Polarized Target Update from UVa

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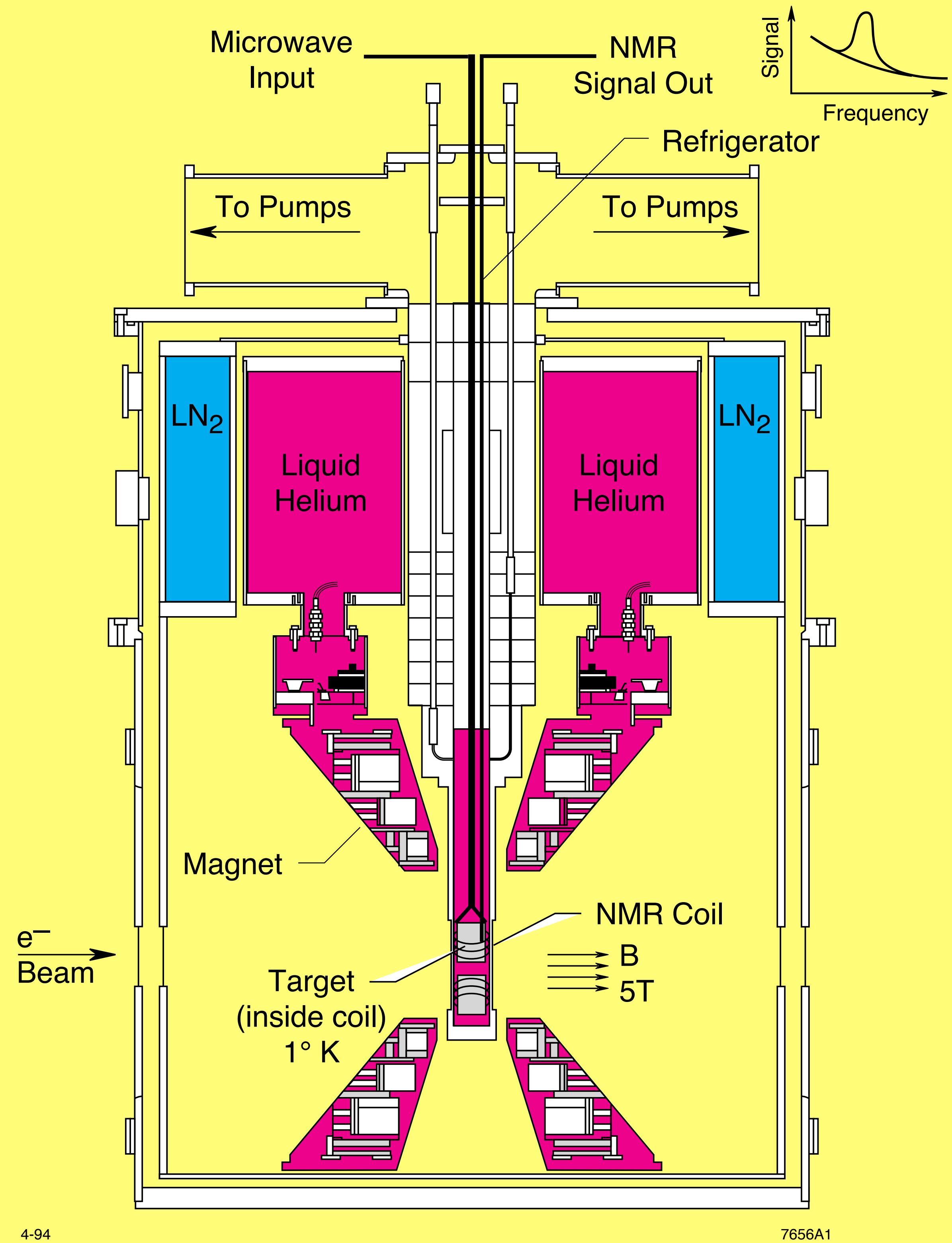
University of Virginia

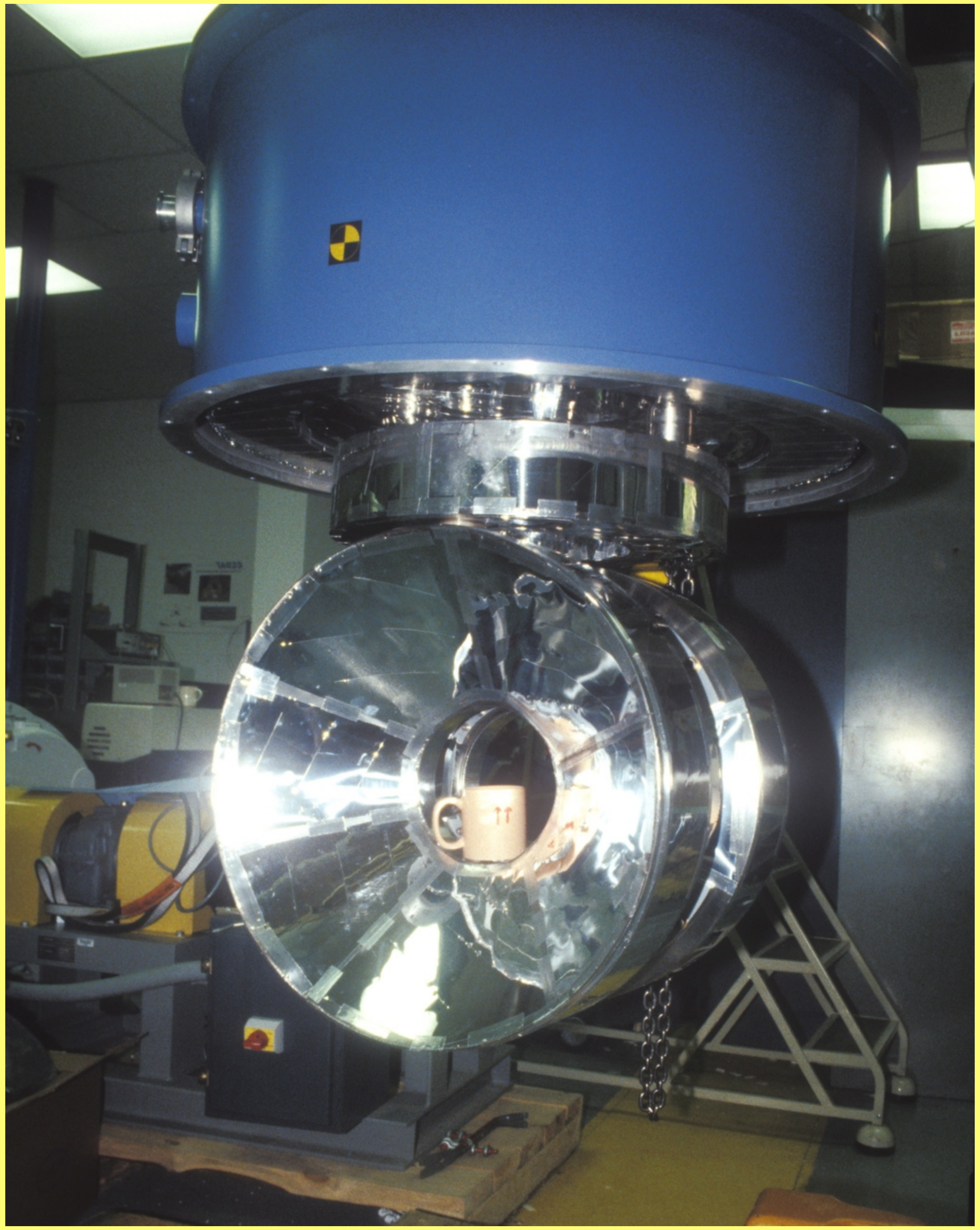
Workshop on High Luminosity Polarized Targets for the 12GeV Era
(Joint Hall A & C Meeting)
June 17-18, 2010

- Experience during SANE
    - Status of Magnet
- Introduction to DNP
- Subsystems
- Materials
- Experiments to Do

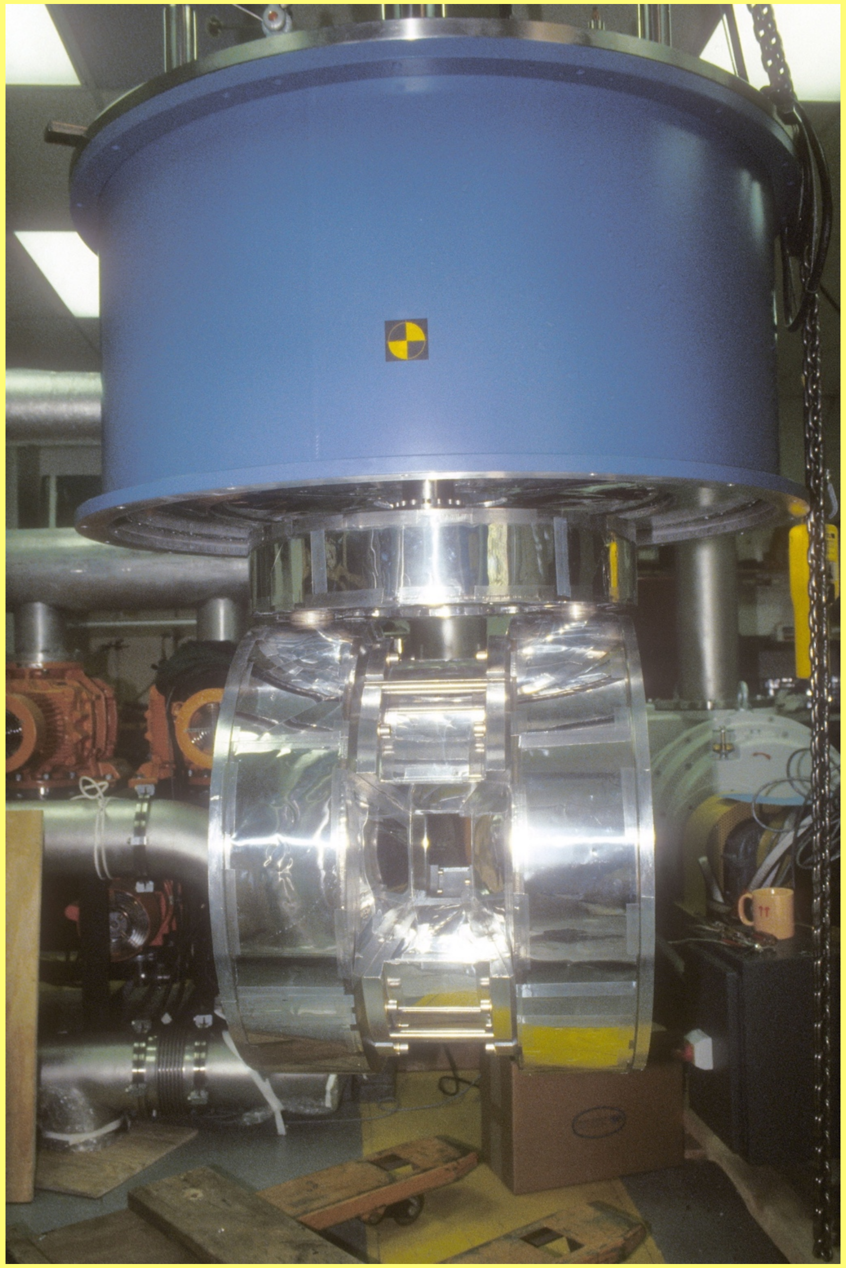
Prelude

- Magnet manufactured by Oxford in 1992 to specifications set by experiments at JLAB. Very large angular acceptances along the bore and the split (both horizontal and vertical)
  - Used in E143, E155, E155x (SLAC), Gen98, Gen01, RSS (JLAB)
    - Quenches infrequent, typically ramping up after being warm for extended period
- Loss of vacuum quench during Gen98 burst coil can, repairs made.
  - No operational problems during Gen01, RSS.
- Loss of vacuum quench in EEL during preparations for SANE.
  - Installed in Hall C for SANE without further testing





The bore



The split

Along the bore the magnet coils form an opening cone of 100 degrees. Along the split the magnet has an opening angle of ± 25° in the vertical and ± 17° in the horizontal.

This is about the optimal magnet design. changing the transverse aperture for instance means at least a reduction in central field, e.g. the Hall B design: 4.2 T (and > $800K).

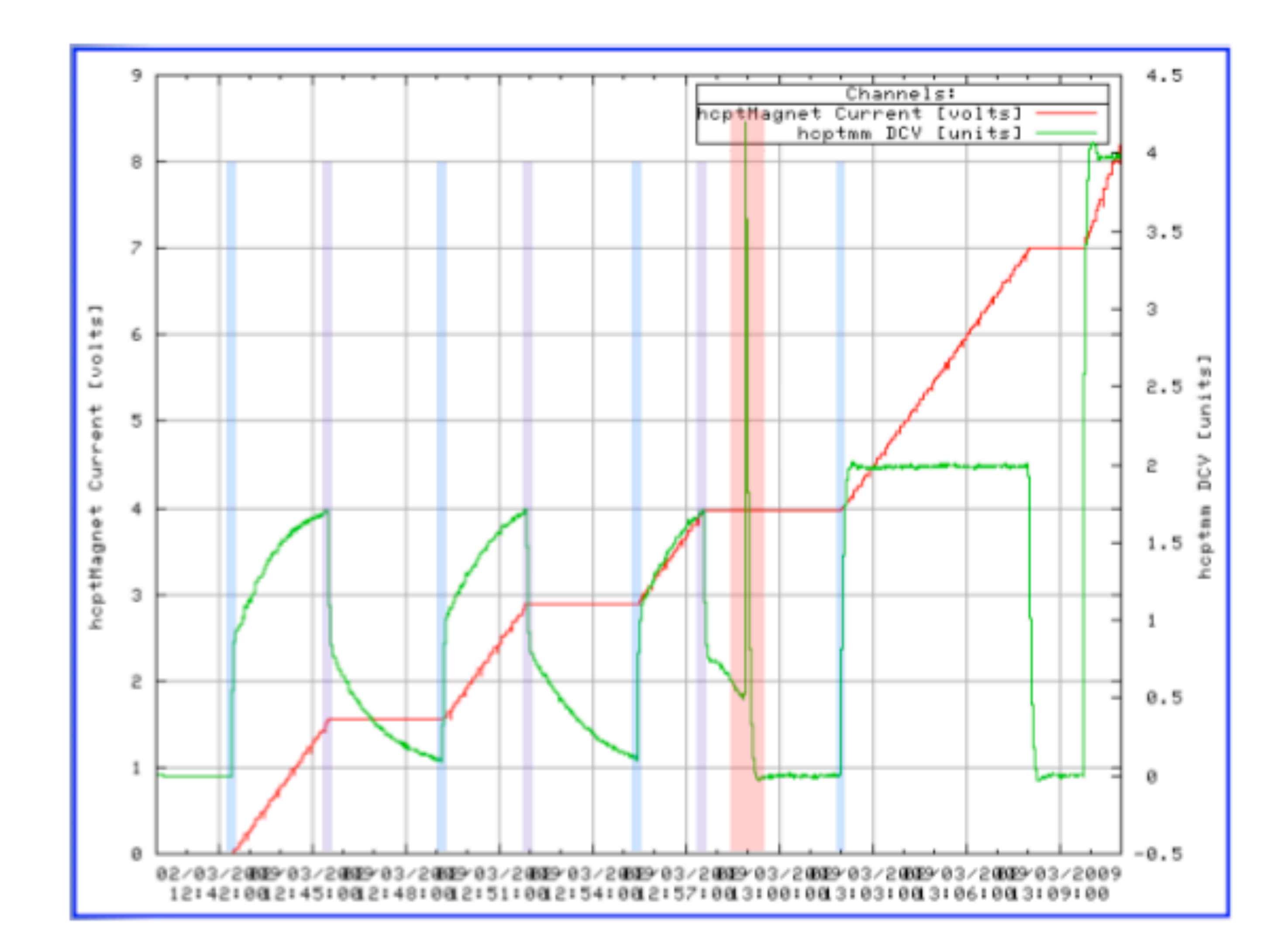
In Hall C

- October 31, 2008: (persistence switch) quench occurred. A communication delay on the bus controller allowed the leads to be ramped down before they were disconnected from the coils.
- November 1: Magnet energized to full field (77.2A) for 2 days of data taking. In order to reverse field direction magnet was ramped down - but at rates that are reserved for a fully trained magnet. Quench occurred at 60 A with rate of 2 instead of 1.5 A/min.
  - Next day magnet was discovered to be resistive.
- Magnet removed from hall, opened up in EEL and damage to wiring discovered. Repairs were made by JLAB personnel with assistance of specialist from Oxford.
- Cause of damage thought to be due to failure of a protection diode (provide a parallel path for magnet current in case of excessive voltage).

Behavior after repair

- Plagued with quenches of two types
  - "Ramping" quenches, either energizing or de-energizing
  - "Resting" quenches (magnet in persistent mode, leads ramped down) with or without beam in hall
- Loss of persistence (0.1% in 48 hours)
  - Superconducting joints made during repairs were (necessarily) of lesser quality - not enough wire to make them as in the original
  - Solution was to reattach magnet to PS to return to full field
- Abnormal Charging Coil Voltage - mini quenches
  - $V \neq L(dI/dt)$

Unique operating conditions: large iron plates within 1 m of magnet

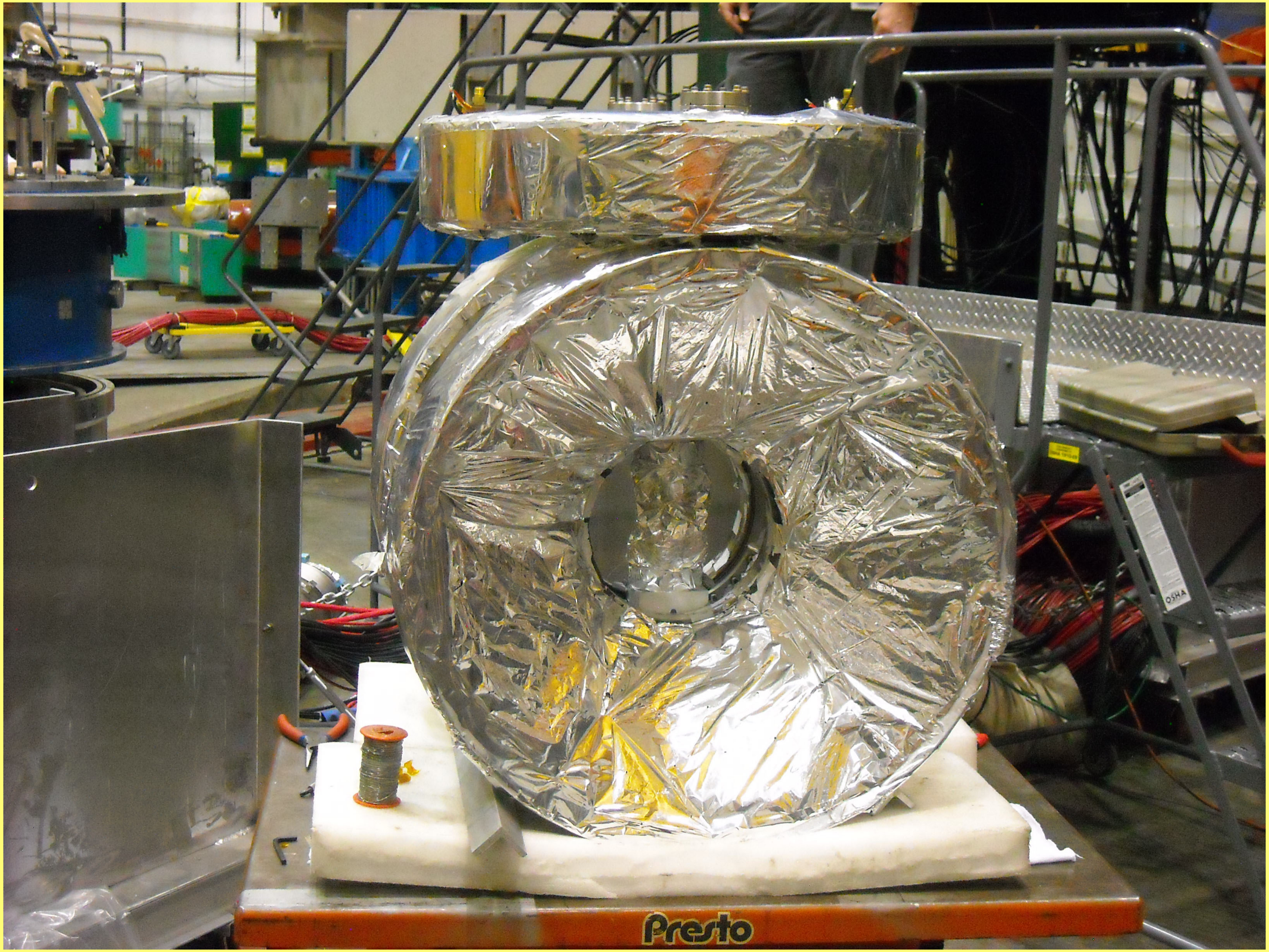


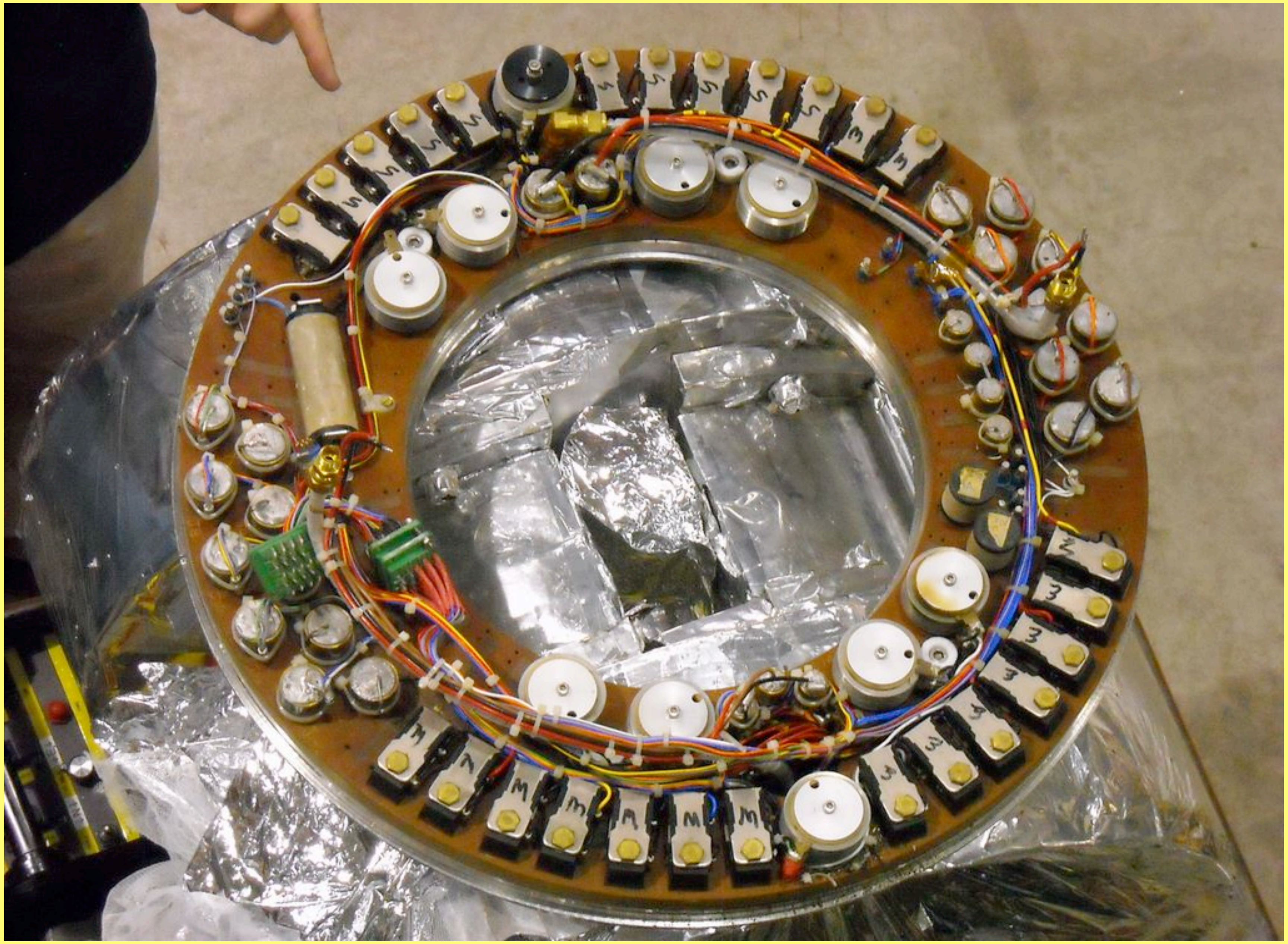
Magnet current
Voltage across magnet

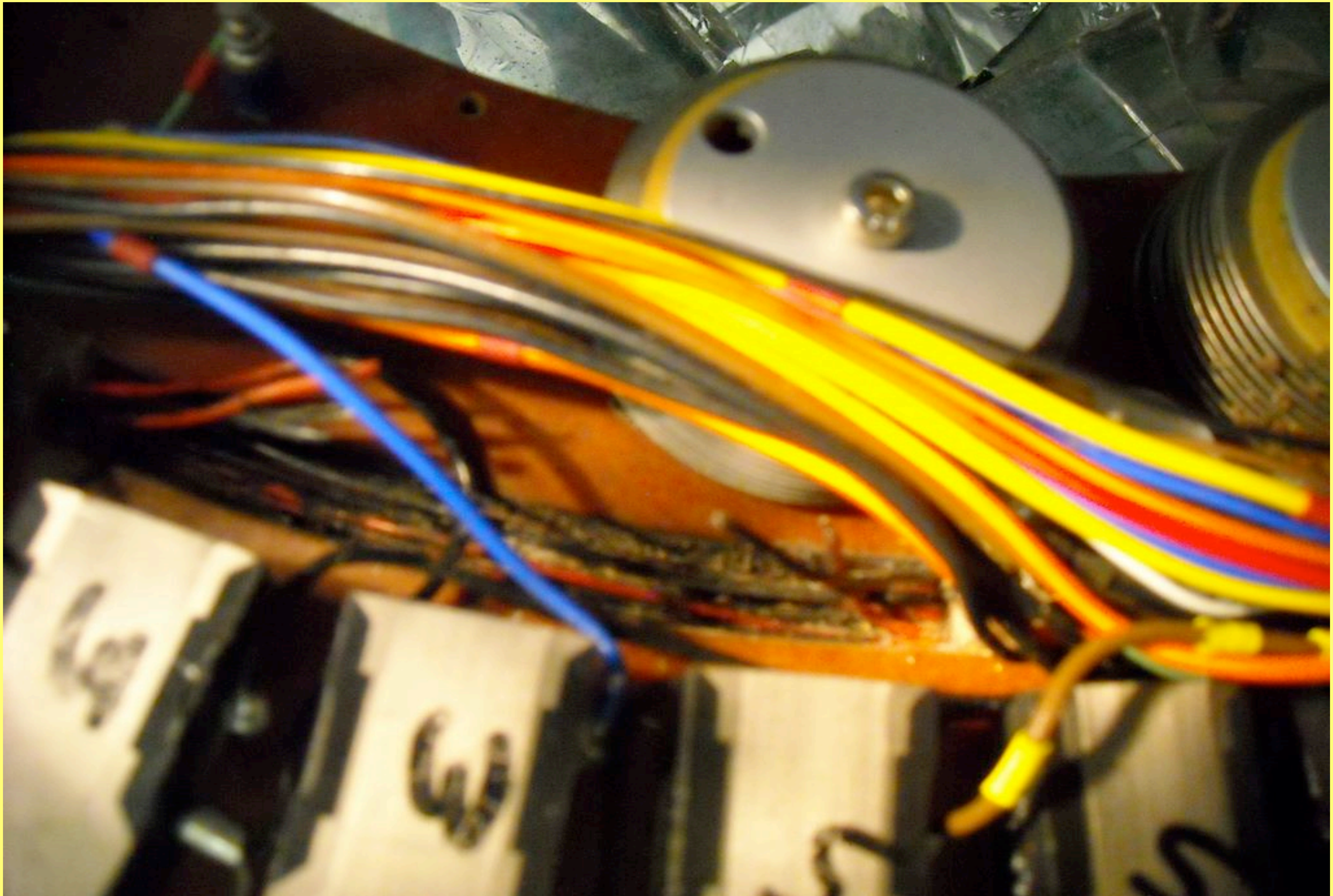
- Abnormal Charging Coil Voltage
  - $V \neq L(dI/dt)$
  - Problem with shim coil switches.
  - Magnet has shim coils (never energized) but they must be connected to a PS in order to dissipate the induced voltage from the main coils.
  - Apparently the Z1 switch not operating, allowing current to build up, feeding back to main coil. After the spike at 3.9A (switch starts working) ramp continues as expected

Assessment

- Donald Crabb reviewed our draft technical report (April 2009) with Oxford:
  - Damaging quench due to bad diode (second in Oxford history).
  - Subsequent quenches due to change in stresses on the coils. The coil clamps have loosened due to the number of quenches and the stress of the nearby iron plates installed to shield the Cerenkov PMT from target field
    - So the repair would involve removing the cones and donut and readjusting the coil clamps.
    - Superconducting joints have to be given some thought as digging into coil is expensive. Not a major problem as is.
    - Study of the shim switches can be done as needed. Or is it simply that we need more current?
    - Cold test will reveal any other problems.
    - Oxford believes that taking off the cones and reinstalling new ones would be in the range of $50K (plus shipping).


Presto





Oxford Tuneup

Clamping torques re-tensioned and replaced a couple of the diodes on the protection circuit.

Magnet Ramp Test

- Ramped to 5.1 T and held in persistent mode for 1.75 hours.

Ramp Rates

Test

0 – 65 A at 1 A/minute

65 - 79.05 A (>5.1 T) at 0.5 A/minute

Operation

0 – 60 A at 1.2 A/minute

60 - 72 A at 0.6A/minute

72 – 78.79 A (5.1 T) at 0.3A/min

Usually operate at 5.003 T

To Do

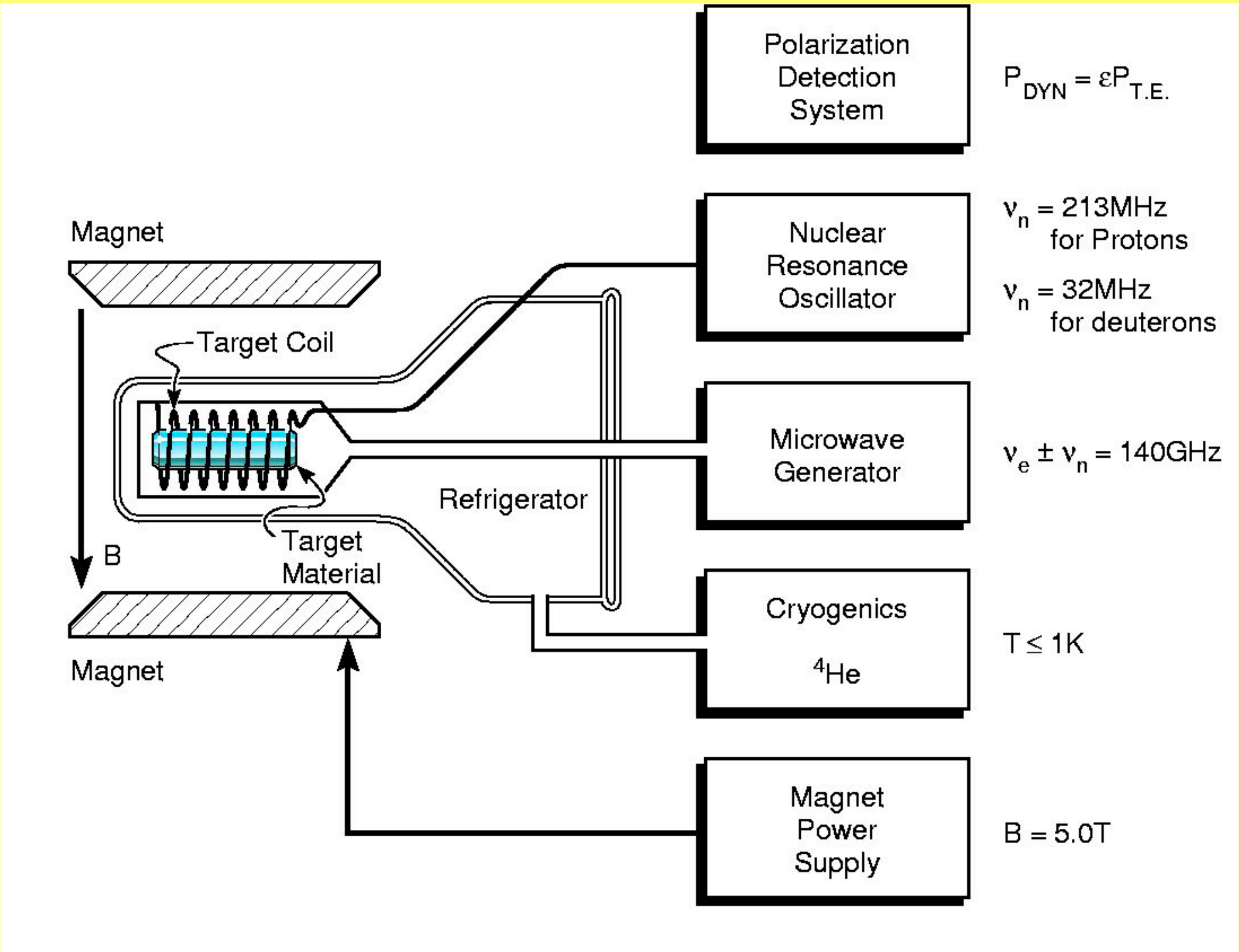
- Make, fit and weld new cones
- Weld on doughnut
- Leak check and ship back to Jlab
- Note: Repaired superconducting joints will not be changed. (not enough wire)

  Field decay: 2 10^{-5} /hour

- The final price will be $60,000 USD + the price of fitting the cones

Dynamic Nuclear Polarization

- Refrigerator - 0.5K to 1 K
- Magnetic Field - 2 T to 6 T
- Microwaves - 55 GHz - 165 GHz
- NMR system
- DAQ



Polarization
protons 70% - 100%
deuterons 20% - 50%
and higher

- Crystal - LMN (lanthanum magnesium nitrate)
- Alcohols - propane-diol, ethane diol, butanol
- Ammonia

Paramagnetism

Substances which possess a permanent magnetic dipole moment

a) atoms, molecules possessing and odd number of electrons, i.e. $S \neq 0$
NO gas, free Na atoms, organic free radicals

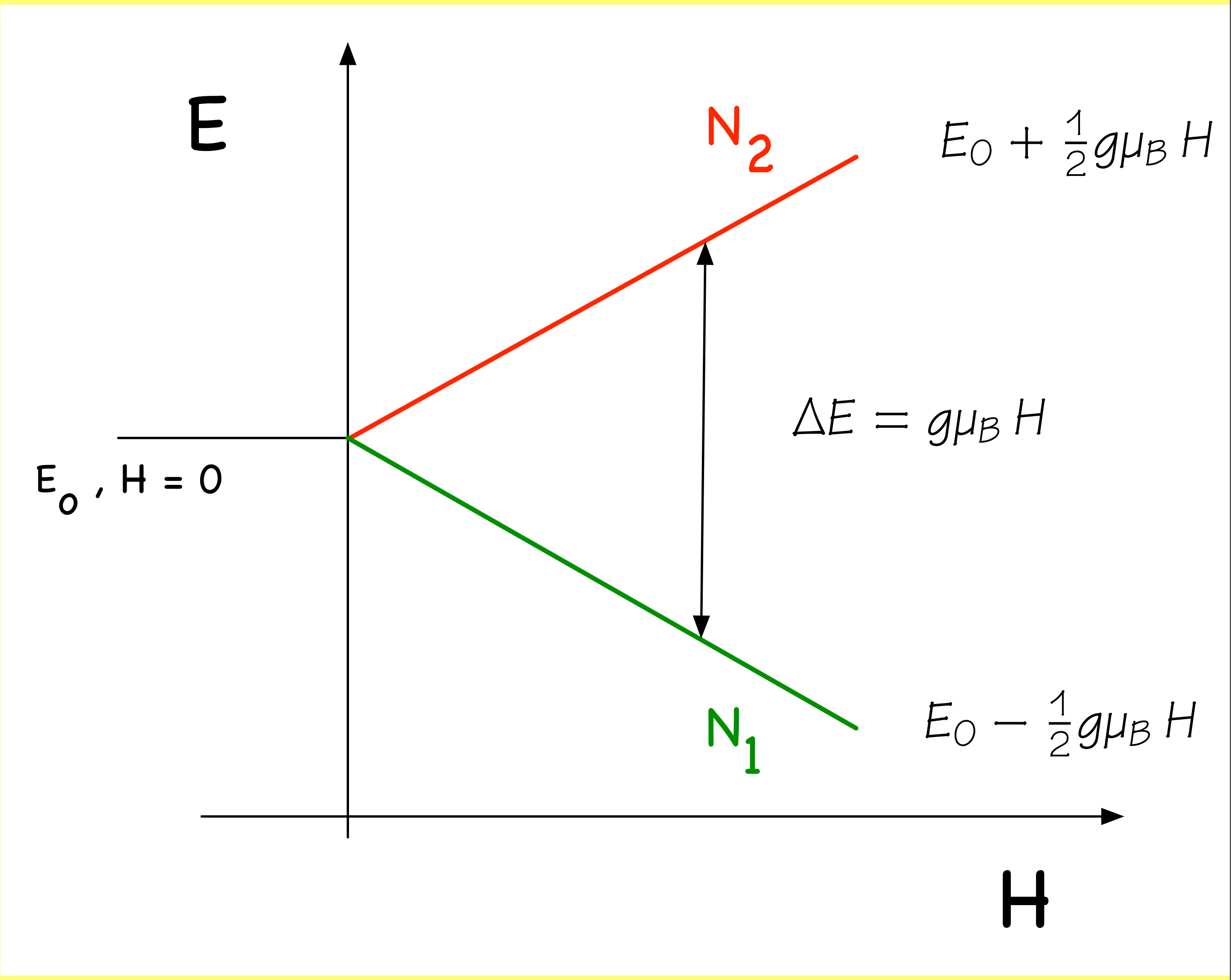
b) Free atoms & ions with partly filled inner shell; transition elements; rare earth & actinide elements Mn^{2+}, Gd^{3+}, U^{4+}

c) Metals

d) Few miscellaneous compounds O_2, organic biradicals

Assembly of paramagnetic atoms (one unpaired electron).
Dilute enough for no magnetic interaction between atoms

Apply external magnetic field



Zeeman Splitting

N_1 atoms || magnetic field (lower energy state) (m_s = -1/2)

N_2 atoms anti-|| magnetic field (higher energy state) (m_s = +1/2)

$N_1 > N_2$ ∴ net magnetization || field

Thermal agitation ⇒ random orientation

Lower temperature ⇒ less agitation

⇒ $N_1 > N_2$ ⇒ larger magnetization

If we let H >> and T <<, eventually $N_2 \Rightarrow 0$

At thermal equilibrium (spin 1/2)

$$\frac{N_2}{N_1} = exp\left[-\frac{g\mu_B H}{kT}\right]$$

$$\text{Polarization} = \frac{N_1 - N_2}{N_1 + N_2}$$

$$= tanh\left[\frac{\mu_B H}{kT}\right]$$

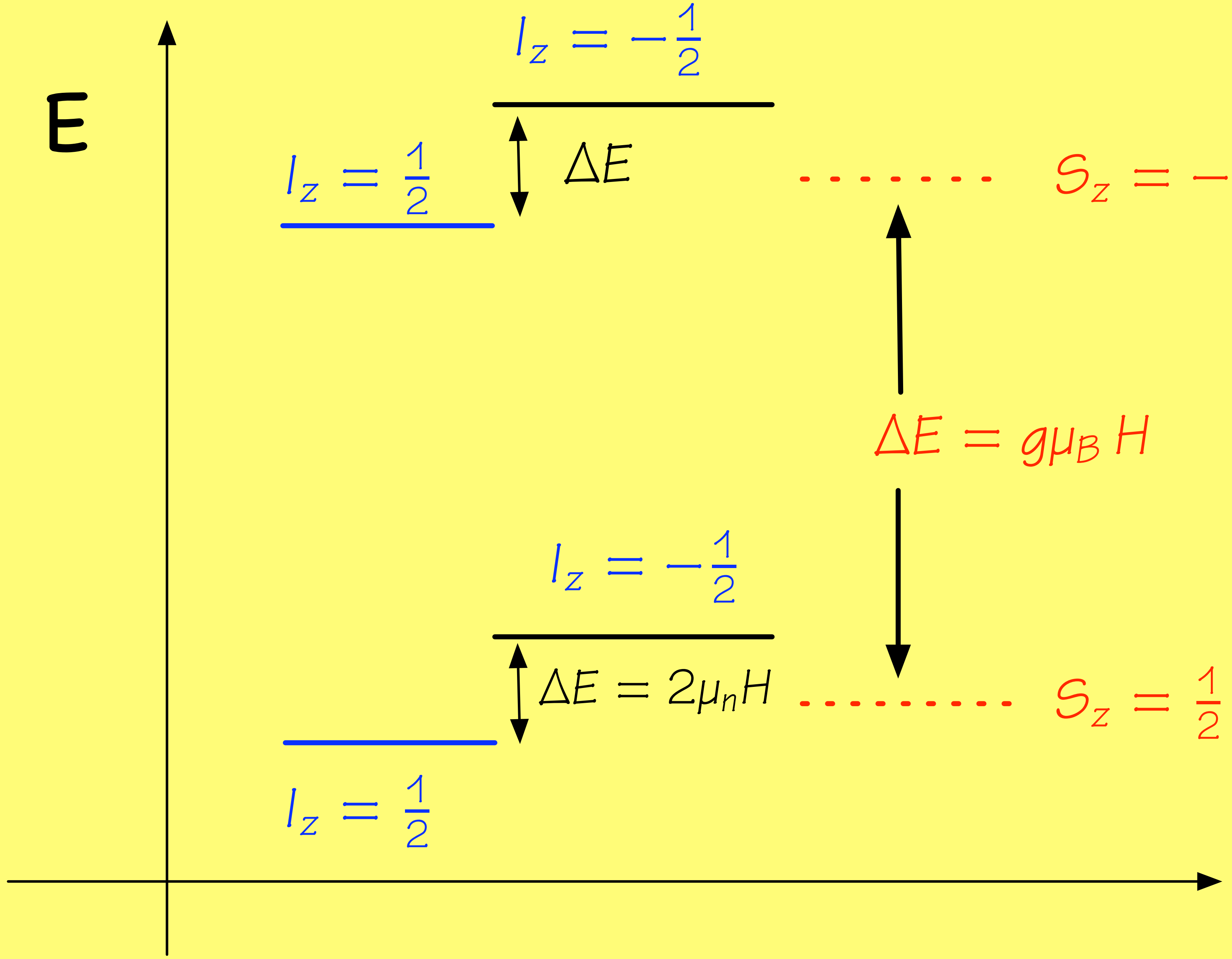
Proton

(g=2) For H = 2.5T, T = 0.5 K P = 0.998

Nucleons and nuclei have magnetic moments too

However $\quad \dfrac{\text{nuclear moments}}{\text{electron moments}} \simeq 10^{-3}$

Include nuclear moments ⇒ hyperfine splitting in magnetic field



Analogous to the electron

$$Polarization = \tanh\left[\frac{\mu_n H}{kT}\right]$$

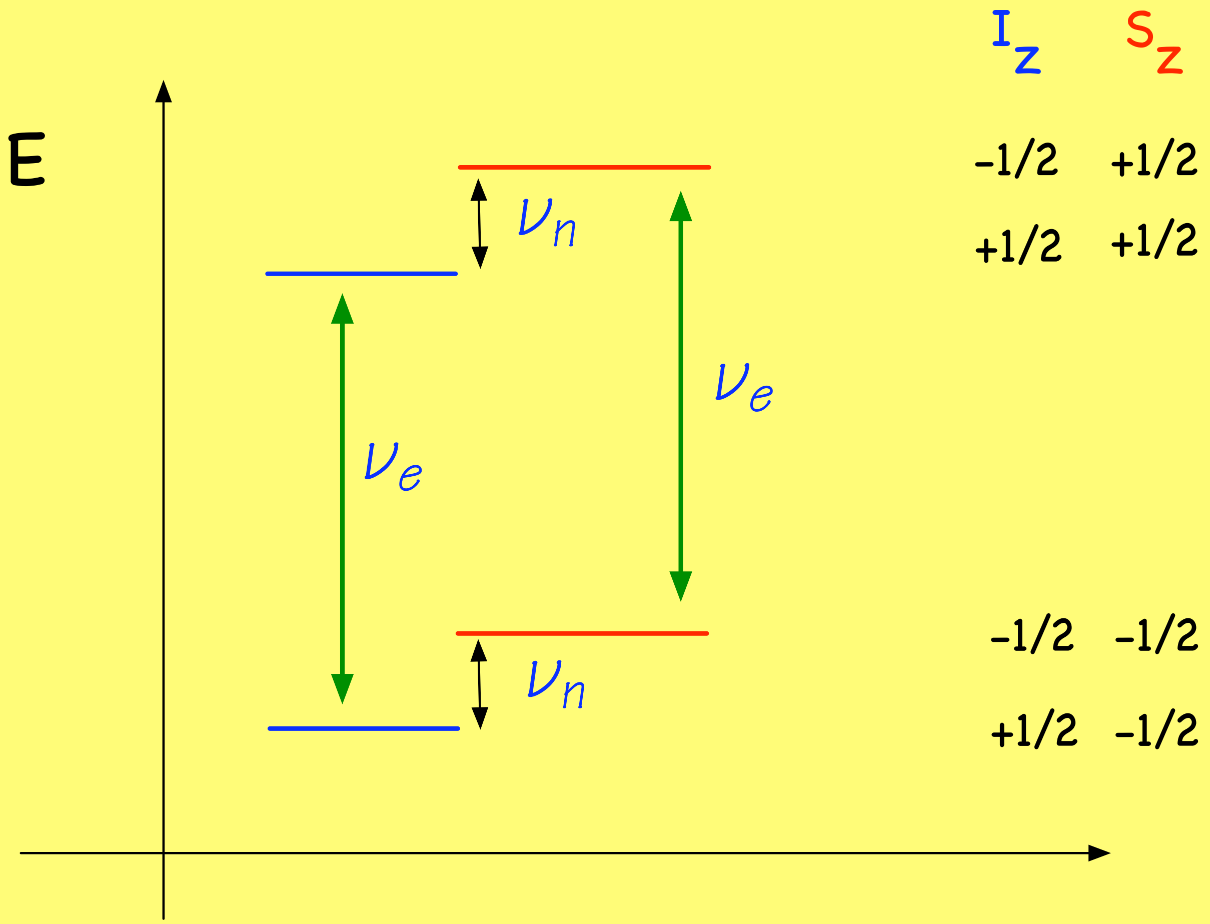
μ_n = proton magnetic moment

Again for H = 2.5T, T = 0.5 K, P = 0.005!

So very small polarizations for the static case.

$$\Downarrow$$

Solution is: RF Induced Transitions



RF fields can be used to induce transitions between spin states

Allowed Transitions

$\Delta I_z, \Delta S_z = 1$

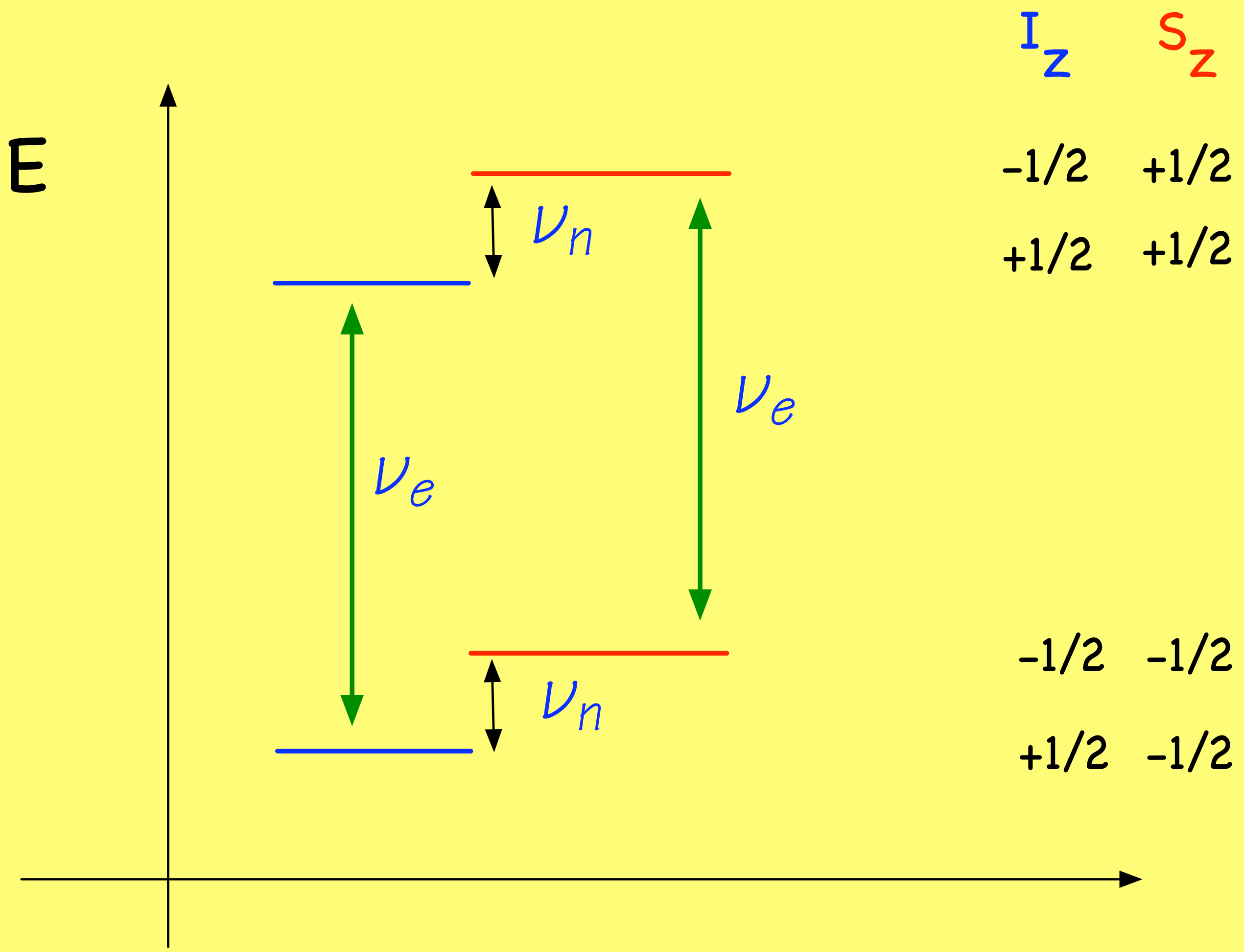
1) $\nu_{RF} \sim \nu_e$ get transitions:

$-- \leftrightarrow -+$

$++ \leftrightarrow +-$

where $\Delta E = g\mu_B H = h\nu_e$ and at 2.5 T ν_e = 70 GHz

Pure electron spin transitions $\uparrow \rightarrow \downarrow$ is electron paramagnetic resonance EPR (or ESR)



2) $\nu_{RF} \sim \nu_n$ get transitions: $+- \leftrightarrow --$

$++ \leftrightarrow -+$

Here $\Delta E = 2\ \mu_n H = h\nu_n$

and ν_n = 106.5 MHz at 2.5 T

Pure nuclear spin transitions

Nuclear Magnetic Resonance $\uparrow \rightarrow \downarrow$

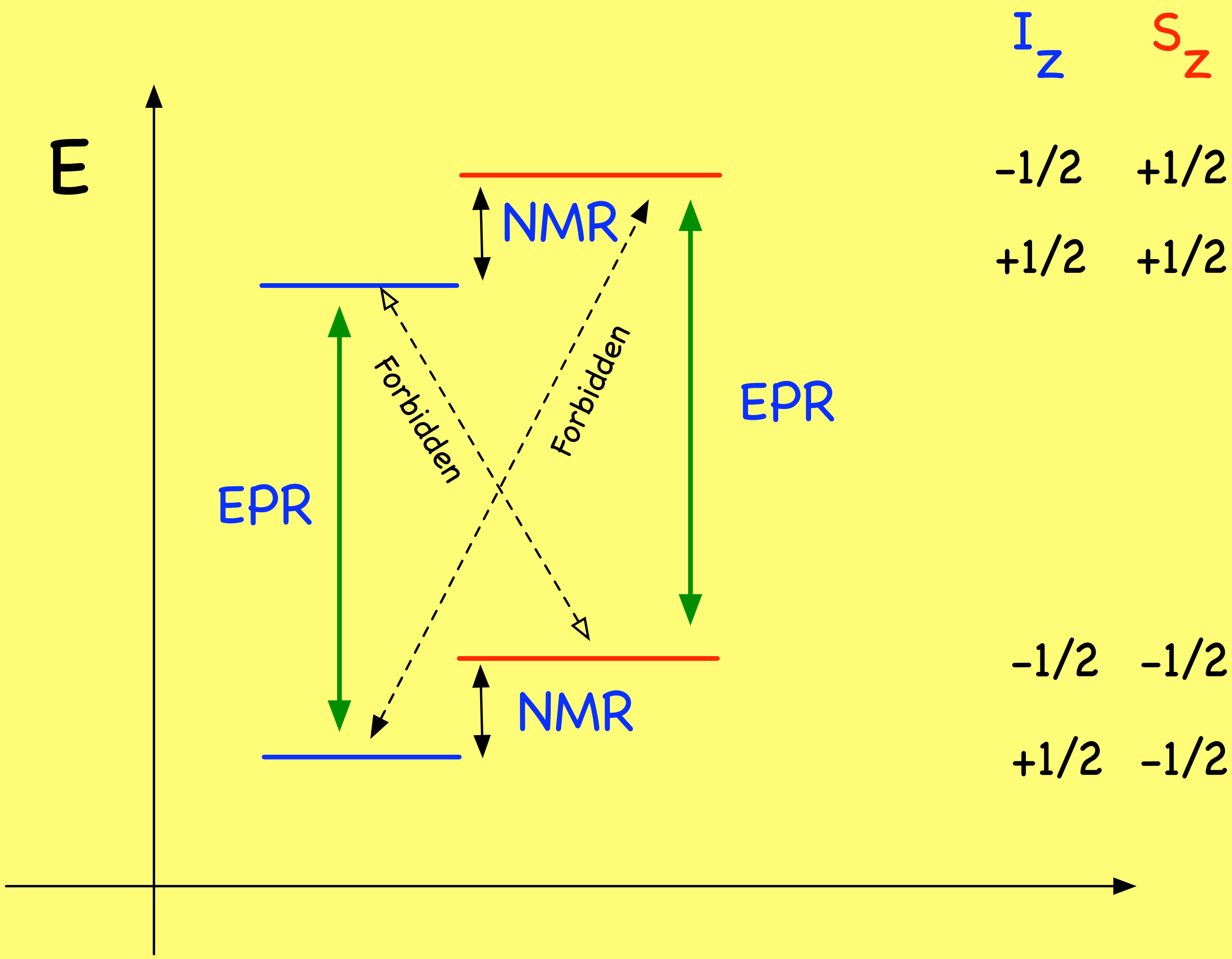
(NMR)

But the population of these states are essentially equal and the transitions do not modify them.

Forbidden Transitions

Transitions between -- and ++ and +- and -+ are forbidden. Unfortunately these are the transitions we want.

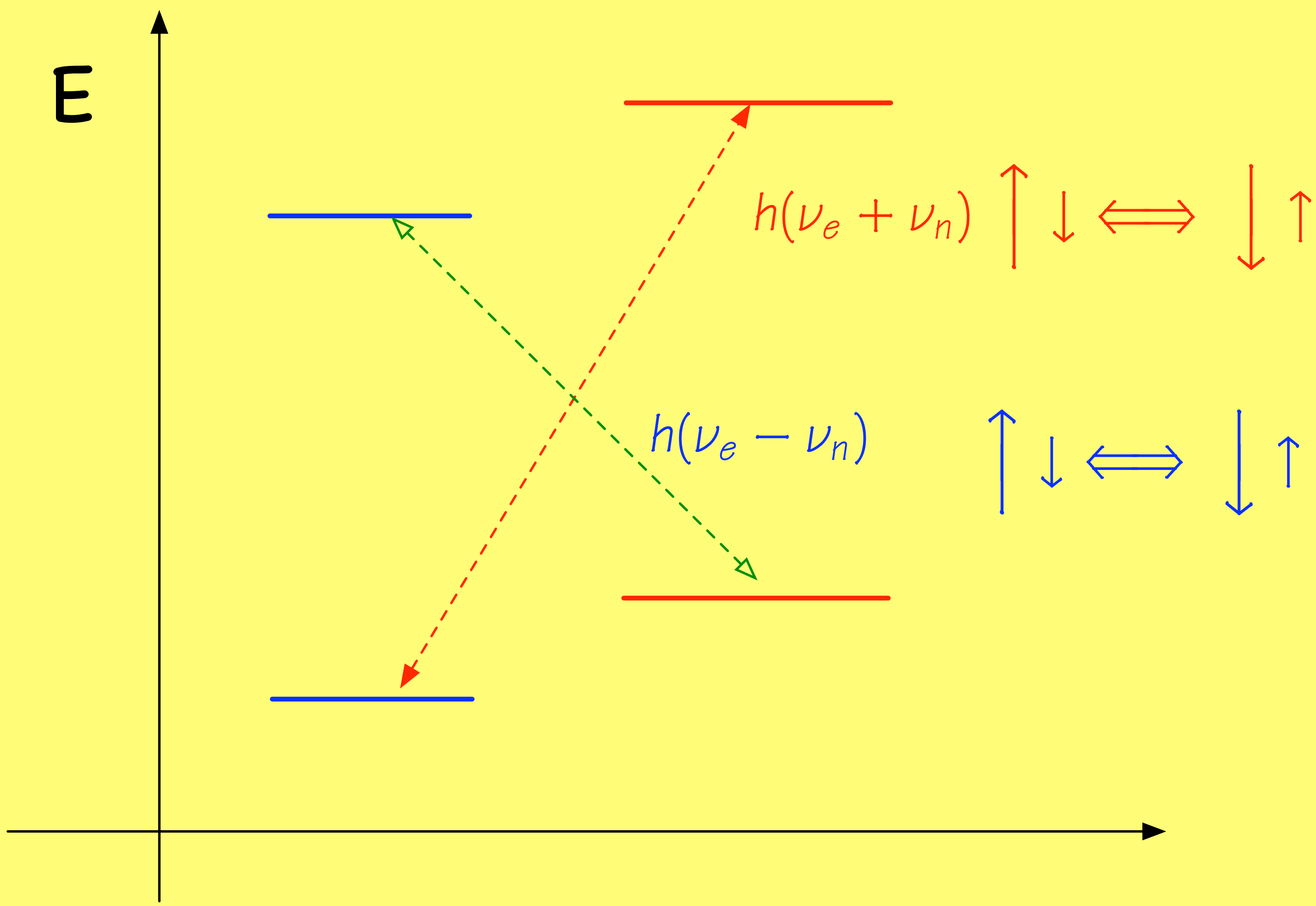
However there exists the dipole-dipole interaction



Two distant magnetic moments → dipole-dipole interaction << Zeeman.

This leads to a slight mixing of the nuclear states which then allows transitions of the type +- ↔ -+ and ++ ↔ -- though with a probability much less (10^{-4}) than allowed transitions.

Forbidden Transitions



The rf field can drive the forbidden transitions which can be visualized as

flips-flops $\quad \Big\uparrow \downarrow \Longleftrightarrow \Big\downarrow \uparrow$

flips-flips $\quad \Big\uparrow \uparrow \Longleftrightarrow \Big\downarrow \downarrow$

$$\Delta(S_z + I_z) = 0,\ 2$$

An objection could be raised that there are only a small number of electron spins - when they all have been pumped up the polarization is still small

$$\Downarrow$$

Spin-Lattice relaxation

A radiationless process by which energy is exchanged between the spin and the lattice (thermal motions of the solid)

Spin polarization -> value corresponding to TE at lattice temperature

Electrons Spins

Strong interaction with the lattice TE achieved very rapidly. The processes amount to electron spin flips of the type $\uparrow \longrightarrow \downarrow$

These are fast: ~ one transition / millisecond

Nuclear Spins

Generally weakly coupled to lattice - therefore slow

$\sim$ one transition / minute

The difference in the relaxation rates between electron spins and nuclear spins is crucial to the polarization process

Real Target Material

We have the beginnings of a mechanism for polarizing nuclear (nucleon) spins but … we have to consider what targets are useful for particle physics

1. Interactions with nucleons are investigated in most experiments
2. Need a high density of nucleons
   a) polarized atomic hydrogen - low density
   b) molecular hydrogen - high density but no polarization
   c) Hydrogenous materials, eg CH_2, NH_3, containing as high a ratio of H/other as possible
3. We still must polarize

In general the materials of (2c) are NOT paramagnetic but

Paramagnetic centers can be doped into bulk target material (chemical or by radiation doping)

So if we have some target material containing free protons with a "dilute" doping of paramagnetic centers we can consider a mechanism by which the protons can be polarized.

The (Resolved) Solid-State Effect

The first polarized target: hydrated Lanthanum Magnesium Nitrate (LMN) $La_2Mg_3(NO_3)_{12} \cdot 24H_2O$ + 0.2% neodymium

Initial conditions: low temperature, strong magnetic field, then $P_e = -100\%$ and $P_n = 0$.

Apply rf at frequency $\nu = \nu_e + \nu_n$. It produces flip-flops but no flip-flips (energy not conserved)

Apply rf at frequency $\nu = \nu_e + \nu_n$. It produces flip-flops but no flip-flips (energy not conserved)

$$\Big\downarrow \uparrow \Longleftrightarrow \Big\uparrow \downarrow$$

but the electron spin rapidly goes back to ↓ while the nuclear spin with its much longer relaxation time stays ↑ and is no longer affected by the rf field.

Eventually $P_n = P_e = -100\%$

In fact P_e may not be 100% because of other relaxation effects and $P_n \leq P_e$.

Similarly: If $\nu = \nu_e - \nu_n$, then $P_n = +100\%$.

One could object that this reasoning applies only to those nuclei in the immediate vicinity of the paramagnetic centers. Forbidden transition probability decreases very rapidly with distance -> most nuclei would not become polarized in a finite time.

Spin Diffusion

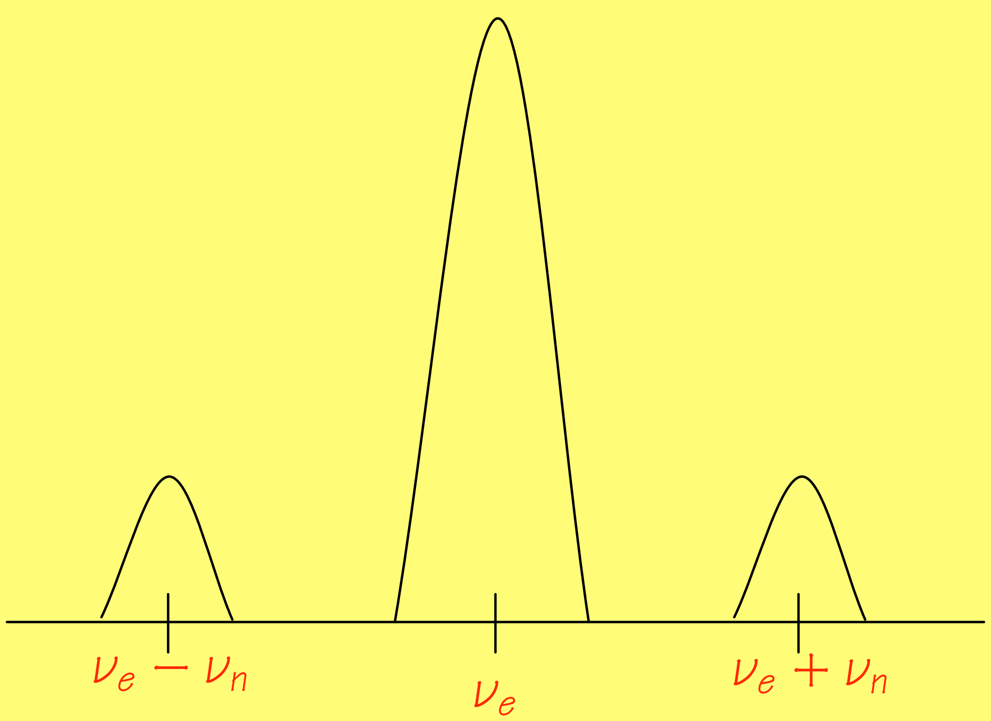
Neighboring nuclei coupled by dipole-dipole interaction which produces energy conserving processes such as

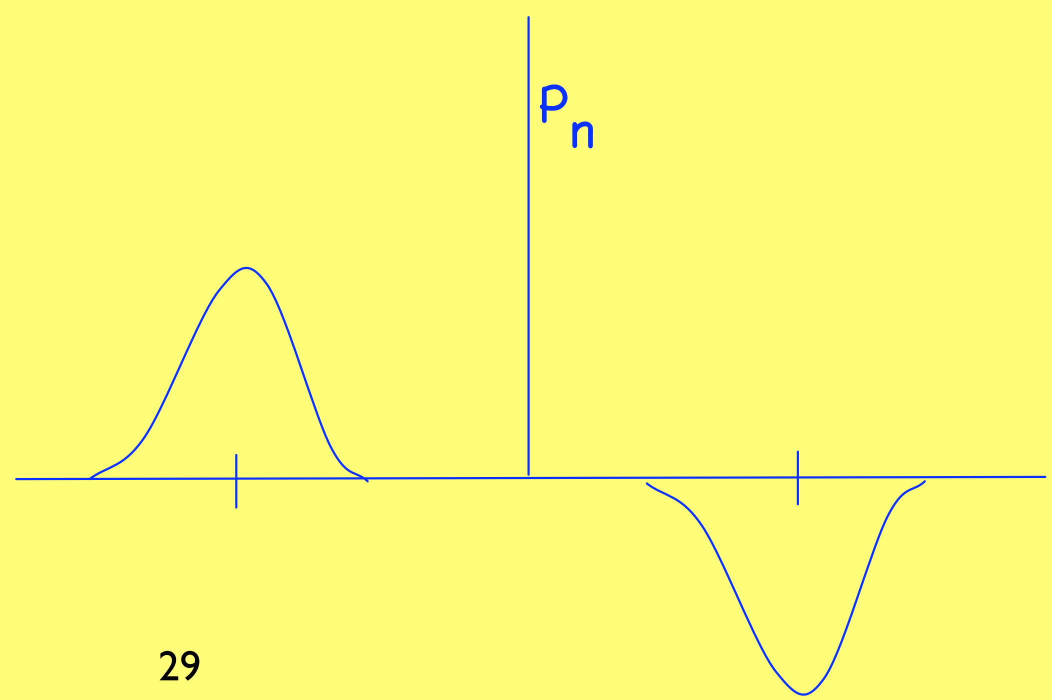
$$\uparrow\downarrow \Longleftrightarrow \downarrow\uparrow$$

Very frequent ~ 10^4/sec and nuclear polarization is transported throughout the sample

or nuclear ordering near nuclear spins is transmitted to all nuclei

Assumption for this process to work is that the line widths must be narrow





For other nuclear species (deuteron) the enhancement frequencies ($\nu_e \pm \nu_n$) will be different from that of the proton because of the different Lamor frequency.

For present-day PT materials (alcohols, ammonia) are not single crystals but rather glassy or amorphous materials. They do not have discrete energy levels and require another mechanism to describe the polarizing process. This is called the Equal Spin Temperature Theory

The phenomena were explained with a model of exchange of energy quanta between a nuclear Zeeman energy reservoir and an electron spin-spin interaction reservoir

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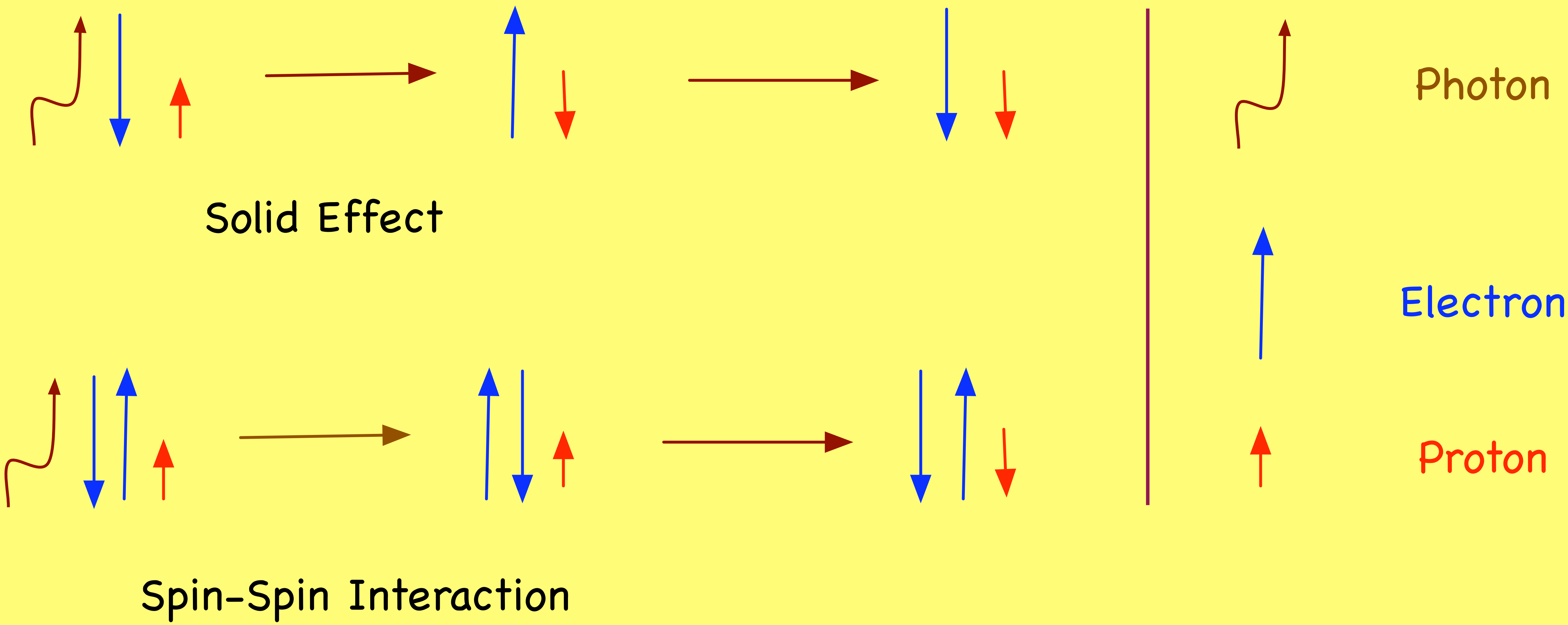


Materials that were studied for polarization at CERN (1965 - 1971)

Benzene
Toluene
Ethanol
Methanol
Propanol
Polyethylene
Polystyrene
LiF
Wax
Para Wax

Plexiglass
M-xylol
Mylar
$C_6H_5CF_3$
Diethylether
Tetracosane
Octacosane
$LiBH_4$
Cyclododecan

Palmitin acid
Polyphene
Thanol
Prophlbenzol
Phenylethylether
Phenylethyl-alcohol
$NaBH_4$
Prehnitene
Durol

Anthracene
Hexanol
Water
Propanol
Methylcyclohexan
Isodurol
Tetrahydrofuran
O-xylol
2,5 Dimethyltetrahydrofuran
1-Hexadecarol
Dioxan
Oppanol
$(CH_3)_4NBH_4$
$(CH_3CH_2)_4NBH_4$
NH_4BH_4
Tetramethylbenzene
Tritetra-butylphenol

Benzene + Ether
Propanol + Ethanol
Ethanol + Water
Ethanol + Methanol
Ethanol + Propanol
Ethanol + Diethylether
Butylalcohol + Methanol
Methanol + Propanol
$NaBH_4 + NH_4F + NH_3$

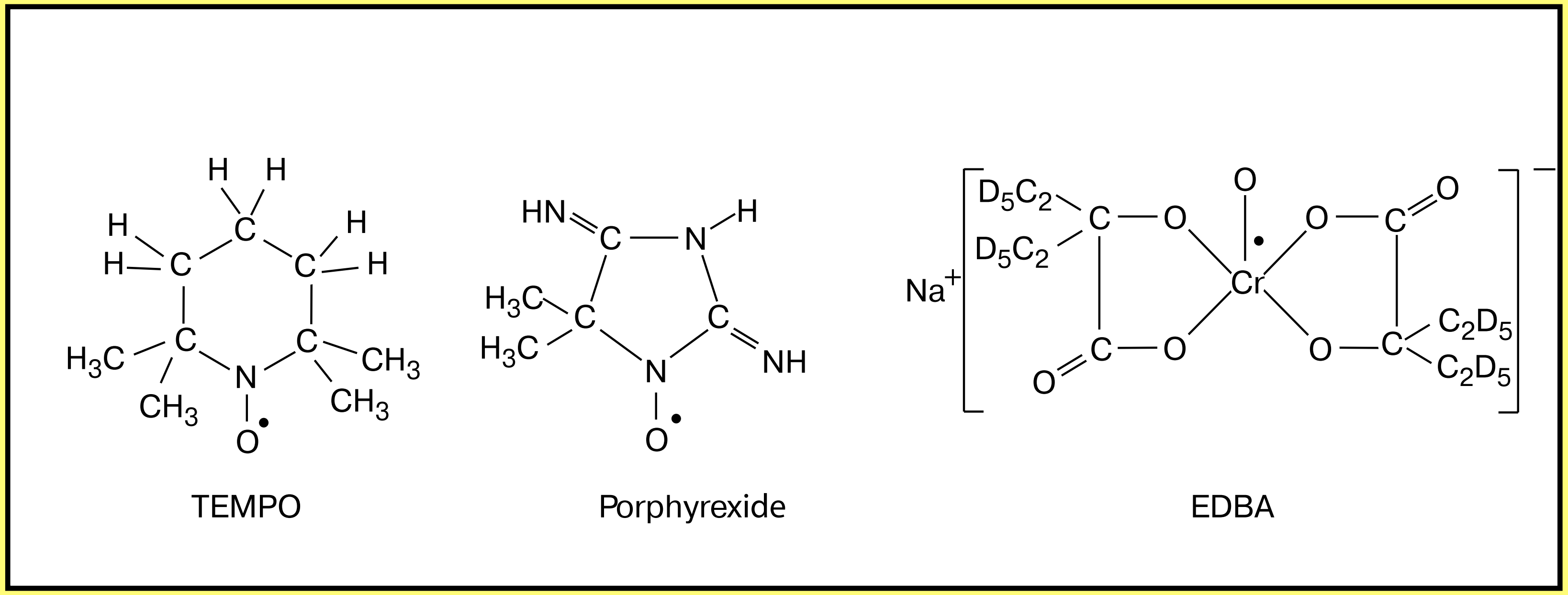
pharmacist's delight

Free Radicals - Dopants

DPPH
PAC
BPA
Shape BPA
Violanthrene
Porphyrexide
TEMPO
Ziegler
Anthracene Na^+
TMR
PB
PR
TMPD
Tri-tetra-bythlphenyl
Tetramethyl 1,3 cyclobutadien
DTBM
etc.

BPA + DPPH
BPA + Cob. Oleale
Ziegler + DPPH
Ziegler + Cob. Oleale
Ziegler + BPA
etc.

neutron irradiation
^{60}Co-γ irradiation
γ - irradiation



Spin Temperature theory: narrow paramagnetic resonance (EPR) line enables creation of high inverse spin temperatures - high polarizations.

Free Radicals - Dopants

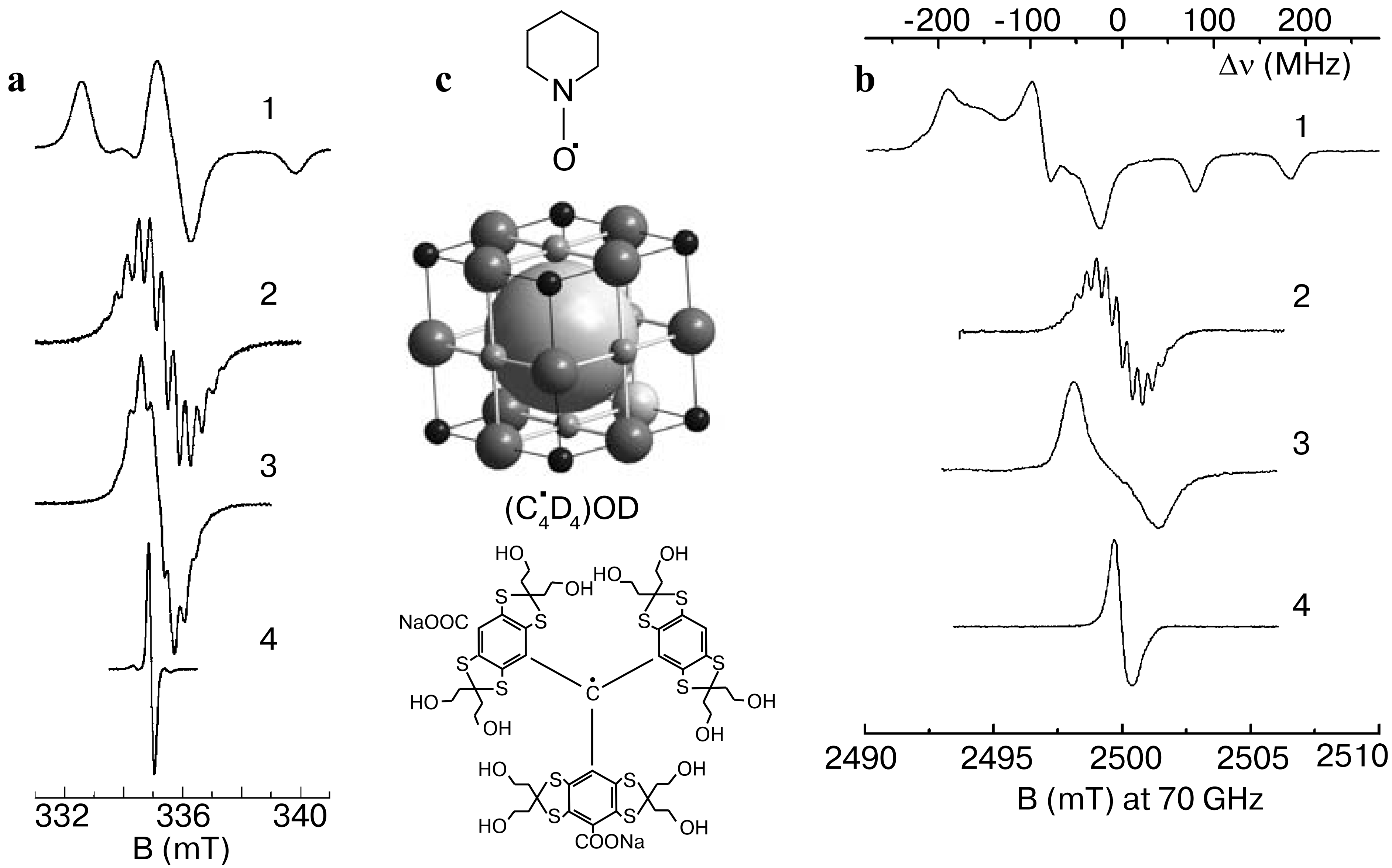


Fig. 6. X-band (**a**) and V-band (**b**) ESR spectra of TEMPO-doped d-butanol (1), irradiated ^{6}LiD (2), irradiated d-butanol (3), and trityl-doped d-propanediol (4). **c** Corresponding radicals.

Recent Progress in the Dynamic Nuclear Polarization of Solid Deuterated Butanol Targets, Appl. Magn. Reson, (2008) 34, 461-473, Heckmann, Hess, Meyer, Radtke, Geicherz and Schiemann

Bochum breaks deuteron polarization records

CERN COURIER Sep 4, 2003

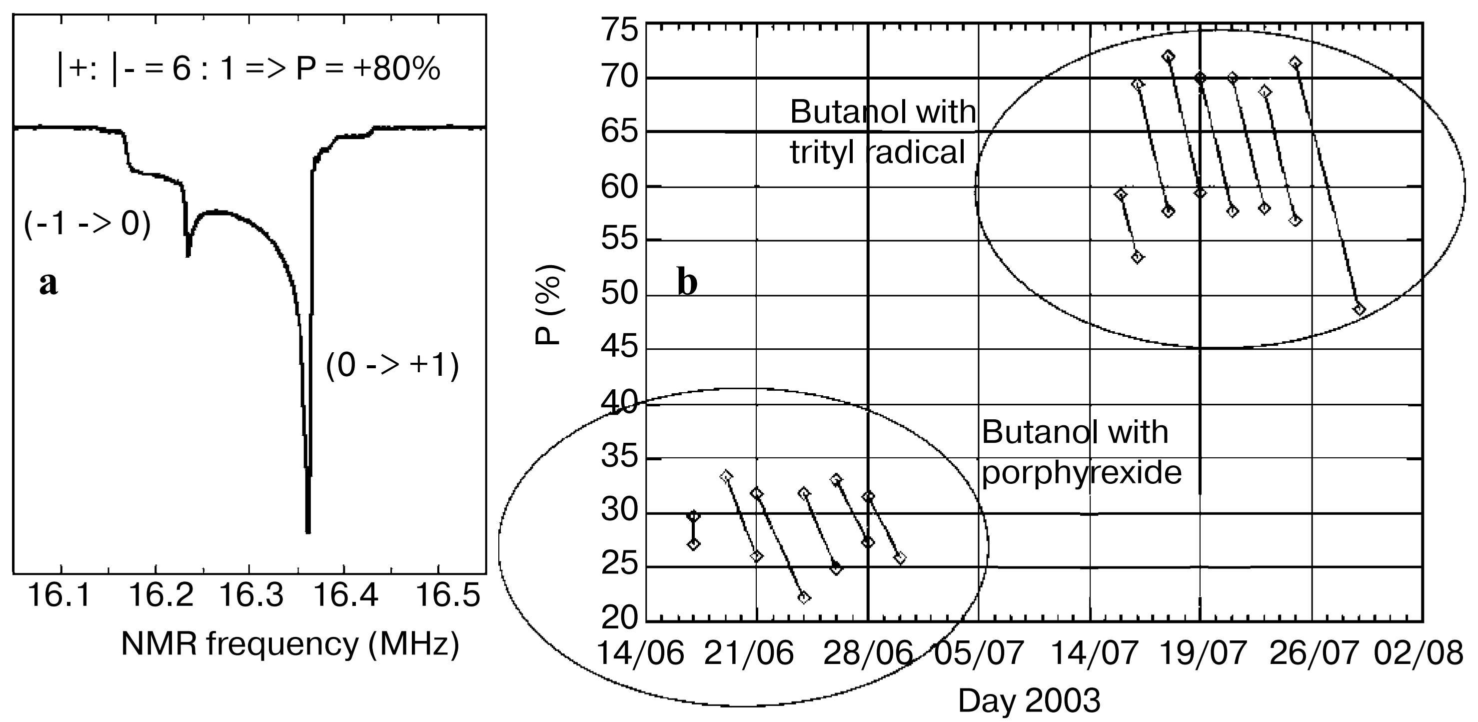


Fig. 5. a NMR signal of highly polarized d-butanol. The deuteron polarization can be estimated from the peak to peak ratio of the signal, the exact polarization value is determined from a signal fit. **b** Polarization path of two GDH data runs at the Mainz microtron with porphyrexide and trityl-doped d-butanol targets.

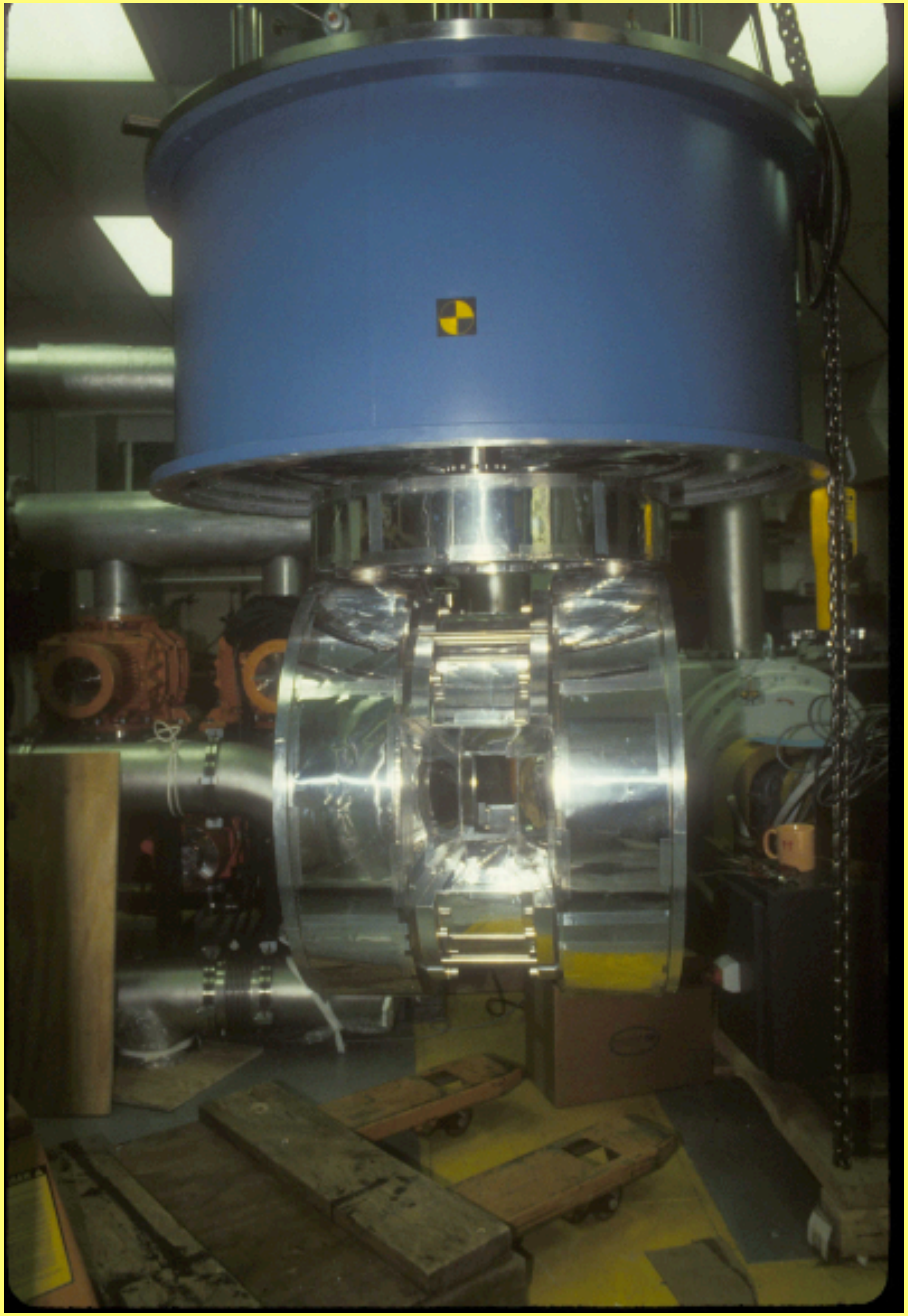
Table 1 Polarized target materials commonly used in particle scattering experiments

Materials and chemical composition	Dopant[a] and method	Polarizable nucleons % by weight	*B*/*T* Tesla/K	Polarization %	Radiation characteristic flux[b] 10^{14} particles/cm^2
LMN $La_2(Co, Mg)_3 (NO)_3 . 24H_2O$	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 $^{14}NH_3$, $^{15}NH_3$	$NH_2\bullet$ Ir	17.5, 16.6	5.0/1.0	+97 −100	70, 175[d]
d-Butanol C_4D_9OD	EDBA Ch	23.8	2.5/0.3	± 50	Not measured
d-Ammonia $^{14}ND_3$, $^{15}ND_3$	$ND_2\bullet$ Ir	30.0, 28.6	3.5/0.3	+49 −53	130(+), 260(−)
Lithium deuteride ^6LiD	f-center Ir	50	6.5/0.2	± 70	400

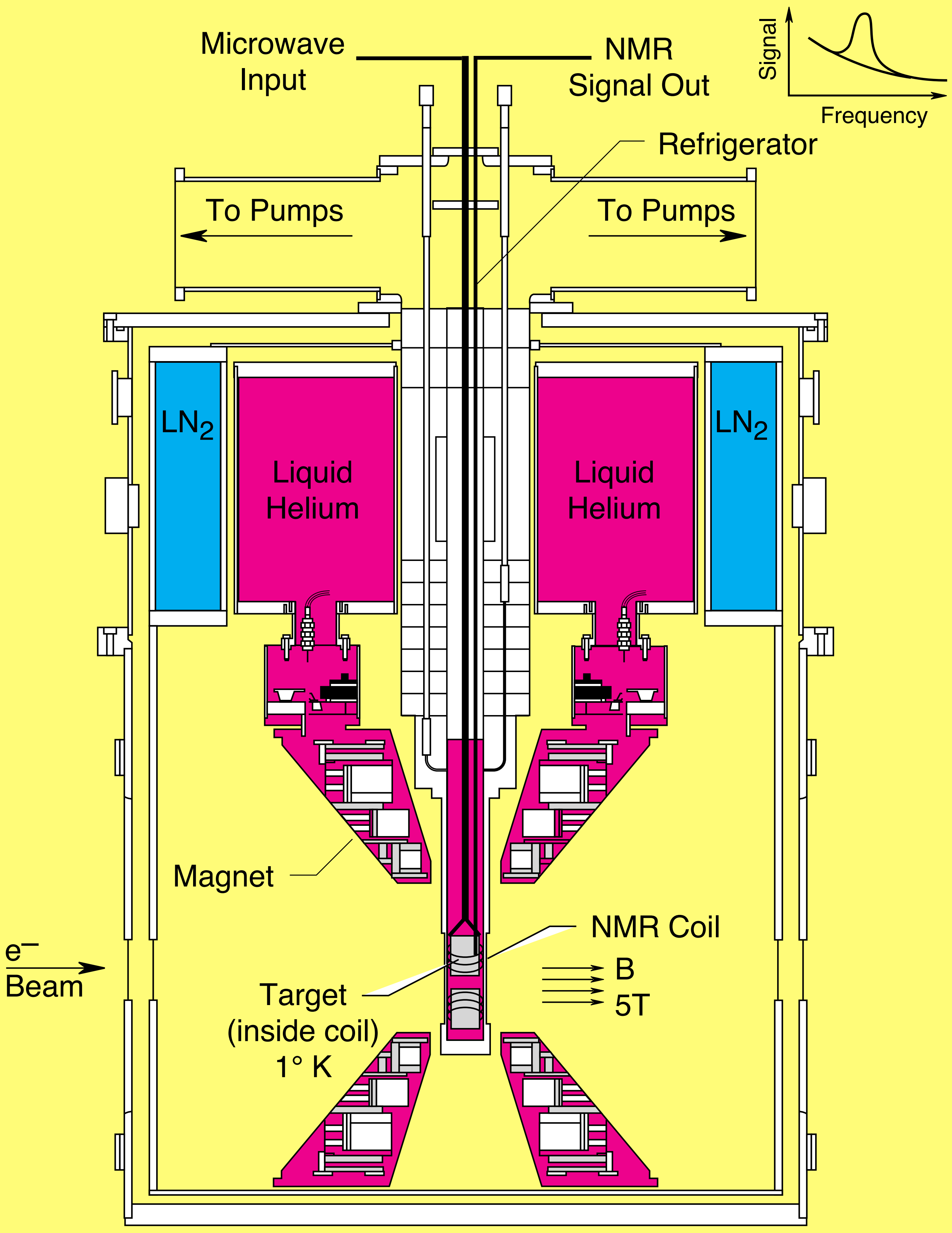
[a]Ch: chemically doped, Ir: doped through irradiation.
[b]The radiation dose which reduces the polarization by e^{-1} of its value.
[c]For positive and negative polarizations, respectively.
[d]In NH_3 there are two distinct regions of decay.

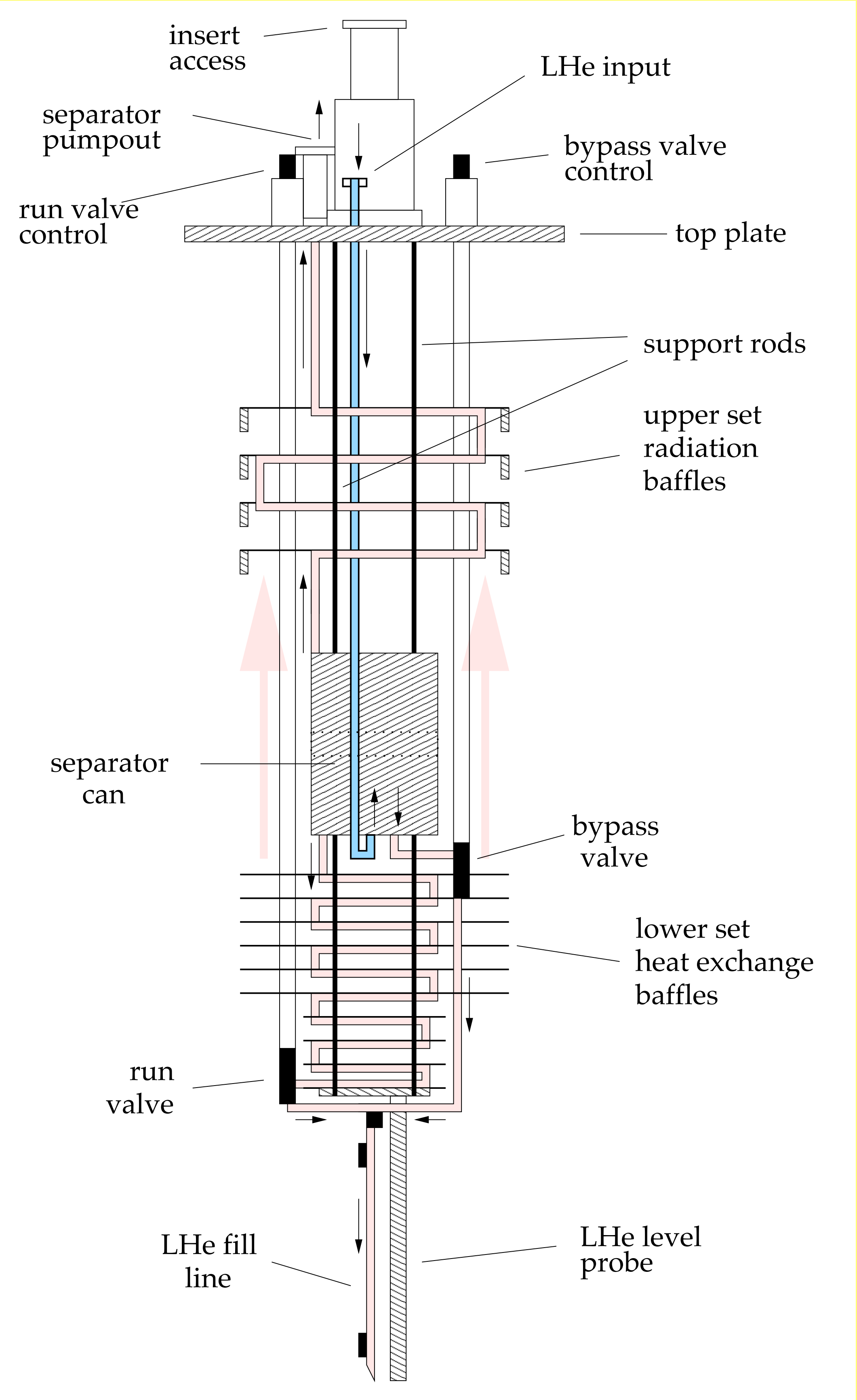
Polarizing Magnets- Split Pair

UVA/JLAB Target

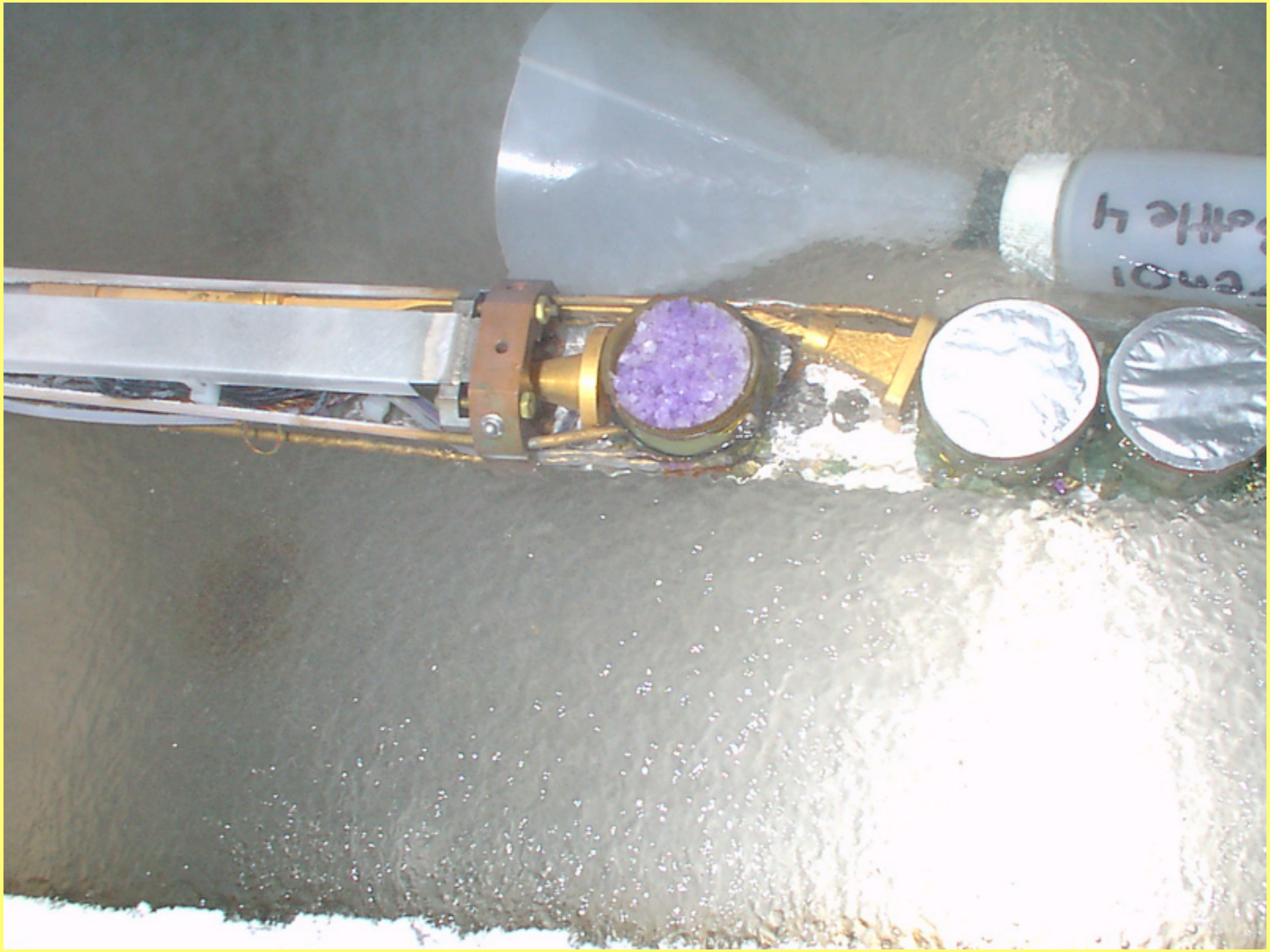


UVA/JLAB Target

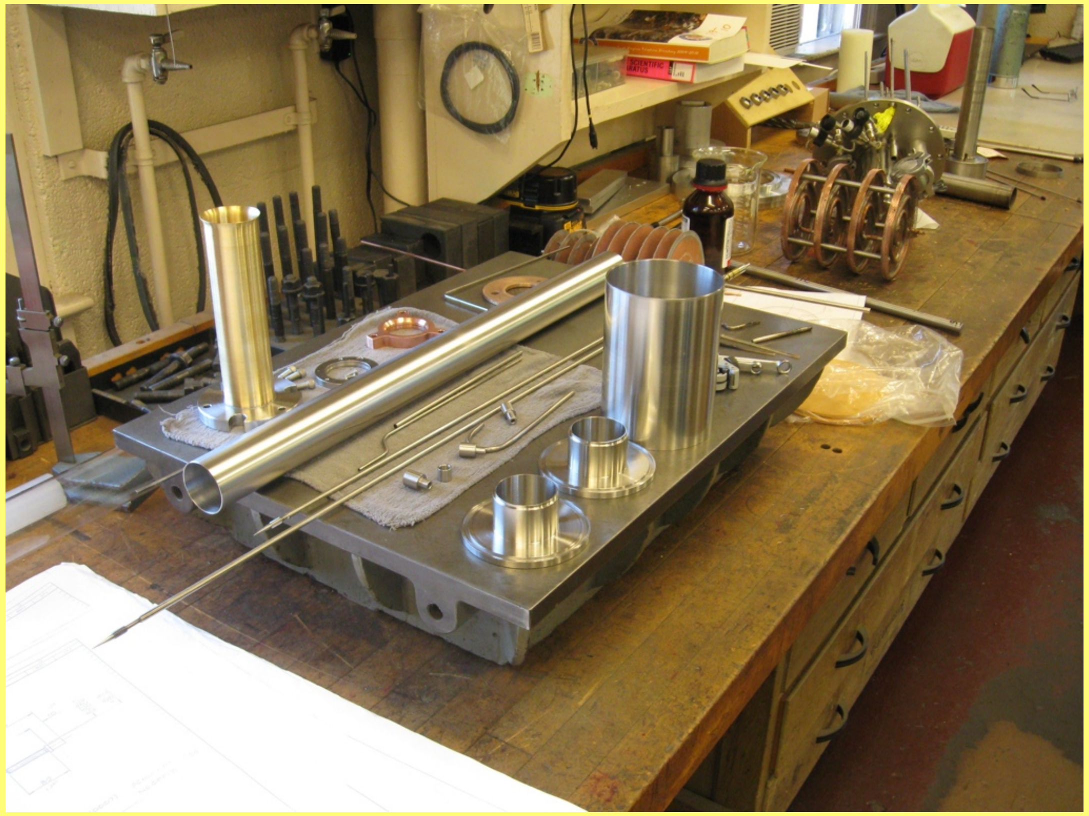


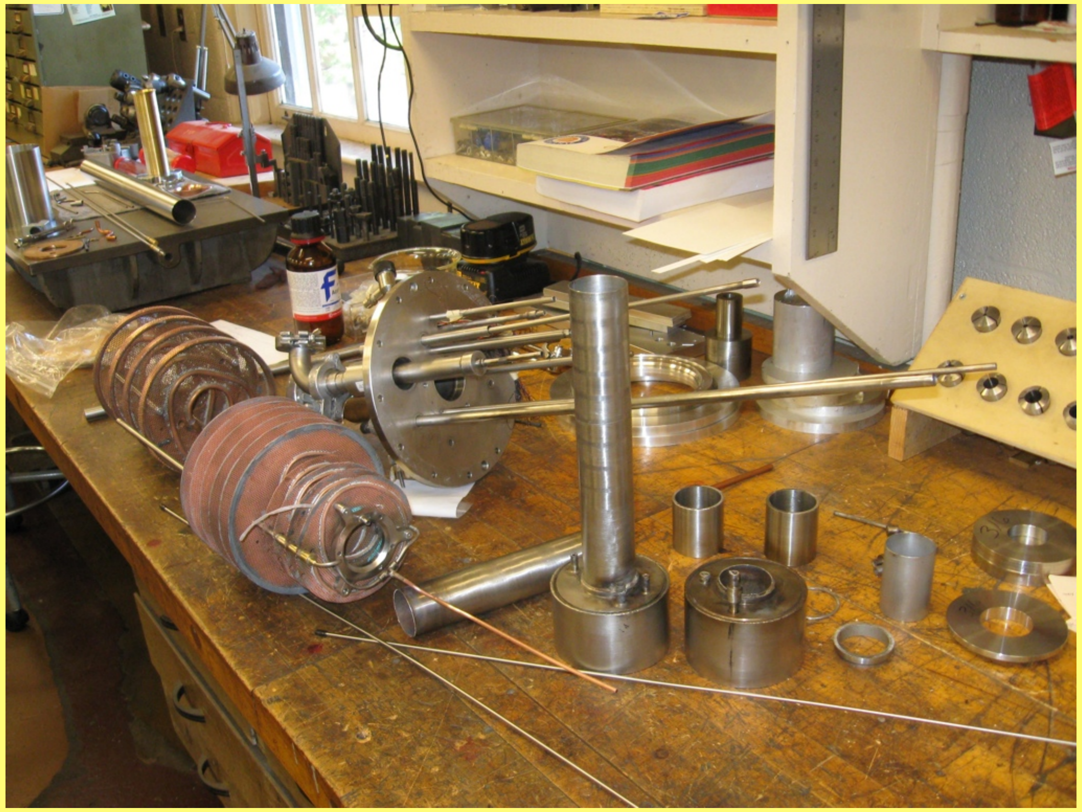


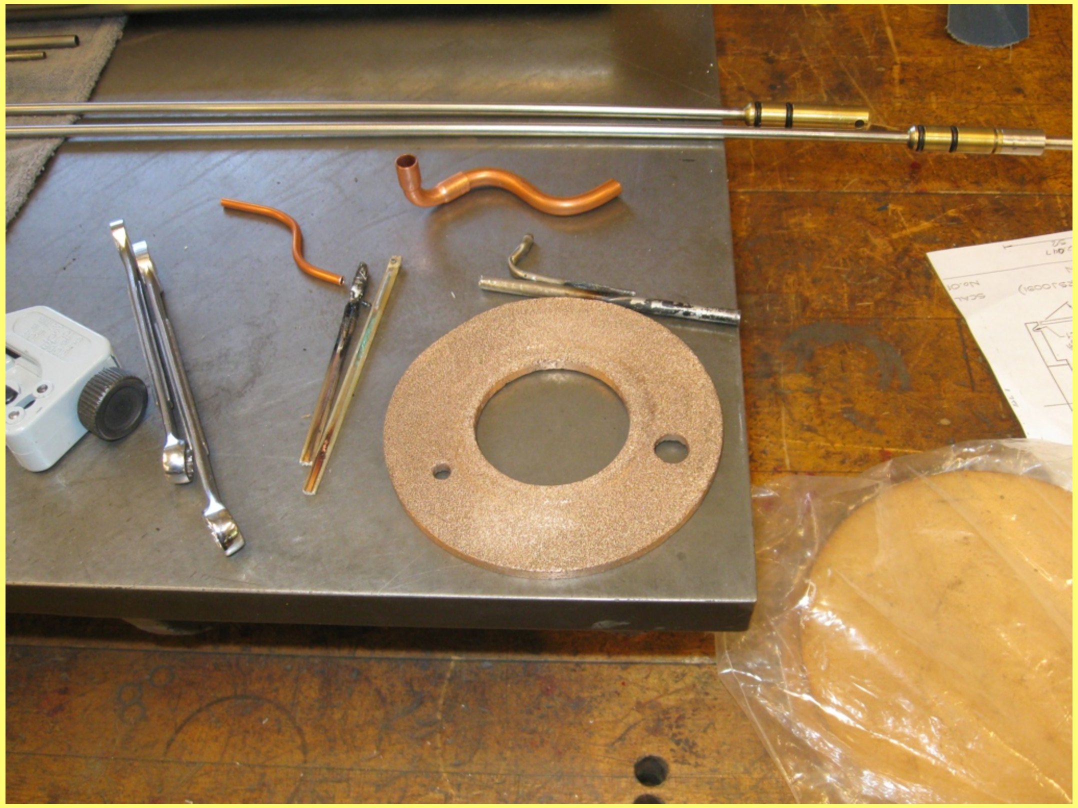
Problems



New refrigerator being built - one at JLAB & one at UVA







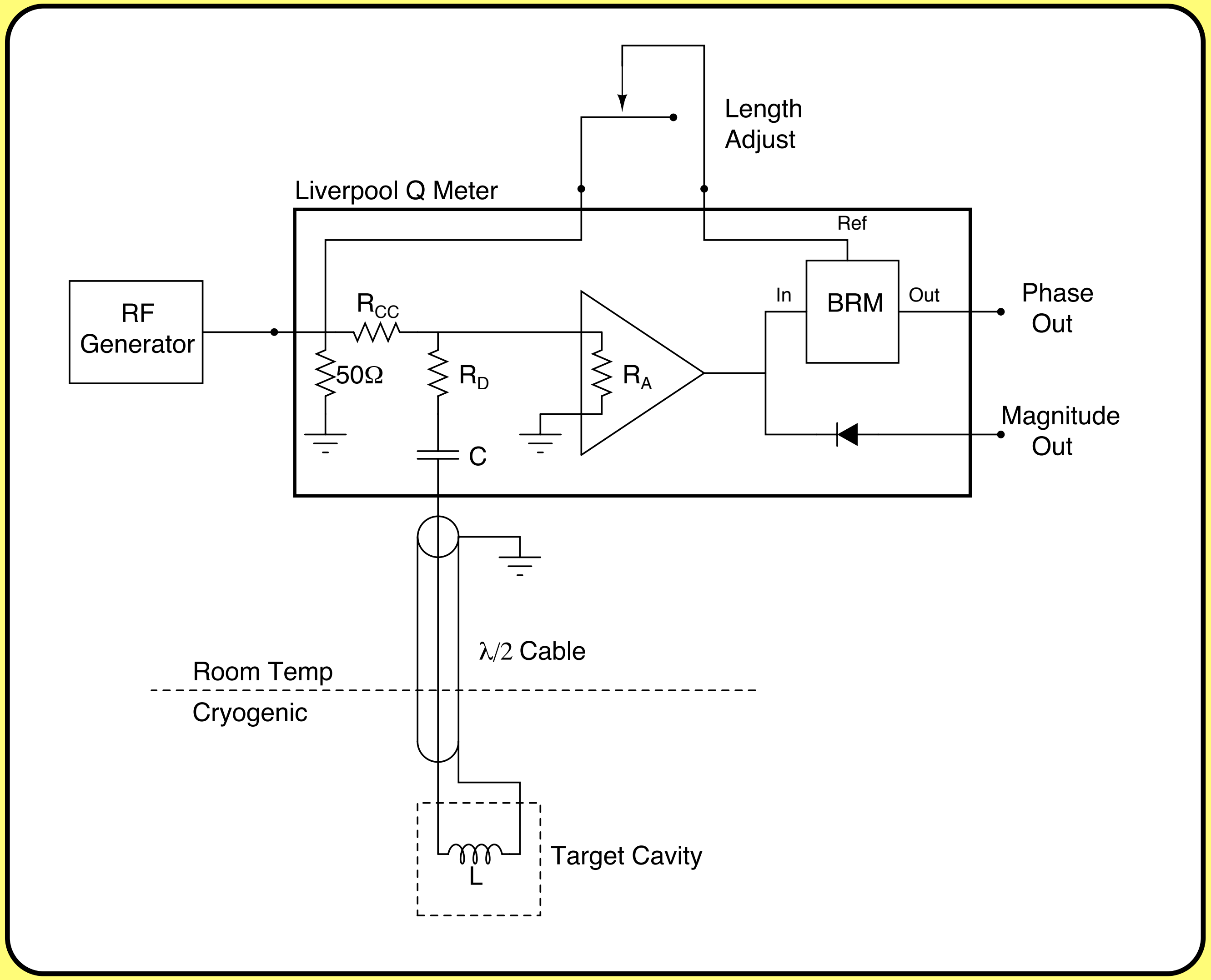
Polarization Measurement

Measuring the polarization is equivalent to measuring the net nuclear magnetization of the material   Nuclear Magnetic Resonance (NMR)

Exposed to rf field at the Lamor frequency, a spin system in a magnetic field either absorbs or emits energy. The response is described by the the magnetic susceptibility

$$\chi(\omega) = \underbrace{\chi'(\omega)}_{\textit{dispersive}} + i\,\underbrace{\chi''(\omega)}_{\textit{absorptive}}$$

$$P = K\int_0^\infty \chi''(\omega)d\omega$$



Series Q-meter connected to NMR coil with inductance L_c and resistance r_c that is embedded in target material

$$Z_c = r_c + i\omega L_c(1 + 4\pi\eta\chi(\omega))$$

$$Z_c = r_c + i\omega L_c(1 + 4\pi\eta\chi(\omega))$$

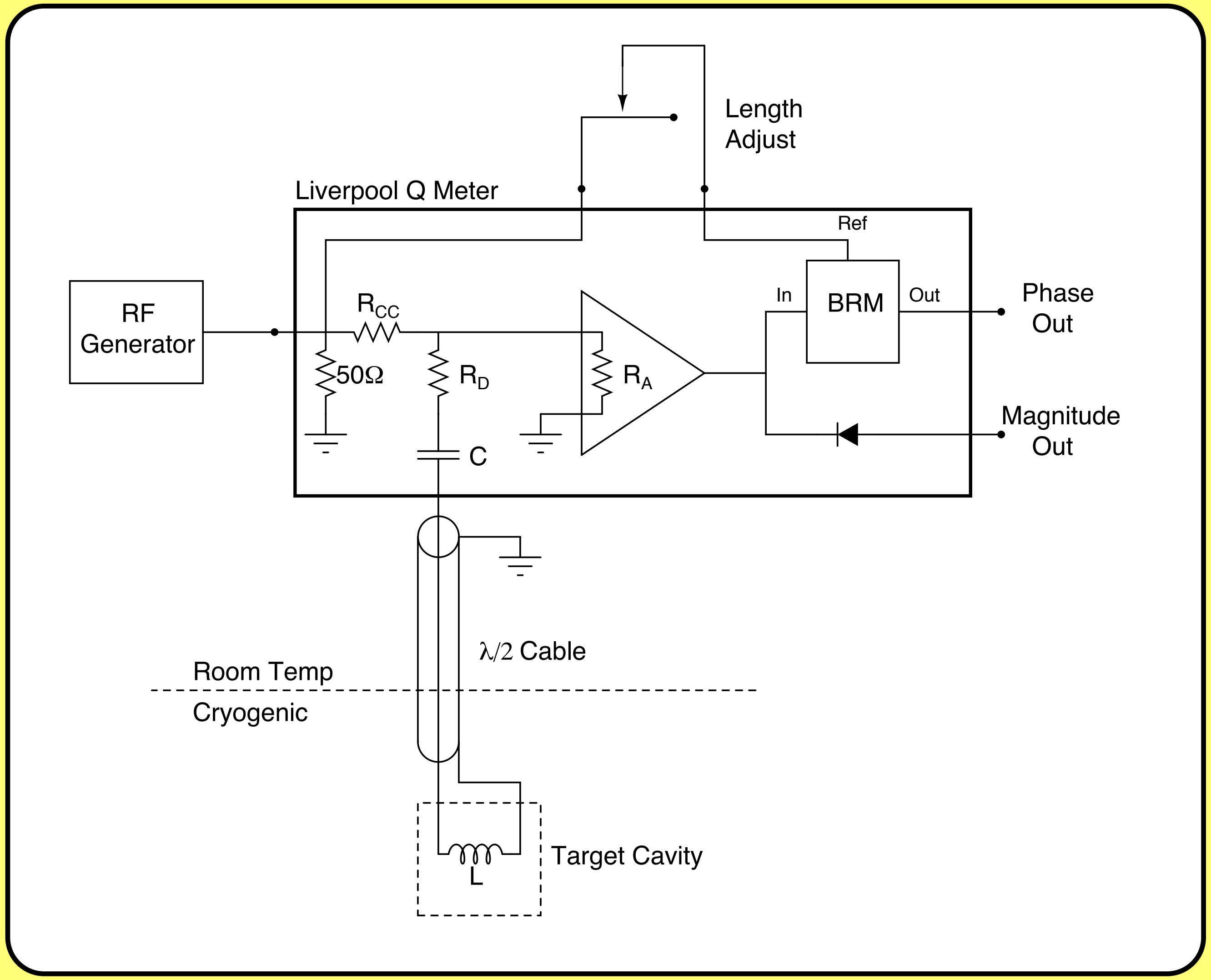
Inductance (and impedance) changes when the material absorbs or emits energy and thus the voltage, $V(\omega,\chi)$

$$S(\omega) = Re(V(\omega,\chi) - V(\omega,0)) \simeq \chi''(\omega)$$

Polarization is calibrated by using the calculable polarization P_{TE}

$$P_{TE} = \tanh\left[\frac{\mu_n H}{kT}\right]$$

$$P = \frac{\int S_{enh}(\omega)d\omega}{\int S_{TE}(\omega)d\omega}$$



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Nuclear Instruments and Methods in Physics Research A 527 (2004) 253–263

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

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High precision measurement of the polarization in solid state polarized targets using NMR

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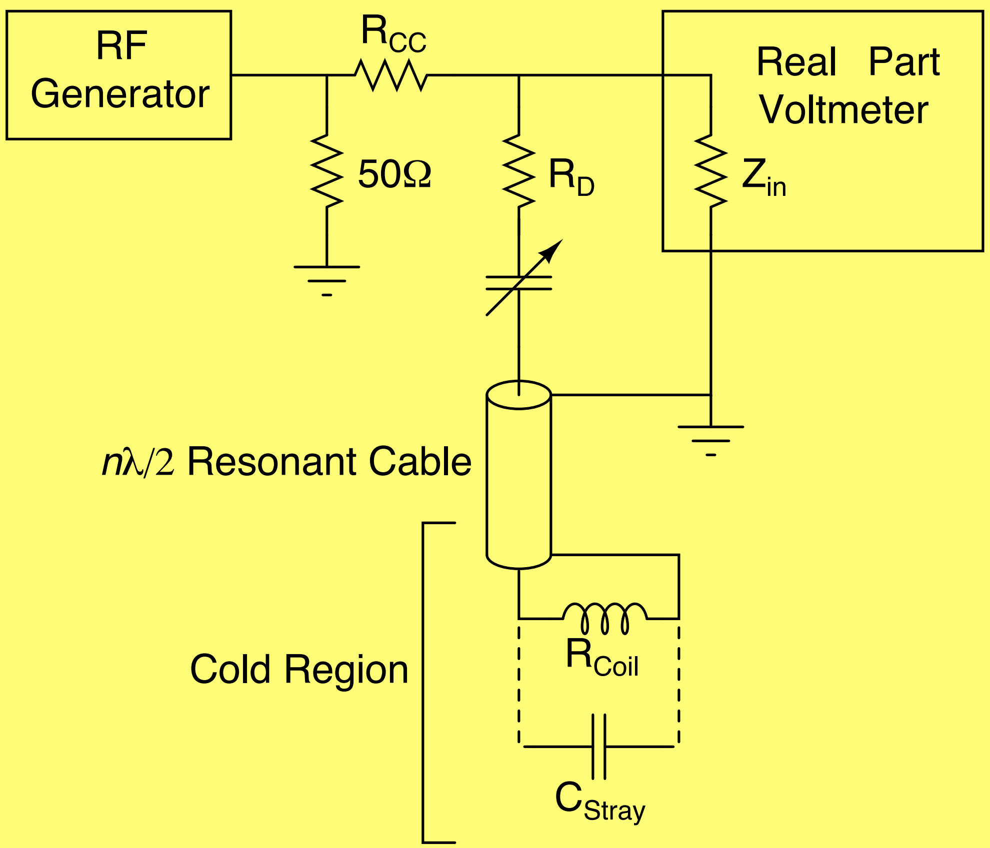
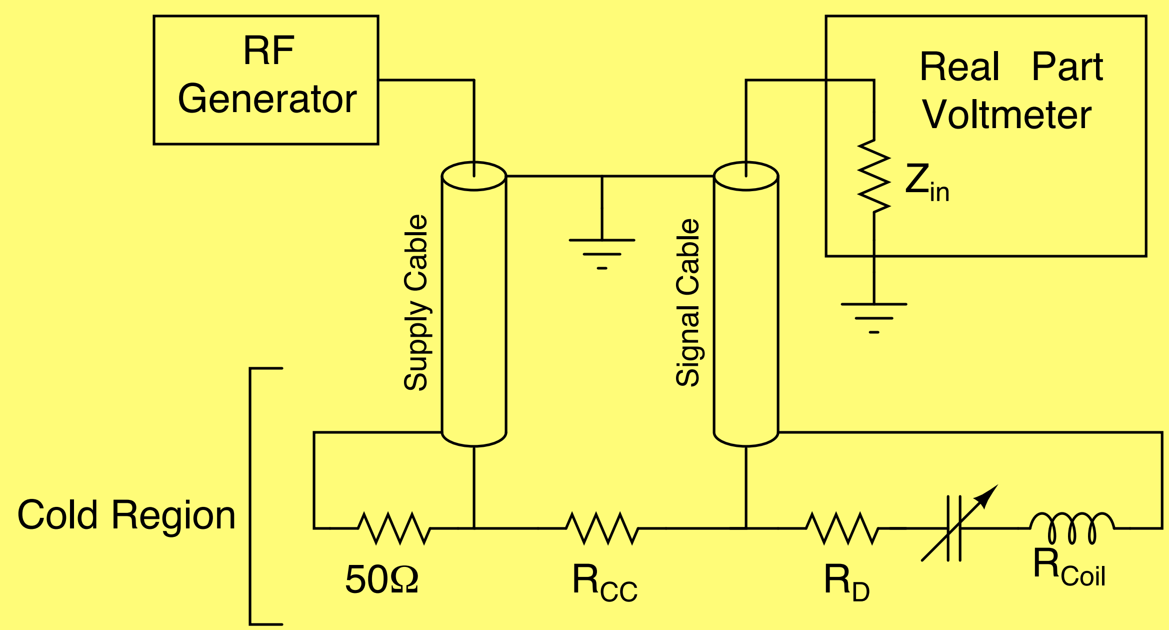
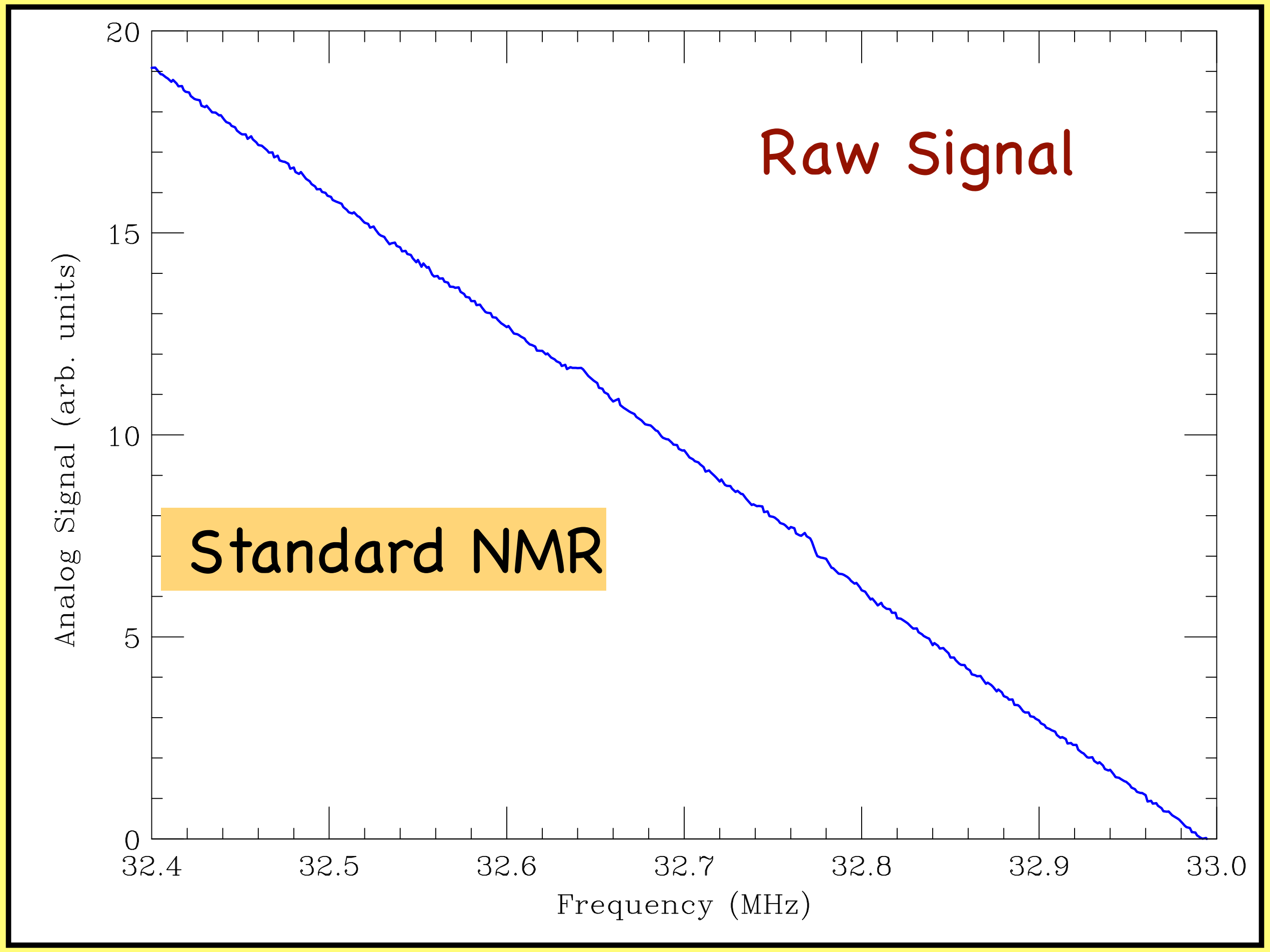
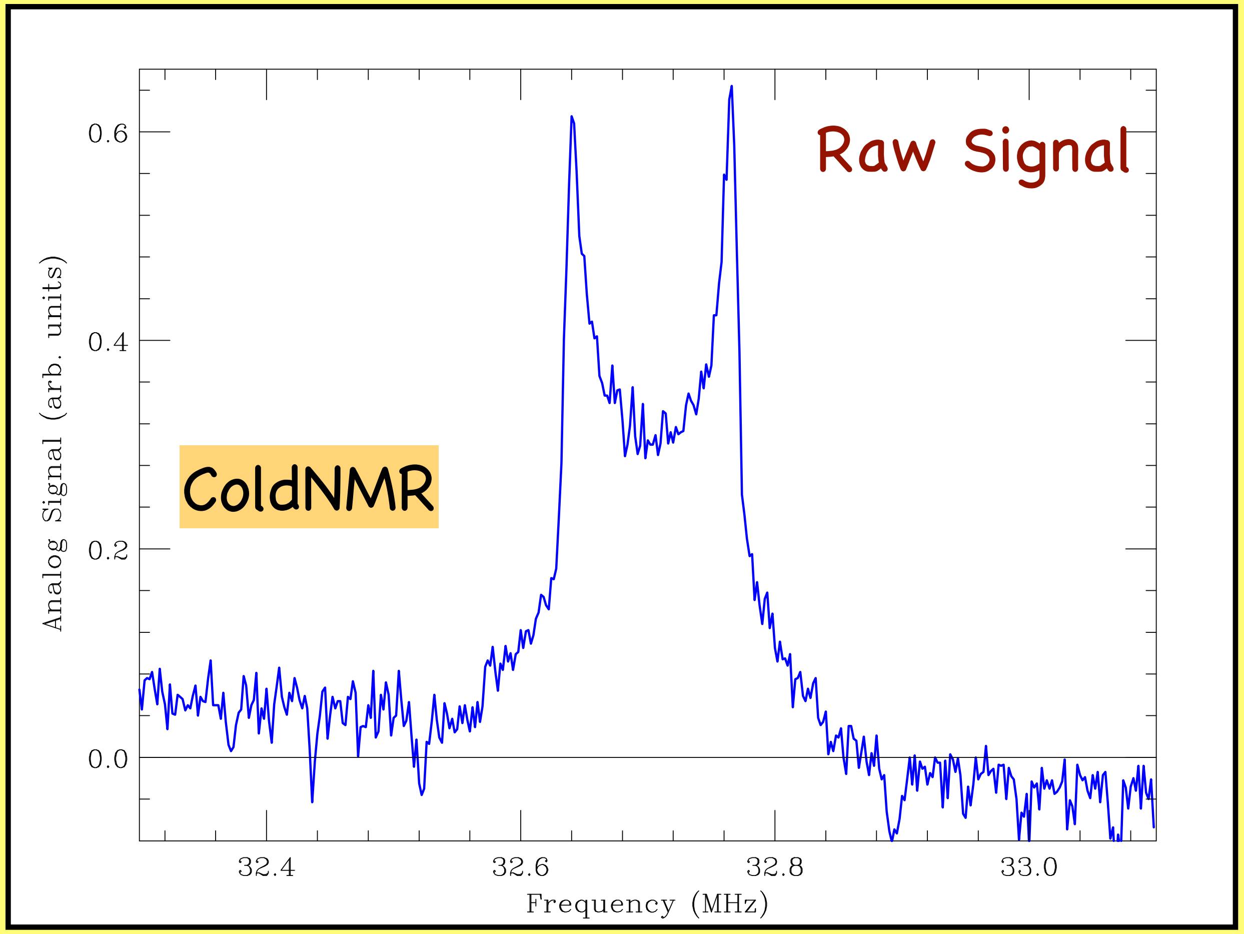
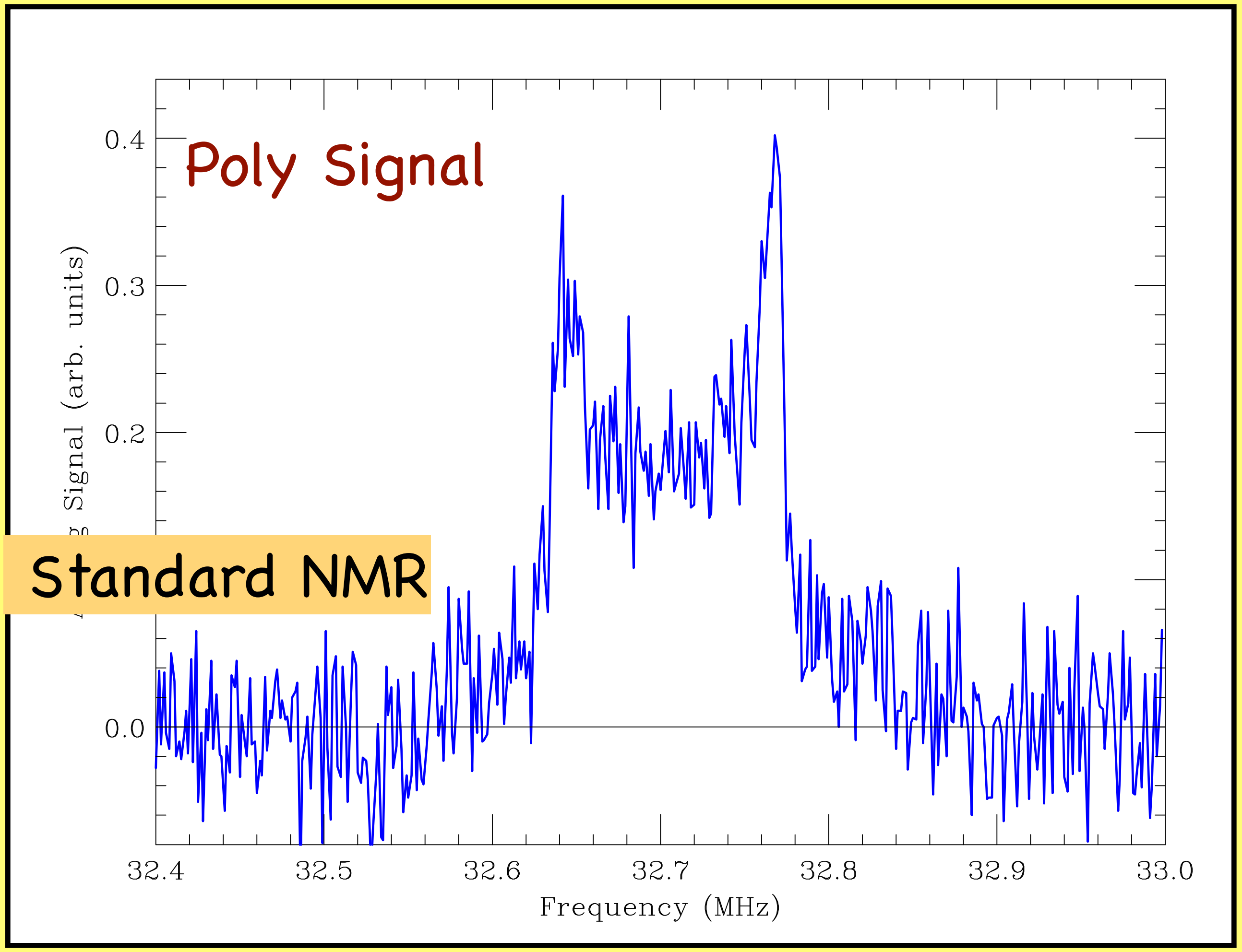
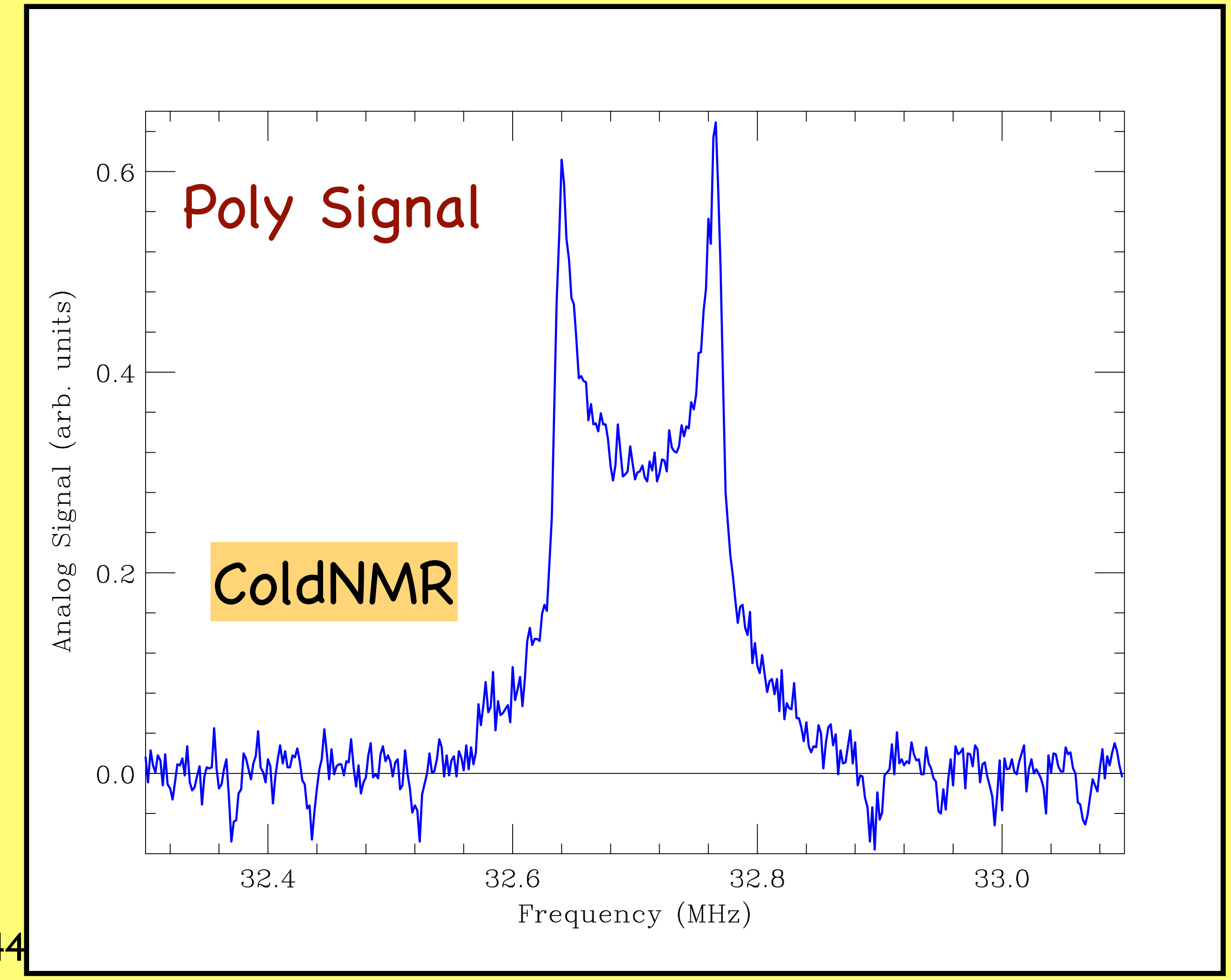


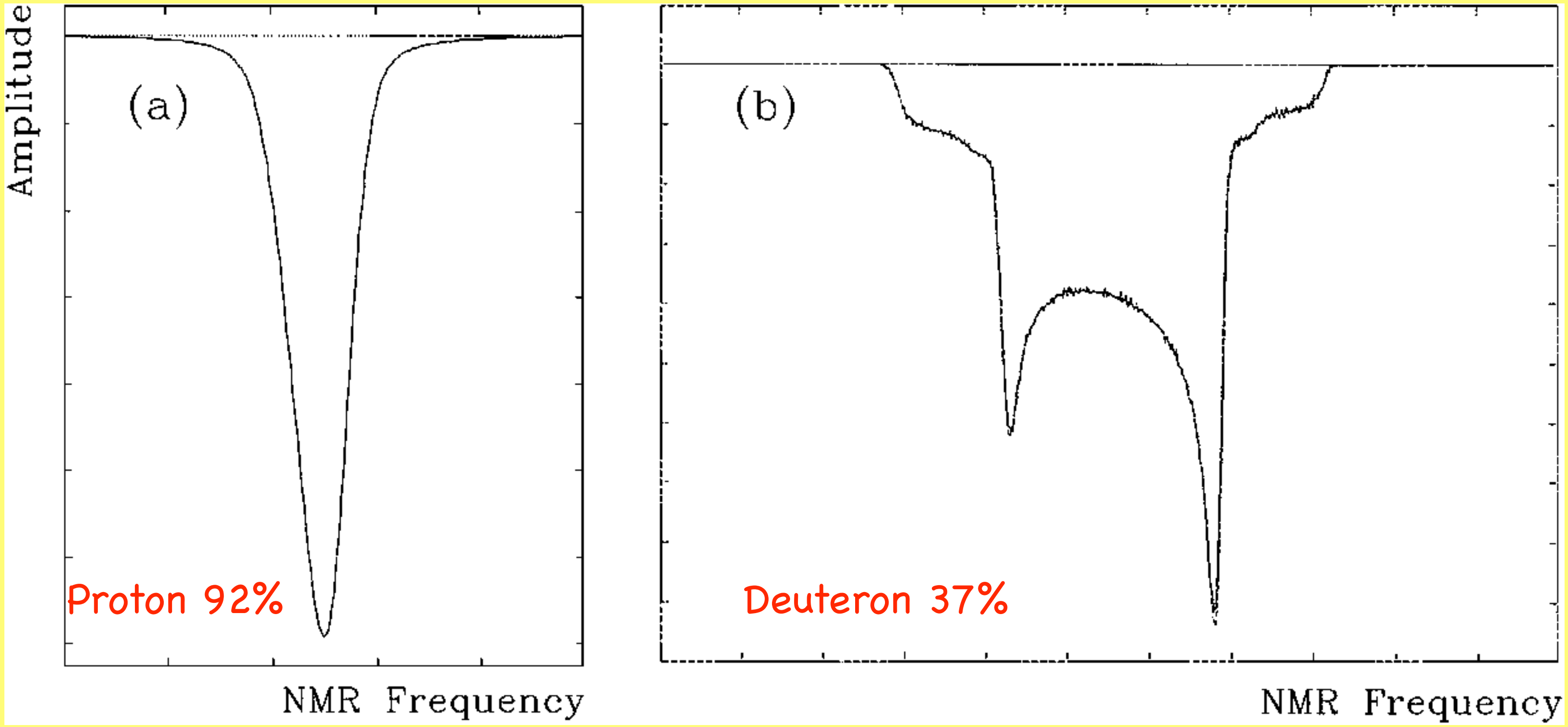



Raw Signal
Standard NMR
Analog Signal (arb. units)
Frequency (MHz)


Raw Signal
ColdNMR
Analog Signal (arb. units)
Frequency (MHz)


Poly Signal
Standard NMR
Frequency (MHz)


Poly Signal
ColdNMR
Analog Signal (arb. units)
Frequency (MHz)



Important criteria

(a) the degree of polarization P

(b) the dilution factor f, which is the ratio of free polarizable nucleons to the total number of nucleons.

$$A = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}} \qquad \epsilon = \frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}} \qquad A = \frac{1}{Pf}\frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}}$$

$$f = \frac{f_A \sigma}{(1 - f_A)\sigma_0 + f_A \sigma}$$

$$\sigma = \sigma_0(1 \pm PA)$$

f_A = fraction of polarized nuclei

where P and f correct for the fact that the target is not 100% polarized and contains other materials

Beam time t necessary to achieve a certain statistical error ΔA has the following dependency

$$t^{-1} \propto \rho(f \cdot P)^2$$

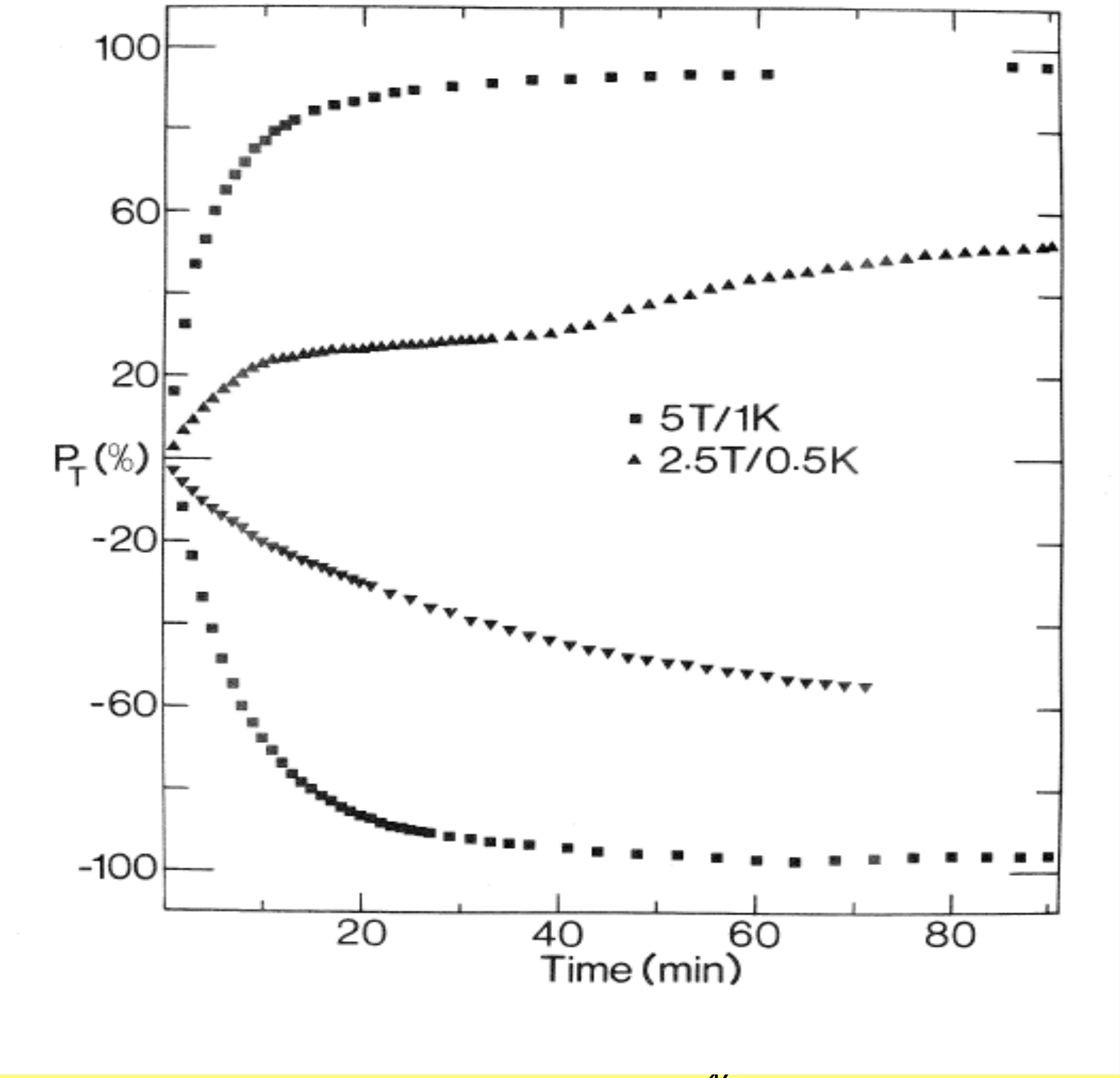
important to optimized f and P

ρ is density

Target materials

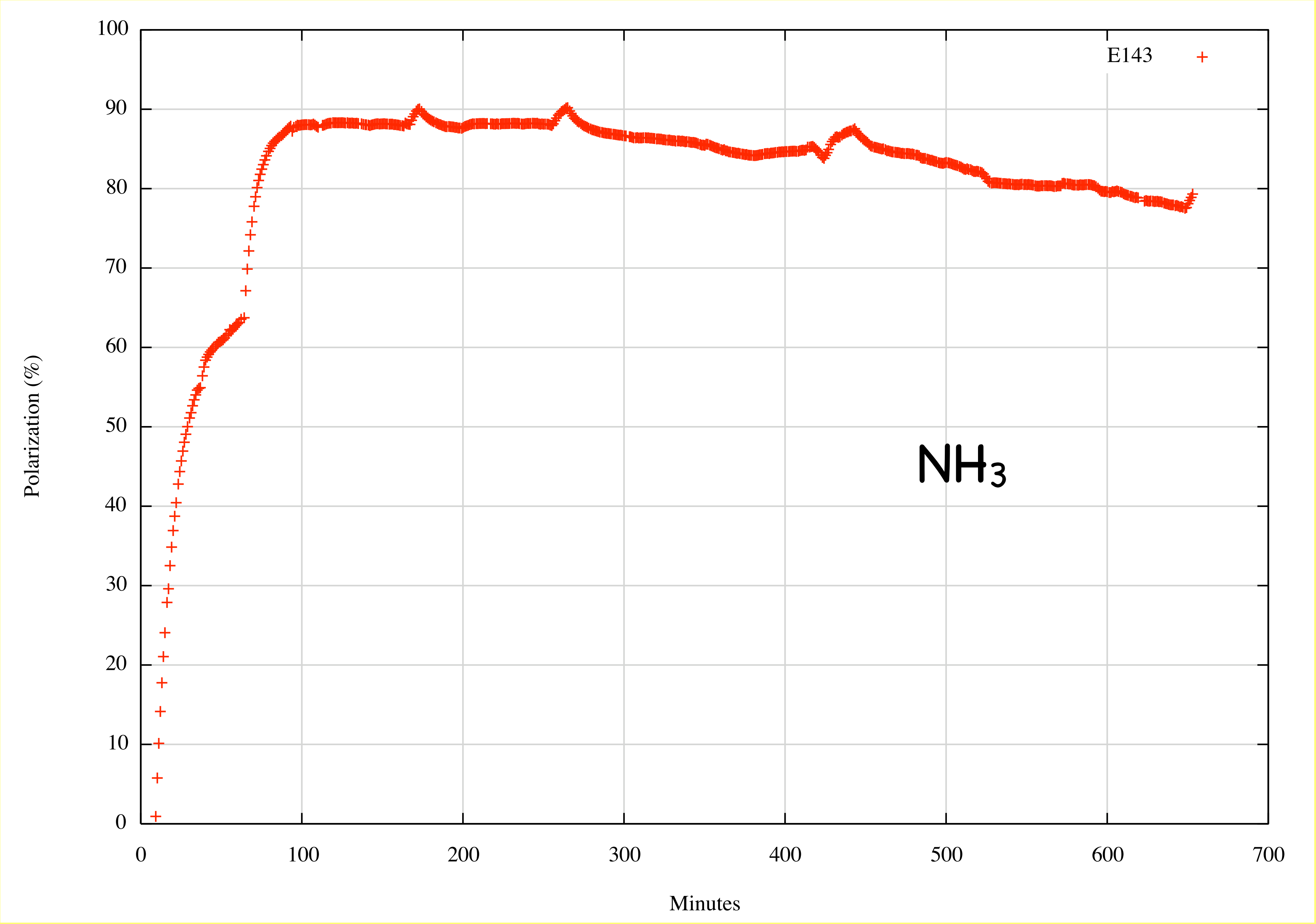
Performance and Experience

Ammonia Proton Polarization



Target materials

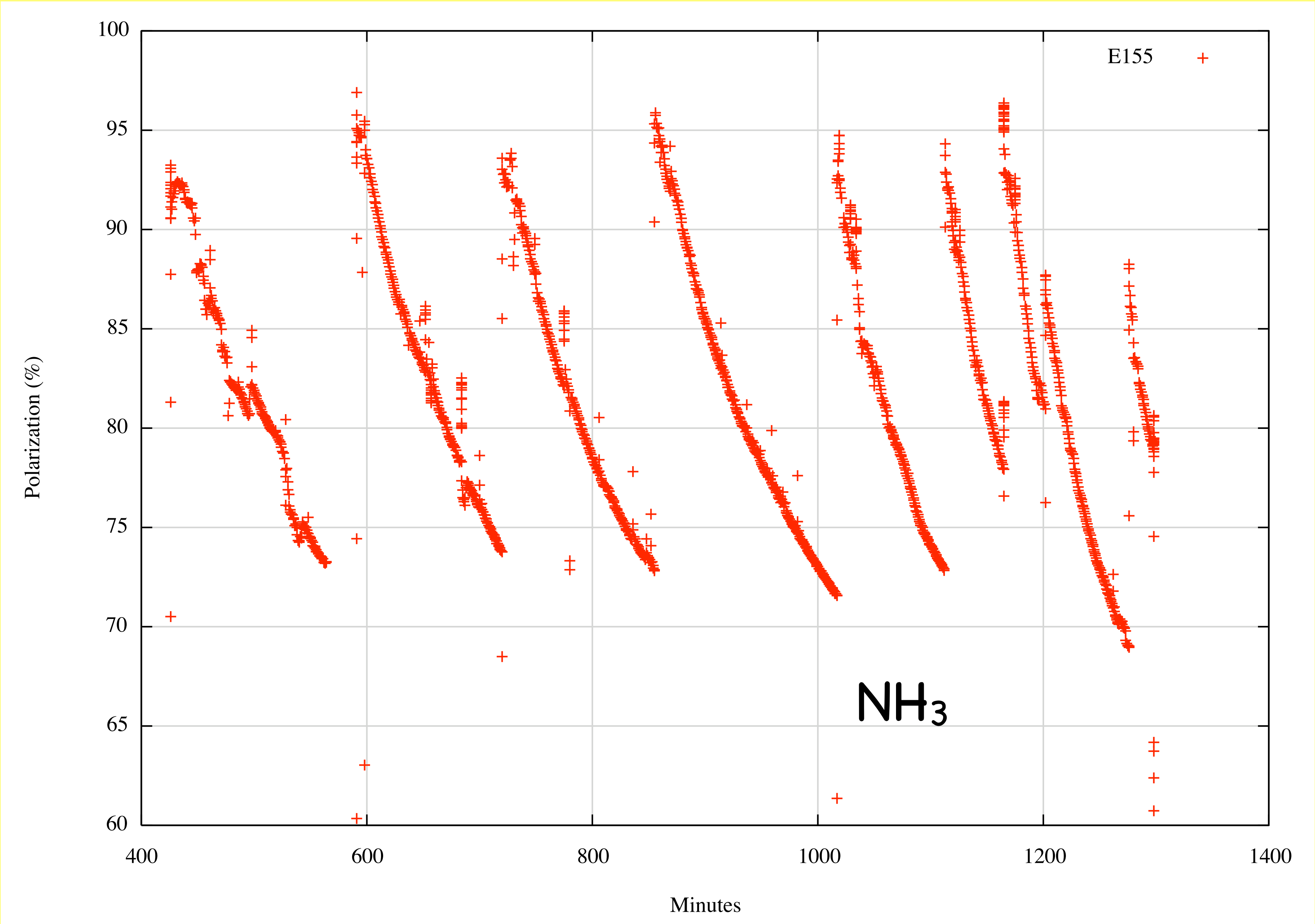
Performance and Experience



Polarization growth, mistuning, beam on/off, and decay

Target materials

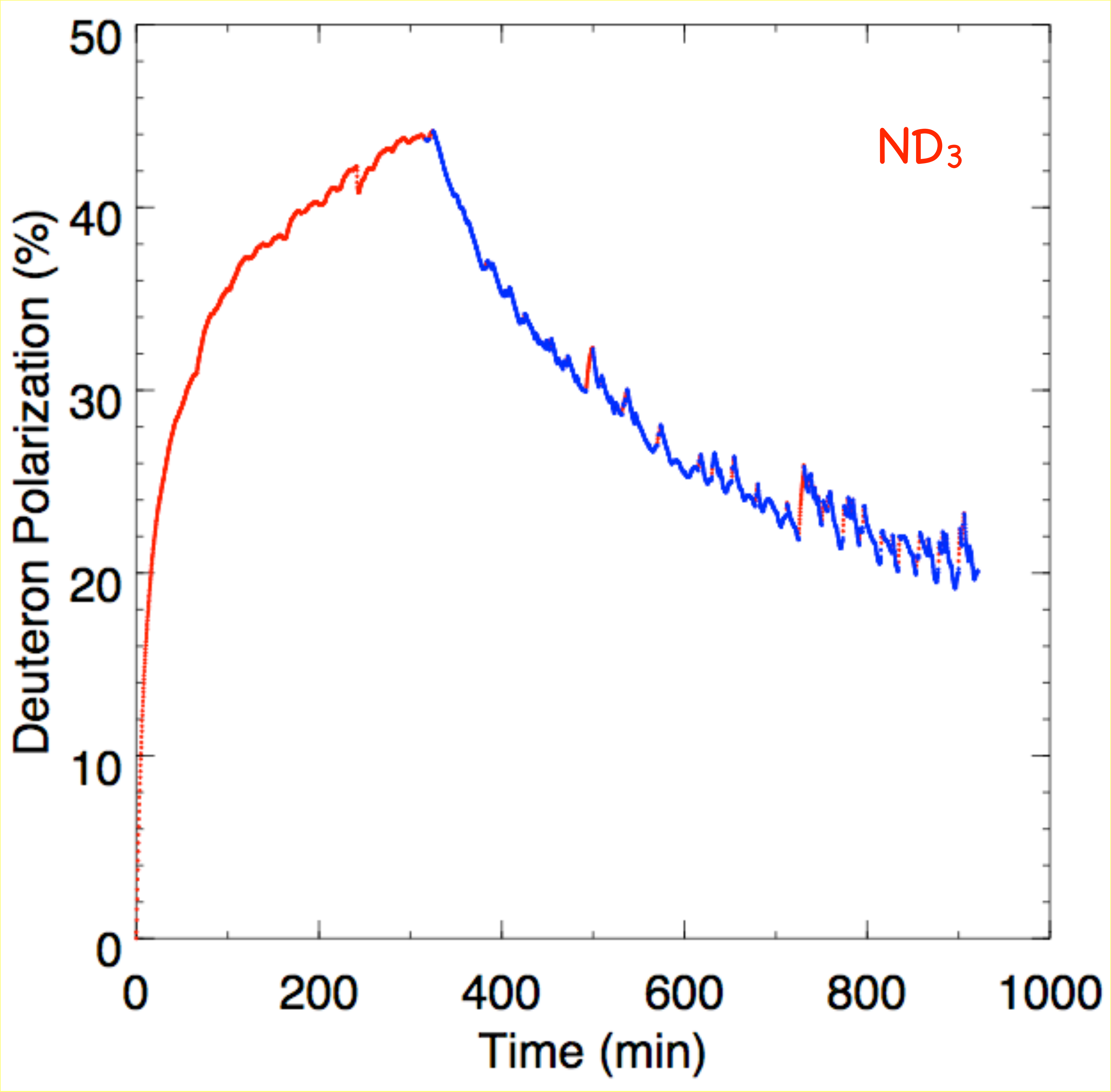
Performance and Experience



Polarization growth, radiation damage, decay of material

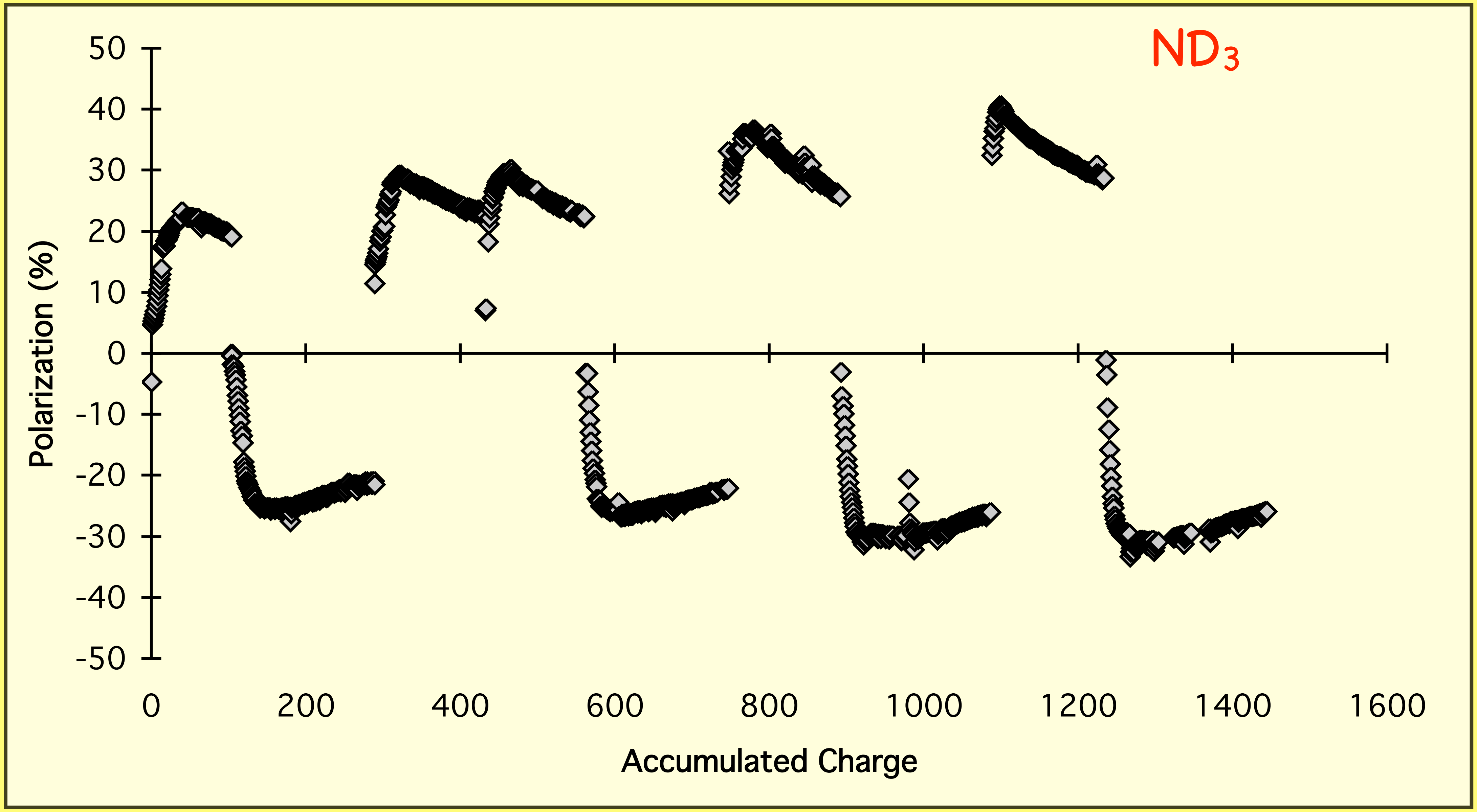
Target materials

Performance and Experience



Target materials

Performance and Experience



Polarization growth, Radiation damage, anneal, reverse sign

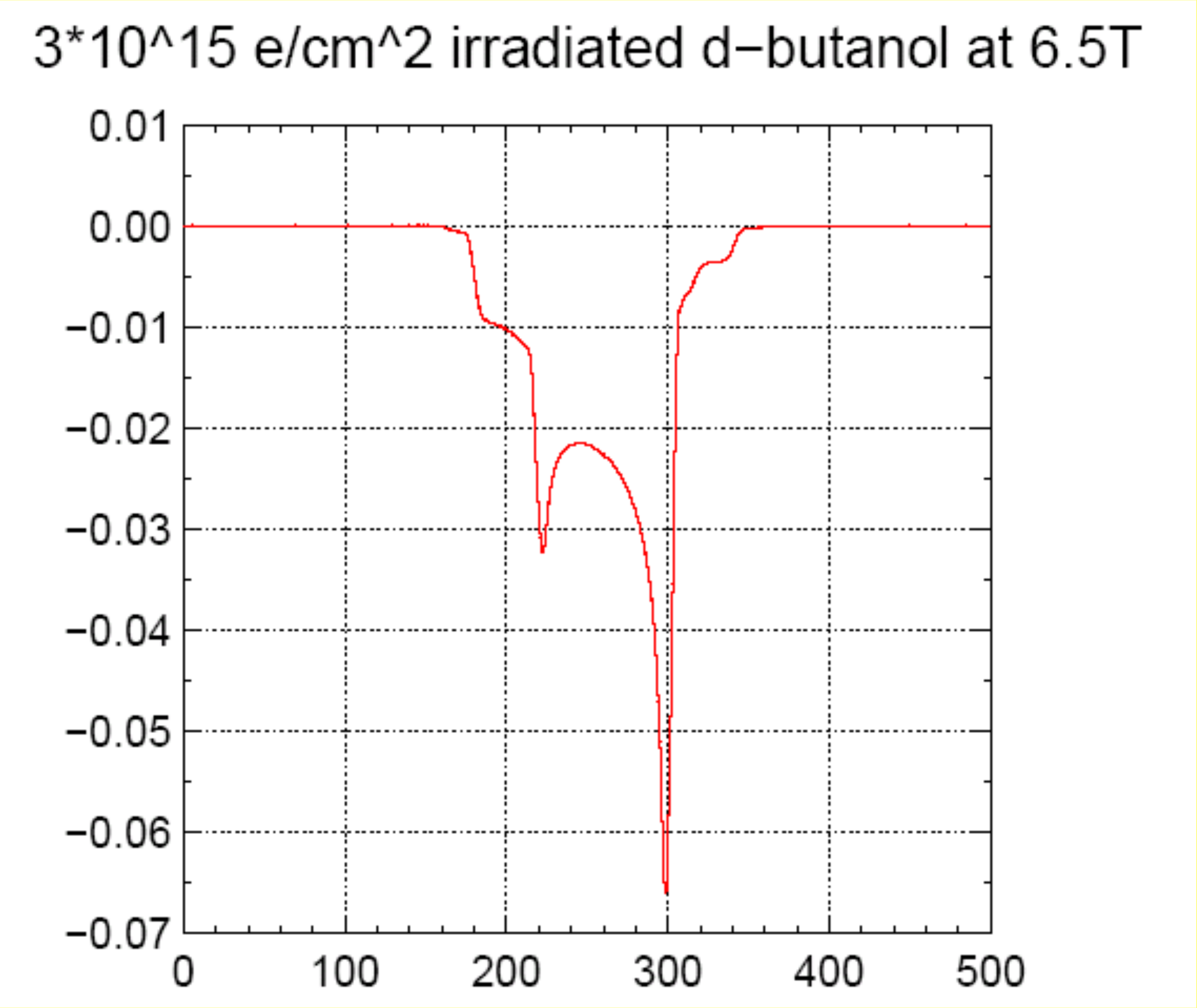
^{6}LiD

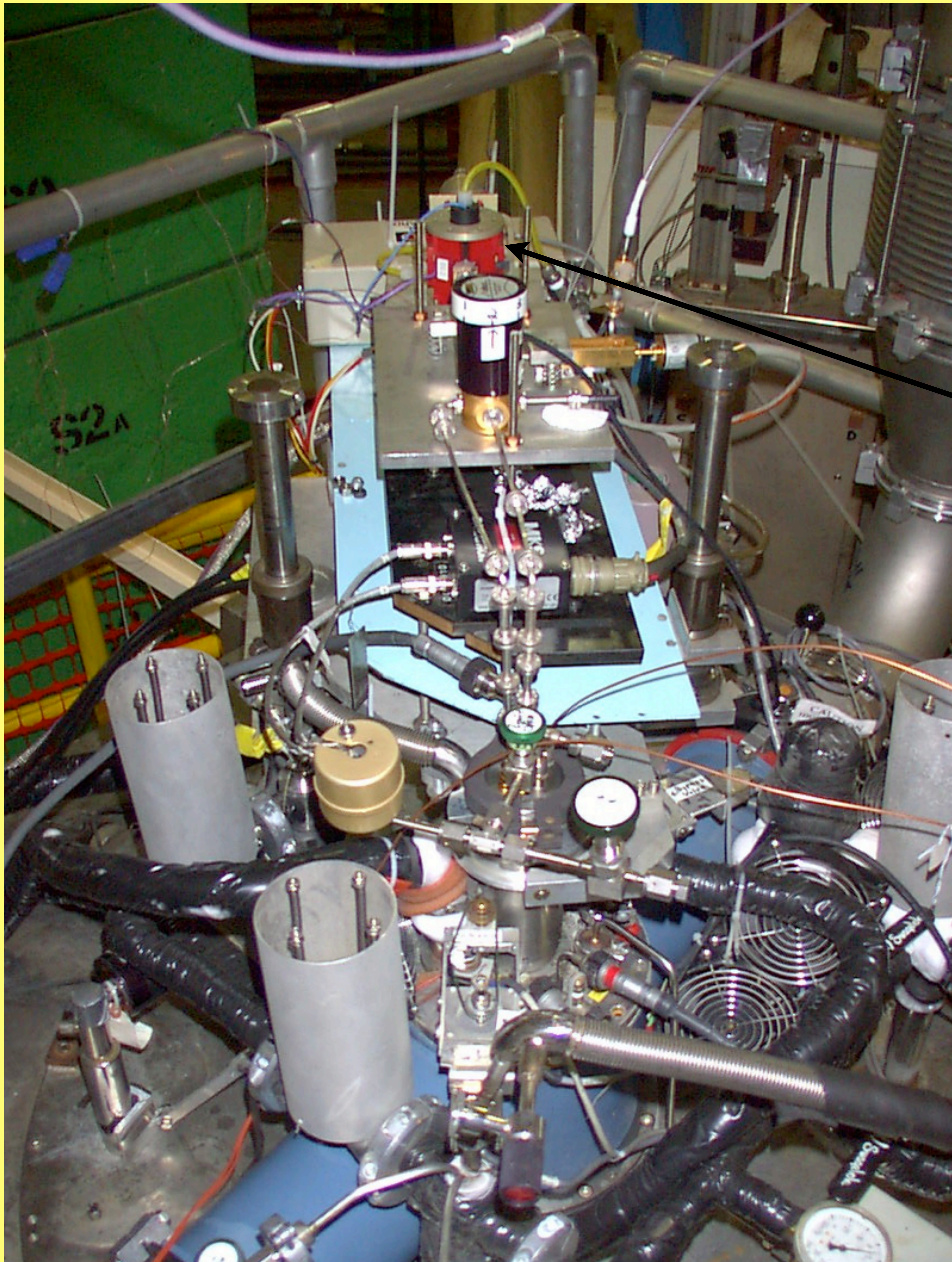
- ^{6}Li ≈ d + alpha ⇒ 50% Dilution Factor
- Actual Dilution factor ≅ 40%
- $P_{Li} \approx P_d$
- Irradiation: at 180 K for ≅ 2. 10^{17} e^- cm^{-2}
- Used in SLAC experiments E155 and E155X (g_1 and g_2 for proton and neutron).
- Now used in COMPASS at CERN

Other Irradiated Materials

- Program to irradiate various materials.
- Best way of doping solids eg. CH_2
- Used MIRF facility at NIST
- Irradiated under liquid Argon
- Program to produce solid CH_3 and CH_4 and irradiate
- Freezing and irradiation must be done under liquid helium.

Irradiated d-butanol Polarization of 63% at 6.5T and 1 K





Microwaves

For DNP the frequency needed is about 28 GHz/T, (140 GHz at 5T) and required power is, at 1K, 1-mW/g target material at 2.5 T (70GHz) and 20 mW/g at 5T (140 GHz)

140 GHz Extended Interaction Oscillator (EIO)

Power is inversely related to frequency and power absorption in microwave components increases with frequency ==> a practical limit at 210 GHz, corresponding to 7.5T.

Also: klystrons, IMPATT and Gunn diodes

IMPact ionization Avalanche Transit-Time

Experiments

- Wide Angle Compton Scattering

  E05-101, A⁻ rating, 14 days

- Semi-Sane

  E04-113, A rating, 25 Days

  PR-08-022, Deferred

- g_1^D

  E07-011A, A rating, 8 days

  High Precision Measurement of the Deuteron Spin-Structure Function g1d/F1d

- G_{ep} (Mark Jones) using BigCal with GEM chambers for electrons and HCAL with GEM chambers for proton

Q^2	Asym	Asym δ	μGe/Gm	μGe/GM δ
11.	0.084	0.0168	0	0.118
7.4	0.140	0.006	0	0.038

Initial State Helicity Correlations in Wide Angle Compton Scattering E05-101

Real Compton Scattering

- Key element in Program of Hard Exclusive Reactions
  - RCS
  - Elastic Form Factors
  - DVCS
  - DVMP
- Common issues:
  - interplay between hard and soft processes
  - Onset of asymptotic regime
  - Role of hadron helicity flip
- Uniqueness
  - Vary both s and t
  - Weighting of quarks, e_q^2
  - independent integral of GPD's, x^{-1}

Compton Scattering off nucleons provides information on the substructure of nucleon in terms of quark and gluon d.o.f. $\longrightarrow$ extremely complicated

Compton scattering in various kinematical regions

- low energy

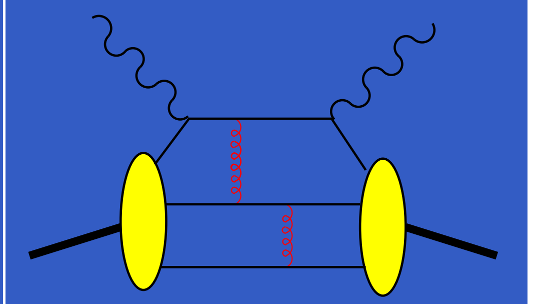
  $\longrightarrow$ dominated by nucleon as a whole

- deeply virtual CS; low $|\mathrm{t}|$, large Q^2

  $\longrightarrow$ handbag diagram involving skewed parton distributions

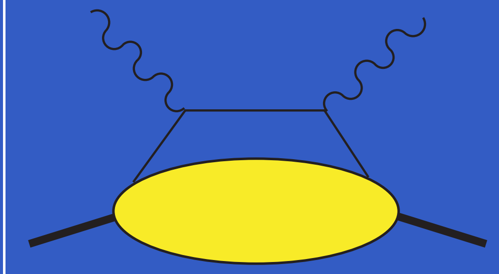
- 'wide angle' CS; low Q^2, large $|\mathrm{t}|$ and s ensures dominance of short distance behaviour

  What is the reaction mechanism?



hard gluon exchange

- 3 active quarks
- 2 hard gluons
- 3-body "form factor"

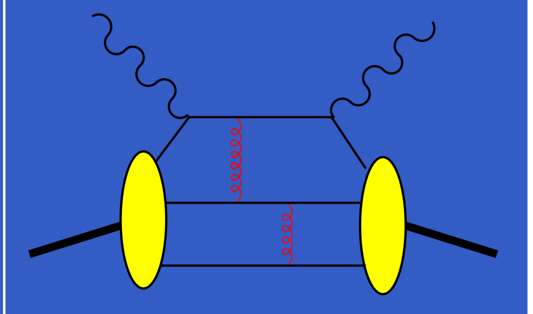


handbag

- 1 active quark
- 0 hard gluons
- 1-body "form factor"

- Which, if either, dominates at few GeV?
- We will be able to distinguish among the competing mechanisms.

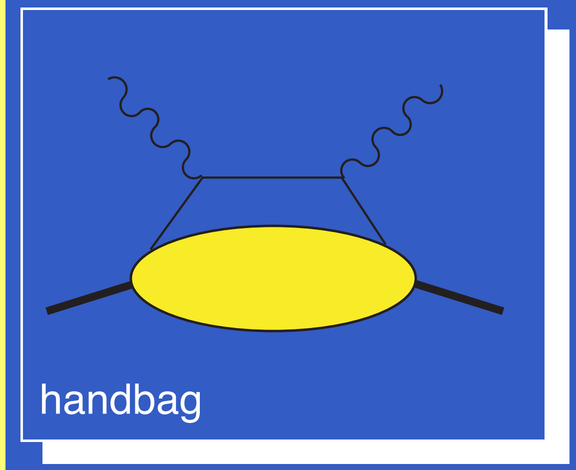
Asymptotic (pQCD) Mechanism



Brodsky/Lepage
Kronfeld, Nizic
Vanderhaeghen, Guichon
Brooks, Dixon, ...

- momentum shared by hard gluon exchange
- 3 active quarks
- valence configuration dominates
- soft physics in distribution amplitudes, $\Phi(x_1, x_2, x_3)$, $\Phi(y_1, y_2, y_3)$
- constituent scaling: $\frac{d\sigma}{dt} = f(\theta_{CM})/s^6$
- Must dominate at "sufficiently" high energy(?)
- Has predictions for polarization observables, $K_{LL} = A_{LL}$

Handbag Mechanism for $(s, -t, -u) \gg M^2$



Radyushkin
Diehl, Feldman, Jakob, Kroll

- One active parton
- Momentum shared by soft overlap
- Feynman mechanism

  struck quark nearly real ($x \sim 1$) (co-linear with proton)

- Form factor like expression

  $\frac{d\sigma}{dt} = \frac{d\sigma}{dt}\Big|_{KN} f(t)$

- Straightforward predictions for polarization observables

Physics Goals

- Measure A_{LL} (never been measured) at two scattering angles:

  $\theta_{\gamma}^{CMS} = 70^{\circ}$ corresponding to $-t = 2.4$ (GeV/c)^2

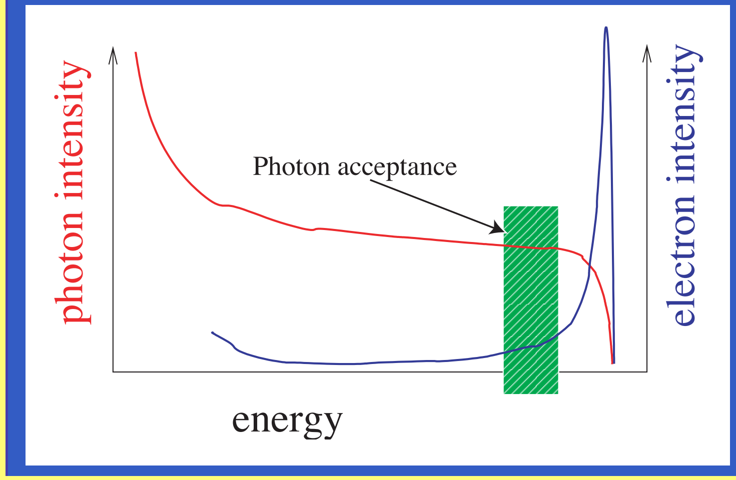
  $\theta_{\gamma}^{CMS} = 140^{\circ}$ corresponding to $-t = 6.4$ (GeV/c)^2
- Provide an experimental test of the RCS reaction mechanism: does the photon interact with a constituent or a current quark?
- Provide an additional test for hadron helicity conservation and pQCD

Experimental Layout

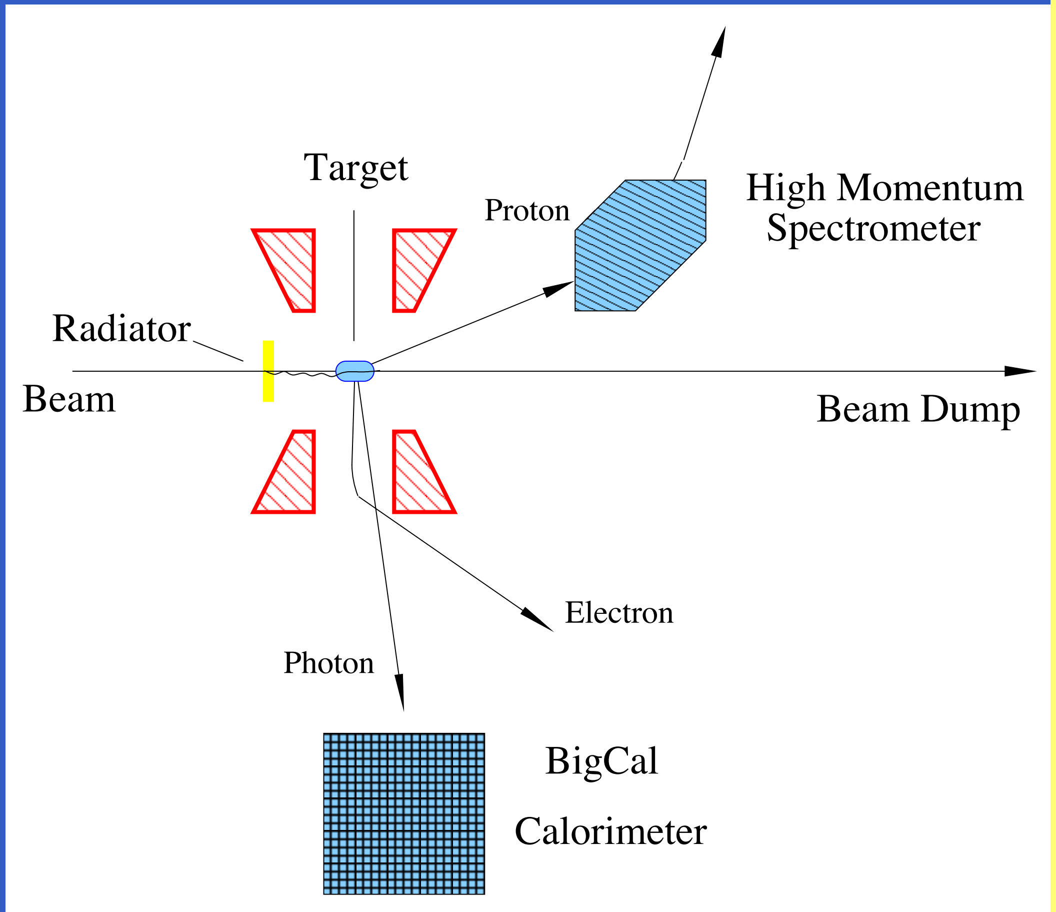
Kinematic Range

$E_\gamma = 4.3$ GeV, $s = 9$ GeV^2
$\theta^{cms} = 70°, 140°$

- mixed $e - \gamma$ beam
  - $\rightarrow$ $e - p/RCS$ discrimination needed
  - $\rightarrow$ control of backgrounds
- good angular resolution
- Polarized target



Require HMS trigger only



Kinematics

kin. P#	t $(\mathrm{GeV}/c)^2$	θ_γ^{lab} degree	θ_γ^{cm} degree	θ_p^{lab} degree	E_γ^{lab} GeV	p_p GeV/c	L m
P1	-2.4	25	70	39	3.00	2.02	7.0
P2	-6.4	82	140	12	0.87	4.25	2.5

kin. P#	θ_γ^{lab} degree	t $(\mathrm{GeV}/c)^2$	θ_γ^{cm} degree	$\frac{d\Omega_\gamma}{d\Omega_p}$	D	N_{RCS} total	ΔA_{LL}
P1	25	-2.4	70	0.58	1.6	1850	**0.05**
P2	82	-6.4	140	24.5	5.5	3250	**0.07**

kin. P#	θ_V^e degree	θ_V^p degree	HMS degree	p(proton) GeV/c	θ^{rms} mrad
1	1.7	4.1	39	2.02	1.75
2	15.4	0.6	12	4.25	0.83

PAC 28 Recommendation

Merely due to lack of available beam time, the PAC recommends that only the kinematic point in the backward hemisphere be measured.
Approved with A^{-} rating for 14 days.

Not scheduled because of QWeak

Pure Photon Beam