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 $\frac{1}{2} \frac{1}{2} \rightarrow \frac{1}{2} \frac{1}{2}$

Matrix elements

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

$$\phi_i (s,t) = \phi^{EM}_i (s,t) + \phi^{HAD}_i (s,t)$$

$$A_N (s,t) \frac{d\sigma}{dt} = \frac{-4\pi}{s^2} \text{Im} \left\{ \phi^*_5 (\phi_1 + \phi_2 + \phi_3 - \phi_4) \right\}$$

$$A_N = \frac{\sigma^\uparrow (t) - \sigma^\downarrow (t)}{\sigma^\uparrow (t) + \sigma^\downarrow (t)} = C_1 \phi^*_\text{flight} \phi^{em}_{\text{non–flip}} + C_2 \phi^*_\text{flight} \phi^{em}_{\text{non–flip}}$$

$$A_N (t,\varphi) \propto \text{Im} [\phi^*_5 \Phi_+] \frac{d\sigma}{dt} \quad r_5 = \text{Re} r_5 + i \text{Im} r_5 = \frac{m\phi_5}{\sqrt{-t} \text{Im} \phi_+}$$
Polarized cross-sections and spin parameters

Cross-section azimuthal angular dependence for transversely polarized beams:

\[ \vec{n} \text{ - is the normal vector to the scattering plane} \]
\[ \vec{s} = \frac{\vec{n} \times \vec{p}}{|\vec{n} \times \vec{p}|} \text{ - is the vector in the scattering plane, normal to the initial momentum} \]
\[ \vec{P}_B; \vec{P}_Y \text{ - polarizations of two colliding beams} \]

Double-spin asymmetry

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

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

\[ \varepsilon_2(\phi) = P_BP_Y \left( (A_{NN} + A_{SS})/2 + (A_{NN} - A_{SS})/2 \cdot \cos 2\phi \right) \]

No angle dependence

Luminosity normalization required to obtain \( \varepsilon(\phi) \)
Cross sections and spin asymmetries

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

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

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

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

$$A_{SS}(s, t) \frac{d\sigma}{dt} = \frac{4\pi}{s^2} \text{Re}\{\phi_1\phi_2^* + \phi_3\phi_4^*\}$$
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 90° out of phase 5% Odderon contribution → 5% $A_{NN}$

T. L. Trueman

Regge poles only

Regge poles and cuts

Odderon spin-flip coupling $\approx$ Pomeron spin-flip coupling

Odderon spin-flip coupling $\approx$ $\rho$ spin-flip coupling
RPs at STAR – small t setup

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

An elastic event has two collinear protons, one on each side of IP
The Setup: few pictures

Roman Pot station in RHIC tunnel

Roman Pot and Si detector package

Włodek Guryn

Diffraction 2014, Primošten, Sept., 2014
Experimental Conditions for this Data Set

- Both beams were transversely polarized with $P_B, P_Y \sim 60\%$ polarization.
- Excellent detector performance – nearly 100% efficiency and only 5 dead/noisy strips per ~14000 active strips.
- $2\pi$ acceptance in $\varphi$.
- Ideal optics $\beta^* = 21m$ 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

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

$A_N(t, \phi) \propto \frac{\text{Im}[\phi^*_5 \Phi_+]}{d\sigma / dt}$

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

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

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

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

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

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


Włodek Guryn  

Diffraction 2014, Primošten, Sept., 2014

Re $r_5 = 0.0017 \pm 0.0017$ (stat.) $\pm 0.061$ (syst.)

Im $r_5 = 0.007 \pm 0.03$ (stat.) $\pm 0.049$ (syst.)

Pomeron spin-flip is consistent with zero
$A_{NN}$ – Existing data

HJet@RHIC
PRD79(09)094014

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

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

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

\[ \chi^2 / \text{ndf} = 79.29 / 70 \]
\[ (A_{NN} + A_{SS})/2 = -0.005988 \pm 0.000599 \]
\[ (A_{NN} - A_{SS})/2 = 0.00147 \pm 0.00089 \]

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 $r_4$

- Im $r_2$ is well constrained – small negative value
- Re $r_2$ is consistent with 0
- $r_4$ components are only 1.2σ and 1.7σ from 0
- 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 $[0.005,0.035] (\text{GeV/c})^2$.


$$\text{Re } r_5 = 0.0017 \pm 0.0017 \text{ (stat.)} \pm 0.061 \text{ (syst.)}$$

$$\text{Im } r_5 = 0.007 \pm 0.03 \text{ (stat.)} \pm 0.049 \text{ (syst.)}$$

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 may 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.