Accessing Δg at the other side of the Atlantic Ocean*

Marco Stratmann

- Some remarks on „How well do we know Δg ?“
- Δg from photoproduction processes
- Other processes sensitive to Δg

* you will find out which side I have in mind

How well do we know Δg ?

sometimes/often/always a controversial issue ...

pdfs with errors are now standard in the unpol.case

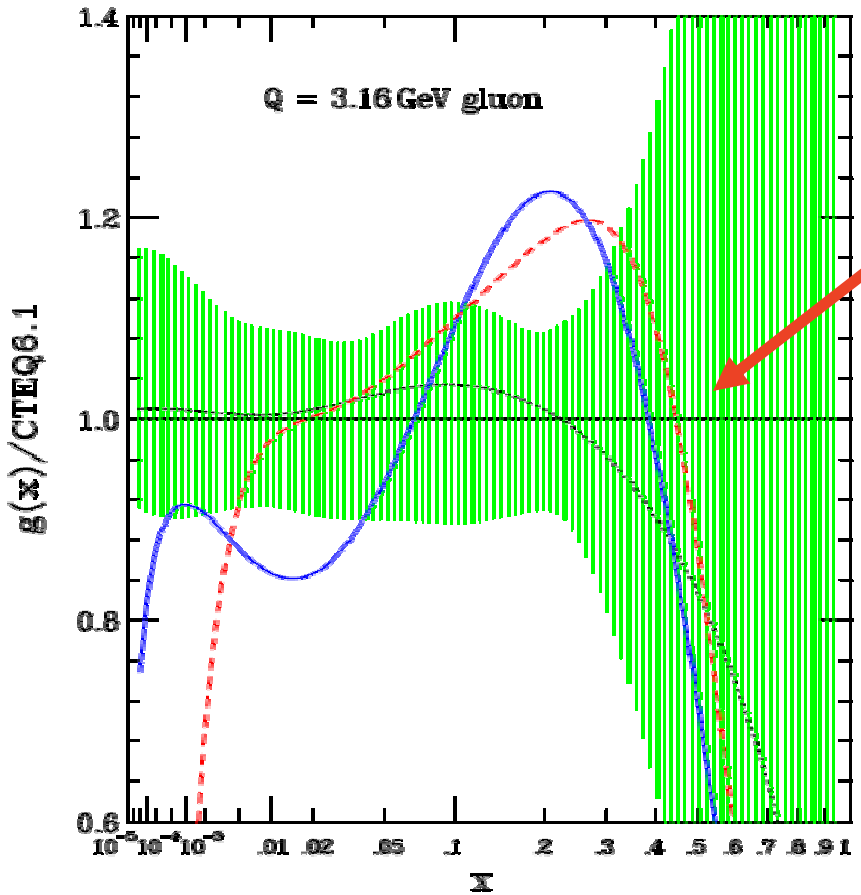
CTEQ, MRST

the definition of „error“ is art, science, and voodoo:

for the relevant fits. To quantitatively define a change of χ^2 that characterizes a significant change in the quality of the PDF fit is a difficult issue in global QCD analysis. In the context of the current analysis, we have argued that an increase by $\Delta\chi^2 \sim 100$ (for $\sim$ 2000 data points) represents roughly a 90% confidence level uncertainty on PDFs due to the uncertainties of the current input experimental data [9, 13–15]. In other words, PDFs with $\chi^2 - \chi^2_{\text{BestFit}} > 100$ are regarded as not tolerated by current data. This *tolerance* will

quote from latest CTEQ paper

Status of unpol. gluon



unpol. gluon largely unknown for x>0.4

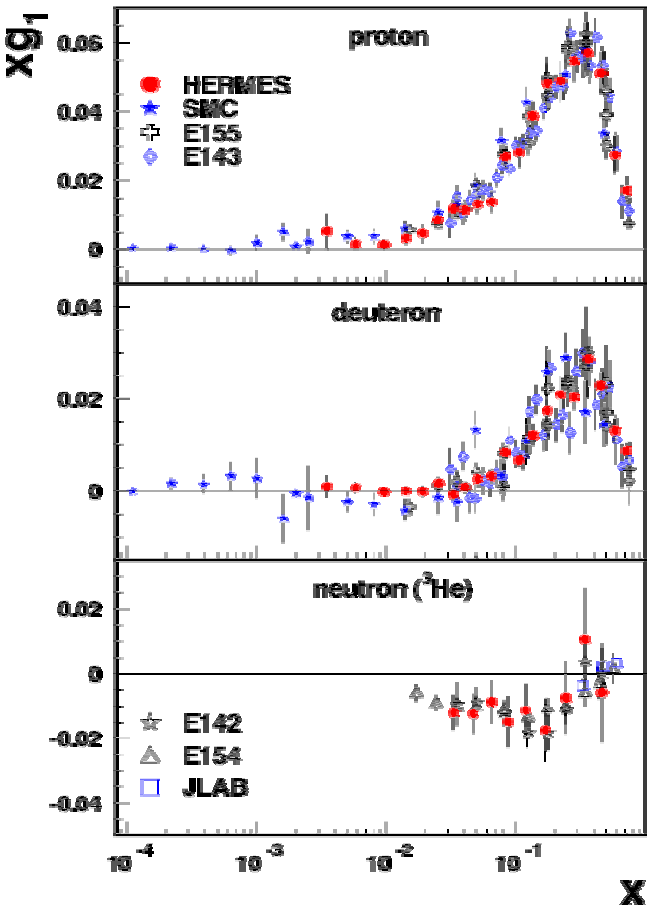
relevant for an extraction of Δg from a $\Delta g / g$ measurement

have to improve knowlegde of g(x)

Status of polarized gluon

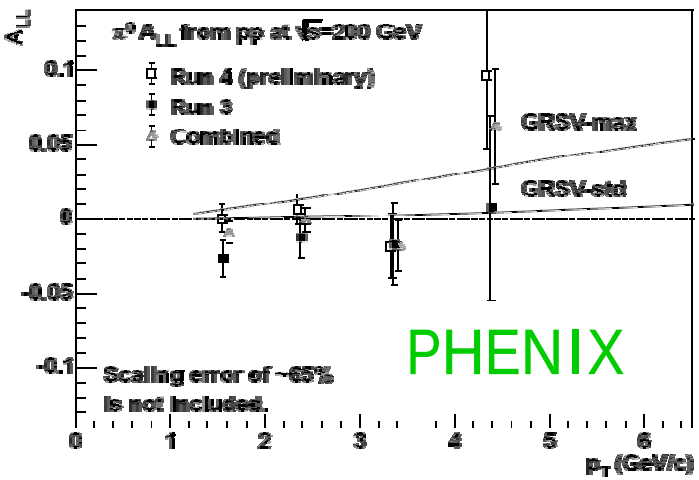
- current knowledge based on DIS data
- first attempts to quantify errors on polarized pdfs

Blümlein, Böttcher, de Nardo;
AAC; Leader, Sidorov, Stamenov

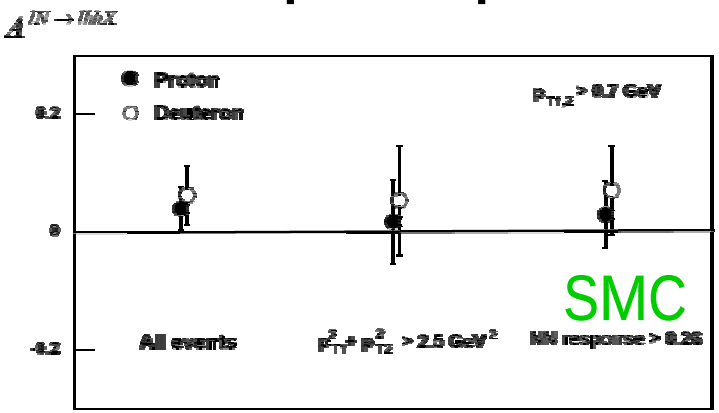


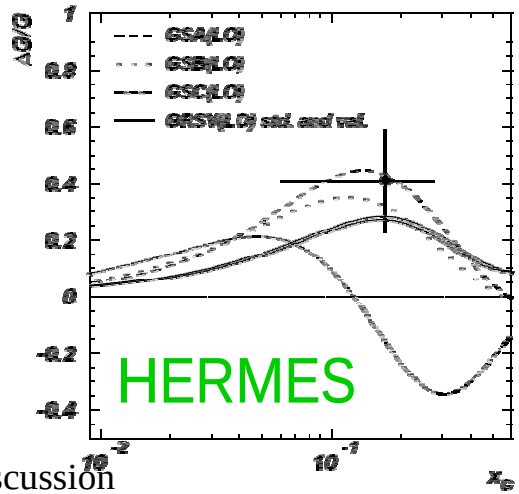
Some „direct“ measurements

from proton-proton:



from lepton-proton:

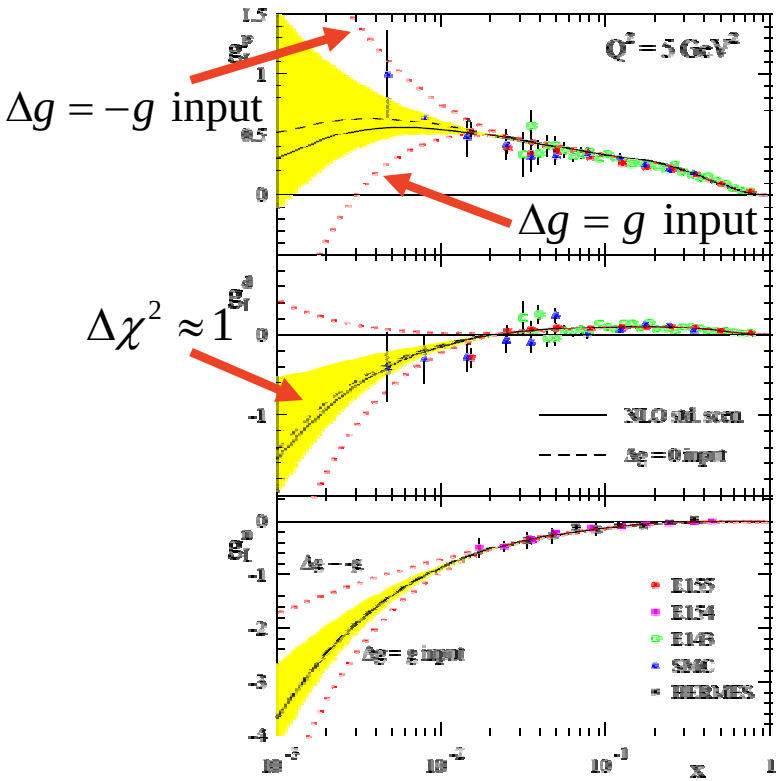




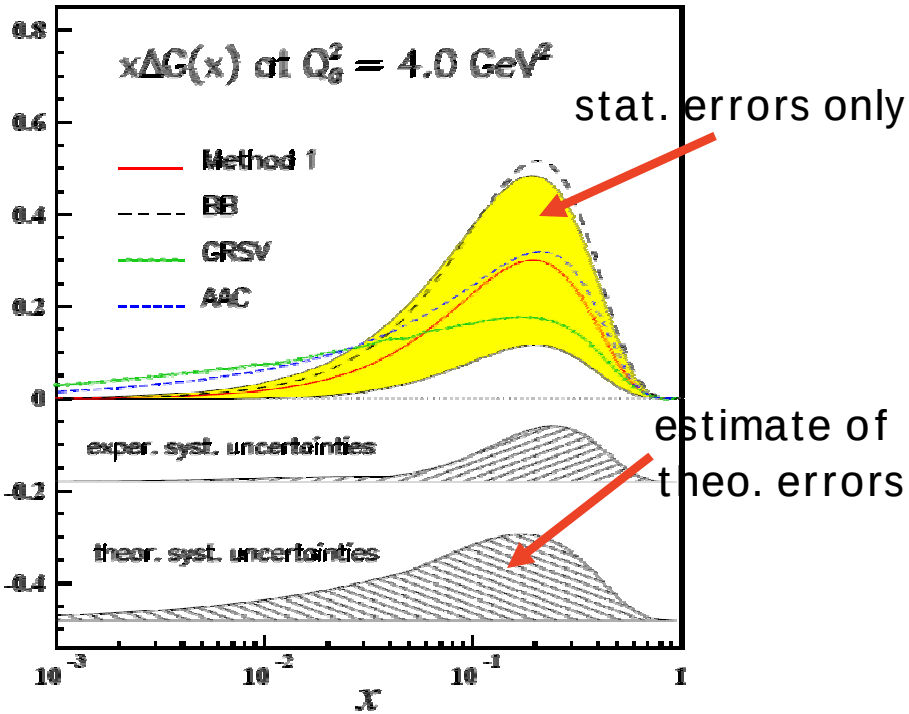
none of these results has been used in „global fits“ so far

Available results

GRSV : all Δg allowed by positivity do a good job



BB : full error analysis



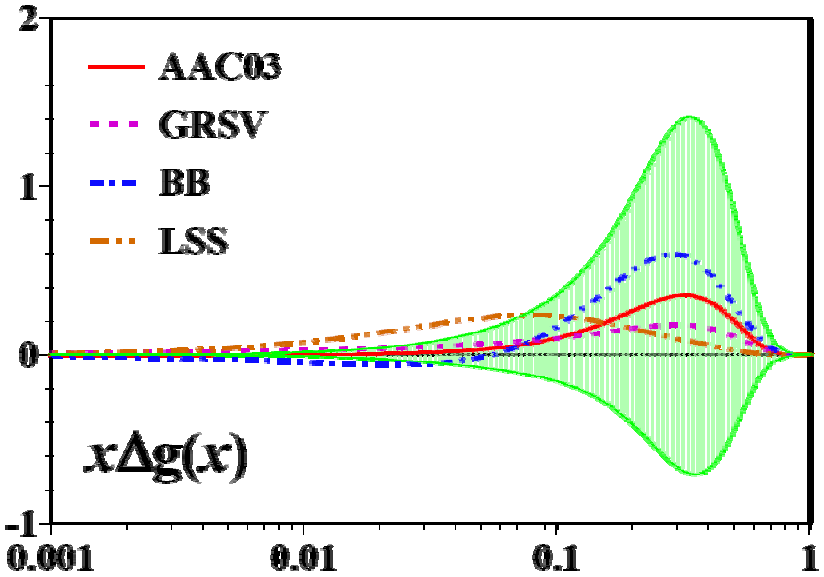
stat. errors only

estimate of theo. errors

Δg can be also negative

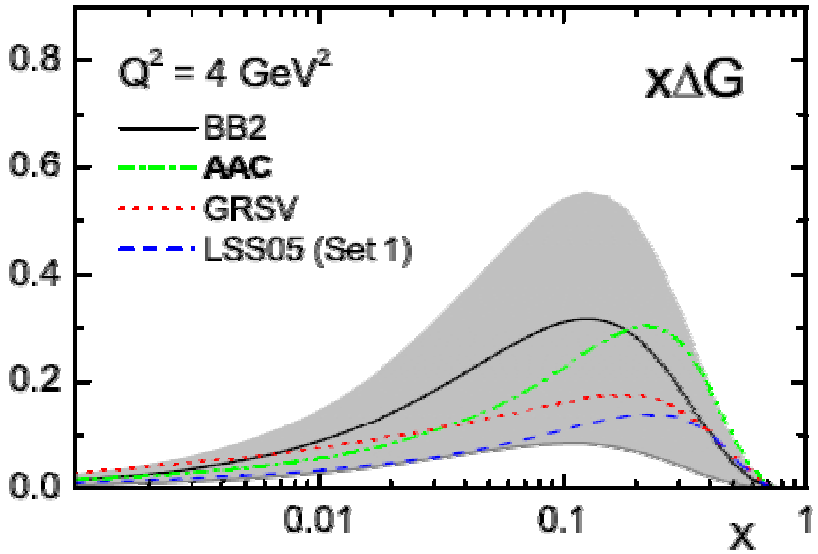
Available results (cont.)

AAC : sophisticated error analysis (Hessian method)



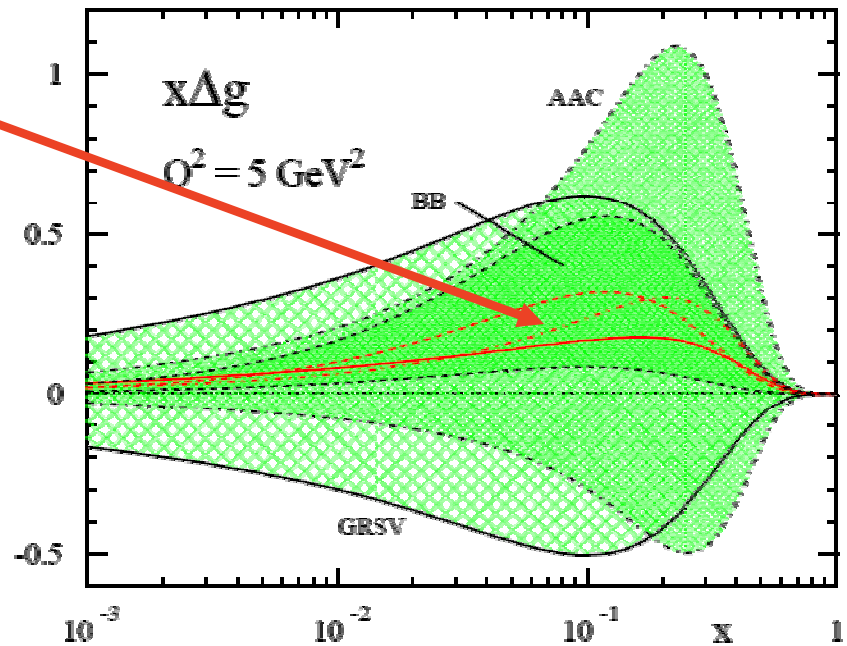
$\Delta\chi^2 \approx 13$ tolerated in fits

LSS : latest analysis (2005) incl. stat. errors



Available results (summary)

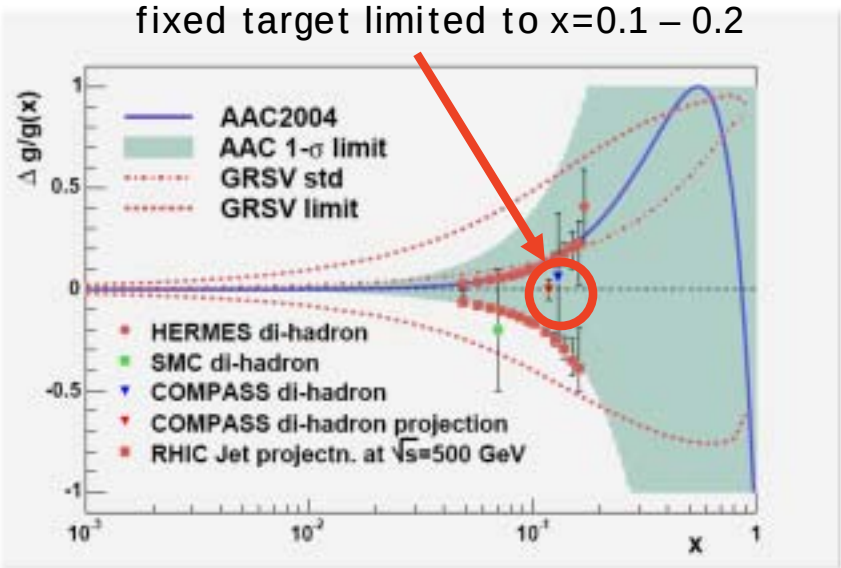
- „best fit“ gluons all positive but small
  (consistent with sparse direct exp. evidence)
- use of negative gluons seems perfectly legal in estimates for RHIC
- gluon can have „zeros“
  (not considered in fits)

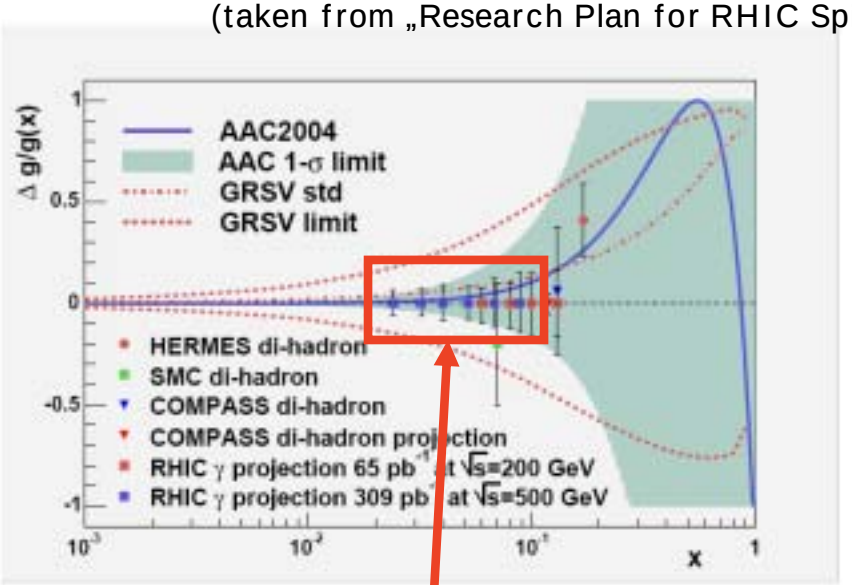


Fixed target experiments:
competition or complementary information?

fixed target limited to x=0.1 – 0.2

(taken from „Research Plan for RHIC Spin“)





incr. difficult at RHIC

(req. large-pT ⟷ large lumi.)

x-range <u>only</u> accessible at RHIC

➡ fixed target and collider measurements are largely complementary

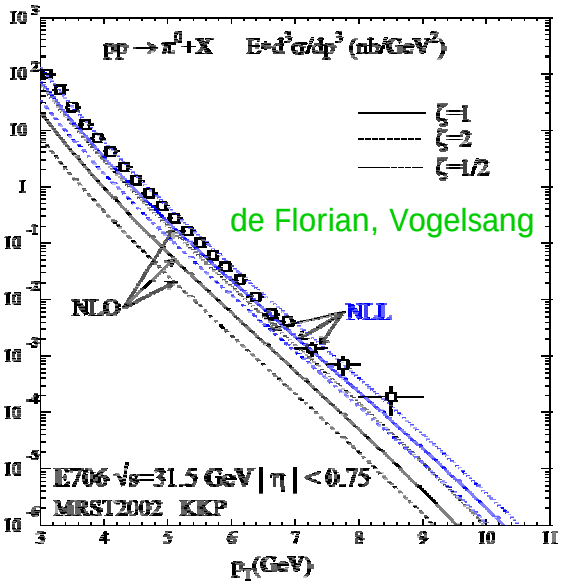
Δg from fixed-target experiments

main topic today

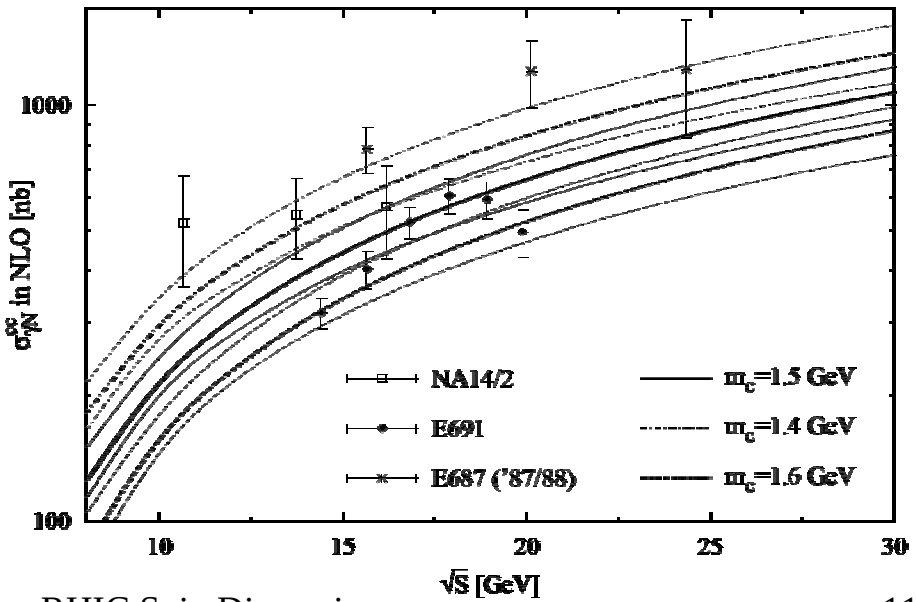
process		theory	
DIS		NLO	Q^2 range not suff. to pin down Δg
hadron pairs	DIS	LO	considered as most promising tool Bravar, v. Harrach, ... (best control of hard scat. Kinematics)
	$Q^2 \approx 0$	LO	
single hadrons	DIS	LO	
	$Q^2 \approx 0$	NLO	Jäger, Vogelsang, MS
heavy flavors	DIS	LO	
	$Q^2 \approx 0$	NLO	Bojak, MS

Is pQCD reliable at low energies ?

- difficult to say; many examples where not
- in general: large theor. (scale) uncertainties
- resummations of thres. logs can be important
- often conflicting exp. results



taken from Bojak



How to check the pQCD framework ?

easy: go for the *un* polarized cross section *first*

back to drawing board

resummations might help

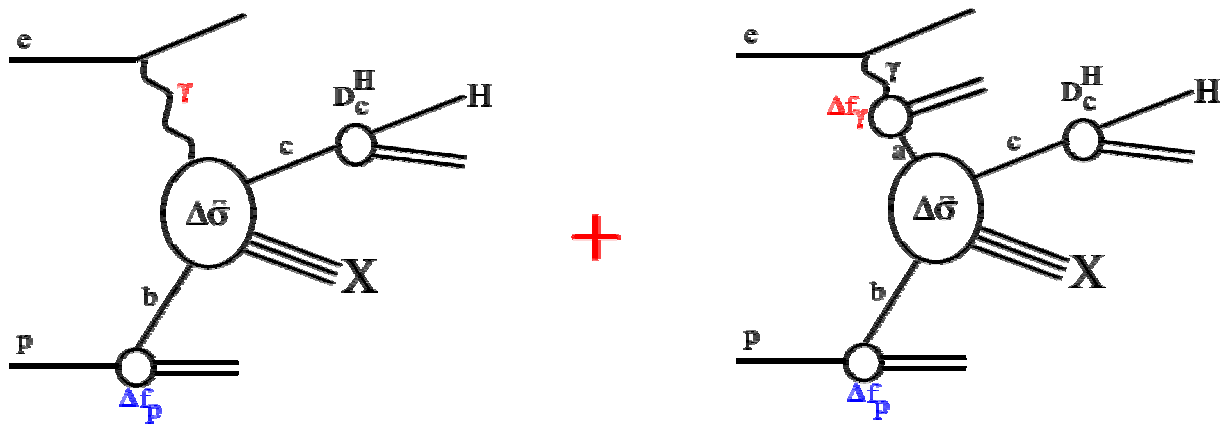
if everything fails: ask for energy upgrade; leave the country; ...

some confidence that spin asymmetries make sense

go for it and extract Δg

Photoproduction: basics

example: high-p_T single-inclusive hadron production $\vec{e}\vec{p} \to HX$ at $Q^2 \simeq 0$
sum of *two* contributions at $\mathcal{O}(\alpha\alpha_s)$ [LO]



elementary photon $\longleftrightarrow$ photon resolves into partons

separation depends on factorization scheme

$$\Delta\sigma_{\rm dir} = \Delta\hat{\sigma} \otimes \Delta f_p \otimes D^H \qquad \Delta\sigma_{\rm res} = \Delta\hat{\sigma} \otimes \Delta f_p \otimes \Delta f_\gamma \otimes D^H$$

$$\updownarrow \qquad\qquad \updownarrow \qquad \updownarrow$$

$$\mathcal{O}(\alpha\alpha_s) \qquad \mathcal{O}(\alpha_s^2) \qquad \mathcal{O}(\tfrac{\alpha}{\alpha_s})$$

Photoproduction: basics (II)

high-p_T processes → standard factorized "picture" for $d\Delta\sigma_{\rm dir/res}$

Libby, Sterman; Ellis et al.; Amati et al.; Collins et al.; . . .

long-distance

from exp.; μ-dep.: $d\Delta\sigma/d\ln\mu = 0$ (pQCD)

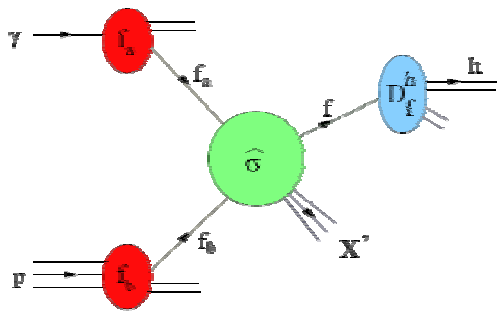
$$\frac{d\Delta\sigma^{\gamma p\to\pi X}_{\rm res}}{dp_T d\eta} = \sum_{abc}\int dx_a\, dx_b\, dz_c\, \Delta f^a_\gamma(x_a,\mu_f)\, \Delta f^b_p(x_b,\mu_f)\, D^\pi_c(z_c,\mu_{f'})$$
$$\times\ \frac{d\Delta\hat\sigma^{ab\to cX'}}{dp_T d\eta}(x_aP_a, x_bP_b, P^\pi/z_c, \mu_f, \mu_{f'}, \mu_r) + \mathcal{O}(\frac{\lambda}{p_T})^n$$

short-distance

calculable in pQCD: power series in α_s

power corrections

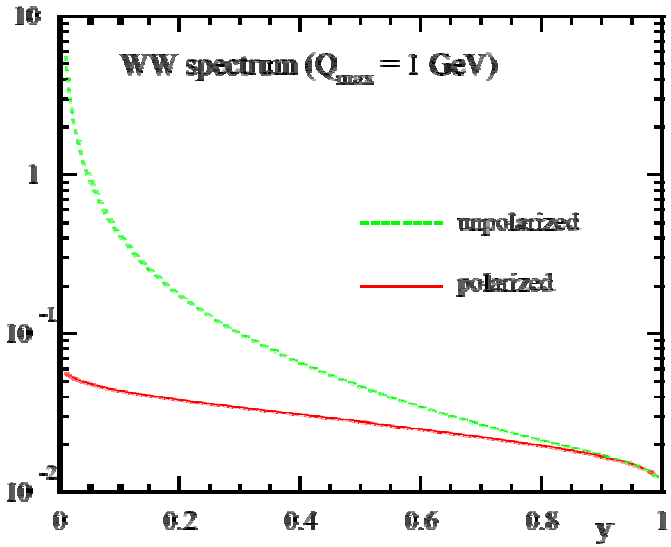
neglected



- $d\Delta\sigma_{\rm dir}$: replace $\Delta f^a_\gamma \to \delta(1-x_a)$
- arbitrary scales $\mu_{f,f',r}$: separate long- and short-dist. physics
- truncated pQCD series: residual dependence on scales

  → main motivation to compute NLO corrections

Photon flux



equivalent photon approximation:

Weizsäcker, Williams

long. pol. electrons → circularly pol. photons

$$\Delta P_{\gamma e}(y) = \frac{\alpha}{2\pi}\frac{[1-(1-y)^2]}{y}\ln\frac{Q^2_{max}(1-y)}{m_e^2 y^2} + \text{non}-\text{log. terms}$$

de Florian, Frixione

consequences/complications:

- energy of "target" photon not fixed but smeared
- "electron pdf's" more appropriate: $\Delta f^a_\gamma \to \Delta f^a_e(x_a) = \int_{x_a}^1 \frac{dy}{y}\Delta P_{\gamma e}(y)\Delta f^a_\gamma\left(x_\gamma = \frac{x_a}{y}\right)$
- strong dilution of polarization for $y \to 0$

Photonic parton densities: evolution

μ^2-evolution of Δf_γ: known up to NLO

LO: Irving, Newland; Hassan, Pilling; Xu
NLO: Vogelsang, MS

$$\frac{\mathrm{d}\Delta f_\gamma^i}{\mathrm{d}\ln\mu^2} = \Delta k_i + (\Delta P_i \otimes \Delta f_\gamma^i) \qquad i=(\mathrm{NS},\mathrm{S})$$

$\uparrow$ inhom. part $\gamma \to i$ splitting

$\uparrow$ homogeneous "hadron"-like contribution

well-known solution: $\Delta f_\gamma^i = \Delta f_{\gamma,\mathrm{pl}}^i + \Delta f_{\gamma,\mathrm{hadr}}^i$ [of $\mathcal{O}(\frac{\alpha}{\alpha_s})$ in LO]

pointlike part:

- depends only on μ_0
  $\Delta f_{\gamma,\mathrm{pl}}^i(\mu_0^2) = 0$
- large x behavior

hadronic part:

- requires *non*-pert. input
- dominates at small-to-medium x

Photonic parton densities: models

idea: use two extreme models to study physics potential of future facilities

Glück, Vogelsang; Glück, Vogelsang, MS

starting point: *positivity*

$$|\Delta f_\gamma| \leq f_\gamma$$

"max." input

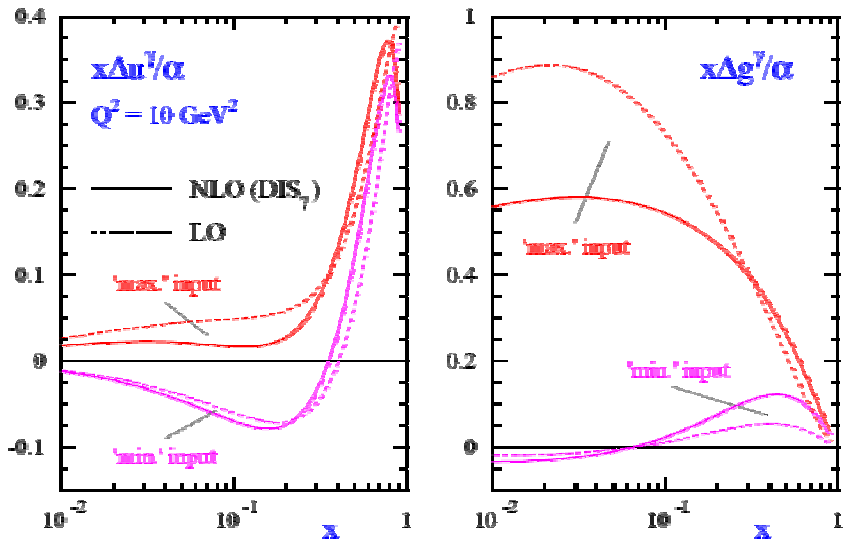
$$\Delta f_\gamma(x) = f_\gamma^{\mathrm{GRV}}(x)$$

"min." input

$$\Delta f_\gamma(x) = 0$$

at the input scale $\mu_0 \simeq 0.6\,\mathrm{GeV}$

- pure VMD input at μ_0
- pointlike for all scales μ



models sufficient to study *upper/lower bounds* for spin asymmetries

1-hadron production at COMPASS

work done in collaboration with: B. Jäger, W. Vogelsang

parameters used: („deuteron“ target)

energy: $E_\mu = 160\ \mathrm{GeV} \longleftrightarrow \sqrt{S} \approx 18\ \mathrm{GeV}$

polarization: $P_\mu \approx 76\%$ $P_d \approx 50\%$ (and 50% target dilution)

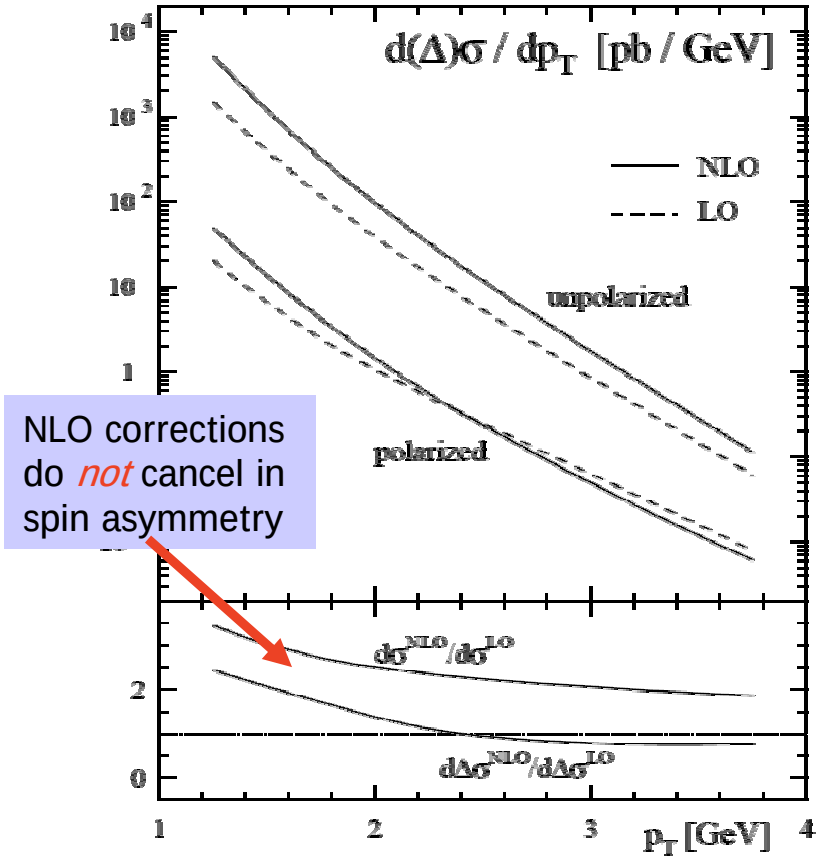
acceptance: $70\ \mathrm{mrad}$

photon flux: $Q^2_{\mathrm{max}} = 0.5\ \mathrm{GeV}$ $0.2 \leq y \leq 0.9$

pdfs: CTEQ (unpol), GRSV (pol), KKP (fragmentation)

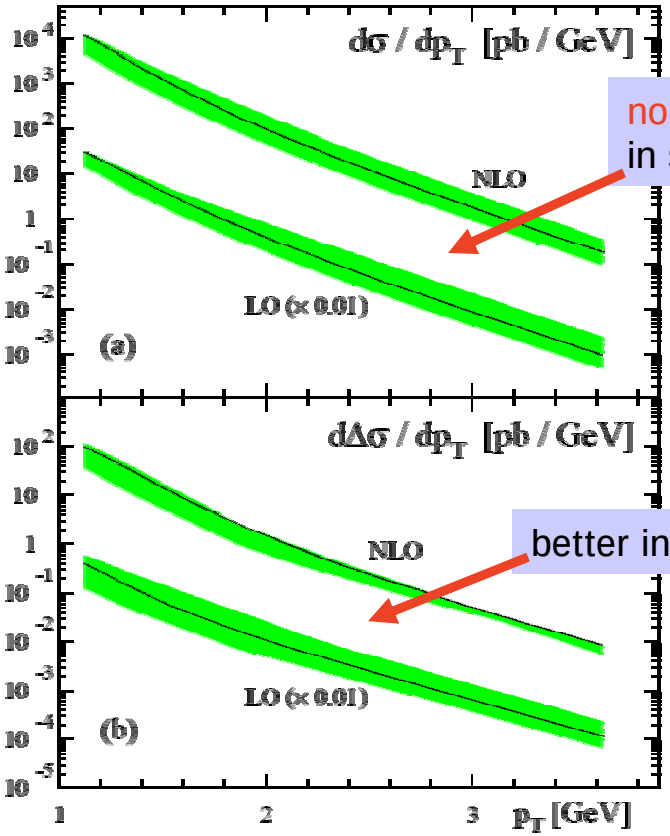
1-hadron @ COMPASS (cont.)

differential cross section:



NLO corrections do *not* cancel in spin asymmetry

scale dependence:

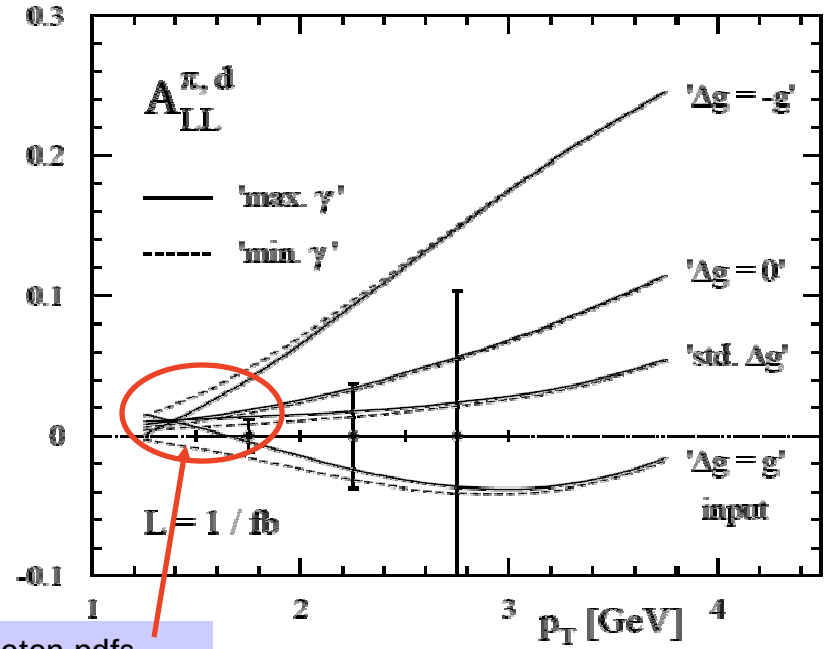


no improvement in scale depend.

better in pol. case

1-hadron @ COMPASS (cont.)

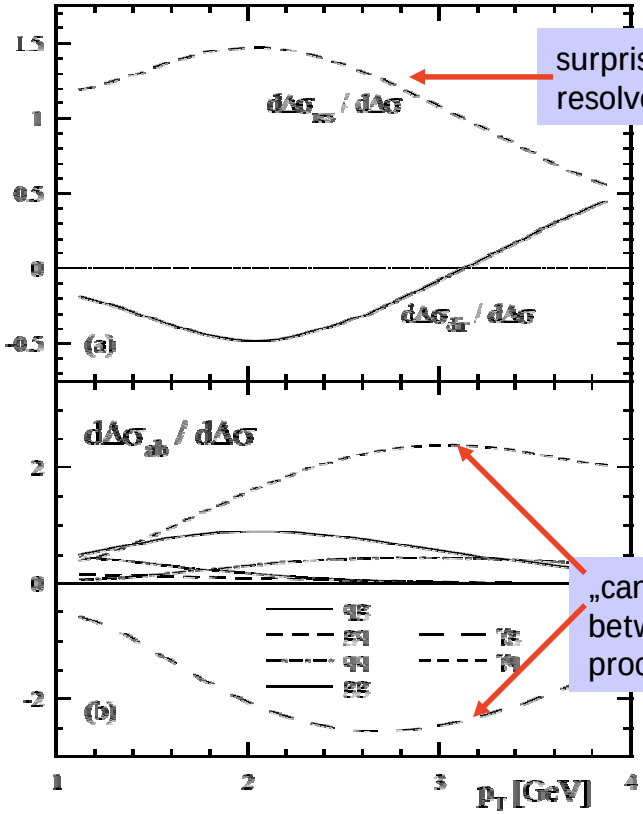
double-spin asymmetry:



photon pdfs. interfere with gluon extraction

almost no dep. on model for photon pdfs
sensitivity to gluon polarization

resolved/direct contributions
+ different partonic processes:



surprisingly large resolved contribution

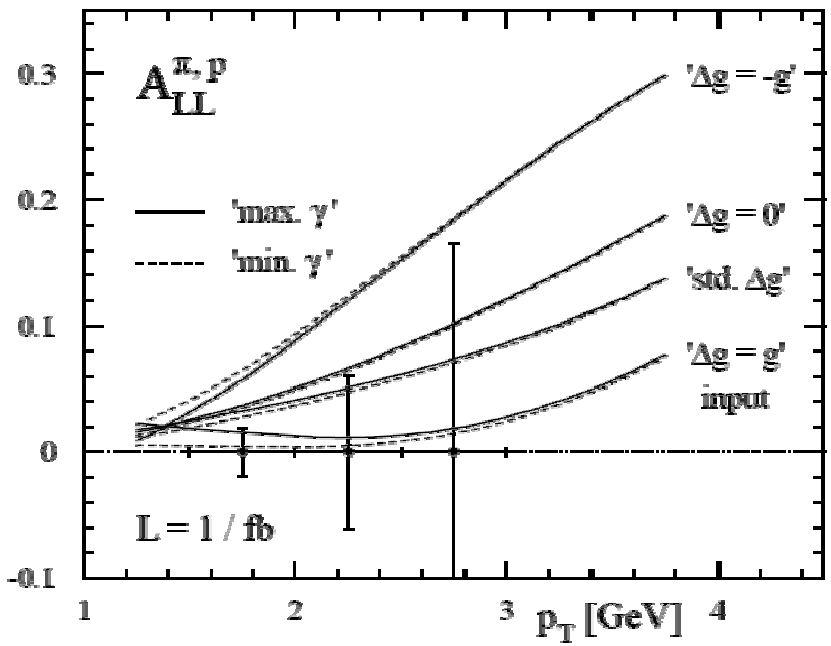
std. gluon/ max. photon used here

„cancellation“ between direct processes

1-hadron @ COMPASS (cont.)

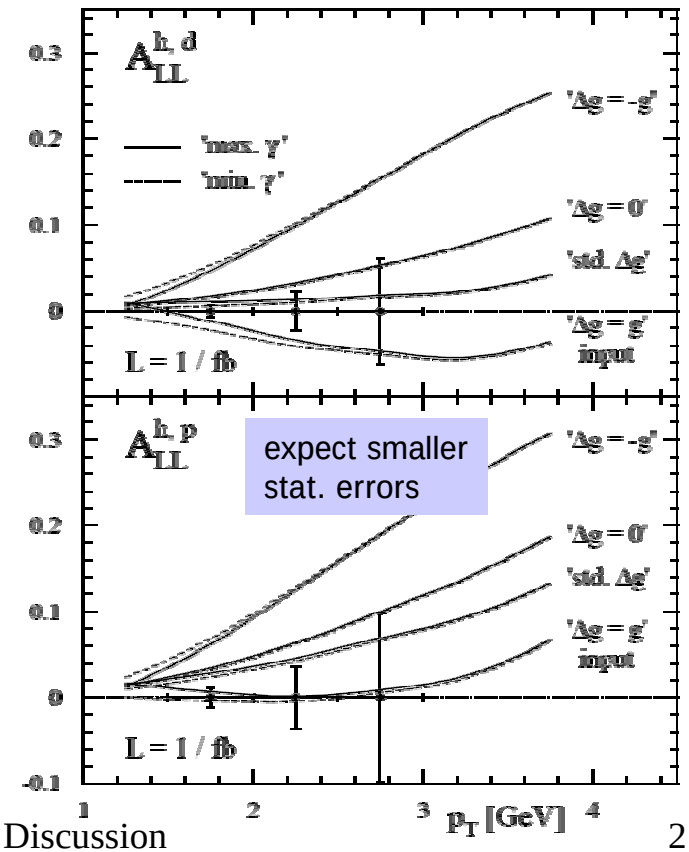
„proton“ target:

(target pol.: 85%; dilution: 17.6%)



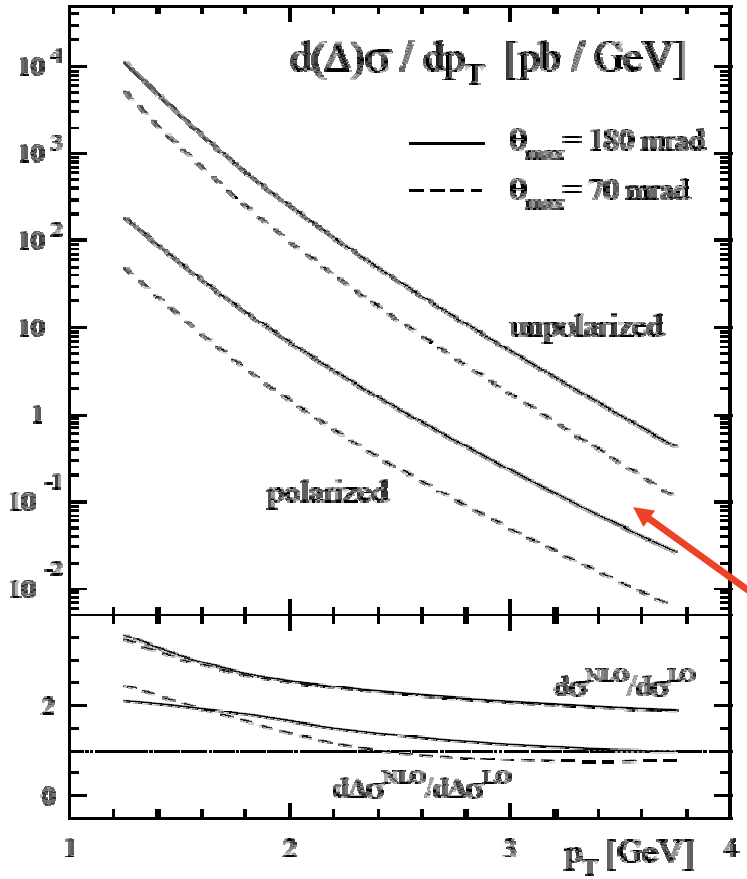
→ very similar results

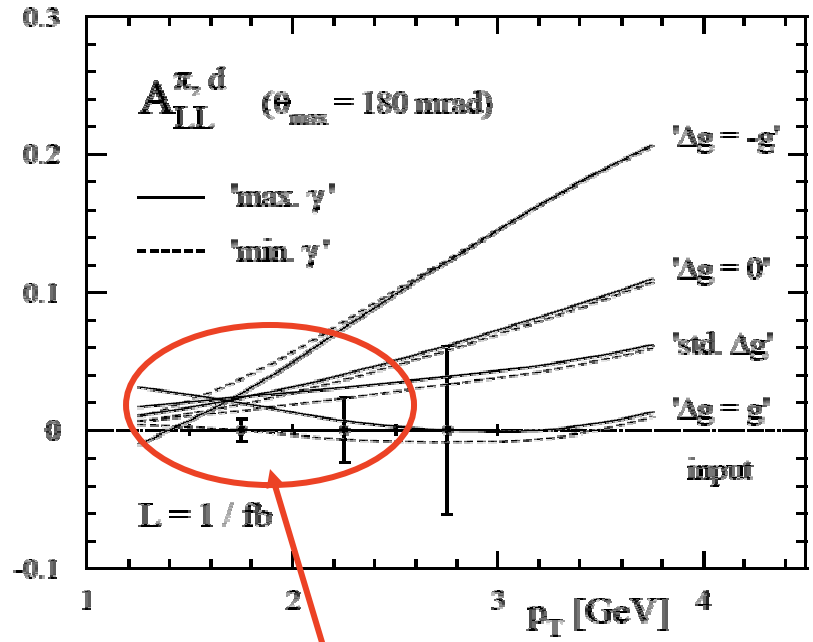
spin asymmetry for sum of charged hadrons:



1-hadron @ COMPASS (cont.)

Some results for future (?) 180 mrad acceptance:





increased cross section but more interference with photon pdfs
→ reduced sensitivity to gluon

1-hadron production at HERMES

work done in collaboration with: B. Jäger, W. Vogelsang

parameters used:

energy: $E_e \approx 27.5\ \mathrm{GeV} \longleftrightarrow \sqrt{S} \approx 7.5\ \mathrm{GeV}$

polarization: $P_e \approx 53\%$ $P_d \approx P_p \approx 85\%$ (no dilution)

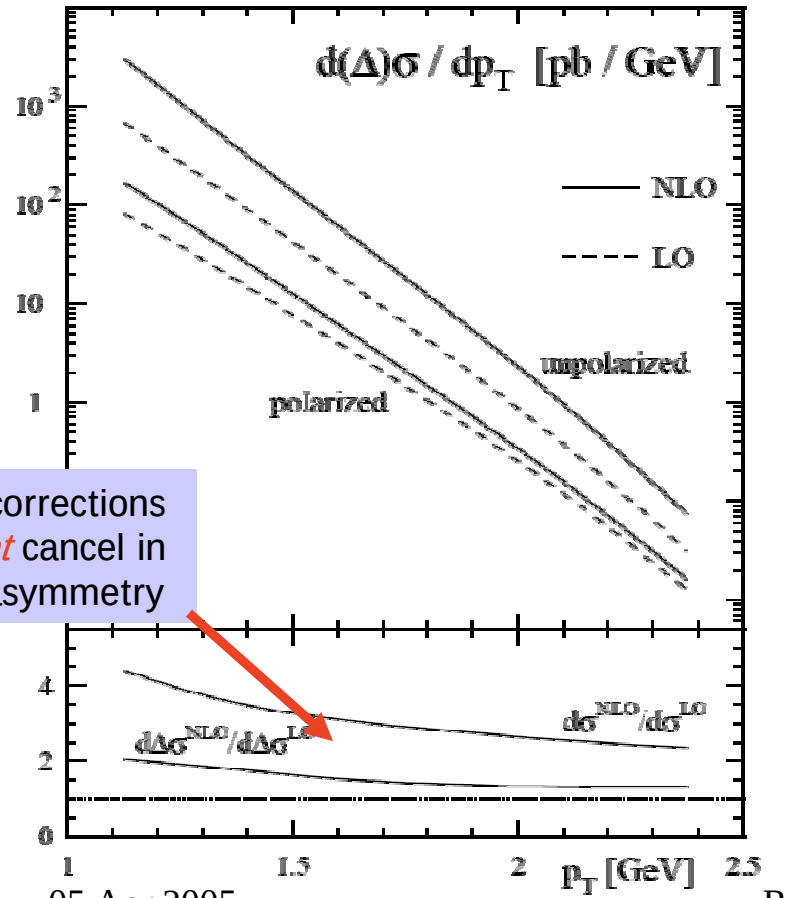
acceptance: $40\ \mathrm{mrad} \leq \Theta \leq 220\ \mathrm{mrad}$

photon flux: $Q^2_{\mathrm{max}} = 0.01\ \mathrm{GeV}$ $0.2 \leq y \leq 0.9$

pdfs: CTEQ (unpol), GRSV (pol), KKP (fragmentation)

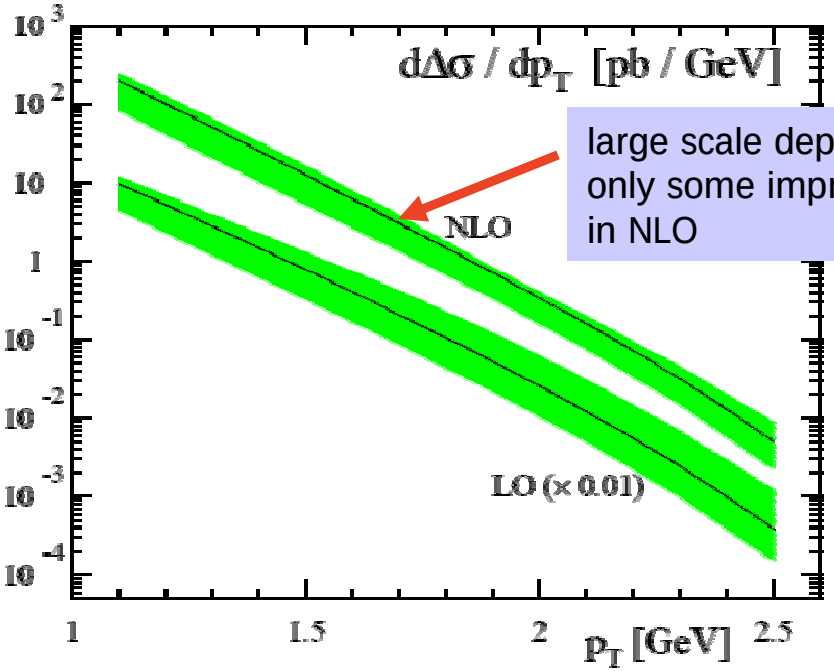
1-hadron @ HERMES (cont.)

differential cross section:



NLO corrections do *not* cancel in spin asymmetry

scale dependence:

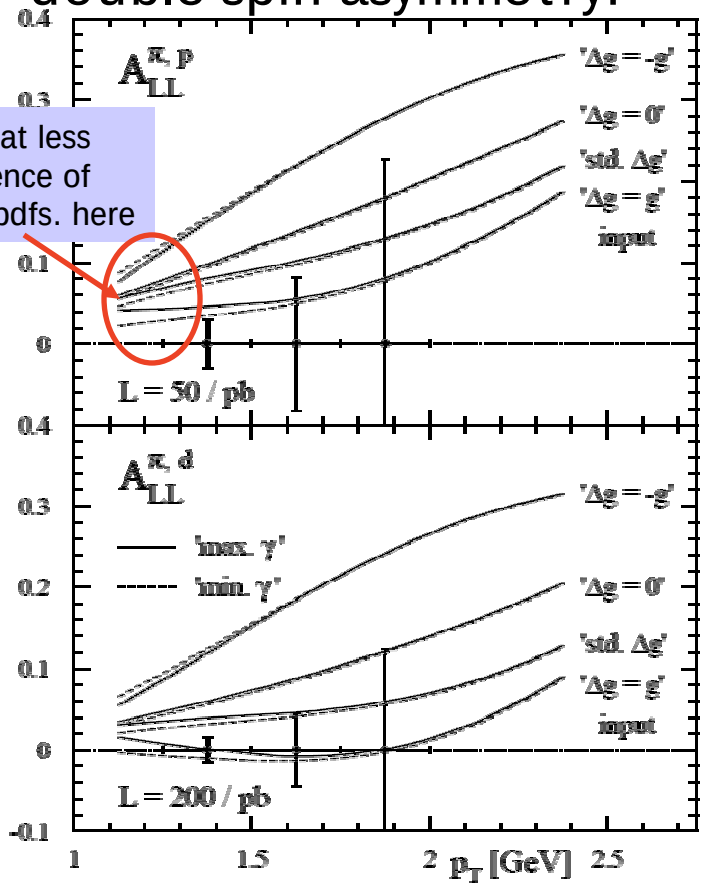


large scale dependence; only some improvement in NLO

even more important to have unpol. ref. cross section first

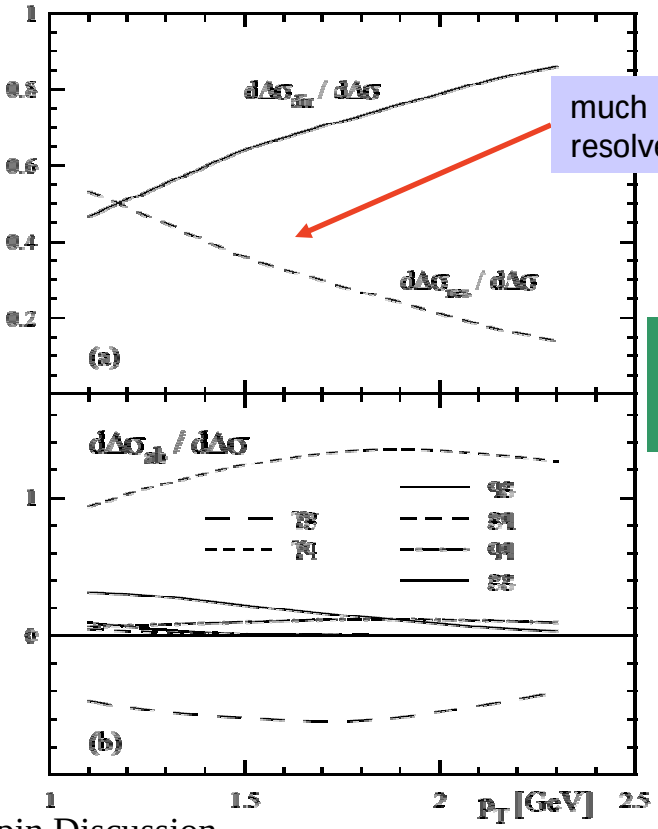
1-hadron @ HERMES (cont.)

double-spin asymmetry:



somewhat less interference of photon pdfs. here

resolved/direct contributions + different partonic processes:



much smaller resolved contribution

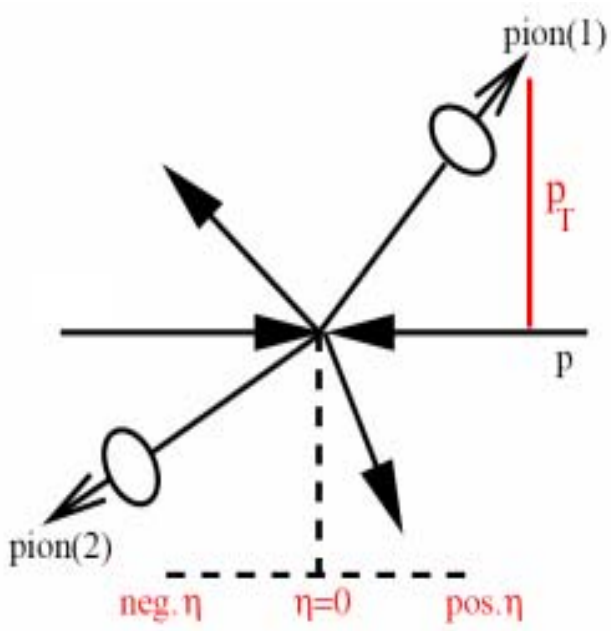
std. gluon/ max. photon used here

Summary on 1-hadron photoproduction

- HERMES and in particular COMPASS have the potential to obtain some information on Δg for x>0.1
- applicability of pQCD not guaranteed in region of 1-2 GeV transverse momenta
- crucial to come up with unpolarized „benchmark“ cross section
- collider and fixed target experiments are largely complementary

2-hadron photoproduction

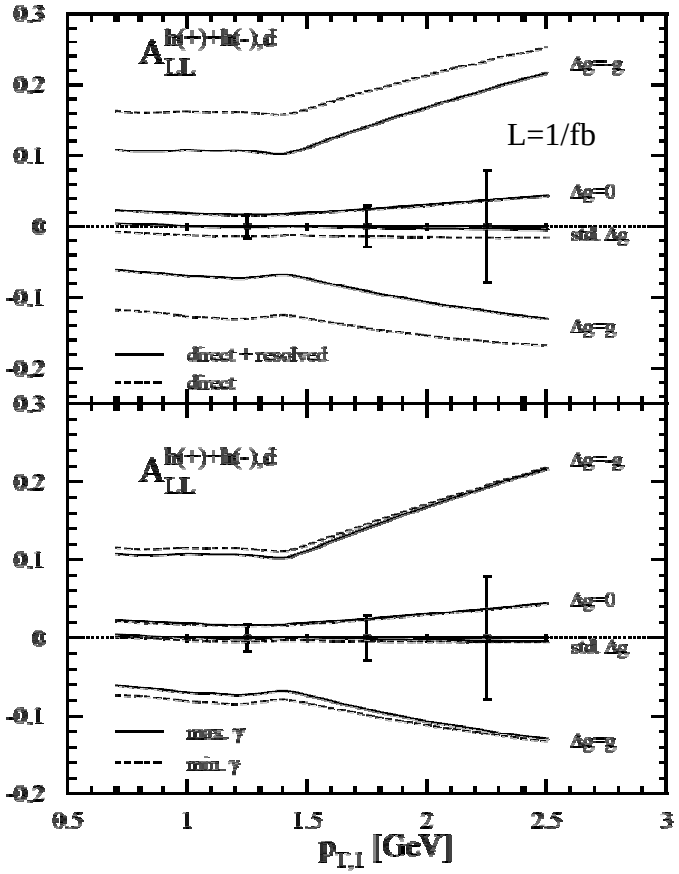
work in progress; with C. Hendlmeier, A.Schafer



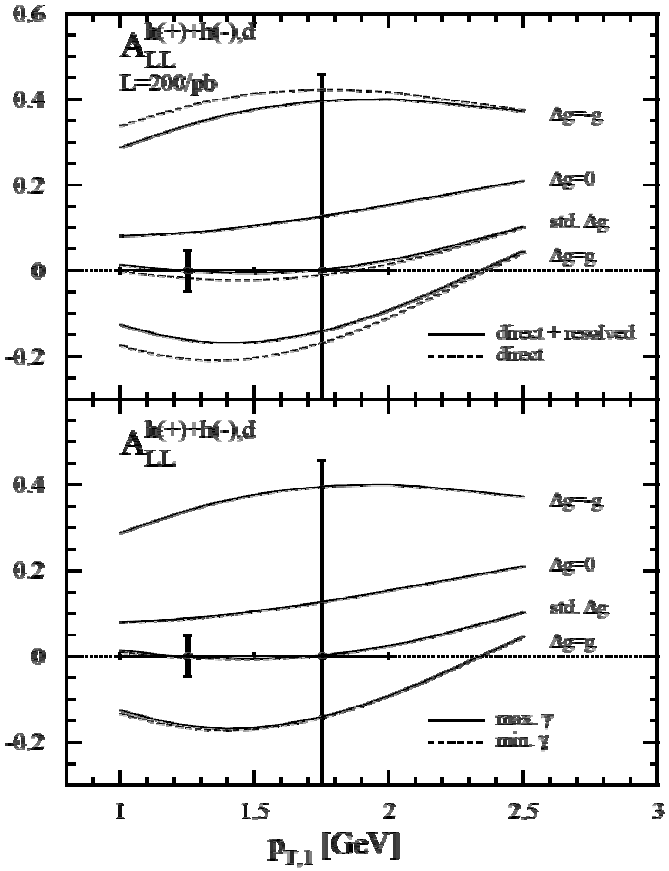
- so far only LO available
- NLO calculation much more complex than for 1-hadron inclusive case; calculation under way
- better „control“ over kinematics of hard scattering

2-hadrons: some LO results

COMPASS:

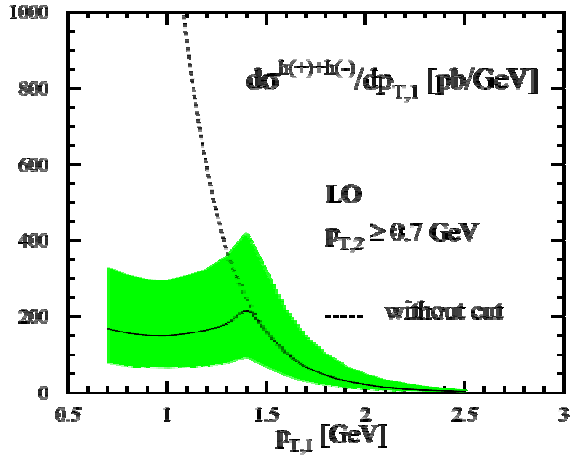


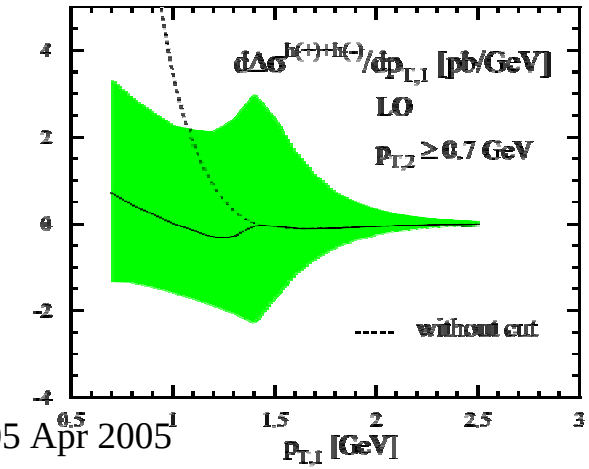
HERMES:



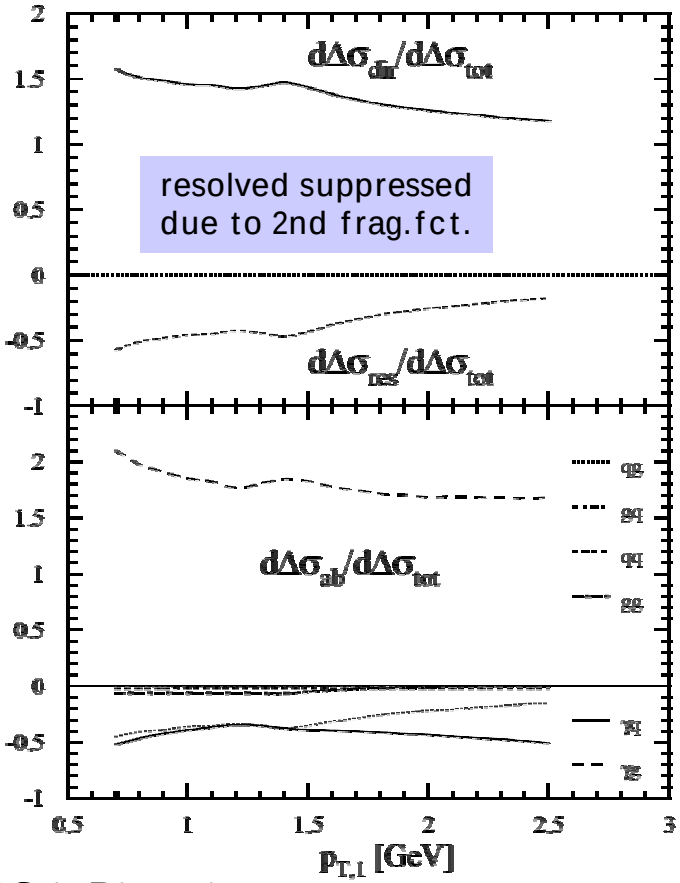
2-hadrons: some LO results

COMPASS: scale dependence



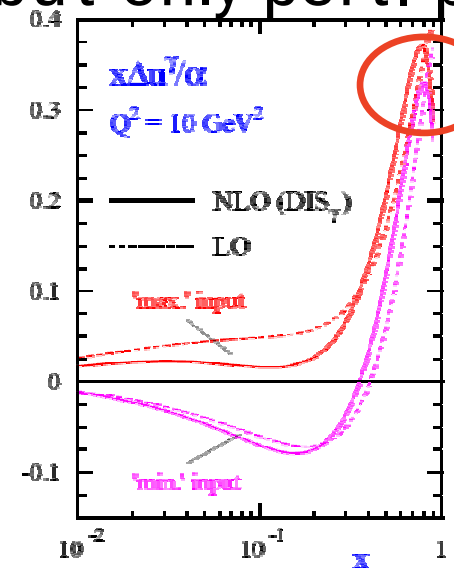


subprocess contributions:



How to access the non-pert. structure of the photon?

- resolved contribution can be large at fixed-target energies but only pert. part (large x) probed



independent of assumptions about non-pert. input

- for the non-pert. structure we need a polarized collider like eRHIC