Polarized ^{3}He Target

On Behalf of the JLab Polarized ^{3}He Target Group

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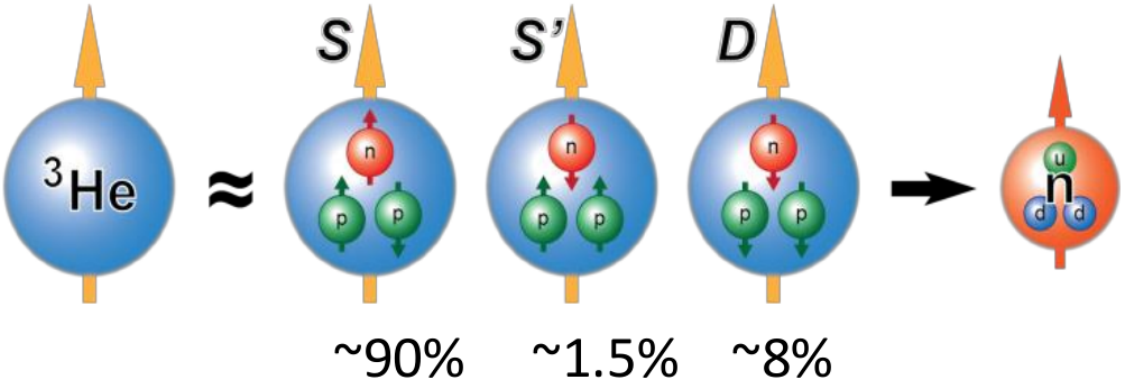
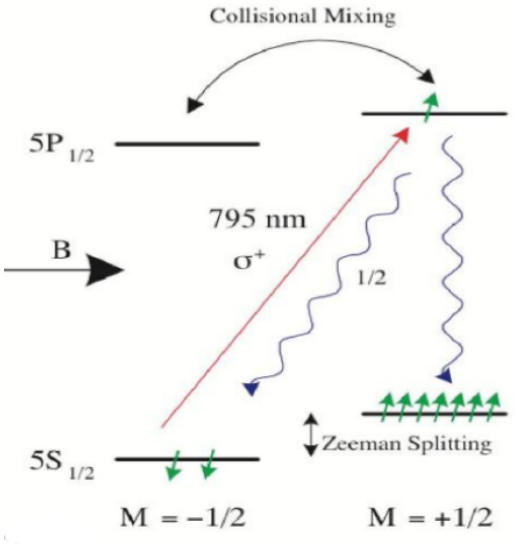
University of Virginia
January 28, 2021

Introduction to ^{3}He Polarization

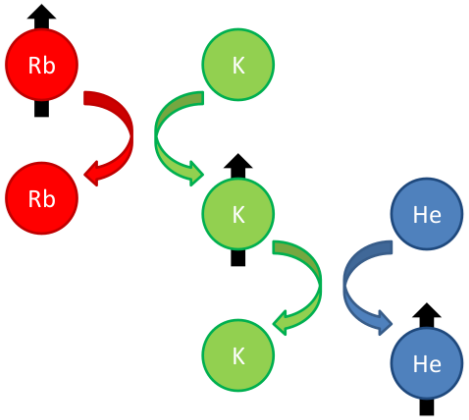


- Polarized target for study the spin structure of nucleon.
- Free neutron mean lifetime: 880.2 s.
- The unpaired neutron carries the majority of the ^{3}He nucleus polarization.
- Polarized ^{3}He is a good effective polarized neutron target.

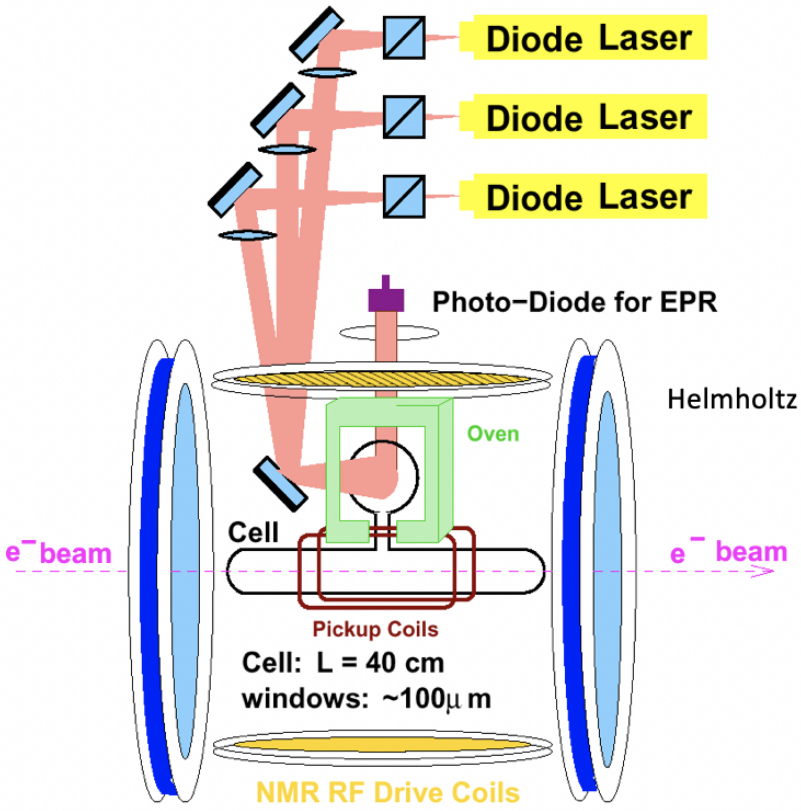
Spin Exchange Optical Pumping
(SEOP)



1. Optical Pumping

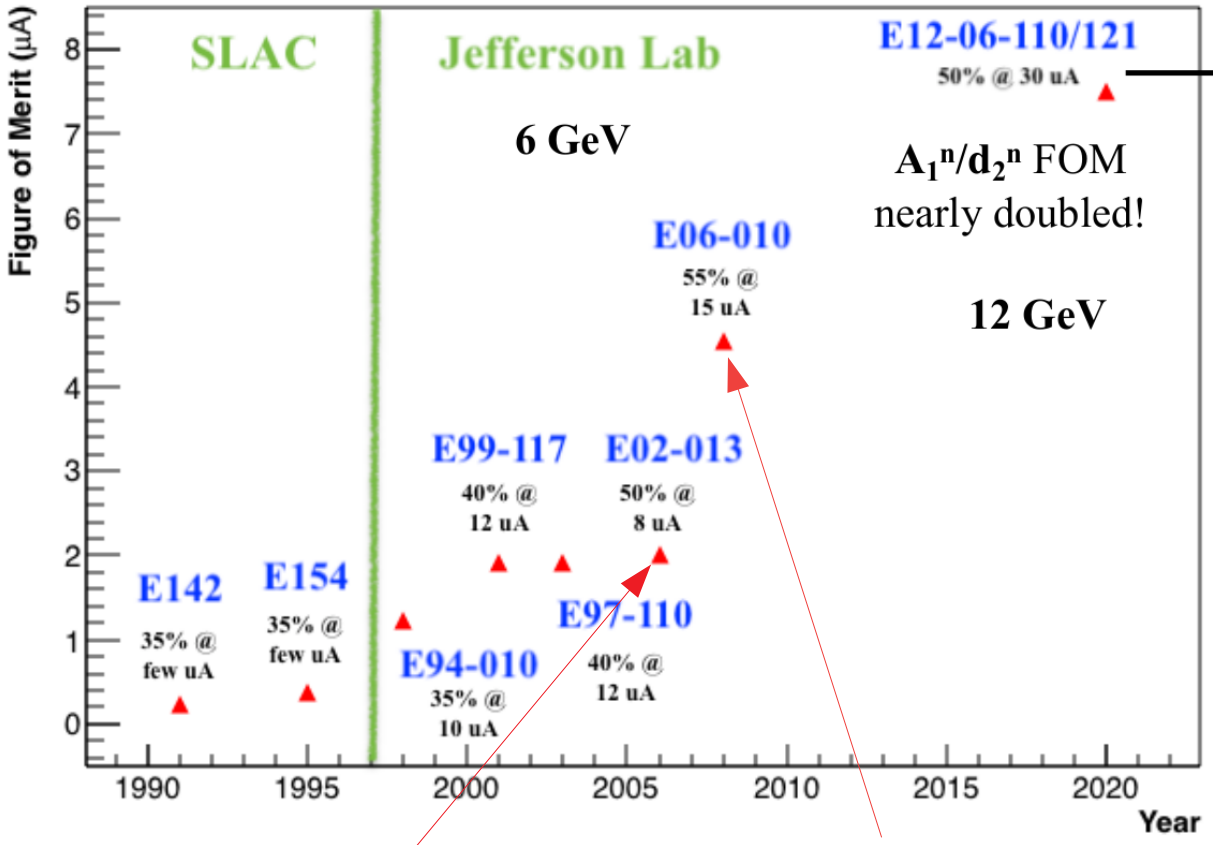


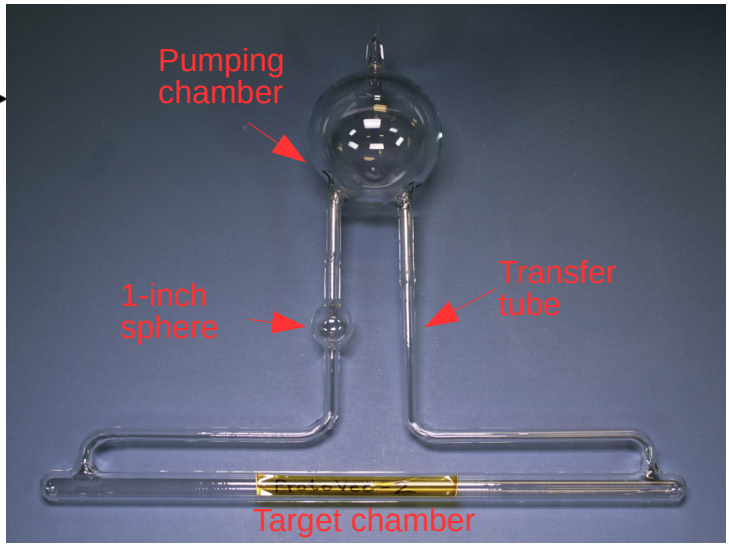
2. Spin Exchange



Polarized ^{3}He Targets Performance Evolution

FOM = (Target Polarization)^2 × Beam Current





- 12 GeV era Target Cell:

Target chamber length: 40 cm

- Beam Current: 30uA

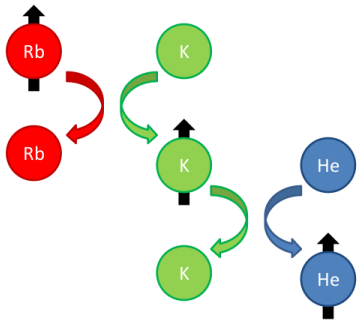
  Reached over 50% in beam polarization

  Luminosity: ~ 2.2x10^{36} cm^{-2}s^{-1}

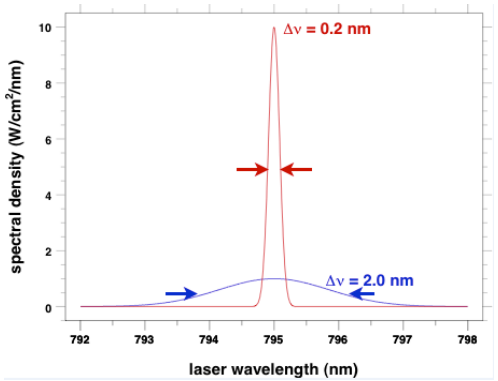
- Convection Cell (instead of diffusion cells used in the 6 GeV era)

  → convection allows for more uniform polarization between target and pumping chamber

G_E^n (E02-013):
Started to use Rb/K hybrid alkali cell.



Transversity (E06-010):
Started to use narrow band laser.



Target Activities

Target Activities at JLab:

People at JLab:

- PhD students: Junhao Chen (W&M, Todd Averett), Mingyu Chen (UVa, Xiaochao Zheng), Murchhana Roy (University of Kentucky, Wolfgang Korsch), Melanie Rehfuss (Temple, Zein-Eddine Meziani)
- Postdoc: Arun Tadepalli, William Henry, Jixie Zhang
- Engineers/Designer (Bert Metzger)
- Installation (Walter Kellner, Hall C technicians)
- Supervisor/coordinator (Jian-ping Chen)

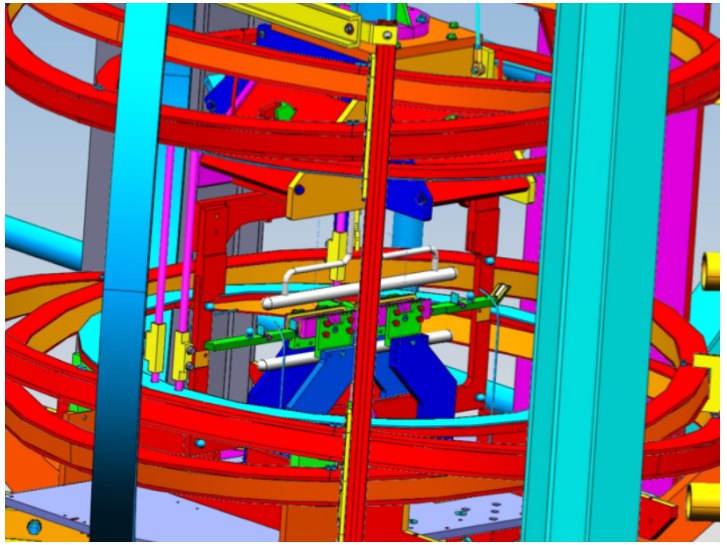
Overview of Activities:

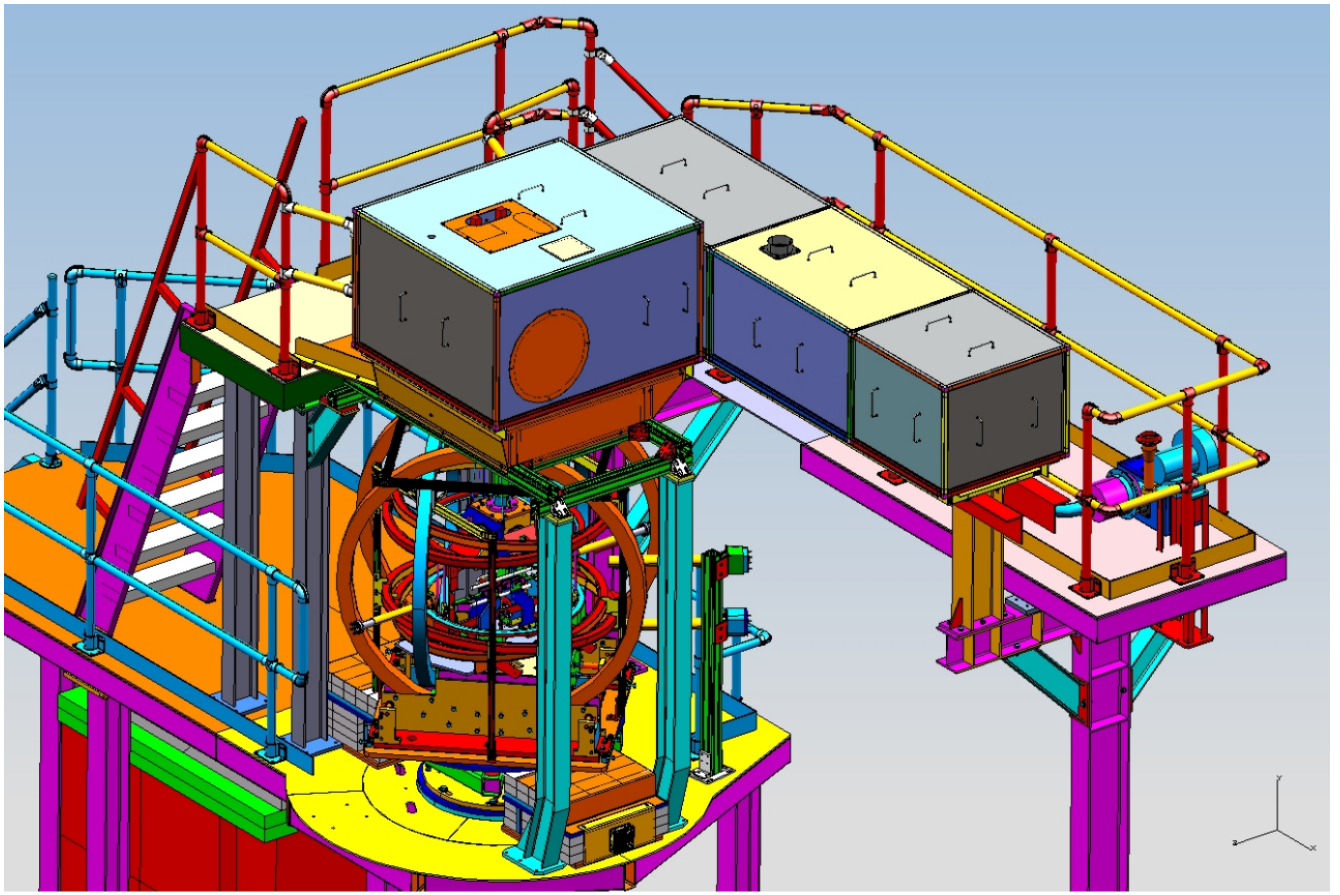
- Design to fit the polarized ^{3}He into Hall C (first time), construction (Bert)
- Develop pulse NMR (Mingyu)
- Upgrade and commissioning EPR (Melanie, Todd, Junhao, Sumudu Katugampola from Uva)
- Commissioning NMR (Junhao, William)
- Field mapping (Jixie et al.)
- Field direction measurement (Murchhana, Arun)
- Reference cell and cooling jets (Todd)
- Target ladder alignment (Alignment group, Bert, Arun)
- Installation (Walter Kellner, Hall C technicians, Bert, alignment group et al.)
- Slow control system (Brad Sawatzky, Ethan Becker, Junhao, Arun, William, Mahlon Long, Mark Taylor, Chris Carlin,Mindy Leffel)

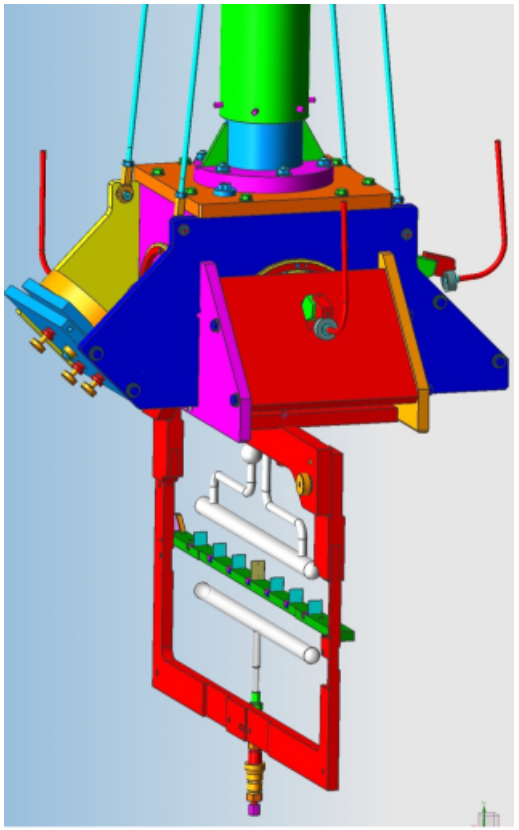
Target Activities at User Institutes:

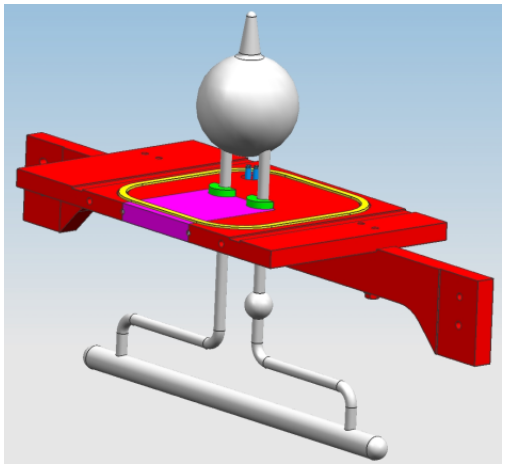
- Cell fabrication and testing: UVa (Gordon Cates), W&M (Todd Averett)
- k_0 measurement: W&M (Todd Averett), UVa

Polarized ^{3}He Target in Hall C



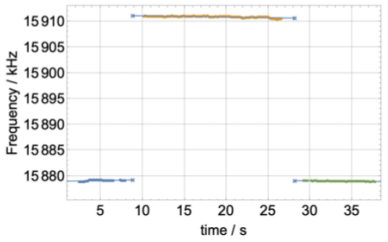


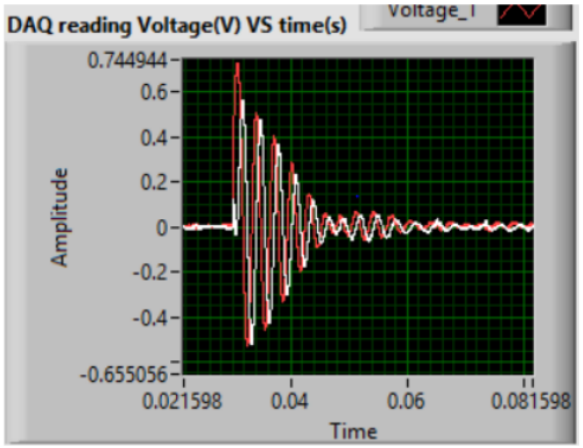


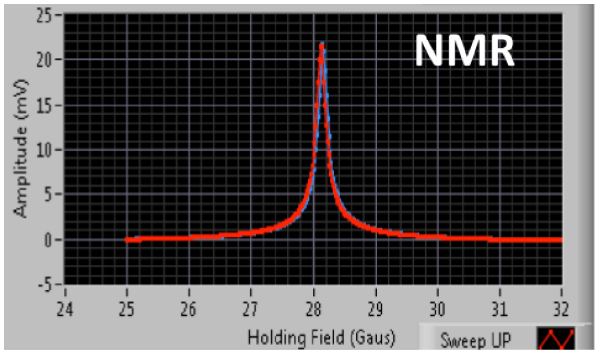


Polarimetry for ^{3}He in Target Cell

EPR







1. Adiabatic Fast Passage Nuclear Magnetic Resonance (AFP-NMR)

- Magnetic Resonance of ^{3}He Nucleus
- Sweep the holding field under AFP condition to flip the Nucleon spin direction back and forth.
- Relative measurement, calibrate with water NMR or EPR.

2. Pulse NMR

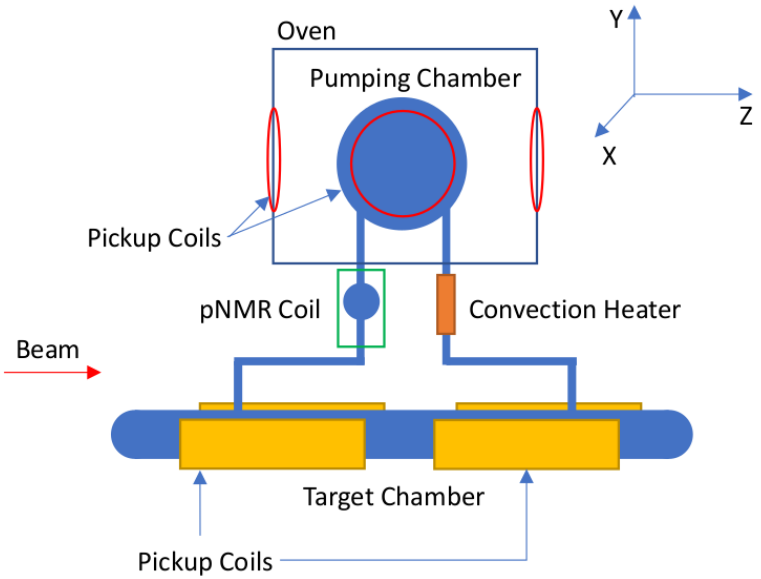
- Use resonance RF pulse at ^{3}He Larmor frequency to tilts the Nucleon spin to a certain angle.
- Relative measurement, calibrate with AFP-NMR.
- Implemented for the first time on polarized ^{3}He target.

3. Electron Paramagnetic Resonance (EPR)

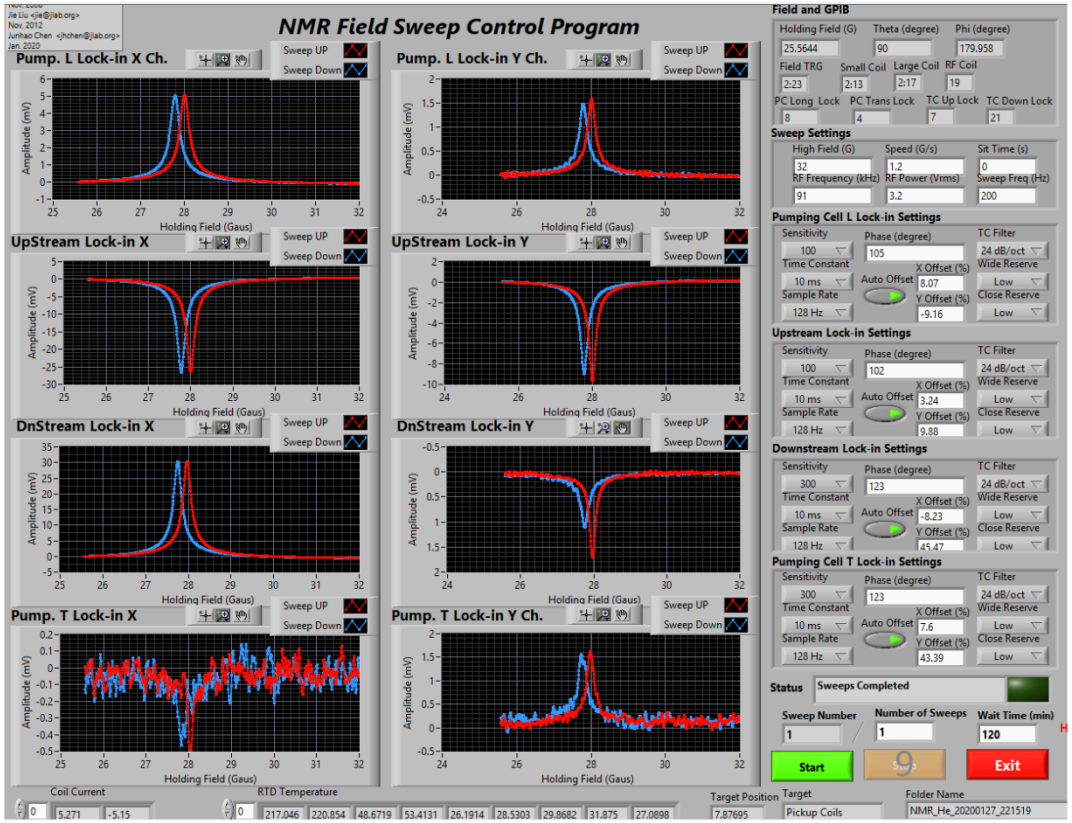
- Magnetic resonance of the alkali atoms
- Resonance shifted due to polarized ^{3}He, get the resonance frequency difference by flipping the ^{3}He polarization direction.
- Get ^{3}He polarization from resonance frequency difference. Absolute measurement.

NMR

(by Junhao Chen)



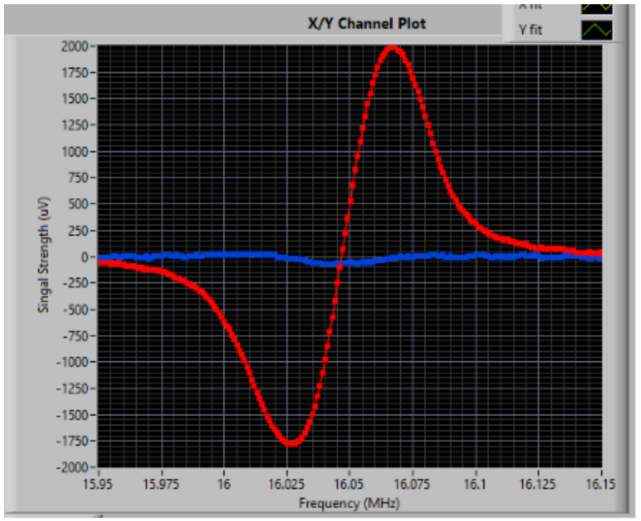
- AFP-NMR was the primary method to measure the ^{3}He target polarization during the production run.
- Two pairs of pumping chamber pickup coils: one in longitudinal direction, another one in transverse direction
- Two pairs of target chamber pickup coils: upstream and downstream
- Target chamber pickup coils are also used to study convection speed



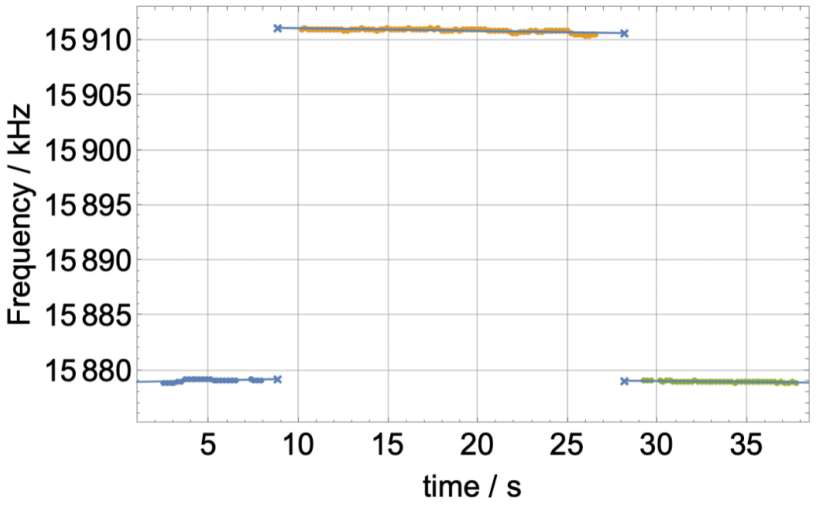
EPR System

(by Melanie Rehfuss and Junhao Chen)

- EPR provides absolute polarimetry.
- EPR polarimetry provided calibrations to NMR system.
- Used a photo diode with D_1 light filter to collect D_2 light.
- The uncertainty for target polarimetry is about ±3%.



- EPR FM Sweep

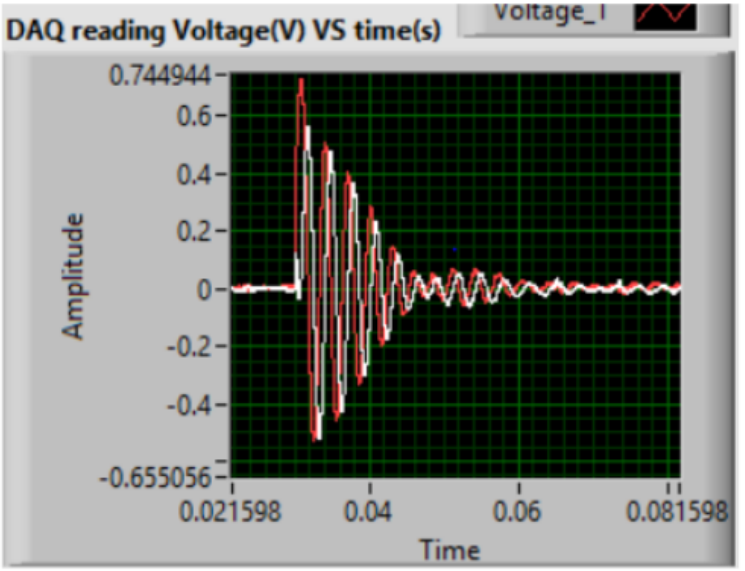


- EPR AFP Sweep

Pulse NMR

(by Mingyu Chen)

- Advantage: Took shorter time to complete measurement, less depolarization compare to AFP-NMR.
- PNMR was performed at transfer tube which was calibrated by AFP-NMR at pumping chamber.
- For most of the measurements, polarization from PNMR agrees with NMR within ±2%.
- However, the drift of holding field magnitude over time changed PNMR signal amplitude and introduce additional uncertainty.
- Still need to do detailed analysis to characterize this effect on PNMR signal and determine the systemic uncertainty for PNMR.



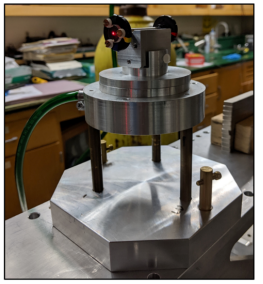
- Current fit for the signal by the FID fitting function to obtain PNMR amplitude A_0.

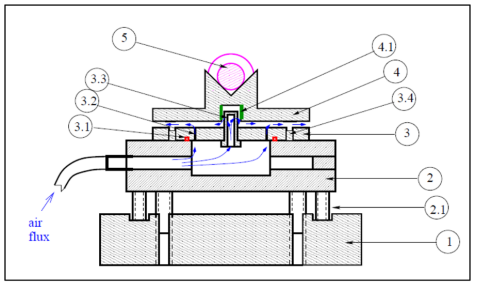
$$S(t) = FID(t) = A_0 \cos(\omega t + \phi_0) e^{-t/T_2} + a*t + b$$

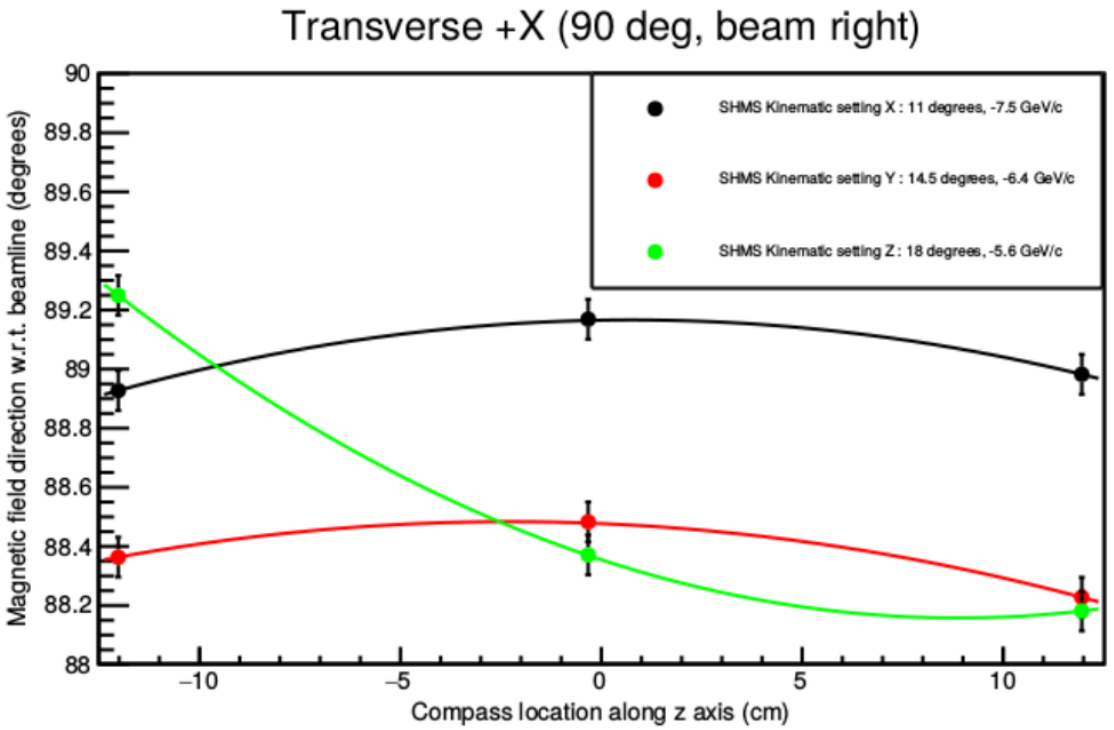
- Obtain $PNMR_{amp}/NMR_{amp}$ ratio in order to calibrate PNMR with NMR.

Magnetic Field Direction Measurement
(by Murchhana Roy)

- A novel air-floated compass was developed and built as the commercially available compasses cannot achieve the desired level of precision.
- The magnetic field direction was determined from the surface normal of the aligned compass mirrors by mapping incident and reflected laser beam spots on a screen.
- The points were surveyed by JLab alignment group in absolute Hall C coordinate system.





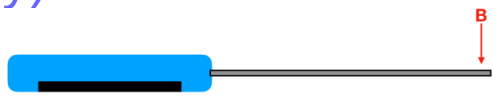


- Measured absolute direction of the target magnetic field in the Hall C coordinate system precisely to about ±0.1°.

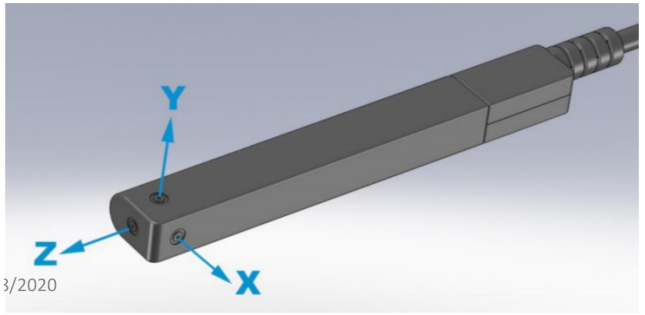
Holding Field Mapping
(by Jixie Zhang and William Henry)

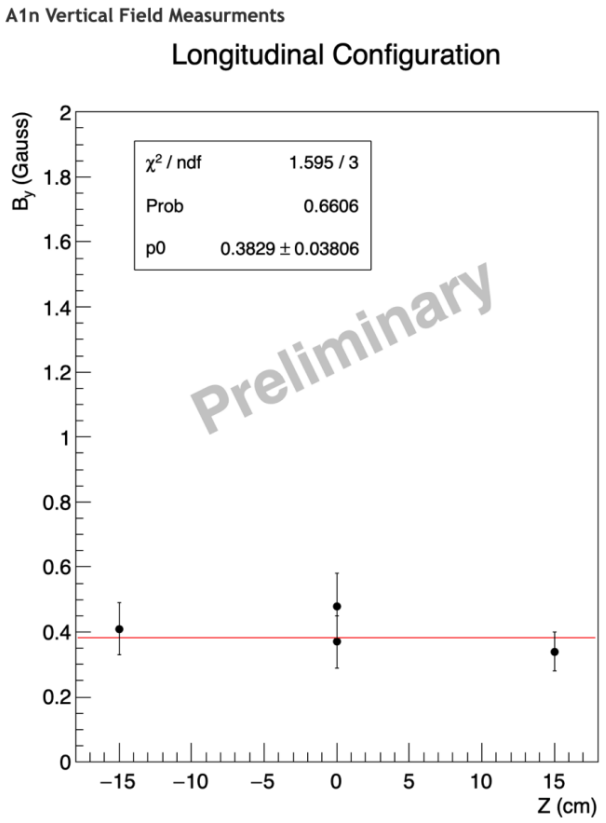
- Measure and correct the field gradient and vertical field components caused by the magnetic structures surrounding the target and fringe field of SHMS HB.
- Use 1D and 3D Hall probe mounted on a 3-axis movable slotted rack .

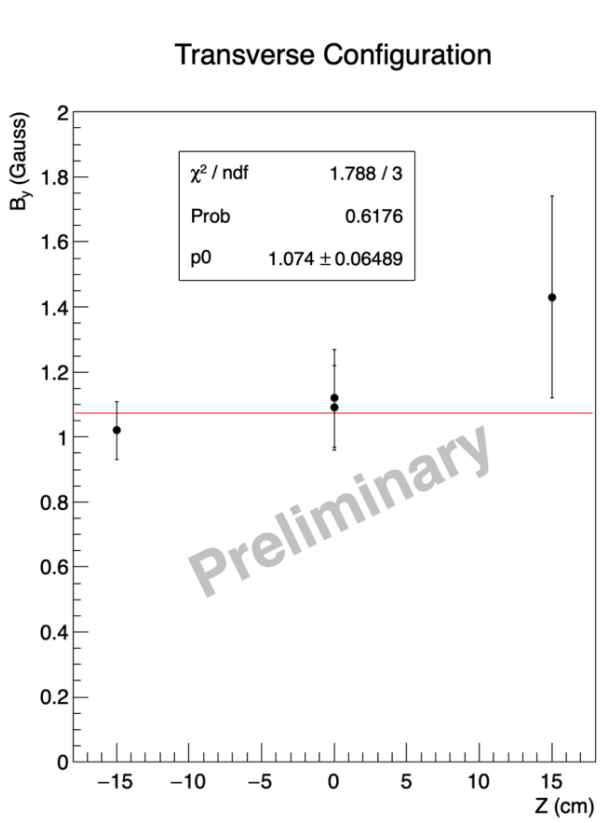
1D Probe

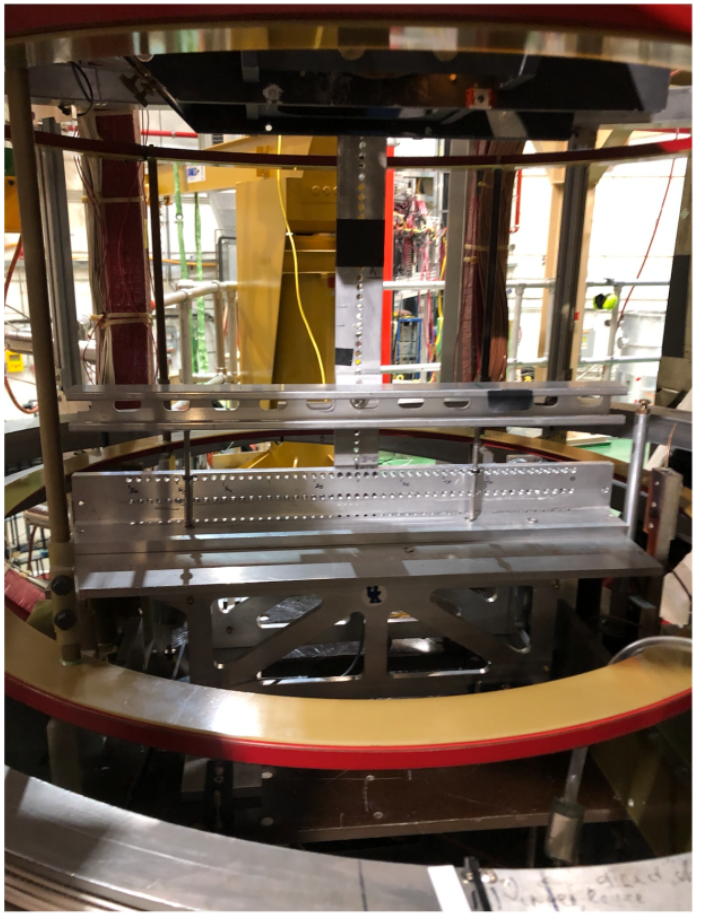


3D Probe



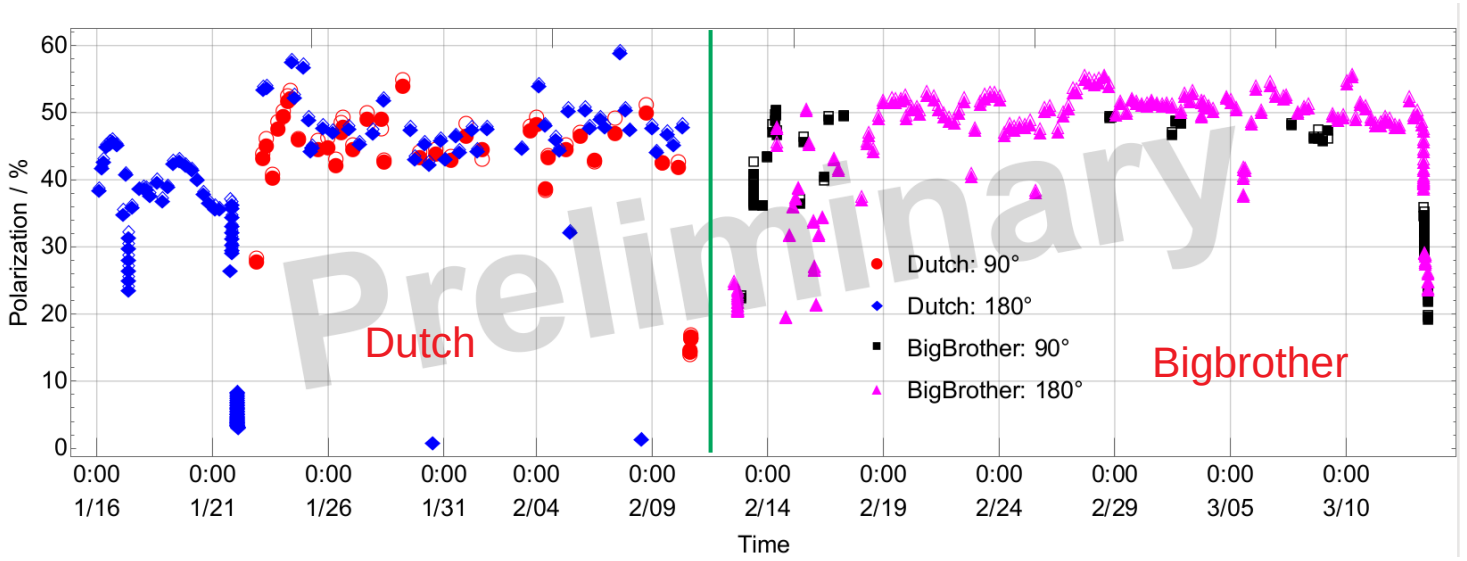






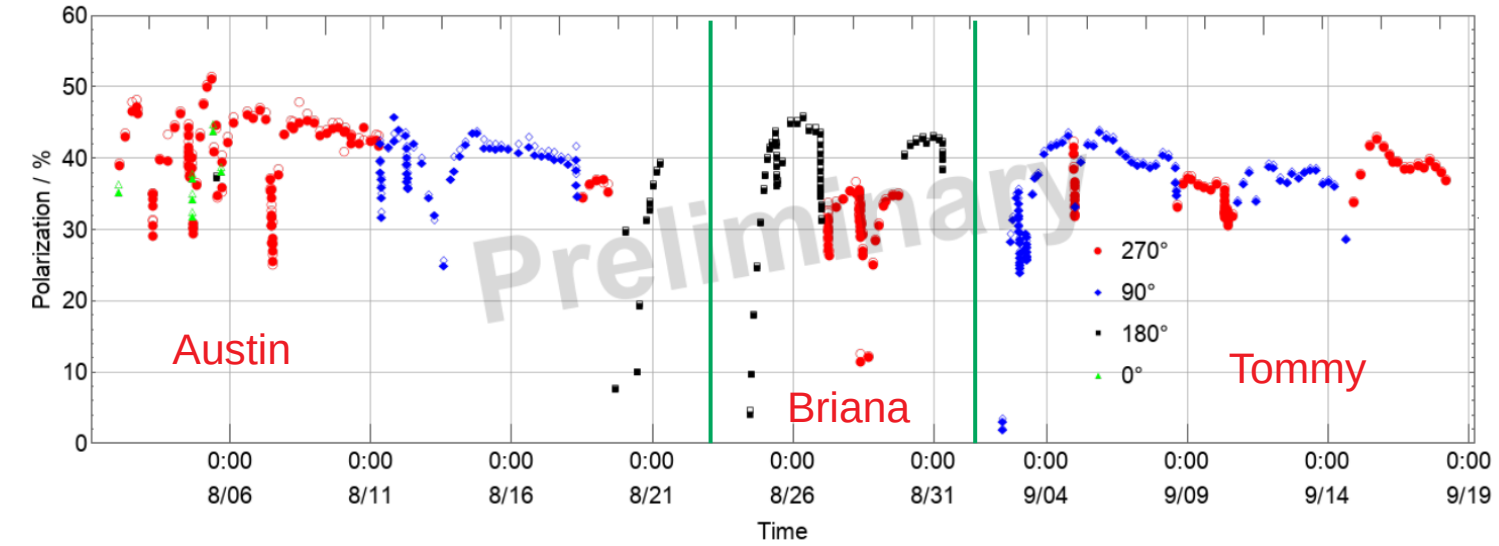
Production Cell Performance

(for A_1^n/d_2^n experiments)



- Target cell polarimetry was performed by AFP-NMR in pumping chamber and calibrated with EPR measurements. Reached over 50% polarization with 30 uA electron beam.

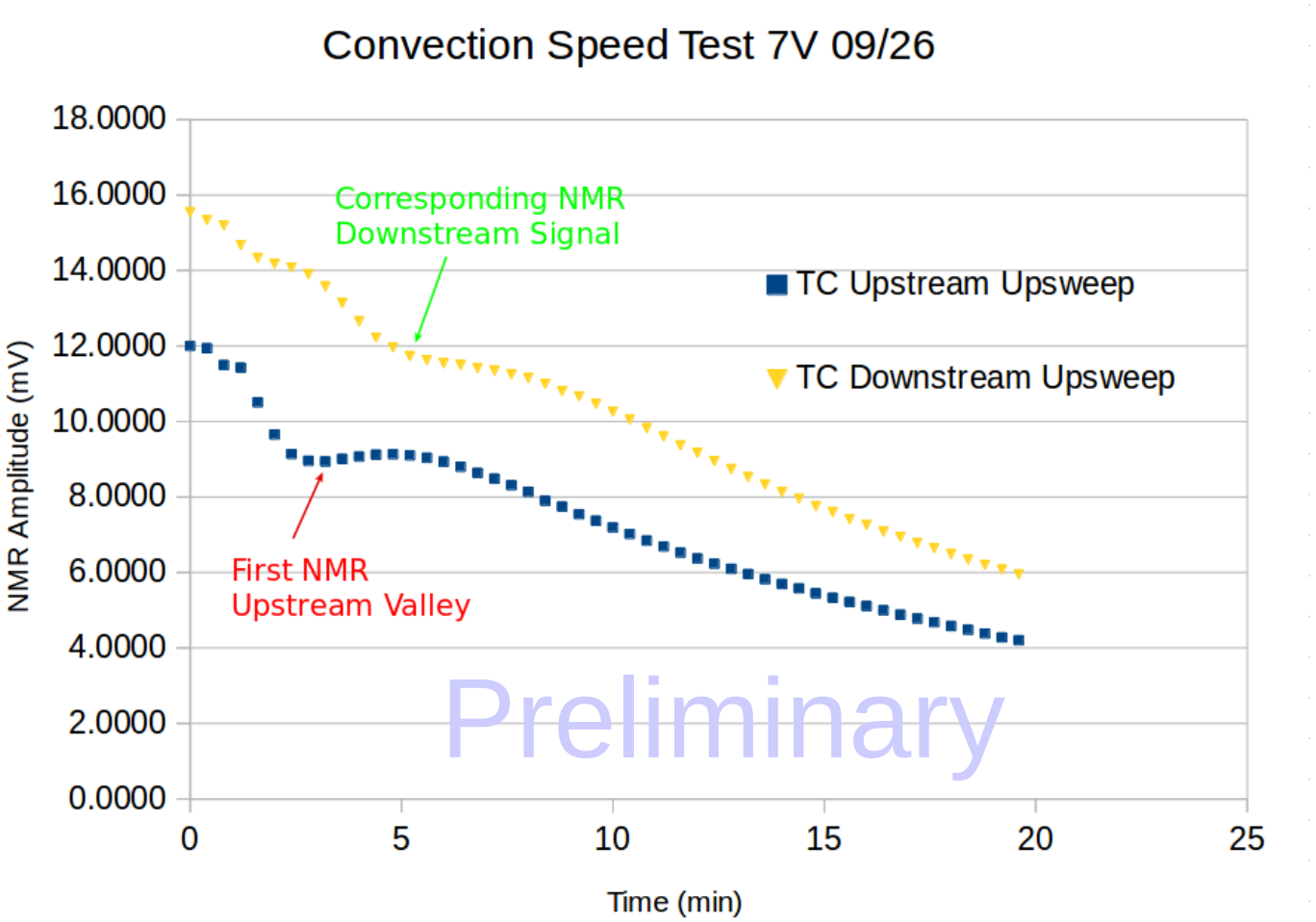
→ Polarized ^{3}He target polarization during A_1^n production running.



→ Polarized ^{3}He target polarization during d_2^n production running.

- Still need to do detailed analysis to get target polarization in target chamber with systemic uncertainties.

Convection Speed Test



- Sent a RF pulse to PNMR coil to depolarize ^{3}He at TT and monitor the evolution of NMR signal at TC Upstream and TC Downstream, then the convection speed was determined.
- From the two curves of NMR signal amp for TC Upstream and TC Downstream, the time difference for first NMR amplitude valley is ~2.0 min.
- Since center of two pick up coil is apart by ~13.4 cm, then convection speed is ~6.7 cm/min.

Production Cells for the Experiment

Cell name	Start time and end time	Cold spin down lifetime [hrs]	Max polarization Measured (no beam) [%]	Status
Dutch	01/04/2020 to 02/10/2020	29.4 (UVa)	52 (UVa)	Used for A_1^n production run
Bigbrother	02/12/2020 to 03/13/2020	26 (UVa)	60 (UVa)	Used for A_1^n production run
Austin	03/20/2020 to 08/21/2020	20 (UVa)	52 (UVa)	Used for d_2^n production run
Briana	08/23/2020 to 08/31/2020	15.3 (UVa)	52.1 (UVa)	Used for d_2^n production run
Tommy	09/03/2020 to 09/21/2020	15.2 (UVa)	54 (UVa)	Used for d_2^n production run
Butterball	NA	19.0 (UVa)	56 (UVa)	Spare target cell

- Production cells are fabricated and filled by Gordon's group at UVa. Professor Todd Averett at W&M helped to fill some of the cells.

Summary

- For the first time, install the upgraded polarized ^{3}He target for 12 GeV era in JLab Hall C. The target reached the expected performance with over 50% ^{3}He polarization in 30 uA electron beam.
- Implement new method of polarimetry (pulse NMR) on the polarized target cell.
- Offline detailed analysis for target polarimetry is in progress.

Acknowledgments

People

D. Androic, W. Armstrong, T. Averett, X. Bai, J. Bane, S. Barcus, J. Benesch, H. Bhatt, D. Bhetuwal, D. Biswas, A. Camsonne, G. Cates, J-P. Chen, J. Chen, M. Chen, C. Cotton, M-M. Dalton, A. Deur, B. Dhital, B. Duran, S.C. Dusa, I. Fernando, E. Fuchey, B. Gamage, H. Gao, D. Gaskell, T.N. Gautam, N. Gauthier, C.A. Gayoso, O. Hansen, F. Hauenstein, W. Henry, G. Huber, C. Jantzi, S. Jia, K. Jin, M. Jones, S. Joosten, A. Karki, B. Karki, S. Katugampola, S. Kay, C. Keppel, E. King, P. King, W. Korsch, V. Kumar, R. Li, S. Li, W. Li, D. Mack, S. Malace, P. Markowitz, J. Matter, M. McCaughan, Z-E. Meziani, R. Michaels, A. Mkrtchyan, H. Mkrtchyan, C. Morean, V. Nelyubin, G. Niculescu, M. Niculescu, M. Nycz, C. Peng, S. Premathilake, A. Puckett, A. Rathnayake, M. Rehfuss, P. Reimer, G. Riley, Y. Roblin, J. Roche, M. Roy, M. Satnik, B. Sawatzky, S. Seeds, S. Sirca, G. Smith, N. Sparveris, H. Szumila-Vance, A. Tadepalli, V. Tadevosyan, Y. Tian, A. Usman, H. Voskanyan, S. Wood, B. Yale, C. Yero, A. Yoon, J. Zhang, Z. Zhao, X. Zheng, J. Zhou

Institutions

A.I. Alikhanian National Science Laboratory; Argonne National Laboratory; Artem Alikhanian National Laboratory (AANL).; Christopher Newport University; Duke University; Florida International University; Hampton University ; James Madison University ; Jefferson Lab; Kent State University; Mississippi State University; Ohio University; Old Dominion University; Rutgers University; Syracuse University; Temple University; The College of William and Mary; Univ. of Ljubljana; University of Connecticut; University of Kentucky; University of Kentucky; University of New Hampshire; University of Regina; University of Tennessee; University of Virginia; University of Virginia; University of Zagreb

PhD Candidates Spokespeople

Other People's Talks

14:35 → 14:50 **A1n Analysis**

Speaker: Melanie Rehfuss (Temple University)

14:50 → 15:05 **D2n Analysis**

Speaker: Junhao Chen (College of William and Mary)

15:05 → 15:25 **Moller Polarimetery Measurements**

Speaker: William Henry (Jefferson Lab)

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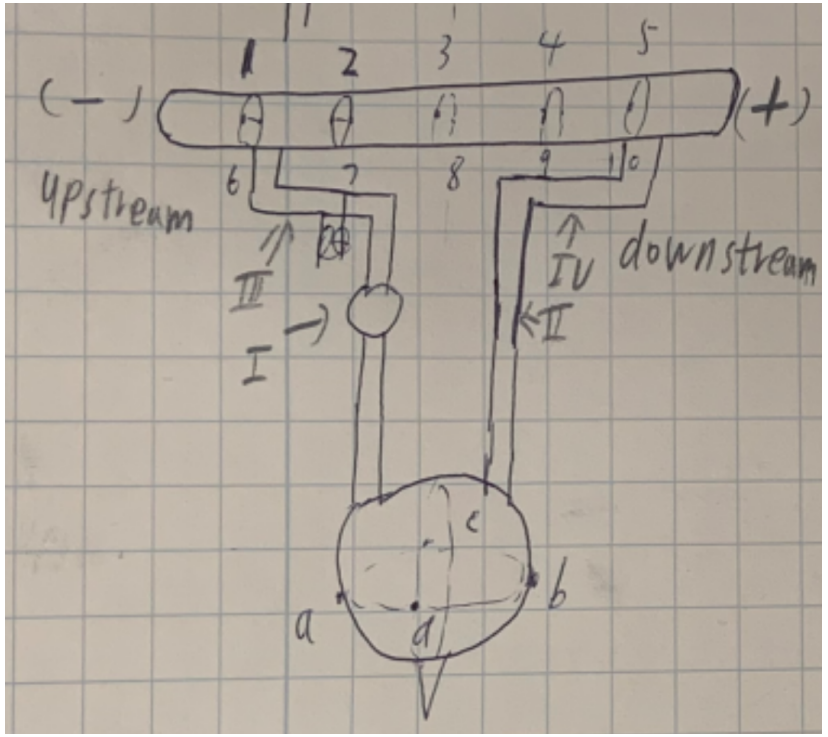
15:25 → 15:35 **He3 Elastic FF**

Speaker: Mike Nycz

Backup Slides

Target Cell Glass Thickness Measurement

- Used ultrasonic thickness gauge to measure the wall thickness of target chamber. (Mingyu Chen)
- Used laser interference pattern to measure the window thickness of target chamber. (Christopher Jantz from UVa)



Production Cell "Bigbrother" Wall Thickness

	Measurement location	Position away from center (along Z) [cm]	Ultrasonic thickness gauge [mm]
TC front	#1	-12.5±0.16	1.507±0.01
	#2	-6.25±0.16	1.531±0.01
	#3	0.0±0.16	1.528±0.01
	#4	6.25±0.16	1.517±0.01
	#5	12.5±0.16	1.533±0.01
TC rear	#6	-12.5±0.16	1.415±0.01
	#7	-6.25±0.16	1.436±0.01
	#8	0.0±0.16	1.407±0.01
	#9	6.25±0.16	1.405±0.01
	#10	12.5±0.16	1.406±0.01
Window Thickness	Front window (um)	Back Window (um)	Cold life Time (hr)
	138.1961±0.059	100.8740±0.0698	26 (UVa)