Measurement of Multijet Production in *ep* Collisions at High Q^2 and Determination of the Strong Coupling α_s

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on behalf of the H1 collaboration

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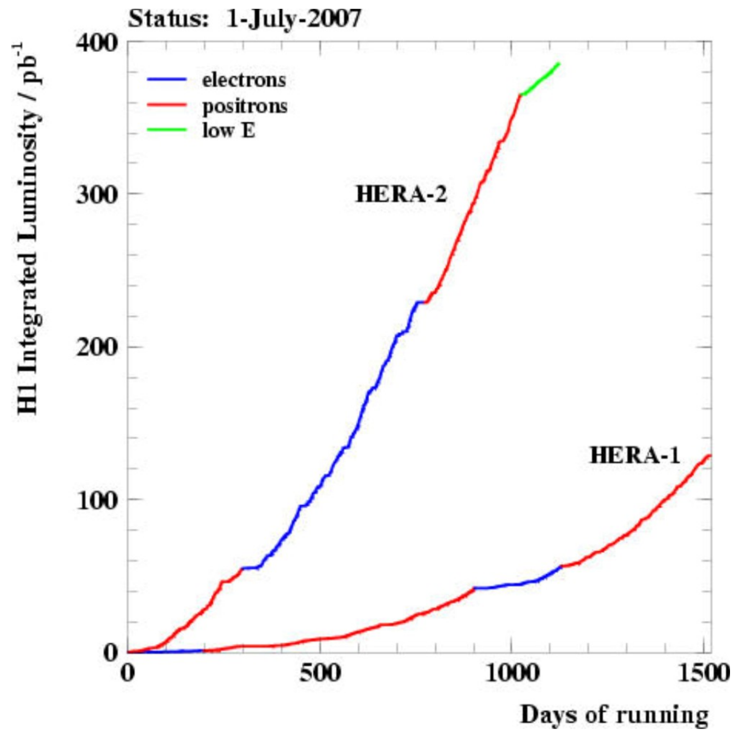
Introduction

HERA was the worlds only $e^{\pm}p$ collider



e$^{\pm}$(27.5 GeV), **p**(460-920 GeV)

centre of mass energy:

$\sqrt{s}$ = 225-318 GeV

Two running periods:

1994-2000: **HERA I data**
2003-2007: **HERA II data**

Two collider experiments: **H1** and **ZEUS**

~0.5 fb^{-1} of luminosity recorded by each experiment

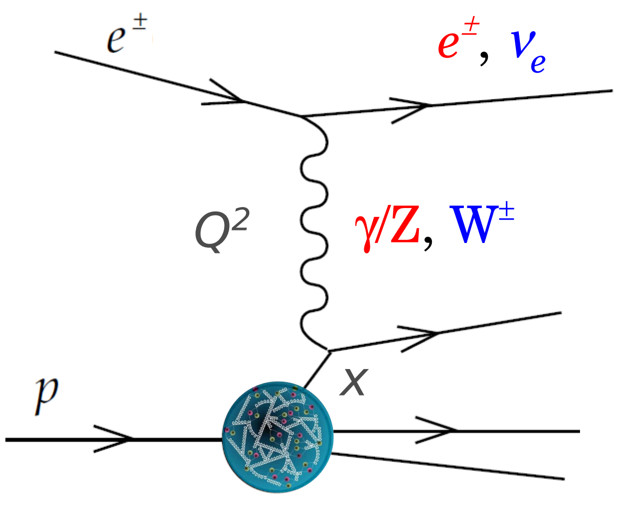
Deep Inelastic Scattering (DIS)

Deep Inelastic Scattering (DIS) at HERA

→ provides unique opportunity to study the structure of the proton

Neutral Current (NC): $ep \to eX$

Charged Current (CC): $ep \to \nu X$



Kinematics:

Q^2 - virtuality of exchanged boson

x – Bjorken scaling variable

y – inelasticity

$Q^2 = sxy$ ($\sqrt{s}$ centre-of-mass energy)

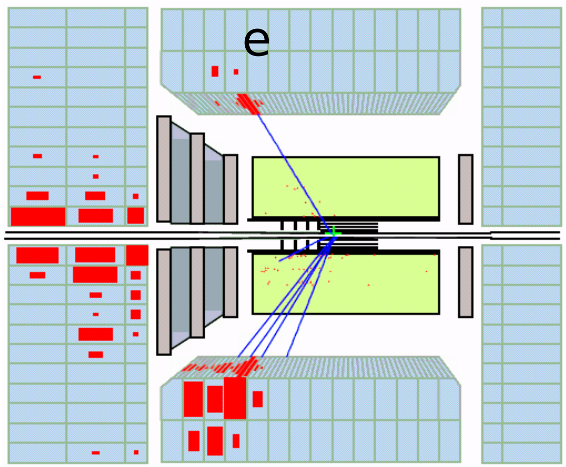
Cross section: a convolution of the PDFs and perturbatively calculable hard-scattering coefficients

$$\sigma = \hat{\sigma} \otimes \text{PDF}$$

ep Scattering at HERA

DIS Neutral and Charged Current cross sections:

Neutral Currents



$$\frac{d^2\sigma_{NC}^{e^\pm p}}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[Y_+ \tilde{F}_2^\pm \mp Y_- x\tilde{F}_3^\pm - y^2 \tilde{F}_L^\pm\right]$$

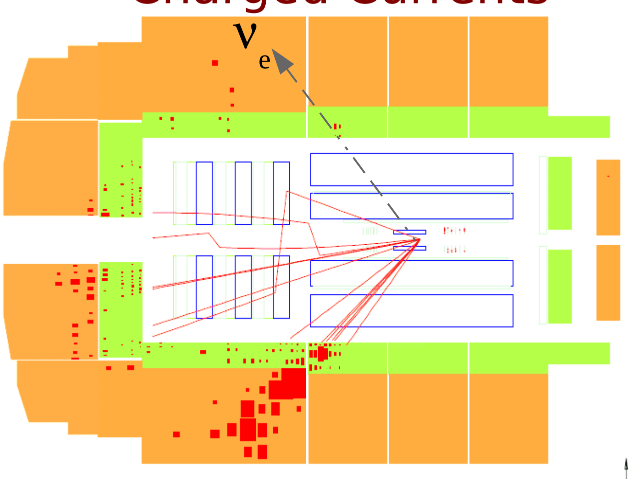
dominant contribution

important at high Q^2

sizable at high y

$$Y_\pm = 1 \pm (1-y)^2$$

Charged Currents



LO: $F_2 \approx x\sum e_q^2 (q+\bar{q})$ (in NLO $(\alpha_s\, g)$ appears)

$xF_3 \approx x\sum 2e_q a_q (q-\bar{q})$

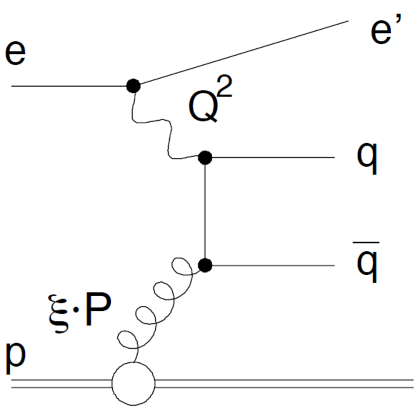
In LO e^+/e^- charged current cross sections are sensitive to different quark densities:

$$e^+: \quad \tilde{\sigma}_{CC}^{e^+p} = x[\bar{u}+\bar{c}] + (1-y)^2 x[d+s]$$

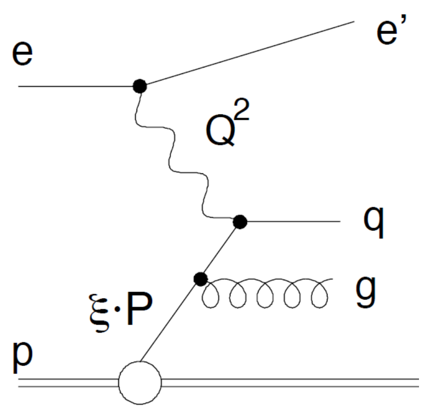
$$e^-: \quad \tilde{\sigma}_{CC}^{e^-p} = x[u+c] + (1-y)^2 x[\bar{d}+\bar{s}]$$

Jet production in NC DIS

Jet production in leading order pQCD:

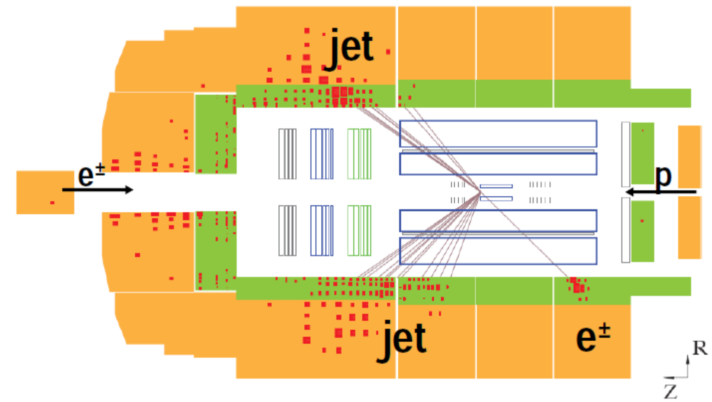


boson-gluon fusion



QCD Compton scattering

proton's longitudinal momentum fraction $\xi = x(1 + M_{12}^2 / Q^2)$

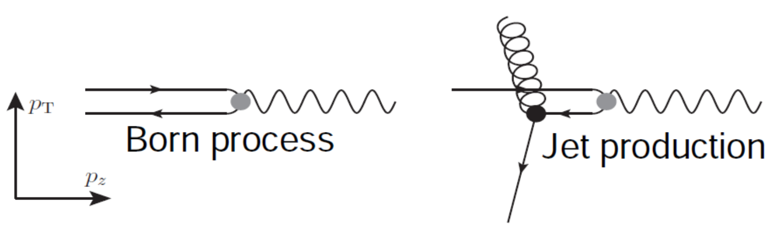


Jet reconstruction:

k_t and anti-k_t algorithms

H1 measurements performed in *Breit frame*

→ virtual boson collides head on with a parton form the proton



Inclusive jets:
measure transverse momentum P_T^{jet}

Dijet and trijets:
average of two/three leading jets

$$\langle P_T \rangle_2 = \frac{1}{2}(P_T^{jet1} + P_T^{jet2})$$

Multijet Production at High Q^2

Simultaneous measurement (351 pb^{-1}) of:

→ **inclusive jet, dijet and trijet cross sections**

and

→ **normalized inclusive jet, dijet and trijet cross sections**

normalization w.r.t. inclusive NC DIS (partial cancellation of experimental uncertainties)

	Extended analysis phase space	**Measurement phase space for jet cross sections**
NC DIS phase space	$100 < Q^2 < 40\,000\,\mathrm{GeV}^2$ $0.08 < y < 0.7$	$150 < Q^2 < 15\,000\,\mathrm{GeV}^2$ $0.2 < y < 0.7$
Jet polar angular range	$-1.5 < \eta^{\mathrm{jet}}_{\mathrm{lab}} < 2.75$	$-1.0 < \eta^{\mathrm{jet}}_{\mathrm{lab}} < 2.5$
Inclusive jets	$P^{\mathrm{jet}}_{\mathrm{T}} > 3\,\mathrm{GeV}$	$7 < P^{\mathrm{jet}}_{\mathrm{T}} < 50\,\mathrm{GeV}$
Dijets and trijets	$3 < P^{\mathrm{jet}}_{\mathrm{T}} < 50\,\mathrm{GeV}$	$5 < P^{\mathrm{jet}}_{\mathrm{T}} < 50\,\mathrm{GeV}$ $M_{12} > 16\,\mathrm{GeV}$

Note: the extended phase space is used to quantify migration effect in this way improving the precision of the measurement

Multijets at High Q^2: Measurement Procedure

Jet cross sections obtained using a regularised unfolding procedure

Multidimensional Regularised Unfolding:

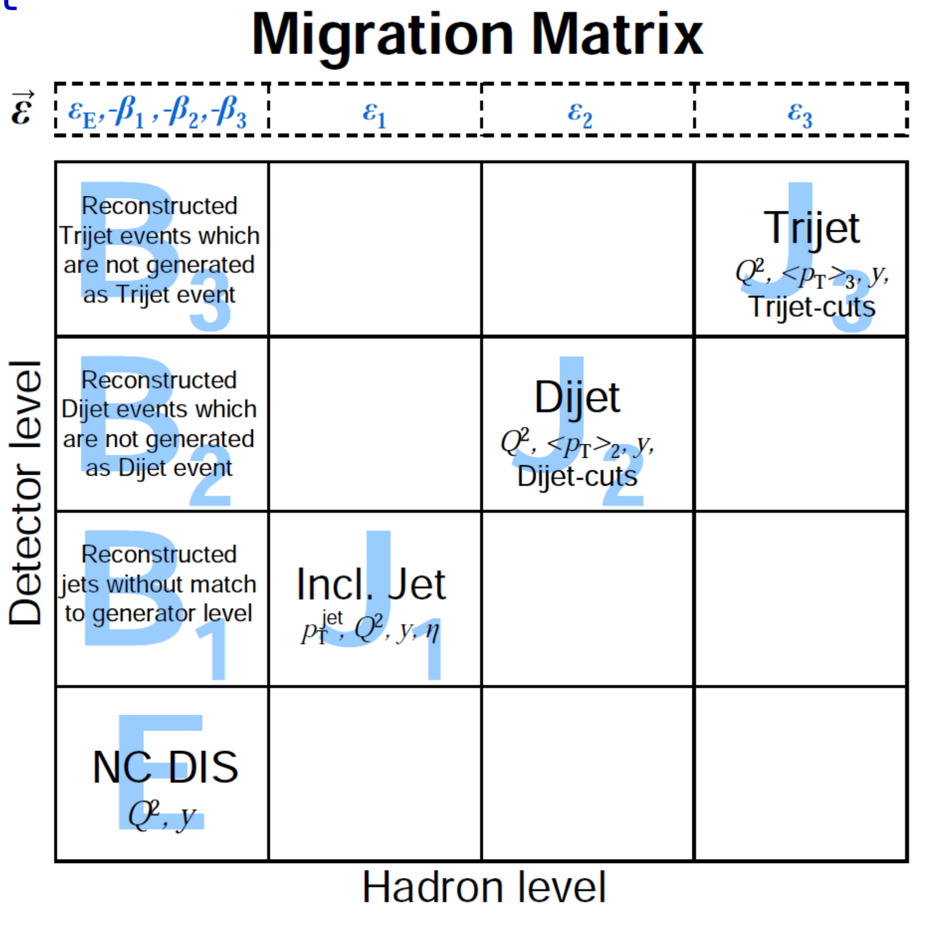
4 double-differential measurements unfolded simultaneously
→ NC DIS, inclusive jet, dijet and trijet

Using TUnfold tool

→ statistical correlations considered

→ enlarged phase space for migrations

→ up to 7 observables are considered for migrations



Multijets at High Q^2: Uncertainties

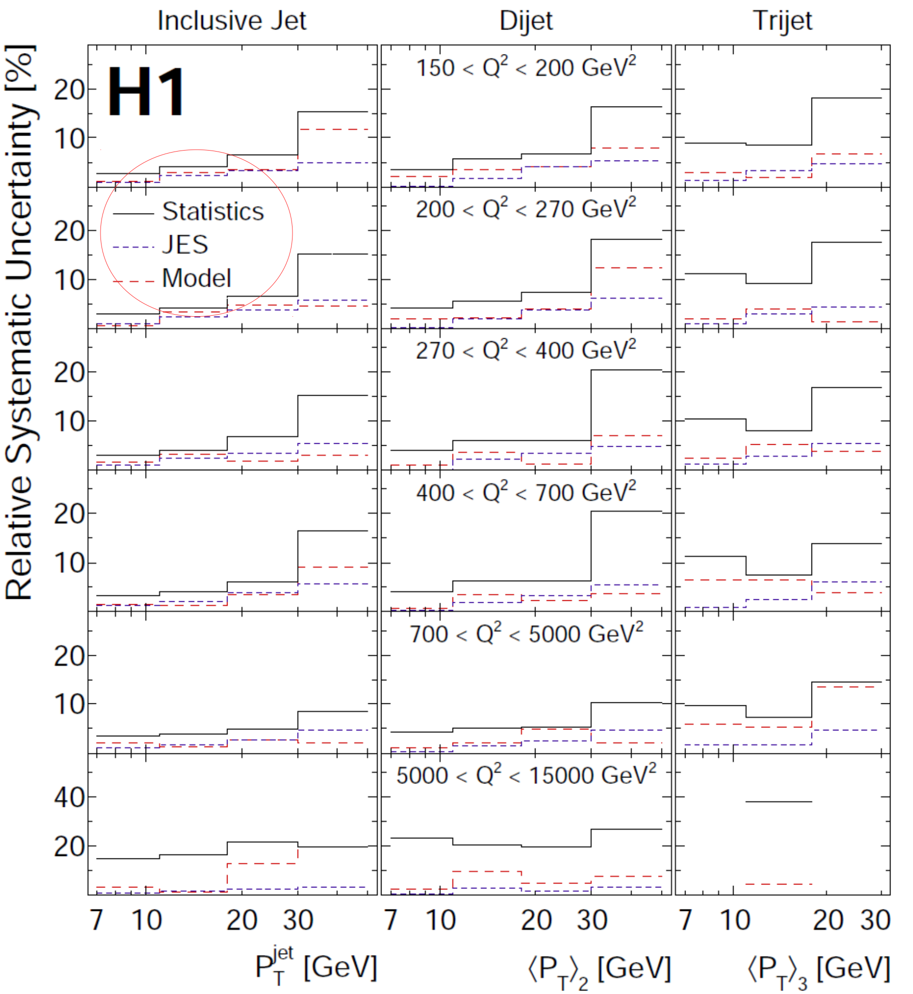
Main experimental uncertainties of the measurement:

→ improved electron calibration and the energy flow algorithm

- Hadronic Final State (HFS):
  → jet energy scale and
  → energy of HFS
  1% (up to 4% for trijets)
- model uncertainty
  → taking into account differences in migration matrices between data and theory (Django, Rapgap)

$$\delta^{\rm Model} = \pm\sqrt{\frac{1}{2}\left(\max\left(\delta^{\rm Model}_{\rm d,R}, \delta^{\rm Model}_{\rm p,R}\right)^2 + \max\left(\delta^{\rm Model}_{\rm d,D}, \delta^{\rm Model}_{\rm p,D}\right)^2\right)}$$

- E of scattered electron (0.5 – 2%) and identification (0.5 – 2%)
- luminosity (2.5%)
- etc



Multijets at High Q^2: Cross Sections

Theory (NLO) calculations:

NLOJet++ corrected for hadronisation and electroweak effects

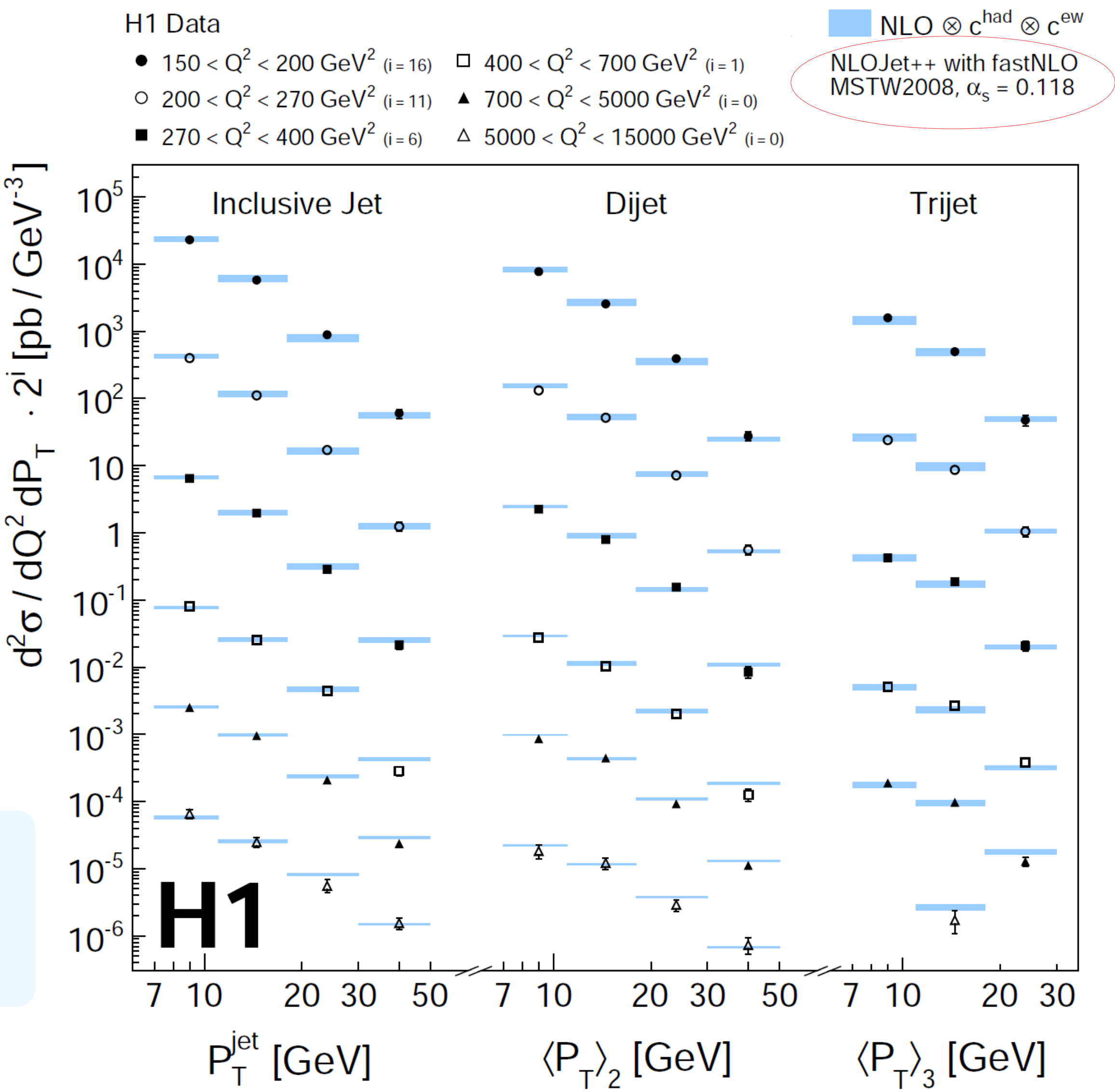
scale choice:

$\mu_f = Q^2$

$\mu_r = (Q^2 + P_T)/2$

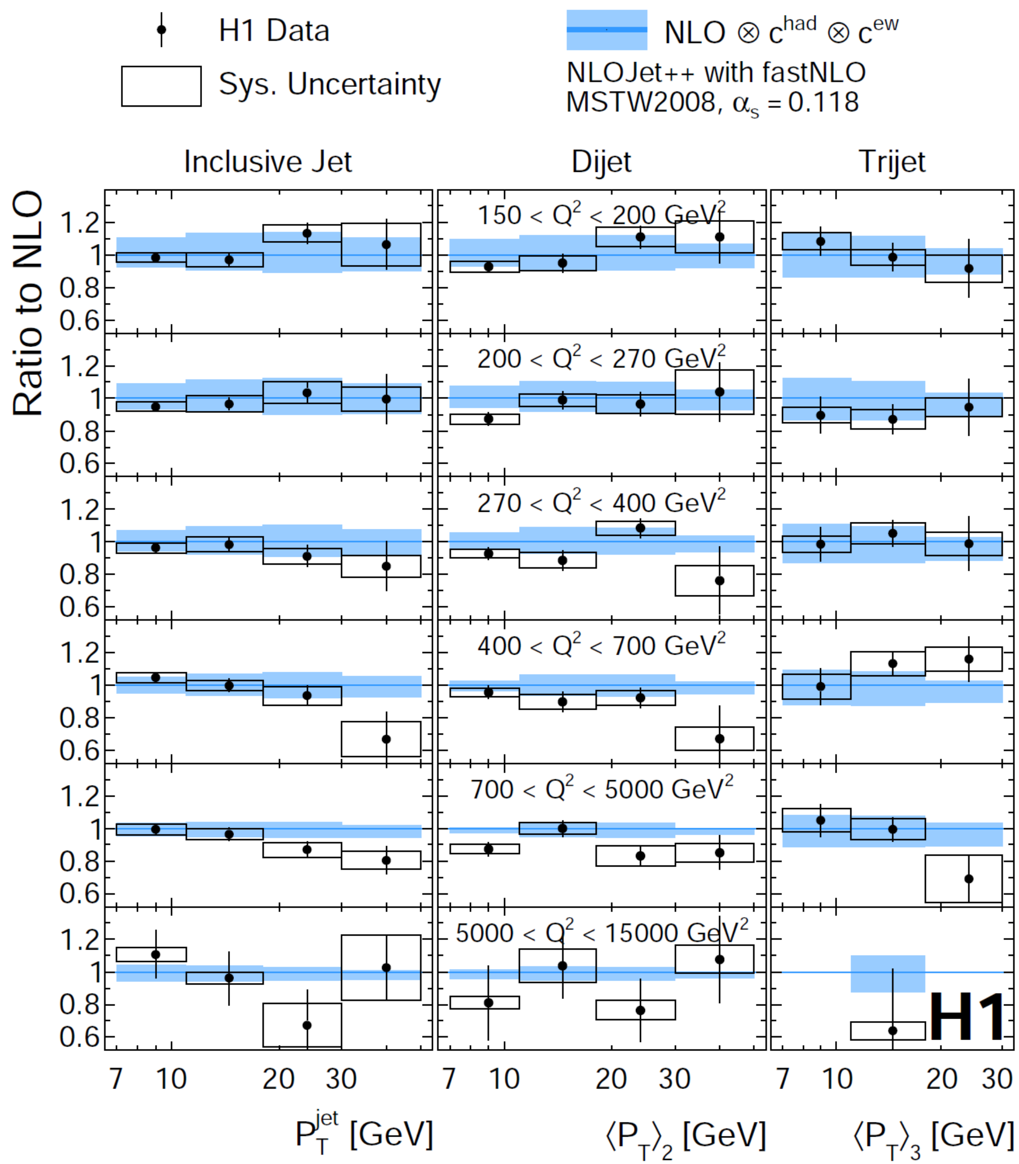
Theory uncertainty obtained by varying scales by factor 2

→ good description of the measured double-differential jet cross sections



Multijets at High Q^2: Cross Sections

Ratio of jet cross sections to NLO predictions as function of Q^2 and P_T



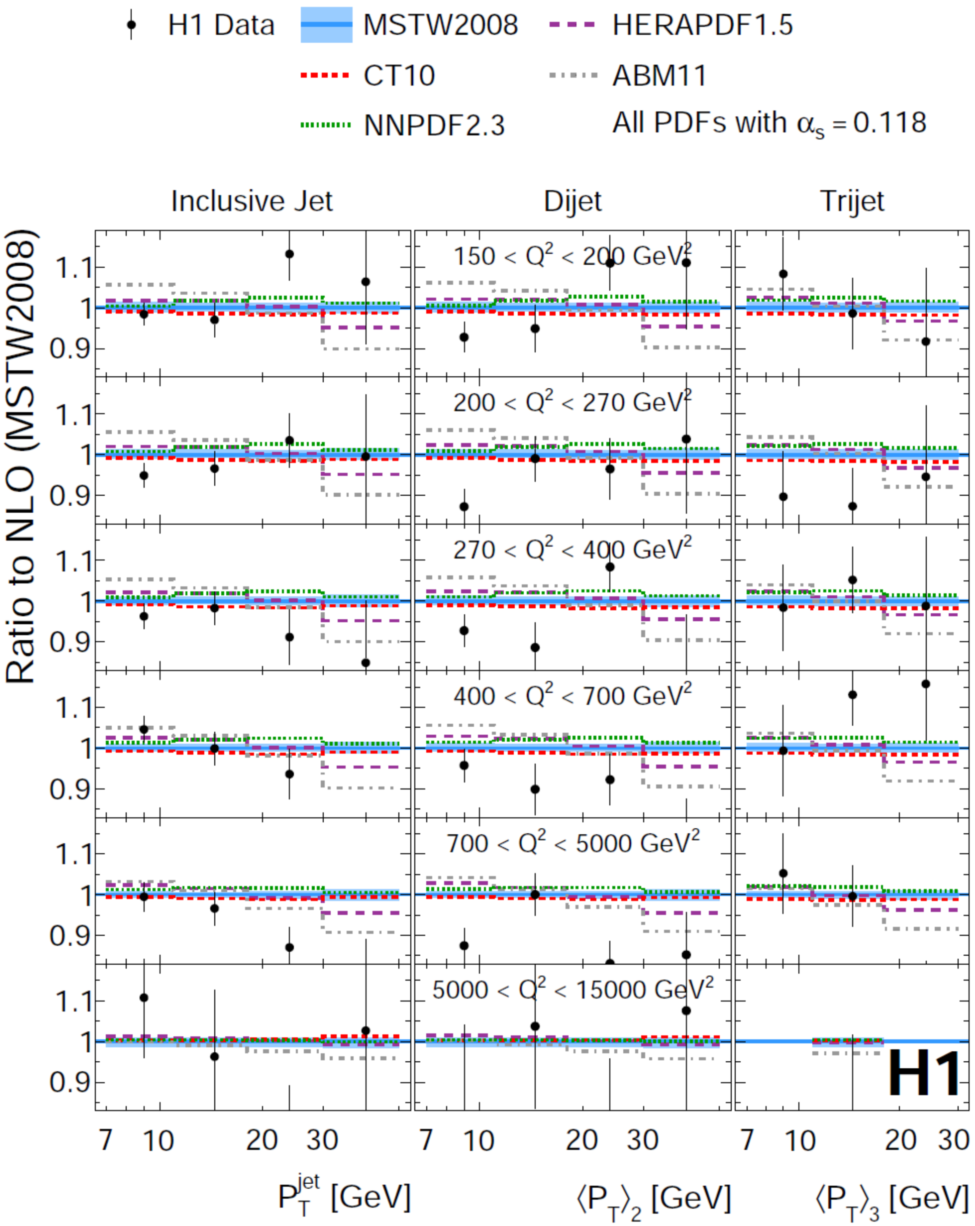
→ precision of the jet data is better than that of the theory calculations

Multijets at High Q^2: Cross Sections

Ratio of NLO predictions with **various PDF** sets to MSTW2008 as function of Q^2 and P_T

→ small differences observed between predictions for different choices of PDF sets

(compared to the theory uncertainty from scale variations)

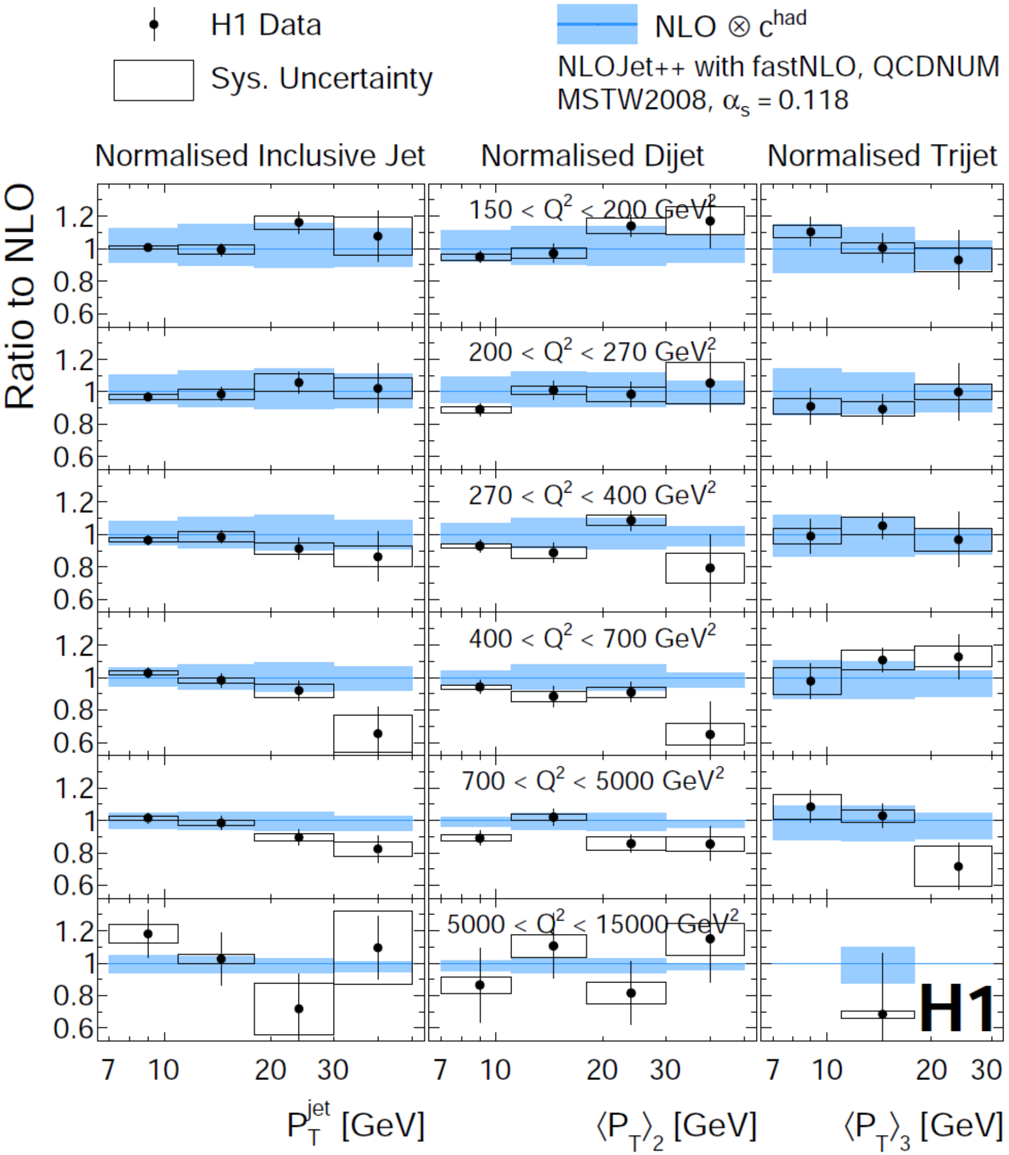


Multijets at High Q^2: Normalised Cross Sections

Ratio of normalised jet cross sections to NLO predictions as function of Q^2 and P_T

→ experimental systematic uncertainties are reduced

→ precision of the jet data is better than that of the theory calculations



Extraction of Strong Coupling Constant α_s

Iterative χ^2 minimisation procedure is used to extract α_s

→ fit theory (t) to data (m) taking statistical correlations into account:

$$\chi^2 = \vec{p}^{\mathrm{T}} V^{-1} \vec{p} + \sum_k^{N_{\mathrm{sys}}} \varepsilon_k^2 \qquad \text{with} \quad p_i = \log m_i - \log t_i - \sum_k^{N_{\mathrm{sys}}} E_{i,k}$$

$\alpha_s(M_Z)$ and ε are free parameters in the fit

Uncertainties δ of m are considered as log-normal distributed with:

$$E_{i,k} = \sqrt{f_k^{\mathrm{C}}} \left(\frac{\delta_{m,i}^{k,+} - \delta_{m,i}^{k,-}}{2} \varepsilon_k + \frac{\delta_{m,i}^{k,+} + \delta_{m,i}^{k,-}}{2} \varepsilon_k^2 \right)$$

nuisance parameters ε_k for each source of systematic uncertainty k are free parameters

→ consistent treatment of all measurement uncertainties

Extraction of Strong Coupling Constant α_s: Results

Jet cross sections are directly sensitive to α_s

The best experimental precision on α_s is obtained from a fit to normalised multijet cross sections:

$$\begin{aligned}\alpha_s(M_Z)|_{k_T} &= 0.1165\ (8)_{\rm exp}\ (5)_{\rm PDF}\ (7)_{\rm PDFset}\ (3)_{{\rm PDF}(\alpha_s)}\ (8)_{\rm had}\ (36)_{\mu_r}\\ &= 0.1165\ (8)_{\rm exp}\ (38)_{\rm pdf,theo}\ .\end{aligned}$$

Experimental uncertainty significantly smaller than theoretical one

→ higher order calculations mandatory

→ value consistent with value extracted using anti-k_t jets

The most precise value of $\alpha_s(M_Z)$ from jet cross sections

→ can be used in PDF fit together with inclusive data

Extraction of Strong Coupling Constant α_s: Results

Determination of α_s at various scales (running)

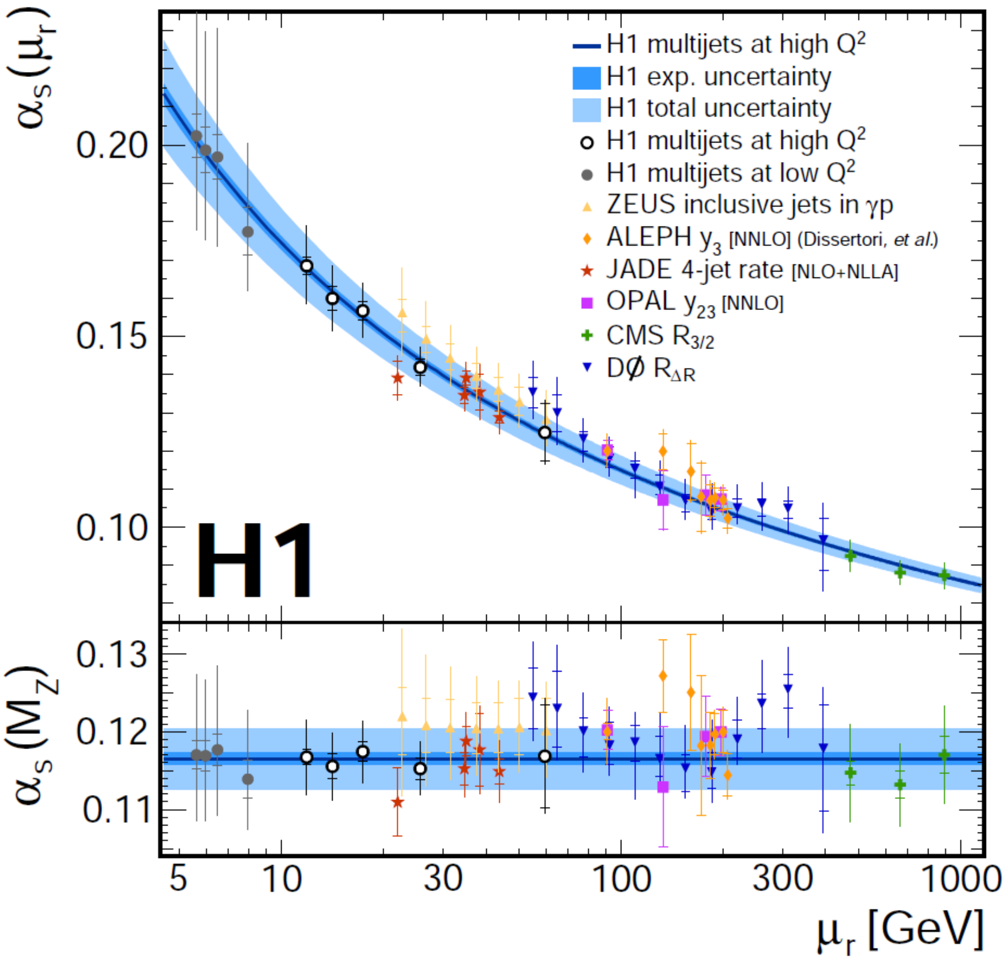
→ H1 multijet cross sections with superior precision

→ consistency with other jet data

→ agreement with the theory prediction over more than two orders of magnitude

→ better than recent CMS results on inclusive jet measurements

arXiv:1410.6765 arXiv:1410.6765



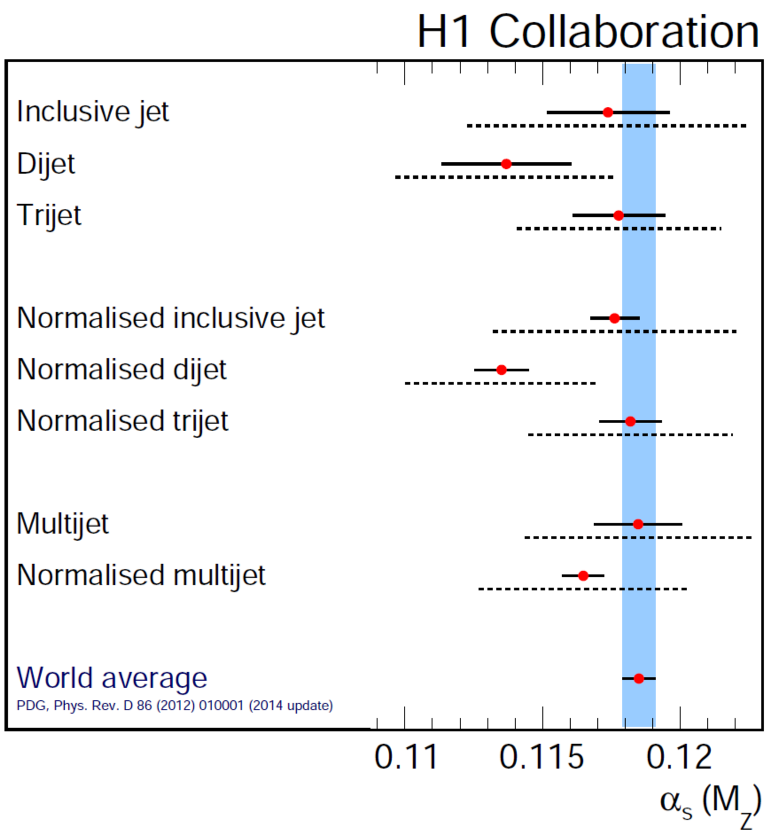
Extraction of Strong Coupling Constant α_s: Results

Comparison of α_s values extracted from different jet measurements

(separately and simultaneously)

→ compared to the world average value of $\alpha_s(M_Z)$

→ values consistent within total uncertainties



→ value of $\alpha_s(M_Z)$ from dijet cross sections is smaller than from inclusive jet or trijets

(most likely attributed to higher order contributions in phase space regions which are different in the dijet and the inclusive jet measurement)

Summary

New QCD results from H1 were presented

Multijet (inclusive, dijet and trijet) cross sections in DIS

→ final results with superior experimental precision
(supersede previously published H1 measurements)

used to **determine the strong coupling constant** α_s

→ obtained value is consistent with the world average

→ most precise value from jet cross sections!

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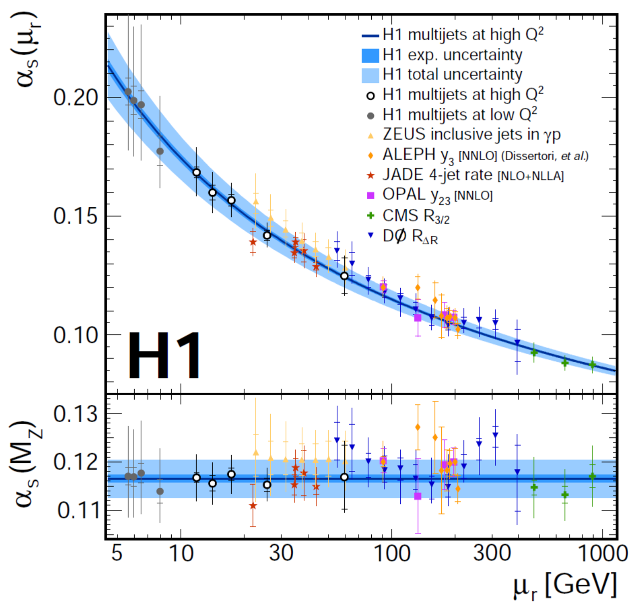

THANK YOU

Back-up slides