Measurement of the parity-violating longitudinal single-spin asymmetry for W boson production in polarized proton-proton collisions at $\sqrt{s} = 500 GeV$
Introduction

The over-all goal of the STAR Collaboration’s spin program at RHIC is to understand the origin of the proton spin in terms of intrinsic quark and gluon spin and orbital angular momentum:

\[ S_z = \frac{1}{2} = \frac{1}{2} \Delta \Sigma + \Delta G + L_z \]

We note that inclusive polarized deep-inelastic scattering (DIS) experiments have shown that only approximately 30% of the spin of the proton is attributable to the polarization of the quarks and the anti-quarks.

We also point out that measurements in the medium x-range have shown that the contribution due to the polarization of the gluons, \( \Delta G \), is negligibly small. A lower x-region will be probed at STAR, run at 500 GeV in 2011, to widen the search for a contribution of \( \Delta G \) to the proton’s spin.
Introduction, contd

Inclusive measurements of $\Delta \Sigma$ do not discern between the various flavours of the quarks and their individual contributions to $\Delta \Sigma$.

$$\Delta \Sigma = \int (\Delta u + \Delta d + \Delta s + \Delta \bar{u} + \Delta \bar{d} + \Delta \bar{s} + \cdots ) \, dx$$

Semi-inclusive DIS measurements can achieve separation of the quark and anti-quark spin contributions by flavour. However the extracted anti-quark polarized Parton Distribution Functions (PDFs) have sizeable uncertainties compared to the well-constrained (quark + anti-quark) sum.
Introduction, contd

A study of $W^\pm$ decays will provide new information on the u-bar & d-bar quark contributions to the spin of the proton, as well as a check on the u and d quark contributions.

$$\Delta \Sigma = \int (\Delta u + \Delta d + \Delta s + \Delta \bar{u} + \Delta \bar{d} + \Delta \bar{s} + \cdots) \, dx$$

Measurements by the STAR collaboration at the RHIC collider during the year 2009 of $W$ production in polarized proton collisions and their subsequent decay through electron/positron channels are the subject of this presentation. Much higher luminosity measurements planned for year 2011 will also be mentioned.
And measures their Parity-Violating Single Spin Helicity Asymmetries, $A_L = (\sigma^+ - \sigma^-)/(\sigma^+ + \sigma^-)$, where at LO:

\[
A_L^{W^+} \propto -\Delta u(x_1)\bar{d}(x_2) + \Delta\bar{d}(x_1)u(x_2)
\]

\[
A_L^{W^-} \propto -\Delta d(x_1)\bar{u}(x_2) + \Delta\bar{u}(x_1)d(x_2)
\]

STAR measures $W^\pm$ through their $e^\pm$ decays:

\[
u + \bar{d} \rightarrow W^+ \rightarrow e^+ + \nu
\]

\[
\bar{u} + d \rightarrow W^- \rightarrow e^- + \bar{v}
\]
What do we know from a global analysis about $x(\Delta \bar{u} - \Delta \bar{d})$?

**Calculations:**

RHICBOS: P.M. Nadolsky & C.-P. Yuan,

**Global Analysis:** deFlorian/Vogelsang
Private Communication, Uncertainties: green & yellow bands
Theoretical foundation

- $A_L$ behavior for STAR mid-rapidity and forward/backward rapidity region

Calculations:
2) deFlorian / Vogelsang: D. deFlorian, *global analysis*. 

George Igo
Simulated W event at STAR

EM shower from W → e
(L2-trigger)

BEMC: lepton energy, veto jets

TPC: vertex in Z,XY
e/h discrimination, veto di-jets,

EEMC: veto di-jets

\[ \vec{p} \]

\[ u (d) \]

\[ W^+ (-) \]

\[ \bar{d} (\bar{u}) \]

\[ \nu \]
W production results: W event

- Event display (W event candidate) and detector signature

We found ~600 of those kinds of events!
We recorded and rejected ~1.5M of those kinds of events!
W production results: $Z^0$ event

- Event display ($Z$ event candidate) and detector signature

We found a handful of those kinds of events!
W production results: Lego plots

Lego plots - STAR BEMC/TPC

Run 9 STAR Data (\(\sqrt{s}=500\text{GeV}\))

W event

Di-Jet event
W Algorithm: Lepton Isolation

Lepton Isolation Cuts:

• Require TPC track with $p_T > 10$ GeV, $W \rightarrow e \nu$, nothing on the away side.
• Extrapolate track to Barrel Calorimeter
• Require highest 2x2 cluster around pointed tower sum $E_T > 15$ GeV
• Require excess $E_T$ in 4x4 cluster < 5%
• Match track to 2x2 cluster position
Mid-rapidity high $p_T$ $e^\pm$ charge separation

- Assign: $Q/p_T > 0$ positrons, $Q/p_T < 0$ electrons

$+$- distance $D: \sim 1/P_T$
- $p_T = 5$ GeV : $D \sim 15$ cm
- $p_T = 40$ GeV : $D \sim 2$ cm

Successful separation of different charge states!
W production results: Jacobian peak distributions

- Charged separated Jacobian peak distributions

- Background distribution and background-subtracted signal distribution
  - $\frac{B}{(S+B)} (E_T > 25\text{GeV}) W^- : 16\%$
  - $\frac{B}{(S+B)} (E_T > 25\text{GeV}) W^+ : 8\%$

Background Events ($E_T > 25$ GeV)

<table>
<thead>
<tr>
<th>Event</th>
<th>$W^- \rightarrow e^- + \bar{\nu}_e$</th>
<th>$W^+ \rightarrow e^+ + \nu_e$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W \rightarrow \tau + \nu_\tau$</td>
<td>$2.7 \pm 0.7$</td>
<td>$8.4 \pm 2.2$</td>
</tr>
<tr>
<td>Missing Endcap</td>
<td>$14 \pm 4$</td>
<td>$13 \pm 4$</td>
</tr>
<tr>
<td>Normalized QCD</td>
<td>$8.0_{-4}^{+20}$</td>
<td>$25_{-9}^{+36}$</td>
</tr>
<tr>
<td>Total</td>
<td>$25_{-7}^{+21}$</td>
<td>$46_{-11}^{+36}$</td>
</tr>
</tbody>
</table>
W production results: Data/MC comparison

- Data/MC Comparison of charge-separated Jacobian peak distributions

- Comparison of data and PYTHIA+GEANT simulations for W signal events at $\sqrt{s}=500\text{GeV}$
- Systematic uncertainties were estimated by varying cuts and normalization regions for QCD background and by varying BEMC energy scale uncertainty ($\pm 7.5\%$)
Total $W^+/W^-$ Cross-section results

<table>
<thead>
<tr>
<th>Process</th>
<th>Theory Evaluated Cross-section</th>
<th>Measured Cross-section</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W^- \rightarrow e^- + \bar{\nu}_e$</td>
<td>$46 \pm 36_{-11}^{+36}$</td>
<td>$513$</td>
</tr>
<tr>
<td>$W^+ \rightarrow e^+ + \nu_e$</td>
<td>$25 \pm 21_{-7}^{+21}$</td>
<td>$156$</td>
</tr>
</tbody>
</table>

### STAR Preliminary Run 9 ($p+p \sqrt{s}=500$ GeV)

- $\sigma_{W^+ \rightarrow e^+ + \nu} = 61 \pm 3$ (stat.) $^{+10}_{-13}$ (syst.) $\pm 14$ (lumi.) pb
- $\sigma_{W^- \rightarrow e^- + \bar{\nu}} = 17 \pm 2$ (stat.) $^{+3}_{-4}$ (syst.) $\pm 4$ (lumi.) pb

Reasonable agreement between measured and theory evaluated cross-sections within uncertainties!
W production results: Asymmetry result

Parity-violating single-spin asymmetry $W^+/W^-$ $A_L$ results

STAR Preliminary Run 9 ($p+p \sqrt{s}=500$ GeV)

$A_L(W^+) = -0.28 \pm 0.10 \text{ (stat.)} \pm 0.02 \text{ (syst.)}$

$A_L(W^-) = 0.14 \pm 0.19 \text{ (stat.)} \pm 0.02 \text{ (syst.)}$

- $A_L(W^+)$ negative with a significance of $3.3\sigma$
- $A_L(W^-)$ central value positive
- Systematic errors of $A_L$ under control
- TPC charge separation works up to $p_T \sim 50$ GeV
- Measured asymmetries are in agreement with theory evaluations using polarized pdf's (DSSV) constrained by polarized DIS data
  
  Universality of helicity distribution functions!
Run 9: First observation of W production at STAR

- First collision of polarized proton beams at $\sqrt{s} = 500$GeV (P~40% / L~12pb$^{-1}$)
  - $W^\pm$ Cross-section and Parity violating single-spin asymmetry measurement

- Critical analysis aspects:
  - Charge-sign discrimination at high $p_T$
  - Rejection and treatment of background

- STAR W program at forward/backward rapidity:
  - Installation of STAR Forward GEM Tracker (1<η<2) (FGT): Summer 2011
Future W Measurements at STAR: Forward Gem Tracker

FGT provides tracking coverage of Endcap (region of higher AL)

Expected installation of FGT in Summer of 2011
The STAR Experiment at RHIC

- **Overview**
  - Calorimetry system with $2\pi$ coverage: BEMC ($-1<\eta<1$) and EEMC ($1<\eta<2$)
  - TPC: Tracking and particle ID
  - ZDC: Relative luminosity and local polarimetry
    - BBC: Relative luminosity and Minimum bias trigger
  - STAR Mid-rapidity $W$ program ($-1<\eta<1$): BEMC and TPC
  - STAR Forward/Backward $W$ program ($1<\eta<2$): EEMC and TPC / FGT (Installation in summer 2011)

First collisions of polarized proton beams at STAR at $\sqrt{s} = 500\text{GeV}$: Run 9 (P~40% / L~12pb$^{-1}$)
• First $\sqrt{s} = 500$ GeV run for physics was March and April, 2009 for a couple weeks.

• Achieved beam polarizations of ~35 – 40%. Two additional RHIC polarimeters were also commissioned.
STAR sees 4 helicity configurations
STAR runs 4 parallel measurements

Helicity of beams colliding at STAR

RHIC measured polarization
Run 9 @ 2x250 GeV

Pol yellow 0.40
Pol blue 0.38
syst. pol (blue+yellow)=9.2%
W trigger in Run 9

- **Trigger**
  - Level 0 trigger – BEMC single high tower threshold $E_T > 7.3$ GeV.
  - Level 2 trigger – BEMC 2 x 2 tower cluster threshold $E_T > 13$ GeV.
  - Use these recorded and triggered events to monitor the luminosity.

### 2009 STAR data @500 GeV

- **100K W-trigger events**
  - **7.3 GeV**
  - **13 GeV**
  - **25-45 GeV $E_T$**

### Tower ADC ~ $E_T$

- **~97% of barrel towers participate in trigger**

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Jan Balewski, MIT

WS @ STAR, results and perspectives

STAR logo
Extracting the W Signal

1. Run analysis with EEMC in veto cuts
2. Run analysis without EEMC in veto cuts
3. Subtract two raw signals

Run 9 Data Missing Endcap Vetoed QCD Background

Total Background

MC Normalized to $L=13.7 \text{ pb}^{-1}$

Data Driven QCD Bkgd.

Signal

Dijets

PYTHIA+GEANT MC

MC Normalized at $E_{T}<19$ GeV Data Driven QCD Bkgd.
Future Ws at mid-rapidity

STAR has shown the capability to detect the W at mid-rapidity.

With the expected 300pb⁻¹ for the 500 GeV program STAR will provide strong constraints on the polarized sea pdfs using the mid-rapidity data.
At forward/backward rapidity, the $A_L$s become more sensitive to a single quark flavor.

The expected uncertainties for the 500 GeV program are shown to the right for the endcap acceptance

$$1 < \eta < 2$$

Measurements rely on the planned Forward GEM Tracker upgrade (see B. Surrow's talk on Sat.)
**W production results: Algorithm Details**

**W reconstruction - Algorithm: Details**

- **General:**
  - Select LFW-E_{T} triggered events
  - Select vertices with |Z|<100 cm

- **Electron isolation cuts:**
  - Electron candidate is any primary TPC track with global P_{T} > 10 GeV/c
  - Extrapolate TPC track to BTOW tower
  - Compute 2x2 tower cluster E_{T}, require E_{T} sum > 15 GeV
  - Require the excess E_{T} in 4x4 tower patch over 2x2 patch to be below 5%
  - Require distance of 2x2 cluster vs. TPC track below 7 cm

- **Near-cone veto:**
  - Compute near-cone E_{T} sum of BEMC+TPC over ΔR=0.7 in eta-phi space
  - Require near-cone excess E_{T} below 12%

- **Away-'cone' cuts: p_{T} balance requirement**
  - Vector sum > 156 GeV/c of: 2X2 tower cluster p_{T} and p_{T} of any number of jets outside near-cone
  - E_{T} of jet > 3.5 GeV