Recent results and future prospects of the high-energy polarized p+p program at RHIC at BNL

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INT Workshop - Science case for an EIC
Seattle, WA, November 16, 2010
Outline

- Selected recent results and future prospects
  - Gluon polarization
  - Quark / Anti-quark polarization
  - Transverse spin dynamics

- Experimental aspects: RHIC / PHENIX / STAR

- Theoretical foundation

- Summary and Outlook
Theoretical foundation

How do we probe the structure and dynamics of matter in ep / pp scattering?

\[ d\sigma_{ep} \propto F_2 = \sum_q x e_q^2 f_q(x) \]

Momentum contribution

\[ f(x) = f^+(x) + f^-(x) \]

Spin contribution

\[ \Delta f(x) = f^+(x) - f^-(x) \]

Universality

Factorization

\[ d\sigma_{pp} \propto f_1 \otimes f_2 \otimes \sigma_h \otimes D^h_f \]
How do we probe the structure and dynamics of matter in ep / pp scattering?

\[ d\sigma_{ep} \propto F_2 = \sum_q x e_q^2 f_q(x) \]

\[ W^2 \approx Q^2 / x \]

\[ f(x) = f^+(x) + f^-(x) \]

\[ \Delta f(x) = f^+(x) - f^-(x) \]

**Universality**

**Factorization**
Proton spin studies addressed by the RHIC Spin program

- Gluon polarization studies based on gluon initiated processes
  - Inclusive measurements of hadrons ($\pi^0$, $\pi^\pm$, $\eta$) and jets
  - Correlation measurements (Di-Jet production / Photon-Jet production)
  - Heavy-flavor production (charm / bottom)

- Quark / Anti-quark polarization
  - W production (Direct sensitivity to u/d-quark and u/d-antiquark polarization) / Charm-associated W production (s-quark polarization)
  - Lambda production (s-quark polarization)

- Transverse spin dynamics focusing on transverse single-spin asymmetry $A_N$
  - Transversity $\otimes$ Collins or Interference fragmentation function (IFF) ($k_T$ - Final-state effect)
  - Sivers mechanism probing correl. of proton spin and trans. motion of parton ($k_T$ - Initial-state effect)
  - Higher-Twist effects
Theoretical foundation

Probing the proton spin structure in high-energy polarized p+p collisions

- Observable: Quark/Antiquark polarization (W production)
  - Longitudinal single-spin asymmetry $A_L$
    \[ A_L = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} \]
  - Parity (Spatial inversion) violating for W production!

- Observable: Gluon polarization (Jet/Hadron production)
  - Double longitudinal single-spin asymmetry $A_{LL}$
    \[ A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} \]

Observable: Transverse spin dynamics

- Transverse single-spin asymmetry $A_N$
  \[ A_N = \frac{\sigma_\uparrow - \sigma_\downarrow}{\sigma_\uparrow + \sigma_\downarrow} \]

\[ a_{LL} = \frac{\Delta \sigma_h}{\sigma_h} \]

\[ \frac{\Delta f_1 \otimes \Delta f_2 \otimes \sigma_h \cdot a_{LL} \otimes D^h_f}{f_1 \otimes f_2 \otimes \sigma_h \otimes D^h_f} \]
Experimental aspects: RHIC

- RHIC pp complex - Layout
Experimental aspects: RHIC

- RHIC pp complex - Layout

- Siberian Snakes
- Absolute Polarimeter (H jet)
- PHENIX
- STAR
- Spin Rotators
- Partial Snake
- Helical Partial Siberian Snake
- Pol. H Source
- Pol. H- Source
- 200 MeV Polarimeter
- AGS polarimeters
- Strong AGS snake
- Rf Dipole
Experimental aspects: RHIC

- **RHIC pp performance**
  - **200GeV production**
    - runs at $\sqrt{s}=200\text{GeV}$:
      - Run 5 / Run 6 / Run 8 / Run 9
  - **First collisions of polarized proton beams at $\sqrt{s}=500\text{GeV}$**: Run 9

![Graph of RHIC polarized proton luminosity L delivered to PHENIX](image)
Experimental aspects: STAR

Overview

\[ \eta = -\ln \left( \tan \left( \frac{\theta}{2} \right) \right) \]
Overview

- Wide rapidity coverage of STAR calorimetry (Jets / π^0 / γ / e^±) system:
  - FPD: -4.1 < \( \eta \) < 3.3
  - BEMC: -1.0 < \( \eta \) < 1.0
  - EEMC: 1.09 < \( \eta \) < 2.0
  - FMS: 2.5 < \( \eta \) < 4.0

- TPC: Tracking and PID using dE/dx for \(| \eta | < 1.3\)

- BBC/ZDC: Relative luminosity and local polarimetry
- BBC: Minimum bias trigger
Experimental aspects: PHENIX

- **Overview**
  - $\pi^0, \eta, \gamma$
    - Electromagnetic Calorimeter (PbSc/PbGl) 
      \[(| \eta | < 0.35, \phi = 2 \times \pi / 2)\]
  - $\pi^\pm, e, J/\psi \rightarrow e^+e^-$
    - Drift Chamber (DC)
    - Ring Imaging Cherenkov Detector (RICH)
    - Electromagnetic Calorimeter (PbSc/PbGl)
  - $\mu, J/\psi \rightarrow \mu^+\mu^-$
    - Muon Id/Muon Tracker (1.2 < $| \eta | < 2.4 + 2\pi$)
  - $\pi^0, \eta$
    - MPC (3.1 < $| \eta | < 3.9 + 2\pi$)
  - **Relative Luminosity**
    - Beam Beam Counter (BBC) (3.0 < $\eta < 3.9$)
    - Zero Degree Calorimeter (ZDC)
Experimental aspects: Asymmetry measurement

- Asymmetry measurement in polarized p+p collisions

\[ A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{P_1 P_2} \frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}} \]

- Require concurrent measurements:
  - Longitudinal beam polarization \( P_{1(2)} \) at STAR IR
  - Direction of polarization vector
  - Relative luminosity \( R \) of bunch crossings with different spin directions
  - Spin dependent yields of process of interest \( N_{ij} \)
Gluon polarization

Gluon polarization - Inclusive measurements

Jet

\[ x_T = \frac{2p_T}{\sqrt{s}} \]

Inclusive Jet production (200GeV: Solid line / 500GeV: Dashed line)

Inclusive measurements

\( \sigma_{ij}/\sigma_{tot} \sim \eta \)

Odderon production

\( gg \quad qg \quad qq \)

Detector

Particle

Parton

\( \pi^+, \pi^0 \)

\( g, q \)

\( \Delta g, \Delta q \)

\( \Delta g, \Delta q \)
Gluon polarization - Correlation Measurements

Correlation measurements provide access to partonic kinematics through Di-Jet/Hadron production and Photon-Jet production - At LO:

\[ x_1(2) = \frac{1}{\sqrt{s}} \left( p_T^3 e^{\eta_3(-\eta_3)} + p_T^4 e^{\eta_4(-\eta_4)} \right) \]

- Di-Jet production / Photon-Jet production
  - Di-Jets: All three (LO) QCD-type processes contribute: gg, qg and qq with relative contribution dependent on topological coverage
  - Photon-Jet: One dominant underlying (LO) process
  - Larger cross-section for di-jet production compared to photon related measurements
  - Photon reconstruction more challenging than jet reconstruction
  - Full NLO framework exists \( \Rightarrow \) Input to Global analysis
Gluon polarization

- PHENIX: Midrapidity Inclusive neutral pion $A_{LL}$ measurement

- Data are well described by NLO pQCD calculations
- Run 9 $A_{LL}$ results in agreement with previous $A_{LL}$ measurements pointing to a small gluon polarization
Gluon polarization

- PHENIX: Midrapidity Inclusive neutral pion $A_{LL}$ measurement

- Data are well described by NLO pQCD calculations
- Run 9 $A_{LL}$ results in agreement with previous $A_{LL}$ measurements pointing to a small gluon polarization
Data are well described by NLO pQCD plus hadronization and underlying event corrections

Run 6 $A_{LL}$ measurement between GRSV-STD and GRSV-ZERO

Substantial improvement expected from Run 9 $A_{LL}$ measurement
Gluon polarization

- Results on $\Delta g$ from Global QCD analysis

- Strong constraint on the size of $\Delta g$ from RHIC data
- Strong indication for a small gluon polarization!
- Next steps: Mapping of $x$-dependence and extension of $x$-coverage needed!

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Results on $\Delta g$ from Global QCD analysis

- Strong constraint on the size of $\Delta g$ from RHIC data
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- Next steps: Mapping of $x$-dependence and extension of $x$-coverage needed!
Gluon polarization

- Results on $\Delta g$ from Global QCD analysis

\[ \Delta G(Q^2 = 1\, \text{GeV}^2) \approx 0.4 \]

\[ \Delta G(Q^2 = 1\, \text{GeV}^2) \approx 0.1 \]

\[ \Delta G(Q^2 = 1\, \text{GeV}^2) \approx -0.1 \]

- Strong constraint on the size of $\Delta g$ from RHIC data
- Strong indication for a small gluon polarization!
- Next steps: Mapping of $x$-dependence and extension of $x$-coverage needed!


\[ \Delta \chi^2 = 1 \]
**Gluon polarization**

- **STAR: Midrapidity Di-Jet $A_{LL}$ measurement**

  - First Di-Jet $A_{LL}$ measurement in agreement with $\Delta g$ constrained by previous inclusive jet result, i.e. small gluon polarization preferred!
  - Run 9 data: Improved stat. precision
    - Constraining $x$ dependence - Crucial input to Global QCD analysis!

- **Data are well described by NLO pQCD plus hadronization and underlying event corrections**

- **Dijet Cross Section**
  - $\int L dt = 5.39 \text{ pb}^{-1}$
  - Preliminary Run 6

- **Systematic Uncertainty**
  - Theory:
    - NLO pQCD + CTEQ6M
    - Had. and UE. Corrections

**Notes**

- Improved statistical precision
- Crucial input to Global QCD analysis!
Gluon polarization

Di-Jet projections at 200GeV

\[ M = \sqrt{x_1 x_2 s} \]

\[ x_1 (2) = \frac{1}{\sqrt{s}} \left( p_{T3} e^{\eta_3 (-\eta_3)} + p_{T4} e^{\eta_4 (-\eta_4)} \right) \]
Gluon polarization

- Di-Jet projections at 200GeV

\[ M = \sqrt{x_1 x_2 s} \]

\[ x_1 (2) = \frac{1}{\sqrt{s}} \left( p_{T3} e^{\eta_3 (-\eta_3)} + p_{T4} e^{\eta_4 (-\eta_4)} \right) \]

\[ \eta_3 + \eta_4 = \ln \frac{x_1}{x_2} \]
Gluon polarization

- Inclusive Jet and Di-Jet projections at 500GeV

- High precision at $\sqrt{s} = 500$GeV at small $x$
  (W program demands large data sample ~300pb$^{-1}$) for
  - Inclusive channels (Here: Inclusive Jets)
  - Correlations measurements (Here: Di-Jets)
Gluon polarization

- Photon-Jet projections
  - Strong direct impact on $\Delta g(x)$
  - Dedicated effort towards first photon analysis from STAR
  - Projections are for EEMC acceptance / FMS will reach lower $x$ region (Few $10^{-3}$)

The graph shows the gluon polarization projection for EEMC Photon + BEMC Jet. The projections are for different experimental conditions:

- $\int Ldt=50$ pb$^{-1}$, $Plo=0.6$, $\sqrt{s}=200$ GeV
- $\int Ldt=300$ pb$^{-1}$, $Plo=0.5$, $\sqrt{s}=500$ GeV

The background $A_{LL}$ subtraction assumes DSSV, and the LDA Efficiency is approximately 70% with purity around 25%.

The data points come from various experiments:
- COMPASS
- HERMES
- SMC
- DSSV $Q^2 = 100$ GeV$^2$
- GRSV STD $Q^2 = 100$ GeV$^2$

The x-axis represents the gluon $x$ value, and the y-axis shows the change in gluon polarization ($\Delta G/G$).
**W boson measurements at mid-rapidity and forward/backward rapidity**

\[
\begin{align*}
\Delta d + \bar{u} &\rightarrow W^- \\
\Delta \bar{u} + d &\rightarrow W^- \\
\Delta \bar{d} + u &\rightarrow W^+ \\
\Delta u + \bar{d} &\rightarrow W^+
\end{align*}
\]

- **Key signature:** High \( p_T \) lepton (\( e^-/e^+ \))
  - (Max. \( M_W/2 \)) - Selection of \( W^+/- \):
  - Charge sign discrimination of high \( p_T \)
    - lepton
- **Required:** Lepton/Hadron discrimination

\[
y_I = y_W + \frac{1}{2} \ln \frac{1 + \cos \theta^*}{1 - \cos \theta^*}
\]

\[
p_T = p_T^* = \frac{M_W}{2} \sin \theta^*
\]

\[
x_1 = \frac{M_W}{\sqrt{s}} e^{y_W}
\]

\[
x_2 = \frac{M_W}{\sqrt{s}} e^{-y_W}
\]

\[
\frac{M_W}{\sqrt{s}} = 0.16
\]

**Quark / Anti-quark polarization**

\[
\begin{align*}
\text{Total cross-section: } &109.9 \text{ pb} \\
\text{Total cross-section: } &20.5 \text{ pb} \\
\text{Total cross-section: } &42.0 \text{ pb}
\end{align*}
\]

\[
\begin{align*}
\text{Total cross-section: } &134.7 \text{ pb} \\
\text{Total cross-section: } &14.3 \text{ pb} \\
\text{Total cross-section: } &8.0 \text{ pb}
\end{align*}
\]

\[
\begin{align*}
\text{Total } (\sqrt{s}=500 \text{ GeV}) \sigma(W^+) &= 135 \text{ pb} \text{ and } \\
\sigma(W^-) &= 42 \text{ pb}
\end{align*}
\]
W boson measurements at mid-rapidity and forward/backward rapidity

\[ \Delta d + \bar{u} \rightarrow W^- \]
\[ \Delta \bar{u} + d \rightarrow W^- \]
\[ p \]
\[ W^+ (W^-) \]
\[ \nu_e (\bar{\nu}_e) \]
\[ e^+ (e^-) \]
\[ \Delta \bar{d} + u \rightarrow W^+ \]
\[ \Delta u + \bar{d} \rightarrow W^+ \]

Key signature: High $p_T$ lepton ($e^+/e^-$)  
(Max. $M_W/2$) - Selection of $W^+/W^-$:  
Charge sign discrimination of high $p_T$ lepton

Required: Lepton/Hadron discrimination

\[ y_l = y_W + \frac{1}{2} \ln \frac{1 + \cos \theta^*}{1 - \cos \theta^*} \]
\[ p_T = p_T^* = \frac{M_W}{2} \sin \theta^* \]
\[ x_1 = \frac{M_W}{\sqrt{s}} e^{y_W} \]
\[ x_2 = \frac{M_W}{\sqrt{s}} e^{-y_W} \]
\[ \frac{M_W}{\sqrt{s}} = 0.16 \]

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- **W boson kinematics**

  - Leptonic rapidity inherits relation to mean $x$
    - Forward rapidity: $\eta > 0$
      - $<x_1>$ larger than $<x_2>$
    - Backward rapidity: $\eta < 0$
      - $<x_1>$ less than $<x_2>$
    - Mid-rapidity: $\eta \sim 0$
      - $<x_1>$ similar to $<x_2>$

  ![Graphs showing $W$ boson kinematics](image)

< $X_{1,2} > \approx \frac{M_W}{\sqrt{S}} e^{[\pm \eta/2]}$
Quark / Anti-quark polarization

Probing the quark flavor structure using W boson production

\[ p^+ p \rightarrow W^\pm + X \rightarrow e^\pm + X \]

STAR \( \sqrt{s} = 500 \text{ GeV} \)

25 < \( E_T^e \) < 50 GeV

\[ A_L^W = \frac{\Delta d}{\bar{u}} \]

\[ A_L^W = \frac{1}{2} \left( \frac{\Delta \bar{u}}{\bar{u}} - \frac{\Delta d}{d} \right) \]

\[ A_L = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} \]

D. deFlorian et al., PRD80, 034030 (2009)
Probing the quark flavor structure using W boson production

\[ p^+ + p \rightarrow W^\pm + X \rightarrow e^\pm + X \]

\[ \text{STAR } \sqrt{s} = 500 \text{ GeV} \]
\[ 25 < E_T^e < 50 \text{ GeV} \]

\[ W^- \]
\[ A_L^{W^-} = -\frac{\Delta d}{\bar{d}} \]

\[ W^+ \]
\[ A_L^{W^+} = -\frac{\Delta u}{u} \]

\[ \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} \]

\[ \langle x_1 \rangle \ll \langle x_2 \rangle \]
\[ \langle x_1 \rangle \approx \langle x_2 \rangle \]
\[ \langle x_1 \rangle \gg \langle x_2 \rangle \]
W production results: W event

Run 9 - First 500GeV RHIC run: Event display

W candidate event

Z candidate event
Phenix: $W^\pm$ reconstruction

- Run 9 data sample: $8.6 \text{pb}^{-1}$
- Background dominated by photon conversion before drift chamber and charged hadrons
- Total background (B):
  - $e^+$: $1.7 \pm 1.0$
  - $e^-$: $1.6 \pm 1.0$
- Total $e^+/e^-$ cand. events (S+B):
  - $e^+$: 42
  - $e^-$: 13

Measured window: $30 < \text{E}_T < 50 \text{GeV}$
Quark / Anti-quark polarization

- STAR: $W^\pm$ reconstruction
  - Run 9 data sample: 12pb$^{-1}$
  - Background dominated by QCD background (Data driven estimate) with smaller fractions from $W$ boson induced $\tau$ decays ($10.4 \pm 2.8 / 0.7 \pm 0.7$) and $Z^0$ boson events ($8.5 \pm 2.0$) (MC estimate)
  - Total background (B):
    - $e^+$: $39 \pm 9$
    - $e^-$: $23 \pm 6$
  - Total $e^+/e^-$ cand. events (S+B): $25 < E_T < 50$GeV
    - $e^+$: 462
    - $e^-$: 139

Measured window: $25 < E_T < 50$GeV

Key

CHE (NLO - MRST2002) $W^+$
CHE (NLO - MRST2002) $W^-$

ATLAS PRELIMINARY $W^+$
ATLAS PRELIMINARY $W^-$

CMS PRELIMINARY $W^+$
CMS PRELIMINARY $W^-$

PHENIX $W^+$
PHENIX $W^-$

STAR PRELIMINARY $W^+$
STAR PRELIMINARY $W^-$

Measured and theory evaluated cross-sections agree within uncertainties
Theory calculations: Full NLO framework
Quark / Anti-quark polarization

- **PHENIX: Midrapidity $A_L$**

  - $A_L$ result consistent with all models
  - A non-zero asymmetry (98.4% CL) is observed in the positive candidates

  ![Graph of $A_L$ vs $y$ for $W^+Z^0$, $p_T > 30$ GeV/c, $|y_e| < 0.35$](image1)

  ![Graph of $A_L$ vs $y$ for $W^-Z^0$, $p_T > 30$ GeV/c, $|y_e| < 0.35$](image2)

  - **PHENIX collaboration, submitted to PRL, arXiv:1009.0505**
PHENIX: Midrapidity $A_L$

$W^+ \rightarrow \mu^+$

$S/B = 3.0$

$W^- \rightarrow \mu^-$

$S/B = 0.3$

$L=150\text{pb}^{-1} / P=50\%$

$\eta_\mu$ (muon pseudorapidity)
Quark / Anti-quark polarization

PHENIX Muon trigger system

MuID Trigger:
Selecting momentum above 2 Gev/c

MuTRG:
Fast selection of high momentum tracks

RPC:
Provide timing information and rough position information

Adding 35 cm Fe absorber:
reduce the lower momentum hadron punch through
(S/B=3:1 instead of 1:3 without absorber)
Quark / Anti-quark polarization

- STAR: Midrapidity $A_L$

$$\vec{p} + p \to W^\pm + X \to e^\pm + X$$

STAR $\sqrt{s} = 500$ GeV

$25 < E_T^e < 50$ GeV

$$A_L^W = \frac{1}{2} \left( \frac{\Delta \bar{u}}{u} - \frac{\Delta \bar{d}}{d} \right)$$

$$A_L = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$
Quark / Anti-quark polarization

- STAR: Midrapidity $A_L$

\[ \vec{p} + p \rightarrow W^\pm + X \rightarrow e^\pm + X \]

STAR $\sqrt{s} = 500$ GeV

$25 < E_T^e < 50$ GeV

\[ A_L = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} \]

- Syst. uncertainty due to background, w/o pol. norm. uncertainty of 9.2%

- $W^-$
  - RHICBOS
  - DNS-K
  - DNS-KKP
  - DSSV08

- $W^+$
  - CHE
  - DSSV08
Quark / Anti-quark polarization

- **STAR: Midrapidity $A_L$**

  \[ A_L^{W^-} = 0.14 \pm 0.19 \text{ (stat.)} \pm 0.02 \text{ (syst.)} \pm 0.01 \text{ (norm.)} \]
  \[ A_L^{W^+} = -0.27 \pm 0.10 \text{ (stat.)} \pm 0.02 \text{ (syst.)} \pm 0.03 \text{ (norm.)} \]


- $A_L(W^+)$ negative with a significance of $\sim 3 \sigma$

- $A_L(W^-)$ central value positive

- Measured asymmetries are in agreement with theory evaluations using polarized pdf’s (DSSV) constrained by polarized DIS data

  $\Rightarrow$ Universality of helicity distr. functions!

\[ \vec{p} + p \rightarrow W \pm + X \rightarrow e^\pm + X \]

STAR $\sqrt{s} = 500$ GeV

$25 < E_T^e < 50$ GeV

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**Quark / Anti-quark polarization**

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  ⇒ Universality of helicity distr. functions!

\[ \bar{p} + p \rightarrow W^\pm + X \rightarrow e^\pm + X \]

$\sqrt{s} = 500$ GeV

25 < $E_T^e$ < 50 GeV

istributions of $W^+$ and $W^-$

Projected uncertainties

Simulated data (S/B=5)

$W^+$

$W^-$

RHICBOS

DNS-K

DNS-KKP

DSSV08

CHE

DSSV08

$L = 100$ pb$^{-1}$, $P = 50\%$
Quark / Anti-quark polarization

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  $A_L^{W^-} = 0.14 \pm 0.19$ (stat.) $\pm 0.02$ (syst.) $\pm 0.01$ (norm.)
  
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- Measured asymmetries are in agreement with **theory evaluations** using polarized pdf’s (DSSV) constrained by polarized DIS data

  $\Rightarrow$ Universality of helicity distr. functions!
Quark / Anti-quark polarization

- STAR Forward GEM Tracker
**Quark / Anti-quark polarization**

- **STAR Forward GEM Tracker**
  - FGT: 6 light-weight triple-GEM disks using industrially produced GEM foils (Tech-Etch Inc.)
  - New mechanical support structure
  - Expected installation: Summer 2011
Quark / Anti-quark polarization

STaR W Impact on polarized QCD sea

D. deFlorian and W. Vogelsang, PRD81, 094020 (2010)

Include W results at RHIC (PHENIX and STAR) assuming -2 < \eta < 2 with 200pb⁻¹

Strong constrain for x>0.05

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Quark / Anti-quark polarization

- **Lambda production**
  - Initial measurements of Lambda production at mid-rapidity
  - High-p_T region important
  - Measurements at forward rapidity very promising!

- **Charm-associated W production**
  - Discussed in RHICII White paper (BNL-77334-2006-IR) to probe Δs
  - Large luminosity, higher CME and forward instrumentation important!


K. Sudoh, 2005

W^+ (m_c=1.2GeV, Q^2=M^2_w, \sqrt{s}=500GeV) \sim 4pb
W^- (m_c=1.2GeV, Q^2=M^2_w, \sqrt{s}=500GeV) \sim 2pb
Quark / Anti-quark polarization

- Larger CME - 650GeV

Cross-section ($p_T > 25\text{GeV}$) is about a factor two larger for $W^+/W^-$

<table>
<thead>
<tr>
<th></th>
<th>$W^+$ (pb)</th>
<th>$W^-$ (pb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>500GeV</td>
<td>86.5</td>
<td>27.0</td>
</tr>
<tr>
<td>640GeV</td>
<td>161.9</td>
<td>58.2</td>
</tr>
<tr>
<td>Ratio (650GeV/500GeV)</td>
<td>1.9</td>
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Larger CME - 650GeV

Cross-section ($p_T > 25\text{GeV}$) is about a factor two larger for $W^+/W^-$

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</table>
\[ A_L \] \( W \) asymmetries at 650\,GeV

Asymmetry \( A_L \) for \( W^+ / W^- \) for \( p_T > 25\,\text{GeV/c} \) shows very small change from 500\,GeV to 650\,GeV (30\% change)
Quark / Anti-quark polarization

Polarized He-3 operation

$A_L^{W^+}$ (p_T > 20 GeV) pp @ 500 GeV

$\Delta u$

- DSSV
- GRSV (std)
- GRSV (val)
- DSSV $\Delta \chi^2 = 1$

$\Delta \bar{d}$

He3-p @ 432 GeV

$A_L^{W^-}$ (p_T > 20 GeV)

$\Delta d$

- $x_0 = 0.67$

$\Delta \bar{u}$

- DSSV with $\Delta d/d \rightarrow 1$ as $x \rightarrow 1$

- GRSV (std)
- GRSV (val)
- DNS (KRE)
- DNS (KKP)

D. deFlorian and W. Vogelsang, PRD81, 094020 (2010)

M. Stratmann, 2010
Transverse spin dynamics

\[ A_N \text{ measurements at RHIC} \]

\[ p+p \rightarrow \pi^0+X \text{ at } \sqrt{s}=200 \text{ GeV} \]

- Large transverse single-spin asymmetries at forward rapidities at \( \sqrt{s}=200\text{GeV} \)
  and \( \sqrt{s}=62.4\text{GeV} \)

- Cross-sections are consistent with pQCD calculations

- Sivers mechanism: Asymmetry in the forward jet or \( \gamma \) production
  - Sensitive to proton spin - parton transverse motion correlations

- Collins mechanism: Asymmetry in the forward jet fragmentation
  - Sensitive to transversity

\[ \eta = 3.1 < \eta < 3.7 \]
Transverse spin dynamics

A_N measurements (Eta, p_T dependence)

- Large measured A_N for forward eta production
- Measured p_T dependence not understood!
Transverse spin dynamics

- **Sivers effect sign change - Drell Yan**
  - Expect sign difference for Sivers effect between SDIS processes (attractive) and Drell-Yan processes (repulsive)
  - Plans for Drell-Yan experiments at RHIC:
    - **STAR / PHENIX**: Long-term upgrading forward direction
    - **Two LOI** presented at June 2010 PAC meeting:
      - **Collider mode**: Initial implementation in progress (RHIC IP2)
      - **Fixed target mode** (Long-term)
  - **PAC recommendation**: Test of 3 IR operation (Luminosity impact) during Run 11 (1-2 days)
  - **ANDY at IP2**:
    - $\eta > 3$
    - $M > 4\text{GeV}$
    - $\sqrt{s} = 500\text{GeV}$
Transverse spin dynamics

- Sivers effect sign change -
  Other related measurements
  - $W A_N$ measurements (Several authors)
  - Photon final state measurements of $A_N$

- Diffractive measurements
  - Elastic pp scattering
  - Single diffraction
  - Central production: Glueball

A. Metz and J. Zhou, arXiv:1006.3097

$pp \rightarrow pp$ at $\sqrt{s} = 200$ GeV

STAR Preliminary
Summary

- High-energy polarized p-p program
  - Transverse spin measurements presented: Deepening understanding on $A_N$ dynamics / Transversity extraction
  - First global analysis incl. RHIC SPIN data ⇒ Evidence for small gluon polarization for $0.05 < x < 0.2$
  - Correlation measurements (Di-Jets / $\gamma$ -Jets) will allow to provide needed constrain on the partonic kinematics ⇒ First Di-Jet $A_{LL}$ and cross-section measurement at RHIC at $\sqrt{s}=200\text{GeV}$
  - First Run 9 W result (Cross-section and $A_L$ for $W^+/W^-$ at mid-rapidity) important milestone!
  - W program: Important information constraining the QCD sea, i.e. u/d antiquarks
## Outlook

### Outlook - RHIC SPIN

- **Three key elements:**
  - **Gluon polarization**
  - **Quark / Anti-Quark Polarization**
  - **Transverse spin dynamics**

<table>
<thead>
<tr>
<th>Recorded Luminosity</th>
<th>Main physics Objective</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>~50pb⁻¹</td>
<td>Gluon polarization using di-jets and precision inclusive measurements</td>
<td>200 GeV</td>
</tr>
<tr>
<td>~100pb⁻¹</td>
<td>W production (Important consistency check to DIS results - Phase I) Gluon polarization (Di-Jets / Photon-Jets)</td>
<td>500 GeV</td>
</tr>
<tr>
<td>~300pb⁻¹</td>
<td>W production (Constrain antiquark polarization - Phase II) Gluon polarization (Di-Jets / Photon-Jets)</td>
<td>500 GeV</td>
</tr>
<tr>
<td>~30pb⁻¹</td>
<td>Transverse spin gamma-jet</td>
<td>200 GeV</td>
</tr>
<tr>
<td>~250pb⁻¹</td>
<td>Transverse spin Drell-Yan (Long term)</td>
<td>200 GeV</td>
</tr>
</tbody>
</table>

INT Workshop - Science case for an EIC  
Seattle, WA, November 16, 2010  
Bernd Surrow
LSS (1)
- New DSSV
  - Include COMPASS SDIS results