NEUTRON ELECTRIC DIPOLE MOMENT

Presentation at Symmetries and Spin Session

SPIN2002

Brookhaven National Laboratory

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LANL

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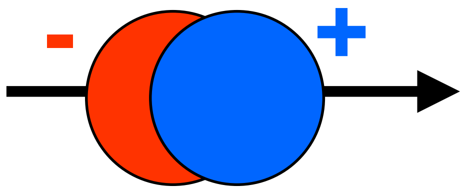
LAUR 02-6264

EDM: A sensitive test of symmetry

$\vec{d}\cdot\vec{E}$



s = 1/2

A permanent neutron EDM requires

Parity and Time Reversal Violation

T Violation implies C P Violation, which is linked to the

Baryon Asymmetry of the Universe

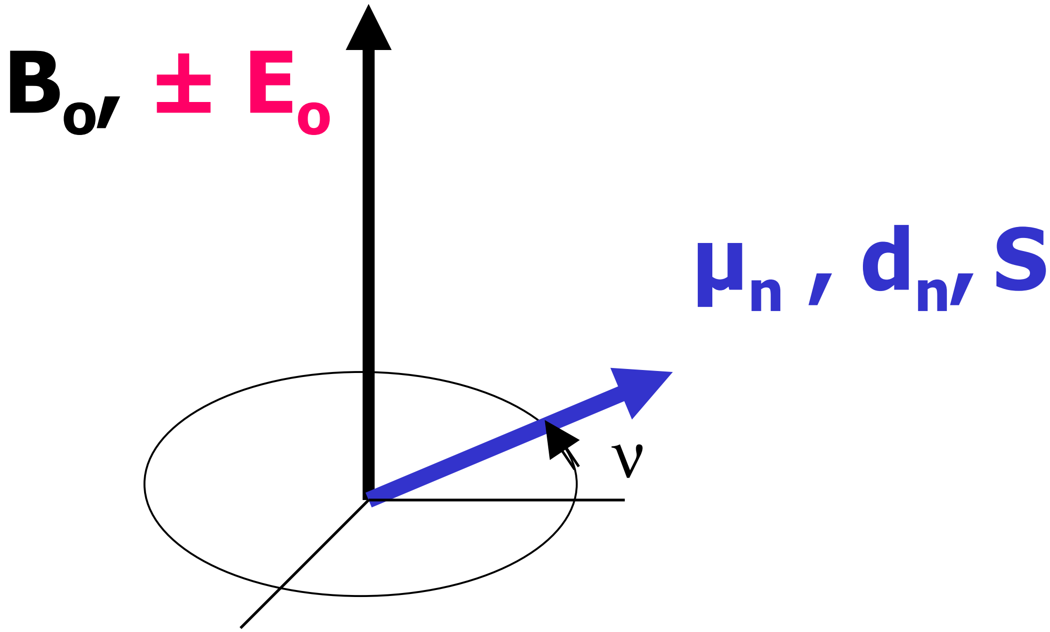
Sources of C P Violation

Standard Model	$d_n < 10^{-31}$ e cm
Super Symmetric Extension	$d_n < 10^{-25}$ e cm
Strong C P Problem	$d_n < 10^{-26}$ e cm
Electroweak baryogenesis	$d_n < 10^{-26}$ e cm

Previous and projected results

LIMIT(e-cm)	CL%	LAB	year
$<1.2 \times 10^{-25}$	95	ILL	’90
$<0.97 \times 10^{-25}$	90	PNPI	’96
$<0.63 \times 10^{-25}$	90	ILL	’99
projected:			
$<1 \times 10^{-26}$	90	ILL	’04
$<5 \times 10^{-28}$	90	PSI	’05?
$<2 \times 10^{-28}$	90	LANL, ILL	’10

Larmor Spin Precession



B ~ 10^{-3} gauss

ν ~ 3 Hz

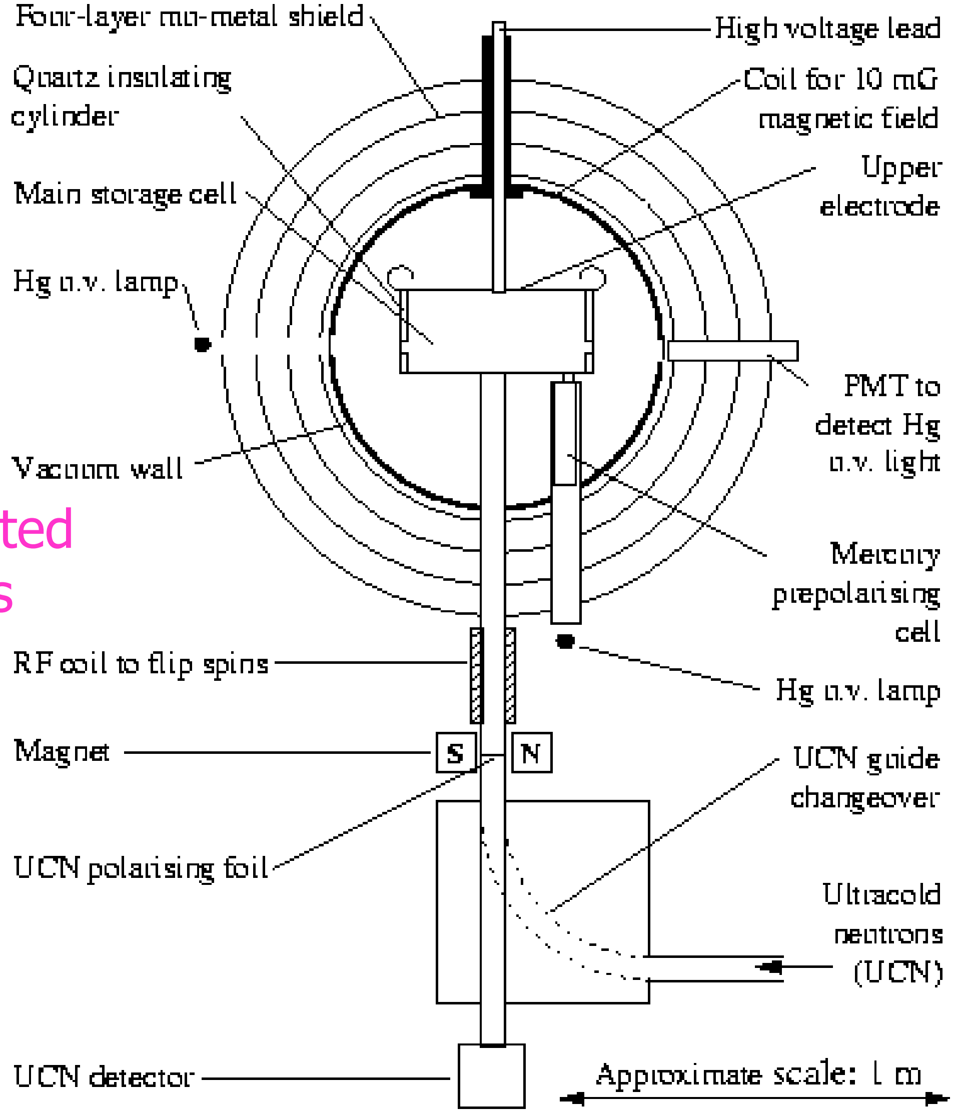
Δν ~ 2.6 μHz

$$\nu(\text{parallel}) = -[\,2\,\boldsymbol{\mu_n} B_o + 2\,\mathbf{d_n} E_o\,]\,/\,h$$

$$\Delta\nu = \nu(\text{parallel}) - \nu(\text{antiparallel}) = -\,4\,E_o\,\mathbf{d_n}\,/\,h$$

ILL Experiment: layout

Ramsey separated oscillating fields



Hg comagnetometer

ILL Experiment

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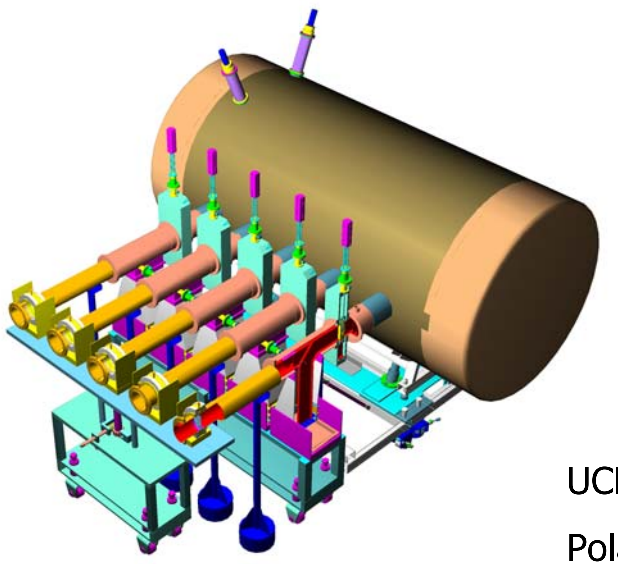
Improvements

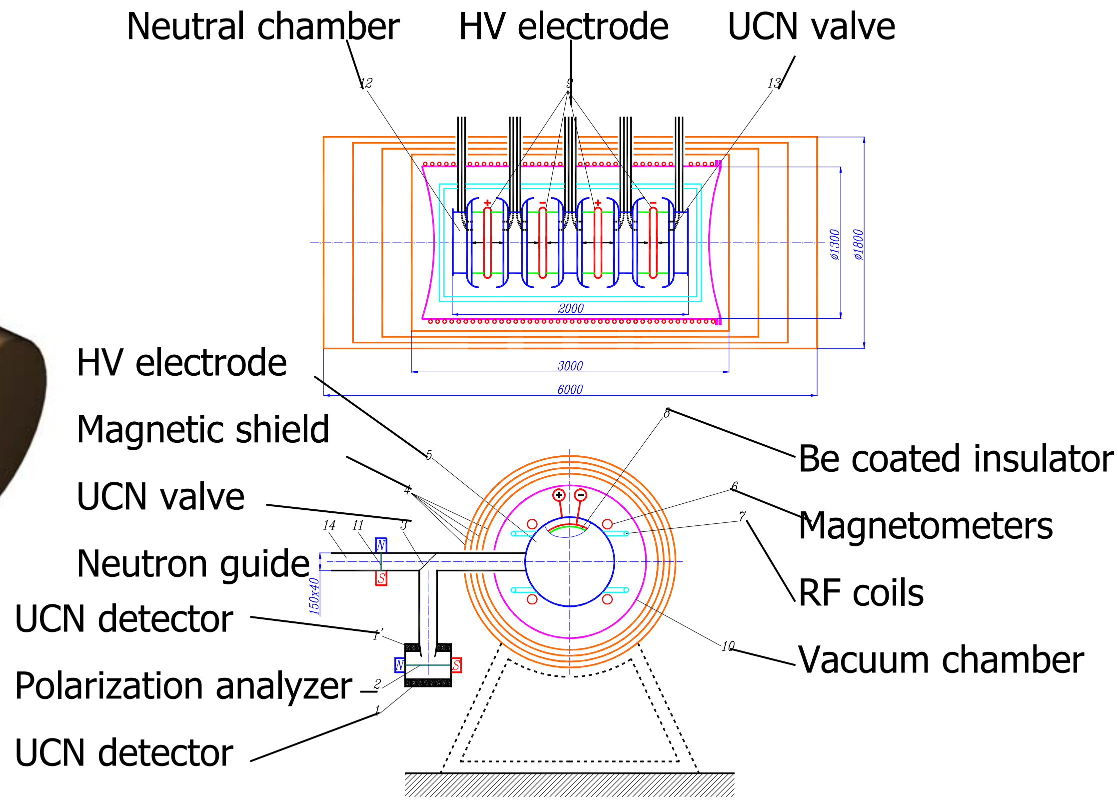
UCN flux by improved transport

UCN storage with better wall coatings

Increased E field with shorter cell

PSI Experiment: layout





PSI Experiment

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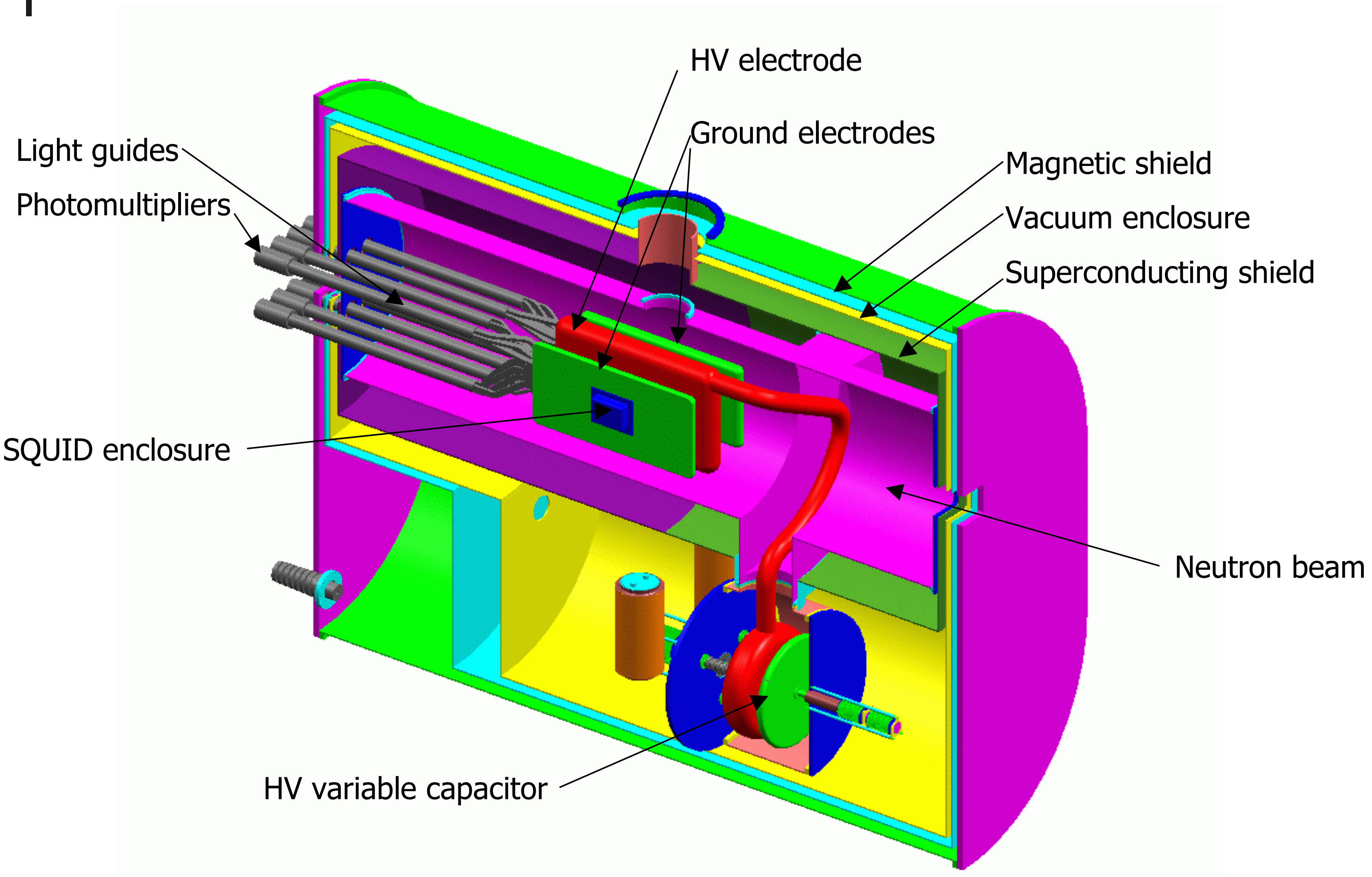
R-00-05, GATCHINA [1] – PSI [2] – FRIBOURG [3] – ILL [4] – CRACOW [5]– St. PETERBURG [6] – HEIDELBERG [7]

Features:

- Solid D2 source for UCN
- Paired volumes
- Active magnetic shielding
  - Temporal stability: 10^{-14} T (rms)@mHz
  - Spatial uniformity: 10^{-12} T/cm

LANL Experiment: layout



Collaboration

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LANL Experiment

Features

- Create UCN in place in ^4He
- ^3He comagnetometer
- HV for E field generated internally
- SQUIDs to detect ^3He spin precession
- ^3He capture/^4He scintillation detection

Experimental Challenges

Distribution of ^3He in ^4He cell		1 %
Uniformity of B Field		0.1 %
Uniformity of E Field		1.0 %
SQUID noise		3 $\mu\Phi_0/Hz^{1/2}$

Neutron Beam

Velocity Filter	=	Chopper & TOF cut
Gamma Filter	=	Bi Absorber
Spin Filter	=	Silicon Super-mirror Polarizer

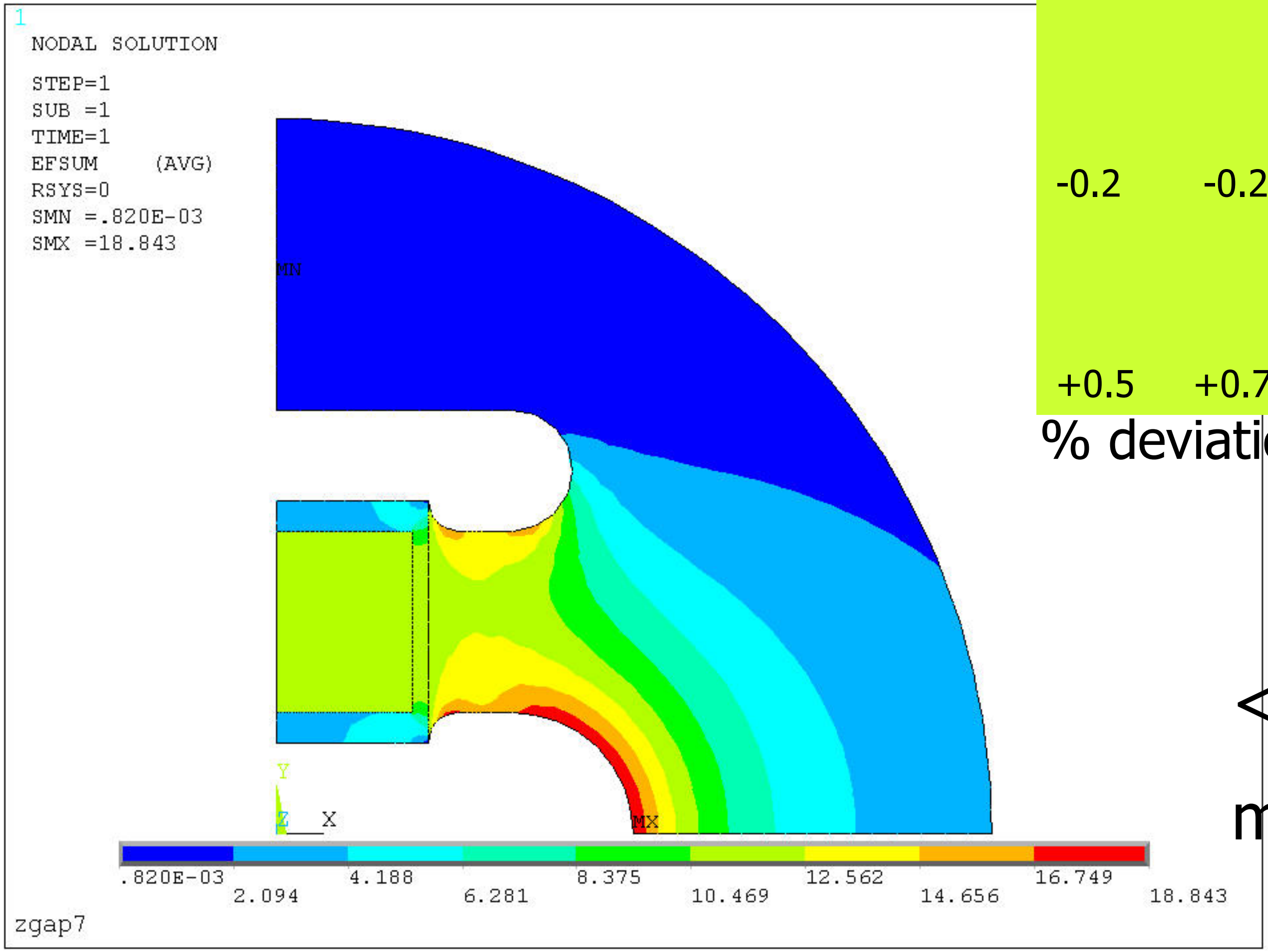
E field contours

10 cm plate

30 cm shell

-0.7	-0.8	-1.1
-0.2	-0.2	+0.6
+0.5	+0.7	+1.2

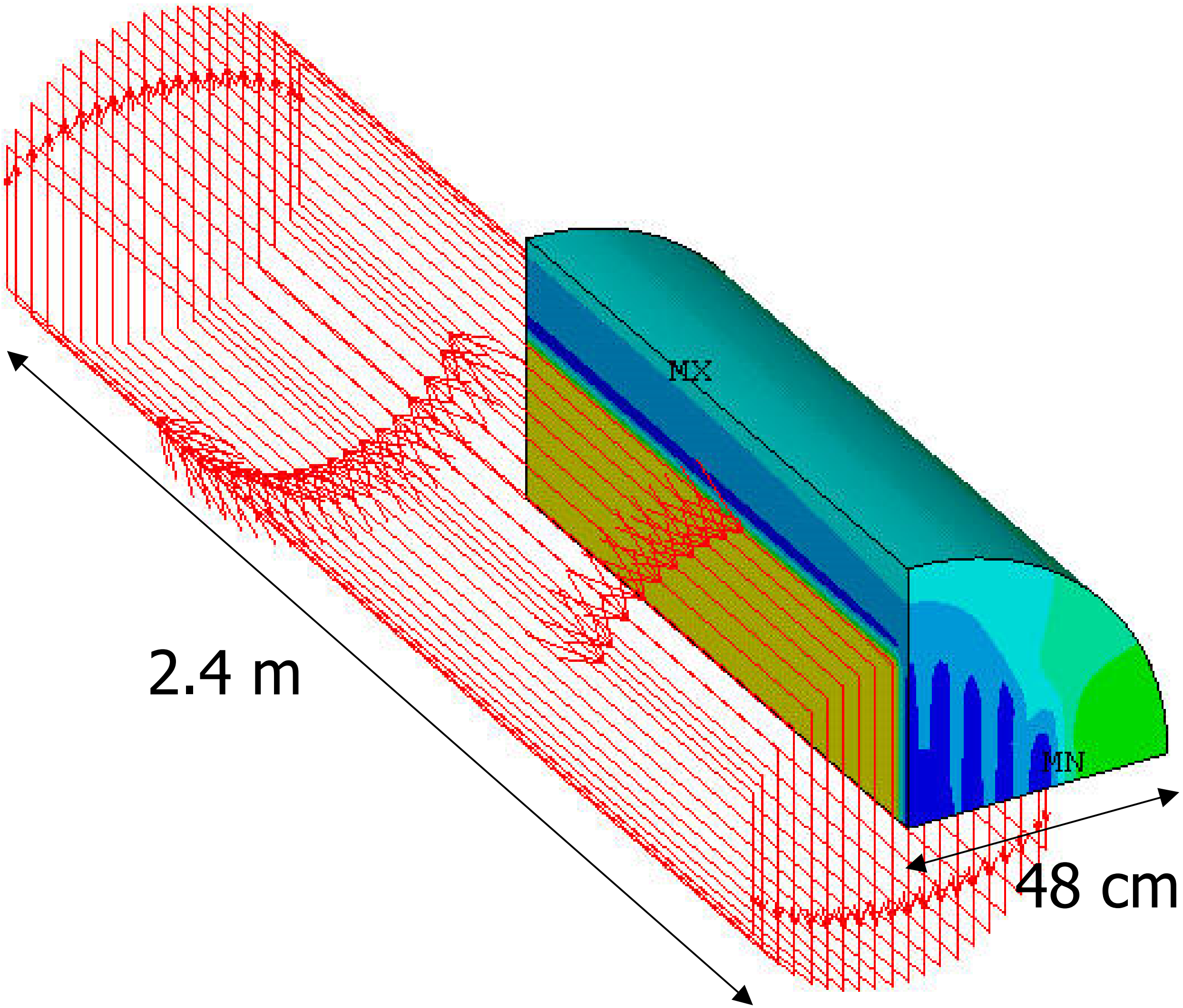
% deviation in cell



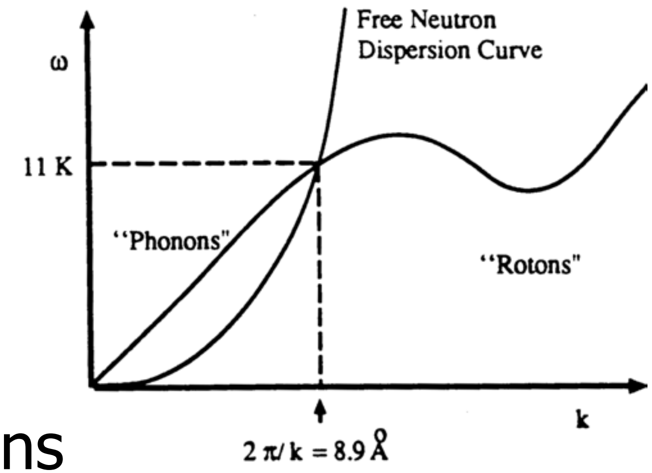
< 1% variation

max/gap = 1.6

B_x contours with cosθ magnet



Source of UCN



Down-scatter cold neutrons

(v = 400 m/s)

in superfluid ^{4}He to give:

UCN (v ≤ 5 m/s) **+** Phonons

Total UCN neutrons :

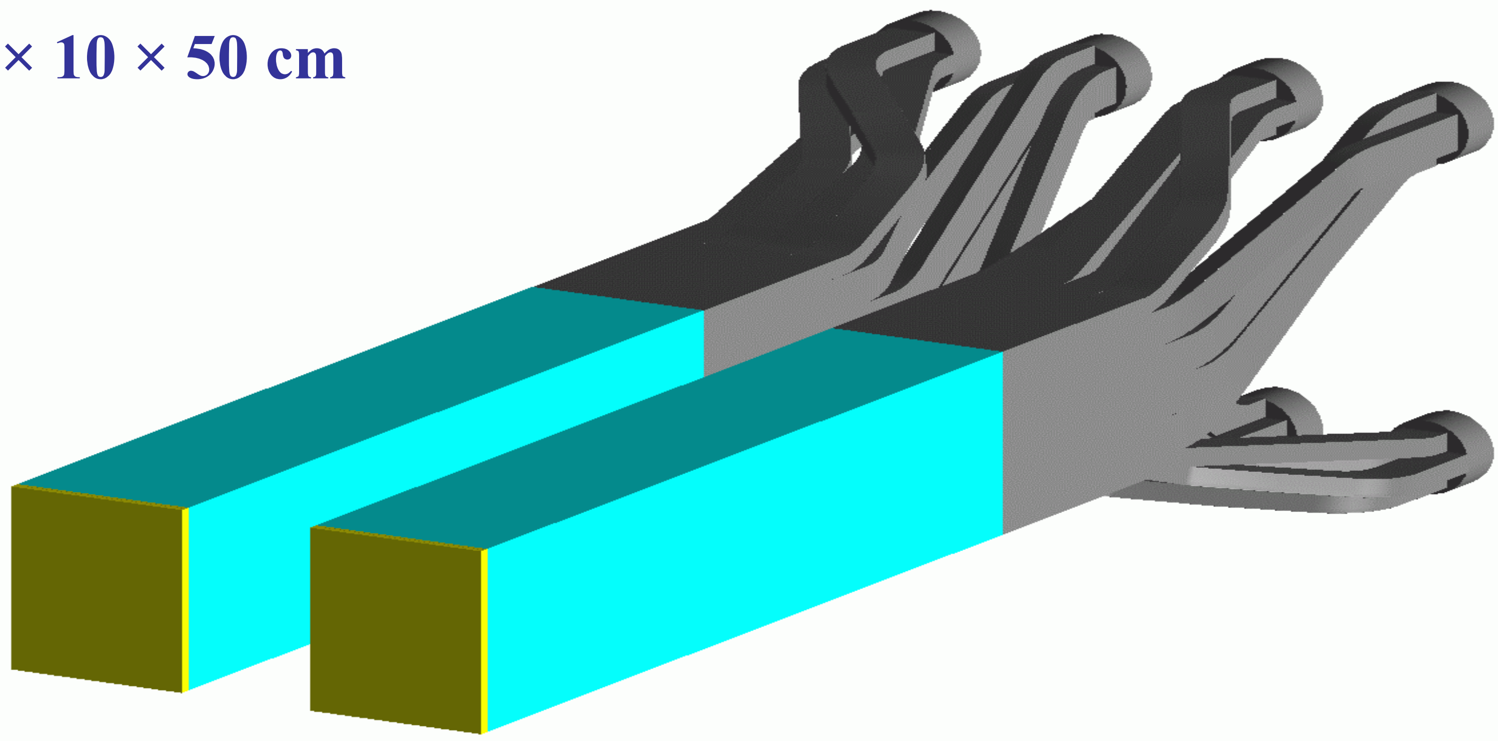
Production rate: 1.0 UCN / cm^3/sec

Density 5.0×10^5 UCN/ lt in 500 sec

Neutron Cells & Light Pipes

Cell Size

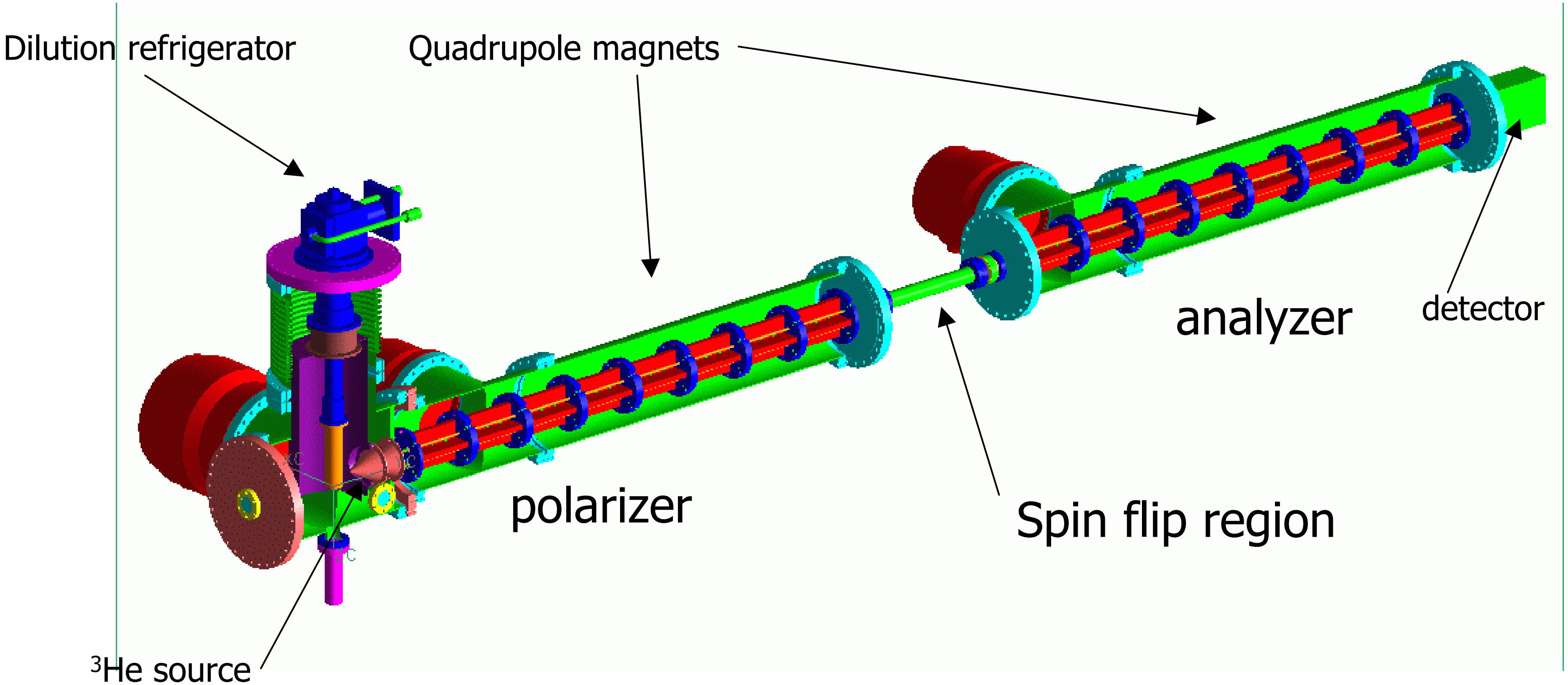
7.5 × 10 × 50 cm



Polarized ^{3}He Source

Atomic beam of polarized ^{3}He

- Current ~ 10^{+14} atoms / sec
- EDM of atomic ^{3}He negligible, Schiff Shielding



^{3}He-Dopant as an analyzer

$^3He + n \rightarrow t + p$ σ(parallel) ~ 0 b
σ(opposite) ~ 10^4 b

UCN loss rate~
$1-\mathbf{p_3}\bullet\mathbf{p_n}=1-p_3\, p_n \cos(\gamma_3-\gamma_n)B_0\, t$
$|\gamma_3-\gamma_n|=|\gamma_n|/10$

^{3}He concentration must be adjusted to keep the lifetime τ reasonable for a given value of the ^{3}He polarization.

The proper value for the fractional concentration of $^3He/^4He$ atoms ~ 10^{-10}

^{4}He as a detector

$^3He + n \rightarrow t + p$

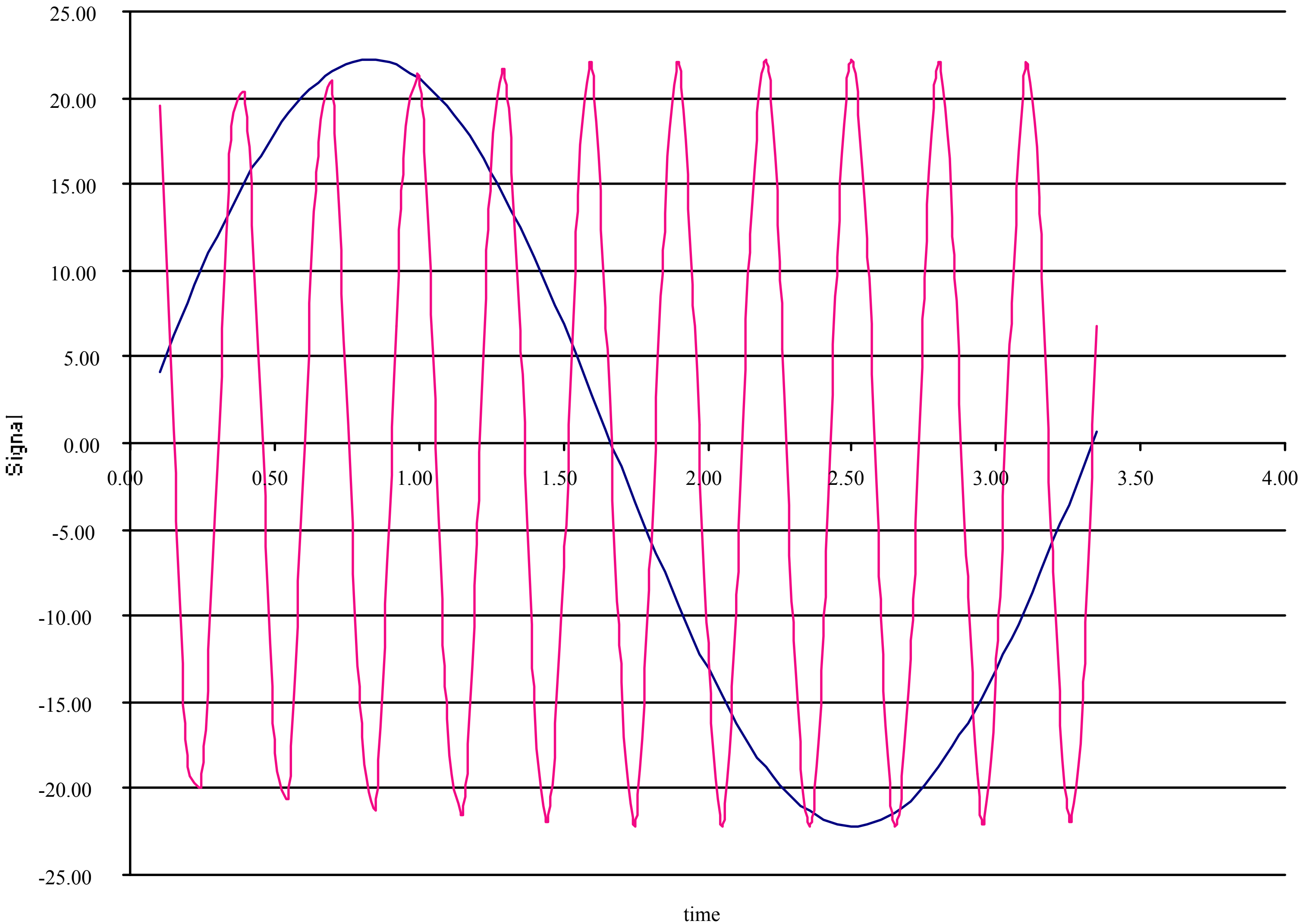
t+p share 764 keV of kinetic energy.
They scintillate while stopping in the He.

The emitted light (~3 photons/keV) is in the XUV ~80 nm.

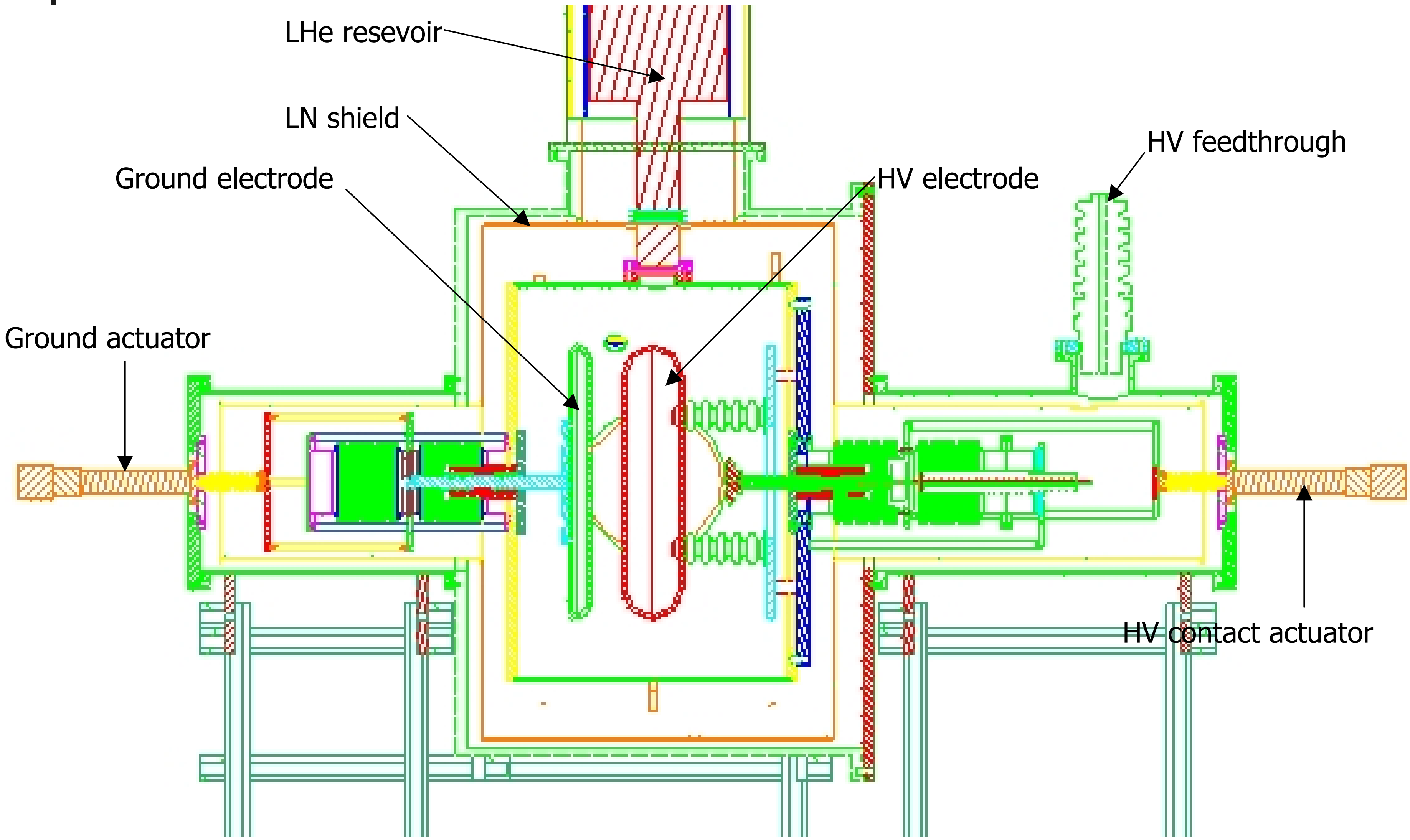
A wavelength shifter (TPB) is used to change the light to blue where it can be reflected and detected.

The cell walls and wavelength shifter must be made of materials that do not absorb neutrons or depolarize ^{3}He. Deuterated materials work for neutrons.
For the ^{3}He ??

SQUID and Scintillator Signals



HV test setup - assembly



Issues for HV test program

Validate variable capacitor design

Measure cryogenic properties of materials

- testbed for engineering issues
- measure dielectric constant of cell materials

HV properties of LHe

- determine dielectric strength

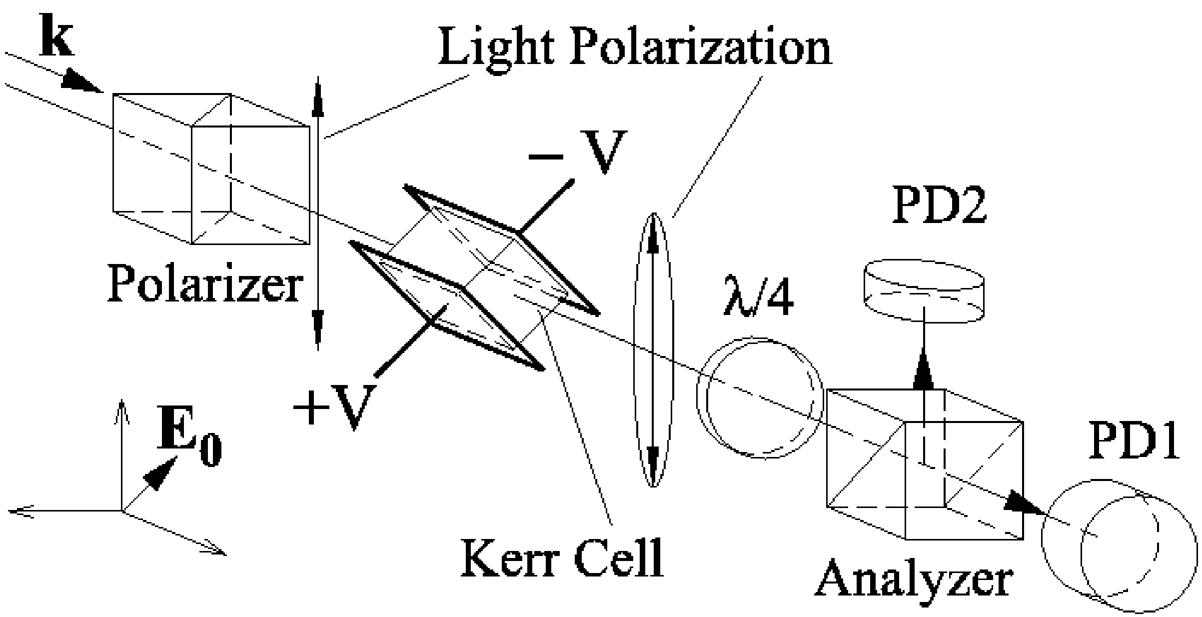
Develop E field measurement with Kerr effect

Investigate effect of E field on scintillation process

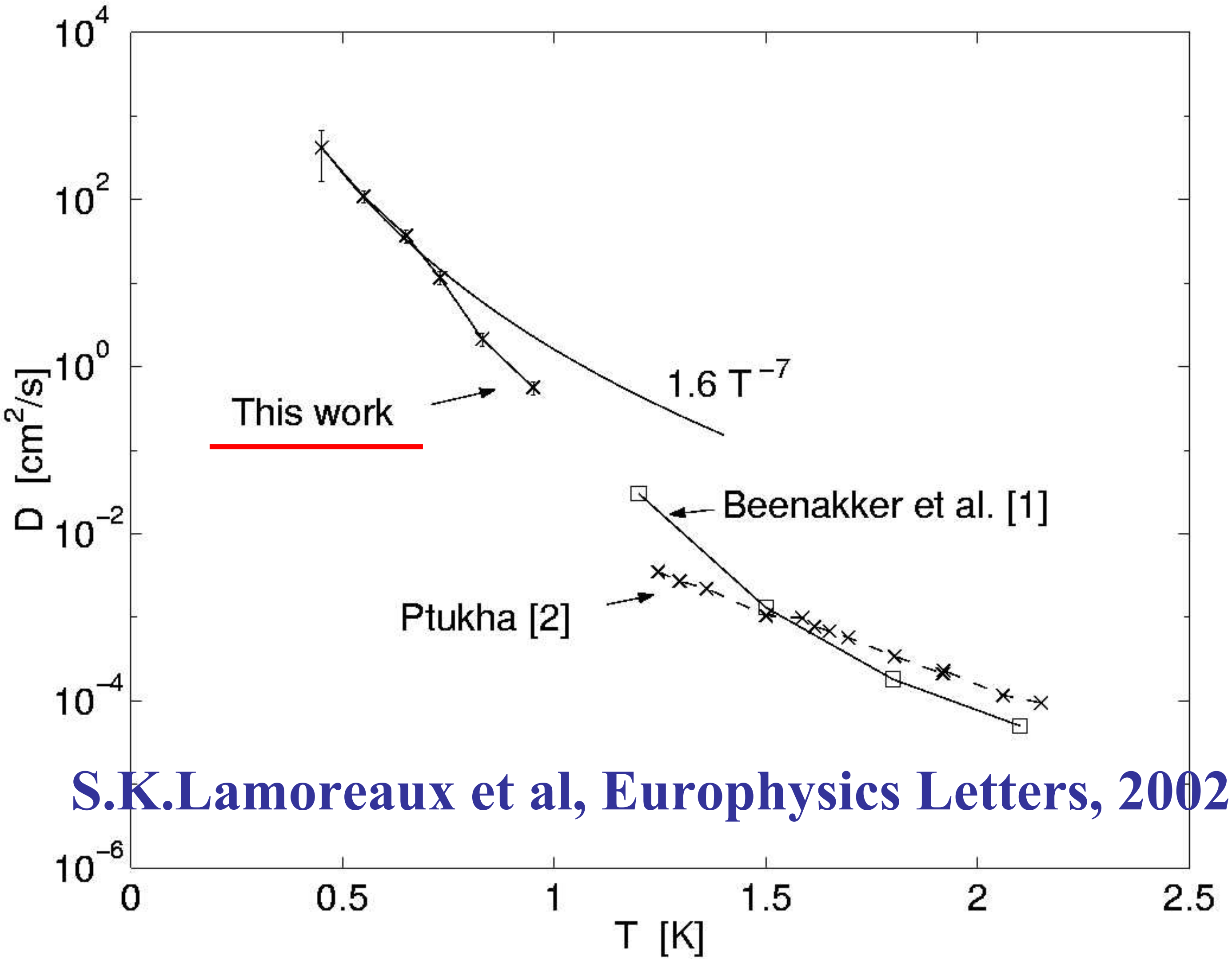
…

Electric Field Measurement

Kerr Effect $\varepsilon = \pi K l E_0^2$

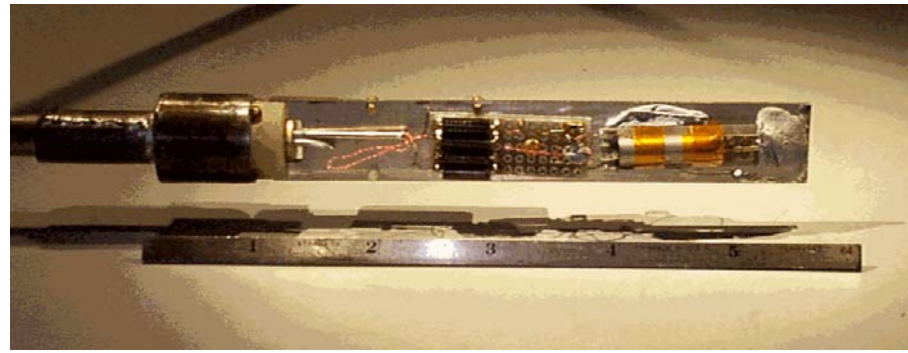


^{3}He Diffusion in ^{4}He Superfluid

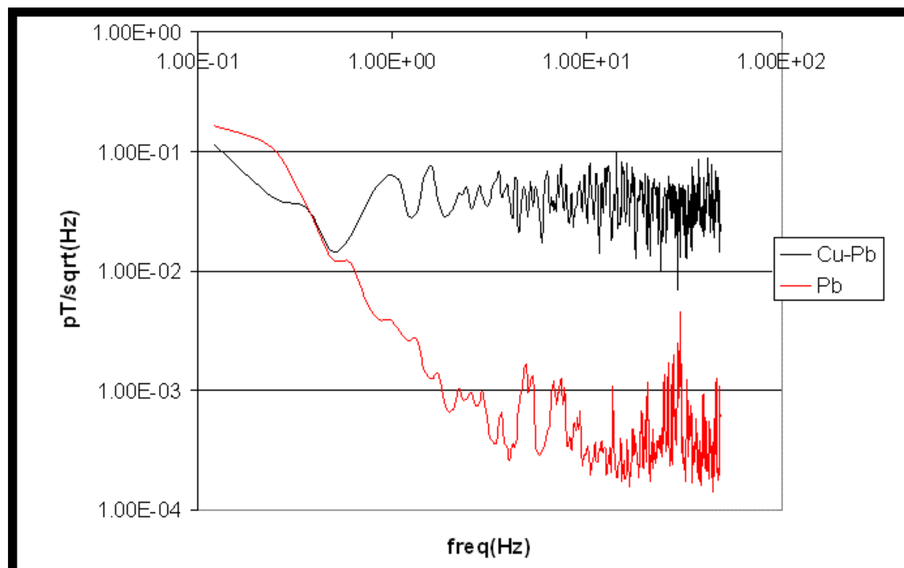


S.K.Lamoreaux et al, Europhysics Letters, 2002

SQUID tests



~100 cm^2 superconducting pickup coil



Flux = 2 x 10^{-16} Tm^2 = 0.1 Φ_0
Noise = 4 $\mu\Phi_0/Hz^{1/2}$ at 10 Hz
~ $T^{1/2}$ (shown experimentally)

Statistical Errors

Figure of Merit for Statistics ~ $E_o \sqrt{(T N_o)}$

$$\sigma \approx h / [4\pi E_o \sqrt{(T N_o m)}\ ]$$

		Goal
E_o	Static Electric Field Strength	x 5
T	Trap Lifetime	x 5
N_o	UCN trapped per sample	x 250
m	number of repeated samples	