Results from the PP2PP Experiment at RHIC and Future Plans (withSTAR)

Włodek Guryn

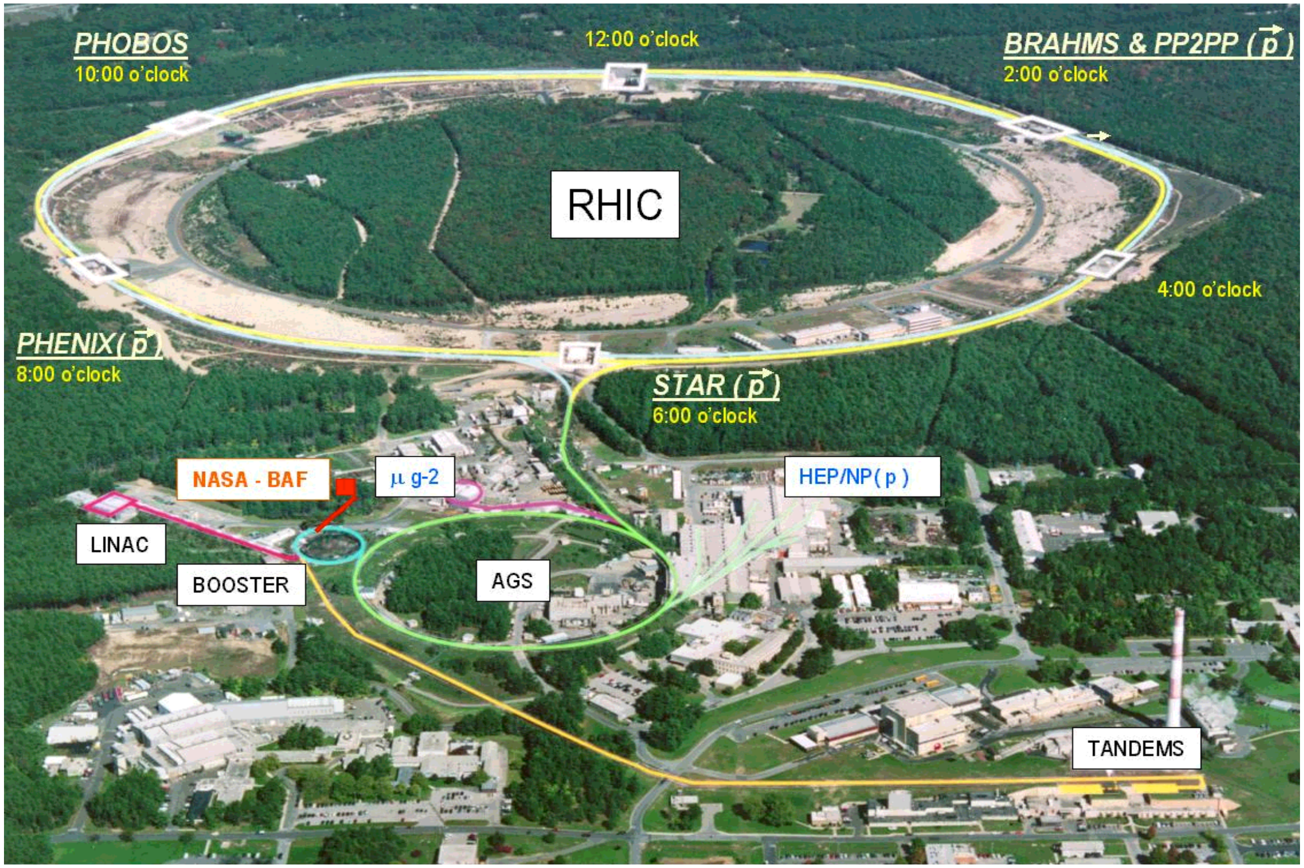
Brookhaven National Laboratory, Upton, NY, USA

OUTLINE of the TALK

- Description of the experiment
- Elastic scattering results and interpretation
- Future plans with STAR

BROOKHAVEN NATIONAL LABORATORY

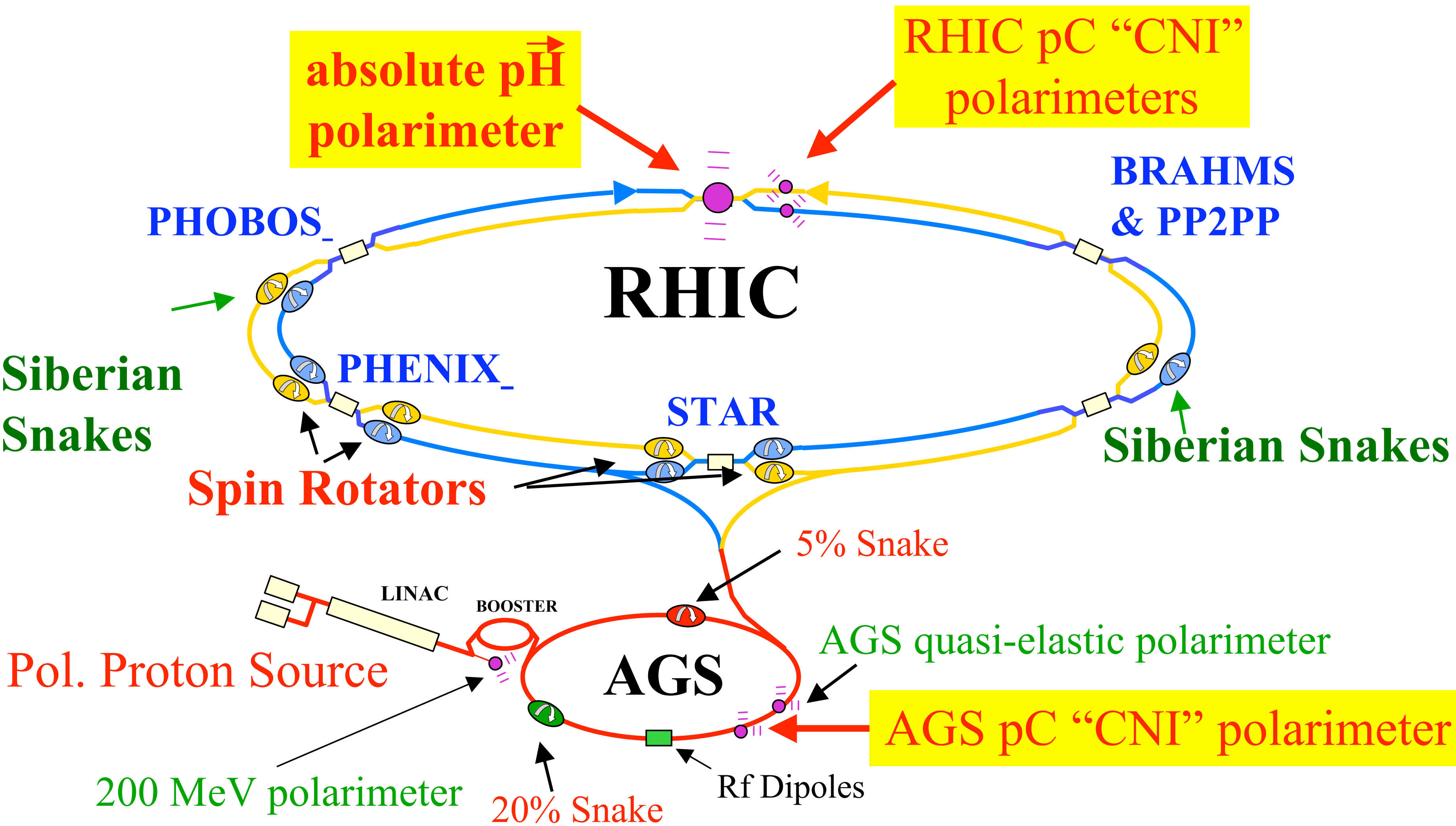
The Relativistic Heavy Ion Collider



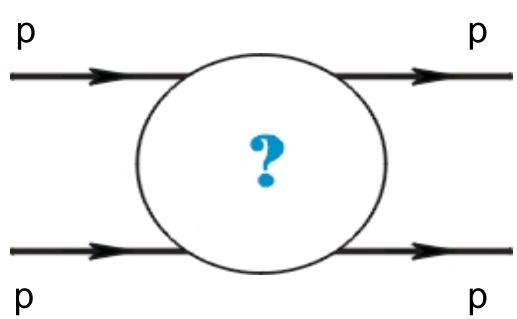
RHIC is a QCD Laboratory:

Nucleus- Nucleus collisions (AuAu, CuCu…); Asym. Nucl. (dAu); Polarized proton-proton; eRHIC - Future

RHIC $p^{\uparrow}p^{\uparrow}$ accelerator complex

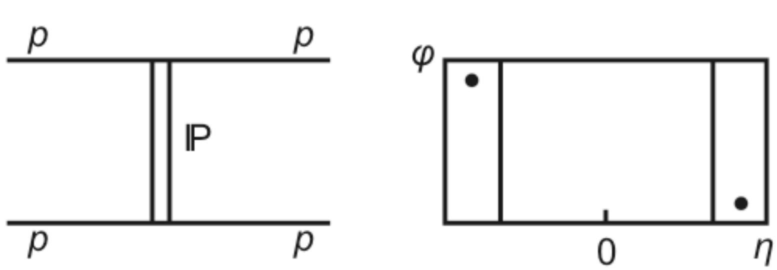


Elastic and Inelastic Processes

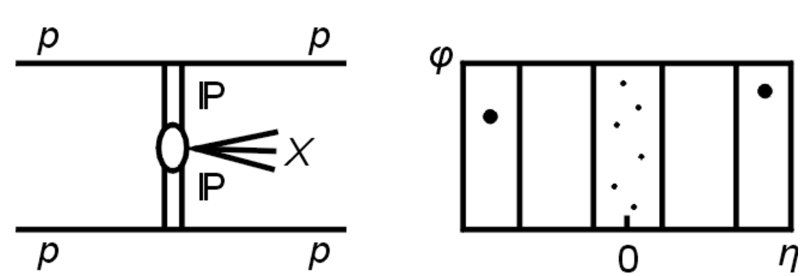


In t-channel it is an exchange with quantum numbers of vacuum

Elastic Scattering



Central Production



In terms of QCD, Pomeron exchange consists of the exchange of a color singlet combination of gluons. Hence, triggering on forward protons at high (RHIC) energies predominantly selects exchanges mediated by gluonic matter.

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

S. Bültmann, I. H. Chiang, R.E. Chrien, A. Drees, R. Gill, W. Guryn*, J. Landgraf, T.A. Ljubičič, D. Lynn, C. Pearson, P. Pile, A. Rusek, M. Sakitt, S. Tepikian, K. Yip
Brookhaven National Laboratory, USA

J. Chwastowski, B. Pawlik
Institute of Nuclear Physics, Cracow, Poland

M. Haguenauer
Ecole Polytechnique/IN2P3-CNRS, Palaiseau, France

A. A. Bogdanov, S.B. Nurushev, M.F Runtzo, M. N. Strikhanov
Moscow Engineering Physics Institute (MEPHI), Moscow, Russia

I. G. Alekseev, V. P. Kanavets, L. I. Koroleva, B. V. Morozov, D. N. Svirida
ITEP, Moscow, Russia

S. Khodinov, M. Rijssenbeek, L. Whitehead, S. Yeung
SUNY Stony Brook, USA

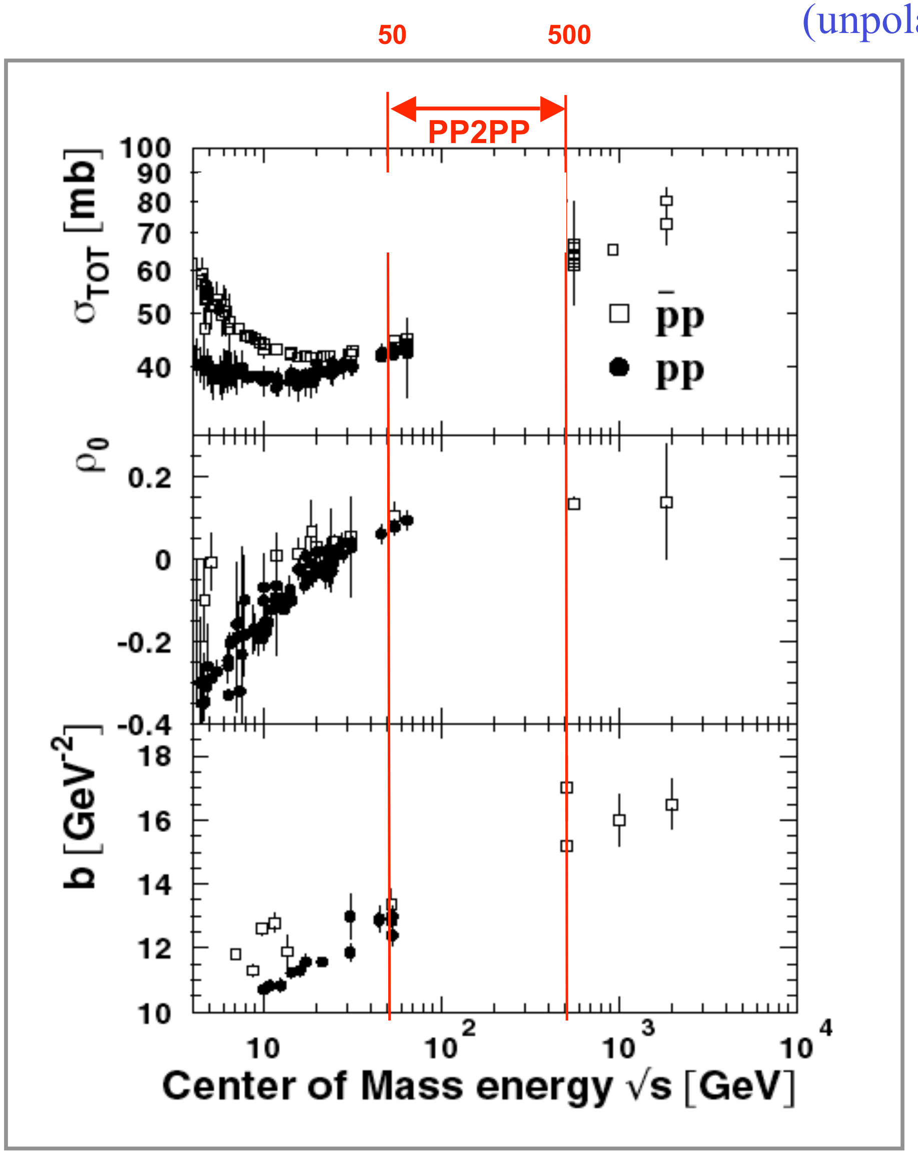
K. De, N. Guler, J. Li, N. Ozturk
University of Texas at Arlington, USA

A. Sandacz
Institute for Nuclear Studies, Warsaw, Poland

* spokesman

Summary of the Existing Data

(unpolarized)



Highest energy so far:

pp: 63 GeV (ISR)

$p\bar{p}$: 1.8 TeV (Tevatron)

pp2pp energy range:

$50 \text{ GeV} \leq \sqrt{s} \leq 500 \text{ GeV}$

pp2pp $|t|$-range:

(at $\sqrt{s}$ = 500 GeV)

$4 \cdot 10^{-4}\ \text{GeV}^2 \leq |t| \leq 1.3\ \text{GeV}^2$

One cannot assume that because of the existence of the models, the data in pp at the ISR, and $p\bar{p}$ data at $Sp\bar{p}S$ and the Tevatron one can predict with sufficient accuracy $d\sigma/dt$ and σ_{tot} in the RHIC √s range.

PP2PP Forward slope B from 2002 engineering run

Fit $|t|$-distribution with

$$\frac{dN}{dt} = C\left[\frac{4\pi\,(\alpha G_E^{\,2})^{2}}{t^{2}} + \frac{(1+\rho^{2})\,\sigma_{tot}^{2}\,e^{+Bt}}{16\pi} + \frac{(\rho+\Delta\Phi)\,\alpha G_E^{\,2}\,\sigma_{tot}\,e^{+\frac{1}{2}Bt}}{t}\right]$$

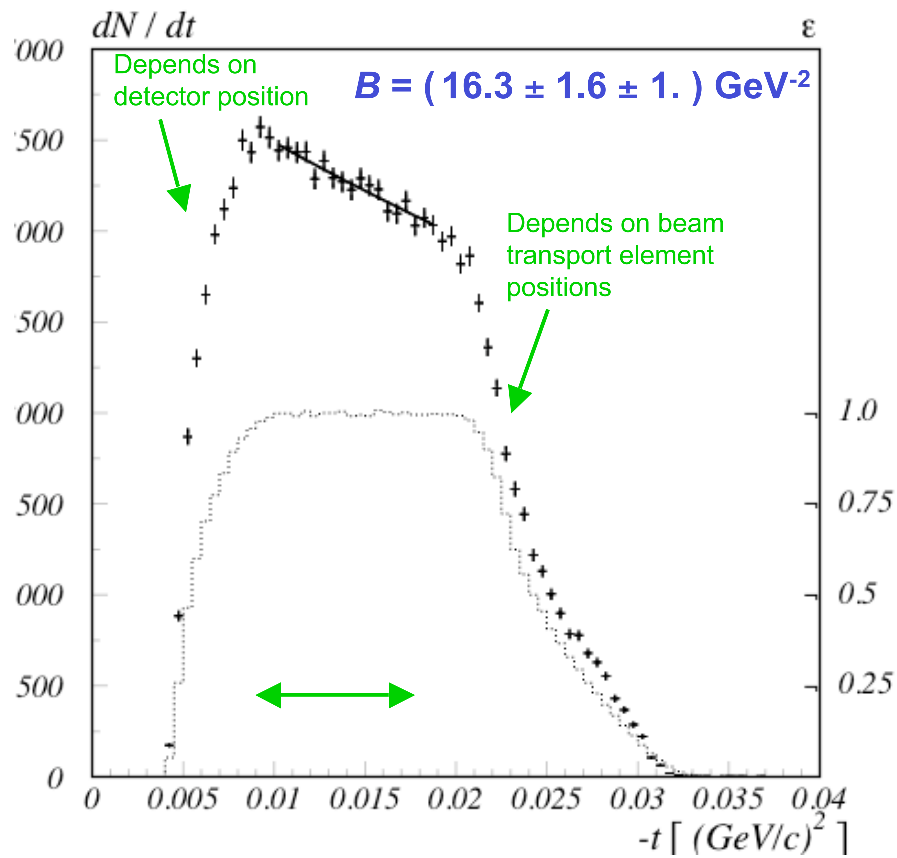
Using fits to world data of σ_{tot} = 51.6 mb

and ρ = 0.13

Fit B for 0.010 GeV^2 ≤ $|t|$ ≤ 0.019 GeV^2

***B* = (16.3 ± 1.6 ± 1.0) GeV^{-2}**

Phys. Lett. B 579 (2004) 245-250



Helicity Amplitudes in Elastic Scattering

Five helicity amplitudes describe proton-proton elastic scattering

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

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

Some of the measured quantities in elastic scattering are:

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

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

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

Source of single spin analyzing power A_N

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

$$\phi_5 = r_5(s)\frac{\sqrt{-t}}{m_p}\mathrm{Im}\frac{1}{2}(\phi_1 + \phi_3) = r_5(s)\frac{\sqrt{-t}}{m_p}\mathrm{Im}\phi_+$$

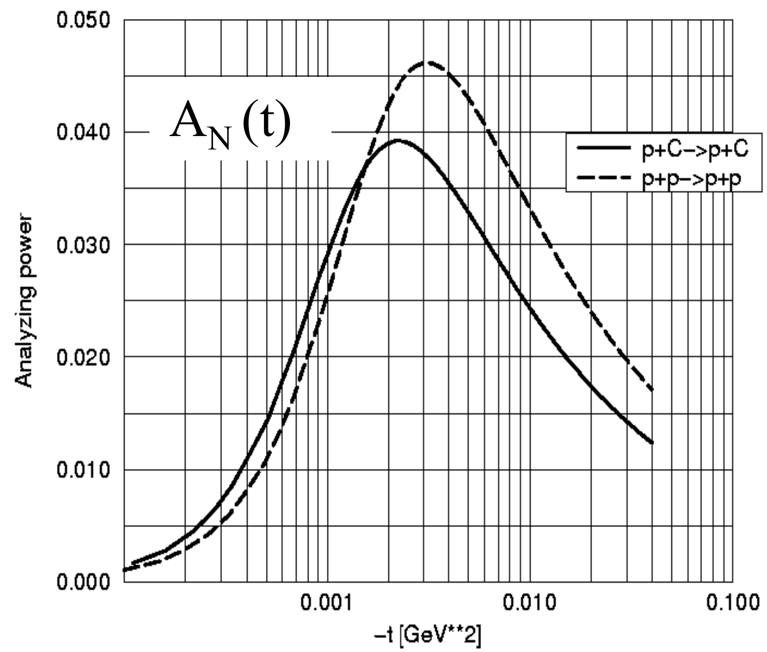
Single spin asymmetry (left -right) A_N arises in the CNI region from to the interference of hadronic non-flip amplitude with electromagnetic spin-flip amplitude.

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

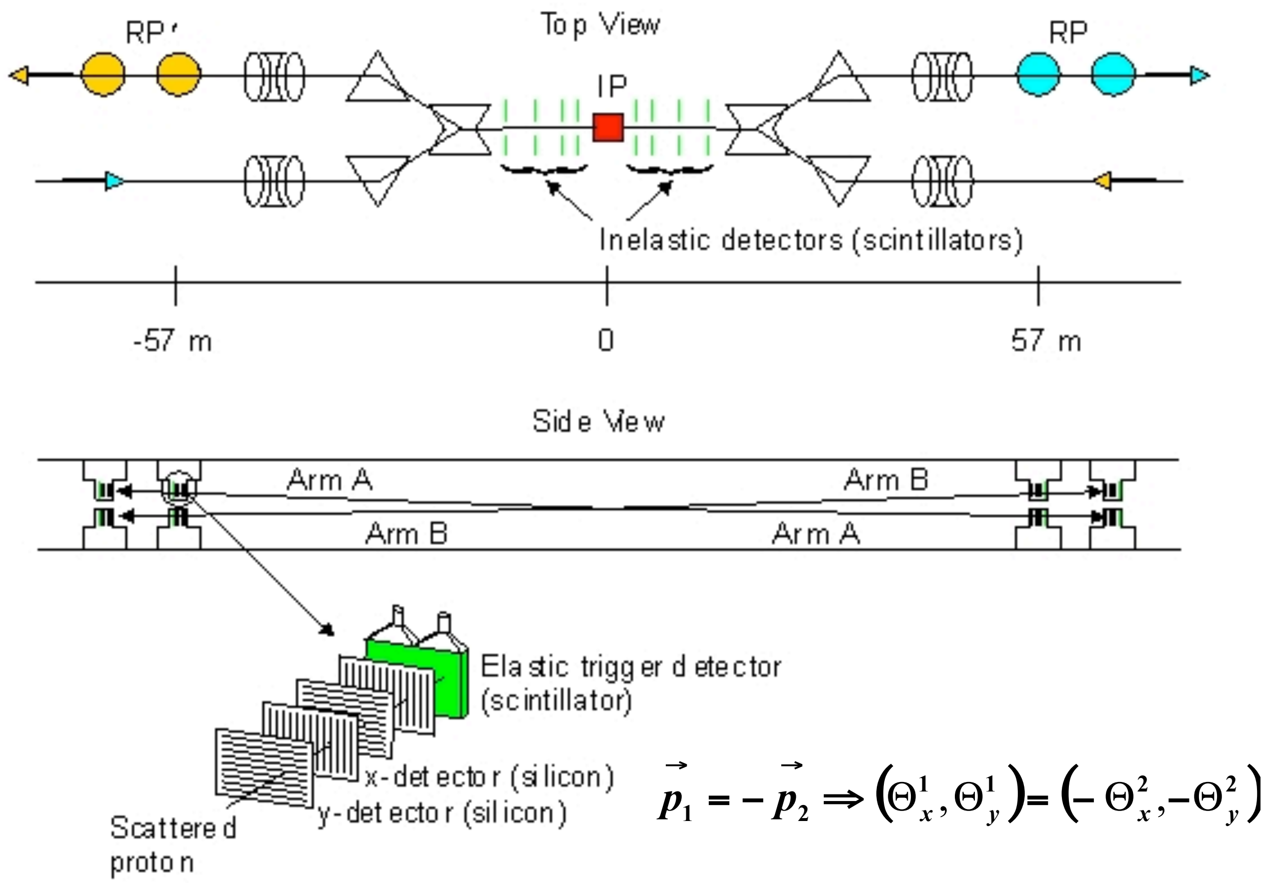
•N. H. Buttimore, B. Z. Kopeliovich, E. Leader, J. Soffer, T. L. Trueman, Phys. Rev. D59, (1999) 114010.

•T.L. Trueman hep-ph/0604153



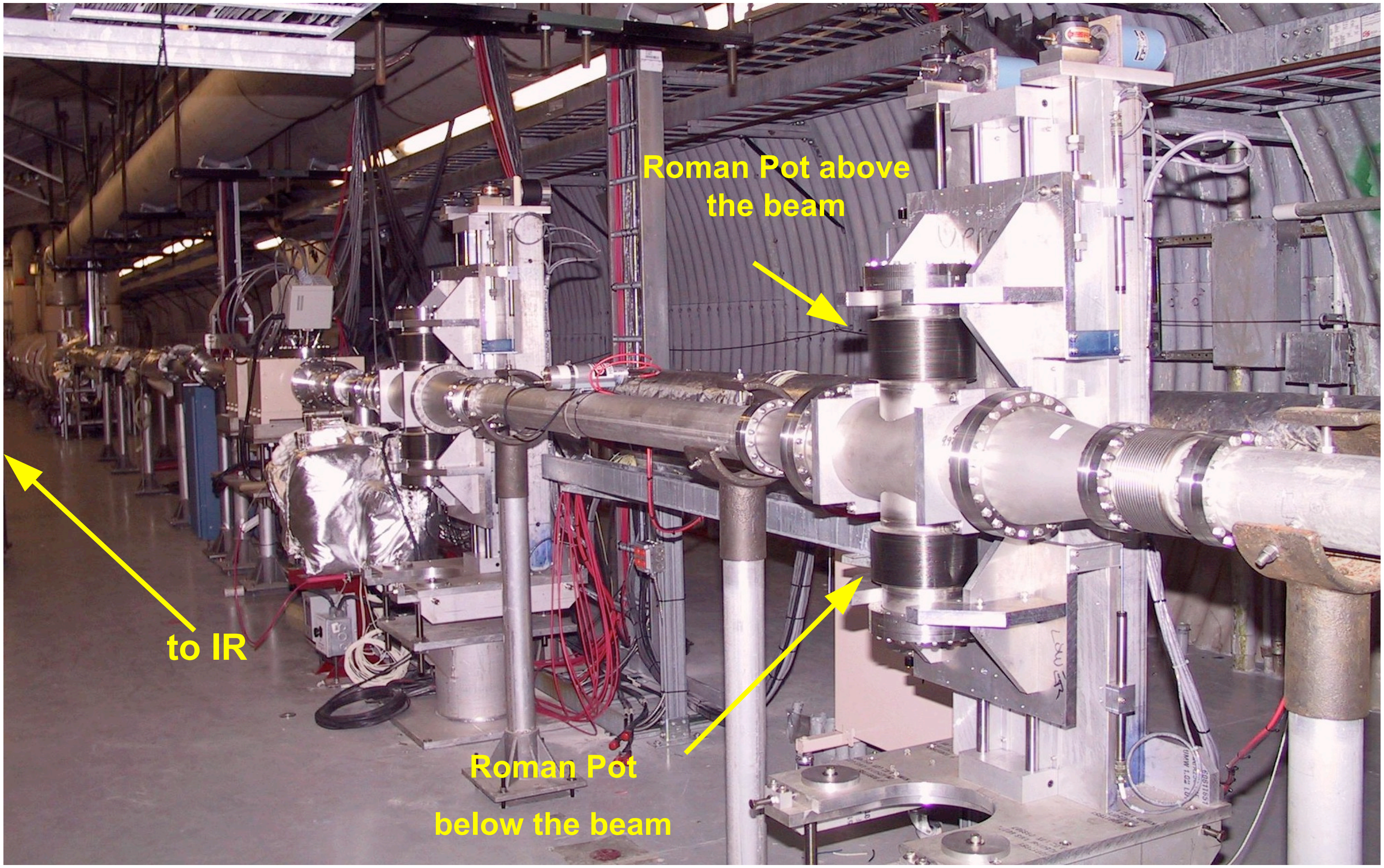
needed phenomenological input: σ_{tot}, ρ, δ (diff. of Coulomb-hadronic phases) also for nuclear targets em. and had need form factors

The Setup



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

Roman Pot Stations at RHIC

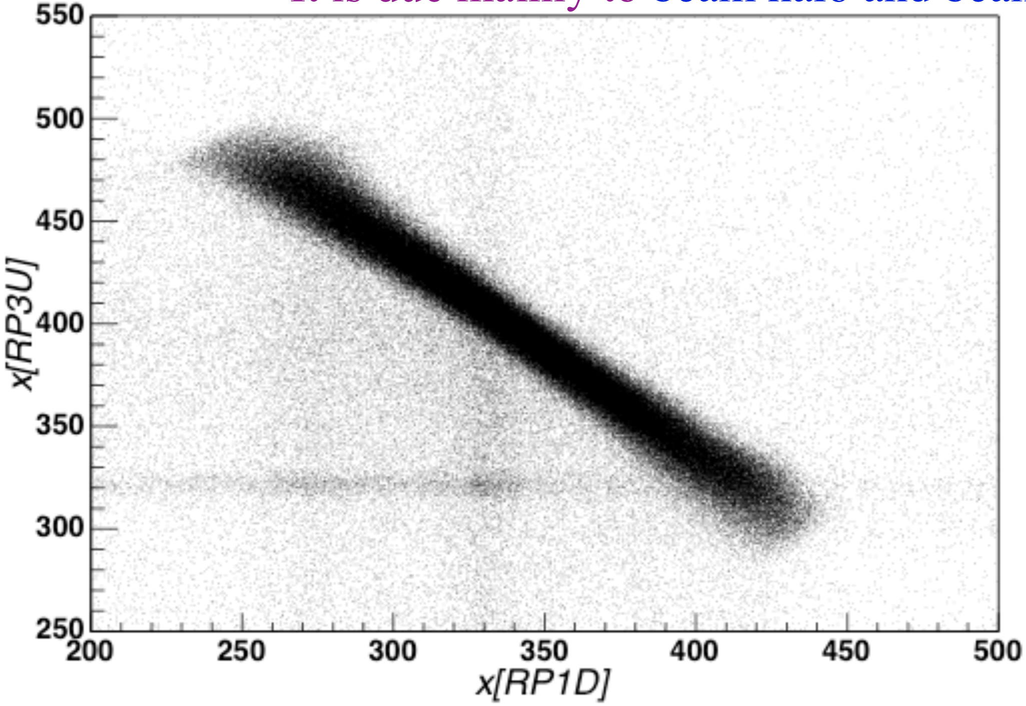


Hit Correlations Before the Cuts

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

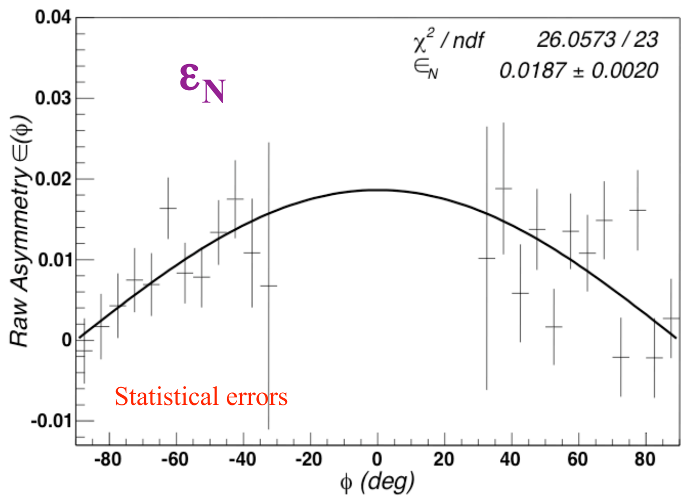
After the cuts the background in the final sample is $\approx 0.5\% \div 2\%$ depending on *y* (vertical) coordinate

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

Fit ε_N cos(φ) dependence to obtain A_N

$P_Y(++,--)=0.345 \pm 0.066$

$P_B(++,--)=0.532 \pm 0.106$



$P_B + P_Y = 0.877 \pm 0.149$

Arm A

Arm B

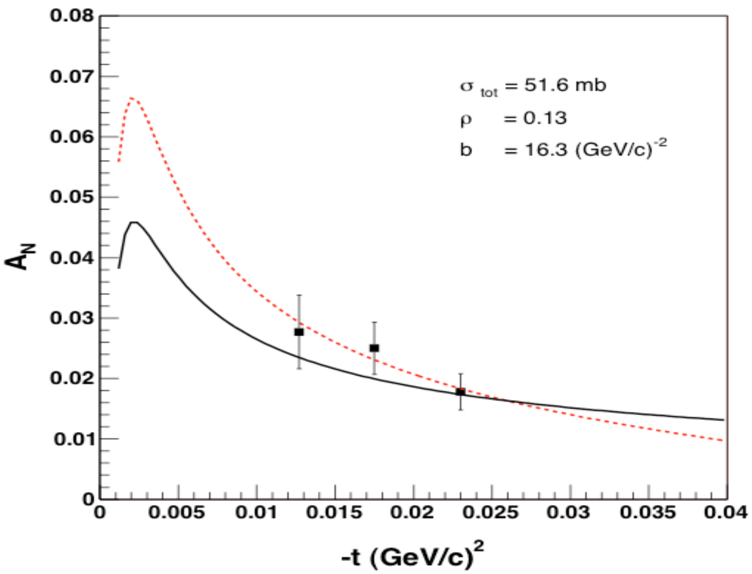
$P_Y(+-,-+)=0.476 \pm 0.085$

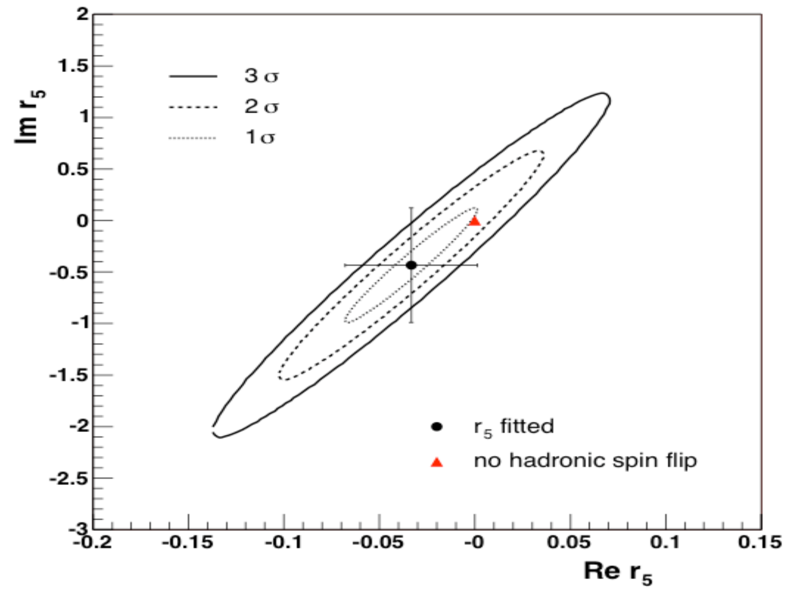
$P_B(+-,-+)=0.430 \pm 0.089$

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

Results: A_N and r_5

Phys. Lett. B 632, (2006) 167-172





Re r_5 = -0.033 ± 0.035 , Im r_5 = -0.43 ± 0.56

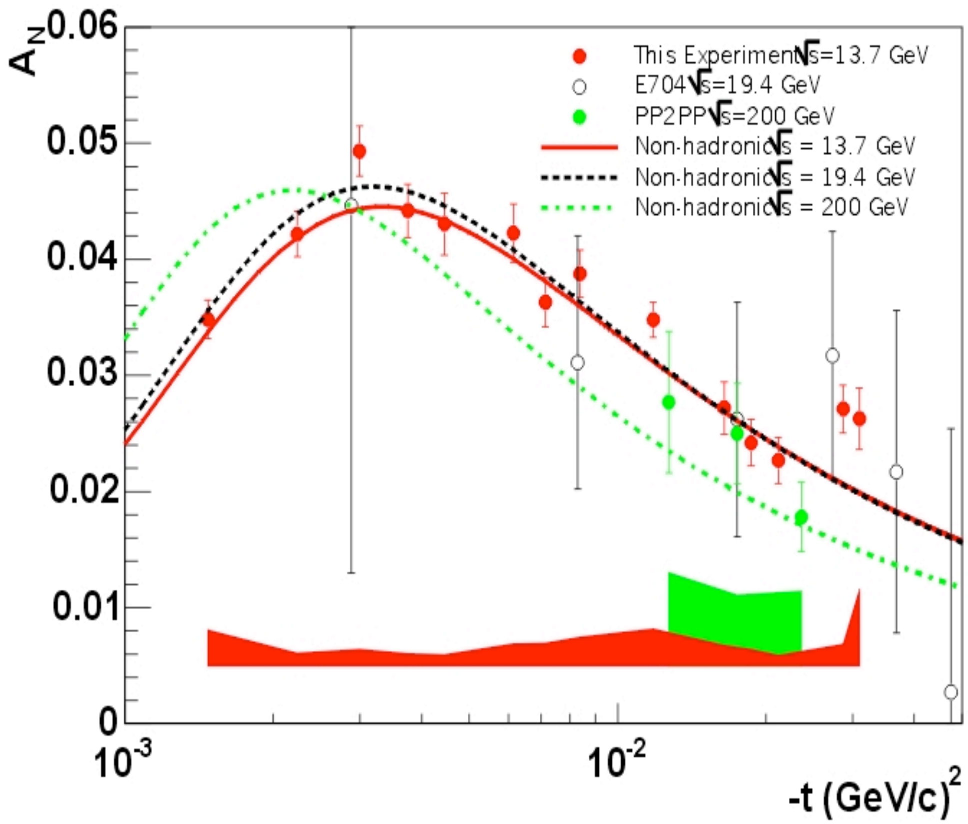
Statistical and systematic errors added in quadratures, 17.0% normalisation error due to beam polarisation uncertainty, not included.

Our result is suggestive at 1σ level of the hadronic spin flip (need more data to resolve).

|t|-range, (GeV/c)^2	<|t|>, (GeV/c)^2	A_{SS}	$\sigma_{Ass\ (st.+sys)}$	A_{NN}	$\sigma_{Ann\ (st.+sys)}$
0.010-0.030	0.019	0.0035	0.0081	0.0298	0.0166

A_N: Polarized jet target at RHIC

H. Okada et. al   Physics Letters B 638 450 (2006) and E704 experiment



$$\phi_5^{had} = r_5(s)\frac{\sqrt{-t}}{2m_p}\left(\phi_1^{had} + \phi_3^{had}\right)$$

Im r_5 = 0.002 ± 0.029

Re r_5 = -0.006 ± 0.007

χ^2/ndf = 10 / 12

uncertainty on the
ρ(Δρ = ± 0.03) parameter
can change at the same level

hadronic spin – flip contribution are small

Calculation of A_{NN} an A_{SS}

$$\delta(\varphi) = \frac{N^{++}(\varphi)/L^{++} + N^{--}(\varphi)/L^{--} - N^{+-}(\varphi)/L^{+-} - N^{-+}(\varphi)/L^{-+}}{N^{++}(\varphi)/L^{++} + N^{--}(\varphi)/L^{--} + N^{+-}(\varphi)/L^{+-} + N^{-+}(\varphi)/L^{-+}}$$

Luminosity normalization is done using:

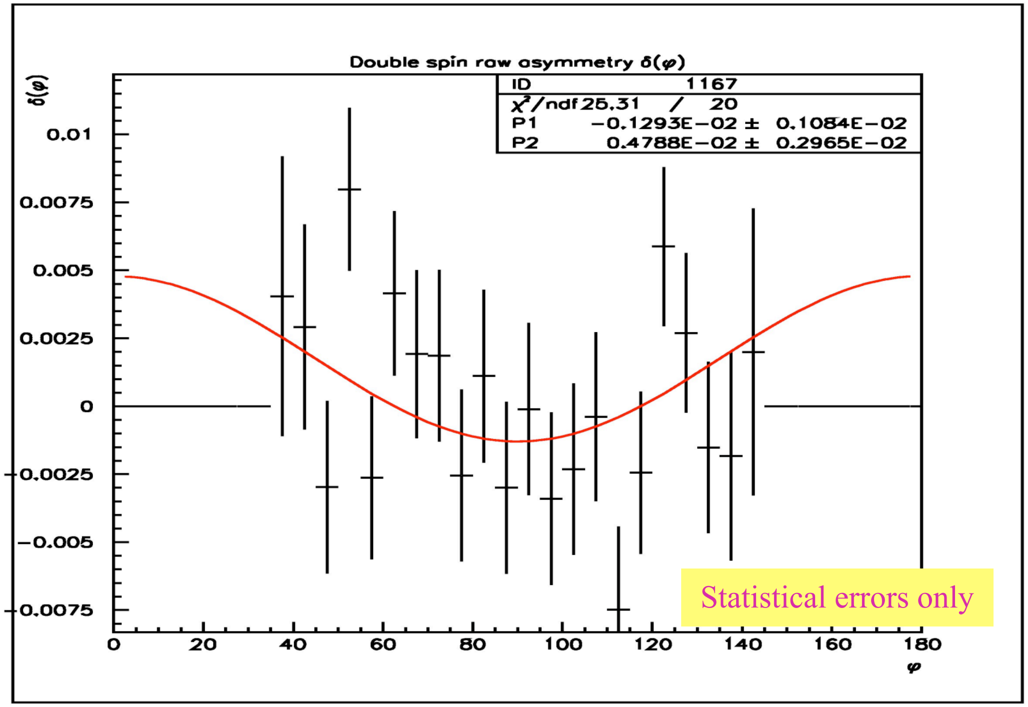
1. The machine bunch intensities: $L^{ij} \sim \Sigma I^{i}_{B} \cdot I^{j}_{Y}$ over bunches with given i,j
2. The inelastic counters

The two methods agreed.

Distributions $\delta(\varphi)$ were fitted with

$(P_1 \cdot \sin^2\varphi + P_2 \cdot \cos^2\varphi)$ where

$P_1 = P_B \cdot P_Y \cdot A_{SS}$ and $P_2 = P_B \cdot P_Y \cdot A_{NN}$



Results: A_{NN} and A_{SS}

PLB 647 (2007) 98-103

|t|-range, (GeV/c)²	<|t|>, (GeV/c)²	A_{SS}	$\sigma_{Ass\ (stat.+norm.)}$	A_{NN}	$\sigma_{Ann\ (stat.+norm.)}$
0.010-0.030	0.019	0.0035	0.0081	0.0298	0.0166

$$r_2 = \phi_2 / (2 \cdot \mathrm{Im}\phi_+), \quad where \quad \phi_+ = \frac{1}{2}(\phi_1 + \phi_3)$$

$$\mathrm{Im}\ r_2 = 0.0019 \pm 0.0052 \quad \mathrm{Re}\ r_2 = -0.025 \pm 0.065$$

r_2 is consistent with zero, still small (5%) contribution of Odderon not excluded

For the latest discussion see
T.L. Trueman hep-ph/0604153

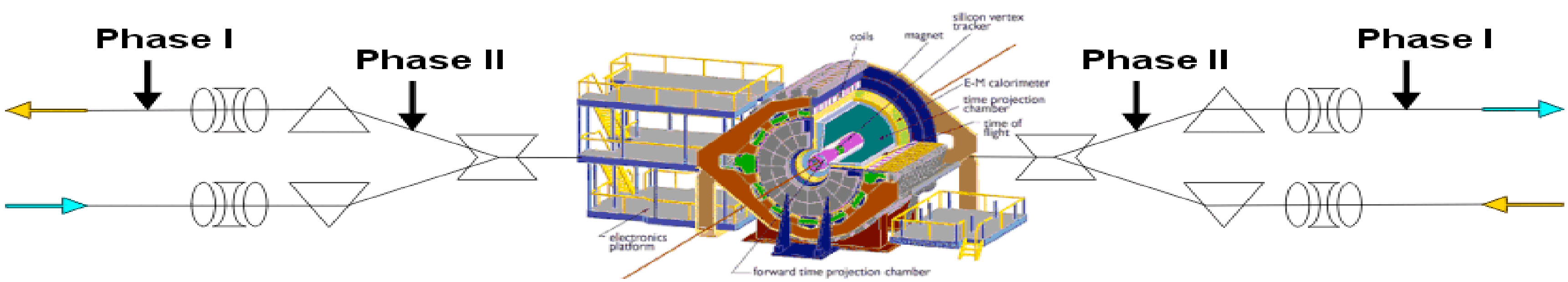
Summary

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 $\approx$ 4-5σ from zero.
3. The A_N is $\approx$ 1σ away from a CNI curve, which does not have hadronic spin flip amplitude. This might be suggestive of the hadronic spin flip.
4. Result on A_{NN}, A_{SS} have been obtained, small contribution from Odderon is not excluded
5. 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}).

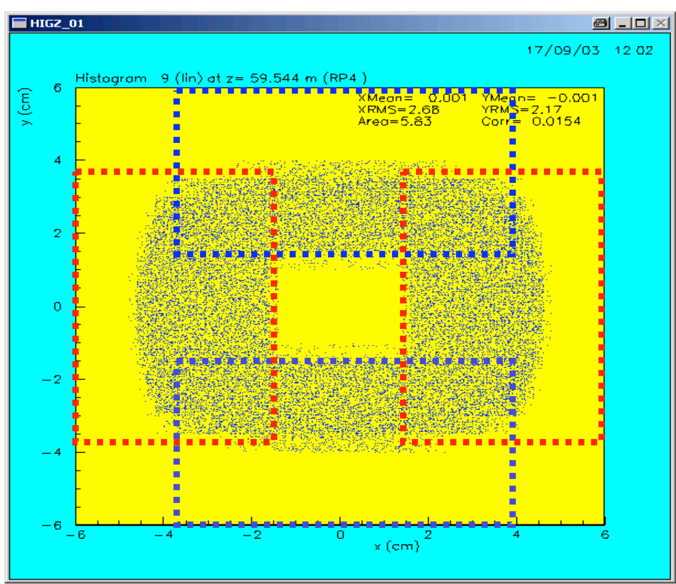
The program of elastic scattering and inelastic diffraction will continue within STAR experiment at RHIC.

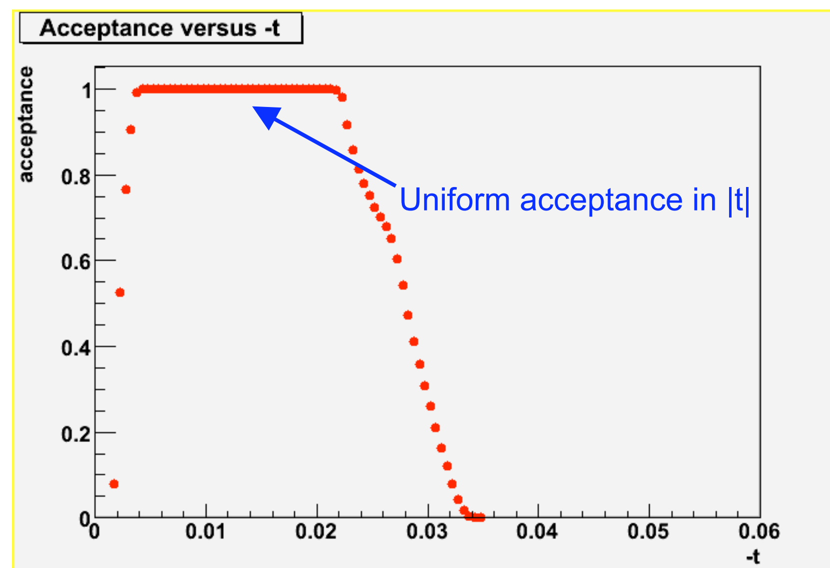
PP2PP Roman Pots and STAR

Need detectors to tag forward protons and detector with good acceptance and particle ID to measure central system

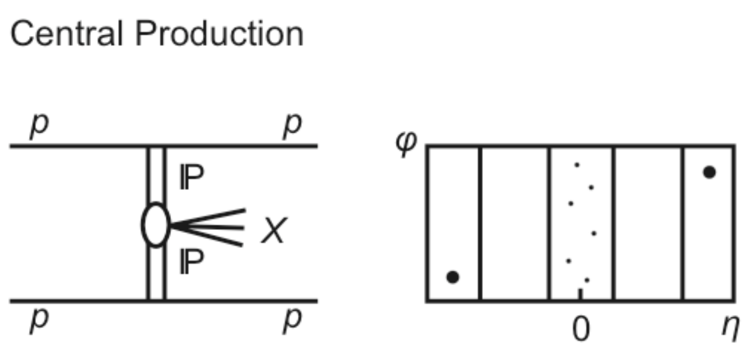


x-y





Central Production in DPE



In the double Pomeron exchange process each proton "emits" a Pomeron and the two Pomerons interact producing a massive system M_X.

The massive system could form resonances or consist of jet pairs. Because of the constraints provided by the double Pomeron interaction, glueballs, and other states coupling preferentially to gluons, will be produced with much reduced backgrounds compared to standard hadronic production processes.

Central Production Has a Long History

A search for glueballs and a study of double pomeron exchange at the CERN ISR
Nuclear Physics B, Volume 264, 1986, Pages 154-184, T. Åkesson, M. G. Albrow, et al.

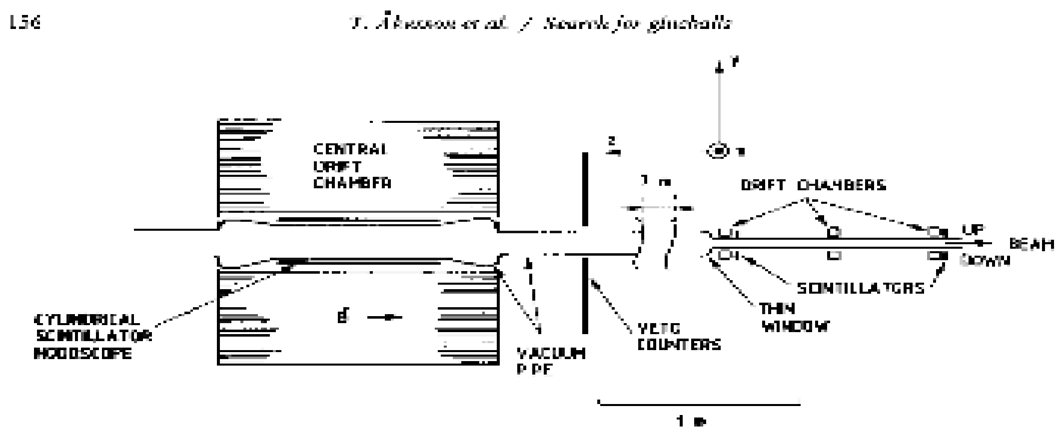
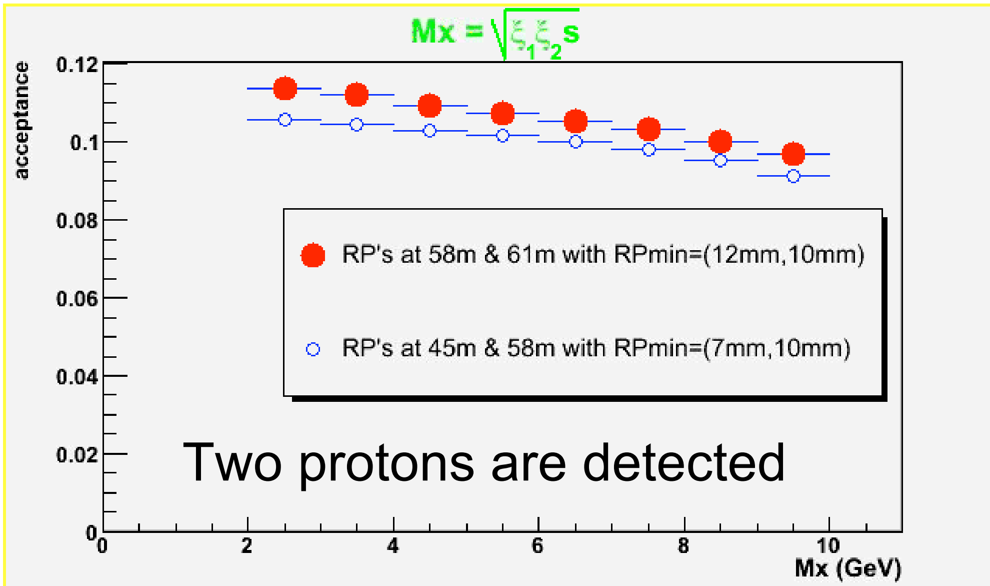


Fig. 1. A schematic side view of the apparatus. Only the right hand forward detectors are shown; the apparatus is left right symmetric.

$3.6 \cdot 10^6$ events, high statistics $pp \rightarrow pp\pi^+\pi^-$ shows behaviour S-wave dominance up to $M_X = 1600$ MeV

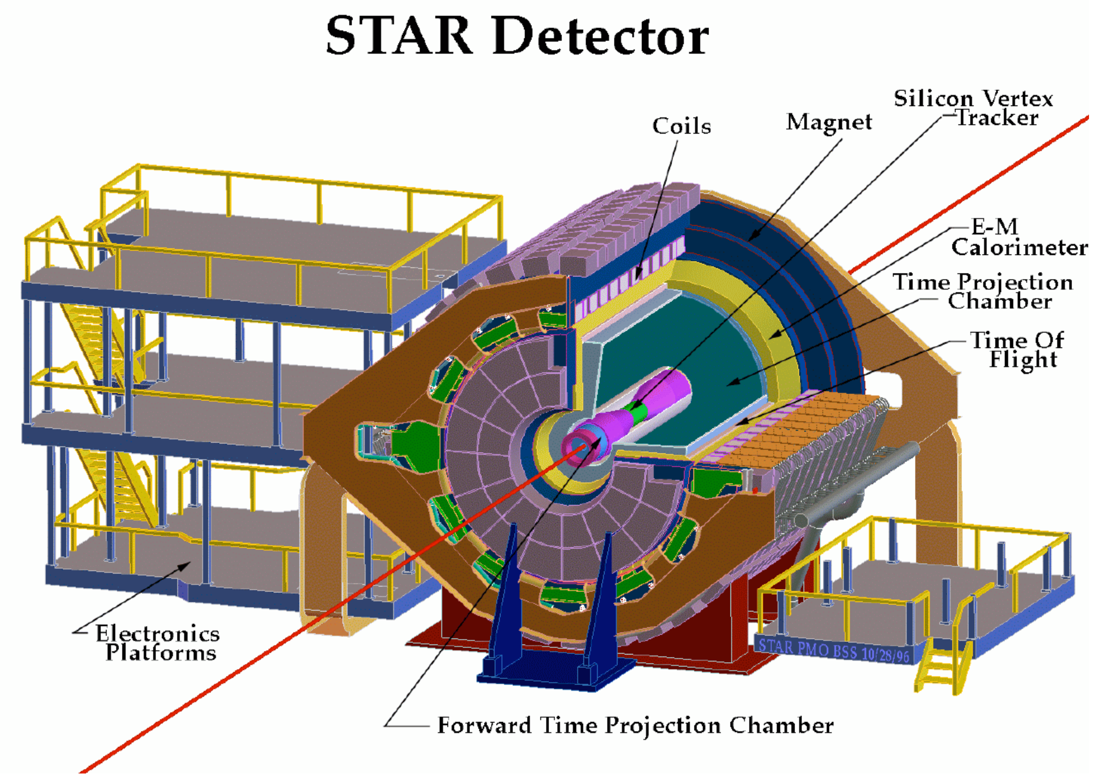
Acceptance Study DPE



With the expected luminosity we can collect about 450,000, triggered DPE events, for which the proton momentum is reconstructed. One assumes a 10μbarn cross section within our acceptance for the DPE process, where it is required that two RPs on each side are used allowing reconstruction of the outgoing proton momentum.

Number of events for which only one proton tag is used is factor of 4-5 higher.

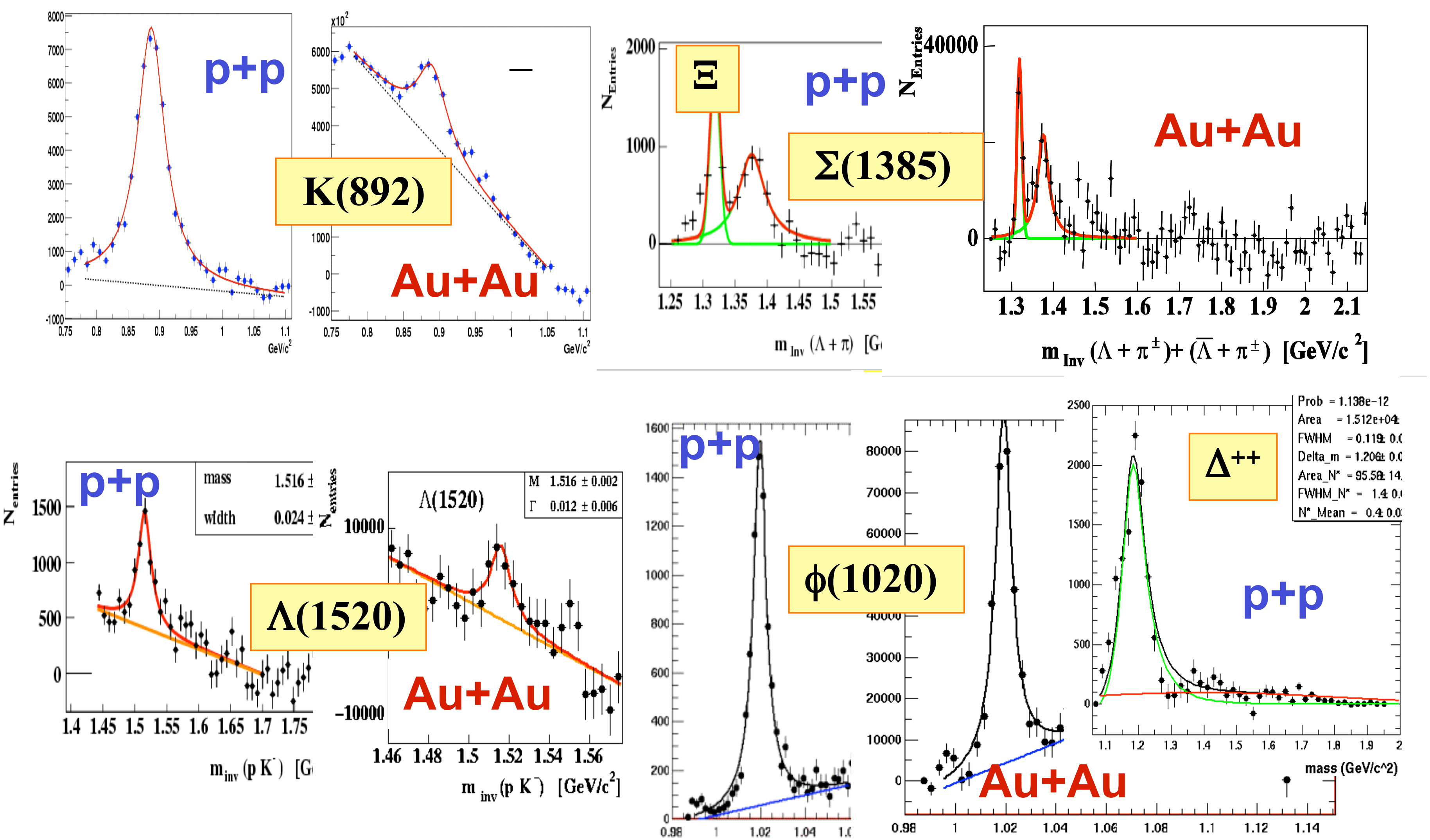
STAR Detector



Time Projection Chamber $\sigma(dE/dx) \approx 8\%$, $|\eta|<1$; EM Calorimeter; ToF system…

See STAR talks by Yuri Gorbunov and Hank Crawford for more details.

Resonance Signal in p+p and Au+Au collisions from STAR



Plan for Run 8 and Performance

With a dedicated run including setup and about 40 hrs of data taking:

1. Elastic scattering:

   - 100% acceptance for elastic scattering for $0.003 < |t| < 0.024$;
   - 20×10^6 elastic events: $\Delta b=0.31\ (\mathrm{GeV/c})^{-2}$, $\Delta\rho=0.01$, $\Delta\sigma_{tot} = 2\text{-}3$ mb;
   - In four t subintervals we shall have 5×106 events in each resulting in corresponding errors $\delta A_n=0.0017$, $\delta A_{nn}=\delta A_{ss}=0.003$.

1. DPE process in Phase I: With luminosity $3\times10^{29}\ \mathrm{cm^{-2}sec^{-1}}$ we estimate:

   - About $4\cdot10^6$ events with the proton tag, proton in either pot, of the order of the ISR experiment.
   - $4.5\cdot10^5$ DPE events with fully reconstructed proton momentum.

Summary

The physics program of tagged forward protons with STAR at RHIC can:

1. Study standard hadron diffraction both elastic and inelastic and its spin dependence in unexplored t and $\sqrt{s}$ range;
2. Study the structure of color singlet exchange in the non-perturbative regime of QCD.
3. Search for central production of light and massive systems in double Pomeron exchange process - glueballs.
4. Search for an Odderon - an eigenstate of CGC.

Those studies will add to our understanding of QCD in the non-perturbative regime where calculations are not easy and one has to be guided by measurements.

There is a great potential for important discoveries