The Strong Coupling and the Gluon Density from Jets in DIS
(Results from H1)

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- **Analysis strategies**
- **Jet measurements: inclusive jet and dijet cross sections**
- **Results**
- **Discussion/Outlook**

Jet Cross Sections in DIS

$$\sigma_{jet} = \sum_n \alpha_s^n(\mu_R) \int_0^1 dx \, \{ \quad c_{g,n}\left(\frac{x_{Bj}}{x}, \frac{\mu_{hard}}{\mu_R}, \frac{\mu_{hard}}{\mu_F}\right) g(x, \mu_F)$$

$$+ \sum_f c_{f,n}\left(\frac{x_{Bj}}{x}, \frac{\mu_{hard}}{\mu_R}, \frac{\mu_{hard}}{\mu_F}\right) q(x, \mu_F)\}$$

set: $\mu_R \simeq \mu_{hard} = E_{T,\,\text{jet, Breit}}$ and $\mu_F = \overline{E}_{T,\,\text{jet, Breit}} = \sqrt{200}$ GeV

- **Analysis strategy 1:** fit α_s , $g(x)$, and $q(x)$
  data used: inclusive jet, dijet and inclusive DIS cross sections

- **Analysis strategy 2:** fit $g(x)$ and $q(x)$
  data used: as above and $\alpha_s(M_Z)$ = 0.1184 $\pm$ 0.0031 (S.Bethke)

- **Analysis strategy 3:** fit α_s only
  data used: inclusive jet cross sections and global pdfs

Requirements on Jet Measurements for Comparison with QCD

- Factorization
  Universal factorizability of initial state divergences for inclusive cross sections.
  Holds also for jet cross sections, if a factorizable jet algorithm is used, typically in the Breit frame.

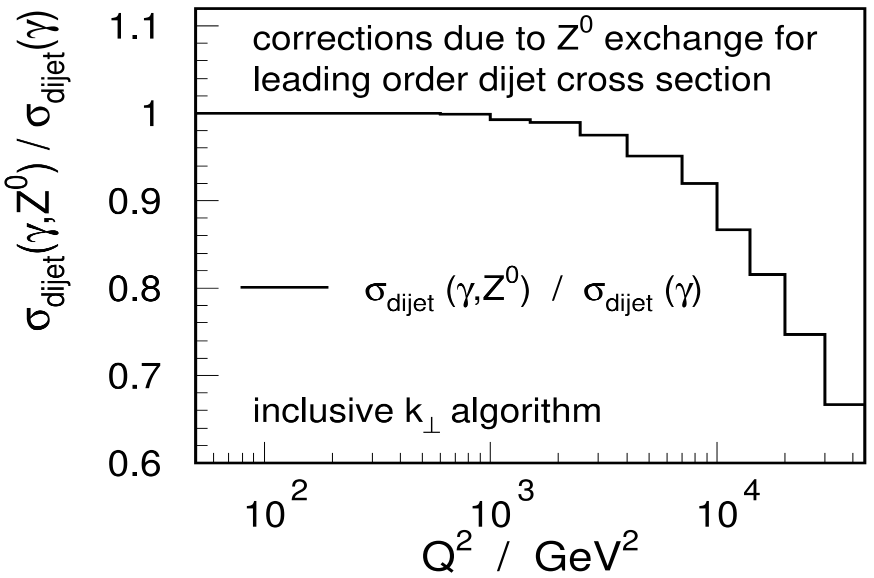
- Infrared and collinear safe jet defintion

- Small hadronization corrections

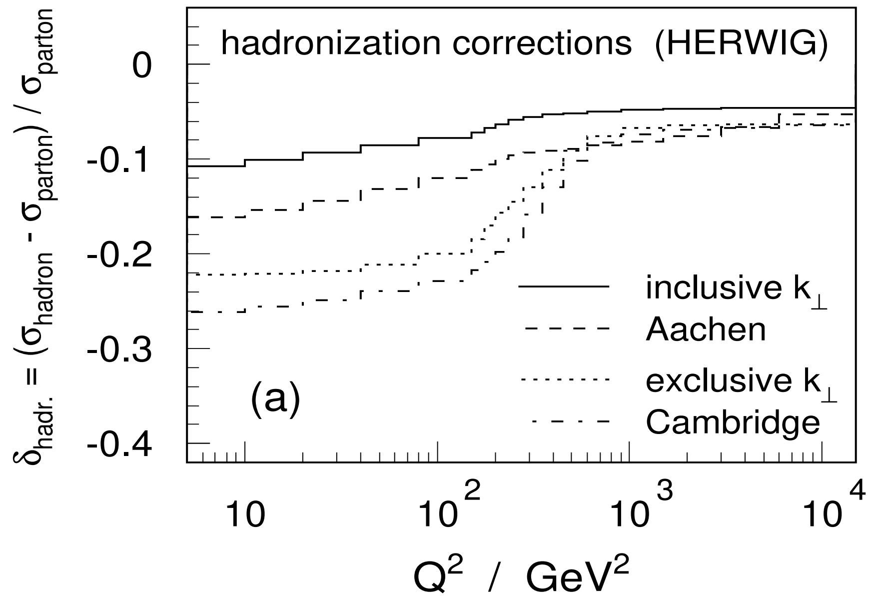
$\Rightarrow$ Inclusive $\boldsymbol{k}_\perp$ jet algorithm in the Breit frame

Requirements on Analysis Phase Space of Data

- Negligible contribution from Z^0 exchange



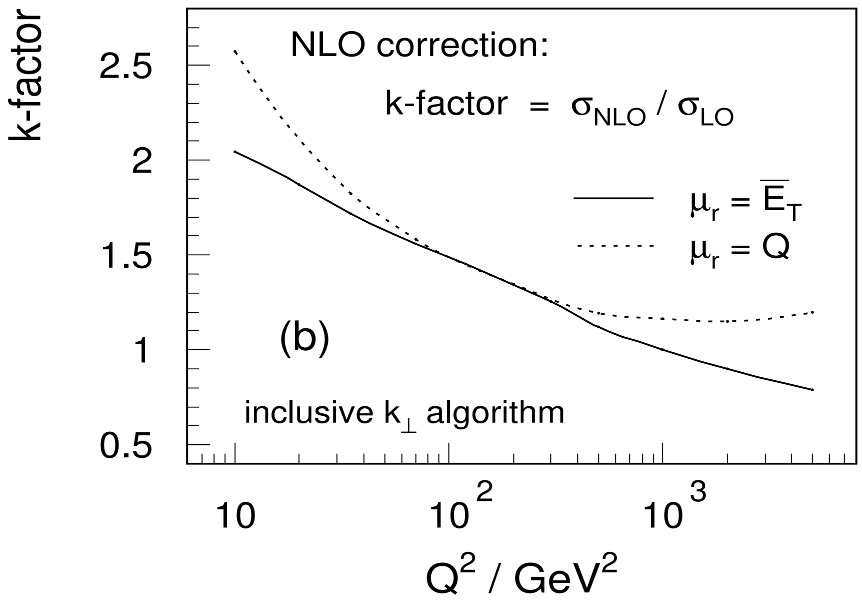
- Small hadronization corrections



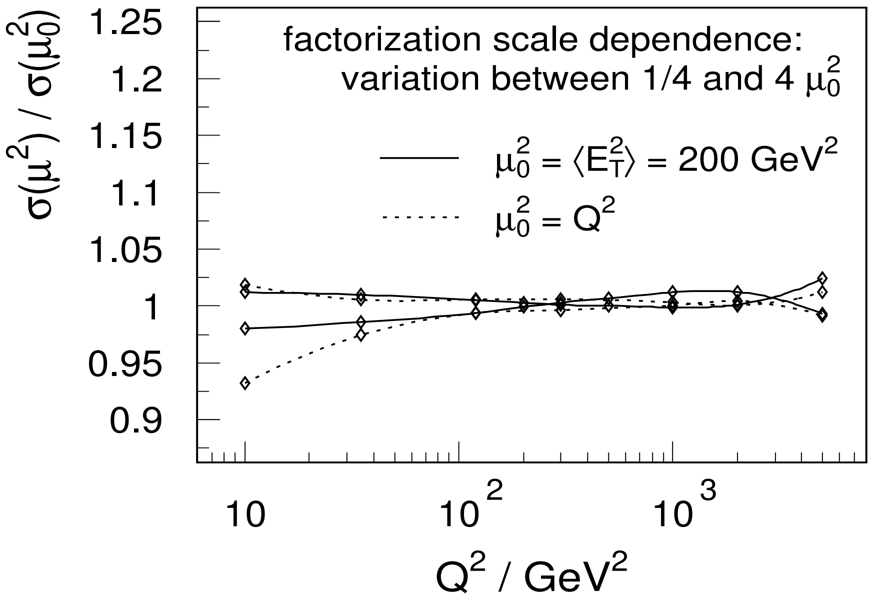
$$\Rightarrow 150 \le Q^2 \le 5000 \text{ GeV}^2$$

Requirements on Analysis Phase Space of Data

- Not too large k-factors (correlated with μ_R scale uncertainty

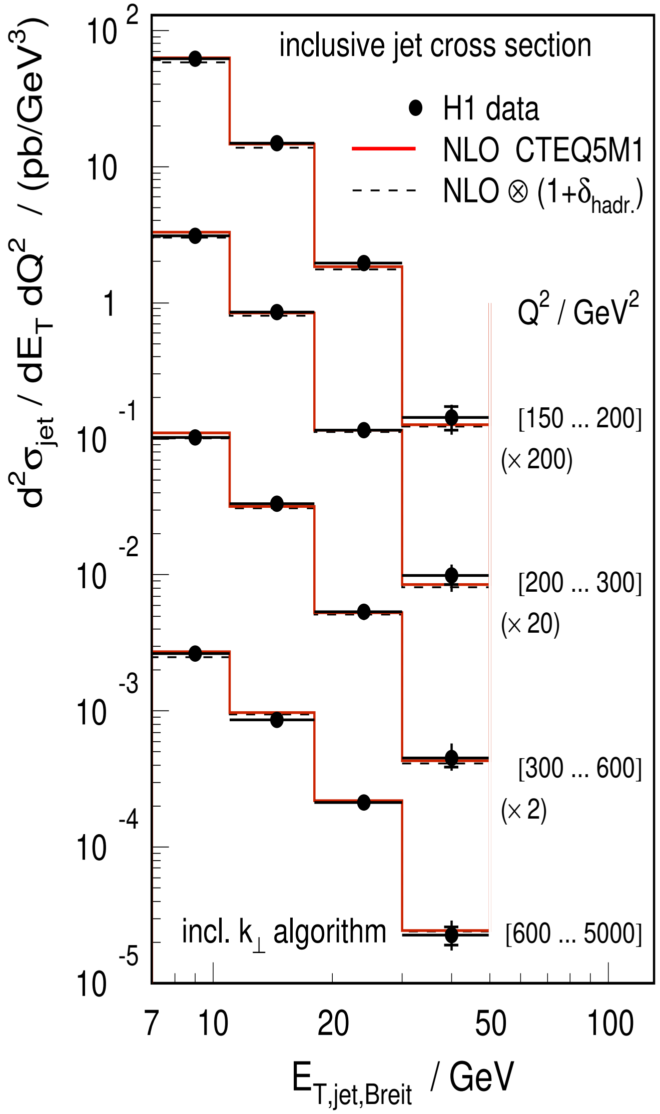


- Little μ_F scale uncertainty

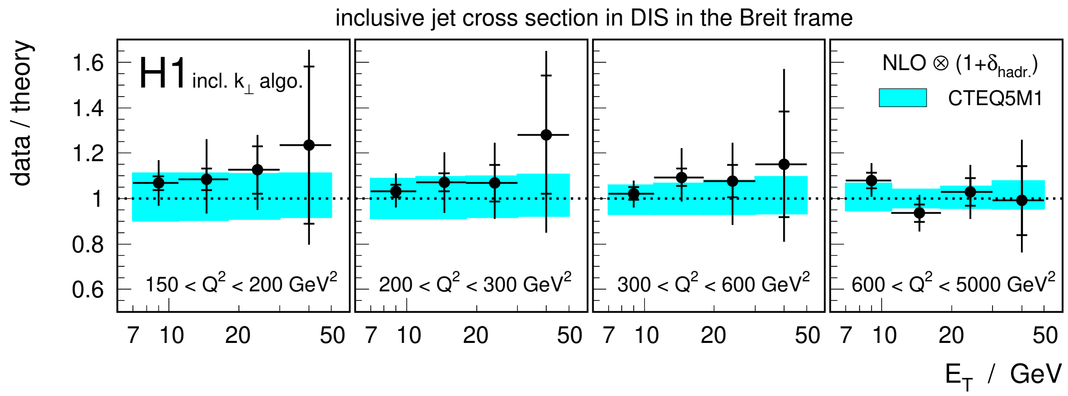


$$\Rightarrow 150 \le Q^2 \le 5000 \text{ GeV}^2$$

Inclusive Double Differential Jet Cross Sections
$\sigma_{\text{jet}}(Q^2, E_T)$

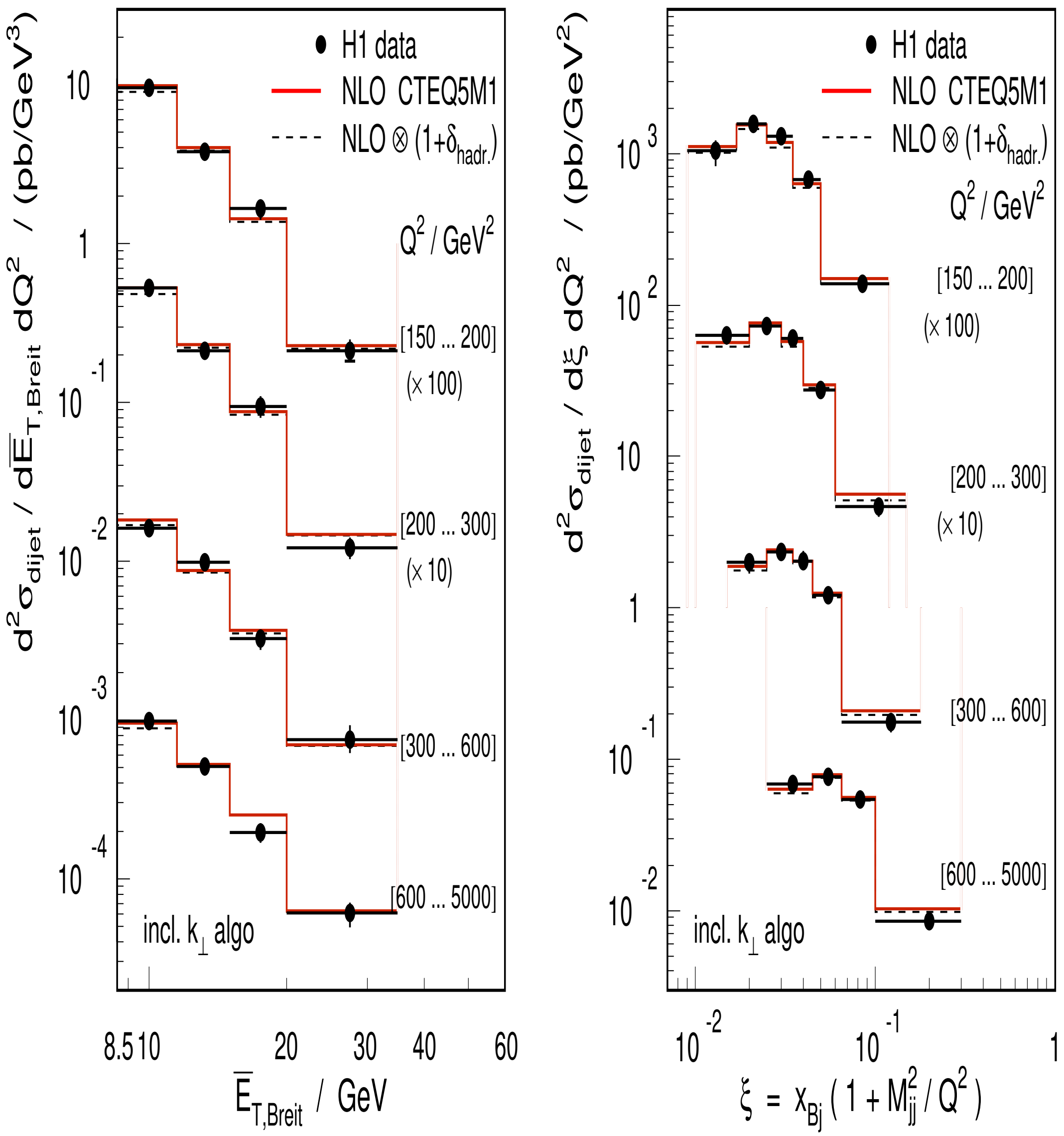


- $150 < Q^2 < 5000$ GeV^2
- $7 < E_{T,\,\text{jet, Breit}} < 50$ GeV
- $\mu_r = E_{T,\,\text{jet, Breit}}$



⇒ Data well described by NLO QCD over whole range in Q^2 and $E_{T,\,\text{jet, Breit}}$

Double Differential Dijet Cross Sections

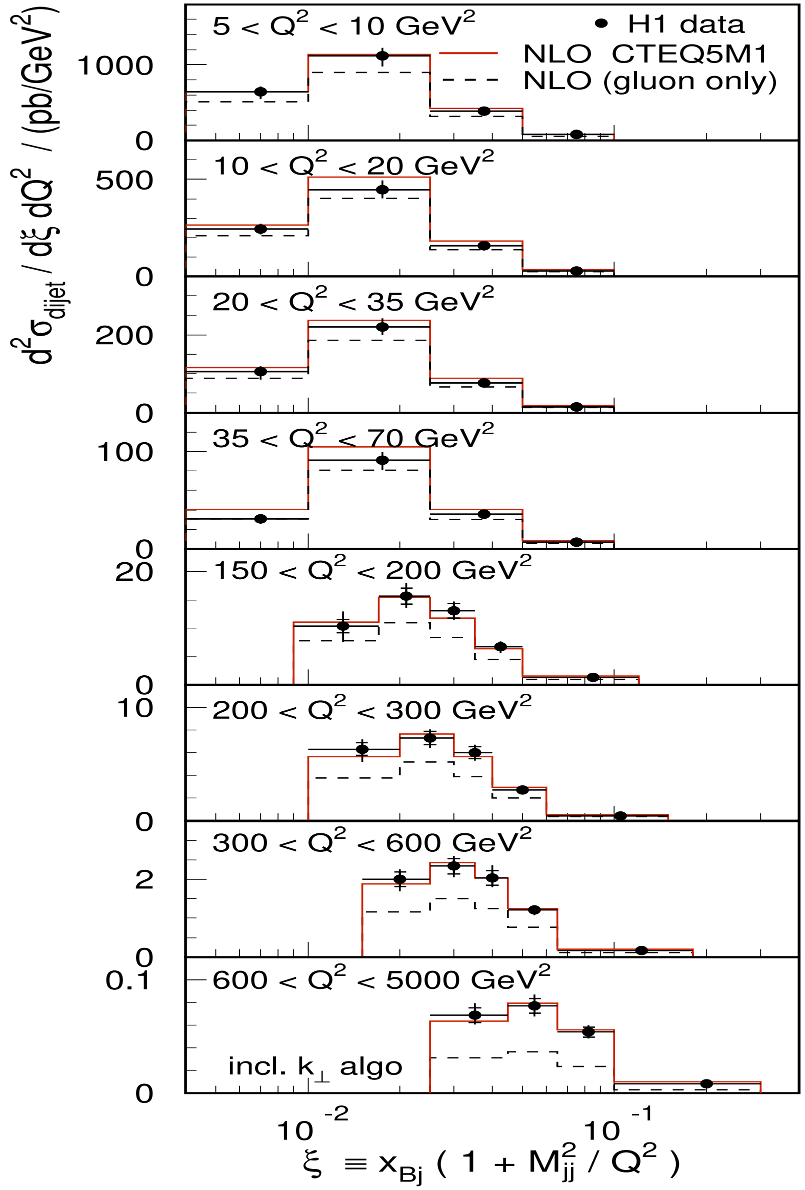


- Small NLO and hadronization corrections for $E_{T,\,1,\,2} > 5$ GeV and $\overline{E}_T > 17/2$ GeV

- Parton momentum fraction $\xi = x_{\text{Bj}}\,(1 + M^2_{jj}/Q^2)$, in LO directly sensitive to parton density at $x = \xi$

$\Rightarrow$ Data well described by NLO QCD, gluon decreasing with Q^2; sensitive to partons with $0.009 < \xi < 0.3$

Double Differential Dijet Cross Sections - Low and High Q^2



- NLO gives reasonable description of data also at low Q^2

- Gluon induced contributions vary from $\approx 80\%$ at low Q^2 to $\approx 40\%$ at the highest Q^2

Linear-Combinations of Parton Density Functions in DIS

Inclusive DIS:

$$\tilde{\sigma}_{\mathrm{incl.\,DIS}} \quad \propto \quad \Delta$$

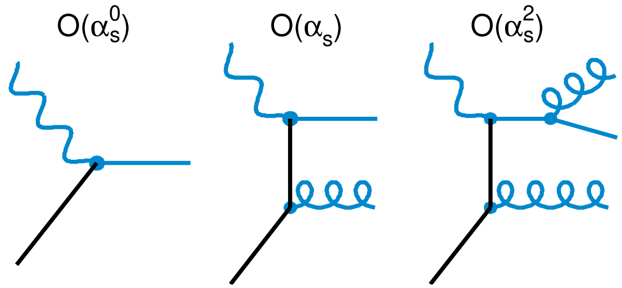
Jets in DIS:

$$\sigma_{\mathrm{jet}}(x,\, \mu_R) \quad \propto \quad \alpha_s \cdot (c_g\, g \,+\, c_\Delta\, \Delta)$$

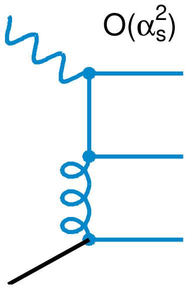
$$\sigma'_{\mathrm{jet}}(x',\, \mu'_R) \quad \propto \quad \alpha_s \cdot (c'_g\, g \,+\, c'_\Delta\, \Delta)$$

$\Rightarrow$ Only two pdfs: quark-Δ and gluon

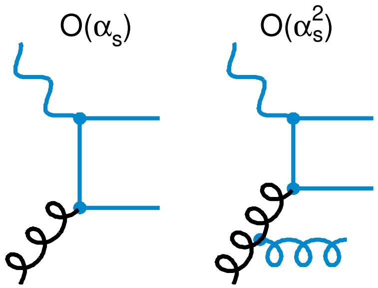
Delta:
$x\,\Delta(x) \equiv x\, \sum_f e_f^2\, (q_f(x) + \bar{q}_f(x))$
inclusive DIS: LO and NLO
jet production: LO and NLO



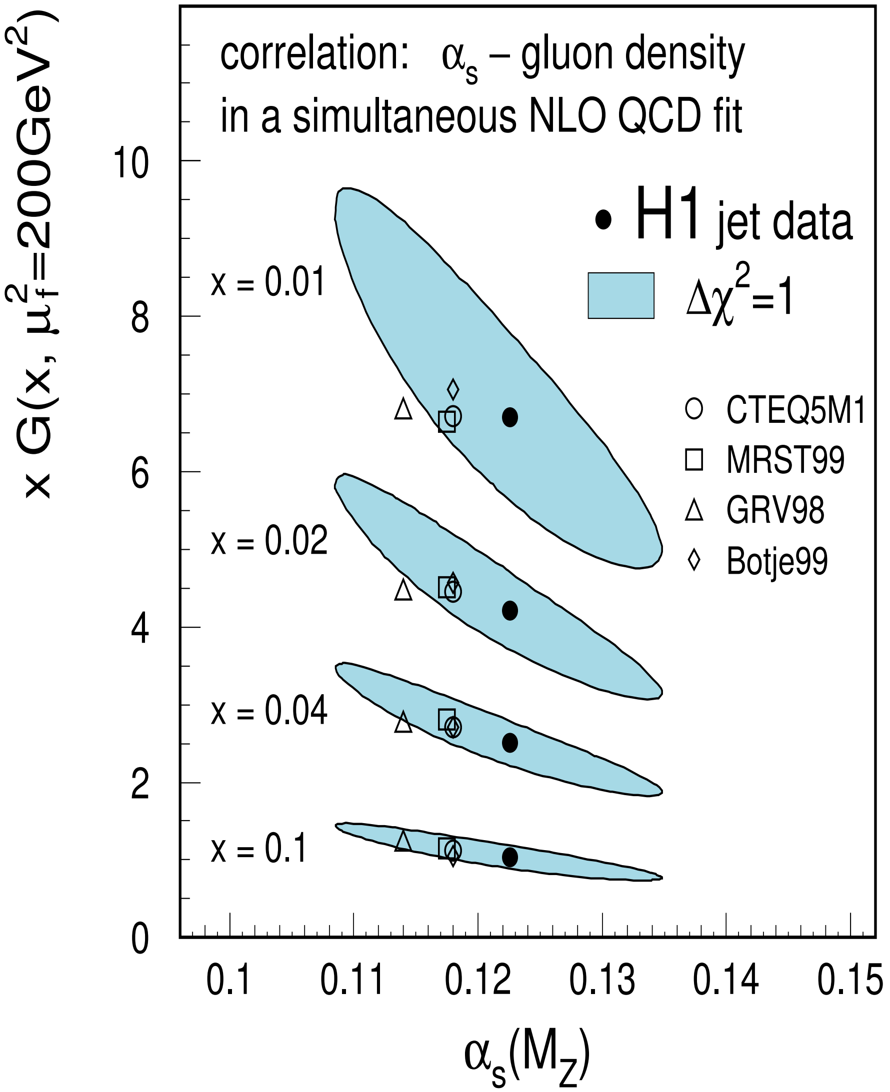
Sigma: $x\,\Sigma(x) \equiv x\, \sum_f (q_f(x) + \bar{q}_f(x))$
(inclusive DIS: NNLO)
jet production: NLO



Gluon: $x\,G(x) \equiv x\, g(x)$
inclusive DIS: NLO
jet production: LO and NLO

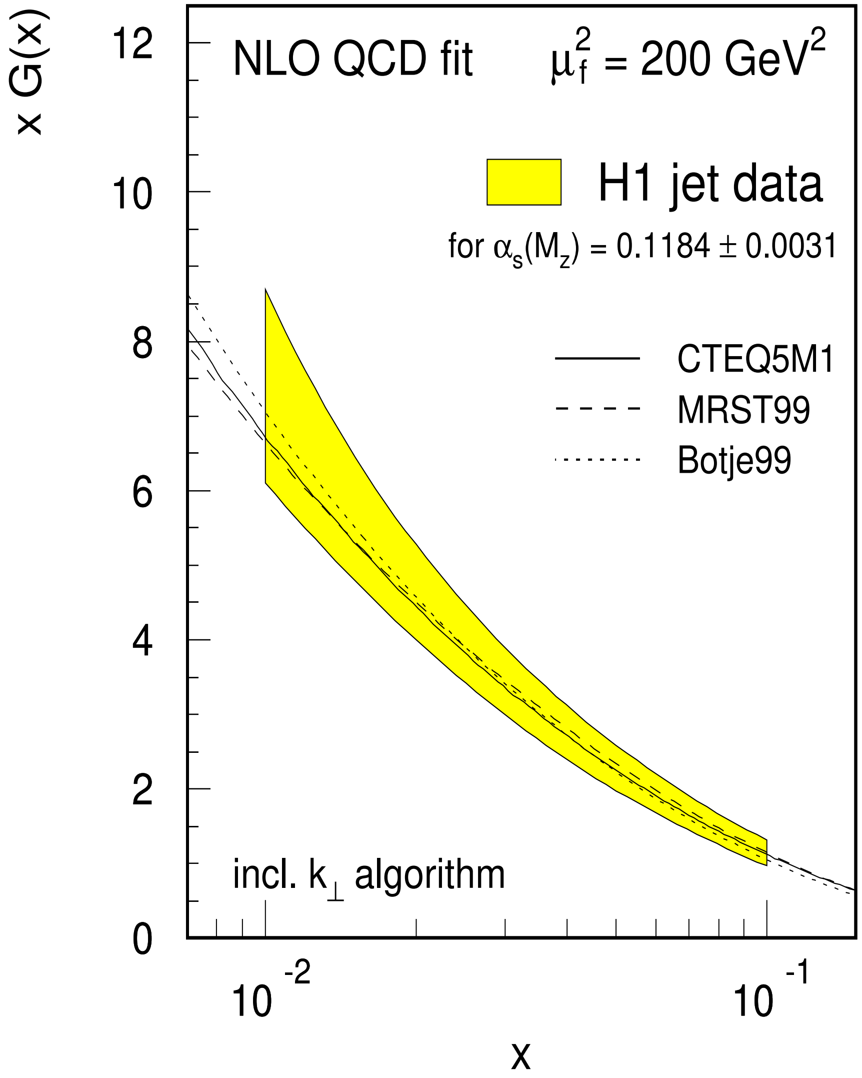


Determination of $\alpha_s(M_Z)$ and $xg(x)$



- Large anti-correlation between $\alpha_s(M_Z)$ and $xg(x)$
- Sensitivity to $\alpha_s(M_Z)$ $xg(x)$
- Currently little sensitivity to each single parameter
- Results on $\alpha_s(M_Z)$ $xg(x)$ are consistent with global fits

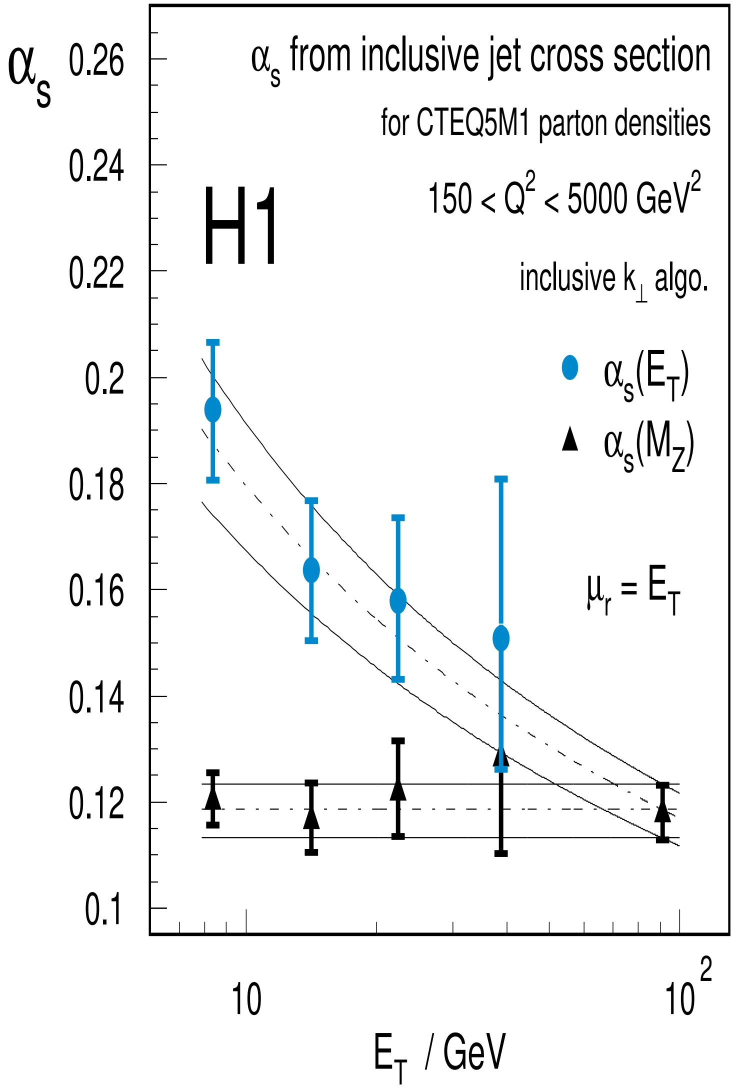
Determination of $xg(x)$



- Jet cross sections directly sensitive to $xg(x)$ and $xq(x)$
- Inclusive DIS (F_2) directly sensitive to $xq(x)$ only
- $\alpha_s(M_Z) = 0.1184 \pm 0.0031$

Direct determination from jets at $0.01 < x < 0.1$ is consistent with results from global fits

Determination of $\alpha_s(M_Z)$



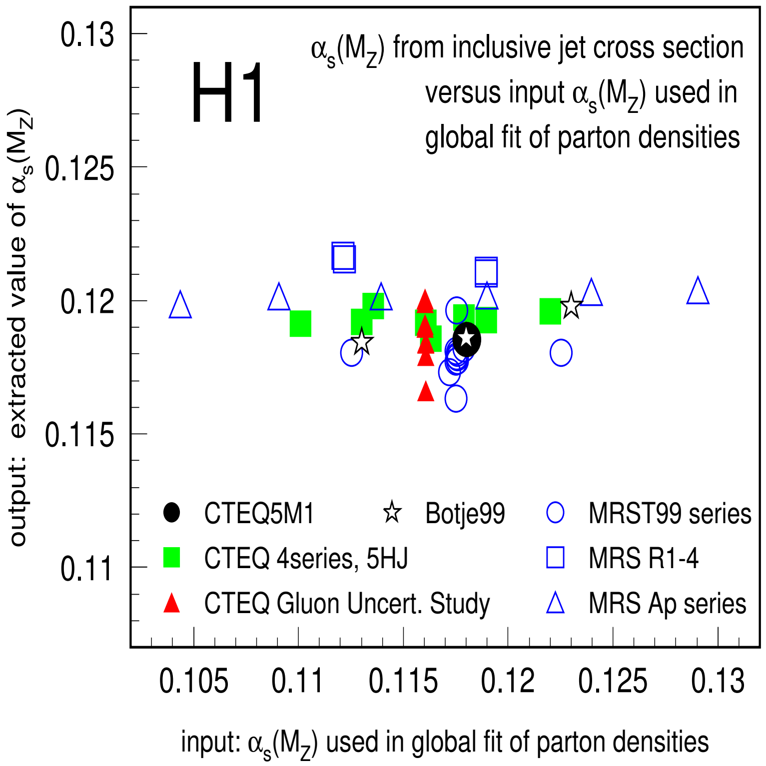
- Central pdf: CTEQ5M1
- Data: $d^2\sigma_{\text{jet}}/dE_T dQ^2$

$$\alpha_s(M_Z) = 0.1186 \pm 0.0030 \text{ (exp.) } {}^{+0.0039}_{-0.0045} \text{ (th.)}$$

- Experimental error:
  - stat. error $= 0.0007$
  - largest syst. error due to hadronic energy scale uncertainty
- Theory error:
  - hadronization uncertainty ≈ 0.0030
  - μ_R scale uncertainty ≈ 0.0030

Running of $\alpha_s(E_T)$ consistent with RGE

Uncertainty in $\alpha_s(M_Z)$ due to Parton Distributions

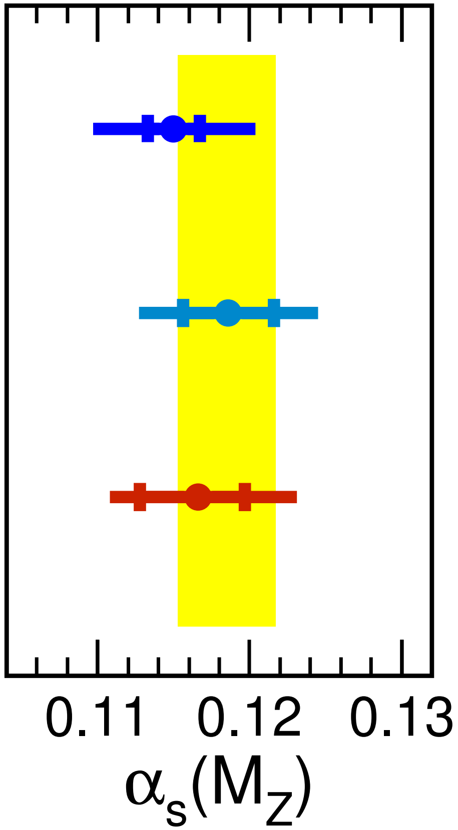


- Study dependence of $\alpha_s(M_Z)$ result on the $\alpha_s(M_Z)$ of the pdf by repeating QCD fit with all recent global pdfs
- Evaluate uncertainty of $\alpha_s(M_Z)$ using the uncertainties of the pdfs determined recently by Botje.
  - includes stat. and syst. errors of the DIS data used in the fit
  - includes syst. errors due to different fit assumptions

$$\Rightarrow \Delta^{pdf}\alpha_s(M_Z) = \pm 0.0019 \text{ (stat.+exp.)} \oplus {}^{+0.0027}_{-0.0013} \text{ (fit syst.)}$$

$$\boxed{\alpha_s(M_Z) = 0.1186 \pm 0.0030 \text{ (exp.)} {}^{+0.0039}_{-0.0045} \text{ (th.)} {}^{+0.0033}_{-0.0023} \text{ (pdf)}}$$

$\alpha_s(M_Z)$ from Jets and F_2 in DIS at HERA



(H1+BCDMS) Structure Functions
$3.5 < Q^2 < 3000\ \mathrm{GeV}^2$ / $\mu_r = Q$

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)

⇒ Consistent new determinations of $\alpha_s(M_Z)$ from jets and from inclusive DIS at HERA

⇒ Small errors allow impact on world average value

Discussion and Outlook: α_s from Jets

	H1	ZEUS
$\alpha_s(M_Z)$	0.1186 ± 0.0059	0.1166 ${}^{+0.0064}_{-0.0058}$
(stat.)	$\pm \mathbf{0.0007}$	$\pm \mathbf{0.0019}$
(exp.)	$\pm \mathbf{0.0030}$	${}^{+\mathbf{0.0031}}_{-\mathbf{0.0038}}$
(th.)	${}^{+\mathbf{0.0039}}_{-\mathbf{0.0045}}$	${}^{+\mathbf{0.0055}}_{-\mathbf{0.0043}}$
(had.)	± 0.0029	± 0.0005
(μ_R)	${}^{+0.0026}_{-0.0034}$	${}^{+0.0055}_{-0.0042}$
(pdf)	${}^{+\mathbf{0.0033}}_{-\mathbf{0.0023}}$	${}^{+\mathbf{0.0012}}_{-\mathbf{0.0011}}$

- Stat. error smaller for H1 because of smaller Q^2
- Exp. error dominated by uncertainty of hadronic energy scale
- Hadronization error quite different between the two experiments
- Renormalization scale dependence smaller for H1
- Uncertainty due to PDF smaller for ZEUS because of cancellations in $R_2 = \sigma_{\text{dijet}}/\sigma_{\text{DIS}}$

Discussion and Outlook: α_s from Jets

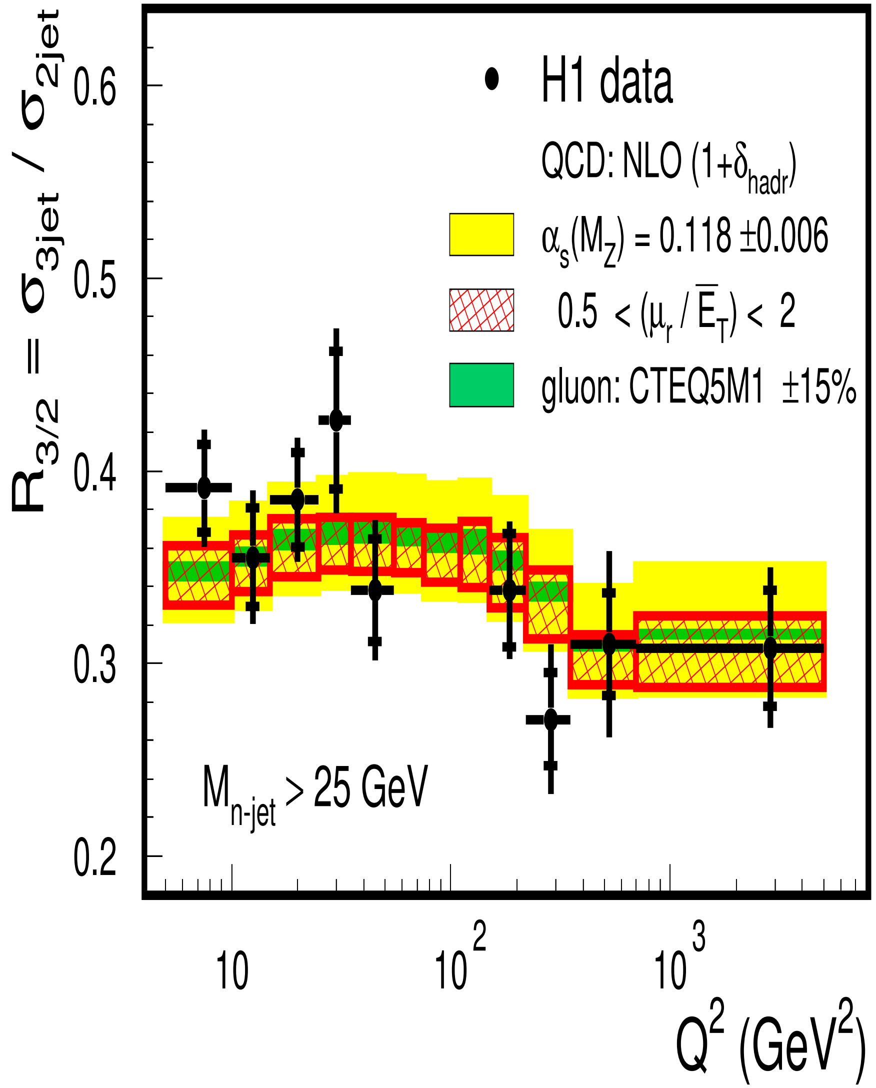
How to improve experimentally?

- Hadronic energy scale calibration
- Optimum requirement on $E_{T,\mathrm{min}}$
- Uncertainty of hadronization correction
- Large jet statistics at lower Q^2
- Reduction of pdf uncertainty

How to improve theoretically?

- NNLO QCD calculations for jets
- Resummed calculations matched to NLO for low Q^2, where $E_T^2 >> Q^2$
- Reduced scale dependence in pdf parameterizations from NNLO QCD fits

Discussion and Outlook: α_s from Jets



Measurement of $R_{3/2} = \frac{\sigma_{3-jet}}{\sigma_{2-jet}}$

- Same cut on $M_{n-jet} > 25$ GeV probes pdfs at same x
- $\rightarrow$ Cancellation of pdf uncertainties

$\Rightarrow$ Good sensitivity to α_s

More details in talk by M.Wobisch in HI WG.

Summary

- Inclusive jet and dijet cross sections for $150 < Q^2 < 5000\,\text{GeV}^2$ and $7 < E_T < 50$ GeV are well described by NLO QCD.

- QCD fits for $\alpha_s(M_Z)$ and $xg(x)$, using jet and inclusive DIS cross sections, show strong anti-correlation.

- QCD fits for $xg(x)$, using jet and inclusive DIS cross sections and world average for $\alpha_s(M_Z)$, allow to extract $xg(x)$ in $0.01 < x < 0.1$ in good agreement with results from global analyses.

- QCD fits for $\alpha_s(M_Z)$ alone, using jet cross sections and pdfs from global parameterizations, yield: $\boxed{\alpha_s(M_Z) = 0.1186 \pm 0.0059 \text{ (tot.)}}$

  Good agreement with the world average. Observed E_T dependence agrees with RGE. Competitive with other measurements.

- With lumi upgrade of HERA II *and* progress in theory, we can expect to further decrease the error on $\alpha_s(M_Z)$.