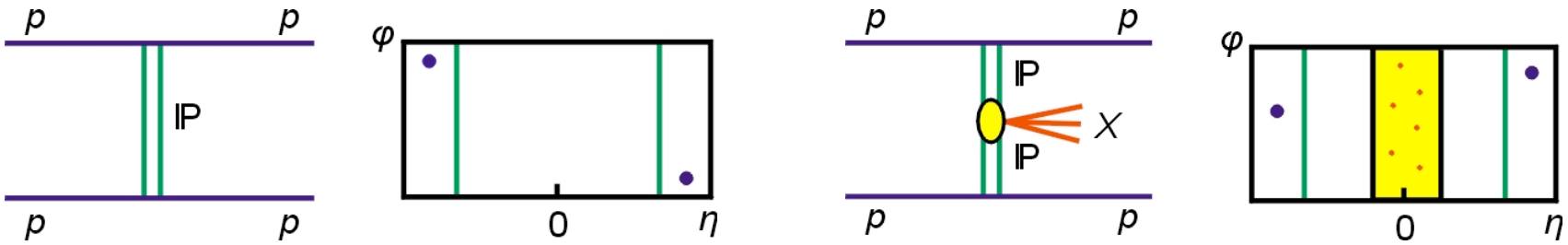
Physics with Tagged Forward Protons at RHIC

Włodek Guryn (Brookhaven National Laboratory)

- Diffraction processes with tagged forward protons
- The pp2pp experiment – elastic scattering
- Central production at RHIC, glueball search in DPE
- Central Production at WA102, ISR, UA8
- Setup at RHIC with the STAR detector
- Expected performance
- Summary

Epiphany 2009, Kraków Jan. 5-7, 2009

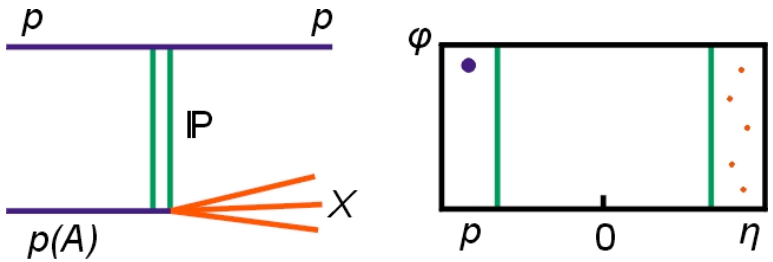
Elastic and Inelastic Processes



Physics with tagged forward protons

p + p → p + p
elastic

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



A (close to me) History

B6 (1975) ACTA PHYSICA POLONICA No 1

CENTRAL DIFFRACTIVE PRODUCTION

By G. Białkowski and J. Kalinowski

Institute of Theoretical Physics, Warsaw University*

(Received April 1, 1974; Revised version received June 1, 1974)

The topological cross sections and some characteristics of the multiplicity distribution for central diffractive production via double pomeron exchange are discussed.

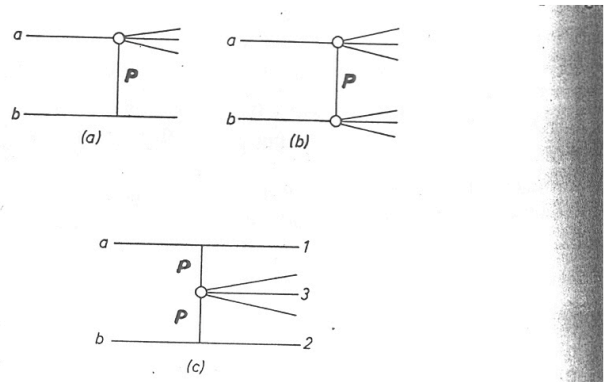
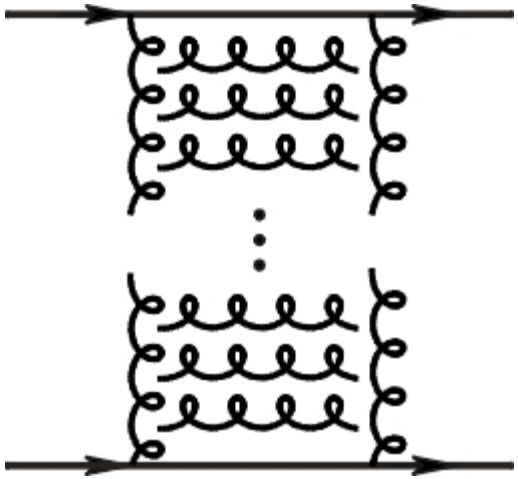
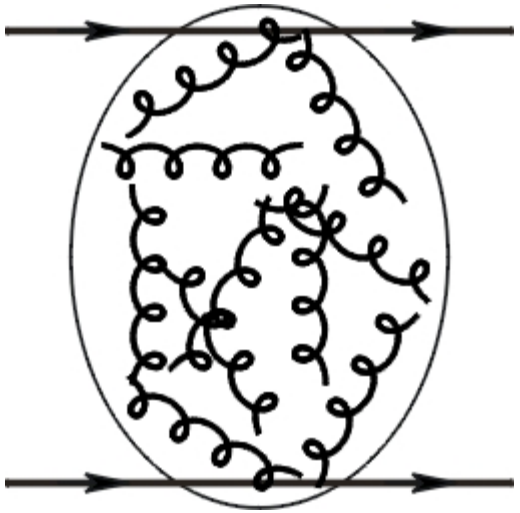


Fig. 1 a) Single diffractive excitation, b) double diffractive excitation,c) central diffractive production diagrams

PQCD Picture



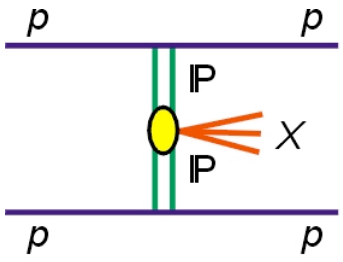
Gluon Ladders

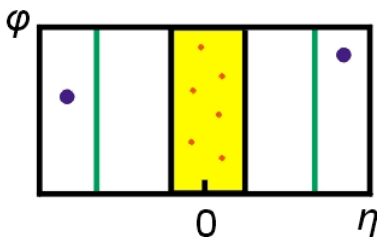


Gluonic Exchanges

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
$\xi = \Delta p/p$
M_X invariant mass

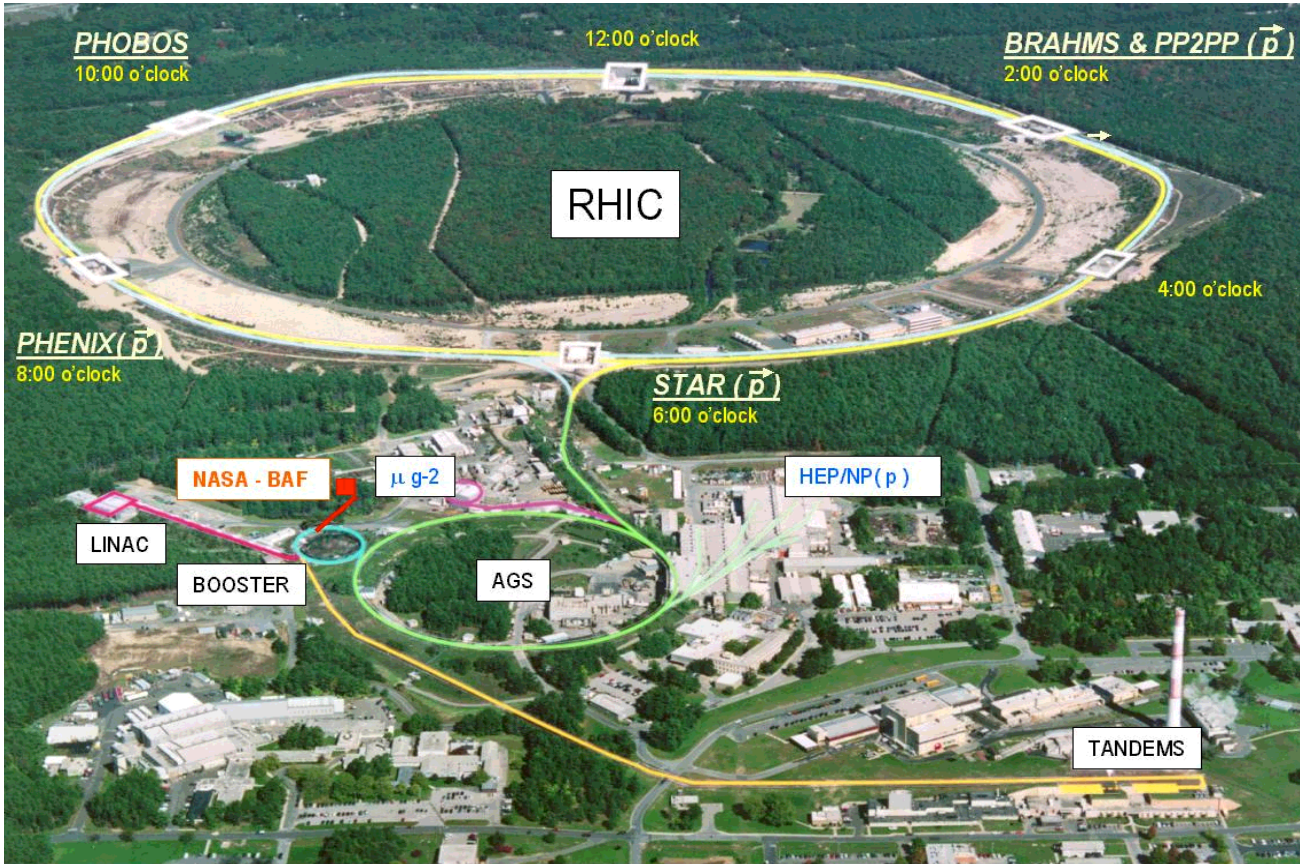
In the double Pomeron exchange process each proton "emits" a Pomeron and the two Pomerons interact producing a massive system M_X

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

Tevatron, SppS LHC

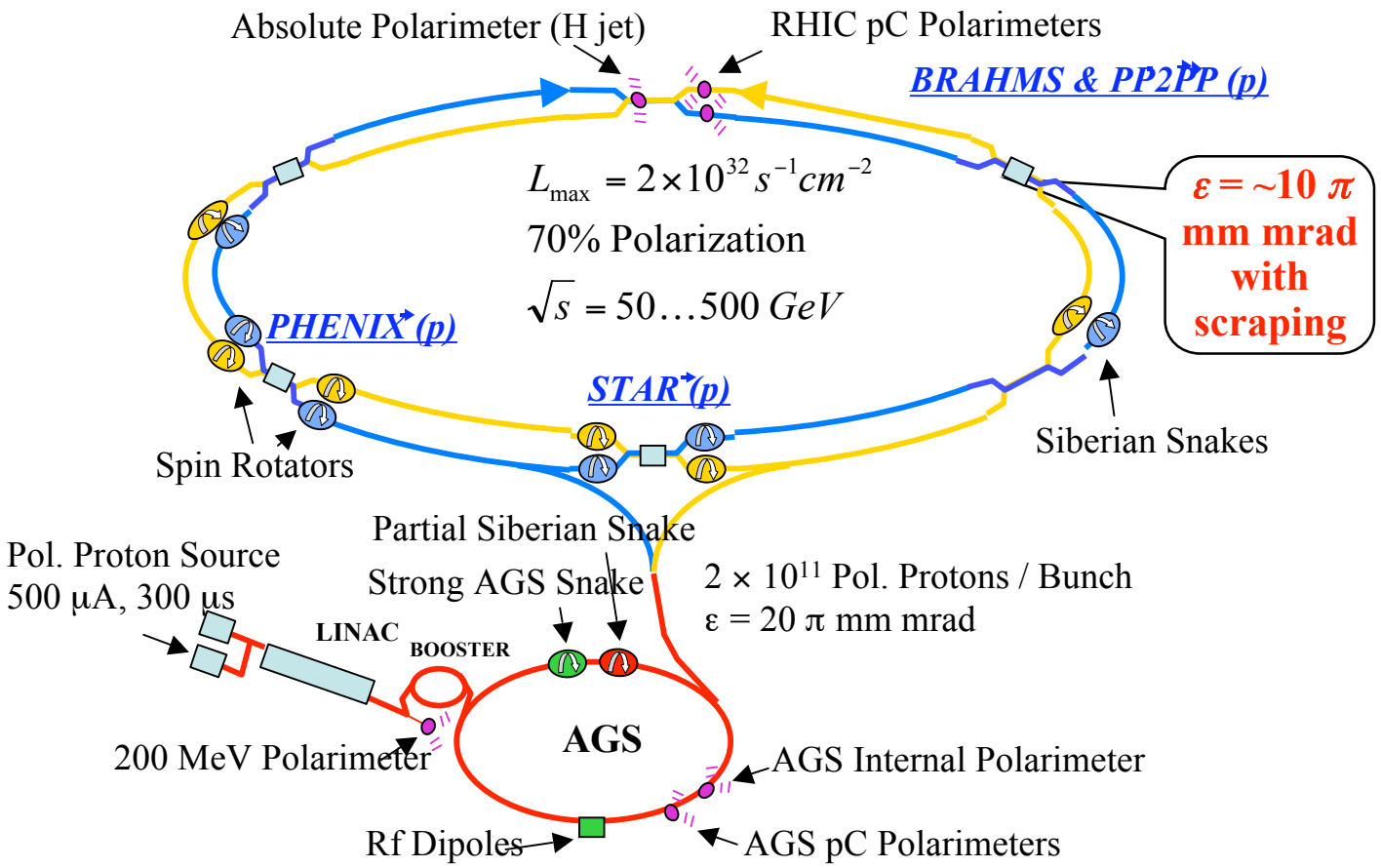
The massive system could form resonances. We expect that because of the constraints provided by the double Pomeron interaction, glueballs, hybrids, and other states coupling preferentially to gluons, will be produced with much reduced backgrounds compared to standard hadronic production processes.

The Relativistic Heavy Ion Collider



RHIC is a QCD Laboratory:
Nucleus- Nucleus collisions (AuAu, CuCu…); Asym. Nucl. (dAu);
Polarized proton-proton; eRHIC - Future

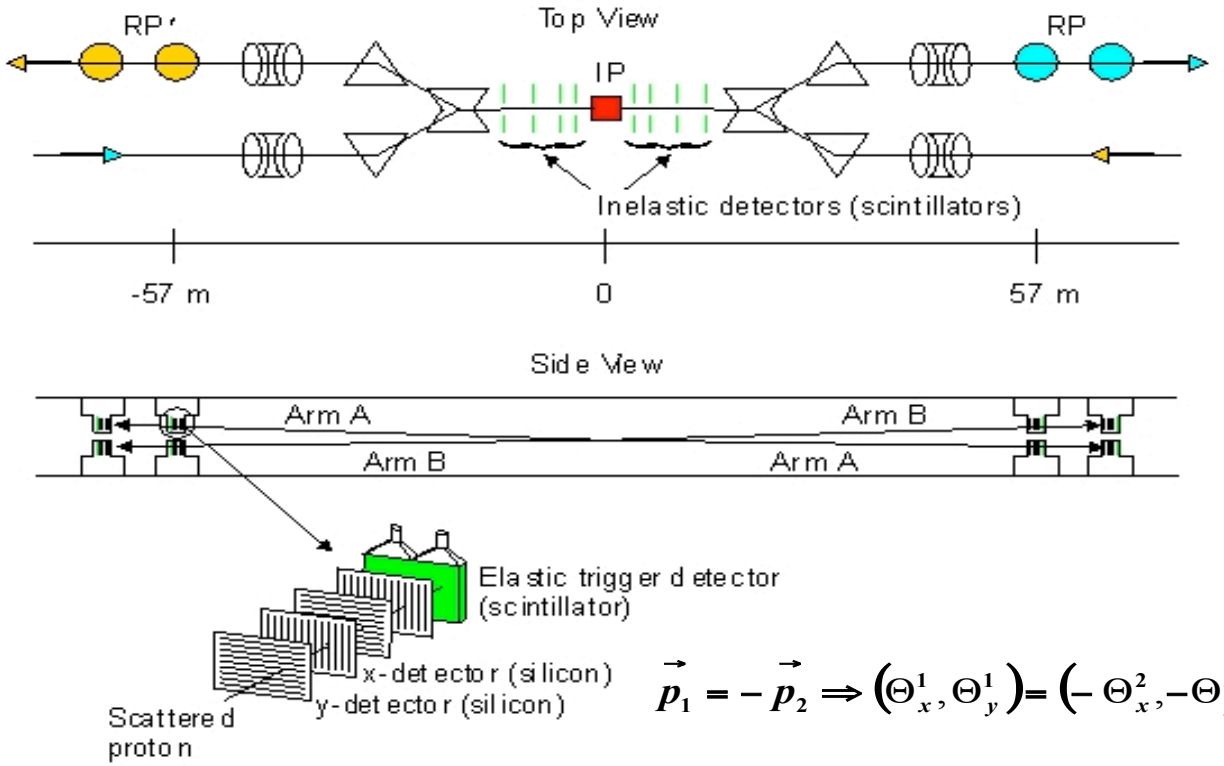
RHIC p↑p↑ accelerator complex



Tagging Forward Protons at RHIC

The PP2PP Elastic Scattering Experimental Setup

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



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

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

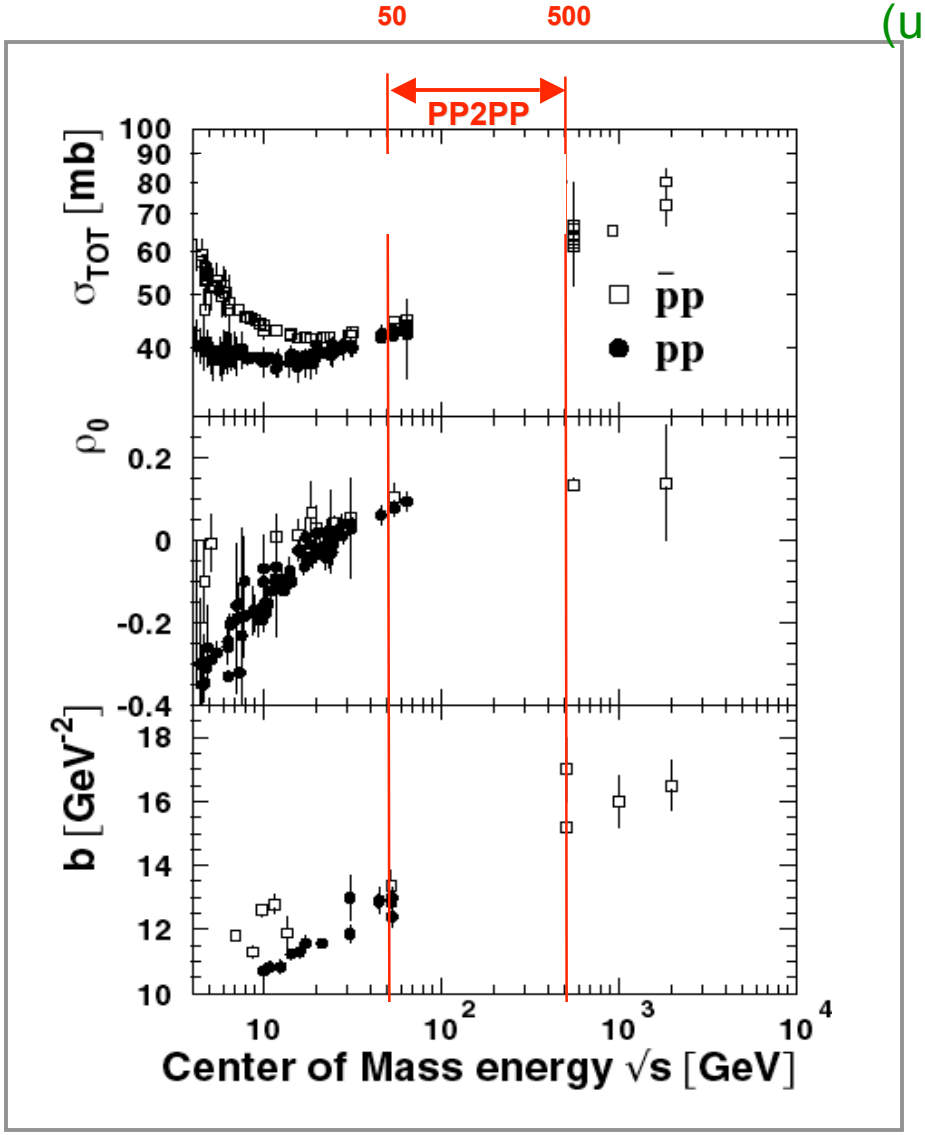
K. De, N. Guler, J. Li, N. Ozturk
University of Texas at Arlington, USA

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 GeV ≤ $\sqrt{s}$ ≤ 500 GeV

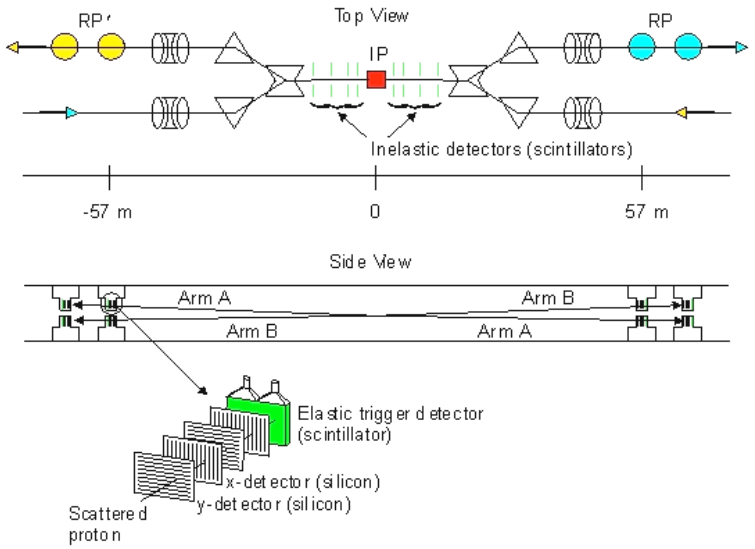
pp2pp $|t|$-range:

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

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

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

Principle of the Measurement of the Forward Protons



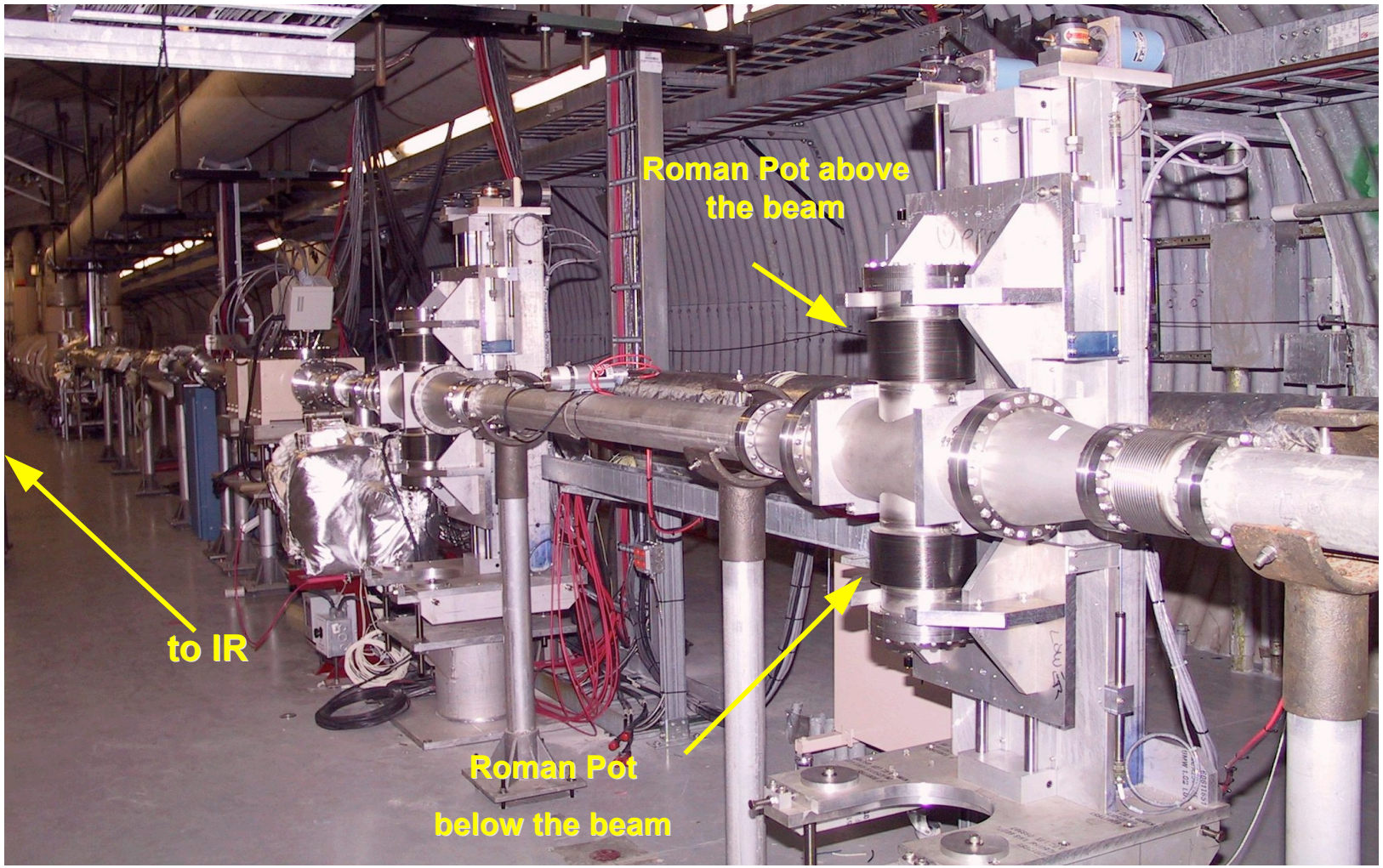
- Forward protons have very small scattering angles θ^*, hence beam transport magnets determine trajectory scattered protons
- The optimal position for the detectors is where scattered protons are well separated from beam protons
- Need Roman Pot to measure scattered protons close to the beam without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

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

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

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

Roman Pot Stations at RHIC



Results: A_N and r_5

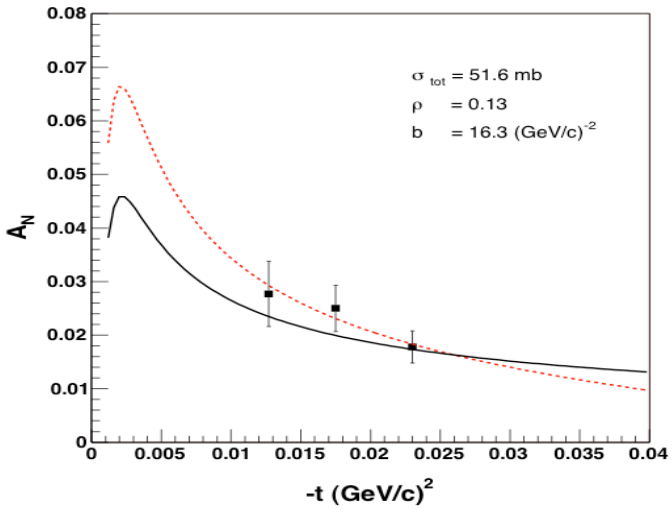
Phys. Lett. B 632, (2006) 167-172

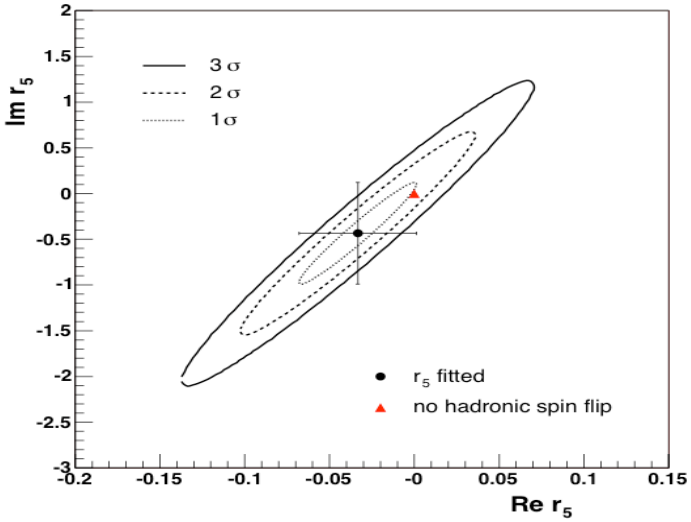
$$\phi_5(s,t) \propto \langle ++ \mid M \mid +- \rangle$$

$$\phi_+ - nonflip$$

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

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





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

Our result is suggestive at 1σ level of the hadronic spin flip.

(Need more data to resolve.)

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

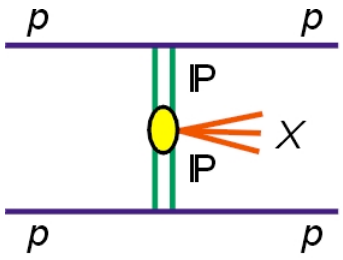
$$r_2 = \phi_2 / (2 \cdot \mathrm{Im}\phi_+), \quad where \quad \phi_+ = \frac{1}{2}(\phi_1 + \phi_3)$$

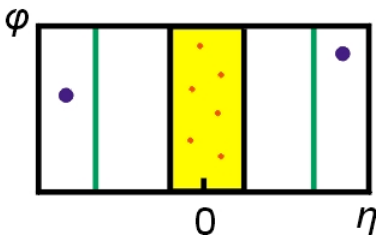
Im r_2 = 0.0019 ± 0.0052 Re r_2 = -0.025 ± 0.065

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

For the latest discussion see
L. Trueman, Phys.Rev.D77:054005,2008

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:

$$dP_T = |\overrightarrow{k_{T1}} - \overrightarrow{k_{T2}}|$$

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

Glueball Spectrum

Sparse spectrum!

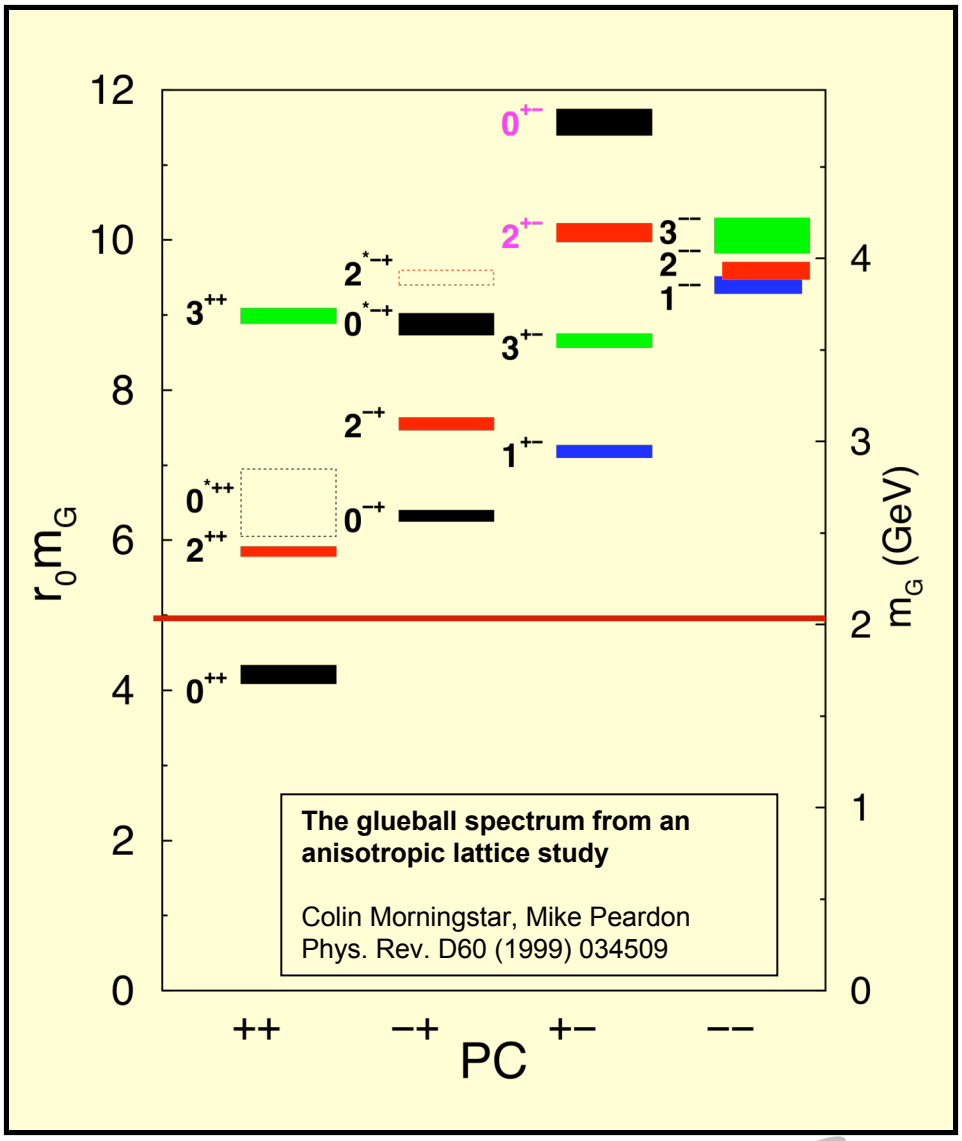
New I=0 mesons starting with

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.

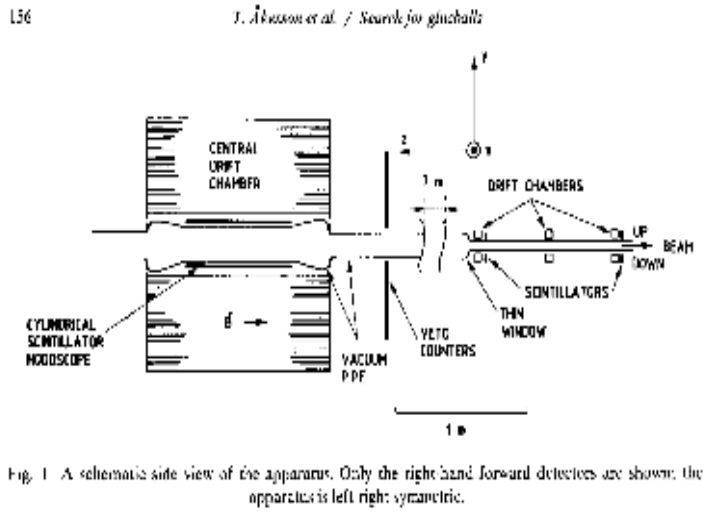
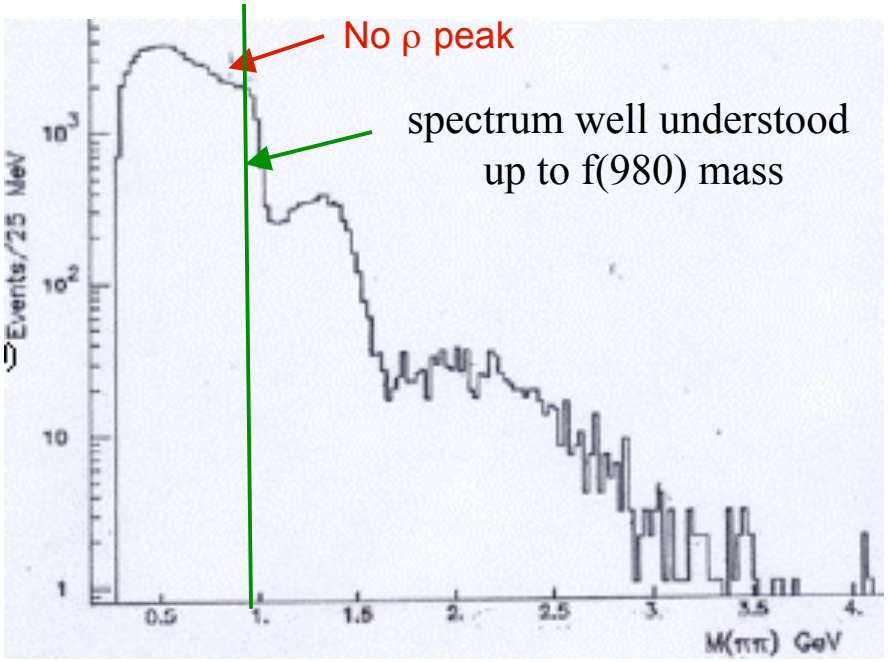
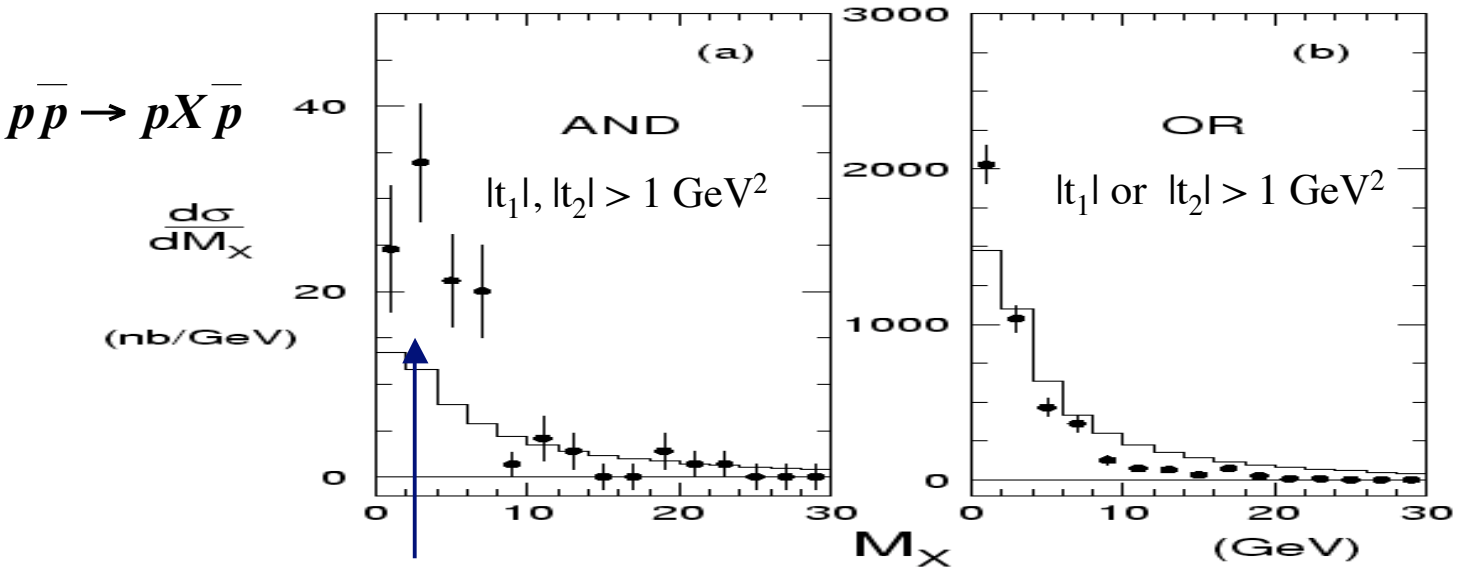


Fig. 1. A schematic side view of the apparatus. Only the right hand forward detectors are shown; the apparatus is left right symmetric.



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

UA8 Double-Pomeron-Exchange at the Spp̄S



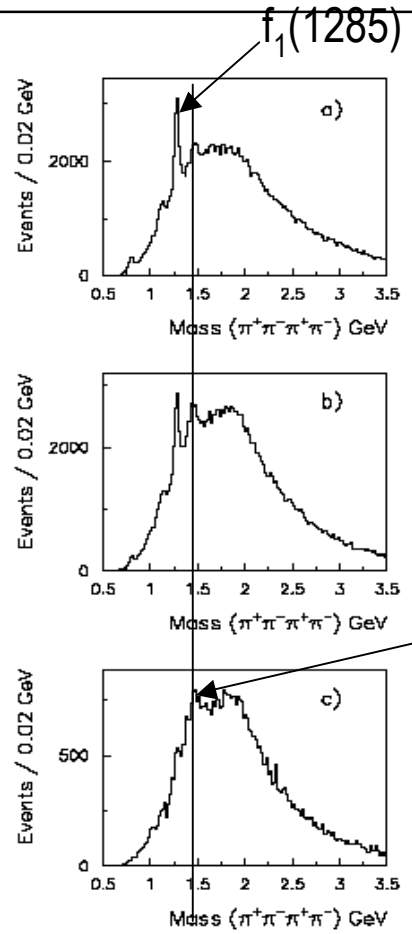
MC
σ_{PP} = 1 mb

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 s_{PP} for $M_x = M_{JJ} < 6$ GeV, very pronounced in the "AND" data with $\Delta P_t = 0$

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

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).

$f_0(1500)$

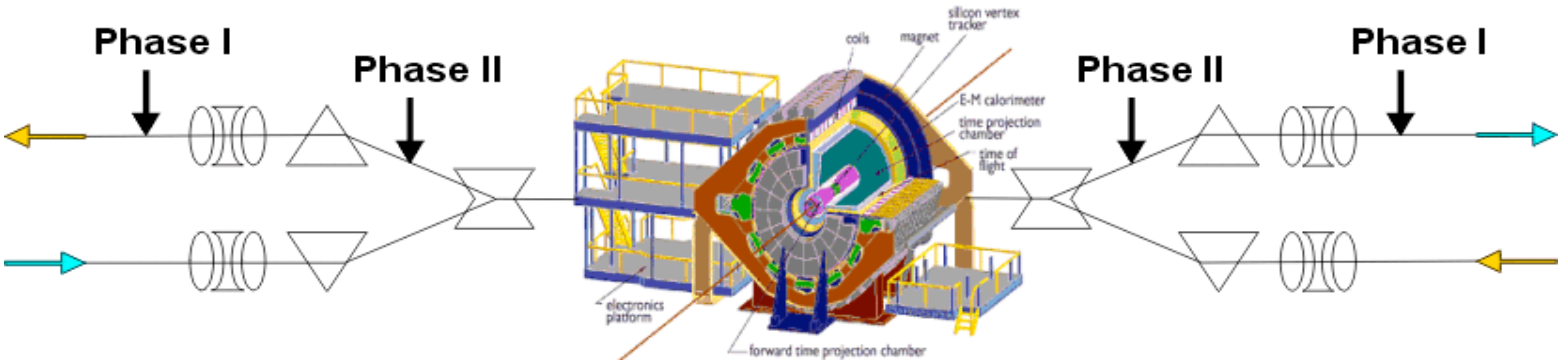
$dP_T < 0.2$ GeV.

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.

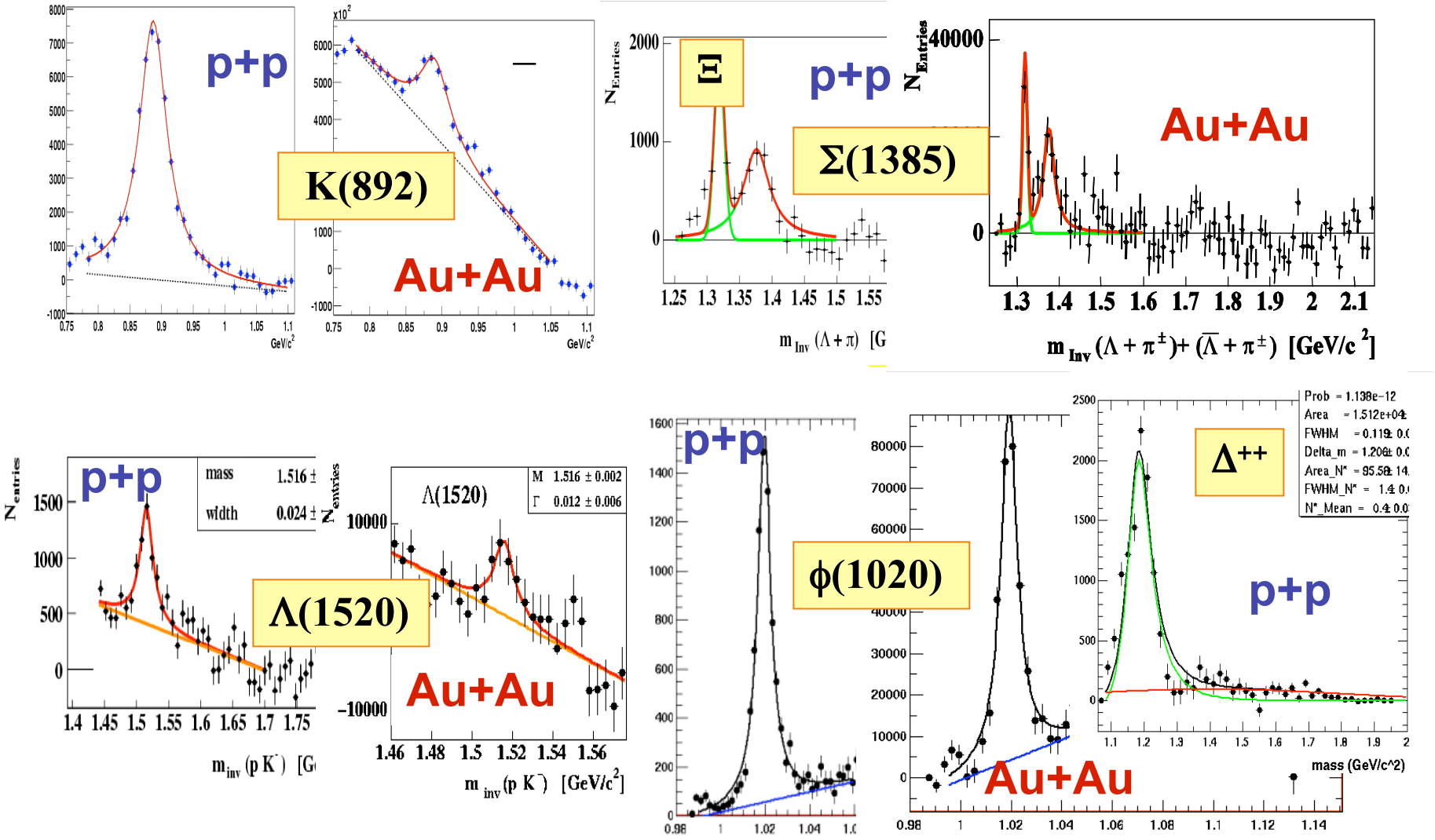
Implementation at RHIC - Detectors

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

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



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

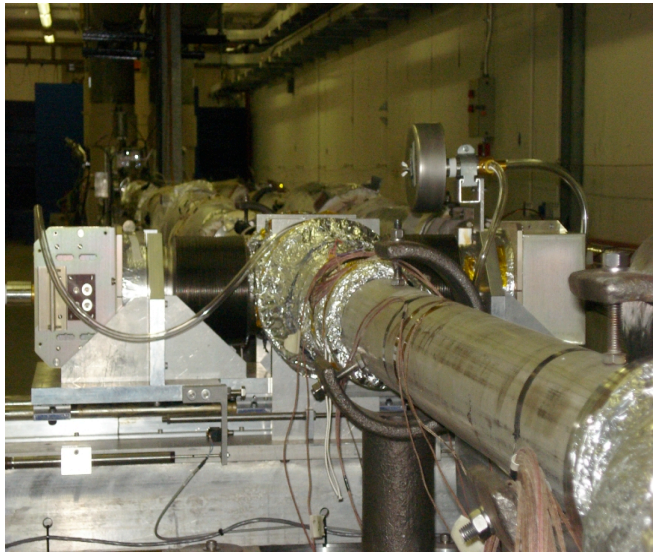
$$\begin{pmatrix} \Theta_x \\ \xi \end{pmatrix} = \frac{1}{Det} \begin{pmatrix} \eta_2; & -\eta_1 \\ -L_2; & -L_1 \end{pmatrix} \begin{pmatrix} x_1 - a_1 x_0 \\ x_2 - a_2 x_0 \end{pmatrix}$$

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

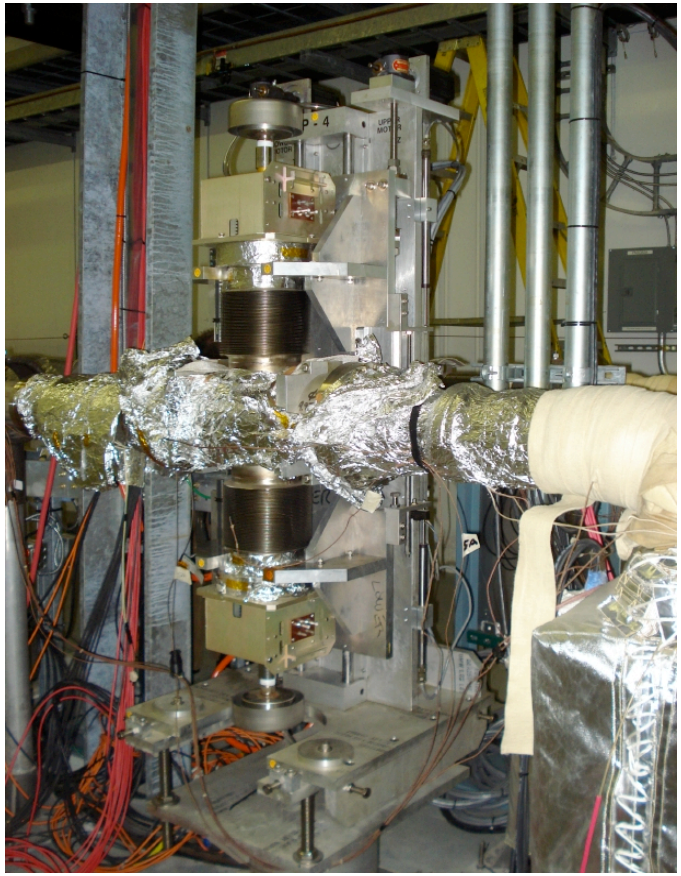
Because Θ and ξ are small special focusing is needed

Status - Roman Pots Installed at RHIC

Horizontal Roman Pots



Vertical Roman Pots



1. The pp2pp setup has been moved to STAR and has been integrated during Run 2008.
2. Integration with the accelerator - worked very well.
3. We used last 2 hrs of the run - dedicated beam time to integrate with STAR trigger, which also worked

We are ready to participate in STAR physics in Run 2009 and beyond.

Run 2009 - Phase I Performance

Important conditions:

- One event in the TPC per proton pair in RPs ⇒ "low luminosity";
- Alignment is very important ⇒ use elastic events;
- Need to reach small t and ξ values to measure small masses of interest ⇒ large β^*~20m, special optics and beam scraping are needed.

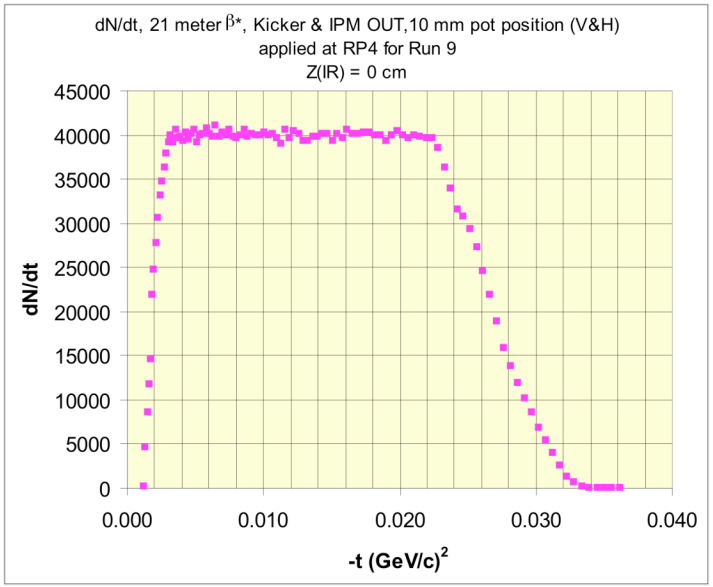
Hence a dedicated three-day run is planned

Elastic scattering:

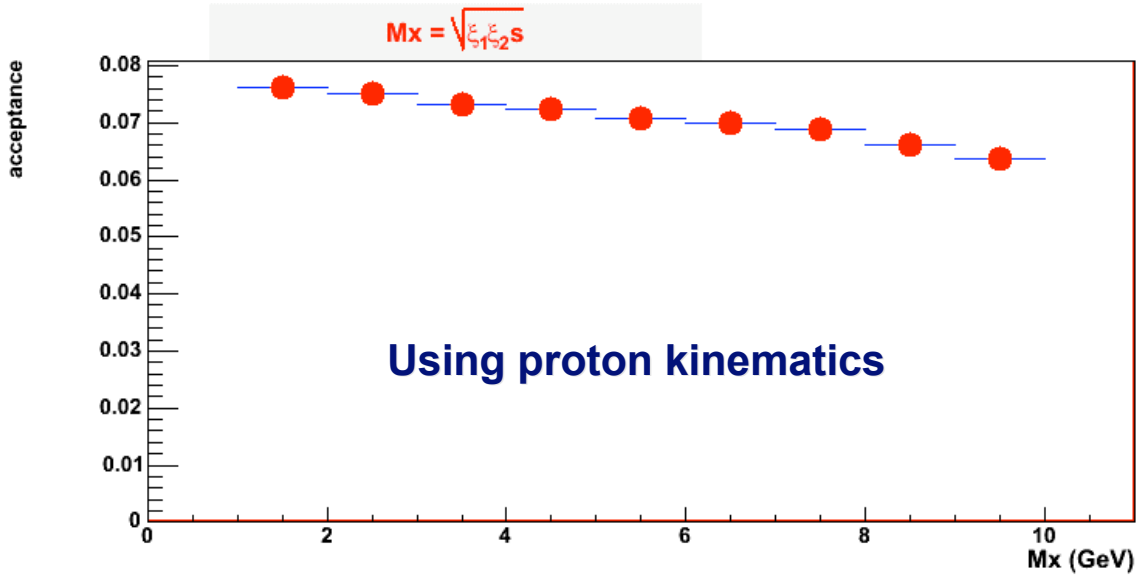
1. 100% acceptance for elastic scattering for $0.003 < |t| < 0.022$;
2. 20-40×10^6 elastic events:

Δb=0.31 (GeV/c)-2, $\Delta\rho$=0.01, $\Delta\sigma_{tot}$ = 2-3 mb;

3. In four t subintervals we shall have 5×10^6 events in each resulting in corresponding errors δA_n=0.0017, $\delta A_{nn}=\delta A_{ss}$=0.003.



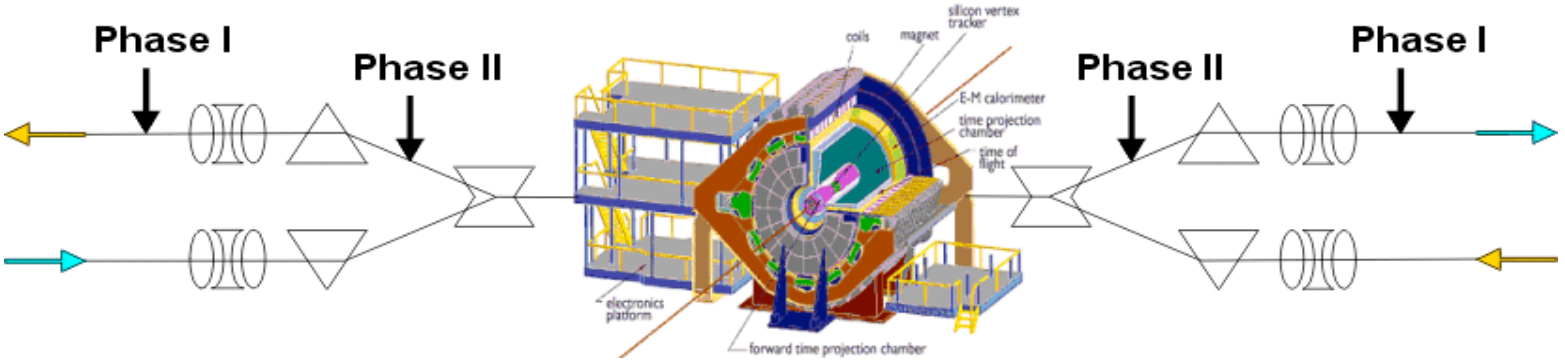
Run 2009 - Phase I Performance CP



With luminosity 3 ×10^{29} $cm^{-2}sec^{-1,}$ an estimated DPE cross section of 140 μbarn, and 40hrs data taking:

- 1·10^5 DPE events with full proton momentum reconstruction;
- 4·10^5 DPE events with tagged protons - good size data sample for this physics.

Phase II



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

- In Phase II hundreds of millions of events can be acquired by running in parallel with STAR

Diffraction at RHIC A. Bravar, W.G., S. Klein, D. Milstead, B. Surrow, J.Phys. G28 (2002) 2885

Summary

The physics program of tagged forward protons at RHIC will:

1. Study the structure of color singlet exchange in the non-perturbative regime of QCD.
2. Study both elastic and inelastic hadron diffraction and its spin dependence in unexplored t and √s range
3. Make first precise measurements at √s= 200 GeV of:
   - spin dependence in elastic scattering, both transverse and longitudinal;
   - unpolarized elastic scattering (Δb=0.31 (GeV/c)$^{-2}$, $\Delta\rho$=0.01, $\Delta\sigma_{tot}$ = 2-3 mb);
3. Search for central production of light and massive systems in double Pomeron exchange process - glueballs, hybrids.
4. Particle production in Central Production and SDD processes.
5. Search for predicted by QCD Odderon in the elastic scattering channel.

There is a great potential for important discoveries.

We are on track to take data during the next pp run in FY 2009 with Phase I program.

BACKUP/Duplicates

Summary

The physics program of tagged forward protons at RHIC will

1. Study both elastic and inelastic hadron diffraction and its spin dependence in unexplored t and √s range. Yielding information on the structure of color singlet exchange in the non-perturbative regime of QCD.

1. Search for central production of light and massive systems in double Pomeron exchange process - glueballs, hybrids.

2. Search for an Odderon - predicted by QCD

There is a great potential for important discoveries.

We are on track to take data during the next pp run in FY 2009 with Phase I program.