Determining α_s from jets in DIS and photoproduction

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Work done in collaboration with T. Biekötter, G. Kramer and M. Michael

DFG

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References

Two recent publications:

- MK, G. Kramer, M. Michael
  NNLO contributions to jet photoproduction and determination of α_s
  Phys. Rev. D 89 (2014) 074032 [arXiv:1310.1724]
- T. Biekötter, MK, G. Kramer
  NNLO contributions to inclusive jet production in DIS and determination of α_s
  Phys. Rev. D (in press) [arXiv:1508.07153]

References

Referring to two final HERA publications:

- H. Abramowicz et al. [ZEUS Collaboration]
  Inclusive-jet photoproduction at HERA and determination of α_s
  Nucl. Phys. B 864 (2012) 1
- V. Andreev et al. [H1 Collaboration]
  Measurement of multijet production in ep collisions at high Q^2 and determination of the strong coupling α_s
  Eur. Phys. J. C 75 (2015) 65

Unified approach to NNLO soft and virtual corrections

N. Kidonakis, Int. J. Mod. Phys. A 19 (2004) 1793

- Full NNLO calculations challenging, slowly making progress
- Soft/virtual corrections often dominant, e.g. close to threshold

$$z \equiv \frac{(p_1+p_2)^2}{(p_a+p_b)^2} \to 1$$

- Resummation of these corrections possible to all orders
- Reexpansion gives approximate NNLO (aNNLO) results
- Results depend on 1PI or PIM kinematics, $\overline{\mathrm{MS}}$ or DIS scheme

NLO master formula

$$
\begin{aligned}
\mathrm{d}\sigma_{ab} &= \mathrm{d}\sigma_{ab}^{B}\frac{\alpha_s(\mu)}{\pi}\left[c_3 D_1(z) + c_2 D_0(z) + c_1\delta(1-z)\right] \\
&+ \frac{\alpha_s^{d_{\alpha_s}+1}(\mu)}{\pi}\left[A^c D_0(z) + T_1^c\delta(1-z)\right] \\
D_l(z) &= \left[\frac{\ln^l(1-z)}{1-z}\right]_+ \\
d_{\alpha_s} &= 0, 1, 2, ..., \text{ if Born is of } \mathcal{O}(\alpha_s^{0,1,2,\cdots})
\end{aligned}
$$

Leading coefficients (simple color flow)

QCD Compton process: $\gamma q \to qg$

$$\begin{aligned}
c_3 &= C_F - N_C, \\
c_2 &= C_F \left[-\ln\left(\frac{\mu_p^2}{s}\right) - \frac{3}{4} + 2\ln\left(\frac{-u}{s}\right)\right] + N_C \ln\left(\frac{t}{u}\right) - \frac{\beta_0}{4}, \\
c_1^{\mu} &= -\frac{3\,C_F}{4}\ln\left(\frac{\mu_p^2}{s}\right) + \frac{\beta_0}{4}\ln\left(\frac{\mu^2}{s}\right)
\end{aligned}$$

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Photon gluon fusion: $\gamma g \to q\bar{q}$

$$\begin{aligned} c_3 &= 2(N_C - C_F), \\ c_2 &= -\frac{3C_F}{2} + N_C \left[-\ln\left(\frac{\mu_p^2}{s}\right) + \ln\left(\frac{tu}{s^2}\right) \right], \\ c_1^\mu &= -\frac{\beta_0}{4}\ln\left(\frac{\mu_p^2}{s}\right) + \frac{\beta_0}{4}\ln\left(\frac{\mu^2}{s}\right). \end{aligned}$$

Leading coefficients (complex color flow)

Quark-(anti-)quark scattering: $qq \to qq$ and $q\bar{q} \to q\bar{q}$

$$\begin{aligned} c_3 &= 2C_F, \\ c_2 &= -C_F \ln\left(\frac{\mu_\gamma^2}{s}\right) - C_F \ln\left(\frac{\mu_p^2}{s}\right) - \frac{11}{2} C_F \\ c_1^\mu &= -C_F \left[\ln\left(\frac{p_T^2}{s}\right) + \frac{3}{2}\right] \ln\left(\frac{\mu_p^2}{s}\right) + \frac{\beta_0}{2} \ln\left(\frac{\mu^2}{s}\right) \end{aligned}$$

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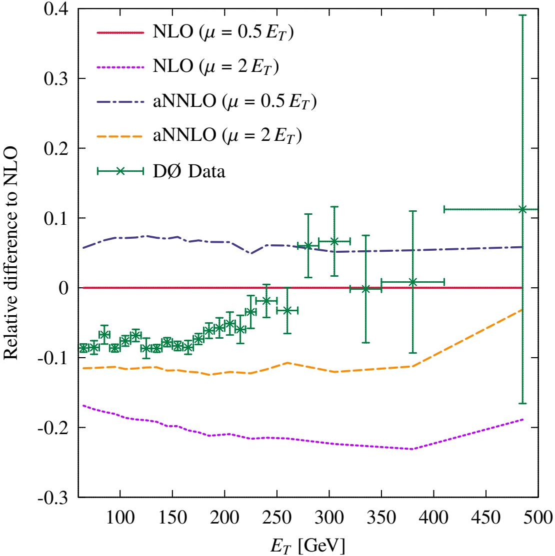
Similarly for $q\bar{q} \leftrightarrow gg$, $qg \to qg$, and $gg \to gg$.

NNLO master formula (simple color flow)

$$\begin{aligned}
\mathrm{d}\sigma_{ab} &= \mathrm{d}\sigma^{B}_{ab}\frac{\alpha_s^2(\mu)}{\pi^2}\left\{\frac{1}{2}c_3^2 D_3(z) + \left[\frac{3}{2}c_3c_2 - \frac{\beta_0}{4}c_3 + \sum_j C_{f_j}\frac{\beta_0}{8}\right] D_2(z)\right.\\
&+ \left[c_3c_1 + c_2^2 - \zeta_2 c_3^2 \frac{\beta_0}{2}T_2 + \frac{\beta_0}{4}c_3 \ln\left(\frac{\mu^2}{s}\right) + \ldots\right] D_1(z)\\
&+ \left[c_2c_1 - \zeta_2 c_2 c_3 + \zeta_3 c_3^2 - \frac{\beta_0}{2}T_1 + \frac{\beta_0}{4}c_2 \ln\left(\frac{\mu^2}{s}\right) + \ldots\right] D_0(z)\\
&+ \left.\left[\frac{1}{2}c_1^2 - \frac{\zeta_2}{2}c_2^2 + \frac{1}{4}\zeta_2^2 c_3^2 + \zeta_3 c_3 c_2 + \ldots + {\color{red}R}\right]\delta(1-z)\right\}
\end{aligned}$$

Jet hadroproduction

N. Kidonakis, J. Owens, Phys. Rev. D 63 (2001) 054019 (Fig. 2)



Jet production in DIS

T. Biekötter, M. Klasen, G. Kramer, Phys. Rev. D (in press)

Experimental conditions:

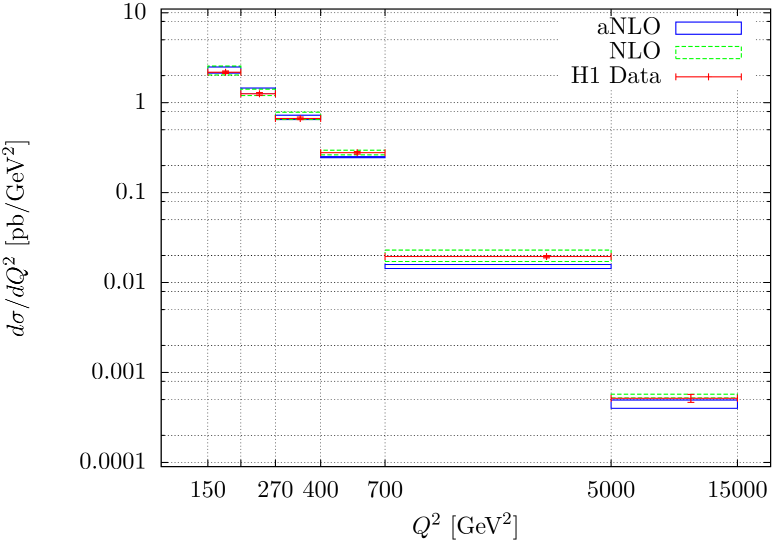
- HERA-II (2003-2007), $\sqrt{S} = 319$ GeV, $\mathcal{L} = 351$ pb^{-1}
- $150 \text{ GeV}^2 < Q^2 < 15000 \text{ GeV}^2$, $0.2 < y < 0.7$
- $p_T^{\rm jet} > 7$ GeV, $-1.0 < \eta^{\rm jet} < 2.5$, k_T-algorithm with $R = 1$

Theoretical input:

- Central scales: $\mu^2 = (Q^2 + p_T^2)/2$, $\mu_p^2 = Q^2$
- Proton PDFs: MSTW2008, $n_f = 5$, $\alpha_s(M_Z) = 0.110...0.130$
- Hadronization corrections modeled with PYTHIA

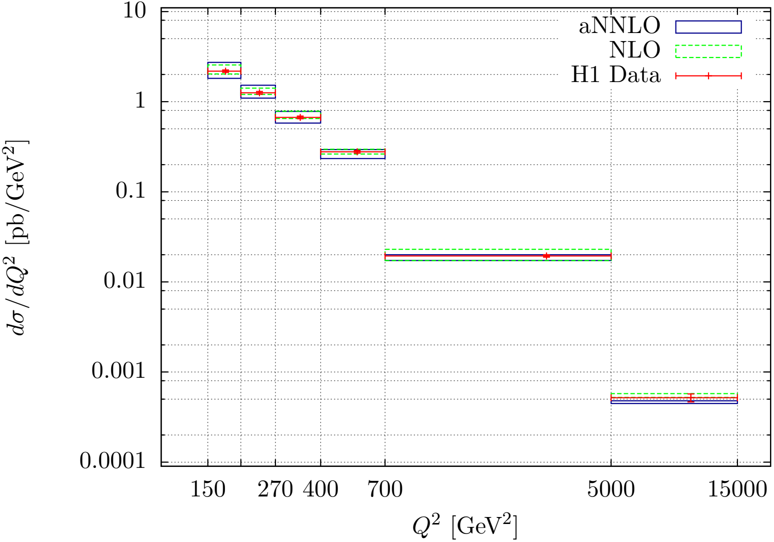
Jet production in DIS

T. Biekötter, M. Klasen, G. Kramer, Phys. Rev. D (in press)



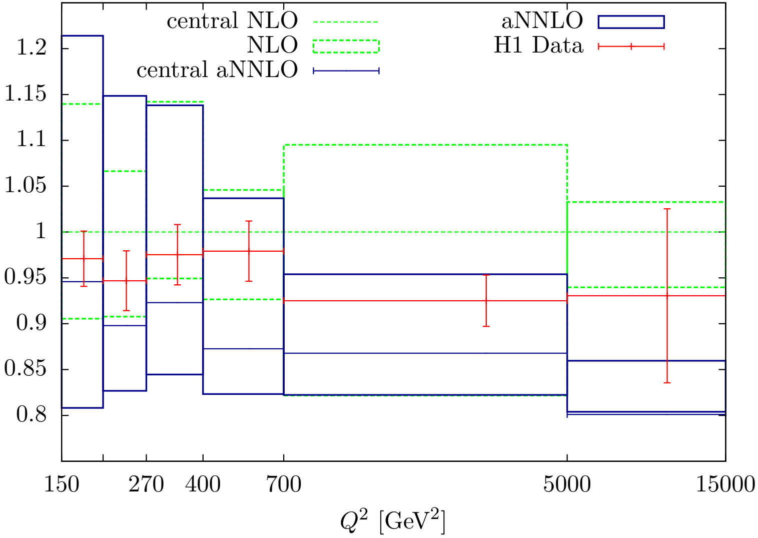
Jet production in DIS

T. Biekötter, M. Klasen, G. Kramer, Phys. Rev. D (in press)



Jet production in DIS

T. Biekötter, M. Klasen, G. Kramer, Phys. Rev. D (in press)



Jet production in DIS

T. Biekötter, M. Klasen, G. Kramer, Phys. Rev. D (in press)

Determination of α_s at NLO:

$$\alpha_s(M_Z) \quad = \quad 0.115 \pm 0.002(\mathrm{exp.}) \pm 0.005(\mathrm{th.})$$

Jet production in DIS

T. Biekötter, M. Klasen, G. Kramer, Phys. Rev. D (in press)

Determination of α_s at NLO:

$$\alpha_s(M_Z) \quad = \quad 0.115 \pm 0.002(\mathrm{exp.}) \pm 0.005(\mathrm{th.})$$

Determination of α_s at aNNLO:

$$\alpha_s(M_Z) \quad = \quad 0.122 \pm 0.002(\mathrm{exp.}) \pm 0.013(\mathrm{th.})$$

Jet photoproduction

M. Klasen, G. Kramer, M. Michael, Phys. Rev. D 89 (2014) 074032

Experimental conditions:

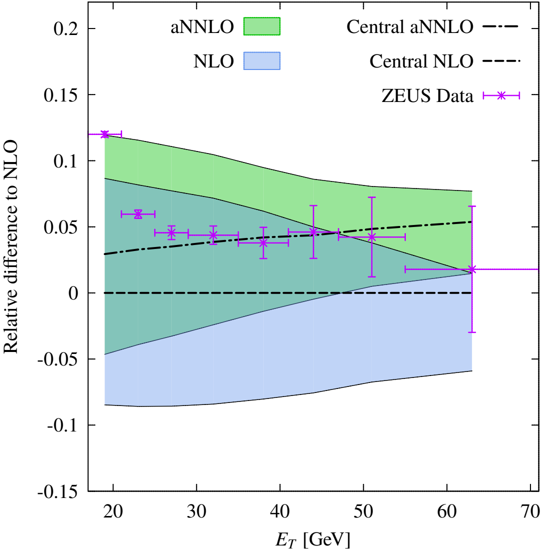
- HERA-II (2005-2007), $\sqrt{S} = 319$ GeV, $\mathcal{L} = 300$ pb^{-1}
- $Q^2 < 1$ GeV^2, 142 GeV $< W <$ 293 GeV
- $p_T^{\rm jet} > 17$ GeV, $-1.0 < \eta^{\rm jet} < 2.5$, k_T-algorithm with $R = 1$

Theoretical input:

- Central scales: $\mu = \mu_p = \mu_\gamma = p_T$
- Proton PDFs: CT10, $n_f = 5$, $\alpha_s(M_Z) = 0.112...0.124$
- Photon PDFs: GRV-HO, transformed from DIS_γ to $\overline{\mathrm{MS}}$
- Hadronization corrections modeled with PYTHIA

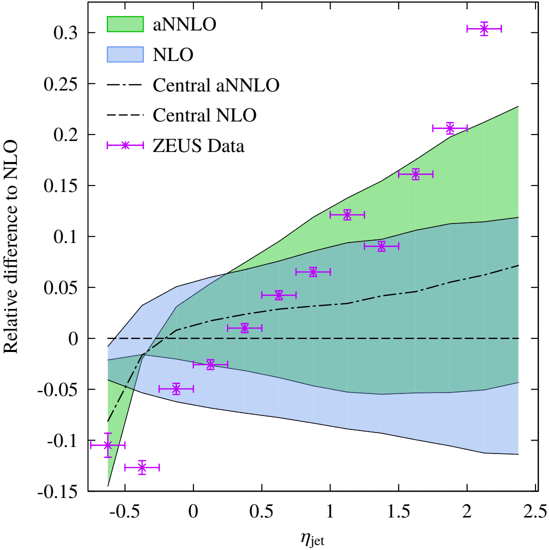
Jet photoproduction

M. Klasen, G. Kramer, M. Michael, Phys. Rev. D 89 (2014) 074032



Jet photoproduction

M. Klasen, G. Kramer, M. Michael, Phys. Rev. D 89 (2014) 074032



Jet photoproduction

M. Klasen, G. Kramer, M. Michael, Phys. Rev. D 89 (2014) 074032

Determination of α_s at NLO:

$$\alpha_s(M_Z) \quad = \quad 0.121^{+0.002}_{-0.002}(\mathrm{exp.})^{+0.005}_{-0.003}(\mathrm{th.})$$

Jet photoproduction

M. Klasen, G. Kramer, M. Michael, Phys. Rev. D 89 (2014) 074032

Determination of α_s at NLO:

$$\alpha_s(M_Z) \quad = \quad 0.121^{+0.002}_{-0.002}(\mathrm{exp.})^{+0.005}_{-0.003}(\mathrm{th.})$$

Determination of α_s at aNNLO:

$$\alpha_s(M_Z) \quad = \quad 0.120^{+0.002}_{-0.002}(\mathrm{exp.})^{+0.003}_{-0.003}(\mathrm{th.})$$

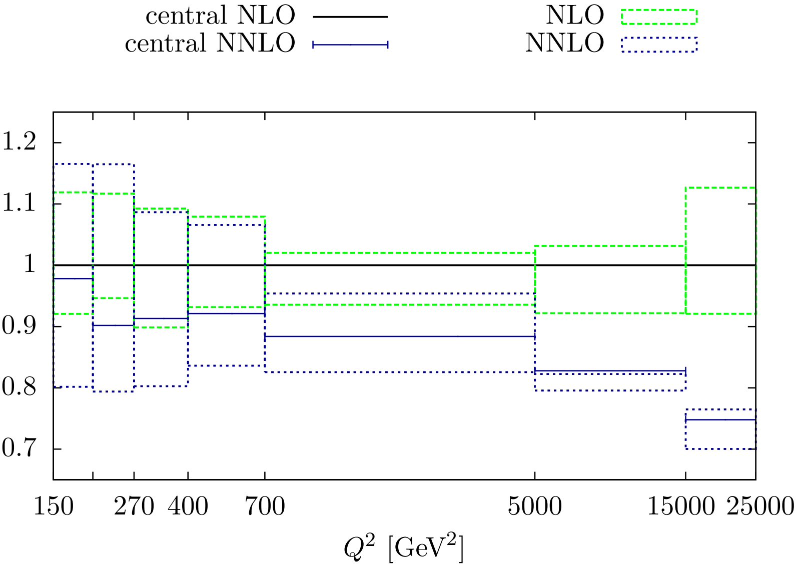
Conclusion and outlook (1)

Theory:

- Approximate NNLO from threshold resummation:
  More reliable at higher Q^2 or E_T
- Improve Kidonakis formalism to account for finite jet mass:
  D. de Florian, P. Hinderer, A. Mukherjee, F. Ringer, W. Vogelsang, Phys. Rev. Lett. 112 (2014) 082001
- Full NNLO calculations, e.g. $gg \rightarrow gg$:
  J. Currie, A. Gehrmann, N. Glover, J. Pires, JHEP 1401 (2014) 110

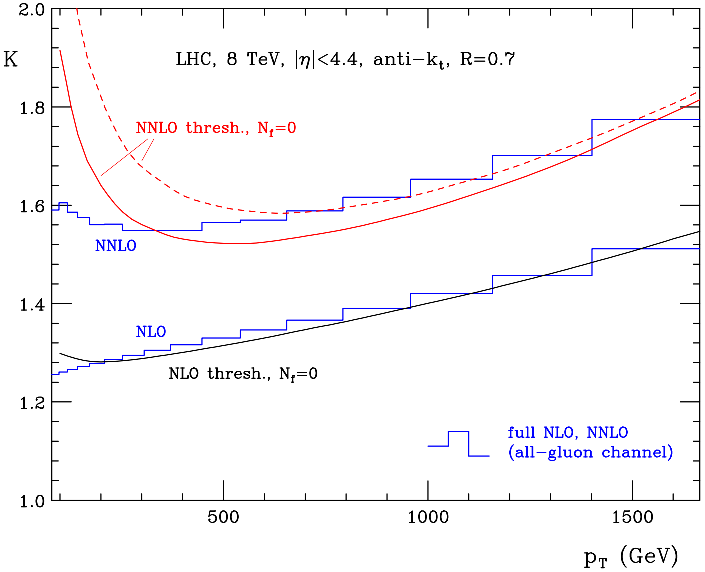
Jet production in DIS at higher Q^2

T. Biekötter, M.Sc. thesis, WWU Münster (2015)



Jet production in DIS at higher Q^2

D. de Florian, P. Hinderer, A. Mukherjee, F. Ringer, W. Vogelsang, Phys. Rev. Lett. 112 (2014) 082001



Conclusion and outlook (2)

Experiment:

- ep: Continuation of HERA program on jet production
  Higher Q^2 and p_T
  Requires (simultaneous) fit of (photon) PDFs
- ee: Continuation of LEP program on F_2^γ
  Select kinematic region with dominant pointlike contribution
  Independence of (photon) PDFs
- pp: Photoproduction (and DIS) in pp?
  Mixed with diffraction → disentangle with leptonic final states
  Much higher photon flux in pA and AA
  Requires (simultaneous) fit of diffractive/photon/lepton PDFs

LEP impact on α_s from F_2^γ

S. Albino, M. Klasen, S. Söldner-Rembold, Phys. Rev. Lett. 89 (2002) 122004

Scheme	χ^2/DF	$\alpha_s(m_Z)$
LO	7.9/ 19	$0.1260 \pm 0.0055(\text{ex})^{+0.0061}_{-0.0055}(\text{th})$
$\overline{\text{MS}}$	9.1/ 19	$0.1183 \pm 0.0050(\text{ex})^{+0.0029}_{-0.0028}(\text{th})$
DIS_γ	8.1/ 19	$0.1195 \pm 0.0051(\text{ex})^{+0.0031}_{-0.0028}(\text{th})$
w/o LEP	3.2/ 7	$0.1244 \pm 0.0126(\text{ex})^{+0.0033}_{-0.0032}(\text{th})$
high Q^2	11.9/ 8	$0.1159 \pm 0.0125(\text{ex})^{+0.0018}_{-0.0018}(\text{th})$