Tensor Polarized Target Development

Exploring QCD with light Nuclei at EIC

Stony Brook University
2020-01-23

Karl Slifer
University of New Hampshire

This Talk

Solid Tensor PolTarg Experiments

E12-13-011: "The b_1 *experiment*"

E12-15-005: "A_{zz} *for x>1*"

LOI-12-16-006: "Nuclear Gluometry"

Extension of these measurementsto EIC

Latest Target Developments

Discussion : Plan Target Studies for EIC

Tensor Program

Jefferson Lab

E12-13-011: "The b_1 *experiment*"

30 Days in Jlab Hall C
A⁻ Physics Rating
Conditional Approval (Target Performance)

Contact : K. Slifer
Solvignon, Long, Chen,
Rondon, Kalantarians

E12-15-005: "A_{zz} *for* $x>1$"

44 Days in Jlab Hall C
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Slifer, Solvignon,
Day, Higinbothan, Keller

Tensor Program

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Both Experiments Need Tensor Polarization > 30%

E12-15-005: "$x>1$"

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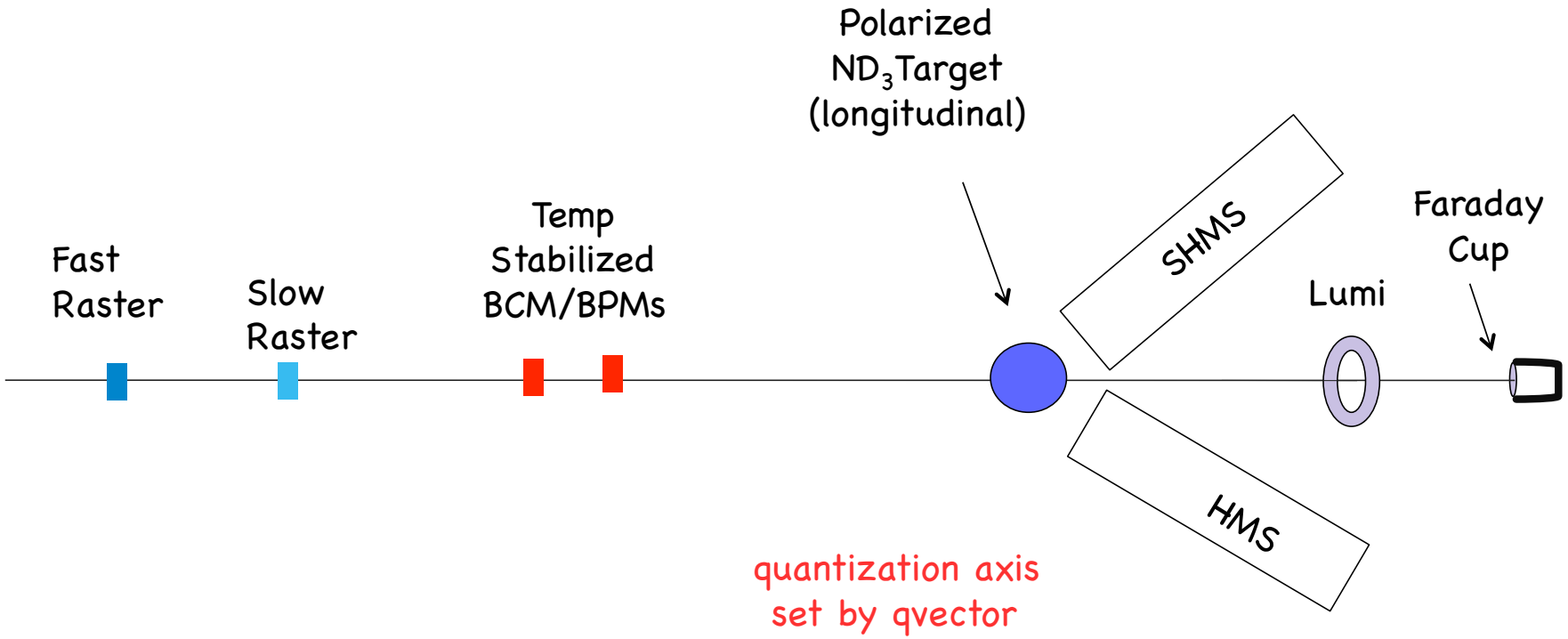
Jlab Hall C



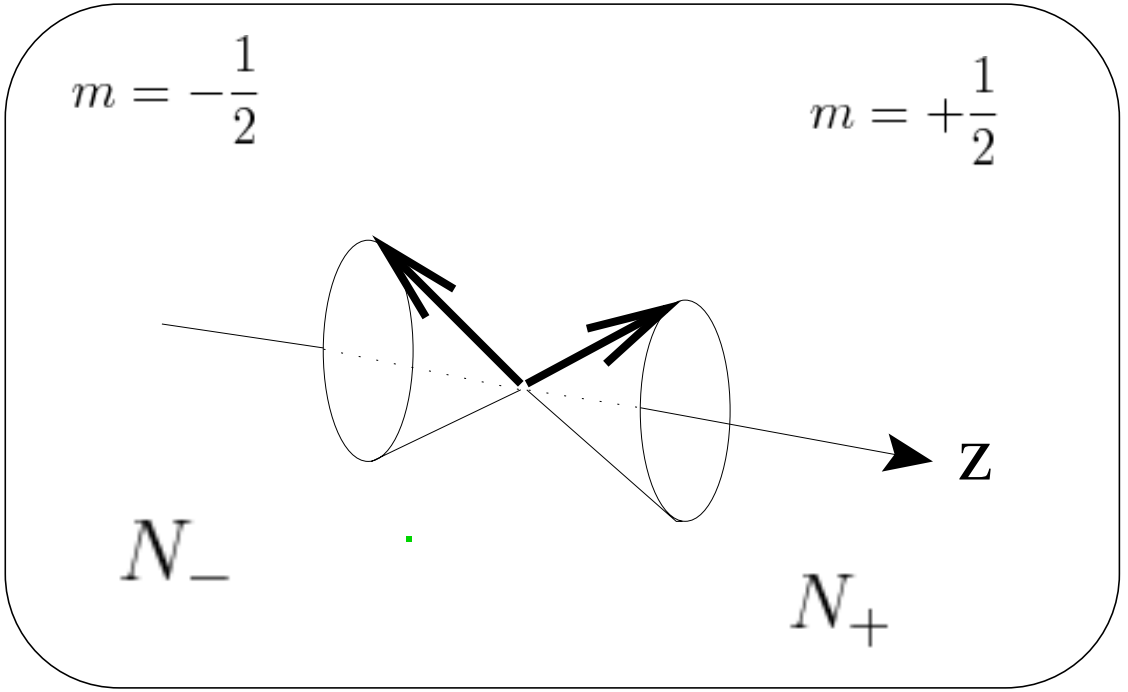
Unpolarized Beam
UVa/JLab Polarized Target

Magnetic Field Held Along qvector

$\mathcal{L}=10^{35}$

Spin-1/2

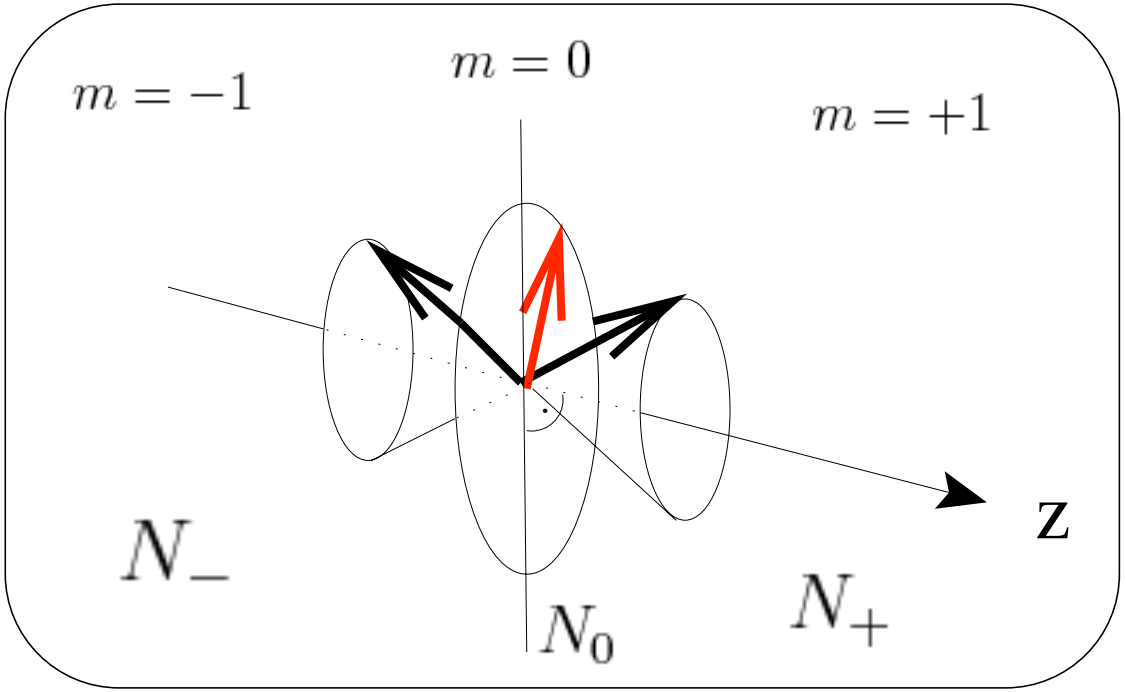
Spin-1/2 system in B-field leads to 2 sublevels due to Zeeman interaction



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

$-1 < P_z < +1$

Spin-1



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

$-1 < P_z < +1$

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

$-2 < P_{zz} < +1$

Experimental Method

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

$$= \frac{2}{fP_{zz}} \left(\frac{N_\dagger}{N_0} - 1 \right)$$

Observable is the Normalized XS Difference

Optimum would be to maximally fill m=0 state

but can measure b1 with any diff of Pzz

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

B-Field, density, temp, etc. held same in both states

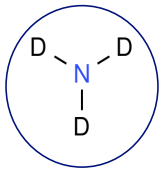
$\sigma_\dagger$: Tensor Polarized cross-section

σ_0 : Unpolarized cross-section

P_{zz} : Tensor Polarizzation

dilution factor

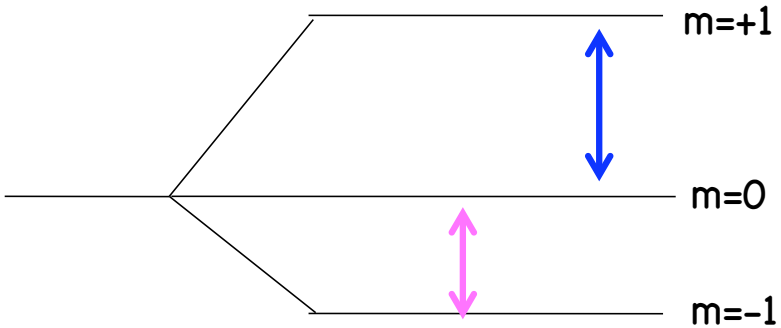
$$f \approx \frac{6}{20}$$



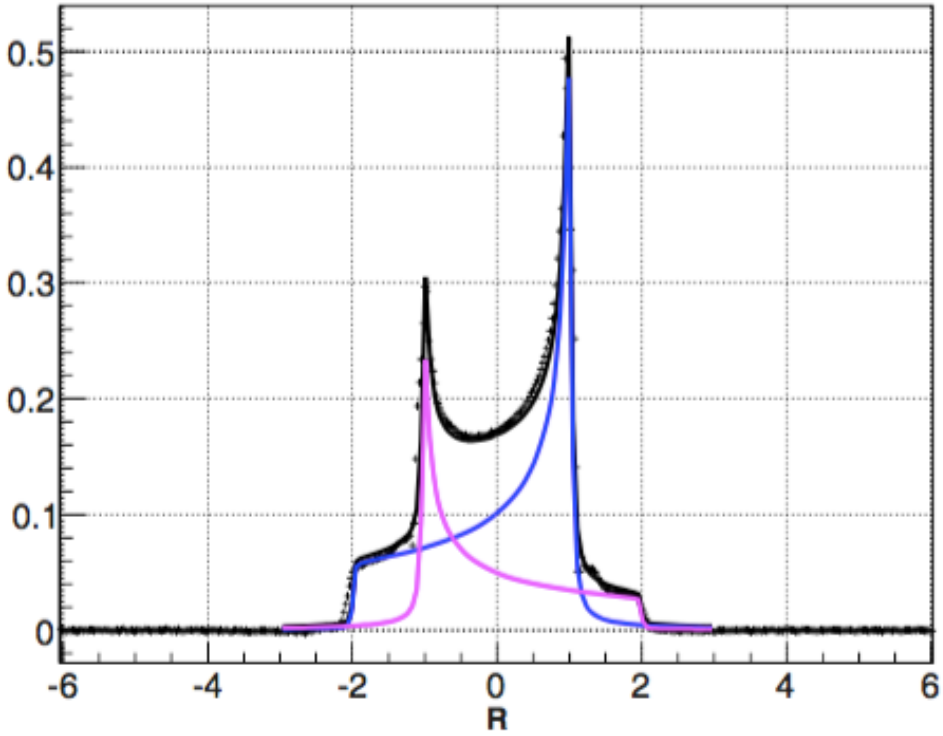
Splitting

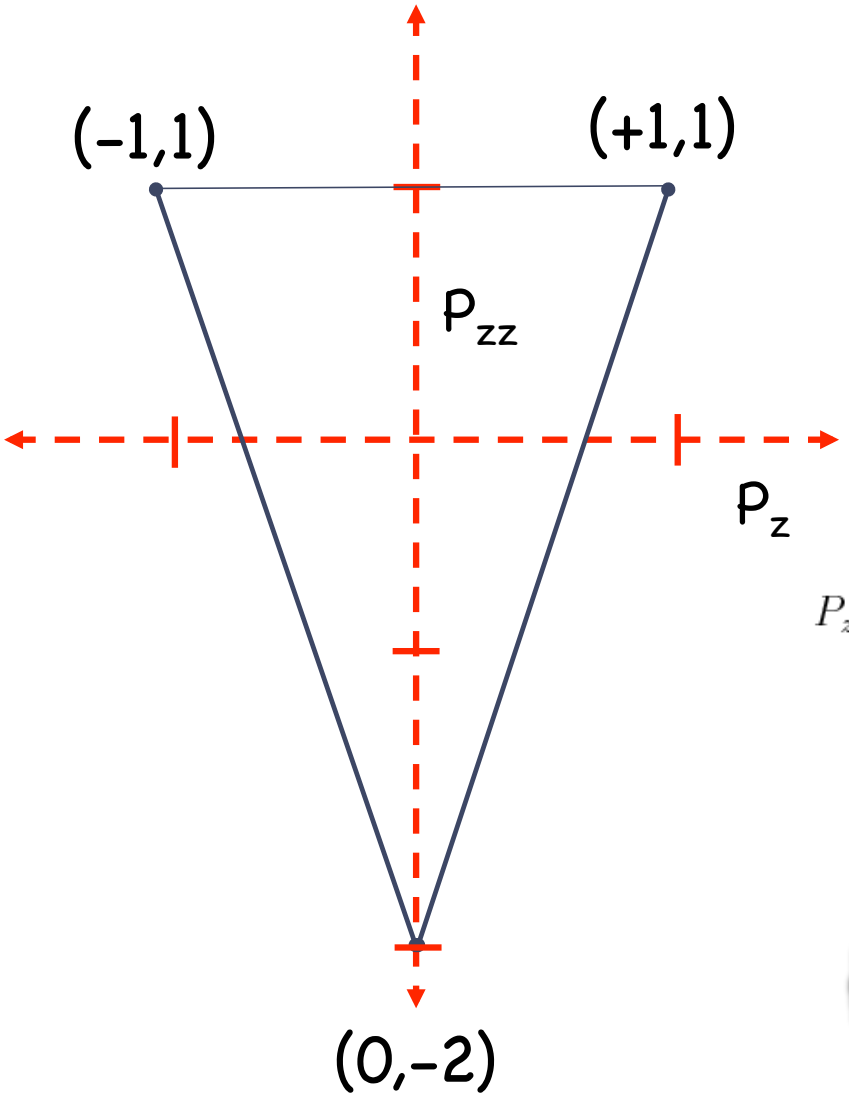
red : 0 <--> -1

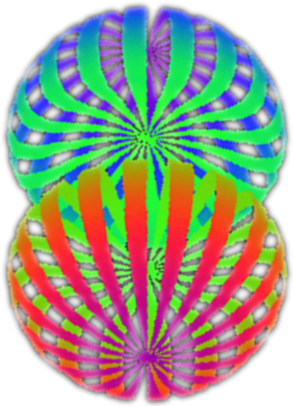
blue : 0 <--> +1



Energy Levels shifted asymmetrically due to quadrupole interaction





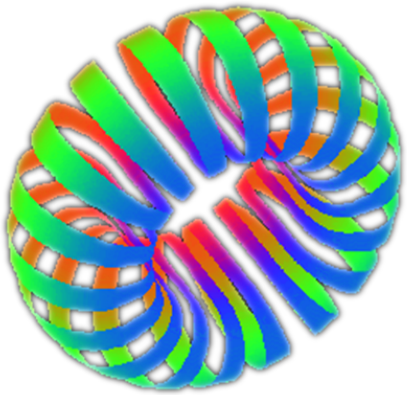


$P_{zz} = +1$

Pure Vector Polarization

m=0 level depopulated

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



$P_{zz} = -2$

Pure Tensor Polarization

All spins in the m=0 level

Extracting P_{zz}

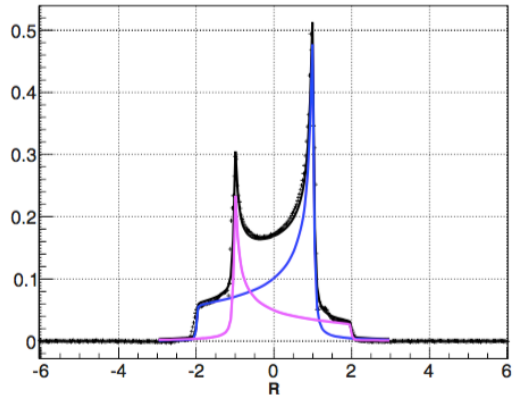
$$P_z = \frac{4 + \tanh \frac{\mu B}{2kT}}{3 + \tanh^2 \frac{\mu B}{2kT}}$$

$$P_{zz} = \frac{4 + \tanh^2 \frac{\mu B}{2kT}}{3 + \tanh^2 \frac{\mu B}{2kT}} \qquad P_{zz} = 2 - \sqrt{4 - 3P_z^2}$$

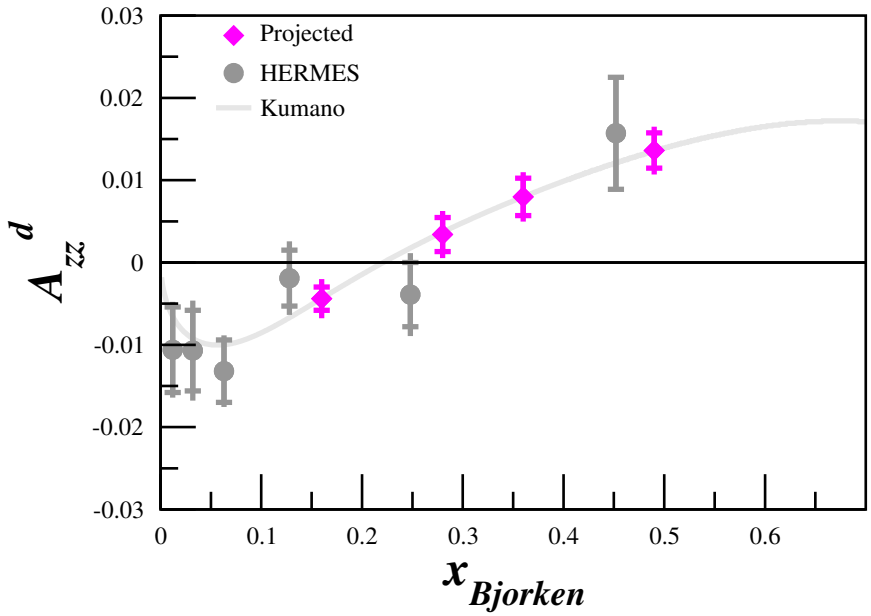
But Only when in Thermal Equilibrium with the Solid Lattice

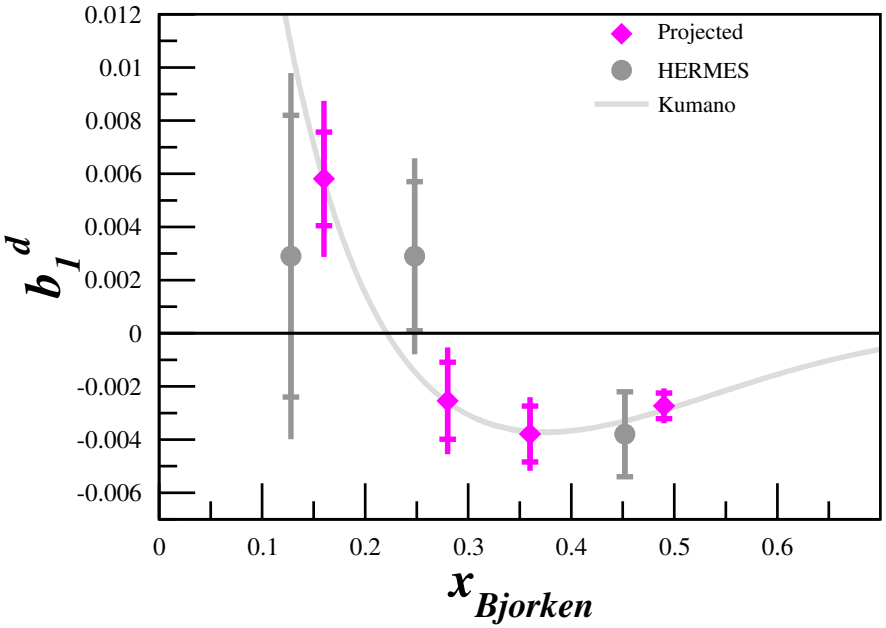
does not hold when actively enhancing P_{zz}

But we can extract the tensor pol
from the difference of Area of the two peaks.



Projected Results for P_{zz} = 35%

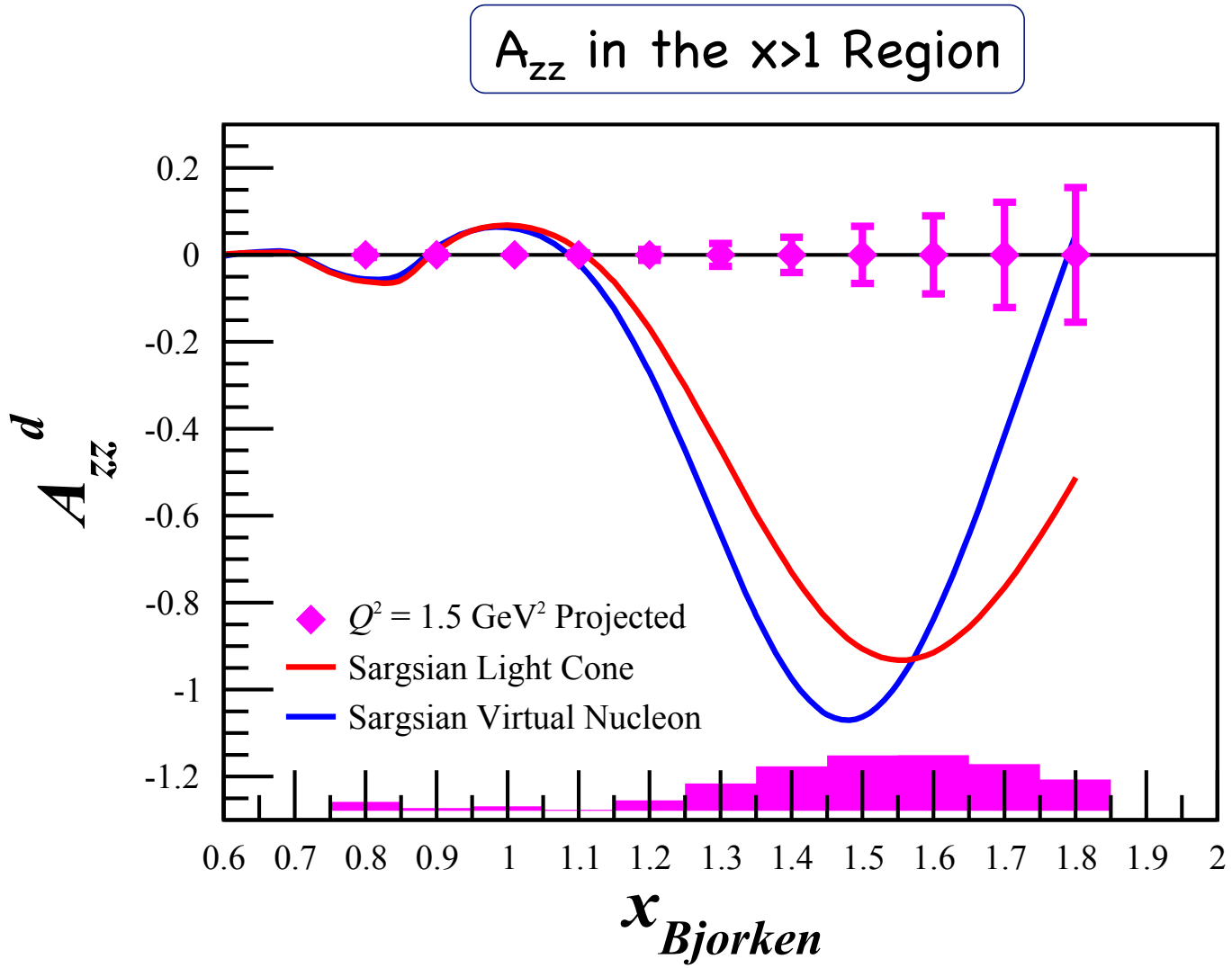




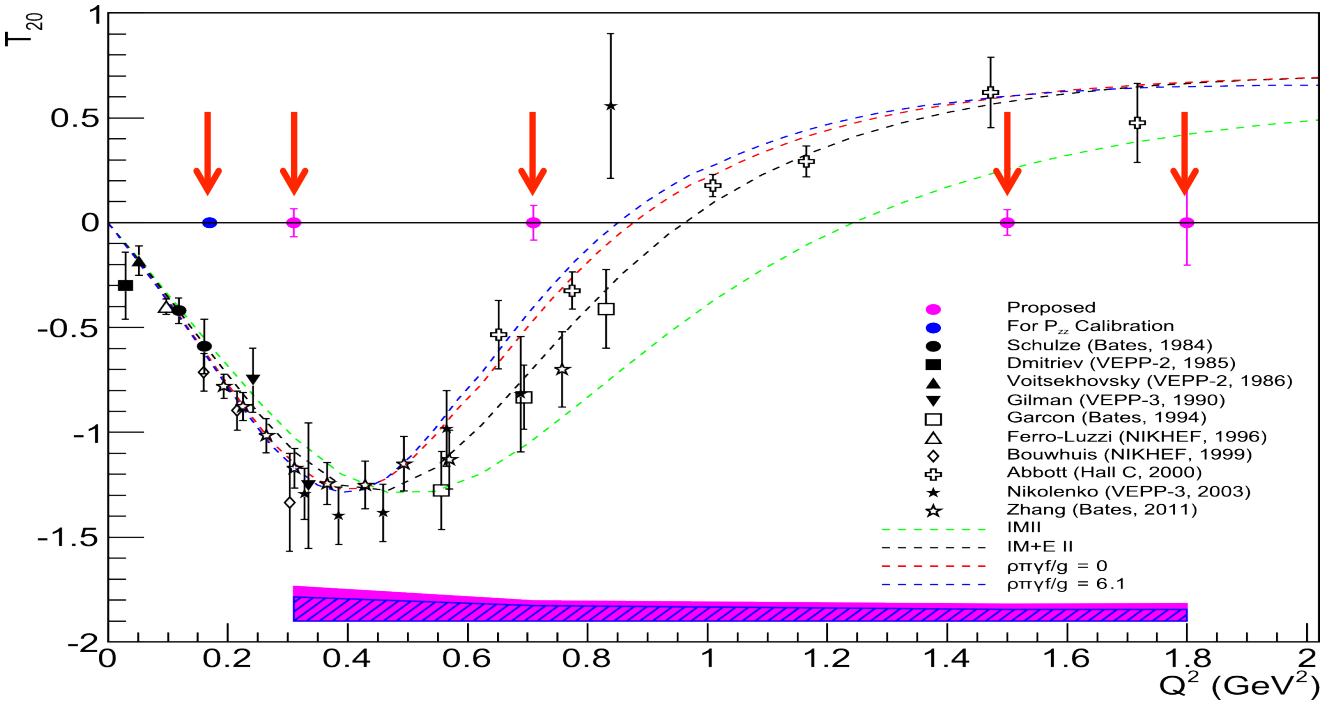
30 Days in Jlab Hall C

verification of zero crossing
essential for satisfaction of CK Sum

Projected Results for P_{zz} = 35%



T_{20}



We simultaneously measure nuclear elastic

-> T_{20} over huge Q^2 range

-> measure T_{20} at largest Q^2 yet

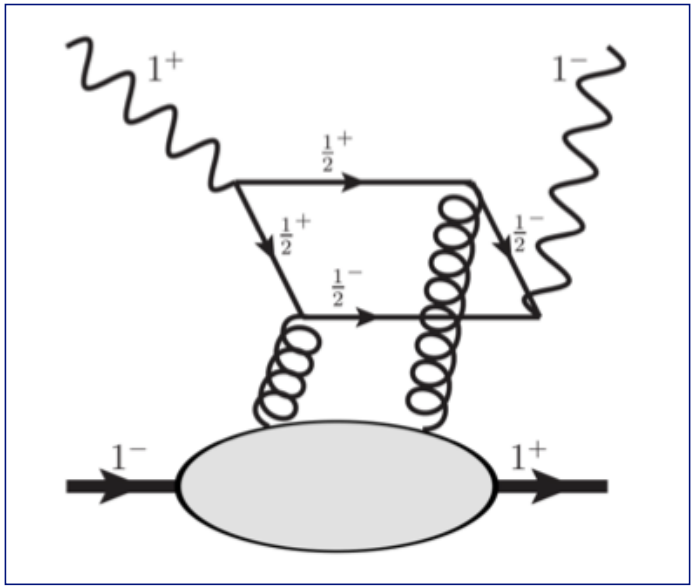
-> will use to cross-check Pzz

LOI-12-16-006

See R. Milner @ Spin2016
"State and Future of Spin Physics"

James Maxwell (contact)

"Nuclear Gluonometry"



Look for novel gluonic components in nuclei that are not present in nucleons

Non-zero value would be a clear signature of exotic gluon states in the nucleus

Deep inelastic scattering experiment:
- Unpolarized electrons
- Polarized $^{14}NH_3$ Target
- Target spin aligned transverse to beam

$\Delta(x,Q^2)$ double helicity flip structure function

Encouraged for full submission by PAC44

Extension to EIC

Summer 2019 : E. Long and myself worked with Jlab EIC staff Julia Furletova to make projections for Azz at EIC. Initial results are very promising!!!

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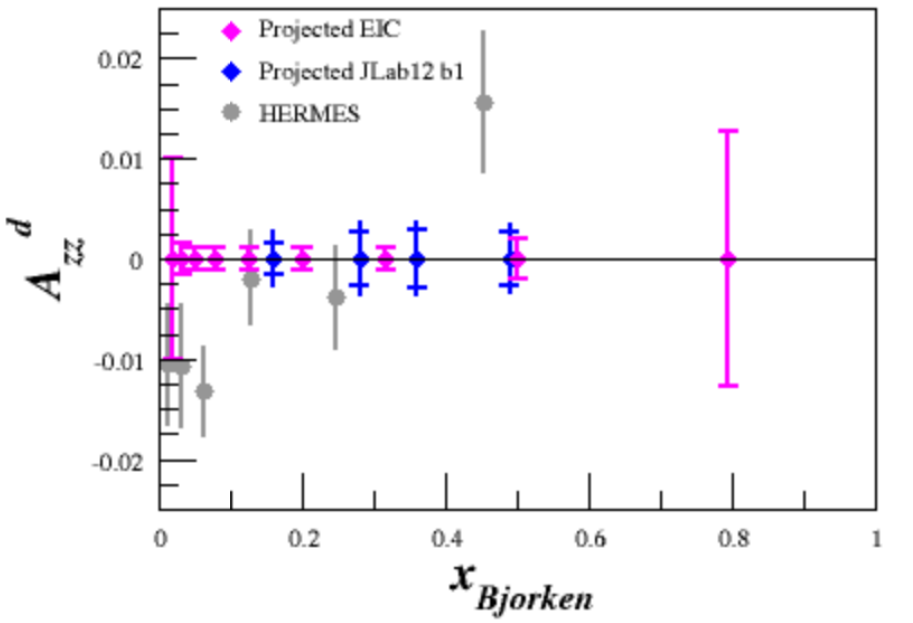
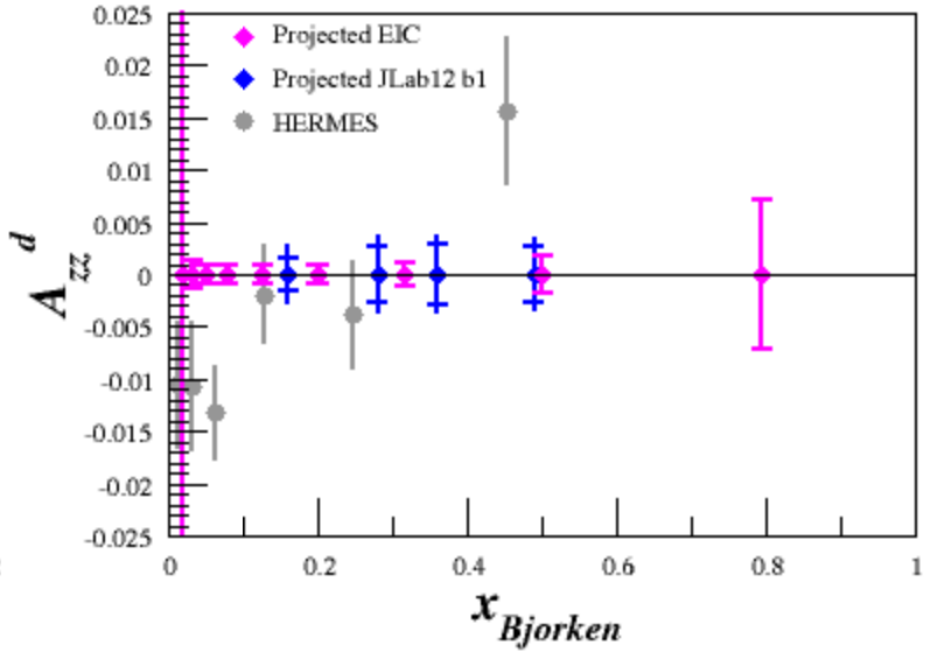


Q^2=10 GeV^2



Q^2=100 GeV^2

2 Weeks of JLEIC Running (4 more Q2 not shown)

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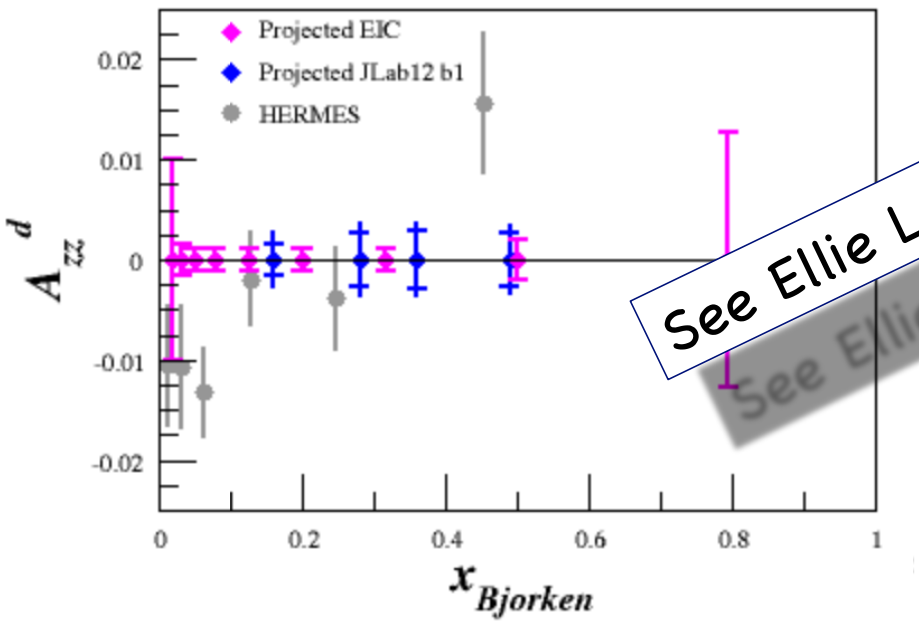

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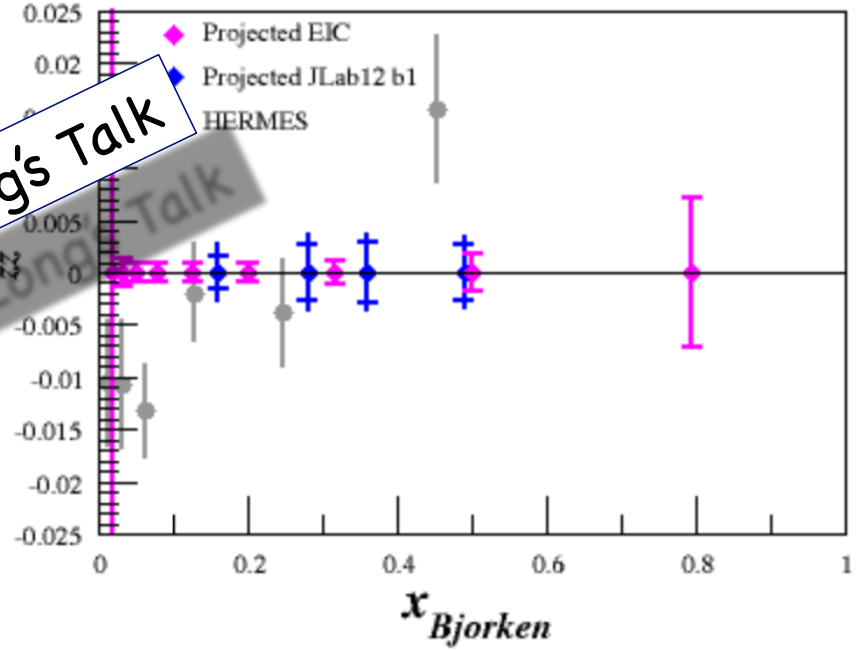
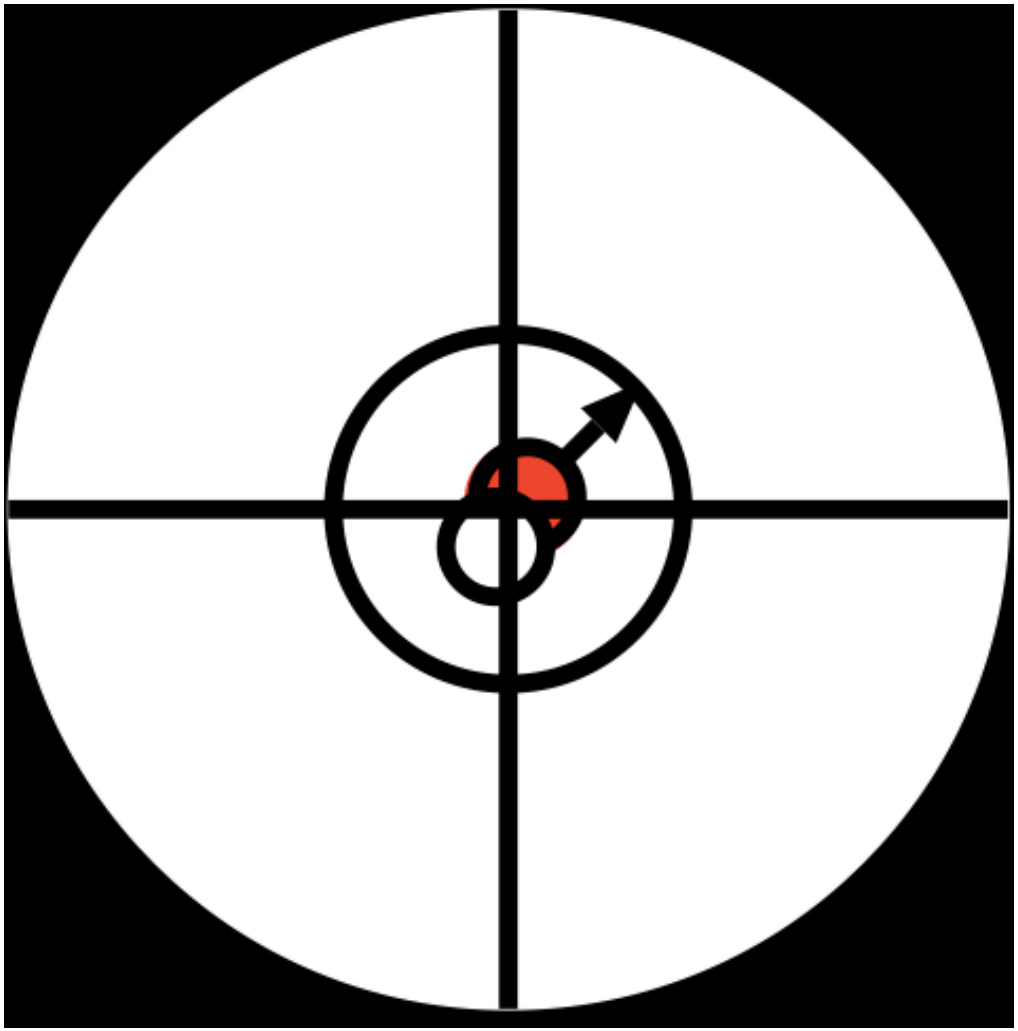


Q^2=100 GeV^2

See Ellie Long's Talk

2 Weeks of JLEIC Running (4 more Q2 not shown)

Polarized Target



UNH Polarized Target

2 faculty, 2 labspaces
-K.Slifer & Ellie Long

1 post-doc MarieBoer

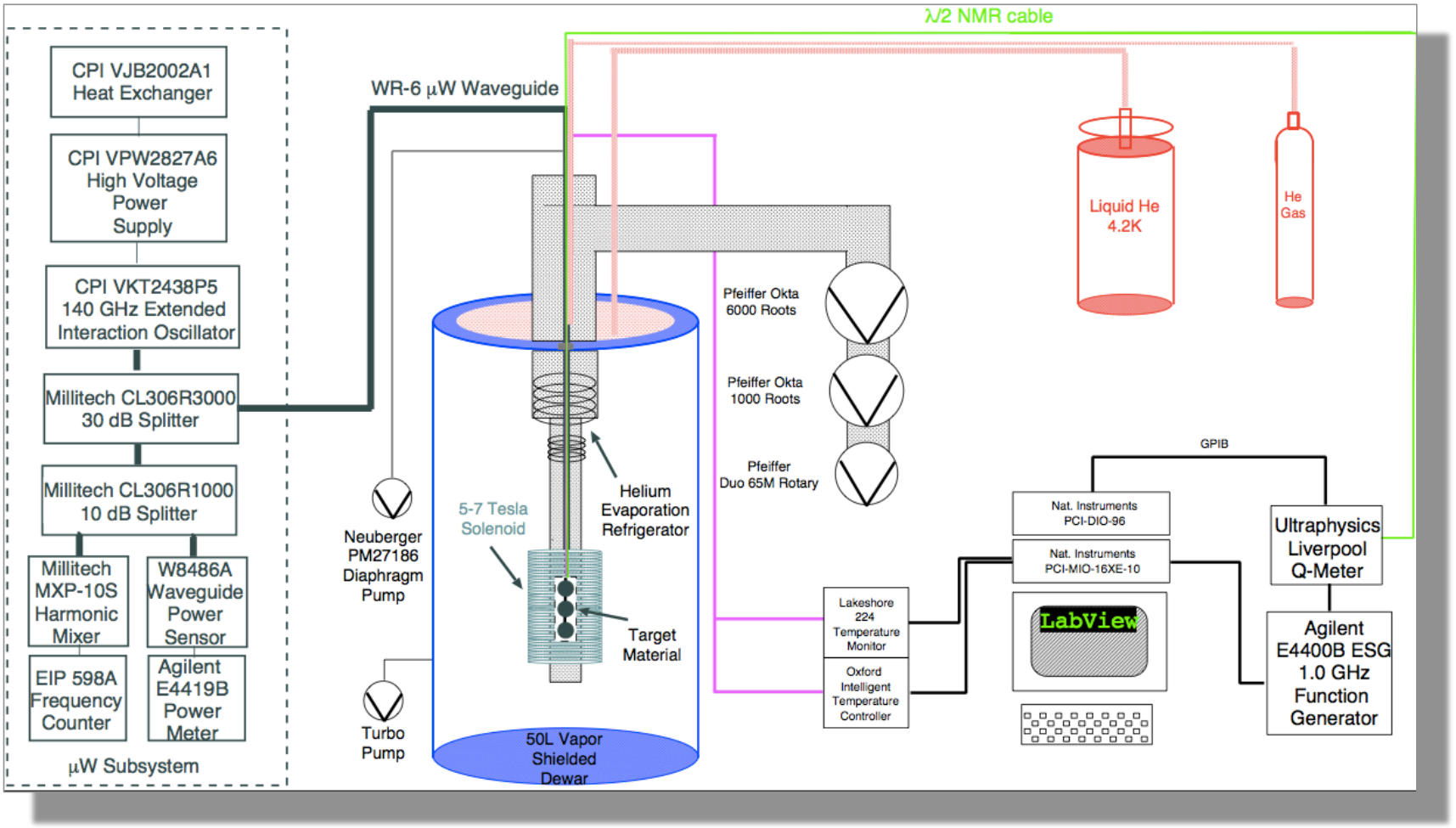
5 grad students (partial time)
2 with Ellie, 3 with KS

lots of undergrads

Projects

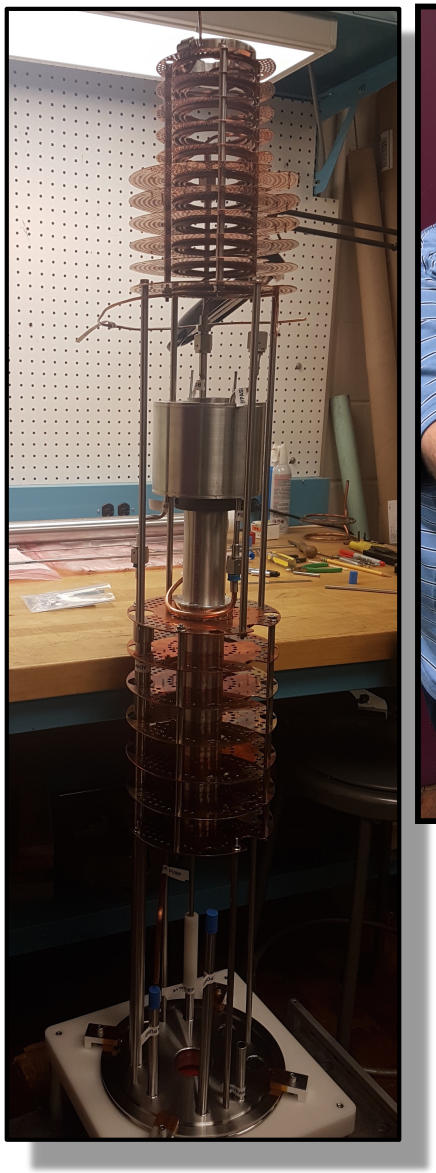
- Polarized Target Support for E1039 (Material Production & Labview controls)
- Tensor Polarization R&D
- Natural to transition some of this over to EIC tensor studies

UNH Polarized Target Lab



Came online in 2018.
3 successful cooldowns since

UNH He Evaporation Refrigerator



(assemb "upside down")

UNH Machinist
Phil DeMaine

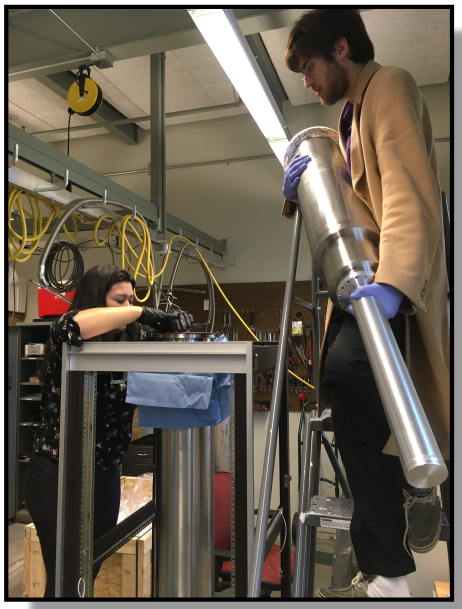
All Machining Completed at UNH

- ✓ Heat Exchanger
- ✓ Separator Pot
- ✓ Radiation Baffles
- ✓ Needle valves
- ✓ Vacuum Shells

Final brazing/welding of needlevalves fittings @ Jlab

UNH He Evaporation Refrigerator

Complete Fridge



Vacuum shells

All Machining Completed at UNH

- ✓ Heat Exchanger
- ✓ Separator Pot
- ✓ Radiation Baffles
- ✓ Needle valves
- ✓ Vacuum Shells

Final brazing/welding of needlevalves fittings @ Jlab

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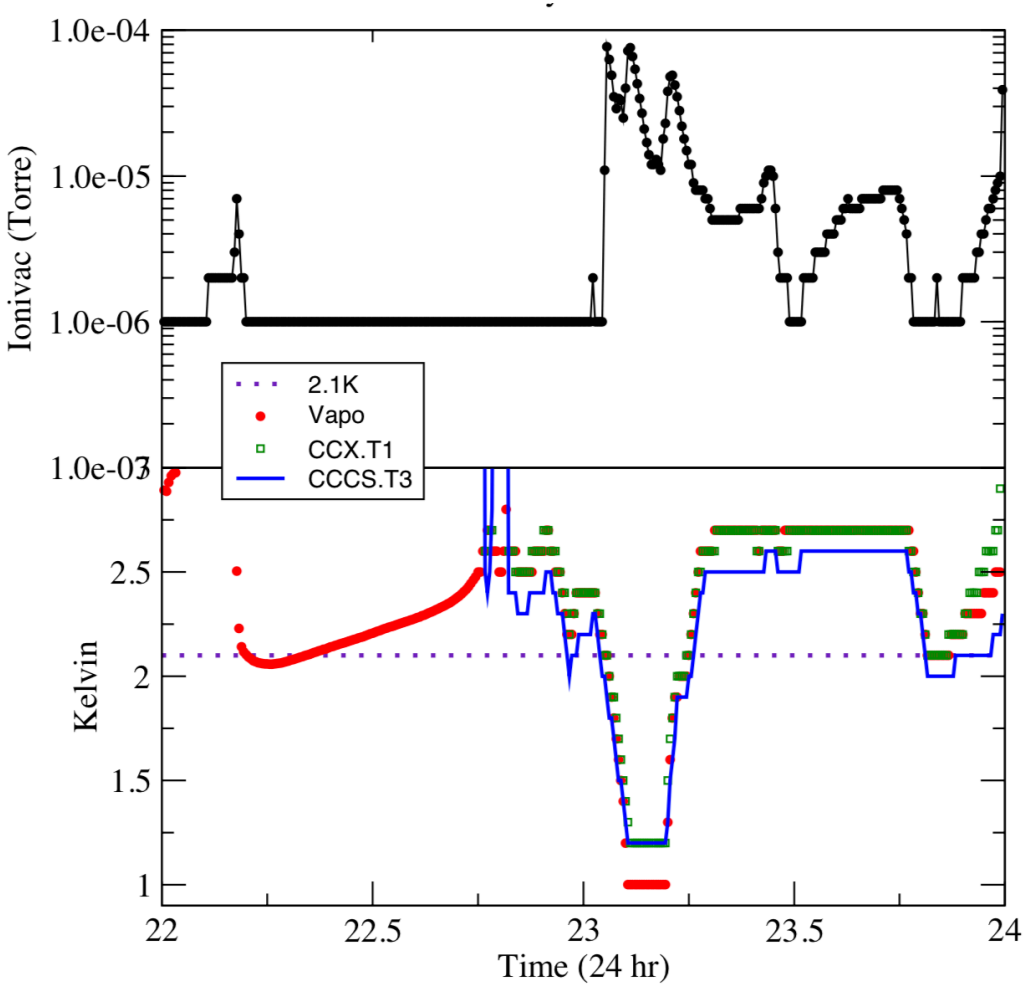


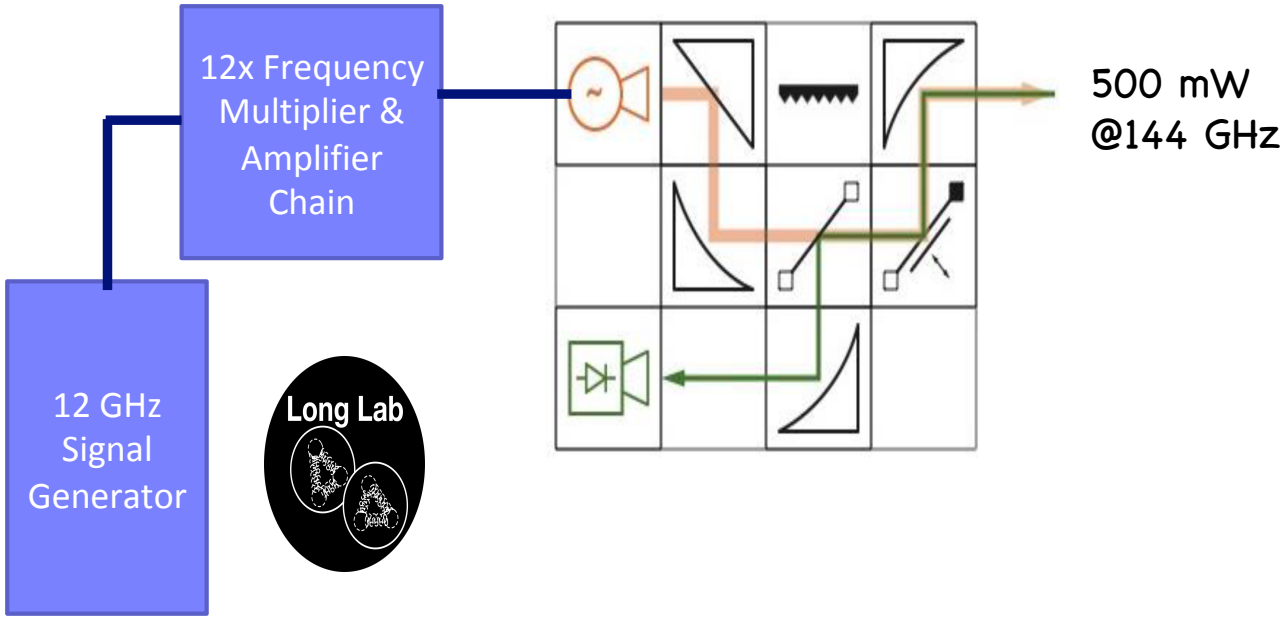
1 Kelvin Running
3 cooldowns

Operationally measured
>45W cooling power!!!!!
at 2K

Wrestling with a superfluid leak that compromises vacuum

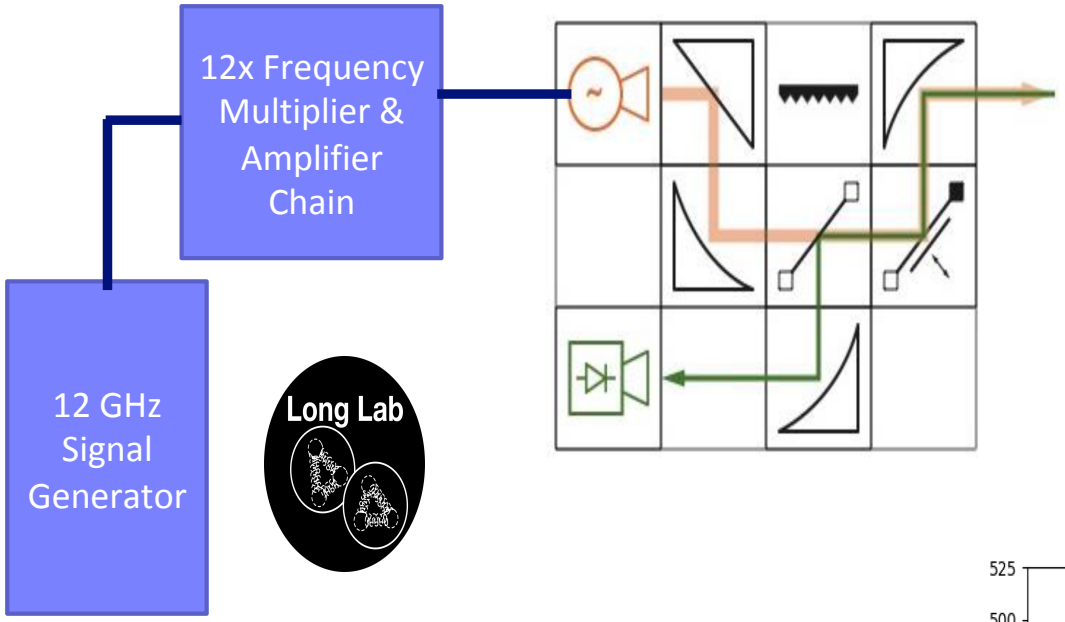
Complete Fridge

Solid State mm-Wave System



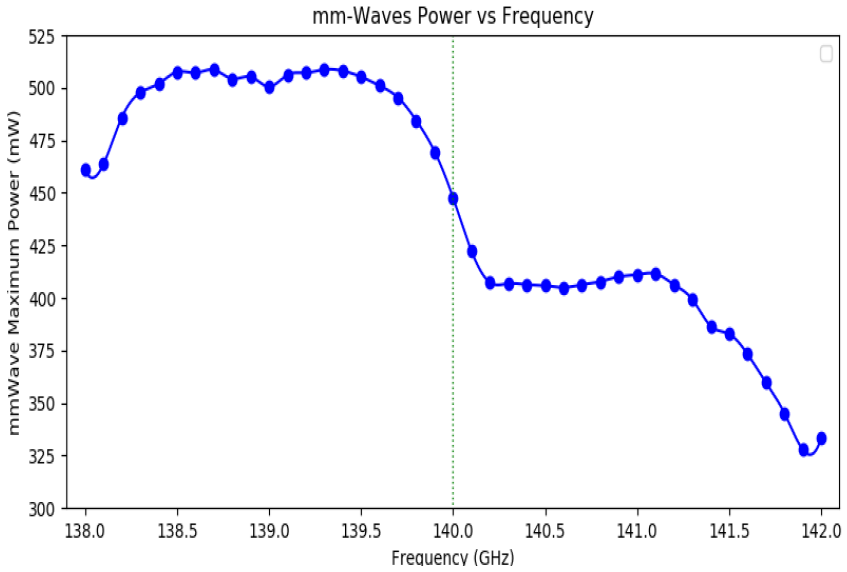
Cheaper than EIO
No cooling
Sits directly above target
Passes thru air gap

Solid State mm-Wave System



500 mW
@144 GHz

Cheaper than EIO
No cooling
Sits directly above target
Passes thru air gap
Low Loss Overmodal waveguide
Wide Frequency Range



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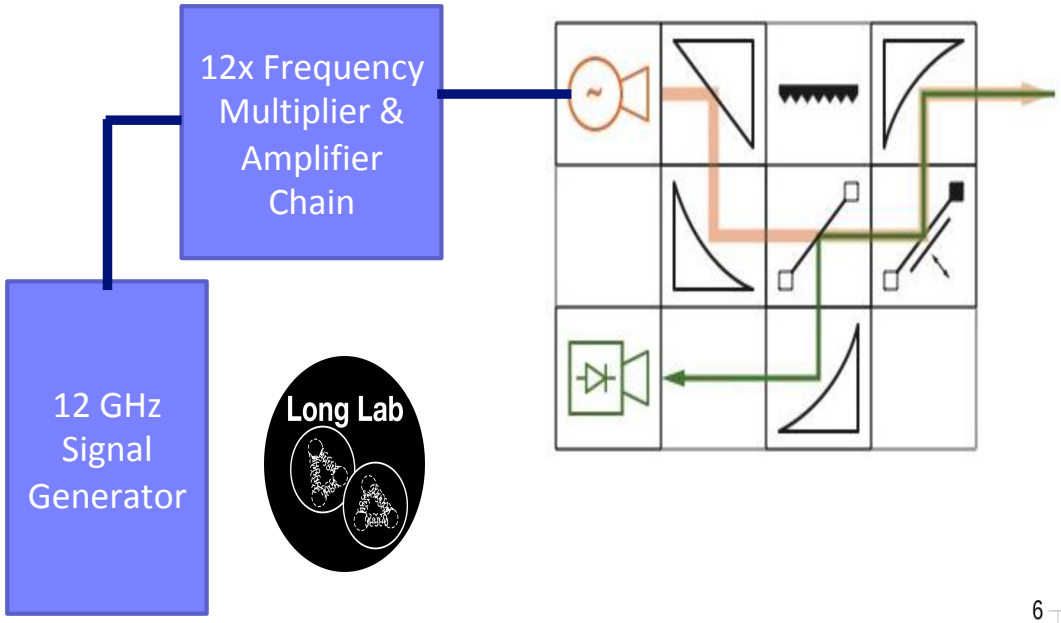

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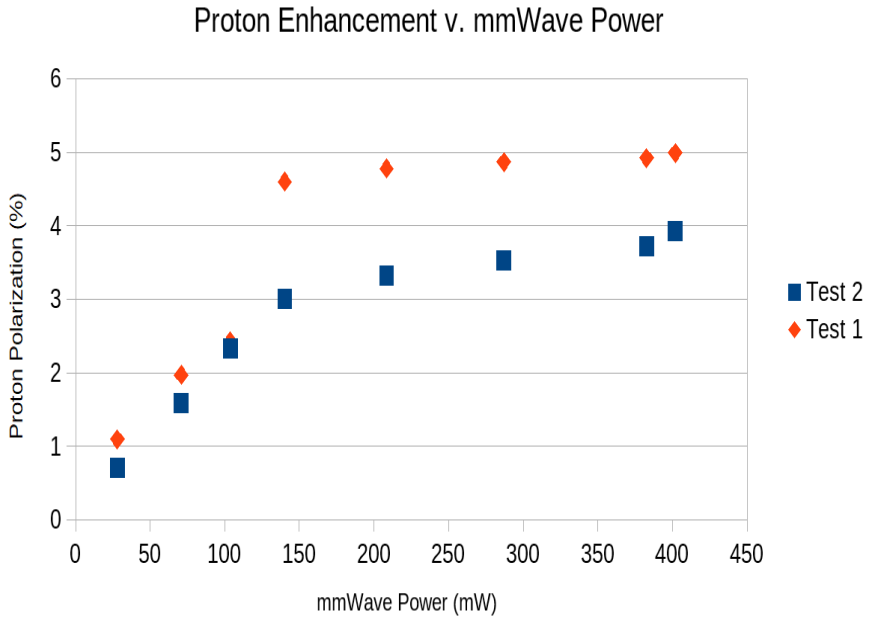
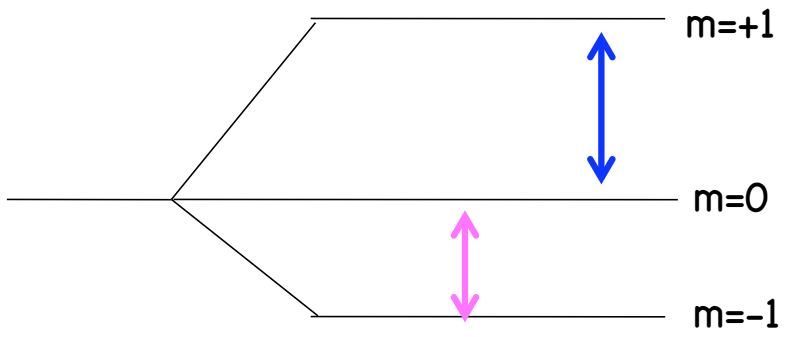


Our tests indicate polarization saturation

Solid State mm-Wave System

Cheaper than EIO
No cooling
Sits directly above target
Passes thru air gap
Low Loss Overmodal waveguide
Wide Frequency Range
Frequency Hopping as fast as 1 khz
(mimics multiple sources for populating m=0)



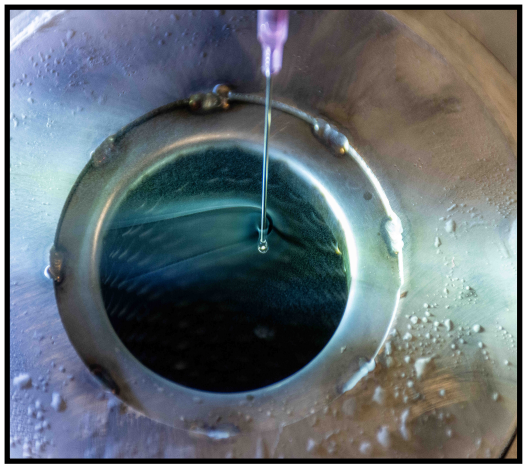
Target Material Production at UNH

-Dedicated fume hood for Handling Ammonia and other caustic/toxic materials

-New Vacuum GloveBox allows for over/underpressuring

-Primarily chemical doping of ammonia and alcohols for now.
But potential to do much more.

Target Material Production at UNH

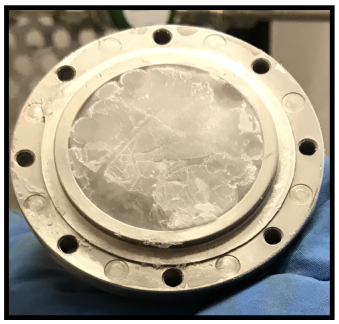


Butanol and other alcohols solidification

grade 5.5 NH_3

Chemically Doping

Rapid vs SlowCooling of NH_3

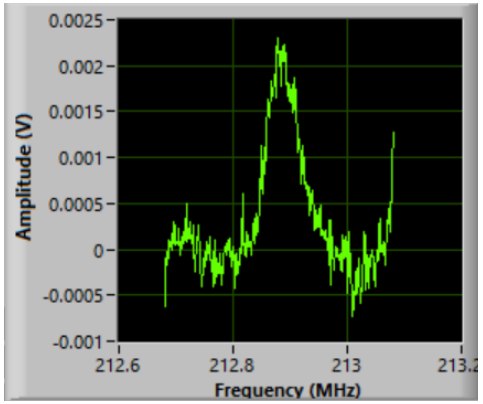


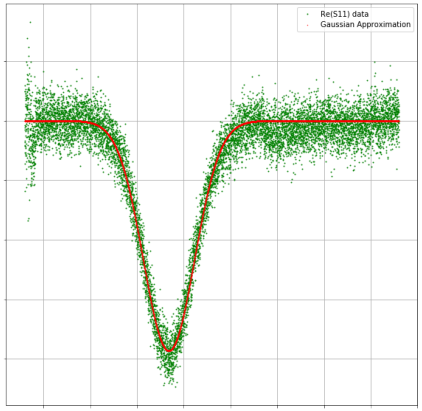
3 NMR Systems

1) Liverpool Q-Meter (thanks Don Crabb : Uva!)
gold standard, but blackbox and difficult to tune

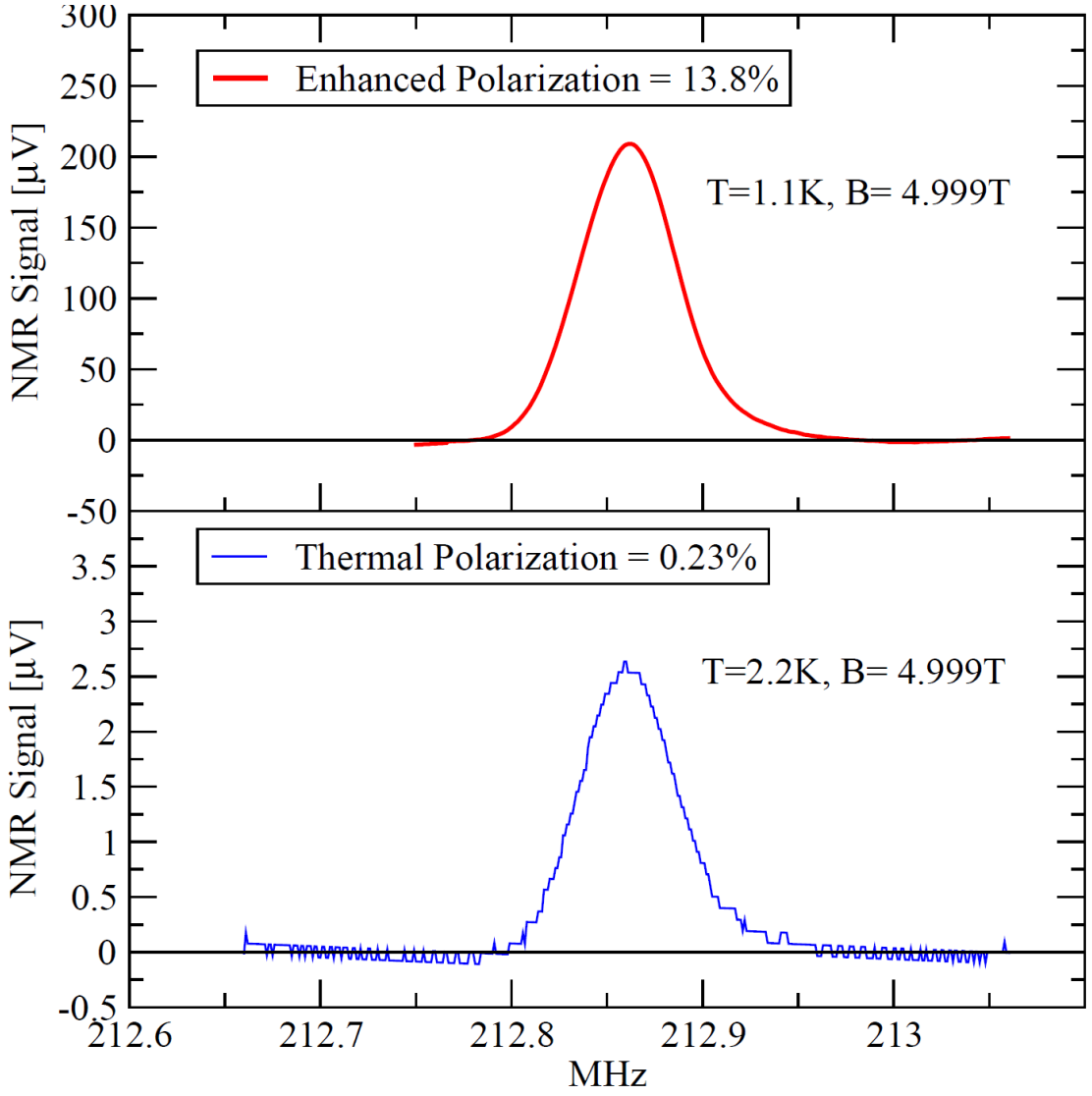
2) VME based replacement (thanks Pat Mcgaughey/Lanl)
our most reliable system at 5T

3) SDR-based Vector Network Analyzers VNA
easy to tune at any frequency
TEs at 1T, 2T, 5T
We haven't yet tested linearity





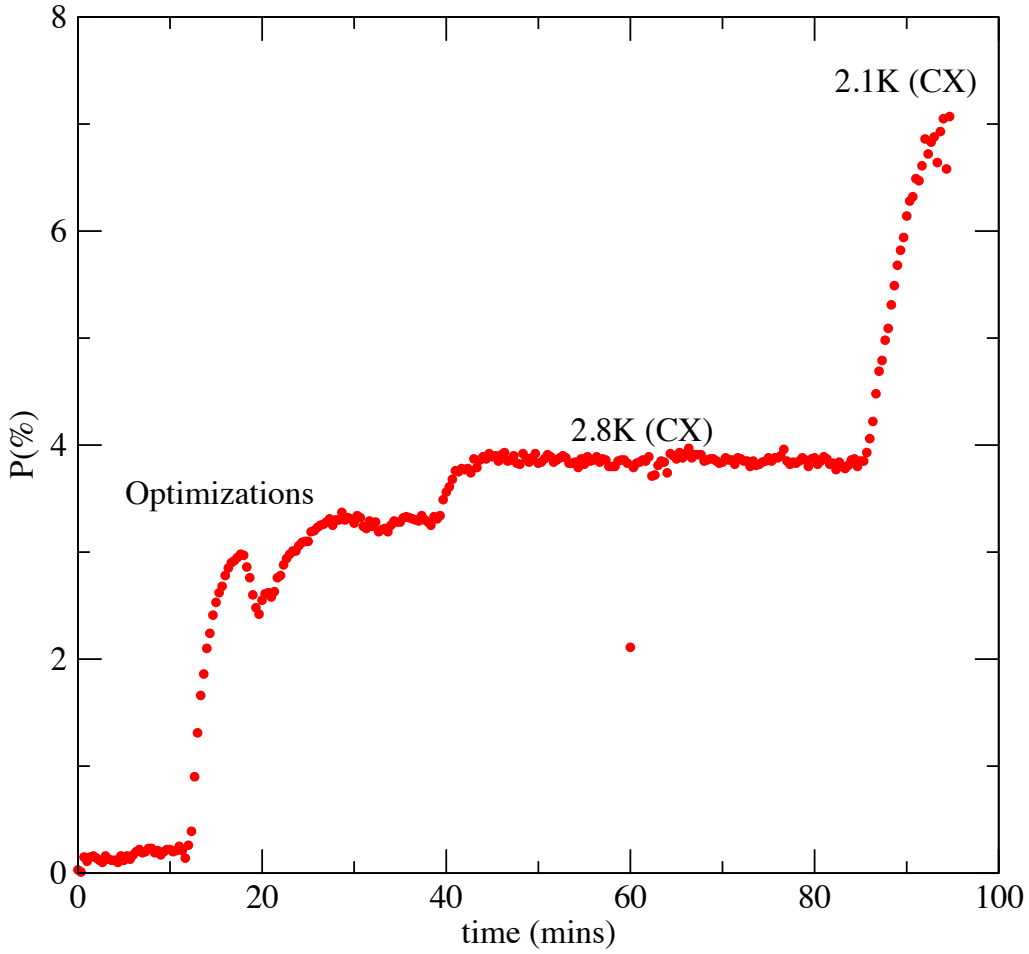
Tempo Doped Polymer



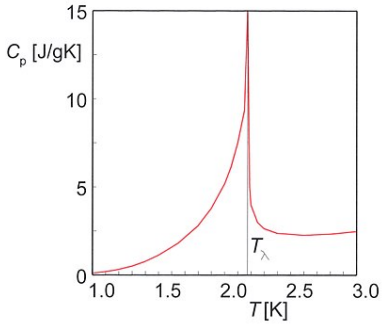
Dynamically Enhanced Polarization

Thermal Signal

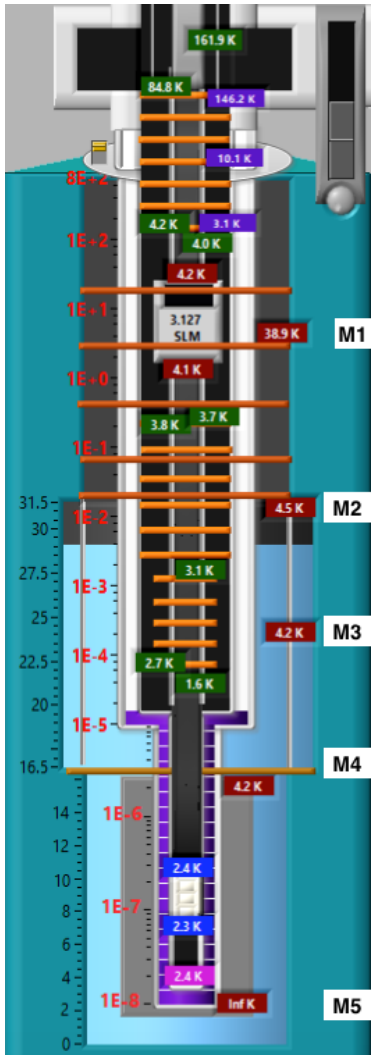
Tempo Doped Butanol Spinup

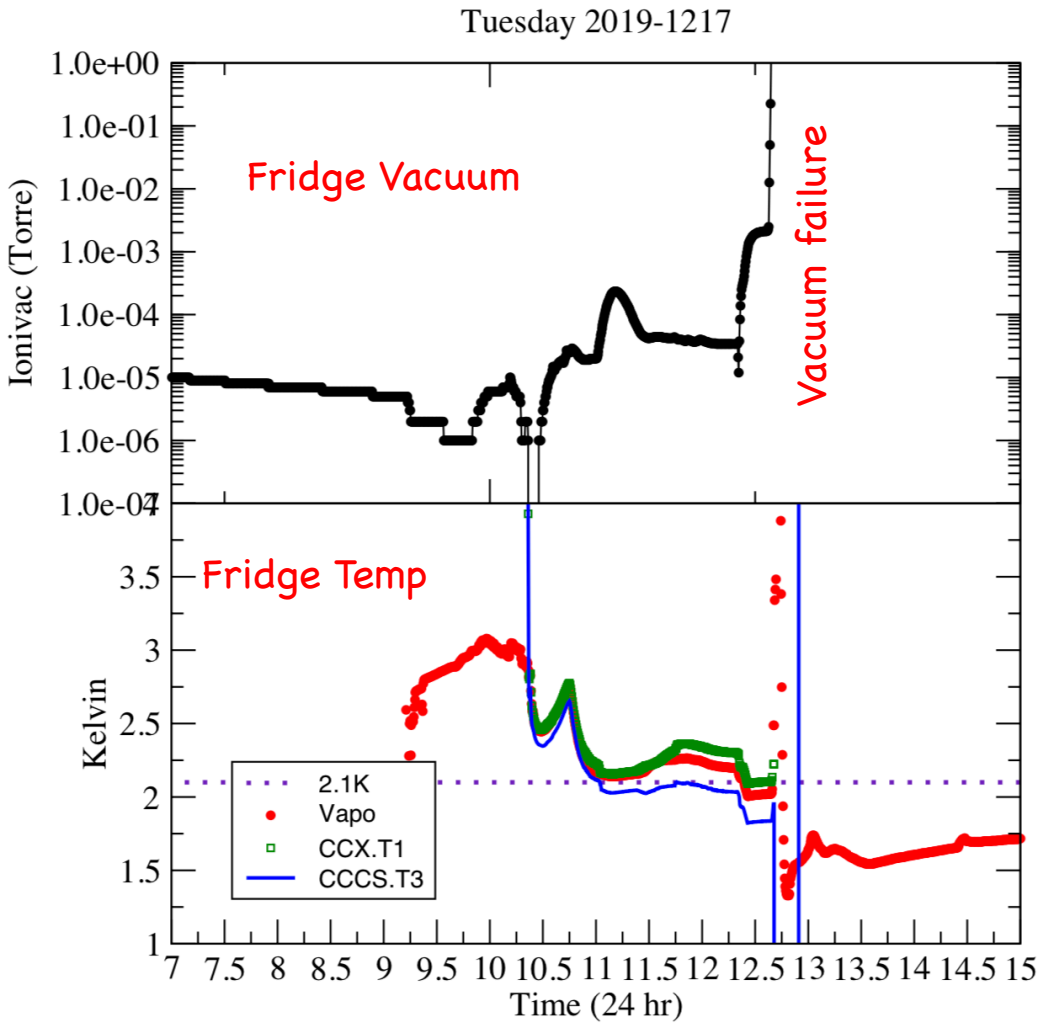


Healthy spin up at 2.1K
But below 2.1K we have a superfluid leak thru an indium seal which destroys our fridge vacuum

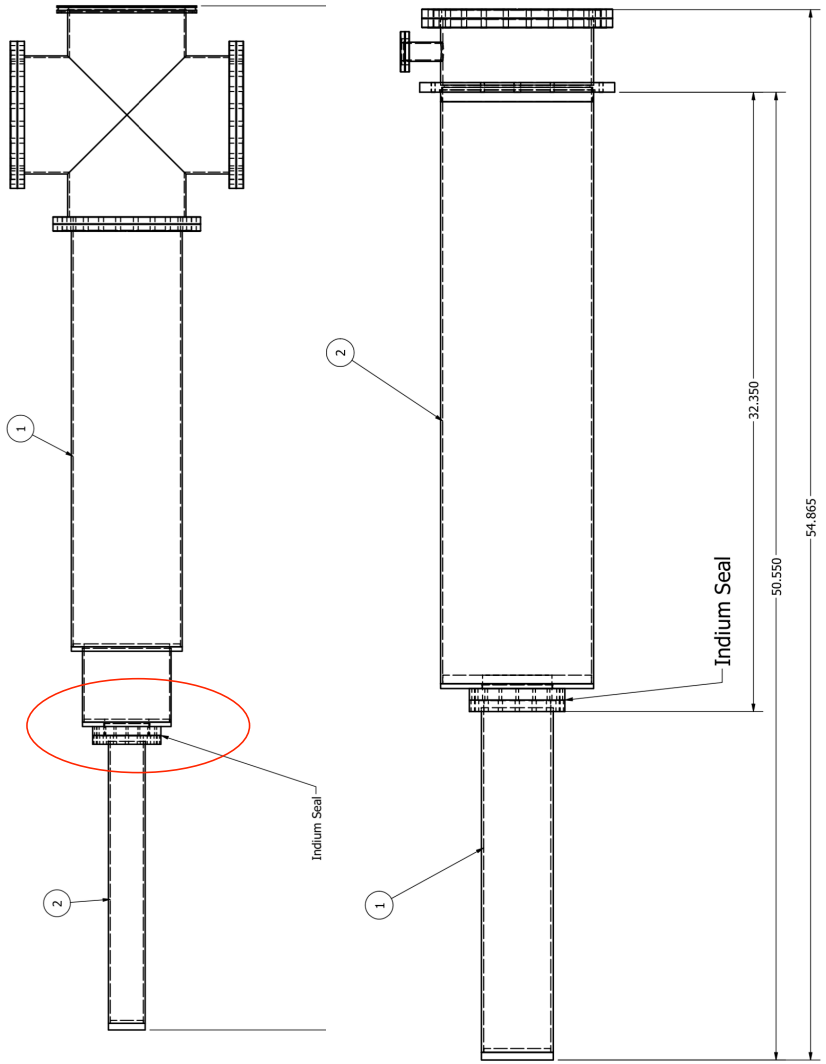


Superfluid Helium Leak





Superfluid Helium Leak

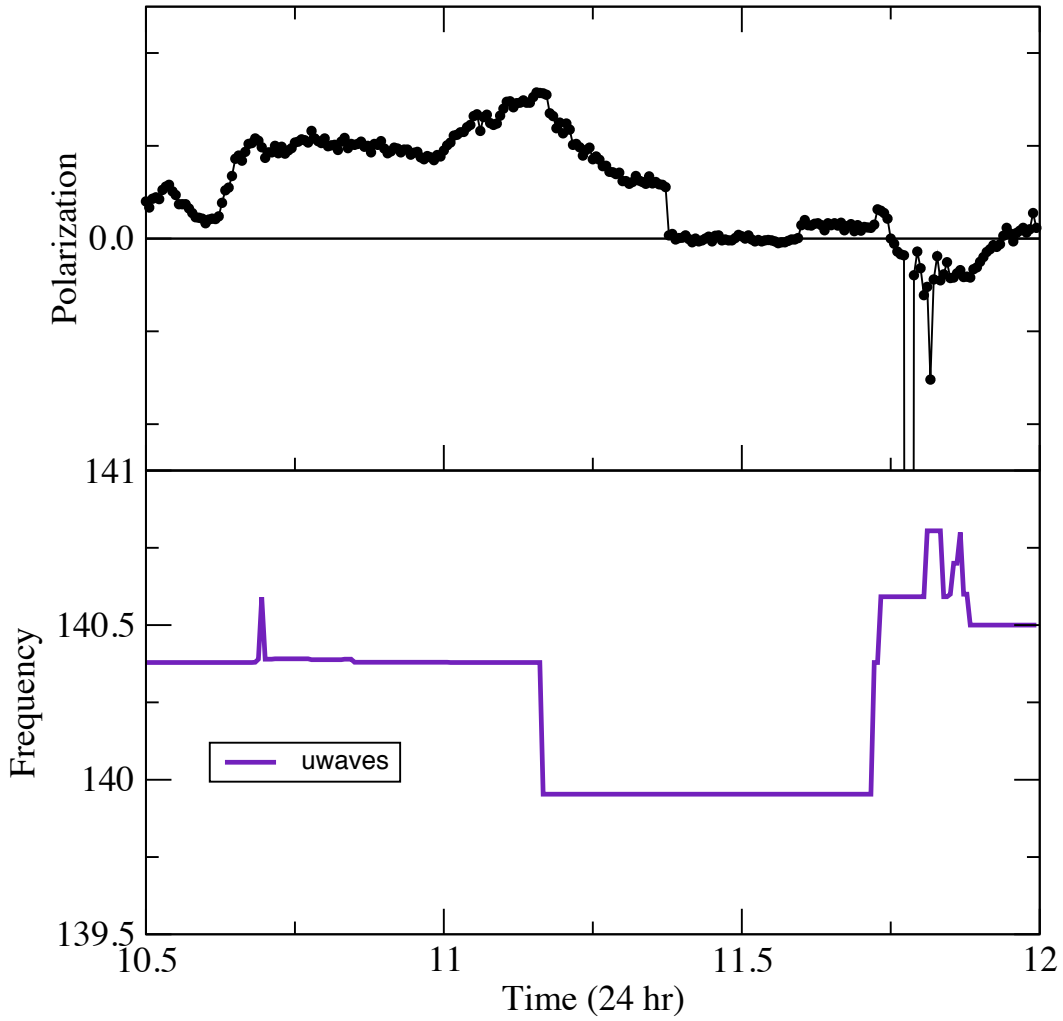


This leak has limited our ability to run at 1K and our max pol.

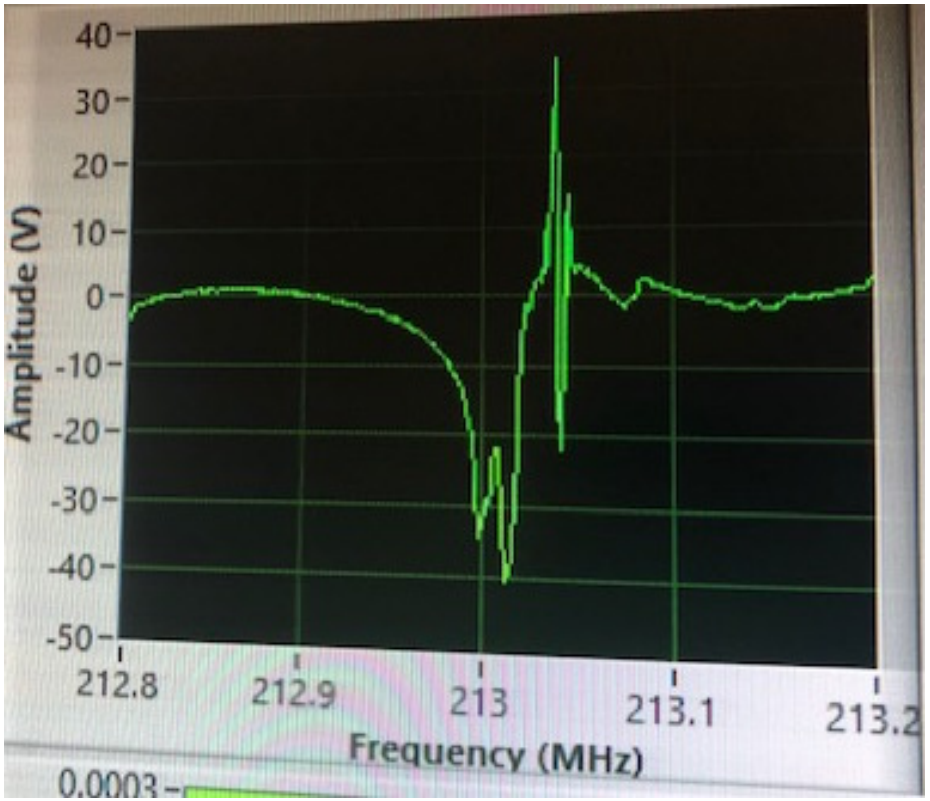
We have new CF shells ordered from Lesker which should fix this.

Also need to replace our needle valves which currently give poor control

DNP Spin Flip



RF Hole Burning



Proven method to enhance
Tensor polarization

We have a working RF system
-READY TO TEST WITH D-material

This technique has been used
By D. Keller at Uva to achieve
P_{zz} =38%

Further Improvements to P_{zz}

Frequency hopping of the microwaves

Directly pumping individual ESR lines simultaneously

Larger Magnetic Field

Lower Temperature with Optimized Cooling

Manipulation of polarization with AFP

Different Materials

Which Target Tests are most interesting to the EIC?

Efficiency of spin rotations

AFP (and DNP) Spin Flips

Maximizing Tensor polarization

Polarimetry (how well will we be able to extract P_{zz})

Lineshape fitting

Summary

Tensor Program

E12-13-001: b_1 of the Deuteron (systematics suppressed by $1/P_{zz}$)

E12-14-002: A_{zz} for x>1 (HUGE asymmetries expected)

LOI12-14-001: Tensor Structure Function Δ

Other ideas : SIDIS, DVCS, Tensor polarized Drell Yan, ...

Significant Target Progress

UNH target lab is fully functional.
- Fridge has healthy cooling power
- SS microwave source works well
- target material preparation going well
- 3 working NMR systems

Biggest issue we are addressing is a superfluid leak which we plan to address with new vacuum vessel and improved needle valves

Next step is moving to deuterated materials

We will be able to tensor polarize soon. Still time to incorporate tests for EIC.

b_1 Structure Function

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

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

Investigate nuclear effects at the level of partons!

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