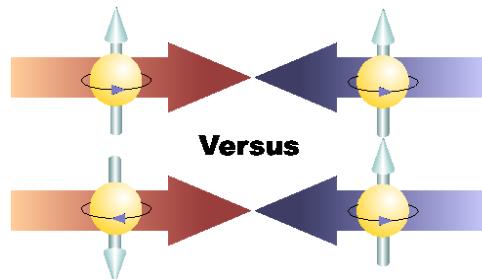


Results on Transverse Spin Asymmetries in Polarized Proton - Proton Elastic Scattering at $\sqrt{s} = 200$ GeV

Włodek Guryń for the STAR collaboration

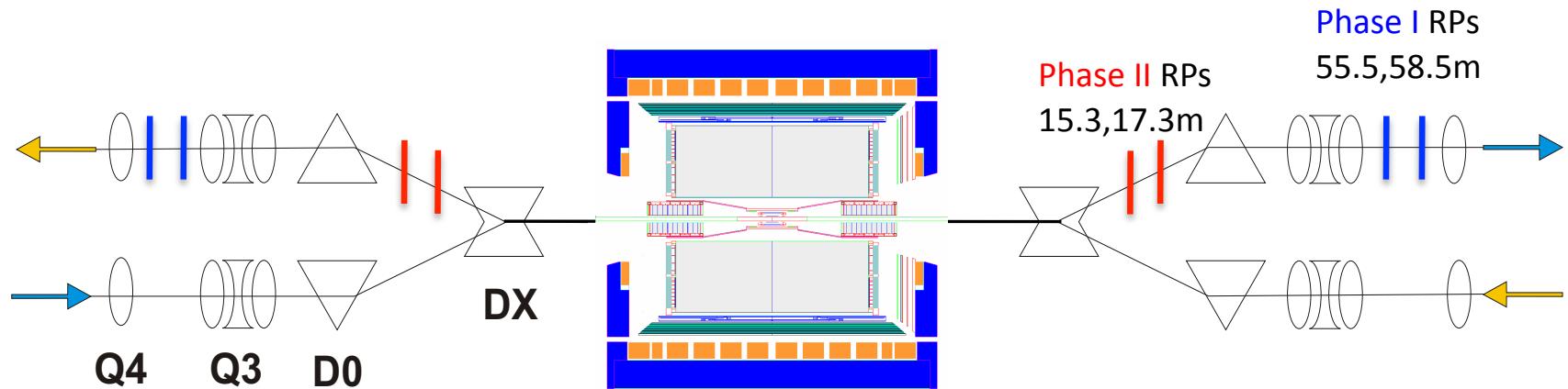
Outline

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

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

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

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

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

$$\phi_5(s, t) = \langle ++ | M | +- \rangle \text{ single spin flip}$$

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

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

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

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

Polarized cross-sections and spin parameters

Cross-section azimuthal angular dependence for transversely polarized beams:

\vec{n} - 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

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

A_{NN} – polarization normal to the scattering plane
 A_{SS} – polarization vector in the scattering plane

$$2\pi \frac{d^2\sigma}{dtd\varphi} = \frac{d\sigma}{dt} \cdot \left(1 + (P_B + P_Y) A_N \cos \varphi + \underbrace{P_B P_Y (A_{NN} \cos^2 \varphi + A_{SS} \sin^2 \varphi)}_{\text{No angle dependence}} \right)$$

$$\varepsilon_2(\varphi) = P_B P_Y \underbrace{((A_{NN} + A_{SS})/2 + (A_{NN} - A_{SS})/2 \cdot \cos 2\varphi)}_{\text{No angle dependence}}$$

Luminosity normalization required to obtain $\varepsilon(\phi)$

Cross sections and spin asymmetries

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

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

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

$$A_{NN}(s,t) \frac{d\sigma}{dt} = \frac{4\pi}{s^2} \left\{ 2|\phi_5|^2 + \text{Re}(\phi_1^*\phi_2 - \phi_3^*\phi_4) \right\}$$

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

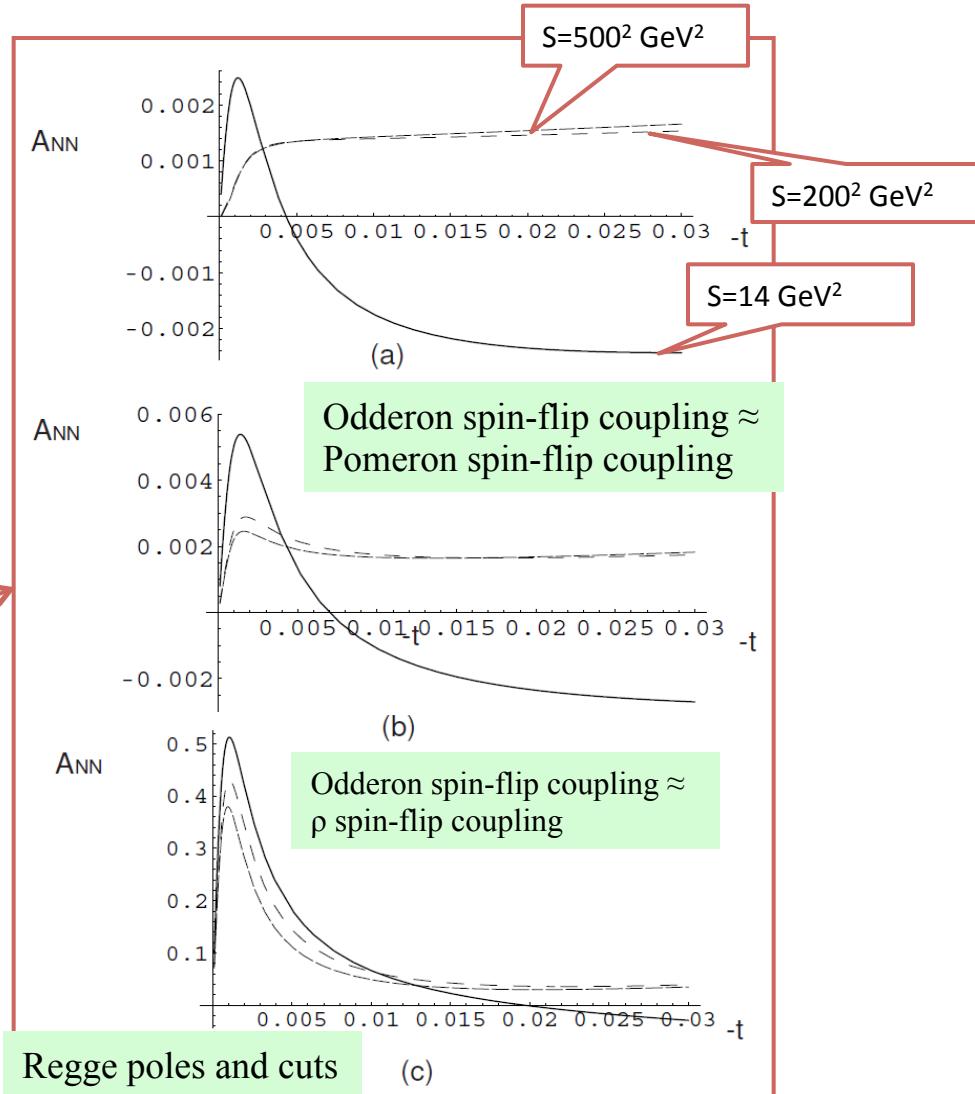
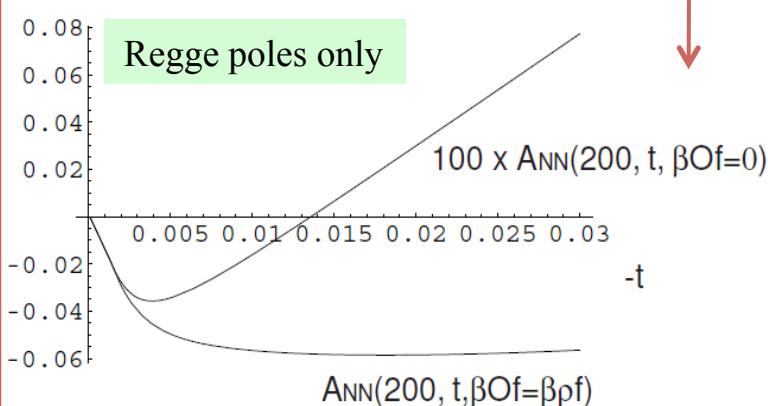
Probing Odderon in polarized pp elastic scattering

E.Leader, T.L.Trueman

“The Odderon and spin dependence of high-energy proton-proton scattering”,
PR D61, 077504 (2000)

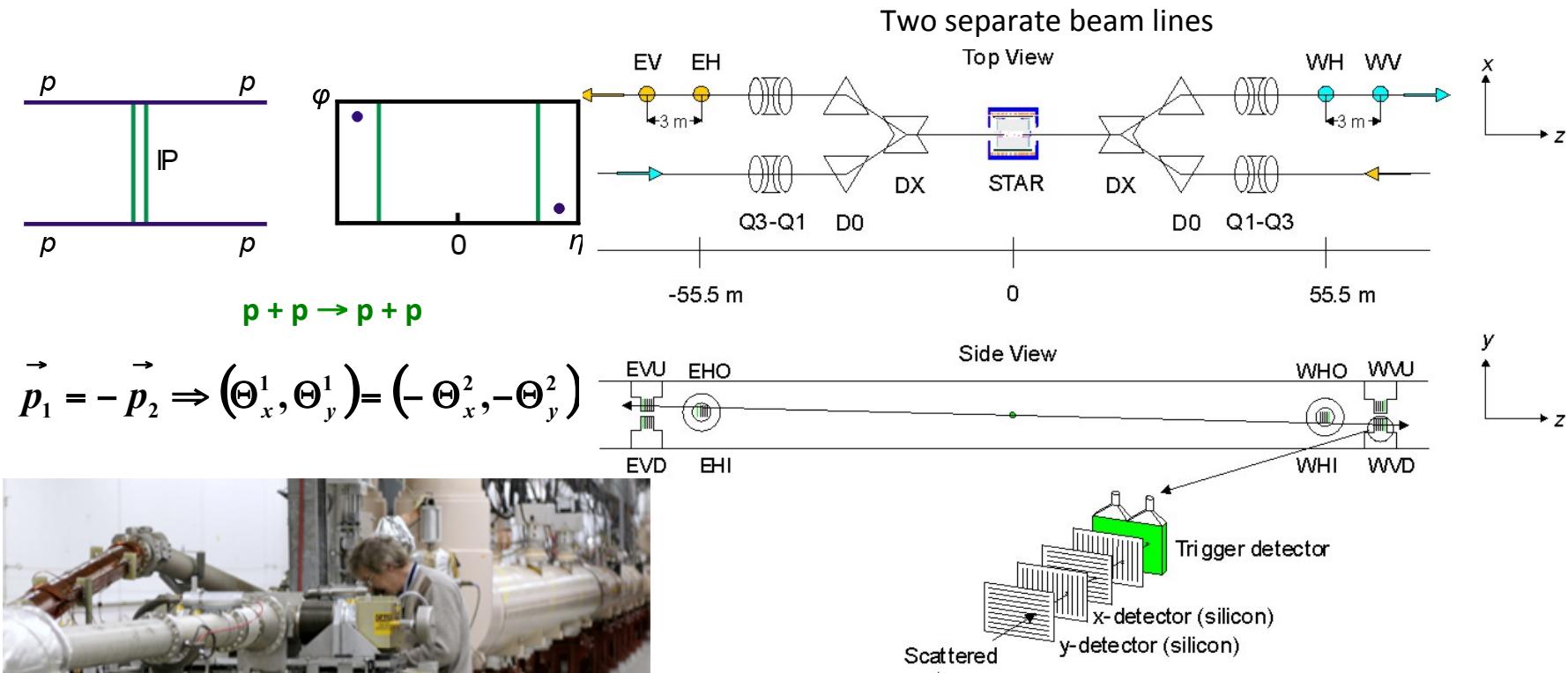
Pomeron and Odderon are 90deg out of phase 5% Odderon contribution \rightarrow 5% A_{NN}

T.L.Trueman
 “Double-spin asymmetry in elastic proton-proton scattering as a probe for the Odderon”,
arXiv:hep-ph/0604153v1 (2006)



RPs at STAR – small t setup

Vertical AND Horizontal RP setup for a complete ϕ coverage

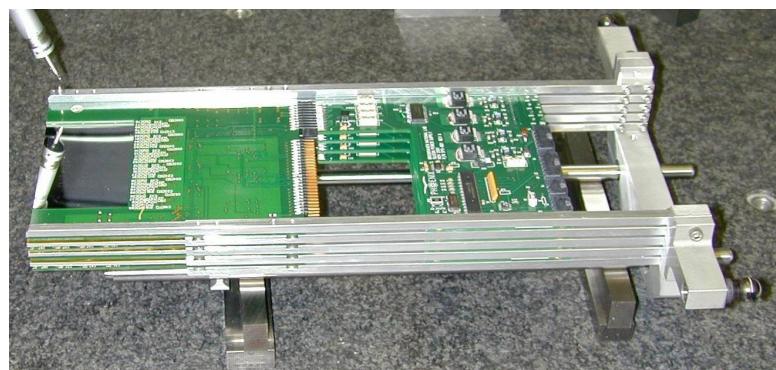


An elastic event has two collinear protons, one on each side of IP

The Setup: few pictures



Roman Pot station in RHIC tunnel



Roman Pot and Si detector package

Experimental Conditions for this Data Set

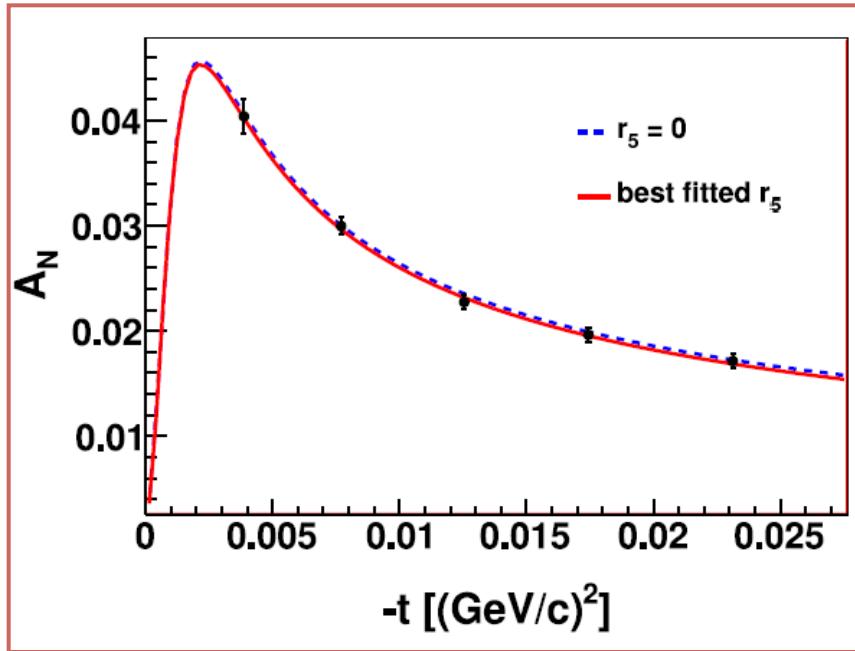
- Both beams were transversely polarized with $P_B, P_Y \sim 60\%$ polarization.
- Excellent detector performance – nearly 100% efficiency and only 5 dead/noisy strips per ~ 14000 active strips.
- 2π acceptance in φ .
- Ideal optics $\beta^* = 21m$ and terms other than L_{EFF} in the transport matrix 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

Phys. Lett. B719 (2013) 62-69



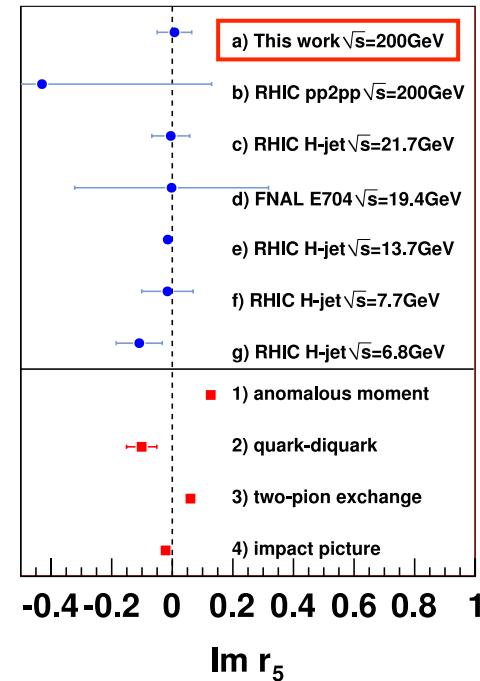
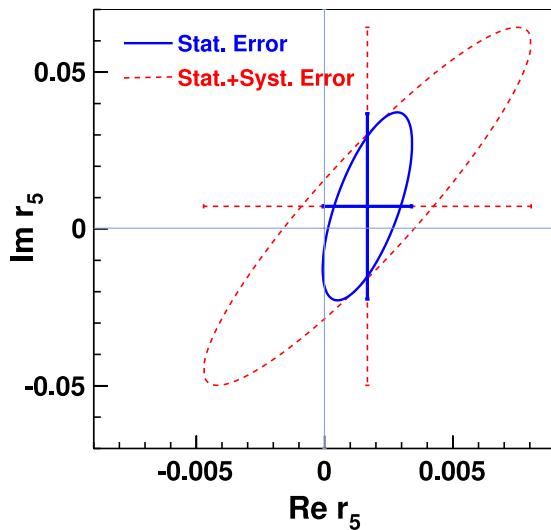
- $\phi_1(s, t) \propto \langle ++ | M | ++ \rangle \leftarrow \text{non-flip}$
- $\phi_2(s, t) \propto \langle ++ | M | -- \rangle \leftarrow \text{double-flip}$
- $\phi_3(s, t) \propto \langle +- | M | +- \rangle \leftarrow \text{non-flip}$
- $\phi_4(s, t) \propto \langle +- | M | -+ \rangle \leftarrow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

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

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

Result on A_N

Phys. Lett. B719 (2013) 62-69

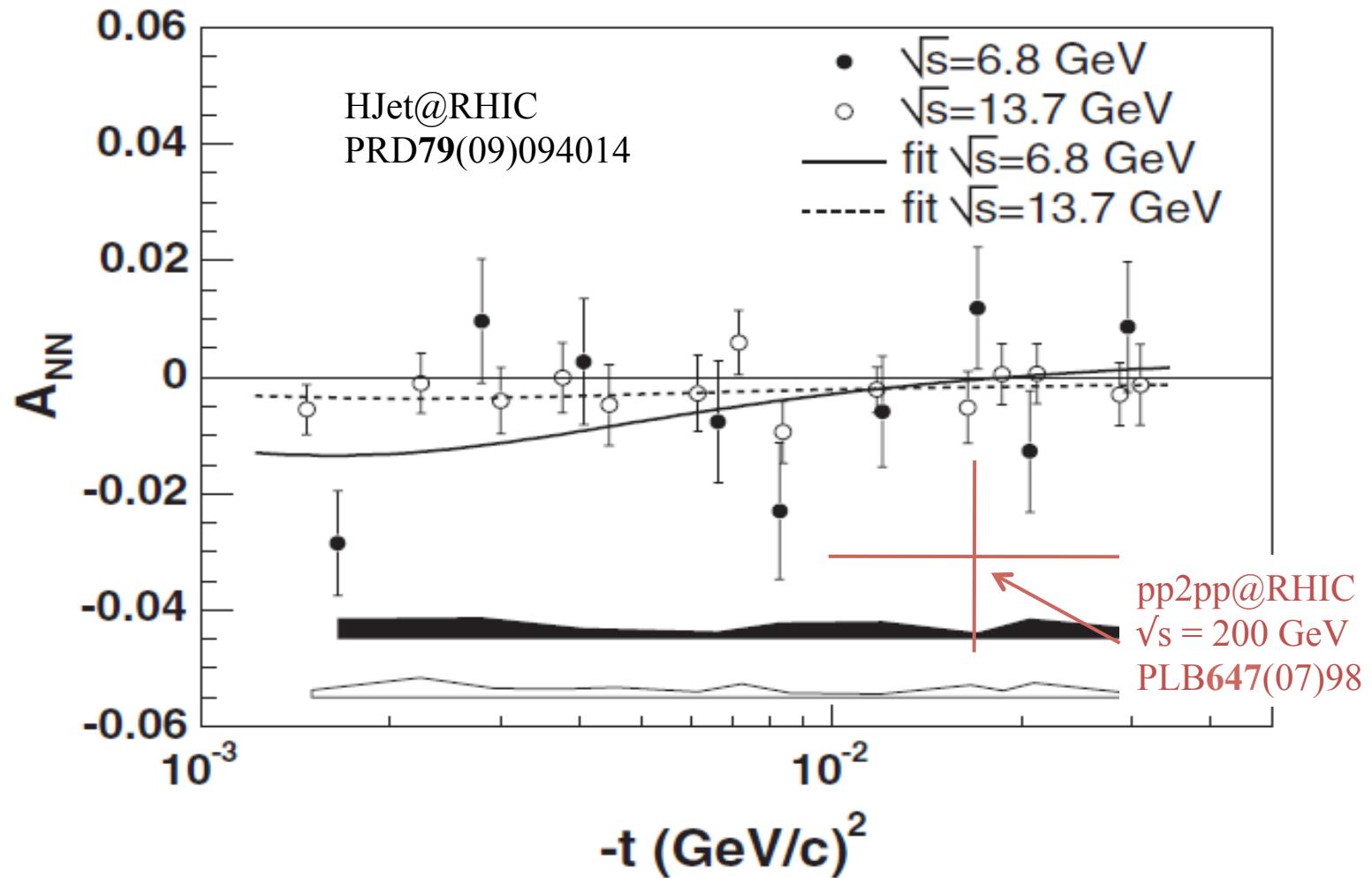


$$\text{Re } r_5 = 0.0017 \pm 0.0017 \text{ (stat.)} \pm 0.061 \text{ (syst.)}$$

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

Pomeron spin-flip is consistent with zero

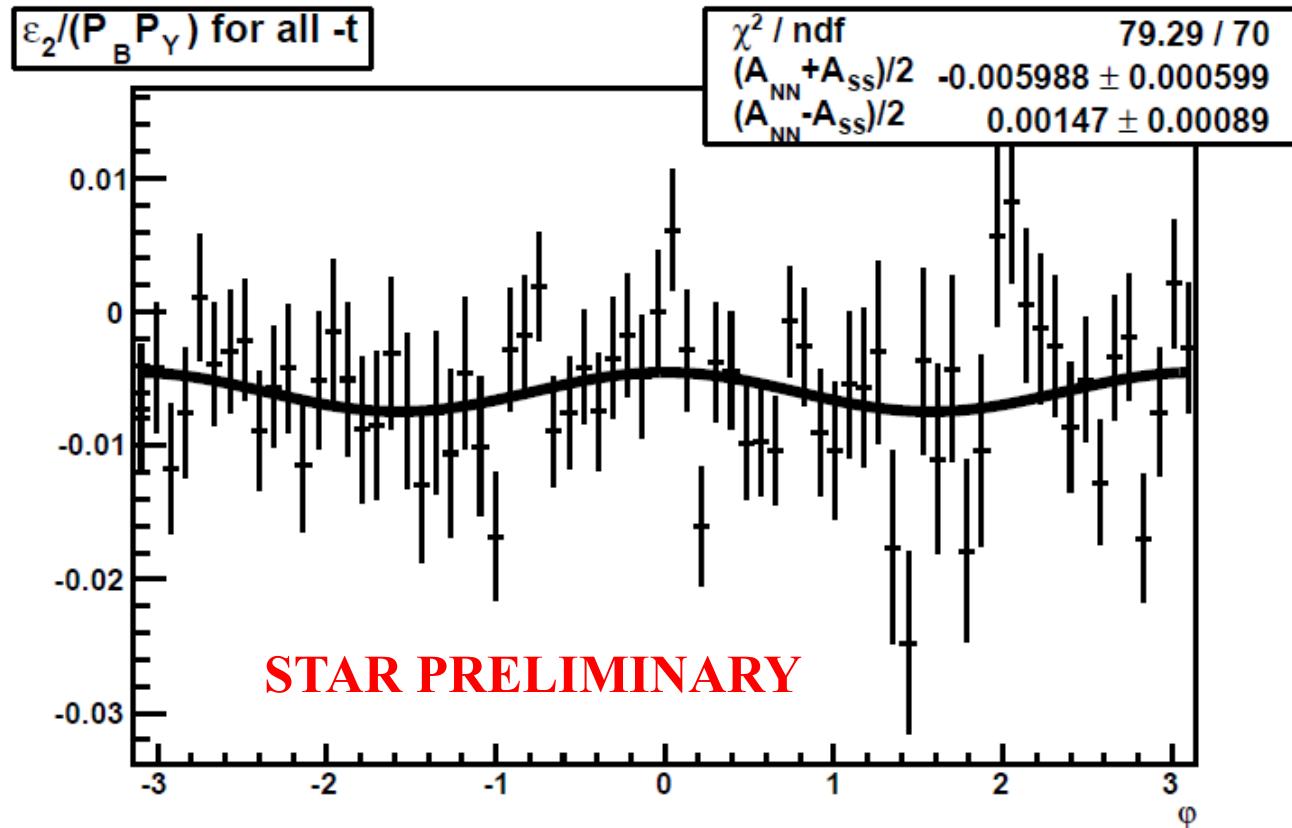
A_{NN} – Existing data



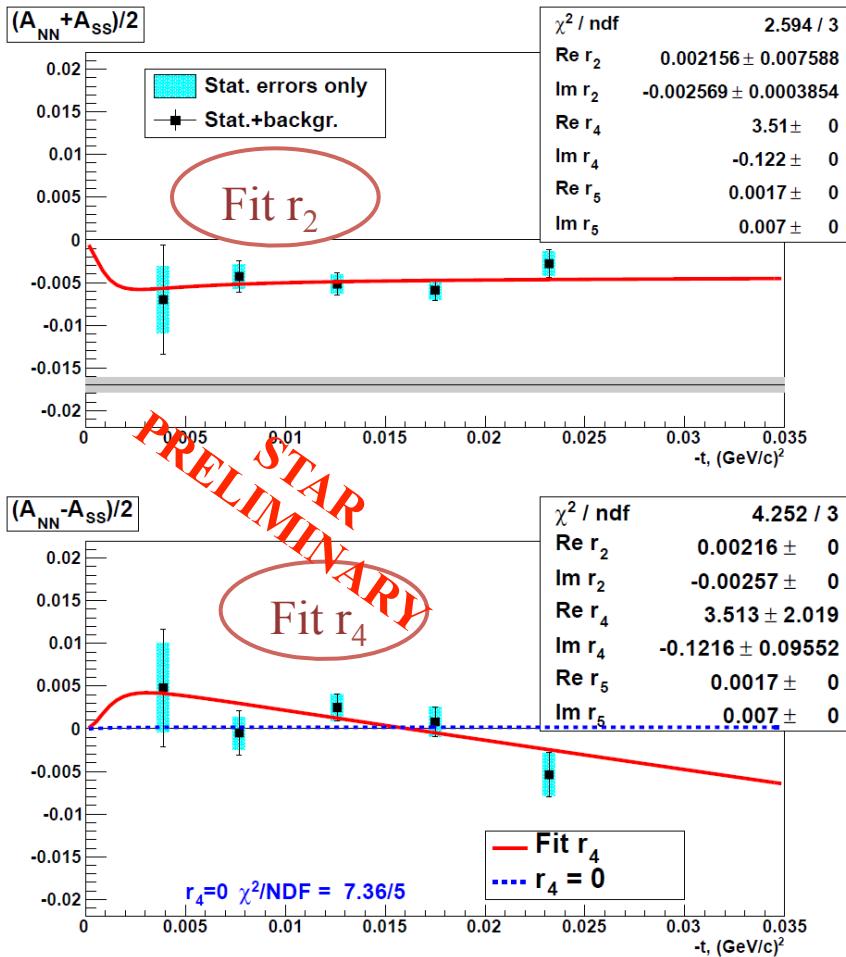
Raw Double Spin Asymmetry

K^{ij} Luminosity normalized counts ↗

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

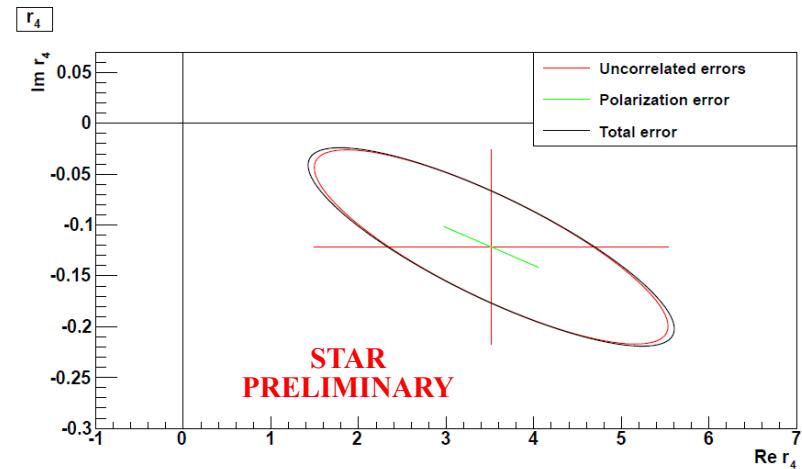
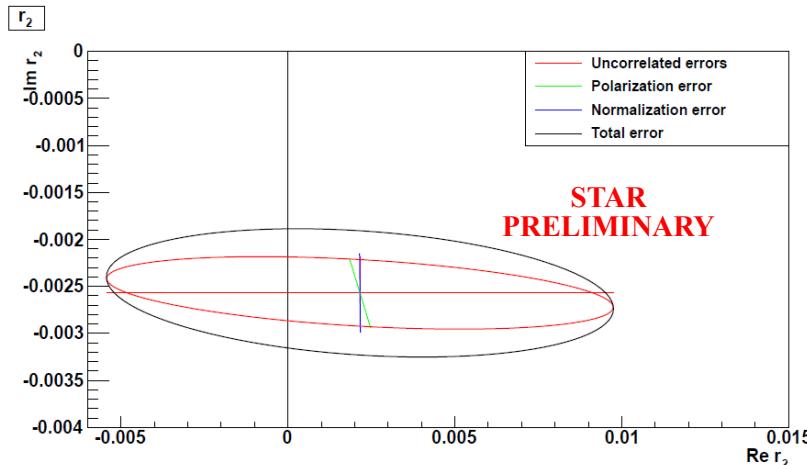


A_{NN} result



- 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]**
- r_5 taken from A_N result from the same data sample at STAR: **Phys. Lett. B719 (2013) 62-69**
- 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: r₂ and r₄



$$\frac{A_{NN} + A_{SS}}{2} \frac{d\sigma}{dt} \approx \frac{4\pi}{s^2} \text{Re } \phi_1 \phi_2^*$$

$$\frac{A_{NN} - A_{SS}}{2} \frac{d\sigma}{dt} \approx -\frac{4\pi}{s^2} \text{Re } \phi_3 \phi_4^*$$

$$r_2 = \frac{\phi_2^{had}}{2 \text{Im } \phi_+^{had}} \quad r_4 = -\frac{m_p^2 \phi_4^{had}}{t \text{Im } \phi_+^{had}}$$

- 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] (GeV/c)².
2. Result on A_N is consistent with CNI, which does not have hadronic spin flip amplitude (Phys. Lett. B719 (2013) 62-69 or arXiv 1206.1928 nucl-ex).

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

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

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.