Present and Future of Central Production with STAR Detector at RHIC

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• 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)

$p + p \rightarrow p + p$ elastic

$p + p \rightarrow p + X + p$
diffractive $X=$ particles, glueballs

$p + p \rightarrow p + X$ SDD

Diffraction 2010  Włodek Guryń
Central Exclusive Production in Double Pomeron Exchange (DPE)

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

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.

Method is complementary to:
- GLUEX experiment (2015)
- PANDA experiment (>2015)
- COMPASS experiment (taking data)
- BESIII
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

**Measure recoil system** $M_x$

- **ZDC Roman pots**
- **ToF**
- **2m**
- **ZDC Roman pots**

Large acceptance detector running since 2000

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

Particle Identification at STAR

Reconstructed hadrons: \(K_S\), \(\phi\), \(\Lambda\), \(\Xi\), and \(\Omega\) 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

The glueball spectrum from an anisotropic lattice study

Colin Morningstar, Mike Peardon

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

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

\[
\sigma_{RR} \sim s^{-2} \\
\sigma_{RP} \sim s^{-1} \\
\sigma_{PP} \sim \text{const. or } s^\alpha \quad \text{where } \alpha \sim (0.1)
\]
$\sigma(f_1) = 7 \mu\text{barn}$

We are sensitive to this level of cross section

$\sigma(f_0) = 3 \mu\text{barn}$

Figure 3: The $4\pi$ 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 ($\pi/K$ separation up to $\sim 1.6$ GeV/c)
- Total DPE cross section 140 $\mu$barn; branching fraction ISR
Phase II - Simulation Performance Plots

Geometrical acceptance

$y$ vs $x$ at $z = 17.3\,\text{m}$ $15\sigma$ ($\sigma = 0.6\,\text{m}$, $e = 15\,\text{m}$)

$dN/dt$ acceptance

Acceptance vs $|t|$ [GeV$^2$]

Phase I

Phase II

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Acceptance and expected yields in $M_X$

Event yields: 2 years of running pp at 500 GeV

- $\pi^+\pi^-\pi^+\pi^- \quad - \quad 2.7 \times 10^6 \text{ events}$
- $\pi^+\pi^- \quad - \quad 10.4 \times 10^6 \text{ events}$
- $K^+K^- \quad - \quad 0.8 \times 10^6 \text{ events}$
Other QCD Processes Possible to measure at STAR in PhaseII: $\chi_c$ Production


CDF: $\sigma(\chi_c) = 76\pm10\pm10$ nb

PRL 102, 242001 (2009)

Table 3: Differential cross section (in nb) at rapidity $y_{\chi} = 0$ for central exclusive $\chi_{cJ}$ production via the $\chi_{cJ} \rightarrow J/\psi \gamma$ 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.

$$\sqrt{s} \text{ (TeV)}$$

<table>
<thead>
<tr>
<th>$d\sigma/dy_{\chi c}$ ($pp \rightarrow pp(J/\psi + \gamma)$)</th>
<th>0.5</th>
<th>1.96</th>
<th>7</th>
<th>10</th>
<th>14</th>
</tr>
</thead>
<tbody>
<tr>
<td>$d\sigma(1^+)/d\sigma(0^+)$</td>
<td>0.59</td>
<td>0.61</td>
<td>0.69</td>
<td>0.69</td>
<td>0.71</td>
</tr>
<tr>
<td>$d\sigma(2^+)/d\sigma(0^+)$</td>
<td>0.21</td>
<td>0.22</td>
<td>0.23</td>
<td>0.23</td>
<td>0.23</td>
</tr>
</tbody>
</table>

BR($\chi_c \rightarrow J/\psi + \gamma$) = 1.14 $\pm$ 0.08 %

CDF: $\sigma(\chi_c) = 76\pm10\pm10$ nb

PRL 102, 242001 (2009)
Other QCD Processes Possible to measure at STAR in PhaseII: $\chi_c$ Production

Szczurek and collaborators

1. $\chi_c(0^{+})$ production:
[arXiv:0709.0857 [hep-ph]];

2. $\chi_c(1^{+})$ production:
[arXiv:0901.4187 [hep-ph]];

3. $\chi_c(2^{+})$ production:
[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 $gg \rightarrow \chi_c$
vertex are included here. Gap survival factor for all $\chi_c$ states is taken here to be equal 0.1. Branching
ratio to the channel of interest should be included in addition.

<table>
<thead>
<tr>
<th>$\chi_c$</th>
<th>without absorption</th>
<th>with absorption</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\chi_c(0^+)$</td>
<td>45</td>
<td>4.5</td>
</tr>
<tr>
<td>$\chi_c(1^+)$</td>
<td>2</td>
<td>0.2</td>
</tr>
<tr>
<td>$\chi_c(2^+)$</td>
<td>2</td>
<td>0.2</td>
</tr>
</tbody>
</table>
Particle Production in UPC

MAIN PHYSICS TOPICS:

• Meson spectroscopy:
  o $\rho' = \text{mix of } \rho(1450) \text{ and } \rho(1700)$ Phys. Rev. C 81 (2010) 44901
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 $\Rightarrow$ J/$\psi$ 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!