Transverse single spin asymmetry in heavy flavor electrons and charged pions production at midrapidity in polarized p + p collisions at 200 GeV

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The Proton Spin Structure

1988 EMC measured: 
\[ \Sigma = 0.123 \pm 0.013 \pm 0.019 \rightarrow \text{Spin Puzzle!} \]

\[ S_{proton} = \frac{1}{2} = \frac{1}{2} \Delta q + \Delta G + L_{q,g} \]

\[ \frac{1}{2} = \frac{1}{2} (\Delta u_v + \Delta d_v + \Delta q_s) + \Delta G + L_{q} + L_{g} \]

\[ \Delta u_v + \Delta d_v + \Delta q_s + \Delta \bar{u}_s + \Delta \bar{d}_s + \Delta \bar{s}_s \]

In the 1980s, the EMC experiment discovered that a proton's valance quarks account for only a fraction of the proton's overall spin. New measurements from RHIC experiment reveal that gluons contribute as much as or possibly more than the quarks.

How is proton's spin correlated with the motion of quarks and gluons? 
-> Transverse Momentum Dependent (TMD) Functions
Transverse Single Spin Asymmetry

Sources of Transverse SSA's

\[ A_N = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} \]

**Sivers Function**
- correlation between proton spin and parton \( k_T \).

**Collins Function**
- Spin momentum correlation in a Fragmentation Function.

**Transverse momentum dependent (TMD) framework**
- two observed scales: \( \Lambda_{QCD} \ll Q_T^2 \), \( P_{h\perp} \ll Q^2 \)
- applicable in SIDIS and Drell Yan

Figures from L. Nogach 2006 RHIC AGS Users Meeting
Higher Twist Effects

**Twist-3 Function**
- Multiparton correlations
- Power suppressed terms in factorization expansion by $\sim 1/Q$
- Applicable when only single hard scale observed, such as in ANs in hadronic collisions. ($A_N \sim 1/p_T$)

- They also contain initial state (correlations in the nucleon) and final state (correlations in the fragmentation) effects
- Several of the higher twist effects can be related to moments over intrinsic transverse momenta of TMDs, such as Sivers moment $\rightarrow$ Efremov-Teryaev-Qiu-Sterman function.
View of the Brookhaven National Laboratory, NY, USA
Tracking
- Drift Chamber (DC) - Pad Chamber (PC1/PC3)

Charged particle Identification
- Ring Imaging Cherenkov Detector (RICH)
- Electromagnetic Calorimeter (PbSc/PbGl)

Relative Luminosity
- Beam Beam Counter (BBC)
- Zero Degree Calorimeter (ZDC)

Acceptance
- $|\eta| < 0.35$  
- $\Delta \varphi = 2 \times \pi/2$
Particle ID for $\pi^\pm$ and $e^\pm$

$\pi^\pm$ identification
- Trigger $\pi^\pm$ with a BBC and EMCal.
- Track can be divided into two categories according to RICH response at $p_T$ 5~16 GeV/c.
  - RICH Hit: $e^\pm$ and $\pi^\pm$.
  - No RICH Hit: $K^\pm$ and $p$.
- $0.2 < \frac{E}{p} < 0.8$
- EM shower shape probability < 0.1

$e^\pm$ identification
- Trigger $e^\pm$ with a BBC and EMCal.
- $|E/p - \langle E/p \rangle| < 2\sigma_{E/p}$ at $(\langle E/p \rangle \sim 1)$
- RICH Hit: $e^\pm$ ($20\, \text{MeV/c} < p$)
- EM shower shape probability > 0.01
- Hit requirement in inner 2 layers of VTX
- Conversion veto cut on opening angle of nearby $e^\pm$ candidates

Energy threshold for the emission of Cherenkov radiation in RICH

<table>
<thead>
<tr>
<th>Particle</th>
<th>Electron</th>
<th>Pion</th>
<th>Kaon</th>
<th>Proton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Threshold</td>
<td>20 MeV/c</td>
<td>4.9 GeV/c</td>
<td>17.3 GeV/c</td>
<td>33 GeV/c</td>
</tr>
</tbody>
</table>

Example at $\sqrt{s} = 510$ GeV
Recent $\pi^0$ and $\eta$ $A_N$ results at 200 GeV with Run-15 data

- $\pi^0$ and $\eta$ production - quark-gluon scattering is dominant process - $A_N$ consistent with zero.
- These results are sensitive to initial and final state effects

Charged pion $A_N$ can provide flavor sensitivity ($u$ and $d$ quarks)
Charged pion background

Comparison of reconstructed particle momentum distributions as a function of the transverse momentum in the data and MC simulations.

- At low $p_T$ below 5 GeV/c the distribution is dominated by electrons (kaons and protons is insignificant)
- At higher $p_T$, electrons are the dominant background.
Charged pion background

- $e/p < 0.2$, electrons from photon conversion decay-in-flight are reconstructed with higher $p_T$
- $e/p > 0.8$, considering that most pions do not deposit all their energy in the electromagnetic calorimeter in contrast to electrons.

- Calibrate electron background fraction from simulation by fitting $E/p$ peak to data
- Correct for electron background using asymmetries from electron enhanced data sample
Charged Pion $A_N$

- First central charged pion AN measurement at PHENIX
- $A_N$ of each charge consistent with zero
- But slight indication of differences with each other. (particularly low $P_T$ region)

Hint of different asymmetries from up and down quarks
Open Heavy Flavor $e^\pm$ Production

- Open charm production is dominant contribution

\[ gg \rightarrow QQ \]

**Dominant contribution @ 200 GeV midrapidity**
- $ggg$ correlator *not* well constrained from previous measurements

\[ qq \rightarrow QQ \]

**Small contribution @ 200 GeV Midrapidity**
- $qqg$ correlator somewhat constrained from previous measurements

Glueon transverseity distributions = 0 → access to trigluon correlator
Open Heavy Flavor $e^\pm$(background)

- Largest contribution from photonic electron background sources ($\pi^0 + \eta + \gamma$) at $p_T < 3$ GeV/c. Asymmetries for these sources well constrained to be zero at 200 GeV midrapidity.

- Largest contribution from $J/\psi$ at $p_T > 3$ GeV/c. $\sigma_{AN}$ affected significantly in this region due to $A_N^{J/\psi}$ suffering from large statistical uncertainty.

See also D. Fitzgerald at DIS2021
• First result of open heavy flavor and nonphotonic electron TSSA at midrapidity

• Consistent with zero in measured range
Open Heavy Flavor Electron $A_N$

- Red line: $D^0 \rightarrow e^\pm$ $A_N$ calculations
- sensitivity to different parameters from charge separated asymmetries
• **First $A_N$ measurements of $\pi^\pm$ at midrapidity**
  - $A_N$ in $\pi^\pm$ production are sensitive to quark flavors.
  
  - With a complementary probe with improved statistics, might help to check the up and down quarks make a different asymmetries.
  
  - It expands $\pi^+$ and $\pi^-$ for each quarks flavor.

• **First open heavy flavor $e^\pm A_N$ result to be published**
  - $p^+ + p$, $\sqrt{s} = 200$ GeV, $|\eta| < 0.35$
  
  - Consistent with zero in measured range
  
  - Charge separated results sensitive to different parameterizations
Thank you.