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Double Spin Asymmetry in Run15
($p^{\uparrow}p^{\uparrow}$, 100 GeV)

Double Spin Asymmetry

$$\frac{d^2\sigma}{dt\,d\varphi} = \frac{1}{2\pi}\frac{d\sigma}{dt}\left[1 + \left(P_{jet} + P_{beam}\right)A_N \sin\varphi + P_{jet}P_{beam}\left(A_{NN}\sin^2\varphi + A_{SS}\cos^2\varphi\right)\right]$$

In HJET $\varphi = \pm\frac{\pi}{2}$. Spin correlated asymmetries $A_N(t)$ and $A_{NN}(t)$ can be derived from 8 measured (statistically independent) parameters.

$$N_L^{\uparrow\uparrow} = N_0\left(1 + a_N^j + a_N^b + a_{NN}\right)\left(1 + \lambda_j\right)\left(1 + \lambda_b\right)\left(1 + \epsilon\right)\left(1 + b_{NN}\right)$$
$$N_L^{\uparrow\downarrow} = N_0\left(1 + a_N^j - a_N^b - a_{NN}\right)\left(1 + \lambda_j\right)\left(1 - \lambda_b\right)\left(1 + \epsilon\right)\left(1 - b_{NN}\right)$$
$$N_L^{\downarrow\uparrow} = N_0\left(1 - a_N^j + a_N^b - a_{NN}\right)\left(1 - \lambda_j\right)\left(1 + \lambda_b\right)\left(1 + \epsilon\right)\left(1 - b_{NN}\right)$$
$$N_L^{\downarrow\downarrow} = N_0\left(1 - a_N^j - a_N^b + a_{NN}\right)\left(1 - \lambda_j\right)\left(1 - \lambda_b\right)\left(1 + \epsilon\right)\left(1 + b_{NN}\right)$$
$$N_R^{\uparrow\uparrow} = N_0\left(1 - a_N^j - a_N^b + a_{NN}\right)\left(1 + \lambda_j\right)\left(1 + \lambda_b\right)\left(1 - \epsilon\right)\left(1 - b_{NN}\right)$$
$$N_R^{\uparrow\downarrow} = N_0\left(1 - a_N^j + a_N^b - a_{NN}\right)\left(1 + \lambda_j\right)\left(1 - \lambda_b\right)\left(1 - \epsilon\right)\left(1 + b_{NN}\right)$$
$$N_R^{\downarrow\uparrow} = N_0\left(1 + a_N^j - a_N^b - a_{NN}\right)\left(1 - \lambda_j\right)\left(1 + \lambda_b\right)\left(1 - \epsilon\right)\left(1 + b_{NN}\right)$$
$$N_R^{\downarrow\downarrow} = N_0\left(1 + a_N^j + a_N^b + a_{NN}\right)\left(1 - \lambda_j\right)\left(1 - \lambda_b\right)\left(1 - \epsilon\right)\left(1 - b_{NN}\right)$$

$$\boldsymbol{a_N^j} = P_{jet}\langle A_N\rangle\,,\ \ \boldsymbol{a_N^b} = P_{beam}\langle A_N\rangle,\ \ \boldsymbol{a_{NN}} = P_{jet}P_{beam}\langle A_{NN}\rangle,\ \ \boldsymbol{b_{NN}} = 0$$

The parameters

$$N_L^{\uparrow\uparrow} = N_0\left(1 + a_N^j + a_N^b + a_{NN}\right)\left(1 + \lambda_j\right)\left(1 + \lambda_b\right)(1 + \epsilon)(1 + b_{NN})$$
$$N_L^{\uparrow\downarrow} = N_0\left(1 + a_N^j - a_N^b - a_{NN}\right)\left(1 + \lambda_j\right)\left(1 - \lambda_b\right)(1 + \epsilon)(1 - b_{NN})$$
$$N_L^{\downarrow\uparrow} = N_0\left(1 - a_N^j + a_N^b - a_{NN}\right)\left(1 - \lambda_j\right)\left(1 + \lambda_b\right)(1 + \epsilon)(1 - b_{NN})$$
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$$N_R^{\downarrow\uparrow} = N_0\left(1 + a_N^j - a_N^b - a_{NN}\right)\left(1 - \lambda_j\right)\left(1 + \lambda_b\right)(1 - \epsilon)(1 + b_{NN})$$
$$N_R^{\downarrow\downarrow} = N_0\left(1 + a_N^j + a_N^b + a_{NN}\right)\left(1 - \lambda_j\right)\left(1 - \lambda_b\right)(1 - \epsilon)(1 - b_{NN})$$

Since all measured parameters, $a_N^j, a_N^b, a_{NN}, \lambda_j, \lambda_b, \epsilon, b_{NN}$ are small, the system can be easily linearized.

In linear approximation, $N_L^{\uparrow\uparrow}$, … define a point in a linear 8-dimensional space. The parameters $N_0, a_N^j, \dots, \epsilon$ are projections of this point to 7 matually orthogonal axises. There is one more orthogonal axis b_{NN}, projection to which is expected to be 0. However, b_{NN} may highlight some systematic errors in measurement.

- Statistical errors in measurement are defined by total statistics $\sigma_{stat} = 1/\sqrt{N_{total}}$.
- Statistical errors are uncorrelated
- Adding b_{NN} into consideration does not affect the evaluation of other parameters.

Square Root Formulas for Double Spin Asymmetries

$$a_N^j = f\left(\sqrt{N_L^{\uparrow\uparrow}N_R^{\downarrow\uparrow}} + \sqrt{N_L^{\uparrow\downarrow}N_R^{\downarrow\uparrow}}, \qquad \sqrt{N_L^{\downarrow\uparrow}N_R^{\uparrow\downarrow}} + \sqrt{N_L^{\downarrow\downarrow}N_R^{\uparrow\uparrow}}\right)$$

$$a_N^b = f\left(\sqrt{N_L^{\uparrow\uparrow}N_R^{\downarrow\uparrow}} + \sqrt{N_L^{\downarrow\uparrow}N_R^{\uparrow\downarrow}}, \qquad \sqrt{N_L^{\uparrow\downarrow}N_R^{\downarrow\uparrow}} + \sqrt{N_L^{\downarrow\downarrow}N_R^{\uparrow\uparrow}}\right)$$

$$a_{NN} = f\left(\sqrt{N_L^{\uparrow\uparrow}N_R^{\downarrow\uparrow}} + \sqrt{N_L^{\downarrow\downarrow}N_R^{\uparrow\uparrow}}, \qquad \sqrt{N_L^{\downarrow\uparrow}N_R^{\uparrow\downarrow}} + \sqrt{N_L^{\uparrow\downarrow}N_R^{\downarrow\uparrow}}\right)$$

$$\lambda_j = f\left(\sqrt[4]{N_L^{\uparrow\uparrow}N_L^{\uparrow\downarrow}N_R^{\uparrow\uparrow}N_R^{\uparrow\downarrow}}, \qquad \sqrt[4]{N_L^{\downarrow\uparrow}N_L^{\downarrow\downarrow}N_R^{\downarrow\uparrow}N_R^{\downarrow\downarrow}}\right)$$

$$\lambda_b = f\left(\sqrt[4]{N_L^{\uparrow\uparrow}N_L^{\downarrow\uparrow}N_R^{\uparrow\uparrow}N_R^{\downarrow\uparrow}}, \qquad \sqrt[4]{N_L^{\uparrow\downarrow}N_L^{\downarrow\downarrow}N_R^{\uparrow\downarrow}N_R^{\downarrow\downarrow}}\right)$$

$$\epsilon = f\left(\sqrt[4]{N_L^{\uparrow\uparrow}N_L^{\uparrow\downarrow}N_L^{\downarrow\uparrow}N_L^{\downarrow\downarrow}}, \qquad \sqrt[4]{N_R^{\uparrow\uparrow}N_R^{\uparrow\downarrow}N_R^{\downarrow\uparrow}N_R^{\downarrow\downarrow}}\right)$$

$$b_{NN} = f\left(\sqrt[4]{N_L^{\uparrow\uparrow}N_L^{\downarrow\downarrow}N_R^{\uparrow\uparrow}N_R^{\downarrow\downarrow}}, \qquad \sqrt[4]{N_L^{\uparrow\downarrow}N_L^{\downarrow\uparrow}N_R^{\uparrow\downarrow}N_R^{\downarrow\uparrow}}\right)$$

$$\boldsymbol{f(A,B) = \frac{A-B}{A+B}}$$

This is a generalization of the “Square root formula” for $p^{\uparrow}p^{\uparrow}$ scattering

Systematic errors in measurements of a_{NN} and b_{NN}

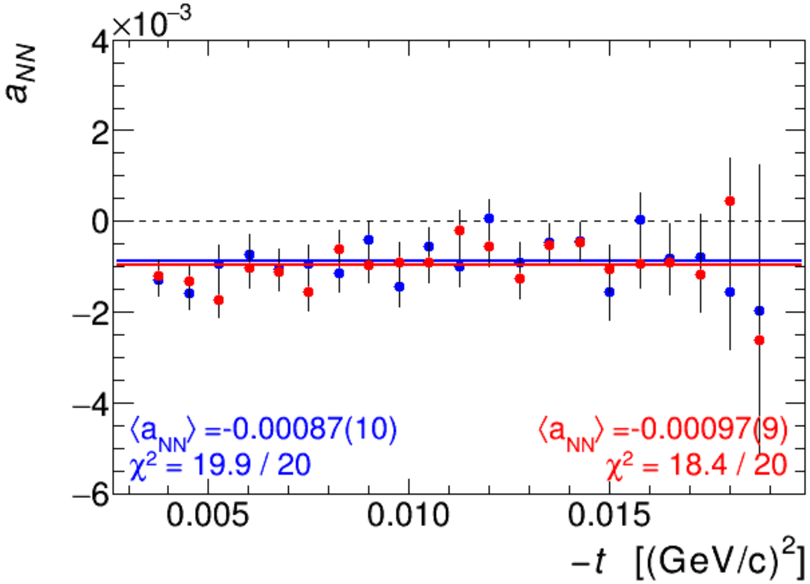
$$\frac{d^2\sigma}{dt\,d\varphi} = \frac{1}{2\pi}\frac{d\sigma}{dt}\left[1 + \cdots + a_{NN}\sin^2\varphi + \boldsymbol{b} + P_{jet}P_{beam}\boldsymbol{b_{NN}}\sin\varphi + \boldsymbol{a_{NN}^{bgr}}\sin^2\varphi\right]$$

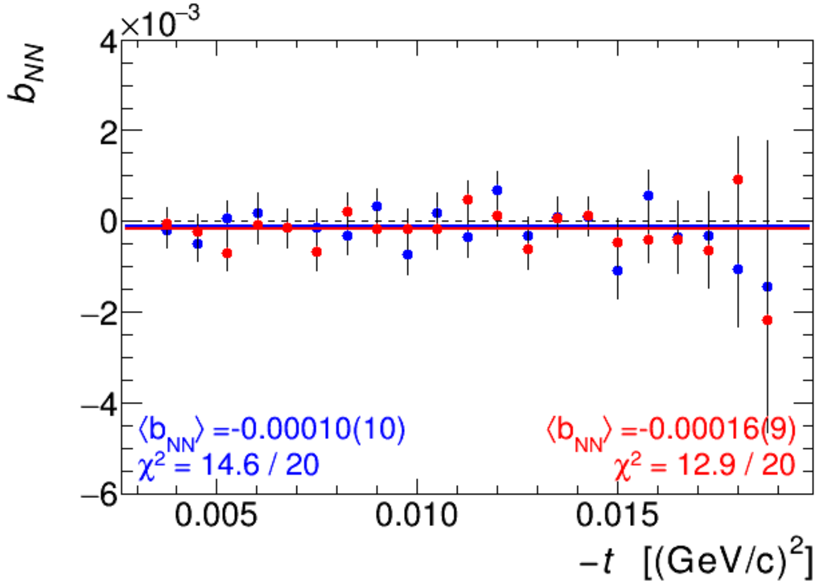
- $\boldsymbol{a_{NN}^{bgr} = 0}$ (No background events spin correlated both with jet amd beam polarization
- $\boldsymbol{b_{NN} = 0}$ (Parity conservation)
- $\boldsymbol{b \neq 0} \;\Rightarrow\; \delta a_{NN}^{syst} = -\left(b^{(L)} + b^{(R)}\right)a_{NN},\;\; \delta b_{NN}^{syst} = \left(b^{(L)} - b^{(r)}\right)a_{NN}$

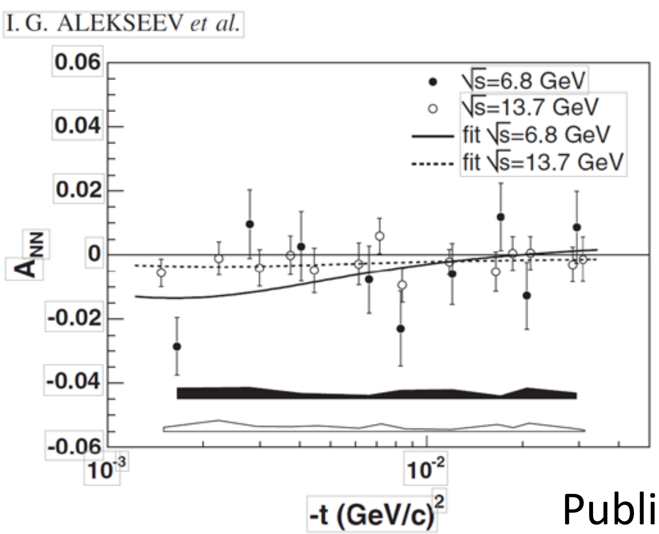
Systematic errors are expected to be negligible if statistical error (relative) is $\gtrsim 5\%$

(unless assumptions $a_{NN}^{bgr} = 0$ and/or $b_{NN} = 0$ are false)

$p^{\uparrow}p^{\uparrow}$, 100 GeV. Results for $T_R > 1.8$ MeV







$P_j = 0.95$, $P_b^B = 0.520$, $P_b^Y = 0.585$

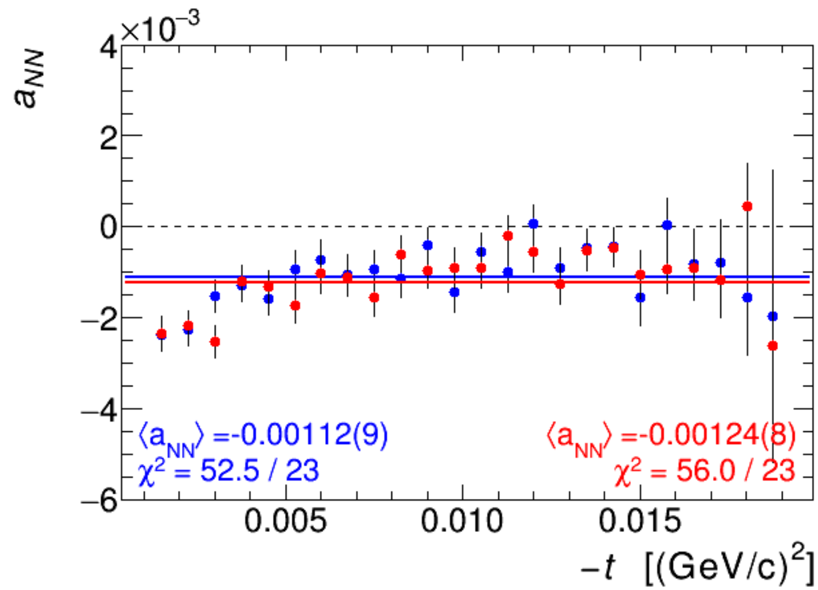
$\langle A_{NN}^B \rangle = -0.00176 \pm 0.00020$

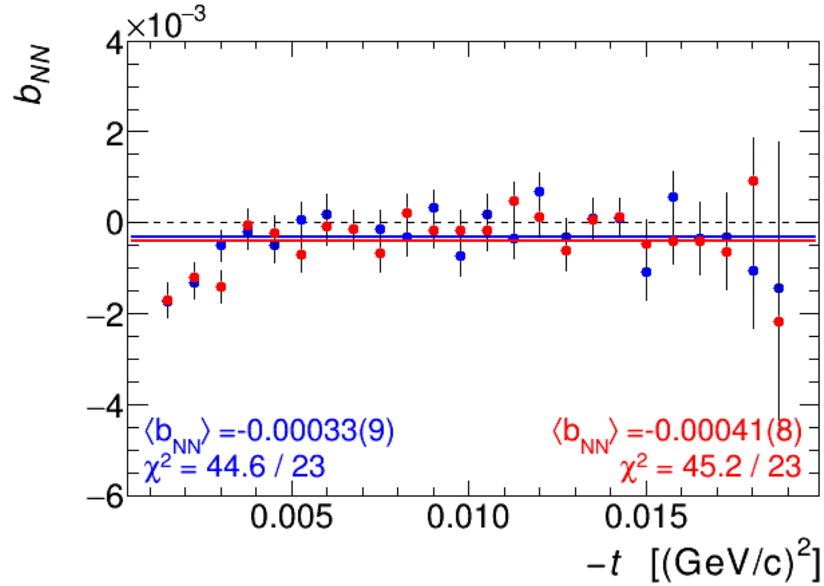
$\langle A_{NN}^Y \rangle = -0.00175 \pm 0.00016$

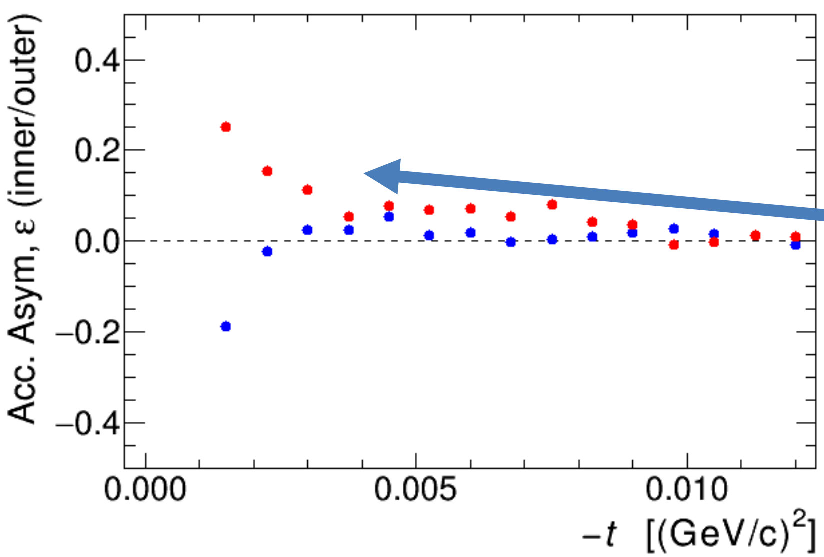
$$\langle A_{NN} \rangle = (-1.75 \pm 0.12) \times 10^{-3}$$
$$(0.003 < -t < 0.017)$$

Published result: $\langle A_{NN} \rangle = (-2.4 \pm 1.4) \times 10^{-3}$

$p^{\uparrow}p^{\uparrow}$, 100 GeV. Results for $T_R > 0.6$ MeV

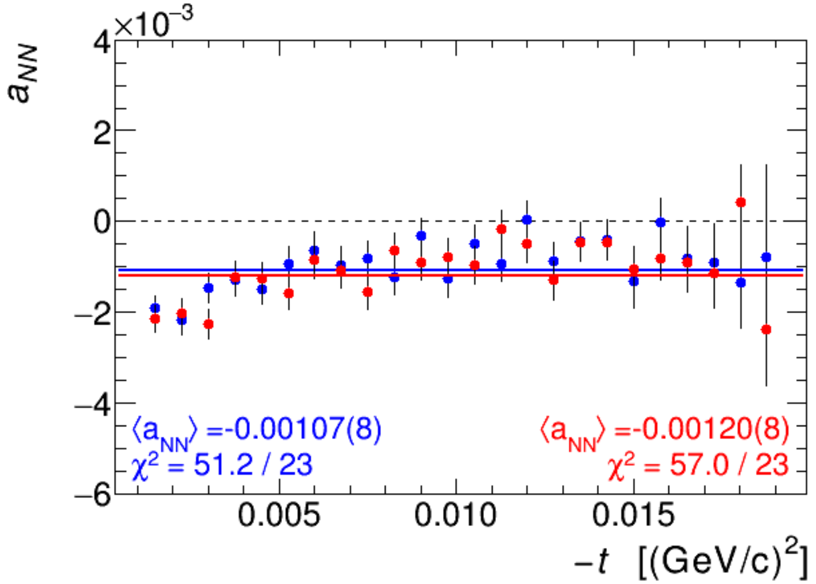


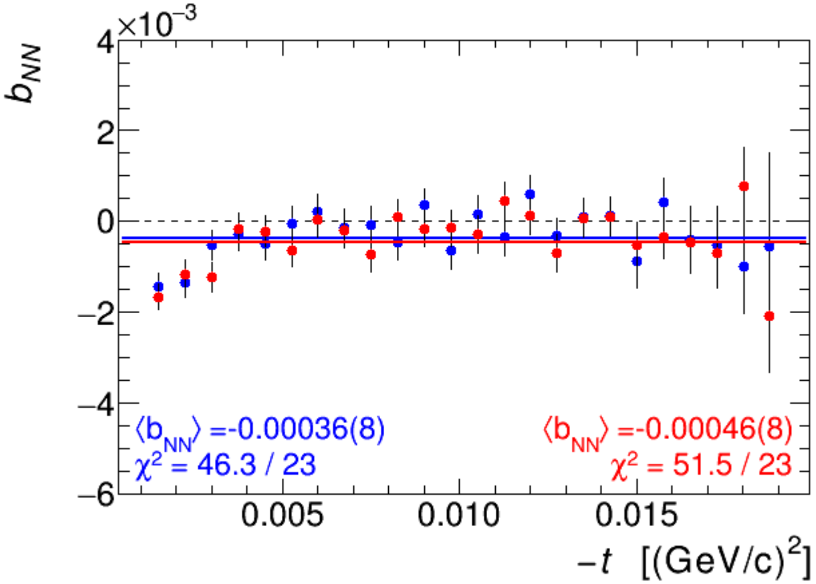




- A correlated systematic error is observed below 1.8 MeV
- No good understanding yet
- Acceptance asymmetry may give a hint

$p^{\uparrow}p^{\uparrow}$, *100 GeV.* *Results for* $T_R > 0.6$ MeV
(no background subtraction)





- The a_{NN} was scaled by $\sim 5\%$ (**as expected**)
- A tiny ~ 0.00004 background related systematic error in b_{NN} cannot be excluded.
  A residual error, after background subtraction is expected to be $< 10^{-5}$

Summary

- "Square root formula" for double spin asymmetries is derived.
- Double spin asymmetry $\langle A_{NN} \rangle = (-1.75 \pm 0.12) \times 10^{-3}$ $(0.003 < -t < 0.017)$ is being observed with negligible systematic errors in Run15 data (pp, 100 GeV)
- No proved evidence of the $A_{NN}(t)$ dependence of momentum transfer is found.
- Significant systematic errors are seen in the low energy $T_R < 1.8\ \mathrm{MeV}$ data
- At the moment, no good understanding of a source of the systematic error.
- The issue has to be resolved to verify the measured double spin asymmetry.