H1/ZEUS Review 2010

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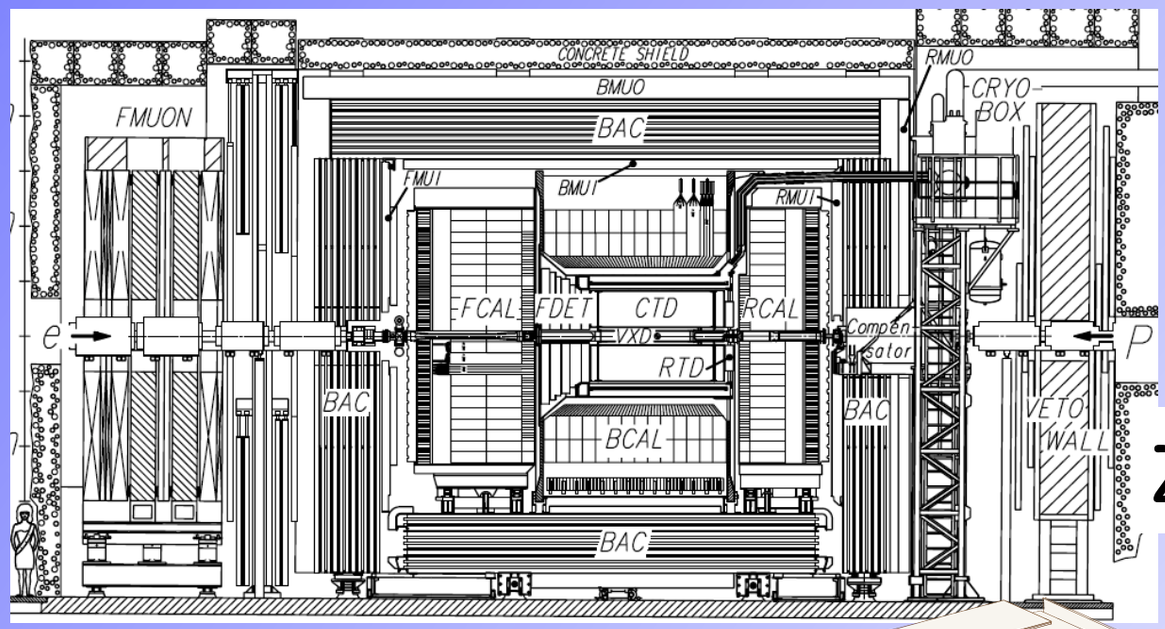
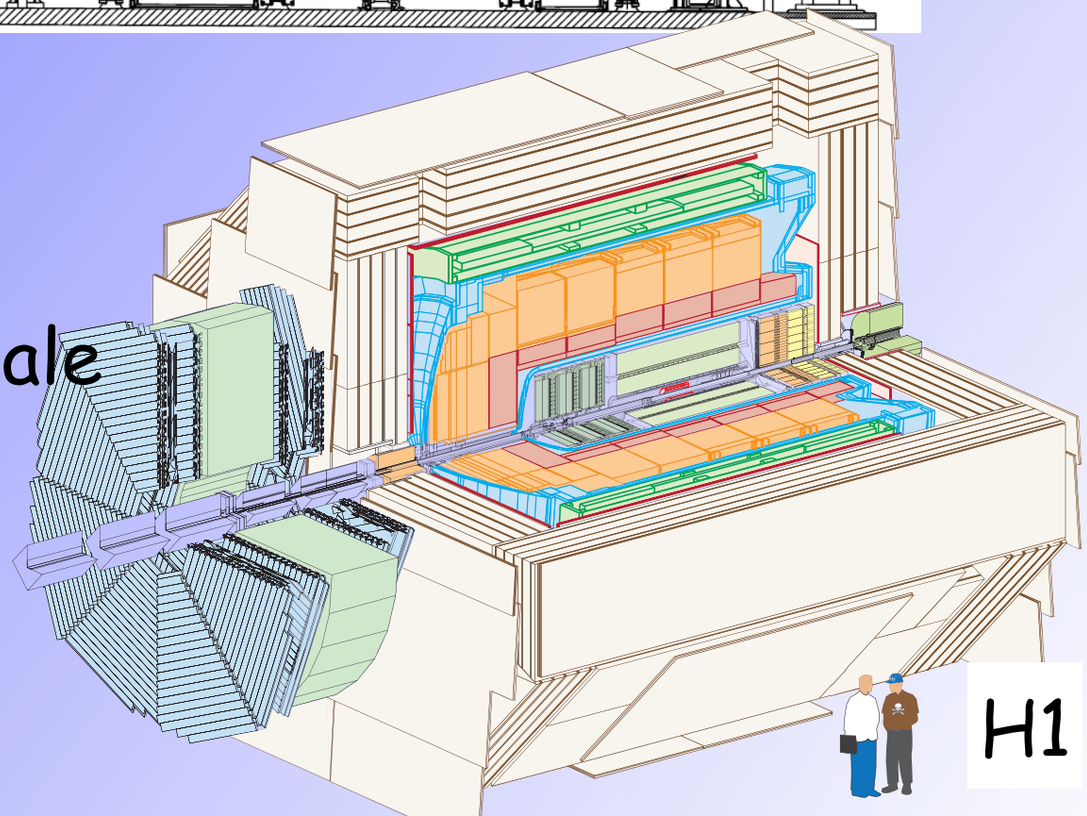
MPI für Physik, München, Dec. 20, 2010

- Introduction
- NC & CC Cross Sections
- HERAPDFs
- $F_L(x,Q^2)$
- Total γ p cross section
- Improving the hadronic energy scale
- Multijet cross sections
- Summary

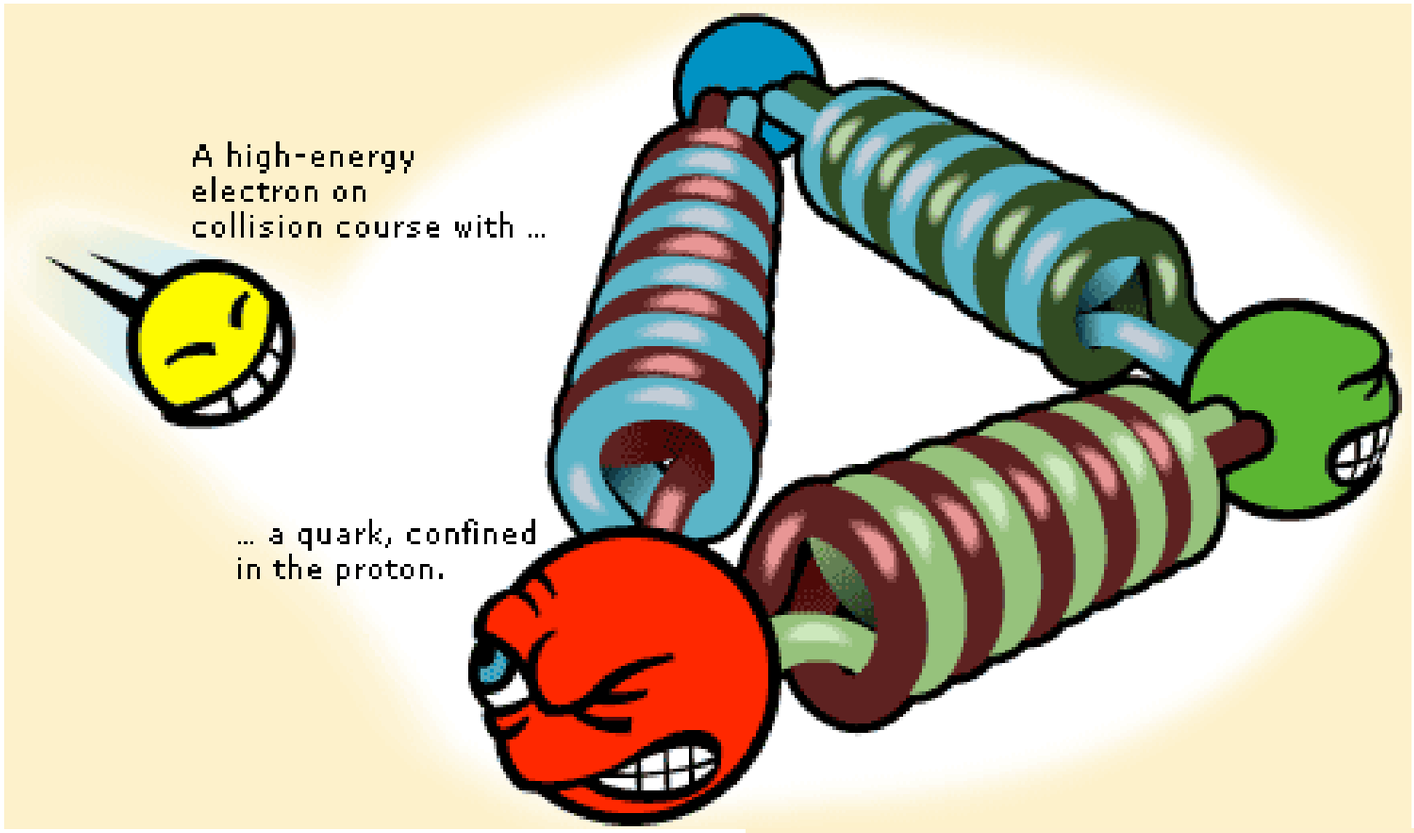


ZEUS



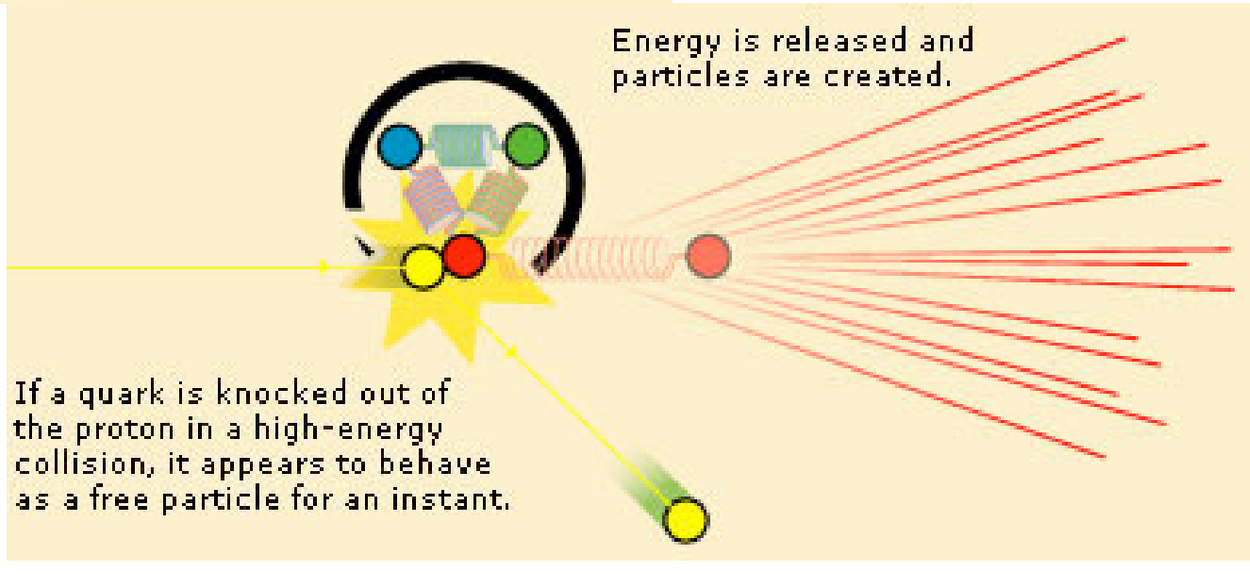
H1

DIS as viewed by the RSAS

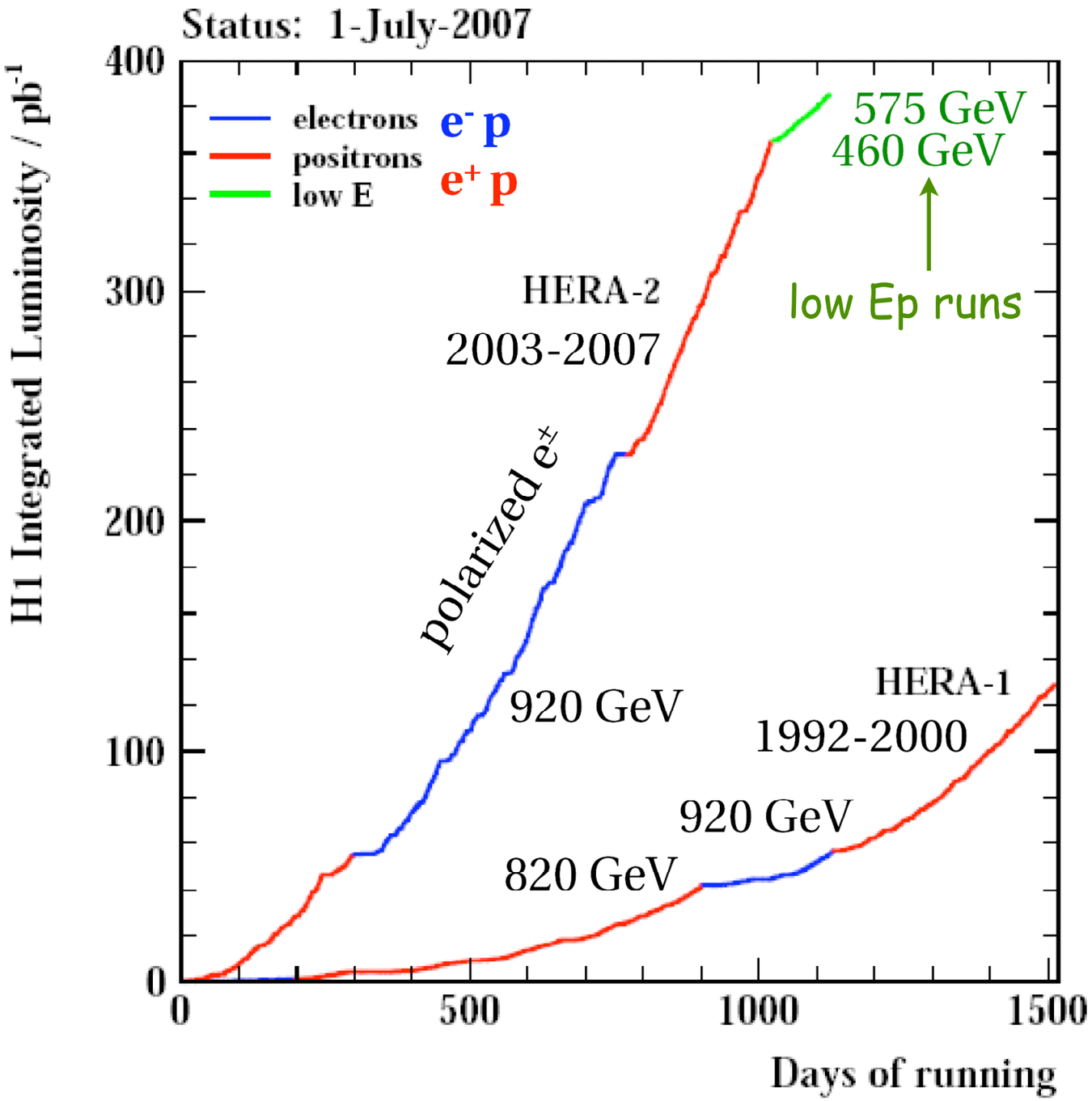


Inside the proton

The three quarks within the proton are held together by the powerful force mediated by the gluons, depicted here as coiled springs. As the distance between the quarks increases, so does the force between them.



HERA-1 and HERA-2: '92-'07



ZEUS, lumi error reduced to 1.8% !

HERA-1: '92-'00

HERA-2: '03-'07

- upgrade of collider & exp.
- 3-4 x luminosity
- longitudinal polarization of lepton beams
- low Ep runs to measure F_L
  $< P_e > 30 - 40\%$

H1+ZEUS in total ~ $1 fb^{-1}$

about equally shared between

- the 2 experiments
- e^+p and e^-p
- positive and negative P_e

Group Members: H1/ZEUS

Director: Allen Caldwell

External scientific member

Halina Abramowicz

Guest:

Aharon Levy (Tel Aviv U, new ZEUS spokesperson)

Staff:

Iris Abt (project leader)

Vladimir Chekelian (project leader)

Günter Grindhammer (QCD convener)

PostDocs:

Burkard Reisert (physics coordinator)

William Schmidke

PhD students:

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Aziz Dossanov

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Daniel Britzger (HH U, DESY)

Vladimir Drugakov (Minsk/DESY)

P. Devgun (Punjab U)

I. Singh (Punjab U)

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Secretarial support:

Franziska Happel (until 11/10)

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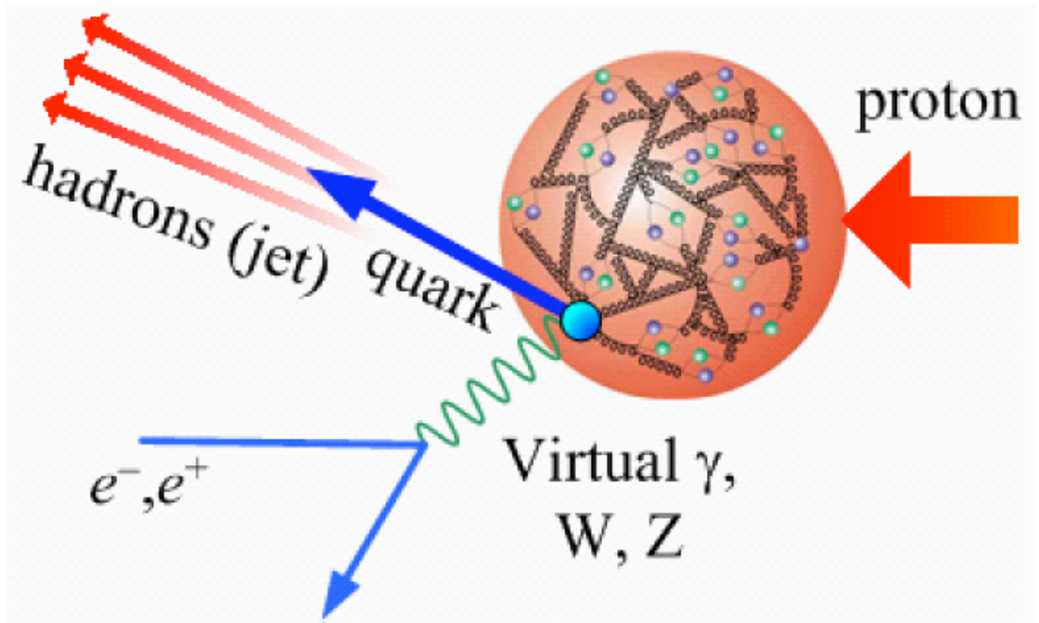
Deep-Inelastic Scattering (DIS)



$Q^2 = -q^2 = -(k-k')^2$ (momentum transfer)^2

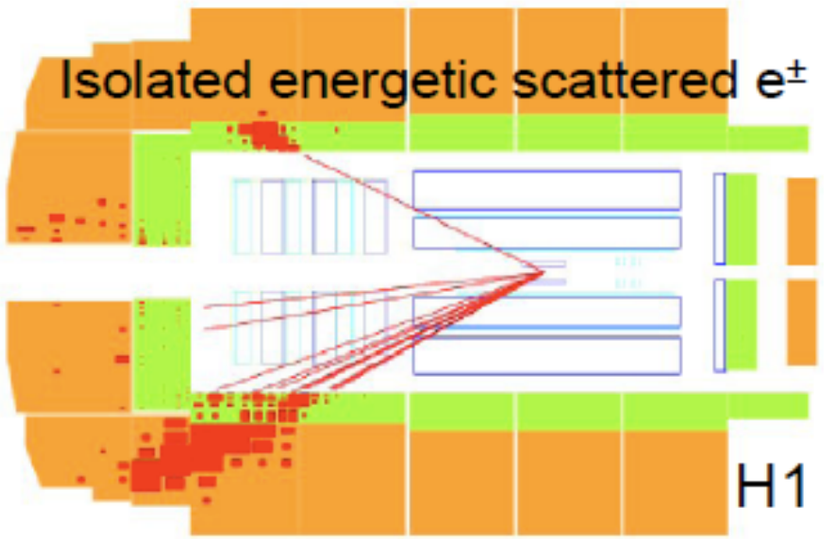
$y = P\cdot q / P\cdot k$ (rel. energy transfer to p)

$x = Q^2/(2P\cdot q)$ (momentum fract. of p carried by interacting parton in LO)

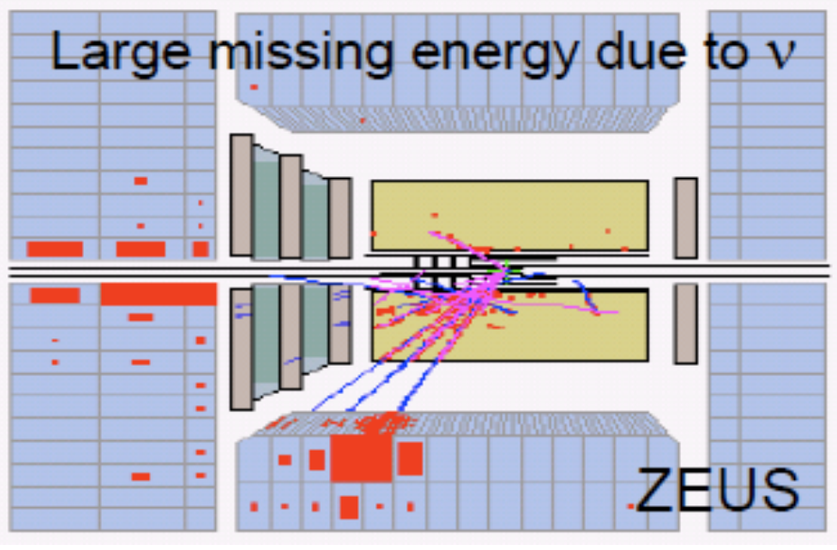
$s = (k+P)^2$ and $Q^2 = sxy$

for fixed s only 2 independent variables

γ, Z : NC e p → e X



$W^{\pm}$: CC e p → ν X



DIS Cross Sections & Proton Structure

➢ Neutral Current: $e^{\pm} p \rightarrow e^{\pm} X$

$$\frac{d^2\sigma^{e^{\pm}p}}{dxdQ^2} \propto \frac{2\pi\alpha^2}{xQ^4}\left[Y_+ F_2(x,Q^2) \mp Y_- xF_3(x,Q^2) - y^2 F_L(x,Q^2)\right] \quad Y_{\pm} \equiv 1 \pm (1-y)^2$$

QPM:
$$\begin{cases} F_2(x,Q^2) \propto x\sum_f q_f(x,Q^2) + \bar{q}_f(x,Q^2) & \text{Dominant contribution} \\ xF_3(x,Q^2) \propto x\sum_f q_f(x,Q^2) - \bar{q}_f(x,Q^2) & Z/\gamma \text{ interference} \end{cases}$$

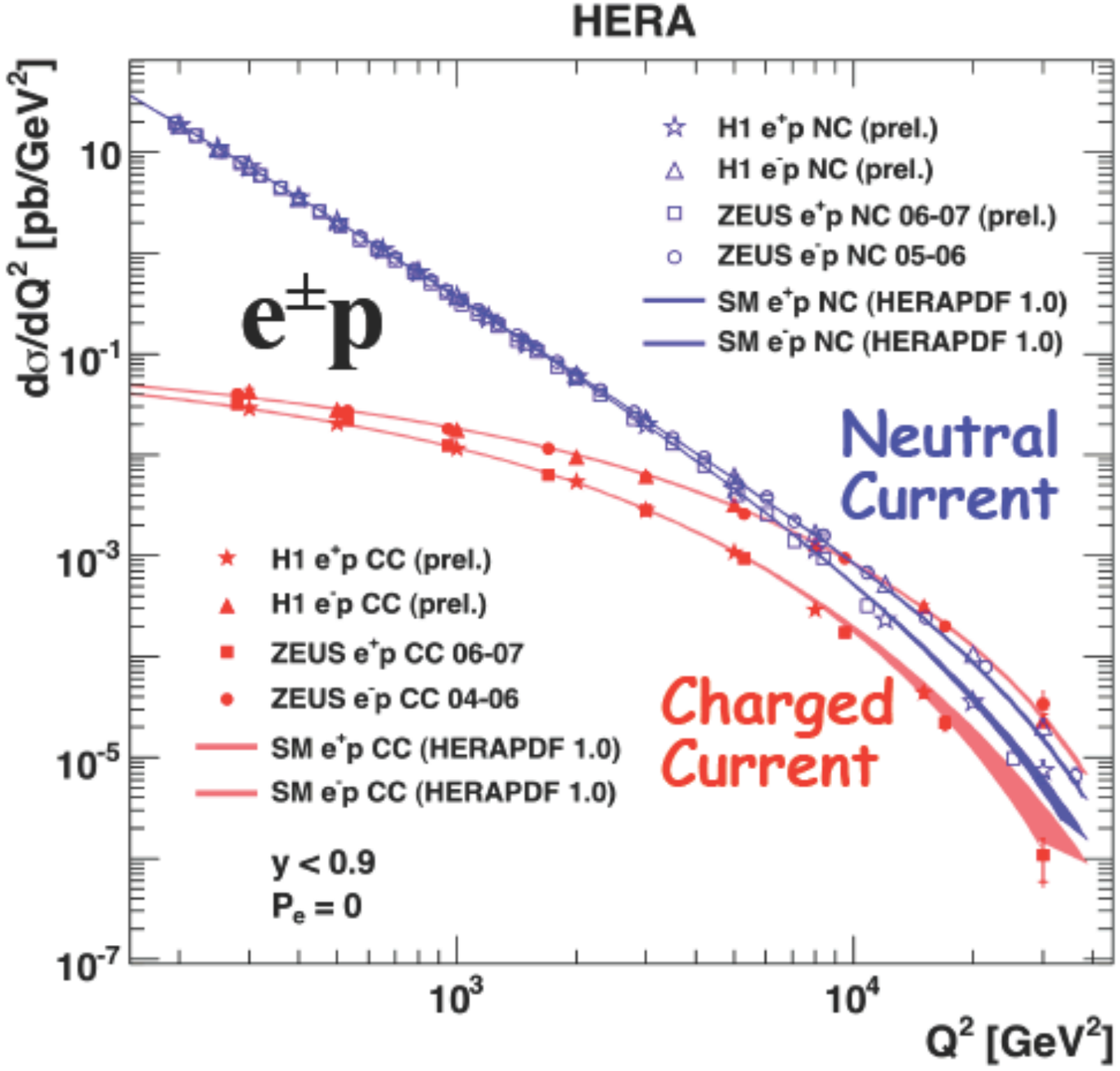
QCD: $F_L(x,Q^2) \propto x\alpha_S g(x,Q^2)$ — Directly sensitive to the gluon & α_S

➢ Charged Current: $e^{\pm} p \rightarrow \nu X$

$\sigma_{CC}^{e^+p} \propto x\{(\bar{u}+\bar{c}) + (1-y)^2(d+s)\}$ — sensitive to d-quark at high x

$\sigma_{CC}^{e^-p} \propto x\{(u+c) + (1-y)^2(\bar{d}+\bar{s})\}$ — sensitive to u-quark at high x

Electroweak Unification

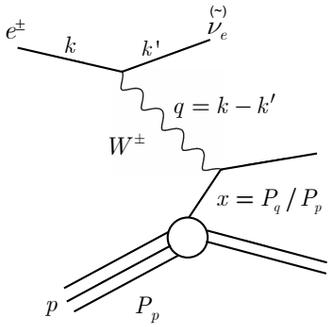


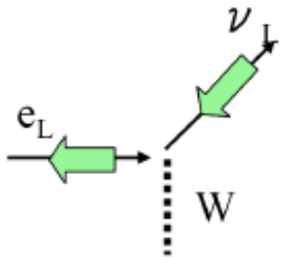
- NC: low Q^2: γ exchange
- high Q^2: Z/ γ interf.
  - constructive in e-
  - destructive in e+
- CC:
  - enhanced due to e^- u
  - suppressed due to e^+ d
- unification: $\sigma_{NC} \approx \sigma_{CC}$ at $Q^2 \geq M_Z^2, M_W^2$

NC/CC well described by the SM

quarks are point-like down to 1/1000 of the proton radius

Are there right-handed weak currents ?





in SM weak CC is purely left-handed (V-A)

Measure the polarization dependence of the CC cross section

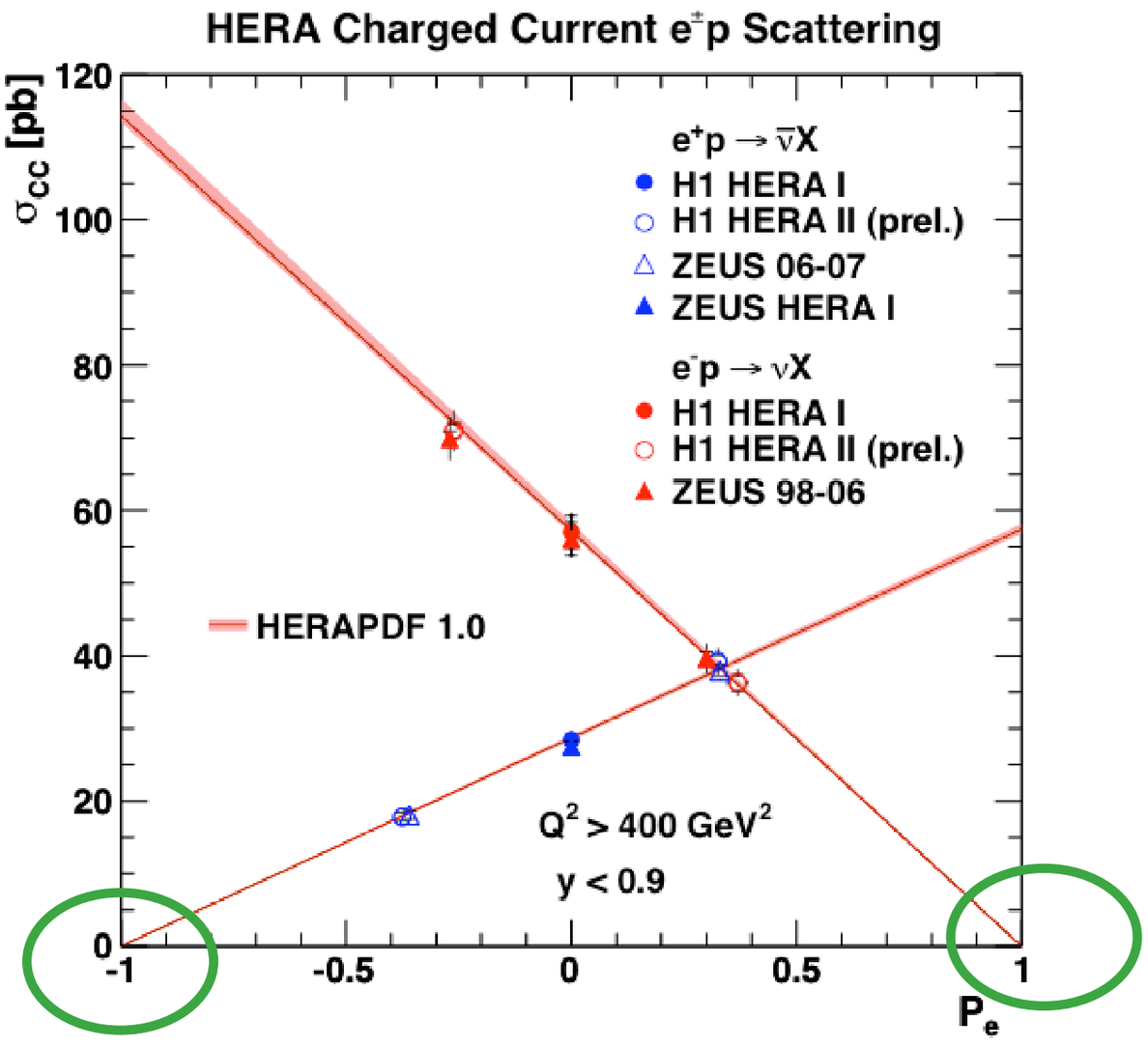
$$\sigma_{CC}^{e^{\pm}p} = (1 \pm P_e)\sigma_{CC}^{e^{\pm}p}(P_e = 0)$$

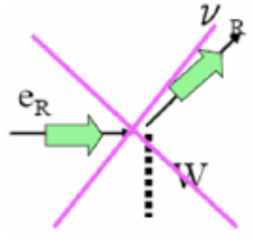
$P_e = (N_R - N_L) / (N_R + N_L)$

- linear dependence on P_e
- SM: $\sigma_{cc}^{+}(P_e = -1) = 0$

  $\sigma_{cc}^{-}(P_e = +1) = 0$

σ_{CC} (Q^2 > 400 GeV^2, y < 0.9)





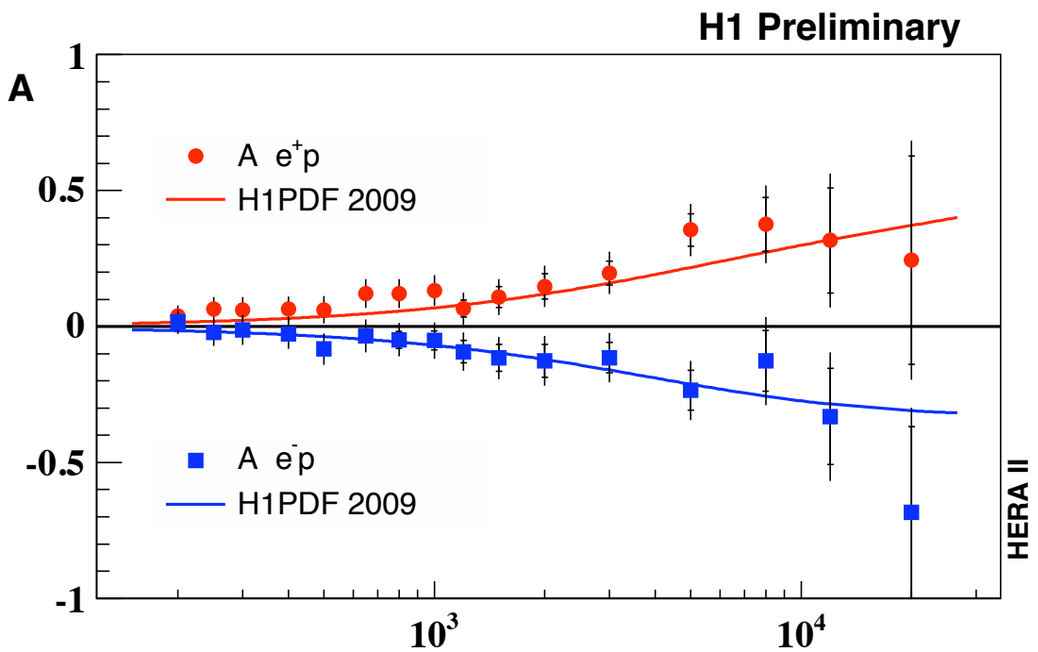
no right-handed weak charged current

Polarization Asymmetry in NC

$$A(e^{\pm}p) = \frac{2}{P_R - P_L}\,\frac{\sigma^{\pm}(P_R) - \sigma^{\pm}(P_L)}{\sigma^{\pm}(P_R) + \sigma^{\pm}(P_L)} \simeq \mp\kappa a_e \frac{F_2^{\gamma Z}}{F_2}$$

A(e±p) depends on the d/u ratio of the valence quarks at large x

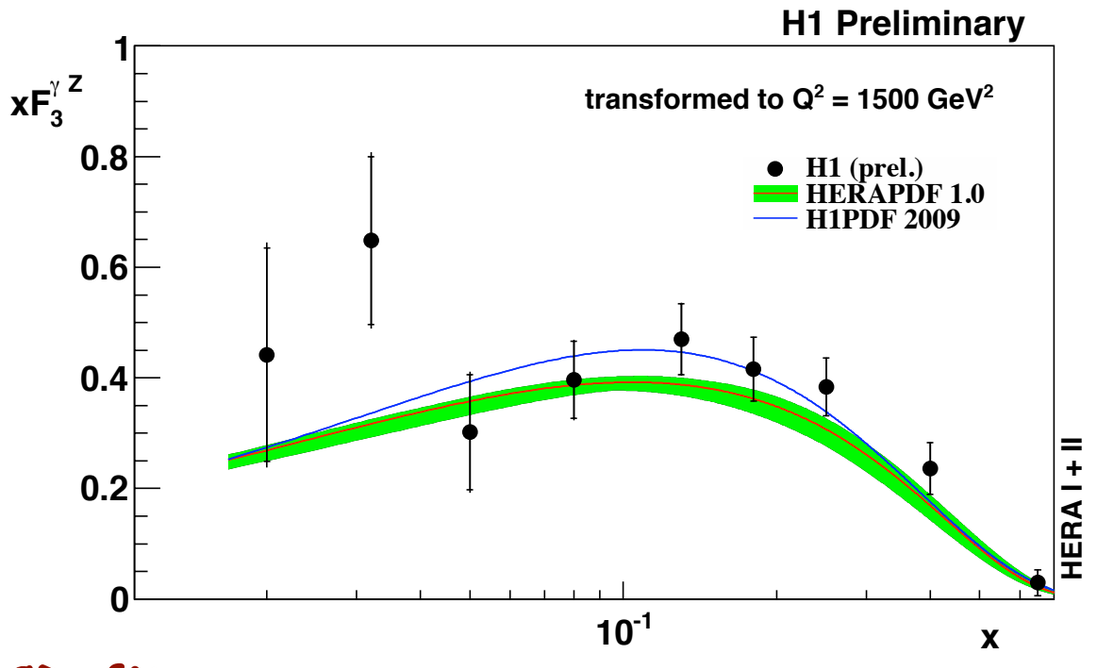
$$A(e^{\pm}p) \simeq \pm\kappa\,\frac{1 + d_v/u_v}{4 + d_v/u_v}$$



for unpolarized leptons and neglecting pure Z exchange

$$xF_3^{\gamma Z} \simeq \frac{2x\tilde{F}_3}{\kappa} = \frac{Y_+}{\kappa Y_-}\left[\sigma_r(e^-p) - \sigma_r(e^+p)\right]$$

which is directly sensitive to the valence quarks



all measurements are consistent with the NLO QCD fits

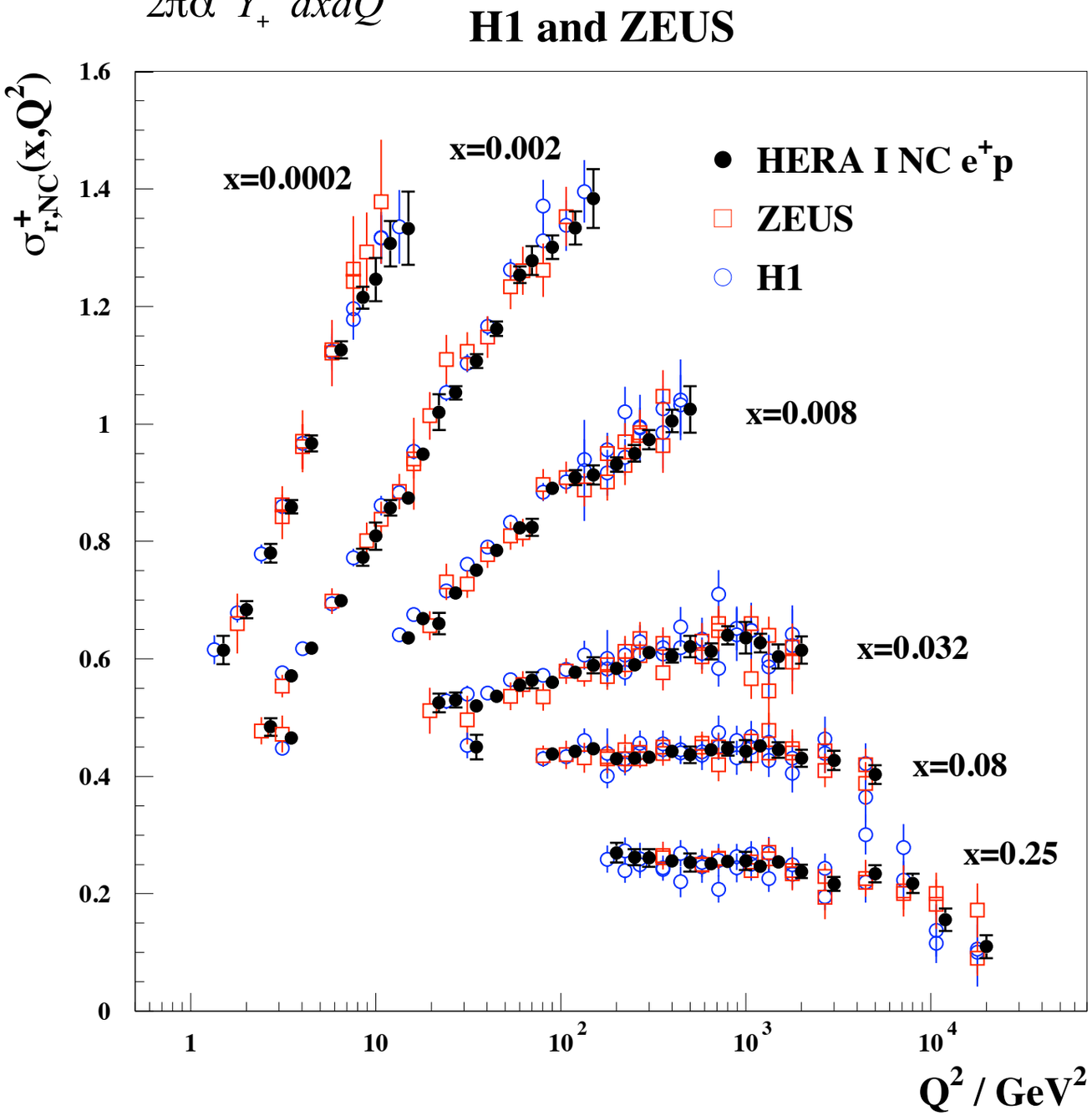
H1 & ZEUS Data Combined

- combine H1 & ZEUS datasets for NC, CC, heavy flavors, ... to obtain ultimate precision via "cross calibration" (taking into account corr. syst. errors to benefit from best features of the 2 complemetary detectors)

- published: comb. of inclusive NC & CC data from HERA-1 (1402 measurements, 110 corr. sources of syst. errors)

- preliminary: comb. of HERA-2 data and HERA-1 & HERA-2

$$\sigma_r = \frac{xQ^4}{2\pi\alpha^2 Y_+}\frac{d^2\sigma}{dxdQ^2}$$

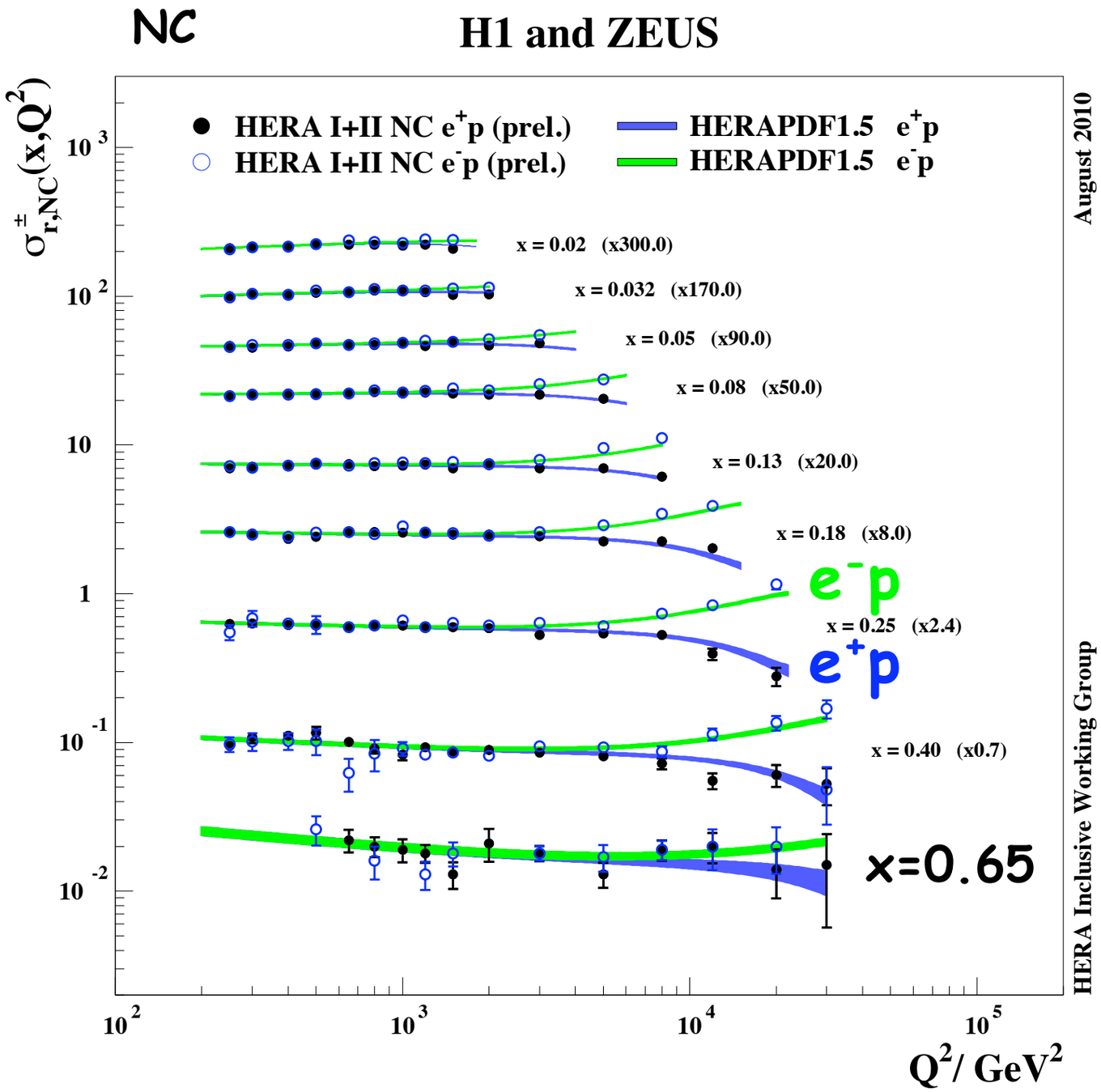


➜ over significant part of the phase space total uncertainties are small (1 - 2%)

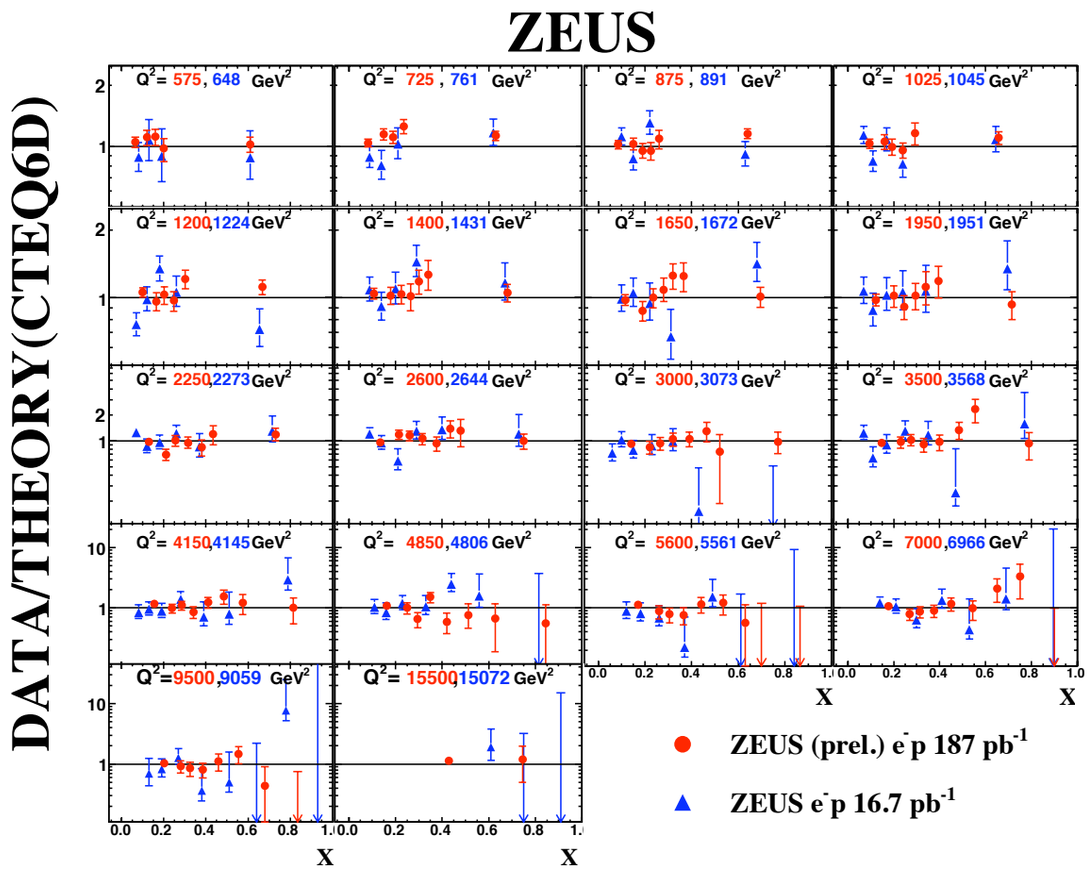
HERA DIS & HERAPDF1.5

$$\tilde{\sigma}^{\pm}_{NC} \equiv \frac{d^2\sigma^{e^{\pm}p}_{NC}}{dxdQ^2}\frac{xQ^4}{2\pi\alpha^2}\frac{1}{Y_+} \equiv \tilde{F}_2 - \frac{y^2}{Y_+}\tilde{F}_L \mp \frac{Y_-}{Y_+}x\tilde{F}_3$$

NC

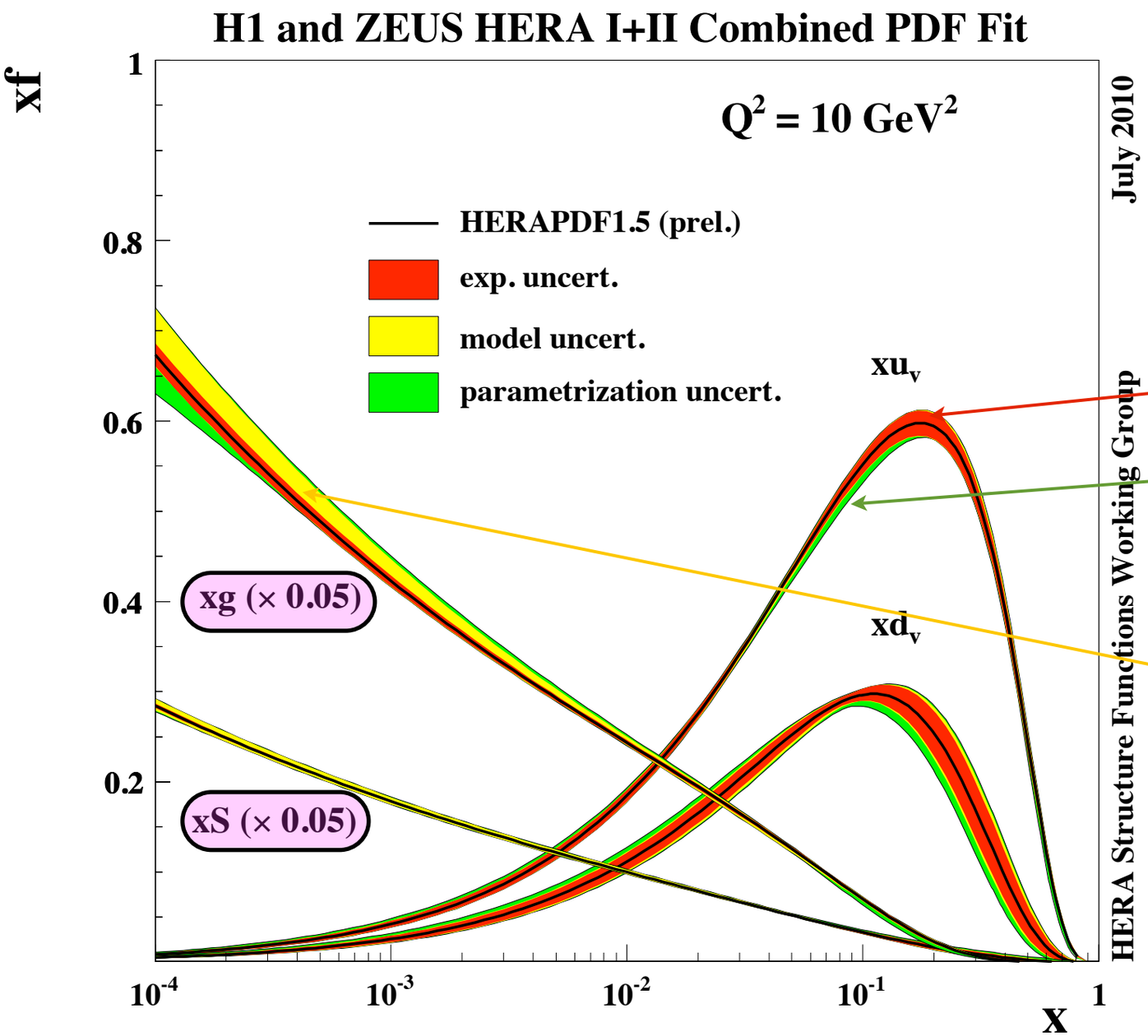


prel. results (data/theory) to access large x up to 1.



QCD and HERAPDF describe HERA NC & CC data very well

HERAPDF 1.5



HERA PDF 1.5:
10 parameter fit to combined HERA data using QCD @ NLO

Experimental uncertainty

Parametrization:

shapes of PDF at starting scale Q_0

Model assumptions:

masses of c, b - quarks,

fraction of strange quarks, $\alpha_s(M_Z)$

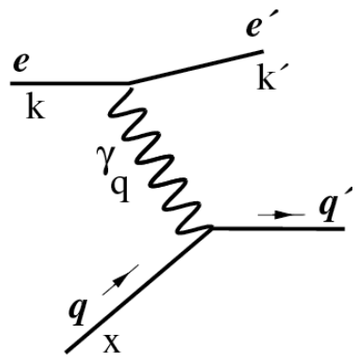
increased range in x (of importance for LHC predictions)

Longitudinal Structure Function

In contrast to F_2, F_L is directly sensitive to the gluon density

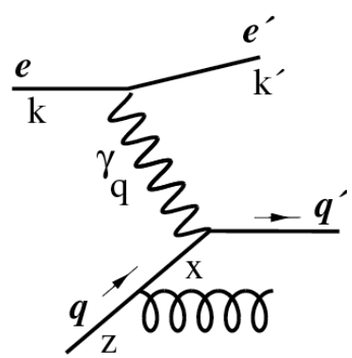
$F_2 \sim (\sigma_T + \sigma_L)$, $F_L \sim \sigma_L$

QPM



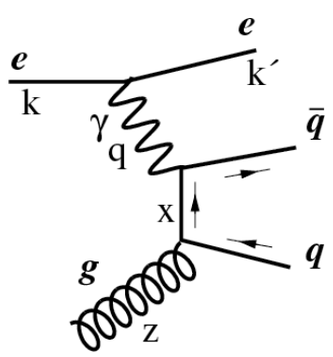
quark helicity $\pm \frac{1}{2}$, F_L=0

QCDC



off-shell quarks may absorb longitudinal photons

BGF



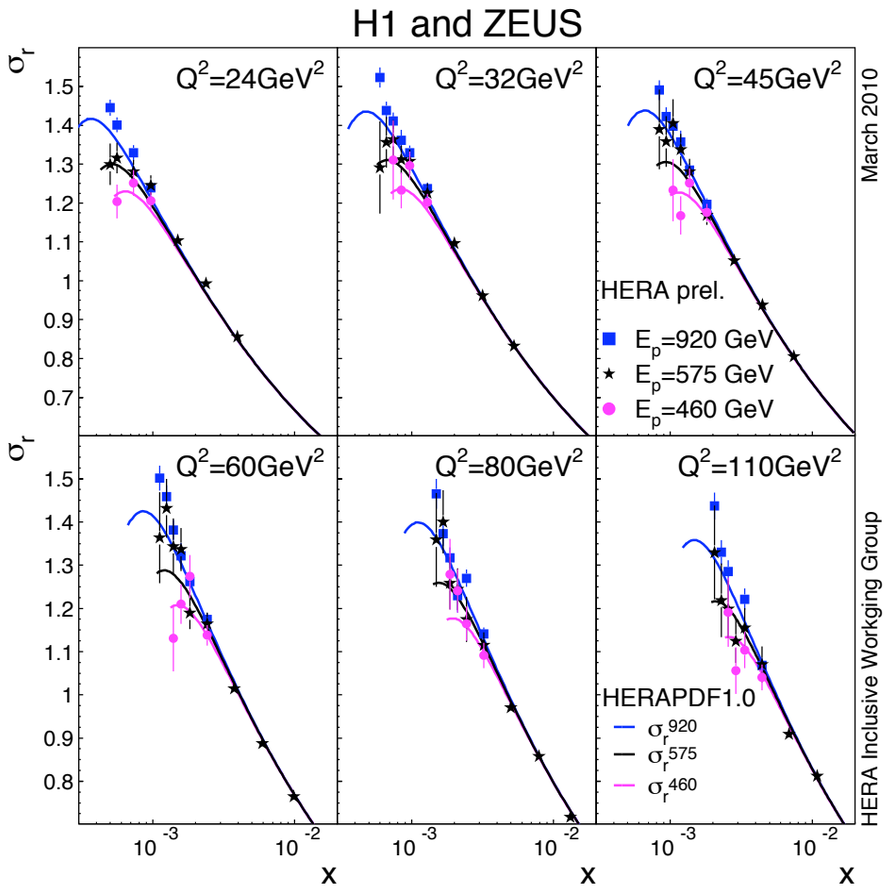
BGF dominant at low Q^2

QCD: $$F_L = \frac{\alpha_s}{4\pi} x^2 \int_x^1 \frac{dz}{z^3} \left[\frac{16}{3} F_2 + 8 \sum_q e_q^2 (1 - \frac{x}{z}) z g(z) \right]$$

quarks radiating a gluon

gluons splitting into quarks

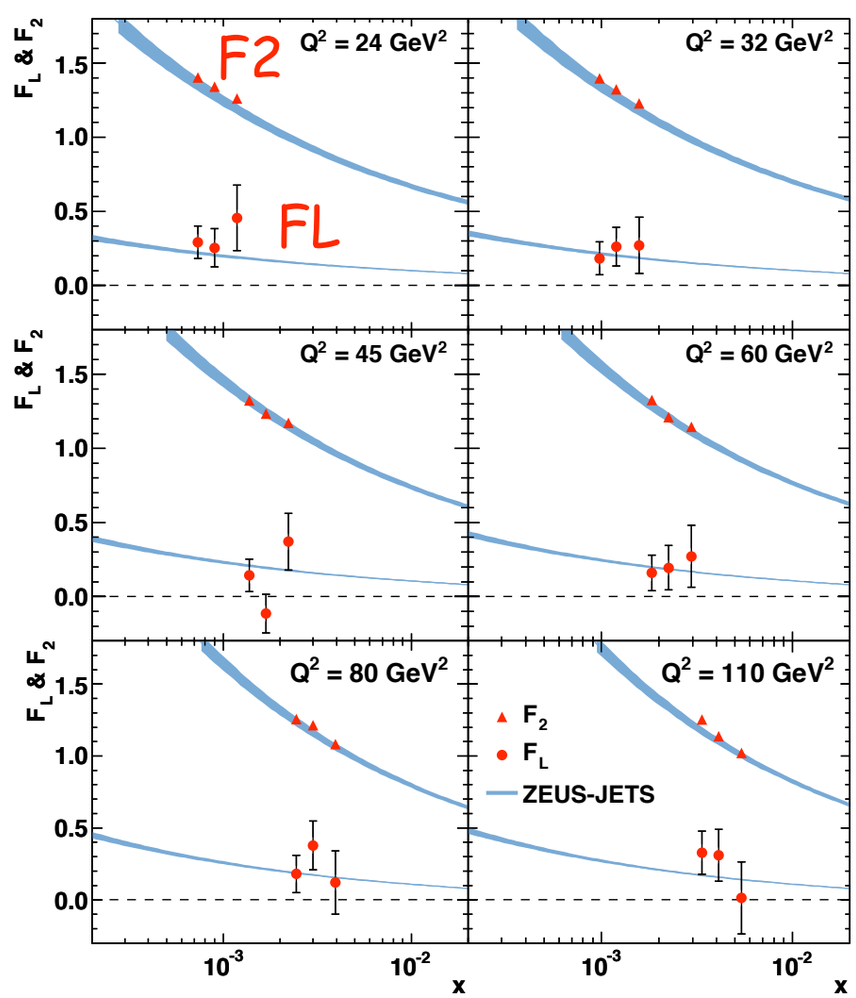
NC Cross Sections and F_L & F_2



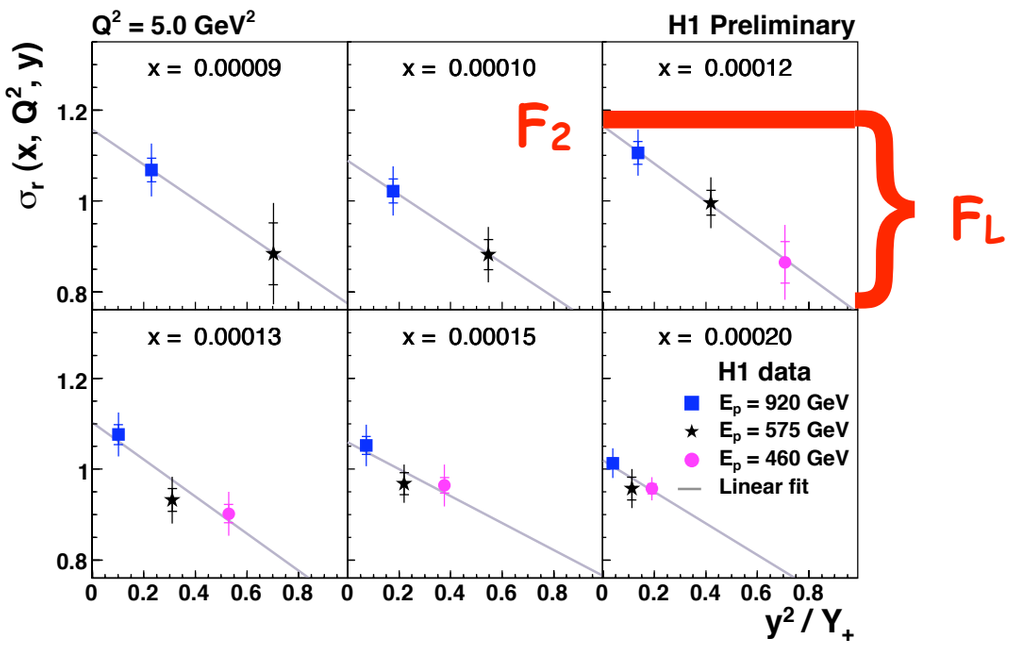
$$\tilde{\sigma}_{NC} = F_2 - y^2/(1+(1-y)^2)\, F_L$$

$y = Q^2 / xs$ ➜ E_p= 460, 575, 920 GeV

or determine F2 & FL from fits to σ_{NC} at different E_p

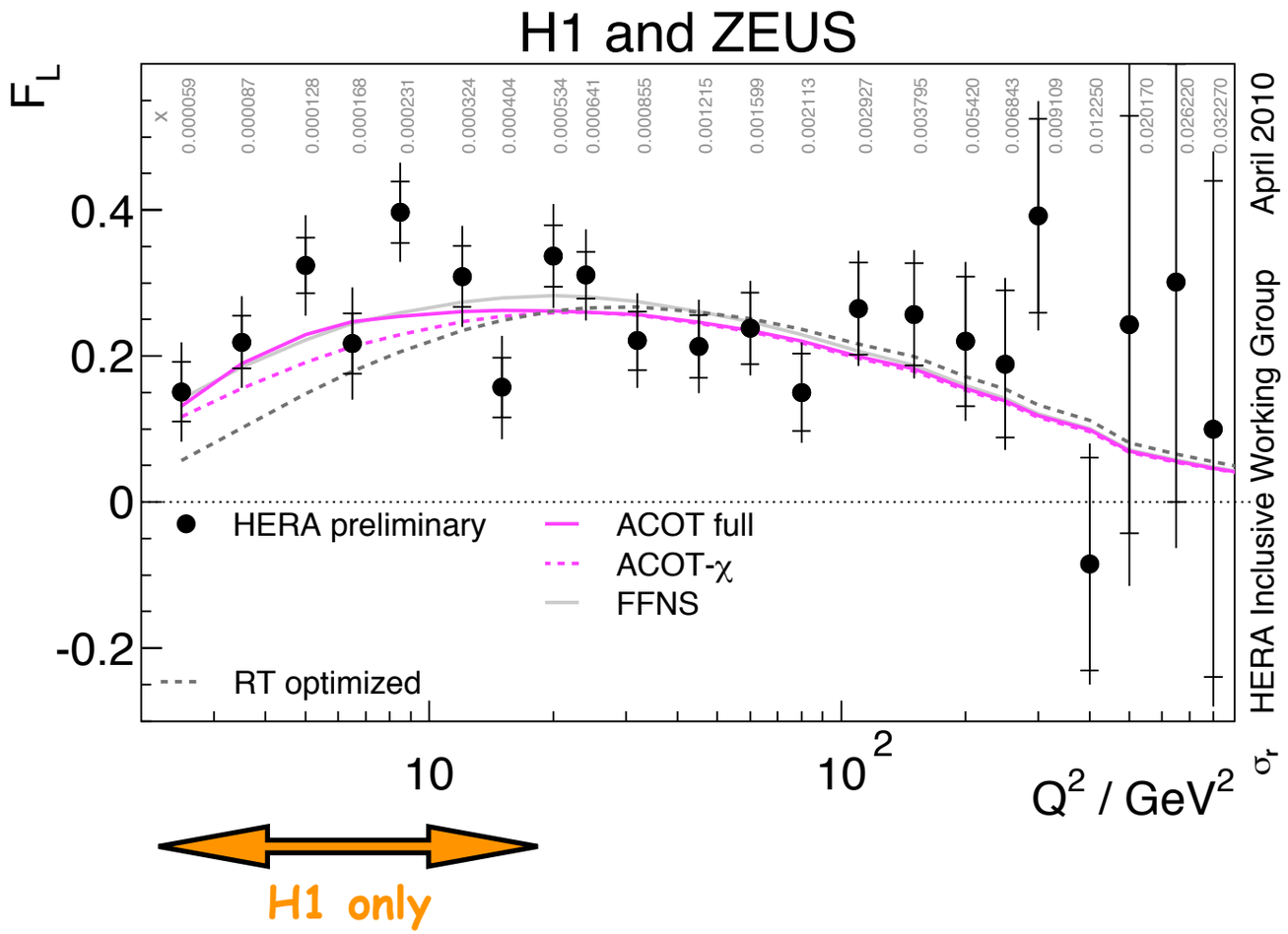


determine F_L and F_2 from linear fits at each x and Q^2



$Y_+ = (1+(1-y)^2)$

Combined H1 & ZEUS Data & FL



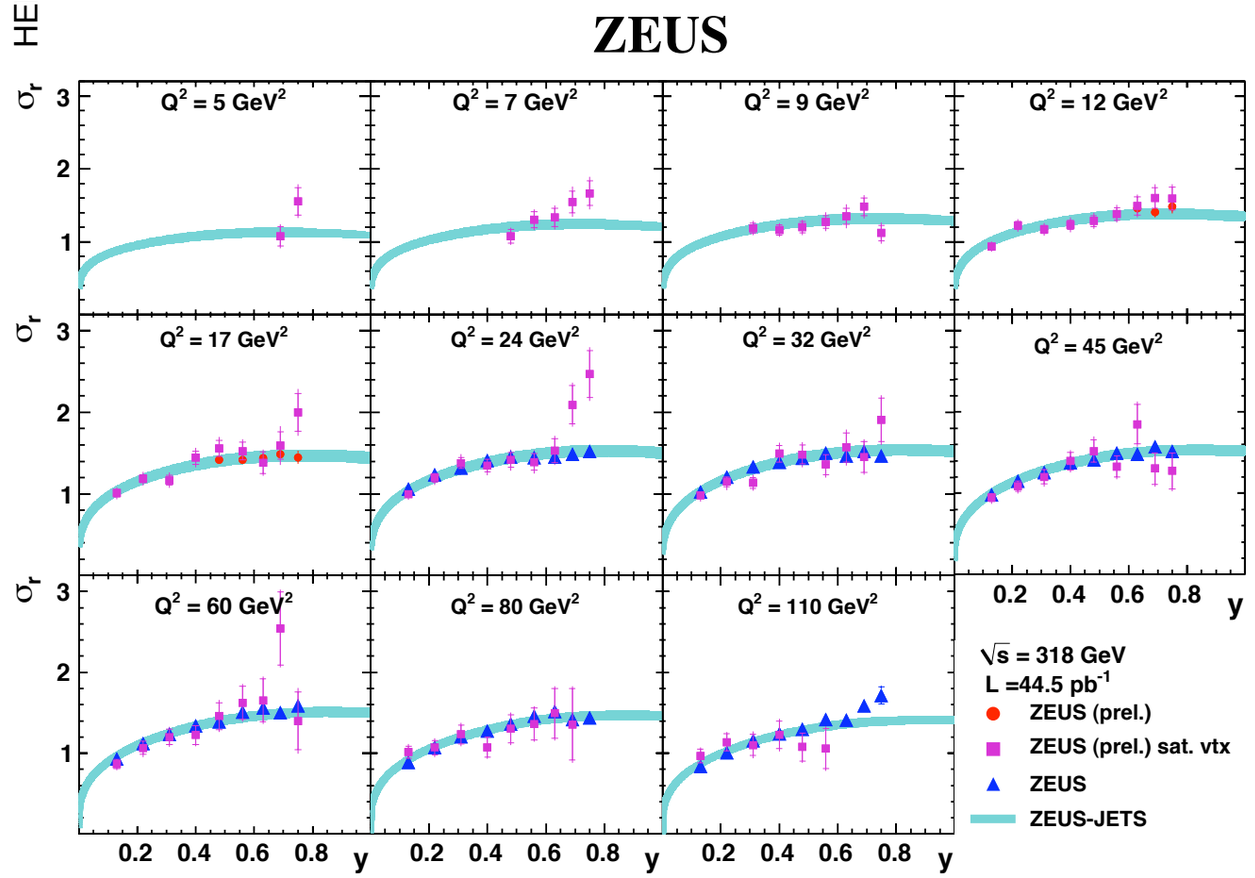
H1 only

F_L data are sensitive to treatment of heavy quarks in HERAPDF fit

F_L consistent with NLO QCD

QCD calculations differ at low Q2

ZEUS accesses low Q^2 by measuring ep interactions at z=+70cm (satellite)

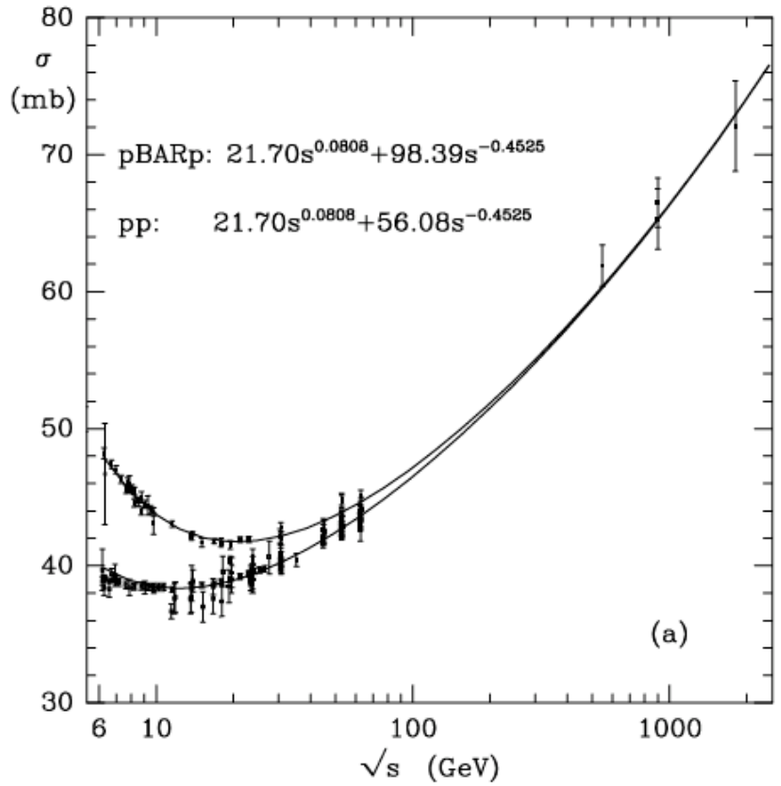


Total γ P Cross Section (ZEUS)

- Donnachie and Landshoff (DL98) found universal behavior of total hadron-hadron cross section: σ_{tot} (had) = $AW^{2\varepsilon} + BW^{-2\eta}$

  with $\varepsilon = \alpha_{IP}(0)-1 = 0.081$ and

  $\eta = 1 - \alpha_{IR}(0) = 0.453$

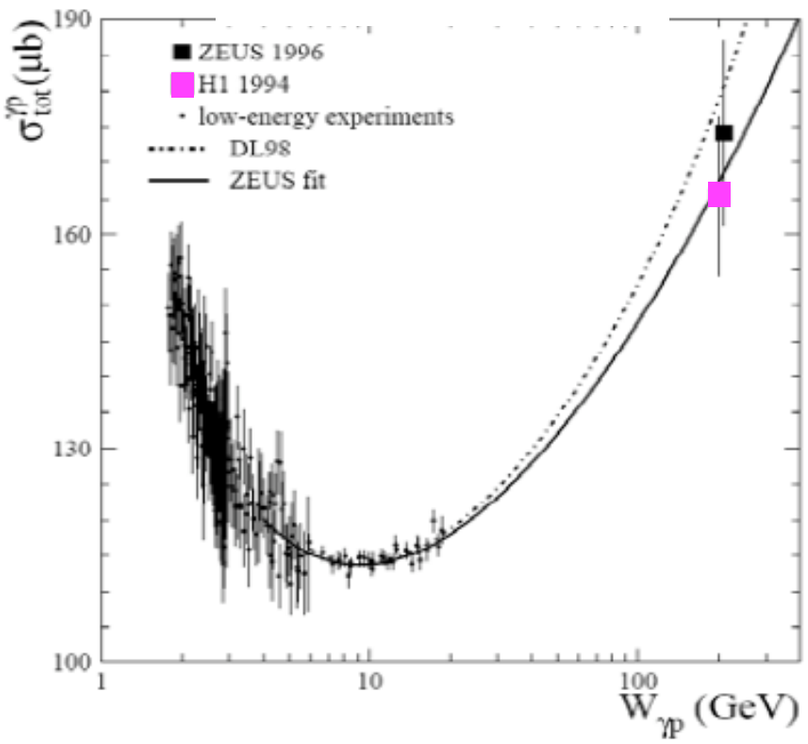


- what is it for γ p at high energies ?

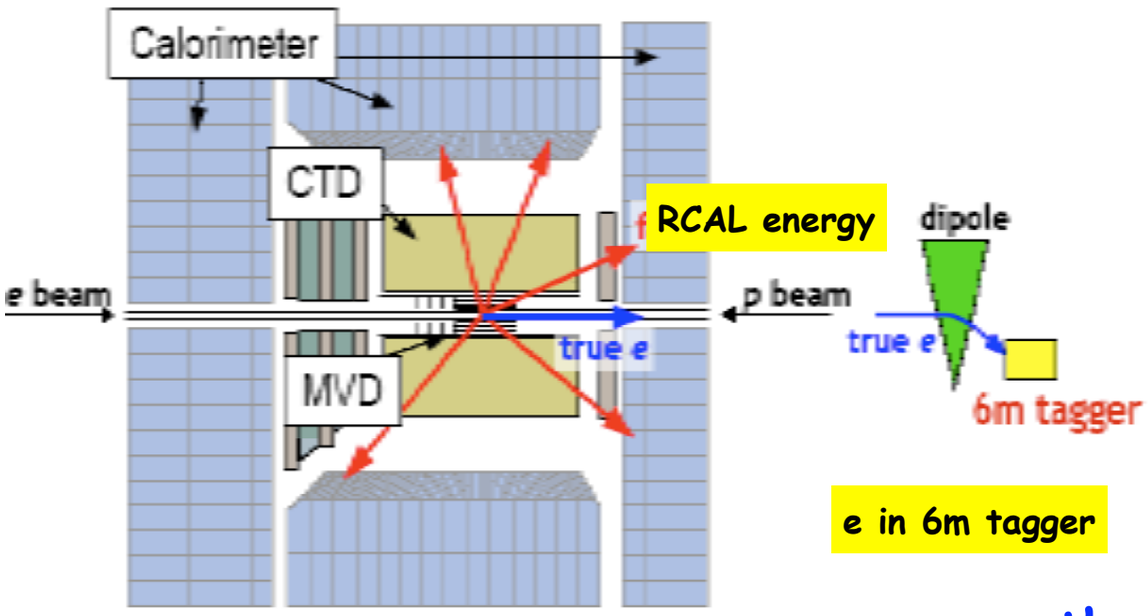
  is the photon behaving like a hadron ?

- it was measured at HERA-1 at one $W_{\gamma p}$ by H1 & ZEUS

H1 & ZEUS



$W_{\gamma p}$ Dependence of $\sigma_{\gamma p,tot}$



e in 6m tagger

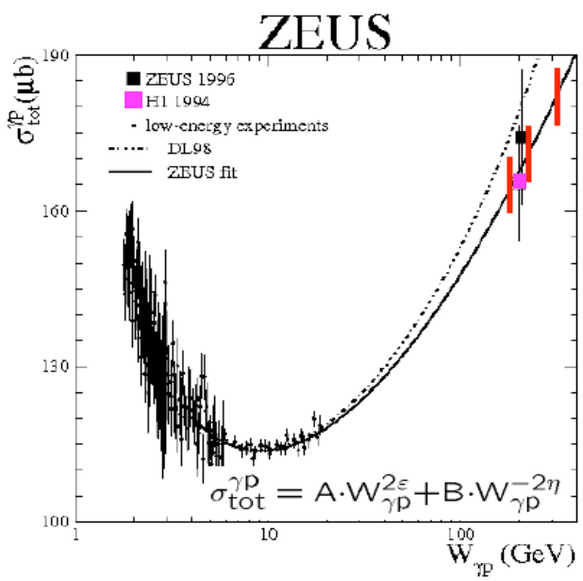
trigger: e in 6m tagger + RCAL energy

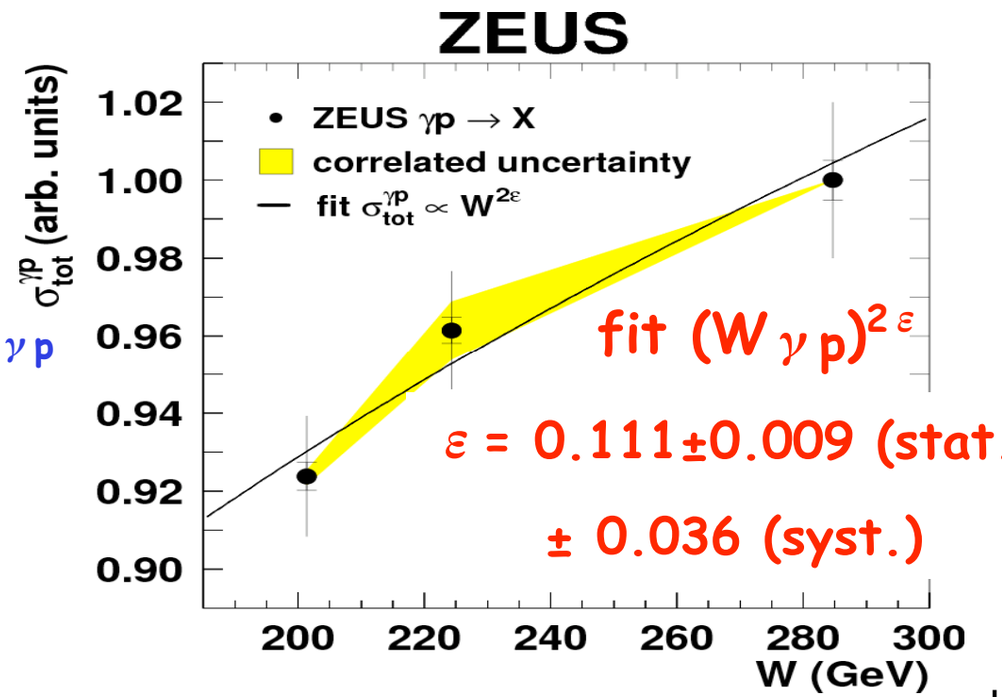
$\sim 10^{-6} < Q^2 < \sim 10^{-3}$ GeV^2

$194 < W_{\gamma p} < 296$ GeV

$\sigma_{ep,tot} = \Phi_\gamma \; \sigma_{\gamma p,tot}$

measure the $W_{\gamma p}$ dependence at 3 points in $W_{\gamma p}$ using E_p = 920, 575 and 460 GeV by measuring $\sigma_{\gamma p,tot}$ at the 2 lower $W_{\gamma p}$ relative to the high one





- First determination of $W_{\gamma p}$ dependence at high $W_{\gamma p}$ in a single experiment
- Measured value of ε is compatible with the energy dependence observed in hadron-hadron coll.

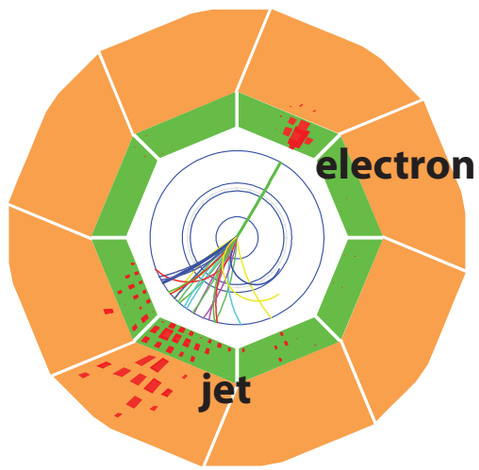
Reducing the jet energy scale uncertainty (H1)

part 1 of Roman Kogler's thesis

work in progress also within our ZEUS group

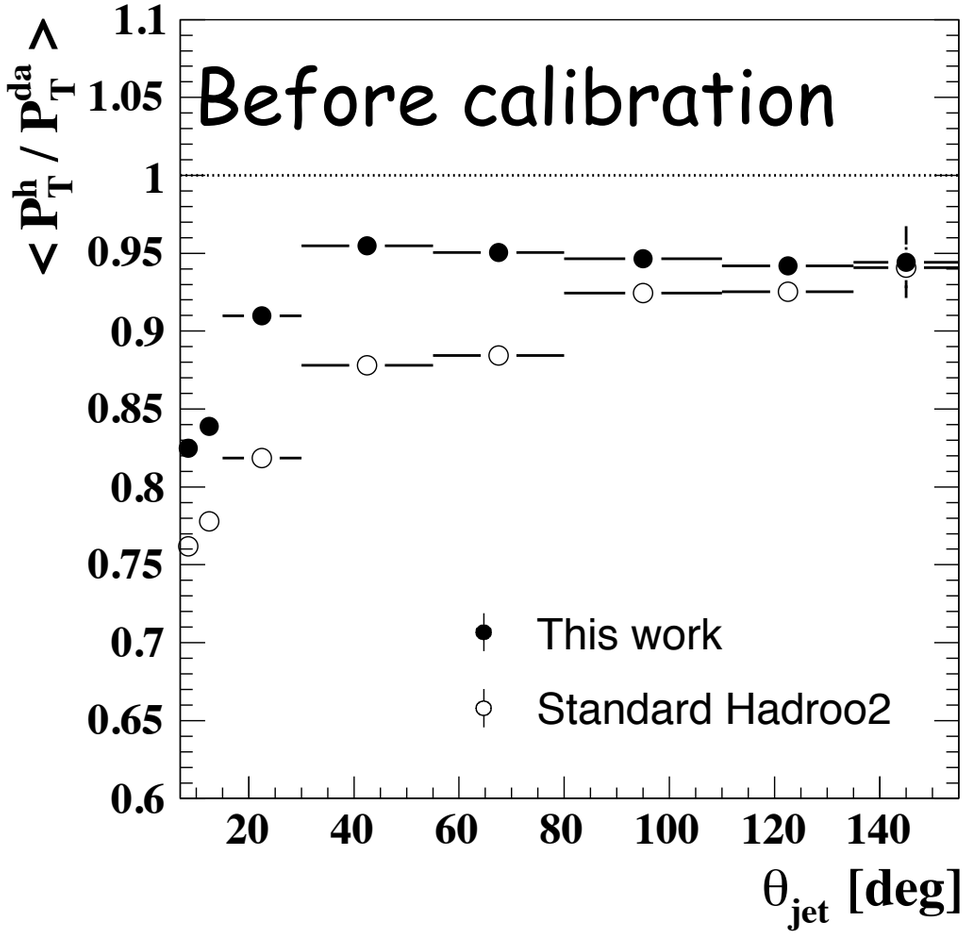
jet/hadronic energy scale uncertainty is dominant exp. uncertainty in measurements of jet cross sections and extractions of α_s

2% (1.5%) uncertainty in (reduced) acceptance achieved so far by H1



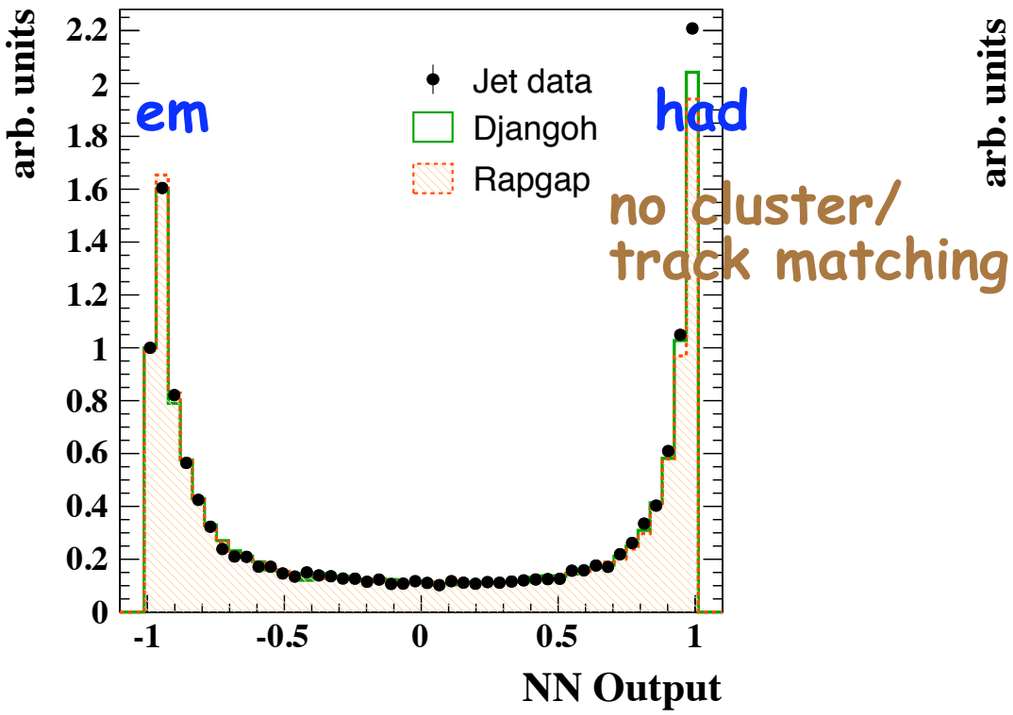
Standard H1 reconstruction (Hadroo2) was optimized to identify em showers, resulting in low efficiency for had showers

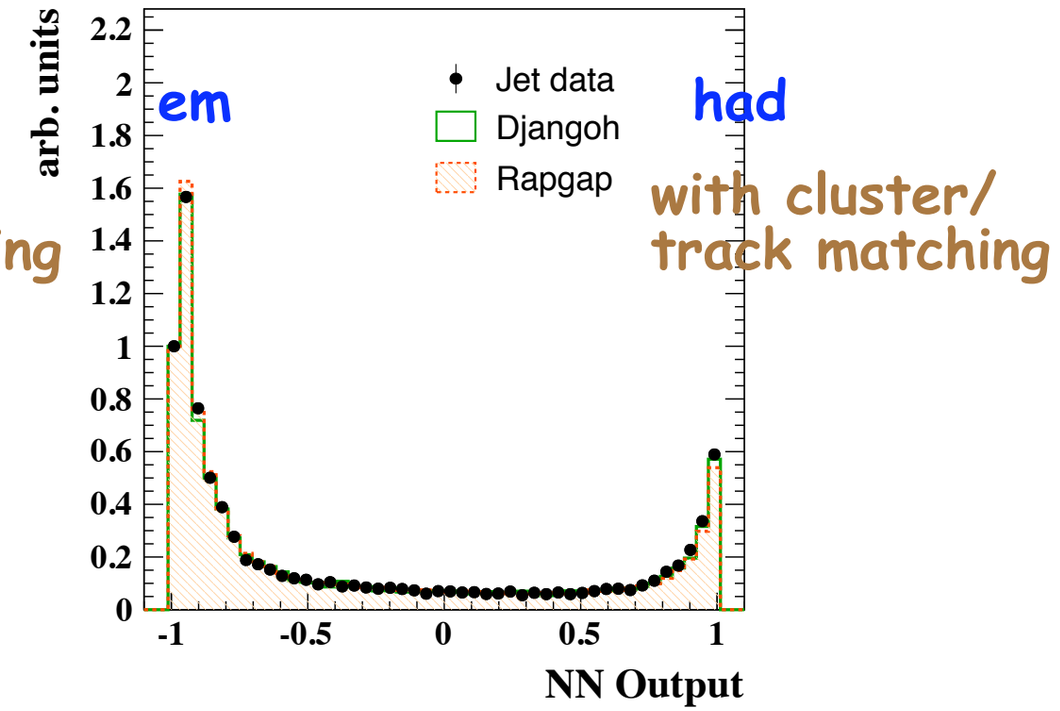
➜ improve em/had shower separation (complex neural network with many cluster shapes/ estimators as input, pre- and postprocessing of input variables, pruning; use energy distribution from particles from jets for training)



New em/had separation

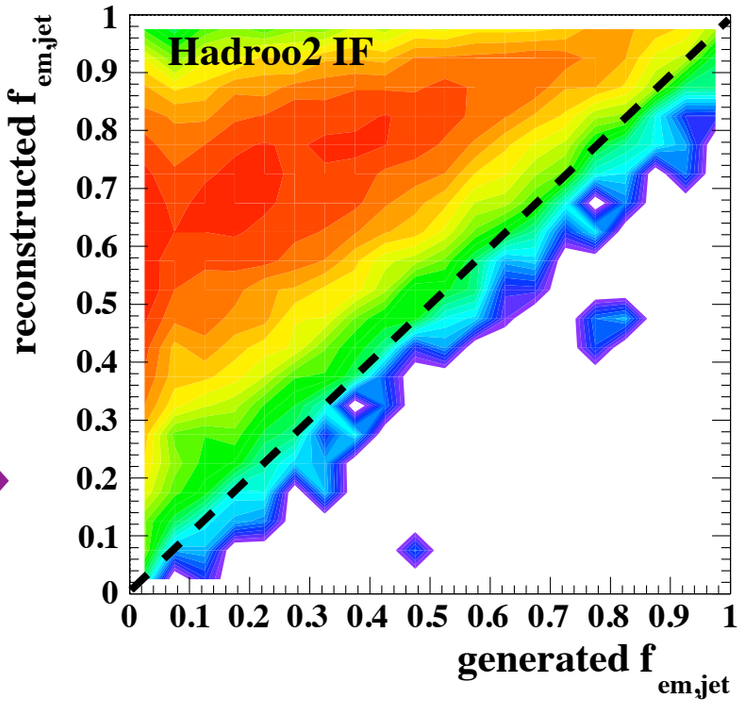
NN ouput for clusters from jet data and from QCD models



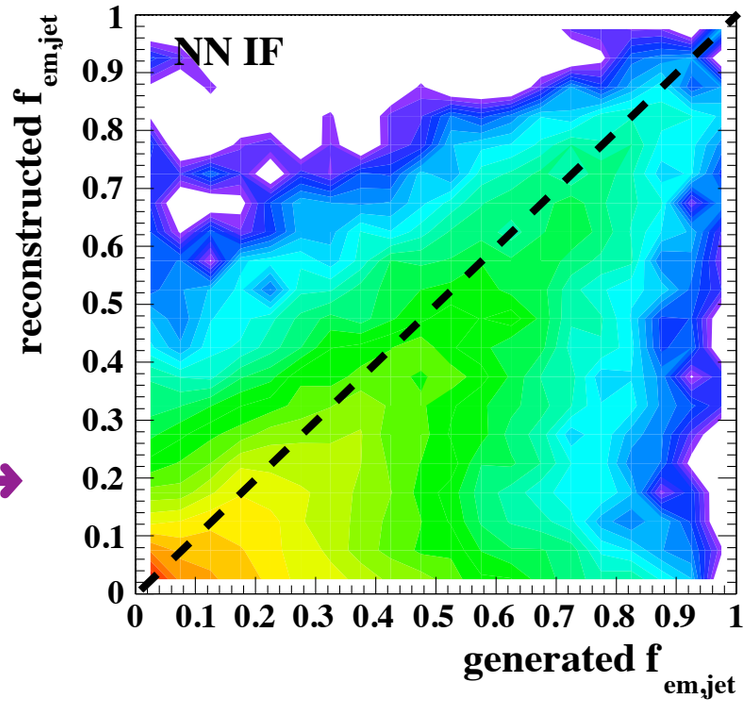


em energy fraction of jets

old →



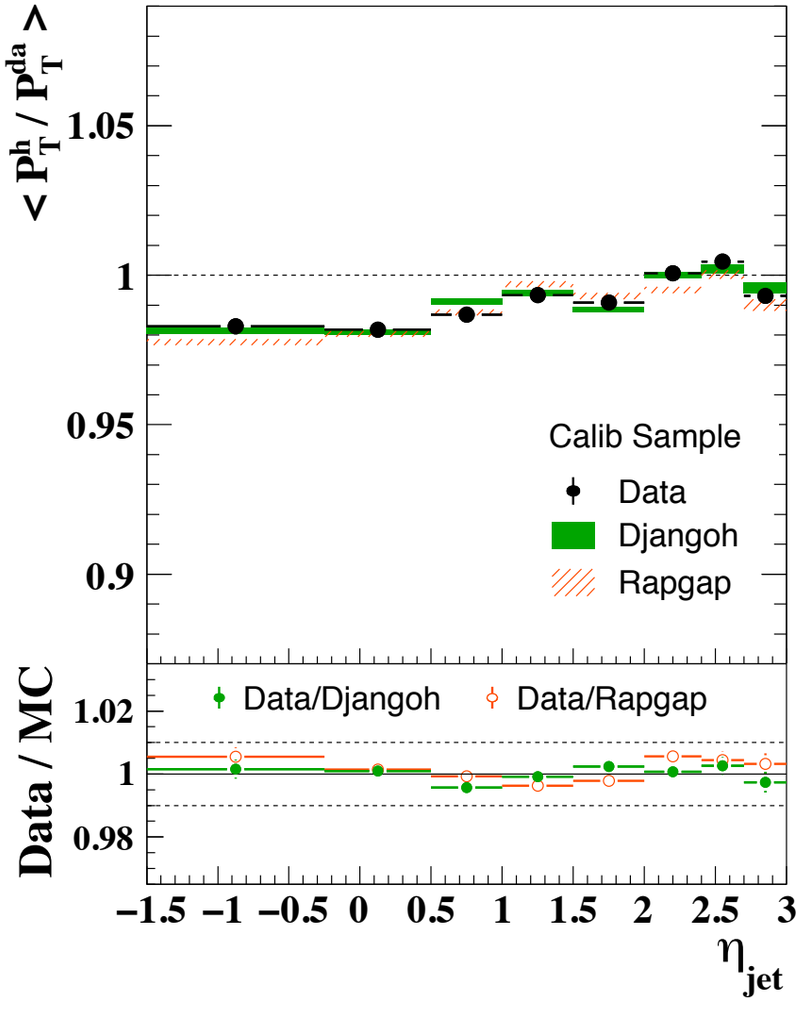
new →

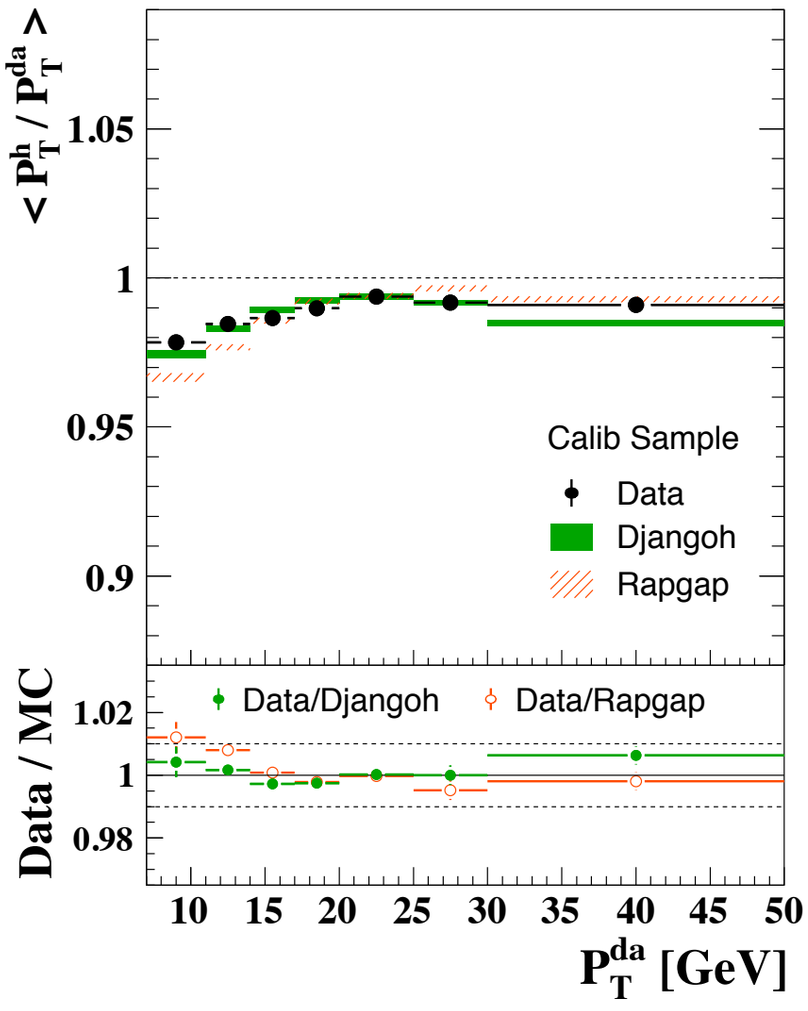


Cluster Energy Calibration

- improve energy flow algorithm (compare measurements from **tracks** and **clusters** and prefer those with better expected resolution; remove tracks/clusters to avoid double-counting of energy.

- **introduce new calibration method** for single clusters, making use of the probability for a single cluster to originate from an em or had shower by obtaining 47 parameters from a global minimisation procedure.

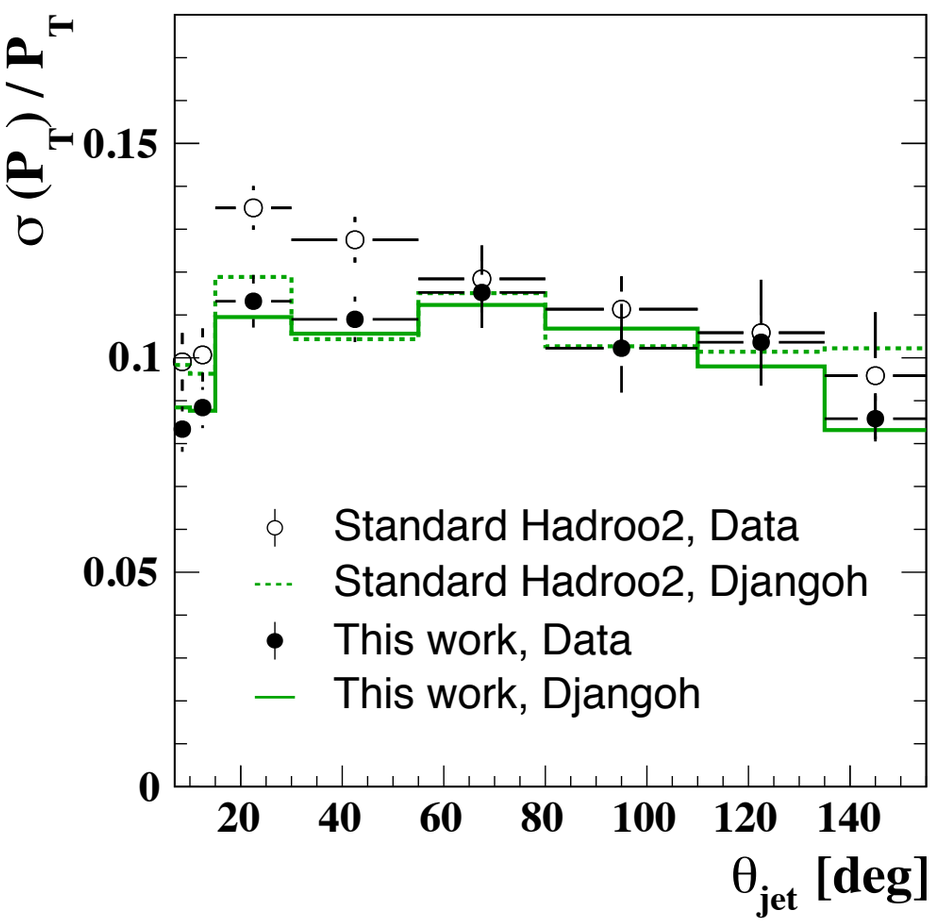


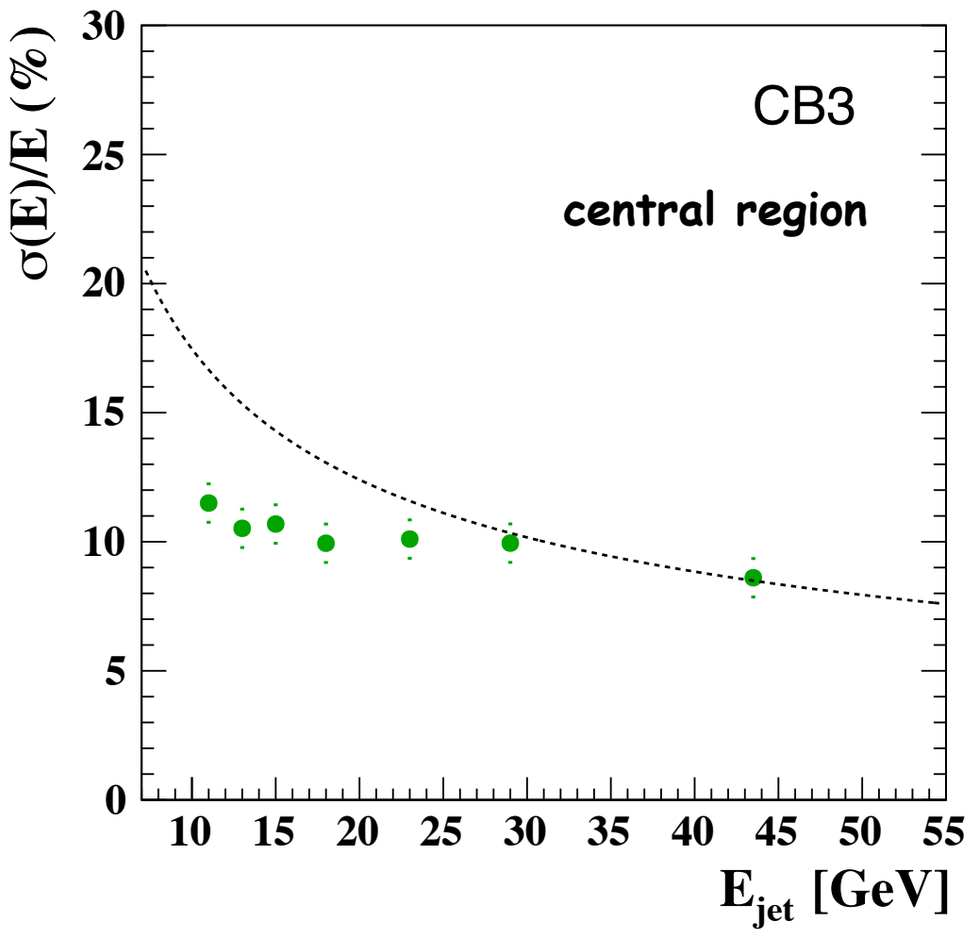


- hadronic final state energy measurement flat within 2% vs. η_{jet}, $P_{T,da}$, $f_{em,jets}$

- 1% energy scale uncertainty is achieved !

Energy Resolution





- in forward region resolution improved by 10-15%
- in central region energy flow algorithm determines the resolution
- overall resolution of jets $\sigma(E)/E \approx 10\%$

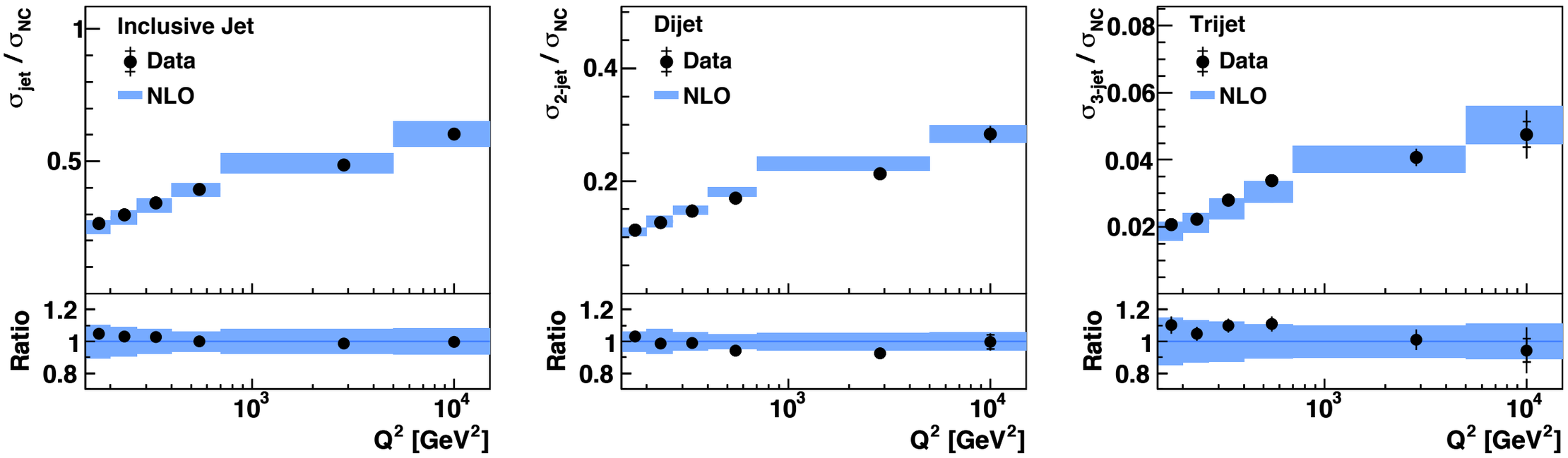
the new em/had separation and calibration have become the new H1 standard

Multijet Measurements

part 2 of his thesis

- NC phase space: $150 < Q^2 < 15000\ GeV^2$, $0.2 < y < 0.7$
- jet phase space: $-1.0 < \eta_{Lab} < 2.5$
  - inclusive jets: $7 < P_T < 50\ GeV$
  - dijets & trijets: $5 < P_T < 50\ GeV$ and $M_{12} > 16\ GeV$
- single and double differential jet cross sections (unnormalized as well as normalized) as a function of Q^2, P_T and ξ

normalized jet cross sections for example:



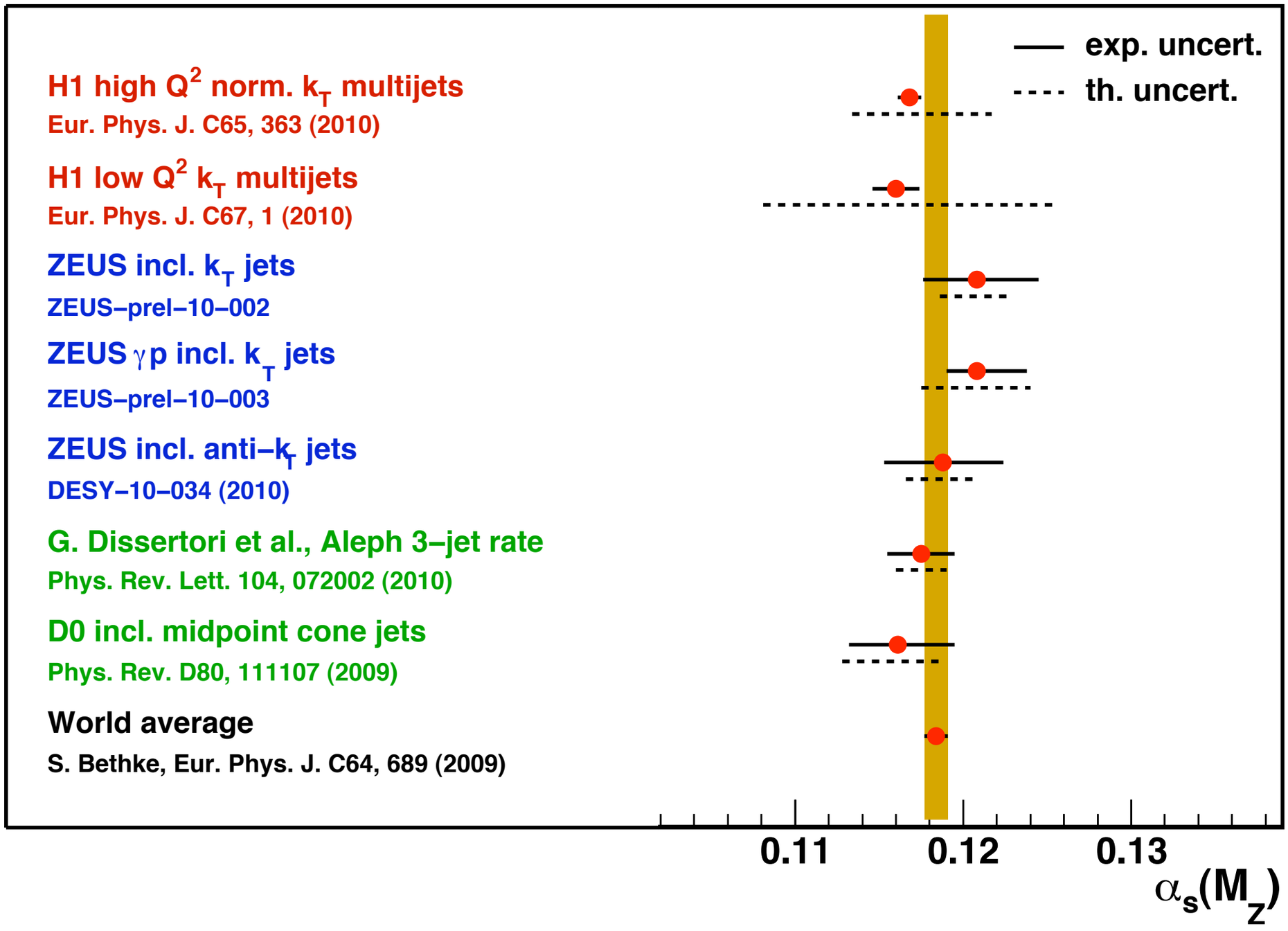
highest precision measurements, total exp. uncertainty (1.9%, 2.4%, 6.5%) ≈ 1/3 NLO uncertainty

Summary

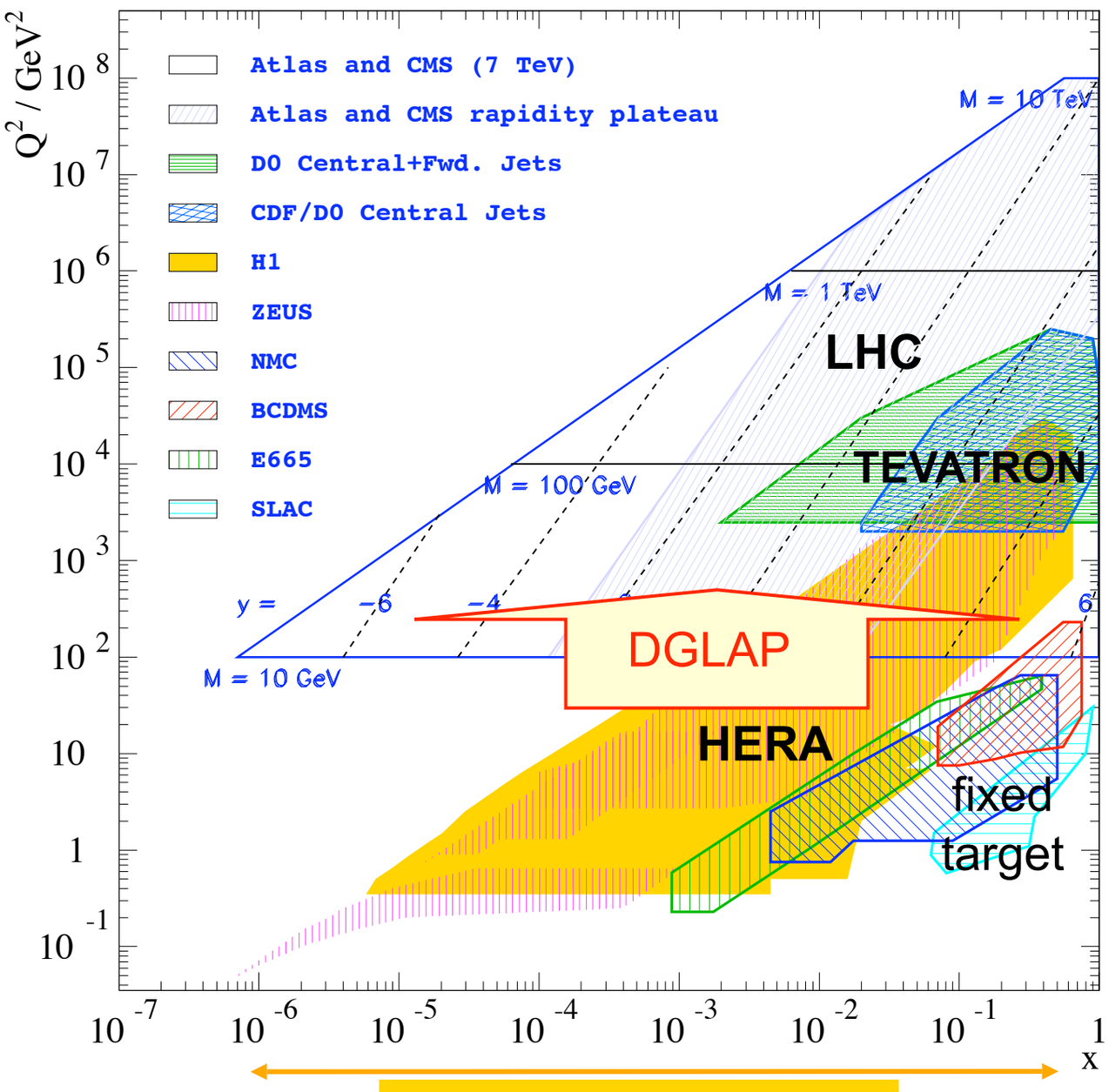
- HERA has stopped data taking in 2007
- the final, large statistics, data sample & application of new ideas/methods has advanced efforts to improve the measurement of the hadronic final state
- the combination of H1 and ZEUS data have allowed to improve the accuracy of NC and CC cross section measurements
- both MPI groups in H1 & ZEUS have high visibility in the HERA community due to the impact of their work
- a continuing and dedicated effort is going on & is still needed to finalize precision results, which will not be obtainable elsewhere soon
- we are on a good way to complete the HERA legacy

Extras

α_s from Jet Cross Sections



HERA PDF & HEP Experiments



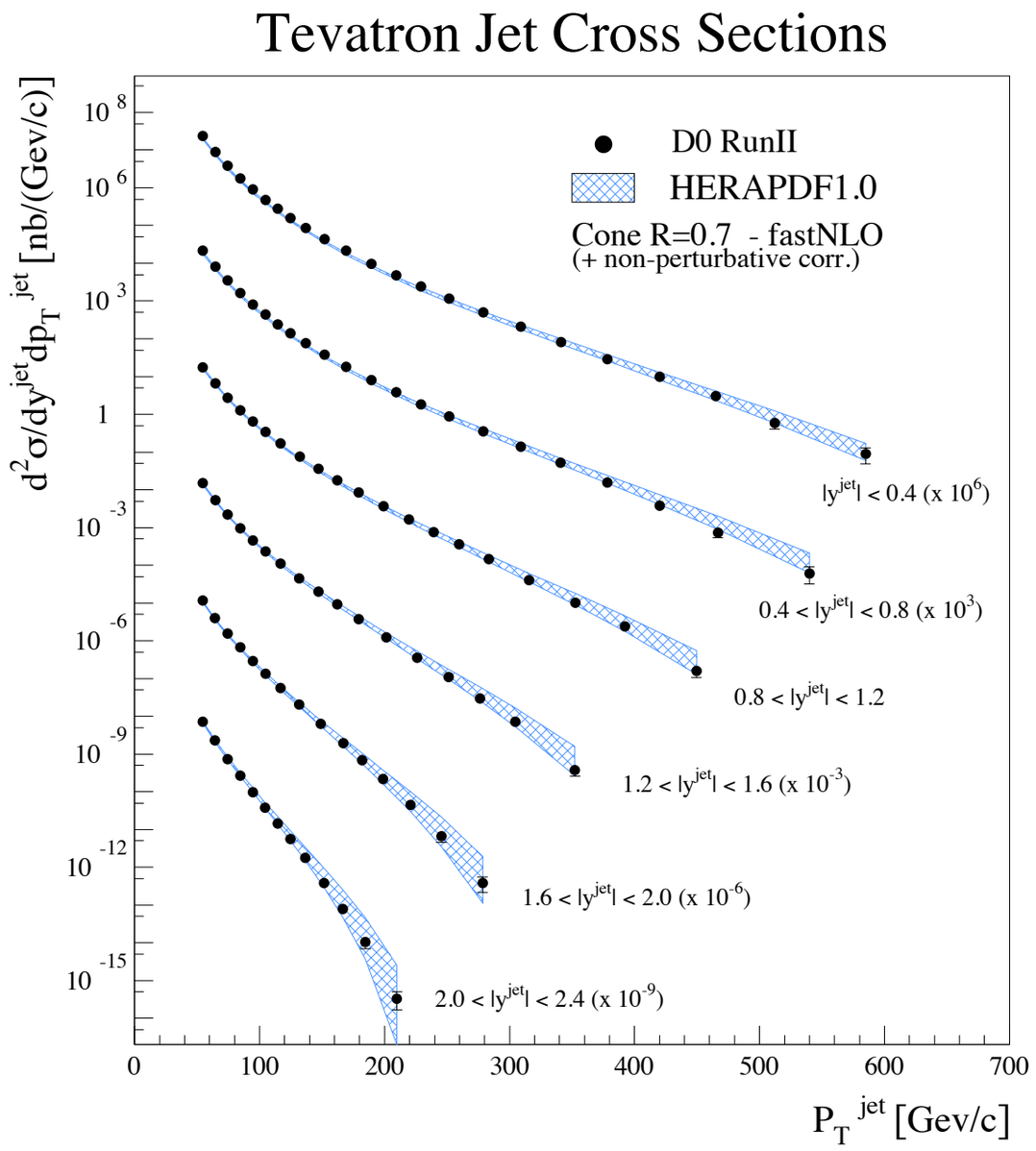
HERA Measurements:

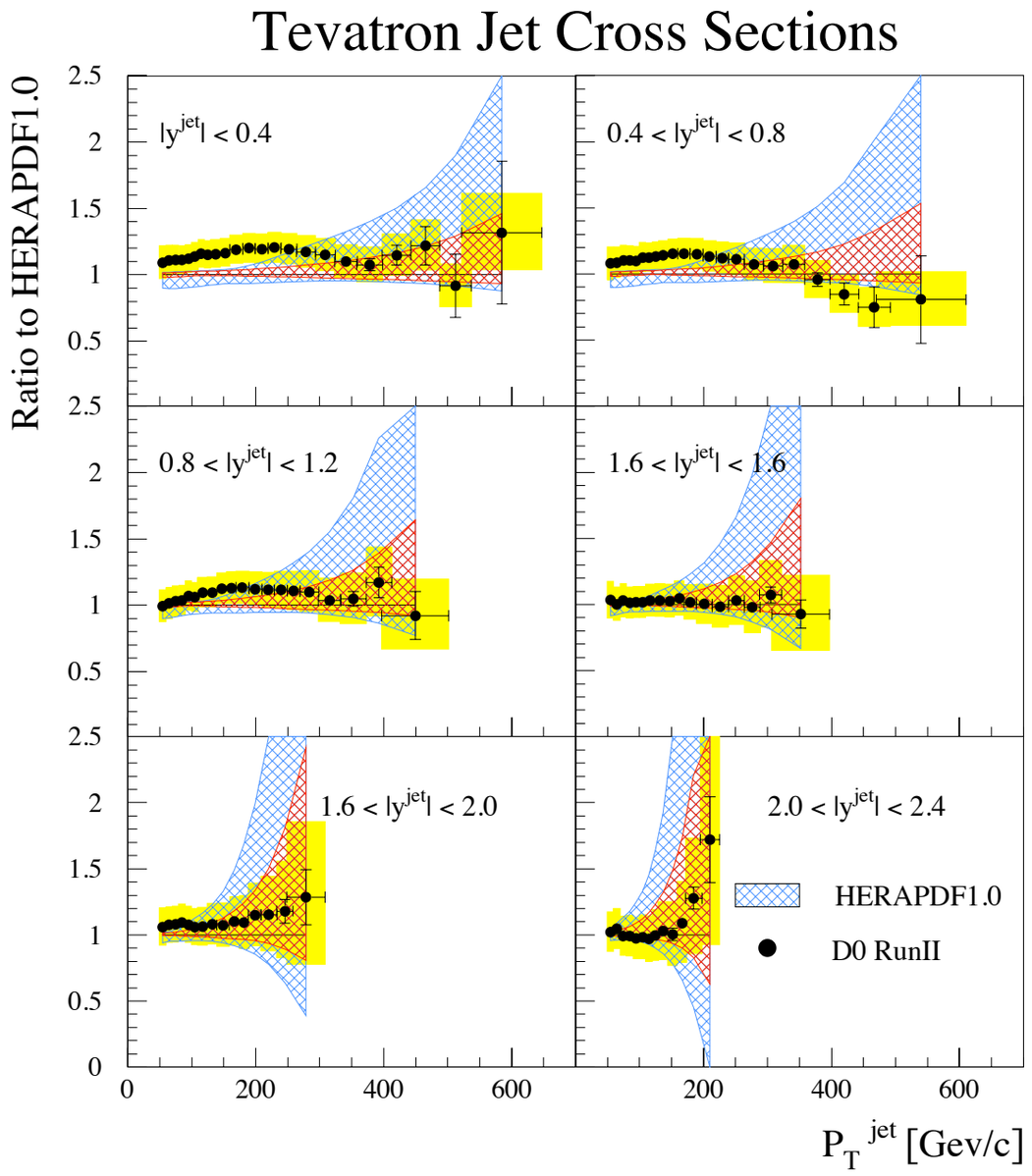
cover large part of the (x,Q^2) plane, provide best constraint at low & medium x

from HERA phase space to Tevatron & LHC:

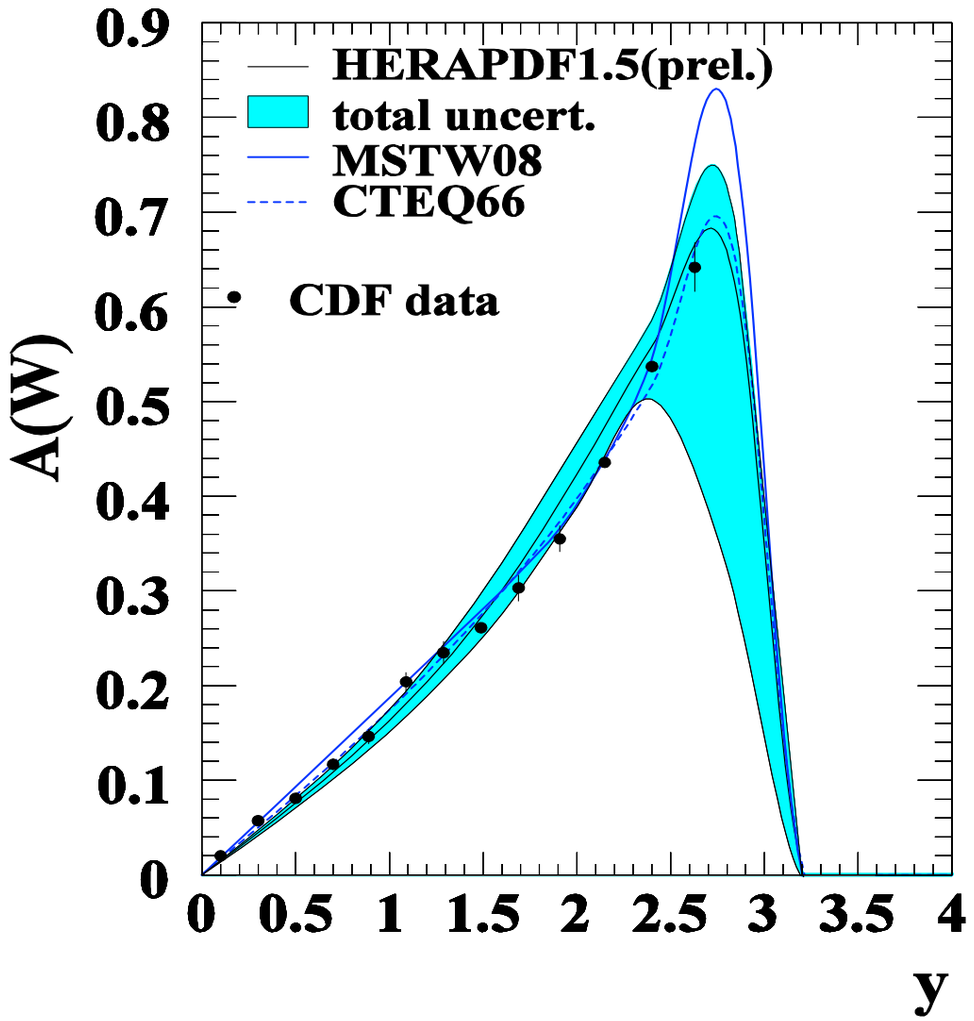
evolution in Q2 via DGLAP

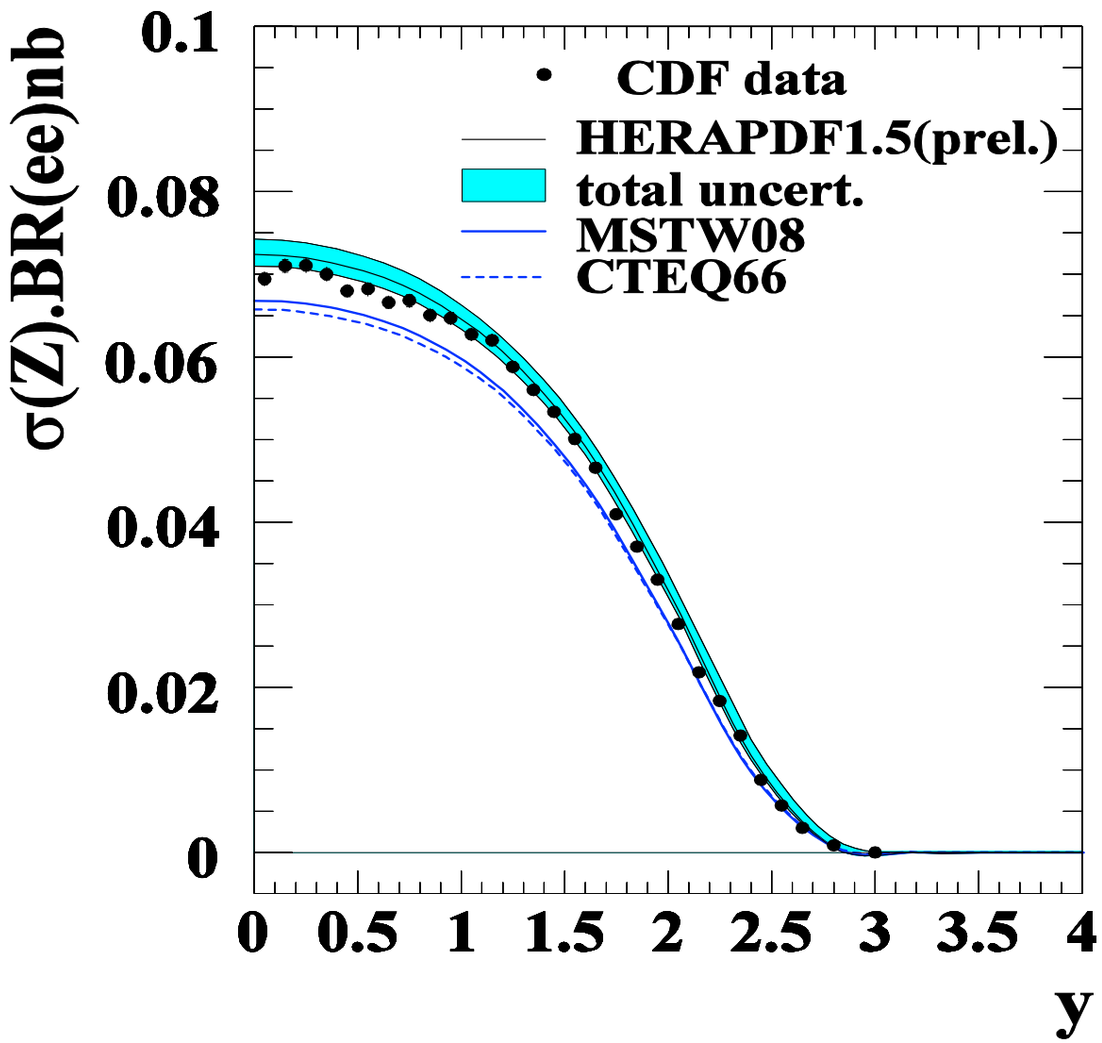
HERAPDF & Jets @ TEVATRON



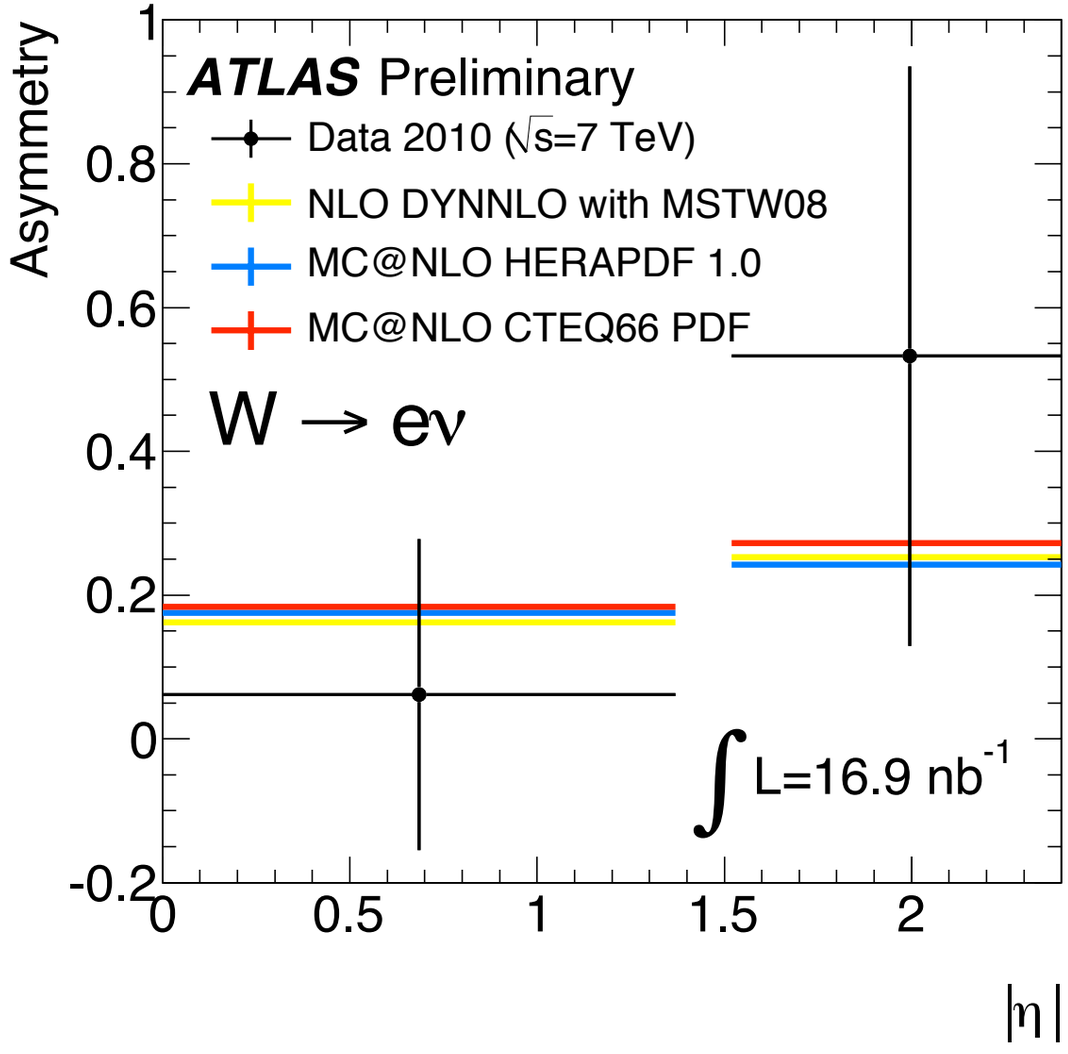


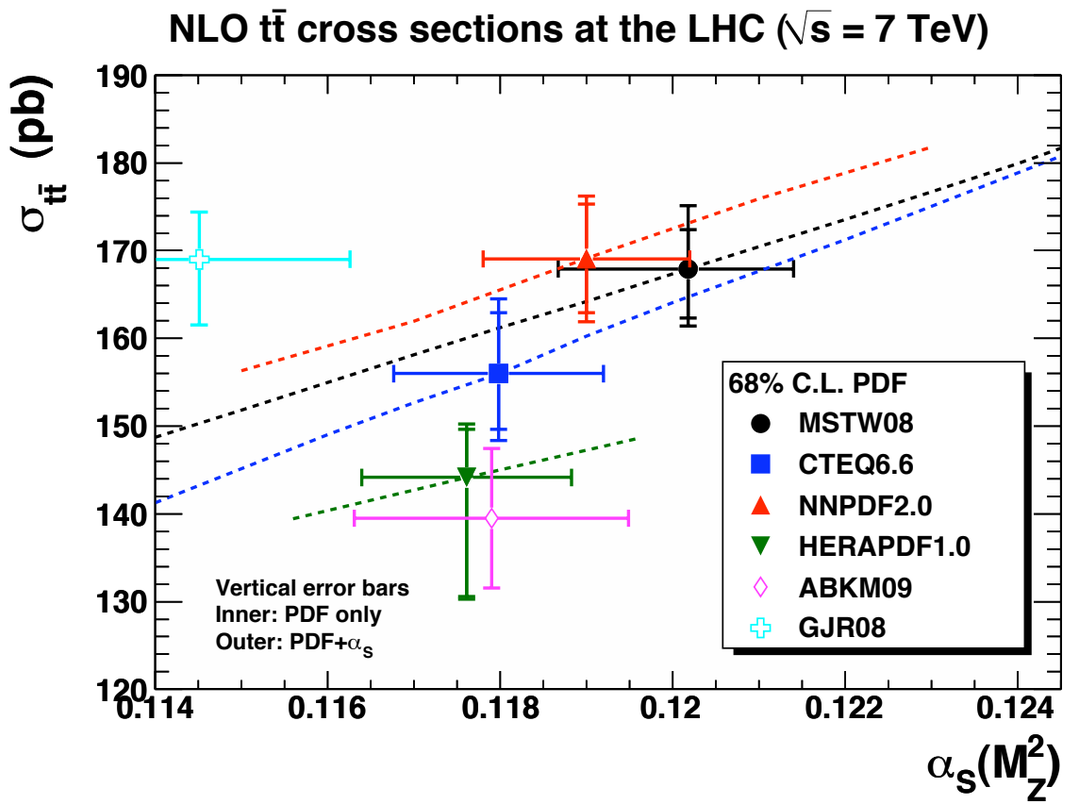
HERAPDF & W/Z @ TEVATRON

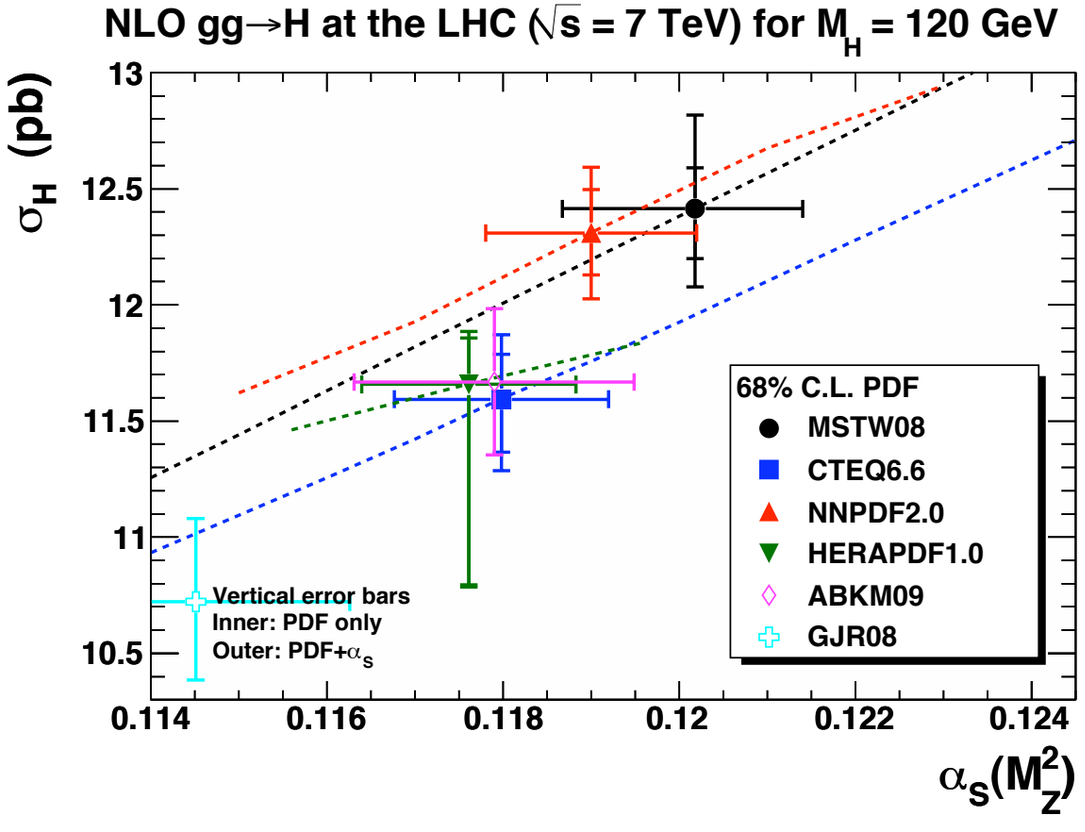




ATLAS & Benchmarks







H1 analyses with substantial involvement of MPI

Inclusive neutral and charged current cross section measurements at high Q^2, the structure functions F_2, xF_3 and F_L, QCD analysis and PDFs

H1prelim-09-042 High Q2 Neutral Current in polarised ep collisions at HERA II

H1prelim-09-043 High Q2 Charged Current in polarised ep collisions at HERA II

H1prelim-08-042 Measurement of the longitudinal structure function F_L at high Q2 at HERA

Combination of the H1 and ZEUS inclusive cross section measurements

H1prelim-10-141, ZEUS-prel-10-017 Combined Measurement of Neutral and Charged Current Cross Sections at HERA

JHEP 1001, 109 (2010) Combined Measurement and QCD Analysis of the Inclusive $e^{+-}p$ Scattering Cross Sections at HERA

Multi-jet cross sections and extraction of the strong coupling

Eur.Phys.J.C65, 363 (2010) Jet Production in ep Collisions at High Q^2 and Determination of α_s

Measurement of charm fragmentation

Eur.Phys.J.C59, 589 (2009) Study of Charm Fragmentation into D^{*+-} Mesons in Deep Inelastic Scattering at HERA

ZEUS analyses with substantial involvement of MPI

MPI leading the analysis:

- Energy dependence of total photon proton cross section
  DESY-10-DIR, to be published in PLB

- Leading Neutron Production in di-jet photoproduction
  DESY-09-140, Nucl. Phys. B 827 (2010) 1-33

- Measurement of the Longitudinal Proton Structure Function at HERA
  DESY-09-036, Phys. Lett. B 682 (2009) 8-22

- Leading Neutron Energy and P_T Distributions in Deep Inelastic Scattering and Photoproduction at HERA,
  DESY-07-011, Nucl. Phys. B 776 (2007) 1-37

Leading responsibilities for publications

- Iris Abt HighQ2 and Exotics ➜ Physics Coordinator (2007—2009)
- Burkard Reisert, Physics Group Convenor & Physics Coordinator (since 2010)