Spin physics in RHICf

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Outline

1. Brief Introduction for RHICf experiment

2. Spin Physics in RHICf
   - Forward neutron $A_N$
   - Forward $\pi^0$ $A_N$

3. Operation
   - RHICf detector
   - DAQ system
   - DATA taking
   - RHIC & Radial Polarized beam
   - Run

4. Comparison with proposal

5. Status of Analysis
RHICf experiment

- Targets in detection: Very forward neutral particles (photons, π0, and neutrons)
- Detectors: STAR ZDC, TPC, Roman pot and VPD + RHICf
- Physics motivations:
  - Cross sections of forward π0 and neutrons
  - $A_N$ of forward π0 and neutrons
- Advantage:
  - Usage of radial polarized beam and various detector position
    → Measurement of neutral particles over wider $p_T$ range with higher position resolution
Spin Physics in RHICf

- Definition of $A_N$:

\[ A_N = \frac{\sigma^\uparrow_L - \sigma^\downarrow_L}{\sigma^\uparrow_L + \sigma^\downarrow_L} = \frac{\sigma^\downarrow_R - \sigma^\uparrow_R}{\sigma^\downarrow_R + \sigma^\uparrow_R} = \frac{\sigma^\uparrow_R - \sigma^\uparrow_R}{\sigma^\uparrow_R + \sigma^\downarrow_R} = \frac{\sqrt{\sigma^\uparrow_L \sigma^\downarrow_R} - \sqrt{\sigma^\downarrow_L \sigma^\uparrow_R}}{\sqrt{\sigma^\uparrow_L \sigma^\downarrow_R} + \sqrt{\sigma^\downarrow_L \sigma^\uparrow_R}} \]

- $\sigma^\uparrow_L$, $\sigma^\downarrow_L$ : cross section for particles produced on left side when spin of incident particle is up(down)

- Also called Left-Right asymmetry
Spin Physics in RHICf

- Measurement of $A_N (1)$: raw asymmetry: $\epsilon_N (\phi) = \frac{\sqrt{N_{\phi}^{-} N_{\phi+\pi}^{-}} - \sqrt{N_{\phi+\pi}^{-} N_{\phi}^{-}}}{\sqrt{N_{\phi}^{-} N_{\phi+\pi}^{-}} + \sqrt{N_{\phi+\pi}^{-} N_{\phi}^{-}}}$

- $N_{\phi}^{-}, N_{\phi}^{+}$: Number of particles going through specific area when spin of incident particle is down(up)
Spin Physics in RHICf

- Measurement of $A_N$ (Modular measurement not applicable): Relative luminosity
  \[ A_N = \frac{\sigma_L^\uparrow - \sigma_L^\downarrow}{\sigma_L^\uparrow + \sigma_L^\downarrow} = \frac{N_L^\uparrow - RN_L^\downarrow}{P(N_L^\uparrow + RN_L^\downarrow)} \]

- Relative luminosity:
  \[ R = \frac{L^\uparrow}{L^\downarrow} = \frac{N^\uparrow}{N^\downarrow} \]

- Measurement of $R$: STAR ZDC, BBC and VPD (vertex position detector)
**A_n for forward neutron**

- Previous result:
  2002: RHIC IP12 experiment
  2006: PHEINX

- Origin of $A_n$ for forward neutrons?
  → Some of interaction models explain it

- $\pi\cdot a1$ reggeon interference model:

- One-Pion exchange model
  → Cross section is okay, But can’t explain large $A_n$
An for $\pi^\pm$ and $\pi^0$

Previous result:
1991: 704 collaboration reported unexpected large $A_N$ ($\sim 30\%$) in $p + p \rightarrow X + \pi^\pm,0$ over large $X_F$ at $\sqrt{s}=19.4\text{GeV}$
2006: PHENIX confirmed small $A_N$ ($\sim 3\%$) of $\pi^0$ over mid pseudo-rapidity ($3.1<\eta<3.7$) at $\sqrt{s}=62.4\text{GeV}$

Higher Twist contribution explain these data

When it comes to $A_N$ within range covered but SMD, $A_N$ is 0 (Due to systematic error $\Delta X$ of SMD $\sim 1\text{cm}$)

Operation

- Measurement Location: 18m away from STAR IP
- 3 different detection position
- Common data taking with STAR(ZDC, Romanpot, BBC and TPC)
- Radial Polarized beam with $\sqrt{s}=510\text{GeV}$ and $\beta^*=8\text{m}$
Detector

- ZDC&SMD: Hadron calorimeter with 5.1 $\lambda$ & 153 $X_0$ (3 modules)
  - Energy resolution: $\sigma_E/E \sim 20\%$ at 100GeV incident neutron
  - Position resolution: $\sim 1$cm

- RHICf: EM calorimeter with 1.7 $\lambda$ & 44 $X_0$
  - Energy resolution: $(\sigma_E/E)_V \sim 5\%$ and $(\sigma_E/E)_n \sim 40\%$
  - Position resolution: $\sim 1$mm
Data taking

- RHICf sends all final trigger signals to STAR DAQ including pedestal triggers.
- STAR issues an Event-ID: Token (12 bits) for each L1 trigger.
- RHICf records the Token+DAQ commands (20 bits in total) and sends data with the Token via network.
- STAR makes event-build and records into a disk.

**Hardware setup**
- FPGA boards managed both sending trigger and recording Token.
- A level converter converts the signal level PECL <-> LvTTL.
RHIC (Relativistic Heavy Ion Collider)

- World 1st high energy polarized beam collider
Radial Polarized beam

Run 18140025 ZDC Asymmetry (Blue)

Run 18177011 ZDC Asymmetry (Blue)

Angle: 1.3 ± 0.3 deg

Angle: -89.1 ± 1.0 deg
Radial Polarized beam
Comparison with proposal

- Estimates for $A_N$ measurement in proposal

![Graph showing asymmetry vs azimutal angle $\phi$](image)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\chi^2 / \text{ndf}$</td>
<td>$2.578 \times 10^{-17} / 6$</td>
</tr>
<tr>
<td>Amplitude</td>
<td>$0.03 \pm 0.0027$</td>
</tr>
<tr>
<td>Phase offset (rad)</td>
<td>$0 \pm 0.09001$</td>
</tr>
</tbody>
</table>

Detector is at the position-1. Number of neutrons observed in the $3 \text{mm} < r < 8 \text{mm}$ ring region in the small calorimeter during 4 hours operation at the position-1 is $1.1 \times 10^6$. In this case $\delta A = 0.0019$ is expected.

- Quick result value for number of neutron: $\sim 7 \times 10^5$
Status of Analysis

• Current parameters of analysis tool are optimized for LHCf experiment.

• Studying MC simulation for optimization of RHICf

• Making full simulation for RHICf
Summary

- $A_N$ is useful observable as tool in studying intrinsic nucleon structure

- In RHICf experiment, $A_N$ over wider $pT$ range with higher $pT$ resolution can be measured. This will be used in figuring out interaction model in soft QCD range
  - neutron: $pT < 0.3 \& pT > 0.6$ at $\sqrt{s}=510$GeV
  - pion: measurement in $3.1<\eta<3.7 \rightarrow$ measurement in $6<\eta$

- Common operation with STAR(ZDC, TPC, VPD and Romanpot)

- Comparing with experiment proposal, RHICf experiment is completed successfully.

- MC studies for optimization in analysis are under going
Backup
An for forward $\pi^\pm$ and $\pi^0$

Fig. 3. The asymmetries $A_N$ in the reactions $\bar{p}p + p\rightarrow \pi^0 + X$ (closed circles) and $pt + p\rightarrow \pi^0 + X$ (open squares, see ref. [1]) at 200 GeV in different regions of $x_F$, integrated over $p_t$ from 0.5 to 2 GeV/c. The quantity $\sigma / \sigma_\uparrow$ is the ratio of the $\pi^0$ production cross sections for opposite beam spins.

Fig. 4. $A_N$ versus $x_F$ for $\pi^+$, $\pi^-$ and $\pi^0$ data.

Figure 1.3: $A_N$ vs. $p_T$ for inclusive $\pi^0$ productions from polarized $pp$ scattering in $\sqrt{s}=19.4$ GeV. The data is shown for $0.5 < x_F < 0.8$. [26]
Quick result (reconstructed $\pi^0$ mass)
Quick result (Hits map for beam center)
Quick result
Quick result (Recorded event #)
Quick result (Statistics in various trigger)

![Graph showing number of recorded events over time](image)

- RHIC Cl Run17 Statistics
- RHIC Cl All
- RHIC Cl-STAR
- L3T Shower
- L3T Special1 (Type-I π²)
- L3T Special2 (High-energy EM)

![Graph showing prescale values over time](image)

- L3T Shower
- L3T Special1 (Type-I π²)
- L3T Special2 (High-energy EM)
Quick result (Event# of RHICf vs of STAR)