Glueball Search and Diffractive Physics with the STAR Detector at RHIC

(aka pp2pp at STAR Phase II)

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- Process of diffraction and physics with forward protons
- Our program in the context of QCD RHIC program
- Physics with forward protons at STAR present and future
- Phase II proposal
- Run 9 PHASE I – status of analysis
- Summary

Glueball Search and Diffractive Physics with the STAR Detector at RHIC

PHASE II of the Physics with Tagged Forward Protons with the STAR Detector at RHIC

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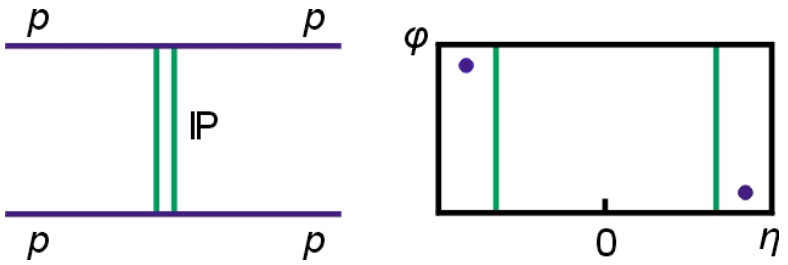
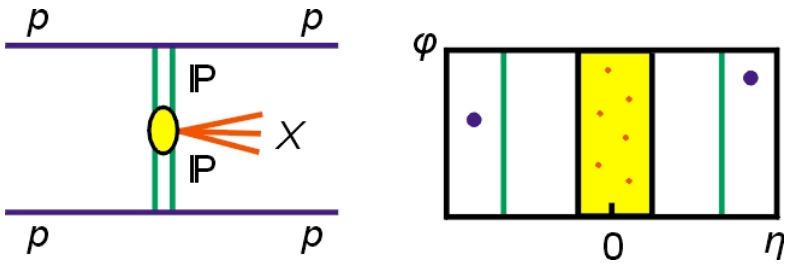
Processes with Tagged Forward Protons

QCD color singlet exchange: C=+1, C=-1



p + p → p + p

elastic



p + p → p + X + p

diffractive X= particles, glueballs

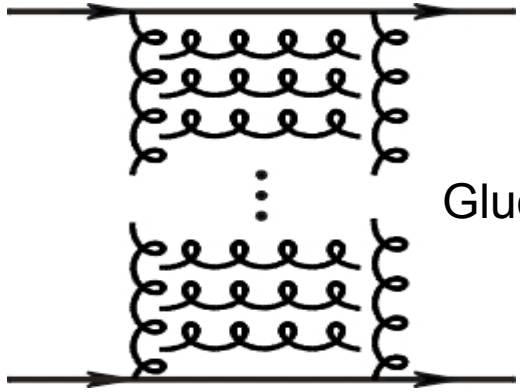
Discovery Physics

At RHIC the cross section is dominated by the Pomeron (gluonic) exchange:

$s_{RR} \sim s^{-2}$

$s_{RP} \sim s^{-1}$

$s_{PP} \sim$ const. or s^{α} where $\alpha \sim O(0.1)$



Gluon Ladders

Our Program in the Context of RHIC the QCD Factory

QCD is the theory of strong interaction: some of the current and future QCD measurements at RHIC are

- Confinement/ phase of QCD - QGP
- Distribution of spin in the nucleon - Spin sum rule
- Saturated gluon state (Color Glass Condensate…)

- Gluonic degree of freedom in Hadrons – exotica (glueballs…)
- QCD nature of diffractive processes – structure of Pomeron, Odderon… (color neutral exchange) and its spin dpenedence

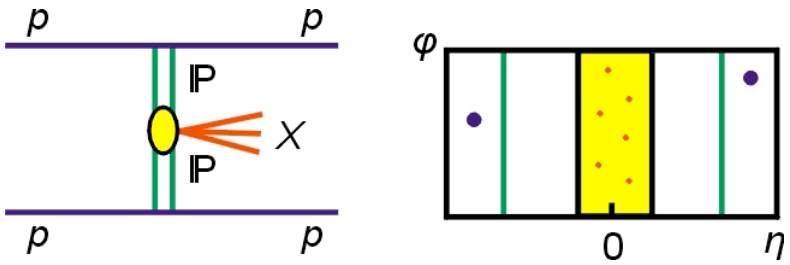
Our Program in the Context of RHIC the QCD Factory

1. The main focus of the upgrade is a glueball search in the Double Pomeron Exchange (DPE) process.

2. The program will naturally include other QCD topics with discovery potential:
   - Search for the Odderon;
   - Spin dependence of the elastic and diffractive scattering in polarized *pp* collisions in the √s up to 500 GeV => hadronic spin flip;
   - Polarized proton on polarized Helium scattering => spin structure of the neutron.
   - A possibility of new physics of sphaleron production (clustering in multiparticle production) in DPE.

The proposed setup does not require special running conditions, hence large data samples can be obtained.

Central Production in DPE



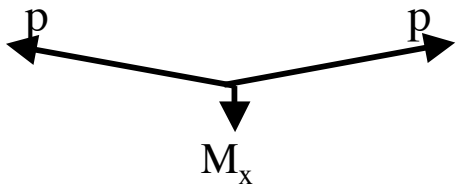
For each proton vertex one has

t four-momentum transfer

$\xi = \Delta p/p$

$M_X = \sqrt{\xi_1 \xi_2 s}$ 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!

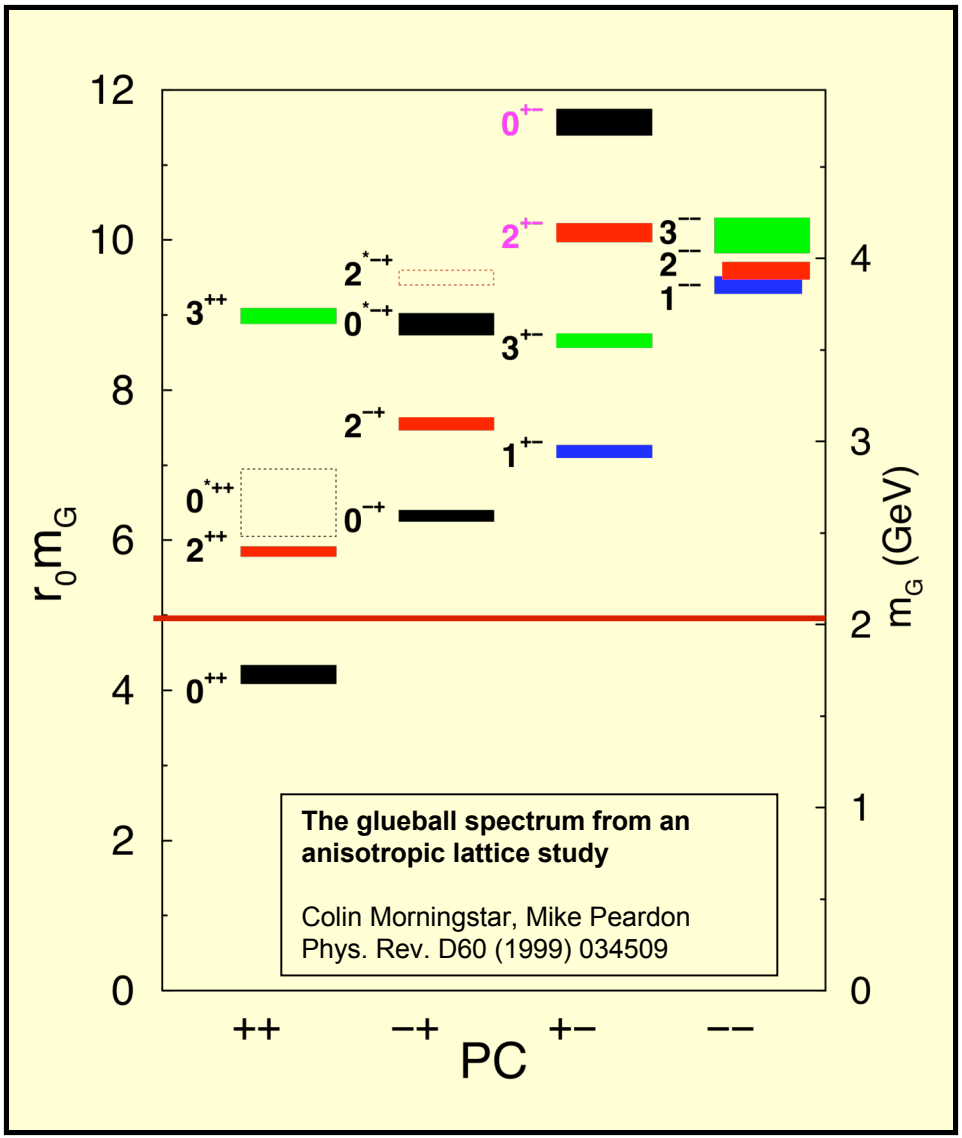
New I=0 mesons starting with

0^{++} 1.6 GeV

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

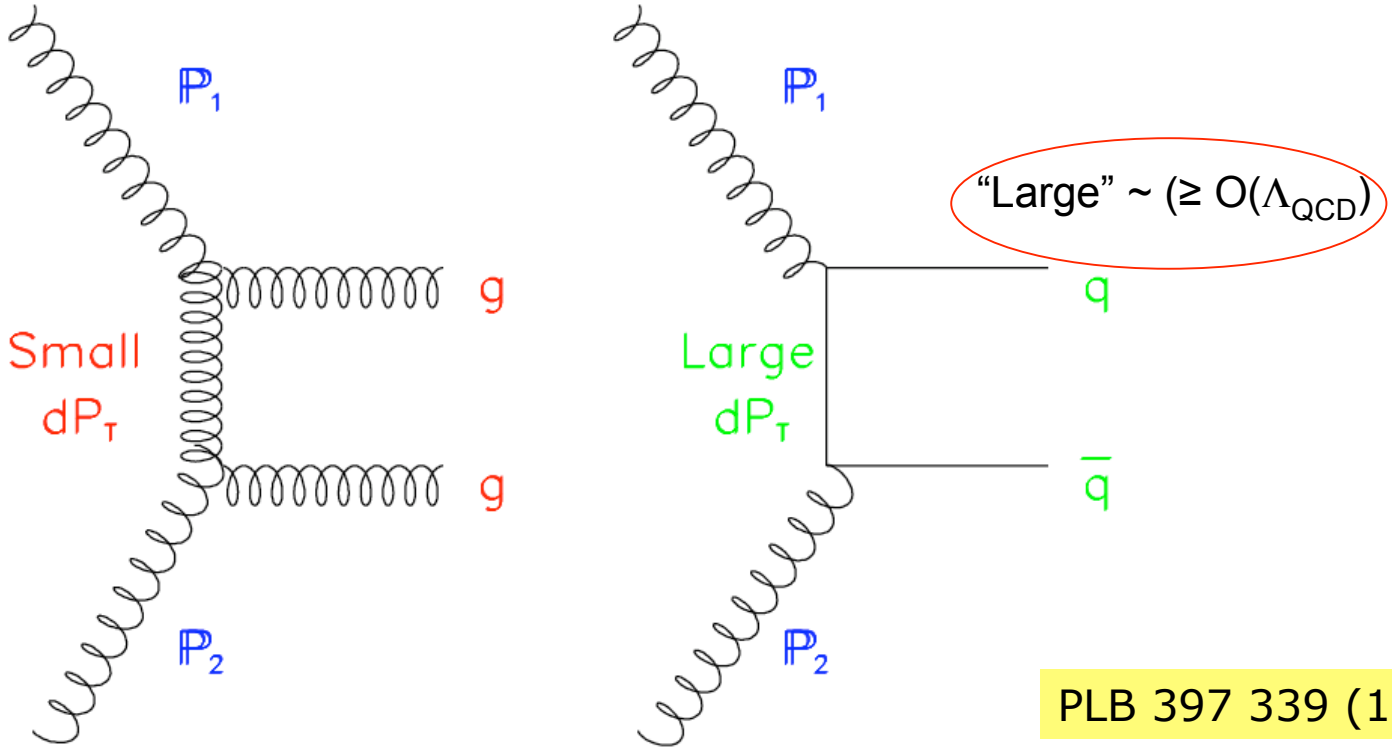
No **J^{PC}-exotic** glueballs until

2^{+-} at 4 GeV



Kinematic "filter" (dp_T) for "gg"

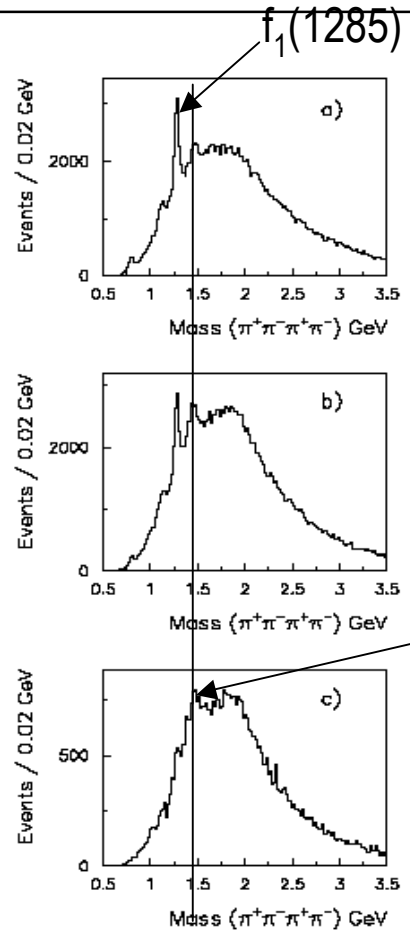
(F. Close et al./W102)



PLB 397 339 (1997)

- Coupling of the exchange particles to the final state mesons for gluon exchange (small dp_T) and quark exchange (large dp_T)
- Spin-dependence of the coupling can be studied at RHIC

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.

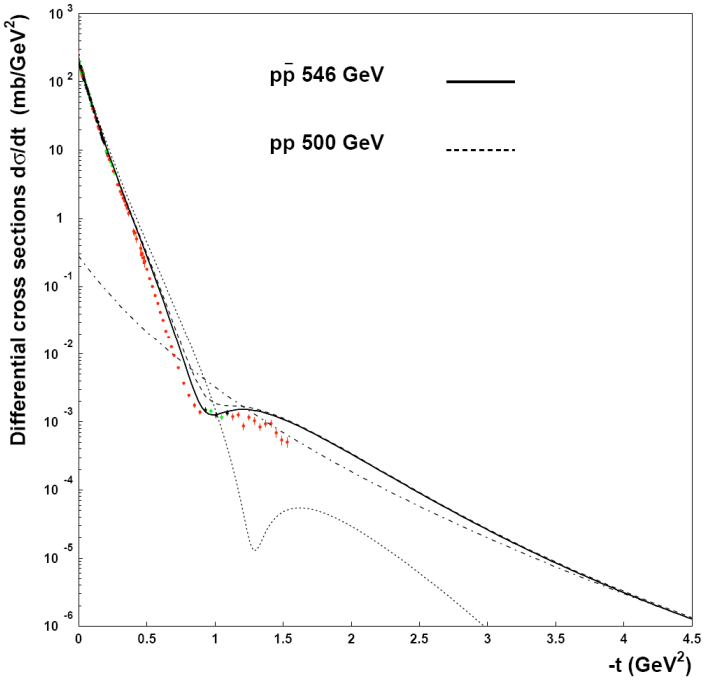
F.E.Close and A.Kirk, PLB397, 333 (1997).

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.

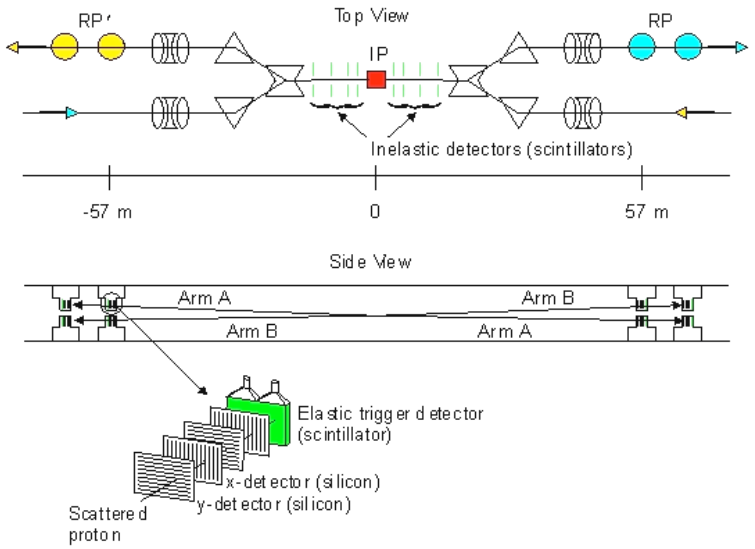
How to identify an Odderon at RHIC?



hep-ph/0210437 M. Islam et al.

- Odderon is a partner of pomeron (C=1) with C=−1:
- "RHIC is the machine to find it" (E. Leader, Odderon Workshop (2005)) by measuring
  - $\Delta\sigma_{pp} - \Delta\sigma_{pbarp} \neq 0$ (~3mb)
  - $d\sigma/dt_{pp} \neq d\sigma/dt_{pbarp}$
  - Shape of Asymmetries: A_{NN}
  - Centrally produced C=−1 particle

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**.

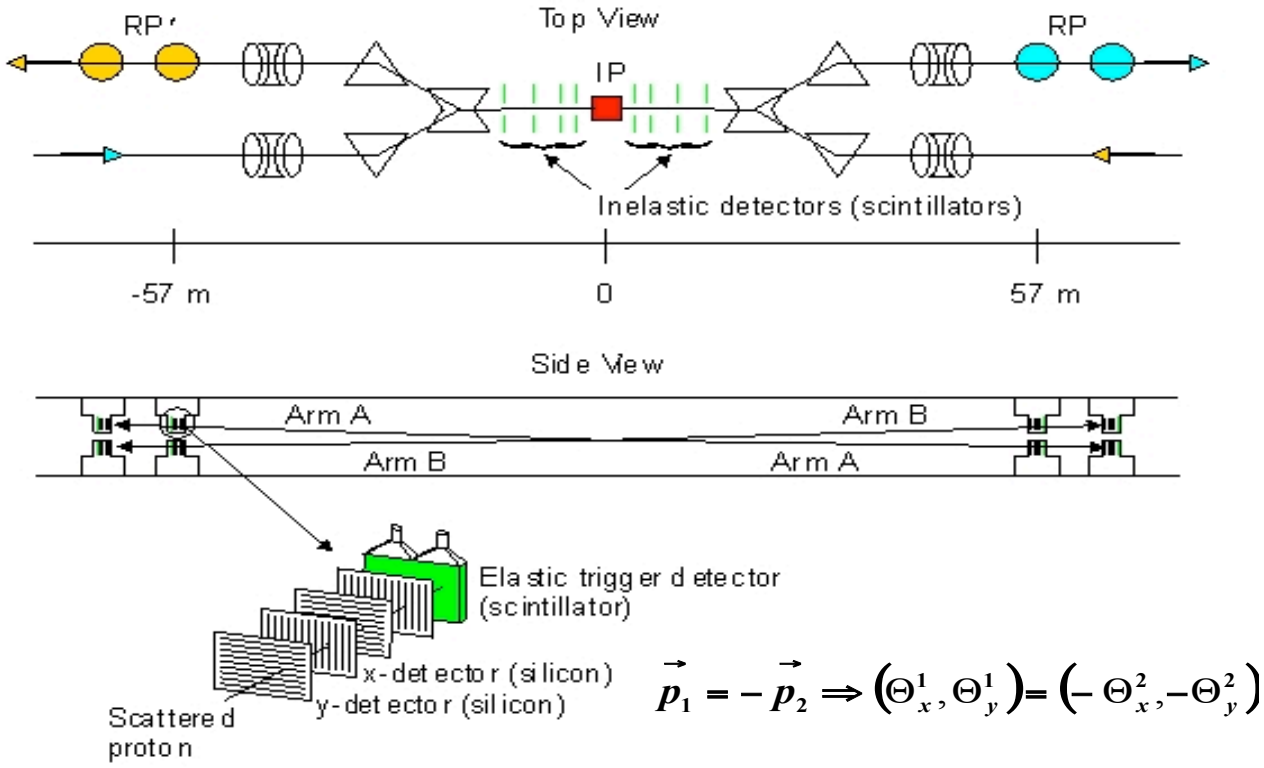
$$\begin{pmatrix} x_D \\ \Theta_D^x \\ y_D \\ \Theta_D^y \end{pmatrix} = \begin{pmatrix} a_{11} & L_{eff}^x & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & L_{eff}^y \\ a_{41} & a_{42} & a_{43} & a_{44} \end{pmatrix} \begin{pmatrix} x_0 \\ \Theta_x^* \\ y_0 \\ \Theta_y^*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

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

Tagging Forward Protons at RHIC

The PP2PP Elastic Scattering Experimental Setup

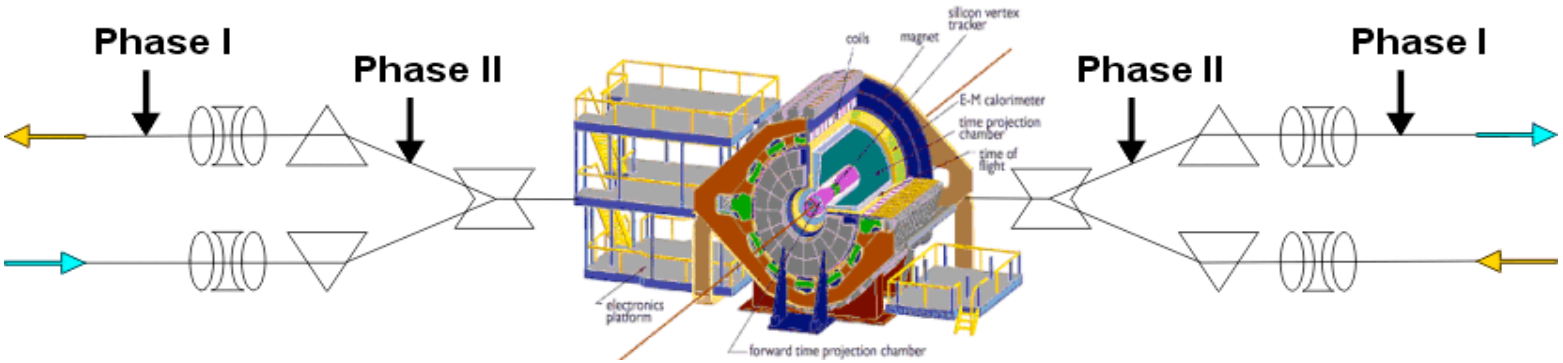
Phys. Lett. B 579 (2004) 245-250, Phys. Lett. B 632 (2006) 167-172, Phys. Lett. B 647 (2007) 98-103



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

DPE at RHIC - Detectors

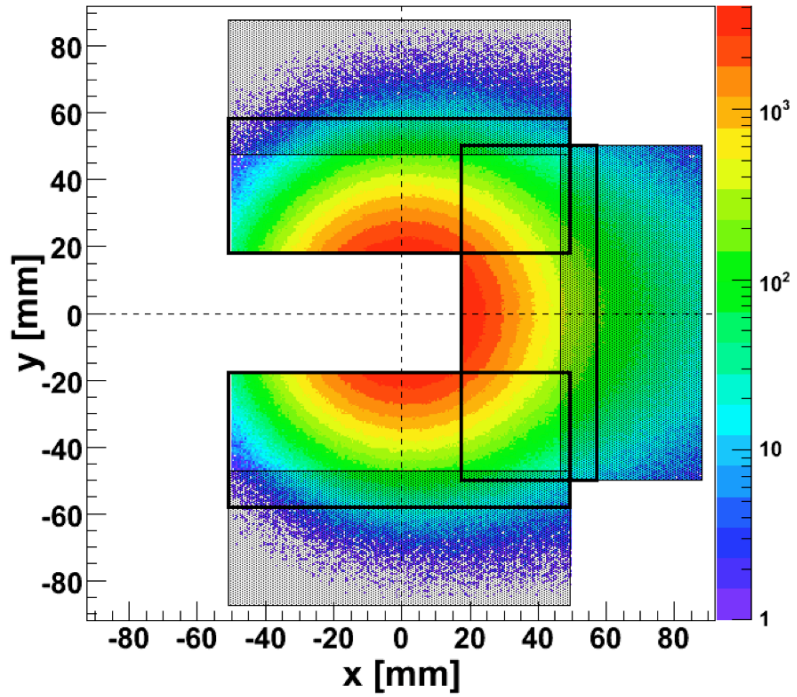
1. Need detectors to measure forward protons: t - four-momentum transfer, $\xi = \Delta p/p$, M_X invariant mass and;
2. Detector with good acceptance and particle ID to measure central system



Roman Pots of pp2pp and STAR - use existing equipment

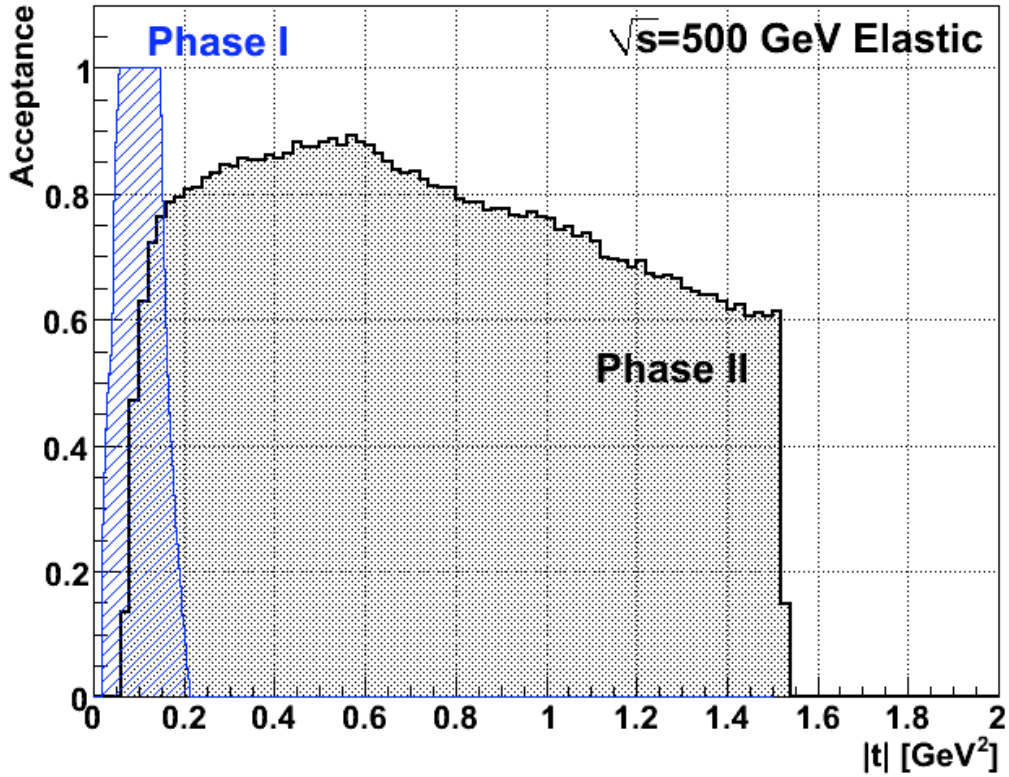
Phase II and beyond

Acceptance for RPs at s = 17.3 m calculated by the beam transport simulator HECTOR



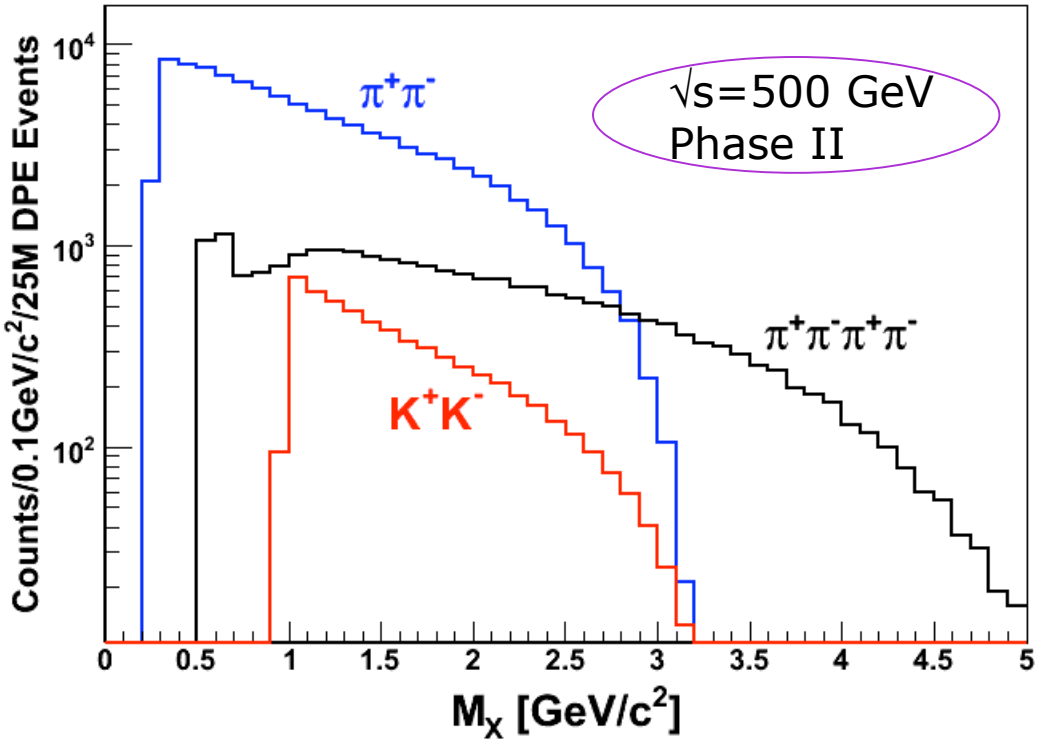
- Phase I and II set-up covers $0.002<t<1.3\ GeV^2$
- Depending on the physics needs/requirements deduced from first measurements, further upgrade will be pursued
- Possibilities of new measurements: central production of exclusive Charmonium?

t-Acceptance of the Roman Pot Setup



- Phase I set-up focuses on low-t
- Phase II covers higher-t range

Acceptance and expected yields in M_X



- Expected reconstructed phase-space including measured at the ISR BR per 25M DPE events
- High-Mx reconstruction is limited by PID (π/K separation up to ~ 1.6 GeV/c)
- Expected Trigger rate for DPE: 80 Hz at L=1x10^{31}cm^{-2}s^{-1}
- Simulations that with 400 pb^{-1} one can collect 2×10^6 K^+K^- and 11×10^6 $\pi^+\pi^-\pi^+\pi^-$ data sample in 1< M_X < 2 GeV/c^2

Run 2009 - Phase I

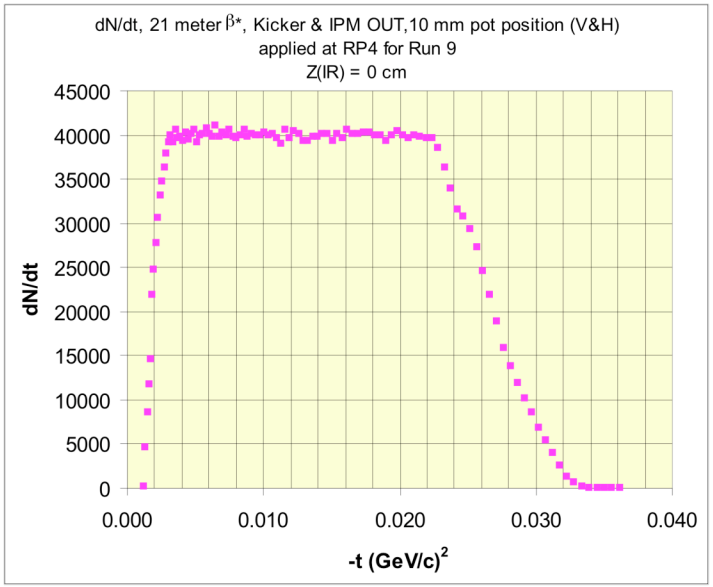
Important conditions:

- One event in the TPC per proton pair in RP;
- Alignment very important ⇒ use elastic events;
- Need to reach small t and ξ values to measure small masses of interest ⇒ large β^*~21m, special optics and beam scraping are needed.

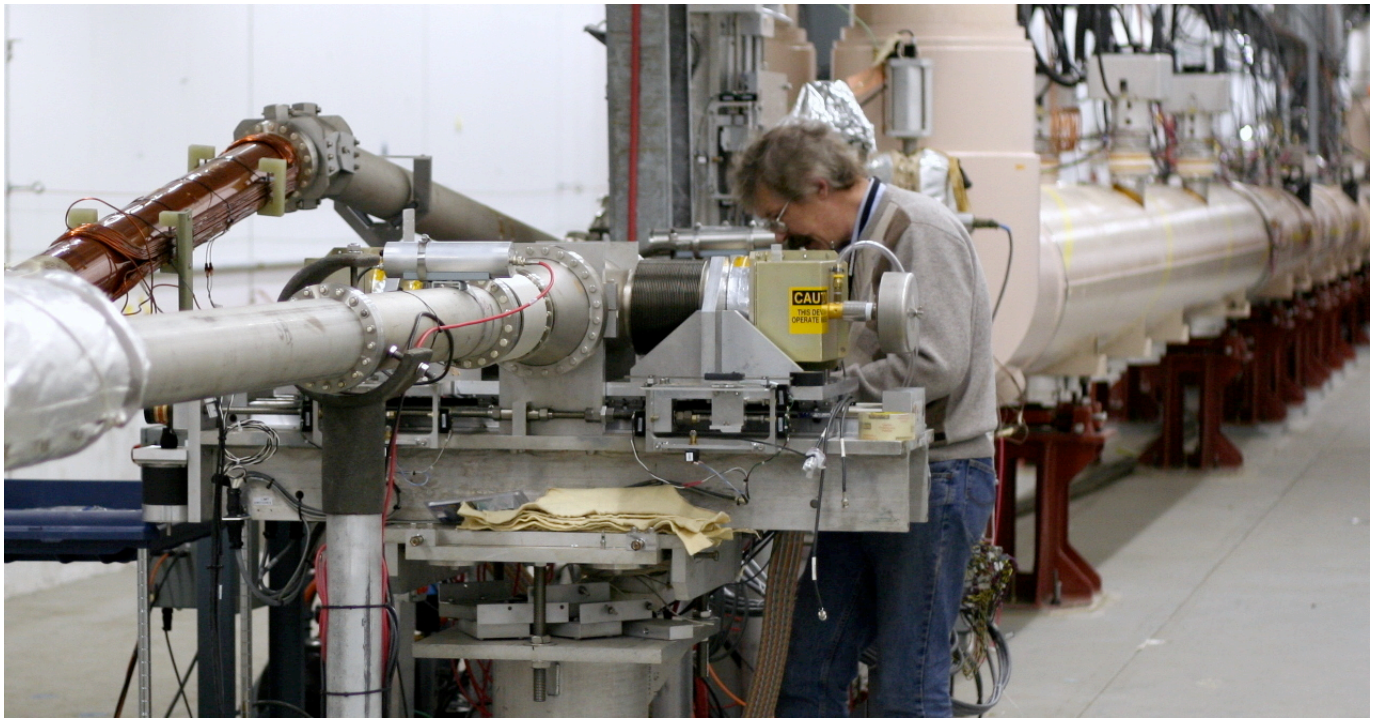
Elastic scattering:

1. 100% acceptance for elastic scattering for $0.003 < |t| < 0.022$;
2. With 20×10^6 elastic events we expect:
   $\Delta b=0.31$ (GeV/c)-2, $\Delta\rho=0.01$, $\Delta\sigma_{tot}$ = 2-3 mb;
3. With 5×10^6, in four t subintervals events in each bin we expect:

$\delta A_n=0.0017$, $\delta A_{nn}=\delta A_{ss}=0.003$.

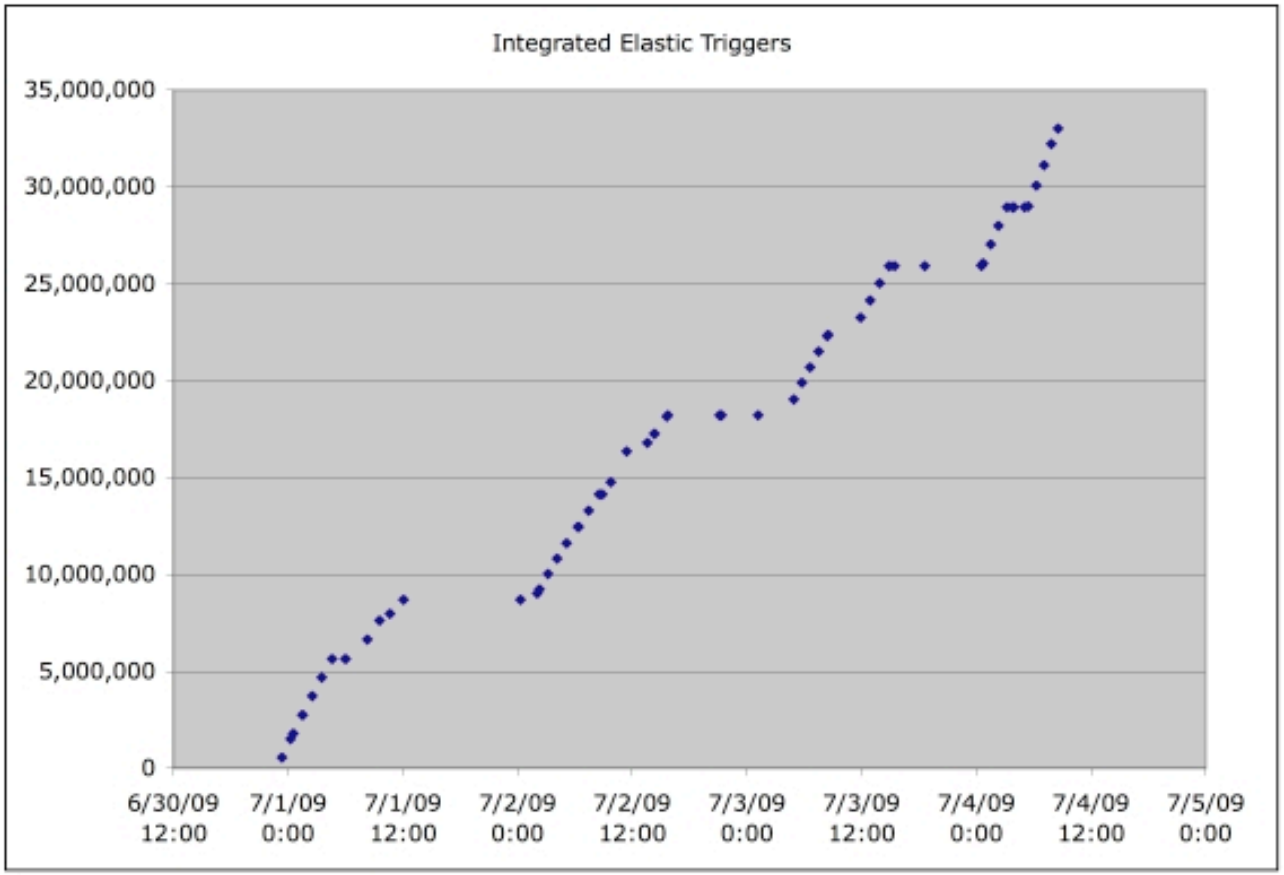


RPs moved to STAR



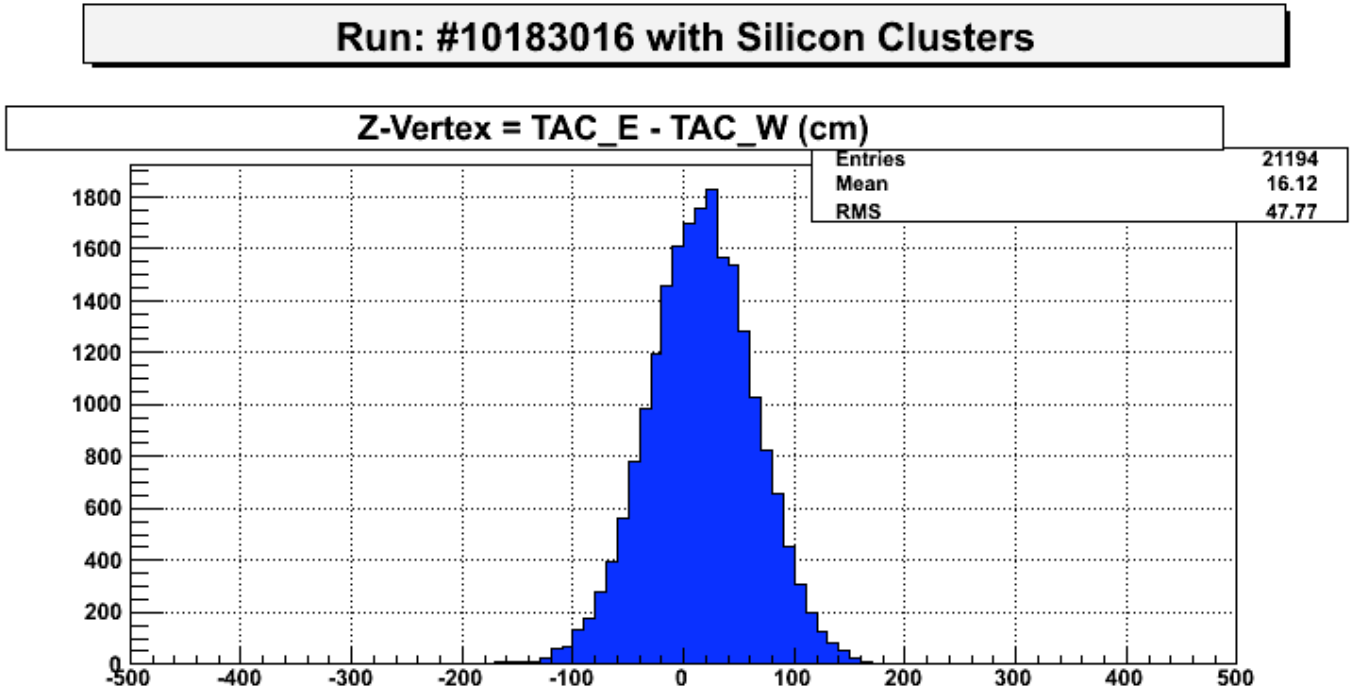
Vertical AND Horizontal RP setup for a complete ϕ coverage

RUN 9: Integrated Elastic Triggers



z-vertex distribution from trigger counters

(no corrections)



Colinearity of candidate elastic events

(we have a very good data sample!)

The “mean” is < 1mm

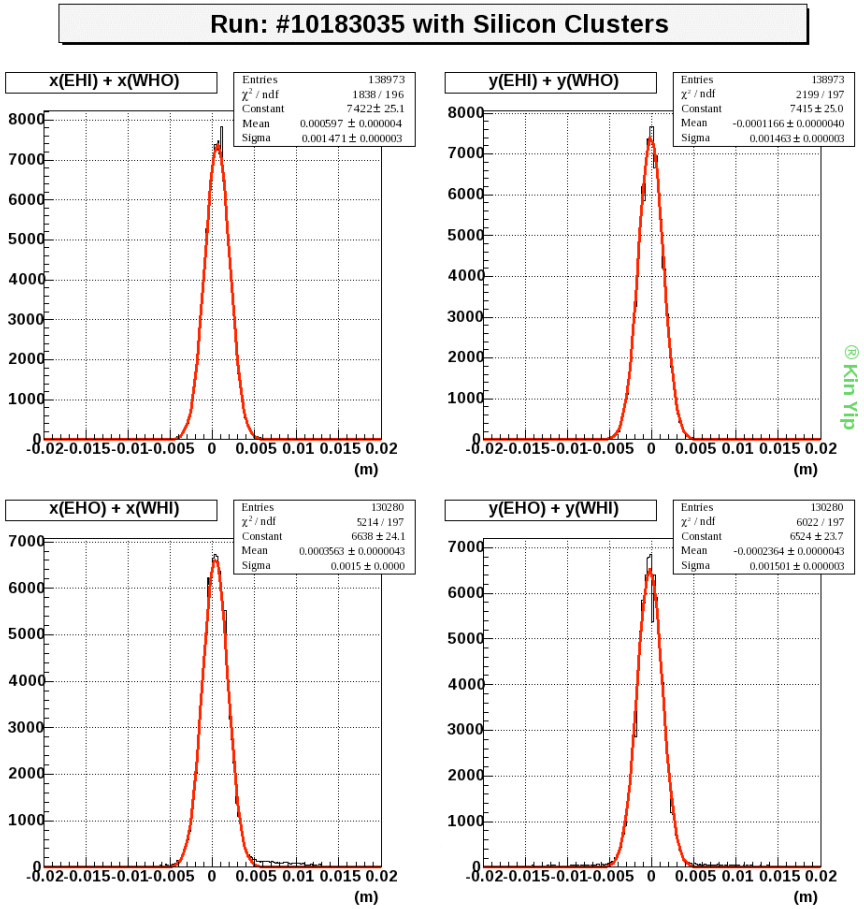
x(EHI-WHO) ~0.6 mm

y(EHI-WHO) ~0.1 mm

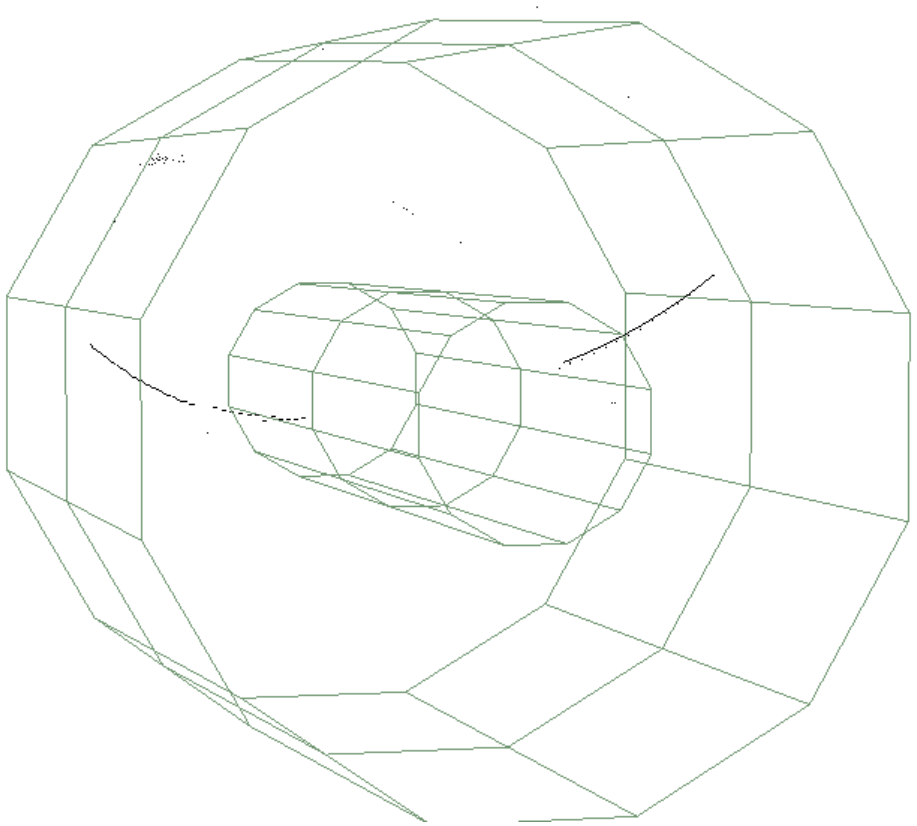
x(EHI-WHO) ~0.4 mm

y(EHI-WHO) ~0.2 mm

Width $\sigma_{x,y}$ ~ 1.4 mm =>
$\sigma_{\theta} \approx 40$ μrad



Run 9 Candidate Central Production Event



Event Information

run: 10183036
Events seen: 25
Event #127

Triggers:

Summary of Run9

- We had a great run - the setup and its integration with STAR worked very well (35M elastic triggers, 700k CP triggers)

- We are working now on data analysis:
  - Elastic scattering - spin dependence A_{NN}, A_N, A_{SS}, A_S, $\Delta\sigma_{tot}$ for the spin combinations.
  - Elastic scattering - spin averaged dN/dt => slope B, σ_{tot}, ρ, luminosity measurement.
  - Diffraction - Central Production, Single Diffraction Dissociation and its spin dependence.

Plan

- Run 11 - five days dedicated run, Phase I setup with longitudinal polarization, $\beta^* = 21$ m

- Phase II
  - Proposal is being reviewed in STAR, Dec. 17-18 review meeting;
  - Current cost estimate k$ 880 (k$450 in Physics and k$430 in C-AD);
  - Technically driven schedule allows for installation before Run 12:
    - Finish engineering by Spring of 2010;
    - Install DX-D0 vacuum chamber Summer 2011;
    - Finish detectors Fall 2011;
    - Ready for Physics Run 12.

Phase II setup can run in parallel with the RHIC Spin program, as no special conditions are required

Summary

- A new rich diffractive physics program with tagged forward protons in polarized proton-proton scattering at RHIC, which uses the Roman Pot technique and the STAR detector, has been launched and its significant expansion is proposed.

- The main physics motivation is to search for theoretically predicted states in QCD: the glueball and the Odderon.

- We stress that the studies we are proposing 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.

- We are exploring possibilities of using the proposed setup to tag coherent particle production in heavy ion collisions, by detecting fragmentation protons in the Roman Pots.

Summary

The physics program with tagged forward protons at STAR will:

1. Search for new physics, including glueballs, Odderon and sphalerons. In particular, *CP* odd glueball production at RHIC could lead to verification of the Odderon hypothesis.

2. Search for diffractive production of light and massive systems in double Pomeron exchange process. Possible Pomeron Odderon interaction => J/ψ production, C−odd glueball.

3. A systematically study the spin dependence of elastic scattering, the shape of the differential elastic cross section $d\sigma/dt$ in unexplored ranges of t and $\sqrt{s}$.

4. The scattering of polarized proton on polarized ^3He ($p^{\uparrow}{}^3He^{\uparrow}$) can be measured without changes to the setup enabling studies of the transverse spin structure of the neutron.