NuFACT'02 (The 4th International Workshop on Neutrino Factories based on Muon Storage Rings)

Polarized Parton Distribution in Neutrino Induced Heavy Flavor Production

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I. Introduction

II. Semi–inclusive $D/\bar{D}$ Production in CC DIS

$$\begin{cases} \nu + \vec{p} \to l^- + D + X \\ \bar{\nu} + \vec{p} \to l^+ + \bar{D} + X \end{cases}$$

III. Numerical Results and Extraction of $\Delta s(x)$

IV. Conclusion

I. Introduction

“ Proton Spin Puzzle ”

$$\frac{1}{2} = \frac{1}{2}(\Delta u + \Delta d + \Delta s) + \Delta G + < L >_{q \leftrightarrow g}$$

$(\Delta u + \Delta d + \Delta s)$: Quark spin $\qquad \Delta G$: Gluon spin
$< L >_{q \leftrightarrow g}$: Orbital angular momentum of Quarks and Gluons

Since the advent of EMC experiment(1988),

Spin contribution from quarks is very small $\lesssim 30\%$

$\Rightarrow$ **Analysis on the spin structure of the nucleon in polarized experiments (RHIC($\vec{p}\vec{p}$), HERMES($\vec{e}\vec{p}$), etc)**

- **Flavor decomposition of the polarized quark distribution from semi–inclusive DIS**

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

Neutrino-induced charm production in CC DIS is interesting and challenging.

Motivation

1. HERMES collaboration (*Phys. Lett.* B464, 123 (1999).)

$\rightarrow$ A direct measurement of the strange sea is required for explaining the violation of the Ellis–Jaffe sum rule.

2. Flavor SU$(3)_f$ is broken ?

$$\begin{cases} \Delta u_s = \Delta d_s = \Delta s = \Delta \bar{u} = \Delta \bar{d} = \Delta \bar{s} & \text{(Flavor SU}(3)_f\text{)} \\ \Delta \bar{u} = \Delta \bar{d} = \lambda \Delta \bar{s} & \text{(E. Leader, } \textit{et al., Phys. Lett.} \text{ B462, 189 (1999).)} \end{cases}$$

- flavor independent sea polarization (HERMES group)

$$\frac{\Delta u_s}{u_s} = \frac{\Delta d_s}{d_s} = \frac{\Delta s}{s} = \frac{\Delta \bar{u}}{\bar{u}} = \frac{\Delta \bar{d}}{\bar{d}} = \frac{\Delta \bar{s}}{\bar{s}} \quad \rightarrow \quad \frac{\Delta s + \Delta \bar{s}}{s + \bar{s}} = \frac{\Delta q_{sea}}{q_{sea}}$$

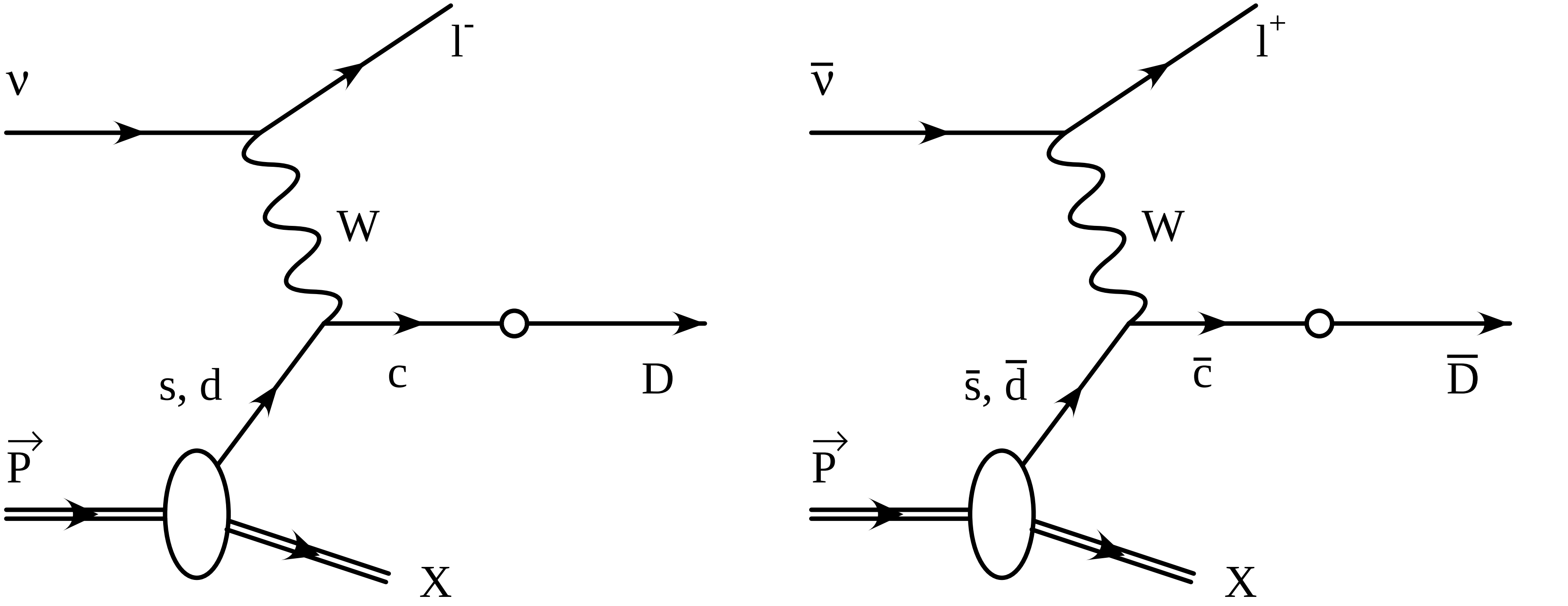
To examine the polarized s–quark distribution, we have studied semi–inclusive $D/\bar{D}$ production in $\nu\vec{p}$ collision.

$$\boxed{\nu + \vec{p} \rightarrow l^- + D + X, \quad \bar{\nu} + \vec{p} \rightarrow l^+ + \bar{D} + X}$$

II. Semi–inclusive $D/\bar{D}$ Production

$\nu + \vec{p} \to l^- + D + X$

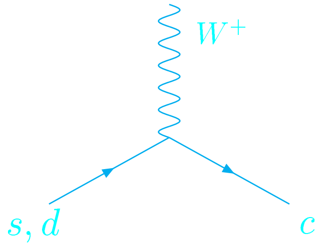
$\bar{\nu} + \vec{p} \to l^+ + \bar{D} + X$



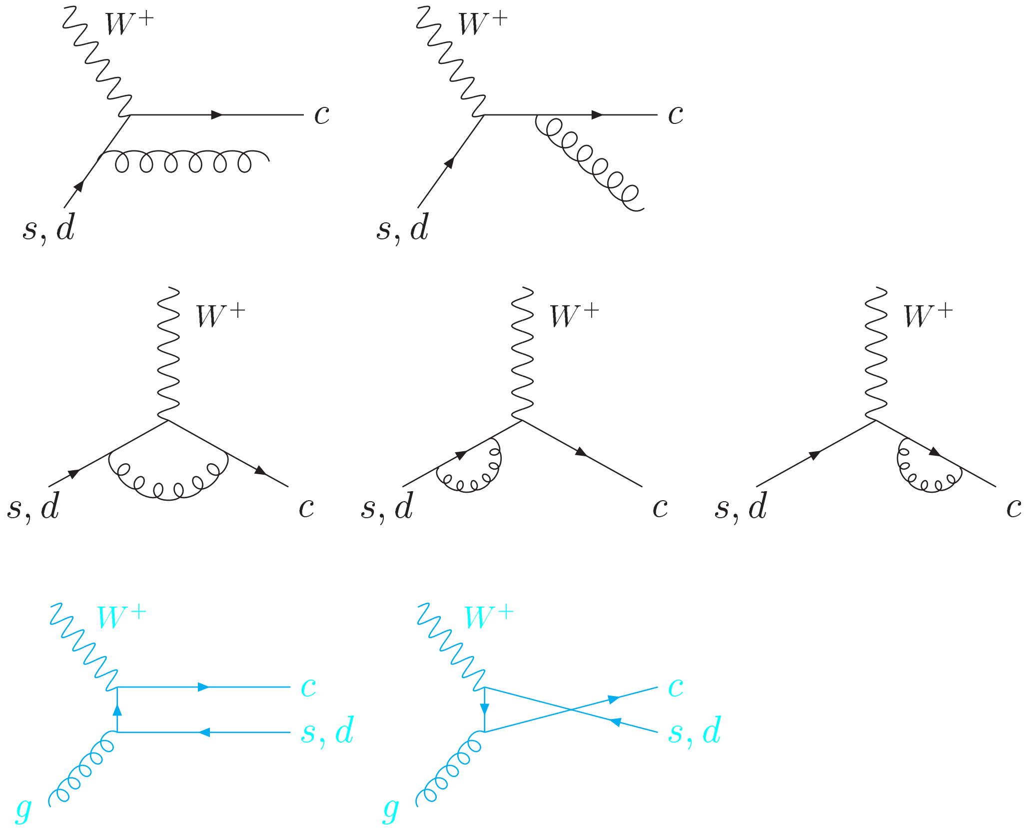
This process might be observed in the forthcoming neutrino experiments.

LO and $\mathcal{O}(\alpha_s)$ NLO diagrams of subprocesses

LO



NLO



Calculation was done in the $\overline{\textbf{MS}}$ scheme.

Observables

To extract the information about polarized parton distribution in proton, we calculated two observables using parton model.

1 : Spin dependent differential cross section

$$\frac{d\Delta\sigma}{dx} \equiv \frac{d\sigma(+) - d\sigma(-)}{dx}$$

x : Bjorken x

$d\sigma(+,-)/dx$: Spin dependent differential cross section with the positive helicity of the target proton or the negative helicity of the target proton

2 : Spin correlation asymmetry (single spin asymmetry)

$$A^D \equiv \frac{d\sigma(+) - d\sigma(-)/dx}{d\sigma(+) + d\sigma(-)/dx} = \frac{d\Delta\sigma/dx}{d\sigma/dx}$$

Differential Cross Sections with structure functions F_i and g_i

Unpol : $$\frac{d^3\sigma^{\nu p}}{dx\,dy\,dz} = \frac{G_F^2 s}{2\pi(1+Q^2/M_W^2)^2}\left[(1-y)F_2^{W^\mp} + y^2 x F_1^{W^\mp} \pm y(1-\frac{y}{2})xF_3^{W^\mp}\right]$$

Pol : $$\frac{d^3\Delta\sigma^{\nu p}}{dx\,dy\,dz} = \frac{G_F^2 s}{2\pi(1+Q^2/M_W^2)^2}\left[(1-y)g_4^{W^\mp} + y^2 x g_3^{W^\mp} \pm y(1-\frac{y}{2})xg_1^{W^\mp}\right]$$

where

$$x = \frac{Q^2}{2P_p\cdot q}, \quad y = \frac{P_p\cdot q}{P_p\cdot P_\nu}, \quad z = \frac{P_p\cdot P_D}{P_p\cdot q}$$

$P_p,\ P_\nu,\ P_D,\ q$	:	Momentum of proton, neutrino, D meson, $W^\pm$ boson
G_F	:	Fermi coupling
s	:	Center of mass energy squared
M_W	:	$W^\pm$ boson mass
$F_i,\ g_i$	:	Unpolarized, Polarized structure functions

The structure functions F_i and g_i in νp scattering are obtained by the following convolutions.

$$\begin{Bmatrix} \mathcal{F}_i^c \\ \mathcal{G}_i^c \end{Bmatrix}(x, z, Q^2) = \begin{Bmatrix} s \\ \Delta s \end{Bmatrix}(\xi, \mu_F^2) \; D_c(z)$$

$$+ \frac{\alpha_s(\mu_R^2)}{2\pi} \int_\xi^1 \frac{d\xi'}{\xi'} \int_{\max(z,\zeta_{\min})}^1 \frac{d\zeta}{\zeta} \left[\begin{Bmatrix} H_i^q \\ \Delta H_i^q \end{Bmatrix}(\xi', \zeta, \mu_F^2, \lambda) \begin{Bmatrix} s \\ \Delta s \end{Bmatrix}(\frac{\xi}{\xi'}, \mu_F^2) \right.$$

$$\left. + \begin{Bmatrix} H_i^g \\ \Delta H_i^g \end{Bmatrix}(\xi', \zeta, \mu_F^2, \lambda) \begin{Bmatrix} g \\ \Delta g \end{Bmatrix}(\frac{\xi}{\xi'}, \mu_F^2) \right] D_c(\frac{z}{\zeta}) \quad .$$

where

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

$$\xi = \frac{Q^2}{2P_p \cdot q}\left(1 + \frac{m_c^2}{Q^2}\right), \quad \xi' = \frac{Q^2}{2p_{s,g} \cdot q}\left(1 + \frac{m_c^2}{Q^2}\right), \quad \zeta = \frac{p_{s,g} \cdot p_c}{p_{s,g} \cdot q}$$

$$\begin{Bmatrix} \mathcal{F}_1^c \\ \mathcal{G}_3^c \end{Bmatrix} = \begin{Bmatrix} F_1^c \\ -g_3^c \end{Bmatrix}, \quad \begin{Bmatrix} \mathcal{F}_3^c \\ \mathcal{G}_1^c \end{Bmatrix} = \frac{1}{2}\begin{Bmatrix} -F_3^c \\ g_1^c \end{Bmatrix}, \quad \begin{Bmatrix} \mathcal{F}_2^c \\ \mathcal{G}_4^c \end{Bmatrix} = \frac{1}{2\xi}\begin{Bmatrix} F_2^c \\ -g_4^c \end{Bmatrix}$$

Patron Distribution Function

Unpolarized PDF's : $s(x, Q^2)$, $g(x, Q^2)$

- **GRV98** M. Glück, *et al.*, *Eur. Phys. J.* C5, 461 (1998).
- **MRST99** A.D. Martin, *et al.*, *Eur. Phys. J.* C14, 133 (2000).

Polarized PDF's : $\Delta s(x, Q^2)$, $\Delta g(x, Q^2)$

- **AAC00** Asymmetry Analysis Collaboration,
  Y. Goto, *et al.*, *Phys. Rev.* D62, 034017 (2000).
- **BB02** J. Blümlein, *et al.*, hep-ph/0203155.
- **GRSV01** M. Glück, *et al.*, *Phys. Rev.* D63, 094005 (2001).
- **LSS02** E. Leader, *et al.*, *Eur. Phys. J.* C23, 479 (2002).

Fragmentation Function : $D(z)$

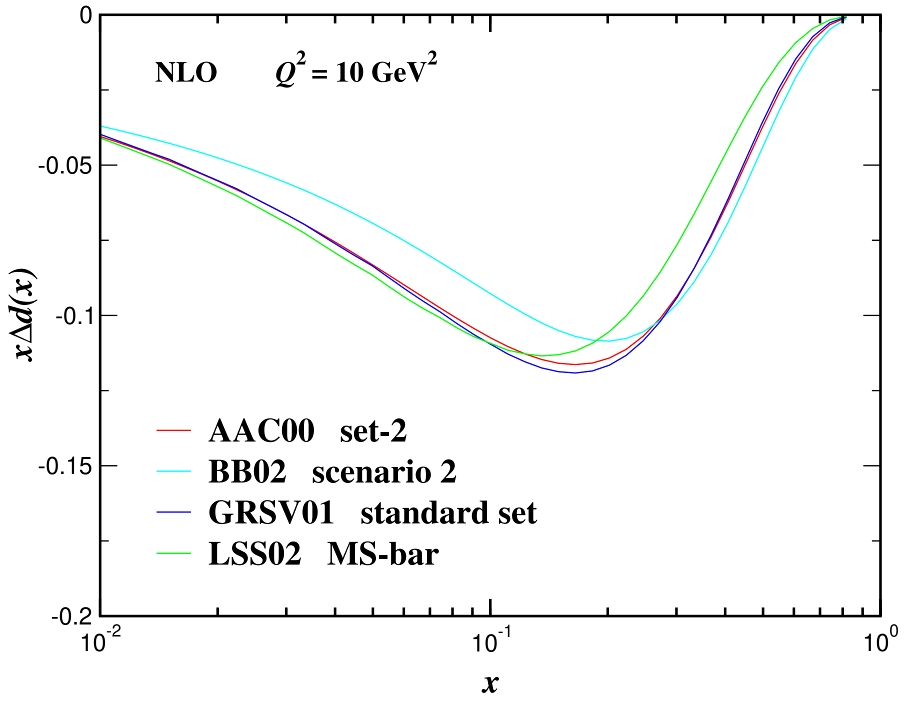
- **Peterson Function** C. Peterson *et. al* *Phys. Rev.* D27, 105 (1983).

Polarized d–quark Distribution Function

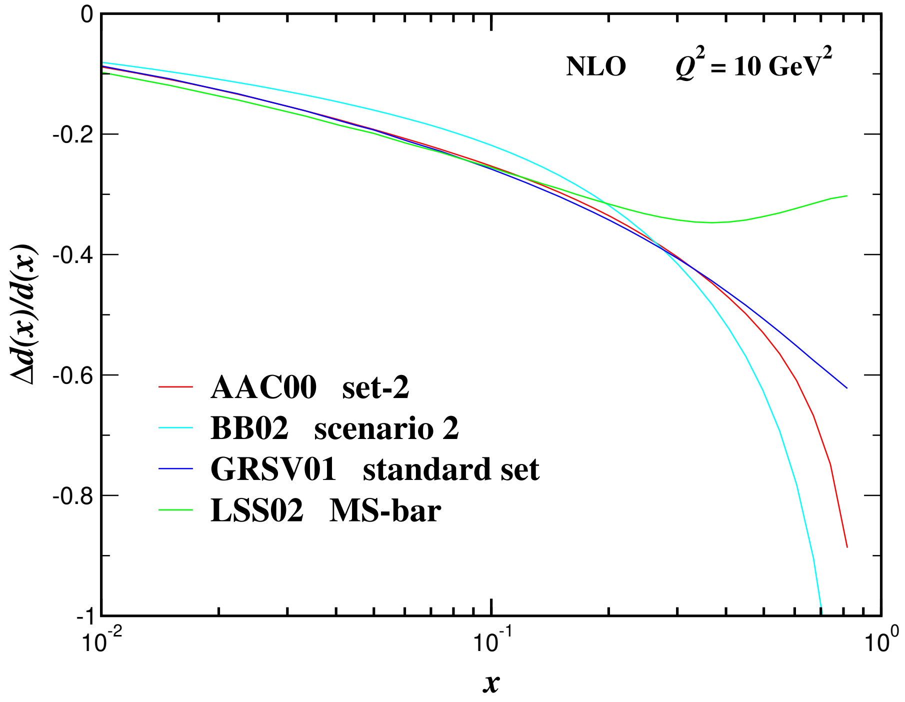
AAC00 vs. BB02 vs. GRSV01 vs. LSS02

NLO Q^2=10 GeV

$x\Delta d(x)$



$\Delta d(x)/d(x)$

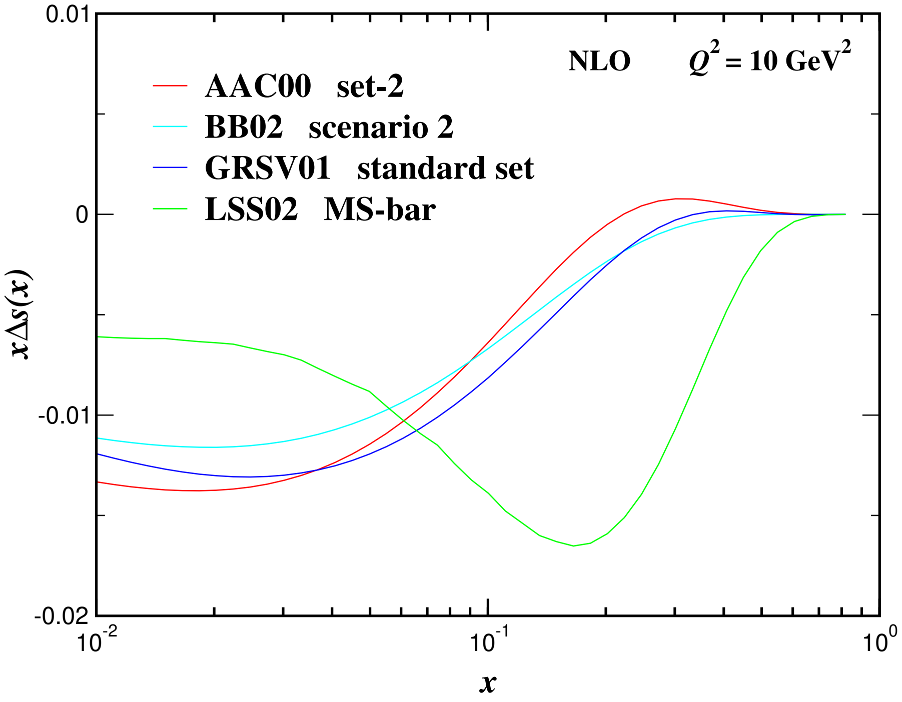


Polarized s–quark Distribution Function

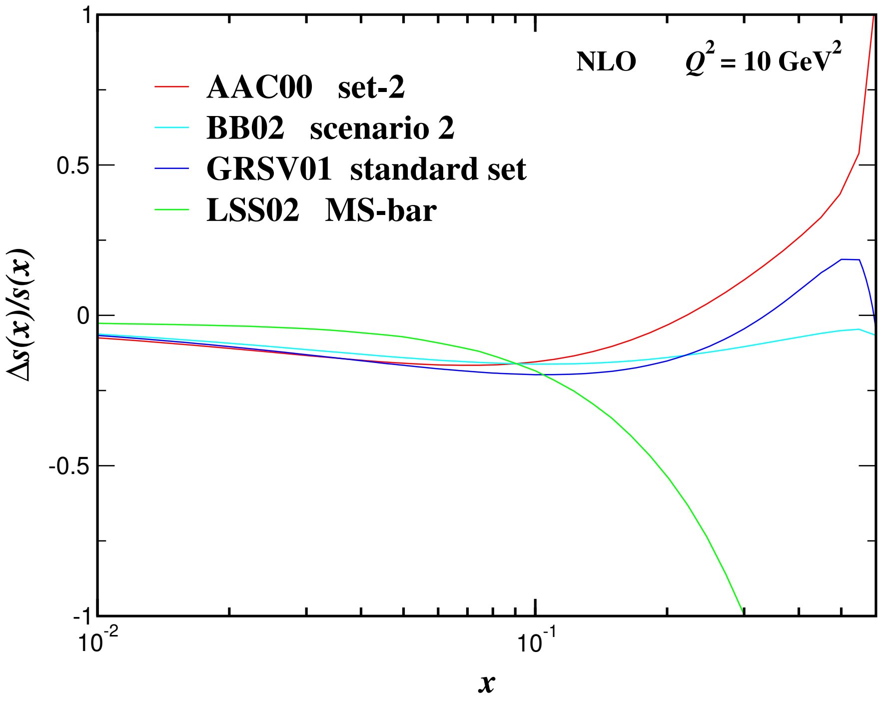
AAC00 vs. BB02 vs. GRSV01 vs. LSS02

NLO Q^2=10 GeV

$x\Delta s(x)$



$\Delta s(x)/s(x)$

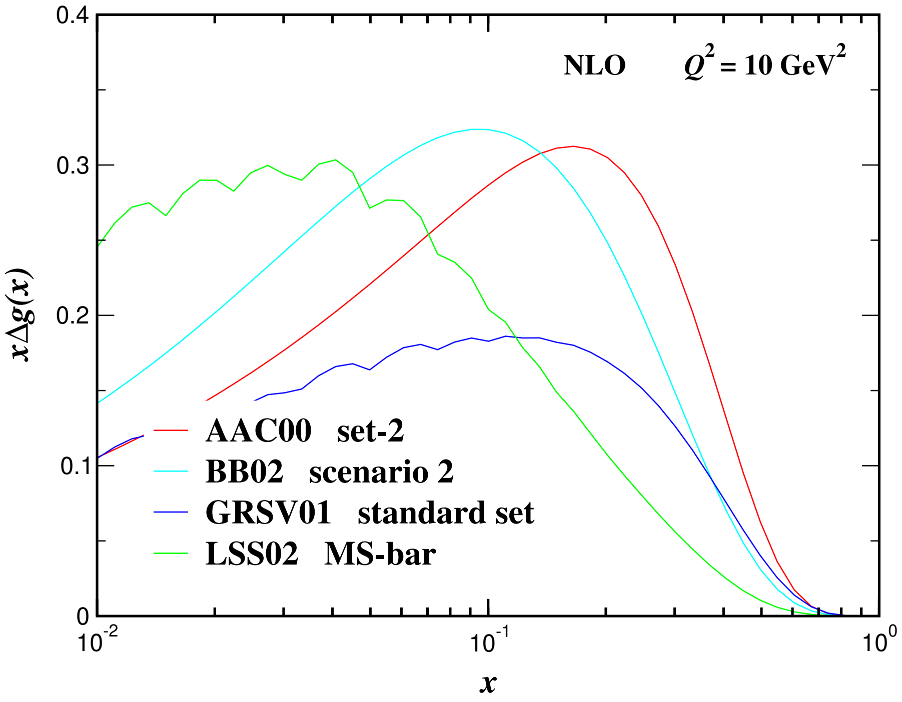


Polarized gluon Distribution Function

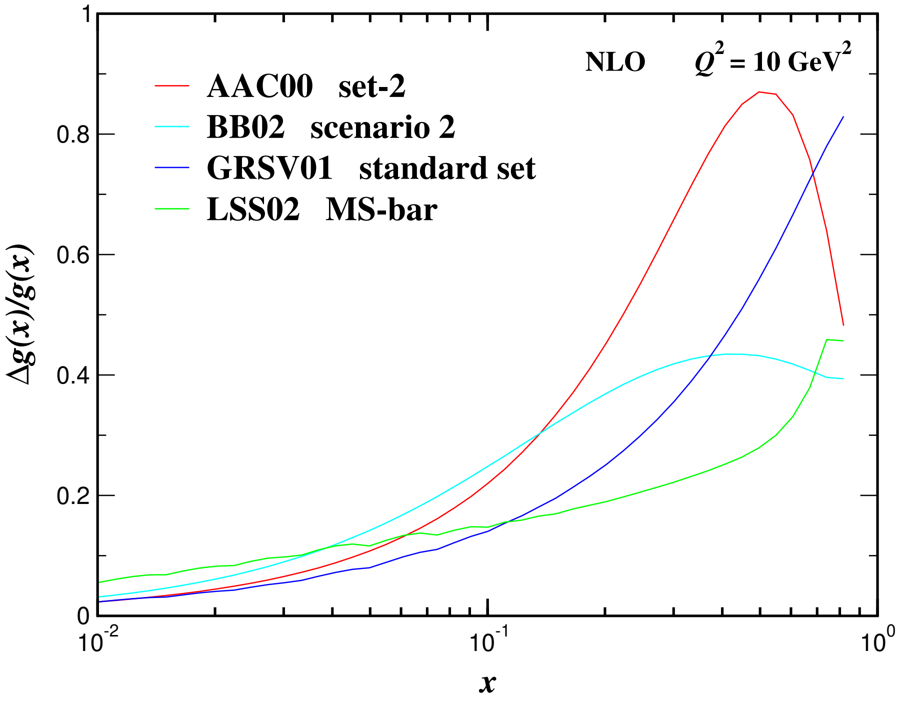
AAC00 vs. BB02 vs. GRSV01 vs. LSS02

NLO Q^2=10 GeV

$x\Delta g(x)$



$\Delta g(x)/g(x)$

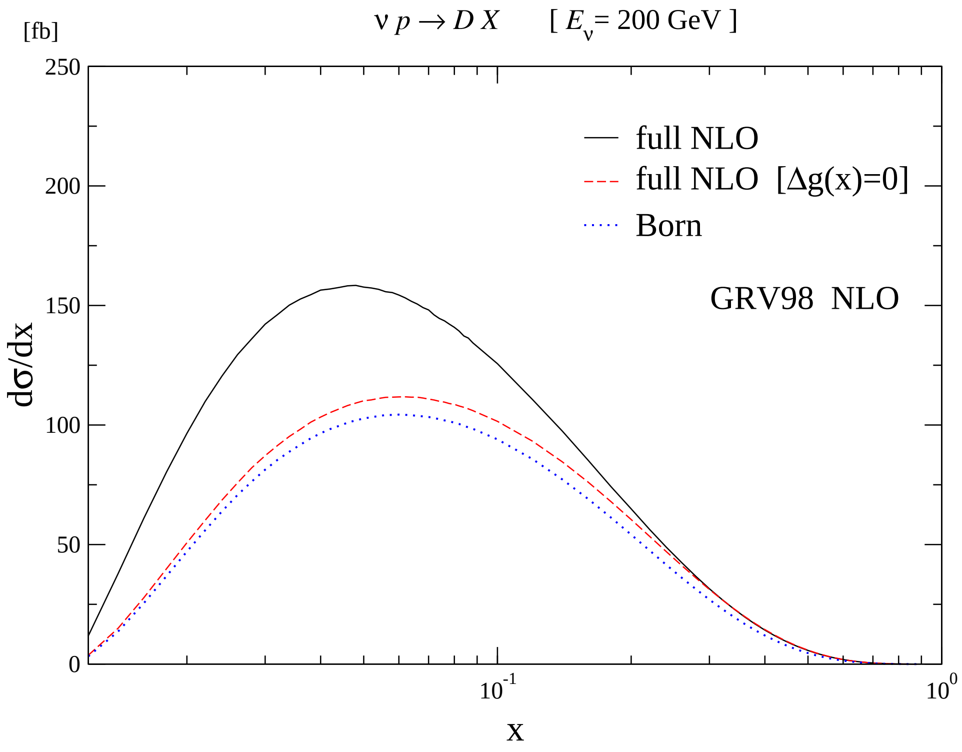


x distribution of unpolarized cross sections

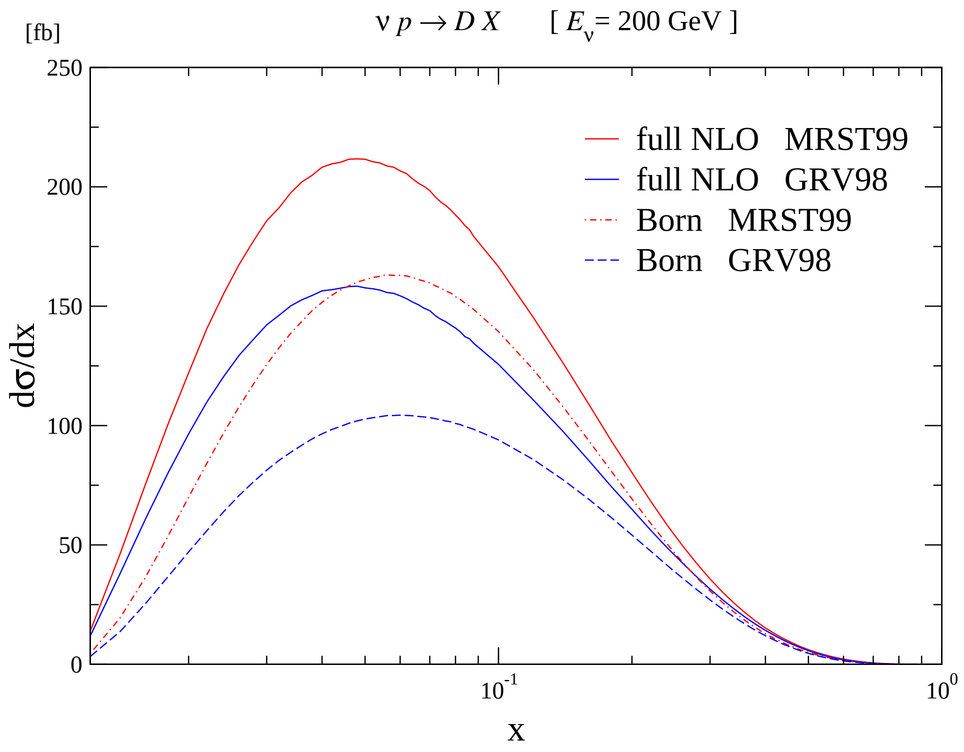
$$\boxed{\nu + \vec{p} \rightarrow l^- + D + X}$$

E_ν=200 GeV

Unpolarized cross sections



Model dependence

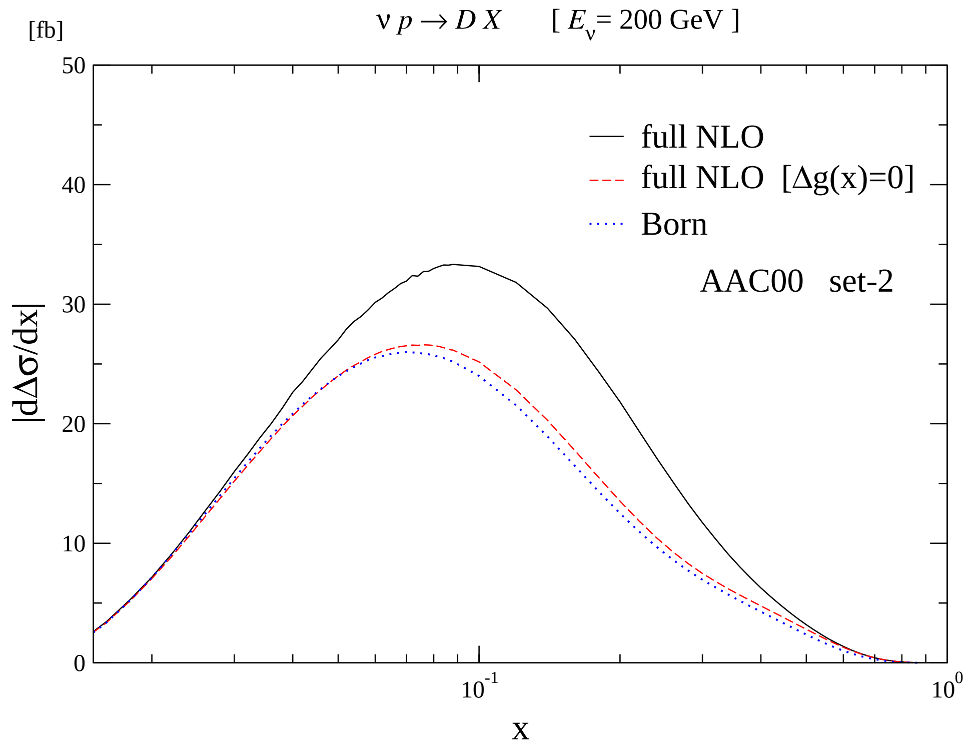


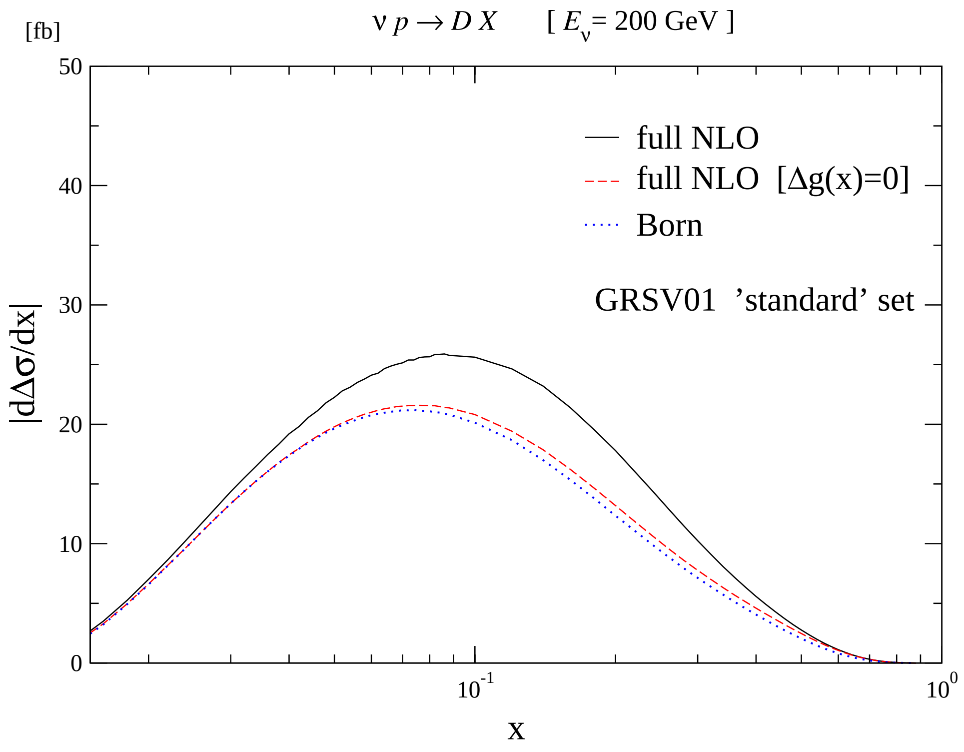
x distribution of polarized cross sections

$$\boxed{\nu + \vec{p} \to l^- + D + X}$$

E_ν=200 GeV

Polarized cross sections





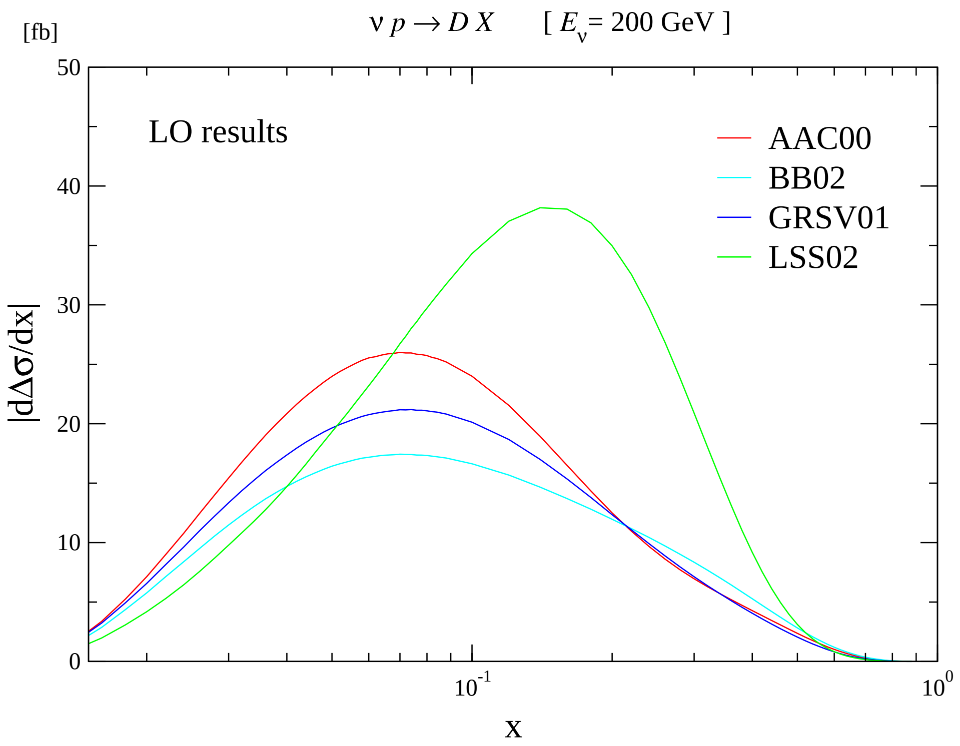
x distribution of polarized cross sections

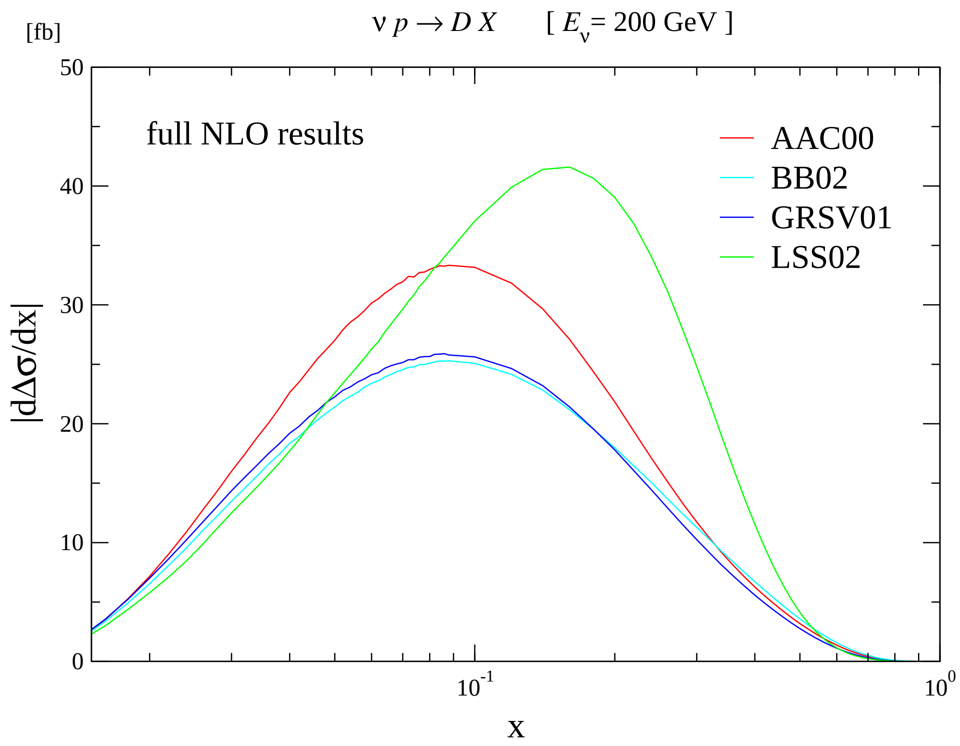
$$\boxed{\nu + \vec{p} \to l^- + D + X}$$

E_ν=200 GeV

Model dependence

LO **full NLO**





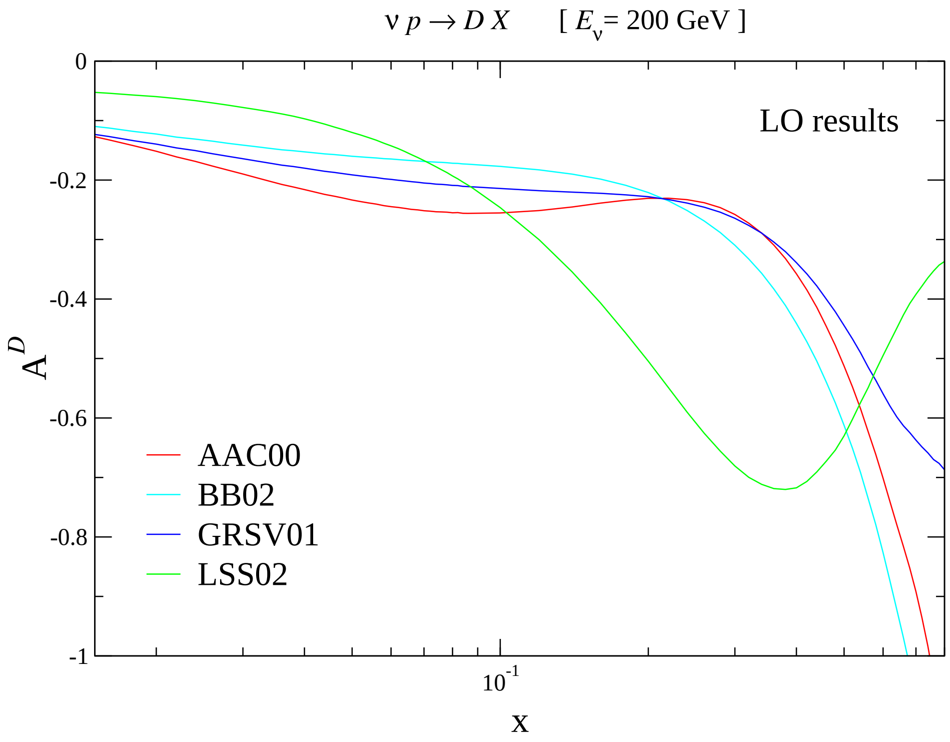
x distribution of spin asymmetry A^D

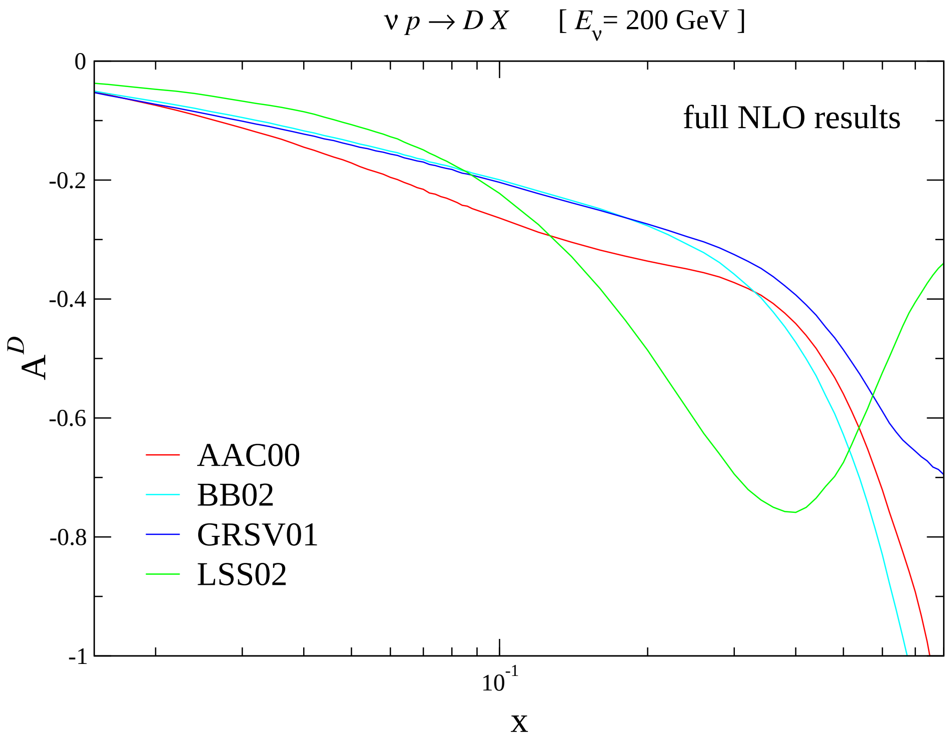
$$\boxed{\nu + \vec{p} \to l^- + D + X}$$

E_ν=200 GeV

Model dependence

LO **full NLO**



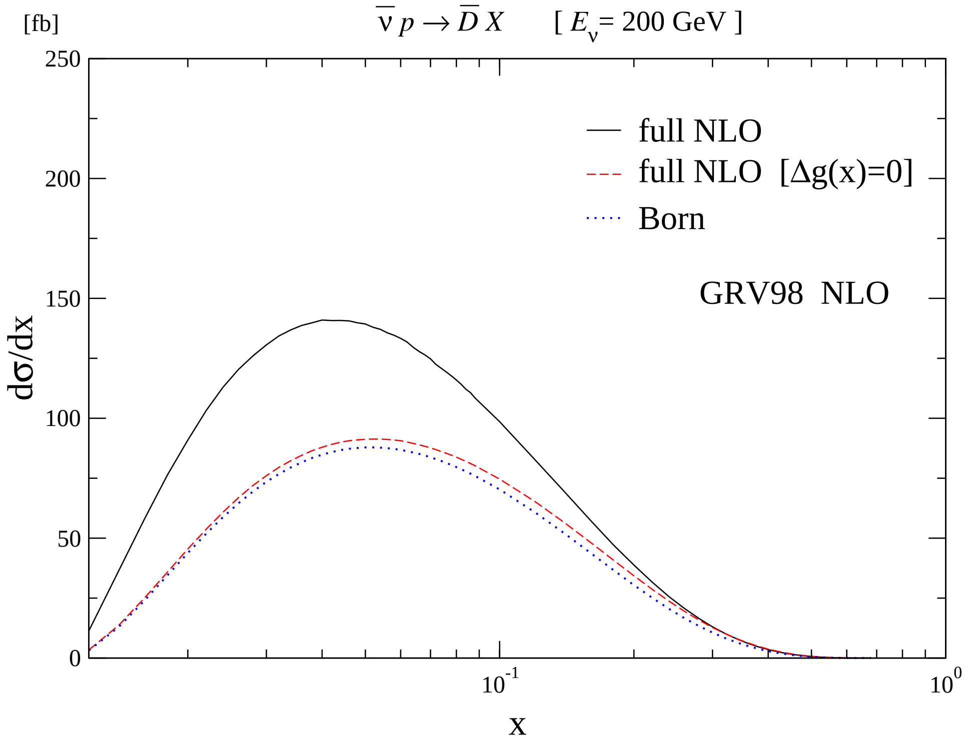


x distribution of unpolarized cross sections

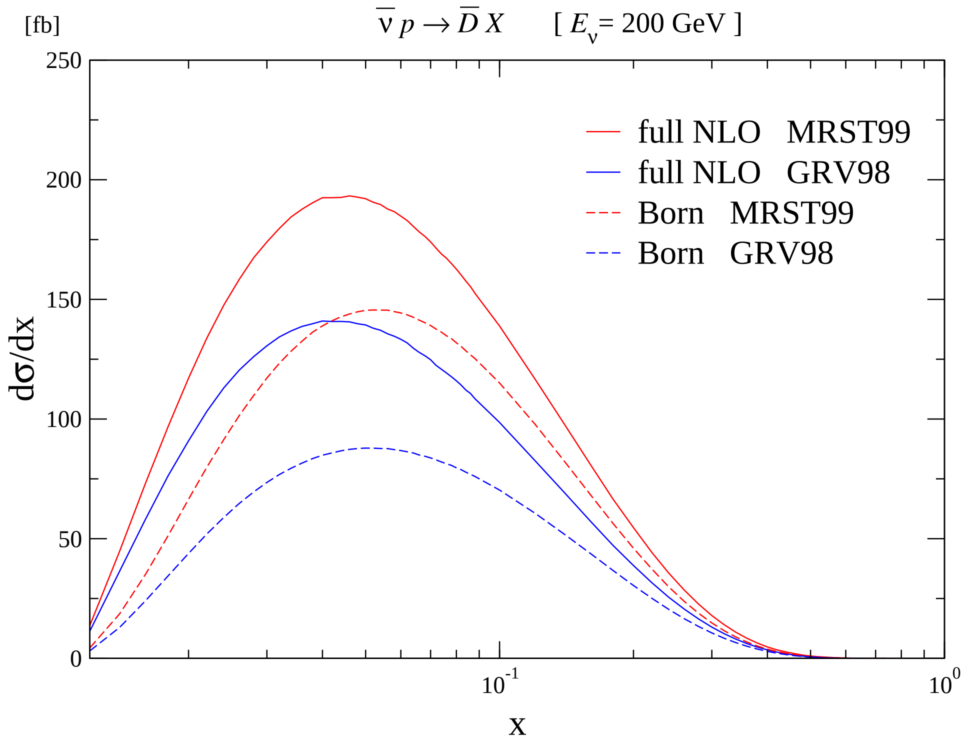
$$\boxed{\bar{\nu} + \vec{p} \to l^+ + \bar{D} + X}$$

E_ν=200 GeV

Unpolarized cross sections



Model dependence

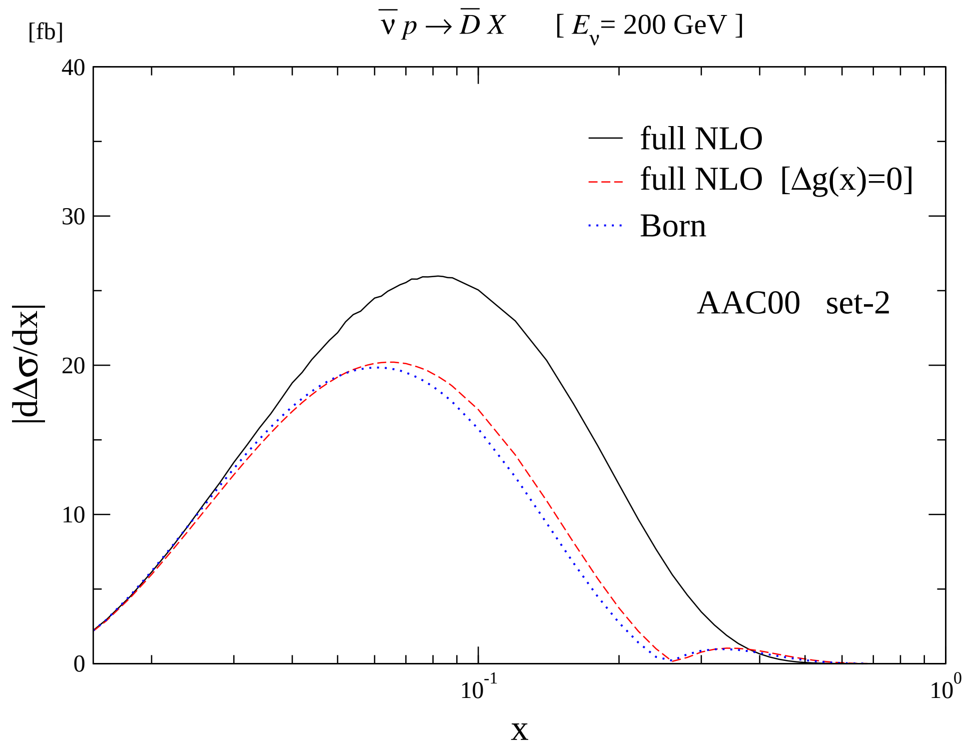


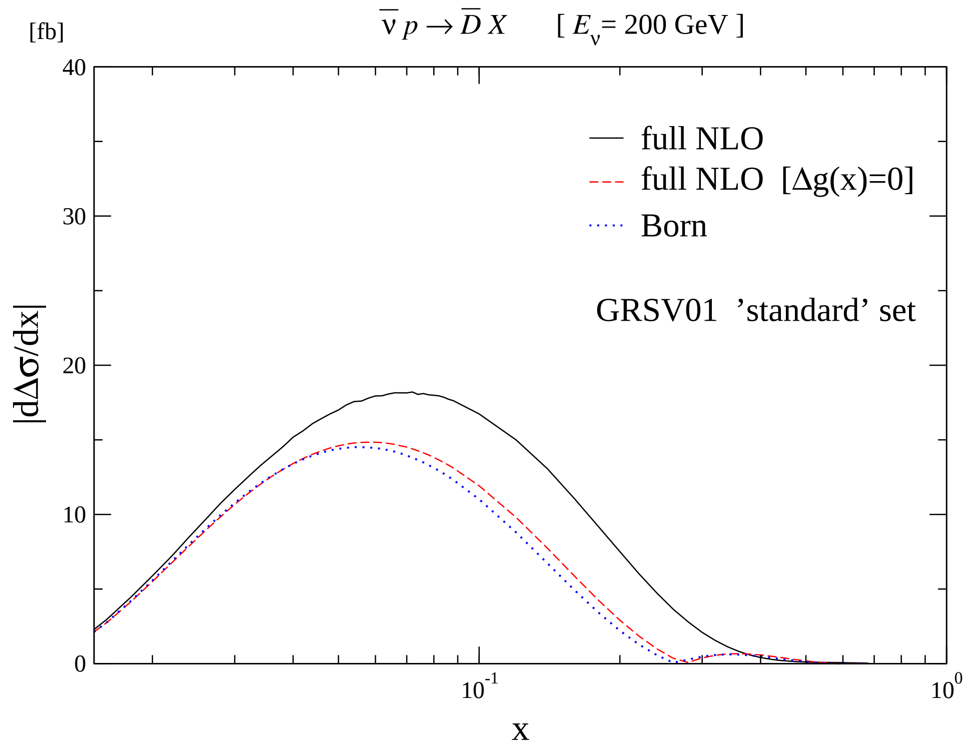
x distribution of polarized cross sections

$$\boxed{\bar{\nu} + \vec{p} \rightarrow l^{+} + \bar{D} + X}$$

E_ν=200 GeV

Polarized cross sections





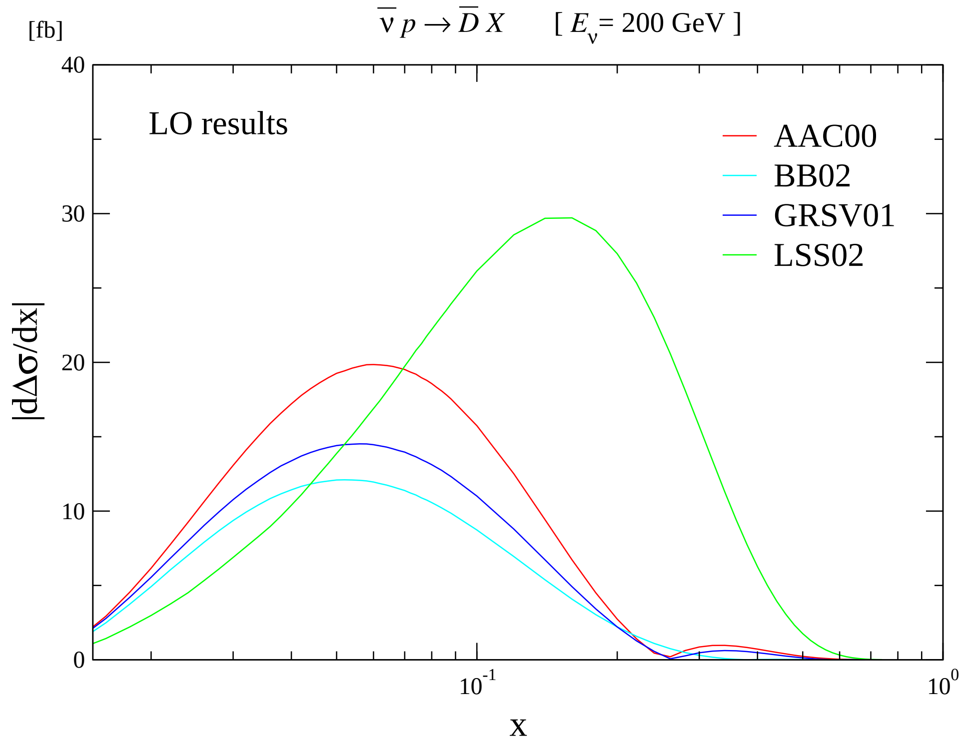
x distribution of polarized cross sections

$$\boxed{\bar{\nu} + \vec{p} \to l^+ + \bar{D} + X}$$

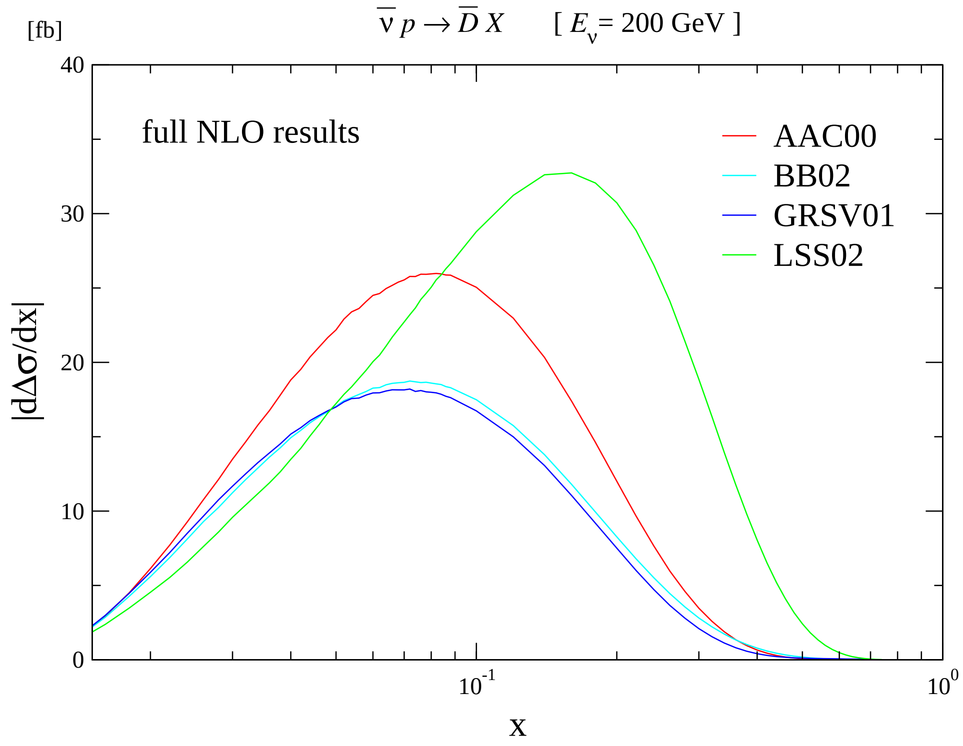
E_ν=200 GeV

Model dependence

LO



full NLO



x distribution of spin asymmetry $A^{\bar{D}}$

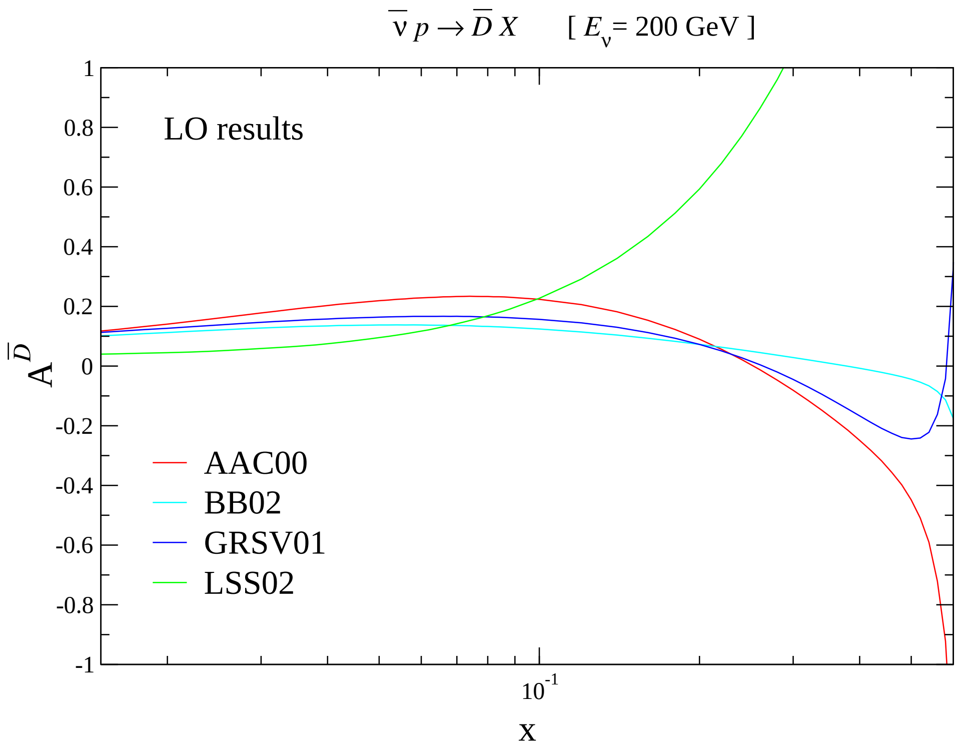
$$\boxed{\bar{\nu} + \vec{p} \to l^{+} + \bar{D} + X}$$

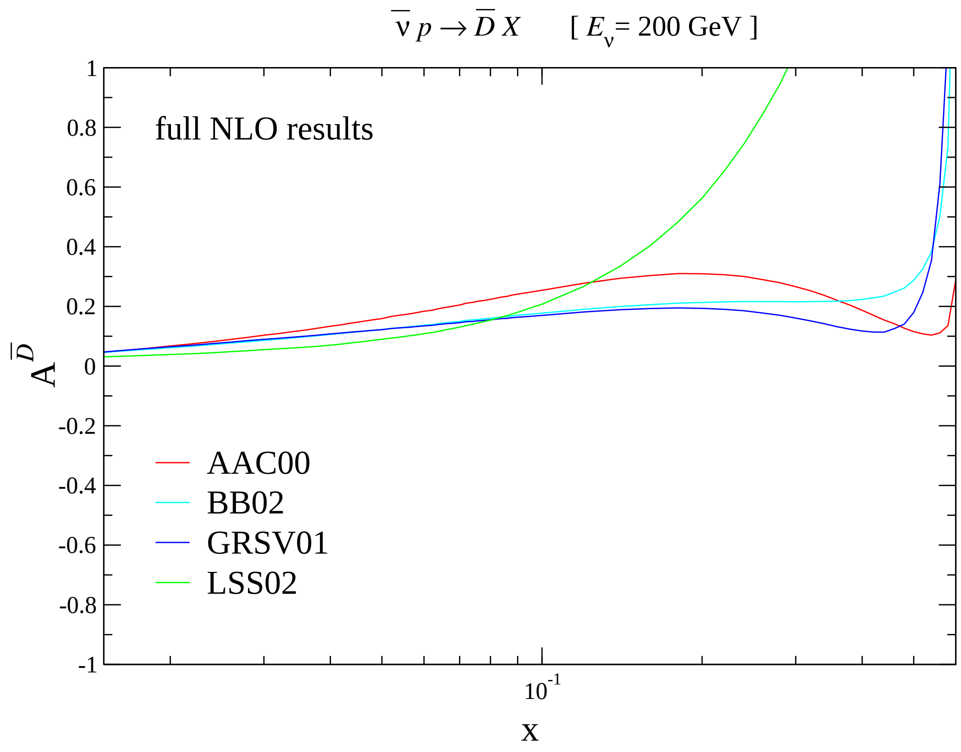
E_ν=200 GeV

Model dependence

LO

full NLO





IV. Conclusion

- $D/\bar{D}$ production in neutrino-induced CC DIS is studied including $\mathcal{O}(\alpha_s)$ corrections.

  The cross sections are dominated by LO ($W^+s \to c$) and NLO boson-gluon fusion process ($W^+g \to \bar{s}c$). Contribution from gluon radiation ($W^+s \to cg$) and virtual correction are small.

  NLO cross sections and asymmetry by GRSV01 are too similar with BB02 in smaller x regions ($x < 0.2$) (on the line!), though we can see difference in LO cross sections and asymmetry.

  While, the cross sections and asymmetry by LSS02 are quite different among of other parametrization models. This is because the sea quark distribution by LSS02 is different.

- $\bar{D}$ production is promissing to extract the sea quark density, since the valence d_v quark contribution is large in D production.

  If we can separate the contribution of Born term and the one of boson-gluon fusion process, we can clearly extract the strange sea $\Delta s(x, Q^2)$.