

ADDITIONAL SLIDES



Hard QCD and Structure Functions



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- **Introduction**
- **I.** Fixed order + Resum + Had. Corrections
- **II.** DGLAP tests.
- **III.** Fixed order + Resum+Had. Cor.+DGLAP
- **VI.** Fixed order + Resum + Power Corrections
- **V.** Tests of parton showers and models of HO
- **VI.** BFKL, Connection with Soft QCD
- **Conclusion**

Introduction (tools)

1. Fixed order pQCD calculations:

Calculation typically to NLO in α_s . exist for "safe" observables.
(sometime to NNLO or beyond..)

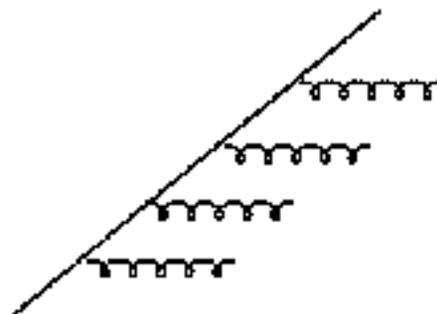
2. Resummations: for some observable R which is becoming small

$$\alpha_s^n (\ln 1/R)^{n+1-l}, (n = 1..∞)$$

may be able to **resum** large logs.
LL ($l=0$), NLL($l=1$) ...

3. Monte Carlo implementations of HO

Parton Showers(Pythia, Herwig...)
Color Dipoles(Ariadne..)



Introduction (tools cont.)

3. DGLAP evolution equations:

Structure functions, fragmentation functions

4. Hadronization Models and Monte Carlos:

LPHD, Cluster fragmentation, String fragmentation, etc.

5. Power corrections:

Infer the behavior of non-pert. part by analyzing the divergence behavior of pert. part.

Analyses usually use combinations of above: each has its limitations.
I have (with some arbitrariness) classified them as follows:



Type I: Fixed Order + Resummation + MC had. cor.
Suited for e^+e^- machines

Type II: DGLAP analyses
Deep Inelastic Scattering, Structure Functions

Type III: I + II , DGLAP + final states:
Jets in DIS, Tevatron

Type IV: Tests of parton showers and other models of HO

Type V: Power corrections
Event shapes

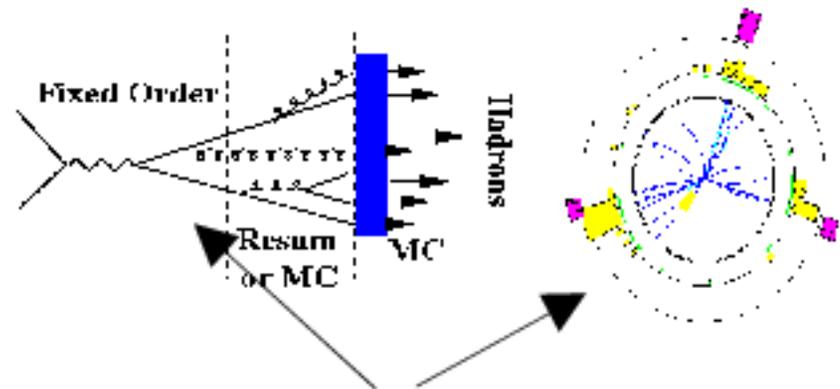
Type VI: Connection with soft QCD, diffraction, BFKL



QCD studies type I:

Jet algorithms: e.g. Durham(or kt)

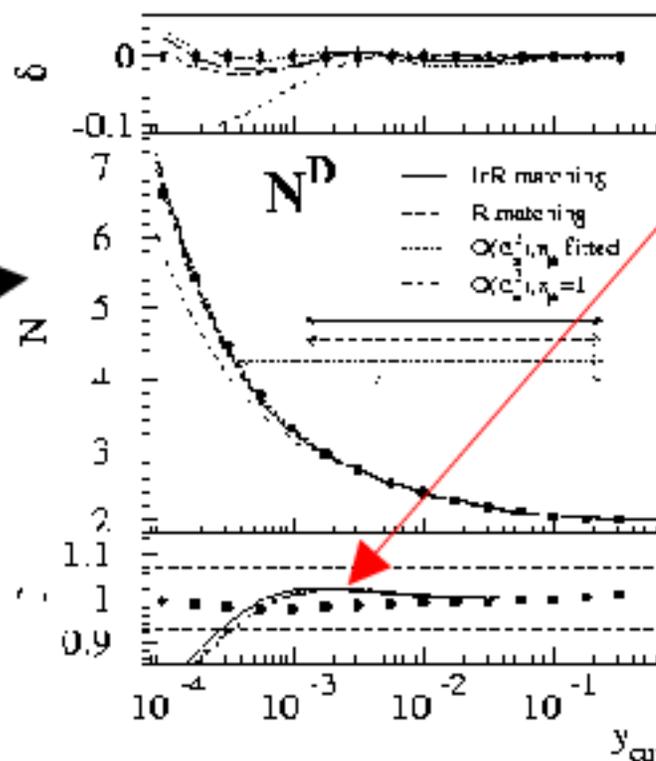
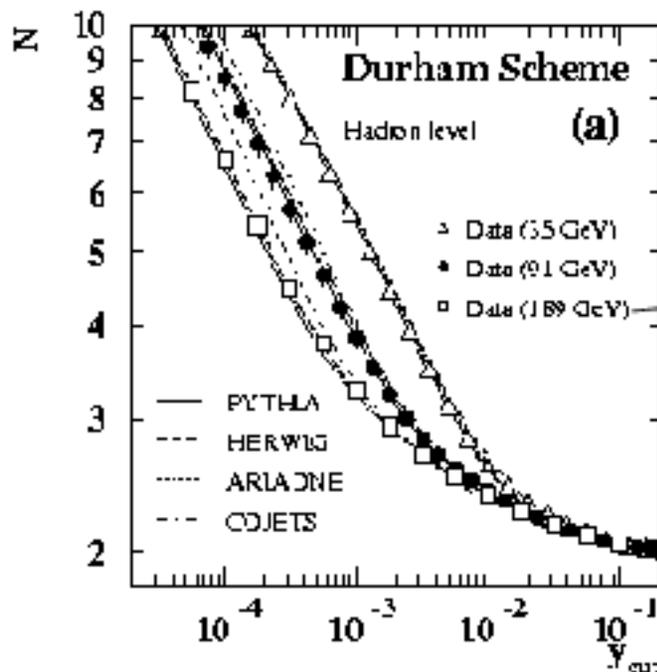
$$y_{ij} = \frac{\min(E_i^2, E_j^2)(1 - \cos(\theta_{ij}))}{s}, \quad y_{ij} \geq y_{cut}$$



Good parton to hadron correspondence:

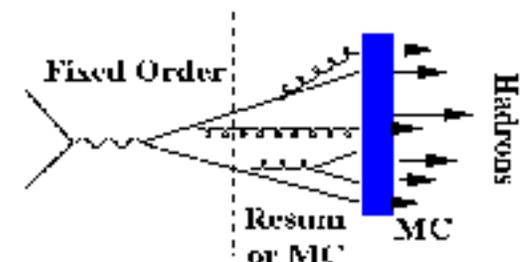
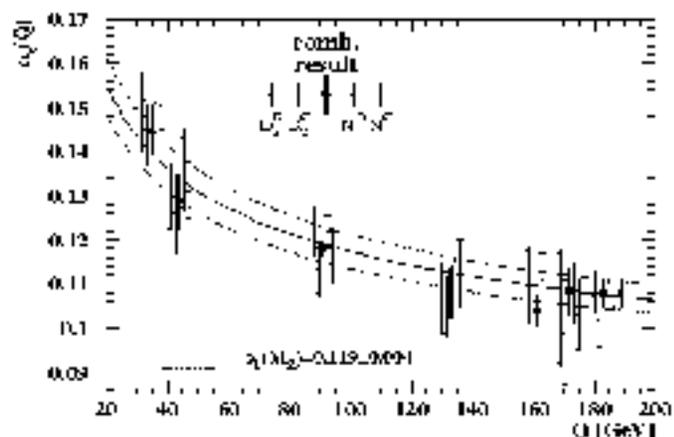
JADE-OPAL analysis (N jets):

Small had. corrections.

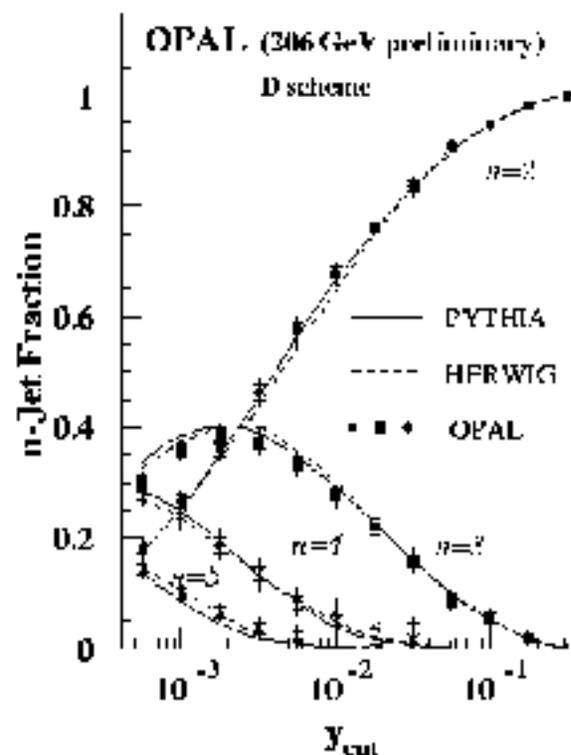


QCD studies type I:

JADE-OPAL result:

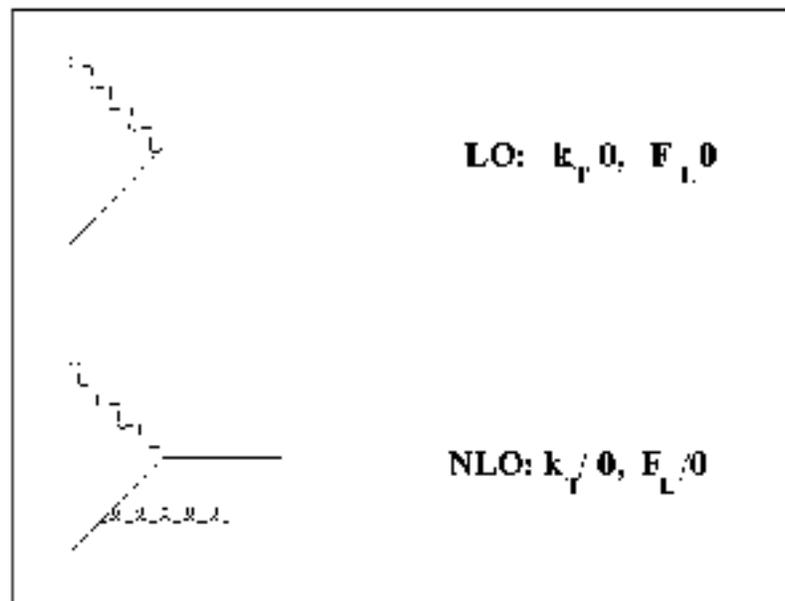


Jets checked to highest LEP energies

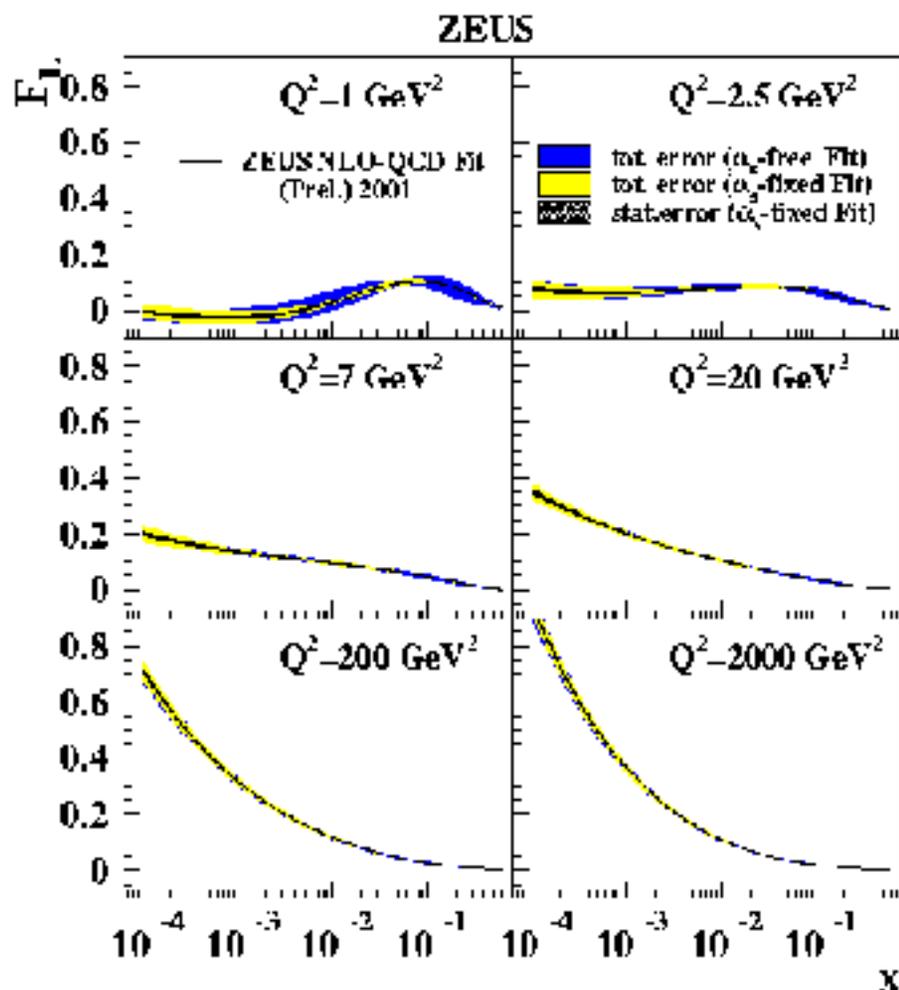


QCD studies type II: DGLAP evolution

Longitudinal Structure Function:

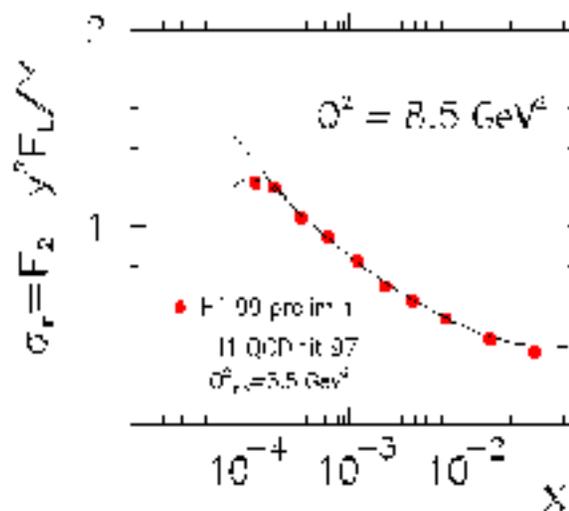


F_L is closely related to the gluon



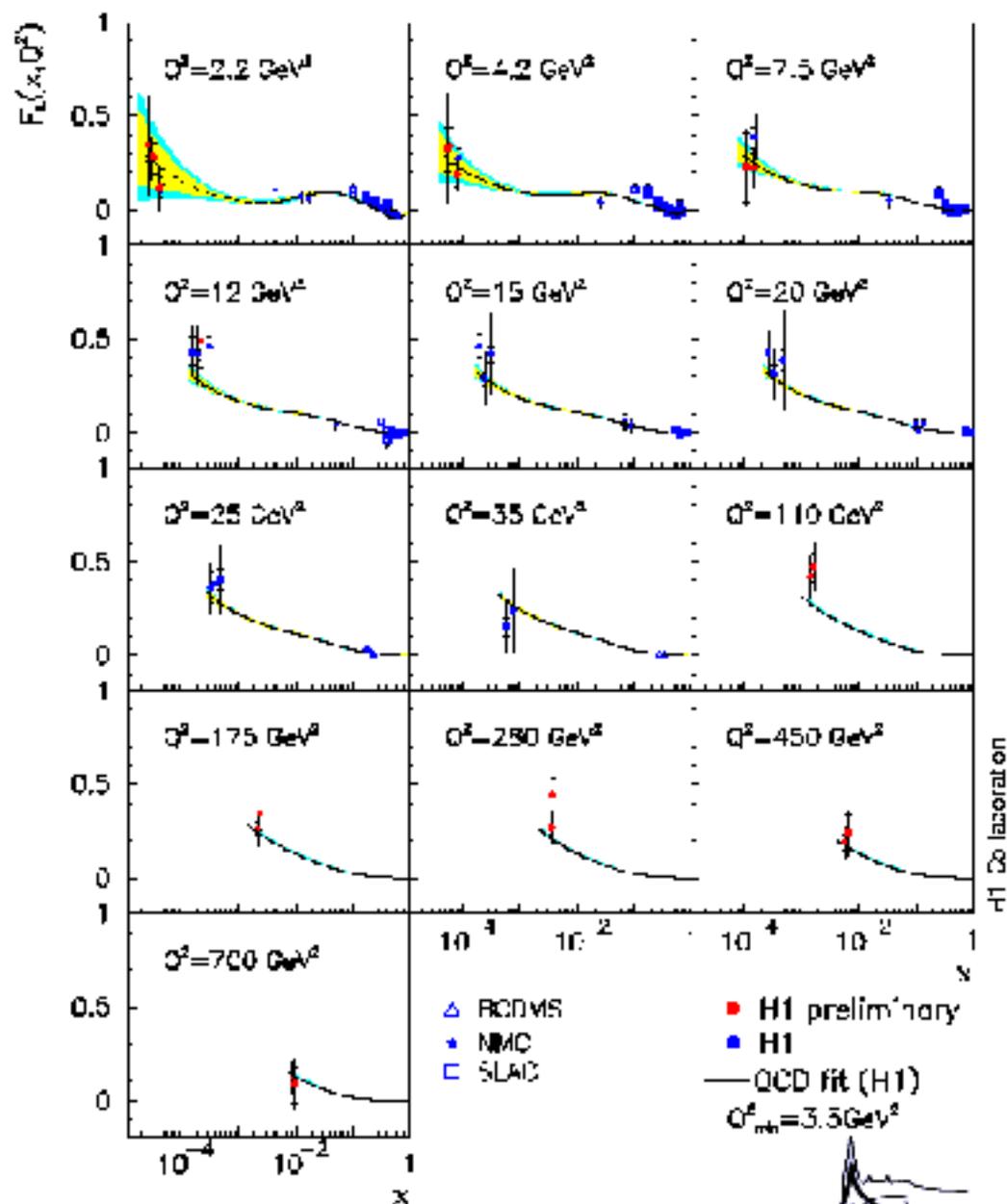
QCD studies type II: DGLAP evolution

F_L structure function



$$\sigma_r = F_2 - y^2 F_L / Y_+$$

**Consistency
check of
DGLAP
description**



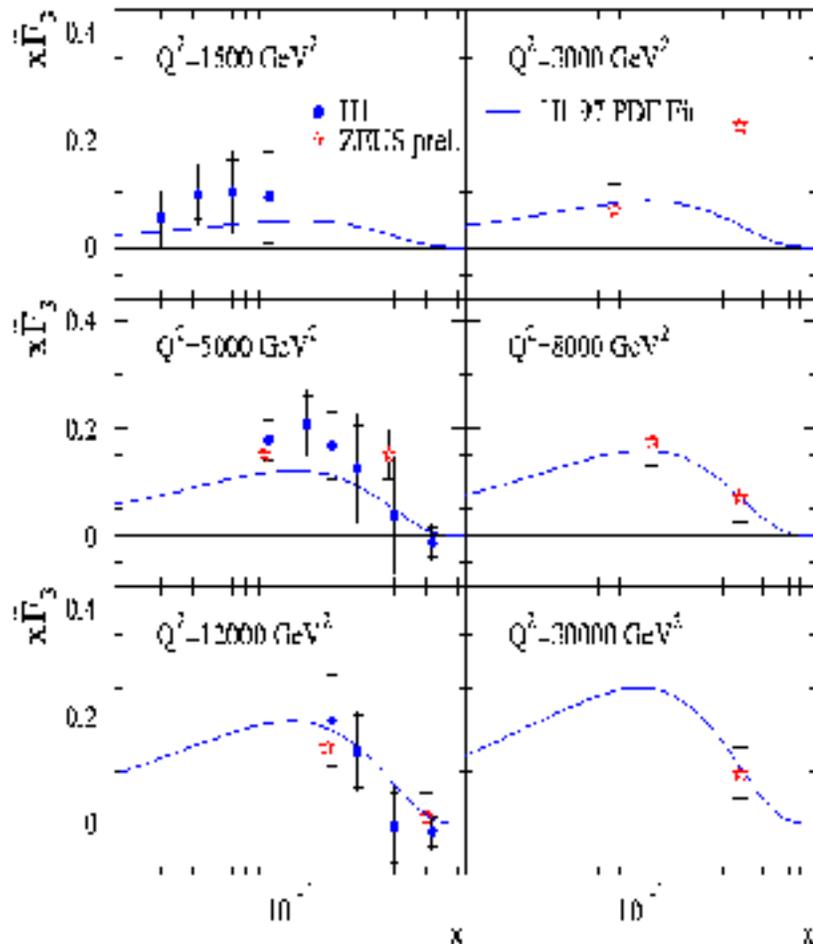
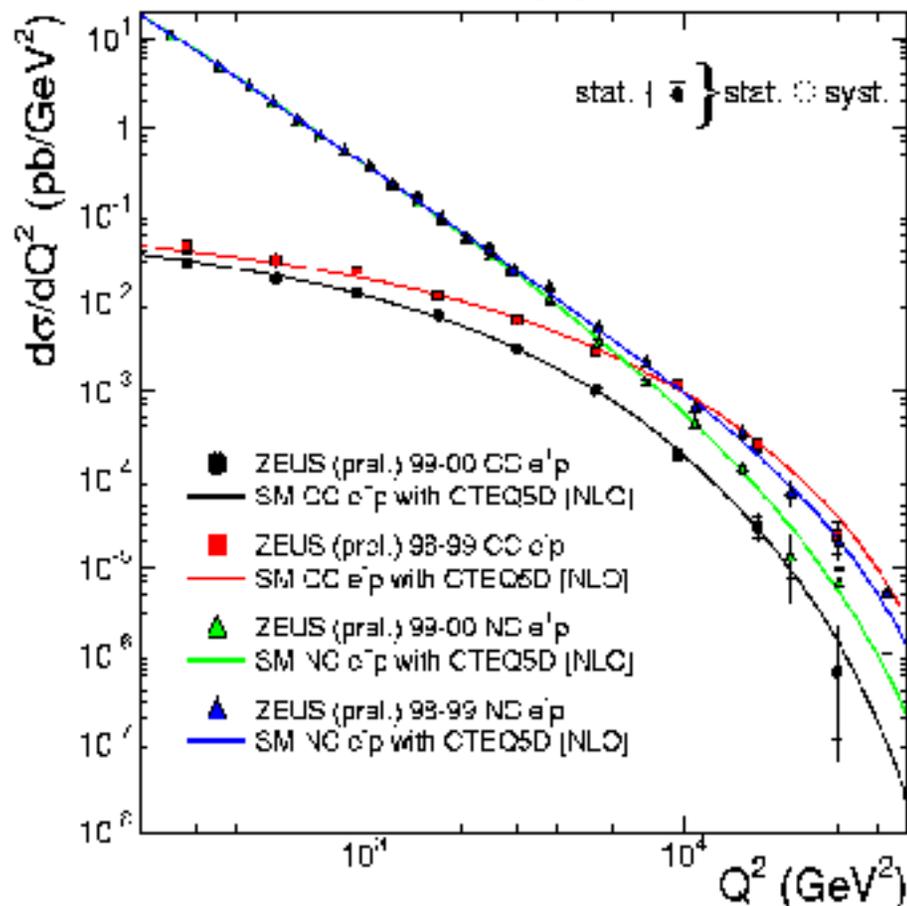
QCD studies type II:

DGLAP evolution

$$\sigma_{\text{rec}}(e^-p) \sim \frac{\alpha^2}{Q^4} [Y_+ F_2 \mp Y_- x F_3]$$

$$xF_3 = \sum B(Q^2)(q - \bar{q}) \quad Y_{\pm} = 1 - (1-y)^{\pm 2}$$

ZEUS



Measurements of NC and CC at HERA

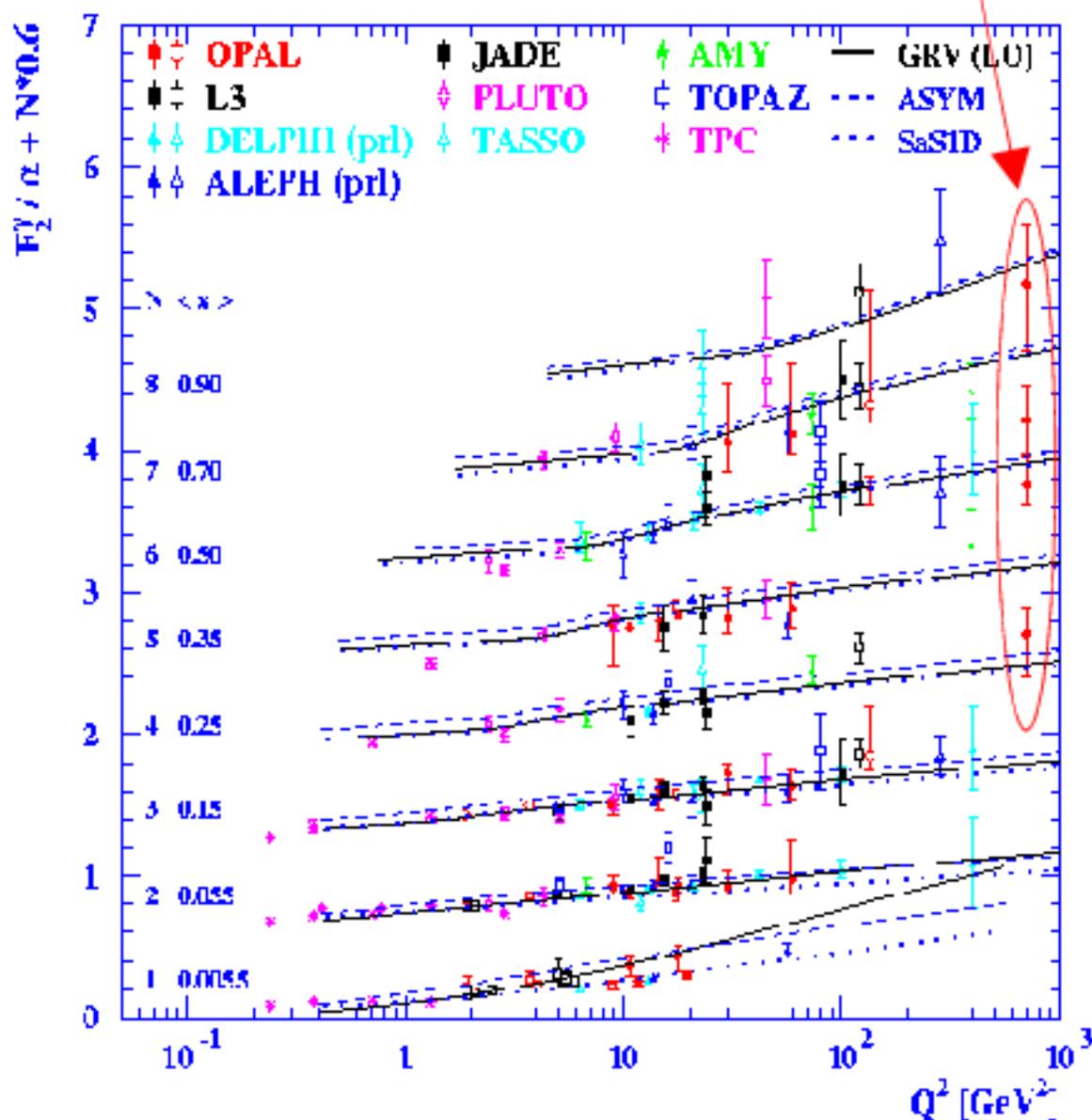
Results ca. $100 \text{ pb}^{-1} e^+p$ and $15 \text{ pb}^{-1} e^-p$

First at high Q^2 and in ep



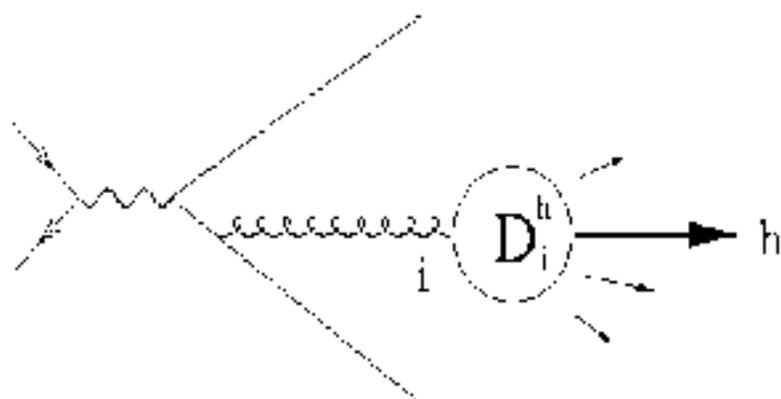
QCD studies type II: DGLAP evolution

new meas. from OPAL



QCD studies type II: DGLAP evolution

QCD factorization of Frag. Fcns.



Distribution of hadron "h"

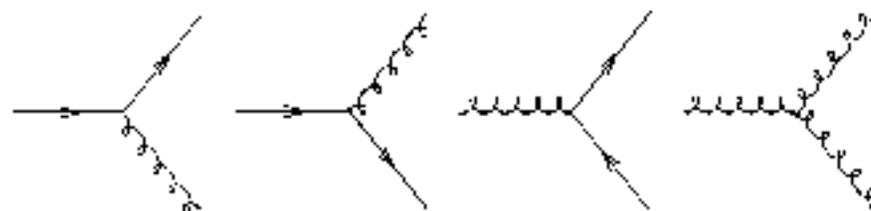
$$F^h(x_p, s) = C \otimes D^h \quad x_p = 2|\vec{p}_h|/\sqrt{s}$$

C – pQCD "coefficient" functions
 D^h – (universal) fragmentation fcn
 (FF's)

FF's are non-perturbative, but it's evolution is predicted via pQCD (DGLAP eq.)

$$\partial D^h / \partial \ln(s) = P \otimes D^h$$

P – splitting functions:
 probability of parton branching

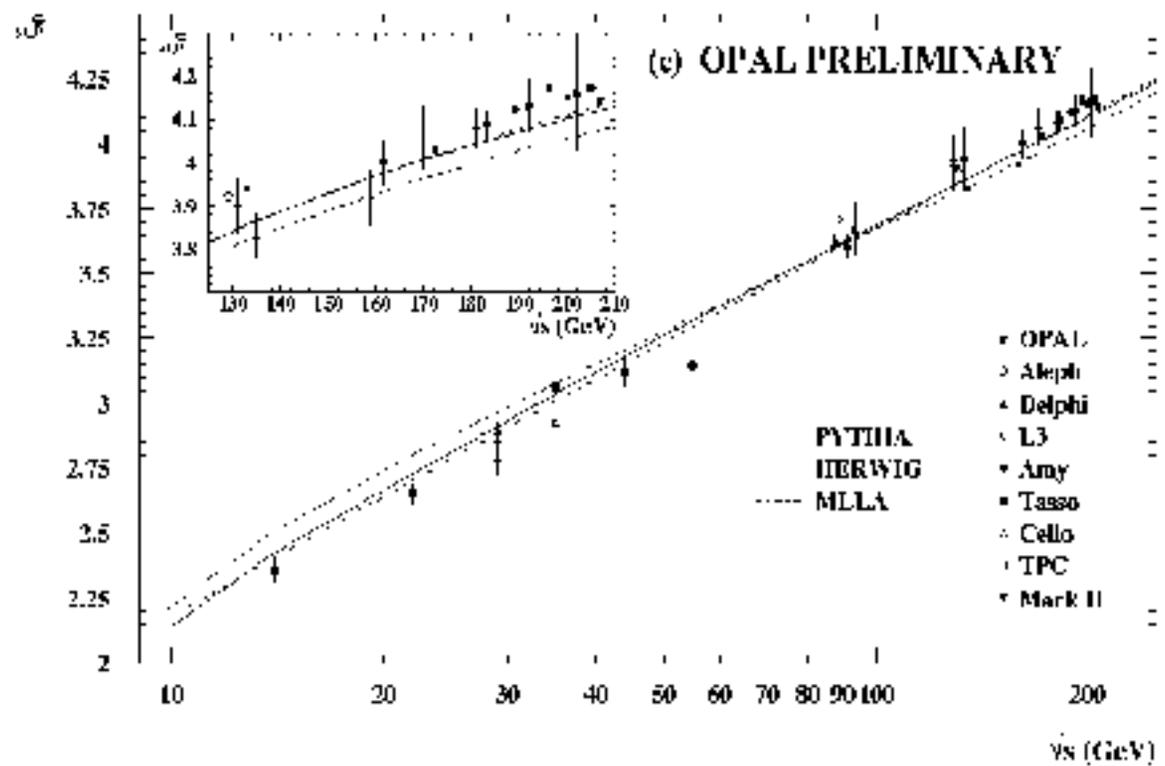
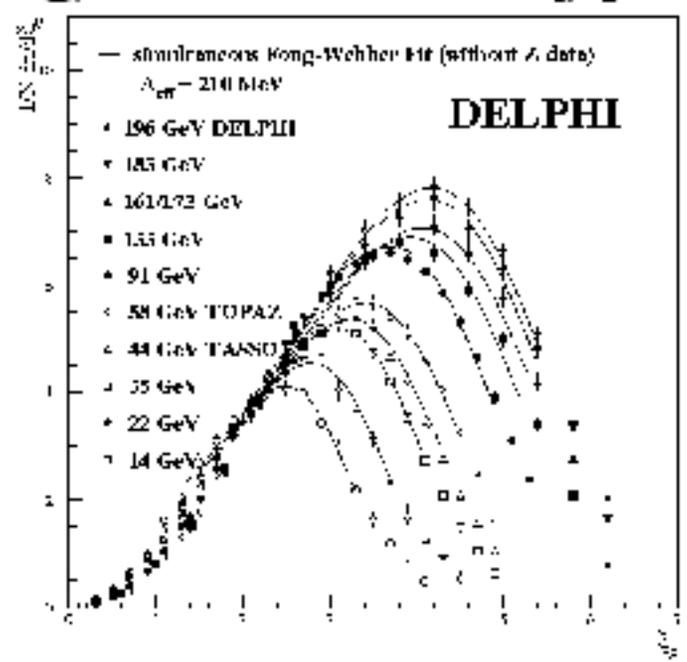


Once particle spectra are measured at some s , predicts evolution with s .



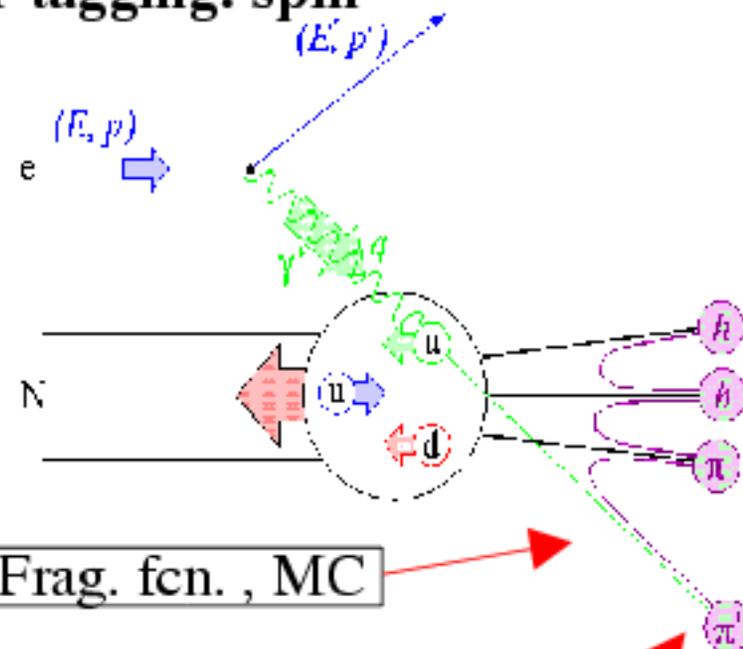
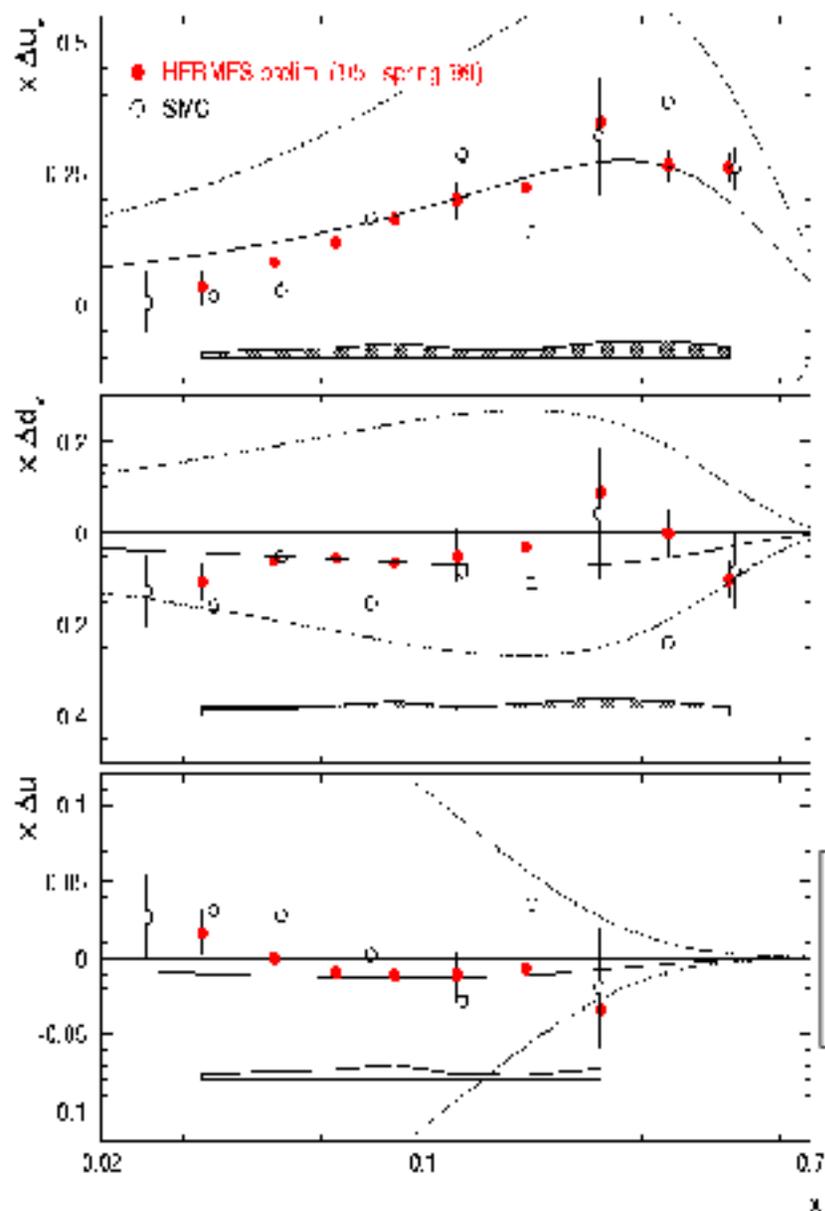
QCD studies type II:

DGLAP evolution



QCD studies type III:

Flavor tagging: spin



Tag charge of leading hadron

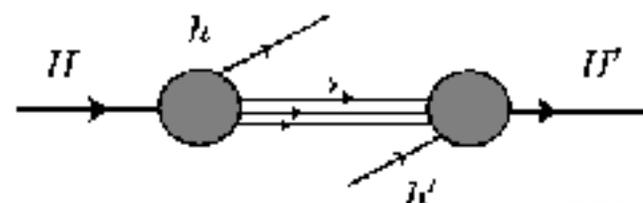
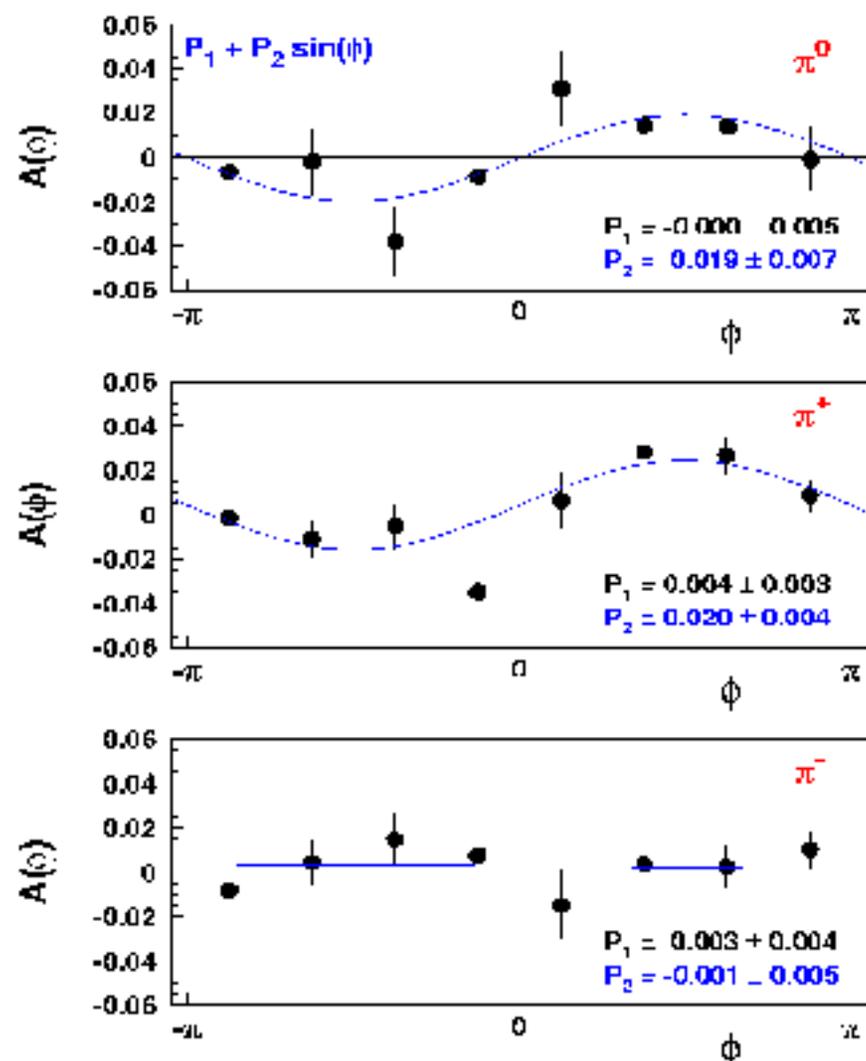
Update from HERMES using deuterium data (more to be analyzed)



QCD studies type III:

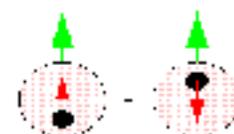
TRANSVERSITY δq

HERMES

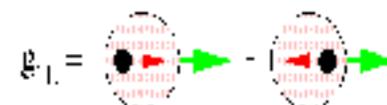


helicity $\delta q \leftrightarrow \begin{pmatrix} \mathbf{H} & \mathbf{h} \\ \frac{1}{2} & -\frac{1}{2} \end{pmatrix} \rightarrow \begin{pmatrix} \mathbf{H}' & \mathbf{h}' \\ -\frac{1}{2} & \frac{1}{2} \end{pmatrix}$

equivalent to



as opposed to



Unpol. e beam \rightarrow Pol. target

long. now trans. in future

Azimuthal Asym. in leading pions

\rightarrow Chiral odd frag. fcn. (Collins fcn.)

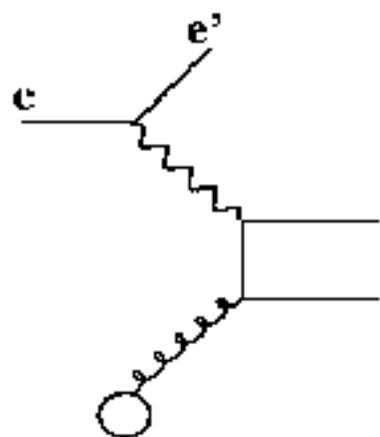
Unique test: unusual evolution

First moment: comparison to lattice?

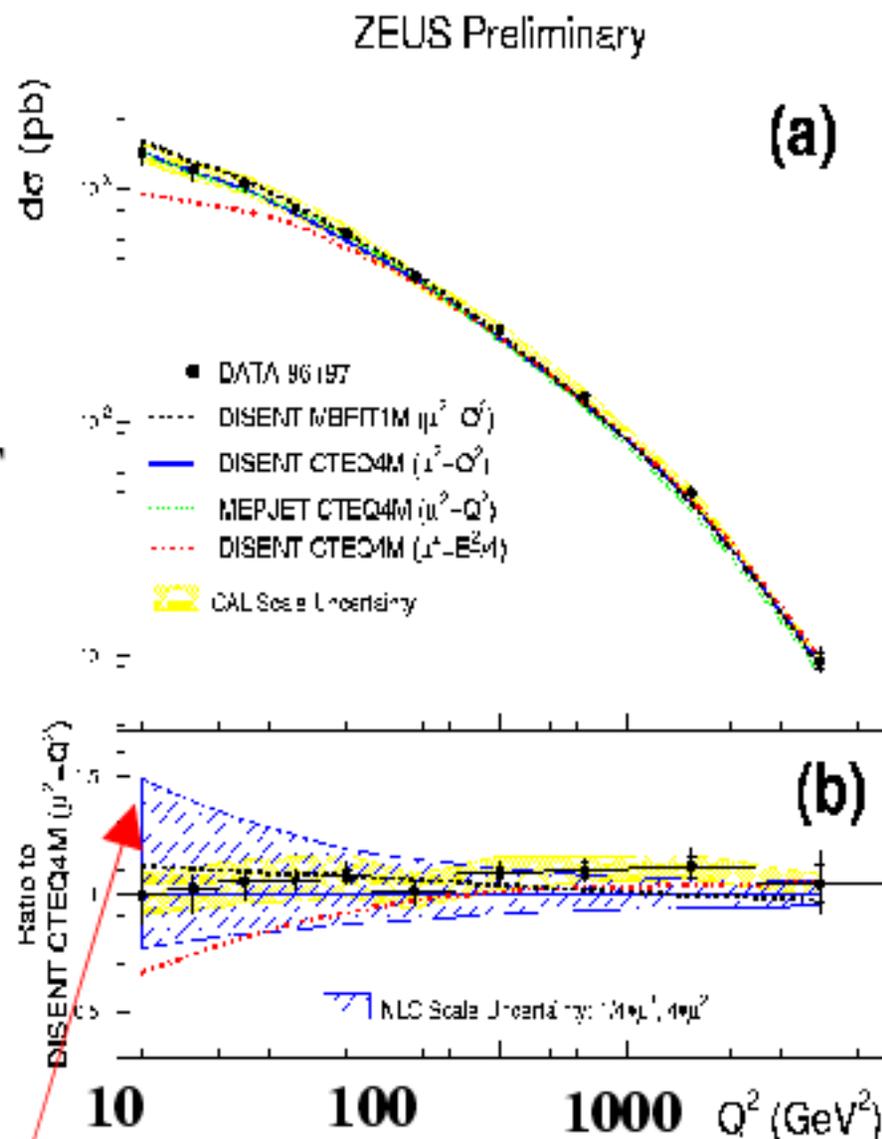
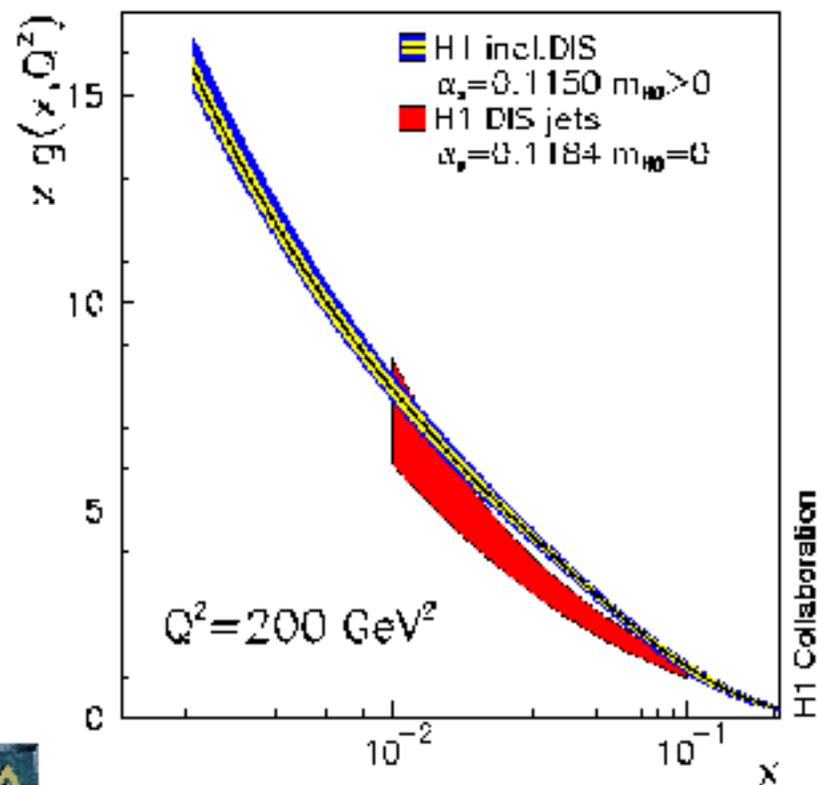
Disentangling frag. fcn. from st. fcn?



QCD studies type III:



Low Q^2
HERA dijets
 mostly from BGF

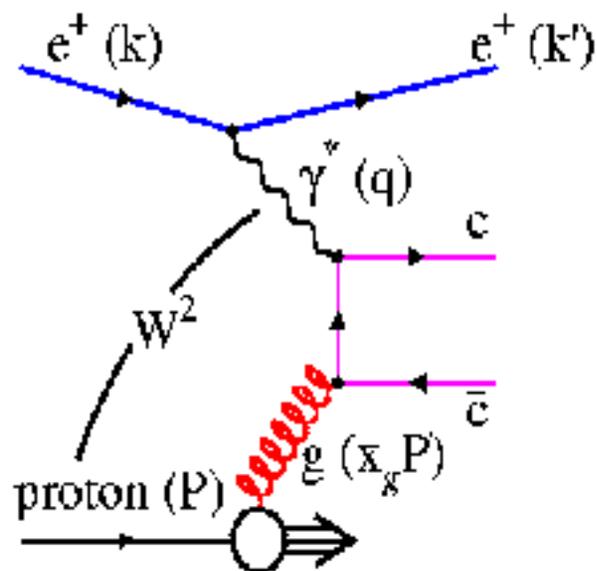


50% ren. scale unc.

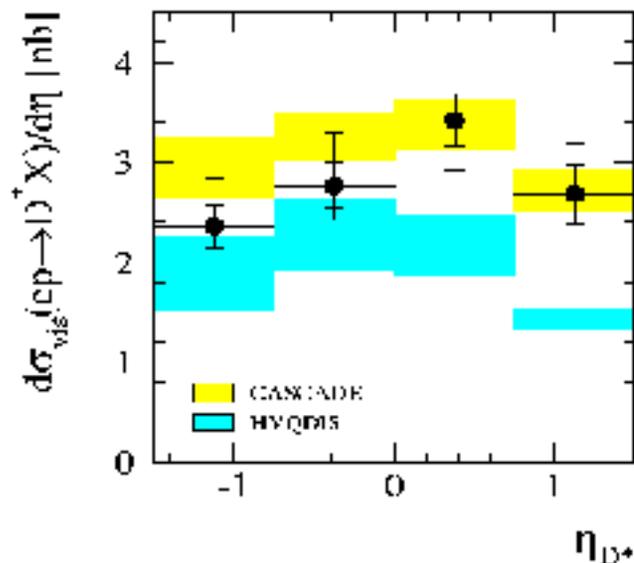
**Consistent with scaling via. gluon
 but does not constrain due to th. uncer.**



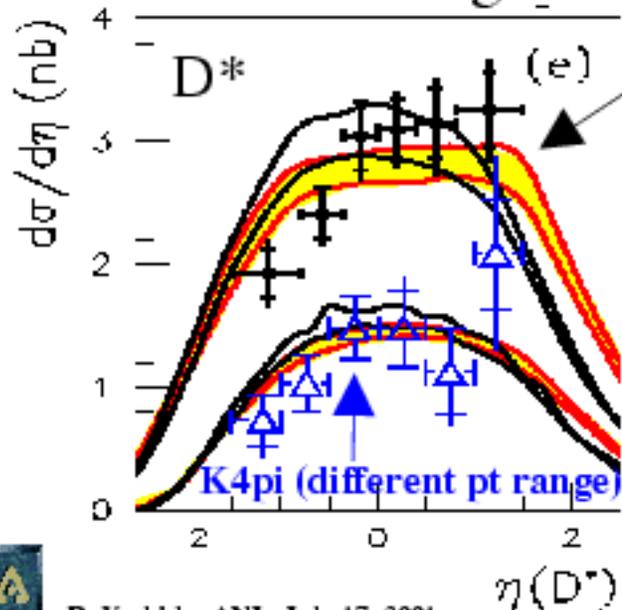
QCD studies type III: Back to unpolarized proton



H1 preliminary



ZEUS fragmentation effect?



New results from H1

Results compatible with ZEUS.
BGF comparison somewhat different (diff. st. fcn.)

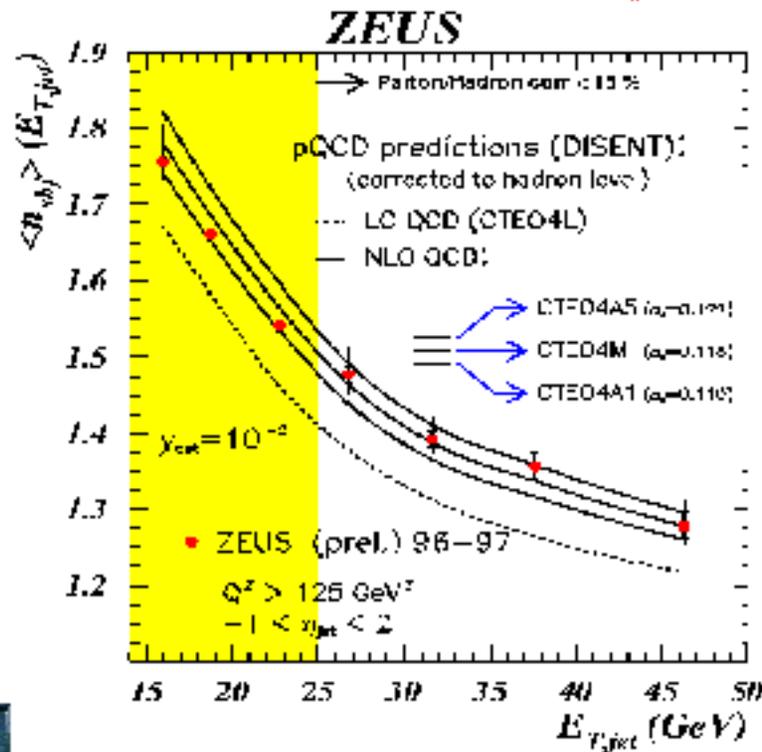
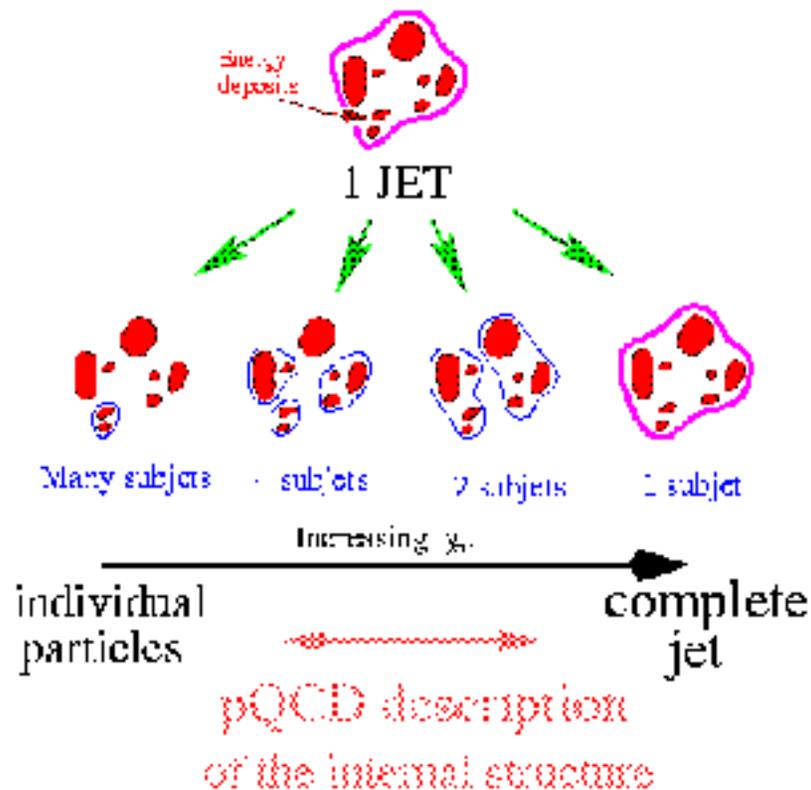
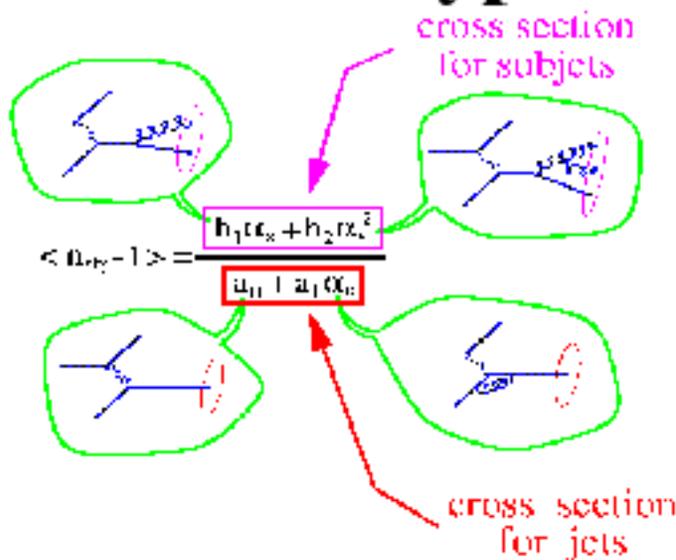
CASCADE favored?

CCFM dynamics
 (non-DGLAP)

Theory:
 BGF (HVQDIS)



QCD studies type III:



ZEUS prel.

$$\alpha_s(M_Z) = 0.1185 \pm 0.0016 \text{ (stat.)}^{+0.0067}_{-0.0048} \text{ (syst.)}^{+0.0050}_{-0.0071} \text{ (th.)}$$

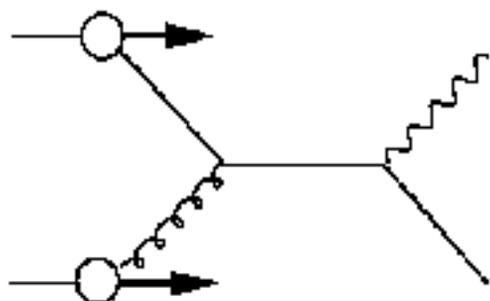
Theory error largest

Similar result from jet shape measurements

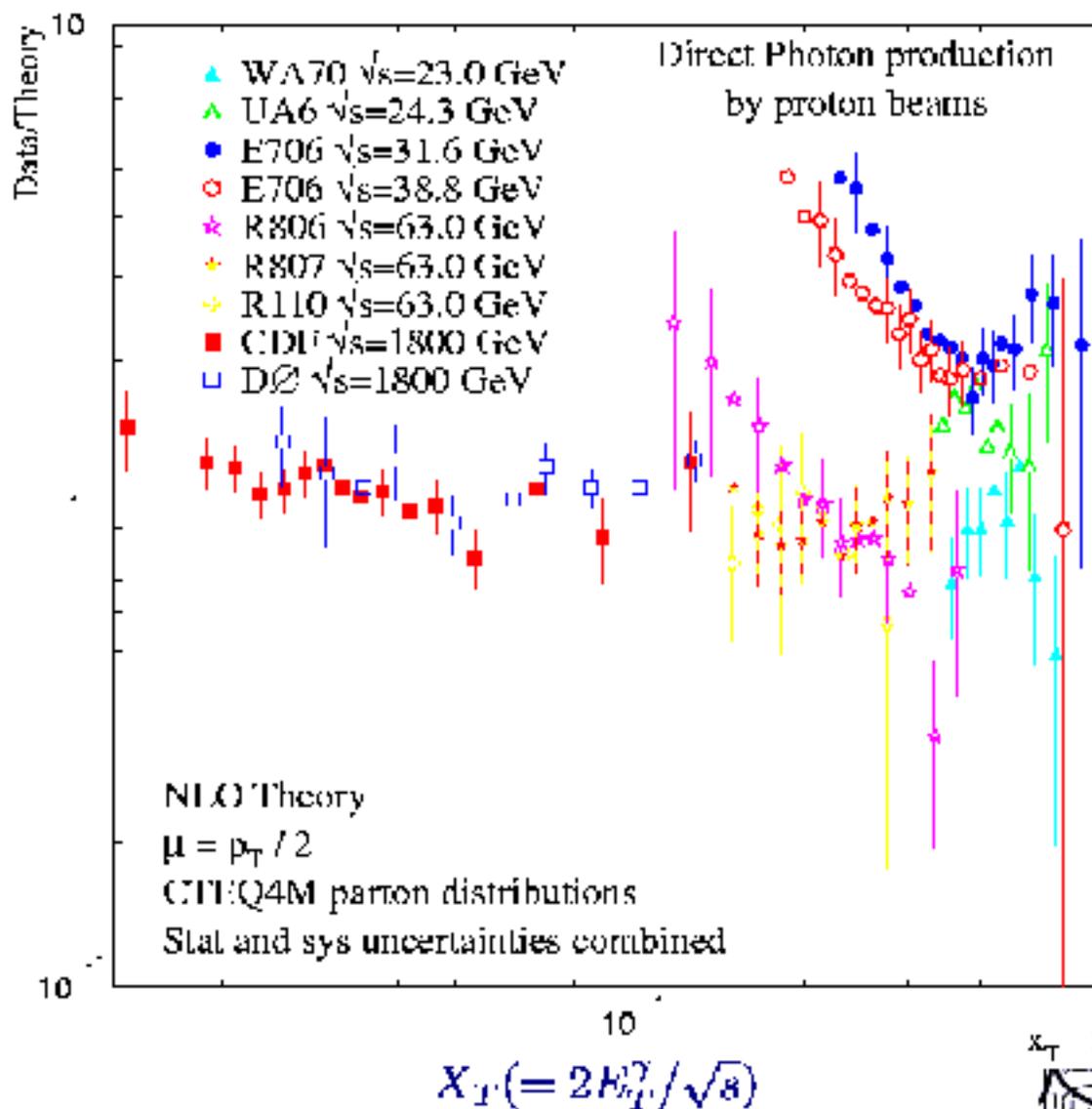


QCD studies type III:

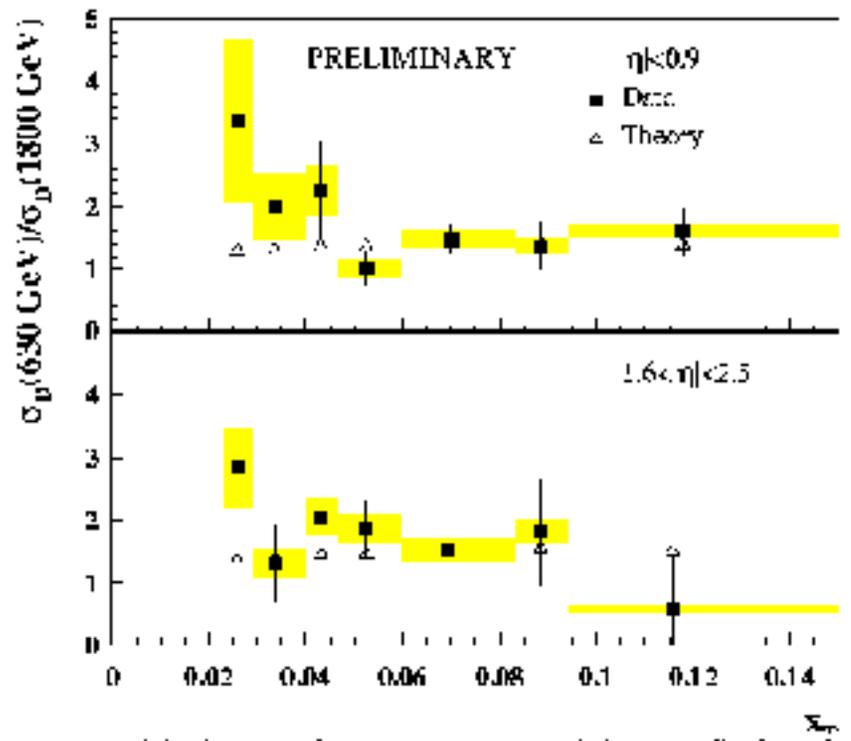
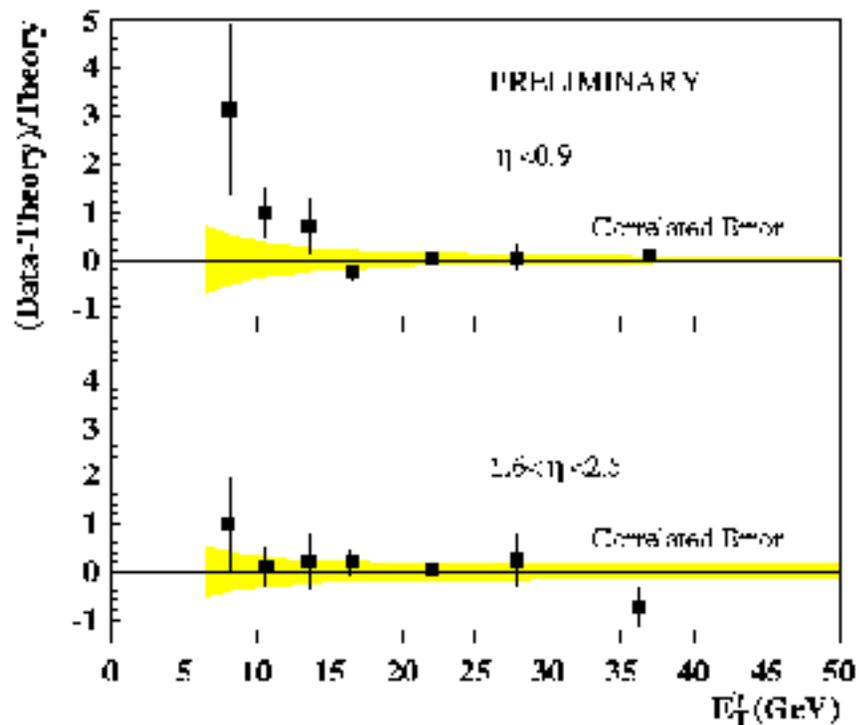
Prompt photon



No uncertainty from hadronization, however...

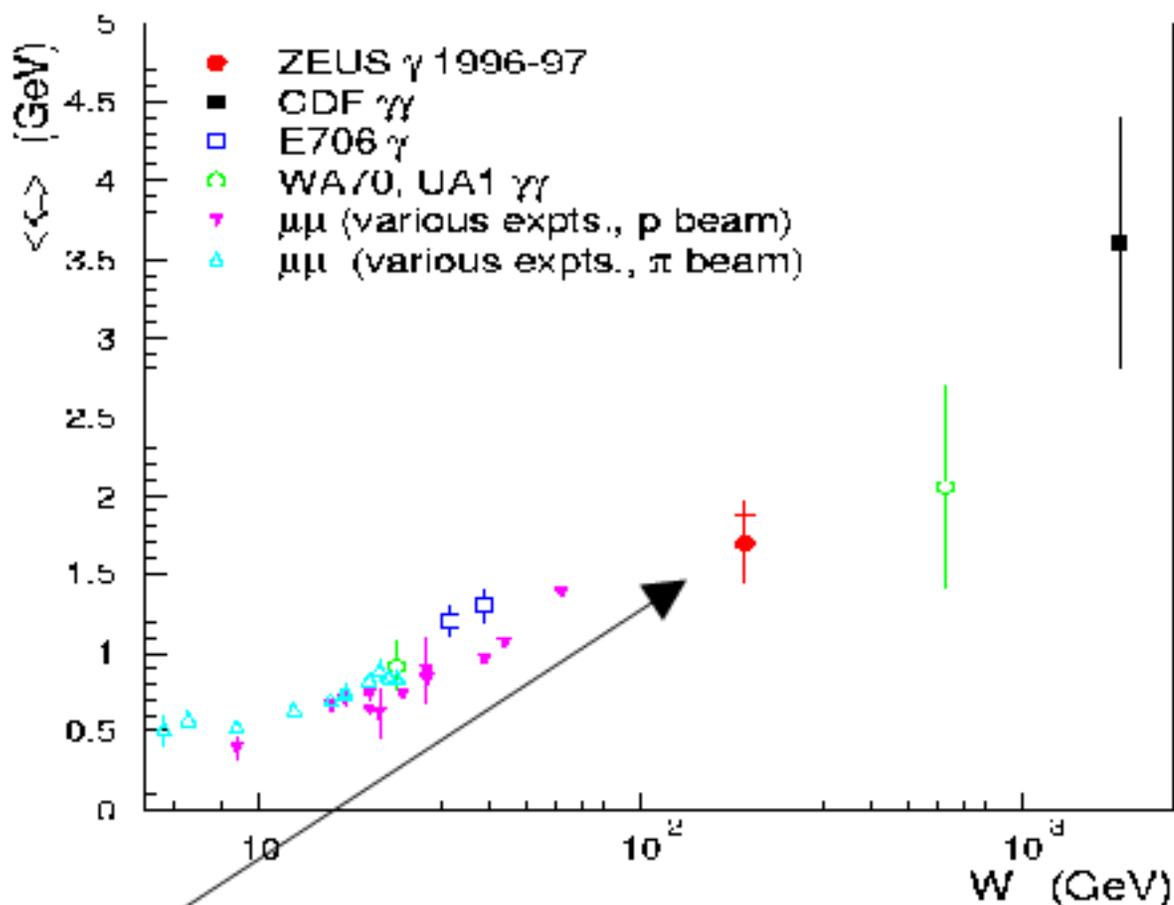
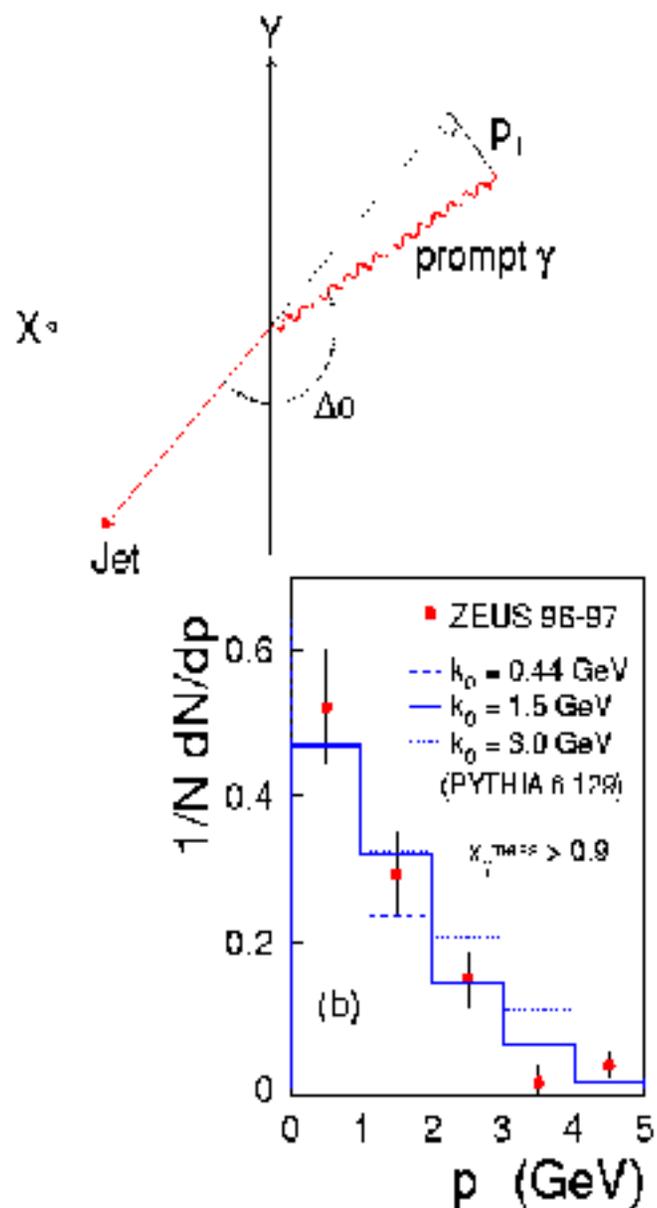


QCD studies type III:



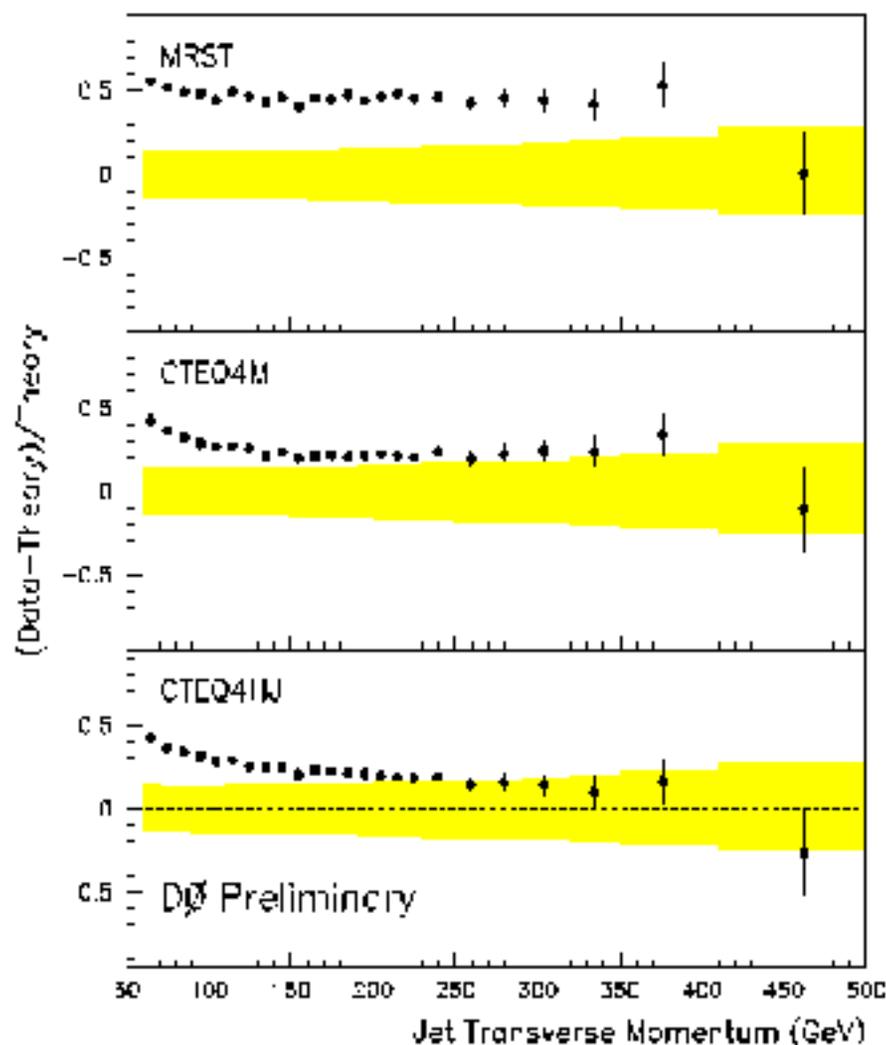
QCD studies type III:

Prompt photon from ZEUS



QCD studies type III: Tevatron jets

D0 using the kt algorithm



Chisquare of theory are ok
(Correlated systematics)

Differences may come from..

- Hadronization
- "Underlying event"
- Showering corrections

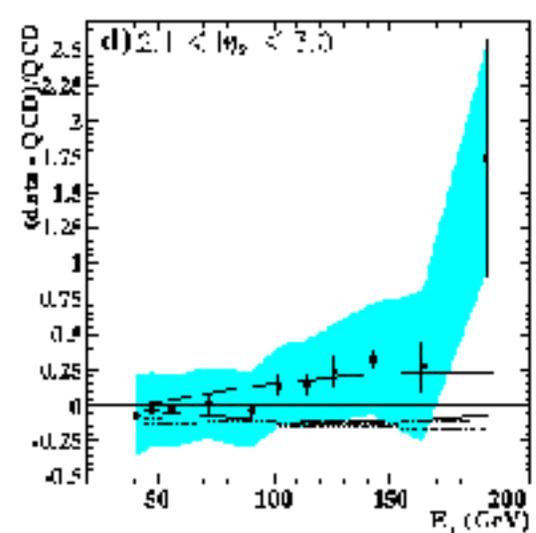
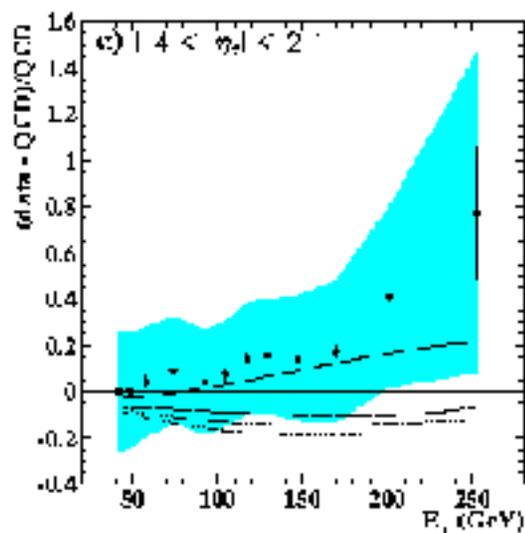
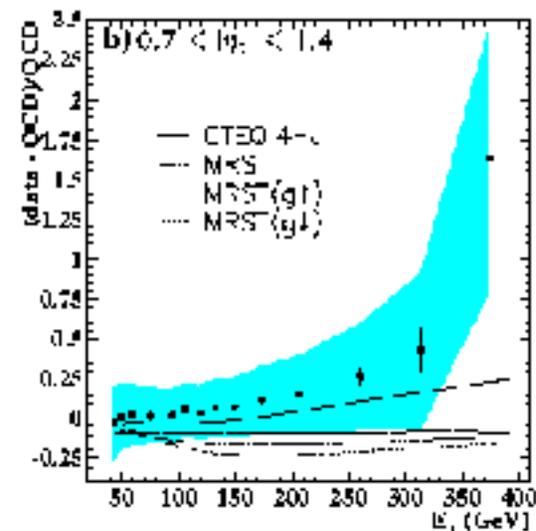
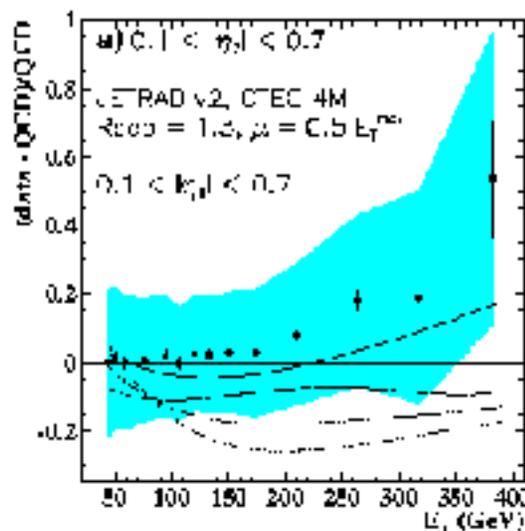
Could the low Et deviation show a need for resummation?



QCD studies type III:

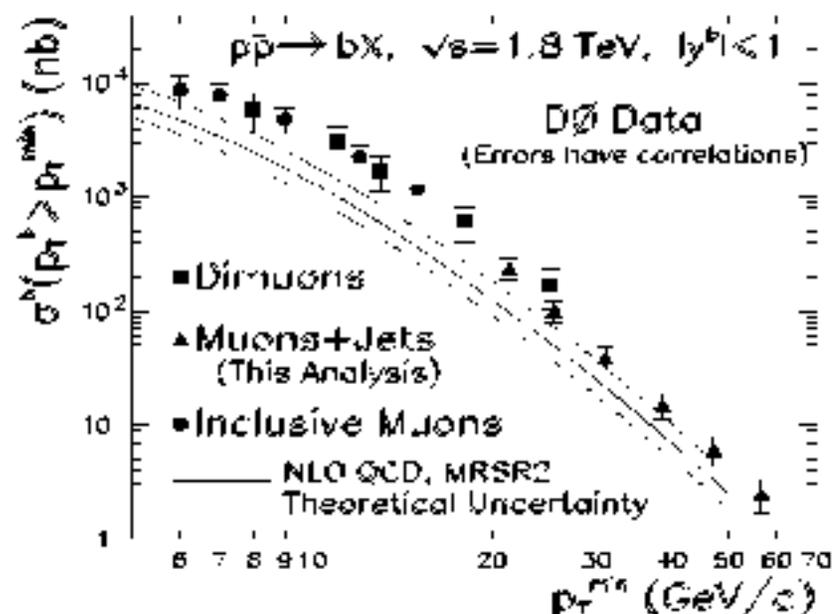
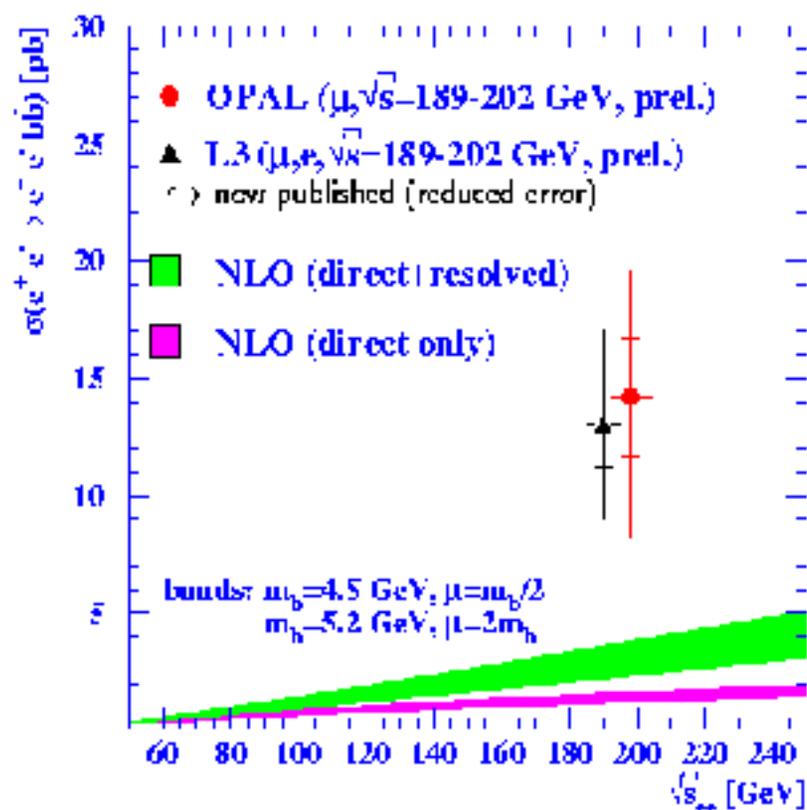
$$x_{12} = \frac{E_T}{\sqrt{s}} (e^{\eta_1} + e^{\eta_2})$$

$$\eta = -\ln(\tan(\theta/2))$$



QCD studies type III:

Gamma-gamma b cross-section

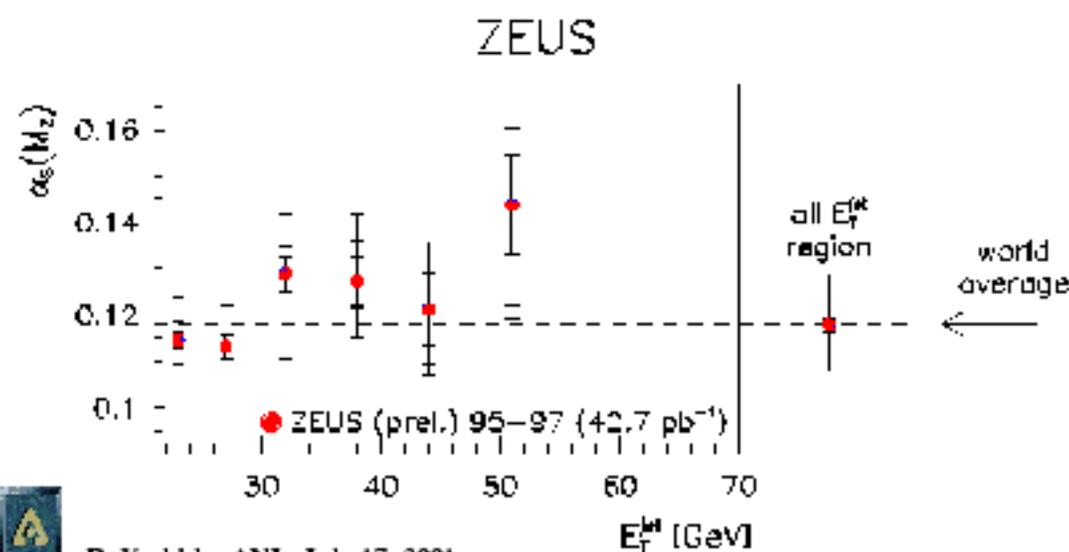
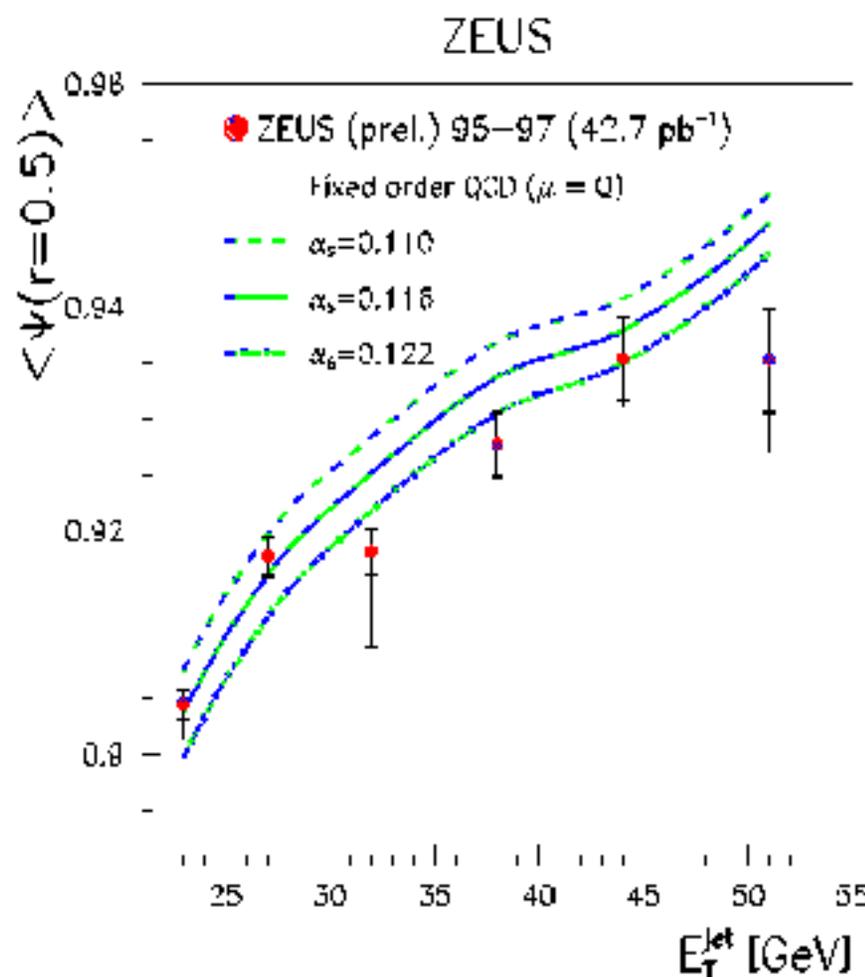
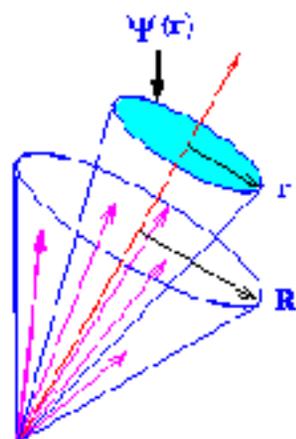


Tevatron b cross-section

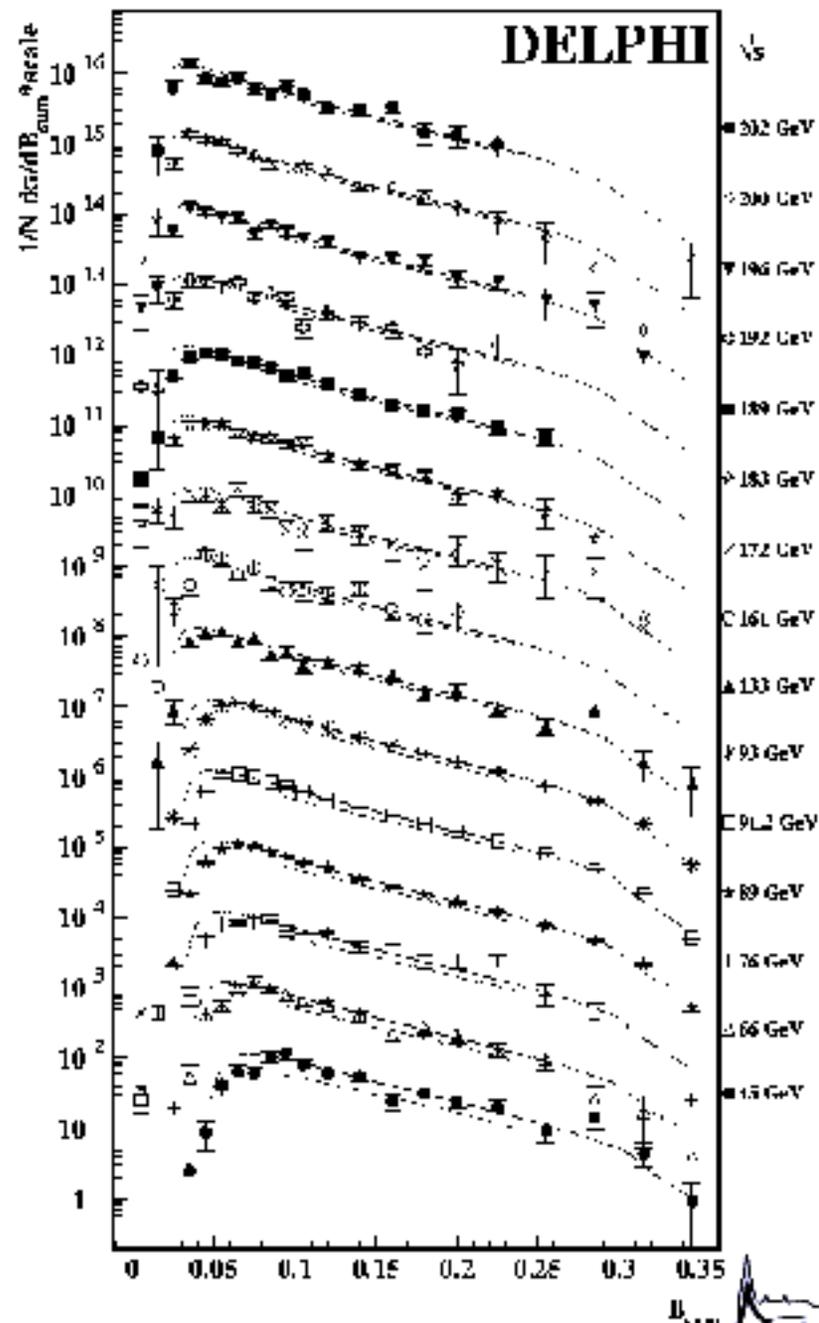
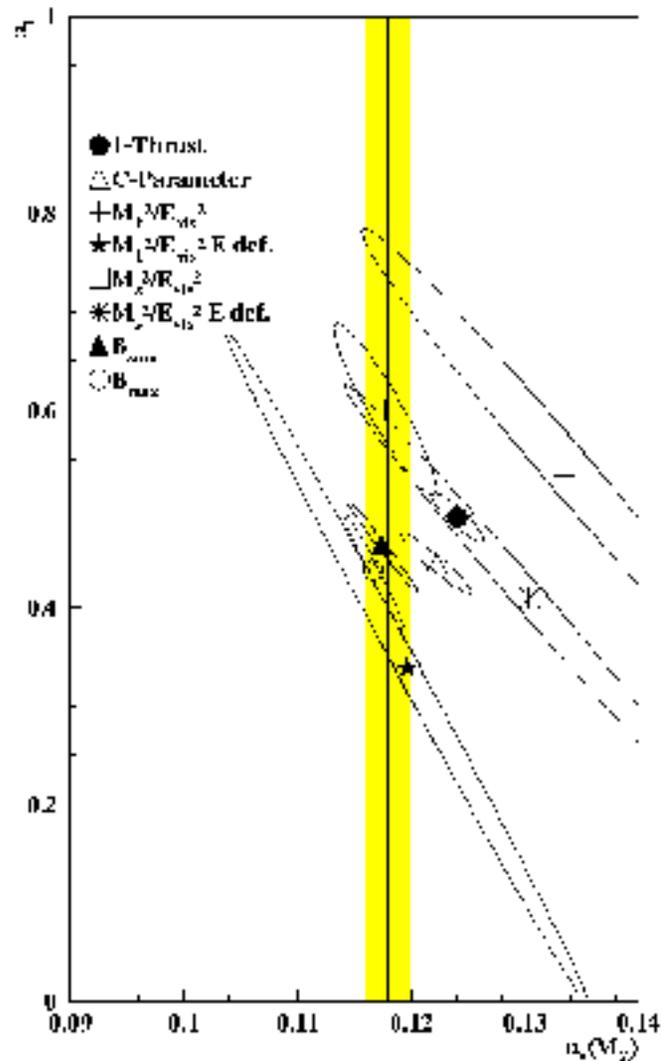


QCD studies type III:

$$\psi(r) = \frac{1}{N_{jets}} \sum_{jets} \frac{E_T(0, r)}{E_T(0, 1)}$$

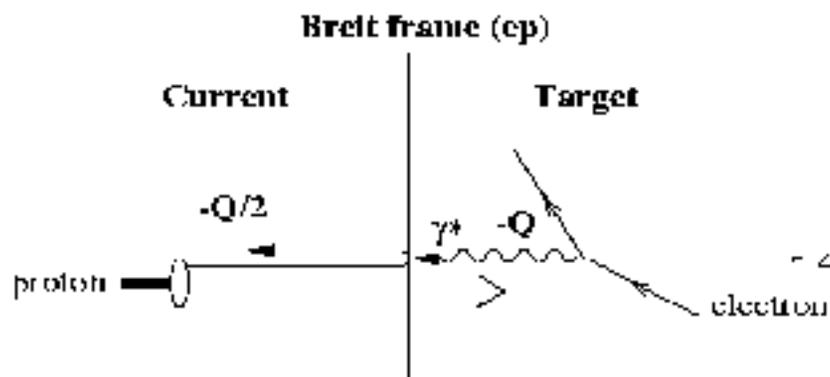
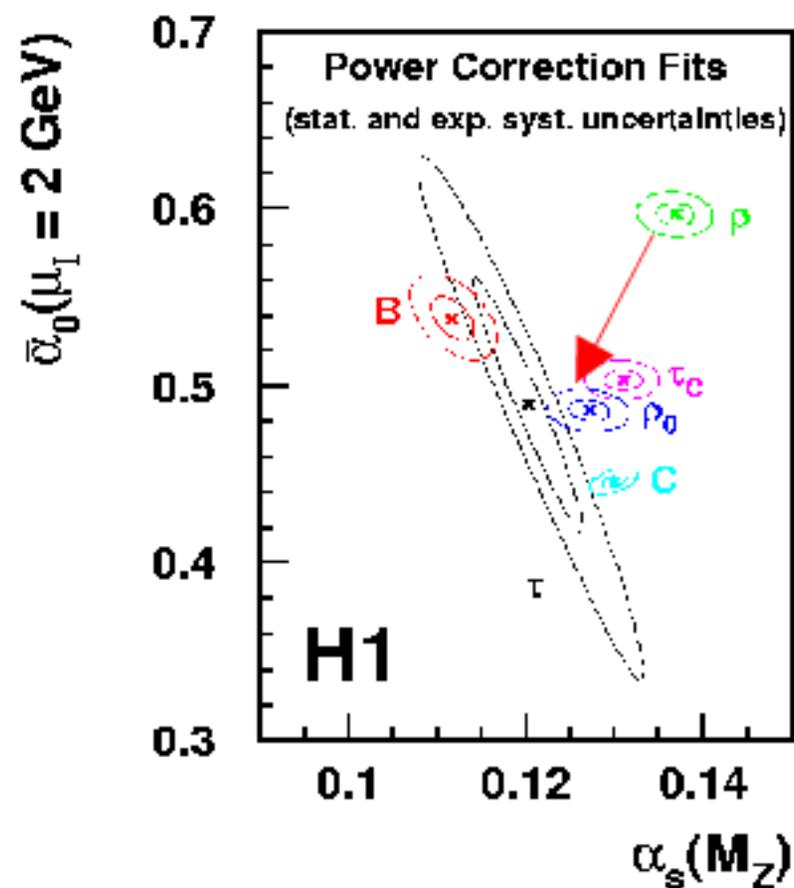


QCD studies type V:



QCD studies type V:

Power Corrections at HERA



Salam and Wicke

Mass effect (not only for DIS)

Dasgupta

Resummed results for DIS

H1 DATA | PRELIMINARY THEORY

