Preliminary Result of A_N Measurement in $p^{\uparrow}p^{\uparrow}$ Elastic Scattering at RHIC, at $\sqrt{s}$ = 200 GeV

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OUTLINE of the TALK

- Description of the experiment
- Description of analysis
- Results and interpretation
- Where do we go from here?

Total and Differential Cross Sections, and Polarization Effects in pp Elastic Scattering at RHIC

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RHIC/AGS Users Mtg.
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Spin Dependence in Elastic Scattering

Five helicity amplitudes describe proton-proton elastic scattering

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

$$\phi_i(s,t) = \phi_i^{em}(s,t) + \phi_i^{had}(s,t)$$
$$\phi_+ = \tfrac{1}{2}(\phi_1 + \phi_3)$$
$$\phi_- = \tfrac{1}{2}(\phi_1 - \phi_3)$$
$$\phi_i^{had} = \phi_i^R + \phi_i^{Asympt.}$$

Some of the measured quantities are:

$$\sigma_{\boldsymbol{tot}}(s) = \frac{4\pi}{s}\mathrm{Im}\left[\phi_+(s,t)\right]_{t=0}, \text{ where } \sigma_{tot} \text{ gives } s \text{ dependence of } \phi_+$$

$$\frac{d\sigma}{dt} = \frac{2\pi}{s^2}(|\phi_1|^2 + |\phi_2|^2 + |\phi_3|^2 + |\phi_4|^2 + 4|\phi_5|^2) \text{ contributes to the shape of } A_N$$

$$\boldsymbol{A_N = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}}$$

Source of single spin analyzing power A_N

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.

Any difference from the above is an indication if other contributions, hadronic spin flip caused by resonance (Reggeon) or vacuum exchange (Pomeron) contributions.

B. Z. Kopeliovich and L. I. Lapidus Sov. J. Nucl. Phys. 114 (19) 1974

N. H. Buttimore, B. Z. Kopeliovich, E. Leader, J. Soffer, T. L. Trueman, Phys. Rev. **D59**, (1999) 114010.

$$A_N(t) = \frac{\sigma^{\uparrow}(t) - \sigma^{\downarrow}(t)}{\sigma^{\uparrow}(t) + \sigma^{\downarrow}(t)} \propto \frac{\mathrm{Im}[\varphi_5^{*}\Phi_+]}{d\sigma/dt}$$

$$r_5 = \Re e_5 + i\Im m_5 = \frac{m\phi_5}{\sqrt{-t}\,\mathrm{Im}\phi_+};\ \tau = -r_5(i+\rho)$$

Experimental Determination of A_N

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

Use *Square-Root-Formula* to calculate spin ($\uparrow\uparrow$, $\downarrow\downarrow$) and false asymmetries ($\uparrow\downarrow$, $\downarrow\uparrow$) .

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

Asymmetry

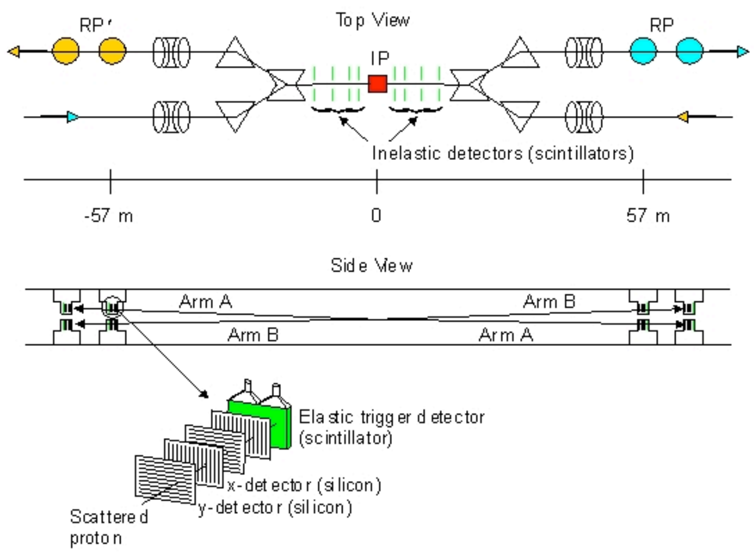
$$\varepsilon_F(\varphi) = \frac{(P_1 - P_2)\cos\varphi \cdot A_N}{1-\delta} = \frac{\sqrt{N_L^{\uparrow\downarrow}(\varphi) N_R^{\downarrow\uparrow}(\pi-\varphi)} - \sqrt{N_R^{\uparrow\downarrow}(\pi-\varphi) N_L^{\uparrow\downarrow}(\varphi)}}{\sqrt{N_L^{\uparrow\downarrow}(\varphi) N_R^{\downarrow\uparrow}(\pi-\varphi)}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

"False" Asymmetry

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

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

Principle of the Measurement



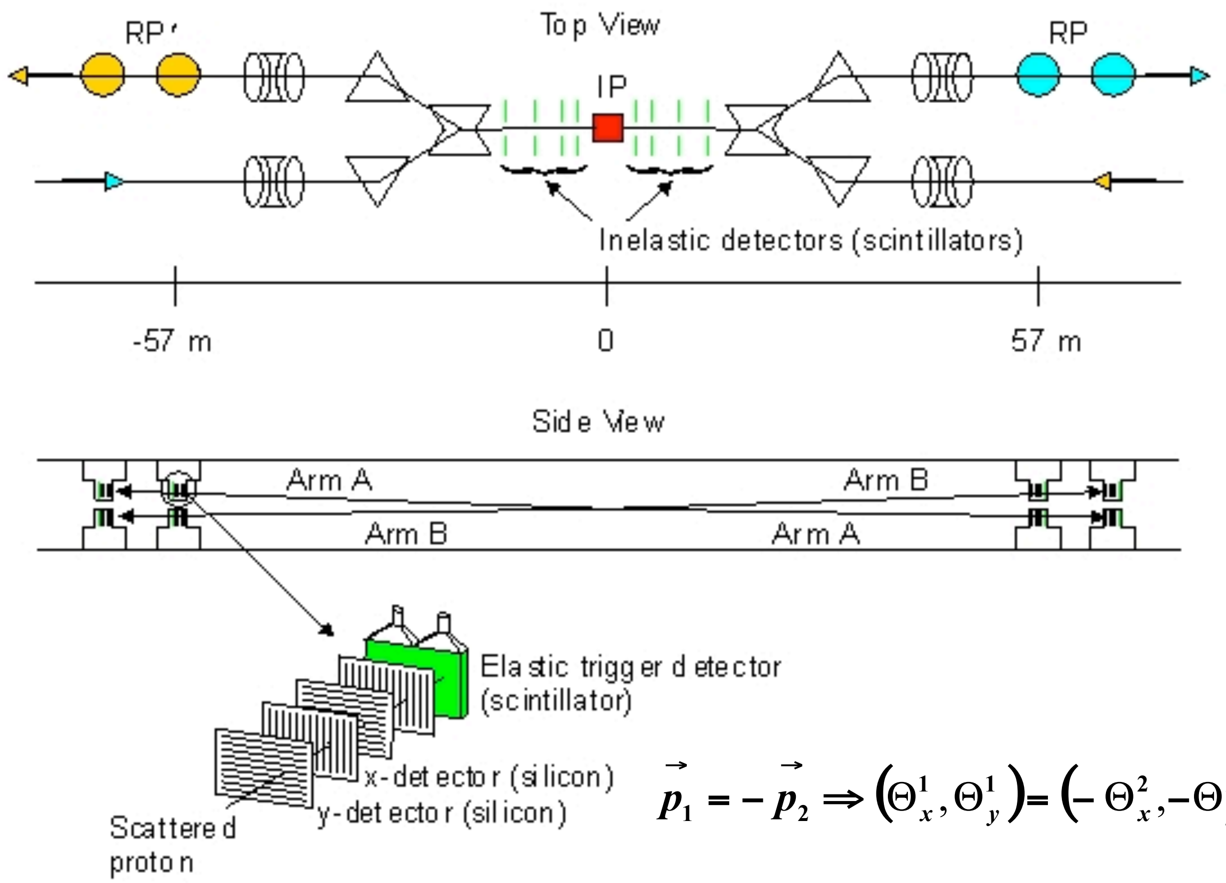
- Elastically scattered protons have very small scattering angle θ^*, hence beam transport magnets determine trajectory scattered protons
- The optimal position for the detectors is where scattered protons are well separated from beam protons
- Need Roman Pot to measure scattered protons close to the beam without breaking accelerator vacuum

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

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

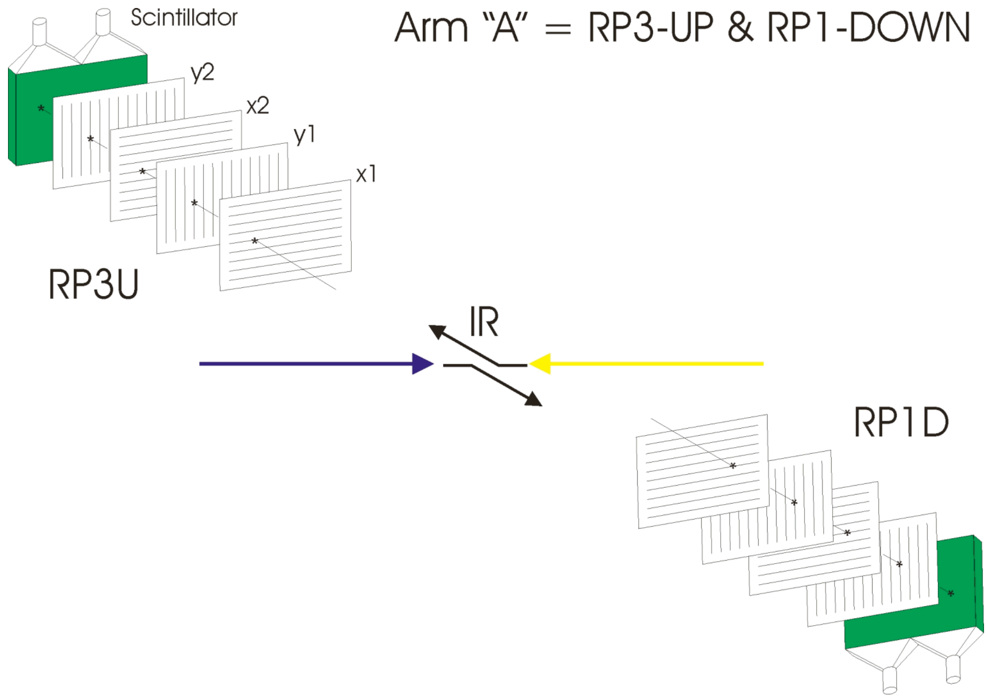
x_0,y_0: Position at Interaction Point
Θ^*_x Θ^*_y : Scattering Angle at IP
x_D, y_D : Position at Detector
Θ^x_D, Θ^y_D : Angle at Detector

The Setup



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

Elastic Event Identification

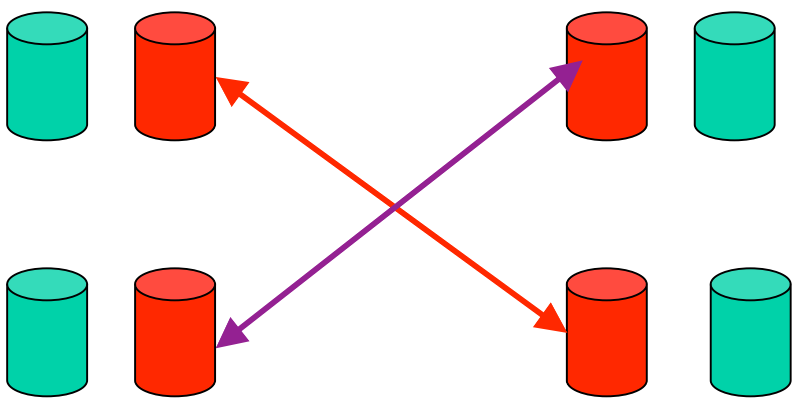


An elastic event has two collinear protons, one on each side of IP

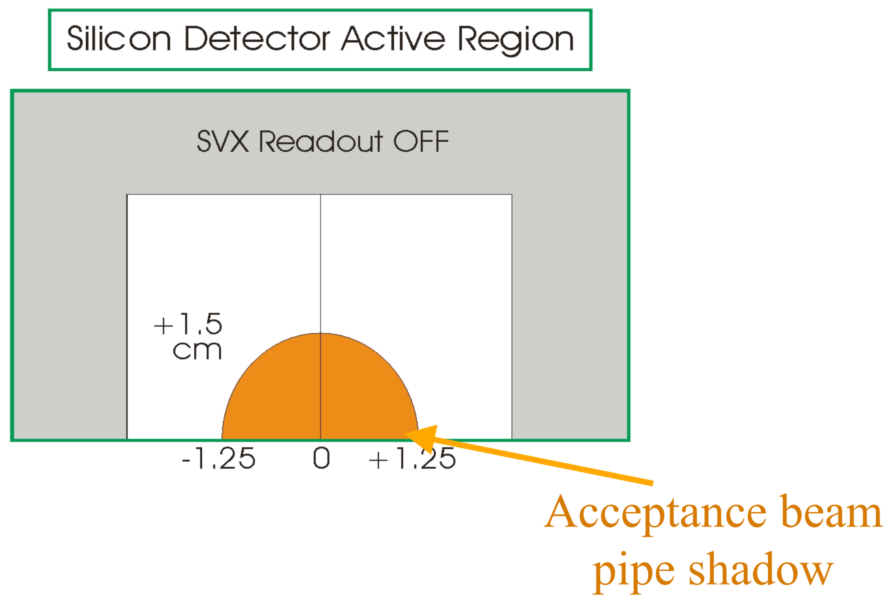
$$\vec{p}_1 = -\vec{p}_2 \Rightarrow \left(\Theta_x^1, \Theta_y^1\right) = \left(-\Theta_x^2, -\Theta_y^2\right)$$

1. It also has eight Si detector "hits", four on each side.
2. Clean trigger: no hits in the other arm and in inelastic counters.
3. The vertex in (z_0) can be reconstructed using ToF.

Trigger



Active area



Only “inner” pots used for trigger and analysis, biggest acceptance

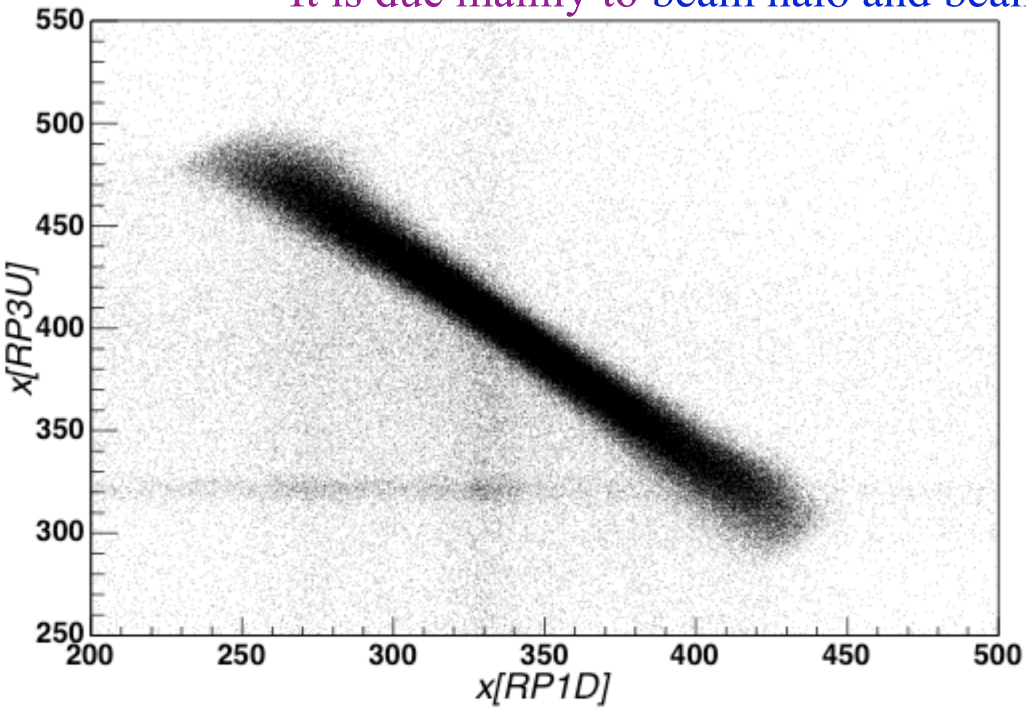
Analyze the data for the closest position (¾ of all data)

Hit Correlations Before the Cuts

Events with only eight hits

Note: the background appears enhanced because of the "saturation" of the main band

It is due mainly to beam halo and beam-gas interactions



Width is mainly due to

beam emittance

$\epsilon = 15\,\pi$ mm · mrad

spread of vertex position

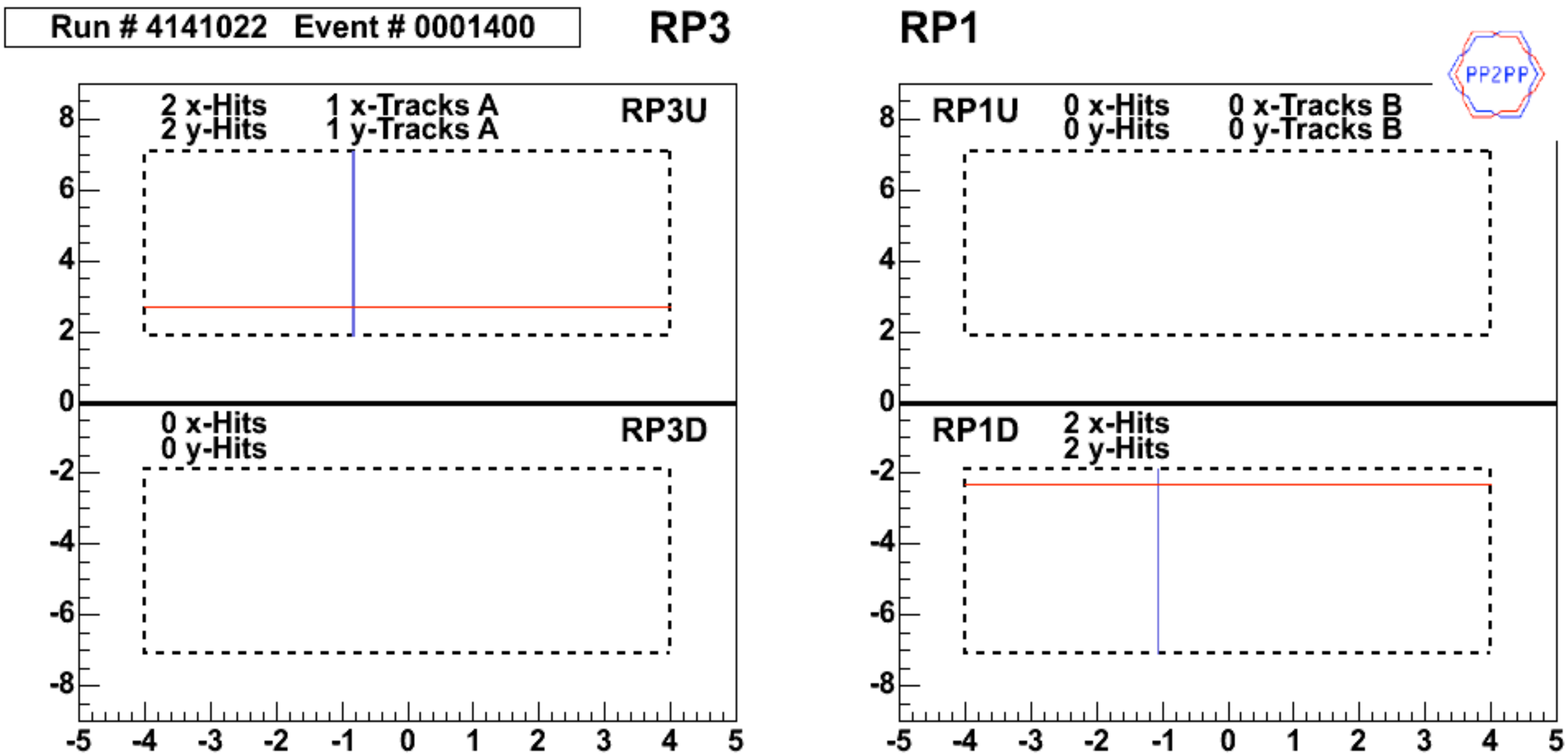
$\sigma_z = 60$ cm

After the cuts the background in the final sample is $\approx 0.5\% \div 2\%$ depending on *y* (vertical) coordinate

Hit selection

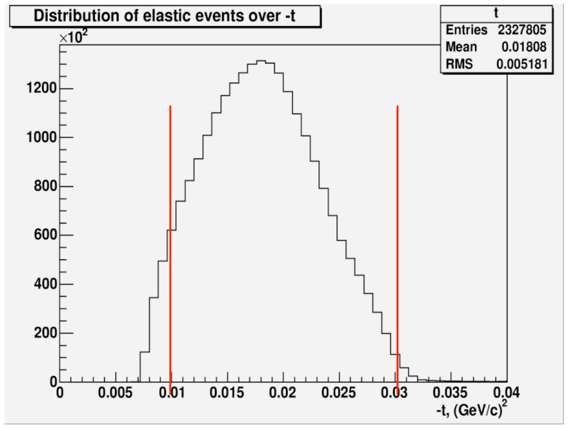
1. Pedestal value, pedestal width (σ) and dead channels (only six) were determined;
2. Valid hit, single strip, has $dE/dx > 5\sigma$ above the pedestal;
3. Cluster size is ≤ 5 consecutive strips above pedestal cut;
4. Valid hit in the Si plane for event reconstruction:
   - is a cluster whose $dE/dx > 20$ ADC counts above pedestal and
   - is within fiducial area of the detector (slide);
   - has for a y-plane $y > 0.2$mm from the edge of the detector.
5. Coordinate for x and y formed from adjacent hits in Sin for each Roman Pot

Elastic Events



Elastic Event Selection III

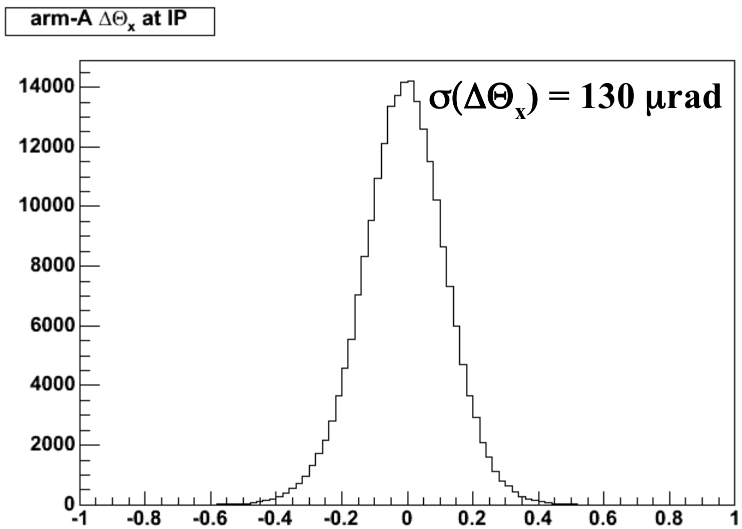
1. Match of coordinates on opposite sides of IP; within 3σ for x and y coordinates.
2. Hit coordinates to be in the acceptance area of the detector.
3. Events with multiple matches were excluded.

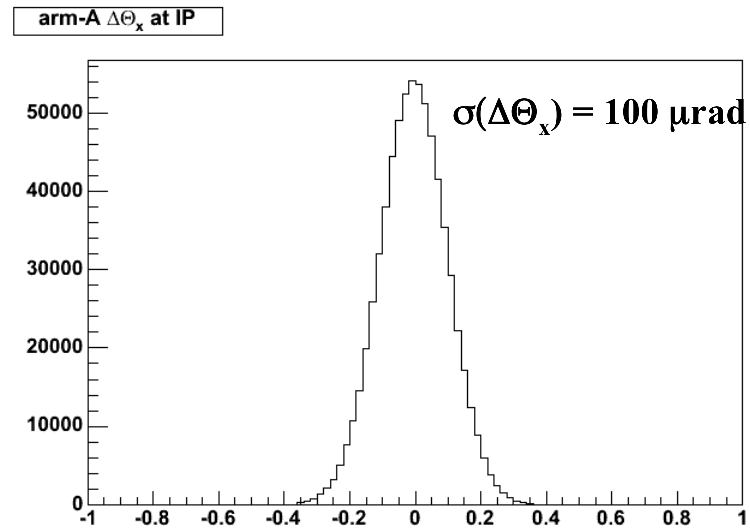


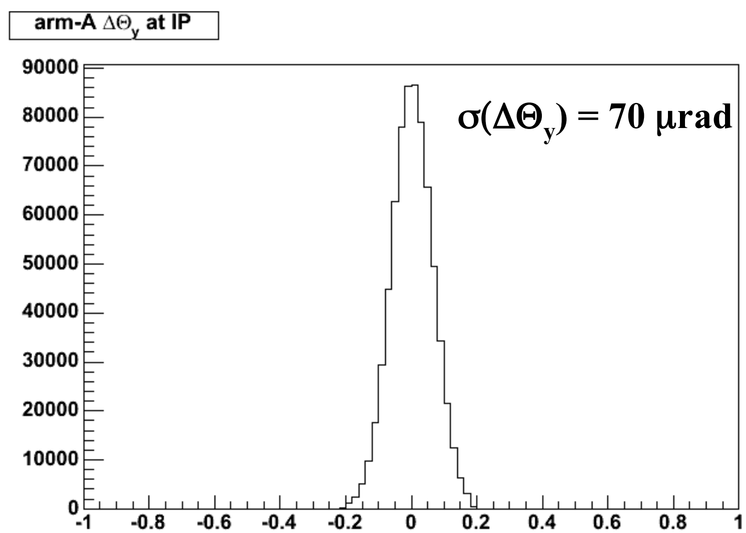
After the cuts 1.14 million elastic events in t-interval [0.010, 0.030] $(\text{GeV/c})^2$

Loss of elastic events due to the selections < 0.035

Collinearity: $\Delta\Theta_x$ before and after z-correction, and $\Delta\Theta_y$







Determination of A_N

Use *Square-Root-Formula* to calculate raw asymmetries.

1. It cancels cancel luminosity dependence and effects of apparatus asymmetries.
2. It uses ↑↑, ↓↓ bunch combinations.

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

Asymmetry

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

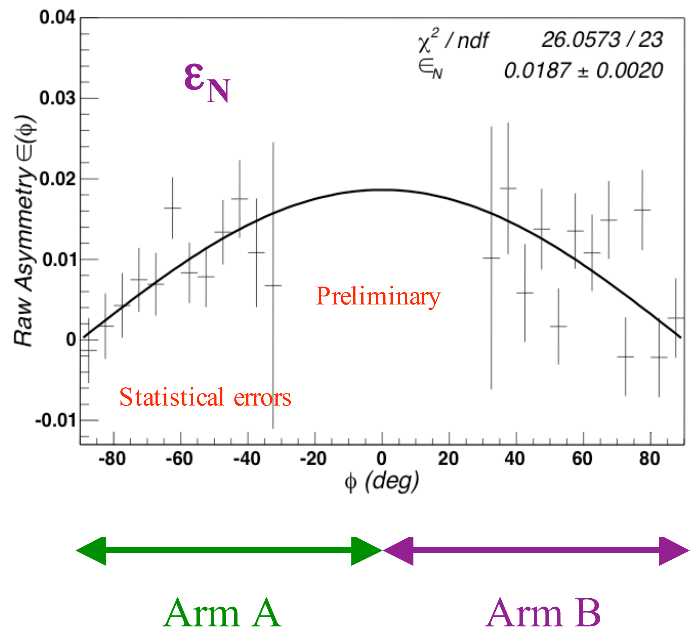
Since A_N is a relative measurement the efficiencies $\alpha(t, \phi)$ cancel

Preliminary Results: Full bin $0.01 < -t < 0.03$ $(GeV/c)^2$

Fit $\varepsilon_N \cos(\varphi)$ dependence to obtain A_N

$P_Y(++,--)=0.345 \pm 0.0734$

$P_B(++,--)=0.532 \pm 0.0988$



Polarization values are working numbers

$P_Y(+-,-+)=0.430 \pm 0.084$

$P_B(+-,-+)=0.479 \pm 0.089$

Note: The calculated false asymmetry $\varepsilon_F = -0.0011$ is consistent with measured $\varepsilon_F = -0.0016$

Systematic Errors on A_N

luminosities ans detector efficiencies cancel	----
background	4.5%
beam positions at the detectors	1.8%
corrections to the standard transport matrices	1.4%
uncertainties on L^x_{eff} and L^y_{eff}	6.4%
neglected term with double-spin asymmetries	2.8%
All above	8.4%
Beam polarization error (systematic 13% + statistical)	16.6%

A_N for $pp \rightarrow pp$ in the CNI Region

$$A_N(t) = \frac{\sqrt{-t}}{m} \frac{Nom}{Denom}$$

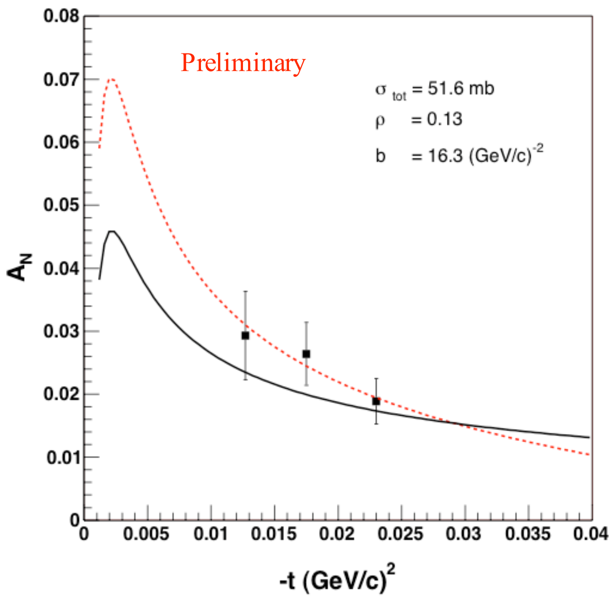
$$Nom = [\kappa(1 - \rho\,\delta) + 2(\delta\,\mathrm{Re}\,r_5 - \mathrm{Im}\,r_5)\,]\,\frac{t_c}{t} - 2(\mathrm{Re}\,r_5 - \rho\,\mathrm{Im}\,r_5)$$

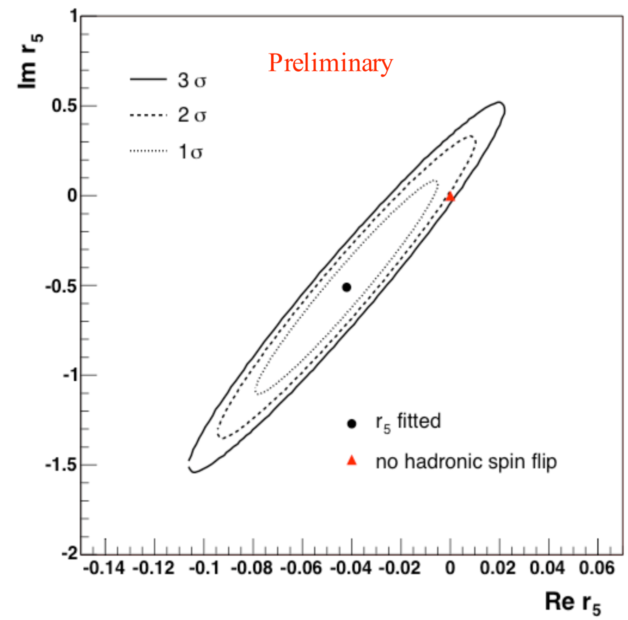
$$Denom = \left(\frac{t_c}{t}\right)^2 - 2(\rho + \delta)\frac{t_c}{t} + \left(1 + \rho^2\right)$$

where $t_c = -8\pi\alpha / \sigma_{tot}$ and κ is anomalous magnetic moment of the proton

The fit to measured $A_N(t)$ gives Re r_5 , Im r_5

Preliminary Results: A_N and r_5





Re r_5 = -0.042 ± 0.037 , Im r_5 = -0.51 ± 0.60

Statistical and systematic errors added in quadratures

16.6% normalisation error due to beam polarisation uncertainty, not included

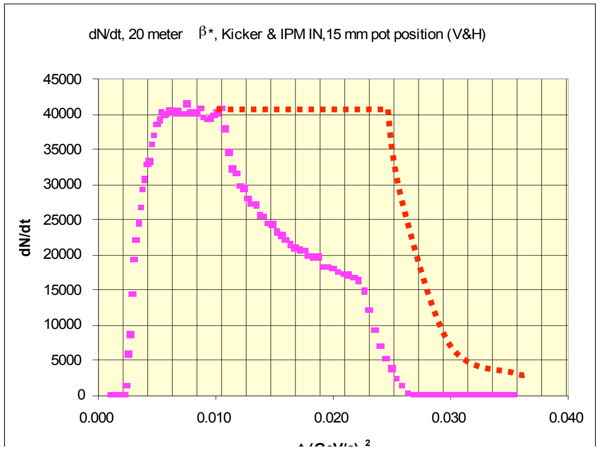
Summary

1. **We have measured the single spin analyzing power A_N in polarized pp elastic scattering at $\sqrt{s}$ = 200 GeV, highest to date, in t-range [0.01,0.03] $(GeV/c)^2$.**
2. **The A_N is ≈ 4-5σ from zero (statistical error.)**
3. **The A_N is ≈ σ away from a CNI curve, which does not have hadronic spin flip amplitude.**
4. **In order to understand better underlying dynamics one needs to map $\sqrt{s}$ and t-dependence of A_N and also measure other spin related variables (A_{NN}, A_{SS}, A_{LL}, A_{SL}).**

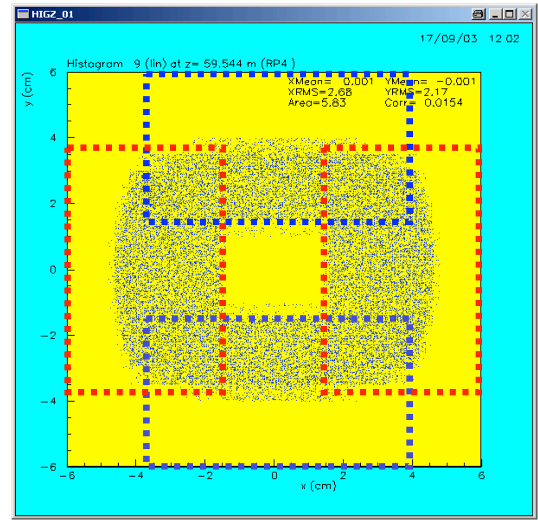
RHIC is a unique place to directly probe spin coupling of Pomeron and search for and Odderon.

Future Possibility – Big Improvement

dN/dt



x-y



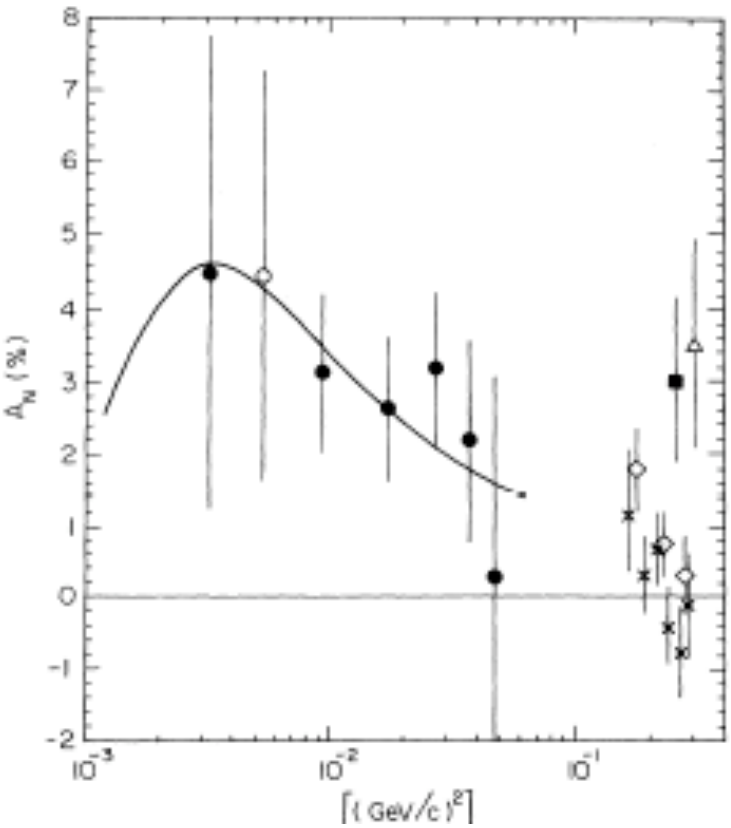
Full acceptance at √s 200 GeV

Without IPM and kicker

With IPM and kicker

√s (GeV)	β^*	|t|-range (Gev/c)^2	Typical errors
200	**20 m**	**0.003 < |t| < 0.02**	**$\Delta B = 0.3$, $\Delta\sigma_{tot} = 2 - 3$ mb** **$\Delta\rho = 0.007$ and $\Delta A_N = 0.002$**

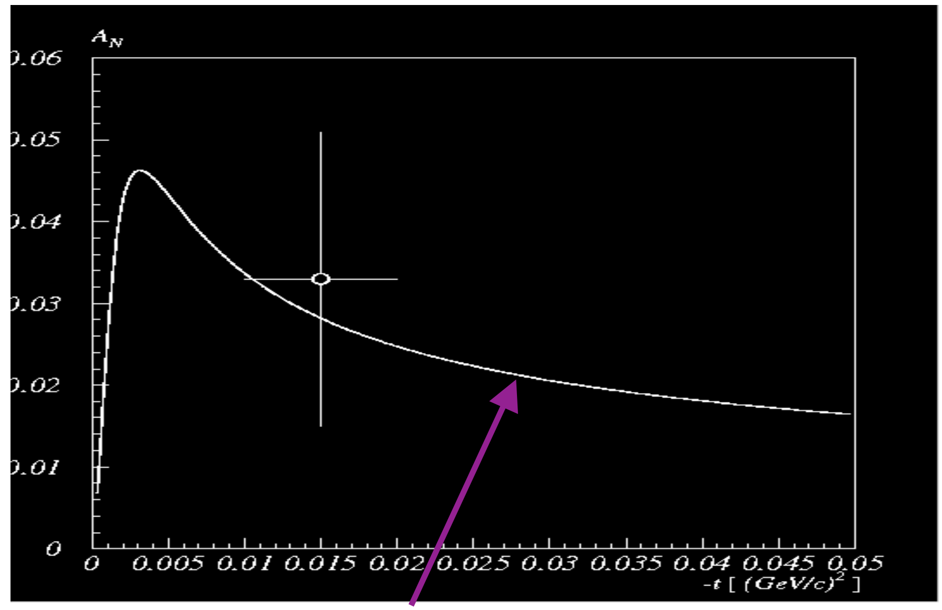
The world data on A_N (pp)



FNAL E704 • $\sqrt{s} \approx 20$ GeV

N. Akchurin *et al.* PRD 48, 3026 (1993)

pp2pp Preliminary run 2002 A_N = 0.033 ± 0.018



CNI curve

N.H. Buttimore *et al*. PRD 59,114010 (1999)

RHIC/AGS Measurements

E950 elastic pC

J. Tojo *et al*. PRL 89, 052302 (2002)

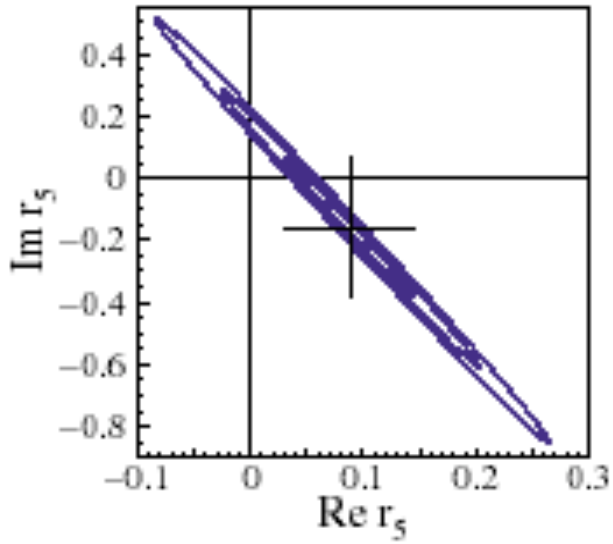


FIG. 4 (color online). Ratio of hadronic spin-flip to nonflip amplitude, r_5, and the 1-, 2-, and 3-sigma contours of χ^2.

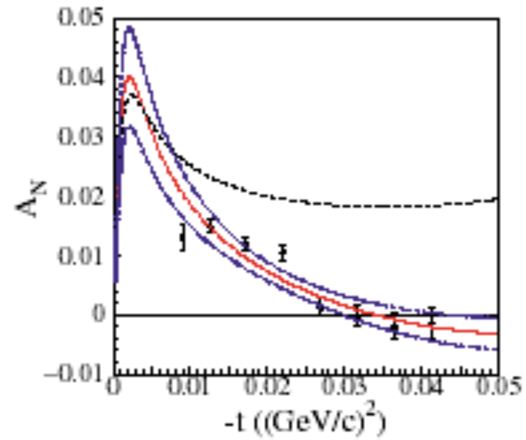


FIG. 3 (color online). The analyzing power, $\mathcal{A}_N$, for pC elastic scattering in the CNI region. The error bars on the data points are statistical only. The solid line is the fitted function from theory [4]. The dotted lines are the 1-sigma error band of the fitting result. The dashed line is the theoretical function with no hadronic spin-flip amplitude ($r_5 = 0$).

There are also be results from polarized jet at RHIC