

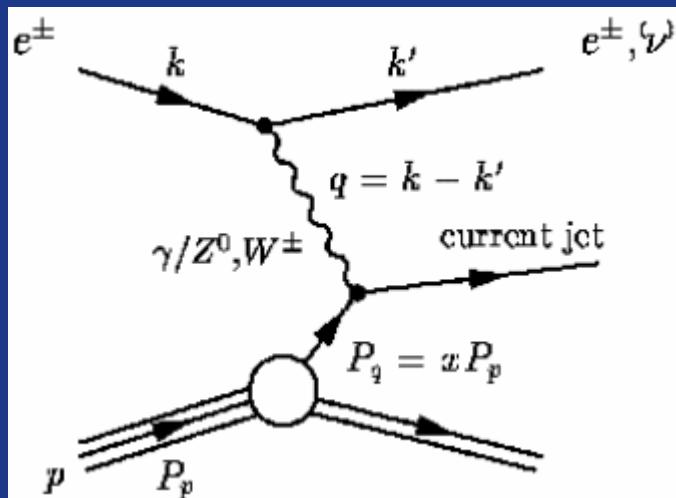
An Introduction to HERA Physics

DESY Summer Student Program
23 August, 2005
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DESY, Hamburg

Part 2

High Q^2 and EW

NC Cross Section and Structure Functions



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

x: momentum fraction of the struck parton

y = Q^2/xs

NC Reduced cross section: $\tilde{\sigma}_{NC}(x, Q^2)$

NC Cross Section:

$$\frac{d^2 \sigma_{NC}(e^\pm p)}{dx d Q^2} = \frac{2\pi \alpha^2}{x Q^4} Y_+ [F_2 - \frac{y^2}{Y_+} F_L \mp \frac{Y_-}{Y_+} x F_3]$$

Dominant contribution

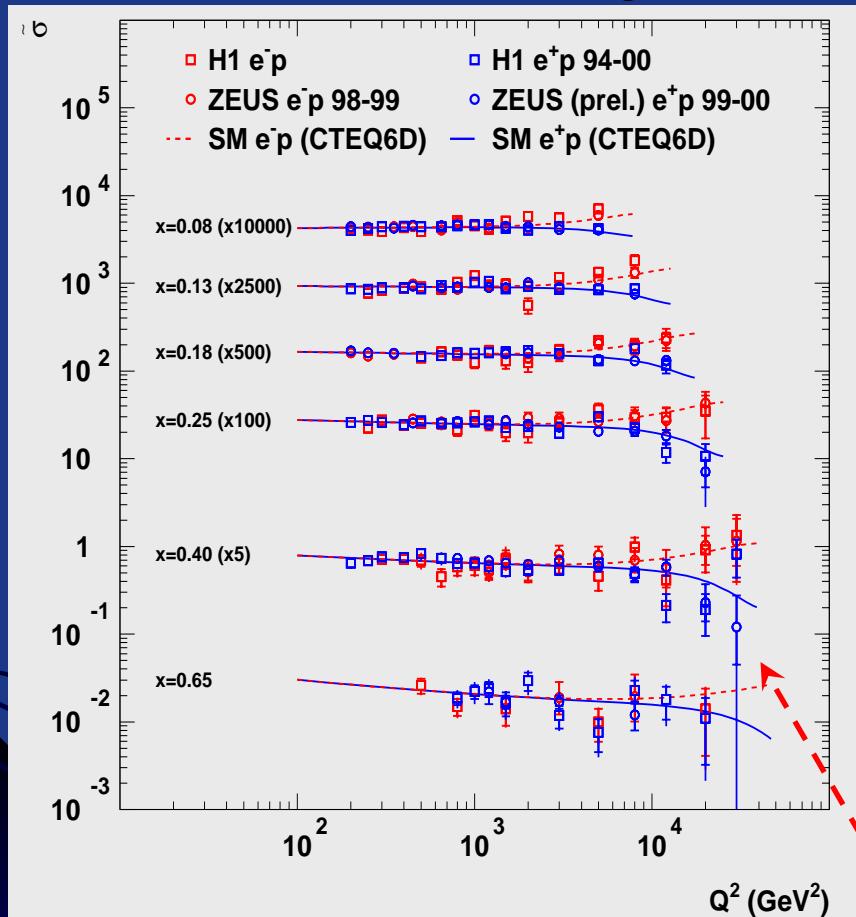
Sizeable only at high y ($y \gtrsim 0.6$)

Contribution only important at high Q^2

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

High Q^2 NC (γ , Z Exchange)

HERA Neutral Current at high x



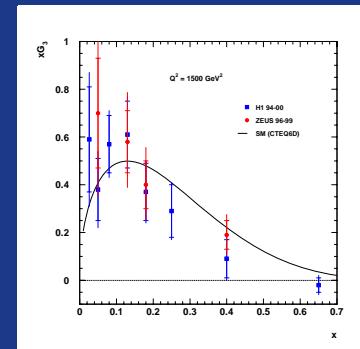
- Note:

- Handle on F_3 :

$$xF_3 \propto \sigma^- - \sigma^+$$

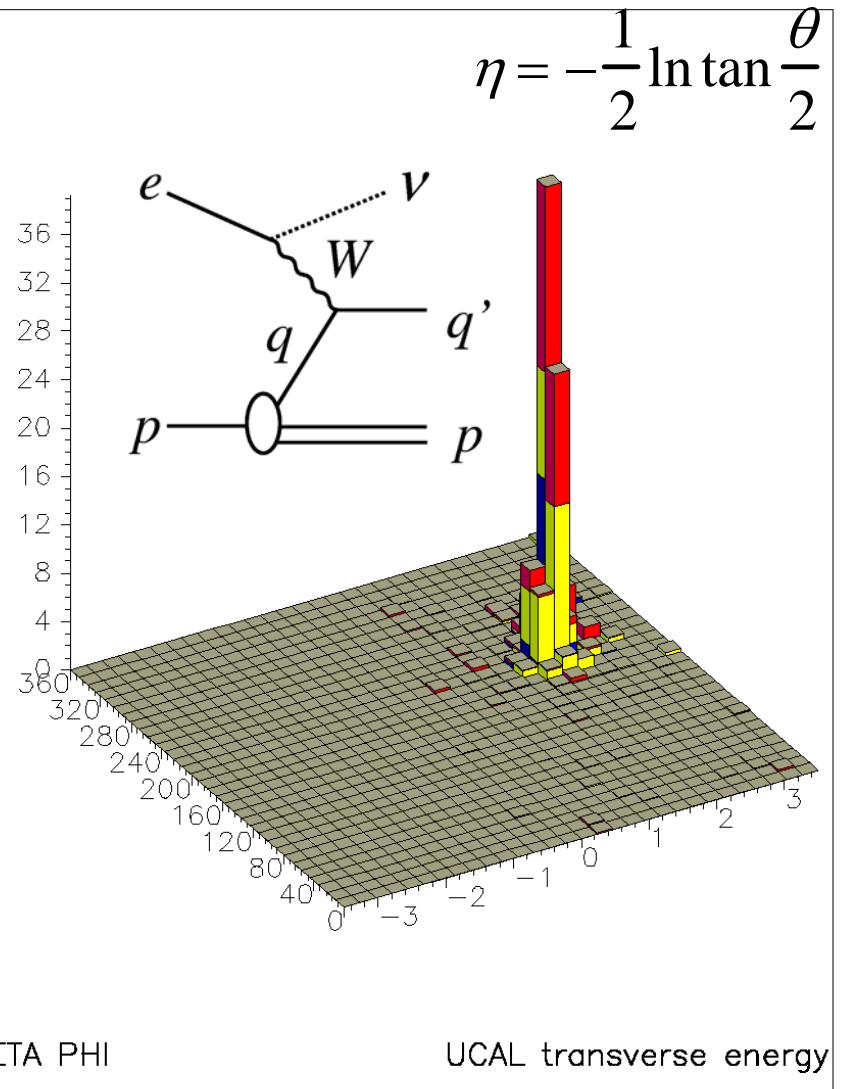
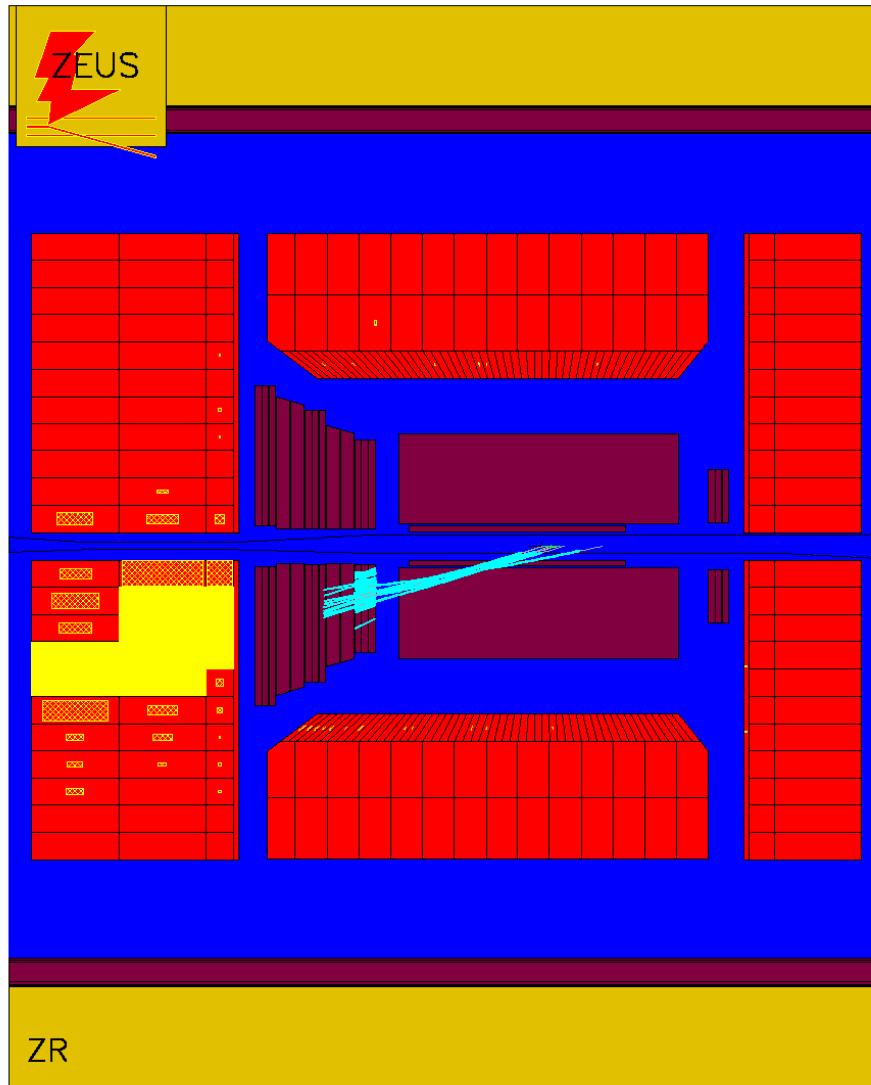
$$xF_3 \propto \sum e_i^2 (xq(x) - \bar{x}\bar{q}(x))$$

- Valence quarks!



γ -Z interference: e^- constructive e^+ destructive

Charged Current Interactions



NC vs CC

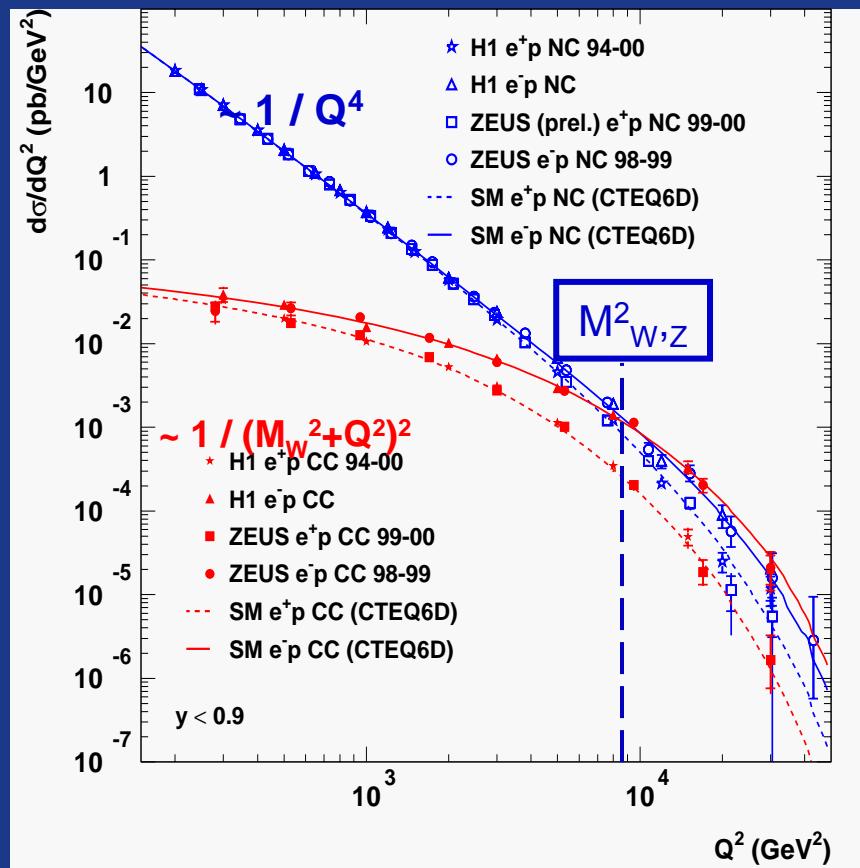
$$\frac{d^2\sigma_{e^-p}^{CC}}{dx dQ^2} = (1 - \lambda) \frac{\pi \alpha^2}{8 \sin^4 \theta_W} \left(\frac{1}{M_W^2 + Q^2} \right) F_2^{CC}(x, Q^2)$$

$\lambda = \pm 1$ for left/right handed e

COUPLING		PROPAGATOR	
NC	$2\pi\alpha^2$		$1/Q^4$
CC	$\pi\alpha^2/8 \sin^4 \theta_W$		$1/(M_W^2 + Q^2)^2$
similar since $\sin^2 \theta_W \sim 1/4$		similar at $Q^2 > M_W^2$	
'Unification' of elm. and weak forces			

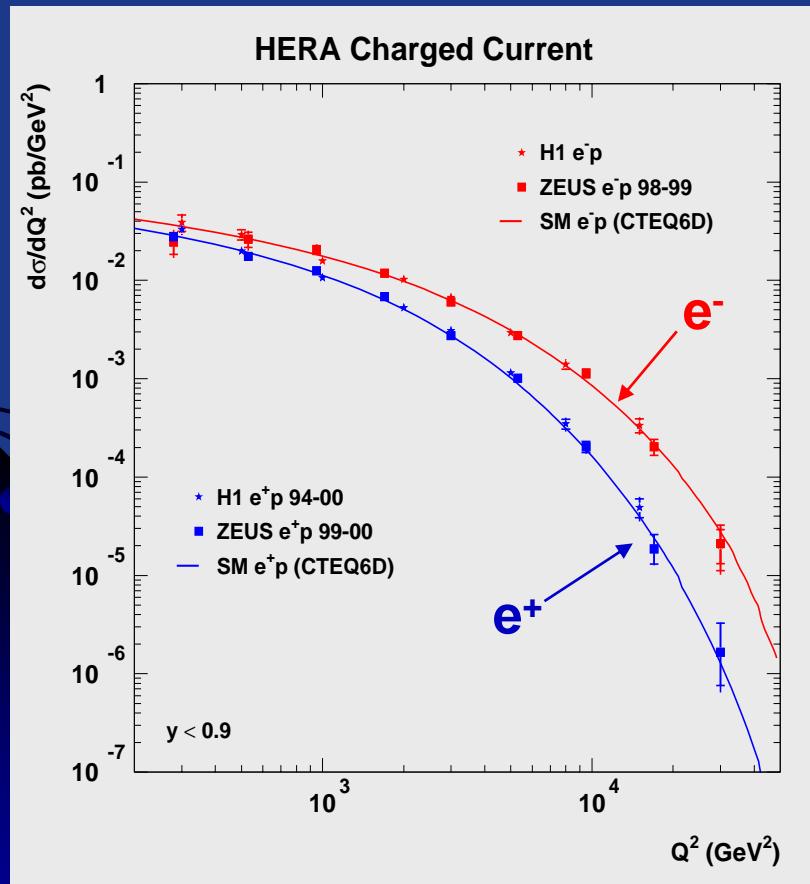
ignore F_L and xF_3

HERA



CC Cross Section

$$\frac{d^2\sigma_{CC}}{dx dQ^2}(e^\pm) = \frac{G_F^2}{4\pi x} \left[\frac{M_W^2}{M_W^2 + Q^2} \right]^2 (Y_+ F_2^\pm \mp Y_- x F_3^\pm - y^2 F_L^\pm)$$



$$\sigma(e^- p) > \sigma(e^+ p)$$

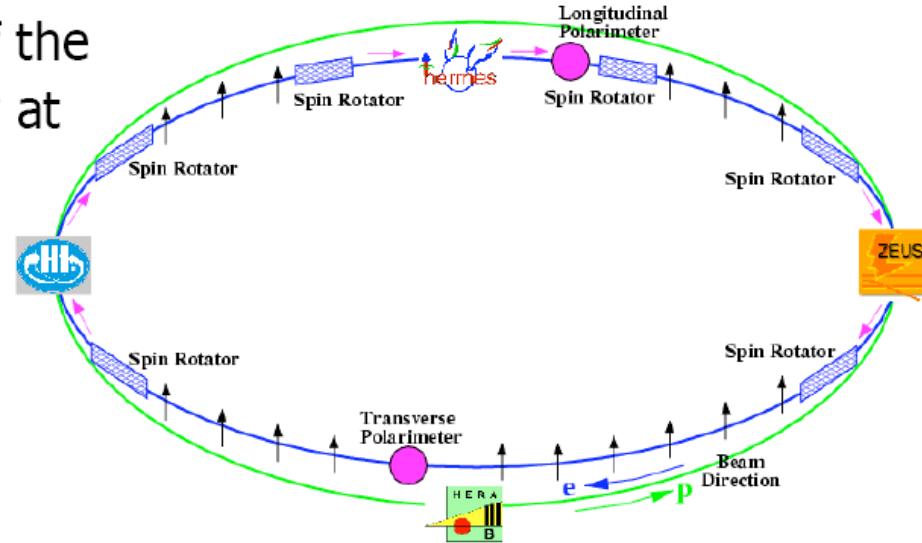
$$\sigma(e^- p) \sim x(u+c) + (1-y^2) \times \bar{d} \bar{s}$$

$$\sigma(e^+ p) \sim x(\bar{u}+\bar{c}) + (1-y^2) \times \bar{d} \bar{s}$$

Polarization

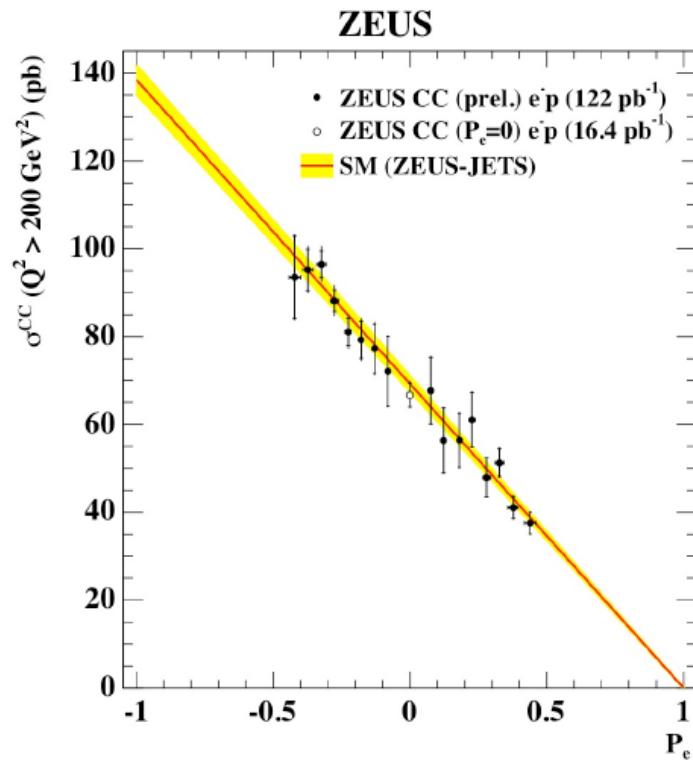
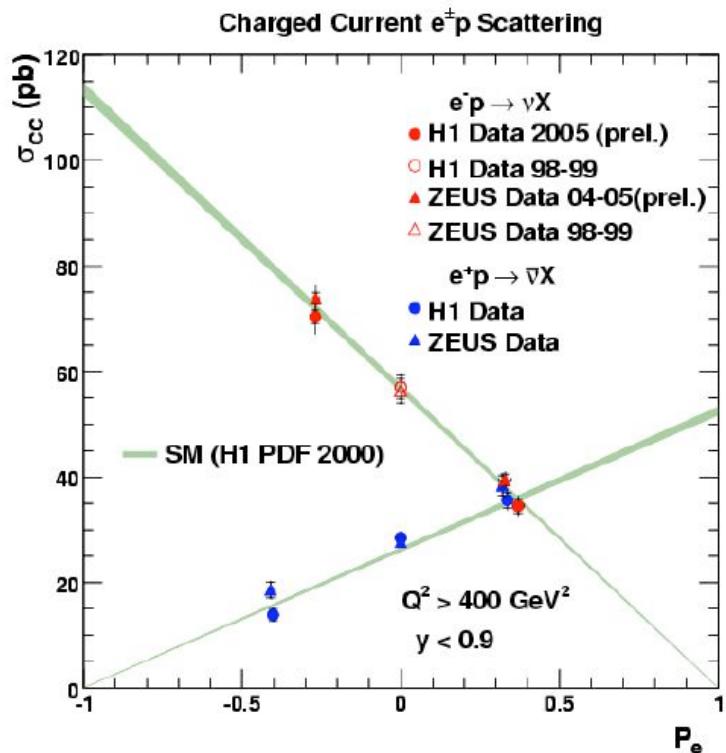
Longitudinal polarisation of the lepton beam at HERA: new at HERA II

$$P_e = \frac{N_R - N_L}{N_R + N_L}$$

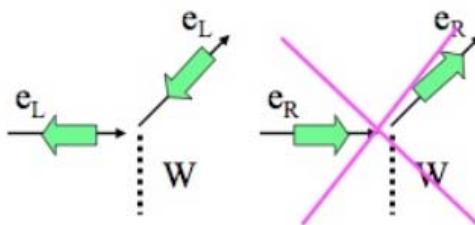


- Transverse polarization builds up naturally in HERA through synchrotron radiation (Sokolov Ternov effect)
- Build up time is ca. 40 minutes
- Spin rotators flip transvere polarization to longitudinal before interaction regions and back afterwards

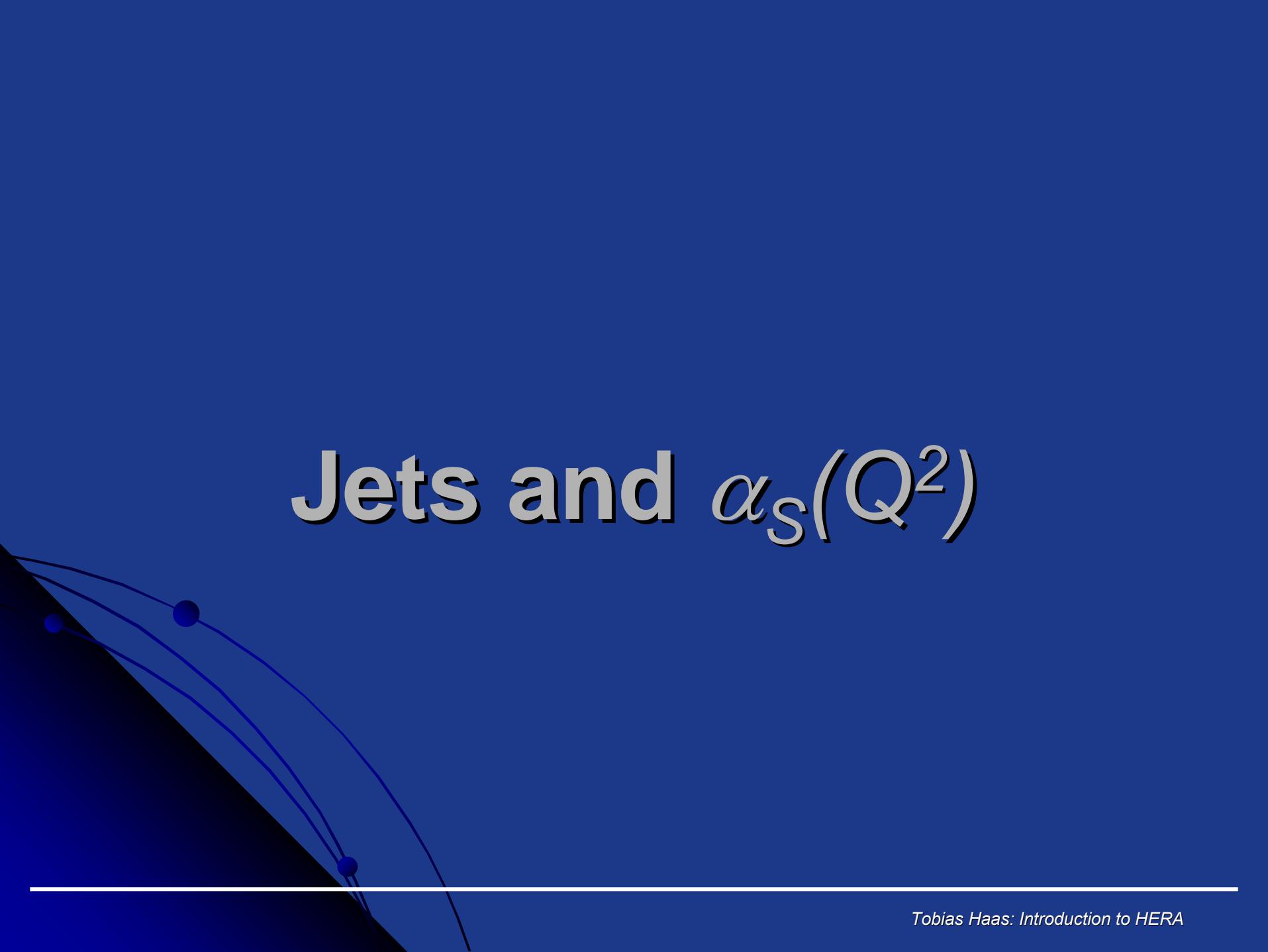
CC Cross Section: Polarized Beams



- Standard Model weak interaction left-handed
 - only LH particles (RH anti-particles) interact

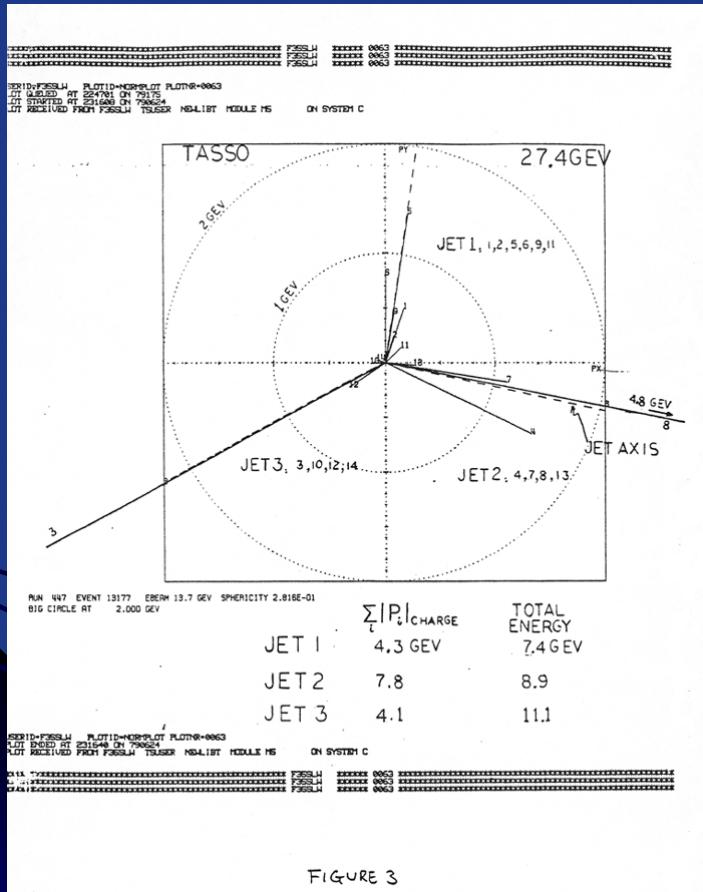


Jets and $\alpha_S(Q^2)$



A dark blue background featuring a black diagonal band from the top-left to the bottom-right. Within this band, there are three small blue dots connected by thin blue lines, forming a triangular pattern.

What are Jets?



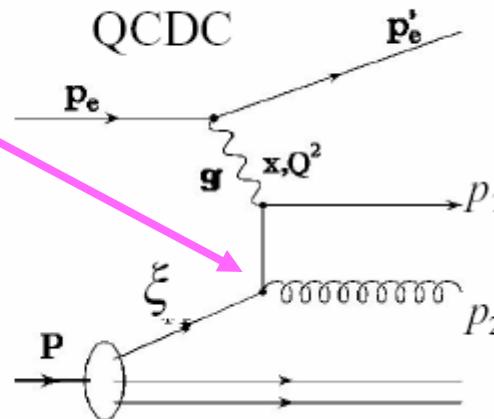
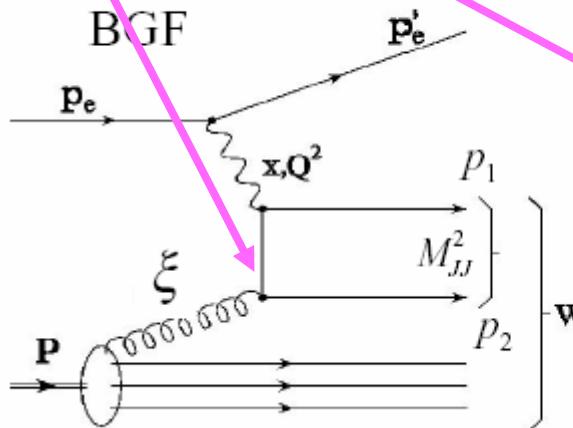
DESY 1979

- Quarks and gluons do not exist as free particles
- Feynman & Field (1977): Pencil like emission of hadrons (jets)
- QCD radiation (gluons) discovered at DESY 1979
- Strength of this radiation is characterized by the strong coupling constant α_S
- Jets are the observable sign of QCD radiation.

α_s

How do you get Jets ?

Leading Order Diagrams:



$$q = p_e' - p_e$$

$$Q^2 = -q^2$$

$$x_{Bj} = \frac{Q^2}{2P \cdot q}$$

$$W^2 \approx \frac{1-x}{x} Q^2$$

- Outgoing partons described by 3 more variables:

$$\xi = x \cdot \frac{Q^2 + M_{JJ}^2}{Q^2}$$

$$z_{P,i} = \frac{P \cdot p_i}{P \cdot q} = \frac{1}{2}(1 - \cos \theta_i^*) \quad \theta_i^* : \text{Scattering Angle in CMS}$$

ϕ : Azimuth

Remark about α_S

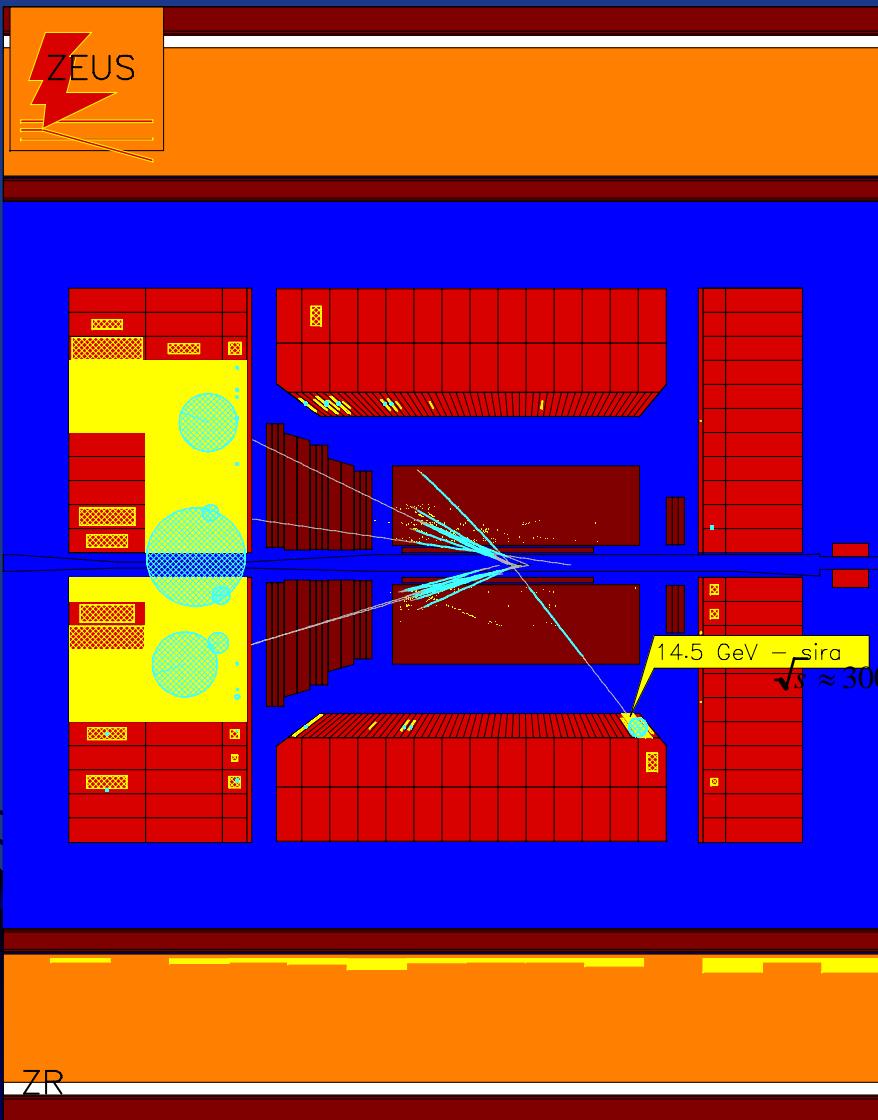
The Nobel Prize in Physics 2004

"for the discovery of asymptotic freedom in the theory of the strong interaction"

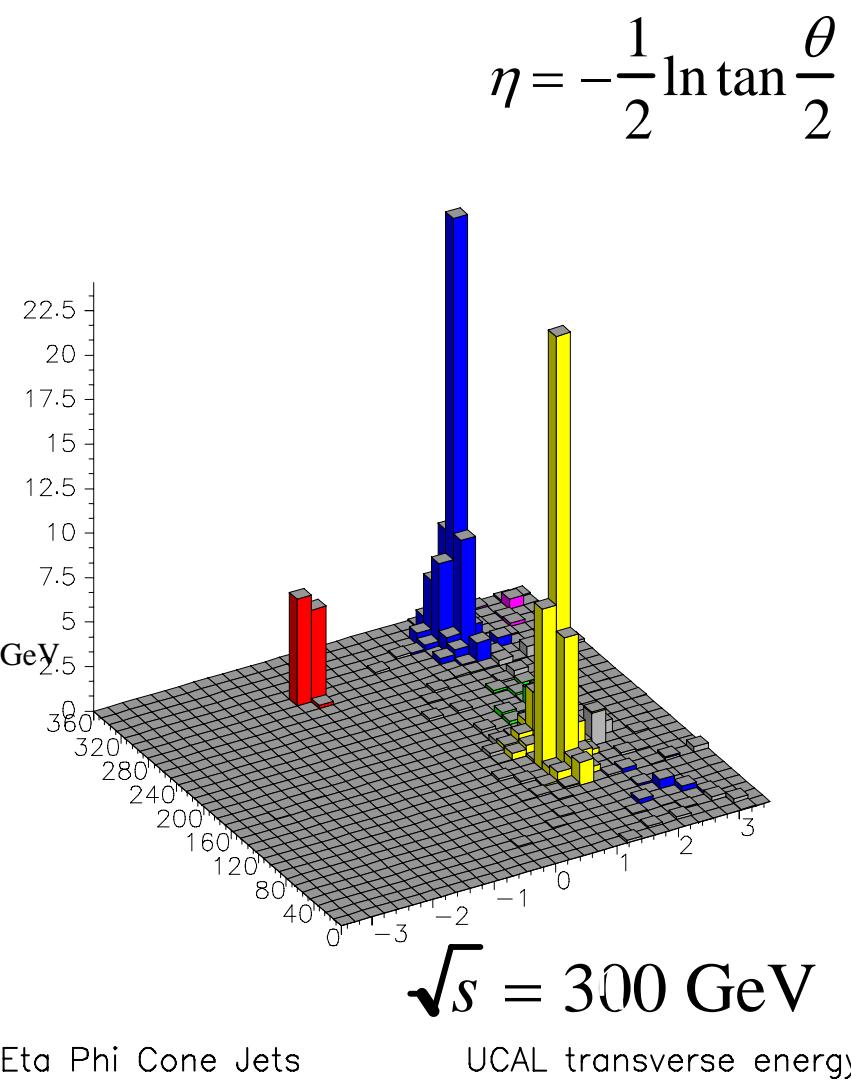


David J. Gross 1/3 of the prize USA Kavli Institute for Theoretical Physics, University of California Santa Barbara, CA, USA b. 1941	H. David Politzer 1/3 of the prize USA California Institute of Technology (Caltech) Pasadena, CA, USA b. 1949	Frank Wilczek 1/3 of the prize USA Massachusetts Institute of Technology (MIT) Cambridge, MA, USA b. 1951
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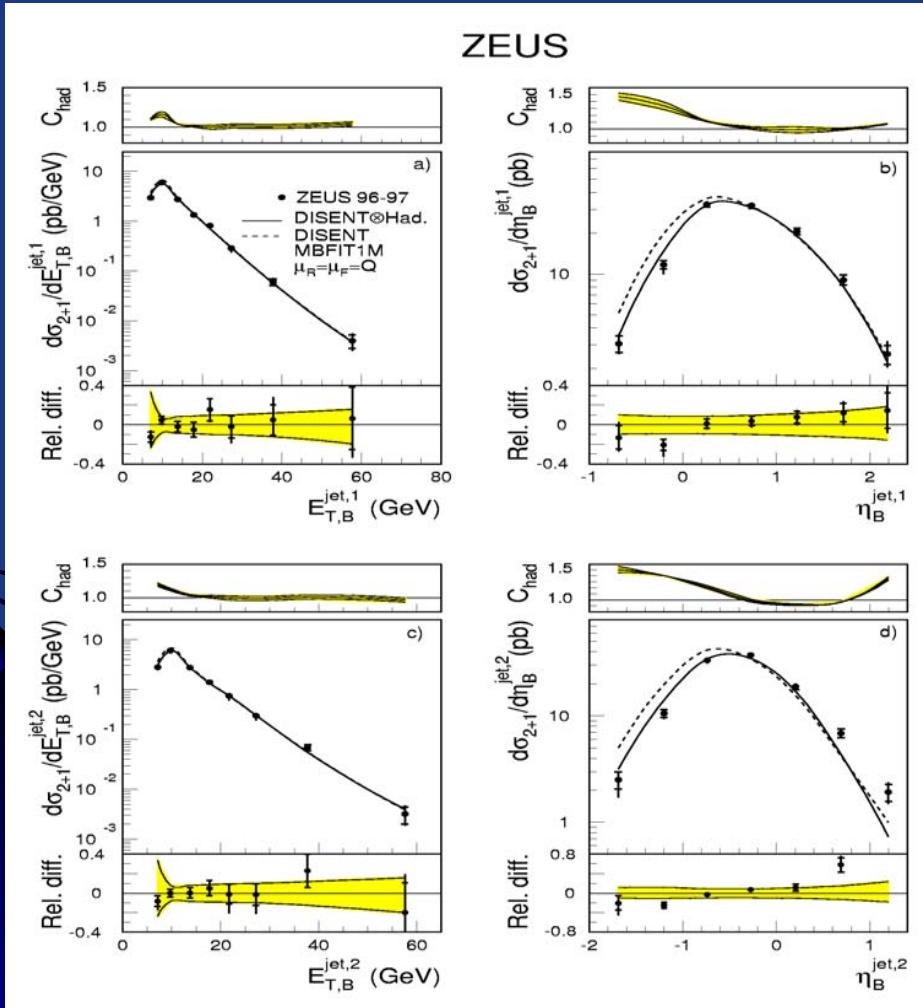
- α_S is not a constant but „runs“
- α_S runs against the historical prejudice...
it decreases with increasing energy
- Effect of „negative β -function“



$e^{+/-} \underline{27.5 \text{ GeV}}$ $p \underline{820/920 \text{ GeV}}$

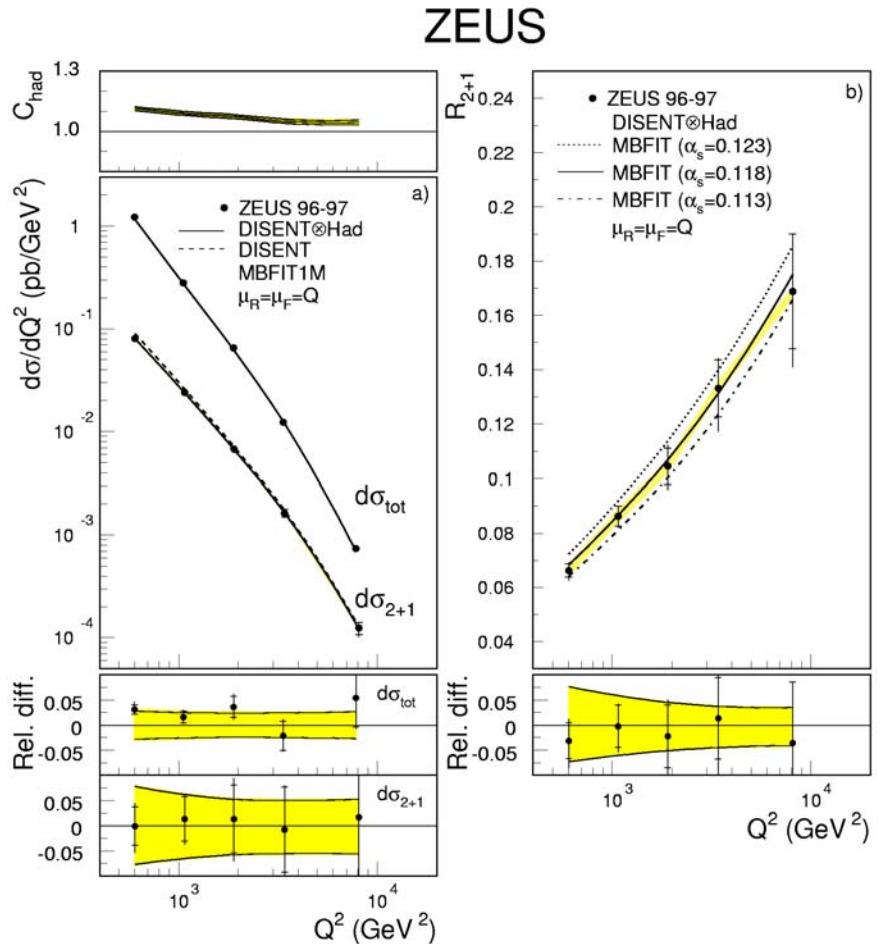


Dijet Cross Section in DIS



- Note:
 - Ingredients in these calculations:
 - NLO QCD calculation
 - parton densities
 - strong coupling, α_S
 - hadronization corrections
 - Make this a test for the strong coupling:
 - take pdfs from inclusive data (F_2)
 - Calculate hadronization using an QCD-inspired MC model (like jetset)
 - fit

Practical consideration: Use Dijet Fraction

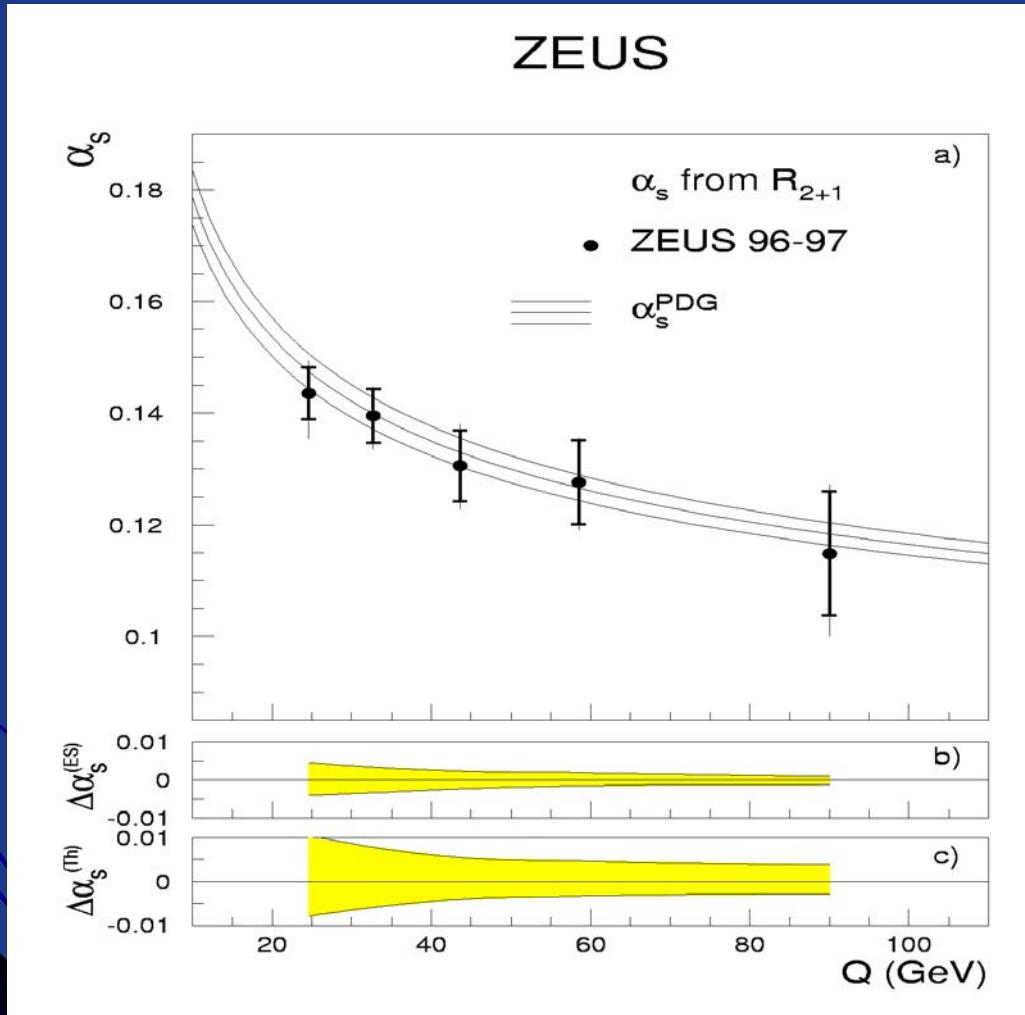


$$R_{2+1} = \frac{\sigma_{2+1}}{\sigma_{tot}}$$

- R_{2+1} has smaller sensitivity to PDFs
- Some experimental errors cancel
- Fit:

$$R_{2+1}(\alpha_s(M_Z)) = A_1 \cdot \alpha_s(M_Z) + A_2 \cdot \alpha_s^2(M_Z)$$

$\alpha_s(Q^2)$ from Dijet Production



$\alpha_s(Q^2)$

- QCD fit of F_2 scaling violations :

$$\alpha_s = 0.1150 \pm 0.0019 \text{ (expt+fit)} \pm 0.0050 \text{ (scale)} \quad \text{H1}$$

$$\alpha_s = 0.1166 \pm 0.0052 \text{ (expt+fit)} \pm 0.0040 \text{ (scale)} \quad \text{ZEUS}$$

- Jet cross sections: 1, 2, 3 jets

$$\alpha_s = 0.1224 \pm 0.002 \text{ (exp)} \pm 0.004-5 \text{ (theory)}$$

