HERA II
Status and Perspectives

Wuppertal, 29.11.2001

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DESY

a personal selection

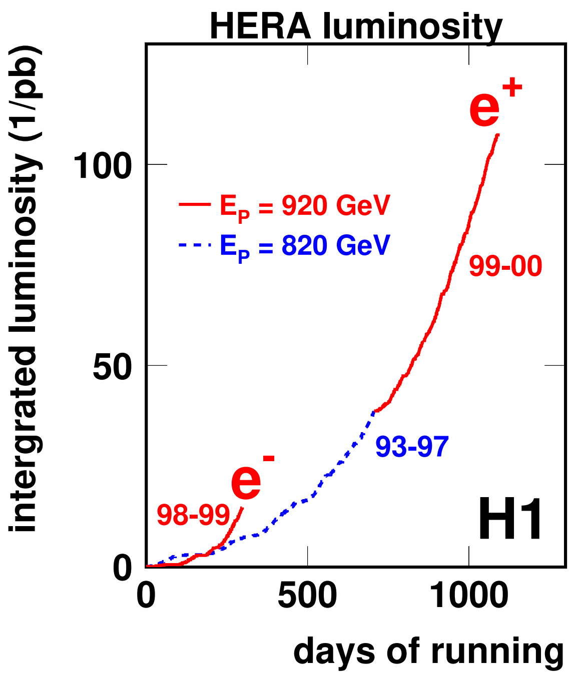
incomplete

speculative

$e^{\pm}p$ collisions at HERA I and II

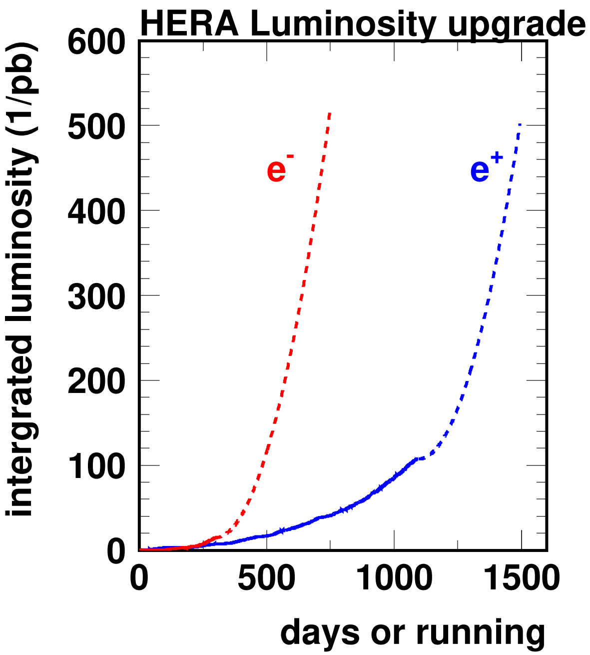
HERA I: 1993-2000

- E_{p_0} =920 GeV
  E_{e_0} =27.5 GeV
- $\sqrt{s}$=320 GeV
- $L \gtrsim$100 pb^{-1}

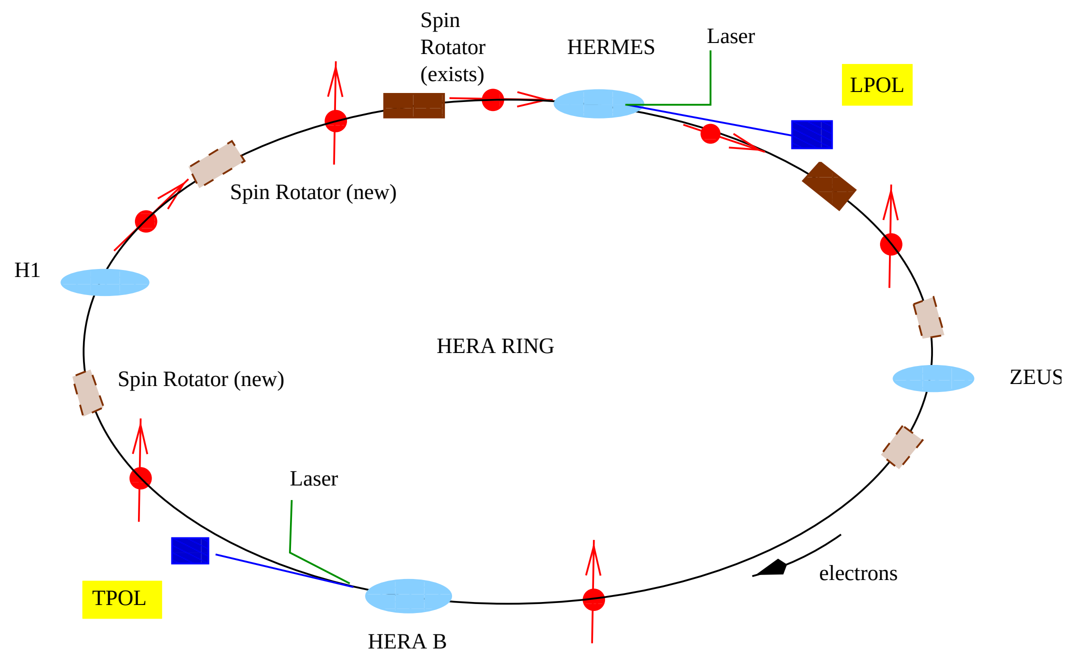


HERA II: 2001-2006 (?)

- Increase to L=1000 pb^{-1}
- e^+ and e^- equally shared
- $e^{\pm}$ polarisation
- Runs with lower/higher E_{p_0}



HERA II



Collider experiments: H1, ZEUS

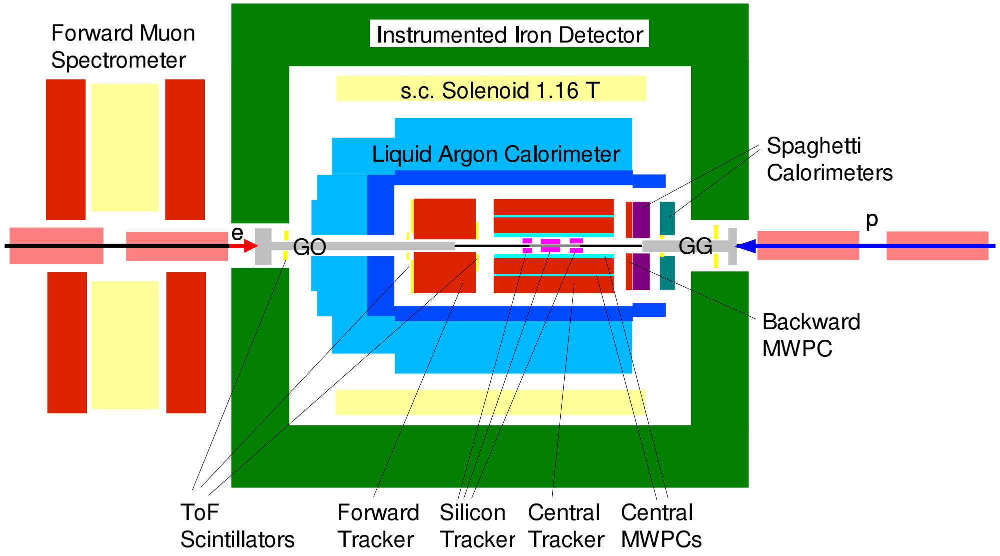
- Stronger focussing close to interaction points
- Spin rotators
- New beam lines

Fixed target experiments: HERMES, HERA-B

- not affected

The HERA upgrade

- Strong focussing at interaction point
- Magnets inside main detector



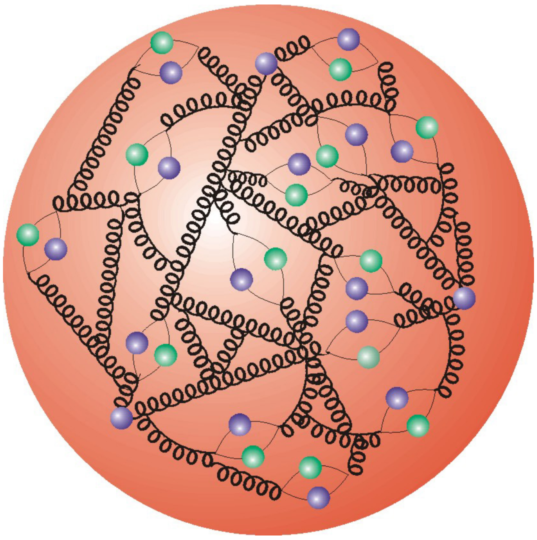
The Challenges

- Synchrotron radiation
- Back scattering from magnets

The Detector upgrades

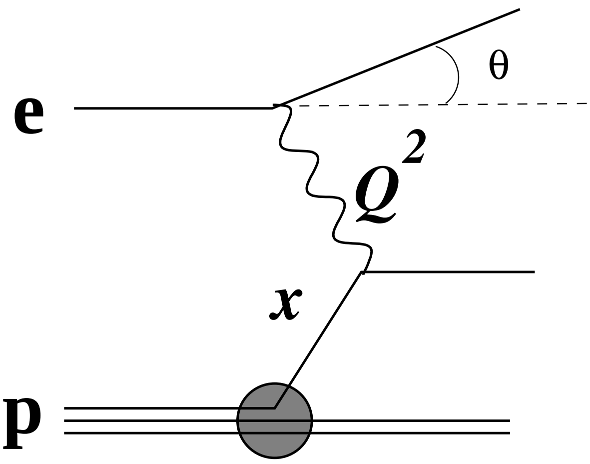
- Trigger !
- New forward tracking
- “4π” silicon tracking
- Forward proton spectrometer
- Smaller acceptance at low angles
- Systematics

Proton Structure



Confinement:
no free quarks, glu-
ons

measuring the deep parton structure



Q^2 = γ -virtuality

1/resolution

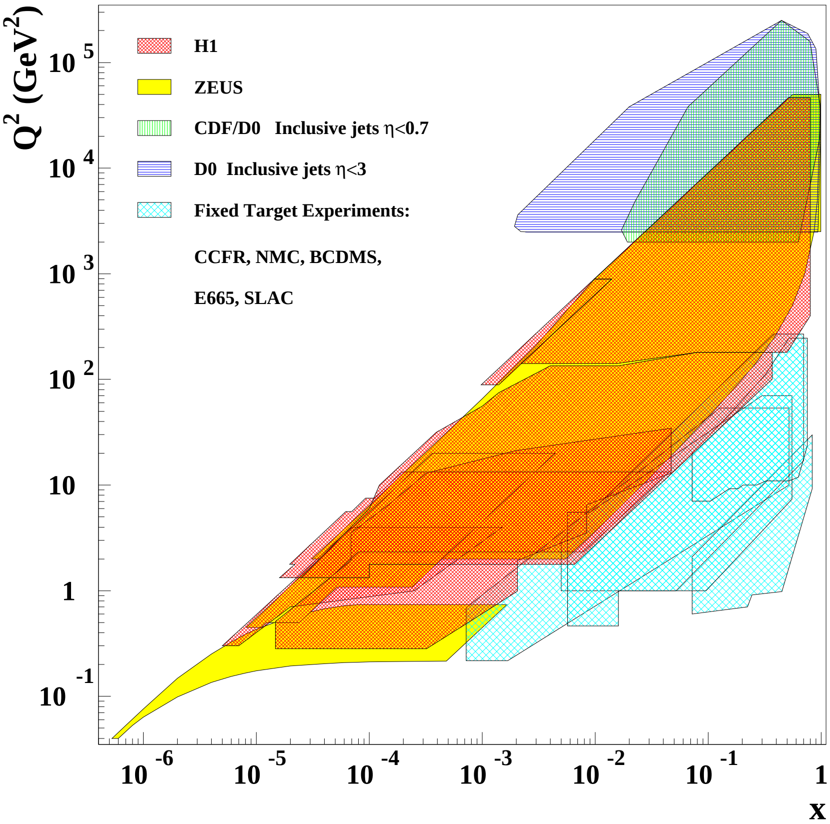
x = $E_{\rm parton} / E_p$

W = $E^{\gamma-p}_{cms}$

HERA kinematics

HERA: $E_{cms} = 320$ GeV

before: $E_{cms} < 20$ GeV



$$R_{proton} < 1/Q < R_{proton}/1000$$

$$10^{-6} < x < 1$$

factor 100 larger in Q^2 / smaller in x

$\rightarrow$ reason why H1 / ZEUS are the leading QCD experiments

Virtues of ep scattering at HERA

- large Q^2 lever arm: precision QCD

  α_s, quark and gluon densities

- small - x: high parton densities

  novel quantum system

- small Q^2: large distance QCD

  non-perturbative, confinement

- large CMS energy:

  (beyond) the EW standard model

  (largest E_{CMS} with lepton in initial state)

QCD Interpretation

$Q^2 \gg 1/r^2_{proton} \quad \rightarrow \tau_{\gamma q} \ll \tau_{qq,qg}$

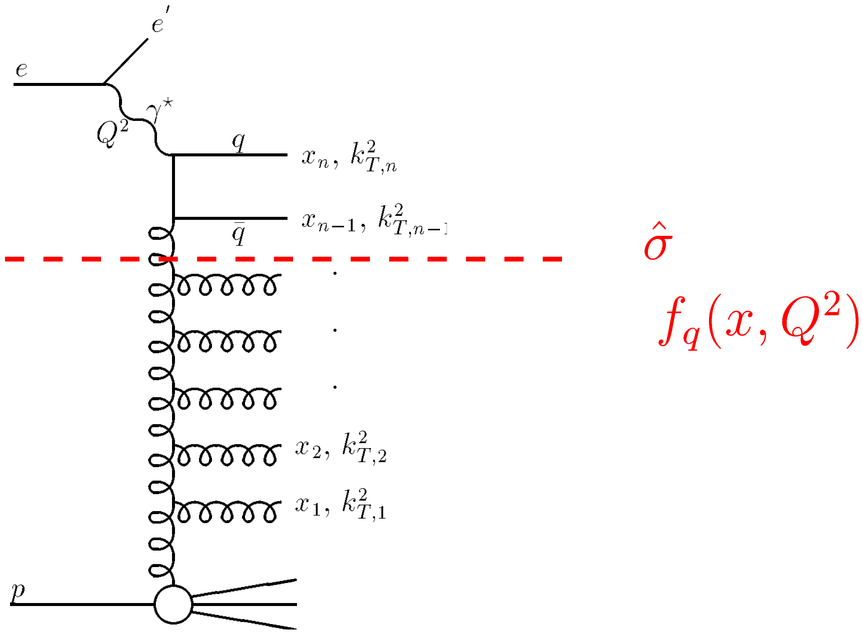
1) Altarelli-Paresi approximation (DGLAP)

assumption: strong order in k_T :

$$Q^2 >> k_{T,i} >> k_{T,i-1} \ldots$$

$\rightarrow$ factorisation in hard and soft parts:

$$\sigma = \sum \hat{\sigma} \times f_q$$



- DGLAP can not be valid if:
  - Q^2 too small (how small ?)
  - x too small (phase space !)
    (long ladder $\rightarrow$ no k_T order)

Partons in the Proton

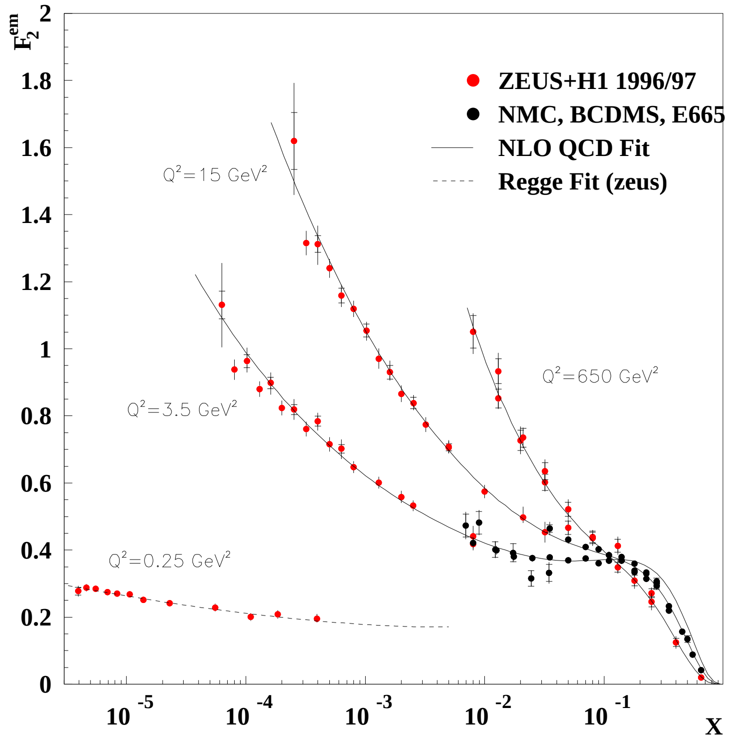
$ep \to eX$ at small Q^2:

$$\frac{d^2\sigma}{dx\, dQ^2} \approx \frac{2\pi\alpha^2}{xQ^4}\ F_2$$

momentum distribution of quarks:

$$F_2\left(x, Q^2\right) \approx \sum e_q^2 q\left(x, Q^2\right)$$

$$dF_2/d\ln Q^2|_x \approx \alpha_s\ \times g\left(x, Q^2\right)$$



small $x \to$ high quark density

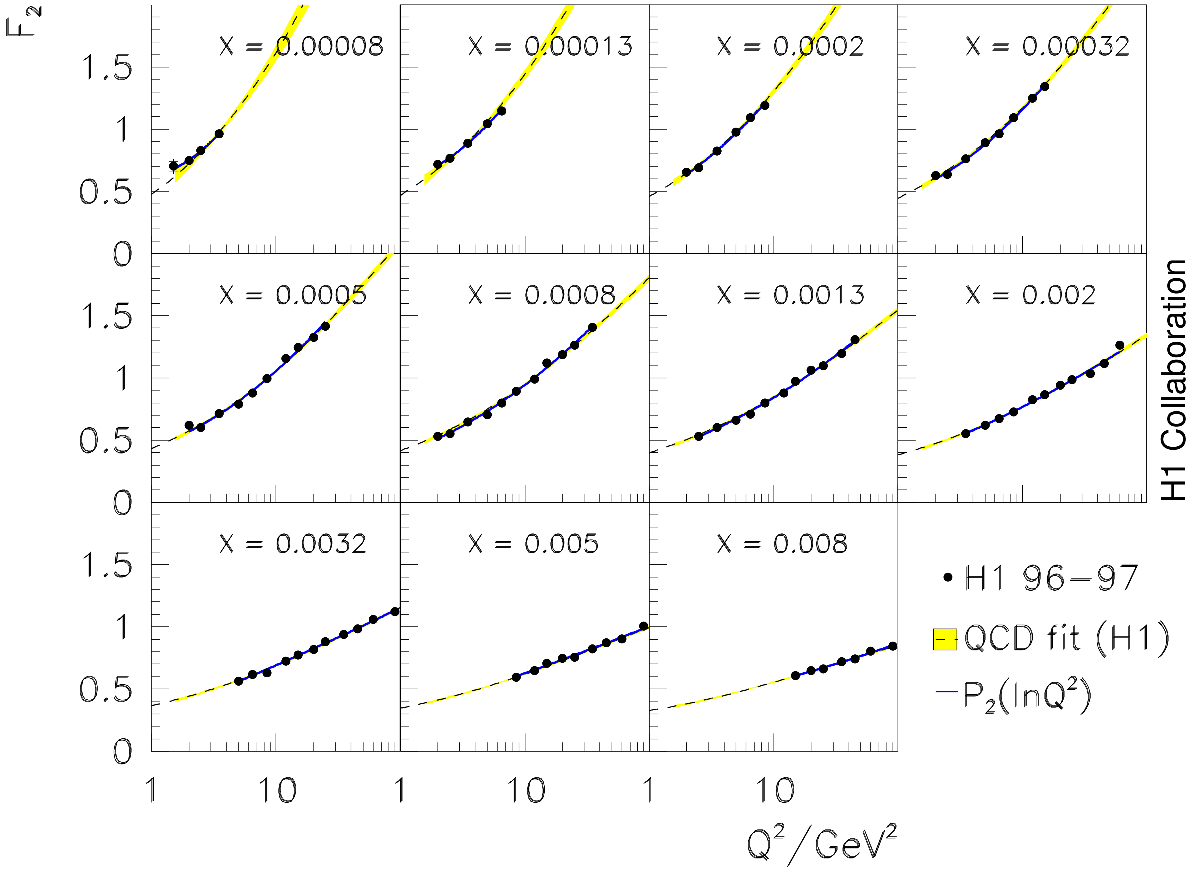
large $Q^2 \to$ strong rise of quark density $\to$ high gluon density

Partons in the proton

pointlike partons:

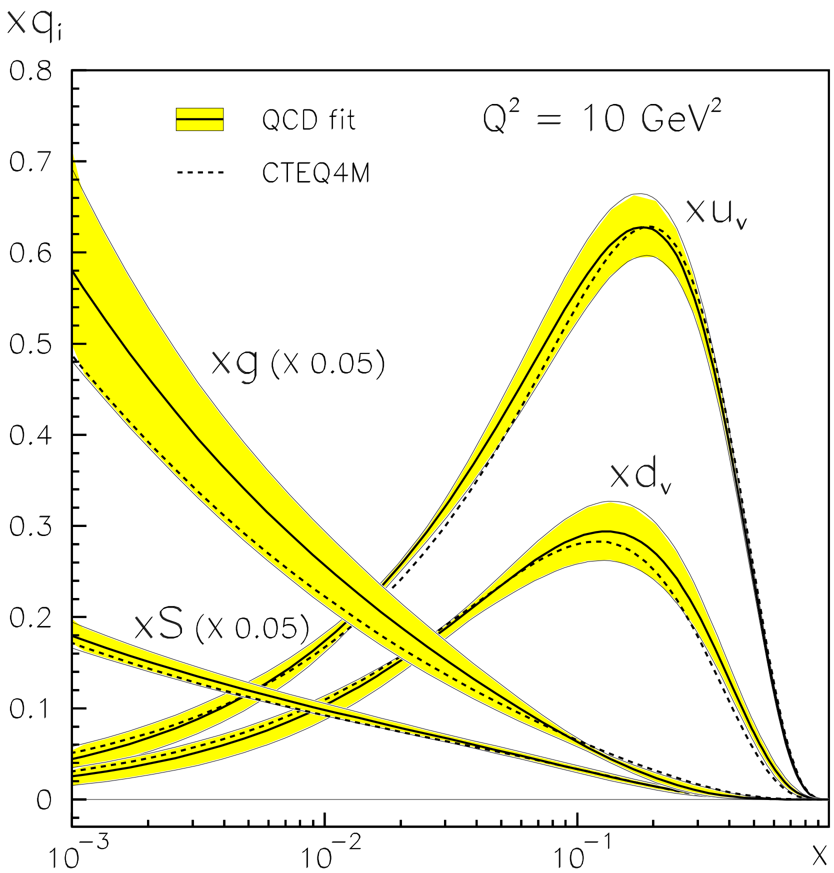
$\rightarrow F_2$ independent of Q^2 $g \rightarrow q\bar{q}$:

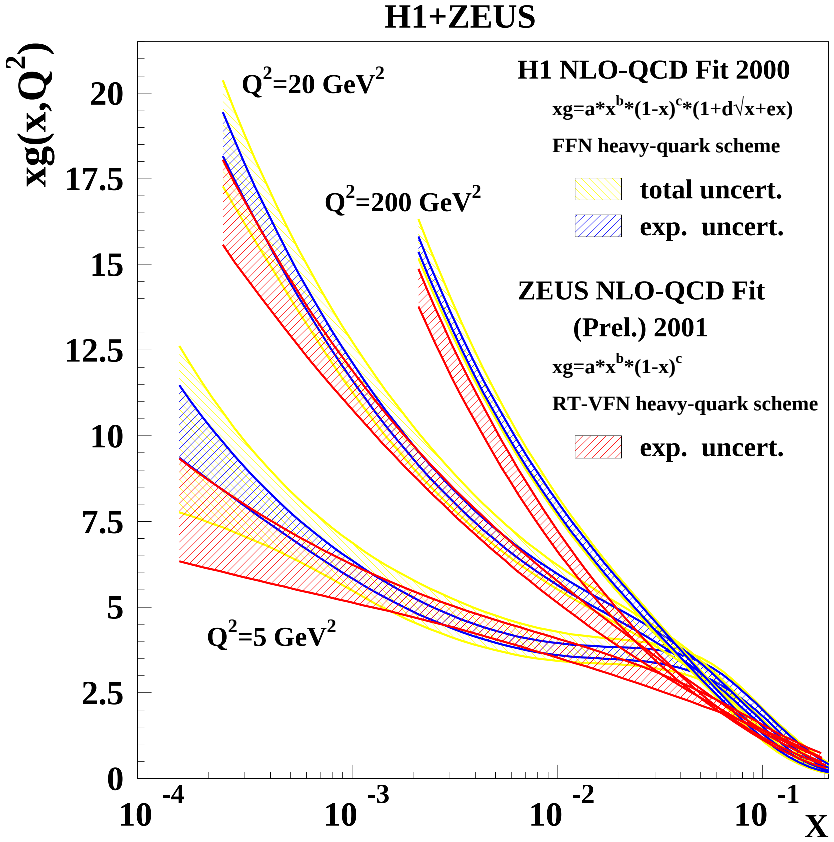
$\rightarrow$ slope $dF_2/d\ln Q^2|_x \approx \alpha_s \times$ gluon density



needs precision !

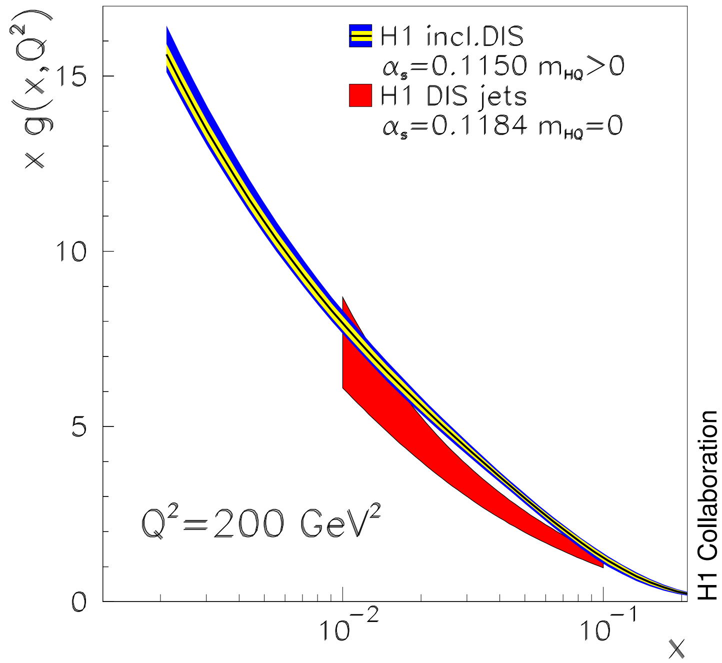
Quark/Gluon Distribution in the Proton



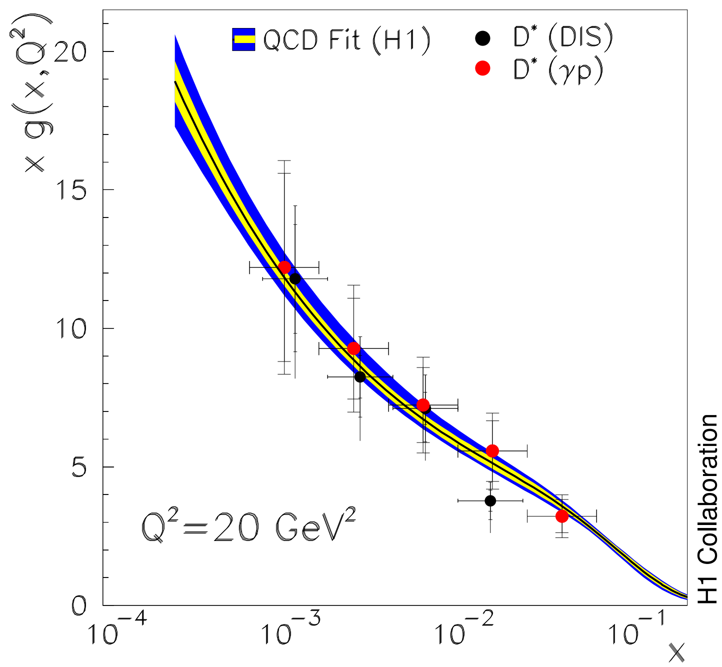


Gluon induced processes

verification of gluon density



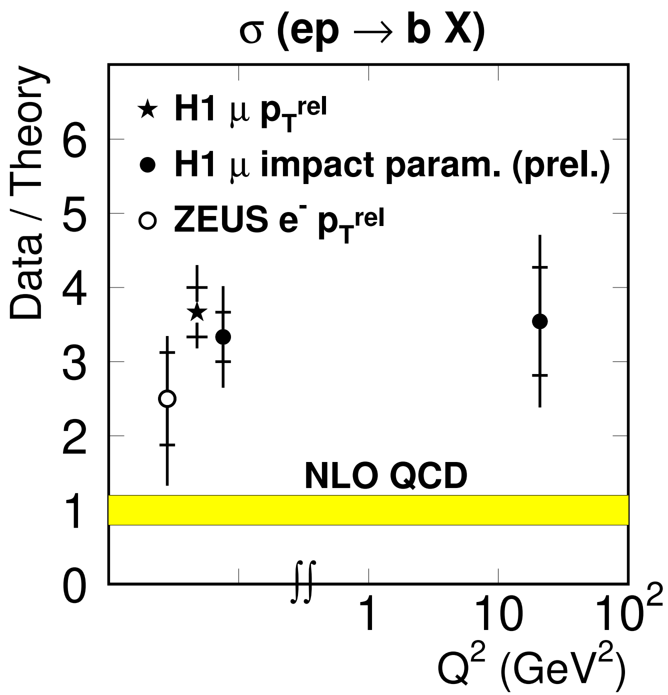
jet production



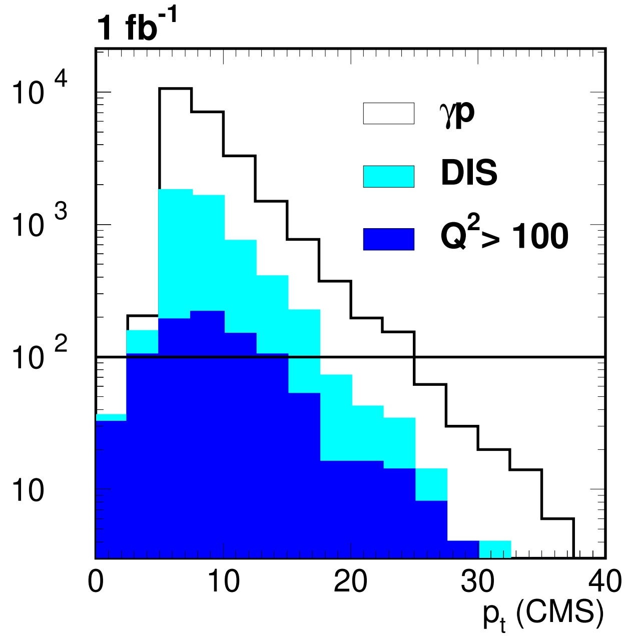
charm production

Bottom production

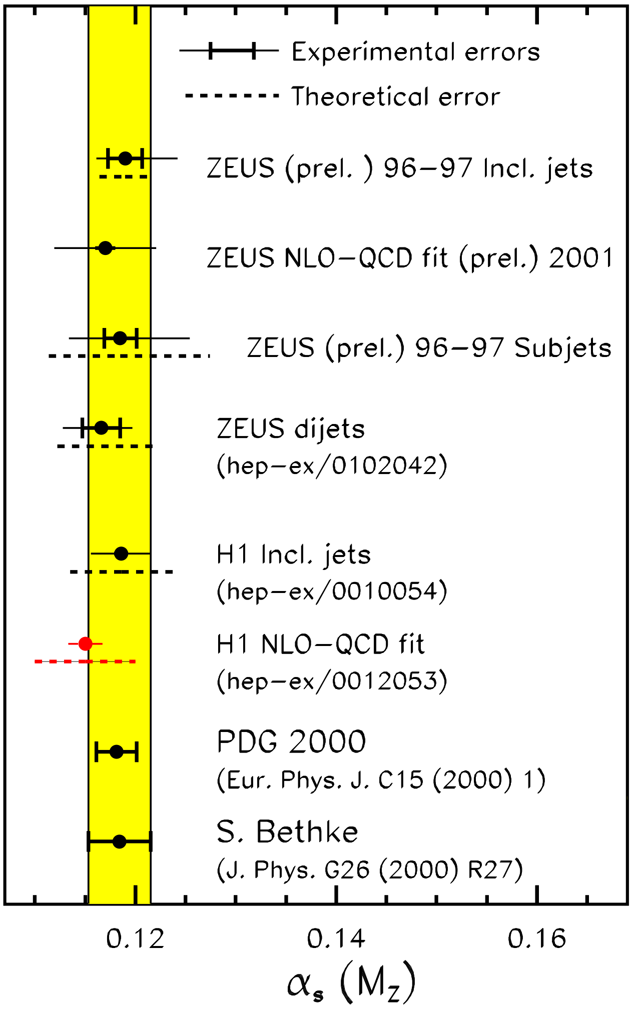
Unexplained large σ_b



HERA II



HERA summary on α_s



- NNLO calculations for F2 (and 2-jet production ?)

$\rightarrow$ reduction of scale errors by factor 2-3 !!

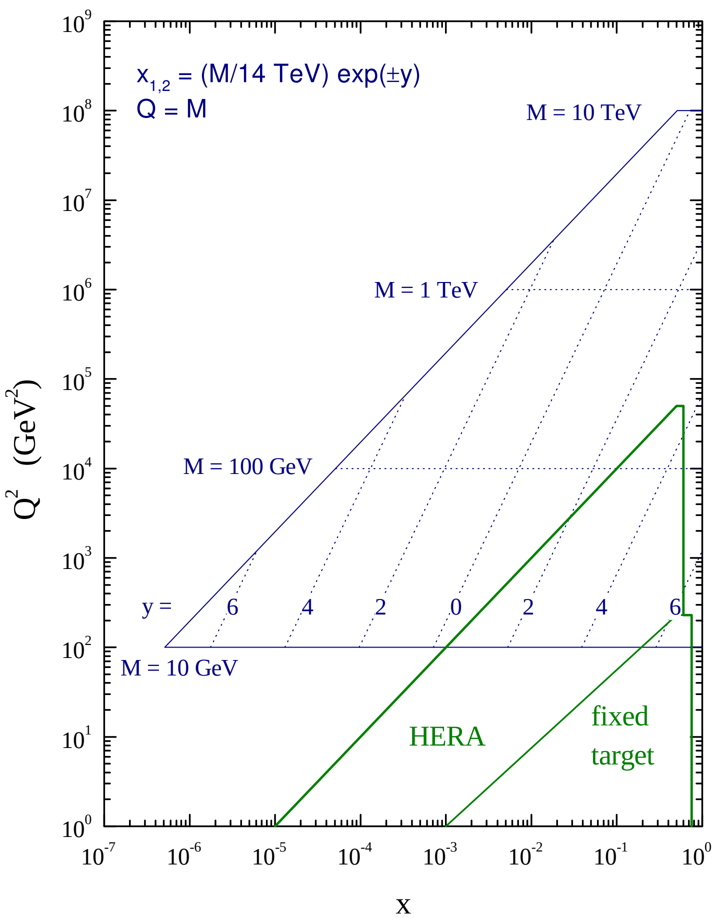
the CHALLENGE: get best α_s ($\pm$ 1%)

needs reduction also of experimental errors !!

Higgs Produktion at LHC

$M_{\rm H} >$108 GeV

LHC parton kinematics



depends on gluon density at $x \lesssim 10^{-3}$

only process: DIS at HERA

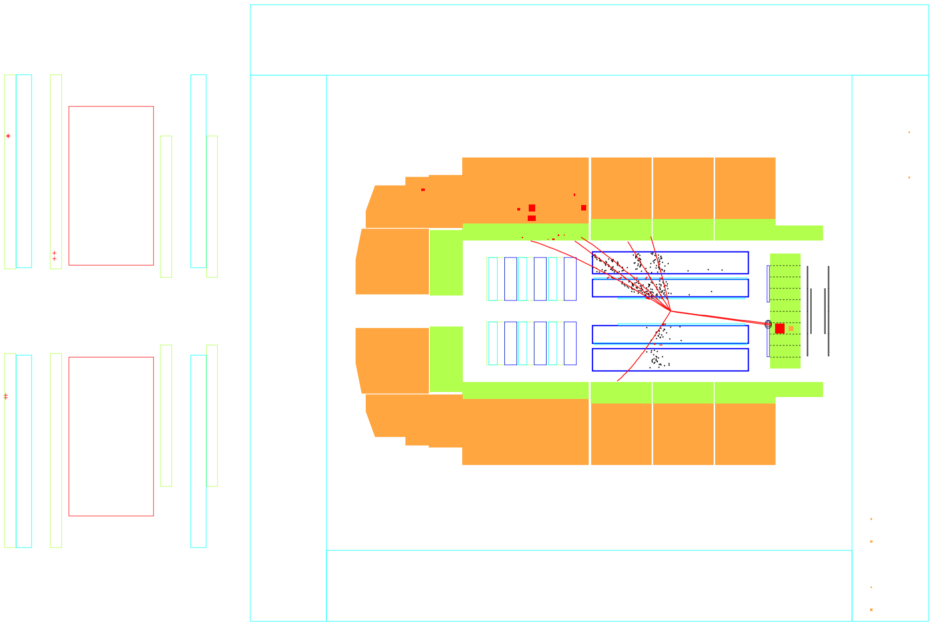
but: $x \lesssim 10^{-4} \rightarrow Q^2 \lesssim 1$ GeV

Diffraction

no

proton

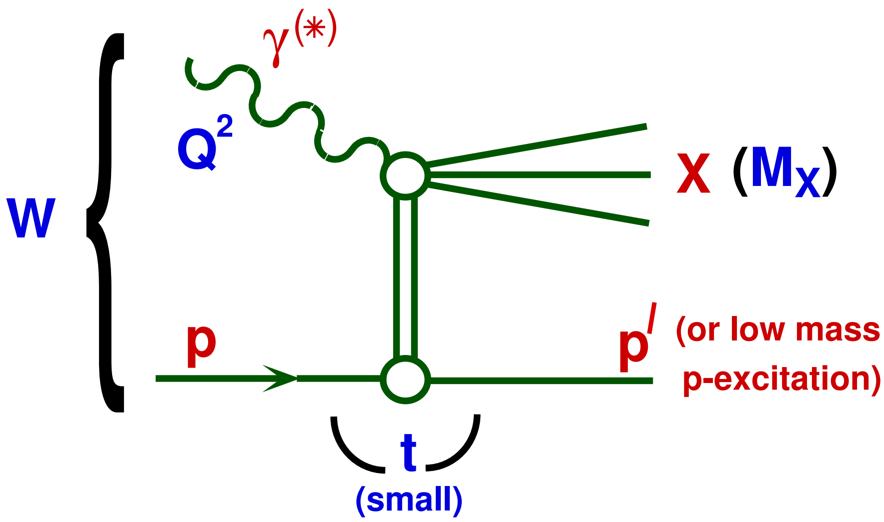
remnants



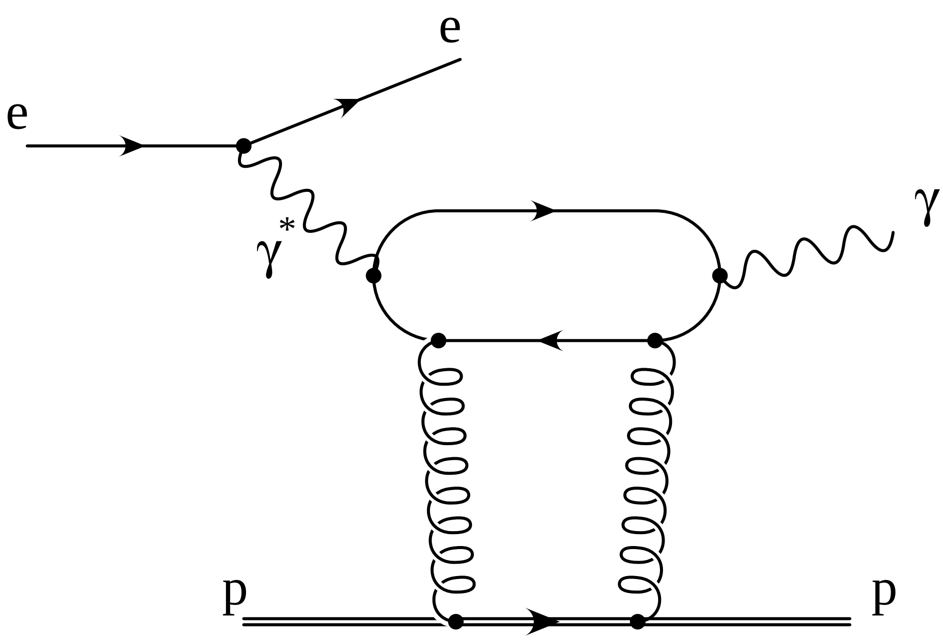
Hard Diffraction:

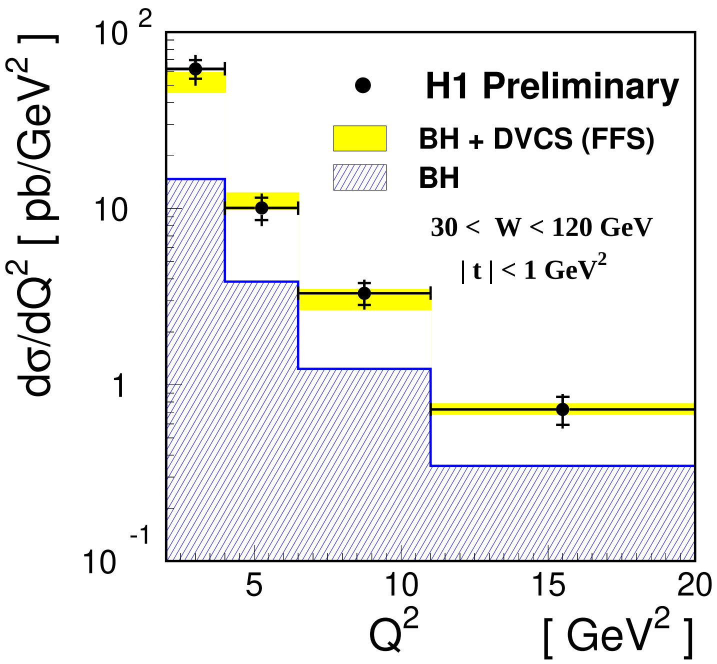
colour singlet exchange on more than one parton (2 gluons or more)

$\rightarrow$ Correlations



Deeply Virtual Compton Scattering





γ- $\times$ gluon-pair $\rightarrow$ QCD describes data !

access to parton correlations: “skewed pdf’s”

$\rightarrow$ new forward proton tagger

DIS cross section

Neutral Current

$$\frac{d^2\sigma_{NC}^{e^\pm p}}{dx\, dQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[Y_+\tilde{F}_2(x,Q^2) \mp Y_- x\tilde{F}_3(x,Q^2) - y^2\tilde{F}_L(x,Q^2)\right]$$

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

$$\tilde{F}_2 \equiv F_2 - \; v_e \; \frac{\kappa_w Q^2}{(Q^2+M_Z^2)} \; F_2^{\gamma Z} + (v_e^2 + a_e^2)\left(\frac{\kappa_w Q^2}{Q^2+M_Z^2}\right)^2 F_2^Z = x\sum A_i(q_i + \bar{q}_i)$$

$$x\tilde{F}_3 \equiv \; - \; a_e \; \frac{\kappa_w Q^2}{(Q^2+M_Z^2)} xF_3^{\gamma Z} + \; (2v_e a_e)\left(\frac{\kappa_w Q^2}{Q^2+M_Z^2}\right)^2 xF_3^Z = x\sum B_i(q_i - \bar{q}_i)$$

v_e, a_e - *vector and axial couplings,* $\quad \kappa_w^{-1} = 4\frac{M_W^2}{M_Z^2}(1 - \frac{M_W^2}{M_Z^2})$

Charged Current

$$\frac{d^2\sigma_{\mathrm{CC}}^{\pm}}{dx\, dQ^2} = \frac{G_F^2 M_W^4}{2\pi x}\frac{1}{(Q^2+M_W^2)^2}\; \phi_{\mathrm{CC}}^{\pm}(x,Q^2)$$

$$\phi_{\mathrm{CC}}^{+} = x\left[(\bar{u}+\bar{c}) + (1-y)^2(d+s)\right] \qquad (in\ \mathrm{LO})$$

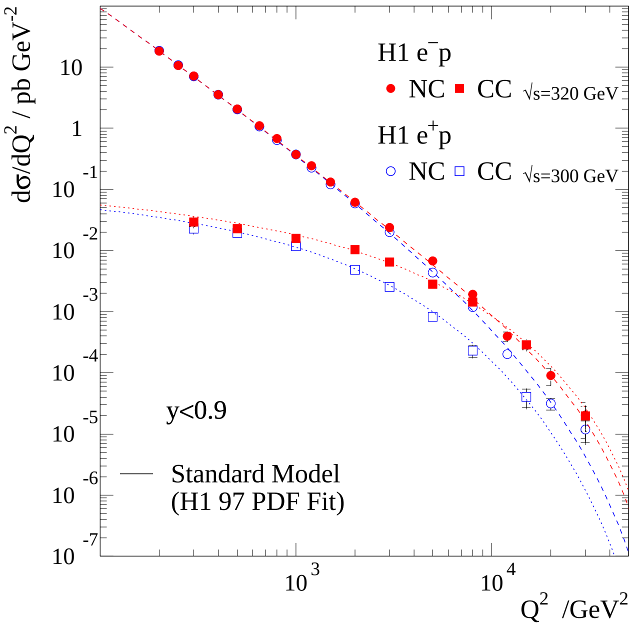
$$\phi_{\mathrm{CC}}^{-} = x\left[(u+c) + (1-y)^2(\bar{d}+\bar{s})\right]$$

Reduced NC and CC cross sections

$$\tilde{\sigma}_{NC}(x,Q^2) \equiv \frac{1}{Y_+}\;\frac{Q^4\;\; x}{2\pi\alpha^2}\;\frac{d^2\sigma_{NC}}{dxdQ^2} = F_2(1 + \Delta_{F_2} + \Delta_{F_3} + \Delta_{F_L})$$

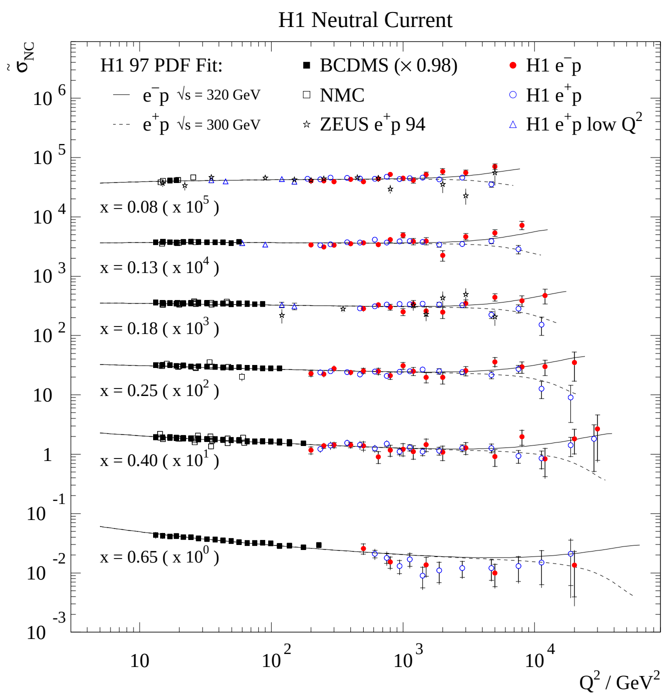
$$\tilde{\sigma}_{CC}(x,Q^2) \equiv \frac{2\pi x}{G_F^2}\left(\frac{M_W^2+Q^2}{M_W^2}\right)^2 \frac{d^2\sigma_{CC}}{dxdQ^2}$$

Weak Interaction



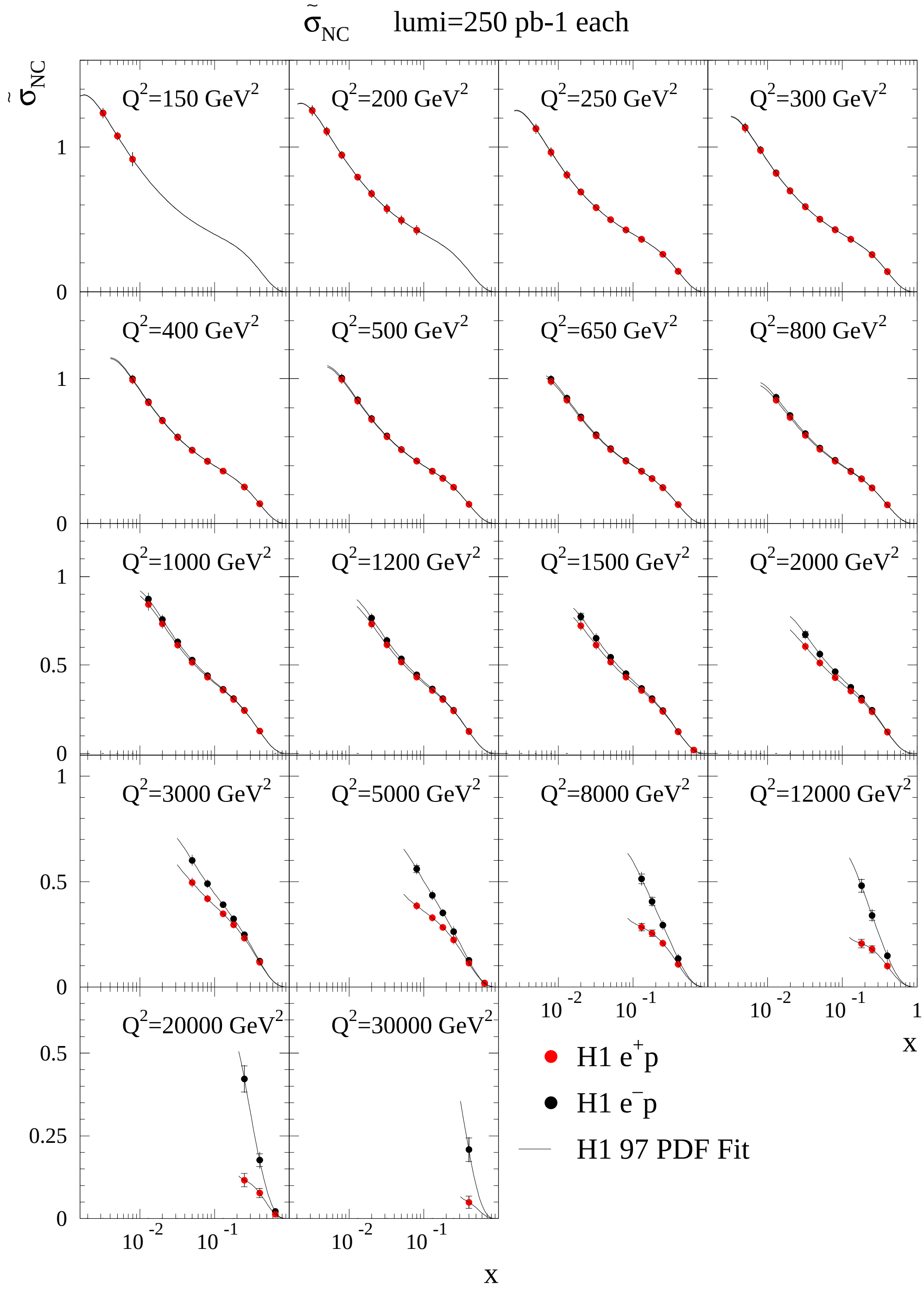
$\gamma/Z \approx W$

Unification



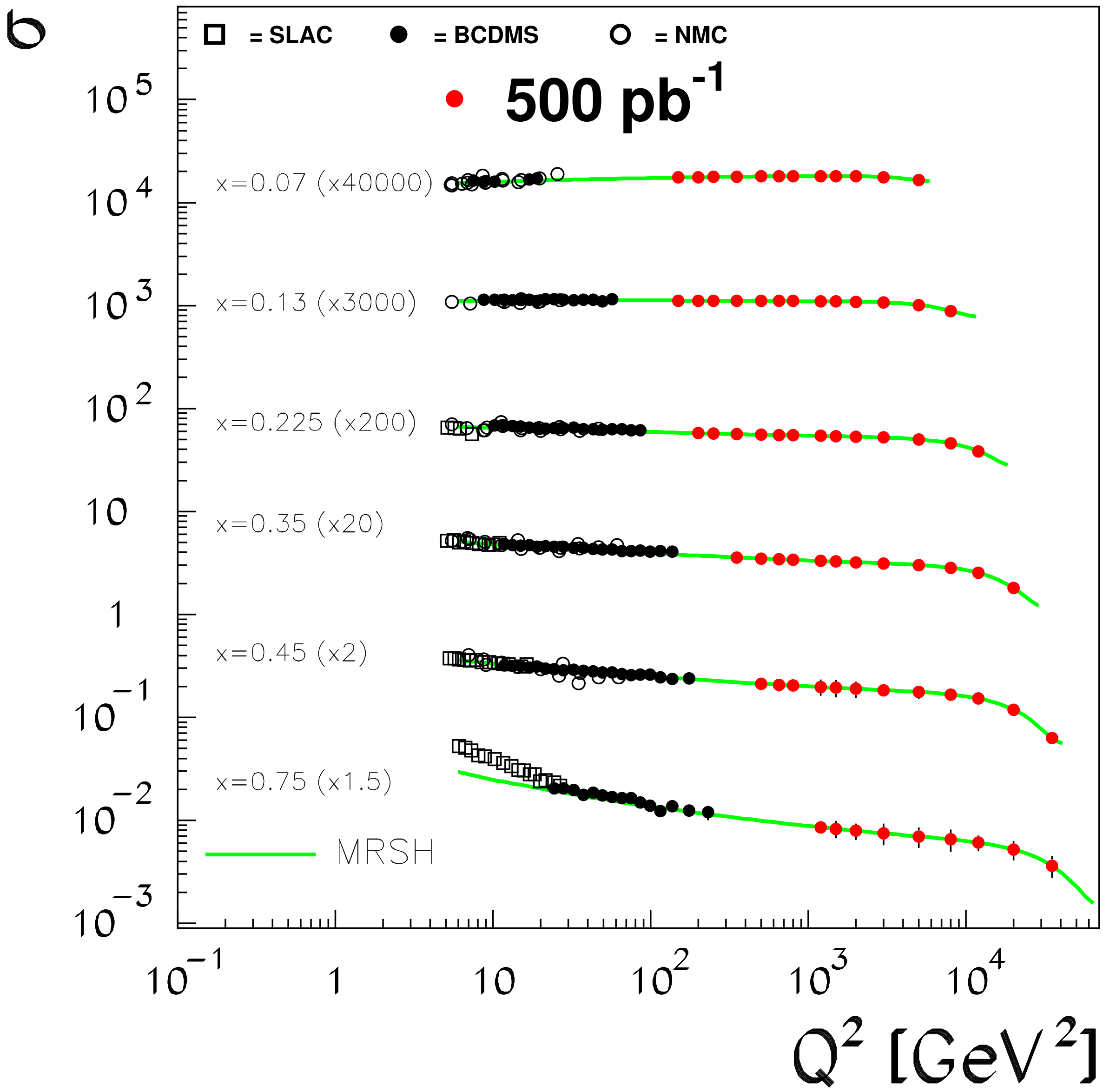
needs more data at large x, Q^2 !

Cross sections at high Q^2



γ/Z: mainly u- quarks

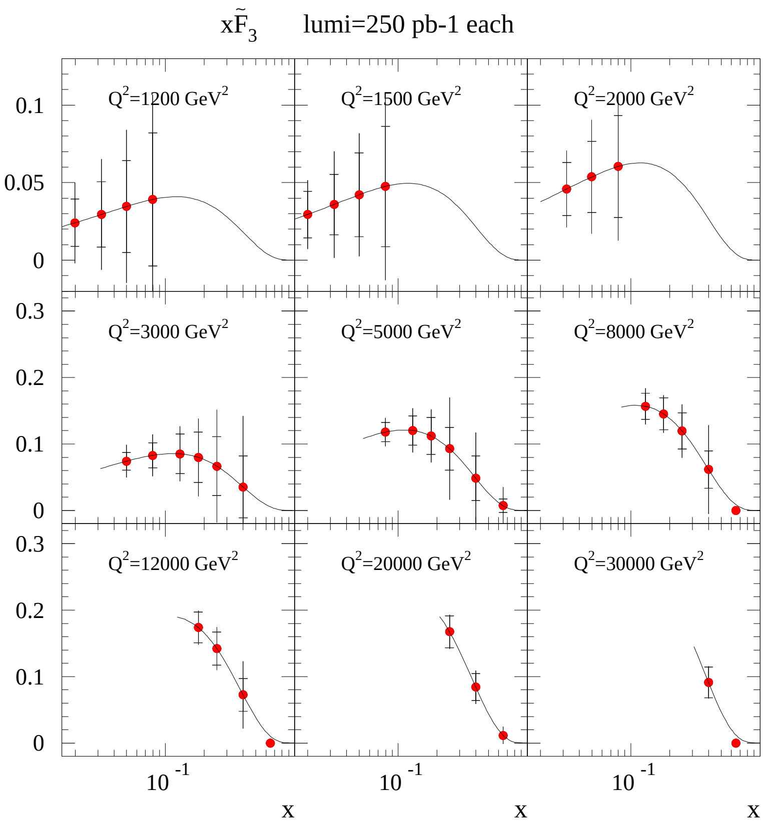
Cross sections at high Q^2



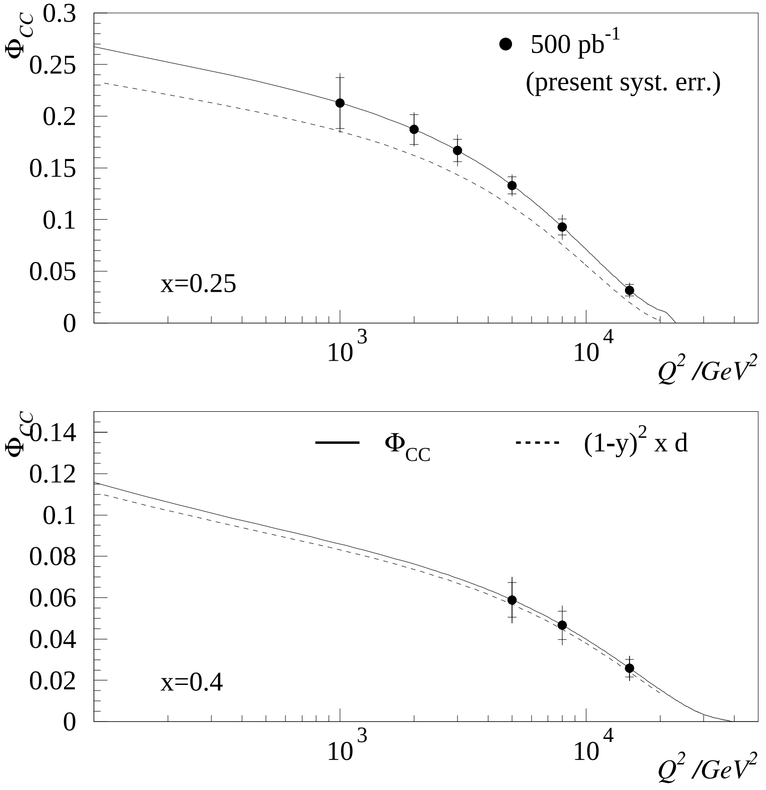
γ/Z: mainly u- quarks

Cross sections at high Q^2

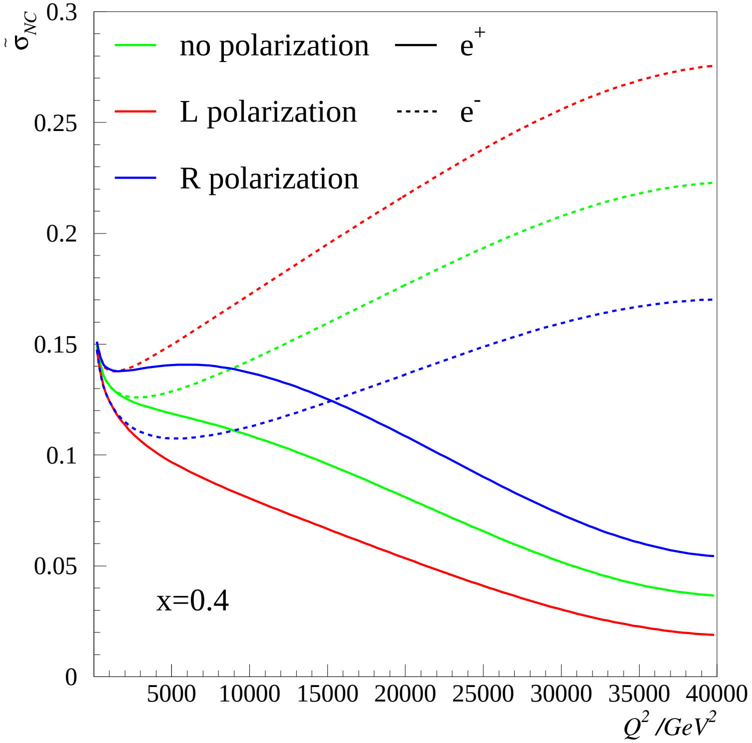
xF_3: Valence quarks



W: mainly d- quarks



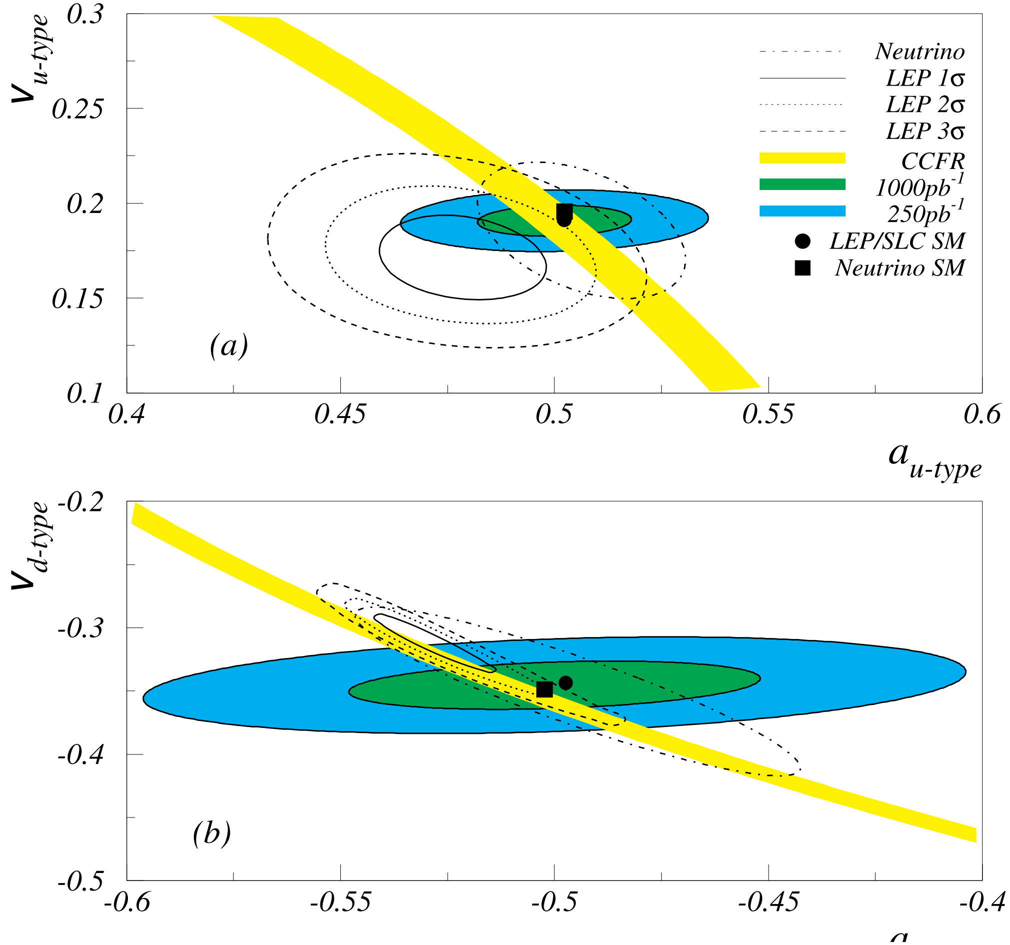
NC cross sections at high Q^2



γZ interference

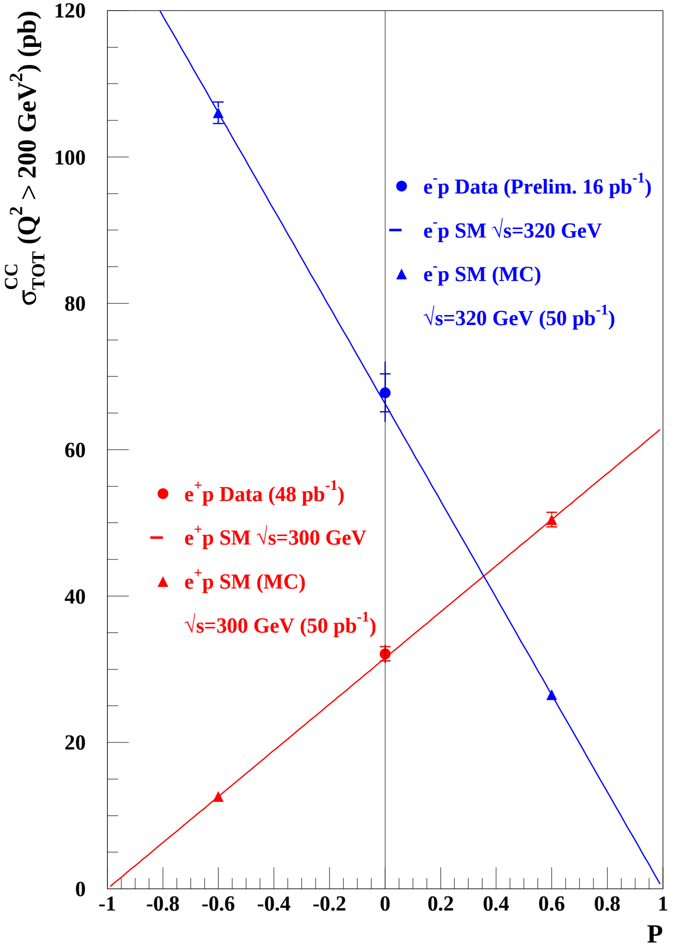
- $\gamma^2 \approx \gamma Z \approx Z^2$ for
  $\frac{\kappa Q^2}{Q^2+M_Z^2} = 1$
  $\rightarrow Q^2 \approx 2M_Z^2 \approx 16000$ GeV^2
- positive / negative interference for $e^-p/\ e^+p$
- 10% effect at high Q^2

Weak couplings of light quarks



- needs measurement of $e_L^+, e_L^-, e_R^+, e_R^-$
- only light quarks from proton
- similar precision as from LEP

Right handed weak currents: W_R

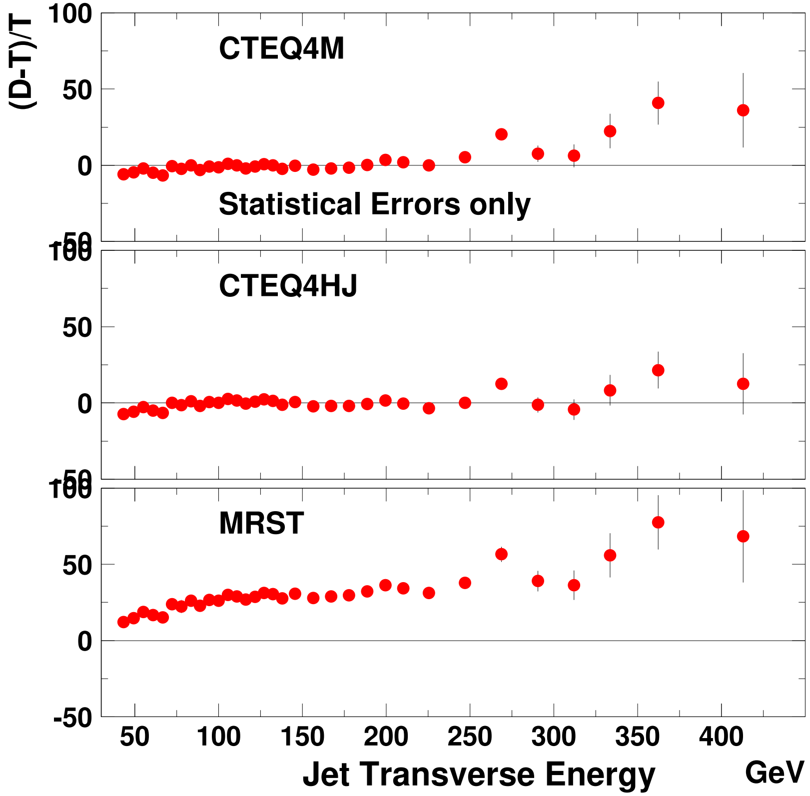


Polarized charged currents

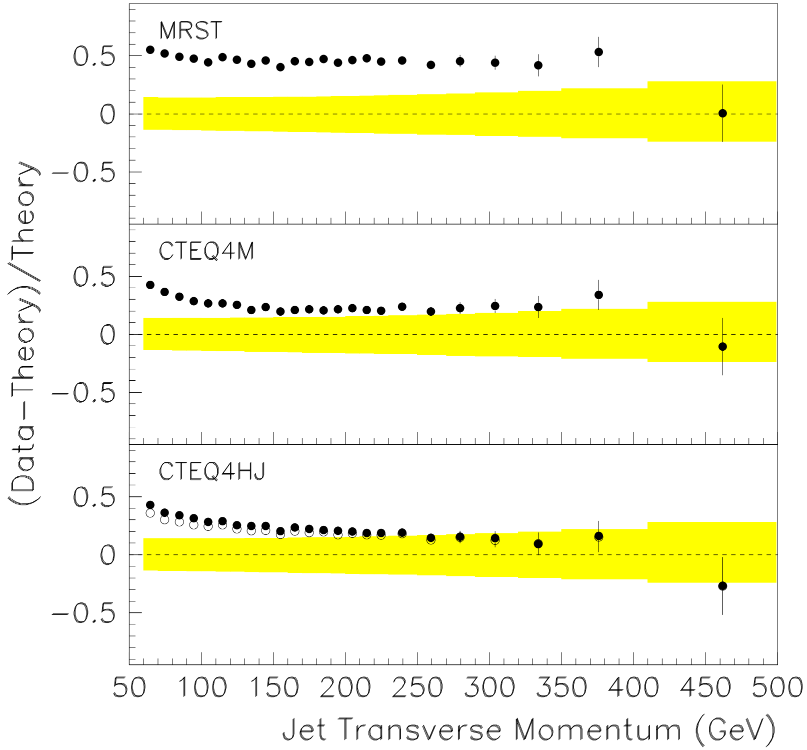
- $\sigma_{CC}(e^{\pm}_{P}) = (1 \pm P)\,\sigma_{CC}(e^{\pm}_{P=0})$
- needs high polarisation
- needs high precision of polarisation
- $M_{W_R} \lesssim$ 600 GeV
- similar to direct search at Tevatron

Tevatron jets at high P_T

CDF: cone algorithm



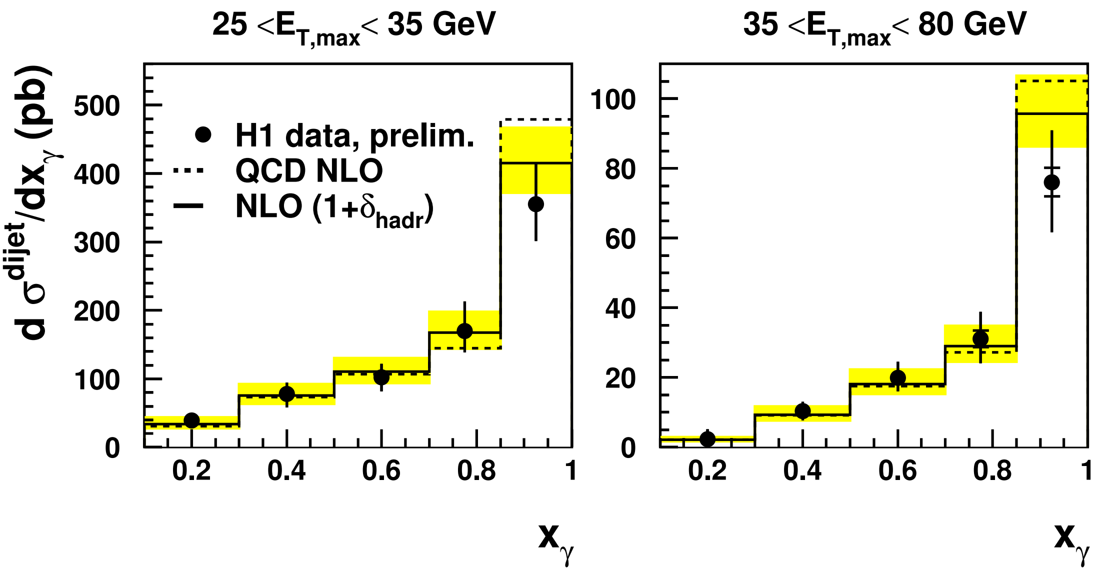
D0: K_T algorithm



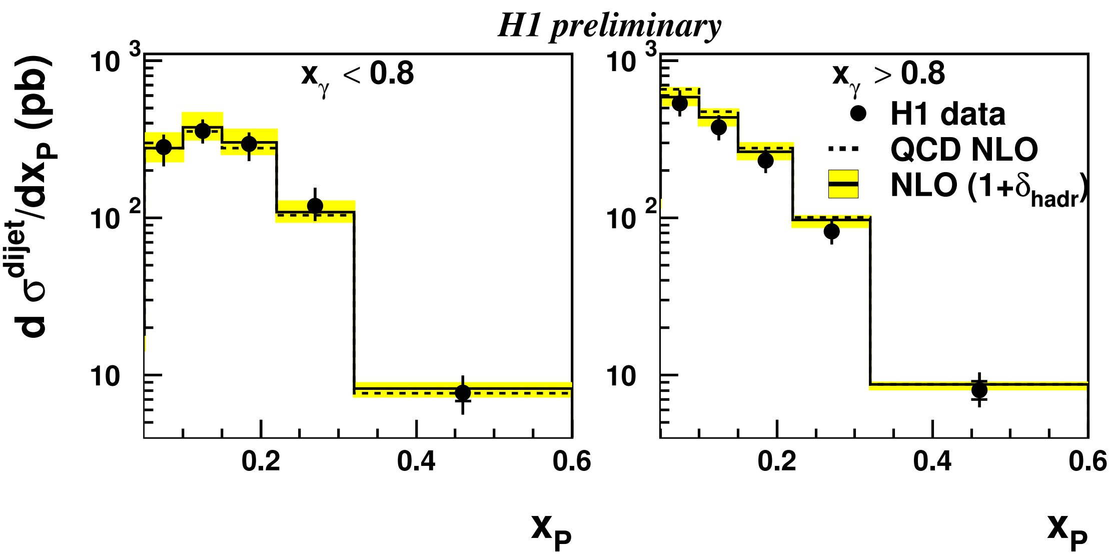
open questions...

Photon and Proton at High x

jets in γp at high E_T



access to proton at high x !

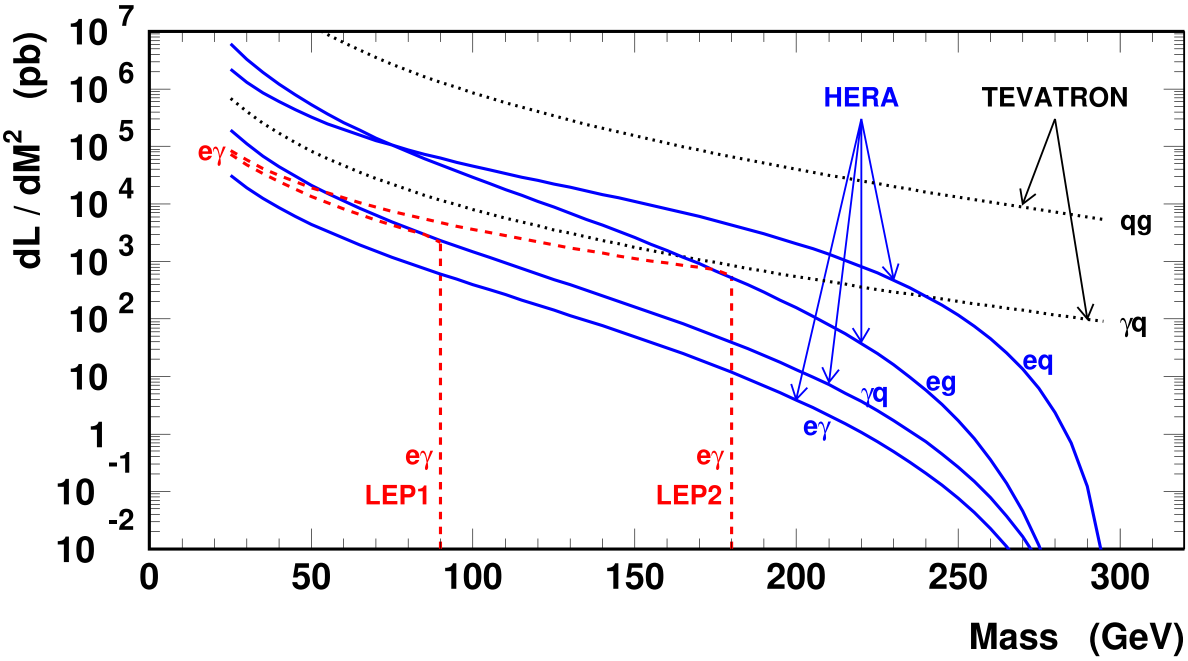


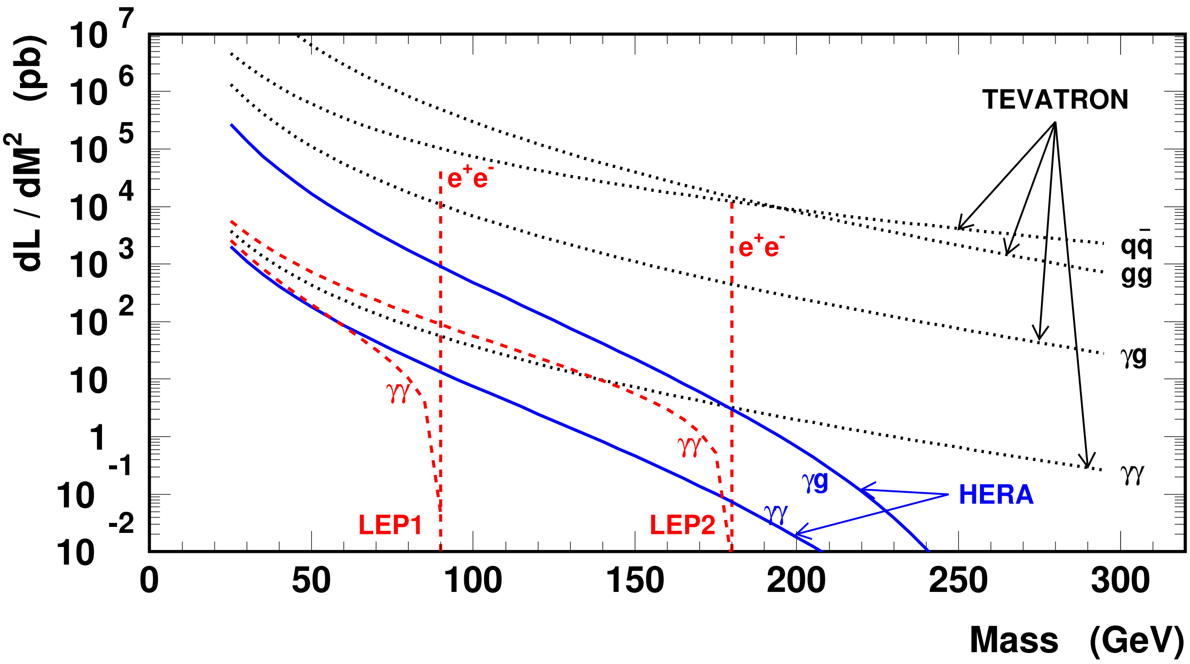
- dominated by direct + pointlike part of γ
- significant contribution from gluon in proton
  $\rightarrow$ Tevatron high E_T jets

Beyond the Standard Model

Parton luminosities: $\sigma_c \approx \hat{\sigma}_{ab\to c}\ dL/d\hat{s}$

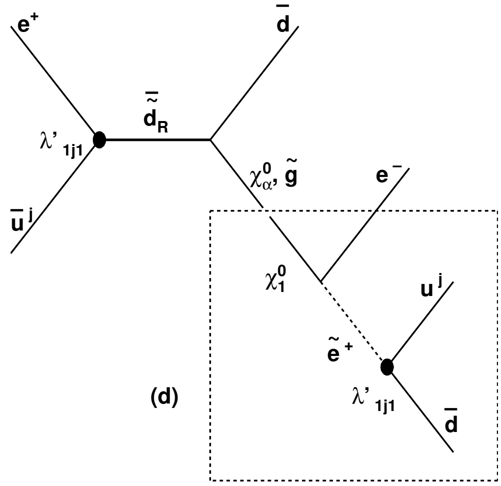
$$\frac{dL}{d\hat{s}} = \frac{1}{s}\int_{\frac{\hat{s}}{s}}^{1} \frac{dx_a}{x_a}\, f_A(x_A,\hat{s})\, f_B(\frac{\hat{s}}{sx_A},\hat{s})$$



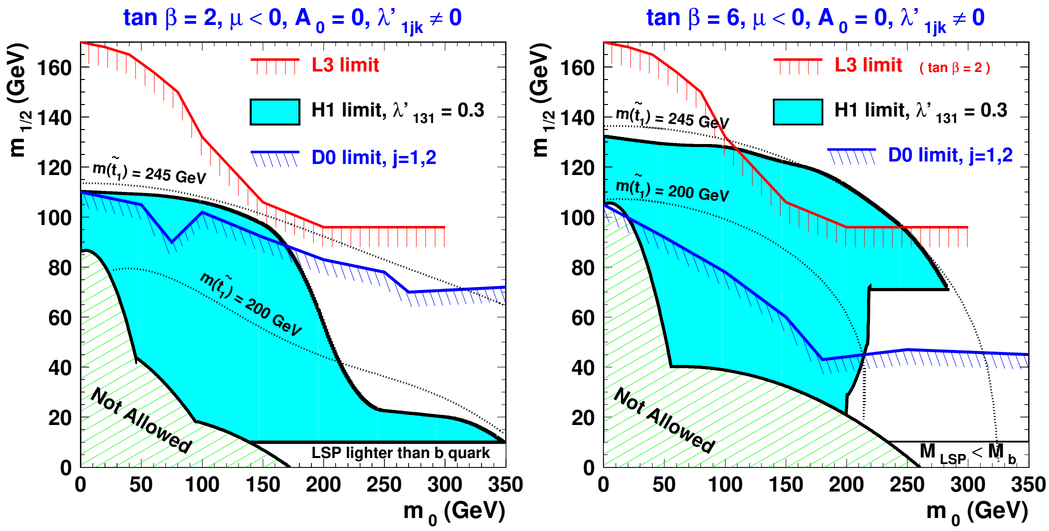


Supersymmetrie

single production of squarks in R-parity violating models



Minimal Supergravity + R_p Violation



- nothing found yet up to $M_{\tilde{q}}$ =245 GeV
- will reach sensitivity of $M_{\tilde{q}} \approx$ 300 GeV

Running Strategy	proton energy	e^+p	e^-p	time/luminosity
Searches	high !!			large L
high PT lepton		L,R	?	as soon as possible
stop		R		early
LQ,CI		L,R	L,R	equally shared
R_q,LED,e^*				
ν^*			L	
High $\mathbf{x}$, high $\mathbf{Q^2}$	high			large L
xF_3		L,R	L,R	equally shared
coupling $uZ,\ dZ$		L,R	L,R	equally shared
u density				
d density		R		
M_W			L	
W_R			R	50 pb^{-1}
QCD	high			large L,small background
jets, c, b				
High $\mathbf{x}$, low $\mathbf{Q^2}$				
F_L (incl & diffr.)	300 + 400 GeV			10 + 10 pb^{-1}
α_s	300 GeV			50 pb^{-1}
Diffraction	high (and low)			
VFPS				> 2002

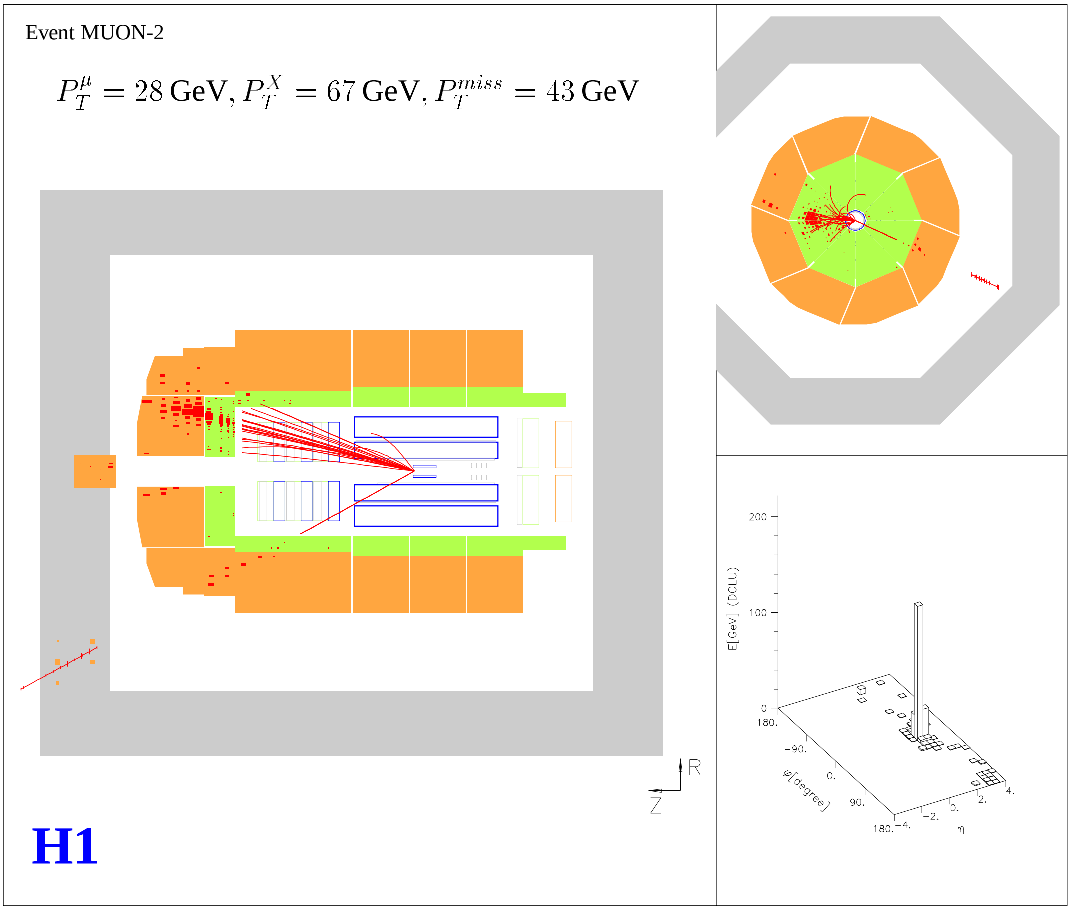
Summary

What did / will we learn from HERA ?

- low-x: new regime of QCD
  the main theoretical activity so far
  BFKL ??
- precision QCD:
  world best value of α_s
  proton structure at HIGH x
- high Q^2: only just started
  luminosity upgrade
  precision test of SM at 10^{-18} m
- searches:
  high P_T lepton events
  Supersymmetry with R_P violation
  contact interactions
  + ??

The unexpected

$$e^+p \to \mu^+ X$$



no explanation up to now !

anomalous W production, $e \to \mu$, supersymmetry ?