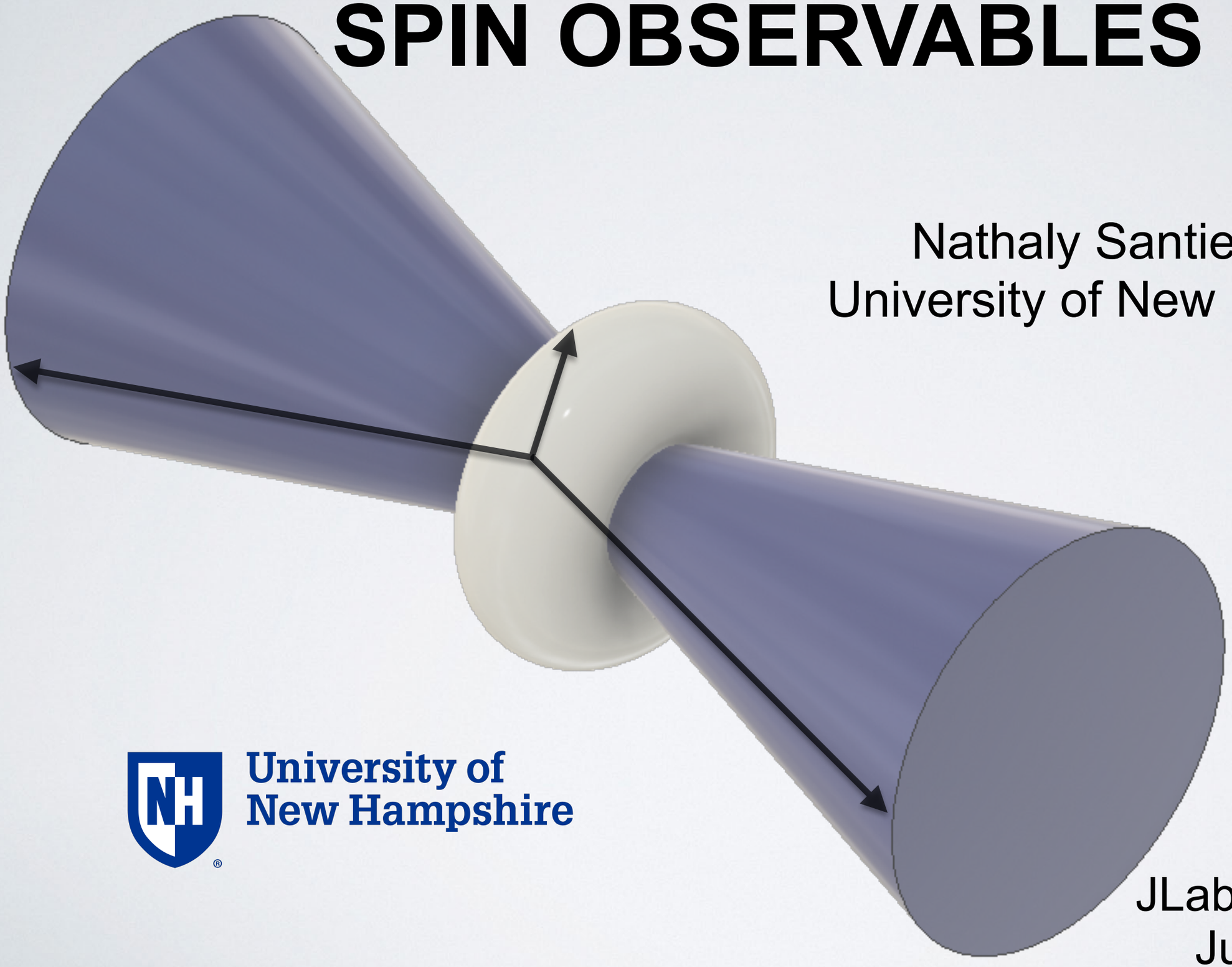
POLARIZED TARGET FOR TENSOR SPIN OBSERVABLES

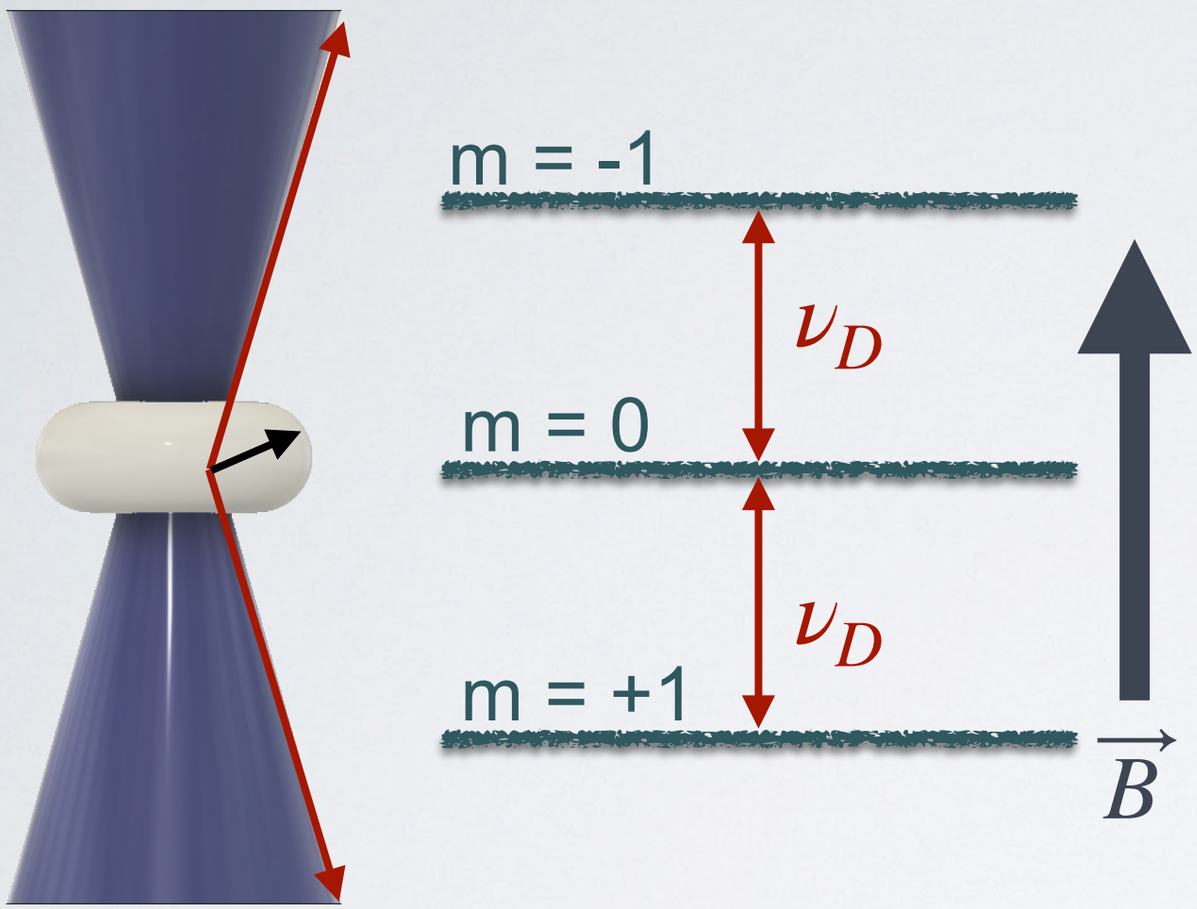


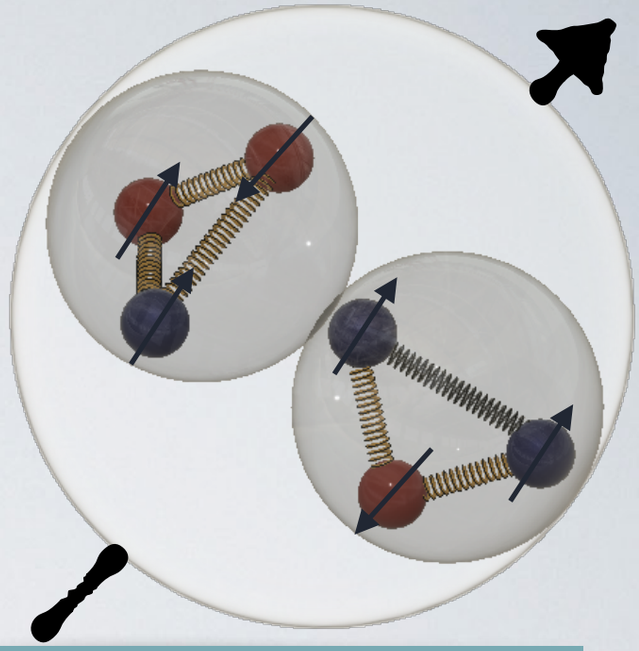
Nathaly Santiesteban
University of New Hampshire

University of New Hampshire

JLab Users Meeting
June 24, 2019

TENSOR POLARIZATION





Spin-1 System

- In a magnetic field ⟶ 3 sublevels (+1, 0, 1) due to Zeeman interaction.
- Two energy transitions (+1⟶0) and (0⟶-1).

No quadruple interaction
D, since the target will be ND_3

$\nu_D = \frac{\mu_D B}{h}$: Larmor frequency

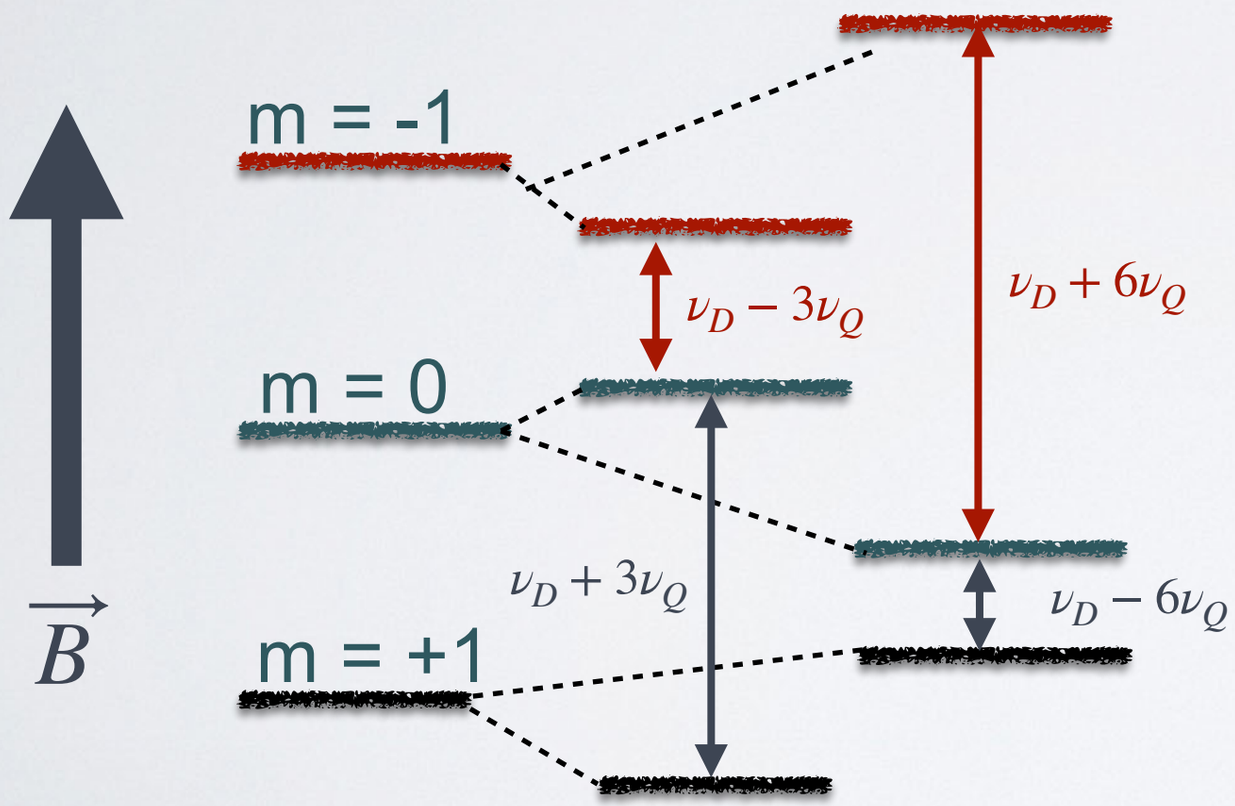
$\nu_D = 6.54 MHz/T$

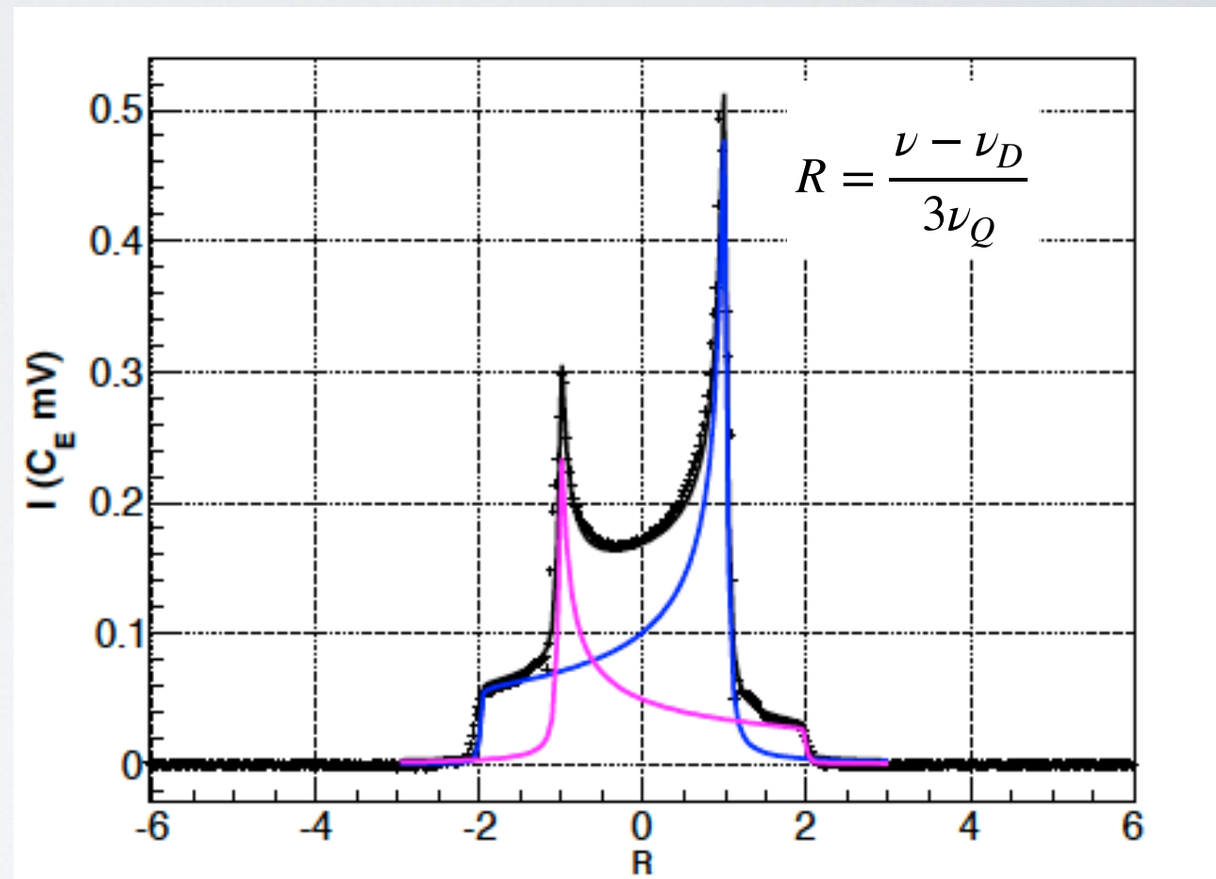
TENSOR POLARIZATION

$$E_m = -h\nu_D m + h\nu_Q(cos^2\theta - 1)(3m^2 - 2)$$

eQ : Electric Quadrupole interaction shifts energy levels
eq : Electric field gradient
θ : angle between *eq* and *B*

$\nu_Q = \frac{e^2qQ}{8h}$: Quadrupole Frequency $\rightarrow \nu_Q = 335.6kHz$

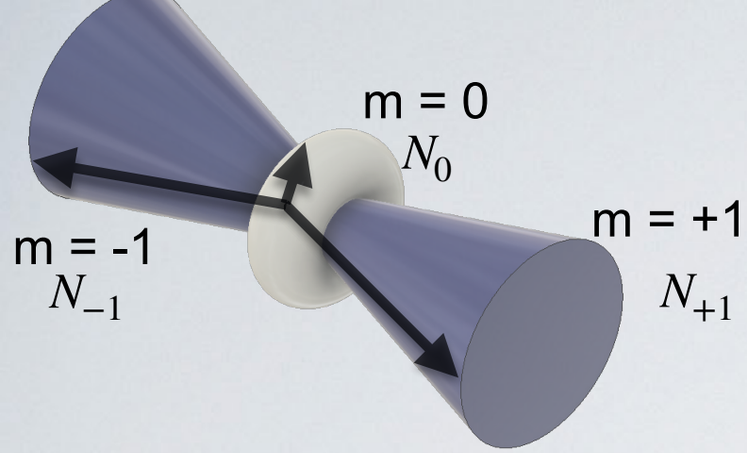


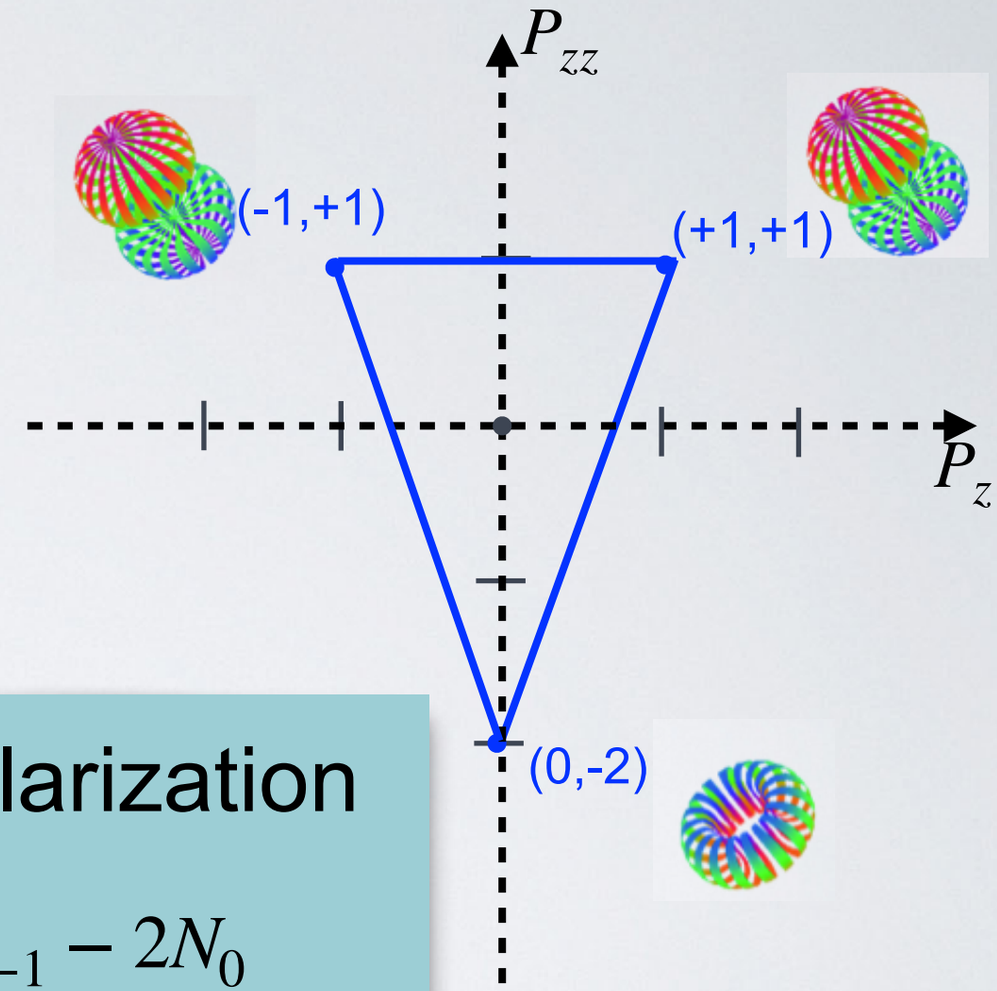


Deuteron NMR Line-shape.

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

TENSOR POLARIZATION



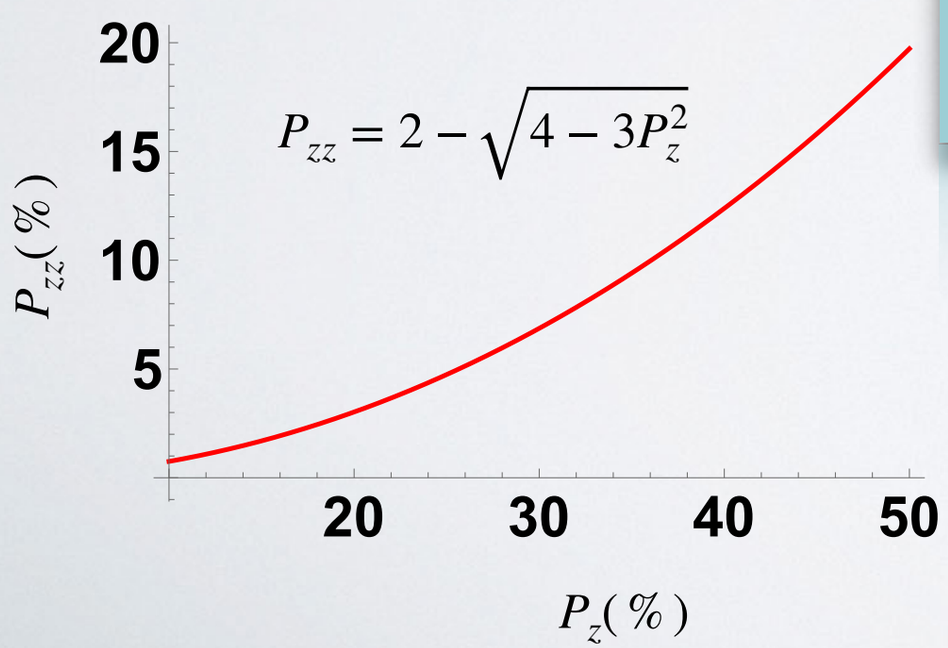


Vector Polarization

$$P_z = N_{+1} - N_{-1}$$
$$-1 < P_z < +1$$

Tensor Polarization

$$P_{zz} = N_{+1} + N_{-1} - 2N_0$$
$$-2 < P_{zz} < +1$$



Normalization:

$$N_{+1} + N_{-1} + N_0 = 1$$

Kielhorn, W. Los Alamos Report LA-12116-T (1991).

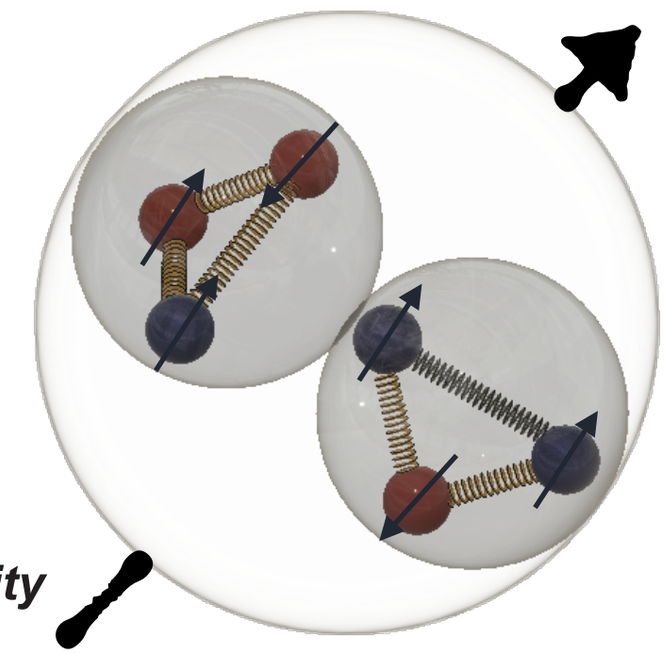
SOME OF THE WORLD DATA FOR TENSOR POLARIZATION EXPERIMENTS

Massachusetts Institute of Technology
Bates Linear Accelerator Center

TRIUMF

Институт Ядерной Физики имени Г.И.Будкера

ELSA



HERMES

NIKHEF

Jefferson Lab
Thomas Jefferson National Accelerator Facility

bmb+f - Förderschwerpunkt
HERMES
Großgeräte der physikalischen Grundlagenforschung

MAMI
MAINZER MIKROTRON

PAUL SCHERRER INSTITUT
PSI

THEORY DEVELOPMENTS

Theoretical estimate on tensor-polarization asymmetry in proton-deuteron Drell-Yan process

S. Kumano[1,2,3] and Qin-Tao Song[1,3]

Tensor-polarized structure function b_1 in the standard convolution description of the deuteron

W. Cosyn,[1] Yu-Bing Dong,[2,3] S. Kumano,[4,5] and M. Sargsian[6]

Transversity generalized parton distributions for the deuteron

W. Cosyn[1] and B. Pire[2]

MEASUREMENT OF THE COMPONENTS OF THE TENSOR ANALYZING POWER IN THE REACTION $\gamma D \to pp\pi^-$ AT LOW PROTON ENERGIES

V. V. Gauzshtein,[1] S. A. Zevakov,[2] M. I. Levchuk,[3] A. Yu. Loginov,[1] S. E. Lukonin,[1] D. M. Nikolenko,[2] I. A. Rachek,[2] R. Sh. Sadykov,[2] D. K. Toporkov,[2,4] and Yu. V. Shestakov[2,4]

Tensor-polarized structure functions: Tensor structure of deuteron in 2020's

S. Kumano

Inclusive and Exclusive Scatterings from Tensor Polarized Deuteron

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Mark I. Strikman
Department of Physics, Pennsylvania State University, University Park, PA 16802
E-mail: strikman@phys.psu.edu

Angular momentum sum rule for spin one hadronic systems

Swadhin K. Taneja,[1,*] Kunal Kathuria,[2,†] Simonetta Liuti,[2,‡] and Gary R. Goldstein[3,§]

Factorization breaking of A_d^T for polarized deuteron targets in a relativistic framework

Sabine Jeschonnek[1] and J. W. Van Orden[2,3]

Hidden Color

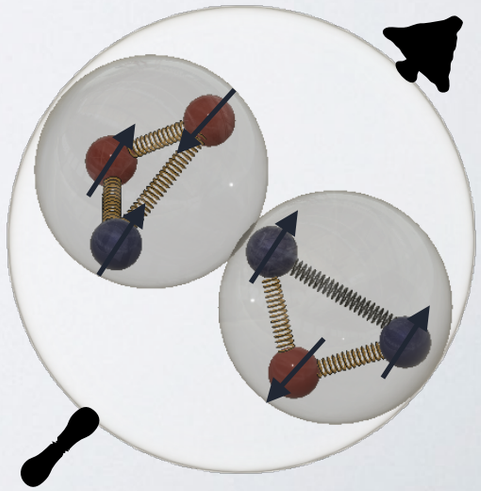
Chueng-Ryong Ji

Pionic and Hidden-Color, Six-Quark Contributions to the Deuteron b_1 Structure Function

Gerald A. Miller

Measurement of the tensor analyzing power for the reaction $\gamma d \to pn\pi^0$

S. E. Lukonin, V. V. Gauzshtein, E. S. Karpenko, M. Ya. Kuzin, M. I. Levchuk, A. Yu. Loginov, D. M. Nikolenko, I. A. Rachek, R. Sh. Sadykov, Yu. V. Shestakov, D. K. Toporkov and S. A. Zevakov



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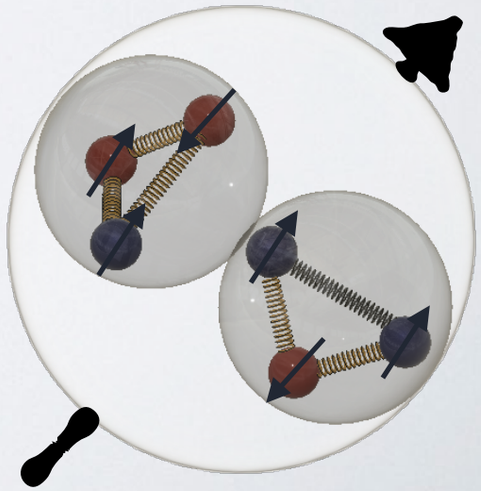
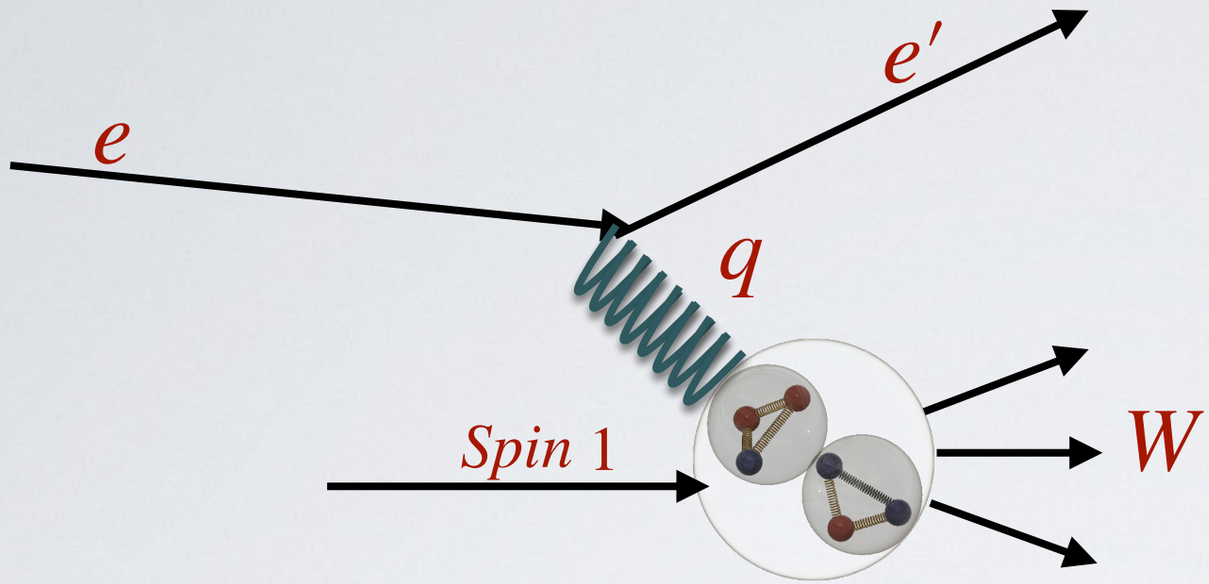


TENSOR SPIN OBSERVABLES



Inclusive Scattering

Upcoming experiments at Jefferson Lab

Slifer, K. et al. E12-13-011 (2013).
Long, E. et al. E12-15-005 (2016).
Maxwell, J. et al. LOI12-16-006 (2016).

What do we measure?

$$\underbrace{\frac{d^2\sigma_p}{dxdE'}}_{\text{Polarized Cross Section}} = \underbrace{\frac{d^2\sigma_u}{dxdE'}}_{\text{Unpolarized Cross Section}}\left(1 - P_z \overset{\text{Beam Polarization}}{P_B} \underset{\text{Vector Asymmetry}}{A_1} + \frac{1}{2}P_{zz}\underset{\text{Tensor Asymmetry}}{Azz}\right)$$

Electron

Upcoming JLab Tensor Experiments $\longrightarrow P_B = 0$

$$\frac{d^2\sigma_p}{dxdE'} = \frac{d^2\sigma_u}{dxdE'}\left(1 + \frac{1}{2}P_{zz}Azz\right)$$

Long. E. and Rondon, O. JLAB-TN-13-029 (2013).

The Deuteron Tensor Structure Function b_1

A Proposal to Jefferson Lab PAC-40
(Update to PR12-11-110)

K. Allada, A. Camsonne, J.-P. Chen,[†]
A. Deur, D. Gaskell, M. Jones, C. Keith, J. Pierce,
P. Solvignon,[†] S. Wood, J. Zhang
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Seoul National University, Seoul 151-747 Korea

H. P. Cheng, H. J. Lu, X. H. Yan
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Abdellah Ahmidouch
Department of Physics, North Carolina A & T State University, Greensboro, NC 27401

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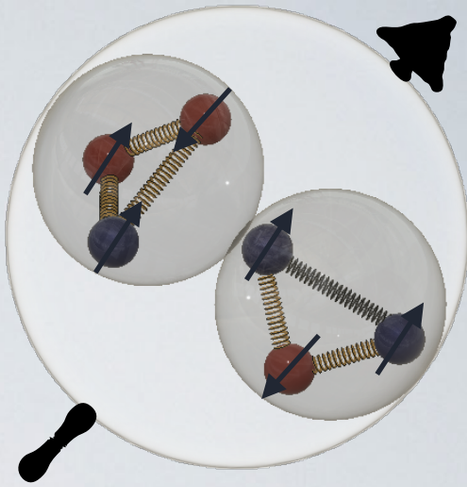
[†]Spokesperson
[‡]Contact



- Solid tensor polarized ND3 target
- A- physics rating
- 30 Days at Hall C

DEEP INELASTIC SCATTERING FROM SPIN-1 TARGETS

$$\frac{d\sigma_p}{d\Omega dE'} \propto L^{\mu\nu} W_{\mu\nu}$$

P. Hoodbhoy, R. L. Jaffe, and A. Manohar, NP B312 (1989) 571.

Unpolarized

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

Vector Polarization

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

$$- b_1 r_{\mu\nu} + \frac{1}{6} b_2 (s_{\mu\nu} + t_{\mu\nu} + u_{\mu\nu}) + \frac{1}{2} b_3 (s_{\mu\nu} - u_{\mu\nu}) + \frac{1}{2} b_4 (s_{\mu\nu} - t_{\mu\nu})$$

Tensor Polarization

$$r_{\mu\nu} = \frac{1}{\nu^2}(q \cdot E * q \cdot E - \frac{1}{3}\nu^2 k) g_{\mu\nu}$$
$$s_{\mu\nu} = \frac{2}{\nu^2}(q \cdot E * q \cdot E - \frac{1}{3}\nu^2 k) \frac{p_\mu p_\nu}{\nu}$$
$$t_{\mu\nu} = \frac{1}{2\nu^2}(q \cdot E * p_\mu E_\nu + q \cdot E * p_\nu E_\mu + q \cdot E p_\mu E_\nu * + q \cdot E p_\nu E_\mu * - \frac{4}{3}\mu p_\mu p_\nu)$$
$$u_{\mu\nu} = \frac{1}{\nu}(E_\mu * E_\nu + E_\nu * E_\mu + \frac{2}{3} M^2 g_{\mu\nu} + \frac{2}{3} p_\mu p_\nu)$$

$$\nu = p \cdot q$$
$$E^2 = -M^2$$
$$k = 1 + \frac{M^2 Q^2}{-i\nu^2}$$
$$s^\sigma = -\frac{i}{M^2} \epsilon^{\sigma\alpha\beta\tau} E_\alpha * E_\beta p_\tau$$

b_1 STRUCTURE FUNCTION

	Nucleon	Deuteron
F_1	$\frac{1}{2}\sum_q e_q^2[q_\uparrow^{1/2} + q_{\downarrow\uparrow}^{-1/2}]$	$\frac{1}{3}\sum_q e_q^2[q_\uparrow^1 + q_\uparrow^{-1} + q_\uparrow^0]$
g_1	$\frac{1}{2}\sum_q e_q^2[q_\uparrow^{1/2} - q_\downarrow^{-1/2}]$	$\frac{1}{2}\sum_q e_q^2[q_\uparrow^1 - q_\downarrow]$
b_1	$\cdots$	$\frac{1}{2}\sum_q e_q^2[2q_\uparrow^0 - (q_\downarrow^1 + q_\downarrow^{-1})]$

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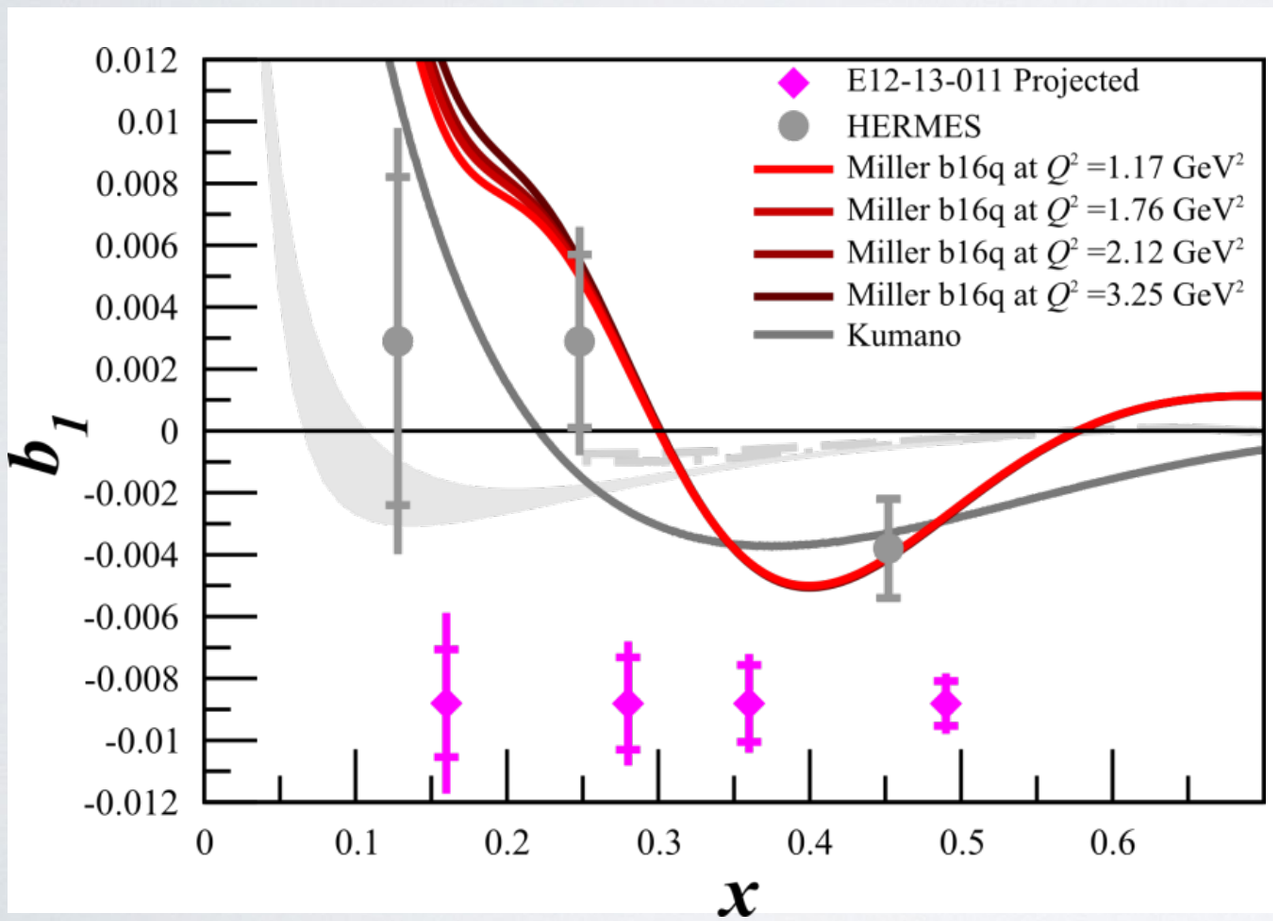
b_1	$\cdots$	$\frac{1}{2}\sum_q e_q^2[2q_\uparrow^0 - (q_\downarrow^1 + q_\downarrow^{-1})]$

$q_\uparrow^m\ (q_\downarrow^m)$ Number density of quarks with spin up(down) along the z axis in a hadron (nucleus) with helicity m with momentum along the z axis.

Hermes PRL **95**, 242001 (2005)



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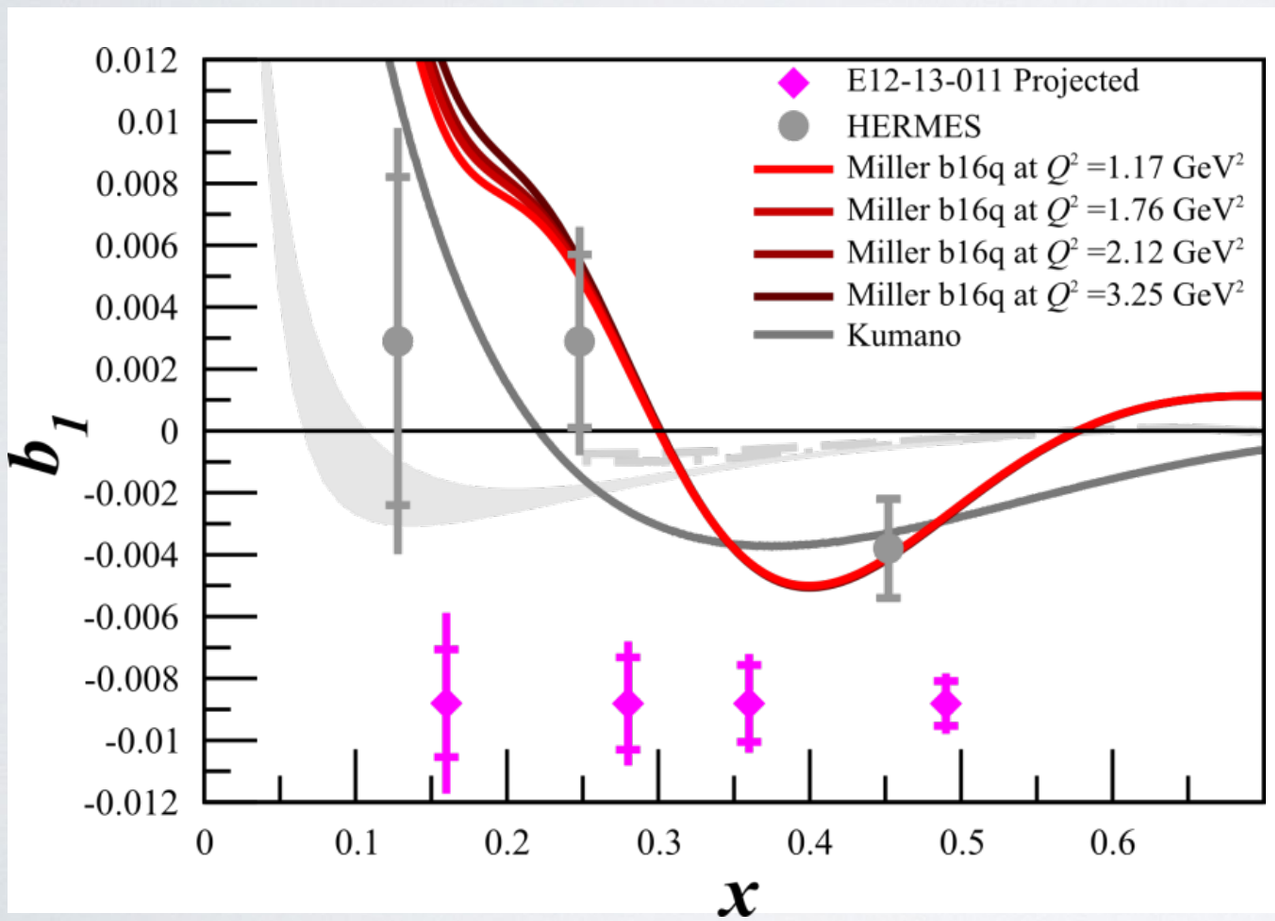
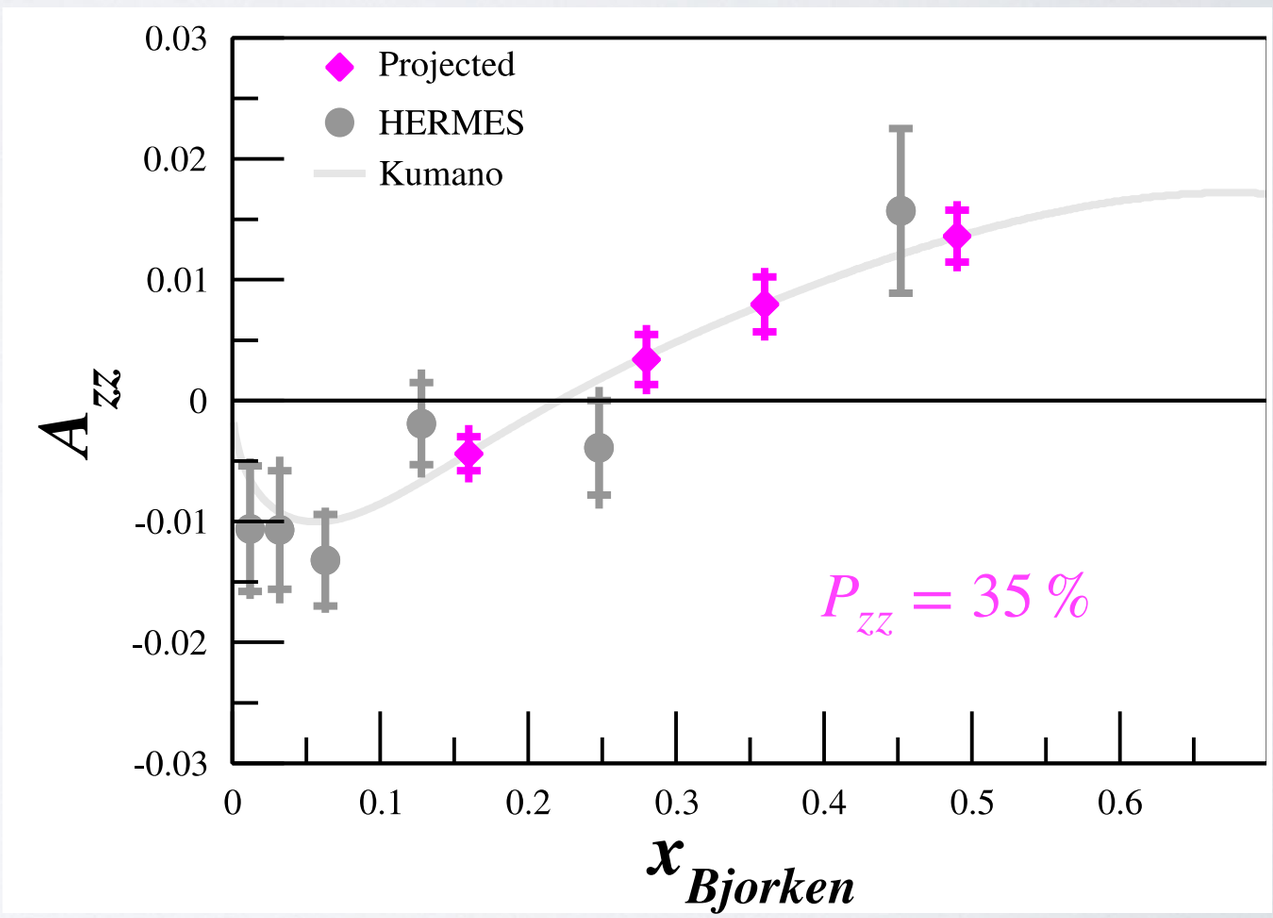
Hermes PRL **95**, 242001 (2005)

New tensor structure functions[1]
Close-Kumano sum rule[2]
6-quark hidden color[3]
Pionic effects[3][4]
Polarized sea quarks[4]

[1] P Hoodbhoy*et al*, Nucl. Phys. **B312,**571 (1989)
[2] FE Close, S Kumano, Phys. Rev. **D42,**2377 (1990)
[3] G Miller, Phys. Rev. **C89,**045203 (2014)
[4] S Kumano, Phys. Rev. **D82,**017501 (2010)





Measurements of the Quasi-Elastic and Elastic Deuteron Tensor Asymmetries

A Proposal to Jefferson Lab PAC 44
(Update to PR12-15-005 and LOI12-14-002)

E. Long,[†] [‡] K. Slifer,[†] P. Solvignon,[†] T. Badman, L. Hammed, M. Holtrop, N. Lajoie, S. Li, K. McCarty, R. Paremuzyan, D. Ruth, S. Santiesteban, B. Yale, R. Zielinski
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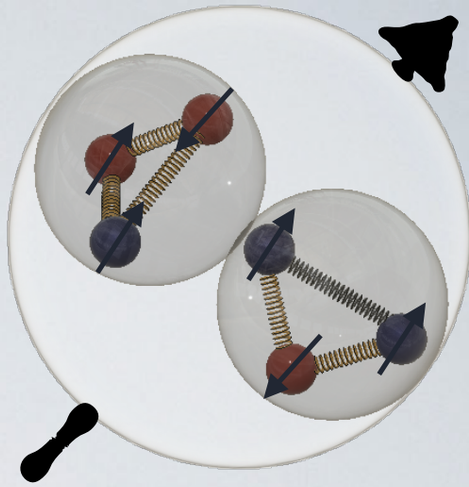

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G. A. Miller
University of Washington, Seattle, WA 98195

D. Androic
University of Zagreb, HR-10000 Zagreb, Bijenicka 32, Croatia

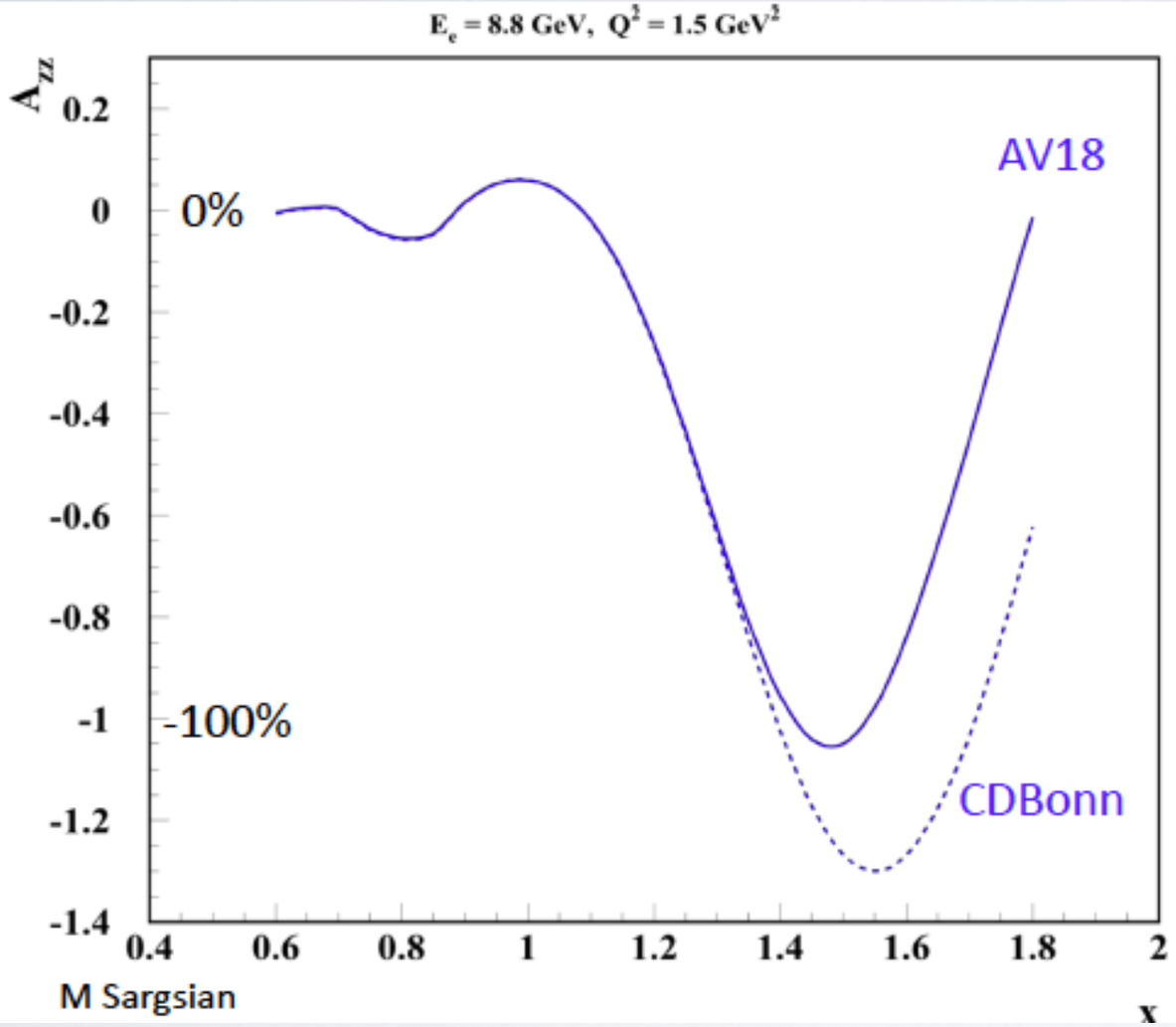
- Solid tensor polarized ND3 target
- A- physics rating
- 45 Days at Hall C

A_{zz} TENSOR ASYMMETRY

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

"further explores the nature of short-range correlations, the discovery of which was one of the most important results of the 6 GeV nuclear program"

PAC44 Theory report



$S \rightarrow u(k)$

$D \rightarrow w(k)$

$$A_{zz} \propto \frac{\frac{1}{2}w^2 - u(k)w(k)\sqrt{(2)}}{u^2(k) + w^2(k)}$$

can be used to separate between soft and hard wavefunctions.

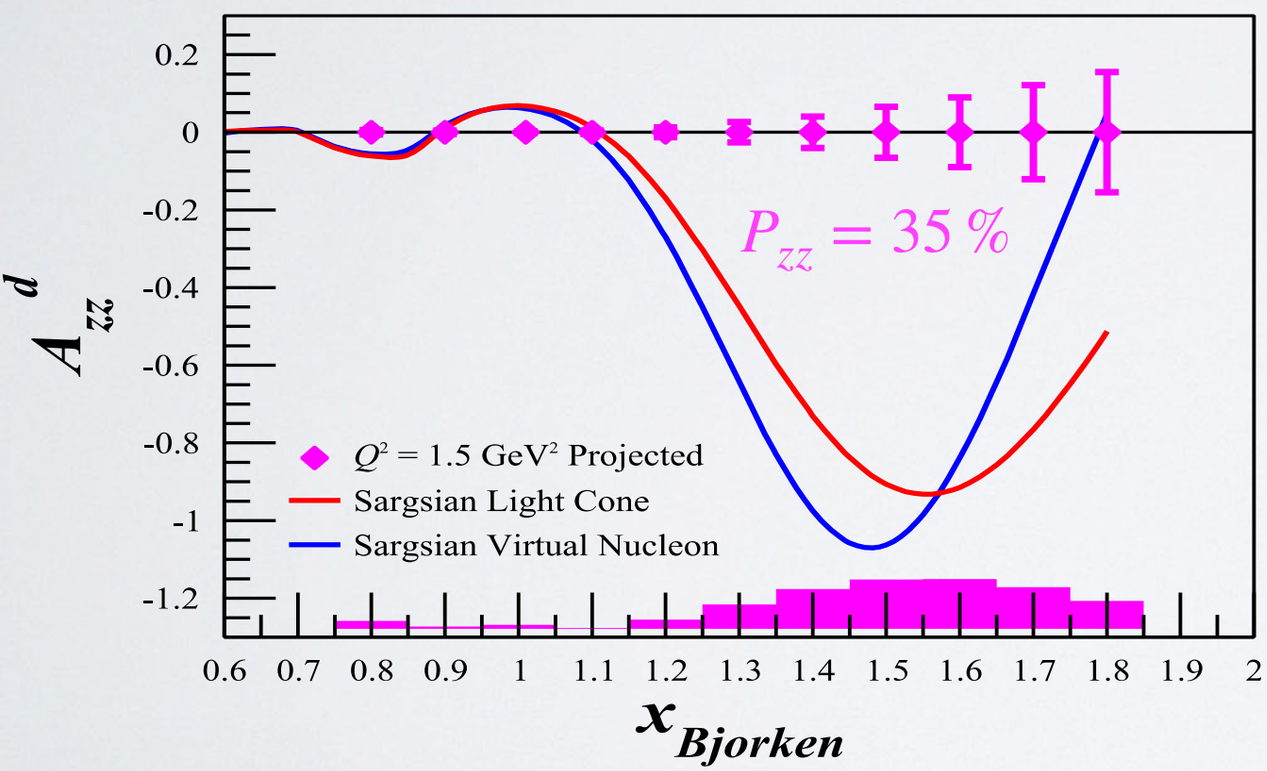
The success of the description of the deuteron using realistic WFs seems to confirm the existence of a short range nucleon—nucleon repulsive interaction. However this evidence is rather indirect.

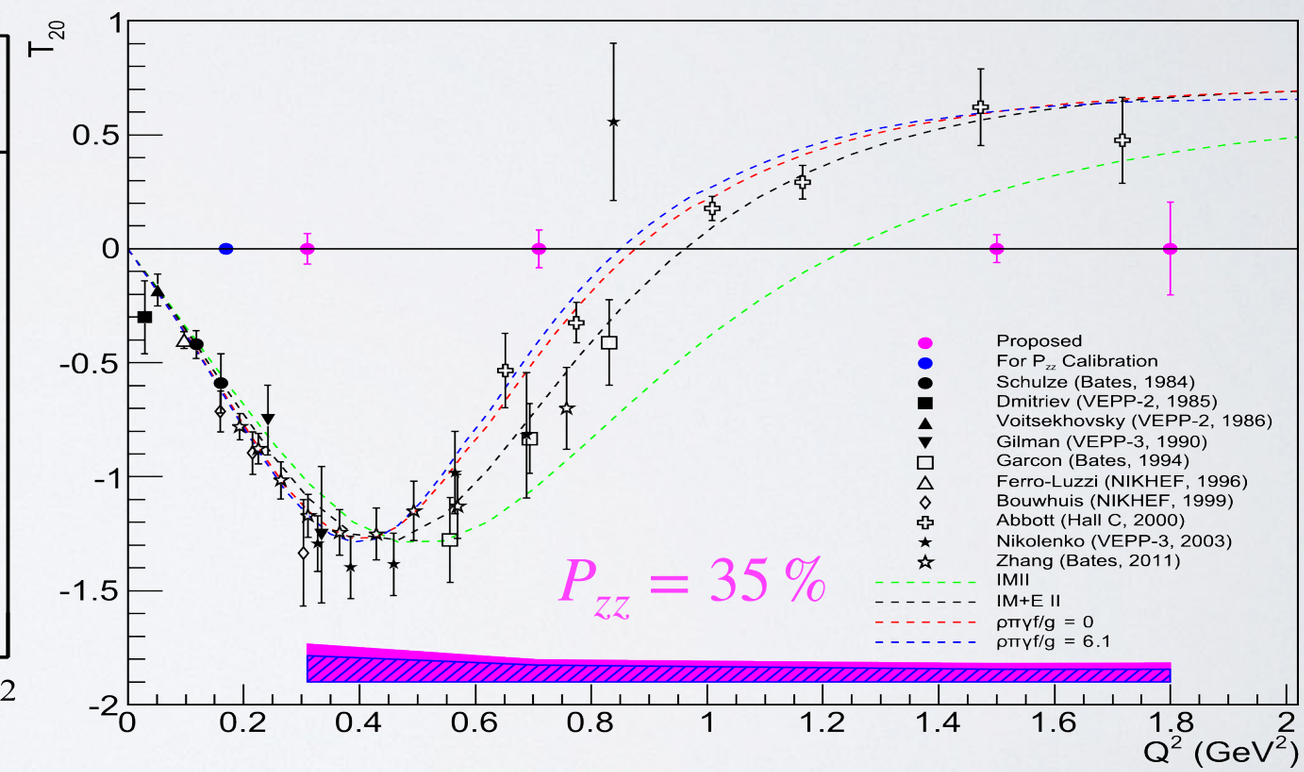
LL Frankfurt, MI Strikman, Phys. Rept. 76 215 (1981)

A_{zz} PROJECTED RESULTS

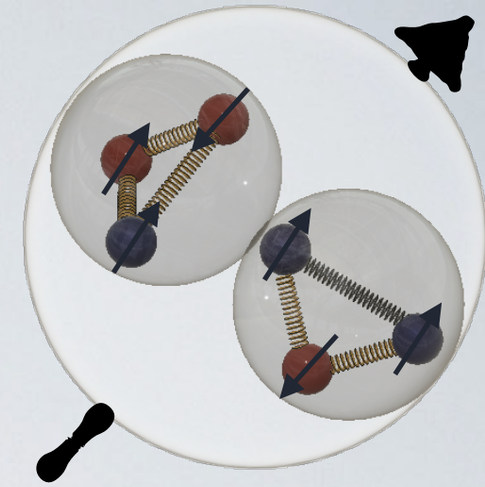
First Azz measurement in the QE region.
T20 elastic measurement.
Differentiate light cone and VN models[1]
Final state interaction models[2]

[1] M Sargsian, Tensor Spin Observables (2014).
[2] W Cosyn, M Sargsian, arXiv:1407.1653





NEW EXPERIMENTS ON THE WAY



A Letter of Intent to Jefferson Lab PAC 44, June 6, 2016

Search for Exotic Gluonic States in the Nucleus

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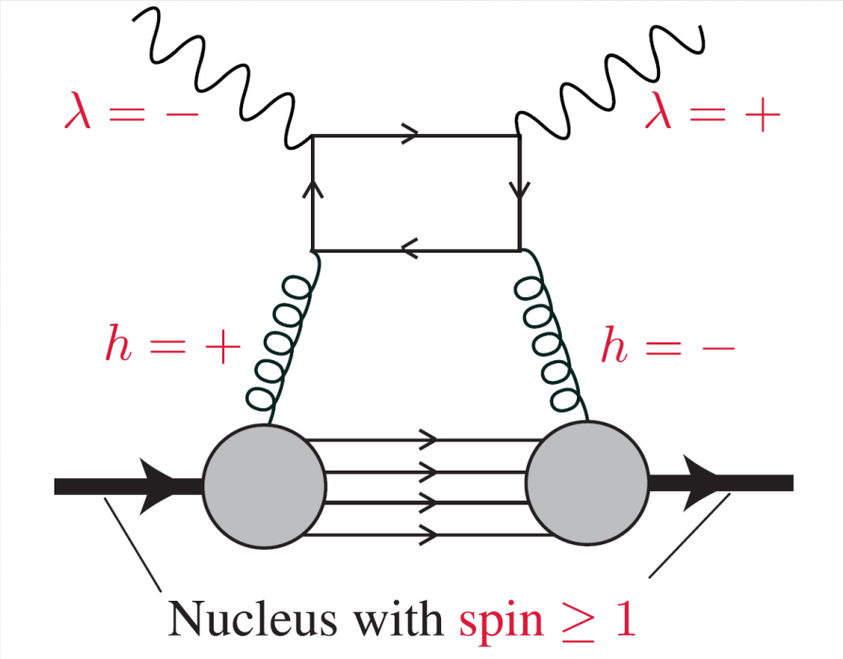
Abstract

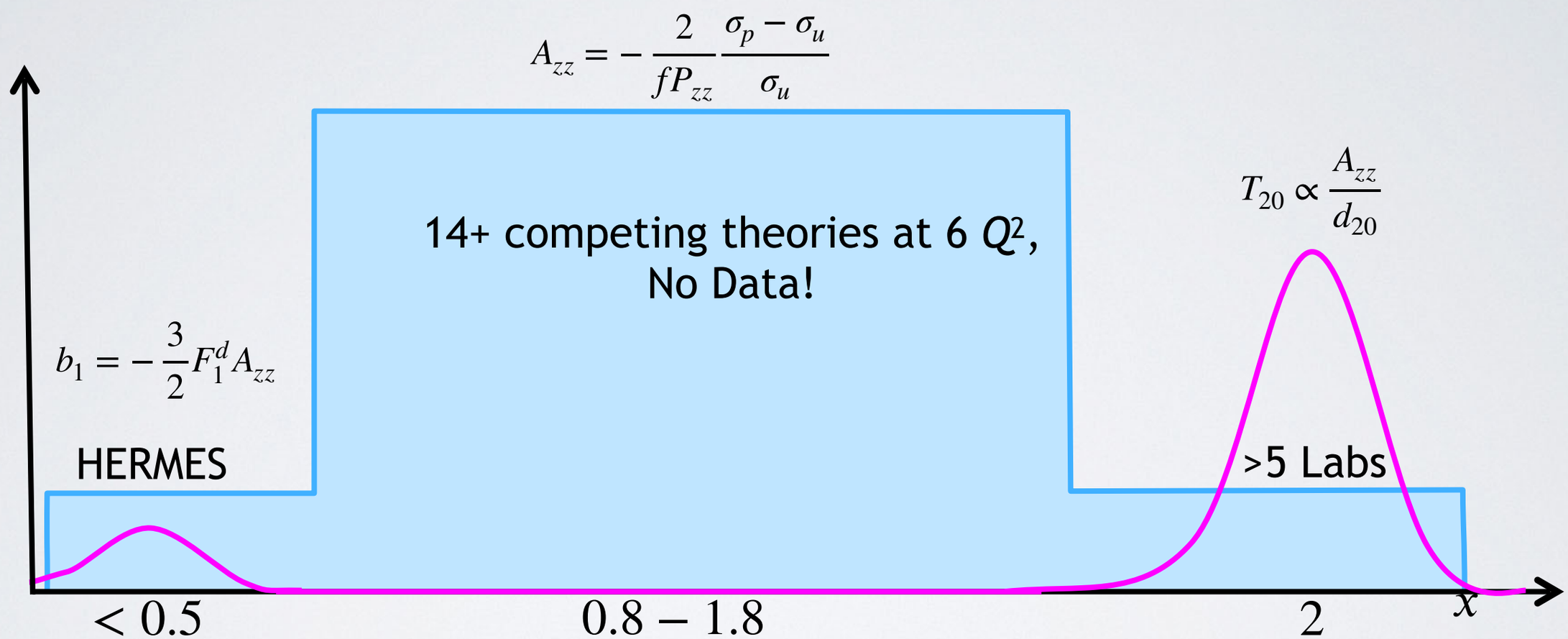
We renew our intent to submit a proposal to perform a search for a non-zero value of the unmeasured hadronic double helicity flip structure function $\Delta(x, Q^2)$, predicted to be sensitive to gluons in the nucleus. This would be performed with an unpolarized electron beam and transversely polarized, spin-1, nuclear target. This structure function was first identified by Jaffe and Manohar in 1989 as "a clear signature for exotic gluonic components in the target," and a recent lattice QCD result by our collaborators has prompted renewed interest in the topic. An inclusive search with deep inelastic scattering, below x of 0.3, via single spin tensor asymmetries may be feasible using the CEBAF 12 GeV electron beam and JLab/UVa solid polarized target, and would represent the first experimental exploration of this quantity.



Non-zero values indicates exotic gluons components[1]
Insensitive to bound nucleons or pions[1]

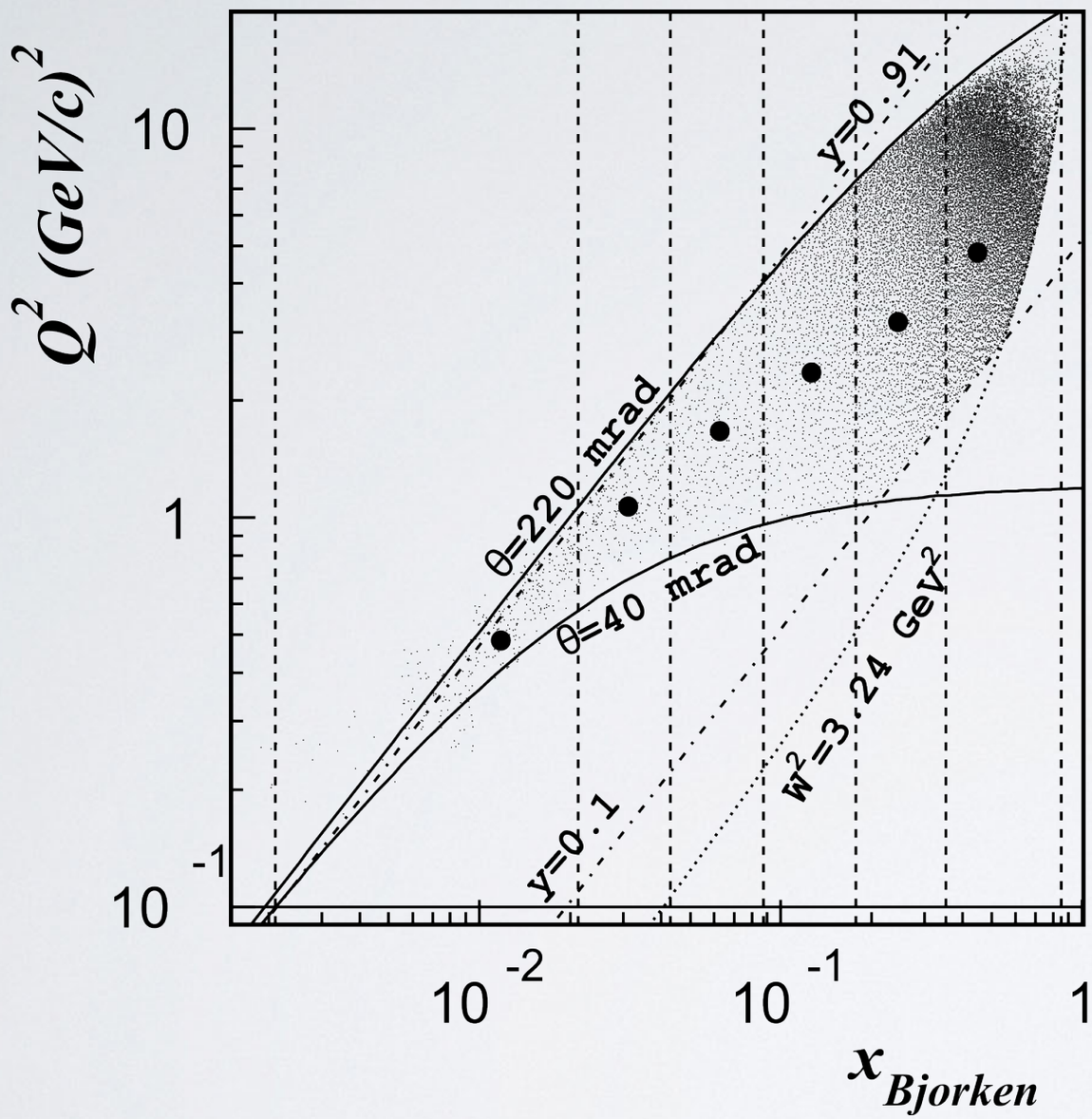
[1] R Jaffe, A Manohar, Phys. Lett. **B223,** 218 (1989)

- ^{14}N polarized tensor target
- Measures the $\Delta(x, Q^2)$ double helicity flip structure function



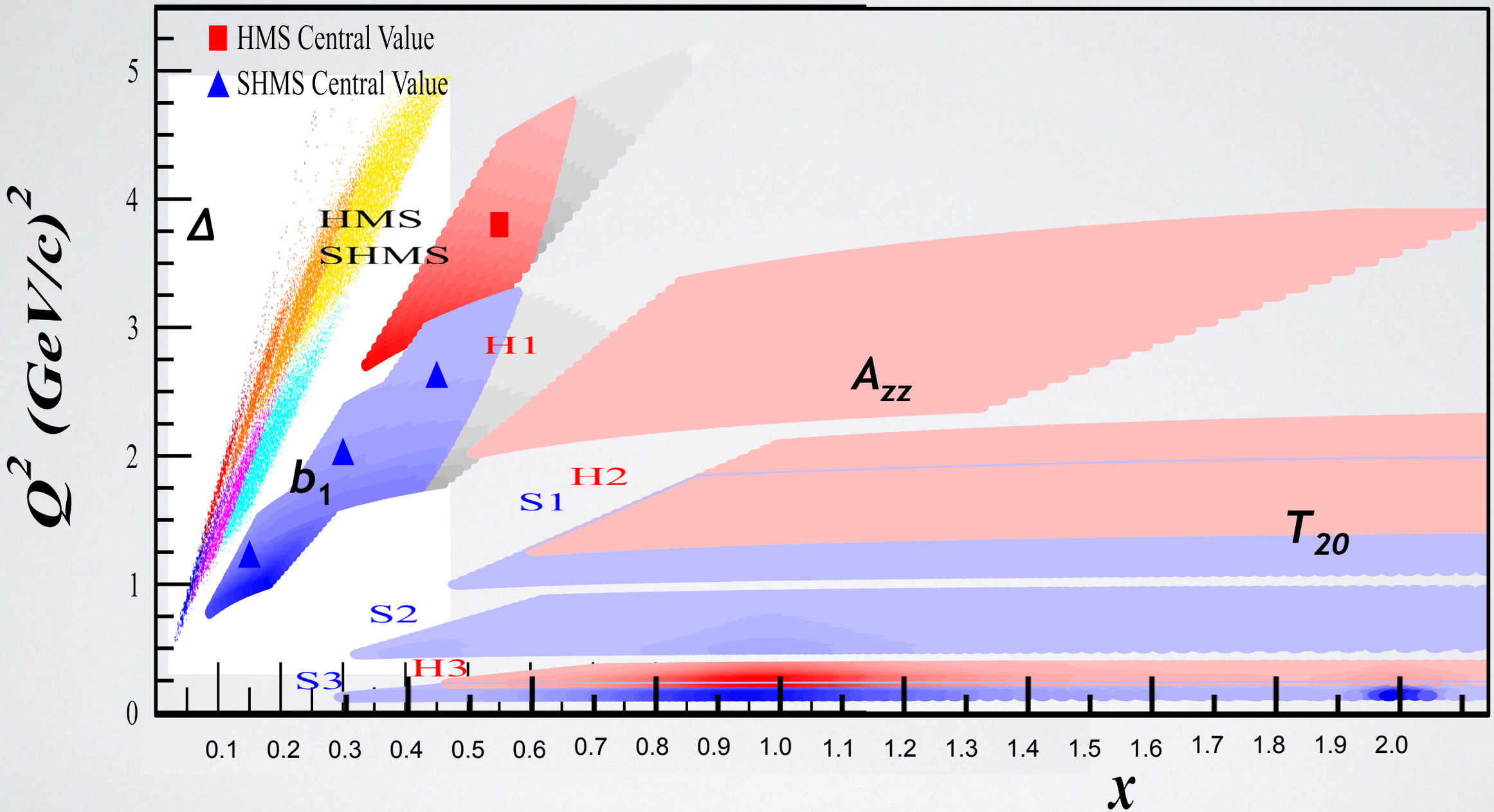
Slifer, K. Polarized Light Ion Physics with EIC (2018).

Long, E. SPIN (2018).



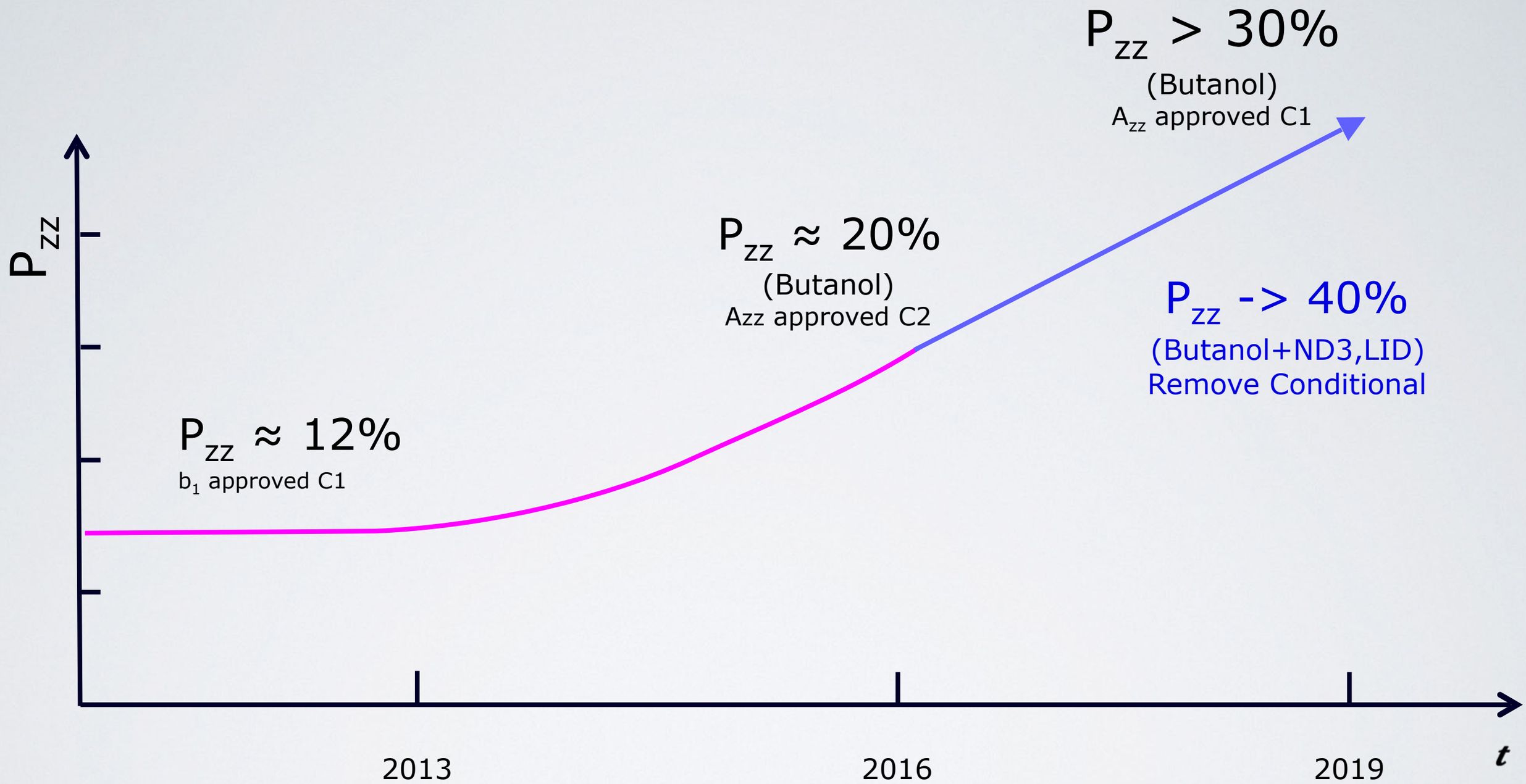
Hermes Kinematics

JLab Kinematics Coverage



Courtesy of E Long.

STATUS OF THE TENSOR TARGET

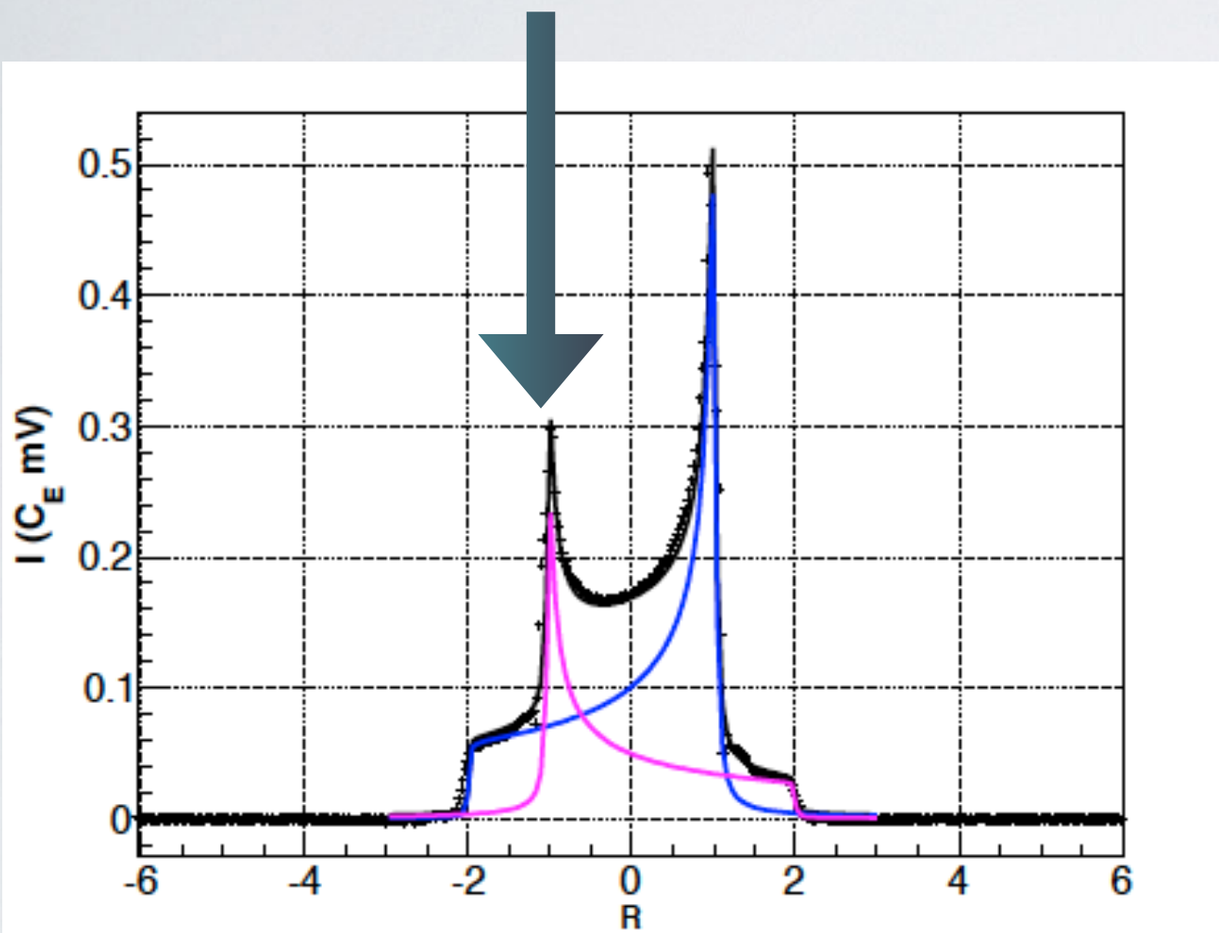


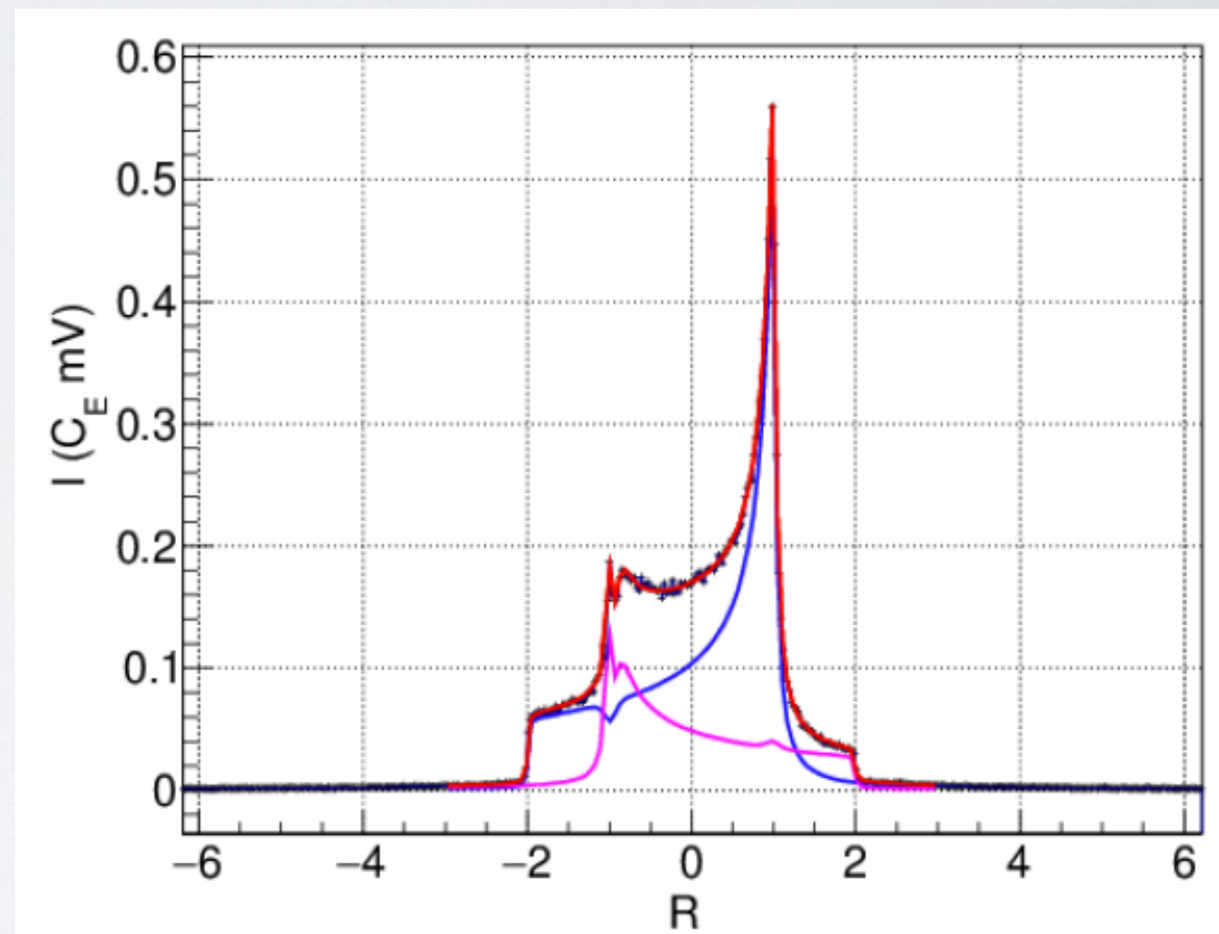
Courtesy of K Slifer.

Tensor enhancement: RF hole Burning

Selective excitation to reduce the size of the smaller transition area.

RF Saturation





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

The UVa Solid Polarized Target Group has shown 38% tensor polarization in Butanol.

SOLID POLARIZED TARGET LABS

SOLID POLARIZED TARGET GROUP *at the* UNIVERSITY *of* VIRGINIA

Jefferson Lab
Thomas Jefferson National Accelerator Facility

Slifer Lab

University of New Hampshire

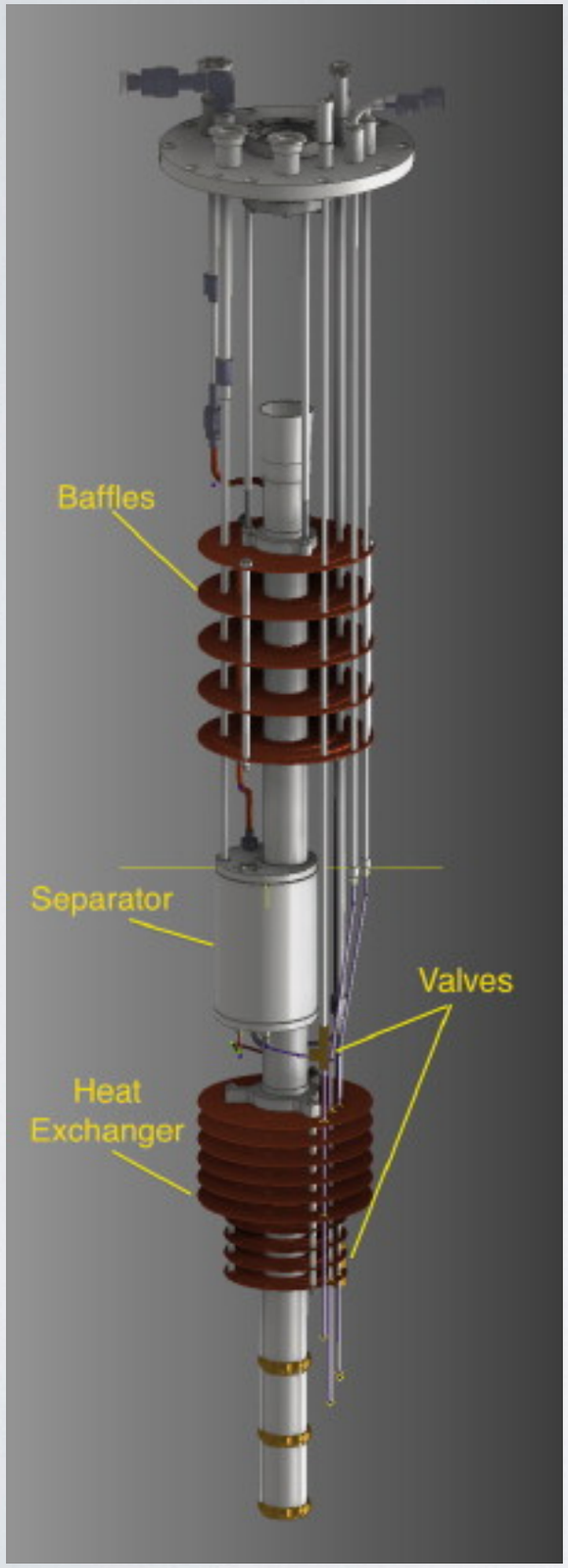
Long Lab

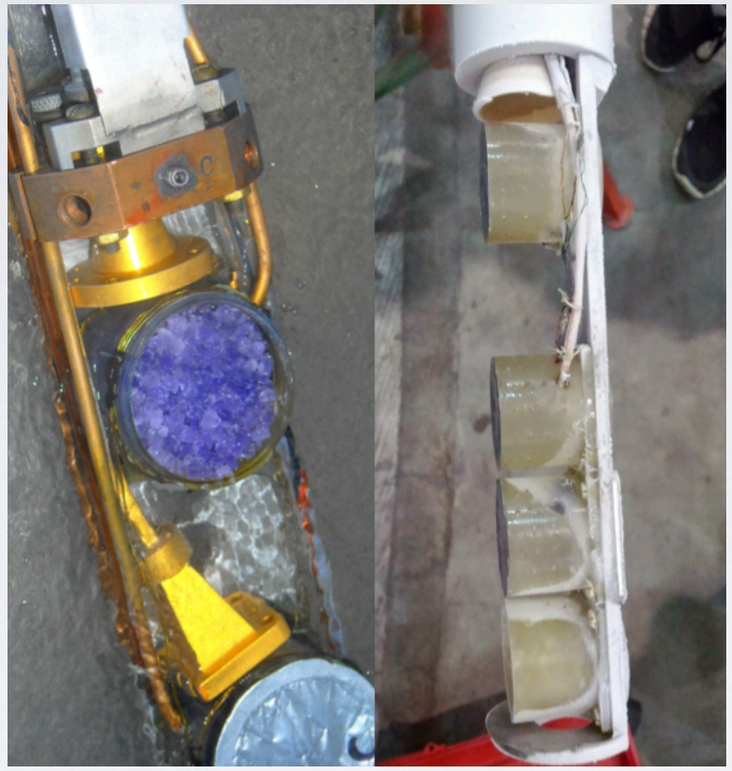
In collaboration with:

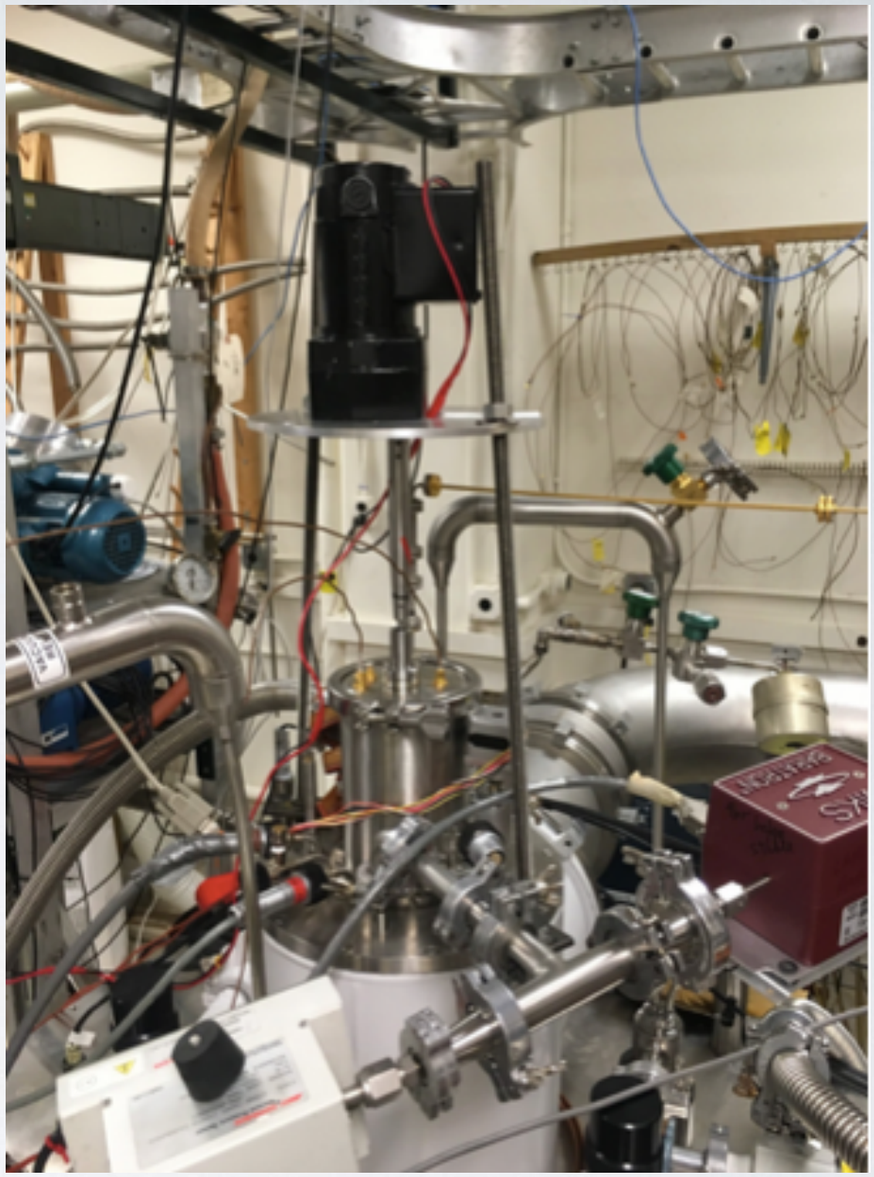
UNIVERSIDAD TECNICA FEDERICO SANTA MARIA

EX UMBRA IN SOLEM

JLab/ UVa Target groups Collaboration

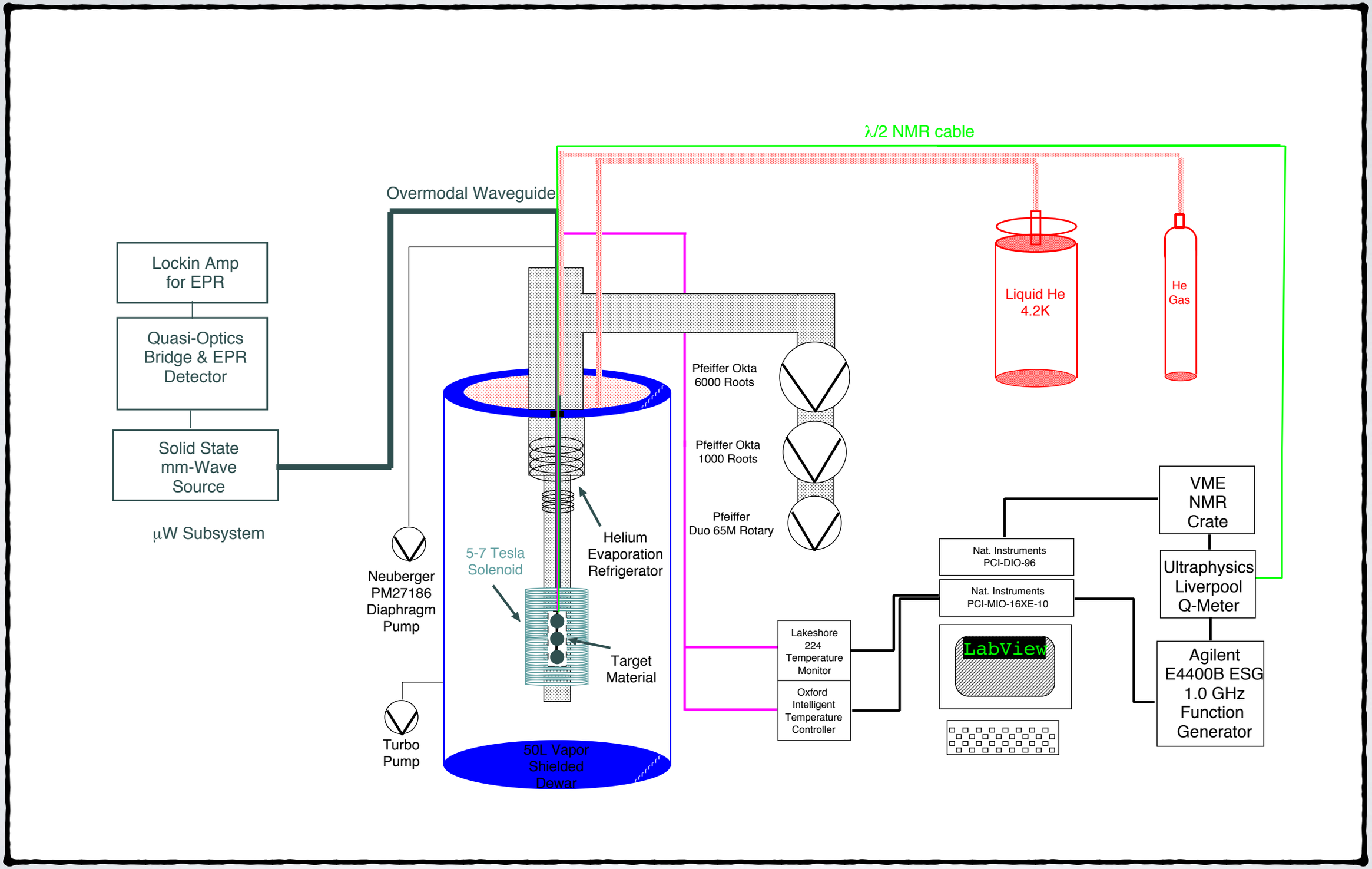






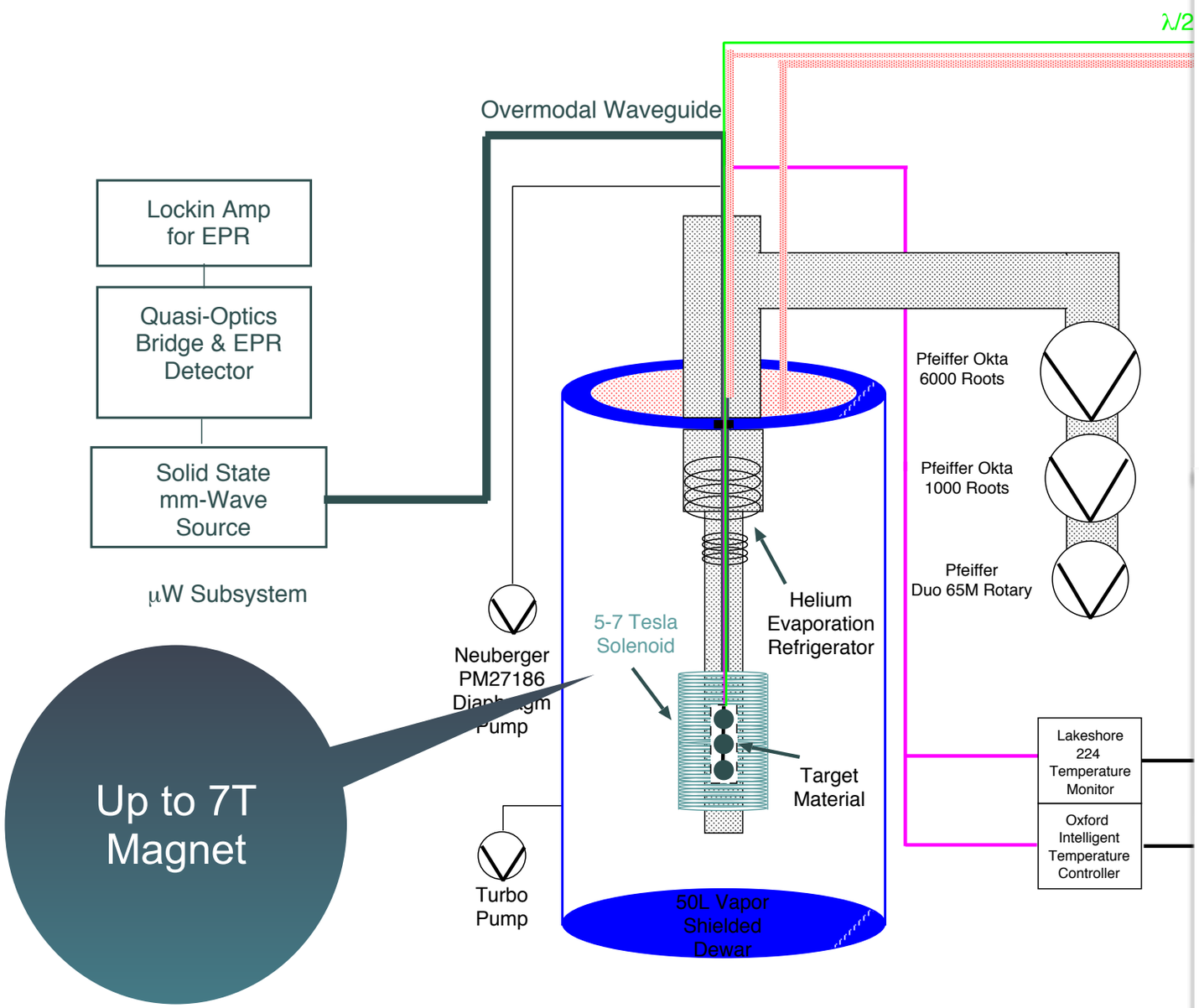
- Several JLab polarization experiments count with JLab/UVa target groups collaboration.
- UNH plans to join the collaboration with its new Polarization Lab.

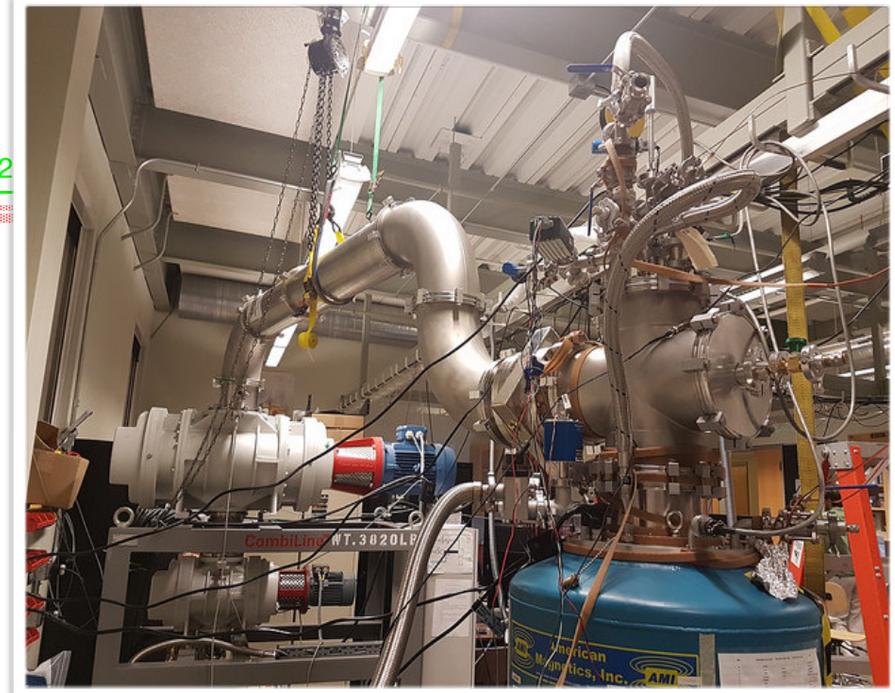
UNH POLARIZED TARGET SYSTEM

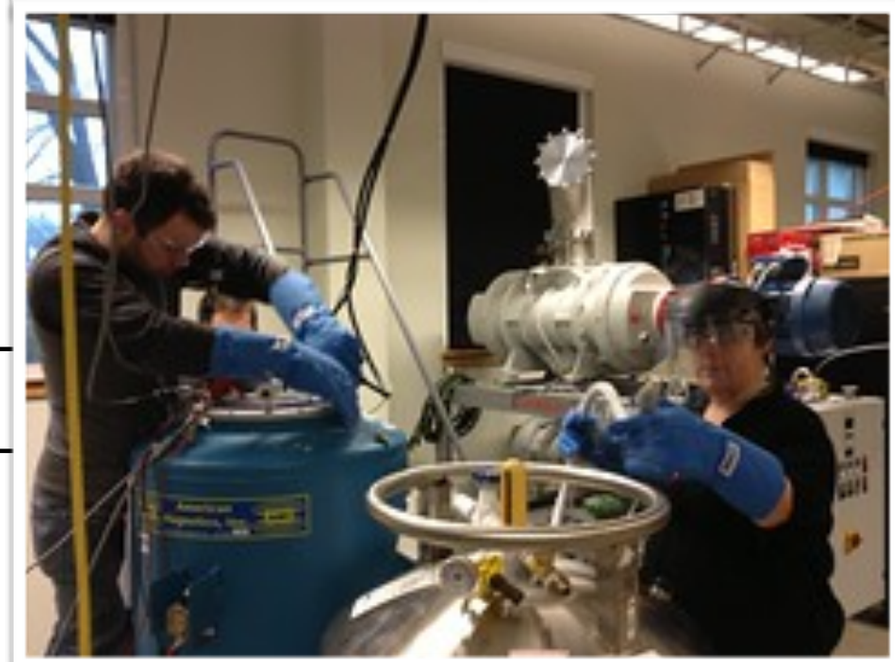


Courtesy of K Slifer.

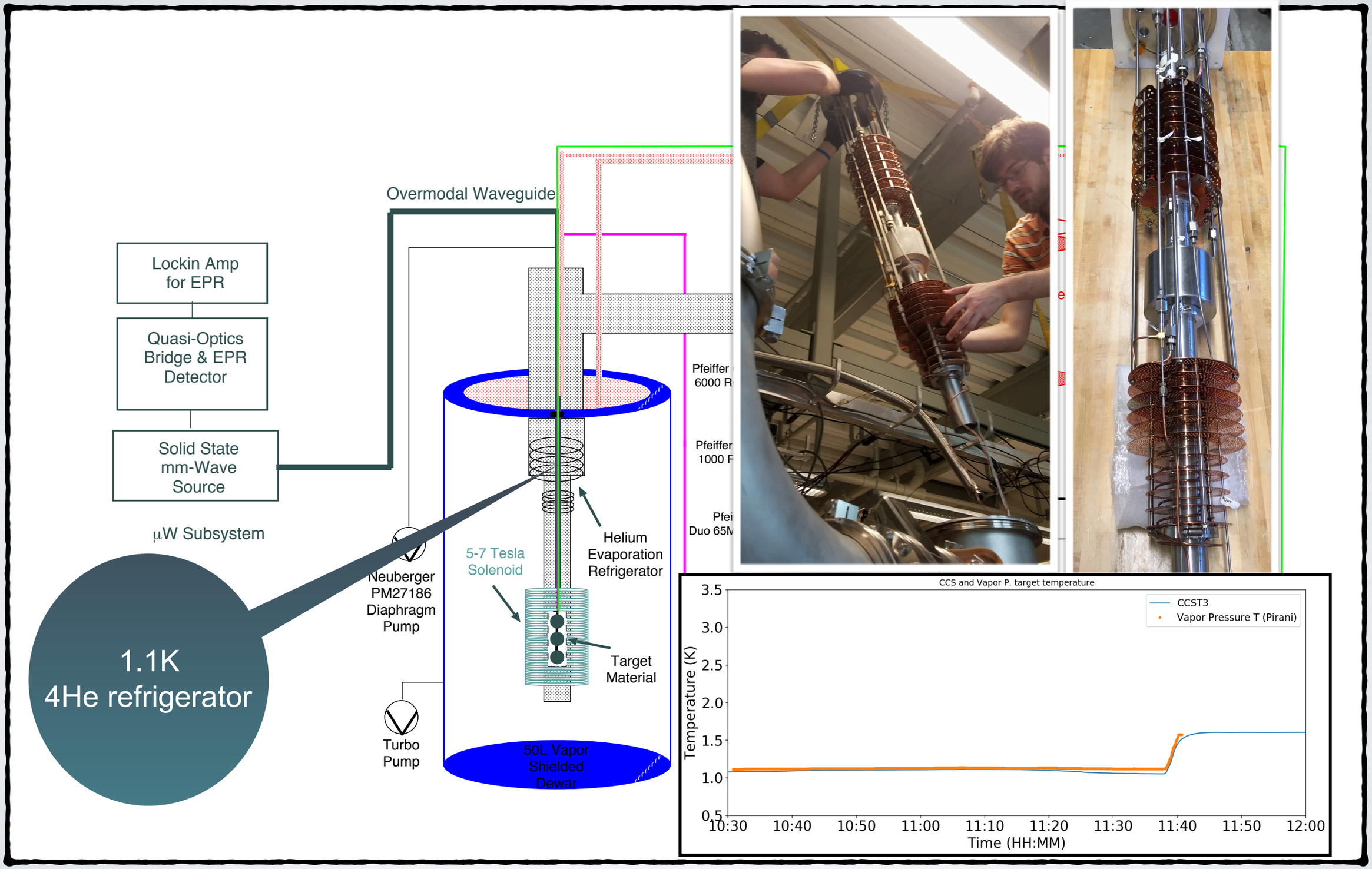
UNH POLARIZED TARGET SYSTEM







UNH POLARIZED TARGET SYSTEM



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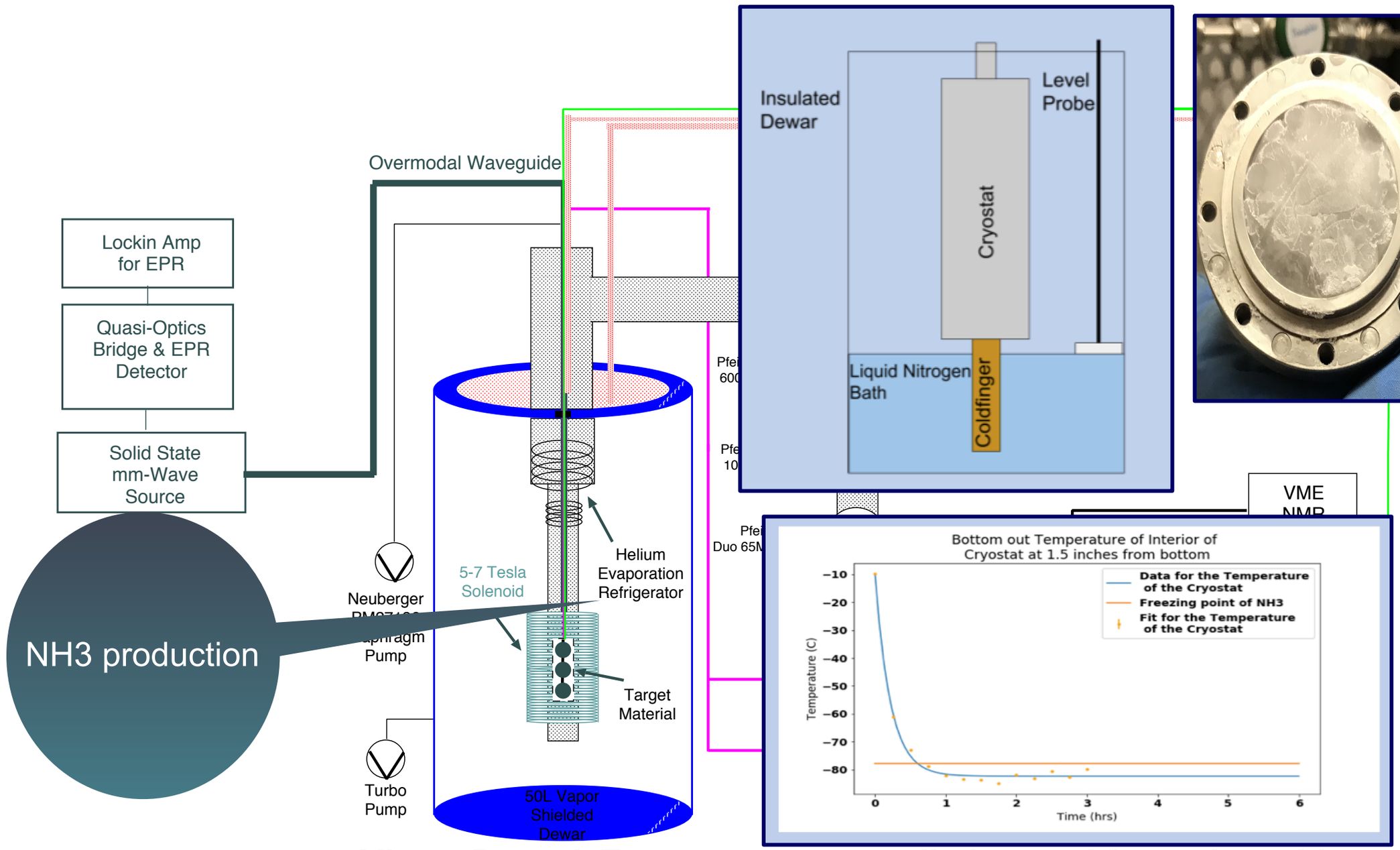
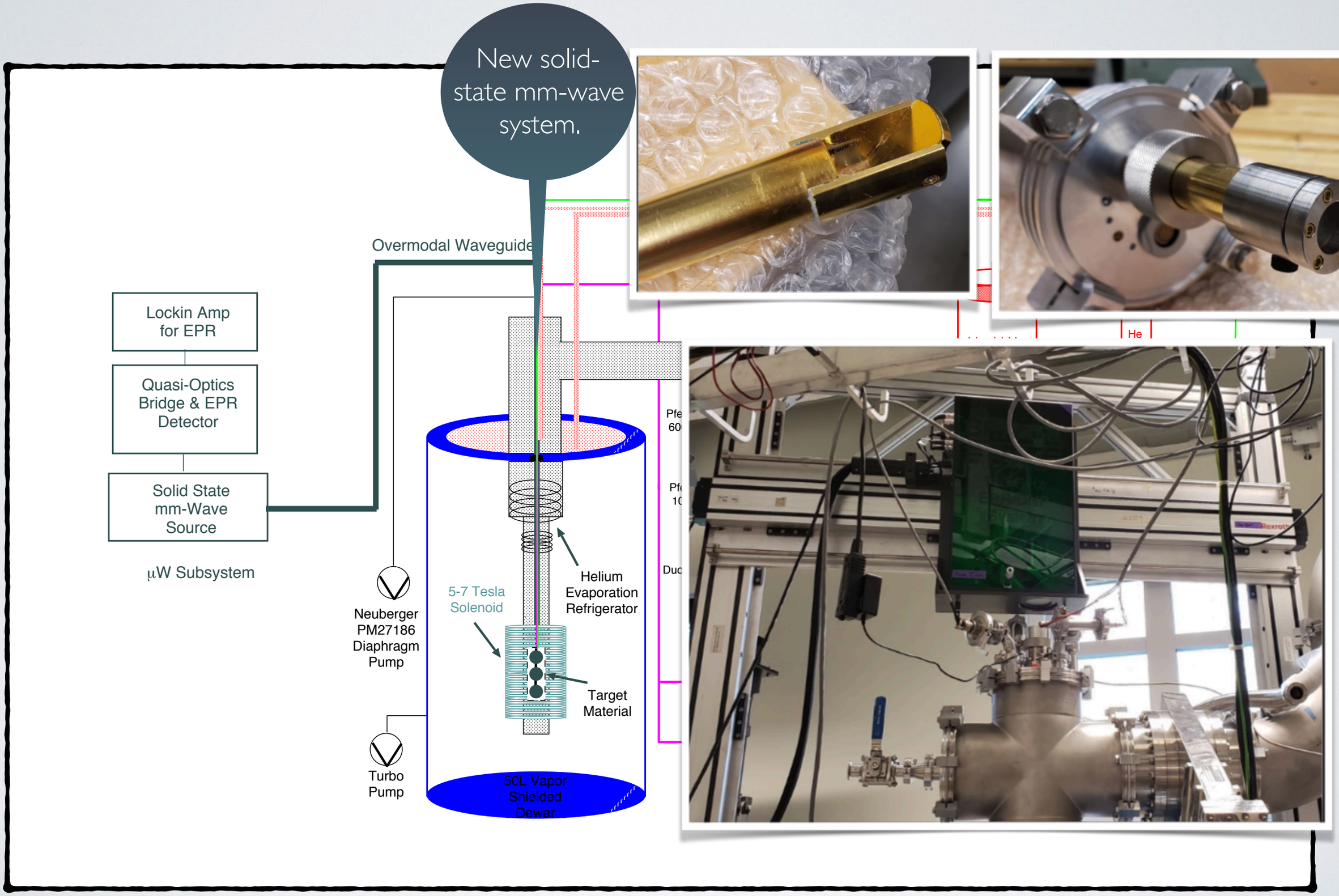
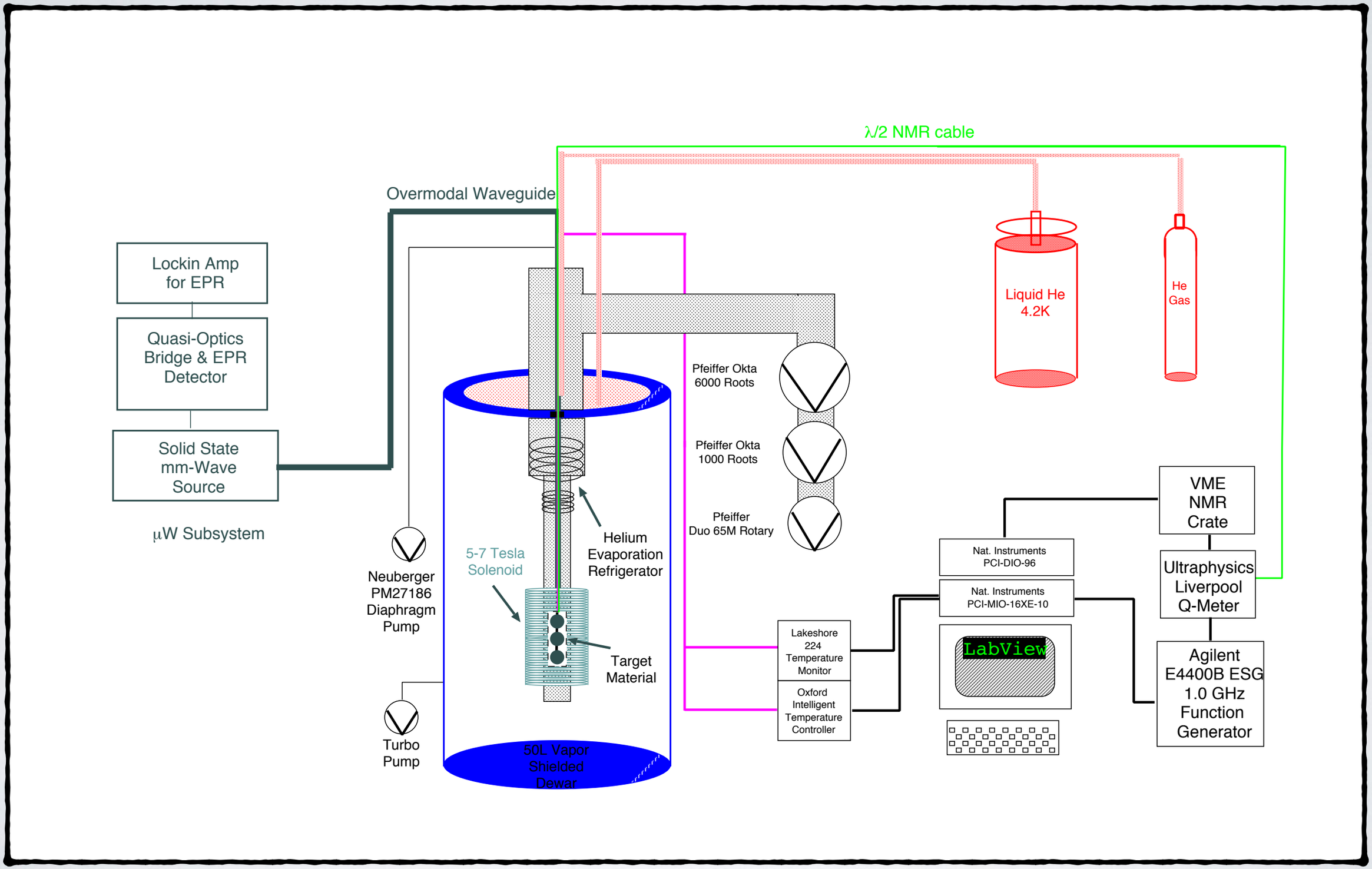


Aliaga, D. et al. Temperature-controlled crystal formation with a new prototype cryogenic device (2018) , Manuscript in preparation.

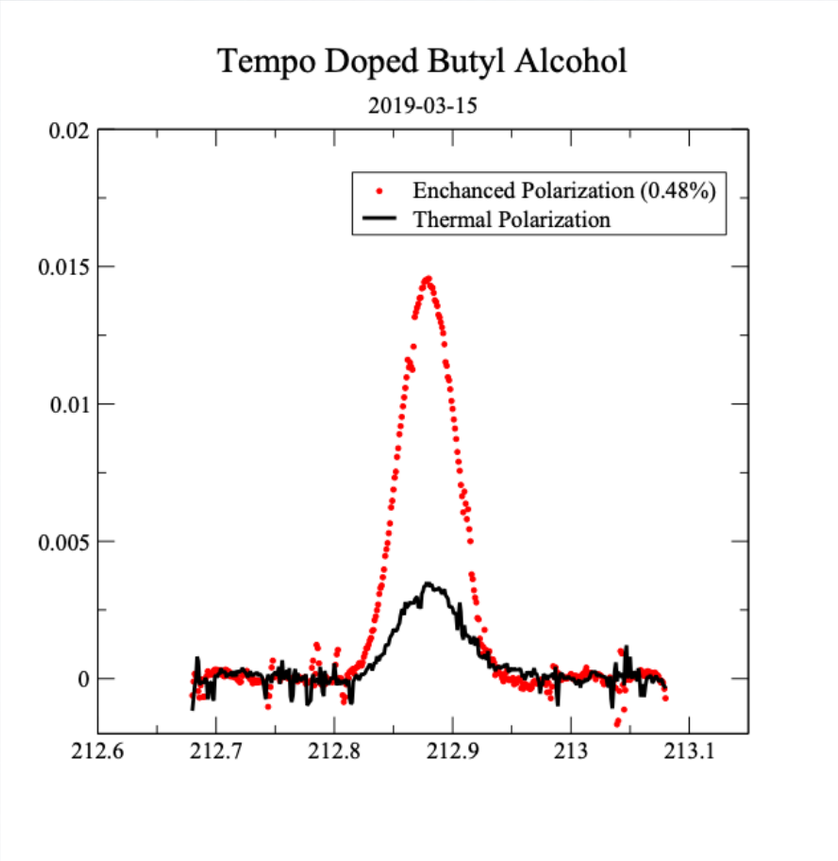
UNH POLARIZED TARGET SYSTEM

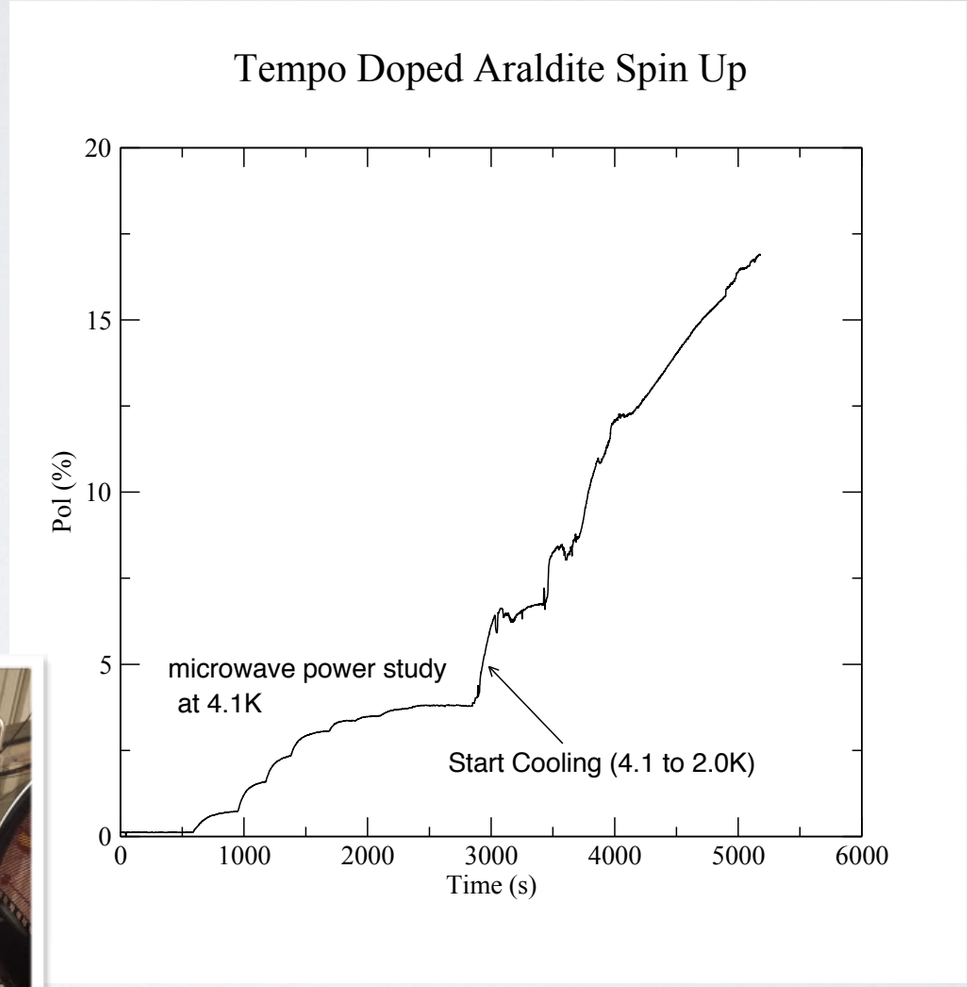


UNH POLARIZED TARGET SYSTEM



UNH PROTON POLARIZATION



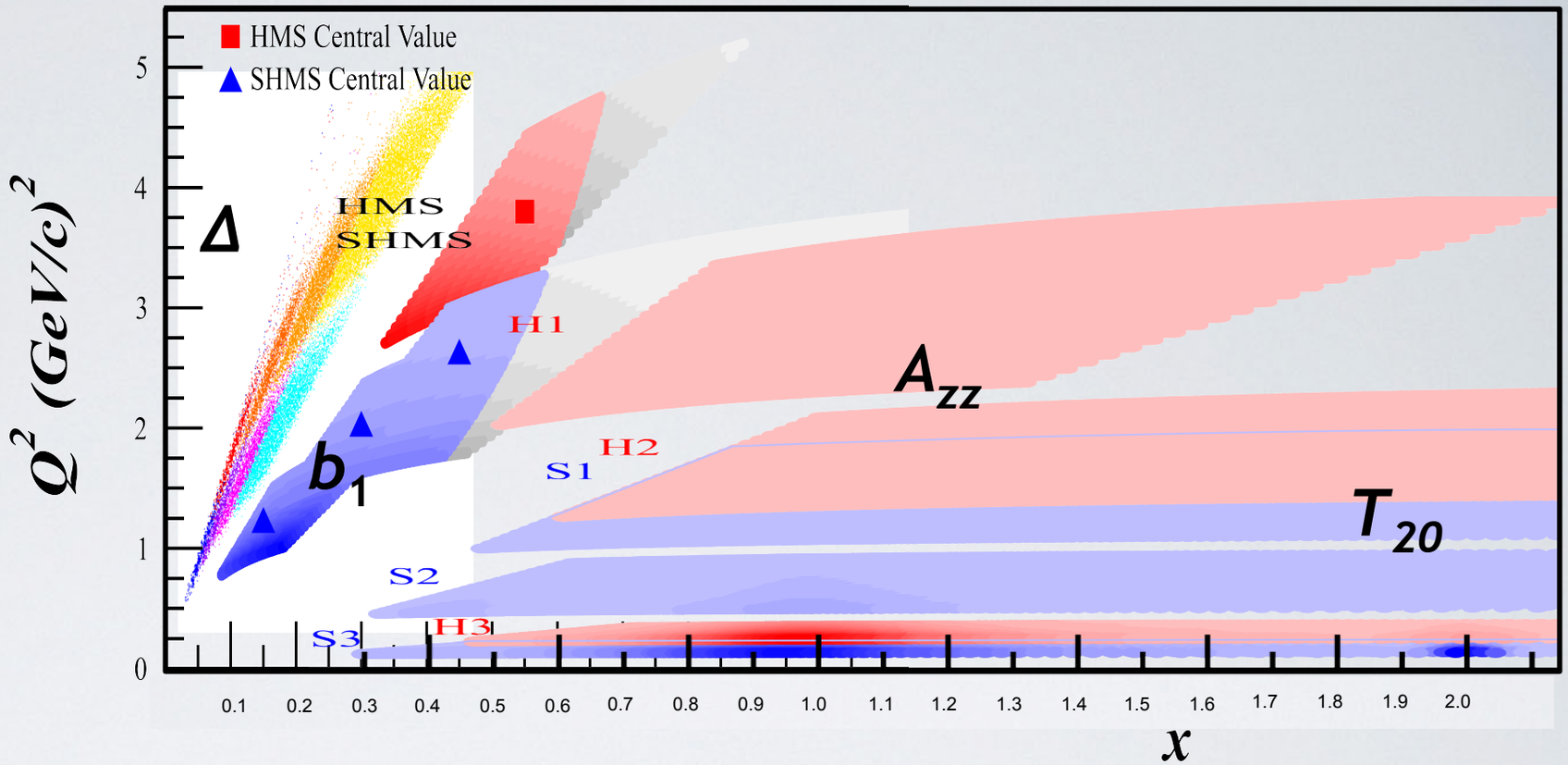


New 3D-Printed Kel-F target cups.

New 3D-Printed target equipment.

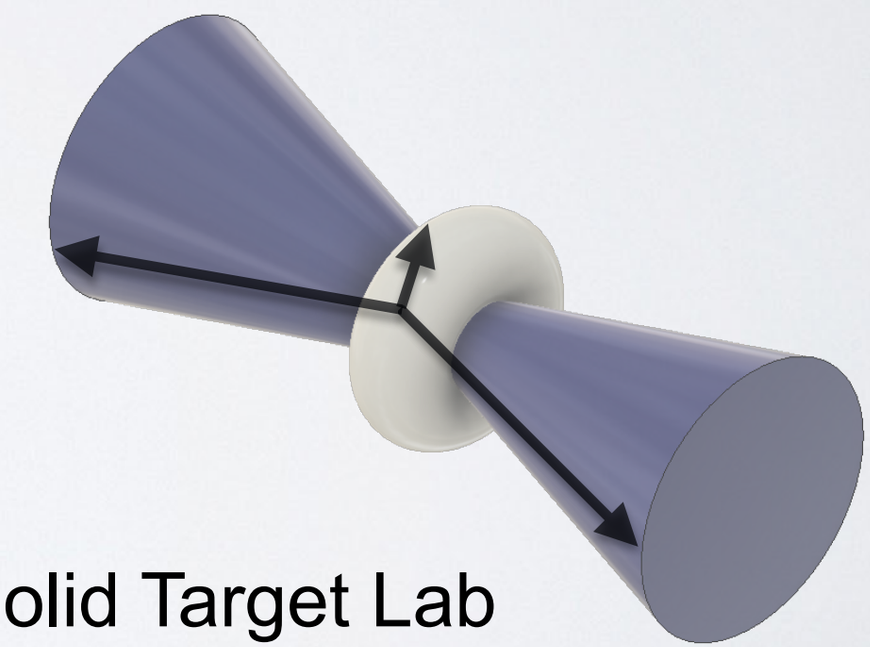
Courtesy K Slifer.

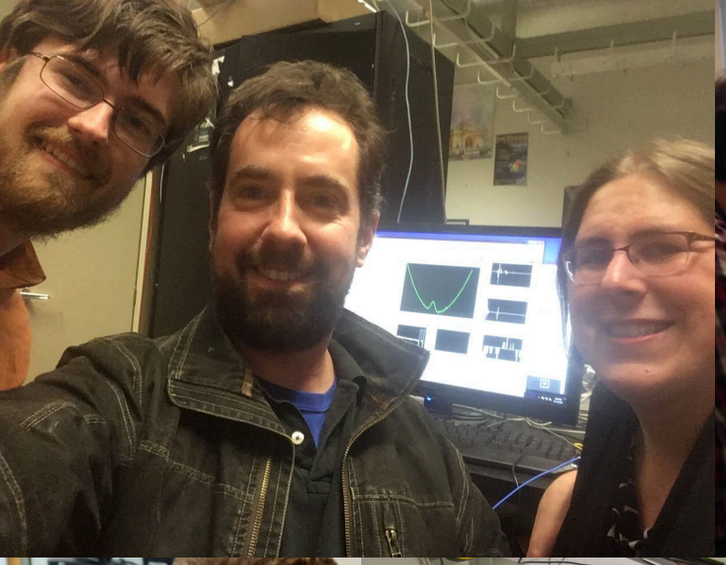
SUMMARY

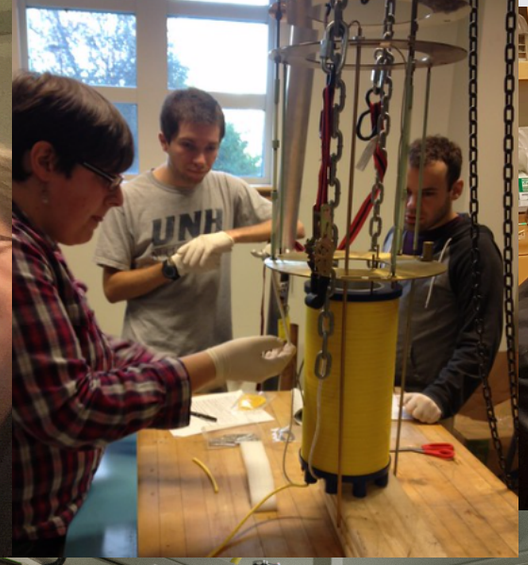


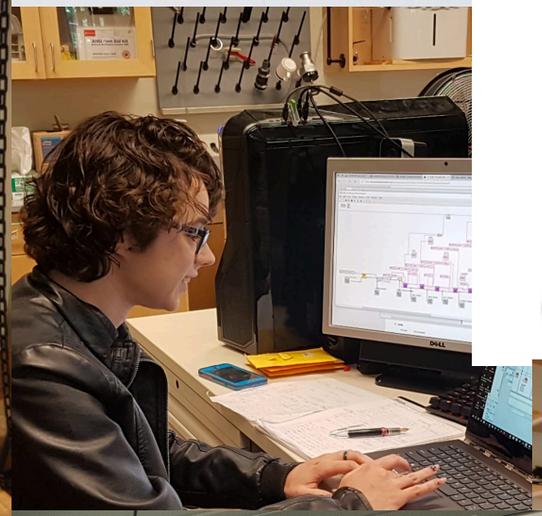
Tensor program at Jefferson Lab

- 2 experiments approved
  E12-13-011
  E12-15-005
- More experiments coming up.
  LOI12-16-006
- 38% of Tensor polarization in Butanol
  Keller, D. Eur.Phys.J. A53 (2017) .
- UNH has a new operational Polarized Solid Target Lab









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