POLARIMETRY FOR IONS AT THE EIC

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for the RHIC Spin Group

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PHYSICS MOTIVATION

Polarimetry for Ions (©EIC)  Ana S. Nunes  BNL, November 14, 2019  2 / 15
Why Ion Polarimetry at the Electron Ion Collider?

- **EIC**: first collider with polarized lepton and polarized hadron beams, to study structure of nucleons and nuclei

- **EIC rich spin physics program**, requiring precision measurements

- Polarized light ions, e.g. D and $^3$He, provide polarized neutrons; neutrons and protons allow flavor separation of u and d quarks; D to study nuclear binding
Fill/store: time unit over which the machine is filled and collides the beams (≈ 8 hours)

- 120 bunches (106 ns spacing)
- \(10^{11}\) protons per bunch
- Bunches have extension in \(x, y, s\)
There is no physical process that can be calculated from first principles that can be used in ion polarimetry

Requirements: precision, polarization profile and lifetime to know polarization in collisions

Two-tier measurement:
- one for the absolute polarization (with low statistical power)
- one for relative polarization (with high statistical power)
A polarized proton jet, with known polarization used as target for elastic scattering in Coulomb-nuclear interference (CNI) region by beam $\vec{p}$. Asymmetry: $\varepsilon = A_N P$.

The analyzing power $A_N$ doesn’t have to be known and allows the **self-calibration** of the polarimeter.

Beam polarization given by

$$P_{\text{beam}} = \frac{\varepsilon_{\text{beam}}}{A_N} = -\frac{\varepsilon_{\text{beam}}}{\varepsilon_{\text{target}}} P_{\text{target}}$$

Silicon strips detect the recoil protons.
Fast and Precise Polarimeter: pC Polarimeter

- **Non-polarized, ultra-thin carbon ribbon** ($w = 10 \, \mu m$), used as target for **elastic scattering in the CNI region** by beam $\vec{p}$

- Azimuthal asymmetries $\varepsilon(\phi)$ measured

- $A_N$ from normalization to the H-Jet; dependence with energy agrees well with models

- Beam polarization: $P_b = \frac{\varepsilon(\phi)}{A_N \cdot \sin(\phi)}$

- Silicon strips detect the recoil carbon nuclei, measurements of 20-30 s in target scan mode
Bunch Transverse Profile

Experiments

\[ P = \frac{\int P(x, y, t) \cdot I_B(x, y, t) \cdot I_Y(x, y, t) \, dx \, dy \, dt}{\int I_B(x, y, t) \cdot I_Y(x, y, t) \, dx \, dy \, dt} \]

HJET Polarimeter

\[ P = \frac{\int P(x, y, t) \cdot I(x, y, t) \, dx \, dy \, dt}{\int I(x, y, t) \, dx \, dy \, dt} \]

Carbon Polarimeter

\[ P = P_{\text{max}} \cdot \left( \frac{I}{I_{\text{max}}} \right)^R \]

B: blue beam; Y: yellow beam
Bunch Longitudinal Profile

- **Top opening parabola shape** (implying corrections to the polarization)
- Effect increases (in absolute value) along the fill
- May be more important in the EIC case
EIC Ion Polarimetry

Requirements:

- Large polarization, long. and transv., flexible bunch polarization orientation
- Small uncertainty in polarization measurement: \( \sim 1\% \)
- Bunch polarization profile in \( x, y \) and \( z \), polarization lifetime
- Polarization per bunch (2 detectors, not all bunches collide at a given IP)
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Challenges:
- Short spacing between bunches (for high luminosity)
- Background to the signal events may contaminate preceding bunch
- Luminosity measurement may depend on polarization: $\sigma_{\text{Brems.}} = \sigma_0 (1 + aP_e P_h)$
- Pioneering light ion beam polarization measurements at high energies
Polarized Light Ion Beams

- **Similar kinematics** of light ions and pp

- **Breakup of light ions** has to be taken into account

- Simplest model:
  \[
  A_N = \frac{\sqrt{x}}{x^2 + 3} \cdot A_N^{opt} = \frac{\sqrt{x}}{x^2 + 3} \cdot \frac{k}{4m_p} \sqrt{-3t_e}
  \]
  with \( x = \frac{t}{t_e}, \ t_e = -\frac{\sqrt{3}Z Z'}{\sigma_{tot}} \)

- Polarimetry using elastic scattering in the CNI region in D-D or D-C very difficult

- A **test with a jet of polarized deuterons with known polarization** can be done in the next few years at the H-Jet

\[
k_p = 1.793, \ k_{3He} = -1.398, \ k_D = -0.143
\]

Figure 1: Analyzing power \( A_N \) versus invariant momentum transfer \( -t \) in (GeV/c)^2 for (1) pp and p p scattering, (2) C p scattering, (3) C h scattering, (4) h h and p h scattering

[N. Buttimore]
Polarized Helium-3 Beams

- Gas of polarized helium-3 nuclei (helion) was used as fixed target at HERMES [Nucl. Instr. & Methods A367 1995 9699], JLab and Jülich

- A helium-3 beam was tested successfully at the AGS C polarimeters

- Source of polarized $^3$He is available; a test with polarized $^3$He in C polarimeters of the AGS can be envisioned
Conclusions

Summary:

- **Hadron polarimetry** requires **small uncertainties**
- **Proton polarimetry** mature and **experience of RHIC essential for EIC**
- **D polarimetry** very difficult
- **Polarized helions** best source of **polarized neutrons**
- Elastic scattering of $^3\text{He}$ ions by $\text{C}$ tested at the **AGS**
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Outlook:

- Tests of D-D at the RHIC H-Jet and of polarized $^3$He on the AGS carbon polarimeters envisaged
- Usage of other technologies, including better timing resolution, considered
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Thank you for your attention!
RHIC Proton-Carbon Polarimeters
Background asymmetry in 2017 pC polarimeter data

\[ \chi^2 / \text{ndf} \quad 10.59 / 9 \]

\[ p_0 \quad -0.0007899 \pm 0.0001657 \]
Alternative Approach for Ion Polarimetry in EIC

- A large asymmetry was measured by PHENIX in forward neutrons from $\vec{p}$ on nuclei (Al and Au)

- $\gamma$ from high Z nucleus scatters on $\vec{p}$ target; parameterizations of $\gamma + \vec{p} \rightarrow n + \pi^+$ (MAID**) and photon flux (STARlight*) describe PHENIX results:

  **Data:**

  [G. Mitsuka, PRC 95, 044908 (2017)]

  **Model vs data**

  **Simulation (pAu):**


- Polarimeter: high Z target (e.g. Xe gas jet) in $\vec{p}$ beam

- Would require a calorimeter to detect neutrons at low angles

- Open questions: can a thin jet ($\sim 100 \mu$m) of Xe gas be produced and allow enough statistics for lifetime of $P$ and profile measurements?


RHIC pC polarimeter data without cuts

## Tests at BNL for hadron polarimetry of EIC

<table>
<thead>
<tr>
<th>Beam</th>
<th>Target</th>
<th>Ring/ Polarimeter</th>
<th>Energy/nucleon</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
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<td>AGS/C</td>
<td>24 GeV</td>
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Maximum energies provide the smallest analysing powers, hence are better suited for tests. X – dedicated setup attached to bottle with gas.
Pythia simulations of the present RHIC H-Jet polarimeter

- **phythiaRHIC (Phythia6),** $E_1 = 255$ GeV, $E_2 = 0.00001$ GeV; $5 \times 10^6$ events, acceptance of the H-Jet silicon detectors
- MSEL=0
  - MSUB(91)=1 ! Elastic
  - MSUB(92)=1 ! Singly diffractive (XB)
  - MSUB(93)=1 ! Singly diffractive (AX)
  - MSUB(94)=1 ! Double diffractive
  - MSUB(95)=1 ! Low-pT scattering
  - MSUB(96)=1 ! Semihard QCD 2 → 2
- Most common particles in the final state: protons, pions, photons, kaons
Bunch length of 3.7 s used to produce the smearing

“Banana” plot is reproduced
High energy produced particles are protons.
It is possible to separate elastic and inelastic scattering protons based on angle and kinetic energy.