Constraining Sea Quark Distributions Through W+/- Cross Section Ratios Measured at STAR

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Outline

❖ Motivation
❖ Experimental Aspects
❖ Recent Preliminary Results
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Current Unpolarized PDFs

Q = 100 GeV
CT10: NLO

NNPDF 2.3: NNLO

nnpdf.hepforge.org

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Many models can predict the general $\bar{d} > \bar{u}$ behavior, but fail to describe the suggested behavior of $\bar{d}/\bar{u} < 1$.
Unpolarized Sea Quark Distributions

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Unpolarized Sea Quark Distributions

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- Ideally to better constrain pdf fits, data over a range of $Q^2$ and **scattering processes** is desired.
- In general this will help **minimize** any process dependent assumptions and more importantly serve as an independent **cross check** of our understanding of the physics.

W Boson Production Through Proton-Proton Collisions

\[ p + p \rightarrow W^+ (W^-) \rightarrow e^+ (e^-) + \nu_e (\bar{\nu}_e) \]
W Boson Production Through Proton-Proton Collisions

\[
\begin{align*}
W^+ & \rightarrow \nu_e + \bar{e}^- \\
W^- & \rightarrow e^+ + \bar{\nu}
\end{align*}
\]

\[
\begin{align*}
u_e & (\bar{\nu}_e) \\
e^+ & (\bar{e}^-)
\end{align*}
\]
W Boson Production Through Proton-Proton Collisions

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

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

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

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

\[ \sqrt{x_1 x_2} = \frac{M_W}{\sqrt{s}} \]

- W Boson’s are **directly sensitive** to quark/anti-quark distributions (no fragmentation functions needed!).
- They can be detected through its **leptonic decay channels** in **proton-proton** collisions.
- **Key signature**: high \( p_T \) lepton near \( M_W/2 \)
- Selection of \( W^+/W^- \) made through **charge sign discrimination** of high \( p_T \) lepton
\[ R(x_F) \equiv \frac{\sigma^+_W}{\sigma^-_W} = \frac{u(x_1) \bar{d}(x_2) + \bar{d}(x_1) u(x_2)}{\bar{u}(x_1) d(x_2) + d(x_1) \bar{u}(x_2)} + NLO + NNLO + \ldots \]
W Cross Section Ratio

\[ R(x_F) \equiv \frac{\sigma^+_{W}}{\sigma^-_{W}} = \frac{u(x_1) \bar{d}(x_2) + \bar{d}(x_1) u(x_2)}{\bar{u}(x_1) d(x_2) + d(x_1) \bar{u}(x_2)} \]

\[ + NLO + NNLO + ... \]

\[ R = \frac{N_O^+ - N_B^+}{N_O^- - N_B^-} \cdot \frac{\epsilon^-}{\epsilon^+} \]
W Cross Section Ratio

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+ = positron from W decay
- = electron from W decay
\( N_O \) = measured lepton decay events
\( N_B \) = background events
\( \epsilon \) = lepton detection efficiency
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Relativistic Heavy Ion Collider
Kinematic Reach at RHIC

- Approximate kinematic range at RHIC:
  \[0.06 < x < 0.4 \quad \text{for} \quad -2 < \eta < 2\]
- Probes distributions at high \(Q^2\):
  \[Q^2 = M_W^2\]
- For collision energies of \(\sqrt{s} = 500 \text{ GeV}\) and \(\eta = 0\) \((x_1 \approx x_2)\)
  \[x = \frac{M_W}{\sqrt{s}} = 0.16\]
Sea Quark Distribution

[Graphs showing quark distributions with data points and theoretical curves labeled E866, NA51, CT10, MSTW2008, and NNPDF2.3]
Sea Quark Distribution: RHIC Reach

- STAR at mid-rapidity $|\eta| < 1$ covers approximately $0.1 < x < 0.3$
- Will be able to provide **constraints** on global PDF fitting for *anti-u* and *anti-d quarks* through W production at higher $Q^2$ than E906.
- Serves as an **independent check** of the Drell-Yan data.
Solenoidal Tracker At RHIC

Barrel Electromagnetic Calorimeter

Time Projection Chamber

Endcap Electromagnetic Calorimeter
Solenoidal Tracker At RHIC

\[ \eta = -\ln \left( \tan \frac{\theta}{2} \right) \]
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Currently still under analysis, but will improve the precision of the W cross section ratio measurements
STAR W Data Collection

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  o 2012 Integrated luminosity: 77 1/pb
  o 2013 Integrated luminosity: 250 1/pb
• ~350 1/pb of W production data was collected over those 3 years!

Preliminary result of combined 2011 and 2012 data set (~100 1/pb) just released
Mid-rapidity Selection Criteria

- Match $p_T > 10$ GeV track to BEMC cluster
- Isolation Cuts
- $p_T$-balance cut

\[ p_T^{bal} = p_T^e + \sum_{\Delta R > 0.7} p_T^{jets} \]

\[ P_T\text{-balance } \cos(\phi) = \frac{p_T^e \cdot p_T^{bal}}{|p_T^e|} \]

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**Efficiency** = (# events reconstructed) / (# events generated)

Covers of contributions from:

- **Trigger efficiency**
- **Vertex efficiency**
- **Tracking efficiency**
- **W Algorithm efficiency**
- **Charge efficiency**
• 2012 running had lower W+/- efficiencies due to running at higher luminosity rates.

• This lead to more pile up in the TPC which resulted in less efficient track reconstruction.

• Minimal charge dependence leads to small contribution to W cross section ratio measurement.
W+/− Background Contributions

Small background contributions from:

- W boson induced tau decays.
- Z boson decays.
$p+p \rightarrow W^\pm + X \rightarrow e^\pm + X$

STAR Preliminary

$\sqrt{s} = 500/510$ GeV
Projected STAR Run-13 Statistical Impact

Run 13 Statistical Impact

- Run-11+12 Stat. Uncertainty

Run-11+12 ~ 100/pb
Projected STAR Run-13 Statistical Impact

Run 13 Statistical Impact

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Run-11+12 ~ 100/pb
Run-13 ~ 250/pb

Inclusion of Run-13 data will improve precision of the cross section ratios
**W boson rapidity** can be determined by reconstructing the W kinematics via its recoil.

Recently through the combination of data and MC simulations, a procedure for reconstructing the W boson rapidity has been established at STAR.

This procedure has been applied to the 2011 + 2012 combined data set.

See talk by Salvatore Fazio for more details.
• Preliminary W cross section ratio results as a function of W boson and lepton rapidities from STAR W production data taken during 2011 and 2012 running have been analyzed.
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• **2011 + 2012** W production reached an **integrated luminosity** of about ~ **100 1/pb**.
Summary

- **Preliminary W cross section ratio** results as a function of W boson and lepton rapidities from **STAR** W production data taken during 2011 and 2012 running have been analyzed.
- **2011 + 2012** W production reached an **integrated luminosity** of about ~ 100 1/pb.
- **Preliminary results** will help to **constrain** pdf global fits to the **unpolarized sea quarks** in the range of \( x \sim 0.1 \) to 0.3
• **Preliminary W cross section ratio** results as a function of **W boson and lepton rapidities** from **STAR** W production data taken during 2011 and 2012 running have been analyzed.

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• **Preliminary results** will help to **constrain** pdf global fits to the **unpolarized sea quarks** in the range of  $x \sim 0.1$ to 0.3

• **STAR 2013** W production reached an even **higher integrated luminosity** near 250 1/pb and will help to further **constrain** global pdf fits of the **unpolarized sea quarks**.
Systematics on W reconstruction

- Systematics on background subtraction (as for the decay lepton)
- Systematics on the reconstruction smearing
  - Calculate the ratio with generated pure MC
  - Calculated the ratio with reconstructed MC after all the analysis
  - Assign the difference as systematic uncertainty