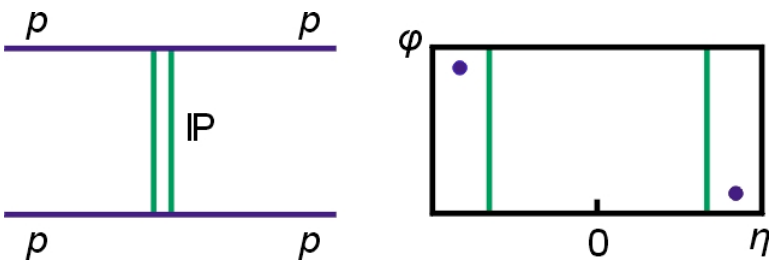
Present and Future of Central Production with STAR Detector at RHIC

Włodek Guryn BNL (for the STAR Collaboration)

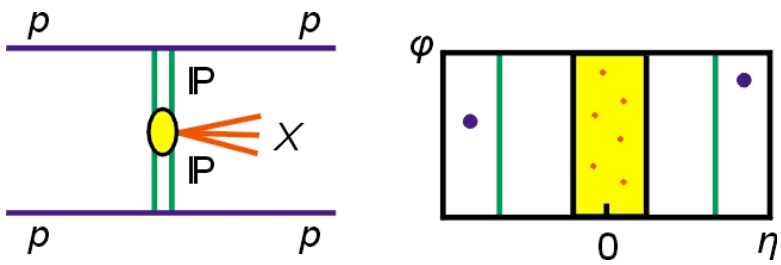
- Process of central production - physics program at STAR with forward protons in (polarized) pp at √s 200 and 500 GeV
- The present: 2009 run preliminary results of Phase I program, elastic scattering (D. Svirida at this conf.), central production (this talk)
- The near future: Continuation of Phase I program
- The future: Phase II program, large data samples for Central Production
- Summary

Processes with Tagged Forward Protons

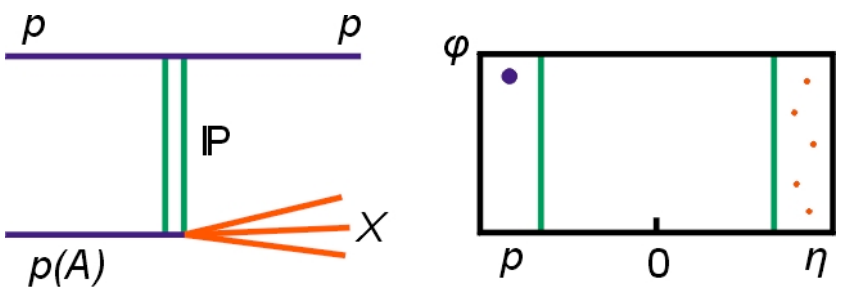
QCD color singlet exchange: C=+1(Pomeron), C=−1(Odderon)



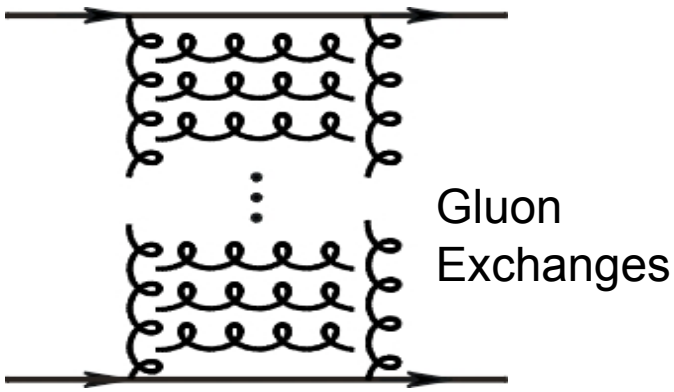
p + p → p + p elastic



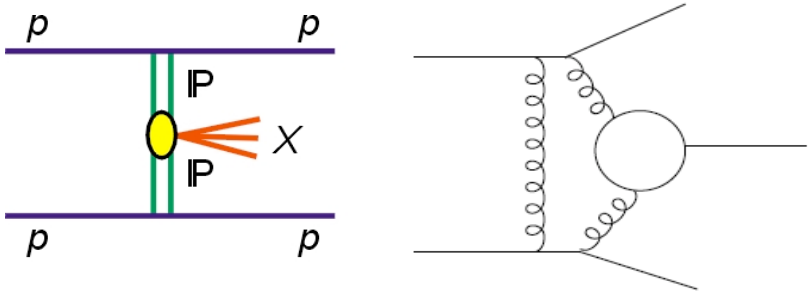
p + p → p + X + p
diffractive X= particles, glueballs



p + p → p + X SDD



Central Exclusive Production in Double Pomeron Exchange (DPE)

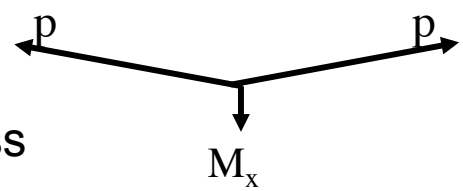


Method is complementary to:

- **GLUEX experiment (2015)**
- **PANDA experiment (>2015)**
- **COMPASS experiment (taking data)**
- **BESIII**

In the Double Pomeron Exchange (DPE) process each proton "emits" a Pomeron and the two Pomerons interact producing a massive system M_X

$M_X=\sqrt{\xi_1\xi_2 s}$ invariant mass

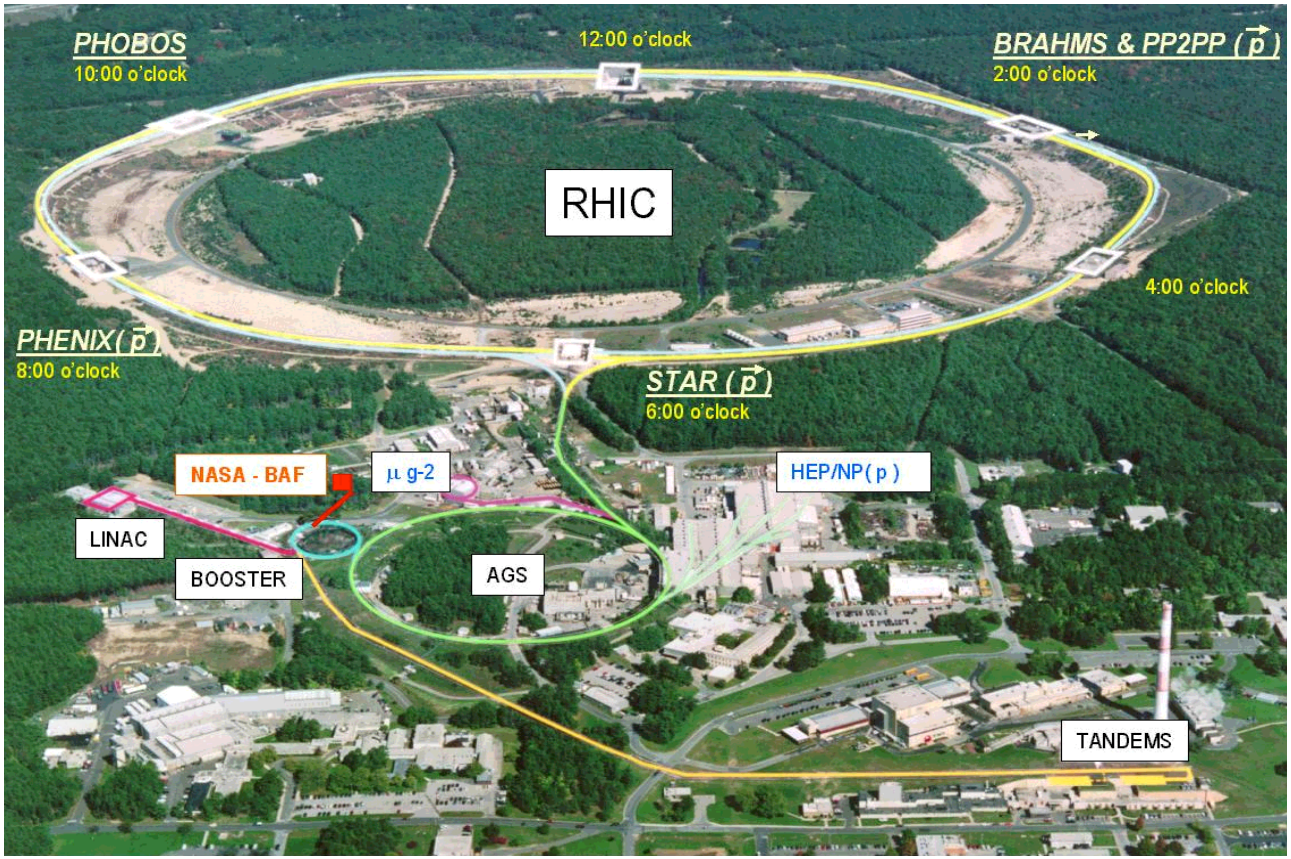


For each proton vertex one has
t four-momentum transfer
$\xi = \Delta p/p$

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.

The Relativistic Heavy Ion Collider

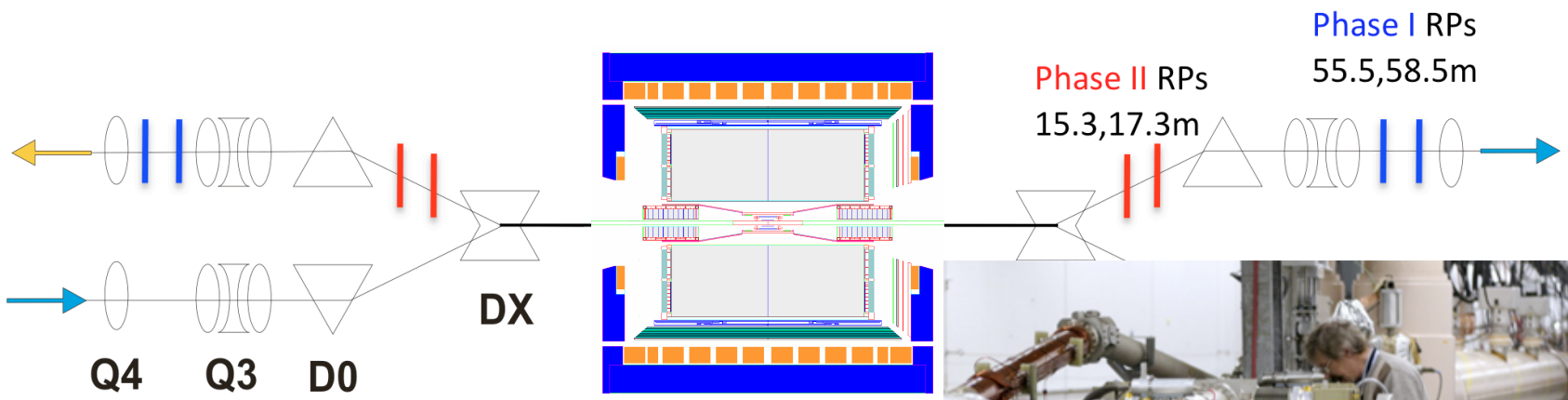


RHIC is a QCD Laboratory:

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

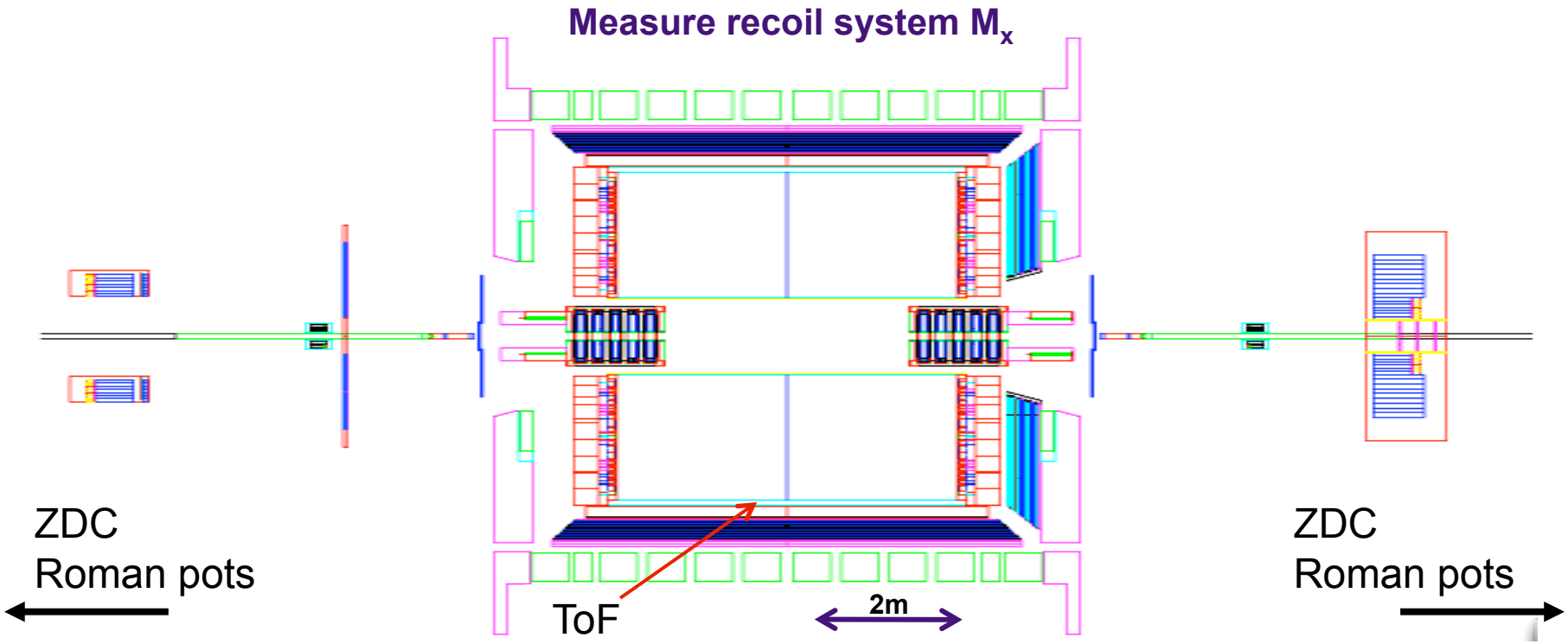
Implementation at STAR + pp2pp

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



1. Roman Pot (RP) detectors - forward protons
2. Staged implementation:
   - Phase I, present: low-t coverage - use existing equipment
   - Phase II, future: higher-t coverage, large data samples – requires new construction

Current ***STAR*** detector in cross section



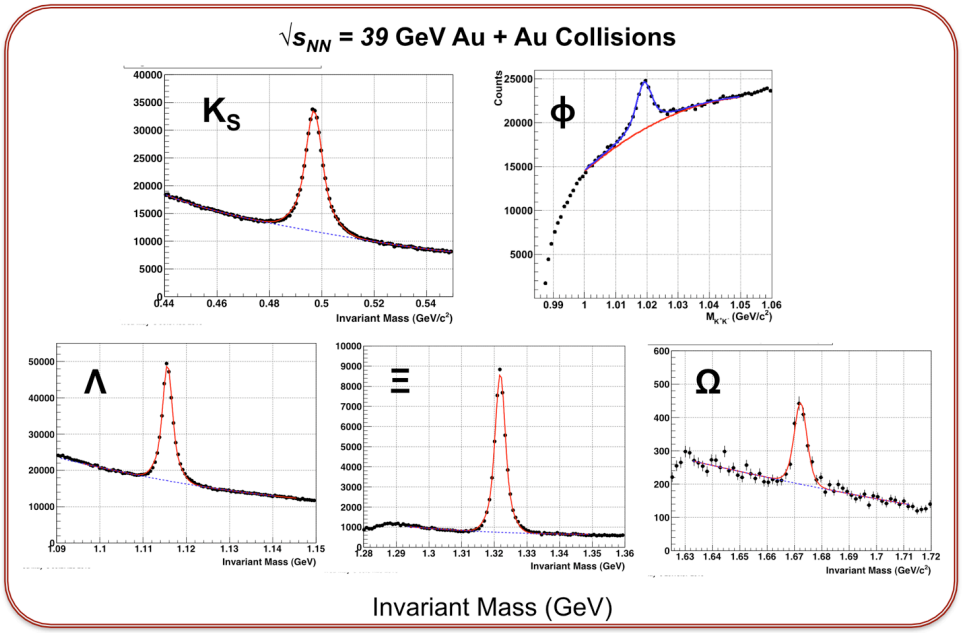
Large acceptance detector running since 2000

- High resolution tracking device: TPC in $-1<\eta<1$, $-\pi<\varphi<\pi$
- Forward rapidity gap veto: FTPC: $2.5<|\eta|<4.2$, BBC: $3.8<|\eta|<5.2$

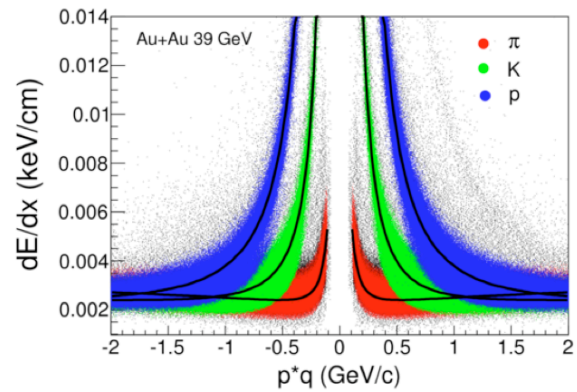
Excellent Charged Particle ID in the STAR TPC

- High resolution tracking device: TPC in $-1<\eta<1$, $-\pi<\varphi<\pi$
- Excellent particle identification capability: TPC dE/dx, ToF

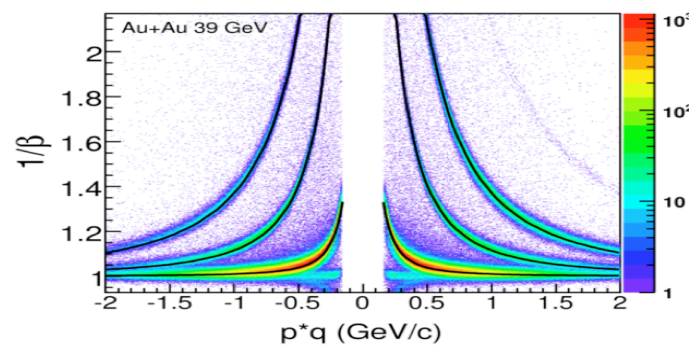
Particle Identification at STAR



Reconstructed hadrons: K_S, ϕ, Λ, Ξ, and Ω in Au+Au collisions at $\sqrt{s_{NN}}$ = 39 GeV



dE/dx vs. rigidity compared with theoretical expectations



Particle identification with new barrel Time-of-Flight system.

Glueball Spectrum from Lattice QCD

Sparse spectrum!

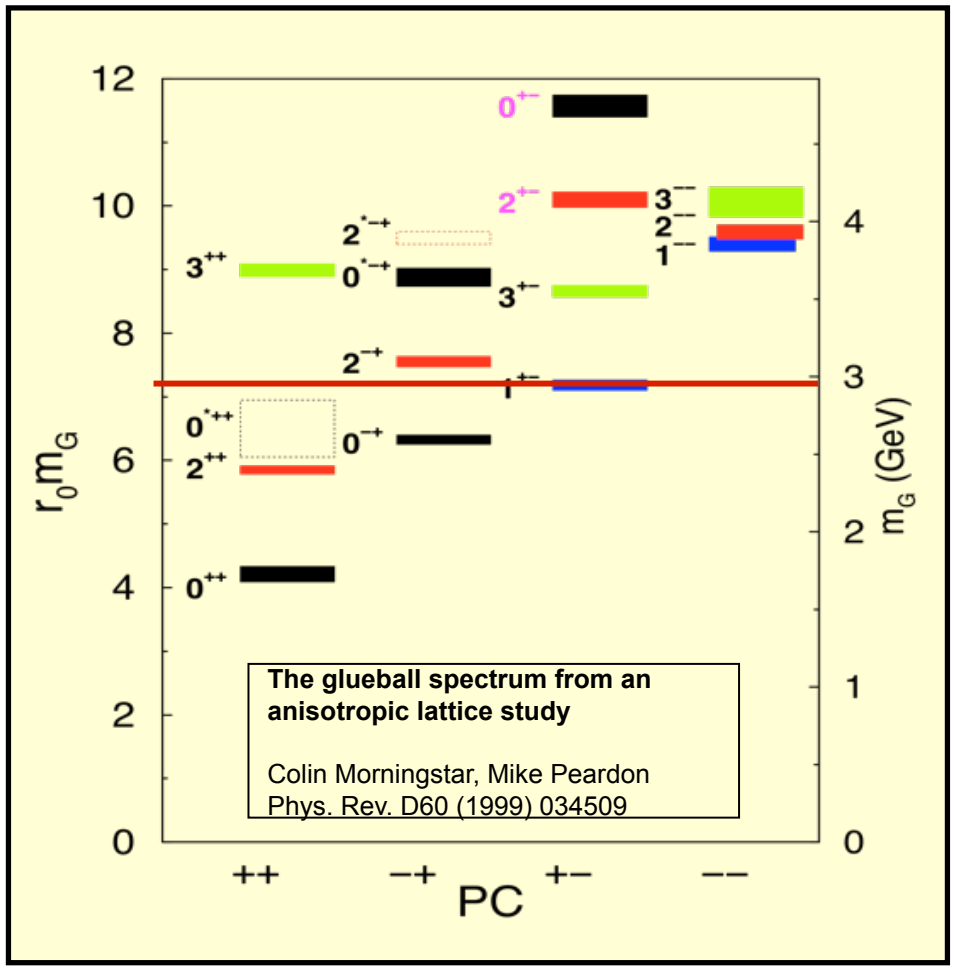
New I=0 mesons starting with

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./WA102)

- 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

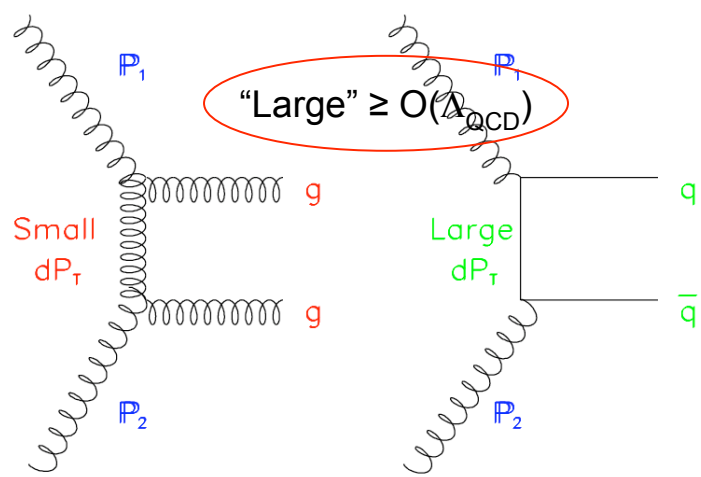
PLB 397 339 (1997)

As predicted by Regge theory the diffractive cross section at RHIC is dominated by the Pomeron (gluonic) exchange, :

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

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

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



WA102 $f_0(1500)$ $\pi^+\pi^-\pi^+\pi^-$

$\sigma(f_1)$= 7 μbarn

We are sensitive to this level of cross section

$\sigma(f_0)$= 3 μbarn

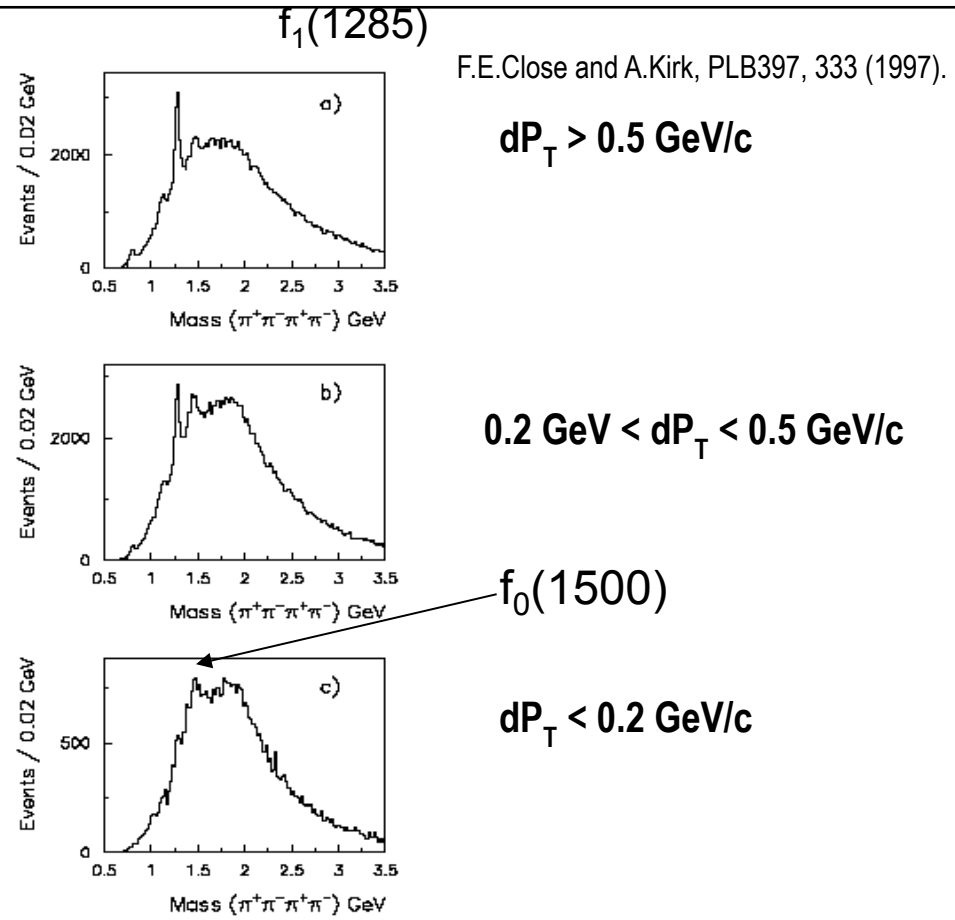
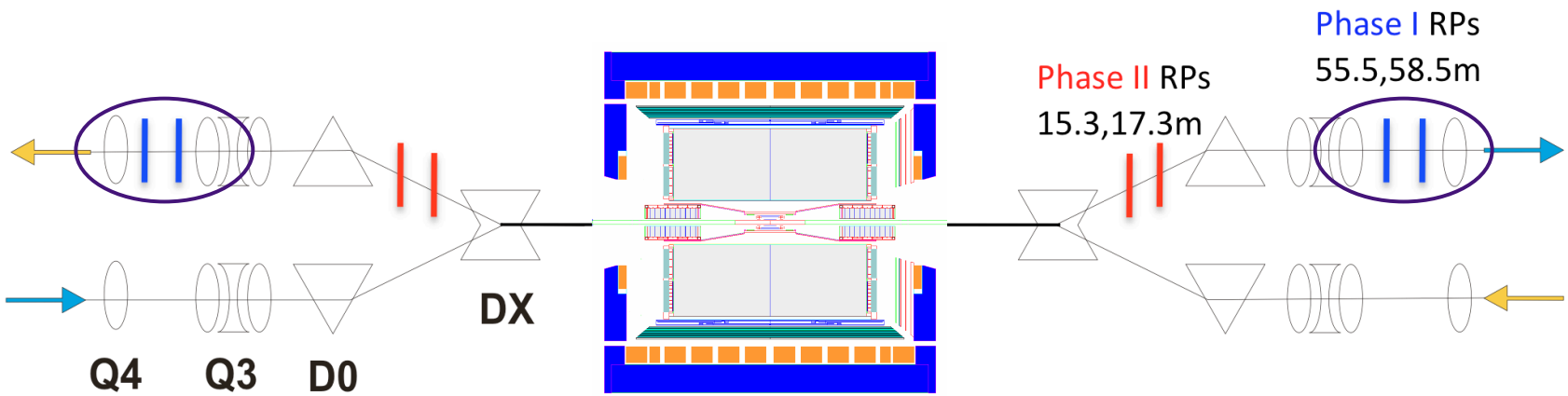


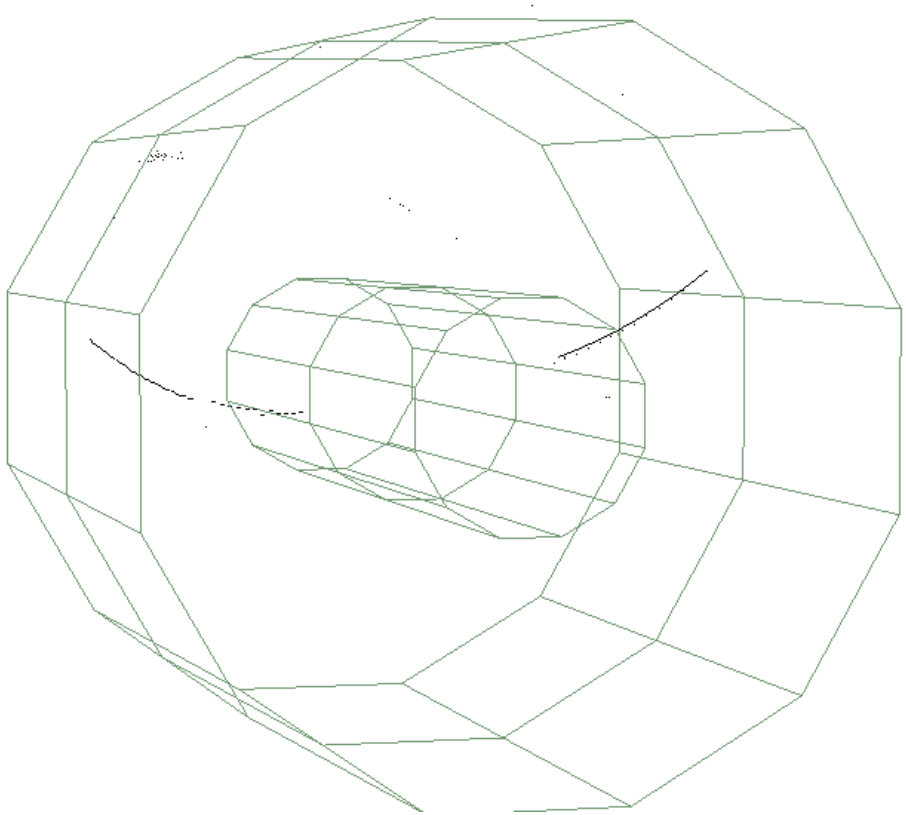
Figure 3: The 4π mass spectra (i) With $dP_T > 0.5$ GeV exhibiting a clear $f_1(1285)$; (ii) $0.2 < dP_T < 0.5$ GeV (iii) $dP_T < 0.2$ GeV where the $f_1(1285)$ has disappeared while the $f_0(1500)$ is seen more clearly.

Phase I: First Look at DPE Data



- Data taken with RP and ToF multiplicity triggers for the central process
- About 700k Central Production triggers collected during a special one week run at RHIC in 2009
- Data analysis is in progress

Run 9 Candidate Central Production Event



Event Information

run: 10183036
Events seen: 25
Event #127

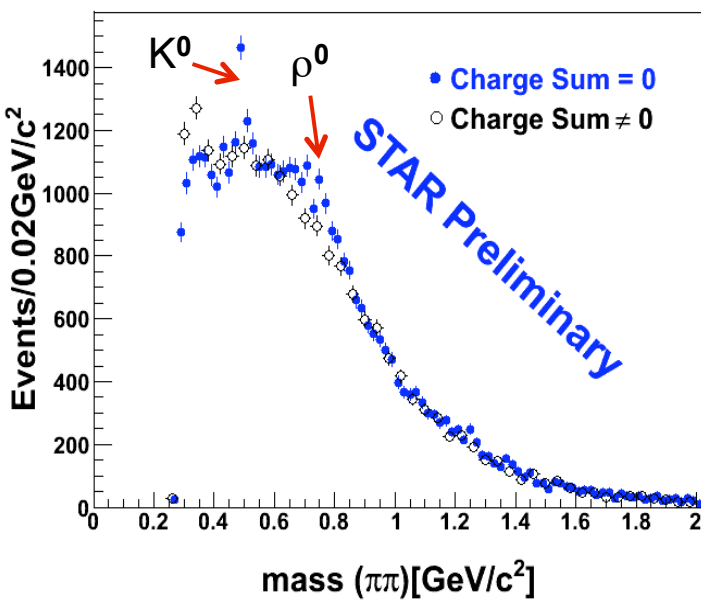
Triggers:

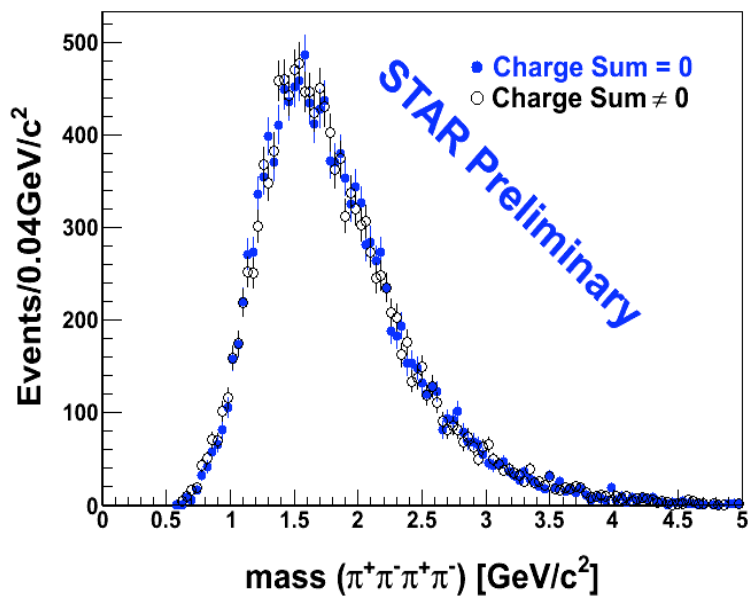
Phase I: First Look at DPE Data

(non exclusive channels)

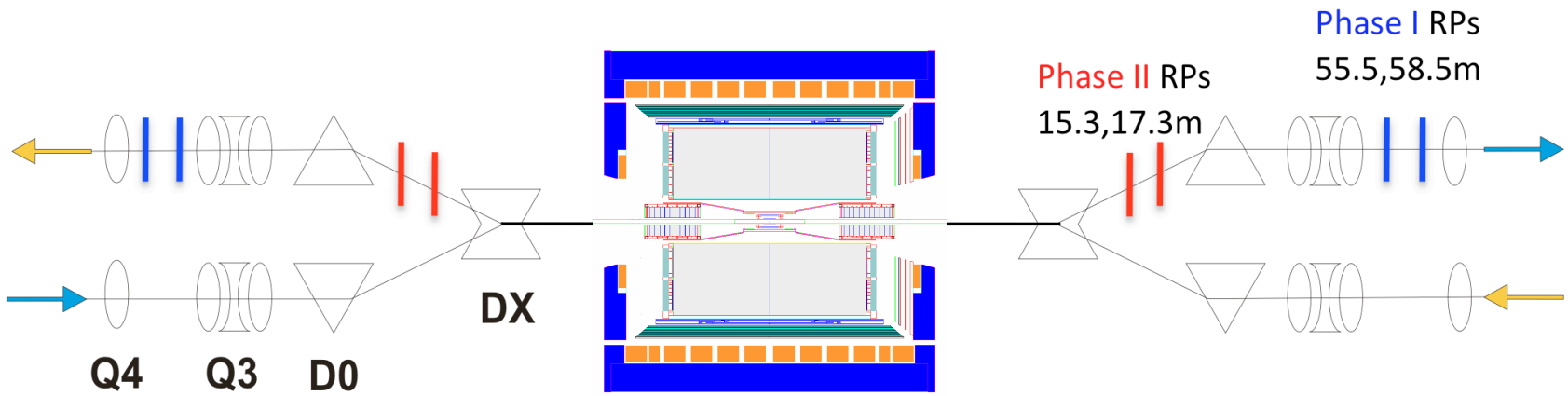
- Tracks reconstructed in the STAR TPC
- Require two reconstructed tracks in opposite direction in the RPs
- Work in progress for identifying exclusive DPE events:

rapidity gaps, PID, p_T-balance, missing-mass





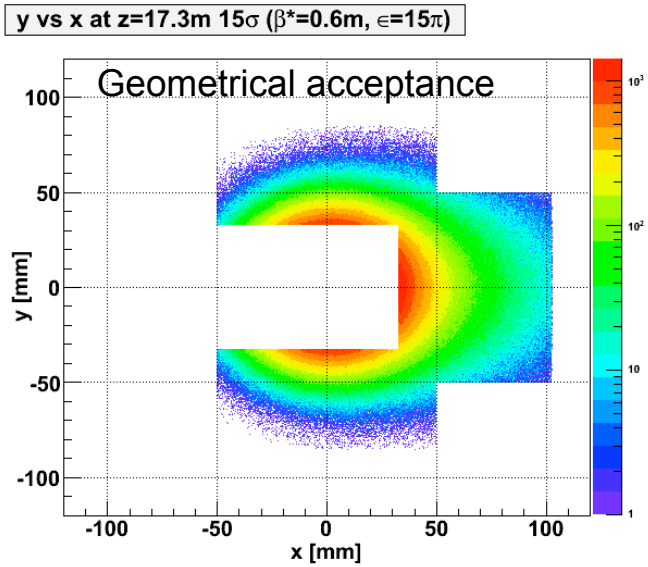
Phase II - no special beam optics required

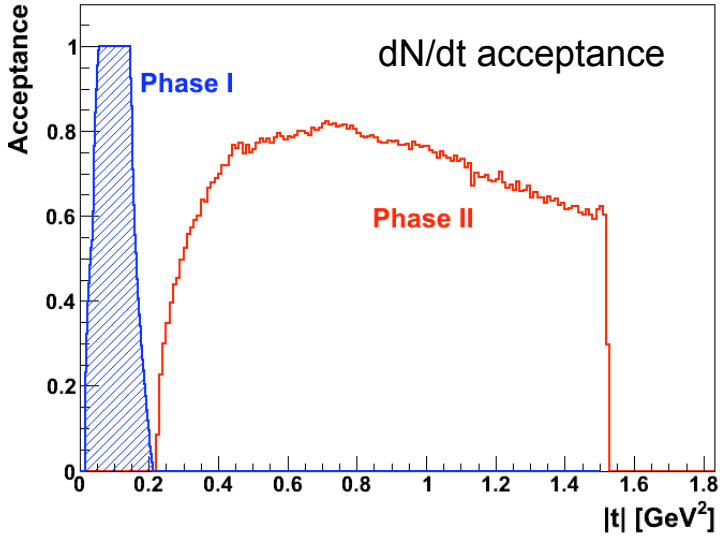


Simulation of performance

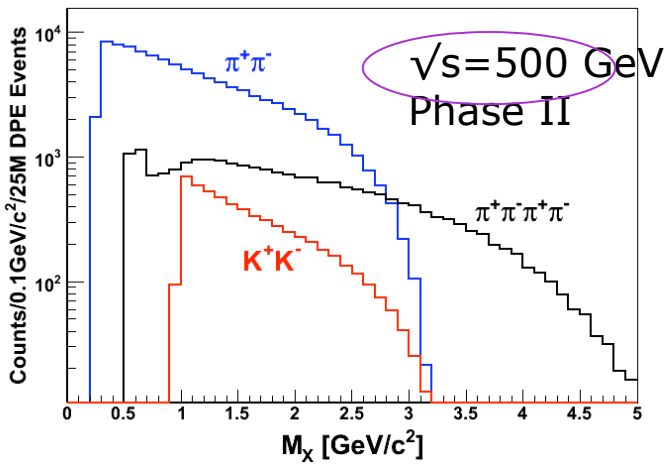
- Mass M_X calculated from the proton kinematics
- Use phase space to determine the decay of mass M_X in a particular channel
- Use STAR TPC acceptance to make sure that all decay products are measured.
- High-M_x reconstruction is limited by PID (π/K separation up to ~ 1.6 GeV/c)
- Total DPE cross section 140 μbarn; branching fraction ISR

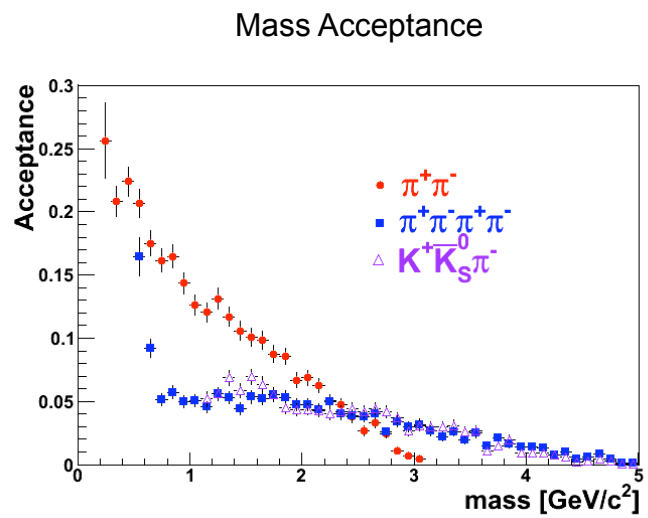
Phase II - Simulation Performance Plots





Acceptance and expected yields in M_X



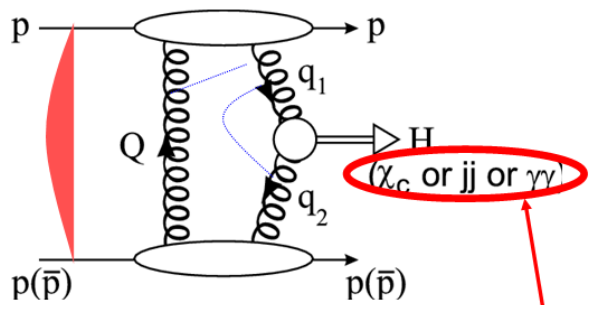


Event yields: 2 years of running pp at 500 GeV

$\pi^+\pi^-\pi^+\pi^-$ - 2.7×10^6 events
$\pi^+\pi^-$ - 10.4×10^6 events
K^+K^- - 0.8×10^6 events

Other QCD Processes Possible to measure at STAR in PhaseII: χ_c Production

arXiv:1005.0695 L.A. Harland-Lang, V.A. Khoze, M.G. Ryskin, W.J. Stirling



RHIC

$\sqrt{s}$ (TeV)	0.5	1.96	7	10	14
$\frac{d\sigma}{dy_{\chi_c}}(pp \to pp(J/\psi + \gamma))$	0.57	0.73	0.89	0.94	1.0
$\frac{d\sigma(1^+)}{d\sigma(0^+)}$	0.59	0.61	0.69	0.69	0.71
$\frac{d\sigma(2^+)}{d\sigma(0^+)}$	0.21	0.22	0.23	0.23	0.23

Table 3: Differential cross section (in nb) at rapidity $y_\chi = 0$ for central exclusive χ_{cJ} production via the $\chi_{cJ} \to J/\psi\gamma$ decay chain, summed over the $J = 0, 1, 2$ contributions, at RHIC, Tevatron and LHC energies, and calculated using GRV94HO partons, as explained in the text.

BR(χ_c => J /ψ+ γ)= 1.14 ± 0.08 %

CDF: σ (χ_c) = 76±10 ±10 nb

PRL 102, 242001 (2009)

Other QCD Processes Possible to measure at STAR in PhaseII: χ_c Production

Szczurek and collaborators

1. $\chi_c(0+)$ production:
R. S. Pasechnik, A. Szczurek and O. V. Teryaev, Phys. Rev. D **78**, 014007 (2008) [arXiv:0709.0857 [hep-ph]];

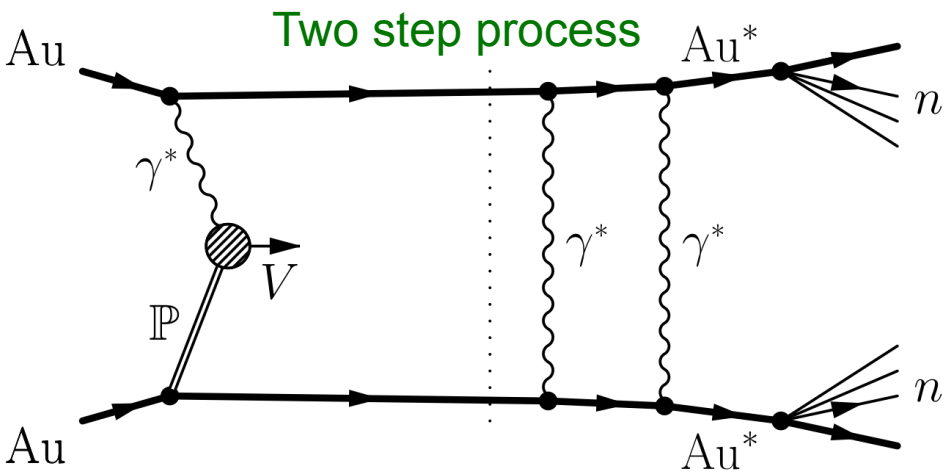
2. $\chi_c(1+)$ production:
R. S. Pasechnik, A. Szczurek and O. V. Teryaev, Phys. Lett. B **680**, 62 (2009) [arXiv:0901.4187 [hep-ph]];

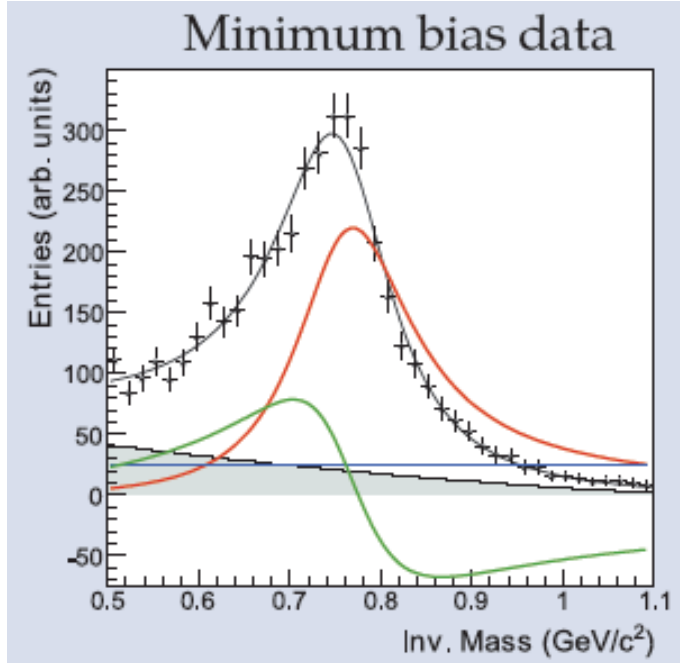
3. $\chi_c(2+)$ production:
R. S. Pasechnik, A. Szczurek and O. V. Teryaev, Phys. Rev. D **81**, 034024 (2010) [arXiv:0912.4251 [hep-ph]].

TABLE I: Integrated over full phase space cross sections (in nb) for the central exclusive $\chi_c(0^+, 1^+, 2^+)$ production at RHIC energy $W = 200$ GeV. Absorption effects and NLO QCD corrections to the $gg \to \chi_c$ vertex are included here. Gap survival factor for all χ_c states is taken here to be equal 0.1. Branching ratio to the channel of interest should be included in addition.

χ_c	without absorption	with absorption
$\chi_c(0^+)$	45	4.5
$\chi_c(1^+)$	2	0.2
$\chi_c(2^+)$	2	0.2

Particle Production in UPC





MAIN PHYSICS TOPICS:

- Meson spectroscopy:
  - ρ^0 (Phys. Rev. Lett. 89 (2002) 272302 and Phys. Rev. C 77 (2008) 34910)
  - ρ' = mix of $\rho(1450)$ and $\rho(1700)$ Phys. Rev. C 81 (2010) 44901)
- e^+e^- pair production (Phys. Rev. C 70 (2004) 031902(R));
- Fundamental tests of Quantum Mechanics: Interference between non overlapping particles Phys. Rev. Lett. 102 (2009) 112301

Summary

1. A rich diffractive physics program with tagged forward protons in polarized proton-proton scattering with the STAR detector at RHIC, has been launched and its significant expansion has been proposed.

2. Preliminary results on particle production were presented.

3. Continuation of Phase I is planned at $\sqrt{s}$ =500 GeV.

4. It will search for new physics, including glueballs, Odderon.

5. It will search for diffractive production of light and massive systems in double Pomeron exchange process. Possible Pomeron - Odderon interaction => J/ψ production, C−odd glueball.

6. Not discussed here - systematic study of the spin dependence of elastic scattering, of the shape of the differential elastic cross section $d\sigma/dt$ in unexplored ranges of t and $\sqrt{s}$ (D. Svirida at this conf.).

RHIC is an exciting, and complementary to other hadron colliders, place to do diffractive physics both in pp and HI

New collaborators are welcome!

STAR ☆