Heavy Quarks in Deep-Inelastic Scattering

Felix Hekhorn

Institute for Theoretical Physics, University of Tübingen

August, 2019

Varenna, Italy

Outline

For a broader introduction please see my papers:

- F. Hekhorn and M. Stratmann, Phys.Rev. D98 (2018) no.1, 014018
- F. Hekhorn and M. Stratmann, PoS DIS2018 (2018) 155
- F. Hekhorn and M. Stratmann, PoS DIS2019 (2019) 177
- F. Hekhorn, PhD Thesis, 2019
- F. Hekhorn and M. Stratmann, *in preparation*, 2019

Introduction - Heavy Quarks (HQ)

- Heavy Quarks (HQ): $\mathrm{c}(m_\mathrm{c} = 1.5\,\mathrm{GeV})$, $\mathrm{b}(m_\mathrm{b} = 4.75\,\mathrm{GeV})$, $\mathrm{t}(m_\mathrm{t} = 175\,\mathrm{GeV})$
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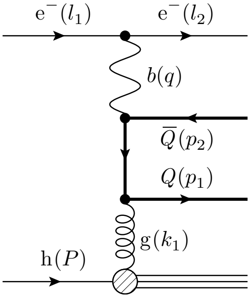
- need improved charm tagging
- no hadronization here

Introduction - DIS Setup

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



- $x = \frac{Q^2}{2q\cdot P}$ and $Q^2 = -q^2 = -(l_1 - l_2)^2$
- massless lepton/hadron $l_1^2 = 0 = P^2$
- parity conserving
  - unpolarized: F_1, F_2
  - polarized: g_1
- parity violating
  - unpolarized: F_3
  - polarized: g_4, g_5 [PDG]
- use cms of b^*h with $\vec{P} \sim \hat{z}$

Introduction - Computation

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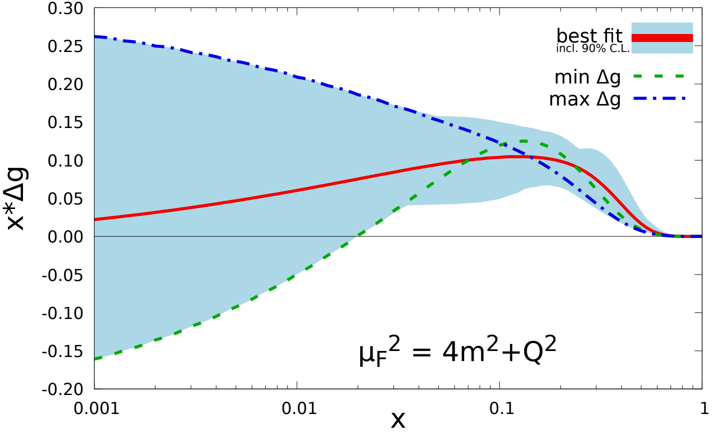
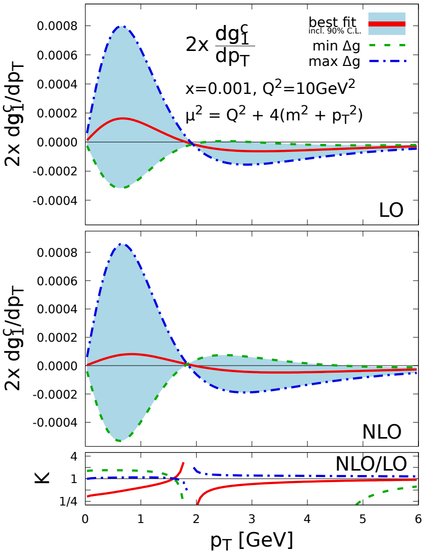
- structure function = $\int$ PDF $\otimes$ ME dPS

- use $\bar{c}$-quark and DSSV2014[de Florian,Sassot,Stratmann,Vogelsang]



Distributions - Transverse Momentum (I)



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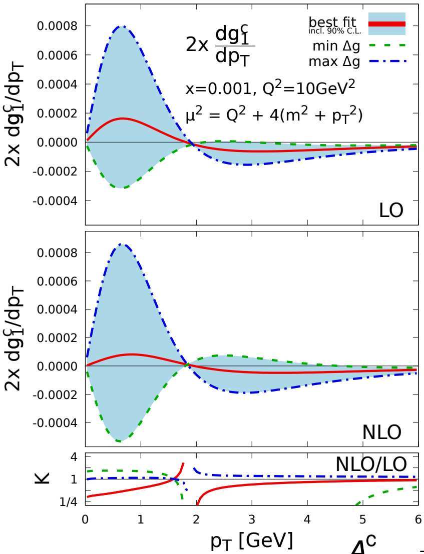

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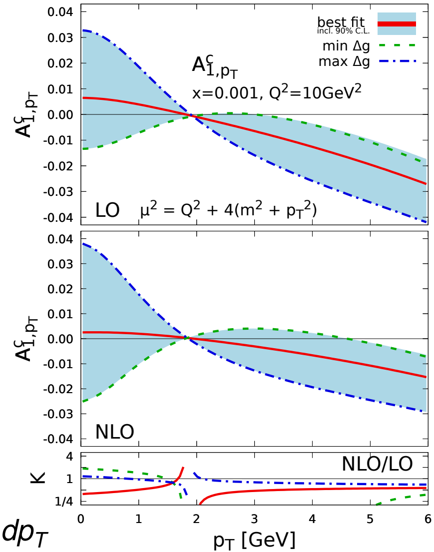
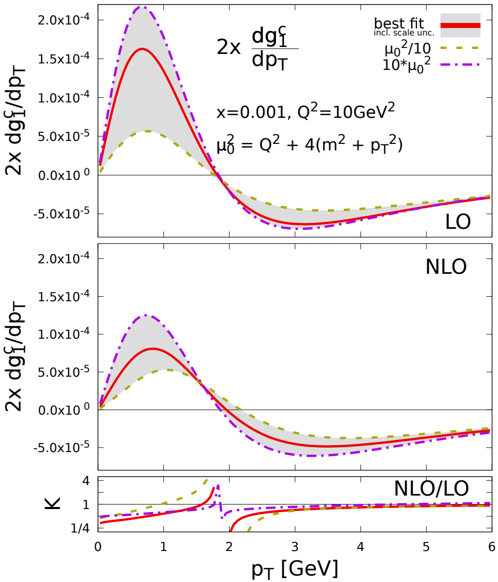
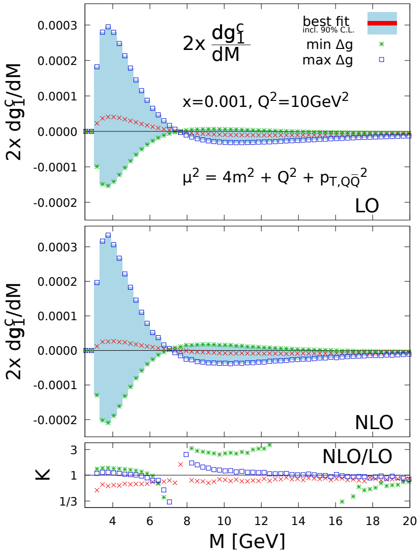


$$A^c_{1,p_T} = \frac{dg_1^c/dp_T}{dF_1^c/dp_T}$$

Distributions - Transverse Momentum (II)



Distributions - Pair Mass



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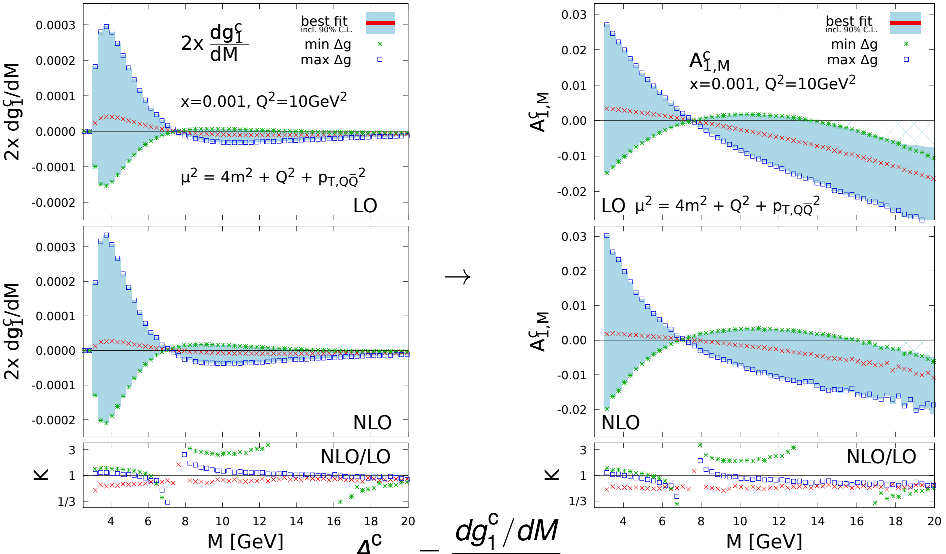


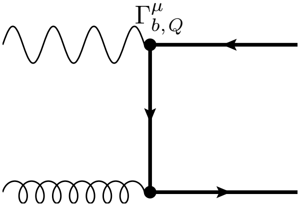
$$A^c_{1,M} = \frac{dg^c_1/dM}{dF^c_1/dM}$$

Neutral Current - Full Neutral Current DIS

define coupling of vector boson $b(q)$ to fermion f: $-ie\Gamma^\mu_{b,f}$ with

$$\Gamma^\mu_{b,f} = g^V_{b,f}\Gamma^\mu_V + g^A_{b,f}\Gamma^\mu_A = g^V_{b,f}\gamma^\mu + g^A_{b,f}\gamma^\mu\gamma^5, \quad b \in \{\gamma, Z\}, f \in \{\ell, q, Q\}$$

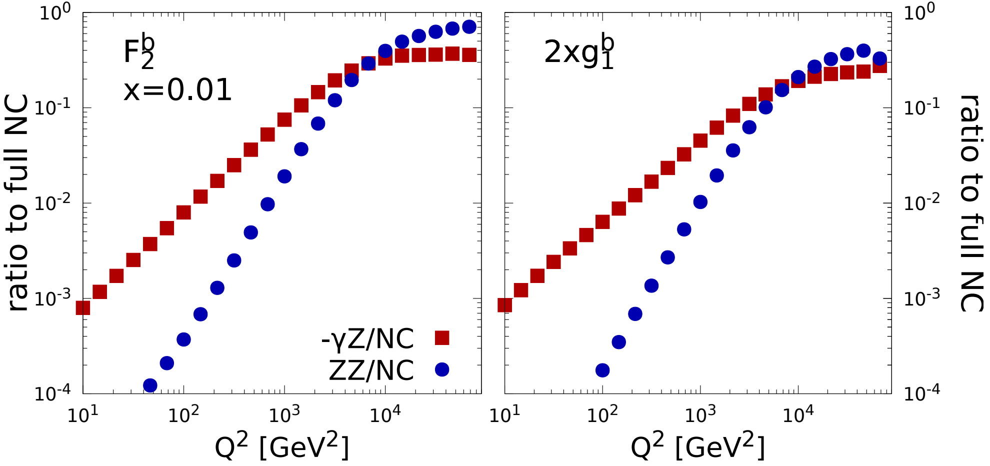
decompose partonic coefficient functions by vector/axial-vector currents:



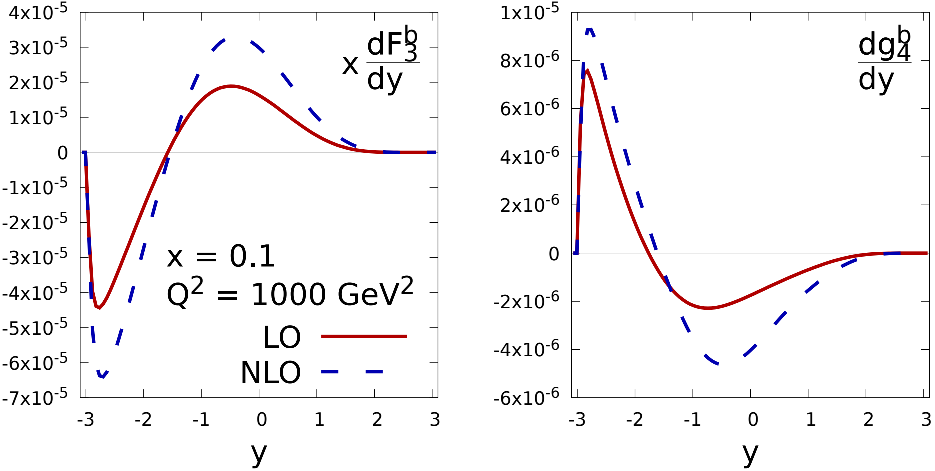
$$B^{VV}_{F_1}, B^{VV}_{F_2}, B^{VV}_{g_1}$$
$$B^{VA}_{F_3}, B^{VA}_{g_4}, B^{VA}_{g_5}$$
$$B^{AA}_{F_1}, B^{AA}_{F_2}, B^{AA}_{g_1}$$

now: change to $\overline{\text{b}}$-quark and use NNPDF sets[NNPDF Collaboration]

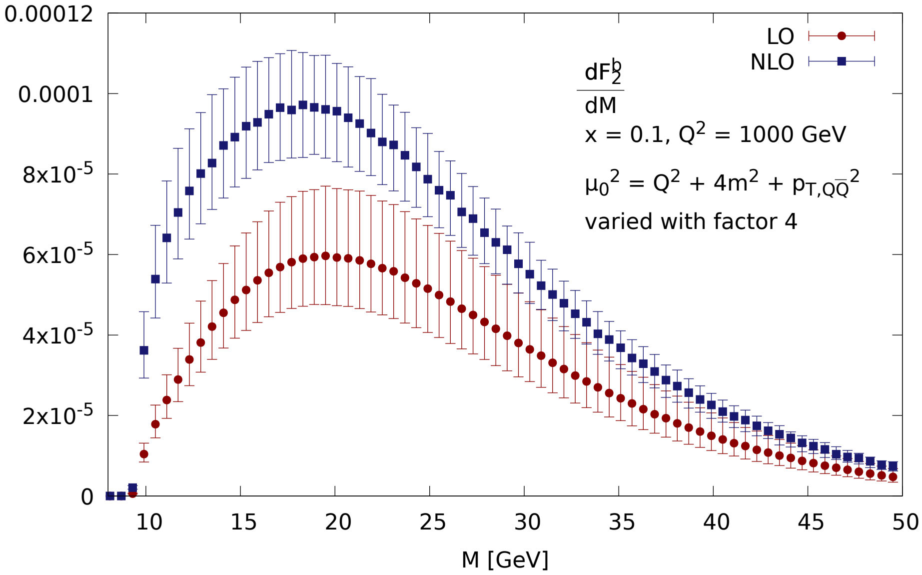
Neutral Current - Fully Inclusive Structure Functions



Neutral Current - Inclusive Distributions



Neutral Current - Correlated Distributions



Outlook

- add (physical) cuts
- move to leptonic reference frame
- add fragmentation, e.g. $\overline{c} \to D$
- fast implementations/fits

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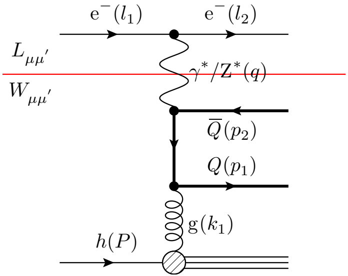
Thank you for your attention!



Deep Inelastic Scattering:

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

$$d\sigma \sim L^{\mu\mu'} W_{\mu\mu'} \text{ with } \hat{P}_\mu = P_\mu - \frac{P \cdot q}{q^2} q_\mu$$

$$W_{\mu\mu'} = \left(-g_{\mu\mu'} + \frac{q_\mu q_{\mu'}}{q^2}\right) F_1 + \frac{\hat{P}_\mu \hat{P}_{\mu'}}{P \cdot q} F_2 - i\varepsilon_{\mu\mu'\alpha\beta} \frac{q^\alpha P^\beta}{2P \cdot q} F_3$$
$$+ i\varepsilon_{\mu\mu'\alpha\beta} \frac{q^\alpha S^\beta}{P \cdot q} g_1 + \frac{S \cdot q}{P \cdot q} \left[\frac{\hat{P}_\mu \hat{P}_{\mu'}}{P \cdot q} g_4 + \left(-g_{\mu\mu'} + \frac{q_\mu q_{\mu'}}{q^2}\right) g_5\right]$$

[PDG]

Backup - HVBM vs. Larin

$$\{\gamma_5, \gamma_\mu\} = 0 \qquad \gamma_5 = \frac{i}{4!}\varepsilon_{\mu\nu\rho\sigma}\gamma^\mu\gamma^\nu\gamma^\rho\gamma^\sigma$$

t'Hooft-Veltman-Breitenlohner-Maison:

$$\{\gamma_5, \gamma_\mu\} = 0 \qquad \mu = 0, 1, 2, 3$$

$$[\gamma_5, \gamma_\mu] = 0 \qquad \text{otherwise}$$

Larin:

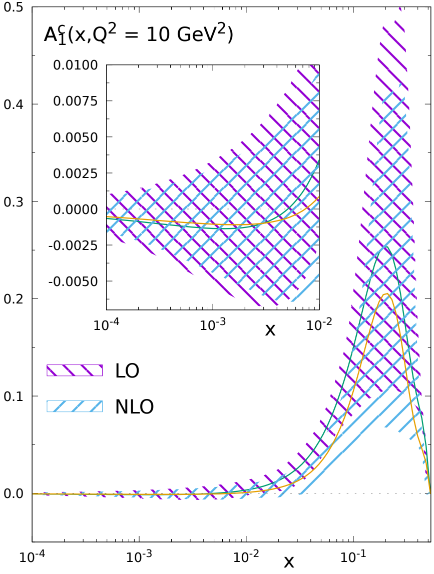
$$\gamma_\mu\gamma_5 = \frac{i}{6}\varepsilon_{\mu\nu\rho\sigma}\gamma^\nu\gamma^\rho\gamma^\sigma$$

$$\varepsilon_{\mu\nu\rho\sigma}\varepsilon^{\alpha\beta\gamma\delta} = \begin{vmatrix} \delta^\alpha_\mu & \cdots \\ \vdots & \ddots \end{vmatrix} = f(D)$$

Moch,Vermaseren,Vogt:

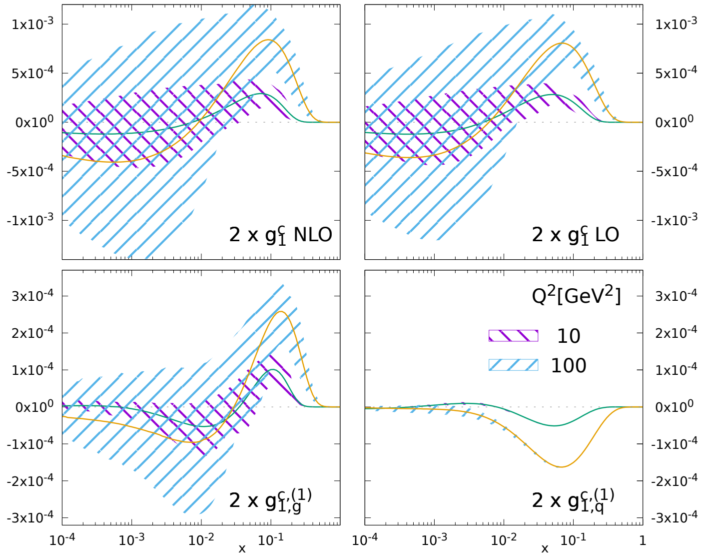
$$\mathrm{tr}\left[\gamma_{\nu_1}\cdots\gamma_\mu\gamma_5\right] := g, \varepsilon, \ldots$$

Backup - Fully Inclusive Asymmetry

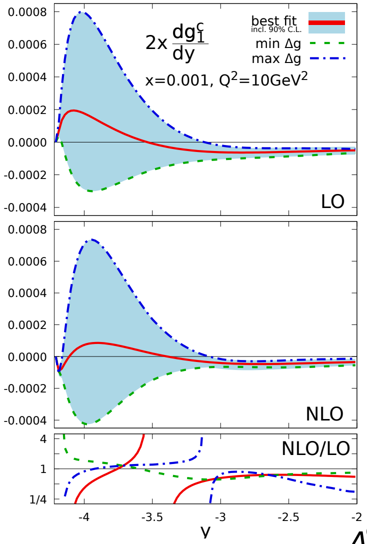


- $A_1^c(x, Q^2) = \frac{g_1^c(x,Q^2)}{F_1^c(x,Q^2)}$
- error band are only due to DSSV uncertainties (no correlations!)
- sign unconstrained
- need measurement of $\mathcal{O}(10^{-3})$
- NLO $\lessapprox$ LO

Backup - Fully Inclusive Asymmetry - Contributions



Backup - Distriubutions - Rapidity



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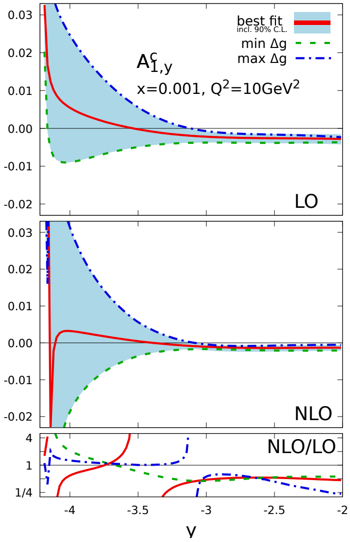
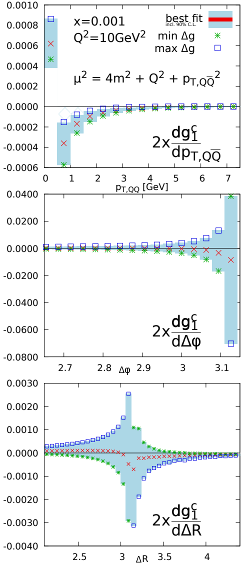
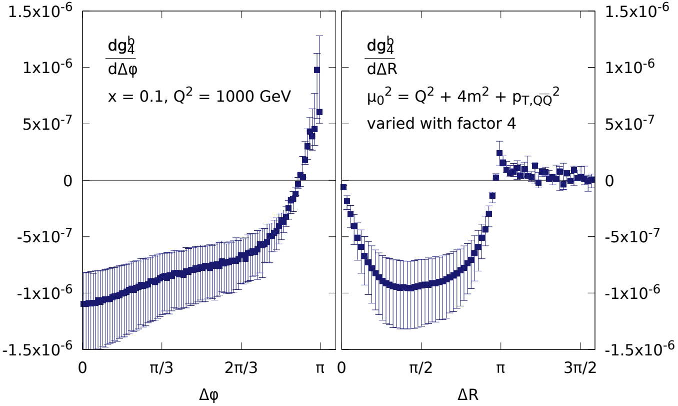


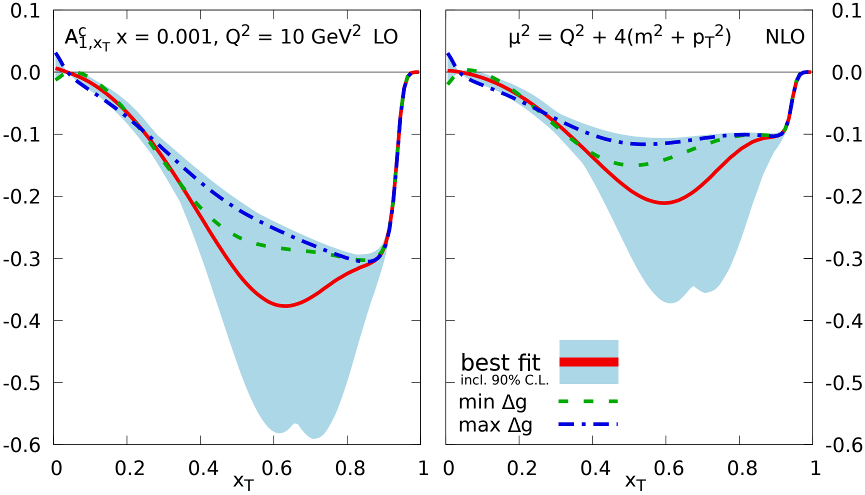
$$A_{1,y}^c = \frac{dg_1^c/dy}{dF_1^c/dy}$$

Backup - Distributions - Monte Carlo





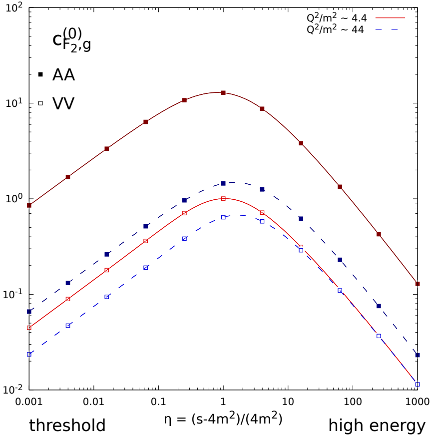
Backup - Distributions - Tranverse Momentum Fraction

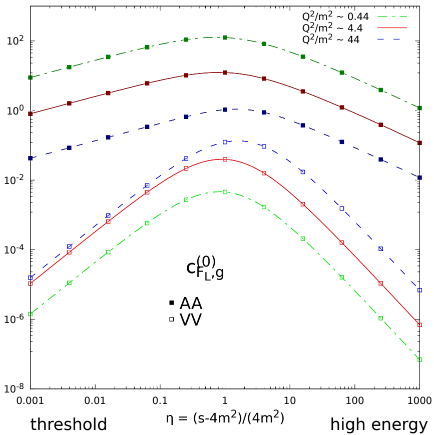


Backup - NC Partonic Gluon Channel

$$F_2^{NC} \sim \left(\frac{Q^2}{M_Z^2+Q^2}\right)^2 F_2^Z$$

$$F_L = F_2 - 2xF_1$$

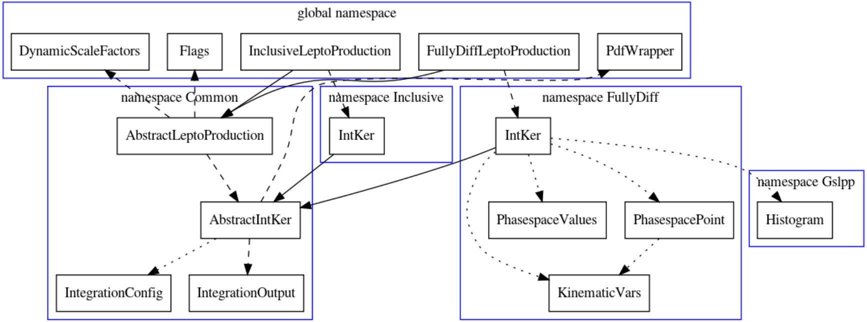




$$\lim_{Q^2\to 0} c^{(0)}_{F_2,AA,g} \sim \frac{m^2}{Q^2}$$

$$\lim_{Q^2\to 0} c^{(0)}_{F_L,AA,g} \sim \frac{m^2}{Q^2}, \text{ but } \lim_{Q^2\to 0} c^{(0)}_{F_L,VV,g} \sim \frac{Q^2}{m^2}$$

Backup - Code


global namespace
DynamicScaleFactors
Flags
InclusiveLeptoProduction
FullyDiffLeptoProduction
PdfWrapper
namespace Common
AbstractLeptoProduction
AbstractIntKer
IntegrationConfig
IntegrationOutput
namespace Inclusive
IntKer
namespace FullyDiff
IntKer
PhasespaceValues
PhasespacePoint
KinematicVars
namespace Gslpp
Histogram