An Introduction to HERA Physics

DESY Summer Student Program
23 August, 2005
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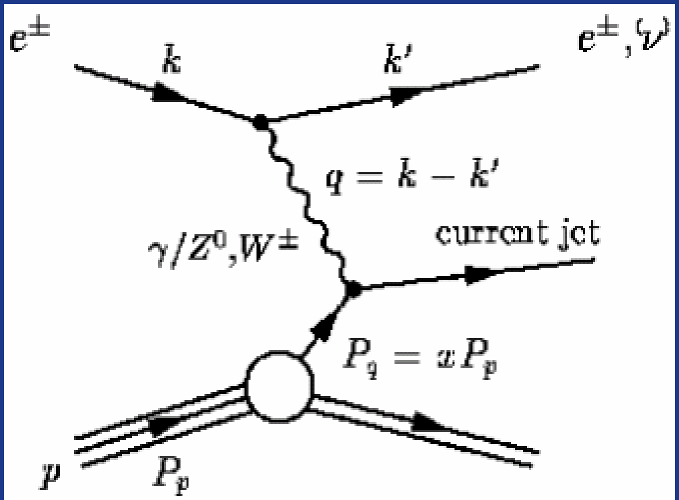
Part 2

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:

$$\frac{d^2\sigma_{NC}(e^\pm p)}{dx\,dQ^2} = \frac{2\pi\alpha^2}{xQ^4}\,Y_+\left[F_2 - \frac{y^2}{Y_+}F_L \mp \frac{Y_-}{Y_+}xF_3\right]$$

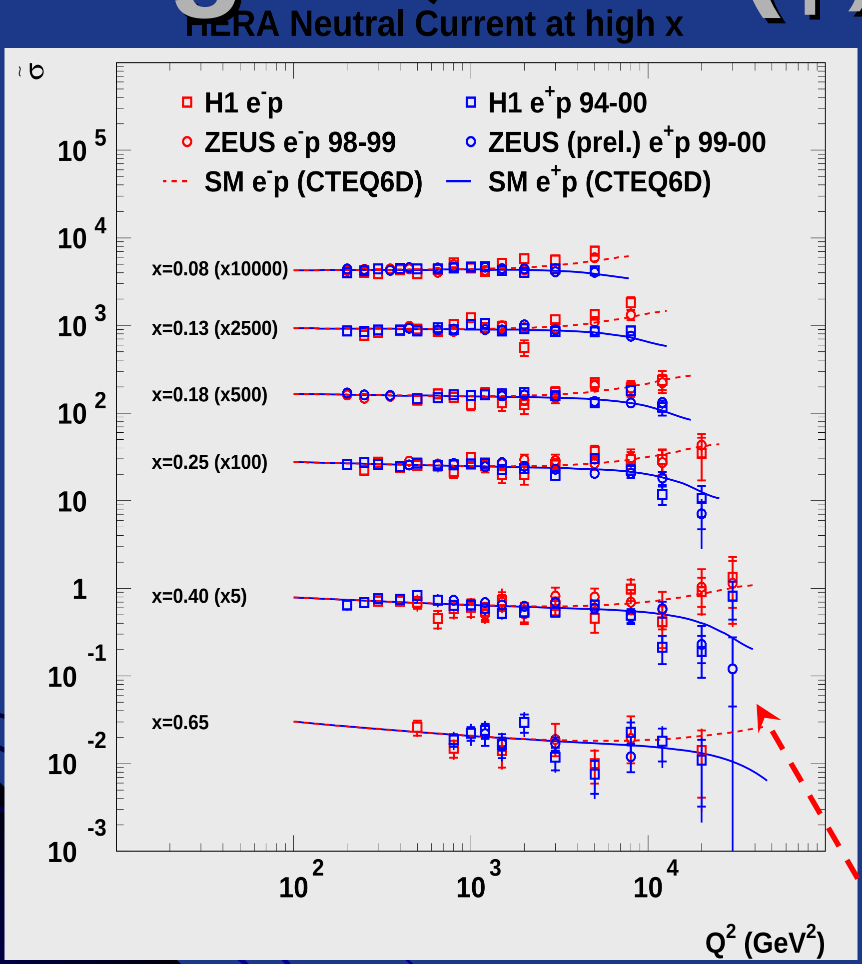
Dominant contribution

Sizeable only at high y (y>~0.6)

Contribution only important at high Q^2

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

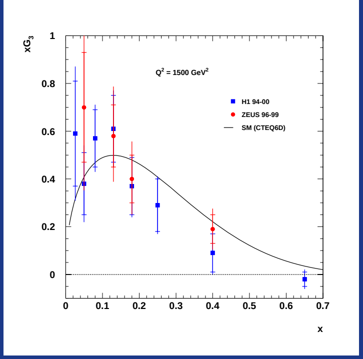
High Q^2 NC (γ, Z Exchange)



- Note:
  - Handle on F_3:

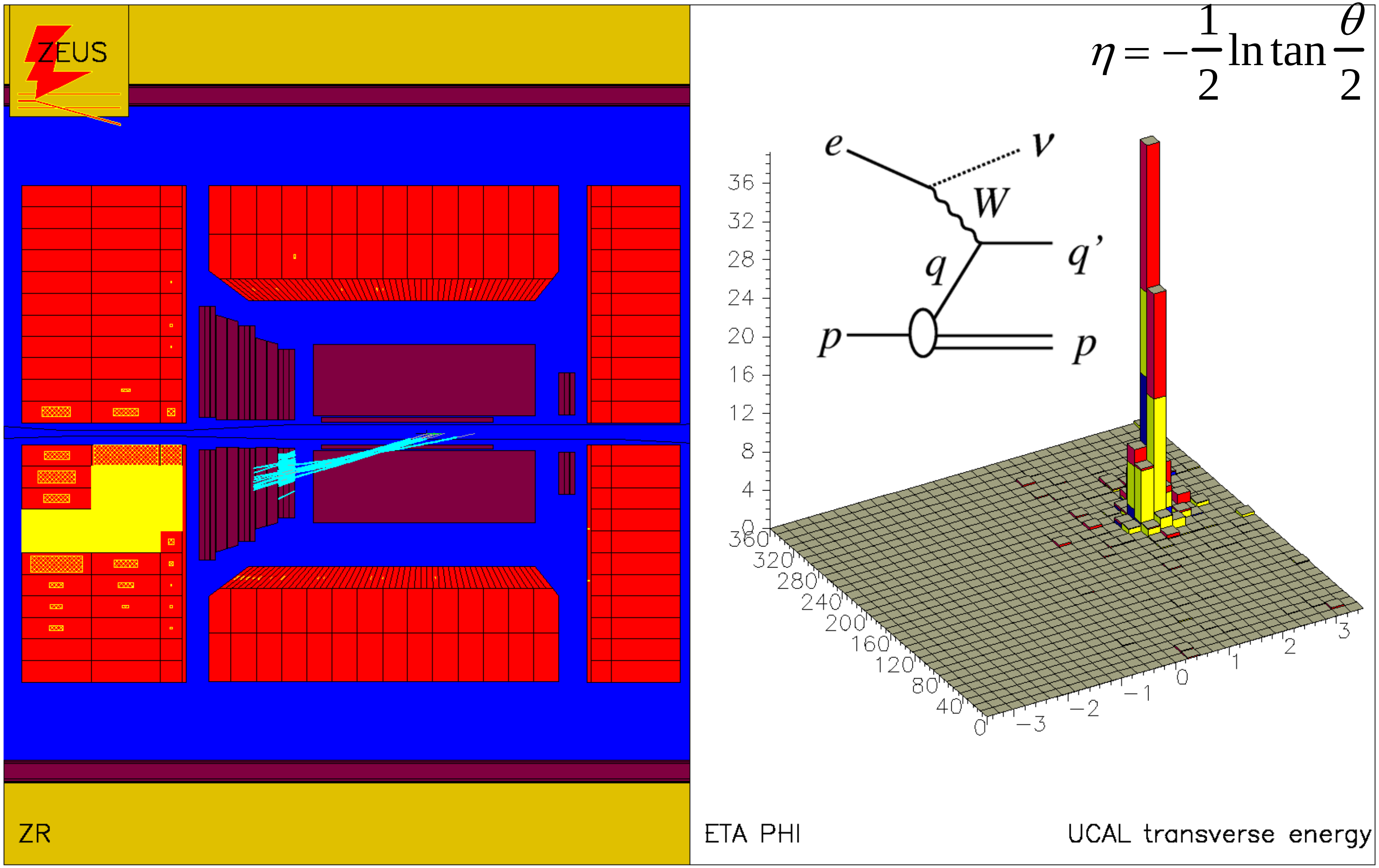
$$xF_3 \propto \sigma^- - \sigma^+$$
$$xF_3 \propto \sum e_i^2 (xq(x) - x\bar{q}(x))$$

  - Valence quarks!



γ-Z interference: e⁻ constructive e⁺ destructive

Charged Current Interactions



NC vs CC

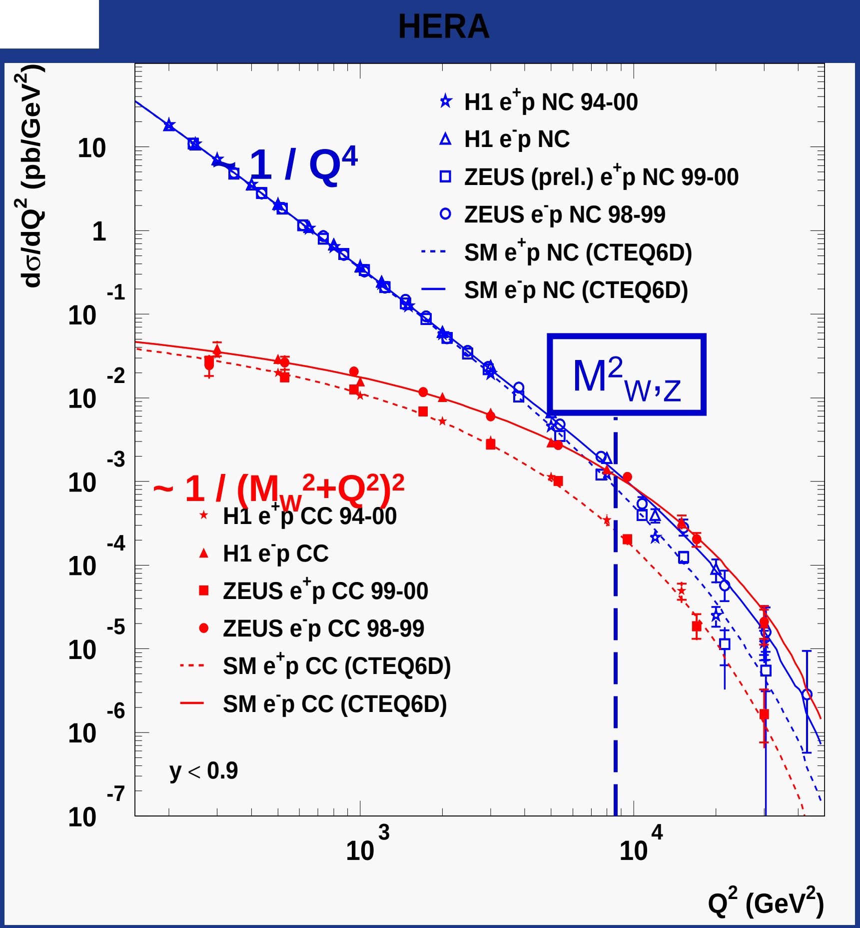
$$\frac{d^2\sigma^{CC}_{e^-p}}{dxdQ^2} = (1-\lambda)\frac{\pi\alpha^2}{8\sin^4\theta_W}\left(\frac{1}{M_W^2+Q^2}\right)F_2^{CC}(x,Q^2)$$

ignore F_L and xF_3

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

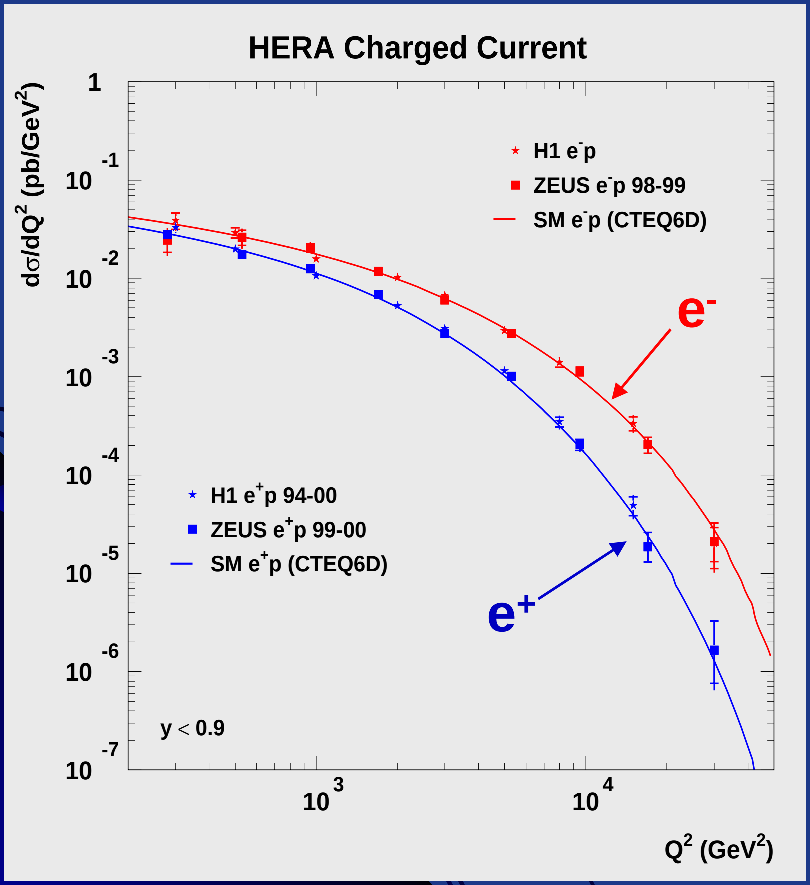
	COUPLING	PROPAGATOR
NC	$2\pi\alpha^2$	$1 / Q^4$
CC	$\pi\alpha^2 / 8 \sin^4\theta_W$	$1 / (M_W^2+Q^2)^2$
	similar since $\sin^2\theta_W \sim 1/4$	similar at $Q^2 > M_W^2$

'Unification' of elm. and weak forces



CC Cross Section

$$\frac{d^2\sigma_{CC}}{dxdQ^2}(e^{\pm}) = \frac{G_F^2}{4\pi x}\left[\frac{M_W^2}{M_W^2+Q^2}\right]^2 (Y_+F_2^{\pm} \mp Y_-xF_3^{\pm} - y^2F_L^{\pm})$$



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

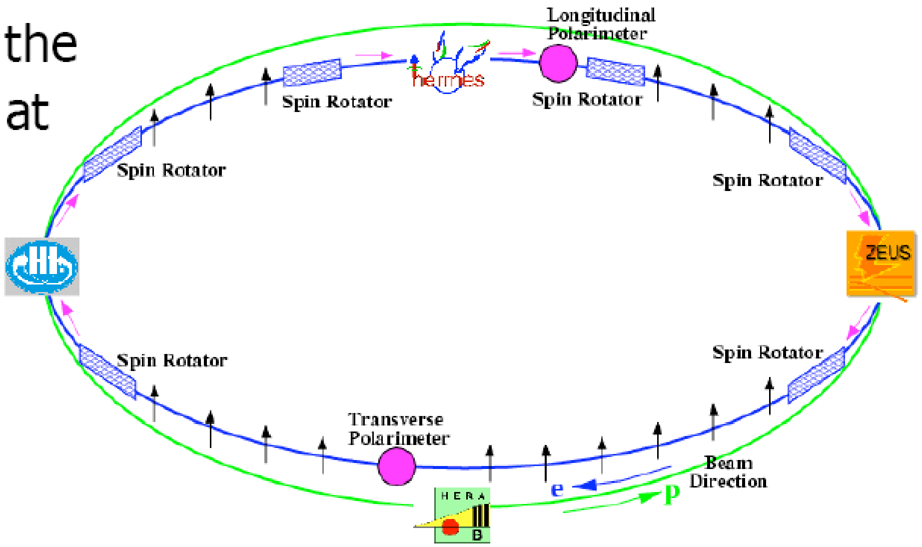
--- $\sigma\,(e^-p) \sim x\,(u+c) + (1-y^2)\;x\,(\bar{d}+\bar{s})$

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

Polarization

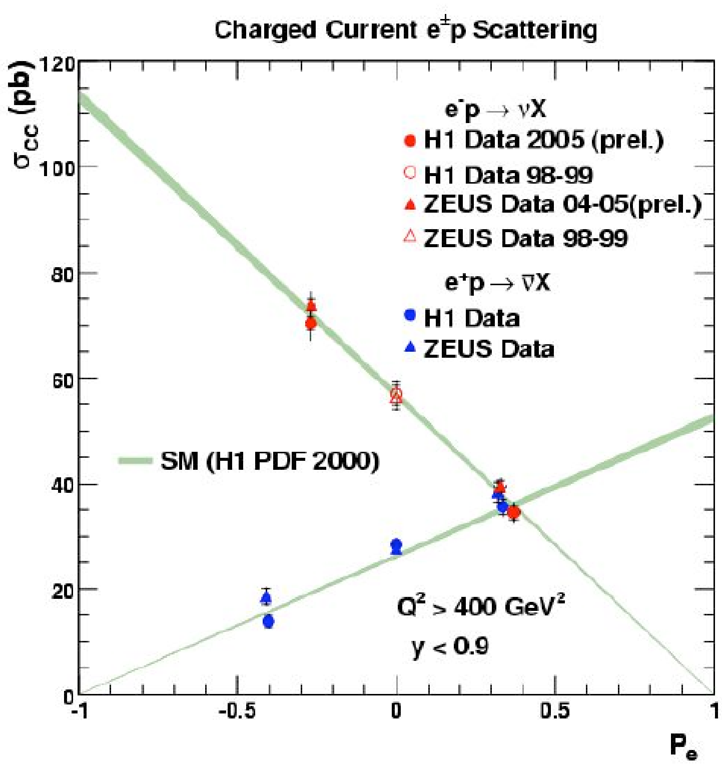
Longitudinal polarisation of the lepton beam at HERA: new at HERA II

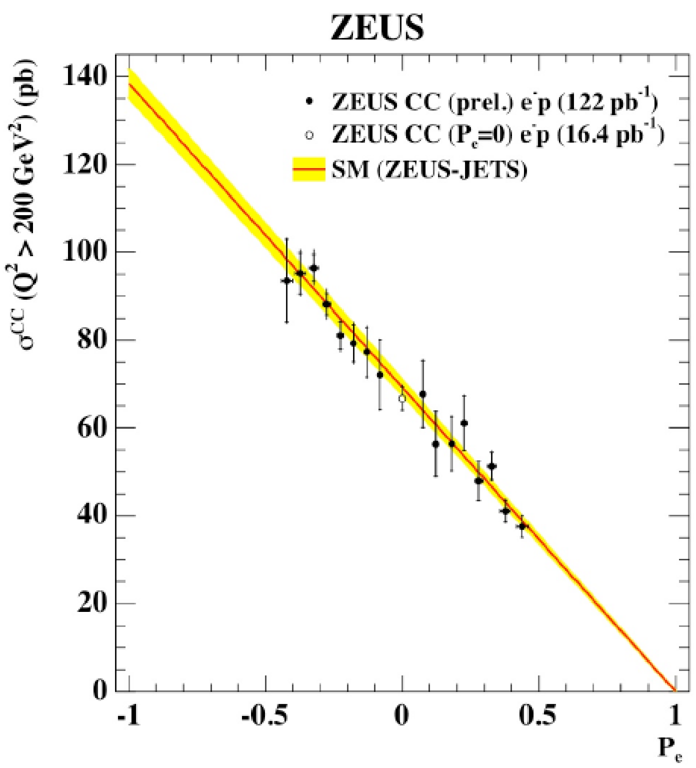
$$P_e = \frac{N_R - N_L}{N_R + N_L}$$



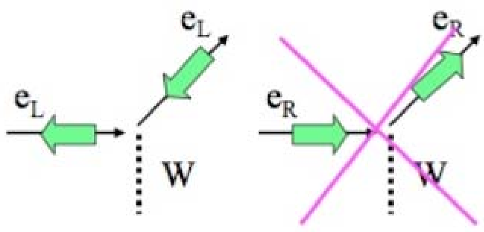
- Transverse polarization builds up naturally in HERA through synchrotron radiation (Sokolov Ternov effect)
- Build up time is ca. 40 minutes
- Spin rotators flip transvere polarization to longitudinal before interaction regions and back afterwards

CC Cross Section: Polarized Beams



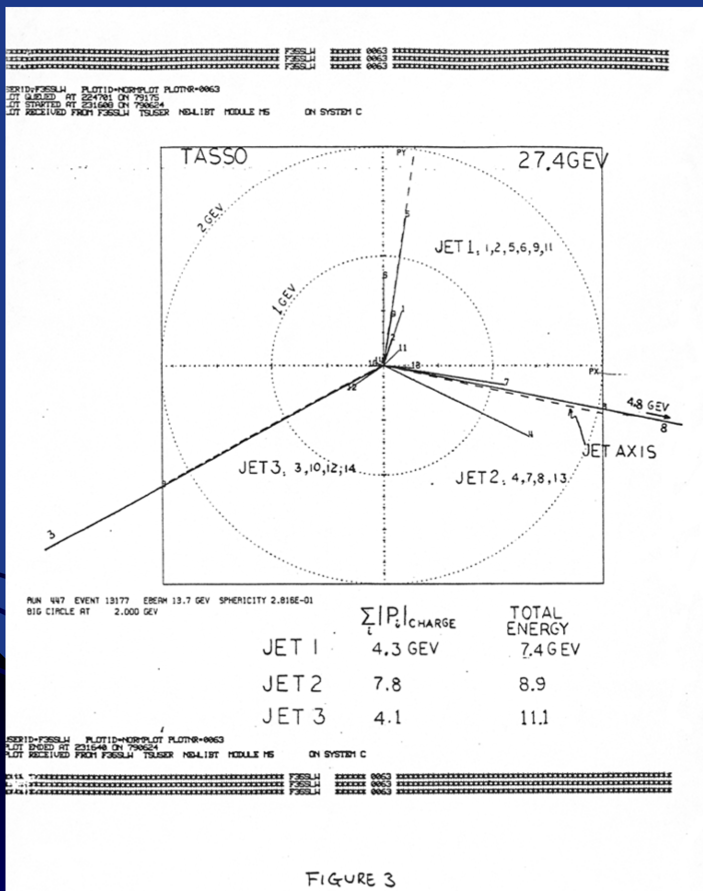


- Standard Model weak interaction left-handed
  - only LH particles (RH anti-particles) interact



Jets and $\alpha_s(Q^2)$

What are Jets?

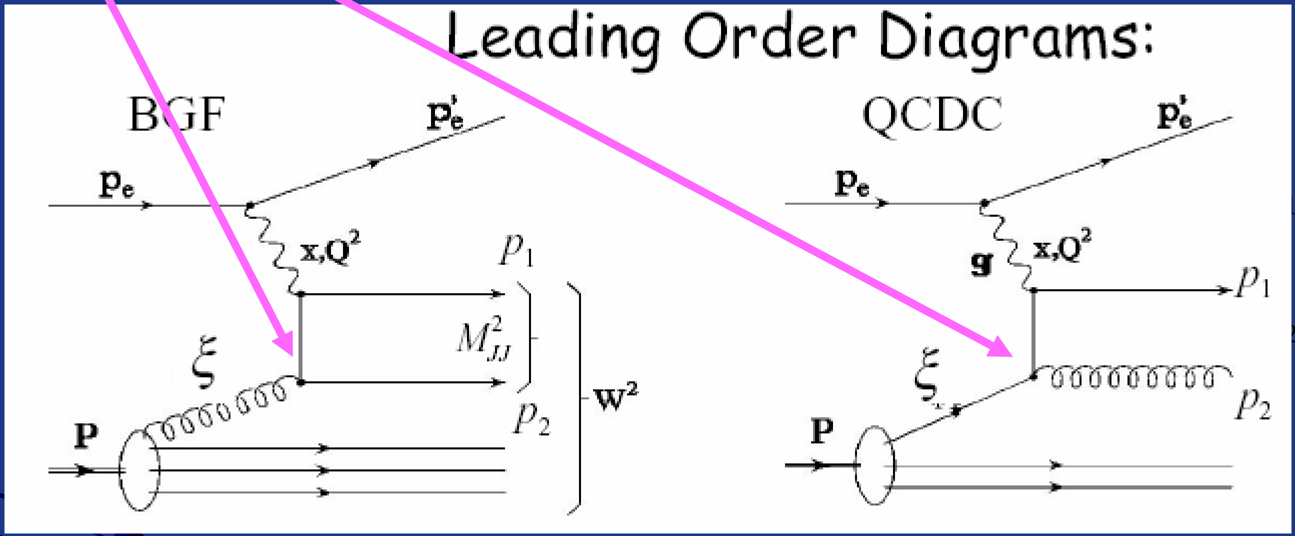


DESY 1979

- 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 ?



$$q = p_e' - p_e$$

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

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

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

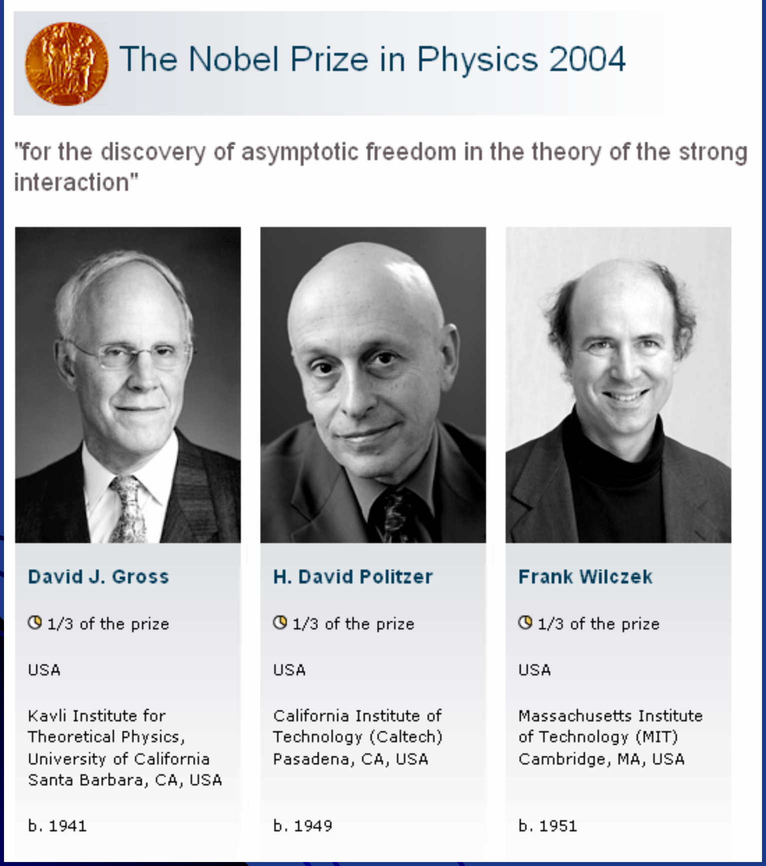
- Outgoing partons described by 3 more variables:

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

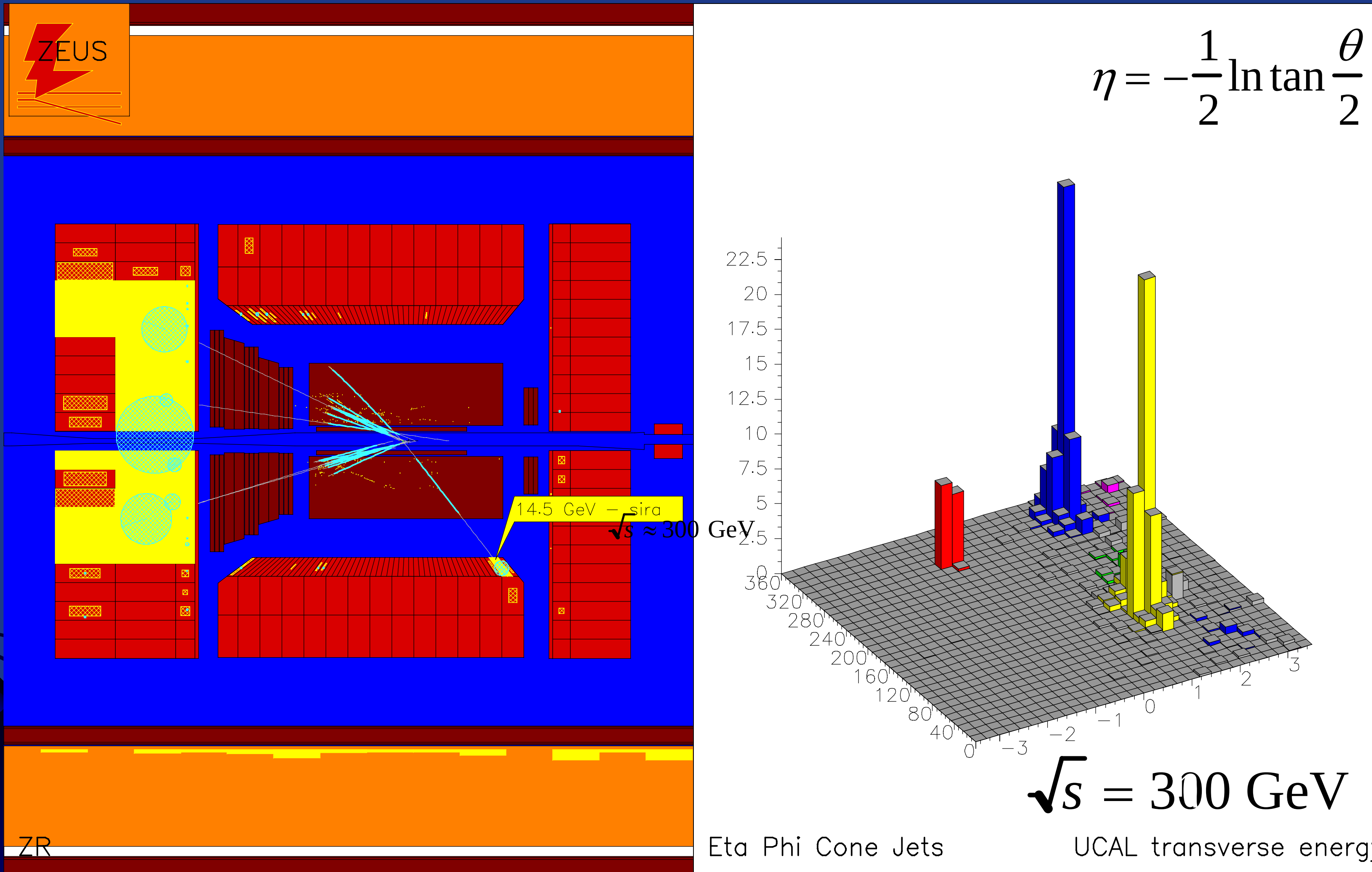
$$z_{P,i} = \frac{P \cdot p_i}{P \cdot q} = \frac{1}{2}(1 - \cos\theta_i^*) \quad \theta_i^* : \text{Scattering Angle in CMS}$$

ϕ : Azimuth

Remark about α_S

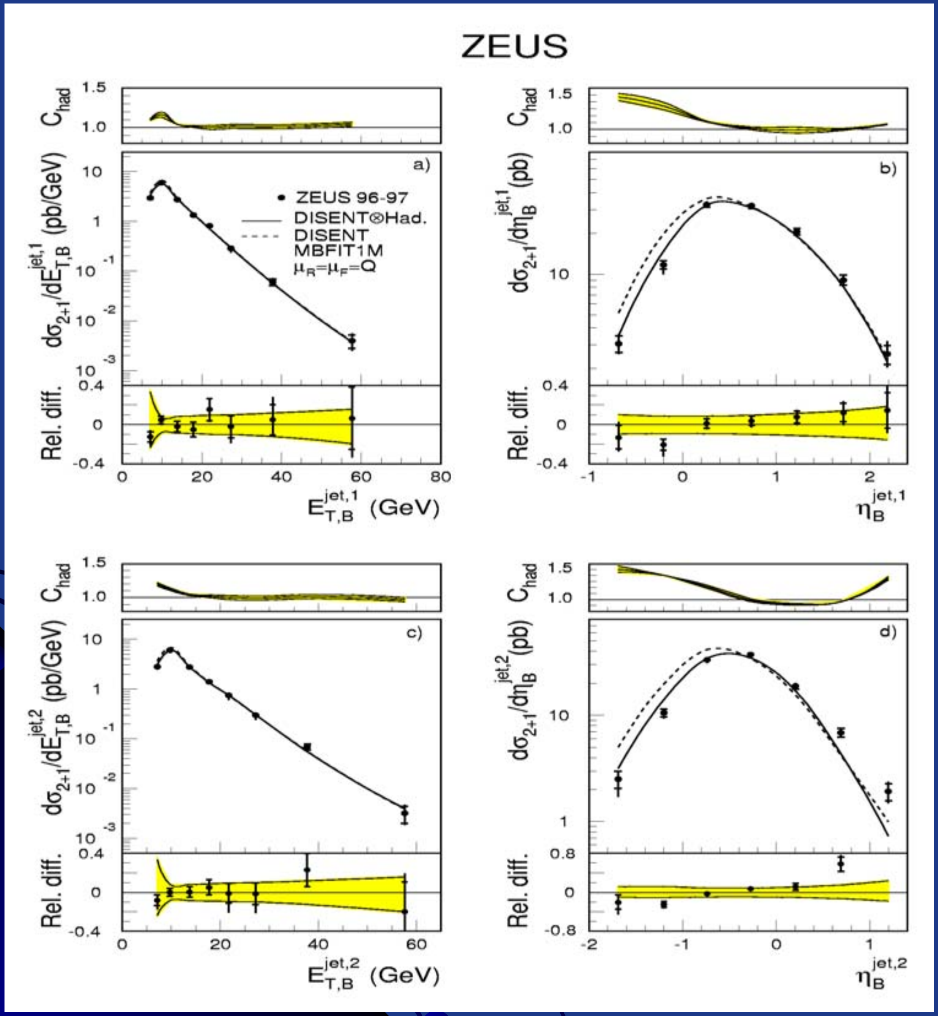


- α_S is not a constant but „runs“
- α_S runs against the historical prejudice…
  it decreases with increasing energy
- Effect of „negative β-function



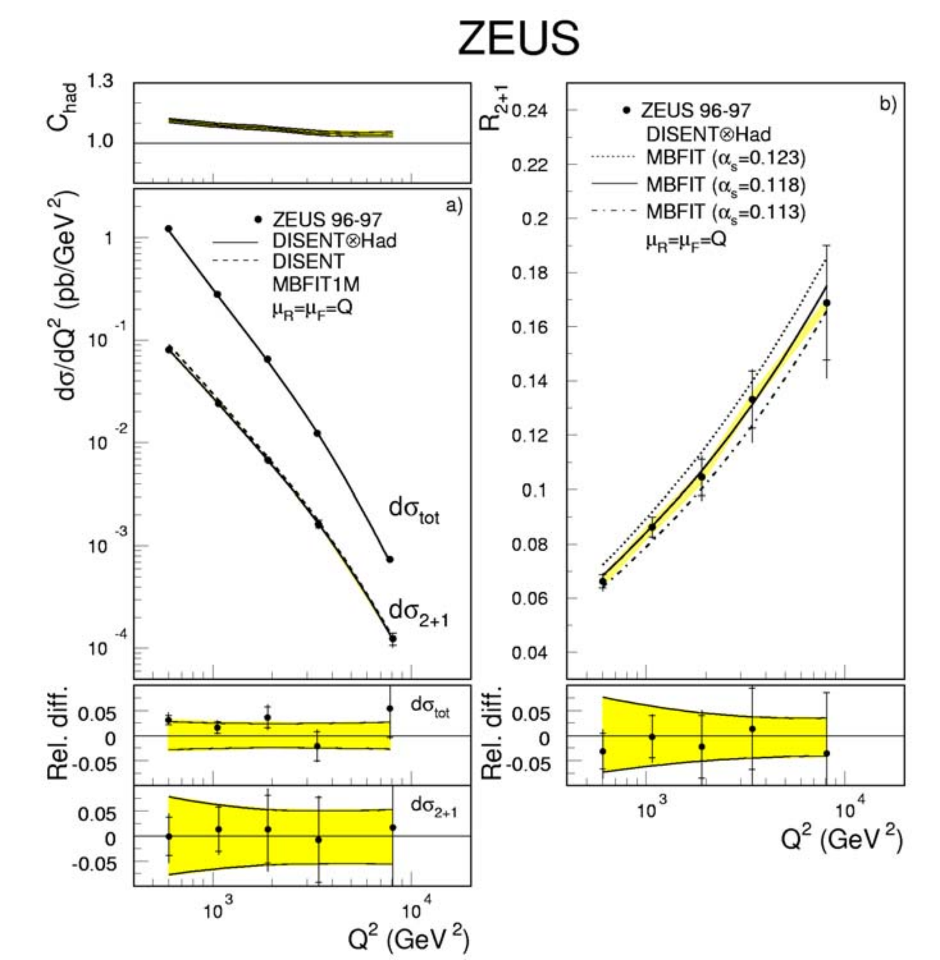
$e^{+/-}$ 27.5 GeV → ← p 820/920 GeV

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 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

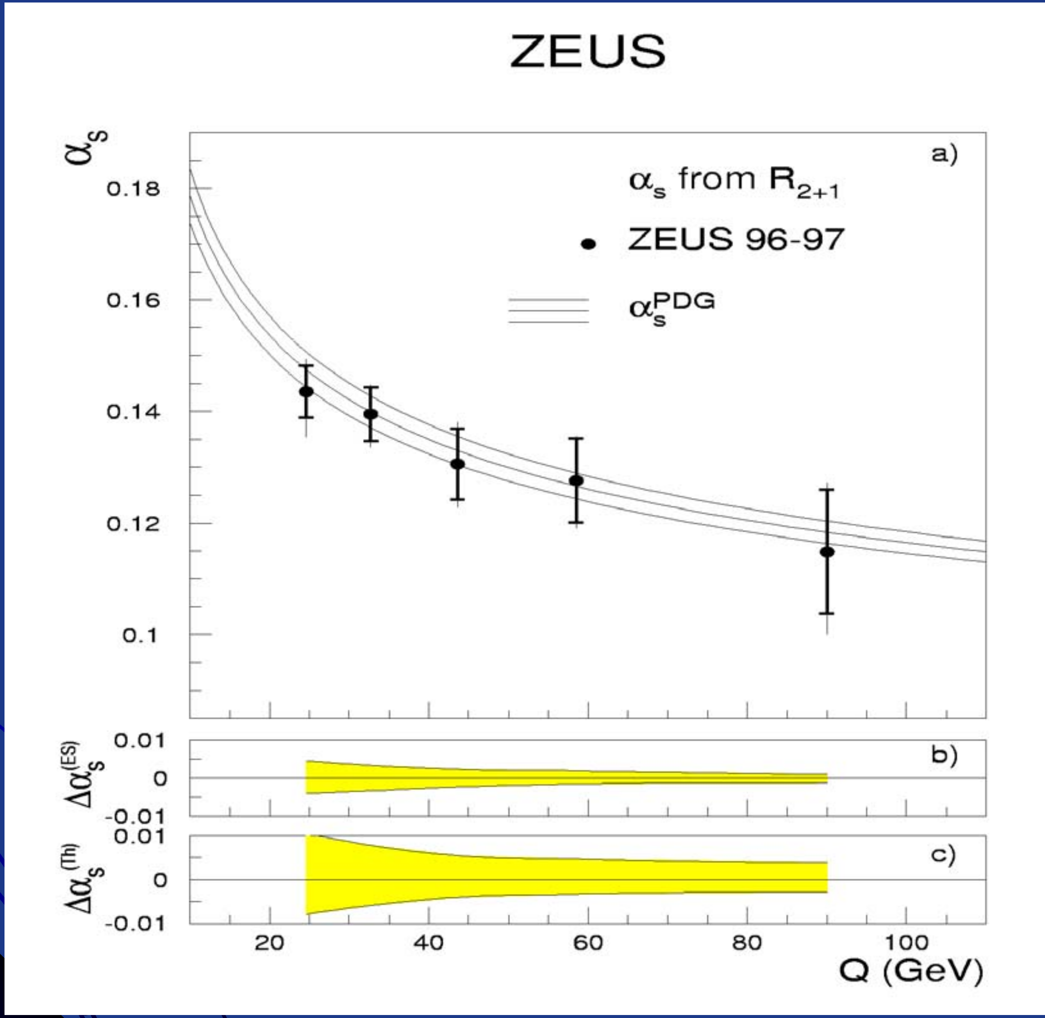


$$R_{2+1} = \sigma_{2+1} / \sigma_{tot}$$

- 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



α_s (Q^2)

- QCD fit of F_2 scaling violations :

  α_s = 0.1150 ± 0.0019 (expt+fit) ± 0.0050 (scale) **H1**

  α_s = 0.1166 ± 0.0052 (expt+fit) ± 0.0040 (scale) **ZEUS**

- Jet cross sections: 1, 2, 3 jets

  α_s = 0.1224 ± 0.002 (exp) ± 0.004-5 (theory)