University of New Hampshire

UNH target group updates

Marie Boër, on behalf of UNH target group

Hall C collaboration meeting, Jan. 29, 2020

Outline

1) Tensor polarization

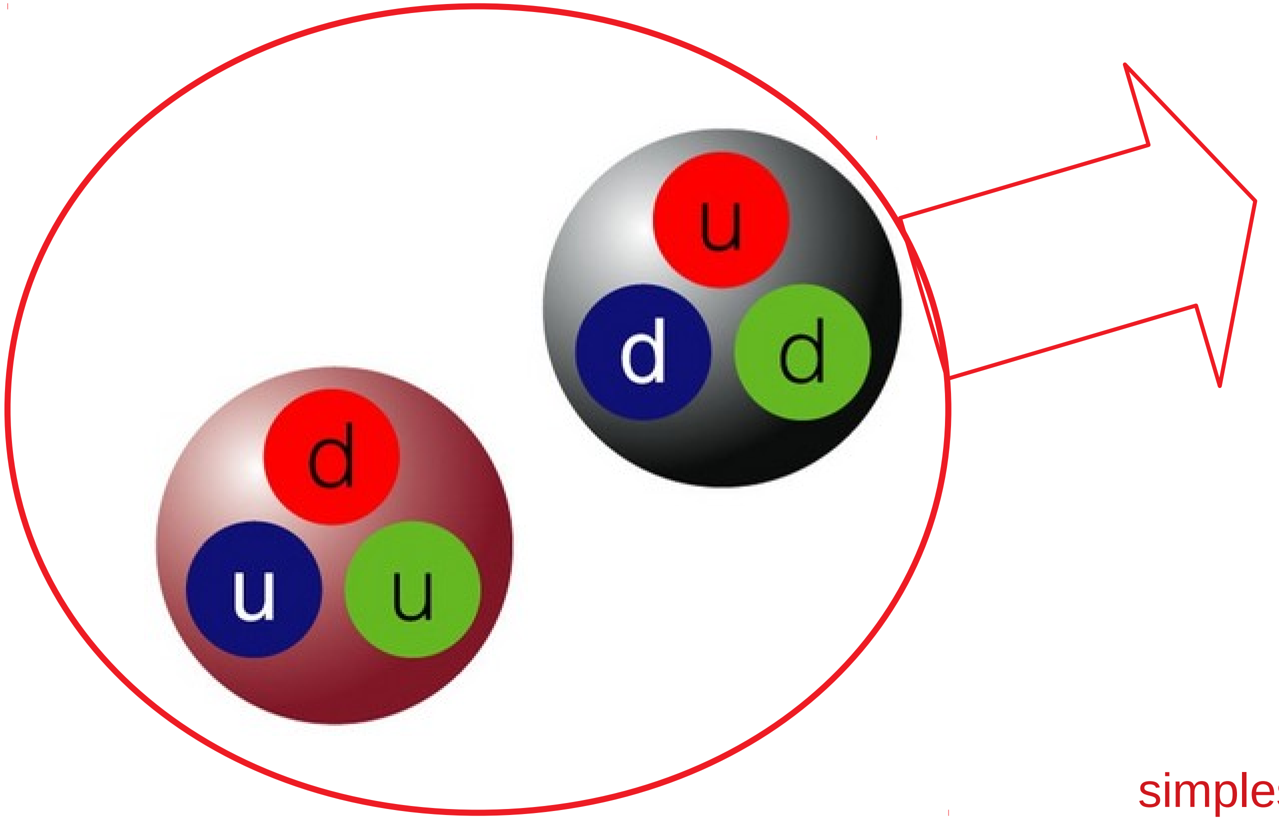
2) Tensor physics program in Hall C: b_1 and A_{zz} experiments

3) UNH target and polarization technique

4) Results from December 2019 cooldown

Note:
many figures or slides stolen or inspired from other people of the group (not credited all the time)

Goal: polarized deuteron structure



simplest QCD bound state

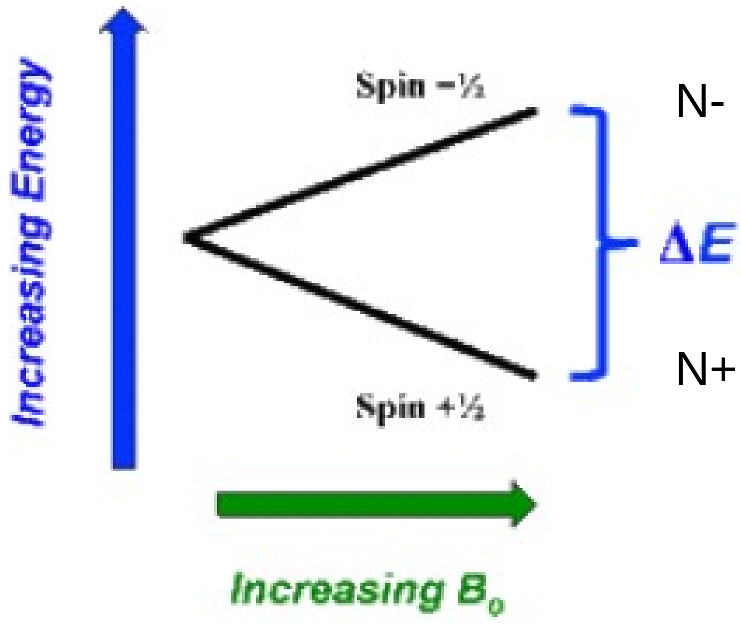
- shadowing effects?

- pion exchanges?

- exotic 6 quark state?

Vector and Tensor polarization

spin 1/2 system splitting in magnetic field (Zeeman effect)



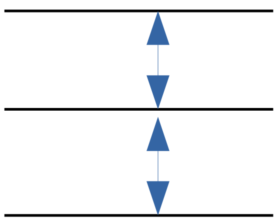
N-

N+

vector polarization:

$$P_z = \frac{N_+ - N_-}{N_+ + N_-}$$

spin 1 deuterium: 3 sub-levels



-1 N-

0 N_0

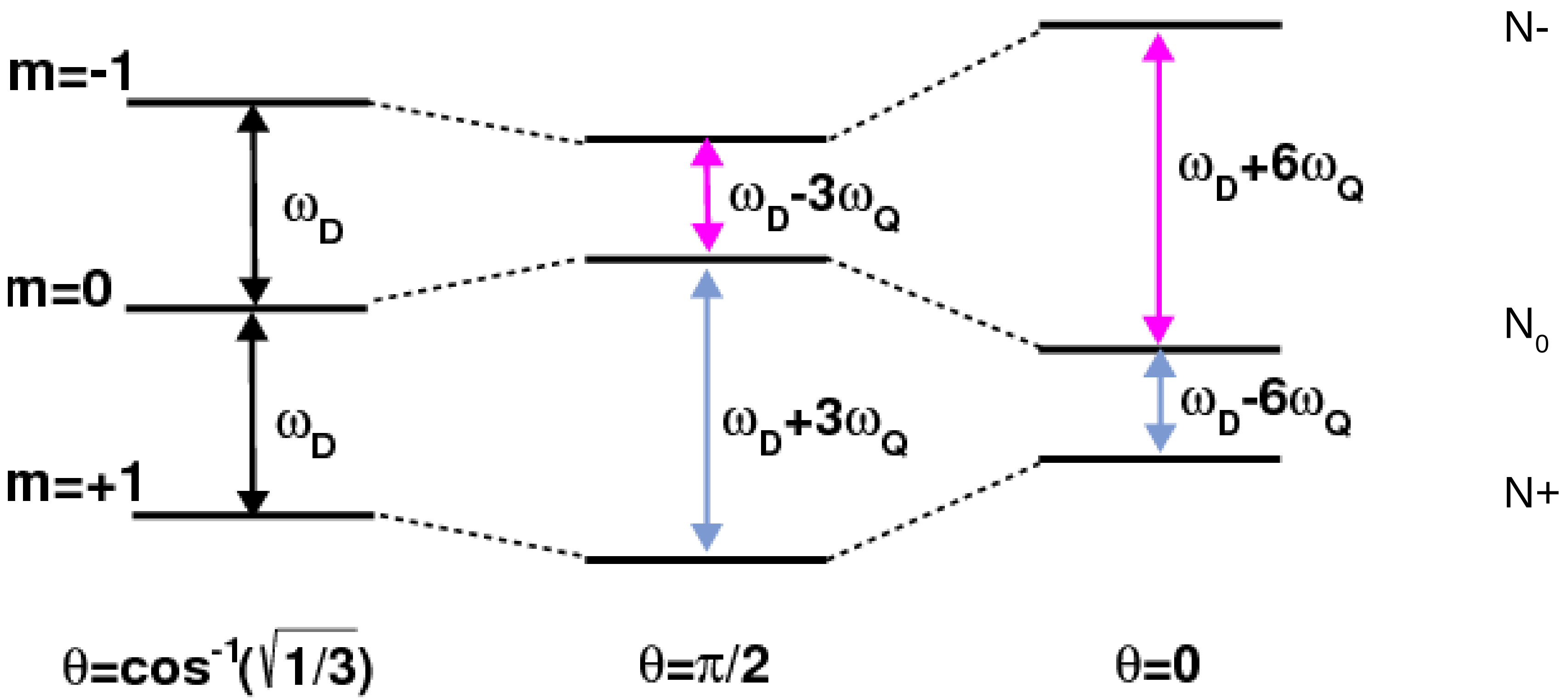
1 N+

Tensor polarization:

$$P_{zz} = \frac{(N_+ - N_0) - (N_0 - N_-)}{N_+ + N_0 + N_-} = \frac{(N_+ + N_-) - 2N_0}{N_+ + N_0 + N_-}$$

Vector and Tensor polarization

Deuterium level splitting from Zeeman effect and quadrupole interaction
[Keller, D. Eur.Phys.J. A53 (2017) no.7]

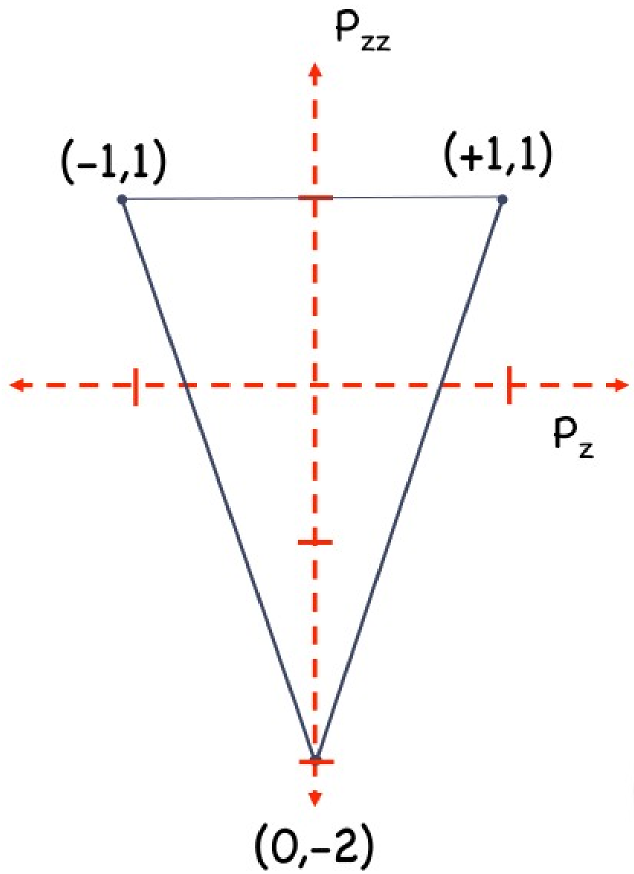


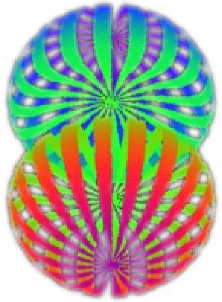
asymmetric levels due to Zeeman + quadrupole effects

$$P_{zz} = \frac{(N_+ - N_0) - (N_0 - N_-)}{N_+ + N_0 + N_-} = \frac{(N_+ + N_-) - 2N_0}{N_+ + N_0 + N_-}$$

Vector and Tensor polarization

spin 1 deuteron polarization:

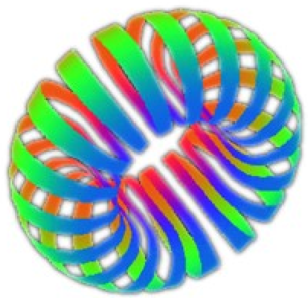




$P_{zz} = +1$

Pure Vector Polarization

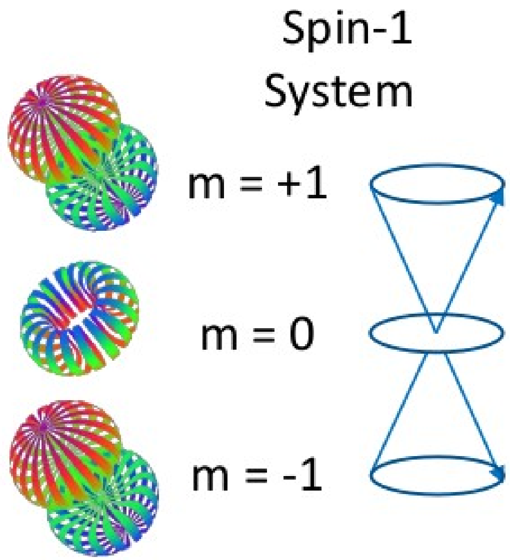
m=0 level depopulated



$P_{zz} = -2$

Pure Tensor Polarization

All spins in the m=0 level

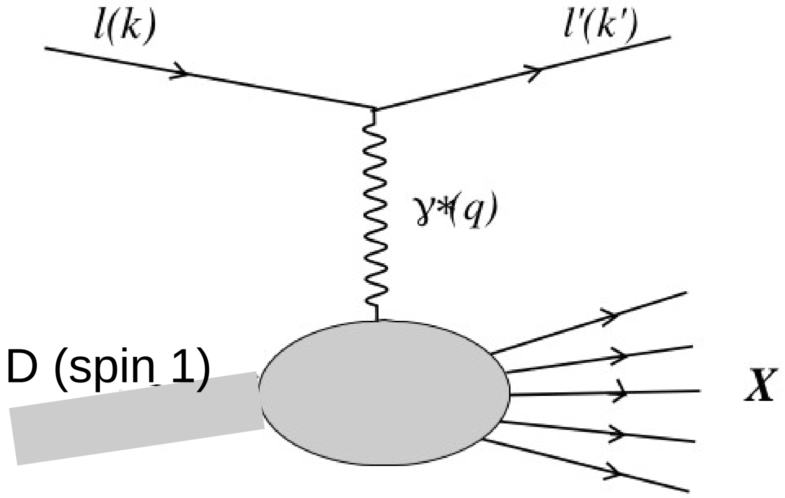


$$P_{zz} = \frac{(N_+ - N_0) - (N_0 - N_-)}{N_+ + N_0 + N_-} = \frac{(N_+ + N_-) - 2N_0}{N_+ + N_0 + N_-}$$

At thermal equilibrium (+ approximations), relation between vector & tensor polar.: $P_{zz} = 2 - \sqrt{4 - 3P_z^2}$

Tensor physics program: Motivations for b_1 experiment

b_1 experiment E12-13-011: The deuteron tensor structure function b_1 with polarized deuterium DIS



$$W_{\mu\nu} = -F_1 g_{\mu\nu} + F_2 \frac{P_\mu P\nu}{\nu}$$

Unpolarized Scattering

$$+i\frac{g_1}{\nu}\epsilon_{\mu\nu\lambda\sigma}q^\lambda s^\sigma + i\frac{g_2}{\nu^2}\epsilon_{\mu\nu\lambda\sigma}q^\lambda(p\cdot qs^\sigma - s\cdot qp^\sigma)$$

Vector Polarization

beam + target "vector" polarized

$$-b_1 r_{\mu\nu} + \frac{1}{6}b_2(s_{\mu\nu} + t_{\mu\nu} + u_{\mu\nu})$$

$$+\frac{1}{2}b_3(s_{\mu\nu} - u_{\mu\nu}) + \frac{1}{2}b_4(s_{\mu\nu} - t_{\mu\nu})$$

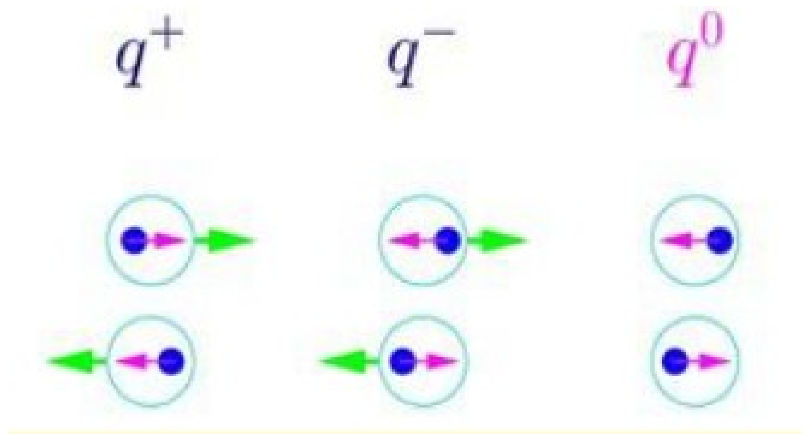
Tensor Polarization

unpolarized beam, "tensor" target

4 additional structure functions compared to spin 1/2

Tensor physics program: Motivations for b_1 experiment

probabilistic interpretations



$q^{\pm}$: the deuteron is in state m=-1 or +1
probability to struck a parton carrying a longitudinal momentum fraction x,
and having helicity aligned/antialigned with respect to the deuteron spin

q°: the deuteron is in state m=0,
probability to struck a parton of mom. fraction x, when D is in m=0

F_1:	proton: $\frac{1}{2}\,\Sigma e^2(q^+ + q^-)$	deuteron: $\frac{1}{3}\,\Sigma\, e^2\,(q^+ + q^- + q^0)$
g_1:	proton: $\frac{1}{2}\,\Sigma e^2(q^+ - q^-)$	deuteron: $\frac{1}{2}\,\Sigma\, e^2\,(q^+ - q^-)$
b_1:		deuteron: $\frac{1}{3}\,\Sigma\, e^2\,(-q^+ - q^- + 2q^0)$

$F_2 = 2x\,(1+R)\,F_1/\,(1+\gamma^2)$
$b_2 = 2x\,(1+R)\,b_1/\,(1+\gamma^2)$
"Callan-Gross"

Close-Kumano sum rule: $\int b_1(x)dx = 0$

HERMES result: $\int_{0.0002}^{0.85} b_1(x)dx = 0.0105 \pm 0.0034 \pm 0.0035$

$2.2\,\sigma \neq 0$

- effect from tensor polarized sea quarks?
- contribution from gluons?

Efremov, Teryaev $\int x\, b_1(x)\, dx = 0$

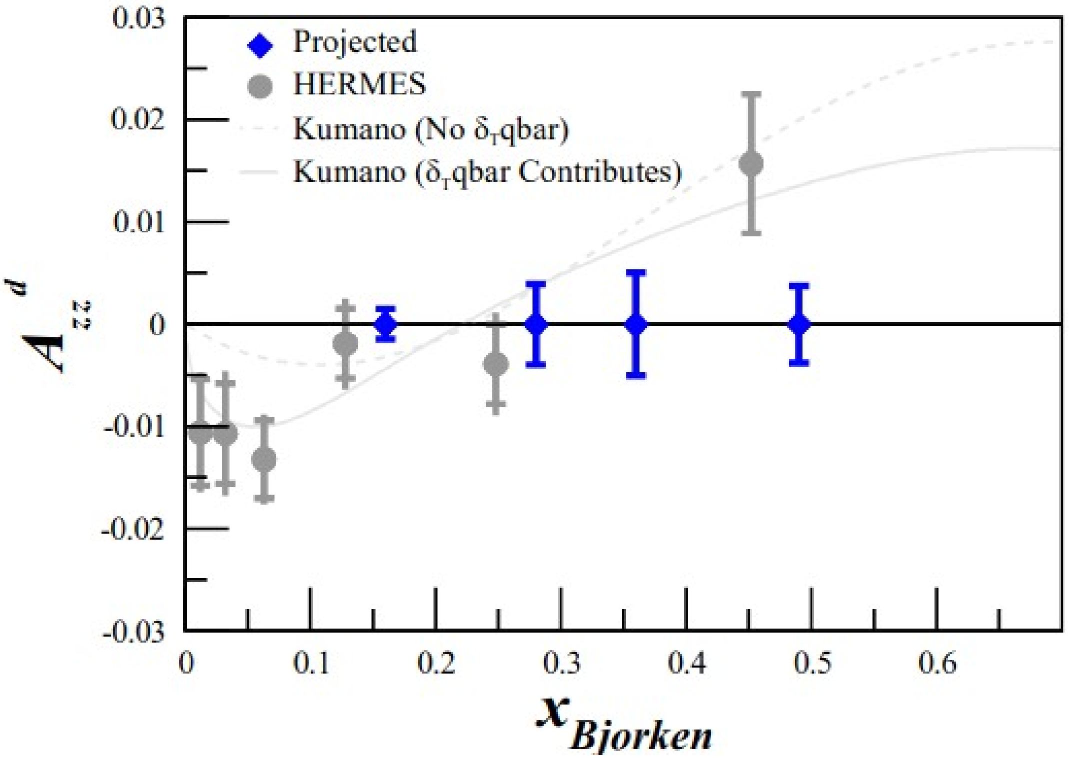
gluons are suppressed, sum rule more likely to be satisfied
Can separate gluon & quarks from 1st and 2d moments of b_1

Projections: b_1 experiment

$$A_{zz} = \frac{2}{fP_{zz}} \frac{\sigma_\dagger - \sigma_0}{\sigma_0}$$

normalized tensor - unpolarized cross section asymmetry
(f: dilution factor ~ 30%)

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



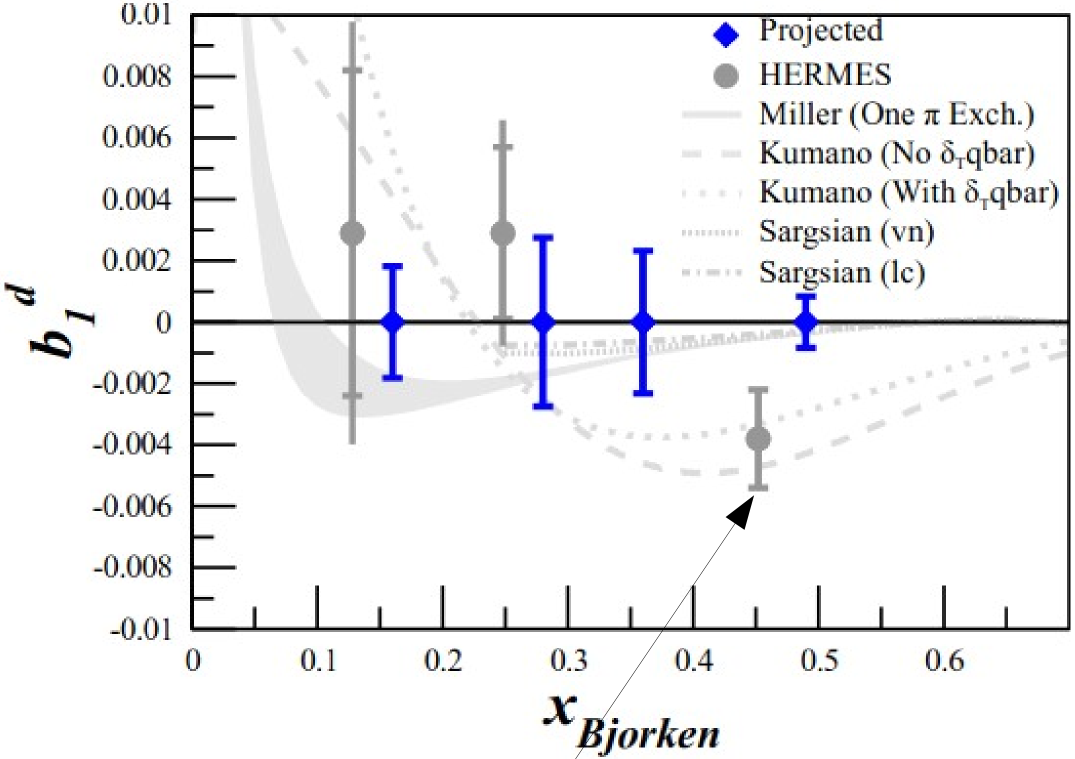


Figure 7: **Top:** Projected statistical errors for the tensor asymmetry A_{zz} with 30 days of beam time. **Bottom:** Projected statistical errors for the tensor structure function b_1. Data at different Q^2 are combined with an x-binning that varies slightly per point, but is approximately ± 0.05. Also shown are the HERMES data [10], and the calculations from Kumano [13], Miller [14, 15], and Sargsian [18].

- b_1=0 : p & n behaves as independent s-states, no nuclear effect
- $b_1 \neq 0$ but expected to be small. Large negative result from HERMES not yet understood

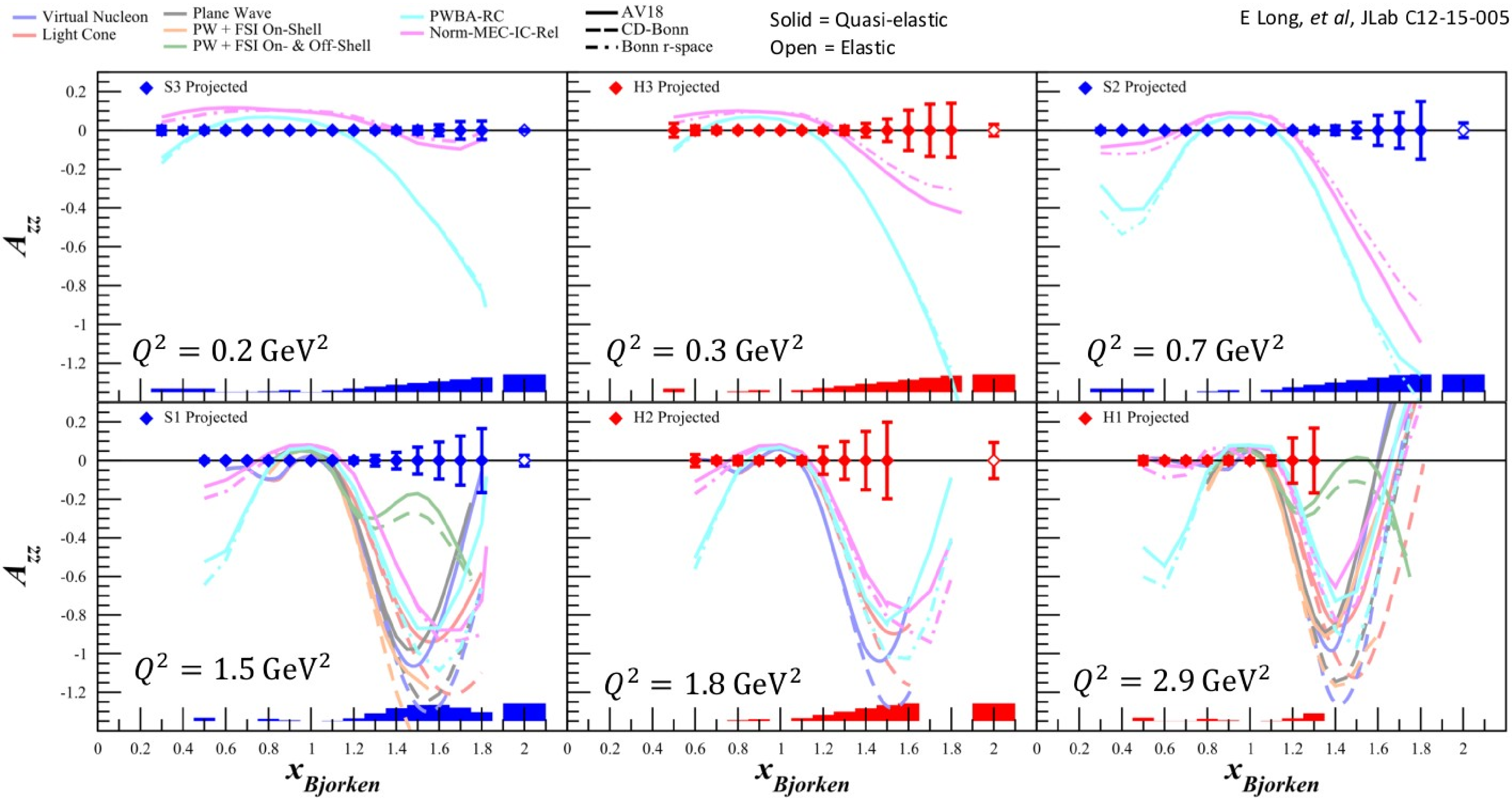
note: could be explained from exotic 6-quark state [Miller, PRC89 045203 2014]

Testing for: Tensor polarization of sea quarks, Close-Kumano sum rule, 6-quark state?

Tensor physics program: projections for A_{zz} experiment

Large x>1 A_{zz} experiment E12-15-005: quasi-elastic to elastic range, short range p-n effects

Data points: Q^2= .2, .3, .7, 1.5, 1.8, 2.9 GeV²



short range repulsion?
N-N tensor force?

$$A_{zz} = \frac{2}{P_{zz}}\left(\frac{\sigma_p - \sigma_u}{\sigma_u}\right)$$

large asymmetries expected

Tensor physics program: projections for A_{zz} experiment

Large x>1 A_{zz} experiment E12-15-005: quasi-elastic to elastic range, short range p-n effects

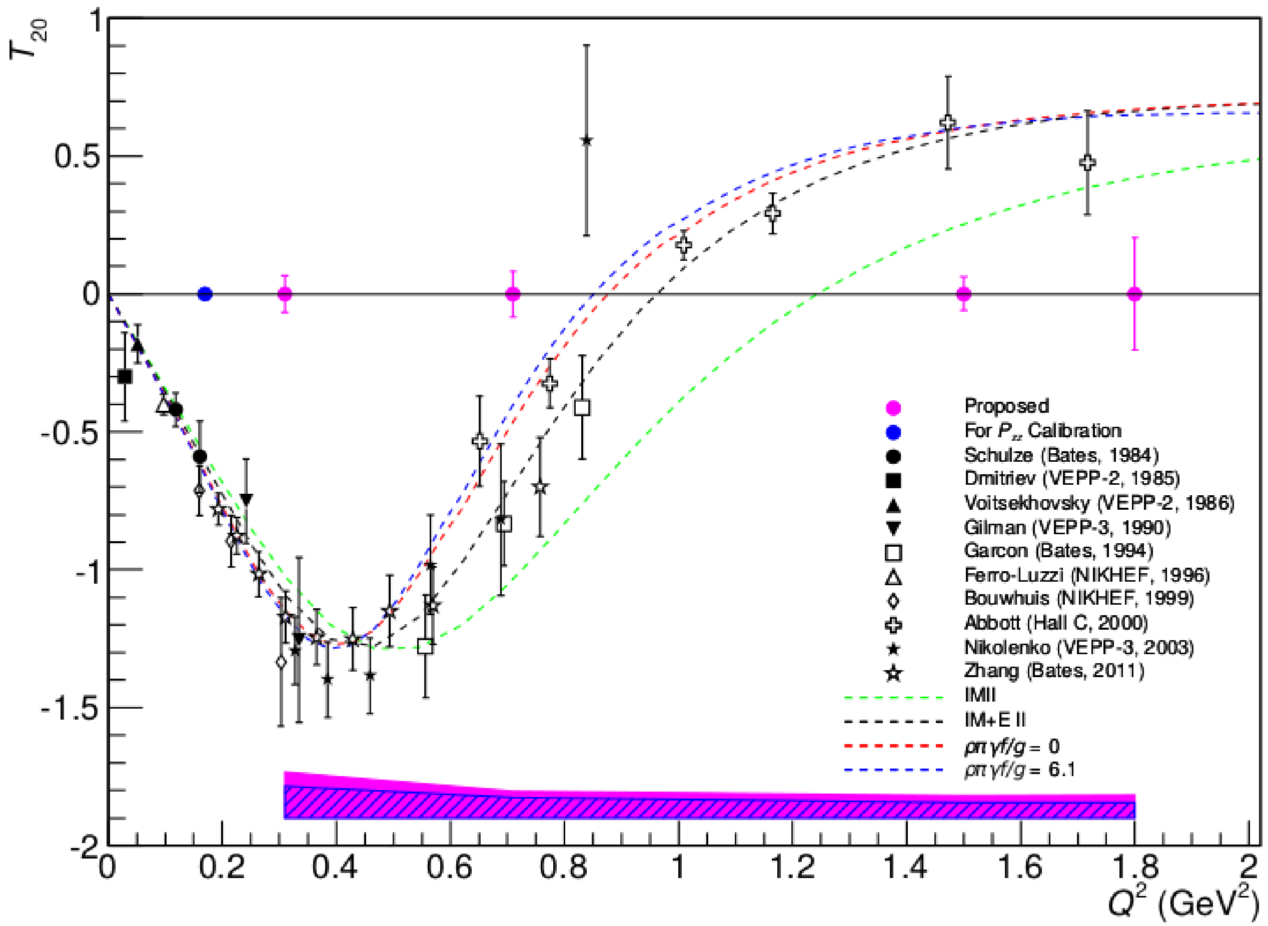


Figure 16: Projected uncertainties for the elastic tensor analyzing power T_{20} with 34 days of beam time are shown alongside the world data [43]. The point shown in blue, measured at $Q^2 = 0.2$ GeV^2 where T_{20} is well known theoretically and experimentally, will be used as a calibration for P_{zz}, and can potentially be used to further reduce the leading systematic uncertainty as indicated by the blue-dashed band.

simultaneous measurement of T_{20}:

- low Q^2: calibration of target NMR polarization measurement (blue point)

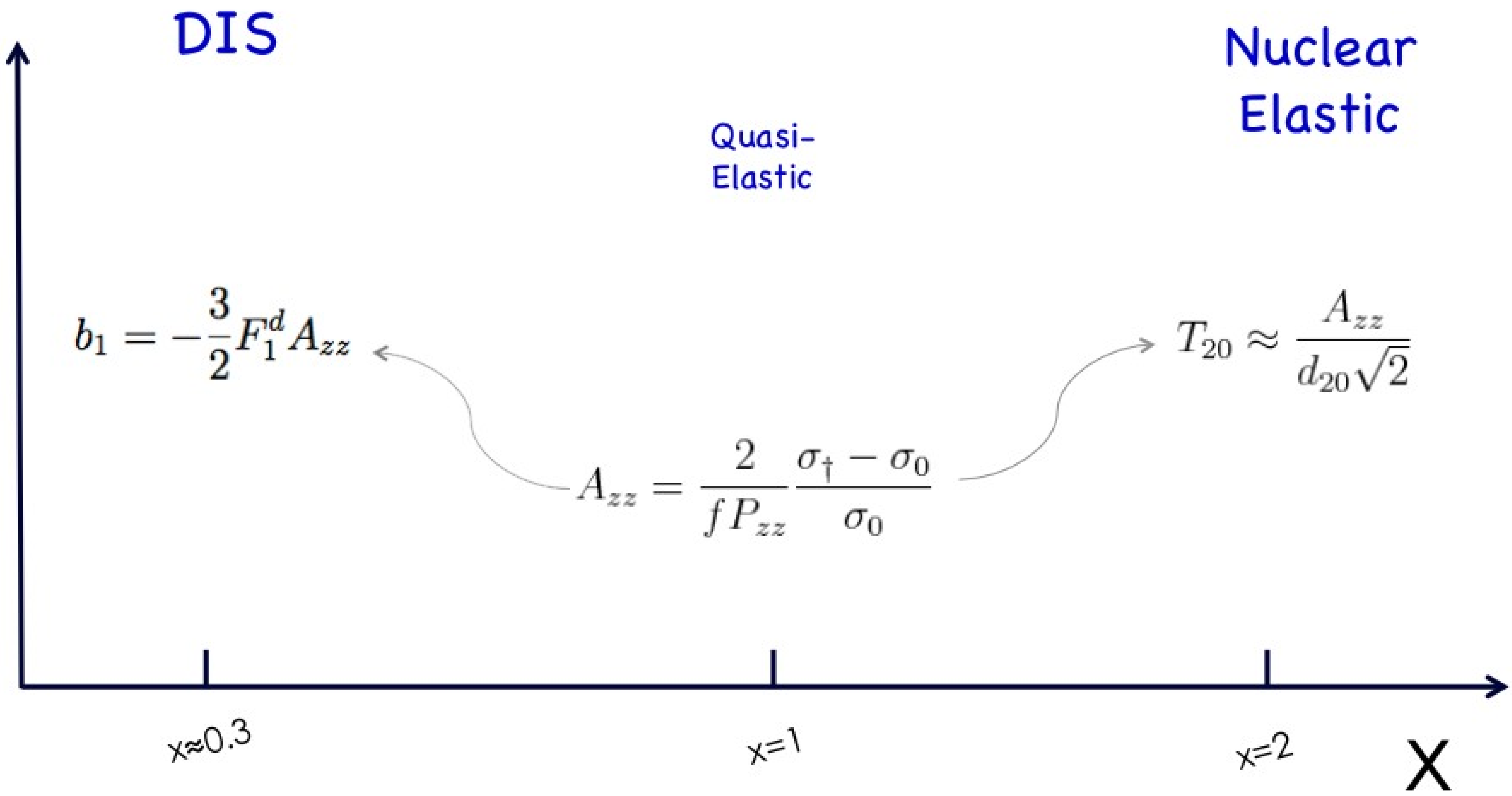
- $Q^2 \approx .7$ GeV^2, discrepancy JLab/MIT-Bates

- need of high $Q^2 > 1$ GeV^2 data

Data points (pink):
$Q^2 = .3, .7, 1.5, 1.8$ GeV^2

Tensor physics program: b_1 and A_{zz} experiment

Tensor Spin Observables

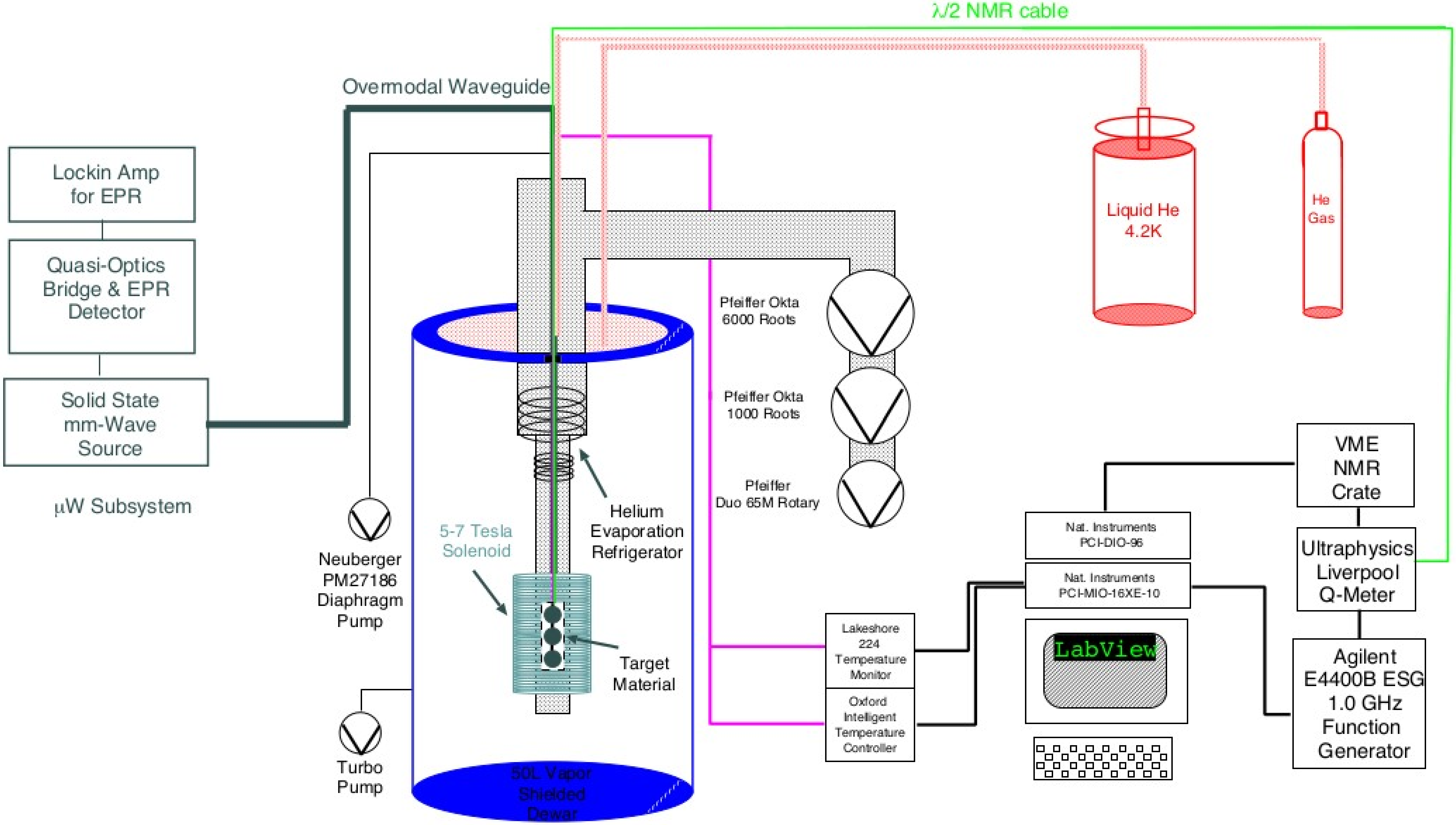


from K. Slifer

For both experiments: PAC condition about tensor polarization needs to be > 30%

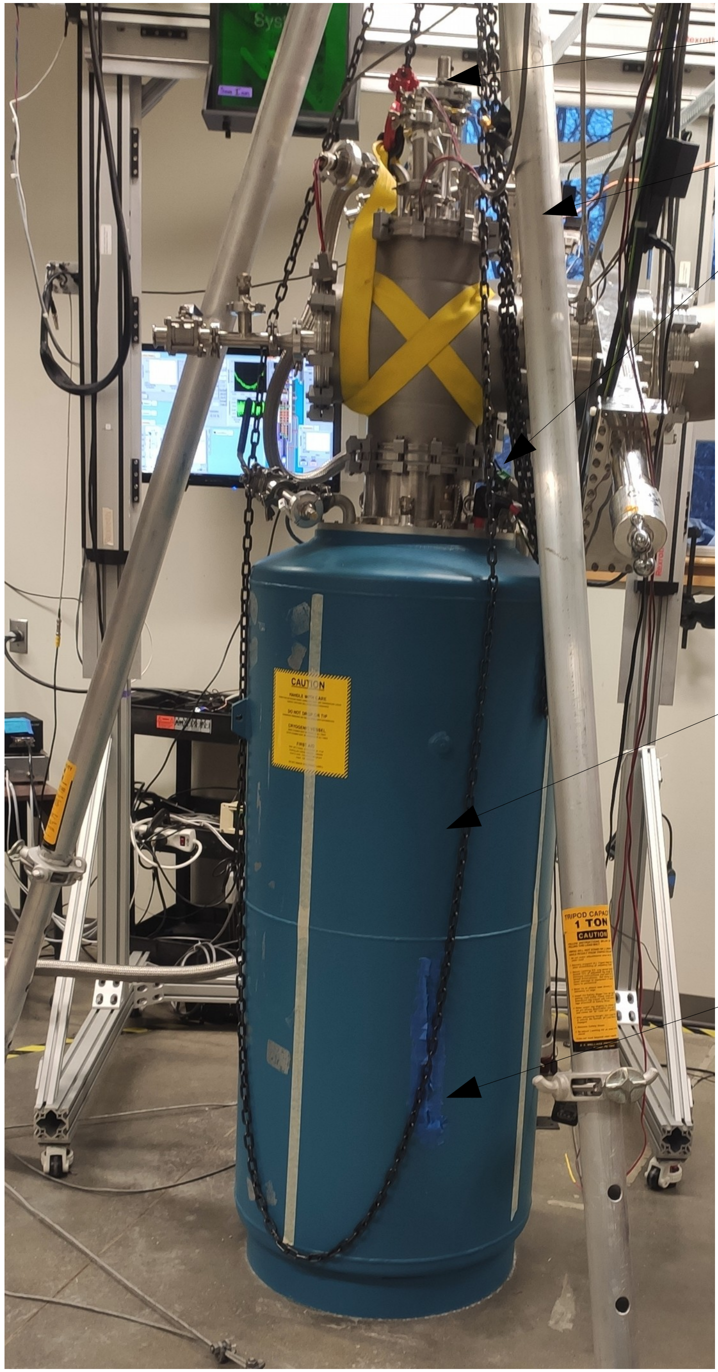
UNH target system

up to 7 T solenoid magnet, with evaporation He fridge system
Polarization measured by NMR and dynamic nuclear polarization through waveguide



from K. Slifer

UNH target system: view outside



target stick insert

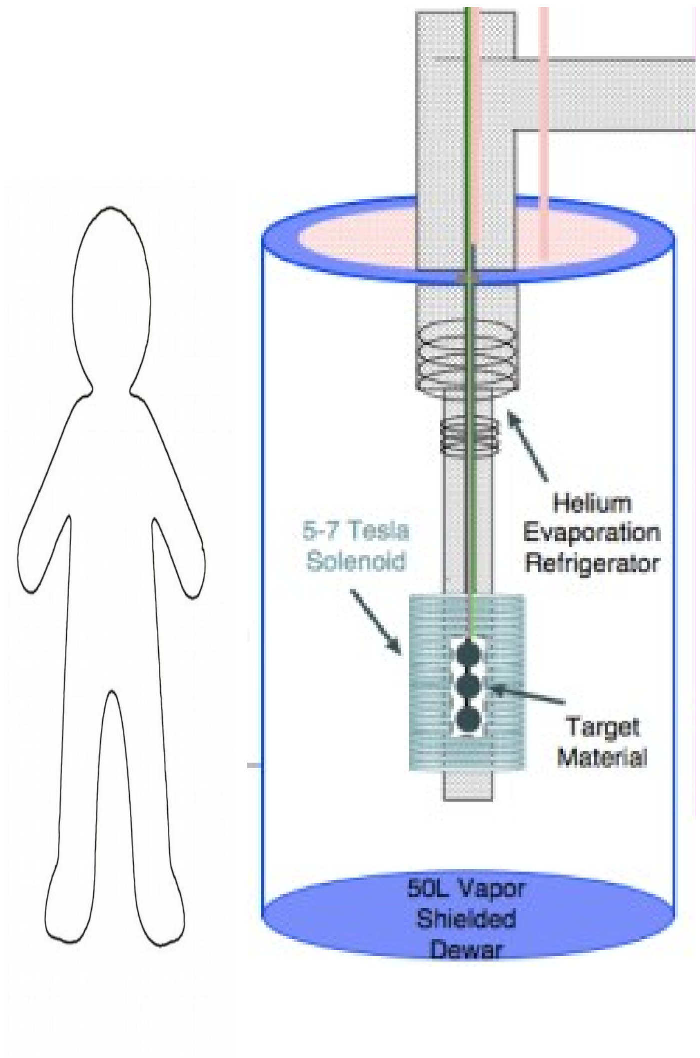
joints

vacuum system

inside dewar
He evaporation
fridge

solenoid magnet

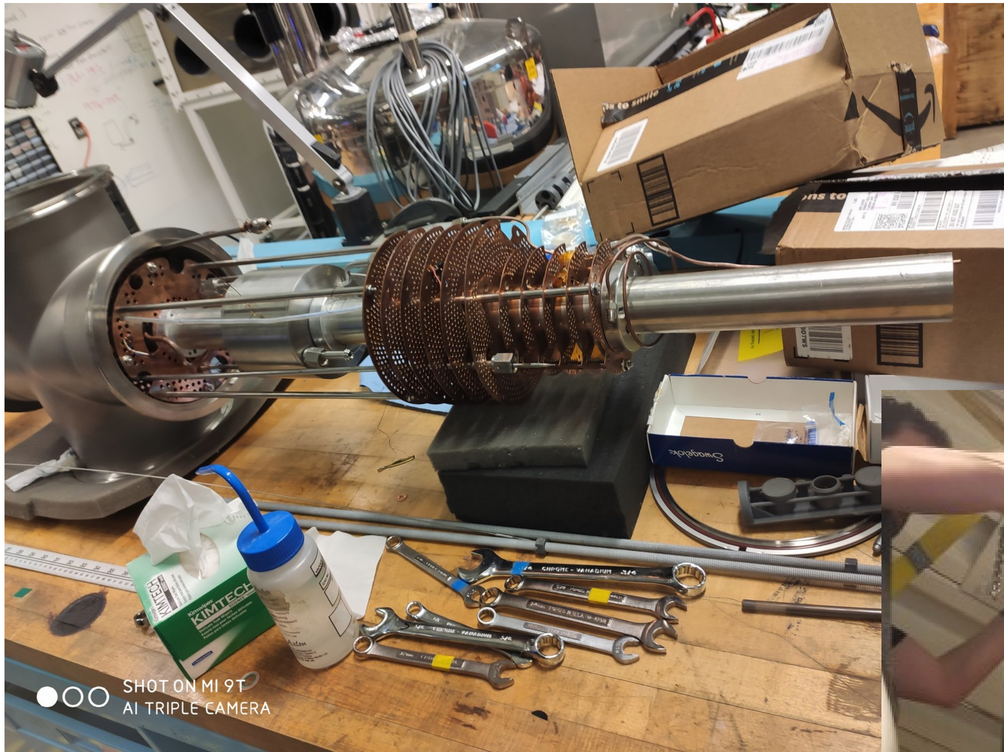
target ladder



UNH target system: He evaporation fridge

separator

heat exchanger



UNH target system: target stick

Prior target ladder version

Latest target stick

(back)

3 cups can be filled out of different materials. 1 or 2 cm diameter

mm-wave guide system

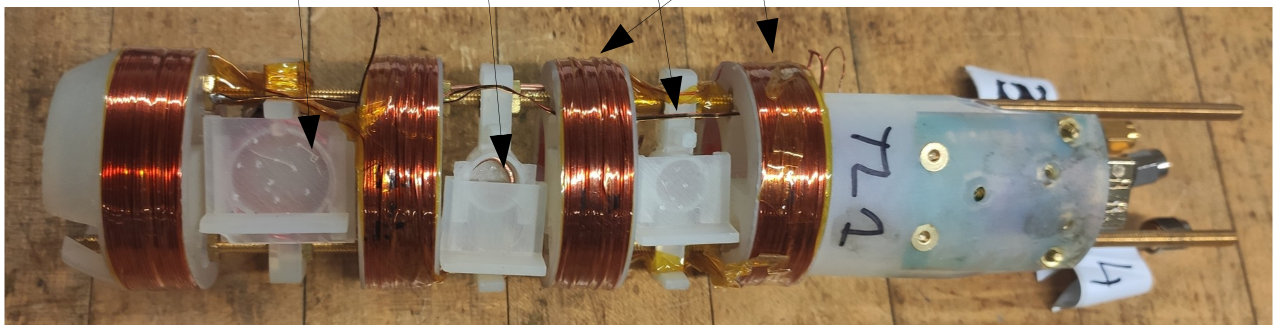
inserted behind target cups

(front)

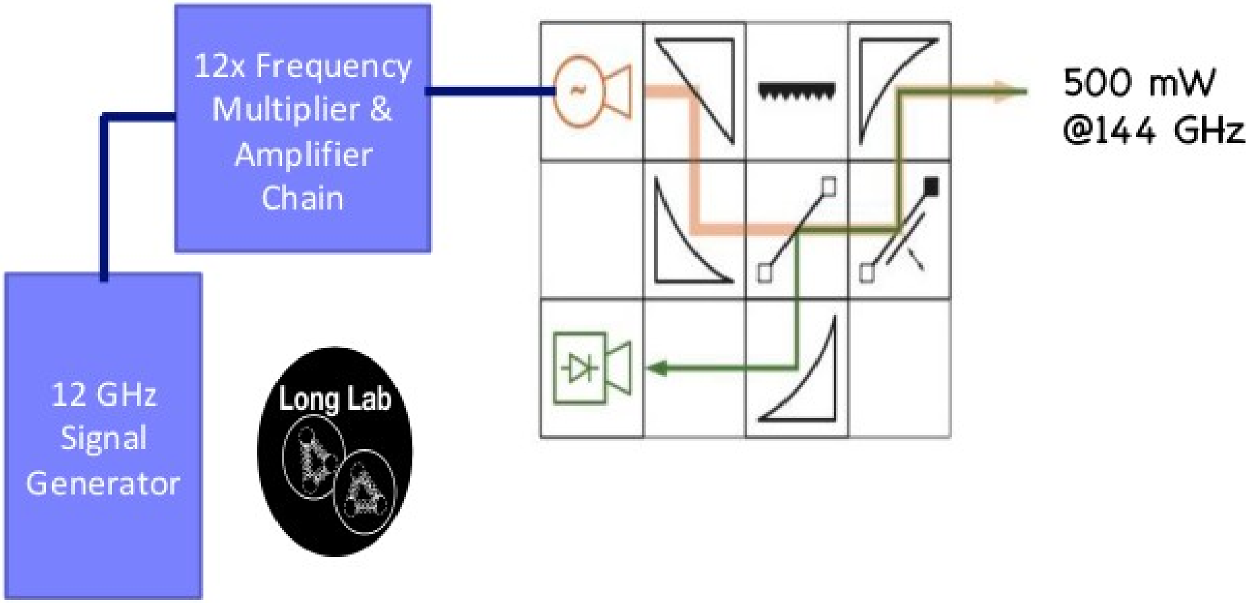
hole burning coil

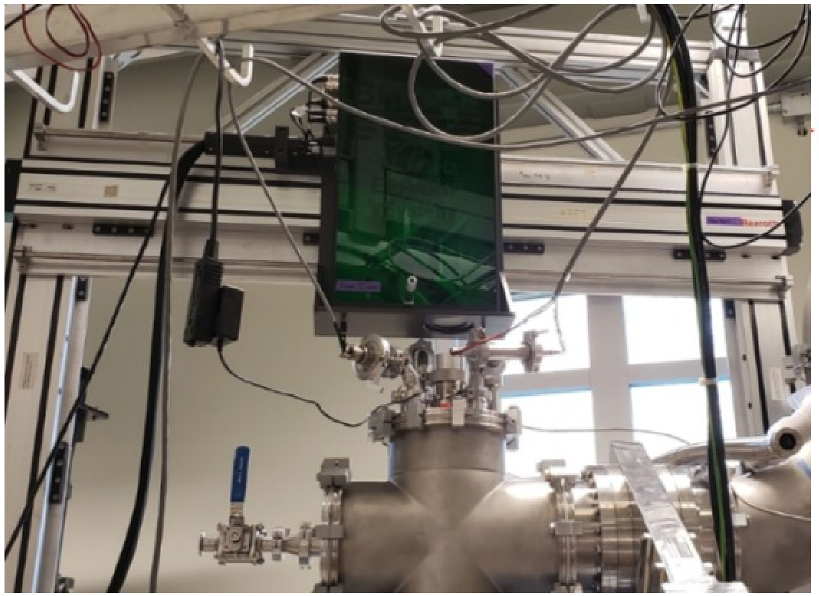
NMR coil

EPR field modulation coils



UNH target system: solid state mm-wave system



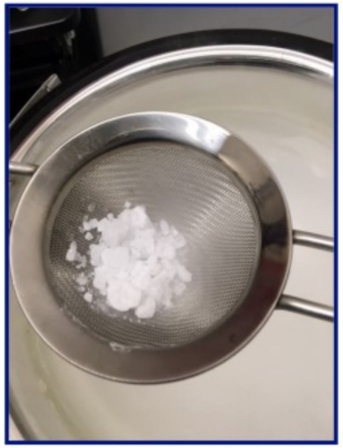


up to 1kHz to modify frequency

UNH target system: materials preparation at the university

1) Preparation of target materials (from K. Slifer)
⇒ done at UNH for several kind

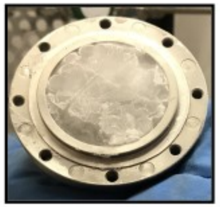
Butanol and other alcohols solidification



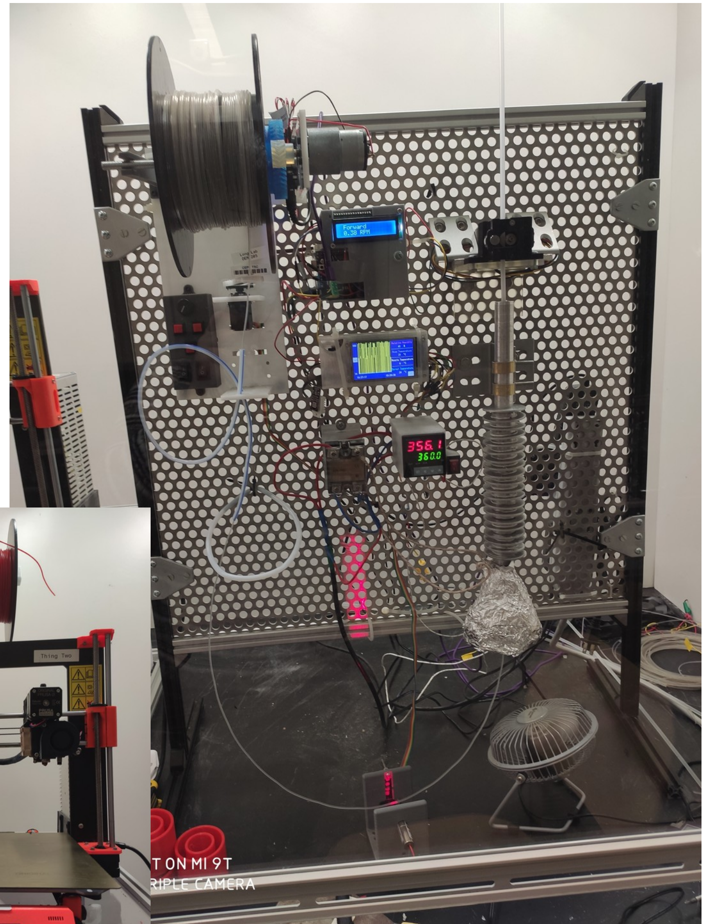
grade 5.5 NH_3

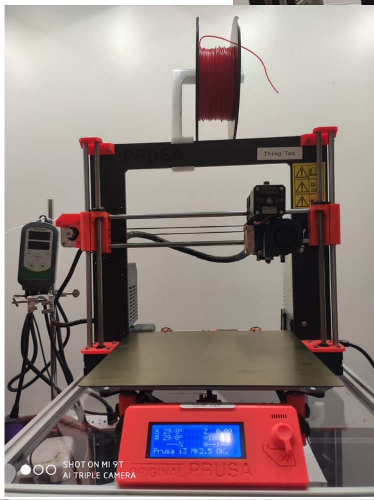
Chemically Doping

Rapid vs SlowCooling of NH_3



2) Extruding system to prepare KelF target cups (McGuire, Long et al.)





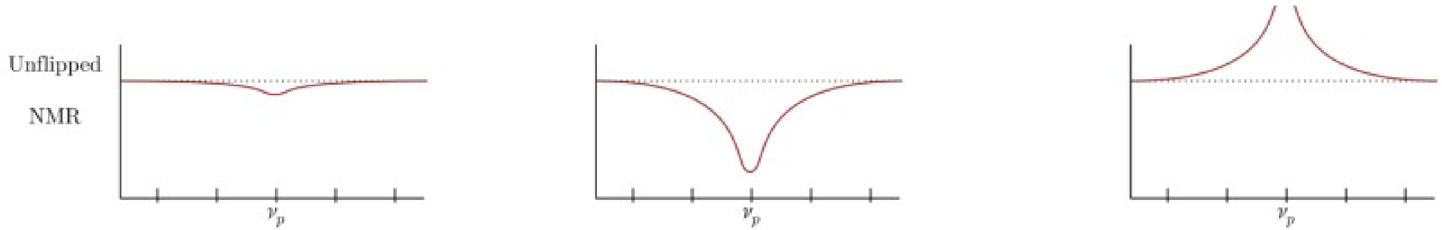
3D printed target elements

production system to solidify gas

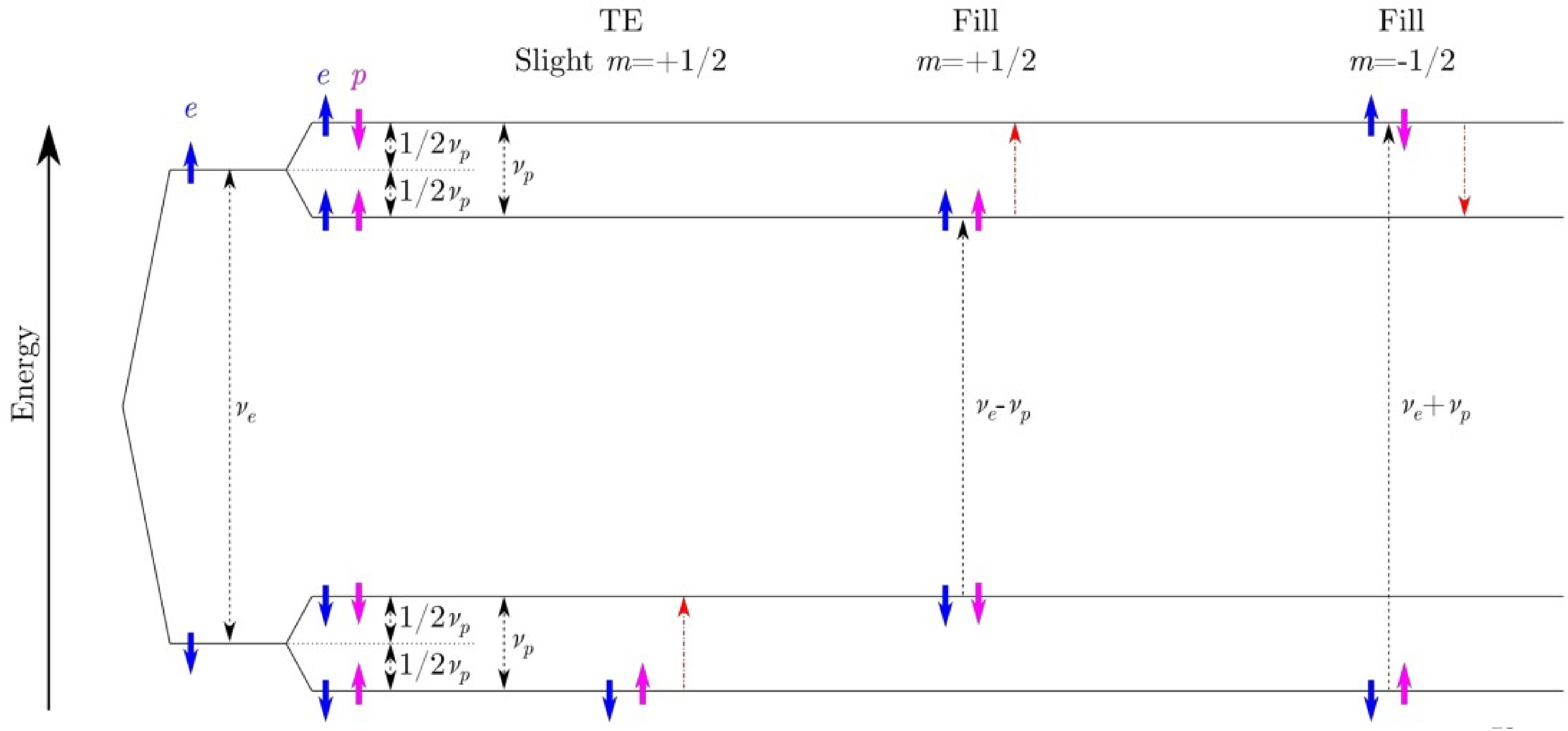
KelF printed target ladder

Polarization technique: proton levels

Proton
DNP/NMR



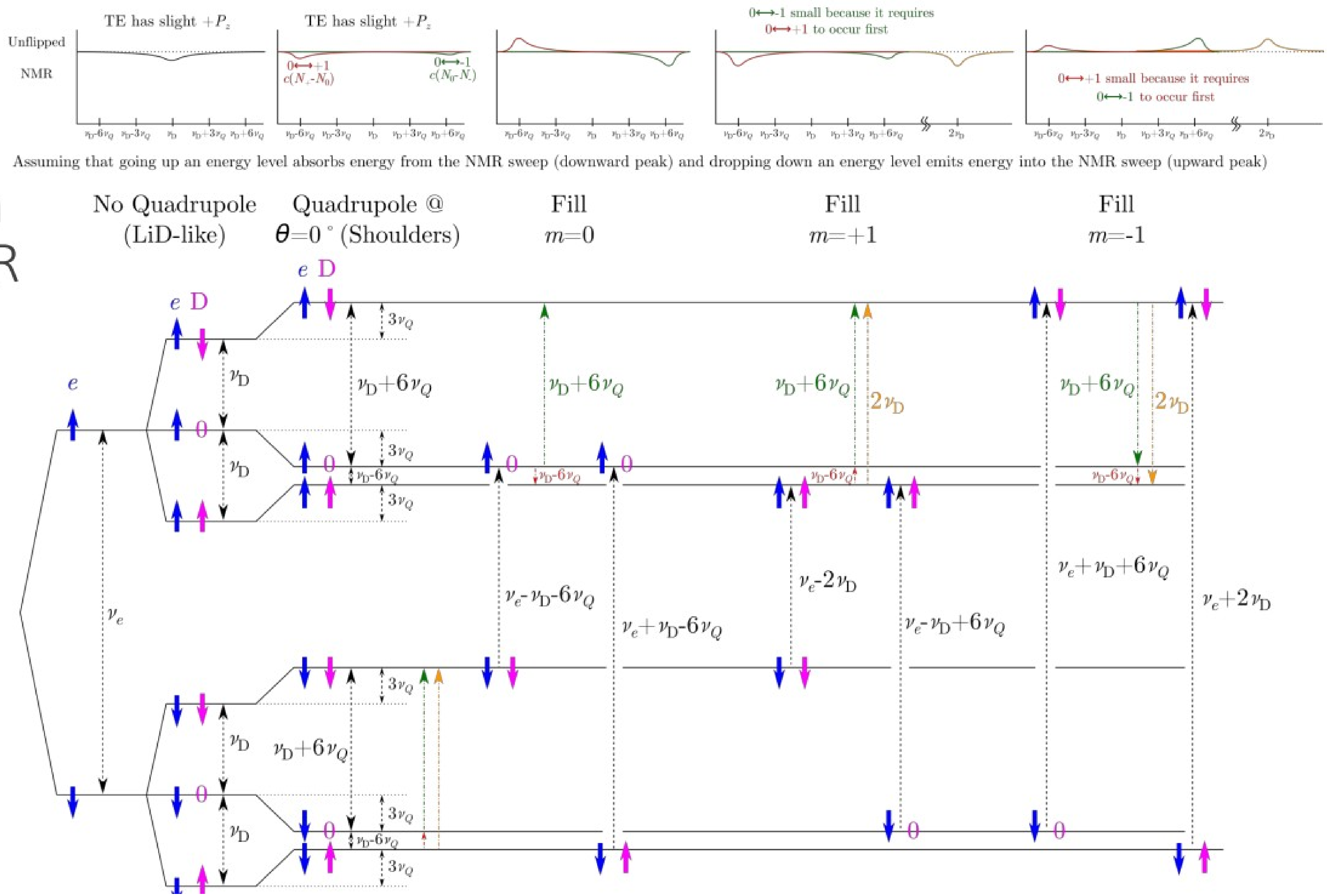
Assuming that going up an energy level absorbs energy from the NMR sweep (downward peak) and dropping down an energy level emits energy into the NMR sweep (upward peak).
This makes sense as Q-meter measures the real part of the impedance, which is derived from the reflection coefficient S_{11}.



slide from E. Long

Polarization technique: deuteron levels

Deuteron DNP/NMR



slide from E. Long

Polarization technique: shape of NMR spectra

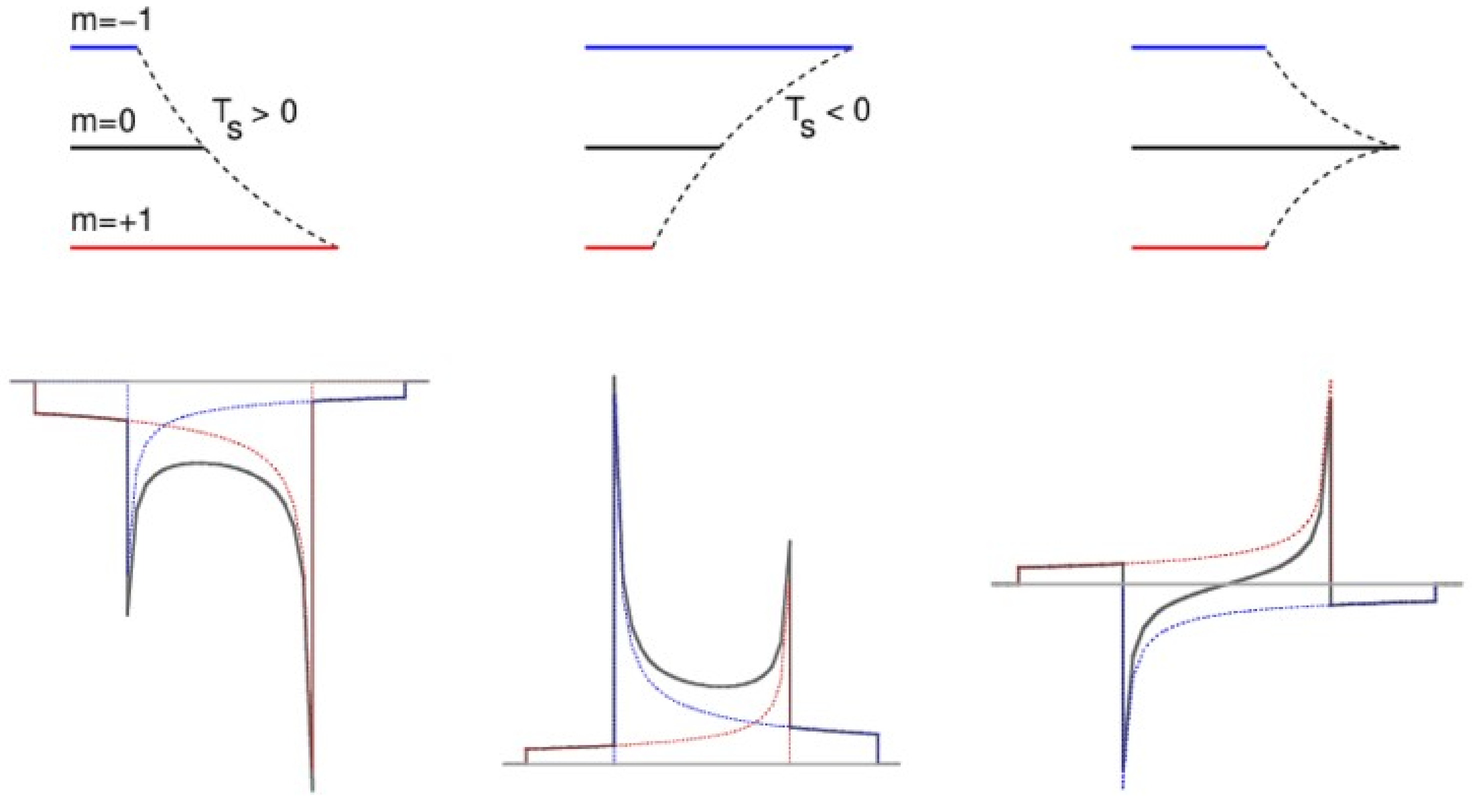


fig. from C. Keith

energy absorption energy emission energy absorption/emission

shape of NMR spectra as a function of states population

Polarization technique: shape of NMR spectra

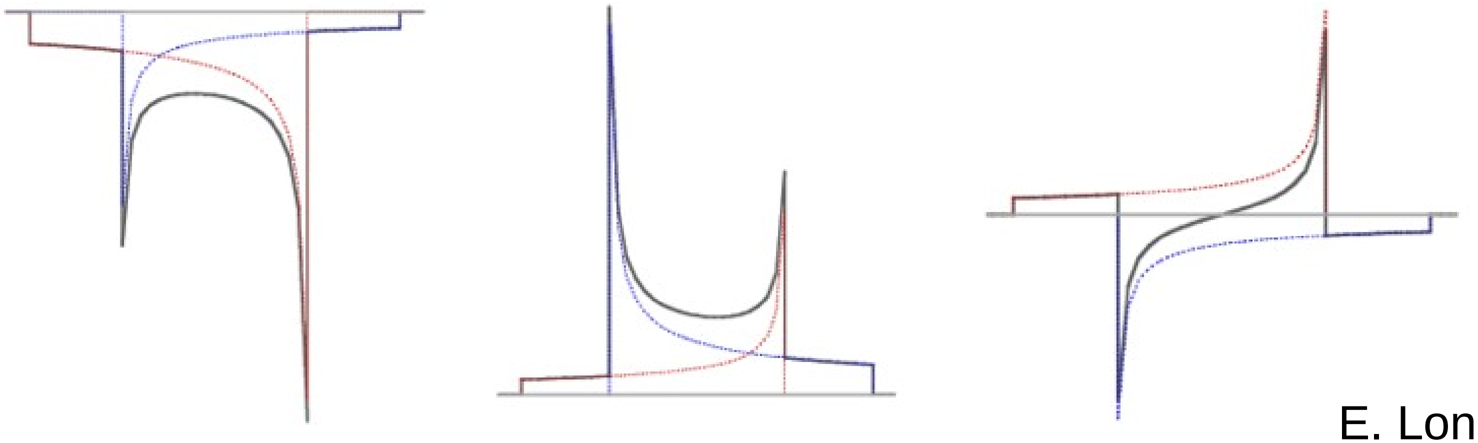
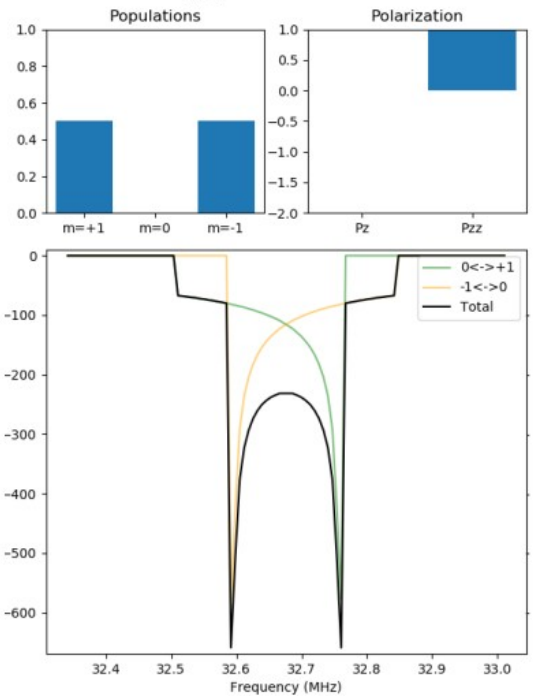


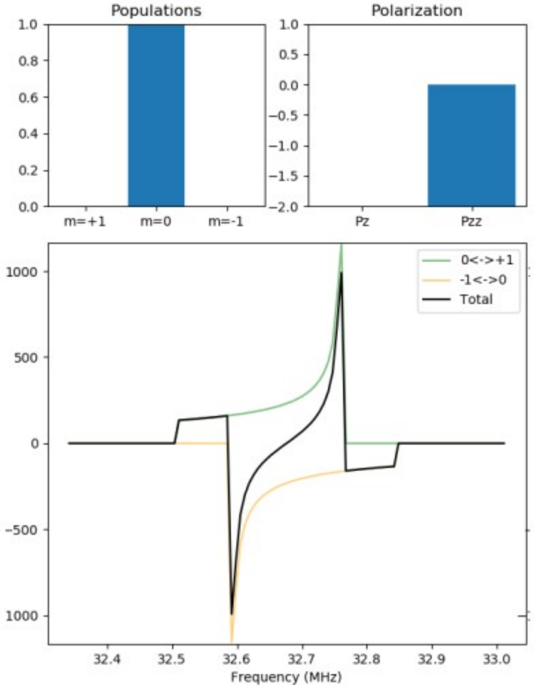
fig. from C. Keith

E. Long NMR/DNP model
⇒ same spectra

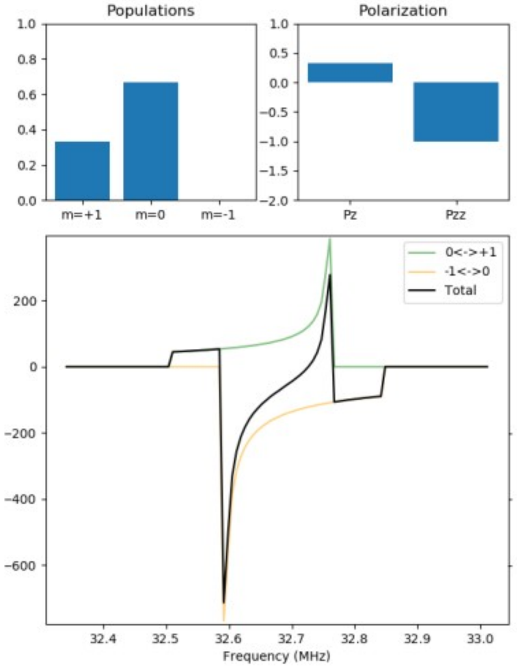
$P_z = 0\%$
$P_{zz} = +100\%$



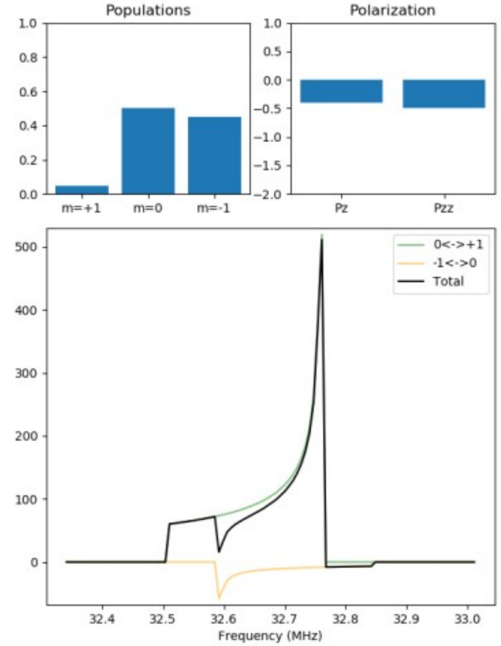
$P_z = 0\%$
$P_{zz} = -200\%$



$P_z = 33\%$
$P_{zz} = -100\%$



$P_z = -40\%$
$P_{zz} = -50\%$



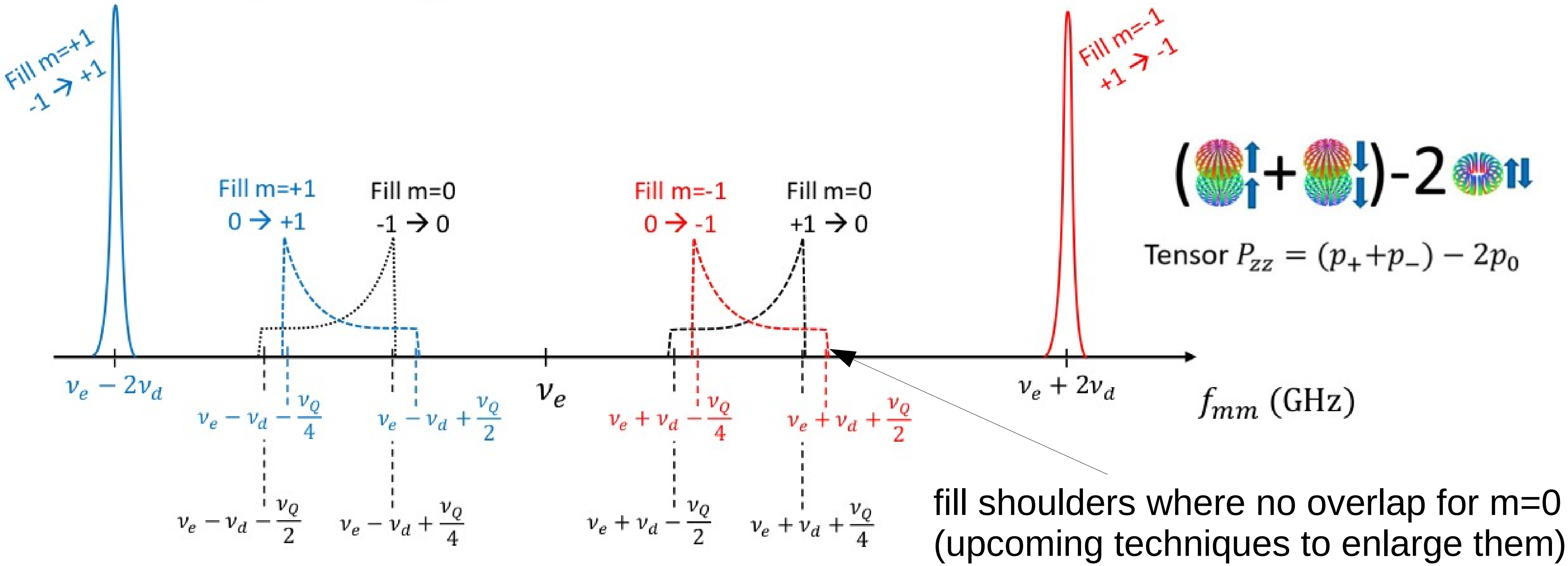
Polarization technique: Elena's model, frequencies to fill energy levels

Simple Deuteron (ND_3) NMR/DNP Model
DNP Transition Frequencies

slide from E. Long

Predicts transition frequencies, most importantly regions with & without overlap

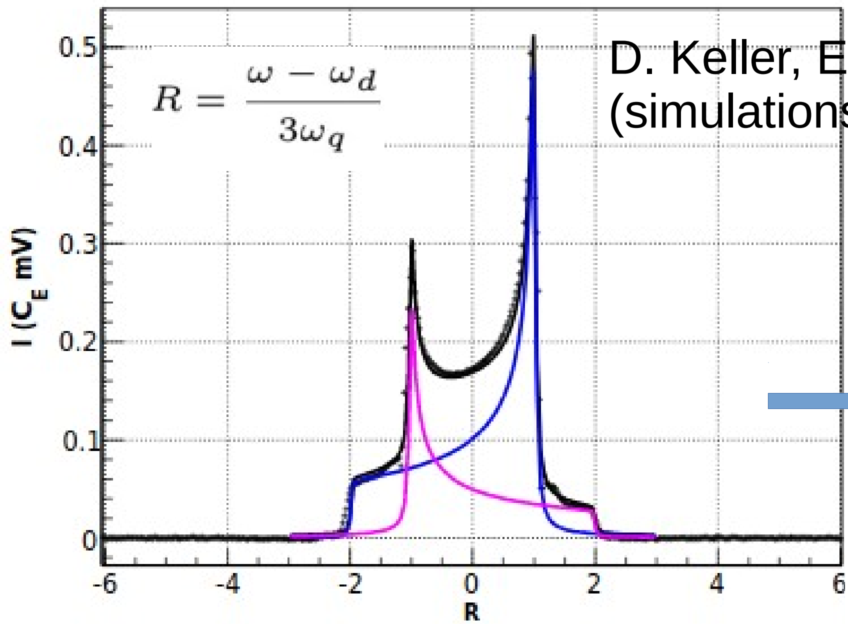
- Can only fill "pure" m=0 transitions at low quadrupole angles, which have low probabilities
- → "Shoulders" = low θ, "Peaks" = high θ ≡ angle between the external magnetic field and the quadrupole electric field



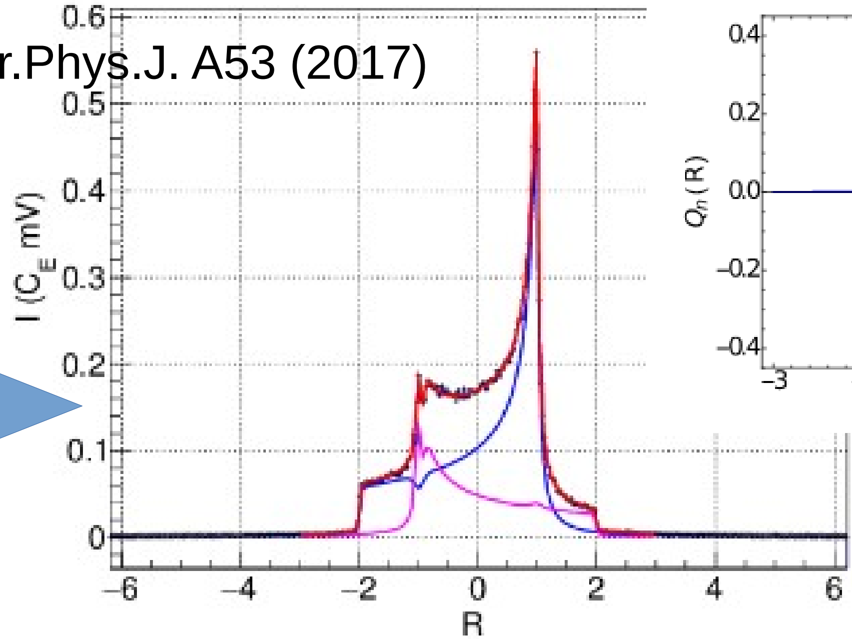
modelizing NMR spectra from Pz, Pzz and probability of nuclei at given θ

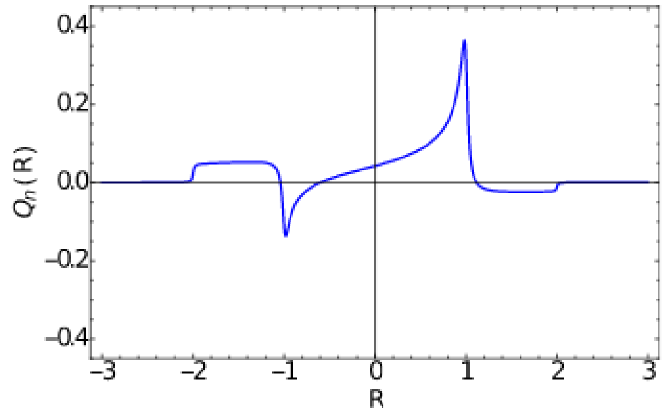
Tensor enhancement: <u>fill and empty m=0 shoulders simultaneously</u> with microwaves, thanks to new UNH fast frequency changing solid-state guide → keep symetric spectra, compared to other methods

Polarization technique: hole burning technique enhancement



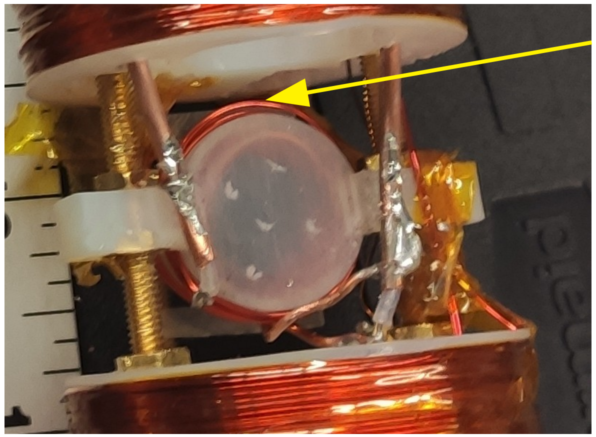
D. Keller, Eur.Phys.J. A53 (2017)
(simulations)





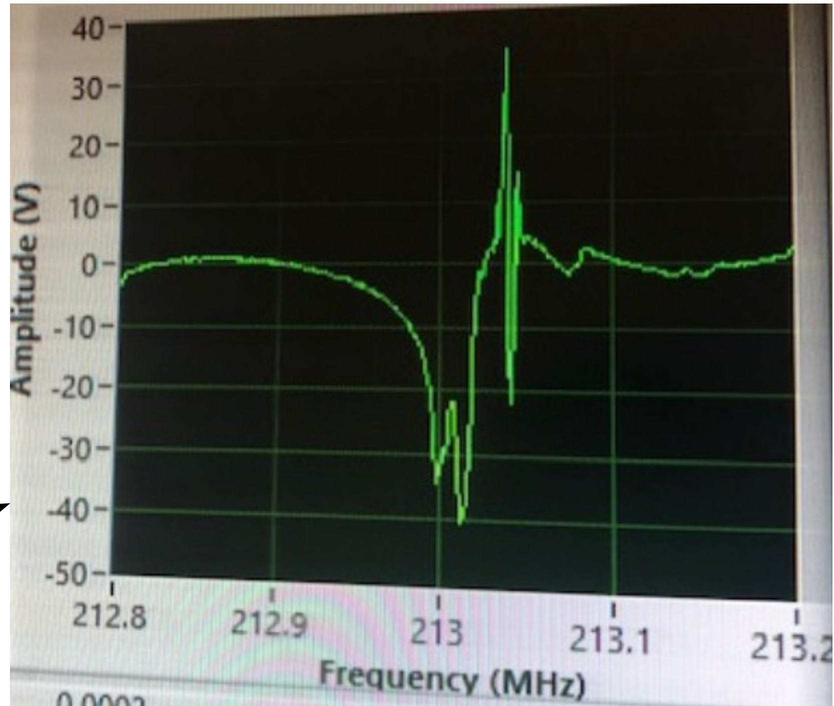
tensor pol. for 42%
vector polarization

using RF to saturate NMR lineshape and enhance tensor polarization
UVa reach 38% tensor polarization using this technique



coil surrounding
target cup

observed with
proton at UNH
(technique
ready for D)



Results from Dec. 2019 target cooldown

Notes:

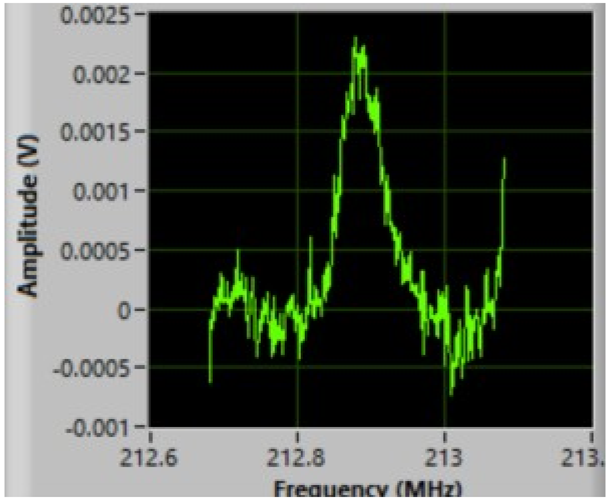
- no deuterium material used
→ the group will get it soon

- observed TE on vector polarization
where expected from past cooldown

- no observed tensor polarization at this
cooldown, good hope for next
(few months from now)

- magnet run up to 5 T

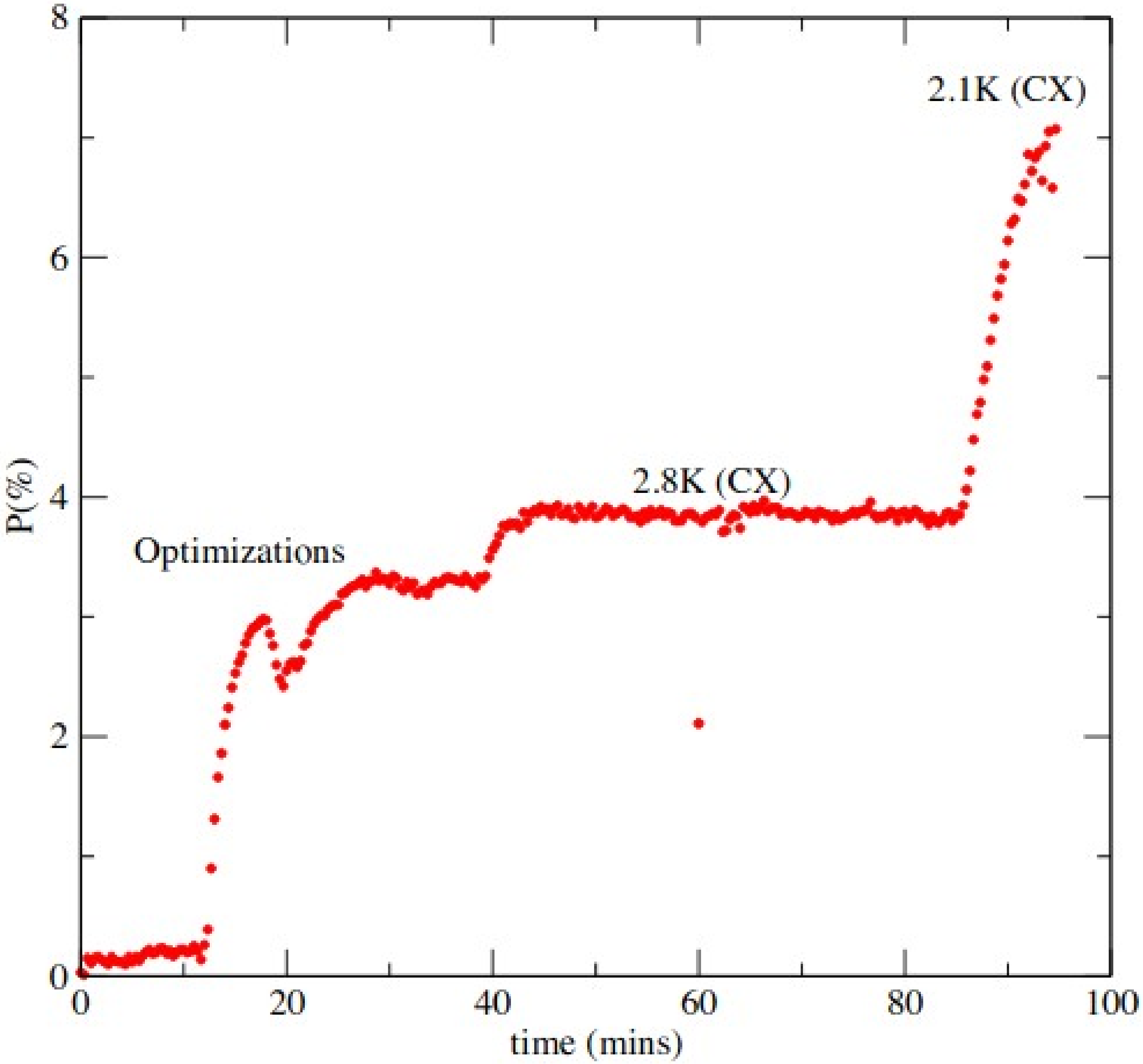
observed TE with VNA system



Results from Dec. 2019 target cooldown

Absolute polarization obtain with butanol versus time (temperature decrease)

note: min temperature = 2.1 K



reach about 7% polarization at 2.1 K

polarization increasing with T decrease

But:
below 2.1 K, leak through indium seal

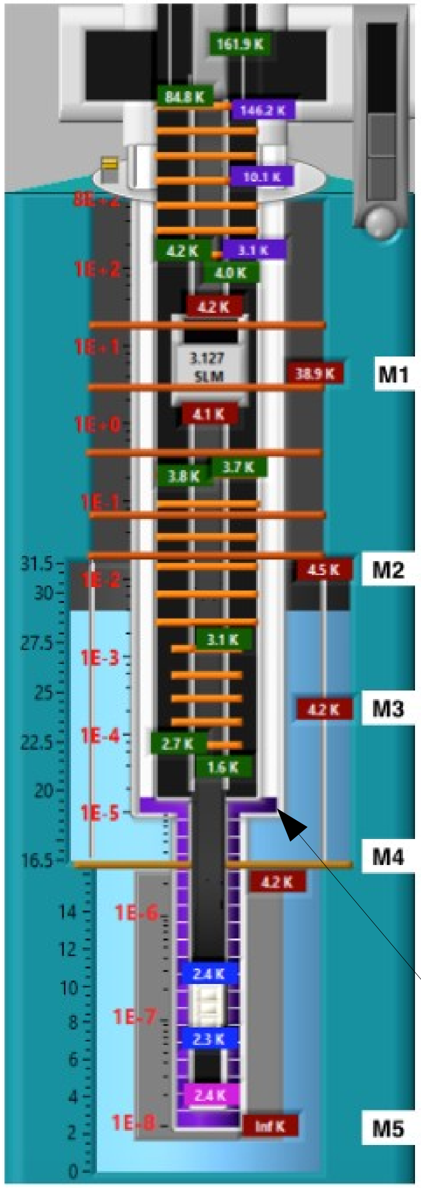
→ we lost vacuum
→ system heat up
→ close to big problem

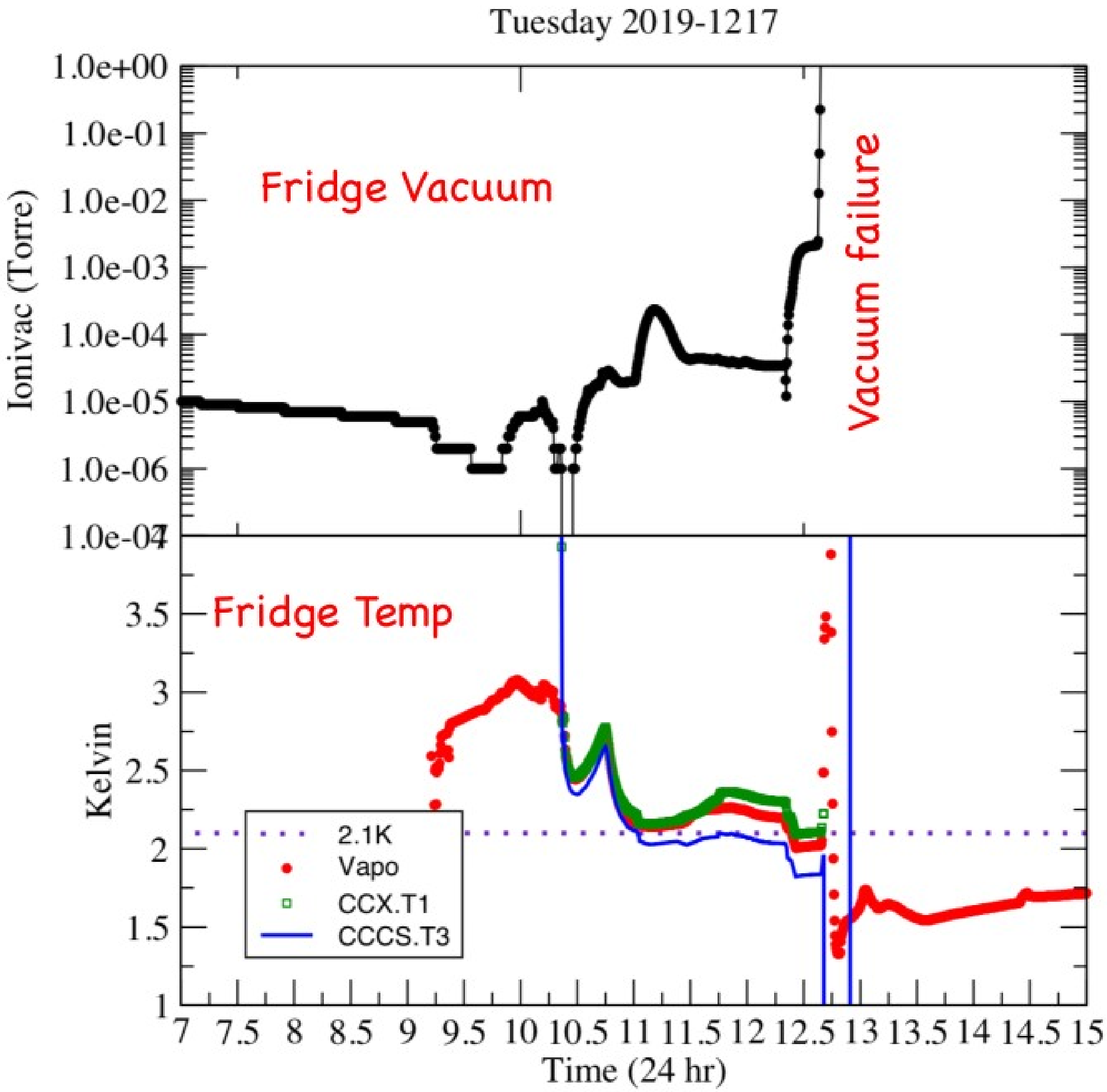
→ group order new vacuum shells

interpretation:
below 2.1 K (went to 1K) He becomes superfluid, leak through sealing

Results from Dec. 2019 target cooldown

scheme: temperature reading



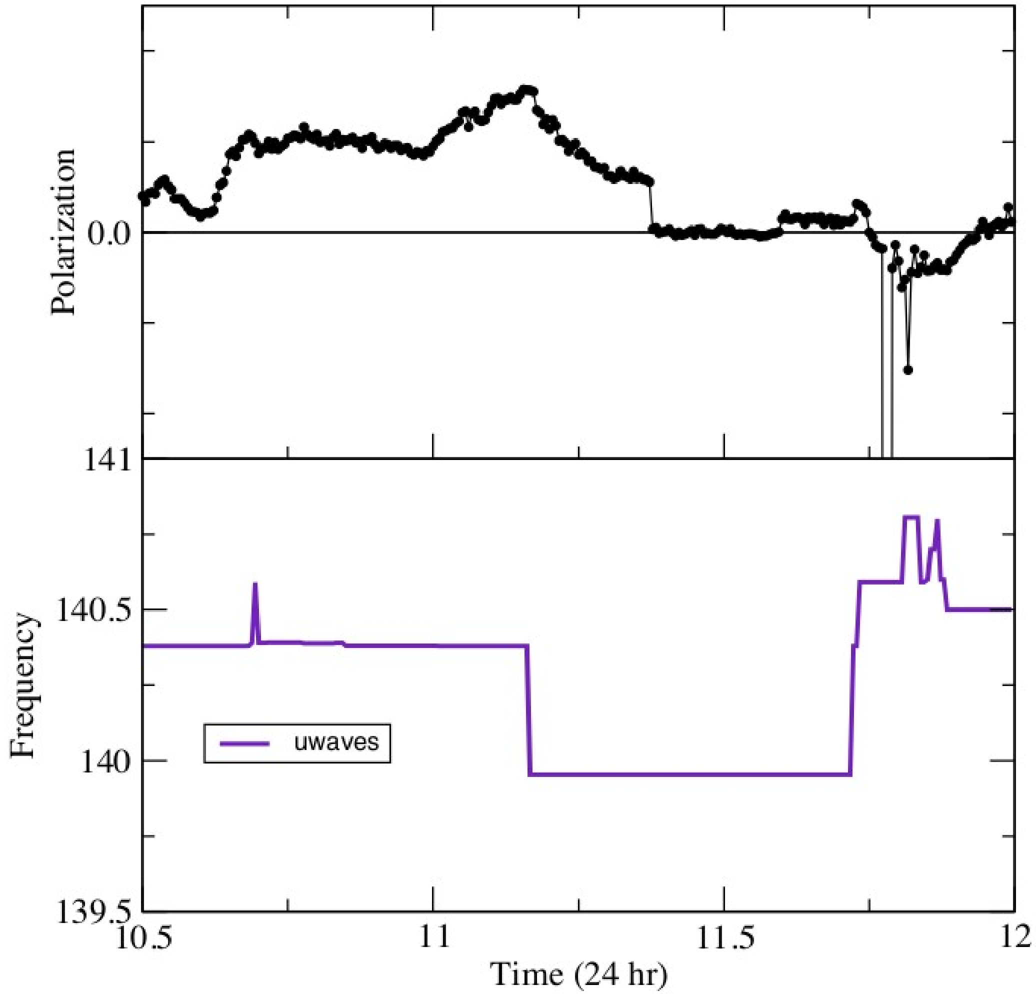


leak from indium seal at this level

slide from K. Slifer

Results from Dec. 2019 target cooldown

Observed spin-flip



proves ability to spin flip during the process by playing with frequency changes

⇒ optimistic to use this method to change spin over experiment and get to negative polarization

SUMMARY

• Tensor program:

- A_{zz} and b_1 experiments will probe the tensor polarization structure of sea quarks and short range effects in nuclei
- possible extensions to exclusive reactions (DVCS) and spin 1 GPDs. (also LOI exist for other physics)

• UNH polarized target lab is fully functional. Material can be prepared and tests conducted

- new "frequency hoping" solid-state microwaves
- new "cold finger" material production method
- new model to better understand effects of rotation
- new methods (Vector Network Analyzer VNA) to measure both real + imaginary part of D NMR signal

• Last cooldown results:

- can rely on the system and method: hole burning, NMR system, fridge...
- issues that will be addressed shortly: seal, vacuum shells, deuterium material...
- couldn't reach max polarization due to leak and limit at 2.1 K

⇒ moving toward addressing PAC requirement of > 30% tensor polarization