Gluon determination from F_2 and F_2^c

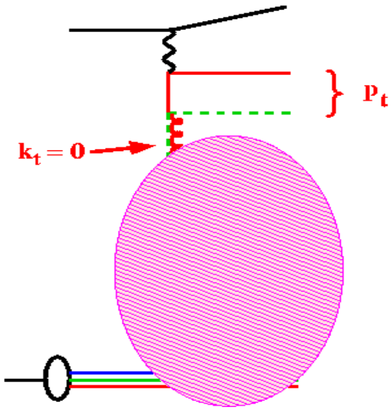
H. Jung (DESY)

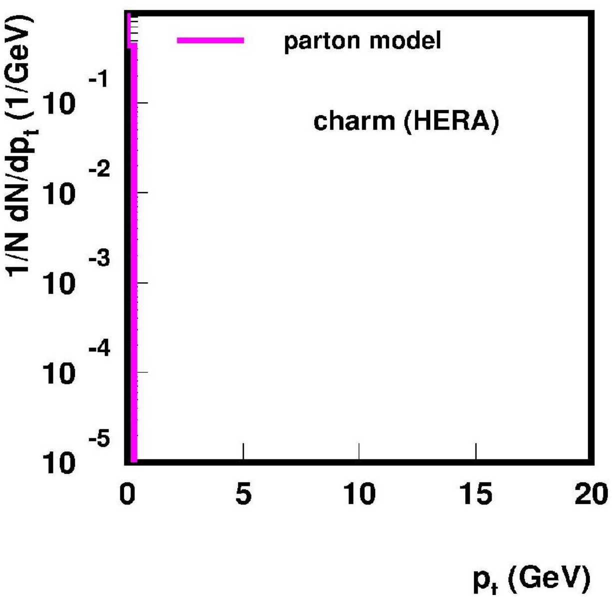
- Towards precision determiantion of uPDFs ....
  - why unintegrated parton density functions (uPDFs) ?
- Determination of uPDFs using F_2, F_2^c
- Is it all consistent ?
- What tells collinear approach ?

Need for uPDFs: transverse momenta

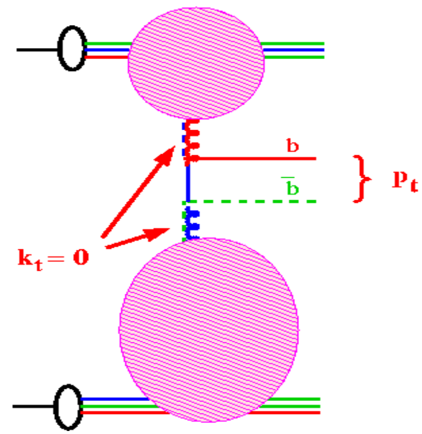
J. Collins, H. Jung hep-ph/0508280

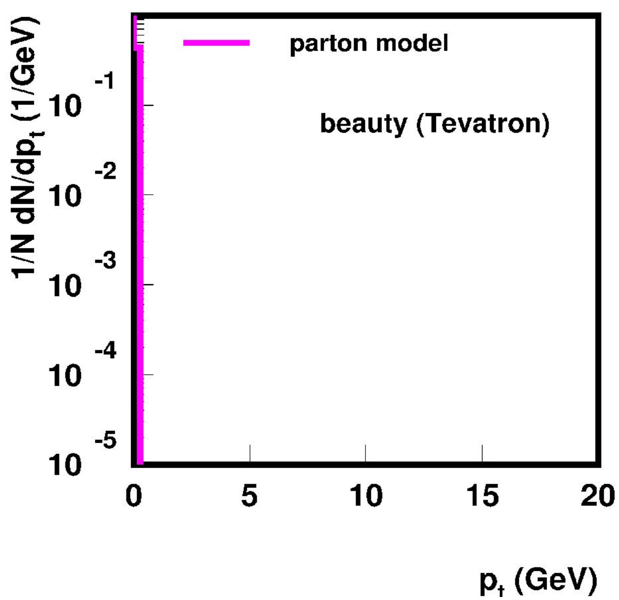
heavy quarks at HERA



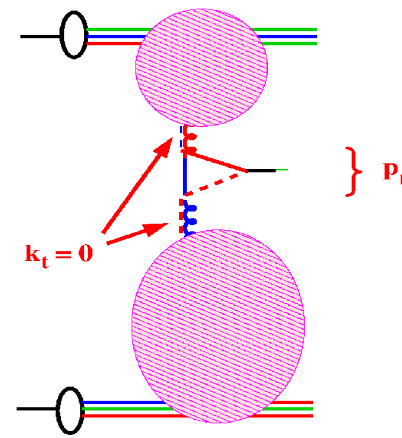


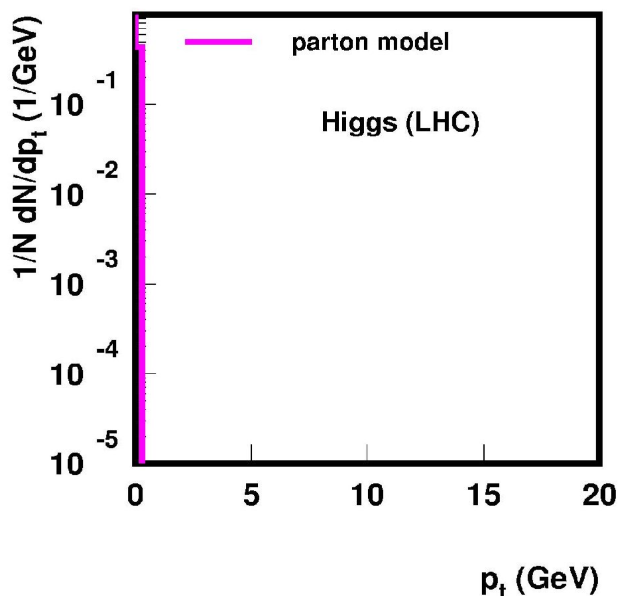
heavy quarks at pp





Higgs at pp



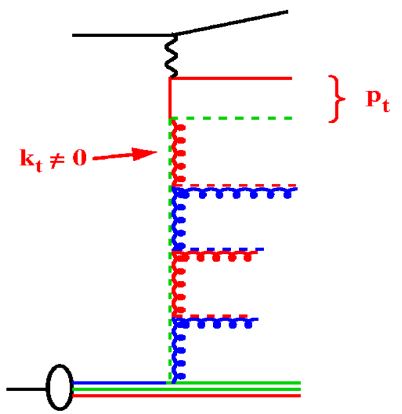


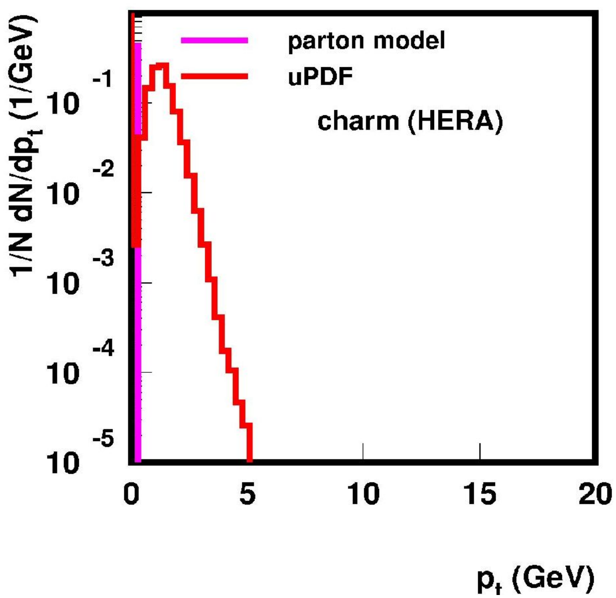
➔ NLO corrections will be very large for these LO processes .....

Need for uPDFs: transverse momenta

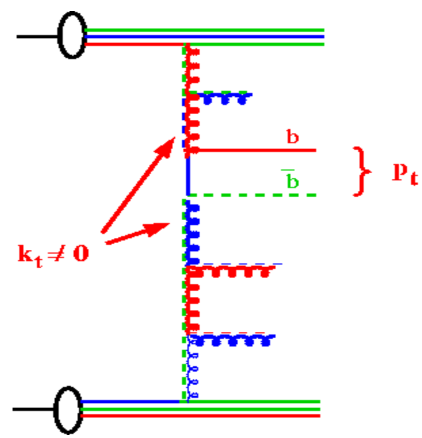
J. Collins, H. Jung hep-ph/0508280

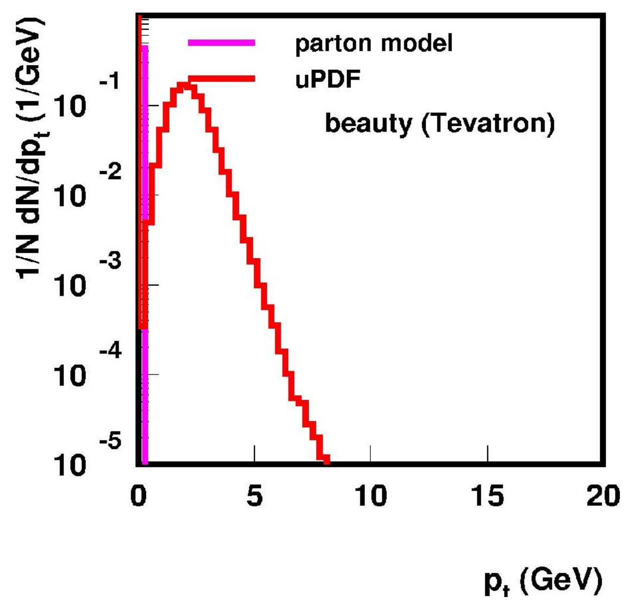
heavy quarks at HERA



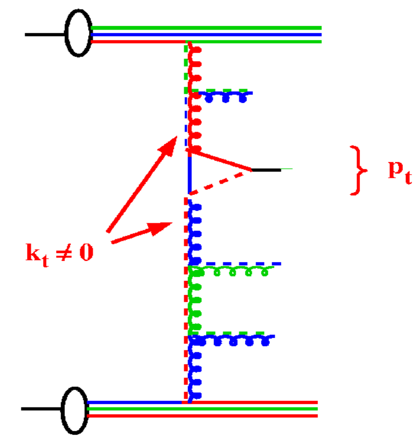


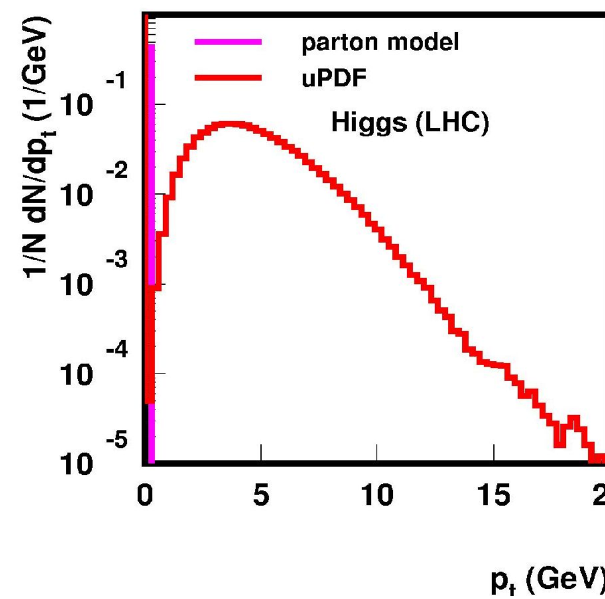
heavy quarks at pp





Higgs at pp





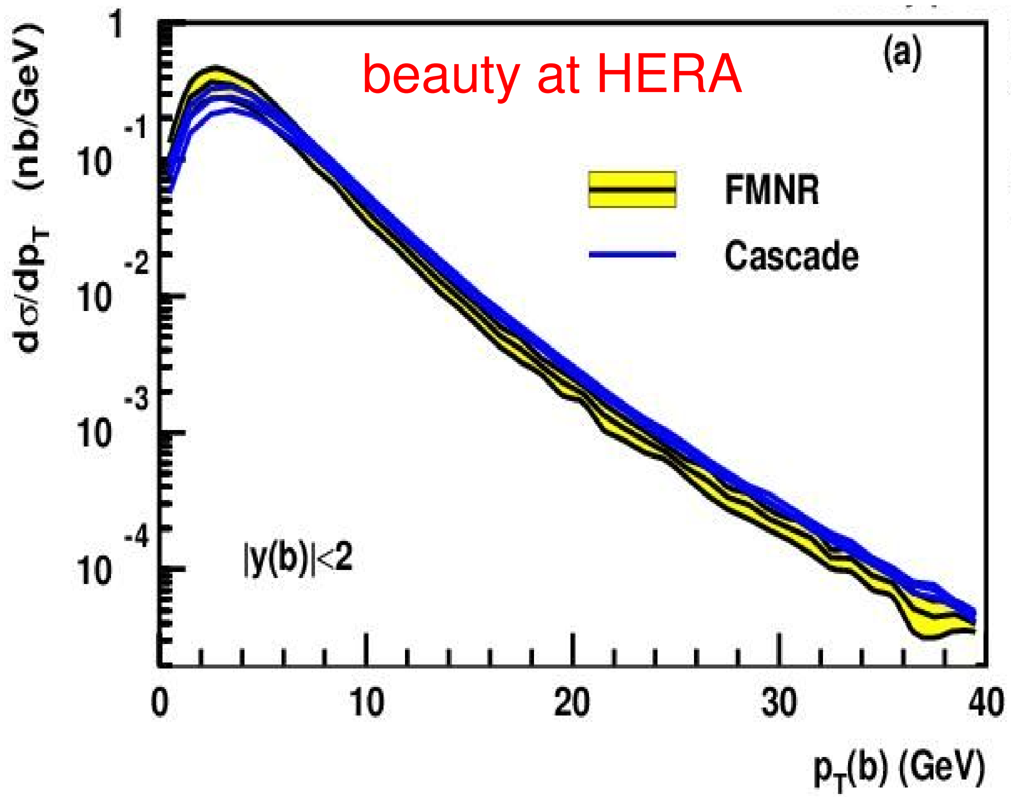
➔ doing kinematics correct at LO, reduces NLO corrections ... **NEED uPDFs !!!!**

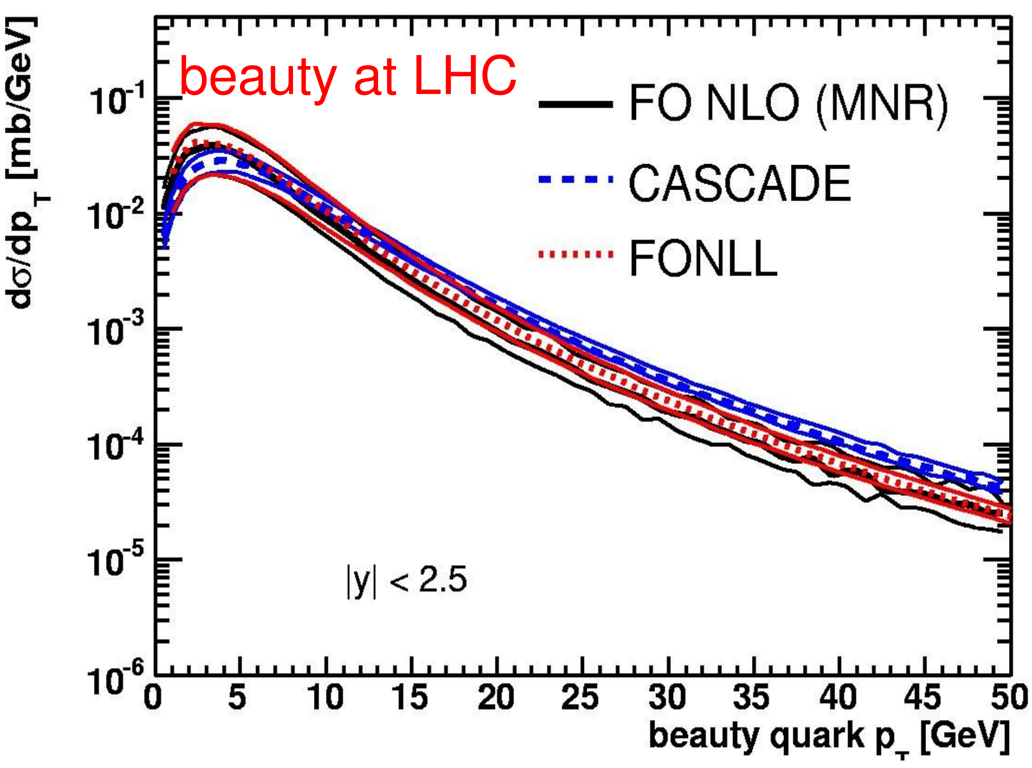
Applications: beauty at HERA and LHC

from Proceedings of the HERA-LHC workshop hep-ph/0601013

Cross sections at parton level in central region

MNR (massive NLO) – FONLL (matched NLL) – CASCADE (uPDF)





"Perfect" agreement of NLO(FMNR) calculation with CASCADE using uPDFs !!!

Evolution of uPDFs and x-section

- unintegrated PDFs (**uPDFs**): keep full k_t dependence during perturbative evolution
  - ➔ using **D**okshitzer **G**ribov **L**ipatov **A**ltarelli **P**arisi, **B**alitski **F**adin **K**uraev **L**ipatov or **C**iafaloni **C**atani **F**iorani **M**archesini evolution equations
  - ➔ **CCFM** treats explicitly real gluon emissions
    - ➔ according to color coherence ... angular ordering
    - ➔ angular ordering includes **DGLAP** and **BFKL** as limits...
- k_t dependence in PDFs: from collinear to k_t factorization
- cross section (in k_t factorization) :

$$\frac{d\sigma^{jets}}{dE_T d\eta} = \sum \int \int \int dx_g \; dQ^2 d \ldots \left[dk_\perp^2 x_g \mathcal{A}_i(x_g, k_\perp^2, \bar{q}) \right] \hat{\sigma}_i(x_g, k_\perp^2)$$

  - ➔ can be reduced to the collinear limit:

$$\frac{d\sigma^{jets}}{dE_T d\eta} = \sum \int \int \int dx \; dQ^2 d \ldots x f_i(x, Q^2) \hat{\sigma}_i(x, Q^2, \ldots.)$$

Evolution of uPDFs and x-section II

- only gluons densities are considered ***here*** **!!!**
- evolve with **CCFM** using
  - ✗ full gluon splitting function and $\alpha_s(M_Z) = 0.118$
  - ✗ starting scale for evolution $Q_0 = 1.2 \text{ GeV}$

Fitting **uPDFs**:

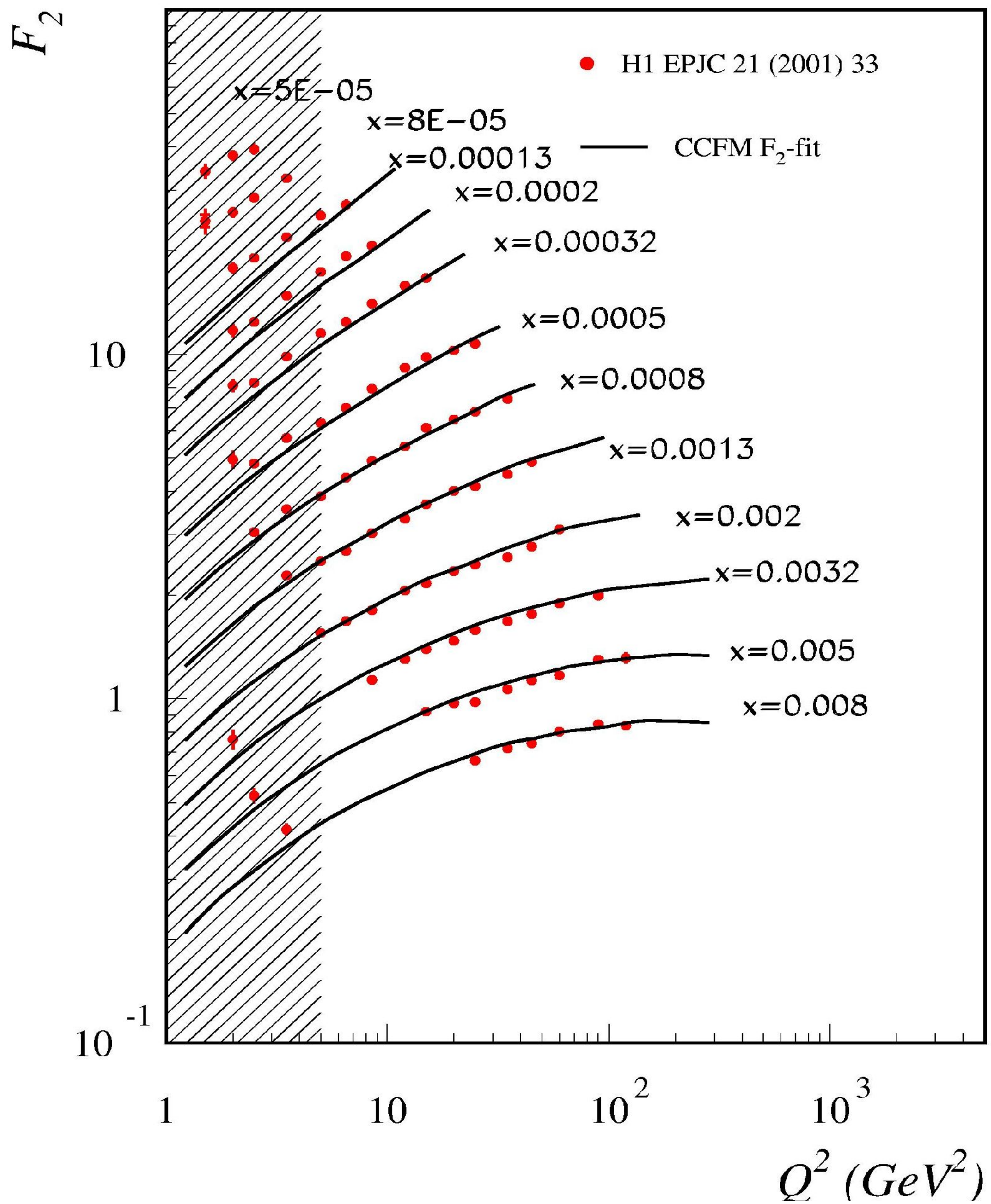
- using **FitPDF** (E. Perez [Saclay])
  - ➔ applicable also for collinear **DGLAP** evolution
  - ➔ allowing different treatment of correlated systematic uncertainties
- **uPDF** is a convolution of starting distribution $\mathcal{A}_0(x_0)$ with perturbative evolution:

$$x\mathcal{A}(x, k_\perp, \bar{q}) = \int dx_0 \mathcal{A}_0(x_0) \cdot \frac{x}{x_0} \tilde{\mathcal{A}}\left(\frac{x}{x_0}, k_\perp, \bar{q}\right)$$

- Calculate x-section for *x, Q^2* for inclusive quantities
  - *Optionally use full event simulation including parton showering and hadronization of CASCADE MC generator for final state predictions*
  - optimize parameters in starting distribution $\mathcal{A}_0(x_0)$ with χ^2
- **General procedure, applicable also for DGLAP fits**

Fit to F_2 data

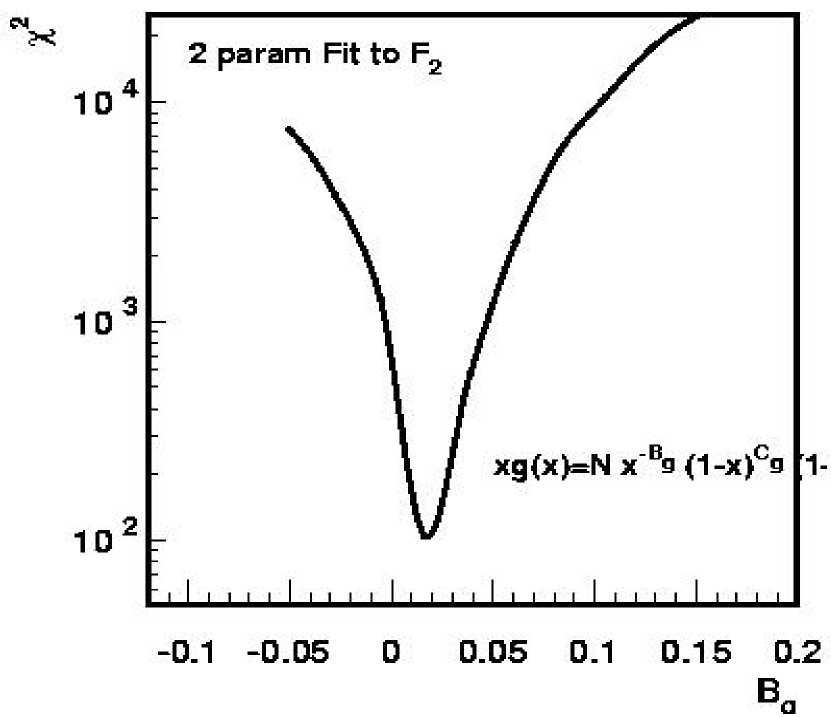
- $$\chi^2 = \sum_i \left(\frac{(T-D)^2}{\sigma_i^{2\ stat} + \sigma_i^{2\ uncor}} \right)$$
- fit parameters of starting distribution
  $$xg(x,\mu_0^2) = N x^{-B_g} \cdot (1-x)^4$$
- using F_2 data H1
  (H1 Eur. Phys. J. C21 (2001) 33-61, DESY 00-181)
  $$x < 0.05 \ \ Q^2 > 5 \text{ GeV}^2$$
- parameters: $\mu_r^2 = p_t^2 + m_{q,Q}^2$
  $$m_q = 250 \text{ MeV}, m_c = 1.5 \text{ GeV}$$
- Fit (only stat+uncorr):
  $$\frac{\chi^2}{\text{ndf}} = \frac{111.8}{61} = 1.83$$
  $$B_g = 0.018 \pm 0.003$$
  ➔ similar to DGLAP fits (~1.5)

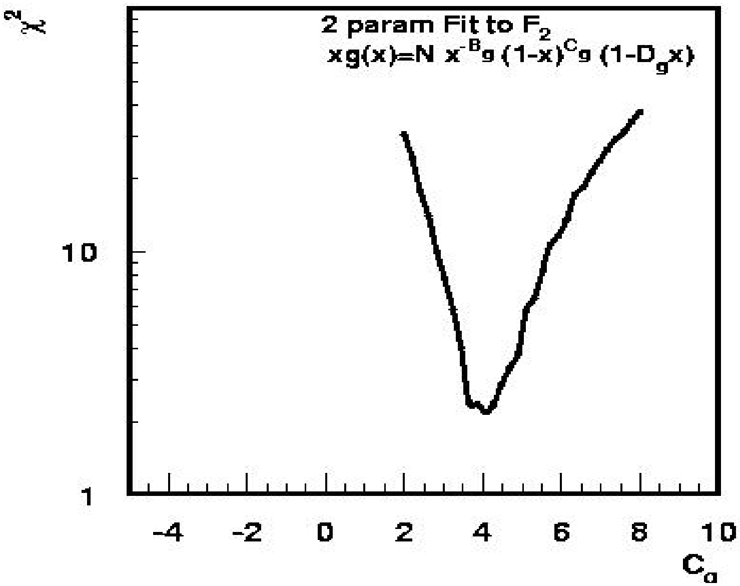


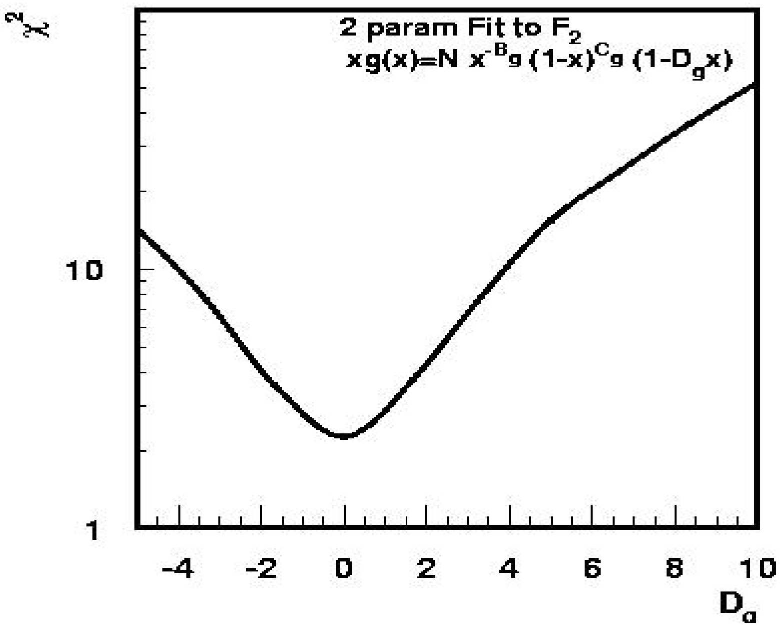
Fit to F_2 data: checking results

- Check sensitivity to parameterization

$$xg(x,\mu_0^2) = N x^{-B_g} \cdot (1-x)^{C_g} \, (1 - D_g x)$$







- Strong sensitivity to small x part B_g
- Clear preference for large x parameters.
  - ➔ keep C_g and D_g fixed in fit....

Fit to F_2 data: α_s

- Check sensitivity to alphas
- sensitive to:

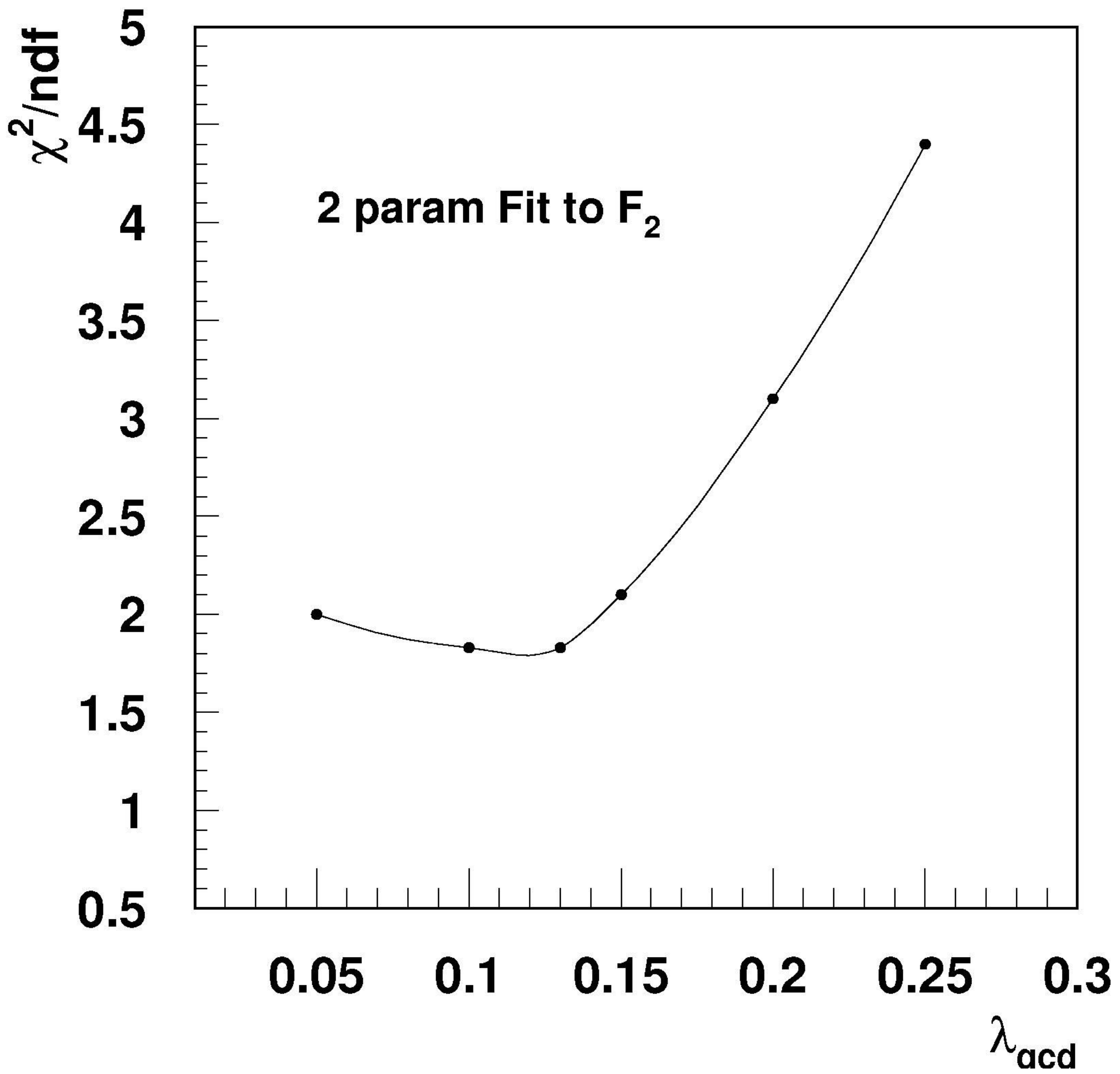
$$\alpha_s(\mu) \cdot x\mathcal{A}(x, k_\perp, \bar{q})$$

- here use (1-loop):

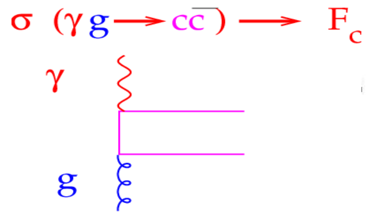
$$\alpha_s(\mu) \sim \frac{1}{\log \frac{\mu}{\Lambda_{qcd}}}$$

- $\Lambda_{qcd} \sim 0.13$ gives:

$$\alpha_s(M_Z) = 0.118$$



Fit to F_2^c data



- $$\chi^2 = \sum_i \left(\frac{(T-D)^2}{\sigma_i^{2\ stat} + \sigma_i^{2\ syst}} \right)$$
- fit parameters of starting distribution

$$xg(x,\mu_0^2) = N x^{-B_g} \cdot (1-x)^4$$

- using F_2^c data H1

(H1 PLB528 (2002) 199, EPJC 40 (2005) 349 ,EPJC45 (2006) 23)

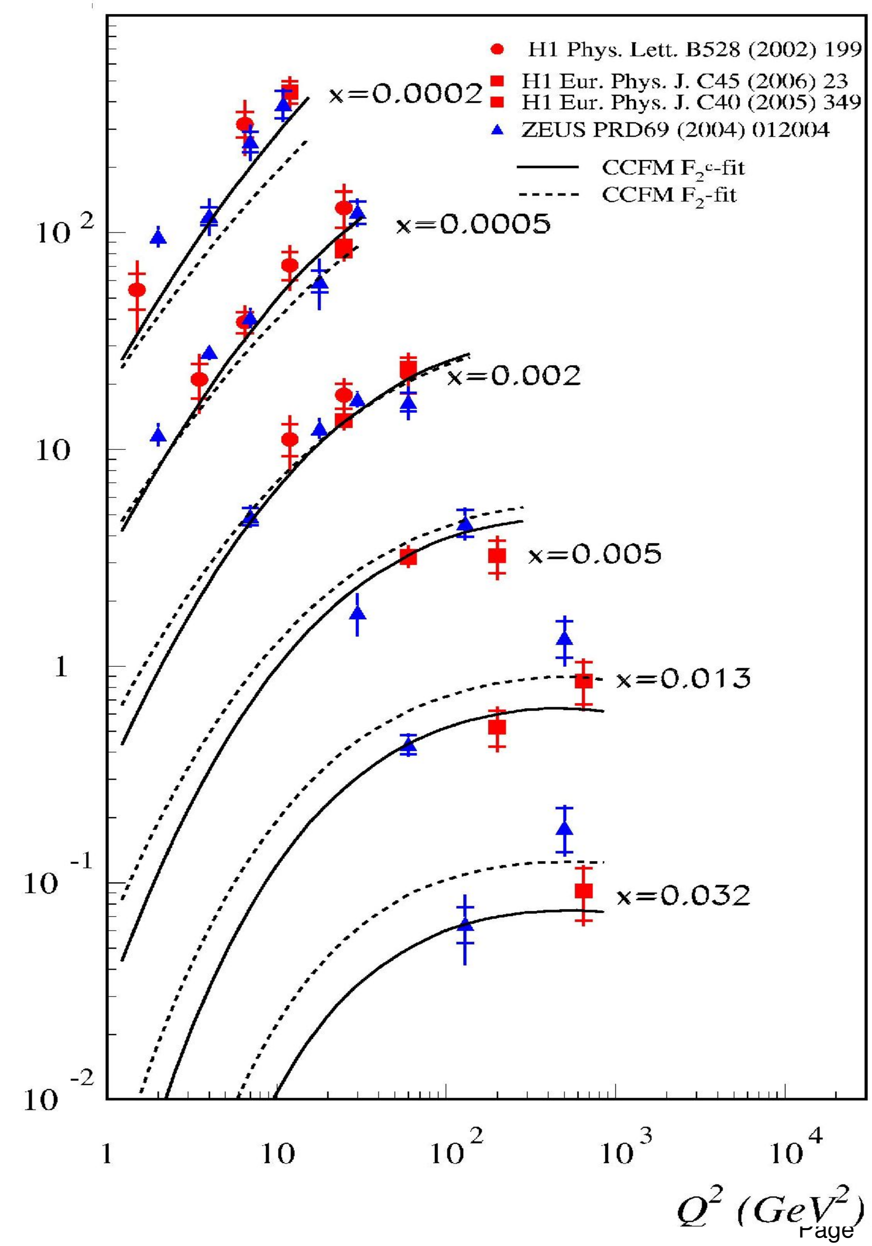
$$Q^2 > 1\ \mathrm{GeV}^2$$

- fit result: $\frac{\chi^2}{\mathrm{ndf}} = \frac{18.8}{20} = 0.94$

with $B_g = 0.286 \pm 0.002$

➔ higher than for F_2 !?!?!?!

➔ compare to $\frac{\chi^2}{\mathrm{ndf}} = \frac{190.4}{50} = 3.81$ for gluon from F_2 fit



Fit to F_2^c data

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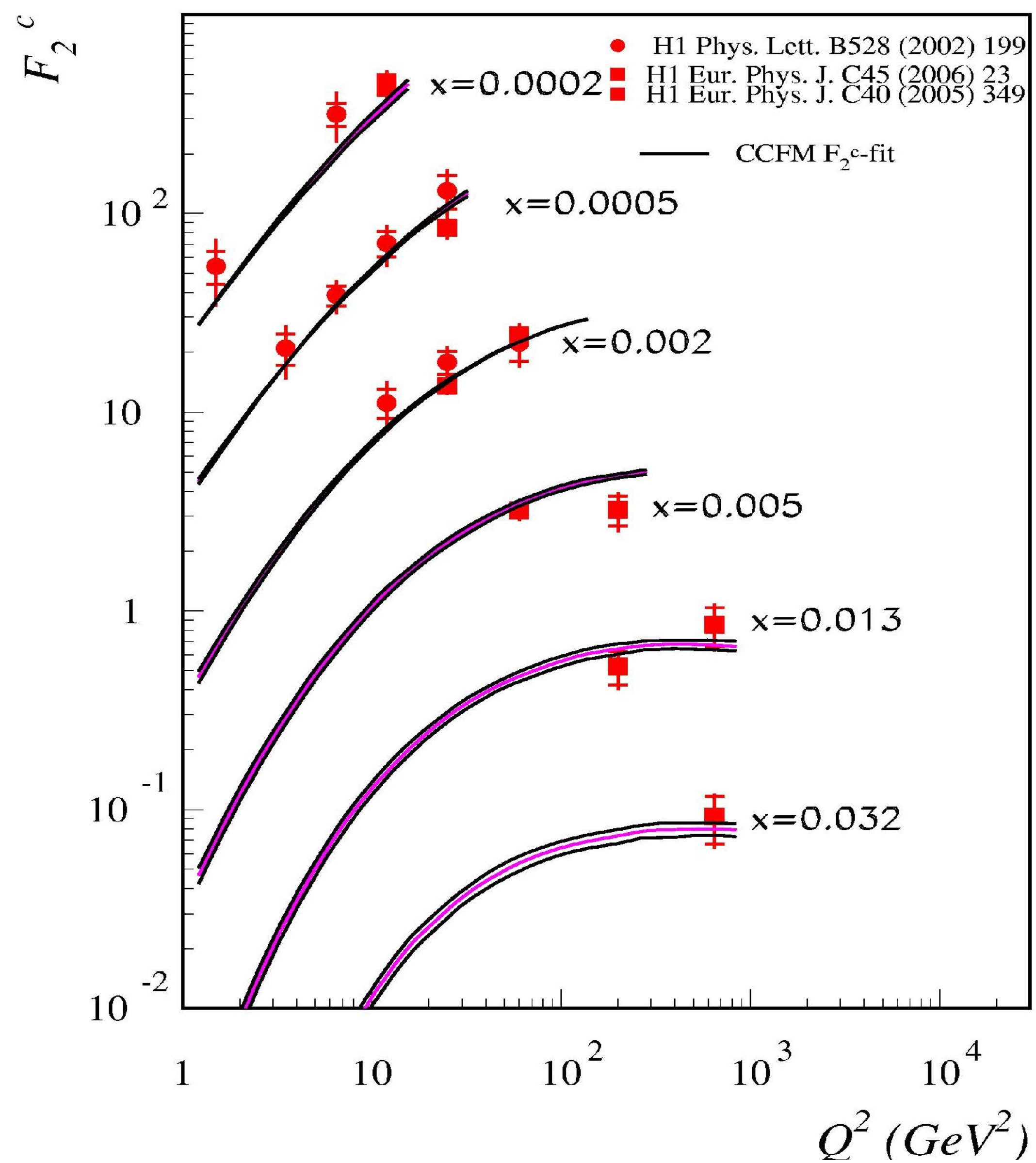
with $B_g = 0.286 \pm 0.002$

- uncertainty obtained with CTEQ (eigenvector) method, using

$\Delta\chi^2 = 1$ but, CTEQ uses tolerance T^2 =100 for global fits....



Fit to F_2^c data

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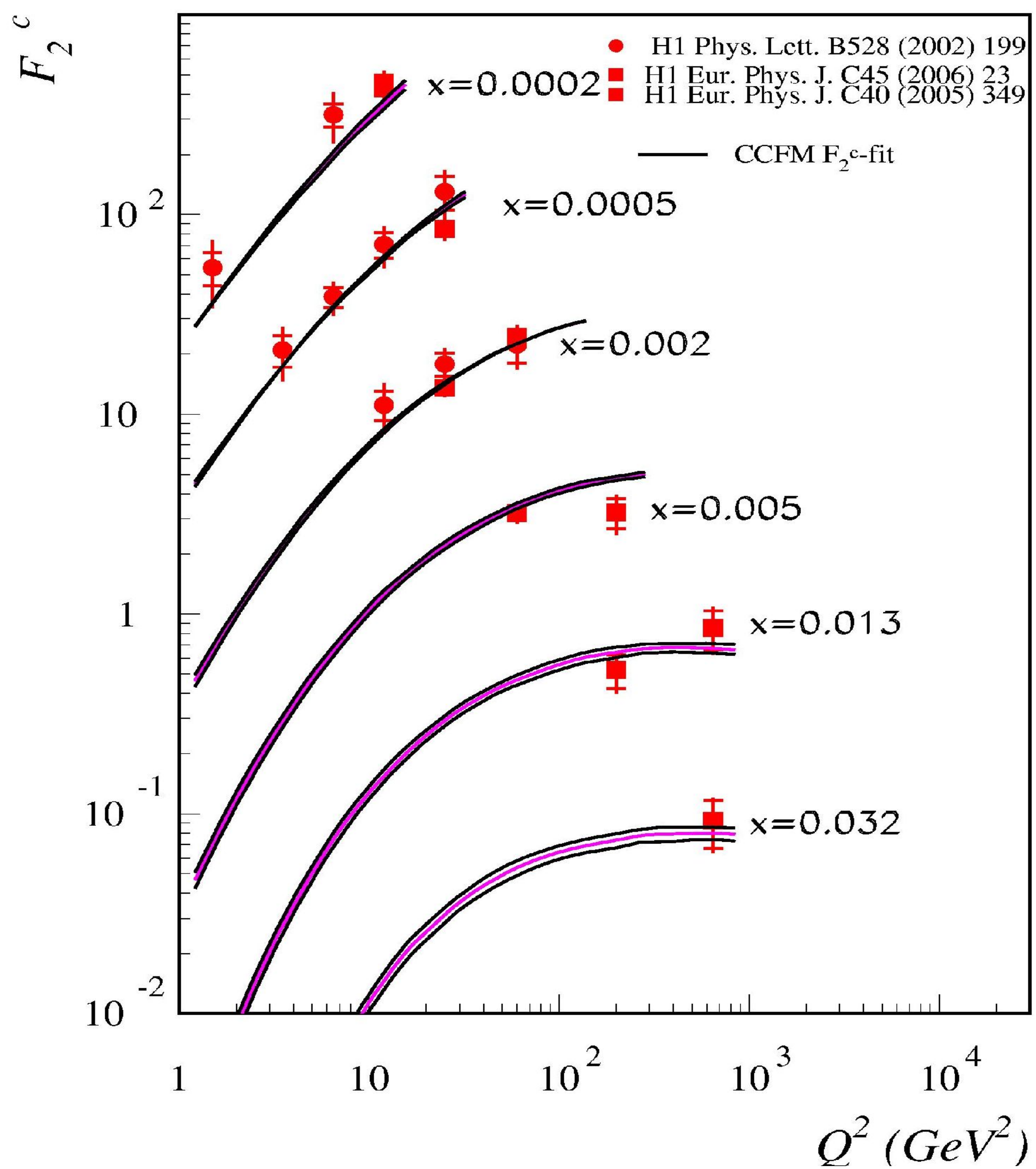
  $$Q^2 > 1 \text{ GeV}^2$$
- fit result: $\frac{\chi^2}{\text{ndf}} = \frac{18.8}{20} = 0.94$
  with $B_g = 0.286 \pm 0.002$
  ➔ higher than for F_2 !?!?!?!
  ➔ significant change of uPDF



Fit to F_2^c data: uPDF

- $$\chi^2 = \sum_i \left(\frac{(T-D)^2}{\sigma_i^{2\ stat} + \sigma_i^{2\ uncor}} \right)$$
- fit parameters of starting distribution
  $$xg(x,\mu_0^2) = N x^{-B_g} \cdot (1-x)^4$$
- using F_2^c data H1
  (H1 PLB528 (2002) 199, EPJC 40 (2005) 349 ,EPJC45 (2006) 23)

$$Q^2 > 1 \text{ GeV}^2$$

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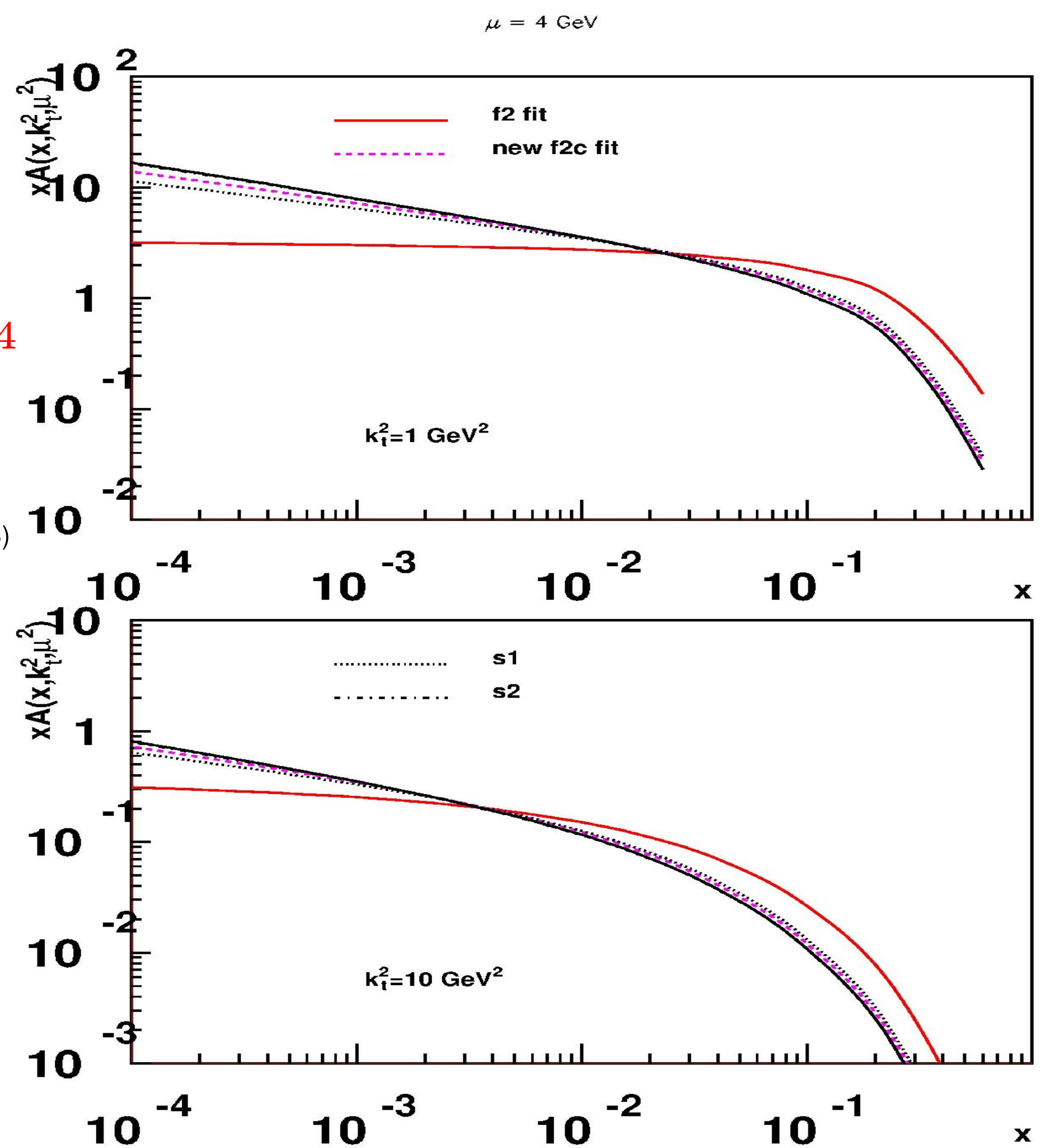
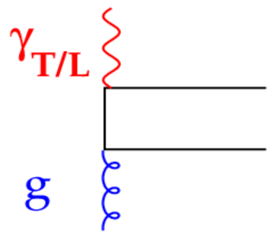


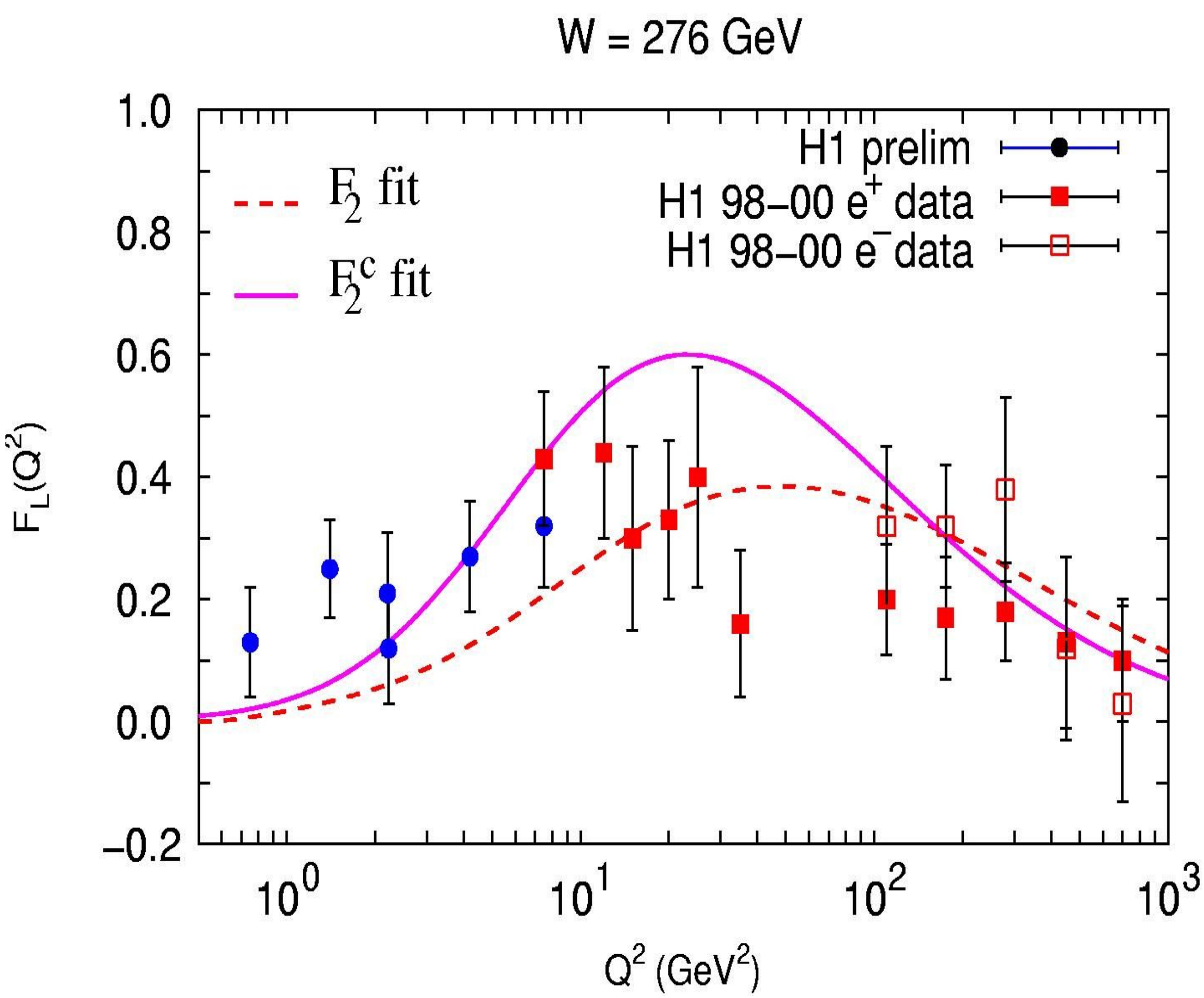
Calculating F_L: sensitive to gluon

A. Kotikov, A. Lipatov, N. Zotov

$\sigma_L(\gamma g \rightarrow q\bar{q}) \longrightarrow F_L$

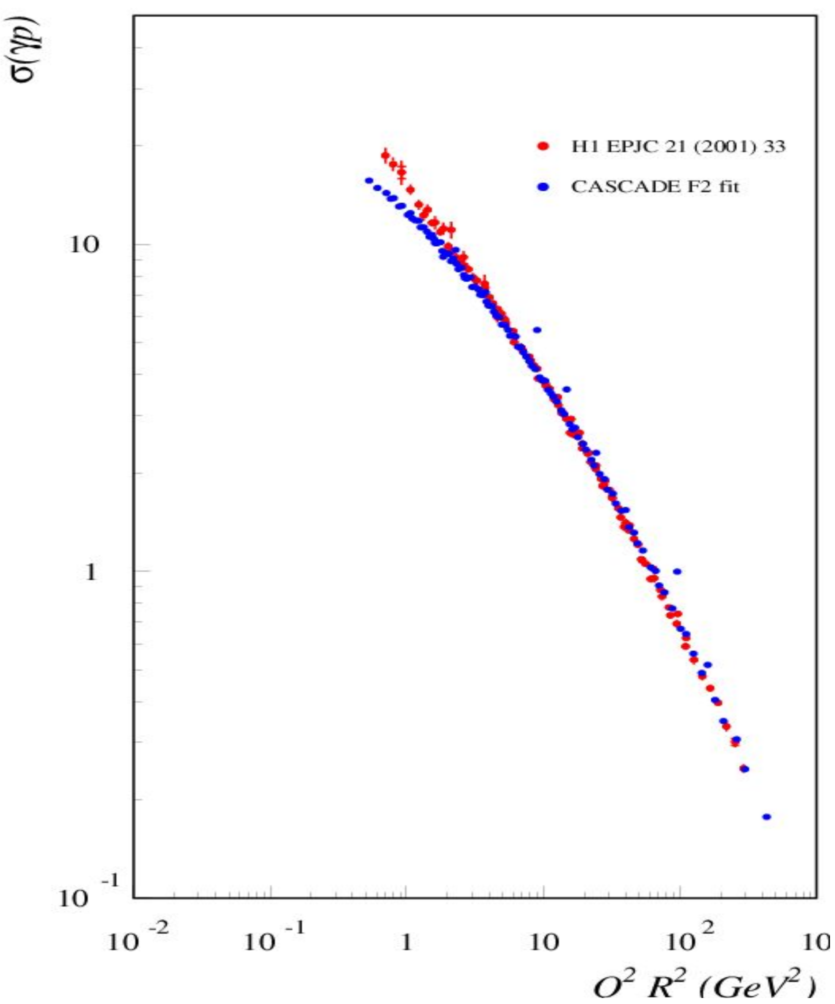


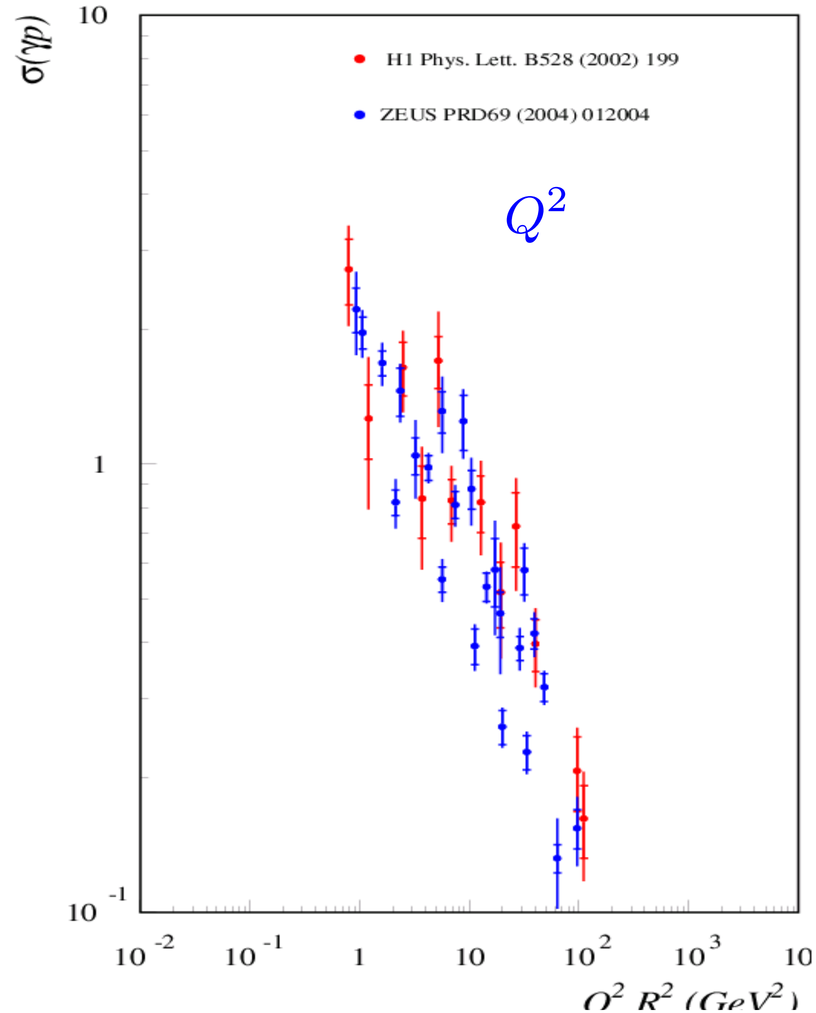
- calculate contribution to F_L in k_t-factorization
- similar level of agreement for CCFM uPDF as obtained in collinear factorization with best parametrization



Geometric scaling: F_2 and F_2^c

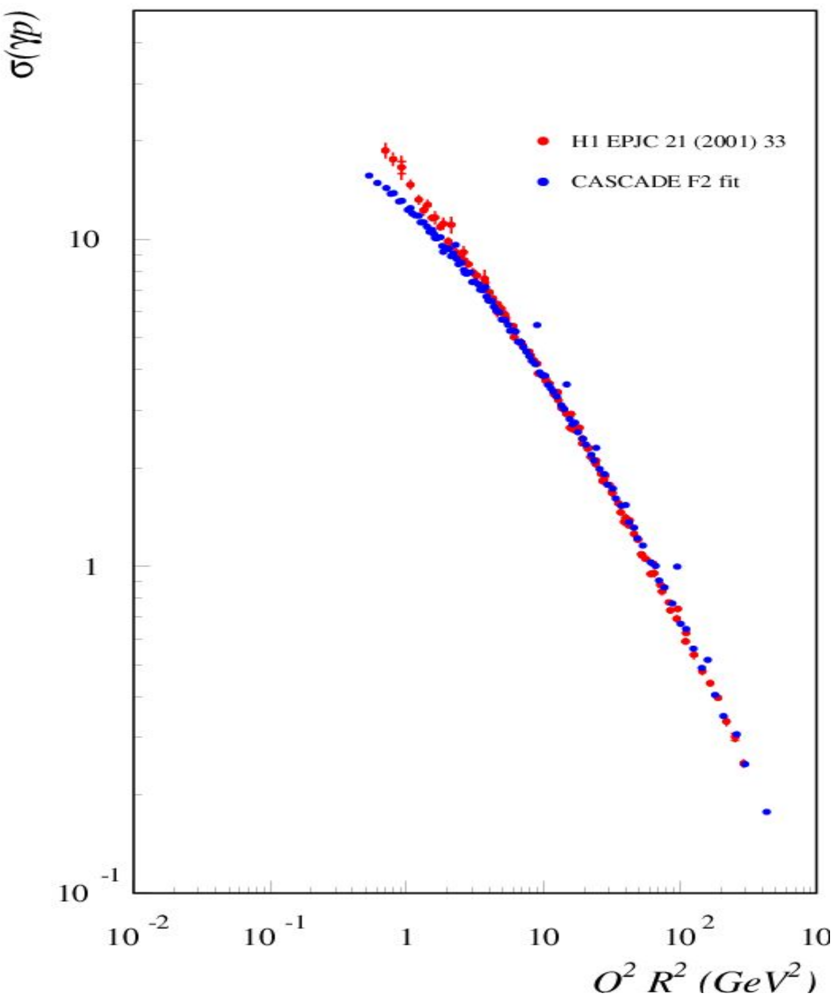
- do we expect geometric scaling also for F_2^c ?

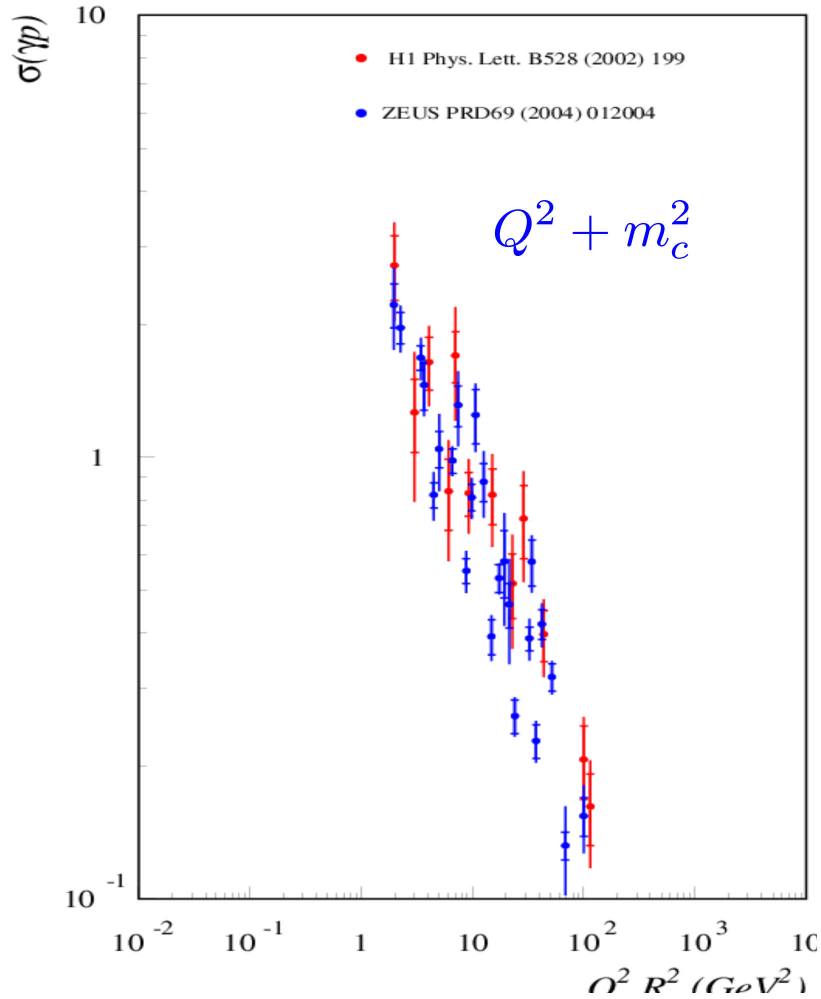




Geometric scaling: F_2 and F_2^c

- do we expect geometric scaling also for F_2^c ?
  - ➔ even not when changing scale to $Q^2 + m_c^2$?





Fit of intrinsic k_t distribution

- Fit parameters of intrinsic k_t distribution

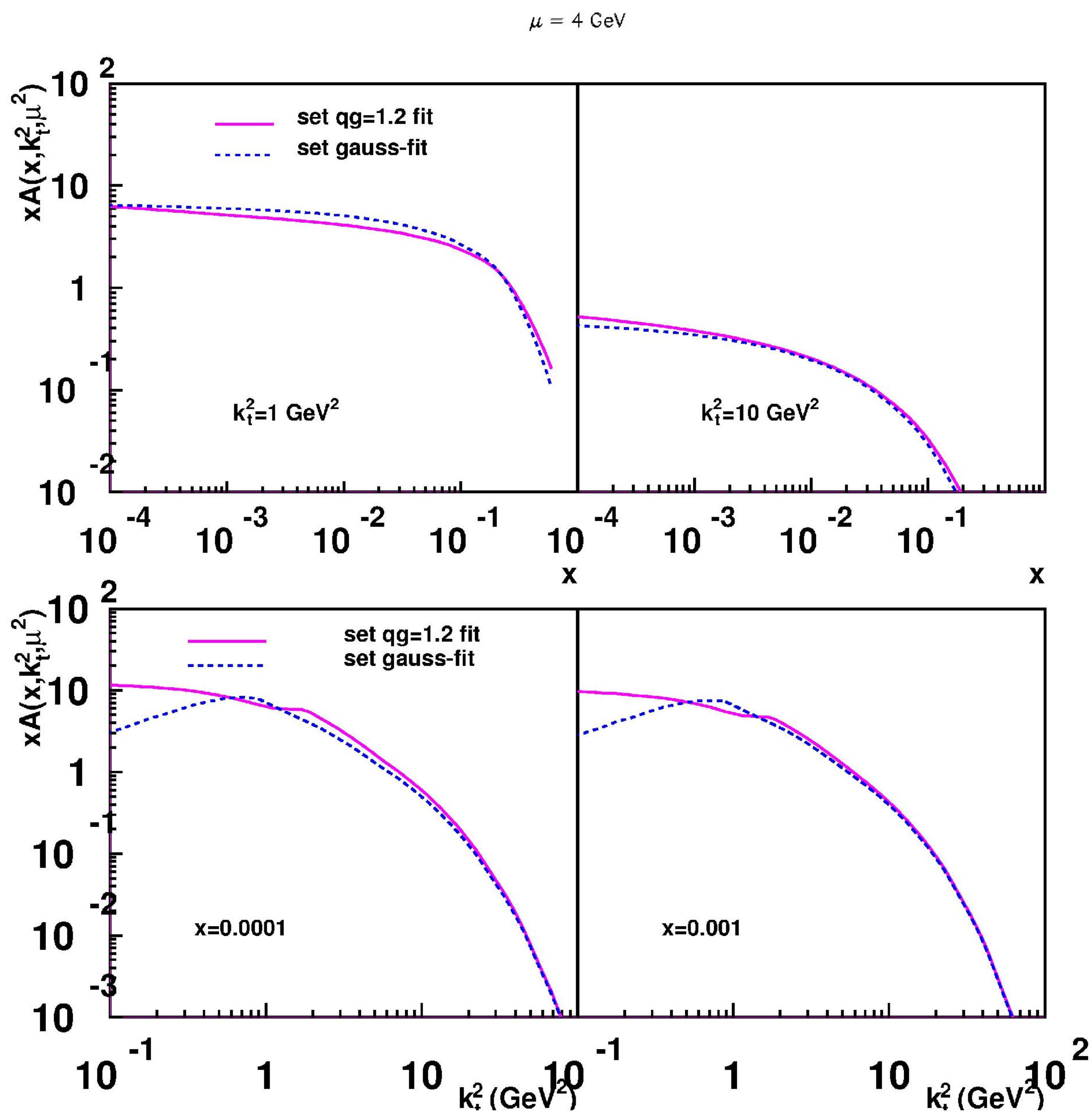
$$\sim \exp\left(-\frac{(k_\perp - \bar{k_\perp})^2}{\sigma^2}\right)$$

- fit results from F_2 fit

$$\bar{k_\perp} \sim 0.8$$

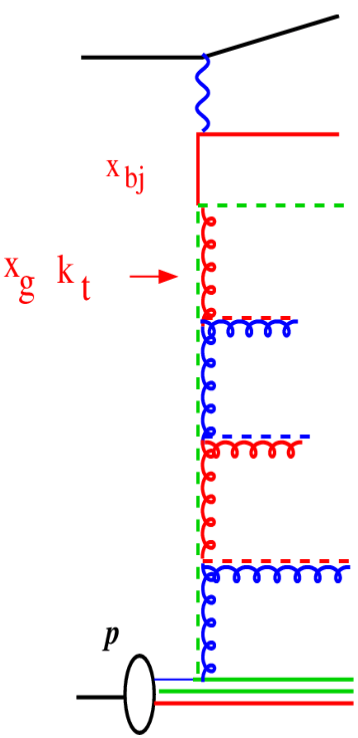
$$\sigma \sim 0.5$$

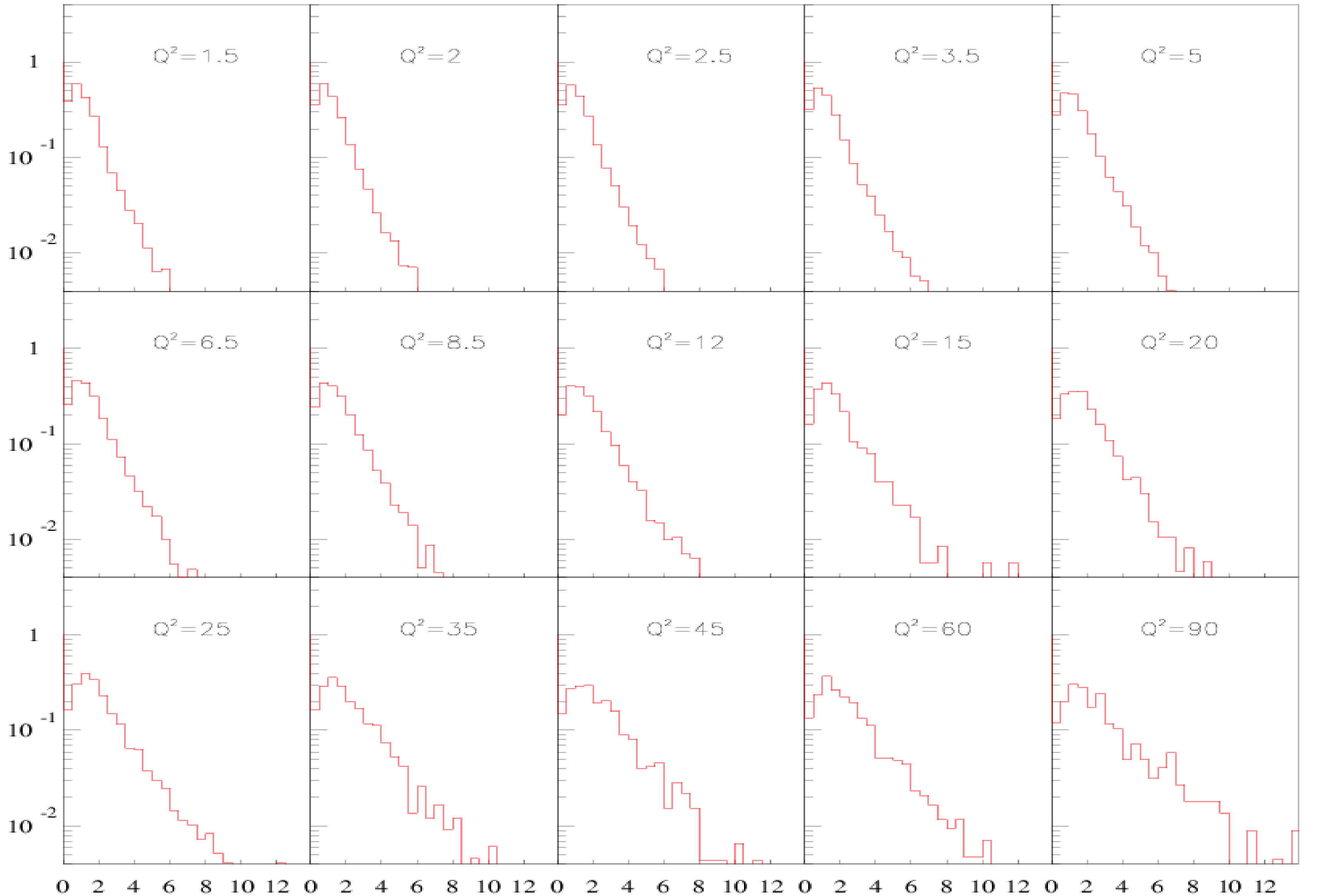
- small change in χ^2
- essentially no sensitivity from F_2^c



k_t in F_2

- investigate k_t from Monte Carlo using uPDF

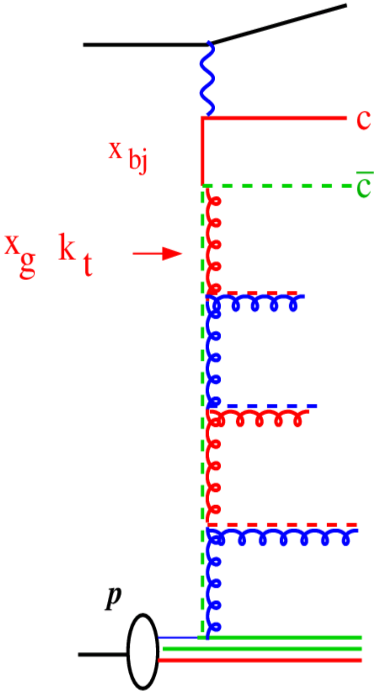


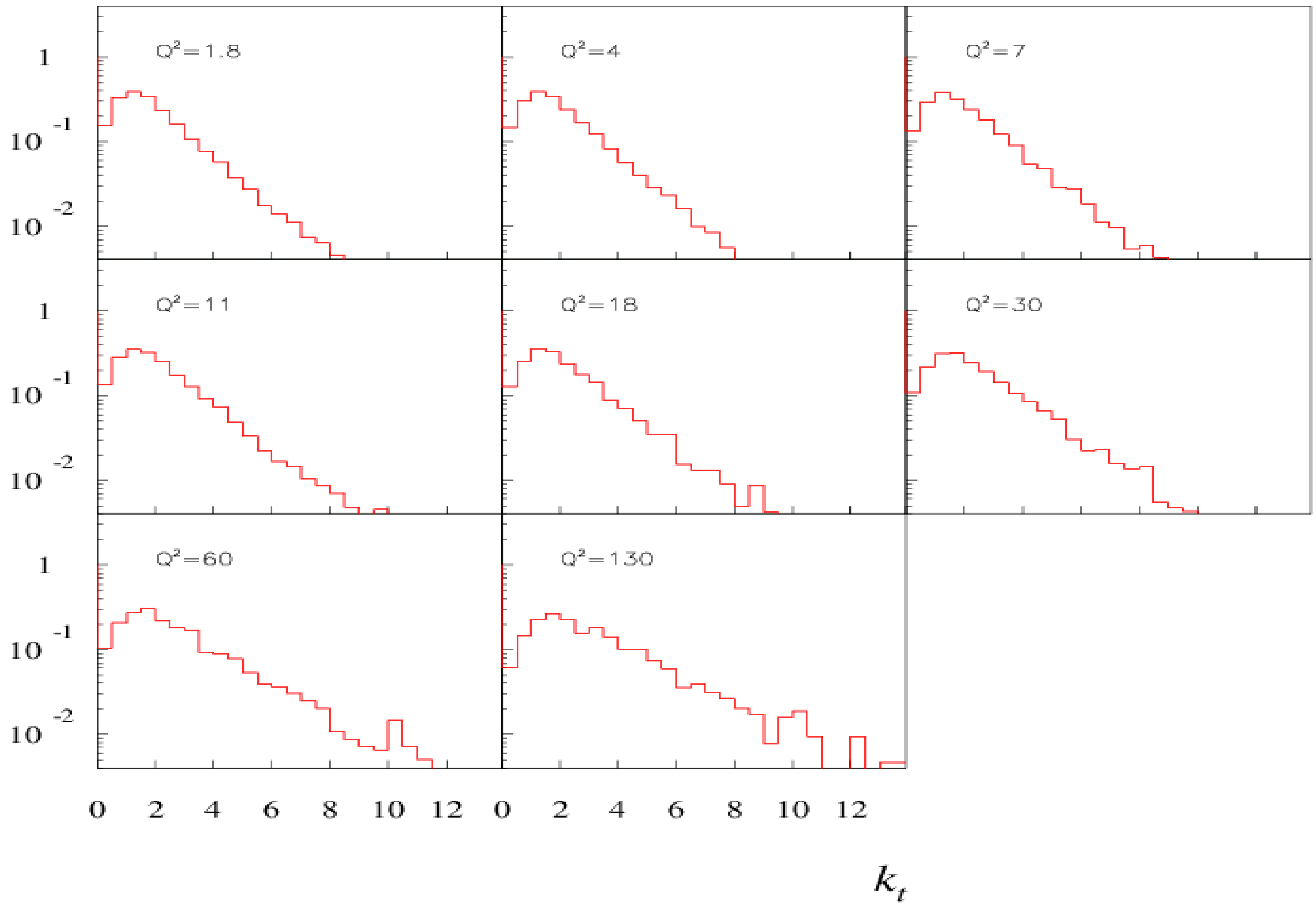


➔ F_2 dominated by small kt ..... large size

k_t in F_2 and F_2^c

- investigate k_t from Monte Carlo using uPDF

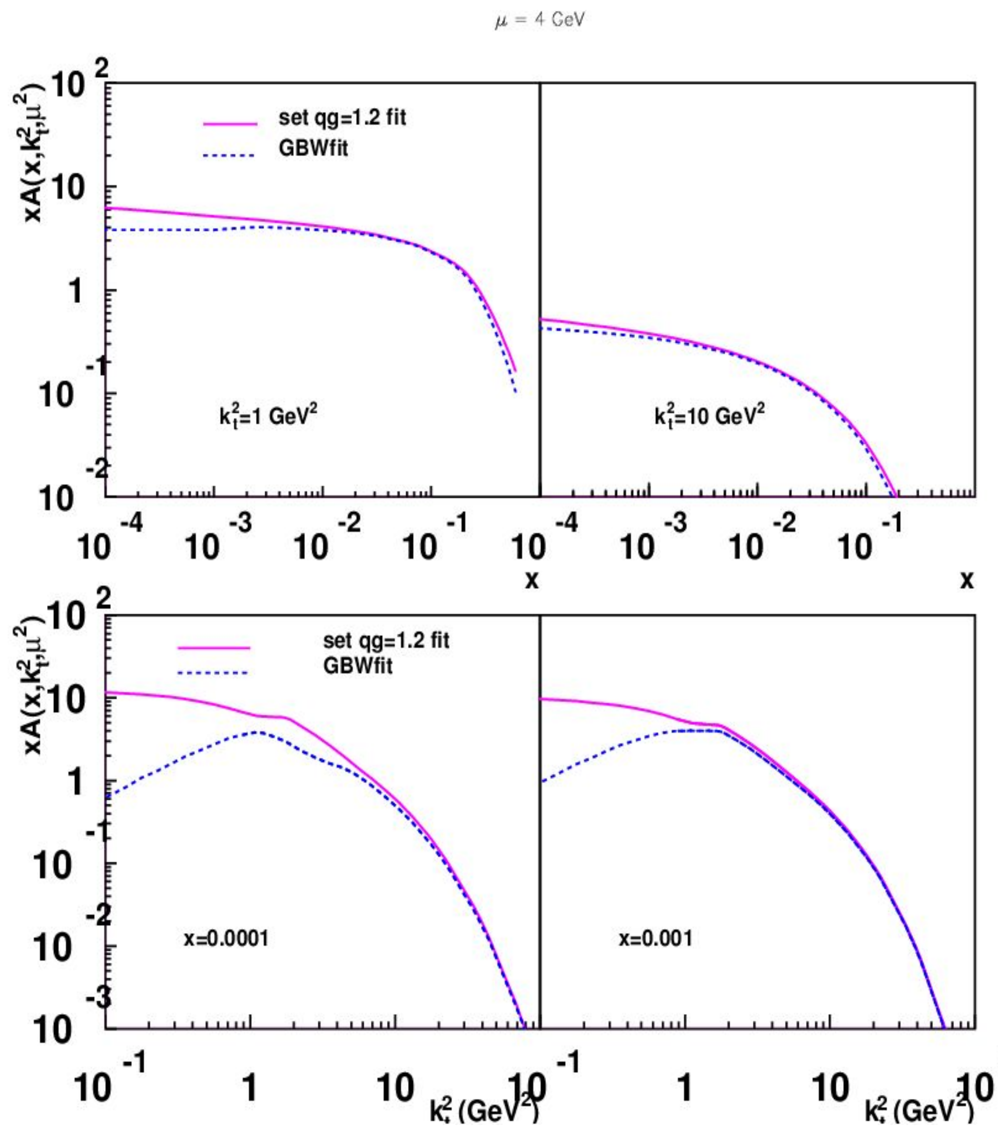




- F_2^c ..... has larger kt (~1 - 2 GeV) ..... smaller size dipole ....

Gluon from F_2 and F_2^c

- investigations:
  - suppress small k_t region for F_2 with different ansaetze:
    - linear suppression
    - GBW k_t distribution
  - ➔ no significant change in steepness of gluon
- fit parameters for GBW agree with original formulation
- fit parameters for gaussian kt are reasonable ....
- ➔ what makes F_2^c so differernt from F_2 ?

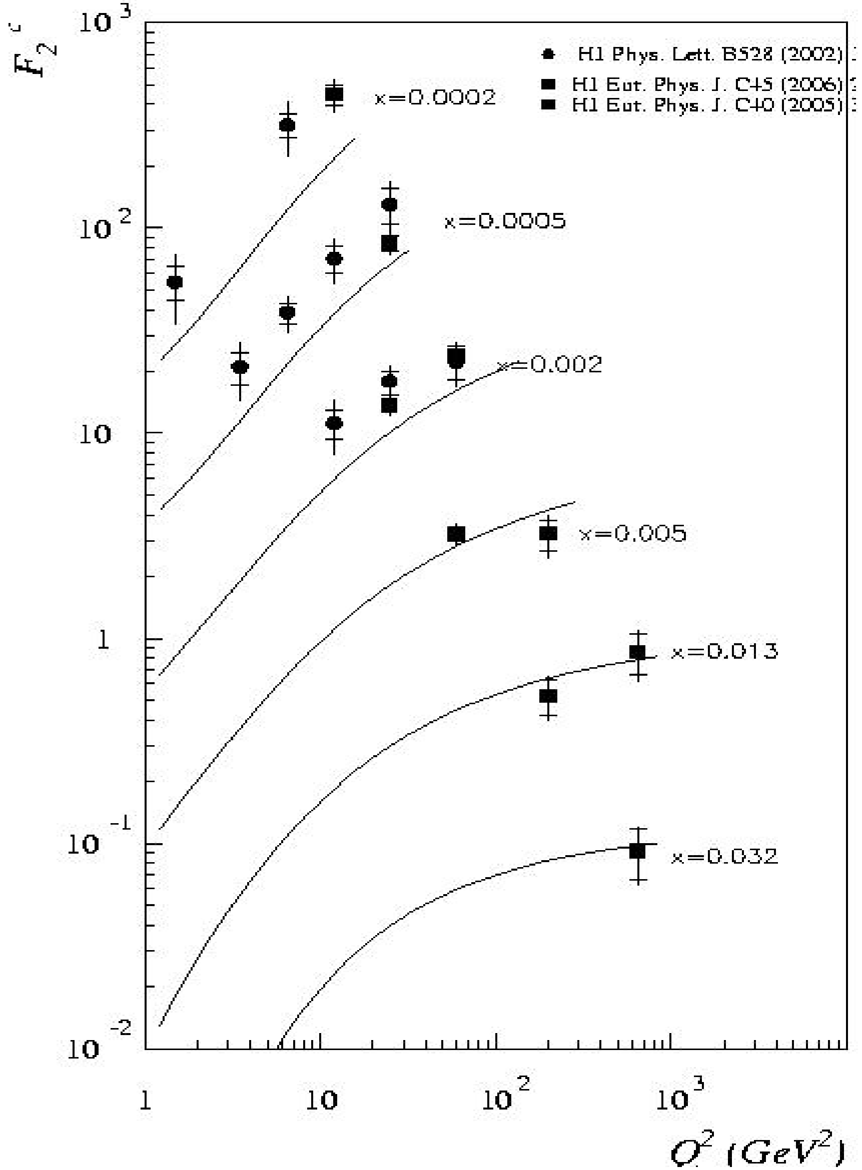


What tells collinear factorization ?

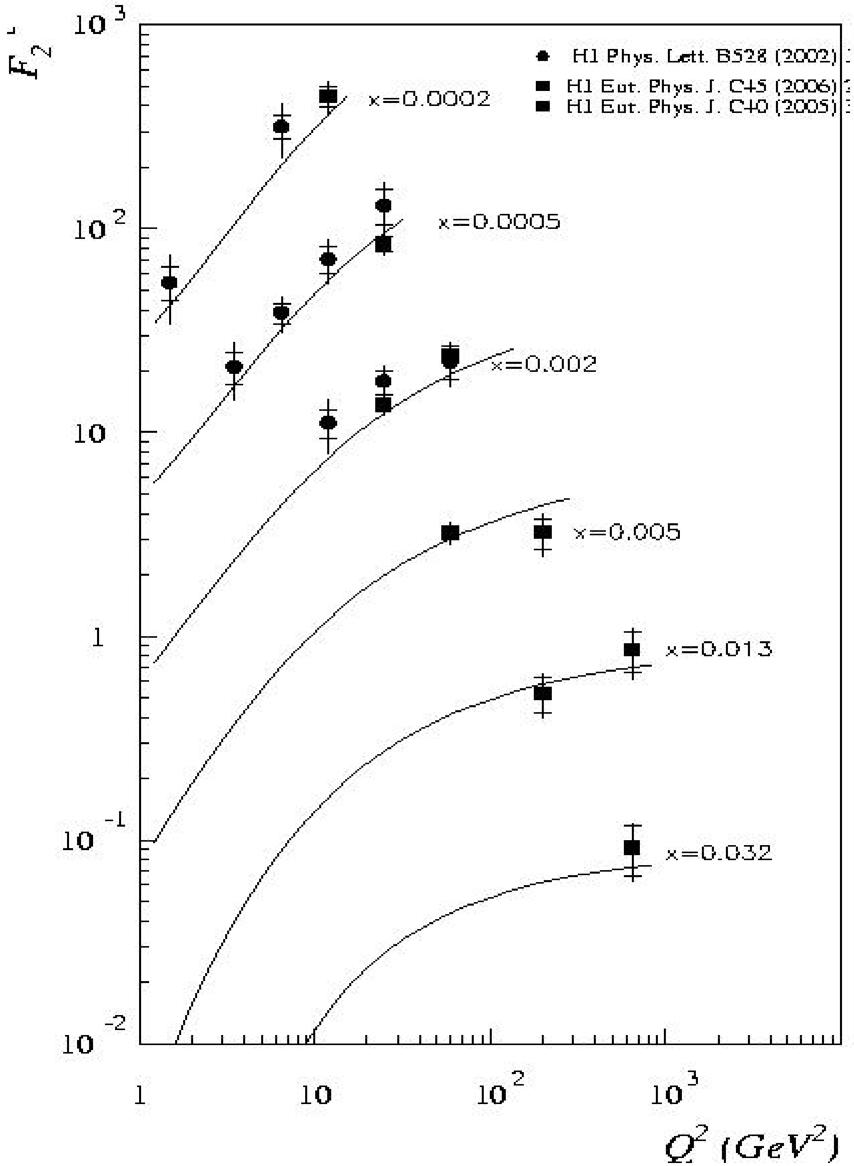
- Are similar effects seen in collinear factorization using DGLAP ?
- Howto constrain parton densities:
  - ➔ in collinear factorization is much more tricky ...
    - ➔ Howto tell the difference of gluon and sea ?
  - ➔ howto find appropriate parameterization ?

Fit to F_2^c in collinear approach

- F_2^c from F_2 fit



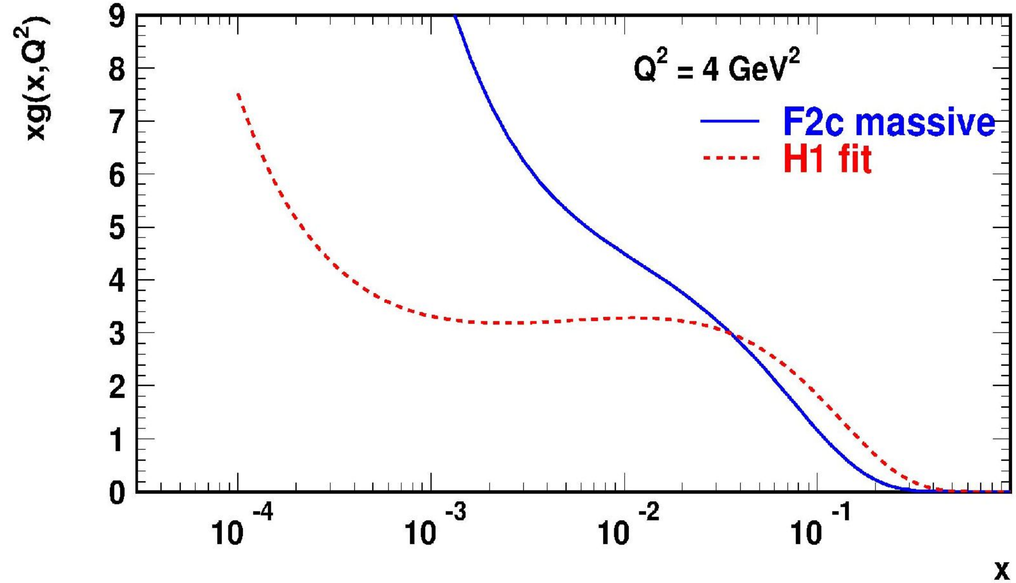
- F_2^c from F_2^c fit

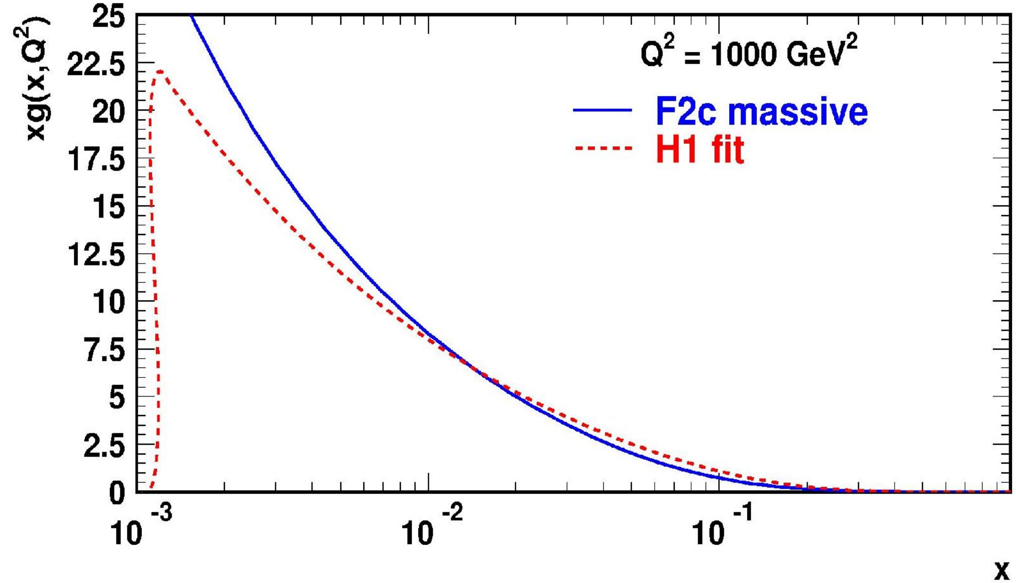


Fit to F_2^c in collinear approach

- Significantly steeper gluon required from F_2^c
- using FitPDF from E. Perez
- compare gluon from F_2 (H1 published) and F_2^c fits .....

- gluon comes out very different... consistent picture ?
  - ➔ fix gluon with F_2^c
  - ➔ fit quarks with F_2
  - ➔ consistent fit ?

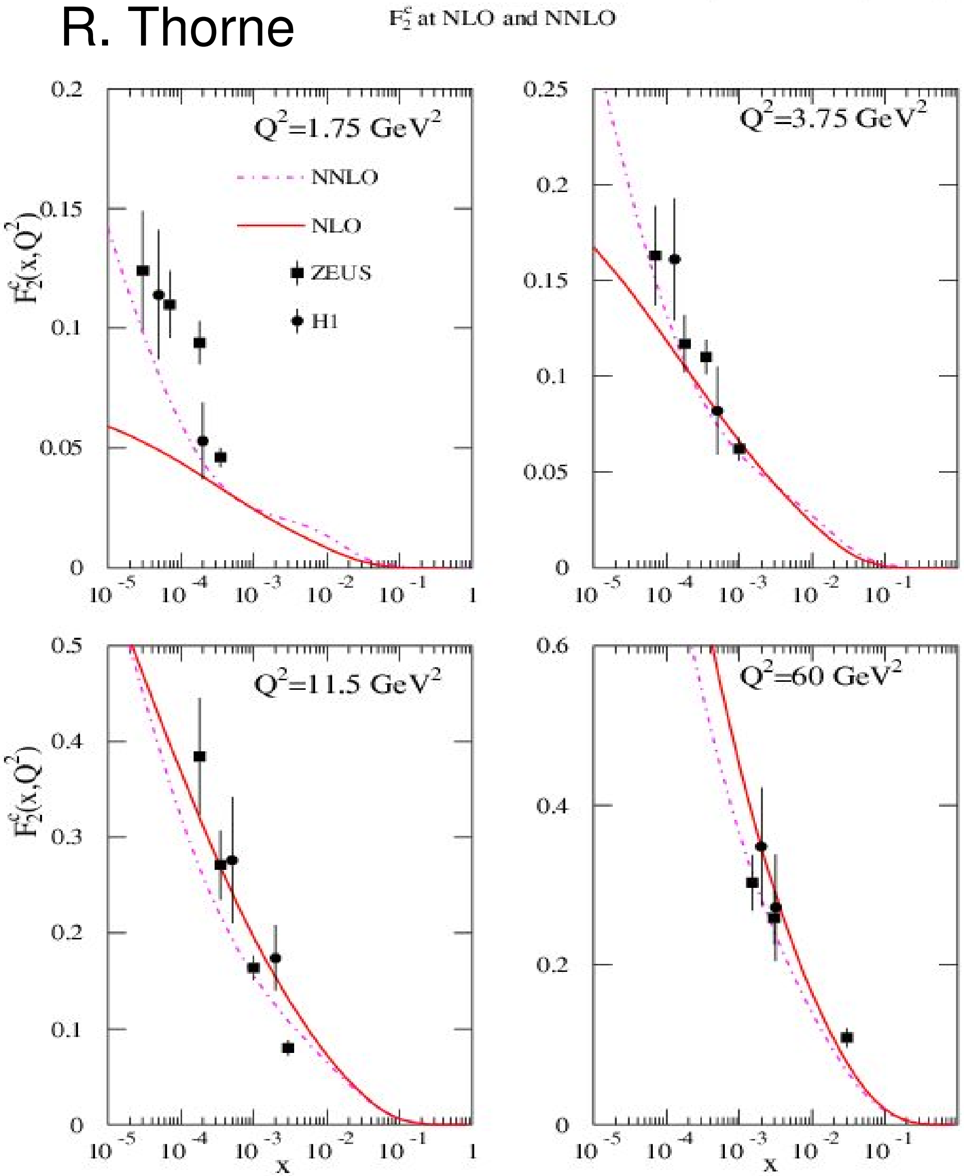




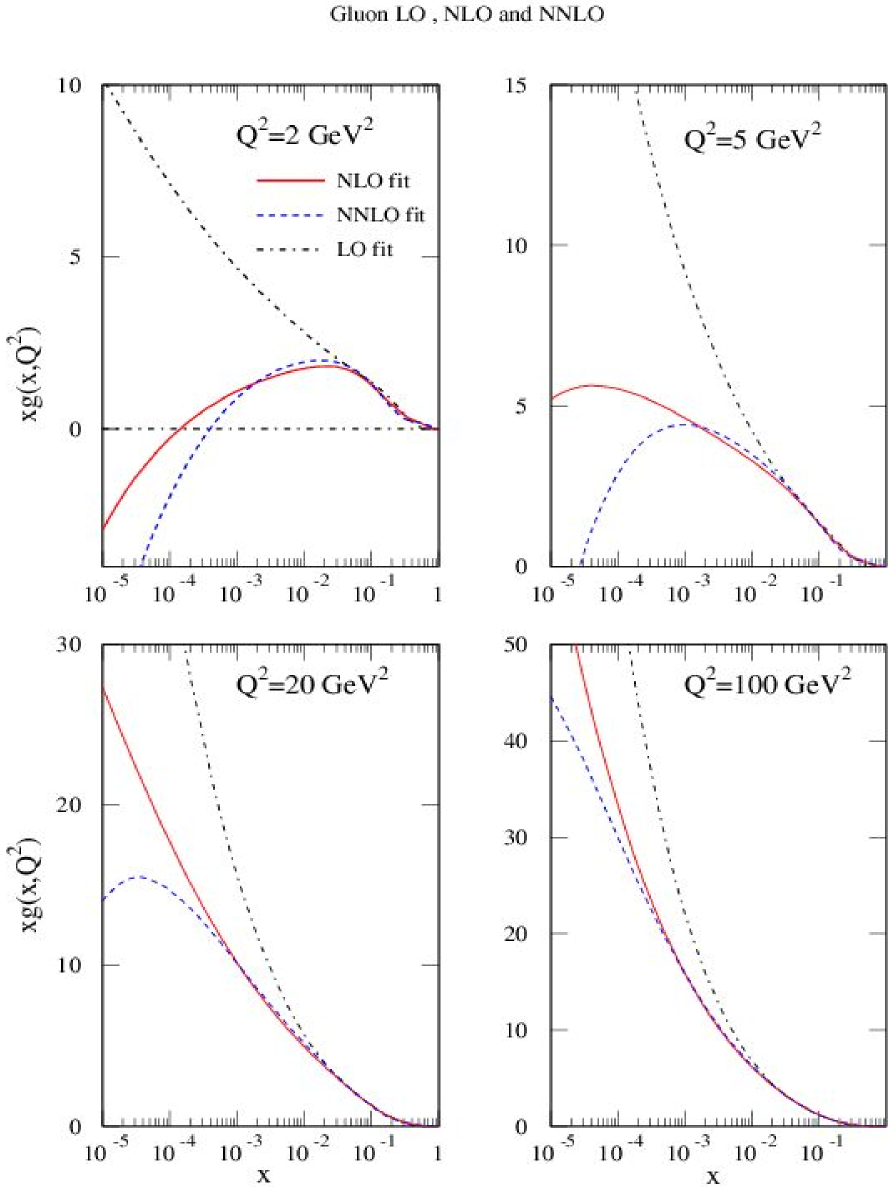
F_2^c in NLO,NNLO

PHYSICAL REVIEW D 73, 054019 (2006)

R. Thorne



R. Thorne, hep-ph/0511351



Conclusion

- Full treatment of kinematics in calculations is necessary – NEED **uPDFs**
  - NLO corrections are MUCH smaller then ....
    - ➔ **uPDFs** are needed for precision calculations at LHC: see heavy quarks, Higgs etc ...
  - first ***real*** uPDF fits to data from HERA presented !!!!
- F_2 data suggest flat gluon distribution
- F_2^c data suggest steeply rising gluon distribution
  - very different from F_2 gluon !!!!
    - even for collinear case !!!
  - ➔ do we see new effects, saturation etc ?

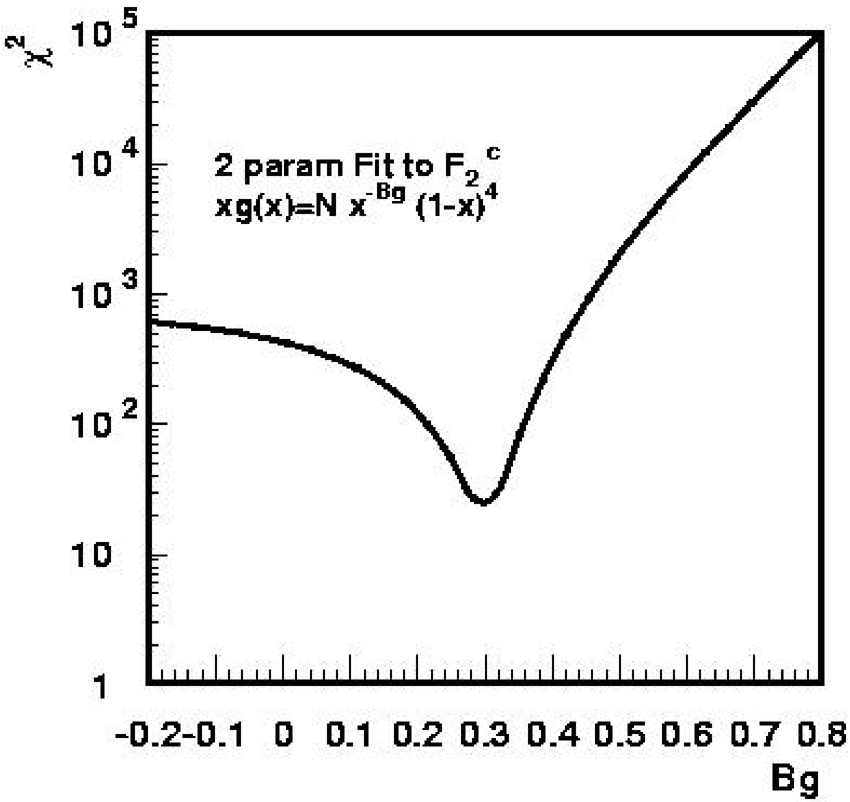
➔ **Heavy quark measurements could be the tool for saturation ... !!!!!!! ????????????**

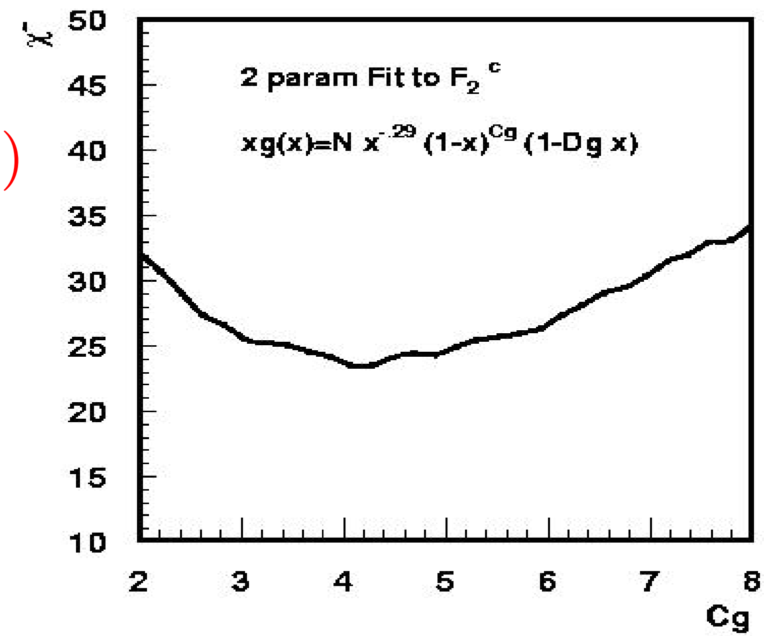
Backup slides

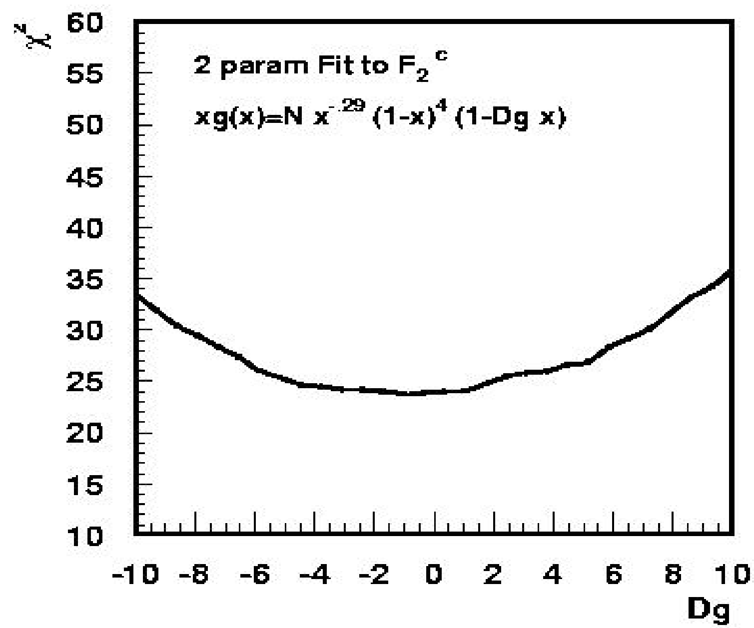
Fit to F_2^c data: checking results

- Check sensitivity to parameterization

$$xg(x,\mu_0^2) = Nx^{-B_g}\cdot(1-x)^{C_g}\,(1-D_g x)$$







- Strong sensitivity to small x rise
- Sensitivity to large x parts...

Fit to F_2 data

- $$\chi^2 = \sum_i \left(\frac{(T-D)^2}{\sigma_i^{2\ stat} + \sigma_i^{2\ uncor}} \right)$$
- fit parameters of starting distribution

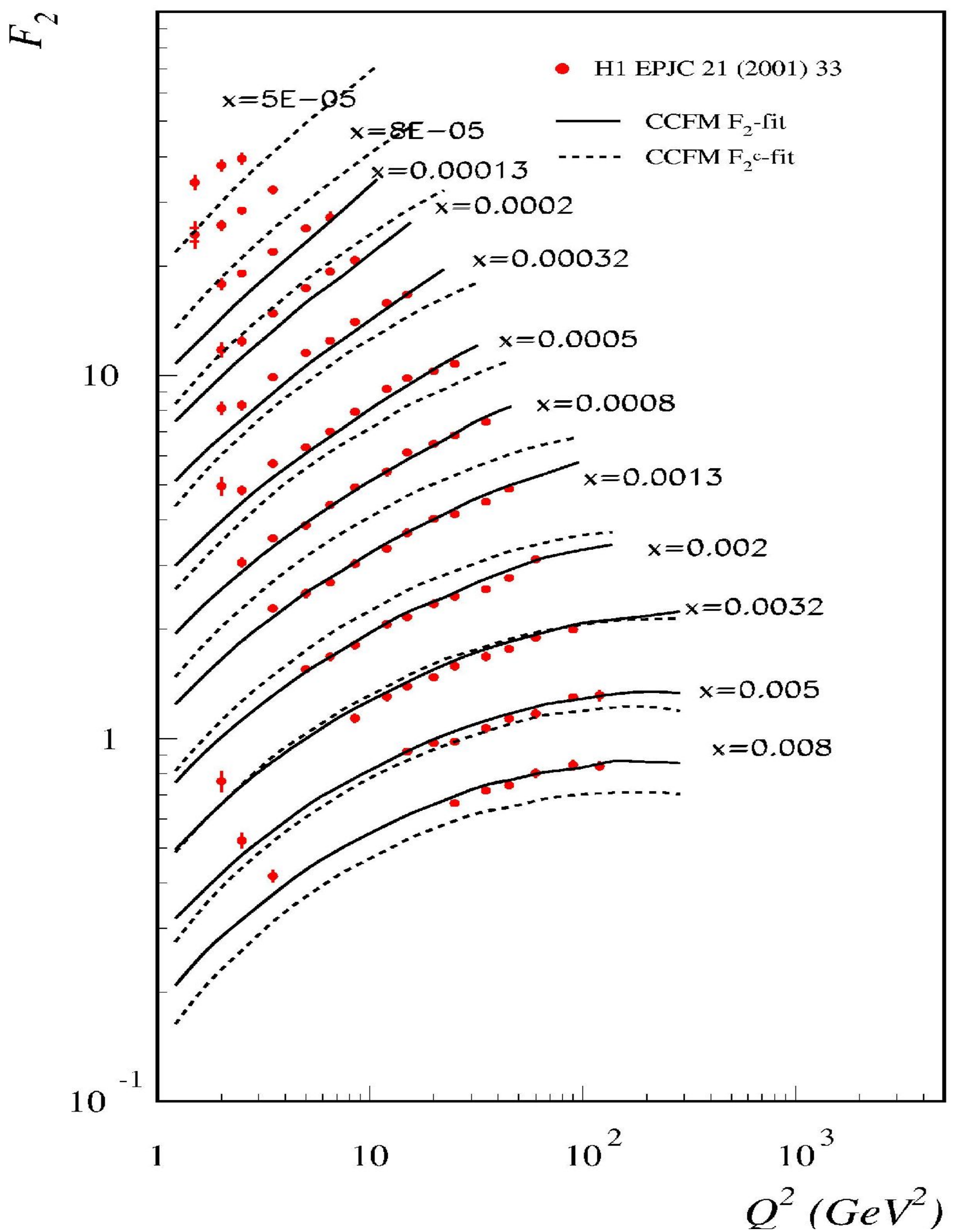
  $$xg(x, \mu_0^2) = N x^{-B_g} \cdot (1-x)^4$$
- using F_2 data H1

  (H1 Eur. Phys. J. C21 (2001) 33-61, DESY 00-181)

  $$x < 0.01 \quad Q^2 > 5 \text{ GeV}^2$$
- Fit (only stat+uncorr):

  $$B_g = 0.018 \pm 0.003 \text{ from } F_2$$

  $$B_g = 0.286 \pm 0.002 \text{ from } F_2^c$$

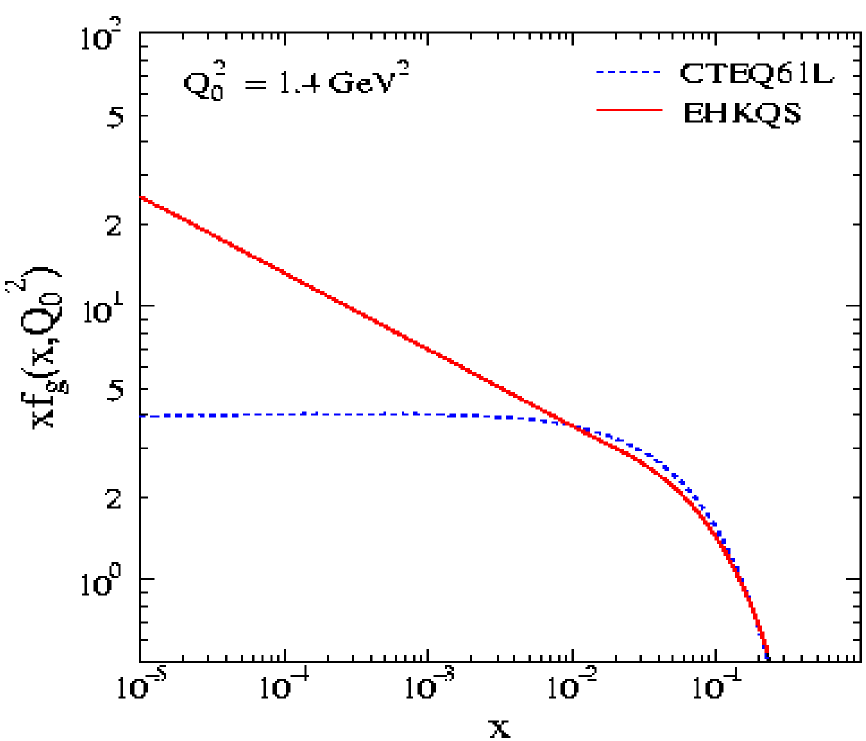


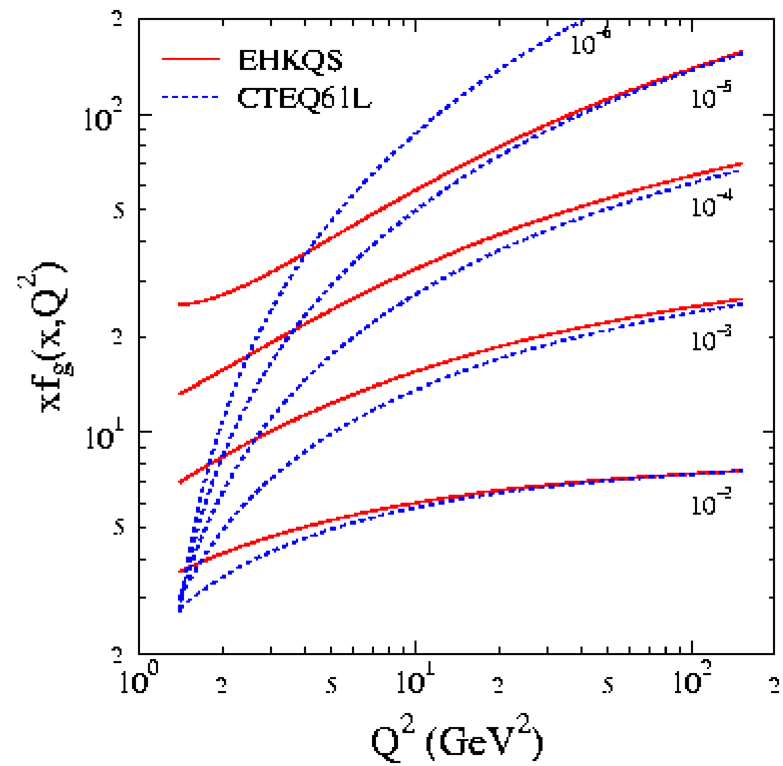
F_2 with GLR effects (EHKQS)

- use F2 HERA data
- fit with DGLAP+GLRMQ

K. Eskola, H. Honkanen, V. Kolhinen, L. Qiu, C.Salgado
EHKQS (Nucl.Phys.B660:211-224,2003)

$$\frac{dxg}{d\log Q^2} \sim \left.\frac{dxg}{d\log Q^2}\right|_{DGLAP} - \frac{1}{R^2} K \otimes [xg]^2$$





Advantage of uPDFs

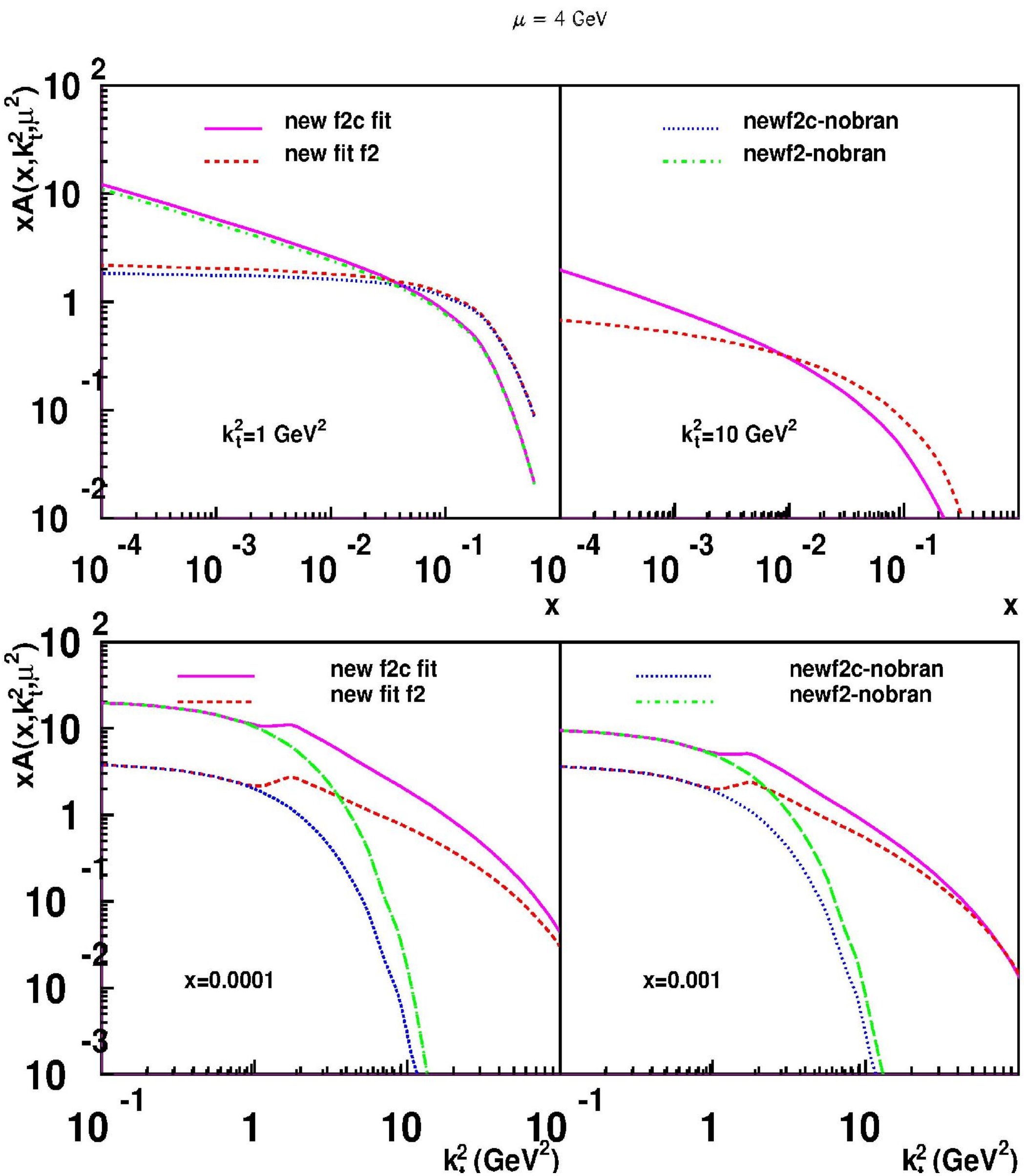
$$\mathcal{A}(x, k_\perp, \bar{q}) = \mathcal{A}_0(x, k_\perp)\Delta_s(\bar{q}, Q_0) + \int \frac{dz}{z}\frac{d^2q}{q^2}\Delta_s(\bar{q}, zq)\cdot\tilde{P}(z, \ldots)\mathcal{A}\left(\frac{x}{z}, k'_\perp, q\right)$$

Advantage of uPDF:

➔ possibility to separate no-branching piece from resolvable branching contributions

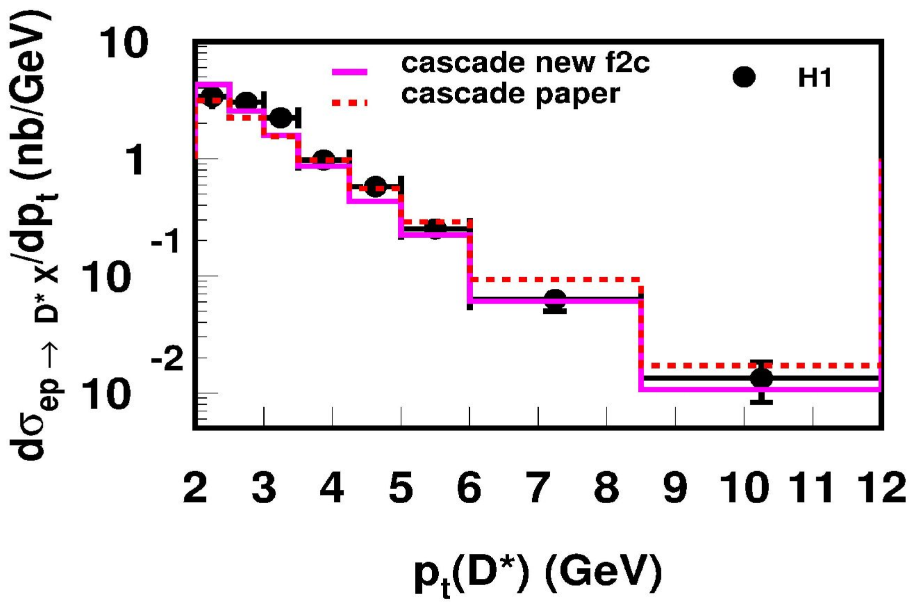
What is actually fitted ?

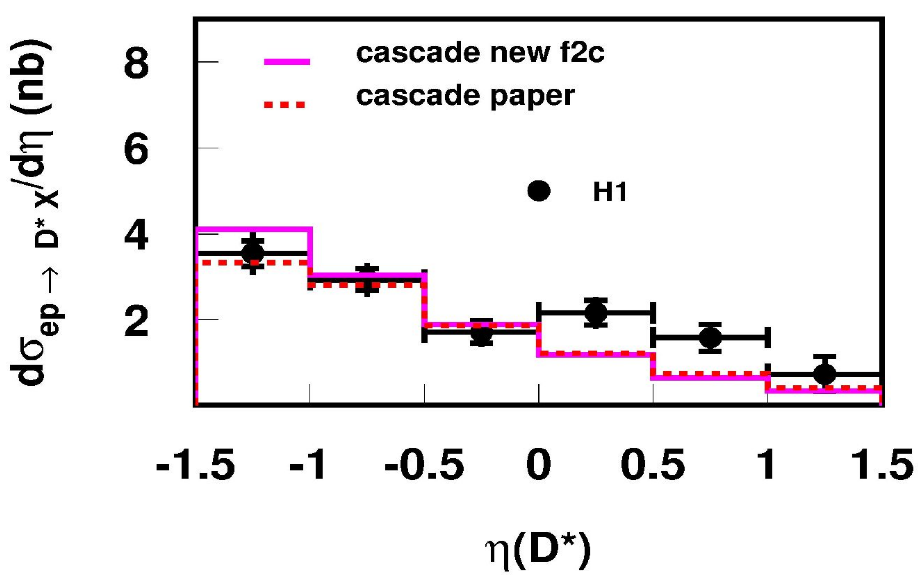
➔ Fit adjusts mainly the no-branching contribution
➔ large kt region fixed by evolution
➔ influence on final state predictions

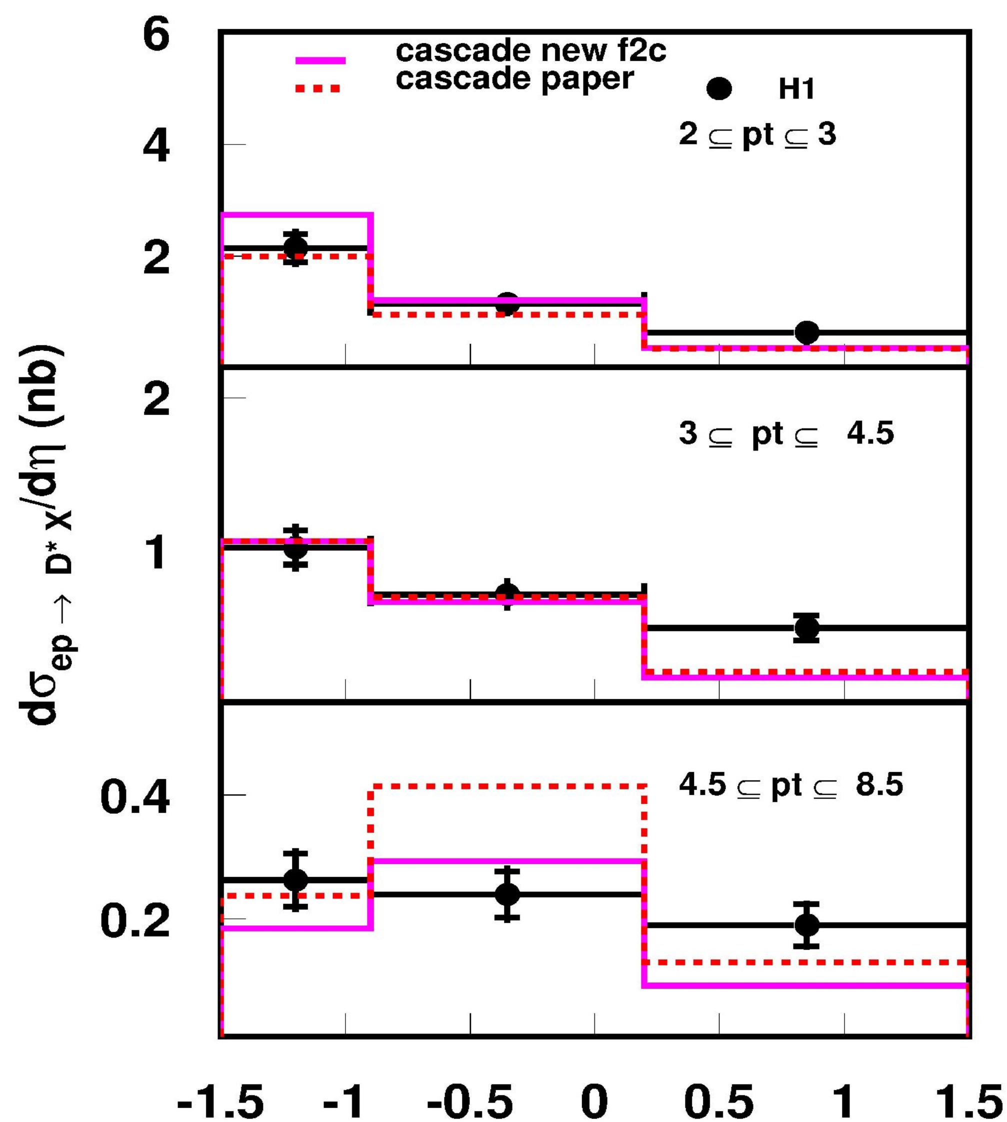


Application to D* + jets in γp

- Geros analysis







D* + jets in γp

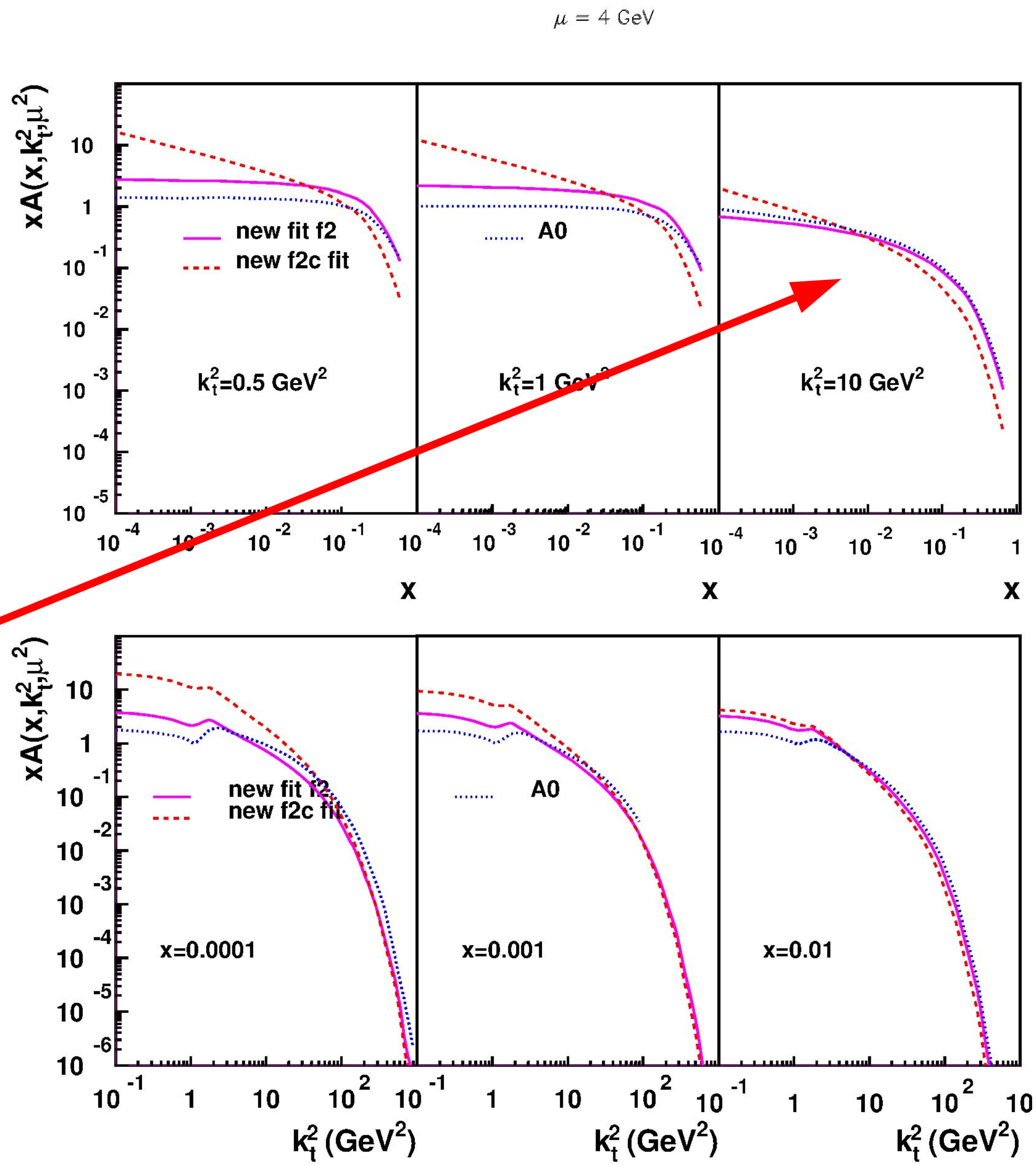
- chi**2 for inclusive D* (*pt* and *eta*)
- F_2 gluon :

  $\chi^2 = 22.32/13 = 1.72$

- new F_2^c gluon:

  $\chi^2 = 24.33/13 = 1.87$

→ no big effect from new fit
  → although gluon is very different
  → $\gamma p \to D^* + X$ probes different xg range: $< x_g >= -2.5$ and $< k_\perp >= 3.7$ compared to F2c
  → is still consistent
  → use sensitivity to kt from jets



F2c in dipole model:

- K.Golec-Biernat and S.Sapeta hep-ph/0607276

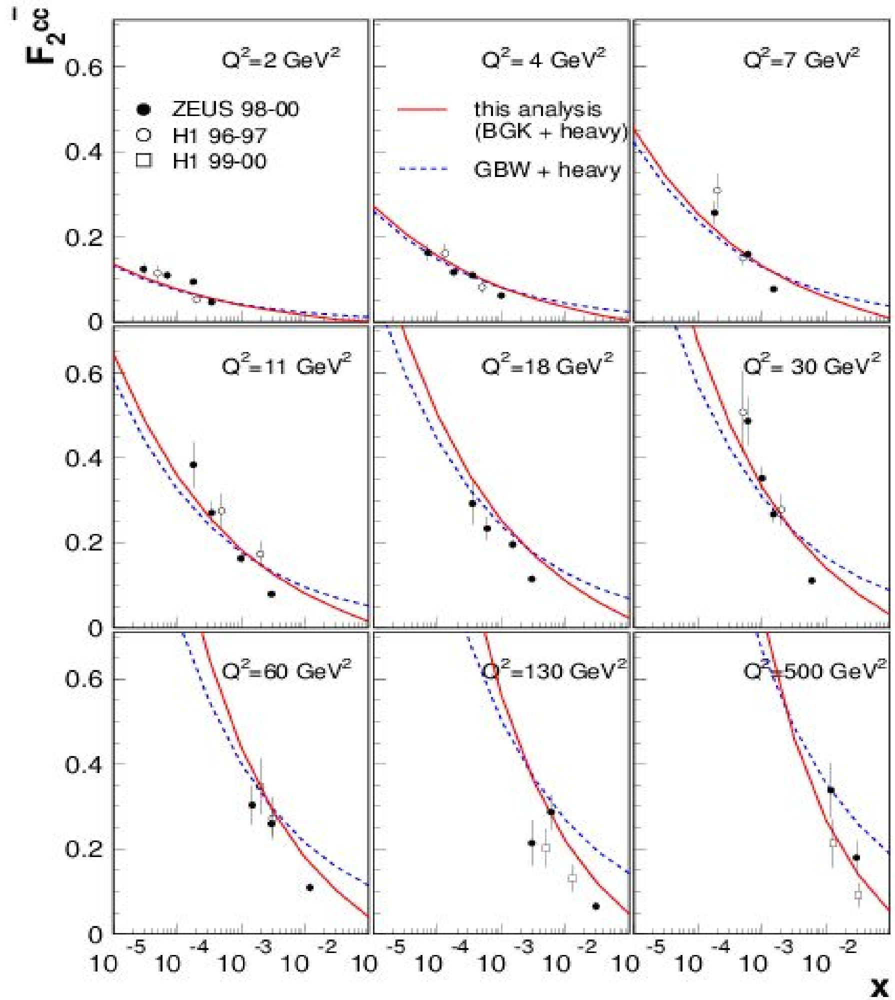


Figure 4: Predictions for the charm structure function $F_2^{c\bar{c}}$ in the BGK model with heavy quarks (solid lines). The predictions in the GBW model [1] are shown for reference (dashed lines).

F2c in dipole model:

H.Kowalski and D.Teaney
hep-ph/0304189

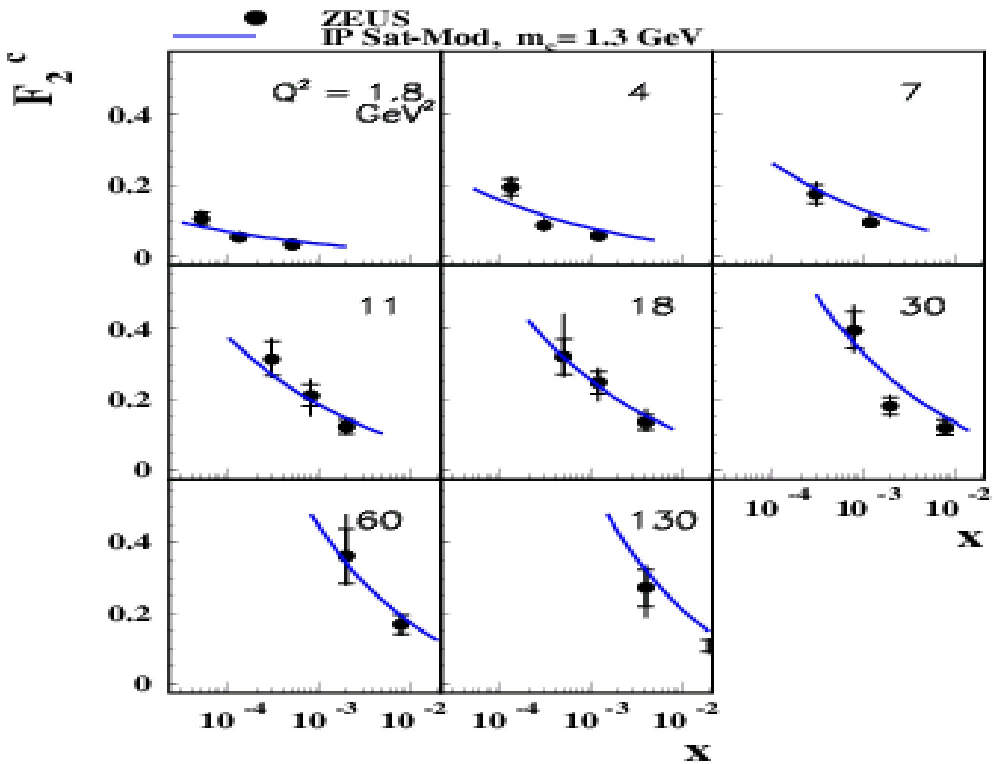


FIG. 11: A comparison of the measured F_2^c [32] to the results of the model.

The dipole model makes a direct prediction for the inclusive charm contribution to F_2. In the dipole approach the charm quark distribution is calculated from the gluon distribution. Figure 11 shows a comparison between the measured and predicted values of the charm structure function F_2^c. The results depend weakly on the charm mass. The good agreement with data for both ZEUS and H1 experiments [32, 33] confirms the consistency of the model and supports the dipole picture.