Next-to-Leading Order QCD Corrections to Inclusive Heavy-Flavor Production in Polarized Deep-Inelastic Scattering

Felix Hekhorn and Marco Stratmann

Institute for Theoretical Physics, University of Tübingen

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Outline

Introduction - Heavy Quarks (HQ)

- Heavy Quarks (HQ): c($m_c = 1.5\,\mathrm{GeV}$), b($m_b = 4.75\,\mathrm{GeV}$), t($m_t = 175\,\mathrm{GeV}$)
- EIC will reach region with HQ relevant to structure functions
- compare unpolarized case HERA@DESY: at small $x \sim 30\%$ charm contributions [Laenen,Riemersma,Smith,van Neerven]

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- measure Δg as dominated by photon-gluon fusion (PGF)
- first full NLO computation of polarized process [Blümlein,Falcioni,De Freitas]

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- need improved charm tagging
- fully inclusive cross section is complicated to reconstruct
- no hadronization here

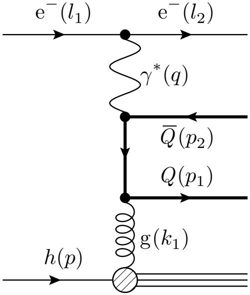
- scale of hard process is in a pertubative regime
  $m > \Lambda_{QCD}$
- finite mass m provides total cross sections

Introduction - Heavy Quarks (HQ)

- scale of hard process is in a pertubative regime $m > \Lambda_{QCD}$
- finite mass m provides total cross sections
- full m^2 dependence makes computations complicated: phase space + matrix elements
- 2-scale problem: $\ln\left(\frac{s-4m^2}{4m^2}\right)$ and/or $\ln(Q^2/m^2)$
- keep analytic expressions

Introduction - DIS Setup

$$e^-(l_1) + h(p) \to e^-(l_2) + \bar{Q}(p_2) + X[Q]$$



- $S_h = (p + l_1)^2 = Q^2/(xy)$, x, y,
  $Q^2 = -q^2 = -(l_1 - l_2)^2 \ll M_Z^2$
- unpolarized cross section: [PDG]
  $$\frac{d^2\sigma}{dxdy} = \frac{2\pi\alpha^2}{xyQ^2}\left(Y_+ F_2(x,Q^2) - y^2 F_L(x,Q^2)\right)$$
  $$2x F_1(x,Q^2) = F_2(x,Q^2) - F_L(x,Q^2)$$
- polarized cross section: [PDG]
  $$\frac{d^2\Delta\sigma}{dxdy} = \frac{4\pi\alpha^2}{xyQ^2} Y_- \cdot 2x g_1(x,Q^2)$$
- with $Y_\pm = 1 \pm (1-y)^2$

Computation Review

- use factorisation theorem: PDF and $s = \xi S_h$
- PGF: $\mathrm{g}(k_1) + \gamma^*(q) \to \bar{Q}(p_2) + Q(p_1)$
- three massive particles: $m^2 > 0, q^2 = -Q^2 < 0$

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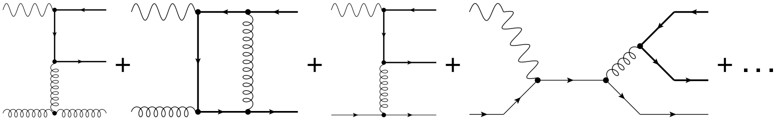
- compute 2-to-3-phase space: e.g. $dPS_3 \sim dt_1 du_1 d\Omega_n d\hat{\mathcal{I}}$ [Laenen, Bojak]
- diagrams:



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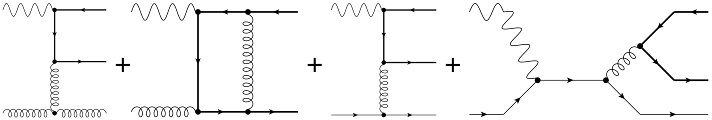
- diagrams:  + …
- collinear poles $\to$ mass factorization ($\overline{\text{MS}}$)
- soft + virtual + renormalization ($\overline{\text{MS}}_m$) + factorization is finite [Laenen,Bojak]

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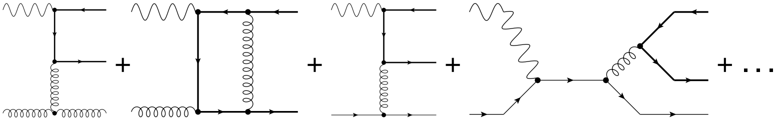
- diagrams: 
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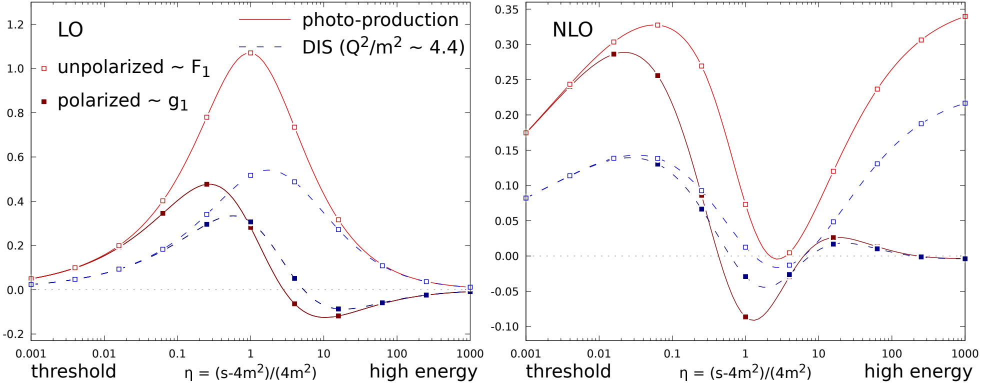
- γ_5 and $\varepsilon_{\mu\nu\rho\sigma}$ in n-dimension? $\to$ HVBM scheme ['t Hooft,Veltman,Breitenlohner,Maison]

Partonic Results - Gluon Channel

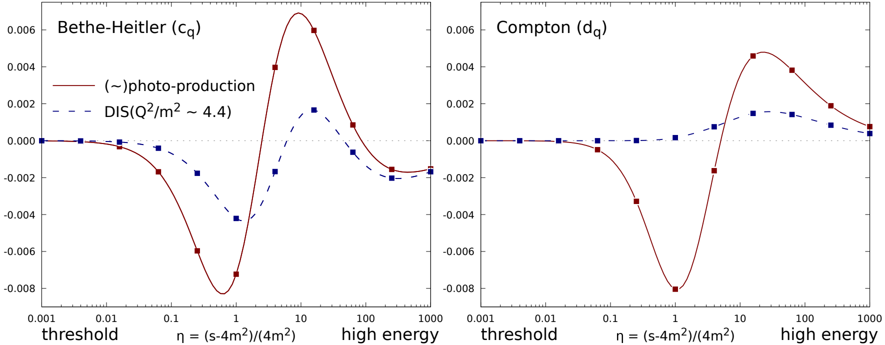
$$g_1 \sim \alpha_s \cdot \Delta g \otimes \left(c^{(0)}_{P,g} + 4\pi\alpha_s \left[c^{(1)}_{P,g} + \ln\left(\frac{\mu^2}{m^2}\right) \bar{c}^{(1)}_{P,g} \right] \right)$$



- polarized $\sim$ unpolarized near threshold, but not at high energy

Partonic Results - Light Quark Channel

$$g_1 \sim \alpha_s^2 \sum_q (\Delta q + \Delta\bar{q}) \otimes \left(e_H^2 \left[c_{P,q}^{(1)} + \ln\left(\frac{\mu_F^2}{m^2}\right) \bar{c}_{P,q}^{(1)} \right] + e_q^2 d_{P,q}^{(1)} \right)$$

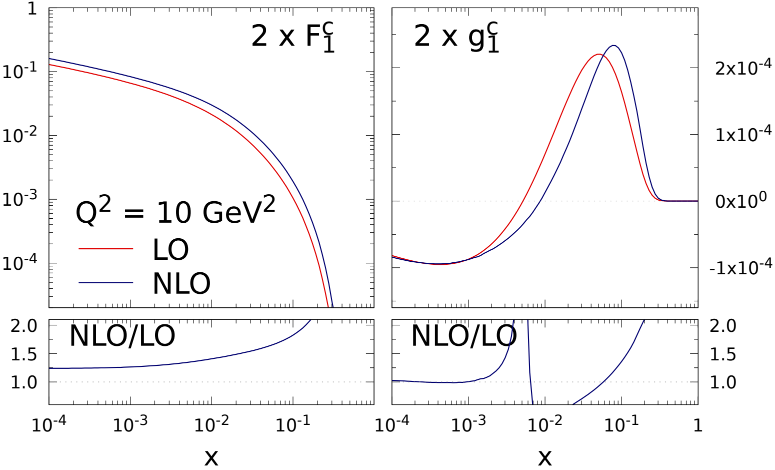


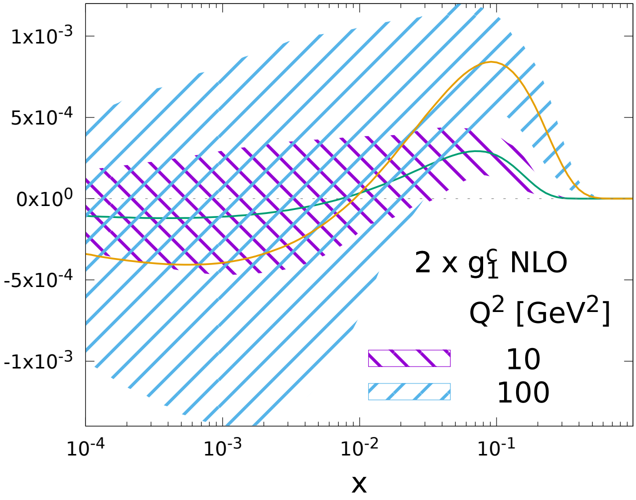
- no interference term $\sim e_H e_q$
- Compton subprocess contains $\ln(Q^2/m^2)$

Hadronic Results - Unpolarized vs. Polarized

unpolarized $\sim$ MSTW2008 $\leftrightarrow$ polarized $\sim$ DSSV2014

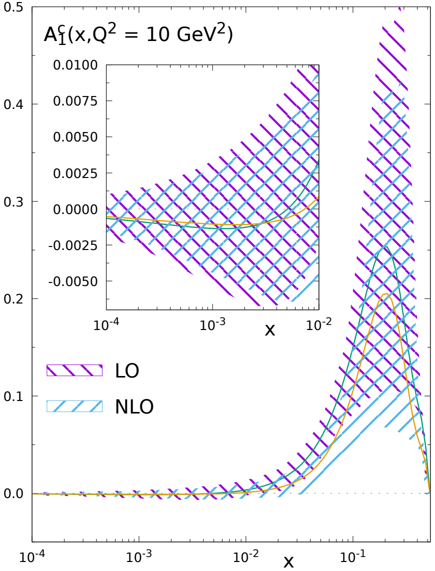
[Martin,Stirling,Thorne,Watt] $\leftrightarrow$ [de Florian,Sassot,Stratmann,Vogelsang]



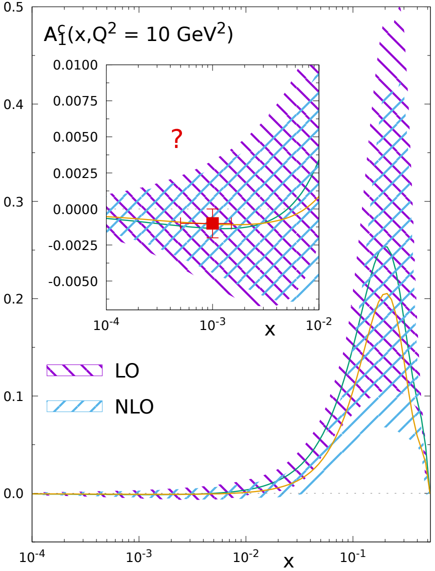


- quark error band is small
- sign unconstrained
- gluon dominates (?)
- default gluon is small

Hadronic Results - PDF Uncertainties DSSV (II)



- $A_1^c(x, Q^2) = \frac{g_1^c(x,Q^2)}{F_1^c(x,Q^2)}$
- error band are only due to DSSV uncertainties (no correlations!)



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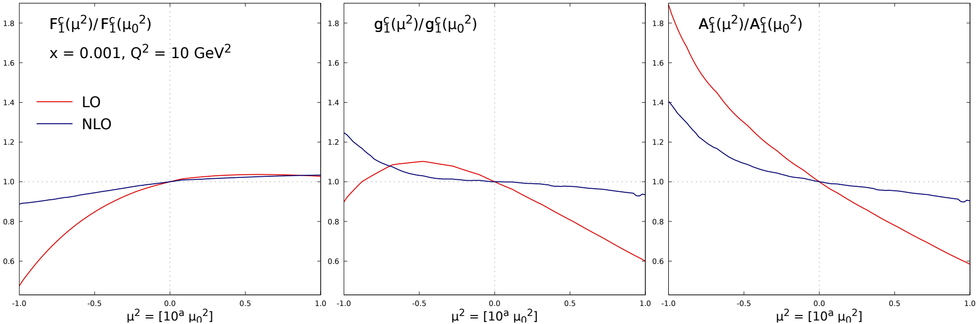
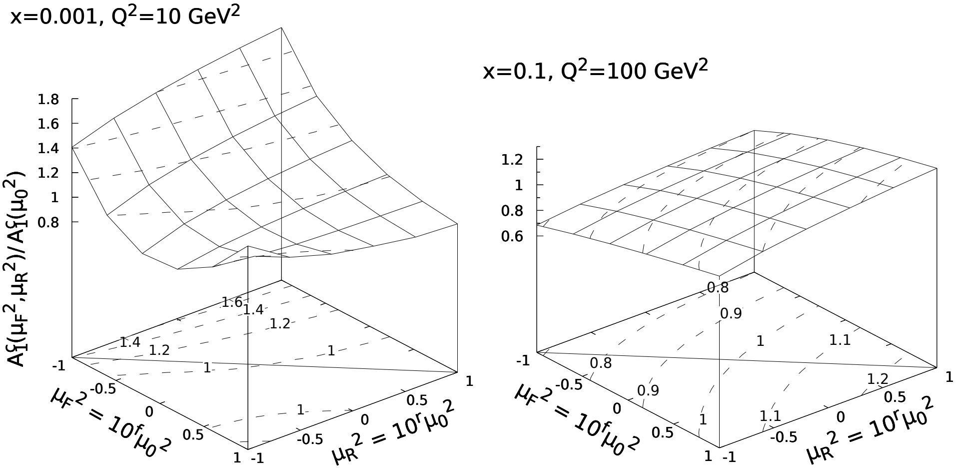
- need measurement of $\mathcal{O}(10^{-3})$
- NLO $\lessapprox$ LO

Hadronic Results - Scale Uncertainties (I)



$$\mu_F^2 = \mu_R^2 = 10^a \mu_0^2 \text{ with } \mu_0^2 = 4m^2 + Q^2$$

Hadronic Results - Scale Uncertainties (II)



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Outlook

- inclusive distributions: $\frac{dg_1}{dp_{T,\bar{Q}}}, \frac{dg_1}{dy_{\bar{Q}}}, \ldots$ [Laenen,Riemersma,Smith,van Neerven]
- correlated distributions: $\frac{dg_1}{dM^2_{Q\bar{Q}}}, \frac{dg_1}{d\phi_{Q\bar{Q}}}$, TMD, $\ldots$ [Harris,Smith]

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- distributions of full NC structure functions: $\frac{dg_1^{NC}}{dp_{T,\bar{Q}}}, \frac{dg_1^{NC}}{dM^2_{Q\bar{Q}}}, \ldots$

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Thank you for your attention!

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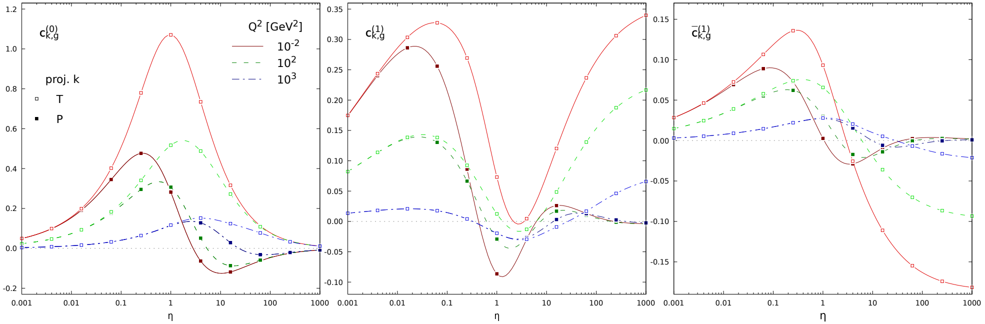

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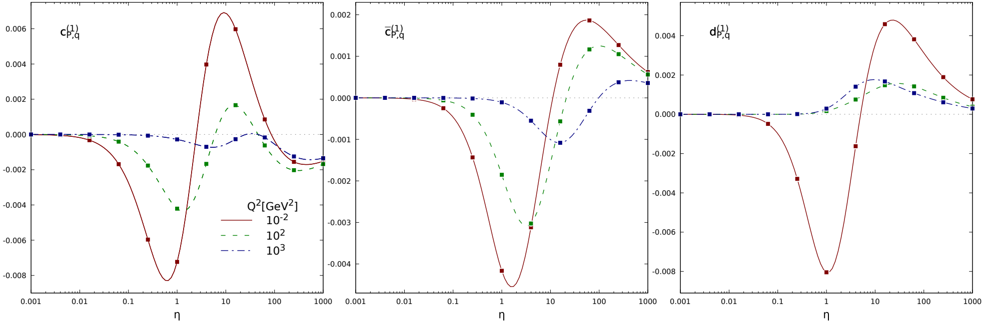

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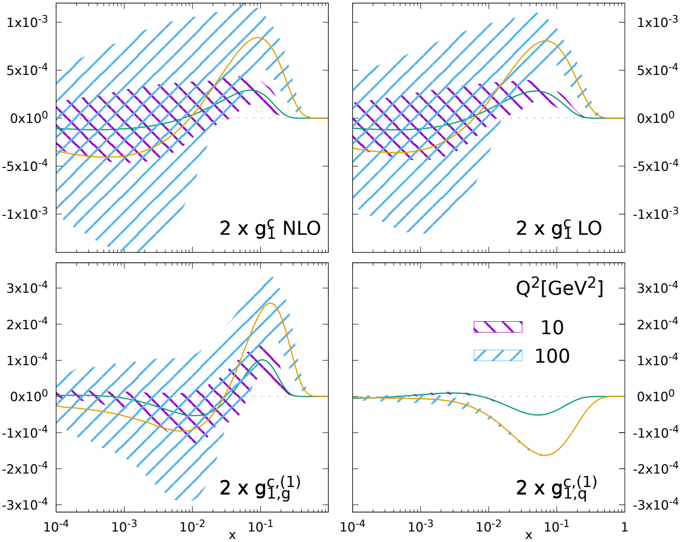
Backup: Hadronic Results - PDF Uncertainties DSSV



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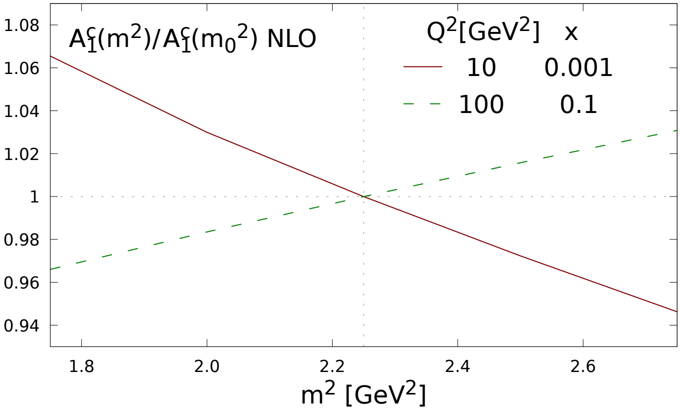
Backup: Hadronic Results - Mass Variation



$$m_0 = 1.5\,\mathrm{GeV}$$