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*Title:* Neutron lifetime experiment at LANL

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Form 836 (7/06)

Neutron Lifetime Experiment at LANL

A proposal will be presented for a new experiment, which has been developed with Los Alamos National Laboratory LDRD funding, to measure the neutron lifetime using ultracold neutrons in a magneto-gravitational trap. In the proposed experiment, an asymmetric bowl-shaped Halbach array of permanent magnets provides the levitating and laterally confining magnetic field for ultracold neutrons produced by the Los Alamos solid deuterium source. Quasi-trapped orbits, in which relatively fast neutrons may escape during the measurement period, are suppressed by the asymmetry of the bowl and small-scale field variations designed into the magnet array. Progress on the construction of the prototype apparatus will be described.

# Neutron lifetime experiment at LANL

Steven Clayton
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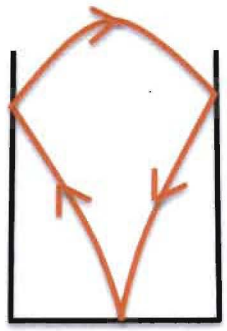
DNP Santa Fe, November, 2010

# Overview

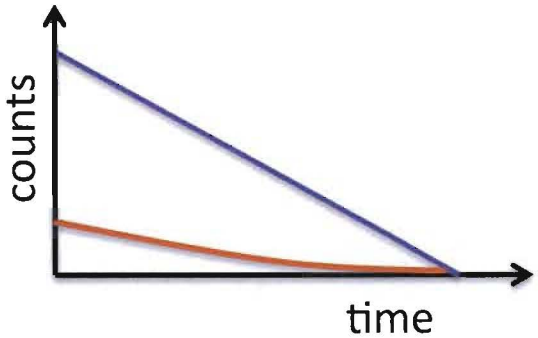
- neutron lifetime
  - fundamental property of n
  - important input governing BBN
  - key input for weak universality tests
    - cleanest extraction of $V_{ud}$
  - current discrepancy in experiments (?)
- new neutron lifetime experiment using UCN
  - will use LANL Solid $D_2$ UCN source
  - magneto-gravitational trap
  - goal is precision ~$10^{-4}$ (~0.1 s)
  - prototype is being constructed using LANL LDRD funds

# Sources of systematic errors

- Finite $\tau_{loss}$ in $N = N_0 \exp(-t/\tau_n - t/\tau_{loss})$
  - upscattering (interaction with matter)
  - quasi-trapped orbits



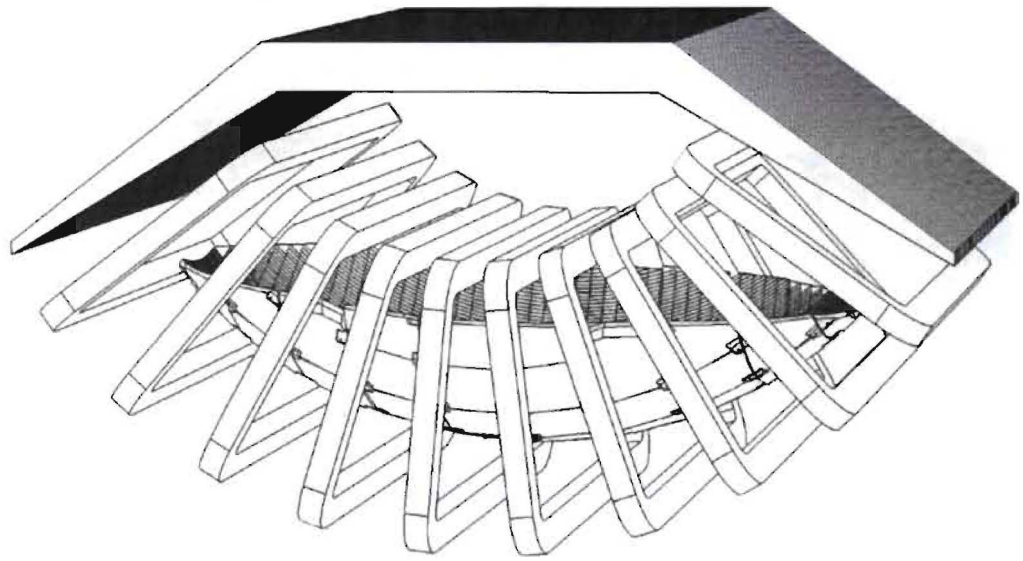
- Detection bias
  - phase space evolution + efficiency variation
  - draining time (if n-counting)
- Time-dependent background
  - background gamma Compton scattering
  - activation of trap materials



# Design requirements

- P.L. Walstrom, J.D. Bowman, S.I. Penttila, C. Morris, A. Saunders, NIMA 599 (2009) 82-92:

Magneto-gravitational trap

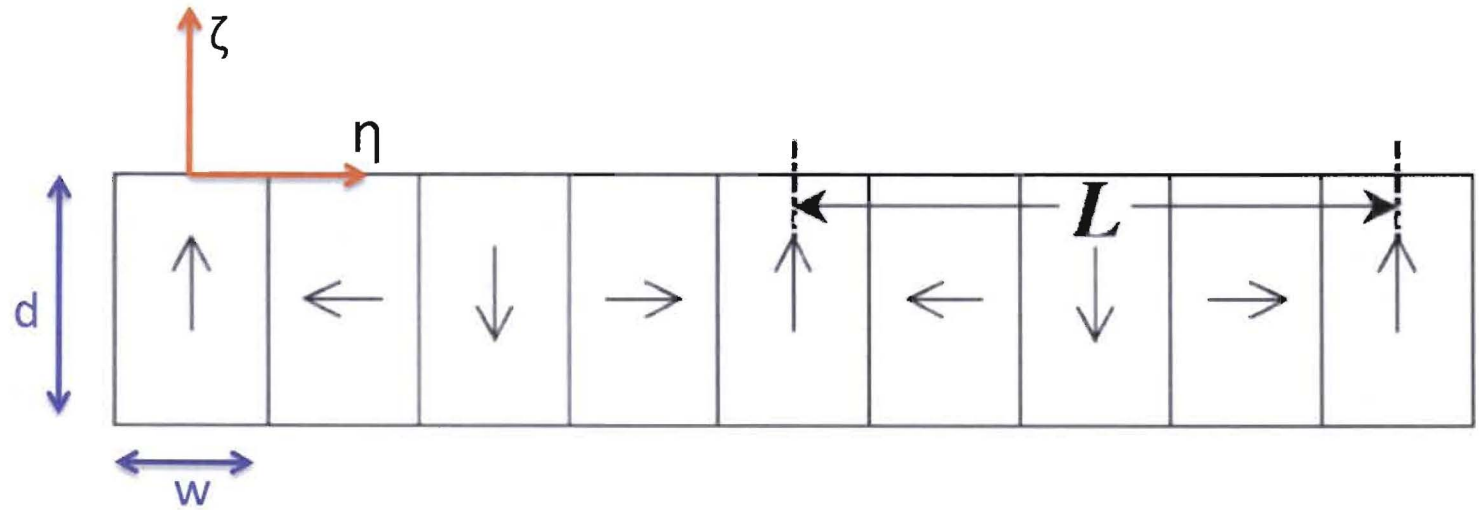


  - No magnetic field zeros
  - Filling mechanism
  - Cleanout procedure for quasi-trapped neutrons
  - No interaction with matter after cleaning

# Halbach array

Walstrom et al, NIMA 599 (2009) 82-92.

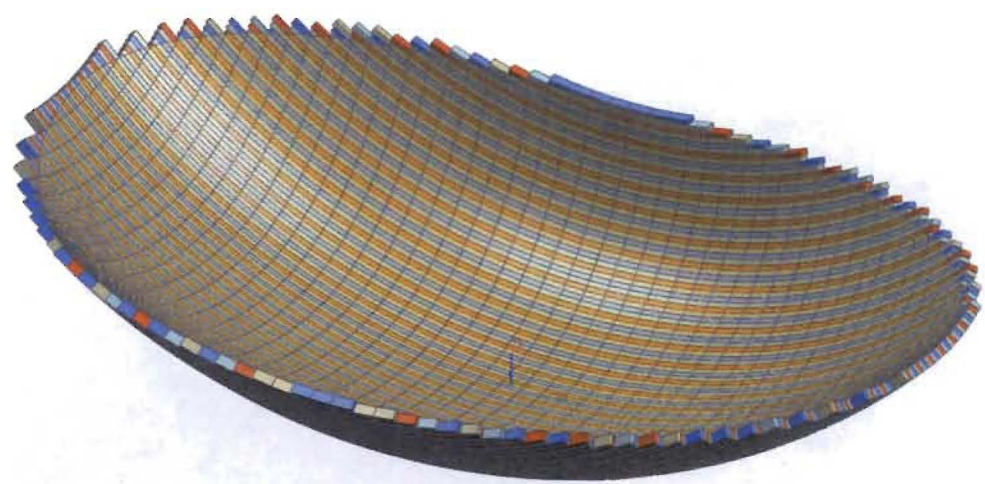
$$|\mathbf{B}| = B_{\mathrm{rem}}(1 - \mathrm{e}^{-kd})\mathrm{e}^{-k\zeta}$$ (if continuous rotation of M)




Parameters:

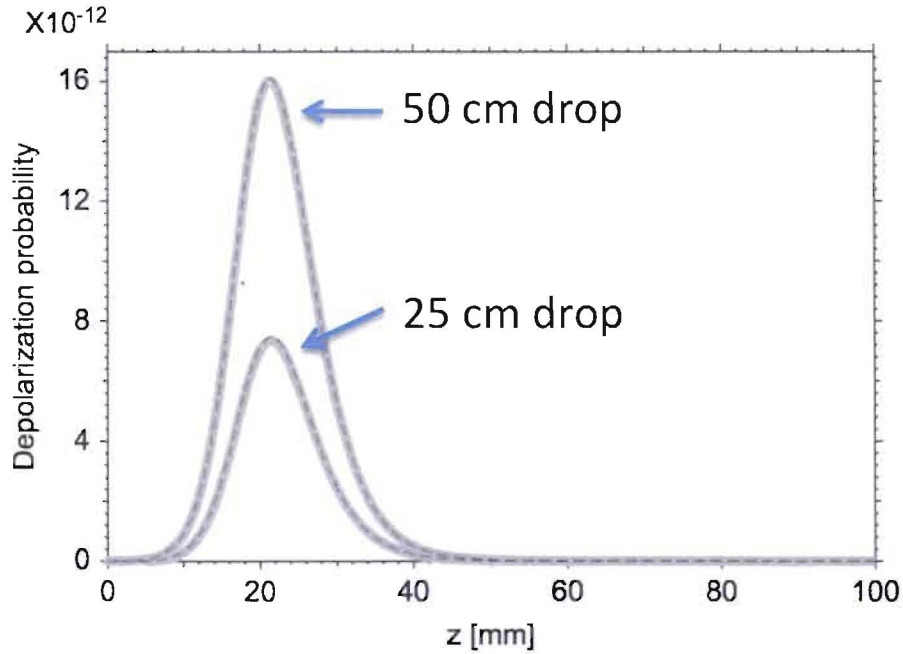
d = 2.54 cm, w = 1.27 cm, $B_{rem}$ = 1.3 T

→ min. trapping field 0.82 T at 2 mm, corresponds to mgh = $|\mu_n B|$ with h = 0.48 m



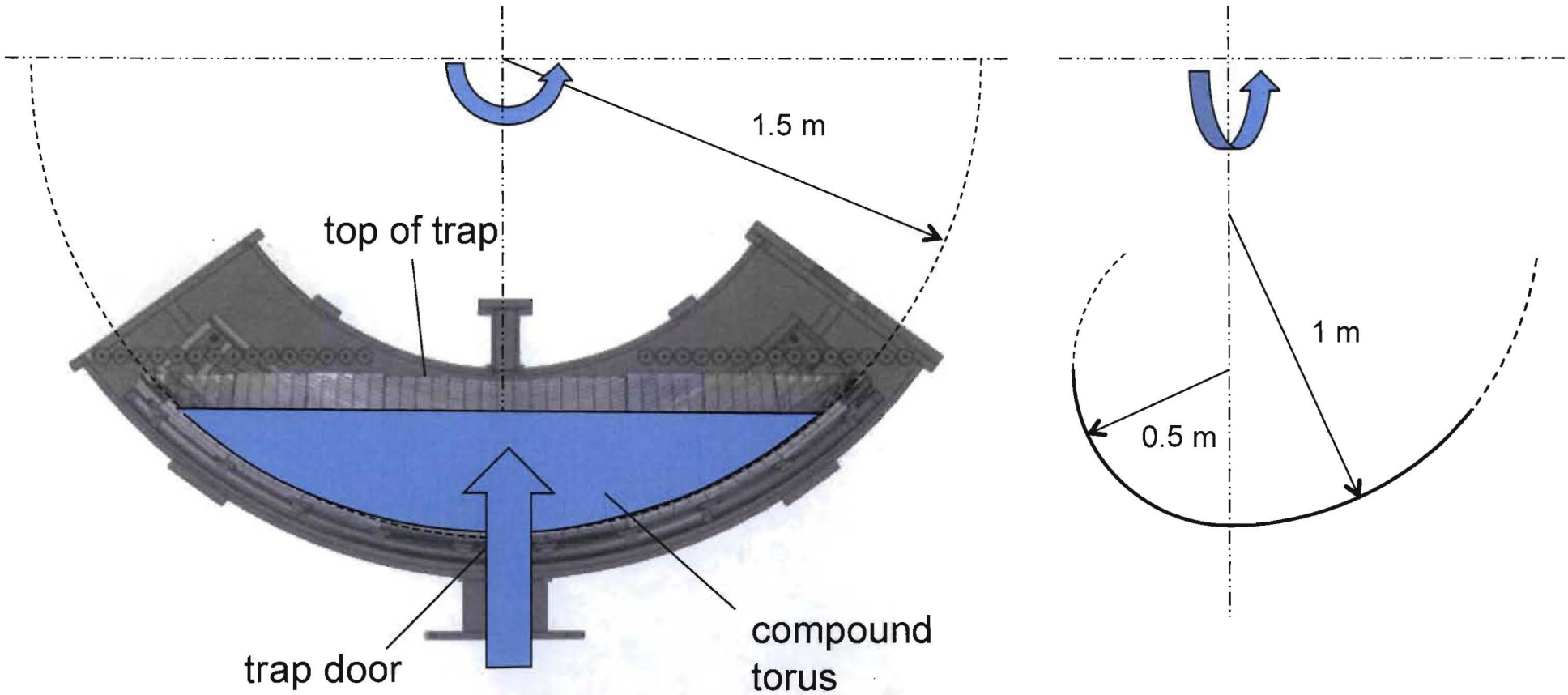
# Losses due to depolarization

- calculated for "worst-case scenario":
  - UCN dropped from 50 cm onto PM array
  - spin-flip loss per bounce ~$10^{-20}$ (negligible)



# Overview of Experiment

- Asymmetric compound toroidal trap fills trap phase space
- UCN trapped by gravity in open-top bowl ("the bathtub")
- UCN fed in from trap door below

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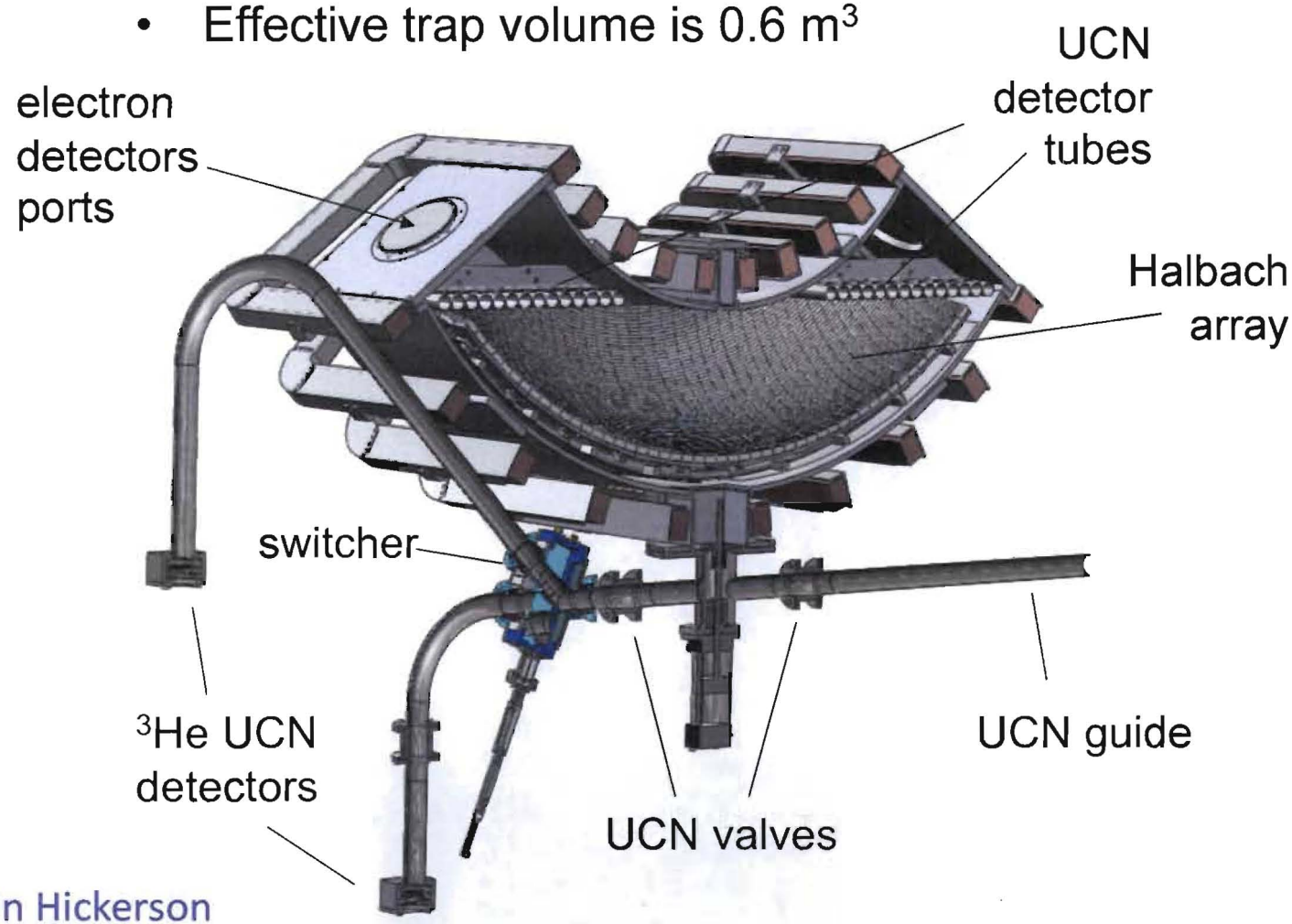
# Overview of Experiment

- Permanent magnets repel UCN on bottom
- Minimize material interactions
- Effective trap volume is 0.6 $m^3$

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# Cleaning of quasi-bound orbits

Walstrom et al., NIMA 599 (2009) 82-92.

$10^5$ simulated UCN started with fixed energy $mgh_{max}$

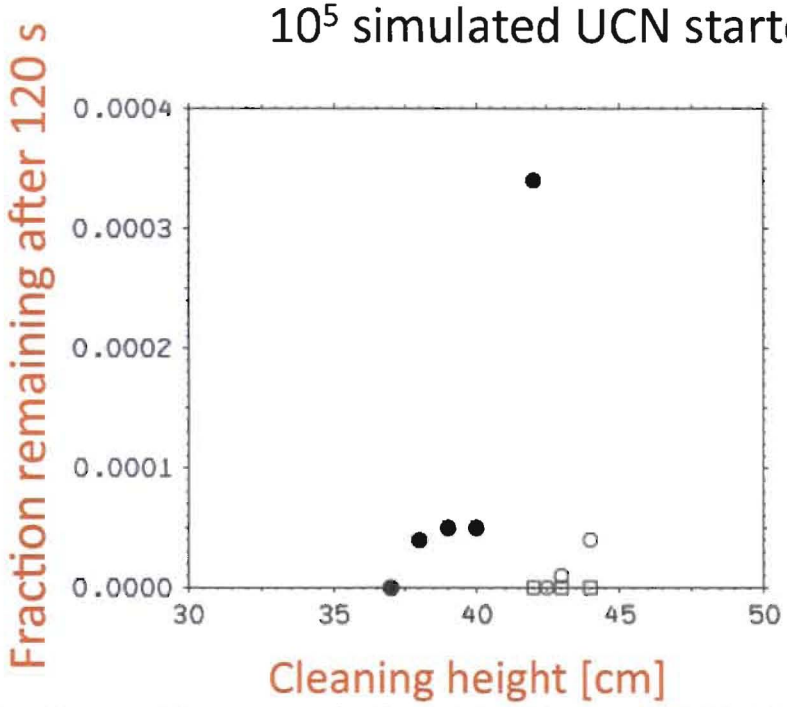



**Fig. 4.** Quasi-trapped fraction vs. cleaning height with a guide field of 0.1 bottom of the trap and various PM field models. Results for the smooth-fiel are indicated by solid circles, for the one-way ripple model by open circles the two-way ripple model by squares.

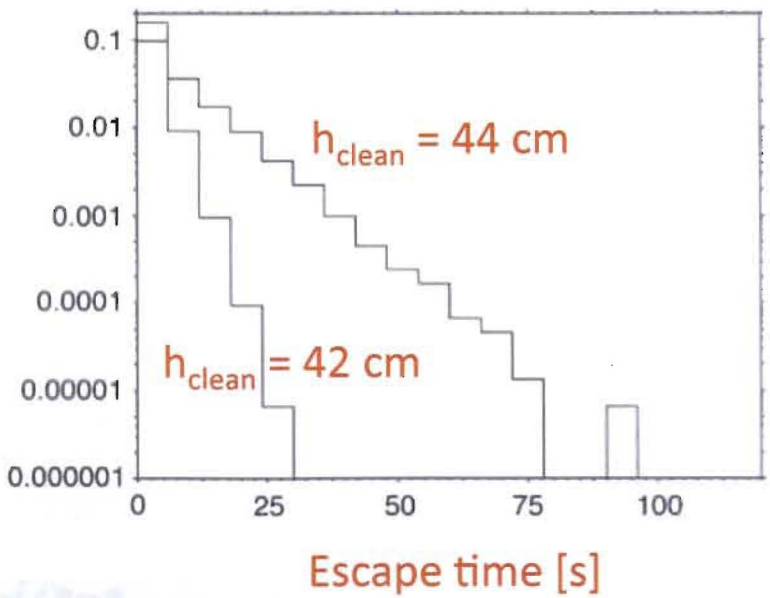
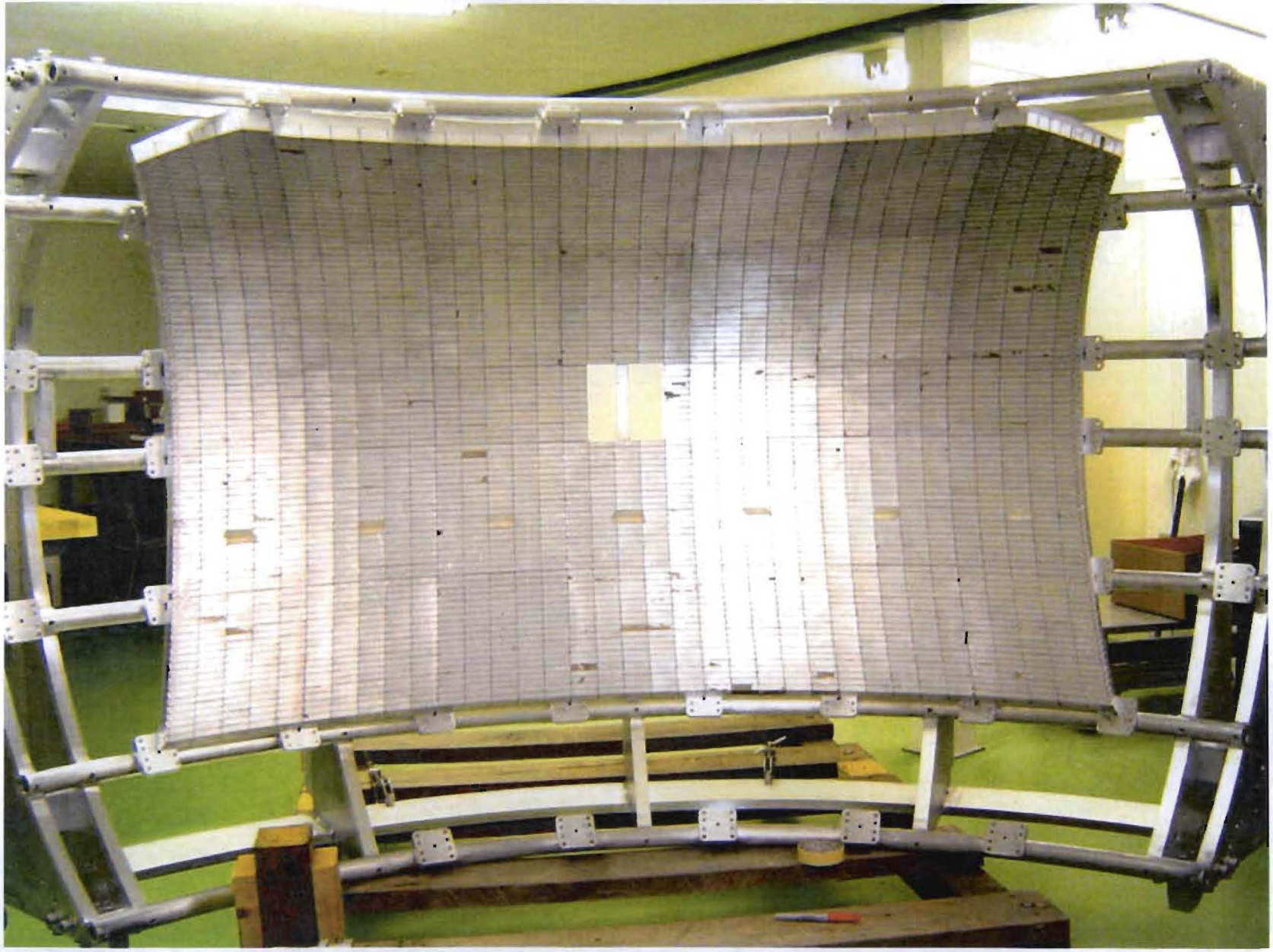



**Fig. 7.** Escape-time histograms for the two-way ripple model with a guide field of 0.1 T and two different cleaning heights: $h_{clean} = 44$ cm for the upper curve and 42 cm for the lower curve.

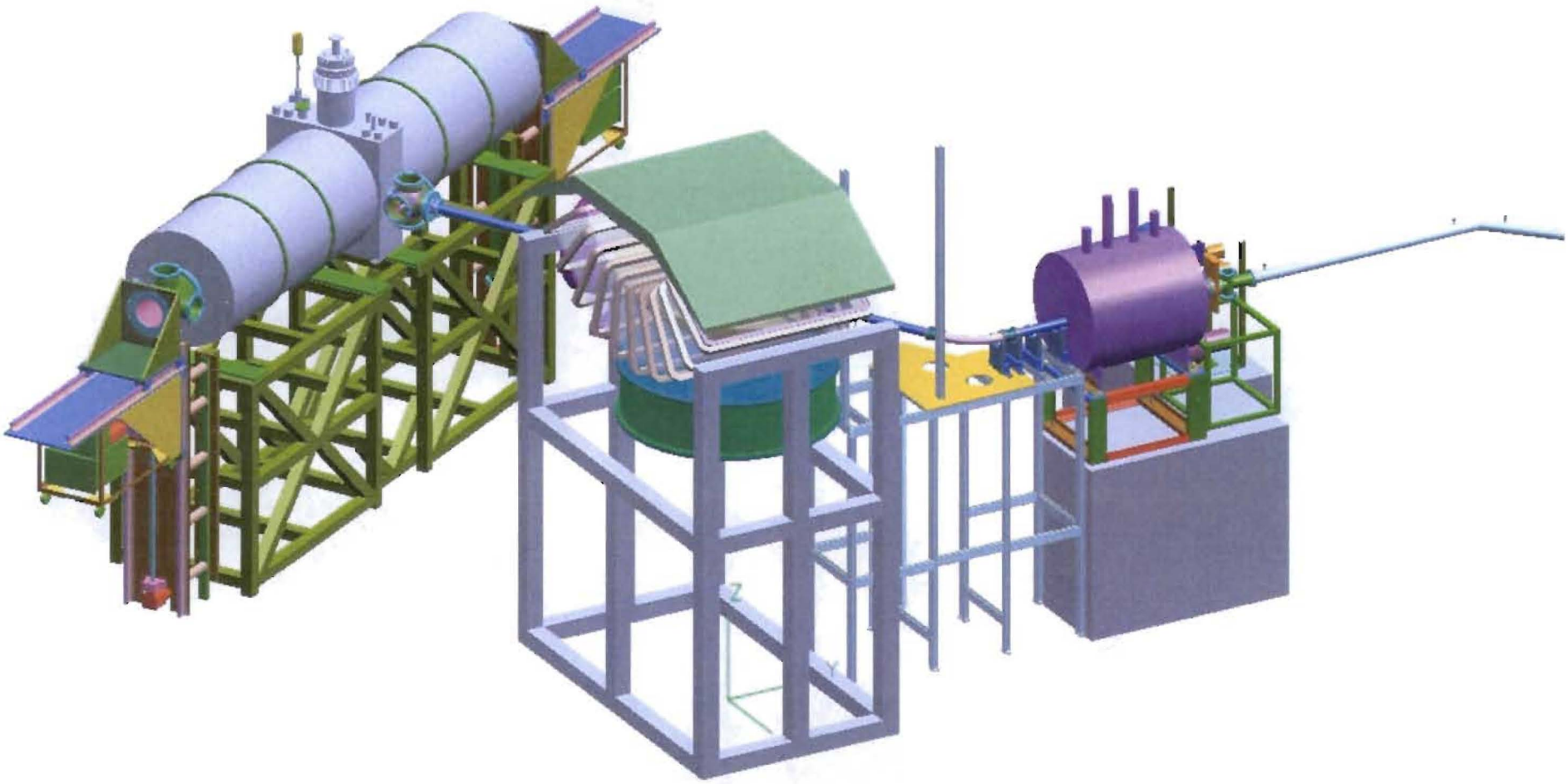
# Draining time

- Do some UCN "circle the drain"?
- Not addressed in Walstrom et al. (orig. scheme was to detect betas)
- Only highest energy UCN see chaotic-orbit-inducing field ripple
- Possible solutions?
  - active absorber
  - more simulation

# Completed magnet array



# n Lifetime experiment in UCN hall

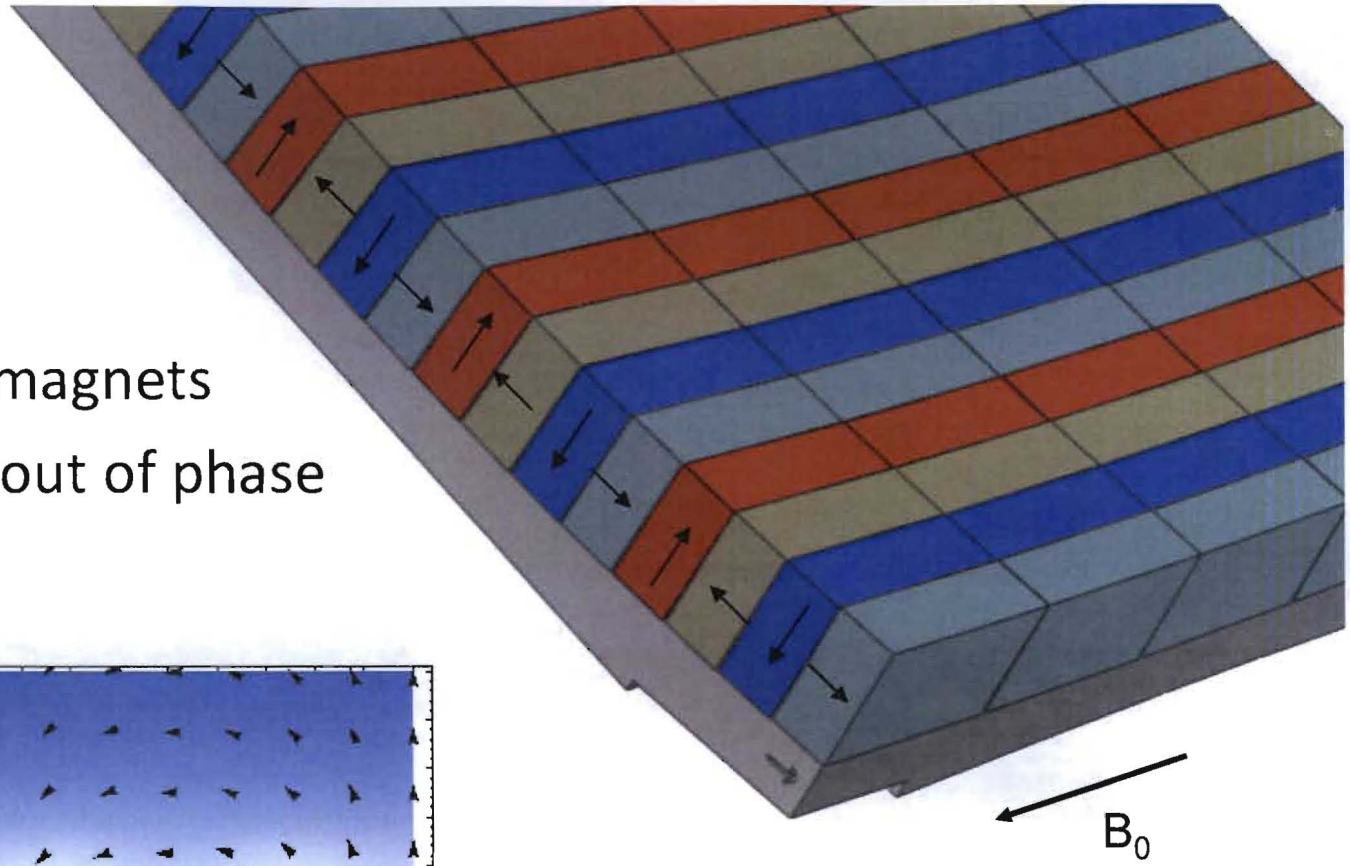


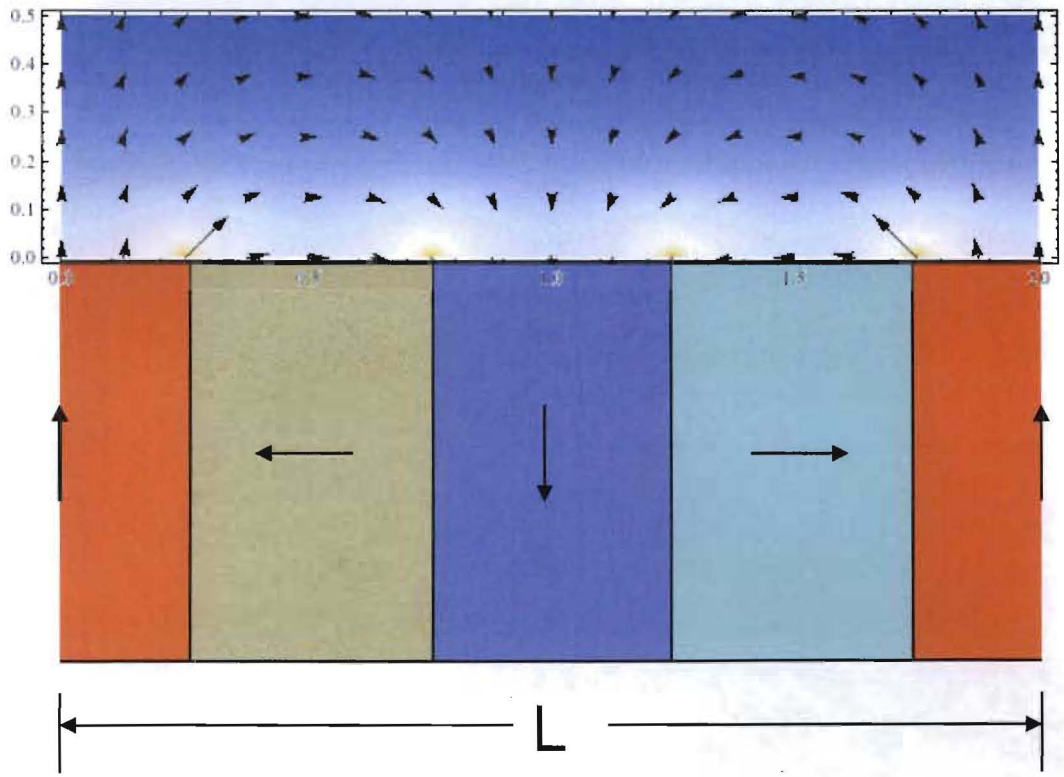
Goal: $10^{-4}$ relative uncertainty (~0.1 s)

Depends on UCN density, backgrounds, ...

# Halbach array

- 1.2 T permanent magnets
- 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 $B_0$

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