Charm-Associated $W^{\pm}$ Production at RHIC

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In collaboration with H. Yokoya (Niigata Univ.)

I. Introduction & Motivation

II. Charm-Associated $W^{\pm}$ Production at RHIC

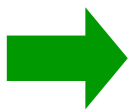
$$p + \vec{p} \rightarrow W^{\pm} + c/\bar{c} + X$$

III. Numerical Results

IV. Conclusion

I. Introduction & Motivation

- **Uncertainty of the polarized sea quark and gluon distributions are large, since only the combinations $\Delta q(x)+\Delta\bar{q}(x)$ can be determined in conventional DIS.**



How about flavor structure of the polarized quark distribution??

- **Charged current (CC) reaction is effective to extract the flavor decomposed parton distribution, since $W^{\pm}$ boson changes the parton flavor.**

Single Spin Asymmetry in inclusive production at RHIC

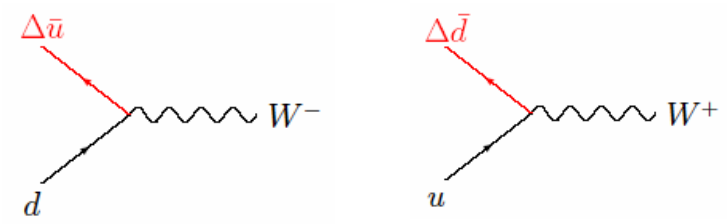
RHIC experiments

- Δg
- ★ – **Prompt photon production**
  - qg **process dominates, no FF ambiguity, low statistics**
  - **Heavy flavor production**
    - gg **process dominates**
  - **Pion production**
    - **High statistics, many sub-processes**

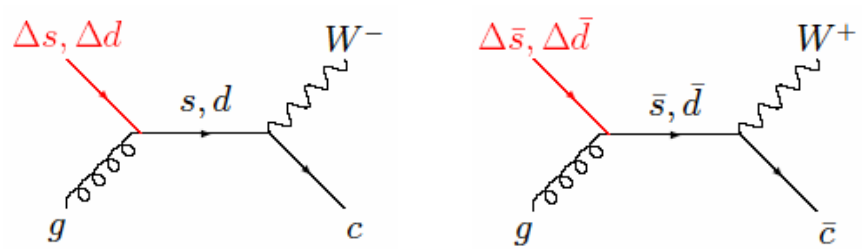
⋮

- $\Delta\bar{q}$
- ★ – $W^{\pm}$ **production:** $\Delta\bar{u}$, $\Delta\bar{d}$
  - **Charm-Associated** $W^{\pm}$ **production:** Δs, $\Delta\bar{s}$
    - **Flavor decomposition**

- **500 GeV Run and Beyond**
  - $W^{\pm}$ **Production**



  - **Charm-Associated** $W^{\pm}$ **Production**



II. Charm-Associated $W^{\pm}$ Production

- **$W^{\pm}$ production is sensitive to $\Delta\bar{u}(x)$, $\Delta\bar{d}(x)$.**

$$\Delta\bar{u} + d \to W^-, \quad \Delta\bar{d} + u \to W^+$$

  - **identified by tagging the charged lepton: $W \to l\nu$**

- **Charm-associated $W^{\pm}$ production is also interesting!!**
  - **LO** $\Delta s'(\Delta g) + g(s') \to W^- + c$
  - **NLO** $\Delta s'(\Delta g) + g(s') \to W^- + c + g$ & **virtual corrections**

$$\Delta g + g \to W^- + c + \bar{c}, \quad \Delta q(\Delta\bar{q}) + \bar{q}(q) \to W^- + c + \bar{s}',$$

$$\Delta s'(\Delta q) + q(s') \to W^- + c + q$$

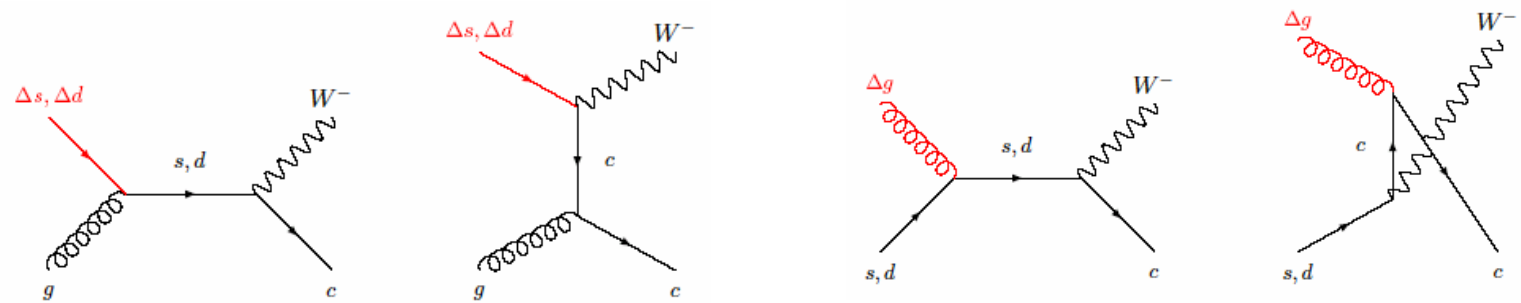
$$s' \equiv |V_{cs}|^2 s + |V_{cd}|^2 d$$

⇨ **Sensitive to the polarized s quark distribution**

$p + \vec{p} \to W^{\pm} + c/\bar{c} + X$ **at RHIC**

LO Diagrams of Subprocesses

- **Subprocesses for $W^{\pm}$ production**
  - **$O(\alpha_s\alpha_w)$ 2→2 tree-level channels in LO**



well-defined in perturbation theory

- **Spin asymmetry is sensitive to $\Delta s(x)$.**

Need to separate $\Delta s \cdot g$ from $\Delta g \cdot s$.
Examine CKM mixing Δs and Δd.

Observables

Longitudinal Single Spin Asymmetry:

$$A_L^W \equiv \frac{[d\sigma_+ - d\sigma_-]/dp_T dy_W}{[d\sigma_+ + d\sigma_-]/dp_T dy_W} = \frac{d\Delta\sigma/dp_T dy_W}{d\sigma/dp_T dy_W}$$

$$\frac{d\Delta\sigma}{dp_T dy_W} \equiv \frac{1}{2}\left[\frac{d\sigma_+}{dp_T dy_W} - \frac{d\sigma_-}{dp_T dy_W}\right] \qquad : \ |y_W| < 1.5, \quad Q^2 = M_W^2$$

$$= \sum_{f_1, f_2} \int_{x_a^{\min}}^1 dx_a \int_{x_b^{\min}}^1 dx_b \Delta f_1(x_a, Q^2) f_2(x_b, Q^2) \frac{d\Delta\hat{\sigma}}{dp_T dy_W}$$

- **Polarized PDFs**: $\Delta f(x, Q^2)$
  - **AAC** — **Asymmetry Analysis Collaboration, Y. Goto, *et al.*, *Phys. Rev.* D62, 034017 (2000).**
  - **GRSV** — **M. Gl"uck, *et al.*, *Phys. Rev.* D63, 094005 (2001).**
  - **LSS** — **E. Leader, *et al.*, *Eur. Phys. J.* C23, 479 (2002).**

Polarized Cross Sections

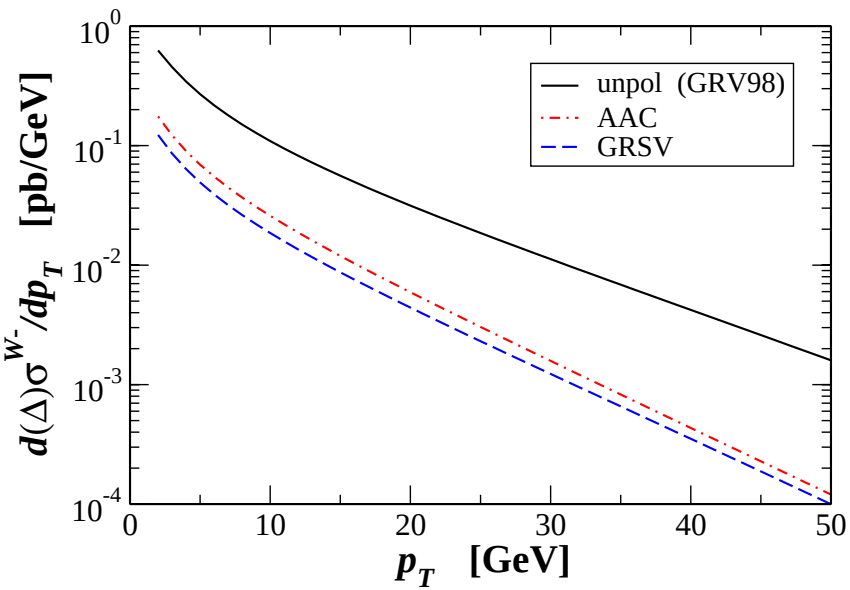
$$p + \vec{p} \to W^- + c + X$$

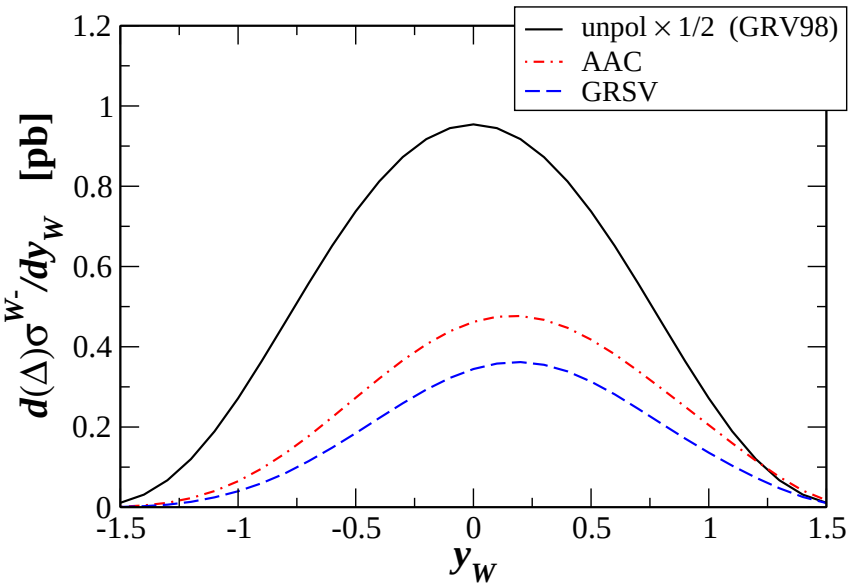
$$\sqrt{s} = 500\,\mathbf{GeV},\ m_c = 1.2\,\mathbf{GeV},\ Q^2 = M_W^2$$

$$\sigma = 4.29\,\mathbf{pb\ (GRV98)},\quad \Delta\sigma = 1.105\,\mathbf{pb\ (AAC)}$$
$$= 0.783\,\mathbf{pb\ (GRSV)}$$

$$\begin{cases} p_T < 50\ \ \mathbf{GeV} \\ -1.5 < y_W < 1.5 \end{cases}$$

- **Rapidity distribution is anti-symmetric due to the pure *V-A* nature of weak interaction**





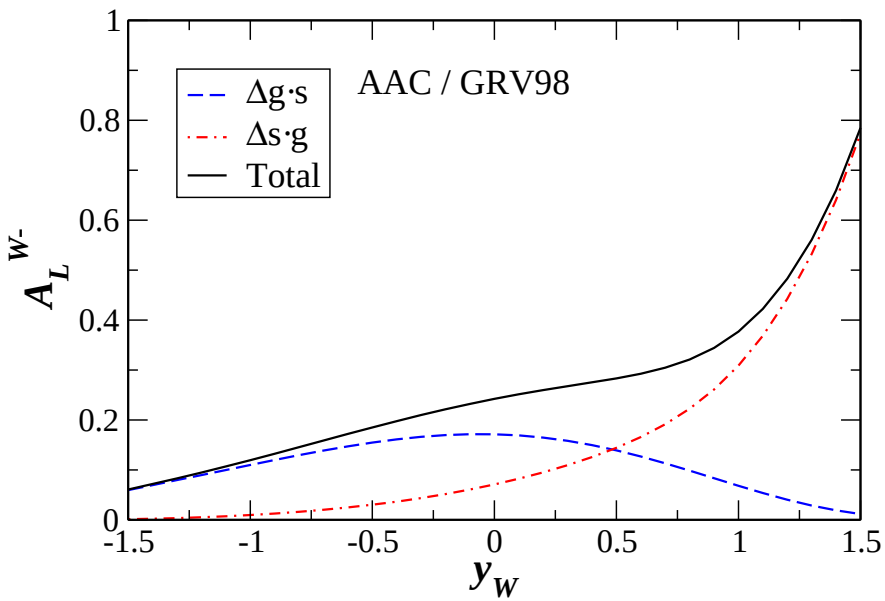
Single Spin Asymmetry

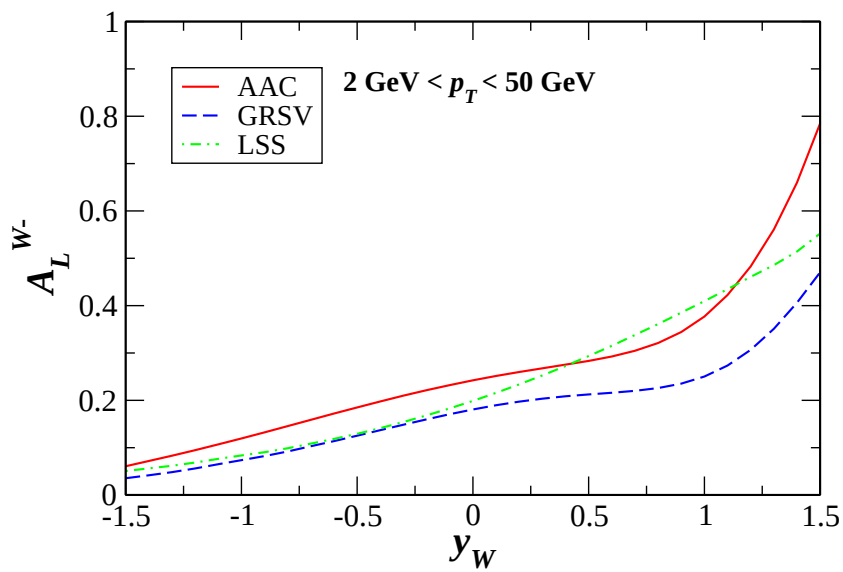
$$p + \vec{p} \rightarrow W^- + c + X$$

$$\sqrt{s} = 500 \ \ \mathbf{GeV}, \quad L = 800\,\mathbf{pb}^{-1}$$

Δs dominates in $y \rightarrow +1.5$, whereas Δg in $y \rightarrow -1.5$.

Possibility to separate Δs from Δa





Rapidity Dependence

$$A_L = \frac{d\Delta\sigma_{\Delta gs} + d\Delta\sigma_{\Delta sg}}{d\sigma_{gs} + d\sigma_{sg}} \approx \frac{\Delta g(x_a)\cdot s(x_b) + \Delta s(x_a)\cdot g(x_b)}{g(x_a)\cdot s(x_b) + s(x_a)\cdot g(x_b)}$$

$$x_a = \tau e^{y_w},\ x_b = \tau e^{-y_w},\ \tau = \textbf{const.}$$

$y \gg 0 \rightarrow x_a$ is large, x_b is small. $g(x_b)$ is enhanced.

$y \ll 0 \rightarrow x_a$ is small, x_b is large. $s(x_b)$ is suppressed.

$$A_L \approx \frac{d\Delta\sigma_{\Delta gs}}{d\sigma_{gs}} \approx \frac{\Delta g(x)}{g(x)} \quad y_W \rightarrow -1.5$$

$$A_L \approx \frac{d\Delta\sigma_{\Delta sg}}{d\sigma_{sg}} \approx \frac{\Delta s(x)}{s(x)} \quad y_W \rightarrow +1.5$$

Error Estimation

- **Expected Statistical E**

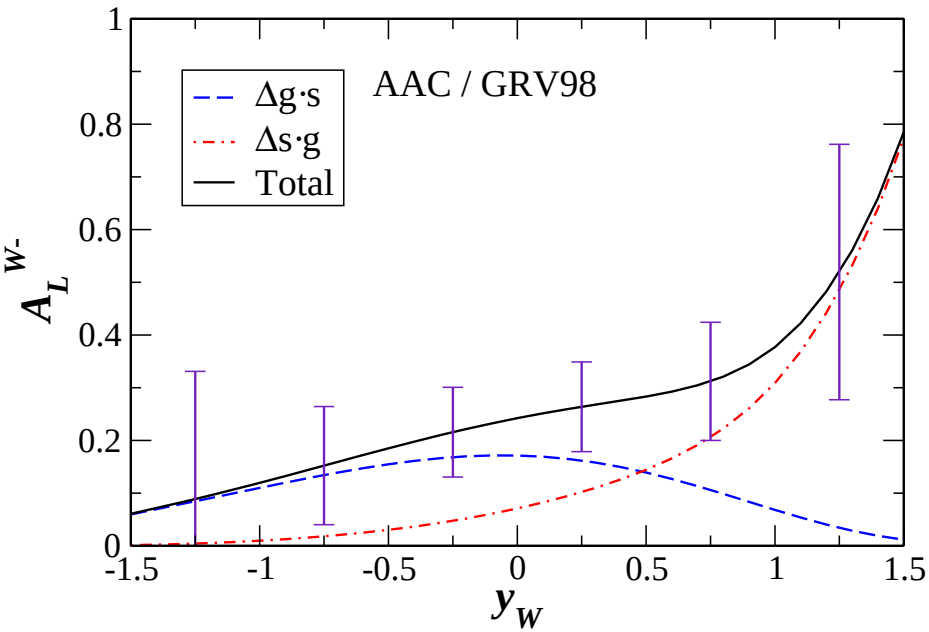
$$\delta A_L^W = \frac{1}{P}\frac{1}{\sqrt{\sigma \cdot L \cdot \varepsilon}}$$

P: **beam polarization** $\sim 70\%$

σ: **total cross section**

L: **integrated luminosity** $\sim 800\,\mathbf{pb^{-1}}$

ε: **detection efficiency** $\sim 10\%$



ε might be overestimated, but the sign of $\Delta s(x)$ might be determined.

Polarized Cross Sections

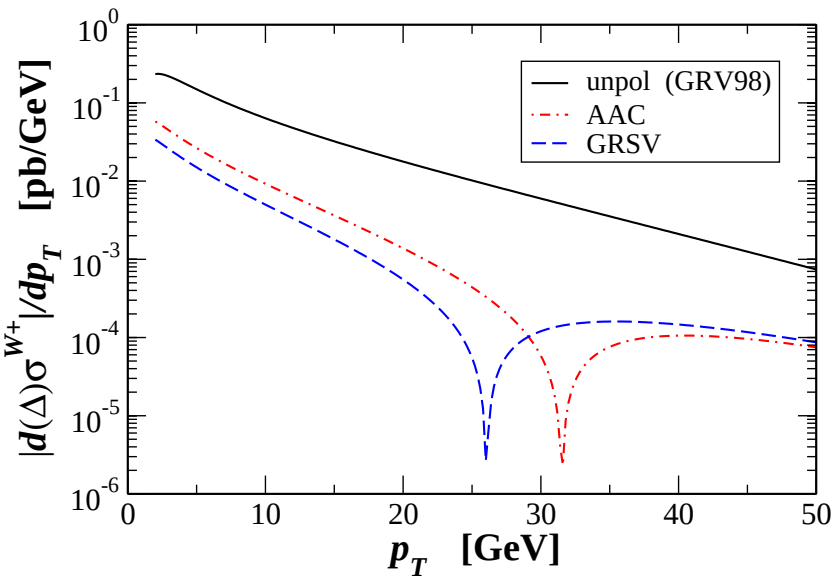
$$p + \vec{p} \to W^+ + \bar{c} + X$$

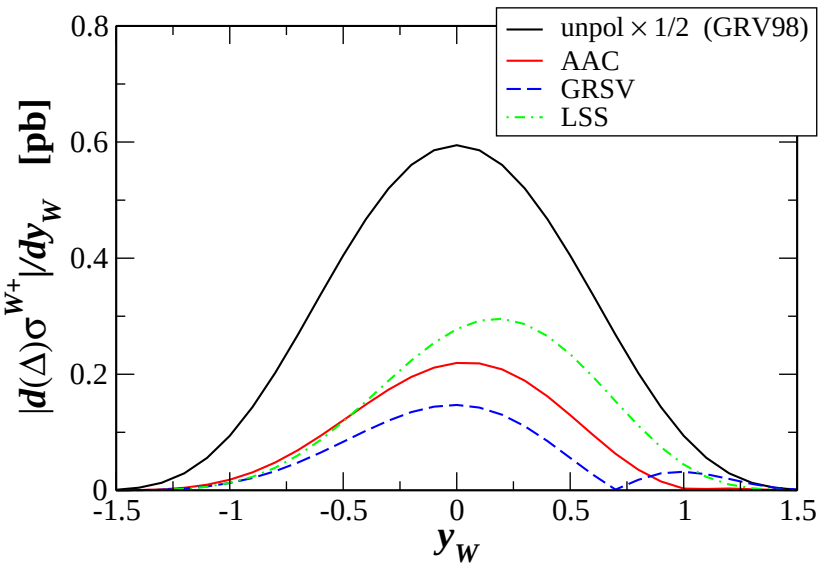
$\sqrt{s} = 500\,\mathbf{GeV}$, $m_c = 1.2\,\mathbf{GeV}$, $Q^2 = M_W^2$

$\sigma = 1.78\,\mathbf{pb}$ **(GRV98)**, $\Delta\sigma = 0.346\,\mathbf{pb}$ **(AAC)**

$= 0.193\,\mathbf{pb}$ **(GRSV)**

$$\begin{cases} p_T < 50 \ \ \mathbf{GeV} \\ -1.5 < y_W < 1.5 \end{cases}$$



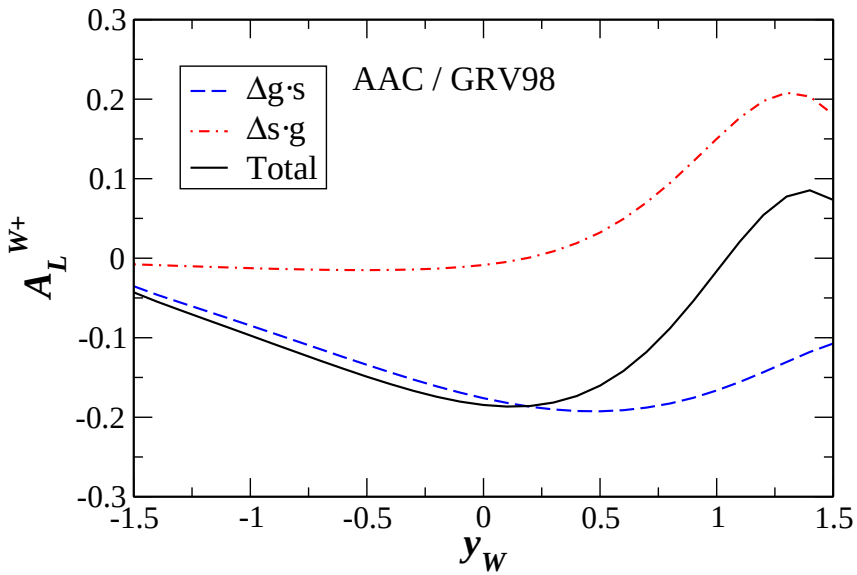


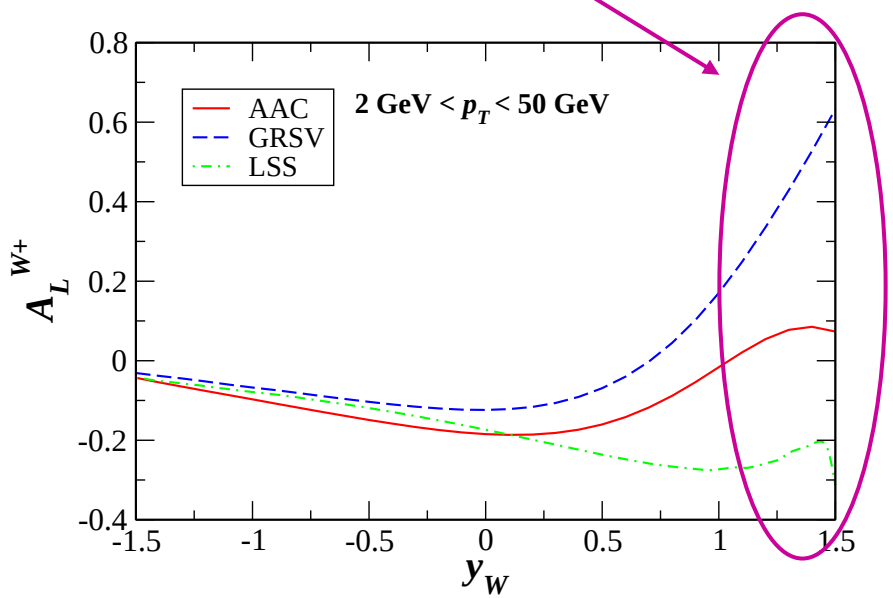
Single Spin Asymmetry

$$p + \vec{p} \rightarrow W^{+} + \bar{c} + X$$

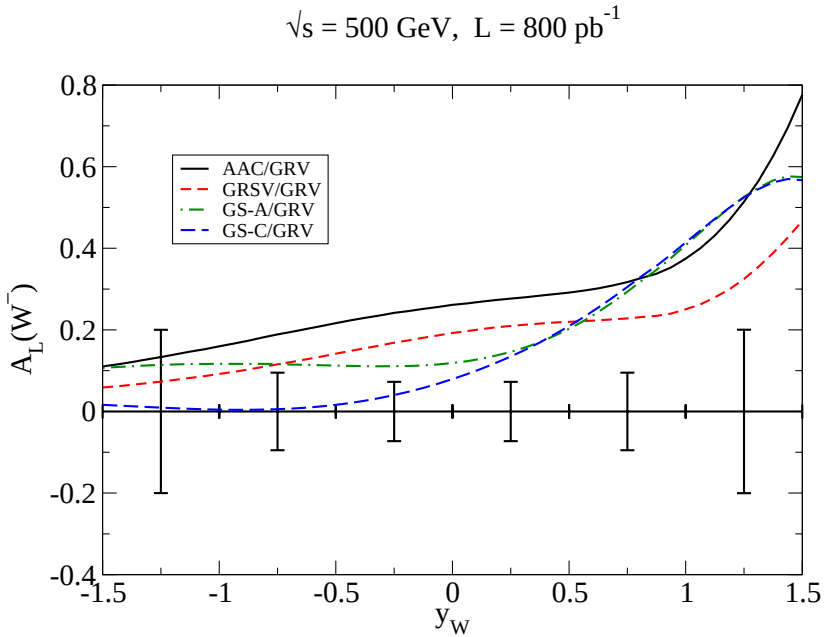
We can remove the contribution from the valence *d*-quark distribution. But $\Delta g(x)$ is still large in y ~1.5.

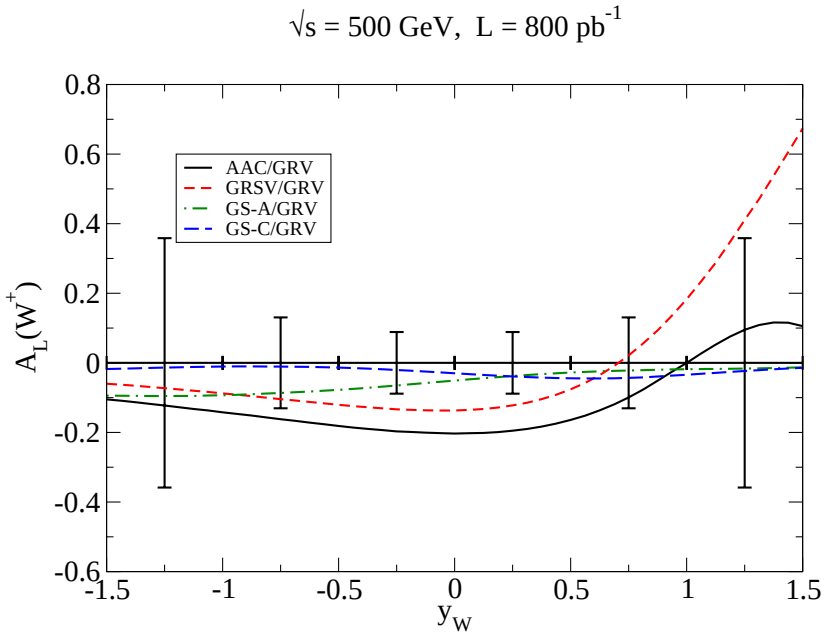
Large y behavior come form ambiguity of $\Delta s(x)$.





K.


√s = 500 GeV, L = 800 pb-1
AAC/GRV
GRSV/GRV
GS-A/GRV
GS-C/GRV
AL(W−)
yW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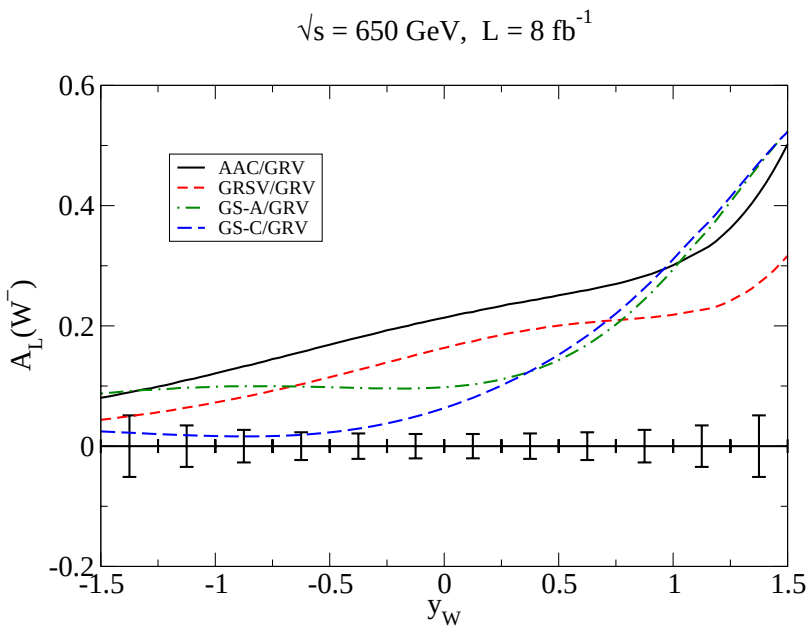
√s = 650 GeV, L = 8 fb-1
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GRSV/GRV
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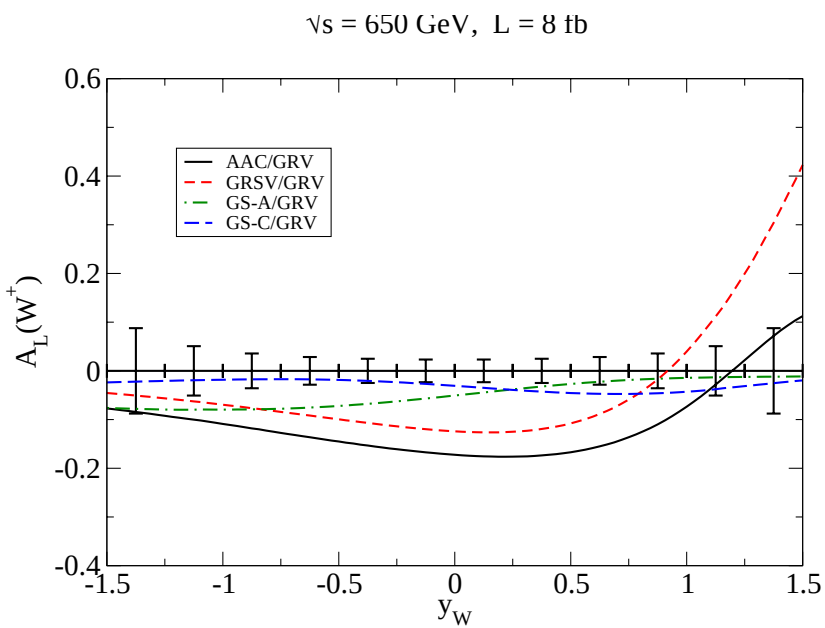
GS-C/GRV
AL(W−)
yW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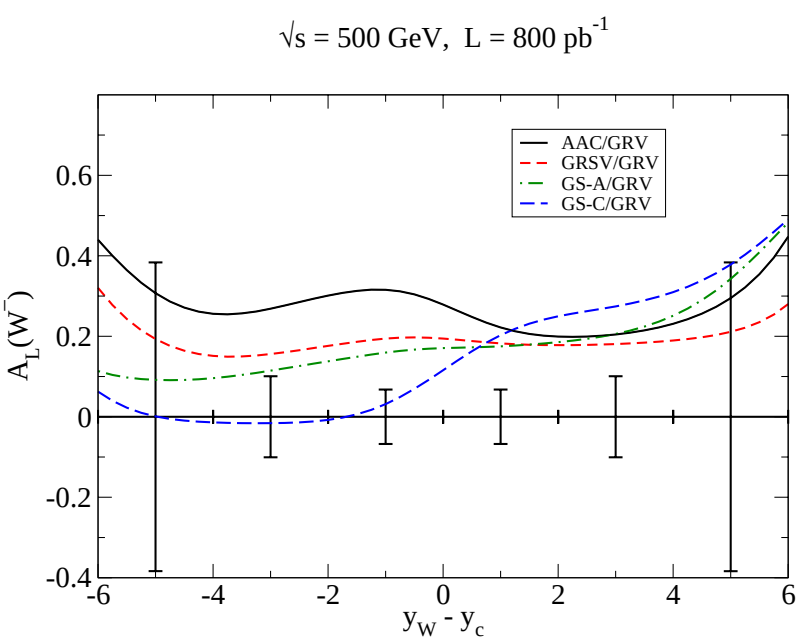
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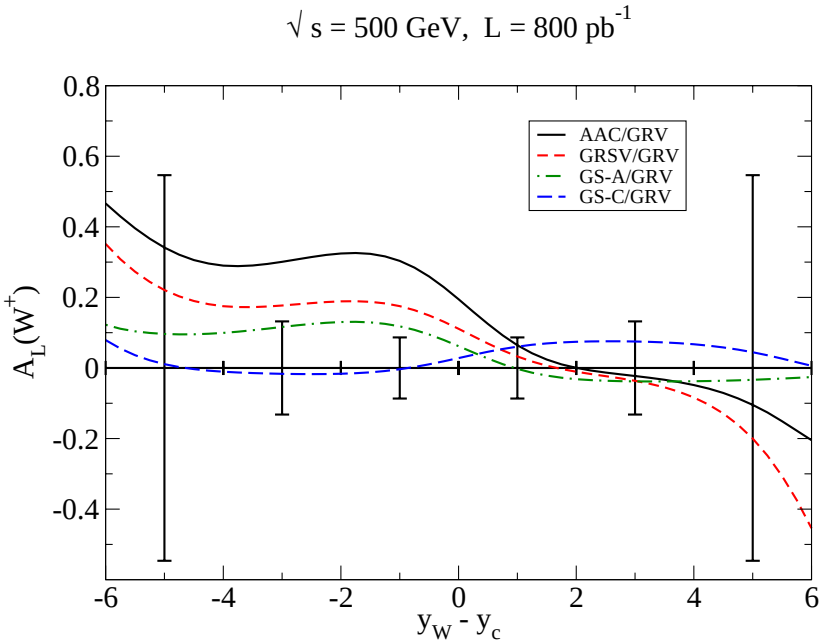
AL(W-)
yW - yc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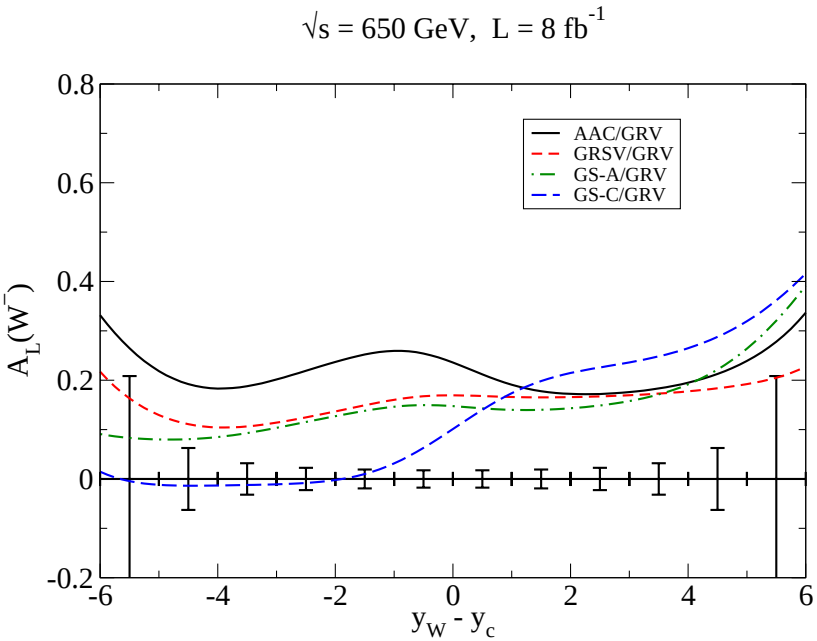
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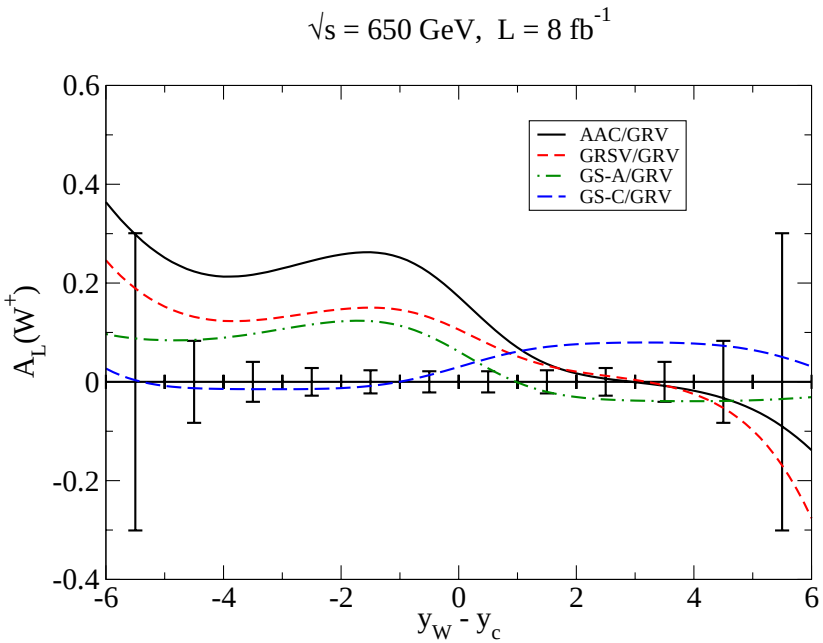
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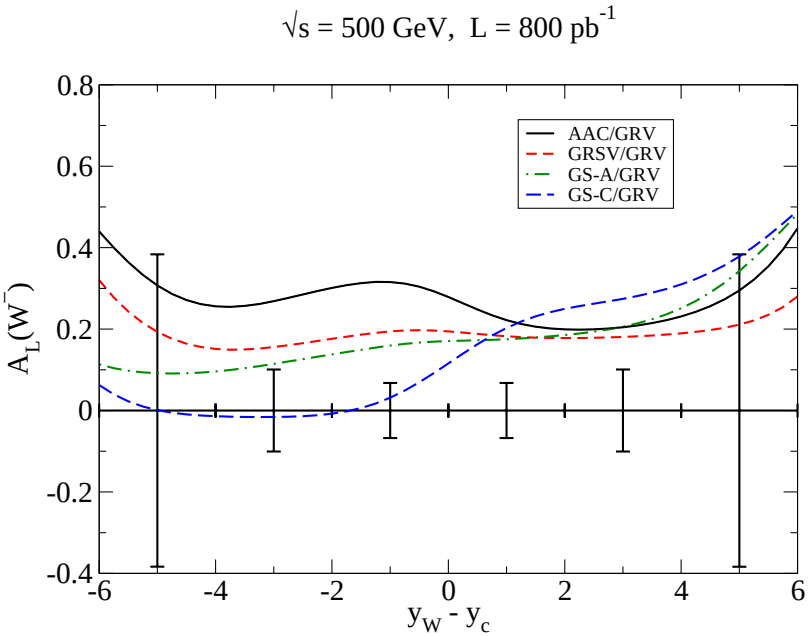
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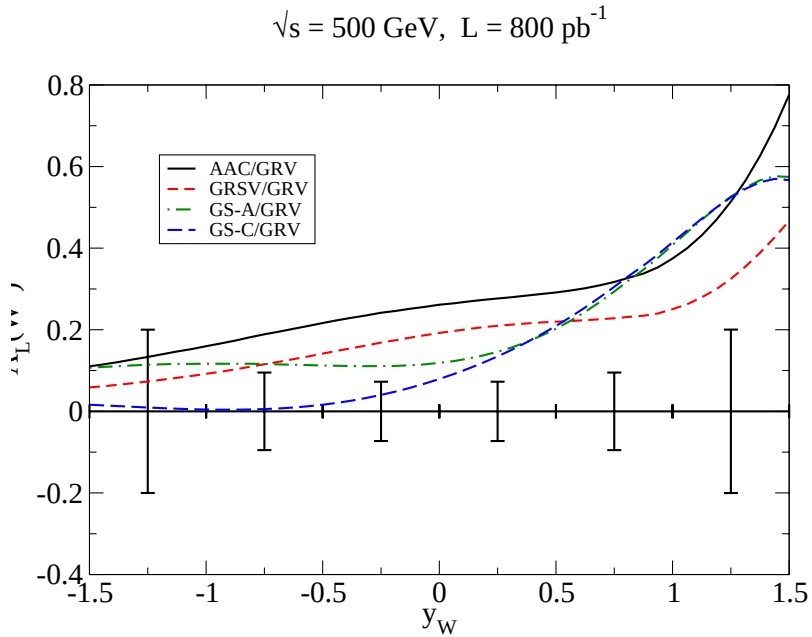
A_L(W-)
y_W - y_c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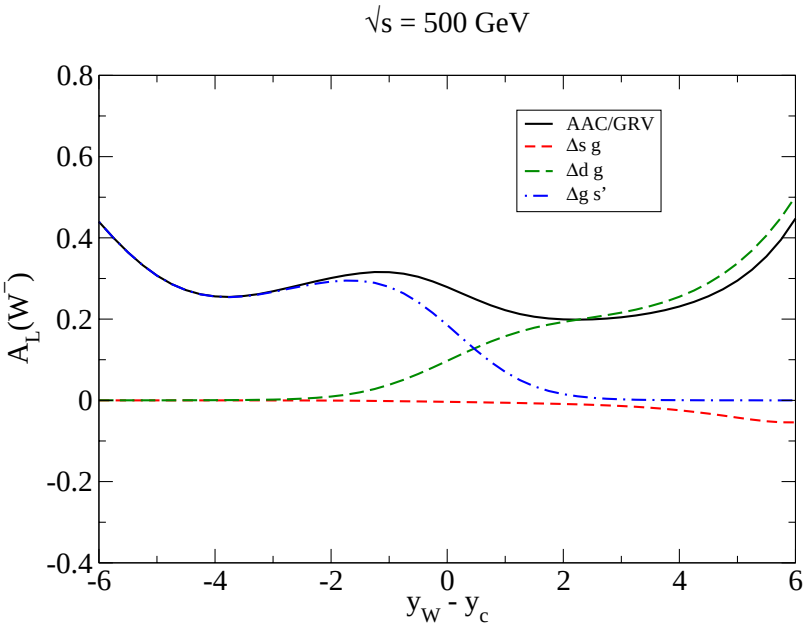
GRSV/GRV
GS-A/GRV
GS-C/GRV
y_W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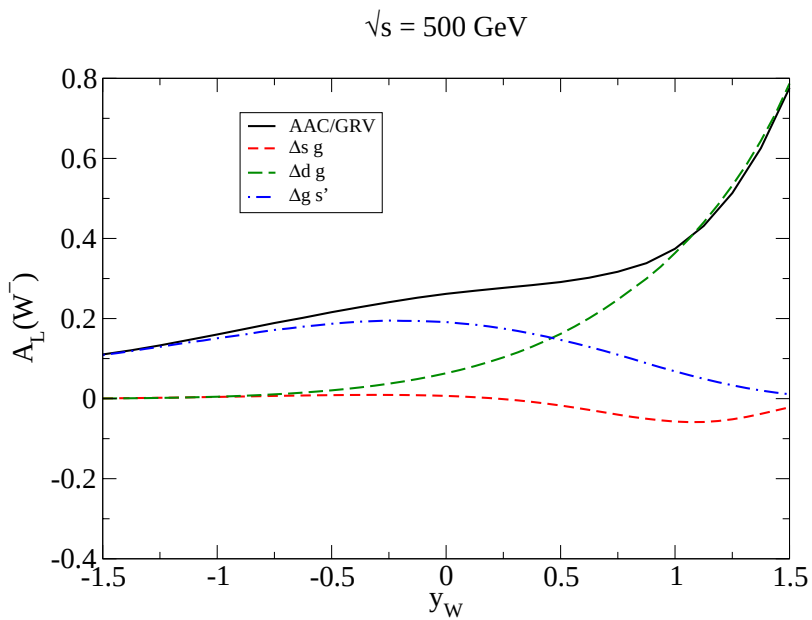
AAC/GRV
Δs g
Δd g
Δg s'
A_L(W-)
y_W - y_c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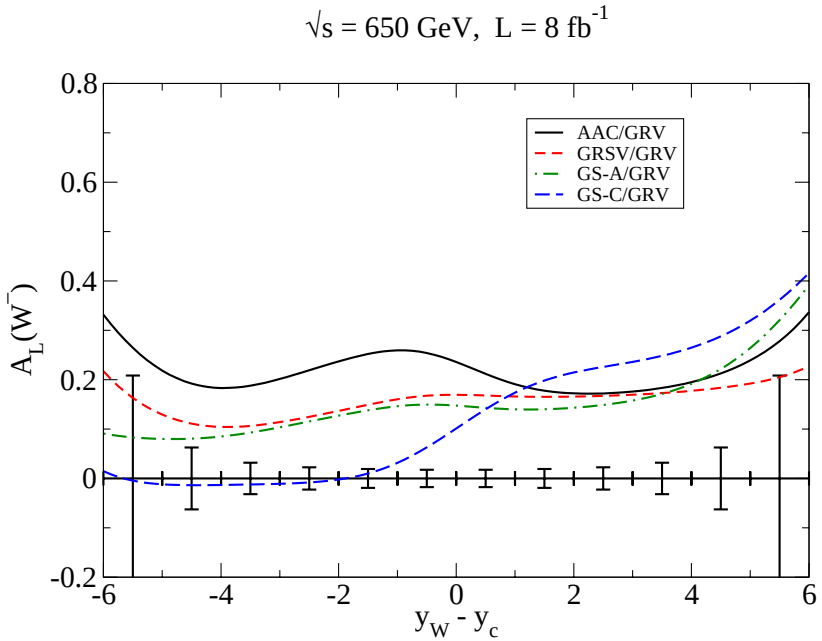
√s = 650 GeV, L = 8 fb-1
AAC/GRV
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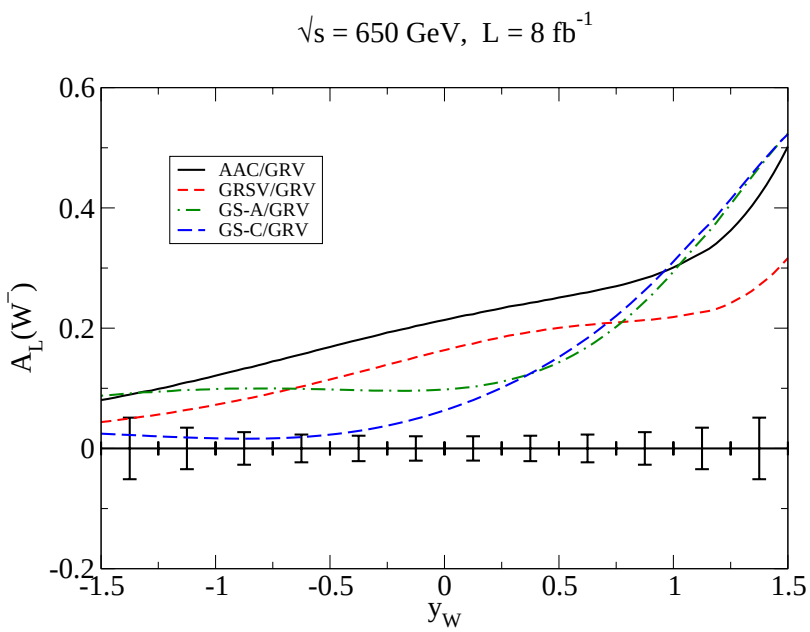
GS-C/GRV
A_L(W^-)
y_W - y_c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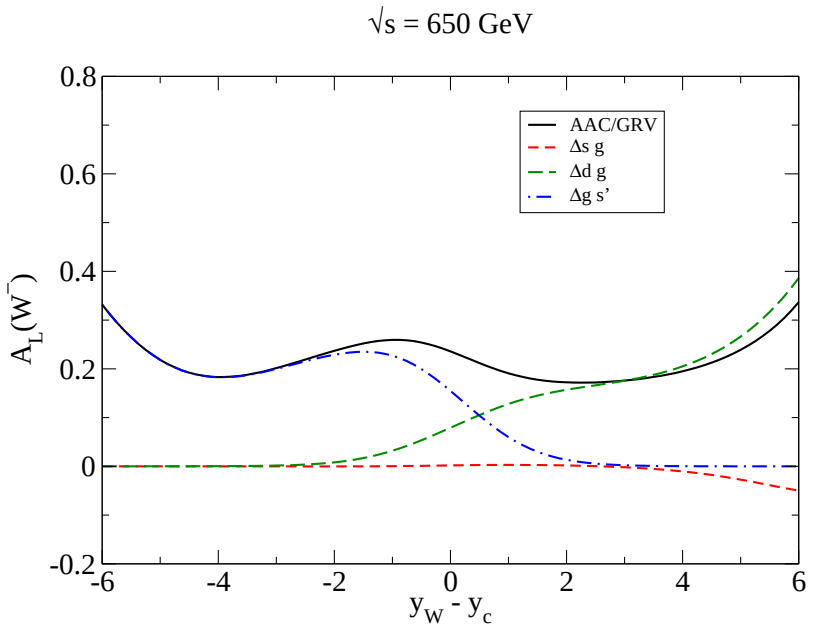
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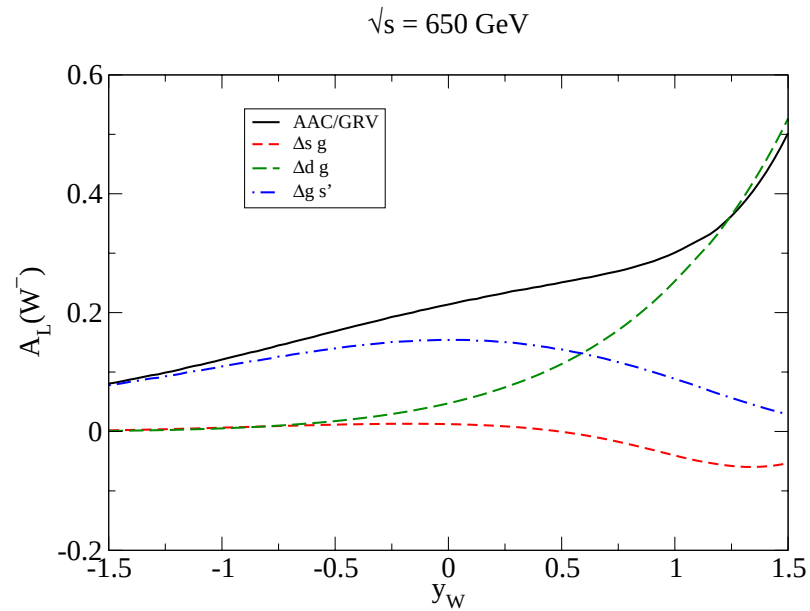
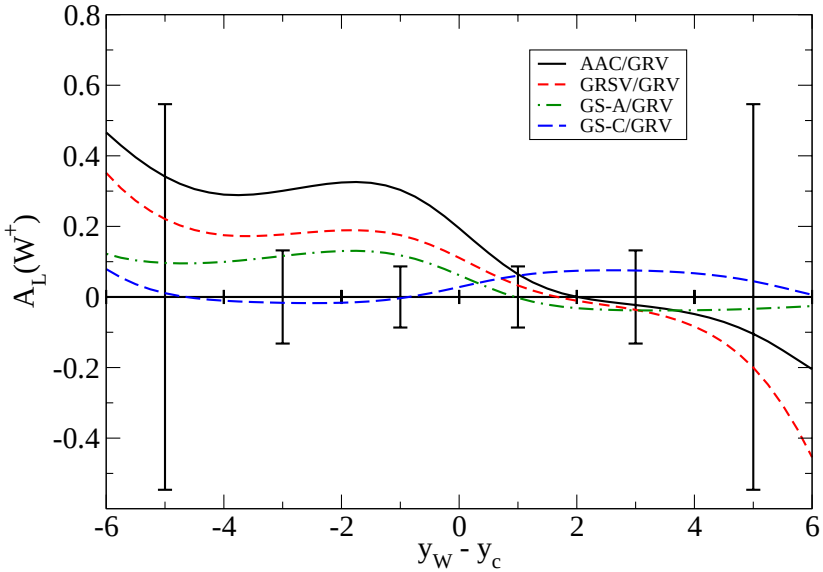
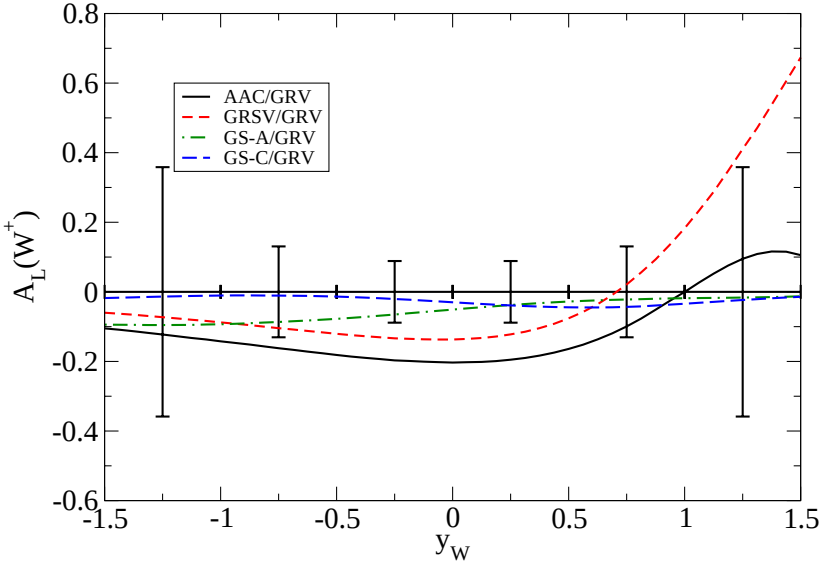
AAC/GRV
Δs g
Δd g
Δg s'
A_L(W^-)
y_W - y_c


√s = 650 GeV
AAC/GRV
Δs g
Δd g
Δg s'
A_L(W^-)
y_W

√ s = 500 GeV, L = 800 pb^{-1}



√s = 500 GeV, L = 800 pb^{-1}



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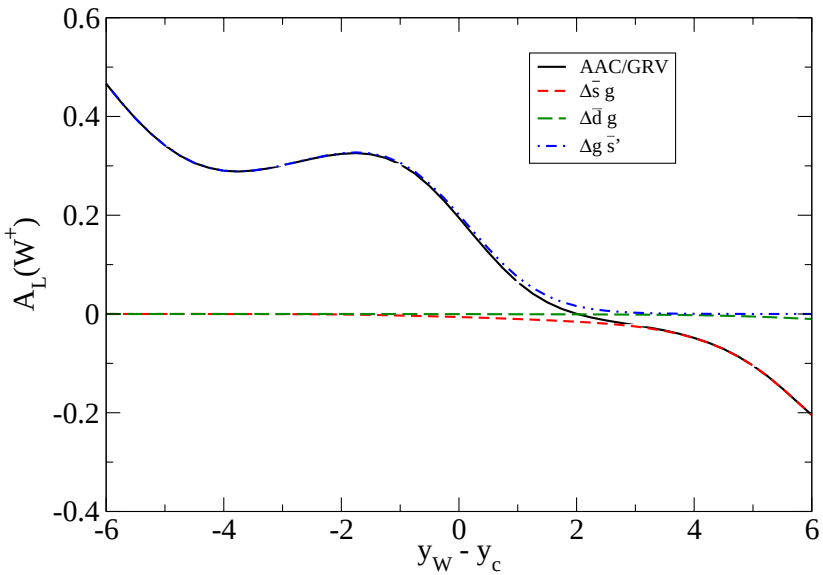

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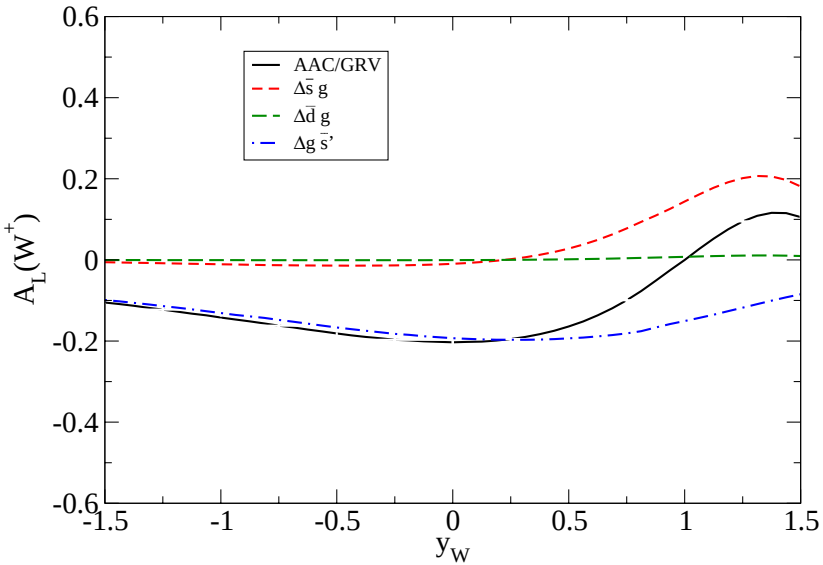

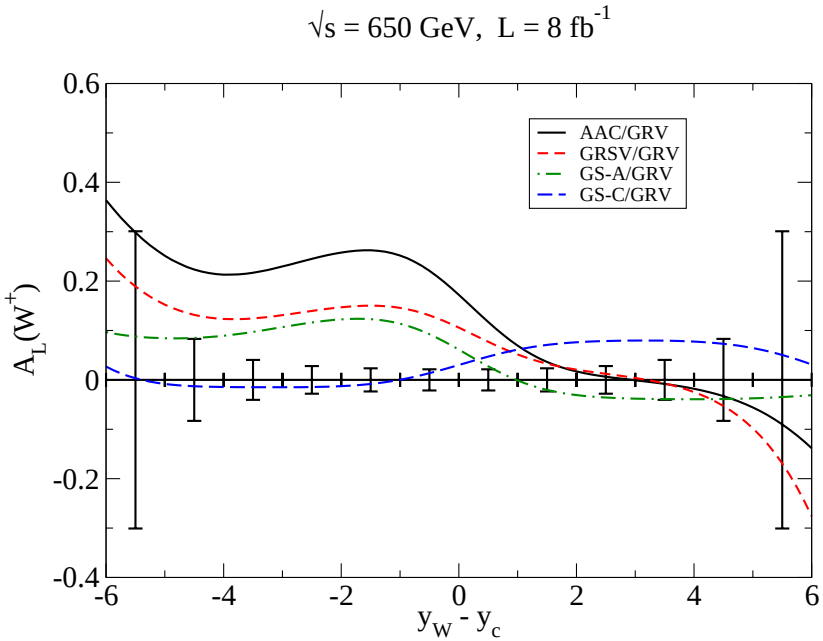
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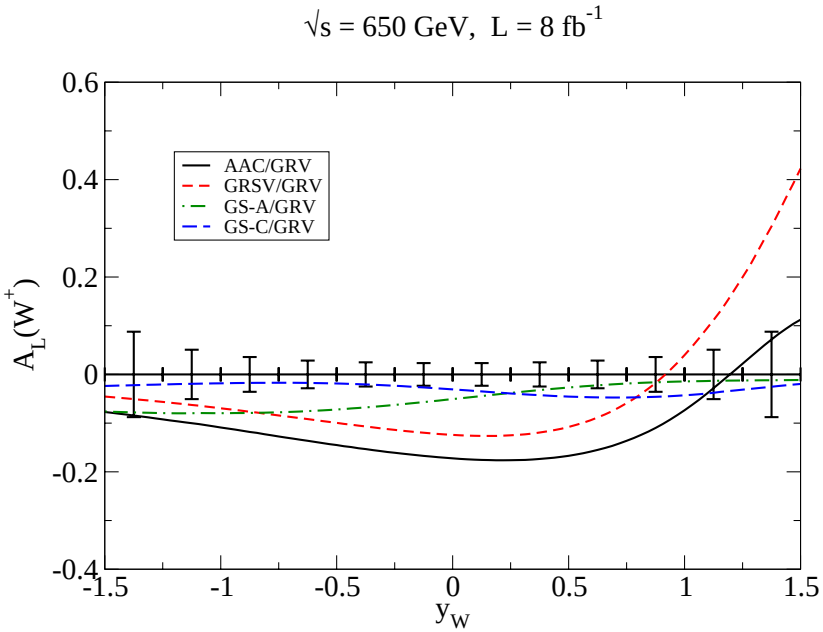
AAC/GRV
GRSV/GRV
GS-A/GRV
GS-C/GRV
AL(W+)
yW - yc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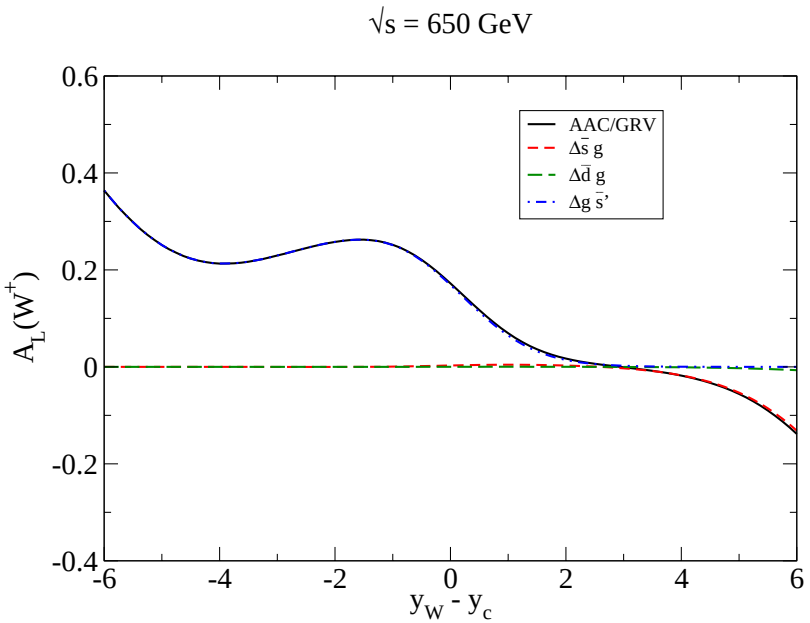
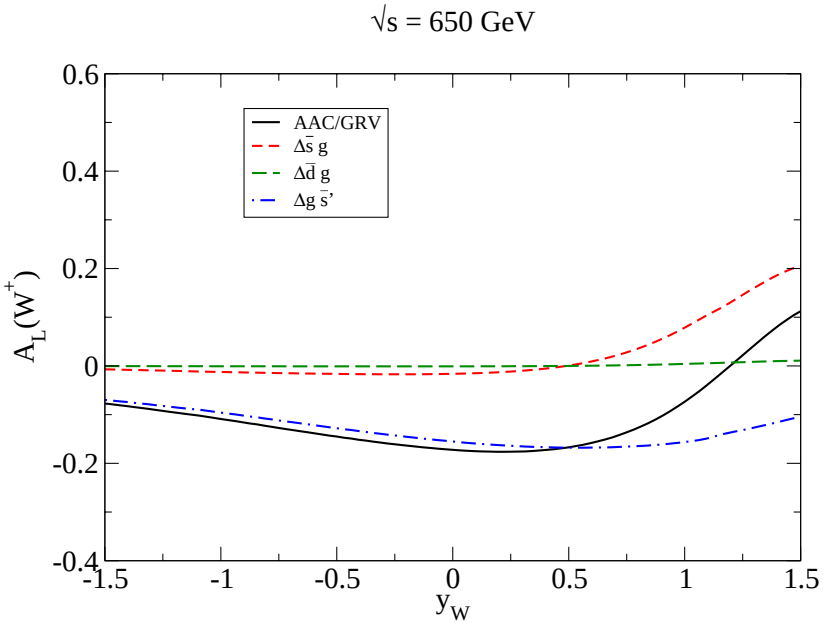

√s = 650 GeV
AAC/GRV
Δs̄ g
Δd̄ g
Δg s̄'
AL(W+)
yW - yc


√s = 650 GeV
AAC/GRV
Δs̄ g
Δd̄ g
Δg s̄'
AL(W+)
yW

IV. Conclusion

- **Single spin asymmetry in charm-associated $W^{\pm}$ production is studied to examine the flavor structure of polarized PDFs.**
  - **The cross section is dominated by $\Delta g \cdot s$ process in $y \ll 0$, while the $\Delta s \cdot g$ process in $y \gg 0$.**

    → We might be able to separate Δs from Δg.
  - **The parametrization model dependence on the asymmetry is large in $y \gg 0$.**

    → Anti-quark distribution is still poorly known.

But!!

Need more energy and luminosity

→ RHIC II ?