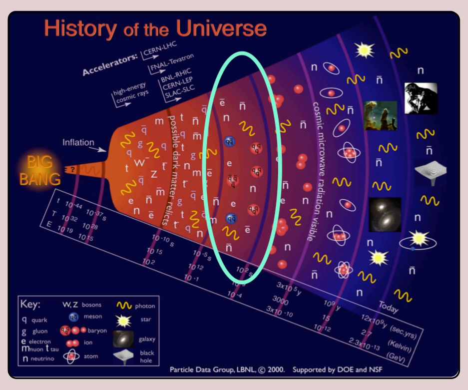
A Permanent Octupole Magnetic UCN Trap for Neutron Lifetime Measurements

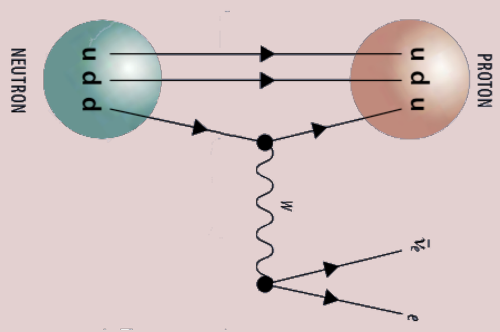
K. Leung[a,b] and O. Zimmer[a,b]

Motivation

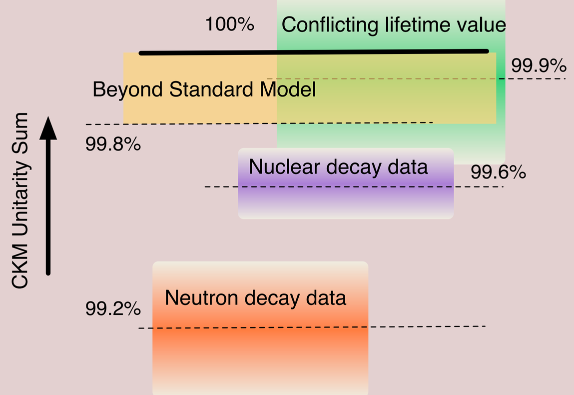
The free neutron is unstable and beta-decays with a lifetime of ~15mins. Precise measurements of this lifetime is important in:



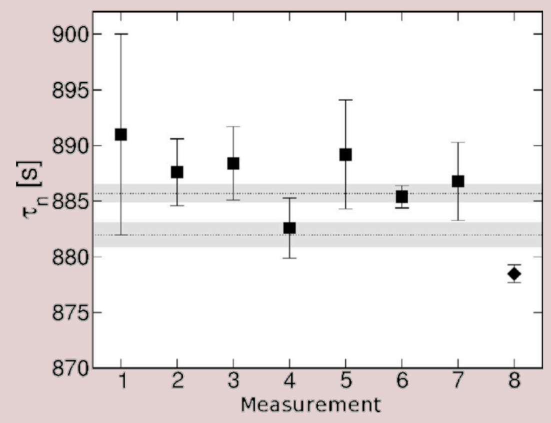
» Experimental tests of Big Bang Nucleosynthesis. Used to calculate the proton:neutron ratio and primordial abundances of the elements a few minutes after the Big Bang.



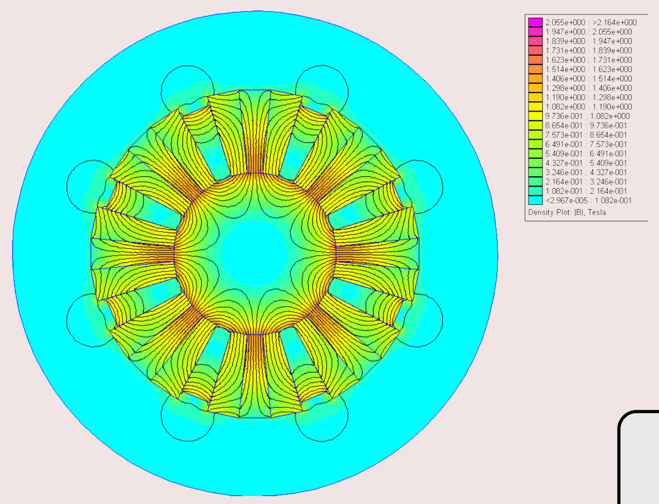
» Tests of the weak interaction in the Standard Model. Unitarity tests of the CKM-quark mixing matrix allows for existence of beyond Standard Model physics.



» Large unresolved disagreements between current results. Due to spurious losses in material storage of UCNs. Aim is to clear discrepency and increase current precision of 0.8s by a factor of 3-4.

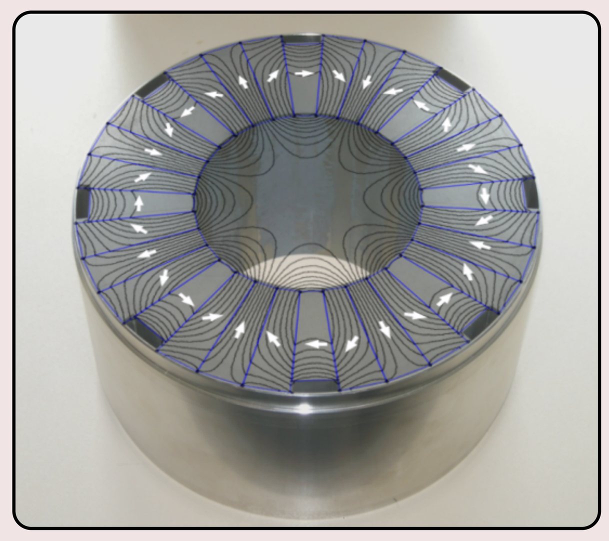


Permanent Octupole Magnet

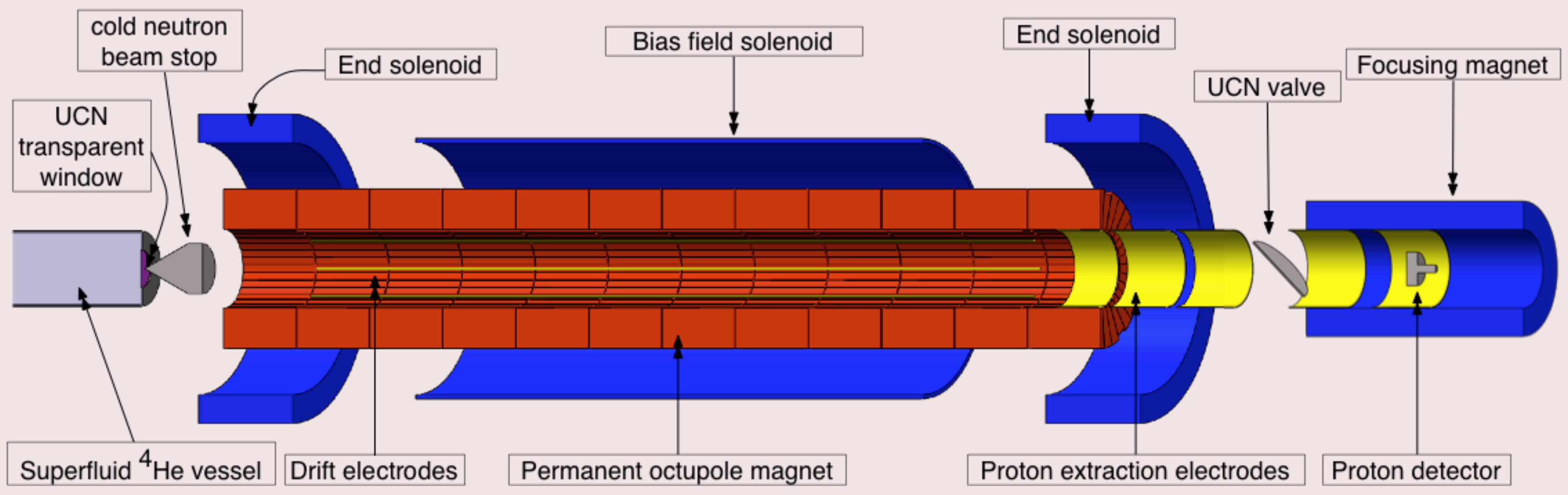


» Magnetic storage provides loss-free storage of UCNs. This should resolve current standing problem in lifetime measurements.

» UCN energy stored by magnetic field is 60 neV/T. Achieve high field strength (~1.3T) with NdFeB Halbach-type octupole permanent magnet system.



Experimental Setup



» High density of UCNs produced in superfluid He by scattering 9Å cold neutrons off single phonons.

» Inner bore of trap is Ø=9.4cm, L=1.3m.

» Octupole field ~1.3T, Bias field ~0.3T, End solenoids ~1.5T, Focusing field ~3T.

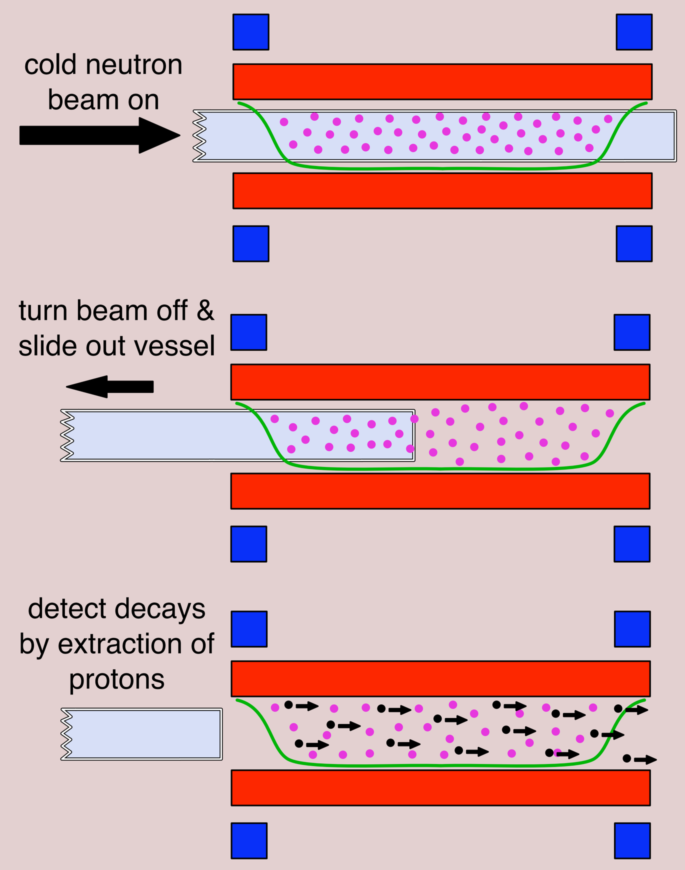
» Window to be made from thin foil of titanium or vanadium (negative optical potential)

» UCN valve can be used to monitor escaping neutrons from trap.

» Superconducting system (blue) used to provide high field strengths.

Experimental Procedure

» Extraction of UCN to vacuum is crucial for high precision lifetime measurements due to reduction of major systematics: excitations in superfluid & losses from He-3 absorption.



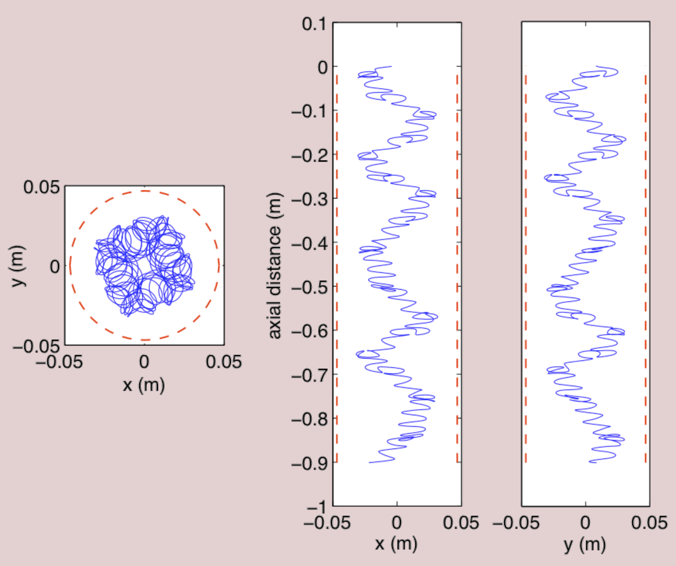
» Speed of foil movement must be not so-fast as to increase UCN energy upon reflection but sufficiently slow to avoid multiple passages.

» In-situ detection of decays offers many advantages over traditional "fill-and-empty" technique: avoids pile-up, same statistics in shorter time, live checks of systematic losses & no assumptions about filling efficiency.

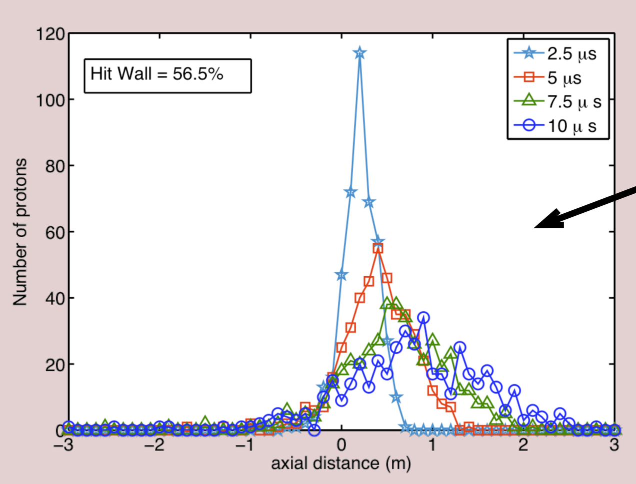
Detection & Extraction of Protons

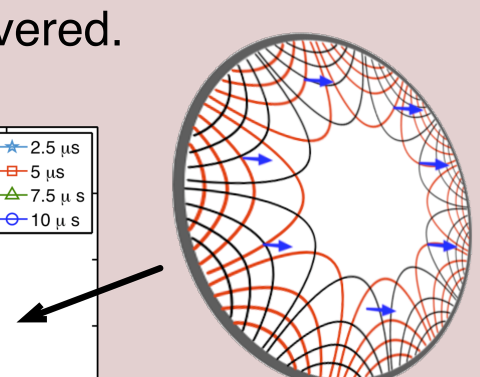
» Protons produced with energy < 0.75 keV. Require 4kV to overcome magnetic mirror of 1.5T end solenoid and 8kV of 3T focussing field. Further 10-15kV is required for detection.

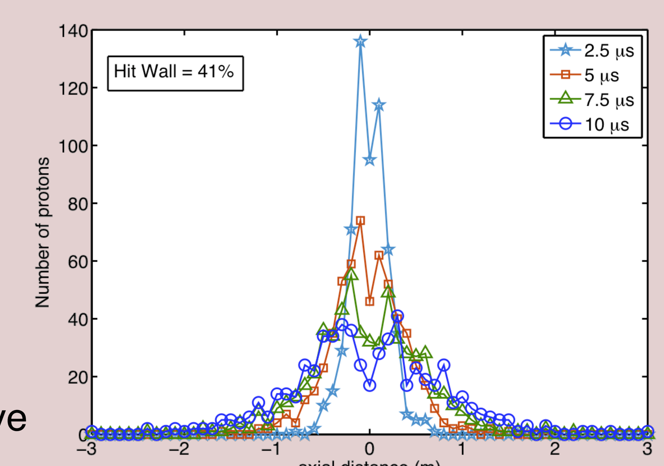
» Protons required to be trapped for long periods of time for high extraction efficiency. Proton trajectory simulations show a general slow "diffusive" movement away from point of production.



» A unique technique of employing an electric octupole super-imposed on the magnetic octupole to produce an ExB drift force for better proton extraction discovered.







*Efficiencies are conservative estimates only.

Summary

» Permanent magnetic UCN storage is versatile and offers the opportunity of loss-free storage.

» We have a high UCN density offered by superfluid helium UCN production.

» Studies of decays take place in vacuum and with in-situ detection of produced protons, avoiding many known systematic effects.

» Cleaning of quasi-bound or above-threshold neutrons in the trap remain the main obstacle for all magnetic storage experiments. Currently cleaning techniques are being investigated to solve this problem.

» Using the H172 monochromated beam at the ILL, expect to store ~1.3x10^6 neutons per fill. This allows an accuracy in measuring the lifetime of 2s per fill and 0.2s in one cycle.

[a]Institut Laue-Langevin
[b]Physik Department E18, Technische Universitàt München

NEUTRONS FOR SCIENCE

This work has been funded by the German BMBF & the ESFRI ILL 20/20 Project.