Neutron Lifetime Review:
Status and future

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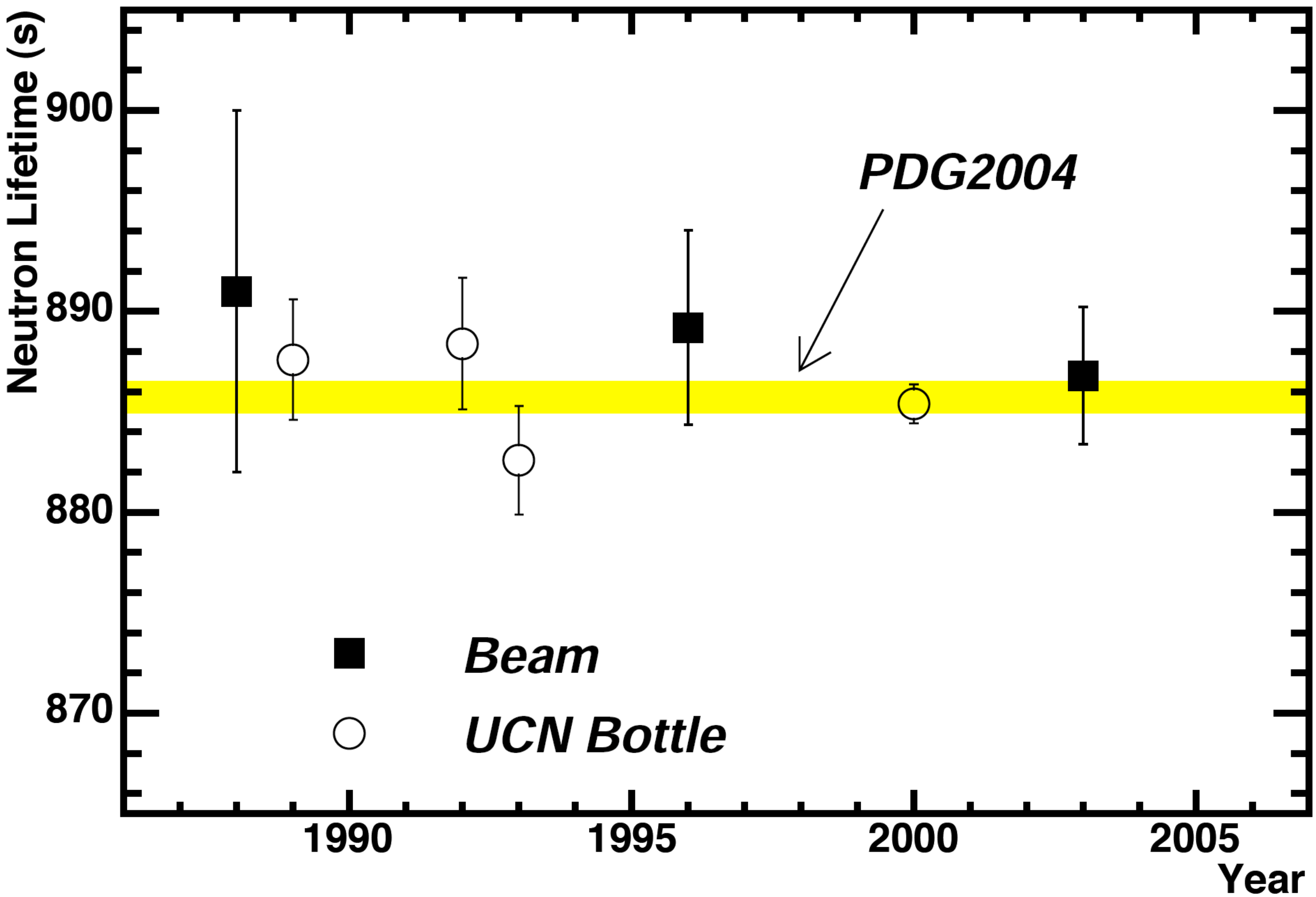
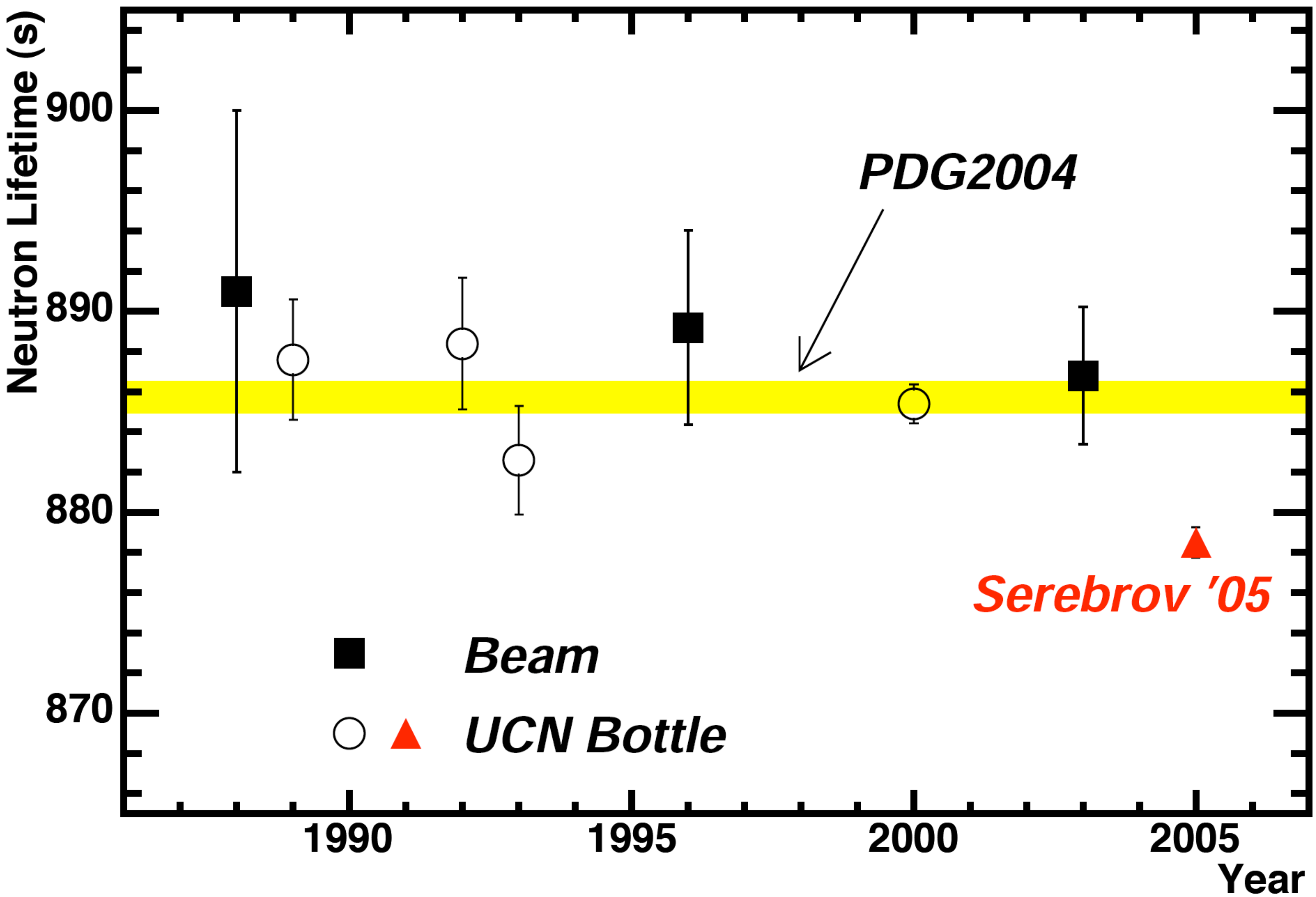
The 4th International Workshop on the
CKM Unitarity Triangle

December 12-16, 2006
Nagoya University
Nagoya, Japan

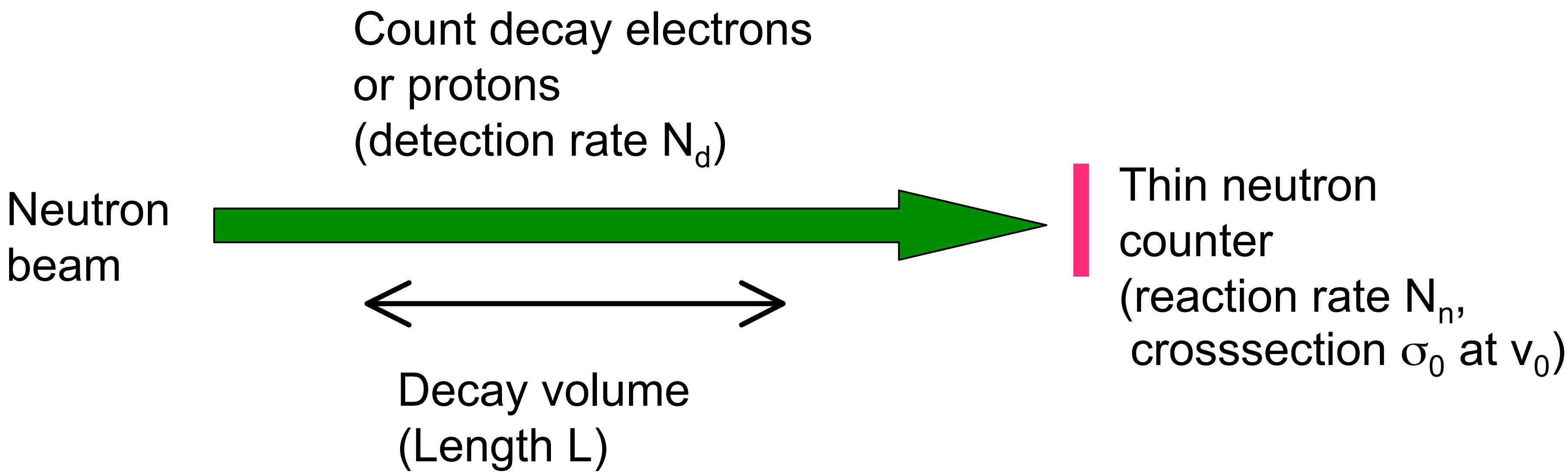
Neutron Lifetime



Neutron Lifetime



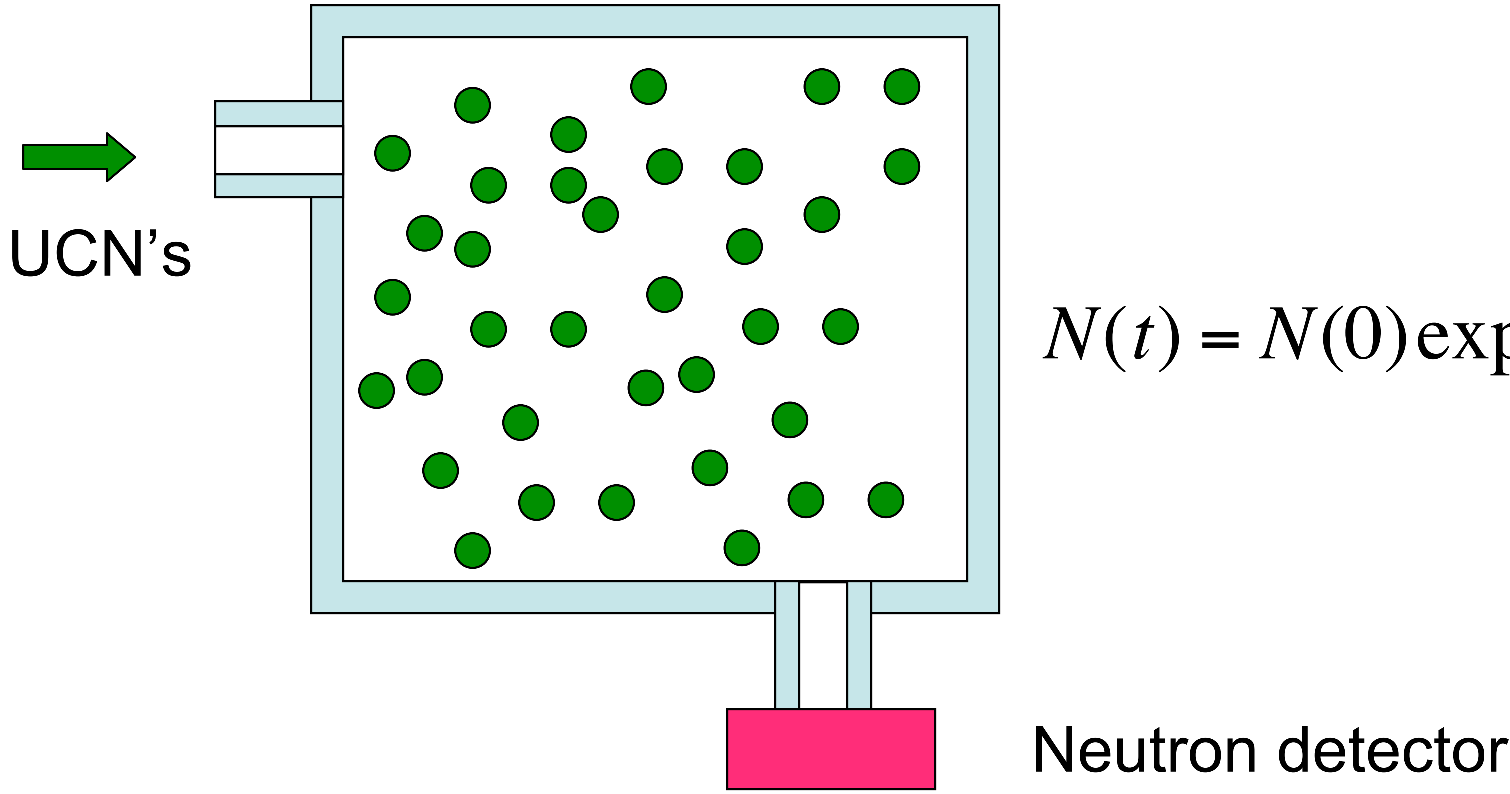
Beam Method



$$N_d = \frac{1}{\tau_n} N \quad \Rightarrow \quad N_d = \frac{1}{\tau_n}[L N_n \sigma_0 v_0 (\rho x)]$$

Problem: Decay volume length and neutron flux measurement

Bottle Method



$$N(t) = N(0)\exp(-t/\tau_n)$$

Problem: neutrons lost through interactions with the wall

Existing measurements from PDG

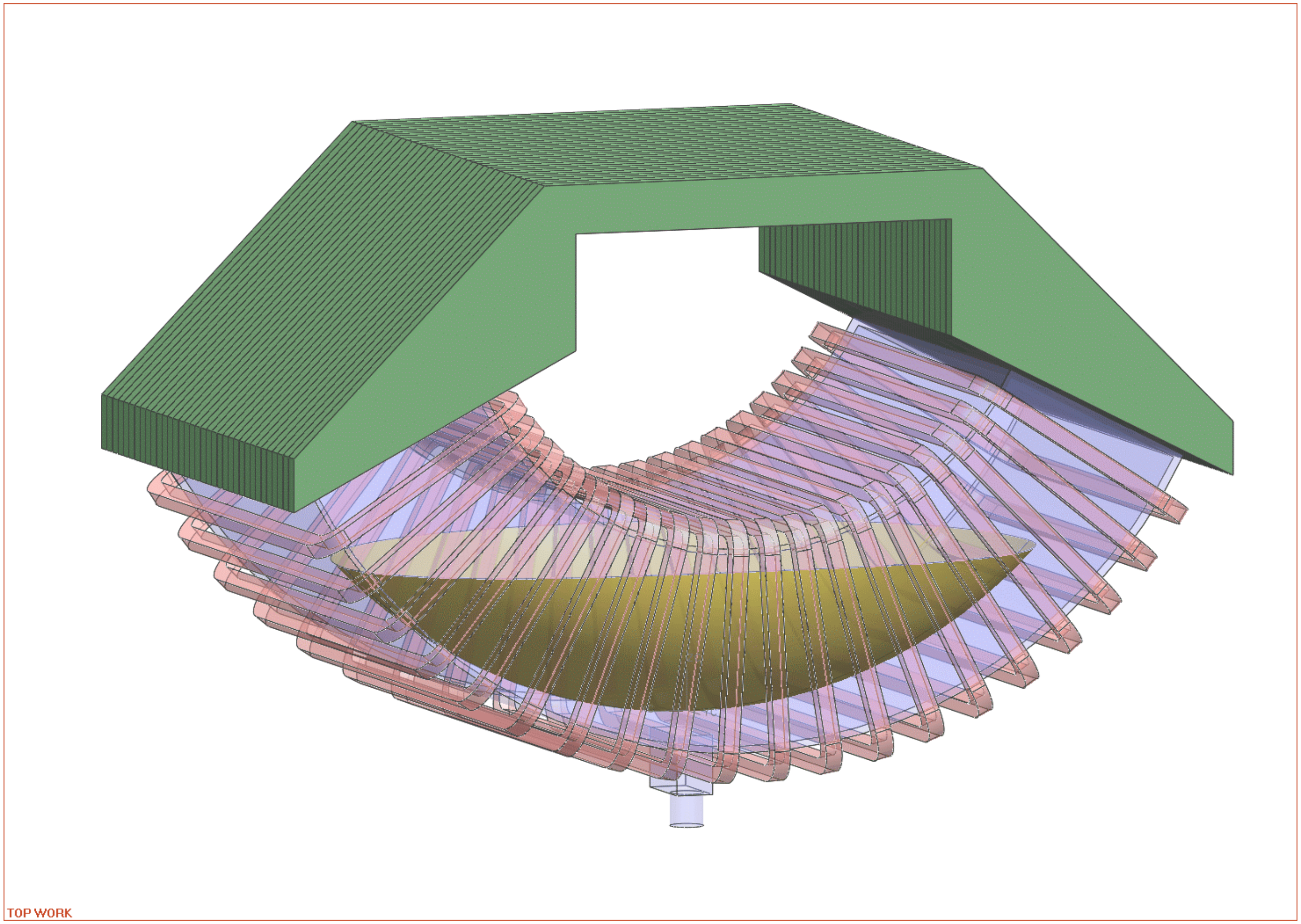
1. Dewey, 03	886.7 ± 1.2 ± 3.2 s
– In-beam Penning trap	
2. Arzumanov, 00	885.4 ± 0.9 ± 0.4 s
04	879 ± 1 s
– UCN material trap	
3. Byrne, 90/96	889.2 ± 3.0 ± 3.8 s
– In-beam Penning trap	
4. Mampe, 93	882.6 ± 2.7 s
– UCN material trap	
Wt. Ave. (excluding 2)	886.7 ± 1.8 s

Measurement of the neutron lifetime using a gravo-magneto trap

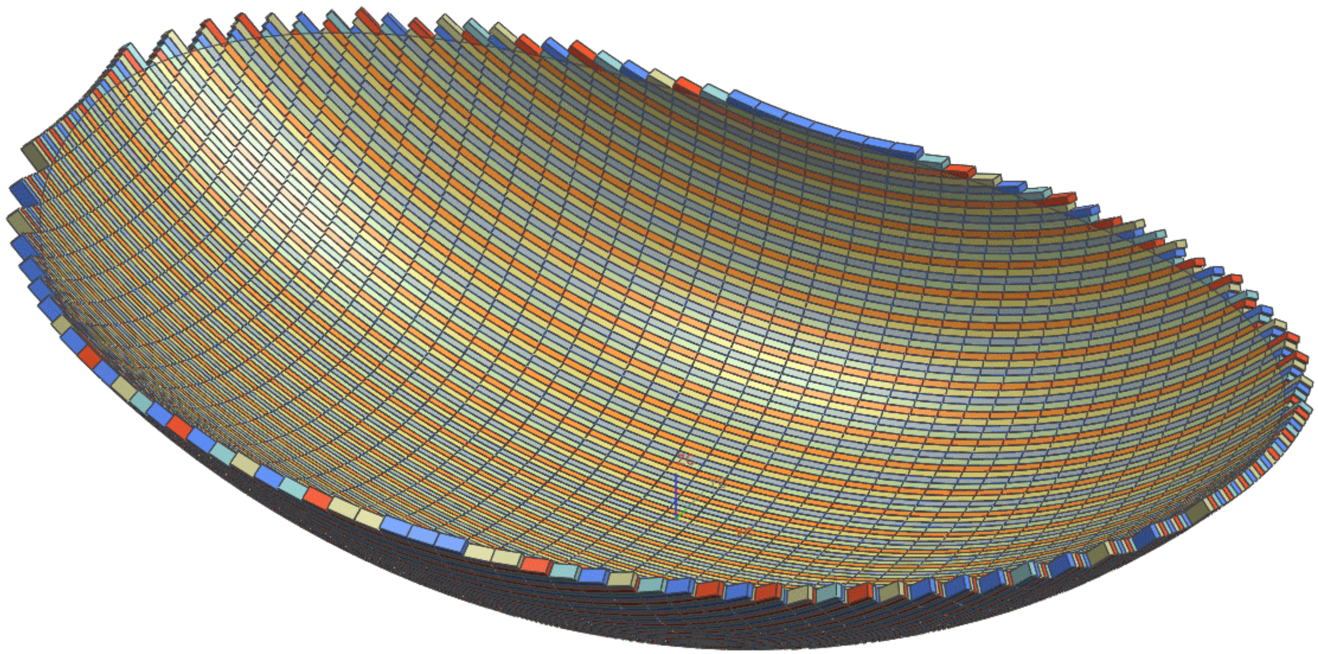
- We want to measure the neutron lifetime to a part in 10^4 to test CKM unitarity using τ_n and the A and/or a correlations.
- Modern measurements have uncertainties of 1-2 sec but are inconsistent
  - Material bottles
  - Decay of cold beams
  - NIST quadrupole-super fluid-He trap

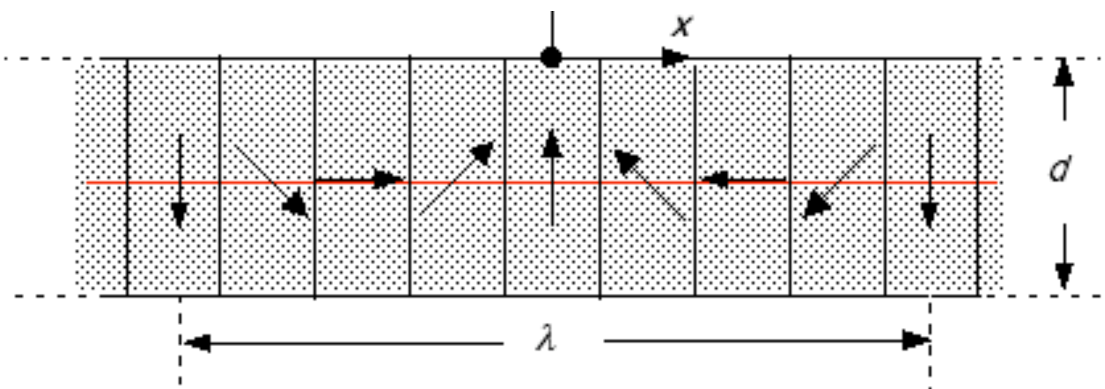
End of introduction

Permanent-Magnet Trap with Guide-Field Coils and Yoke



Finite Halbach Arrays





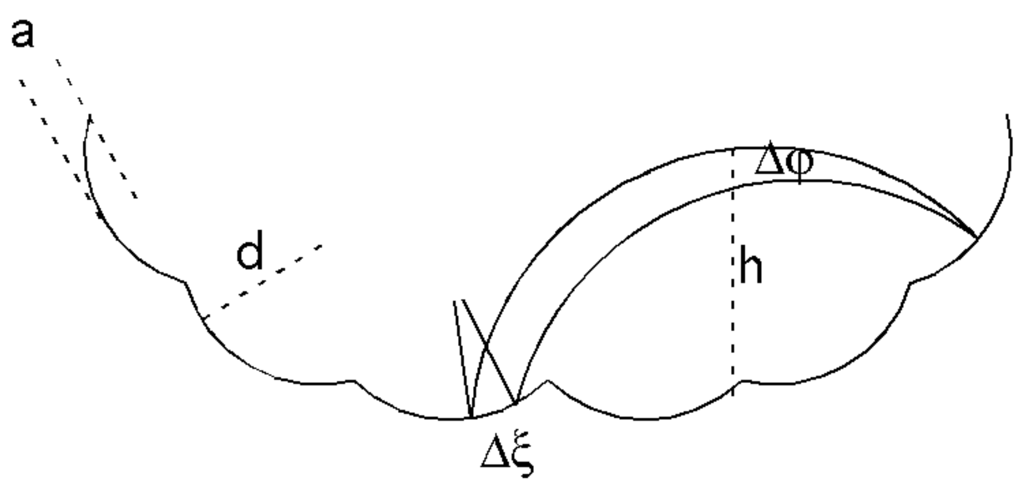
Experimental problems

- Interactions of neutrons with matter
- Neutron losses due to spin-flip transitions
- Quasi-stable orbits
- Statistics
  - 10^8 events for 10^{-4} uncertainty in τ
  - Efficient collection of betas
- Activation of trap during filling
- Filling time << neutron lifetime

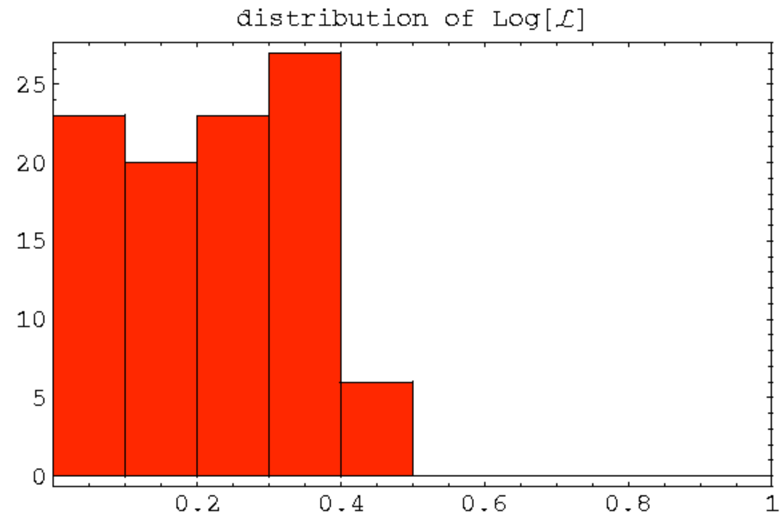
Robustness of cleaning strategy

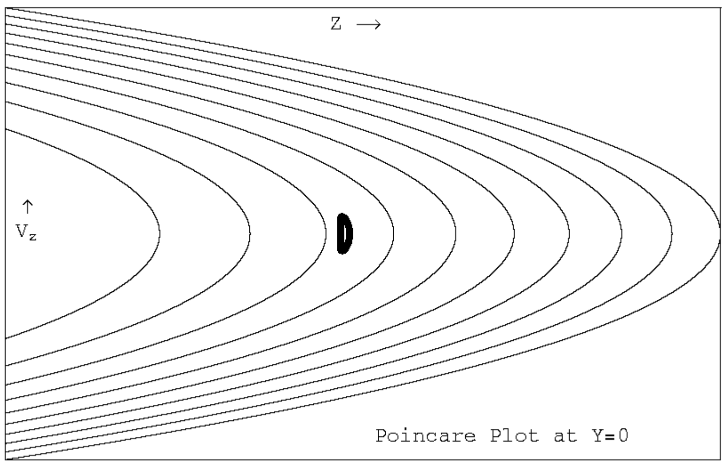
- It is necessary to eliminate quasi-trapped orbits. These orbits are not energetically trapped and they may leave the trap in times ~ neutron lifetime.
- There are two limiting types of motion in the trap
  - A smooth trap gives deterministic orbits
  - An irregular trap gives chaotic orbits
- We have devised a strategy that works for both limits and in between

Scaling parameter for chaos, $\lambda = ah/d^2$



$$\Delta\xi/\Delta\varphi \sim \frac{a\,h}{d^2}$$





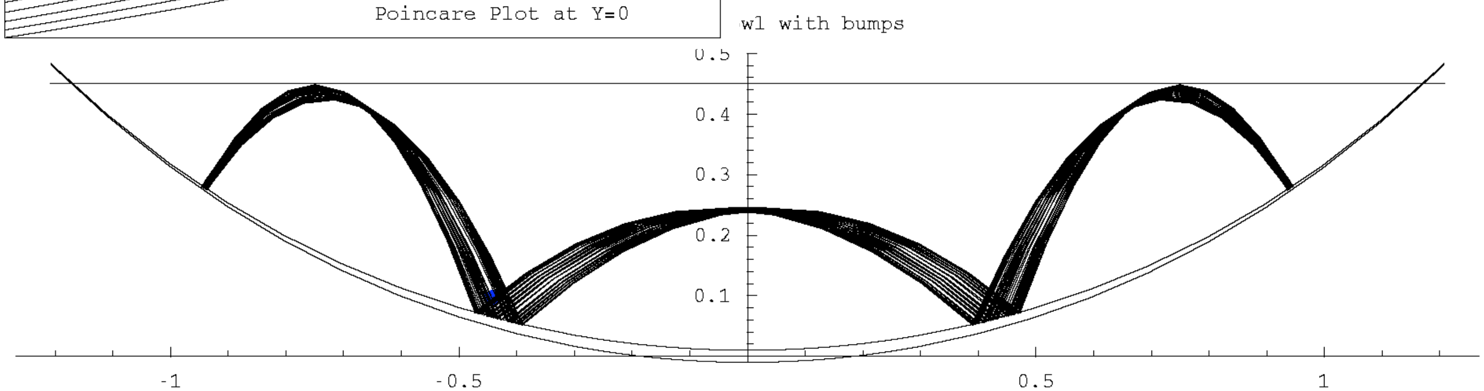
Deterministic case

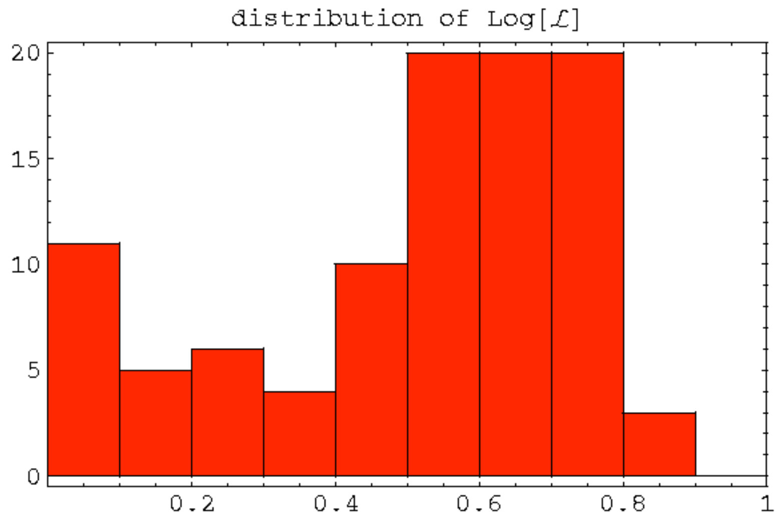
$a = .01$

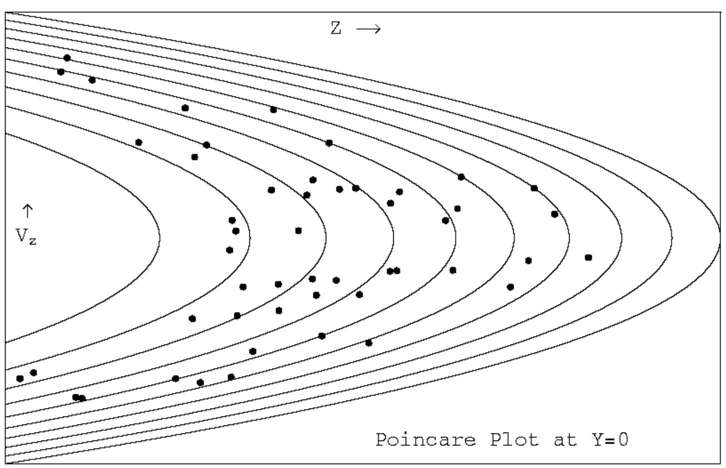
$h_0 = .5$

$period = 6h_0$

$\lambda = 2.2\,10^{-3}$







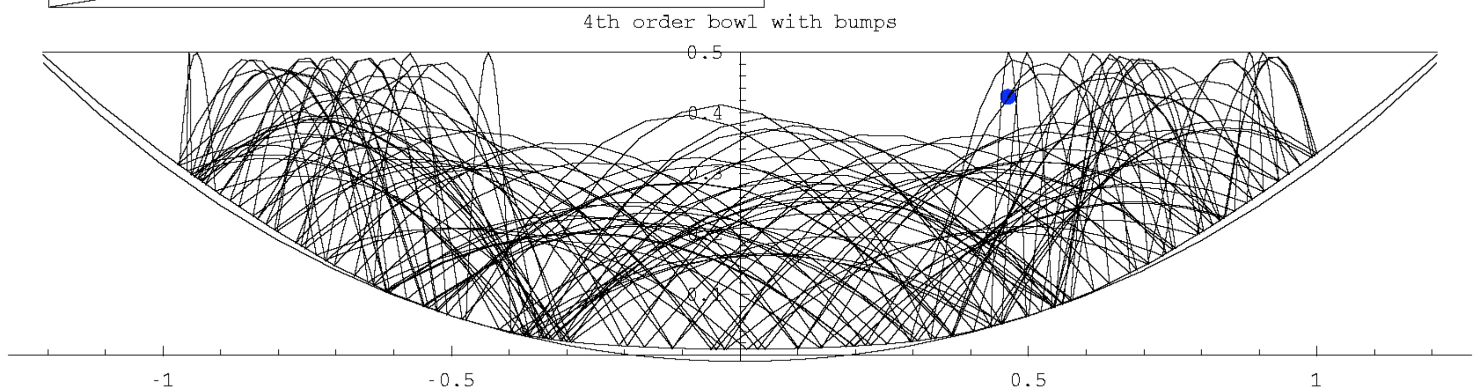
Transitional case

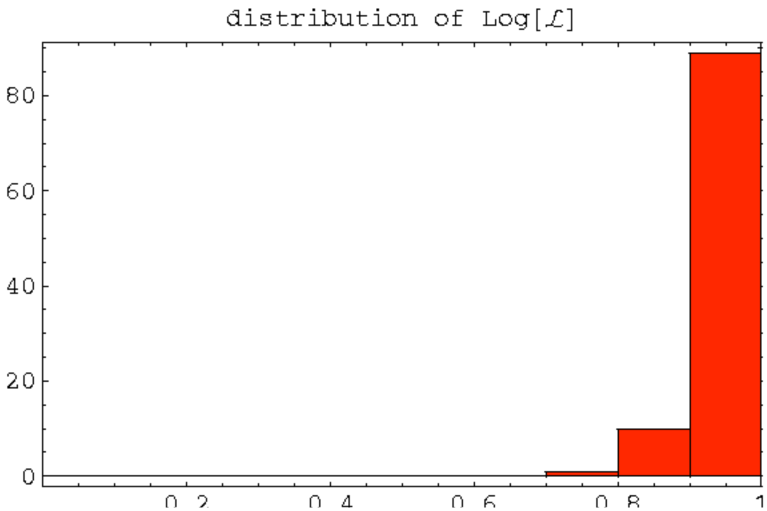
$a = .01$

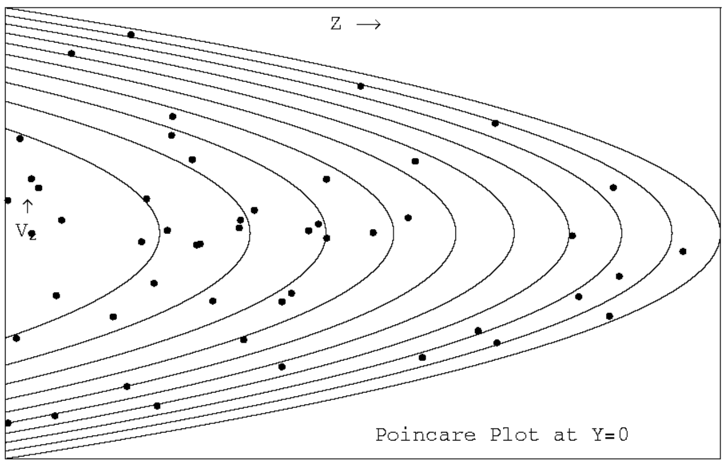
$h_0 = .5$

$period = 2h_0$

$\lambda = 5\,10^{-3}$







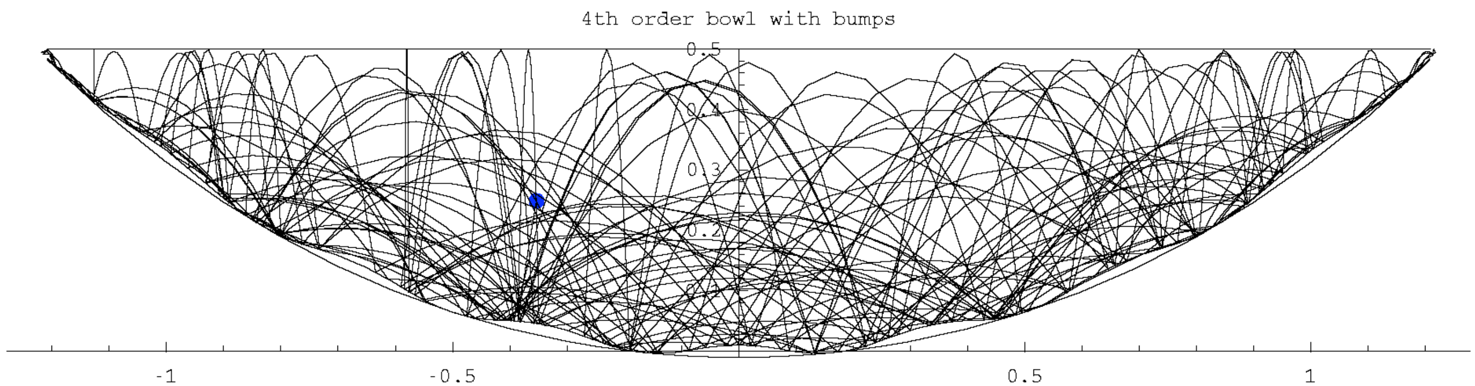
Chaotic case

$a = .01$

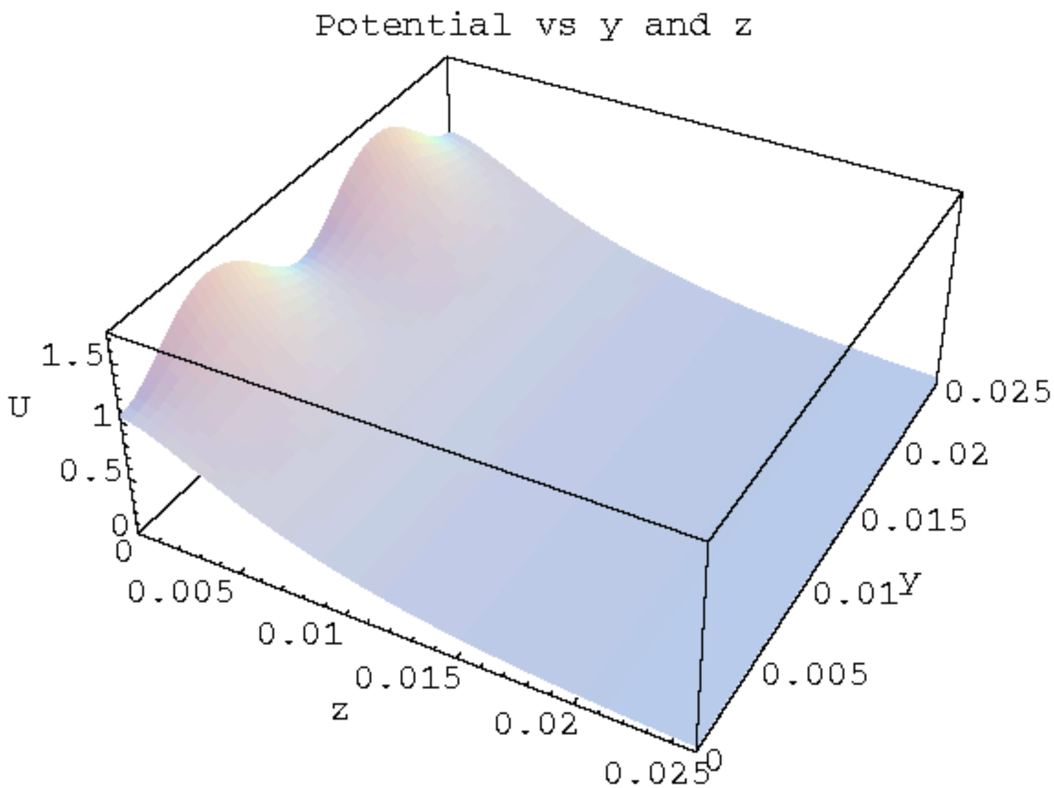
$h_0 = .5$

$period = 2/3\ h_0$

$\lambda = 4.5\ 10^{-2}$



Halbach ripples



Replace the potential with a reflecting boundary.

$a = .00062$ meters, $p = .0125$ meters, $\xi = \dfrac{a\,h}{p^2} = 1.98!$

The trajectories are strongly chaotic.

Neutron interactions with matter

- After the trap is filled and cleaned, the neutrons interact only with gravity and magnetic fields.
- There is no interaction with matter if the vacuum is $< 10^{-5}$ Torr.

Spin-flip losses

- The Halbach field and the guide field are everywhere orthoginal. They add in quadrature. There are no zeros. The adiabaticity parameter is very large.

Statistical uncertainty in τ

$$\frac{\sigma_\tau}{\tau} \sim \frac{1}{\sqrt{N}}$$

For a UCN density of 100 per cc we expect 4 10^5 neutrons per fill.

Assume that we count for 3 lifetimes and refill the trap every hour.

3 hours are required for a 10^{-3} measurement and 300 for 10^{-4}.

Collection of betas

- The toroidal field guides a large fraction of the betas to the detector.
- The gradB×B drift is small, a few cm.

Activation during filling

- Neutrons may interact with matter while the trap is being filled.
- To measure the activation, go through the sequence of fill, clean, and count, but after cleaning insert a CH_2 absorber. CH_2 absorbs, but does not become activated.
- Any counts observed are from activation

Filling time

- The filling time is less than a minute << neutron lifetime.

Conclusions

- We have a conceptual design for a gravo-magnetic UCN trap to measure the neutron lifetime to 10^{-4} in a few hundred hours provided UCN densities of 100/cc are available
- We use chaos to eliminate troublesome quasi trapped orbits
- The trap and experiment design eliminates systematic uncertainties as discussed above