Spin Transfer Studies for Λ_c^+ Production at RHIC

Kazutaka Sudoh (KEK)
RHICII Meeting, BNL
8 Oct. 2005

In collaboration with **V. L. Rykov** (RIKEN/RBRC)

I. Introduction & Motivation
II. Polarized Λ_c^+ Production at RHIC

$$p + \vec{p} \rightarrow \vec{\Lambda}_c^+ + X$$

III. Numerical Results
IV. Conclusion

I. Introduction

- **Polarized Gluon Distribution: $\Delta g(x)$**
  - **A key for understanding the nucleon's spin**

    Theoretical and experimental uncertainties are large.
  - **Prompt photon, Heavy flavor production**

    observing cross section asymmetry A_{LL}
- **Polarized Fragmentation function: $\Delta D^h(z)$**
  - **Our knowledge are very poor.**

Spin transfer : A correlation between the spins of initial and final particles

Connected to above objects for hadron production in polarized proton collisions.

Spin Transfer Studies

- **Experiments**
  - **Studied only for Λ hyperon**
  - **Significantly non-zero spin transfers have been observed.**

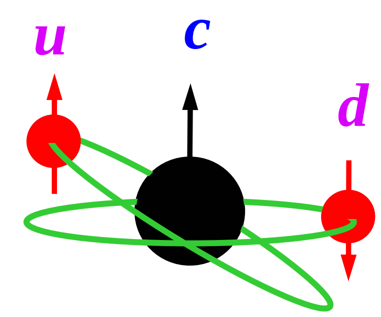
E704 Collab., PRL 78, 4003 (1997).
E665 Collab., EPJ C17, 263 (2000).
HERMES Collab., PRD 64, 112005, (2005).

- **Theory**
  - Λ^0 **D. de Florian et al., PRL81, 530 (1998); PLB439, 176 (1998).**
    Many by J. Soffer, W. Vogelsang, Bo-Q. Ma, M. Strarmann.
  - Σ^+ **Xu Qing-Hua and Liang Zuo-Tang, PRD70, 034015 (2004).**
  - Λ_c^+ **K. Ohkuma, KS, T. Morii, PLB491, 117 (2000).**

We extend this analysis to helicity-to-general spin correlations.

Why Λ_c^+ ?

- Λ_c^+ **baryon consists of heavy c quark and anti-symmetrically combined light u and d quarks.**



Polarization of Λ_c^+ baryon
~ Polarization of c quark

- **Non-relativistic Quark Model**

p	$u\uparrow u\uparrow d\downarrow$
Λ	$s\uparrow u\uparrow d\downarrow$
Λ_c	$c\uparrow u\uparrow d\downarrow$
Λ_b	$b\uparrow u\uparrow d\downarrow$

Non-relativistic treatment breaks down.

?

Non-relativistic picture might be applicable due to the heavy quark mass.

It is interesting whether this naive picture is valid.

Why Λ_c^+ ? (cont.)

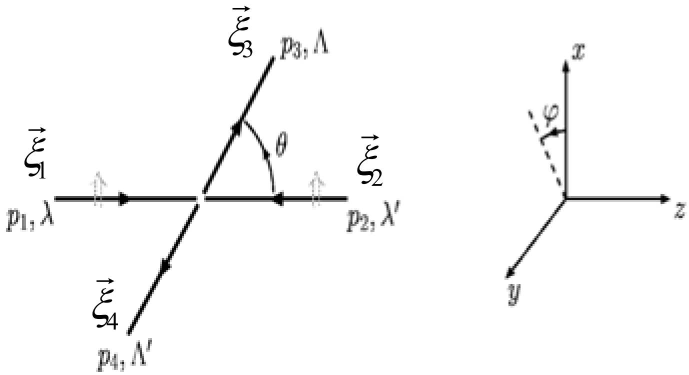
- c quark is not main constituent of proton
  - c quark is produced in hard processes mainly through gluon-gluon fusion

⇨ There is a correlation between the gluon polarization and the produced c quark polarization

- Λ_c^+ is produced from c quark fragmentation
  - We have no knowledge about polarized FF.
  - Spin flip effect is small due to heavy quark mass??
  - Ansatz: $\Delta D(z) = C(z)D(z)$, $C(z) = z^\alpha$

Measurement of Λ_c^+ polarization gives us information about $\Delta g(x)$ and/or $\Delta D(z)$ of Λ_c^+.

What can be measured at RHIC



- **Unpolarized cross-section**

$$\frac{d\sigma}{d\Omega}\left(p_1, p_2; p_3, p_4\right)$$

- **Only initial particles polarized**

$$\frac{d\sigma}{d\Omega}\left(\vec{p}_1, \vec{p}_2, \vec{\xi}_1, \vec{\xi}_2; \vec{p}_3, \vec{p}_4\right)$$

- **All particles polarized**

$$\frac{d\sigma}{d\Omega}\left(\vec{p}_1, \vec{p}_2, \vec{\xi}_1, \vec{\xi}_2; \vec{p}_3, \vec{p}_4, \vec{\xi}_3, \vec{\xi}_4\right)$$

➢ **Spin Asymmetries (examples):**

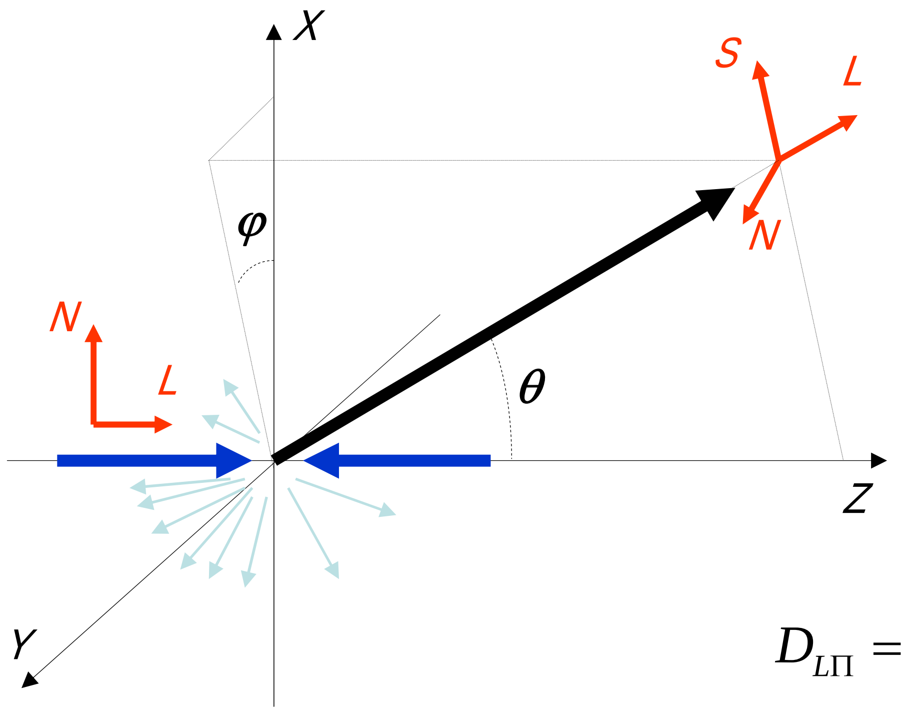
✓ Cross-section asymmetry:

$$A = \frac{\sigma(\vec{\xi}_1 \cdot \vec{\xi}_2 = 1) - \sigma(\vec{\xi}_1 \cdot \vec{\xi}_2 = -1)}{\sigma(\vec{\xi}_1 \cdot \vec{\xi}_2 = 1) + \sigma(\vec{\xi}_1 \cdot \vec{\xi}_2 = -1)}$$

✓ Spin transfer:

$$D = \frac{\sigma(\vec{\xi}_1 \cdot \vec{\xi}_3 = 1) - \sigma(\vec{\xi}_1 \cdot \vec{\xi}_3 = -1)}{\sigma(\vec{\xi}_1 \cdot \vec{\xi}_3 = 1) + \sigma(\vec{\xi}_1 \cdot \vec{\xi}_3 = -1)}$$

Notation



Spin transfer from initial L (Π=L, S, Z, X)

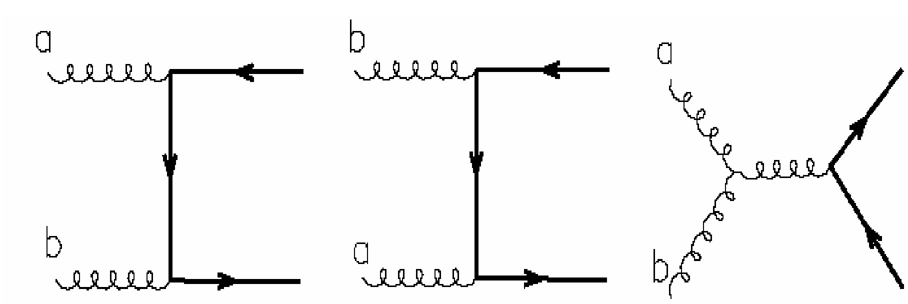
$$\frac{\sigma_{L\Pi}^{+;+} - \sigma_{L\Pi}^{+;-} + \sigma_{L\Pi}^{-;-} - \sigma_{L\Pi}^{-;+}}{\sigma_{L\Pi}^{+;+} + \sigma_{L\Pi}^{+;-} + \sigma_{L\Pi}^{-;-} + \sigma_{L\Pi}^{-;+}} = D_{L\Pi}$$

pQCD framework is available in high energy

$$D_{L\Pi} = \sum_{a,b,c} \int \hat{d}_{L\Pi}^{ab\to cX} \otimes \Delta f_a(x_a) \otimes f_b(x_b) \otimes \Delta D_c(z)$$

gluon fusion

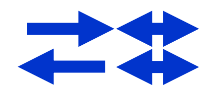
$$gg \to q\bar{q}$$



Spin Transfer $D_{L\Pi}$

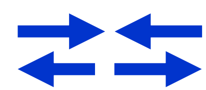
- **Spin transfer from initial L (Π = L, S, Z, X):**

$$D_{L\Pi} \equiv \frac{\sigma_{L\Pi}^{+;+} - \sigma_{L\Pi}^{+;-} + \sigma_{L\Pi}^{-;-} - \sigma_{L\Pi}^{-;+}}{\sigma_{L\Pi}^{+;+} + \sigma_{L\Pi}^{+;-} + \sigma_{L\Pi}^{-;-} + \sigma_{L\Pi}^{-;+}}$$

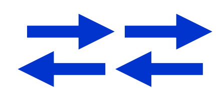


- **In addition, following observables are introduced:**

$$D_{L\Pi}^{++} \equiv \frac{\sigma_{L\Pi}^{++;+} - \sigma_{L\Pi}^{++;-} + \sigma_{L\Pi}^{--;-} - \sigma_{L\Pi}^{--;+}}{\sigma_{L\Pi}^{++;+} + \sigma_{L\Pi}^{++;-} + \sigma_{L\Pi}^{--;-} + \sigma_{L\Pi}^{--;+}}$$



$$D_{L\Pi}^{+-} \equiv \frac{\sigma_{L\Pi}^{+-;+} - \sigma_{L\Pi}^{+-;-} + \sigma_{L\Pi}^{-+;-} - \sigma_{L\Pi}^{-+;+}}{\sigma_{L\Pi}^{+-;+} + \sigma_{L\Pi}^{+-;-} + \sigma_{L\Pi}^{-+;-} + \sigma_{L\Pi}^{-+;+}}$$



  – **$D_{L\Pi}$ is a weighted average of these parameters**

$$D_{L\Pi} = \frac{D_{L\Pi}^{++}\sigma^{++} + D_{L\Pi}^{+-}\sigma^{+-}}{\sigma^{++} + \sigma^{+-}} = \frac{1}{2}\left[D_{L\Pi}^{++}(1 + A_{LL}) + D_{L\Pi}^{+-}(1 - A_{LL}) \right]$$

where $A_{LL} \equiv (\sigma^{++} - \sigma^{+-})/(\sigma^{++} + \sigma^{+-})$

Relation with A_{LL}

- **Relation between A_{LL} and spin transfer $D_{L\Pi}$**

$$A_{LL} \equiv \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} = \frac{2D_{L\Pi} - D_{L\Pi}^{++} - D_{L\Pi}^{+-}}{D_{L\Pi}^{++} - D_{L\Pi}^{+-}}$$

  - **Free from systematic errors due to relative luminosity monitoring**

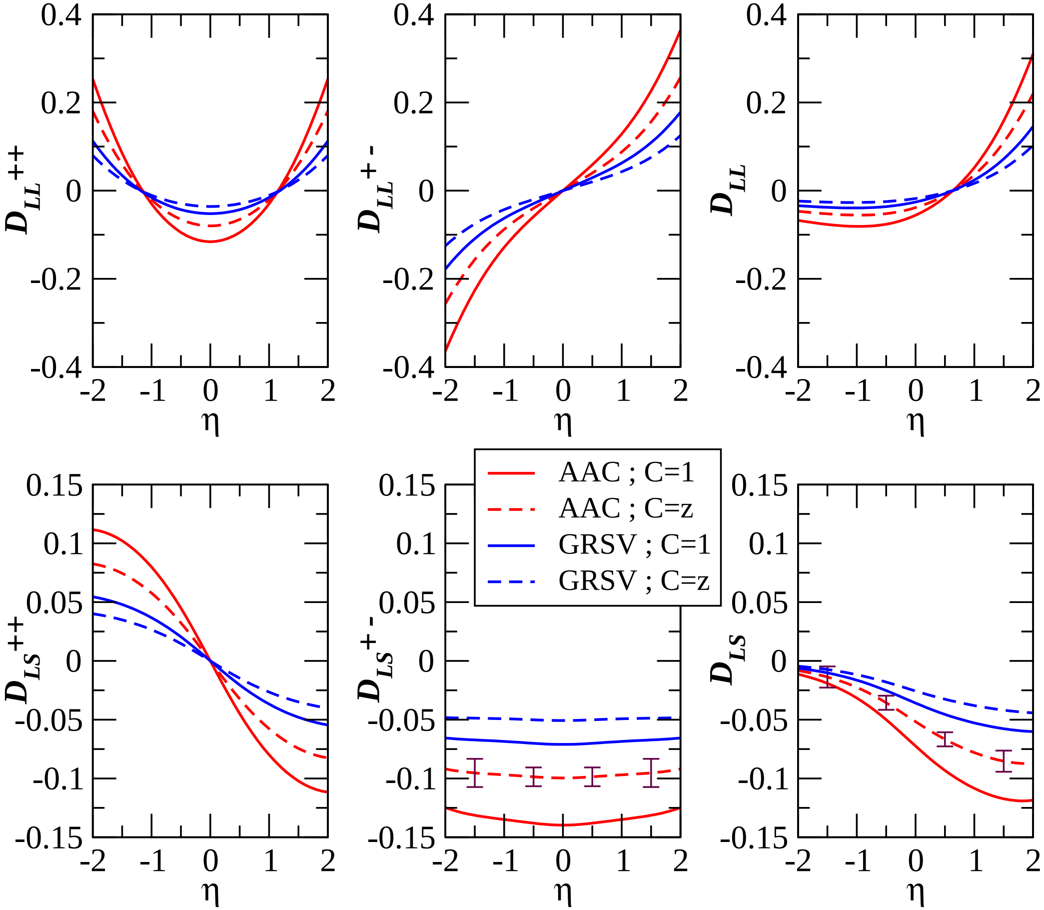
- **Statistical Error**

$$\delta A_{LL} \approx \frac{2\sqrt{6}}{\alpha P \left| D_{L\Pi} \right| \sqrt{N}}$$

α **: hyperon decay asymmetry parameter**
P **: beam polarization**
N **: combined statistics in 3 measurements**

  - **This error is larger than that of "direct" A_{LL} measurement.**
  - **If the systematic due to relative luminosity monitoring rather than statistics is a key issue, these measurements could be an option.**

LO spin transfer in $p\uparrow + p\uparrow \rightarrow \Lambda_c^+\uparrow + X$ at $\sqrt{s}$=200 GeV



Polarized PDFs: $\Delta G(x, Q^2)$

AAC: *Y. Goto, et al., PR* ***D62*** *(2000) 034017*

GRSV: *M. Glück, et al., PR.* ***D63*** *(2001) 094005*

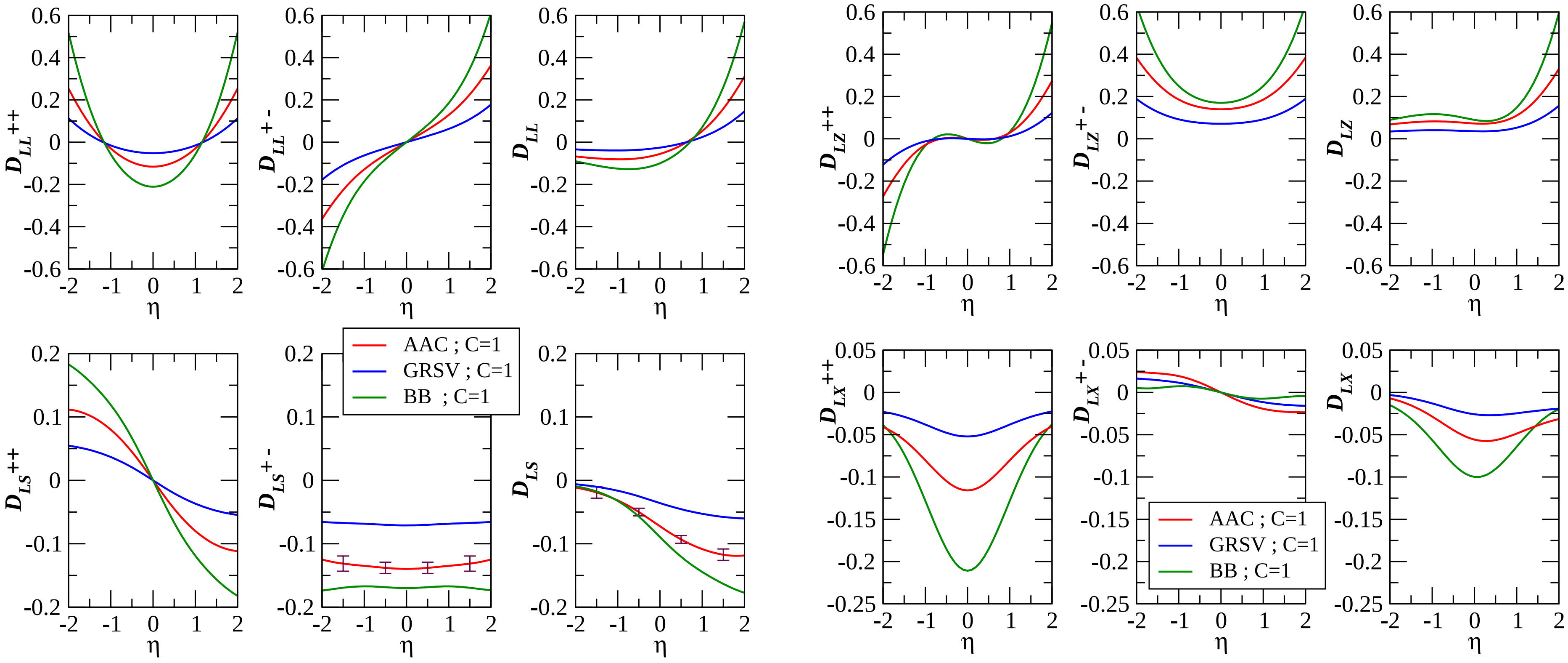
Polarized fragmentation function:

$$\Delta D = C(z) \cdot D(z)$$

D(z) – unpolarized fragmentation func.

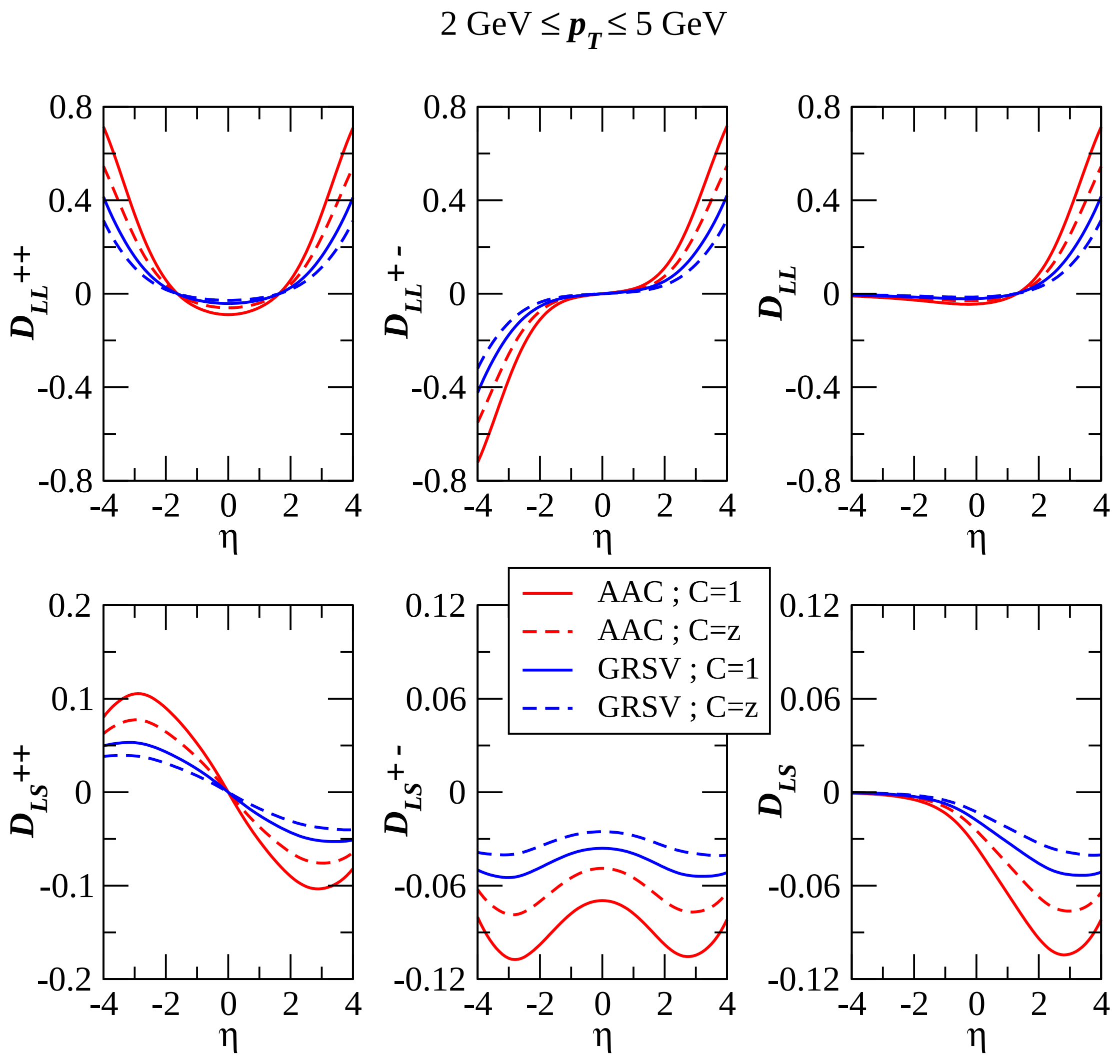
- Only the dominant $gg \rightarrow c\bar{c}$
- $2 < P_T < 5$ GeV/c
- L = 320 pb^{-1}
- $\Lambda_c^+ \rightarrow \Lambda^0 \pi^+ \rightarrow p\pi^-\pi^+$
  Br = 0.9%, α = -0.98
  ε = 10%

Model Dependence at $\sqrt{s}$=200 GeV



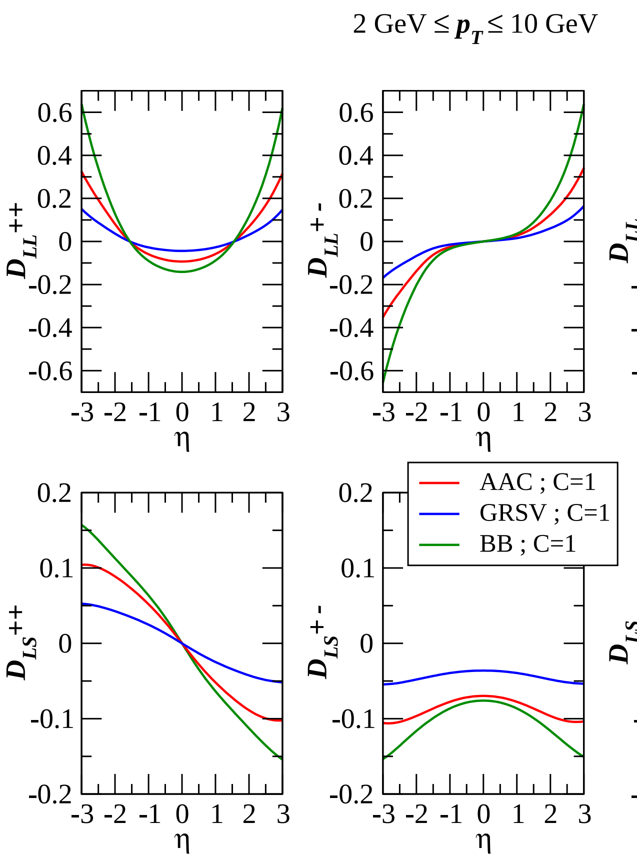
$\Delta g(x)$ **AAC**: **Y. Goto, *et al., Phys. Rev.* D62, 034017 (2000).**
GRSV: **M. Gl"uck, *et al., Phys. Rev.* D63, 094005 (2001).**
BB: **J. Bl"umlein, *et al., Nucl. Phys.* B636, 225 (2002).**

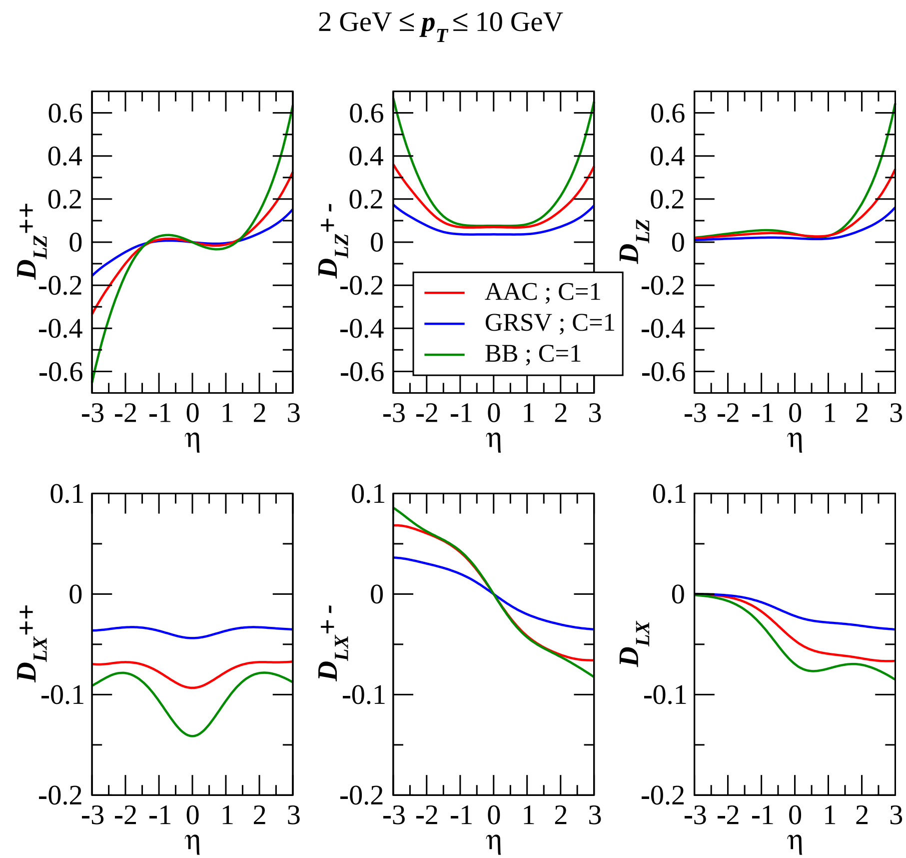
LO spin transfer in $p\uparrow + p\uparrow \to \Lambda_c^+\uparrow + X$ at $\sqrt{s}$=500 GeV



Behavior is similar to cases at $\sqrt{s}$=200 GeV.

Model Dependence at $\sqrt{s}$=500 GeV





$\Delta g(x)$ **AAC**: **Y. Goto, *et al.*, *Phys. Rev.* D62, 034017 (2000).**
GRSV: **M. Gl"uck, *et al.*, *Phys. Rev.* D63, 094005 (2001).**
BB: **J. Bl"umlein, *et al.*, *Nucl. Phys.* B636, 225 (2002).**

VII. Summary

- **Spin transfers for $pp \rightarrow \Lambda_c^+ + X$ at RHIC are studied.**
  - **Not only helicity correlation D_{LL}, but also D_{LS}, D_{LZ}, D_{LX}.**
  - **Relation with asymmetry A_{LL} is derived.**

- **Significantly non-zero spin transfers are predicted.**
  - **In the central region at $\sqrt{s}$=200 GeV, the effect is expected ~5-15%, while RHIC statistical errors ~1%.**
  - **The larger spin transfers, up to 20-50%, are expected at η ~2 and beyond.**

- **Information about $\Delta g(x)$ and/or $\Delta D(z)$ can be alternatively extracted.**
  - **Spin transfers strongly depend on $\Delta g(x)$ and $\Delta D(z)$.**
  - **Spin structure of Λ_c^+ is also interesting.**