New Physics Opportunities with an Active Polarized Neutron Target

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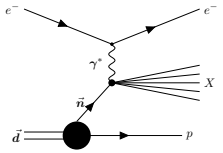
Physics with an Active Polarized Neutron Target

PAC54: Letter of Intent 12-26-002

$\vec{d}$ target using DNP ND_3 with spectator proton tagging

- Scattered electron + proton coincidence **eliminates target dilution**
- ND_3 target **figure-of-merit improves by factor a of 50-100!**: $f.o.m. \propto P_T^2 \boldsymbol{f}^2$
- Provide a clean **neutron** observable — Factor of 4 better sensitivity to down quark distribution
- Paired with NH_3 $\rightarrow$ significant reduction in systematics associated with valence flavor separation



$$\sigma_p \propto \frac{8}{9}\sigma_u + \frac{1}{9}\sigma_d$$
$$\sigma_n \propto \frac{2}{9}\sigma_u + \frac{4}{9}\sigma_d$$
$$\sigma_{^2\mathrm{H}} \propto \frac{10}{9}\sigma_u + \frac{5}{9}\sigma_d$$

Polarized DIS

- Long. target: Polarized EMC effect in neutron
  $\rightarrow$ Defines free neutron $\rightarrow$ complementary to $^3\vec{\mathrm{He}}$ effort
- Transverse target double spin asymmetry $A_\perp$
  $\rightarrow$ Measure A_1 **and** A_2
- Extract twist-3 distributions from g_2 spin structure function
  $\rightarrow$ precision d_2^n, and helicity dependent PDF extraction
- Are quark-gluon correlations (higher twists) a sensitive probe to nuclear medium effects?
  d_2 is **average color Lorentz force** felt by struck quark

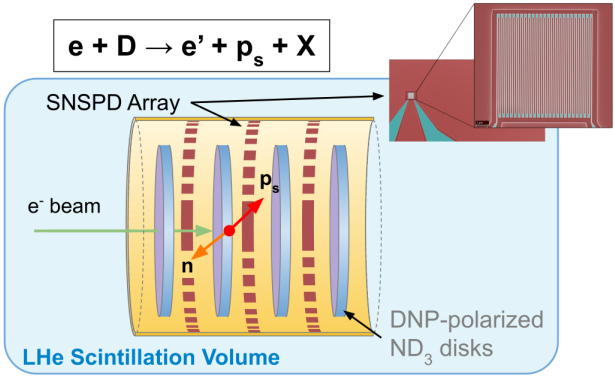
SIDIS

- Transversely Polarized SIDIS — Sivers shift on the neutron
  $\rightarrow$ better sensitivity to down quarks than deuteron.
- Flavor separation of Sivers TMD: $f_{1T}^{\perp(1)}$
  Can precision measurements of this purely QCD generated observable have sensitivity to charge symmetry violation effects in the TMD (quark mass effects)
- Neutron worm-gear TMD shifts.

And more physics via hard exclusive channels...

Overview of Active Polarized Target Concept

Thin, frozen ND_3 disks in liquid He — scintillation tag for low-energy spectator protons



SNSPD Tagging Enables

- Isolate neutron scattering
  - Tag low-energy spectator protons to select neutron events.
- Detect low-energy recoils
  - Use LHe scintillation and SNSPDs to identify weak proto signals.
- Access spin observables
  - Tagged g_1^n, polarized EMC effect, and future Sivers asymmetry measurements.

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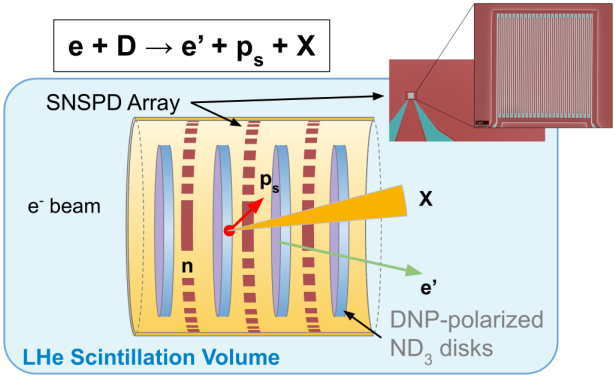

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Forward Progress on Recommendations from the PAC

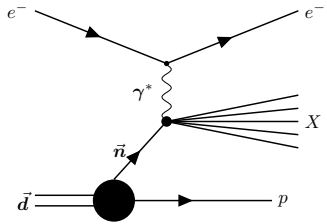
LOI12-26-002: Physics with an Active Polarized Neutron Target: The Neutron Polarized EMC Effect

The proposed active polarized neutron target could enable innovative studies of nucleon spin structure, including the polarized EMC effect. However, its feasibility depends on the successful development of the target system. The PAC encourages the proponents to reduce the remaining technical uncertainties before submitting a full proposal

From the PAC Report

Before starting a significant cryogenic R&D effort, the proponents need to :

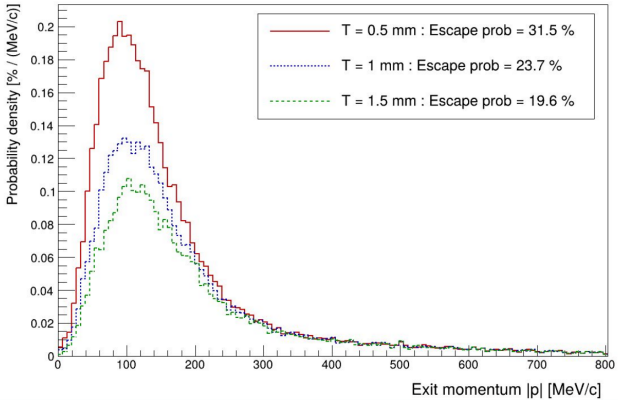
- Conceptual Design $\rightarrow$ realistic design
- Proof of concept – including important parameters such as the thickness and spacing of the solid ND3 wafers as well as the location and number of the SNSPDs. Those parameters determine the quality of the active target system such as the
- Proton tagging efficiency
- Accidental background rate
- Contamination from 14N and 4He nuclei ("dilution").
- Estimate dilution event rate
- Accidental background rate quantitatively via reliable nuclear simulations based on measurements and clarify the requirement for the number of photons to be detected by SNSPDs (namely, dE/dx resolution).



Overview of Active Polarized Target Concept

Realistic Nucleon Momentum Distribution in Deuteron (AV18)

- Disk geometry
  Thinner disks allow more low-energy spectator protons to reach the surrounding LHe.
- LHe scintillation
  15,000 photons / MeV deposited by protons. SNSPDs detect the scintillation light for tagging.
- Geometry Optimization Engineered ND3 geometry could further boost escape rates beyond the flat disk baseline



Polarized EMC Effect in the Neutron

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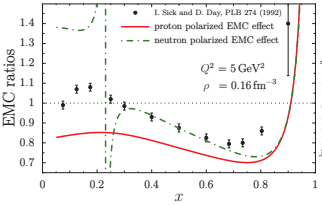
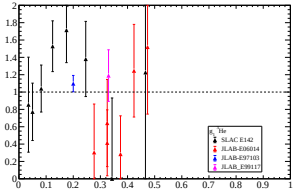
- $\vec{n}$ from ^{2}H **should be best** option for extracting g_1^n with minimal nuclear effects $\rightarrow$ is experimentally challenging due to large dilution and low polarization, $g_1^d \simeq g_1^p$
- ^{3}He dominates recent DIS data from polarized neutron target – better polarization from target technology advances
- First neutron pEMC ratio is $^3\mathrm{He}/n^*$ – no predictions, mean field model does not apply for A=3

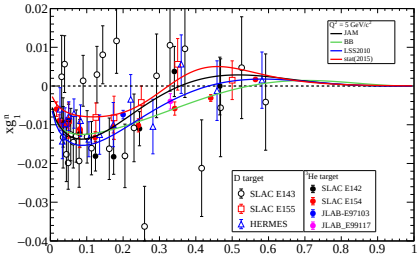
$$R_{As}^{^3\mathrm{He}} = \frac{g_1^{^3\mathrm{He}}}{P_n g_1^n + P_p g_1^p}$$





Polarized EMC effect with ^{3}He needs better ^{2}H data

- Tag spectator proton: $\vec{e} + \vec{D} \rightarrow e' + p + X$
- Improve g_1^n to better constrain zero-crossing region
- $g_1^{^3\mathrm{He}}$ sensitive to non-nucleonic degrees of freedom Bissey et al. 2002
- Low moments more sensitive to Δ contributions to WF Ethier and Melnitchouk 2013

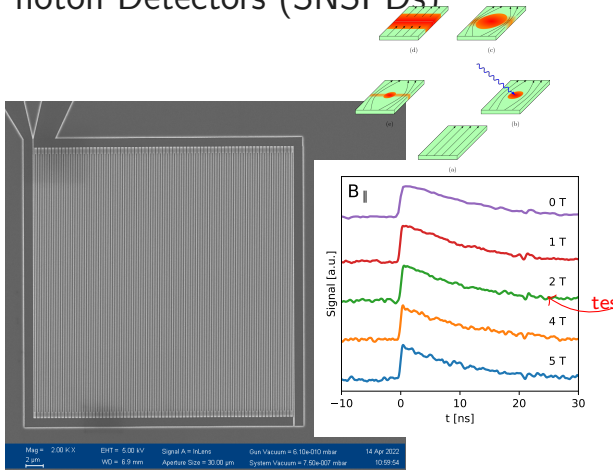


- JLab 12 GeV program will produce more precise polarized ^{3}He data.
- EIC will have spectator tagging with $\vec{D}$, however, new technology enables opportunities at JLab for active $\vec{D}$ targets.

Superconducting Nanowire Single Photon Detectors (SNSPDs)

Superconducting nanowire detectors

- Quantum sensor operates at $T < 5$K
- Superconducting thin film, 10 nm thick NbN film, bulk $T_c \simeq 14K$ Tomas Polakovic et al. 2018
- Meandering wire geometry: width $\simeq 100$ nm, 200 nm pitch
- Current biased at roughly 20 µA
- Nearly zero dark count rate
- SNSPD pixels 10×10 µm to 100×100 µm
- Detect photons at high rate in strong magnetic field > 5 T T. Polakovic et al. 2020
- Microelectronics R&D underway to develop high-channel count cryogenic readout ASIC for SNSPDs



Summary

- Lots of new physics enabled with an active polarized neutron target.
- No show stoppers on the technology side. Need R&D for estimates of material shaping capabilities.
- Simulations at a mature state.
- Most backgrounds understood and simulated.
- If you are interested, please reach out to me.

Thanks!

References I