# Longitudinal single-spin asymmetries in $p^{\uparrow}p$ - scattering with a hadronic final state

## – work in progress –

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# Outline

- Helicity distribution $\Delta q$
- $A_L$ with hadronic final states
  - hadronic jets
  - charmed final state
- $A_L$ with different $\Delta q$
  - based on chiral Quark Soliton Model
  - other parametrization
- Leading-Log resummation
- other parity violating asymmetries
- Summary and Outlook

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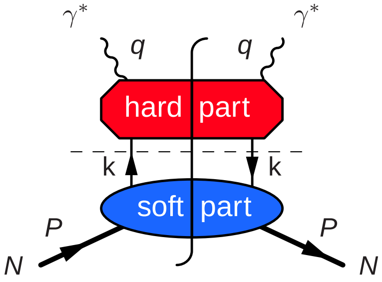
# Helicity distribution




- helicity distribution is a forward parton distribution
- probability to find a parton with positive helicity minus probability to find a parton with negative helicity

| | |
|---|---|
| unpolarized parton distribution | $q(x)$ |
| helicity distribution | $\Delta q(x)$ |
| unpolarized fragmentation function | $D_1^q(z)$ |
| momentum fraction of parton | $x$ |
| momentum fraction of produced hadron | $z$ |

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# Measurements of $\Delta q\,(x)$

- deep-inelastic scattering $l^{\uparrow}N^{\uparrow} \longrightarrow l' + X$
  - can only measure sum of $\Delta q$ over all flavors
- semi-inclusive deep-inelastic scattering
  $l^{\uparrow}N^{\uparrow} \longrightarrow l' + h + X$ (double-spin-asymmetry)
  - $A_{LL} \propto \frac{\sum_q e_q^2 \Delta q(x) D_1^q(z)}{\sum_q e_q^2 q(x) D_1^q(z)}$
  - $\Rightarrow$ accuracy is limited to knowledge of $D_1^q(z)$,
    $\left(\Delta s = \Delta \bar{u} = \Delta \bar{d} = \Delta \bar{s}\right)$
- proton-proton-scattering e.g. $p^{\uparrow}p \longrightarrow jet + X$
  - $p^{\uparrow}p$ - scattering with heavy boson exchange
    $\longrightarrow$ due to $(V - A)$ interaction, only one proton needs to be polarized $\longrightarrow A_L$
  - leptonic an hadronic final state
  - with hadronic final state, leading contribution is
    $A_L \propto \frac{\alpha_S \alpha_W}{\alpha_S^2 + (\alpha_S \alpha_W)}$
  - advantages of hadronic to leptonic final state:
    - origin of jet is clear
    - larger counting rates

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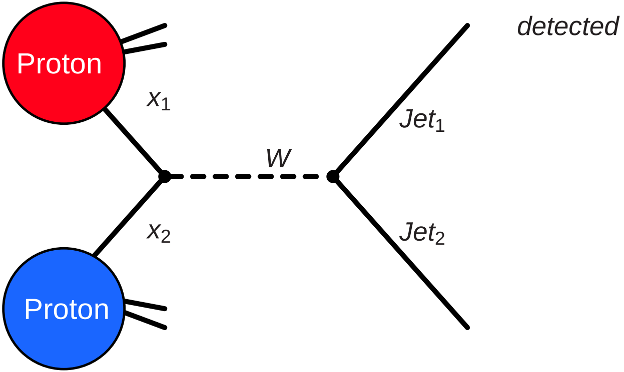
# $p^{\uparrow}p$ - scattering




have transverse momentum $p_{\perp}$
and (pseudo-) rapidity $\eta = -ln\left(tan\left(\frac{\theta}{2}\right)\right)$

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# $p^{\uparrow}p$ - scattering with hadronic final state

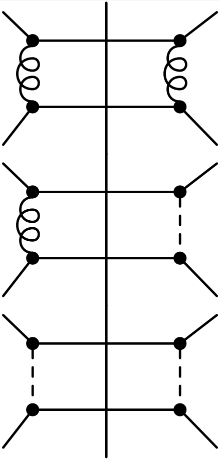
polarized cross-section : $\mathcal{O}(\alpha_S \alpha_W) + \mathcal{O}(\alpha_W^2)$

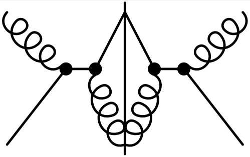
unpolarized cross-section : $\mathcal{O}(\alpha_S^2) + \mathcal{O}(\alpha_S \alpha_W) + \mathcal{O}(\alpha_W^2)$

$\mathcal{O}(\alpha_S^2)$

$\mathcal{O}(\alpha_S \alpha_W)$

$\mathcal{O}(\alpha_W^2)$





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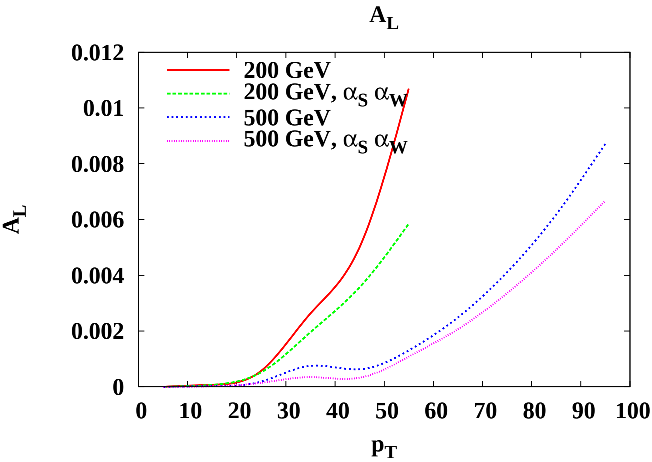
# expected asymmetry $A_L$




$q(x) \longrightarrow$ M. Gluck, E. Reya, A. Vogt, Eur.Phys.J.C **5**,1998
$\Delta q(x) \longrightarrow$ M. Gluck, E. Reya, M. Stratmann, W. Vogelsang, Phys.Rev.D **63**, 2001 $\longrightarrow$ GRSV
C.Bourrely, J.Ph.Guillet and J.Soffer, Nucl. Phys. B **361**, 72 (1991)

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# Maximized asymmetry

## Asymmetry as function of $p_\perp$ and $\eta$

$$\frac{d^2\sigma}{d\eta dp_\perp} = \int_{x_{min}}^{1} dx_1 \frac{2p_\perp}{\sqrt{x_1 - \frac{p_\perp}{\sqrt{s}} e^{-\eta}}} x_1 f_1(x_1)\, x_2 f_1(x_2) \cdot d\sigma_{partonic}$$

- check kinematic range for maximal asymmetry
- e.g. check $\eta$ range at fixed $p_\perp$ and integrate $\eta$ over important range
- get larger asymmetry $A_L(p_\perp)$
- use $s = (500\, GeV)^2$, smaller asymmetry, but much larger counting-rates
  $\Rightarrow$ much smaller statistical error

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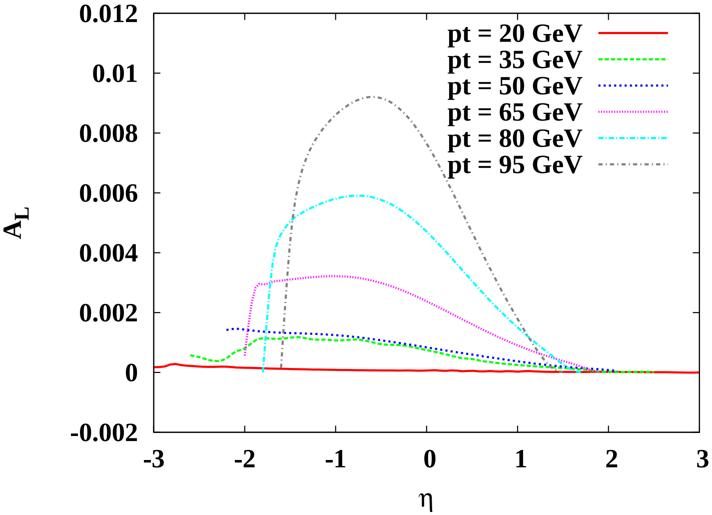
# Asymmetry as a function of jet-rapidity

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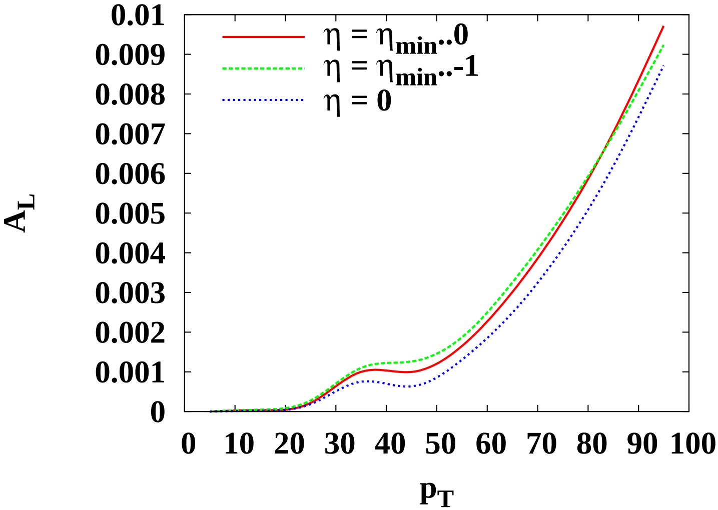
# maximized Asymmetry

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# c-quark in final state

- suppress large gluon contributions in denominator of asymmetry
- no charm contribution in initial state
- look for c-quark in final state $\longrightarrow$ detect D-Meson
- $P_{c\to D} \gg P_{q\to D}$, $P_{c\to D} \gg P_{c\to \bar{D}}$ $\longrightarrow$ c-quark can be identified directly
- reduces the number of processes which contribute to the asymmetry
- determine important $\eta$-region in the same way as before.

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# c-quark in final state

There are some differences in the calculation of the charmed final state

- crossed channels are no longer to be added
- denominator in $\mathcal{O}\left(\alpha_s^2\right) \Rightarrow q\bar{q} \longrightarrow c\bar{c}$ and $gg \longrightarrow c\bar{c}$
- in $\mathcal{O}\left(\alpha_s \alpha_w\right)$ only contribution comes from $W \leftrightarrow g$
- large d-quark contribution goes with small CKM element
- $\Rightarrow$ main contributions are $\mathcal{O}\left(\alpha_w^2\right)$
- $\longrightarrow$ increase of asymmetry!

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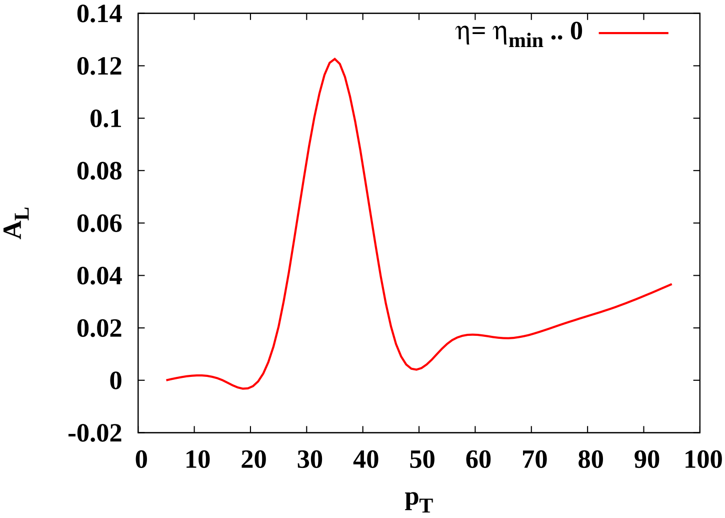
# maximized asymmetry, c-quark in final state

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# calculation of statistical error

$$A_L = \frac{\sigma_{++} + \sigma_{-+} - \sigma_{+-} - \sigma_{--}}{\sigma_{++} + \sigma_{-+} + \sigma_{+-} + \sigma_{--}} = \frac{N_{++} + N_{-+} - N_{+-} - N_{--}}{N_{++} + N_{-+} + N_{+-} + N_{--}}$$

with $\delta N = \sqrt{N}$. By Gaussian error propagation one gets

$$\Rightarrow \Delta A_L = \frac{1}{0.7\sqrt{\mathcal{L}\left(\sigma_{++} + \ldots\right)}} = \frac{1}{0.7\sqrt{\mathcal{L}\left(\sigma_{unpol}\right)}}$$

for small asymmetries and same luminosity in all helicity combinations.

For RHIC II:

| | | |
|---|---|---|
| polarization: | P | 70 % |
| int. luminosity: | L | 500 $pb^{-1}$ |

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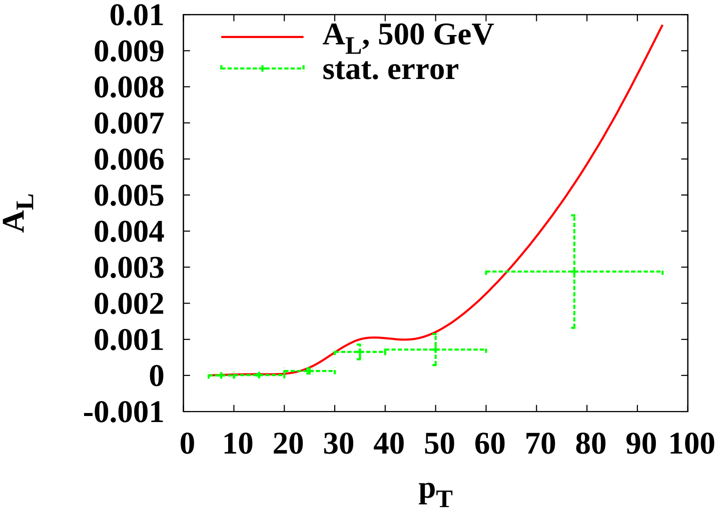
# Complete final state

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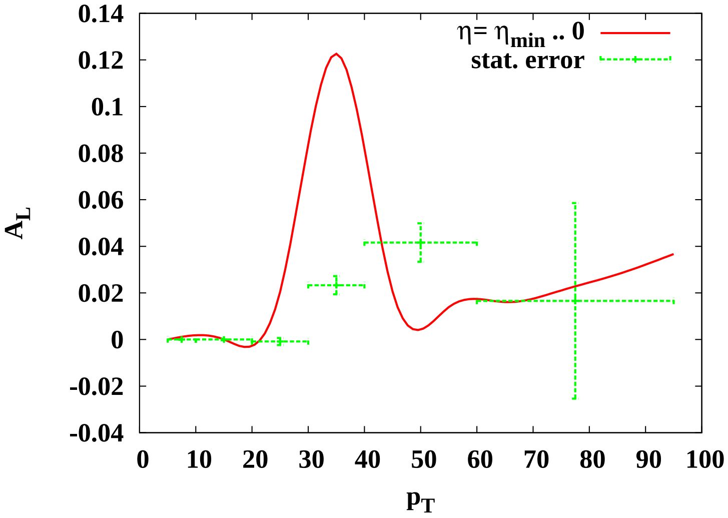
# Charmed quark in final state

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# Different input for $\Delta q(x)$

one can make a prediction for $\Delta q(x)$ based on $q(x)$ and the chiral Quark Soliton Model (cQSM)

D.Diakonov, V.Petrov, P.Pobylitsa, M.Polyakov and C.Weiss

Nucl. Phys. B **480**, 341 (1996)

Main differences between GRSV and cQSM

| | GRSV | cQSM |
|---|---|---|
| Sign of $\Delta q$ | + except for $\Delta d$ | - for $\Delta d$ and $\Delta \bar{d}$ |
| $\Delta \bar{d}$ | positive | negative |
| | might learn something about $\bar{d}$-distribution | |
| Gluons | no gluons in cQSM | |
| | cQSM only used in $\sigma_{pol} \rightarrow$ no gluons | |

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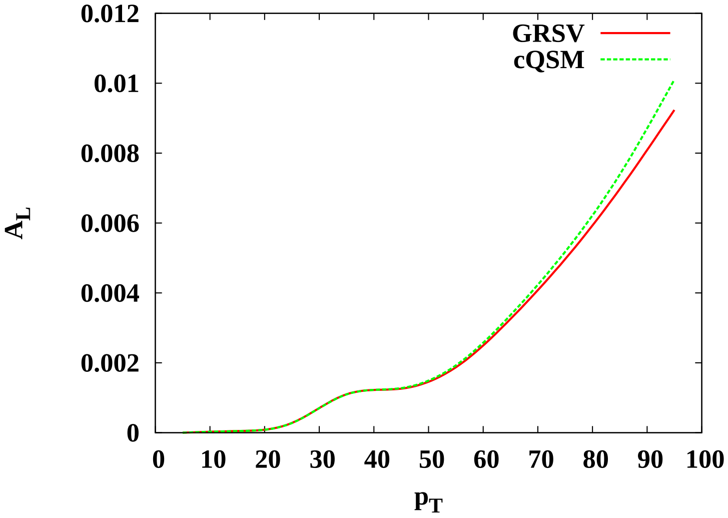
# Chiral Quark Soliton Model

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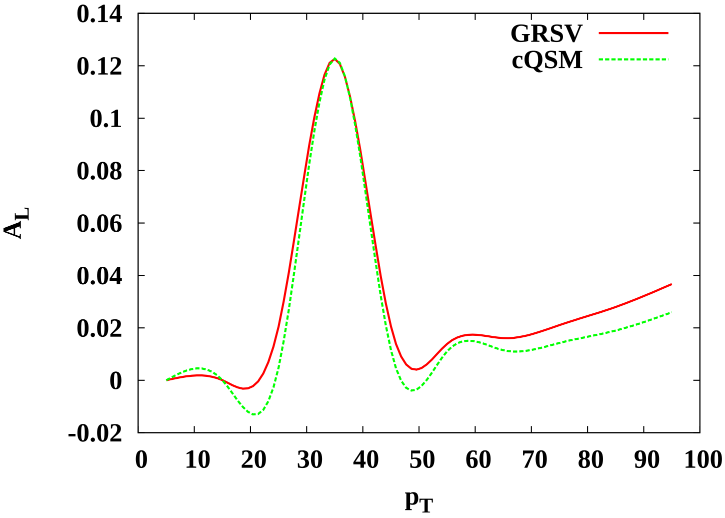
# Chiral Quark Soliton Model

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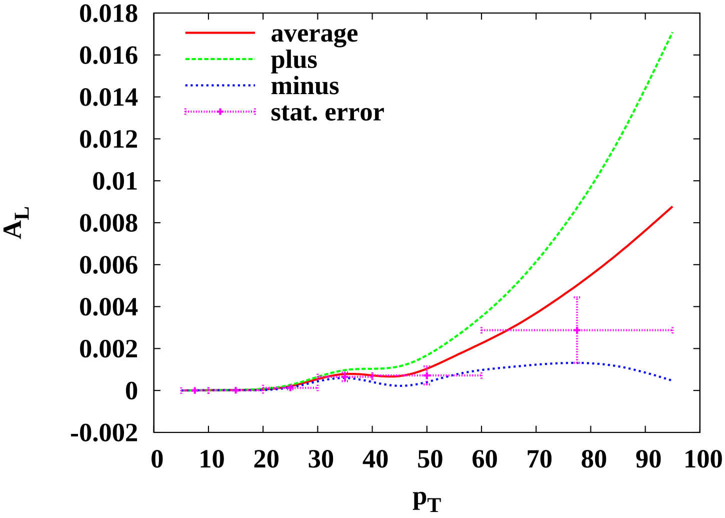
# $A_L$ with varying $\Delta q(x)$




J. Bluemlein and H. Boettcher ; Nucl.Phys.**B**636 (2002) 225

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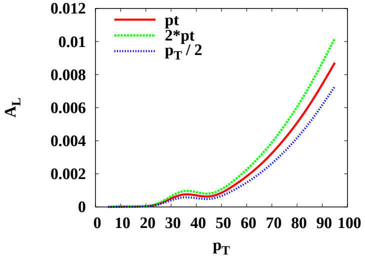
# Leading-Log resummation (LL)

- near partonic threshold $\left(\sqrt{s} = 2p_T\right)$ corrections arrise
- $\propto \alpha_S^k\,(p_T)\, ln^{2m}\left(1 - \hat{x}_T^2\right)$,
  LL $\rightarrow m = k$
  $\hat{x}_T = \frac{2p_T}{\sqrt{s}}$
- resummation can reinstate perturbation theory




- resummation enhances the cross-sections
- reduce scale dependece of $A_L$

Daniel de Florian, Werner Vogelsang; arXiv:0704.1677v1 [hep-ph]

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# Leading-Log resummation (LL)

in Mellin-moment space (integrated over $\eta$)

$$\hat{\sigma}^{res} = \sum_{c,d} C_{ab} \Delta_N^a \Delta_N^b J_N^{c\prime} J_N^d \left[ G^I_{ab\to cd} \Delta_{I\,N}^{(int)ab\to cd} \right] \hat{\sigma}^{(Born)}_{ab\to cd}$$

| | |
|---|---|
| $C_{ab}$ | N-indep. hard virtual corrections |
| $\left[ G^I_{ab\to cd} \Delta_{I\,N}^{(int)ab\to cd} \right]$ | large angle soft gluon emission, NLL |
| $\Delta_N^a$ | soft gluon radiation collinear to the initial state partons |
| $J_N^d$ | radiation in the unobserved jet |
| $J_N^{c\prime}$ | radiation in the observed jet, NLL |

$\Delta_N^a$, $J_N^d$ do not depend on $\eta$ or $p_T$ in LL
$\Rightarrow$ could also be used for the $\eta$-dependent cross-sections

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# Leading-Log resummation

in LL the resummation coefficients do not depend on $p_T$
$\Rightarrow$ resummation effects can be included in the pdf's

$$\hat{\sigma}^{res} = \sum_{c,d} C_{ab} \Delta_N^a \Delta_N^b J_N^d \hat{\sigma}^{(Born)}_{ab\to cd}$$

$$q_{a/H_1}(x_1)\, \Delta q_{b/H_2}(x_2)\, \hat{\sigma}_{res}$$

$$\underbrace{[q(N) * \Delta_q(N)]}_{\longrightarrow \tilde{q}(x_1)} * \underbrace{[q(N) * \Delta_q(N) * J_q(N)]}_{\longrightarrow \hat{q}(x_2)} * \sigma^{Born}$$

in $\sigma_{unpol}$: $\left(\tilde{q}(x_1) \star \hat{q}(x_2) + \hat{q}(x_1) \star \tilde{q}(x_2)\right)/2$
$\Delta_q(N) J_q(N)$ for $q \to q$, $\Delta_q(N) J_g(N)$ for $q \to g$

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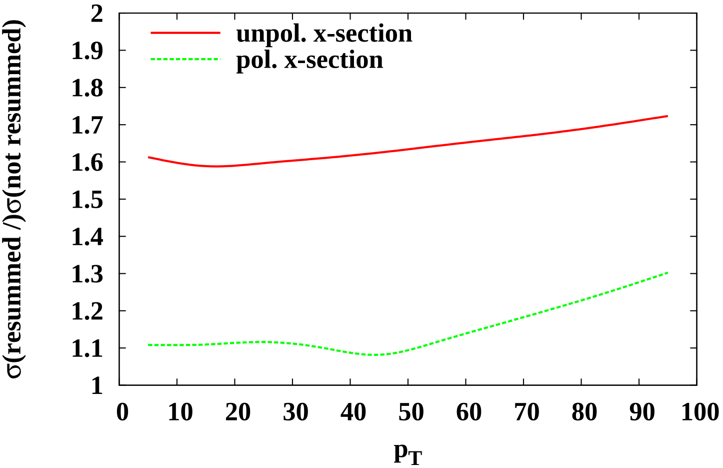
# Leading-Log resummation

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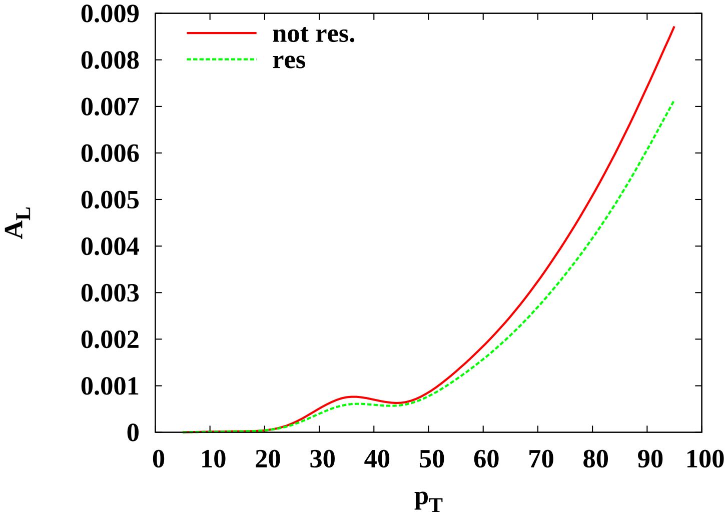
# Leading-Log resummation

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# Other possible Asymmetries to measure $\Delta q(x)$

C. Bourrely, J.Ph. Guillet and J. Soffer,
Nucl. Phys. B **361**, 72 (1991)

Asymmetry in parity-violating $A_{LL}$ can become twice as big!

There are two parity violating double-spins asymmetries

$$\frac{\sigma_{++} - \sigma_{--}}{\sigma_{++} + \sigma_{--}} \quad \text{and} \quad \frac{\sigma_{+-} - \sigma_{-+}}{\sigma_{+-} + \sigma_{-+}}$$

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# Summary and Outlook

## Summary

- $\Delta q$ in pp-scattering (jet-production)
- $A_L$ with different hadronic final states
- choose kinematic ranges in which $\Delta q$ can be measured
- charmed final state raises the asymmetry
- stat. errors are reasonable
- prediction is stable w.r.t. different models as input for $\Delta q$
- LL resummation

## Outlook

- look at double-spin asymmetries

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