Central Production with Tagged Forward Protons and the STAR Detector at RHIC

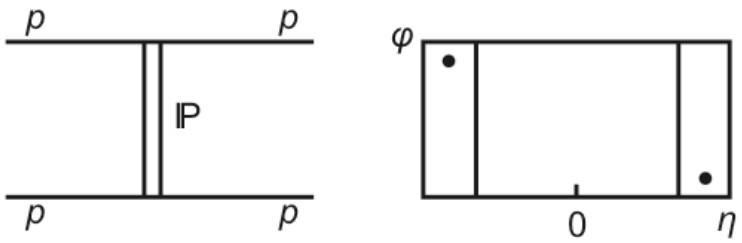
Włodek Guryn
Brookhaven National Laboratory

- Process of diffraction and Central Production
- Central production at RHIC, glueball search in DPE
- Setup at RHIC with the STAR detector
- Summary

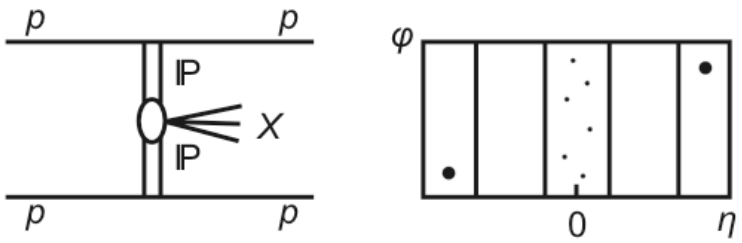
Hadron07 Frascatti 8 - 13 October, 2007

Elastic and Inelastic Processes

Elastic Scattering



Central Production



Physics with tagged forward protons

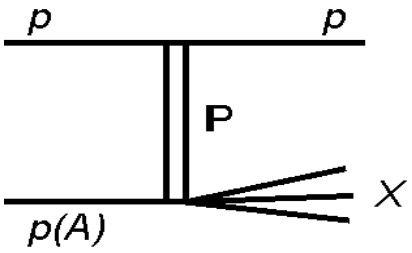
p + p → p + p

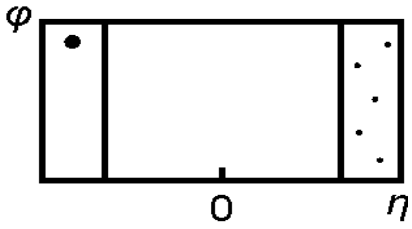
elastic

p + p → p + X + p

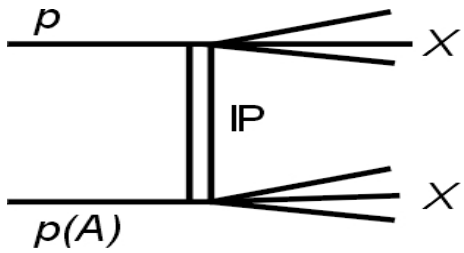
diffractive X= particles, jets, W, J/Ψ, Higgs, glueballs….

Single Diffraction

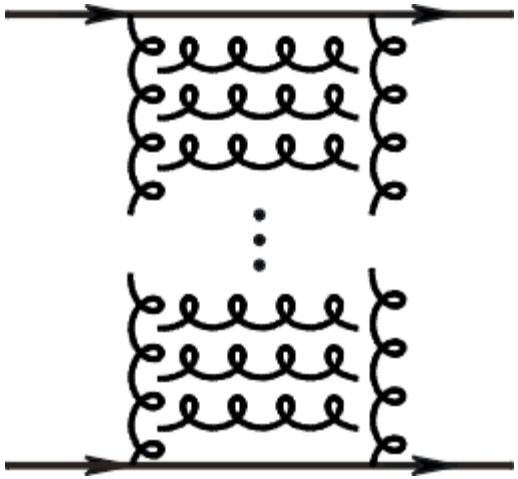




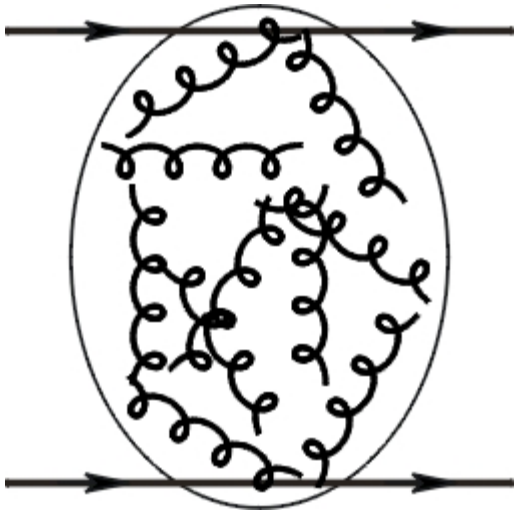
Double Diffraction



PQCD Picture



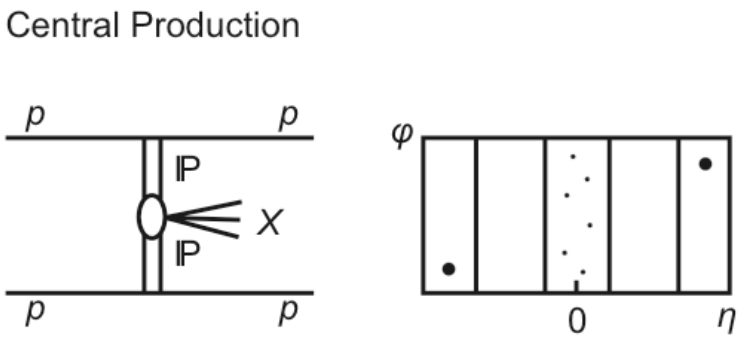
Gluon Ladders



Gluonic Exchanges

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

Central Production in DPE



For each proton vertex one has
t four-momentum transfer
ξ = Δp/p
M_X invariant mass

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

where $M_X = \pi^+\pi^-, \chi_c(\chi_b)$, qq(jets), H(Higgs boson), gg(glueballs)

The massive system could form resonances. We expect that because of the constraints provided by the double Pomeron interaction, glueballs, hybrids, and other states coupling preferentially to gluons, will be produced with much reduced backgrounds compared to standard hadronic production processes.

Glueball Spectrum

Sparse spectrum!

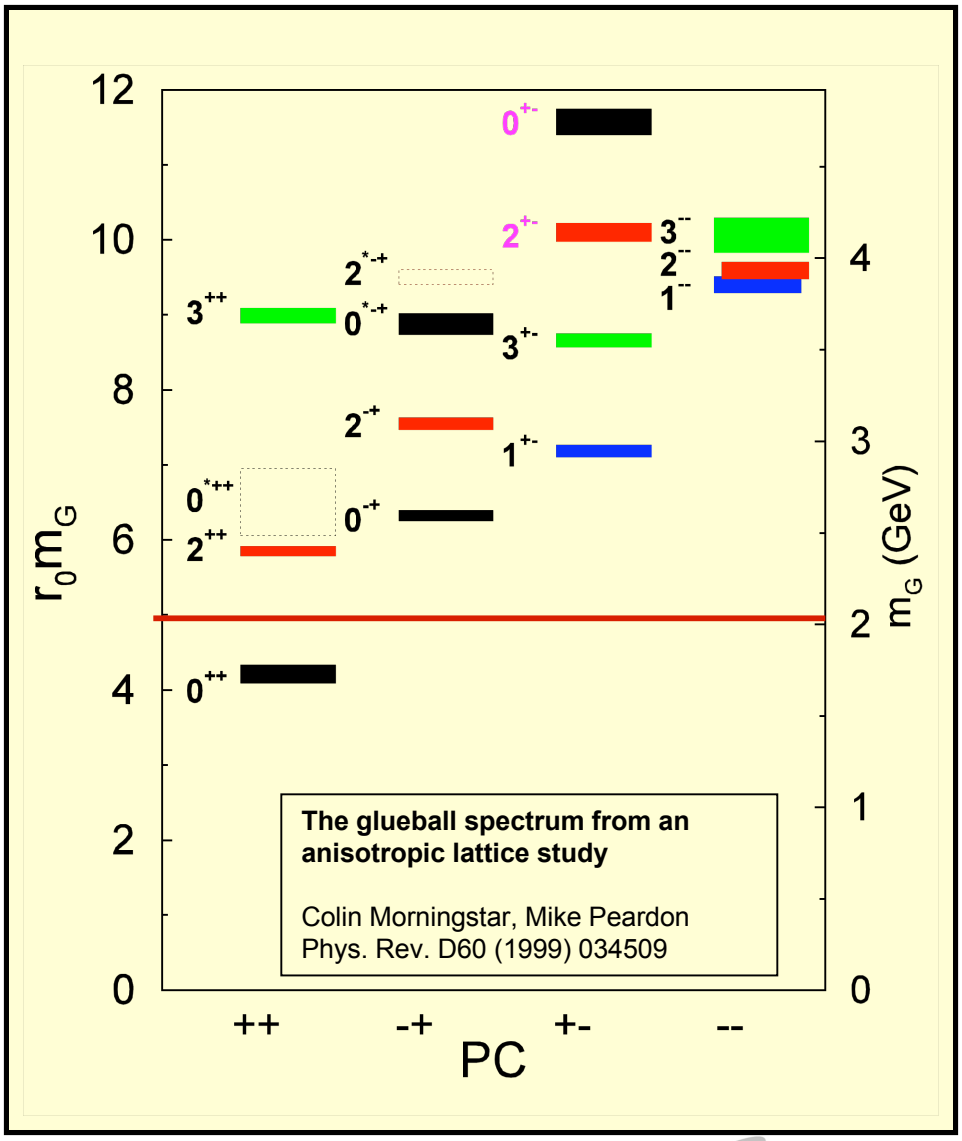
New I=0 mesons starting with

0^{++} 1.6 GeV

0^{-+} , 2^{++} 2.3 - 2.5 GeV

No **J^{PC}-exotic** glueballs until

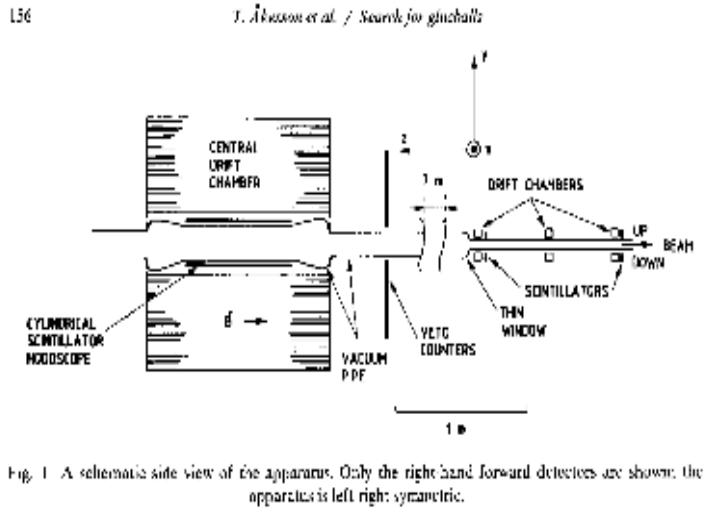
2^{+-} at 4 GeV

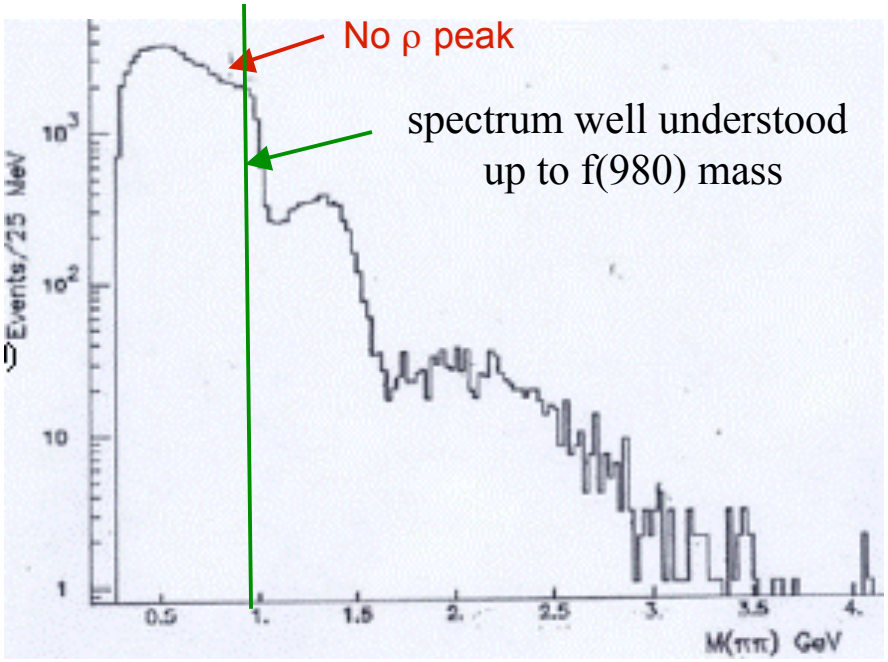


Central Production Has a Long History

First collider exp: *A search for glueballs and a study of double pomeron exchange at the **CERN ISR***

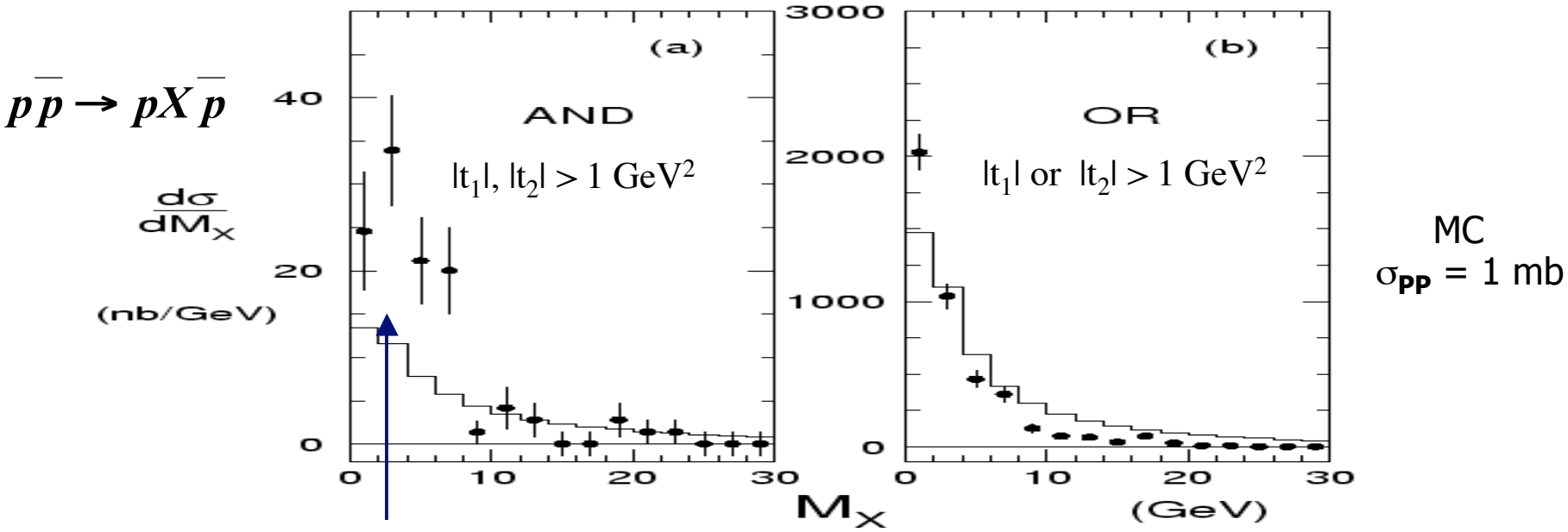
Nuclear Physics B, Volume 264, 1986, Pages 154-184, T. Åkesson, M. G. Albrow, et al.





$3 \cdot 10^6$ events, high statistics $pp \rightarrow pp\pi^+\pi^-$ shows behaviour S-wave (no ρ production)

UA8 Double-Pomeron-Exchange at the Spp̄S

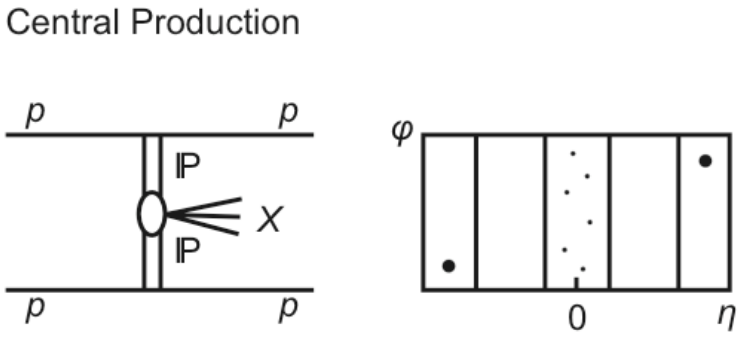


UA8 pioneered hard diffraction - jet production.

"AND" data sample: Proton and Antiproton seen; "OR" data sample: Proton or Antiproton seen. There is large enhancement, as compared to factorization prediction in σ_{PP} for $M_x = M_{JJ} < 6$ GeV, very pronounced in the "AND" data with $\Delta Pt = 0$

This may be a signature for glueball production or questions the assumption of factorization in the model.

Glueball Central Production at RHIC



Method is complementary to:
- GLUEX experiment
- PANDA experiment
- BES
- COMPASS

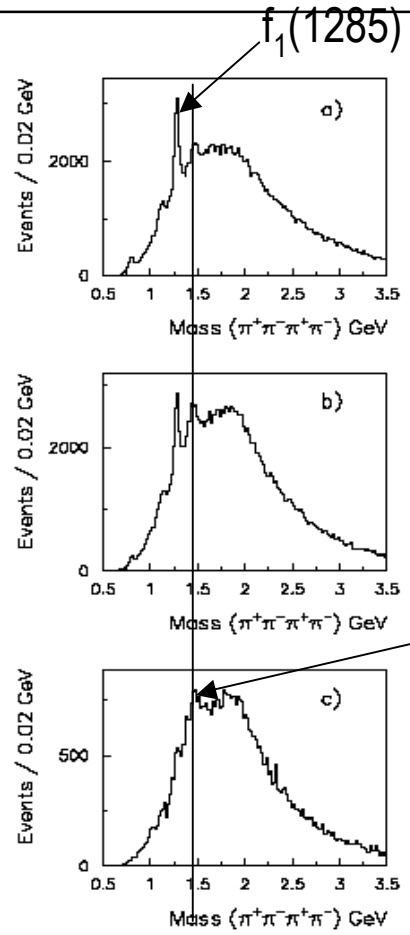
The idea that the production of glueballs is enhanced in the central region in the process pp → pM_Xp was first proposed by F.Close and was demonstrated by WA102 expt.

The pattern of resonances produced in central region depends on:

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

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

WA102 F(1500) $\pi^+\pi^-\pi^+\pi^-$



$dP_T > 0.5$ GeV.

Strong $q\bar{q}$ $f_1(1285)$, weak G? $f_0(1500)$

0.2 GeV < dP_T < 0.5 GeV.

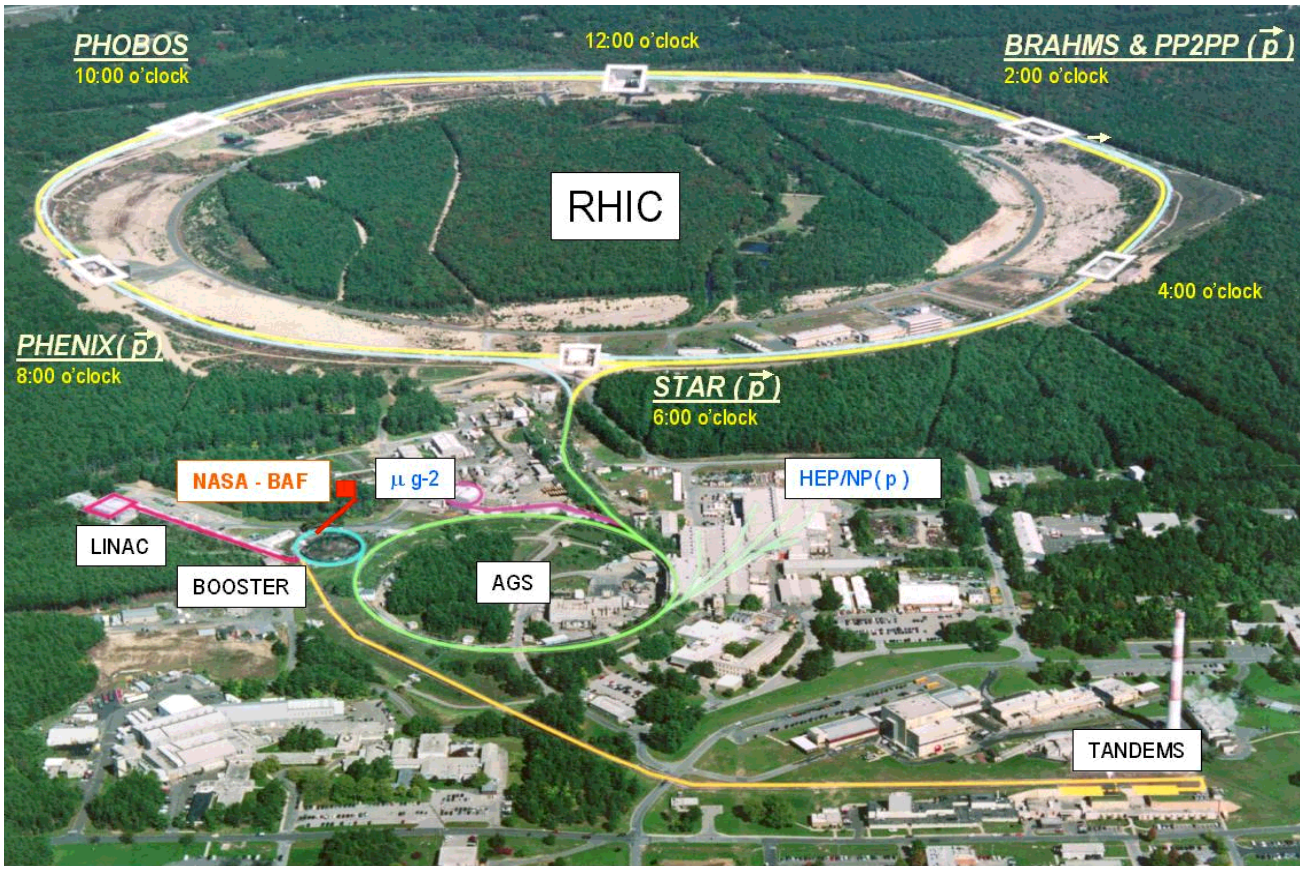
F.E.Close and A.Kirk, PLB397, 333 (1997).

$dP_T < 0.2$ GeV.

Very weak $q\bar{q}$ $f_1(1285)$, stronger G? $f_0(1500)$

Figure 3: The 4π mass spectra (i) With $dP_T > 0.5$ GeV exhibiting a clear $f_1(1285)$; (ii) $0.2 < dP_T < 0.5$ GeV (iii) $dP_T < 0.2$ GeV where the $f_1(1285)$ has disappeared while the $f_0(1500)$ is seen more clearly.

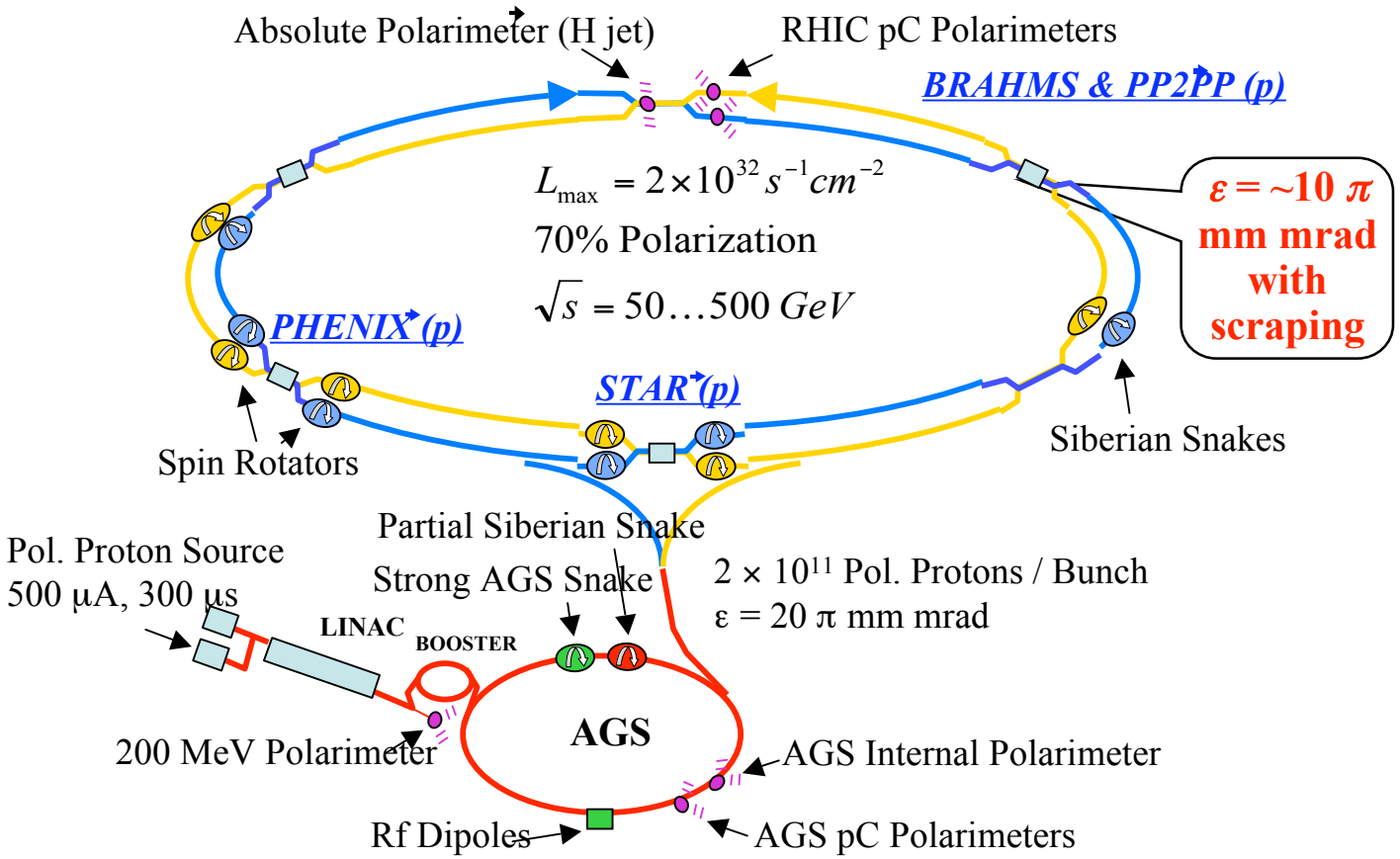
The Relativistic Heavy Ion Collider



RHIC is a QCD Laboratory:

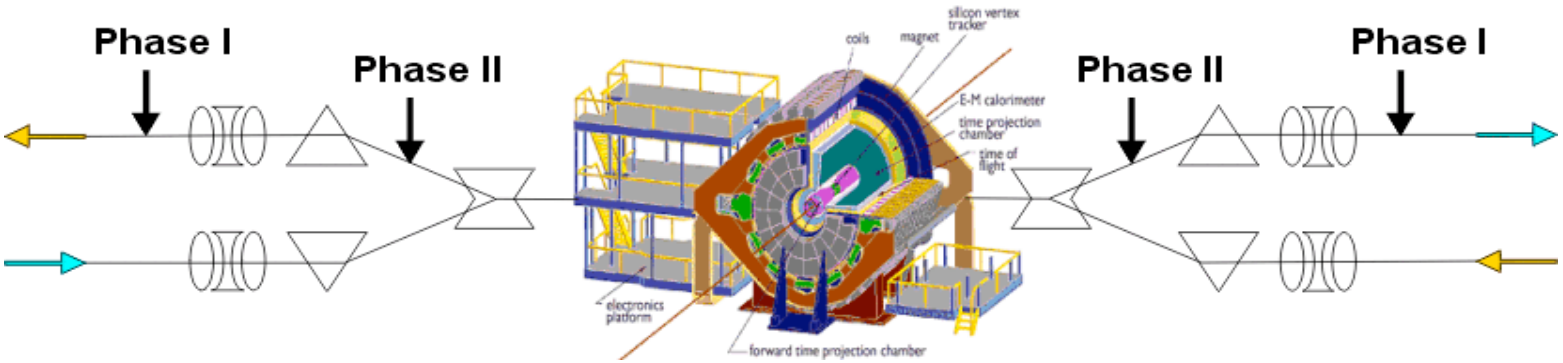
Nucleus- Nucleus collisions (AuAu, CuCu…); Asym. Nucl. (dAu);
Polarized proton-proton; eRHIC - Future

Polarized Proton Collisions at RHIC



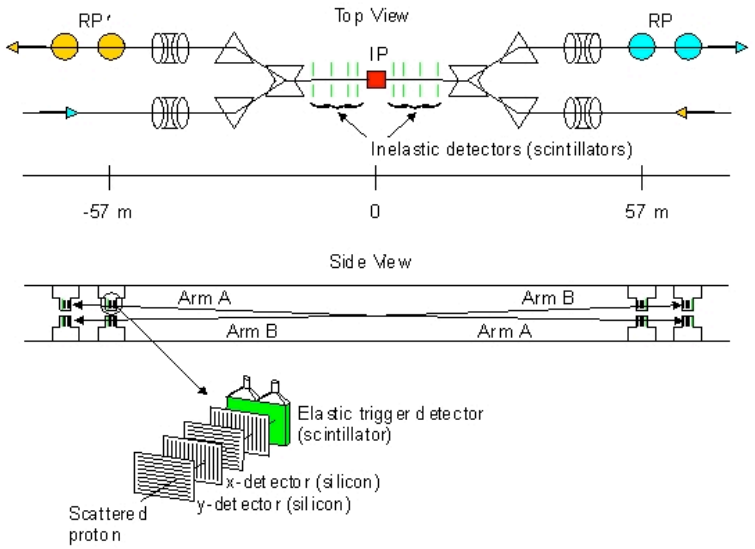
Implementation at RHIC

1. Need detectors to measure forward protons: t - four-momentum transfer, $\xi = \Delta p/p$, M_X invariant mass and;
2. Detector with good acceptance and particle ID to measure central system



Roman Pots of pp2pp and STAR - use existing equipment

Principle of the Measurement of the Forward Protons



- Forward protons have very small scattering angles 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**.

$$\begin{pmatrix} x_D \\ \Theta^x_D \\ y_D \\ \Theta^y_D \end{pmatrix} = \begin{pmatrix} a_{11} & L^x_{eff} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & L^y_{eff} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{pmatrix} \begin{pmatrix} x_0 \\ \Theta^*_x \\ y_0 \\ \Theta^*_y \end{pmatrix}$$

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

Reconstruction of the Proton Momentum Loss ξ

1. Need to measure vector at the detection point, hence two RPs are needed on each side of STAR.

2. For a proton, which scatters with Θ and ξ we have:

$$x_1 = a_1 x_0 + L_1 \Theta_x + \eta_1 \xi ; \quad \text{detection point 1}$$
$$x_2 = a_2 x_0 + L_2 \Theta_x + \eta_2 \xi ; \quad \text{detection point 2}$$

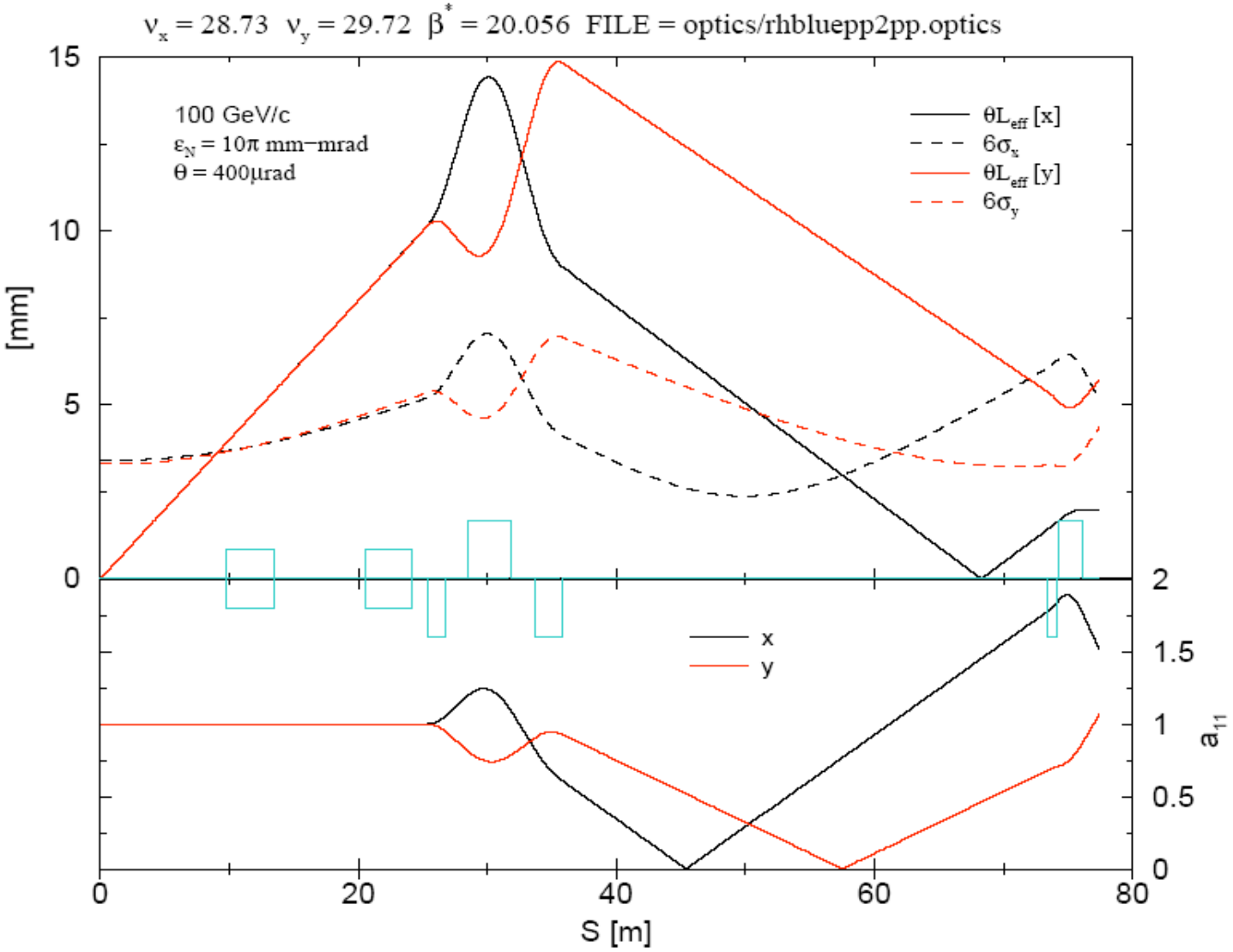
⇐ Accelerator transport

$$\begin{pmatrix} \Theta_x \\ \xi \end{pmatrix} = \frac{1}{Det} \begin{pmatrix} \eta_2; & -\eta_1 \\ -L_2; & -L_1 \end{pmatrix} \begin{pmatrix} x_1 - a_1 x_0 \\ x_2 - a_2 x_0 \end{pmatrix}$$

$$M_X = \sqrt{\xi_1 \xi_2 s} \approx 2\xi \cdot p \Rightarrow \quad \text{For } M_X = 2 \text{ GeV } \xi = 0.01$$

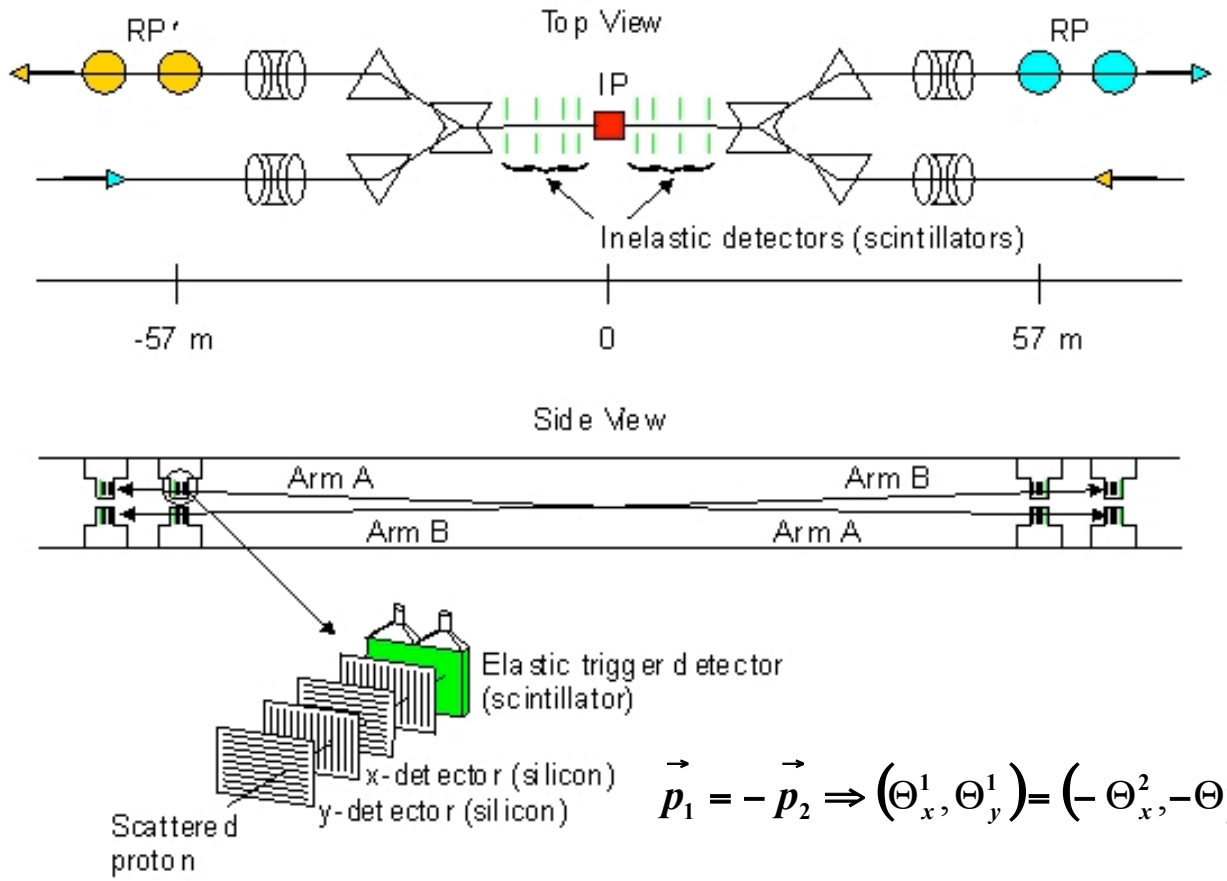
Because Θ and ξ are small special focusing is needed

Proton Trajectory



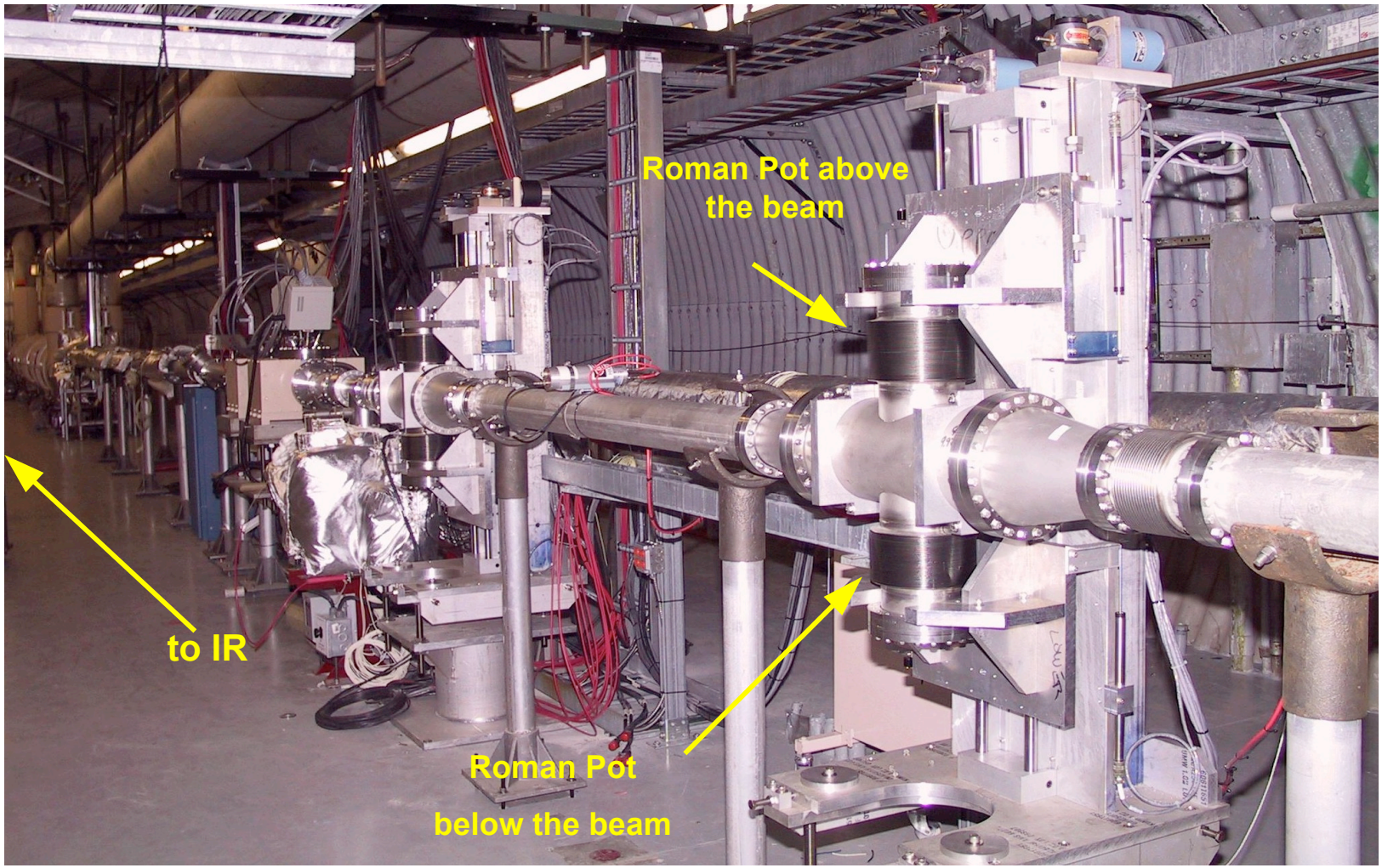
PP2PP Setup - tag forward protons

Phys. Lett. B 579 (2004) 245-250, Phys. Lett. B 632 (2006) 167-172, Phys. Lett. B 647 (2007) 98-103



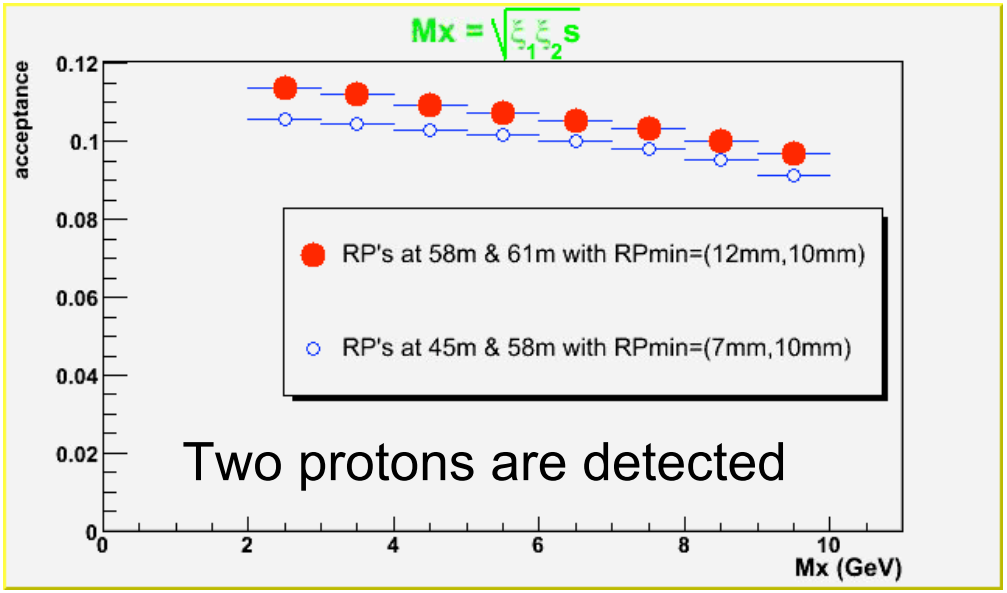
$$\vec{p}_1 = -\vec{p}_2 \Rightarrow (\Theta^1_x, \Theta^1_y) = (-\Theta^2_x, -\Theta^2_y)$$

Roman Pot Stations at RHIC



RHIC: Acceptance Study DPE

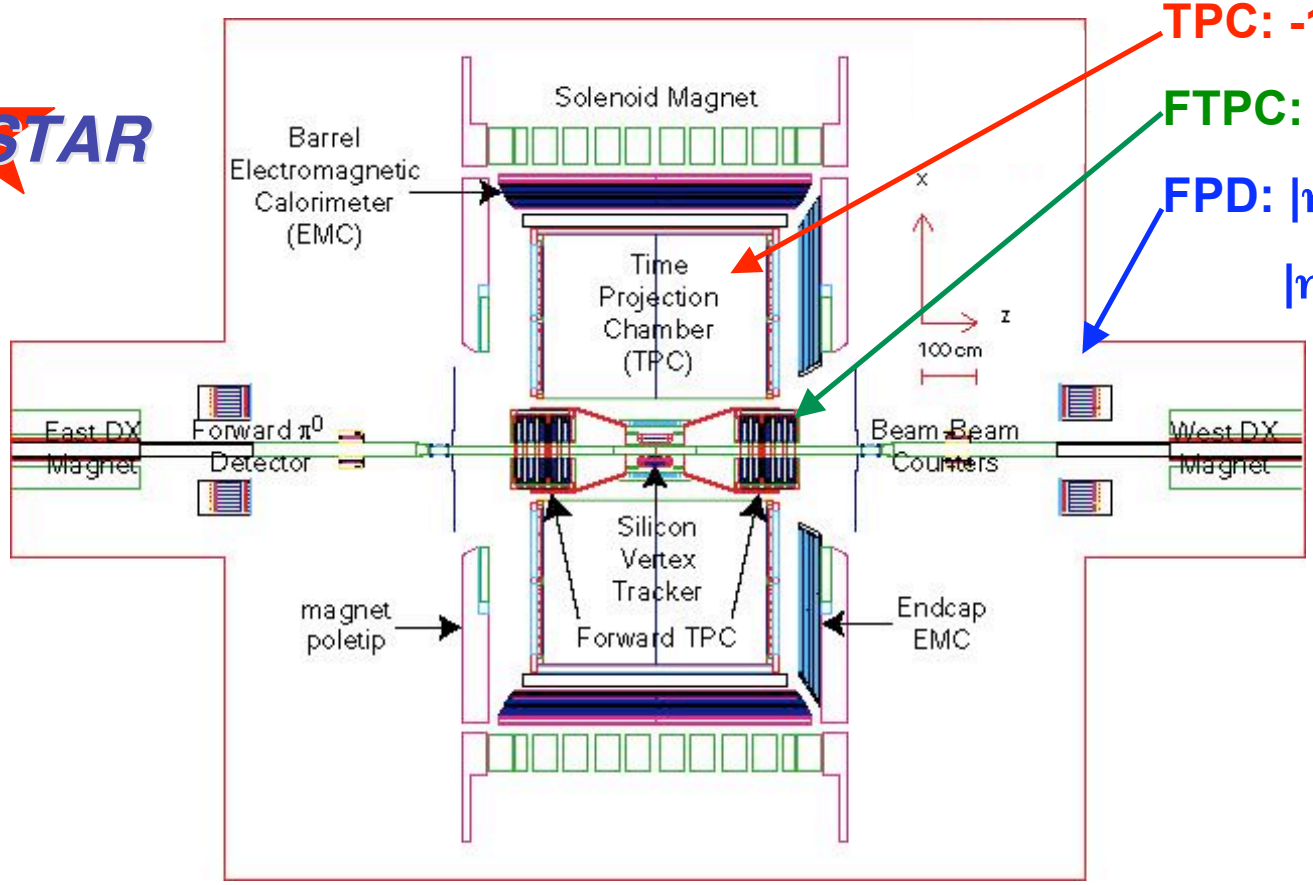
Proton kinematics



In a three day dedicated run we can collect about ~ $4 \cdot 10^6$ triggered DPE events. One assumes a 10μbarn cross section within our acceptance for the DPE process.

Number of events with fully reconstructed proton momentum is factor of ~10 lower (where it is required that two RPs on each side are used).

STAR Detector - measure recoil system M_x



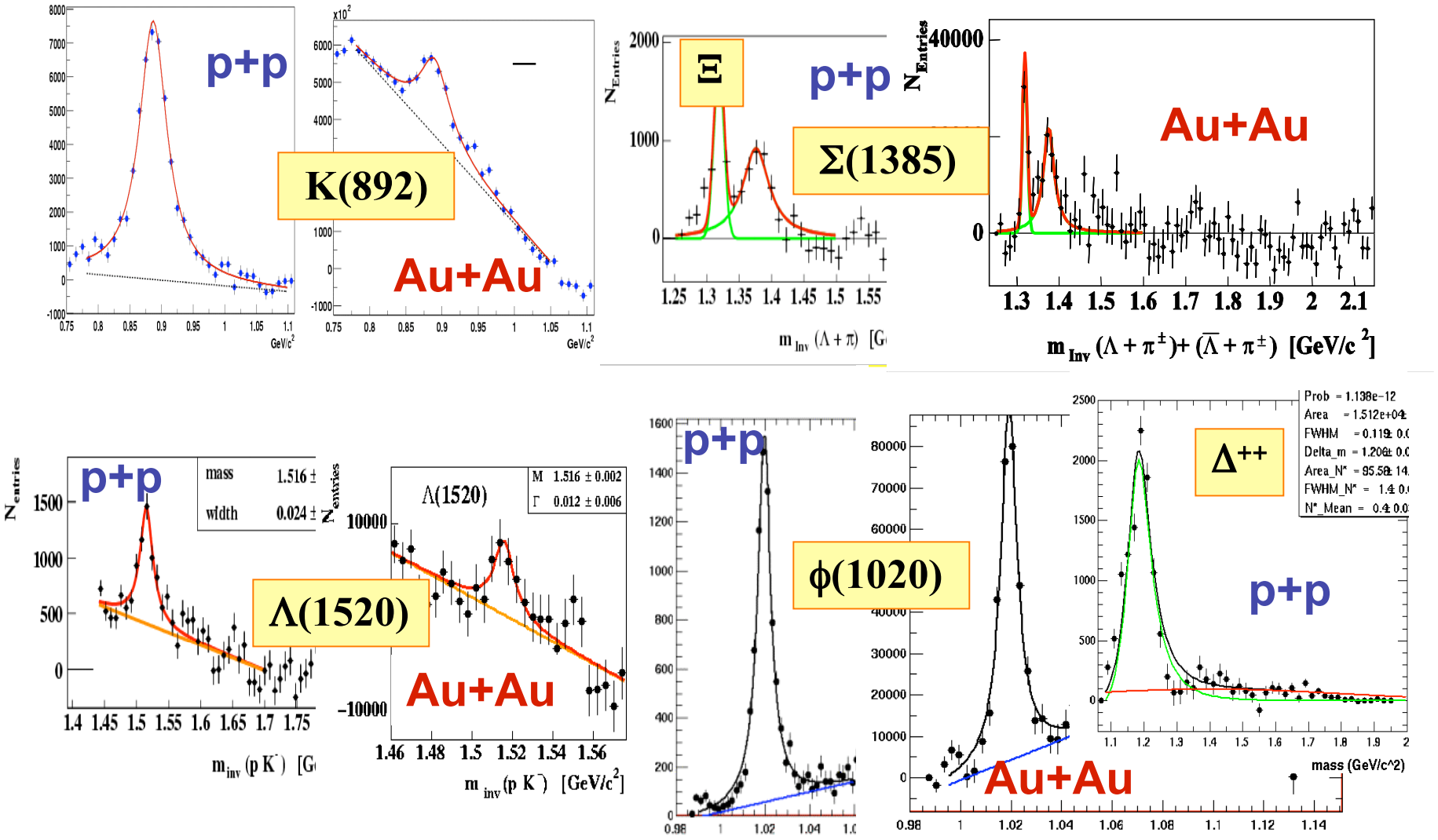
TPC: $-1.0 < \eta < 1.0$

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

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

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

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



Run in 2008 - Phase I Performance

Need to reach small t and ξ values to measure small masses of interest $\Rightarrow$ large β^*=20m, special optics and beam scraping are needed.

Hence a dedicated three-day run is planned (already approved)

Elastic scattering:

1. 100% acceptance for elastic scattering for $0.003 < |t| < 0.024$;
2. 20×10^6 elastic events: Δb=0.31 (GeV/c)-2, $\Delta\rho$=0.01, $\Delta\sigma_{tot}$ = 2-3 mb;
3. In four t subintervals we shall have 5×106 events in each resulting in corresponding errors δA_n=0.0017, $\delta A_{nn}=\delta A_{ss}$=0.003.

DPE process: Luminosity few $\times10^{29}$ $cm^{-2}sec^{-1}$:

- $4.5\cdot10^5$ DPE events with full proton momentum reconstruction;
- $5\cdot10^6$ DPE events with tagged protons - good size data sample for this physics.

Future Possibilities

- Phase II - install RPs so that we can run with STAR without special conditions. RPs need to be between DX-D0 magnets.

- For RPs between DX-D0 - need to study mass acceptance to understand how low in (ξ, t) one can get. Since it is hard to get small t and ξ with standard running there is a problem with low mass acceptance.

- In the future, after Phase II, if this method works, a dedicated experiment could be proposed with a detector which has good photon detection to measure the neutrals would require a substantial team!

Summary

The physics program of tagged forward protons with STAR at RHIC in addition to the elastic scattering will:

1. Study standard hadron diffraction both elastic and inelastic and its spin dependence in unexplored t and √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, hybrids.

4. Search for an Odderon - an eigenstate of CGC.

There is a great potential for important discoveries.

We on track to take data during the next pp run, FY 2008 with Phase I program.

Hope some of you and others will join this effort.