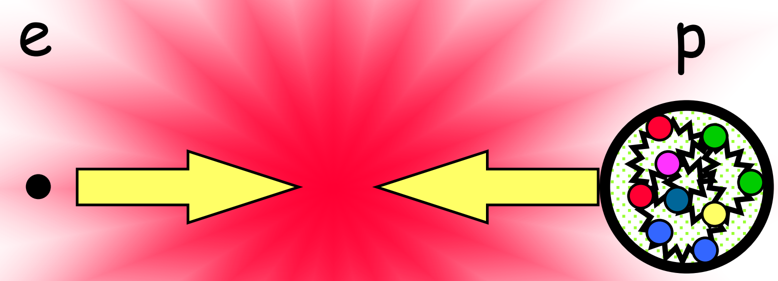
HERA /ZEUS



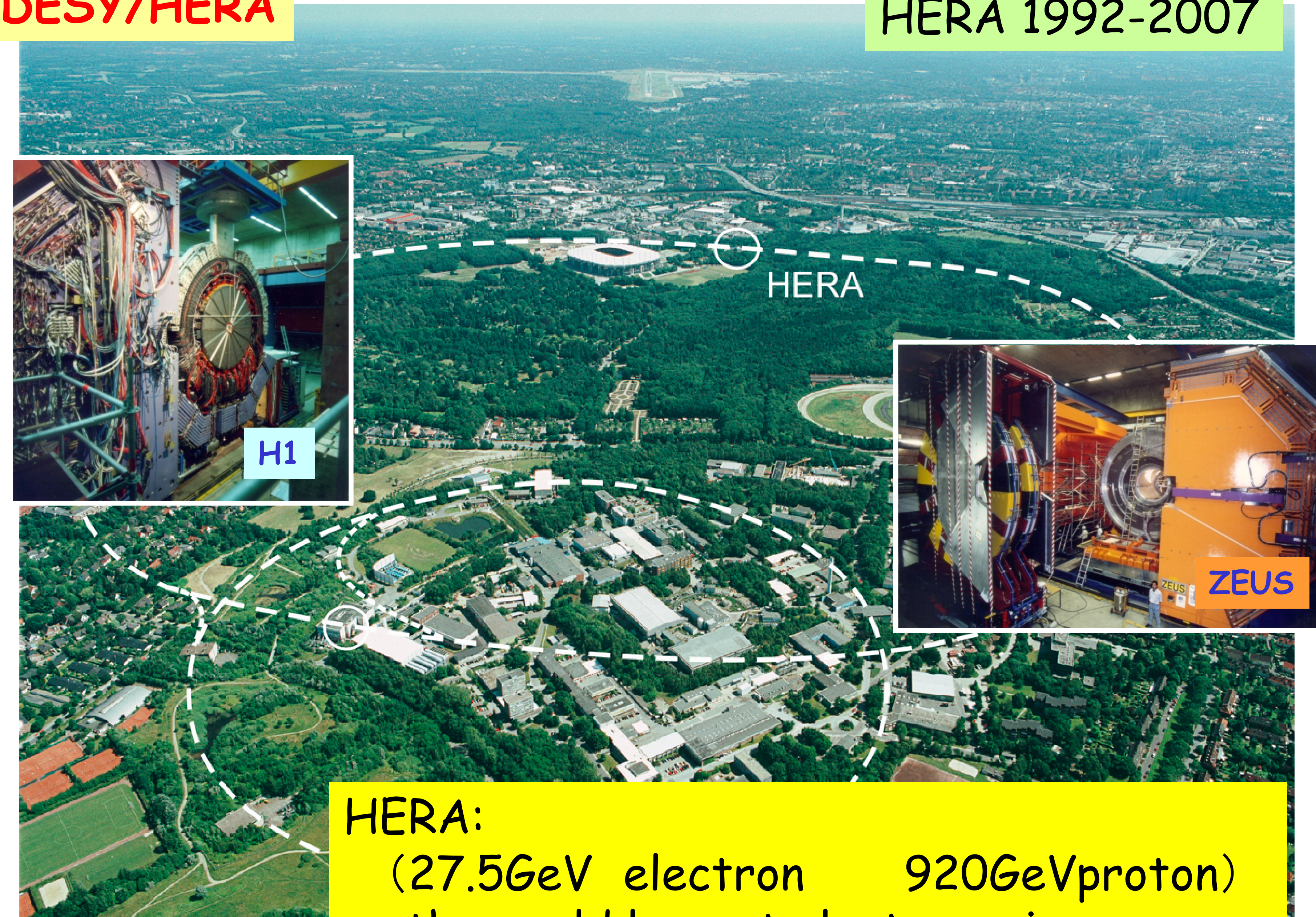
Contents

- 15 year running of HERA and H1/ZEUS
- ZEUS Detector concept:
  - Initial design and
  - upgrade

Katsuo Tokushuku
(KEK, ZEUS)
Phenix WS @ RIKEN

DESY/HERA

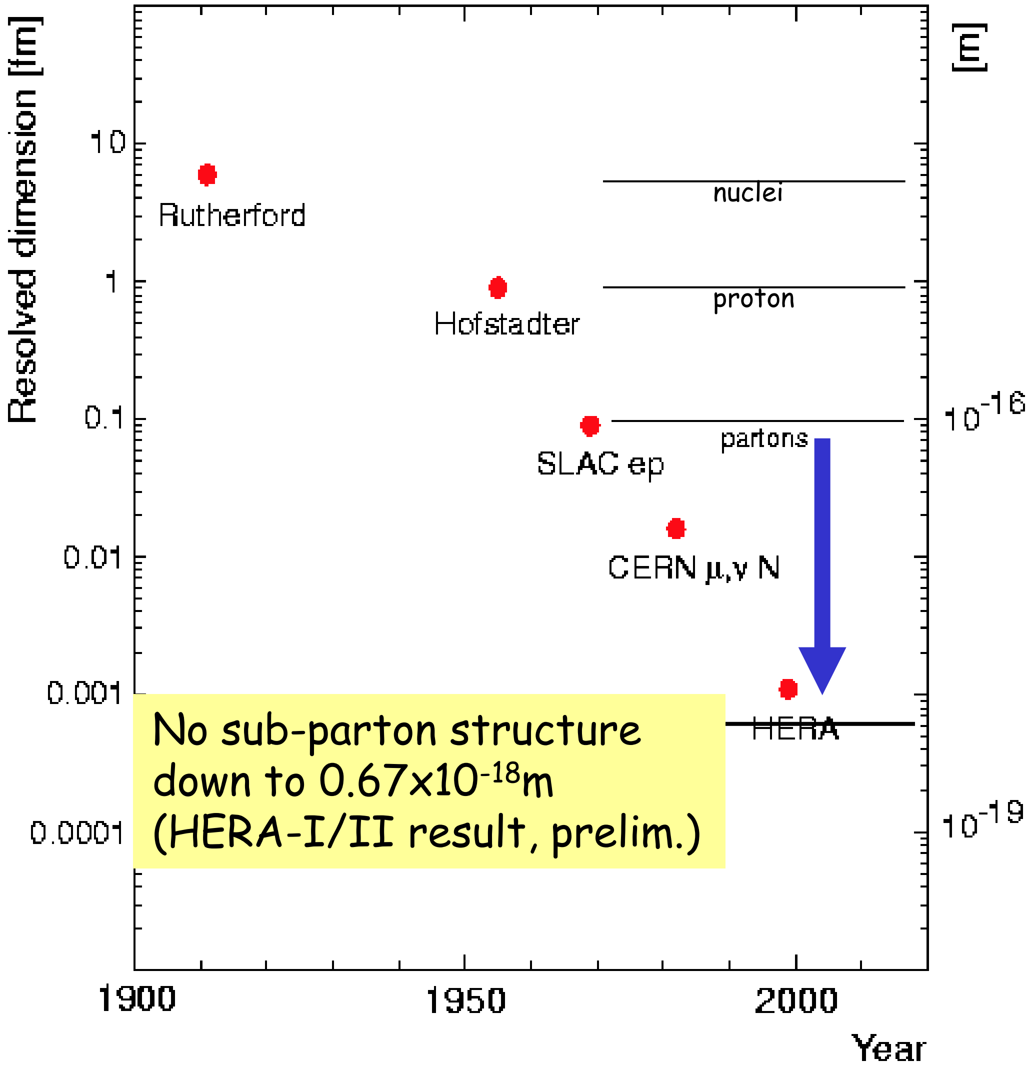
HERA 1992-2007



HERA:
(27.5GeV electron 920GeVproton)
the world largest electron microscope

Resolution $\sim$ (Wavelength)$^{-1}$ $\sim \hbar / Q$

$$Q^2 \equiv (q_i - q_f)^2$$



Progress in accelerator enables us to investigate the smaller structure.

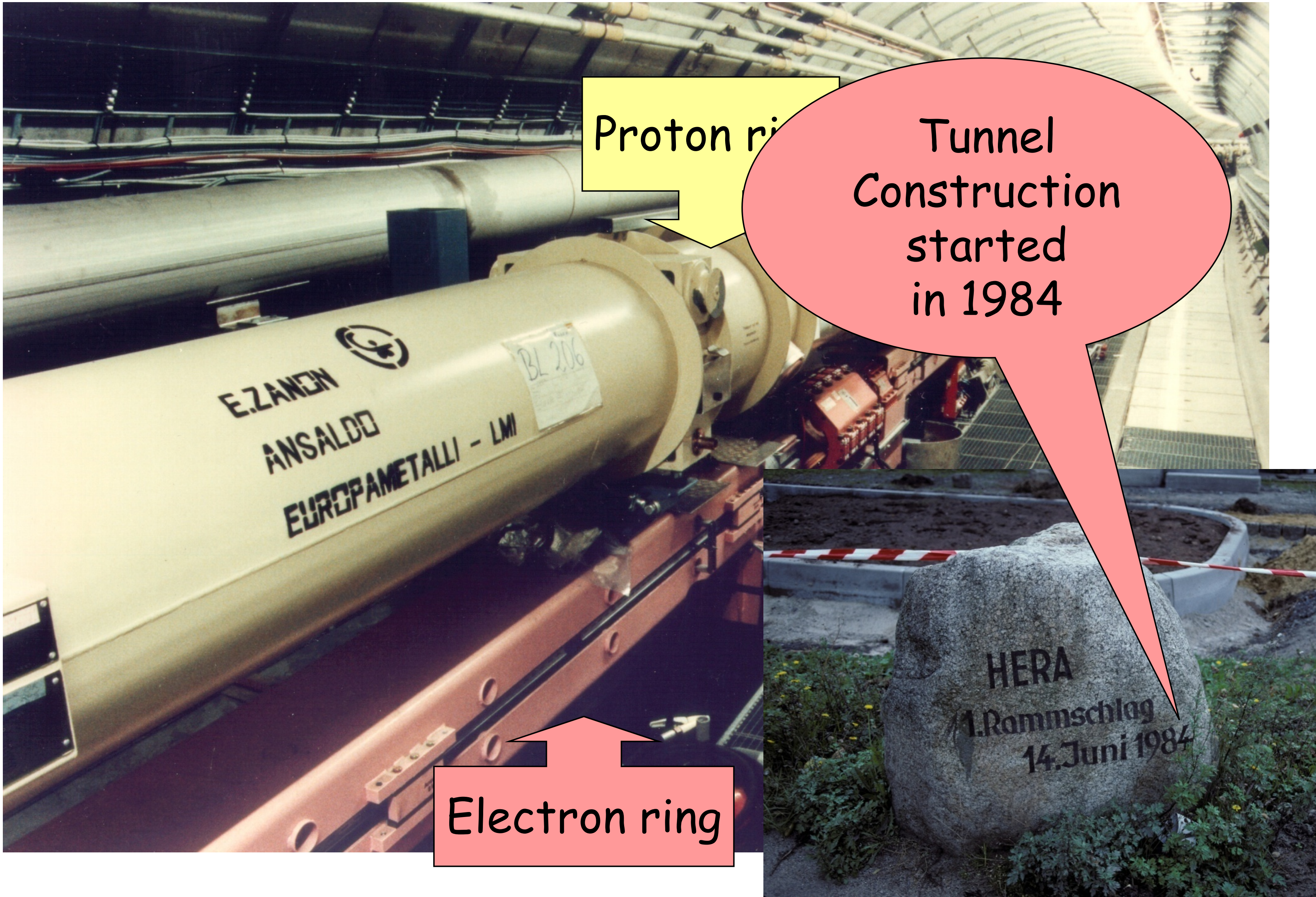
HERA:
(27.5GeV electron(positron)
vs. 920 GeV proton)

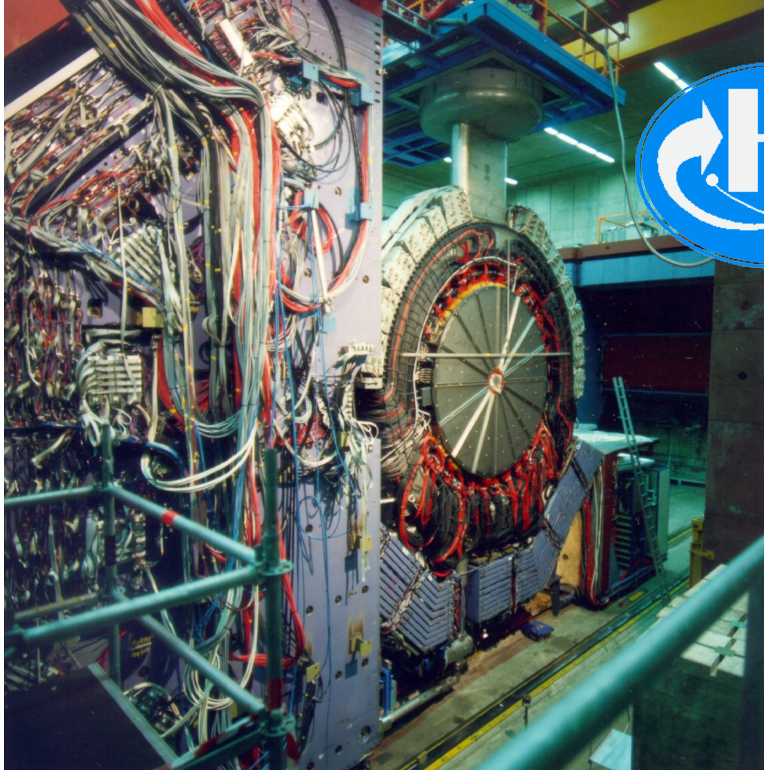
$Q^2_{max} = s = 4E_eE_p \sim 10000\text{GeV}^2$

cf. in the rest frame
$s = 2E_eM_p$

In order to obtain the same CMS energy as HERA in a fixed target experiment, it requires 54TeV electron beam.

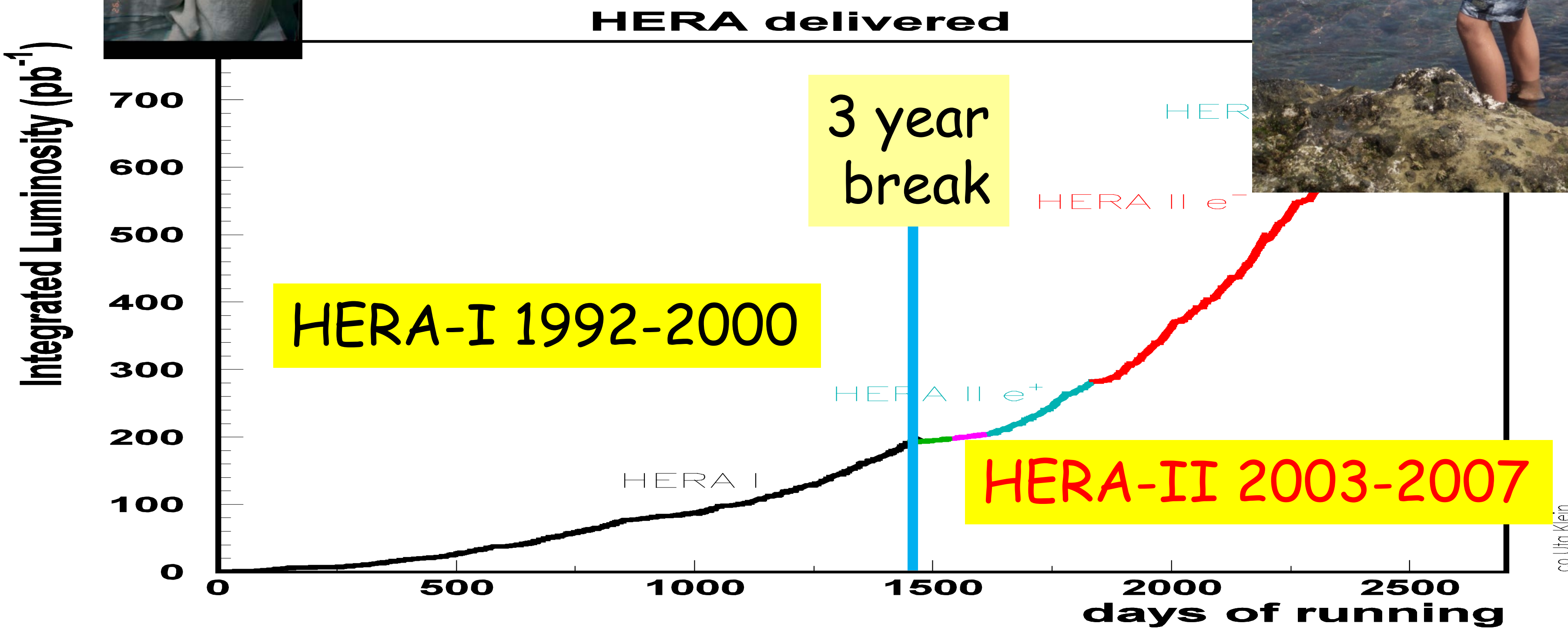
A view of the HERA ring tunnel



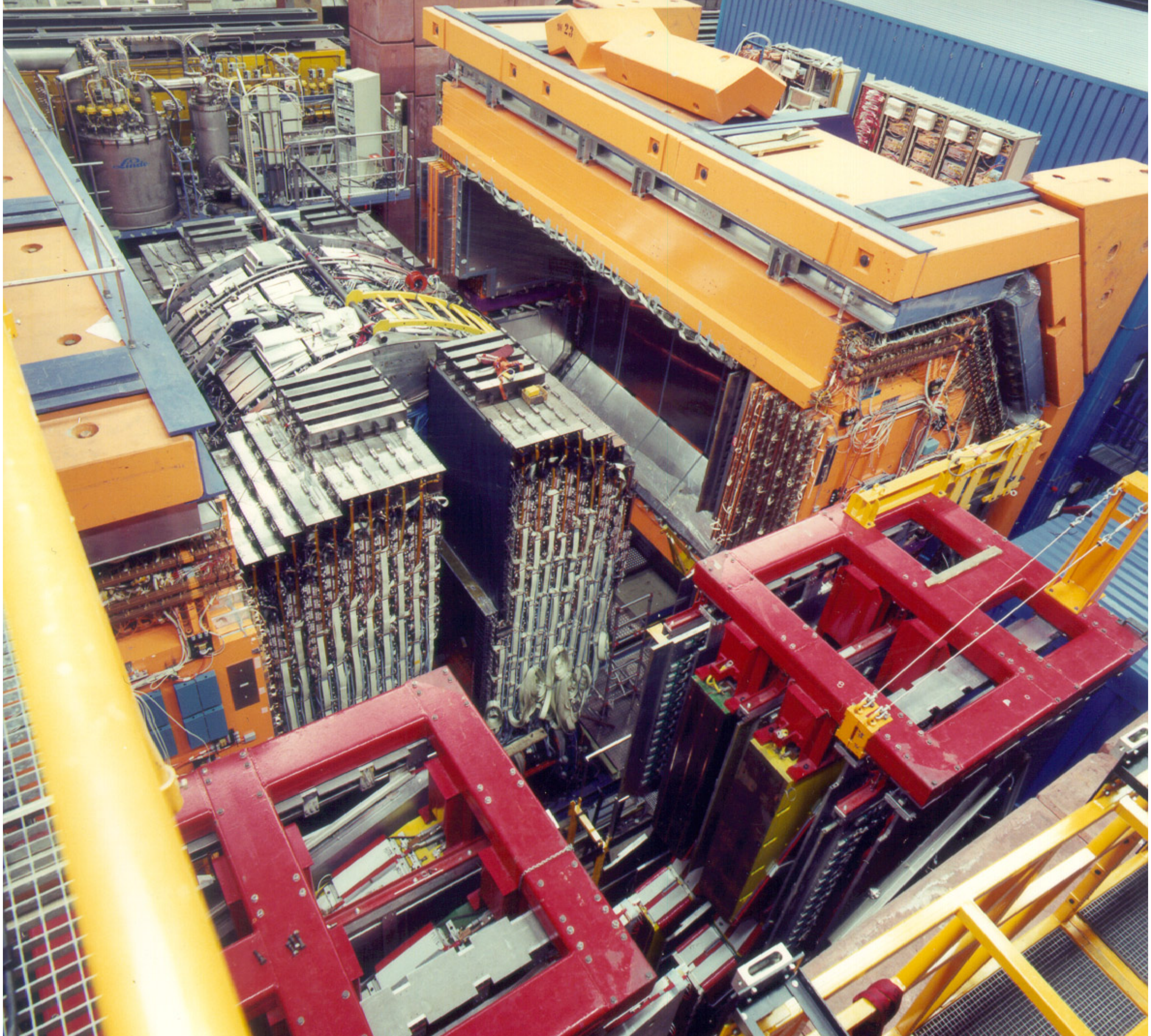


Experiments started in 1992

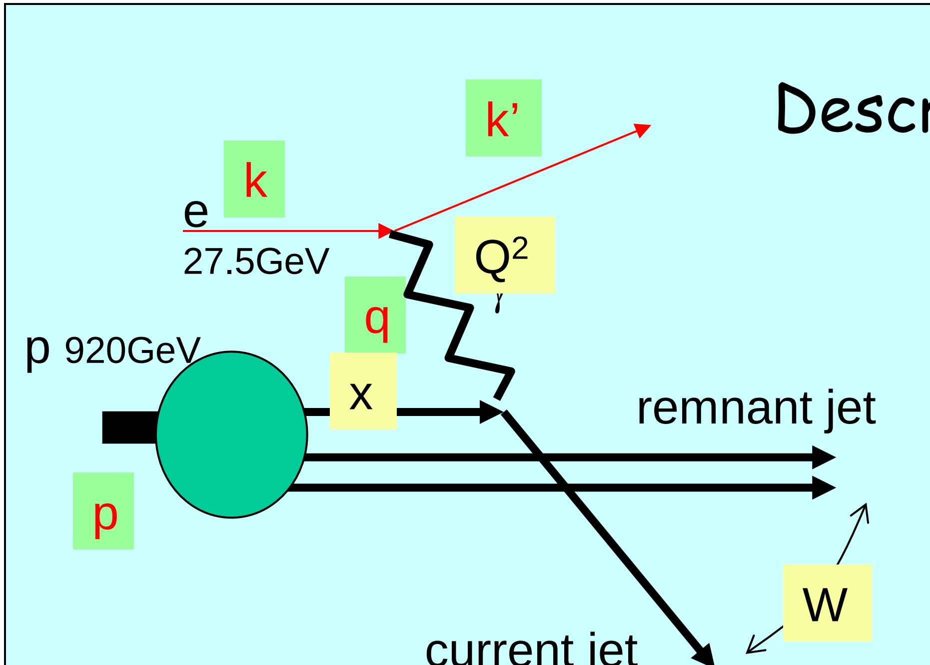
HERA History (1992-2007)



HERA operation ended at the end of June in 2007



Introduction: Deep Inelastic Scattering



Described by 2 kinematic variables

$Q^2 = -q^2$ photon virtuality

$x = Q^2/2p.q$ Bjorken x

$y = p.q/p.k$ Inelasticity

$s = Q^2 xy$

$$\frac{d\sigma^2_{e^\pm p}}{dx dQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left(Y_+ F_2 - y^2 F_L \mp Y_- x F_3\right)$$

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

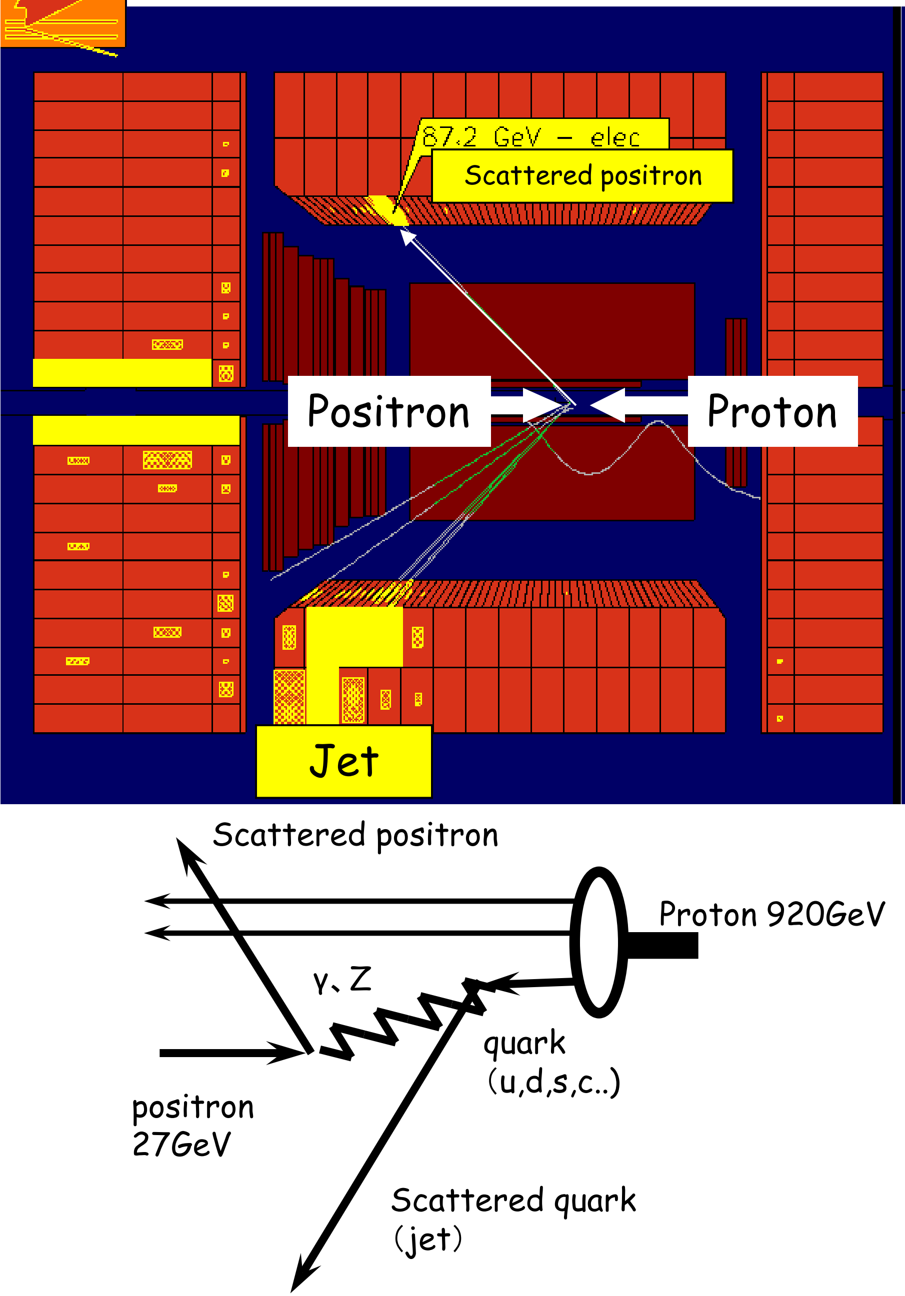
F_L : Longitudinal Str. Ft. (0 in QPM)

F_3 : Small at $Q^2 \ll M_Z^2$

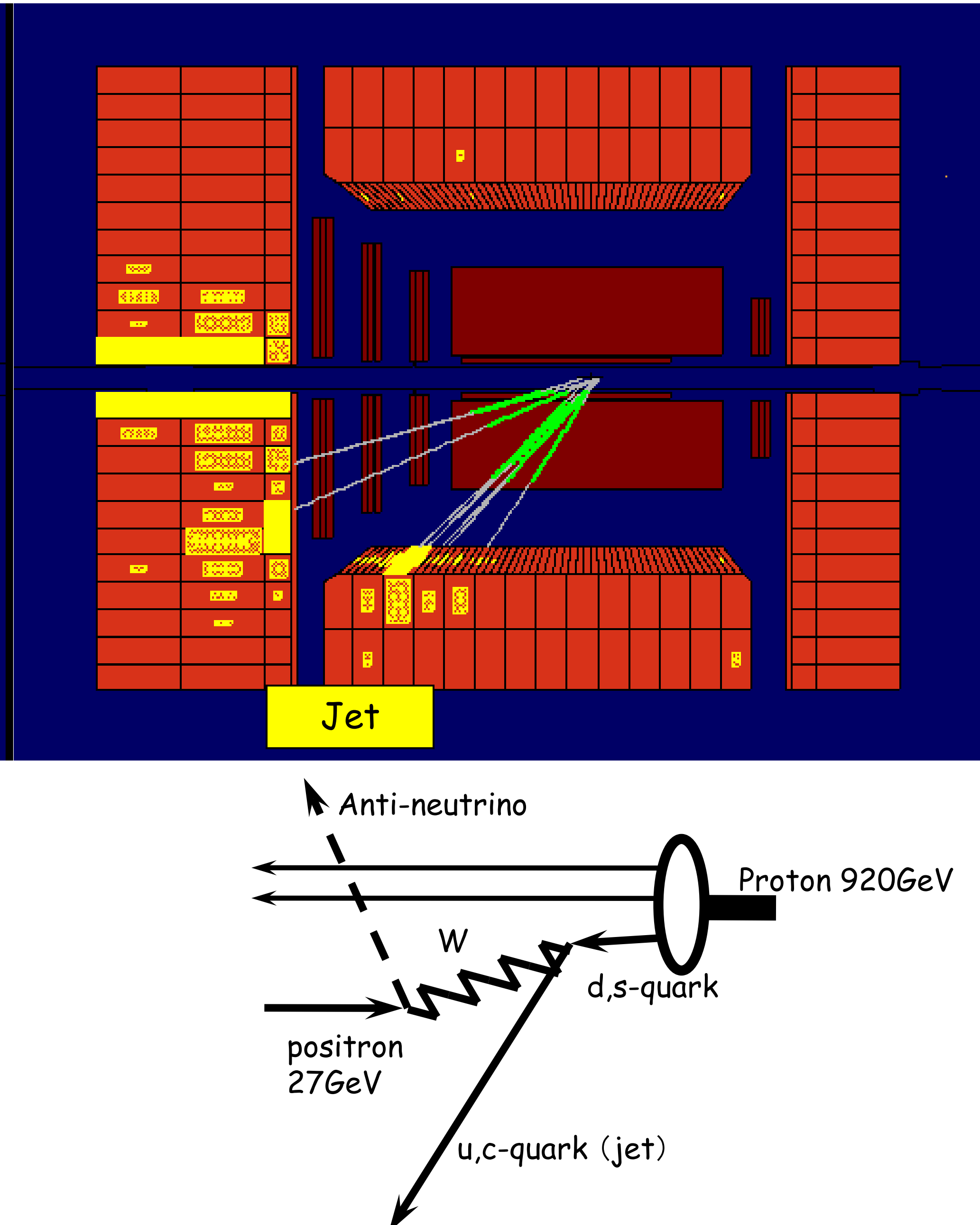
$$F_2 = \sum_f e^2 x q_f(x, Q^2)$$

$q_f(x, Q^2)$: quark distribution function

Neutral Current (NC)



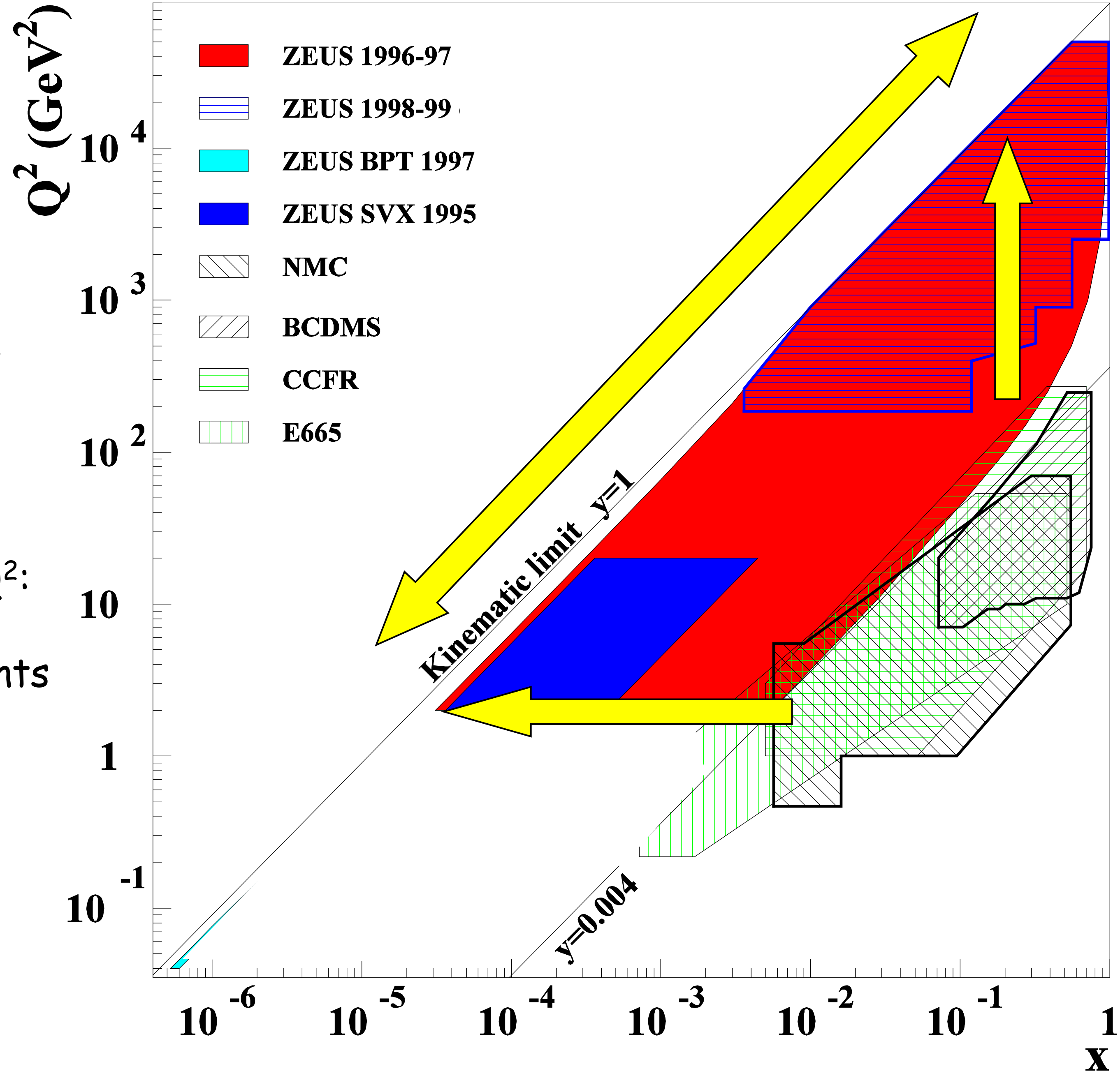
Charged Current (CC)



Kinematical region for HERA structure function measurements

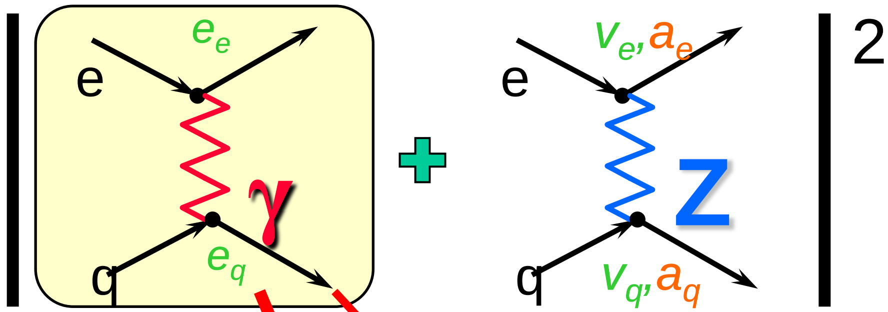
- 2 order higher region in Q^2,
- 2 order lower region in x
- Wide span in Q^2:

Precise measurements for Q^2 evolution



ZEUS experiment at DESY

- Almost hermetic 4pi calorimetory
- Good balance in EM/Hadron resolution (compensated calorimeter U/Sci)
- Good electron ID (against hadron)
  pad detector at shower max. (HES)
  TRD in Fwd direction (proton side)



In SM, $v_q = I_q^3 - 2e_q \sin^2\theta_W$,

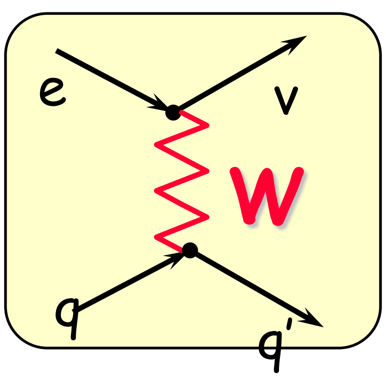
$a_q = I_q^3$

$$P_z = \frac{1}{\sin^2 2\theta_w} \frac{Q^2}{Q^2 + M_Z^2}$$

$$F_2(x,Q^2) = \sum_q \{e_q^2 - 2e_q v_q v_e P_Z + (v_q^2 + a_q^2)(v_e^2 + a_e^2)P_Z^2\}\left[xq(x,Q^2) + x\bar{q}(x,Q^2)\right]$$ parity +

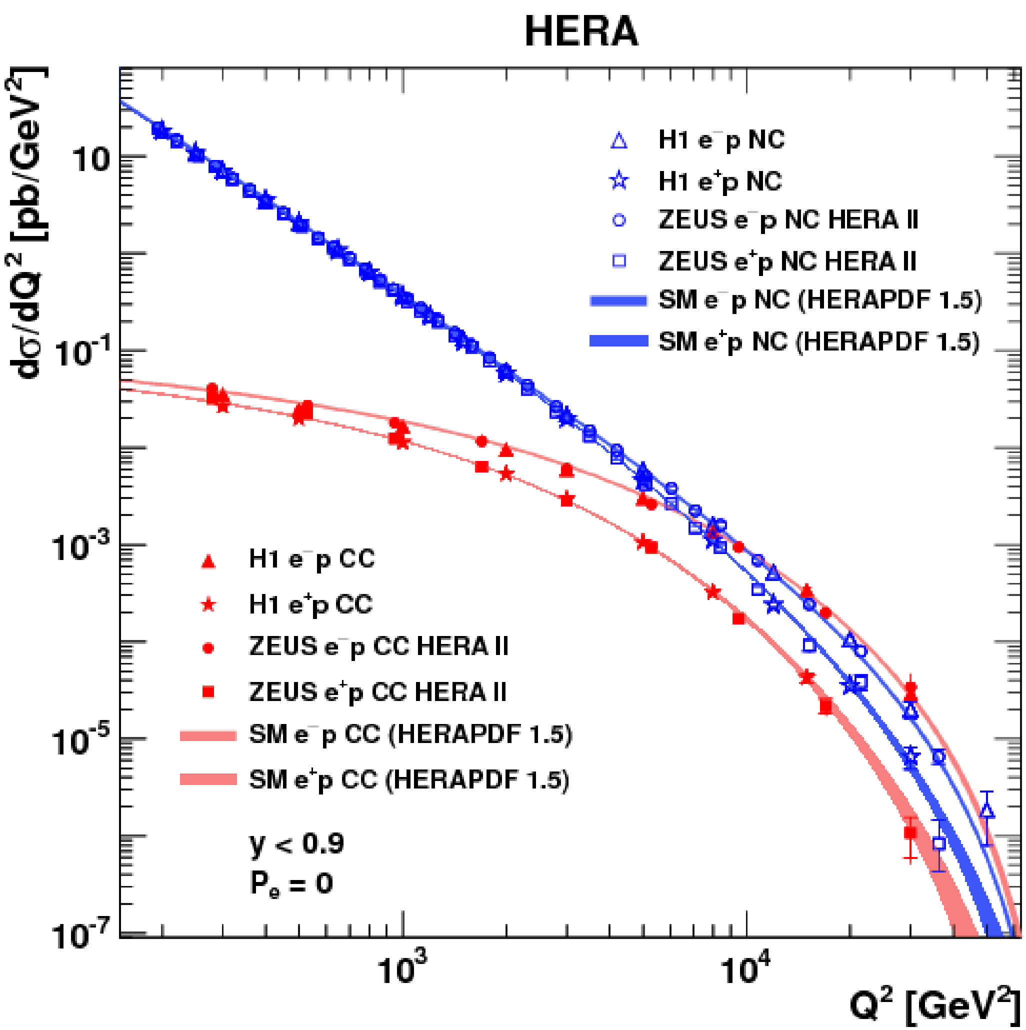
$$xF_3(x,Q^2) = \sum_q \{-2e_q a_q a_e P_Z + 4v_q a_q v_e a_e P_Z^2\}\left[xq(x,Q^2) - x\bar{q}(x,Q^2)\right]$$ parity -

$$\frac{d^2\sigma_{e^\pm p}}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[\{1 + (1-y)^2\}F_2 \mp \{1 - (1-y)^2\}xF_3\right]$$



$$\frac{d^2\sigma^{CC}_{e^\pm p}}{dxdQ^2} = \frac{G_F}{2\pi}\left(\frac{M_W^2}{M_W^2 + Q^2}\right)^2\left[\{1 + (1-y)^2\}F_2 \mp \{1 - (1-y)^2\}xF_3\right]$$

Measurements of NC/CC Cross sections



HERA-II Final Results

At high Q^2 ($Q^2 \sim M_{W,Z}^2$),

$\sigma_{NC} \sim \sigma_{CC}$

$$\frac{d\sigma}{dQ^2} \propto \frac{\alpha'^2}{\left(Q^2 + M_{Exchange}^2\right)^2}$$

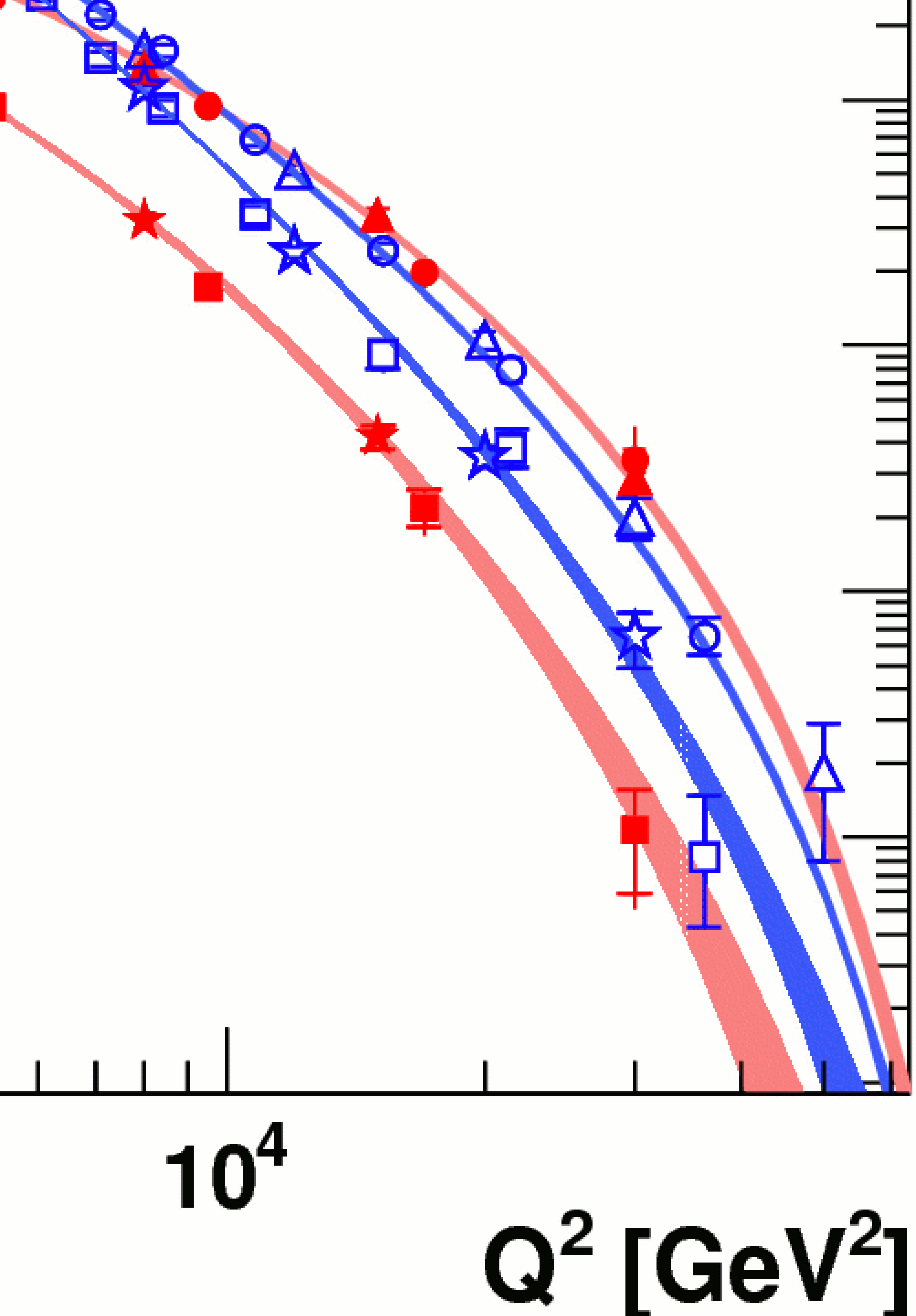
$\alpha_{NC} \sim \alpha_{CC}$

→ Electroweak unification

Good agreement with the SM

- $NC(e^+p) < NC(e^-p)$
  ← γZ interference
- $CC(e^+p) < CC(e^-p)$
  ← u,d-quark distribution in the proton

sections



HERA-I Final Results

At high Q^2 ($Q^2 \sim M_{W,Z}^2$),

$\sigma_{NC} \sim \sigma_{CC}$

$$\frac{d\sigma}{dQ^2} \propto \frac{\alpha'^2}{\left(Q^2 + M_{Exchange}^2\right)^2}$$

$\alpha_{NC} \sim \alpha_{CC}$

→ Electroweak unification

Good agreement with the SM

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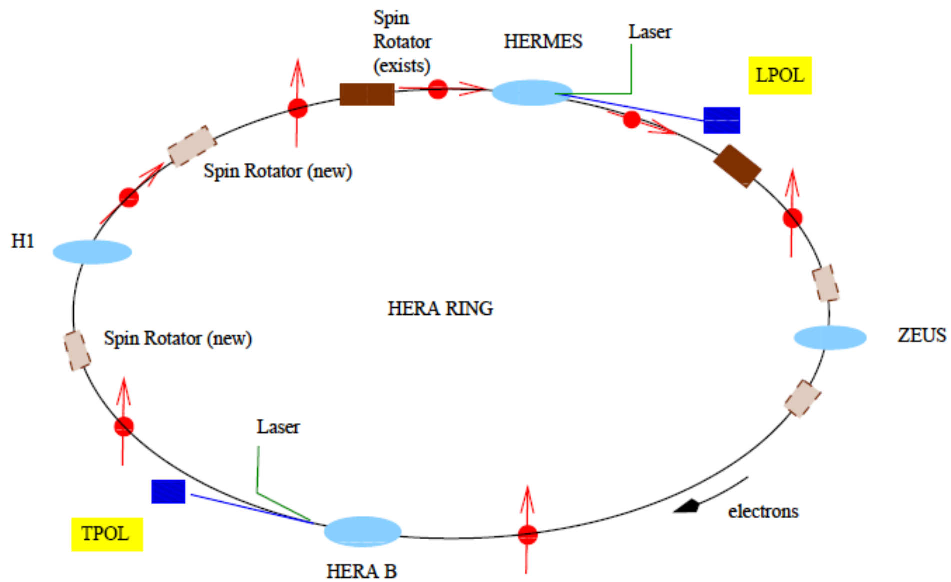
HERA I → II

Longitudinal polarization of lepton beam : → Direct EW sensitivity

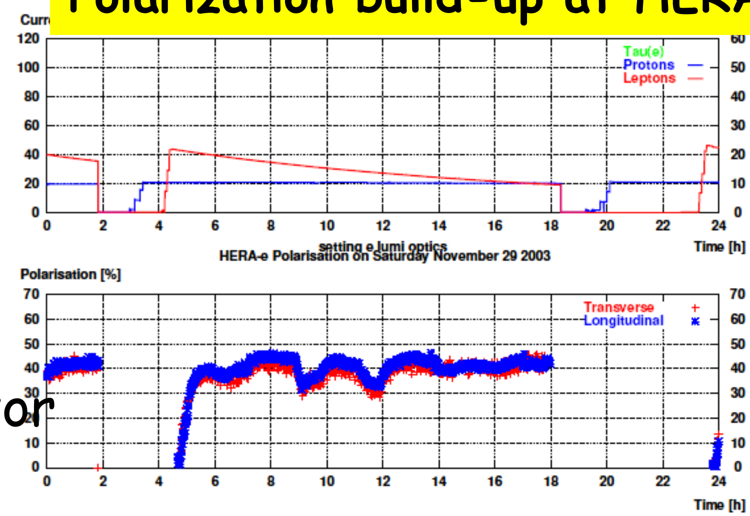


- Sokolov-Ternov effect → Lepton beam has transverse polarization

+

- Spin rotator before/after the H1/ZEUS/HERMES

Polarization build-up at HERA

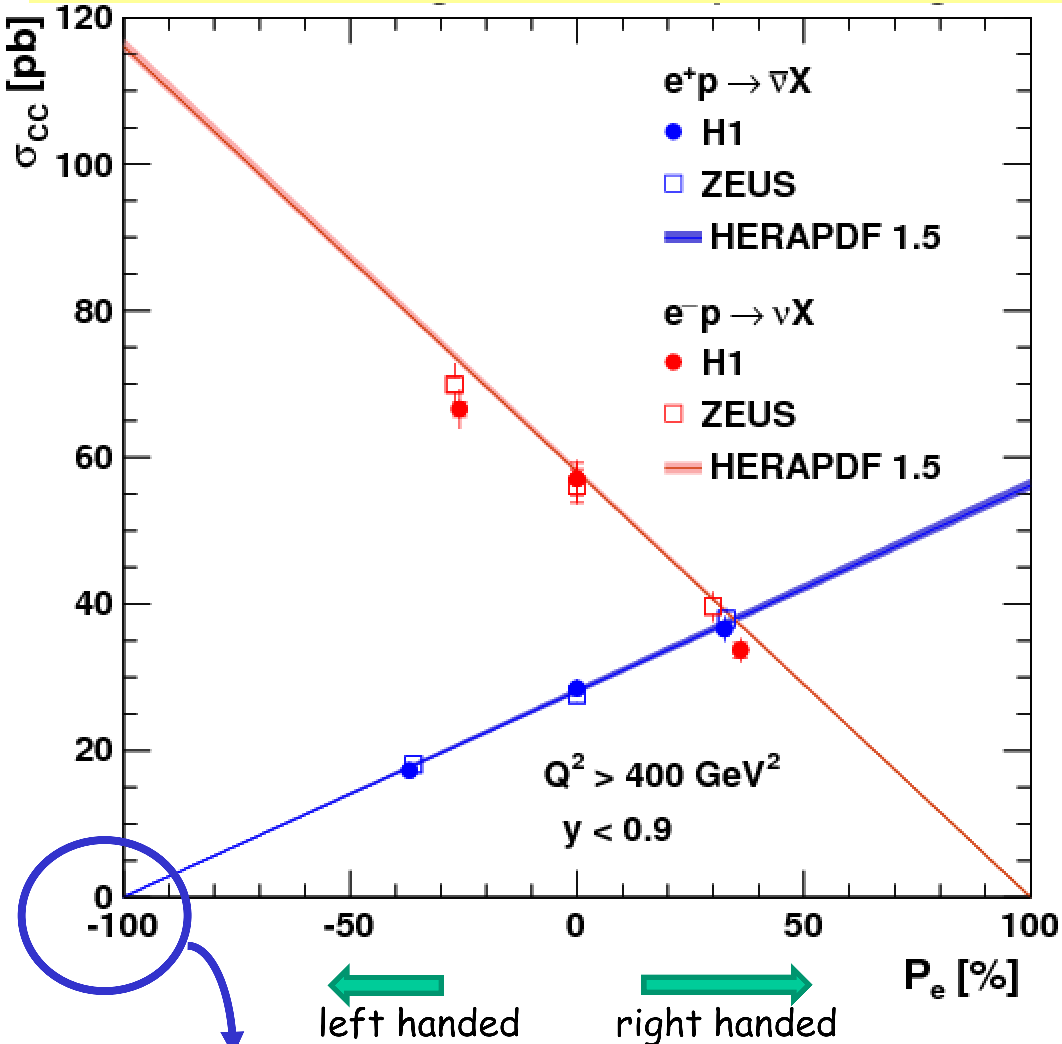


30 ~40% on average

Luminosity Upgrade :
← High-Q^2 requires large luminosity

- Final focusing magnets in the detector

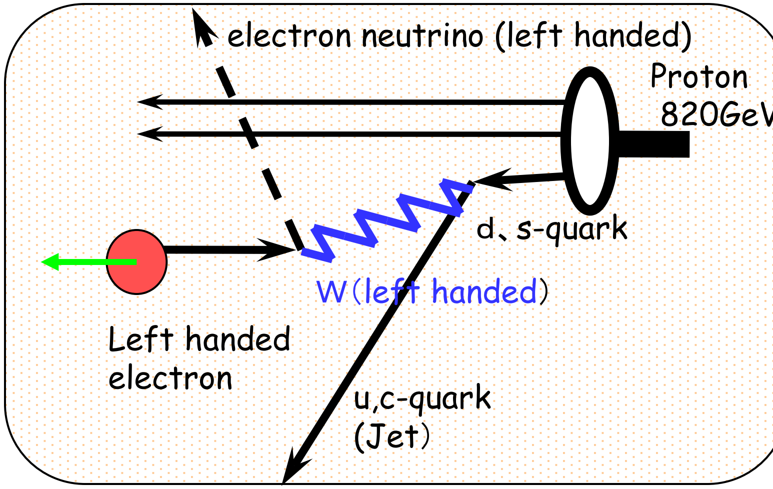
Charged Current Scattering

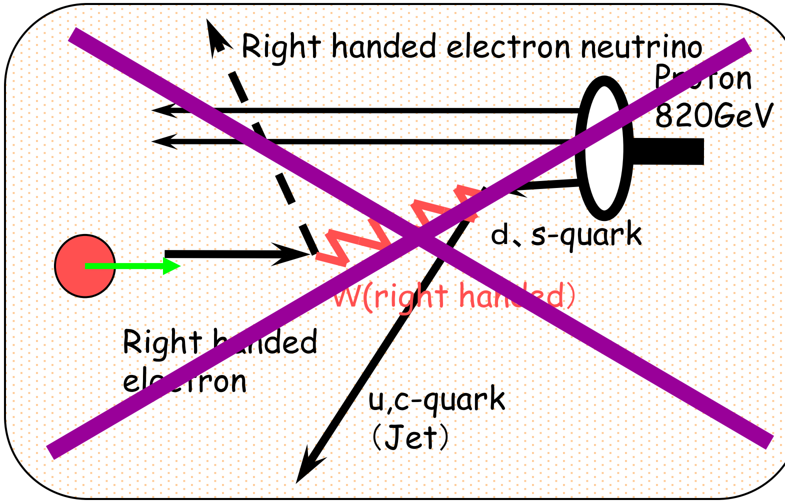


$$\sigma_{CC}^{tot}(P_e = +1, e^- p) = -1.3 \pm 2.4_{\text{exp}} \pm 1.5_{\text{lumi}} \pm 1.2_{\text{pol}}\,\text{pb}$$

$$\sigma_{CC}^{tot}(P_e = -1, e^+ p) = -0.5 \pm 1.3_{\text{exp}} \pm 0.7_{\text{lumi}} \pm 0.4 \ldots \text{pb}$$

H1 prelim.





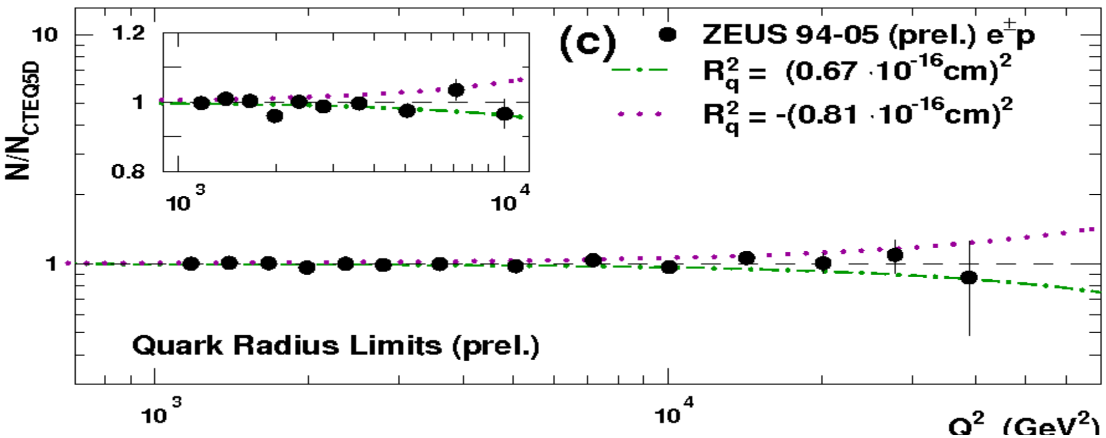
- The first measurement of Left/Right asymmetry in CC in this energy region.

What we dreamed of (and we could not discover)

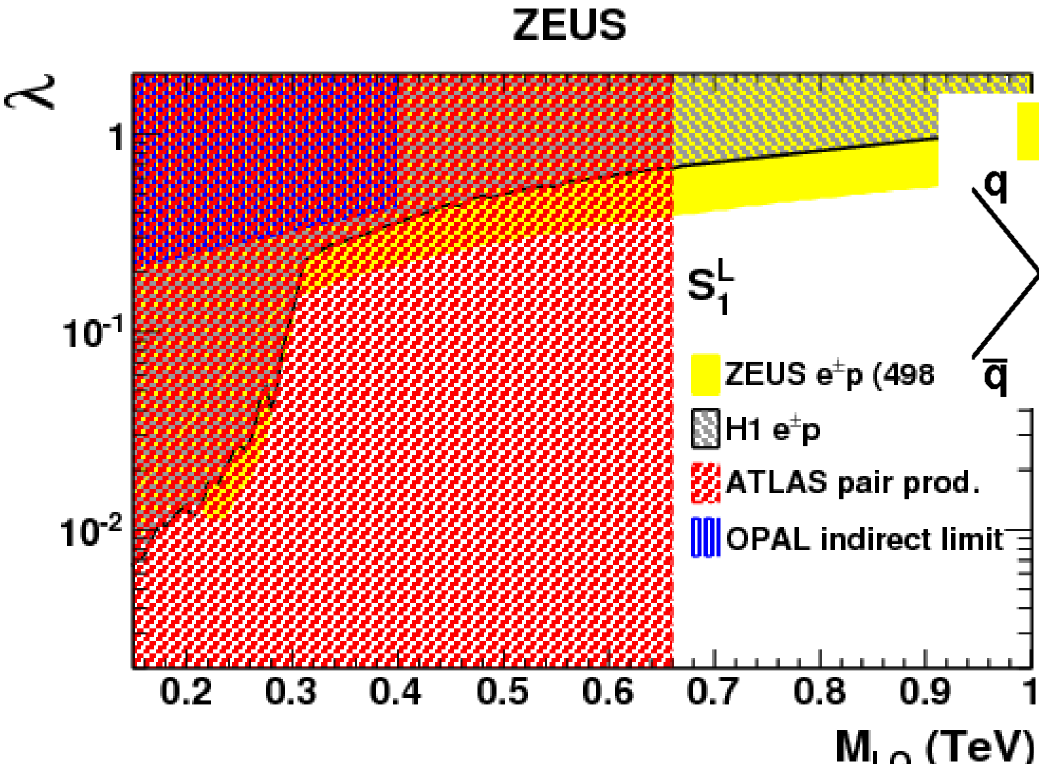
- Leptoquark (LQ)
- Indirect searches for Extra bosons (Z') from the high-Q2 scatterings
- Top quark (from photon-gluon fusion gamma g -> t b)

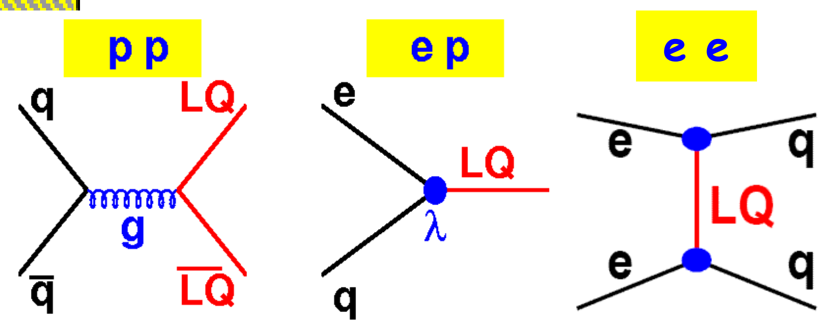
- Leptoquark with generation mixing.
  - eq -> LQ -> tau top : three N prizes!

Seaches of BSM



"softer" scattering
If the quark is not point-like



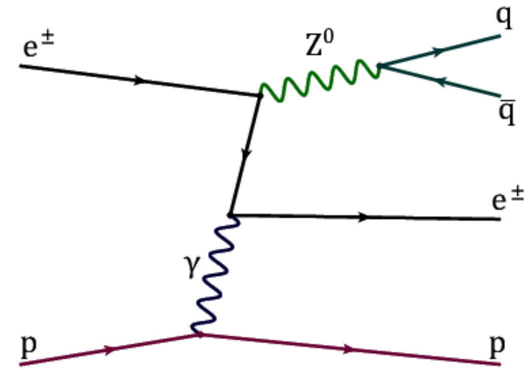


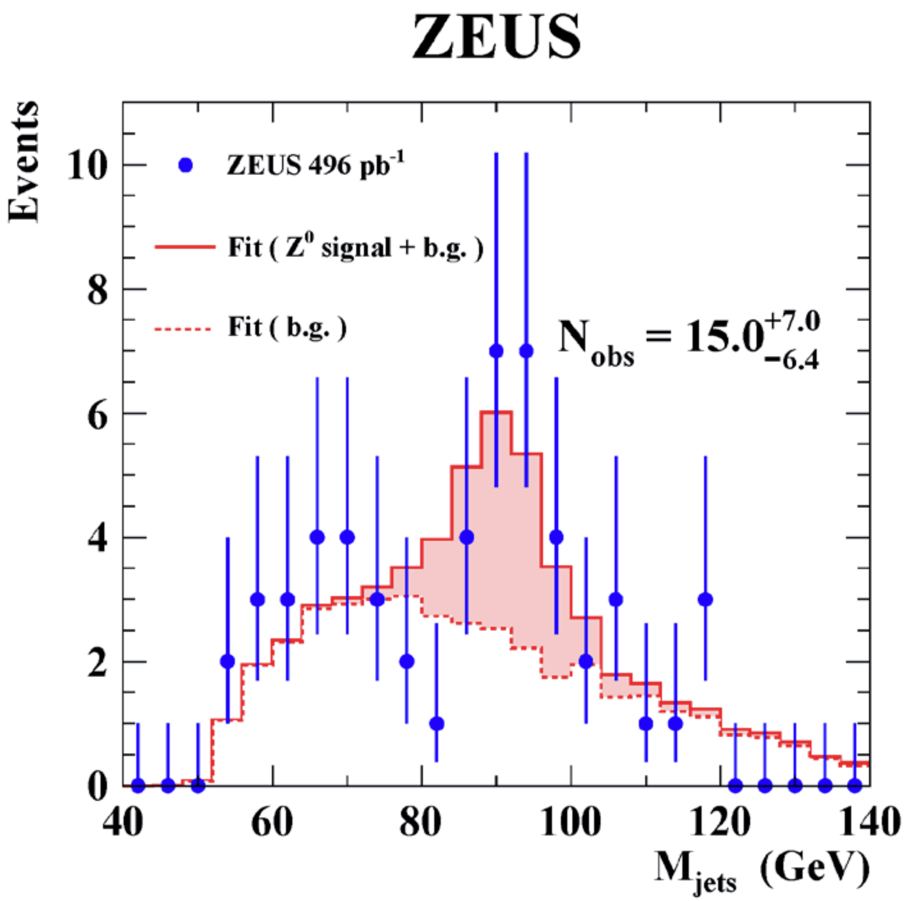
Good agreement with the SM

Quark Radius $< 0.67 \times 10^{-16}$cm (prelim.)
No signal for Leptoquarks so far

Phys. Rev. D 86, 012005 (2012)

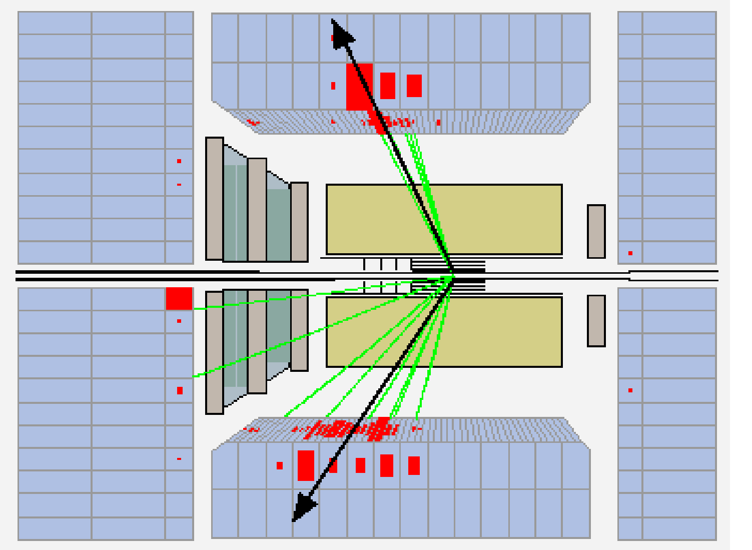
Seaches of BSM





No top but hadronic Z decays were observed.

Z mass reconstruction with Z-> jet jet



Phys. Lett. B718 (2013) 915

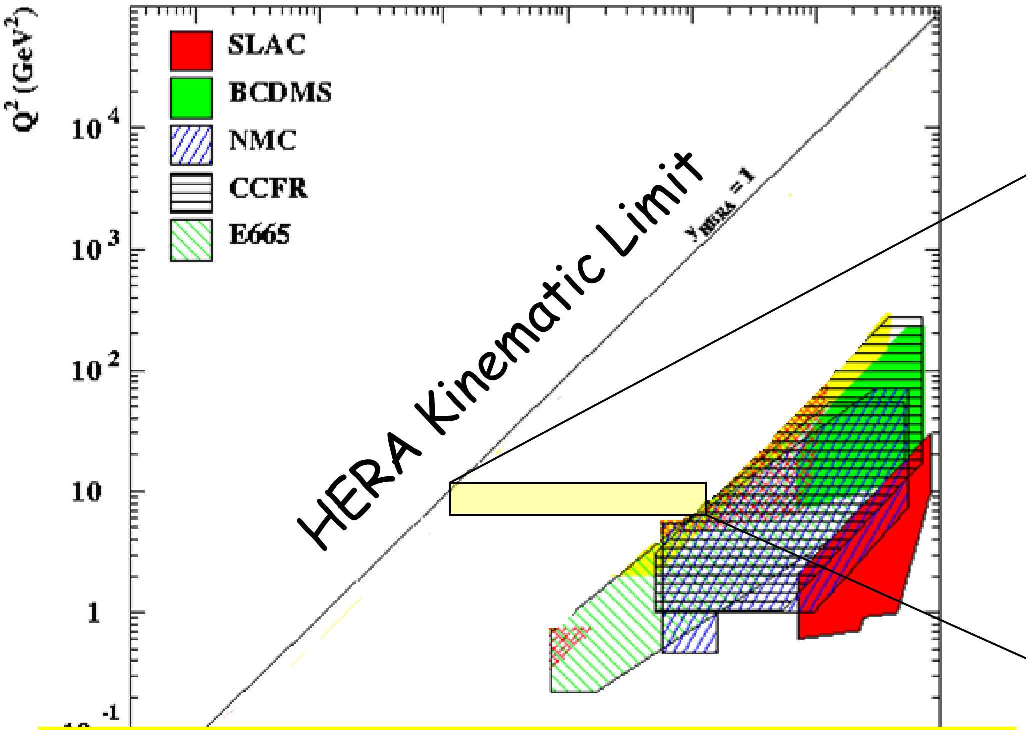
What we planned to measure (and are well measured)

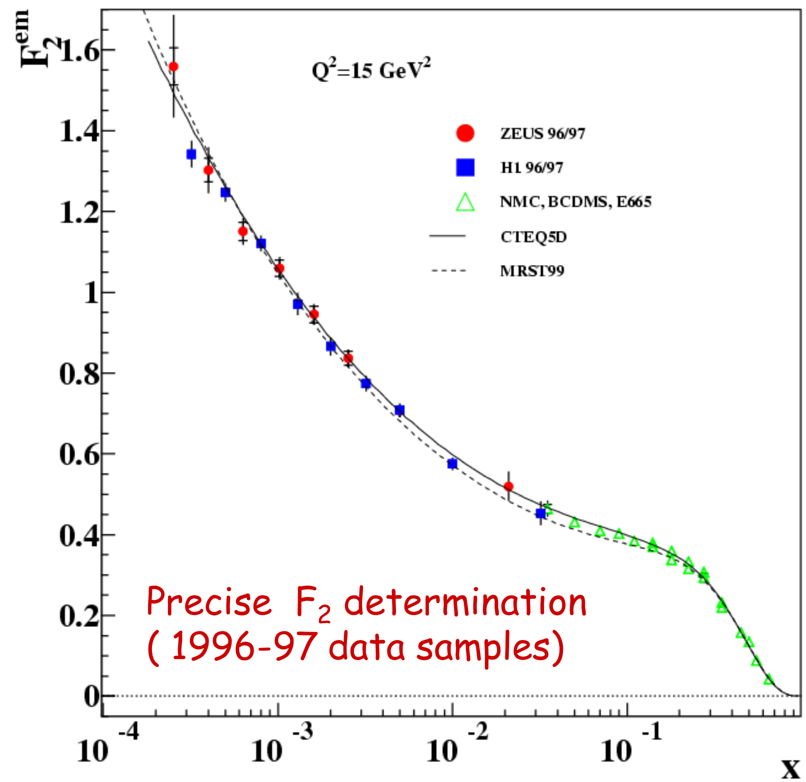
- Proton Structure
- QCD -> Precision theory

Predictions of F_2

Gluck, Reya and Vogt

"pQCD" : parton evolution





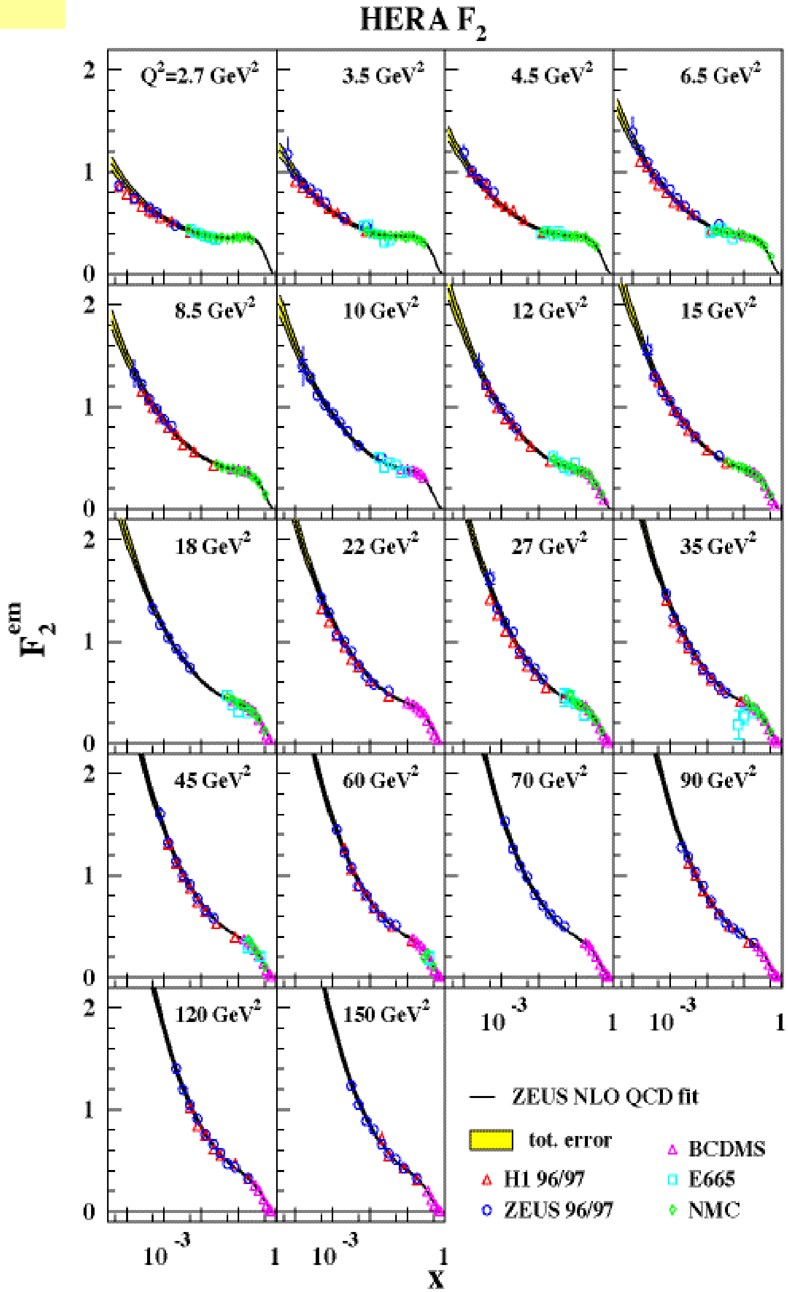
Early HERA data showed rapid increase of F_2 at low x.

Donnachie & Landshoff

"Hadronic": Regge theory behavior of γp total cross section

Results of F_2 Structure Function

- Strong rise of F_2 as x decreases
  - Soft 'sea' of quarks in the proton
- Slope of rise gets steeper as Q^2 goes up
- Good agreement with fixed-target experiments at middle - high x
  - Sea + valence quarks

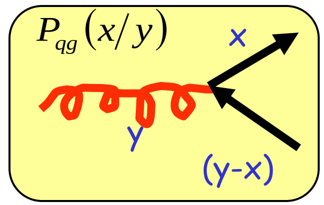


F_2 for fixed x, as a function of Q^2

- At low x, strong scaling violation is seen.

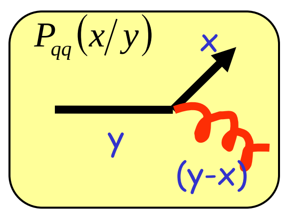
  Large gluon density + $g \to q\bar{q}$ splitting

  $\to F_2$ increases

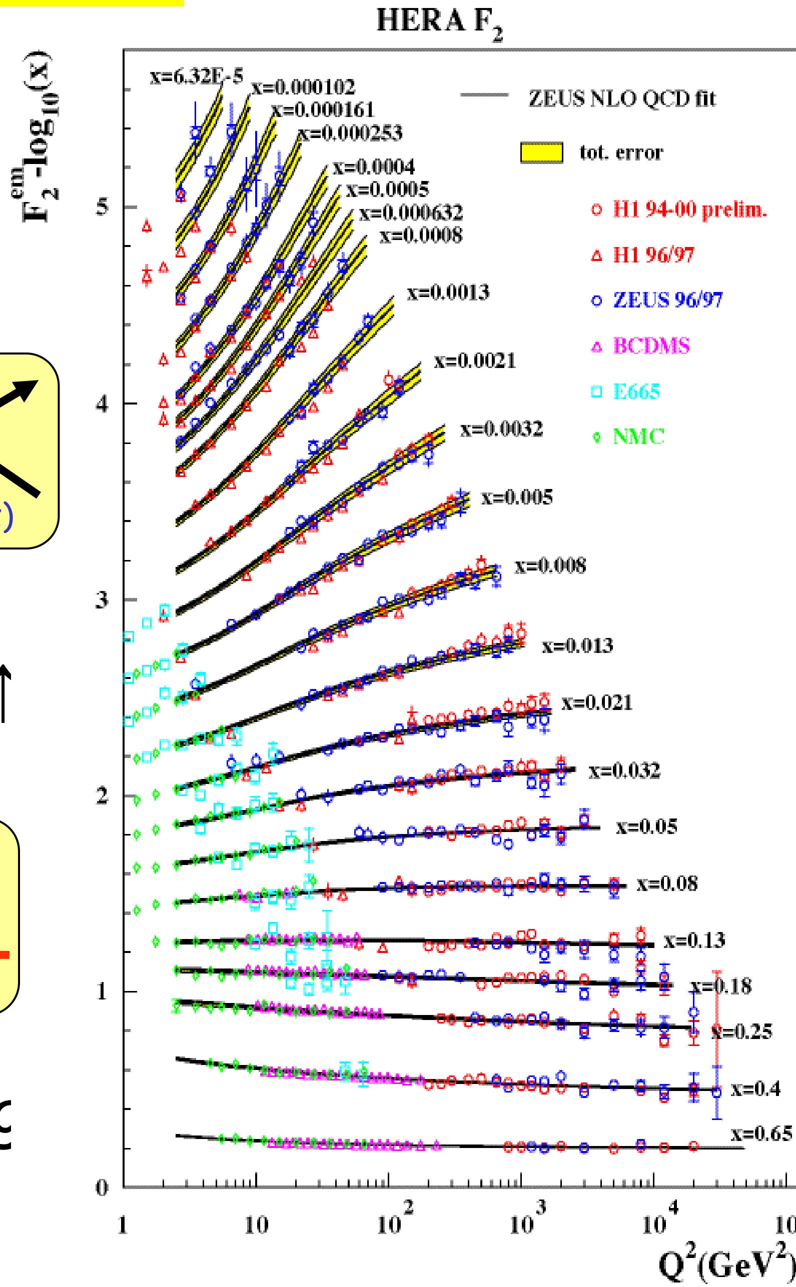


- At $x \sim 0.1$, approximate scaling.
- At higher x, F_2 decreases as $Q^2 \uparrow$

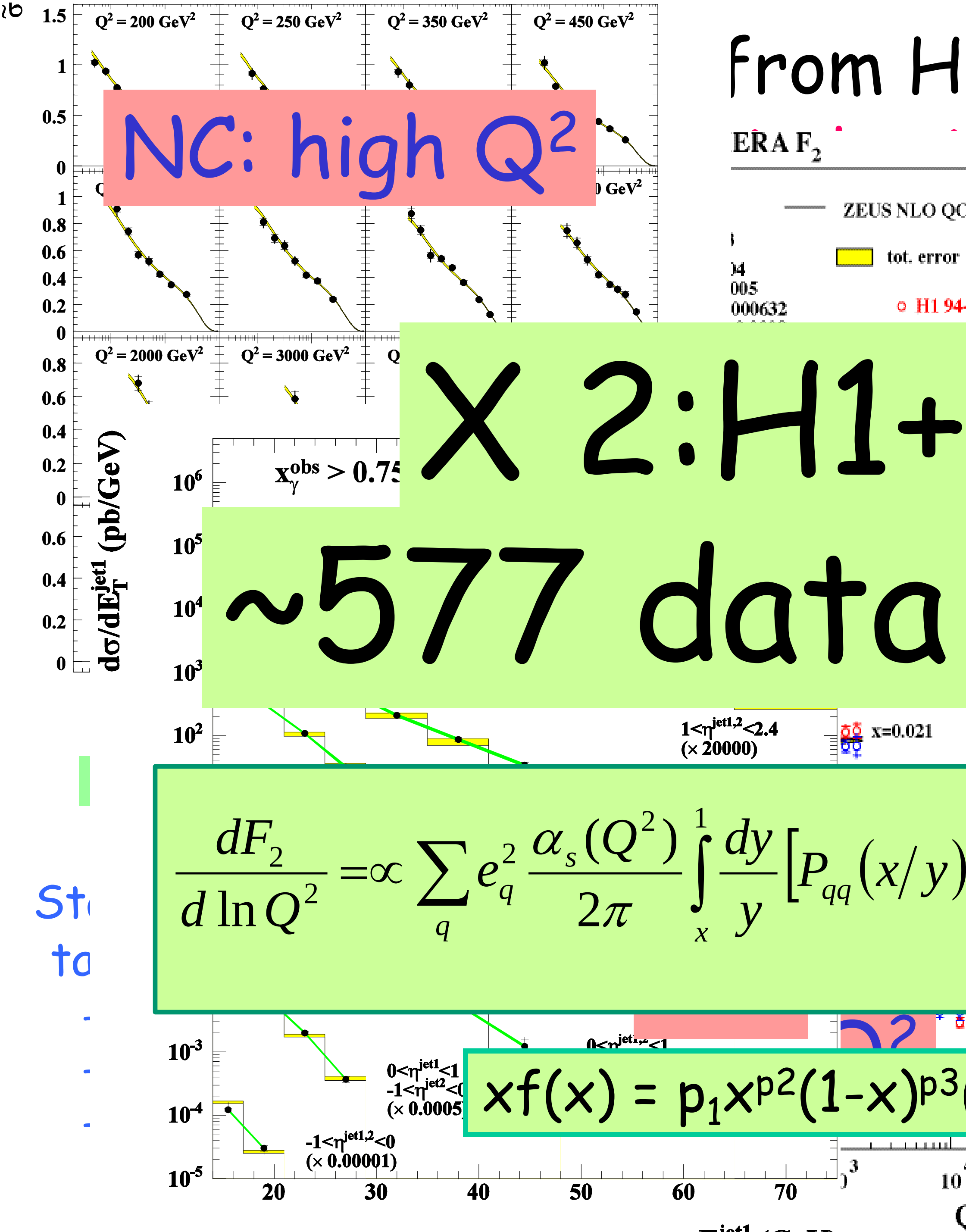
  Quark radiates off gluon: $q \to qg$



- Line = result of QCD fit (comming slides)
  - All data points well described.



from HERA



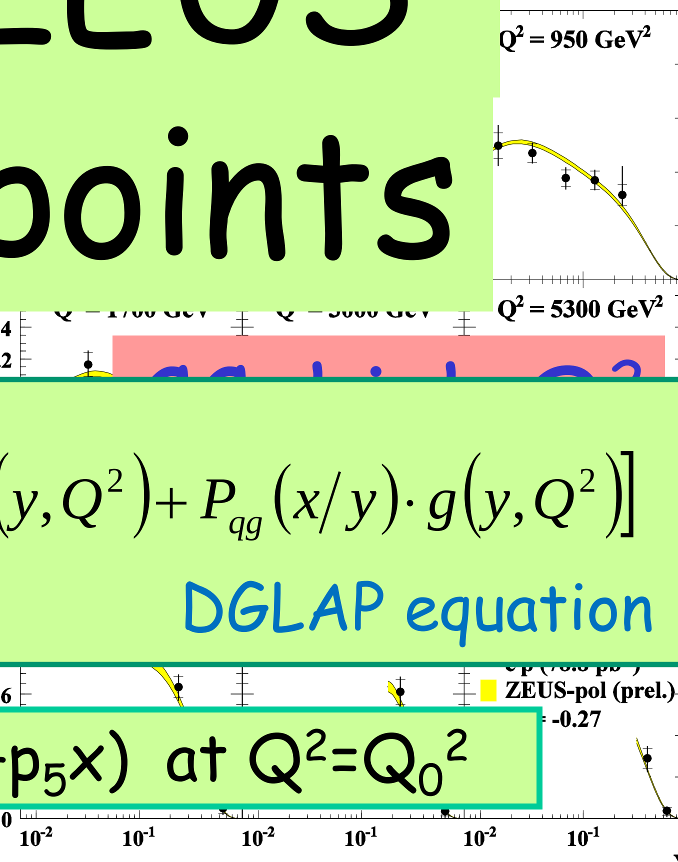
HERA data

QCD + EW physics

Z^0 exchange

X 2:H1+ZEUS

~577 data points



$$\frac{dF_2}{d\ln Q^2} = \propto \sum_q e_q^2 \frac{\alpha_s(Q^2)}{2\pi} \int_x^1 \frac{dy}{y} \left[P_{qq}(x/y)\cdot q(y,Q^2) + P_{qg}(x/y)\cdot g(y,Q^2) \right]$$

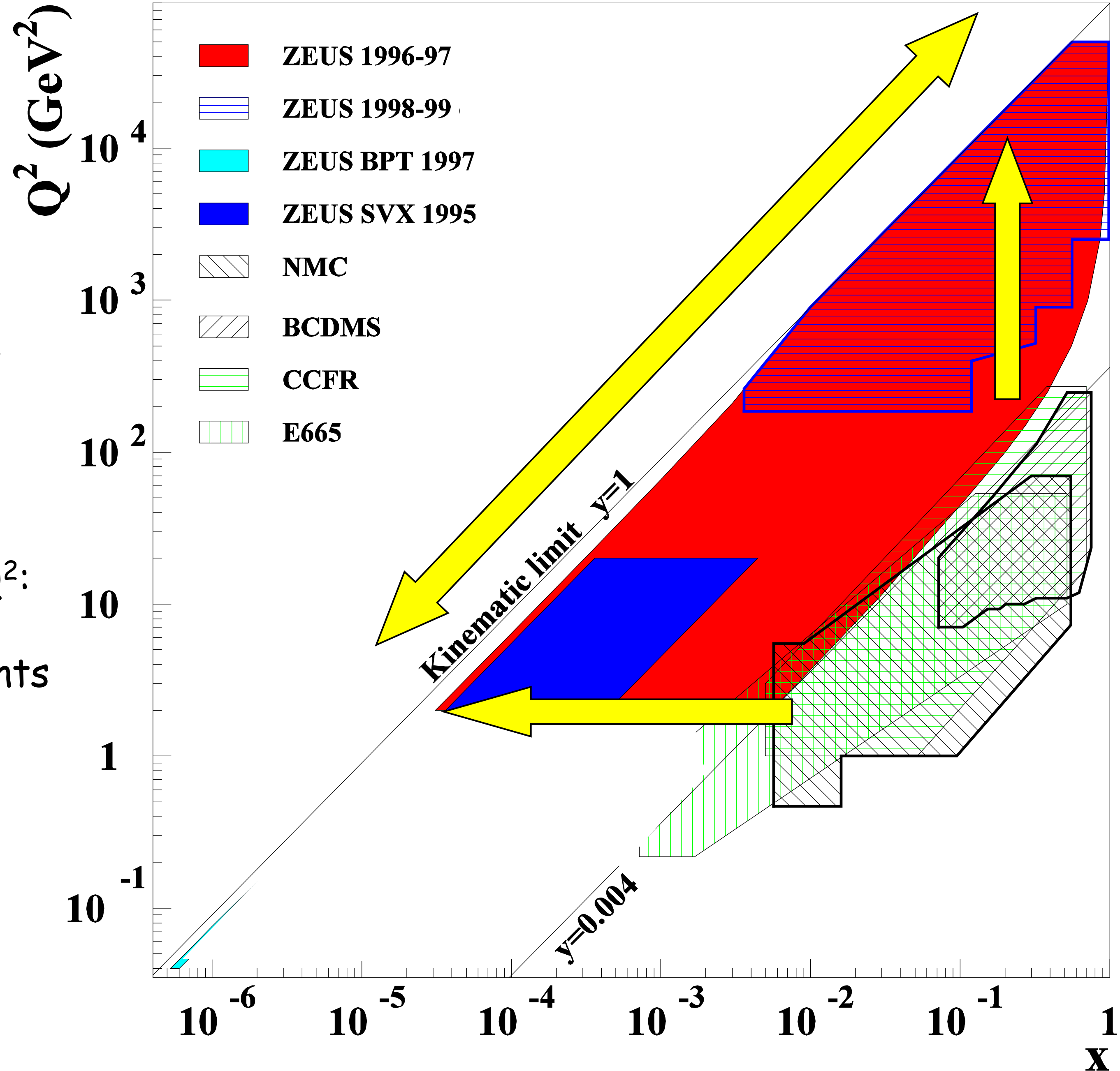
DGLAP equation

$xf(x) = p_1 x^{p2}(1-x)^{p3}(1+p_5 x)$ at $Q^2=Q_0^2$

Kinematical region for HERA structure function measurements

- 2 order higher region in Q^2,
- 2 order lower region in x
- Wide span in Q^2:

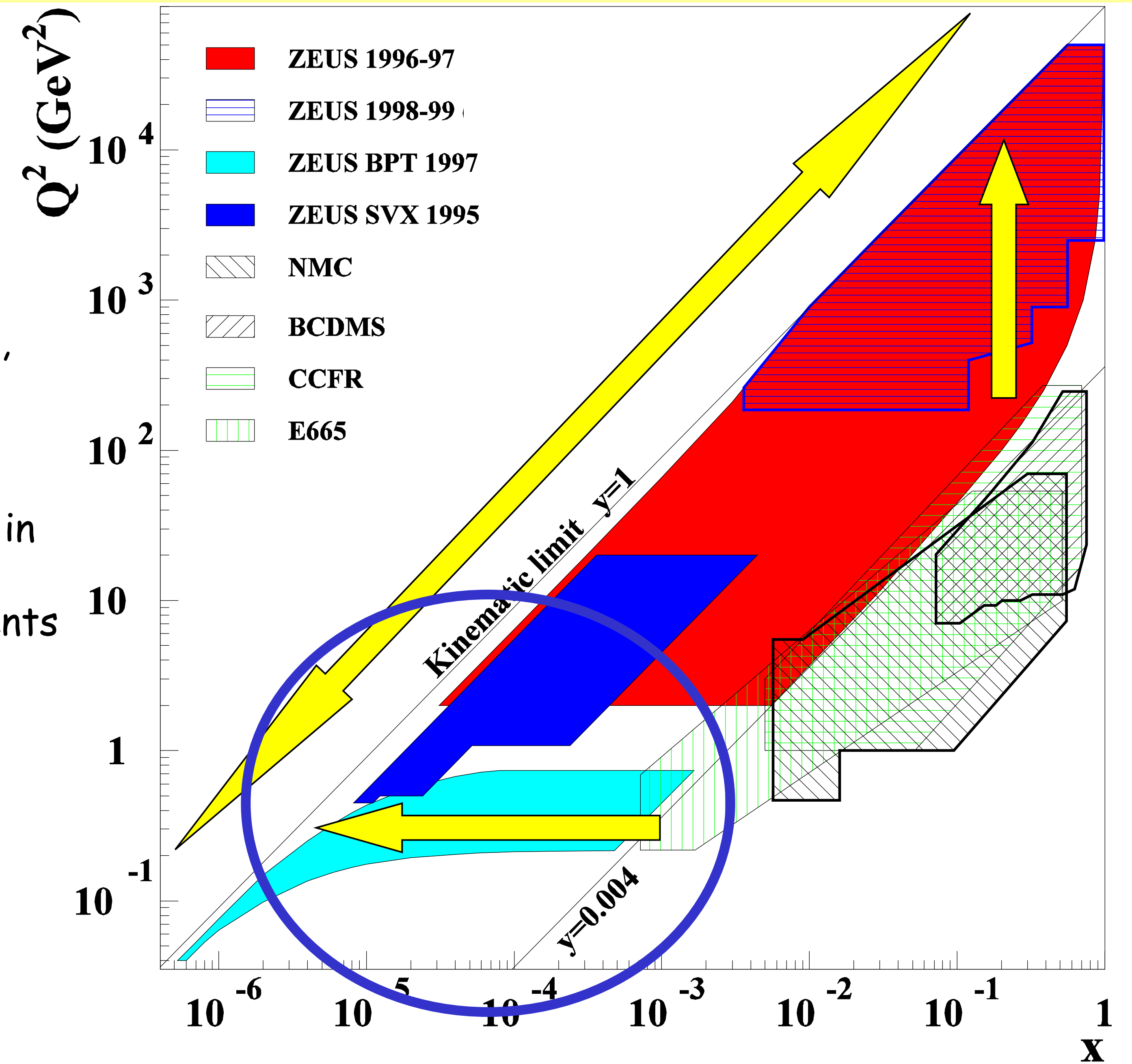
Precise measurements for Q^2 evolution



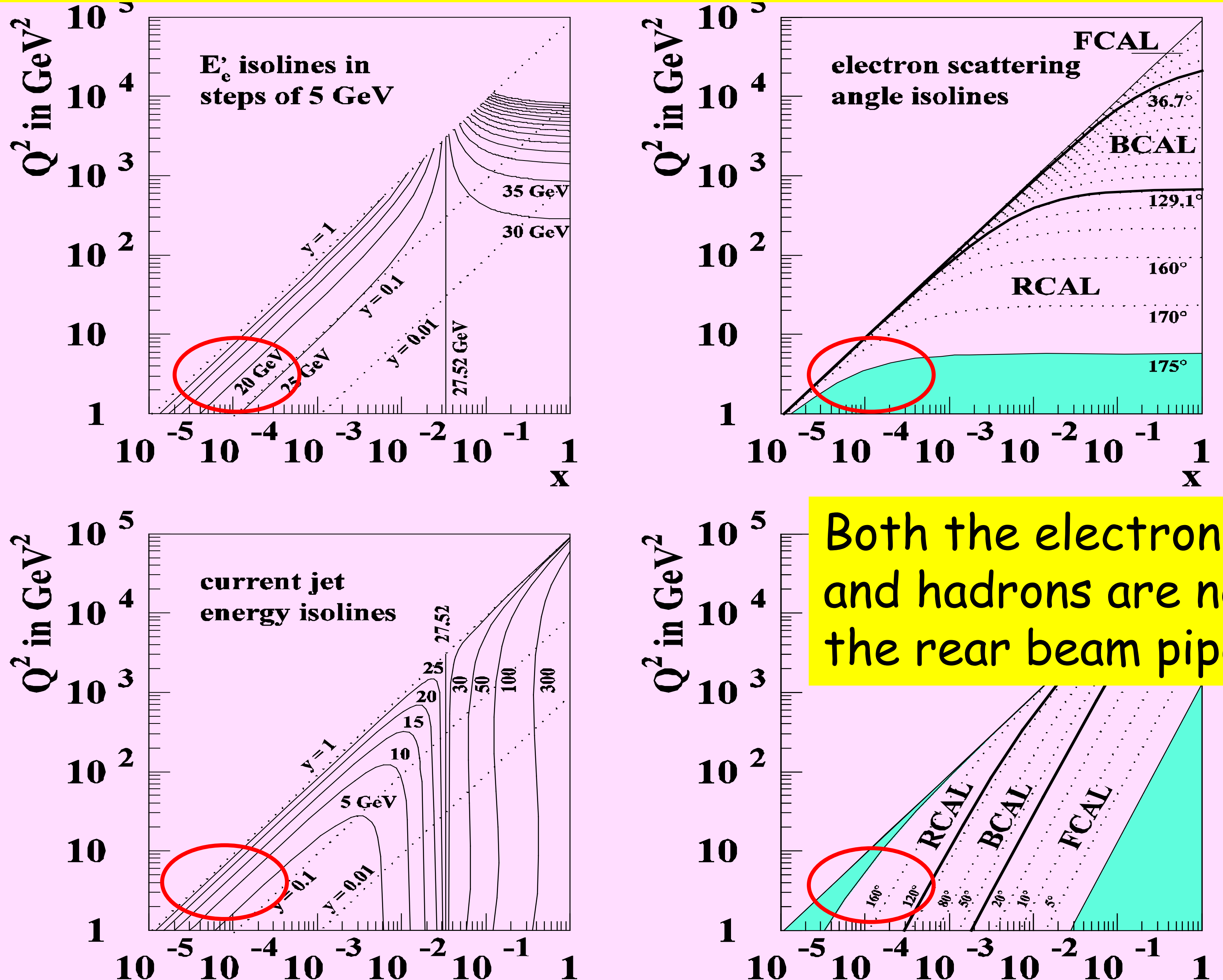
Kinematical region for HERA structure function measurements

$s = Q^2 x y$

- 2 order higher region in Q^2,
- 2 order lower region in x
- Wide ($O(10^6)$) span in Q^2: Precise measurements for Q^2 evolution

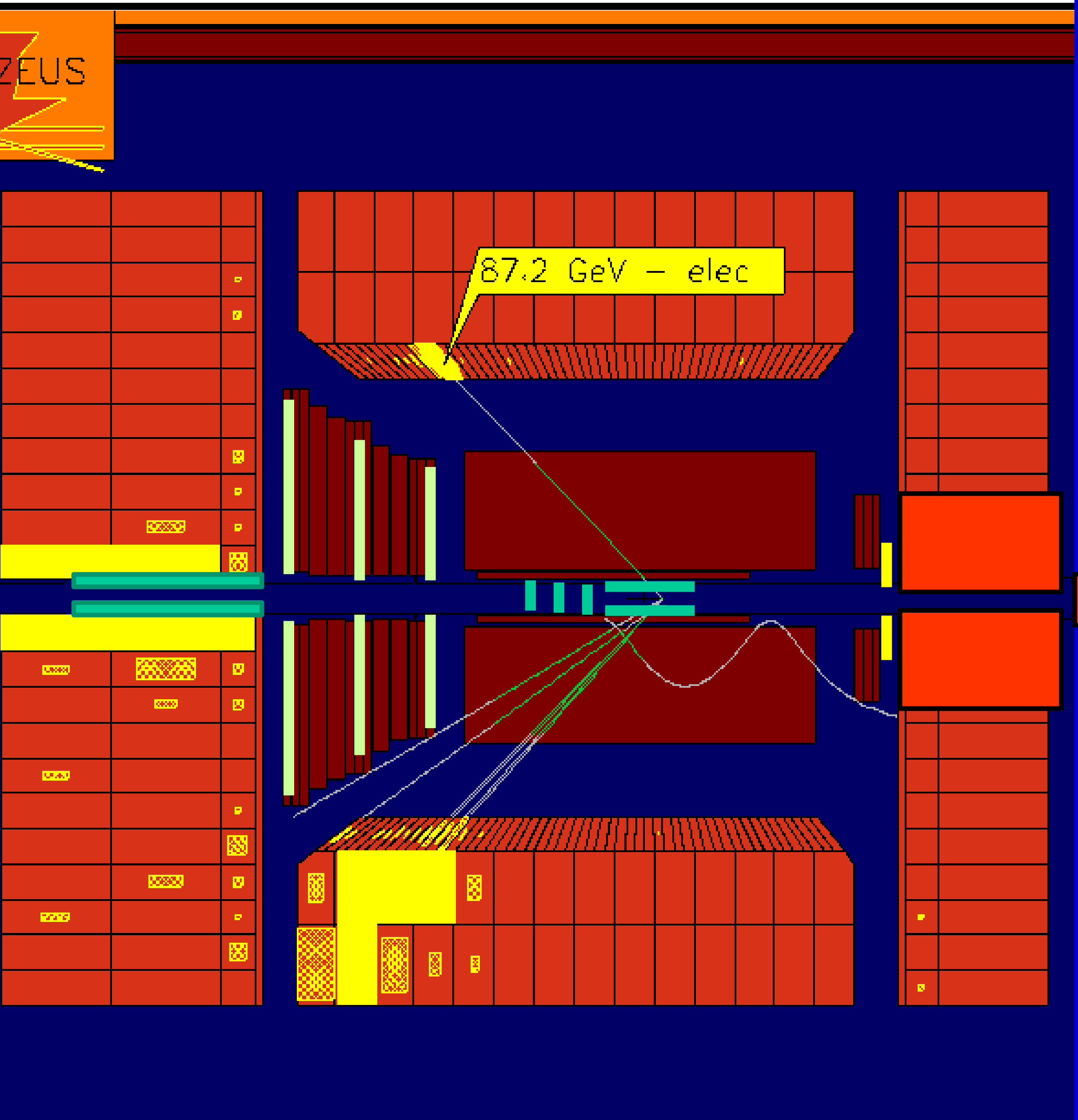


Direction and Energy of scattered electron (and hadrons)



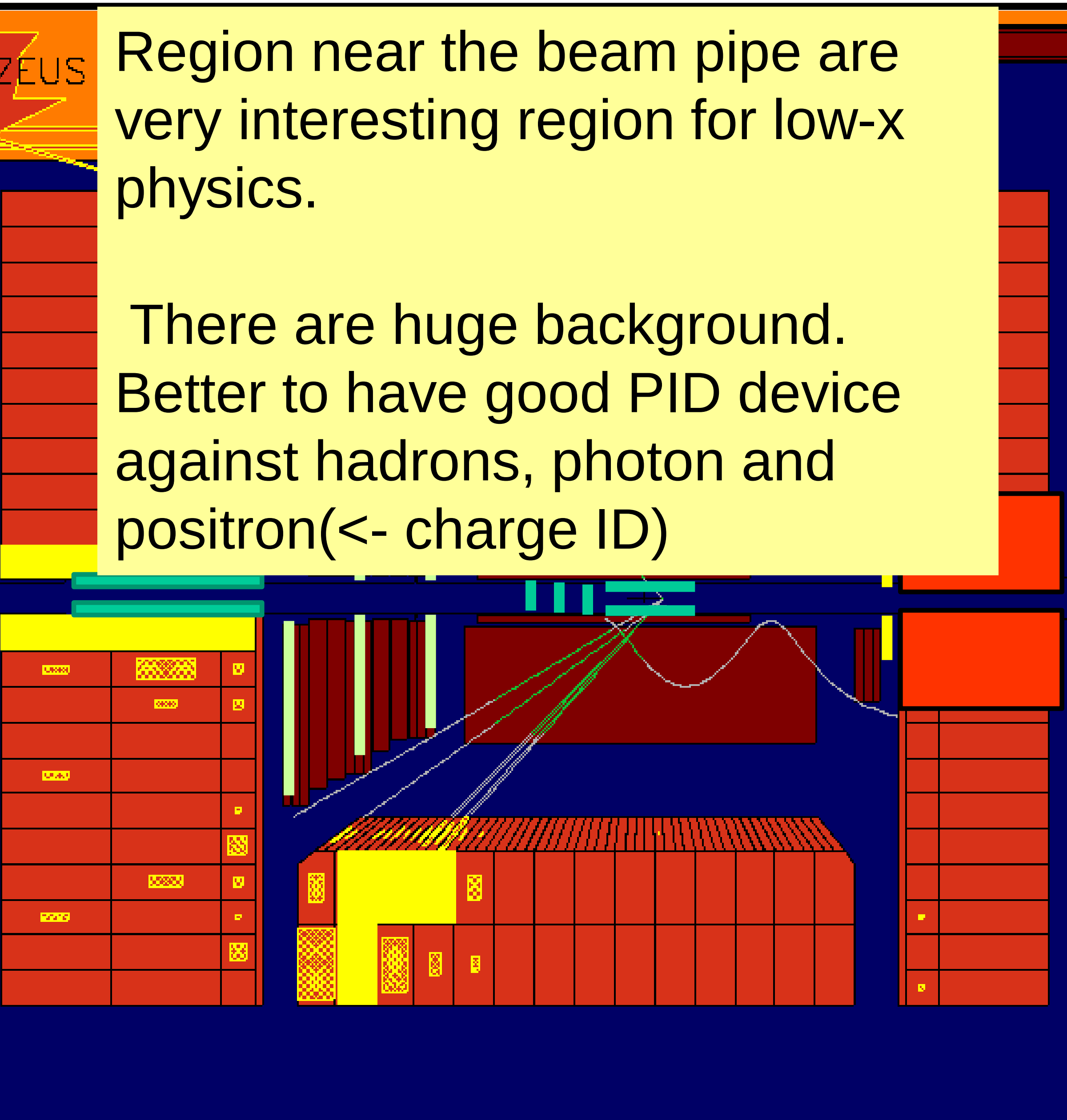
Both the electron and hadrons are near the rear beam pipe.

ZEUS upgrade



1. Sci-strip detector SRTD: for better electron position.
2. Moving RCAL beampipe hole: 20x20 -> 10x20cm
3. Beam pipe CAL (H1 Better RCAL)
4. FWD plug CAL
5. Silicon vertex detector
6. Straw Tracker at FWD
7. Very FWD neutron/ proton spectrometer

ZEUS upgrade



Region near the beam pipe are very interesting region for low-x physics.

There are huge background. Better to have good PID device against hadrons, photon and positron(<- charge ID)

1. Sci-strip detector SRTD: for better electron position.
2. Moving RCAL beampipe hole: 20x20 -> 10x20cm
3. Beam pipe CAL (H1 Better RCAL)
4. FWD plug CAL
5. Micro vertex detector (MVD)
6. Straw Tracker at FWD
7. Very FWD neutron/ proton spectrometer

Summary

- HERA and ZEUS/H1 experiments
  - Collider = x100 extended region in Q^2 and x.
  - Precise measurement of proton structure: QCD is now high preciesion physics.

- (With lack of signature of new physics), we extended the measurements to lower-x region. High performance detectors to measure the low-angle scattered electron are very important.

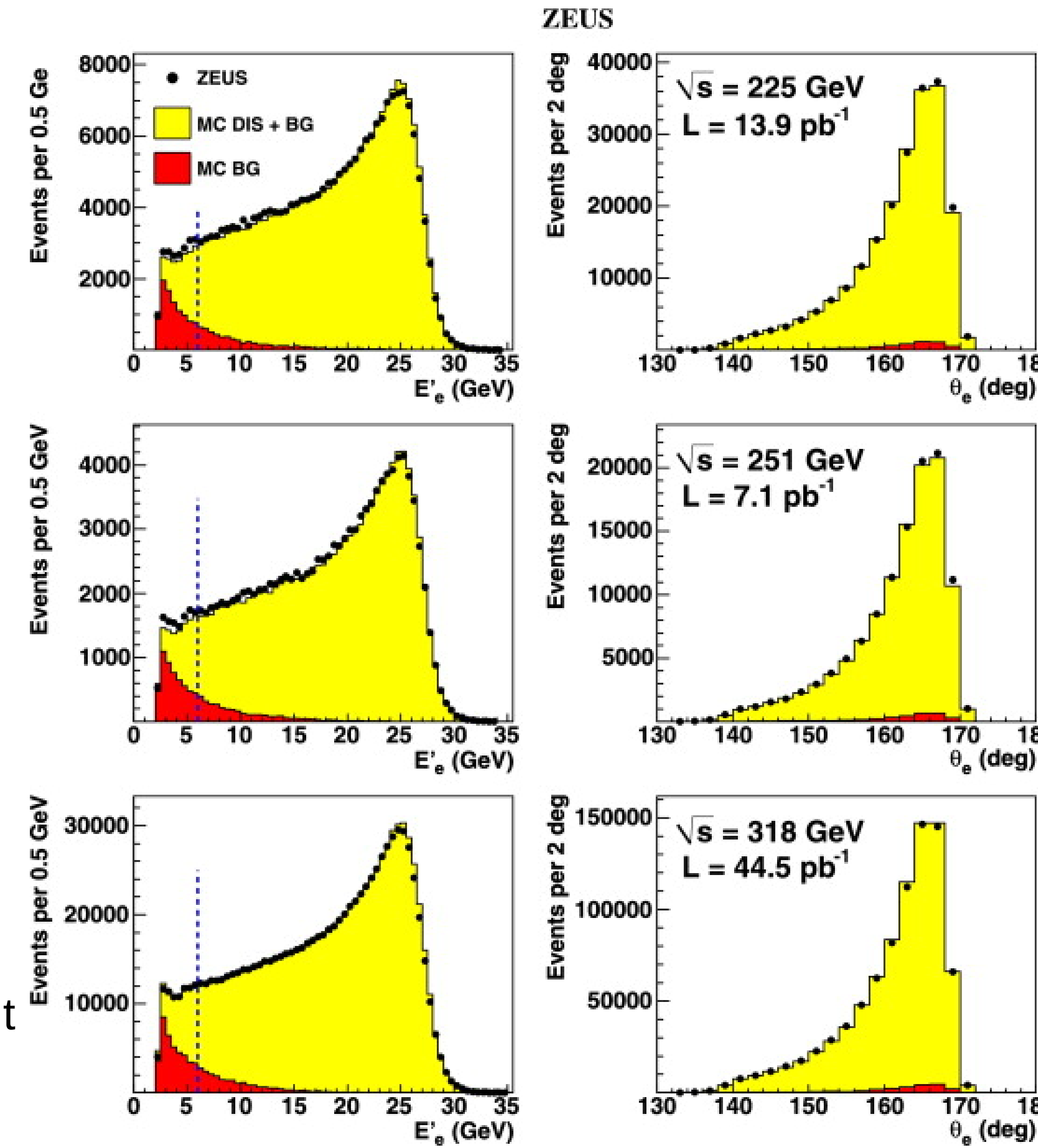
Backgrounds (Example)

ZEUS FL paper:
PL B682 (2009) 8-22

- Electron identified with CAL
- Some hits in the trackers (CTD/MVD)
- No charge/momentum measurement with track

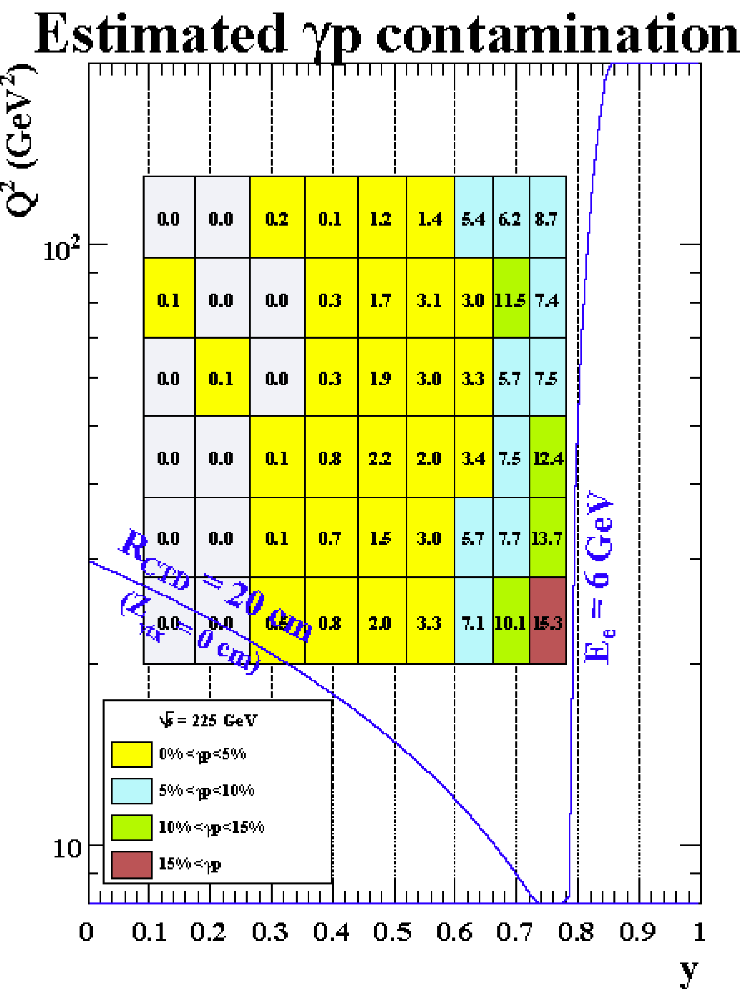
As Low-x -> low E_e Background is severer for low-x
The main background is Photoproduction events. (the scattered electron escaped in the beampipe. Electron/positron from pi0 Probably from photon remnant

ZEUS measurements are for Q^2>28GeV^2. The limit mainly come from, Ee thresholds and CTD/MVD hit requirement (i.e. threshold in the scattered angle)



Php-background

http://www-zeus.desy.de/physics/sfe/theses/shimaFL.pdf



(c) LER

>10% background
for highest low-x bin