DEVELOPMENT OF A NEW EXPERIMENT TO SEARCH FOR AN ELECTRIC DIPOLE MOMENT OF THE NEUTRON

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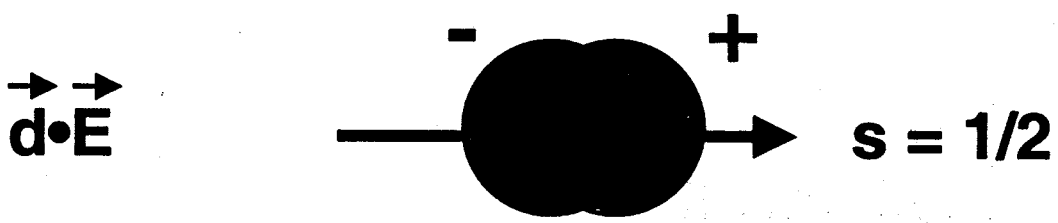
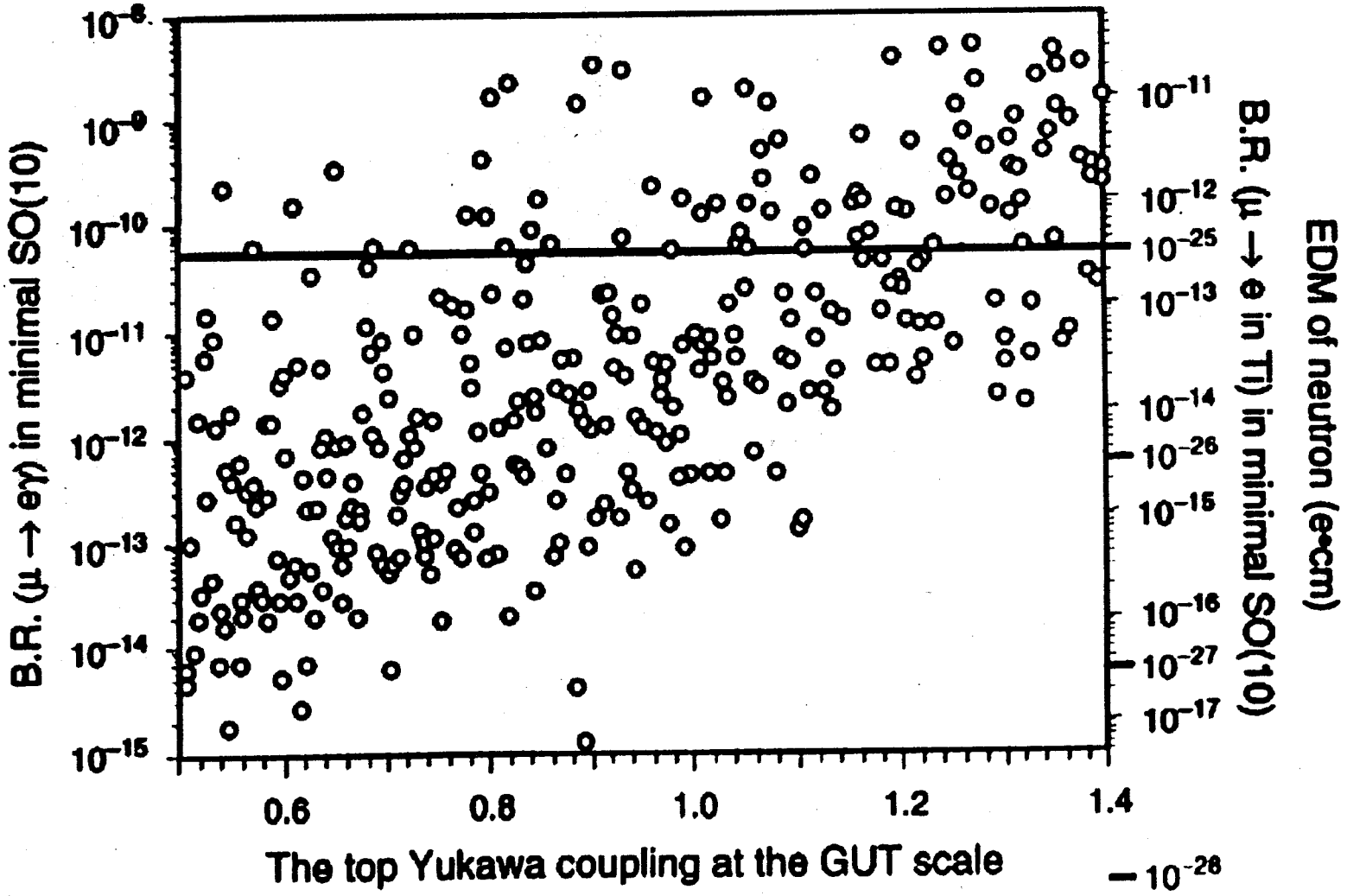
The Permanent EDM of the Neutron

- A permanent EDM $\vec{d}$

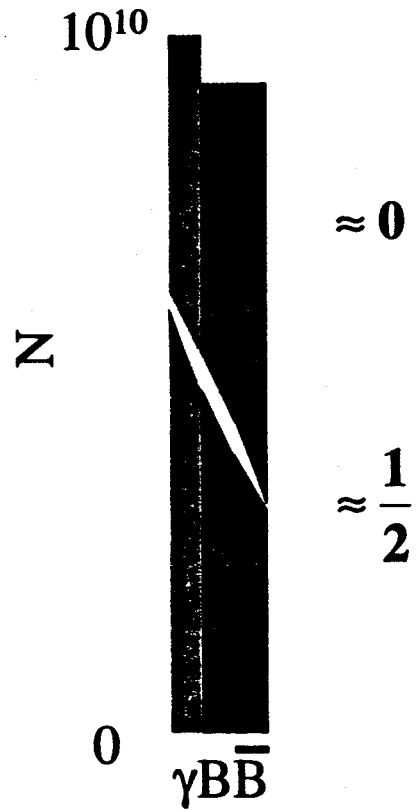


- The current value is roughly $< 10^{-25}$ e•cm
- We hope to obtain roughly $< 10^{-28}$ e•cm with UCN in superfluid He


B.R. (μ → eγ) in minimal SO(10)
B.R. (μ → e in Ti) in minimal SO(10)
EDM of neutron (e•cm)
The top Yukawa coupling at the GUT scale
0.6
0.8
1.0
1.2
1.4

B-$\bar{B}$ ASYMMETRY IN THE UNIVERSE

Before Phase Transition



≈ 0

$\approx \frac{1}{2}$

After Phase Transition

$\approx 10^{-10}$

$\approx \frac{1}{2}$

Today

$$A_{B\bar{B}} = \frac{N_B - N_{\bar{B}}}{N_B + N_{\bar{B}}} = 1$$

$$\frac{N_B}{N_\gamma} \approx 10^{-10}$$

STATUS OF EDM MEASUREMENTS
(e-cm)

Fundamental Particles

n	ILL	$\lvert d_n \rvert$	$< 1.2 \times 10^{-25}$
	PNPI	$\lvert d_n \rvert$	$< 1.1 \times 10^{-25}$
	ILL (^{199}Hg)	$\lvert d_n \rvert$	$< 6(3) \times 10^{-26}$
	PSI	$\lvert d_n \rvert$	$< (1) \times 10^{-27}$
	LANSCE (^{3}He)	$\lvert d_n \rvert$	$< (2) \times 10^{-28}$
p		$\lvert d_p \rvert$	$< 10^{-22}$
Λ	$\Lambda \rightarrow p\pi^-$ assym.	$\lvert d_\Lambda \rvert$	$< 1.5 \times 10^{-16}$
e	g-2	$\lvert d_e \rvert$	$< 4 \times 10^{-16}$
ν	reactor exp.	$\lvert d_\nu F_3 \rvert$	$< 2 \times 10^{-20}$
μ	g-2	$\lvert d_\mu \rvert$	$< 1.1 \times 10^{-18}$
		$\lvert d_\mu \rvert$	$< 10^{-24}$
τ	$\Gamma(Z \rightarrow \tau^+\tau^-)$	$\lvert d_\tau \rvert$	$< 4.5 \times 10^{-18}$

Paramagnetic Atoms

H	Lamb shift		$\lvert d_e \rvert < 2 \times 10^{-13}$
Fe^{+3}	$d_{3/2}$		$\lvert d_e \rvert < 2 \times 10^{-22}$
Rb	5s	$\lvert d_a \rvert < 1.2 \times 10^{-23}$	$\lvert d_e \rvert < 5 \times 10^{-25}$
Cs	6s	$\lvert d_a \rvert < 1.3 \times 10^{-23}$	$\lvert d_e \rvert < 1 \times 10^{-25}$
Tl	$5p_{1/2}$	$\lvert d_a \rvert < 2(?) \times 10^{-24}$	$\lvert d_e \rvert < 4(?) \times 10^{-27}$

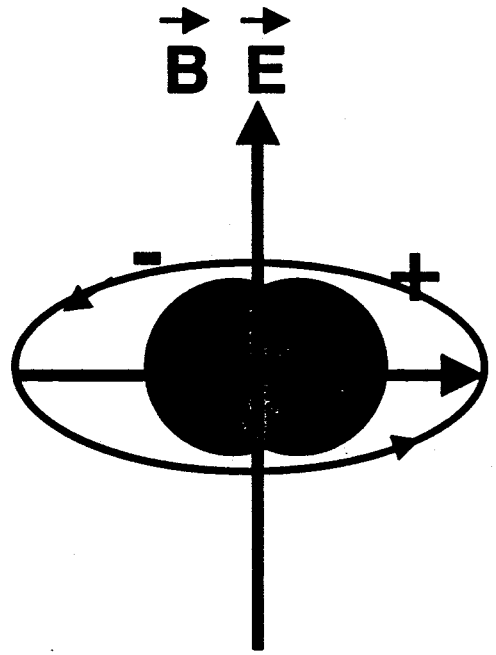
Diamagnetic Atoms

^{129}Xe	Wash.	$\lvert d_a \rvert < 2 \times 10^{-26}$	$\lvert d_n \rvert < 2 \times 10^{-23}$
^{199}Hg	Wash.	$\lvert d_a \rvert < 2(?) \times 10^{-28}$	$\lvert d_n \rvert < 2(?) \times 10^{-26}$

Polar Molecules

YF	$\lvert d_e \rvert < 10^{-28}$
PbO	$\lvert d_e \rvert < 10^{-30}$

THE BASIC TECHNIQUE



Look for a precession frequency ω_d

s = 1/2 dipole moment d_n

Figure of Merit for EDM Experiments ~ $E\sqrt{N\tau}$ $\rightarrow$ 175

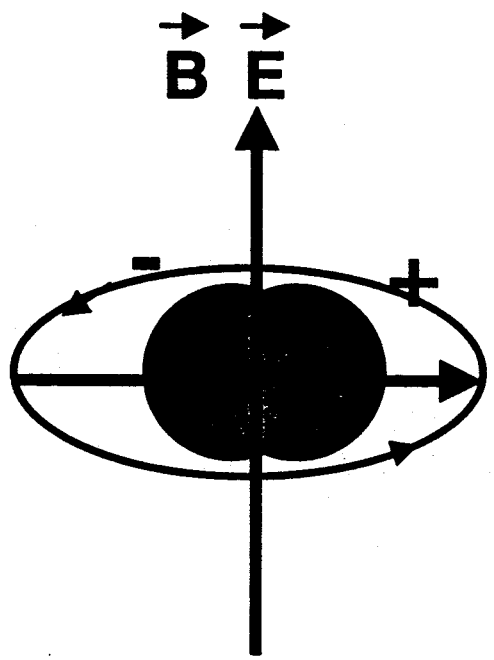
E $\rightarrow$ 5E $\tau \rightarrow 5\tau$ N $\rightarrow$ 250 N

LIFETIME τ IN A BOTTLE

$$\frac{1}{\tau} = \frac{1}{\tau_n} + \frac{1}{\tau_w} + \frac{1}{\tau_3} + \frac{1}{\tau_{up}}$$

where τ_n is the neutron lifetime,
τ_w is the wall lifetime,
τ_3 is absorption lifetime,
τ_{up} is upscattering lifetime.

THE BASIC TECHNIQUE



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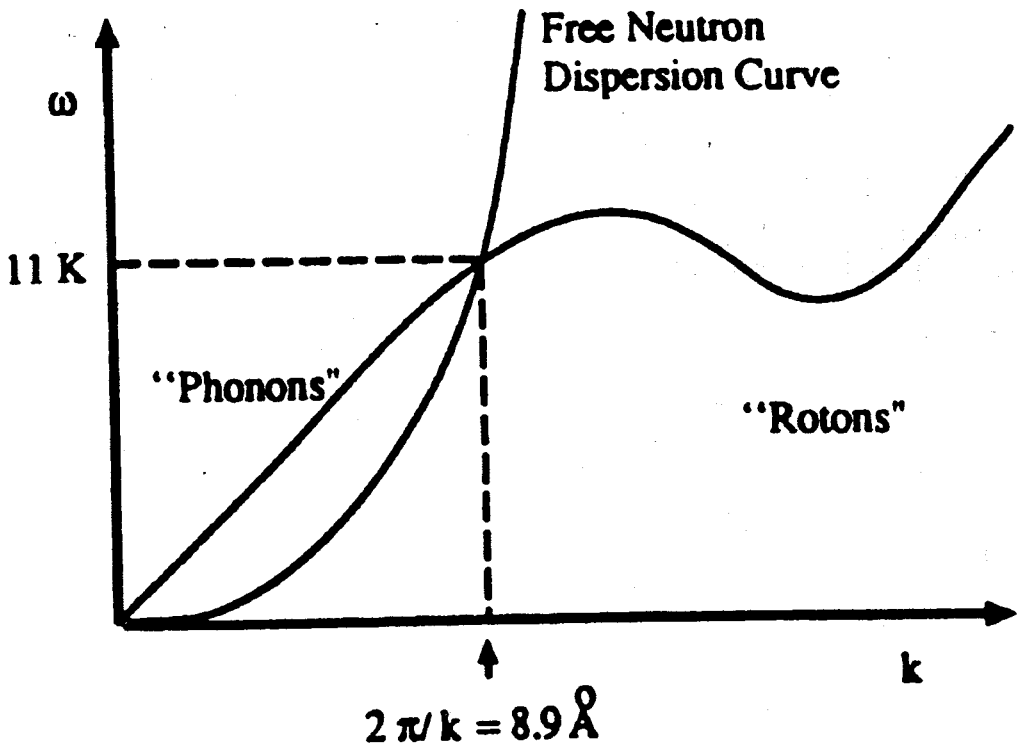
SUPERTHERMAL SOURCE OF UCNs

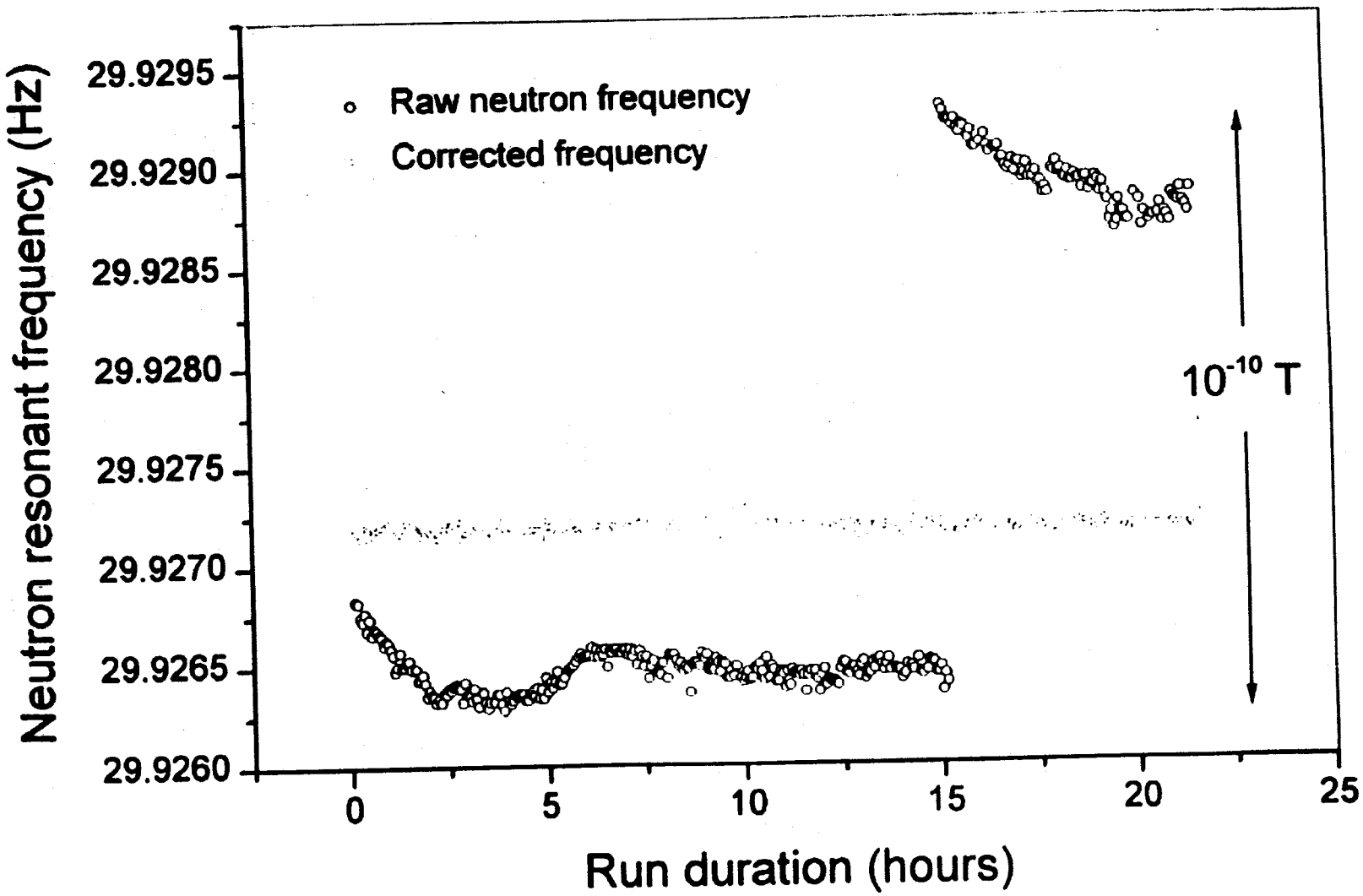


U_w = 200 neV
U_{LHe} = 20 neV

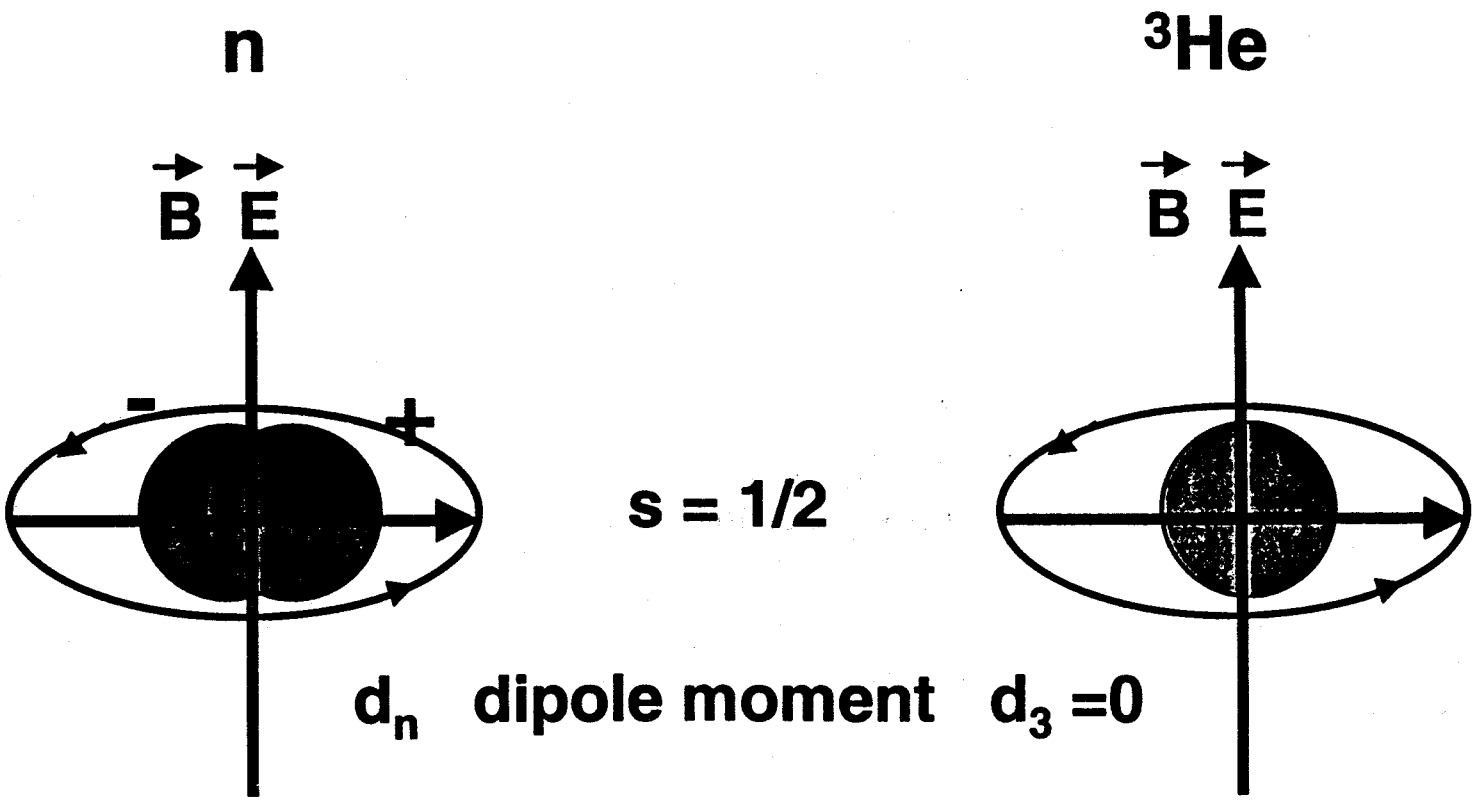
Quasi two-level system with single phonon upscattering suppressed by a large Boltzman factor.

$\tau_{up} \sim 100\ T^{-7}$ from 2-phonon upscattering

Magnetic Field Drift Correction



^{3}He MAGNETOMETRY



Look for a difference in precession frequency $\omega_n - \omega_3 \pm \omega_d$ dependent on E and corrected for temporal changes in ω_3

^{3}He-DOPANT AS AN ANALYZER

$^3\vec{He} + \vec{n} \rightarrow t + p$ $\sigma(\text{parallel}) < 10^2$ b

$\sigma(\text{opposite}) \sim 10^4$ b

UCN loss rate ~

$1-\vec{p}_3 \bullet \vec{p}_n = 1-p_3 p_n \cos(\gamma_n-\gamma_3)B_0 t$

$|\gamma_n-\gamma_3| = |\gamma_n|/10$

^{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 x = Atoms-^{3}He/Atoms-^{4}He ~ 10^{-10}.

^{4}He AS A DETECTOR

$$^3\vec{He} + \vec{n} \rightarrow t + p$$

t + p share 764 keV of kinetic energy. They scintillate while stopping in the ^{4}He. Light detected from the cell is a signature that the neutron had a polarization opposite to the ^{3}He.

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

A wavelength shifter (TPB) is used to change it to the blue, where it can be reflected and detected. Getting the light out of a cryogenic system is a challenge.

The walls and the wavelength shifter must be made of materials that do not absorb neutrons or depolarize ^{3}He. For the neutrons, deuterated wavelength shifter and Ni will do; for the ^{3}He, ???

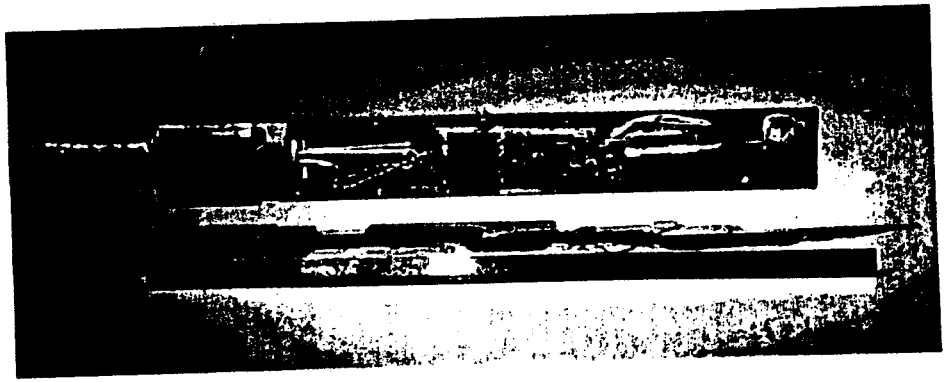
SQUIDs

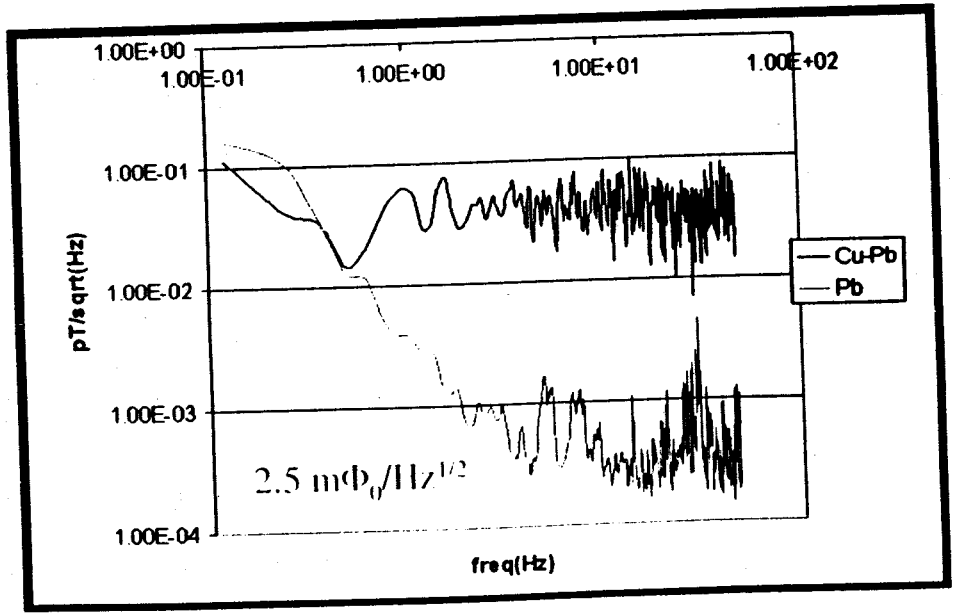
M. Espy, A. Matlashov, R. Kraus, P. Ruminer, M. Cooper, S. Lamoreaux

~100 cm^2 superconducting pickup coil

Flux = 2×10^{-16} $Tm^2 = 0.1\ \Phi_0$

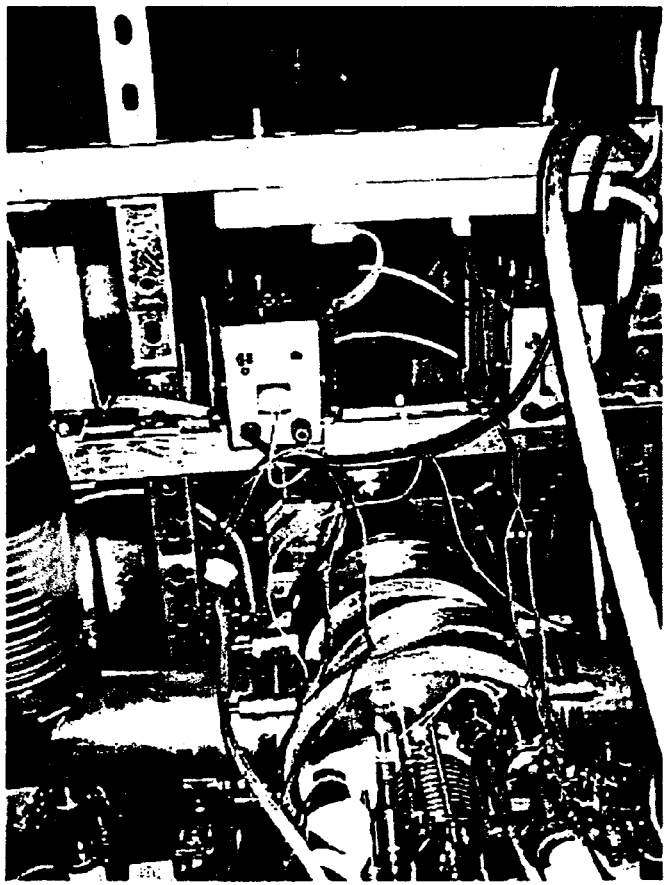
Noise = 4 $m\Phi_0/Hz^{1/2}$ at 10 Hz ~ $T^{1/2}$

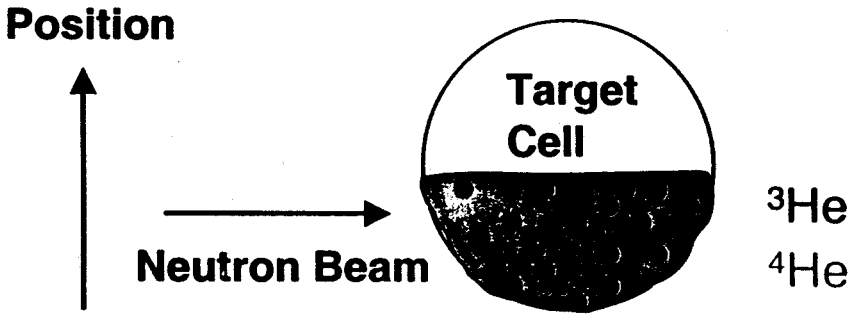


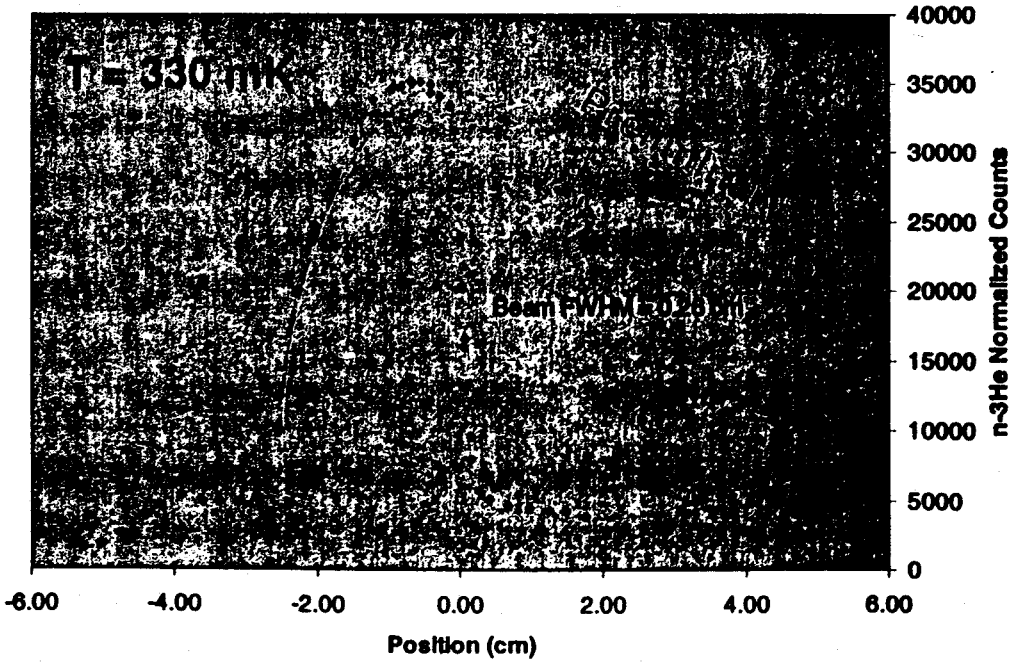


^{3}He Distributions in Superfluid ^{4}He

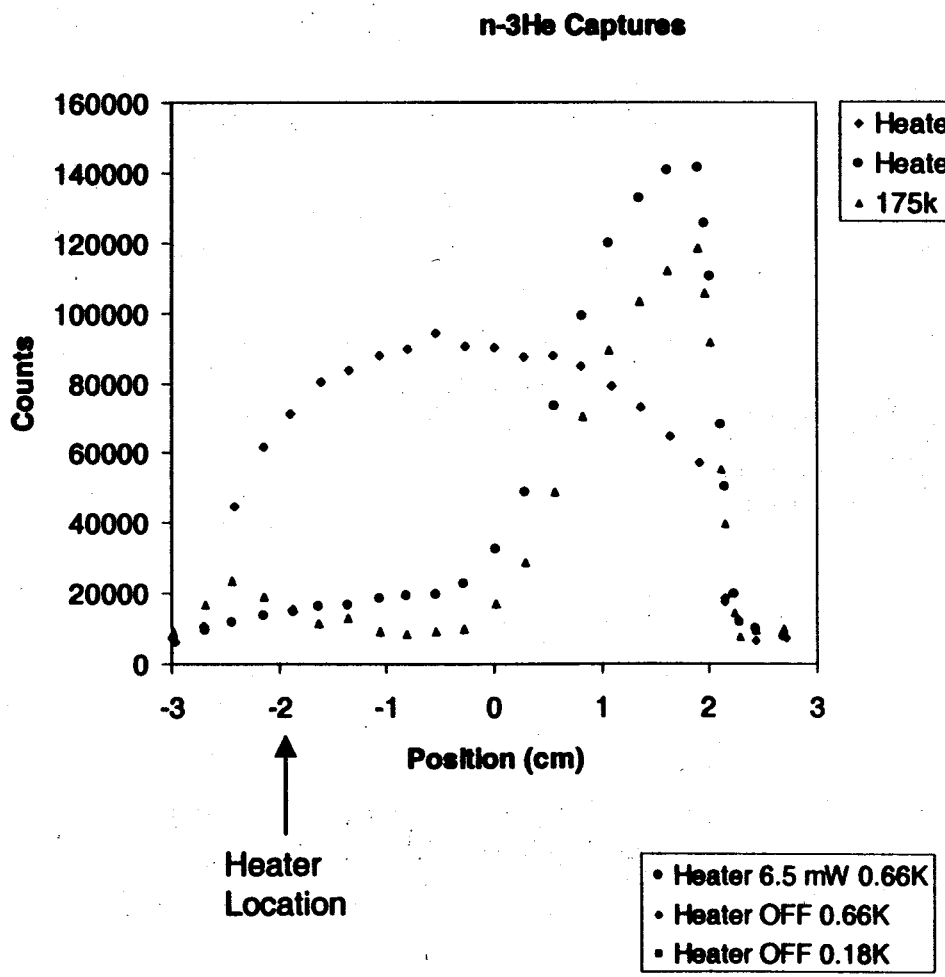
Dilution Refrigerator at LANSCE Flight Path 11a

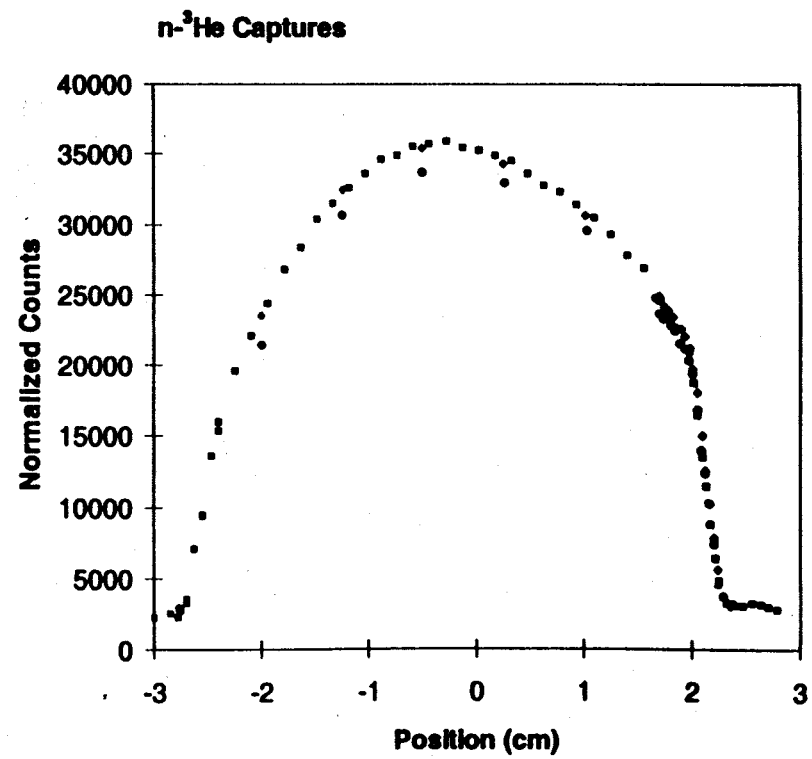




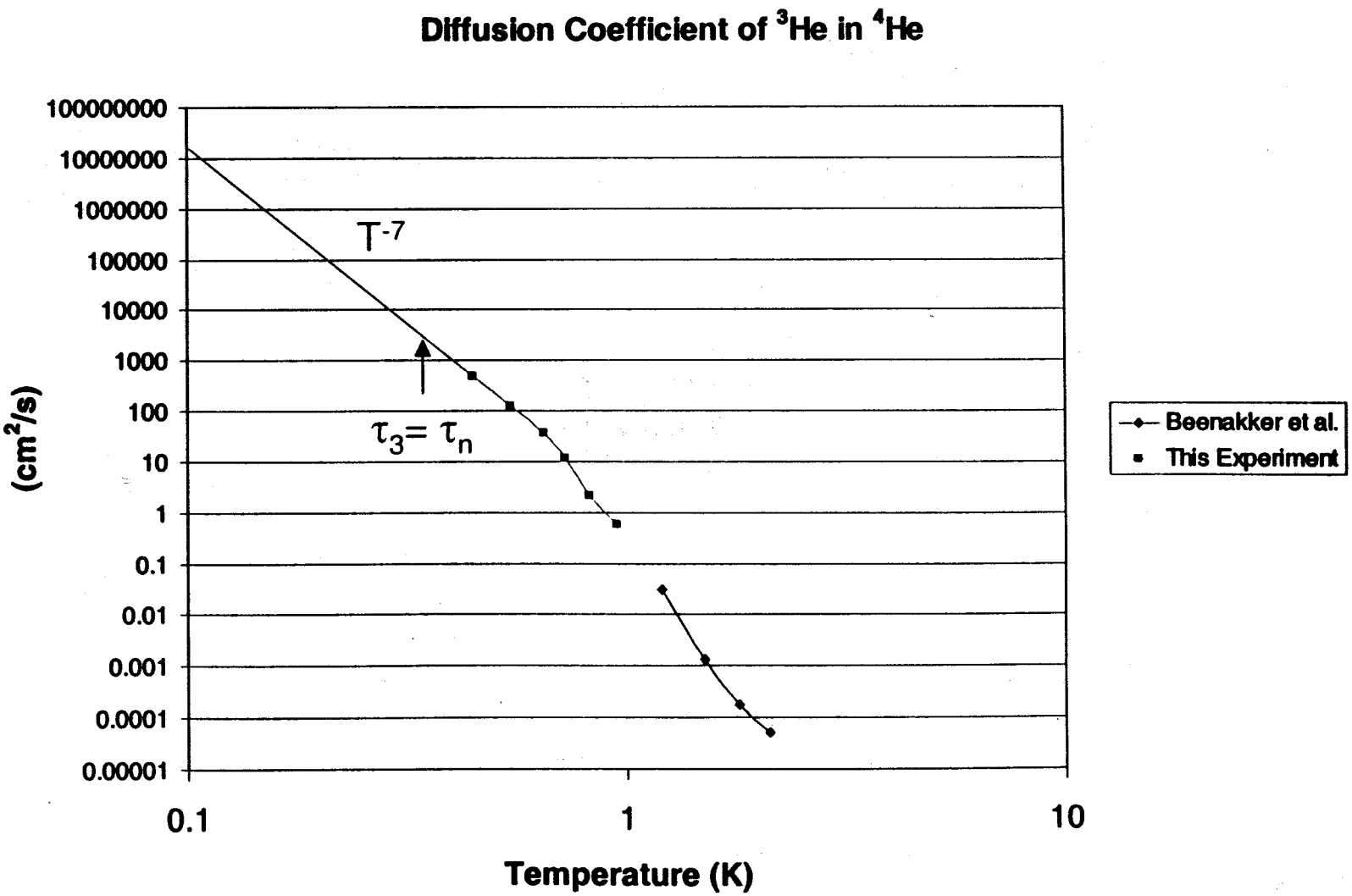


HEAT EFFECTS

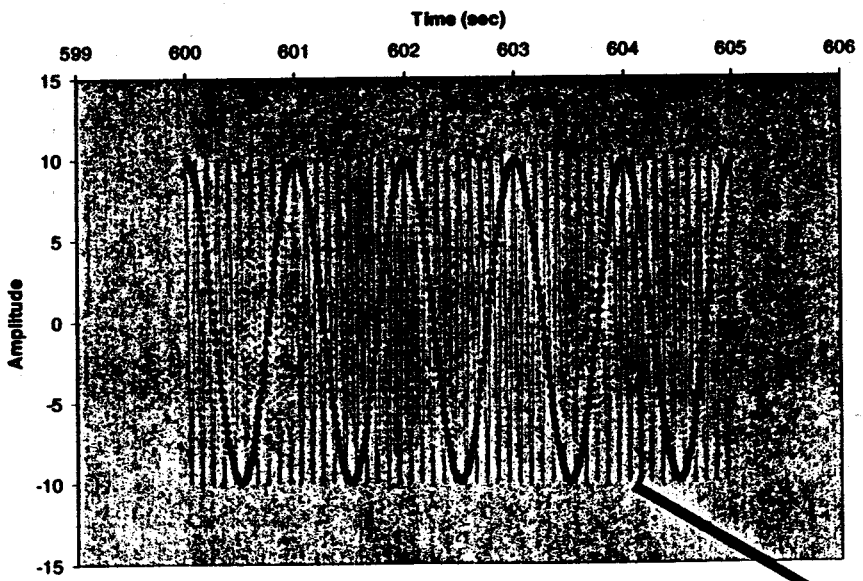


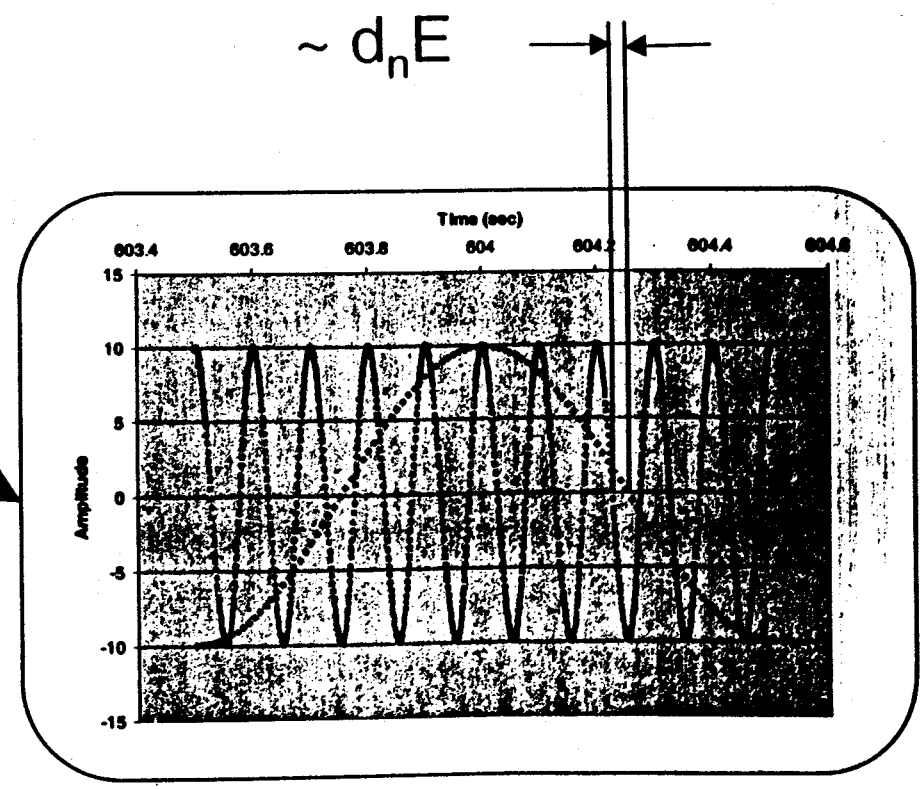


OTHER DATA


Diffusion Coefficient of ^{3}He in ^{4}He
100000000
10000000
1000000
100000
10000
1000
100
10
1
0.1
0.01
0.001
0.0001
0.00001
(cm^2/s)
T^{-7}
$\tau_3 = \tau_n$
0.1
1
10
Temperature (K)
Beenakker et al.
This Experiment

THE SIGNAL





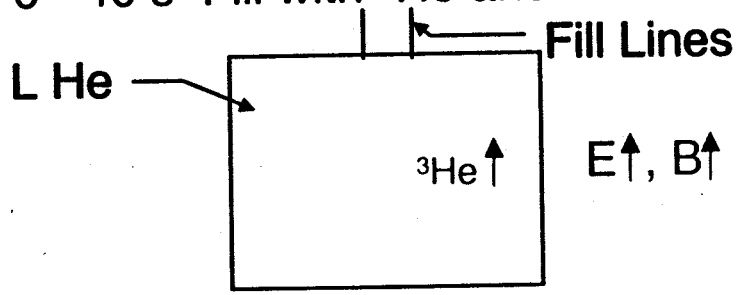
^{3}He(n,p)t Scintillation Light

$\nu \sim (\gamma_3 - \gamma_n)$

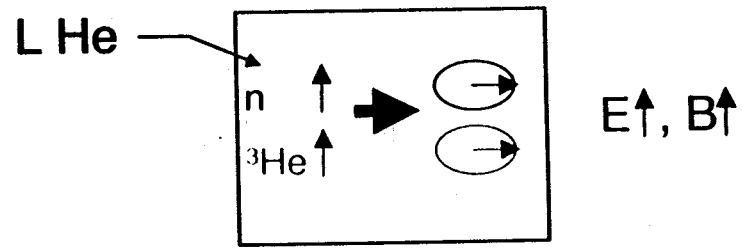
SQUID $\nu \sim \gamma_3$

EXPERIMENT CYCLE

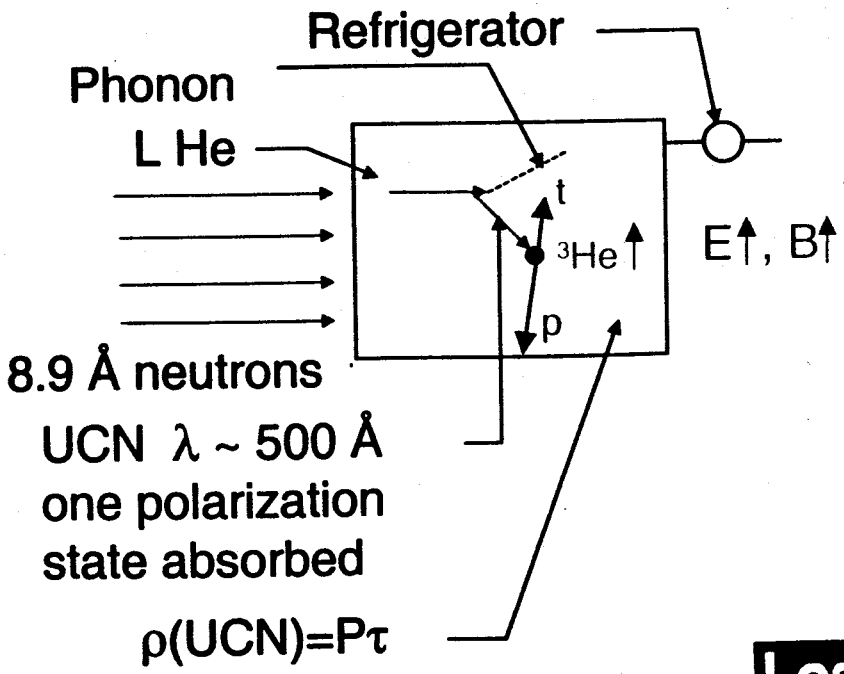
T = 0 - 40 s Fill with ^{4}He and $^3\vec{\text{He}}$



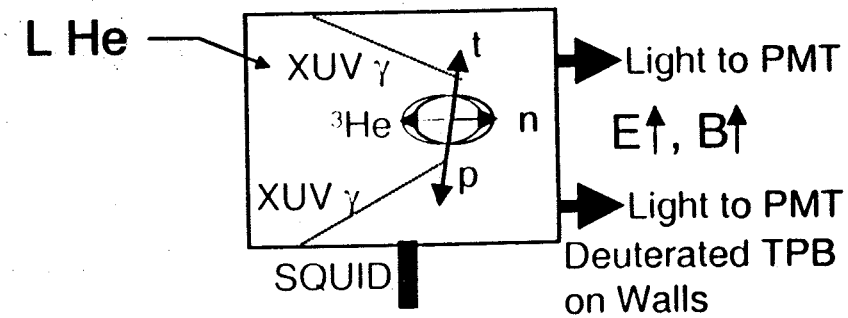
T = 450 - 460 s $\pi/2$ pulse



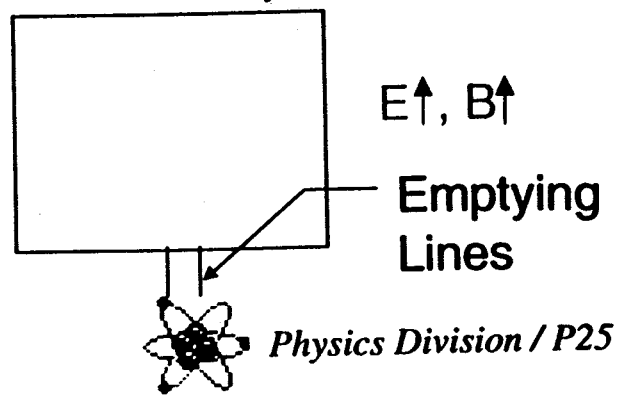
T = 40 - 450 s $\vec{\text{UCN}}$ from Cold n



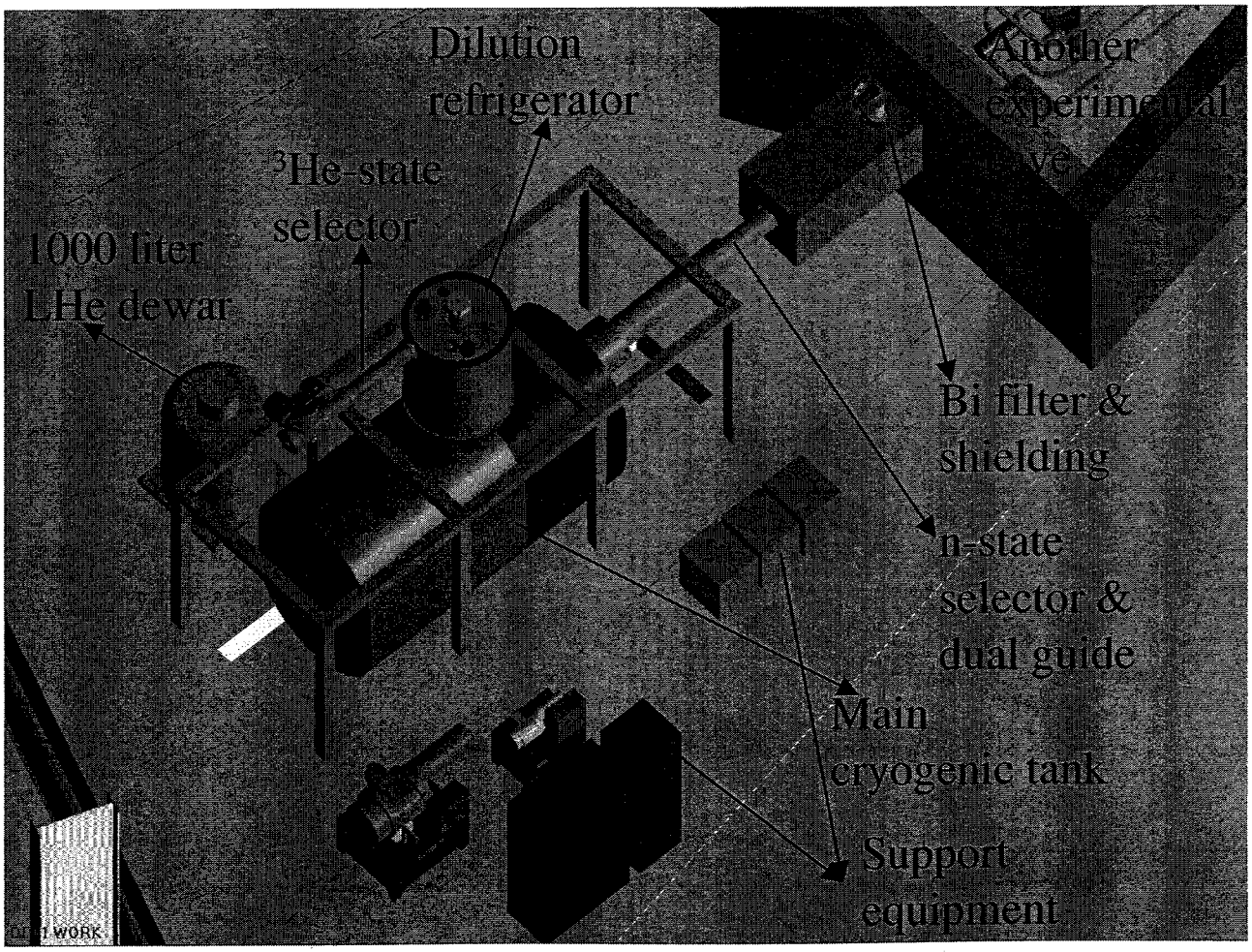
T = 460 - 960 s Precession about $\vec{E}$ & $\vec{B}$



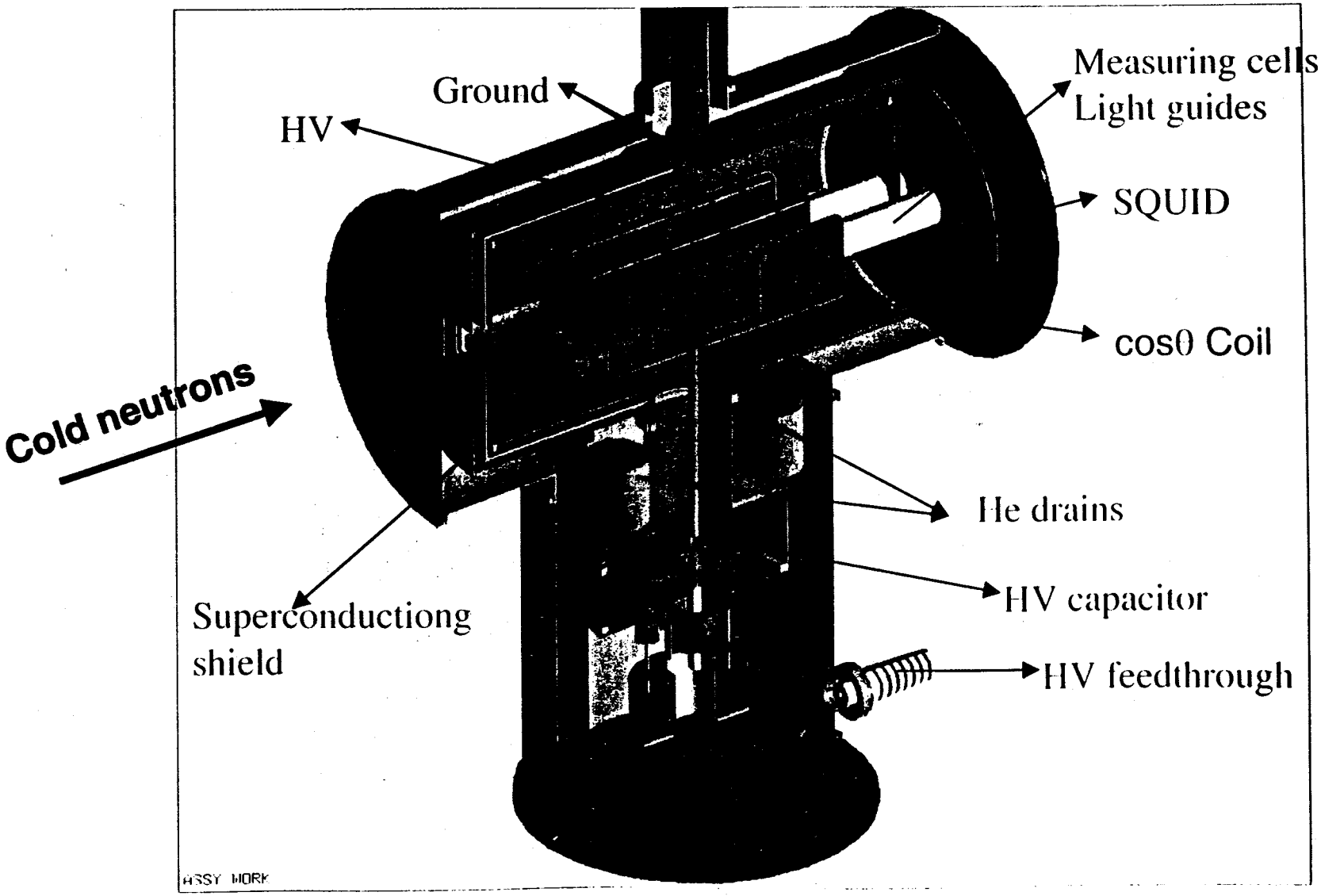
T = 960 - 1000 s Recycle He



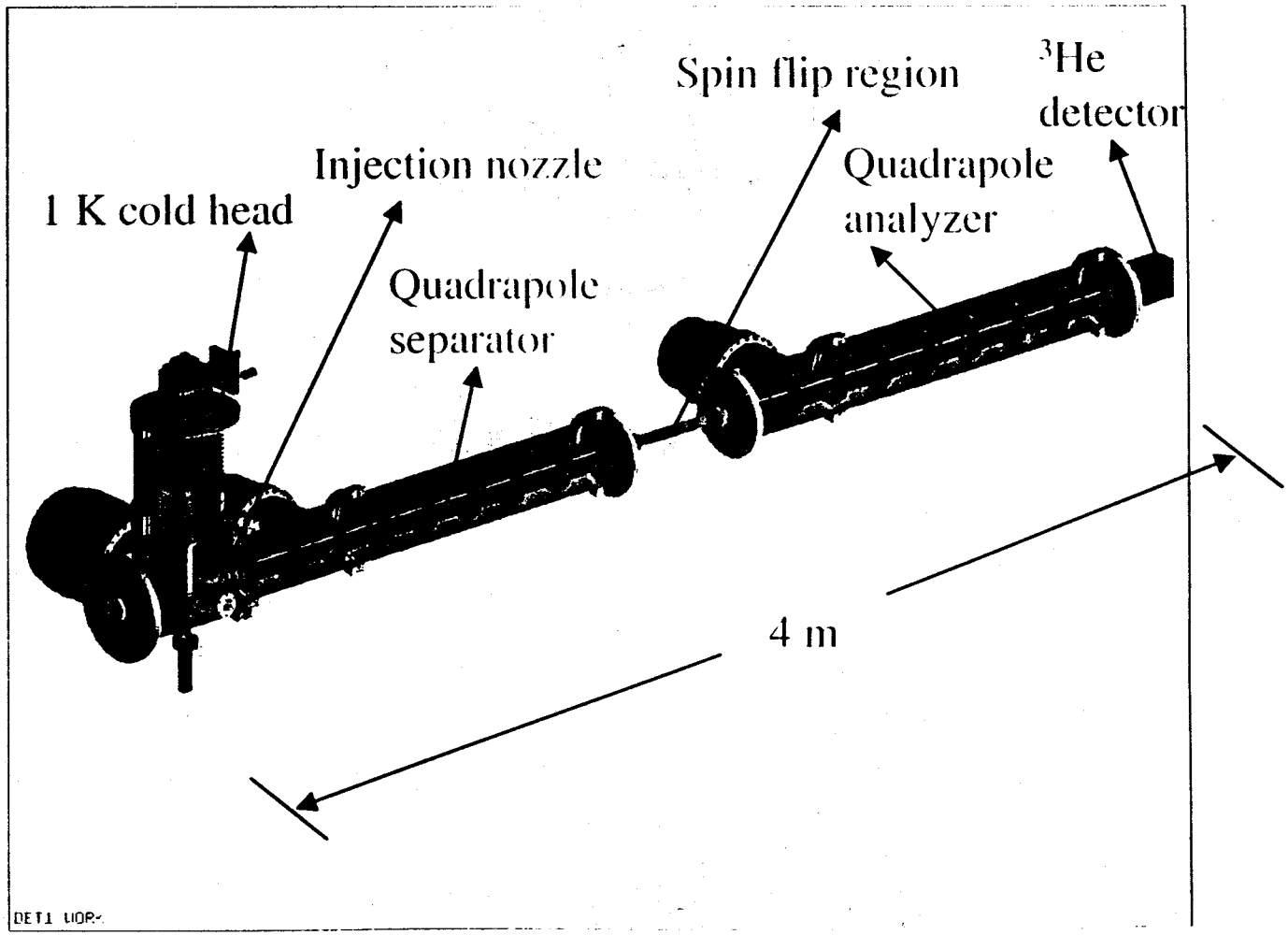
FLOOR LAYOUT



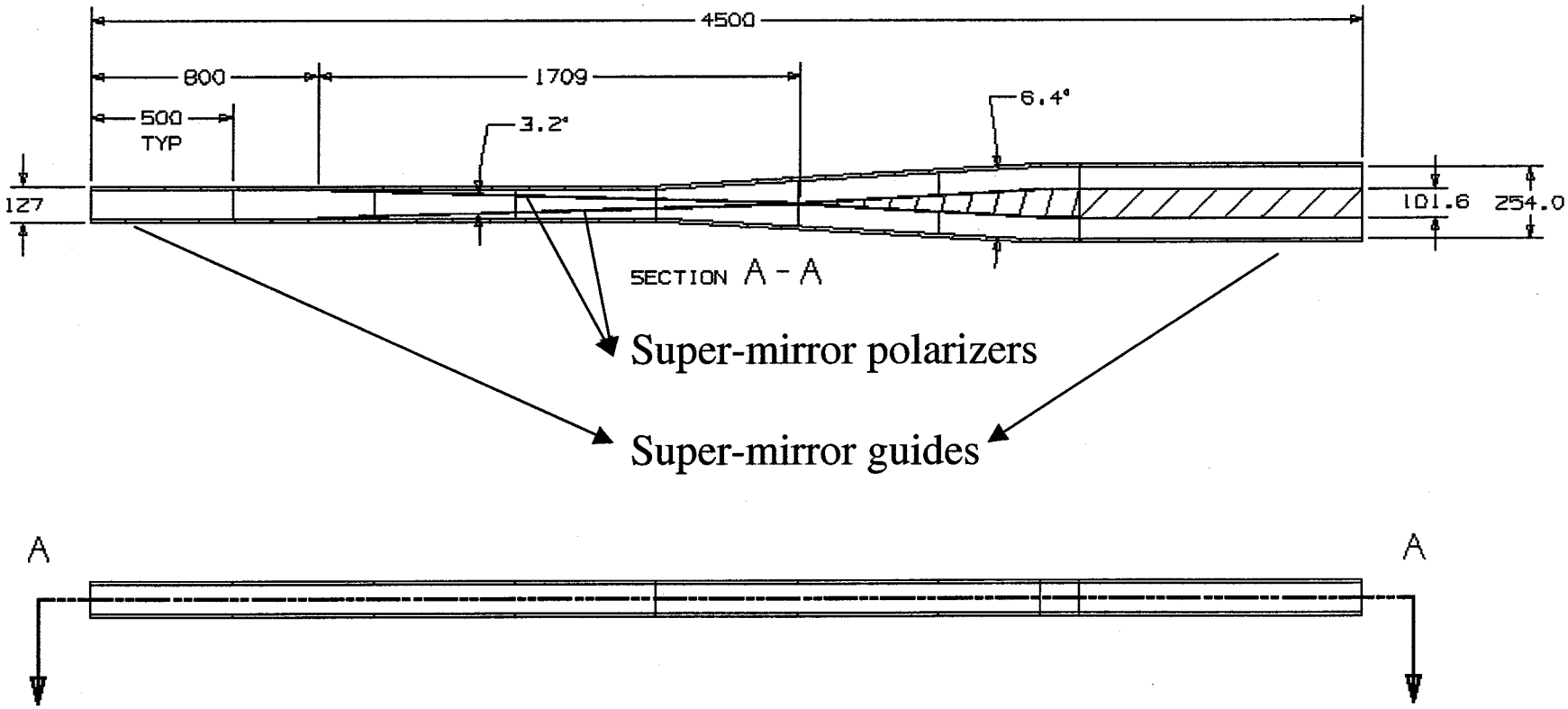
CONCEPTUAL DESIGN



POLARIZED ^{3}He SOURCE

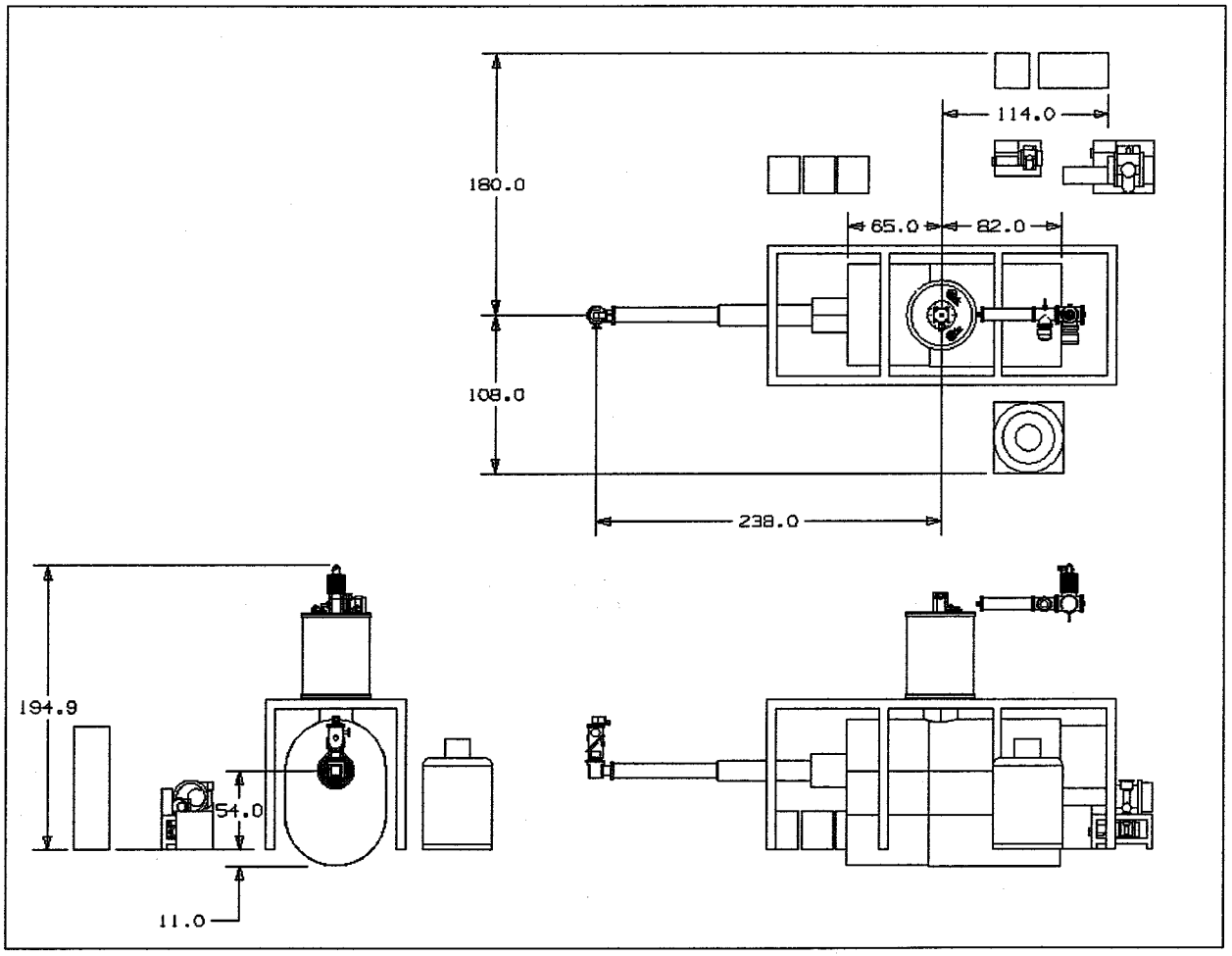


n-STATE SELECTOR



Units are mm

LAYOUT OF EDM EXPERIMENT



Units are inches

BEAM AREA SPECIFICATIONS

Area without shielding but including beam splitter and cryogenics support	- ‖ to beam	10 m
	- ⊥ to beam	±4 m
Height		5 m
Beam height from base		1.7 m
Shielding minimized by Bi filter		
Vibration-isolation pad		
Elevated service platforms		
Crane lift height and clearance		7 m
Power 480 (60 A circuits), 240 3-phase, 120 V		150 kW
Magnetic isolation		1 gauss
T_0 and frame overlap choppers to select 9 Å neutrons		
Water chiller		10 gal/min
Cryogen vents		
Convenient LHe Source		100-2000 L/wk