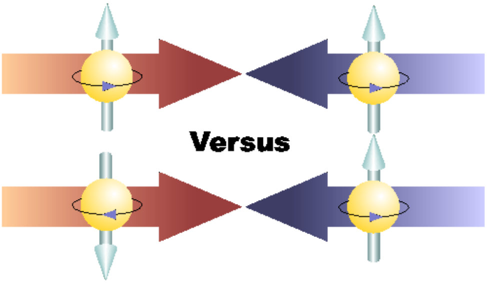
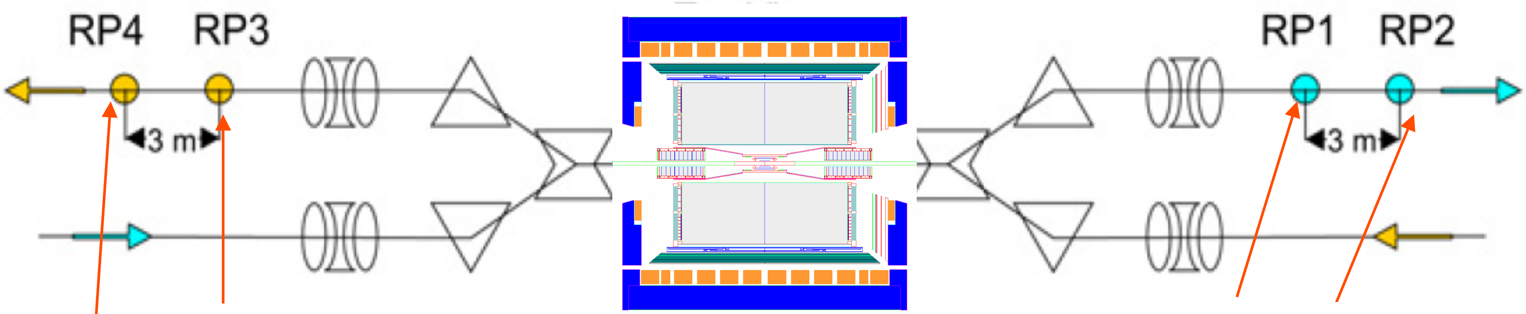
Transverse spin asymmetries in the CNI region in polarized proton-proton elastic scattering at STAR

Włodek Guryn for the STAR experiment

OUTLINE of the TALK

- Physics motivation
- Description of the experiment
- Results on A_N and preliminary results A_{NN}, A_{SS}
- Summary and future plans with STAR





Horizontal (-55.5 m)
Vertical (-58.5 m)

IP (STAR)

Horizontal (55.5 m)
Vertical (58.5 m)

Source of A_N

Five helicity amplitudes describe proton-proton elastic scattering

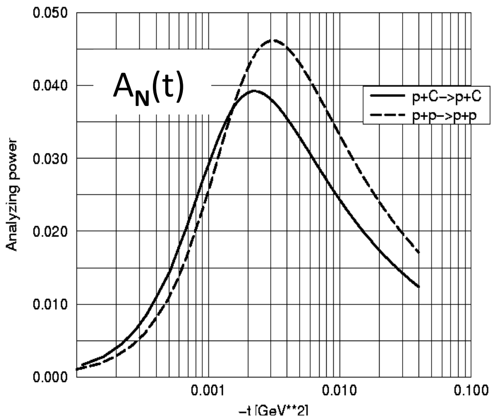
$$\phi_1(s,t) \propto \langle ++ | M | ++ \rangle \leftarrow \text{non-flip}$$

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

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

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

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



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

$$A_N(t,\varphi) \propto \frac{\mathrm{Im}[\varphi_5^{*}\Phi_{+}]}{d\sigma / dt} \qquad r_5 = \mathrm{Re}\, r_5 + i\, \mathrm{Im}\, r_5 = \frac{m\phi_5}{\sqrt{-t}\ \mathrm{Im}\phi_{+}}$$

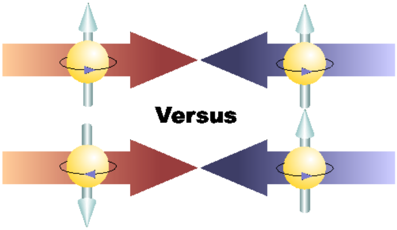
Single spin asymmetry A_N arises in the CNI region is due to the interference of hadronic non-flip amplitude with electromagnetic spin-flip amplitude.

<u>Any difference from the above is an indication of other contributions: hadronic spin flip caused by resonance (Reggeon) or vacuum exchange (Pomeron) contributions.</u>

B. Z. Kopeliovich and L. I. Lapidus Sov. J. Nucl. Phys. 114 (19) 1974 and N. H. Buttimore, B. Z. Kopeliovich, E. Leader, J. Soffer, T. L. Trueman, Phys. Rev. D59, (1999) 114010.

Experimental Determination of A_N

$$A_N = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}} \text{ or } A_N = \frac{1}{P_{beam}} \frac{N^{\uparrow}/L^{\uparrow} - N^{\downarrow}/L^{\downarrow}}{N^{\uparrow}/L^{\uparrow} + N^{\downarrow}/L^{\downarrow}}$$



With both beams polarized one can take advantage of (↑↑,↓↓) and (↑↓, ↓↑) combinations (*Square-Root-Formula*) to calculate spin (↑↑,↓↓) and false asymmetries (↑↓, ↓↑) .

$$\varepsilon_N(\varphi) = \frac{(P_1 + P_2)\cos\varphi \cdot A_N}{1+\delta} = \frac{\sqrt{N_L^{\uparrow\uparrow}(\varphi) N_R^{\downarrow\downarrow}(\pi-\varphi)} - \sqrt{N_R^{\uparrow\uparrow}(\pi-\varphi) N_L^{\downarrow\downarrow}(\varphi)}}{\sqrt{N_L^{\uparrow\uparrow}(\varphi) N_R^{\downarrow\downarrow}(\pi-\varphi)} + \sqrt{N_R^{\uparrow\uparrow}(\pi-\varphi) N_L^{\downarrow\downarrow}(\varphi)}}$$

Asymmetry

$$\varepsilon_F(\varphi) = \frac{(P_1 - P_2)\cos\varphi \cdot A_N}{1-\delta} = \frac{\sqrt{N_L^{\uparrow\downarrow}(\varphi) N_R^{\downarrow\uparrow}(\pi-\varphi)} - \sqrt{N_R^{\uparrow\downarrow}(\pi-\varphi) N_L^{\uparrow\downarrow}(\varphi)}}{\sqrt{N_L^{\uparrow\downarrow}(\varphi) N_R^{\downarrow\uparrow}(\pi-\varphi)} + \sqrt{N_R^{\uparrow\downarrow}(\pi-\varphi) N_L^{\uparrow\downarrow}(\varphi)}}$$

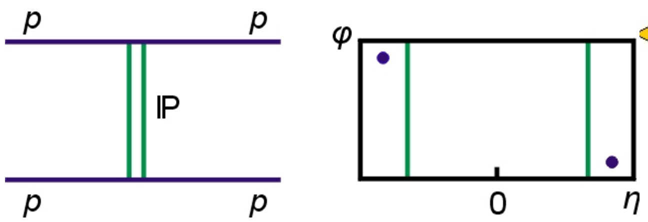
“False” Asymmetry

$$\text{where } \delta = P_1 P_2 \left(A_{NN} \cos^2\varphi + A_{SS} \sin^2\varphi \right), \text{ in our case } \delta \leq 0.028$$

Since the above is a relative measurement the efficiencies $\alpha(t, \phi)$ cancel, as does the relative luminosity normalization

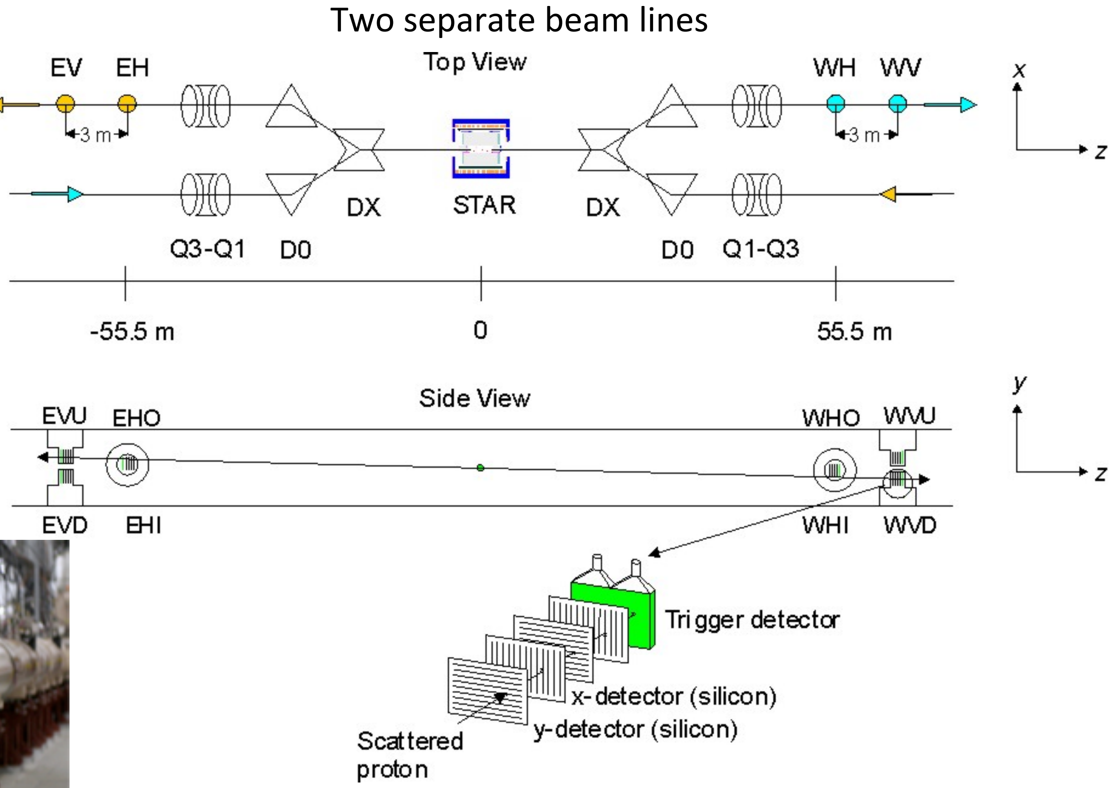
RPs at STAR – small t setup

Vertical AND Horizontal RP setup for a complete ϕ coverage



p + p → p + p

$$\vec{p}_1 = -\vec{p}_2 \Rightarrow \left(\Theta_x^1, \Theta_y^1\right) = \left(-\Theta_x^2, -\Theta_y^2\right)$$



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

Principle of the Measurement of the Forward Protons

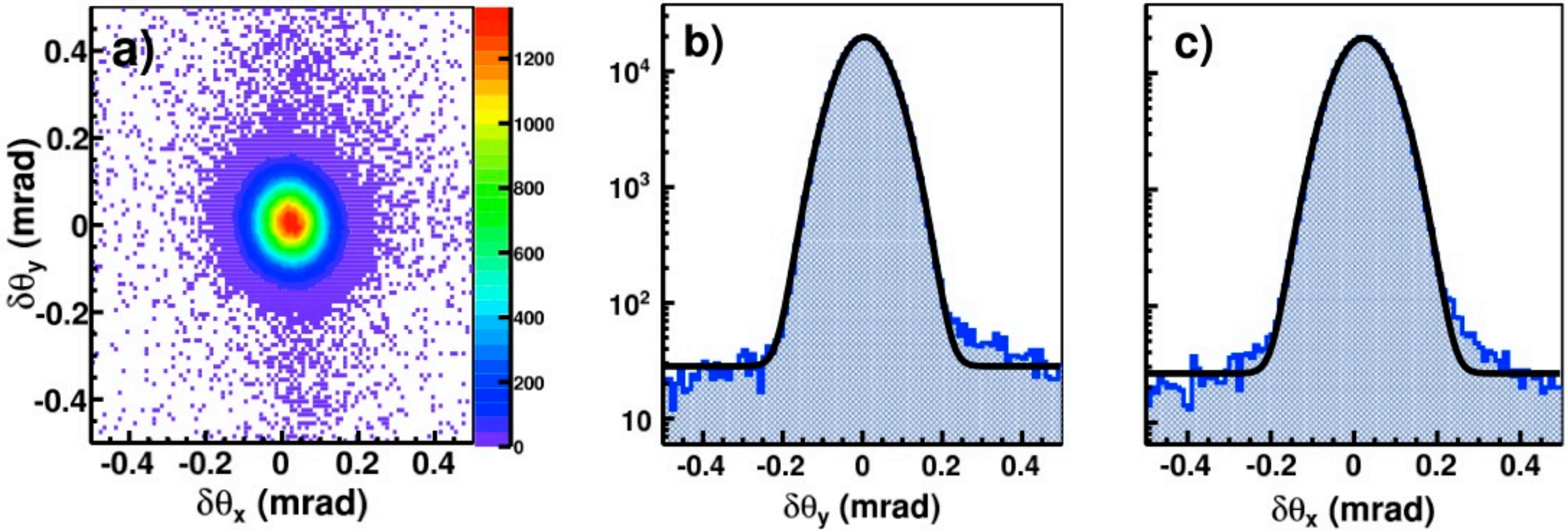
Beam transport equations relate measured position at the detector to scattering angle.

$$\begin{bmatrix} x_D \\ \Theta_D^x \\ y_D \\ \Theta_D^y \end{bmatrix} = \begin{pmatrix} a_{11} & L_{eff}^x & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & L_{eff}^y \\ a_{41} & a_{42} & a_{43} & a_{44} \end{pmatrix} \begin{bmatrix} x_0 \\ \Theta_x^* \\ y_0 \\ \Theta_y^* \end{bmatrix}$$

x_0, y_0: Position at Interaction Point
Θ^*_x Θ^*_y : Scattering Angle at IP
x_D, y_D : Position at Detector
Θ^x_D, Θ^y_D : Angle at Detector

- Both beams were transversely polarized with 60% polarization.
- Excellent detector performance – nearly 100% efficiency and only 5 dead/noisy strips per ~14000 active strips.
- Two separate beam lines allow 2π acceptance in ϕ.
- Ideal optics β^*= 21m and terms other than L_{Eff} in the transport matrix were very small.
- Single beam divergence ~ 40 mrad (typical scattering angle 1 mrad)
- $0.003 < -t < 0.03$ $(\mathrm{GeV/c})^2$

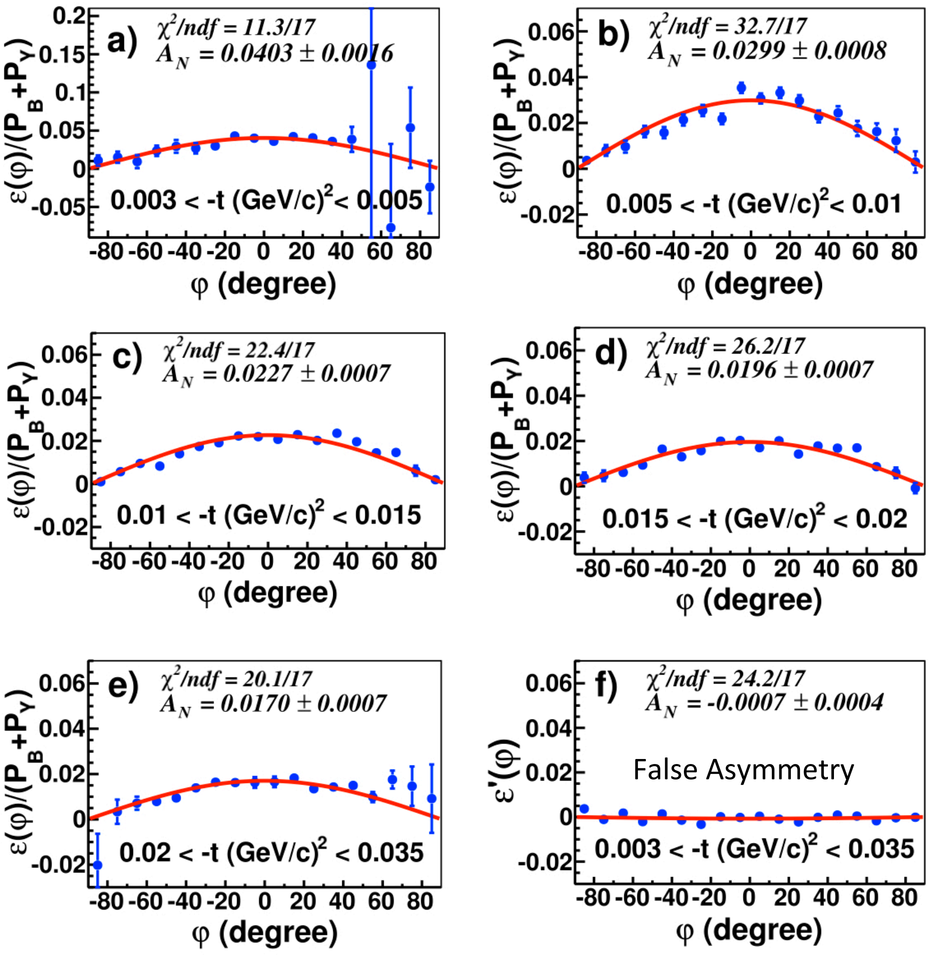
Detector performance and Elastic cuts

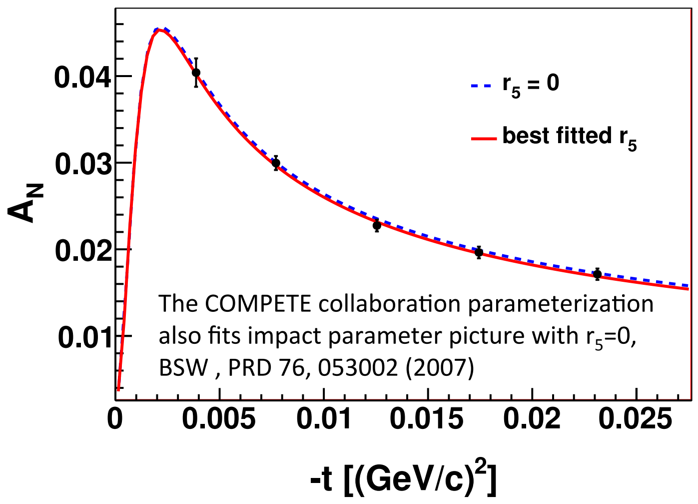


Total no. of events processed (elastic and inelastic)	58M
Total no. of events also with elastic trigger	33M
Total no. of events also are collinear – used for analysis	21M

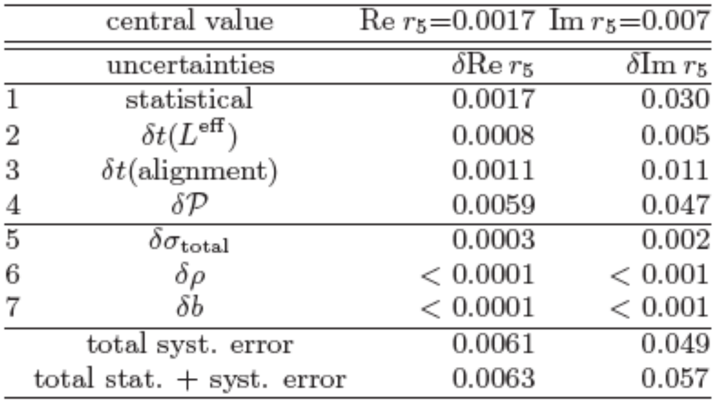
Results A_N and r_5

arXiv 1206.1928 nucl-ex





The COMPETE collaboration parameterization also fits impact parameter picture with r_5=0, BSW , PRD 76, 053002 (2007)



	central value	Re r_5=0.0017	Im r_5=0.007
	uncertainties	$\delta\mathrm{Re}\, r_5$	$\delta\mathrm{Im}\, r_5$
1	statistical	0.0017	0.030
2	$\delta t(L^{\mathrm{eff}})$	0.0008	0.005
3	$\delta t(\mathrm{alignment})$	0.0011	0.011
4	$\delta\mathcal{P}$	0.0059	0.047
5	$\delta\sigma_{\mathrm{total}}$	0.0003	0.002
6	$\delta\rho$	< 0.0001	< 0.001
7	δb	< 0.0001	< 0.001
	total syst. error	0.0061	0.049
	total stat. + syst. error	0.0063	0.057

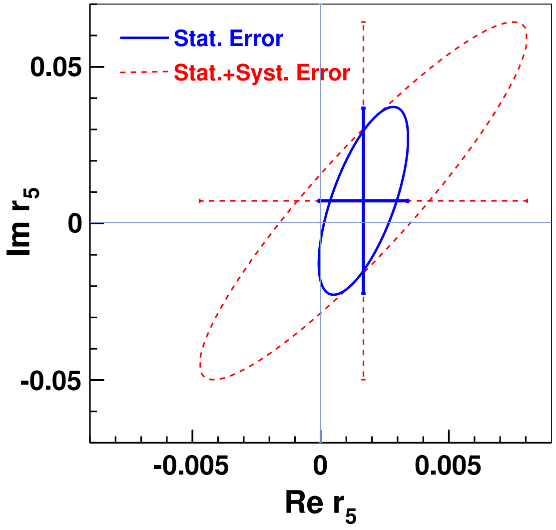
Re r_5 = 0.0017 +-0.0017 (stat.) +-0.0061 (syst.)

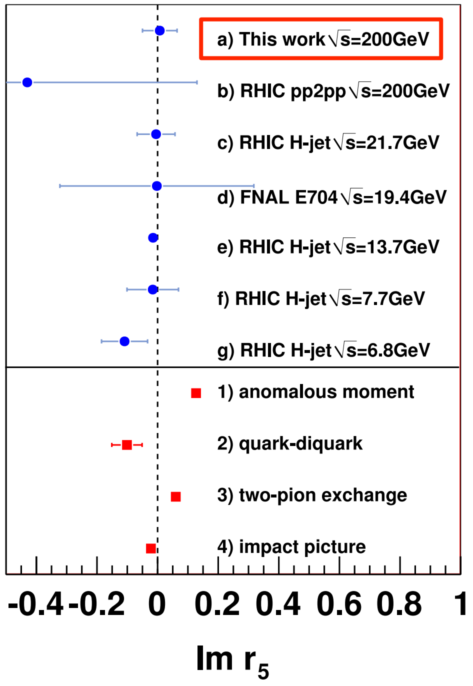
Im r_5 = 0.007 +-0.03 (stat.) +- 0.049 (syst.)

Result on A_N

arXiv 1206.1928 nucl-ex

Re r_5 = 0.0017 +-0.0017 (stat.) +-0.061 (syst.)
Im r_5 = 0.007 +-0.03 (stat.) +- 0.049 (syst.)





Pomeron spin-flip is consistent with zero

Preliminary Results A_{NN}, A_{SS}

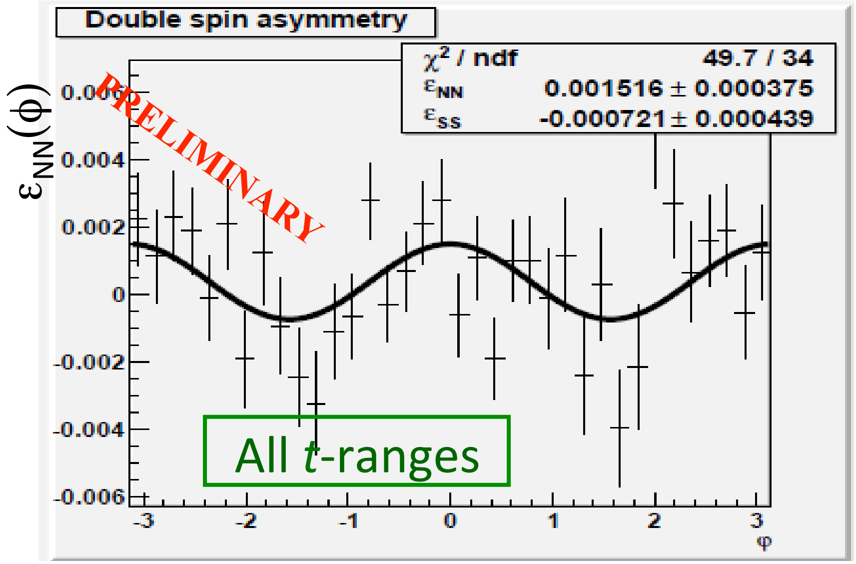
Gives more information on helicity amplitudes ϕ_2 and ϕ_4

Cannot use square root formula – have to rely on normalized counts $K^{+/-}$

$$\varepsilon_{NN}(\varphi) = P_B P_Y (A_{NN}\cos^2\varphi + A_{SS}\sin^2\varphi) =$$

$$= \frac{(K^{++}(\varphi) + K^{--}(\varphi)) - (K^{+-}(\varphi) + K^{-+}(\varphi))}{(K^{++}(\varphi) + K^{--}(\varphi)) + (K^{+-}(\varphi) + K^{-+}(\varphi))}$$

$$\boxed{P_B P_Y = 0.372 \pm 0.023}$$



- Both A_{NN} and A_{SS} are very small ~10^{-3} (except for the lowest *t*-range where larger systematic shifts may occur)
- Need more systematic error studies for the final result

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] $(GeV/c)^2$.
2. Result is compatible with CNI, which does not have hadronic spin flip amplitude (arXiv 1206.1928 nucl-ex).

   Re r_5 = 0.0017 +-0.0017 (stat.) +-0.061 (syst.)
   Im r_5 = 0.007 +-0.03 (stat.) +- 0.049 (syst.)

3. Preliminary result on A_{NN}, A_{SS} has been obtained. It indicates that transverse double spin asymmetries are small but non-zero.
4. The program of elastic scattering measurements will continue. Results on σ_{tot} at $\sqrt{s}$ = 200 GeV and more data at $\sqrt{s}$ = 500 GeV are expected.
5. The Central Exclusive Production program has started, talk by L. Adamczyk at this conference later today.