

WB, Bologna, DIS 2001

PHYSICS AT HERA II *

- Beyond the Standard Model
- Electroweak Interactions
- Strong Interactions

References

Workshops on Physics e HERA : 1980 ,
1983 , 1987 , 1991 , 1996

Transparencies of H1 - ZEUS talks 2001

* HERA II : polarisation , $\sim 1 \text{ fb}^{-1}$

THE VIRTUES OF HERA

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Talk presented to the Workshop: Experimentation at HERA, Amsterdam, June 9-11,
1983.

Beyond the Standard Model

Revolution around the
Com, i.e. **compositeness**
with 'Regge trajectories',

$$L^*, q^*, \dots$$

or **large extra dimensions**,
i.e. string theory at TeV scale,
with Kaluza-Klein towers,
novel contact interactions, ...

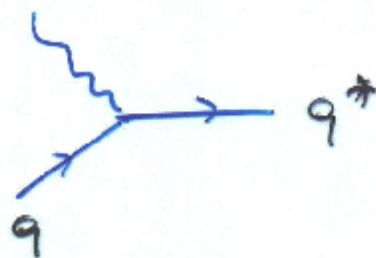
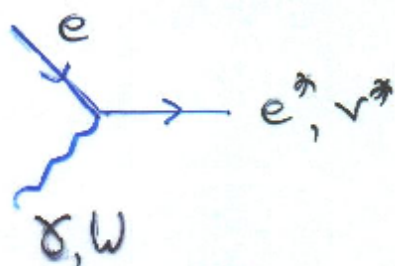
Unification, far away,
with SUSY around the Com, i.e.

$$\tilde{L}, \tilde{q}, \tilde{\delta}, \dots$$

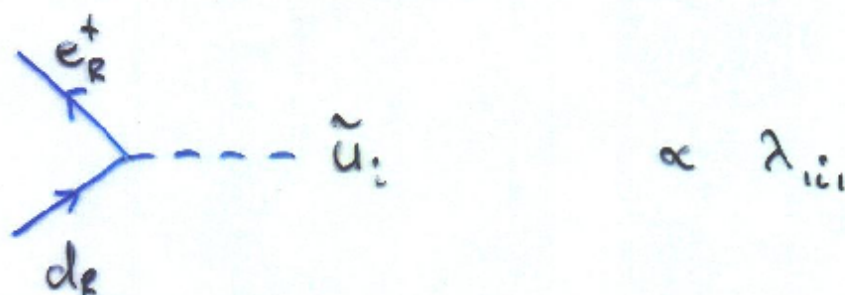
and **small neutrino masses**,
so far the only evidence for
physics beyond the SM,
lepton flavour violation, ...

New particles and interactions

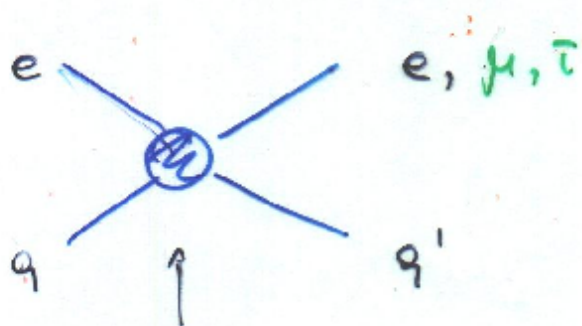
excited leptons and quarks



scalar quarks (or leptoquarks), e.g.,



contact interactions

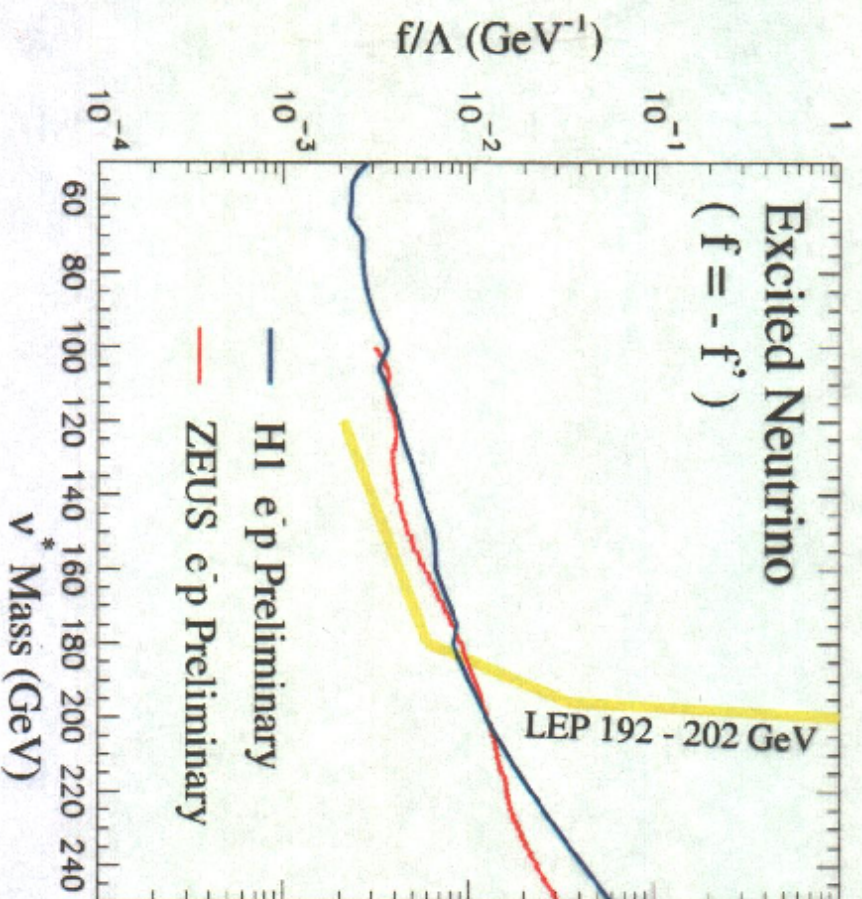


heavy particles, Kaluza-Klein gravitons, ...

important : lepton flavour violation

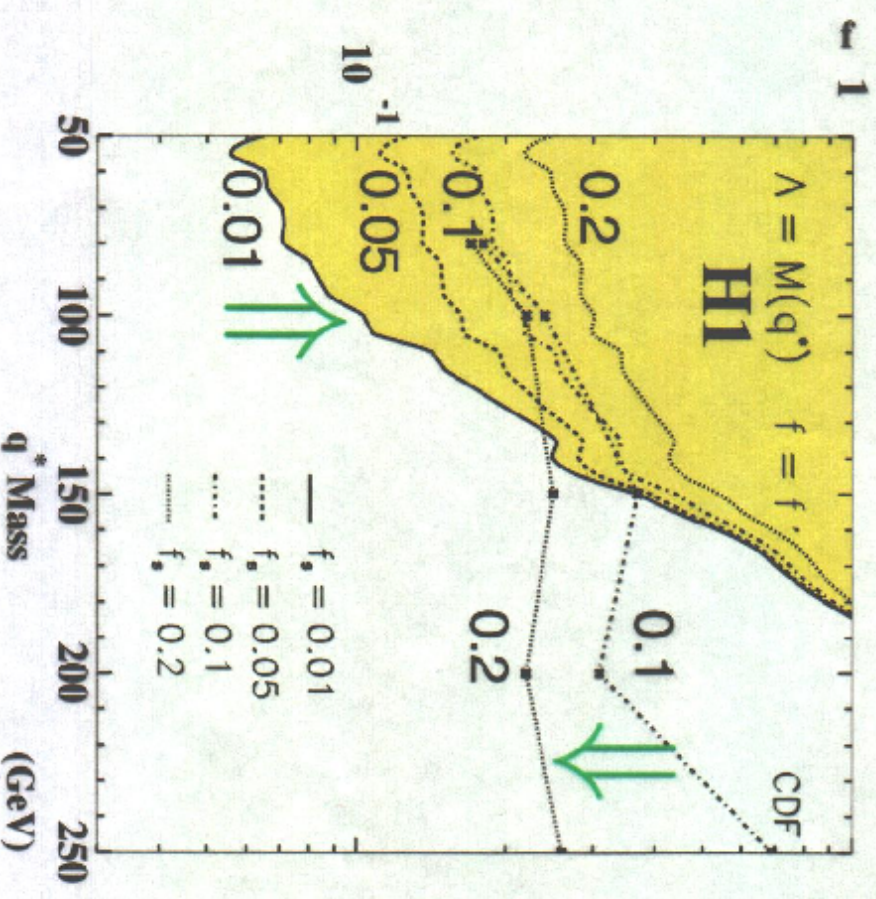
Limits on Excited Fermions

e.g. Excited Neutrinos



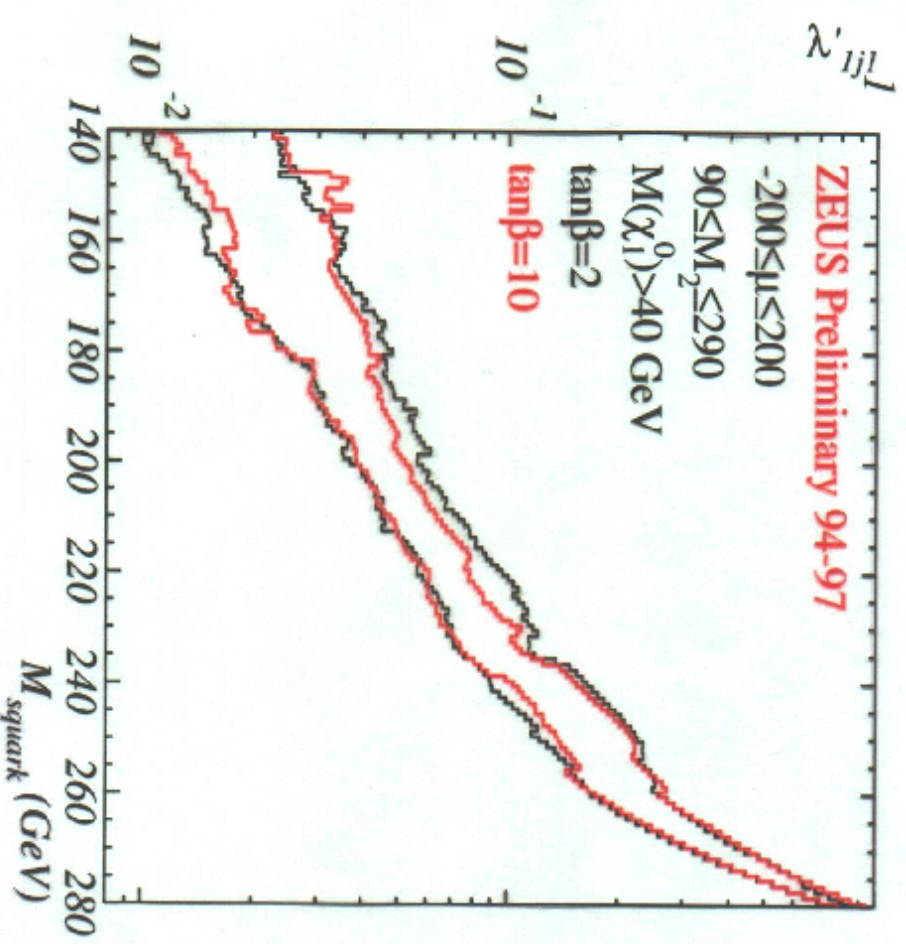
HERA extends LEP limits
beyond $M > 200$ GeV

Excited Quarks

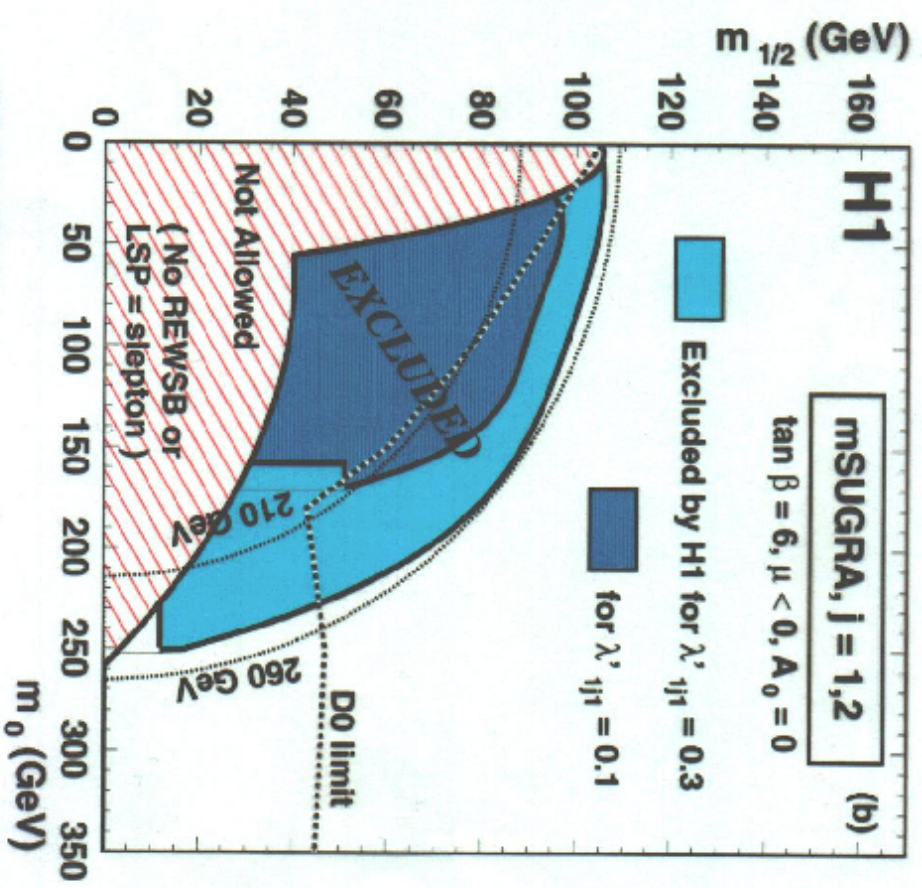


Limit on f for $\Lambda = M(q^*)$
 $\Rightarrow$ HERA more sensitive for small f_s

Limits in SUSY parameter space



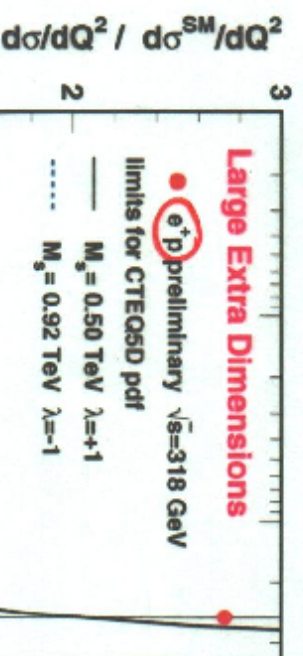
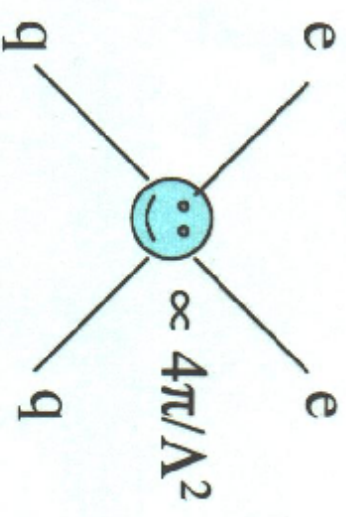
- Unconstrained MSSM:
limits variation in parameter scan



- mSUGRA:
For reasonably large λ' values,
HERA exclusion exceeds TeVatron
limits

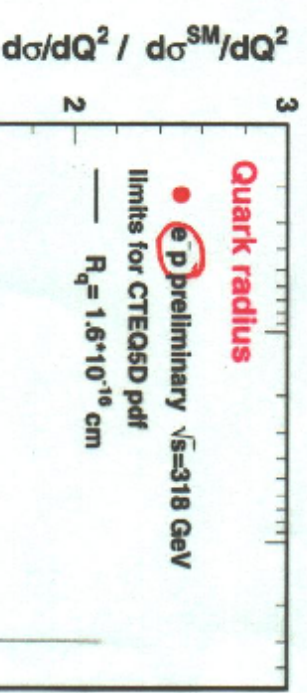
Contact Interactions

- Look for deviation at highest Q^2
- Probed distance $= 1/Q \sim 0.001$ fm for $Q^2 \sim 10^4 \text{ GeV}^2$
- General $eeqq$ CI: limits depend on chirality combination (LL, LR, VV, AA...), up to **9 TeV**
- Comparable to LEP ($e^+e^- \rightarrow \text{hadrons}$), TeVatron (Drell-Yan)
- Limits also set on some specific models:



← Kaluza-Klein graviton exchange in **Large Extra Dimension** models

Interpretation in quark form factor:
 $F=(1-R^2Q^2/6)$
R: quark "radius"



Example: SUSY SM with R_p yields

connection between ν -mixing and $\tilde{\chi}$ production

Pickel, WB

neutrino mass matrix

$$m_{\nu_{ij}} = m \quad f_{ij}$$

$< 1 \text{ eV}$

seesaw or loops

O(1)

after ν 's : $\sin^2 2\theta_{\text{after}} \approx 1$

slow ν 's : LMA favoured

SUSY SM :

$$W = h_{eij} E_i^c L_j H_1 + h_{dij} Q_i D_j^c H_1 + \dots$$

$$\begin{pmatrix} \nu_e \\ e^- \end{pmatrix}$$

$$\begin{pmatrix} H^0 \\ H^- \end{pmatrix}$$

same weak isospin
and hypercharge

motivates R_p -violating interactions :

$$W_R = \frac{1}{2} \lambda_{ijk} L_i L_j E_k^c + \lambda'_{ijk} L_i Q_j D_k^c$$

implies lepton number violation, c.f.

Gouvea, Lola, Tobe, hep-ph/0008085

leptons. Similarly to what discussed in Sect. 4, if electrons and quarks have common constituents, additional, contact, interactions should add to the γ and Z exchange, and give rise to an anomalous deep-inelastic cross-section at large Q^2 . This point has been brought up in Ref. (29) where it is shown that detectable effects should result for:

$$\Lambda \approx \frac{1}{R_e} \approx \frac{1}{R_q} \lesssim 1 \div 2 \text{ TeV}$$

as illustrated in Fig. 15. The situation would be strikingly similar to the Rutherford's finding of anomalous, large Q^2 , events in the scattering of α -particles against gold nuclei, in addition to the softer scattering produced by the Coulomb nuclear field.

7. - Conclusions

Stringent tests of the Standard Theory can be performed with HERA.

A convincing indication for a modification of the Standard Theory in the TeV region exists. Although many ideas are proposed as for what one may find there, none is really outstanding. Therefore, there is room for HERA to contribute to new and important developments.

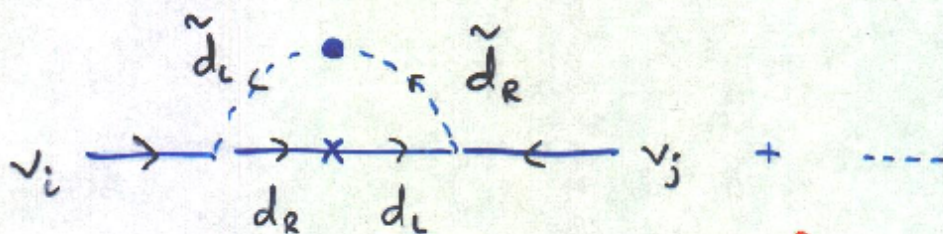
In particular, HERA has good chances to find scalar electrons, if low energy supersymmetry is the answer to the naturality problem.

The possibility that the electron and quarks turn out to be composite objects of the same constituents is certainly fascinating. With HERA, this idea can be put to a severe test.

Ausatz für R_p -violating couplings, $L_i \sim H_i$,

$$\lambda'_{ijk} = \lambda'_i h_{djk}, \quad \lambda_{ijk} = \dots, \quad \lambda'_i = O(1)$$

i.e., 'flavour alignment'; Majorana ν -masses:



$$m_{\nu ij} = m_{\nu}^{(d)} \lambda'_i \lambda'_j + \dots, \quad \text{large mixing}$$

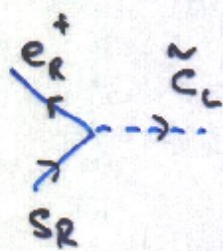
$$m_{\nu}^{(d)} \simeq \frac{N_c}{16\pi^2} \frac{A_d v_1^2}{m_d^2} \text{tr}[(h_d h_d^\dagger)^2]$$

FCNC: $\Delta S = 1, 2$, $\Delta B = 1, 2$ suppressed due to 'flavour alignment'; most 'dangerous':

$$\text{BR}(D^0 \rightarrow \mu\mu, \mu e) \sim 10^{-5}, \quad \text{BR}(\tau \rightarrow K^+ K^- e_\mu) \sim 10^{-5}$$

close to exp. limits!

Predictions: $\lambda'_{iii} \sim \frac{m_d}{v} \tan\beta \sim 0.003$ (0.004, $\beta \beta_{0v}$)



$$\lambda'_{122} \sim \frac{m_s}{v} \tan\beta \sim 0.05$$

$$H(37 \text{ pb}^{-1}): 0.29$$

within reach
at HERA II!

Electroweak Interactions

At $Q^2 \sim 10^4 \text{ GeV}^2$ electroweak unification,

$$\sigma(\text{NC}) \sim \sigma(\text{CC})$$

Polarisation at HERA II allows the **classic** test of the electroweak theory,

$$\sigma^{\text{CC}}(e_R^- p) = \sigma^{\text{CC}}(e_L^+ p) = 0$$

Polarisation asymmetry yields determination of $\sin^2 \Theta_w$, complementary to LEP,

$$A(e_L^- - e_R^-) = \frac{d\sigma(e_L^-) - d\sigma(e_R^-)}{d\sigma(e_L^-) + d\sigma(e_R^-)},$$

$$\frac{A}{Q^2} = a(y) + b(y) \sin^2 \Theta_w$$

Polarisation crucial for physics beyond the SM,
e.g., scalar quark production,

$$\sigma(e_R^+ p \rightarrow \tilde{e}_L X) \propto \lambda_{12}^2, \quad \sigma(e_L^+ p \rightarrow \tilde{e}_L X) = 0$$

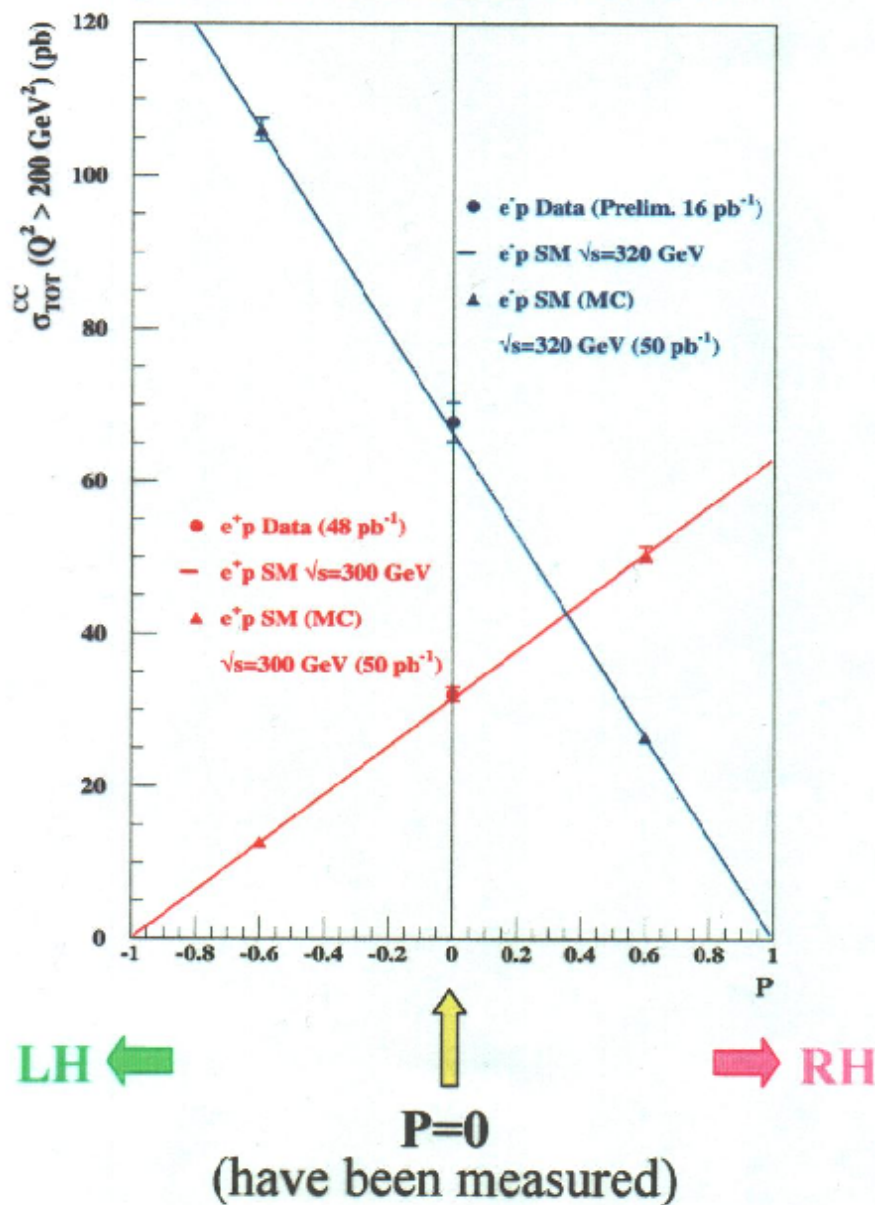
theory: right-handed currents unlikely!

Outlook for HERA II

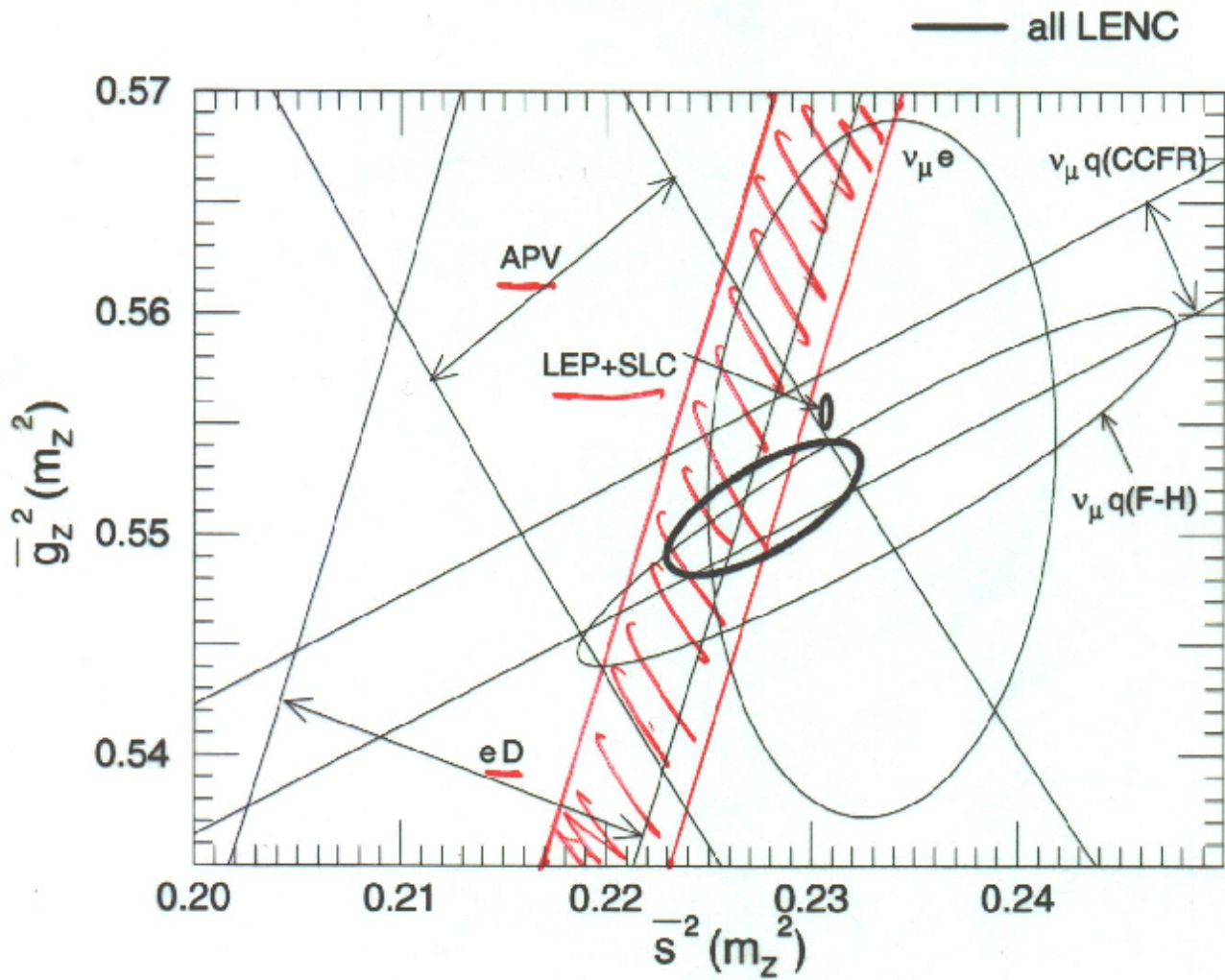
(2001 ~ 2005+)

- Luminosity upgrade : 1 fb^{-1} in total.
(Focusing magnets inside the detectors)
- LH/RH longitudinally polarized e^+/e^- beam.

Expected Cross Sections from ~1 Year



Haidt



↑
HERA II

$$A(e_L^{\bar{\tau}} - e_R^{\bar{\tau}})$$

QCD

- proton and photon structure fs
- jets, α_s
- hadronic final states
- instantons
- charm and beauty
- vector mesons
- diffraction

structure functions

jets

charm

Important results at HERA I :

- growth of parton densities at low x
- large fraction of diffractive events in DIS at low x

→ both phenomena are related to large gluon densities !

What do we know about gluons in non-diffractive and diffractive processes ?

→ scaling violations
dijets
charm

in inclusive and diffractive DIS

Inclusive DIS

gluon densities from scaling violation, dijets
and charm, consistent at next-to-leading order
role of DGLAP, BFKL, saturation... ?

Diffraction DIS

Q^2 -evolution in β , not x or $x_p \approx \bar{x}$,

$$Q^2 \frac{\partial}{\partial Q^2} F_2^D(\xi, \beta, Q^2) = 2 \sum_q e_q^2 \times \frac{\alpha_s}{2\pi} \int_{\beta}^1 \frac{db}{b} \left(P_{qq}\left(\frac{\beta}{b}\right) \frac{dg(b, \xi, \mu^2)}{d\xi} + P_{qg}\left(\frac{\beta}{b}\right) \frac{dg(b, \xi, \mu^2)}{d\xi} \right)$$

diffraction quark and gluon densities

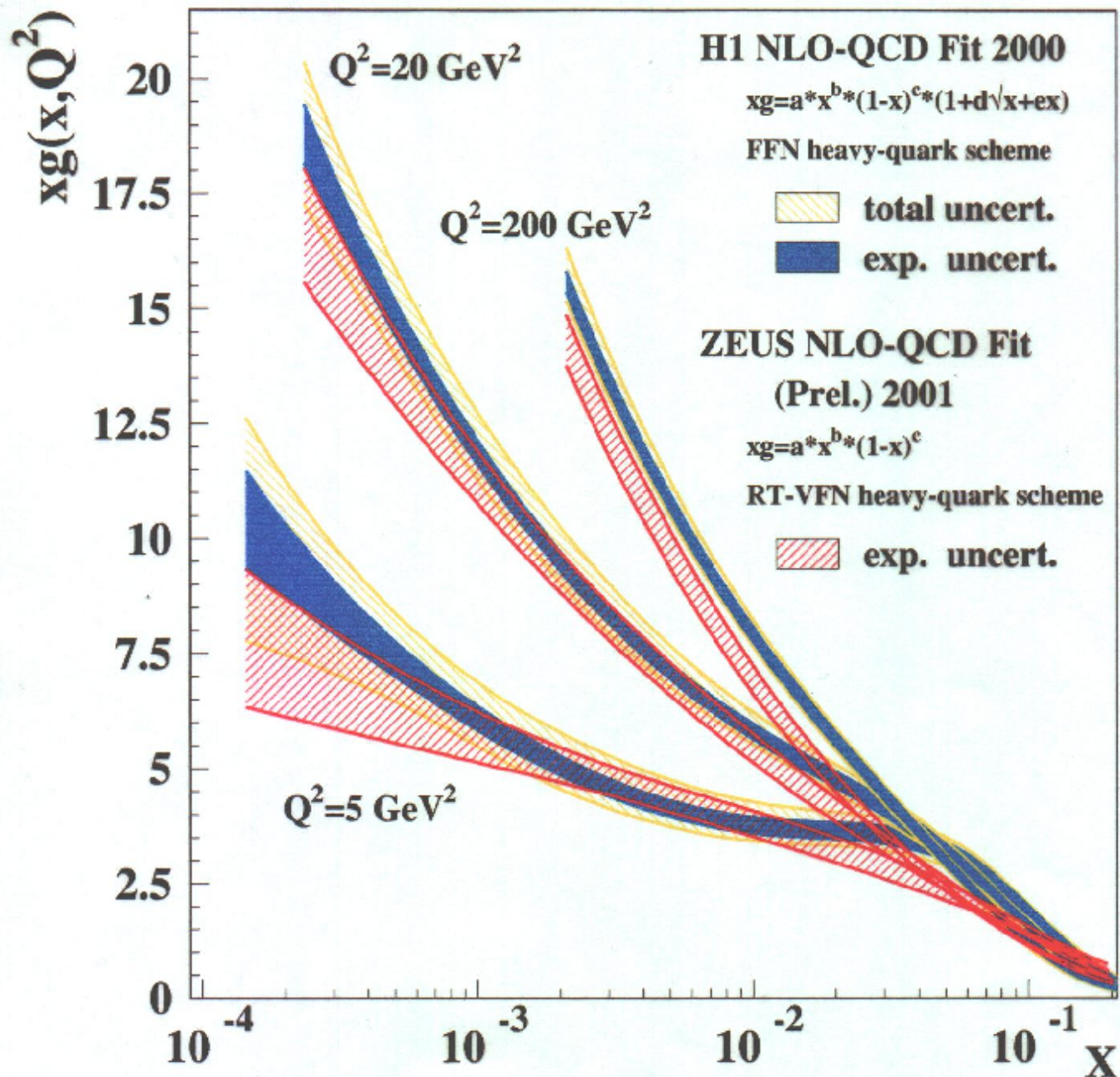
Trentadue, Veneziano; Berera, Sopu; Collins

consequence : ω -, i.e. $\mathbb{S}$ -dependence unperturbative,
different from x -dependence of $F_2(x, Q^2)$!

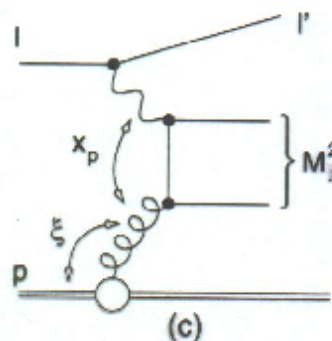
important : higher twist , for $M^2 > 4 \text{ GeV}^2$,
with $\beta = Q^2 / (Q^2 + M^2)$, in accessible β -range

Bartels, Ellis, Kowalski, Wüsthoff

H1+ZEUS

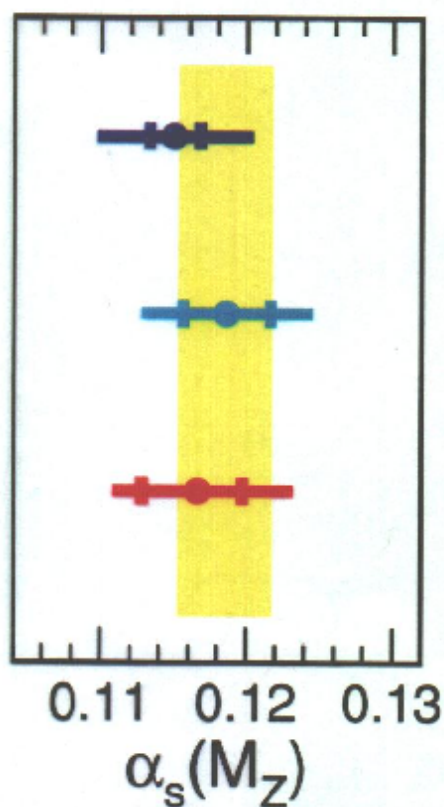
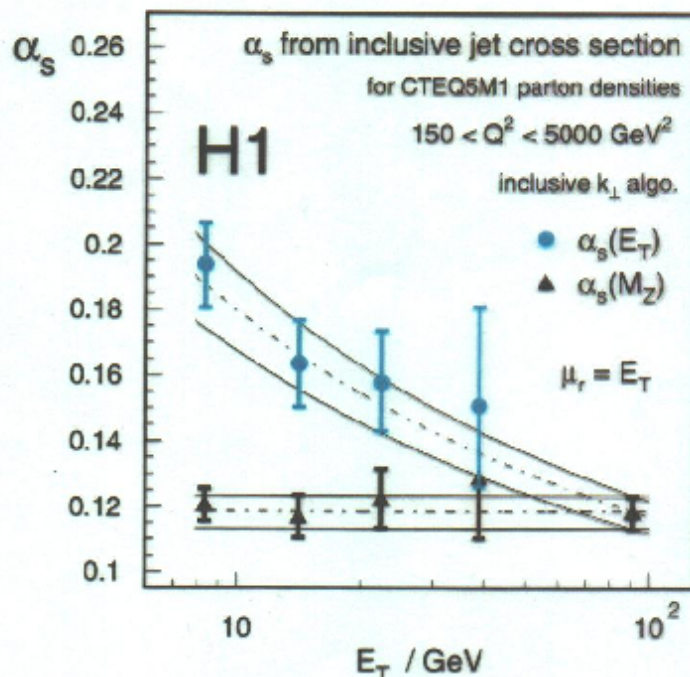
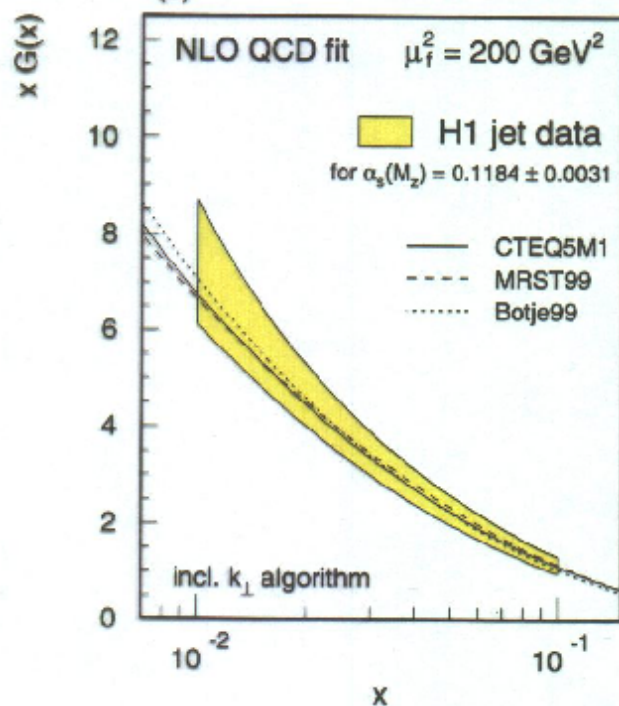
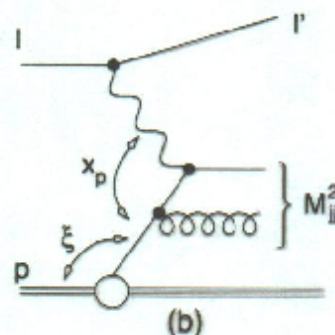


Gluon and α_s from jets



BGF: similar to $c\bar{c}$

with $M_{jj} \gg M_{c\bar{c}}$ (i.e. higher x)
and more background $\rightarrow$



(H1+BCDMS) Structure Functions

$3.5 < Q^2 < 3000 \text{ GeV}^2$ / $\mu_r = Q$

H1 – Inclusive Jet Cross Section

$150 < Q^2 < 5000 \text{ GeV}^2$ / $\mu_r = E_T$

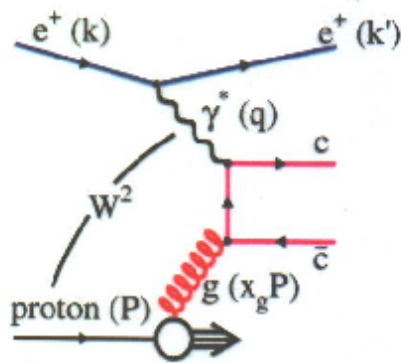
ZEUS – Dijet Rate

$470 < Q^2 < 20000 \text{ GeV}^2$ / $\mu_r = Q$

World average

(S. Bethke, J.Phys. G26 (2000) R27)

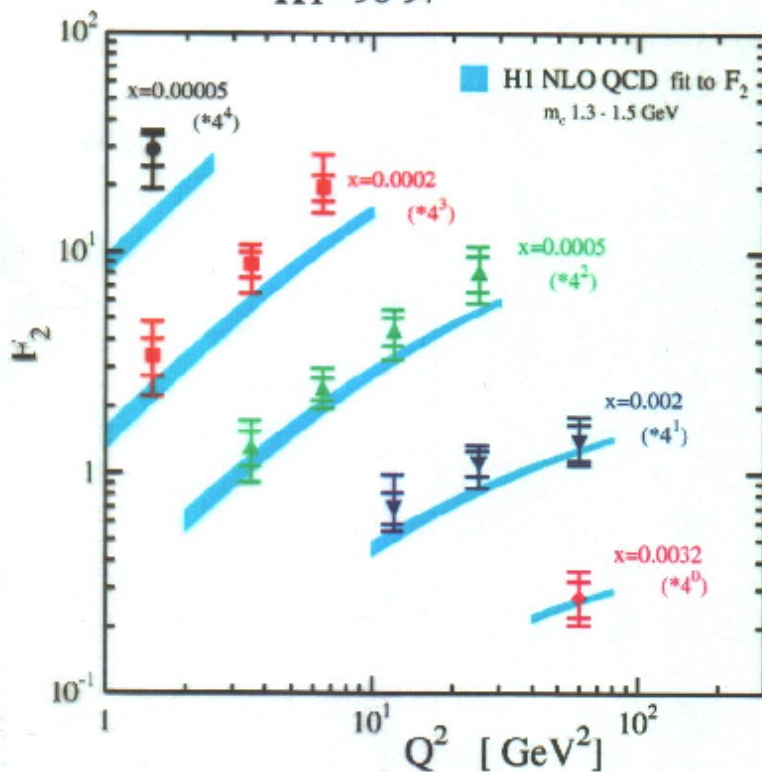
Charm contribution to $F_2(x, Q^2)$



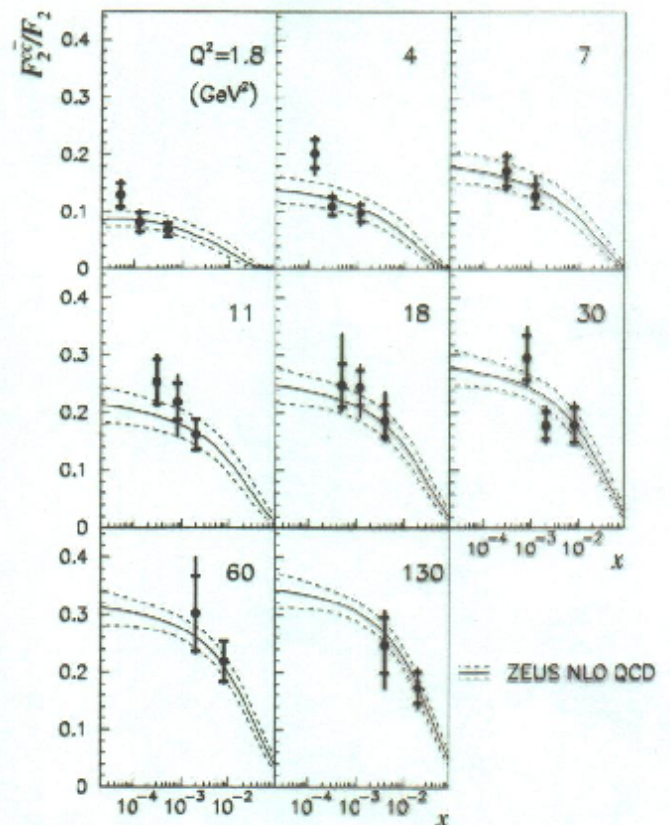
Boson Gluon Fusion (BGF)

$$D^* \rightarrow D^0 \pi_{slow} \rightarrow K \pi \pi_{slow}$$

F_2^c in the NLO DGLAP scheme
H1 96-97



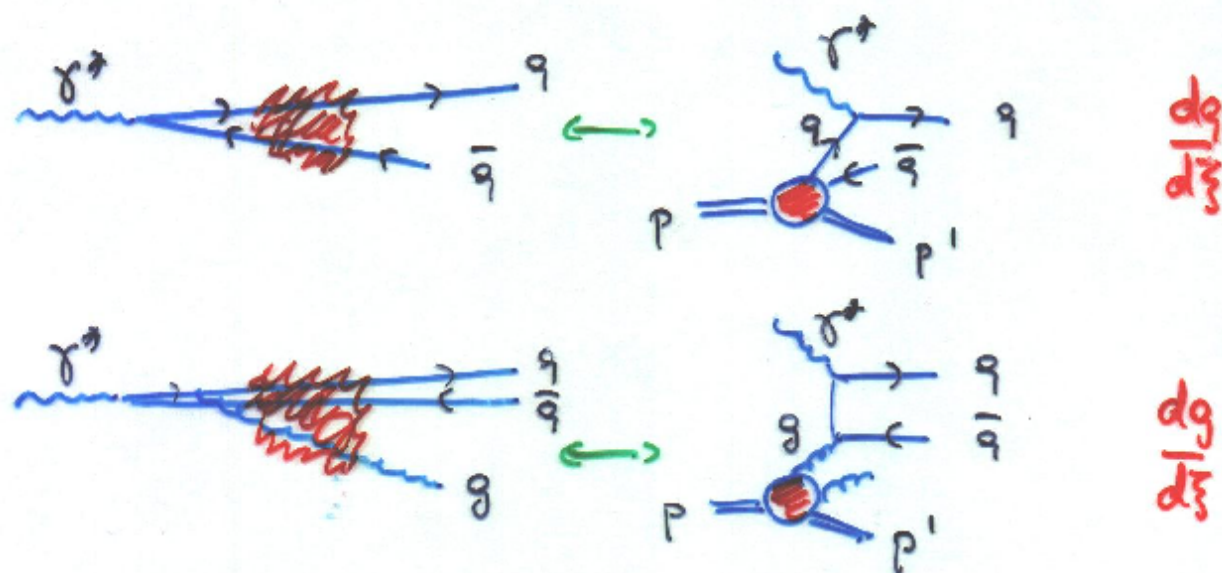
ZEUS 1996-97



- charm contribution is up to 25 – 30%
- in agreement with gluon from scaling violations

F8

- Diffractive gluon density
so far best determination from dijets, consistent with scaling violation, **much progress ahead!** Eq. 10
- Toy model for quark and gluon densities
very instructive: comparison of proton rest frame and Breit frame,



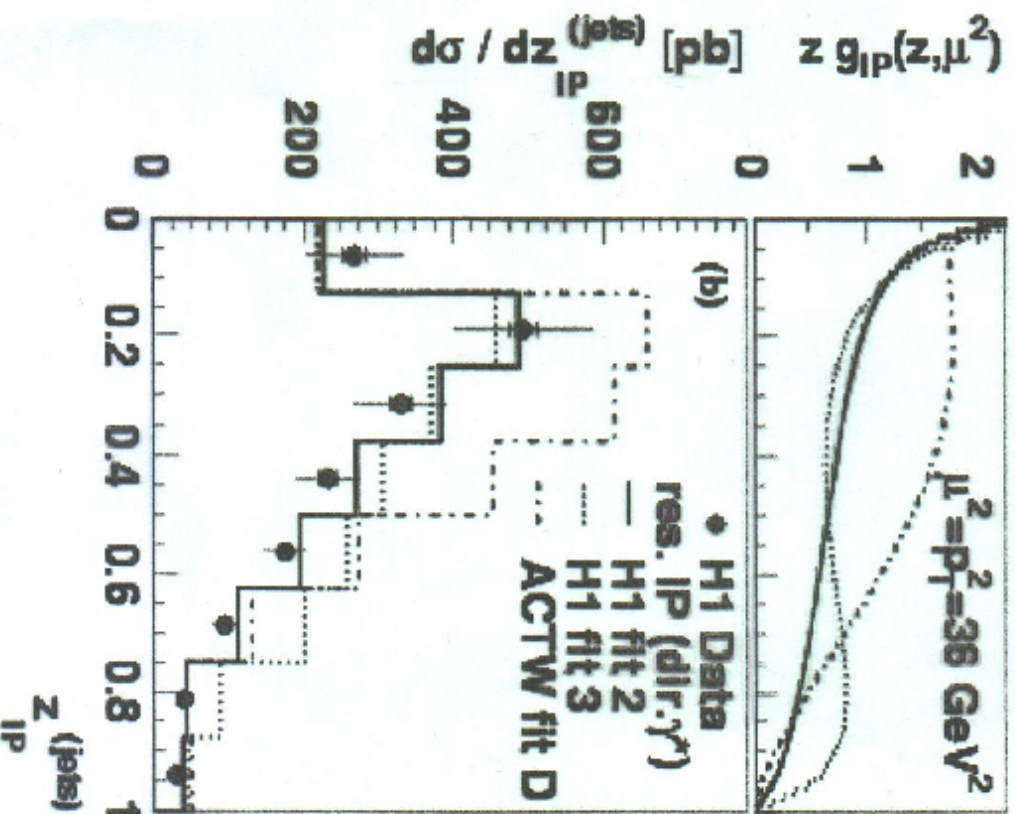
parton densities related to dipole cross sections;
for 'large' target with uncorrelated domains, e.g.,

$$\frac{d\sigma(\xi, \beta, x^2)}{d\xi} = \Omega U_c \frac{2\beta}{(1-\beta)^3} \int \frac{d^2l_1 d^2l_2}{(2\pi)^6} \int_{y_1, y_2} e^{i l_1 \cdot (y_1 - y_2)} \frac{y_1 \cdot y_2}{y_1 y_2} K_1(y_1 N) K_1(y_2 N) (1 - e^{-\alpha y_1}) (1 - e^{-\alpha y_2})$$

Gehrman, Hebecker, WB; Mueller; Golec-Biwiat, Wisthoff
dipole model beyond LT: saturation, estimate of HT Eq. 12

Jets in Diffraction

H1 Diffractive Dijets



- ▷ Use diffractive parton densities and make predictions for diffractive final states

Diffractive dijet production:

$$ep \rightarrow e' j j X p'$$

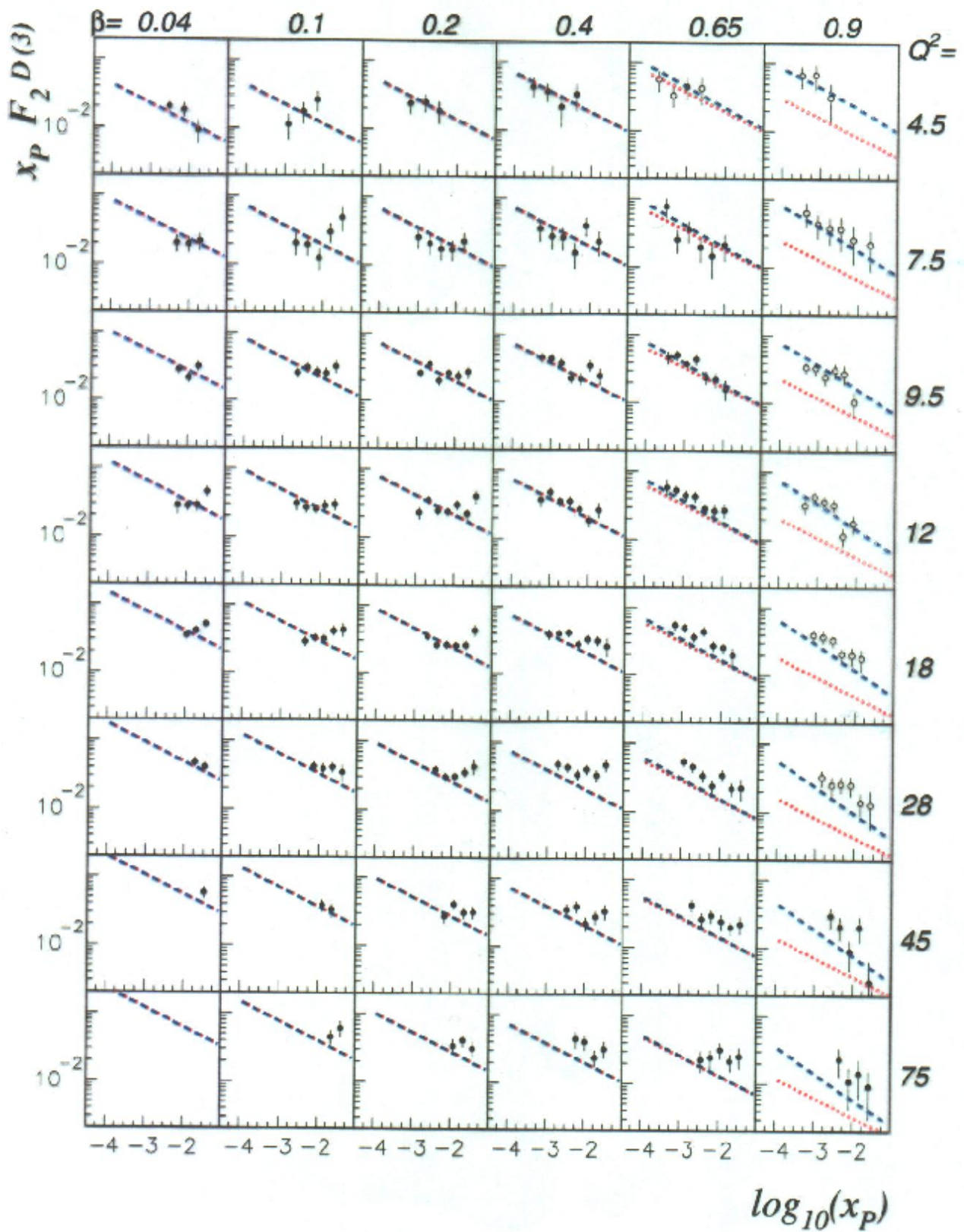
$z_{IP} \sim$ fraction of energy of system X contained within dijets

- ▷ Sensitive to changes in gluon distribution
- ▷ Large gluon component preferred
- ▷ Diffractive gluon tightly constrained by dijet data
- ▷ Approach looks consistent with resolved IP

- ▷ Results from diffractive charm production - no clear picture yet

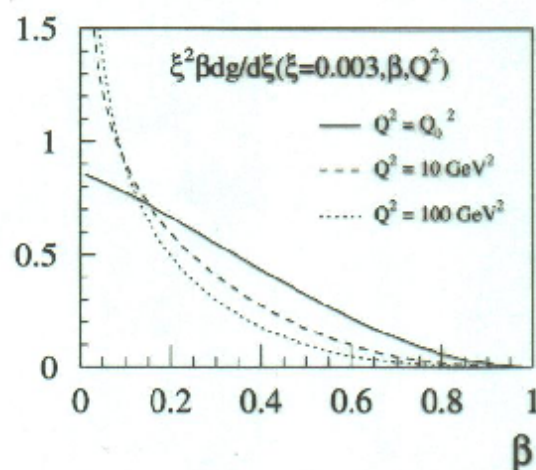
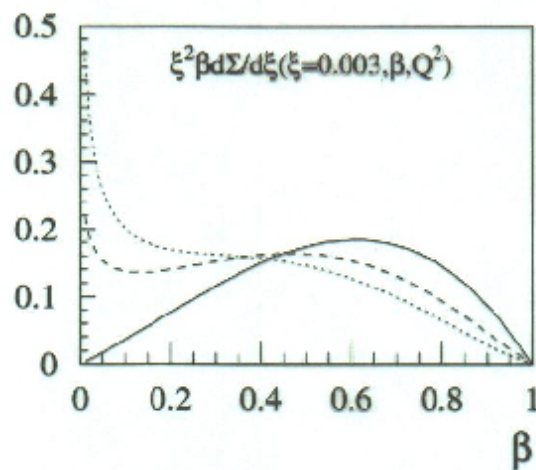
- ▷ Large model discrimination in diffractive charm

H1 DATA (1994)



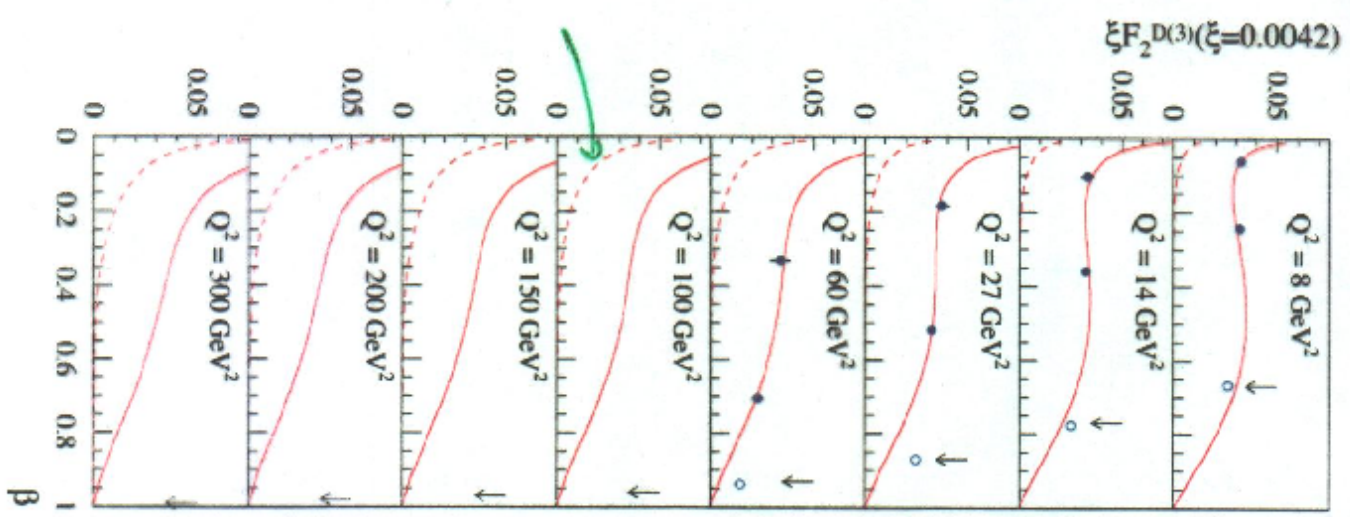
Gelrmann, Hebecker, WB

Diffrective quark and gluon distributions



ZEUS
DATA

charm



Cabreria,
Hebecker, 1993

Progress at HERA I/II

- determine diffractive gluon density
- extension to higher Q^2
- scaling violation of F_2^D , dijets and charm consistent?
- **theoretical prediction:**
 evolution in β and Q^2 , hence
 x_F -dependence unchanged, nonperturbative !
- comparison with inclusive DIS ,

$$\frac{dg}{d\xi} \propto \alpha_s g \quad ?$$
- comparison of event shapes in diffractive and inclusive DIS
- **theoretical prediction:**
 diffractive structure function almost unchanged at higher Q^2 due to relative size of quark and gluon densities

THE VIRTUES OF HERA

- Searches for physics beyond the standard model ; for squark production improved sensitivity reaches theoretically interesting parameter region
- Study of QCD at high gluon density , yields new insights into novel nonperturbative effects of nonabelian gauge theories , only possible at HERA in a clean and controllable way