The15th International Spin Physics Symposium

Charmed Hadron Production in Polarized *pp* Collisions

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I. Introduction

Proton Spin Puzzle

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta g + < L >_{q+g}$$

$\Delta\Sigma$:Quark spin Δg :Gluon Spin

$< L >_{q+g}$: Orbital angular momentum of Quarks and Gluons

Experimental results : $\Delta\Sigma \sim 0.3$

Naive quark model does not work!

Need more information about polarized partons in the proton!!

However!

The knowledge of the polarized gluon in the proton is still poor!

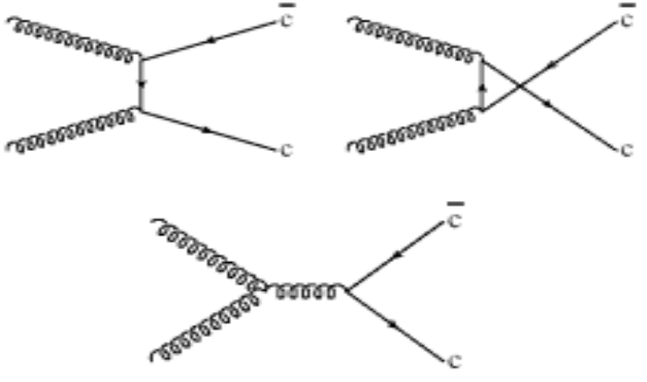
To extract the information about the polarized gluons, we propose such two processes:

$$\vec{P} + P \longrightarrow \vec{\Lambda}_c^+ + X,$$
$$\vec{P} + P \longrightarrow \vec{D}^* + X.$$

Why Charmed Hadron Process?

★ *c* quarks are not main constituents of the proton.

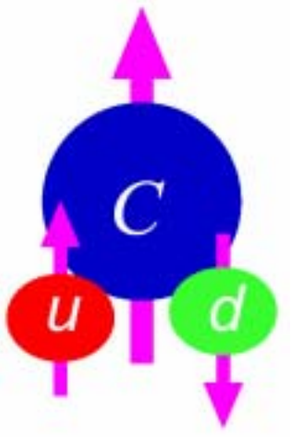
★ *c* quark which is component of Charmed hadron is mainly produced via gluon-gluon fusion.



There is relation between the gluon spin and produced *c* quark spin.

Especially

Λ_c^+ is interesting !



Because!

★ Λ_c^+ baryon is composed of heavy *c* quark and antisymmetrically combined light *u* and *d* quarks.

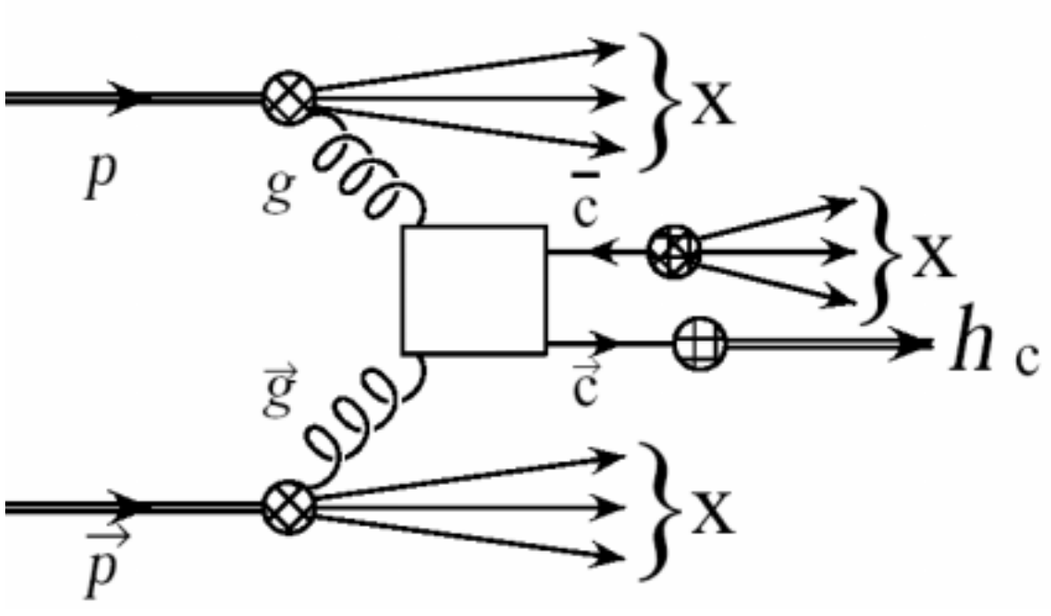
Spin of Λ_c^+ baryon Spin of *c* quark

- Gluon in the initial proton is related produced *c* quark.

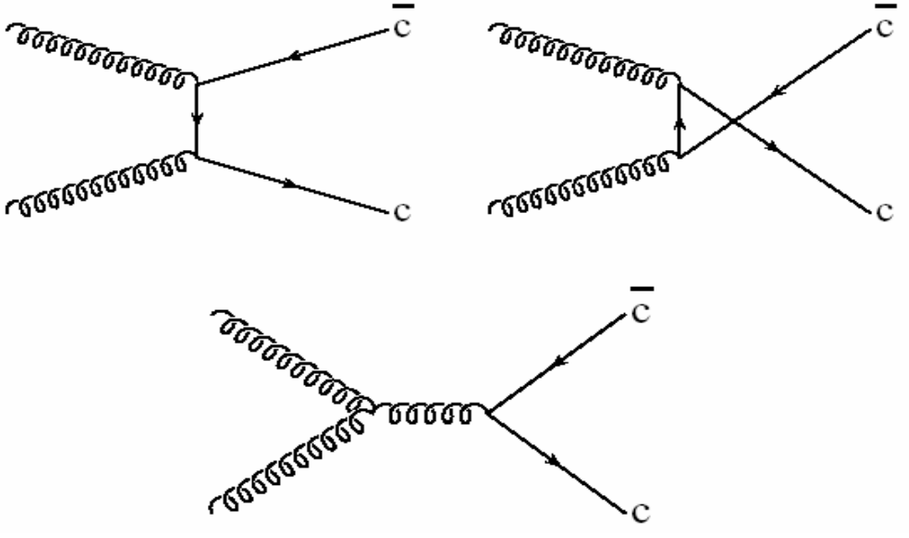
Observation of the spin of the produced Λ_c^+ give us information about the polarized gluon in the proton

II. Charmed Hadron production in *pp* reaction

$$\vec{p} + p \rightarrow \vec{h}_c + X$$



Subprocesses



This process can be measured by RHIC experiment!!

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

p_T distribution

1. The spin correlation differential cross section

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

p_T : Transverse momentum of Λ_c^+

$d\sigma(+,-)/dp_T$: Spin dependent differential cross section

- $+$ → The positive helicity of the target proton
- $-$ → The negative helicity of the produced Λ_c^+

2. The Spin correlation asymmetry

$$A_{LL} \equiv \frac{d\sigma(++) - d\sigma(+-) + d\sigma(--) - d\sigma(-+)/dp_T}{d\sigma(++) + d\sigma(+-) + d\sigma(--) + d\sigma(-+)/dp_T} = \frac{d\Delta\sigma/dp_T}{d\sigma/dp_T}$$

η distribution

1. The spin correlation differential cross section

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

η : Pseude-rapidity of Λ_c^+

2. The Spin correlation asymmetry

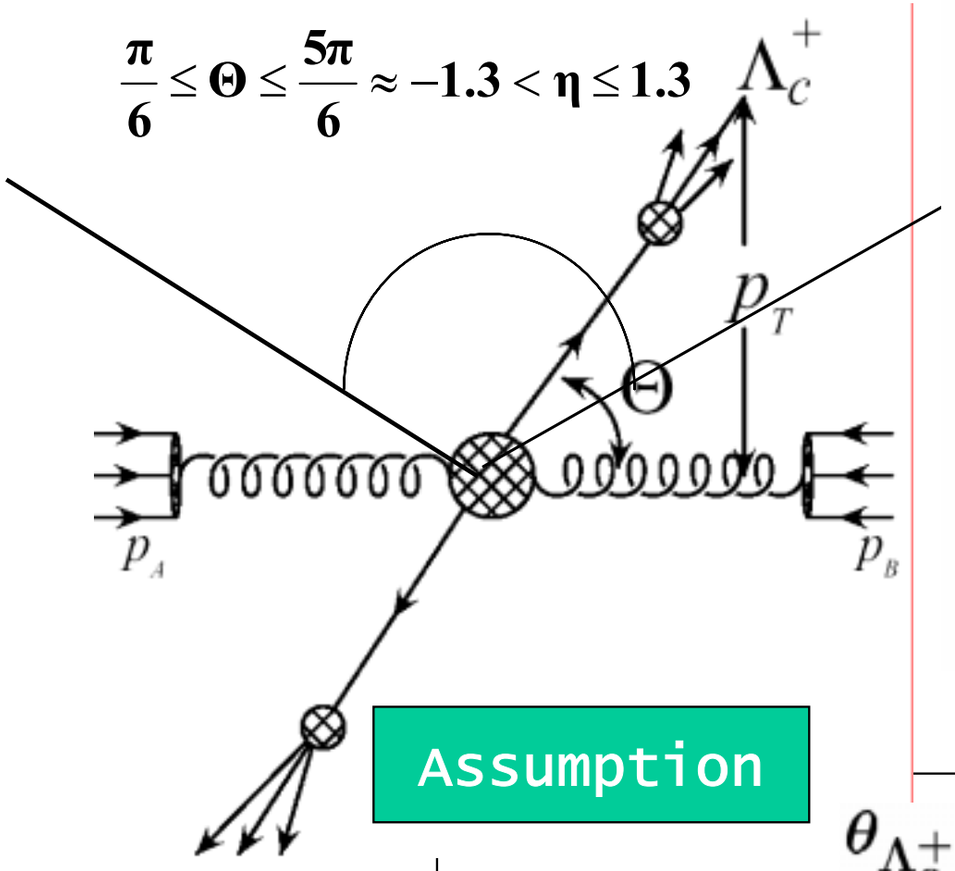
$$A_{LL} \equiv \frac{d\sigma(++) - d\sigma(+-) + d\sigma(--) - d\sigma(-+)/d\eta}{d\sigma(++) + d\sigma(+-) + d\sigma(--) + d\sigma(-+)/d\eta} = \frac{d\Delta\sigma/d\eta}{d\sigma/d\eta}$$

We will investigate

which distribution is the more optimal one ?

Proton-proton center of mass frame

$$\frac{\pi}{6} \le \Theta \le \frac{5\pi}{6} \approx -1.3 < \eta \le 1.3$$



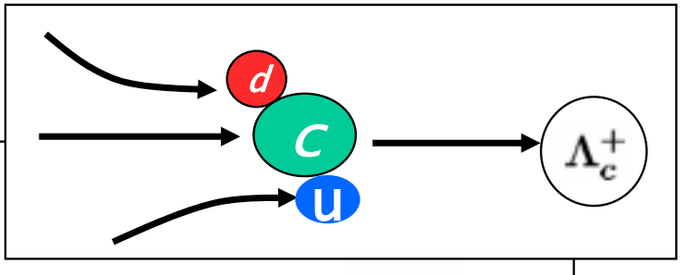
$$p_{A/B} = \frac{\sqrt{s}}{2}(1, \pm\beta, \vec{0}) \ , \ \beta \equiv \sqrt{1 - \frac{4m_p^2}{s}}$$

$$p_{\Lambda_c} = (E_{\Lambda_c}, p_L, p_T)$$
$$= \left(\sqrt{m_{\Lambda_c}^2 + (p_T \cosh\eta)^2}, p_T \sinh\eta, p_T\right)$$

$$p_{a,b} = x_{a,b} p_{A,B} \quad , \quad p_c = \frac{p_{\Lambda_c}}{z}$$
$$\eta = -\ln\tan\left(\frac{\Theta}{2}\right)$$

Assumption

$$\theta_{\Lambda_c^+} \simeq \theta_c \equiv \Theta$$



$\theta_{\Lambda_c^+}$:Scattering angle of the produced Λ_c^+

θ_c :Scattering angle of the c quark in subprocess.

The spin correlation differential cross section

p_T distribution

$$\frac{d\Delta\sigma}{dp_T} \equiv \int_{\eta^{\min}}^{\eta^{\max}} \int_{x_a^{\min}}^{1} \int_{x_b^{\min}}^{1} G_{g_a/p_A}(x_a, Q^2) \Delta G_{\vec{g}_b/\vec{p}_B}(x_b, Q^2) \times \frac{d\Delta\hat{\sigma}}{d\hat{t}} \Delta \mathrm{D}_{\vec{\Lambda}_c^+/\vec{c}}(z) \mathcal{J}\, d\Theta dx_a dx_b$$

$G_{g_a/p_A}(x_a, Q^2)$:Unpolarized gluon distribution function

$\Delta G_{\vec{g}_b/\vec{p}_B}(x_b, Q^2)$:Polarized gluon distribution function

$d\Delta\hat{\sigma}/d\hat{t}$:Spin correlation differential cross section for subprocess

$\Delta \mathrm{D}_{\vec{\Lambda}_c^+/\vec{c}}(z)$:Spin dependent fragmentation function

$\mathcal{J}$:Jacbian which transform the variables z and $\hat{t}$ into η and p_T

III. Numerical Calculation

Gluon Distribution Function of the Proton

★ Unpolarized Parton Distribution : $G_{g_a/p_A}(x_a, Q^2)$

- GRV 98
  M. GluÜck, *et al.* Euro. Phys. J. C5(2000)461

★ Polarized Parton Distribution : $\Delta G_{\vec{g}_b/\vec{p}_B}(x_b, Q^2)$

- AAC
  Y. Goto, *et al.* Phys.Rev.D62(2000)034017

- GRSV 01
  M. GluÜck *et al.* Phys.Rev.D63(2001)094005

These parameterization models are widely used.

Fragmentations Function

★ Unpolarized fragmentation : $D_{\Lambda_c^+/c}(z)$

● Peterson Fragmentation Function

C. Peterson, *et al.* Phys. Rev. D27(1983)461

★ Unpolarized fragmentation : $\Delta D_{\vec{\Lambda}_c^+/\vec{c}}(z)$

Unfortunately, We have at present no data about $\Delta D_{\vec{\Lambda}_c^+/\vec{c}}(z)$

The analogy with the study of Λ polarization.

$$\Delta D_{\vec{\Lambda}_c^+/\vec{c}}(z) = C_{\Lambda_c^+/c}(z) D_{\Lambda_c^+/c}(z)$$

$C_{\Lambda_c^+/c}(z)$: scale-independent spin transfer coefficient

- Naïve non-rela. Quark model $C_{\Lambda_c^+/c}(z) = 1$
- Jet fragmentation model $C_{\Lambda_c^+/c}(z) = z$

A. Bartl et al. Z. Phys. C6(1980)335

Statistical Sensitivity for A_{LL}

$$\delta A_{LL} \sim \frac{1}{\mathrm{p}} \frac{1}{\sqrt{br_c \, \epsilon \, \mathcal{L} \, T \, \sigma}}$$

P : beam polarization = 70 %

Br_c : Branching ratio $Br(\Lambda_c^+ \to pK^-\pi^+) \approx 5\%$

E : The detecting efficiency = 10 %

L : luminosity

L = 8 X 1031 cm-2 sec-1 for $\sqrt{s} = 200\mathrm{GeV}$

L = 2 X 1032 cm-2 sec-1 for $\sqrt{s} = 500\mathrm{GeV}$

T : running time = 100-day

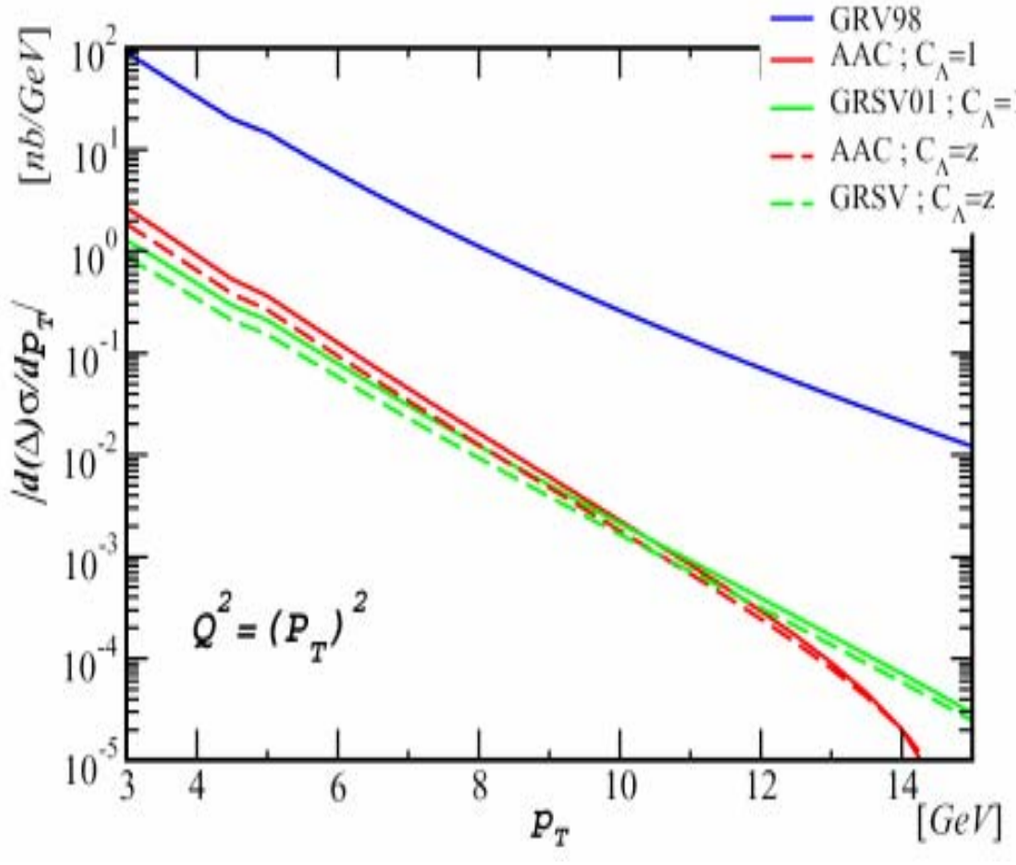
σ : unpolarized cross section integrated suitable p_T or η region.

$$\Delta p_T = 1\mathrm{GeV} \quad \Delta\eta = 0.1$$

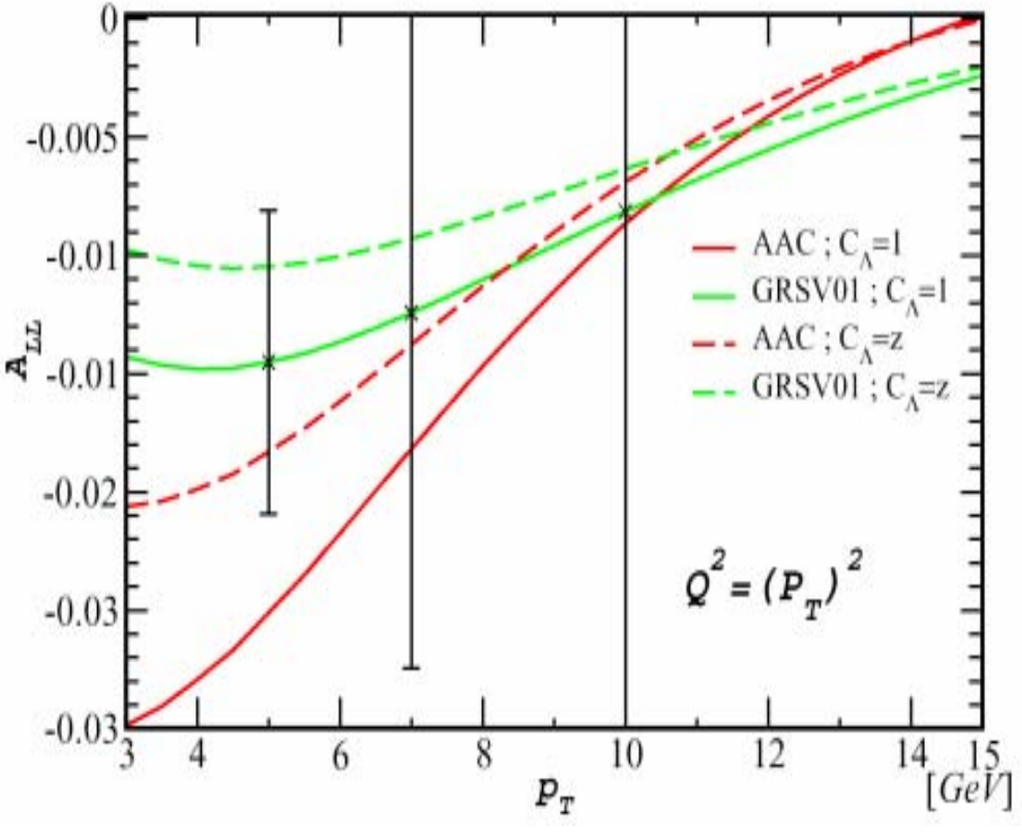
p_T distribution of $\frac{d(\Delta)\sigma}{dp_T}$ and A_{LL} at $\sqrt{s} = 200GeV$

$-1.3 \leq \eta \leq 1.3$

$\frac{d(\Delta)\sigma}{dp_T}$



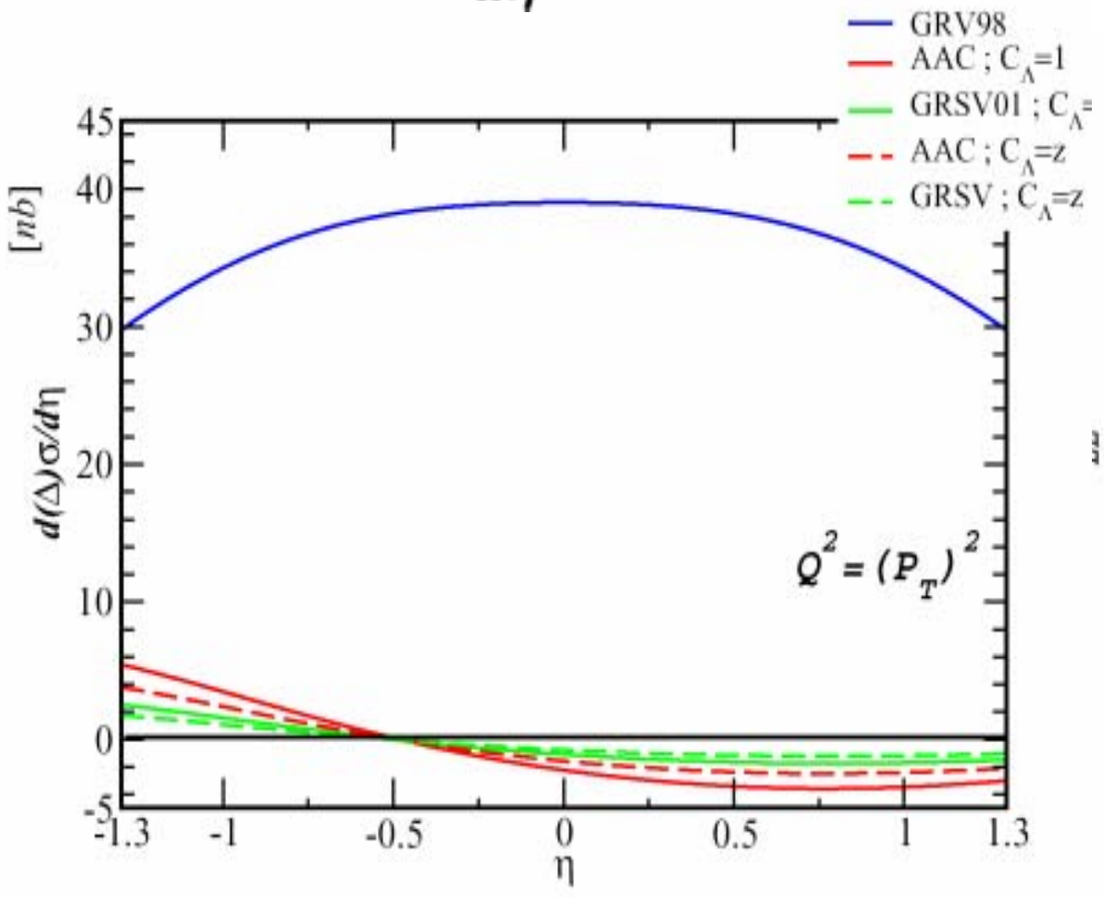
A_{LL}



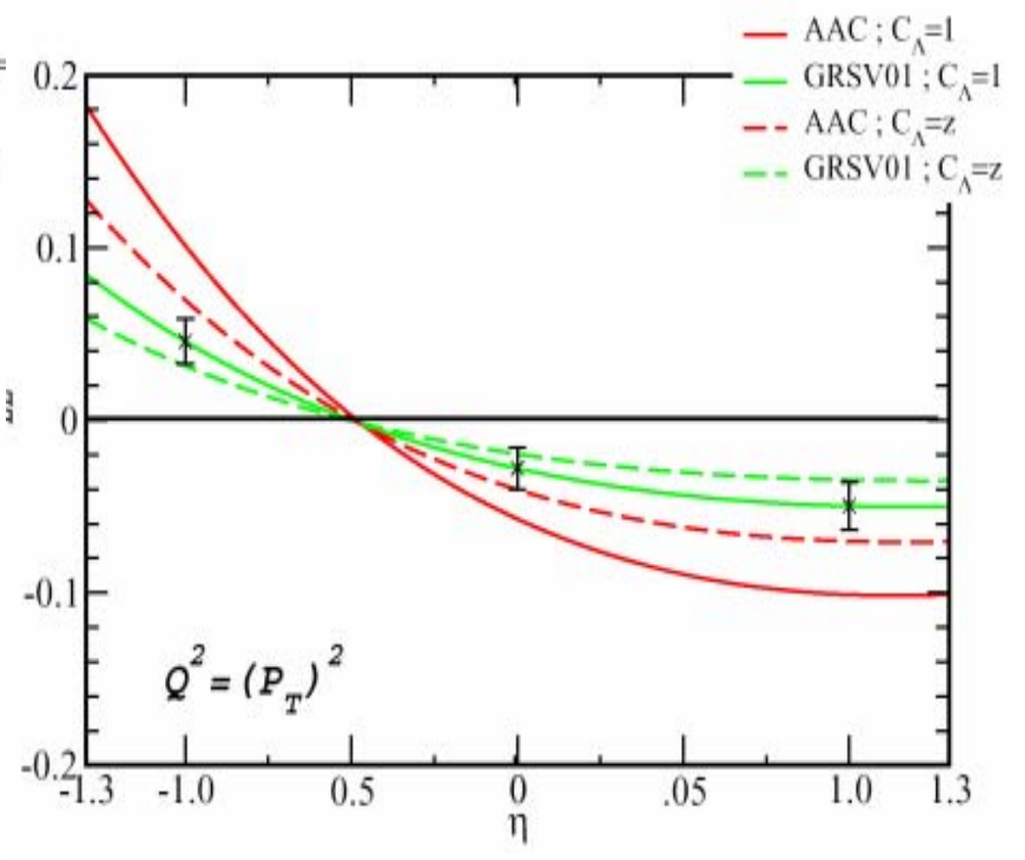
η distribution of $\frac{d(\Delta)\sigma}{d\eta}$ and A_{LL} at $\sqrt{s} = 200GeV$

$$3 \leq p_T \leq 15$$

$\frac{d(\Delta)\sigma}{d\eta}$



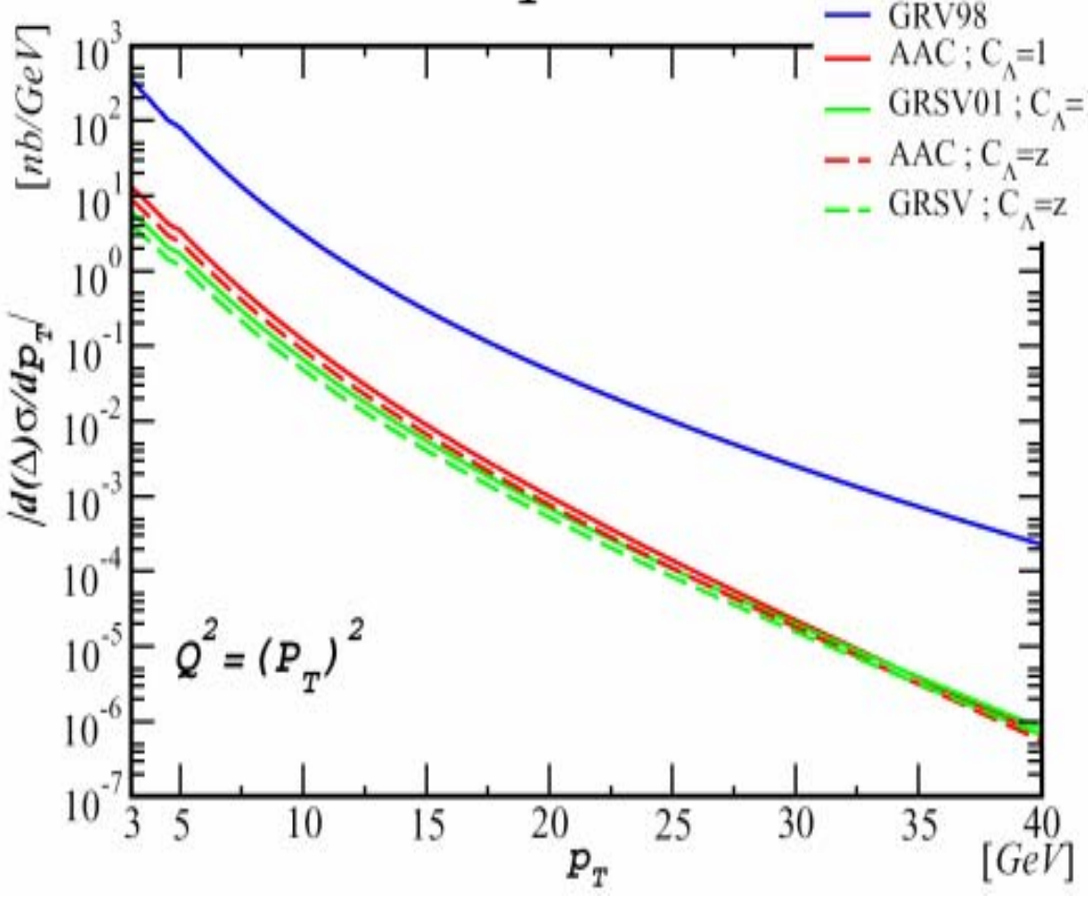
A_{LL}



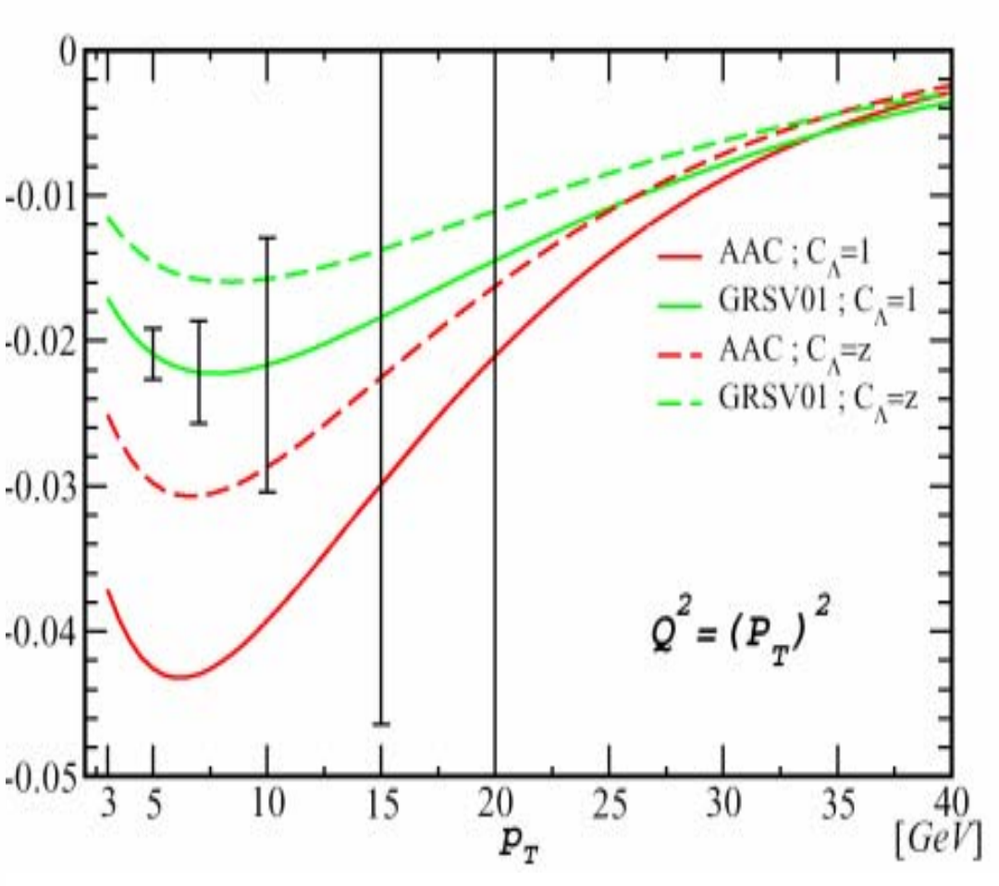
p_T distribution of $\frac{d(\Delta)\sigma}{dp_T}$ and A_{LL} at $\sqrt{s} = 500GeV$

$-1.3 \leq \eta \leq 1.3$

$\frac{d(\Delta)\sigma}{dp_T}$



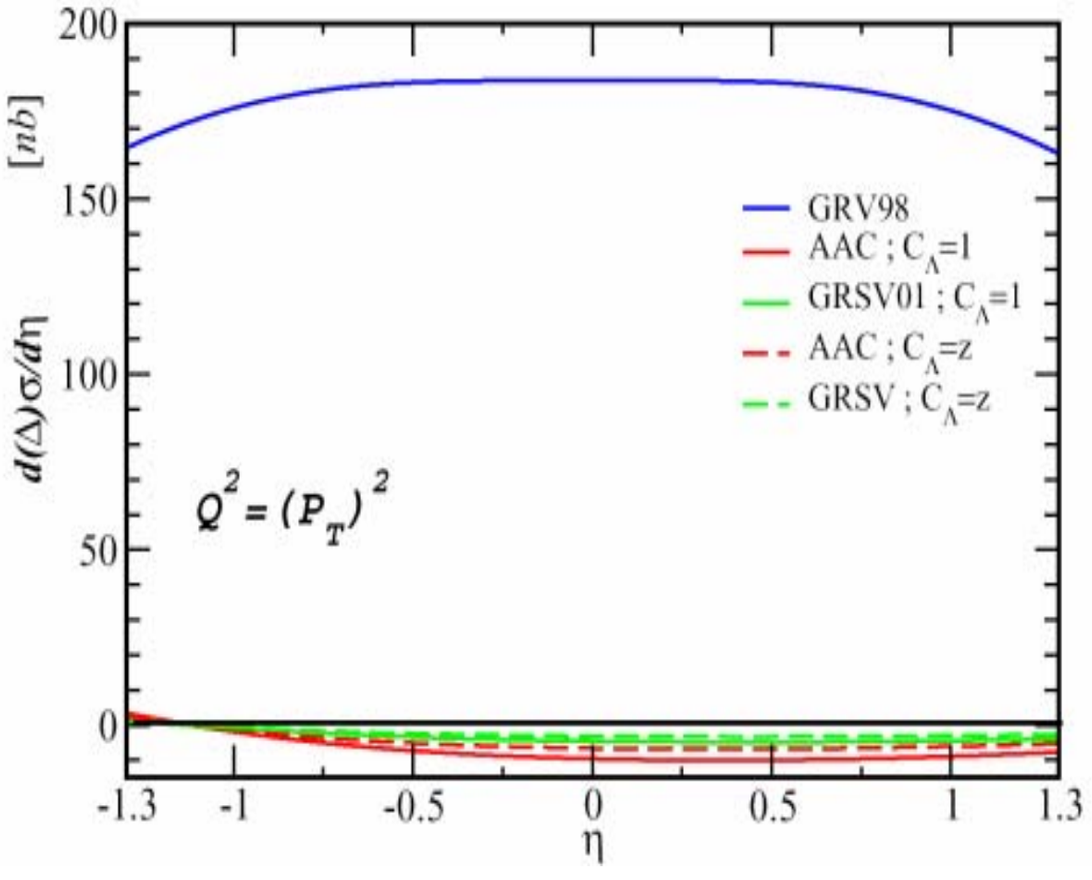
A_{LL}



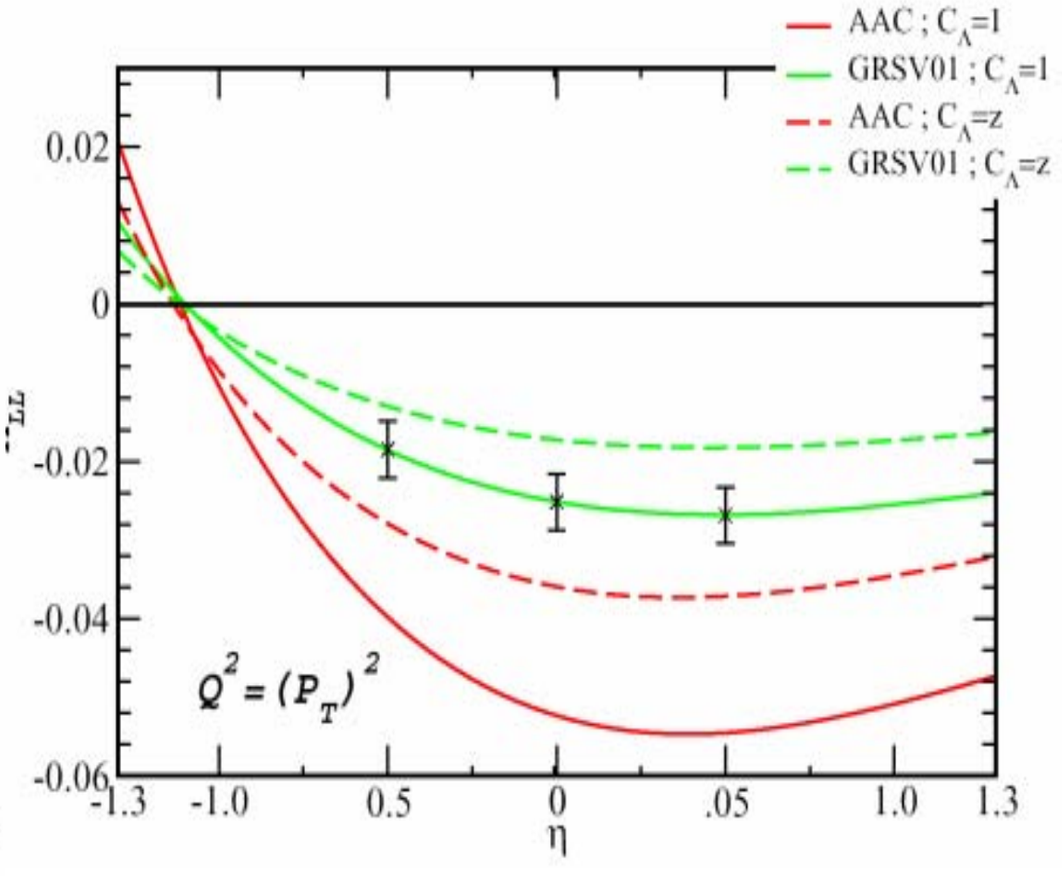
η distribution of $\frac{d(\Delta)\sigma}{d\eta}$ and A_{LL} at $\sqrt{s} = 500GeV$

$$3 \leq p_T \leq 40$$

$\frac{d(\Delta)\sigma}{d\eta}$



A_{LL}



IV. Summery (for Λ_c production)

RHIC Experiment can measured this process.

For the process; $\vec{P} + P \longrightarrow \vec{\Lambda}_c^+ + X$,

- The spin correlation diffractive cross section, $\frac{d(\Delta)\sigma}{d\eta} \Big/ \frac{d(\Delta)\sigma}{dp_T}$ and spin asymmetry, A_{LL}, have been calculated for $\sqrt{s} = 200GeV$ and $\sqrt{s} = 500GeV$.
- The statistical sensitivity, δA_{LL} is estimated for RHIC experiment parameters.

⇓

★ A_{LL} is sensitive to polarized gluon function.
- η distribution for A_{LL} is optimal observable.
  - A_{LL} at $\sqrt{s} = 200GeV$ is good observable for test of parameterization models for polarized gluon.

- Study of polarized fragmentation function is important.

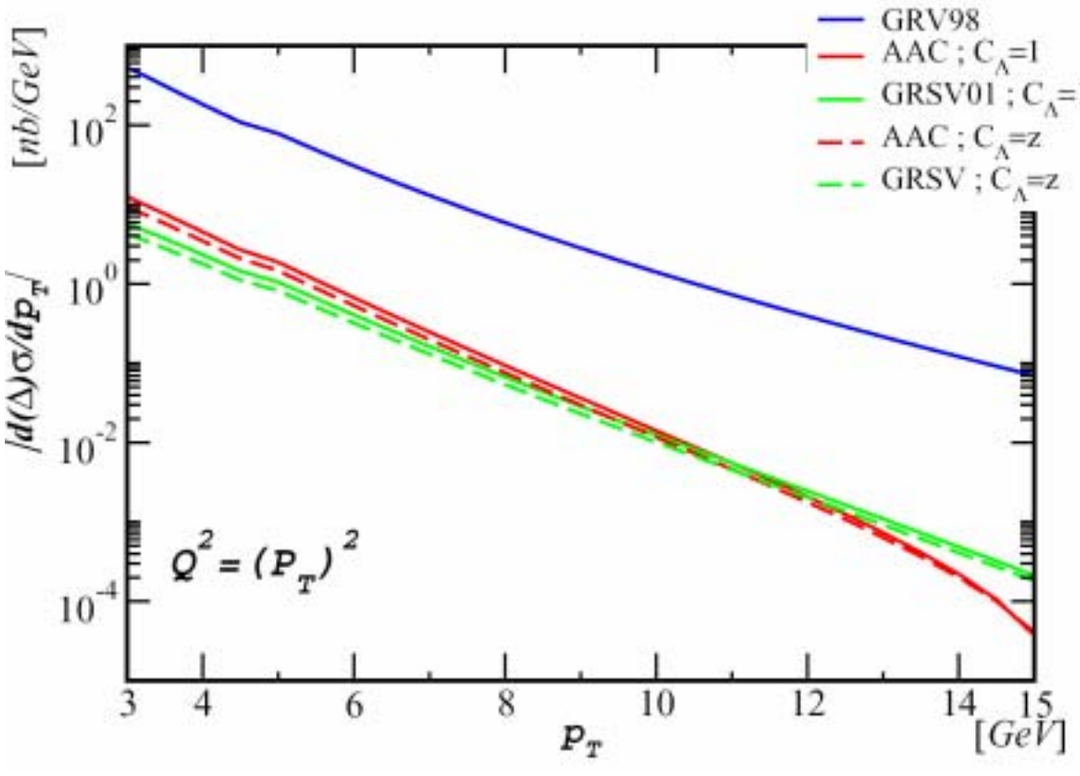
→ D^* Process is also give us interesting information about polarized gluon in the proton.

D* meson production

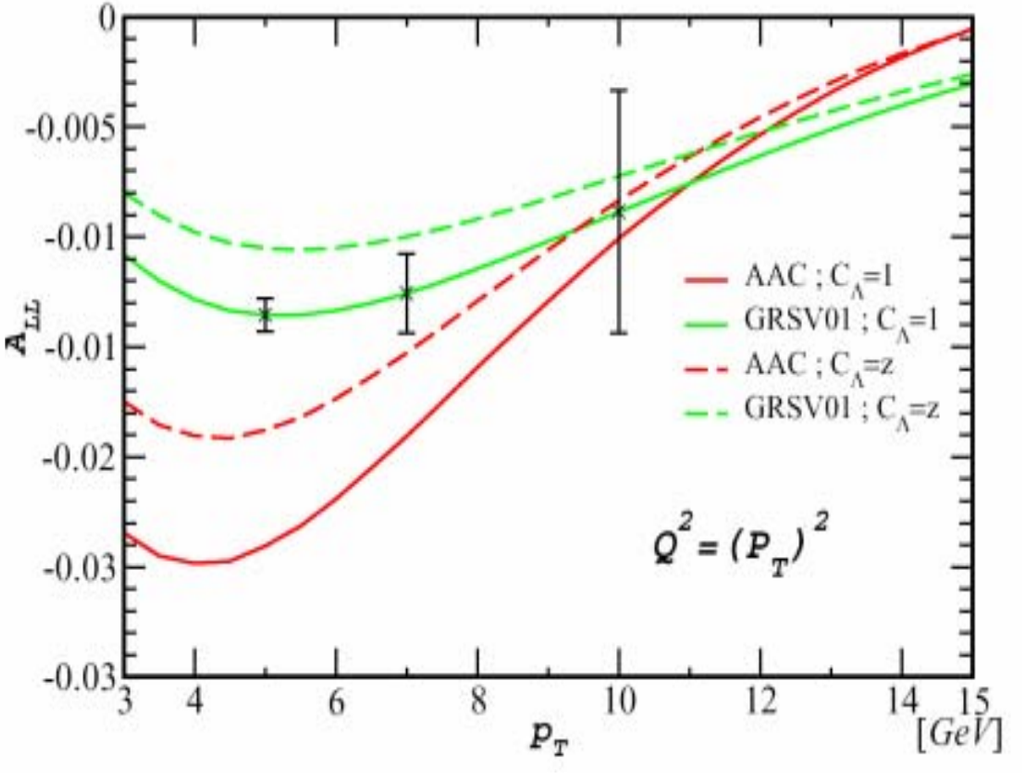
p_T distribution of $\frac{d(\Delta)\sigma}{dp_T}$ and A_{LL} at $\sqrt{s} = 200GeV$

$$-1.3 \leq \eta \leq 1.3$$

$\frac{d(\Delta)\sigma}{dp_T}$



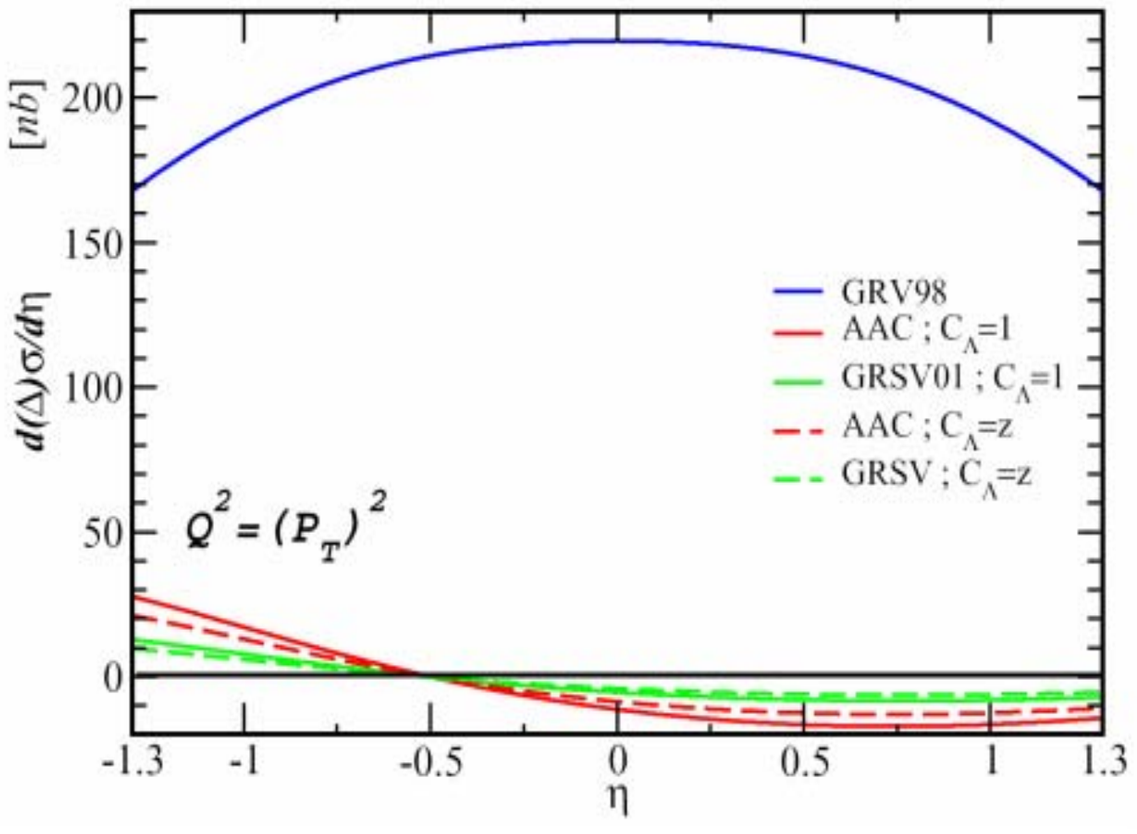
A_{LL}



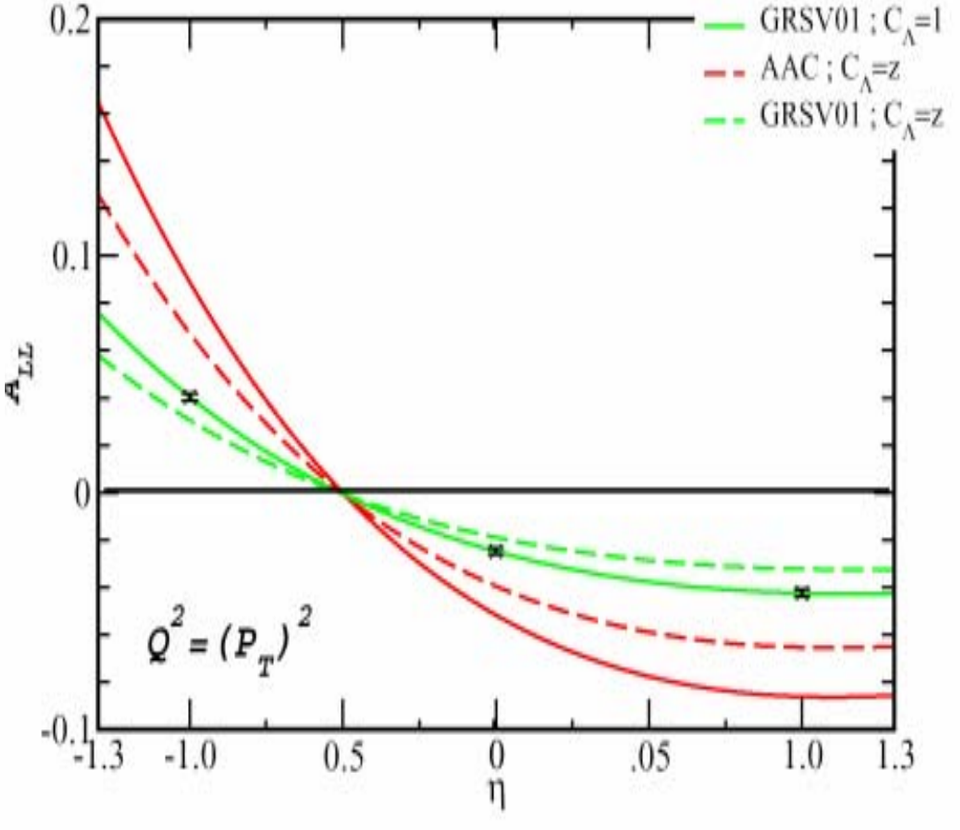
η distribution of $\frac{d(\Delta)\sigma}{d\eta}$ and A_{LL} at $\sqrt{s} = 200GeV$

$$3 \leq p_T \leq 15$$

$\frac{d(\Delta)\sigma}{d\eta}$



A_{LL}



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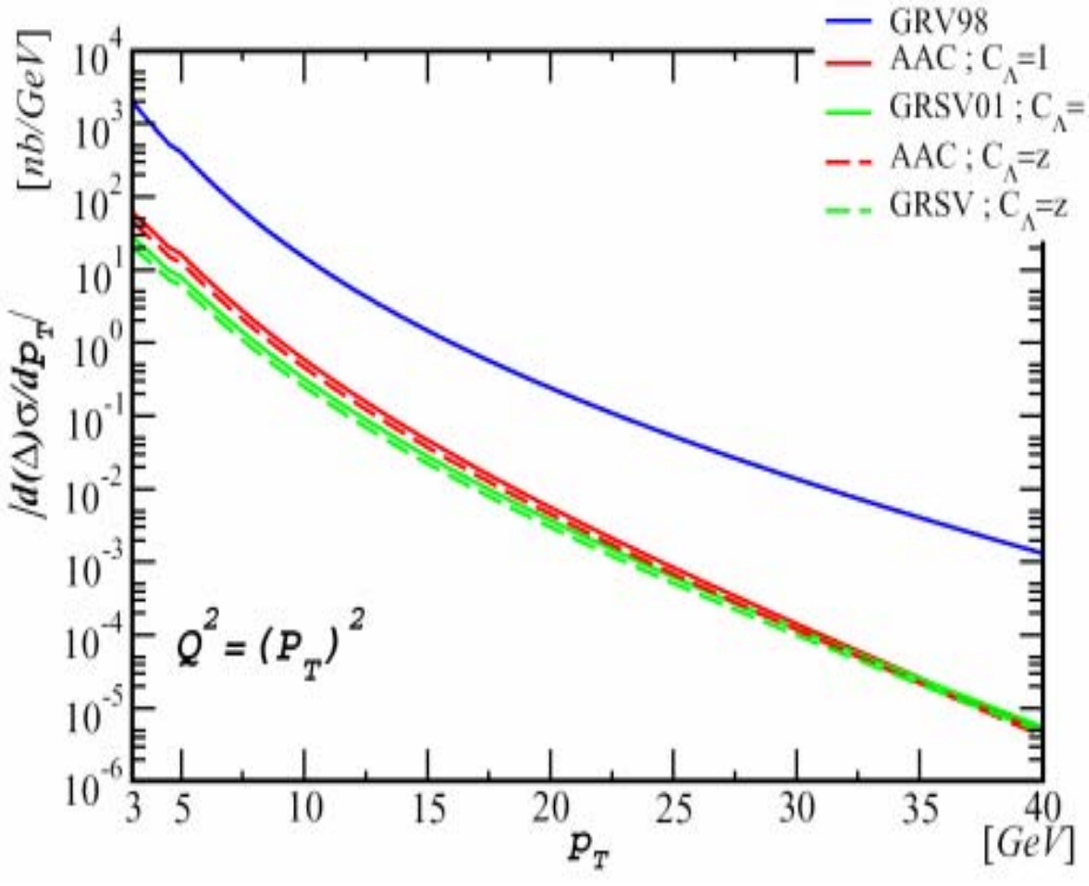
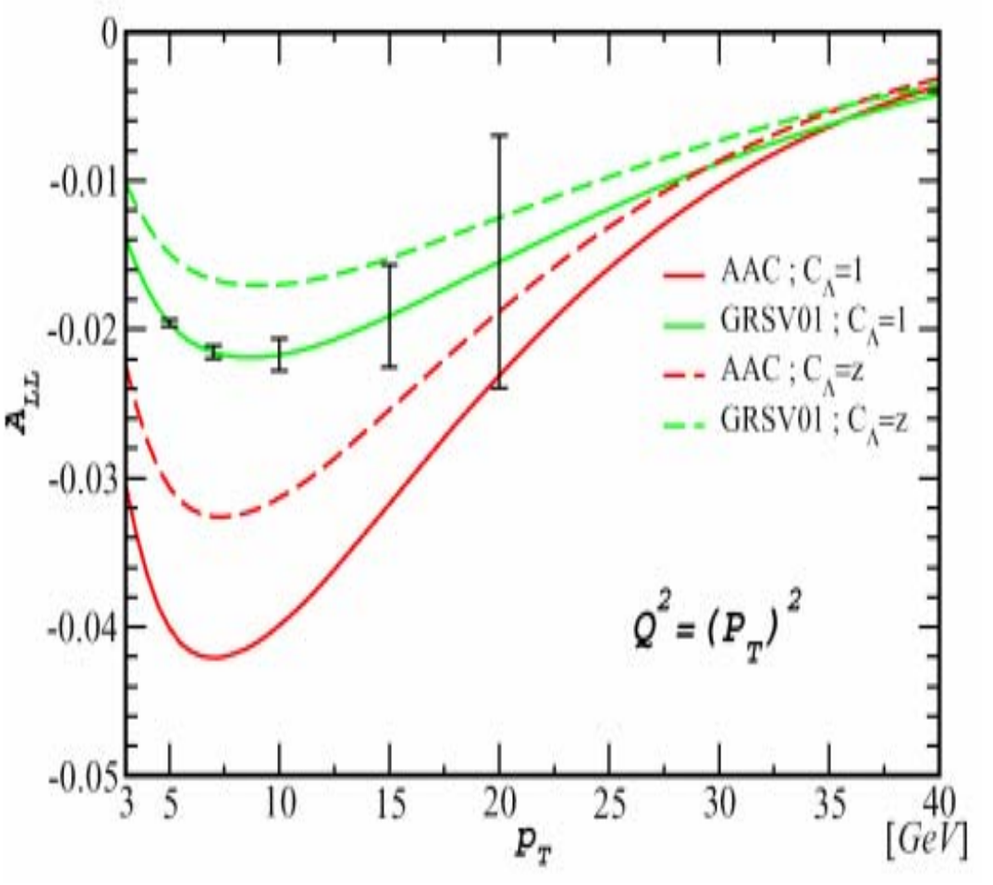
$$-1.3 \leq \eta \leq 1.3$$

$\frac{d(\Delta)\sigma}{dp_T}$



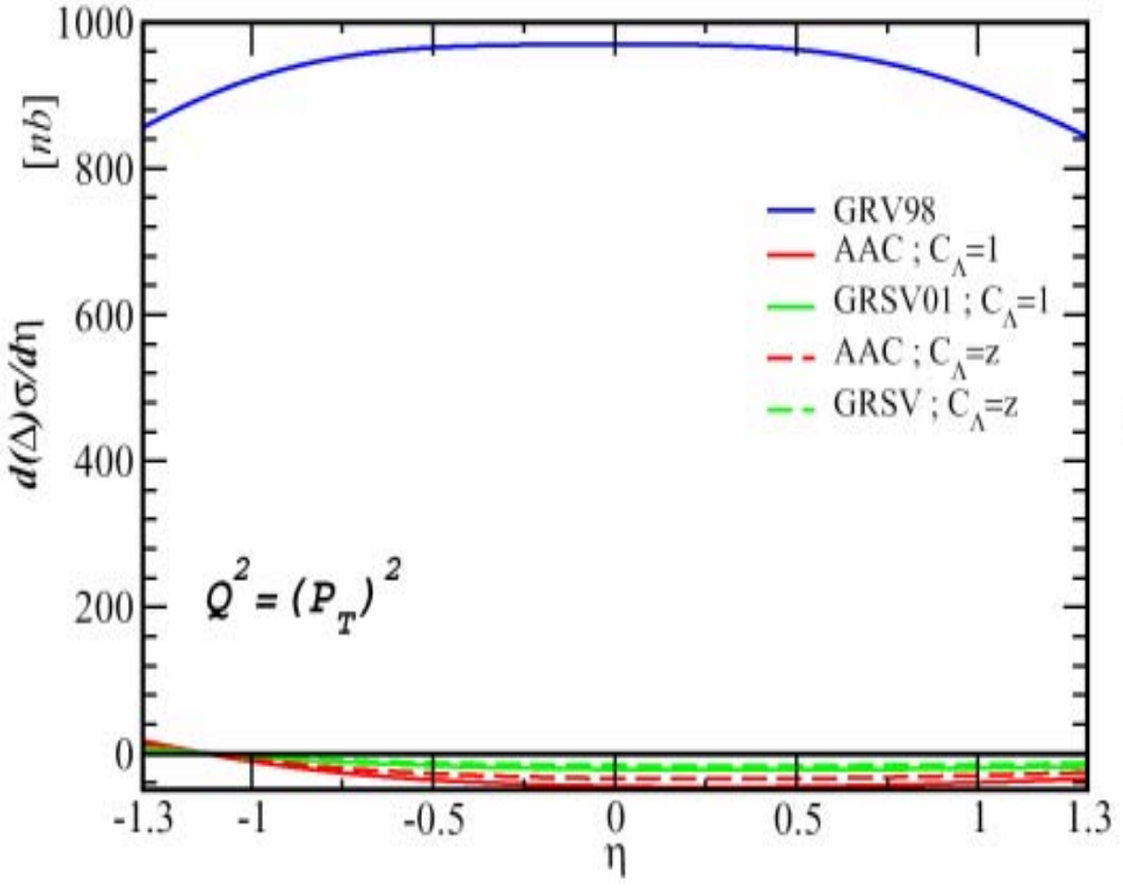
A_{LL}



η distribution of $\frac{d(\Delta)\sigma}{d\eta}$ and A_{LL} at $\sqrt{s} = 500GeV$

$$3 \leq p_T \leq 40$$

$\frac{d(\Delta)\sigma}{d\eta}$



A_{LL}