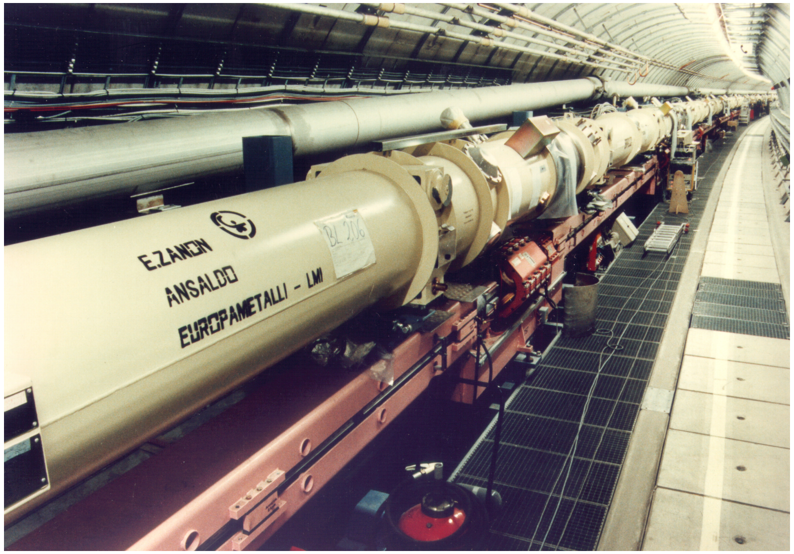


Proton Structure and QCD at HERA

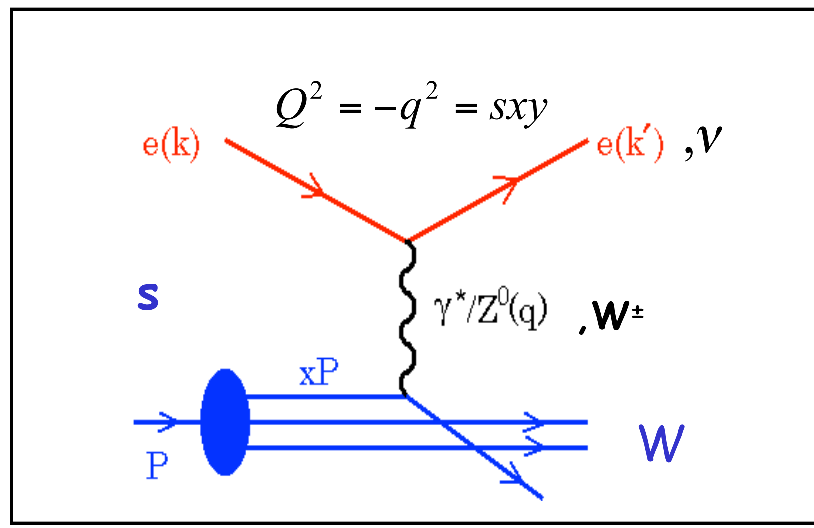
Max Klein

DESY

STORI 05, Bonn

23rd of May, 2005

- HERA
- H1 & ZEUS
- Low x physics
- Strong coupling constant & xg
- Quark distributions
- Heavy flavour physics
- Diffractive ep scattering
- Remarks to HERA III
- DIS at the energy frontier



Deep Inelastic Scattering and Photoproduction (Q^2~0)

1. HERA (Hoch Energie Ring Anlage – high energy ep STOrage RIng 92)

ep-collider expts H1, ZEUS @319GeV [and polarised target expt HERMES @7GeV]

HERA and its Pre-Accelerator Chain

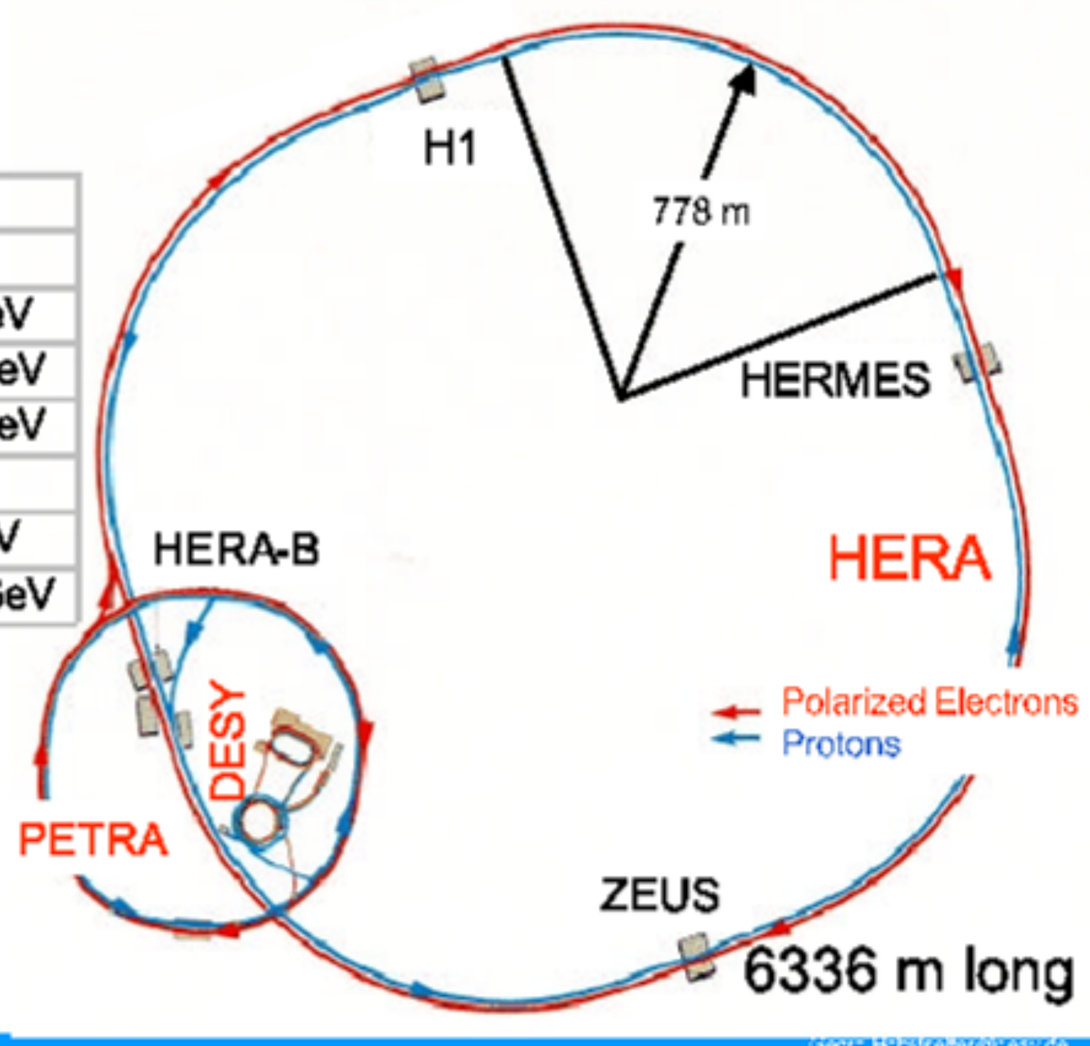
	Protons	Electrons	
20 keV	Source	Source	150 keV
750 keV	RFQ	Linac II	450 MeV
50 MeV	Linac III	Pia	450 MeV
8 GeV	DESY III	DESY II	7 GeV
40 GeV	PETRA	PETRA	12 GeV
920 GeV	HERA-p	HERA-e	27.5 GeV

$E_e = 15..30 GeV, E_p = 400..1000 GeV$

$polarisation: P(e) = -0.5...0...+0.5$

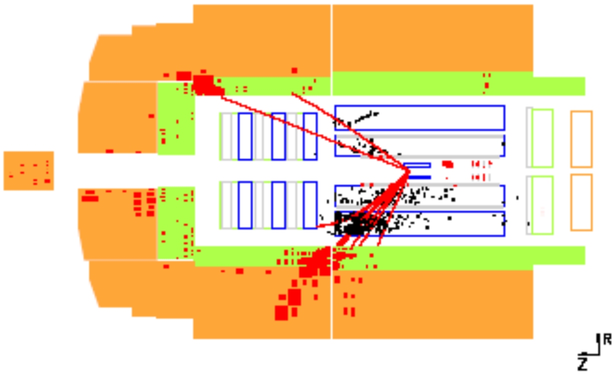
$L_{spec} \approx 0.4...2 \cdot 10^{30} cm^{-2} s^{-1} mA^{-2}$

$I_e = 20...50 mA, I_p = 60...100 mA$

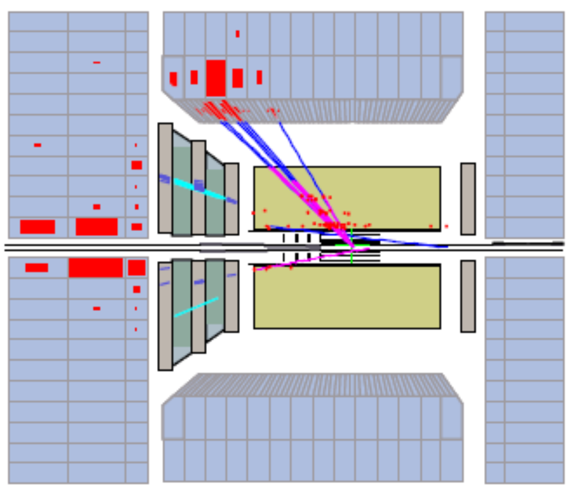


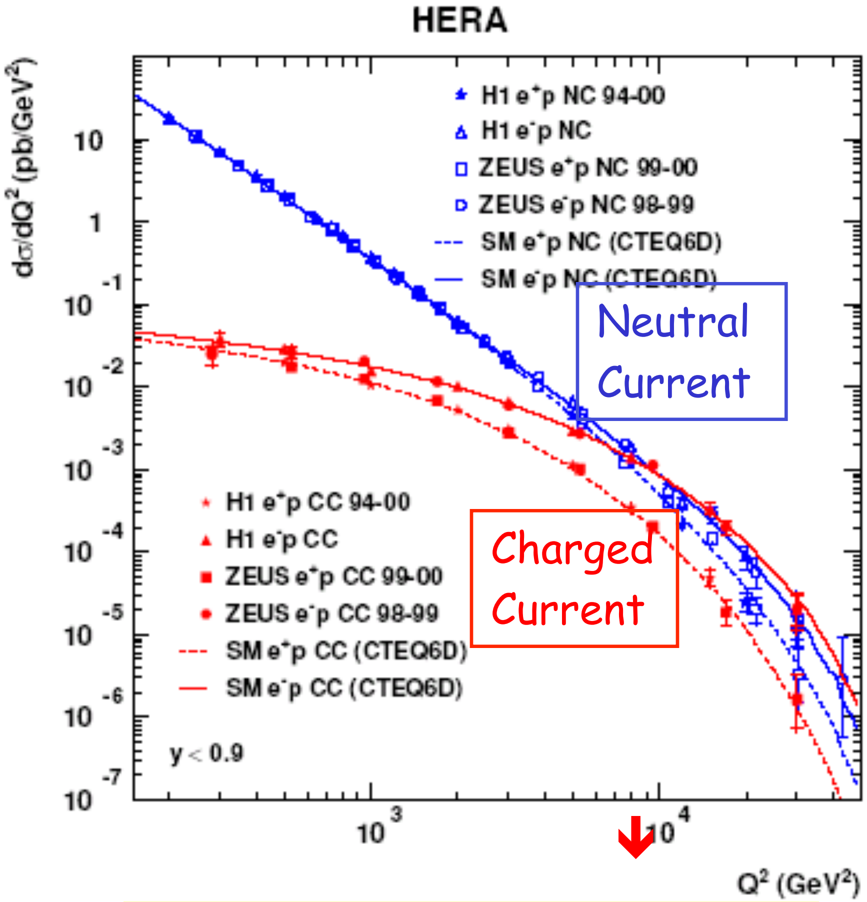
HERA was built to find physics beyond the standard model (as were LEP, Tevatron) and to study the unification of electromagnetic and weak interactions at high Q^2

Neutral current $e^+ p \to e^+ X$



Charged current $e^+ p \to \bar{\nu} X$





$$\sigma_{NC}^{\pm} \approx \sigma_{CC}^{\pm} \leftrightarrow Q^2 \approx M_Z^2 \approx 10^4 GeV^2$$

… its physics is much richer

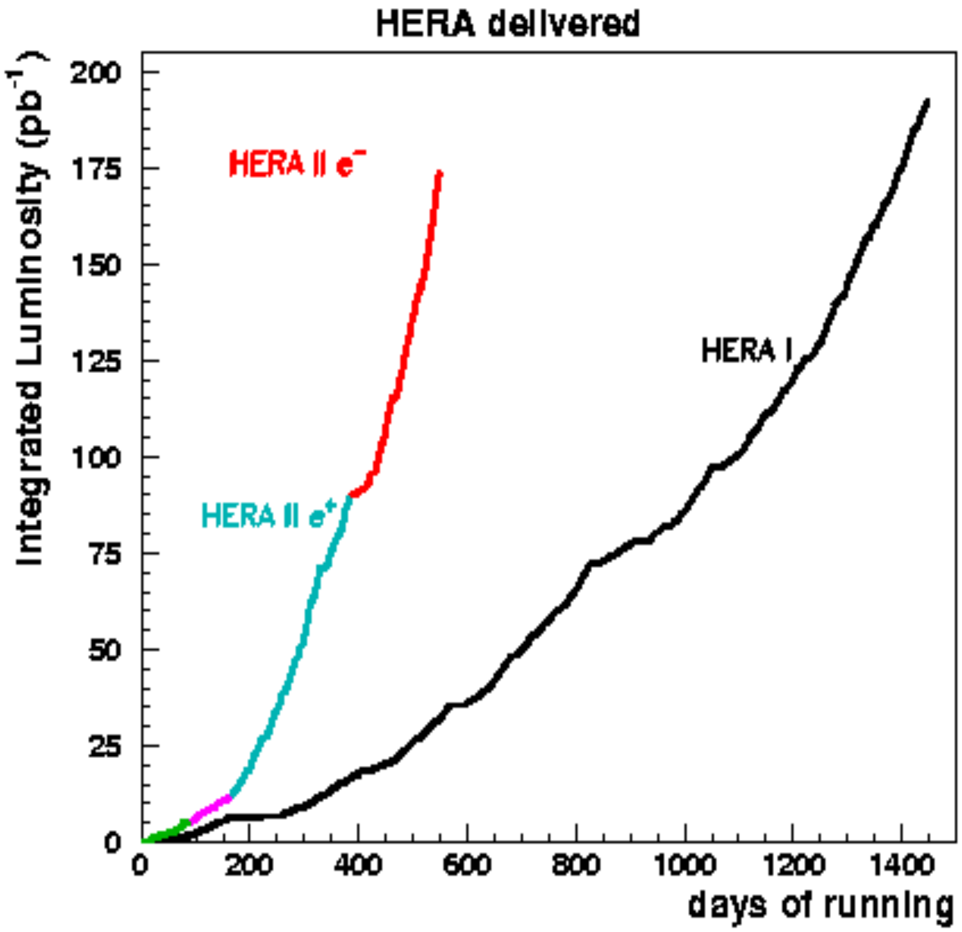
Physics at HERA (the expected and the unexpected)

- classic DIS
  - Inclusive ep measurements (NC, CC-inverse neutrino i.a.) → pdf's, gluon,
- QCD
  - Low x physics: small coupling and high density of partons → "CGC, BFKL.."
  - Heavy flavour physics (c and b: production and fragmentation dynamics)
  - Final state physics (parton emission,,jets, multiparticles, dijet correlations)
  - Diffraction [all related: e.g. "the structure of charm jets in diffraction"]
  - Parton amplitudes (DVCS)
- Searches
  - Searches for exotic states (pentaquarks) and less? exotic ones (instantons)
  - Searches: substructure, leptoquarks, SUSY, isolated lepton events (17/5)
- elweak
  - Electroweak physics (spacelike region)

for HERA physics see also:

- Talks at DIS05, April 2005, Madison
- Ringberg Workshop (2003) Proceedings ed by G.Grindhammer, B.Kniehl, G.Kramer

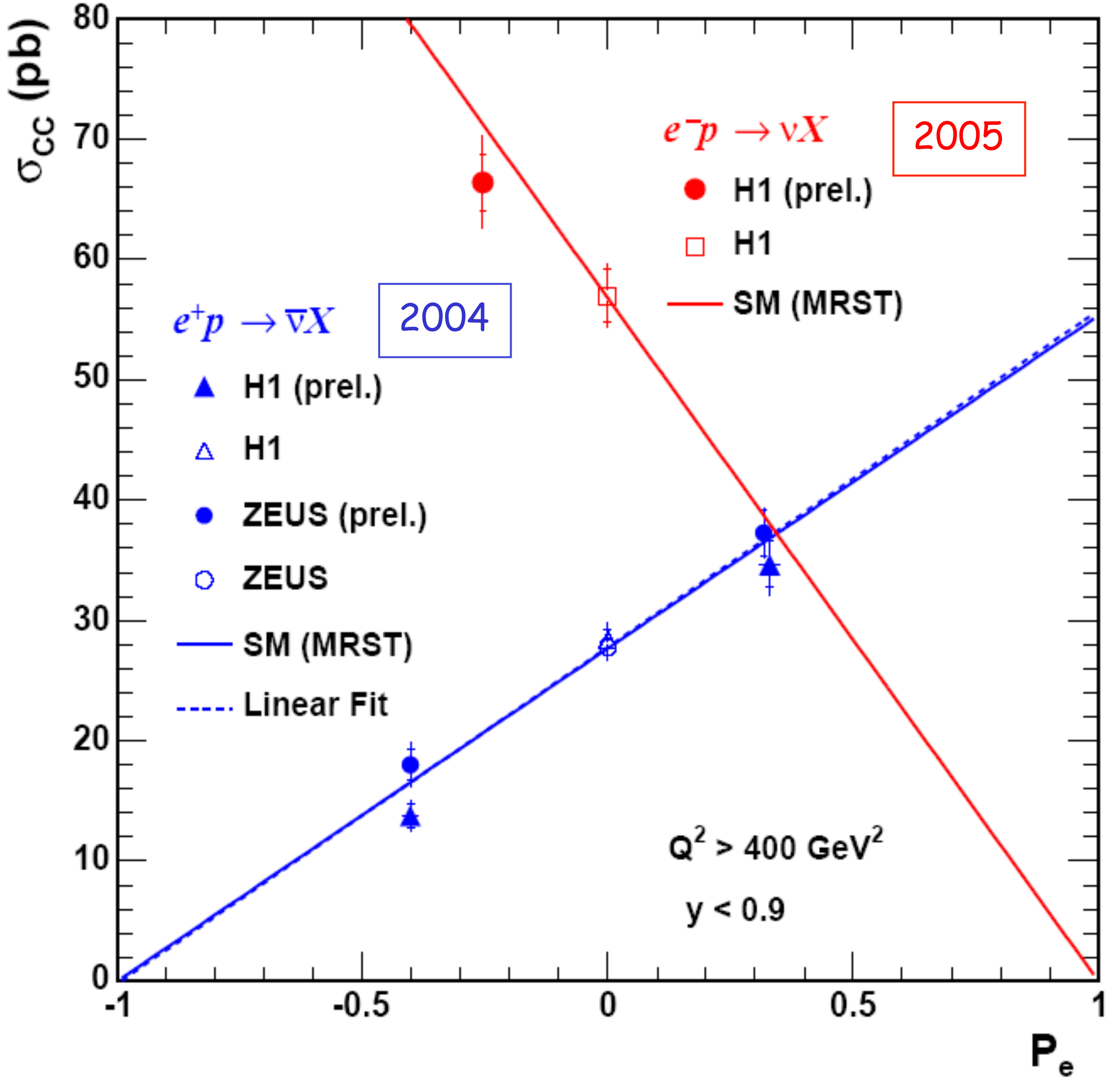
Luminosity development at HERA (I: 92-00, II: 03-07)



Have reached HERA delivering 1pb^{-1} /day and HV on

- HERAI: H1 and ZEUS took about 130pb^{-1} with HV on (1992-2000)
- 2001 "luminosity upgrade"
- 2002/03 background problems
- 2004: positrons (50 pb^{-1})
- 2005: electrons: so far 40 (H1) 60 (ZEUS)
- 2007: scheduled end of HERA: PETRA III

First Measurements of the helicity dependence of the CC cross section

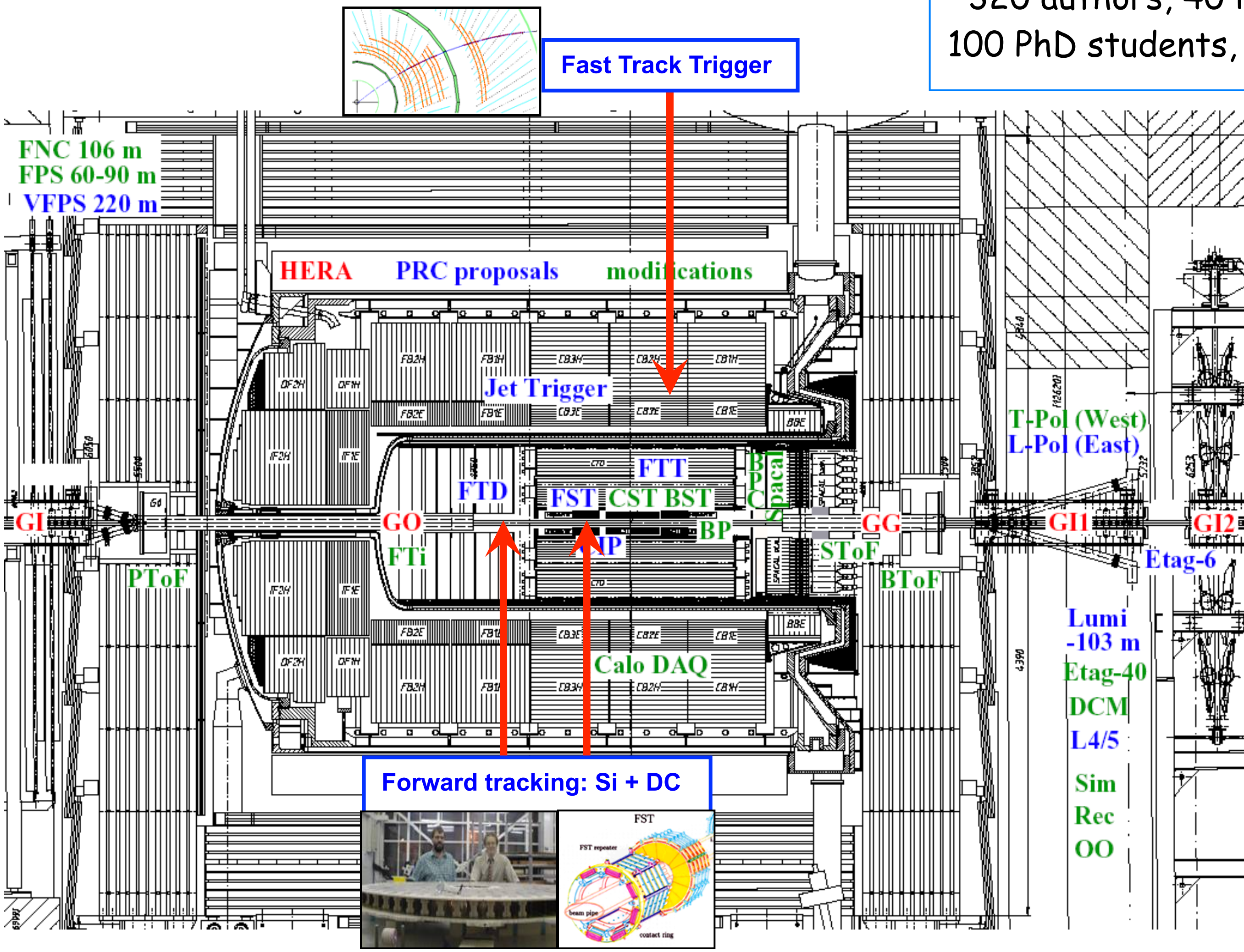


$$\sigma_{e^+p\to\bar{\nu}X}(P_{e^+} = -1) = 0.2 \pm 1.8(sta) \pm 1.6(sys)\,pb$$

2. The Collider Detectors: H1 and ZEUS

320 authors, 40 institutes
100 PhD students, 50 engineers

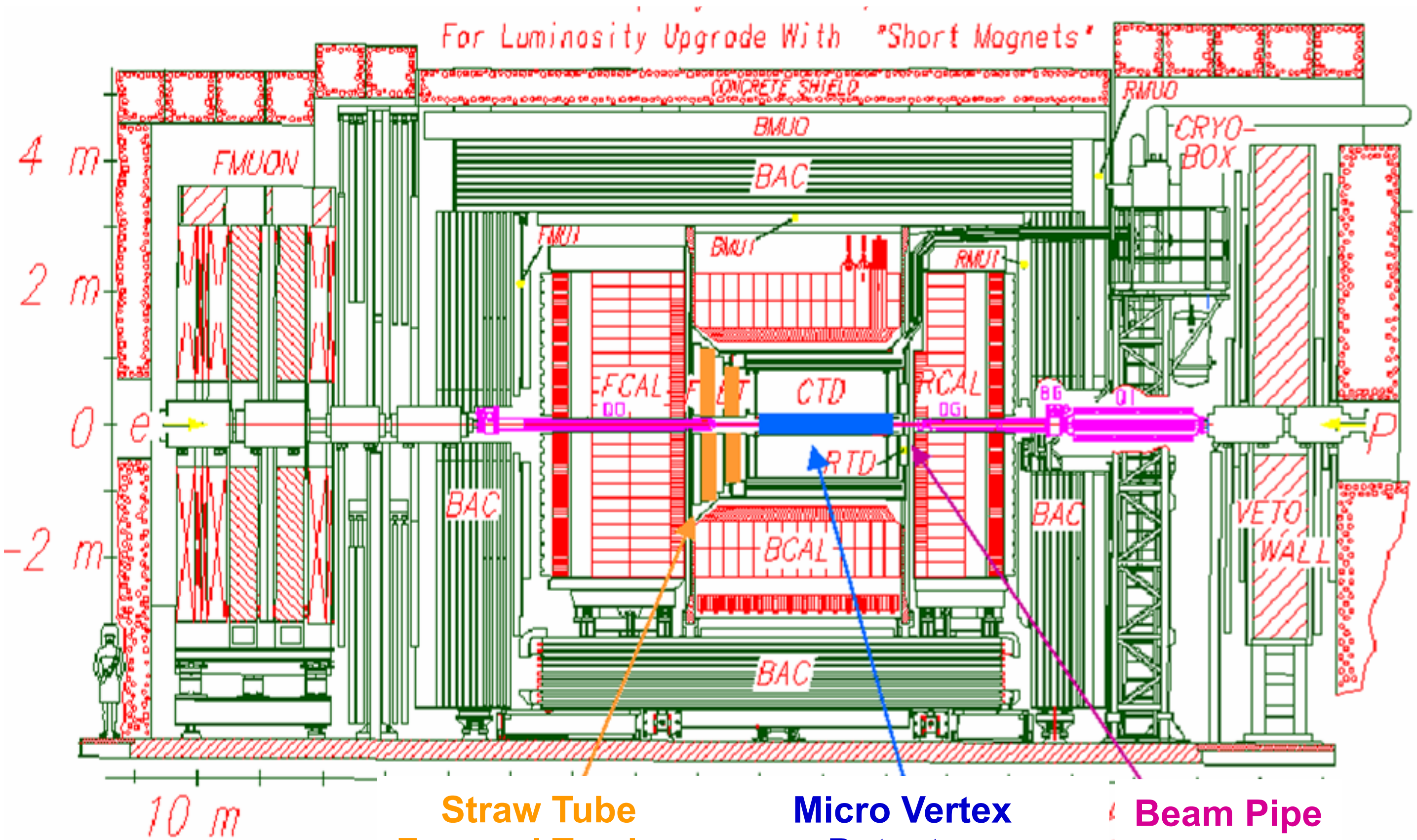
Forward Proton and Neutron Spectro-meters



Luminosity spectrometer

→ **e** 27.5 GeV

← **p** 920 GeV

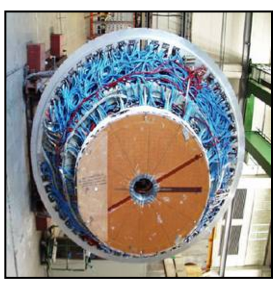


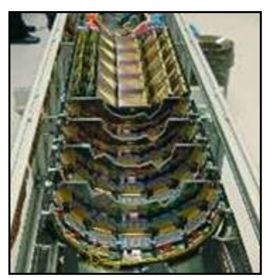
Luminosity spectrometer

Straw Tube Forward Tracker

Micro Vertex Detector

Beam Pipe Magnets





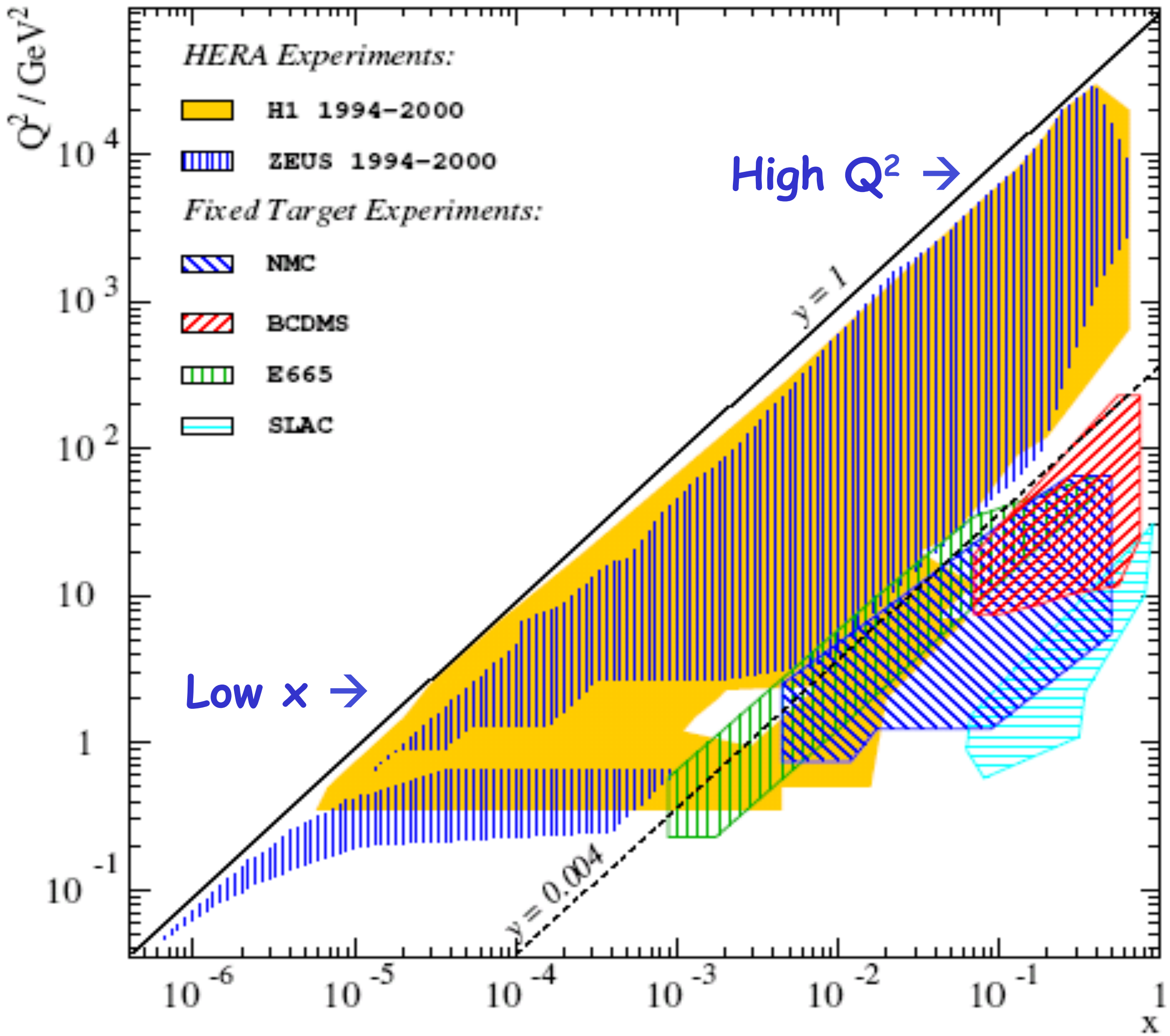
ZEUS

350 authors
~35 institutes

HERA collider experiments are precision experiments because

- Measure $E'_{e,}$ θ_e, E_h, θ_h → Reconstruct x, Q^2: Kinematics is overconstrained
- Highly efficient, 4π Detectors (Calorimeters, Chambers in solenoidal field)
- Energy calibration: double angle method and kinematic peak constraint
  [high resolution calorimeters: 10%...35%/$\sqrt{E'_e}$ and 30-50%/$\sqrt{E_h}$]
- Energy momentum conservation ($E-p_z$): reduces radiative (QED) corrections
- Polar angle measurement using redundant trackers. Run vertex accurate
  [drift chambers: 200μm and Si trackers: 20μm resolution]
- Luminosity from Bethe-Heitler scattering [ep → epγ] to 1%.

- Precision, stori and QCD: all require time, patience, luck, ingenuity and dedication huge extension of kinematic range: DIS and searches at energy frontier



$E_e = 27.6 GeV, E_p = 920 GeV$

$\sqrt{s} = 2\sqrt{E_e E_p} = 319 GeV$

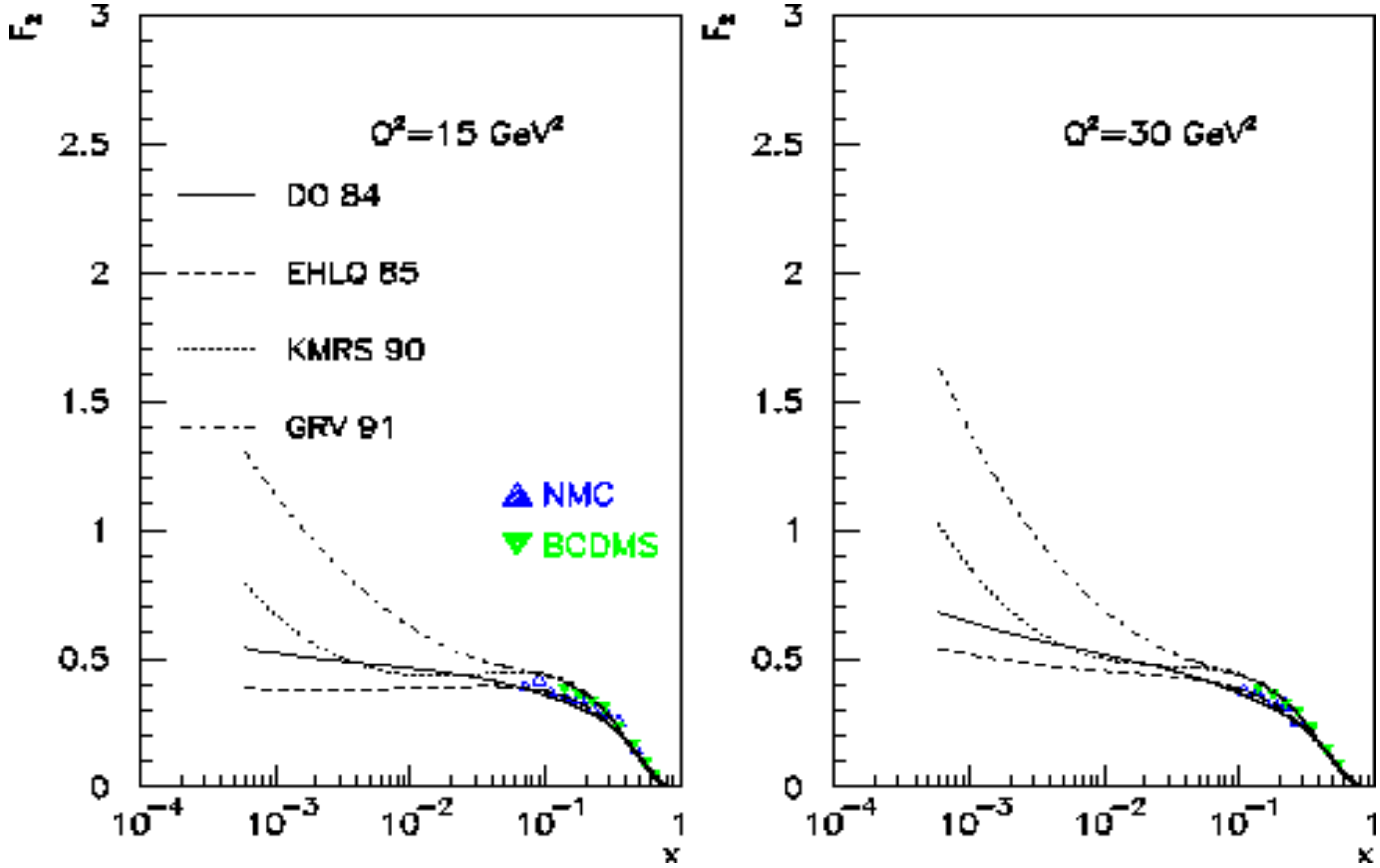
$\Leftrightarrow E_e^{ft} = 54.1 TeV$

$Q^2 = sxy - high$

$x = Q^2 / sy - low$

3. Low x Physics

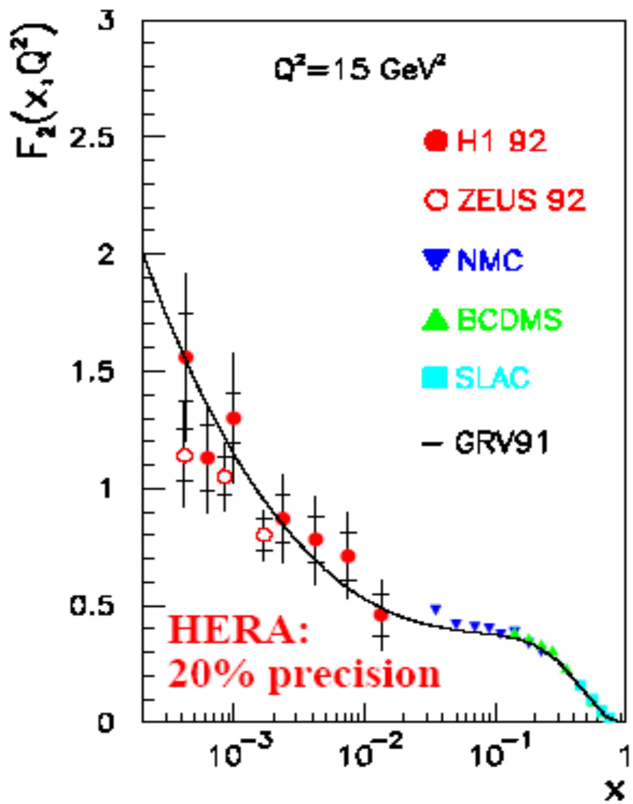
the first discovery of HERA and its development



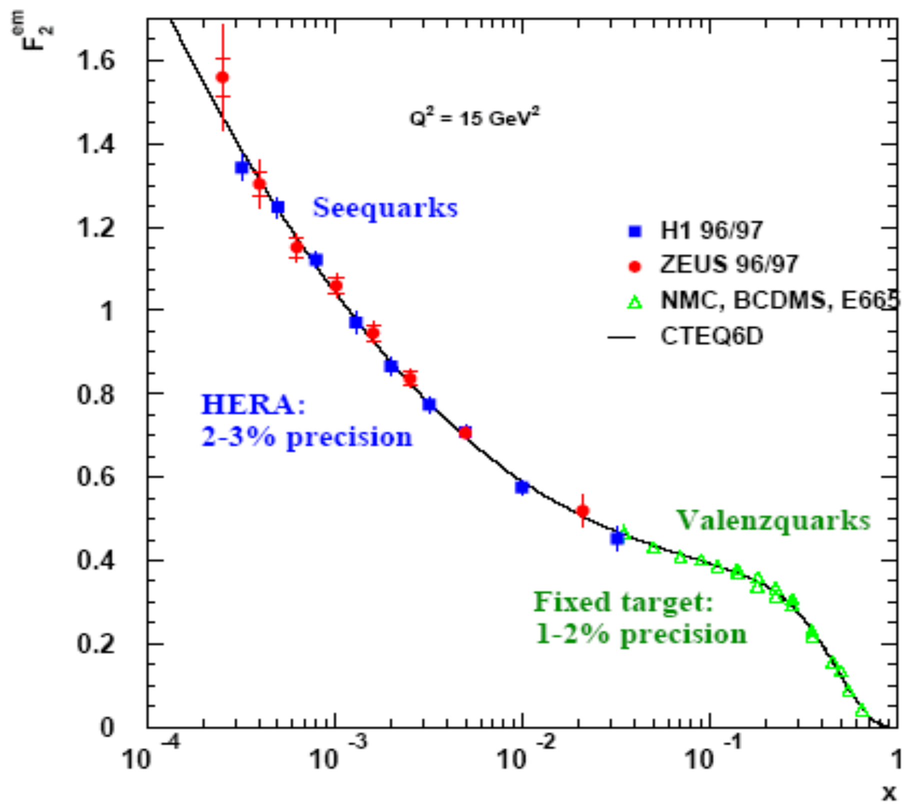
$$F_2 = x \sum e_q^2 [q + \overline{q}]$$

$$u = u_v + u_s , \overline{u} = u_s , d , s = \overline{s} , c = \overline{c} , \ldots$$

1992 data ~30nb-1



1997 data ~30pb-1



consequences, regarding the pointwise evolution of structure functions, were derived. The most dramatic of these, that protons viewed at ever higher resolution would appear more and more as field energy (soft glue), was only clearly verified at HERA twenty years later.

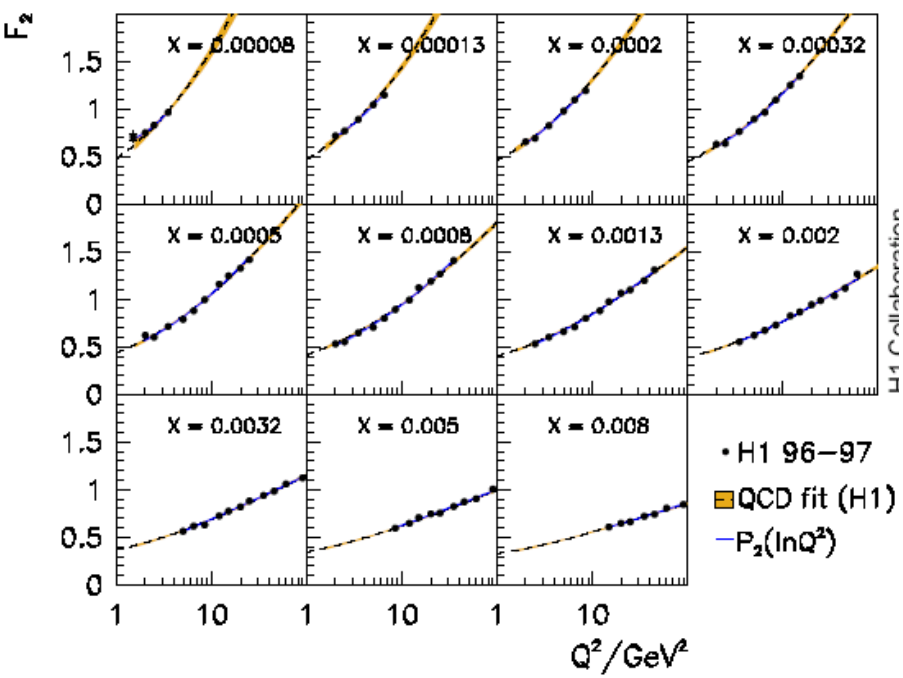
F. Wilczek

Rise of F_2 towards low x and with Q^2

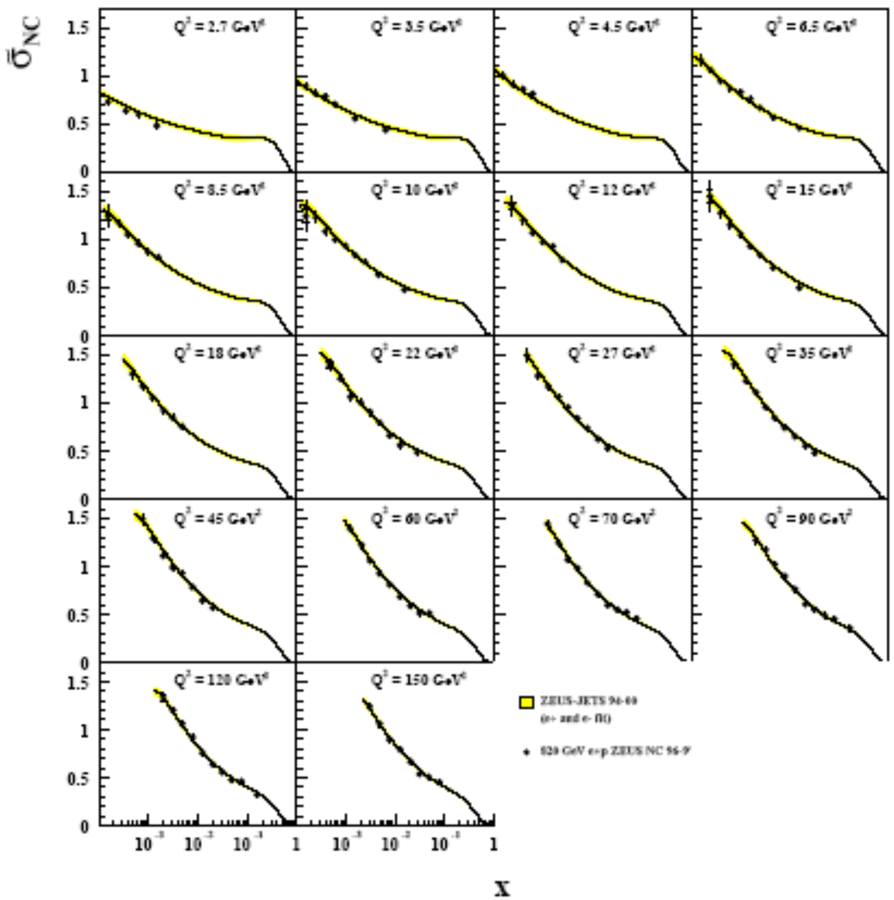
→ high density QCD (RHIC, Alice)

→ neutrino astrophysics

H1



ZEUS

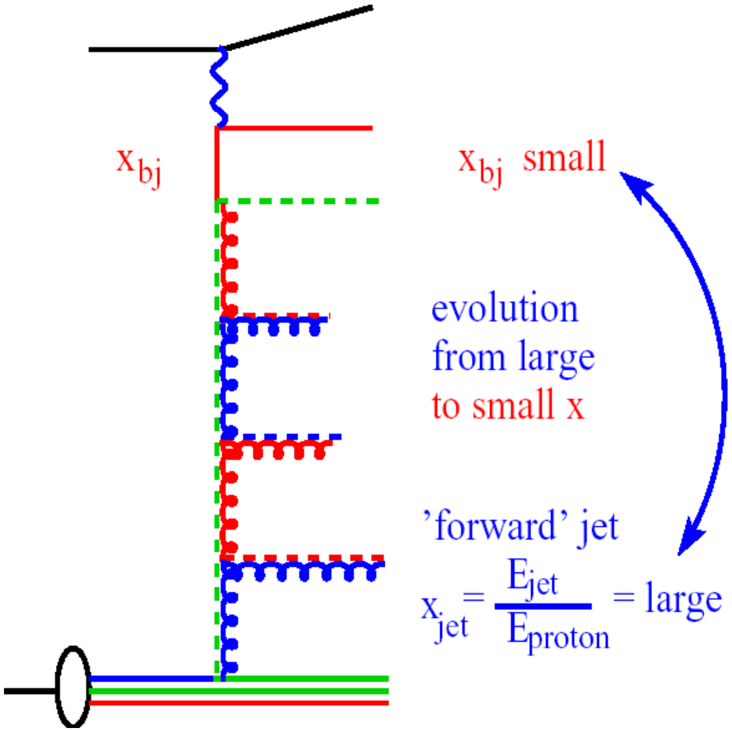


Precision has reached 2-3%, aim is 1%

→ predictions for the LHC, precision test of QCD

is DGLAP evolution valid at low x? measurement of F_L

Low x parton radiation: forward particle production (in p direction).



How are partons (gluons) emitted?

kt ordered

- DGLAP(Dokshitzer-Gribov-Lipatov-Altarelli-Parisi)
  DISENT/NLOJET

angular ordered

- CCFM(Ciafaloni-Catani-Fiorani-Marchesini)
  CASCADE

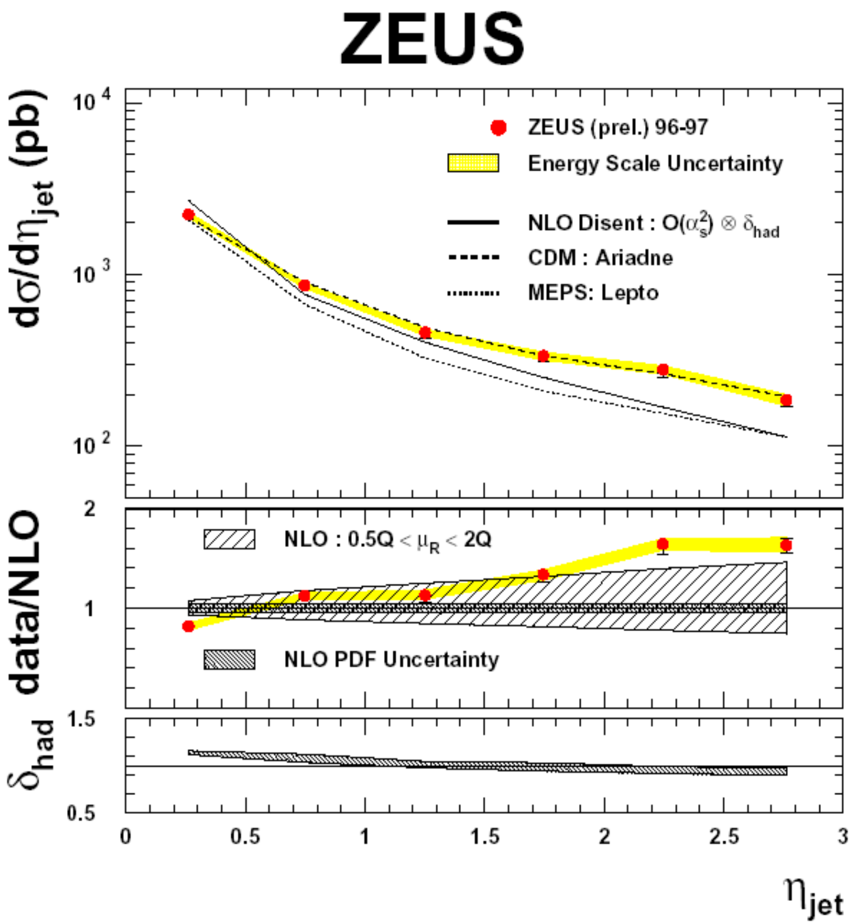
x ordered

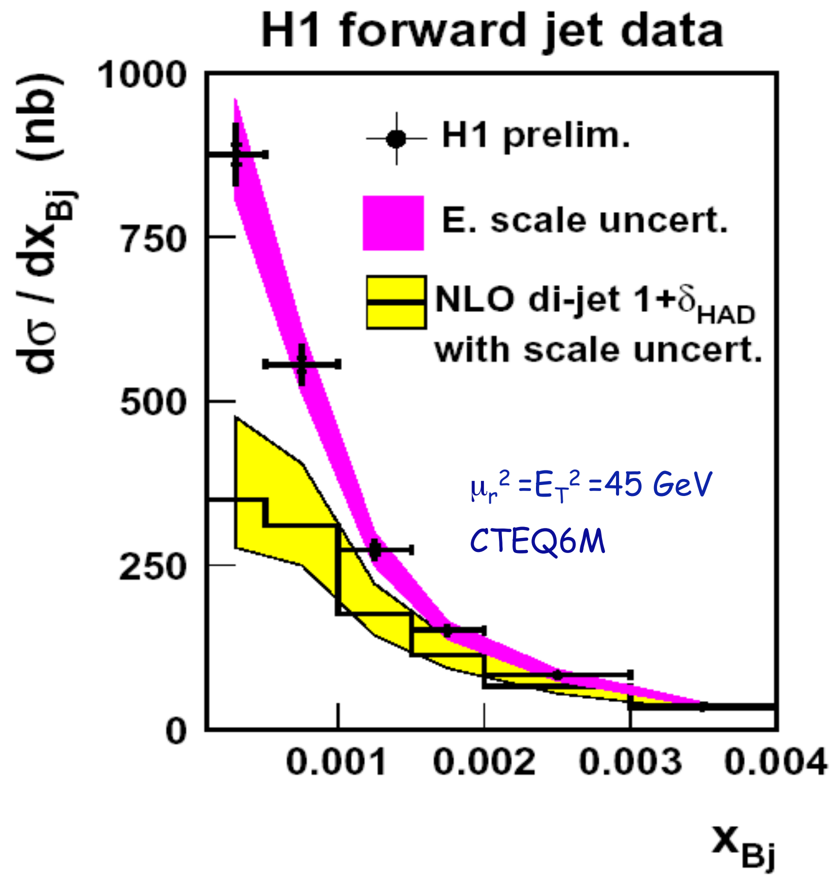
- BFKL(Balitsky-Fadin-Kuraev-Lipatov)
  ARIADNE (colour dipole. random in kt)

$x_{jet} = E_{jet}/E_{proton} >> x_{Bj}$ enhances BFKL effect

$E^2_{T,jet} \sim Q^2$ suppress DGLAP evolution

Forward jet production in deep inelastic scattering





- Standard NLO pQCD prescription poor at lowest x for jets in forward direction where scale uncertainty is largest (higher orders? different radiation mechanism? best described by Ariadne – CDM – “BFKL like”)

[interesting azimuthal (de)correlations. Also: kt dependent (“unintegrated”) pdf’s] ← no time

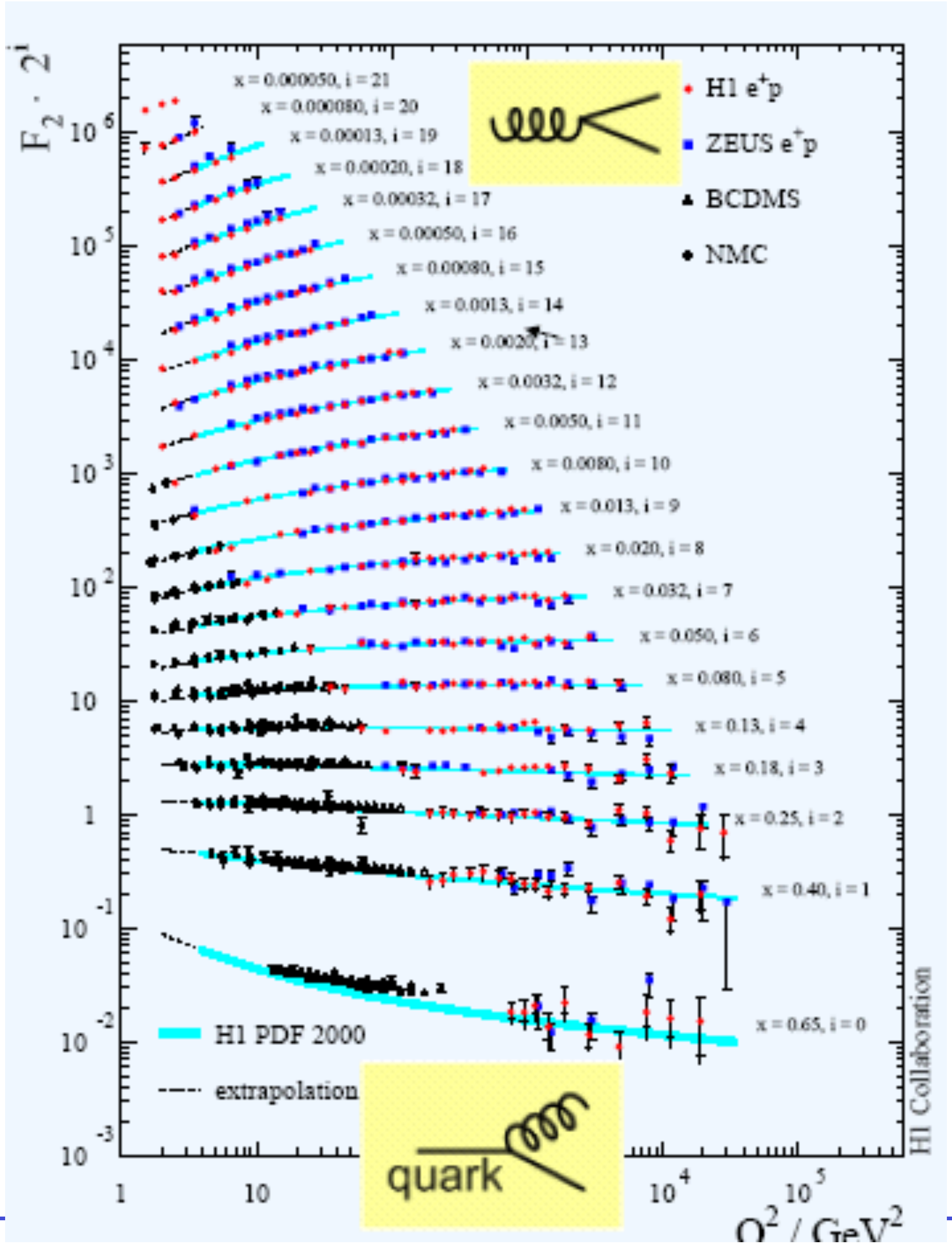
4. Strong Coupling and xg

$$\frac{\partial F_2}{\partial \ln Q^2} \propto \alpha_s(Q^2) xg(x,Q^2)$$

resolve correlation
of coupling and gluon
by accessing wide
range of x and Q^2

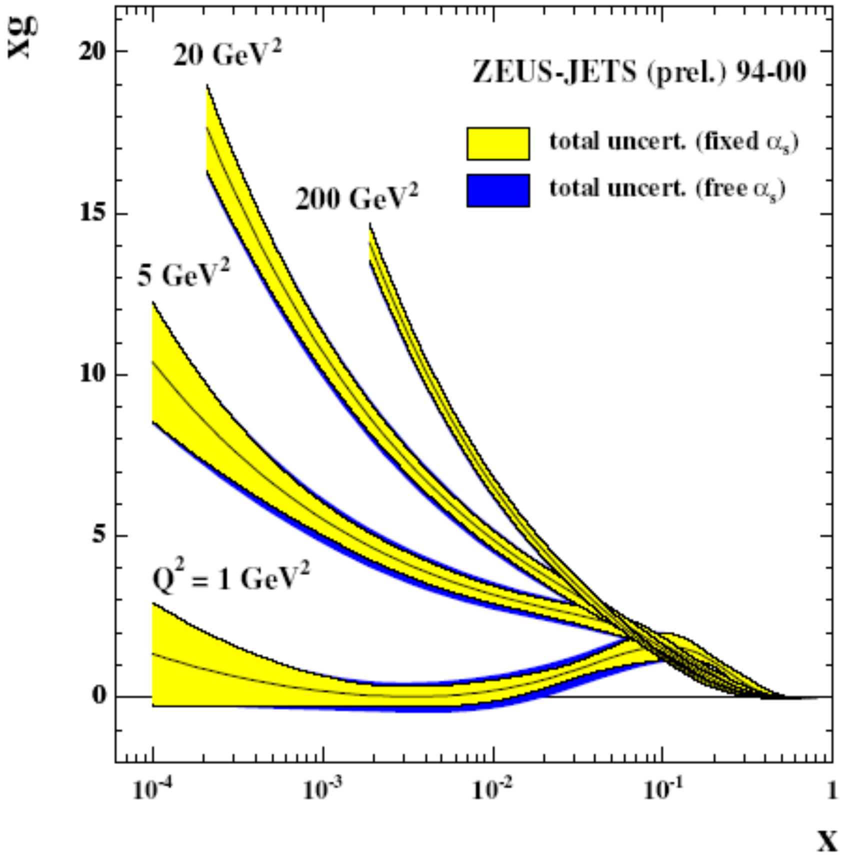
assume DGLAP evolution
though that neglects ln(1/x)

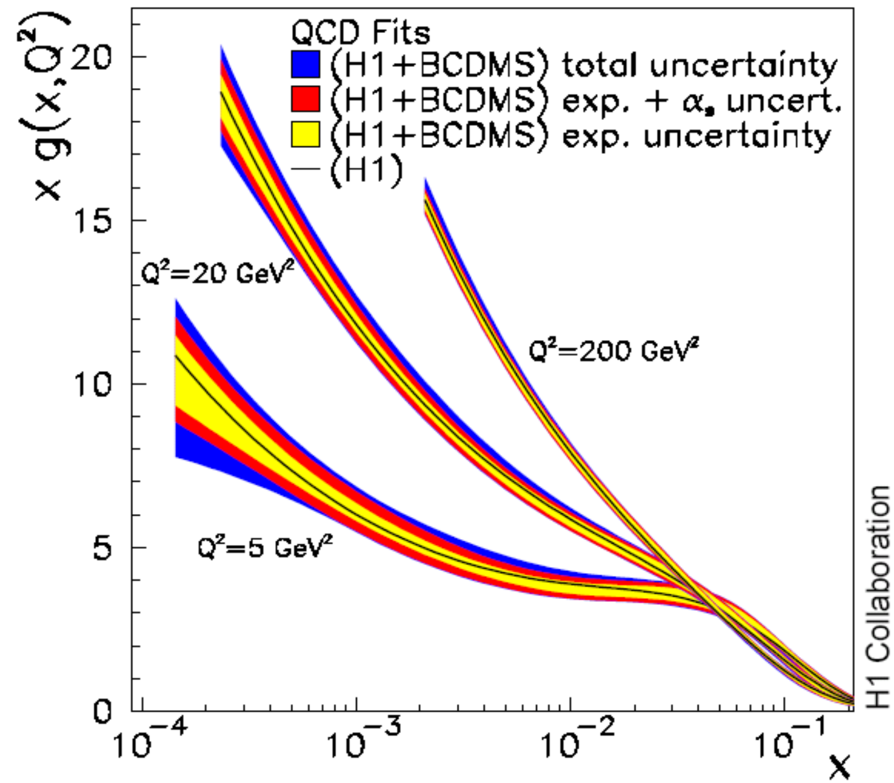
$$\frac{\partial F_2}{\partial \ln Q^2} \propto \alpha_s(Q^2) q(x,Q^2)$$



ZEUS inclusive NC+CC & jets

H1 inclusive NC+CC

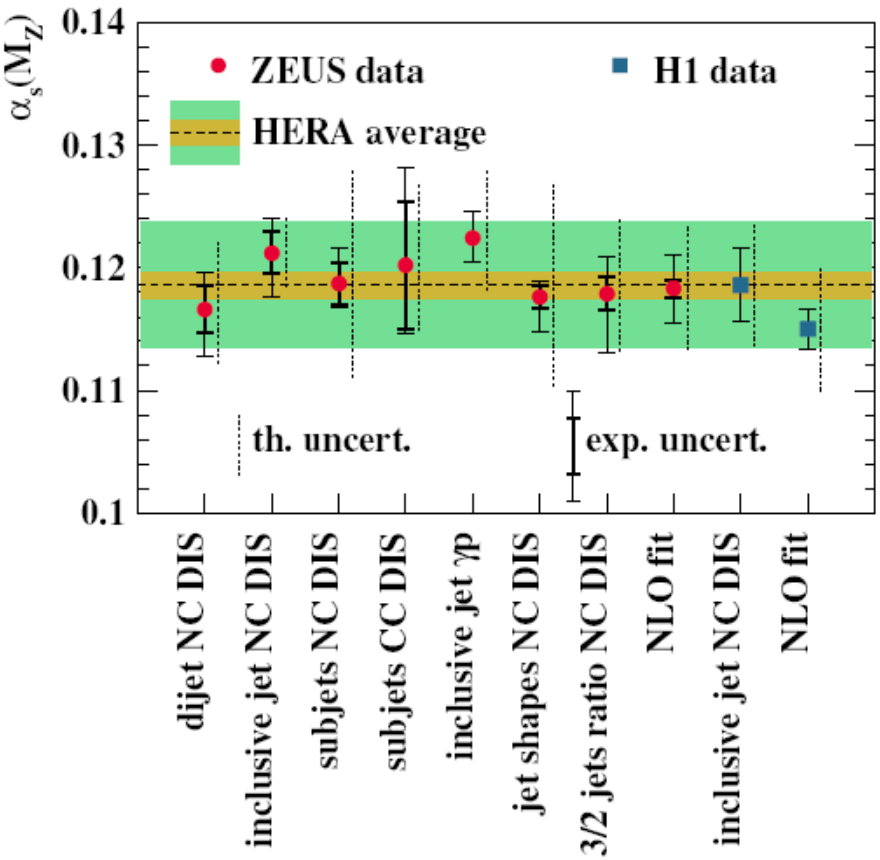


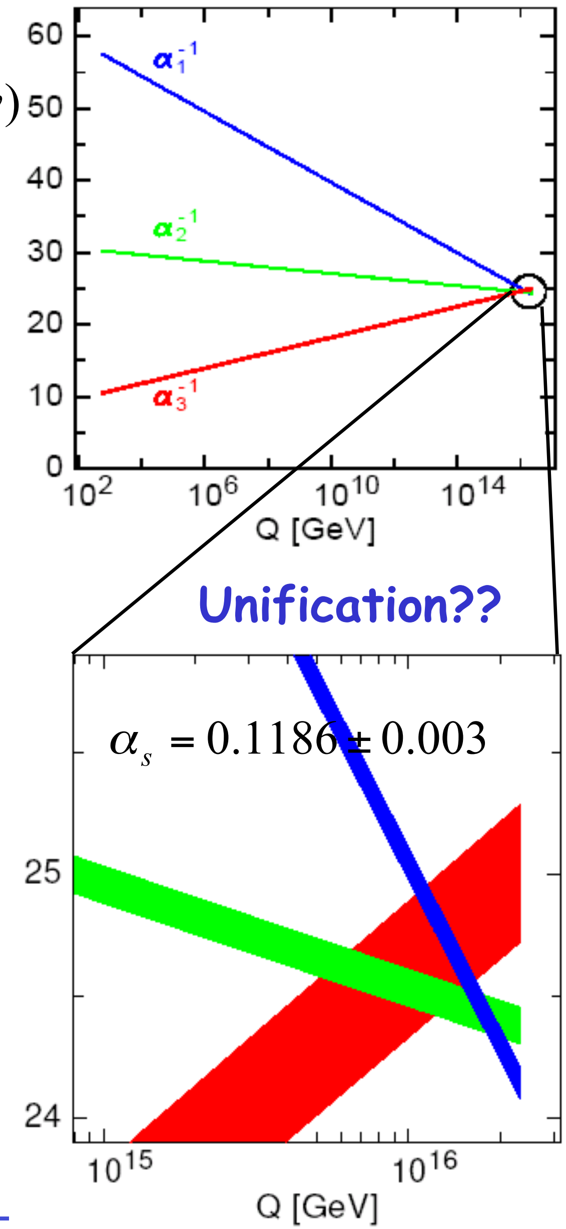


xg is NOT an observable. Charm treatment important (ZEUS: VFNS RT, H1: FFNS)
In the region of low x and $Q^2 \sim 1$ GeV^2 the gluon distribution becomes very small
→ transition from hadronic to partonic behaviour at about 0.3 fm

HERA may determine strong coupling best

$$HERA(prel.) - \alpha_s(M_Z^2) = 0.1186 \pm 0.0011(\exp) \pm 0.005(thy)$$

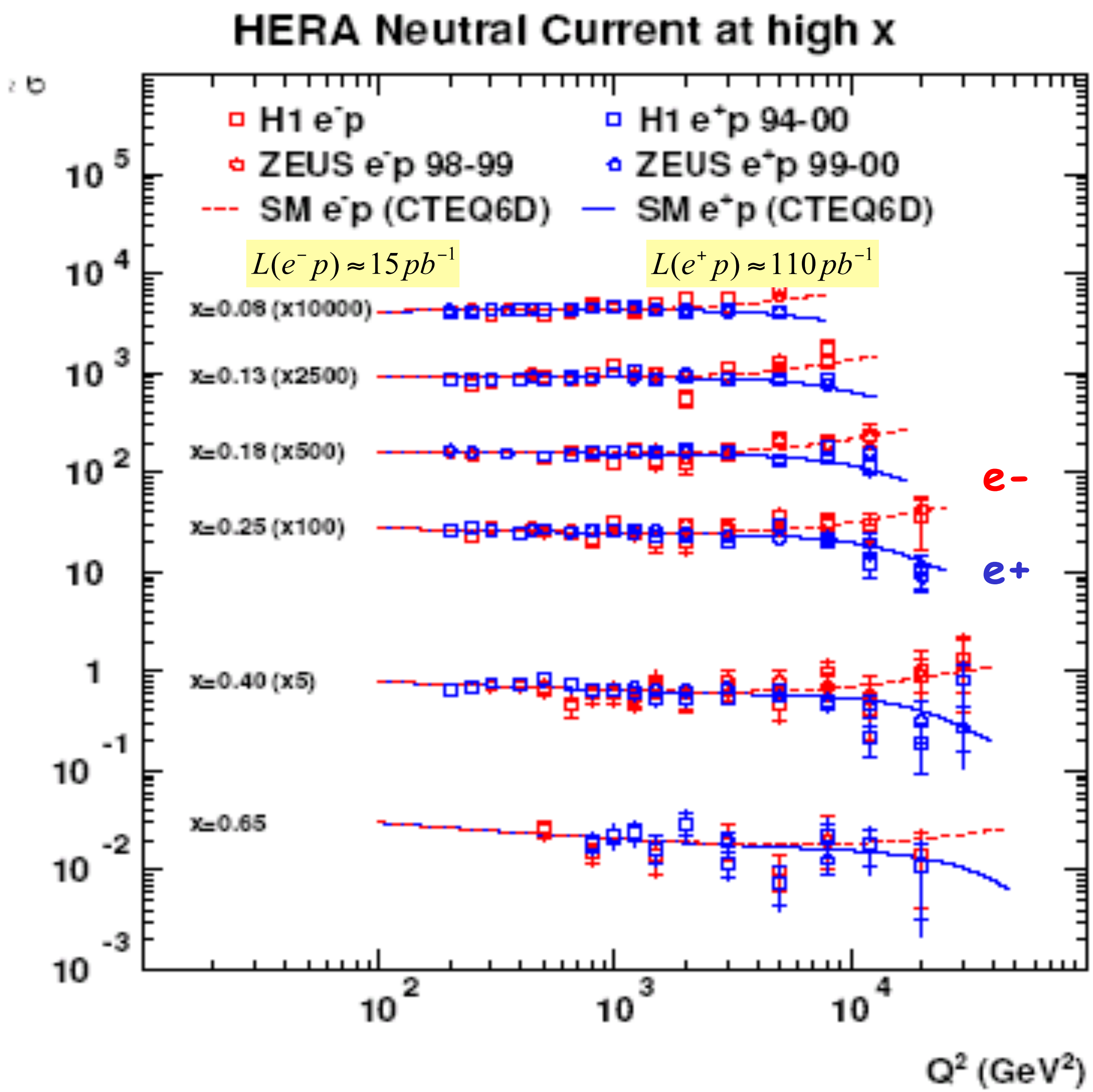




Next steps: higher accuracy data and NNLO

hep-ph/0407067 B.Allanach … P.Zerwas

5. Quark momentum distributions



$$\sigma_{NC}^{\pm}(x,Q^2) \sim F_2 \mp f(y) x F_3$$

$$F_2 = e_u^2 x(U + \overline{U}) + e_d^2 x(D + \overline{D})$$

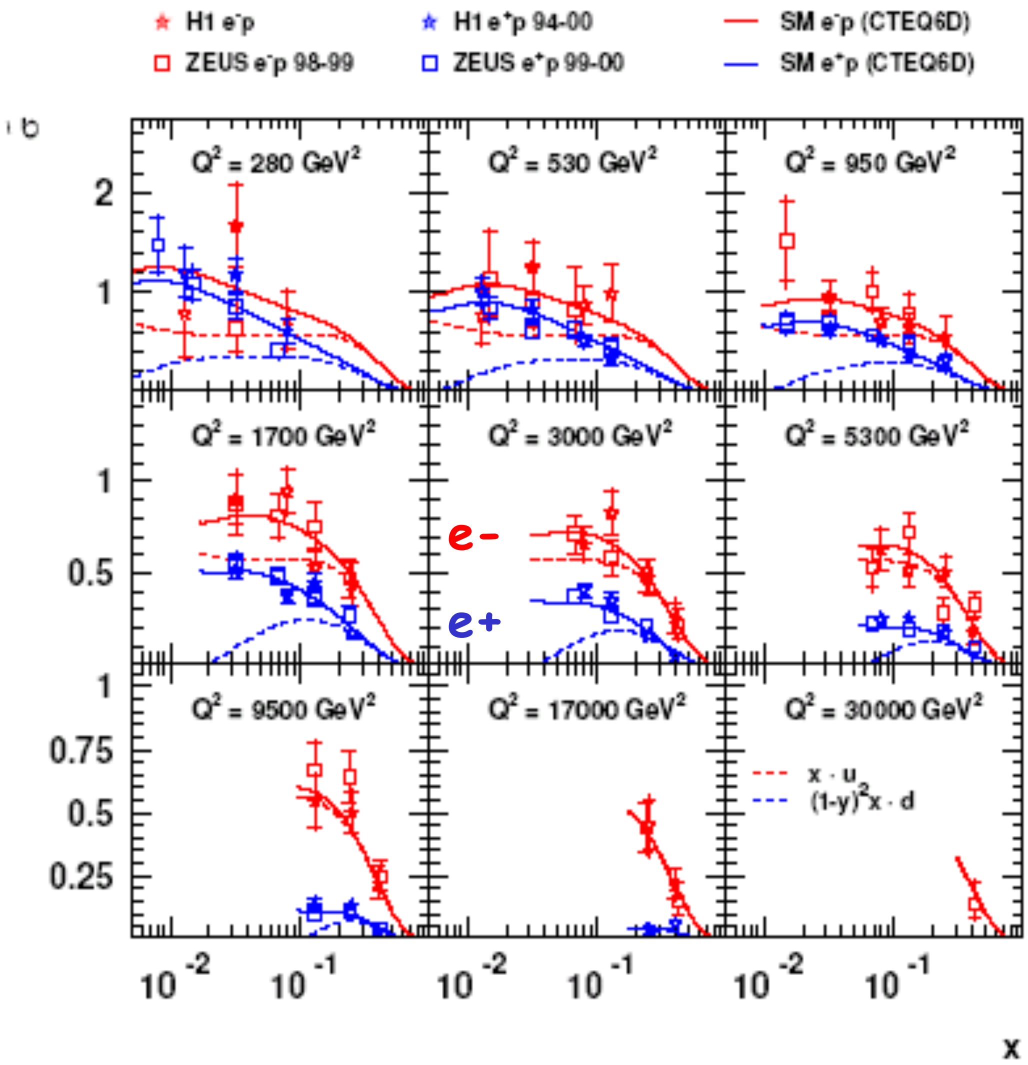
$$xF_3^{\gamma Z} = x(2u_v + d_v)/3$$

$$U = u + c + b$$

$$D = d + s$$

Z exchange enhances electron proton cross section and reduces positron proton cross section at large Q2

Reduced charged current scattering cross section

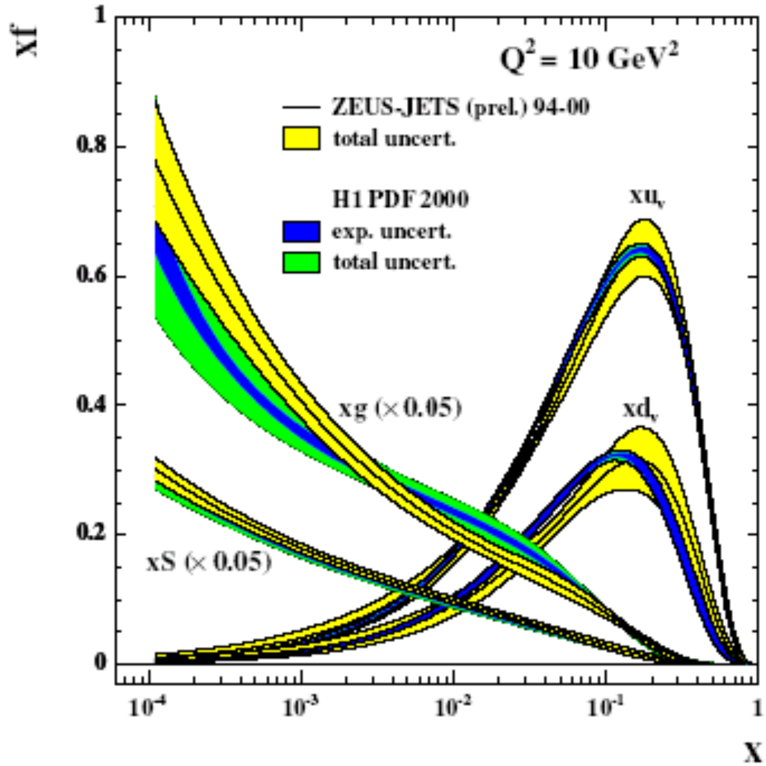


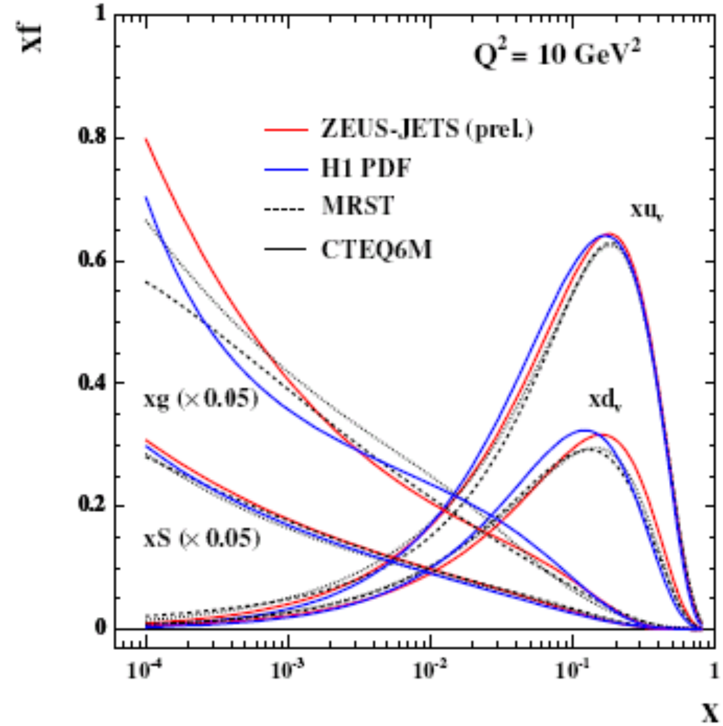
$$\sigma^{-}_{CC} \sim xU + (1-y)^2 x\overline{D} \rightarrow xu_v$$

$$\sigma^{+}_{CC} \sim x\overline{U} + (1-y)^2 xD \rightarrow (1-y)^2 xd_v$$

HERA can disentangle parton distributions at large Q^2 and large x > 0.01 within single experiments, independently of nuclear corrections and free of higher twists

Parton distributions unfolded with H1 data and with ZEUS data only, compared with global fits.





- H1 and ZEUS parton distributions are in agreement
- HERA experiment's fits agree with global fits
- Treatment of systematic, model and theoretical errors subject to conventions

QCD fits parameterise initial PDFs

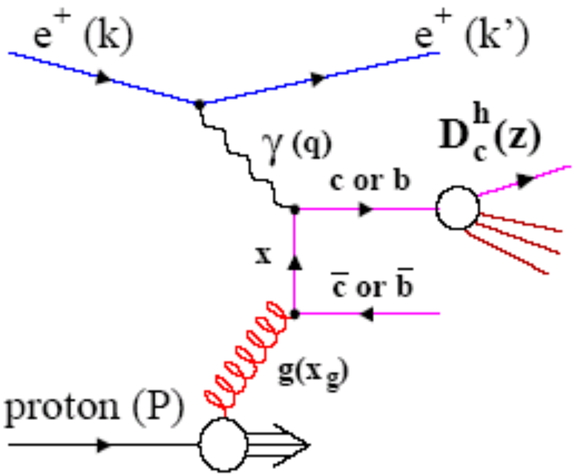
H1 $U,\overline{U},D,\overline{D},xg \leftrightarrow V,A,xg - \alpha_s$

ZEUS $u_v,d_v,\overline{u}\pm\overline{d},xg-\alpha_s$

6. Heavy flavour physics at HERA

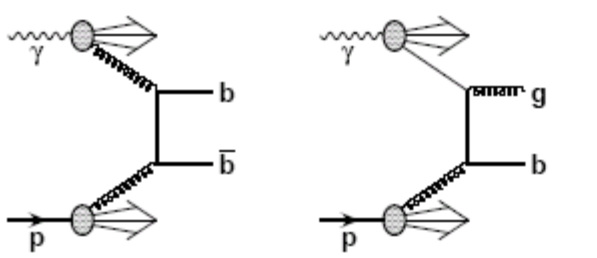
$$q(p) \otimes \sigma(\gamma g \rightarrow b\bar{b}) \otimes q(\gamma) \otimes D_c^h$$

Boson-Gluon fusion



- evolved test of QCD at NLO [+jets, diffraction]
  - γp: FMNR (Frixione, Mangano, Nason, Ridolfi)
  - DIS: HVQDIS (Harris, Smith)

Heavy flavours in photoproduction



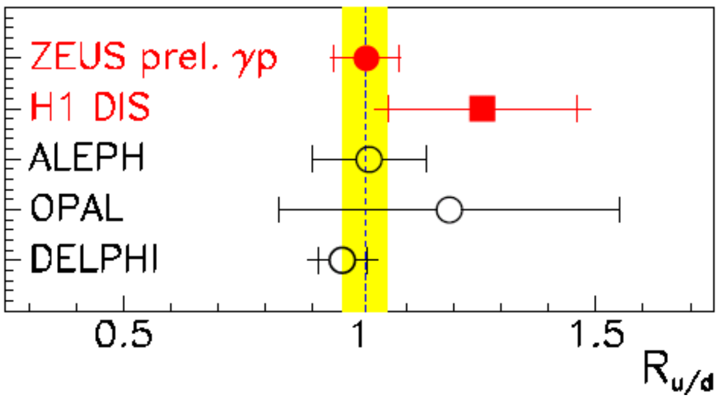
- Fraction of c,b to inclusive $F_2 \rightarrow F_2^c, F_2^b$
- Treatment of c,b in QCD evolution : extrinsic or intrinsic, heavy or light?
- Parton radiation (DGLAP vs CCFM)
- Fragmentation functions – universal?
- Gluon in the proton
- Heavy quark and gluon content of the photon

Charm fragmentation in ep scattering

$$D^+, D^0, D_s^+, D^{*+}, \Lambda_c$$

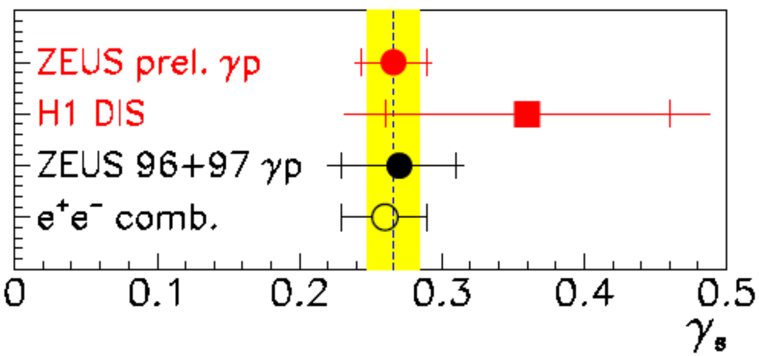
$$R_{u/d} = \frac{c\bar{u}}{c\bar{d}} = \frac{\sigma(D^{0,*0})}{\sigma(D^{\pm,*\pm})} = \frac{\sigma^{untag}(D^0)}{\sigma(D^\pm) + \sigma^{tag}(D^0)}$$

The vacuum as seen by the charm quark contains an equal number of u and d quarks



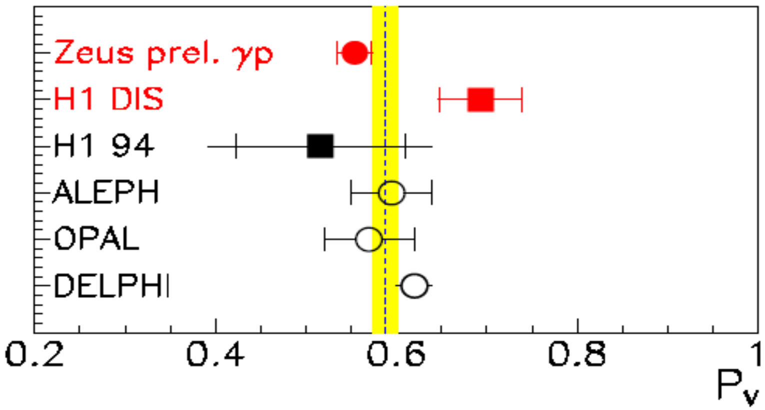
$$\gamma_s = \frac{2c\bar{s}}{c\bar{d} + c\bar{u}} = \frac{2\sigma(D_s^\pm)}{\sigma^{dir}(D^\pm) + \sigma^{dir}(D^0) + 2\sigma(D^{*\pm})}$$

s quarks are suppressed by a factor of 4



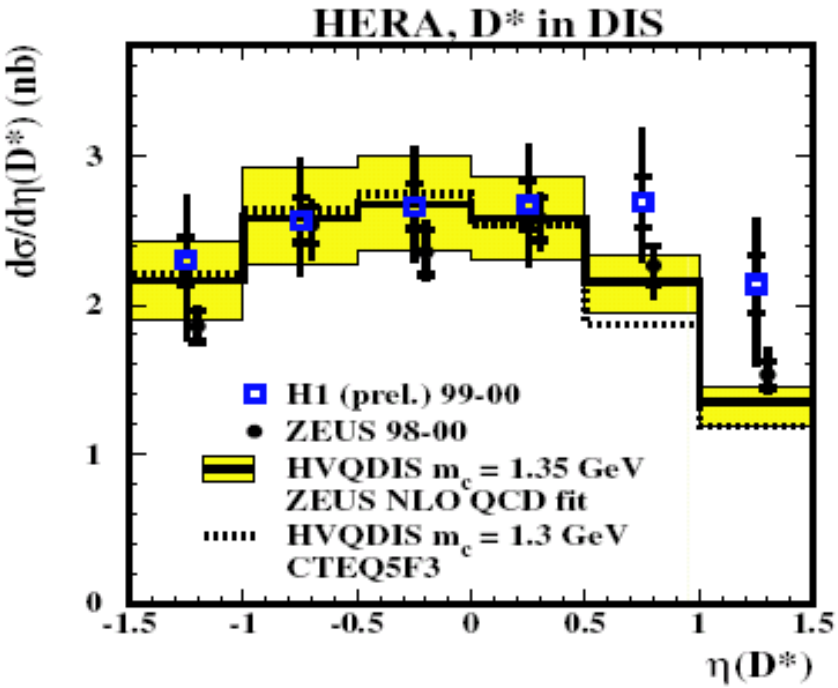
$$P_V = \frac{V}{V+P} = \frac{\sigma(D^*)}{\sigma(D^*) + \sigma^{dir}(D)} \neq 3/4$$

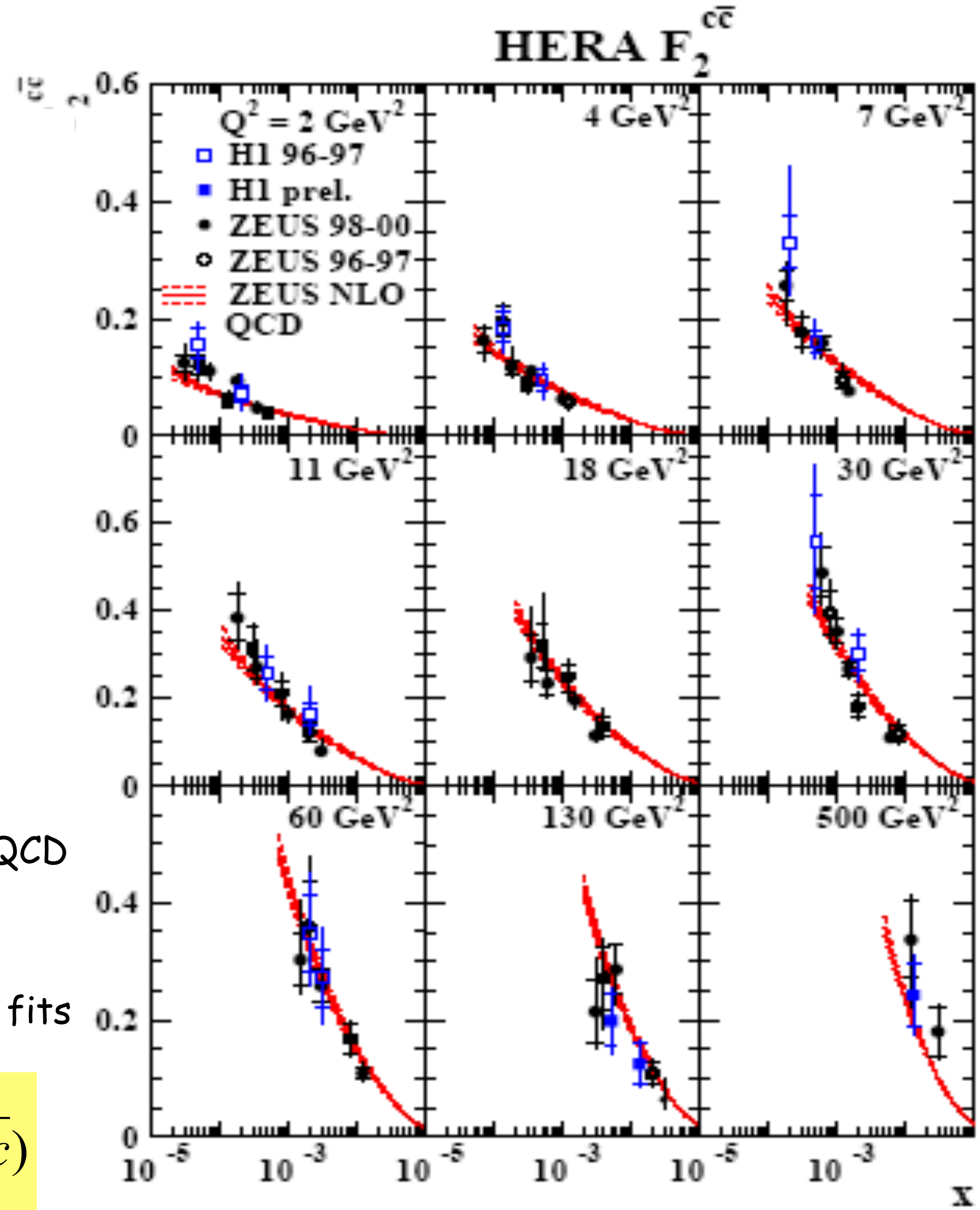
Naïve spin counting does not work for charm



Fragmentation fractions f(c→D), f(c→Λ_c) also determined. Agree/compete with e+e-
→ universal behaviour of charm fragmentation

Inclusive charm production in deep inelastic scattering

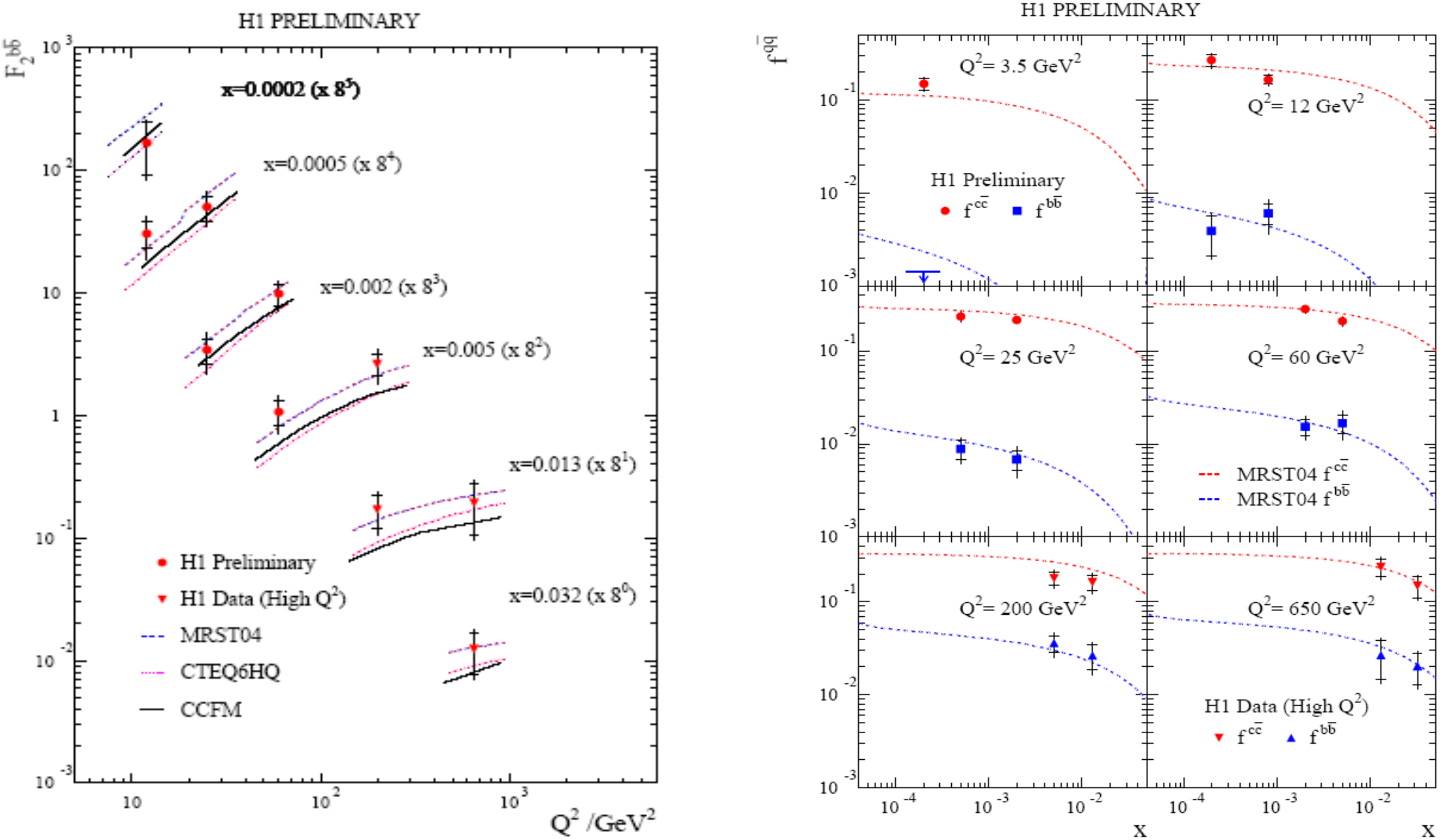




- Inclusive measurements consistent with NLO QCD
- Discrepancies when associated with jets.
- Large theoretical uncertainties (scale)
- Data accurate to 10-30% → can constrain PDF fits

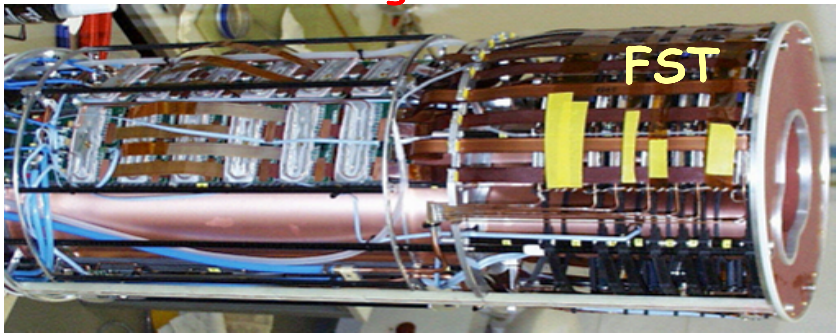
$$\frac{d\sigma^{ep\to ec\bar{c}X}}{dxdQ^2} \propto \frac{F_2^{c\bar{c}}(x,Q^2)}{Q^4}, F_2^{c\bar{c}} = \frac{4}{9}x(c+\bar{c})$$

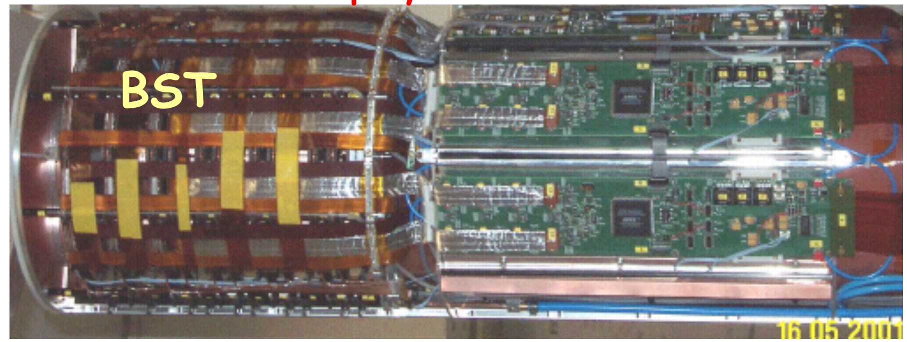
Measurements of heavy quark distributions testing QCD



→Lifetime: small extrapolations for c and b, high luminosity [b per mille fraction!], extend to fwd/bwd regions

New tracking detectors of H1 and ZEUS for HF physics in HERA II



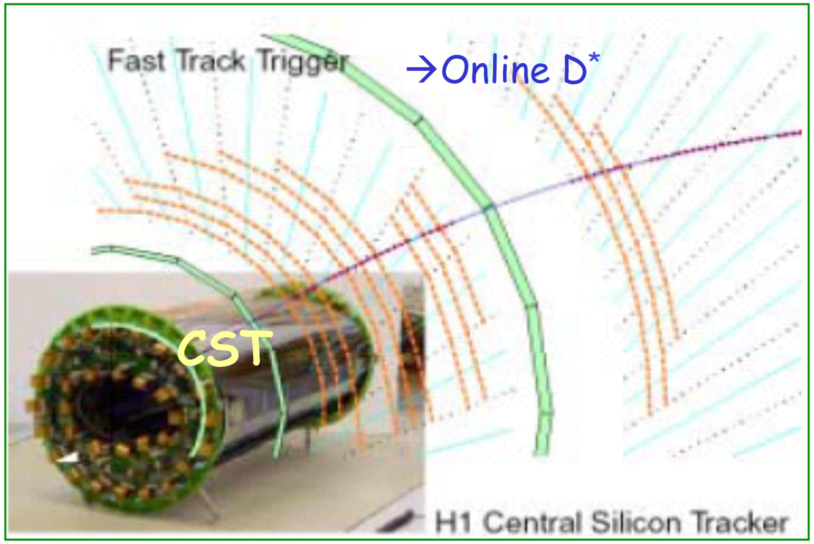


charm and beauty

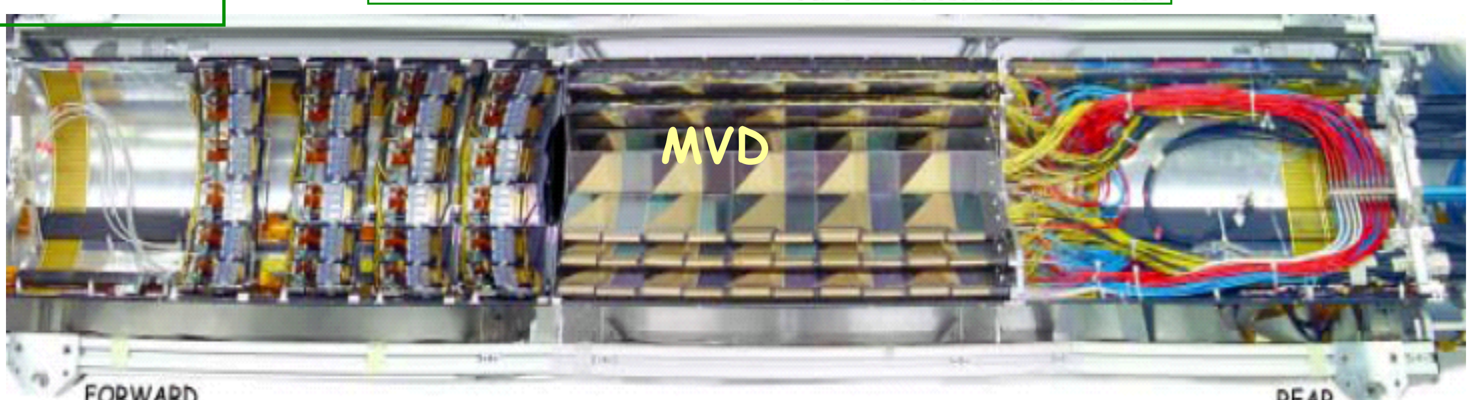
evt vtx (lo and hi y)

eID (DVCS, J/Ψ, searches)

F_L

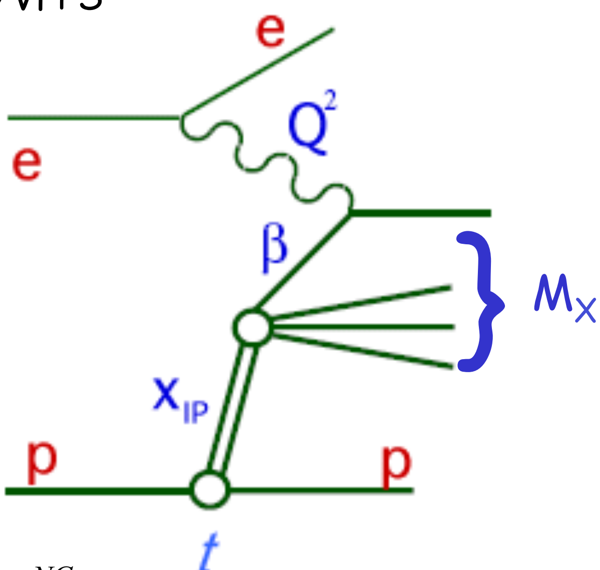


Huge investments for high lumi phase by H1 and ZEUS & fwd chambers



7. Hard Diffractive ep Scattering

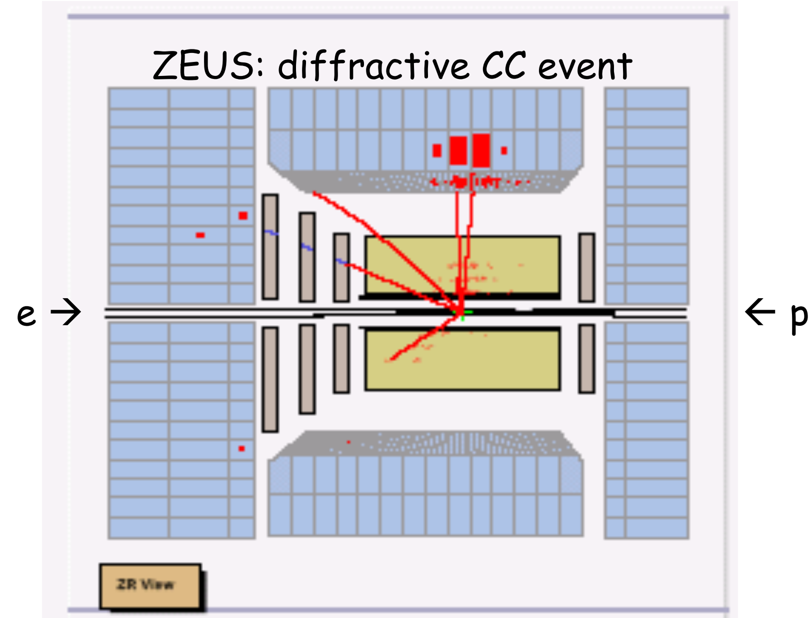
~10% of NC DIS events have gap between p and central tracks. Measure gap or detect p with LPS/VFPS



$$\frac{d\sigma_{diff}^{NC}}{dx_{IP}dtd\beta dQ^2} \propto \frac{1}{Q^4} F_2^{D(4)}(x_{IP},t,\beta,Q^2)$$

Cross section factorises into coefficient functions and diffractive parton distributions

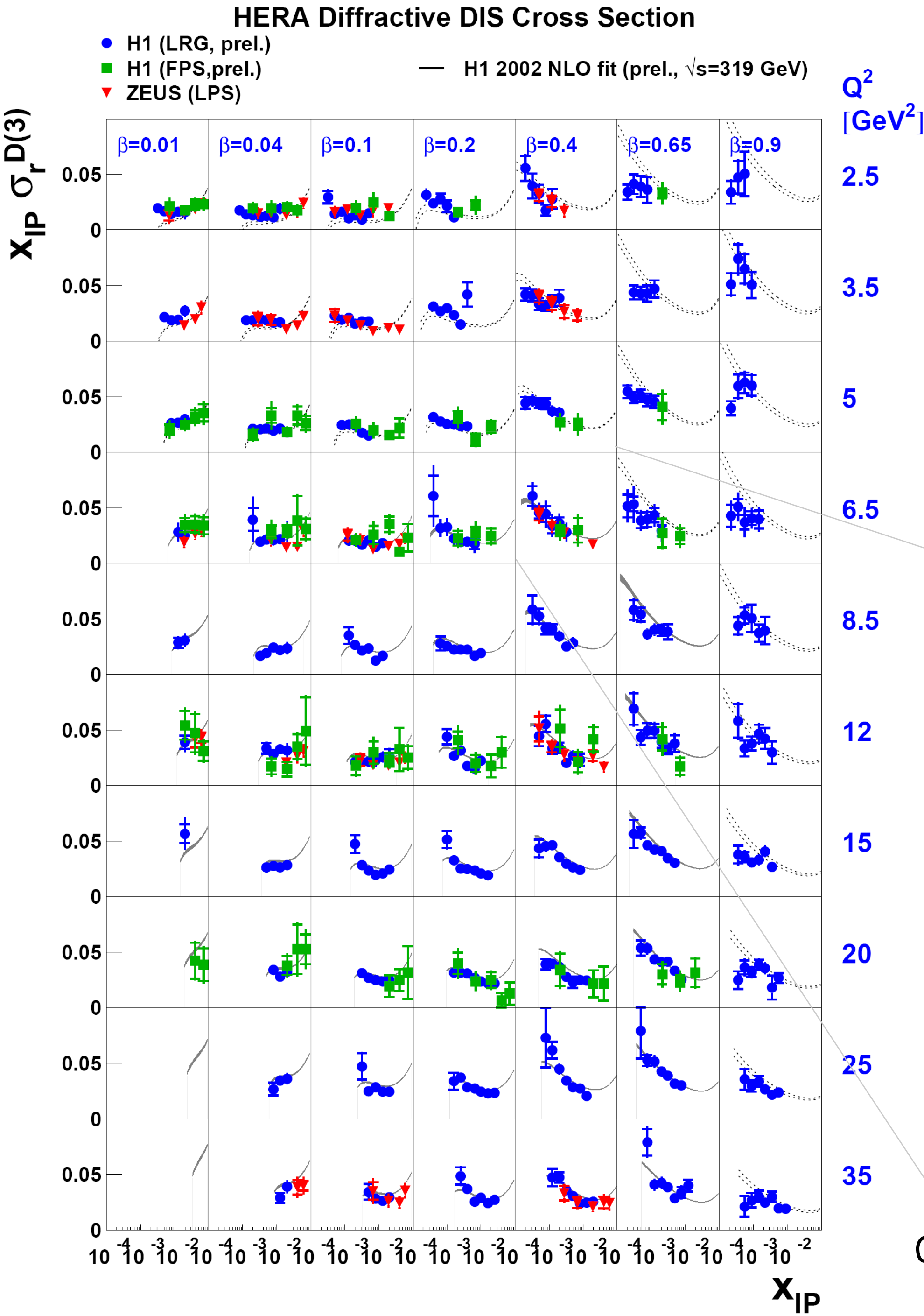
(Trentadue, Veneziano, Berera, Soper, Collins, ...)



First observation by ZEUS and H1 of diffraction in charged current scattering at high Q^2: 2-3%

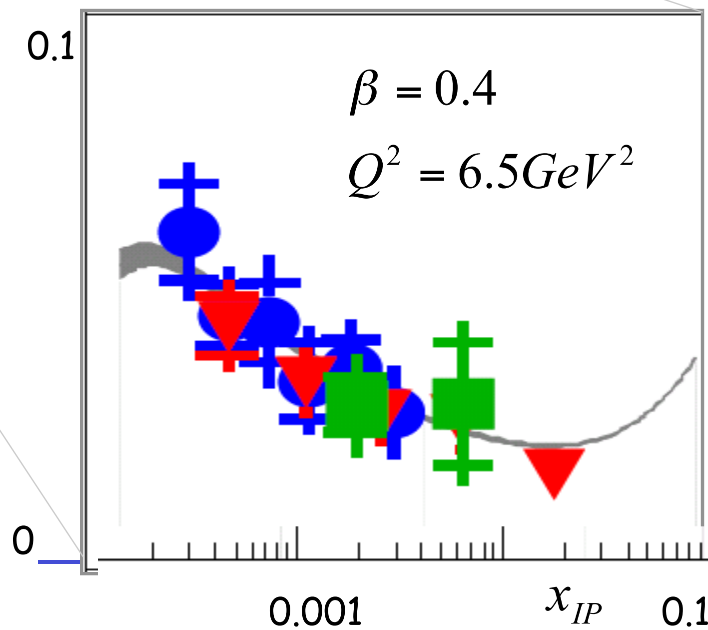
- Why does the p sometimes remain intact?
- Understand nature of diffractive exchange
- Does diffraction affect p PDF's [Martin et al]
- Is diffractive exchange universal, ep – pp?
- 2 g exchange → high gluon density – unitarity?
- Study an old phenomenon at hard scales!

HERA allows detailed, quantitative studies.
Many new results presented to ICHEP04+DIS05 (inclusive, resolved y, CC, charm, jets..)

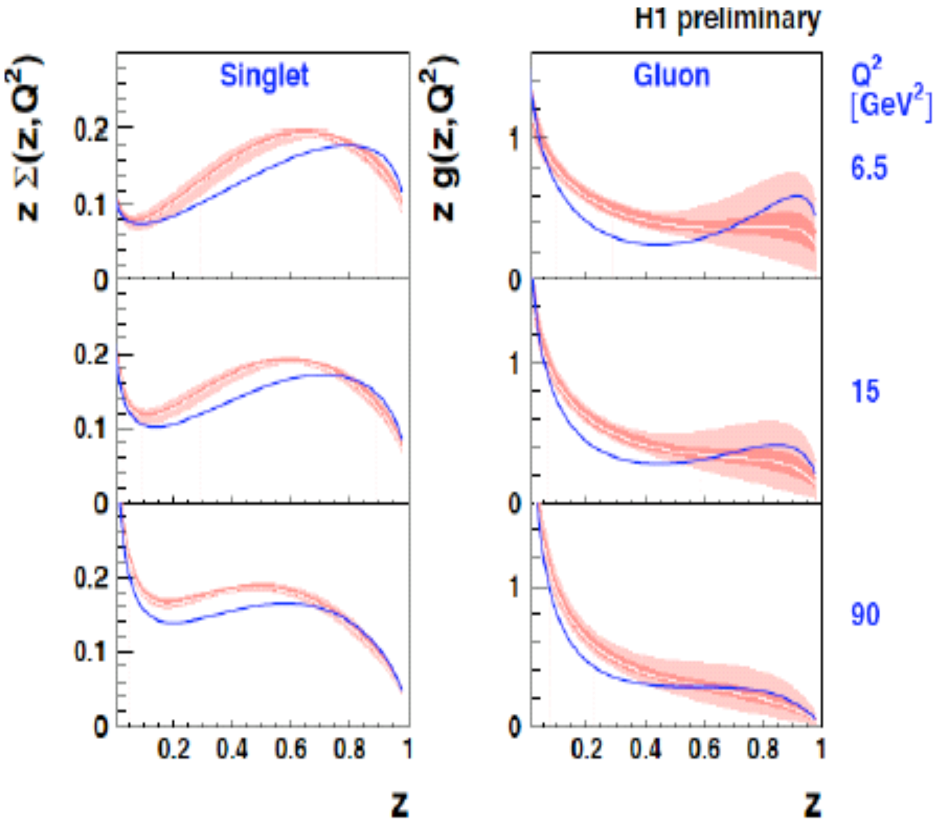


- New diffractive DIS data tagged with:
  - Large rapidity gap i.e. forward detector veto.
  - Tagged proton using Forward p Spectrometer FPS (H1) Leading p Spectrometer LPS (ZEUS)
- Good agreement between all data [M_X vs rapidity gap selection??]

$$x_{IP}\sigma_r^{D(3)} = x_{IP}[F_2^{D(3)} - f(y)F_L^{D(3)}]$$



Diffractive parton distributions



H1 2002 σ_r^D NLO QCD Fit
(exp. error)
(exp.+theor. error)

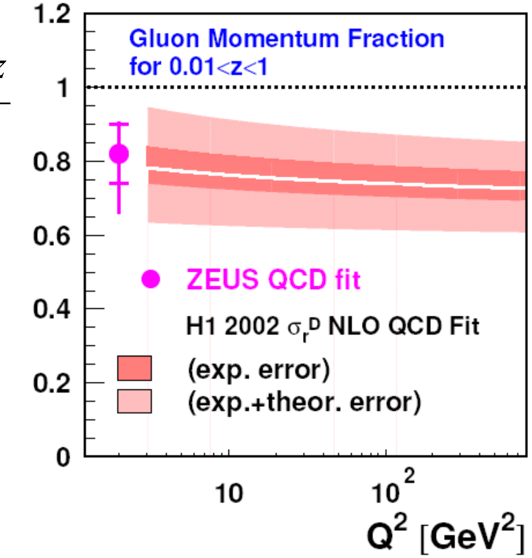
H1 2002 σ_r^D LO QCD Fit

$z = \beta$

in QPM

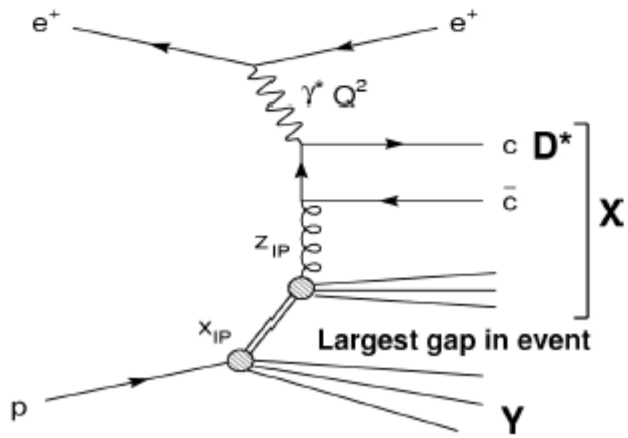
uses Regge flux ('resolved Pomeron model')

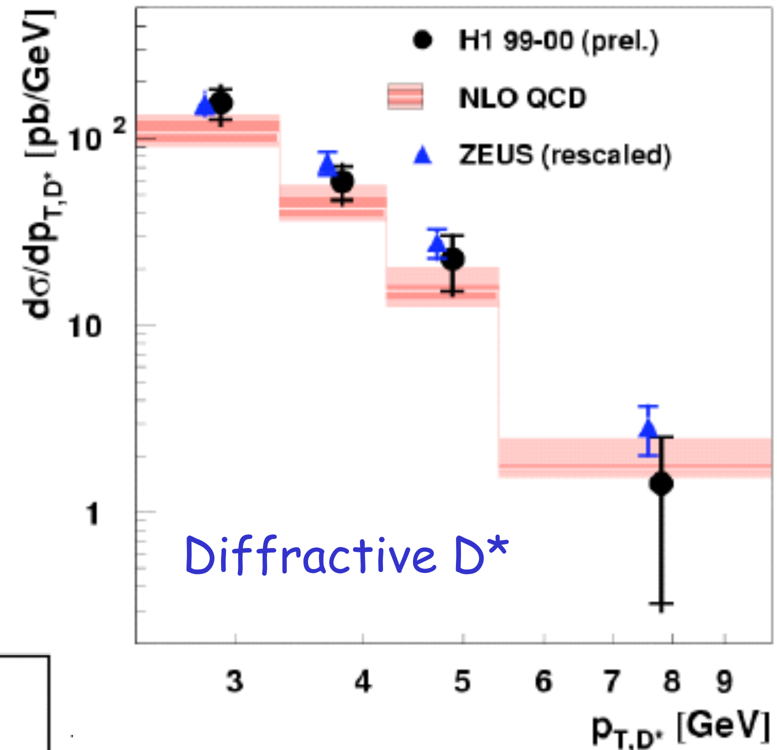
$$\frac{\int zg(z,Q^2)dz}{\int z[g+\sum]dz}$$

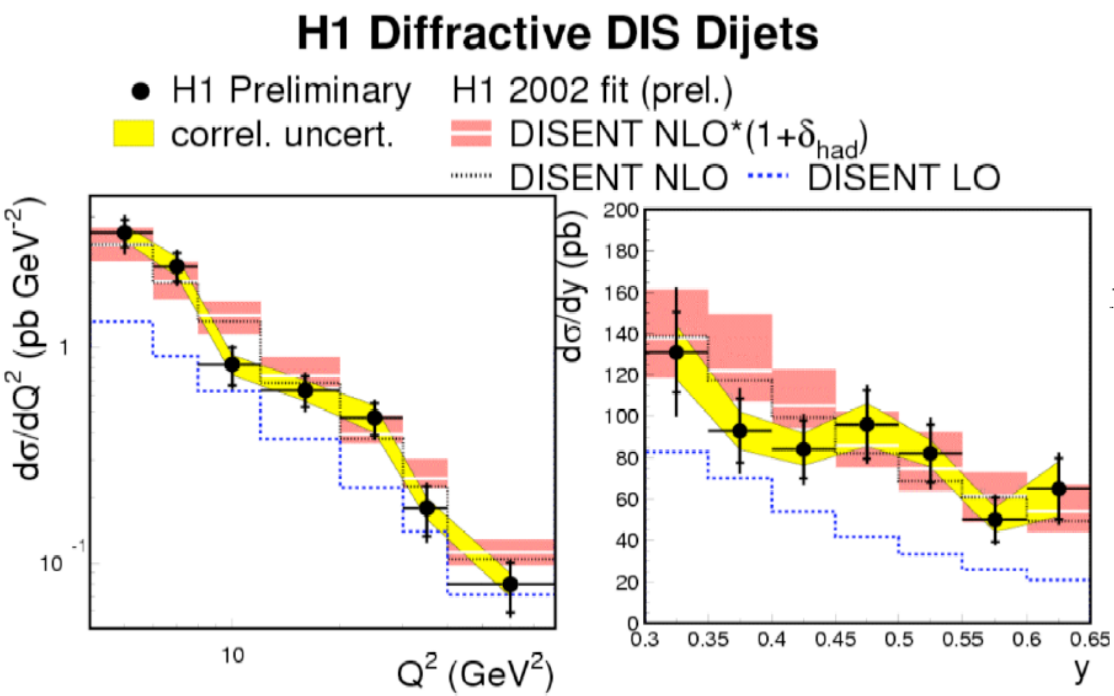


- Extract diffractive PDFs from NLO fit to inclusive diffractive structure functions
- Momentum distribution of quarks and gluons in the 'Pomeron': gluons dominate at large z > 0.01 unlike the non diffractive xg.
- QCD evolution (DGLAP) fits recent F_2^D data up to Q^2=2000 GeV^2.
- If factorisation holds, these PDFs are universal and NLO QCD should describe diffractive final states and Tevatron data

Final states in diffractive deep inelastic scattering

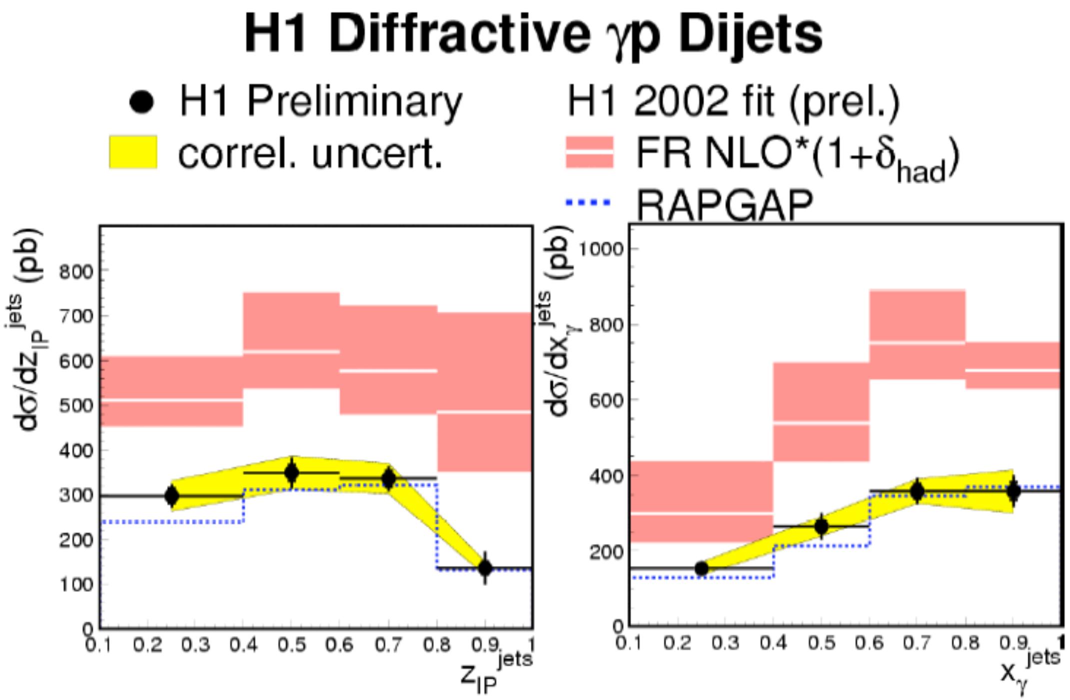


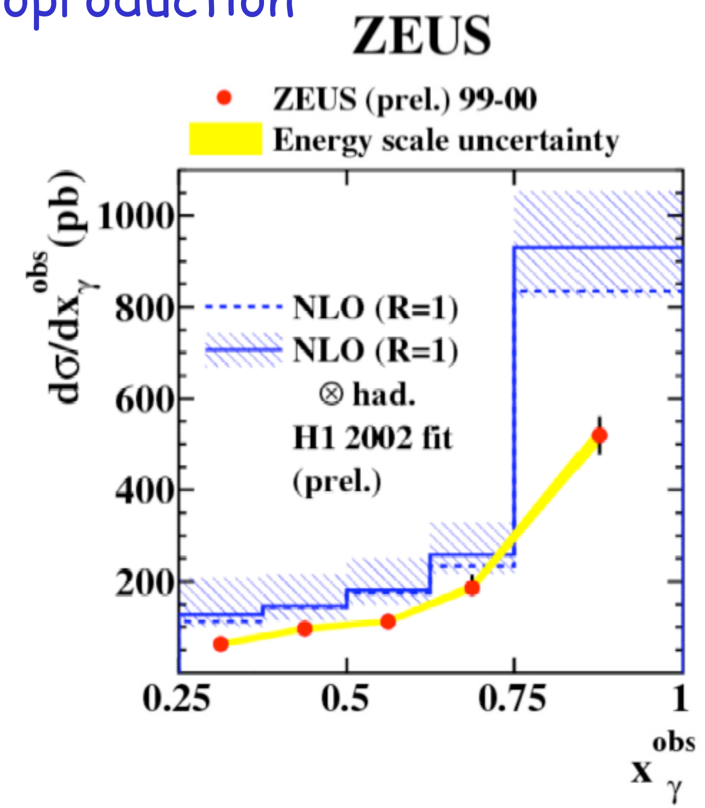


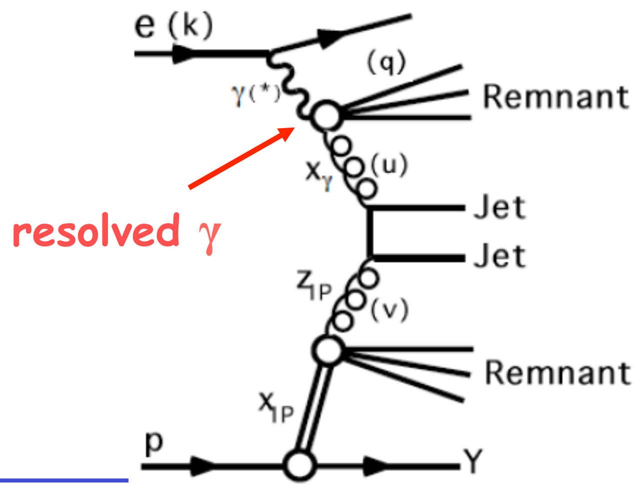


➔ factorisation holds
in DIS – jets, D*

Final states in diffractive photoproduction







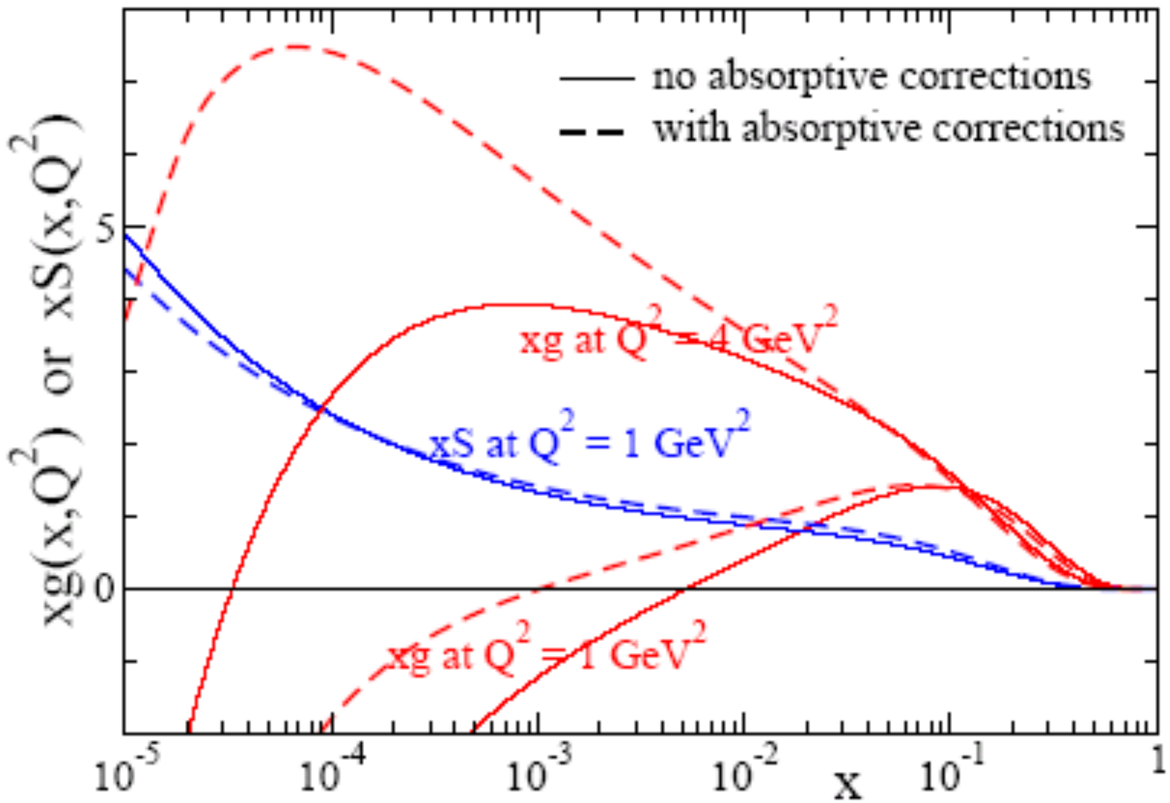
In photoproduction need factor of ~2 suppression of NLO theory to describe the data, both in the resolved region, which is similar to pp where a factor of ~10 is needed, and in the direct region which resembles DIS

Kaidalov et al.: predicted suppression of only the resolved part

How diffraction has to be treated is not really clarified yet

Ignored (inclusive scattering)? As an absorptive correction?

→ gluon distribution depends on theory, is not observed directly



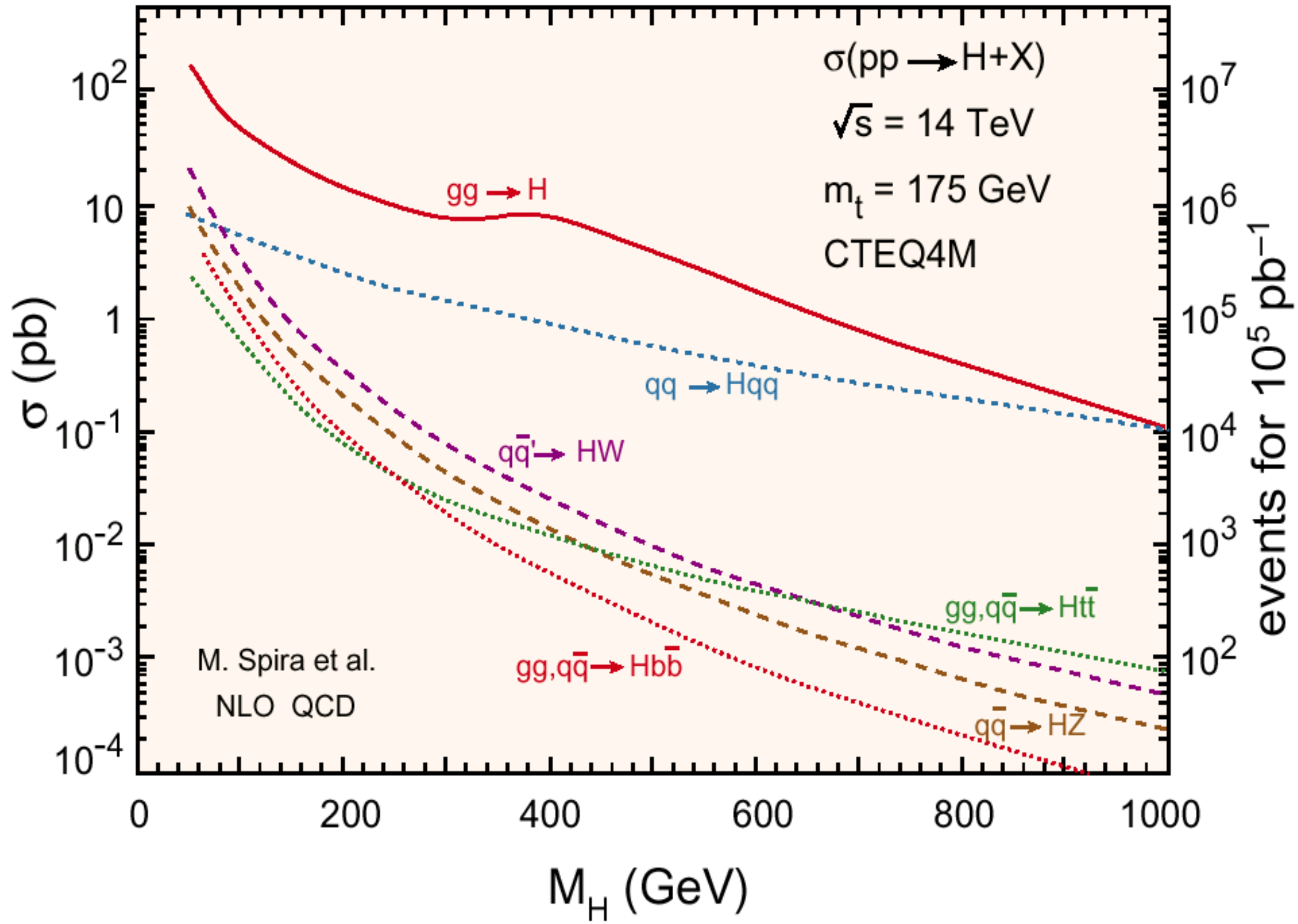
?

more accurate diffractive data from HERA II.

extra info on gluon, charm, F_L

- Martin, Ryskin, Watt: absorptive corrections to F_2. analysis of F_2 and F_2^D → xg ??
  note that without absorptive correction xg differs from H1/ZEUS gluons!

Higgs production reactions at the LHC



Any jet, Higgs or exotic particle production in pp needs HERA's partons and theory understood!
Forward particle production (double diffraction) at the LHC may help to find the Higgs particle.

8. Remarks to the HERA III Programme

In 2001 it was decided to use PETRA as a 3rd generation synchrotron light source considering the HERA programme to be exploited by 2006 and TESLA to be the next accelerator project of the laboratory.

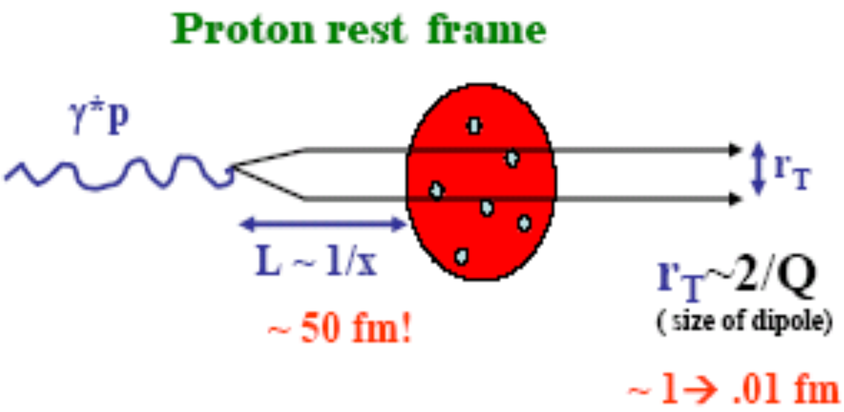
Meanwhile HERA is scheduled to end in 2007.

Physics at HERA (the expected, the unexpected and the unclarified)

4 areas of fundamental physics can not be exploited (further) in the HERA range

- Low x precision physics – the transition from hadrons to partons - ep, dedicated
- The structure of the neutron (sea quark symmetry, evolution,..) – eD, tagged
- The structure of nuclei, nuclear pdf's, saturation, black body limit,.. - eA
- Low x and large Q^2 spin physics [difficult: polarisation and hi lumi]

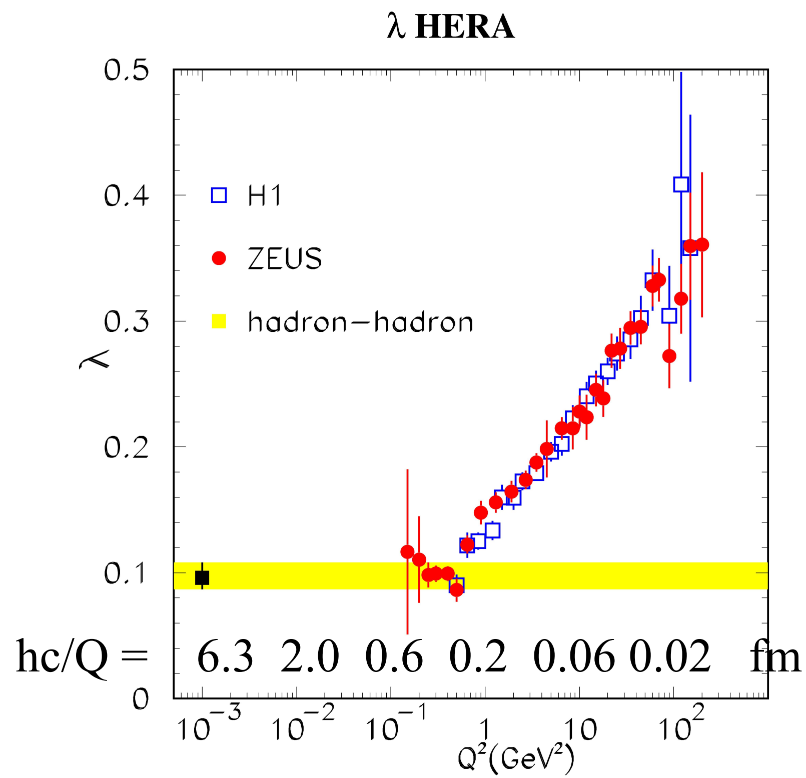
Low x Precision Measurement at HERA III



At low x<0.01 a color dipole of variable size 2/Q interacts with the proton at high CM energy $s^{\gamma p} = W^2 \approx Q^2/x \approx 1000 \div 90000\ \text{GeV}^2$

Low x = high energy scattering!

Q^2 steers the transition from hard collisions (perturbative QCD) to soft hadron physics.

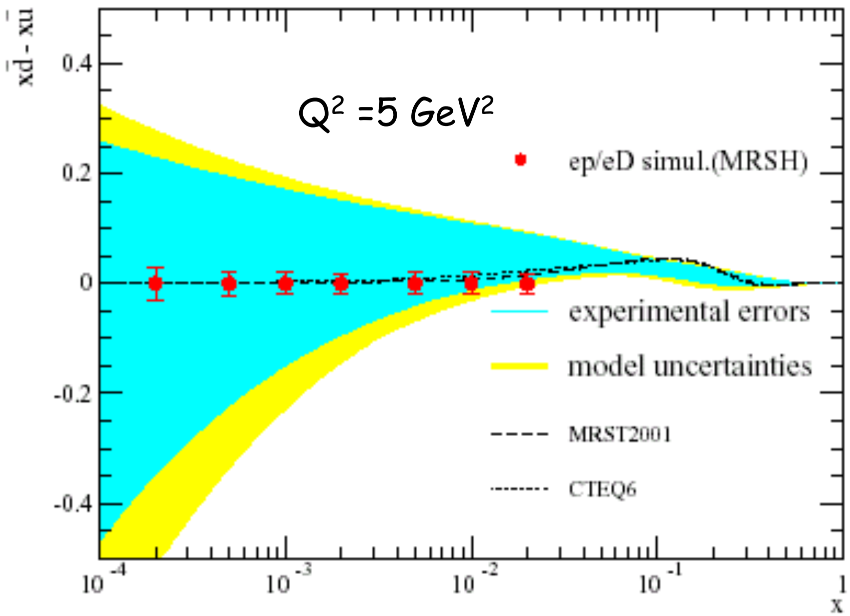


Precision measurements of F_L, VM Diffraction, Saturation.?

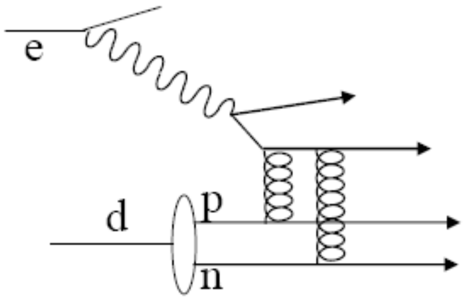
$F_2 \propto x^{-\lambda}$ at small x

Electron-Deuteron Scattering at HERA III

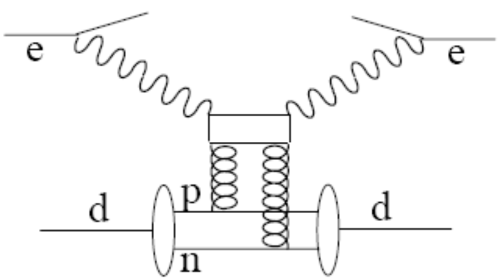
simulated accuracy ($20pb^{-1}$ eD, 40 ep)



Glauber-Gribov shadowing is related



to diffraction

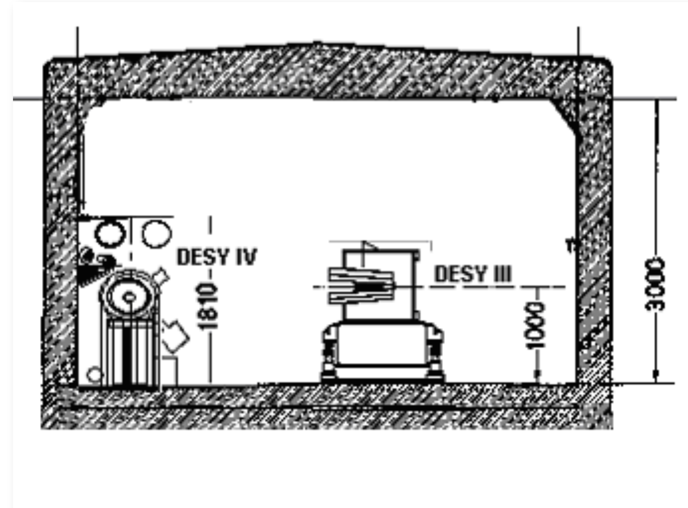


Sea asymmetry: important for astrophysics, LHC!

QCD evolution (low x) constrained with singlet F_2^N

Could tag proton accurately and reconstruct en cross section 'free' of nuclear corrections

HERA beyond 2007 would require new injectors



Possible site for a new HERA p-injector

F. Willeke at DIS04

Preliminary ideas:

- Direct injection from DESY II into HERA-e (alternatively via a damping ring in the DESY tunnel)
- New tunnel for DESY III and a new superconducting 40GeV Proton Booster

HERA will be left untouched, but HERA III misses human and financial resources

Parton interaction discoveries at the energy frontier*)

1970	→	2000	→	2015
DIS: Bjorken scaling – QPM, PV neutral currents scaling violations – QCD		high parton densities diffraction		?
e+e-: J/Ψ gluons – 3jet events		three neutrinos electroweak theory		… ILC
hh: open charm, W,Z,bottom quark		top quark		LHC …

the standard model emerged as a result of decades of joint research in e+e-, ep, hh accelerator experiments including quark and neutrino mixing

→ 9. Towards deep inelastic scattering at the TeV scale

*) incomplete

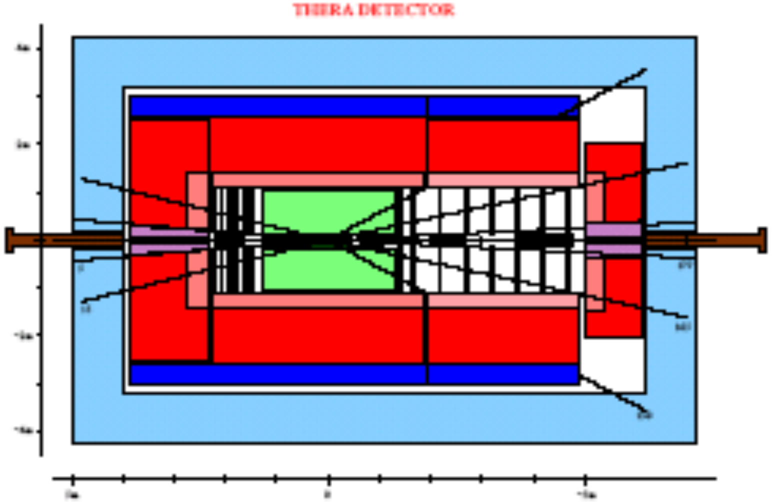
DIS at the TeV scale

DESY 01-123F vol. 4
DESY-LC-REV-2001-062
December 2001

Physics and Experimentation at a Linear Electron–Positron Collider

Volume 4: The THERA Book.
Electron–Proton Scattering at $\sqrt{s} \sim 1$ TeV

THERA DETECTOR



Editors: U. Katz, M. Klein, A. Levy and S. Schlenstedt

ISSN 0418-9833

LEP-LHC

A. Verdier LHC Workshop Aachen 90, p.820
E. Keil LHC Project Report 93 (1997)

THERA

R. Brinkmann, F. Willeke THERA book and Proceedings Snowmass 2001

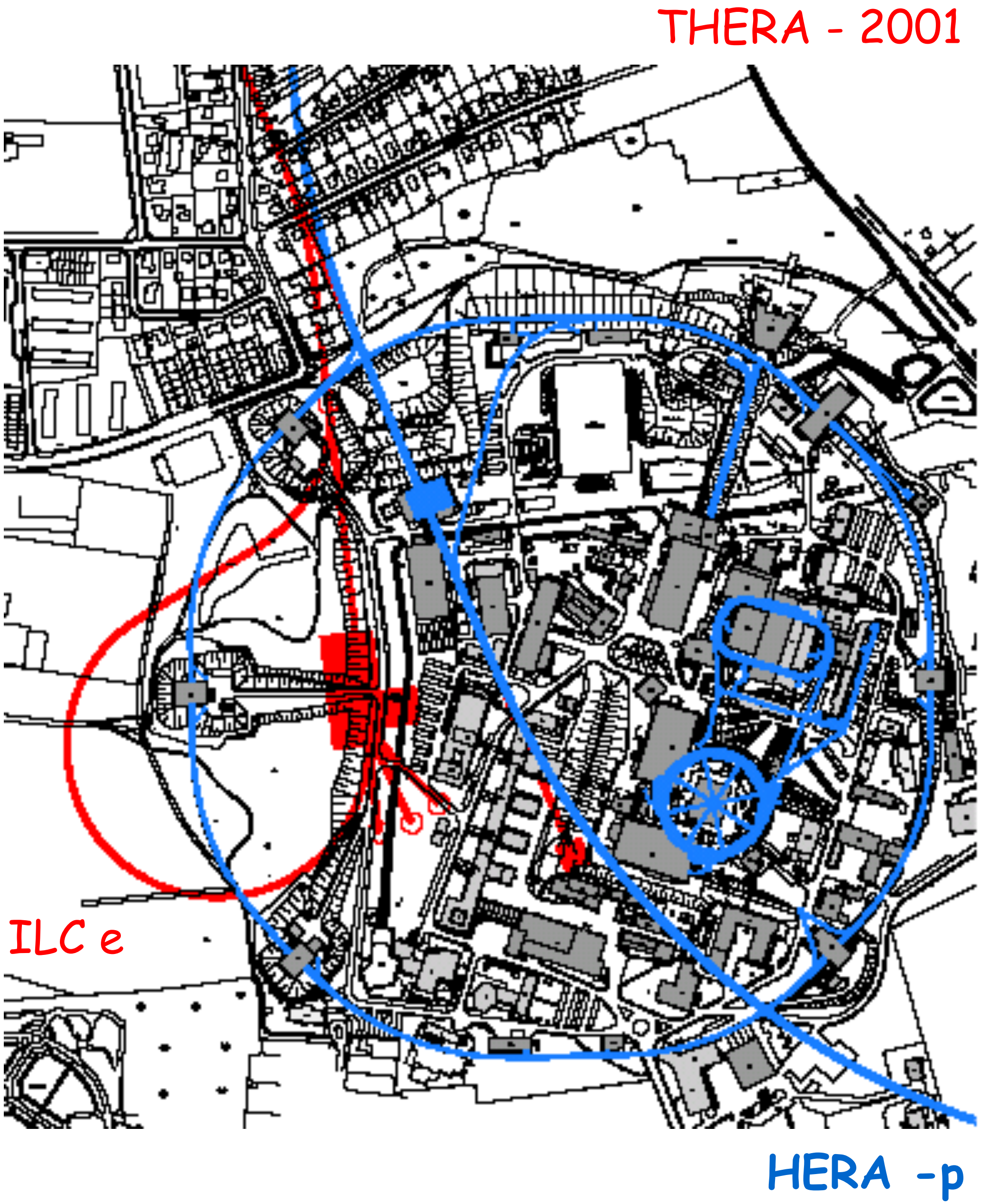
QCD explorer (CLIC-LHC')

D. Schulte, F. Zimmermann CLIC 608

LHEC

F. Willeke (a study)

All these ep options are 'cost effective'



$\sqrt{s}$ up to 2TeV
x down to 10^{-6} in DIS region

e can be highly polarised
→ LQ spectroscopy

Peak luminosity up to 4 10^{31}
depending on Ee=Ep
and IR layout (dynamic focus)
note: I(e) is constant with time
[40 .. 200 pb-1 per year, 50%]

Cavities will be cold:
-standing wave type: acc. in
both directions to double E(e)
-time structure of few 100ns fits
to HERA and Tevatron bc time

→THERA or ILC-Tevatron
remain possible

CERN-AB-2004-079
CLIC Note 608

QCD EXPLORER BASED ON LHC AND CLIC-1

D. Schulte, F. Zimmermann
CERN, Geneva, Switzerland

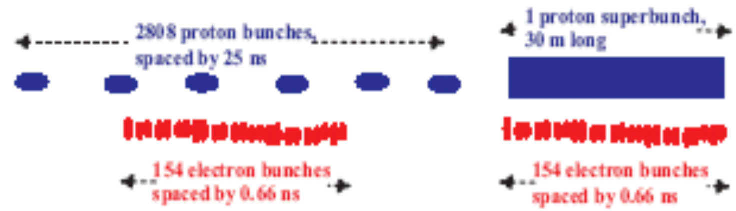
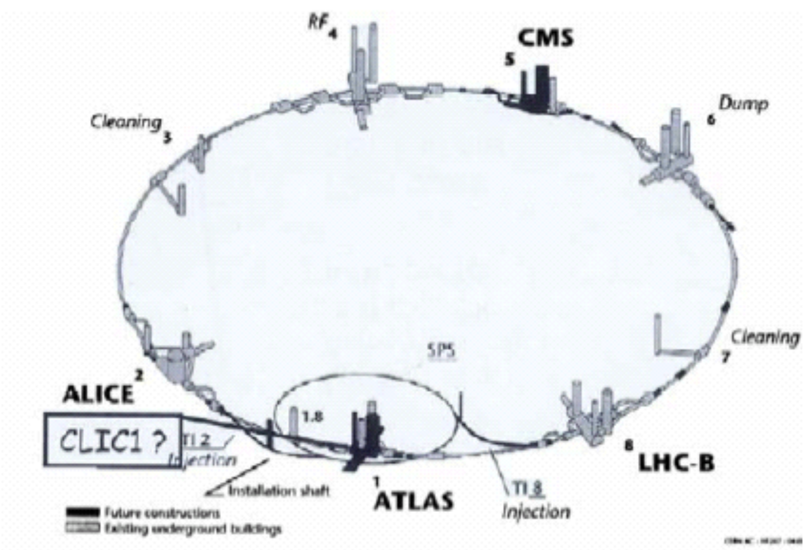


Figure 1: Bunch filling patterns in LHC and CLIC for the nominal LHC (left) and with an LHC superbunch (right).

Upgraded LHC and CLIC



$1.1\ 10^{31}\ cm^{-2}\ s^{-1}$

Table 1: Beam Parameters

parameter	symbol	electrons	protons
beam energy	E_b	75 GeV	7 TeV
bunch population	N_b	4×10^9	6.5×10^{13}
rms bunch length	σ_z	35 μm (Gaussian)	12.4 m (uniform)
bunch spacing	$L_{\rm sep}$	0.66 ns	N/A
number of bunches	n_b	154	1
effective line density	λ	2.0×10^{10} m^{-1}	2.1×10^{12} m^{-1}
IP beta function	$\beta^*_{x,y}$	0.25 m	0.25 m
spot size at IP	$\sigma_{x,y}$	11 μm	11 μm
full interaction length	$l_{\rm IR}$	2 m	
norm. rms emittances	$\gamma\epsilon_{x,y}$	73 μm	3.75 μm
collision frequency	$f_{\rm coll}$	100 Hz	
luminosity	L	1.1×10^{31} cm^{-2}s^{-1}	
beam-beam tune shift	$\xi_{x,y}$	N/A	0.004

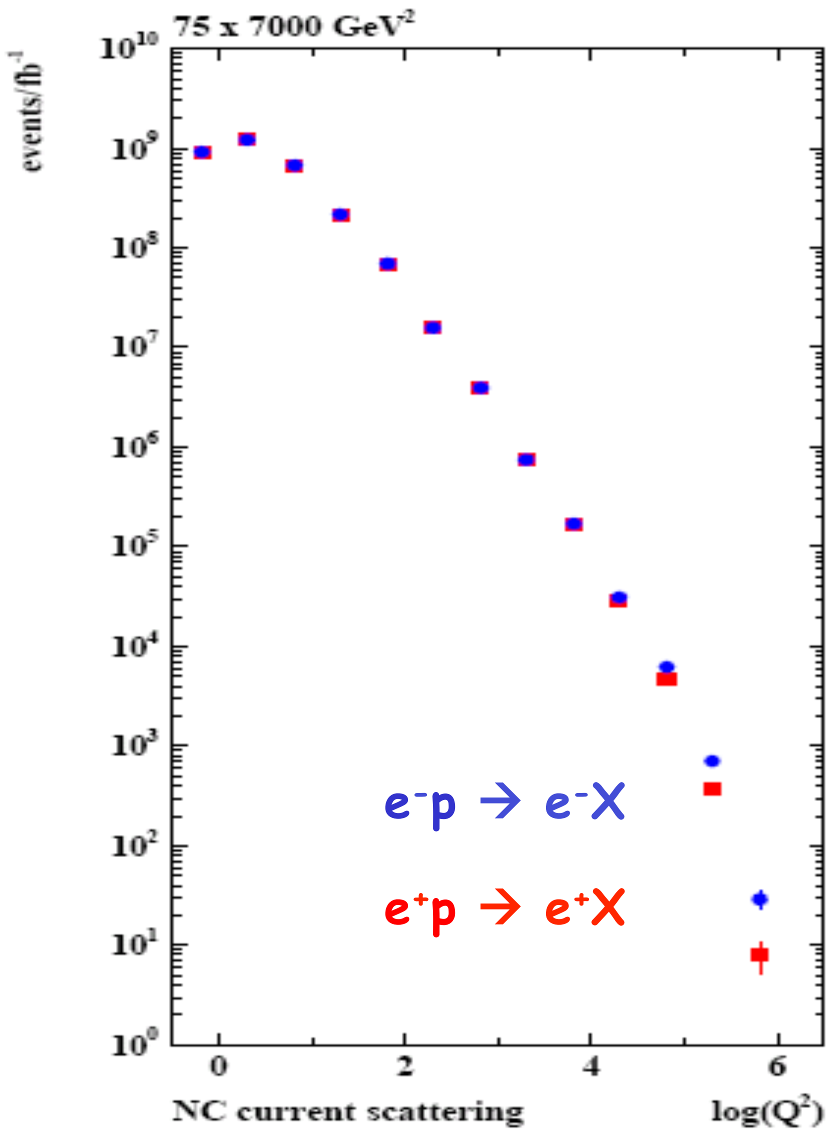
L perhaps higher with TESLA cavities
(L. Gladilin et al., hep-ph/0504008)

The challenge for ep (HEP) to conquer the TeV scale is the luminosity

•Low and medium x:

needs energy and acceptance but modest luminosity

NOTE: can do eA at THERA and LHEC (RHIC, ALICE)



High x and Q^2 can only be accessed with a collider with peak luminosities of $\sim 10^{32}$ cm^{-2} s^{-1}

A tentative lattice study – a new electron ring on top of the LHC

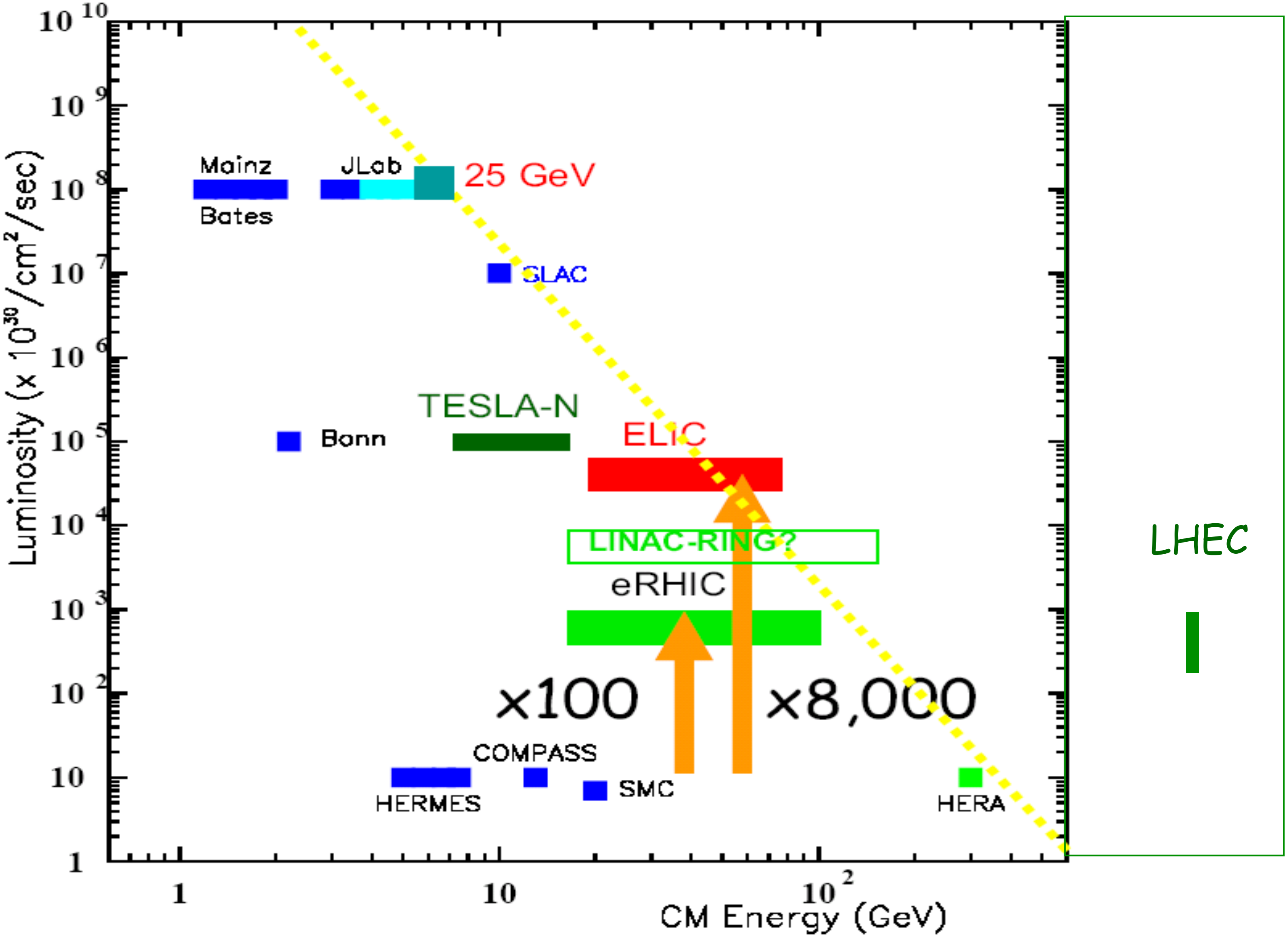
Design to be studied further and discussed with CERN

Beam Energies	$E_p = 7 \times 10^3\,\mathrm{GeV}$	$E_e = 75\,\mathrm{GeV}$
Beam Currents	$I_p = 566.6\ \mathrm{mA}$	$I_e = 49.77\ \mathrm{mA}$
Emittance	$\varepsilon_{Np} = 4\,\mu\mathrm{m}$	$\varepsilon_{xe} = 18\,\mathrm{nm}$
β^*	$\beta_{xp} = 1.8\,\mathrm{m}$	$\beta_{xe} = 0.055\,\mathrm{m}$
	$\beta_{yp} = 0.5\,\mathrm{m}$	$\beta_{ye} = 0.055\,\mathrm{m}$
p Bunch Length	$\sigma_s = 7\,\mathrm{cm}$	
Synchrotron Radiation Power		$P_{erf} = 60\,\mathrm{MW}$
beam-Beam Tuneshift	$\Delta\nu_{xp} = 1.69 \times 10^{-3}$	$\Delta\nu_{xe} = 0.019$
	$\Delta\nu_{yp} = 3.21 \times 10^{-3}$	$\Delta\nu_{ye} = 0.037$
Crossing Angle	$\theta_c = -2.5\,\mathrm{mr}$	
Hourglass factor	$R(\sigma_s) = 0.925$	
Center of Mass Energy	$E_s = 1.449\,\mathrm{TeV}$	
Peak Luminosity	$L_{peak} = 2.40 \times 10^{32}\,\mathrm{sec}^{-1}\cdot\mathrm{cm}^{-2}$	

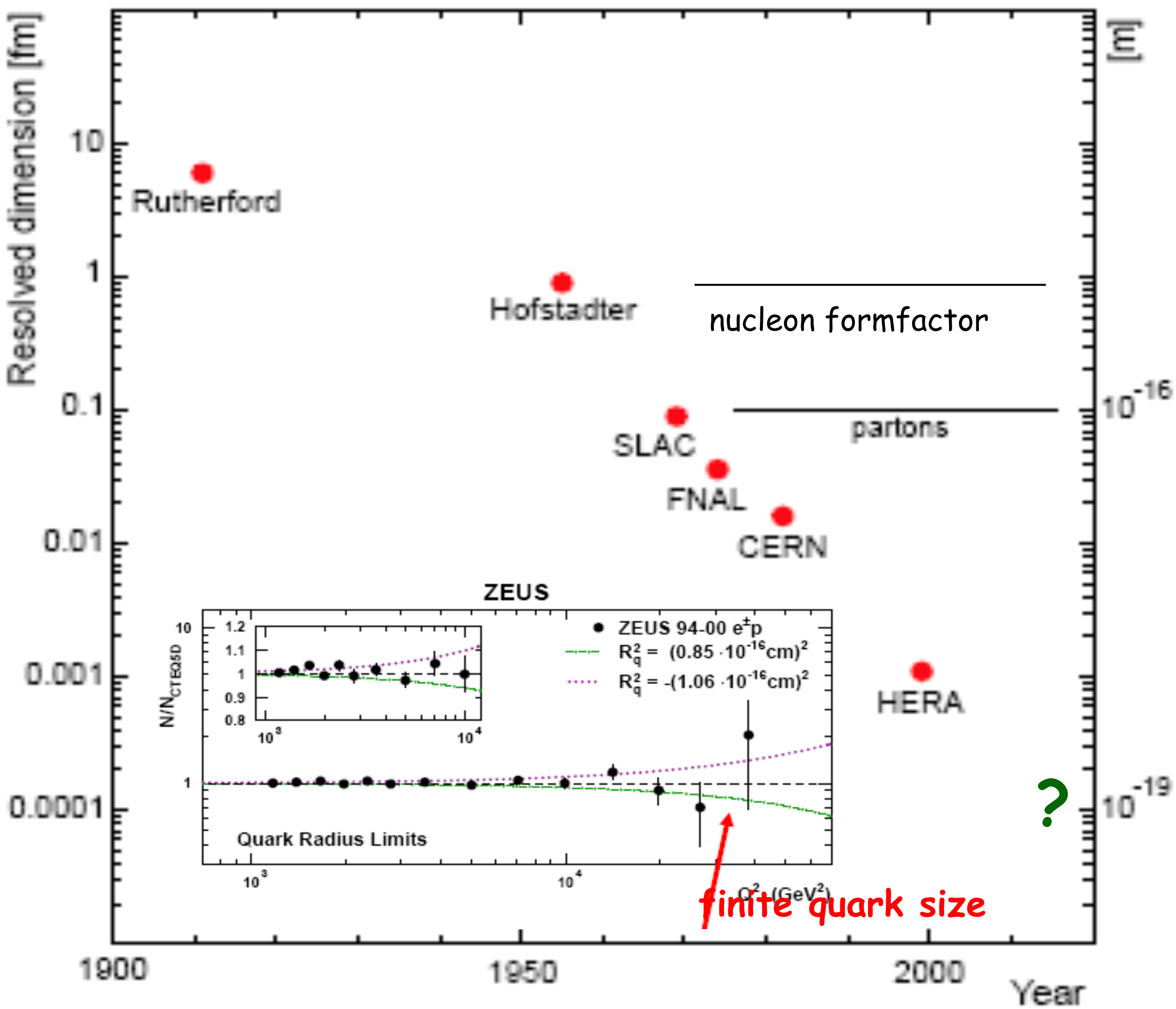
F. Willeke 23.4.05

Possible gain factor 2-4 by reducing E_e to 60 GeV and reducing bunch distance.
Parasitic operation. Lower E_e possible. Focusing magnets (10° clearance). …

Lepton nucleon scattering - machines and visions



HERA: quarks are pointlike down to proton radius/1000

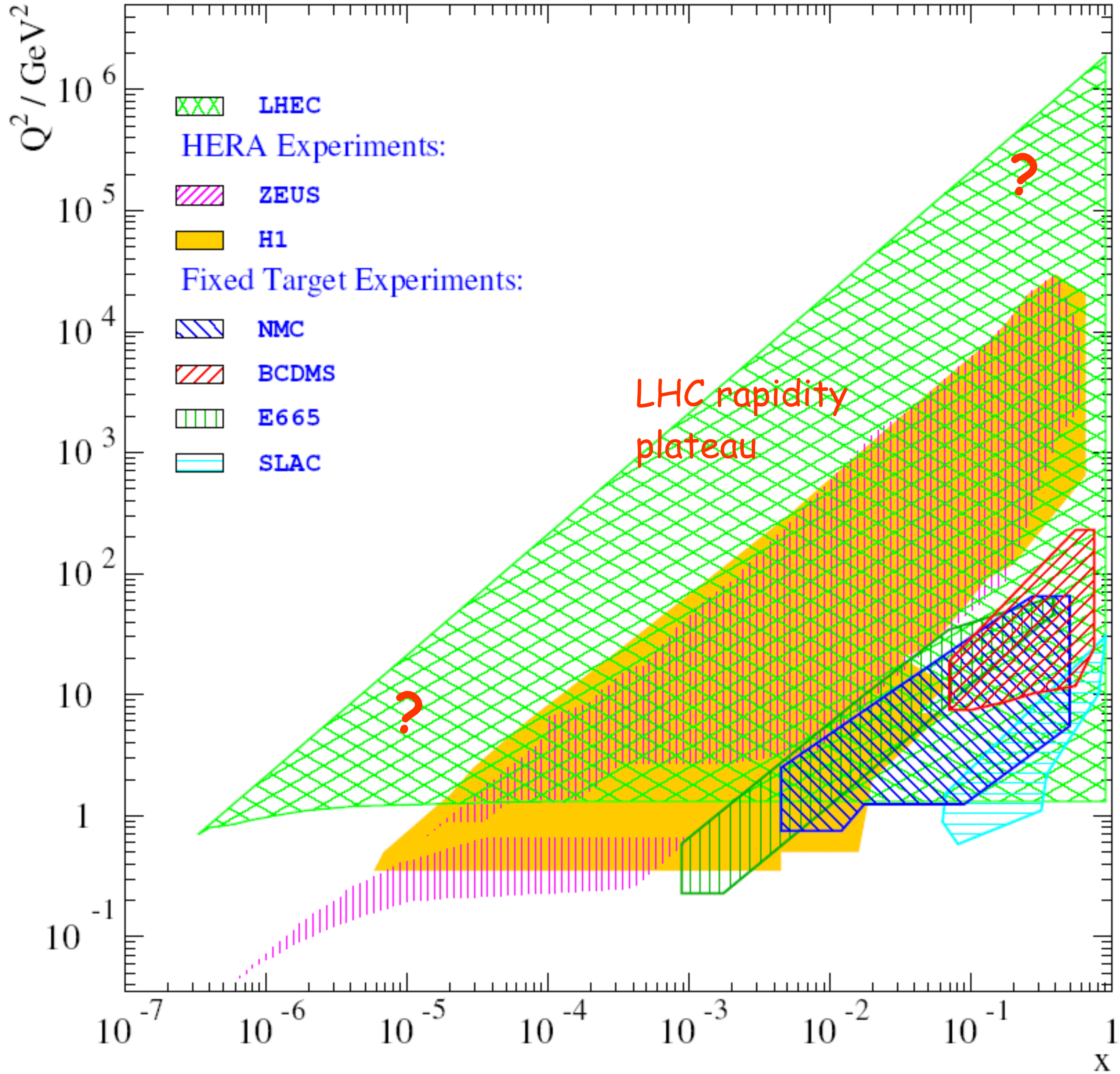


Inclusive cross section ep → eX exhibits no extra formfactor
→ Limits on SUSY, leptoquarks, extra dimensions, quark radius…

..Luminosity upgrade

present limits

ZEUS r < 0.85
H1 r < 1.0 10^{-18}m



LHEC
HERA Experiments:
ZEUS
H1
Fixed Target Experiments:
NMC
BCDMS
E665
SLAC
LHC rapidity plateau
?
?
Q^2 / GeV^2
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
x

Remarks

•HERA has made enormous progress with classic DIS in the new kinematic range

•HERA has observed and developed many new phenomena (QCD at high densities..)

•The more data are taken the richer appears HERA's ep programme [and HERMES']
HERA is expected to lead to still further insight in the nature of strong partonic interactions and the interplay of partons and hadrons in the coming years of high accuracy analyses and data. Experiment and theory develop together.

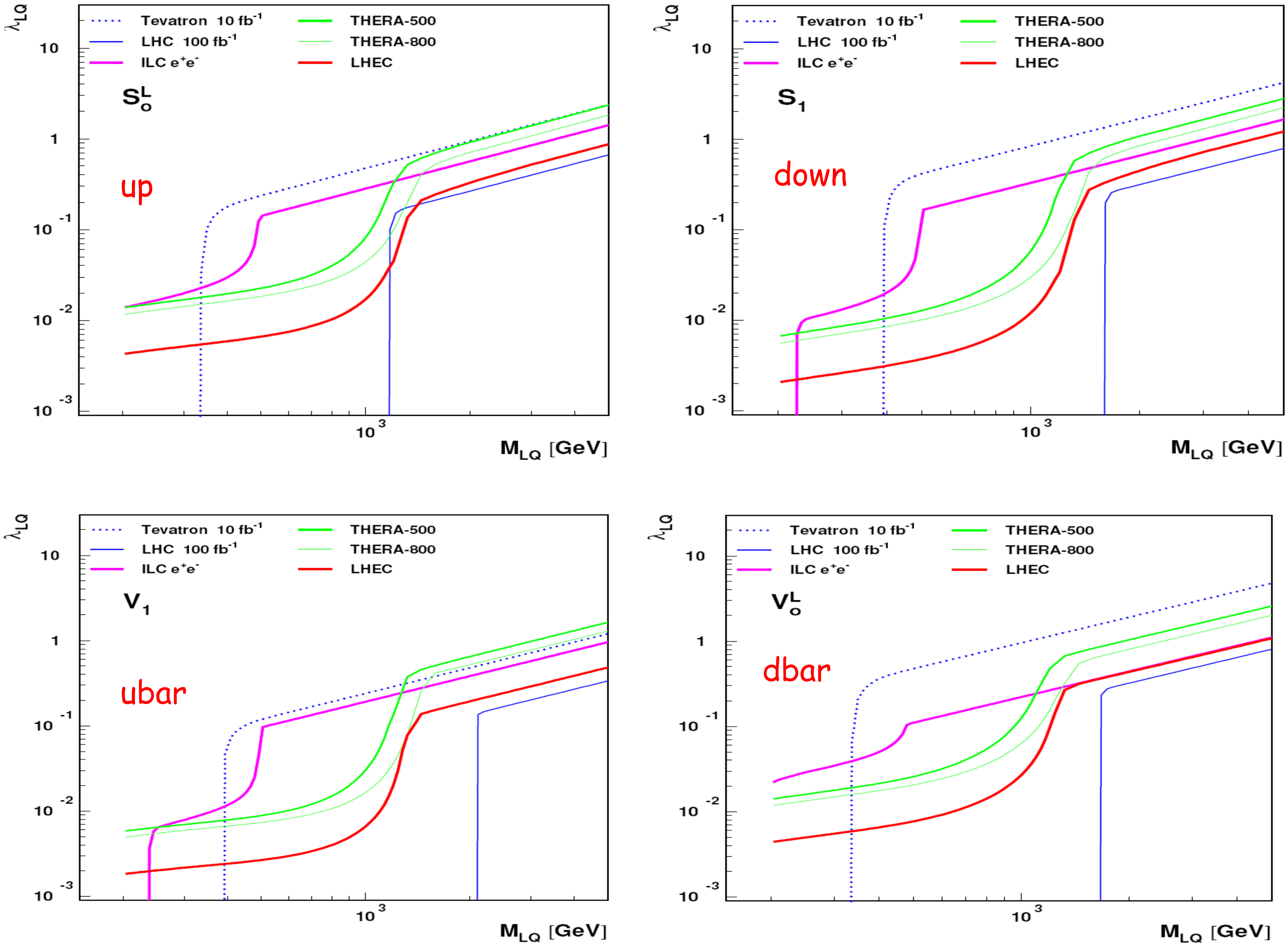
•For further use of HERA proposals, ideas and letters of intent and of theorists exits but no adequate resources [for an up to 10 years research programme].

•The future of HEP requires that after the LHC (pp) new machines will be built for ee and for ep scattering investigations at the new energy frontier. For ep this can be a combination of the ILC with p or LHC with e rings to be cost effective.

•A new theory of particle physics may emerge at the TeV scale. Whether or not is a key adventure of physics but in any case QCD + p structure will have to be investigated much further and deeper, at all scales.

The end --- backup slides

Leptoquark discovery limits



F. Zarnecki (prel)

Simultaneous determination of partons and light quark weak neutral current couplings

use electroweak thy to access partons

(2uv+dv and possible sea quark asymmetry at lower x)