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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Spin Dependence in Elastic Scattering

Five helicity amplitudes describe proton-proton elastic scattering

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

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

Some of the measured quantities are

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

σ_{tot} of gives s dependence of ϕ_+

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

Contributes to the shape of A_N

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*.

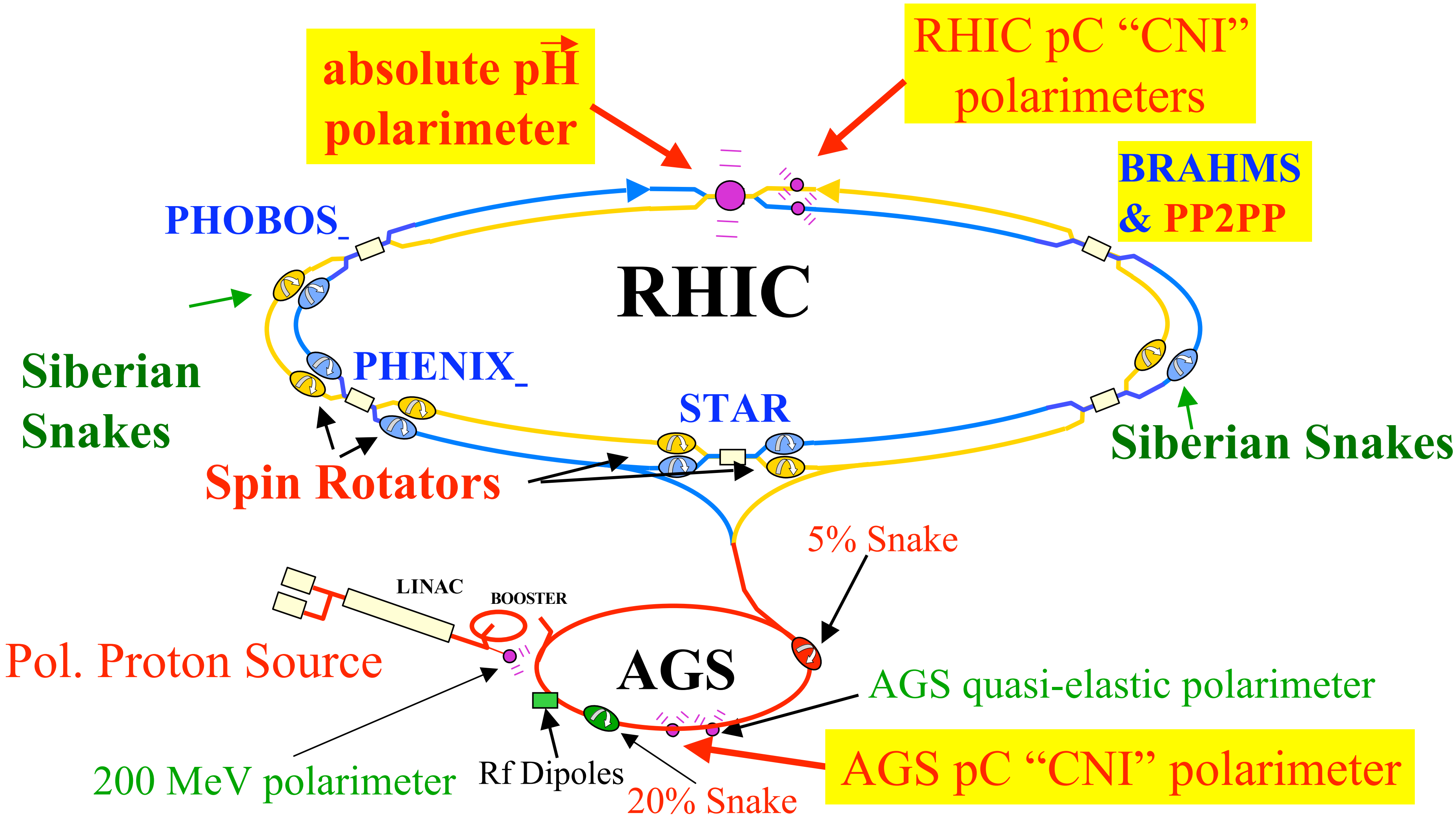
Any difference from the above is an indication of other contributions, hadronic spin flip caused by resonance (Reggeon) or vacuum exchange (Pomeron) contributions.

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

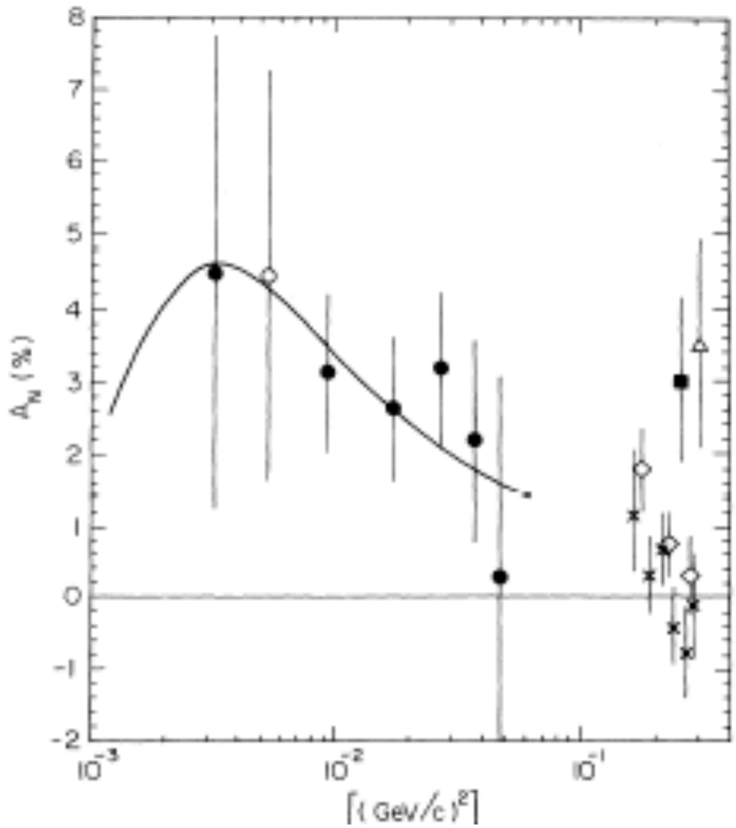
$$A_N(t,\varphi) \propto \frac{\mathrm{Im}[\varphi_5^* \Phi_+]}{d\sigma / dt}$$

$$r_5 = \mathrm{Re}\, r_5 + i\,\mathrm{Im}\, r_5 = \frac{m\phi_5}{\sqrt{-t}\,\mathrm{Im}\,\phi_+}$$

RHIC-Spin Accelerator Complex



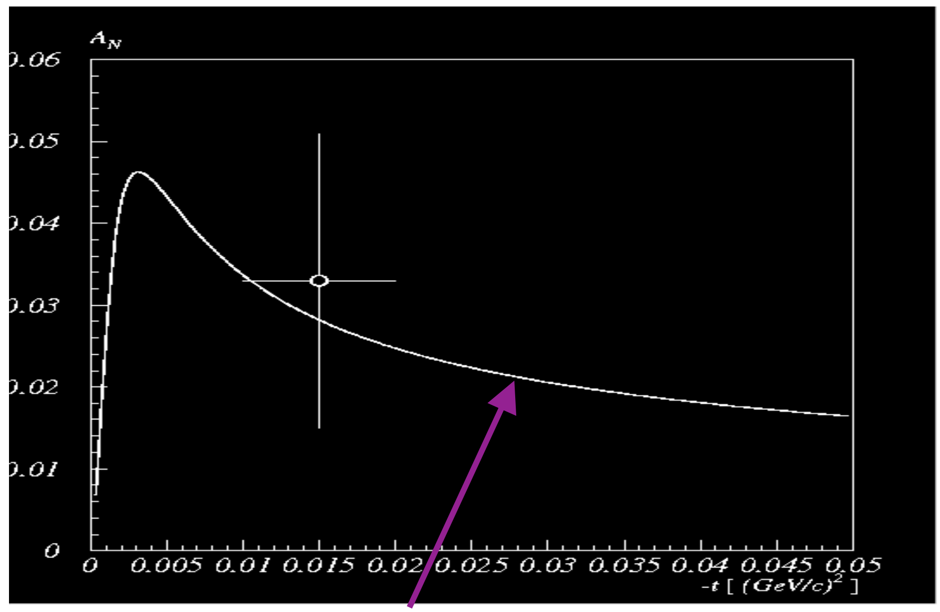
The world data on A_N (pp) in CNI Region



FNAL E704 • √s ≈ 20 GeV

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

Preliminary 2002



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)

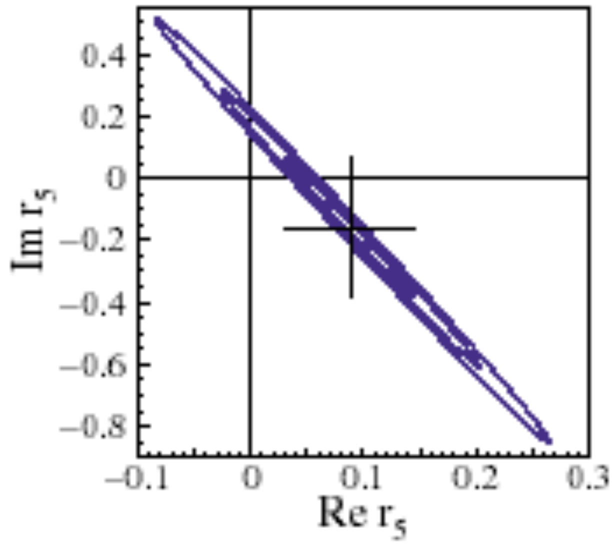


FIG. 4 (color online). Ratio of hadronic spin-flip to nonflip amplitude, r_5, and the 1-, 2-, and 3-sigma contours of χ^2.

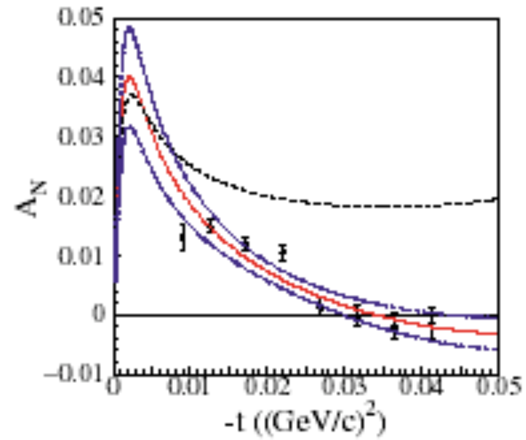


FIG. 3 (color online). The analyzing power, $\mathcal{A}_N$, for pC elastic scattering in the CNI region. The error bars on the data points are statistical only. The solid line is the fitted function from theory [4]. The dotted lines are the 1-sigma error band of the fitting result. The dashed line is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

There will also be results from polarized jet at RHIC

Experimental Determination of A_N

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

This formula cancels luminosity dependence and apparatus asymmetries.

For given t:

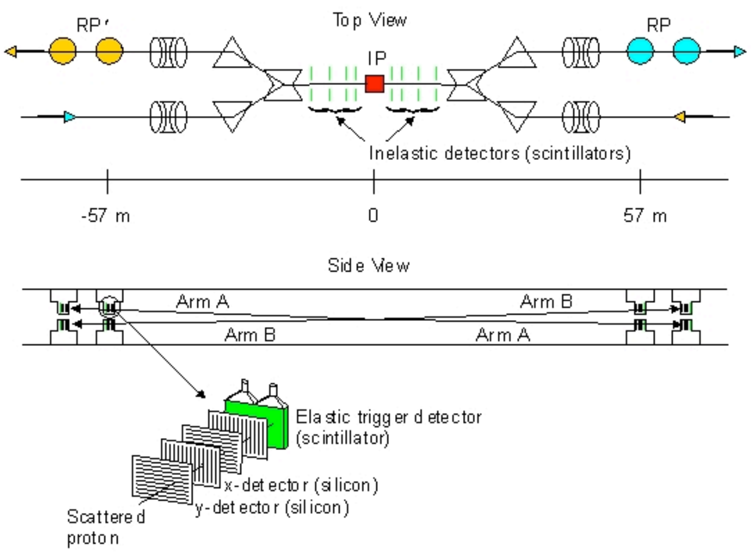
$$A_N(\varphi) = \frac{1}{(P_1 + P_2)\cos\varphi} \frac{\sqrt{N_L^{\uparrow\uparrow} N_R^{\downarrow\downarrow}} - \sqrt{N_R^{\uparrow\uparrow} N_L^{\downarrow\downarrow}}}{\sqrt{N_L^{\uparrow\uparrow} N_R^{\downarrow\downarrow}} + \sqrt{N_R^{\uparrow\uparrow} N_L^{\downarrow\downarrow}}} (1 + \delta)$$

Where :

$$\delta = \mathrm{A}_{\mathrm{NN}} \mathrm{P}_1 \mathrm{P}_2 \langle \cos\varphi \rangle^2 + \mathrm{A}_{\mathrm{SS}} \mathrm{P}_1 \mathrm{P}_2 \langle \sin\varphi \rangle^2 \approx 0.03 \text{ is small}$$

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

Principle of the Measurement



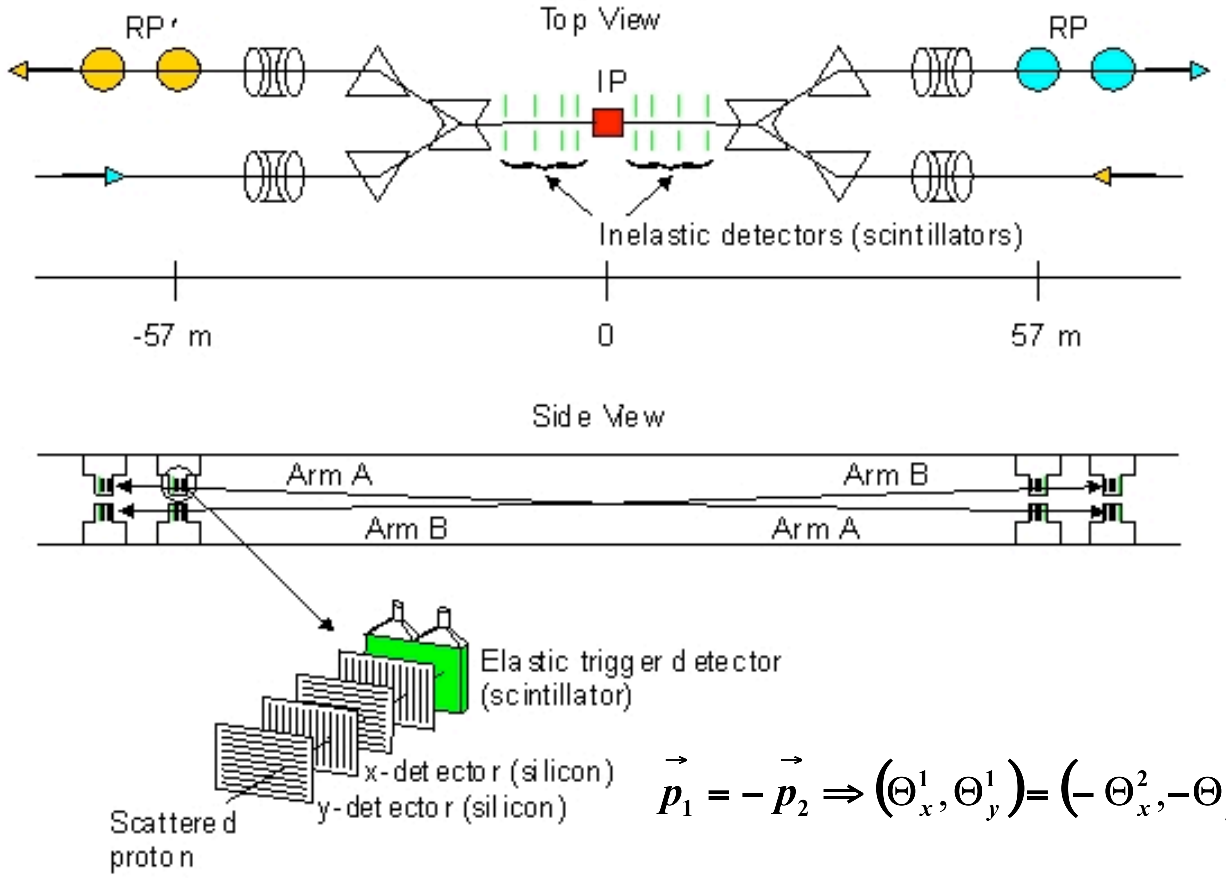
- Elastically scattered protons have very small scattering angle θ^*, hence beam transport magnets determine trajectory scattered protons
- The optimal position for the detectors is where scattered protons are well separated from beam protons
- Need Roman Pot to measure scattered protons close to the 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
$\Theta^x{}_D$, $\Theta^y{}_D$: Angle at Detector

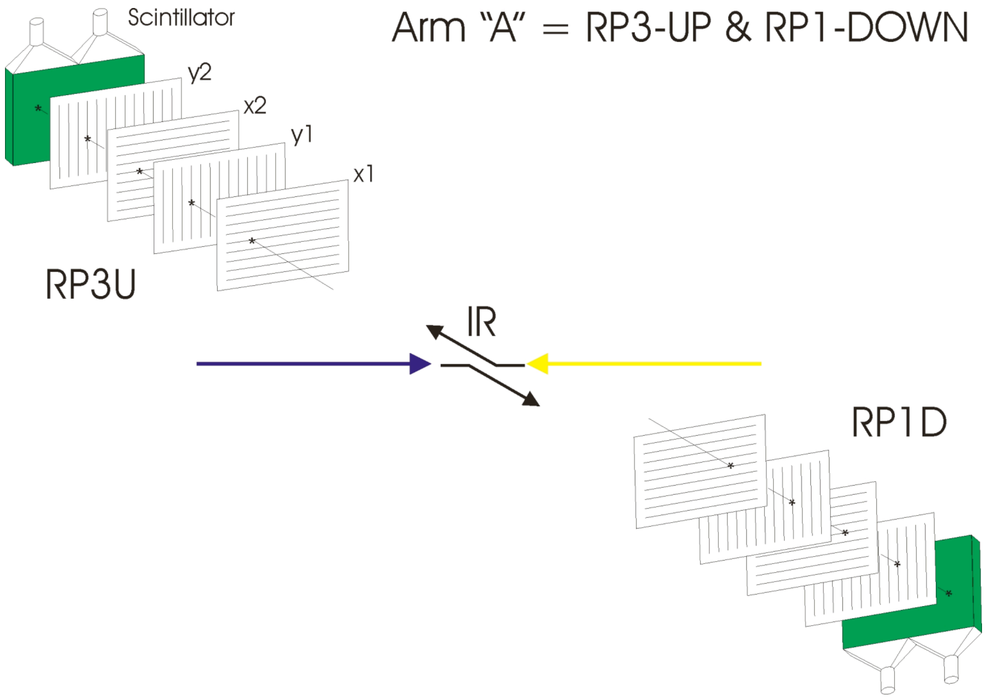
The Setup



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

Elastic Event Identification

Arm "A" = RP3-UP & RP1-DOWN

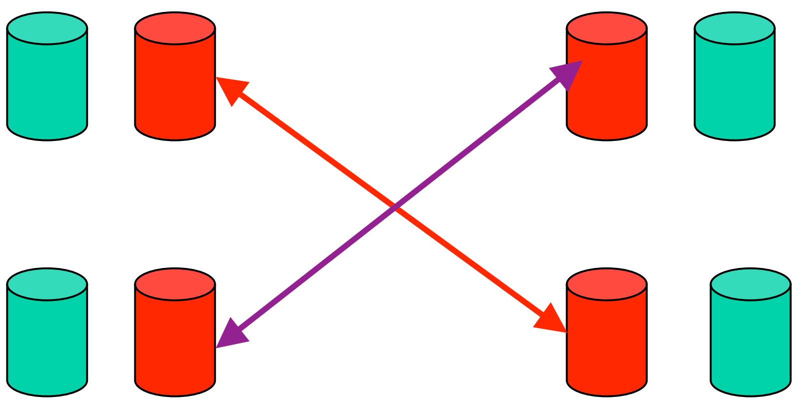


An elastic event has two collinear protons, one on each side of IP

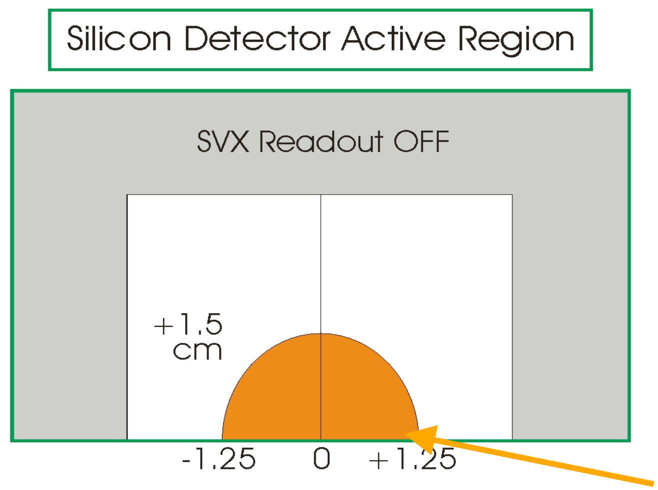
$$\vec{p}_1 = -\vec{p}_2 \Rightarrow \left(\Theta_x^1, \Theta_y^1\right) = \left(-\Theta_x^2, -\Theta_y^2\right)$$

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



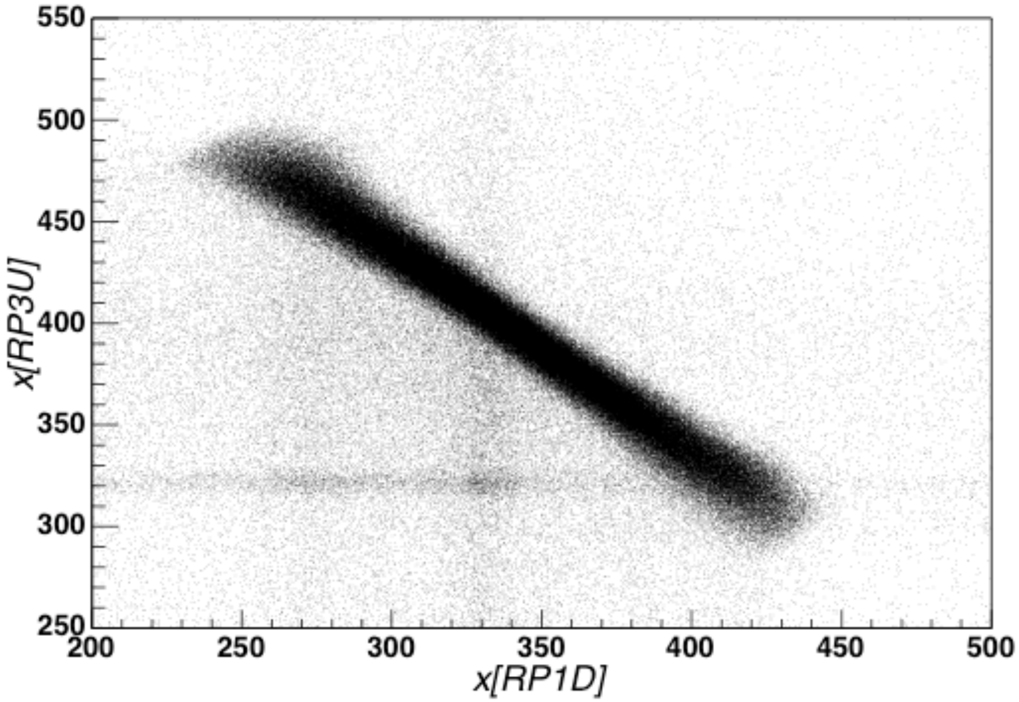
Only "inner" pots used for trigger and analysis, biggest acceptance

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 and it is eliminated by requiring collinearity between scattered protons



Elastic Event Selection

- A match of hit coordinates (x,y) from detectors on the opposite sides of the IP was required to be within 3σ for x and y-coordinate.
- The hit coordinates (x,y) of the candidate proton pairs were also required to be in the acceptance area of the detector, determined by the aperture of the focusing quadrupoles located between IP and the RP's.
- In case that there were more than one match between the hits on opposite sides of the IP the following algorithm was applied.
- If there is only one match with number of hits equal to 4, it is considered to be the "elastic event track". If there is no match with 4 hits or there are more than one such match, the event is rejected.
- The average detector efficiency was 0.98, and the upper bound of the elastic events loss due to all criteria was 0.035.
- The background originates from particles from inelastic interactions, beam halo particles and products of beam-gas interactions. The estimated background fraction varies from 0.5% to 9% depending on the y-coordinate.
- Since in our analysis the coordinate area was essentially limited to y > 30 strips, the background in the final sample does not exceed 2\%.

Event Yields after Cuts

After the above cuts, the sample of 1.14 million events in the t-interval:

$$\mathbf{0.010 \leq -t \leq 0.030}$$

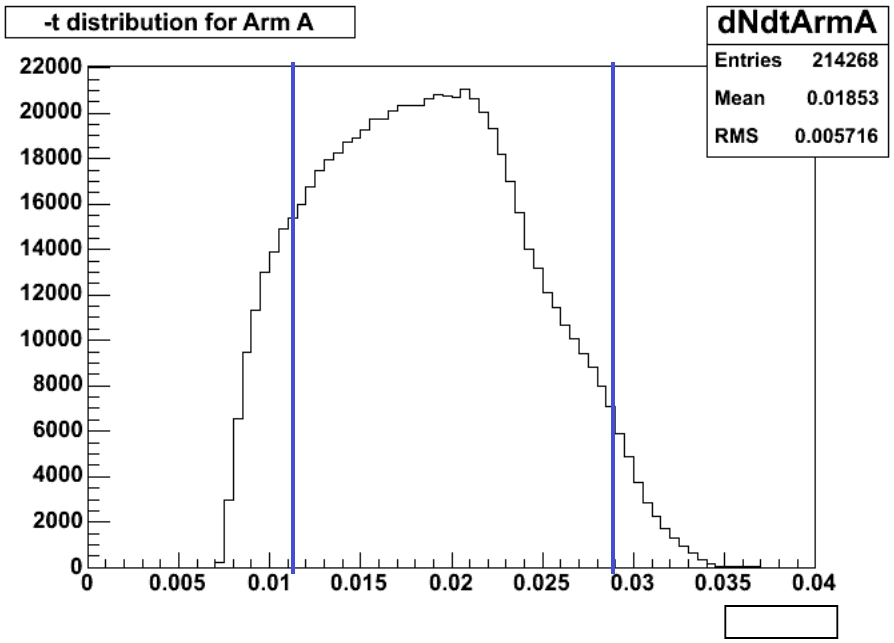
subdivided into three intervals:

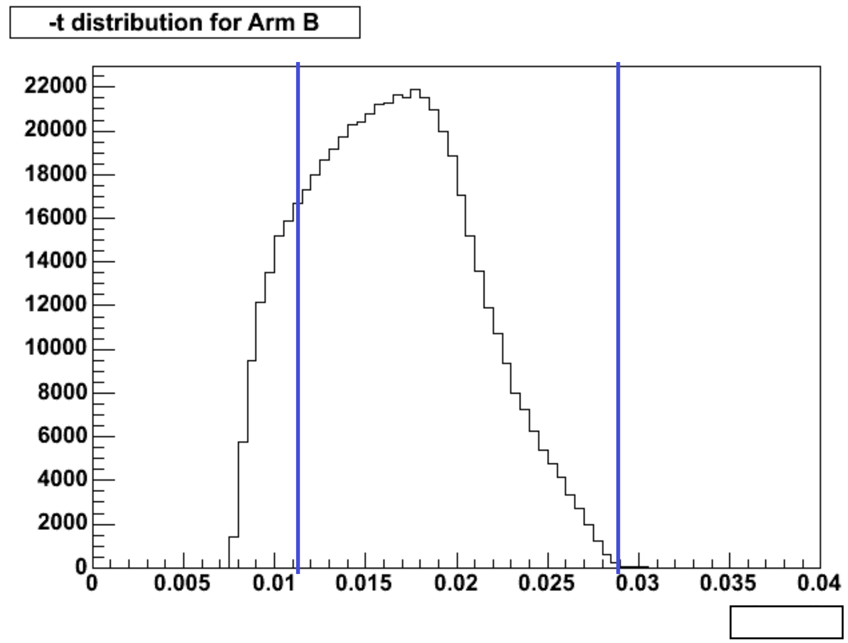
$$\mathbf{0.010 \leq -t < 0.015,\ \ 0.015 \leq -t < 0.020,\ 0.020 \leq -t < 0.030,}$$

was used to determine $A_{\mathbf{N}}$.

In each t-interval the asymmetry was calculated as a function of azimuthal angle ϕ using 5°-bins.

dN/dt





Useful t-interval [0.011,0.029] $(\mathrm{Gev/c})^2$

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.

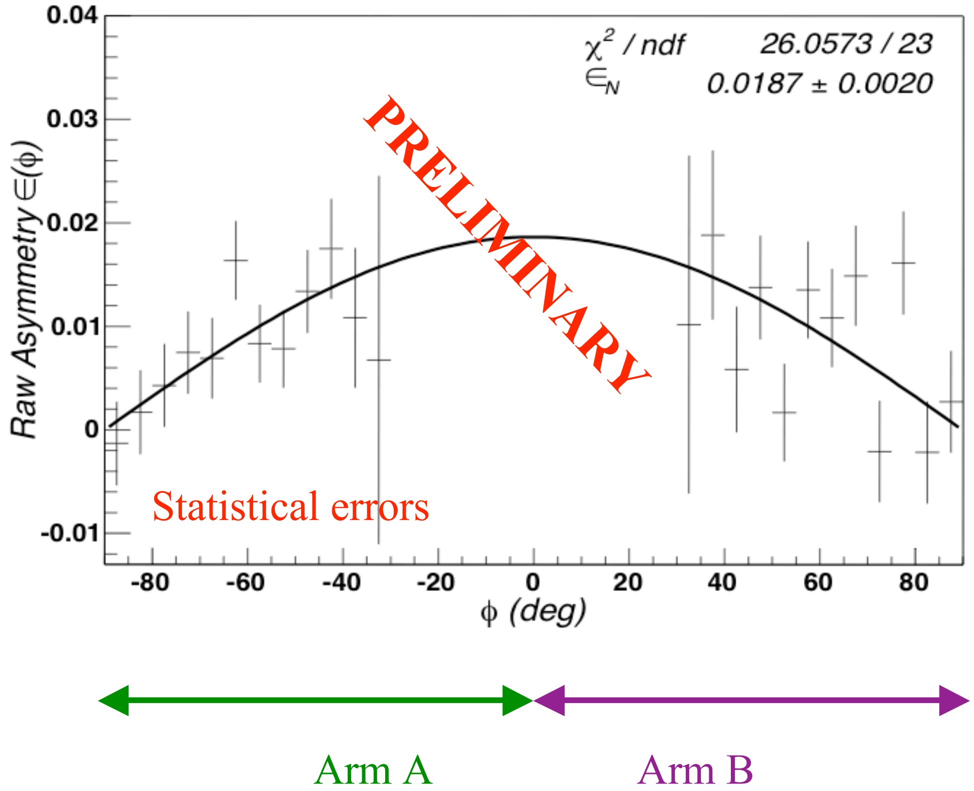
$$A_N(\varphi) = \frac{1}{(P_1 + P_2)\cos\varphi} \frac{\sqrt{N_L^{\uparrow\uparrow} N_R^{\downarrow\downarrow}} - \sqrt{N_R^{\uparrow\uparrow} N_L^{\downarrow\downarrow}}}{\sqrt{N_L^{\uparrow\uparrow} N_R^{\downarrow\downarrow}} + \sqrt{N_R^{\uparrow\uparrow} N_L^{\downarrow\downarrow}}}(1+\delta)$$

Where :

$$\delta = \mathrm{A}_{\mathrm{NN}}\mathrm{P}_1\mathrm{P}_2\langle\cos\varphi\rangle^2 + \mathrm{A}_{\mathrm{SS}}\mathrm{P}_1\mathrm{P}_2\langle\sin\varphi\rangle^2 \approx 0.03 \text{ is small}$$

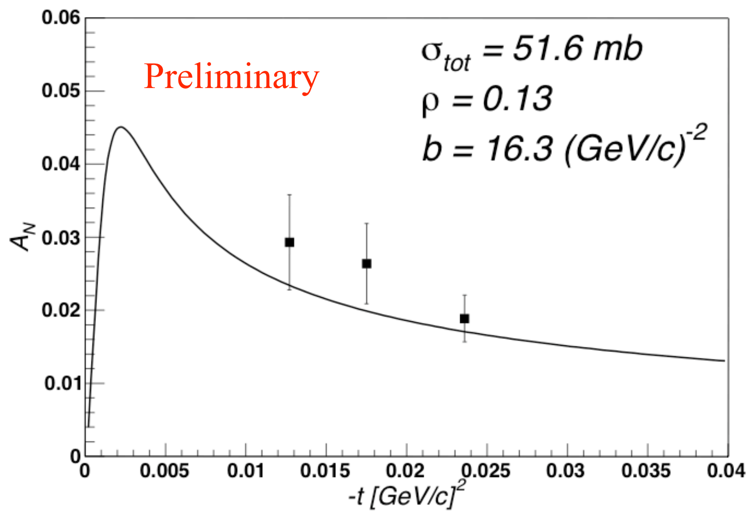
Since A_N is a relative measurement the efficiencies $\varepsilon(t, \phi)$ cancel

Preliminary Results: Full bin $0.011 < -t < 0.029\ (\mathrm{GeV}/c)^2$



Results: comparison with CNI

CNI parameters



Statistical errors

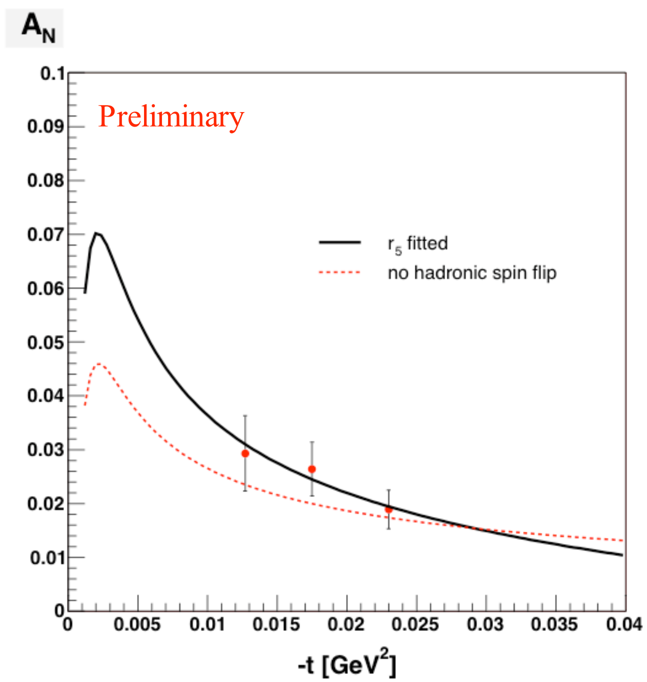
ΔA_N- stat. ≈ 10.9% (combined full interval)

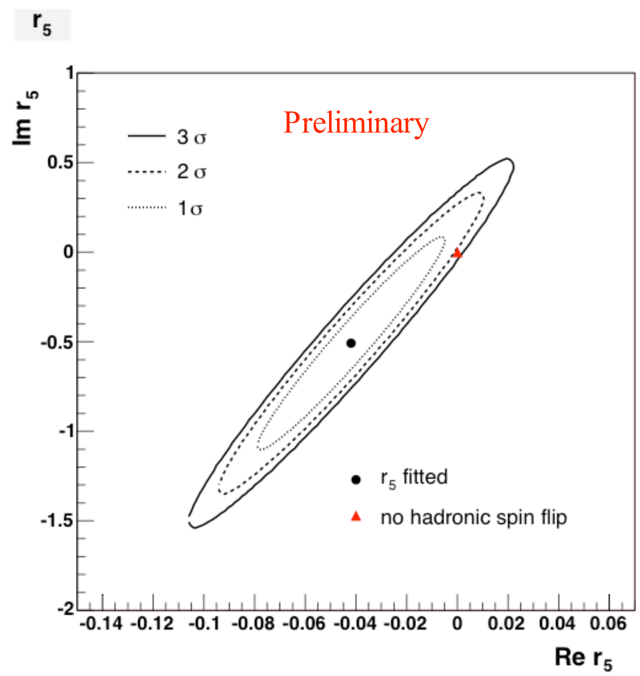
ΔA_N- syst. ≈ 8.4% (combined full interval)

ΔA_N- pol. ≈ 13.6% (scale error)

Limits on r_5

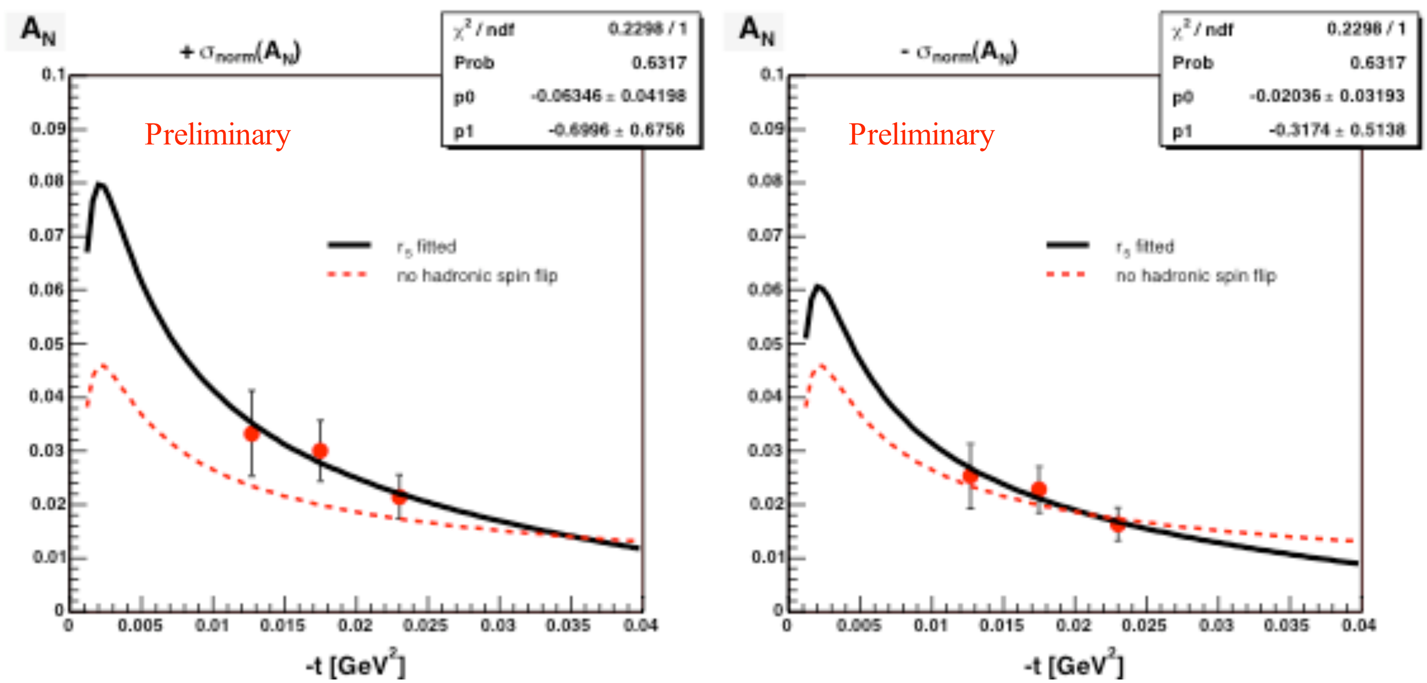
$$r_5 = \frac{m\phi_5}{\sqrt{-t}\,\mathrm{Im}\,\phi_+}$$





Limits on r_5 continued

Effects of polarization systematic error ± 12%



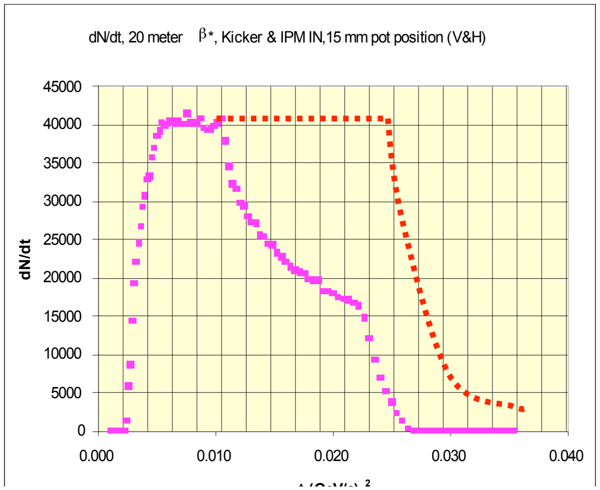
Summary

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 [0.011,0.29] $(GeV/c)^2$.
2. The A_N is ≈ 4σ from zero (statistical error.)
3. The A_N is ≈ 1.5 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}….

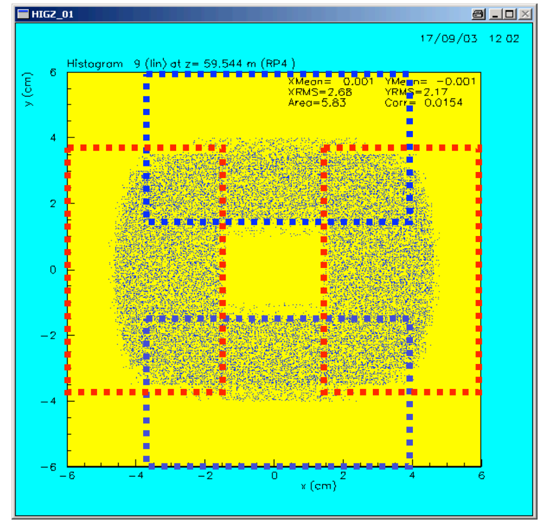
RHIC is a great and unique place to do this physics and we have a plan how to do it and do it better!

Future Possibility – Big Improvement

dN/dt



x-y



Full acceptance at $\sqrt{s}$ = 200 GeV

$\sqrt{s}$ (GeV)	β^*	$\lvert t\rvert$-range $(GeV/c)^2$	Typical errors
200	**20 m**	**$0.003 < \lvert t\rvert < 0.025$**	**$\Delta B = 0.3$, $\Delta\sigma_{tot} = 2 – 3$ mb** **$\Delta\rho = 0.007$ and $\Delta A_N = 0.002$**