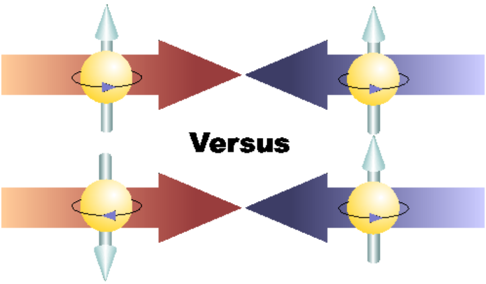
Results on Transverse Spin Asymmetries in Polarized Proton - Proton Elastic Scattering at $\sqrt{s}$ = 200 GeV

Włodek Guryn for the STAR collaboration

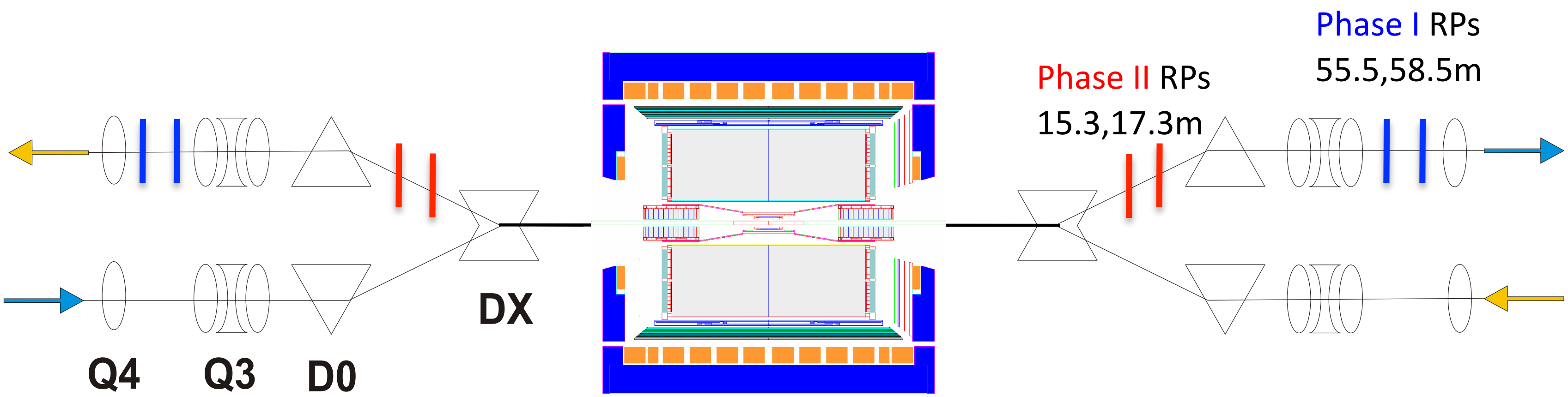
Outline

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 ½ ½ → ½½

Matrix elements

$\phi_1(s,t) = \langle ++|M|++\rangle$ non–flip

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

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

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

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

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

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

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

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

Cross sections and spin asymetries

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

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

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

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

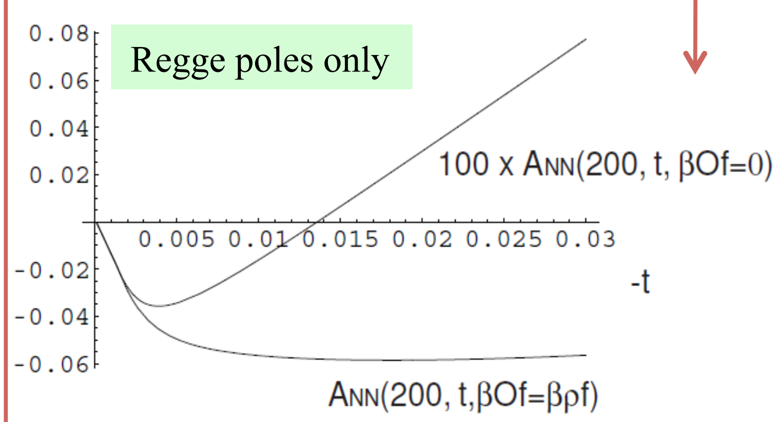
$$A_{SS}(s,t)\frac{d\sigma}{dt} = \frac{4\pi}{s^2}\mathrm{Re}\left\{\phi_1\phi_2^* + \phi_3\phi_4^*\right\}$$

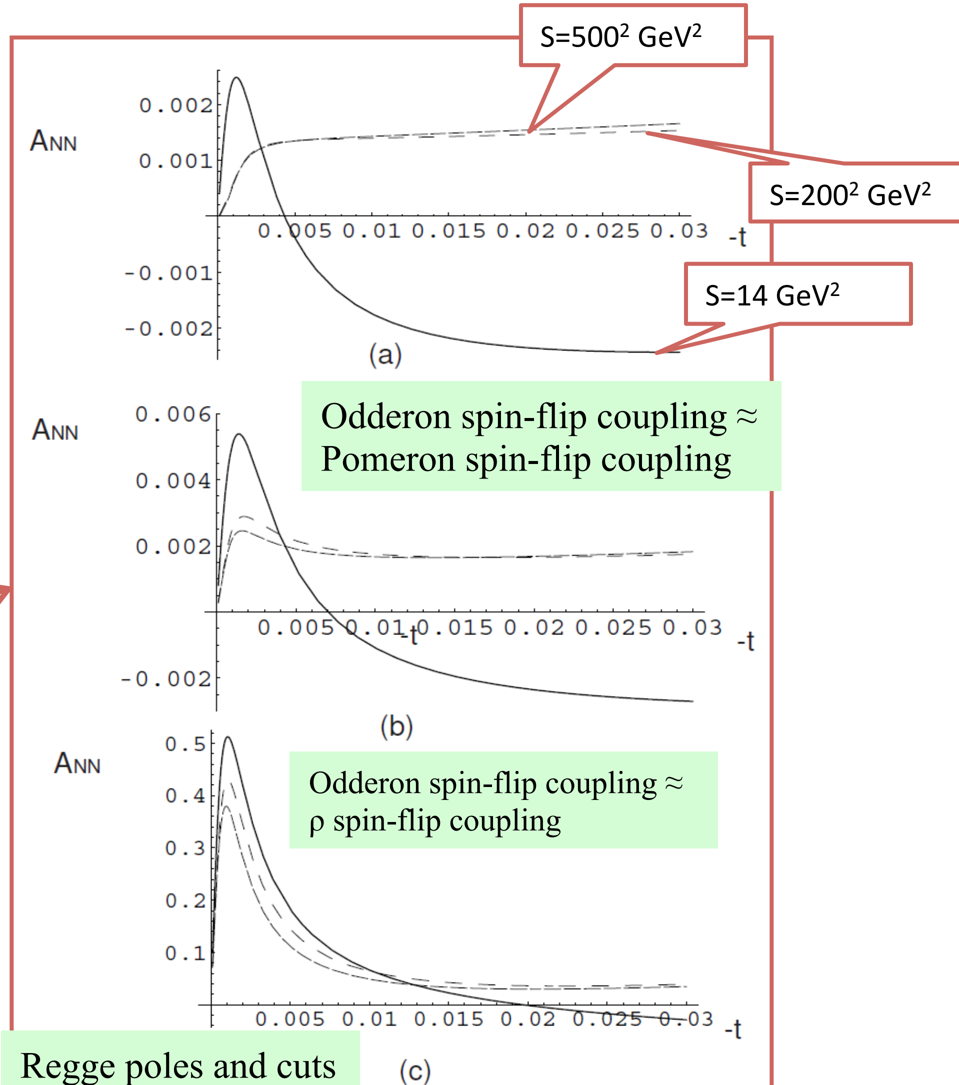
Probing Odderon in polarized pp elastic scattering

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}

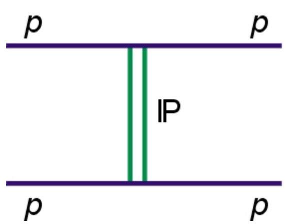
T.L.Trueman
"Double-spin asymmetry in elastic proton-proton scattering as a probe for the Odderon",
arXiv:hep-ph/0604153v1 (2006)

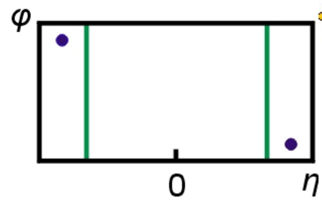




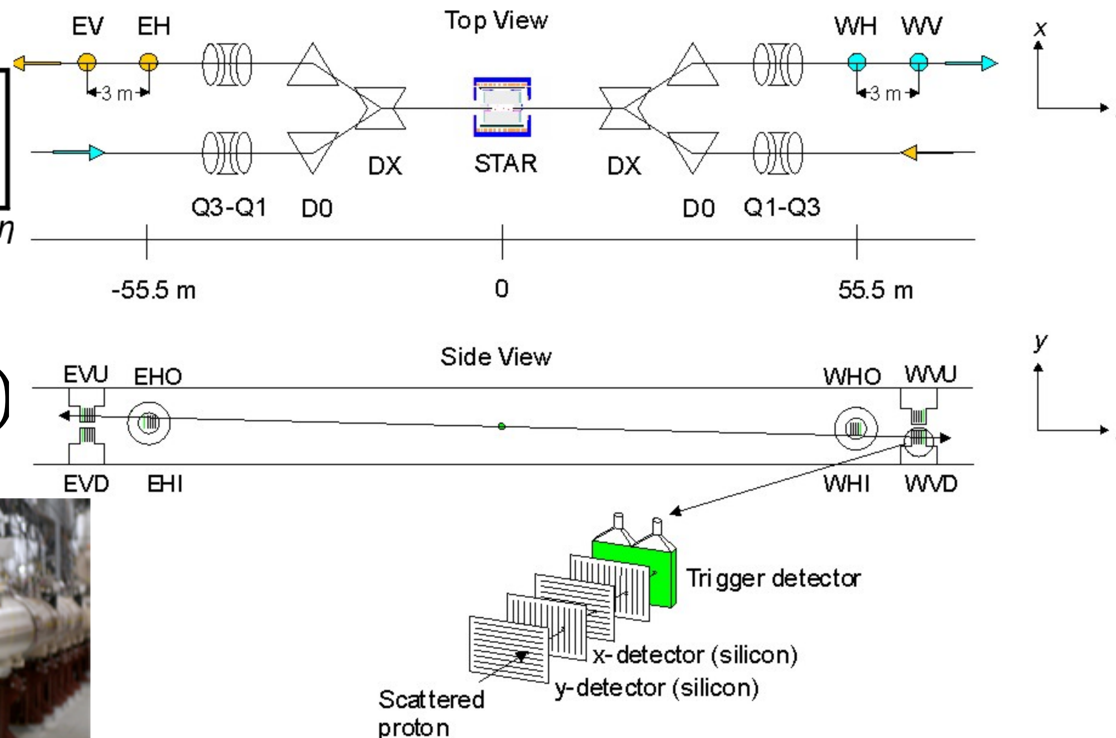
RPs at STAR – small t setup

Vertical AND Horizontal RP setup for a complete ϕ coverage





Two separate beam lines



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

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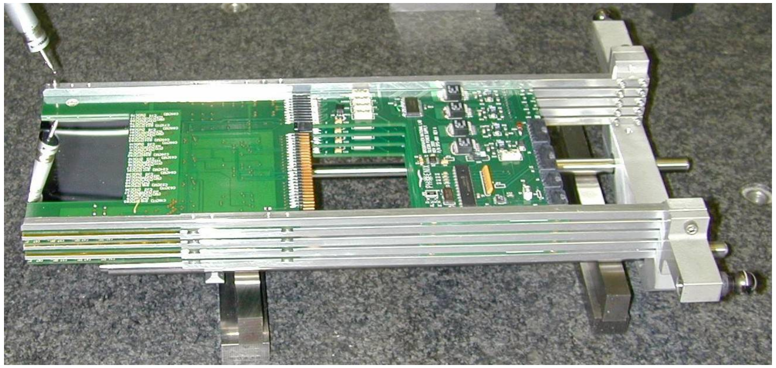
The Setup: few pictures

Roman Pot station in RHIC tunnel



Roman Pot and Si detector package

Experimental Conditions for this Data Set

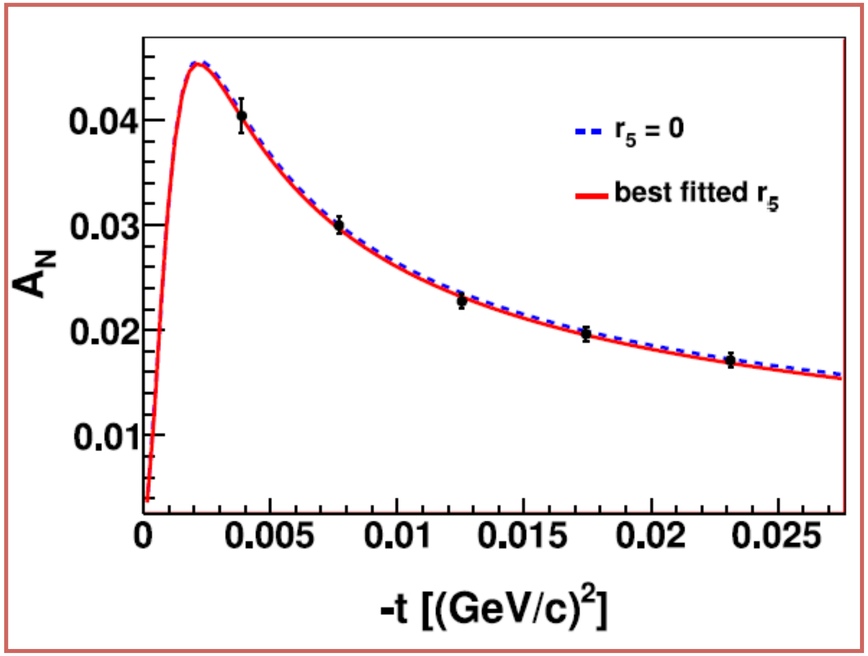
- Both beams were transversely polarized with 60% polarization.
- Excellent detector performance – nearly 100% efficiency and only 5 dead/noisy strips per ~14000 active strips.
- 2π acceptance in φ.
- Ideal optics β^*= 21m and terms other than L_{EFF} in the transport matrix were very small.
- $0.003 < -t < 0.03$
- 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



$\phi_1(s,t) \propto \langle ++ | M | ++ \rangle \leftarrow$ **non – flip**

$\phi_2(s,t) \propto \langle ++ | M | -- \rangle \leftarrow$ **double – flip**

$\phi_3(s,t) \propto \langle +- | M | +- \rangle \leftarrow$ **non – flip**

$\phi_4(s,t) \propto \langle +- | M | -+ \rangle \leftarrow$ **double – flip**

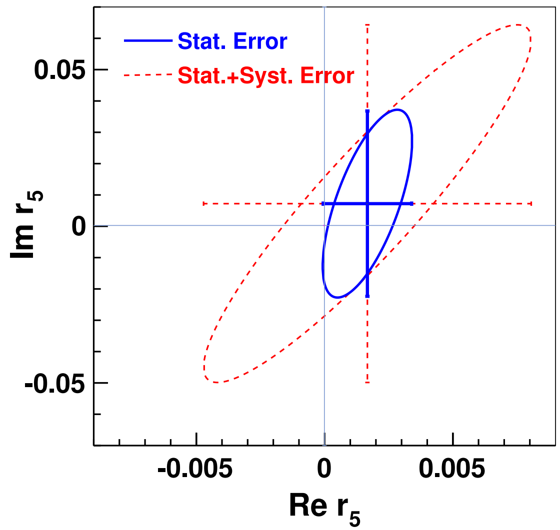
$\phi_5(s,t) \propto \langle ++ | M | +- \rangle \leftarrow$ **single – flip**

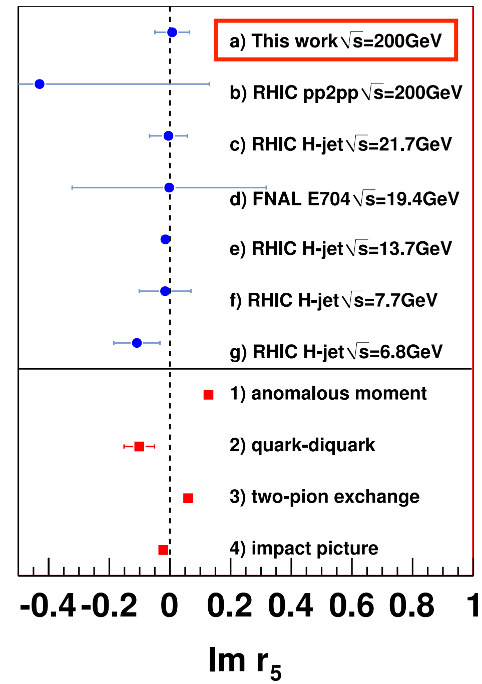
$$A_N = \frac{\sigma^{\uparrow}(t) - \sigma^{\downarrow}(t)}{\sigma^{\uparrow}(t) + \sigma^{\downarrow}(t)} = C_1 \phi_{flip}^{em\,*} \phi_{non-flip}^{had} + C_2 \phi_{flip}^{had*} \phi_{non-flip}^{em}$$

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

Result on A_N

Phys. Lett. B719 (2013) 62-69





$\mathrm{Re}\ r_5$ = 0.0017 +-0.0017 (stat.) +-0.061 (syst.)

$\mathrm{Im}\ r_5$ = 0.007 +-0.03 (stat.) +- 0.049 (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 <u>in the scattering plane</u>, 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

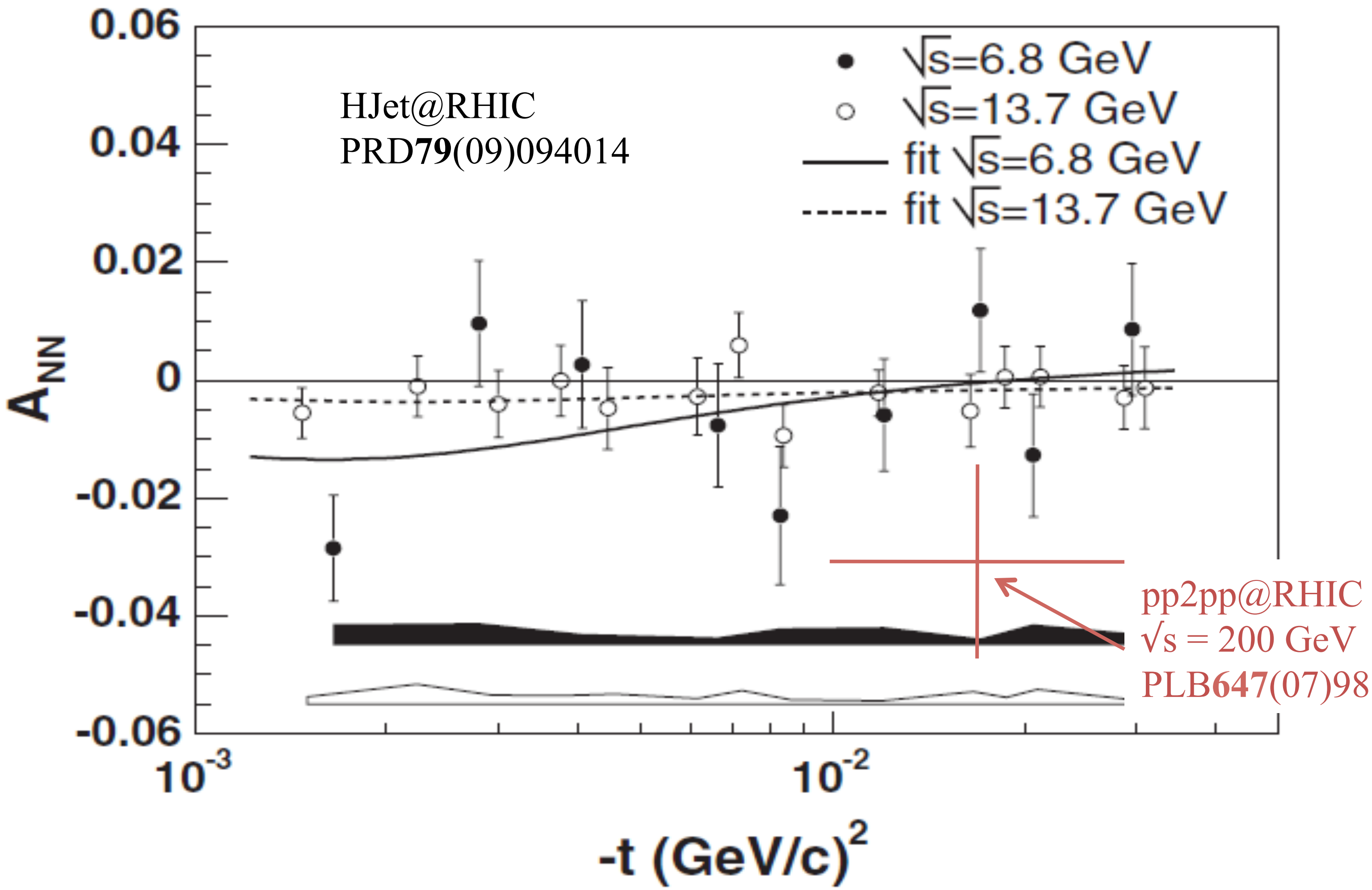
$$2\pi \frac{d^2\sigma}{dt d\varphi} = \frac{d\sigma}{dt} \cdot \left(1 + (P_B + P_Y) A_N \cos\varphi + P_B P_Y (A_{NN} \cos^2\varphi + A_{SS} \sin^2\varphi)\right)$$

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

No angle dependence

Luminosity normalization required to obtain ε(ϕ)

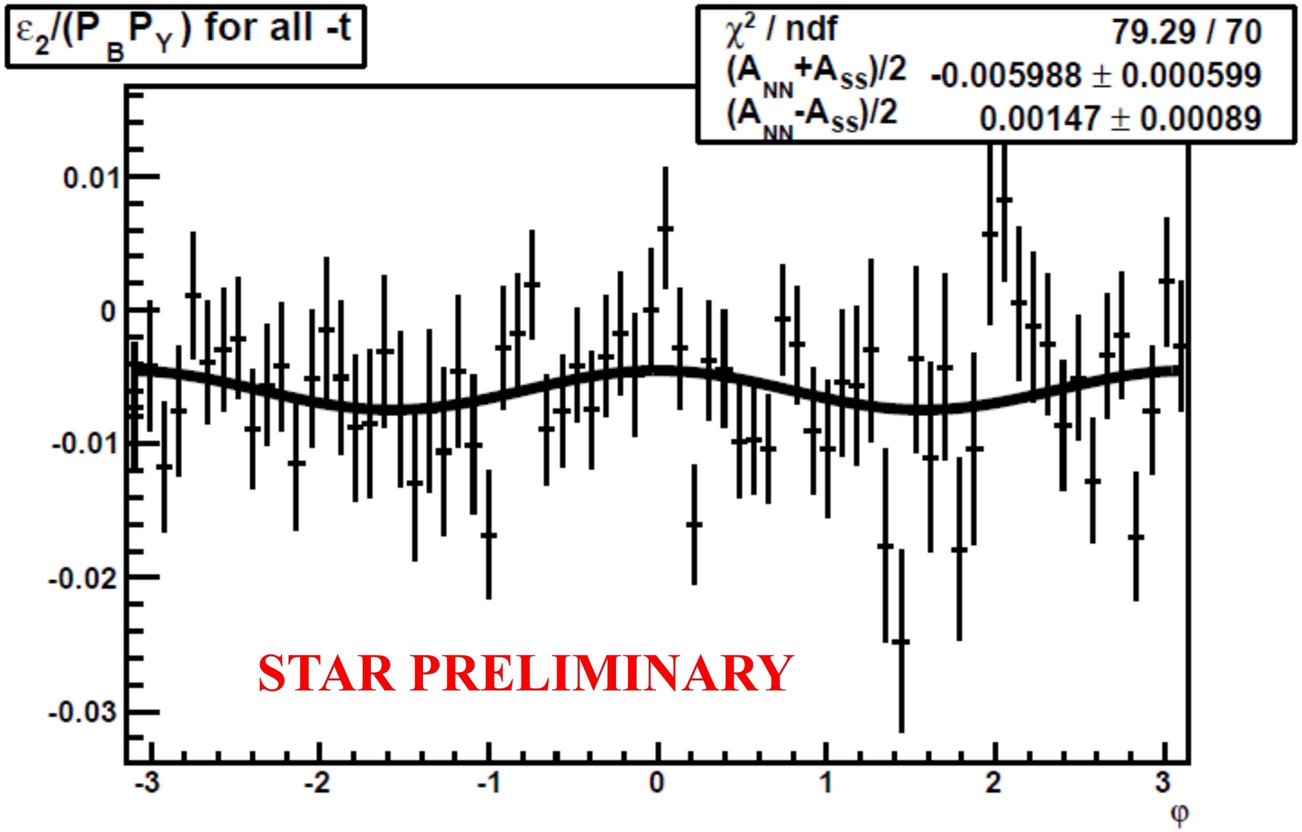
A_{NN} – Existing data



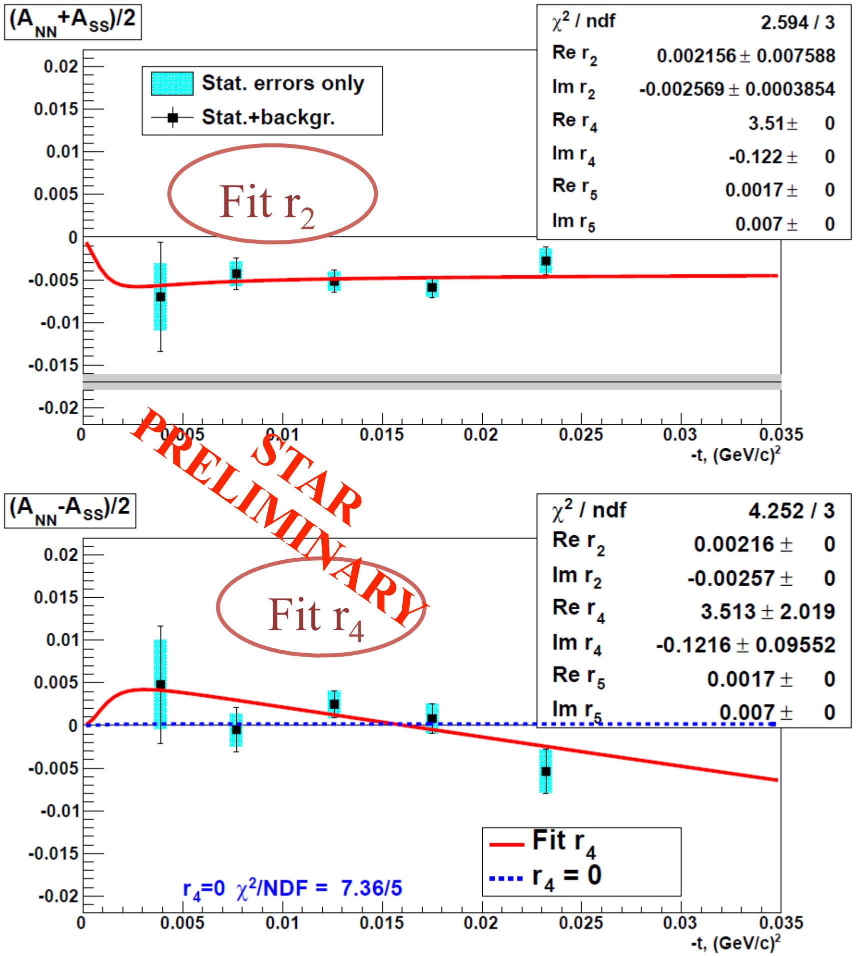
Raw Double Spin Asymmetry

K^{ij} Luminosity normalized counts

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

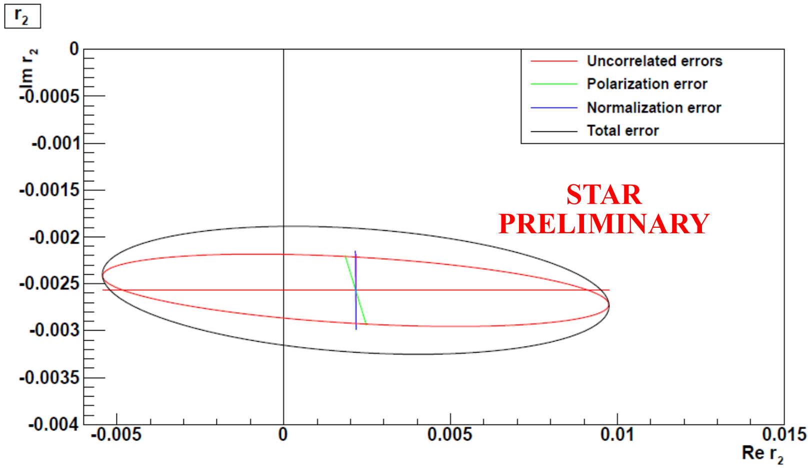


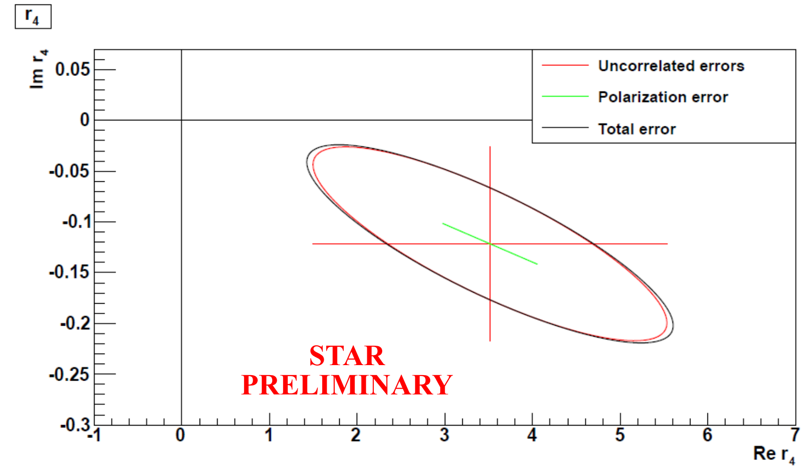
A_{NN} result



- 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: r_2 and r_4





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

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

$$r_2 = \frac{\phi_2^{had}}{2\,\mathrm{Im}\,\phi_+^{had}} \qquad r_4 = -\frac{m_p^2\phi_4^{had}}{t\,\mathrm{Im}\,\phi_+^{had}}$$

- Im r_2 is well constrained – small negative value
- Re r_2 is compatible 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 is compatible 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 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.