High p_T jets in DIS and γp at HERA

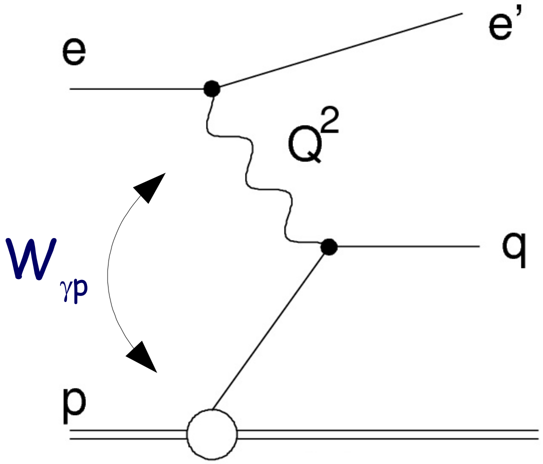
ISMD 2007, Berkeley, USA 4-9 August 2007

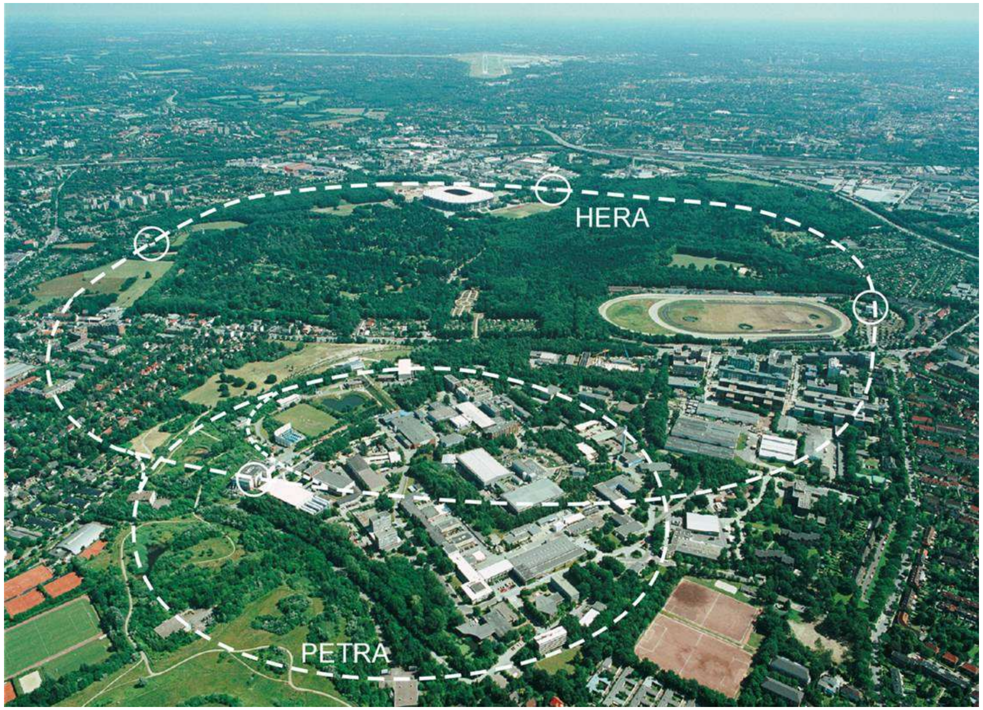
Nicola Coppola

On behalf of the H1 and ZEUS collaborations

- Introduction/Motivations
- Results: inclusive and di- Jets in γp and DIS regime, integrated jet shape and combined α_s determination
- Conclusions

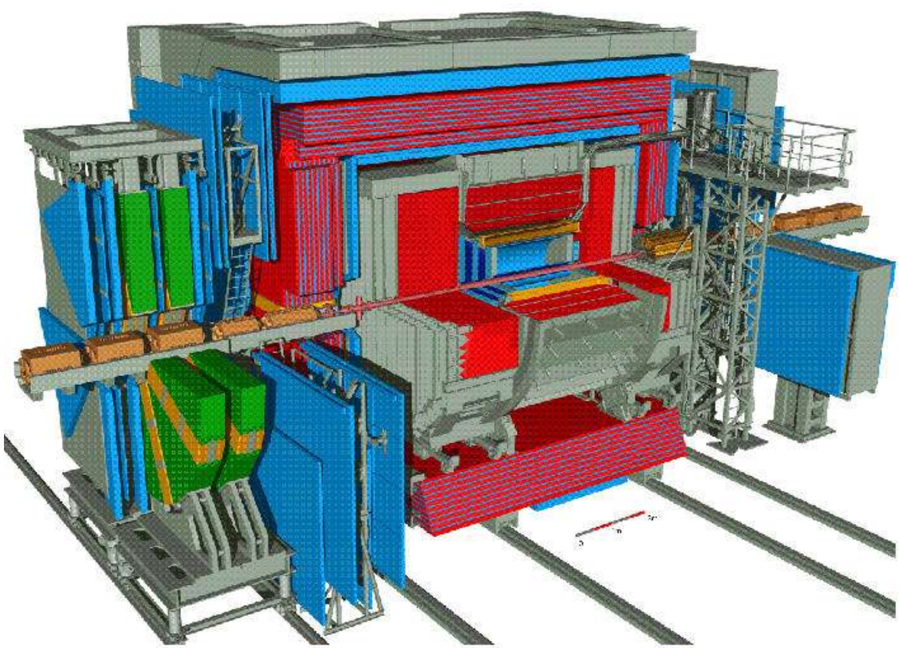
HERA Collider



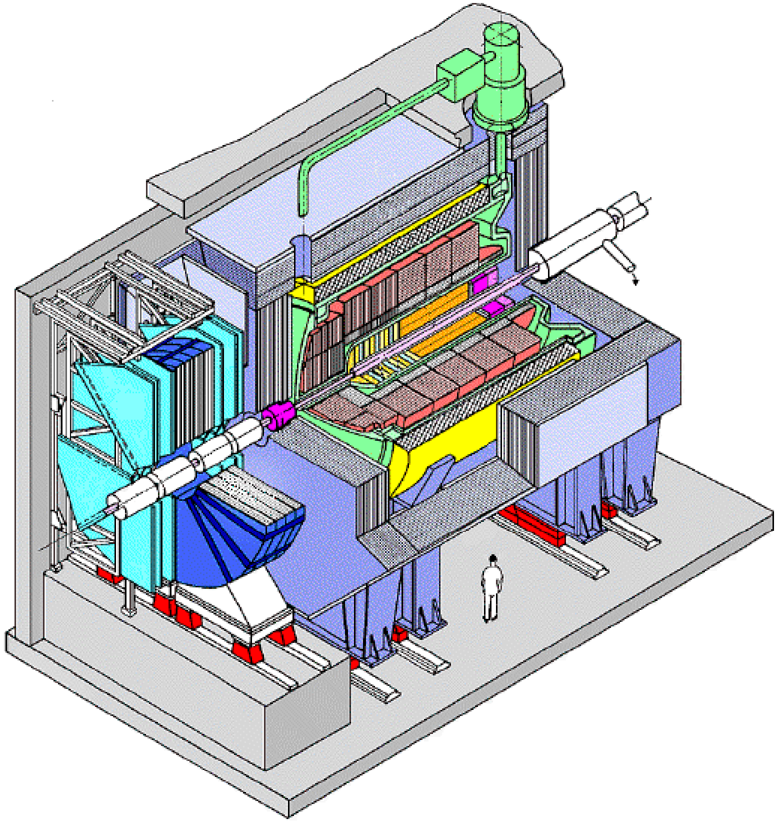


ep kinematics:
photon virtuality Q^2
energy c.m. $\sqrt{s}$=300-320 GeV
inelasticity $y=Q^2/(x_{Bj}\,s)$
energy γp c.m. $W_{\gamma p}^2 \approx ys-Q^2$
two regimes: $Q^2 \approx 0$ GeV^2 – photoproduction (γp)
$Q^2 > 1$ GeV^2 -- electroproduction (DIS)
only 2 independent variables out of y, x_{Bj}, Q^2

ZEUS and H1 detectors



ZEUS



H1

- Tracking ⇒ momentum measurement, particle ID
- Calorimetry ⇒ energy measurement

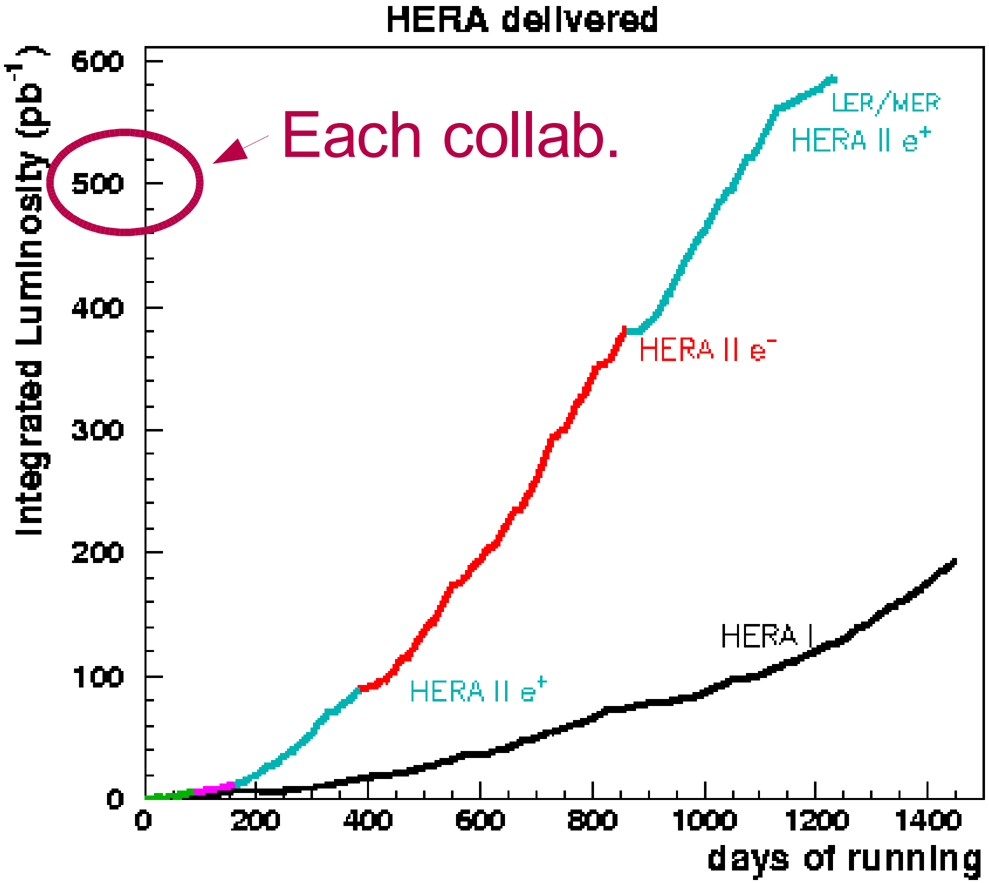
Luminosity from HERA

On June 30th

data taking ended ☹

but

Large increase of integrated luminosity collected, available for future analyses!!!



Each collab.

(some of the data presented here are based on HERA I data only)

Introduction

Why high p_T jets production?

- In pQCD calculation of jet cross sections:

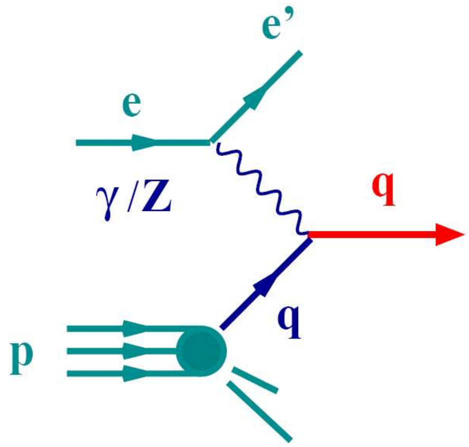
$$d\sigma_{ep} = \sum_{ab} \int dy f_{\gamma/e}(y) \int\int dx_p dx_\gamma f_p(x_p, \mu_F^2) f_\gamma(x_\gamma, \mu_F^2) d\hat{\sigma}_{ab}(x_p, x_\gamma, \mu_R^2)$$

  - f_a: parton a density in the proton, determined from experiment; long-distance structure of the target
  - $d\hat{\sigma}_{ab}$: subprocess cross section, calculable in pQCD; short-distance structure of the interaction

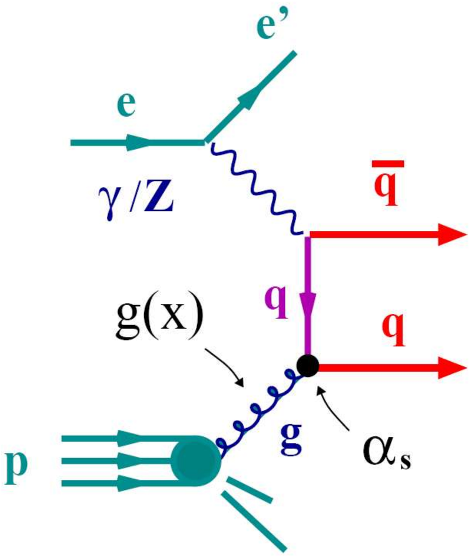
- At sufficiently high p_T^{jet}, fragmentation effects negligible, jet production and substructure are expected to be calculable by pQCD

Jet production in NC DIS

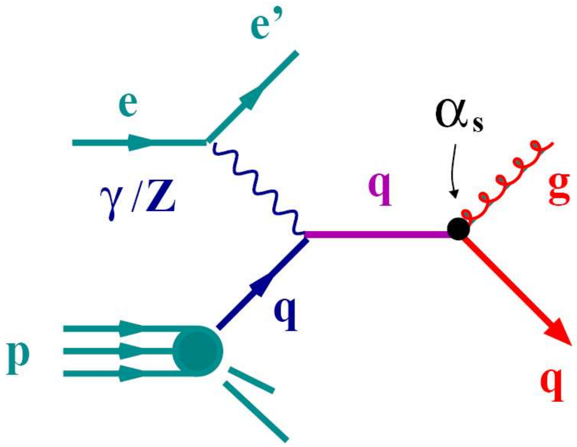
Jet production in neutral current deep inelastic scattering up to $\mathcal{O}(\alpha_s)$:



Quark-Parton Model



Boson-Gluon Fusion

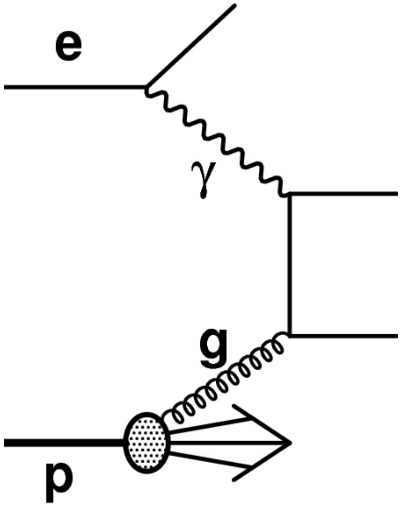


QCD Compton

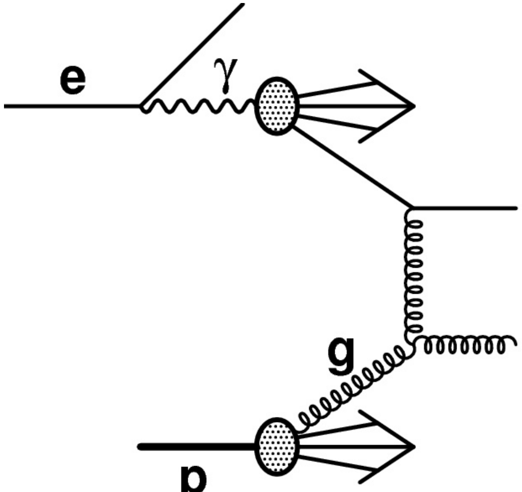
sensitive to proton PDF

Jet production in γp

Jet production in photoproduction
2 processes



direct-γ
(enhanced for $x_\gamma^{obs}>0.8$)



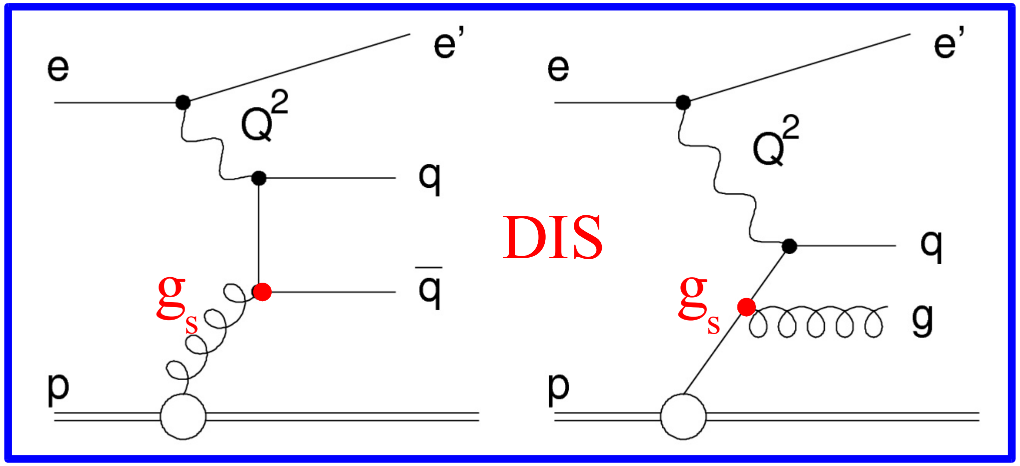
resolved-γ
(enhanced for $x_\gamma^{obs}<0.8$)

$$x_p^{\mathrm{obs}} = \frac{E_T^{\mathrm{jet1}} e^{\eta^{\mathrm{jet1}}} + E_T^{\mathrm{jet2}} e^{\eta^{\mathrm{jet2}}}}{2E_p}$$

$$x_\gamma^{\mathrm{obs}} = \frac{E_T^{\mathrm{jet1}} e^{-\eta^{\mathrm{jet1}}} + E_T^{\mathrm{jet2}} e^{-\eta^{\mathrm{jet2}}}}{2yE_e}$$

⇒sensitivity to proton's and photon's structures

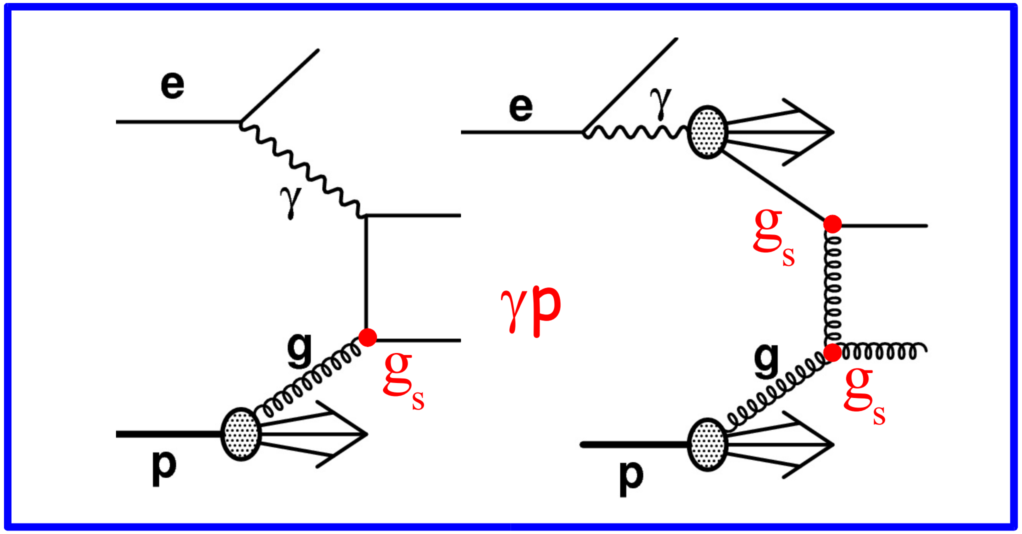
DIS and γp: Experimental def.



$Q^2 > 125$ GeV^2

$|\cos(\gamma_{had})| < 0.65$ (ZEUS)

$0.2 < y < 0.7$ (H1)



$Q^2 < 1$ GeV^2

$0.44 < y < 0.92$ (ZEUS)

$0.1 < y < 0.9$ (H1)

Jet reconstruction

Longitudinal invariant k_T algorithm

- Iterative clustering:

  $d_{ij}=\min(E_{T,i}^2,E_{T,j}^2)\cdot R_{ij}/R$

  $R_{ij}=(\eta_i-\eta_j)^2+(\phi_i-\phi_j)^2$

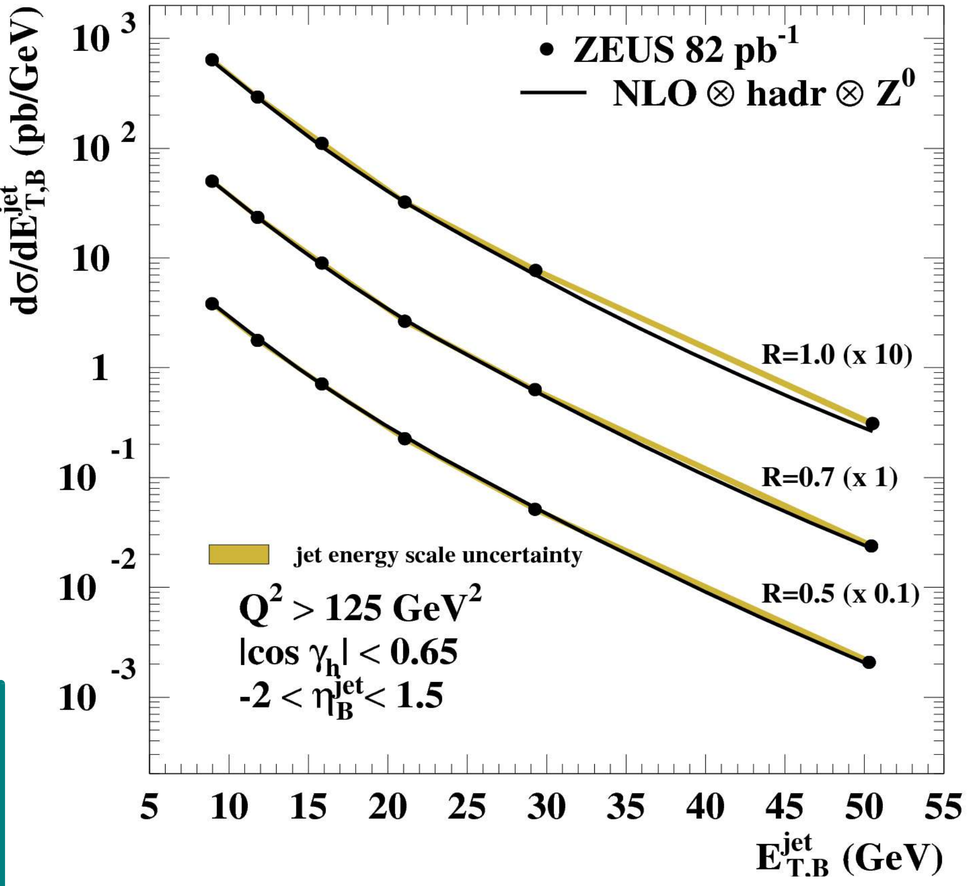
  $d_i=E_{T,i}^2$

- p_T- weighted recomb. scheme

- Resulting jets: n jets with $R_{ij}>R$

- Collinear and infrared safe

Usually R=1, but inclusive jets data are well described also for R=0.5; 0.7; 1



Probing photon structure in γp

2-jet γp:

$E_T^{jet1} > 25$ GeV & $E_T^{jet2} > 15$ GeV

$-0.5 < \eta_{jet} < 2.75$ (H1)

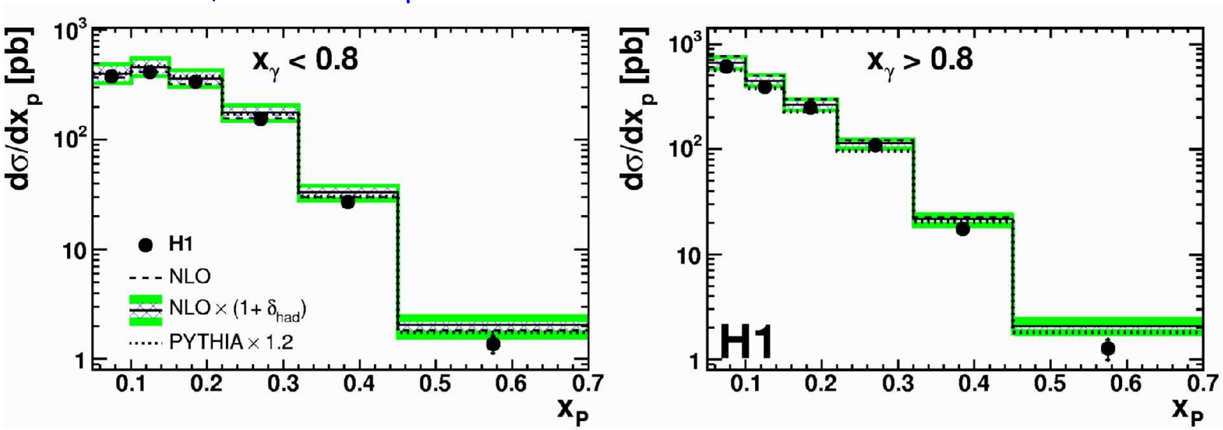
$E_T^{jet1} > 20$ GeV & $E_T^{jet2} > 15$ GeV

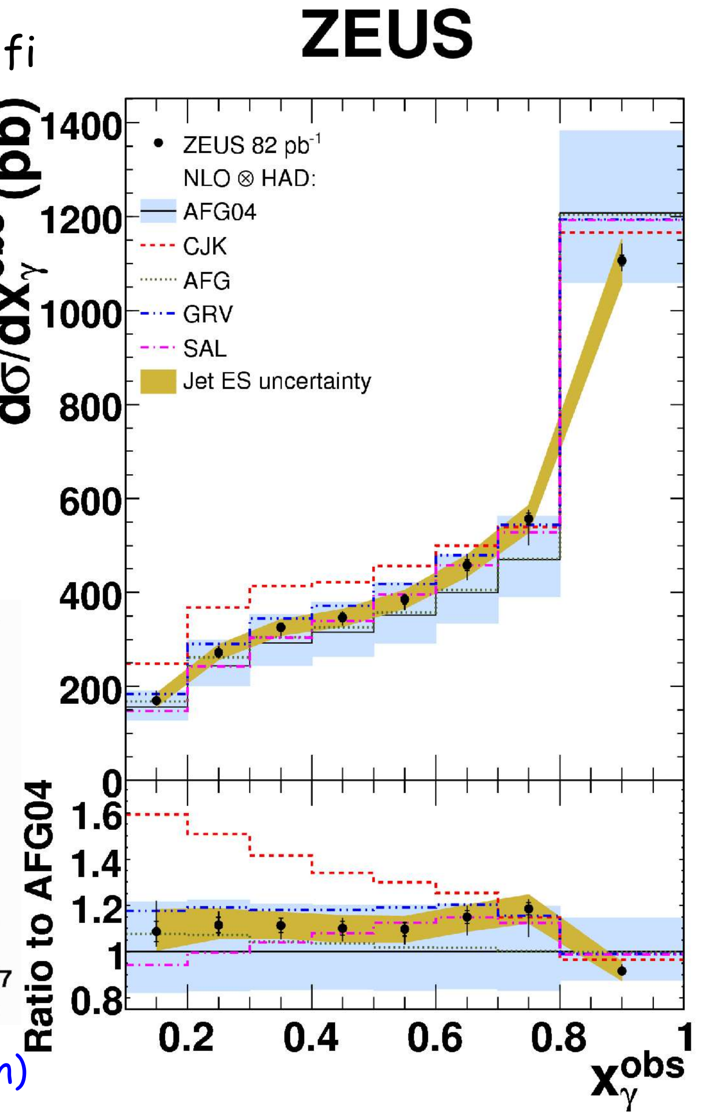
$-1 < \eta_{jet} < 3.0$ (at least 1 jet $-1 < \eta_{jet} < 2.5$) (ZEUS)

Sensitive region to gluons in the photon:

low x_γ, high x_p

NLO Frixione Ridolfi



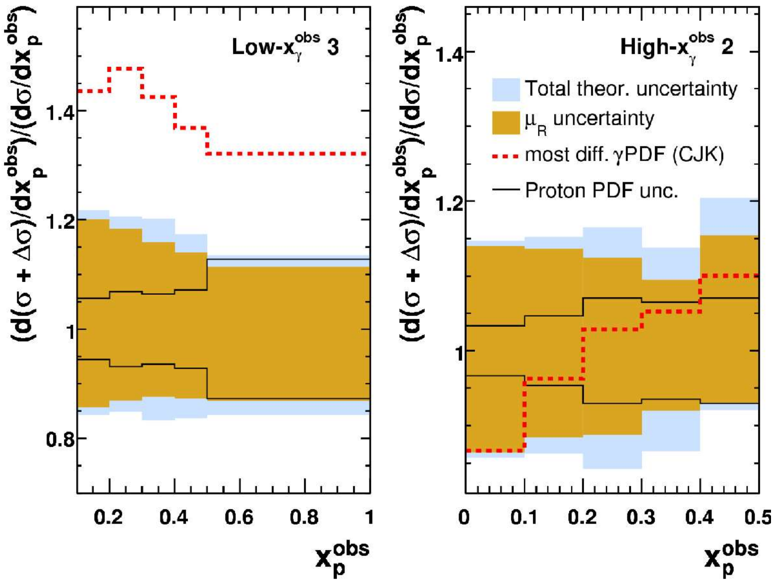


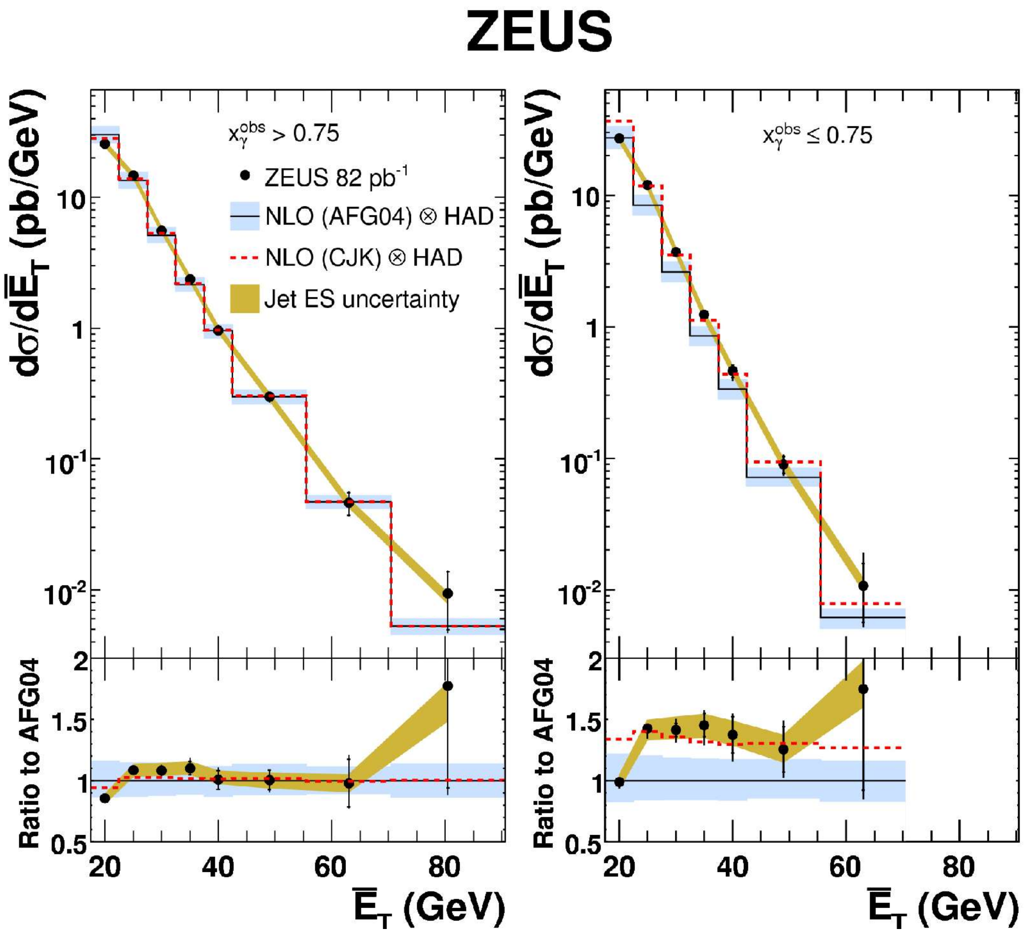
($x_p < 0.1$ gluon induced interaction, $x_p > 0.1$ quark induced interaction)

Jets help constraining gluon content of the proton

Largest uncertainty μ_R

but in some phase space corners PDF uncertainty as large



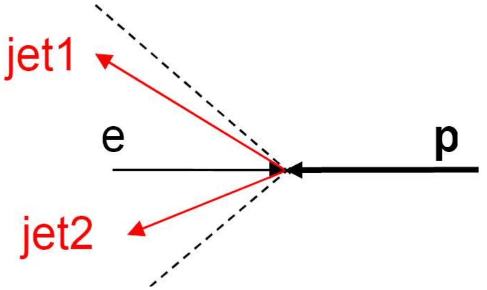


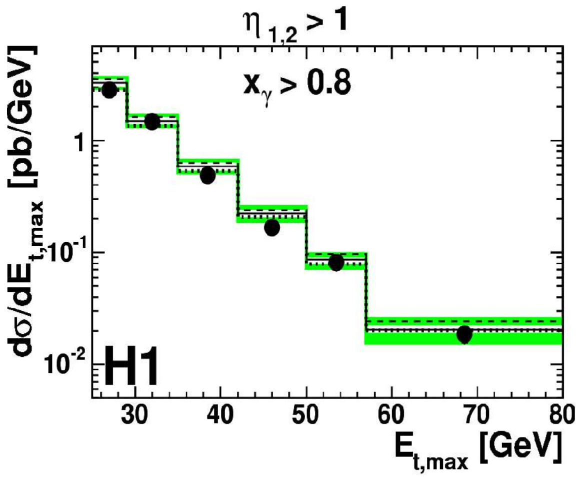
Good description over 4 orders of magnitude, although data tend to be higher than NLO for $x_\gamma^{obs}<0.75$

Probing gluon content of proton in γp

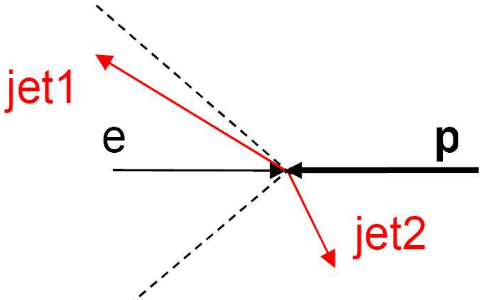
2-jet "**direct**" γp

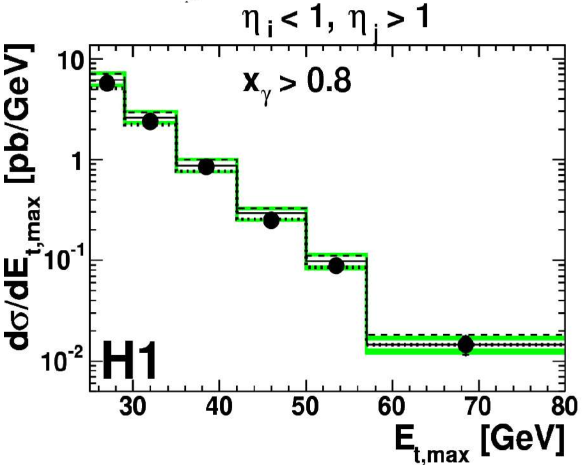
forward topology



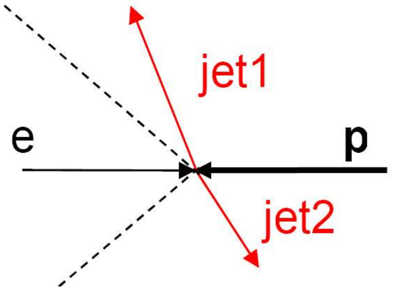


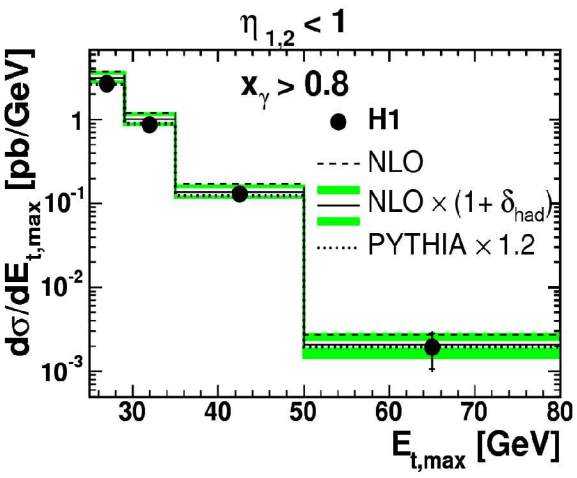
forward-central topology





central topology



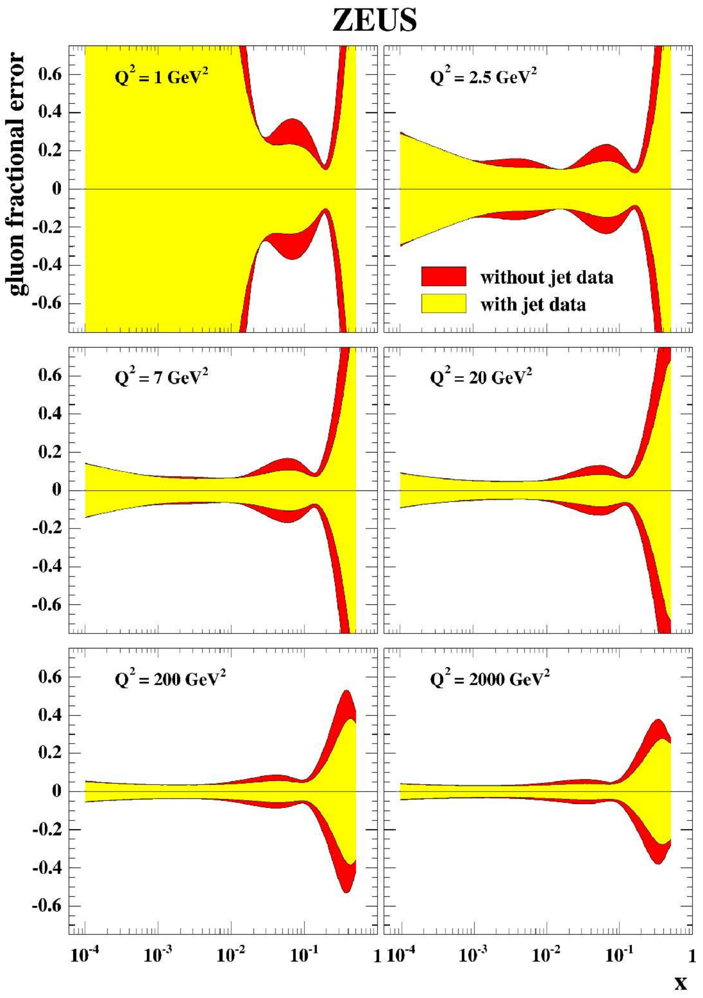


High precision measurement in "**optimized**" exclusive topologies leads to an important constraint to the gluon content of the proton

Jets help constraining gluon content of the proton

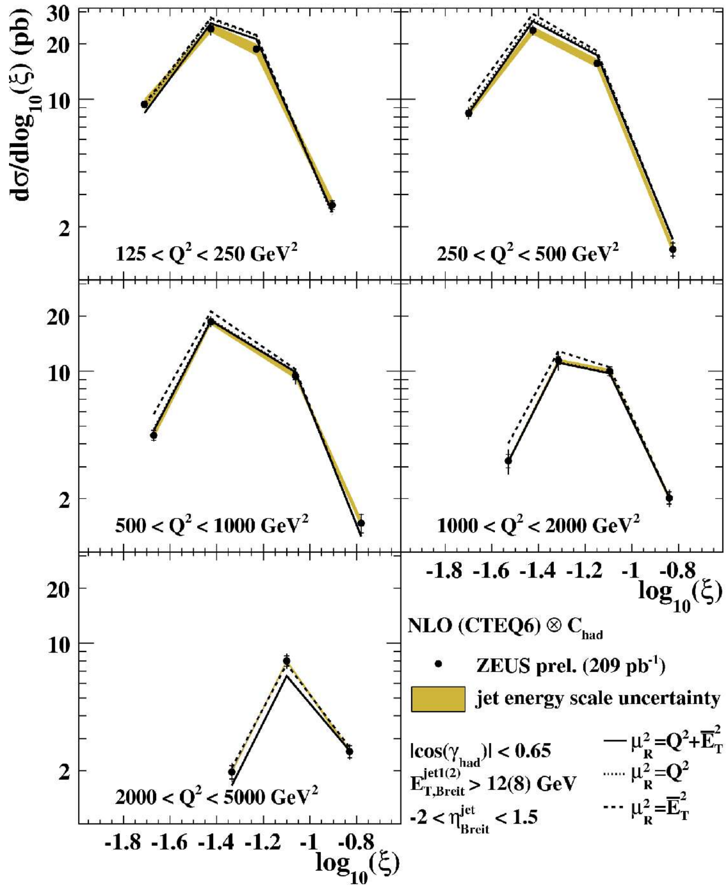
Jet data (Incl. Jets in DIS and 2-jet in γp 96/97) already used in PDF fits by ZEUS collaboration to further constrain results of PDF fits obtained via inclusive DIS analysis performed with scaling violations of structure function F_2

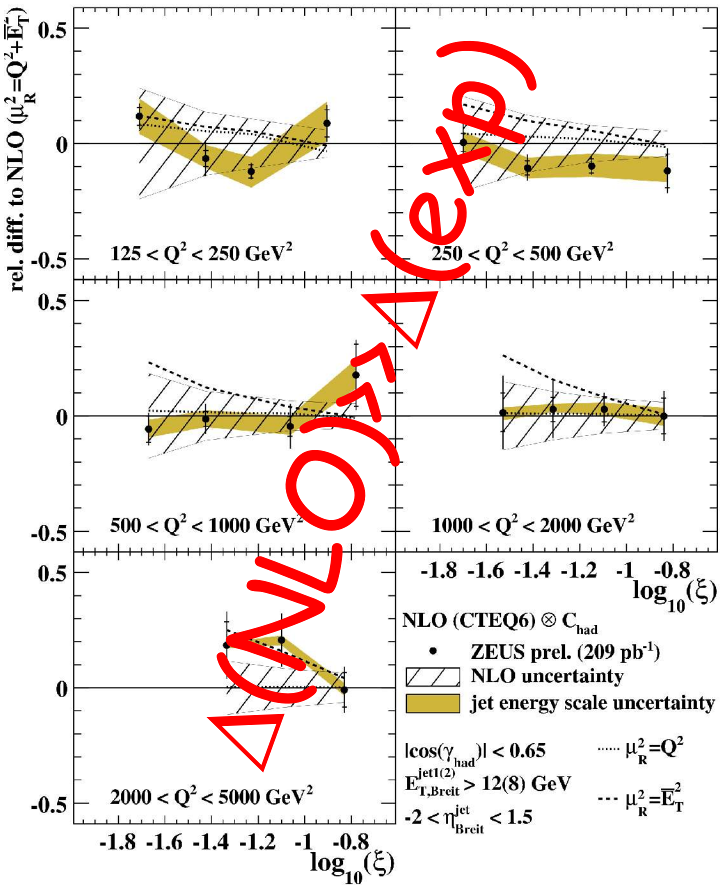
>10x more luminosity available than what was used



Probing gluon content of proton in DIS

2-jet DIS (ZEUS): $E_T^{jet1}>12$ GeV & $E_T^{jet2}>8$ GeV $\eta_{breit}<2.5$





$\Delta(\mathrm{NLO}) > \Delta(\mathrm{exp})$

HERA I + part of HERA II data: 209 pb^{-1} (prev 82 pb^{-1})

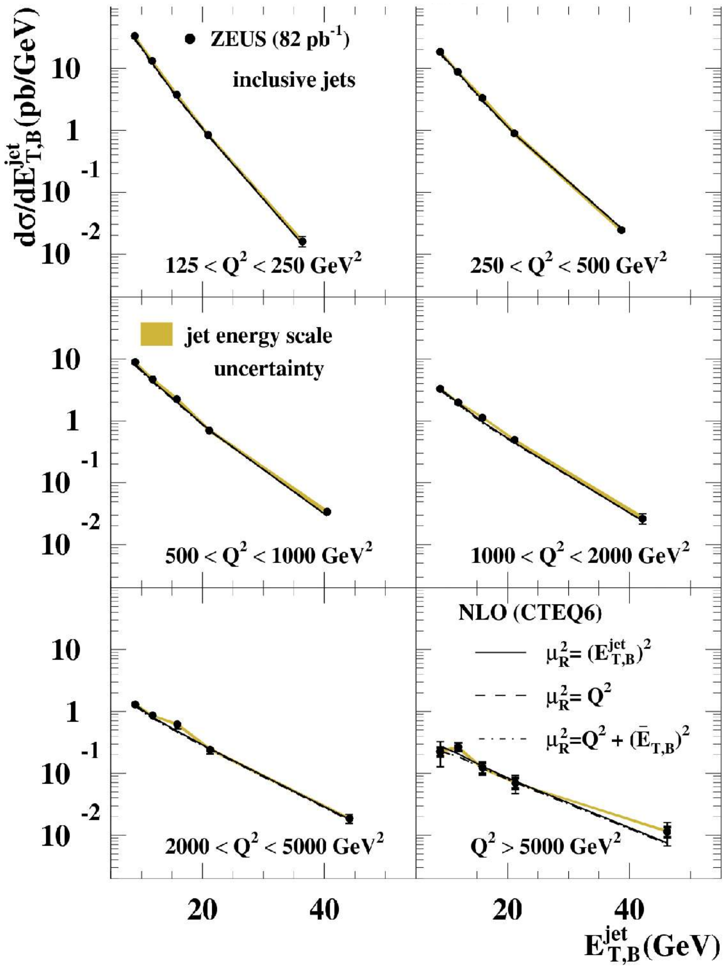
High precision QCD measurement tool

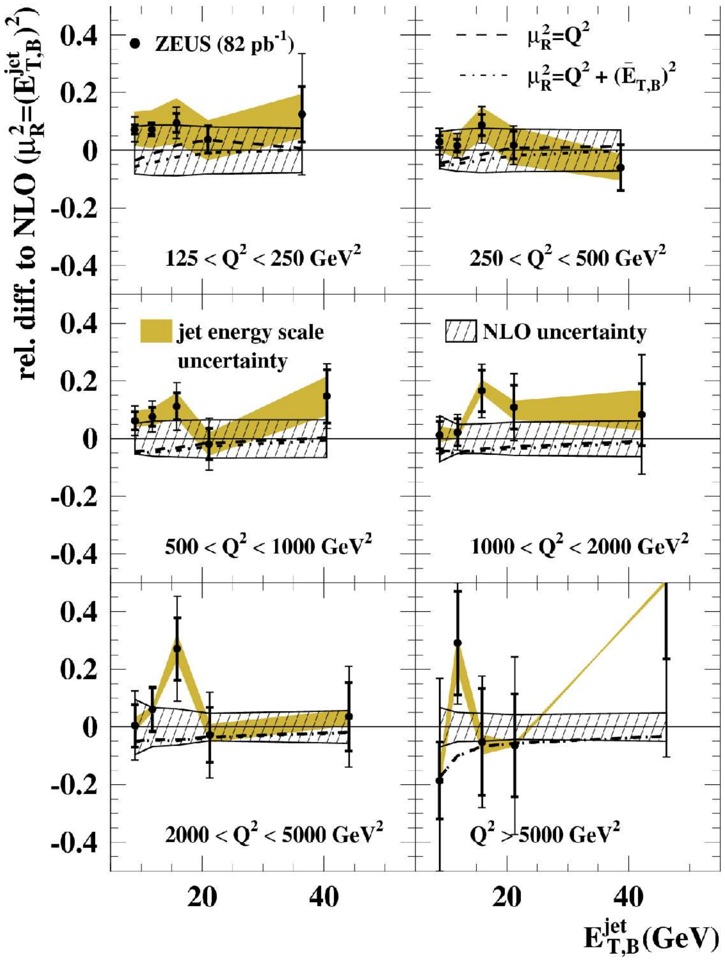
Incl-jet DIS (ZEUS): (proton PDF and α_s extraction)

E_T>8 GeV

$-2<\eta^{jet}_{breit}<1.5$

NLO pQCD (DISENT)





High Q^2 jet multiplicity

Inclusive jet normalized to DIS NC (H1)

HERA I – 65.4 pb^{-1}

HERA II – 320 pb^{-1}

reduced jet phase space

$-0.8<\eta^{jet}_{lab}<2$

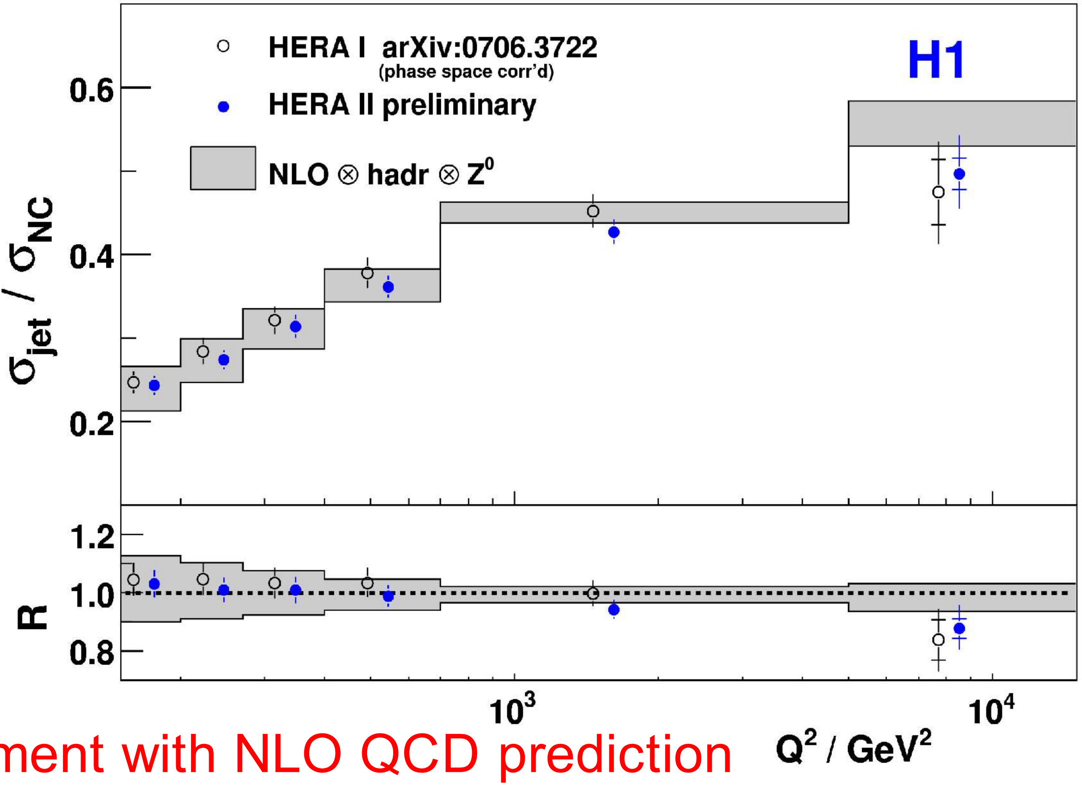
NLO pQCD (FastNLO)

$\mu_F=Q$; $\mu_R=E_T$

Partial cancellation of exp. syst. uncert.
~7% → 6% on multiplicity
⇒ ~40% reduction of exp. uncert. on α_s

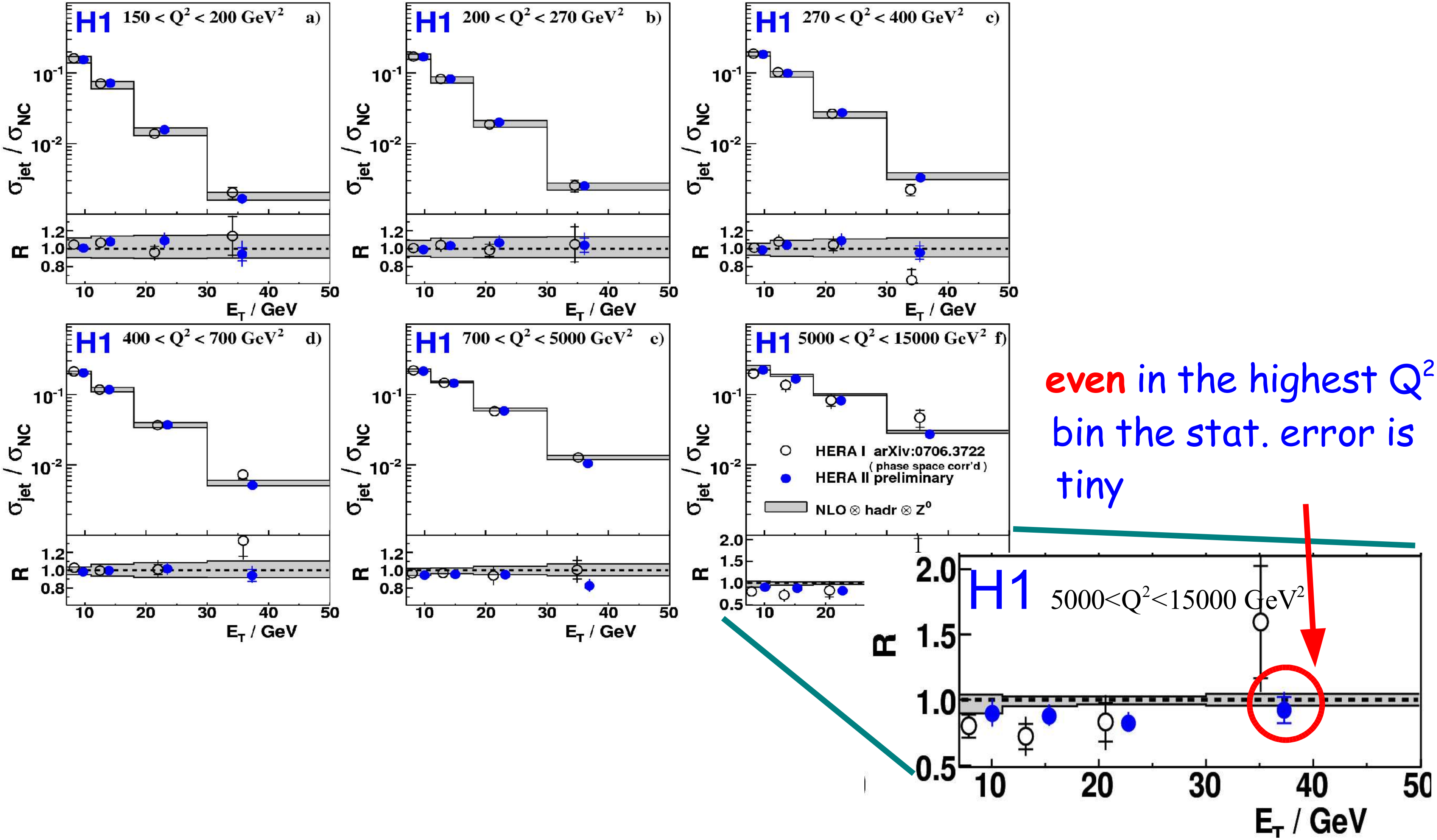
experimental uncertainty (~6%)
- jet energy scale ~4%
- data correction
  model dependence ~2-3%

theory uncertainty (~5-10%)
- renormalization scale dependence
- PDF dependence



Good agreement with NLO QCD prediction

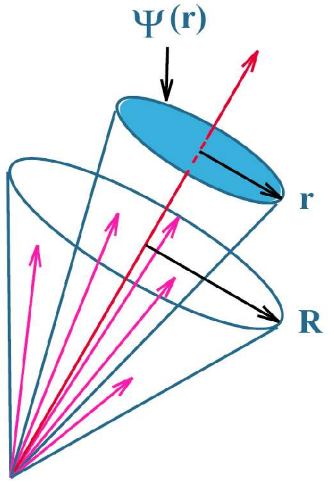
DIS results with whole H1-$\mathcal{L}$



even in the highest Q^2 bin the stat. error is tiny

Jet substructure in NC DIS

Measurement of jet substructure allows investigations on
→differences between quark- and gluon-initiated jets
→the dynamics of the different partonic final states,
→as well as determinations of α_s

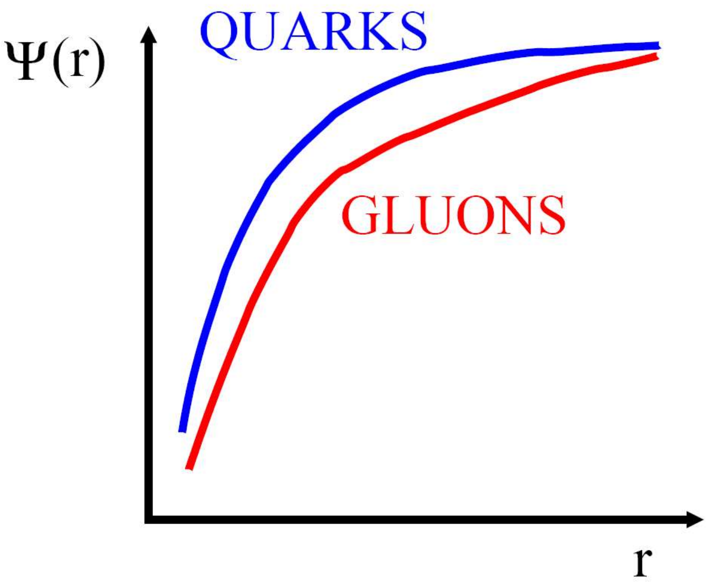


- Integrated jet shape: $$\langle\Psi(r)\rangle = \frac{1}{N_{jets}} \sum_{jets} \frac{E_T(r)}{E_T^{jet}}$$

Average fraction of the jet's transverse energy that lies inside a circle in the $\eta-\phi$ plane of radius r concentric with the jet axis

- QCD predicts that gluon jets are broader than quark jets

⇒ $\Psi_{QUARKS}(r) > \Psi_{GLUONS}(r)$



Jet substructure, results

Measurement $\langle\Psi(r)\rangle$ in NC DIS with $Q^2 > 125$ GeV^2

using HERA II data $\mathcal{L}=368$ pb^{-1}

2 samples:

- One jet events: (NLO DISENT)

$E_T^{jet} > 14$ GeV; $-1 < \eta_{jet} < 2.5$

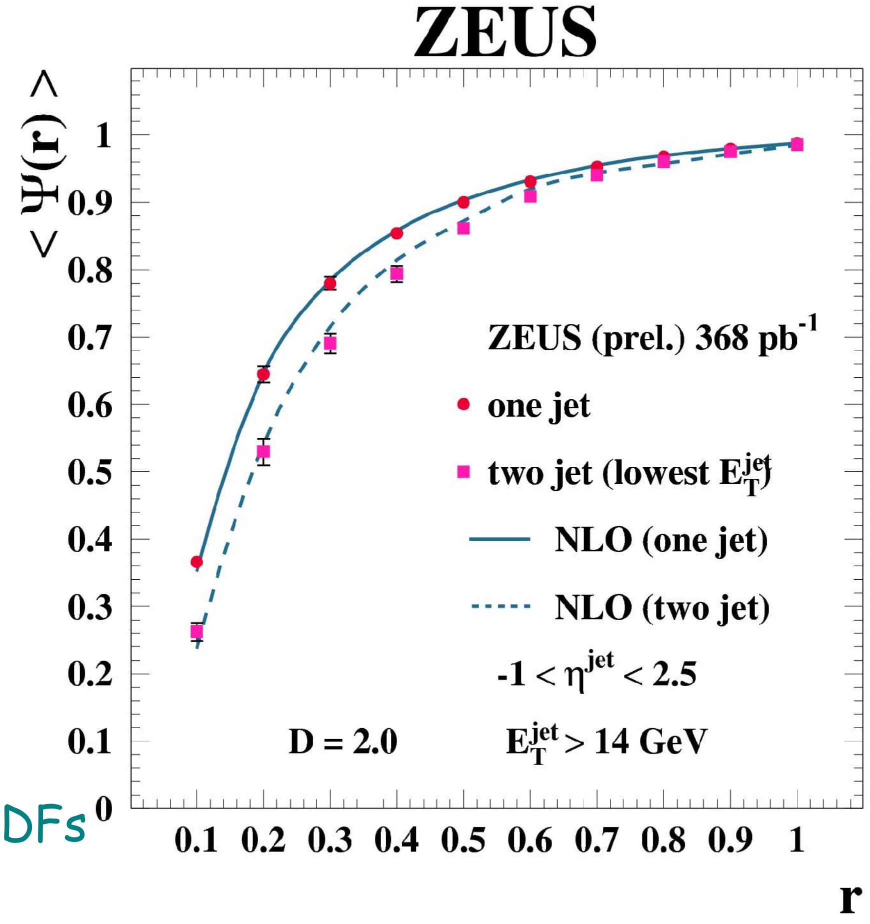
- Two jet events: (NLO NLOJET++)

both jets $E_T^{jet} > 14$ GeV; $-1 < \eta_{jet} < 2.5$

and close to each other $(\Delta\eta^2 + \Delta\phi^2)^{1/2} < 2$

the lowest E_t^{jet} is considered

for NLO: $\alpha_s(M_Z)=0.118$; $\mu_R=\mu_F=Q$; CTEQ6 pPDFs



⇒ the lowest-E_t^{jet} jet is broader

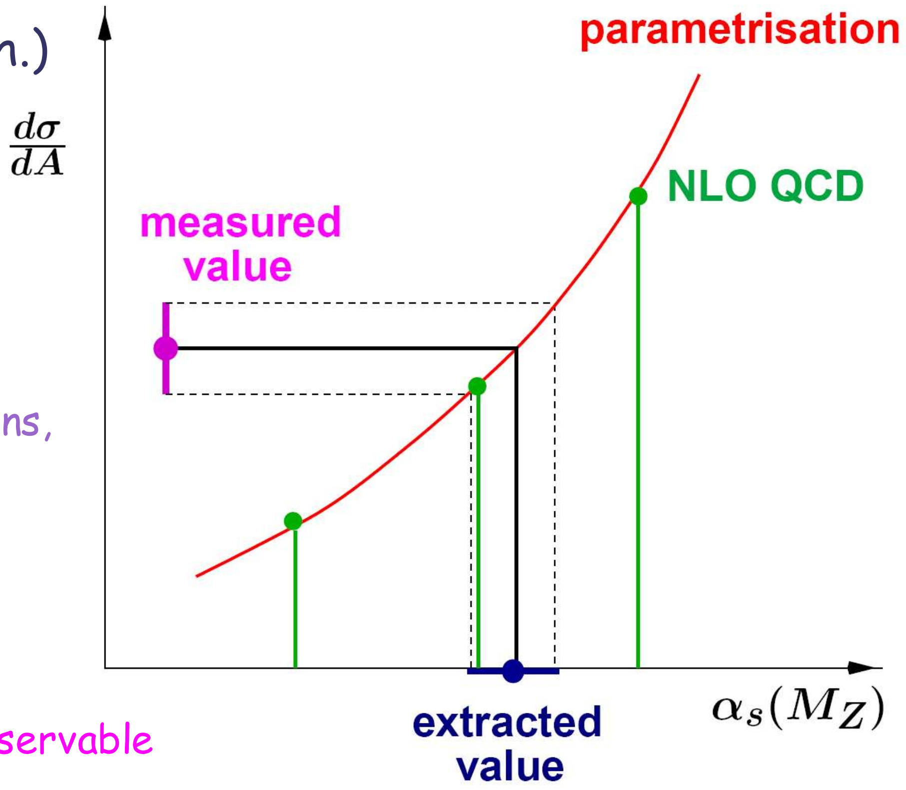
⇒ NLO, corrected for hadr. Eff. (<10%, for $r \geq 0.4$), reproduce data reasonably well; in particular, differences between 2 samples

α_s extraction

For the first time using both H1 and ZEUS data to extract α_s directly;

optimizing against theory uncertainties
and experimental correlations:
HERA average obtained using already published results

$\alpha_s(M_Z)=0.1186\pm0.0011(\text{exp.})\pm0.0050(\text{th.})$



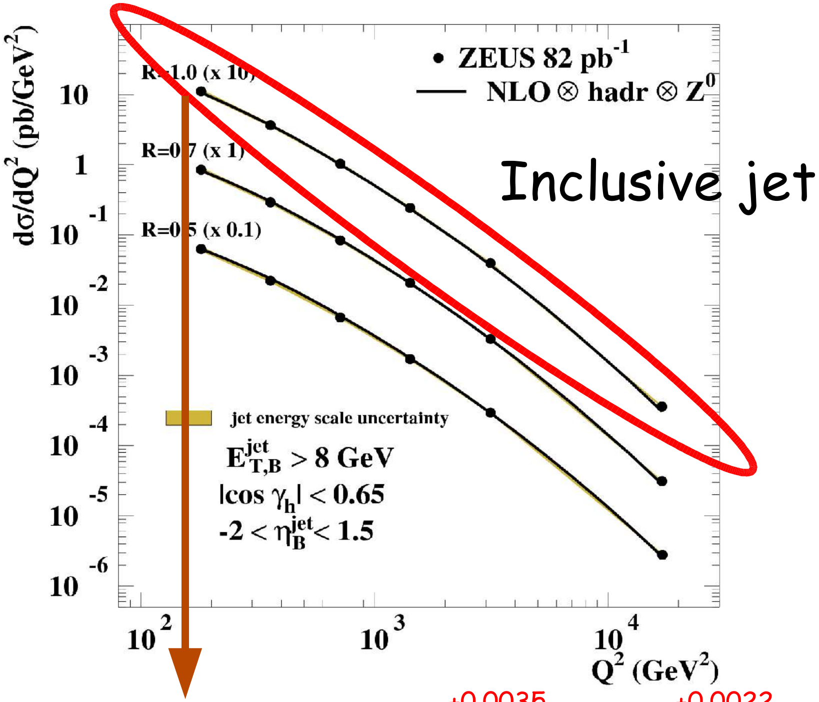
Method:

use the α_s-dependence of the pQCD calculations,

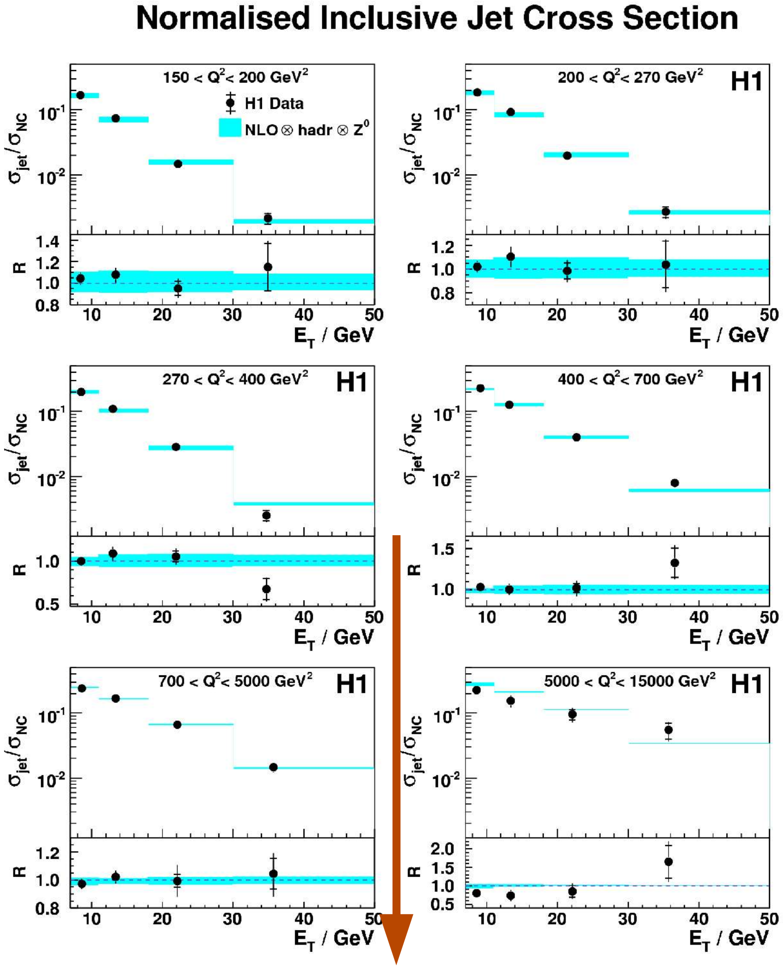
taking into account correlations of PDFs:

- perform NLO calculations with many PDF
- use for each as input proper value $\alpha_s(M_Z)$
- parametrize α_s-dependence of observable
- determine $\alpha_s(M_Z)$ from measured value of observable

data used for α_s extraction



Inclusive jet



$\alpha_s(M_Z)=0.1207\pm0.0014(\text{stat.})^{+0.0035}_{-0.0033}(\text{exp.})^{+0.0022}_{-0.0023}(\text{th.})$

- exp. unc. dominated by jet ene-scale ($\Delta\alpha_s/\alpha_s$=2%)
- th. unc.
  - term beyond NLO ($\Delta\alpha_s/\alpha_s$=1.5%)
  - unc. pPDF ($\Delta\alpha_s/\alpha_s$=0.7%)
  - had. Corr. ($\Delta\alpha_s/\alpha_s$=0.8%)
  - μ_F uncertainty negligible

$\alpha_s(M_Z)=0.1179\pm0.0024(\text{exp.})^{+0.0052}_{-0.0032}(\text{th.})\pm0.0028(\text{PDF})$

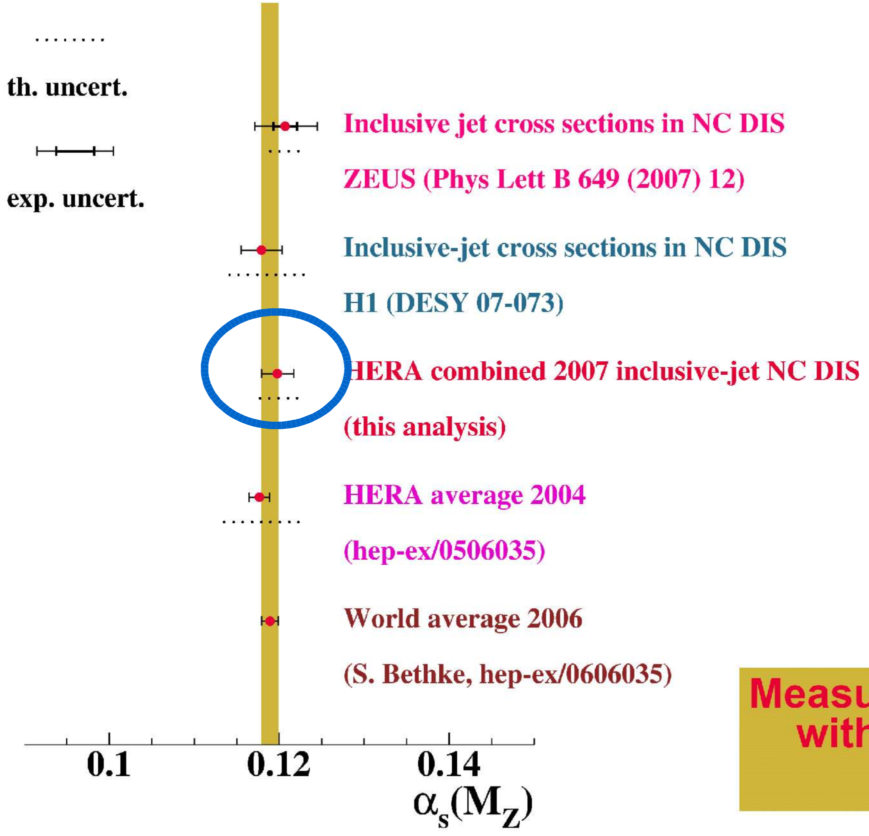
Phase space & extraction method

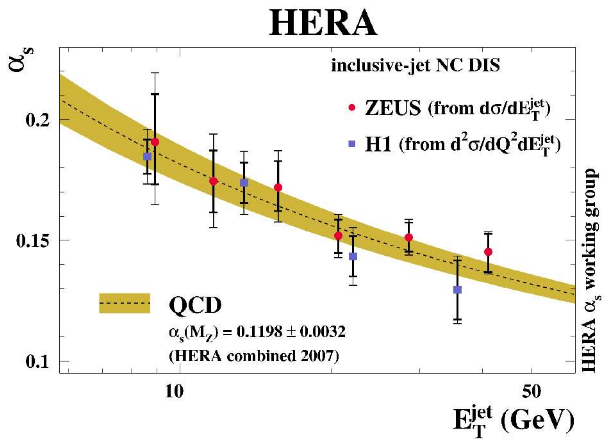
- Simultaneous fit to 30 measurement:
  → 24 H1 data points from double-differential cross section ($150<Q^2<15000$ GeV^2)
  → 6 ZEUS data points from single-differential Q2 cross section ($125<Q^2<10^5$ GeV^2)
- NLO QCD calculations:
  → differential cross section calculated at NLO ($\mathcal{O}(\alpha_s^2)$)
    — pPDFs MRST2001 sets
    — renormalisation scale $\mu_R=E_{T,B}^{jet}$ of each jet
    — factorization scale $\mu_F=Q$
- Experimental uncertainties on combined $\alpha_s(M_z)$
  → 0.0019 (Hessian method; fit sources of sys. unc., eg: energy scale, luminosity, mod. dep.
- Theoretical uncertainties on combined $\alpha_s(M_z)$
  → terms beyond NLO: 0.0021 (Jones et al. Method, JHEP 122003007)
  → factorisation scale: 0.0010 (by varying μ_F by factors 2 and 0.5)
  → pPDFs: 0.0010 (by using 30 sets of MRST2001)
  → hadronisation: 0.0004 (using different parton-shower models)

HERA combined 2007 $\alpha_s(M_Z)$ value

- HERA combined 2007 $\alpha_s(M_Z)$ value

  $\alpha_s(M_Z)=0.1198\pm0.0019(\text{exp.})\pm0.0026(\text{th.})$





HERA combined 2007 (2.7%)

HERA average 2004 (4.3%)

World average (0.8%)

Measurements consistent with each other and the world average

Conclusions

Precise measurements in wide kinematic ranges have been presented

- inclusive and di-jet cross sections were measured in DIS and photoproduction giving handle to photon and proton structure functions
- 2-jets cross sections in DIS with higher $\mathcal{L}$ should lead to additional constraints on gluon in proton PDF and other QCD param.
- jet radius dependence of inclusive jet cross section & integrated jet shapes (full HERA II stats) in DIS well described by pQCD prediction
- H1 jet multiplicities in DIS with full HERA II data sample released
- inclusive jet in DIS HERA I data were used by ZEUS and H1 collaborations for a high precision α_s common fit for the first time
- for the future:

  plenty more of results from the large luminosity recorded

Jet substructure, results

Measurement <$\Psi(r)$> in NC DIS with $Q^2>125$ GeV^2 using HERA II data $\mathcal{L}=368$ pb^{-1}

2 samples:

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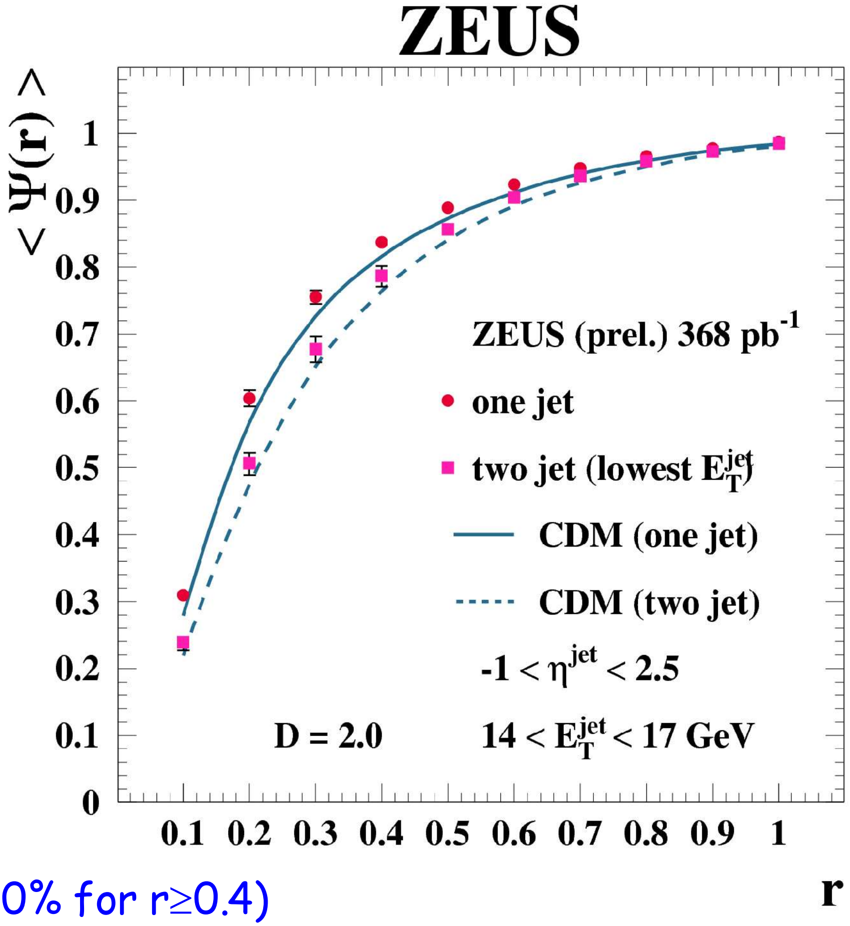
- Two jet events:

both jets $E_T^{jet}>14$ GeV; $-1<\eta_{jet}<2.5$

and close to each other $(\Delta\eta^2+\Delta\phi^2)^{1/2}<2$

the lowest E_t^{jet} is considered



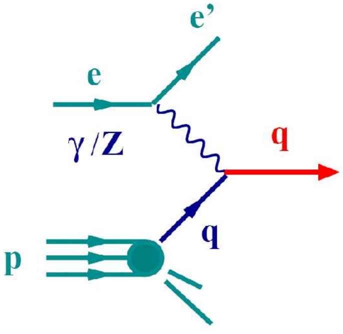
(measurement corrected for detect effects, <10% for r≥0.4)

⇒ MEPS predicts too broad jets

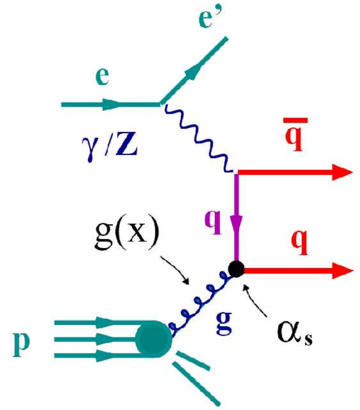
⇒ the lowest-E_t^{jet} jet is broader

Jet production in NC DIS

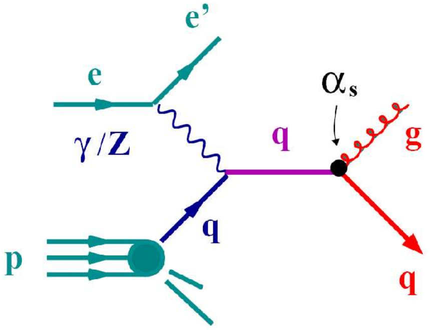
Jet production in neutral current deep inelastic scattering up to $\mathcal{O}(\alpha_s)$:



Quark-Parton Model



Boson-Gluon Fusion



QCD Compton

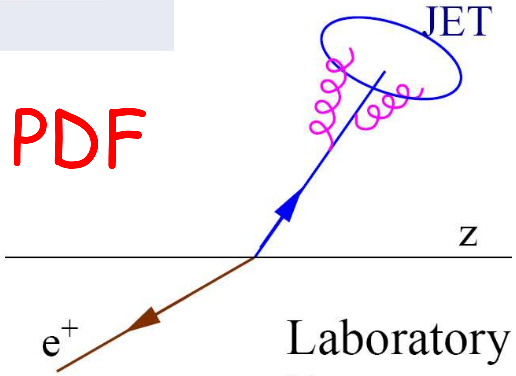
$$x_p^{obs} = \frac{E_T^{\text{jet1}} \cdot \exp^{\eta^{\text{jet1}}} + E_T^{\text{jet2}} \cdot \exp^{\eta^{\text{jet2}}}}{2 \cdot E_e \cdot y}$$

$x_p < 0.1$

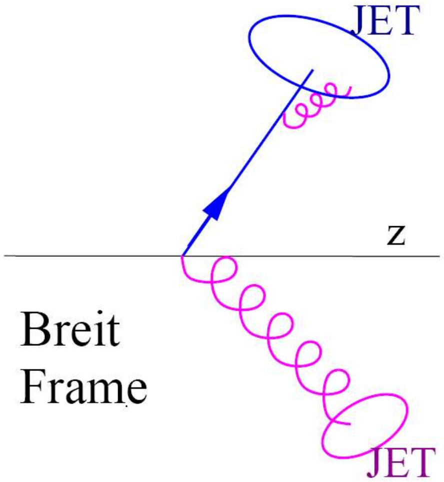
$x_p > 0.1$

sensitive to proton PDF

in Breit frame no
Born contribution from QPM



Laboratory Frame

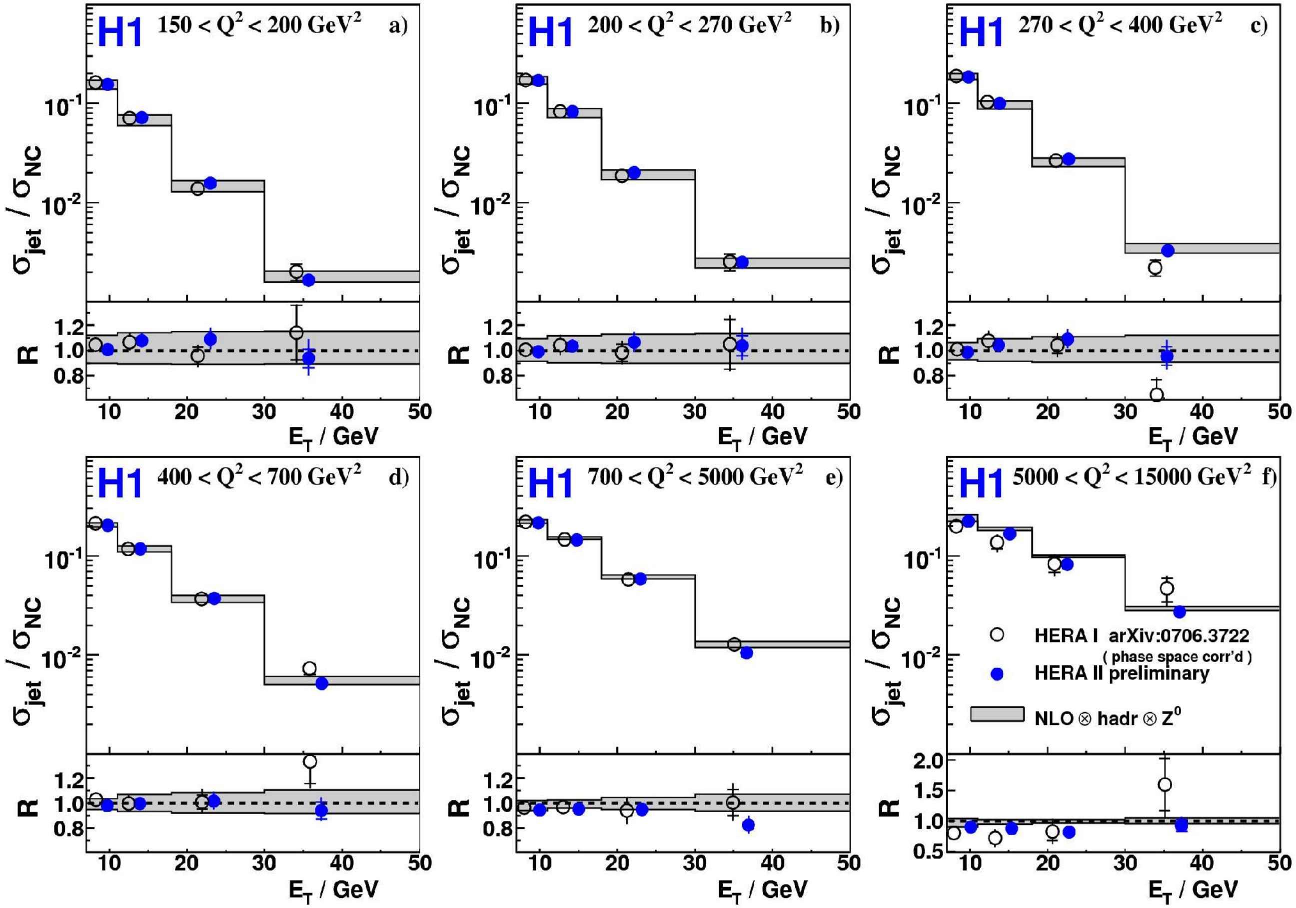


Breit Frame

Bla

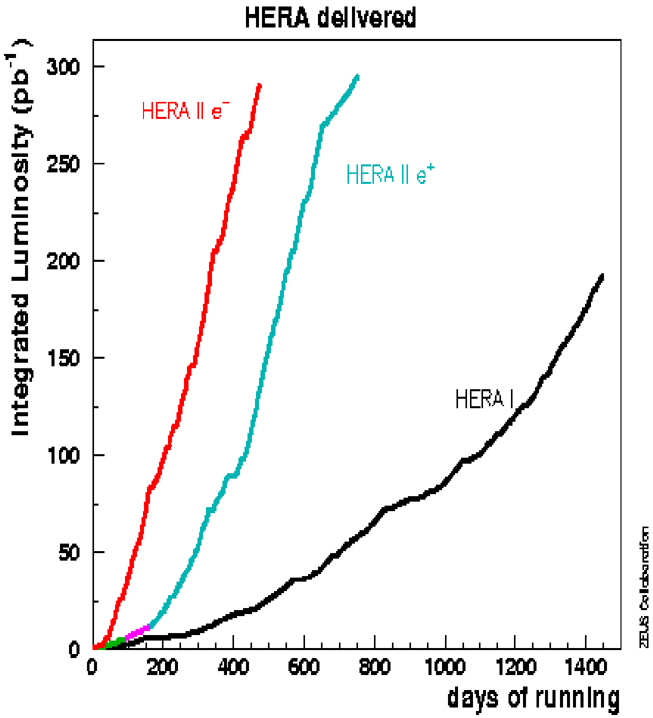
High Q^2 jet multiplicity

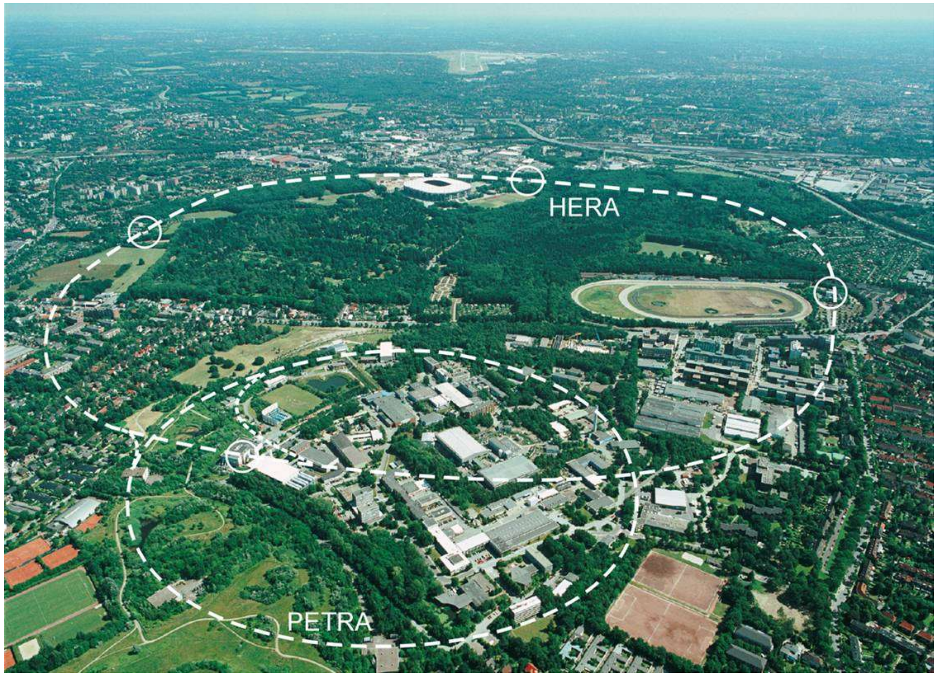
Inclusive jet normalized to DIS NC (H1)



Significant errors improvement at high Q^2 and E_T in HERA II

HERA Collider





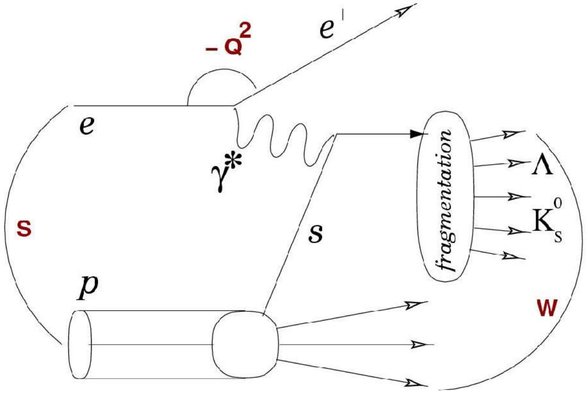
ep kinematics

photon virtuality Q^2

inelasticity $y=Q^2/(x_{Bj}\,s)$

$Q^2 \approx 0$ GeV^2 -- photoproduction

$Q^2 > 1$ GeV^2 -- electroproduction (DIS)



Kinematics

$e(k)p(P) \rightarrow e(k')V(v)p(P')$

$Q^2=-(k-k')^2$

$s=(k+P)^2$

$W^2=(q+P)^2$

$y=(P \cdot q)/(P \cdot k)$

$x=Q^2/(2P \cdot q)$