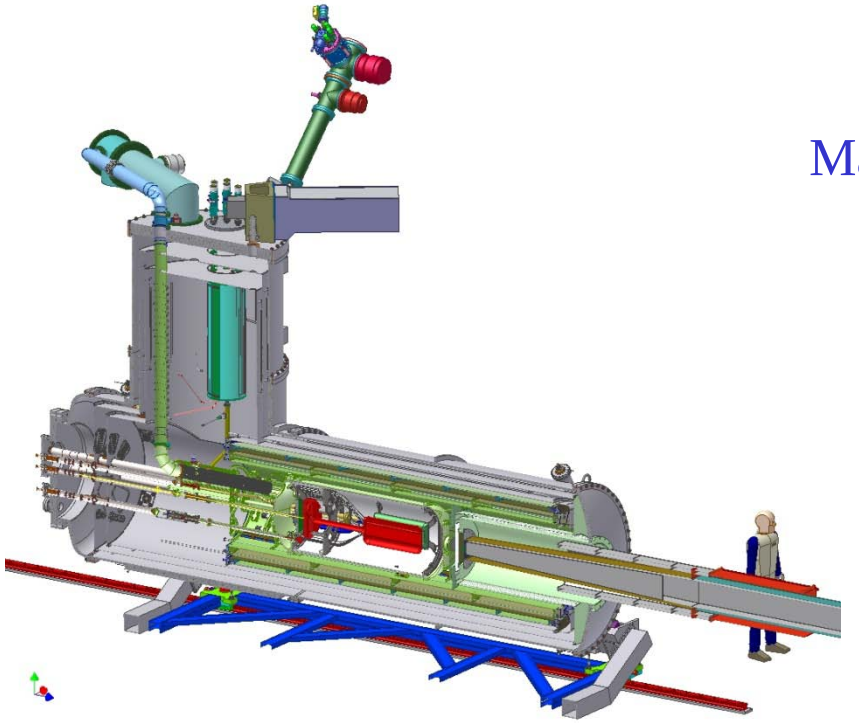
Measurement Cell Development for nEDM (SNS)



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for presentation to

Neutron EDM Workshop
Oak Ridge National Laboratory
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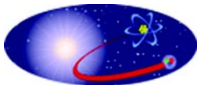

Outline

- Requirements
- Cell Construction
- Storage Time Measurements
- Conclusions and Future Work

Requirements

There are four principal properties needed from the nEDM measurement cells

- Ultra-cold neutron (UCN) production
  - Transverse size determined by cold neutron phase space and E field
  - Length balanced between UCN production and B-field uniformity (T_2, etc.)
  - Internal dimensions: 7.5 cm wide x 10 cm high x 40 cm long ~ 3 liters
- Convert the UV from $^3He(\vec{n},p)t$ to blue light and be a good light guide
  - Build the cell from UVT acrylic (hydrogenated at present)
  - Coat the inner cell walls with dTPB (25-40%) in a dPS matrix: >1 μm
  - Blue light transmission loss < 15%
  - Optical quality glue joints
- Long depolarization time for the ^3He
  - Verified to be ~25,000 s for dTPB in a dPS matrix when scaled to nEDM dimensions in experiments at Duke/NCSU and UIUC
- Long storage and depolarization times for the UCNs
  - Negligible losses in joints and valve holes
  - Coating thickness > 100 nm
  - Coating thickness < 4 μm to prevent crazing during thermal cycling
  - Desired average wall-loss per bounce $f \sim 10^{-5}$ at < 1 K to be negligible compared to decay and ^3He absorption

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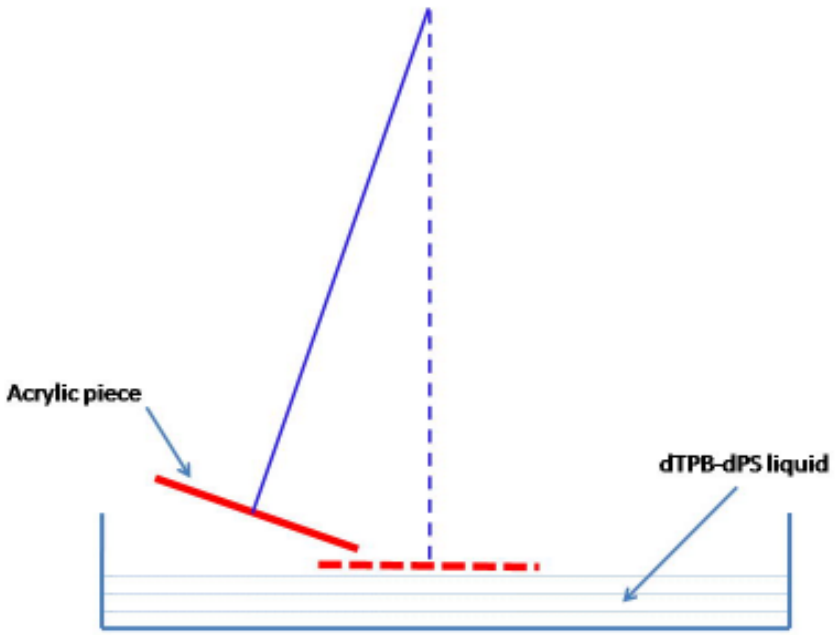
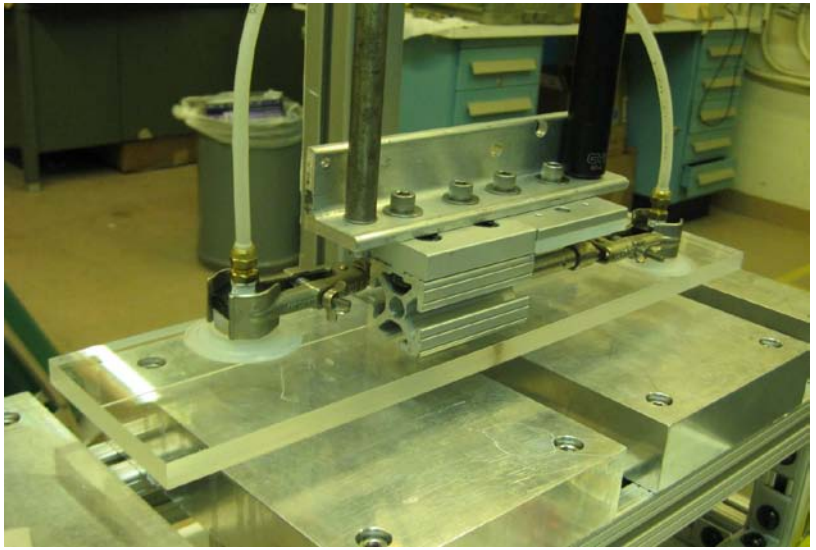
Swing Coating

Cell is built from 6 plates. Four are roughly 10 cm x 40 cm x 1.3 cm and two are roughly 4 cm x 4 cm x 0.6 cm. Eventually, the small ones will be deuterated.

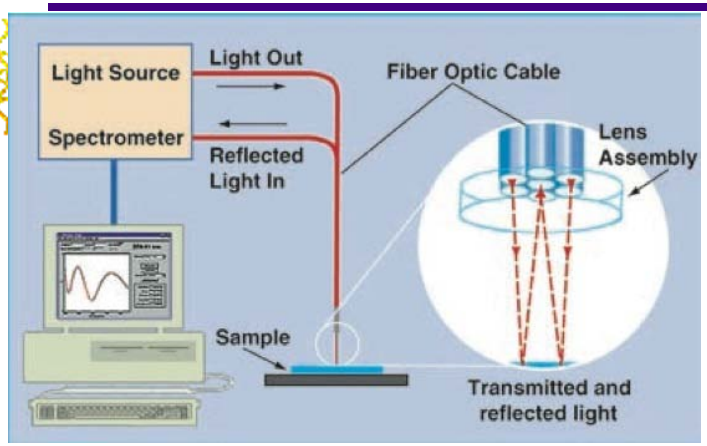


- Technique developed during ^{3}He wall depolarization studies (Gao, Golub, Ye)
- Plate is dipped into d-toluene+dPS/dTPB solution, swung out very slowly and smoothly
- Quality of results depends on the viscosity
- NCSU is also investigating using an automated applicator to drip the coating mixture onto the plate – excess liquid is then shaken off

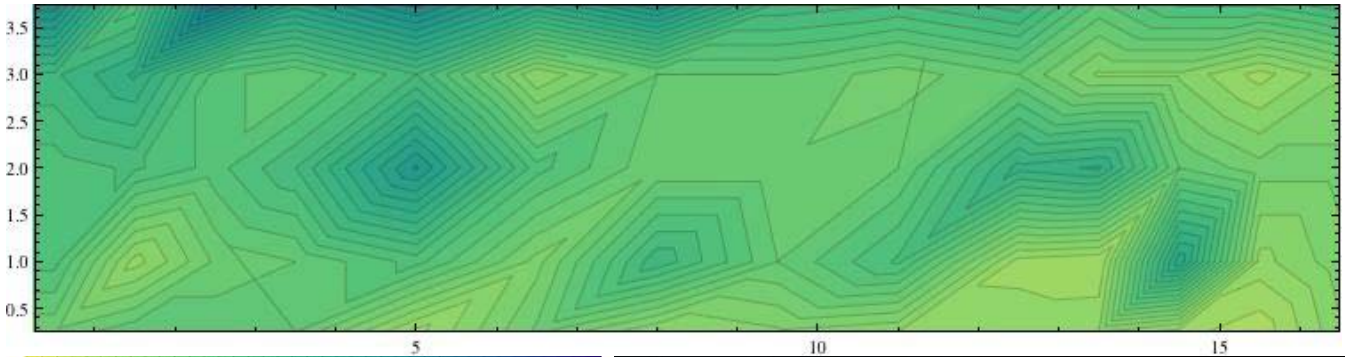
Swing Coating

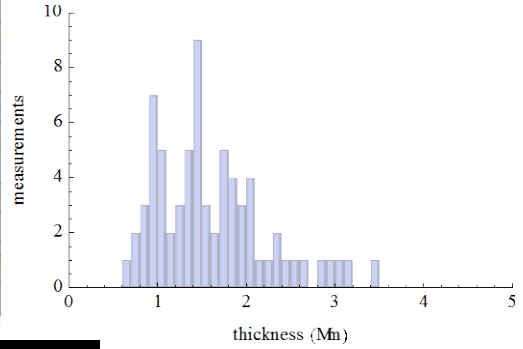


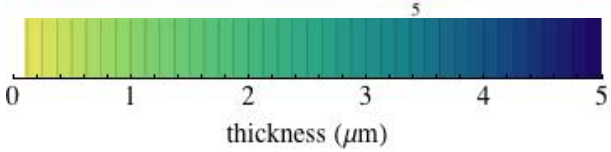
Coating Thickness

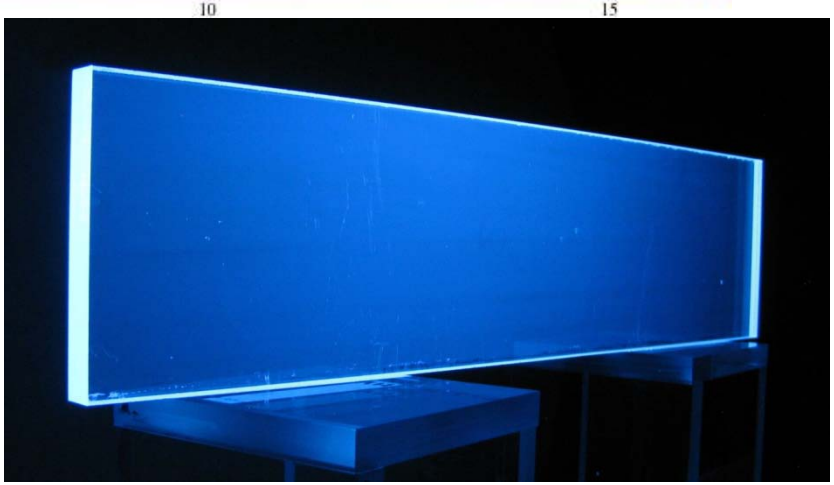


- Coating thickness is checked with a spectral reflectometer
- Coating observed with UV light for imperfections; transparent in room light
- TPB degradation may not allow these techniques in final cells

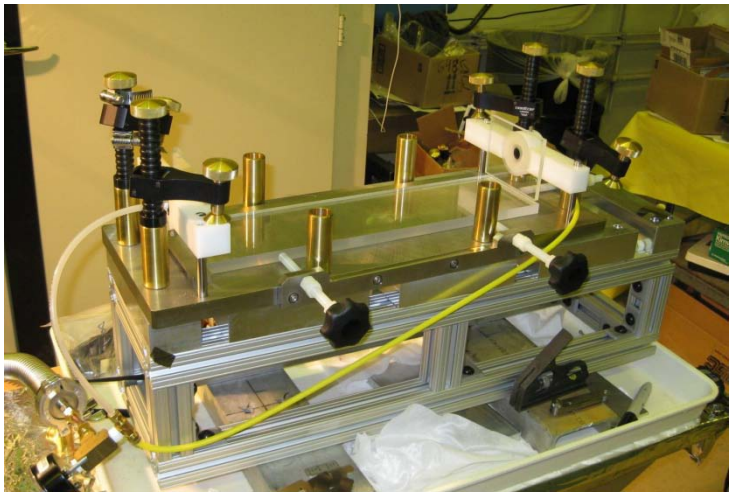


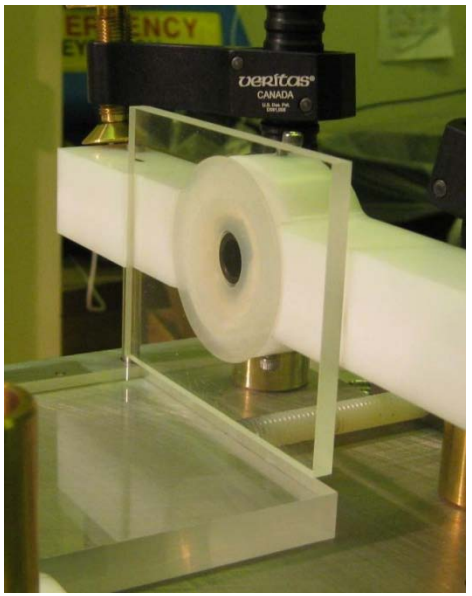




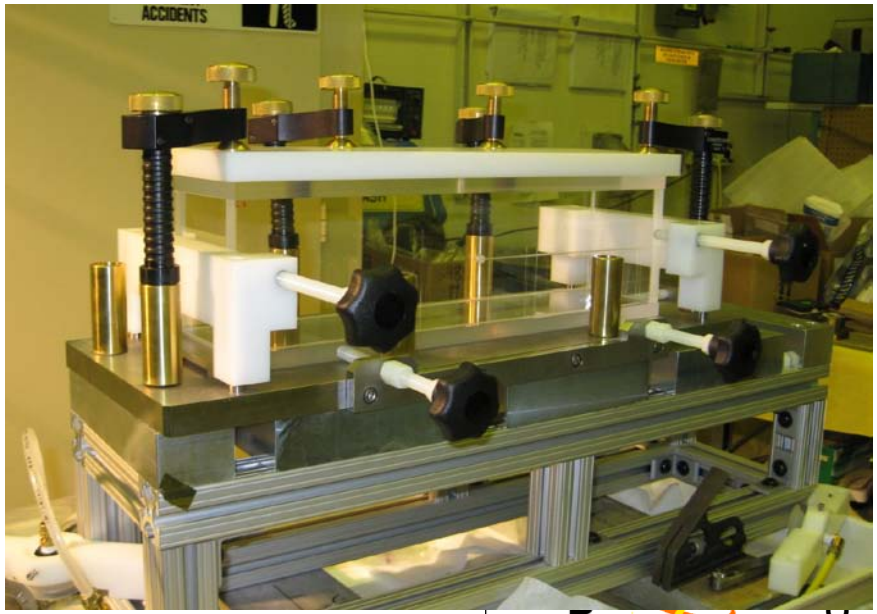


Gluing Jig

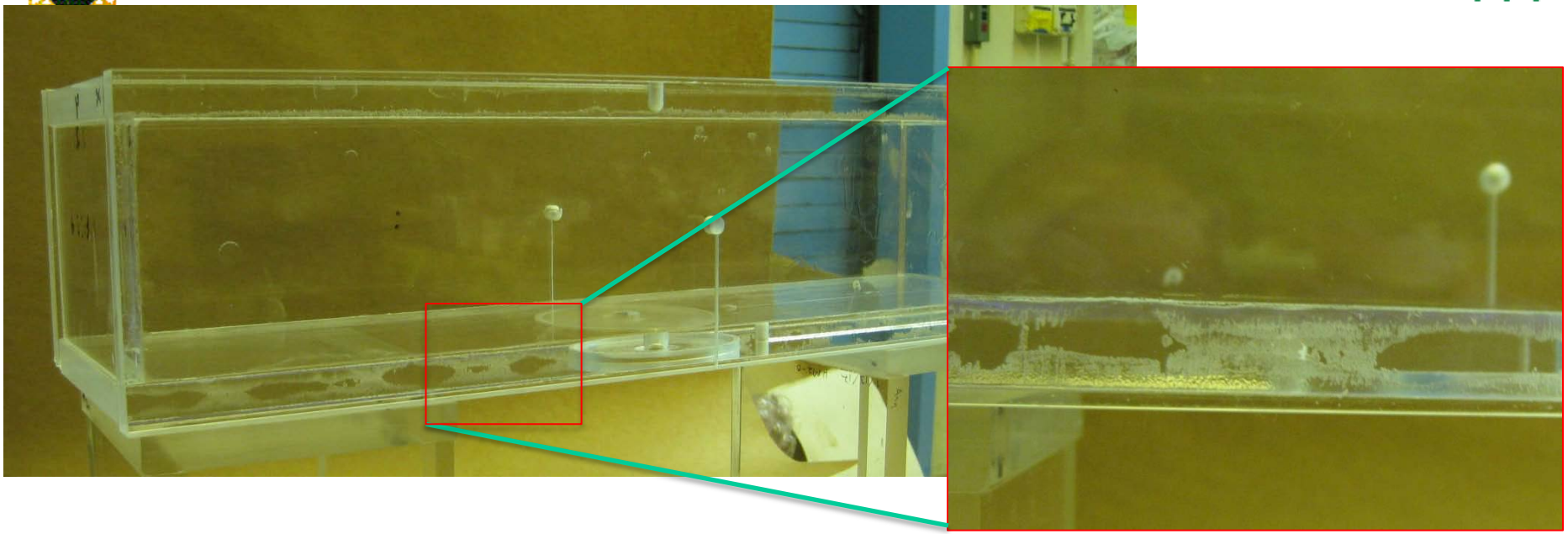


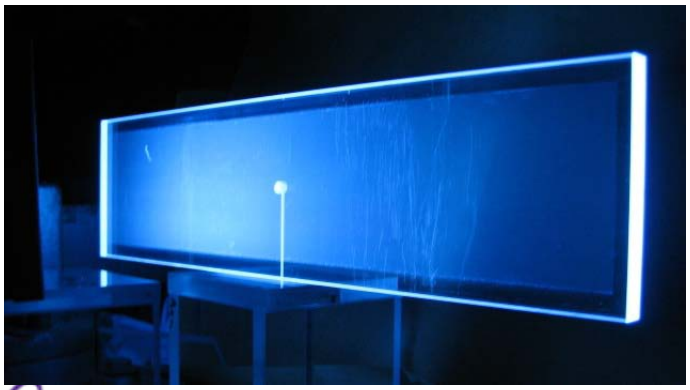


- Need to precisely position plates while minimizing handling and without touching inner surfaces
- Initial steps use external suction cups to hold plates
- Glue: deuterated MC-Bond
  - methylene chloride (81%), methyl methacrylate (14%), acetic acid (5%)



Edge Cleaning

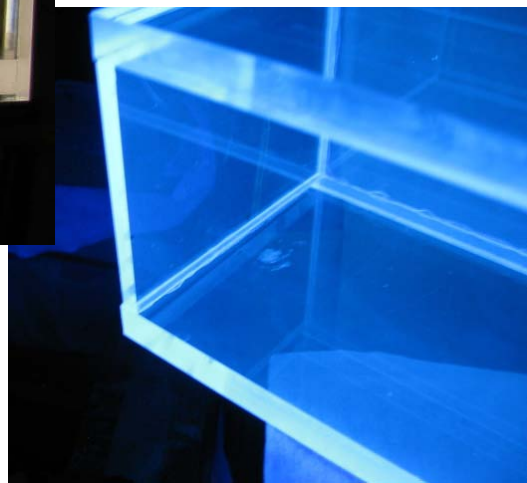




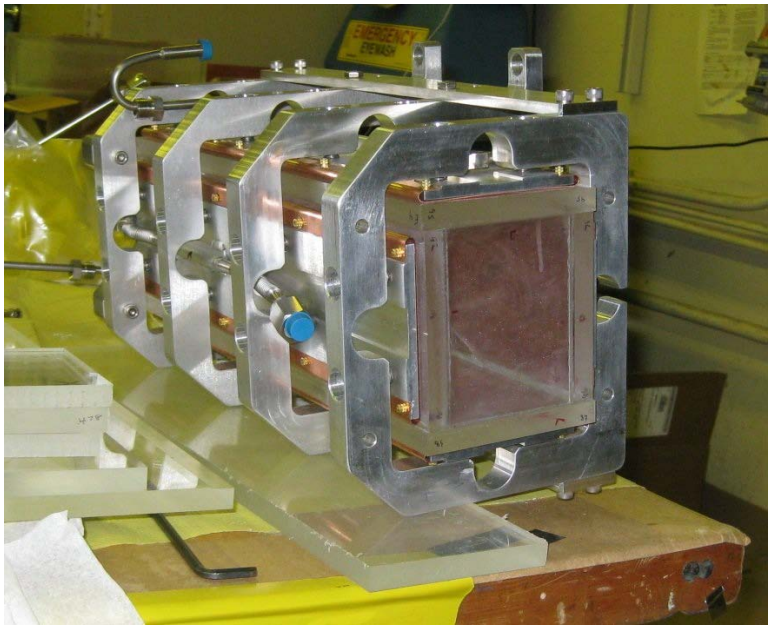
- Have found that PS/TPB layer can cause bubbling in glue joint
- For consistent results, need to clean coating off of glued areas
- Coating removed by dipping in toluene to within 1 mm of inner surface of cell

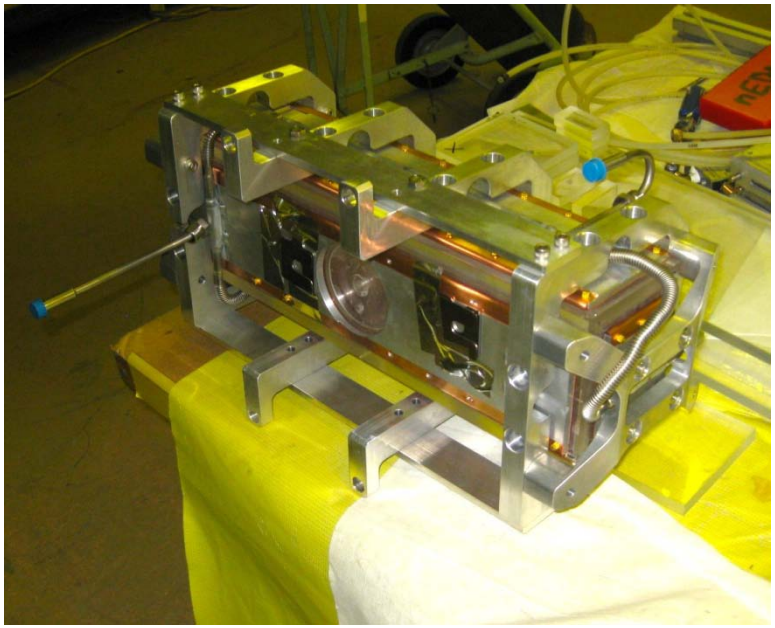
Glue Joints

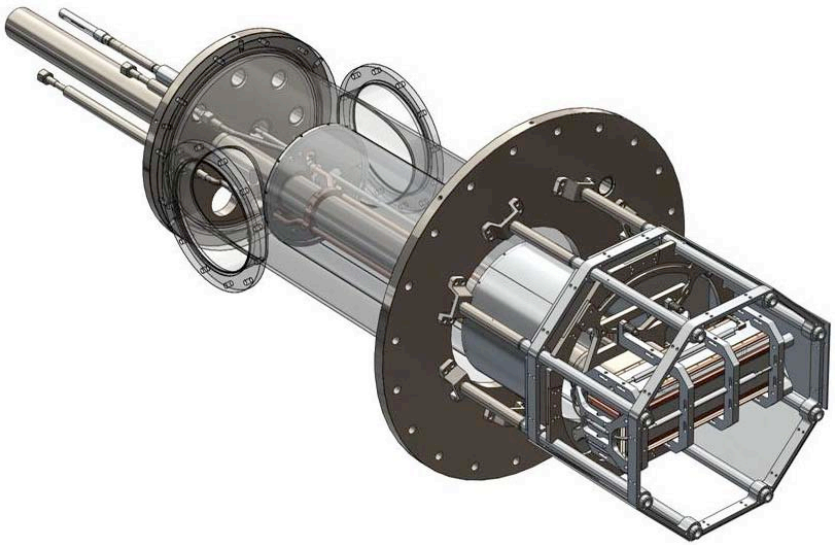
- Joints are optically clear, mostly bubble-free, have survived multiple temperature cycles without cracking



Cooling Jacket







- Spring loaded cooling plates are pressed against cell walls
- Jacket/frame also responsible for making tight contact with the UCN entrance valve

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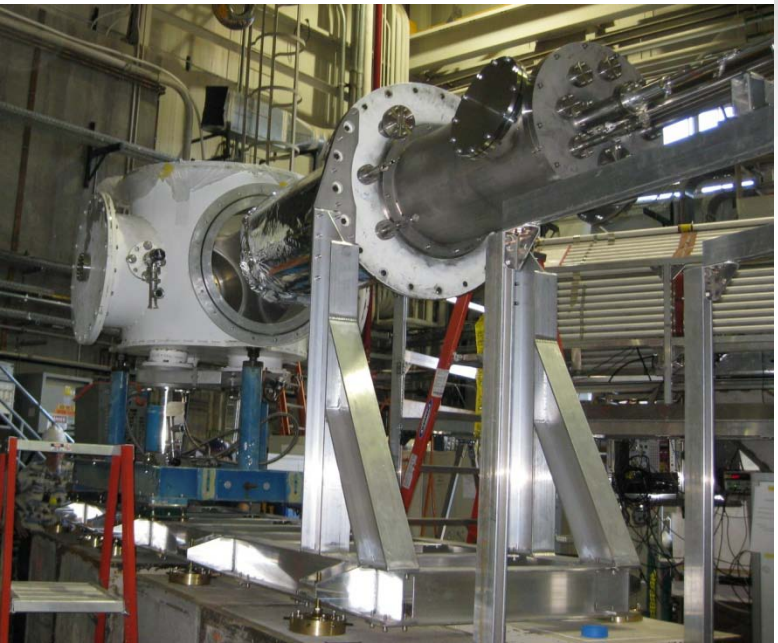
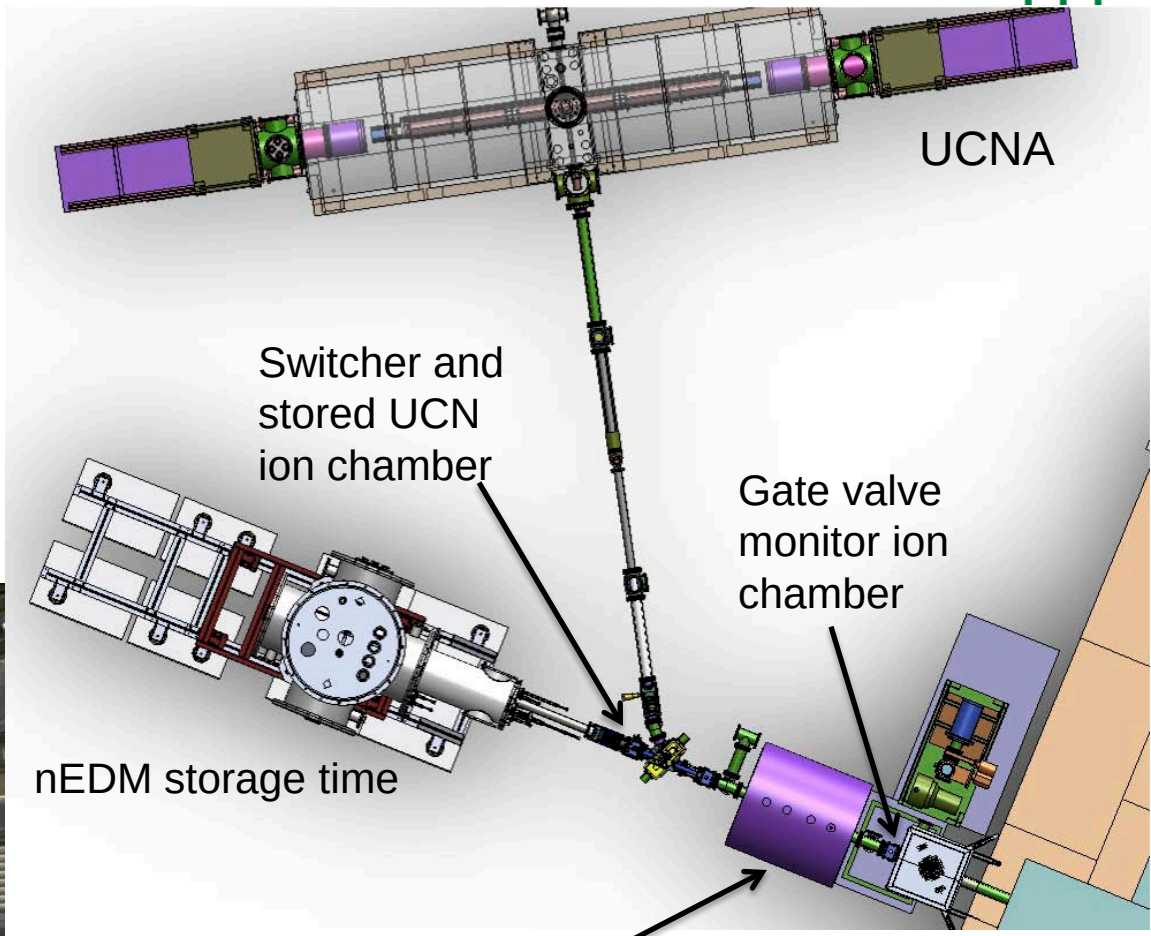
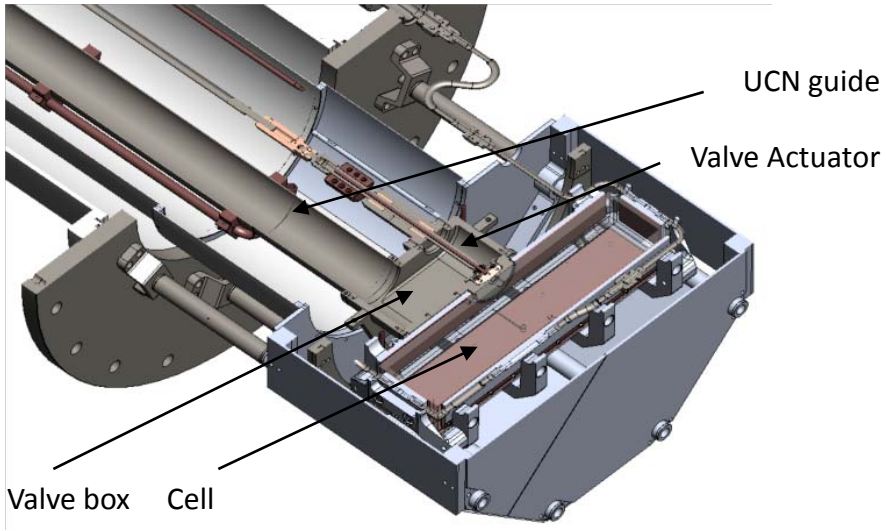
LANL UCN Storage Time Tests

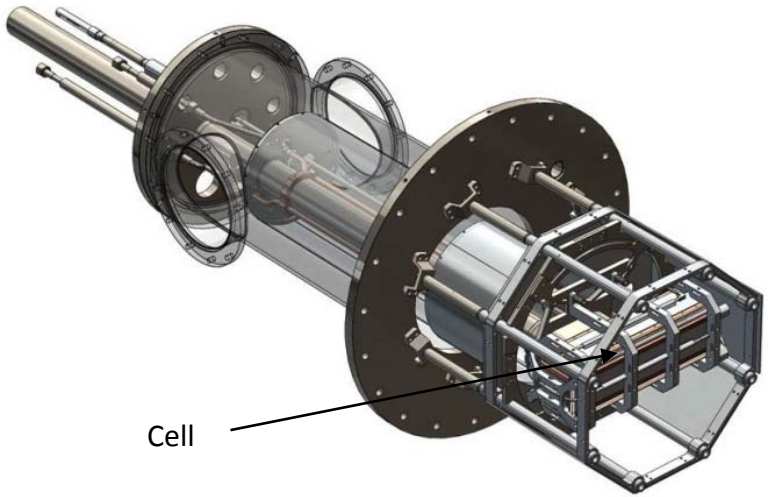
- Utilizes currently operating LANSCE UCN source
- Test wall coatings and cell construction for UCN storage





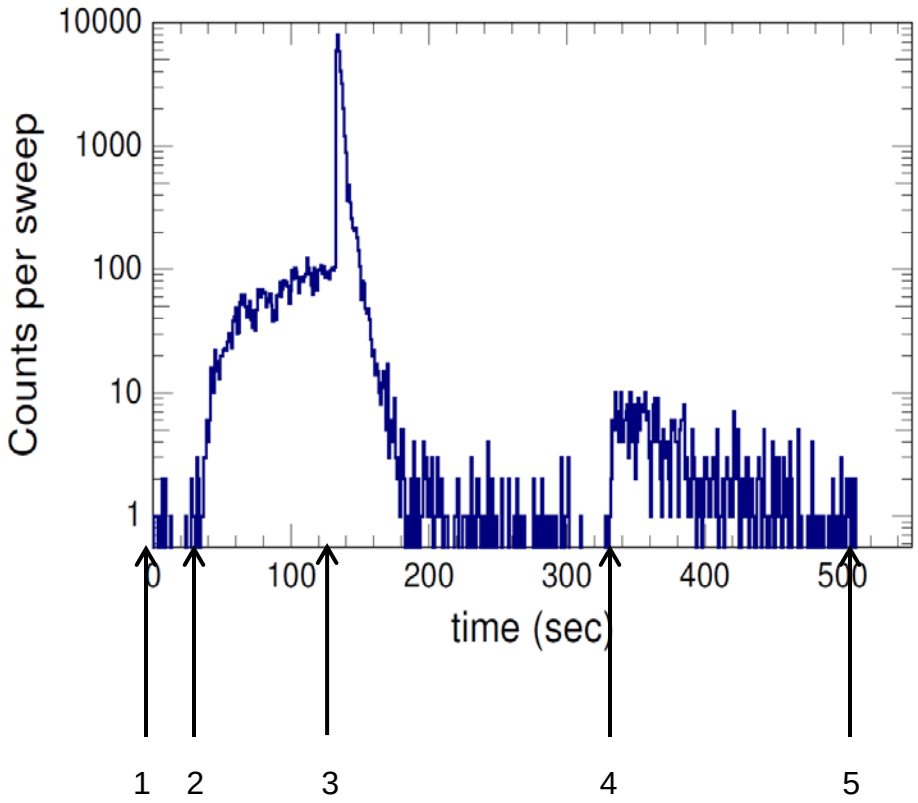
Cell Mounting





- 1-cm diameter entrance hole in middle of a long face
  - same as eventual nEDM cells where it is used for ^{3}He exchange
- Demonstrated < 25 μm valve gap
  - 25 μm gap gives 4000 s hole loss time in 3 liter cell
- 25 μm Gortex (PTFE) filler between cell and valve box
  - Spring loaded

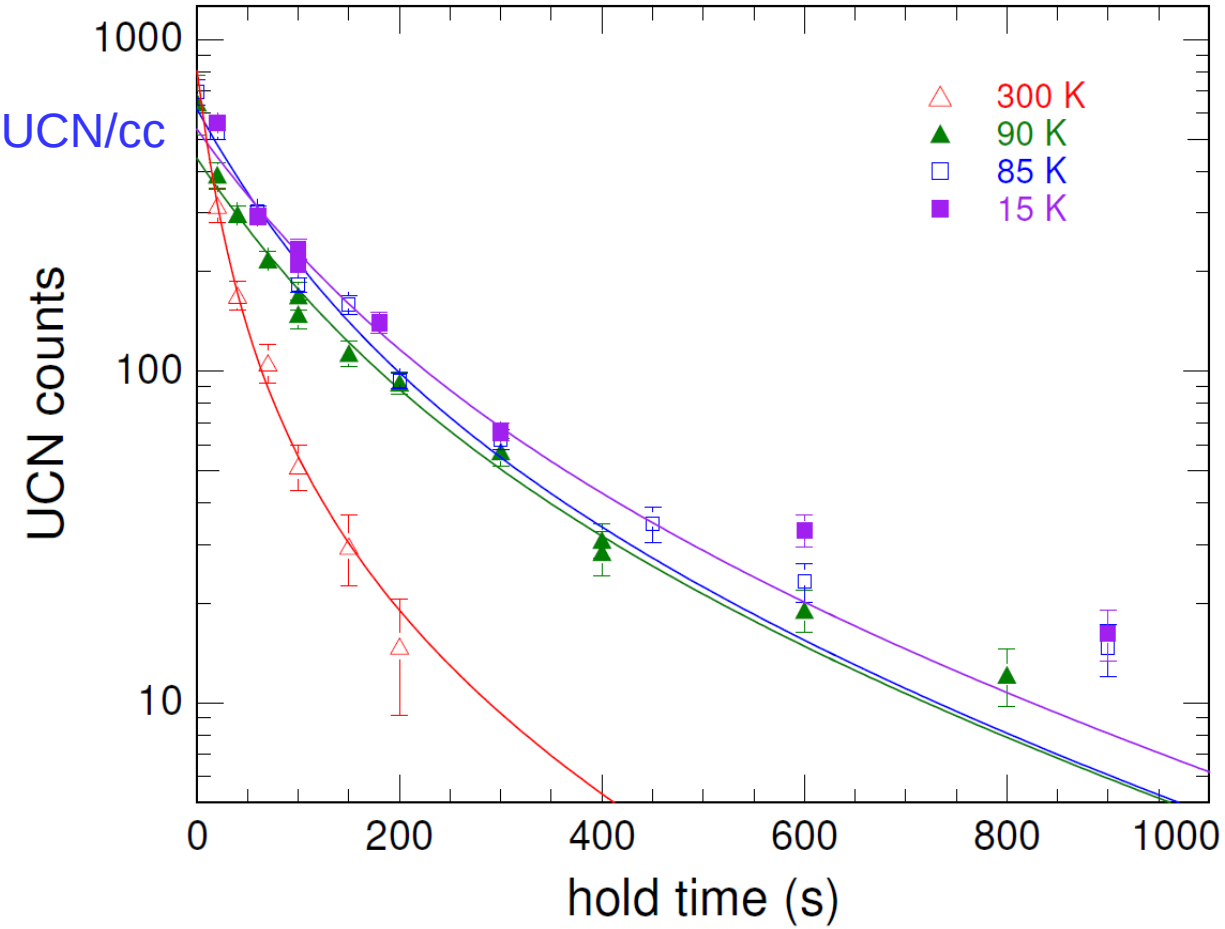
Measurement Cycle



1. 000 s – Wait 30 s beam gated off and cell open to UCN counter
2. 030 s – Fill the cell and guide – raise the switcher guide, remove the proton beam gate, open the gate valve
3. 130 s – Close the cell, lower the switcher guide to drain the UCN in the guide into the counter, gate the proton beam off, close the gate valve
4. 330 s – After an additional delay time, e.g. 200 s in this case, open the cell valve and count the UCN from the cell
5. 540 s – Go to 1 after done counting.

Storage Times

$\rho_n(0) = 0.25/\varepsilon_n$ UCN/cc



Expect storage time curves to change versus temperature, viz. Korobkina et al, PRB, 035409 (2004) for a Cu bottle. The up-scatterering from hydrogen is freezing out.

Rate Equations

Production

$$dN_{UCN}(v) = P(v)dt - N_{UCN}(v)\sum\Gamma_i(v)dt$$

$$N_{UCN}(v) = P(v)\tau(v)\left(1 - e^{-\Gamma(v)t}\right) = P(v)\tau(v)\left(1 - e^{-t/\tau(v)}\right)$$

Storage

$$dN_{UCN}(v) = -N_{UCN}(v)\sum\Gamma_i(v)dt$$

$$N_{UCN}(v) = N_0(v)e^{-\Gamma(v)t} = N_0(v)e^{-t/\tau(v)}$$

where $P(v) \sim v^n$ is the UCN production rate for the source

In the LANSCE superthermal UCN source, n = 3 from phase space and UCN self absorption in the solid deuterium

Equations are valid for each velocity

Storage Time τ in a Bottle

$$\frac{1}{\tau(v)} = \frac{1}{\tau_n} + \frac{1}{\tau_w(v)} + \frac{1}{\tau_{hole}(v)} + \frac{1}{\tau_b(v)} + \frac{1}{\tau_3} + \ldots$$

where

τ_n	neutron decay
τ_w	losses on the wall
τ_{hole}	losses through a hole
τ_b	barrier penetration
τ_3	^{3}He absorption

Integrating over velocity produces deviations from exponential storage time curves

Wall Losses

$$\frac{1}{\tau_{wall}(v)} = \frac{v}{\lambda} 2 f \left[\frac{V}{E} \sin^{-1}\left(\frac{E}{V}\right)^{\frac{1}{2}} - \left(\frac{V}{E} - 1\right)^{\frac{1}{2}} \right]$$

where
- v neutron velocity
- λ mean free path
- f average loss per bounce = W / V
- V real nuclear potential
- W imaginary nuclear potential
- E neutron kinetic energy = $\frac{1}{2} m v^2$

From Golub, Richardson, and Lamoreaux

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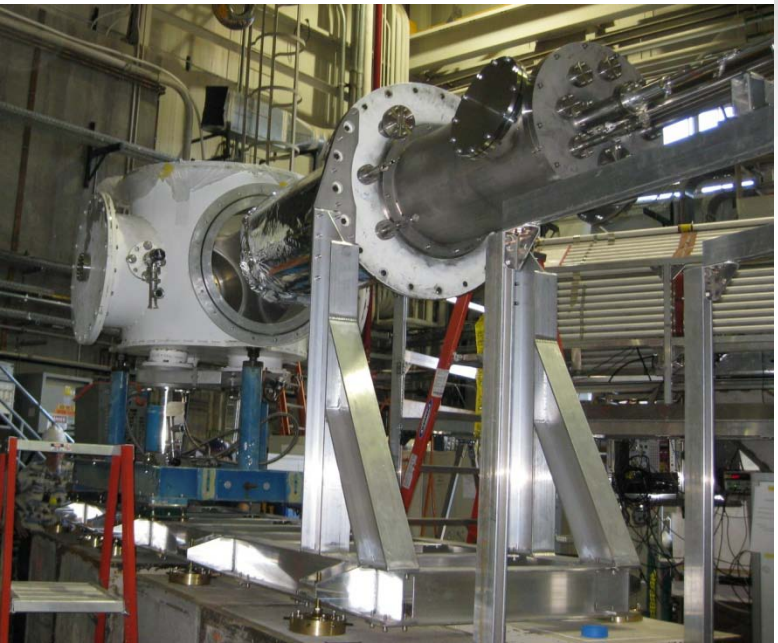
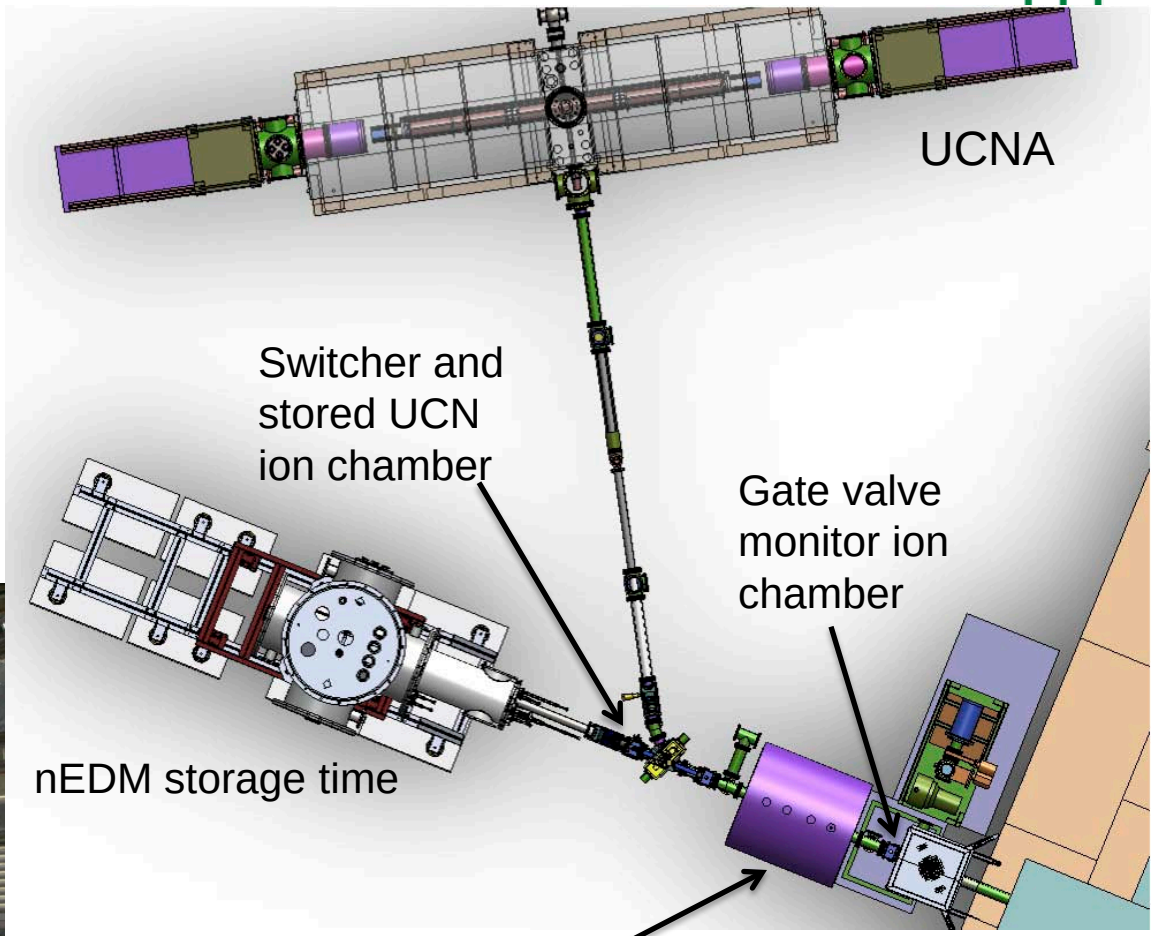
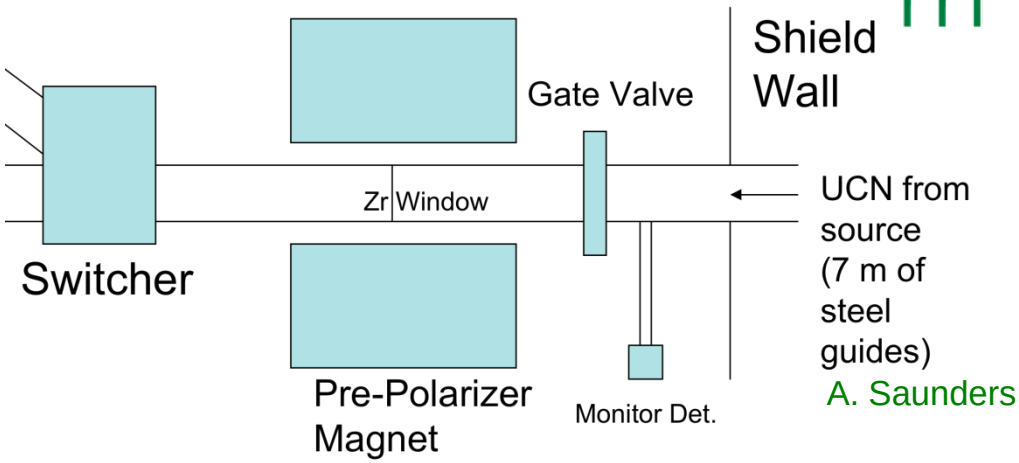


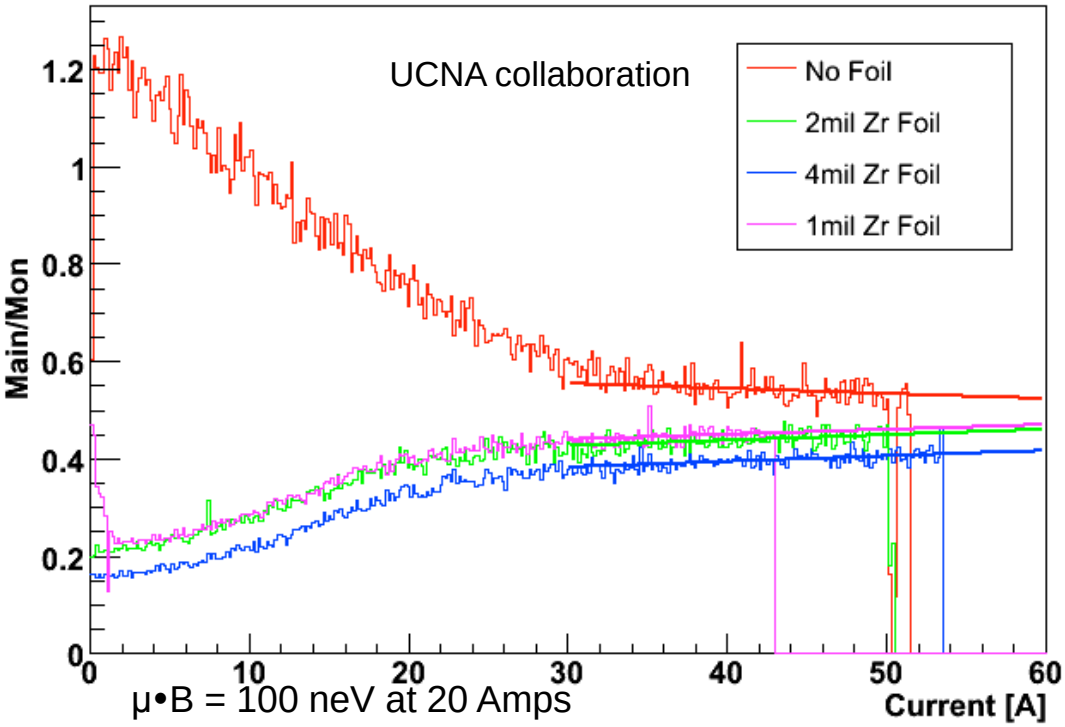


PPM Scan

- Zr foil window separates the UCN source from the detector region
- Varying the field in the Pre-Polarizing Magnet (PPM) gives a variable low energy cutoff for UCNs transmitted through the window $(\frac{1}{2}mv^2 + \vec{\mu}\cdot\vec{B})_{\perp}$ due to modified magnetic energy and focusing or defocusing for the two polarization states
- Only the highest energy UCN enter the cell with the PPM off

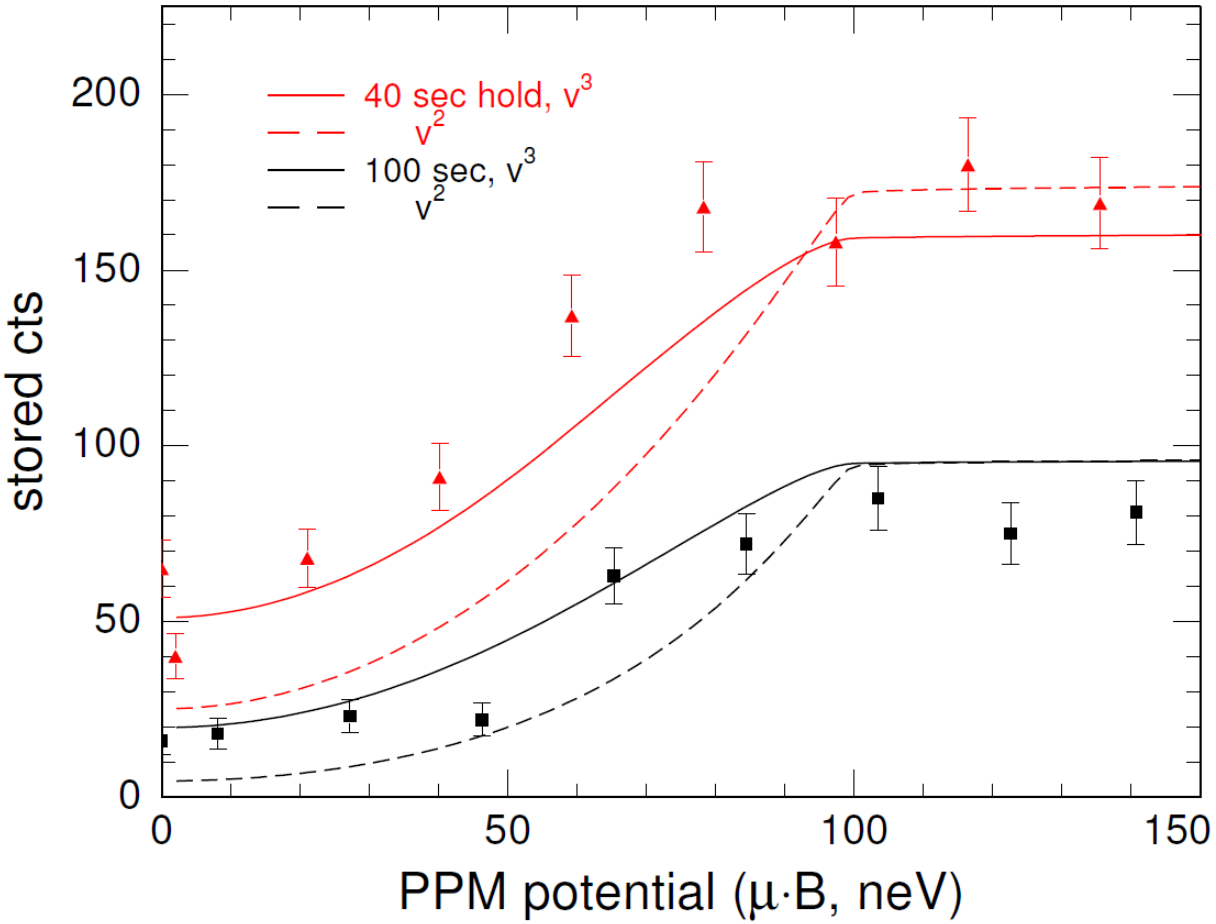


A. Saunders



μ•B = 100 neV at 20 Amps

PPM Scan


40 sec hold, v3
v2
100 sec, v3
v2
stored cts
PPM potential (μ·B, neV)
0
50
100
150
200

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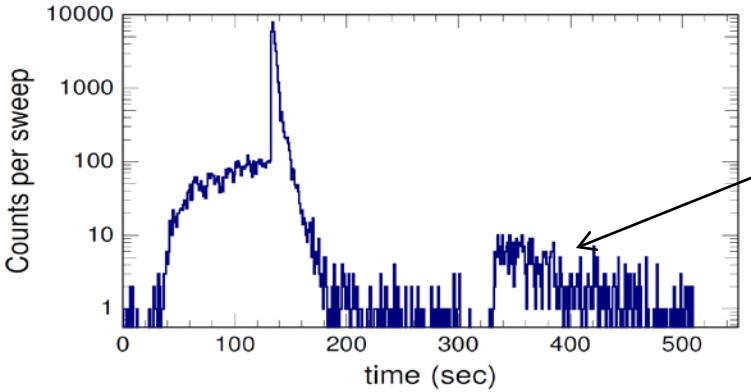
Values for f

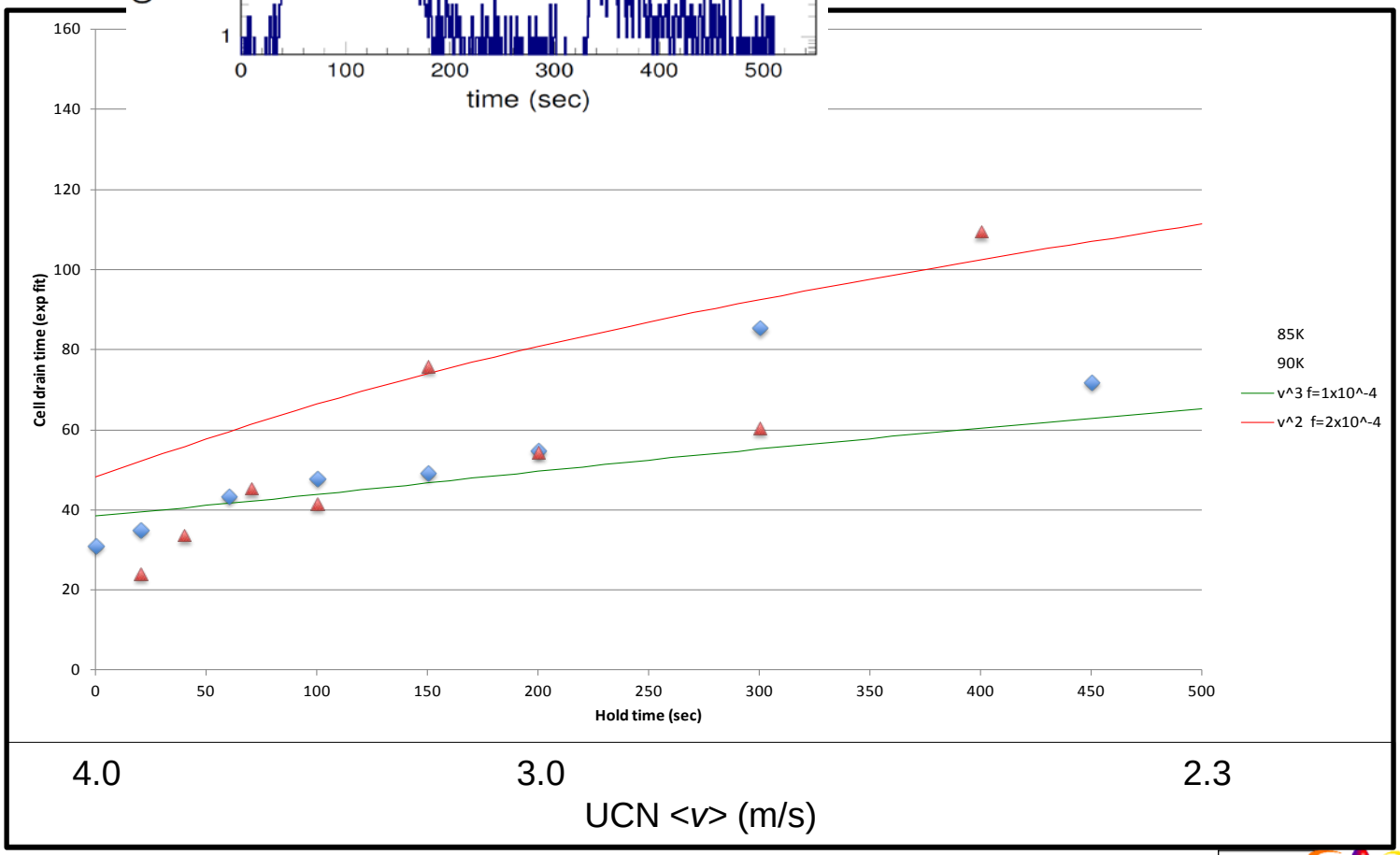
	Fits assume v^3 for source output phase space					
	All Hold Times			Hold Times < 300 s		
T (K)	$f(10^{-4})$	$\Delta f(10^{-4})$	χ^2/DOF	$f(10^{-4})$	$\Delta f(10^{-4})$	χ^2/DOF
300	6.9	1.7	0.5			
90	1.06	0.11	1.7	1.13	0.14	1.8
85	1.26	0.20	5.9	1.46	0.19	4.3
15	0.98	0.21	7.4	1.16	0.21	4.7

	Fits assume v^2 for source output phase space					
	All Hold Times					
T (K)	$f(10^{-4})$	$\Delta f(10^{-4})$	χ^2/DOF			
300	21.5	15.0	2.00			
90	2.18	0.22	0.83			
85	2.53	0.30	2.11			
15	1.99	0.42	3.64			

Source Production – v^2 or v^3



Cell drain time
from exponential fit



4.0 3.0 2.3

UCN <*v*> (m/s)

Conclusions and Future Work

- Have measured storage times with a cell sized for nEDM
- Consistency between storage time measurements, PPM sweeps, and cell drain times with v^3 source phase space
- Measured values of f are larger than desired
- Work in progress

- Flushing with Ar and baking cell at 50 °C for ~2 weeks to explore low mass surface contaminations
- Looking into other loss mechanisms, e.g. rough surfaces or vibrations
- RGA shows a hint of d-methylene chloride from the glue
- Looking to make our modeling more sophisticated