FY2025 NPP LDRD Type B Pre-Proposal presentation

Determining the proton beam polarization vector at a specific point in AGS and EIC

Frank Rathmann (PI)
Oleg Eyser (Co-PI)
Haixin Huang (Co-PI)
Zhengqiao Zhang (Co-PI)

Brookhaven National Laboratory

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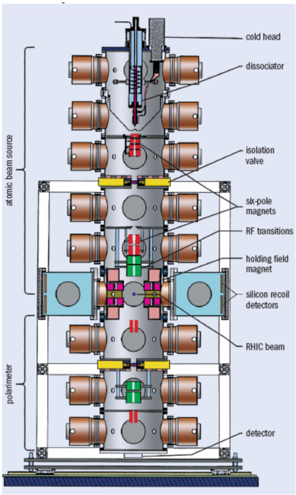
Motivation

- At present, RHIC delivers beam polarization around $|\vec{P}| \approx 0.52 - 0.55$, but EIC requires $|\vec{P}| = 0.7 \to > 60\%$ increase in FOM.
- Primarily reconstructed now in the polarimeters is polarization component P_y.
- We want to find out how well the complete spin vector

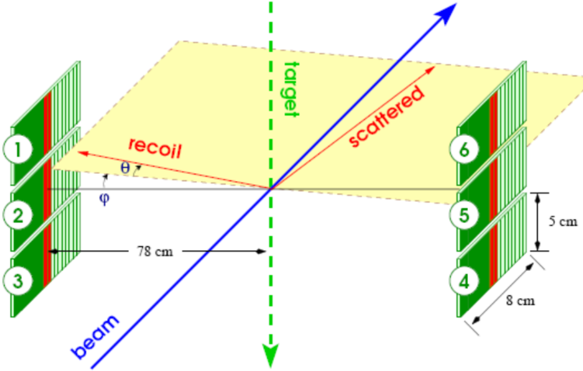
$$\vec{P} = \begin{pmatrix} P_x \\ P_y \\ P_z \end{pmatrix}$$

  at the location of the polarized hydrogen jet target (HJET) can be determined,
    - by a more refined use of *pp* elastic scattering in the CNI region.
- Proposed research aims at active minimization of unwanted beam spin components, while at present, P_y only is maximized:
    - Example: Even with $P_y \simeq 0.99$, unwanted components of $P_{x,z} \approx 0.1$ may still persist in the beam, as $P_y = \sqrt{1 - P_x^2 - P_z^2} = 0.99$.
- **Goals of project:**
    - Develop scenarios for AGS & EIC to determine $\vec{P}$ and optimize polarization transmission and reduce systematic errors of beam polarization measurement.

Present setup of polarized hydrogen jet at RHIC (HJET)



- Presently at HJET, only P_y is measured through L/R asymmetry near 90°: $\epsilon = P_y A_y = \frac{\text{L}-\text{R}}{\text{L}+\text{R}}$



Spin-dependent pp elastic cross section

With polarized beam $\vec{P}$ and polarized target $\vec{Q}$, all components of $\vec{P}$ can be determined from spin-dependent cross section, as shown in Table below [1, 2]:

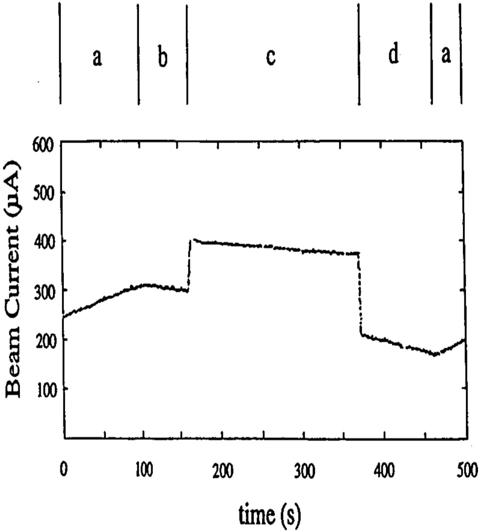
$$\begin{aligned}\sigma/\sigma_0 = 1 &+ A_y\left[(P_y+Q_y)\cos\phi-(P_x+Q_x)\sin\phi\right]\\ &+ A_{xx}\left[P_xQ_x\cos^2\phi+P_yQ_y\sin^2\phi+(P_xQ_y+P_yQ_x)\sin\phi\cos\phi\right]\\ &+ A_{yy}\left[P_xQ_x\sin^2\phi+P_yQ_y\cos^2\phi-(P_xQ_y+P_yQ_x)\sin\phi\cos\phi\right]\\ &+ A_{xz}\left[(P_xQ_z+P_zQ_x)\cos\phi+(P_yQ_z+P_zQ_y)\sin\phi\right]+A_{zz}P_zQ_z\end{aligned}$$

- Full angular distributions of all A_{ik}'s were determined.
- Single input: $A_y = 0.2122 \pm 0.0017$ at $\theta_{\text{lab}} = 8.64^\circ \pm 0.07^\circ$ [3], known from $A_y = 1$ point in $p + {}^{12}\text{C}$ elastic scattering [4].

	$\pm x$		$\pm y$		$\pm z$	
	PRE	POST	PRE	POST	PRE	POST
P_x	0.0052(47)	0.0089(44)	0.0052(47)	0.0089(44)	0.0052(47)	0.0089(44)
P_y [a]	**0.5801(34)**	**0.5425(32)**	**0.5802(34)**	**0.5417(32)**	**0.5765(34)**	**0.5447(32)**
P_z	−0.0021(47)	0.0003(44)	−0.0021(47)	0.0003(44)	−0.0021(47)	0.0003(44)
Q_x	**0.7401(59)**	**0.7394(56)**	−0.0039(59)	0.0039(56)	−0.0071(23)	−0.0052(23)
Q_y	0.0111(59)	0.0039(56)	**0.7400(59)**	**0.7406(56)**	−0.0055(59)	−0.0034(56)
Q_z	0.0158(60)	0.0240(60)	−0.0174(61)	−0.0121(61)	**0.7401(42)** [b]	**0.7400(40)** [b]
S_{P_y}	−0.0008(18)	−0.0005(17)	−0.0008(18)	0.0005(17)	−0.0008(18)	0.0005(17)
S_{Q_x}	0.0017(23)	−0.0007(23)	−0.0040(23)	−0.0031(23)	−0.0043(23)	−0.0024(23)
S_{Q_z}	−0.0091(82)	−0.0162(82)	−0.0177(82)	−0.0197(82)	0.0013(82)	−0.0086(82)

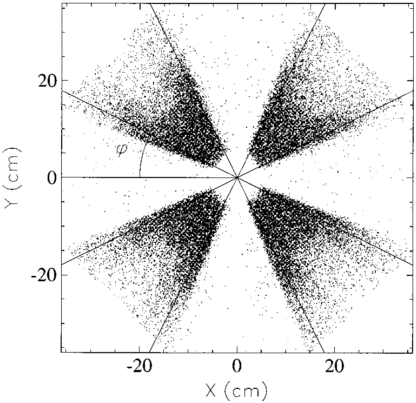
Beam polarization export/calibration to arbitrary energy [5]

- PRE ≡ b (197.4 MeV)
- Export ≡ c (399.1 MeV)
- POST ≡ d (197.4 MeV)



Detector symmetry required to accomplish the task

For spin $\frac{1}{2}$ + spin $\frac{1}{2}$ scattering, a suitable geometry below shows the pattern of detected azimuthal angles [1].



For spin $\frac{1}{2}$ + spin 1 scattering, a higher segmentation is needed, because besides $\sin\phi$ and $\sin 2\phi$, also terms $\sin 3\phi, \ldots$ contribute to the asymmetries, see, e.g., [6].

Personnel and deliverables

The following ingredients need to be studied and optimized:

1. Detector system should be azimuthally symmetric to cope with dependencies on $\sin\phi$ and $\sin 2\phi, \ldots$ from spin $\frac{1}{2}$ + spin$\frac{1}{2}$ scattering:
   - Such a system will deliver new possibilities for beam and target luminosity and detector efficiency corrections, see [7].
2. Polarized target will be operated with single hyperfine state in weak field:
   - Opens up space for detector.
   - Polarization reversal/reorientation via weak magnetic guide field $\vec{B}$ at IP.
   - No HFT transition switching needed in HJET.
3. HJET sextupole magnet system needs to be mildly reconfigured:
   - Atom tracking calculations need to be revisited.

The work shall be carried out by a PostDoc within a time period of 2 years. Three deliverables are anticipated in the from of technical reports:

1. Simulation calculations for upgrade of the detector system.
2. Development of a weak magnetic guide field system: $\vec{B} = (B_x, B_y, B_z)$ [8].
3. Re-optimization of the atomic focusing system in HJET and Breit-Rabi polarimeter, see e.g., [9, 10, 11].

Summary

- **Goal of the investigation**:
  Find out how the absolute beam polarimeter for EIC can be improved to allow the reconstruction of the full beam spin vector at the target.
- **Personnel:**
  The work shall be carried out by a Postdoc within a time period of 2 years.
- **Three deliverables** (technical reports):
  1. Simulation calculations of the detector upgrade.
  2. Development of a weak magnetic guide field system for the HJET.
  3. Re-optimization of the atomic focusing system in HJET and Breit-Rabi polarimeter.

Outlook:

- The comprehensive approach proposed here promises improved accuracy and efficiency in the characterization of beam polarization in both AGS and EIC.

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