The b1 (E12-13-011) Polarized Target Experiment

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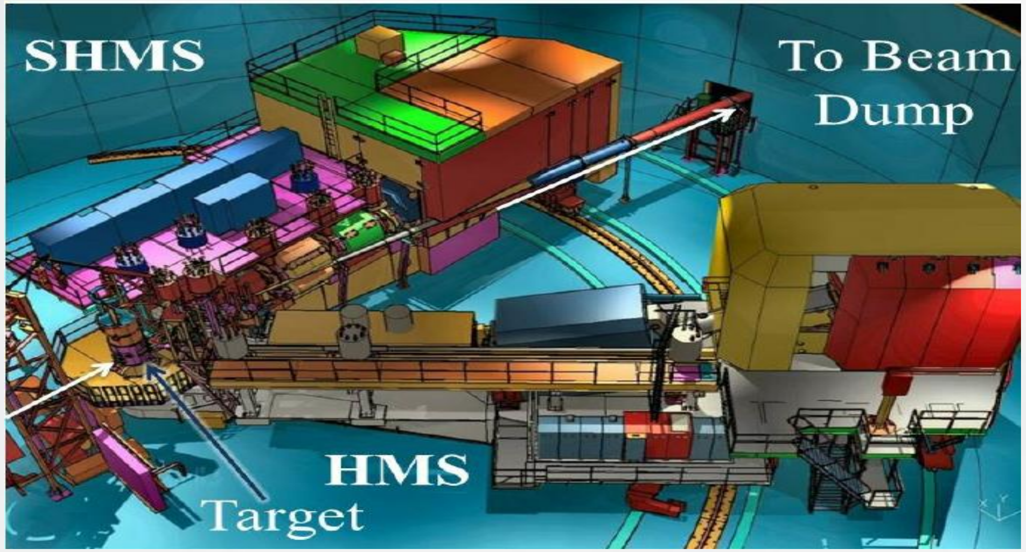
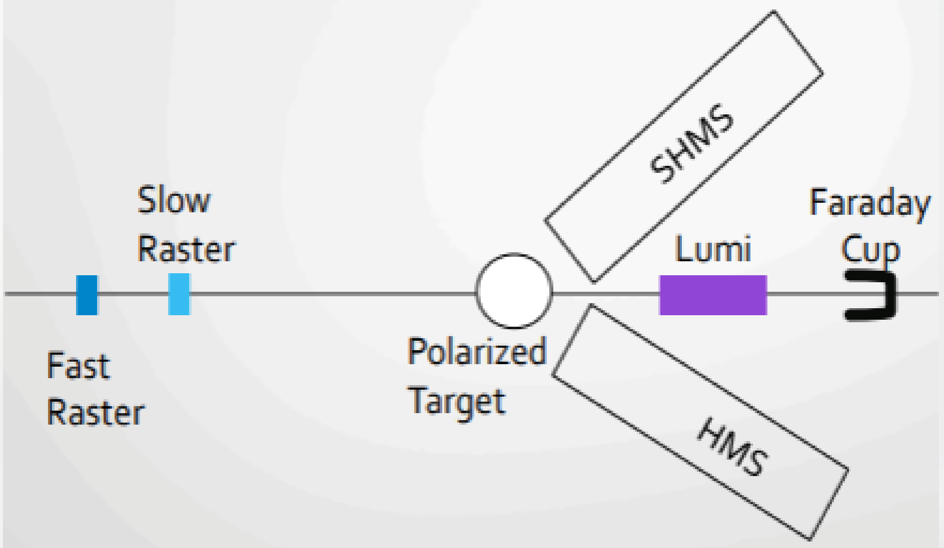
HUGS | 40 years!

Contents

b_1 (E12-13-011) and A_{zz} (E12-15-005) Experiments in the Hall C (Jefferson Lab)

- UNH Nuclear Group planning for the b_1 and A_{zz} experiments at JLab at the beam energy of 11.0 GeV with 115 nA beam current.
- DNP Target with the Hall C stacked array of detectors to study the deuteron spin observables and asymmetries on polarized beam and target.
- Implement tensor enhancement techniques: selective semi-saturated RF (ssRF) and Adiabatic Fast Passage (AFP).





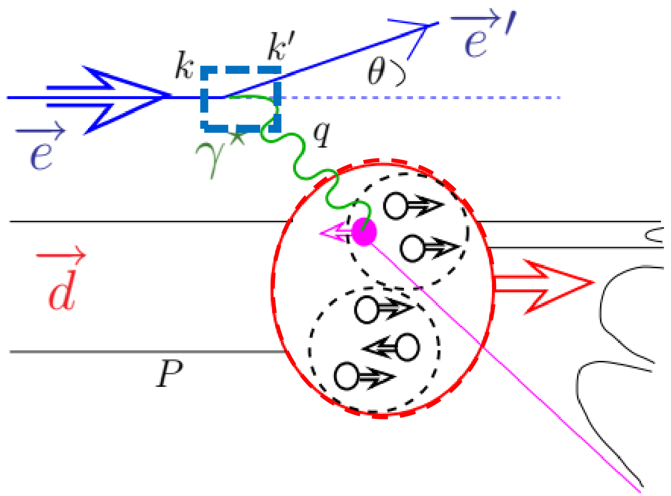
- **E12-13-011: The Deuteron Tensor Structure Function b_1.**
  - Approved by JLab with A^- Physics Rating. Link
- **E12-15-005: Measurement of the Quasi-Elastic and Elastic Deuteron Tensor Asymmetries.**
  - Approved by JLab with A^- Physics Rating. Link

CAA Proposal

- **Spin 1 Transverse Momentum Dependent Tensor Structure Functions in CLAS12.**

- We are analyzing the CLAS RGC polarized deuteron data (which has a small tensor polarization) to prepare for the b_1 and A_{zz} experiments

b_1 (E12-13-011) and A_{zz} (E12-15-005) Experiment in the Hall C (Jefferson Lab)



Polarized Deep-Inelastic lepton-deuteron reaction. Ref: Link

- The DIS cross-section:

$$\left.\frac{d^2\sigma}{dE'd\Omega}\right| = \frac{\alpha^2}{2MQ^4}\frac{E'}{E}L_{\mu\nu}W^{\mu\nu}$$

- $L_{\mu\nu}$ is a Leptonic tensor
- $W^{\mu\nu}$ is a hadronic tensor

$W_{\mu\nu}$ = Unpolarized Structure Functions + Spin-dependent Structure Functions + Tensor Polarization Structure Functions

$$W_{\mu\nu} = -F_1 g_{\mu\nu} + F_2\frac{P_\mu P_\nu}{\nu} + i\frac{g_1}{\nu}\epsilon_{\mu\nu\lambda\sigma}q^\lambda s^\sigma + i\frac{g_2}{\nu^2}\epsilon_{\mu\nu\lambda\sigma}q^\lambda(p.qs^\sigma - s.qp^\sigma) - b_1 r_{\mu\nu} + \frac{1}{6}b_2(s_{\mu\nu} + t_{\mu\nu} + u_{\mu\nu}) + \frac{1}{2}b_3(s_{\mu\nu} - u_{\mu\nu}) + \frac{1}{2}b_4(s_{\mu\nu} - t_{\mu\nu})$$

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

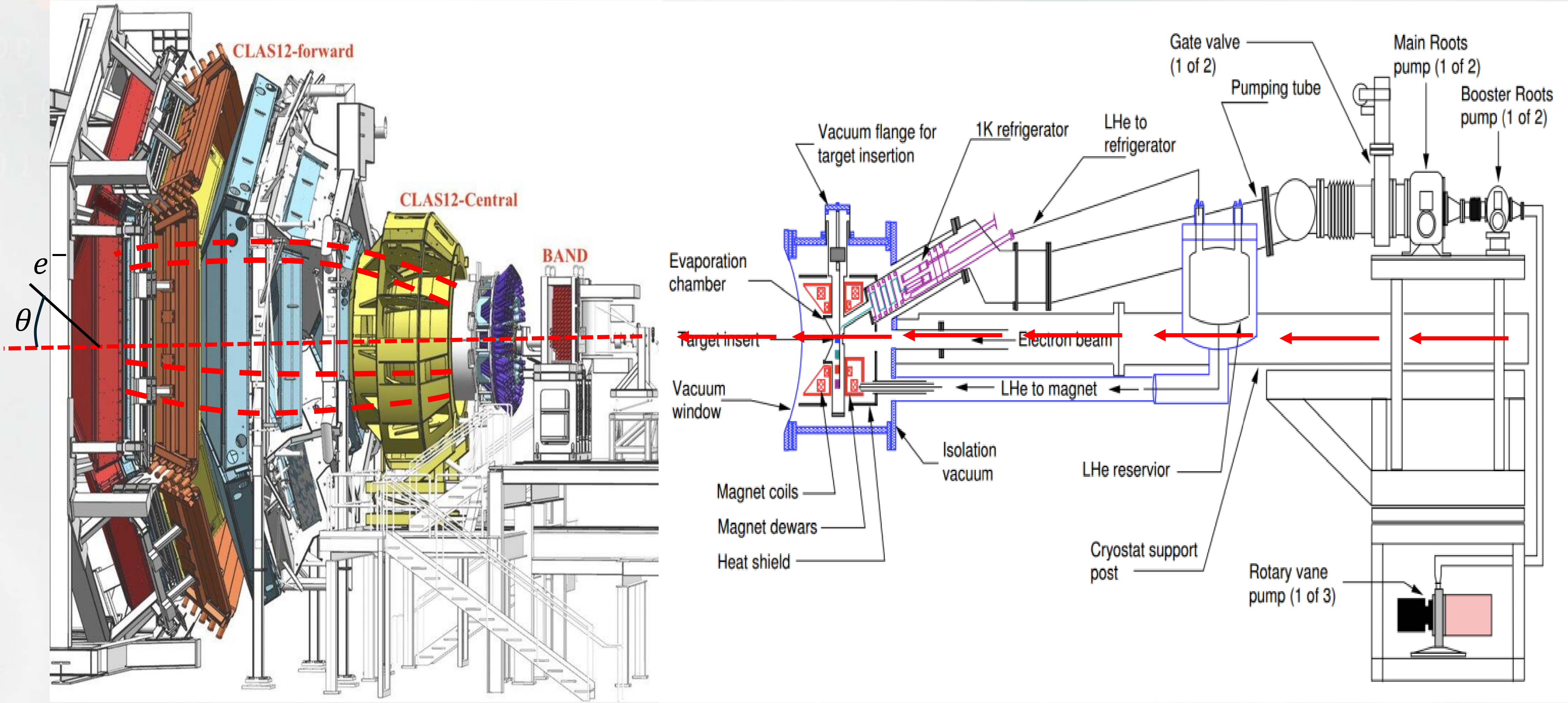
σ_T: Tensor Polarized Cross-section
σ_0: Unpolarized Cross-section
P_{zz}: Tensor Polarization
f : Dilution Factor

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

Physics Motivation:

- Probe the Quark Structure of Spin-1 Nuclei
- Probe exotic nuclear components beyond nucleons
- Understand nuclear medium effects on spin structure

RGC Polarized Target System Hall B



[Link]

τ and T_1 Extraction of RGC Data

Spin-up Polarization Formula:

$$-(P_{max} - P_{offset}) * (1 - e^{-\frac{t}{\tau}}) + P_{max}$$

- P_{max} is a maximum polarization in the given range of data selection for fitting.
- P_{offset} is a polarization at time t=0 in the given range of data selection for fitting.
- τ is a ramp rate of polarization during DNP.
- The polarization $P(t)$, as a function of t, is determined by two competing processes:
  - Microwave-induced polarization transfer (via DNP).
  - Spin-lattice relaxation (which drives the system back to thermal equilibrium).

Role of Microwave Power in Polarization Ramp-Up

The dynamic equation describing the change in polarization is:

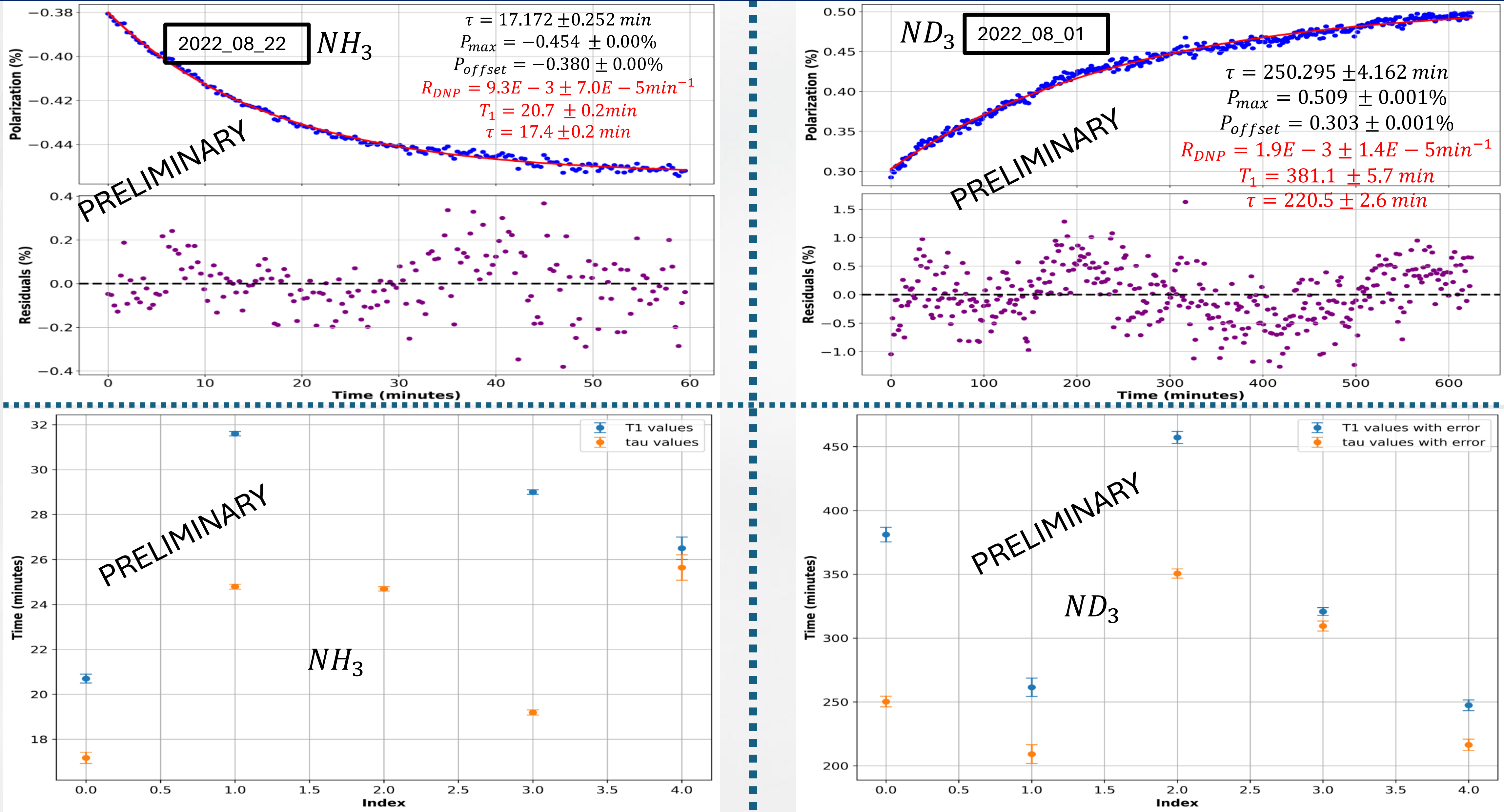
Where:

- R_{DNP}: Rate constant for DNP polarization transfer (depends on microwave power).
- T_1: Spin-lattice relaxation time (characterizes nuclear spin relaxation in the absence of microwaves).

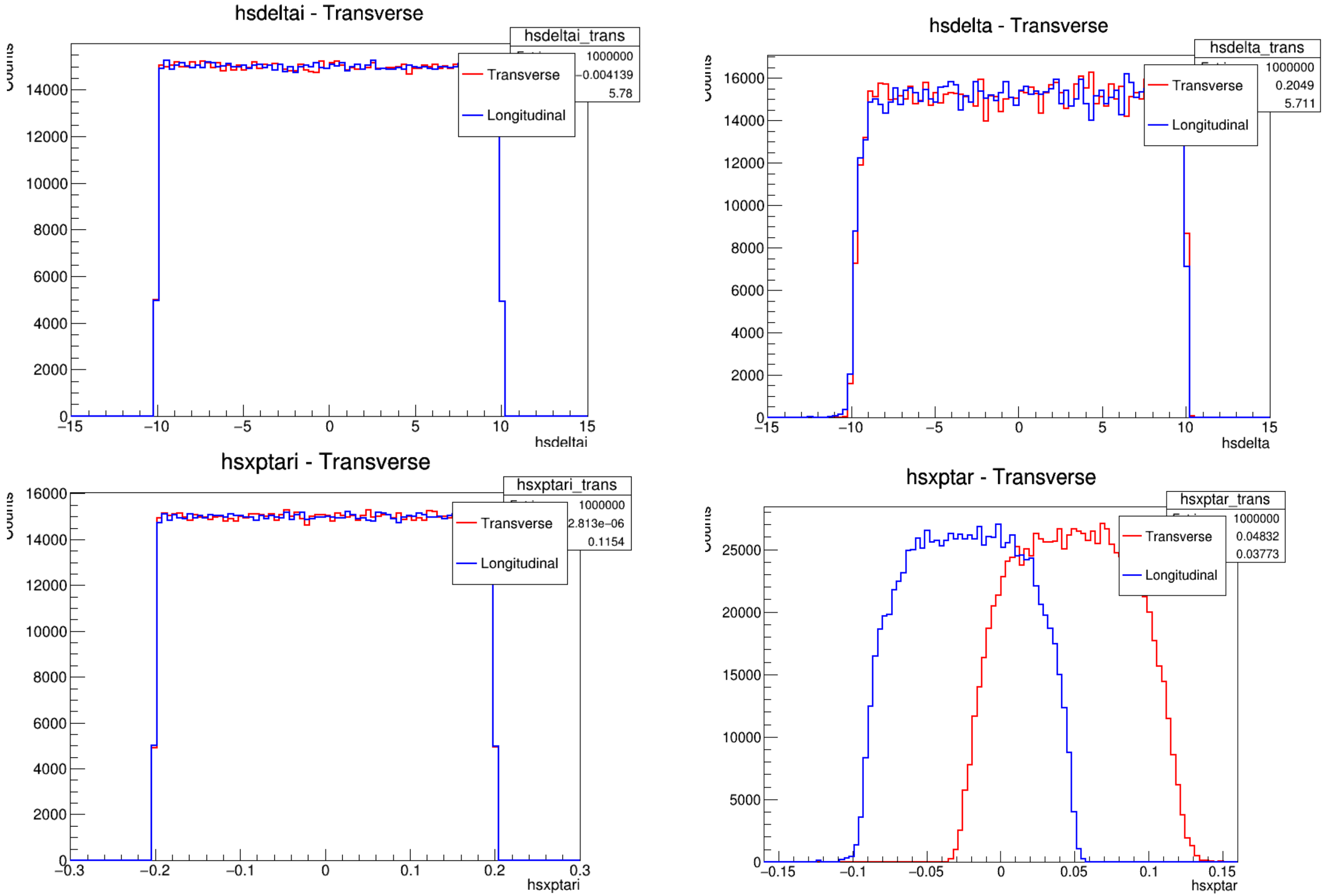
$$\boxed{P(t) = \frac{(R_{DNP} * T_1 * P_{max})}{(1 + R_{DNP} * T_1)} * \left(1 - e^{-t/\tau}\right)} \qquad \boxed{\tau = \frac{T_1}{1 + R_{DNP} * T_1}}$$

- For fitting, R_{DNP}, T_1, and τ are free parameters and P_{max} is fixed parameter.
- **Note: I used Online NMR data and the results are preliminary.**

τ and T_1 Extraction of RGC Data



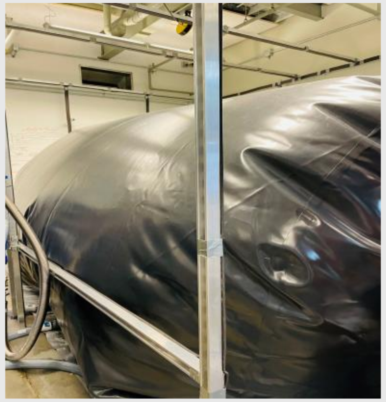
- Simulate particle transport, acceptance & detector response for a single spectrometer arm in Hall C.
- Optimize experiment kinematics (angle, momentum) and collimator/sieve settings.
- Compute Spectrometer acceptance and resolution.
- It helps to integrate with target-field (longitudinal/transverse).



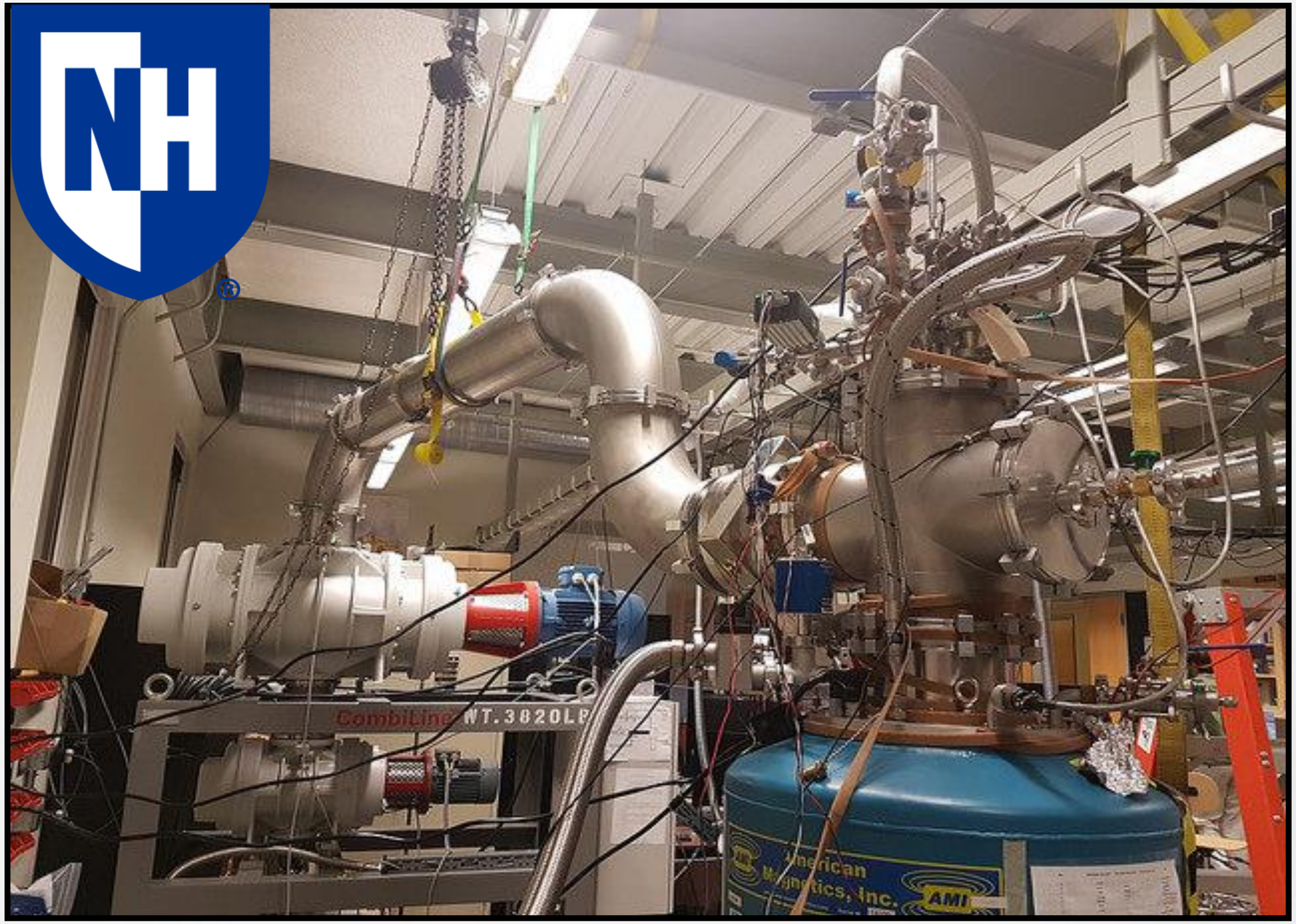
- Github Link: https://github.com/gaskelld/mc-single-arm/tree/target-field

UNH Polarized Target System

HP Gas Cylinders



He Gas Bag



500 L Helium Dewar

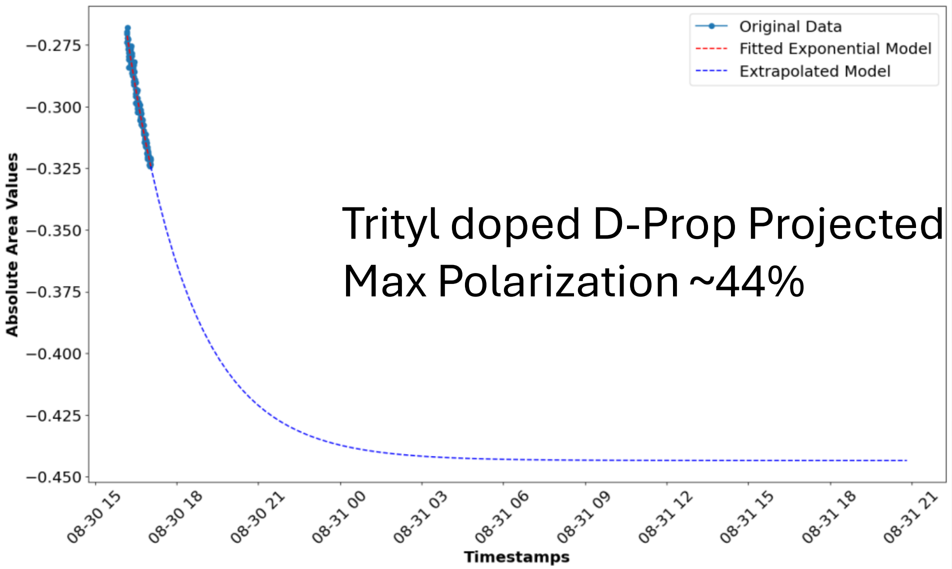
Helium Purifier

5T Superconducting Magnet, 1K Evaporation Refrigerator attached with roughing pumps, 140 GHz Microwave Source, Vector and Tensor Polarization.

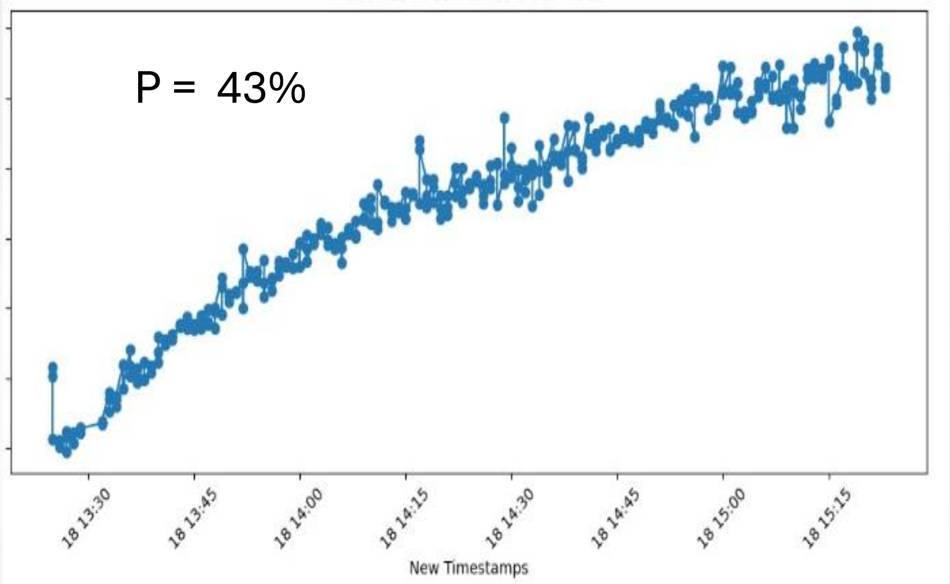
Polarization Studies at UNH

- We performed several cooldowns at UNH.

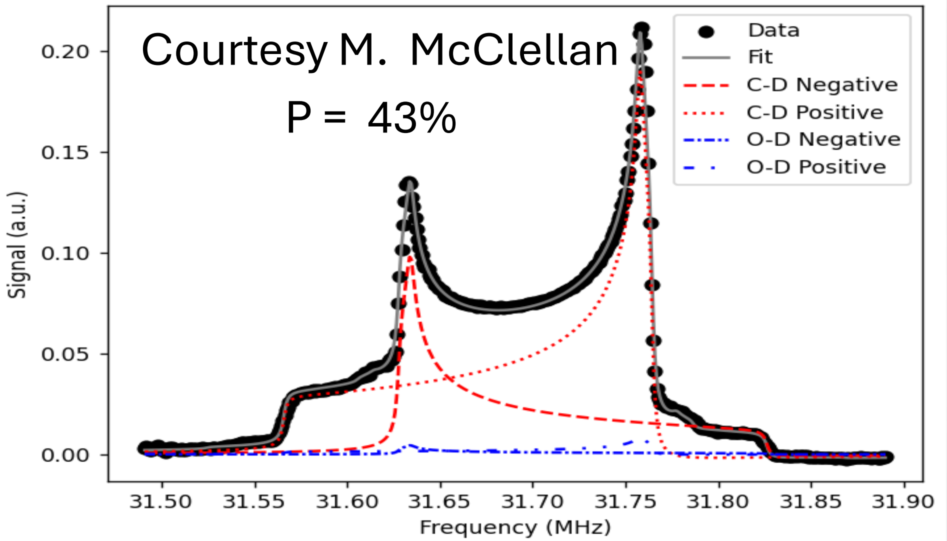
Irradiated D-Prop..



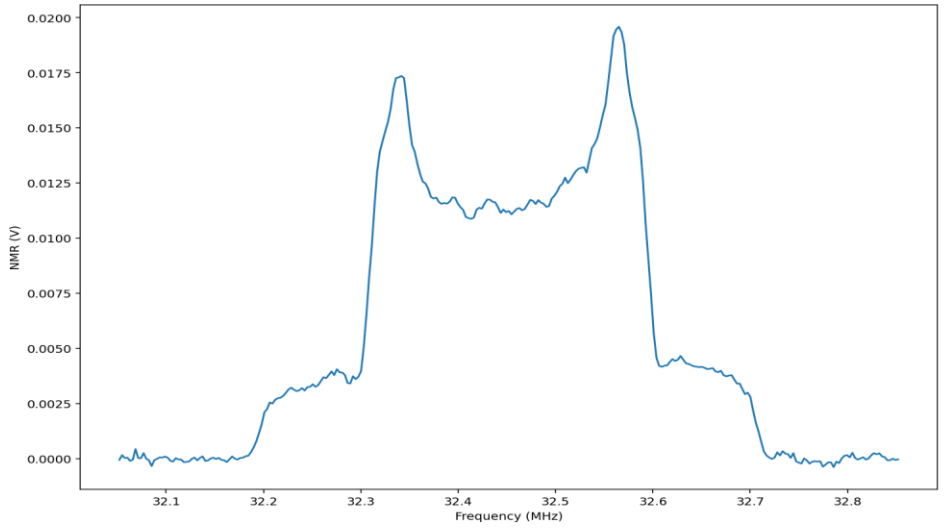
Irradiated D-Butanol



Irradiated D-Butanol



Warm Irradiated D-Ammonia



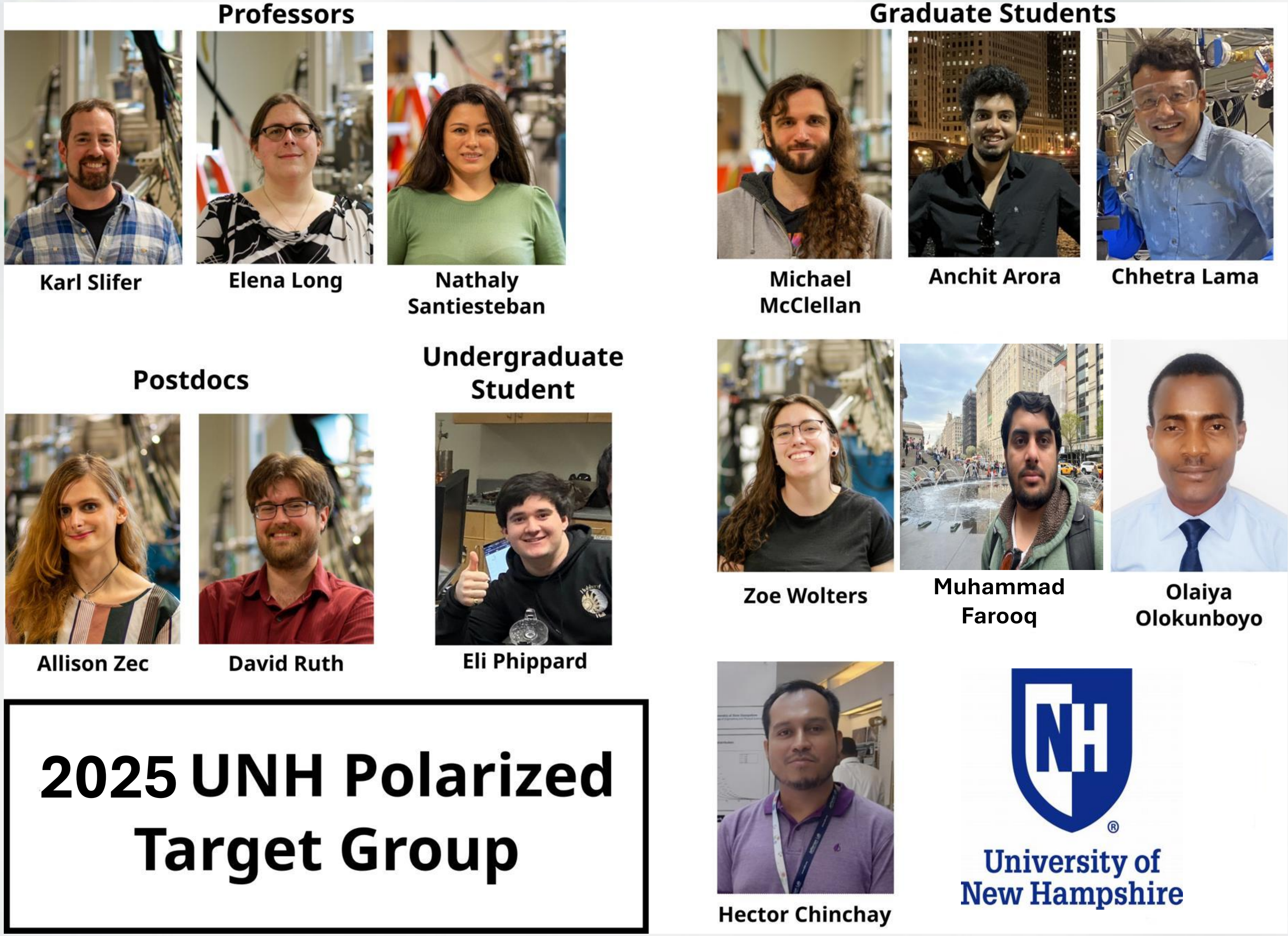
What Next…

- I am analyzing CLAS data to prepare for the b1/Azz experiment.
  - Extraction of tensor Asymmetry.
  - Extraction of b_1 structure function.
  - Offline Polarization Analysis for ND_3 Material.
  - Analysis note for τ and T_1 extraction for ND_3 and NH_3 materials.
  - I am attending RG-C, DIS, and tensor meetings with JLab.
- Cooldown preparations at University of New Hampshire
  - Preparing Deuterated-ammonia for irradiation by the JLab target group.
  - Polarization Studies.
  - τ and T_1 extraction for ND_3 material.
  - Offline Polarization Analysis using HPC (GPU Computing).

Target Material Production and Irradiation

Target Materials are prepared using chemically doped and irradiation method. Materials are irradiated at MIRF NIST Facility.

Polarized Target Group at UNH



Credit: **Allison Zec**

Summary

- **b1 and Azz Experiment in Hall C:** UNH Nuclear Group planning to run b1 and Azz Experiments in Hall C to study deuteron Asymmetries and polarization.

- **RGC Polarized Target:** RGC Polarized Target Analysis performed using NMR (Nuclear Magnetic Resonance), 140 GHz Microwave, Superconducting magnet, 1K evaporation refrigerator, and target materials (NH3/ND3).
- **Single Arm Monte-Carlo:** Working on Single arm Monte-Carlo for the Hall C.
- **UNH Target System**: Utilization of high magnetic fields (5T) and microwaves (140GHz) for vector and tensor polarization of protons and deuterons in scattering experiments.

- **Future Directions**:
  - New Target Stick: better wave guide/RF Coils/NMR Coils
  - Deuteron TE
  - AFP commissioning
  - SSRF Optimizing with ND_3
  - Dedicated program at Jlab to investigate Tensor Spin Observables
  - Material Production D-butanal, ND_3, ...

- **Computational Strategy:**
  - Implementing AI, HPC (GPU Computing, and Algorithm Optimization).

Please join the effort:

- Karl Slifer (karl.slifer@unh.edu) [Spokesperson of b_1(E12-13-011) Experiment]

  - **E12-13-011: The Deuteron Tensor Structure Function b_1.** Link

- Elena Long (elena.long@unh.edu) [Spokesperson of A_{zz} (E12-15-005) Experiment]

  - **E12-15-005: Measurement of the Quasi-Elastic and Elastic Deuteron Tensor Asymmetries.** Link

Thanks

University of New Hampshire

UNH NPG

U.S. DEPARTMENT OF ENERGY | Office of Science

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Backup Slides

Target Materials

- The ***figure of merit* (FOM)** is crucial for target material:

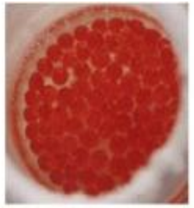
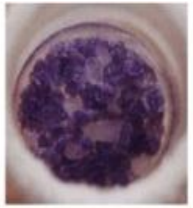
$$FOM = P_T^2 . f^2 . \rho . \kappa$$

- The dilution factor and the target polarization have the largest impact on the FOM
- The filling factor $\boldsymbol{\kappa}$ is linked to the thermal conductivity and the shape of the target material
- **Basic Dilution factor:** ratio of number of polarizable nucleons to total no. of nucleons in the target.

$$f_{NH_3} = \frac{N_H}{N_H + NN_{14}} = \frac{3}{3+14} = 0.176\,;\, f_{ND_3} = \frac{N_D}{N_D + NN_{14}} = \frac{6}{3+17} = 0.3$$

- **Kinematic Dilution factor:** ratio of cross-section of polarizable nucleons to the cross-section of all the nucleons in the target.

$$f(x) = \frac{N_H \sigma_{pp\uparrow}^{DY(x)}}{N_H \sigma_{pp\uparrow}^{DY(x)} + NN_{14}\sigma_{pp\uparrow}^{DY(x)} + NHe\sigma_{pp\uparrow}^{DY(x)} + NAl\sigma_{pp\uparrow}^{DY(x)} + \cdots}$$


Material	Butanol	Ammonia, NH_3	Lithium Hydride, ^7LiH
Dopant	Chemical	Irradiation	Irradiation
Dil. Factor (%)	13.5	17.6	25.0
Polarization (%)	90-95	90-95	90
Material	D-Butanol	D-Ammonia, ND_3	Lithium Deuteride, ^6LiH
Dil. Factor (%)	23.8	30.0	50.0
Polarization (%)	40	50	55
Rad. Resistance	moderate	high	very high
Comments	*Easy to produce and handle*	*Works well at 5T/1K*	*Slow polarization, but long T_1*

Target Material Figure of Merit

- More detail in SPIN2023 by M. Farooq: https://inspirehep.net/literature/2814906

Dynamic Nuclear Polarization (DNP)

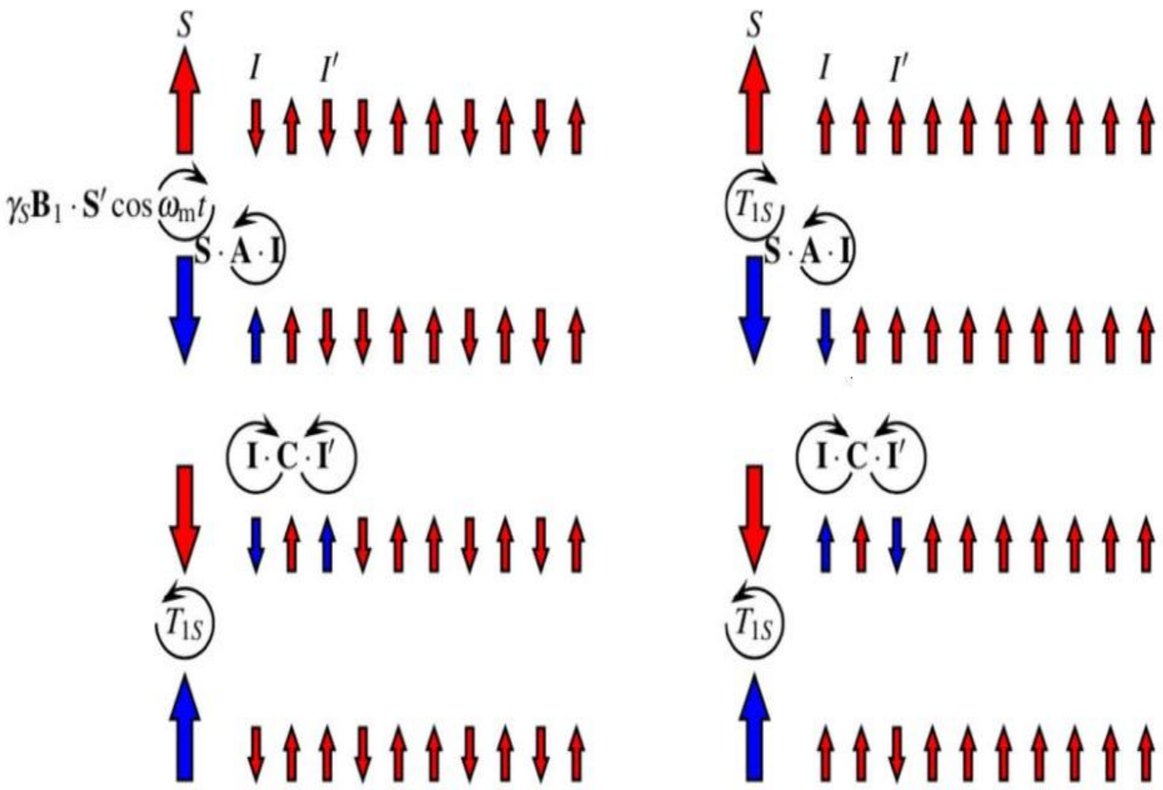
- Transfer of spin polarization from electrons to nuclei using RF irradiation in an external magnetic field
- The $\mu_e = 660\mu_p$. Whereas the polarization at 5T and 1K of electrons is 98% and protons is 0.5%.
- Dipole-dipole interaction between electron and proton provides contact between spin species.

- By applying RF-field at 140 GHz very close to electron ESR frequency electron high polarization can be transferred to proton.

- One electron transition/millisecond

- One proton transition/minute

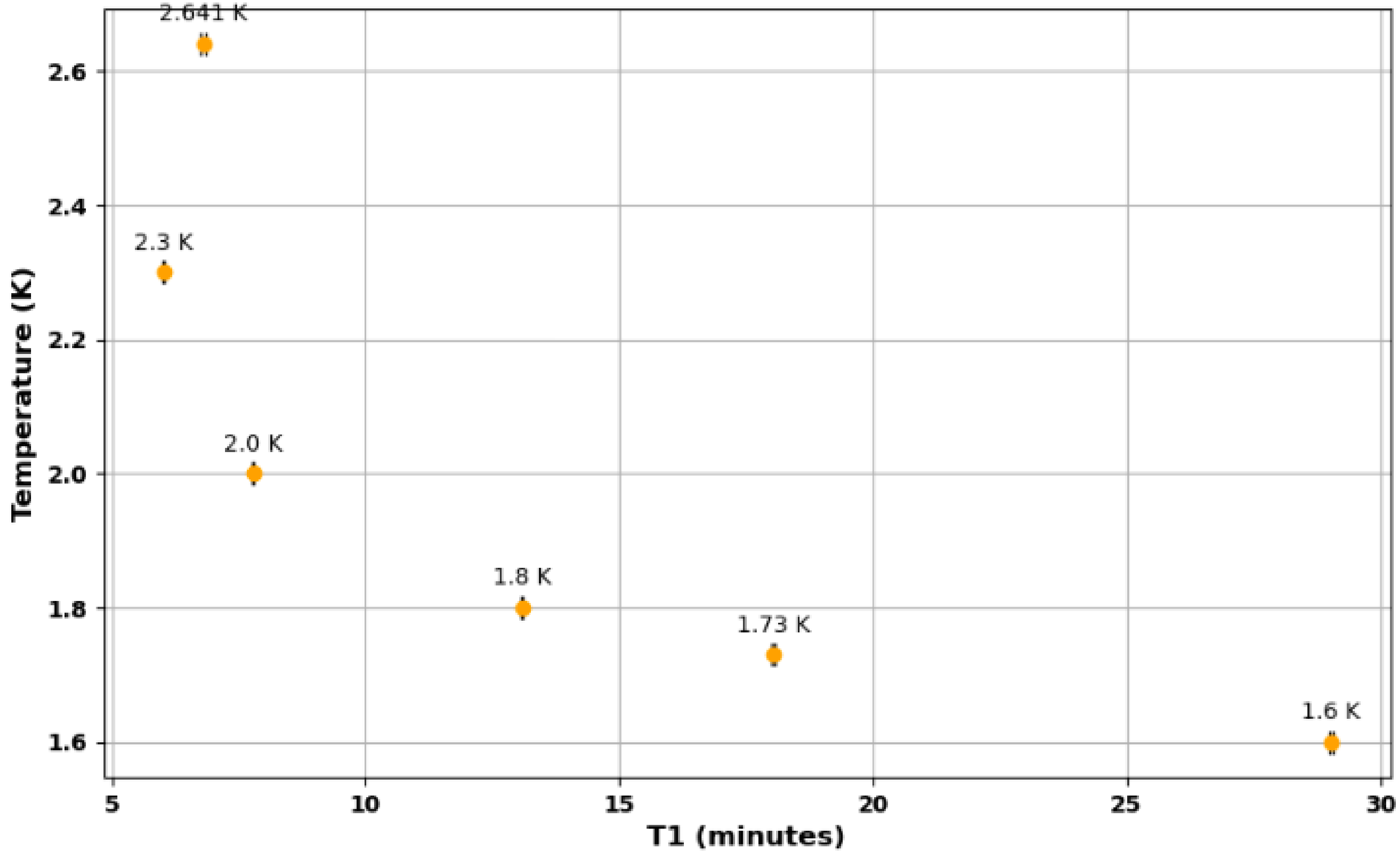
- The model is valid if the ESR spectrum is narrow.



Solid State Effect (SSE)

T_1 Extraction (Spin-Lattice Relaxation Time) Extraction

- Extraction of T_1 at different settings of liquid helium bath temperature.



- Slide Taken from APS DNP Meeting 2024 by M. Farooq.

SpinQuest (E1039) Data