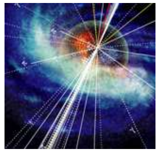


03/16/2004

Jefferson Lab

Polarized Photoproduction at an $\vec{e}\vec{p}$ Collider

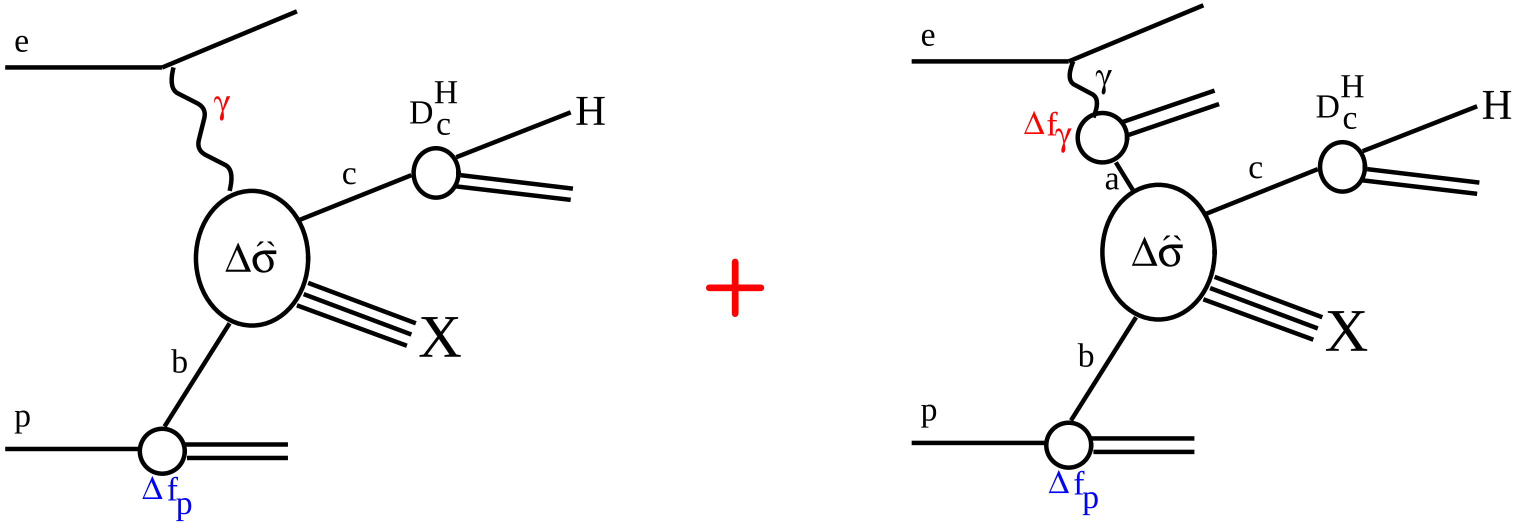
Marco Stratmann

University of Regensburg

- **QCD Framework for $\vec{e}\vec{p}$ Photoproduction Processes**
- **Accessing the Parton Densities of Polarized Photons**
- **Summary: Physics Goals and Machine/Detector Requirements**

Photoproduction (I): *direct* vs. *resolved* photons

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

$$\Delta\sigma_{\text{dir}} = \Delta\hat{\sigma} \otimes \Delta f_p \otimes D^H$$

$$\updownarrow$$

$$\mathcal{O}(\alpha\alpha_s)$$

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

$$\updownarrow \qquad \updownarrow$$

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

Photoproduction (II): perturbative QCD approach

high-p_T processes → standard factorized “picture” for $d\Delta\sigma_{\mathrm{dir/res}}$

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)

$\downarrow \quad \downarrow \quad \downarrow$

$$\boxed{\begin{aligned}\frac{d\Delta\sigma_{\mathrm{res}}^{\gamma p\to\pi X}}{dp_T d\eta} &= \sum_{abc}\int dx_a\,dx_b\,dz_c\,\Delta f_\gamma^a(x_a,\mu_f)\,\Delta f_p^b(x_b,\mu_f)\,D_c^\pi(z_c,\mu_{f'})\\ &\times \frac{d\Delta\hat{\sigma}^{ab\to cX'}}{dp_T d\eta}(x_aP_a,x_bP_b,P^\pi/z_c,\mu_f,\mu_{f'},\mu_r)+\mathcal{O}(\frac{\lambda}{p_T})^n\end{aligned}}$$

$\uparrow$

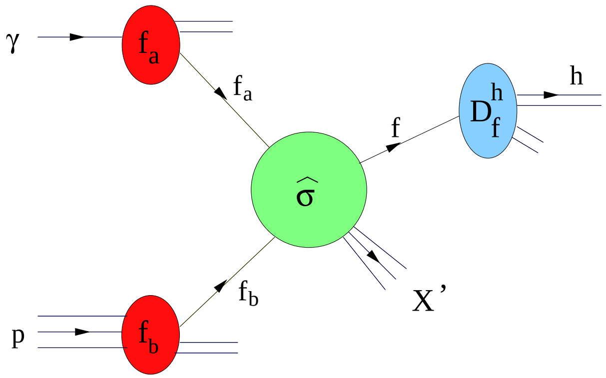
short-distance

calculable in pQCD: power series in α_s

$\uparrow$

power corrections

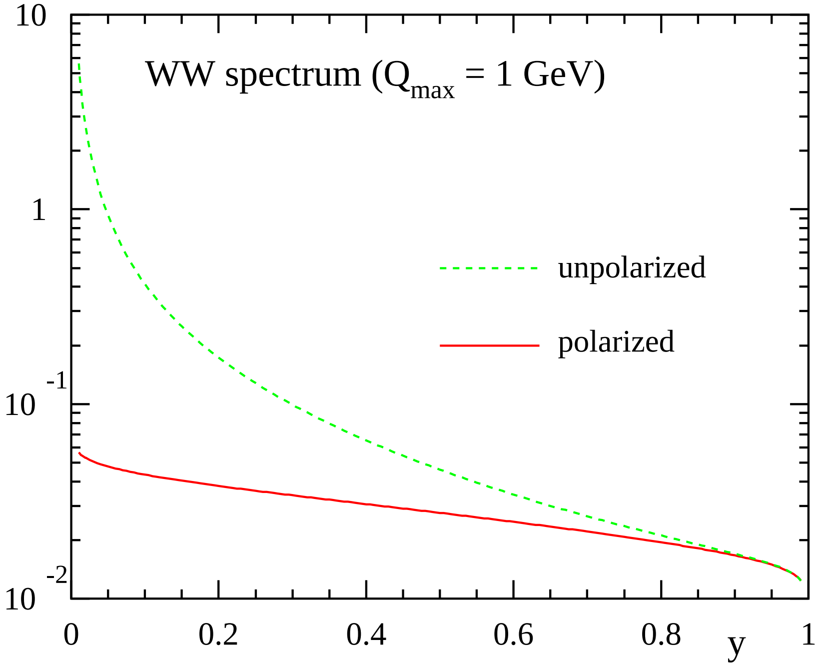
neglected



- $d\Delta\sigma_{\mathrm{dir}}$: replace $\Delta f_\gamma^a \to \delta(1-x_a)$
- 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

Photoproduction (III): photon flux



equivalent photon approximation:

Weizsäcker, Williams

long. pol. electrons → circularly pol. photons

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

de Florian, Frixione

consequences/complications:

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

Photonic Parton Densities (I): evolution

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

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

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

$\uparrow$ 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 (II): models

no experimental information → have to fully rely on models

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

Glück, Vogelsang; Glück, Vogelsang, MS

starting point: *positivity*

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

$$\swarrow \qquad\qquad \searrow$$

"max." input

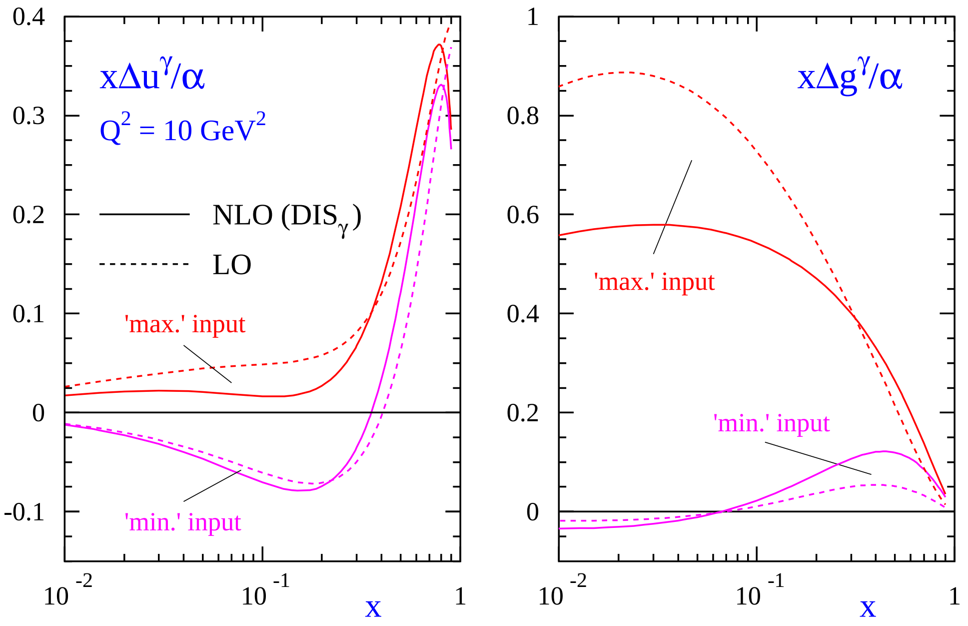
$$\boxed{\Delta f_\gamma(x) = f_\gamma^{\mathrm{GRV}}(x)}$$

"min." input

$$\boxed{\Delta f_\gamma(x) = 0}$$

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

Accessing Δf_γ at eRHIC (I): strategy

Δf^γ accessible from *resolved* part of photoproduction cross section

general problem: separating off "unwanted" direct-γ contribution

most promising processes:

all successfully used by H1 and ZEUS to extract f^γ !!

- **single-inclusive reactions**

only indirect direct/resolved "separation" via

$$(\Delta)\sigma_{\rm dir} \quad \text{dominant} \quad \eta_{\rm lab} < 0 \quad (\leftrightarrow x_\gamma \to 1)$$

$$(\Delta)\sigma_{\rm res} \quad \text{for} \quad \eta_{\rm lab} > 0 \quad (\leftrightarrow x_\gamma \ll 1)$$

[positive η: proton direction]

- **di-jet/hadron production**

reconstruction of x_γ possible in experiment

→ *define* direct and resolved samples via x_γ-cut

old idea: Forshaw, Roberts

Accessing Δf_γ at eRHIC (II): status of pQCD calculations

NLO QCD results mandatory for meaningful quantitative comparison with experiment

- much reduced μ-dep. (th. error)
- more realistic final state
- LO fails at HERA

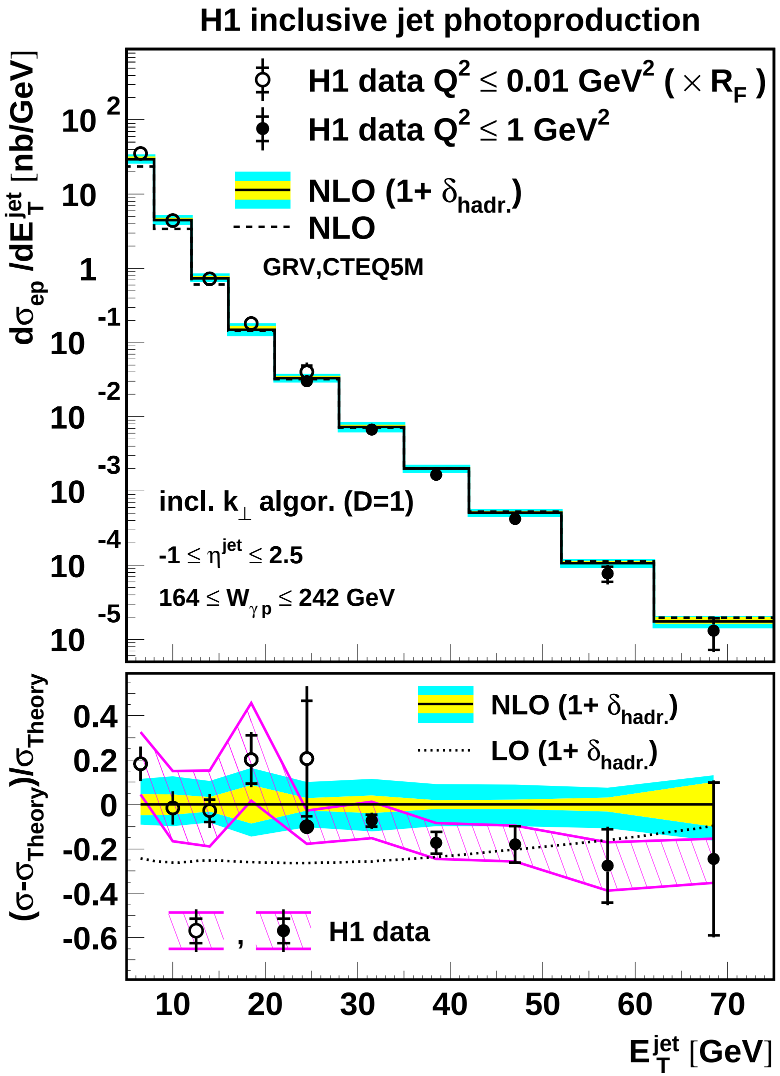
currently available NLO results:

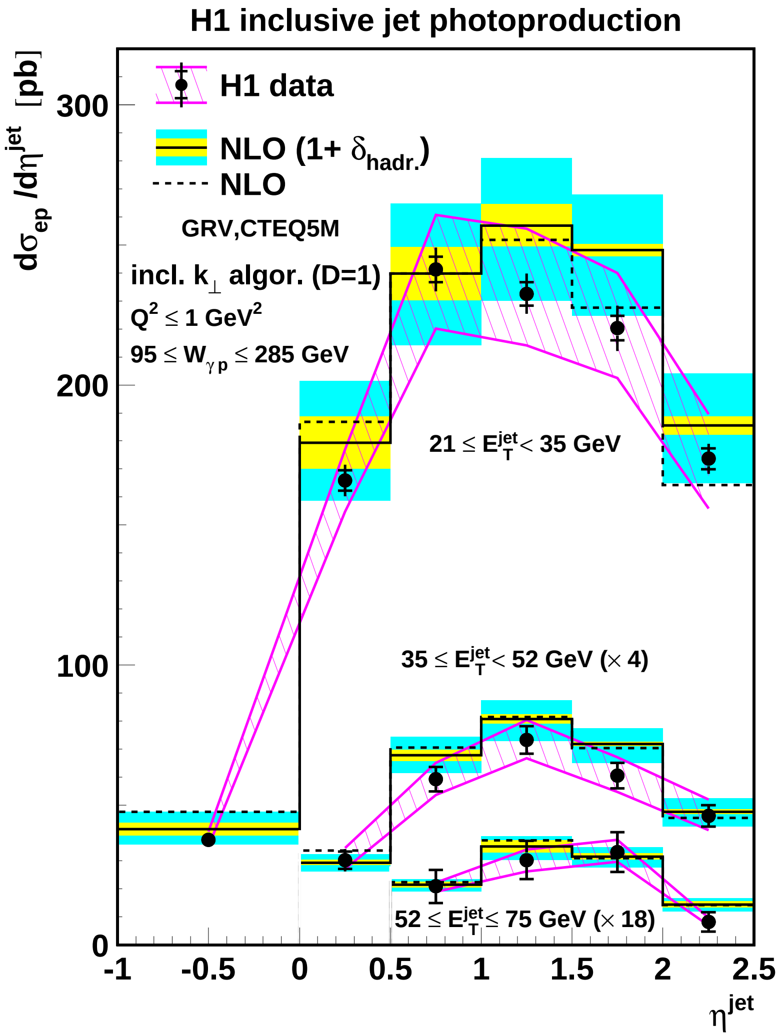
we still have a couple of years ...

jets	$\vec{\gamma}\vec{p} \rightarrow \mathrm{jet} + X$	direct	✓	De Florian, Frixone; Jäger et al.
		resolved	✓	De Florian et al.; Jäger et al.
	$\vec{\gamma}\vec{p} \rightarrow \mathrm{jet}_1 + \mathrm{jet}_2 + X$	direct	✓	De Florian, Frixone
		resolved	✓	De Florian, Frixone, Signer, Vogelsang
hadrons	$\vec{\gamma}\vec{p} \rightarrow H + X$	direct	✓	De Florian, Vogelsang; Jäger et al.
		resolved	✓	De Florian; Jäger, MS, Vogelsang
	$\vec{\gamma}\vec{p} \rightarrow H_1 + H_2 + X$	direct	×	
		resolved	×	work in progress
heavy quarks	$\vec{\gamma}\vec{p} \rightarrow Q\bar{Q}X$	direct	✓	Bojak, MS; Contogouris et al.
		resolved	✓	Bojak, MS

Accessing Δf_γ at eRHIC (III): lessons from HERA

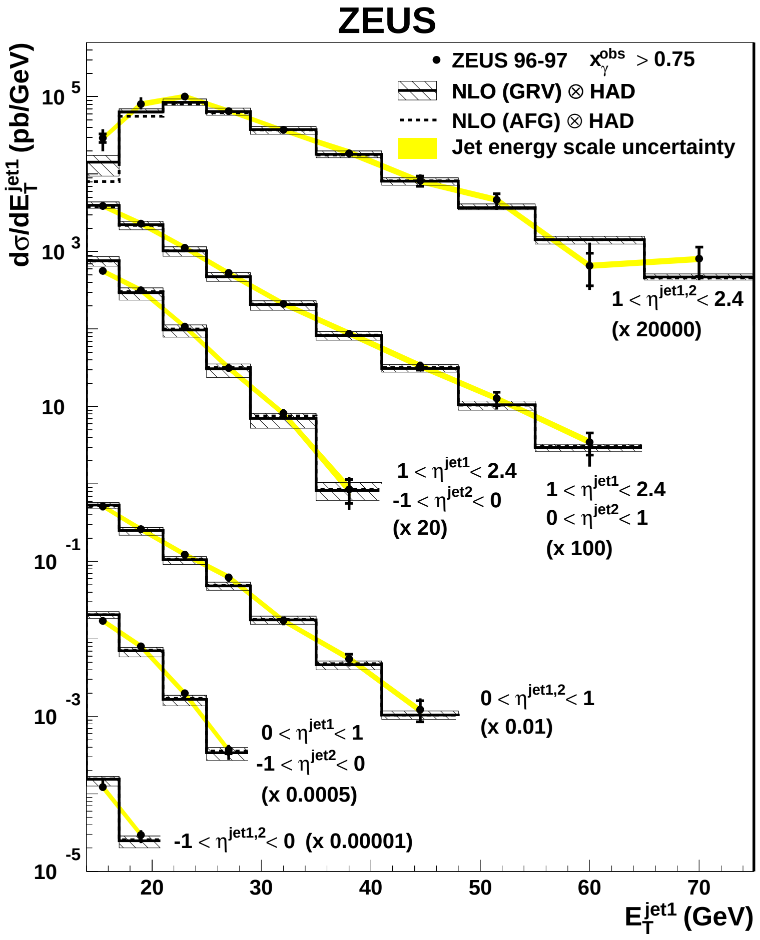
a lot of experience from HERA measurements: e.g. 1-jet from

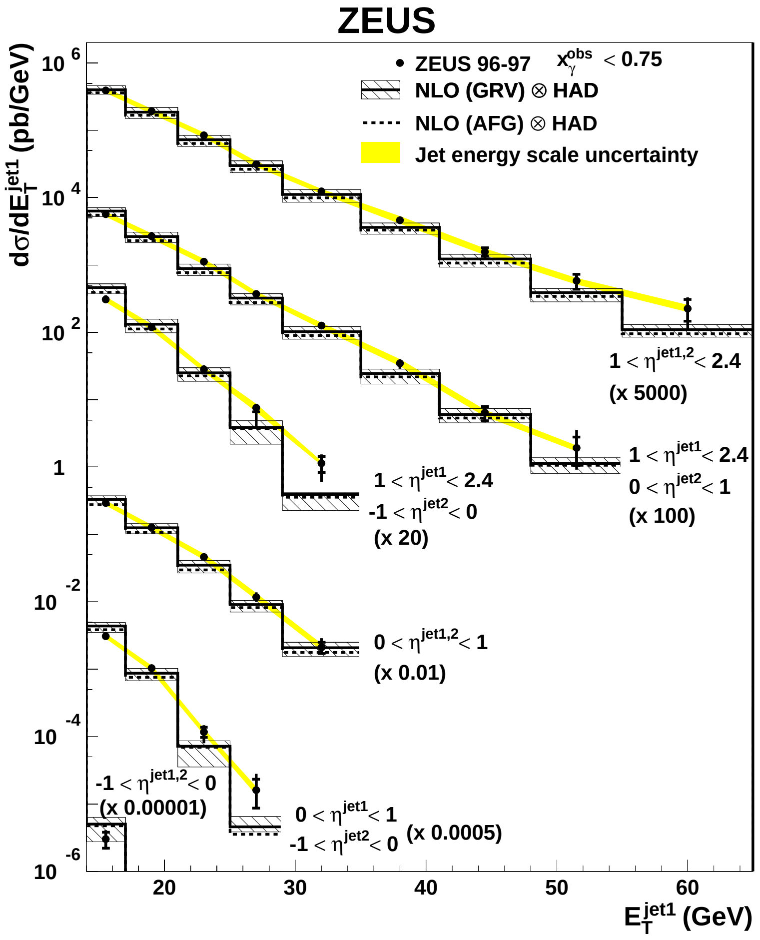

H1 inclusive jet photoproduction


H1 inclusive jet photoproduction

. . . lessons from HERA (cont.)

e.g. 2-jet measurement from with x_γ-cut



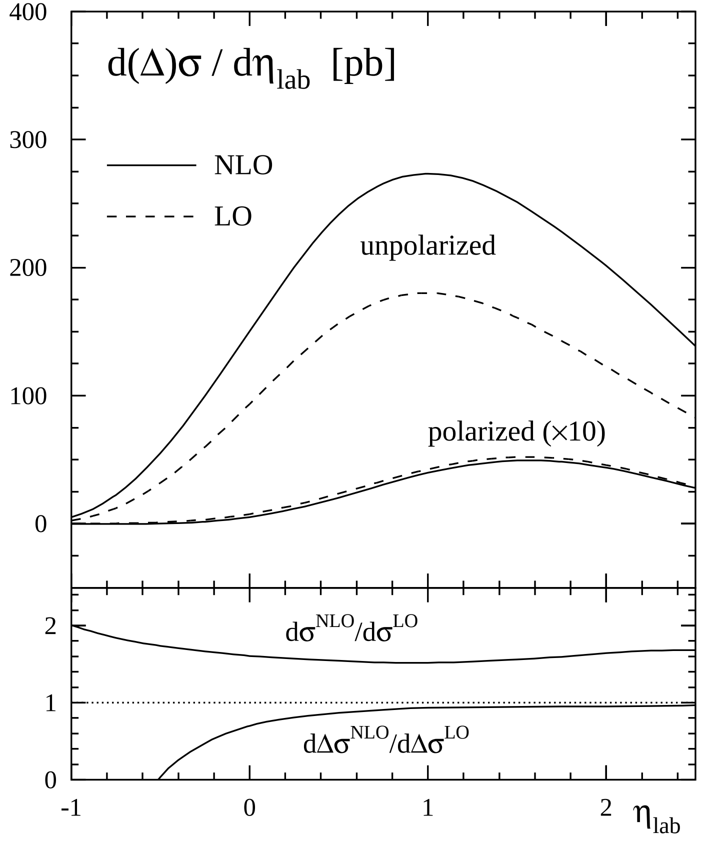


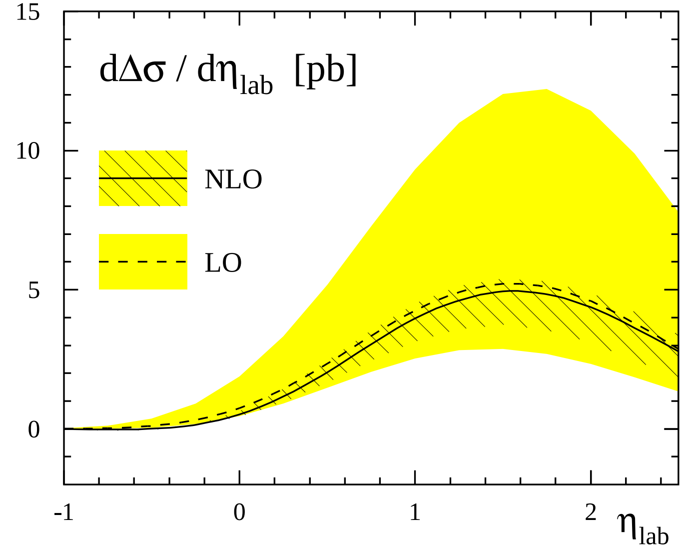
Expectations for eRHIC (I): single-inclusive hadrons

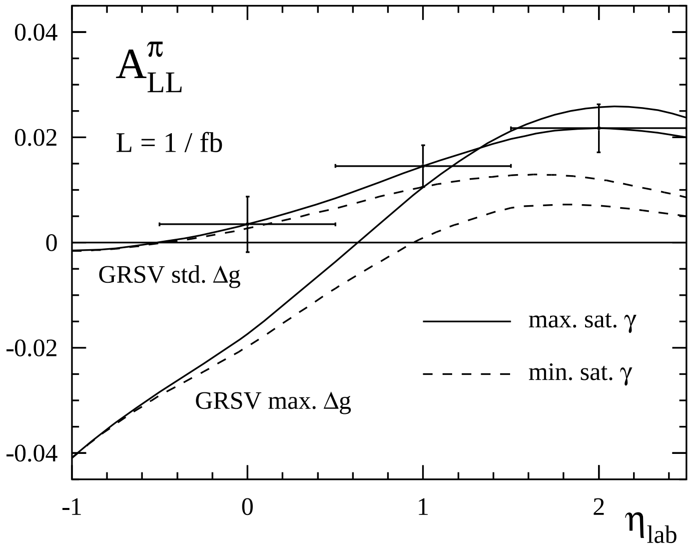
Jäger, MS, Vogelsang

$S_{ep}^{1/2} = 100\,\mathrm{GeV};\ 0.2 \leq y \leq 0.85;\ Q_{\max} = 1\mathrm{GeV}$

$p_T^{\min} = 4\,\mathrm{GeV};\ \mathcal{P}_{e,p} = 0.7;\ \mathcal{L} = 1/\mathrm{fb}$



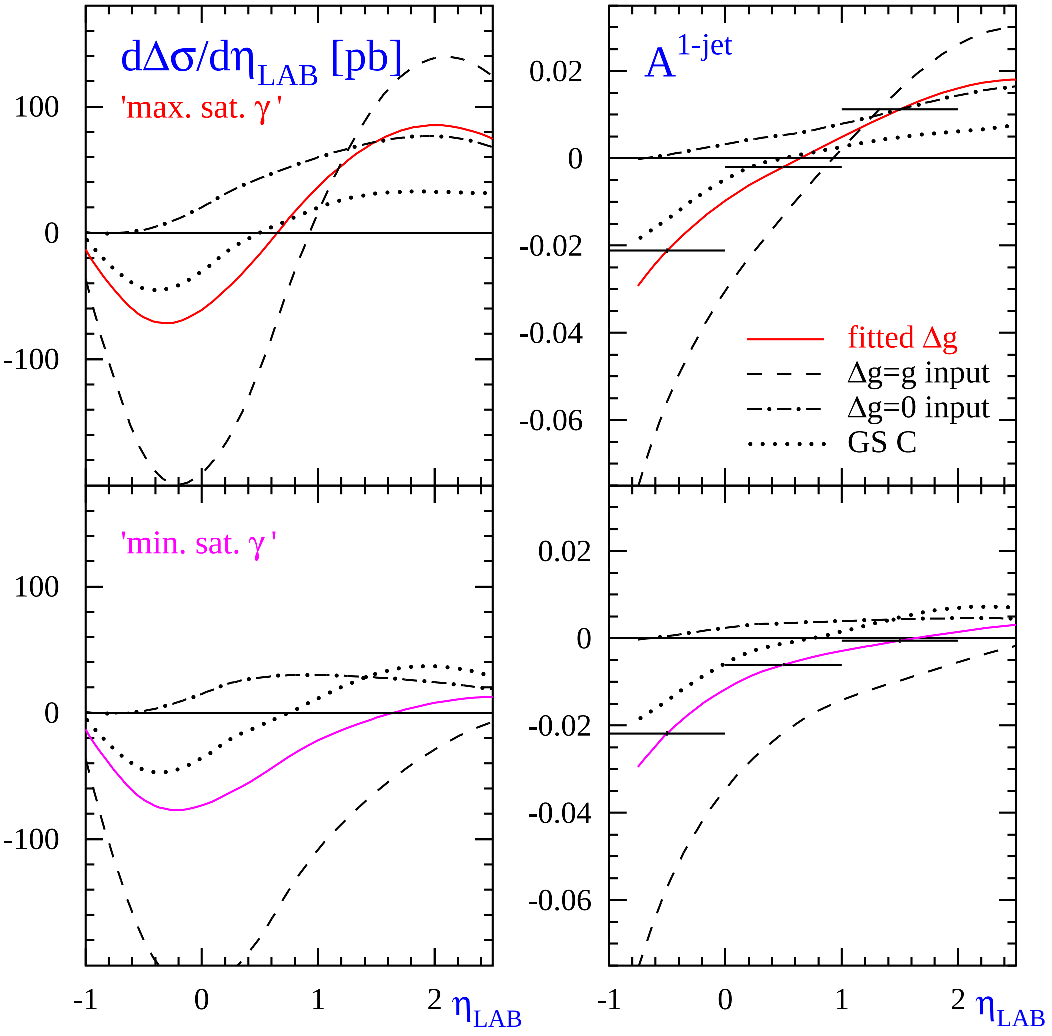




- much improved scale dependence
- expected sensitivity to Δf_γ at large η_{lab}

Expectations for eRHIC (II): single-inclusive jets

MS, Vogelsang



← LO estimate only

[no NLO studies at $S_{ep}^{1/2} = 100\,\mathrm{GeV}$]

parameters used:

$$S_{ep}^{1/2} = 100\,\mathrm{GeV};\ p_T^{\min} = 5\,\mathrm{GeV}$$

$$0.2 \leq y \leq 0.85;\ Q_{\max} = 1\,\mathrm{GeV}$$

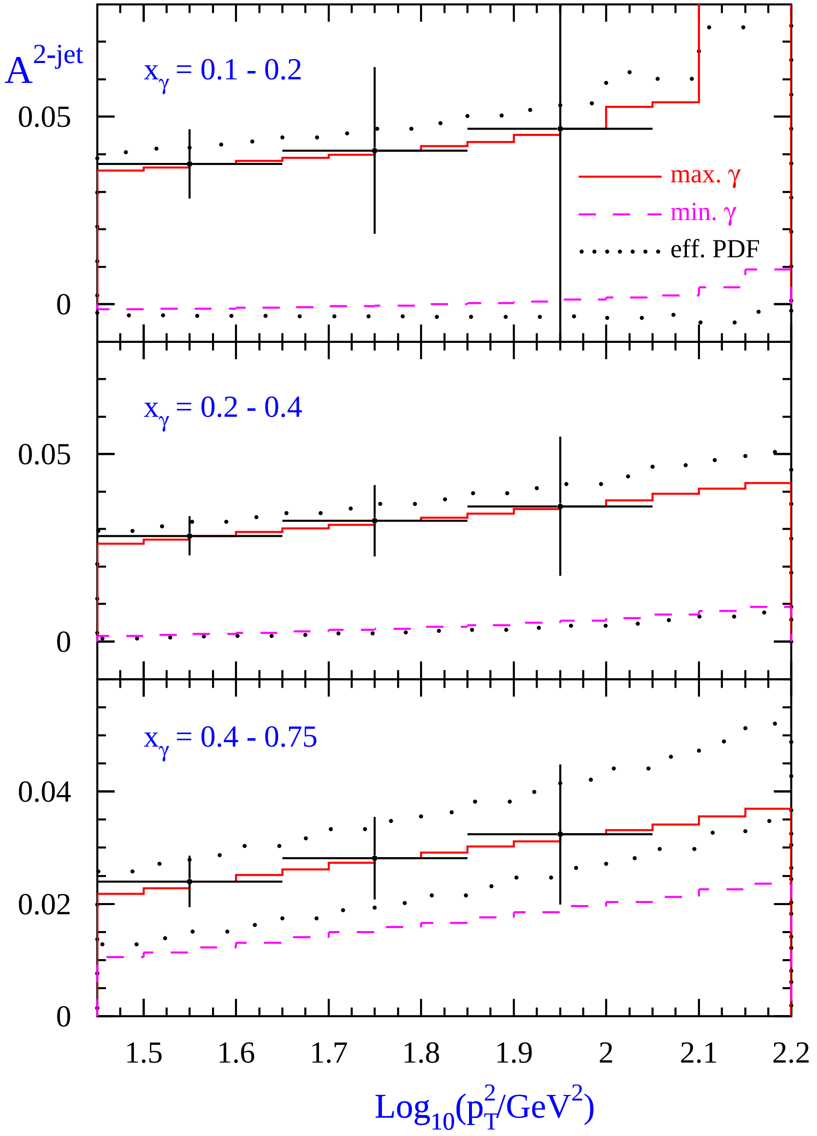
$$\mathcal{P}_{e,p} = 0.7;\ \mathcal{L} = 500/\mathrm{pb}$$

main results:

- expected sensitivity to Δf_γ at large η_{lab}
- $\eta_{\mathrm{lab}} < 0$ to double-check on Δg

Expectations for eRHIC (III): di-jets

MS, Vogelsang



← LO estimate only

[no NLO studies at $S_{ep}^{1/2} = 100\,\mathrm{GeV}$]

parameters used:

$$S_{ep}^{1/2} = 100\,\mathrm{GeV}$$

$$|\eta_1 - \eta_2| \leq 1;\ 0 \leq \frac{\eta_1+\eta_2}{2} \leq 2$$

$$0.2 \leq y \leq 0.85;\ Q_{\max} = 1\,\mathrm{GeV}$$

$$\mathcal{P}_{e,p} = 0.7;\ \mathcal{L} = 500/\mathrm{pb}$$

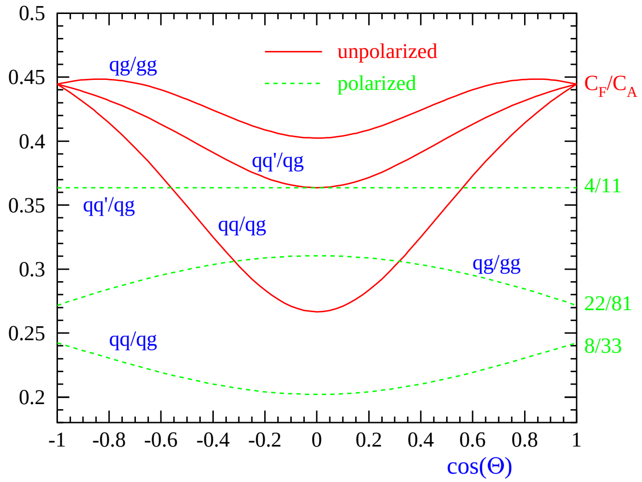
main feature:

- x_γ-cut → sensitivity to Δf_γ
- eff. pdf approx. works reasonably well

. . . di-jets (cont.)

extraction of Δf_γ from spin asymmetries: non-trivial unfolding

$\longrightarrow$ try *“effective pdf approach”* as $0^{\rm th}$ approximation:



idea: $qq'/qg \simeq qg/gg \simeq C_F/C_A = 4/9$

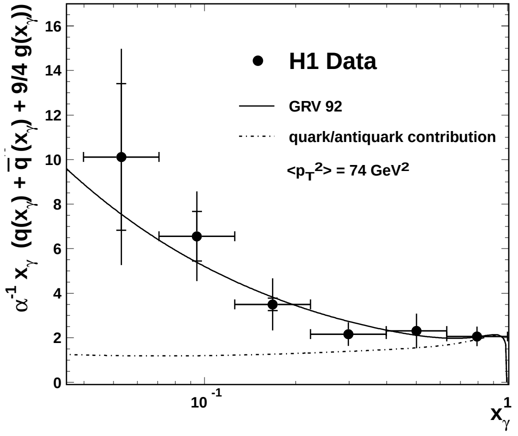
Combridge, Maxwell

$\to d\sigma_{\rm res} \simeq f_p^{\rm eff} \otimes f_\gamma^{\rm eff} \otimes d\hat{\sigma}_{qq'\to qq'}$, $f^{\rm eff} \equiv \sum_q (q+\bar{q}) + \frac{9}{4} g$

pol. case: $qq'/qg \neq qg/gg$

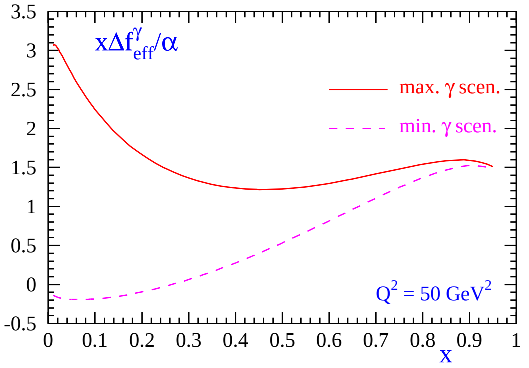
Vogelsang, MS

however, $\Delta f^{\rm eff} \equiv \sum_q (\Delta q + \Delta\bar{q}) + \frac{11}{4} \Delta g$ works



$\longleftarrow$ successfully used by

$\Delta f_\gamma^{\rm eff}$ for our two models $\longrightarrow$



Summary (I): physics goals

prime goal: 1^{st} determination of Δf_γ

- unique physics case for an $\vec{e}\vec{p}$ collider
- important test of pQCD
- almost all tools available in NLO

making use of the "background": extract Δf_p

- direct part sensitive to Δg
- important test of universality of pol. pdfs after RHIC
- high statistics $\longrightarrow$ may reduce errors on pdfs
- $\sqrt{S_{ep}} = 100\,\mathrm{GeV}$ new territory also for unpol. ep collisions

Summary (II): machine/detector requirements

photoproduction physics certainly doable

- H1 and ZEUS are teaching us how to do it
- moderate luminosities required: $500 \div 1000 \ \mathrm{pb}^{-1}$
- need to tag/anti-tag scattered electron to define photoproduction ($Q^2 \simeq 0$)
- H1/ZEUS-like detector to measure jets and different hadrons with good p_T and η coverage and resolution