Diffractive Physics Program with Tagged Forward Protons at STAR/RHIC

J.H. Lee
For STAR Collaboration

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Outline

- Diffraction measurements with Roman Pots in STAR at RHIC (Phase I, Phase II)
- Polarized elastic diffraction
  - Motivation
  - Preliminary results on Single Spin Asymmetries at CNI region
- Inelastic diffraction: central production
  - Motivation
  - First look at the data
- Outlook
RHIC as $p^+p^+$ Collider

- **Absolute pH polarimeter**
- **RHIC pC “CNI” polarimeters**
- **(BRAHMS)**
- **(PP2PP)**
- **Siberian Snakes**
- **PHENIX**
- **STAR**
- **Spin Rotators**
- **Pol. Proton Source**
- **200 MeV polarimeter**
- **RF Dipoles**
- **AGS**
- **AGS quasi-elastic polarimeter**
- **AGS pC “CNI” polarimeter**

- $\mathcal{L}_{\text{max}} = 2 \times 10^{32} \text{s}^{-1} \text{cm}^{-2}$
- 70% Polarization
- $\sqrt{s} = 50 \ldots 500 \text{ GeV}$

$\text{max} \times = - -$
Diffractive Physics Program with tagged forward protons at RHIC studying mainly:

- Polarized elastic scattering for understanding structure of Pomeron (and Odderon)

- Central production for searching for the glueball in Double Pomeron Exchange (DPE) processes
Forward Proton Tagging

- **Roman Pot (RP) detectors** to measure forward scattered protons in diffractive processes
  - **Staged implementation** to cover wide kinematic coverage
    - Phase I (Installed): for low-t coverage
    - Phase II (planned): for higher-t coverage
Summary of the Existing Elastic Data (unpolarized)

- **Highest energy so far:**
  - pp: 62 GeV (ISR)
  - pp: 1.8 TeV (Tevatron)

- **RHIC energy range:**
  - $50 \text{ GeV} \leq \sqrt{s} \leq 500 \text{ GeV}$

- **Elastic measurements:** Details on the nature of elastic scattering at high energy (Pomeron) are NOT well understood: Unique measurements in wide $t$-range with polarized beams
Can Odderon be identified at RHIC?

- Odderon is a counterpart of Pomeron (C=1) with C=-1 and not yet experimentally established: “RHIC is the machine to find it” (E. Leader, Odderon Workshop (2005)) by measuring
  - $\Delta \sigma_{pp} - \Delta \sigma_{\bar{p}p} \neq 0 ~(\sim 3mb)$
  - $d\sigma/dt_{pp} \neq d\sigma/dt_{\bar{p}p}$
  - Shape of Asymmetries: $A_{NN}$
  - Centrally produced $C=-1$ particle

Probing the Spin-Structure of Pomeron: Single Spin Asymmetries ($A_N$) at the Coulomb-Nuclear Interference (CNI) Region

- **Hadronic spin-flip** (QCD) part can be measured as a modification of $A_N$ from the CN interference (QED) at small-$t$ region (Kopeliovich, Lapidus 1974)
- $A_N$ data at CNI region available at lower energies ($\sqrt{s}<20$ GeV). At the RHIC energies, hadronic diffractive processes are expected to be dominated by the **Pomeron**
First high-statistics measurement of CNI at high-energy ($\sqrt{s}=200$ GeV)

- Statistical errors + systematic $t$-scale uncertainty (10%) in the fit
- Higher-$t$ reach planned from the upcoming $\sqrt{s}=500$ GeV (and with Phase II set-up) at RHIC
Hadronic Spin-Flip amplitude

- Fit to the data with hadronic spin-flip ($r_5$-fit)
  
  \[ r_5 = \text{Re} r_5 + i \text{Im} r_5 = \frac{m\phi_5}{\sqrt{-t} \text{Im} \phi_+} \]
  
  relative amplitude between hadronic spin-flip ($\Phi_5$) and non-flip ($\Phi_+$) helicity amplitudes

- No significant Hadronic spin-flip required in the fit

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t-Acceptance of Roman Pots

- Phase I set-up focuses on low-\(t\) (installed)
- Phase II covers higher-\(t\) range (planned to be installed in 2013)
Inelastic Process: DPE
\[ p_1 p_2 \rightarrow p_1' M_x p_2' \]

- Exclusive process with “small” momentum transfer: \(-t_1(p_1 \rightarrow p_1')\) and \(-t_2(p_2 \rightarrow p_2')\)
- \(M_x\) is centrally (nearly at rest) produced via a Double Pomeron Exchange/Fusion
- In pQCD, Pomeron is considered to be made of two gluons: natural place to look for gluon bound state
- \(M_x(\sim 1 – 3 \text{ GeV/c}^2) \rightarrow \pi^+\pi^-, \pi^+\pi^-\pi^+\pi^-, \text{K+K-},\ldots\)
- Lattice cal.: Lightest glueball \(M(0^{++})=1.5-1.7 \text{ GeV/c}^2\) (PRD73 2006)
- Search for glueball \((gg)\) candidates in \(M_x\)
- Candidates with conventional quantum numbers: need to be studied in wide kinematic ranges
DPE Central Production at RHIC

- **Pomeron** ($\mathcal{P}$) dominant over **Reggeon** ($R$) exchanges
  - $\sigma_{RR} \sim s^{-2}$, $\sigma_{RP} \sim s^{-1}$, $\sigma_{PP} \sim$ const. (or $s^x$ where $x \sim O(0.1)$)

- **Wide rapidity gap**
  - Beam rapidity at $\sqrt{s} = 500$ GeV: $y_{\text{beam}} \sim 6.3$
  - $M_X < 3$ GeV/$c^2$ will have a rapidity gap $> 4$ units

- **Higher reach in $M_X$**
  - 200 GeV: $M_{X \text{ max}} \sim 10$ GeV/$c^2$,
  - 500 GeV: $M_{X \text{ max}} \sim 25$ GeV/$c^2$

- Polarization dependence of DPE: provide extra constraint for theoretical interpretation and DPE filtering
Reconstructing centrally produced system in the \textbf{STAR detector}

\textbf{STAR: 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 particle identification capability: TPC $dE/dx$, ToF
First Look at DPE data from Phase I set-up

- Taken with RP and ToF multiplicity triggers for the central process
- Track reconstruction in TPC
- 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...
- Main data taking will be with Phase II set-up at $\sqrt{s}=500$ GeV
Expected yields as function of $M_X$ at $\sqrt{s}=500$ GeV

- **Expected reconstructed phase-space** including 140 µbarn DPE Cross-section and branching ratios measured at ISR per 25M DPE events
- $M_X=1-3$ GeV/c$^2$ is kinematically well accessible in pion and Kaon decay channels
- Expected Trigger rate for DPE: $\sim 100$ Hz at $\mathcal{L}=1 \times 10^{31}$ cm$^{-2}$s$^{-1}$
- 20 Week RHIC running: $\sim 2$M $K^+K^-$ $\sim 6$M $\pi^+\pi^-\pi^+\pi^-$ sample
New diffractive physics program with the STAR detector at RHIC to study properties of the Pomeron and search for the Odderon and the Glueball
- At high energies where the Pomeron interaction is expected to be dominating
- Using large acceptance and high resolution detector
- With polarized high luminosity beam

First high statistics data of spin asymmetries at CNI region and more to come

Looking forward to rich diffractive and spectroscopy programs with staged Roman Pot implementation at STAR
Back-Up
Spin Dependence in Elastic Scattering

Five independent helicity amplitudes describe proton-proton elastic scattering

\[
\begin{align*}
\phi_1(s,t) & \propto \langle ++ | M | ++ \rangle \leftarrow \text{non – flip} \\
\phi_2(s,t) & \propto \langle ++ | M | -- \rangle \leftarrow \text{double – flip} \\
\phi_3(s,t) & \propto \langle +– | M | +– \rangle \leftarrow \text{non – flip} \\
\phi_4(s,t) & \propto \langle +– | M | –+ \rangle \leftarrow \text{double – flip} \\
\phi_5(s,t) & \propto \langle ++ | M | +– \rangle \leftarrow \text{single – flip}
\end{align*}
\]

Some of the measured quantities are

\[
\sigma_{\text{tot}}(s) = \frac{4\pi}{s} \text{Im}\left[\phi_+^*(s,t)\right]_{t=0} \quad \sigma_{\text{tot}} \text{ of gives } s \text{ dependence of } \phi_+
\]

\[
\frac{d\sigma}{dt} = \frac{2\pi}{s^2} (|\phi_1|^2 + |\phi_2|^2 + |\phi_3|^2 + |\phi_4|^2 + 4|\phi_5|^2) \quad \text{Contributes to the shape of } A_{N}
\]

\[
\phi_i(s,t) = \phi_i^{em}(s,t) + \phi_i^{had}(s,t)
\]

\[
\begin{align*}
\phi_+ & = \frac{1}{2}(\phi_1 + \phi_3) \\
\phi_- & = \frac{1}{2}(\phi_1 - \phi_3) \\
\phi_i^{had} & = \phi_i^R + \phi_i^{Asympt.}
\end{align*}
\]
Experimental Determination of $A_N$

Use **Square-Root-Formula** to calculate

spin ($\uparrow\uparrow$, $\downarrow\downarrow$) and false asymmetries ($\uparrow\downarrow$, $\downarrow\uparrow$)

$$A_N(\varphi) = \frac{1}{(P_1 + P_2)\cos\varphi} \sqrt{N^\uparrow\uparrow N^\downarrow\downarrow} - \sqrt{N^\uparrow\downarrow N^\downarrow\uparrow}$$

$$A^F_N(\varphi) = \frac{1}{(P_1 + P_2)\cos\varphi} \sqrt{N^\uparrow\uparrow N^\downarrow\downarrow} - \sqrt{N^\uparrow\downarrow N^\downarrow\uparrow}$$

Since $A_N$ is a relative measurement the efficiencies $\varepsilon(t, \phi)$ cancel
Measurements of $A_N$ as a function of $\sqrt{s}$ and $t$

- $\sqrt{s} = 13.7$ GeV
- $\sqrt{s} = 19.4$ GeV
- $\sqrt{s} = 200$ GeV

The results of this experiment which are measured at $\sqrt{s} = 13.7$ GeV are indicated by the filled-red circles. The empty circles are measured at $\sqrt{s} = 19.4$ GeV by the E704 experiment at FNAL. The filled-green circles are measured at $\sqrt{s} = 200$ GeV by the PP2PP experiment at BNL. The errors on the data points are statistical.

The red solid, black dashed and green dotted-dashed lines are the functions without allowing for a hadronic spin-flip contribution to $A_N$ for these $\sqrt{s}$, respectively.
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 \(dp_T\))
- Filtering angular momentum?
- Spin-dependence of the coupling can be studied at RHIC

PLB 397 339 (1997)
Roman Pots (Phase II)

- Phase II: 8(12) Roman Pots at ±15 and ±17m
- Planned to be implemented in ~2013
- Doesn’t require special beam optics: main set-up for central DPE processes requiring wide-coverage and high-luminosity
- $2\pi$ coverage in $\phi$ will be limited due to machine constraint (incoming beam)
$d{p_T}$ "filter": WA102 ($\sqrt{s}=29$ GeV)

Fig. 3. $K^+K^-$ mass spectrum for a) $d{p_T} < 0.2$ GeV, b) $0.2 < d{p_T} < 0.5$ GeV and c) $d{p_T} > 0.5$ GeV and the $\pi^+\pi^-\pi^+\pi^-$ mass spectrum for d) $d{p_T} < 0.2$ GeV, e) $0.2 < d{p_T} < 0.5$ GeV and f) $d{p_T} > 0.5$ GeV.
Many measurements in $\sqrt{s} \sim 10$-60 GeV

- Fixed Target
  - CERN $\Omega$ (~1990)
    - WA76 ($\sqrt{s} = 12.6$ GeV), WA91(23.7), WA102(29.1)
  - CERN GAMS ($\sqrt{s} = 29.1$) (~1990)
  - FNAL E690 ($\sqrt{s} = 38.8$) (~1990)

- Collider
  - ISR AFS R807 ($\sqrt{s} = 62$) (~1980)

In this energy range, likely significant Reggeon-Reggeon contribution: difficulties in interpretations
**dp_T-dependent accepted yield (Simulation for Phase II)**

- \( dp_T = |p_{T1} - p_{T2}| \) for the “kinematic filter”

No significant \( dp_T \)-dependence in shape of the acceptance in \( M_X > 1 \text{ GeV/c}^2 \)