Polarized Drell-Yan Experiments

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Introduction

• Sidney Drell and Tung-Mow Yan in 1970, proposed the Drell-Yan process which can be described as the virtual photon production due to the quark-antiquark annihilation in hadron-hadron collisions.

• The simplest process in hadron-hadron reactions
  • No QCD final state effect, no fragmentation process

• Drell-Yan process can be used as a tool to understand the internal properties of nucleons, both in terms of longitudinal and transverse degrees of freedom of the constituents.
Longitudinal helicity distributions

- Spin dependent quark distribution
  Polarized Parton distribution function (pPDF)
  \[ \Delta q(x) : \Delta u \text{ and } \Delta d \text{ are well known from the (SI)DIS data} \]
  \[ \Delta \bar{q}(x) : \Delta \bar{u} \text{ and } \Delta \bar{d} \text{ measured with larger uncertainties} \]

- Some of the experiments that provide the \( \Delta u \) and \( \Delta d \) measurements
  - RHIC \( W^{\mp} \)
  - RHIC Drell-Yan (very low \( x \sim 0.002 \))

\[
A_{DY}^{DLL} = -\frac{\sum_q e_q^2 \{ \Delta q(x_1) \Delta \bar{q}(x_2) + \Delta \bar{q}(x_1) \Delta q(x_2) \}}{\sum_q e_q^2 \{ q(x_1) \bar{q}(x_2) + \bar{q}(x_1) q(x_2) \}}
\]

\[ \approx -\frac{\Delta u(x_1)}{u(x_1)} \cdot \frac{\Delta \bar{u}(x_2)}{\bar{u}(x_2)} \]

- u-quark dominates in p+p
  (84% of time Drell-Yan involves a u quark)
Transverse Momentum Distributions

- TMDs encode the relation between the transverse spin and the transverse momentum of the partons and nucleons.

- All the quark TMDs can be classified into eight categories through the Polarizations of the nucleon and the quark inside the nucleon.
Sivers Function in Drell-Yan

- Describes transverse-momentum distribution of unpolarized quarks inside transversely polarized proton

- Fundamental QCD prediction

\[ f_{1T}^{\perp}(x, k_T) \bigg|_{SIDIS} = - f_{1T}^{\perp}(x, k_T) \bigg|_{DY} \]

- Sivers Function captures non-perturbative spin-orbit coupling effects inside a polarized proton

- Identifying a non-vanishing sea quark Sivers distribution could indicate orbital angular momentum could be a major part of the “missing spin”.

11/11/2016
Drell-Yan in PHENIX (RHIC)

- **Focus**
  - Measurement of longitudinal double spin asymmetry ($A_{LL}$) and cross-section at $\sqrt{s} = 500$ GeV
  - Measurement of Single spin asymmetry ($A_N$) at $\sqrt{s} = 200$ GeV

11/11/2016
Drell-Yan in PHENIX Predictions

• Interested invariant mass : $4.5 \text{ GeV} < M < 8 \text{ GeV}$

• Rapidity coverage : $1.2 < |\eta| < 2.4$

• Access low $x$ ($\sim 2 \times 10^{-3}$)

• Suffer from low statistics ($\sim 1000$ Drell-Yan event in narrow vertex)
Drell-Yan at Compass

- Transversely polarized $p(\text{NH}_3)$ Target
- $190 \text{ GeV/c } \pi^-$ beam
- High beam flux $\sim 10^9 \pi^-$/spill

3D view of the DY set-up in COMPASS MC simulation.

COMPASS II (2012–2017)

- 2015: Drell–Yan with T-polarised $p$ target
  \[ \pi^- + p^\uparrow \rightarrow \mu^+ + \mu^- + X. \]

Jan Matousek (spin 2016)
Drell-Yan at Compass: Results

- Data collected ~18 weeks
- 55000 DY events ($M_{\mu\mu} > 4 \text{ GeV/}c^2$) in the final 2015 data set after stability, quality and kinematic cuts

Aim to triple a total polarized data sample in order to achieve the statistical error on Sivers asymmetry (2015+2018) of ~ 0.02

Drell-Yan at Fermilab (E1039)

• x-range:
  • $x_b = 0.35 – 0.85$ (valence quarks in proton beam)
  • $x_t = 0.1 – 0.45$ (sea quarks in proton target)

• Proton Beam 120 GeV/c

• Invariant mass range:
  • $M = 4 – 8.5$ GeV

• Transverse momentum:
  • $p = 0 - 3$ GeV

• Goal: Probe Sea-quark Sivers Asymmetry with a polarized proton target at SeaQuest

\[
A_{N}^{DY} \propto \frac{u(x_b) \cdot f_{1T}^{1T}(x_t)}{u(x_b) \cdot \bar{u}(x_t)}
\]
Target developed at UVA: 5T Magnet

- Original design by S. Penttila, Oxford Instr.
  - kept at LANL storage since ~2000

- Feasibility study
  - Shipped to UVA in 2013
  - 1st cooldown 06/2013

- Rotation of the coils
  - Shipped to Oxford Instruments
  - New configuration, 2nd cooldown
  - $\frac{dB}{B} < 10^{-4}$ on 3d grid, 5T over 8cm

- Back to UVA
  - 3rd cooldown, rotated coils test
  - Magnet is in a very good shape
Target developed at UVA: Fridge

- Fridge modifications
  - Replaced separator can
  - Cleaned heat exchangers oxide/corrosion
  - Leak checked
  - Refitted run and bypass valves
  - Installed new LHe channel
  - Installed 8 temperature sensors
  - Manufactured new nose, 10mil window

- Fridge alignment

- Fridge tests
  - 4th and 5th cool-downs
  - Reached 1K 07/2015
New Developments at UVA for E1039

Microwave controller developments

- frequency seeking algorithm
- standalone plug & play controller for DC motor driven EIO tubes
- rates and run environment MC simulation
- new LabView package to control stepper motor driven EIO tubes

Power Supply
E1039 Predictions

<table>
<thead>
<tr>
<th>$x_2$ bin</th>
<th>$&lt;x_2&gt;$</th>
<th>NH$_3$ ($p^+$)</th>
<th>ND$_3$ ($d^+$)</th>
<th>$n^+$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.10 - 0.16</td>
<td>0.139</td>
<td>$5.0 \times 10^4$</td>
<td>$5.8 \times 10^4$</td>
<td>5.4</td>
</tr>
<tr>
<td>0.16 - 0.19</td>
<td>0.175</td>
<td>$4.5 \times 10^4$</td>
<td>$5.2 \times 10^4$</td>
<td>5.7</td>
</tr>
<tr>
<td>0.19 - 0.24</td>
<td>0.213</td>
<td>$5.7 \times 10^4$</td>
<td>$6.6 \times 10^4$</td>
<td>5.0</td>
</tr>
<tr>
<td>0.24 - 0.60</td>
<td>0.295</td>
<td>$5.5 \times 10^4$</td>
<td>$6.4 \times 10^4$</td>
<td>5.1</td>
</tr>
</tbody>
</table>

Expected results after two years of running on NH$_3$ and ND$_3$ targets.

Absolute systematic uncertainty is estimated to be <1.0%.

The relative systematic uncertainty is 4.0%.
Summary

• Two types of experiments to measure Drell-Yan asymmetries
  • Collider experiment (RHIC)
    • Low luminosity (Lack of statistics)
    • Access sea-quarks polarization at very low x
  • Fixed target experiments
    • High luminosity
    • High polarization proton/deuteron target
    • Can explore higher-x region with better sensitivity

<table>
<thead>
<tr>
<th>Beam Pol.</th>
<th>Target Pol.</th>
<th>Favored Quarks</th>
<th>Physics Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMPASS</td>
<td>No</td>
<td>Yes</td>
<td>Sign change and size of Sivers distribution for valence quark</td>
</tr>
<tr>
<td>E-1039</td>
<td>No</td>
<td>Yes</td>
<td>Size and sign of Sivers distribution for sea quarks, if DY AN≠ 0.</td>
</tr>
</tbody>
</table>
Thank You...!!!
Backup
E1039 Polarized Target

- **NMR**
- **Microwave**
- **Pumps**
- **Insert**
- **Target material**
- **Fridge**
- **Magnet**

11/11/2016
TMDs and Polarized Drell-Yan experiment

- **Transversity**: correlation between transverse proton spin and quark spin
  \[ A_{TT} \propto \delta q(x_1)\delta q(x_2) \]

- **Sivers**: correlation between transverse proton spin and quark transverse momentum
  \[ A_T \propto q(x_1) f_{1T}^{q}(x_2, k_T^2) \frac{(\vec{P} \times \vec{k_T}) \cdot \vec{S}_P}{M} \]

- **Boer/Mulders**: correlation between transverse quark spin and quark transverse momentum
  \[ N(\phi) \propto h_1^{\perp q}(x_1, k_T^2) \frac{(\vec{P} \times \vec{k}_T) \cdot \vec{S}_q}{M} \cdot h_1^{\perp \bar{q}}(x_2, k_T^2) \frac{(\vec{P} \times \vec{k}_T) \cdot \vec{S}_{\bar{q}}}{M} \]
# A summary of Drell-Yan experiments

<table>
<thead>
<tr>
<th>experiment</th>
<th>particles</th>
<th>energy (GeV)</th>
<th>$x_b$ or $x_t$</th>
<th>rFOM</th>
<th>timeline</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMPASS (CERN)</td>
<td>$\pi^- + p^\uparrow$</td>
<td>190, $\sqrt{s} = 17.4$</td>
<td>$x_t = 0.1 - 0.3$</td>
<td>$1.1 \times 10^{-3}$</td>
<td>2015-2016</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2018</td>
</tr>
<tr>
<td>PAX (GSI)</td>
<td>$p^\uparrow + \bar{p}$</td>
<td>collider, $\sqrt{s} = 14$</td>
<td>$x_b = 0.1 - 0.9$</td>
<td>$2.3 \times 10^{-5}$</td>
<td>&gt;2022?</td>
</tr>
<tr>
<td>PANDA (GSI)</td>
<td>$\bar{p} + p^\uparrow$</td>
<td>15, $\sqrt{s} = 5.5$</td>
<td>$x_t = 0.2 - 0.4$</td>
<td>$1.1 \times 10^{-4}$</td>
<td>&gt;2020?</td>
</tr>
<tr>
<td>NICA (JINR)</td>
<td>$p^\uparrow + p$</td>
<td>collider, $\sqrt{s} = 20$</td>
<td>$x_b = 0.1 - 0.8$</td>
<td>$6.8 \times 10^{-5}$</td>
<td>&gt;2020</td>
</tr>
<tr>
<td>fsPHENIX (RHIC)</td>
<td>$p^\uparrow + p^\uparrow$</td>
<td>$\sqrt{s} = 200$, $\sqrt{s} = 510$</td>
<td>$x_b = 0.1 - 0.5$</td>
<td>$4.0 \times 10^{-4}$</td>
<td>&gt;2021</td>
</tr>
<tr>
<td>SeaQuest (unpol.) (FNAL E-906)</td>
<td>$p + p$</td>
<td>120, $\sqrt{s} = 15$</td>
<td>$x_t = 0.1 - 0.45$</td>
<td>- -</td>
<td>2012-2017</td>
</tr>
<tr>
<td>pol tgt DY (FNAL E-1039)</td>
<td>$p + p^\uparrow$</td>
<td>120, $\sqrt{s} = 15$</td>
<td>$x_t = 0.1 - 0.45$</td>
<td>0.09</td>
<td>&gt;2018</td>
</tr>
<tr>
<td>pol beam DY (FNAL E-1027)</td>
<td>$p^\uparrow + p$</td>
<td>120, $\sqrt{s} = 15$</td>
<td>$x_b = 0.35 - 0.85$</td>
<td>1</td>
<td>&gt;2020</td>
</tr>
</tbody>
</table>