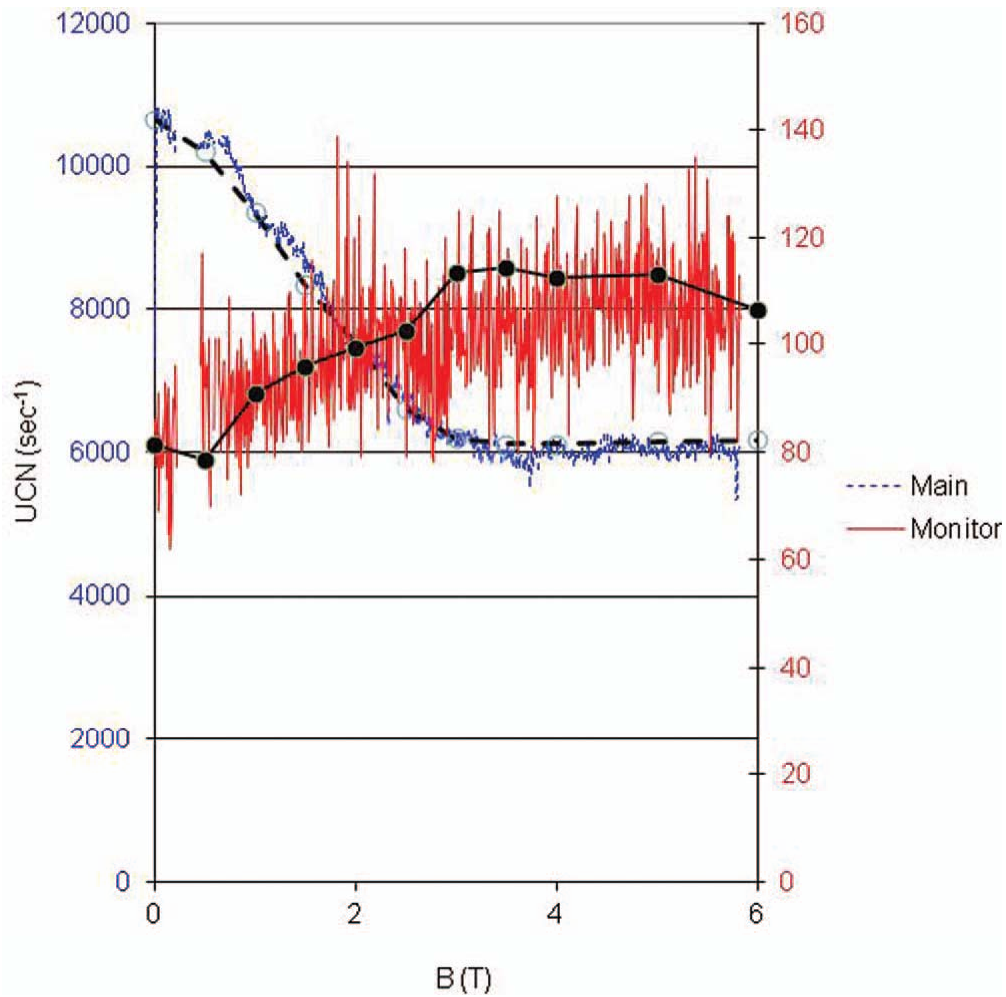




External UCN Measurements: Confirmation of monitor normalization

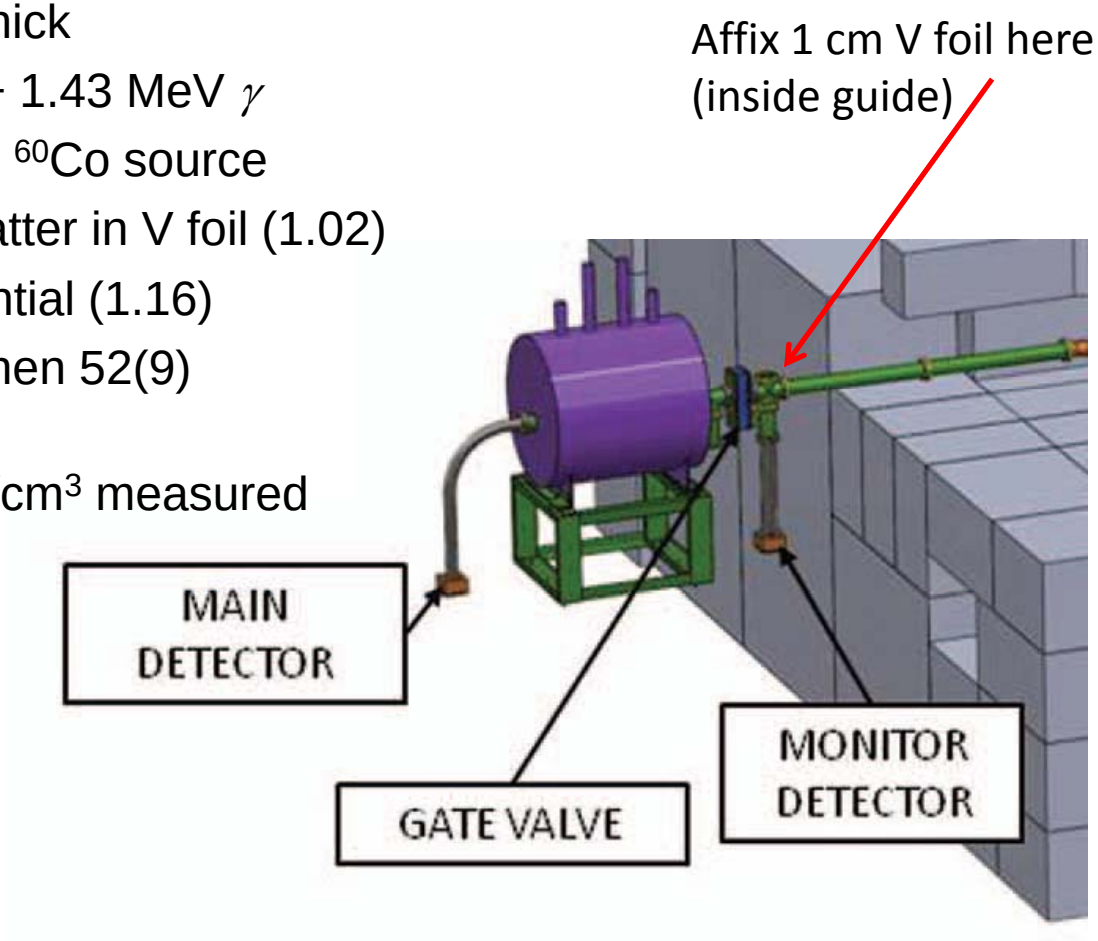
- Main vs monitor comparison checks modeling of monitor port
- Varying magnetic field also allows extraction of UCN velocity distribution
- Calibrated MC allows prediction of UCN density throughout system
- Track back to density in D2: 60(12) UCN/μC/cm^3
- UCN density at monitor port @6 μA: 79(16) UCN/cm^3



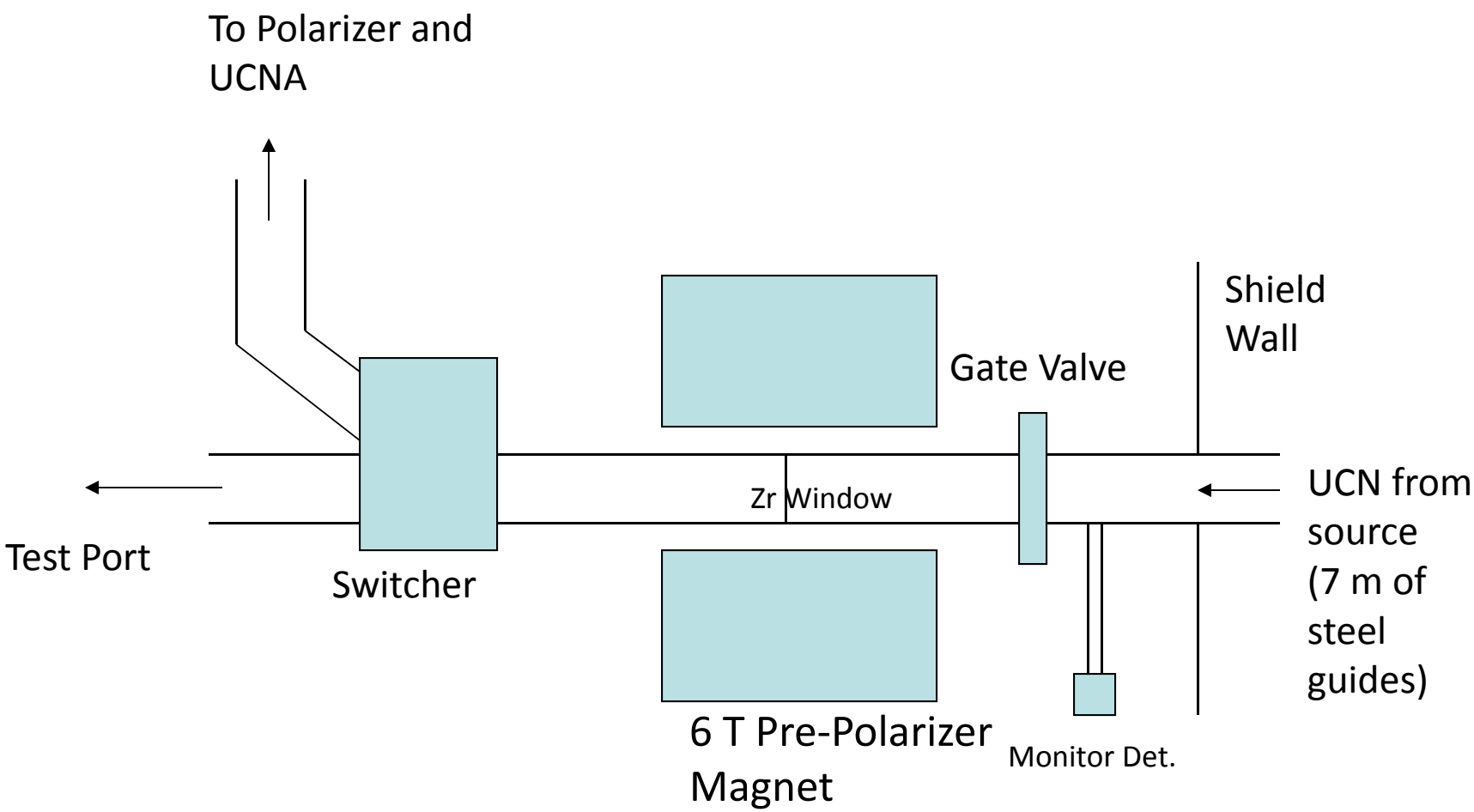


Direct Measurement of UCN density at Shield Exit

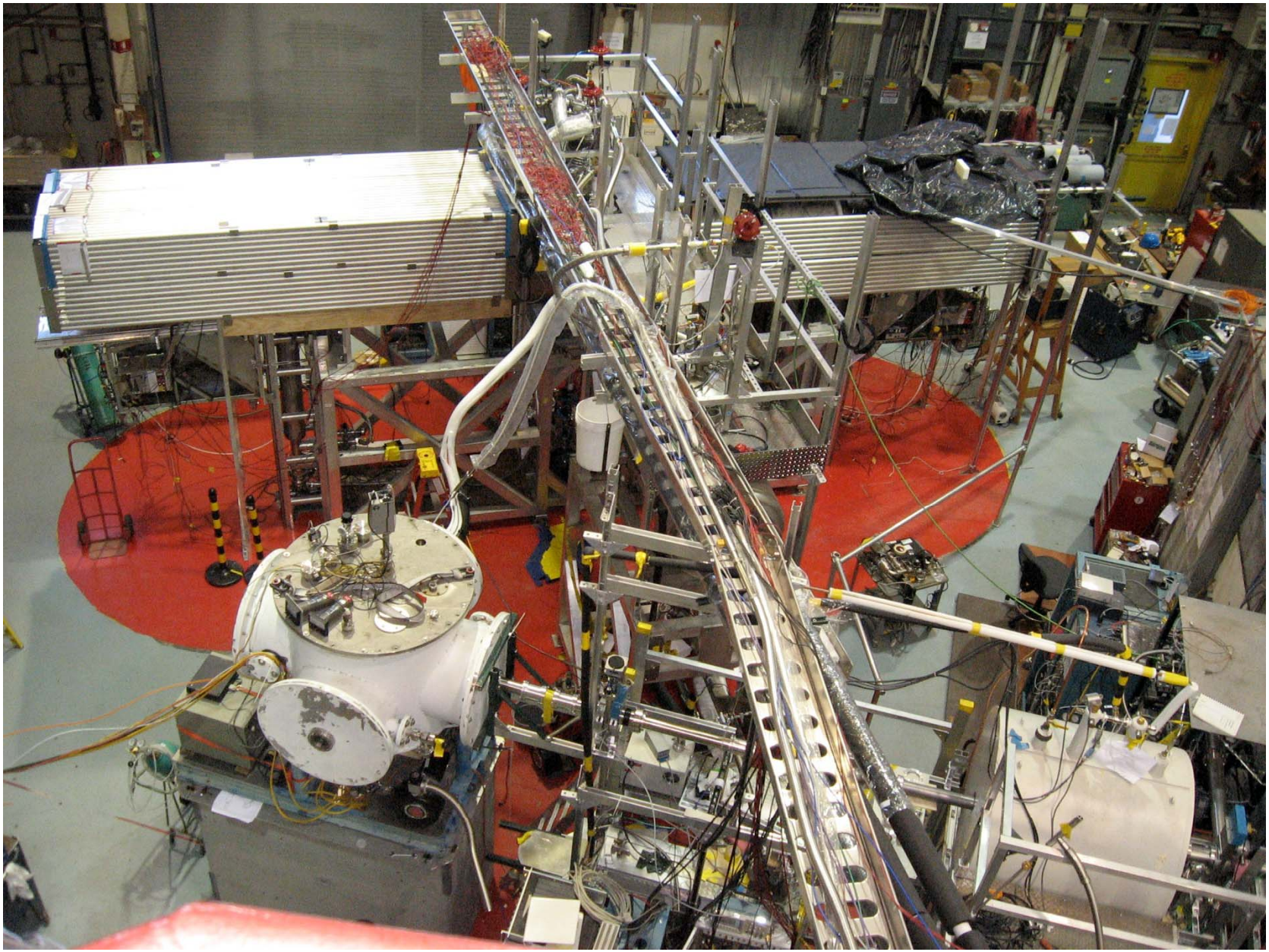
- Direct measurement of UCN density using V foil
- 1 cm diameter, 250 μm thick
- $^{51}V + n \rightarrow {}^{52}V \rightarrow {}^{52}Cr + \beta + 1.43\ MeV\ \gamma$
- Calibrate solid angle with ^{60}Co source
- Correct for thermal upscatter in V foil (1.02)
- Correct for V oxide potential (1.16)
- UCN density @ 6 μA is then 52(9) UCN/cm^3
- Compare to 79(16) UCN/cm^3 measured indirectly



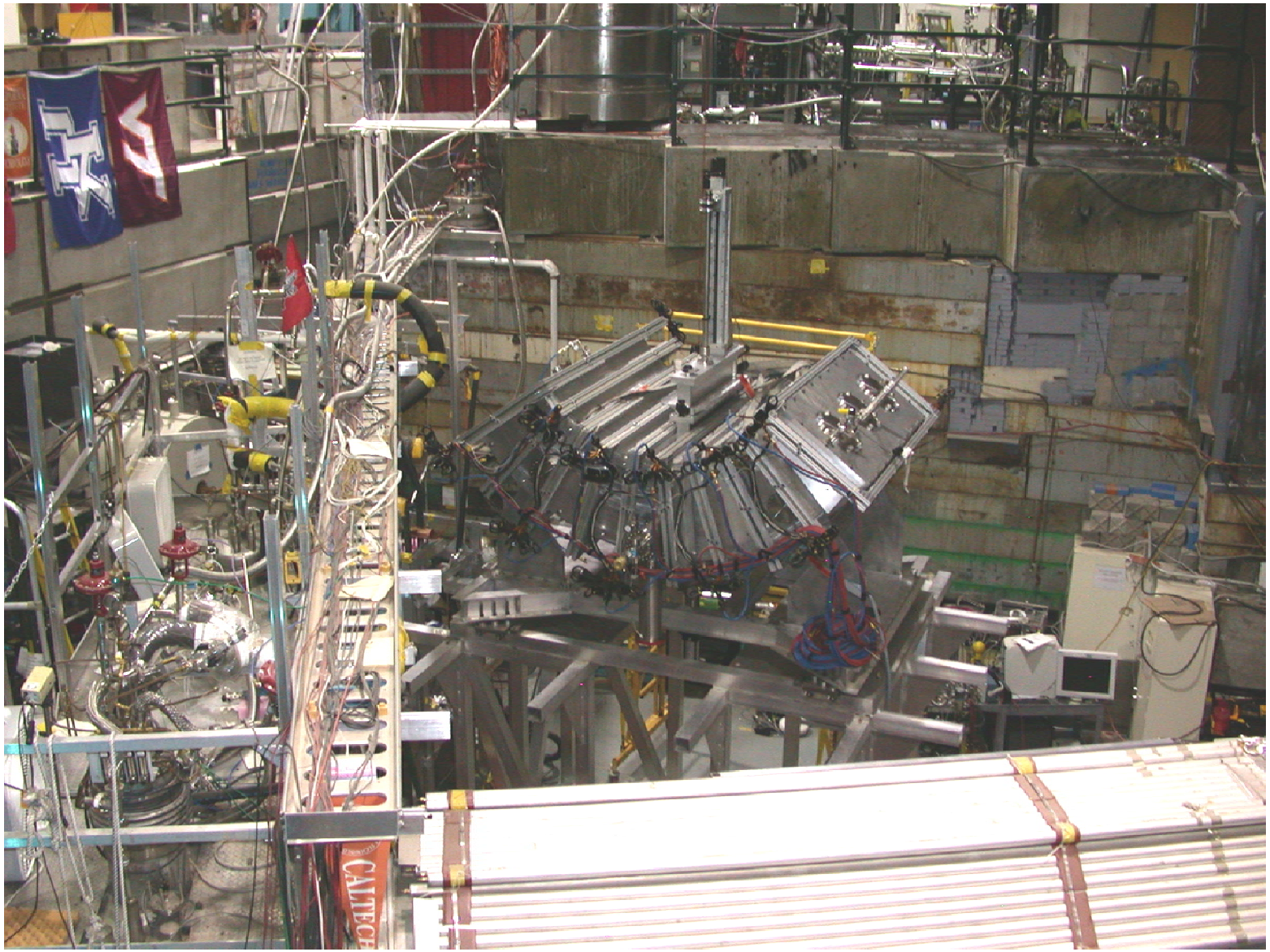
Layout of Test Port Area



User Experiment location in LANSCE Area B



Neutron Lifetime Experiment on Test Port



The Bottom Line

- Source and Test Port are available and running now
- Parameters:
  - LANSCE runs 7 months/year
  - Proton beam is shared with PRAD
    - available ~100 hrs/wk while accelerator is on
  - UCN source is shared with UCNA
    - Test port beam can be on 10 minutes per hour while UCNA runs
  - ~25 UCN/cc at Test Port (after PPM), 52 at shield wall, up to 180 neV (at 5 kW incident proton power)
  - UCNs at Test Port are polarized to be high-field seekers
  - Backgrounds outside of beam gate are largely natural
    - Beam gate is 0.2 s per 5 s
- Allocation by UCNA Executive Committee for now
  - But we hope for a PAC process soon

Future Improvements???

- Improved proton beam tune
  - x ~2
  - Requires 0.2 M$ for new beam pipe and diagnostics
- Beam pattern: spread out pulses
  - x ~2
  - Requires 0.5 M$ for safety equipment
- Lower loss, higher V guides
  - x ~3
  - Requires 0.3 M$ and six months to replace guides
- Duty factor: kick beam to pRad
  - x ~2
  - Requires 3 M$ for kicker and shield wall

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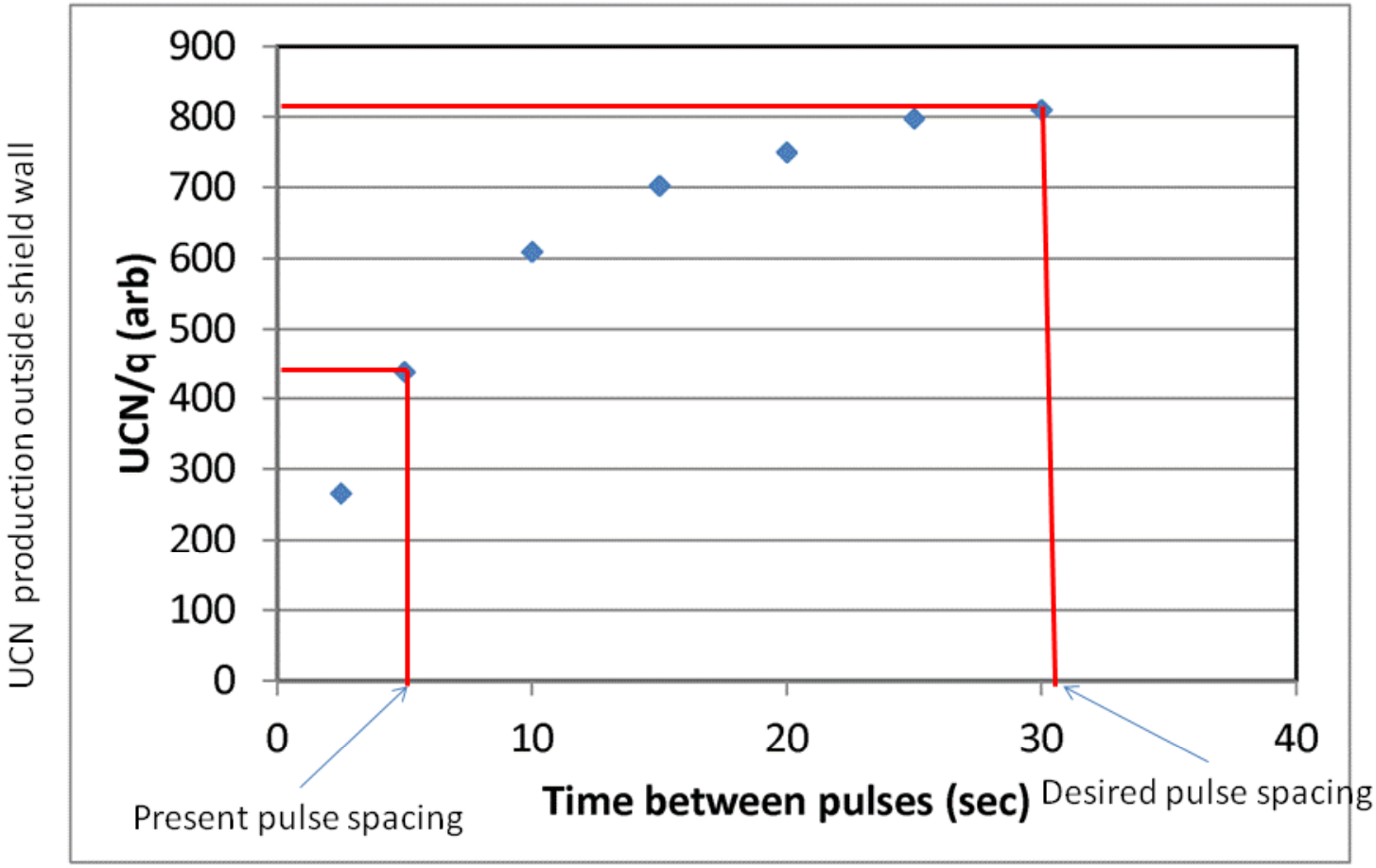
UCN Production Improvement by Spreading out Beam pulses



- Data taken in August, 2012, at low current
- Matching pulse spacing to lifetime above flapper optimizes UCN production at equal average current
- Present spacing limited by beamline current limiting devices (hardware), not by safety requirements

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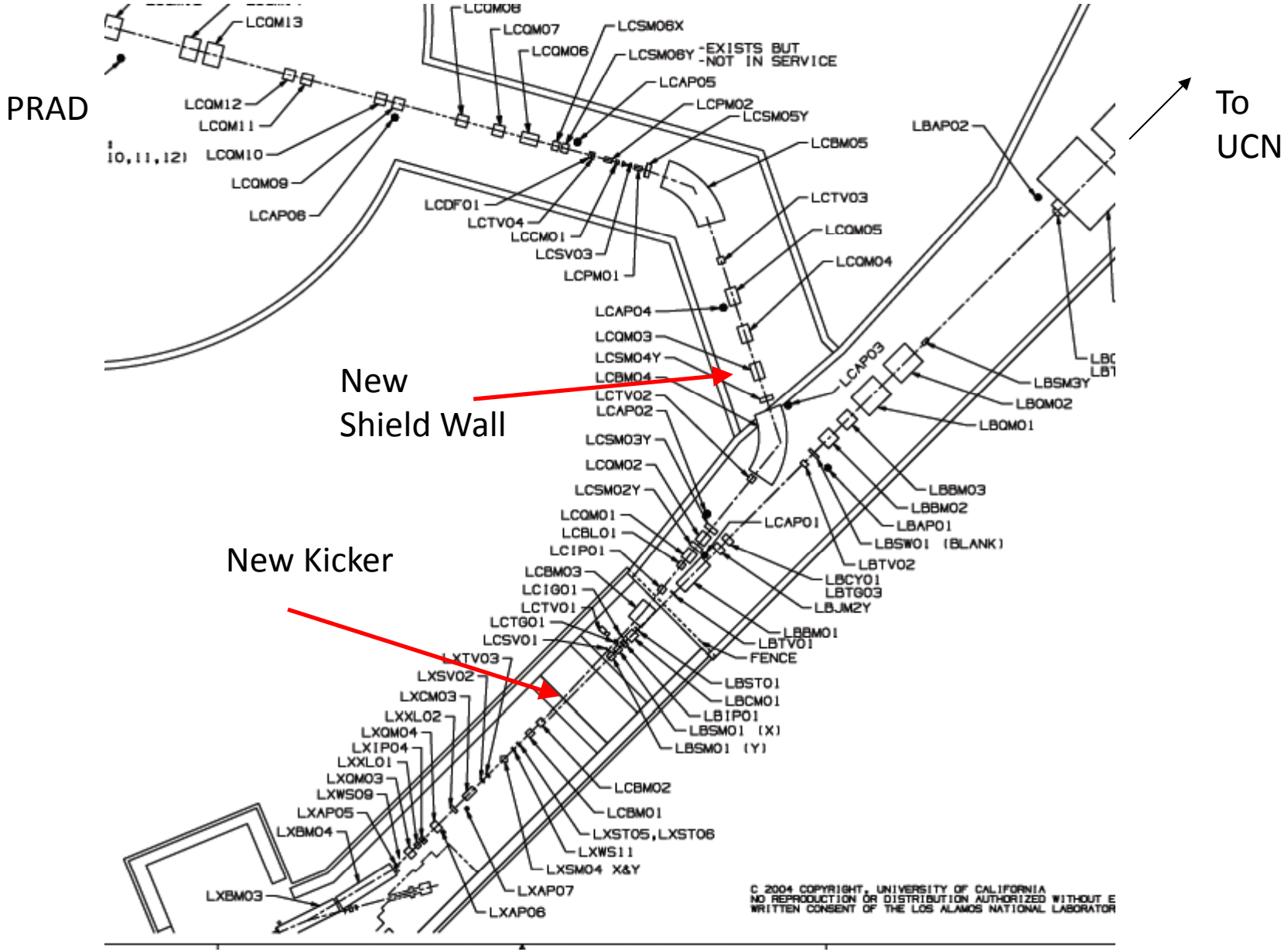
- Duty factor: kick beam to pRad
  - x ~2
  - Requires 3 M$ for kicker and shield wall
  - Wall alone increases time available to UCN by ~20%
  - Kicker in addition increases time by 100%


PRAD
To UCN
New Shield Wall
New Kicker
LCQM13
LCQM12
LCQM11
LCQM10
LCQM09
LCAP08
LCQM08
LCQM07
LCQM06
LCSM06X
LCSM06Y -EXISTS BUT -NOT IN SERVICE
LCAP05
LCPM02
LCSM05Y
LCBM05
LCTV03
LCQM05
LCQM04
LCDF01
LCTV04
LCCM01
LCSV03
LCPM01
LCAP04
LCQM03
LCSM04Y
LCBM04
LCTV02
LCAP02
LCSM03Y
LCQM02
LCSM02Y
LCQM01
LCBL01
LCIP01
LCBM03
LCIG01
LCTV01
LCTG01
LCSV01
LXTV03
LXSV02
LXCM03
LXXL02
LXQM04
LXIP04
LXXL01
LXQM03
LXWS09
LXAP05
LXBM04
LXBM03
LCAP03
LCAP01
LBAP02
LBSM3Y
LBQM02
LBQM01
LBBM03
LBBM02
LBAP01
LBSW01 (BLANK)
LBTV02
LBCY01
LBTG03
LBJM2Y
LBBM01
LBTV01
FENCE
LBST01
LBCM01
LBIP01
LBSM01 (X)
LBSM01 (Y)
LCBM02
LCBM01
LXST05,LXST06
LXWS11
LXSM04 X&Y
LXAP07
LXAP06
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Conclusions

- Full suite of neutron beta decay experiments at Los Alamos
- UCNs give unique advantages
- UCNA producing competitive results
  - Will eventually reach ~0.2%
- UCNτ will start acquiring data soon
- UCNB will probe new territory
- LANSCE UCN Source is in production
  - Supplying beam to UCNA, nEDM, UCNτ, UCNb
- Source performance has been measured and modeled
  - CN and UCN measurements match MC predictions
- Incremental improvements are still possible
- Technology is not near fundamental limits