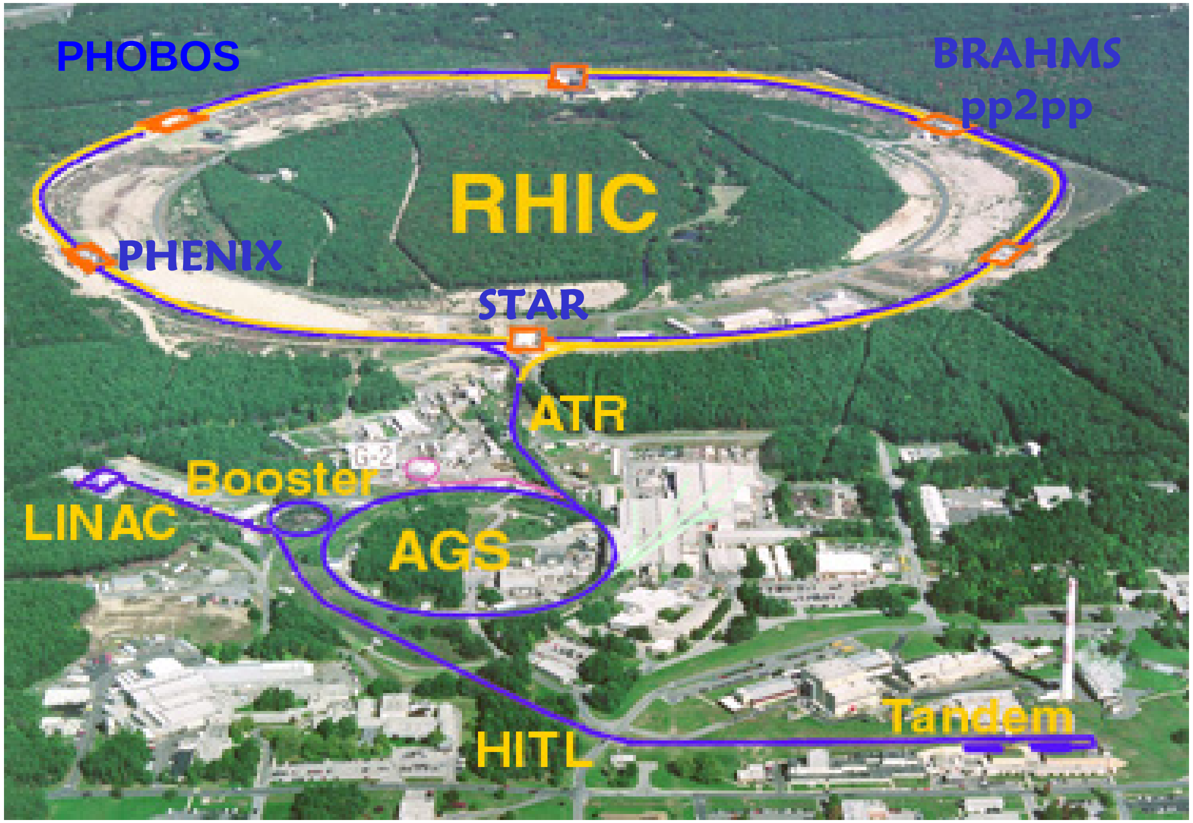
Experimental Possibilities at RHIC

Włodek Guryn
Brookhaven National Laboratory, Upton, NY, USA

OUTLINE of the TALK

- RHIC complex;
- RHIC experiments: STAR and pp2pp;
- What can be done at RHIC?
- Where do we go from here?

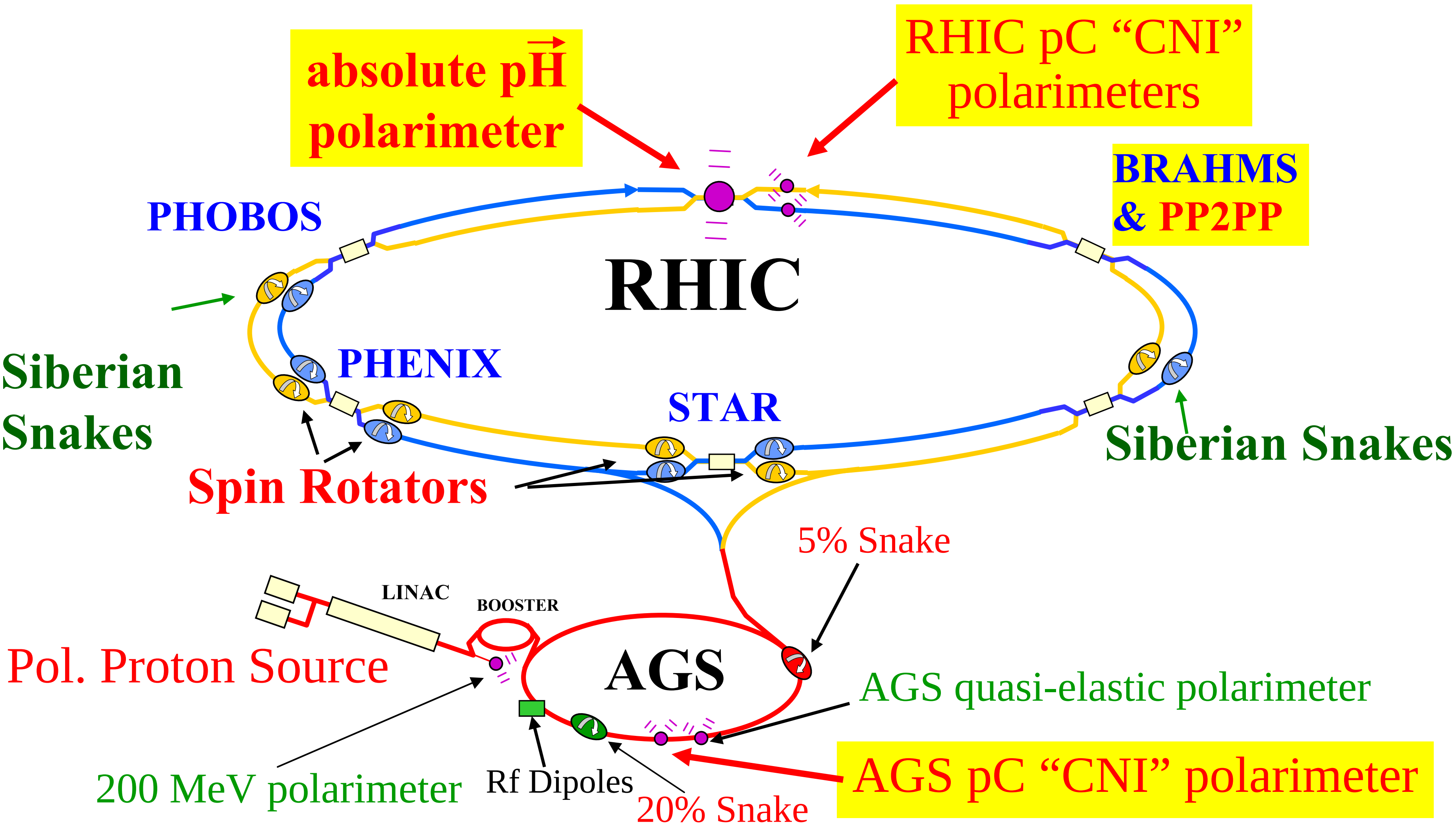
The Relativistic Heavy Ion Collider



RHIC is a QCD Laboratory:

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

RHIC-Spin Accelerator Complex



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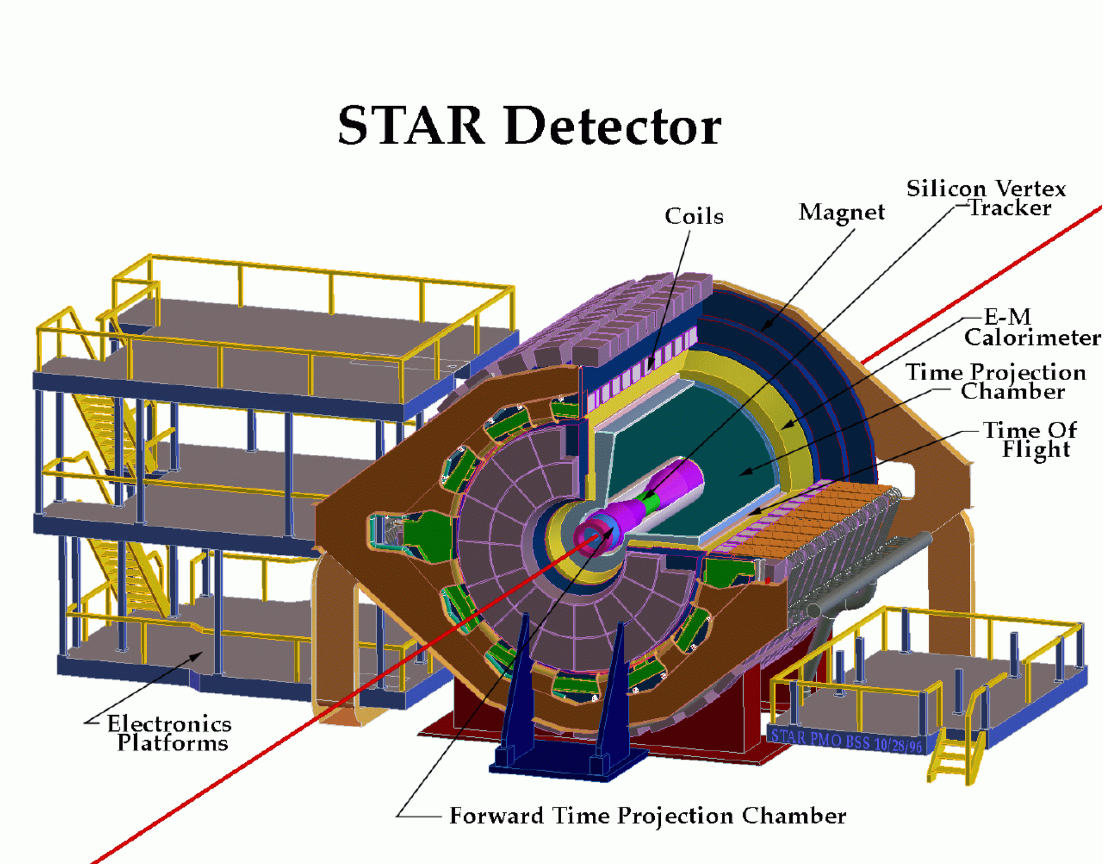
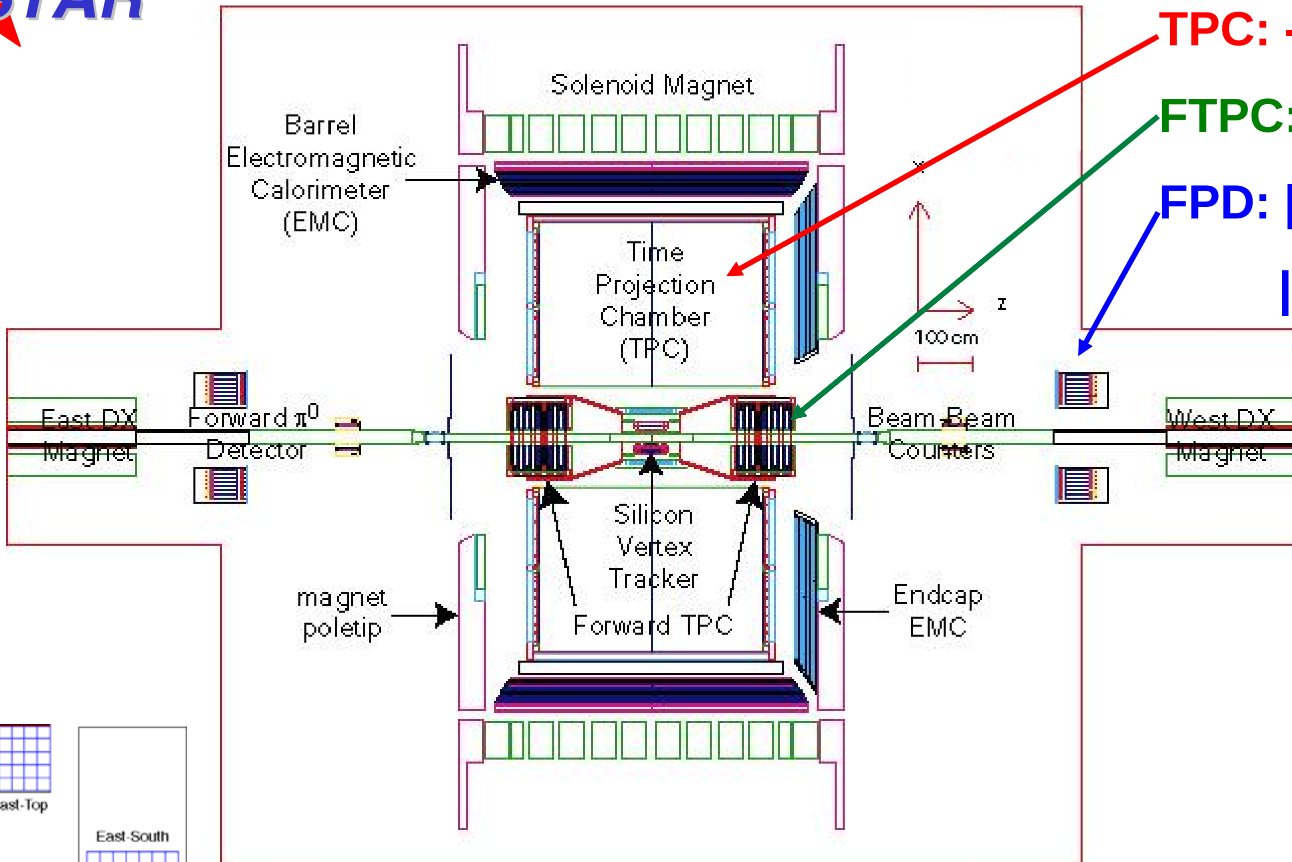
STAR Detector



Time Projection Chamber: 45 padrow, 2 meters (radius), σ(dE/dx)≈8%, $-1<\eta<1$

Multi-gap Resistive Plate Chamber TOFr: 1 tray (~1/200), σ(t)=85ps

STAR Detector

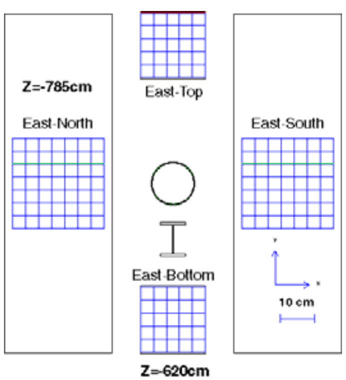


TPC: $-1.0 < \eta < 1.0$

FTPC: $2.8 < |\eta| < 3.8$

FPD: $|\eta| \sim 3.8$ (p+p)

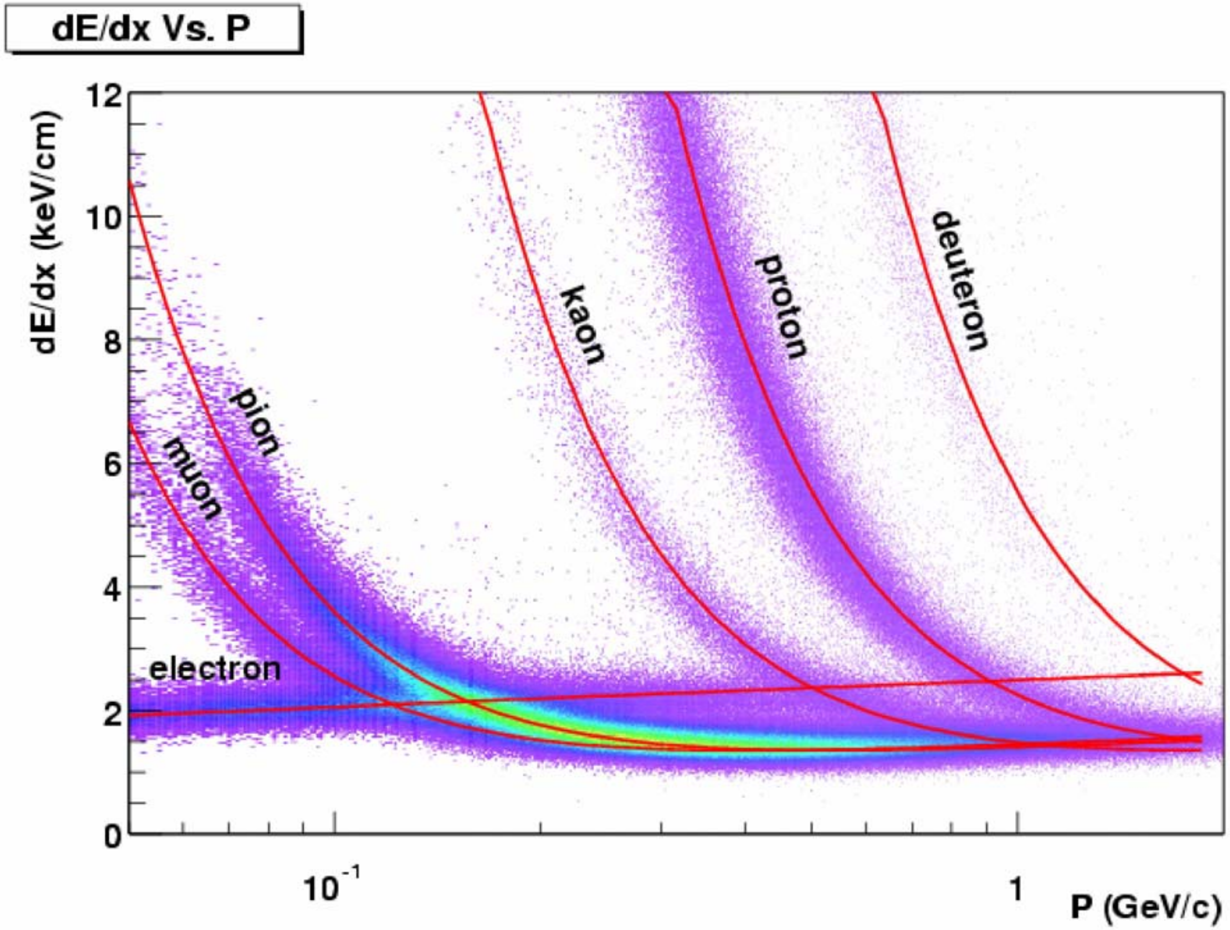
$|\eta| \sim 4.0$ (p+p, d+Au)



Forward π^0 Detector (FPD)

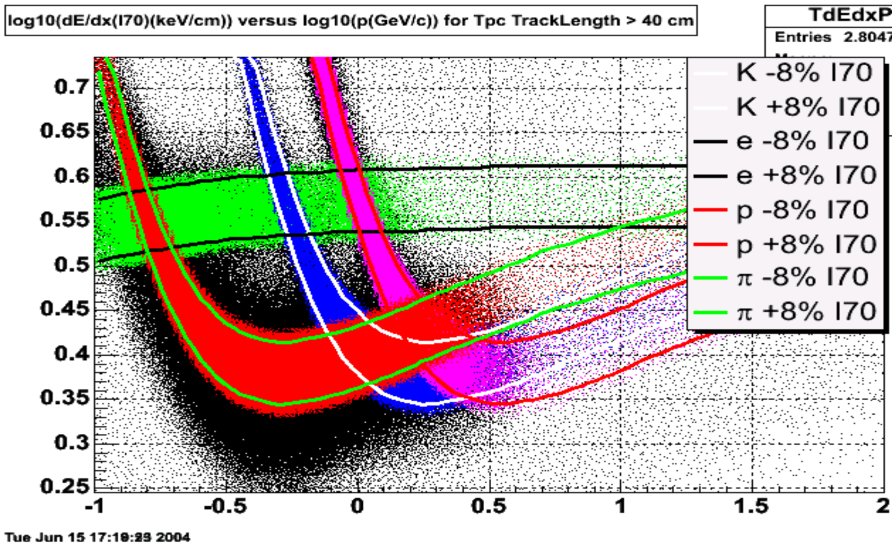
- **Pb-glass EM calorimeter**
- **Shower-Maximum Detector (SMD)**
- **Preshower**

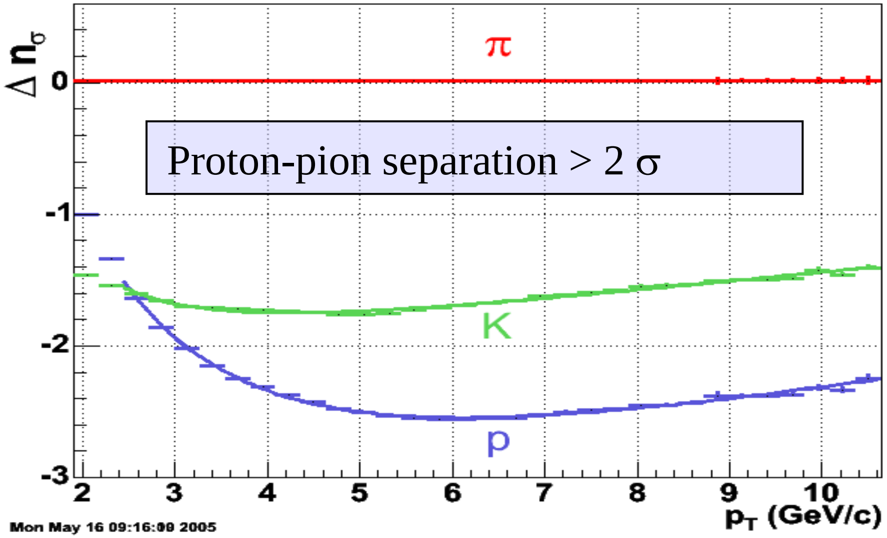
TPC dE/dx at low p_T



M. Anderson et al., Nucl. Instrum. Meth. A 499, 659 (2003)

TPC dE/dx at higher p_T

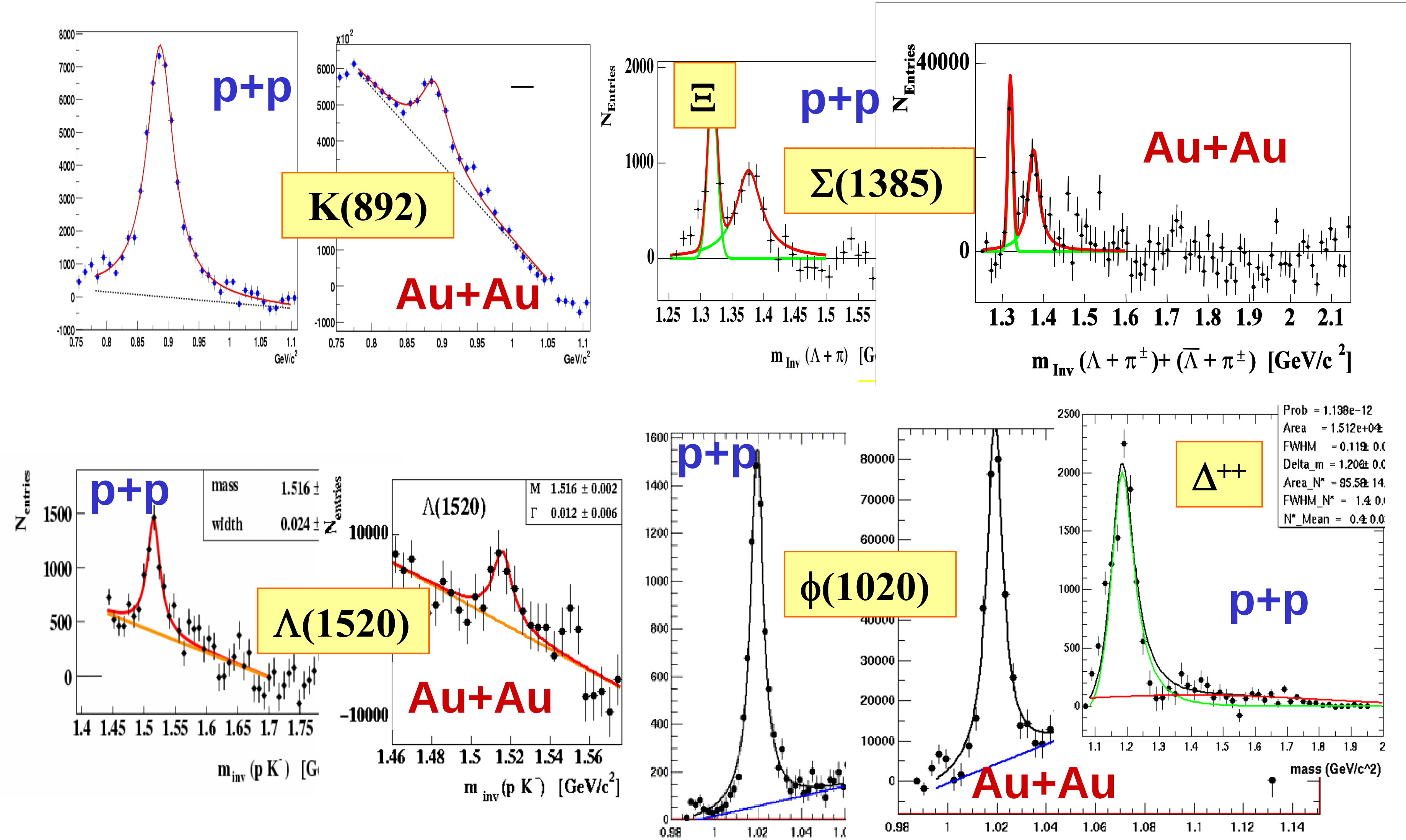




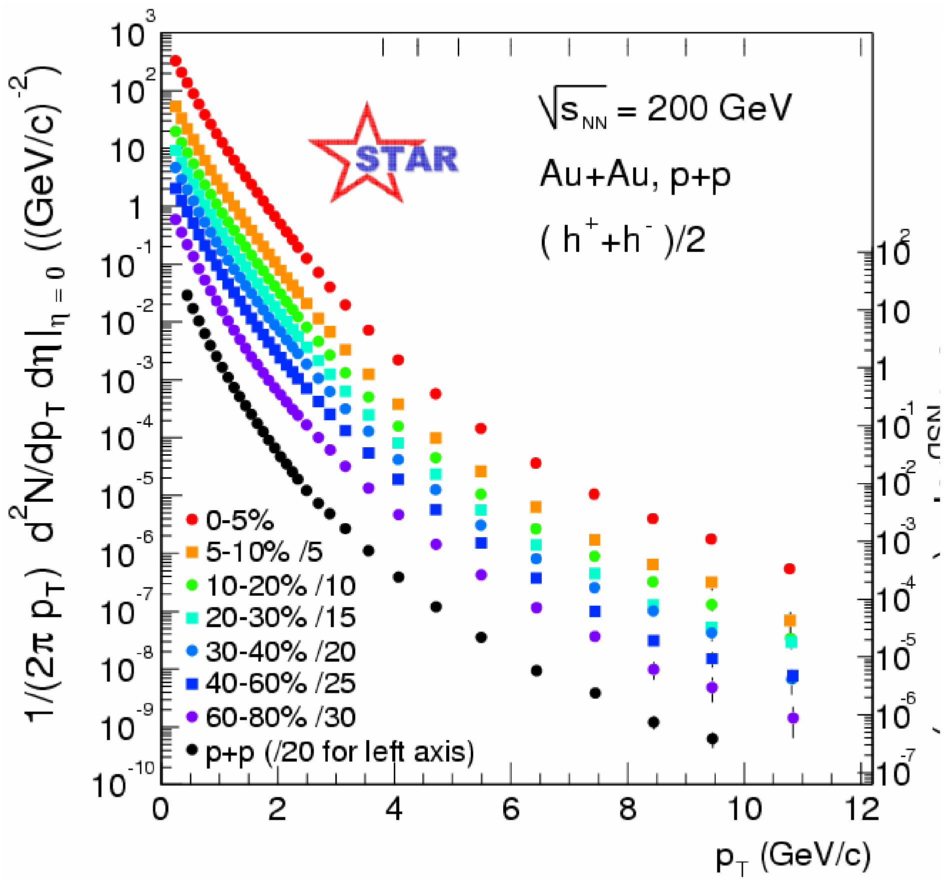
Momentum: $3 < p < 10$ GeV/c

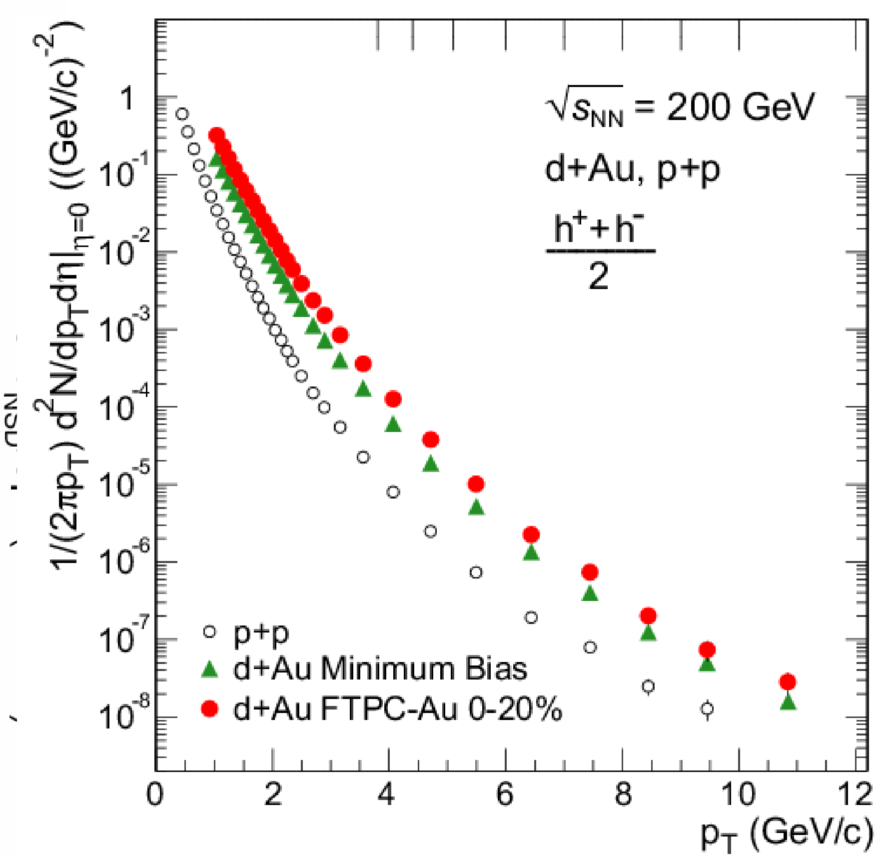
dE/dx of π (K,p) separation: 2σ

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



Leading particle spectra`

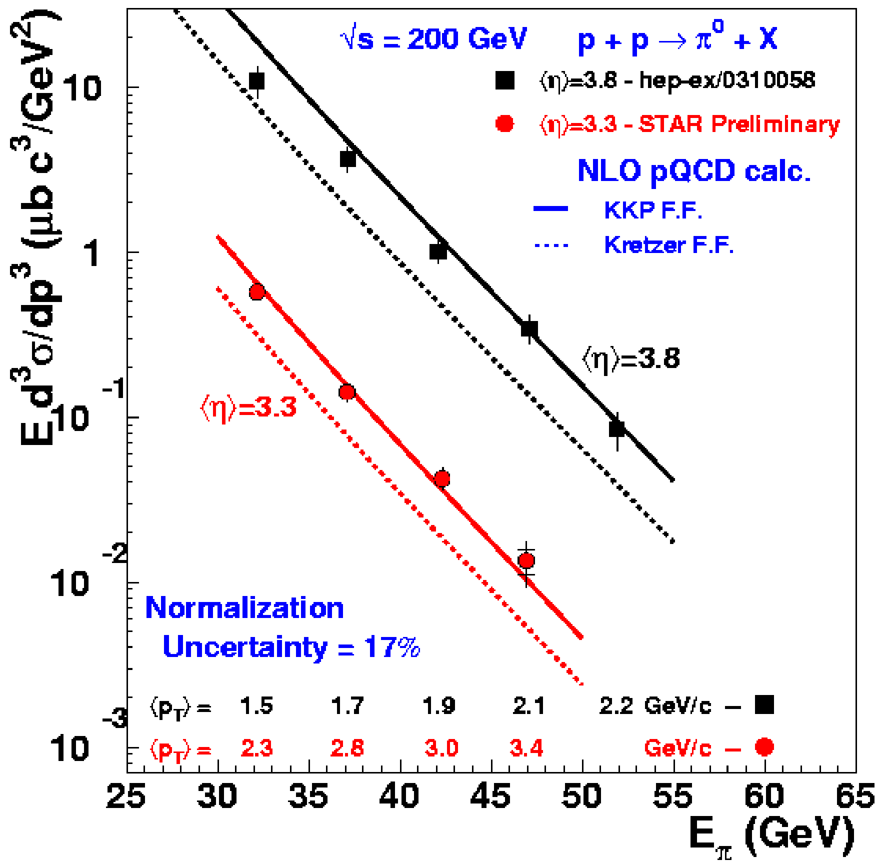




Charged hadron p_T distributions measured up to 12 GeV
in Au+Au, d+Au and p+p reference

Forward π^0 Production

STAR



Run-2 STAR data at

- $\langle\eta\rangle$= 3.8 (PRL **92**, 171801 (2004); hep-ex/0310058)
- $\langle\eta\rangle$= 3.3 (hep-ex/0403012, Preliminary)

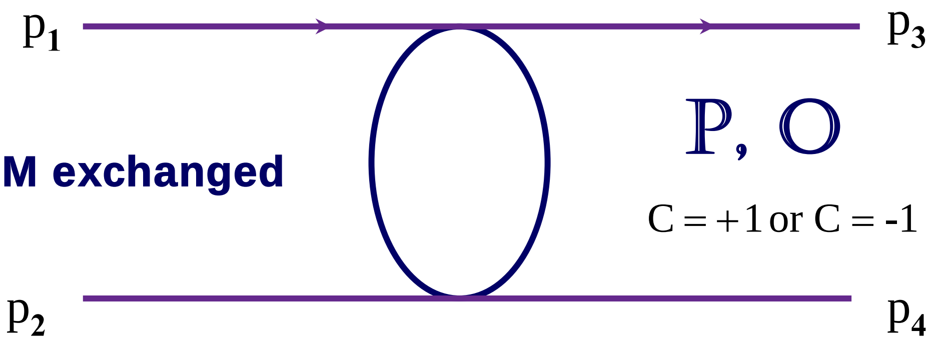
NLO pQCD calculations at fixed η with equal factorization and renormalization scales = p_T

STAR are data consistent with Next-to-Leading Order pQCD calculations, unlike at smaller $\sqrt{s}$

The pp2pp Experiment

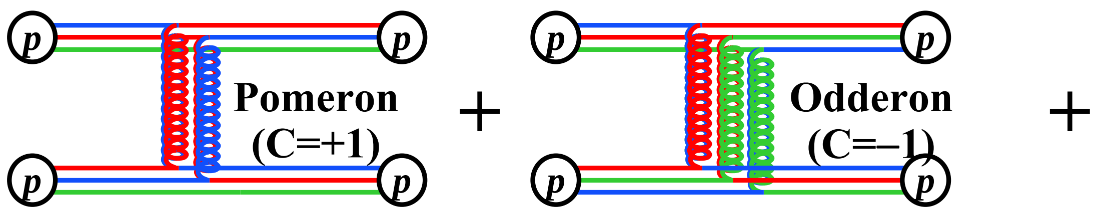
(proton proton elastic scatetring)

Vacuum QM exchanged



$$A(pp \rightarrow pp) = A_P + A_O$$
$$A(p\bar{p} \rightarrow p\bar{p}) = A_P - A_O$$

Perturbative QCD Picture



$s = (p_1 + p_2)^2 =$ (C.M energy)^2 $t = (p_1 - p_3)^2 = -$ (four momentum transfer)^2

$s \rightarrow \infty$ $|t| \leq 1$ (GeV/c)^2 – Non-perturbative regime

Elastic scattering $d\sigma/dt$ + optical theorem $\Rightarrow$ total cross section σ_{tot}

Summary of Existing Data

Highest energy so far:

pp: 63 GeV (ISR)

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

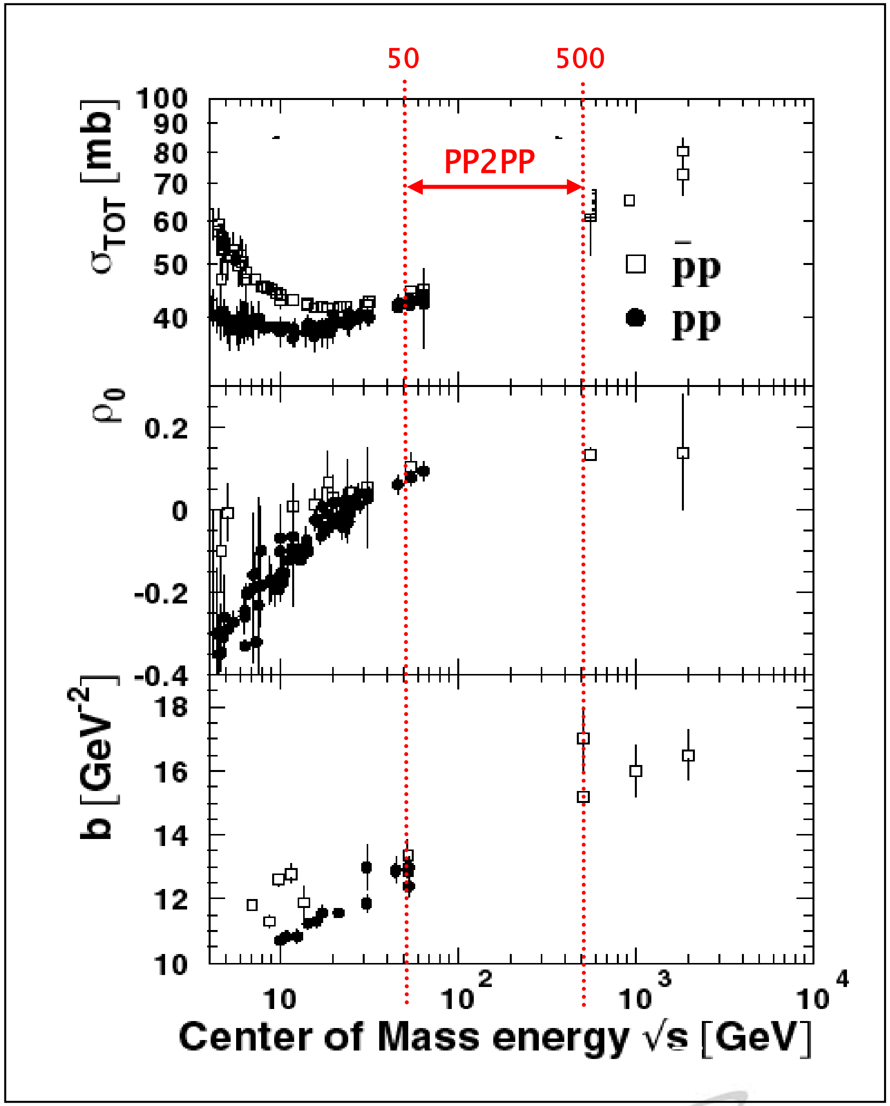
pp2pp energy range:

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

pp2pp t–range:

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

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



Elastic pp Scattering

1. The elastic scattering process contributes about 20% of the total interaction cross section.
2. pp and $p\bar{p}$: the predicted total cross sections still differ in RHIC range, the difference needs to be measured experimentally.
3. The Odderon, an exchange with C = -1, has not been observed, even though QCD predicts its existence, a comparison of the diffractive minimum pp and $p\bar{p}$ could provide an answer.
4. Most of the $\sigma_{\mathbf{el}}$ is in the non-perturbative regime of QCD.
5. Spin dependence is a total unknown in the RHIC $\sqrt{s}$ range 50-500 GeV.
6. Great potential for measuring spin dependence in elastic scattering, connection between polarized and unpolarized (dip and A_N crossing zero) will help study dynamics of vacuum exchange processes in QCD.

Spin Dependence in Elastic Scattering

Five helicity amplitudes describe proton-proton elastic scattering

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

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

Some of the measured quantities are

$$\sigma \quad (s) = \frac{4\pi}{s} \operatorname{Im}\left[\phi_+(s,t)\right]_{t=0}$$

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

pp2pp Physics Progarm

RHIC has the **UNIQUE** capability for colliding **POLARIZED** proton beams, further elucidating the exchange dynamics:

Allows measuring the spin dependence of proton-proton elastic scattering and diffraction.

CNI region:_

$0.0004 < -t < 0.02$ (GeV/c)^2 $\sqrt{s} = 200$ GeV

$0.0004 < -t < 0.13$ (GeV/c)^2 $\sqrt{s} = 500$ GeV

σ_{tot}, ρ, B, $d\sigma/dt$, $A_N(t)$, $A_{NN}(t)$

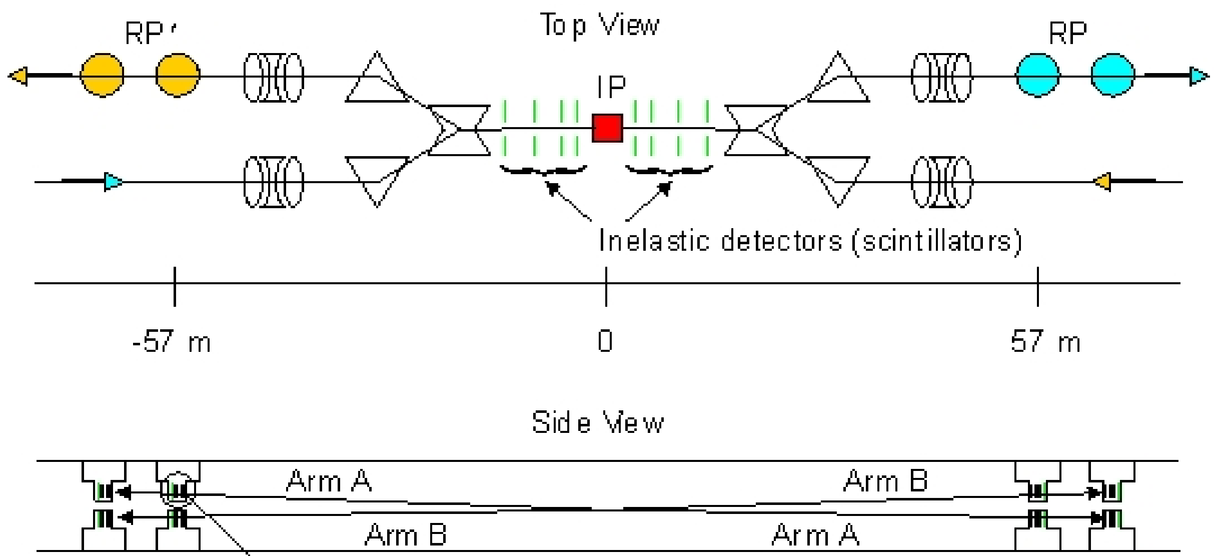
$\Delta\sigma_{tot}$ = 1-2 mbarn (0.5%), $\Delta\rho = 0.005$ (4%), $\Delta A_N(t)$, $\Delta A_{NN}(t) = 0.001$

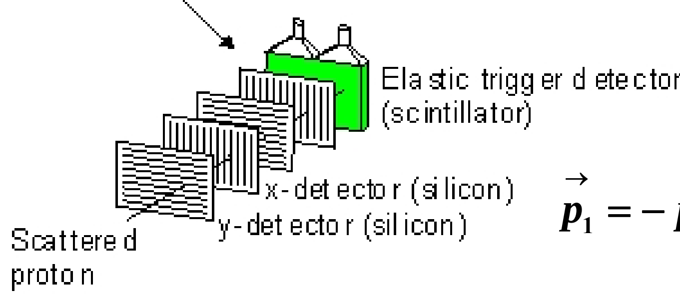
Medium |t| region:

$0.1 < -t < 1.3$ (GeV/c)2 $\sqrt{s} = 500$ GeV

diffractive minimum (peaks and bumps) and their spin dependence

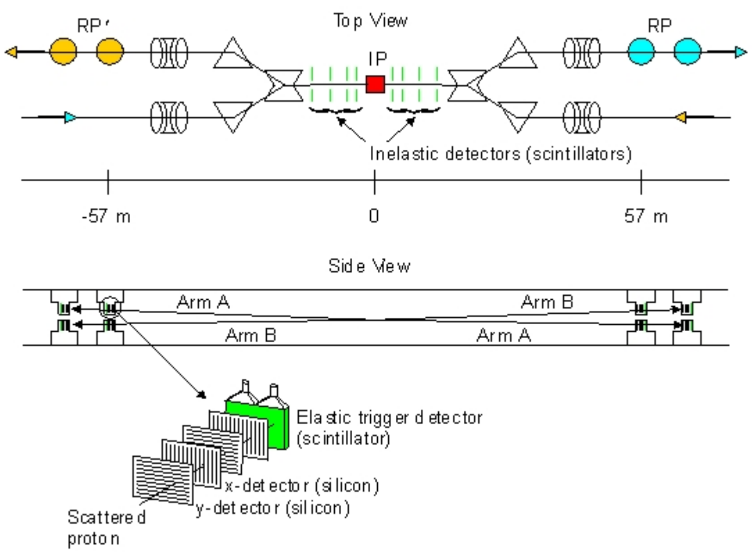
The Setup of pp2pp Experiment





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

pp2pp Setup



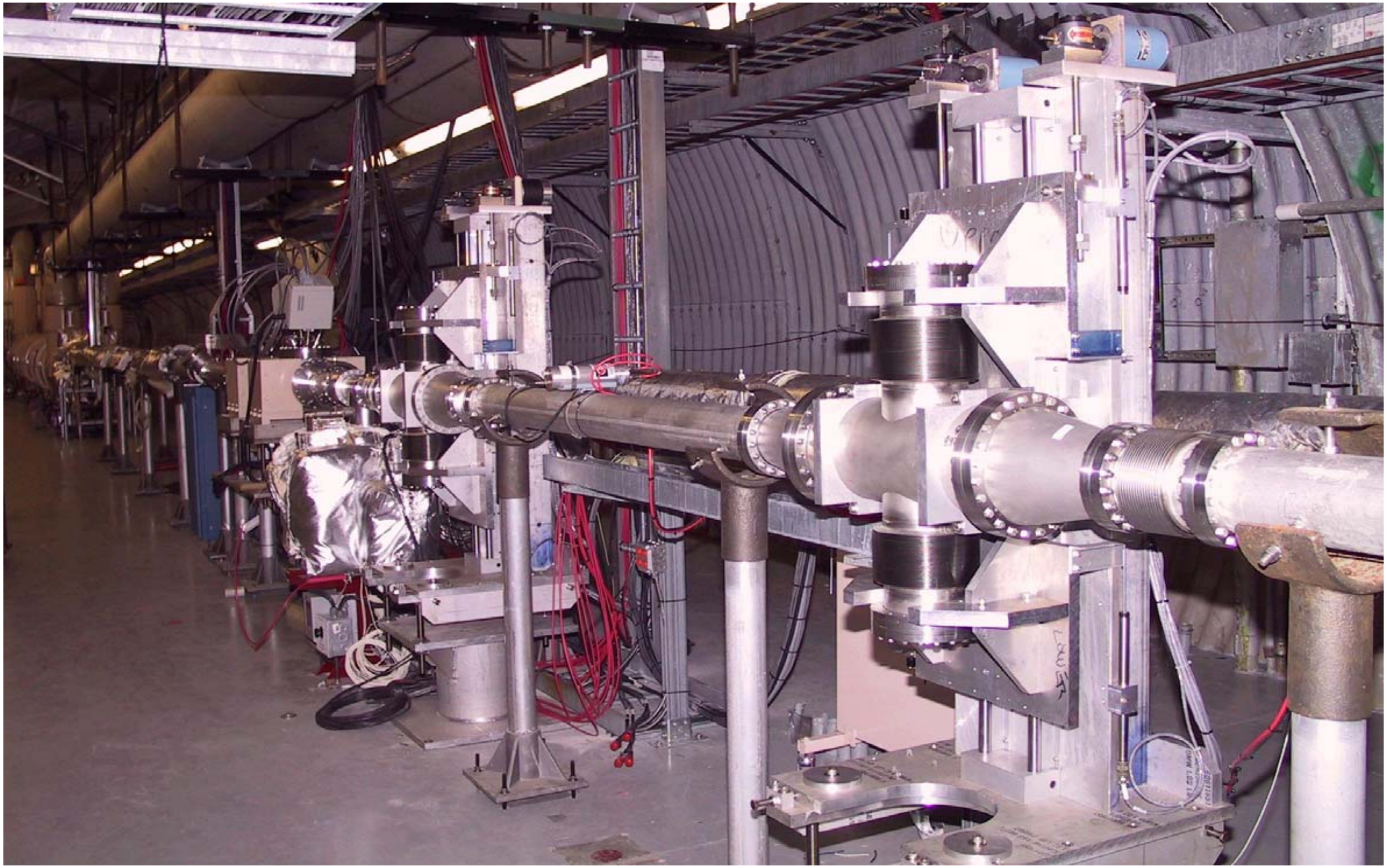
- Elastically scattered protons have small scattering angle θ^*, hence beam transport magnets determine trajectory scattered protons
- The optimal position for the detectors is where scattered protons are well separated from beam protons
- Need Roman Pot to measure scattered protons close to the beam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

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

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

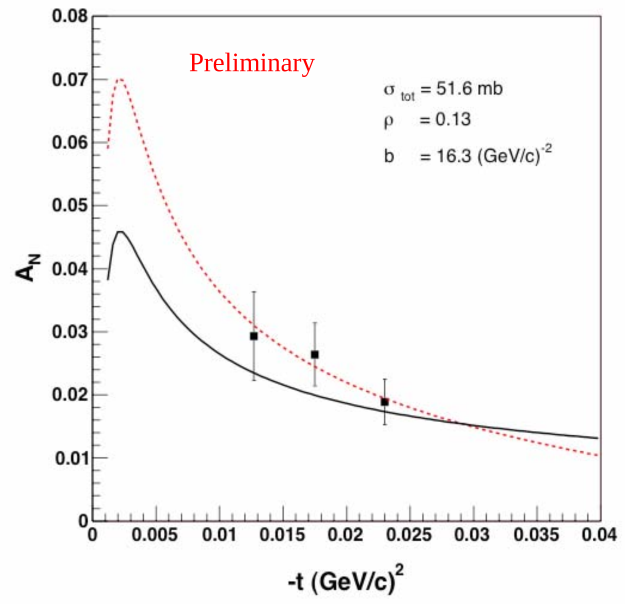
x_0,y_0: Position at Interaction Point
Θ^*_x Θ^*_y : Scattering Angle at IP
x_D, y_D : Position at Detector
Θ^x_D, Θ^y_D : Angle at Detector

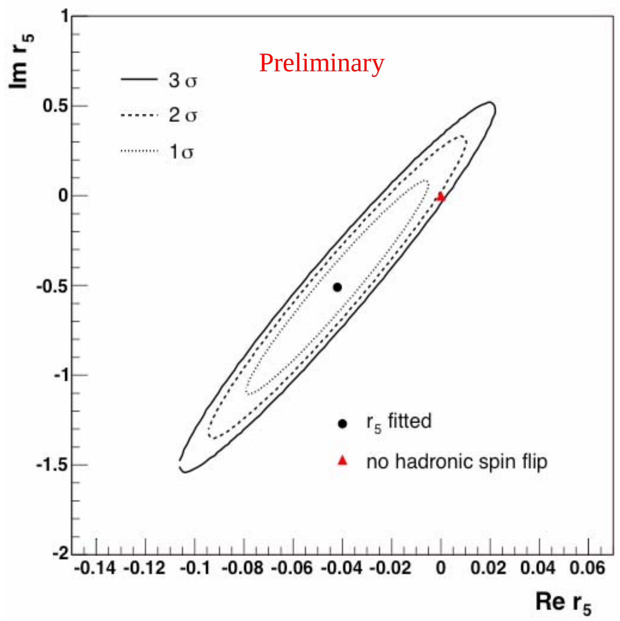
The pp2pp Experimental Setup



Preliminary Results: A_N and r_5

nucl-ex/0507030
Submitted to Phys. Lett. B





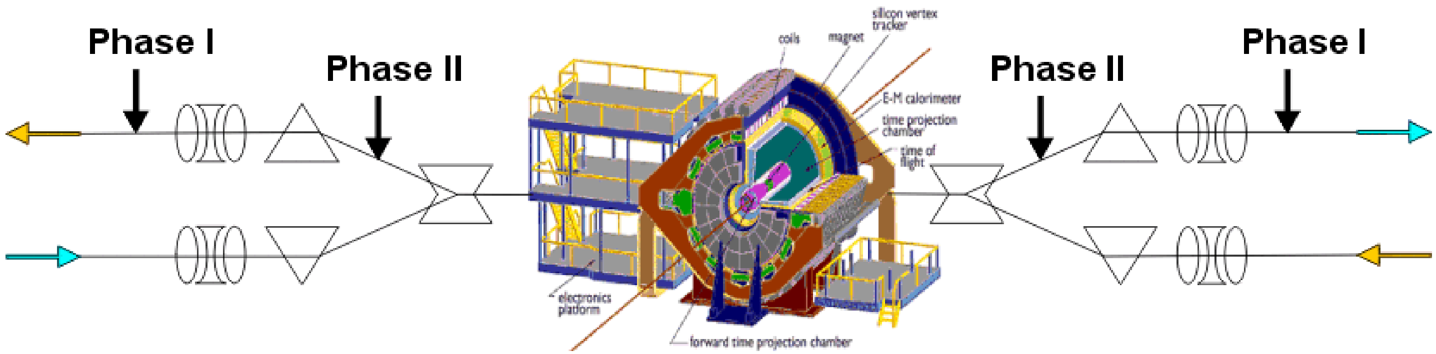
$\text{Re}\, r_5 = -0.042 \pm 0.037$, $\quad \text{Im}\, r_5 = -0.51 \pm 0.60$

Statistical and systematic errors added in quadratures

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

Implementation at RHIC

Detectors to tag forward protons (Roman Pots of pp2pp)
and detector with good acceptance and
particle ID to measure central system (STAR)



Roman Pots of pp2pp and STAR

Physics with Tagged Forward Protons with the STAR Detector at RHIC

H. Spinka
Argonne National Laboratory, USA

R.E. Chrien, R. Gill, W. Guryn*, B. Hackenburg, J. Landgraf, T.A. Ljubičič, D. Lynn,
C. Pearson, P. Pile, S. Tepikian, K. Yip
Brookhaven National Laboratory, USA

A. A. Bogdanov, S.B. Nurushev, M.F Runtzo
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

B. Surrow
MIT, Boston USA

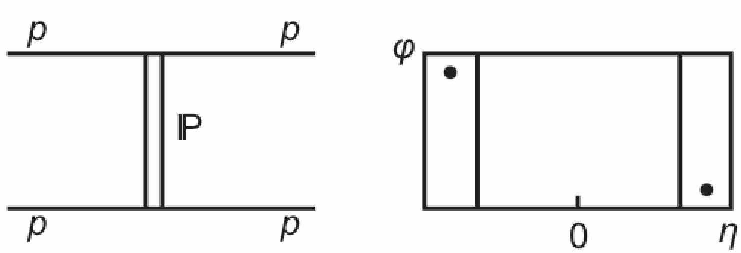
S. Khodinov, M. Rijssenbeek
SUNY Stony Brook, USA

A.Sandacz
Soltan Institute for Nuclear Studies, Warsaw, Poland

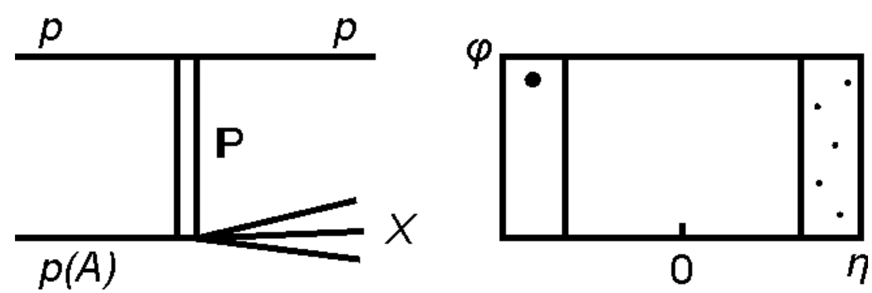
*Contact person

Elastic and Inelastic Processes

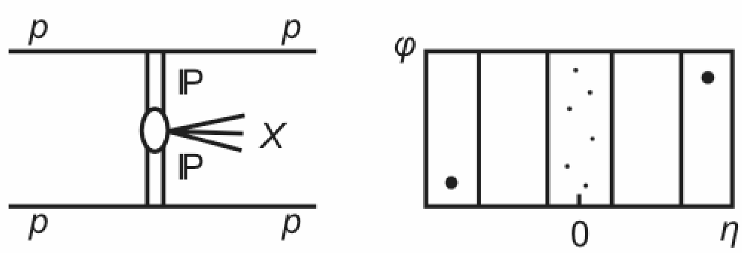
Elastic Scattering



Single Diffraction



Central Production



For each proton vertex one has

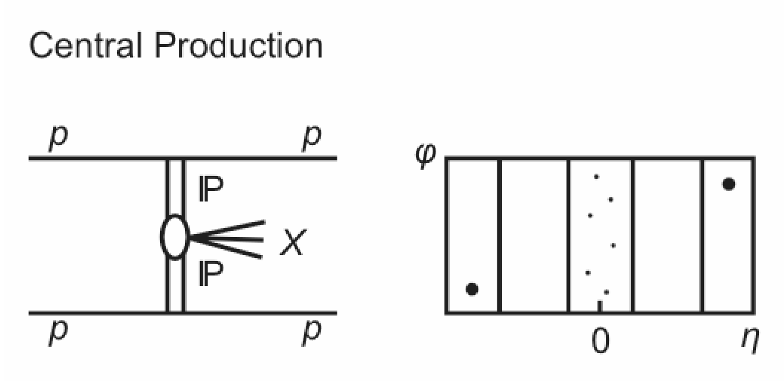
t four-momentum transfer

$\xi = \Delta p/p$

M_X invariant mass

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.

Central Production in DPE

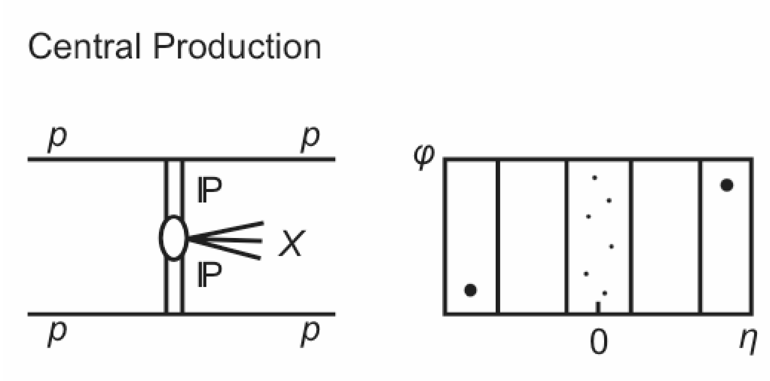


In the double Pomeron exchange process each proton “emits” a Pomeron and the two Pomerons interact producing a massive system MX.

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.

Applies to processes with Odderon exchange: PO or OO

Glueball Central Production in DPE



The idea that the production of glueballs is enhanced in the central region in the process $pp \rightarrow pM_X p$ was first proposed by F.Close and was demonstrated by WA102.

The pattern of resonances produced in central region depends on:

$$dP_T = |\ \bar{k}_{T1} - \bar{k}_{T2}|$$

When $dP_T \propto$ LQCD $\bar{q}q$ states are prominent and when dP_T is small the surviving resonances include glueball candidates.

Summary

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

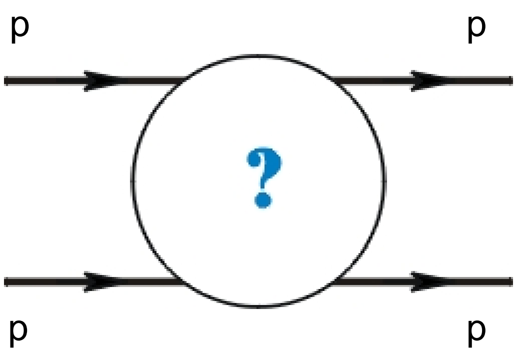
- Study of standard hadron diffraction both elastic and inelastic and its spin dependence in unexplored t and $\sqrt{s}$ range;
- Study of the structure of color singlet exchange in the non-perturbative regime of QCD.
- Study of processes with leading particle(s).

- Search for central production of light and massive systems in double Pomeron exchange process - glueballs (final states with charged particles).
- Search for an Odderon - a firm prediction of QCD and an eigenstate of CGC.

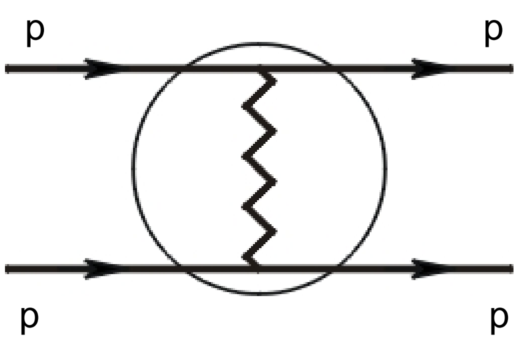
The expectation of this workshop is to formulate the plan for Odderon search at RHIC and possibly other exciting topics.

There is a great potential for important discoveries at RHIC in the field of elastic and inelastic diffraction.

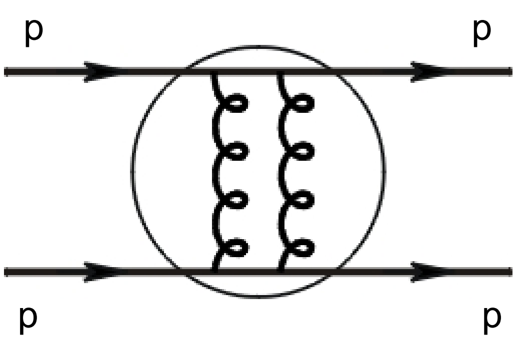
Physics Processes



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



Non Pert. QCD



PQCD picture