UCN Production in Oxygen: Experimental Results

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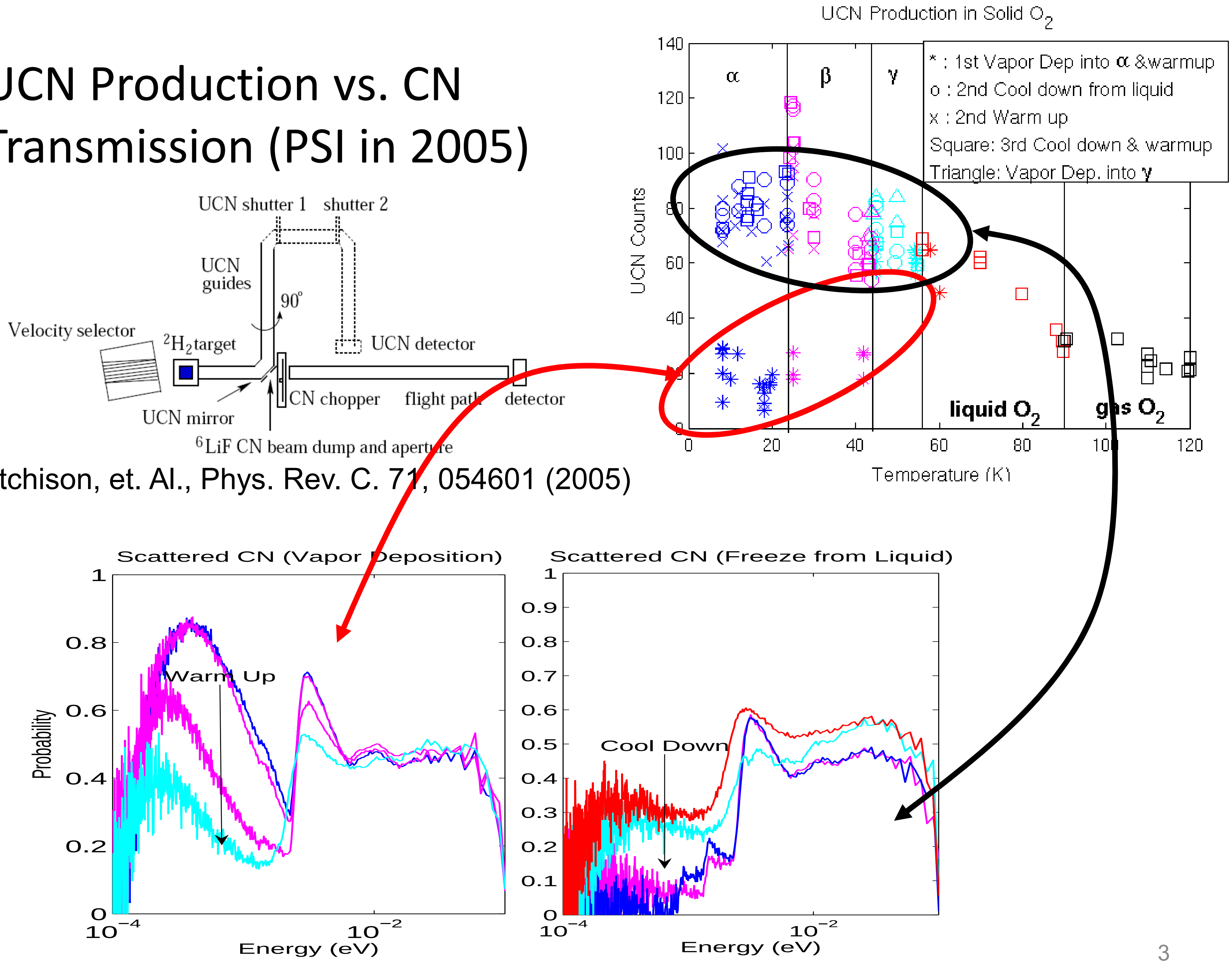
Outline

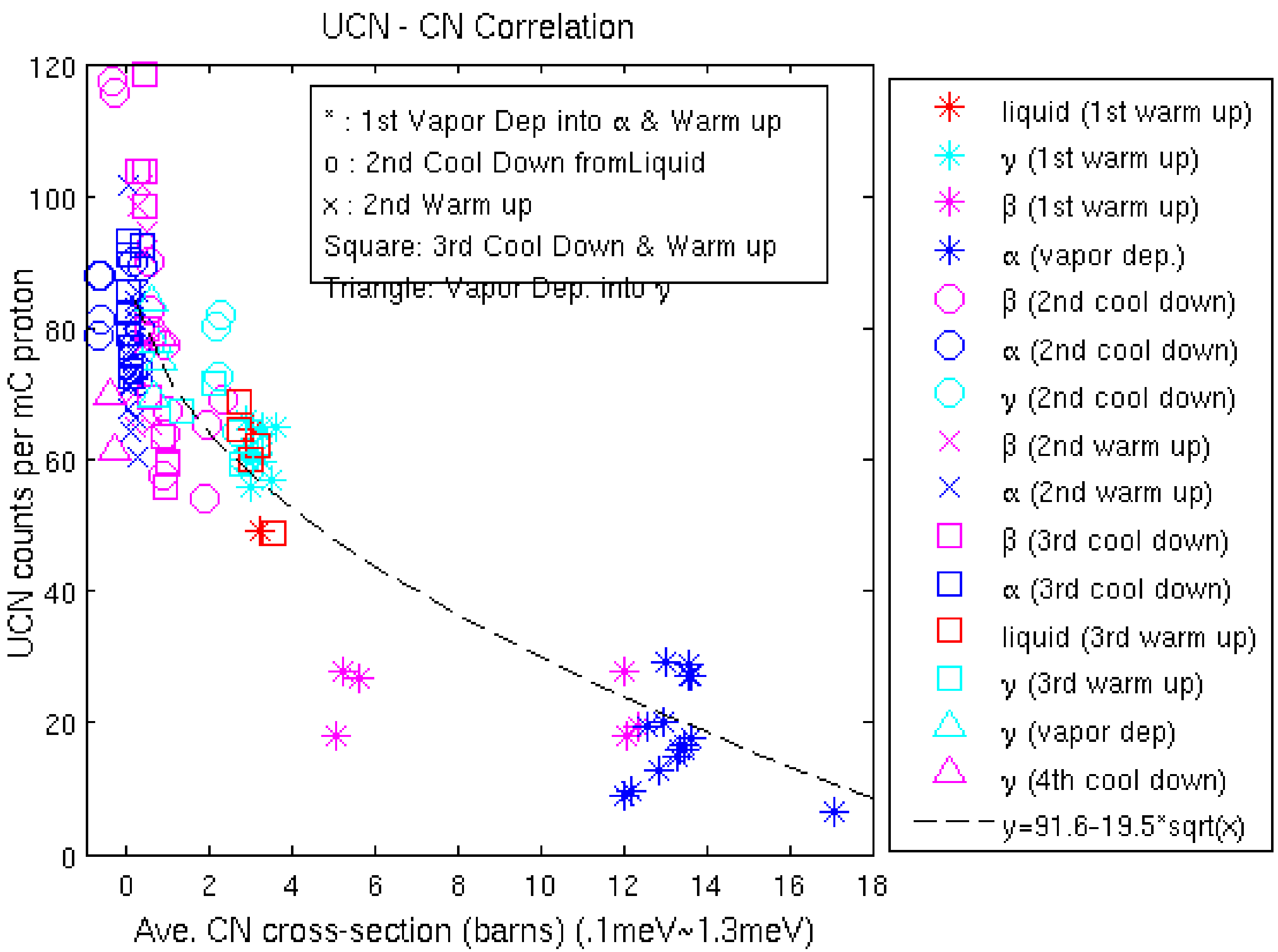
- Apparatus specifications
- Calibration with 97.3% o-D_2
- Discussion of uncertainties
- UCN Signal with O_2
- UCN mean-free-path in O_2

UCN Production vs. CN Transmission (PSI in 2005)



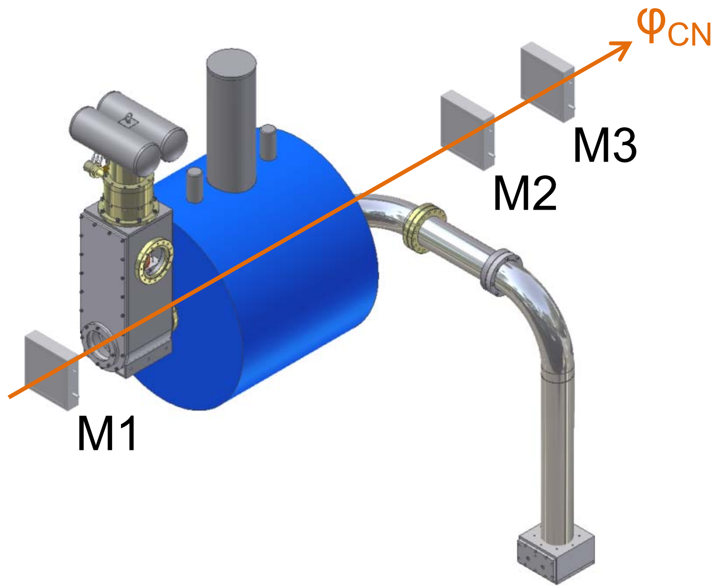
F. Atchison, et. Al., Phys. Rev. C. 71, 054601 (2005)

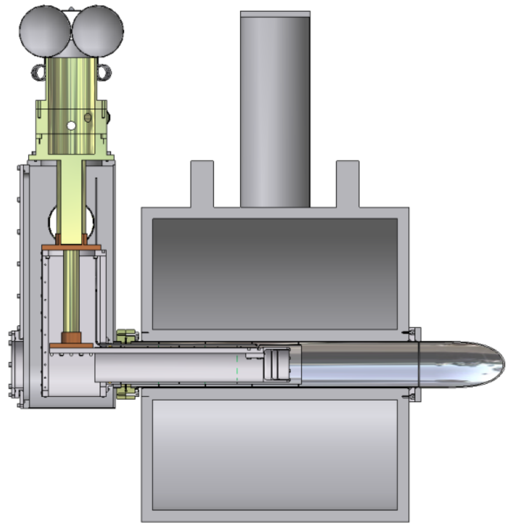
Cold Neutron Monitors Can Probe Crystal Quality



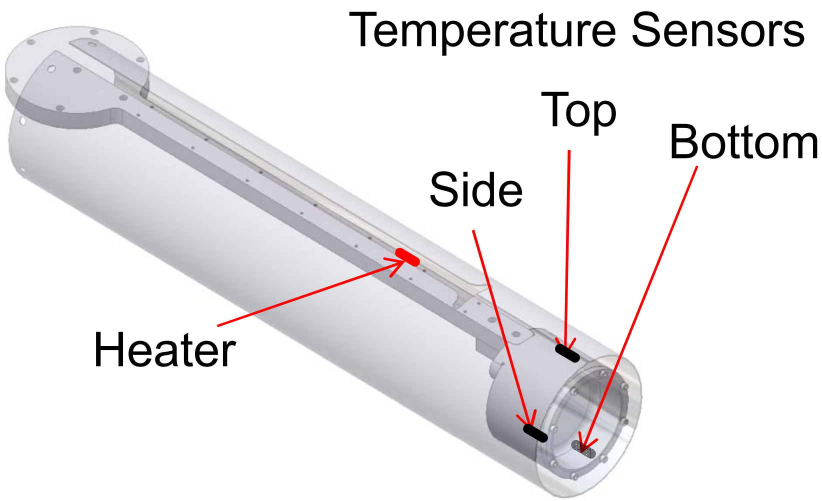
Instrument Overview

- Temperatures down to 5 K with Pulse-Tube refrigerator
- Cylindrical target 6.6 cm radius, 1.1, 3.5, 8.6 cm lengths
- Electro-polished S.S. UCN Guides (Rath)
  - Four inch inner diameter
  - 186 neV effective potential
  - Electro-polished (0.25 µm Ra)
- Helium-3 Ion Chamber detector (courtesy P-25 at LANL)
- Installed at LANSCE Lujan Center's flight path 12
- 5.5 Tesla external field using NbTi S.C. magnet





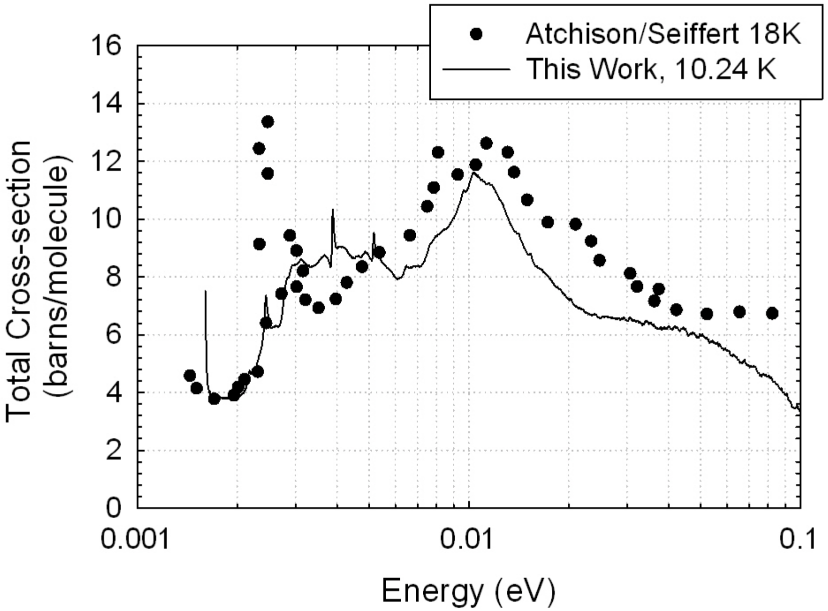
Cryogenics

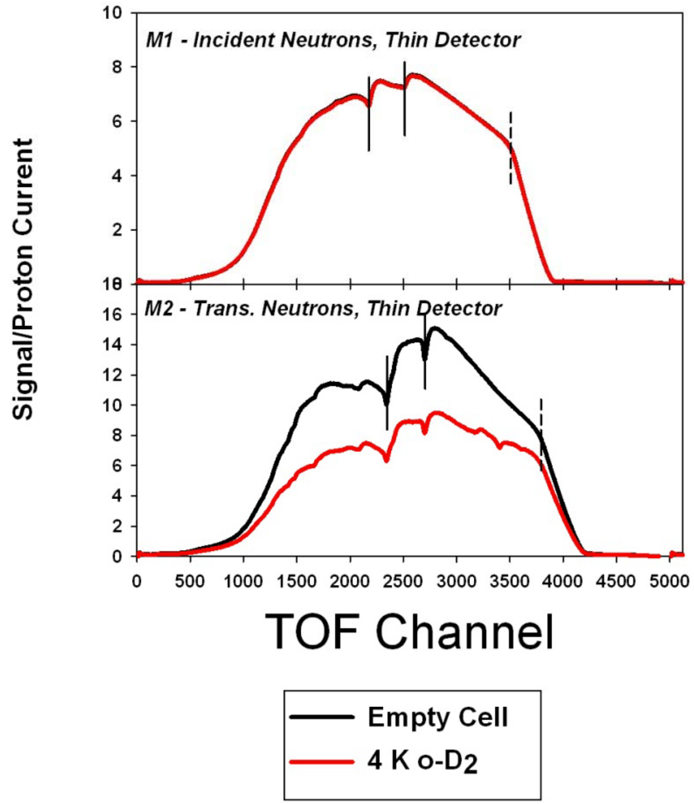


- 6061 Al
- Temperature stability 15-20 mK
- 60 mK temperature gradient across cell
- Very slow cool-downs possible (50 mK/hr)
- Nickel lined cold shield (M.C. suggests 10-20% of UCN re-claimed)
- Cold neutron monitors assess crystal quality
- Pressure sensors on gas fill line and storage tank

Beam Monitors and Normalization

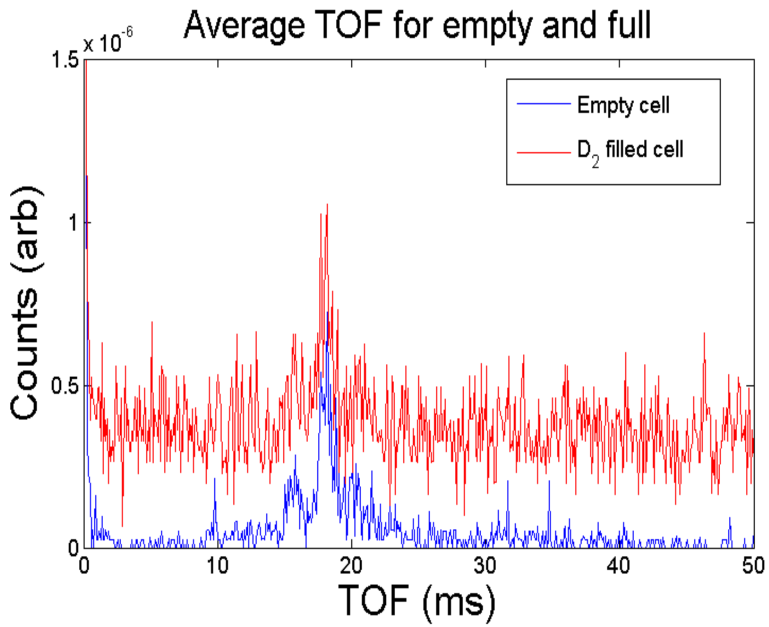
- M1, M2 thin detectors
- TOF spectra integrated over each run
- M1 gives normalization to CN flux ($8.6 \cdot 10^4$ n/cm^2/s/µA) (S. Penttila, C. Crawford, Y. Shin)
- Pulsed CN source at 20Hz repetition rate
- M2/M1 provides transmission measurement of total cross-section

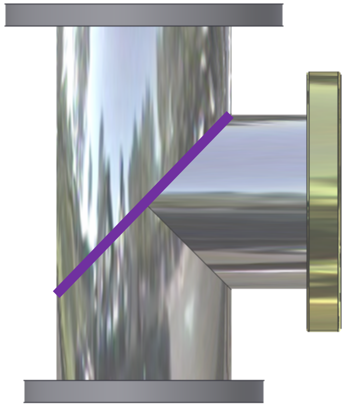




Background

- Lithium and Borated Polyethylene to shield from radiation in experimental area. 200 Hz to 150mHz background with shielding.
- Diffraction from steel contaminates UCN signal with Bragg peaks
- Background data sufficient to fit and subtract
- Signal to background 5 with elbow, 12 with Ni Mirror





Background – Steel Diffraction + Incoherent Scattering

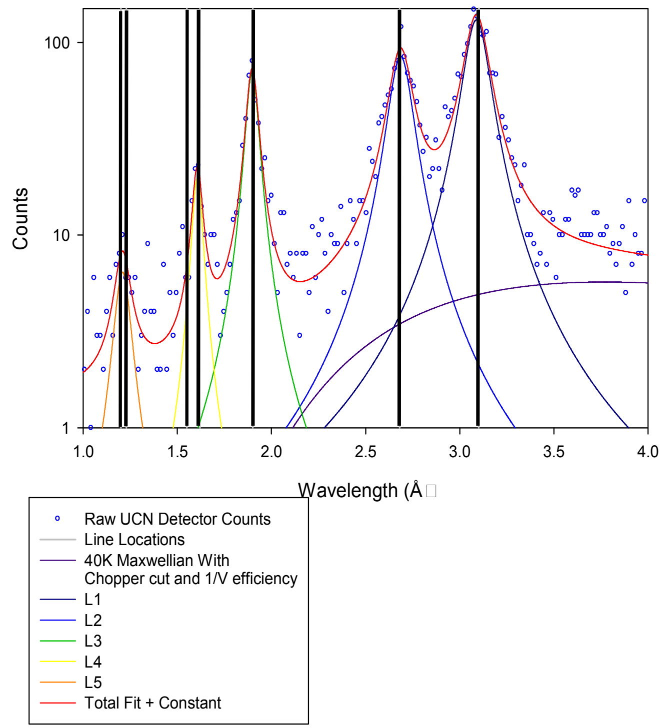
- We know that the steel is 316L stainless steel (16-18Cr, 10-14Ni + 2-3Mo), FCC Lattice

J. Appl. Crys. 36, 1159-1168 (2003).

Table 1
The measured lattice parameters and applied stresses for the austenitic steel at applied strains of 692 με and 1075 με.

Load (με)	Slope	$a_{\perp}$ (Å)	Stress (MPa)	a_0^{mech} (Å)
692	2.9 (1) × 10^{-3}	3.60824 (4)	137 (7)	3.60891 (5)
1075	3.8 (1) × 10^{-3}	3.6079 (6)	178 (2)	3.60889 (6)

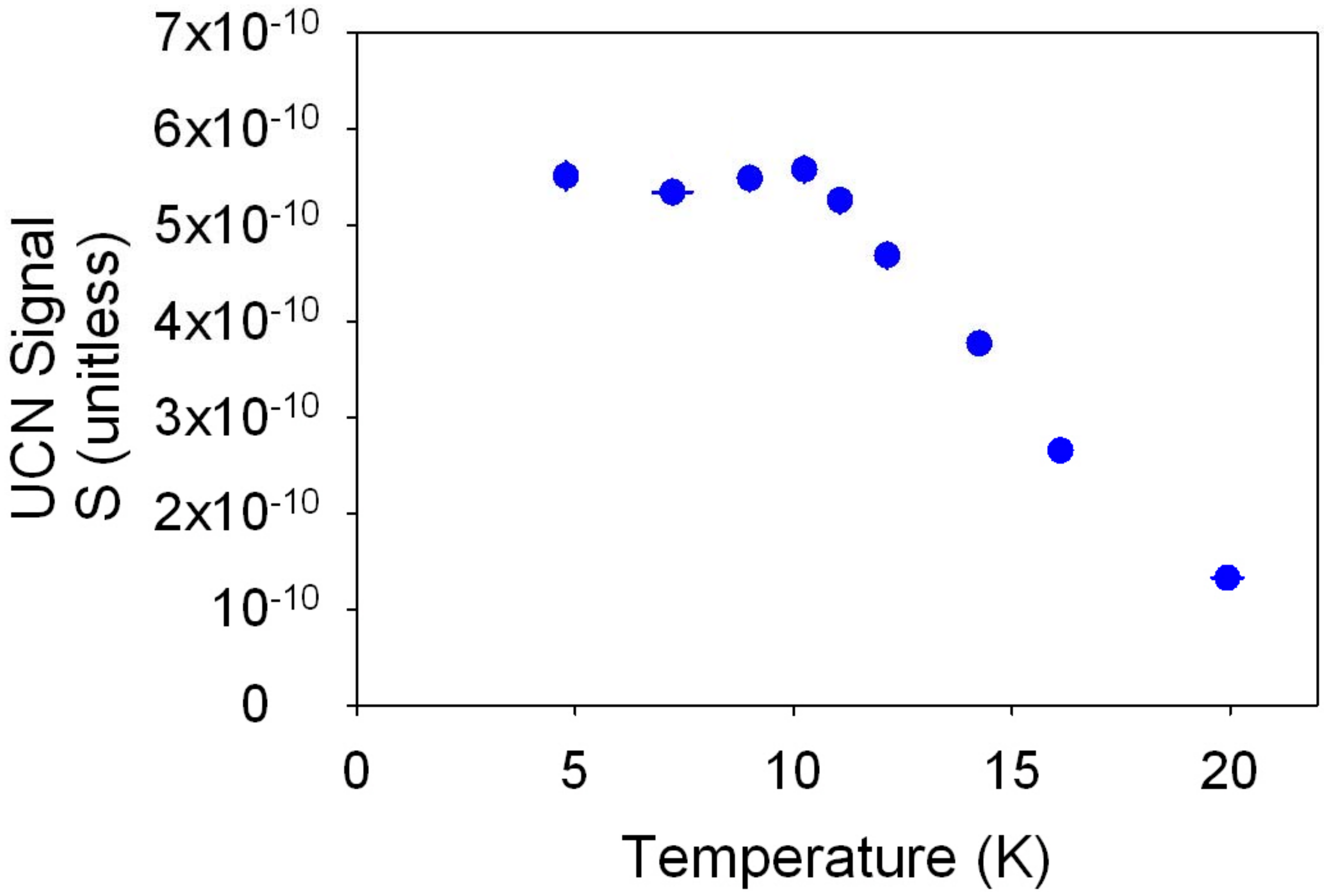
Miller	Calc	Observed
111	3.10	3.09 (L1)
200	2.69	2.69 (L2)
220	1.90	1.90 (L3)
311	1.62	1.61 (L4)
222	1.55	-
331	1.23	-
420	1.20	1.21 (L5)



The Measurements

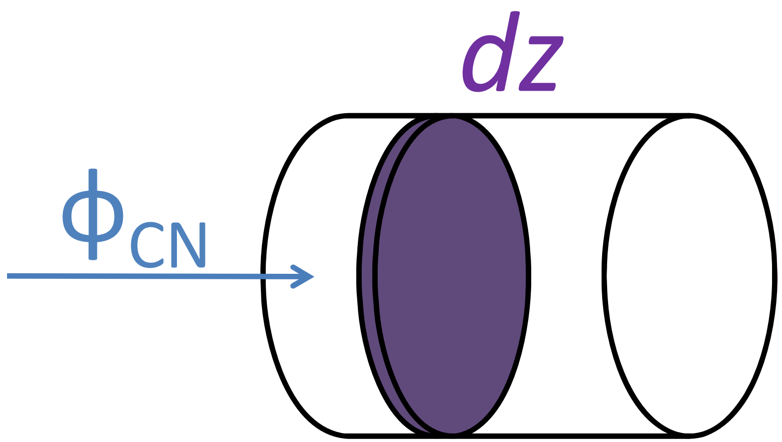
- Method
  - Cryogen condensed to liquid, slowly frozen, annealed at phase transitions
  - Slow scans from liquid phase to 5k
- Data acquired
  - 1000 second integrations of UCN time of flight, and beam monitor time of flight
  - Temperature, pressure recorded once per second

D_2 calibration

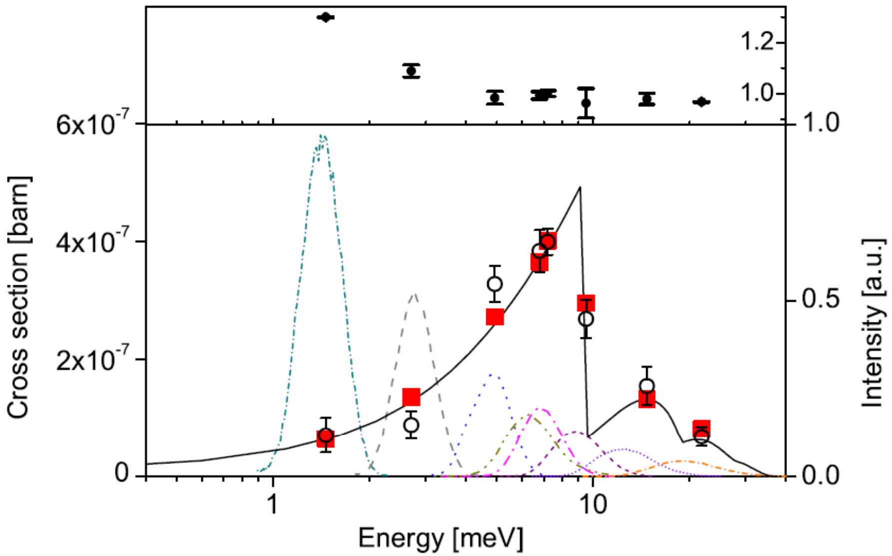


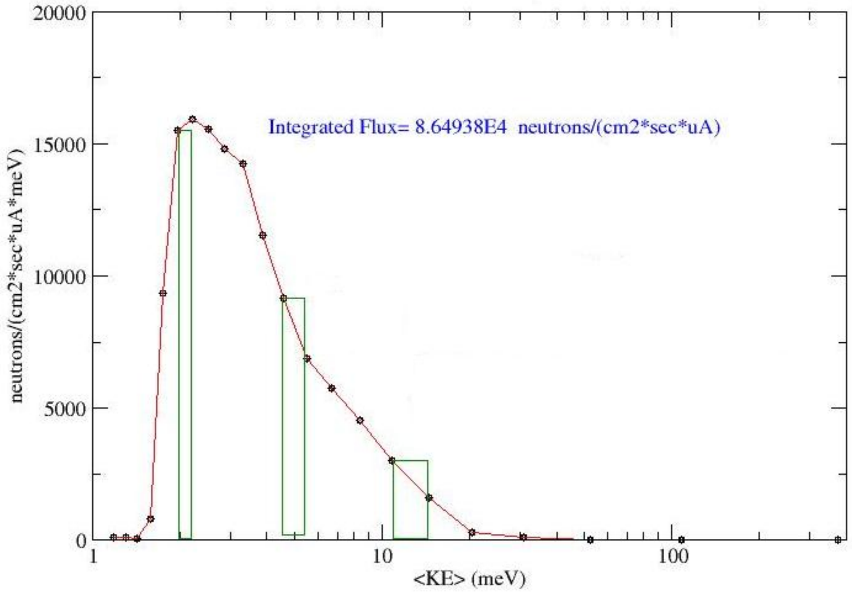
Volumetric Flux Dependence

$$\varphi(z) = \varphi_0 \cdot e^{-n\langle\sigma_s\rangle z}$$



Initial State Energy Dependence



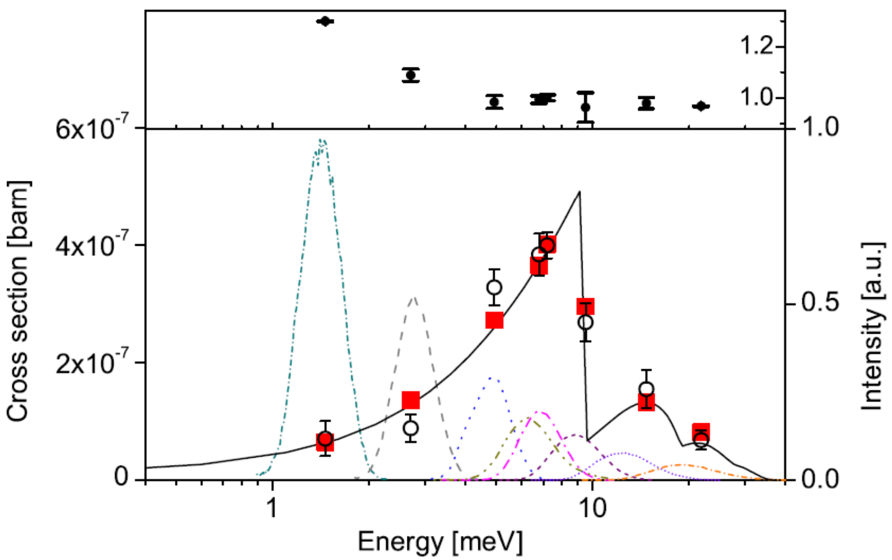


[1]F. Atchison, et al. PRL 99, 262502 (2007)

$$\bar{\sigma} = \frac{\int_0^\infty dE\,\phi(E)\sigma(E \rightarrow E_{ucn})}{\int_0^\infty dE\,\phi(E)},$$

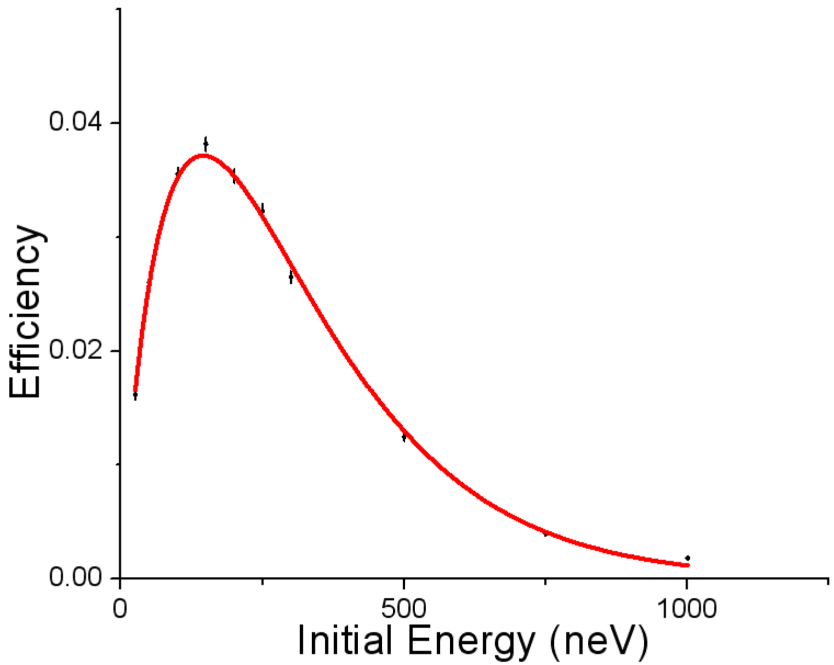
$\sigma = 1.84 \times 10^{-7}$ b

Final State Energy Dependence



$$\frac{\partial \sigma_p}{\partial E_{UCN}} = \frac{3\overline{\sigma}}{2} \cdot \sqrt{\frac{E_{UCN}}{E_{cutoff}}}$$

Understanding The Apparatus



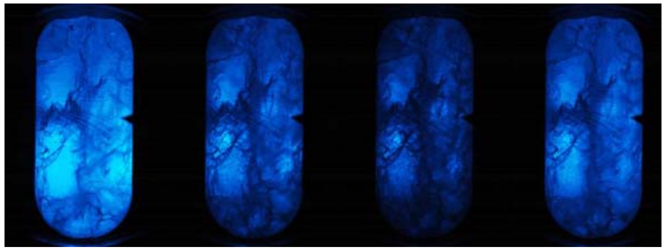
$$\varepsilon(E_{UCN}) = \varepsilon_0 \cdot E_{UCN} \cdot e^{-\frac{E_{UCN}}{E_0}}$$

$\varepsilon_0 = 7.14 \cdot 10^{-4}$
$E_0 = 145.359$ neV

$$U = \int_0^L dz \cdot nA\varphi(z) \cdot \int_0^\infty \frac{\partial \sigma_p}{\partial E_{UCN}} \varepsilon(E_{UCN}) dE_{UCN} \Rightarrow \boxed{U = nA \frac{9E_0^{2.5}\varepsilon_0\sigma_0}{8}\sqrt{\frac{\pi}{E_{cutoff}^3}}\varphi_0 \cdot \frac{1-e^{-n\sigma_s L}}{n\sigma_s}}$$

Uncertainties

- Typical count rates of 100s of mHz – low statistics
- Incident flux, D_2 production[1], D_2 transmission[2] cross section measurements constrain transport & detection efficiency to be ~1-3%
- Temperature cycling reduces crystal quality



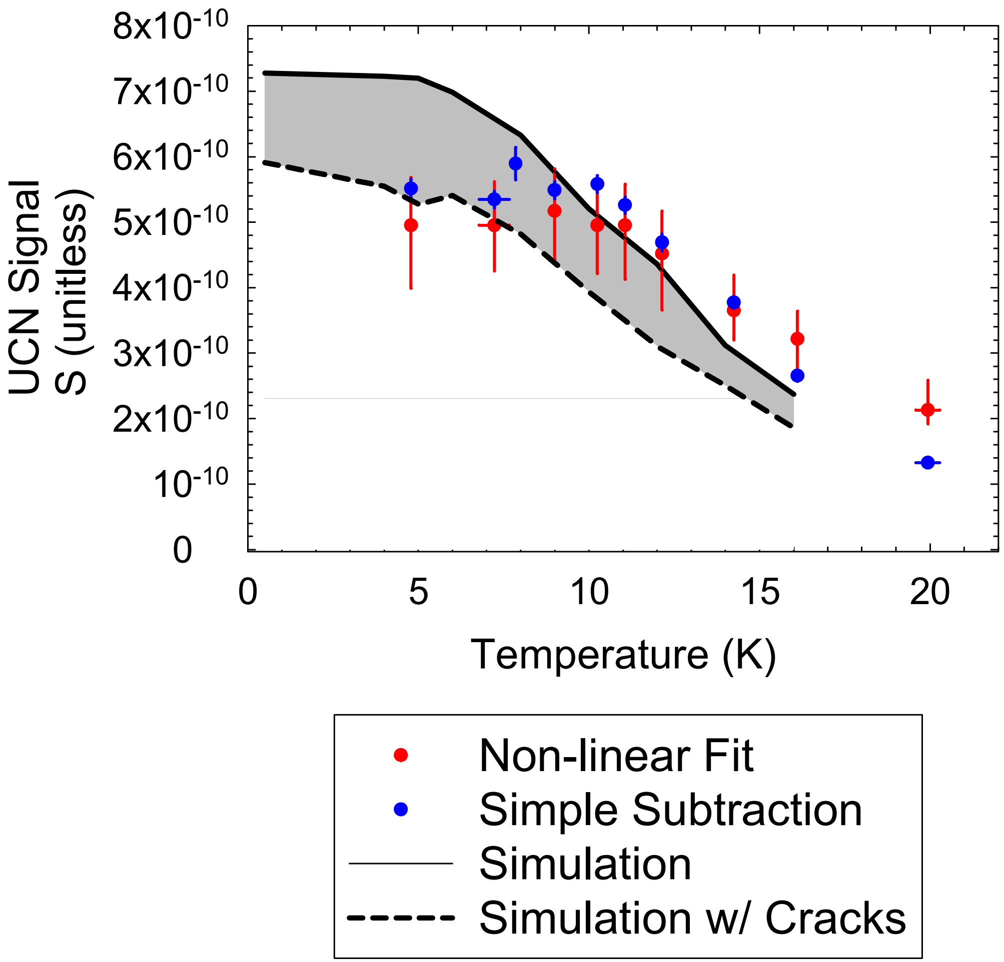
[1]F. Atchison, et al. PRL 99, 262502 (2007)
[2]F. Atchison, et al. PRL 95, 182502 (2005)

U=0.4 Hz

U_{meas}=0.6 Hz

- 5% uncertainty on measurements
- 7-10% uncertainty in incident flux
- X% UCN scattering xs in D_2
- Large material parameter uncertainties in GEANT4UCN Input parameters
  - Guide diffusivity, loss
  - Transmission through Al Windows

Temperature Dependence in Geant4UCN

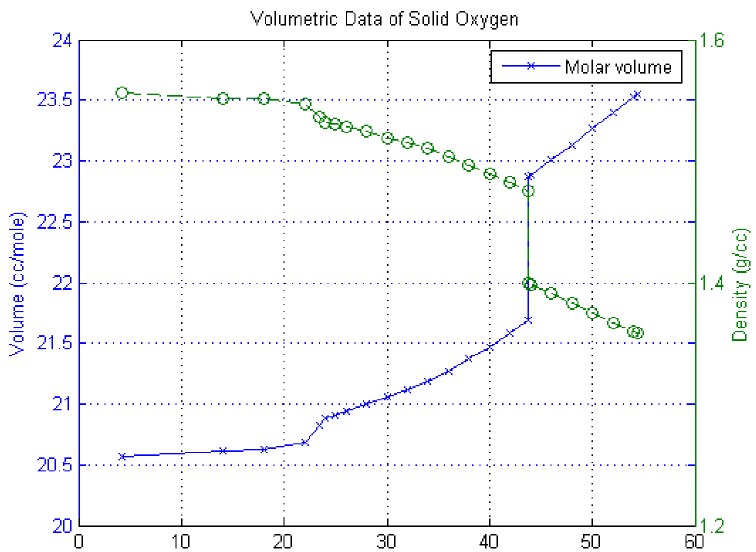


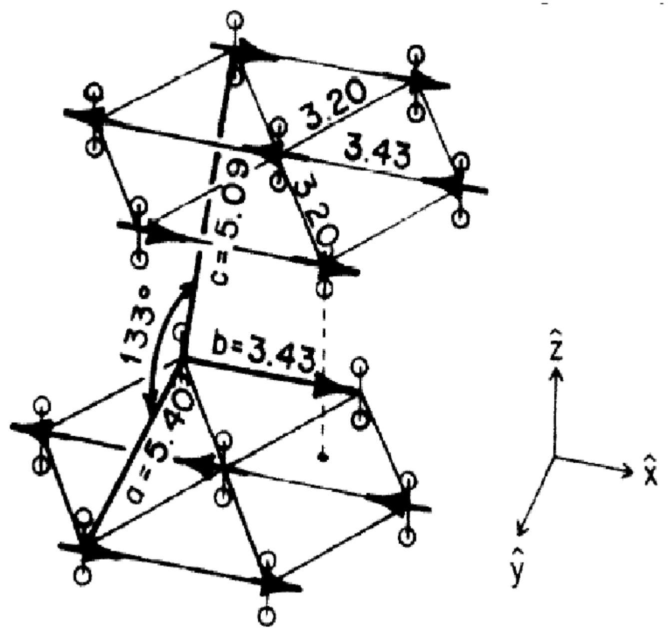
Why Oxygen?

	σ_{coh}	σ_{inc}	σ_{abs}	$\sigma_{scat}/\sigma_{abs}$
H	1.76	80.27	0.3326	$2.47\cdot10^2$
^2H	5.59	2.05	0.000519	$1.47\cdot10^4$
^{16}O	4.23	0	0.0001	$4.23\cdot10^4$
^4He	1.13	0	0	∞

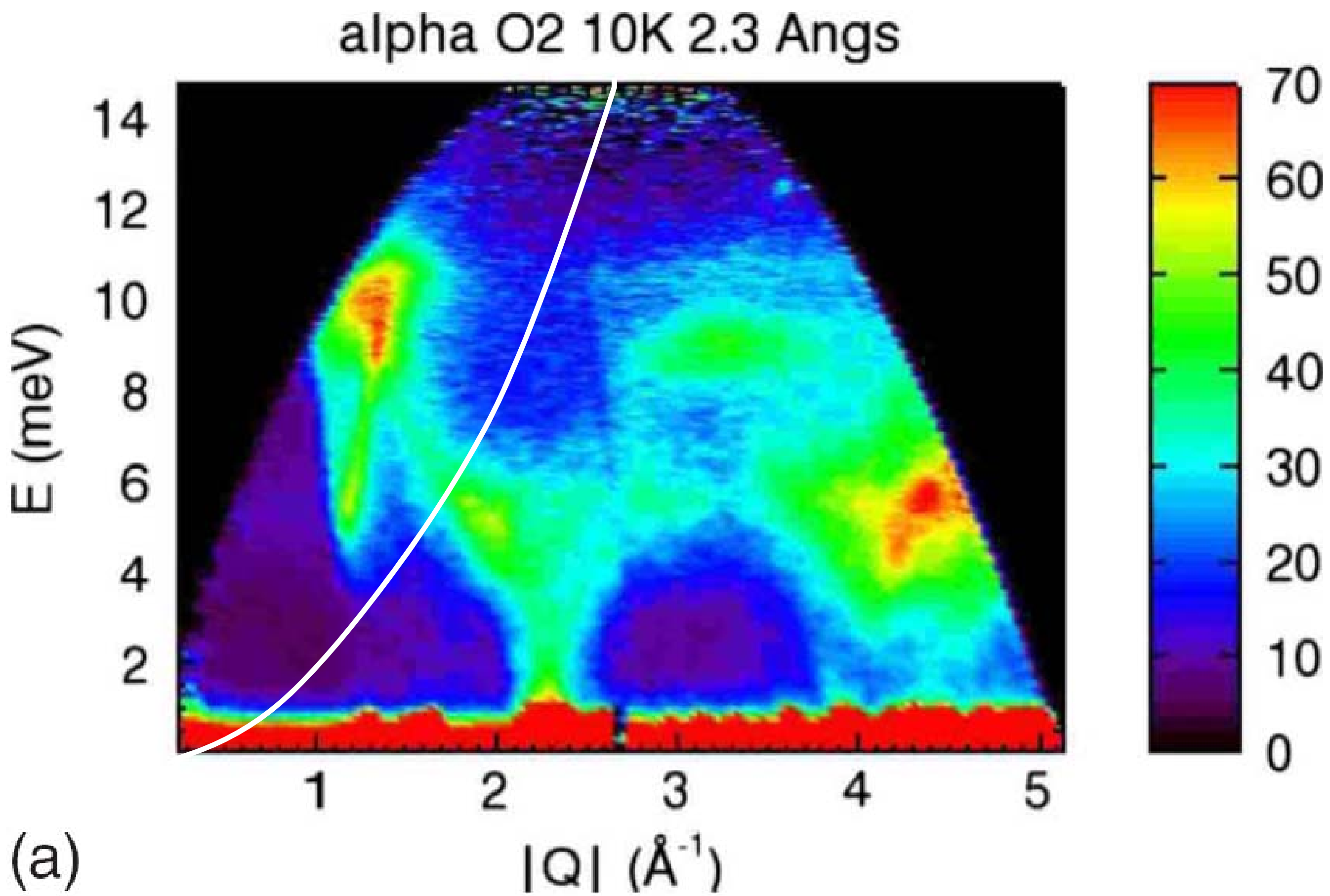
About Solid Oxygen

Phase	Temperature (K)	Description
α	0-23.9	Anti-Ferromagnetic monoclinic crystal
β	23.9-43.8	Rhombohedral Paramagnetic crystal
γ	43.8-54.36	Cubic magnetically disordered crystal



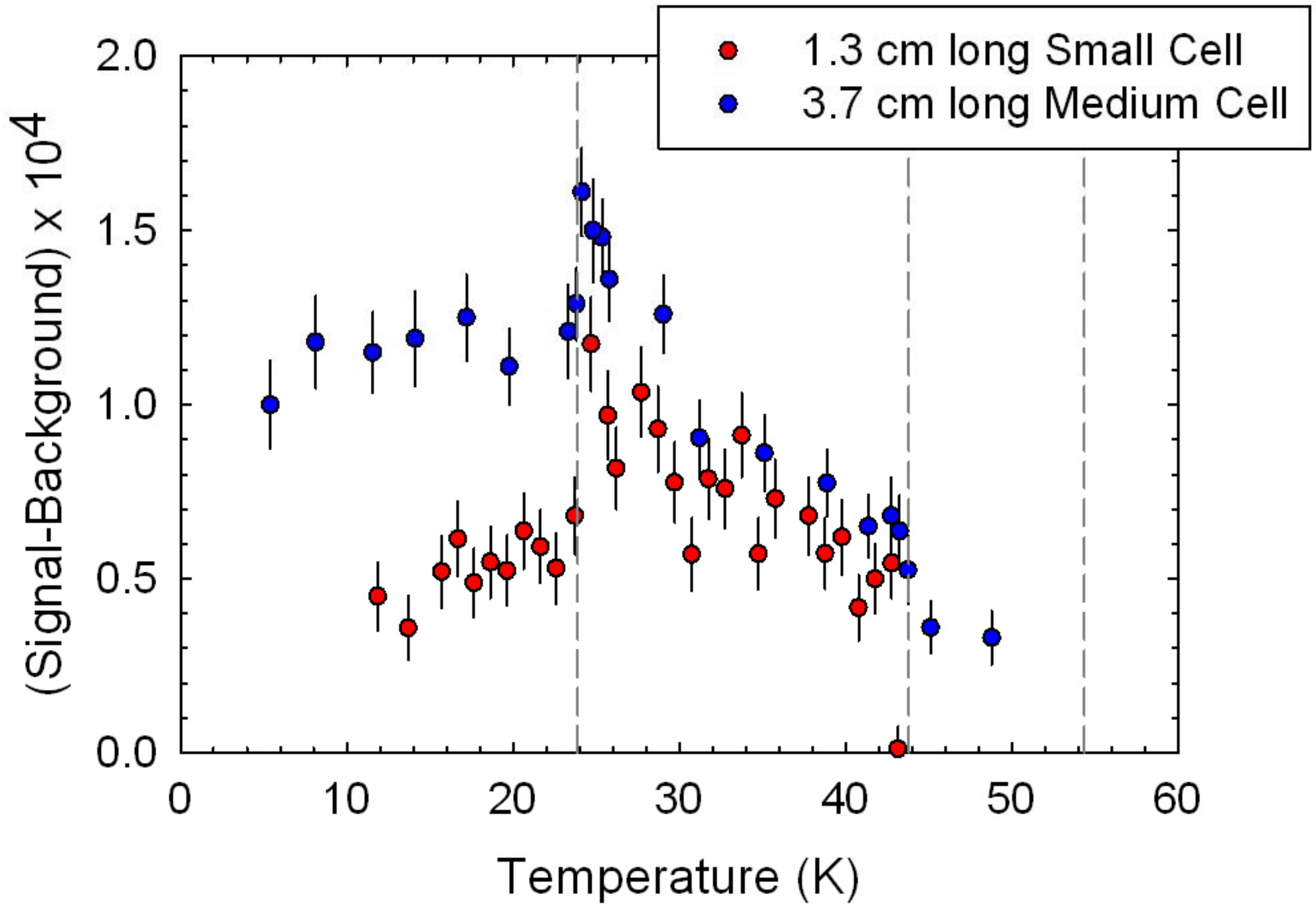


Down-scattering

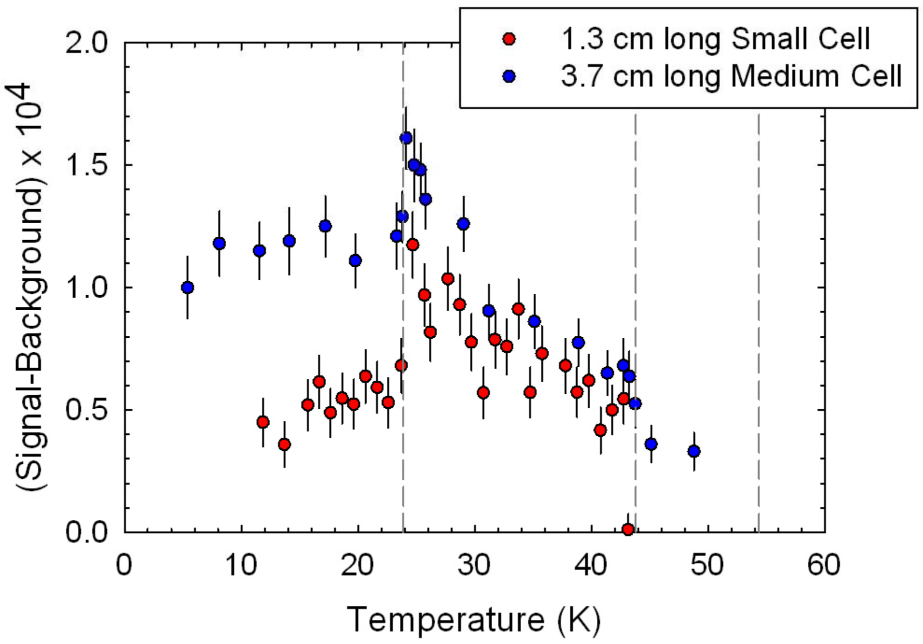


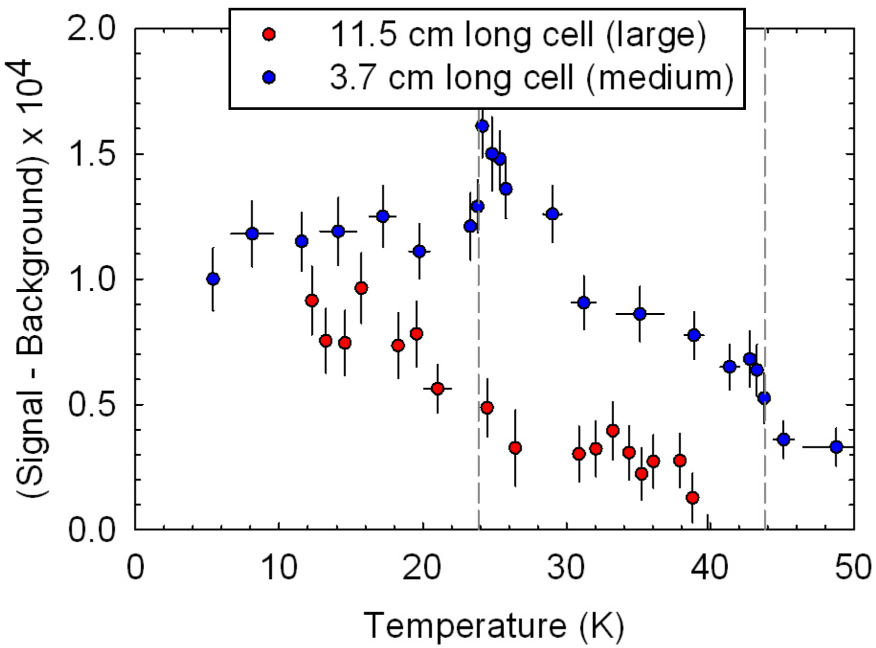
D. Kilburn, et al. PRB 78, 214304 (2008)

Cell Length Dependence

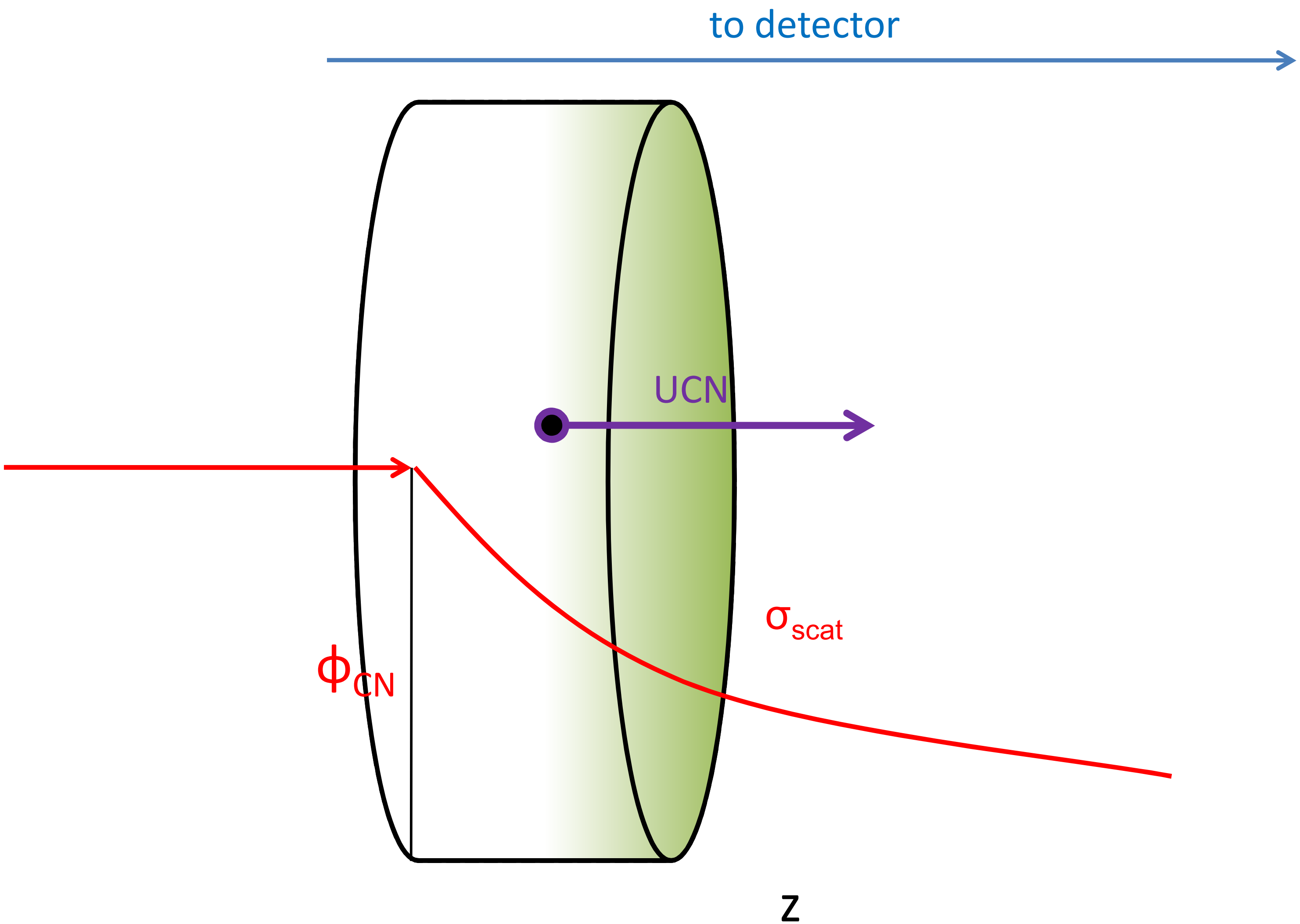


Cell Length Dependence

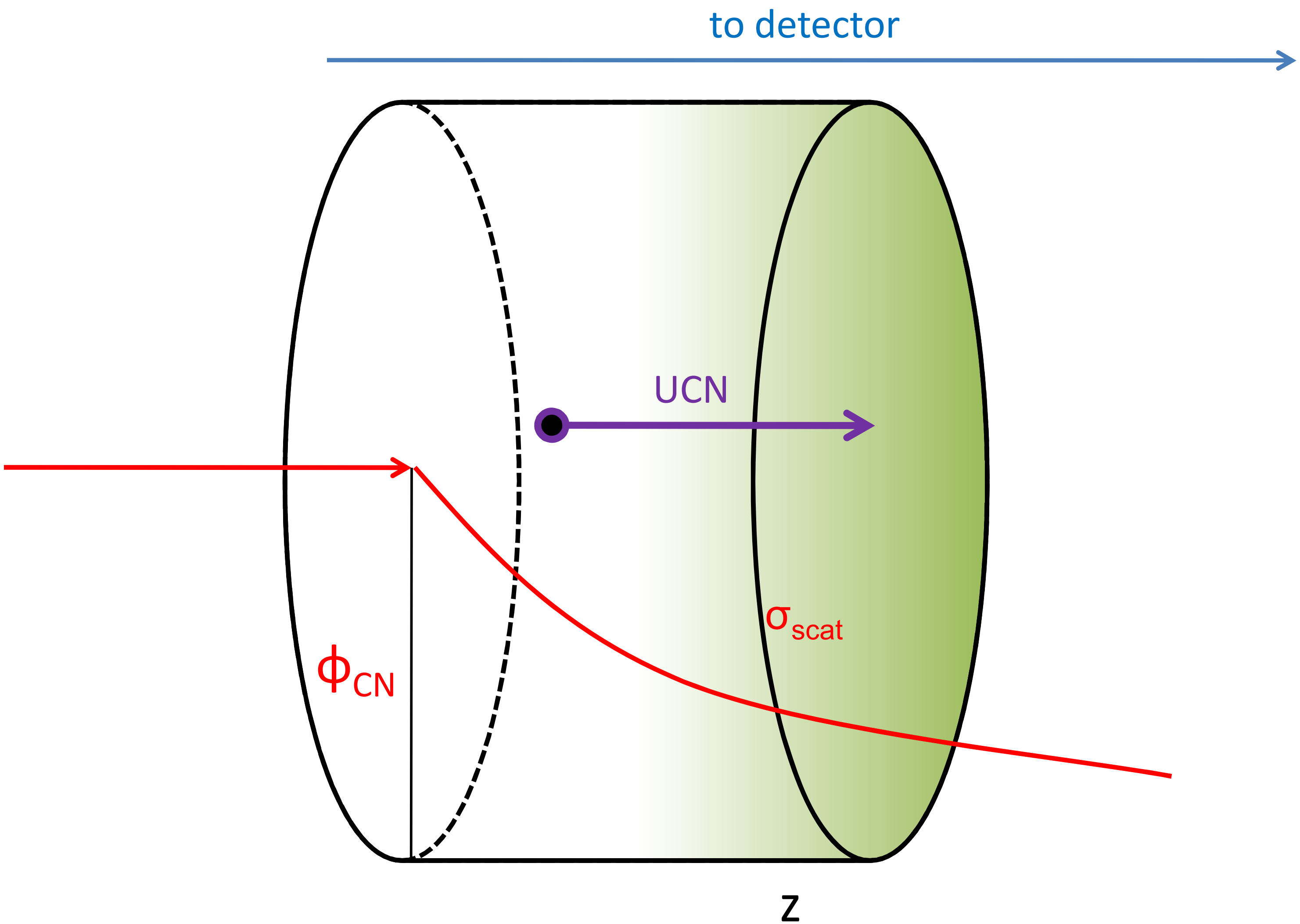




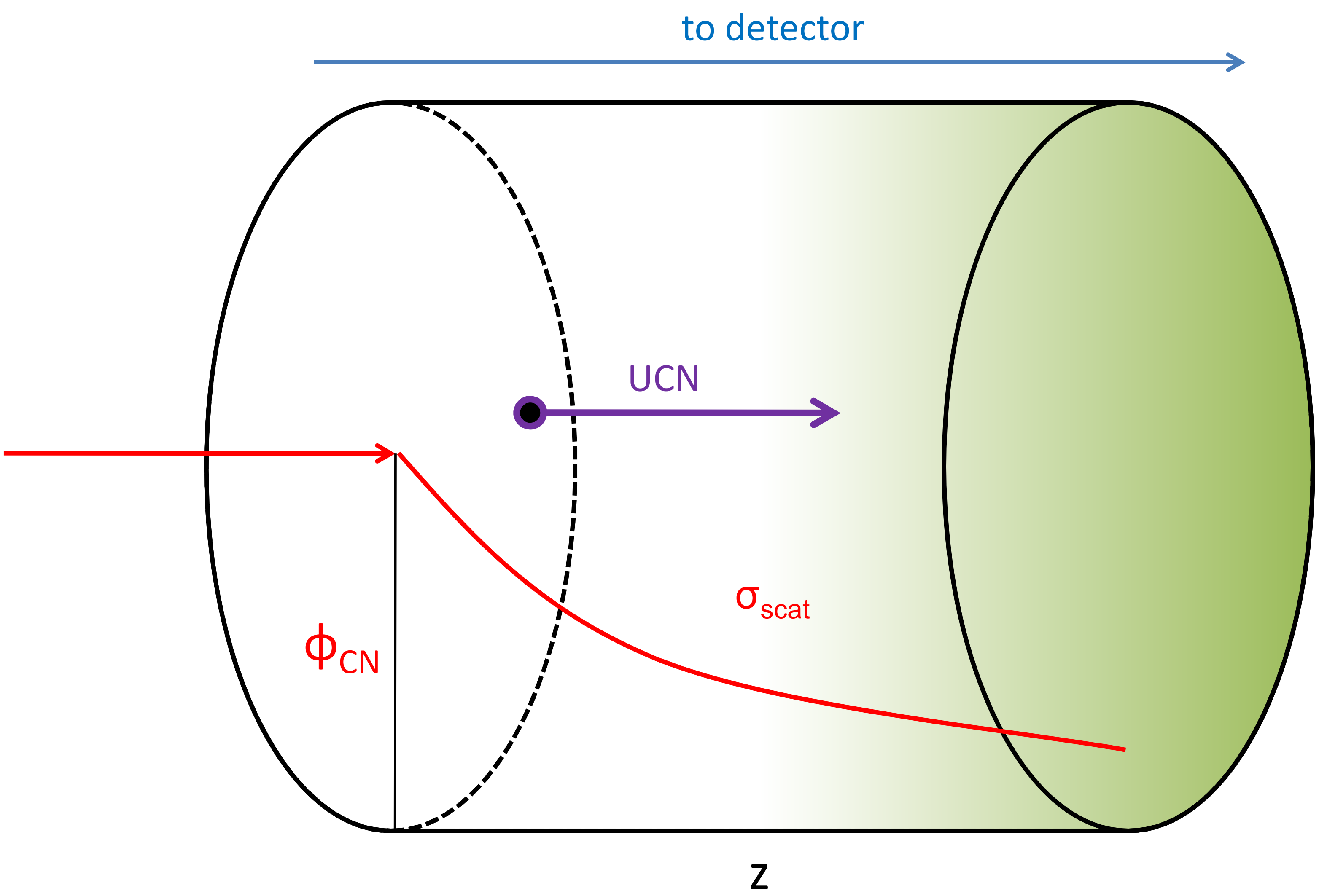
Small Cell



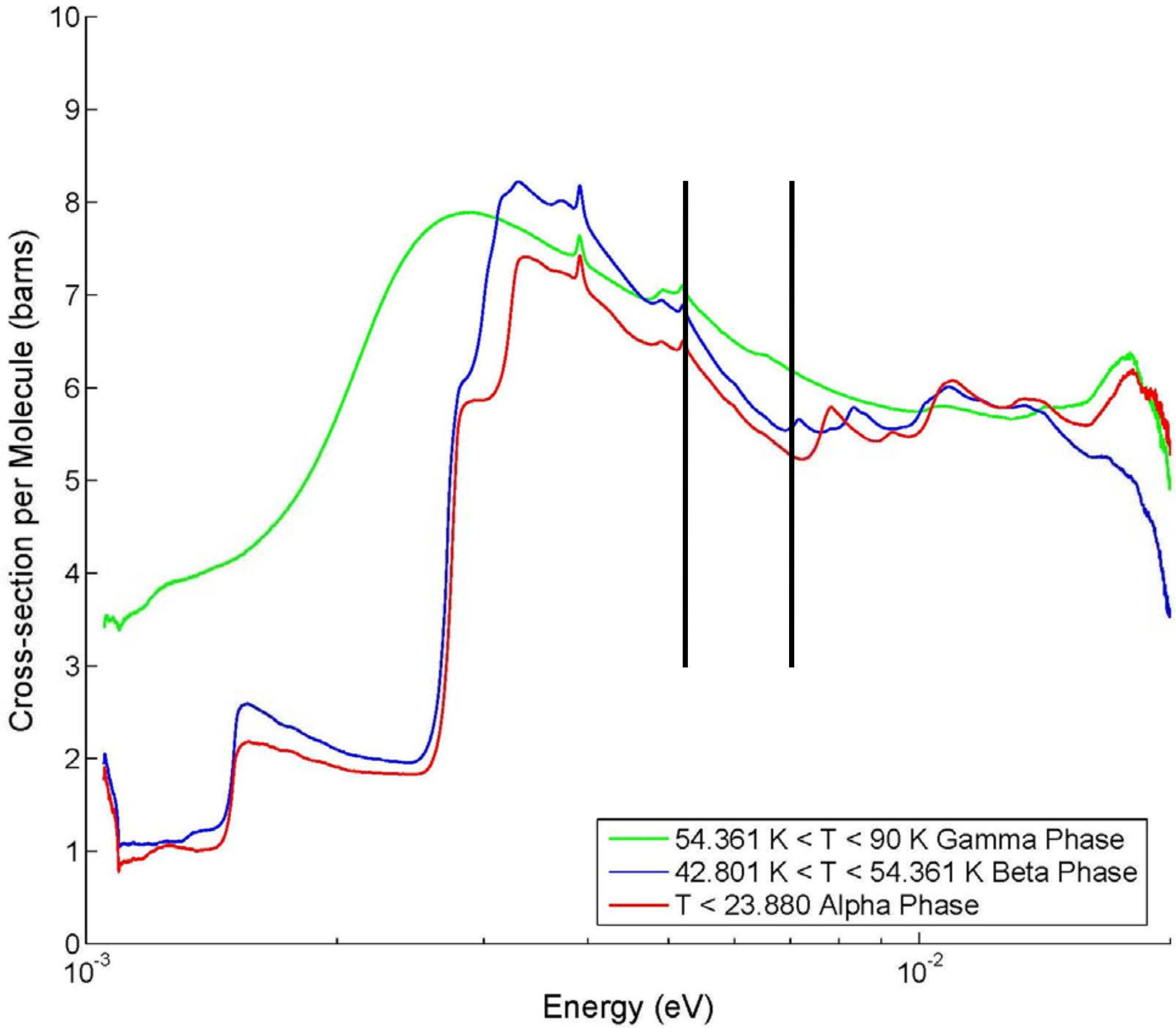
Bigger Cell



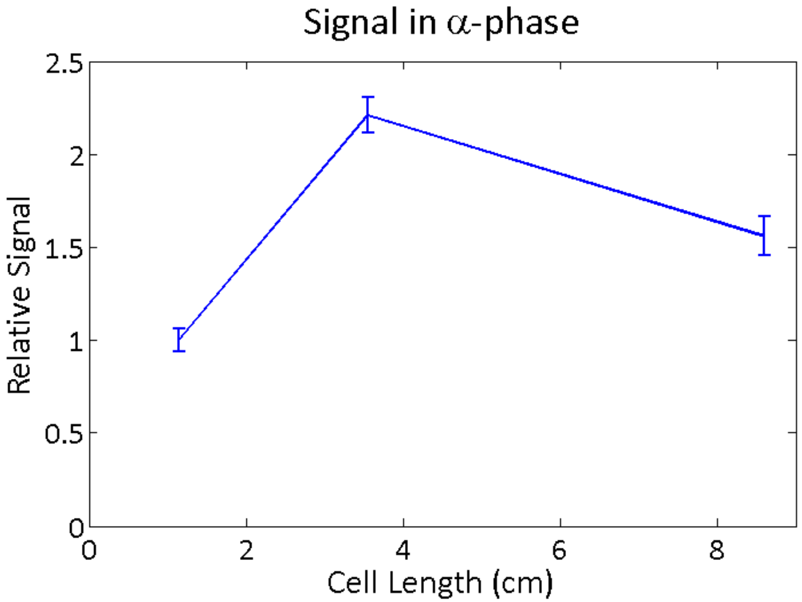
Large Cell



Beam Attenuation



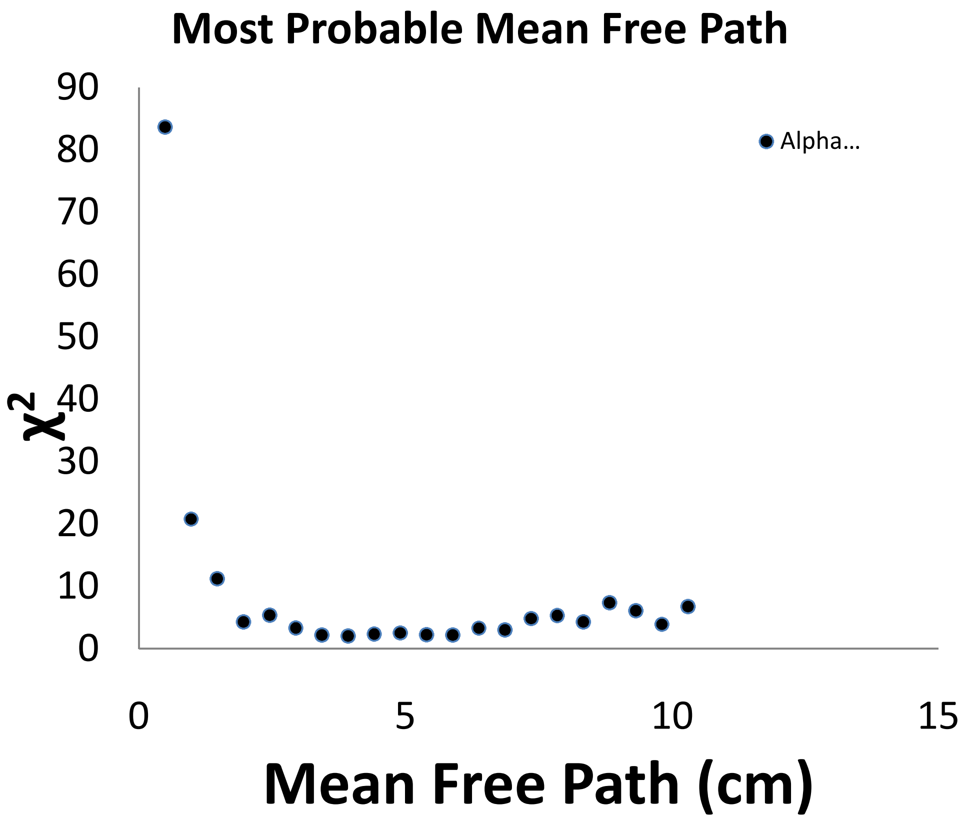
Extracting the UCN MFP

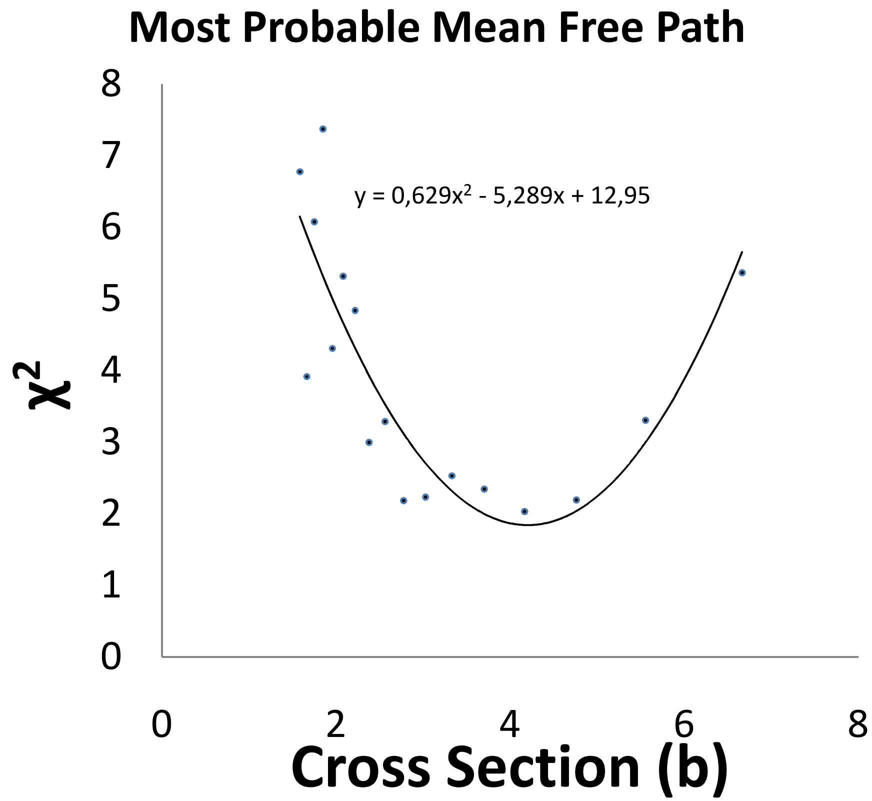


- Geant4UCN simulation reproduces relative signal between cells
- σ_0 is a free parameter
- χ^2 minimized
- Corrections needed due to geometric differences between small, medium, and large cell data
- CN and UCN mean-free-paths inversely related

$$\ell_{UCN} = \frac{1}{n \cdot \left[\sigma_{abs} + \sigma_{inc.el.} + \boxed{\sigma_0}\right]}$$

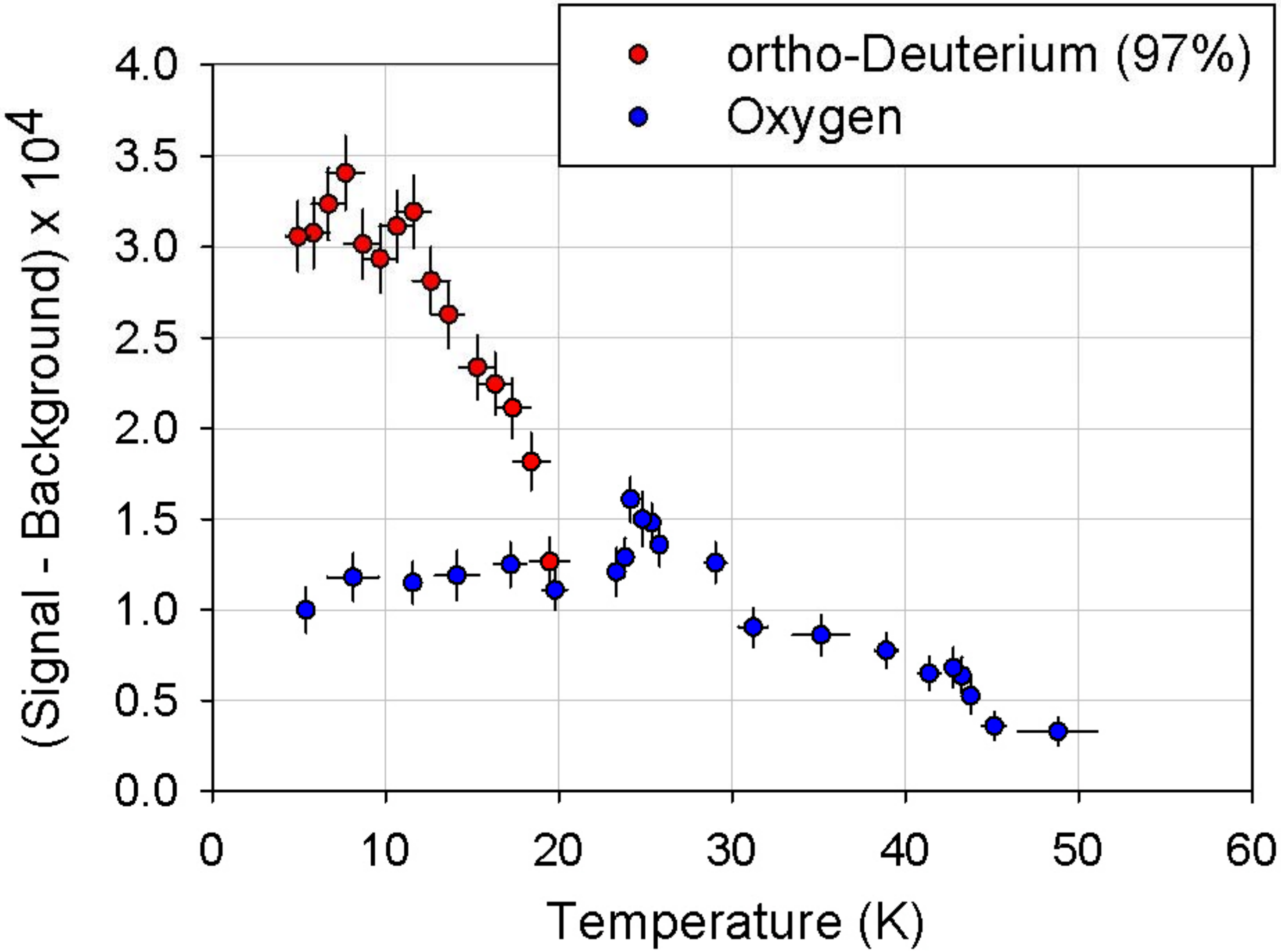
Preliminary Result





4.2±1.7 cm

D_2 vs. O_2



ortho-Deuterium (97%)
Oxygen
(Signal - Background) x 10^4
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
10
20
30
40
50
60
Temperature (K)

Outlook

- Further sophistication of Monte Carlo to extract UCN mean-free-path
- UCN signal under applied field – next talk

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- LANSCE UCN Source
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- NCSU
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