Review of solid polarized targets

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~~Review~~ Update of solid polarized targets

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Jefferson Lab

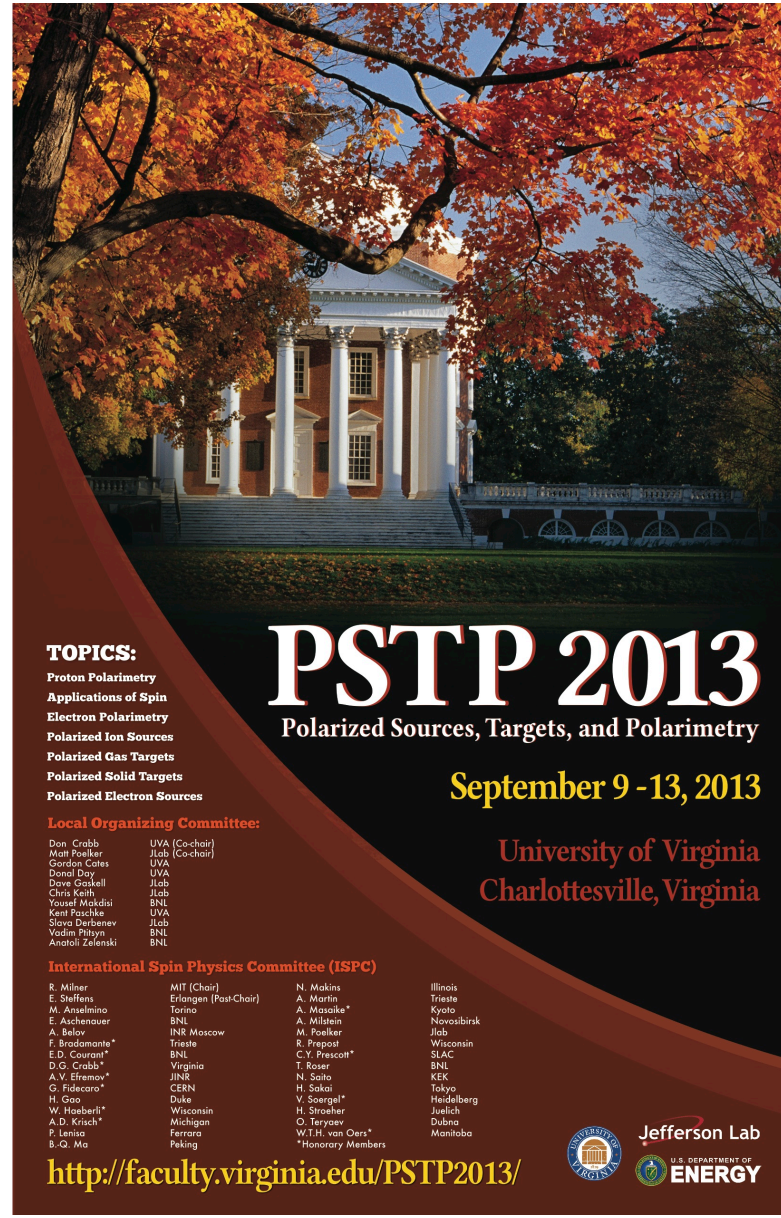
Outline

- Highlights of Solid Targets at PSTP2013
- Highlights of Tensor Workshop at JLab
- Future target activities, primarily in the US

PSTP 2013
Charlottesville VA
Sept. 9-13, 2013

Three sessions (~ one dozen speakers) dedicated to polarized solid targets
http://faculty.virginia.edu/PSTP2013/

Proceedings are published online
http://pos.sissa.it/cgi-bin/reader/conf.cgi?confid=182



Physics of Polarized Targets
– Tapio Niinikoski, ex-CERN

PSTP2013
Charlottesville, VA
http://pos.sissa.it/cgi-bin/reader/conf.cgi?confid=182

Physics of Polarized Targets

Presented in PSTP2013, Charlottesville, USA
with tributes to the work of Michel Borghini and Franz Lehar

1. Introduction to spins in solids at low temperature
   - tributes to the work of Michel Borghini and Franz Lehar
   - quantum statistics and spin temperature
   - saturation and relaxation in magnetic resonance
2. Equal spin temperature model for DNP
3. Magnetic resonance and relaxation at low temperatures
4. Radiolytic paramagnetic impurities usable for DNP
5. Weak saturation during NMR polarization measurement
6. Refrigeration using quantum fluids

Neutron spin filter based on dynamically polarized protons using photo-excited triplet states
— Tim Eichhorn, PSI

PSTP2013
Charlottesville, VA
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The photo-excited triplet state as source of paramagnetism

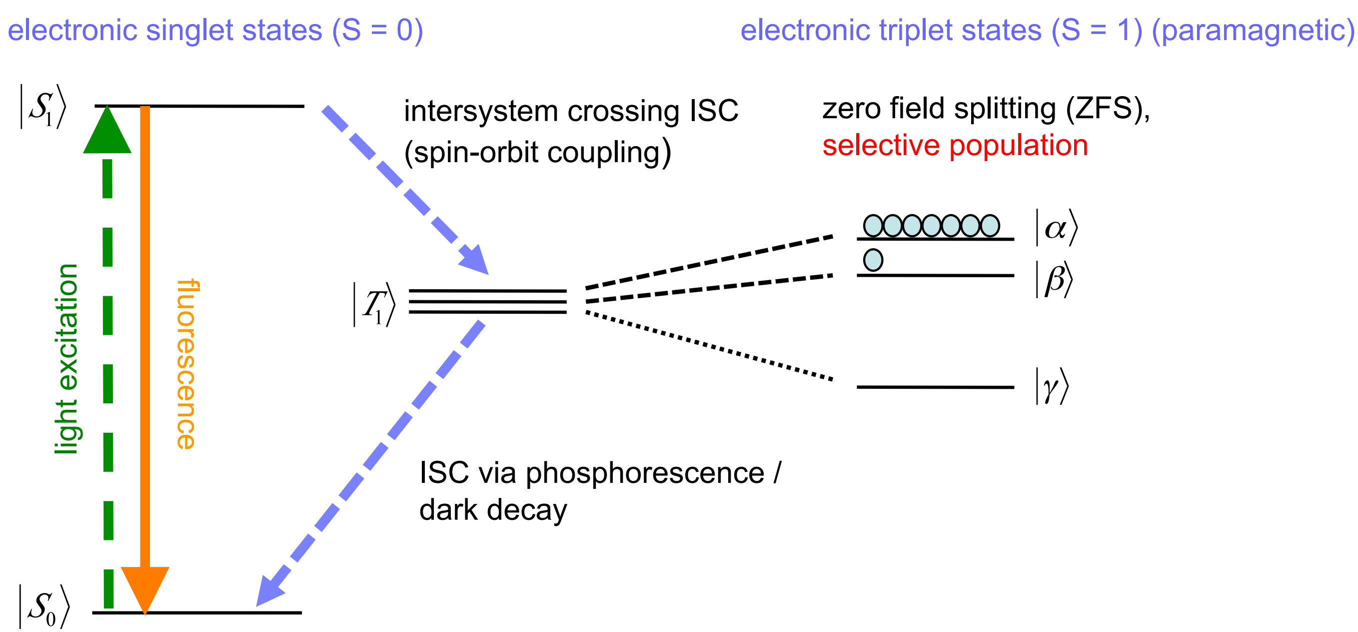

Photo-excited triplet states of pentacene replace paramagnetic radicals polarized at low temperature, high field.

Neutron spin filter based on dynamically polarized protons using photo-excited triplet states
– Tim Eichhorn, PSI

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Charlottesville, VA
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1st setup on neutron beamline BOA

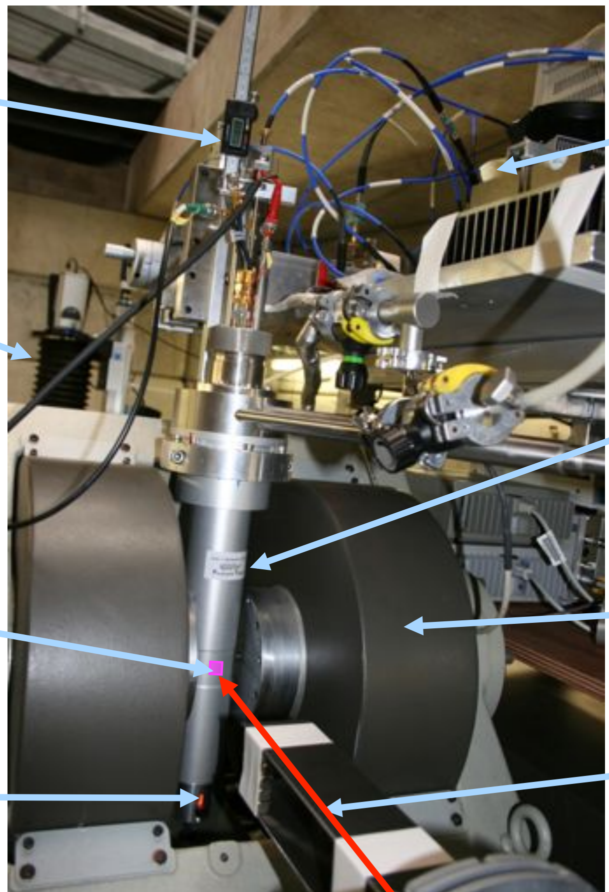
Caliper for sample positioning

Neutron detector

Target Crystal

P ~ 50%

Fiber coupled laser light @ 600 nm



pulse ESR / DNP system 9 GHz

Pulse NMR system

Cryostat T ~ 100 K

Magnet, 0.3 T (max 0.6 T)

Neutron beam

Double Polarized Measurements with Frozen Spin Target at MAMI
– Andreas Thomas, Mainz

PSTP2013
Charlottesville, VA
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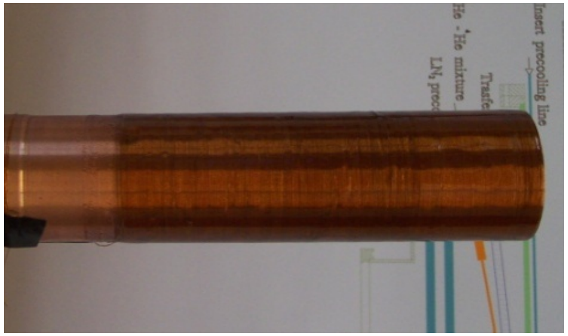
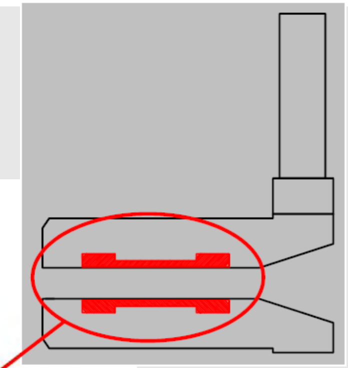


DNP at 200mK and 2.5T with 70GHz microwaves.
Frozen spin target (25mKelvin, 0.6T).
Secondary particles punch through holding coil.
Longitudinal and transverse holding coils.

P_{proton} ~ 85%
$P_{deuteron}$ ~ 75%
τ~1000 ….2000 hours

Internal Magnet Development

Idea: reduce the magnetic volume of the large external pol. magnet to the size/dimensions of the internal holding coil



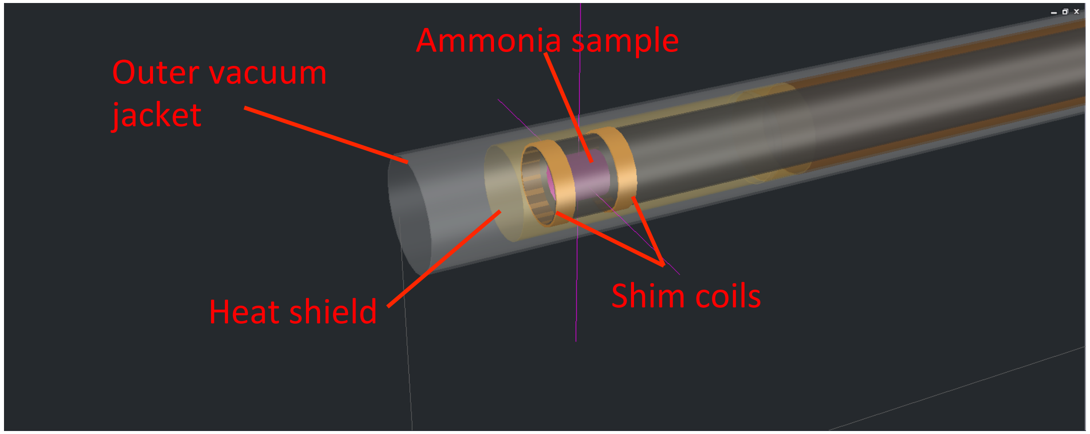
- field strength: ~ 2.5 T
- as thin as possible (minimized absorption) ~ 2 mm
- homogeneity dB/B ≤ 10^{-3}

$$B = \mu_0 \cdot N \cdot \tfrac{I}{l}$$

NC: ampere-turn : N·I ~ 300 kA → superconducting wire necessary
High current operation (~100 A) in a dilution refrigerator

Longitudinally Polarized Target for CLAS12 at JLab

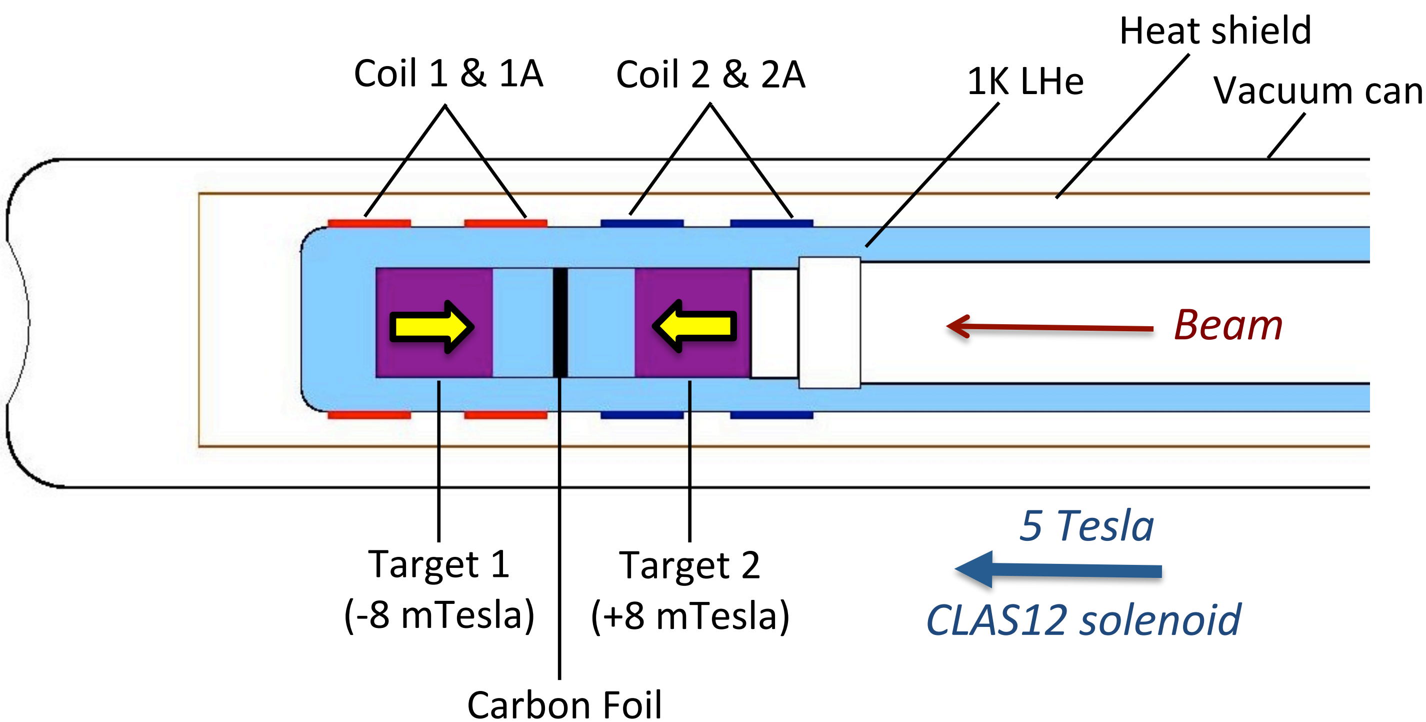
We intend to use internal superconducting *shim* coils to ensure the 5 T polarizing magnet (i.e. the CLAS12 solenoid) has $\Delta B/B \leq 10^{-4}$



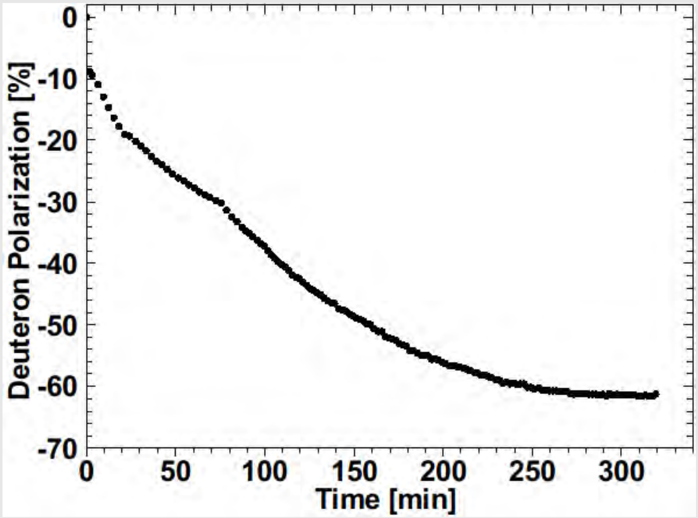
Conceptual design of superconducting shim coils for CLAS12 polarized target

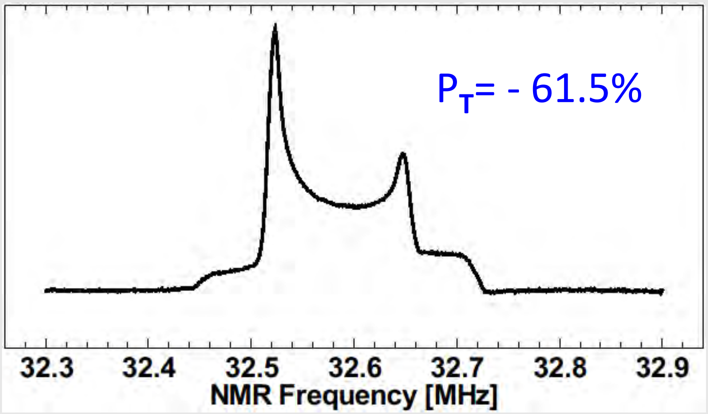
Longitudinally Polarized Target for CLAS12 at JLab

We also hope to use internal superconducting shim coils to adjust the polarizing field for multiple target samples, allowing independent polarizations with one microwave source



Polarization of FinlandD36-doped C_8D_8





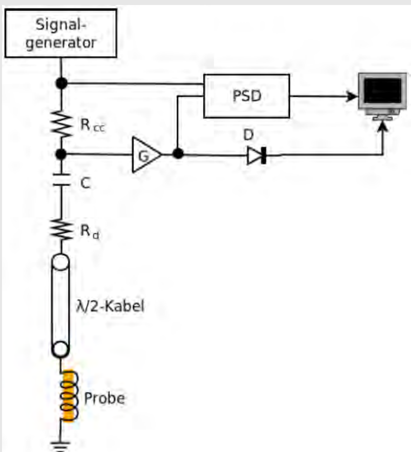
Sample	MW (GHz)	d-pola. (%)	$T_{1,d}$ (min)	$T_{build-up}$ (min)
d-PS(98%-d)	139.723	+56.1	863	100
+Finland D36	139.825	-61.5		

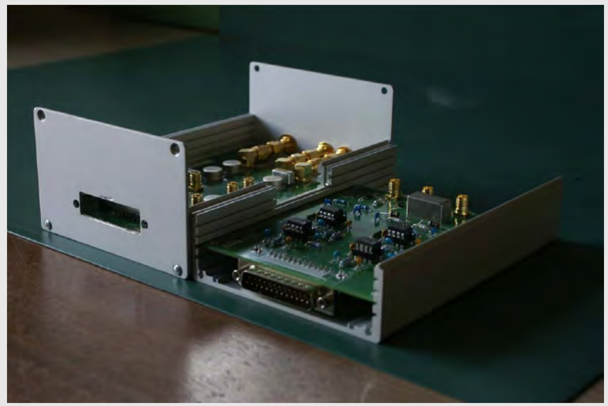
$f_{d,NMR}$=32.6MHz

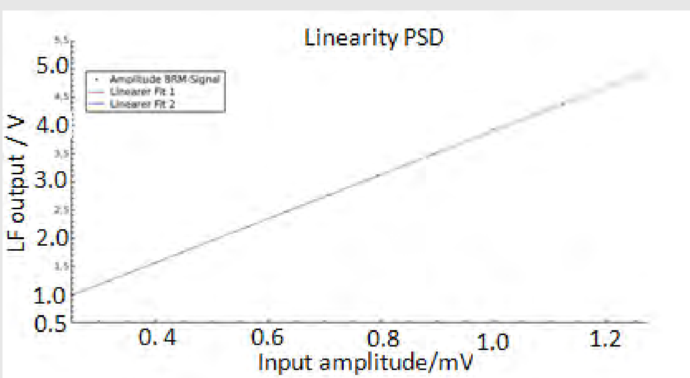
Temperature = 400 mK and magnetic field = 5 T

Wang Li | NIMA 729 (2013) 36–40

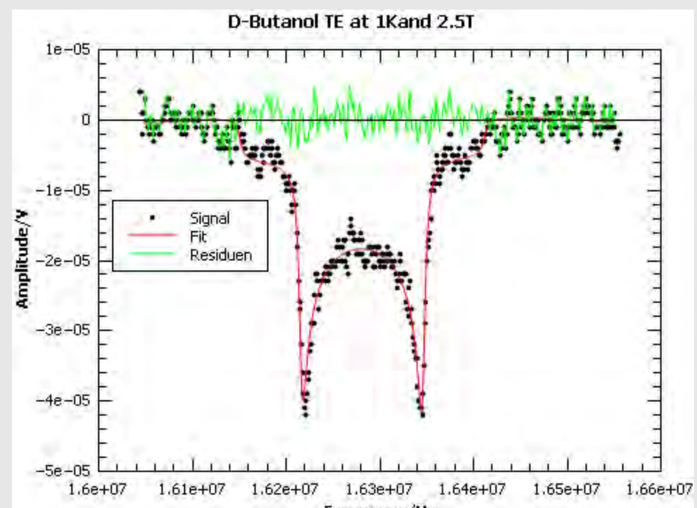
Bochum NMR Box







H. Vondracek | Master Thesis (2013) Bochum



Recent research activities and results of the Bochum/Bonn Polarized Target Group – Gerhard Reicherz, Bochum

PSTP2013
Charlottesville, VA
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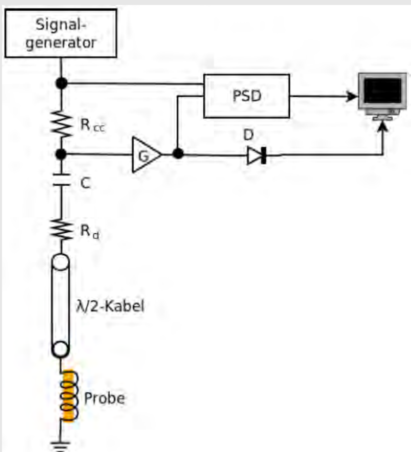
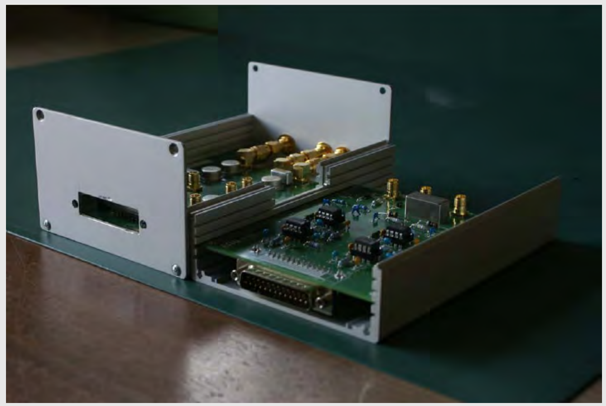
Bochum NMR Box

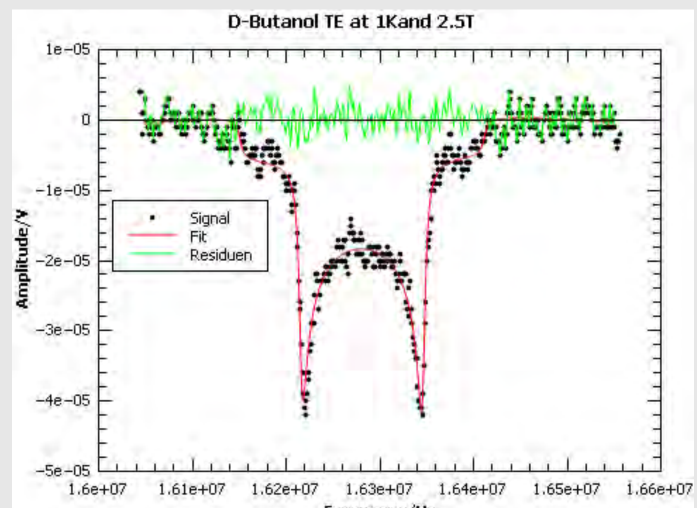




New NMR Systems also being developed at

- Los Alamos
- PSI

3) Bochum



Boosting Deuteron Polarization in HD Targets – Xiangdong Wei, JLab

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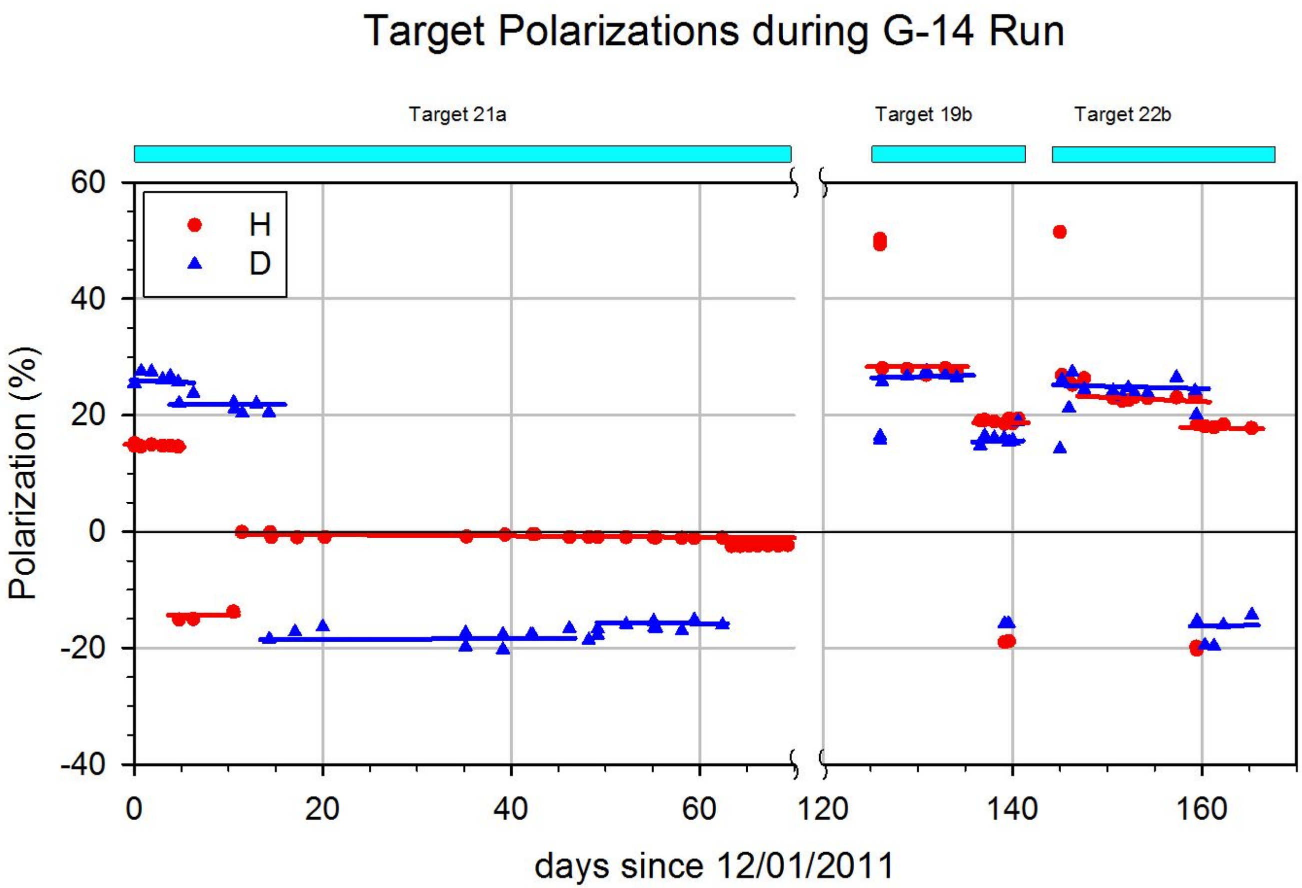

HDice targets used in frozen spin mode during E06-101 (G-14) photon run.

Relaxation times were longer than a year at B=0.9T and T<100mK.

Electrons on the HDice Target: Results and Analysis of Test Runs at JLab in 2012
— Mike Lowry, JLab

PSTP2013
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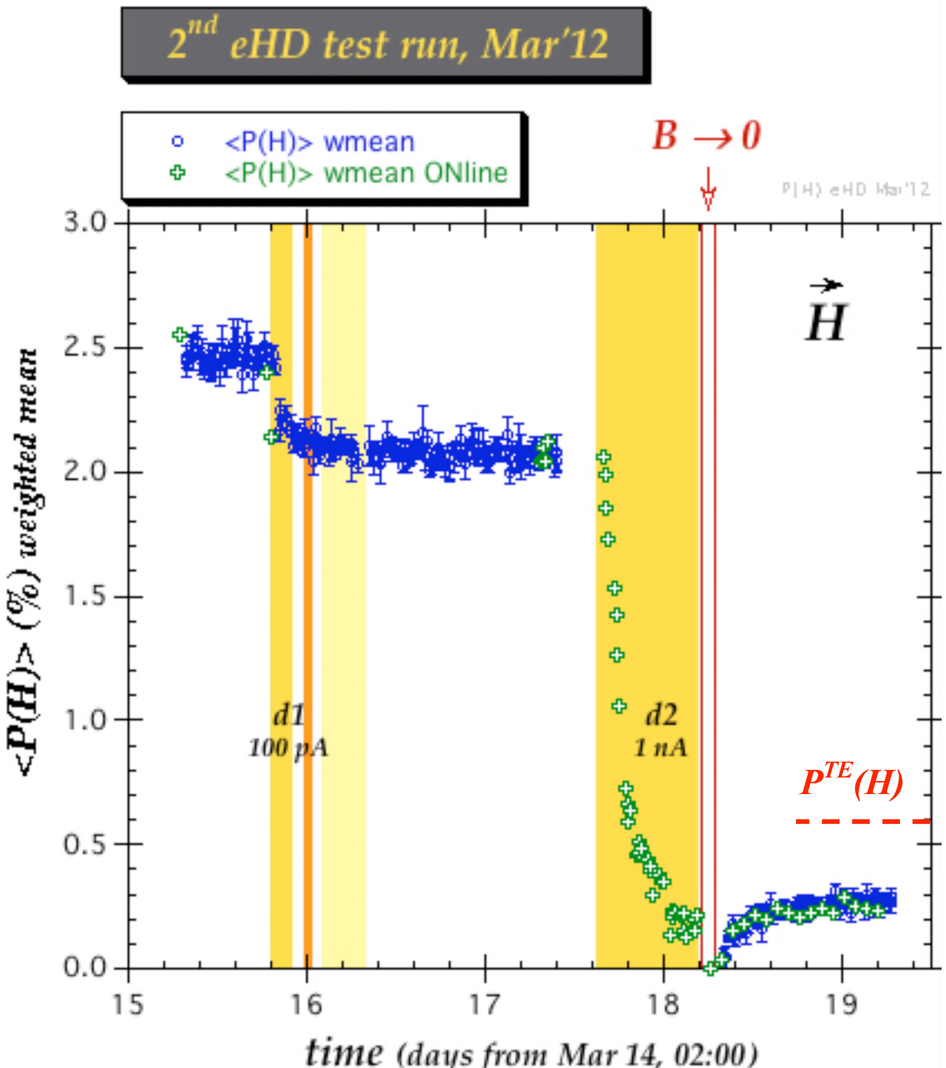
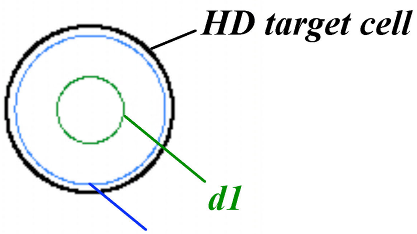


raster profiles:



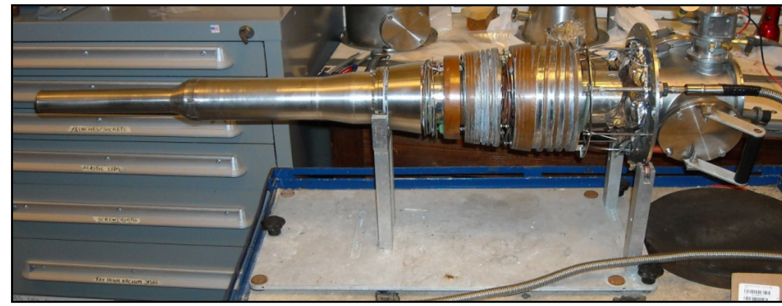
- Directed at during-irradiation effects
- Confirm NMR RF screening
- Polarization decay T1 ~ 3-6 hr
- Re-growth after B zero'ing shows mechanism still active after beam gone but freeze out after 6-12 hr

P(H) during the Mar'12 eHD test, with 0.3 tesla holding field during exposures. Shaded vertical bands indicate beam-on periods.

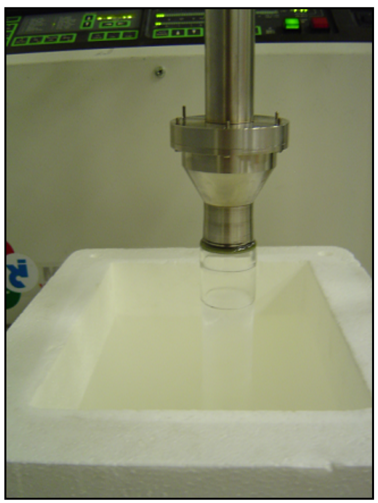
HIGS Frozen Spin Target System (HIFROST)
– Pil-Neyo Seo, UVa/TUNL

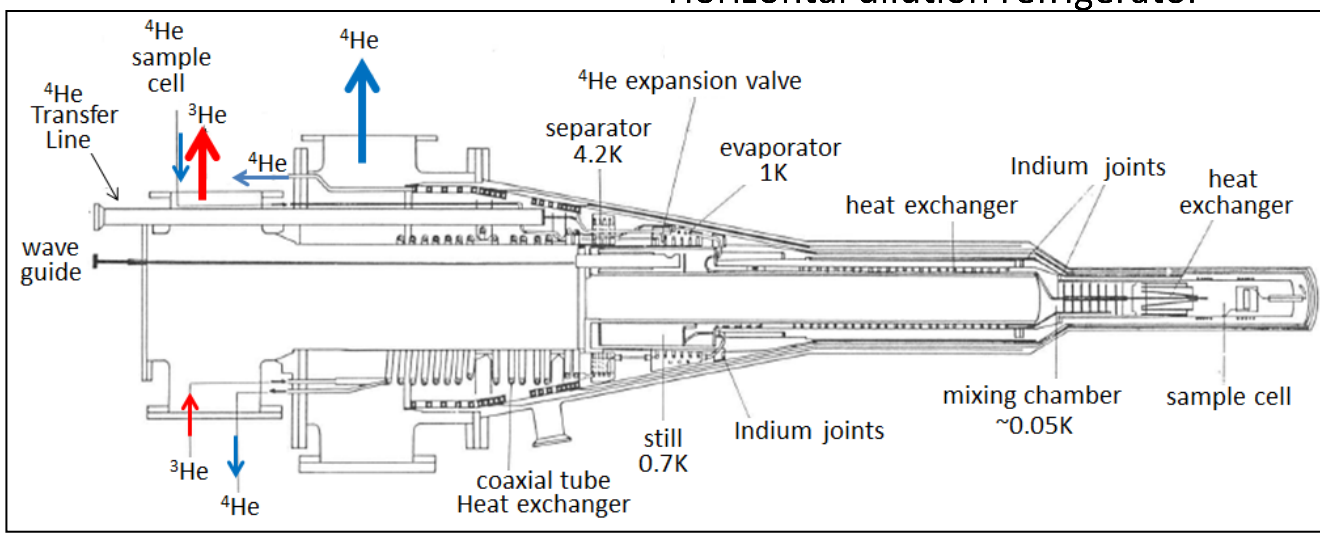
PSTP2013
Charlottesville, VA
http://pos.sissa.it/cgi-bin/reader/conf.cgi?confid=182

new mixing chamber



Horizontal dilution refrigerator



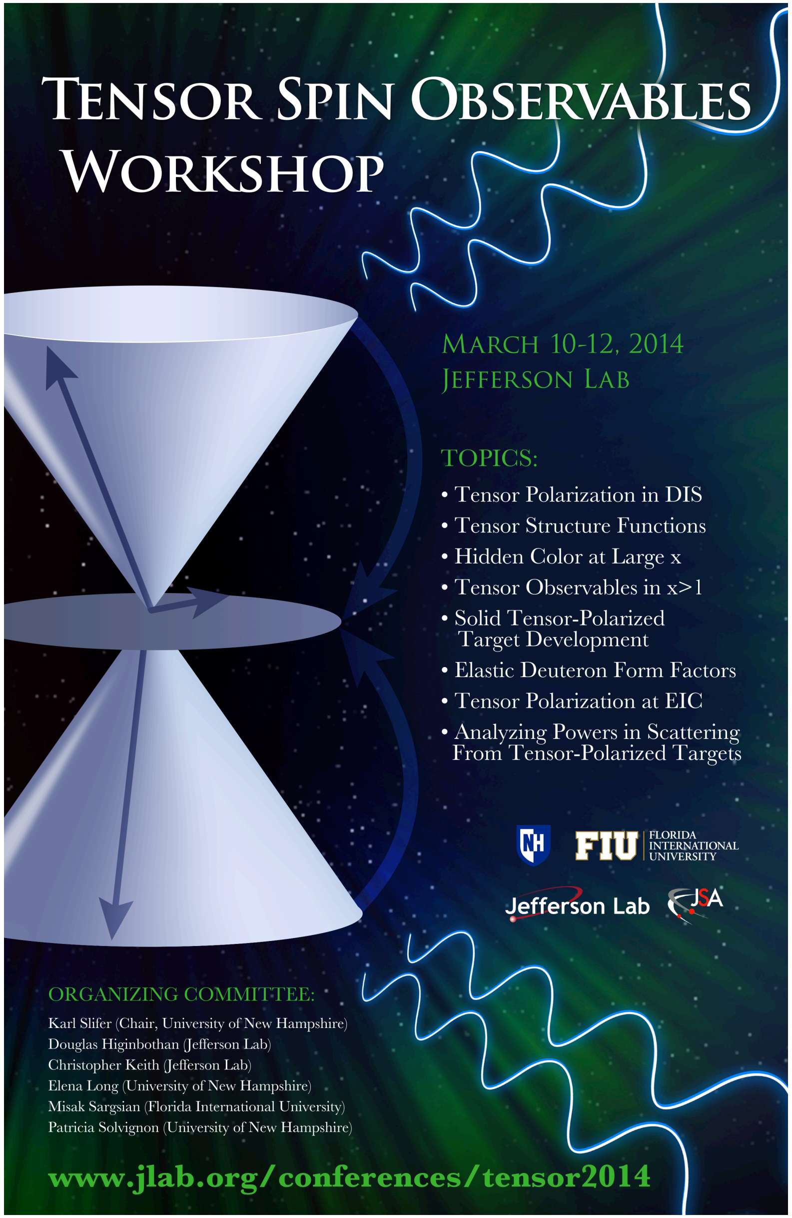


Tensor Spin Observables
Jefferson Lab
March 10-12, 2014

A three day workshop with approximately 40 participants and two dozen speakers.
http://www.jlab.org/conferences/tensor2014/

One day devoted to tensor-polarized deuteron targets.

Proceedings will be published online.



The Deuteron Polarized Tensor Structure Function b_1
— Karl Slifer, UNH

Tensor Spin Observables Workshop
Jefferson Lab
http://www.jlab.org/conferences/tensor2014/

b_1 Structure Function

$$b_1(x) = \frac{q^0(x) - q^1(x)}{2}$$

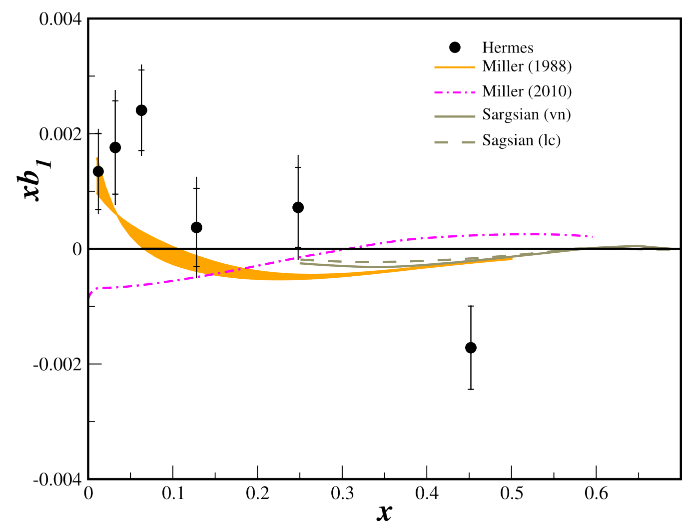
q^0 : Probability to scatter from a quark (any flavor) carrying momentum fraction x while the *Deuteron* is in state m=0

q^1 : Probability to scatter from a quark (any flavor) carrying momentum fraction x while the *Deuteron* is in state |m| = 1

<u>Nice mix of nuclear and quark physics</u>

measured in DIS (so probing quarks), but depends solely on the deuteron spin state

Investigate nuclear effects at the level of partons!



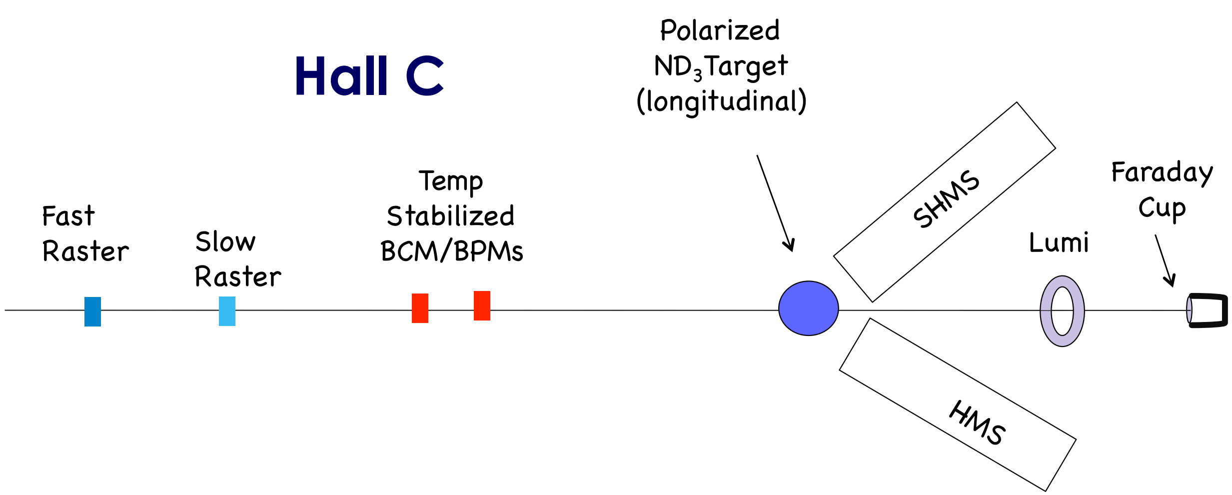
All conventional models predict small or vanishing values of b_1 in contrast to the HERMES data

The Deuteron Polarized Tensor Structure Function b_1
— *Karl Slifer, UNH*

Tensor Spin Observables Workshop
Jefferson Lab
http://www.jlab.org/conferences/tensor2014/

Jefferson Lab E12-13-011 (conditionally approved)

E. Long, K. Slifer, P. Solvignon (U. New Hampshire) J.P. Chen (JLab)
O. Rondon, D. Keller (U. Virginia) N. Kalantarians (Hampton U.)



$$b_1 = -\frac{3}{2} F_1^d A_{ZZ}$$

$$A_{ZZ} = \frac{2}{f P_{ZZ}} \frac{\sigma_T - \sigma_0}{\sigma_0} = \frac{2}{f P_{ZZ}} \left(\frac{N_T}{N_0} - 1 \right)$$

σ_T : tensor pol. cross section
σ_0 : unpolarized. cross section
P_{ZZ} : tensor polarization
f : dilution factor

Unpolarized electron beam: 115 nA
Luminosity: 10^{35} $s^{-1}cm^{-2}$
Tensor polarized deuteron target: 30%

Tensor Polarization of the Deuteron

The deuteron is a spin-1 nucleus with three magnetic substates,
m = +1, 0, and -1

Three quantities are required to fully describe an ensemble of the spins

Vector polarization $P_Z = \left(N_{+1} - N_{-1}\right)$

Tensor polarization $P_{ZZ} = (N_{+1} - N_0) - (N_0 - N_{-1}) = \left(1 - 3N_0\right)$

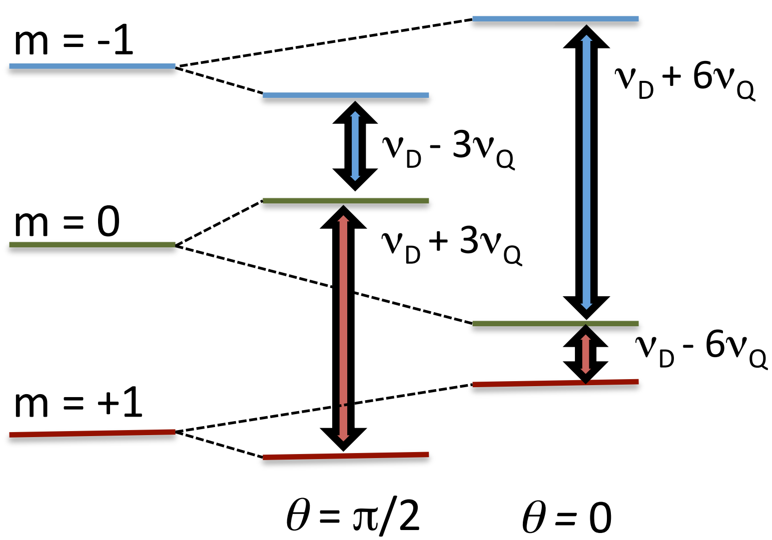
Normalization $\left(N_{+1} + N_0 + N_{-1}\right) = 1$

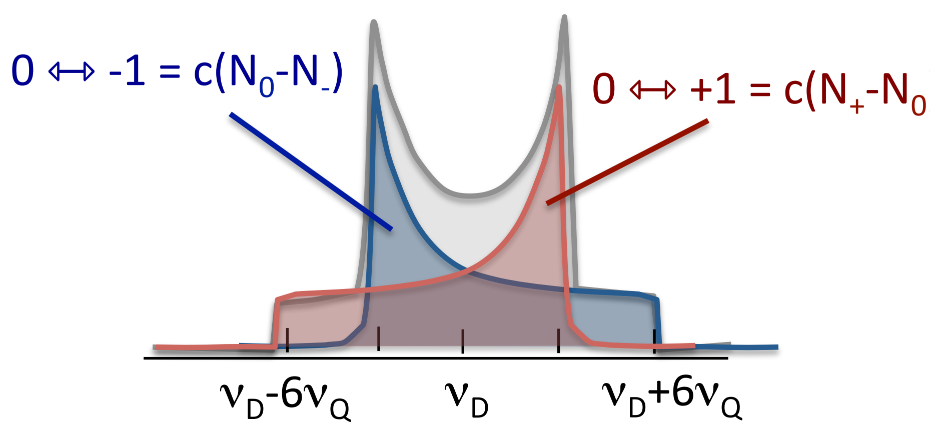
Vast majority of experiments using solid, polarized deuteron targets focus on the vector polarization (exceptions at Bonn and TRIUMF, for example)

- Deuteron also has an electric quadrupole moment, eq_D = 2.86 e·fm^2
- eq_D interacts with electric field gradients within the lattice producing two, overlapping NMR lines (Pake doublet)

$$E_m = -h\nu_D m + h\nu_Q\left[3\cos^2\theta - 1\right]\left[3m^2 - I(I+1)\right]$$

ν_D = deut. Larmor freq.
ν_Q = ND_3 quadrupole freq.
eq = deuteron quadrupole moment
θ = angle between elec. & mag. fields





Spin Temperature Hypothesis: Zeeman levels are populated according to the Boltzmann relation with a (positive or negative) *spin temperature* T_s

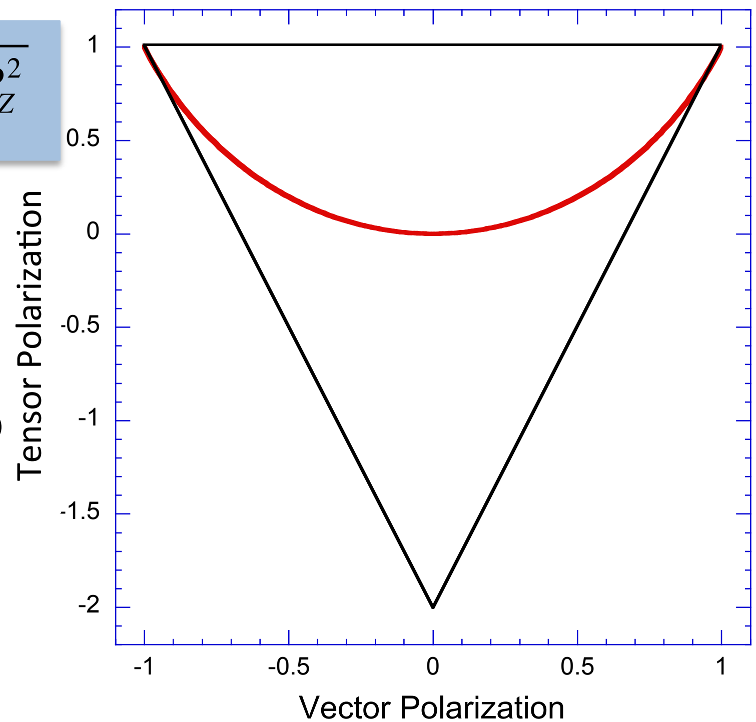
$$P_Z = \frac{4\tanh\left(\frac{\mu B}{2kT_s}\right)}{3+\tanh^2\left(\frac{\mu B}{2kT_s}\right)}$$

$$P_{ZZ} = \frac{4\tanh^2\left(\frac{\mu B}{2kT_s}\right)}{3+\tanh^2\left(\frac{\mu B}{2kT_s}\right)}$$

$$P_{ZZ} = 2-\sqrt{4-3P_Z^2}$$

- Mutually allowed values for the vector and tensor polarizations are generally restricted to be on or within the black triangle, but…

- *Spin Temperature hypothesis* restricts the polarizations to only those values on the red parabola. Note: no negative P_{ZZ} values!



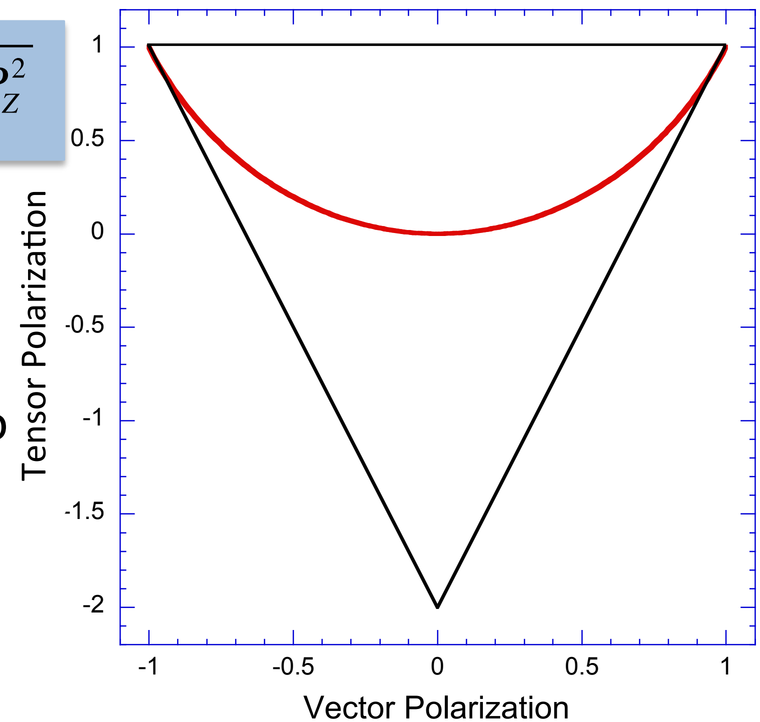
Spin Temperature Hypothesis: Zeeman levels are populated according to the Boltzmann relation with a (positive or negative) *spin temperature* T_s

Some Spin Temperature Values

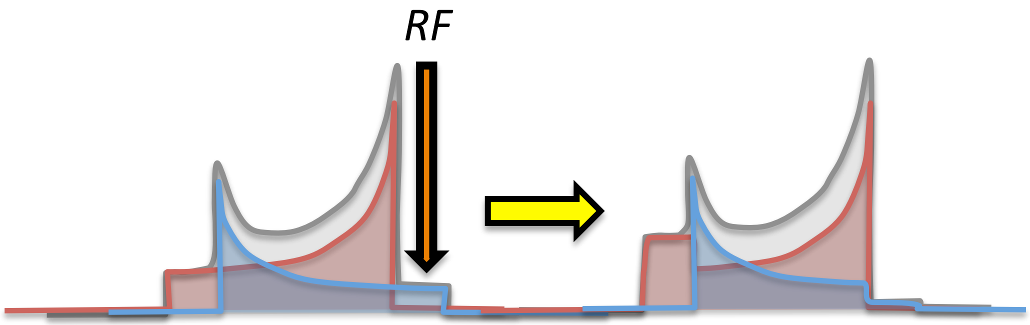
Pz	Pzz
0%	0%
10%	1%
20%	3%
30%	7%
40%	12%
50%	20%
60%	29% ⇐ b_1 goal
70%	41%
80%	56%
90%	75%
100%	100%

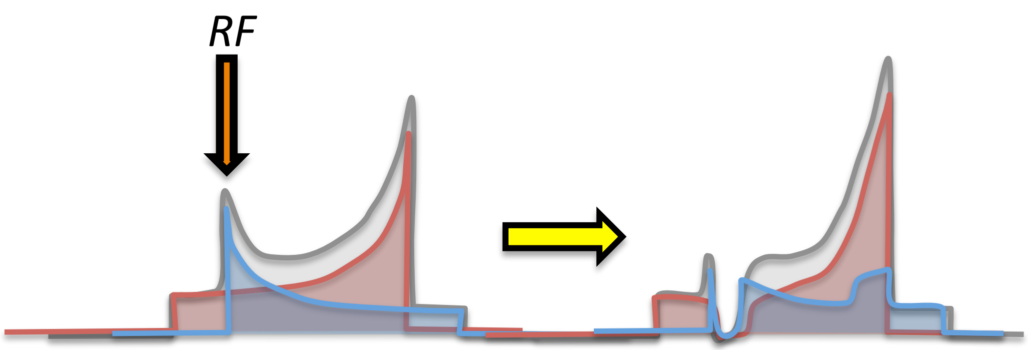
P … $2-\sqrt{4-3P_Z^2}$

- … tor and … estricted to … ut…
- … ts the … the red parabola. Note: no negative P_{ZZ} values!



RF saturation (hole burning) can be used to decrease the *m=0* population and increase the tensor polarization. The effect can be significant, but not tremendous.





Example: Burning a pedestal*

$P_Z = 50.0\%$ $P_{ZZ} = 19.7\%$

$P'_Z = 48.6\%$ $P'_{ZZ} = 23.9\%$

$\Delta P_Z = -1.4\%$ $\Delta P_{ZZ} = 4.2\%$

Example: Burning a peak*

$P_Z = 50.0\%$ $P_{ZZ} = 19.7\%$

$P'_Z = 45.0\%$ $P'_{ZZ} = 23.2\%$

$\Delta P_Z = -5.0\%$ $\Delta P_{ZZ} = 3.5\%$

*These estimates assume no dipolar broadening of the NMR line, and no spectral diffusion (cross relaxation) through the line.

Tensor Target Polarization at TRIUMF
– Greg Smith, JLab

Tensor Spin Observables Workshop
Jefferson Lab
http://www.jlab.org/conferences/tensor2014/

- Perform 1st expt. ever using a tensor polarized target!
- $\sigma(pol)/\sigma(unpol) = 1 + 1/\sqrt{2}\ p_{zz} T_{20}$, with longitudinal B
  - We thought we were pioneering this back in 1984
    - Knew about some CERN tech notes on pol tgts
      - deBoer etal PL46A, 143 (1974), Ninnikoski, Scheffler, Guckelsberger & Udo NIM137, 415 (1976), Hamada etal NIM189, 561 (1981)
  - No double scattering/recoil polarimeter
  - Fewer systematic errors: msr xsec ratios
  - Develop a large dΩ detection system with lots of θ multiplicity
  - Crucial to insure $|\theta_B - \theta_\pi| < 1^\circ$ to suppress other T_{ij}
    - Used a split counter with field on/off to do this, lasers & mirrors
  - Be damn sure you can msr p_{zz}

Tensor Target Polarization at TRIUMF – Greg Smith, JLab

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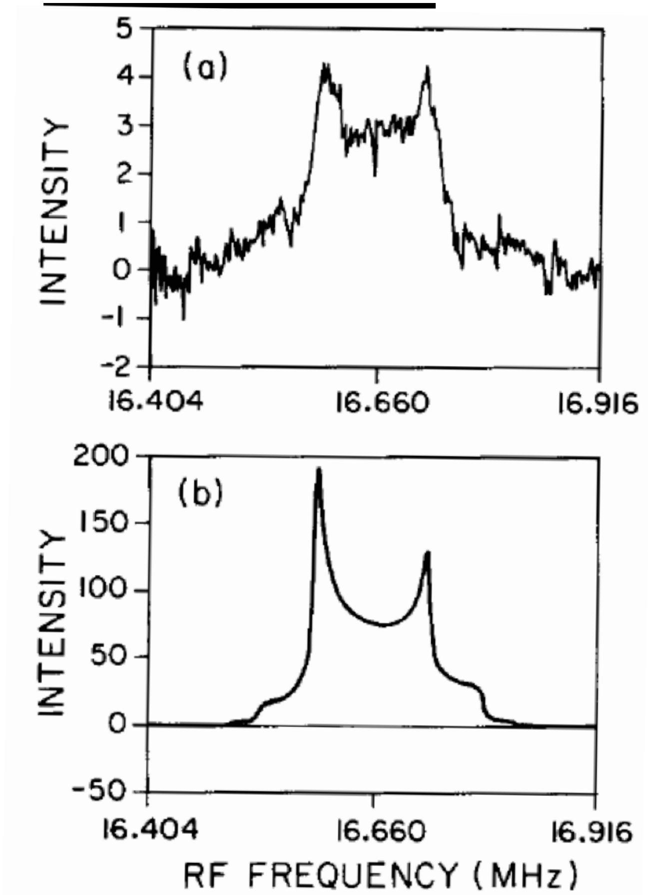
Conditions:



Dilution fridge ~ 120 mK
- s.b. 50 mK!

Longitudinal 2.5 T sc split pair
- $\Delta B/B \sim 10^{-4}$, persistent mode

1 mm φ deuterate butanol beads
- 95% deuterate n-butyl alcohol
- 5% D_2O doped with EHBA (Cr^{V})
- Teflon cell 16x16x5 mm^3

$P_z = 0.333 \pm .015$ $P_{zz} = 0.085 \pm .008$

- 3 techniques used to msr P_{zz}
1. Thermal equilibrium calibration
2. $P_z = (1 - R^2)/(1+R+R^2)$
3. DIRECT MSR of P_{zz} from $T_{20}(90°)$

Future Use of Polarized Solid Targets

- COMPASS (Polarized Drell-Yan)
- MAMI (Compton Scattering)
- FermiLab (Polarized Drell-Yan)

Polarized Solid Targets at 12 GeV JLab

HALL A

(E12-11-108) *SIDIS with a transversely polarized proton target*
(E12-11-108A) *Target single spin asymmetries using the SoLID spectrometer*

HALL B

(E12-06-109) *Longitudinal spin structure of the nucleon*
(E12-06-119) *DVCS with CLAS at 12 GeV*
(E12-07-107) *Spin-orbit correlations with a longitudinally polarized target*
(E12-09-009) *Spin-orbit correlations in kaon electroproduction in DIS*
(E12-12-001) *EMC effect in spin structure functions*
(C12-11-111) *SIDIS on a transversely polarized target*
(C12-12-009) *Di-hadron production in SIDIS on a transversely polarized target*
(C12-12-010) *DVCS on a transversely polarized target in CLAS12*

HALL C

(E12-14-006) *Helicity correlations in wide-angle Compton scattering*
(C12-13-011) *The deuteron tensor structure function b1*
(LOI-12-14-001) *Search for exotic gluonic states in the nucleus*
(LOI-12-14-002) *Tensor asymmetry Azz in the x<1 region*

SUMMARY

- No *earth-shattering* breakthroughs in recent years, but there has been steady progress and continuing R&D efforts are in progress
- Demand for polarized targets are at an all time high, especially at JLab
- We need more people (especially *young* people) to meet this demand