Physics with Tagged Forward Protons and Results from Ultra-Peripheral Collisions at STAR

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• Process of diffraction and physics with forward protons - program at RHIC

• Our program in the context of QCD RHIC program

• Run 9 PHASE I – status of analysis

• Phase II proposal

• Results from HI UPC collisions (AuAu)

• Summary

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Jan. 4-8 2010

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The Relativistic Heavy Ion Collider

RHIC is a QCD Laboratory:
Nucleus- Nucleus collisions (AuAu, CuCu...); Asym. Nucl. (dAu);
Polarized proton-proton; eRHIC - Future
Our Program in the Context of RHIC the QCD Factory

- Study non perturbative regime of QCD
- Gluonic degree of freedom in Hadrons – exotica (glueballs…)
- Non-pert. QCD nature of diffractive processes – structure of Pomeron, Odderon… (color neutral exchange) and its spin dependence

- The program will naturally include other QCD topics:
  - Spin dependence of the elastic and diffractive scattering in polarized $pp$ collisions in the $\sqrt{s}$ up to 500 GeV $\Rightarrow$ hadronic spin flip;
  - Spin averaged elastic scattering ($\rho$, $\sigma_{\text{tot}}$, $d\sigma/dt$, B-slope);
  - A possibility of new physics of sphaleron production (clustering in multiparticle production) in DPE.
**RHIC-SPIN ACCELERATOR COMPLEX**

- **Pol. Proton Source**
- **Spin Rotators**
- **RHIC**
  - **RHIC pC “CNI” polarimeters**
  - **Former location of pp2pp**
- **Siberian Snakes**
- **PHENIX**
- **STAR**
- **AGS**
  - **AGS pC “CNI” polarimeter**
  - **AGS quasi-elastic polarimeter**
  - **200 MeV polarimeter**
  - **RF Dipoles**
  - **15% Snake**
  - **5% Snake**
  - $\beta^* \sim 21 \text{ m for pp2pp/STAR in 2009}$

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Processes with Tagged Forward Protons

QCD color singlet exchange: $C=+1(IP), C=-1(O)$

$p + p \rightarrow p + p$ elastic

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

Discovery Physics

$p + p \rightarrow p + X$ SDD
Central Production in DPE

In the double Pomeron exchange process each proton “emits” a Pomeron and the two Pomerons interact producing a massive system $M_X$:

\[ M_X = \sqrt{\xi_1 \xi_2 s} \text{ invariant mass} \]

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

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)
Implementation at RHIC - tag forward protons

PP2PP Setup


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

Phase I Roman Pots of pp2pp and STAR - use existing equipment
Vertical AND Horizontal RP setup for a complete $\phi$ coverage
Resonance Signal in p+p and Au+Au collisions from STAR
RUN 9 - Integrated Elastic Triggers

Expect about 20-25M elastic events for analysis

z-vertex distribution from trigger counters (no corrections)

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Colinearity of candidate elastic events
(we have a very good data sample!)

The “mean” is < 1 mm

Width $\sigma_{x,y} \sim 1.4$ mm $\Rightarrow$ $\sigma_\theta \approx 40$ µrad
Run 9 Candidate Central Production Event

Event Information
run: 10183036
Events seen: 25
Event #127

Triggers:
Glueball Spectrum

Sparse spectrum!

New J=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)

- 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, :

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

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

$\sigma_{PP} \sim \text{const. or } s^{\alpha}$ where $\alpha \sim (0.1)$
WA102 $f_0(1500)$ $\pi^+\pi^-\pi^+\pi^-$

\[ \sigma(f_1) = 7 \, \mu \text{barn} \]

We are sensitive to this level of cross section

\[ \sigma(f_0) = 3 \, \mu \text{barn} \]

$F.E.\, \text{Close and A.\,Kirk, PLB397, 333 (1997).}$

\[ dP_T > 0.5 \, \text{GeV/c} \]

$0.2 \, \text{GeV} < dP_T < 0.5 \, \text{GeV}.$

$0.2 \, \text{GeV} < dP_T < 0.5 \, \text{GeV}.$

Figure 3: The $4\pi$ mass spectra (i) With $dP_T > 0.5 \, \text{GeV}$ exhibiting a clear $f_1(1285)$; (ii) $0.2 < dP_T < 0.5 \, \text{GeV}$ (iii) $dP_T < 0.2 \, \text{GeV}$ where the $f_1(1285)$ has disappeared while the $f_0(1500)$ is seen more clearly.
Simulation Performance Plots

Simulation done using the beam transport simulator HECTOR

![Geometrical acceptance](image)

![dN/dt acceptance](image)

![Momentum Spectrum](image)

![Mass Acceptance](image)

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Acceptance and expected yields in \( M_X \)

- We assume the DPE cross section 140 ubarn, and branching ratios as measured at the ISR.
- High-\( M_X \) reconstruction is limited by PID (\( \pi/K \) separation up to \( \sim 1.6 \) GeV/c).

Rates for major channels:

\[
\begin{align*}
\pi^+\pi^-\pi^+\pi^- & \text{ events 27 Hz} \\
\pi^+\pi^- & \text{ events 23 Hz} \\
K^+K^- & \text{ events 2.3 Hz}
\end{align*}
\]

Event yields for 20 week run at 500 GeV:

\[
\begin{align*}
\pi^+\pi^-\pi^+\pi^- & \sim 2.7 \times 10^6 \text{ events} \\
\pi^+\pi^- & \sim 10.4 \times 10^6 \text{ events} \\
K^+K^- & \sim 0.8 \times 10^6 \text{ events}
\end{align*}
\]
Plan and Timeline

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

• **Phase II:**

  Technically driven schedule allows for installation before Run 12:
  
  • Finish engineering by Summer of 2010;
  • Install DX-D0 vacuum chamber Summer 2011;
  • Finish detectors Fall 2011;
  • Ready for Physics Run 2012.
Ultra Peripheral Collisions

Ultra Peripheral Collisions – nuclei miss each other (γγ and γP interactions)

Requires $b > R_A + R_B$

Weizsacker-Williams approach: a field of almost real photons

MAIN PHYSICS TOPICS

- $e^+e^-$ pair production;
- Meson spectroscopy: $\rho$, $\omega$, $\phi$, $\rho'$ state which believed to consist of $\rho(1450)$ and $\rho(1700)$;
- Transition from soft physics ($\rho, \omega, \phi$) to pQCD ($J/\Psi, \Upsilon$);
- Fundamental tests of Quantum Mechanics Interference between non overlapping particles.
Signature and Triggering

- **Signatures:**
  - Coherent production dominates
  - Low transverse momentum ($p_T \leq 2h/RA \approx 60$ MeV)
  - Low multiplicity events with vertex
  - Events with nuclear breakup accompanied by forward neutrons

- **Trigger:**
  - **Minimum bias**
    - Low multiplicity
    - Neutrons in both ZDCs
  - **Topology ToF and TPC:**
    - Low multiplicity events
    - Coincidence of North and South
    - Top and Bottom veto cosmics
The $\rho^0$ photoproduction cross section

- Goncalves & Machado (EPJ C29, 2003)
  - QCD color dipole approach
  - Nuclear effects and parton saturation phenomena
  - Generalized vector dominance (VDM)
  - QCD – Gribov-Glauber approach
- Klein & Nystrand (PR C60 014903, 1999)
  - VDM
  - Classical mechanical approach for scattering

Klein & Nystrand model agrees well with the data, $|y|<1$ does not allow to discriminate based on shape.

Red total cross section
Blue cross section with mutual excitation.
Simulation based on Klein & Nystrand

Coherent and incoherent form factors
Double exponential fit function
$\sigma_{\text{incoh}}/\sigma_{\text{coh}} \approx 0.29 \pm 0.03$
Photoproduction of $\pi^+\pi^-\pi^+\pi^-$

arXiv:0912.0604

- Expected to be largely through a radially excited
  - Could be $\rho(1450)$ and/or $\rho(1700)$
- Studies of the substructure showed low mass pion pairs accompanied by $\rho(770)$

$$\frac{\sigma_{\text{coh}}(\pi^+\pi^-\pi^+\pi^-)}{\sigma_{\text{coh}}(\rho[770])} = 13.4 \pm 0.8 \%$$

Peak at low $p_T$ is due to the coherent production

no signal for $\rho' \rightarrow \pi^+\pi^-$ channel
UPC Summary

- STAR measured e⁺e⁻ pair production
- STAR measured ρ⁰ photo production cross section:
  - Cross section is in agreement with theoretical models
    - √s = 130, 200 GeV
    - Analysis of data at √s = 62 GeV is in progress
- Observed interference effects in ρ⁰ production
- Observed production of π⁺π⁻π⁺π⁻ final state

Summary

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

2. 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 $\sqrt{s}$.

3. It will search for new physics, including glueballs, Odderon and sphalerons.

4. 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.

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

New collaborators are welcome!
BACKUP
Interference In $\rho^0$ Production

PRL 102, 112301 (2009)

- Impossible to distinguish source of $\gamma$ and target
  - VM are short lived
  - Decay points are separated in space-time
    - No interference
    OR
    - The wave function retains amplitudes for all possible decays, long after decay occurs
      - Non-local wave function $\Rightarrow$ Non factorizable $\Psi_{\pi^+\pi^-}=\Psi_{\pi^+}\Psi_{\pi^-}$
      - Example of the Einstein-Podolsky-Rosen paradox

- $\rho, \omega, \phi, J/\psi$ are $J^{PC}=1-$
- $\sigma \sim |A_{1(b,y)} - A_{2(b,-y)} e^{ip\cdot b}|^2$ where $b$ is impact parameter
  - Suppression at low $p_T \leq h/\langle b \rangle$

- Different triggers provide access to different median impact parameter
  - Topology data: median $b \approx 46$ fm
  - Minimum bias: median $b \approx 18$ fm (extends interference effects to larger $p_T$)

- Fit to the data $dN/dt = A \exp(-kt)[1+c(R(t)-1)]$
  - Allows to separate nuclear form factor and interference

  Combined interference $c=0.87 \pm 0.05$ (stat.) $\pm 0.08$ (syst.)%
Implementation at RHIC - STAR Detector
measure recoil system $M_x$
$L_{\text{max}} = 2 \times 10^{32} \text{s}^{-1} \text{cm}^{-2}$
70% Polarization
$\sqrt{s} = 50 \ldots 500 \text{GeV}$