Recent Progress and Perspectives in Solid Polarized Targets

D. G. Crabb

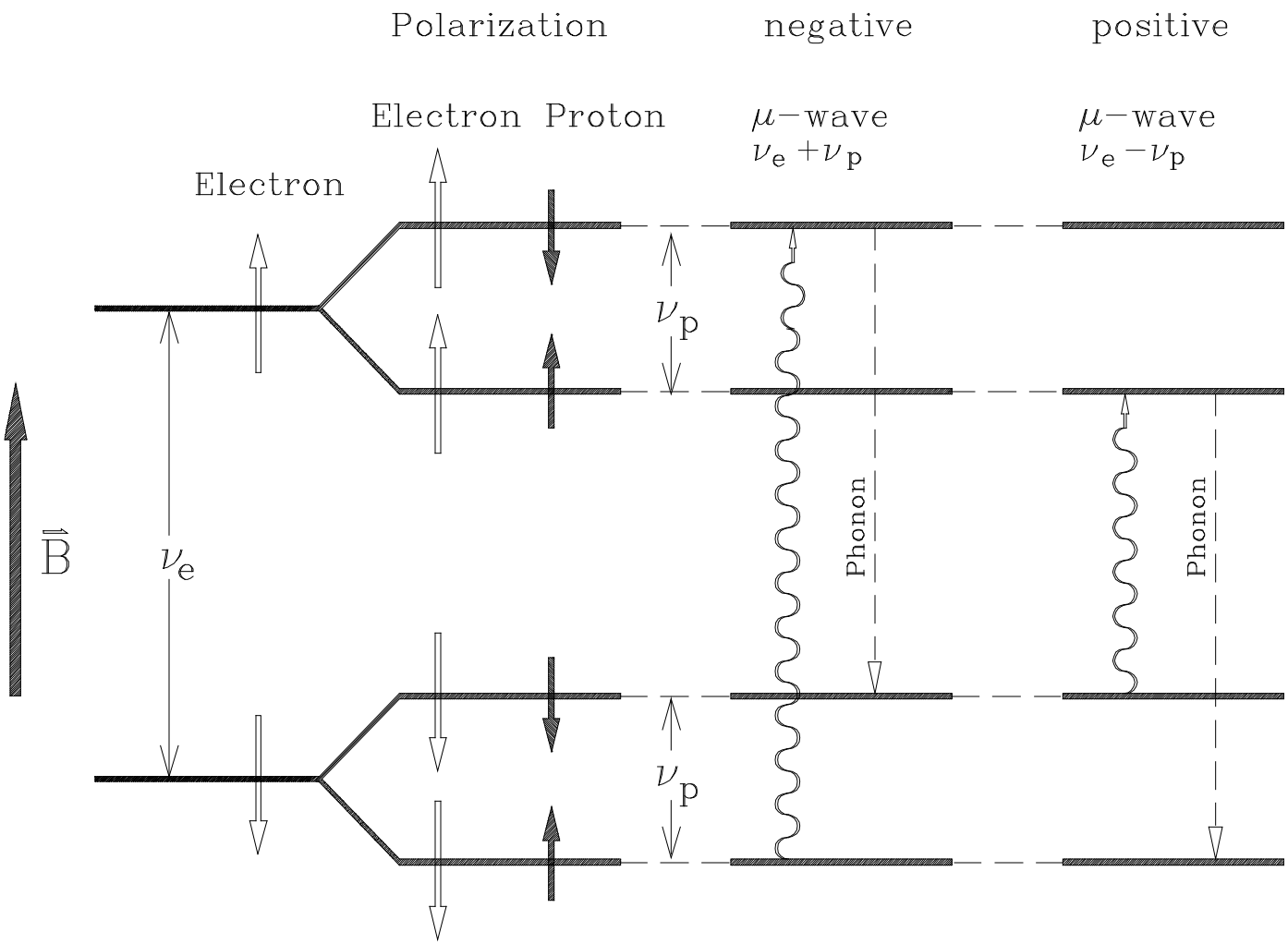
University of Virginia

Contents

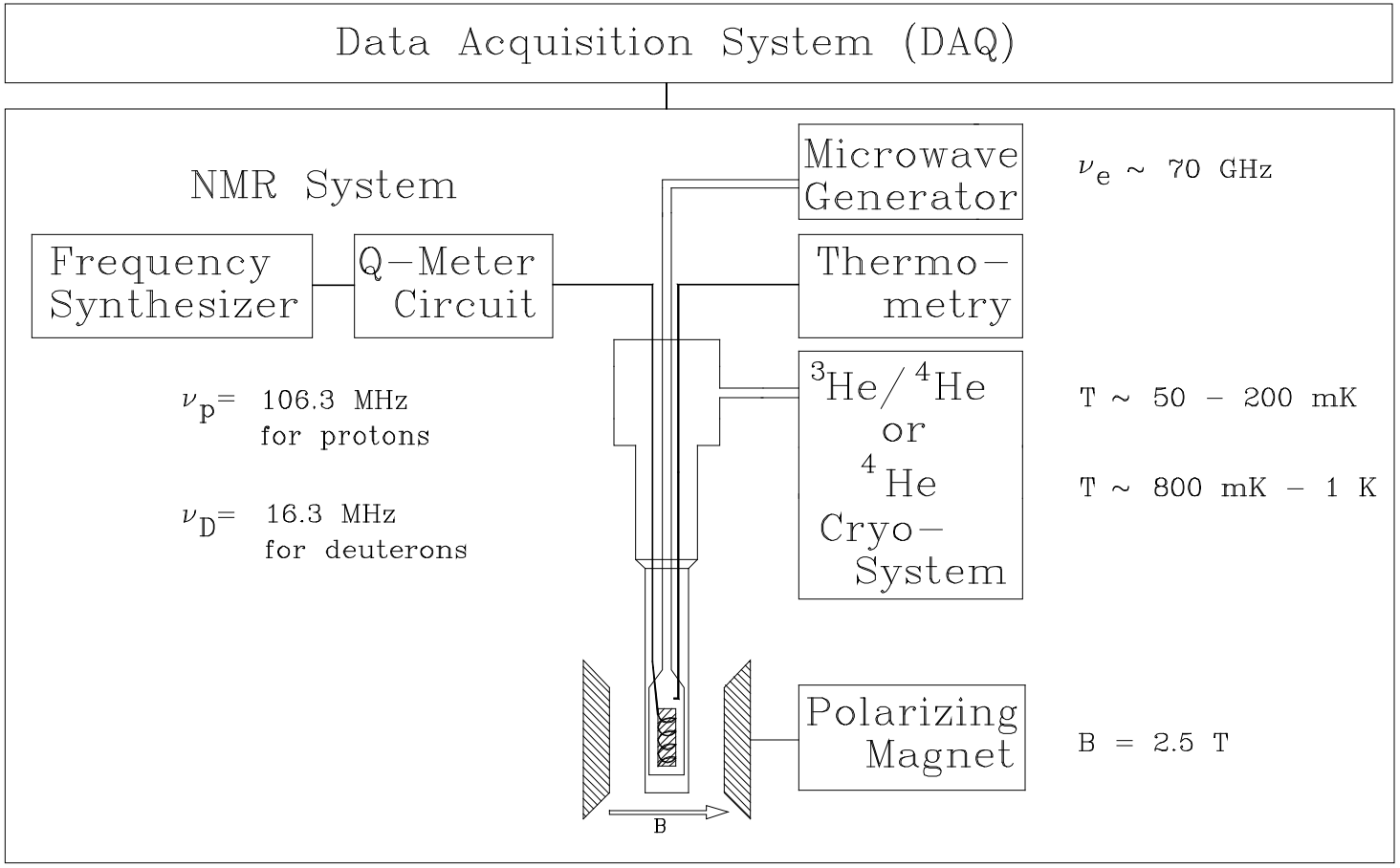
Introduction
DNP Solid Targets

- Mature Technology (since early 1960s)
- Used in MRI research, neutron spectroscopy etc.
- Devoted to particle physics experiments: continuing research mainly in materials.
- Will not discuss Hdice target or warm (LN_2) target.

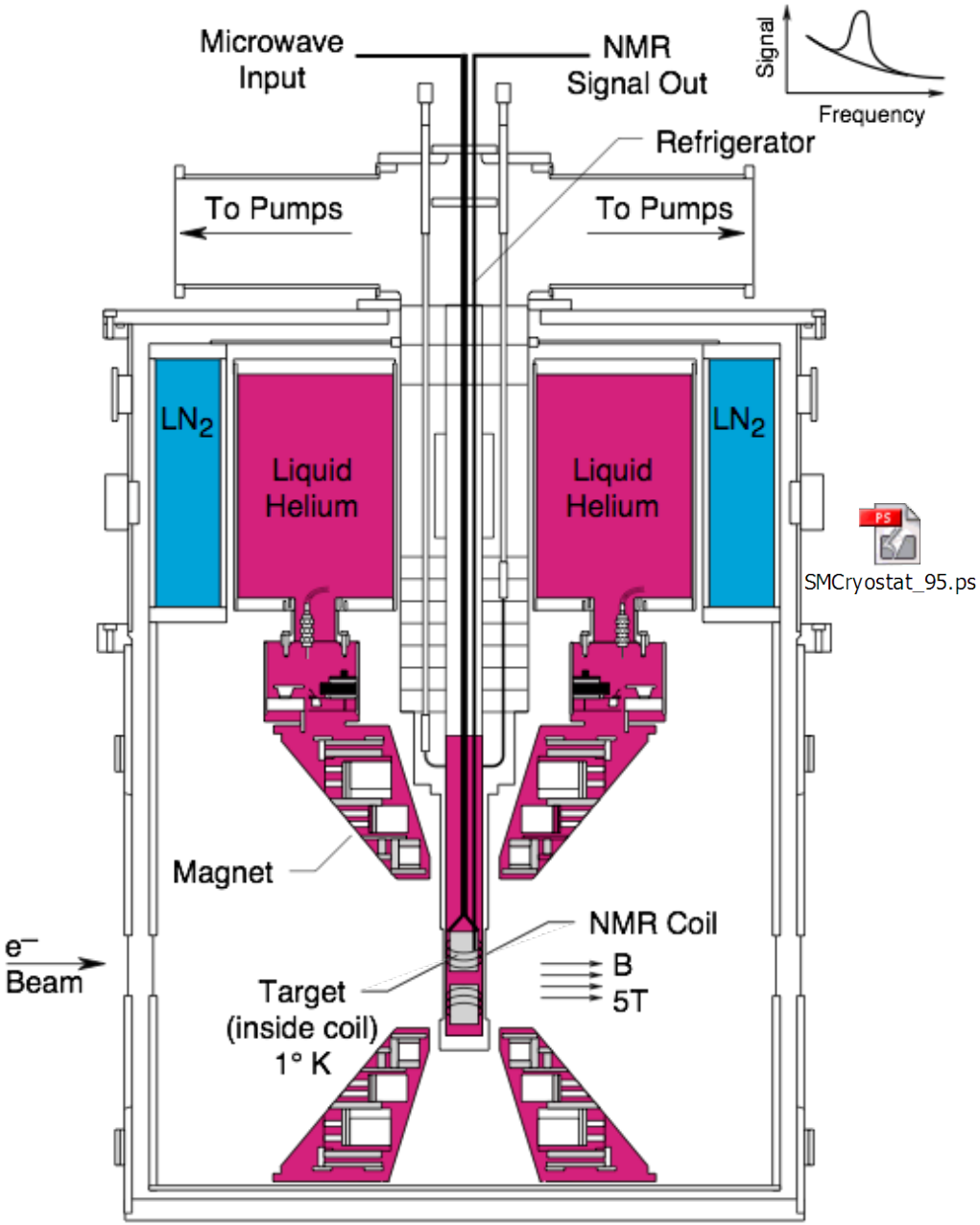
DNP


Polarization
negative
positive
Electron
Proton
μ−wave
$\nu_e + \nu_p$
μ−wave
$\nu_e - \nu_p$
Electron
ν_p
$\vec{B}$
ν_e
Phonon
Phonon
ν_p

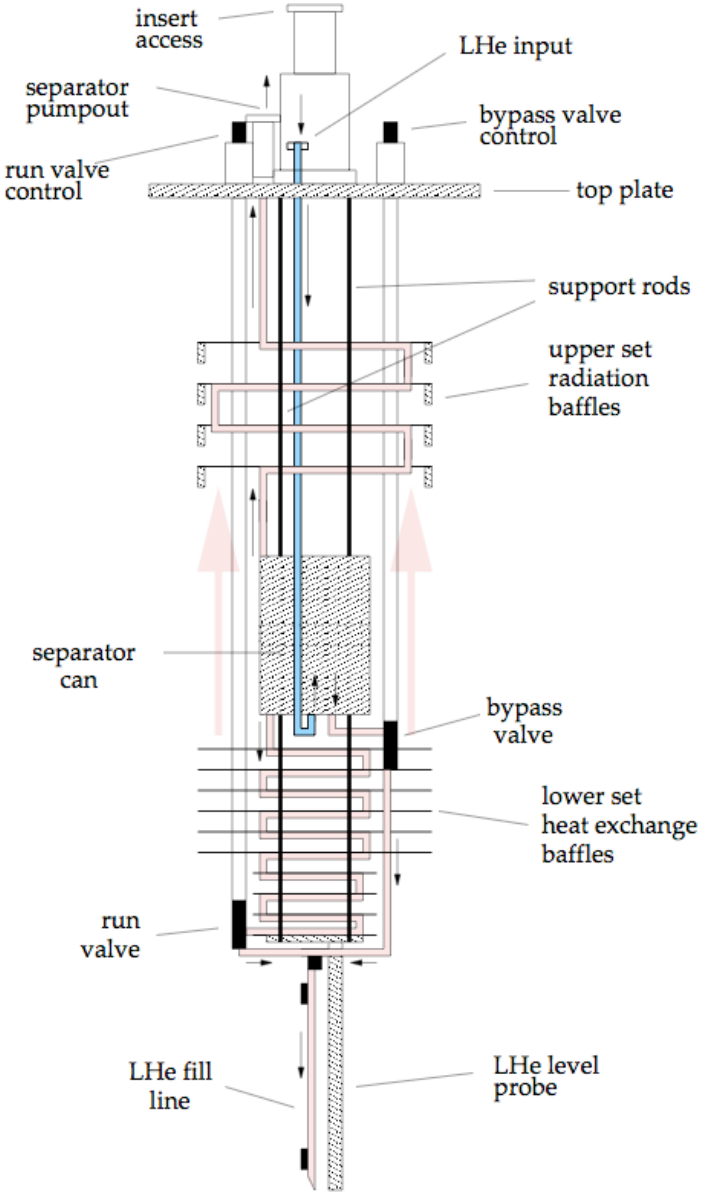
Major Polarized Target Systems

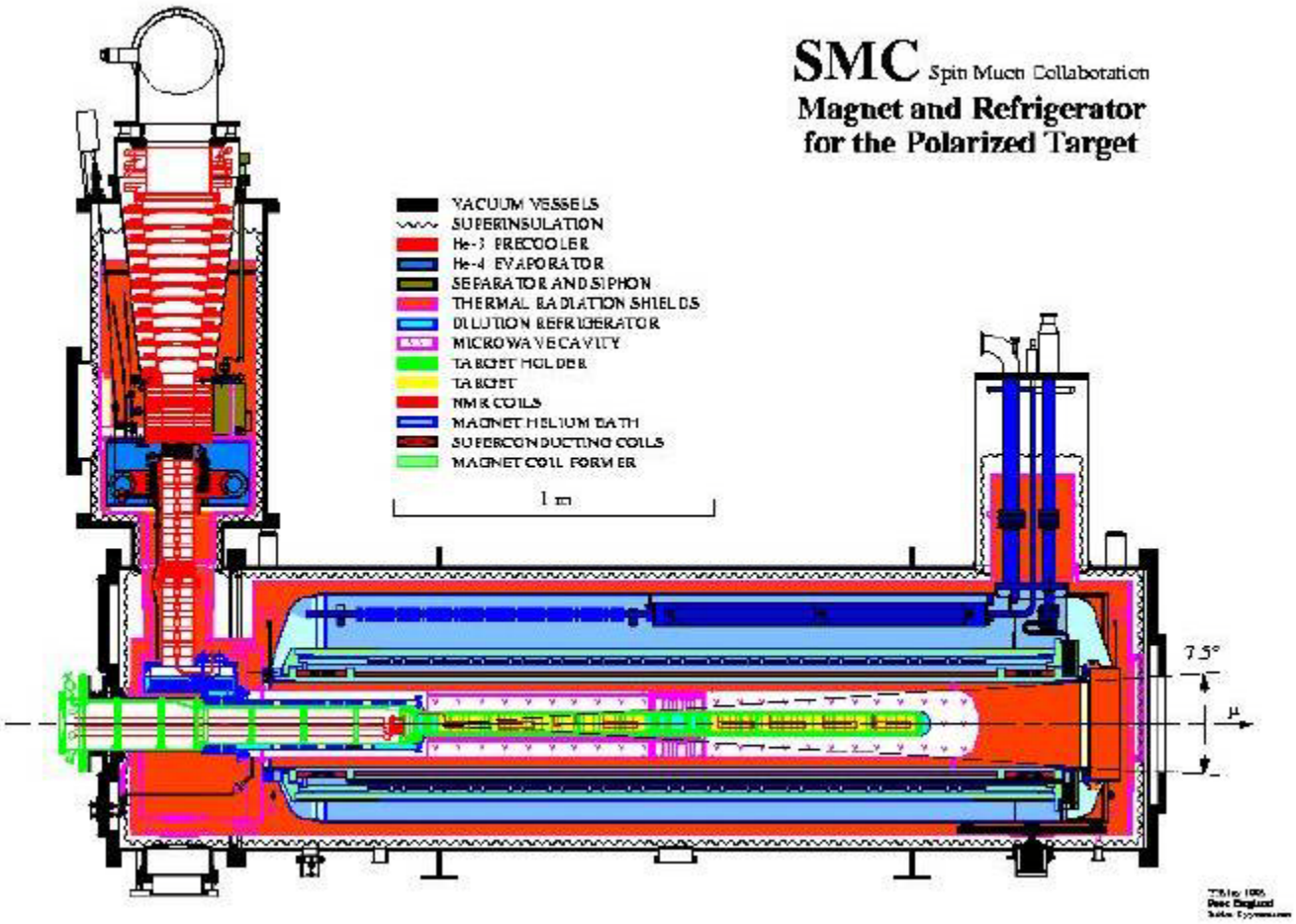


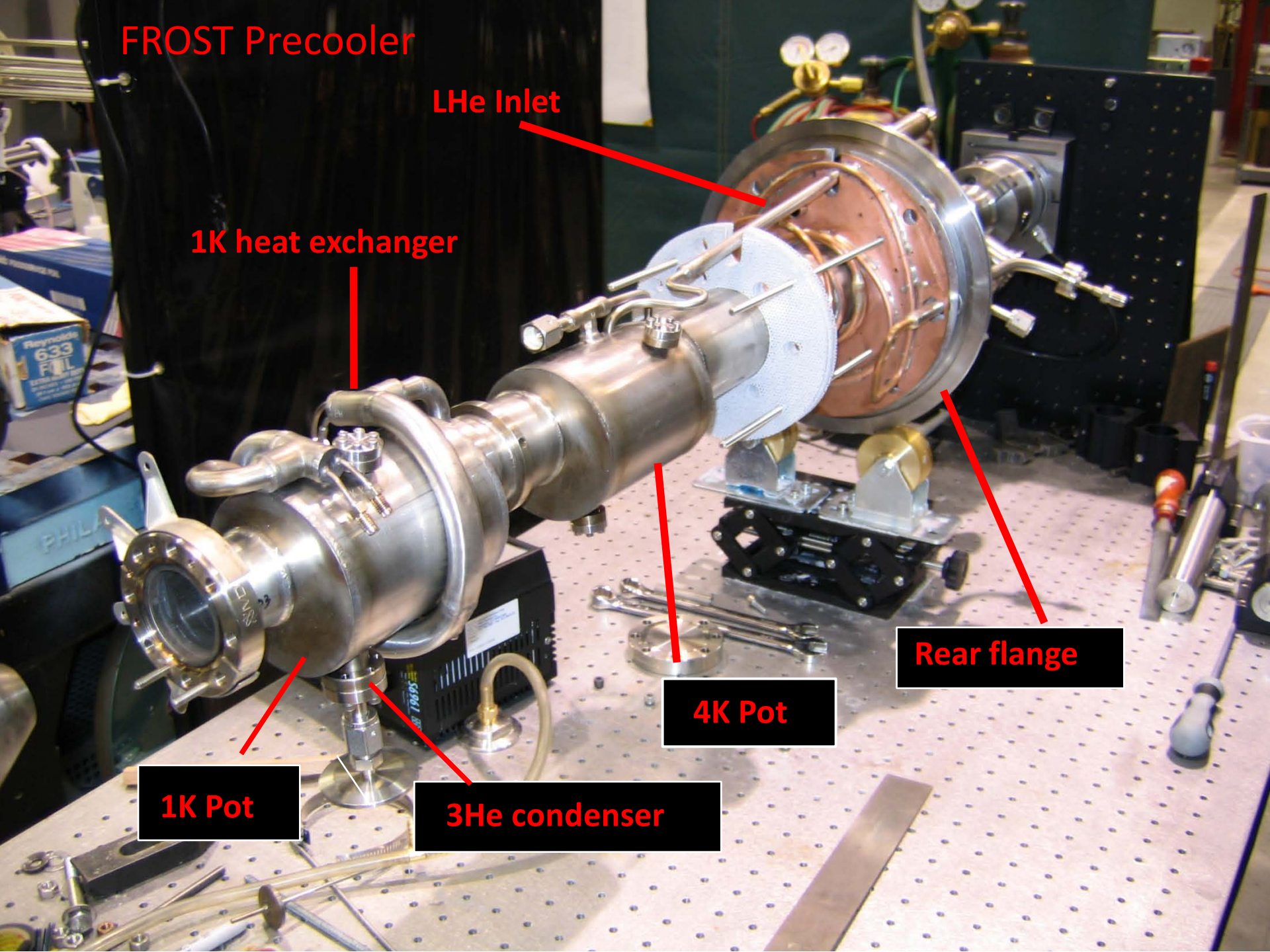
UVA/SLAC/JLAB Target



SMCryostat_95.ps




SMC Spin Muon Collaboration
Magnet and Refrigerator
for the Polarized Target
VACUUM VESSELS
SUPERINSULATION
He-3 PRECOOLER
He-4 EVAPORATOR
SEPARATOR AND SIPHON
THERMAL RADIATION SHIELDS
DILUTION REFRIGERATOR
MICROWAVE CAVITY
TARGET HOLDER
TARGET
NMR COILS
MAGNET HELIUM BATH
SUPERCONDUCTING COILS
MAGNET COIL FORMER
1 m
7.5°
μ


FROST Precooler
LHe Inlet
1K heat exchanger
Rear flange
4K Pot
1K Pot
3He condenser

Microwaves

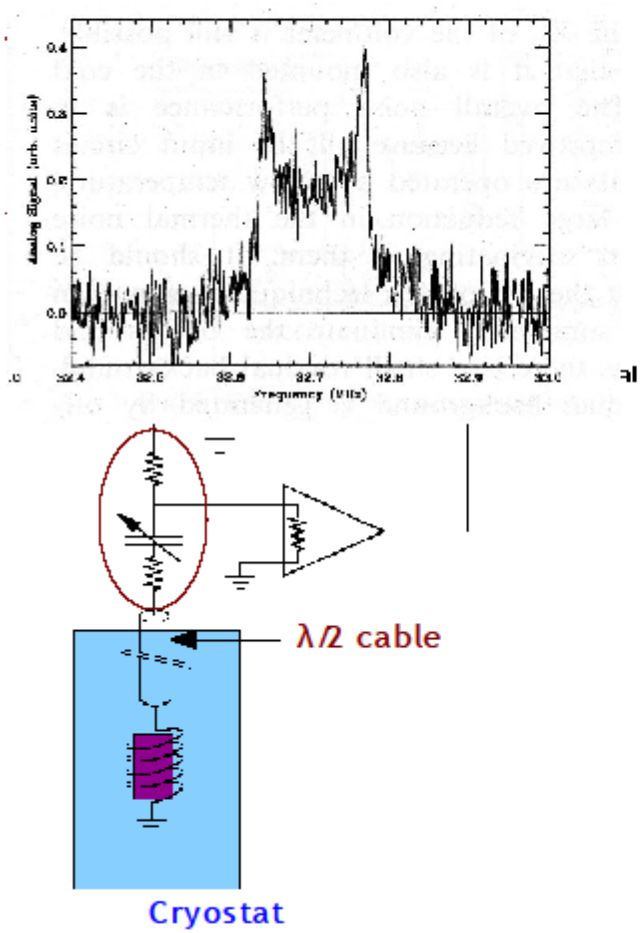
- EIO "standard" especially at higher frequencies – eg. 140 GHz 10 – 15 W
- But can now obtain ~3 to 5 W close to 200GHz ~6W at 183GHz and 2.5 W at 211 GHz
- But no mechanical tuning – electrical tuning range ~200 MHz . Move magnetic field to reach both polarization signs.

Solid State Devices (Impatt Diodes) ~ 0.5 W at 100GHz

NMR

- Liverpool Q-meter - standard for many years.
- Modification - Resonant circuit mounted very near target – reduced noise, increased stability.
- Pulsed NMR ???
- AFP

A few words about NMR



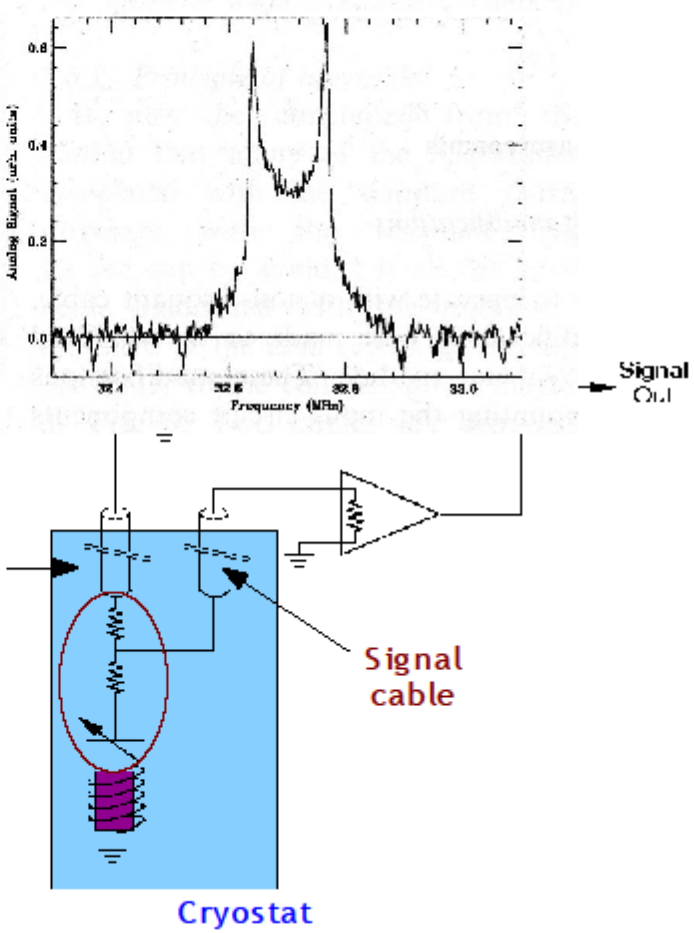


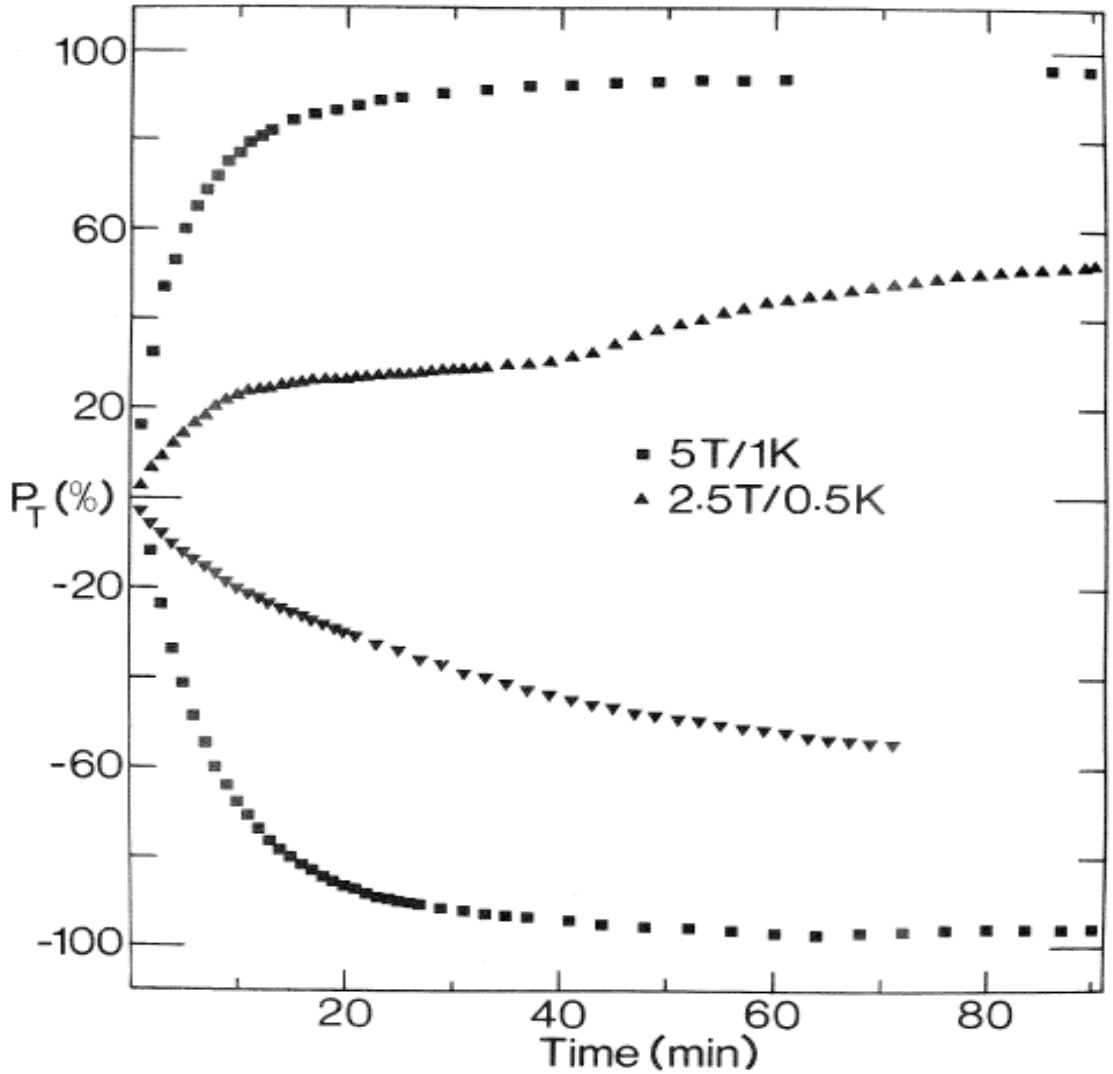
Table of polarized Target Materials

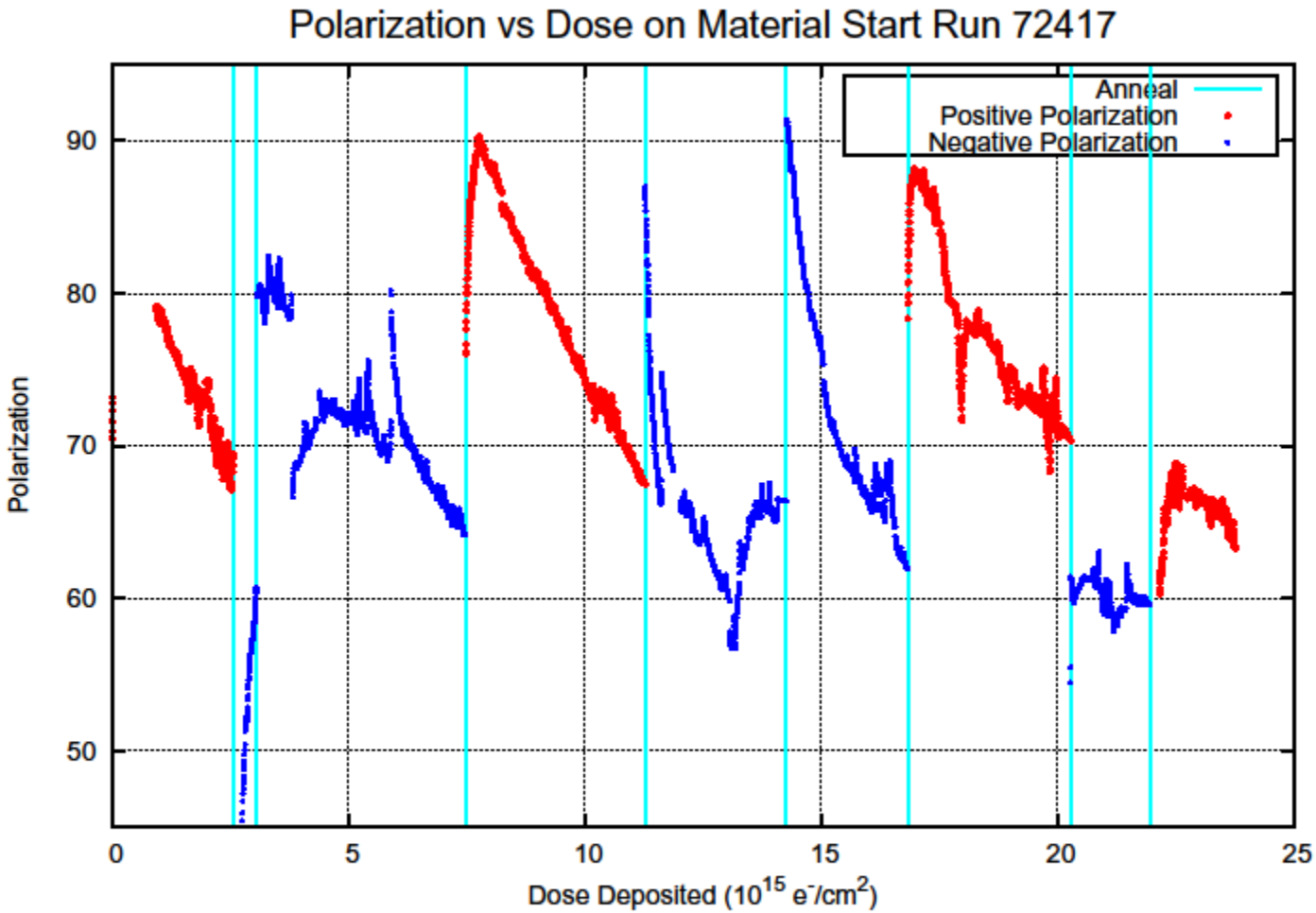
Table 1 Polarized target materials commonly used in particle scattering experiments

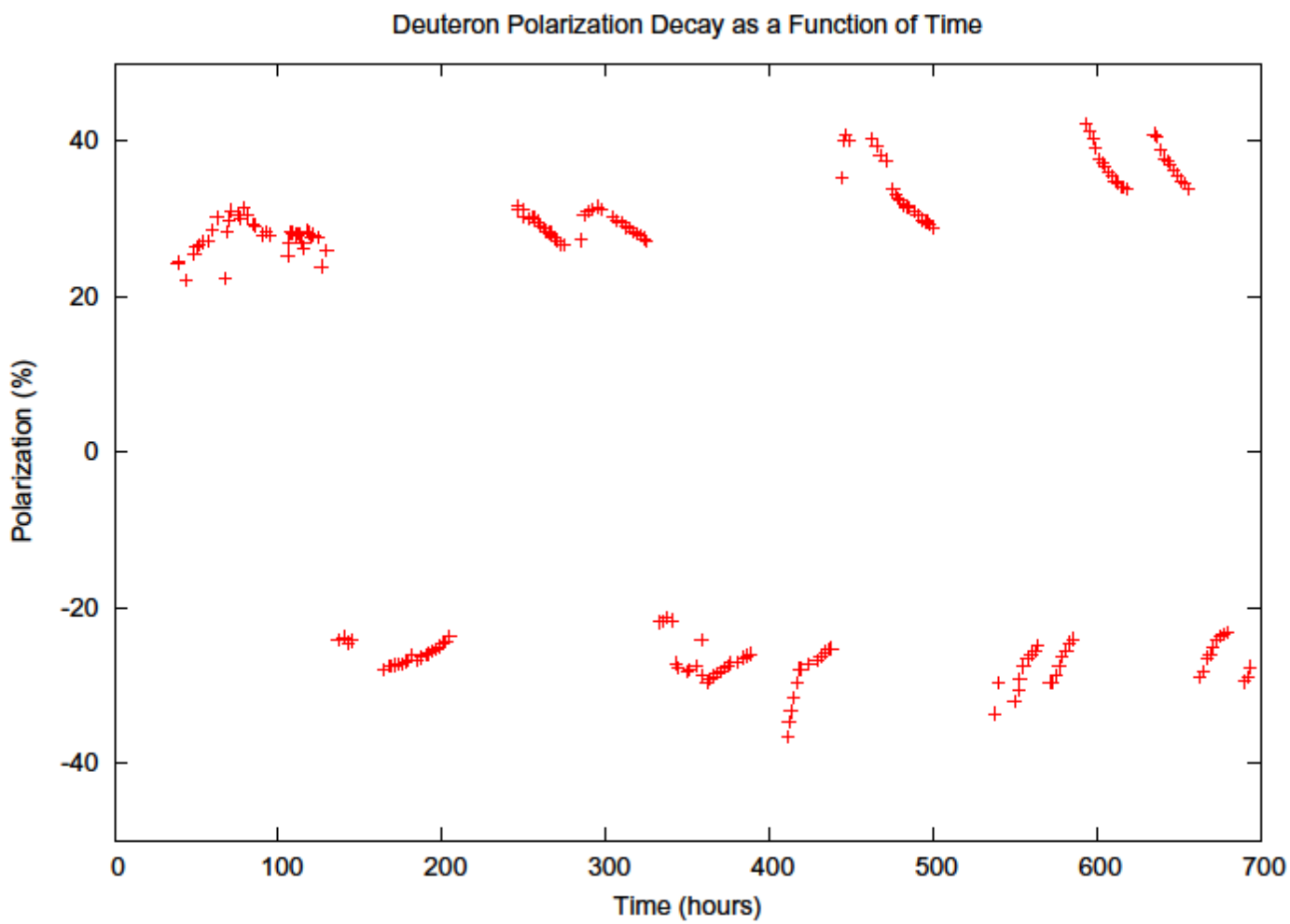
Materials & Chem. Comp.	Dopant[a] & Method	Polarizable Nucleons % by weight	B/T Tesla/K	Max. Polarization %	Radiation Damage Characteristic Flux[b] 10^{14} particles/cm^2
LMN $La_2(Co, Mg)_3$ $(NO)_3 \cdot 24H_2O$	Neodymium Ch	3.1	2.0/1.5	±70	~ 0.01
1,2 Propanediol $C_3H_6(OH)_2$	Cr (V) Ch	10.8	2.5/0.37	+98 −100	~ 1
1,2 Ethanediol $C_2H_4(OH)_2$	Cr (V) Ch	9.7	2.5/0.5	±80	~ 2
Butanol C_4H_9OH	EHBA Cr (V) Ch	13.5	2.5/0.3	±93	3 - 4
EABA $C_2NH_7BH_3NH_3$	EHBA Cr (V) Ch	16.5	2.5/0.5	+75 −73	7(+), 3.5(−)[c]
Ammonia $^{14}NH_3$, $^{15}NH_3$	NH_3• Ir	17.6, 16.6	5.0/1.0	+97 100	7, 17.5[d]
d-Butanol C_4D_9OD	EDBA Cr (V) Ch	23.8	2.5/0.3	±50	not measured
d-Ammonia $^{14}ND_3$, $^{15}ND_3$	ND_3• Ir	30.0, 28.6	3.5/0.3	+49 −53	13(+), 28(−)
Lithium deuteride ^6LiD	f-center Ir	50	6.5/0.2	±70	> 100

[a] Ch: chemically doped, Ir: doped through irradiation
[b] The radiation dose which reduces the polarization by e^{-1} of its value
[c] For positive and negative polarizations, respectively
[d] In NH_3 there are two distinct regions of decay

Ammonia Polarization

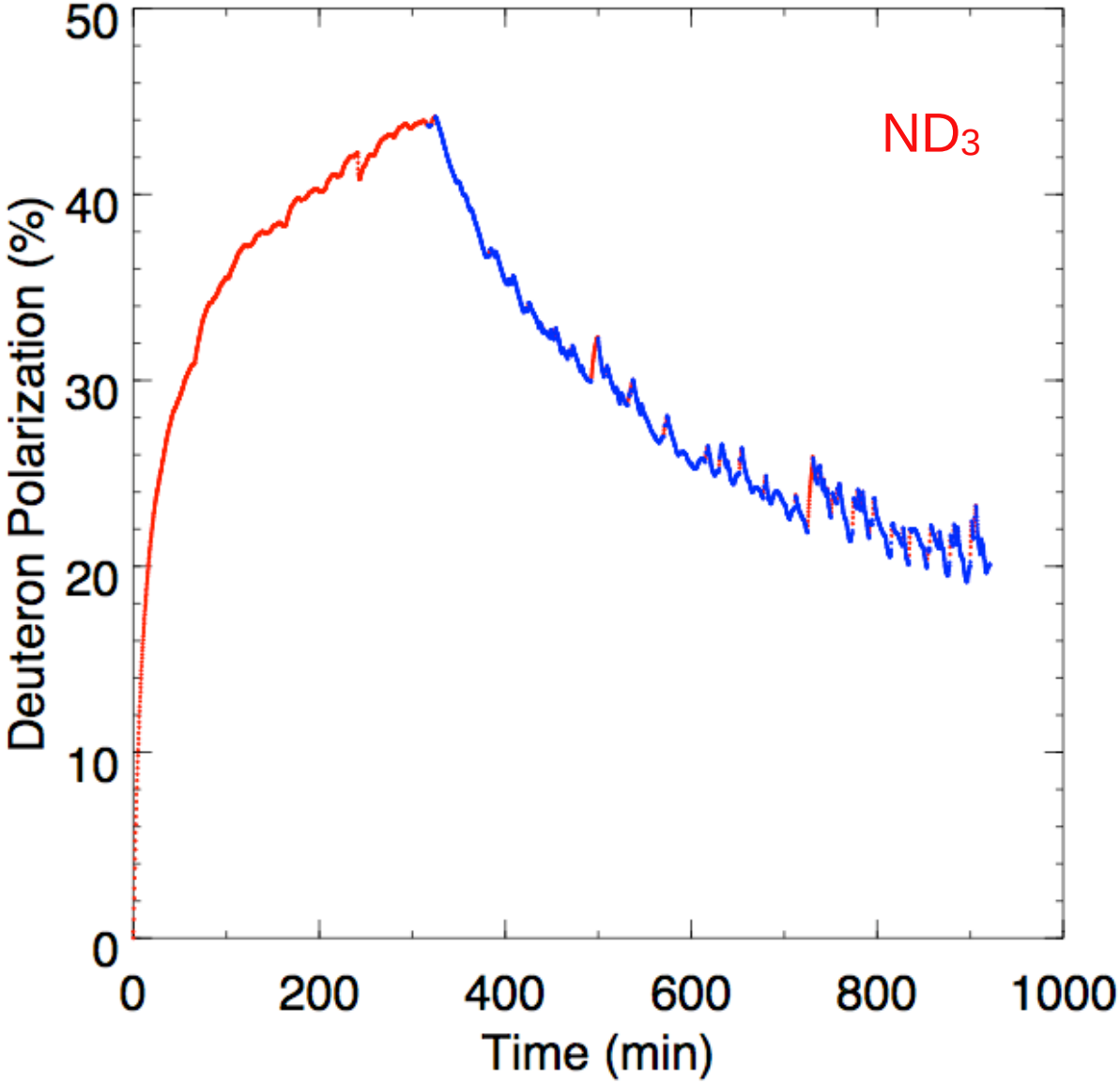



Polarization vs Dose on Material Start Run 72417
Anneal
Positive Polarization
Negative Polarization
Polarization
90
80
70
60
50
0
5
10
15
20
25
Dose Deposited (10^{15} e^-/cm^2)


Deuteron Polarization Decay as a Function of Time
Polarization (%)
40
20
0
-20
-40
0
100
200
300
400
500
600
700
Time (hours)

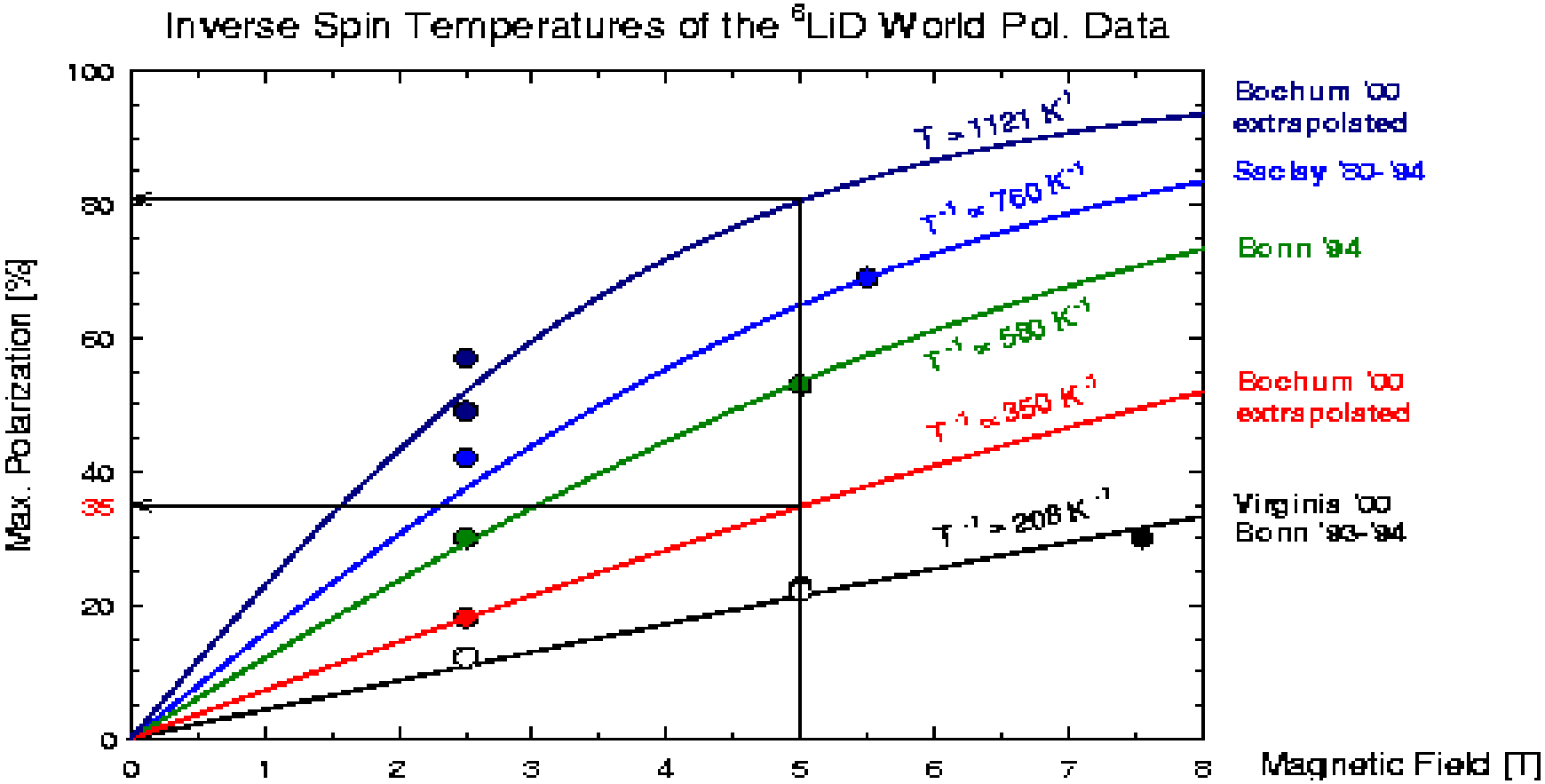
Target materials

Performance and Experience



^{6}LiD

- ^{6}Li ~ d + alpha → 50% Dilution Factor
- Actual Dilution factor ~ 40%
- $P_{Li} \sim P_d$
- Irradiation: at 180 K for ~2. 10^{17} e^- cm^{-2}
- Used in SLAC experiments E155 and E155X (g_1 and g_2 for proton and neutron).
- Now used in COMPASS at CERN

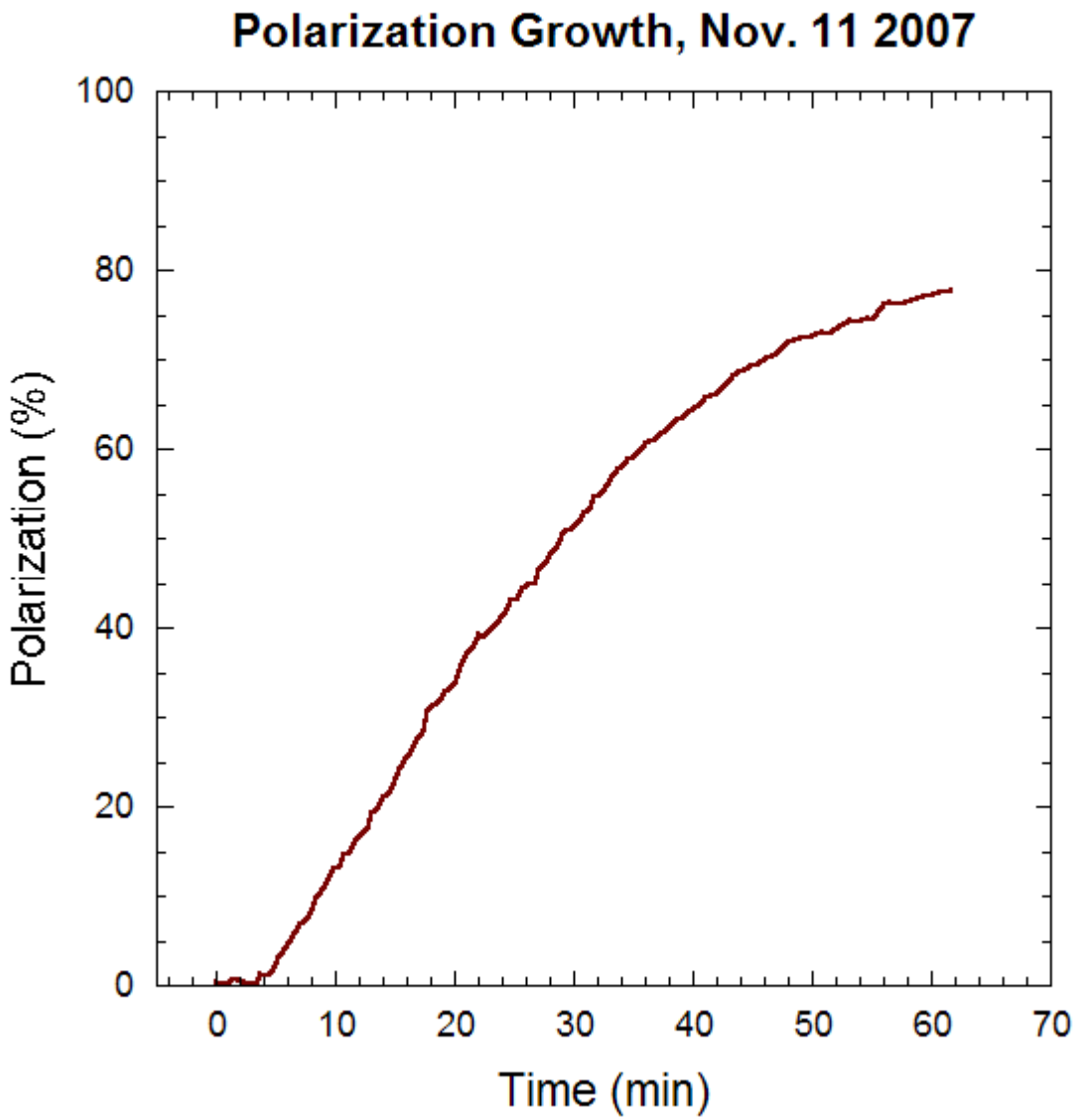


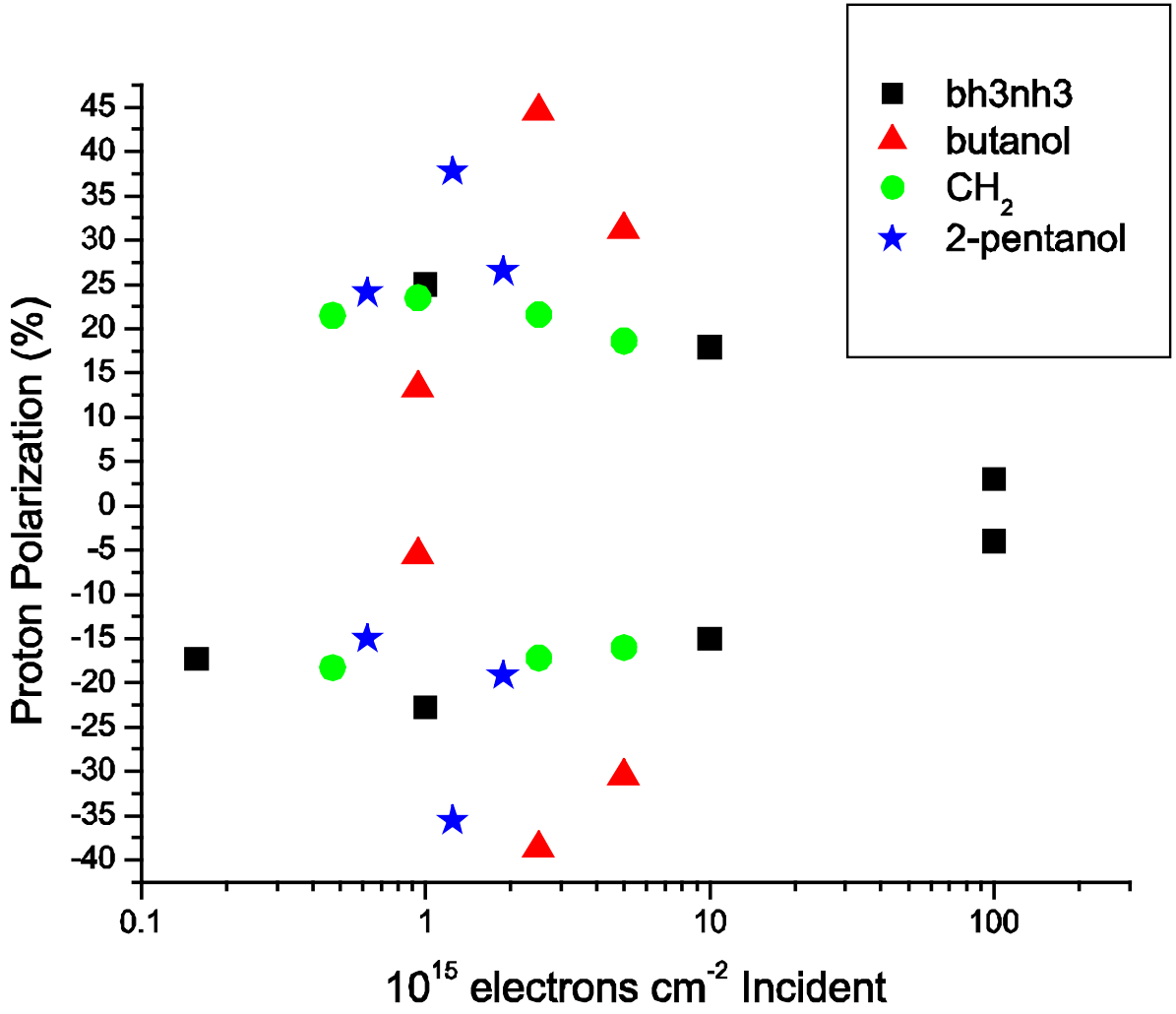
$$P = \frac{4 \tanh(g_J \mu_N B / 2kT)}{3 + \tanh^2(g_J \mu_N B / 2kT)} \sim 4/3\,(g_J \mu_N B / 2kT)$$

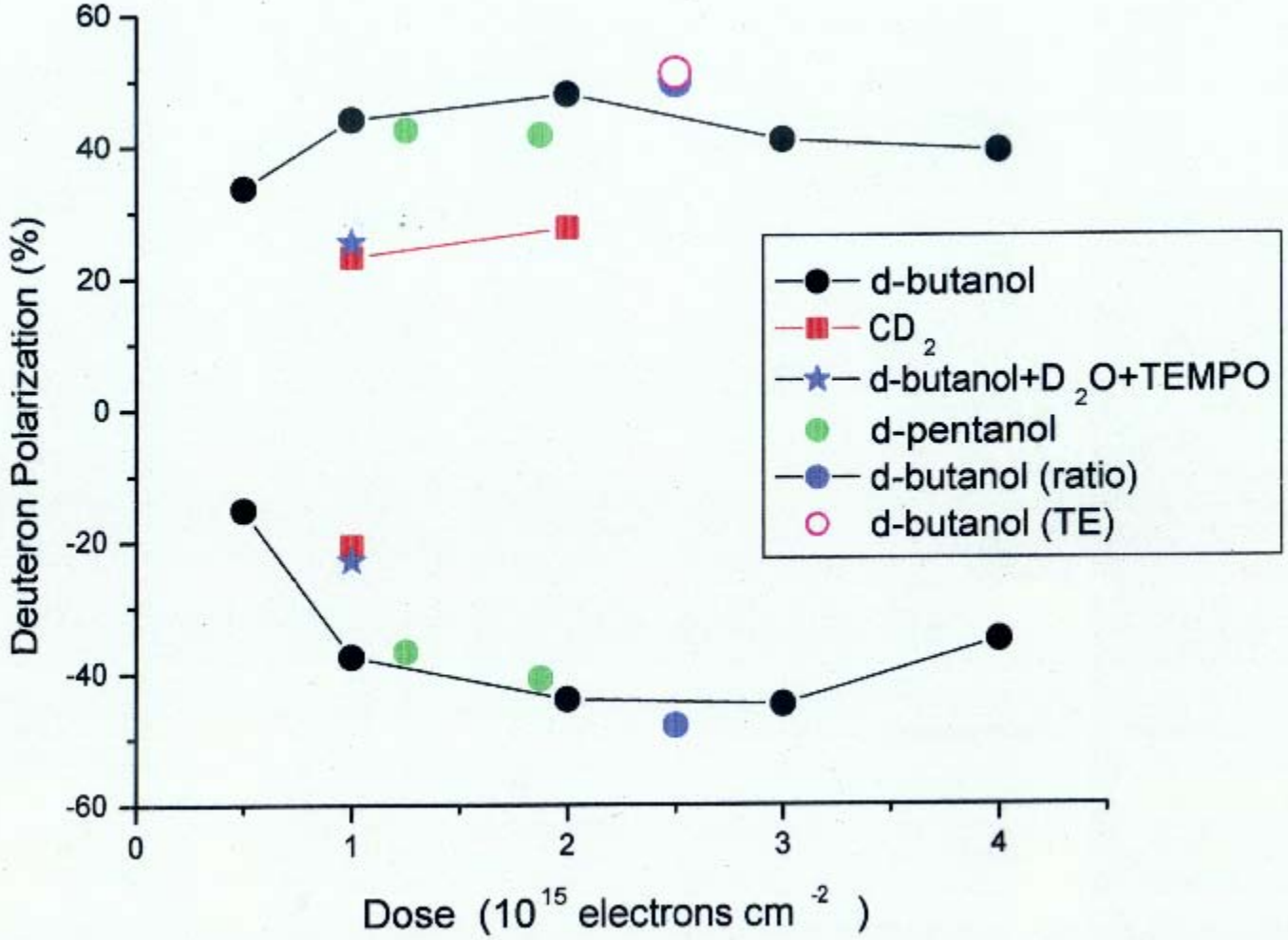
^{7}LiH

- $^{7}Li \rightarrow \alpha + t$??
- Less study than ^{6}LiD. Used in an experiment at PSI.
- ^{7}Li and H polarizations ~ 50%; long polarizing times.
- More study needed for future experiments.

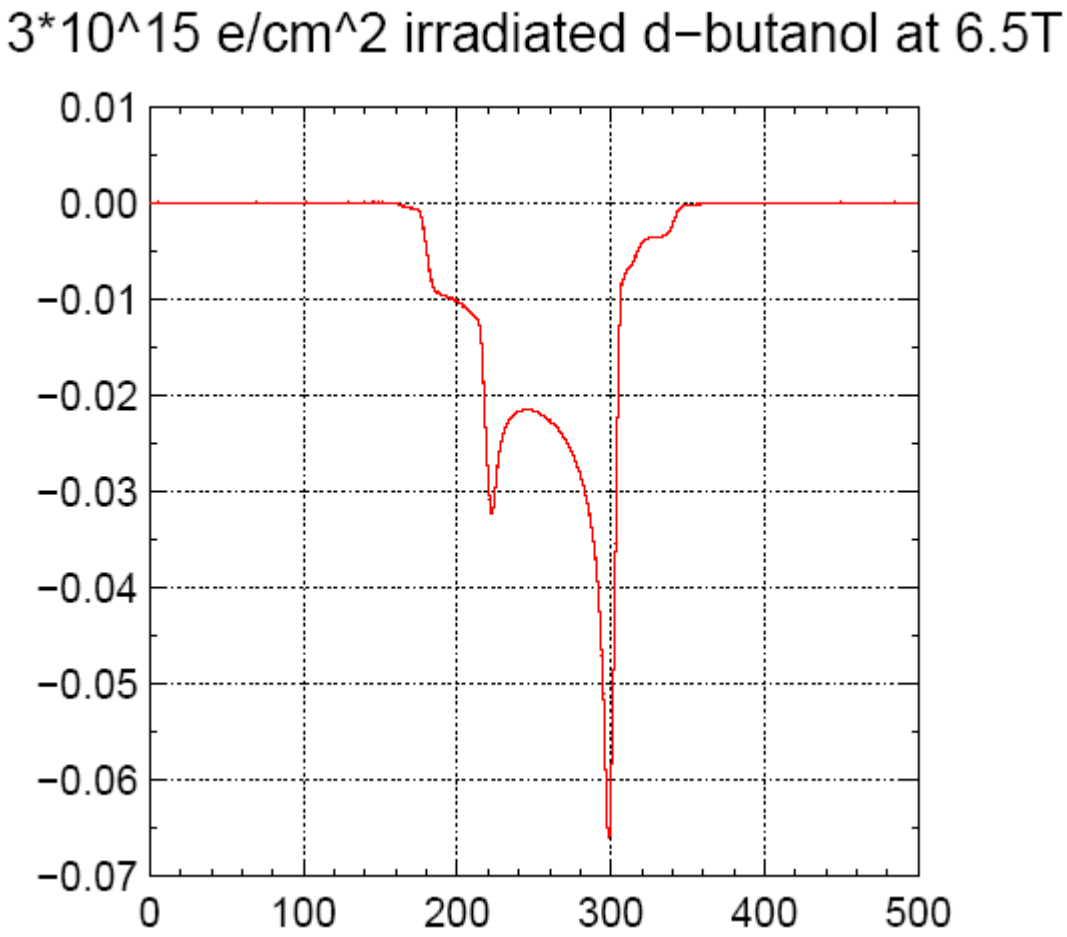
BUTANOL (FROST)




bh3nh3
butanol
CH2
2-pentanol
Proton Polarization (%)
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
0.1
1
10
100
10^15 electrons cm^-2 Incident

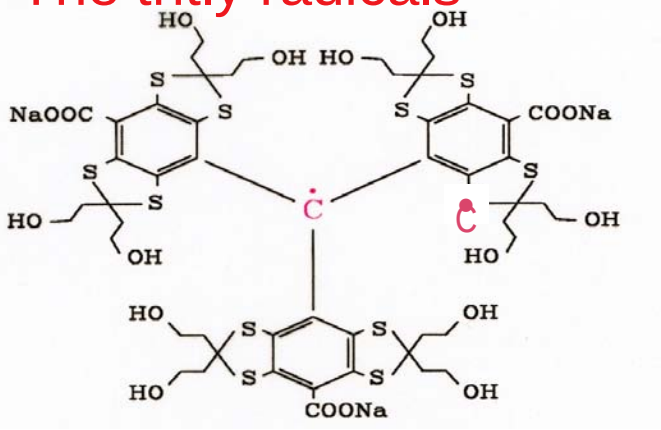

60
40
20
0
-20
-40
-60
Deuteron Polarization (%)
0
1
2
3
4
Dose (10^15 electrons cm^-2)
d-butanol
CD 2
d-butanol+D 2O+TEMPO
d-pentanol
d-butanol (ratio)
d-butanol (TE)

Deuteron Polarization of 63% at 6.5T and 1 K

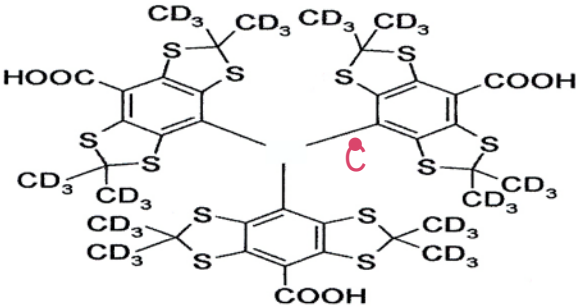


narrow EPR line

The tritly radicals



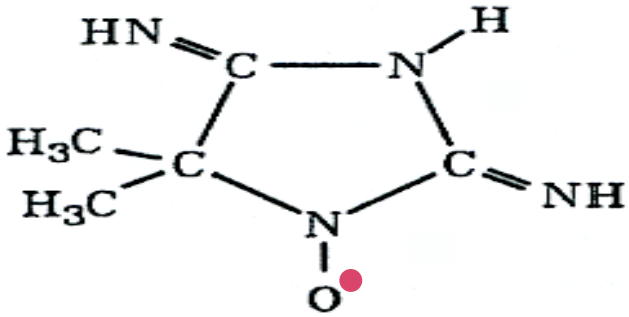
OX 063 M.W.: 1426.78



Finland D36 M.W.: 1036.9

The nitroxid radicals

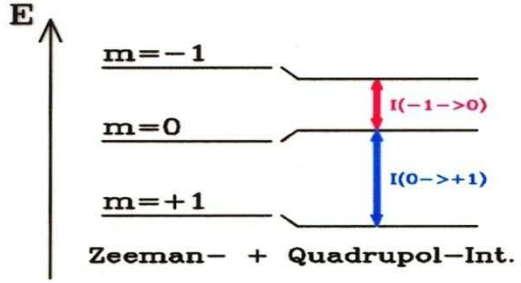
TEMPO M.W.: 144

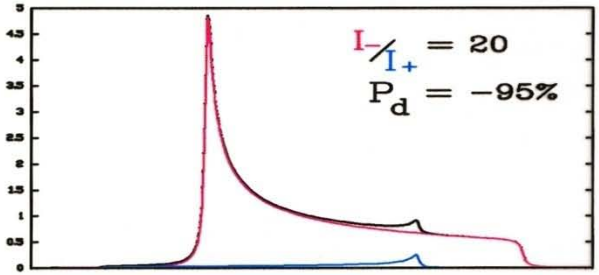


Porphyrexid M.W.: 141

Results on trityl doped hydrocarbons

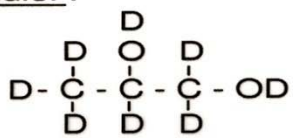
The deuteron NMR signal with quadrupole interaction

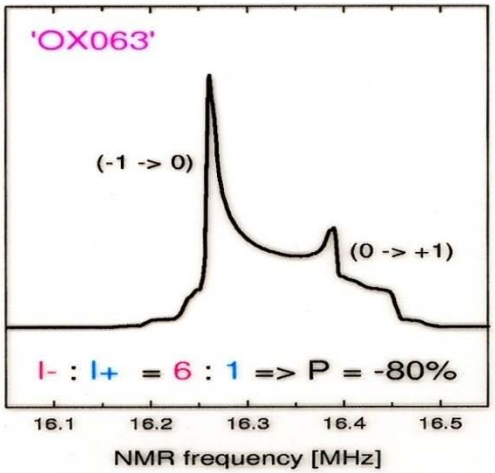




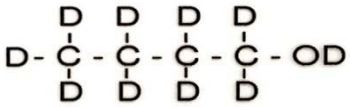
The maximum polarizations at B = 2.5 T !!

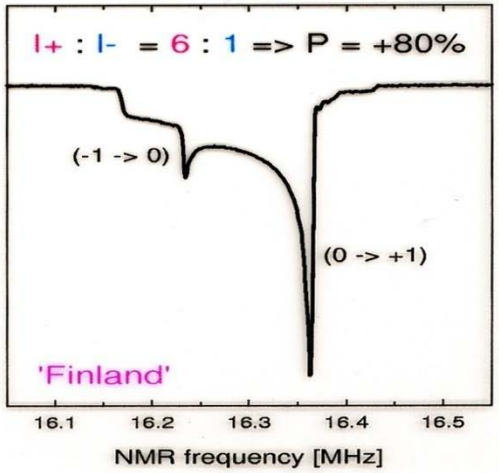
D-Propandiol :

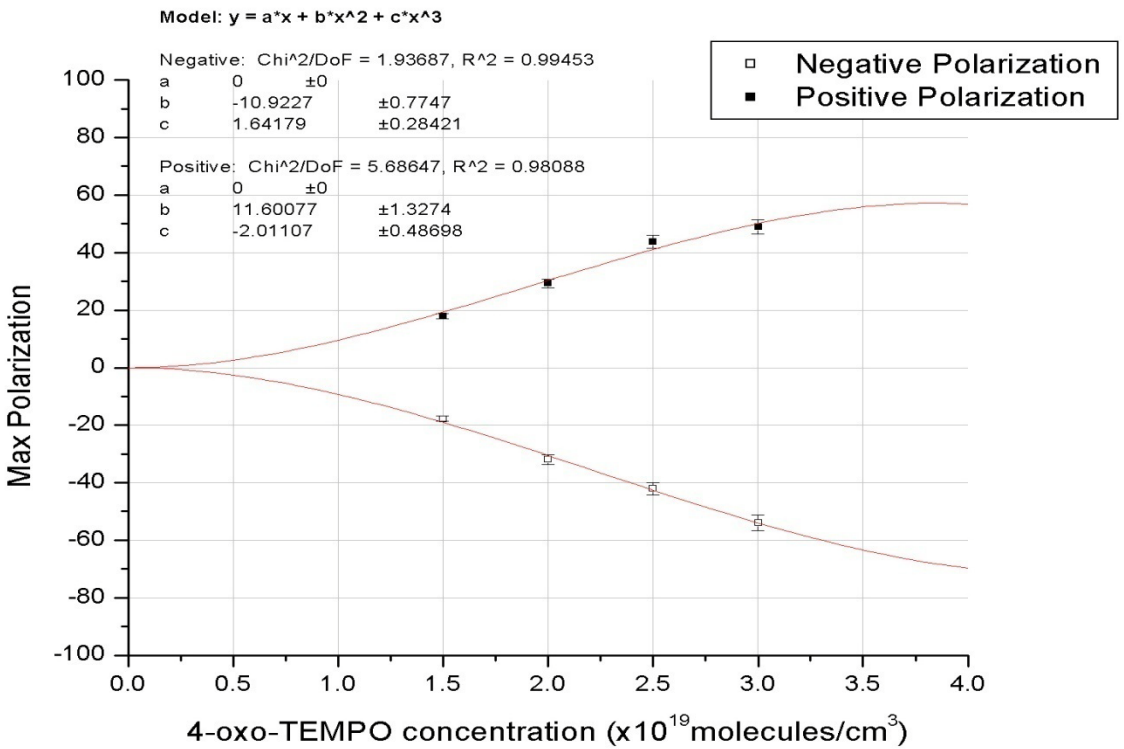




D-Butanol :






Model: y = a*x + b*x^2 + c*x^3
Negative: Chi^2/DoF = 1.93687, R^2 = 0.99453
a 0 ±0
b -10.9227 ±0.7747
c 1.64179 ±0.28421
Positive: Chi^2/DoF = 5.68647, R^2 = 0.98088
a 0 ±0
b 11.60077 ±1.3274
c -2.01107 ±0.48698
Negative Polarization
Positive Polarization
Max Polarization
100
80
60
40
20
0
-20
-40
-60
-80
-100
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4-oxo-TEMPO concentration (x10^19 molecules/cm^3)

Conclusions

- Mature Technology
- Being used in other areas, eg MRI Studies; ^{13}C
- Proton Polarizations > 90%
- Deuteron Polarizations > 70%
- Nuclear Polarizations eg ^{6}Li ~ 60%
- Material studies eg CH_3 , CH_4 (irradiation)
- NMR improvements and modifications.