Results on Transverse Spin Asymmetries in Polarized Proton - Proton Elastic Scattering at $\sqrt{s} = 200$ GeV

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Outline

1. Physics
2. The experiment
3. Data set
4. Results $A_N$, $A_{NN}$, $A_{SS}$
5. Conclusions
Program with Tagged Forward Protons at STAR

1. Need detectors to measure forward protons: $t$ - four-momentum transfer squared, $\xi = \Delta p/p$, $M_X$ invariant mass Roman Pots of PP2PP and;
2. Detector with good acceptance and particle ID to measure central system: STAR

1. Roman Pot (RP) detectors to measure forward protons
2. Staged implementation for wide kinematic coverage
   - Phase I, present- low-t coverage
   - Phase II*, no special conditions required, expect data taking in 2015 higher-t coverage, large data samples
Helicity amplitudes for spin $\frac{1}{2} \frac{1}{2} \to \frac{1}{2} \frac{1}{2}$

Matrix elements

$$\phi_1 (s, t) = \langle ++ | M | ++ \rangle \text{ non--flip}$$
$$\phi_2 (s, t) = \langle ++ | M | -- \rangle \text{ double spin flip}$$
$$\phi_3 (s, t) = \langle +-- | M | +-- \rangle \text{ non--flip}$$
$$\phi_4 (s, t) = \langle +-- | M | --+ \rangle \text{ double spin flip}$$
$$\phi_5 (s, t) = \langle ++ | M | +-- \rangle \text{ single spin flip}$$
$$\phi_i (s, t) = \phi_i^{\text{EM}} (s, t) + \phi_i^{\text{HAD}} (s, t)$$

$$A_N (s, t) \frac{d\sigma}{dt} = \frac{-4\pi}{s^2} \text{Im} \{ \phi_5^* (\phi_1 + \phi_2 + \phi_3 - \phi_4) \}$$

$$A_N = \frac{\sigma^\uparrow (t) - \sigma^\downarrow (t)}{\sigma^\uparrow (t) + \sigma^\downarrow (t)} = C_1 \phi_{\text{em}}^{\text{flip}} \phi_{\text{had}}^{\text{non--flip}} + C_2 \phi_{\text{had}}^{\text{flip}} \phi_{\text{em}}^{\text{non--flip}}$$

$$A_N (t, \varphi) \propto \text{Im} [\phi_5^* \Phi_+] \frac{d\sigma}{dt}$$

$$r_5 = \text{Re} r_5 + i \text{Im} r_5 = \frac{m\phi_5}{\sqrt{-t} \text{Im} \phi_+}$$
Cross sections and spin asymmetries

\[ \sigma_{tot} = \frac{4\pi}{s} \text{Im}\left\{ \phi_1 + \phi_3 \right\}_{t=0} = \frac{4\pi}{s} \text{Im}\phi_+|_{t=0} \]

\[ \frac{d\sigma}{dt} = \frac{2\pi}{s^2} \left\{ |\phi_1|^2 + |\phi_2|^2 + |\phi_3|^2 + |\phi_4|^2 + 4|\phi_5|^2 \right\} \]

\[ \Delta\sigma_T = \sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow} = -\frac{8\pi}{s} \text{Im}\left\{ \phi_2 \right\}_{t=0} \]

\[ A_{NN}(s,t) \frac{d\sigma}{dt} = \frac{4\pi}{s^2} \left\{ 2|\phi_3|^2 + \text{Re}\left( \phi_1^* \phi_2 - \phi_3^* \phi_4 \right) \right\} \]

\[ A_{SS}(s,t) \frac{d\sigma}{dt} = \frac{4\pi}{s^2} \text{Re}\left\{ \phi_1\phi_2^* + \phi_3\phi_4^* \right\} \]
Probing Odderon in polarized pp elastic scattering

E. Leader, T. L. Trueman
“The Odderon and spin dependence of high-energy proton-proton scattering”,
PR D61, 077504 (2000)

Pomeron and Odderon are 90deg out of phase
5% Odderon contribution → 5% $A_{NN}$

T. L. Trueman
“Double-spin asymmetry in elastic proton-proton scattering as a probe for the Odderon”,

Regge poles only

Regge poles and cuts

Odderon spin-flip coupling ≈ Pomeron spin-flip coupling

Odderon spin-flip coupling ≈ $\rho$ spin-flip coupling

$S=500^2 GeV^2$

$S=200^2 GeV^2$

$S=14 GeV^2$

Włodek Guryn

DIS 2014, Warsaw, Apr. 28- May 2, 2014

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RPs at STAR – small t setup

Vertical AND Horizontal RP setup for a complete $\phi$ coverage

$p + p \rightarrow p + p$

$p_1 = -p_2 \Rightarrow (\Theta_1^x, \Theta_1^y) = (-\Theta_2^x, -\Theta_2^y)$

An elastic event has two collinear protons, one on each side of IP

Włodek Guryn (BNL)
The Setup: few pictures

Roman Pot station in RHIC tunnel

Roman Pot and Si detector package
Experimental Conditions for this Data Set

• Both beams were transversely polarized with 60% polarization.
• Excellent detector performance – nearly 100% efficiency and only 5 dead/noisy strips per ~14000 active strips.
• $2\pi$ acceptance in $\phi$.
• Ideal optics $\beta^* = 21\text{m}$ and terms other than $L_{\text{EFF}}$ in the transport matrix were very small.
• $0.003 < -t < 0.03$
• A good statistics of about $2 \cdot 10^7$ elastic events with background less than 1%, in four days of data taking.

$$P_B P_Y = 0.372 \pm 0.052$$

*Averaged for data period from the official Run’09 CNI polarimeter results https://wiki.bnl.gov/rhicspin/Results
Single spin $A_N$ asymmetry result


$A_N = \frac{\sigma^\uparrow(t) - \sigma^\downarrow(t)}{\sigma^\uparrow(t) + \sigma^\downarrow(t)} = C_1 \phi_{em}^{\text{flip}} \phi_{\text{non-flip}}^{\text{had}} + C_2 \phi_{\text{flip}}^{\text{had}} \phi_{\text{non-flip}}^{\text{em}}$

$A_N(t,\varphi) \propto \frac{\mathrm{Im}[\phi_5^* \Phi_+]}{d\sigma/dt}$

$r_5 = \Re r_5 + i \Im r_5 = \frac{m\phi_5}{\sqrt{-t} \Im \phi_+}$

$\phi_1(s,t) \propto \langle ++ | M | ++ \rangle \leftarrow \text{non-flip}$

$\phi_2(s,t) \propto \langle ++ | M | -- \rangle \leftarrow \text{double-flip}$

$\phi_3(s,t) \propto \langle +-- | M | +-- \rangle \leftarrow \text{non-flip}$

$\phi_4(s,t) \propto \langle +-- | M | --+ \rangle \leftarrow \text{double-flip}$

$\phi_5(s,t) \propto \langle ++ | M | +-- \rangle \leftarrow \text{single-flip}$
Result on $A_N$

\[
\text{Re } r_5 = 0.0017 \pm 0.0017 \text{ (stat.)} \pm 0.061 \text{ (syst.)}
\]
\[
\text{Im } r_5 = 0.007 \pm 0.03 \text{ (stat.)} \pm 0.049 \text{ (syst.)}
\]

Pomeron spin-flip is consistent with zero
Polarized cross-sections and spin parameters

Cross-section azimuthal angular dependence for transversely polarized beams:

\[ \vec{n} \] is the normal vector to the scattering plane

\[ \vec{s} = \frac{\vec{n} \times \vec{p}}{|\vec{n} \times \vec{p}|} \] - is the vector in the scattering plane, normal to the initial momentum

\[ \vec{P}_B; \vec{P}_Y \] - polarizations of two colliding beams

Double-spin asymmetry

\[ A_{NN} ; A_{SS} = \frac{\sigma^{\uparrow\uparrow+\downarrow\downarrow} - \sigma^{\downarrow\downarrow+\uparrow\uparrow}}{\sigma^{\uparrow\uparrow+\downarrow\downarrow} + \sigma^{\downarrow\downarrow+\uparrow\uparrow}} \]

\[ A_{NN} \] – polarization normal to the scattering plane

\[ A_{SS} \] – polarization vector in the scattering plane

\[ 2\pi \frac{d^2\sigma}{dt d\varphi} = \frac{d\sigma}{dt} \cdot \left( 1 + (P_B + P_Y)A_N \cos \varphi + P_B P_Y (A_{NN} \cos^2 \varphi + A_{SS} \sin^2 \varphi) \right) \]

\[ \varepsilon_2(\varphi) = P_B P_Y ((A_{NN} + A_{SS})/2 + (A_{NN} - A_{SS})/2 \cdot \cos 2\varphi) \]

No angle dependence

Luminosity normalization required to obtain \( \varepsilon(\phi) \)
$A_{NN} -$ Existing data

HJet@RHIC
PRD79(09)094014

$\sqrt{s} = 6.8$ GeV
$\sqrt{s} = 13.7$ GeV
fit $\sqrt{s} = 6.8$ GeV
fit $\sqrt{s} = 13.7$ GeV

pp2pp@RHIC
$\sqrt{s} = 200$ GeV
PLB647(07)98
Raw Double Spin Asymmetry

\[ \varepsilon_{NN}(\varphi) = P_B P_Y (A_{NN} \cos^2 \varphi + A_{SS} \sin^2 \varphi) = \frac{(K^{++}(\varphi) + K^{--}(\varphi)) - (K^{--}(\varphi) + K^{++}(\varphi))}{(K^{++}(\varphi) + K^{--}(\varphi)) + (K^{--}(\varphi) + K^{++}(\varphi))} \]

\[ \varepsilon_2/(P_B P_Y) \text{ for all } t \]

\[ \chi^2 / \text{ndf} \quad 79.29 / 70 \]

\[ (A_{NN} + A_{SS})/2 \quad -0.005988 \pm 0.000599 \]

\[ (A_{NN} - A_{SS})/2 \quad 0.00147 \pm 0.00089 \]

\( K_{ij} \) Luminosity normalized counts

STAR PRELIMINARY
$A_{NN}$ result

- Error bars represent statistical only errors (boxes) and total uncorrelated errors including those due to background subtraction.

- Accurate formulas from: N.H. Buttimore et al. [hep-ph/9901339]


- Grey bar – common systematic uncertainty on $(A_{NN}+A_{SS})/2$ due to luminosity normalization

- $(A_{NN}+A_{SS})/2$ is small and consistent with Hjet data, but higher precision

- $(A_{NN}-A_{SS})/2$ points average consistent with zero
$A_{NN}$ Result: $r_2$ and $r_4$

- $\text{Im } r_2$ is well constrained – small negative value
- $\text{Re } r_2$ is compatible with 0
- $r_4$ components are only $1.2\sigma$ and $1.7\sigma$ from 0
- $\text{Re } r_4$ is large because of kinematic factor $m^2/t$.
- Assumption $r_4=0$ is reasonable
Summary

1. We have measured the single spin analyzing power $A_N$ in polarized pp elastic scattering at $\sqrt{s} = 200$ GeV, with greatly improved precision at the highest $\sqrt{s}$ to date, in the CNI region, $-t$-range $[0.005,0.035]$ (GeV/c)$^2$.


   \[
   \text{Re } r_5 = 0.0017 \pm 0.0017 \text{ (stat.) } \pm 0.061 \text{ (syst.)} \\
   \text{Im } r_5 = 0.007 \pm 0.03 \text{ (stat.) } \pm 0.049 \text{ (syst.)}
   \]

3. This is the most precise measurement of the transverse double spin asymmetries in the CNI region at collider energies performed. Over the whole interval $A_{NN}$ and $A_{SS}$ are small and

   \[
   A_{NN} \approx A_{SS} = -0.0051 \pm 0.0006 \text{(stat)} \pm 0.0010 \text{(sys)}
   \]

4. The result is could indicate non-zero Odderon spin flip coupling. More theoretical work is needed.

5. The new $A_{NN}$ value is in the region where lower energy results are.