Jet Production at HERA and Measurement of α_s

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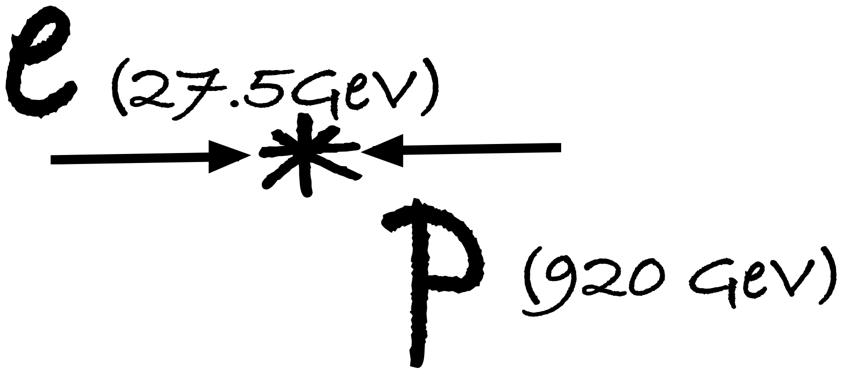
Overview

1) Background - HERA
2) A bit of physics
3) Analyses
    a) Inclusive jets
    b) Multijets
    c) Forward jets
4) Summary

HERA

* Proton-electron collider ($\sqrt{s}$ = 320GeV) situated in Hamburg, Germany
* 220 bunches, 96ns crossings
* Equivalent to a 50TeV fixed target beam
* 6.4 km circumference



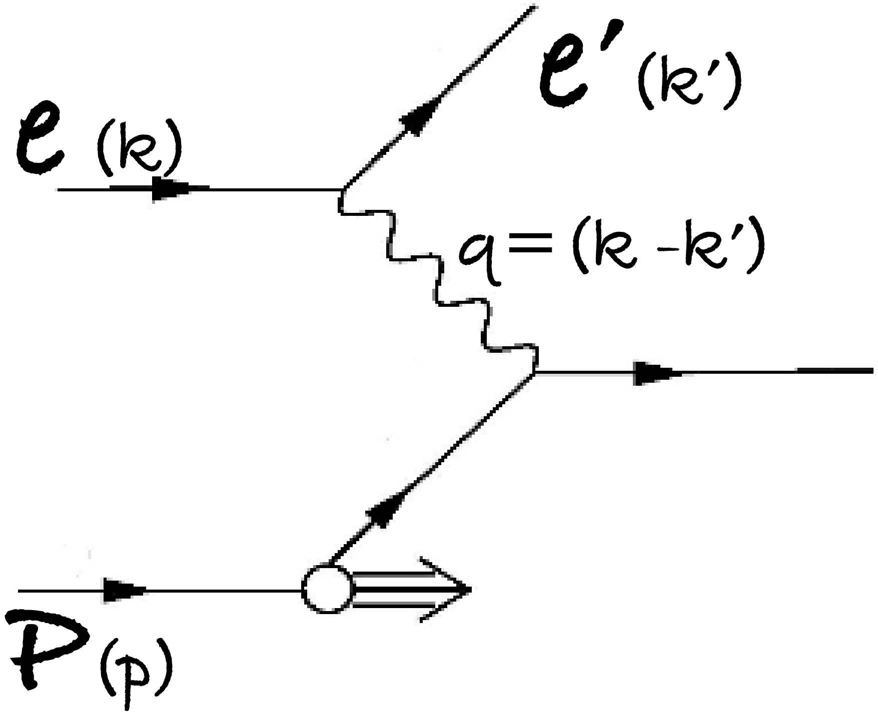
Deep-Inelastic Scattering

* Virtual boson interacts with constituent particle of proton

* Momentum transfer, $Q^2 = -q^2$
  - Virtuality of exchanged boson.

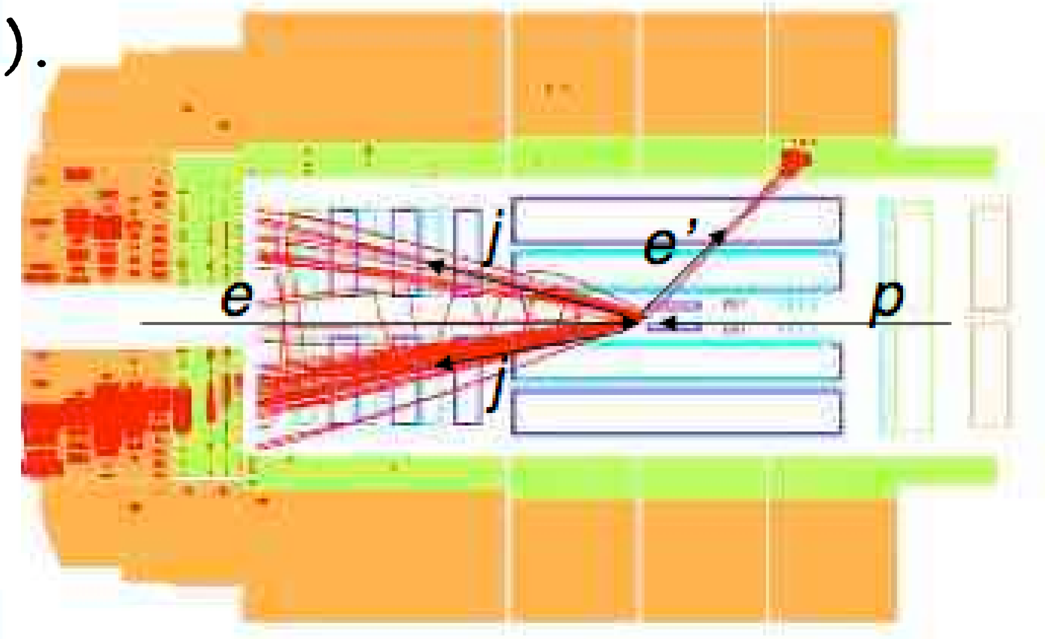
* Björken $x = Q^2 / 2p.q$
  - Fractional momentum of struck parton.

* Inelasticity, $y = p.q / p.k$
  - Relative energy of electron transferred to proton.



Jet Production

* 'Struck' parton quickly hadronises
* Forms tight spray of hadrons - a jet
* Further jets may occur due to QCD radiation (gluons).
* Jets studies can reveal much about the internal structure of the proton.
* Require precise jet measurements.



* HERA experiments have excellent jet resolution.

Jet Production

* Neutral Current DIS jet cross-section :

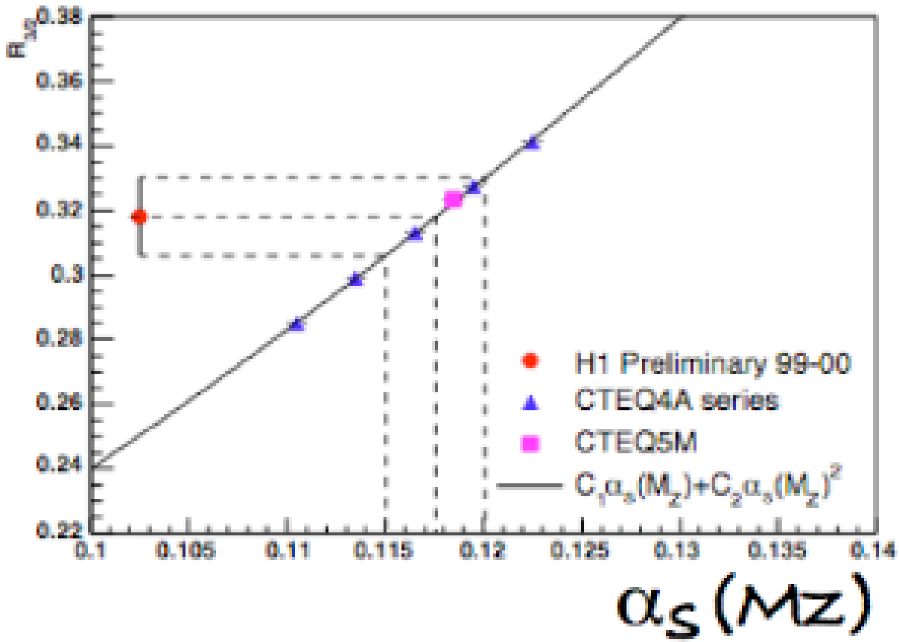
$$\sigma_{jet} = \sum_{a=q,\bar{q},g} \int dx \cdot \underbrace{f_a(x,\mu_F,\alpha_s)}_{(1)} \cdot \underbrace{d\sigma_a(x,\mu_R,\mu_F,\alpha_s(\mu_R))}_{(2)} \cdot \underbrace{(1+\delta_{Had})}_{(3)}$$

* (1) Parton Distribution Function (PDF). Determined experimentally, evolution predicted by QCD.
* (2) Hard scattering cross-section. Calculable from QCD.
* (3) Effect of Hadronisation.

α_s Extractions

"While the true is Godlike, it does not appear directly. We must divine its reality from its manifestations." - Goethe

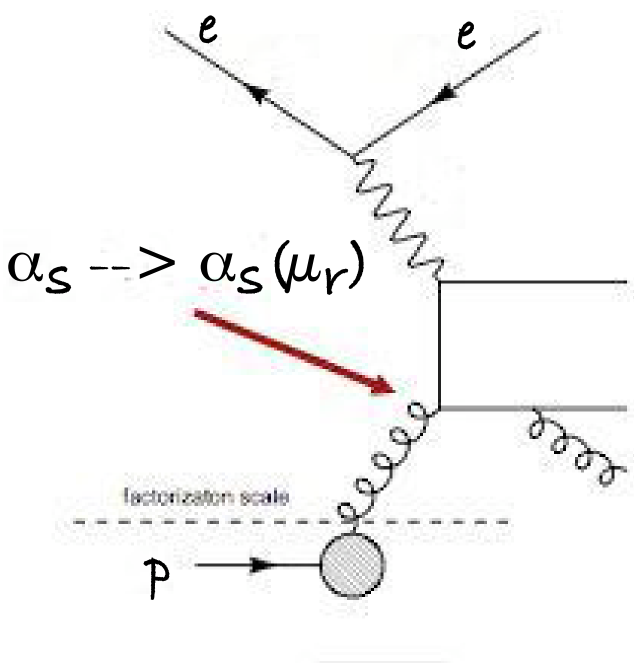
* The strong coupling, the only free parameter of QCD, can not be measured directly.



* Data from processes thought to depend on α_s must be compared against theory predictions and the strong coupling extracted.

QCD Uncertainties

* Renormalisation scale (μ_r) - scale at which strong coupling evaluated



* Factorisation scale (μ_f) - scale at which parton densities evaluated

* Cross-section only not dependent on μ_r for all order perturbation.

* Uncertainty can be as large as 50%, even at NLO.

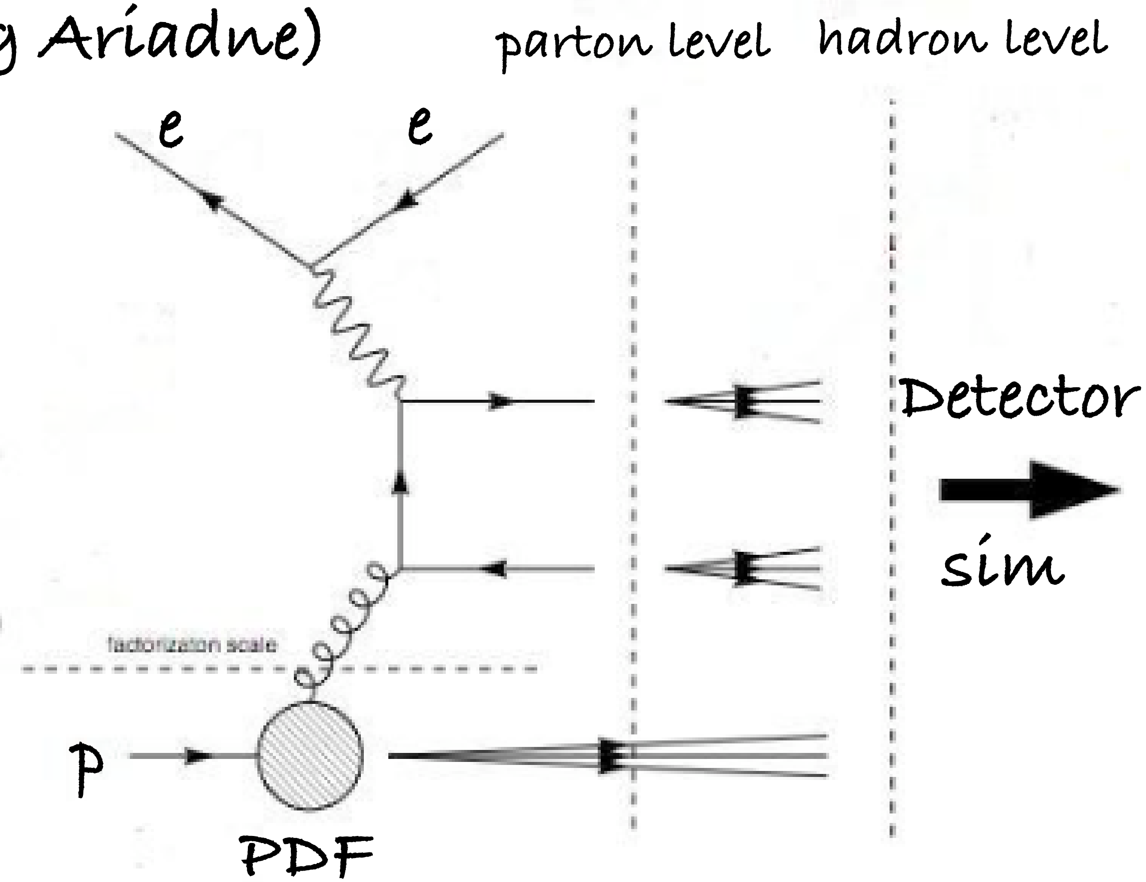
NLO calculations

* Older programs e.g. DISENT, DISASTER still used.
* NLOJET++ is now most popular.
* Interfaced to various PDFs eg. CTEQ, MRST
* Parton level cross-sections - need to rely on LO MC for hadronisation corrections
* No Z exchange - excludes highest Q^2 regions from QCD analysis where theory uncertainty ought to be lowest.
* Theory errors dominate - factor four larger than experimental errors for HERA average $\alpha_s(M_Z)$

* Only Leading Order Monte Carlos available for DIS
- Matrix element + parton showers (e.g. Rapgap, Lepto)
- Colour dipole model (e.g Ariadne)

* Hadronisation model
  - Lund string fragmentation
  - Herwig Cluster

* Used for detector, QED and hadronisation corrections

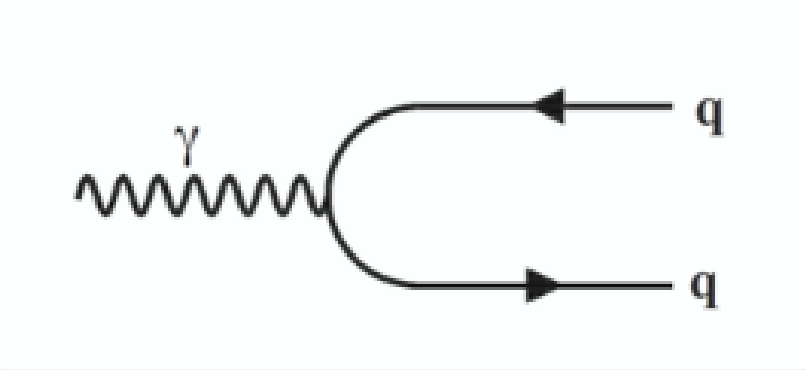


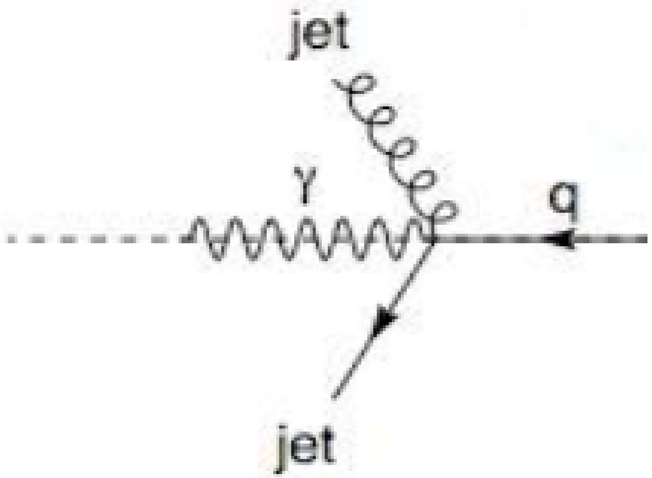
The Breit frame

* Frame where virtual boson is entirely spacelike

* At lowest order, quark is back scattered

* Practical - High E_t jet events must be at least order α_s



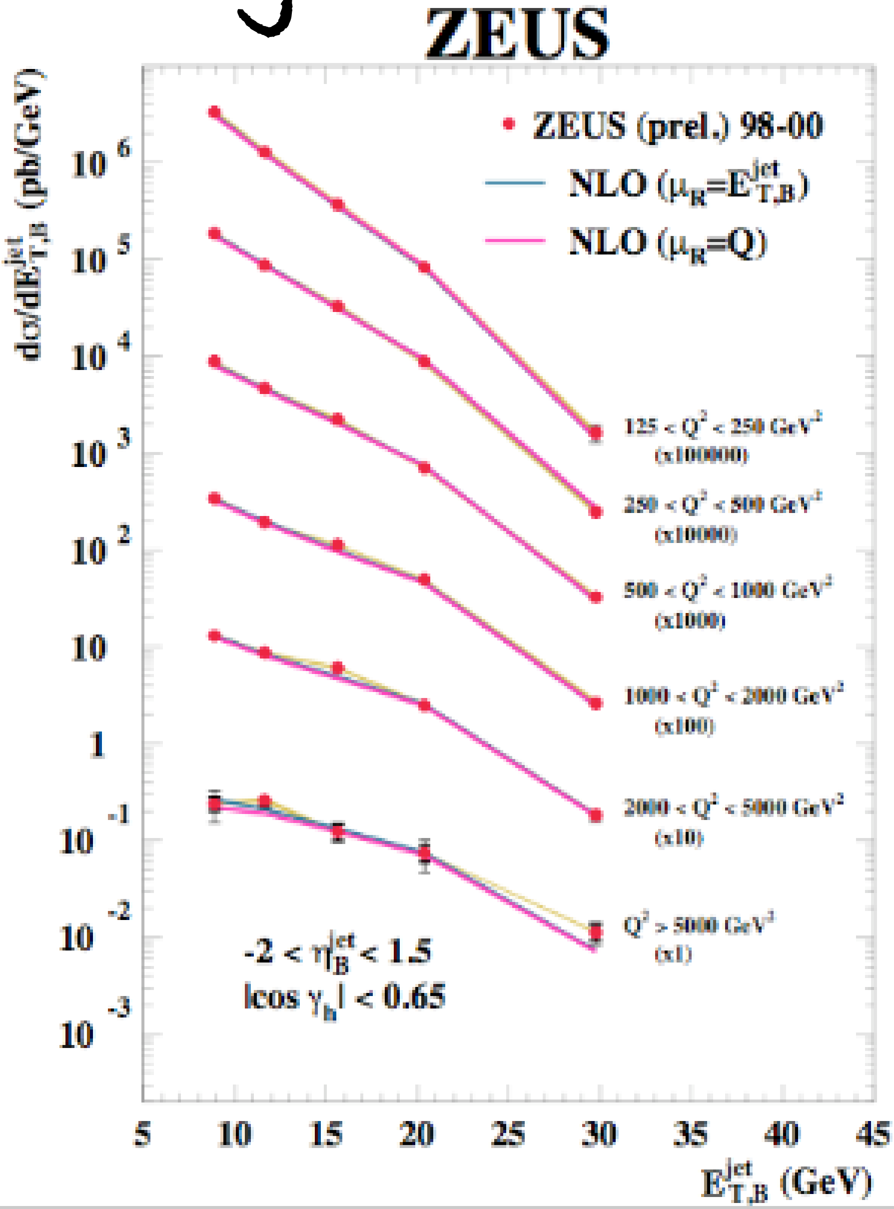


Inclusive jets in DIS

* Study of the inclusive jet cross-section.

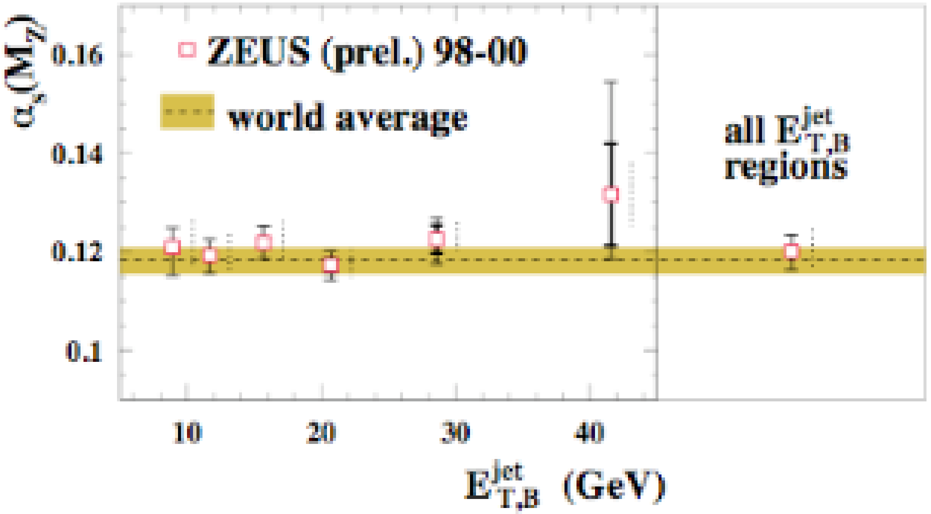
* Cross-sections measured as functions of Et and Q^2

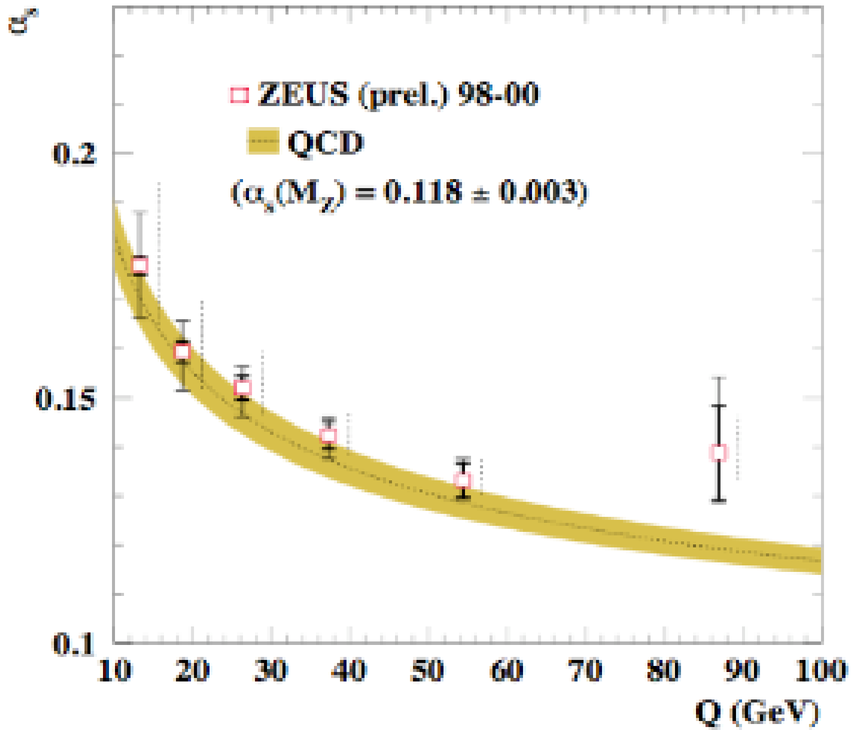
* Excellent agreement between data and NLO over many orders of magnitude.



Inclusive jets in DIS

* α_s extracted with competitive uncertainties over a large range of Et and momentum transfer.

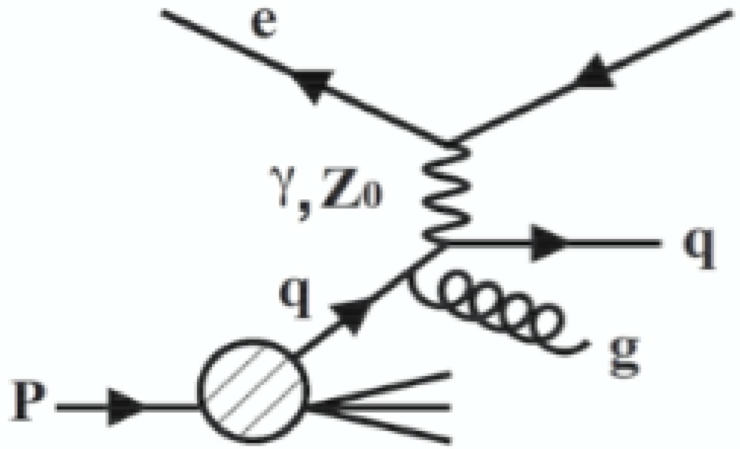


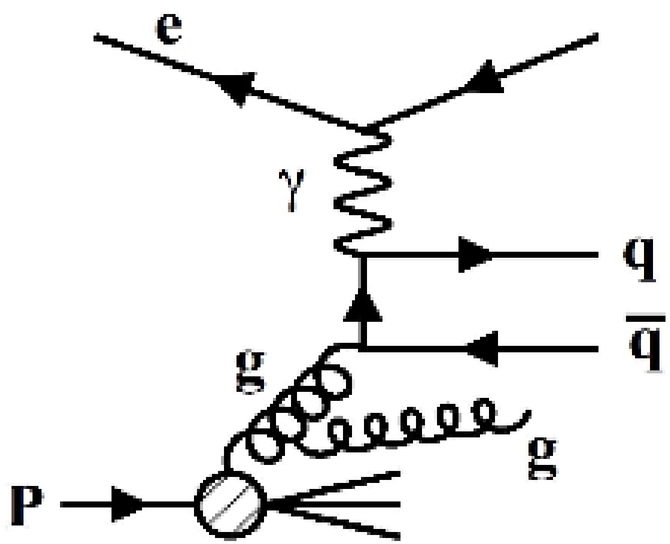


* Running of coupling clearly seen.

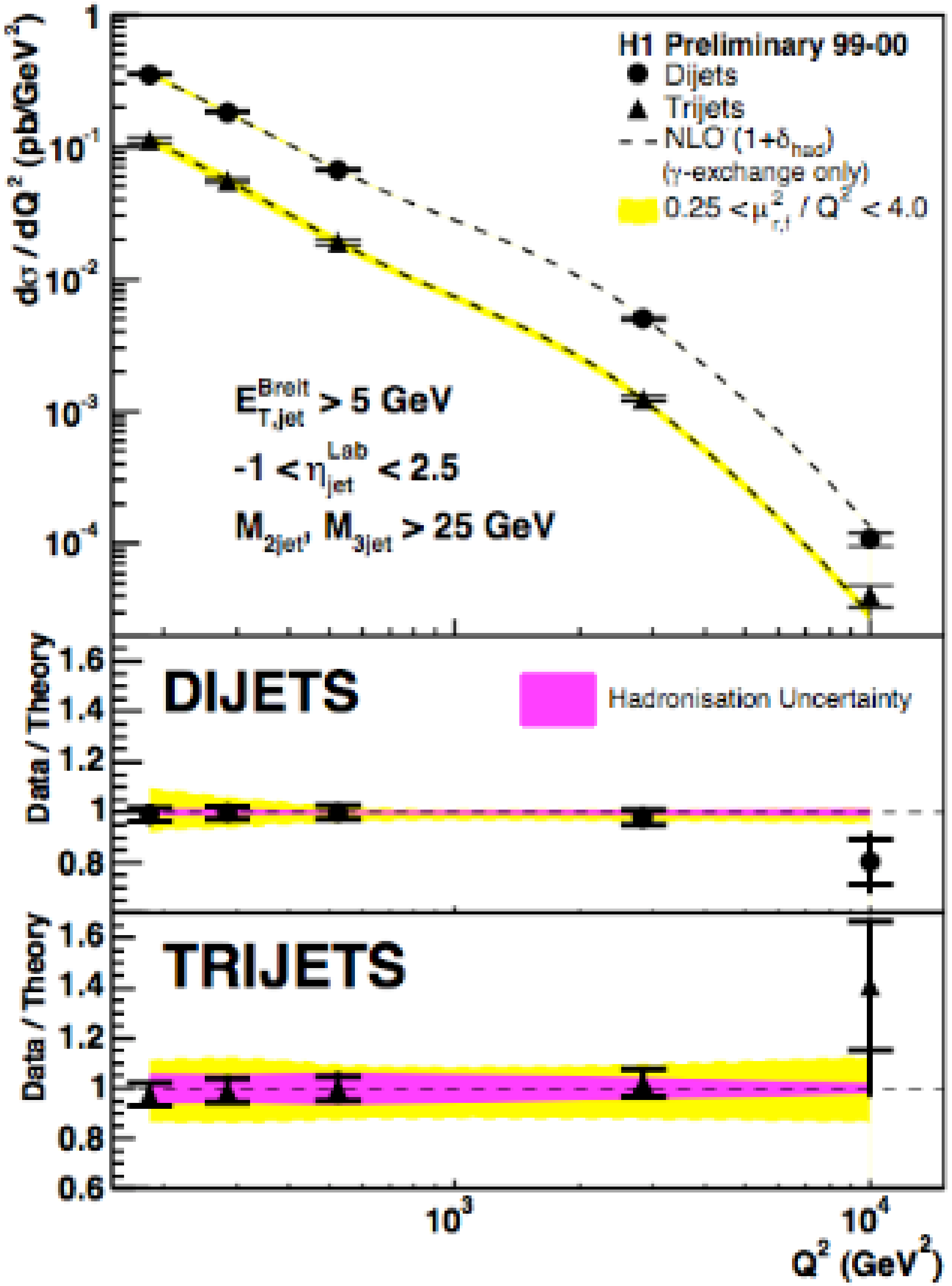
Multijets

* Study the trijet and dijet cross-sections and their ratio
* (LO) Three jet processes are of order α_s^2
* (LO) Two jet processes are of order α_s
* The α_s dependancy of their ratio is a sensitive test of pQCD.





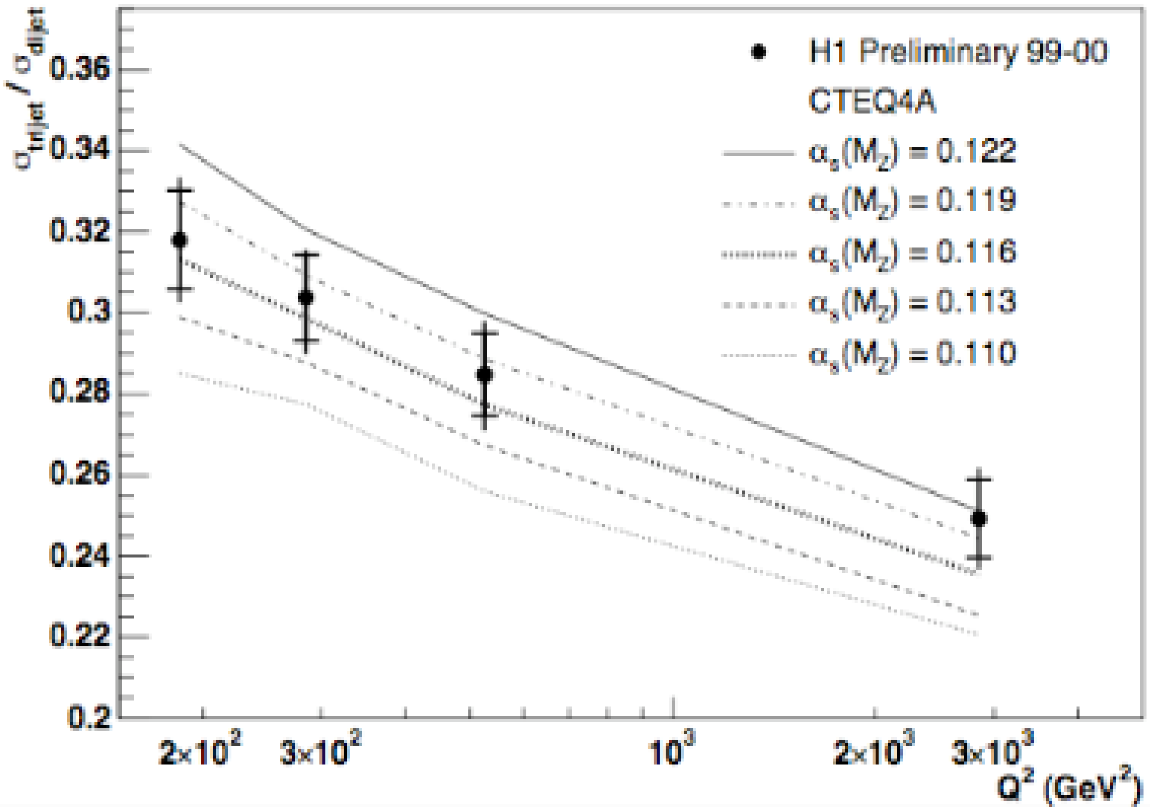
* $150 < Q^2 < 15000$ GeV^2
  (photon exchange only)
* Cross-sections with respect to Q^2 show excellent agreement.
* Sufficient accuracy to take ratio, $R_{3/2}$
* Small experimental uncertainties - success for HERA!



Multijets

* Cross-section ratio is very sensitive to the strong coupling.

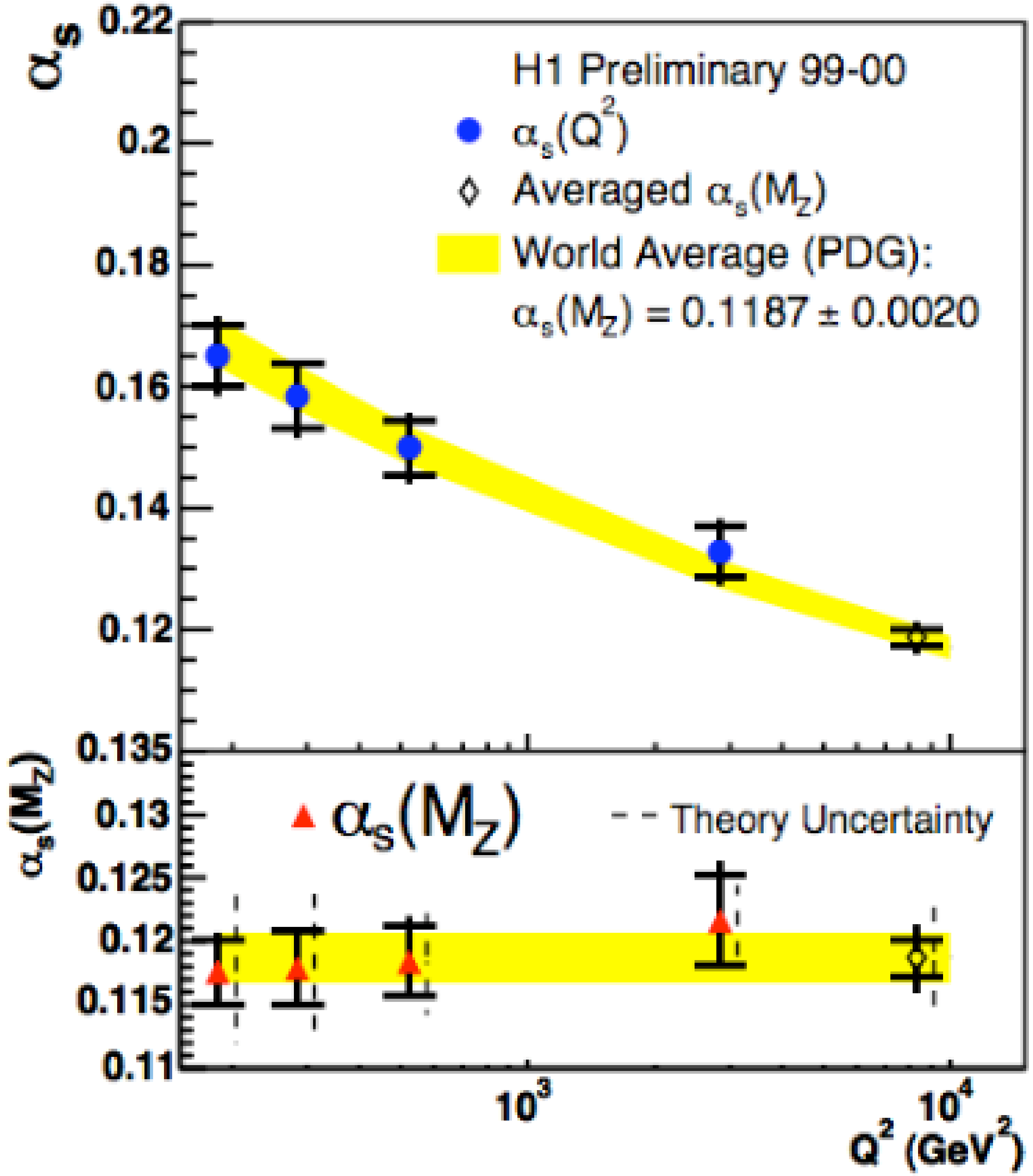
* Able to extract strong coupling with competitive uncertainties.



* Full HERA2 data set will allow finer binning at higher Q^2 where theory uncertainties are smallest.

* High precision α_s extraction. Excellent agreement compared with World Average (PDG)

* Running of strong coupling clear as function of Q^2

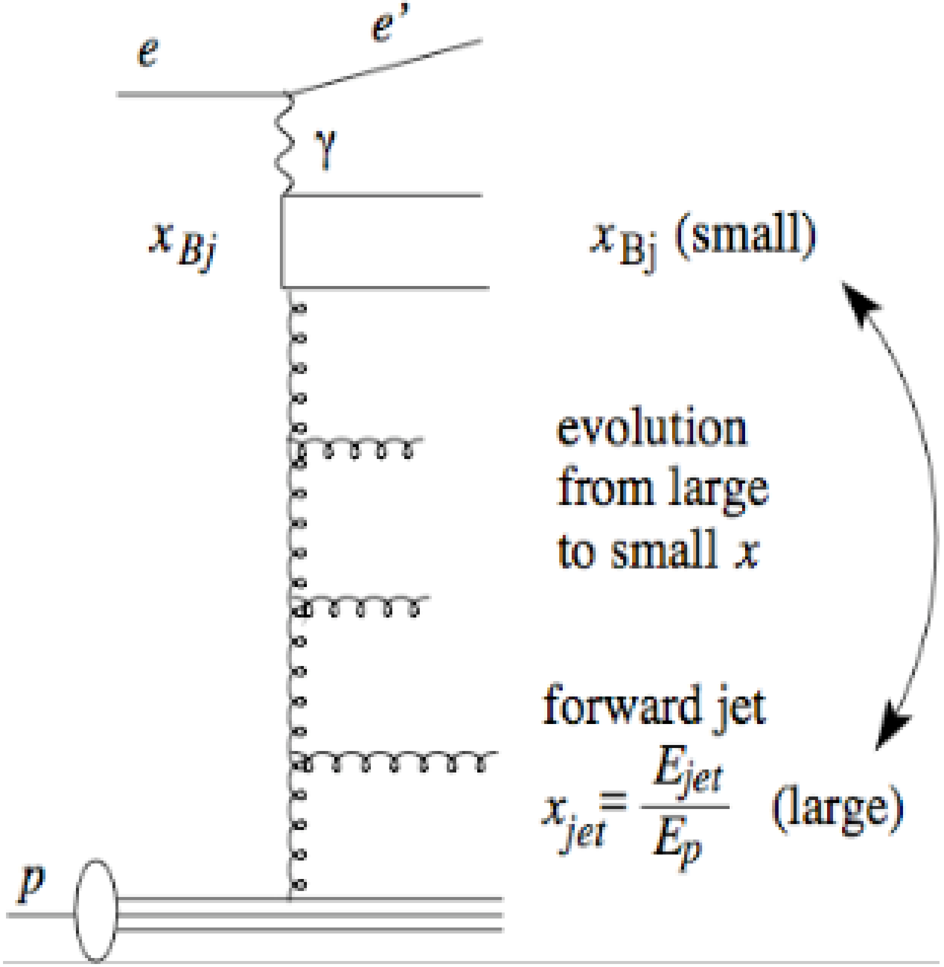


Forward jets

* HERA extends x_{bj} region down to 10^{-4}

* Parton can induce QCD cascade, before interacting with virtual photon.

* Interesting region to study parton dynamics

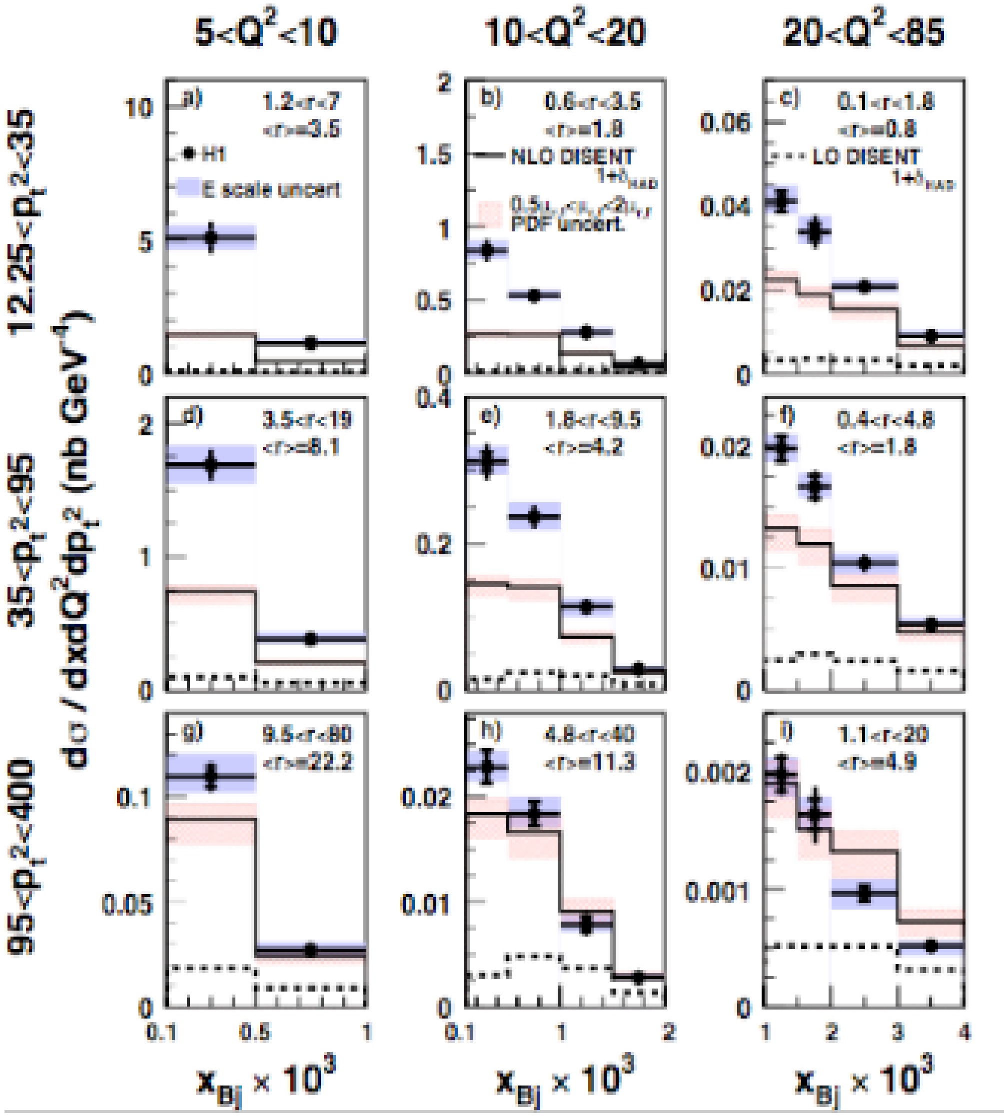


Forward jets

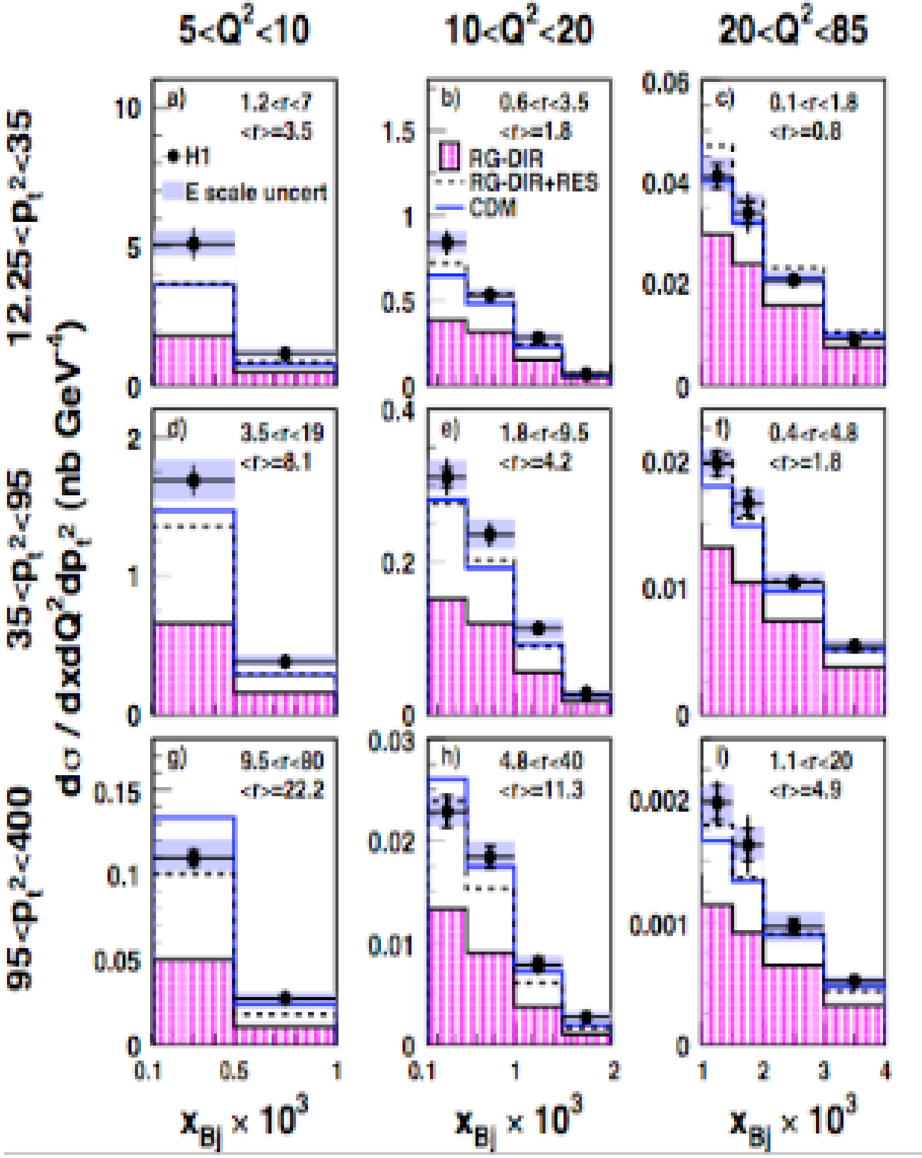
* NLO only describes high Pt forward jet data.

* Perhaps higher orders required c.f. difference between LO and NLO.

* Other QCD based models perform better in this region



Forward jets



* Conventional DGLAP calculations order partons in virtuality.

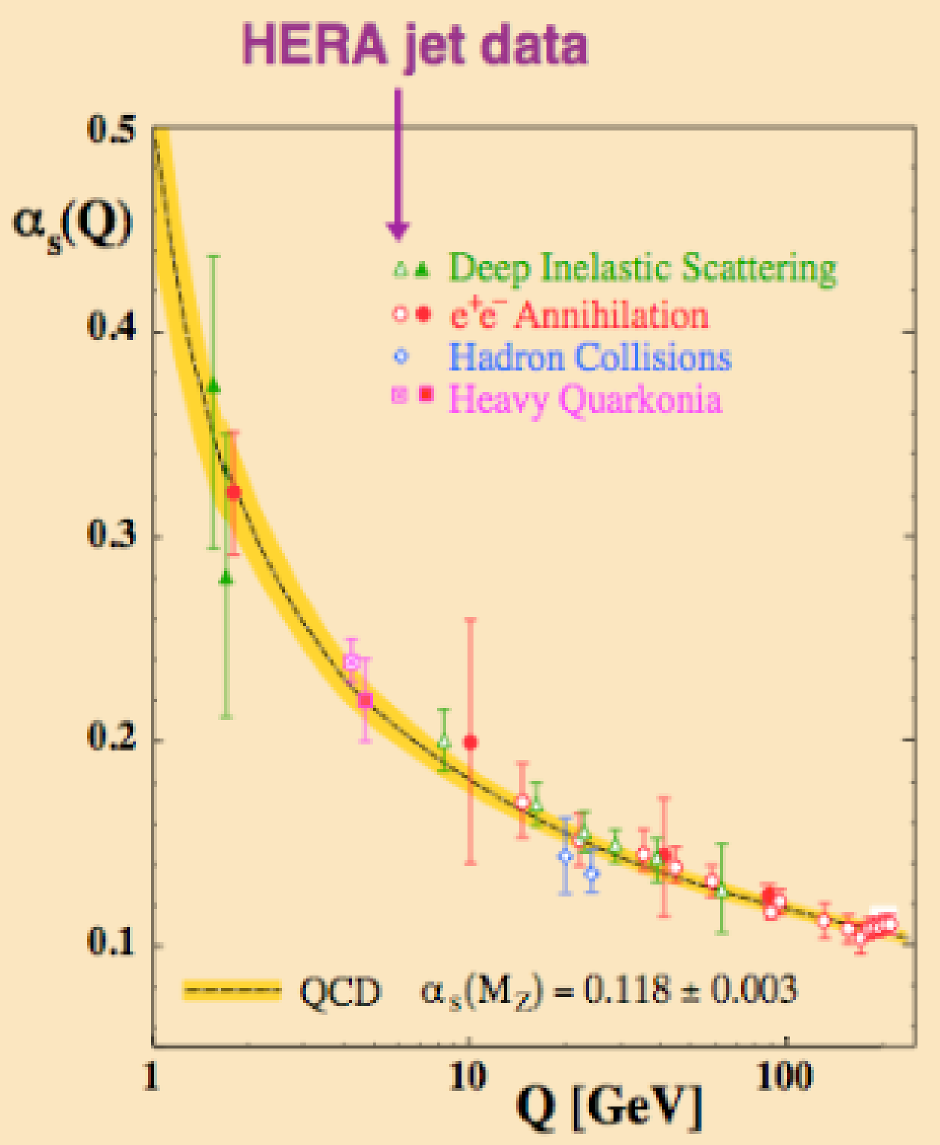
* Models including breaking of ordering describe data better.

* Higher order parton emissions required to describe radiation pattern at low X

$\alpha_s(M_Z)$ summary

Process	Alpha_S (Mz)	Statistical	Systematic		Theoretical	
Inclusive DIS (ZEUS)	0.1196	± 0.0011	+	0.0019	+	0.0029
			-	0.0025	-	0.0017
Multijets (H1)	0.1187	± 0.0014	+	0.0022	+	0.0050
			-	0.0024	-	0.0050
Inclusive DIS (H1)	0.1197	----	+	0.0016	+	0.0046
			-	0.0016	-	0.0048
Multijets (ZEUS)	0.1179	± 0.0013	+	0.0028	+	0.0064
			-	0.0046	-	0.0046
HERA	**0.1186**	----	+	**0.0011**	+	**0.0050**
			-	**0.0011**	-	**0.0050**

α_s(Mz) Comparison



* HERA determinations consistent with other experiments.

* Uncertainties are very competitive.

* More data to come from HERA2 = more measurements at higher precision.

Summary and Outlook

* NLO (usually) describes jet physics to high precision.
* Able to extract competitive α_s from HERA experiments.
* HERA is a unique facility for QCD studies.
* 700 pb^{-1} expected from HERA2.
* More data and improved theory calculations will allow highest ever precision for jet physics in DIS.
* An excellent step towards full understanding of backgrounds at LHC.