Polarized ^{3}He in CLAS12

High-Field MEOP Target Status

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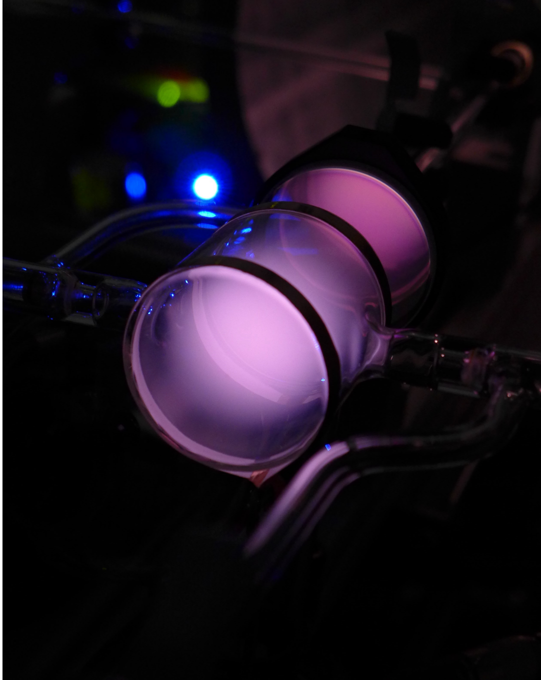
Jefferson Lab
TARGET Group

CLAS Collaboration Meeting
April 28, 2020



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)**

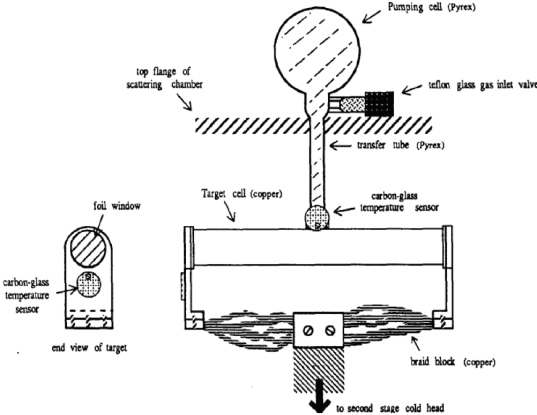
MEOP

- 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 at high field

MEOP Double-Cell Cryo Target: Bates 88-02

- Quasi-elastic asymmetries in 1988, 1993
- MEOP pumping cell at 2 mbar, 300 K
- 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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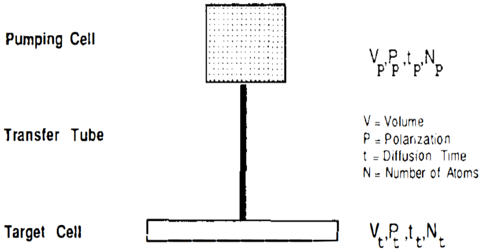
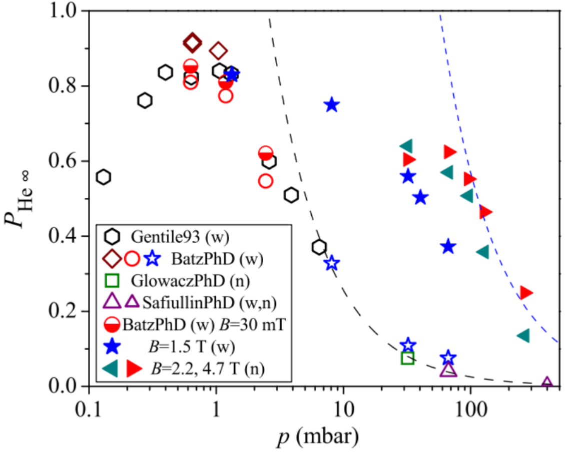


High Magnetic Field MEOP

- Weak hyperfine coupling ⇒ inefficient MEOP?
- Kastler-Brossel Lab at ENS in Paris found by increasing B_0, MEOP effective at higher p
- Zeeman splitting separates states for laser pumping, also giving convenient transitions to probe for polarization measurement
- We have pursued this technique for a Polarized ^{3}He Ion source for EIC



From Gentile, Nacher, Saam, Walker (2017)

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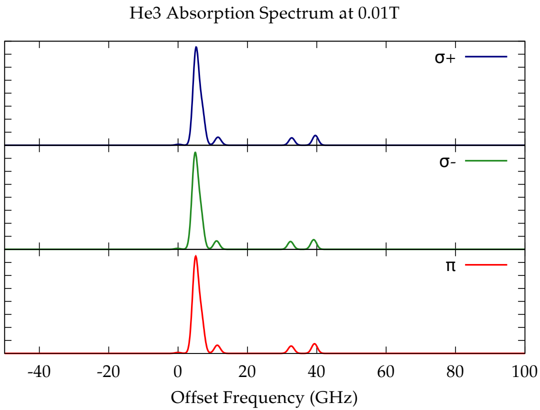

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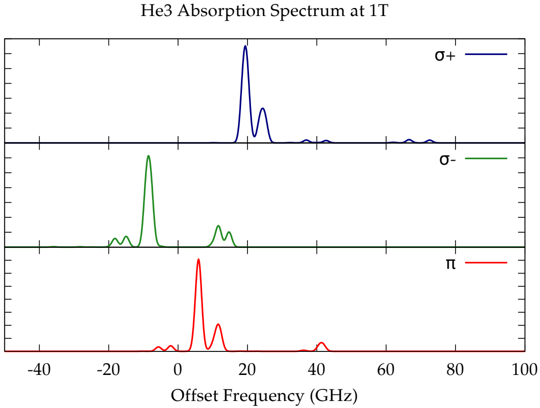

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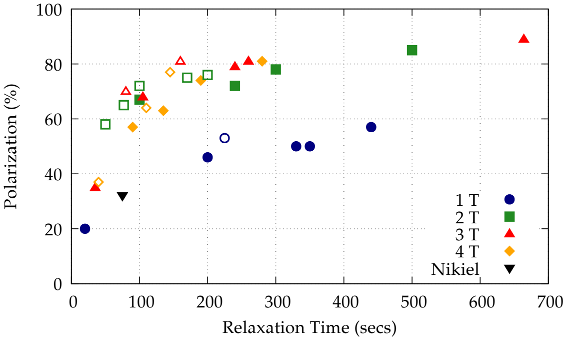


Results at 1.3 mbar

The Idea

Double-Cell Cryo Target

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

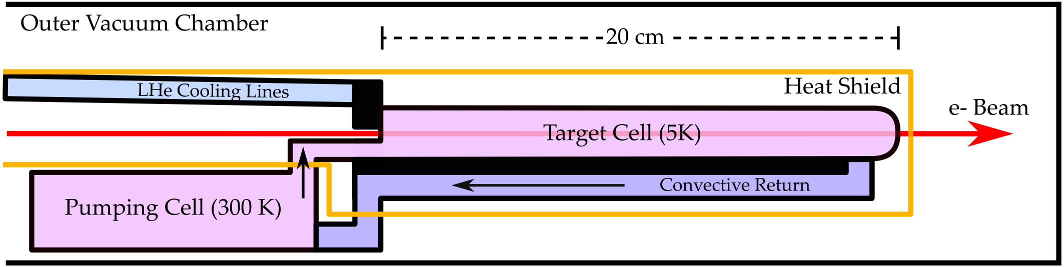
+

High Field MEOP

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

- MEOP at 1 mbar offers 10,000× less density than SEOP at 10 bar
- This scheme increases MEOP density by 6,000×
- Reaches CLAS12 max luminosity with 4.5×10^{34} ^{3}He/cm^2/s at 2.5 μA

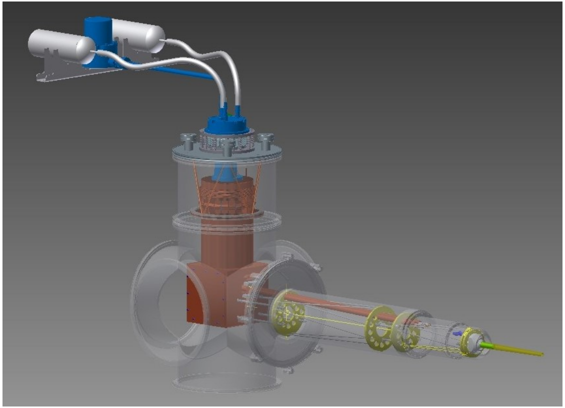
Proposed Target



- Cell volumes: 100 cm^3, Cell pressure: 100 mbar, Polarization: 60%
- Beam Current: 2.5 μA, Luminosity: 4.5×10^{34} ^{3}He/cm^2/s at 2.5 μA
- Must fit in tight space constraint of CLAS12 ($\sim$10 cm)

Path to CLAS12 Polarized ^{3}He

- Cryogenics: Pulse Tube for 2 W at 4.2 K
- Heat load looks to be less than 500 mW
- Al cells, 200μm windows
- Coating of H_2 prevents wall depolarization below 6 K (Lefevre-Seguin, 1988)
- Field depolarization no problem
- Beam depolarization: production of $^3He_2^+$ (Milner, 1987), but may be counteracted by high field (Bonin, 1988)
- Convection to allow balance between beam depolarization and pumping



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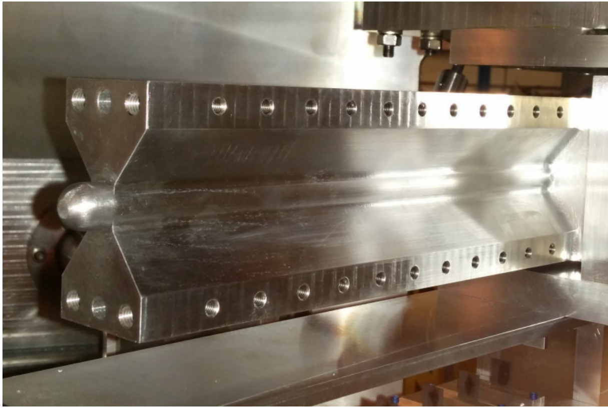

MARATHON target cell

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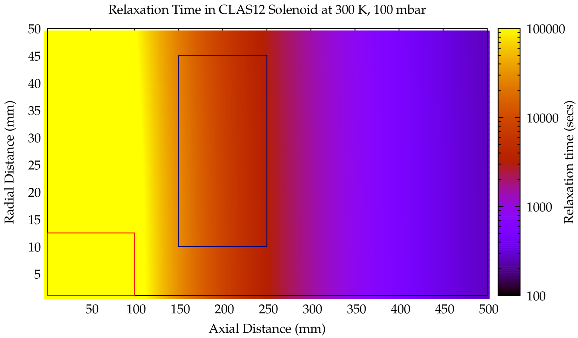

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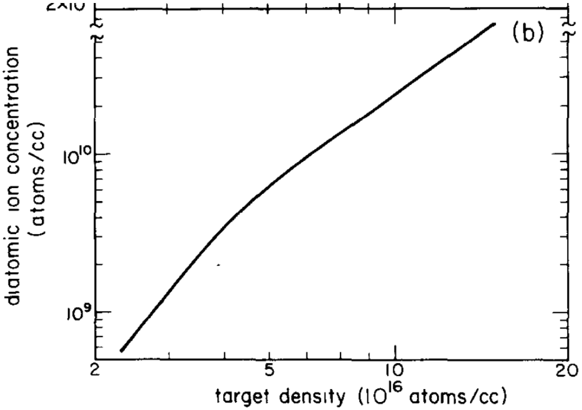
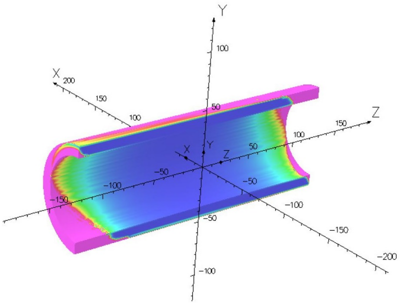


Milner (1987)

Transverse Polarized ^{3}He in CLAS12?

- Transverse HD-Ice: bulk superconductor to cancel 2 T and create a 1.5 T holding field
- Cond. approved: C12-11-111, C12-12-009, C12-12-010
- Use same concept, but holding field ∼50 G
- Pumping cell in longitudinal field
- Rotate spin adiabatically in transit to target cell
- Needs development



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

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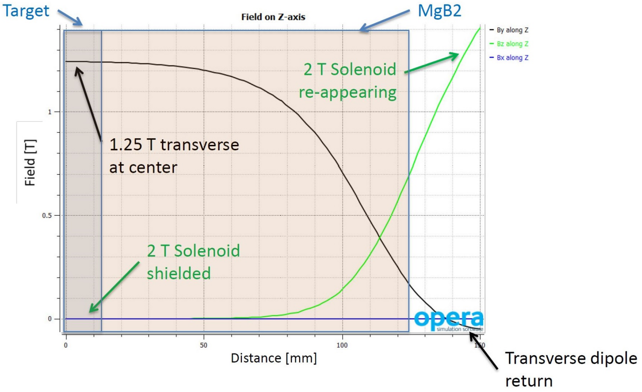
Field along Cylinder Axis



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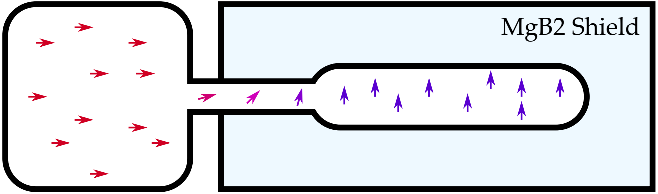


Outlook

- Meeting with Hall B, Target Group technical staff in 2019: idea is sound
- Design in progress for tests of convection
- Target Group working with M. Lowry on his bulk superconductor Opera simulations
- DOE early career grant proposal to investigate full system, including transverse and UITF studies, submitted in March
- JLab 2020 LDRD proposal in progress, three year program

Test Target LDRD Procurement Budget

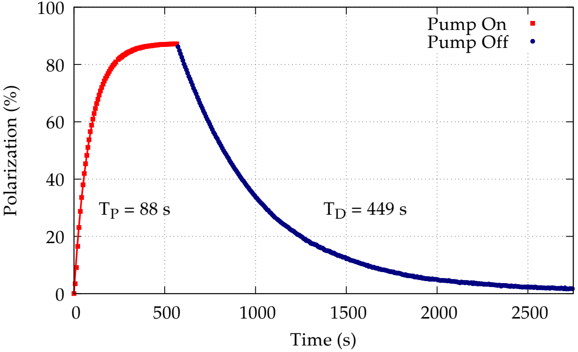
- 7T Magnet: $160,000.00
- Pump Laser (2): $28,500.00
- Probe Laser (2): $24,790.60
- Cryopump: $12,400.00
- Signal Generator: $3,900.00
- RF Amplifier: $2,100.00
- Pfieffer Dry Turbopump Set: $7,995.00
- Pulse Tube: $63,790.00
- Wavelength Meter: $27,100.50
- Cryostat: $45,000.00
- Pfieffer Turbopump Set: $19,500.00
- Glass cells: $20,000.00
- Optics: $10,000.00
- Vacuum equipment: $20,000.00
- Thermometry: $10,000.00

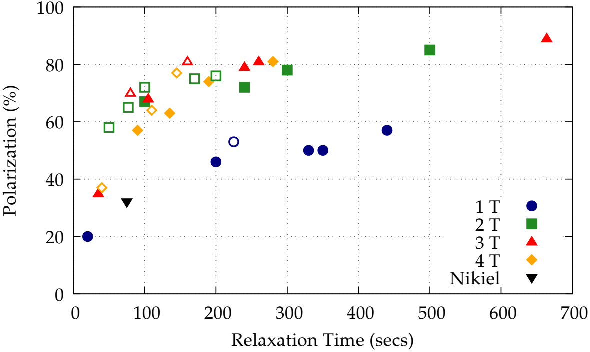
Total: $508,000.00

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}

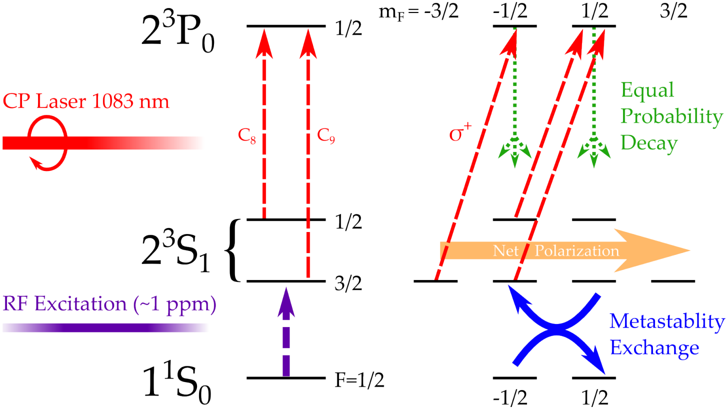
High Field MEOP at 1 mbar





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
- Effectively 10^5 faster pump rate (but 10^4 lower pressure)



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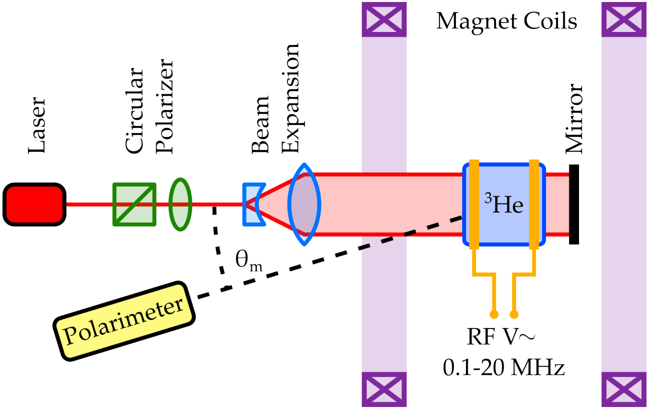

CLAS12 Target Constraints

- Getting a conventional polarized ^{3}He target in CLAS12 is tricky:
  - Remove solenoid, OR
  - Put target upstream of solenoid, OR
  - Transfer polarized gas into solenoid
- To operate in the standard configuration:
  - Fit inside solenoid (10 cm diameter space to work with)
  - Operate at 5 T