

Photoproduction Of Hadron Pairs At Fixed-Target Experiments

Christof Hendlmeier¹

with

Marco Stratmann² and Andreas Schäfer¹

¹Institut für Theoretische Physik, Universität Regensburg, Germany

²Radiation Laboratory, RIKEN, Wako, Japan

19 March 2007



Outline

Motivation

pQCD Framework

Some Results

Summary and Outlook

Proton Helicity Sum Rule

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma(Q^2) + \Delta G(Q^2) + L_q(Q^2) + L_g(Q^2)$$

polarized DIS:

$$\Delta\Sigma \sim 0.25$$

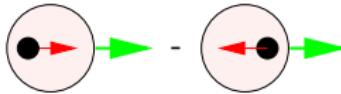
~~ sizable contribution from gluon spin $\Delta G(Q^2)$
or orbital angular momenta $L_{q,g}(Q^2)$

Spin-dependent Gluon Distribution $\Delta g(x, Q^2)$

- in the light cone gauge ($A^+ = 0$):

$$\Delta G(Q^2) = \int_0^1 \Delta g(x, Q^2) dx$$

with $\Delta g(x, Q^2) \equiv g^+(x, Q^2) - g^-(x, Q^2)$.

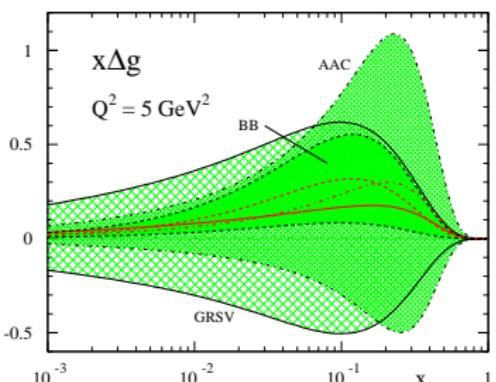


- extraction of $\Delta g(x, Q^2)$ via polarized DIS:

$$g_1(x, Q^2) = \frac{1}{2} \sum_{q=u,d,s} e_q^2 [\Delta q(x, Q^2) + \Delta \bar{q}(x, Q^2)] + \mathcal{O}(\alpha_s)$$

Spin-dependent Gluon Distribution $\Delta g(x, Q^2)$

- extraction of $\Delta g(x, Q^2)$ via scaling violations



Aidala C. et al. , <http://spin.riken.bnl.gov/rsc/report/masterspin.pdf>

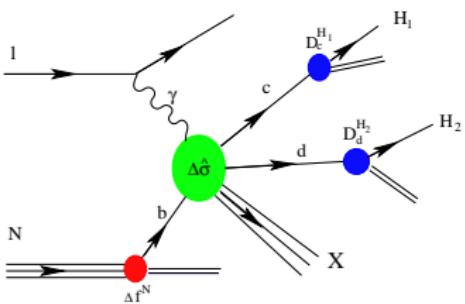
→ study other processes, where Δg enters at LO, e. g. charm, prompt photon, heavy quarks, single hadron, hadron pair production

Perturbative QCD framework

Photoproduction of hadron pairs:

$$\vec{l}(P_A) + \vec{N}(P_B) \rightarrow H_1(P_C) + H_2(P_D) + X$$

use the factorization theorem:



non-perturbative ingredients:

parton distribution function (Δ) f^N , fragmentation functions $D_c^{H_1}$, $D_d^{H_2}$

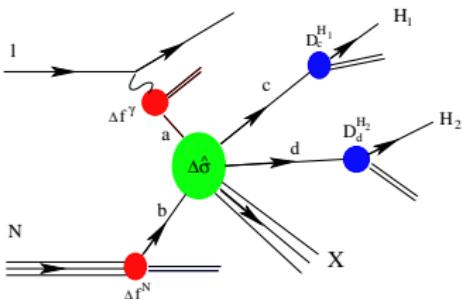
perturbative ingredients: hard partonic cross section (Δ) $\hat{\sigma}$

Perturbative QCD framework

Photoproduction of hadron pairs:

$$\vec{I}(P_A) + \vec{N}(P_B) \rightarrow H_1(P_C) + H_2(P_D) + X$$

use the factorization theorem:



non-perturbative ingredients:

parton distribution function (Δ) $f^N(\Delta)$ f^γ , fragmentation functions $D_c^{H_1}$, $D_d^{H_2}$

perturbative ingredients: hard partonic cross section (Δ) $\hat{\sigma}$

The hadronic cross section

- observation of hadron's transverse momenta p_T 's and (pseudo-)rapidities η 's
- NO selection of partons taking part in the hard scattering
 \rightsquigarrow sum over all possible partonic reactions $a b \rightarrow c d$

$$\begin{aligned}
 d\Delta\sigma^{\vec{IN} \rightarrow H_1 H_2 X} = & \sum_{abcd} \int dx_a dx_b dz_c dz_d \Delta f_a^I(x_a, \mu_f) \Delta f_b^N(x_b, \mu_f) \\
 & \times D_c^{H_1}(z_c, \mu'_f) D_d^{H_2}(z_d, \mu'_f) \\
 & \times d\Delta\hat{\sigma}^{ab \rightarrow cdX'}(x_a P_a, x_b P_b, P^{H_1}/z_c, P^{H_2}/z_d, \mu_f, \mu'_f, \mu_r) \\
 & + O\left(\frac{\lambda}{p_T}\right)^n
 \end{aligned}$$

typical choice: $\mu_f \approx \mu_r \approx \mathcal{O}(p_T)$

pQCD at NLO

- Collinear, IR and UV divergencies, coming up as poles $1/\varepsilon$ and $1/\varepsilon^2$ in dimensional regularization ($n = 4 - 2\varepsilon$)
- What contributes in NLO?
 - ↝ virtual contributions: selfenergies, vertex corrections, box diagrams in interference with appropriate born diagrams

$\gamma g \rightarrow q\bar{q}$ and $\gamma q \rightarrow gq$

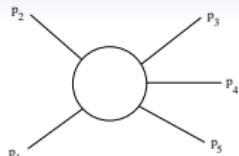


↝ real contributions: all possible $2 \rightarrow 3$ diagrams

$\gamma q \rightarrow q'\bar{q}'q$, $\gamma q \rightarrow q\bar{q}q$, $\gamma q \rightarrow ggq$, $\gamma g \rightarrow q\bar{q}g$

$$\left| \begin{array}{|c|c|} \hline & \\ \hline \end{array} \right|^2$$

pQCD at NLO



~~> the $2 \rightarrow 3$ phase space:

$$\begin{aligned} PS_3 &= \int \frac{d^n p_3}{(2\pi)^{n-1}} \frac{d^n p_4}{(2\pi)^{n-1}} \frac{d^n p_5}{(2\pi)^{n-1}} (2\pi)^n \delta(p_1 + p_2 - p_3 - p_4 - p_5) \delta^+(p_3^2) \delta^+(p_4^2) \\ &\quad \times \delta^+(p_5^2) \delta\left(v - 1 - \frac{\hat{t}}{\hat{s}}\right) \delta\left(w + \frac{\hat{u}}{\hat{s} + \hat{t}}\right) \delta(z - m \cdot p_4) \end{aligned}$$

with $\hat{s} \equiv (p_1 + p_2)^2$, $\hat{t} \equiv (p_1 - p_3)^2$, $\hat{u} \equiv (p_1 - p_4)^2$, $z \equiv -\frac{\vec{p}_{T,3} \cdot \vec{p}_{T,4}}{p_{T,3}^2}$, $m \equiv \frac{p_3 \hat{s} + p_2 \hat{t} + p_1 \hat{u}}{\hat{t} \hat{u}}$

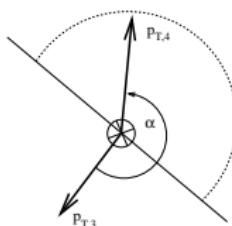
leads to:

$$\begin{aligned} PS_3 &= \frac{\pi \hat{s}}{8(2\pi)^5} \left(\frac{4\pi}{\hat{s}} \right)^\varepsilon \frac{v}{\Gamma(1-2\varepsilon)} \left(\frac{4\pi}{\hat{s}vw(1-v)} \right)^\varepsilon v^{-\varepsilon} (1-w)^{-\varepsilon} 2 \sqrt{\frac{w(1-v)}{1-vw}} \\ &\quad \times \left(\frac{1-w+4w(1-v)z(1-z)}{1-vw} \right)^{-\varepsilon} \int_0^\pi d\theta_2 \sin^{-2\varepsilon}(\theta_2) \end{aligned}$$

with θ_2 the angle between one observed and the not observed parton

$$\text{The } z\text{-variable: } z \equiv -\frac{\vec{p}_{T,3} \cdot \vec{p}_{T,4}}{p_{T,3}^2}$$

- restriction to $z > 0$: two observed hadrons must be in opposite hemispheres
 - angle between hadrons: $\alpha \in [90^\circ, 270^\circ]$

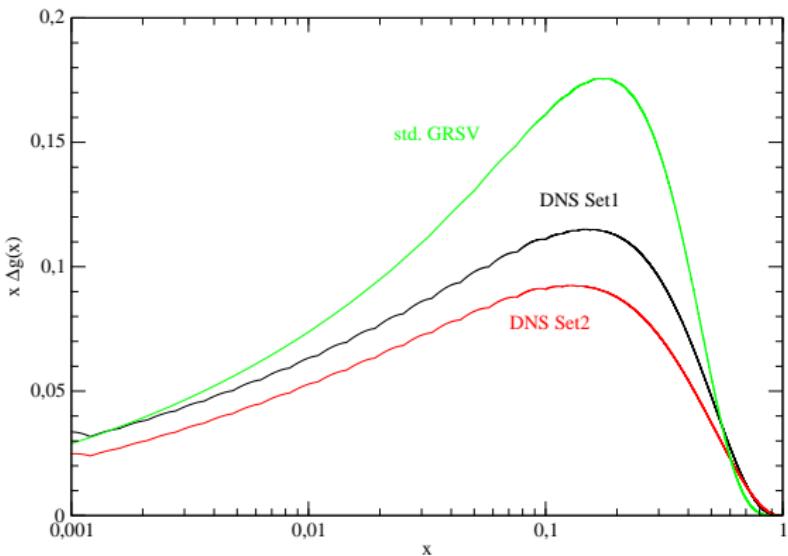


- information on second hadron via z -variable:
 - no rapidity cut possible for second hadron
 - cut on transverse momenta via z -variable:

$$z = -\frac{\vec{p}_{T,3} \cdot \vec{p}_{T,4}}{p_{T,3}^2} = -\frac{p_{T,4}}{p_{T,3}} \cos \alpha$$

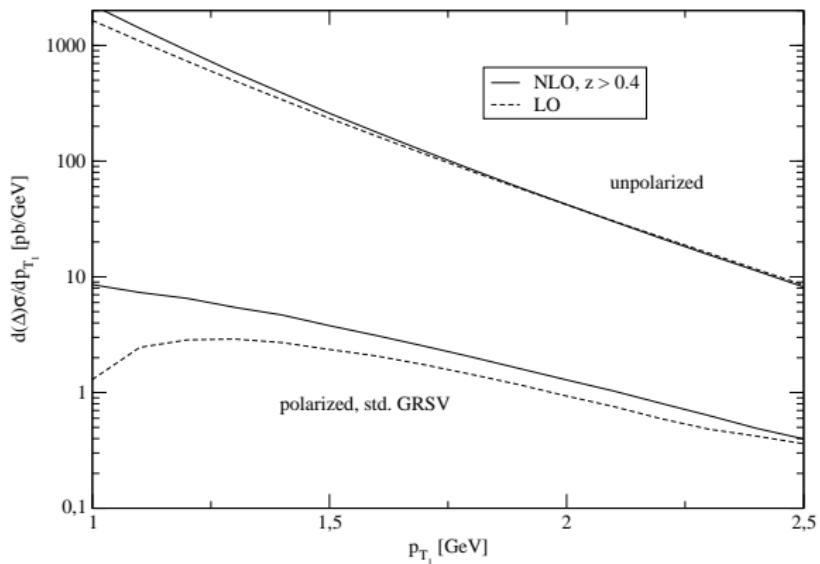
- use different cuts for z : 0.2, 0.4, 0.6

Different Gluon Distributions



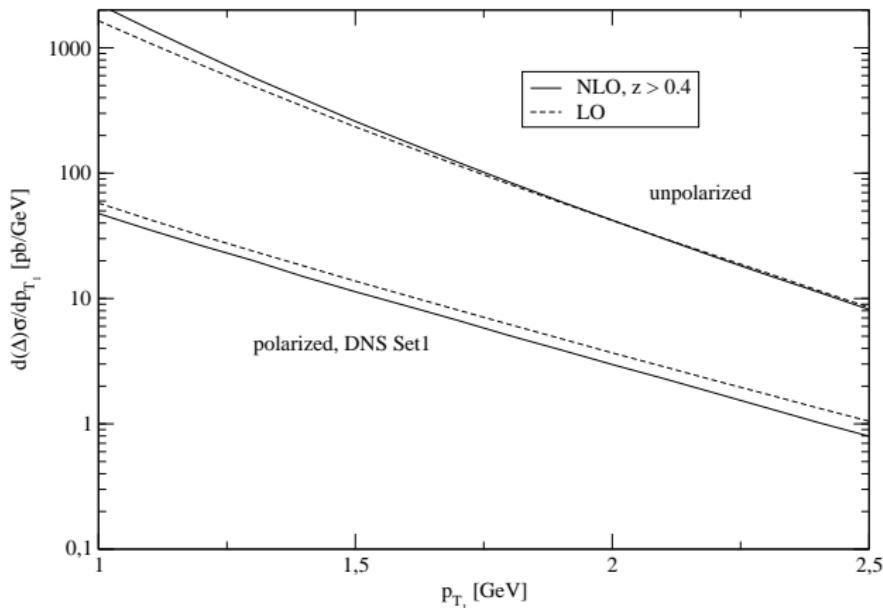
Cross sections @ COMPASS: LO vs. NLO

All results are preliminary!



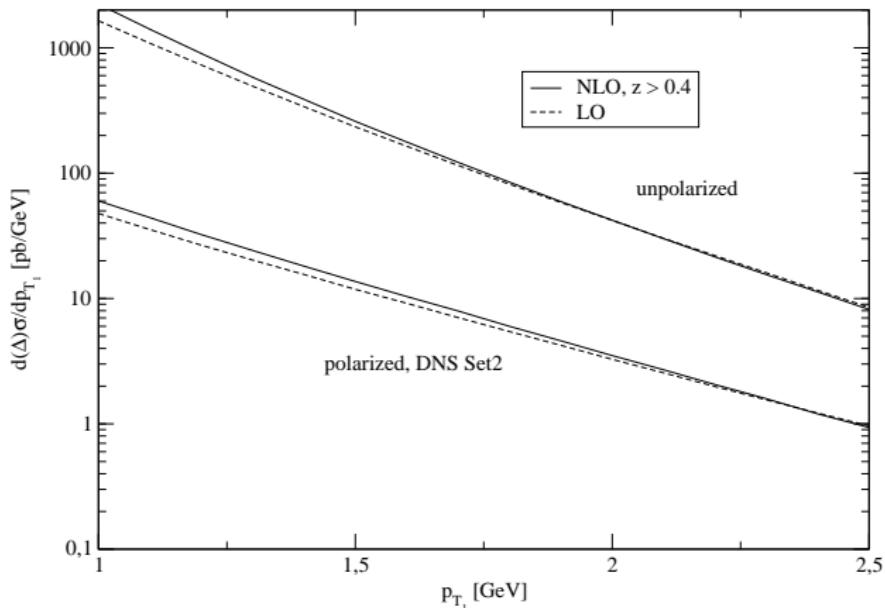
Cross sections @ COMPASS: LO vs. NLO

All results are preliminary!



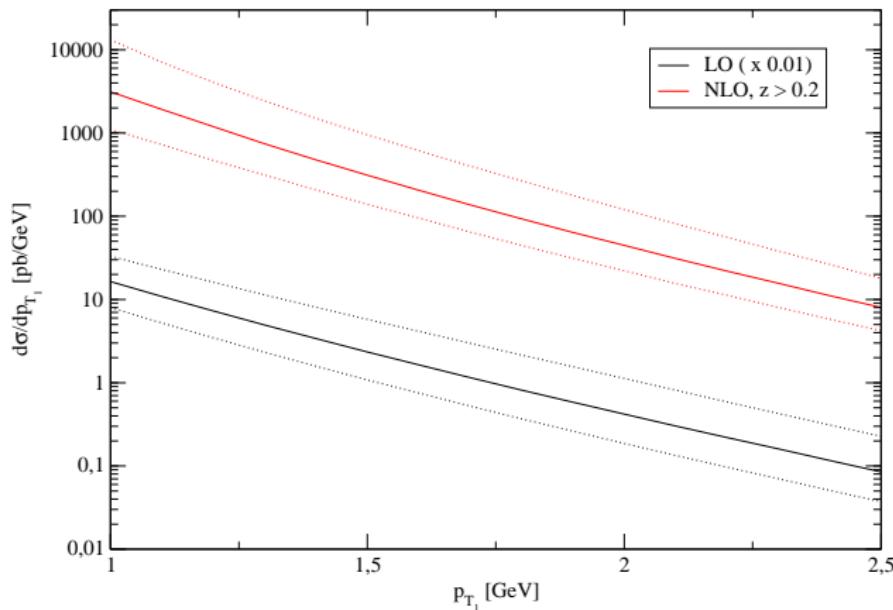
Cross sections @ COMPASS: LO vs. NLO

All results are preliminary!



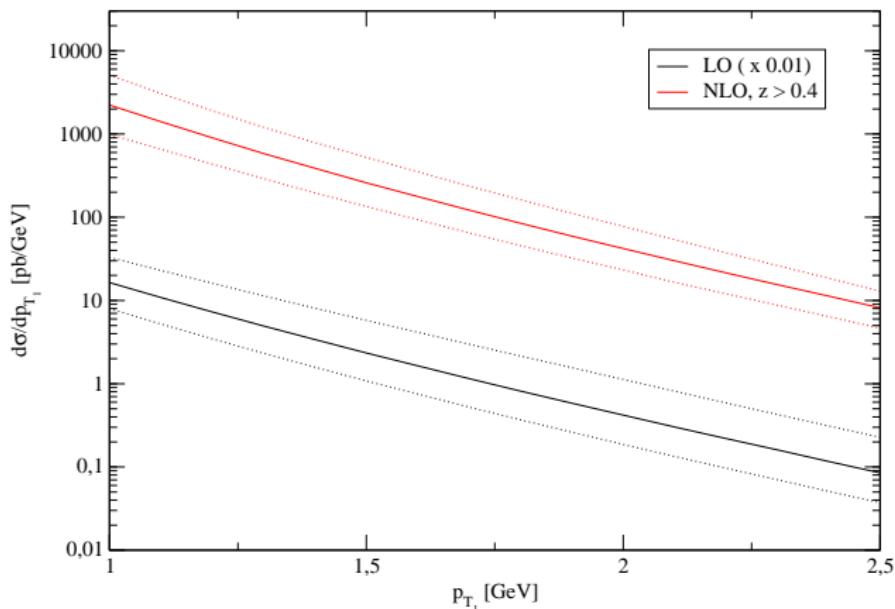
Unpolarized cross section @ COMPASS: LO vs. NLO

Scale dependence



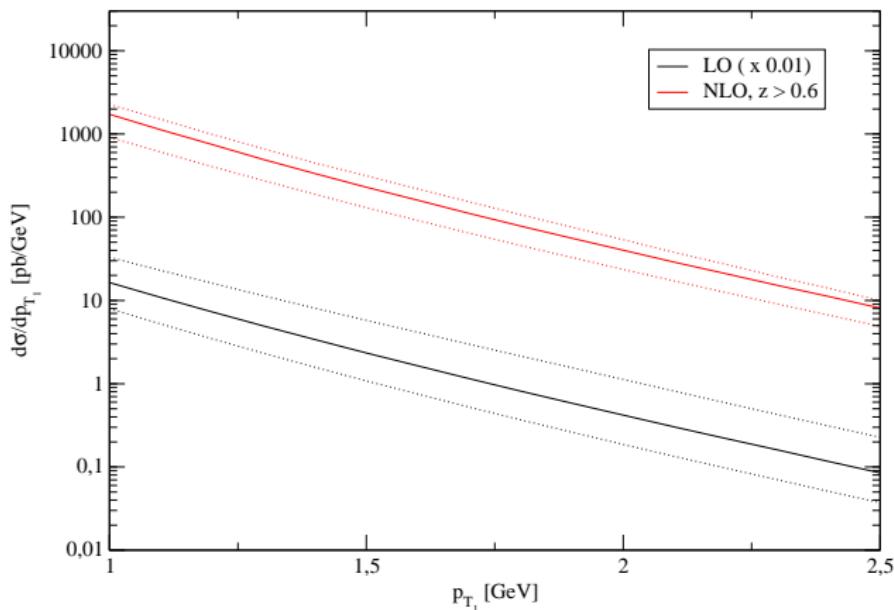
Unpolarized cross section @ COMPASS: LO vs. NLO

Scale dependence



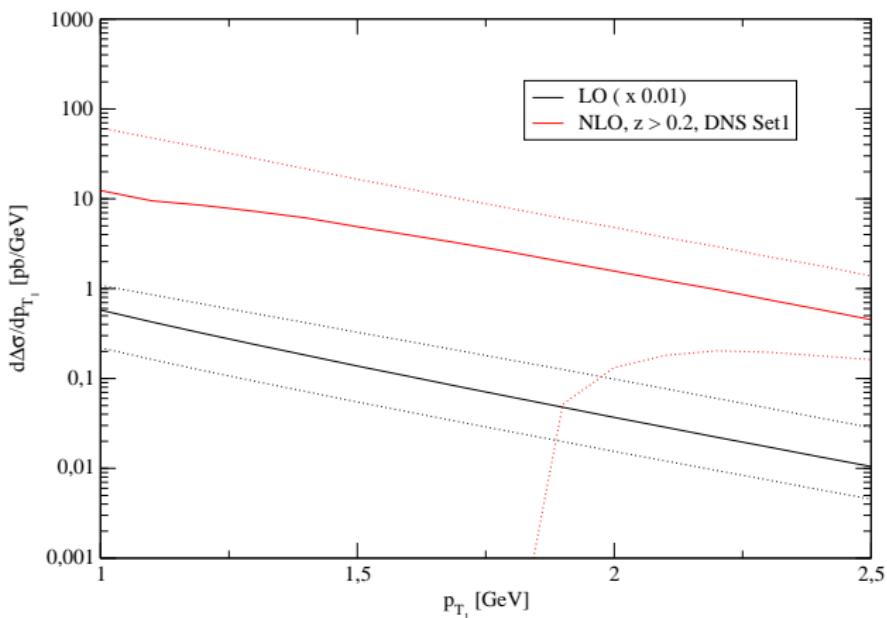
Unpolarized cross section @ COMPASS: LO vs. NLO

Scale dependence



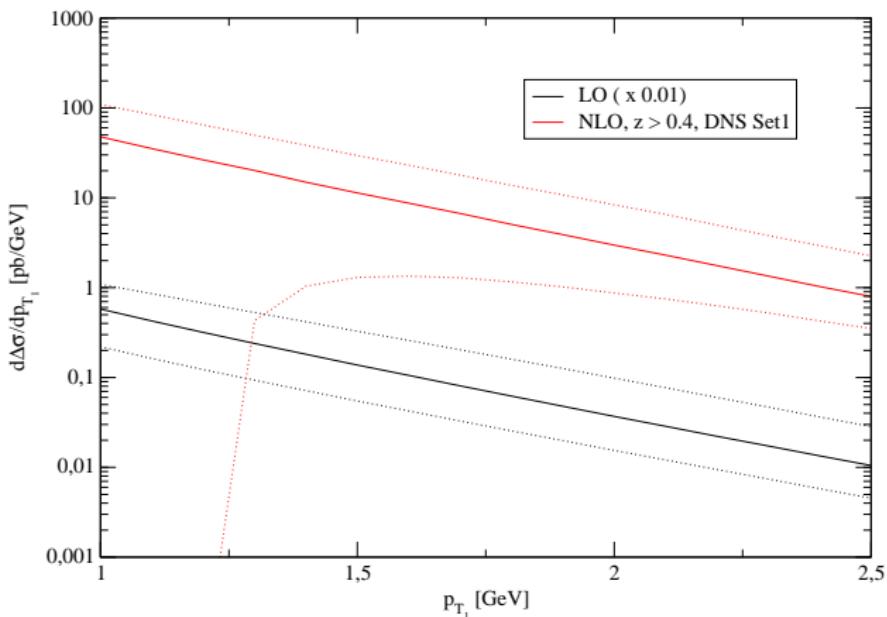
Polarized cross section @ COMPASS: LO vs. NLO

Scale dependence



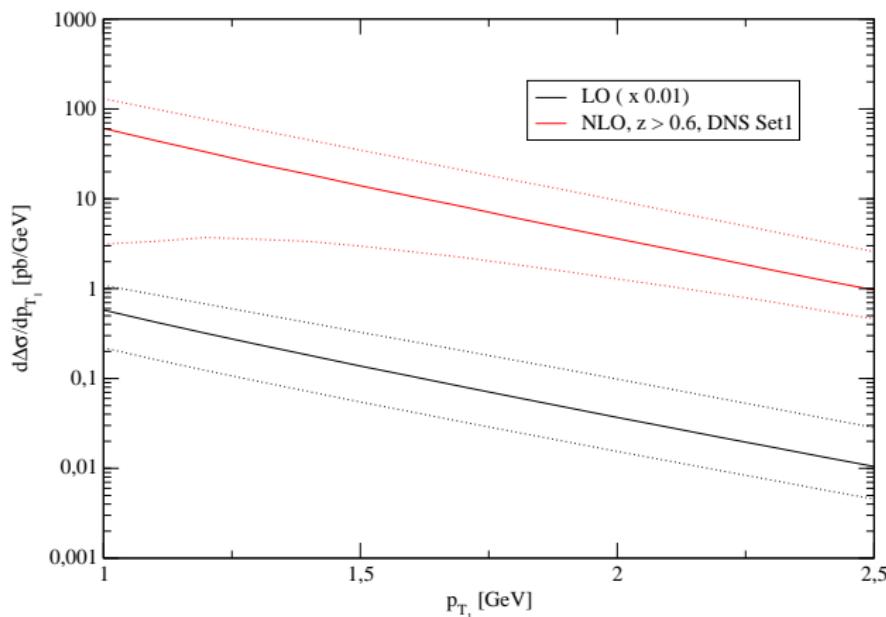
Polarized cross section @ COMPASS: LO vs. NLO

Scale dependence



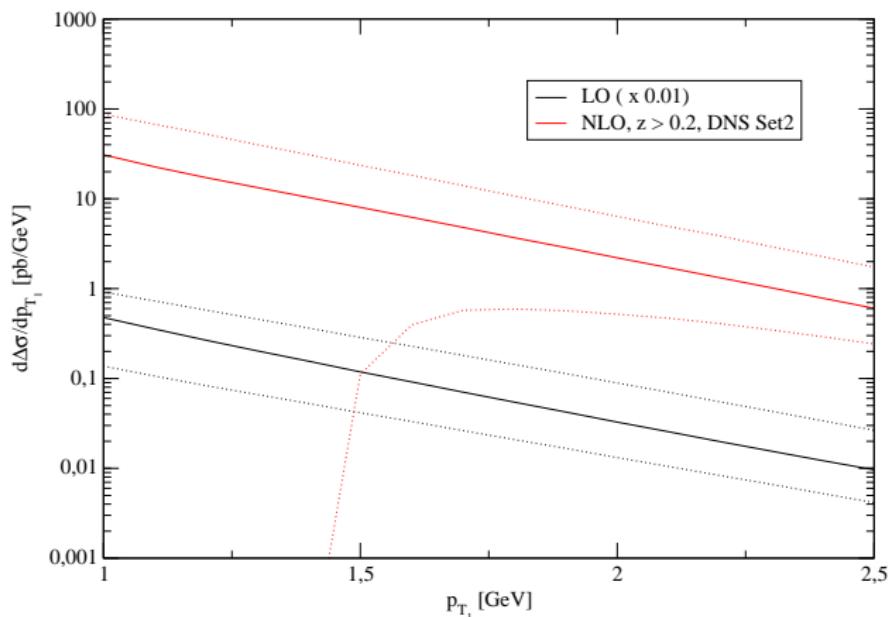
Polarized cross section @ COMPASS: LO vs. NLO

Scale dependence



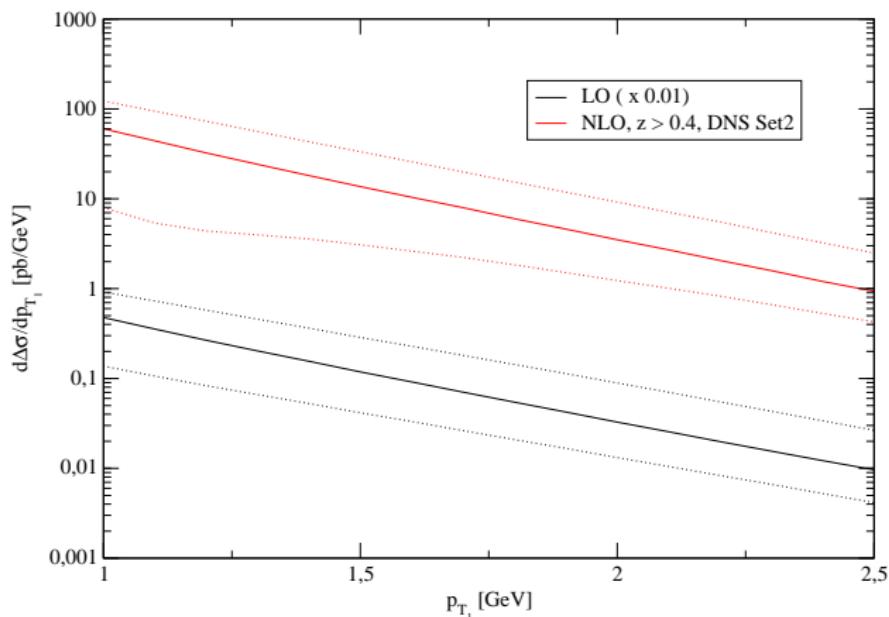
Polarized cross section @ COMPASS: LO vs. NLO

Scale dependence



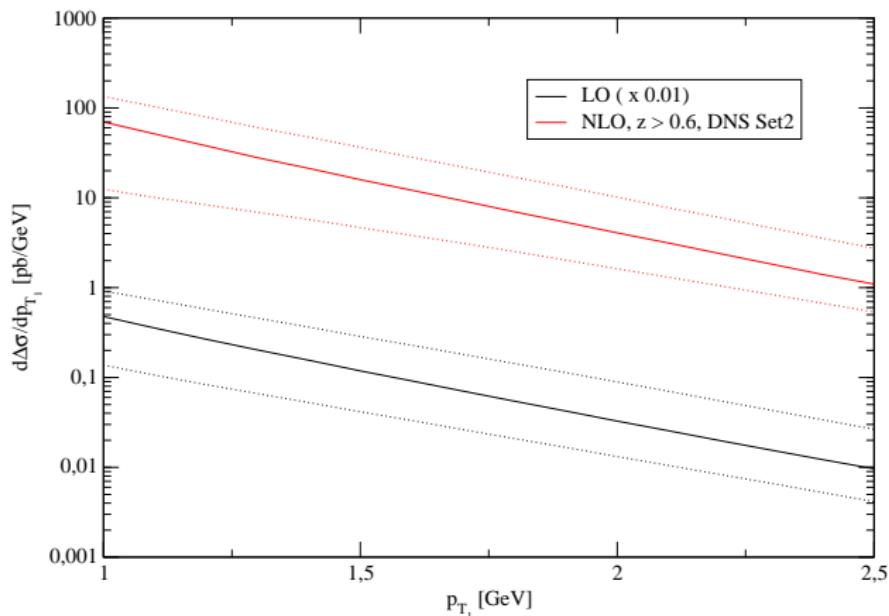
Polarized cross section @ COMPASS: LO vs. NLO

Scale dependence



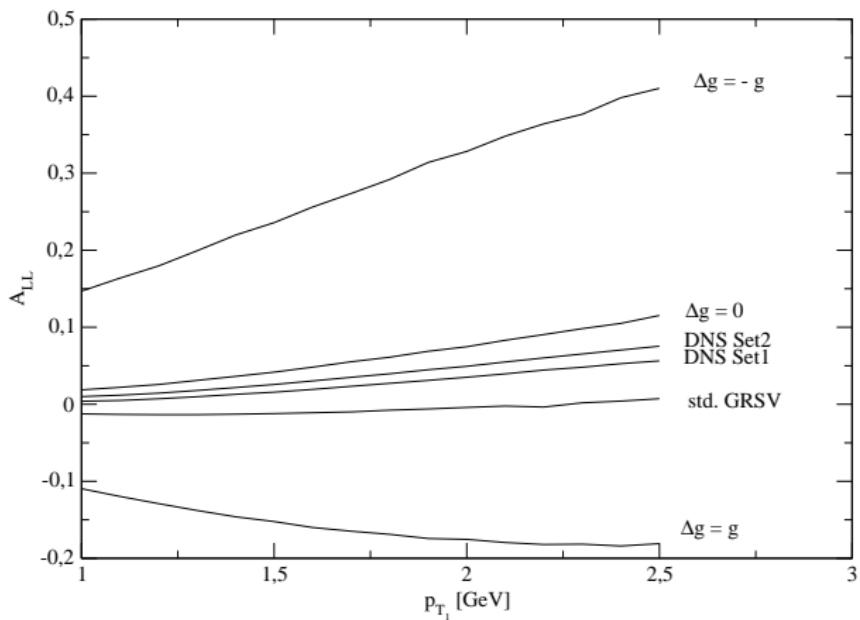
Polarized cross section @ COMPASS: LO vs. NLO

Scale dependence



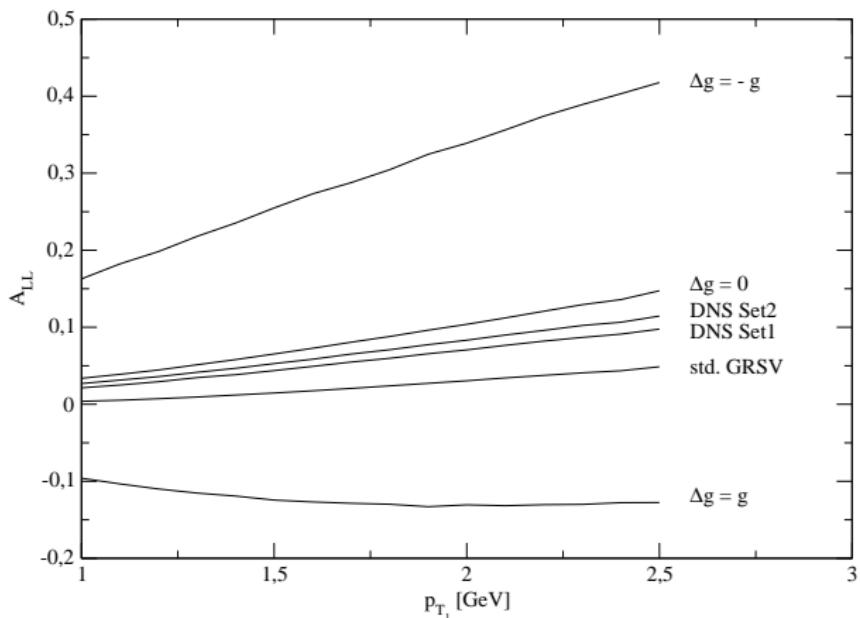
Double Spin Asymmetry A_{LL} @ COMPASS

$z > 0.2$



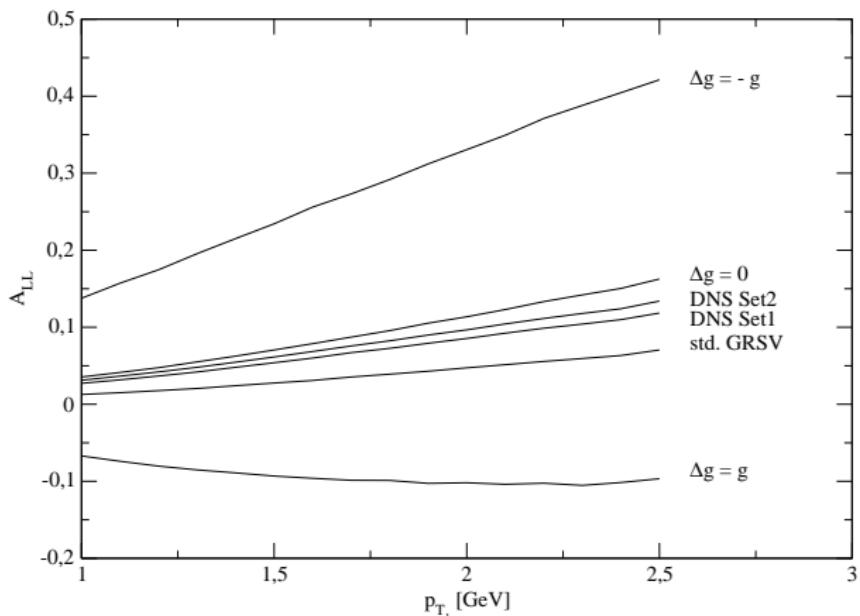
Double Spin Asymmetry A_{LL} @ COMPASS

$z > 0.4$

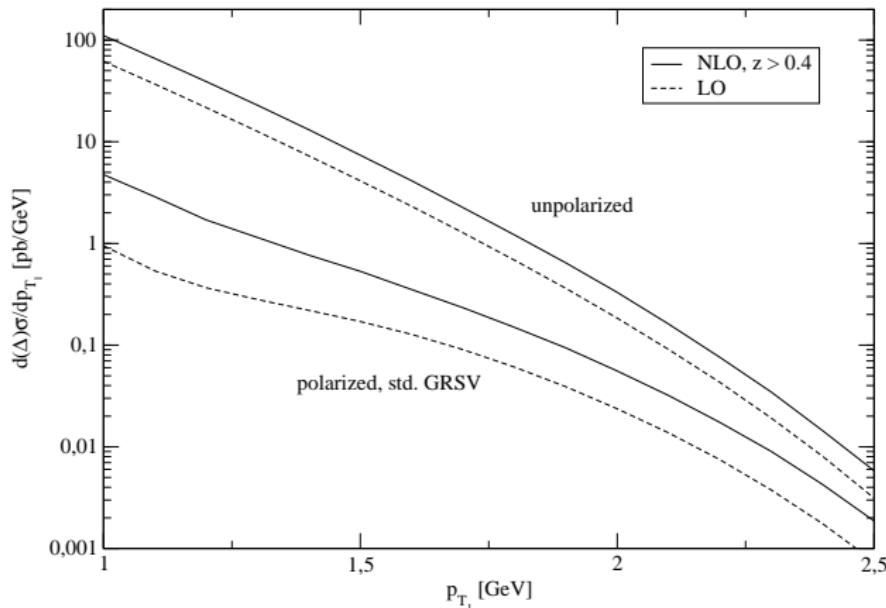


Double Spin Asymmetry A_{LL} @ COMPASS

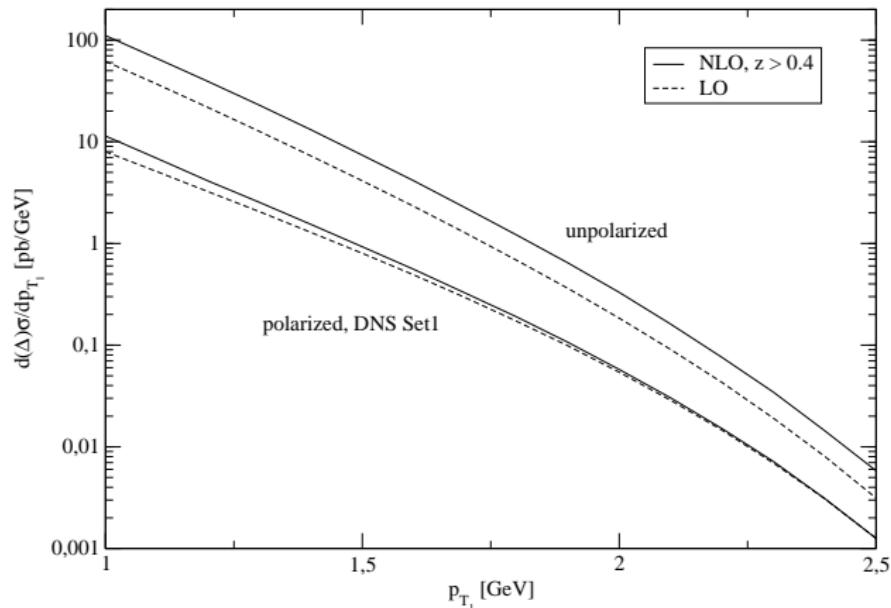
$z > 0.6$



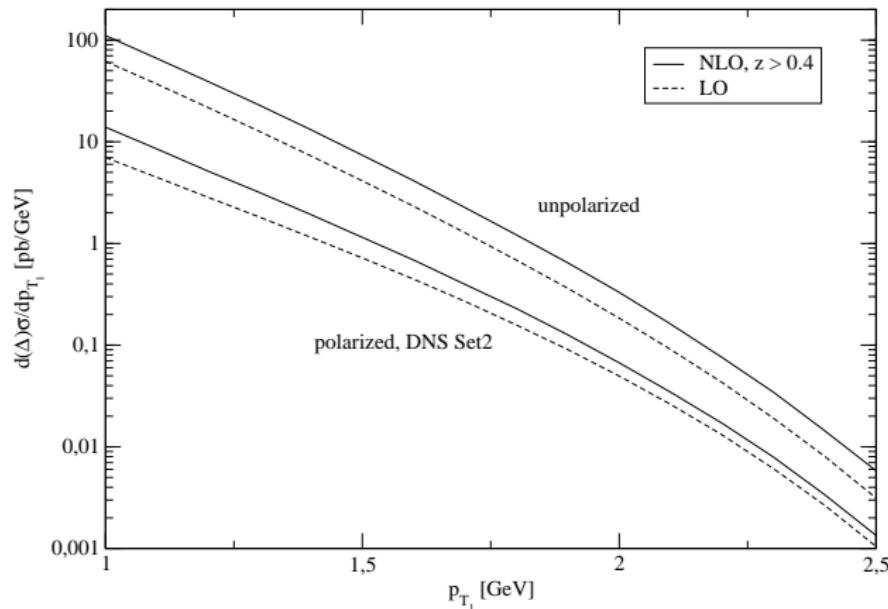
Cross sections @ HERMES: LO vs. NLO



Cross sections @ HERMES: LO vs. NLO

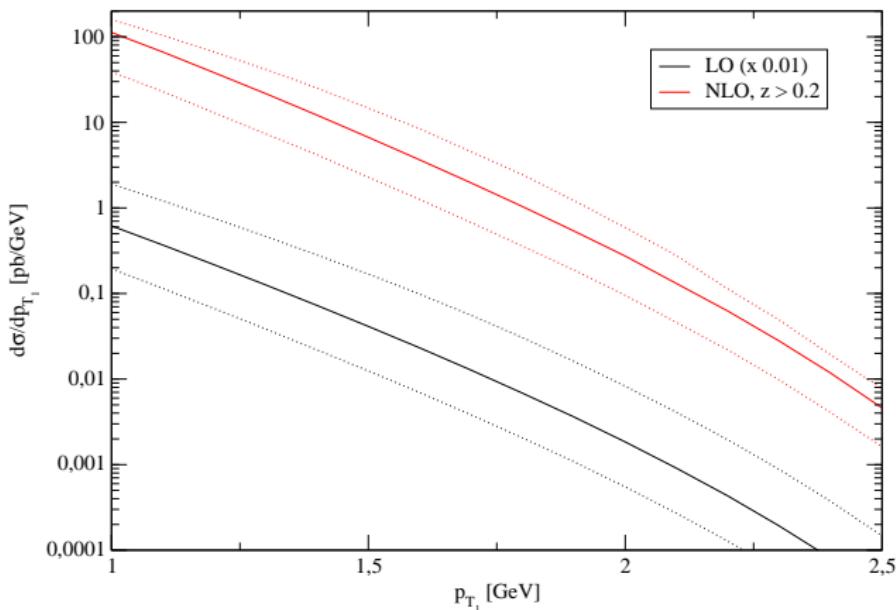


Cross sections @ HERMES: LO vs. NLO



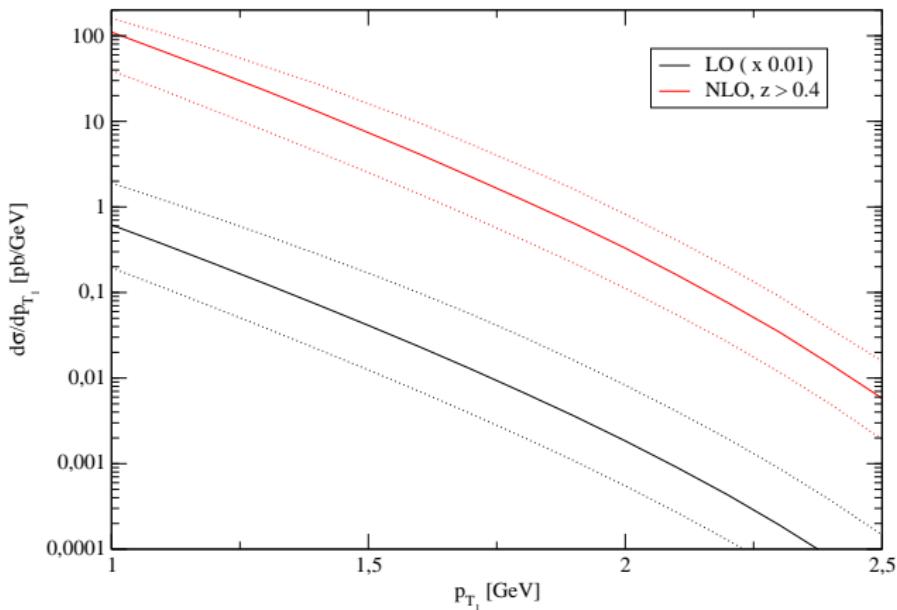
Unpolarized cross section @ HERMES: LO vs. NLO

Scale dependence



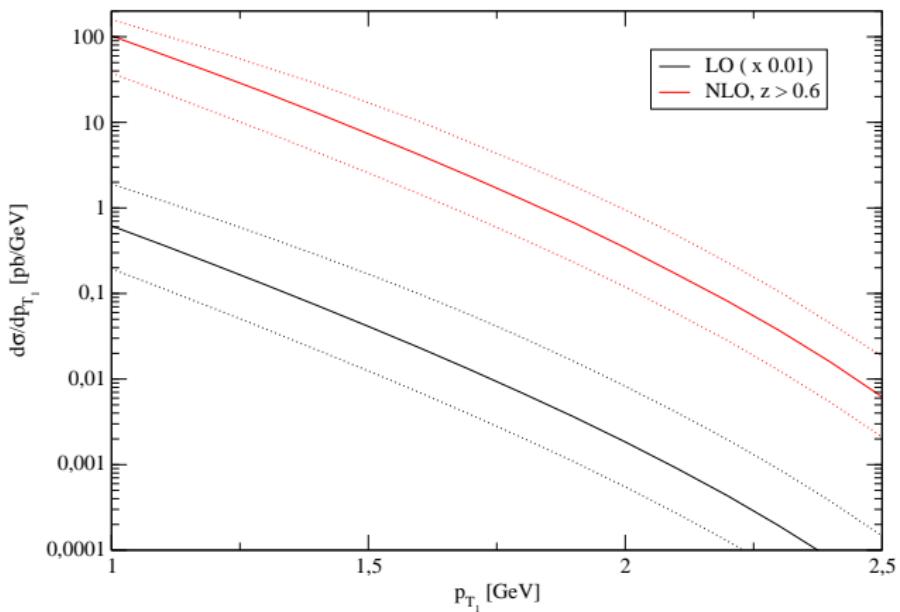
Unpolarized cross section @ HERMES: LO vs. NLO

Scale dependence



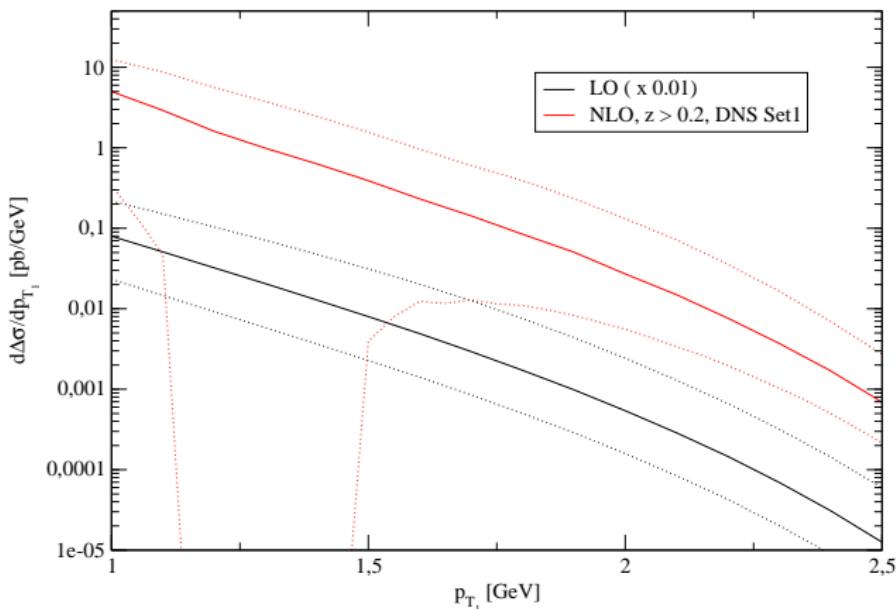
Unpolarized cross section @ HERMES: LO vs. NLO

Scale dependence



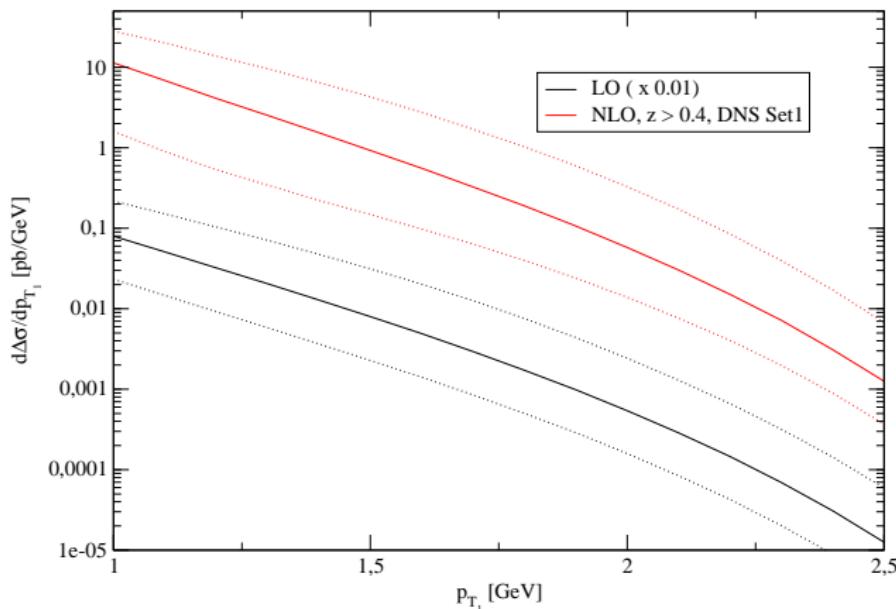
Polarized cross section @ HERMES: LO vs. NLO

Scale dependence



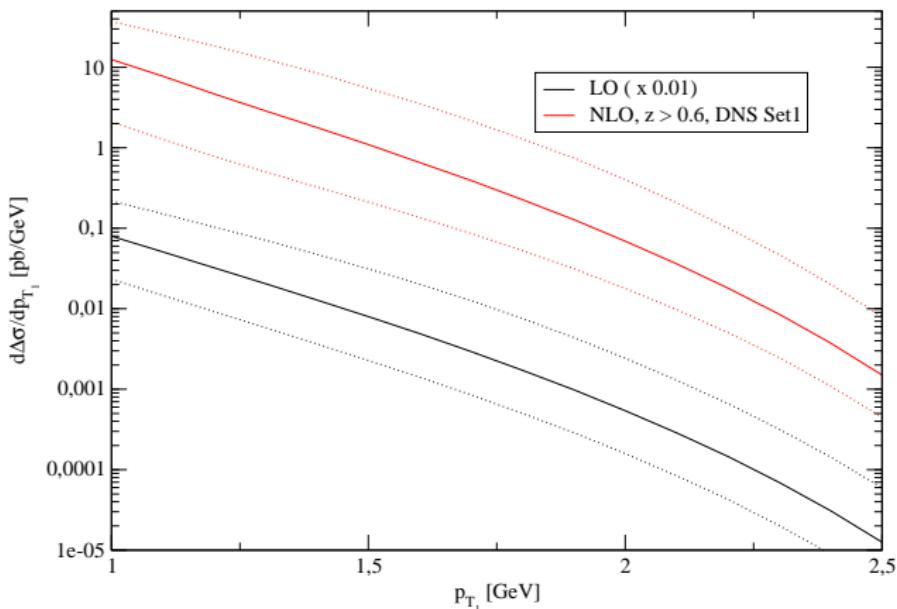
Polarized cross section @ HERMES: LO vs. NLO

Scale dependence



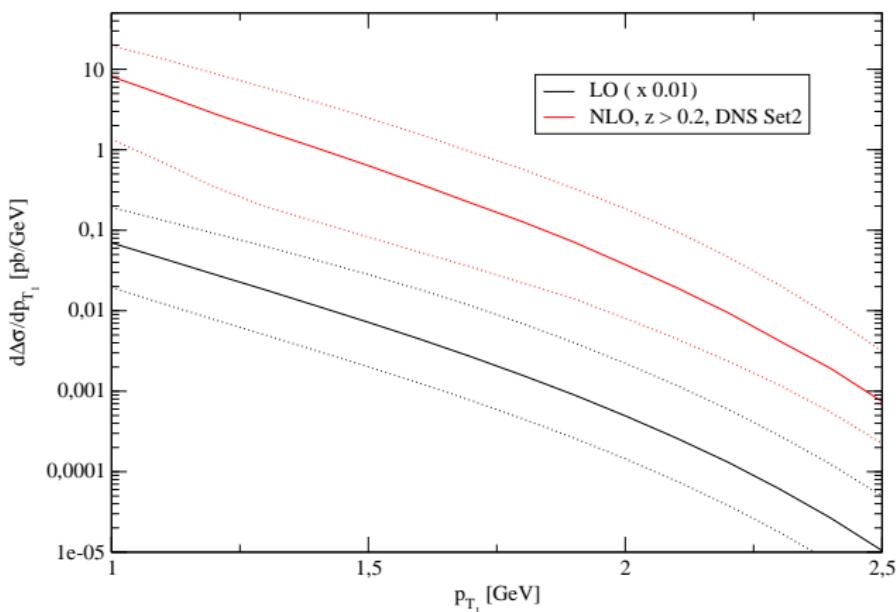
Polarized cross section @ HERMES: LO vs. NLO

Scale dependence



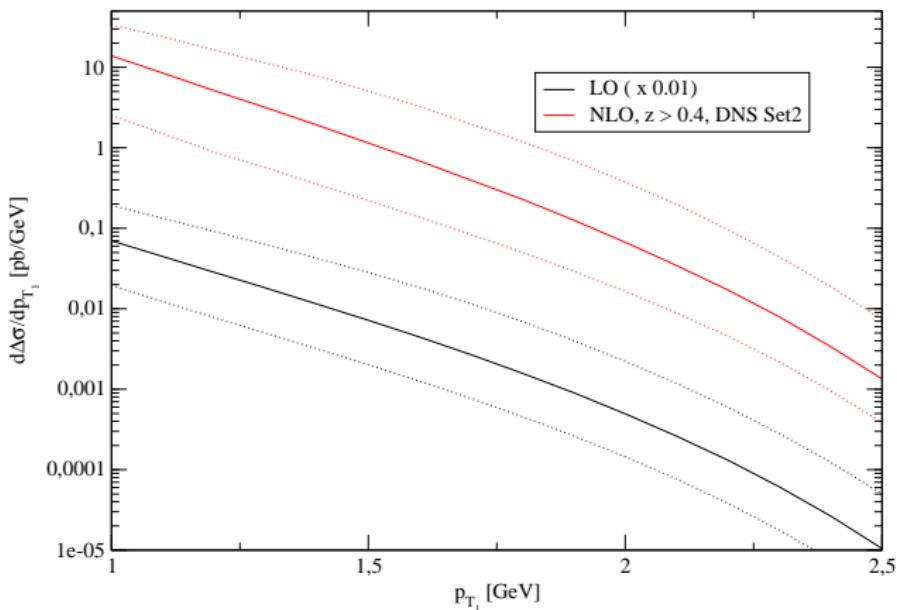
Polarized cross section @ HERMES: LO vs. NLO

Scale dependence



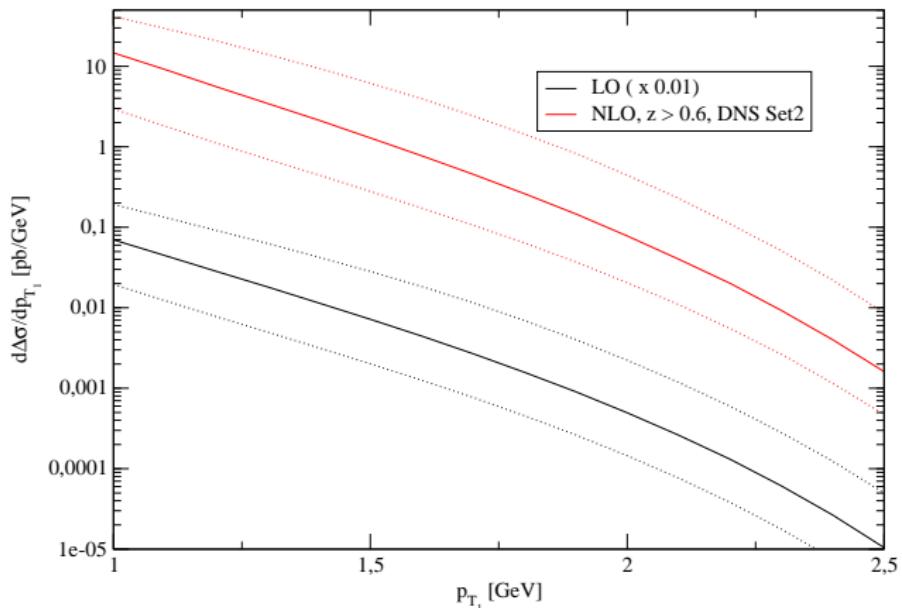
Polarized cross section @ HERMES: LO vs. NLO

Scale dependence



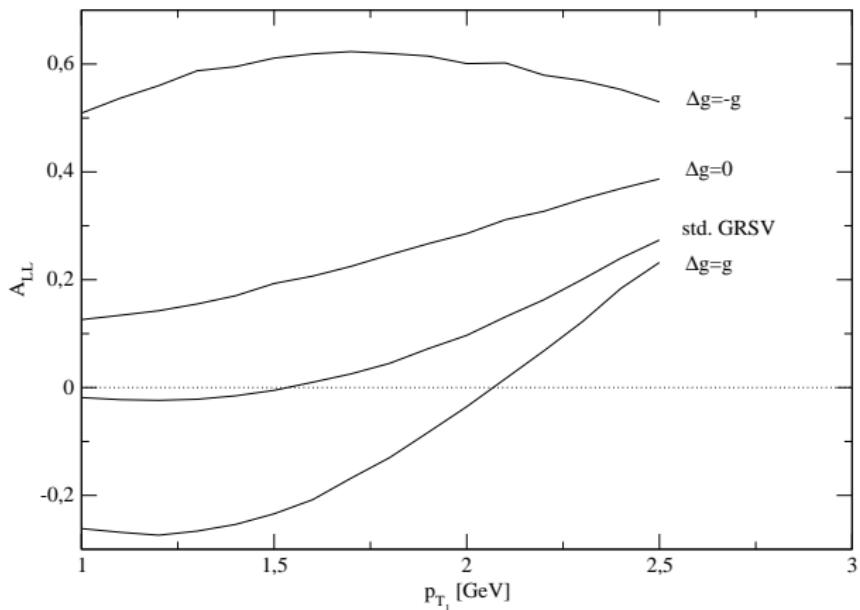
Polarized cross section @ HERMES: LO vs. NLO

Scale dependence



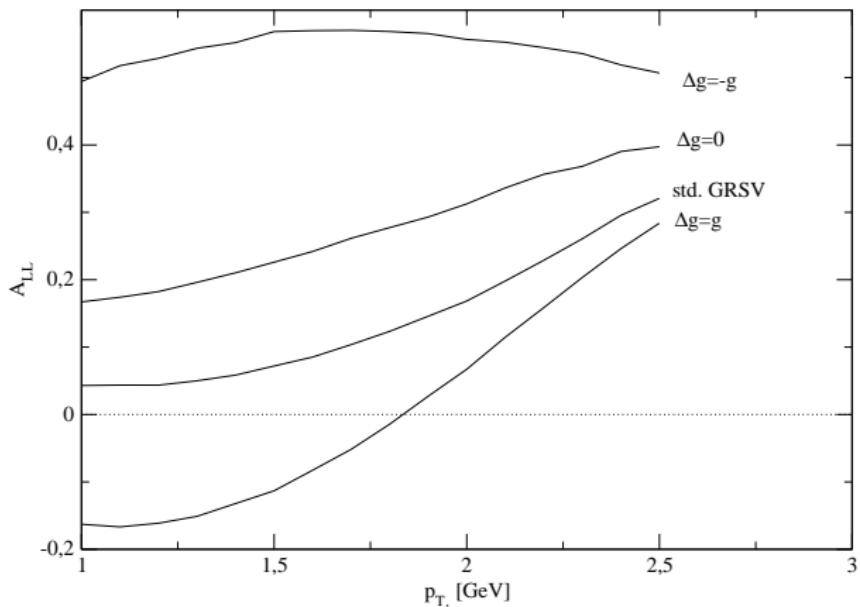
Double Spin Asymmetry A_{LL} @ HERMES

$z > 0.2$



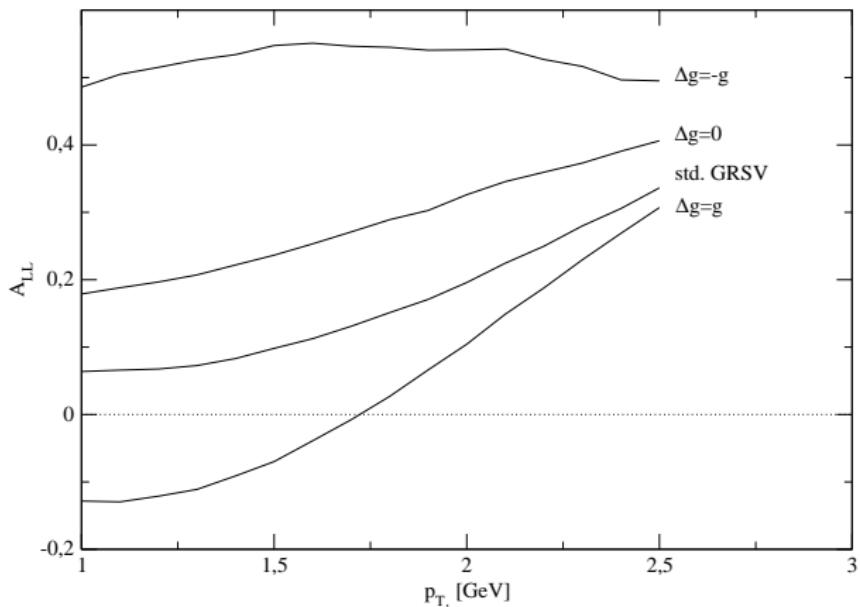
Double Spin Asymmetry A_{LL} @ HERMES

$z > 0.4$



Double Spin Asymmetry A_{LL} @ HERMES

$z > 0.6$



Summary and Outlook

- Photoproduction of high- p_T hadrons are good candidates for accessing the polarized gluon content inside the nucleon
- theoretical framework for single inclusive hadrons and hadron pairs is developed

This still has to be done...

- compare unpolarized data with theoretical predictions to verify applicability of pQCD for fixed-target experiments
- one further step: electroproduction ($Q^2 > 0$) of high- p_T hadrons

Acknowledgments

Thank you for invitation!

Thanks to: Stefan Solbrig for the fancy clock! ;-)