Photoproduction Of Hadron Pairs At Fixed-Target Experiments

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with
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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:

$$\Delta\Sigma \sim 0.25$$

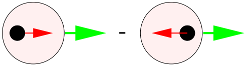
$\rightsquigarrow$ sizable contribution from gluon spin $\Delta G(Q^2)$
or orbital angular momenta $L_{q,g}(Q^2)$

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:

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

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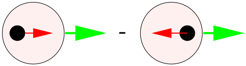
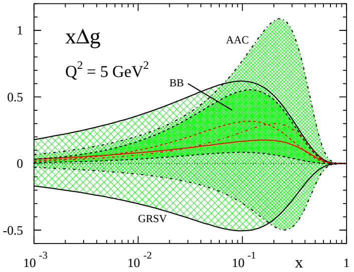


- extraction of $\Delta g(x, Q^2)$ via polarized DIS:

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

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

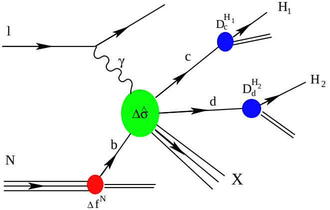
$\rightsquigarrow$ study other processes, where Δg enters at LO, e. g. charm, prompt photon, heavy quarks, single hadron, hadron pair production

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 $(\Delta)f^N$, fragmentation functions $D_c^{H_1}$, $D_d^{H_2}$
perturbative ingredients: hard partonic cross section $(\Delta)\hat{\sigma}$

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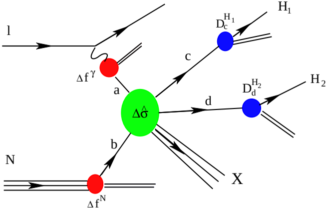

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parton distribution function $(\Delta)f^N(\Delta)f^{\gamma}$, fragmentation functions $D_c^{H_1}$, $D_d^{H_2}$

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

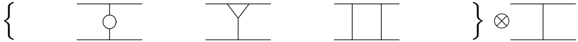
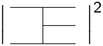
The hadronic cross section

- 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 $a\,b \longrightarrow c\,d$

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

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

pQCD at NLO

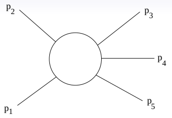
- What contributes in NLO?
  ⇝ virtual contributions: selfenergies, vertex corrections, box diagrams in interference with appropriate born diagrams
  $\gamma g \to q\bar{q}$ and $\gamma q \to gq$
  
  ⇝ real contributions: all possible $2 \to 3$ diagrams
  $\gamma q \to q'\bar{q}'q$, $\gamma q \to q\bar{q}q$, $\gamma q \to ggq$, $\gamma g \to q\bar{q}g$
  

- Phasespace for virtual contributions: $2 \to 2$ kinematics, like in LO

$$
\begin{aligned}
dPS_2 &= \int \frac{d^n p_3}{(2\pi)^{n-1}} \frac{d^n p_4}{(2\pi)^{n-1}} (2\pi)^n \delta(p_1 + p_2 - p_3 - p_4) \delta(p_3^2) \delta(p_4^2) \\
&= \frac{1}{\Gamma(1-\varepsilon)} \left(\frac{1}{4\pi}\right)^{1-\varepsilon} \frac{1}{2\hat{s}} \left(\frac{\hat{t}\hat{u}}{\hat{s}}\right)^{-\varepsilon} \delta(\hat{s} + \hat{t} + \hat{u}) d\hat{u}\, d\hat{t}
\end{aligned}
$$

with $\hat{s} \equiv (p_1 + p_2)^2$, $\hat{t} \equiv (p_1 - p_3)^2$, $\hat{u} \equiv (p_1 - p_4)^2$

pQCD at NLO



- the $2 \longrightarrow 3$ phase space:

$$dPS_3 = \int \frac{d^n p_3}{(2\pi)^{n-1}} \frac{d^n p_4}{(2\pi)^{n-1}} \frac{d^n p_5}{(2\pi)^{n-1}} (2\pi)^n \delta(p_1 + p_2 - p_3 - p_4 - p_5) \delta(p_3^2) \delta(p_4^2)$$
$$\times \delta(p_5^2) \delta\left(v - 1 - \frac{\hat{t}}{\hat{s}}\right) \delta\left(w + \frac{\hat{u}}{\hat{s} + \hat{t}}\right) \delta(z - m \cdot p_4)$$

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

leads to:

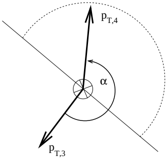
$$dPS_3 = \frac{\pi \hat{s}}{8(2\pi)^5} \left(\frac{4\pi}{\hat{s}}\right)^{\varepsilon} \frac{v}{\Gamma(1-2\varepsilon)} \left(\frac{4\pi}{\hat{s} v w (1-v)}\right)^{\varepsilon} v^{-\varepsilon} (1-w)^{-\varepsilon} 2 \sqrt{\frac{w(1-v)}{1-vw}}$$
$$\times \left(\frac{1 - w + 4w(1-v)z(1-z)}{1-vw}\right)^{-\varepsilon} \int_0^{\pi} d\theta_2 \sin^{-2\varepsilon}(\theta_2)\, dv\, dw\, dz$$

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

Aurenche et al., Z. Phys. C24, 309 (1984)

The z-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
  $\rightsquigarrow$ angle between hadrons: $\alpha \in [90^\circ, 270^\circ]$

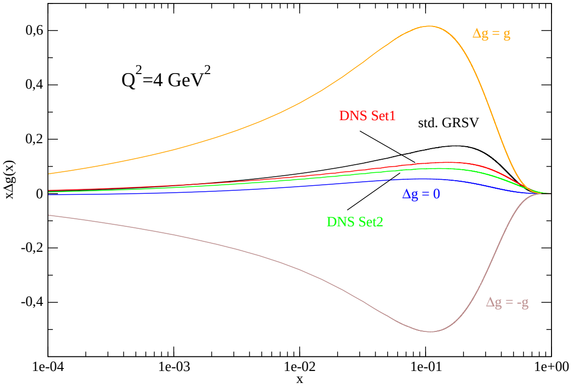


- information on second hadron via z-variable:
  $\rightsquigarrow$ no rapidity cut possible for second hadron
  $\rightsquigarrow$ cut on transverse momenta via z-variable:

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

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

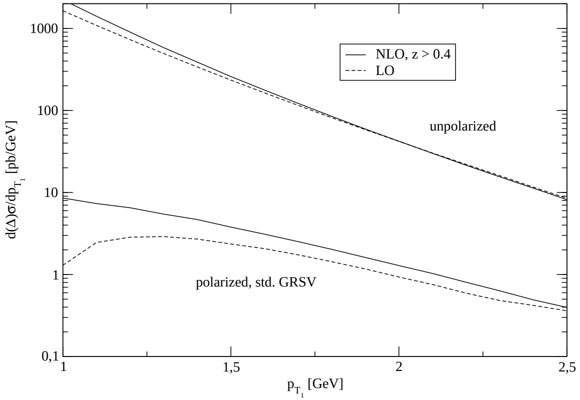
Different Gluon Distributions



GRSV: Phys. Rev. D63 (2001) 094005, DNS: Phys. Rev. D71 (2005) 094018

Cross sections @ COMPASS: LO vs. NLO

All results are preliminary!



LO: CH, Marco Stratmann, Andreas Schäfer, Eur. Phys. J. C **48**, 135 (2006)

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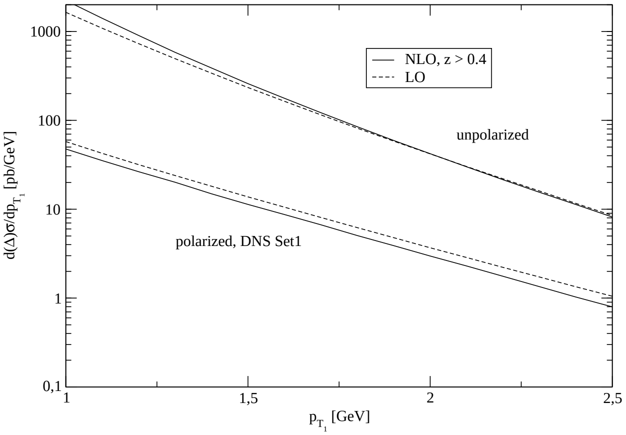

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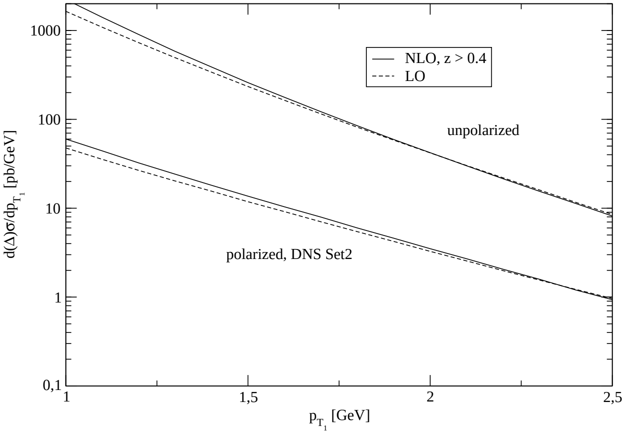
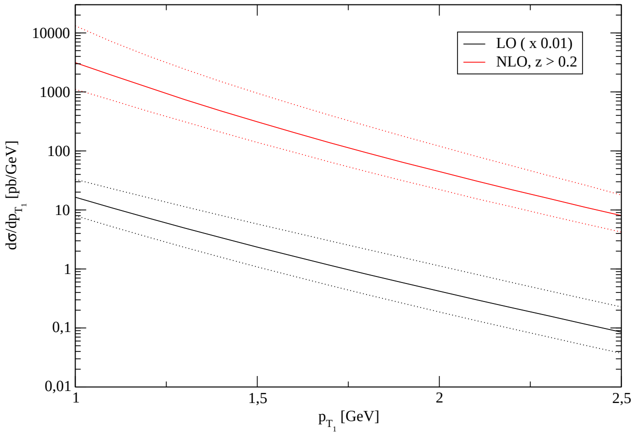


Unpolarized cross section @ COMPASS: LO vs. NLO

Scale dependence



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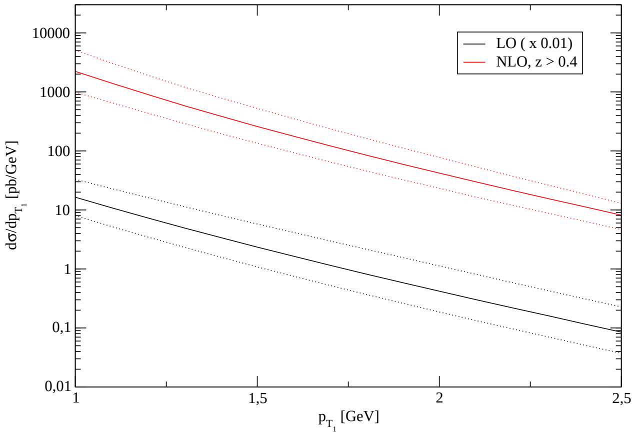

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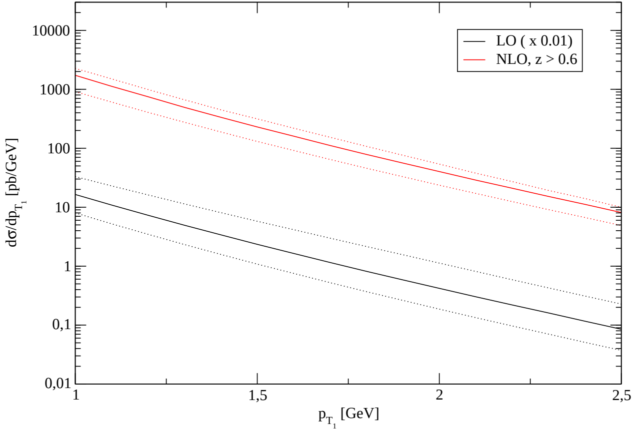

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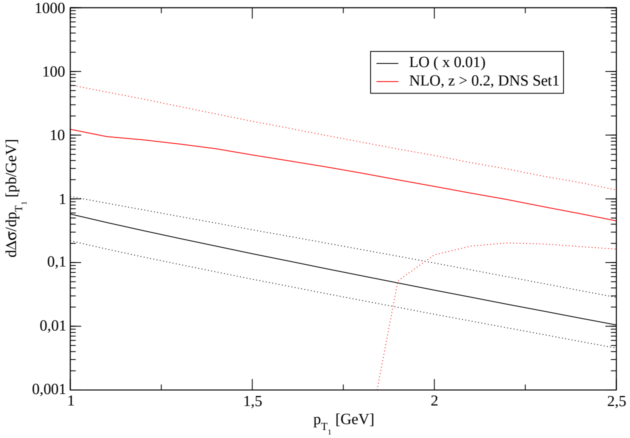

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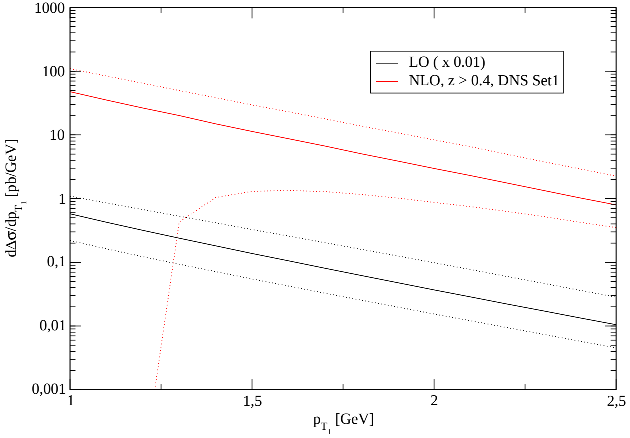

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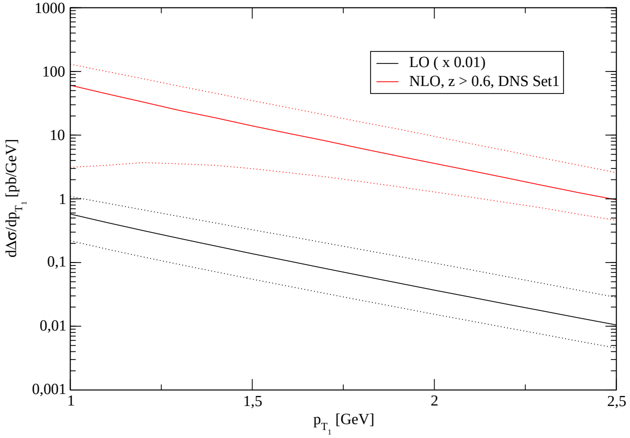

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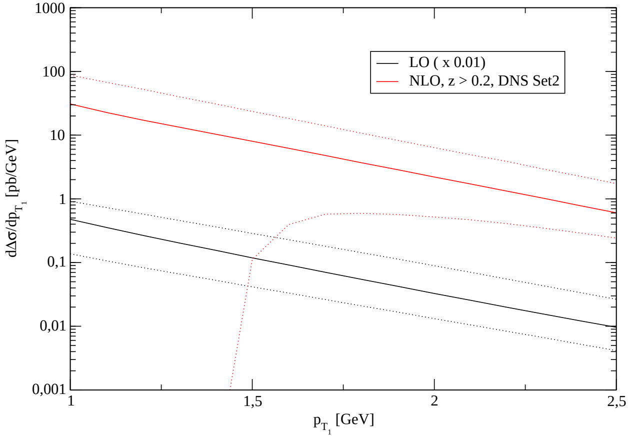

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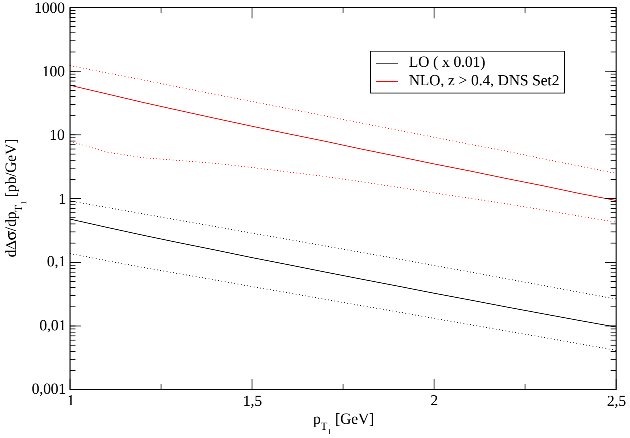

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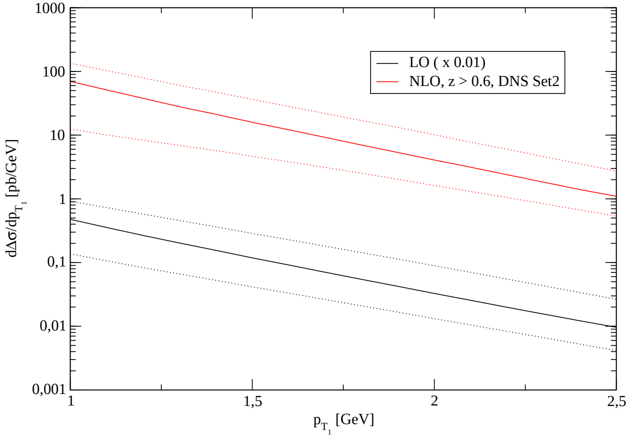
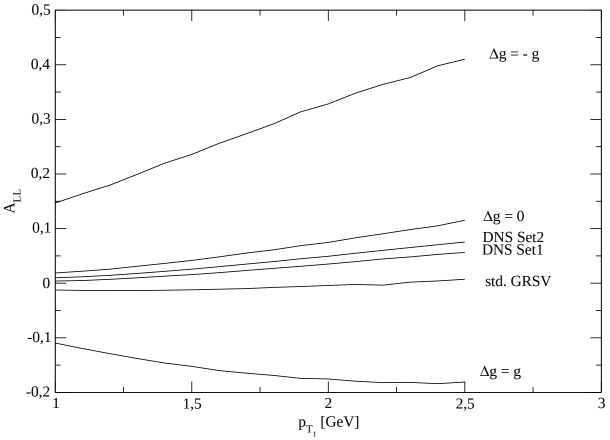


Double Spin Asymmetry A_{LL} @ COMPASS

$z > 0.2$



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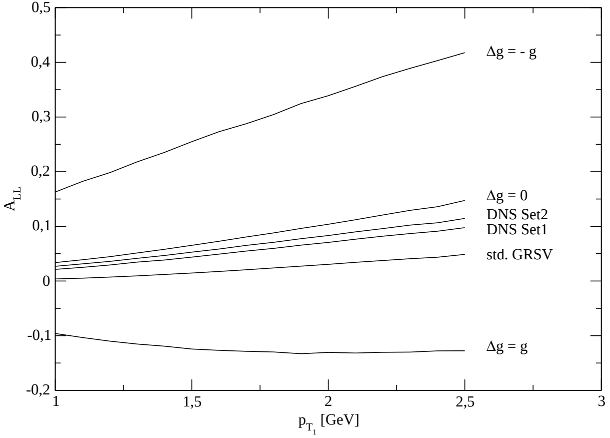
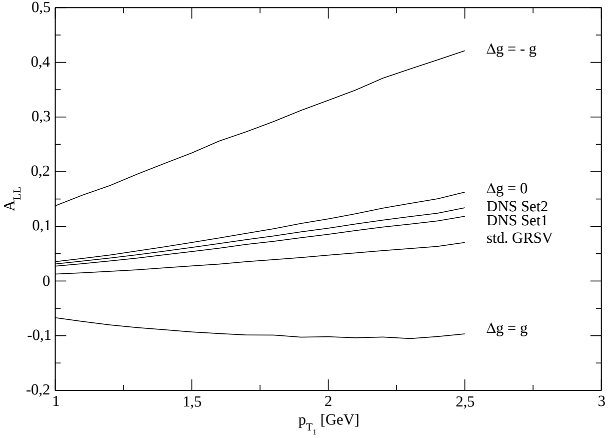
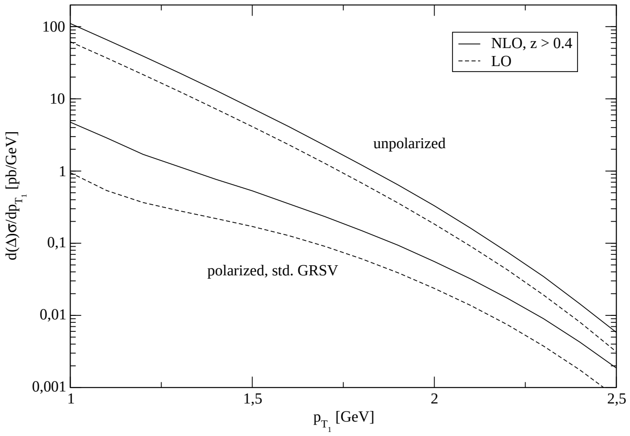


Double Spin Asymmetry A_{LL} @ COMPASS

$z > 0.6$



Cross sections @ HERMES: LO vs. NLO



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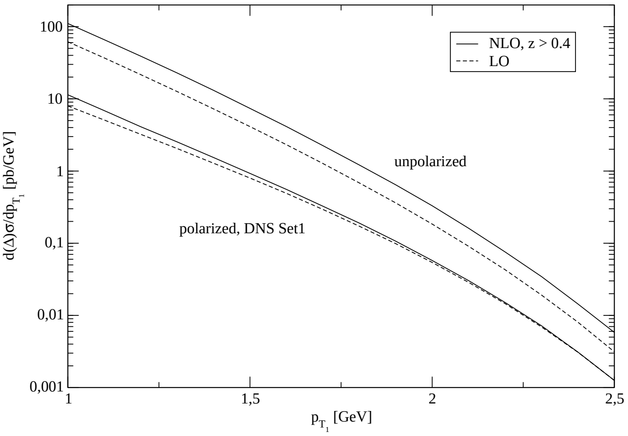

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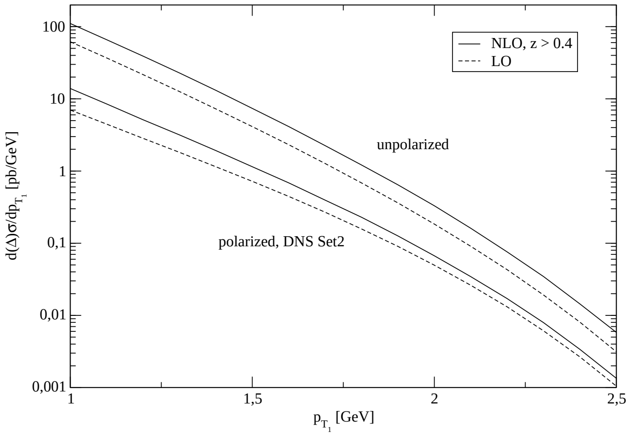

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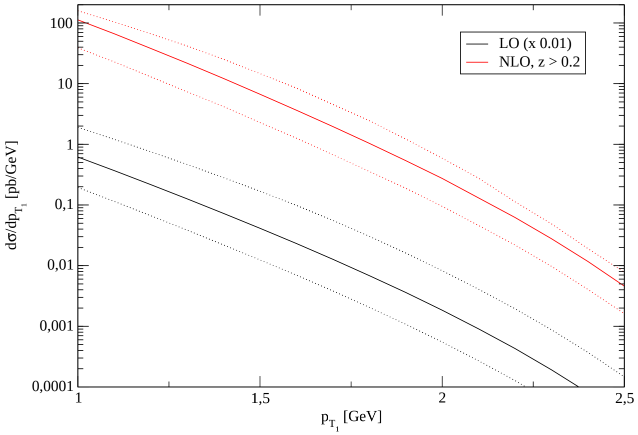

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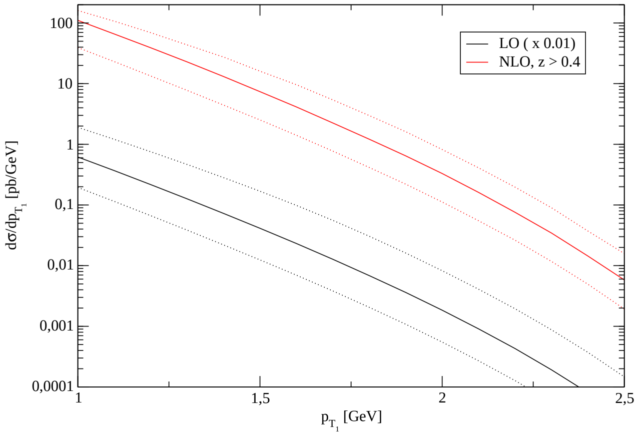

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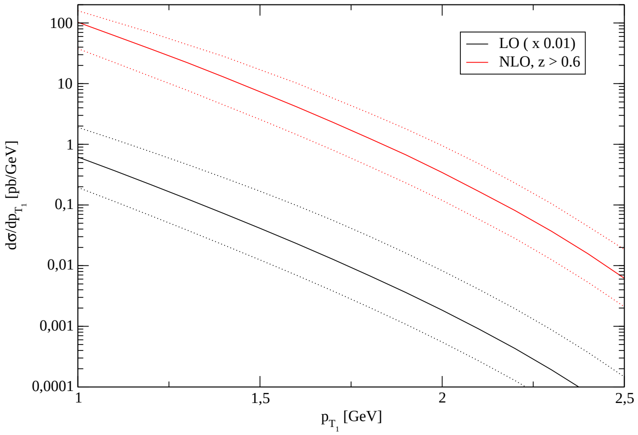

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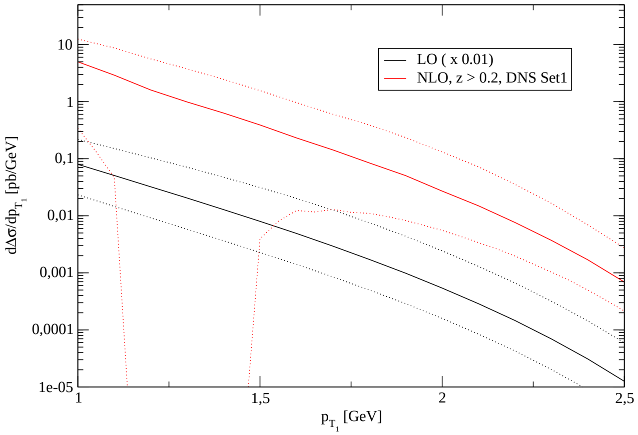

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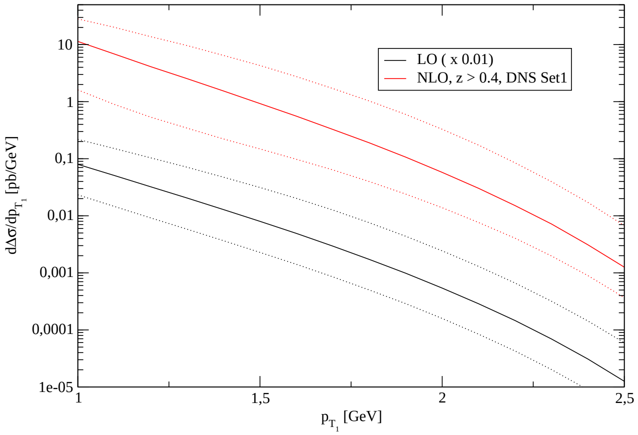

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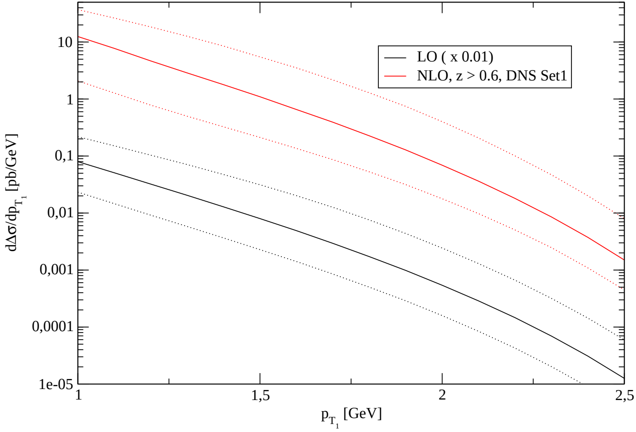

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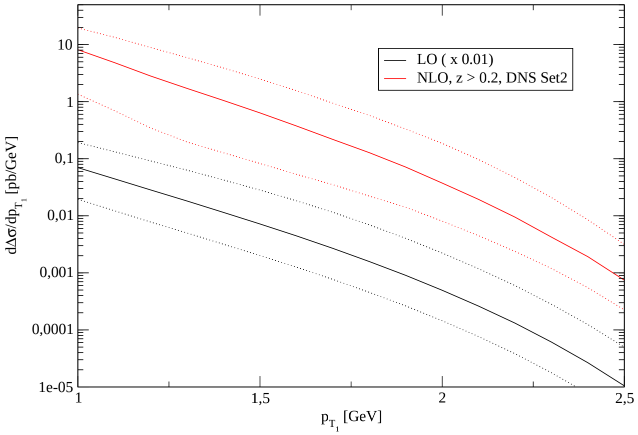

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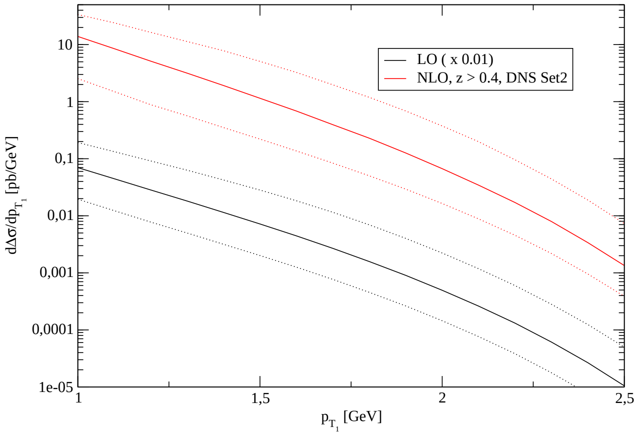

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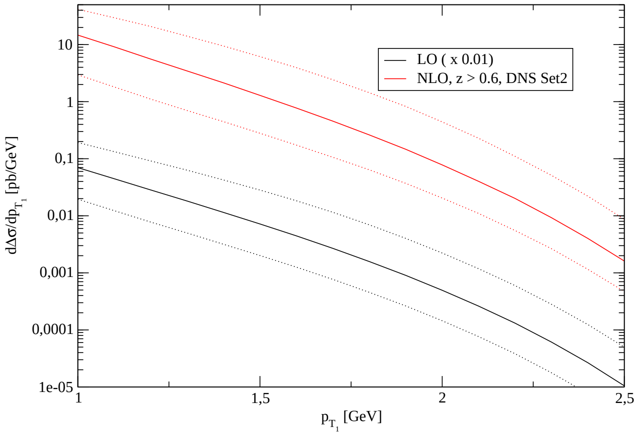

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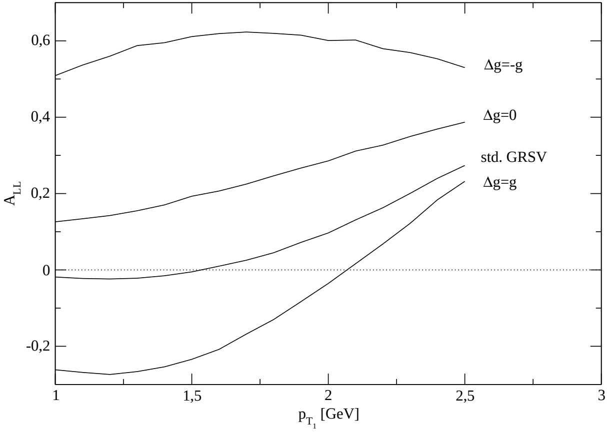

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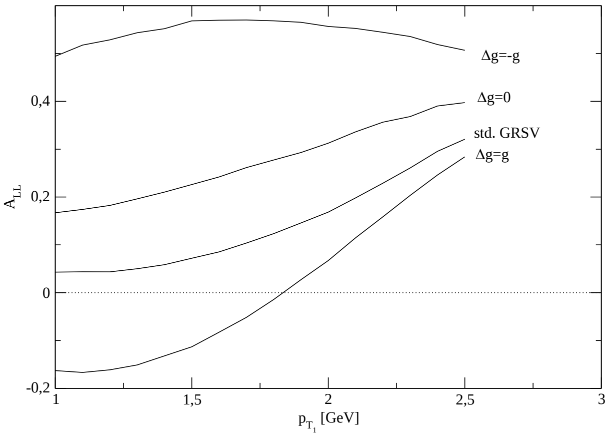

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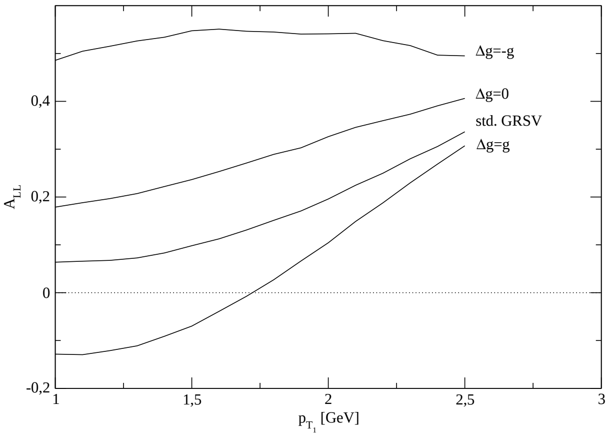

Summary and Outlook

- 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! ;-)