Starke Wechselwirkung mit γ und Proton

Heidelberg, 16.2.2001

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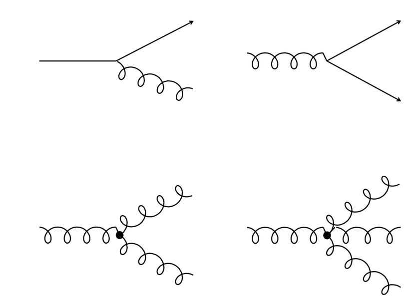
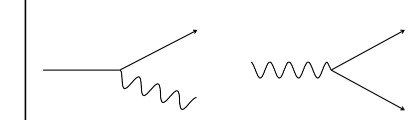
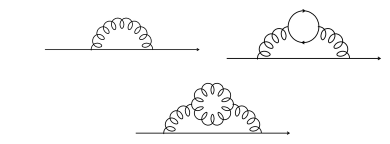
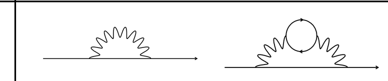
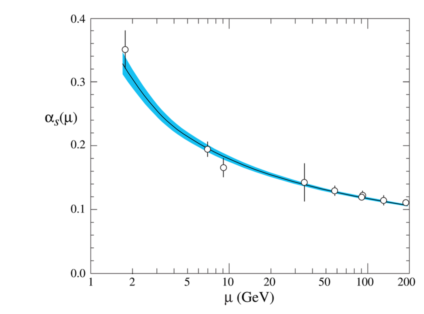
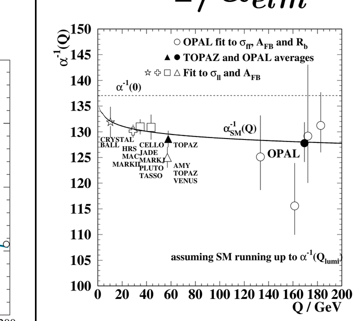
DESY

mit Daten von

bei HERA

Starke Wechselwirkung

Quanten-Chromo-Dyn.	Quanten-Elektro-Dyn.
QCD	QED
3 Farben	1 Ladung
6 Quarks	6 Quarks, 3 Leptonen
	
× 3 Quarkfarben	
× 8 Gluonen	

QCD	QED
	
α_s	$1/\alpha_{elm}$
	

Confinement:

keine freien Quarks oder Gluonen

Proton

$p = uud\ +$ Quantenfluktuationen

Vielkörperproblem: keine exakten Lösungen

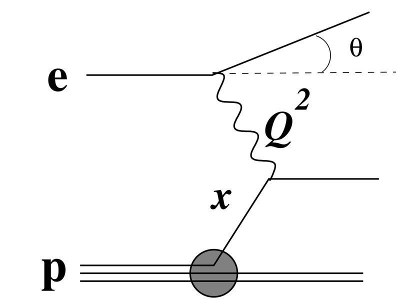
QCD Störungsrechnungen haben keine Vorhersagekraft für:

- Masse $\longleftarrow$ Bindungsenergie
- Radius
- Quanteninhalt: Quarks, Gluonen
- Spin-Zusammensetzung
- Dynamische Vorgänge im Confinement-Bereich

hier: Parton-Dynamik im Proton

Streuung mit Photonen im/am Proton

Auflösungsvermögen $\ll$ Radius$_{Proton}$



Q^2 = γ -Virtualität

x = E_{parton} / E_p

Auflösungsvermögen = $1/Q$

$Q = 200$MeV $\leftrightarrow$ $r = 1$ fm

$ep \rightarrow eX$ bei kleinen Q^2:

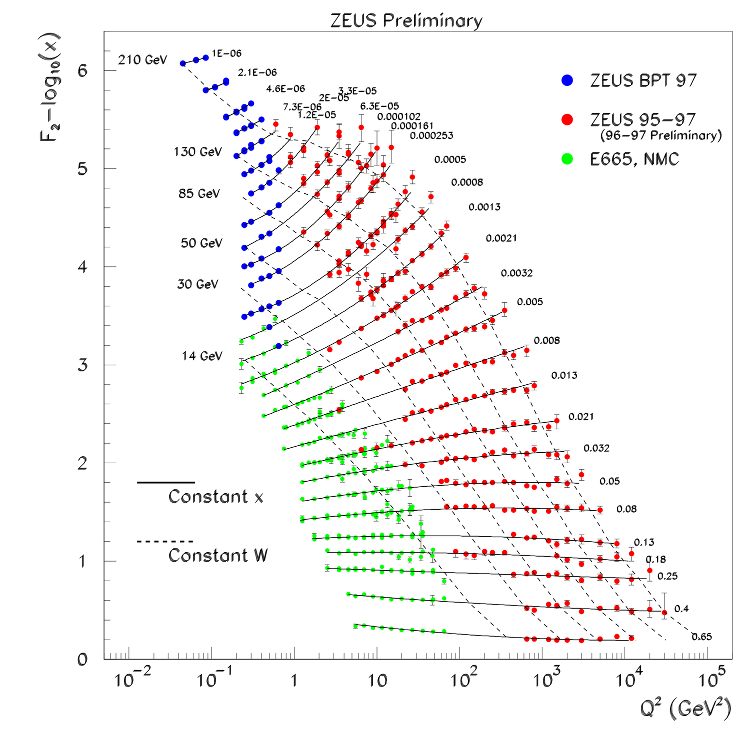
$$\frac{d^2\sigma}{dx\,dQ^2} \approx \frac{2\pi\alpha^2}{xQ^4}\, F_2$$

Impulsverteilung der Quarks im Proton:

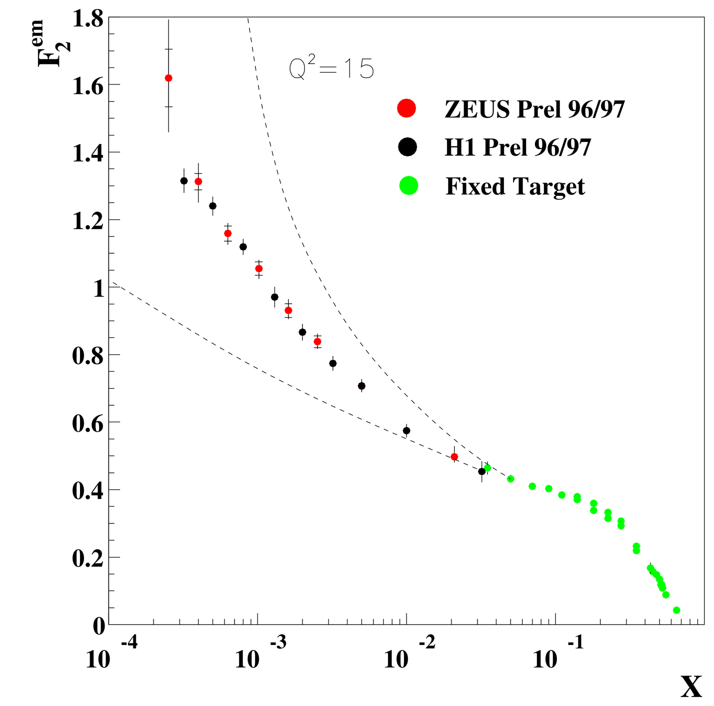
$$F_2\left(x, Q^2\right) \approx \sum_{q\bar{q}} e_q^2 f_q\left(x, Q^2\right)$$

HERA

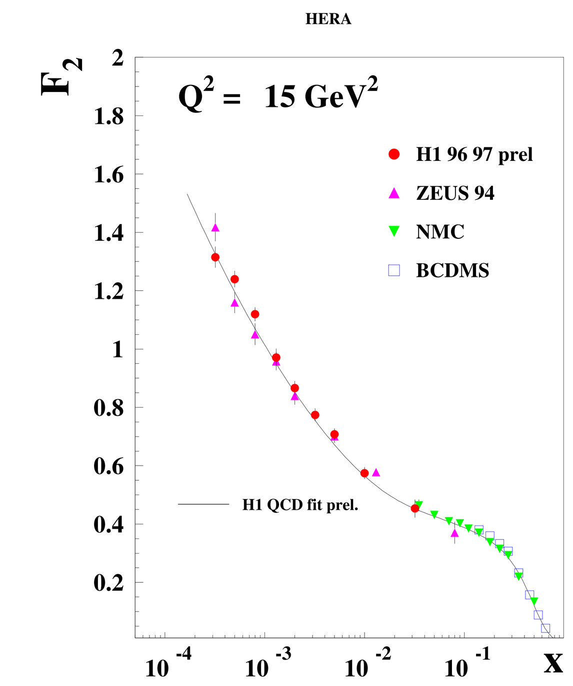
$E_e = 27.5$ GeV, $E_P = 920$ GeV
$\rightarrow E_{cms} = 320$ GeV
vor HERA: $E_{cms} < 20$ GeV



Faktor 100 höher in Q^2 **/ tiefer in** x

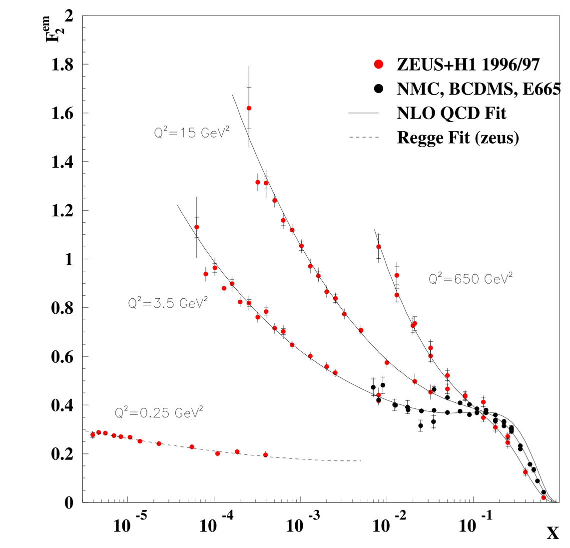


Viele Quarks bei kleinen x !!



Viele Quarks bei kleinen x !!

Gluonen im Proton



kleine x, große Q^2 $\rightarrow$ viele Abstrahlungen, hohe Parton-Dichten

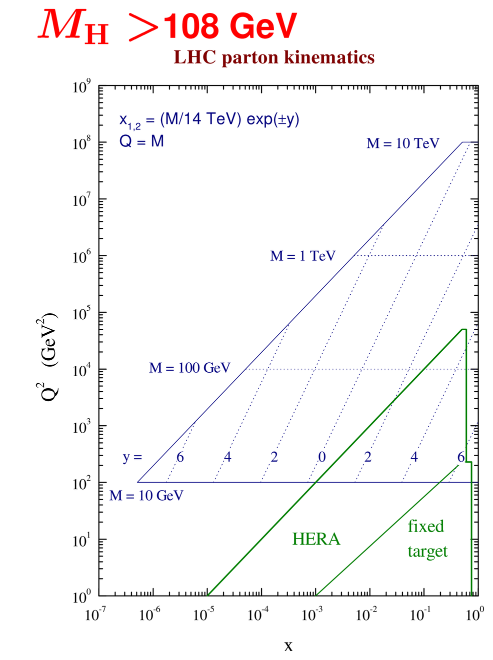
Interesse an kleinen x

- Parton-Dynamik, Test der QCD nach vielen Abstrahlungen (Gluon-Selbst-WW)
- Grenzen der Parton-Dichten ?
  Gluon-Interferenz (Saturation)
- Confinement
- Anwendungen bei Proton-Proton Beschleunigern (LHC): HIGGS
- Anwendung bei Schwer-Ionen Physik, kosmischer Strahlung
- Gravitation in extra Dimensionen

$\longrightarrow$ Boom in low-x Physik

Higgs Produktion bei LHC

$M_{\mathrm{H}} >$ **108 GeV**



abhängig von Gluon-Dichte bei $x \lesssim 10^{-3}$

Einziger Prozess: Tief-inelastische Streuung bei HERA:

jedoch: $x \lesssim 10^{-4} \rightarrow Q^2 \lesssim$ 1GeV

$Q^2 \gg 1/r^2_{proton} \quad \rightarrow \tau_{\gamma q} \ll \tau_{qq,qg}$

Momentaufnahme der Partonkonfiguration

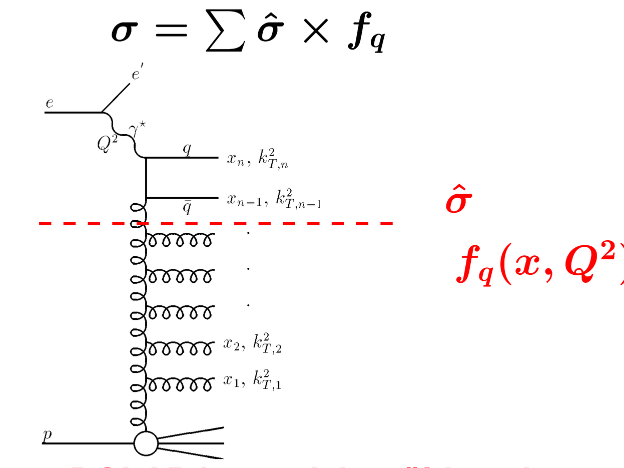
1) Altarelli-Paresi Näherung (DGLAP)

Annahme: starke Ordnung in k_T :

$$Q^2 >> k_{T,i} >> k_{T,i-1} ...$$

$\rightarrow$ **Faktisierung in harte und weiche Anteile:**

$$\sigma = \sum \hat{\sigma} \times f_q$$

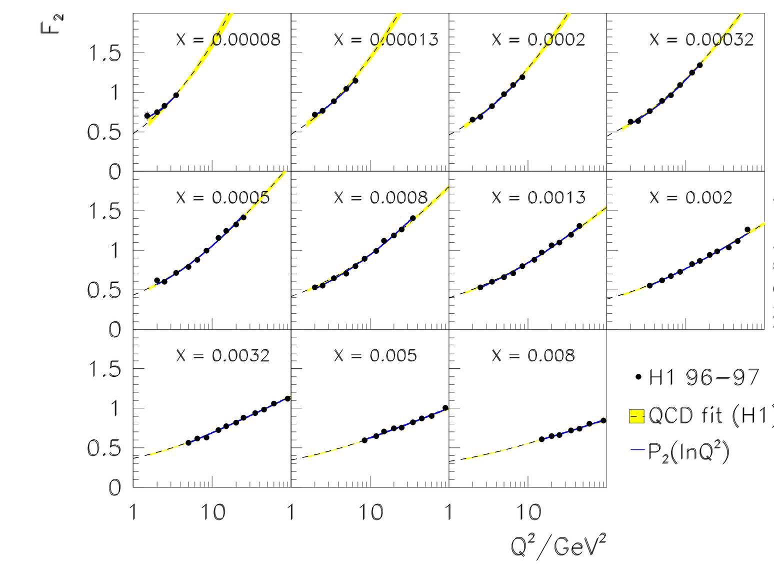


- **DGLAP kann nicht gültig sein wenn:**
  - Q^2 **zu klein (wie klein ?)**
  - x **zu klein (Phasenraum !)**
    (lange Leiter $\rightarrow$keine k_T Ordnung)

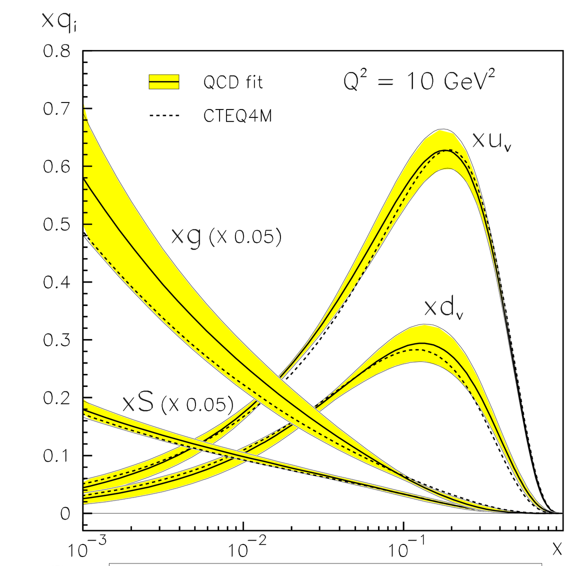
punktförmige Partonen:

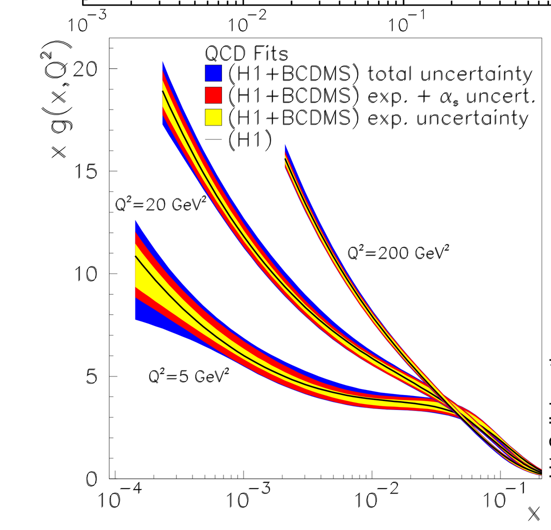
$\rightarrow F_2$ **unabhängig von** Q^2 $g \rightarrow q\bar{q}$**:**

$\rightarrow$ **Steigung** $dF_2/d\ln Q^2|_x \approx$**Gluondichte**



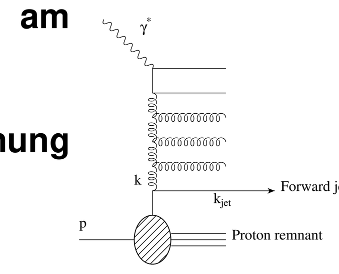
Braucht Genauigkeit !


xq_i
QCD fit
CTEQ4M
Q² = 10 GeV²
xu_v
xg (x 0.05)
xd_v
xS (x 0.05)
x


x g(x,Q²)
QCD Fits
(H1+BCDMS) total uncertainty
(H1+BCDMS) exp. + α_s uncert.
(H1+BCDMS) exp. uncertainty
(H1)
Q²=20 GeV²
Q²=200 GeV²
Q²=5 GeV²
H1 Collaboration
x

Factorisierung in der QCD

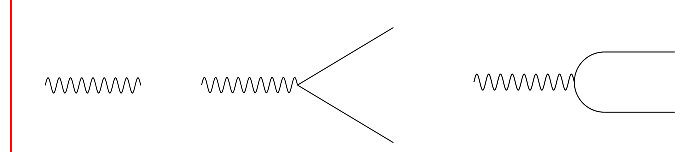
Bsp: Jets nahe am Proton:
keine klare Ordnung von Q^2 nach k_T^2



Alternativen zu DGLAP:

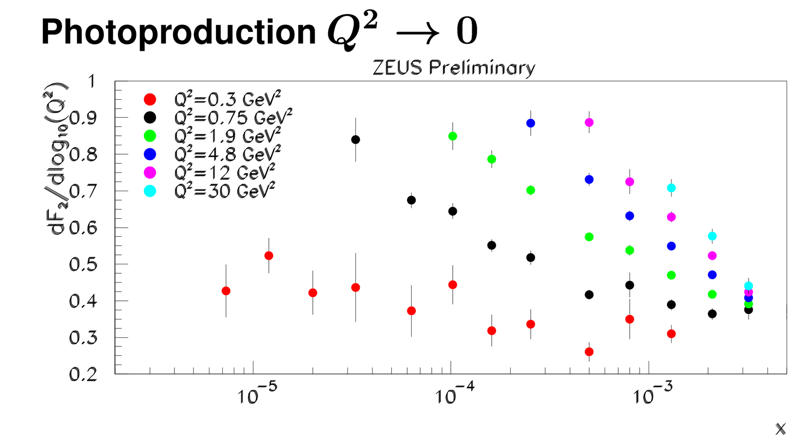
- **Ordnung nach Abstrahlungswinkel**
  Unintegrierte Parton-Dichten:
  $f(x, k_T^2, Q^2)$
  BFKL, CCFM
- **Photon-Struktur**
  Fluktuation des γ in Farb-Dipol ($q\bar{q}$)

  "direct" + "point-like" + "hadron-like"

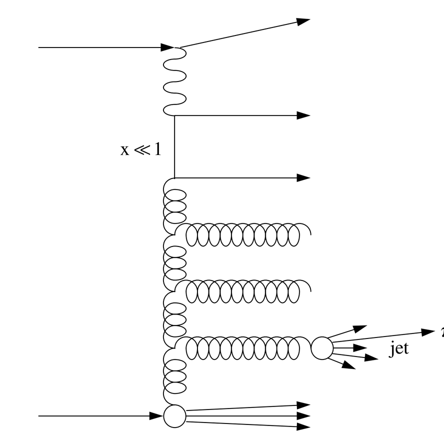
  

  – **"direct" und "point-like" Teil sind vorhergesagt**
  – **"hadron-like" Anteil klein wenn $Q^2 \gg 1$GeV^2**

extrem kleine x (hohe Gluon Dichten)
$\rightarrow$ kinematisch auch Übergang zur
Photoproduction $Q^2 \rightarrow 0$



kein Effekt sichbar bei festem $Q2$
$Q^2 \rightarrow 0$: keine Auflösung mehr, keine
Struktur ($F_2 \rightarrow 0$) $Q^2 < 1$GeV^2: schwierig
Effekte bei kleinen x von Effekten bei kleinen
Q^2 auseinander zu halten

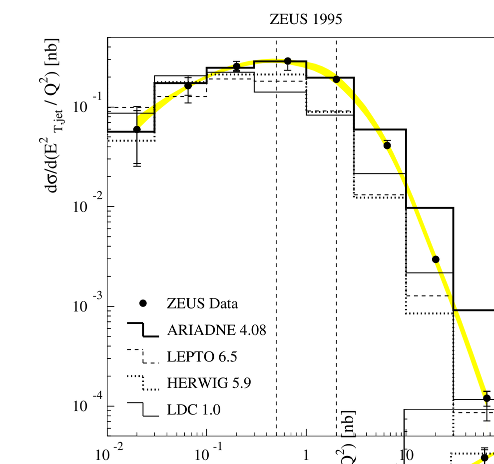


selektiere:

- kleine -x
- Jets "vorne" (π^0)
- $Q^2 \approx E^2_{T,jet}$

keine k_T Ordnung

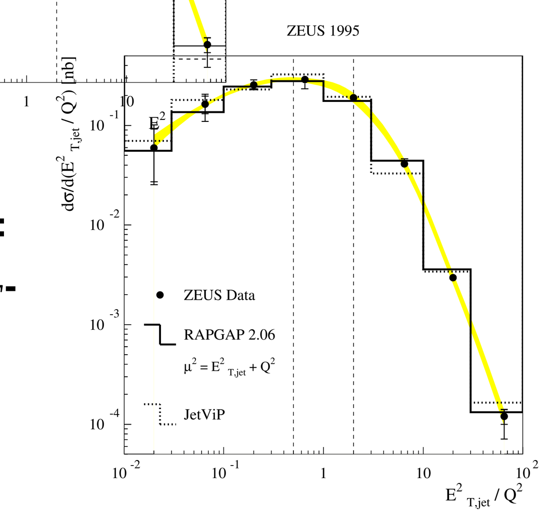
- Testfall für BFKL, CCFM und Farb-Dipol



DGLAP:

versagt für

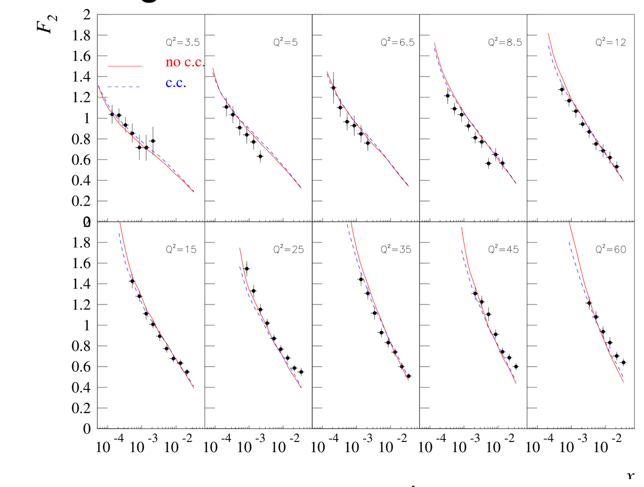
$Q^2 \lesssim E^2_{T,jet}$



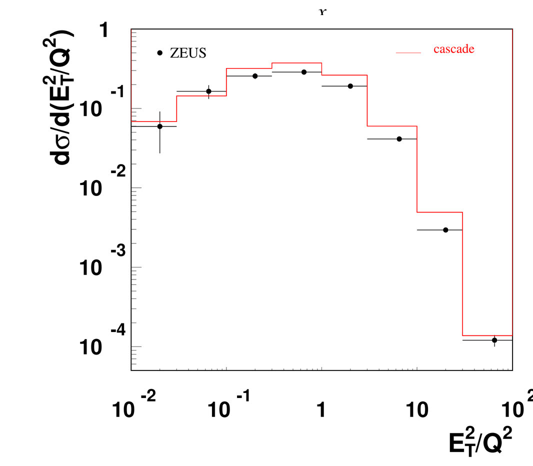
Farb-Dipol o.k.:

Zeichen für k_T-Unordnung

unintegrierte Parton-Dichten aus Fit an F_2

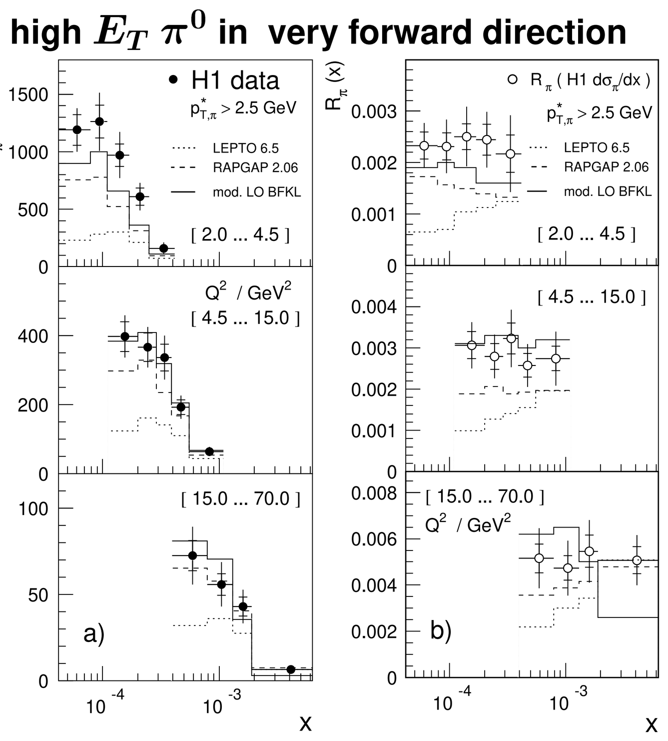


CCFM für Jets



QCD dynamics: Forward π^0

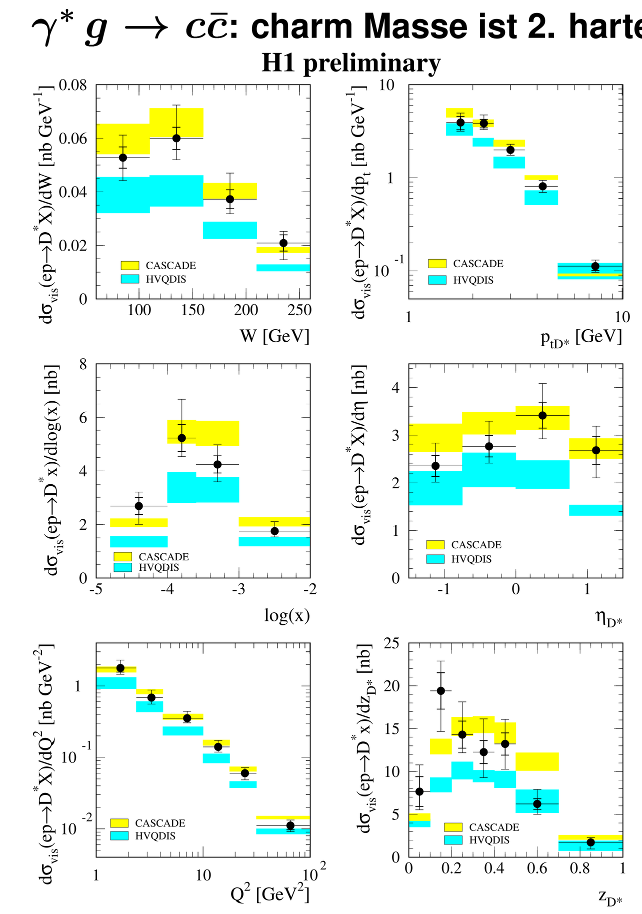
high E_T π^0 in very forward direction



only hint on dynamics beyond

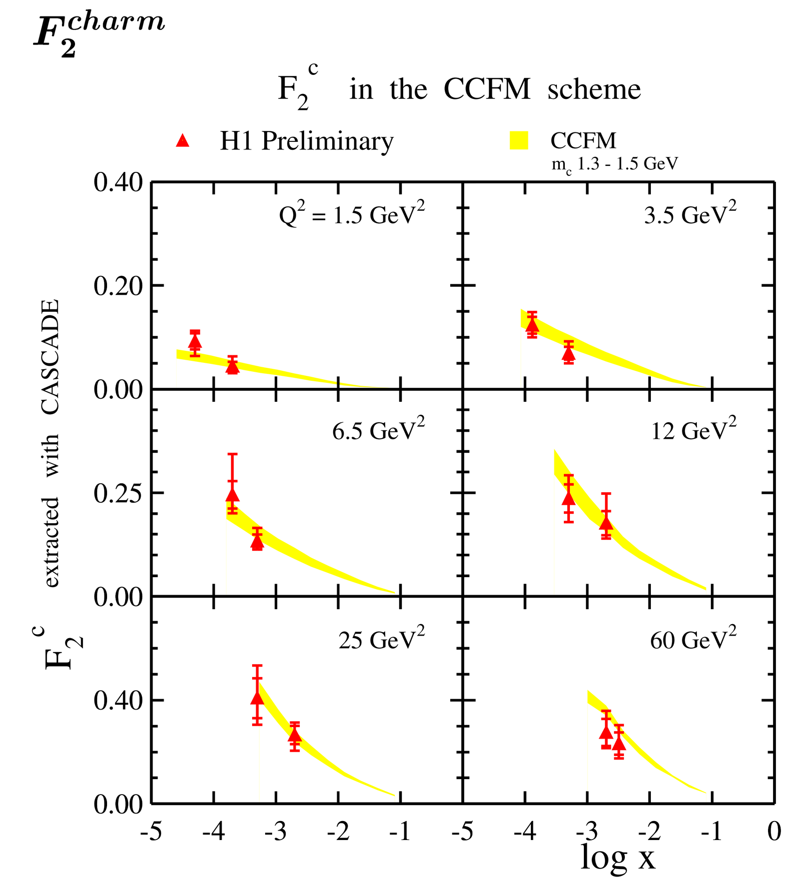
'resolved virtual photon'

$\gamma^* g \to c\bar{c}$: charm Masse ist 2. harte Skala



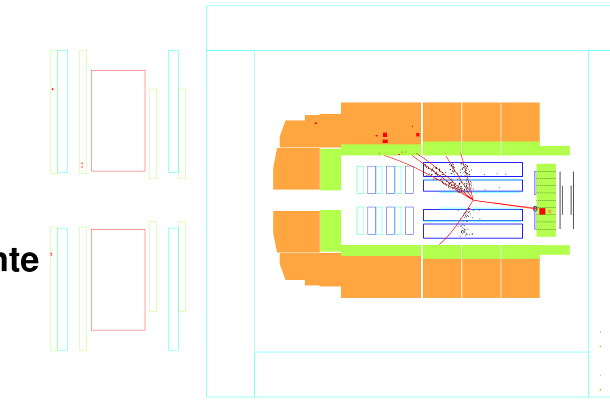
CCFM etwas besser als DGLAP

F_2^{charm}


F_2^c in the CCFM scheme
H1 Preliminary
CCFM
m_c 1.3 - 1.5 GeV
F_2^c extracted with CASCADE
$Q^2 = 1.5$ GeV^2
3.5 GeV^2
6.5 GeV^2
12 GeV^2
25 GeV^2
60 GeV^2
log x

Parton Korrelationen

keine
Proton
Fragmente



10% aller Ereignisse

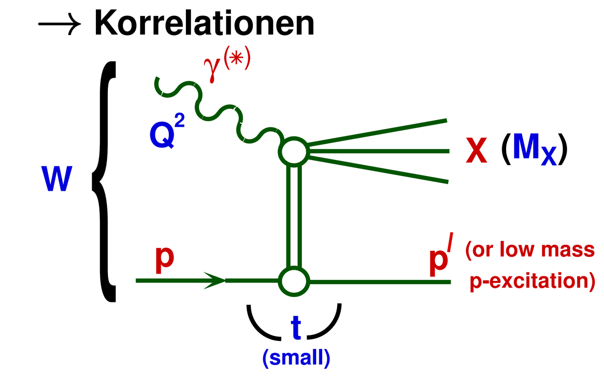
elastische Streuung: $\gamma^* p \to Xp$

γ^* trifft Quark aber p überlebt

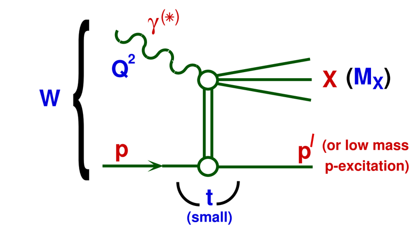
<u>Diffraktion:</u>

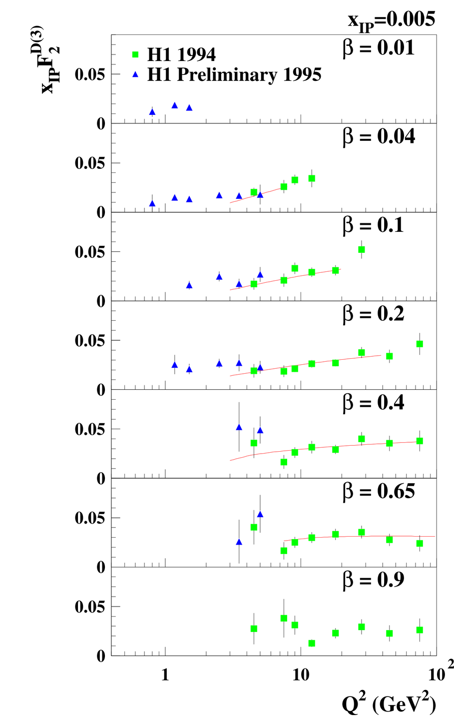
keine Streuung an einzelnen Quarks/Gluonen

$\to$ Korrelationen



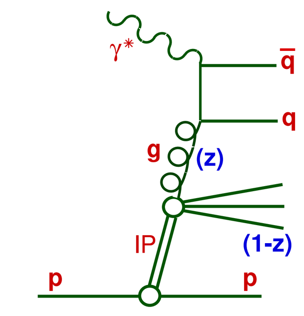
Diffractive Parton-Dichten



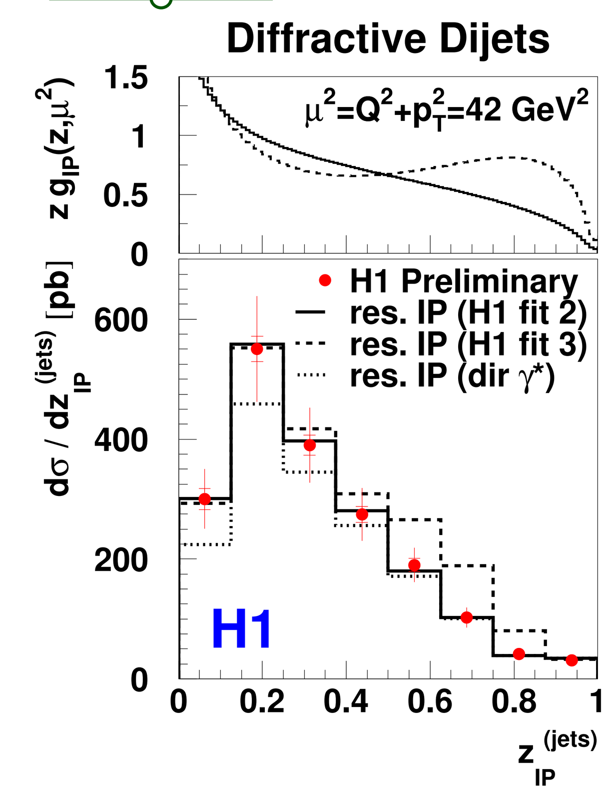


$F_2^{D(3)}$ **steigt mit** Q^2**:**

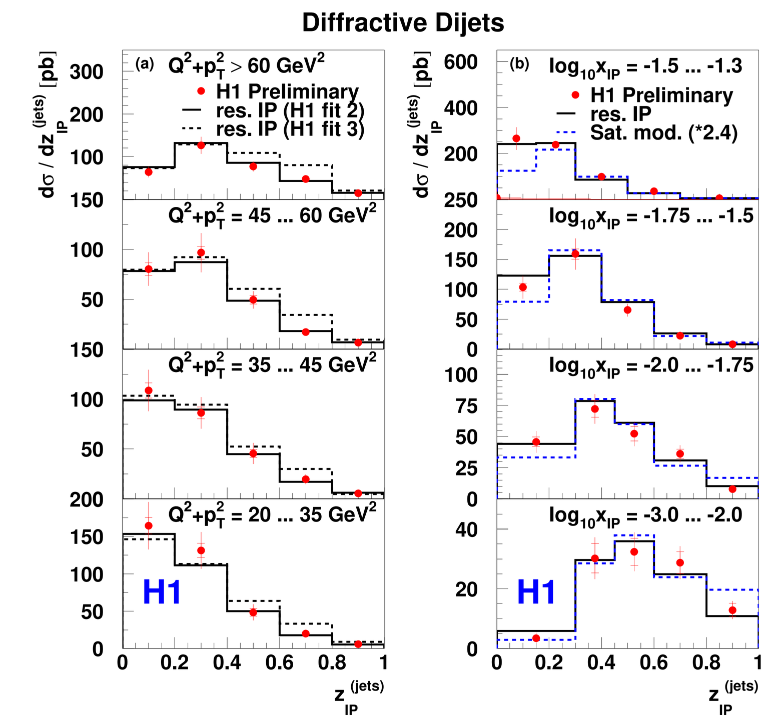
Gluonen (Glueball ?)



direkt sensitiv auf Gluonen

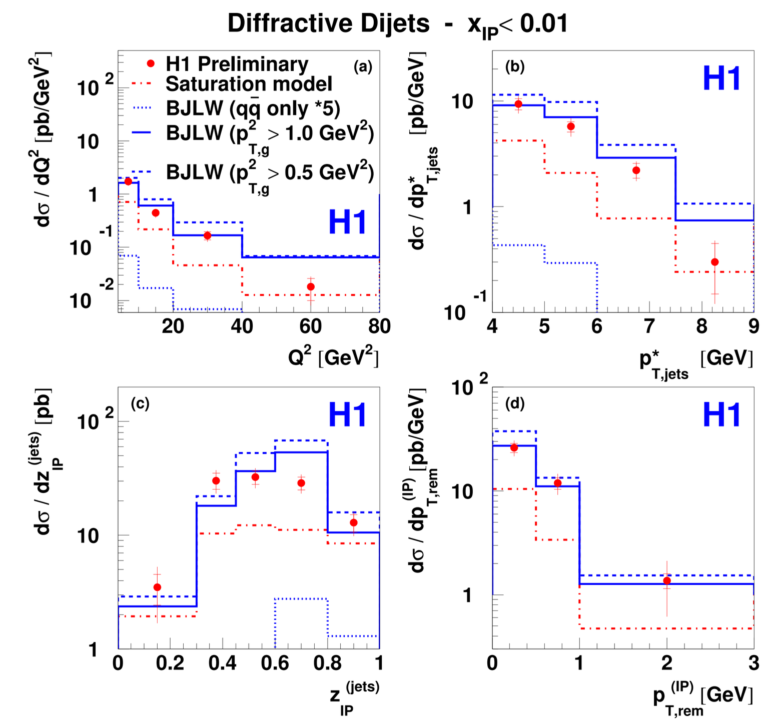


Confirmation of QCD interpretation within picture of Reggee factorisation



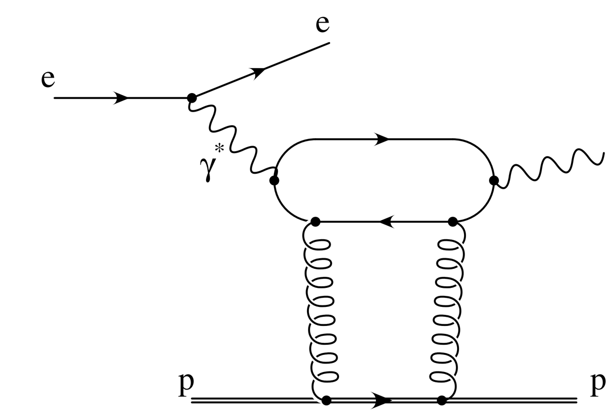
fully consistent picture from $F_2^{D(3)}$ and jets in either Q^2, $x_{I\!P}$, or z

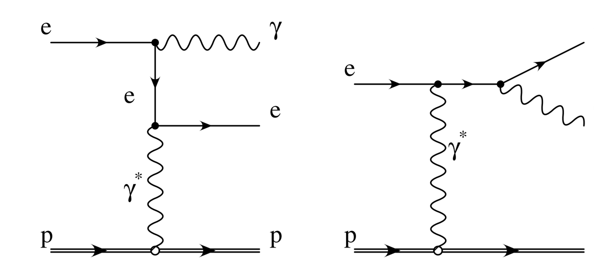
Comparison with QCD calculation for 2-gluon exchange $\sigma \sim |g(z, Q^2)|^2$



Note: reasonable agreement, considerable energy not contributing to hard process: remnant of colour singlet at low P_T

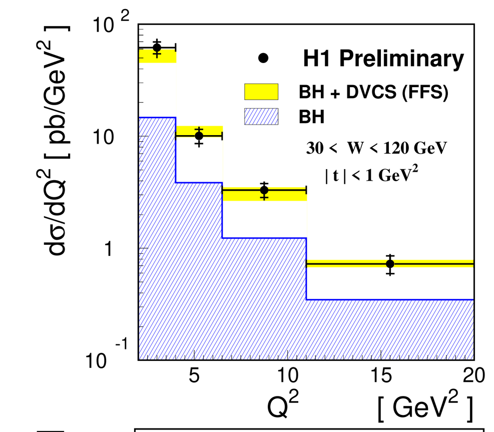
Deeply Virtual Compton Scattering

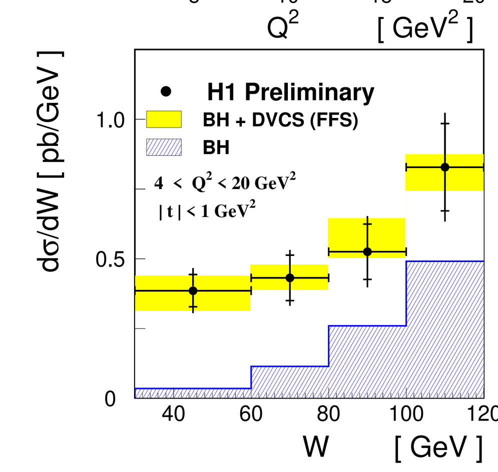




Interferenz hängt ab von Skewed Parton Distributions $f(x_1, x_2, Q^2)$

Deeply Virtual Compton Scattering

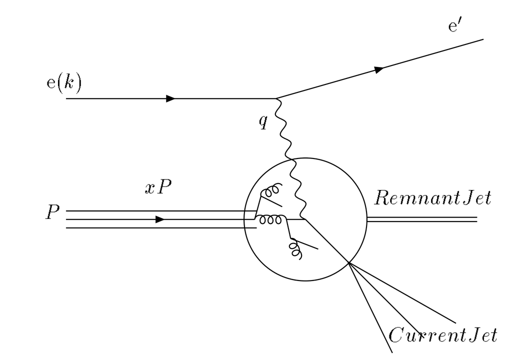




γ- $\times$ Gluon-Paar beschreibt Daten !

Mehr Daten !

Zusammenfassung



- **Quark - Gluon Bild des Protons**
  präzise gemessen, $\lesssim$ 10% Fehler
- **neuer Bereich der QCD:**
  theoretisch schwierig hohe q / g Dichten bei kleinen x
- **Korrelationen von Partonen**
- **HERA II: Faktor 5 mehr Daten:**
  große x und Q^2