A High-Field Polarized ^{3}He Target

for Jefferson Lab's CLAS12 Spectrometer

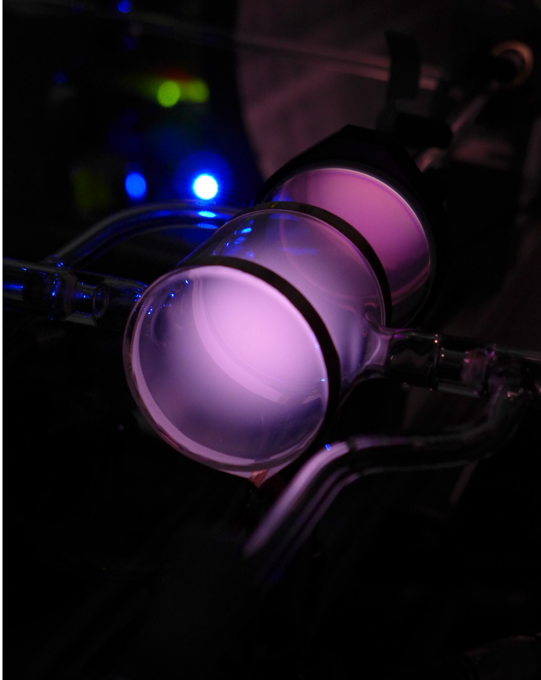
J. Maxwell

for CLAS12 Polarized 3He Collaboration

Jefferson Lab

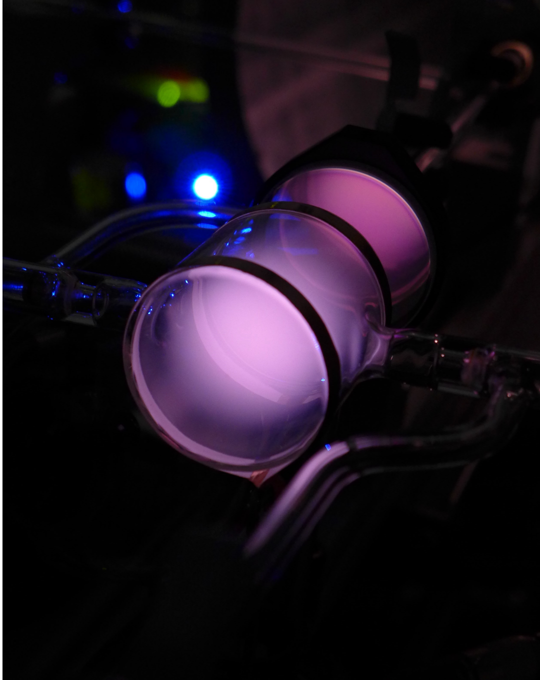
Massachusetts Institute of Technology

24th International Spin Symposium
Matsue, Japan
October 21, 2021



Outline

1. Polarized ^{3}He for Nuclear Physics
   - Optical Pumping
   - Opportunity for a New Target
2. Proposed Target for CLAS12
   - Design
   - Development
3. Outlook
   - Projected Schedule
   - Transverse Polarization?



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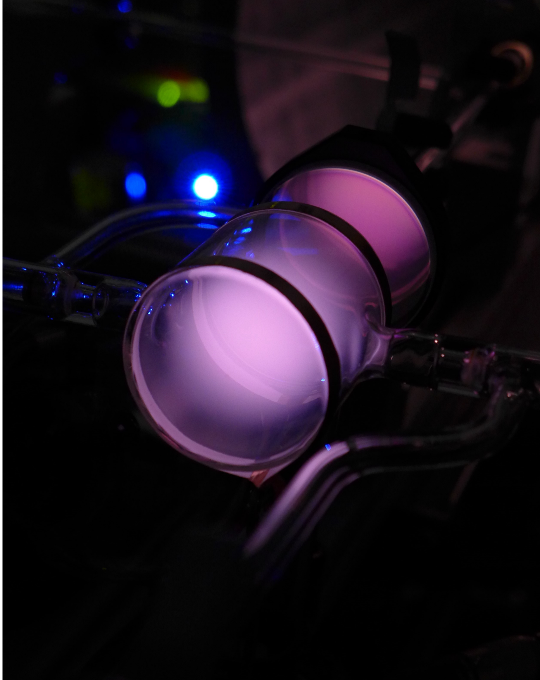
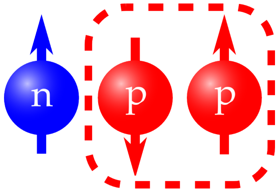


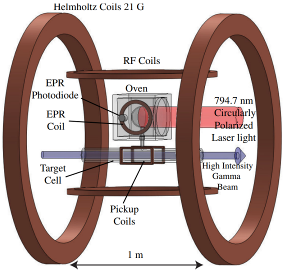
Why Polarized Helium 3?



- About 90% of the time, ^{3}He's 2 proton spins are anti-aligned in a spin singlet
- ^{3}He spin is primarily neutron spin
- By polarizing ^{3}He, we have a surrogate for polarized free neutrons

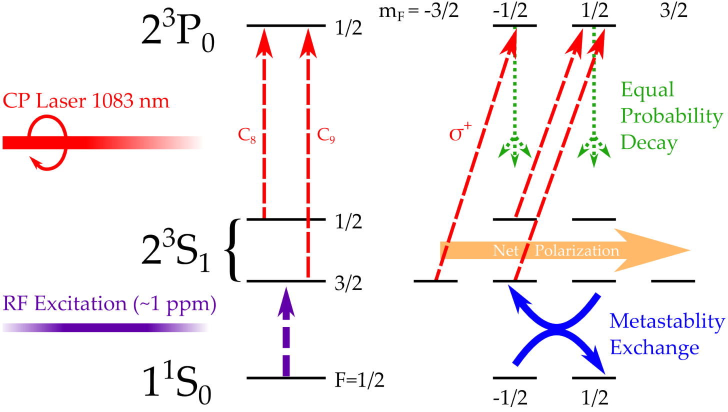
Polarized ^{3}He Targets at JLab

- 6 GeV era: 13 experiments in Hall A
- 12 GeV era: 7 experiments approved
- Spin Exchange Optical Pumping
- 60% in-beam polarization in 10 bar gas



Metastability Exchange Optical Pumping

- 1963, Colgrove *et al* (TI)
- Pure ^{3}He, ~30 G field
- Discharge promotes states to 2^3S_1
- Laser drives polarization
- Collisions between 2^3S_1 and ground state polarize nuclei
- Requires ~2 mbar, >100 K
- 10^5 faster than SEOP
- 10^4 lower pressure has limited use for scattering experiments



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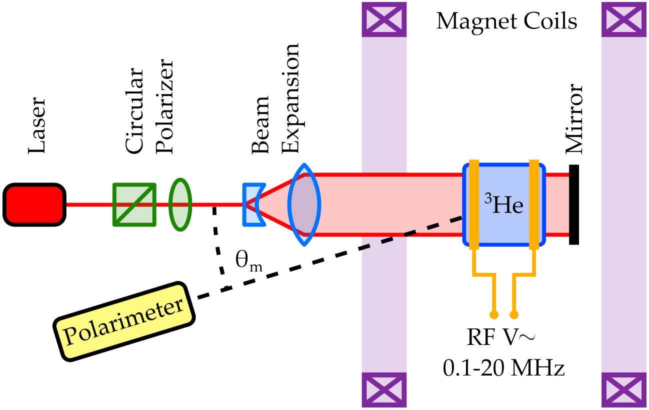
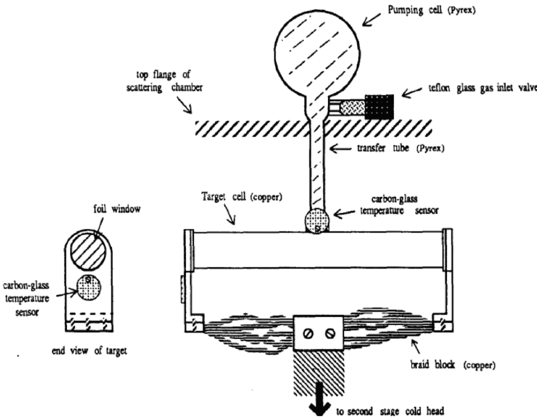


MEOP Double-Cell Cryo Target: Bates 88-02

- Quasi-elastic asymmetries in 1988, 1993
- MEOP pumping cell at 2 mbar, 300 K, 30 G: 40% in-beam polarization
- Cu target cell at 2 mbar, 17 k
- Cu foil beam windows (4.6 μm)
- Cold surfaces coated with N_2 to reduce depolarization from wall interactions
- 7.2×10^{32} ^{3}He/cm^2/s Luminosity w/ 10μA
- P measurement performed in pumping cell
- P in target inferred from rate equations: P relaxation and diffusion



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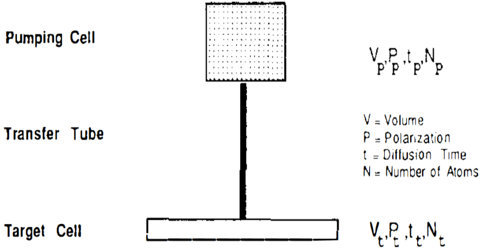
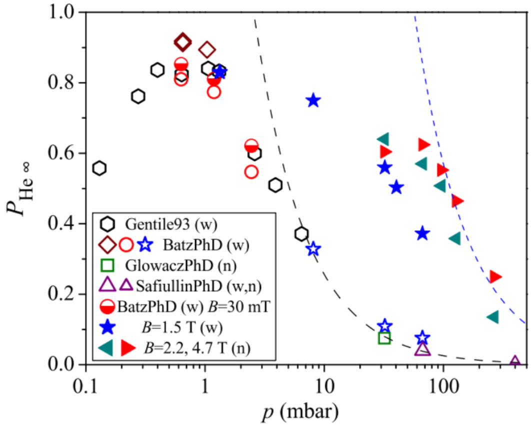


High Magnetic Field MEOP

- OP not historically done at high B
  - SEOP: Increasing wall relaxation
  - MEOP: Weak hyperfine coupling...?
- Kastler-Brossel Lab at ENS in Paris found by increasing B_0, MEOP effective at higher pressures
  (Nikiel-Osuchowska *et al*, Eur. Phys. J.D., 2013.)
- Near 60% at 100 mbar!
- Zeeman splitting separates states for laser pumping
  - Decouples relaxation paths
  - Creates probe transitions



Solid points above 1 T

From Gentile, Nacher, Saam, Walker (2017.)

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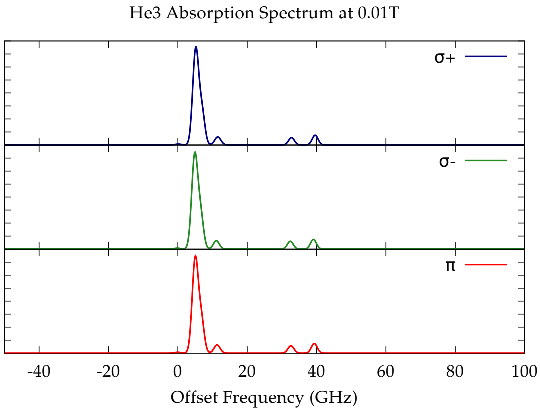

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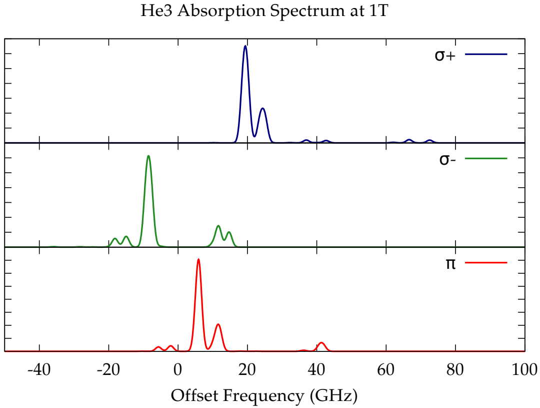
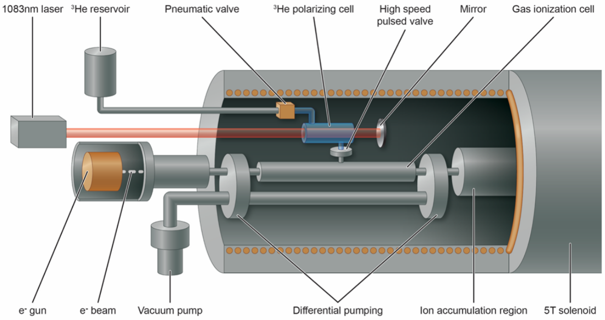


High Magnetic Field MEOP for EIC

- High field MEOP techniques already being applied for nuclear physics
- BNL-MIT collaboration to create a Polarized ^{3}He Ion Source for EIC

- BNL's Electron Beam Ion Source operates at 5 T
- MEOP within 5 T field, transfer into EBIS for ionization and extraction
- Tests between 2 to 4 T gave nearly 90% max polarization (Maxwell *et al.*, NIM A **959**, 2020)
- Installation in 2023



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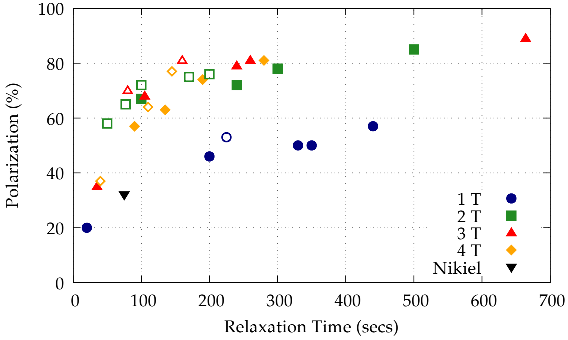
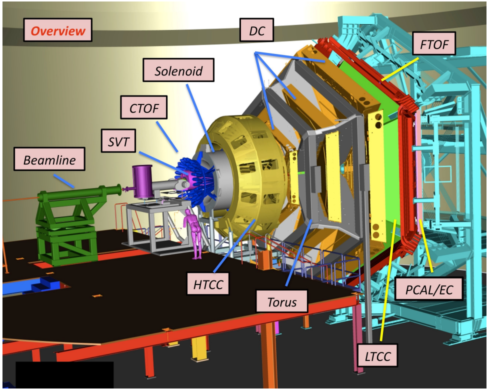


Results at 1.3 mbar

An Opportunity in Hall B's CLAS12

- CEBAF Large Acceptance Spectrometer for Jefferson Lab's 12 GeV upgrade
  - High luminosity electron scattering
  - Multi-particle final state response
- PR12-20-002: A program of spin-dependent electron scattering using a polarized ^{3}He target in CLAS12
  - P_T-dependence of n longitudinal spin structure
  - Nuclear corrections to SIDIS
  - Conditionally approved with A- rating
  - Spokespeople: Avakian, Maxwell, Milner, Nguyen
- 5 T solenoid in interaction region
- Novel target needed for standard config



Creating a New Target for CLAS12

Double-Cell Cryo Target

- Polarize at 300 K
- Transfer to 5 K target cell
- Density increase 60×

+

High Field MEOP

- High Polarization (∼60%)
- High magnetic fields (5 T)
- Pressure increase 100×

- By combining established technologies: a new polarized target
  (Maxwell, Milner, NIM A, 2021.)
- Achieve 5.4 amg, roughly half JLab SEOP target gas density
- Polarize within 5 T solenoid: CLAS12 standard configuration

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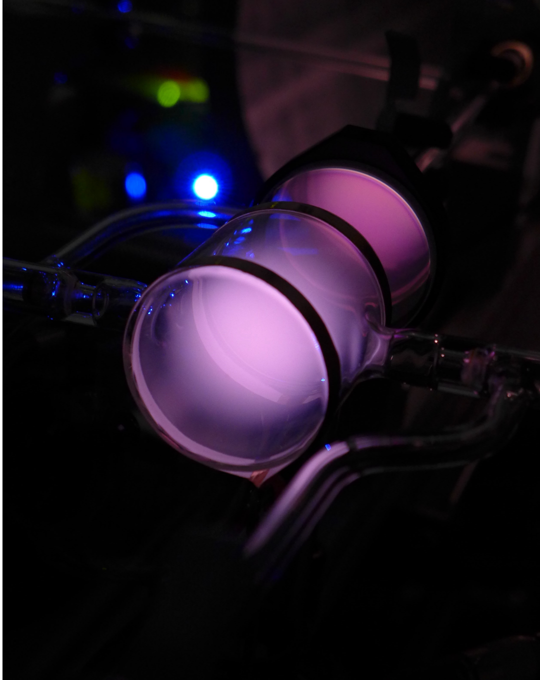
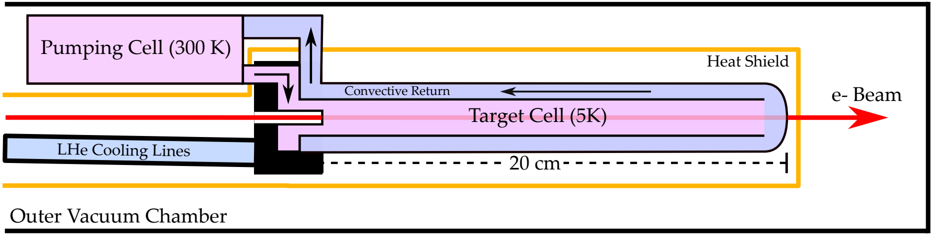


Proposed Target



293 K Pumping Cell

- 200 cm^3 borosilicate glass
- MEOP to 60% polarization
- Annular cylindrical volume

5 K Target Cell

- 100 cm^3, 20 cm long aluminum cell
- Cooled by LHe heat exchanger
- Luminosity of 2.7×10^{34} nuc/cm^2/s at 0.5 μA

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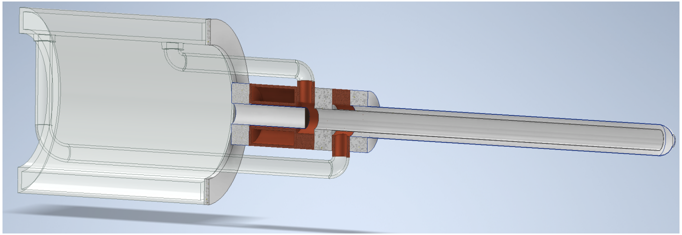

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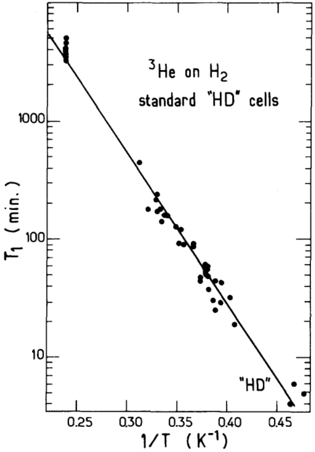
Depolarization Mechanisms

- Wall relaxation on Al: H_2 coatings yield days long relaxation at 4 K
  (Lefevre-Seguin, Low Temp. P. 1988.)
- Depolarization from transverse magnetic field gradients, dependent on pressure, temperature
  - In CLAS12 solenoid: minimal
- Beam produces $^3He_2^+$ ions: increase with density, but decrease with higher field.
  (Bonin, PRA, 1988)



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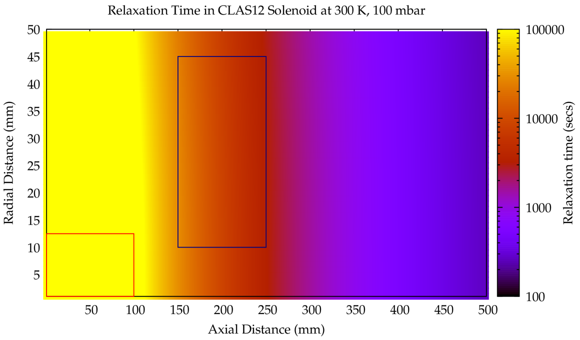

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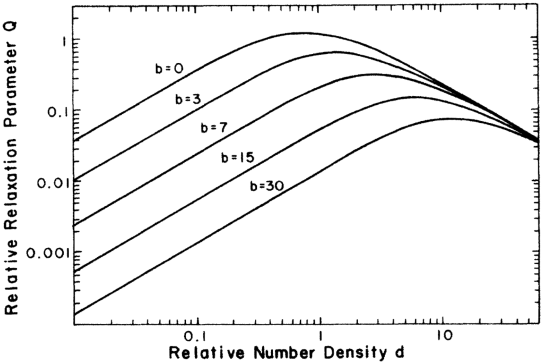

Cryogenics and Heat Load

- Heat loads on 5 K target cell:
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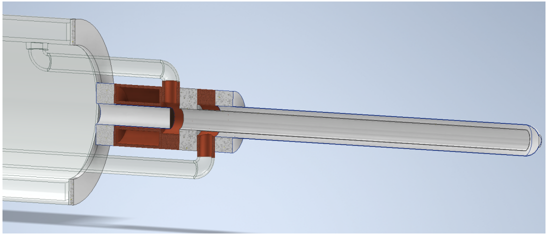
  - Pumping cell at 293 K, transfer through glass and gas (<500 mW)
  - Radiative heating minimized by heat shield (<20 mW)
- Pulse-tube cryocooler for 2 W at 4.2 K should be sufficient
- JLab's Hall D cryotarget provides liquid H_2 and He_2
  - Few modifications needed to design to support a MEOP double-cell cryotarget



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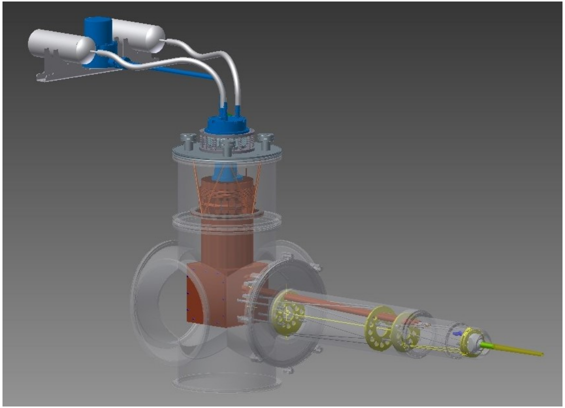
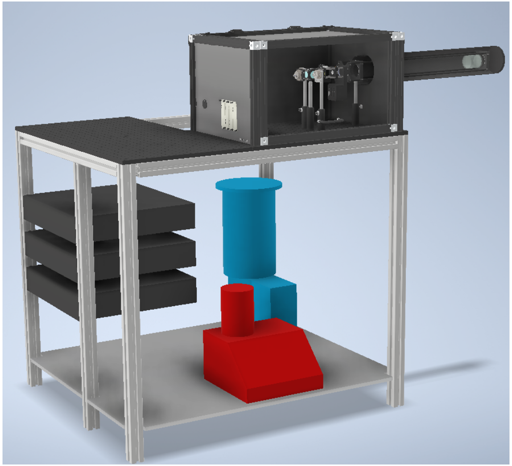


Research Program

- High field MEOP test stand
  explore high field polarization vs. pressure and field, reproduce results of KBL
- Flow tests between cold and warm cells with Target Group's 4 K test stand
- Full, double-cell prototype within three years to allow in-beam tests at JLab's Upgraded Injector Test Facility



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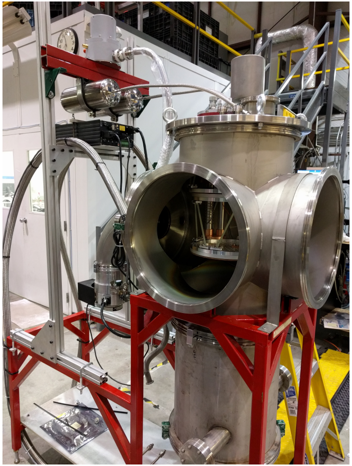

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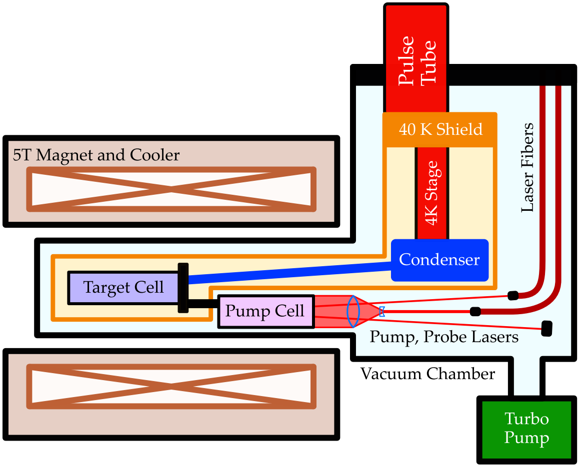

Current Progress

- Polarization cart constructed
  - Enclosed, interlocked system (class 1)
  - On wheels to allow transport to 5 T warm-bore solenoid
- Approval for laser safety protocols received, lasers energized on October 7
- Shakedown with low-field Helmholtz pair
  - Low-field, 668 nm liquid crystal polarimeter (Maxwell *et al.*, NIM A, 2014.)
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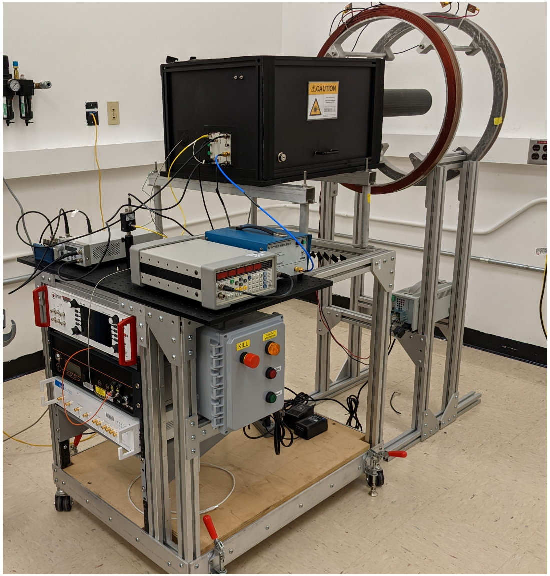
  - 60% nuclear polarization with 80 sec relaxation
- Next: high-field, then varied pressure



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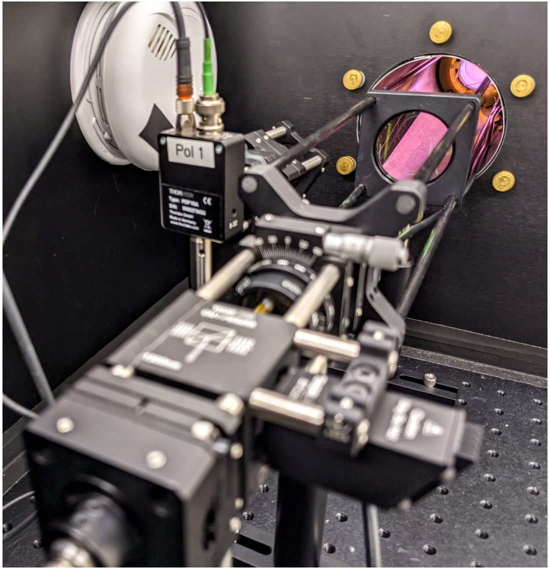

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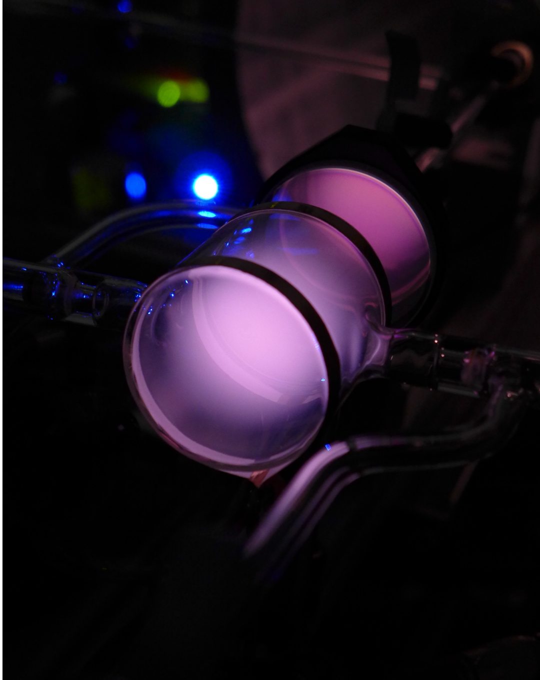

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- How much flow between cells can we produce?
- How much polarization relaxation is expected at 100 mbar and 5 K in 0.5 μA beam while inside a 5 T magnetic field?

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- Polarization at varied pressures: April 2022
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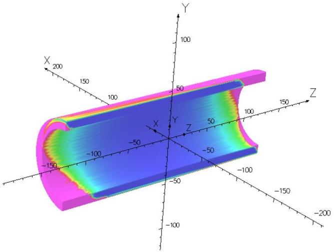
- Three high-impact Hall B experiments hoped to use transversely polarized HD-Ice Target
- Transverse with CLAS12: bulk superconductor
  - Cancel 2 T || CLAS12 field
  - Create a 1.5 T ⊥ holding field
- See Tuesday's talk: F. Larano, INFN
- For ^{3}He: same but holding field ∼50 G
- Pumping cell in longitudinal field
- Rotate spin adiabatically in transit to target cell



MgB2 cylinder:
86 mm Ø
250 mm long
7 mm wall

1.25 T transverse magnetization
2.0 T axial shield
5x10-3 uniformity (Y_{20}/Y_{00})
over 20 mm radius sphere

M. Lowry

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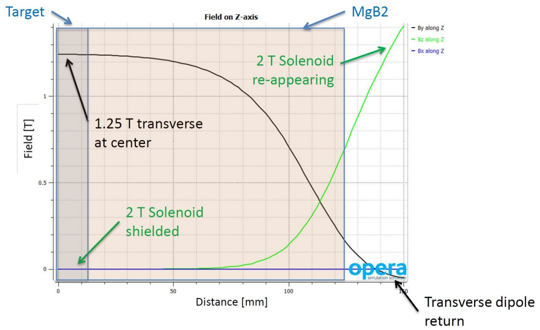
Field along Cylinder Axis



M. Lowry

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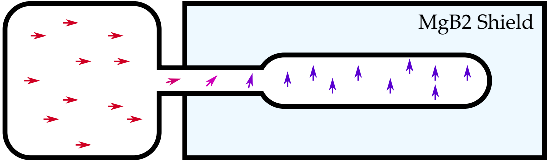


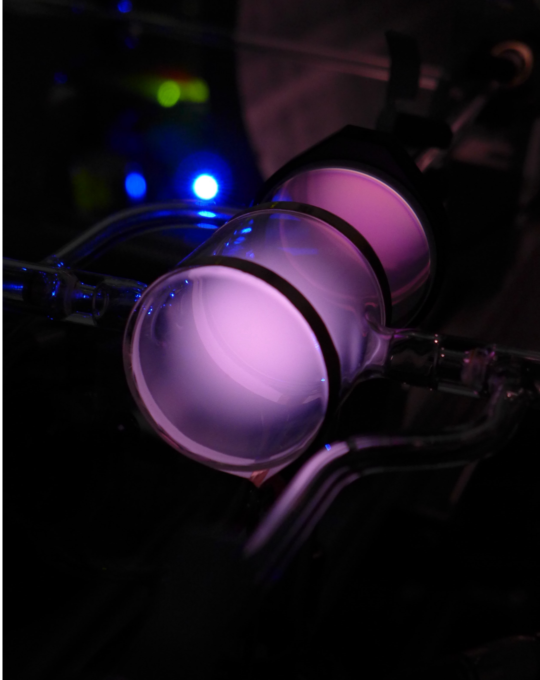
Summary

- A polarized ^{3}He target in CLAS12 would offer a wide new class of observables of quark and gluonic structure in the neutron.
- We are developing a novel target system to operate within CLAS12 without significant modification to the spectrometer.
- Combines the successful design of the Bates 88-02 double-cell cryotarget with new developments in high magnetic field MEOP.
- Polarization tests have begun at Jefferson Lab, with an aggressive development schedule aiming to provide a target to Hall B within the next few years.

CLAS12 Polarized 3He collaboration:

- **MIT**: X. Li, R. Milner
- **JLab**: H. Avakian, J. Maxwell, D. Nguyen

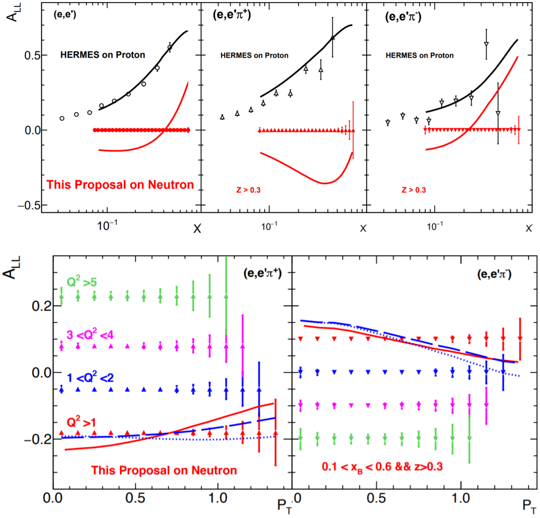
Thank you for your attention!



Parameter	Bates 88-02 Target Achieved	CLAS12 Target Proposed
Pumping cell pressure (mbar)	2.6	100
Pumping cell volume (cm^3)	200	120
Target cell volume (cm^3)	79	100
Target cell length (cm)	16	20
Number of atoms in pumping cell	1.2×10^{19}	3×10^{20}
Number of atoms in target cell	6×10^{19}	1.5×10^{22}
Holding field (T)	0.003	5
Polarization	40%	60%
Incident electron beam energy (GeV)	0.574	10
Cell temperature (K)	17	5
Target thickness (^{3}He/cm^2)	1.2×10^{19}	3×10^{21}
Beam current (μA)	10	2.5
Luminosity (^{3}He/cm^2/s)	7.2×10^{32}	4.5×10^{34}

Spin-Dependent Scattering from Polarized ^{3}He in CLAS12

- Proposal to JLab PAC 48 for 30 days
  - P_T-dependence of the neutron longitudunal spin structure
  - Nuclear corrections to SIDIS
- Complement to studies on dueteron
- Synergistic with efforts such as SoLID
- Luminosity 2.7×10^{34} nucleons/cm^3/s with 0.5 μA beam current
- Approved with A- rating, conditional on target development



Metastability Exchange and Spin Exchange Optical Pumping

SEOP

- Pump: alkali metals in mixture
- Transfer: spin exchange
- Low pumping rate
- Walls carefully selected
- Needs oven (473 K)
- 100 W laser typical
- **Large pressure range (1 to 13 bar)**

MEOP

- Pump: metastable population
- Transfer: metastability exchange
- High pumping rate
- Less sensitive to wall interactions
- Temperature above 100 K
- 4 W laser typical
- **Limited pressure ($\sim$1 mbar)**

- Pressure attainable has made SEOP the most attractive tool for JLab
- Neither have historically worked in high magnetic fields