Jet Production in Deep-Inelastic Scattering at HERA

M. Wobisch, DESY
for the H1 and the ZEUS Collaborations

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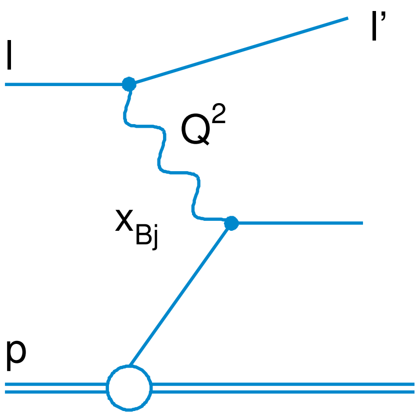
- Introduction:
  Jets in Deep-Inelastic Scattering

- Experimental results:
  Dijet Cross Sections, Dijet Rates,
  Inclusive Jet Cross Sections

- QCD analyses:
  Fits of α_s and the Gluon Density in the Proton

Jets in Deep-Inelastic Scattering



event kinematics:

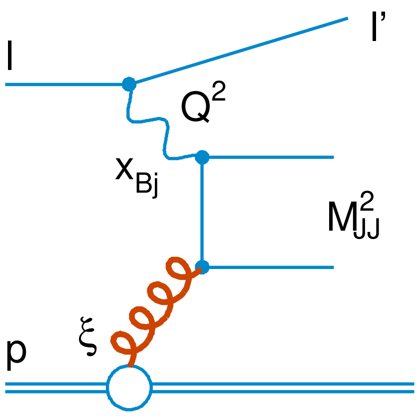
$$\sqrt{s} = 300 \text{ GeV}$$

$$Q^2 = -q^2 = -(l - l')^2$$

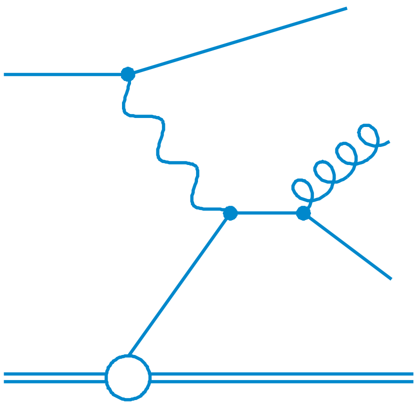
$$x_{\text{Bj}} = \frac{Q^2}{2pq}$$

⇒ inclusive DIS cross section:

directly sensitive to quark densities in the proton



photon-gluon fusion



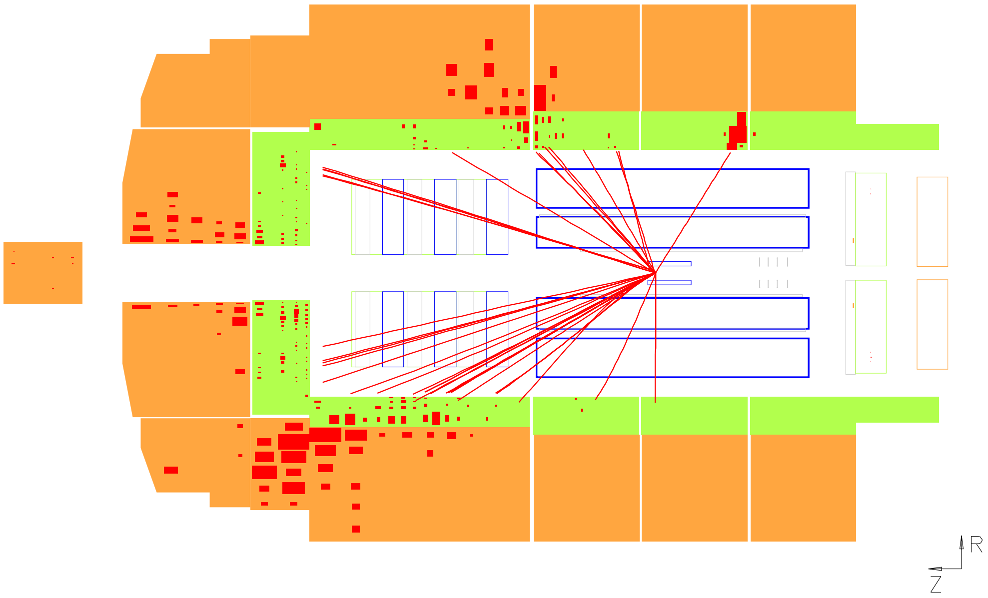
QCD-Compton

kinematics of multi-jet system: M_{jj}, ξ , E_T

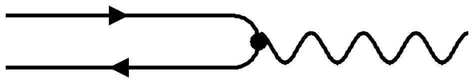
⇒ multi-jet cross sections in DIS:

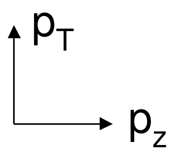
directly sensitive also to α_s and the gluon density in the proton

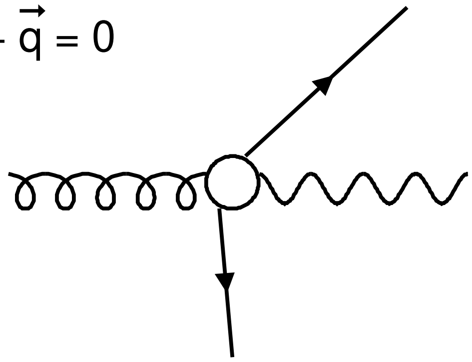
Multi-jet production in the Breit frame



Breit frame: $2x_{Bj}\,\vec{P} + \vec{q} = 0$







Born process

boson-gluon fusion

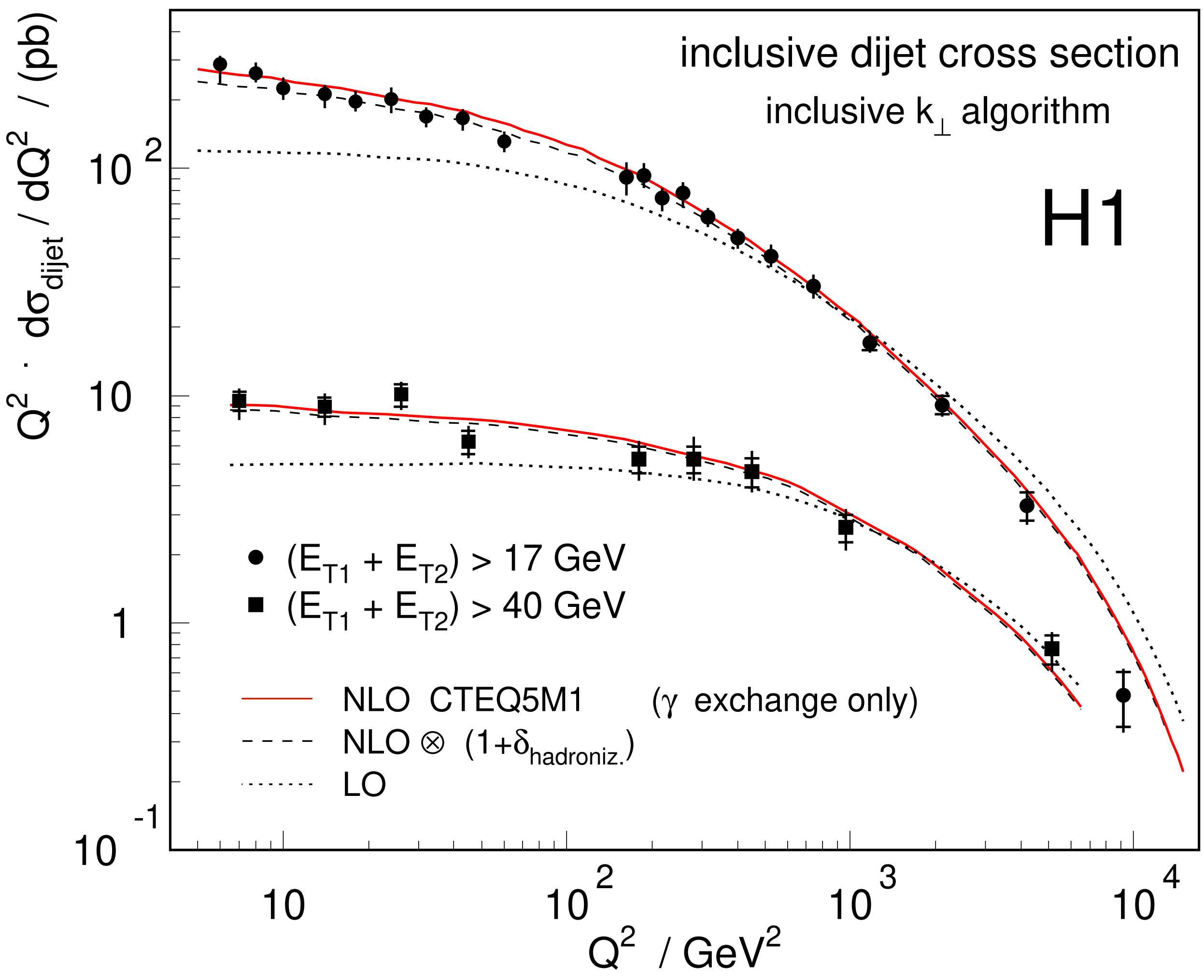
pQCD processes $\mathcal{O}(\alpha_s)$ $\Longleftrightarrow$ high E_T in Breit frame

two hard energy scales: E_T, Q – choice of μ_r?

this talk: $5 < Q^2 < 20000\ \mathrm{GeV}^2$, $25 < E_T^2 < 2500\ \mathrm{GeV}^2$

dijet cross section: $5 < Q^2 < 15\,000\ \mathrm{GeV}^2$

$\sum E_{T,\mathrm{Breit}} > 17\ \mathrm{GeV}$ and $\sum E_{T,\mathrm{Breit}} > 40\ \mathrm{GeV}$



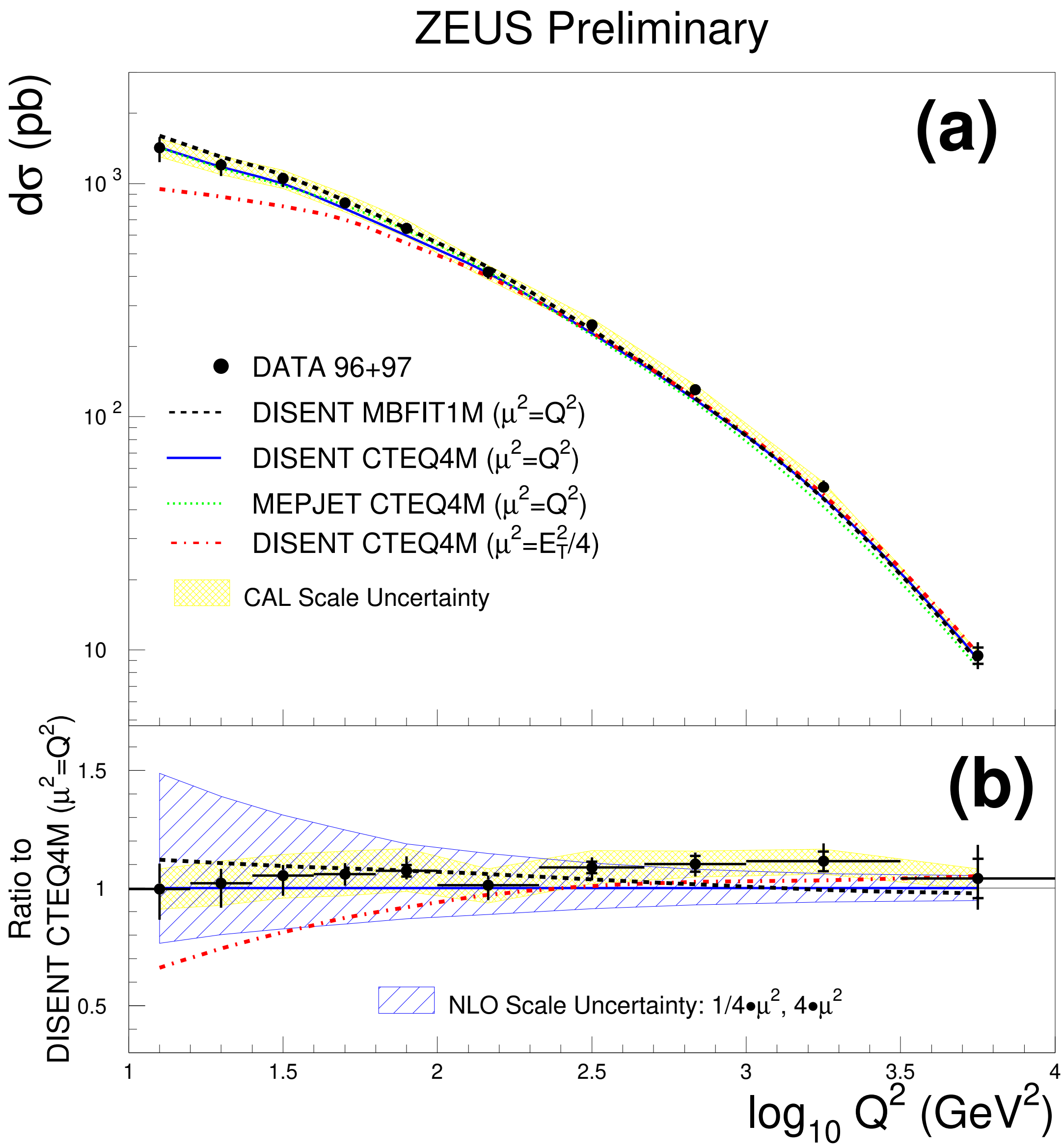
$\mu_r = E_T$

$\Longrightarrow$ small NLO corrections at $Q^2 > 200\ \mathrm{GeV}^2$

agreement theory/data over whole Q^2 range

dijet cross section: $10 < Q^2 < 10\,000\ \mathrm{GeV}^2$

$E_{T,\mathrm{Breit},1} > 8\ \mathrm{GeV}, \quad E_{T,\mathrm{Breit},2} > 5\ \mathrm{GeV}, \quad E_{T,\mathrm{Lab}} > 5\ \mathrm{GeV}$



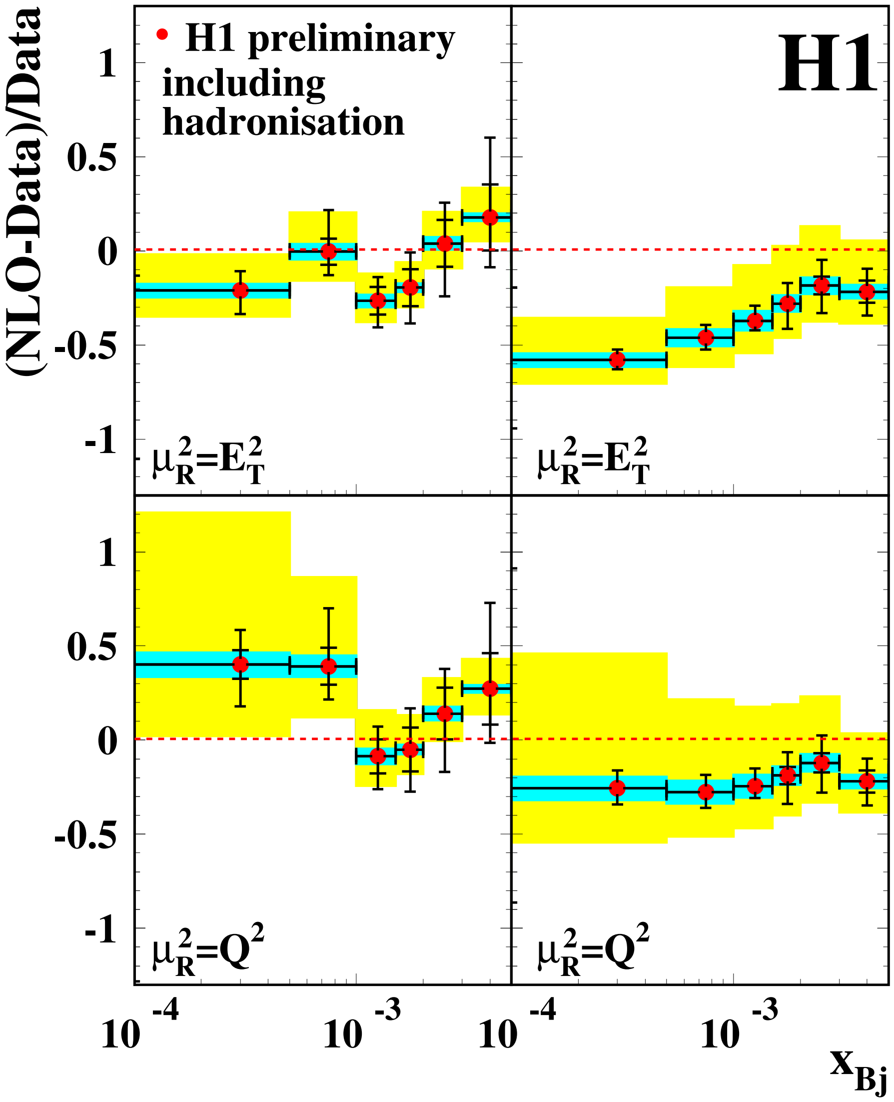
$\Rightarrow$ good agreement over whole Q^2 range for $\mu_r = Q$

for $\mu_r = E_T$: deviations at $Q^2 < 100\ \mathrm{GeV}^2$

the inclusive jet cross section – low Q^2

$$5 < Q^2 < 100\,\text{GeV}^2 \qquad E_{T,\text{Breit}} > 5\,\text{GeV}$$

central region $\leftarrow$ $0.5 < \eta_{lab} < 1.5$ $\qquad$ $1.5 < \eta_{lab} < 2.8$ $\rightarrow$ forward dir.



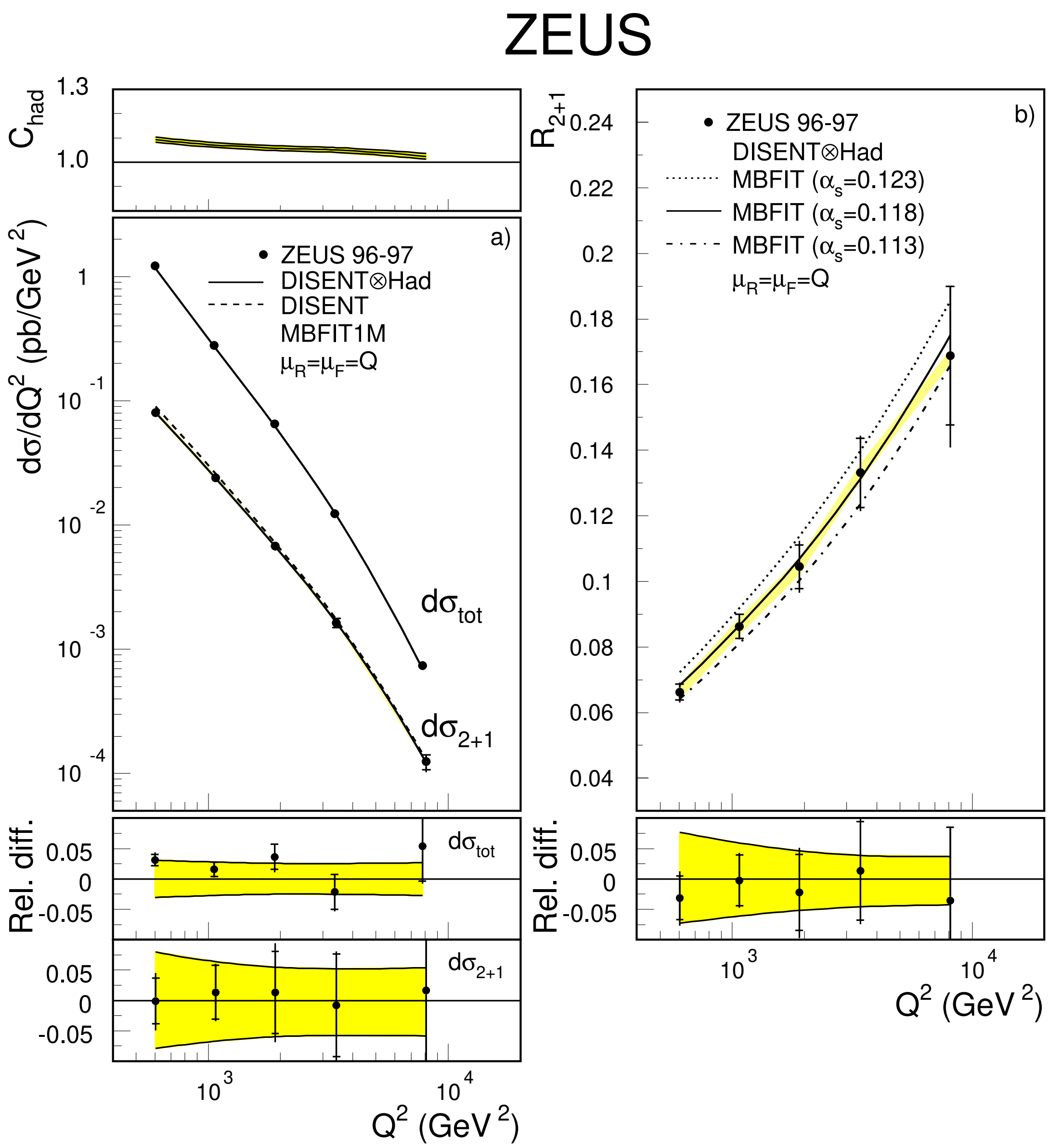
$\Longrightarrow$ reasonable description in central region

forward region: poor for $\mu_r = E_T$
large μ_r dependence for $\mu_r = Q$

the dijet rate $R_2(Q^2)$ – high Q^2

$470 < Q^2 < 20\,000\ \text{GeV}^2$ $\quad\quad (\mu_r = Q)$

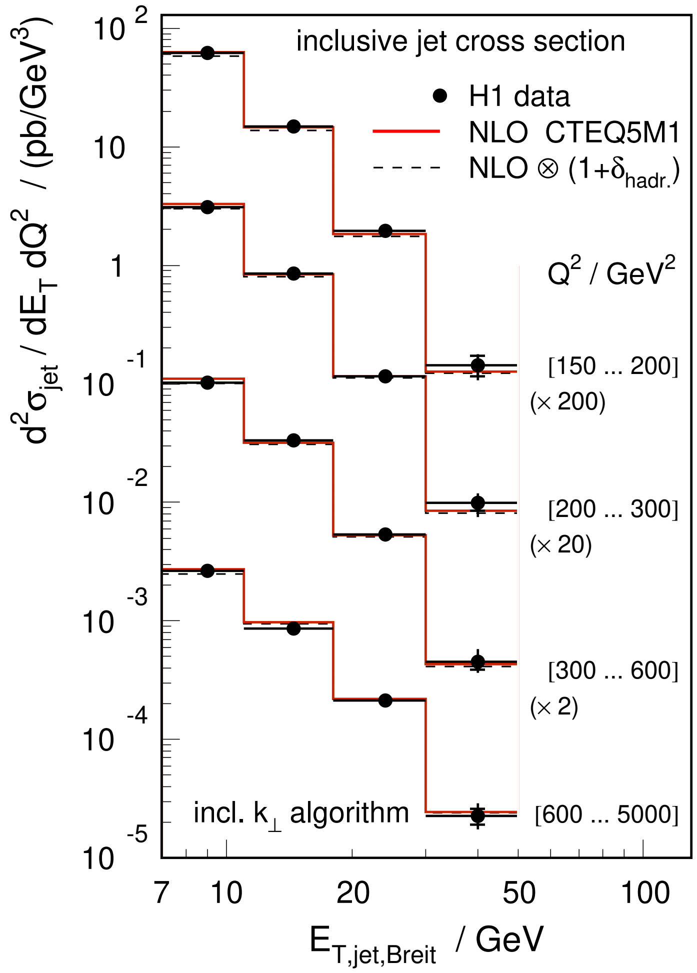
$E_{T,\text{Breit},1} > 8\ \text{GeV}\ , \quad E_{T,\text{Breit},2} > 5\ \text{GeV}$



⇒ dijet rate increasing with Q^2

good description of the data by NLO

the inclusive jet cross section – high Q^2

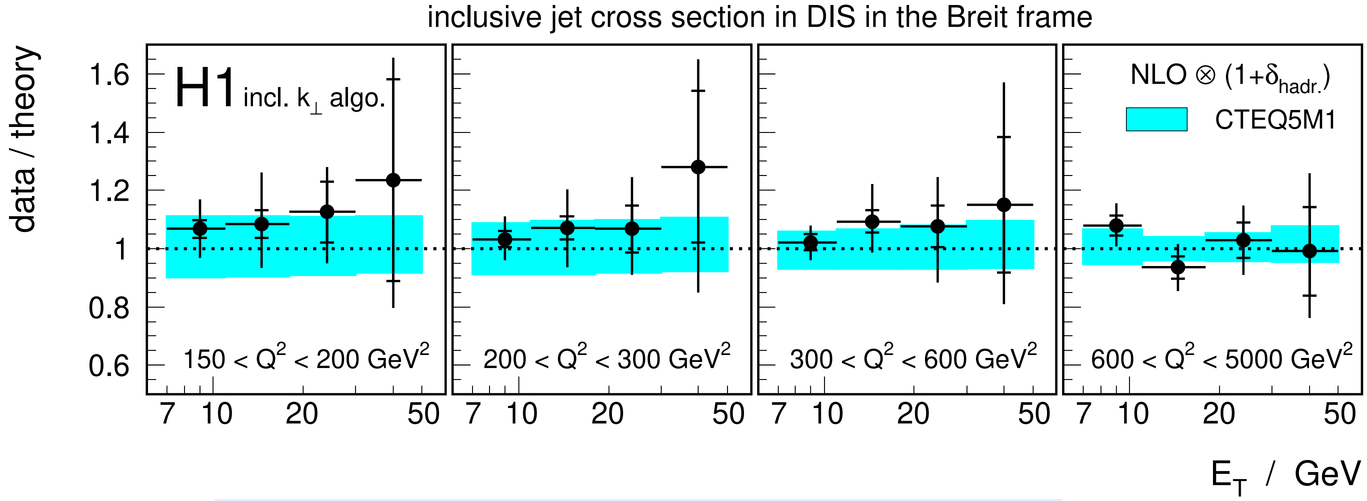


double differential
$\sigma_{\text{jet}}(Q^2, E_T)$

$150 < Q^2 < 5000\,\text{GeV}^2$

$7 < E_{T,\text{Breit}} < 50\,\text{GeV}$

$\mu_r = E_T$



$\Longrightarrow$ data described by NLO pQCD over whole range of E_T and Q^2

QCD analyses of the data

Studies of high E_T jet production show:

NLO pQCD calculations not predictive at $Q^2 < 100\,\mathrm{GeV}^2$

at $Q^2 > 200\,\mathrm{GeV}^2$:
– small NLO corrections
– small renormalization scale dependence
– small non-perturbative corrections

$\Rightarrow$ perform quantitative studies at high Q^2

<u>three analysis strategies:</u>

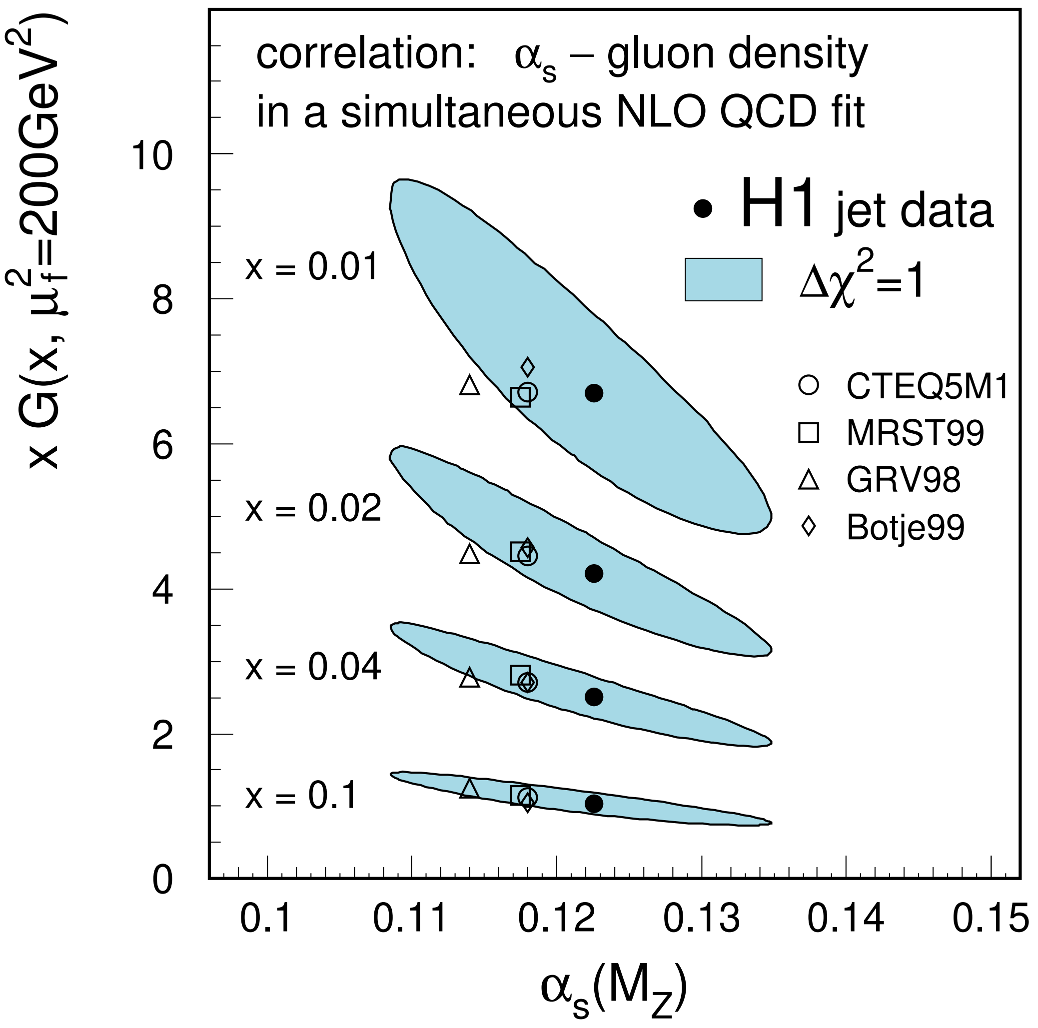
- attempt to fit everything simultaneously:
  $\alpha_s(M_Z)$, the gluon, and the quark densities

- take external knowledge of proton pdfs
  $\Rightarrow$ determine α_s

- take world average value of $\alpha_s(M_Z)$
  $\Rightarrow$ extract the gluon and the quark densities in the proton

simultaneous: $\alpha_s(M_Z)$ and $xg(x)$

inclusive DIS cross section $d^2\sigma_{\text{DIS}}/dQ^2\,dx_{\text{Bj}}$
dijet cross section $d^2\sigma_{\text{dijet}}/d\xi\,dQ^2$
inclusive jet cross section $d^2\sigma_{\text{jet}}/dE_T\,dQ^2$

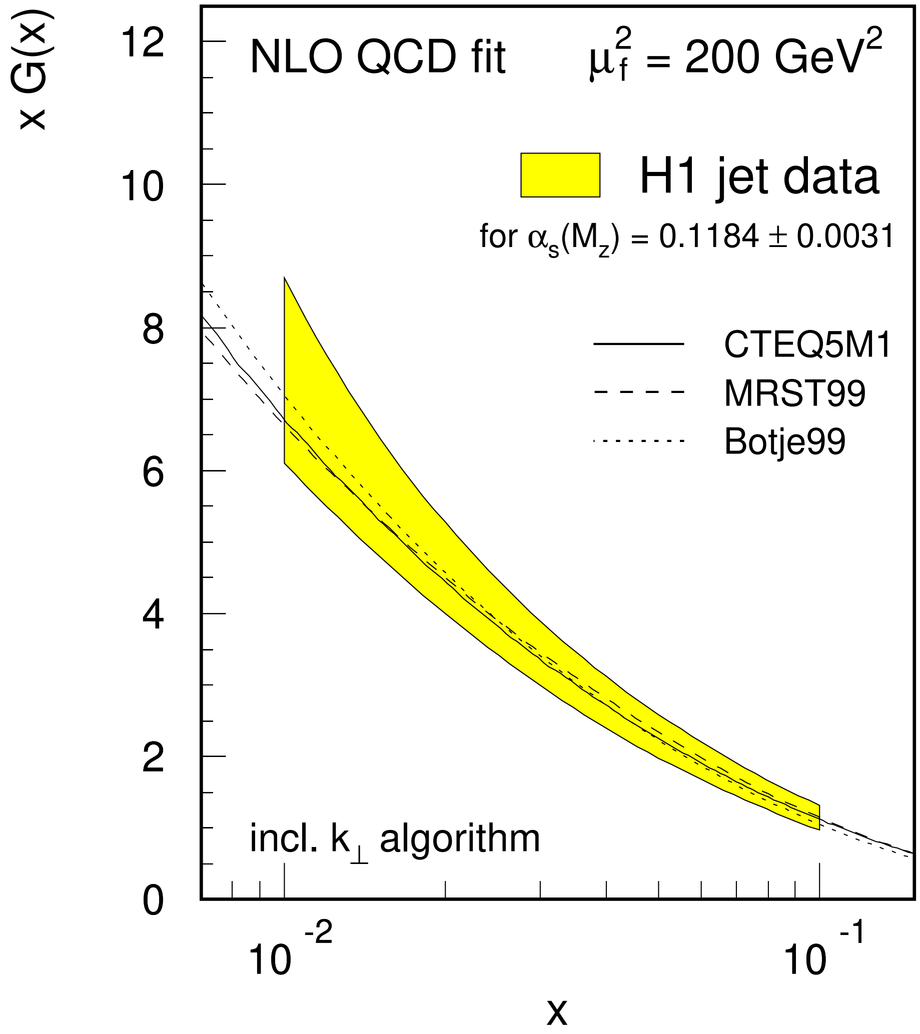


large anticorrelation between α_s and gluon visible

currently small sensitivity to both single parameters
but reasonable sensitivity to product

the gluon density from jet data

inclusive DIS cross section	$d^2\sigma_{\mathrm{DIS}}/dQ^2\,dx_{\mathrm{Bj}}$
dijet cross section	$d^2\sigma_{\mathrm{dijet}}/d\xi\,dQ^2$
inclusive jet cross section	$d^2\sigma_{\mathrm{jet}}/dE_T\,dQ^2$



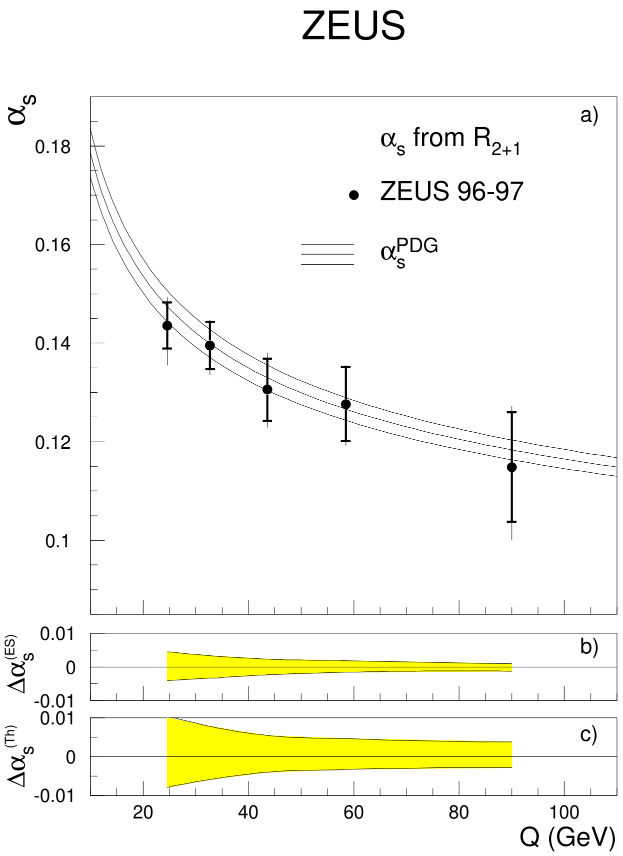
$\Rightarrow$ direct determination from jets at $0.01 < x < 0.1$

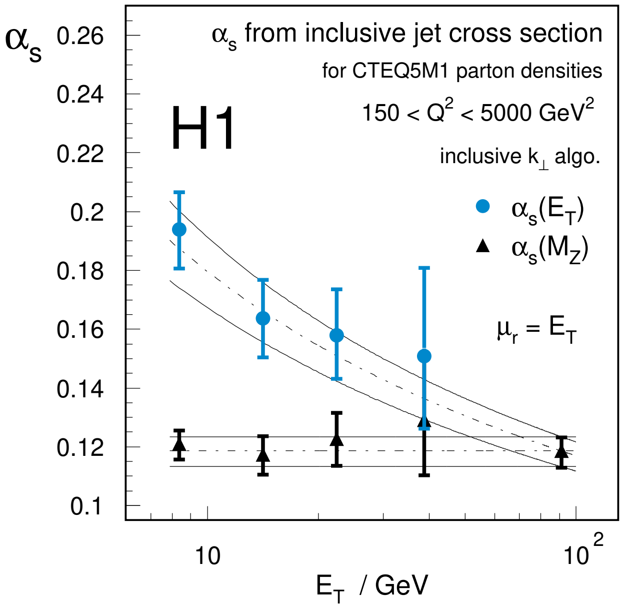
consistent with results from global fits

$\Rightarrow$ universality of gluon density

determination of α_s

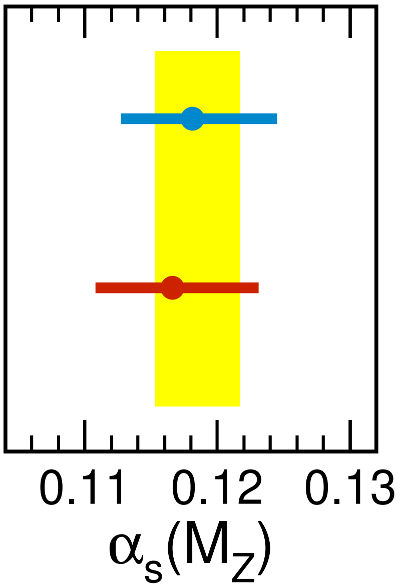
ZEUS: $\mu_r = Q$ – use Q^2 dependence of dijet rate
H1: $\mu_r = E_T$
– use E_T dependence of inclusive jet cross section





$\Longrightarrow$ energy dependence of $\alpha_s(\mu_r)$ consistent with prediction of renormalization group equation

α_s from Jet Production in DIS at HERA



H1 – Inclusive Jet Cross Section
$150 < Q^2 < 5000\ \mathrm{GeV}^2$ / $\mu_r = E_T$

ZEUS – Dijet Rate
$470 < Q^2 < 20000\ \mathrm{GeV}^2$ / $\mu_r = Q$

World average
(S. Bethke, J.Phys. G26 (2000) R27)

	H1	ZEUS	
$\alpha_s(M_Z)$	0.1186	0.1166	
(exp.)	± 0.0030	$^{+0.0031}_{-0.0038}$	
(th.)	$^{+0.0039}_{-0.0045}$	$^{+0.0055}_{-0.0043}$	($\leftarrow$ limiting)
(pdf)	$^{+0.0033}_{-0.0023}$	$^{+0.0012}_{-0.0011}$	($\leftarrow$ minor)

$\Longrightarrow$ consistent new $\alpha_s(M_Z)$ determinations from jets by HERA experiments

small errors $\longrightarrow$ impact on world average value

summary: jet production in DIS

- high E_T jet data in DIS – new level of precision covering large range of Q^2: $5 < Q^2 < 20000\,\mathrm{GeV}^2$

- at $Q^2 < 100\,\mathrm{GeV}^2$ $\quad (E_T^2 > Q^2)$:
  large differences between $\mu_r = E_T$ and $\mu_r = Q$
  $\mu_r = Q$ reasonable descr. – but: large μ_r dependence
  $\mu_r = E_T$: typically too low — but o.k. at higher E_T

- at $Q^2 > 200\,\mathrm{GeV}^2$:
  jet data well described by NLO pQCD with small theoretical uncertainties $\Longrightarrow$ quantitative QCD tests

- QCD results
  - simultaneous, direct determination of α_s and the gluon density in the proton
  - determinations of α_s:
    running according to RGE — $\alpha_s(M_Z)$ consistent with world average
  - extracted gluon density in $0.01 < x < 0.1$
    good agreement with results from global analyses