Photon 2013

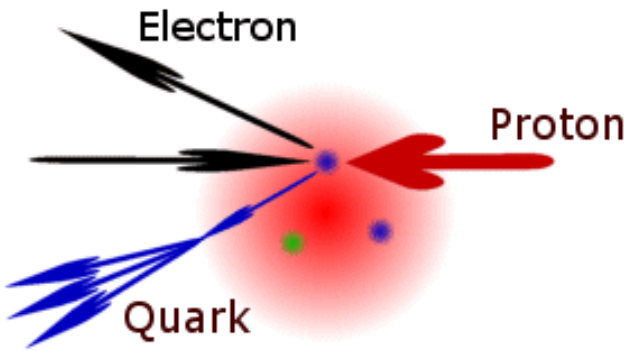
Paris 20-24 may 2013

1973-2013

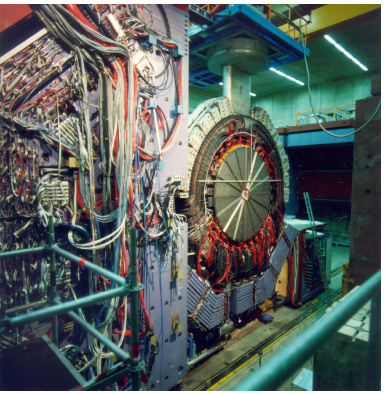
Electroweak Physics at HERA

Katarzyna Wichmann
on behalf of
the H1 and ZEUS Collaborations

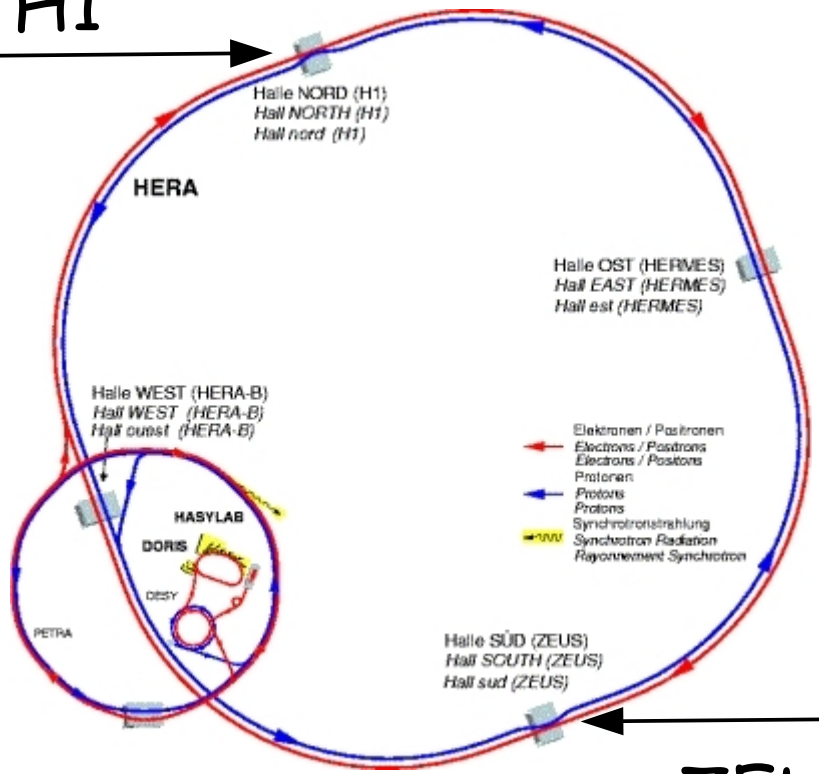
HERA Accelerator



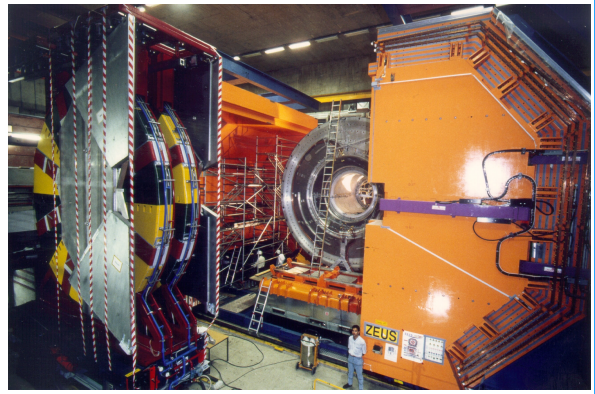
- HERA: ep collider, $\sqrt{s}$ = 320 GeV
- 2 colliding-beam experiments: H1 & ZEUS
- collected 0.5 fb^{-1}/exp of luminosity in 1992-2007



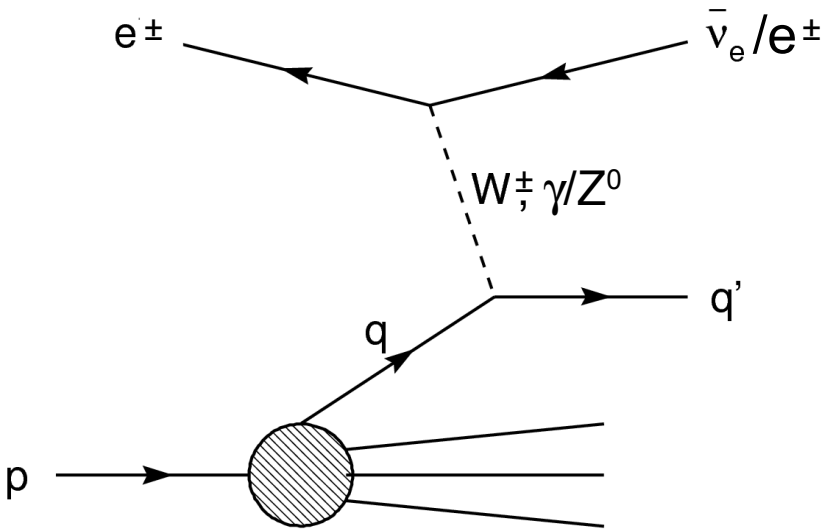
H1



ZEUS



Deep Inelastic Scattering @ HERA



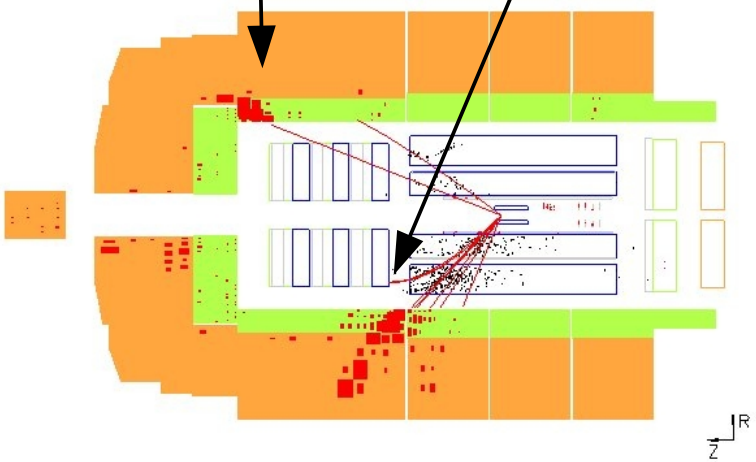
$$Q^2 = -q^2 = -(k - k')^2$$

$$x = \frac{Q^2}{2p \cdot q} \qquad y = \frac{p \cdot q}{p \cdot k}$$

$$s = (p + k)^2 \qquad Q^2 = x \cdot y \cdot s$$

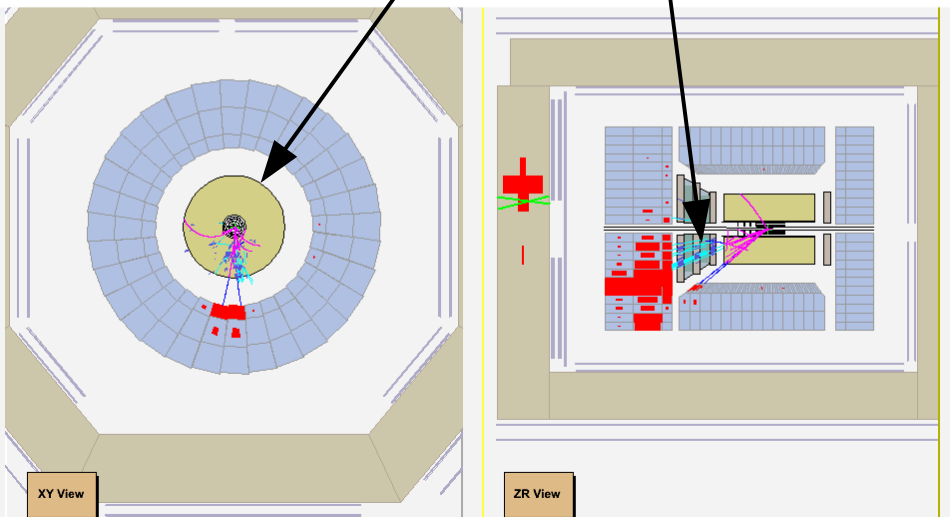
Neutral Current (NC): γ,Z exchange

electron + jet

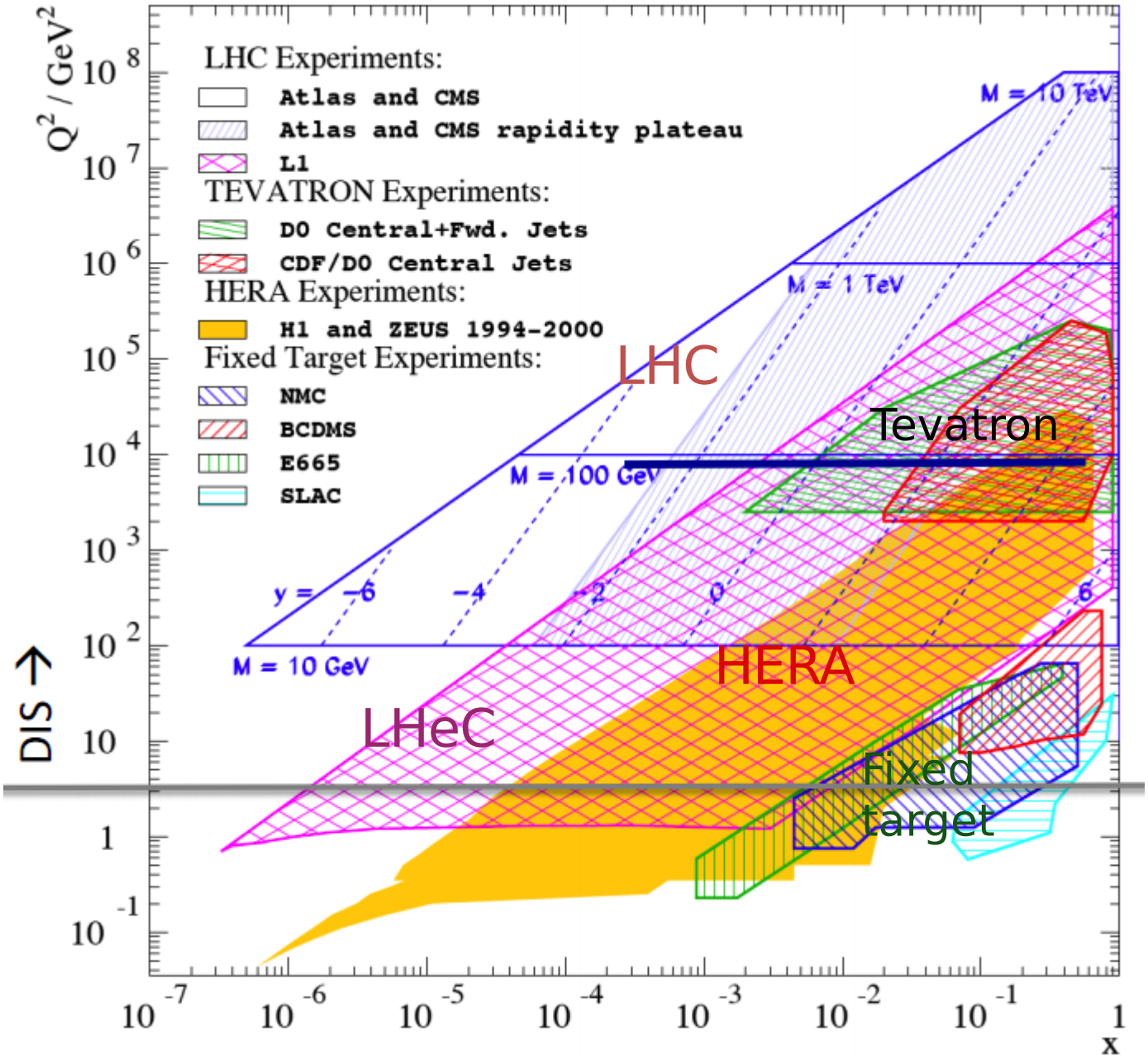


Charge Current (CC): W exchange

missing p_T + jet

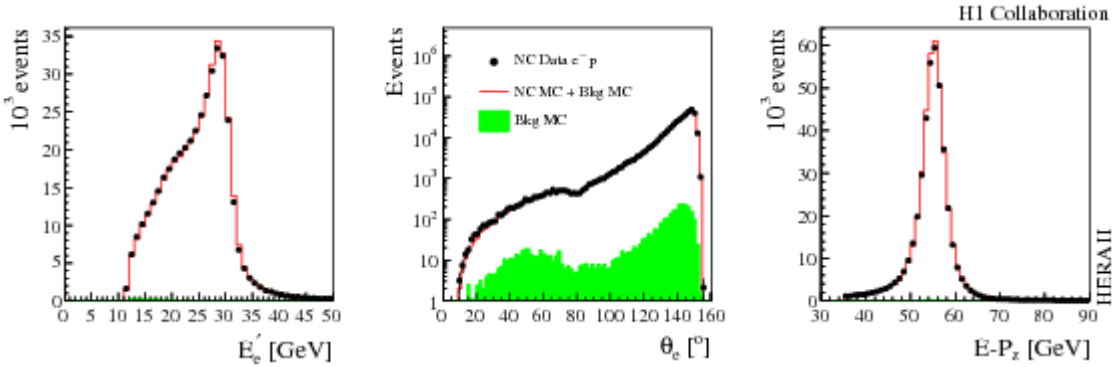


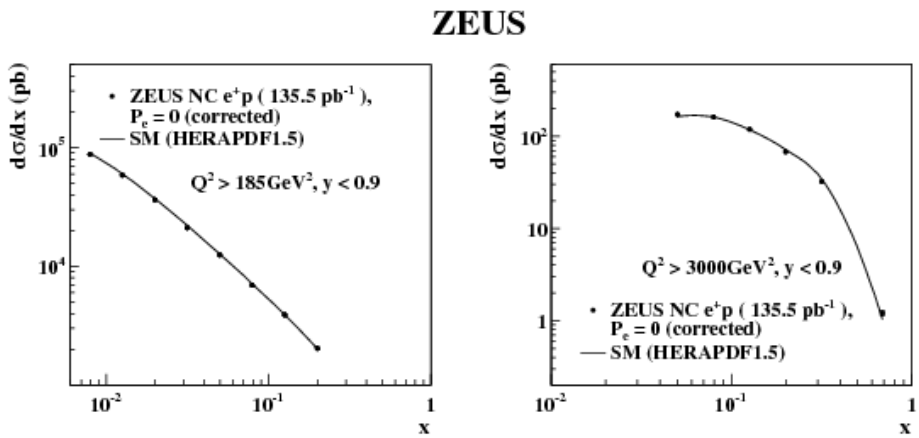
HERA kinematic plane

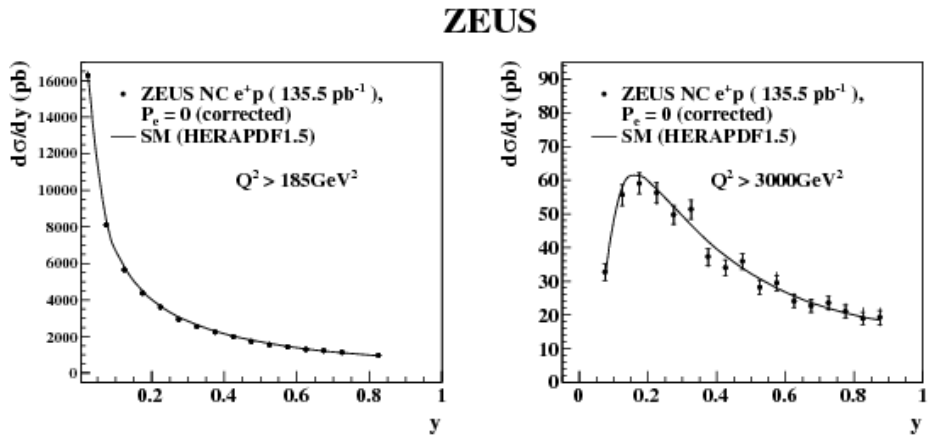


Outstanding precision

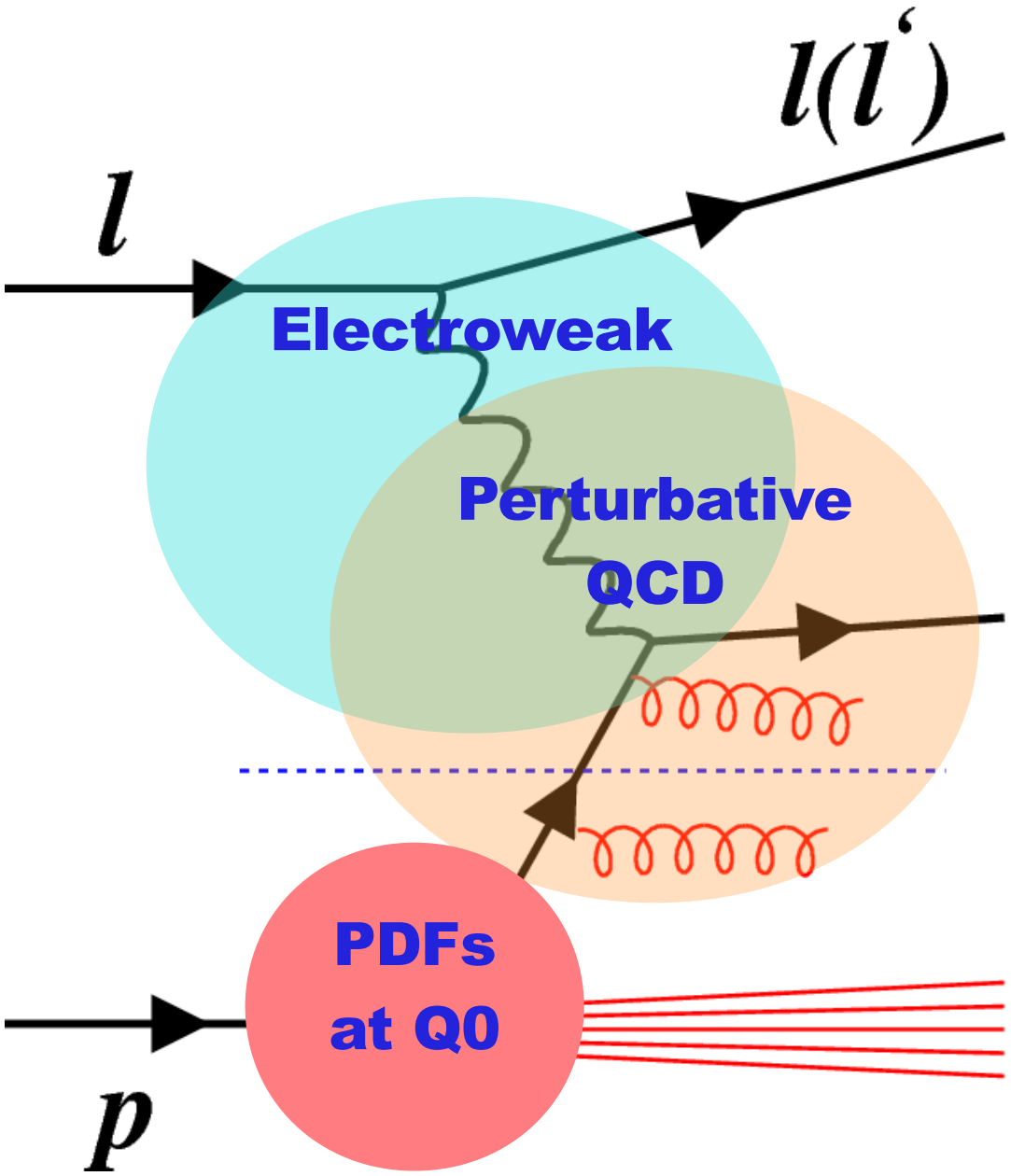
- Final measurements of DIS cross sections completed by H1 and ZEUS collaborations
  - Very good understanding of experimental conditions
  - Very high precision
- Plethora of very precise results







Inclusive DIS @ HERA



- Fix pQCD ⊕ PDFs

  → Test Electroweak

Main topic!

- Fix Electroweak & pQCD

  → Determine PDFs

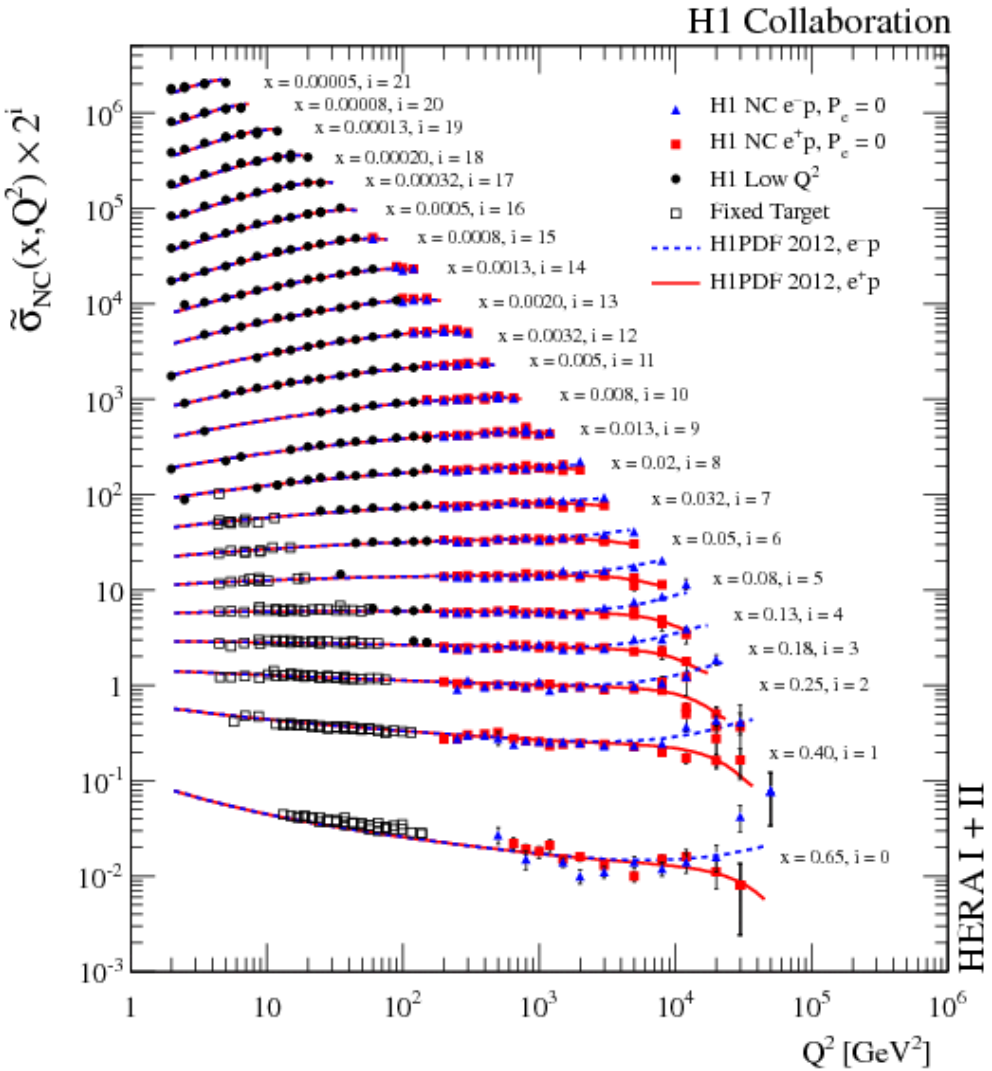
Few slides here
for details see V. Chekelian's talk

- Fix Electroweak

  → Test pQCD ⊕ PDFs

One example!
For more see various talks: A. Baghdasaryan, I. Brock, A. Iudin

QCD Tests @ HERA



Example of QCD tests

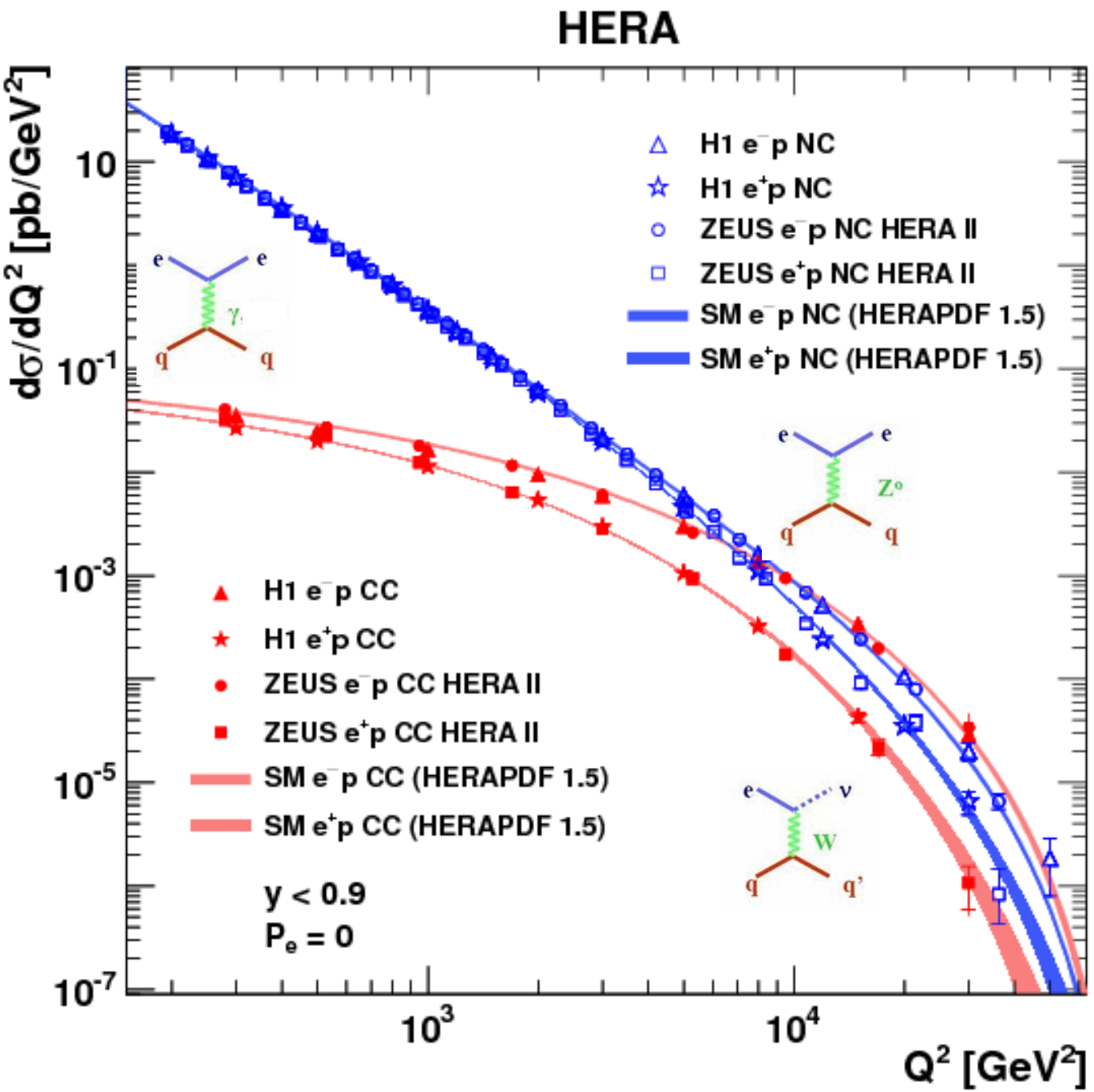
- NC reduced cross sections

$$\tilde{\sigma}^{+}{}_{\mathrm{NC}}(x,Q^2) = \frac{\mathrm{d}^2\sigma^{e^+p}_{\mathrm{NC}}}{\mathrm{d}Q^2\mathrm{d}x}\frac{xQ^4}{2\pi\alpha^2 Y_+}$$

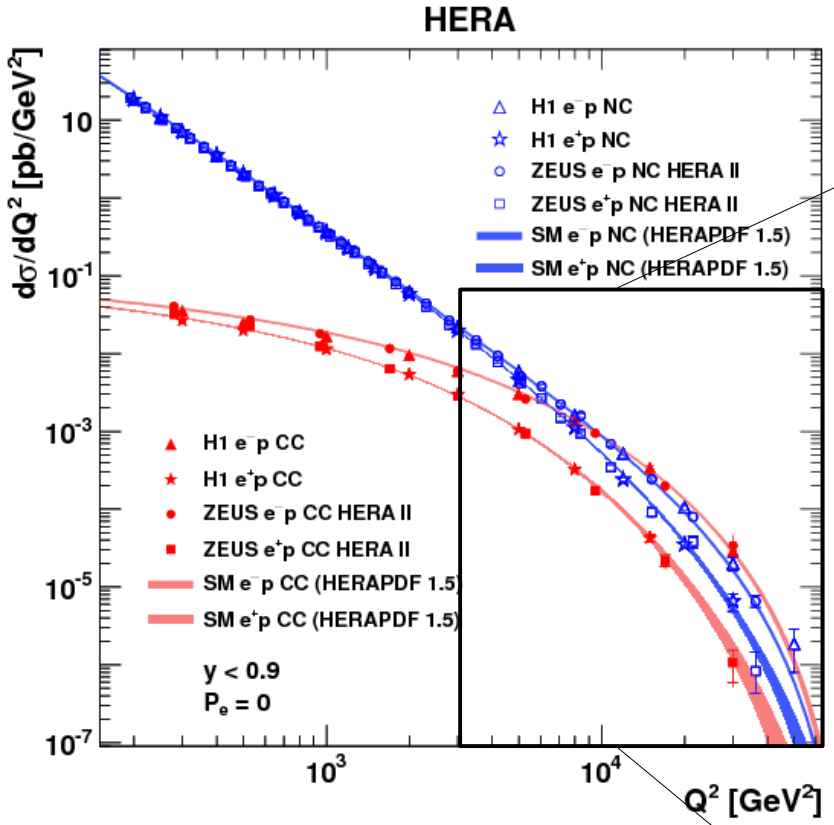
- 5 orders in magnitude in Q^2 and 4 orders in x covered!
- Approximate scaling at middle-x
- Clear scaling violation at low and high x

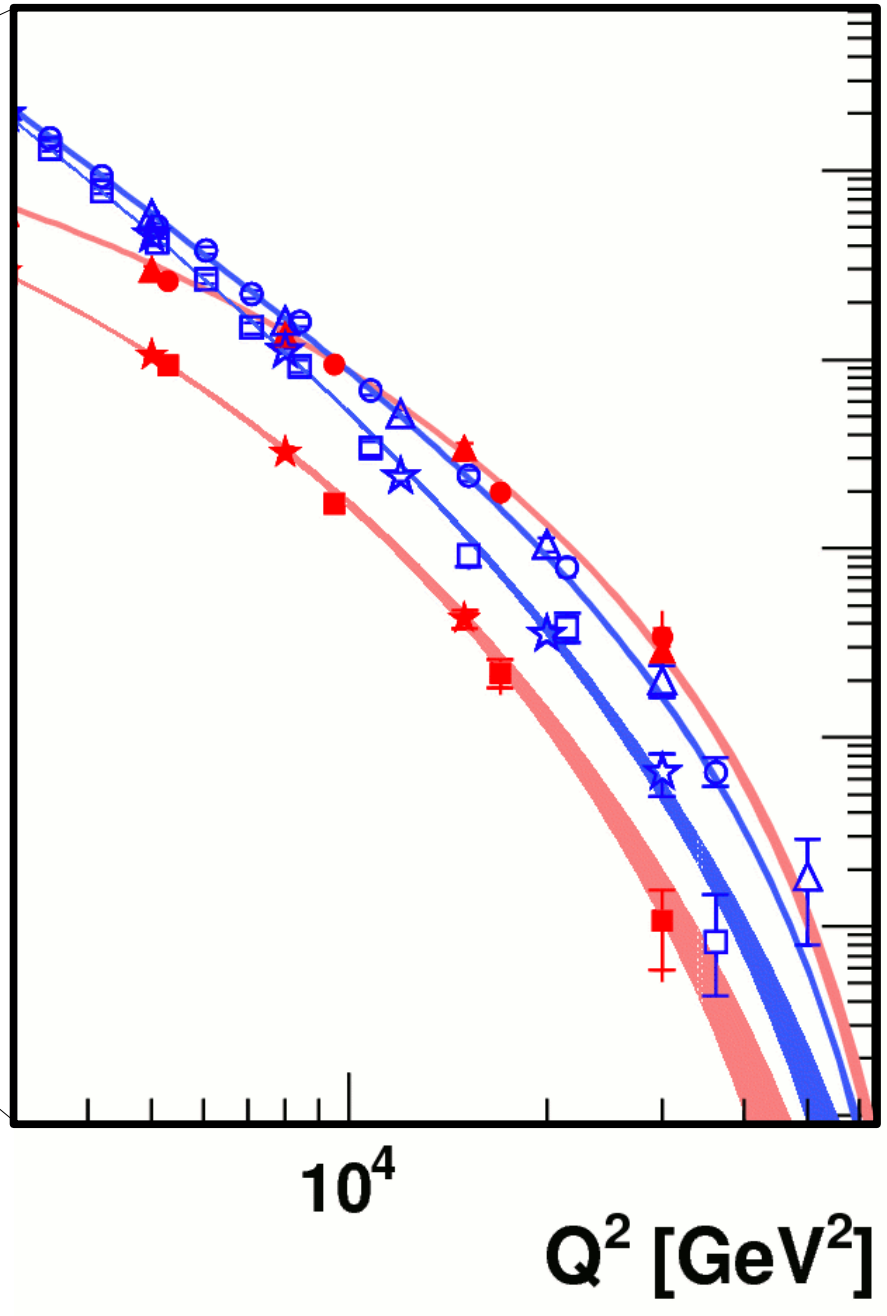
DGLAP works – great success of QCD

Electroweak Unification



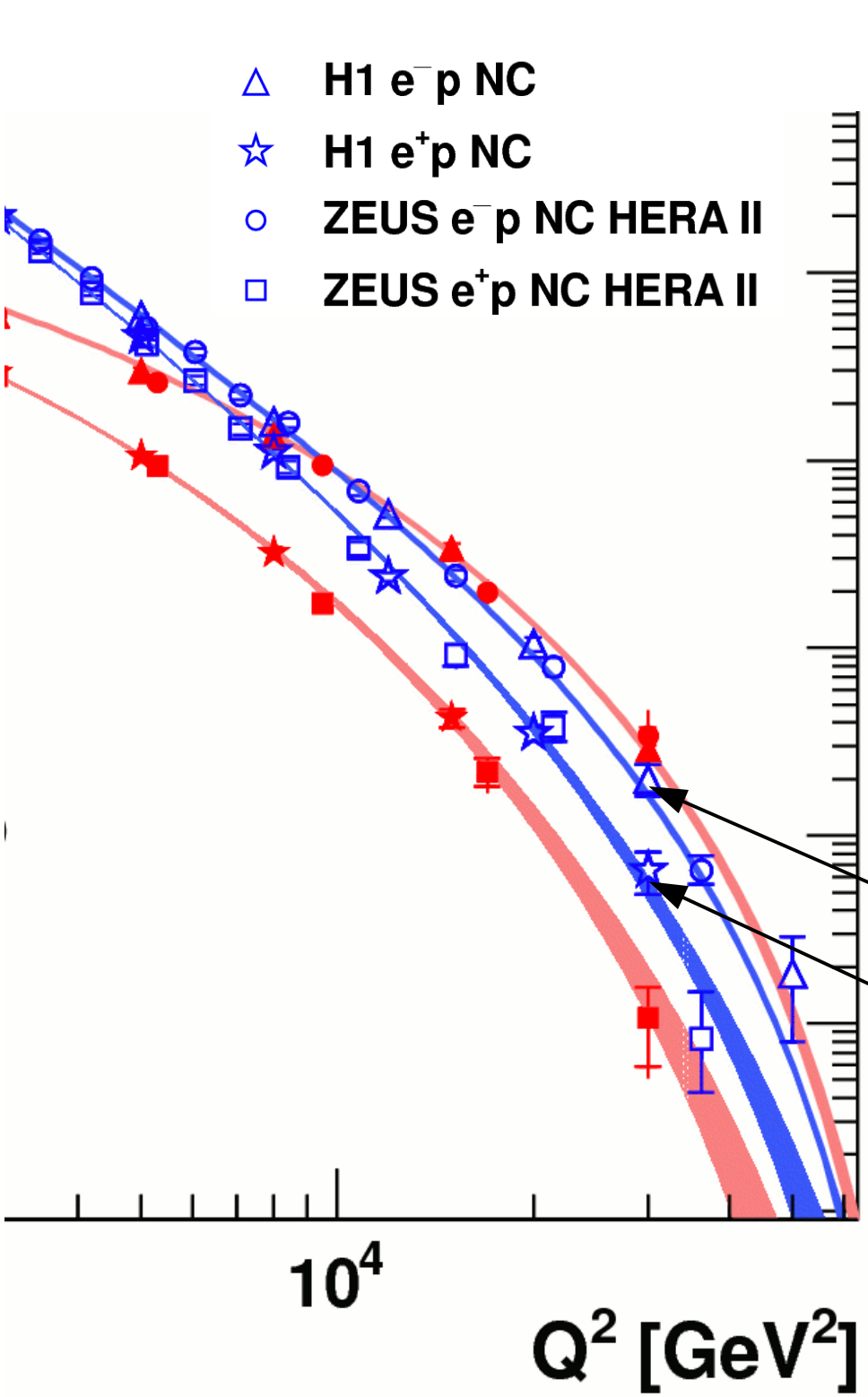
Fantastic precision





- Allows for studying details

Fascinating picture

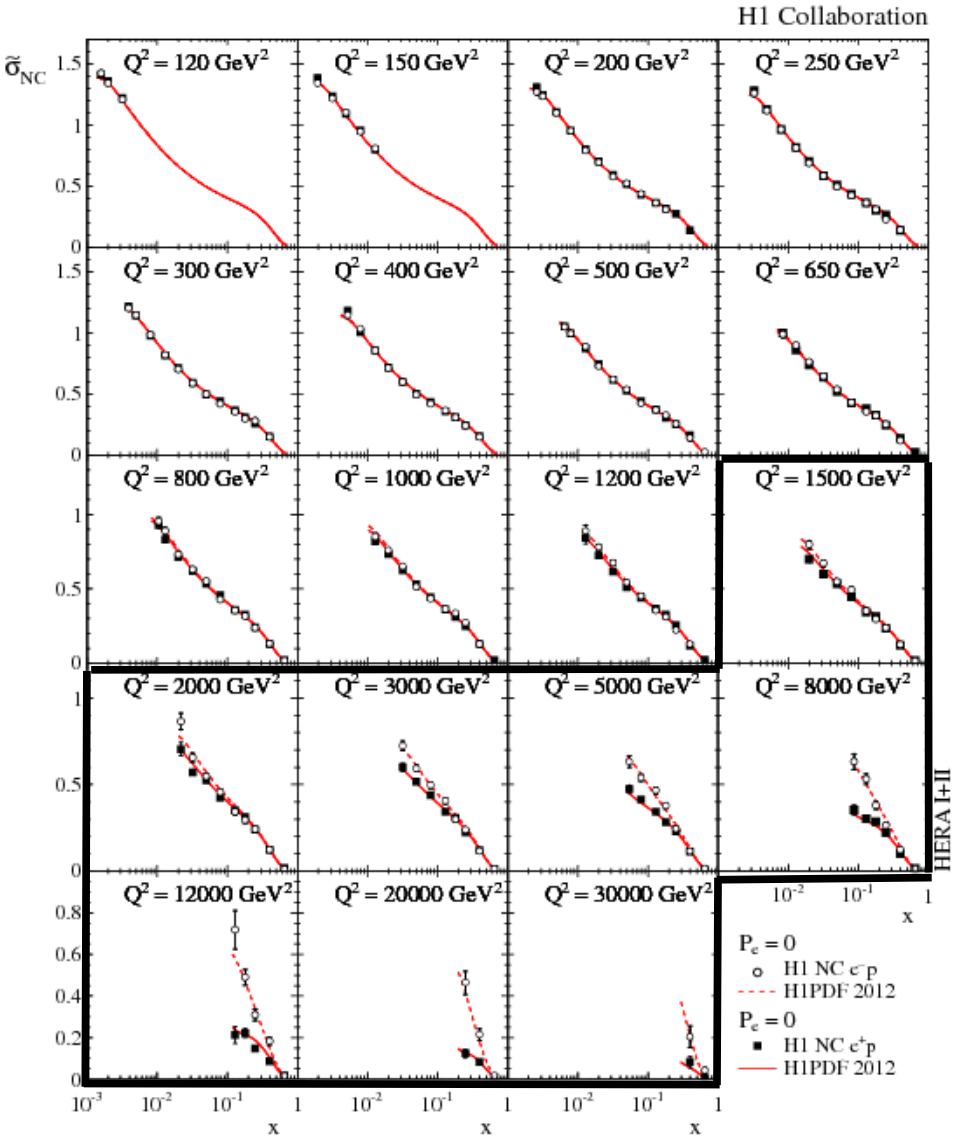


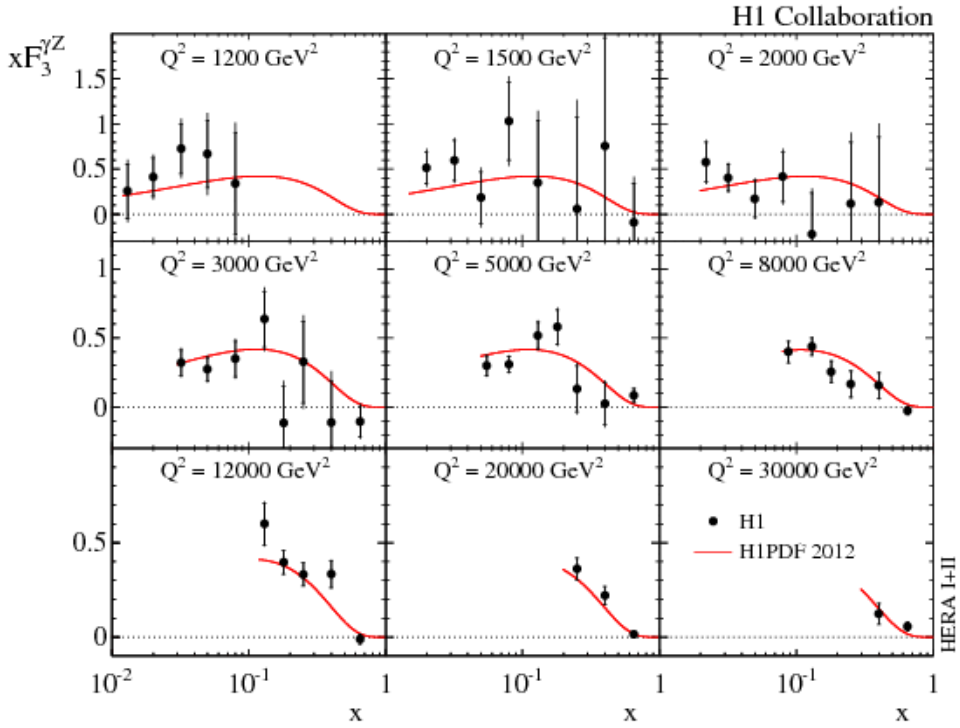
- At high Q^2 e^+p and e^-p NC differ
  - Why?
- $Q^2 \sim M_Z^2 \rightarrow$ Z exchange important
  - γZ interference clearly seen
- In e^-p NC positive γZ interference
- In e^+p NC negative γZ interference

Extraction of xF_3

Difference in NC e^+p and e^-p used to extract $xF_3^{\gamma Z}$

$$\frac{\mathrm{d}^2\sigma^{\pm}_{NC}}{\mathrm{d}x\mathrm{d}Q^2} = \frac{2\pi\alpha^2}{Q^4 x}\left[Y_+ F_2(x,Q^2) \mp Y_- xF_3(x,Q^2)\right] \qquad (Y_\pm = 1 \pm (1-y)^2)$$





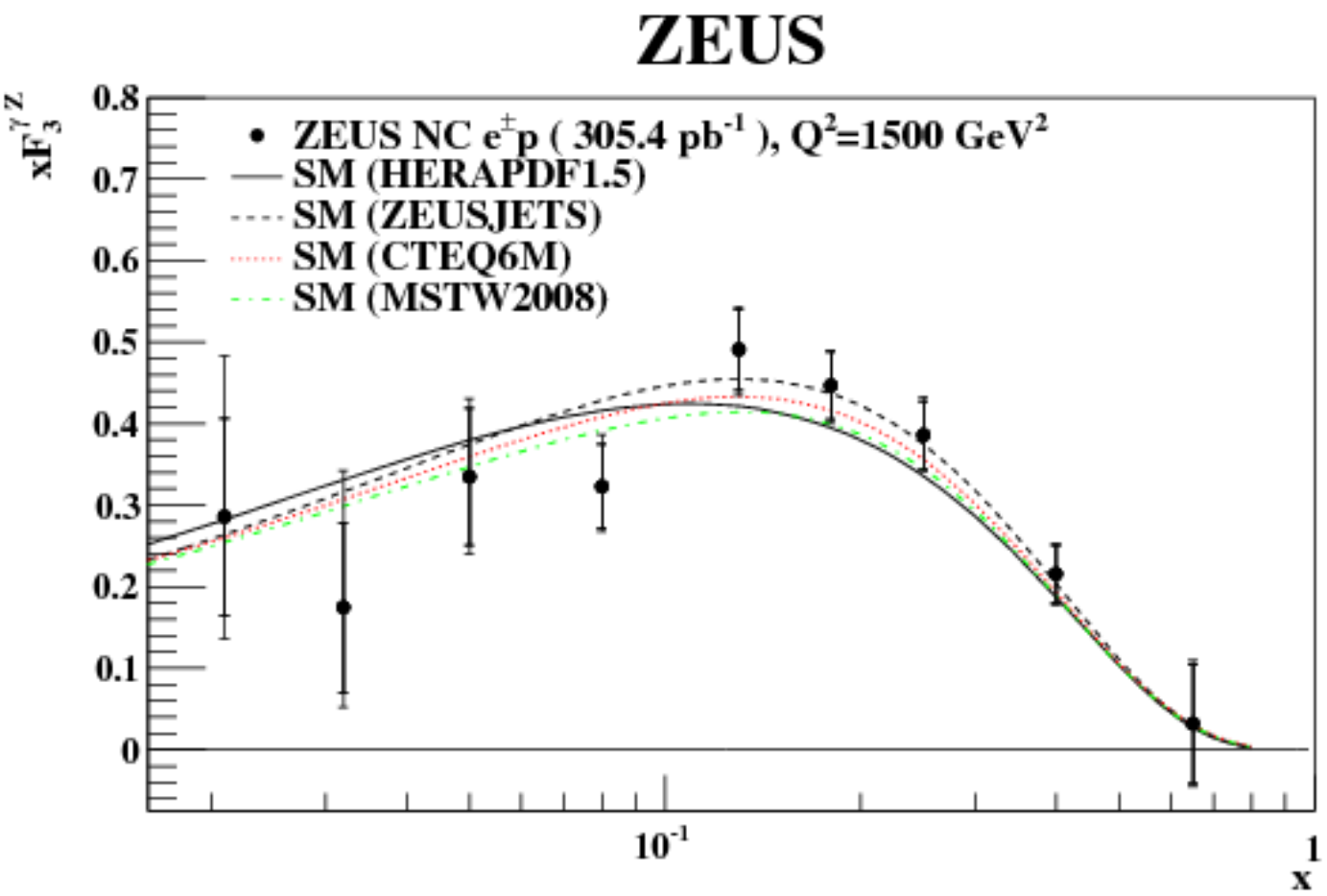
xF3 is almost independent of Q^2

→can be combined common Q^2

Valence Distribution

x dependence of $xF_3^{\gamma Z}$ reflects parton composition

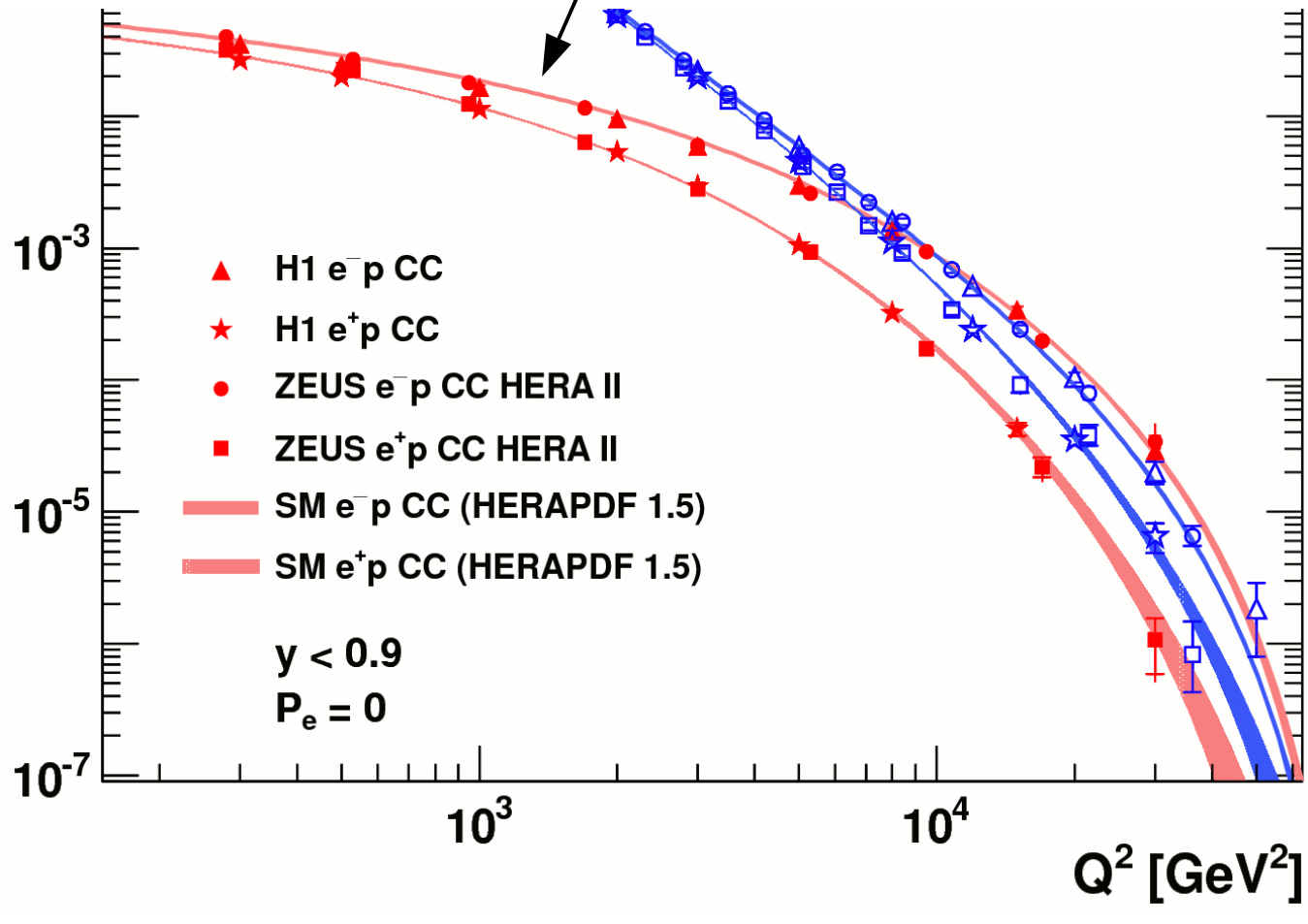
$$xF_3^{\gamma Z} \sim xq_v$$

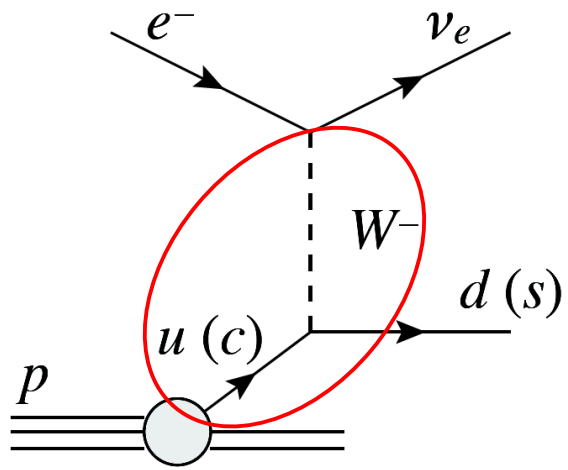


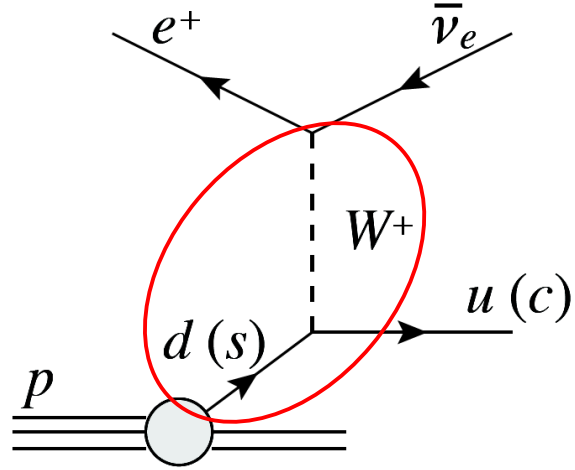
Good description by various PDFs

Fascinating picture

- CC e^-p ~ two times larger than CC e^+p
- Why?

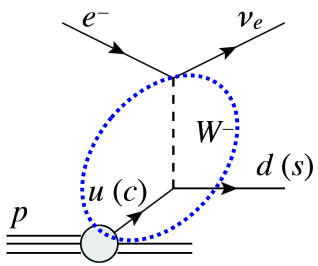


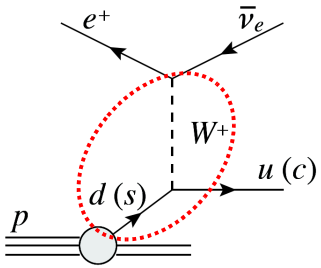


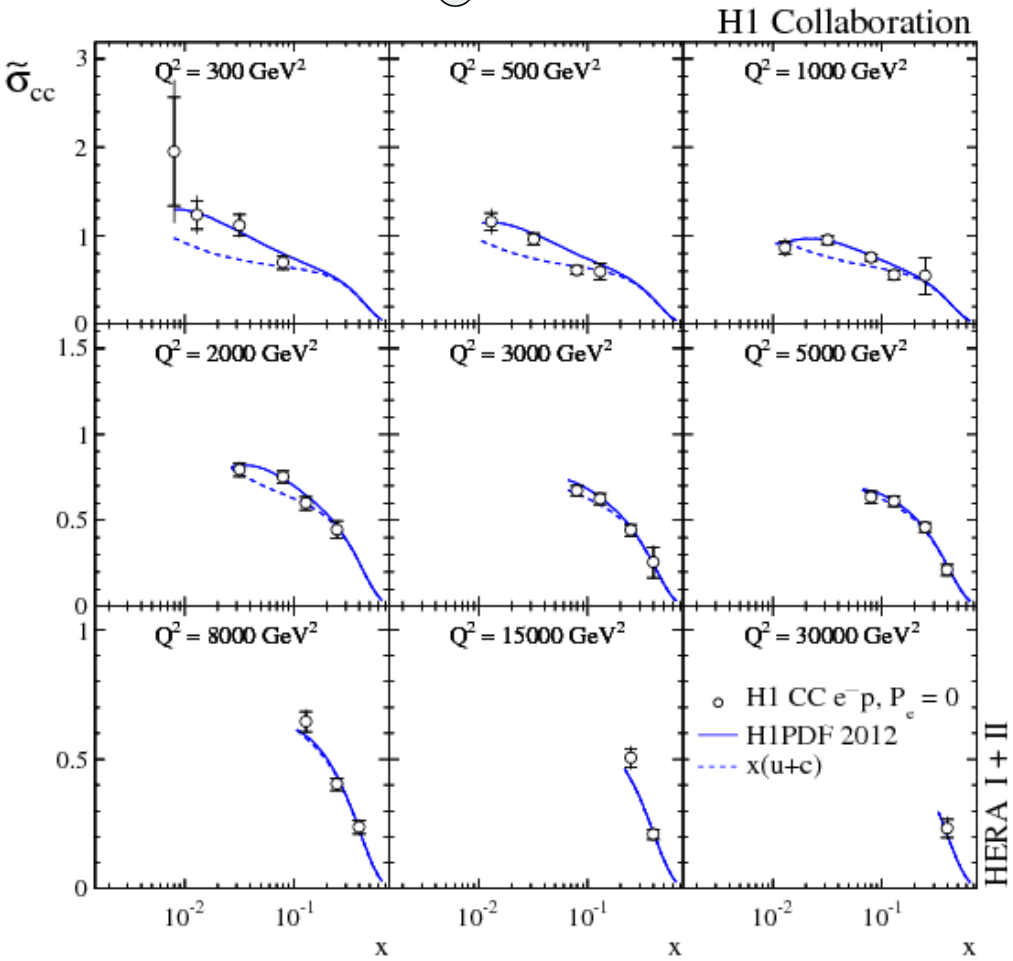


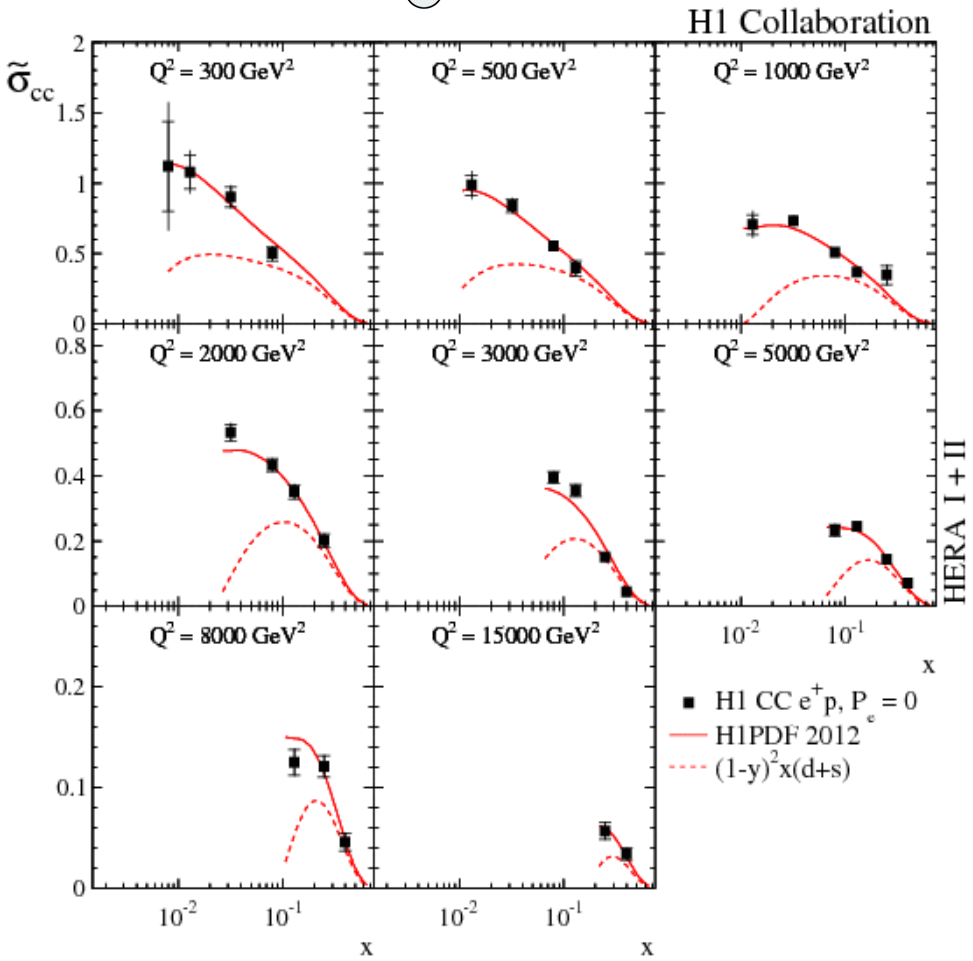
Twice as much u than d in proton

Up/Down Quark Separation





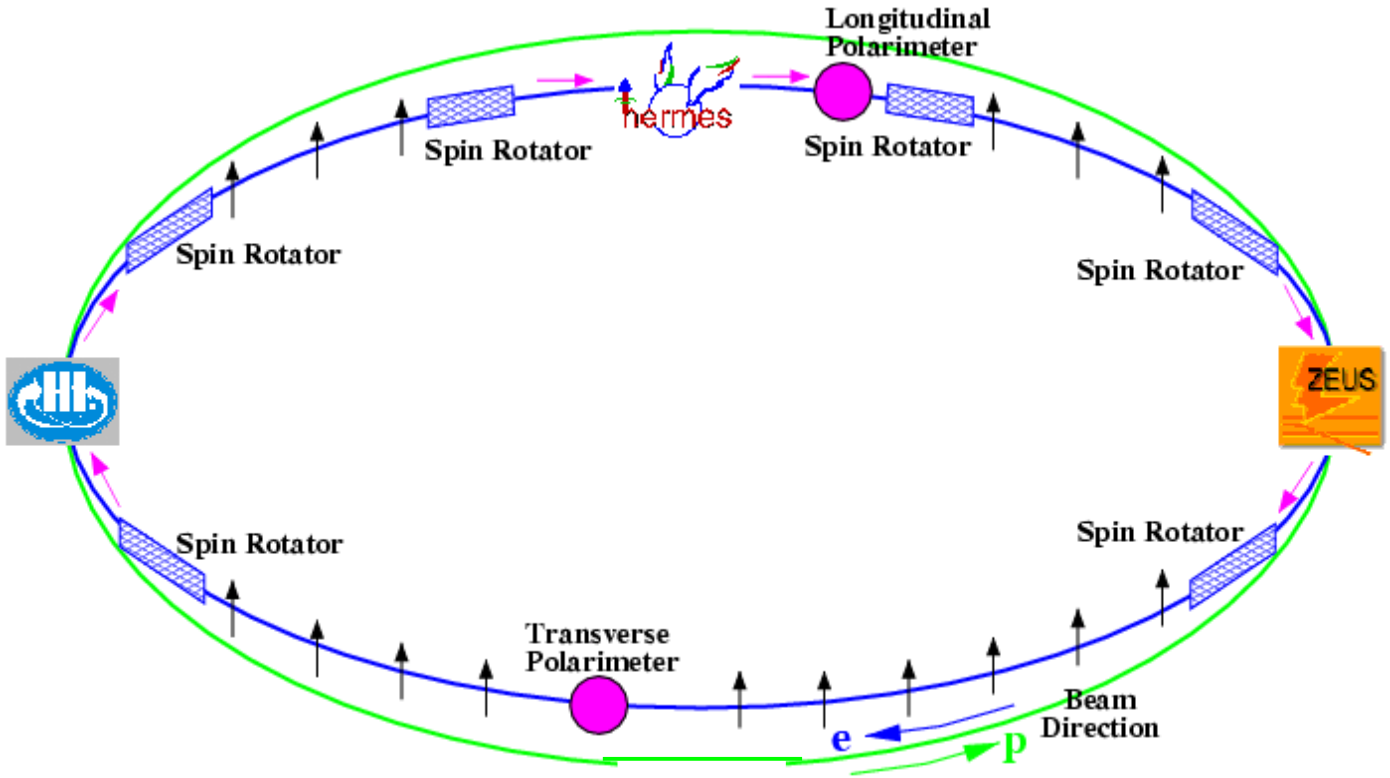




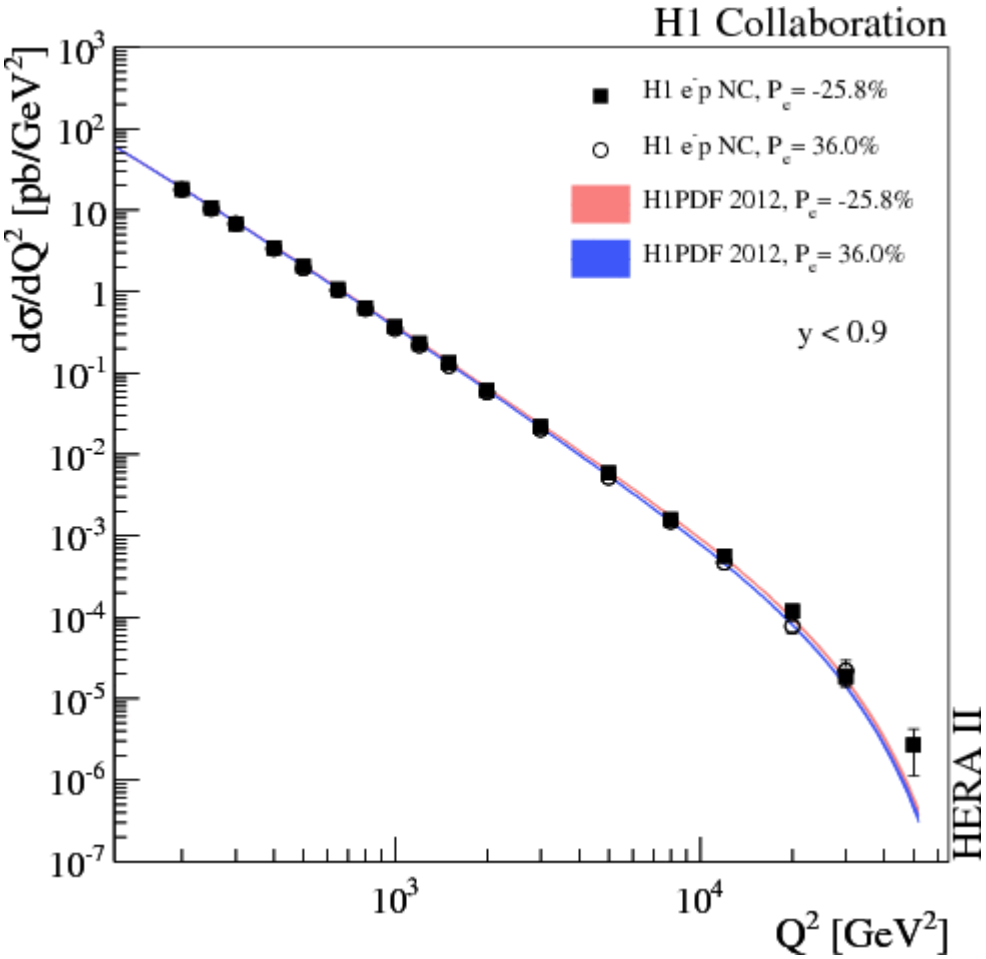
CC data can be used to separate up/down distributions in proton

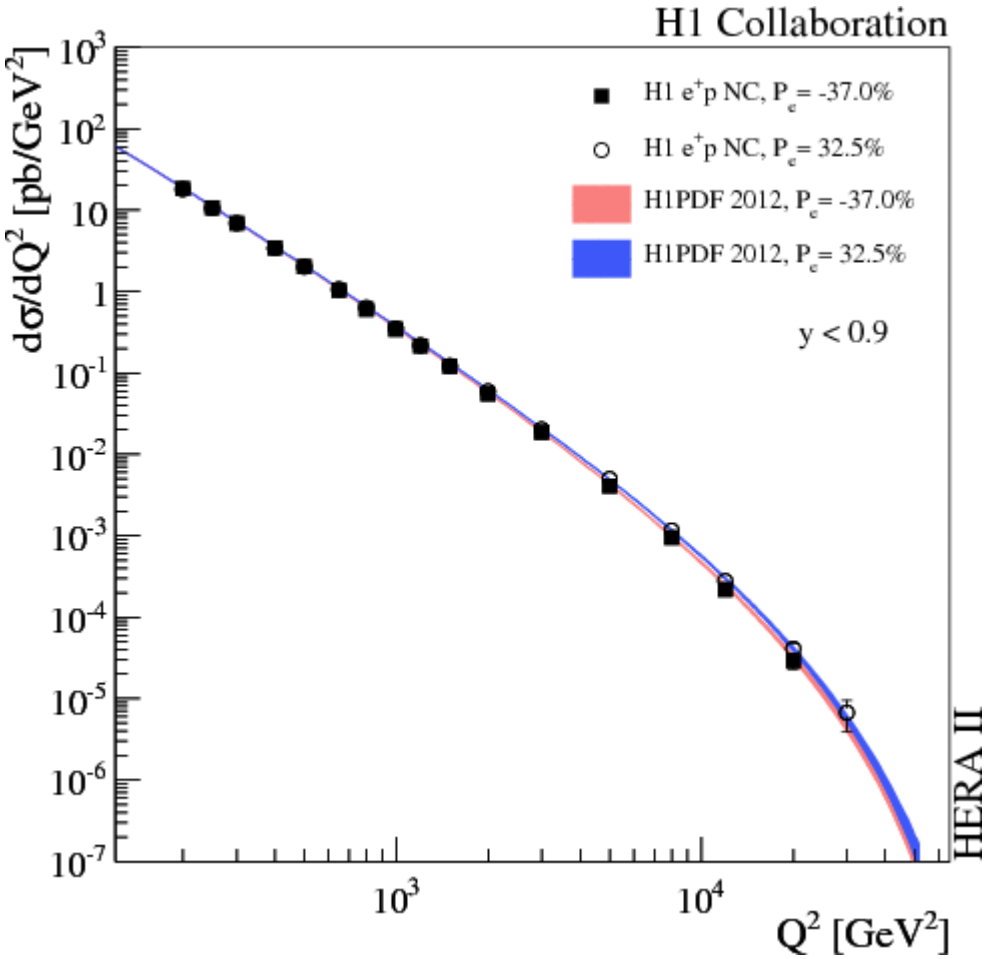
Polarization @ HERA

- From 2003 polarized lepton beam
  - Spin rotators flipping transverse polarization to longitudinal and vice versa
- Positive and negative helicities possible
- Polarization of ~30-55% achieved



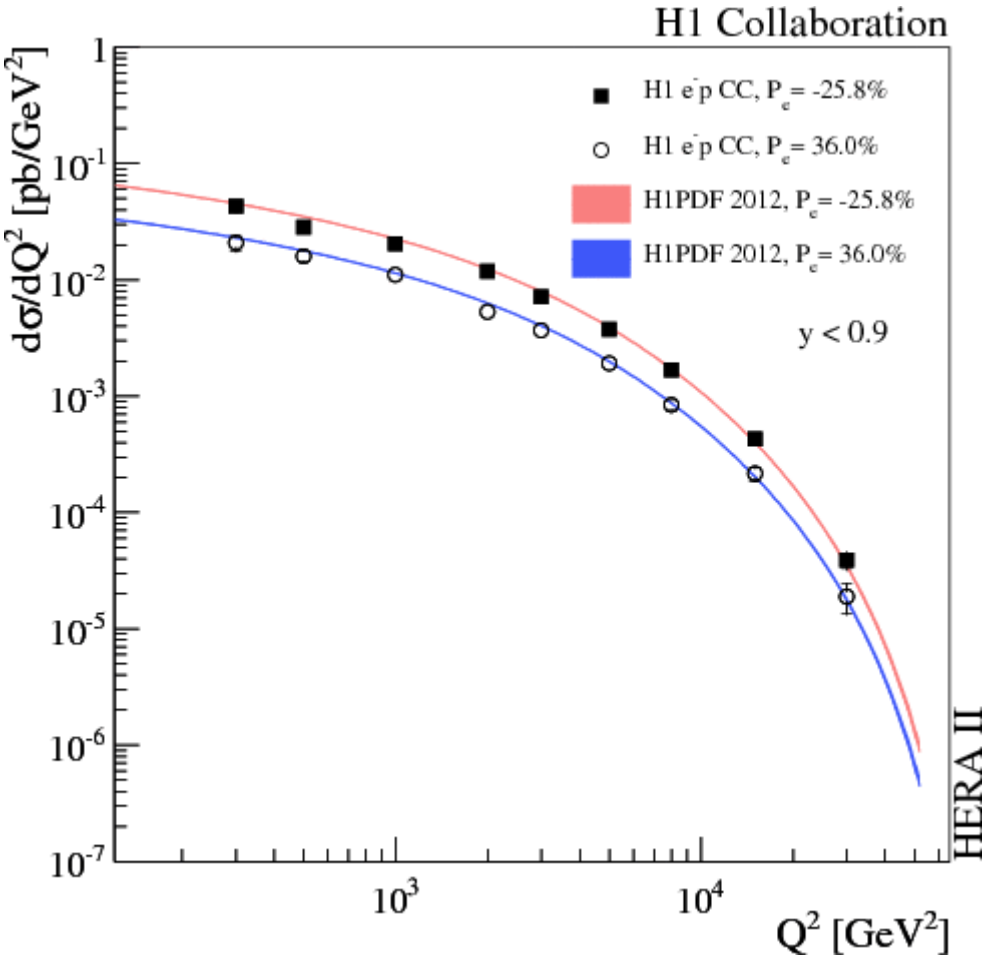
Polarized NC DIS

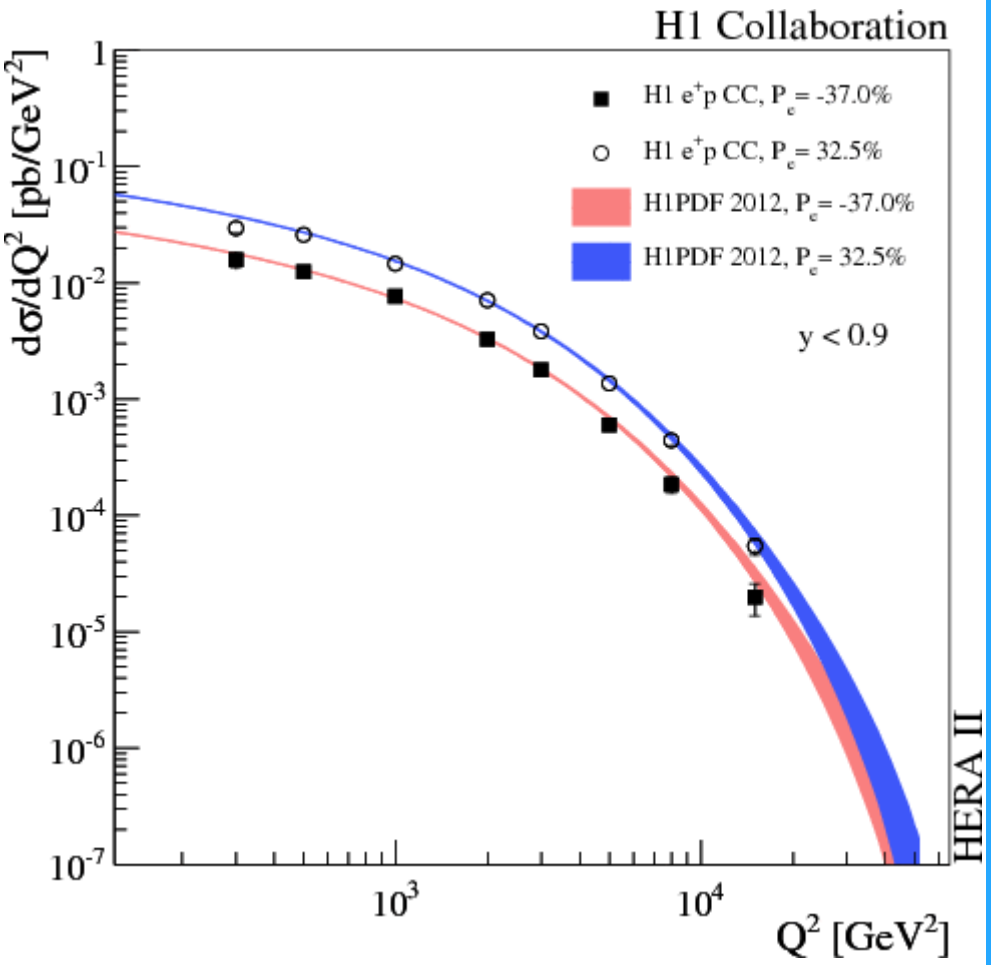




- No significant dependence on polarization in NC DIS
- In agreement with the Standard Model using H1PDF2012

Polarized CC DIS

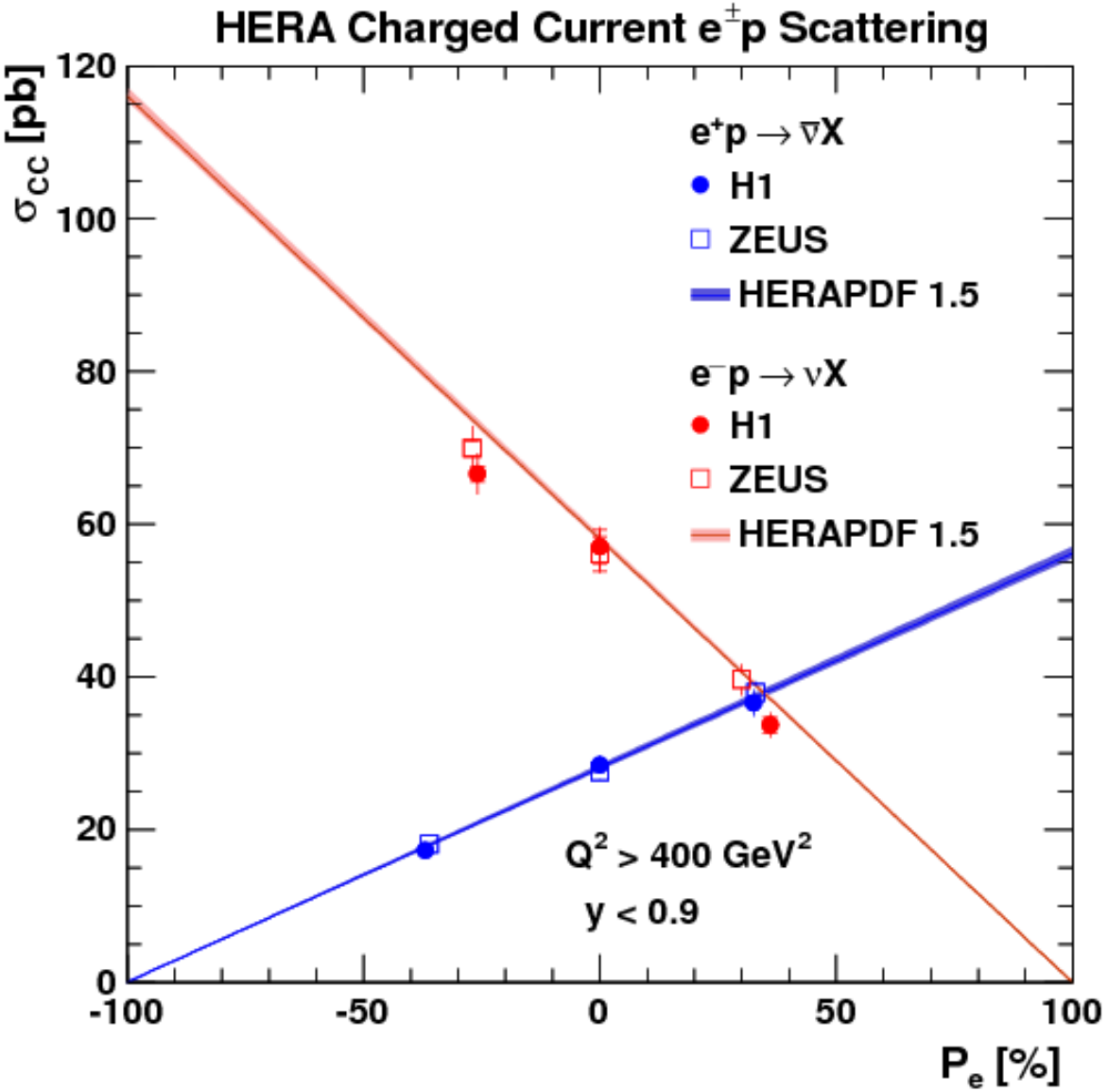




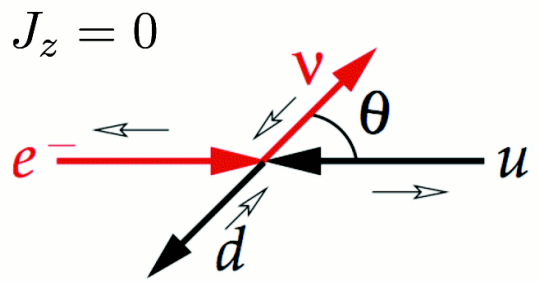
- Very clear dependence on polarization in CC DIS
- In agreement with Standard Model using H1PDF2012

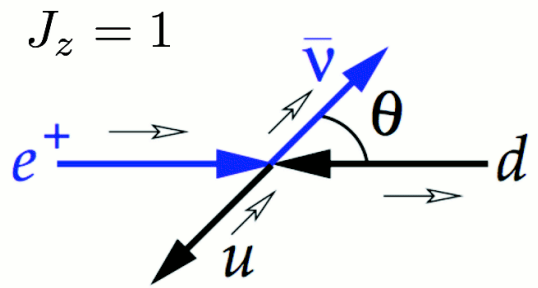
CC polarization dependence in SM

$$\frac{\mathrm{d}^2\sigma^{\pm}_{CC}(P_e)}{\mathrm{d}x\mathrm{d}Q^2} = (1 \pm P_e)\frac{\mathrm{d}^2\sigma^{\pm}_{CC}}{\mathrm{d}x\mathrm{d}Q^2}$$



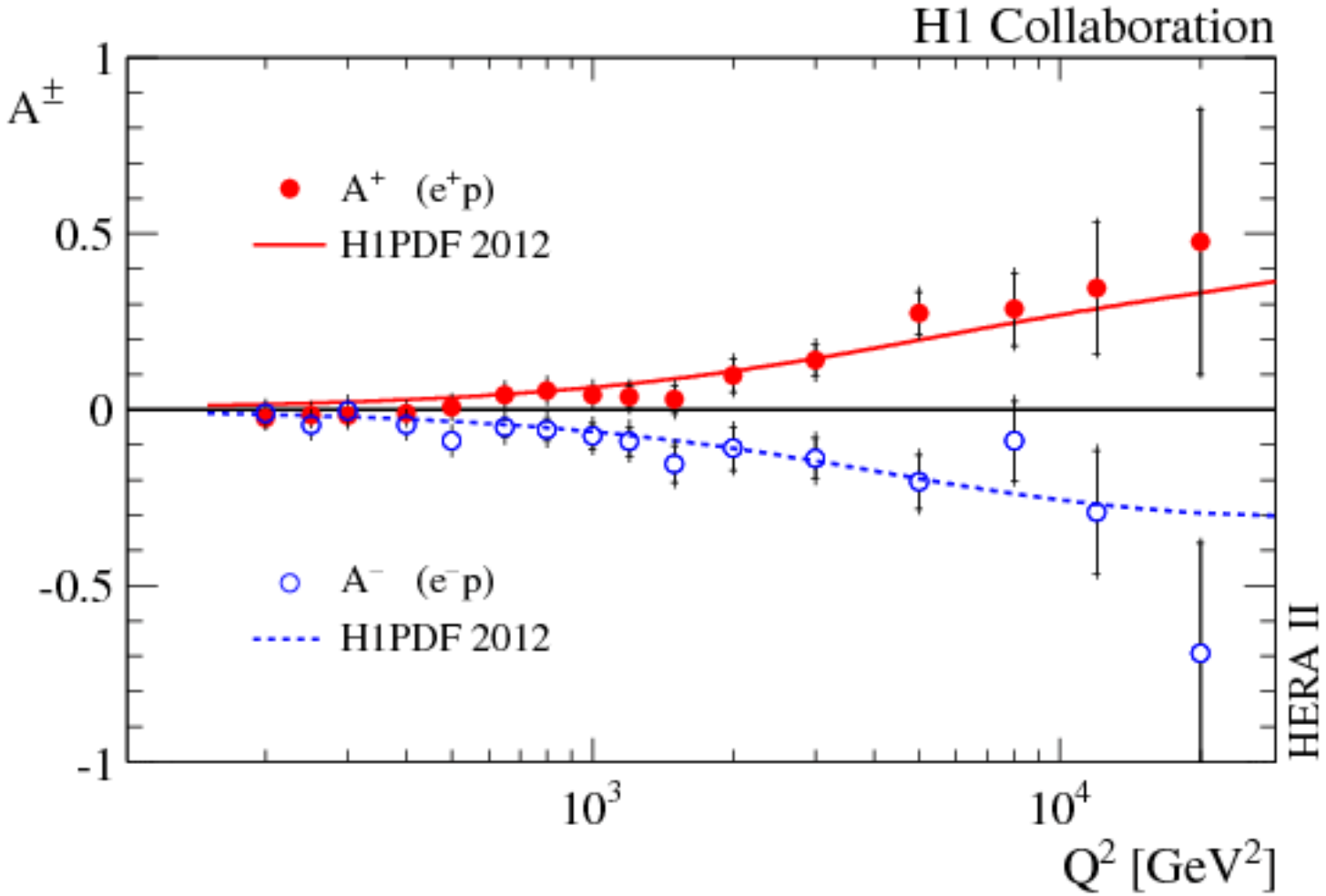
- Chiral structure of EW interactions probed
- Agreement with theory
- no sign for right-handed currents





Parity Violation in NC DIS

NC polarization asymmetry $A^{\pm} = \frac{2}{P_L^{\pm} - P_R^{\pm}} \cdot \frac{\sigma^{\pm}(P_L^{\pm}) - \sigma^{\pm}(P_R^{\pm})}{\sigma^{\pm}(P_L^{\pm}) + \sigma^{\pm}(P_R^{\pm})}$

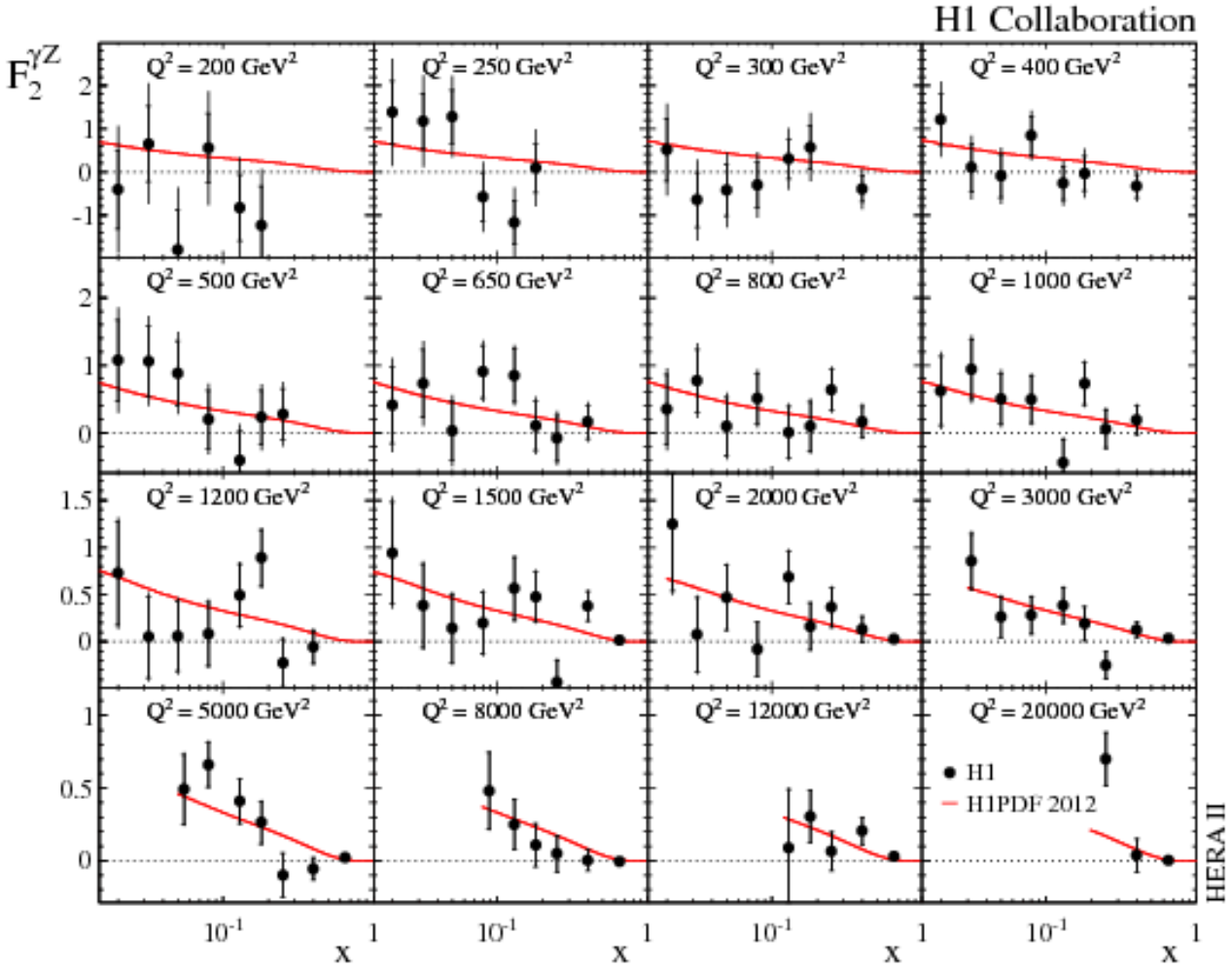


Direct measure of parity violation effect in NC DIS

Quark-Antiquark Distribution

Parity violating structure function $F_2^{\gamma Z}$ extracted from polarized NC cross sections

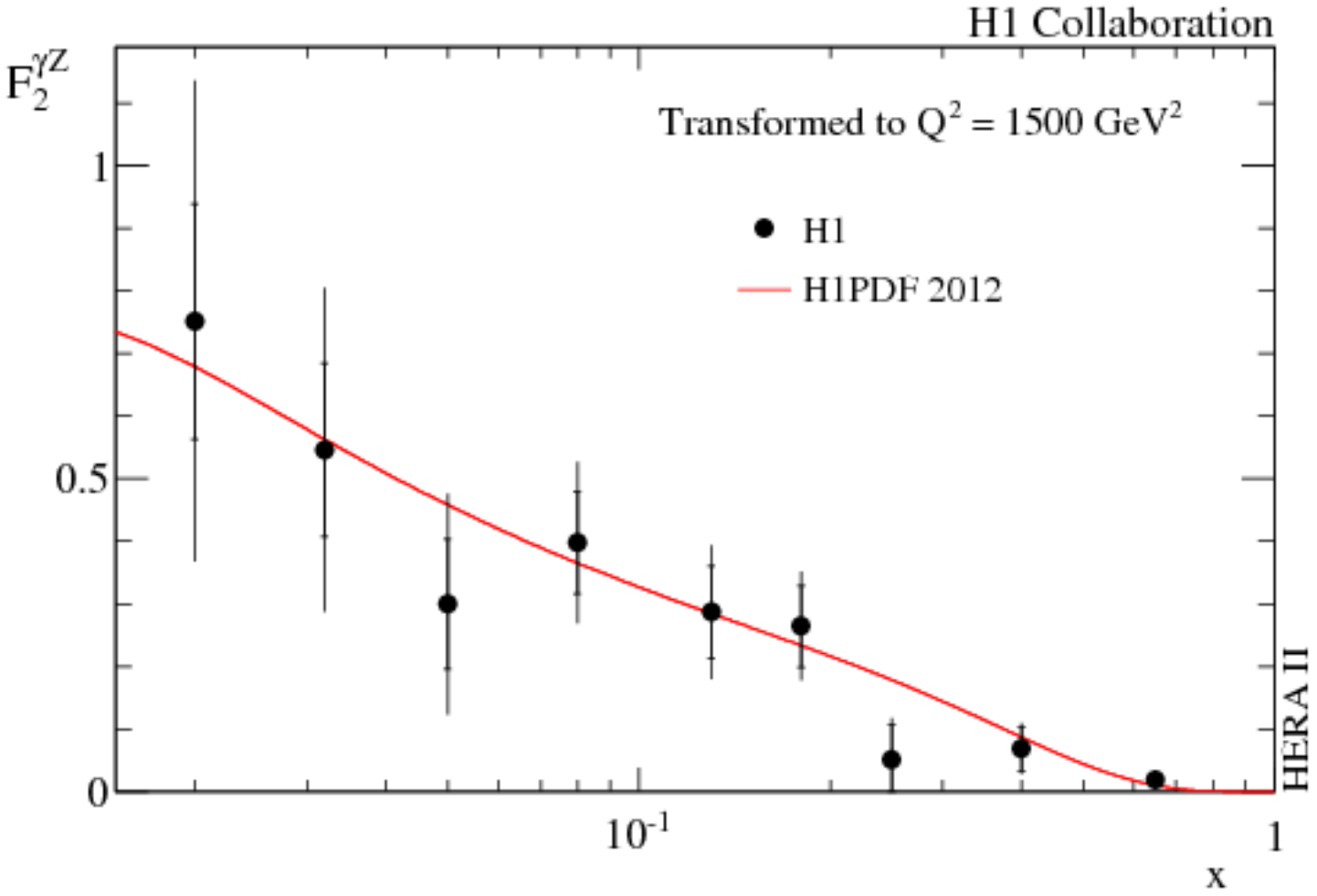
$$\frac{\sigma^{\pm}(P_L^{\pm}) - \sigma^{\pm}(P_R^{\pm})}{P_L^{\pm} - P_R^{\pm}} = \frac{\kappa Q^2}{Q^2 + M_Z^2}\left[\mp a_e F_2^{\gamma Z} + \frac{Y_-}{Y_+} v_e x F_3^{\gamma Z} - \frac{Y_-}{Y_+}\frac{\kappa Q^2}{Q^2 + M_Z^2}(v_e^2 + a_e^2) x F_3^Z\right]$$



First measurement of $F_2^{\gamma Z}$

Quark-Antiquark Distribution

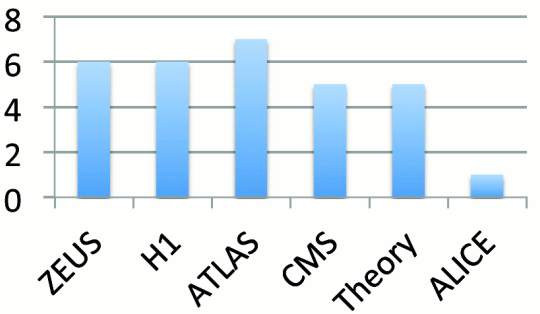
$F_2^{\gamma Z} \sim q+\bar{q}$



HERAFitter: from HERA to LHC

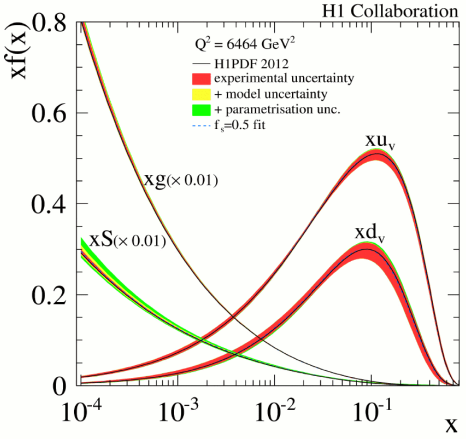
- Series of HERAPDF extracted using HERA data only
  - HERAPDF1.0 based on published HERA I data
  - HERAPDF1.5 based on preliminary HERA I + II data

- Results above based on HERAFitter
  - ➔ Open source project for QCD fits: available at herafitter.org
  - ➔ heritage of HERA transferred to the world
  - ➔ developers: ~30, equally spread among experiments & theory groups

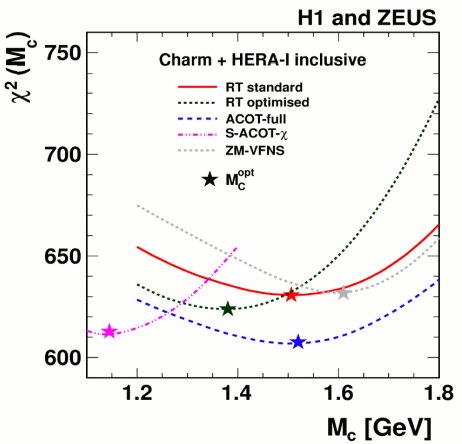


- Recent results based on HERAFitter from HERA & LHC

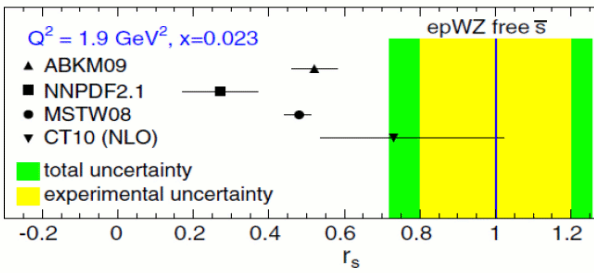
JHEP 09 (2012) 061



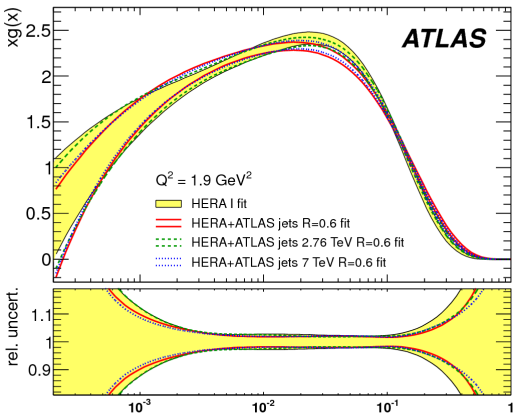
Eur.Phys.J. C73(2012, 2311)



Phys.Rev.Lett. 109 (2012) 012001

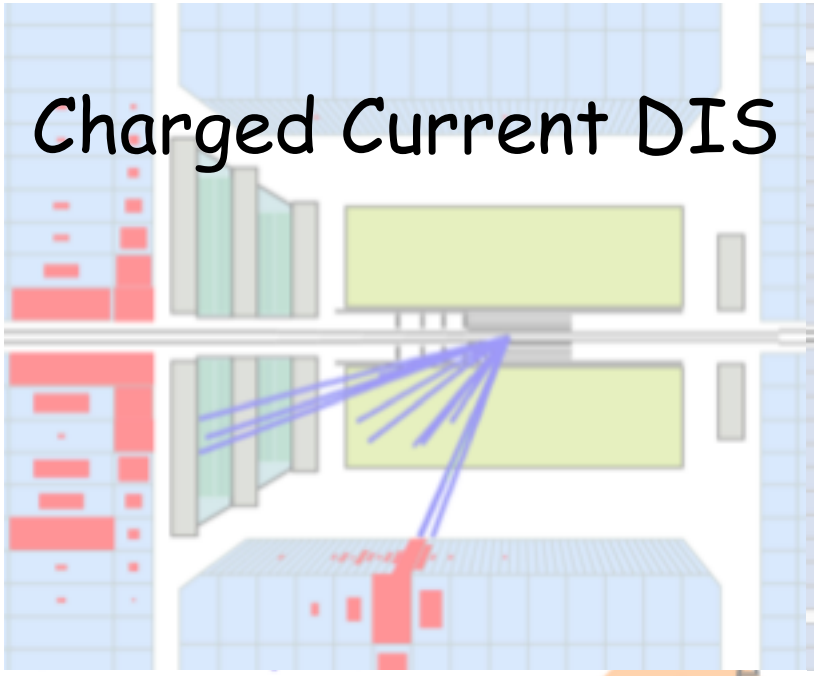


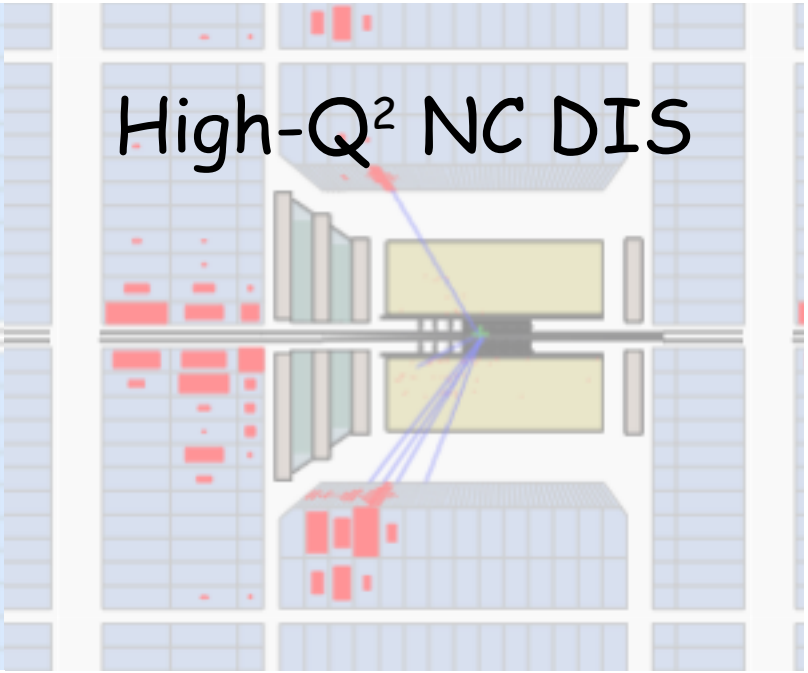
CERN-PH-EP-2013-036
arXiv:1304.4739



Electroweak Bosons @ HERA

	W	Z
Virtual	Charged Current DIS	High-Q^2 NC DIS
Real	High-p_T lepton+$\not{E}_T$	

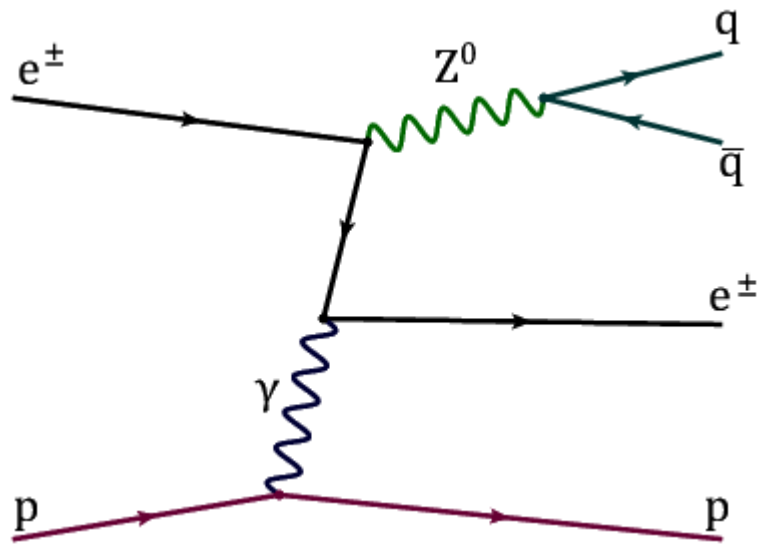




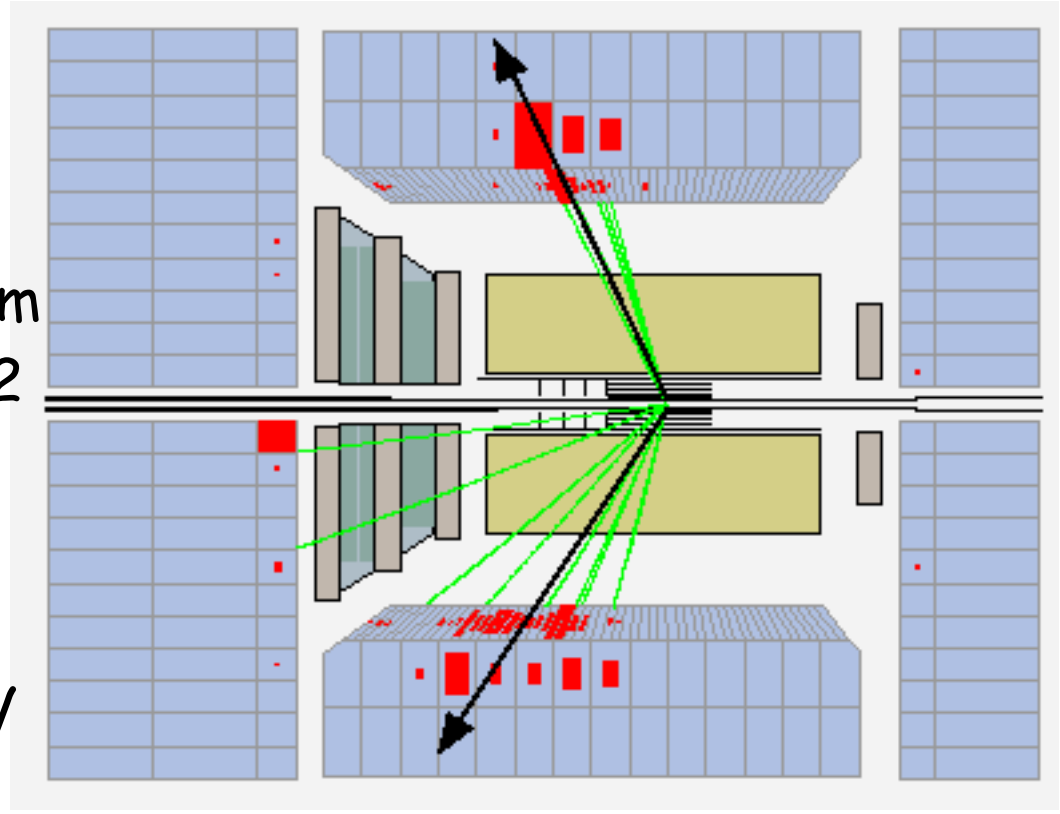
1.06±0.16(stat.)±0.07(syst) pb

Missing piece in HERA EW program?

Real Z^0 production @ HERA



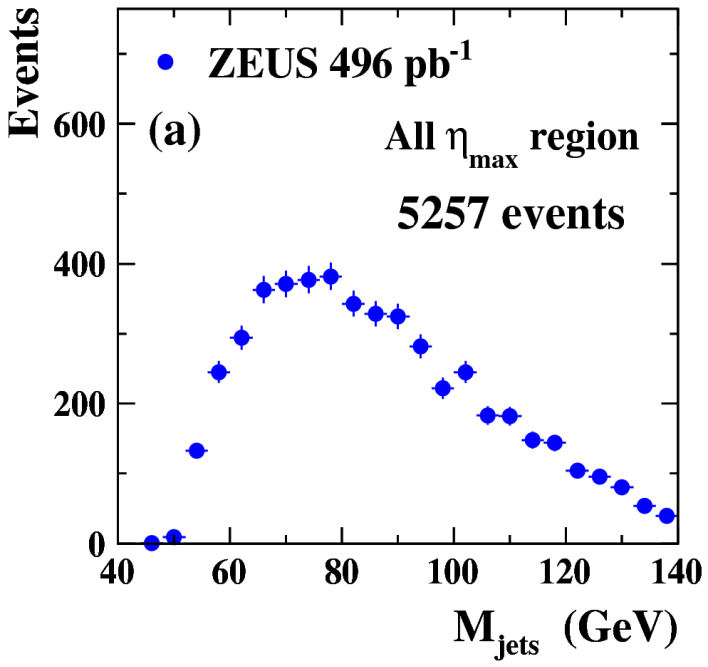
- Z^0 produced on-shell by radiation from quark/lepton lines
- SM σ(Z) expected to be ~ 0.4pb
- Only hadronic decays accessible (leptonic BR too small)
- Select events with at least 2 high-E_T jets
  - calculate invariant mass from all jets with E_T>4GeV & |η|<2



M_{jj} = 92.4 GeV

Elastic Selection

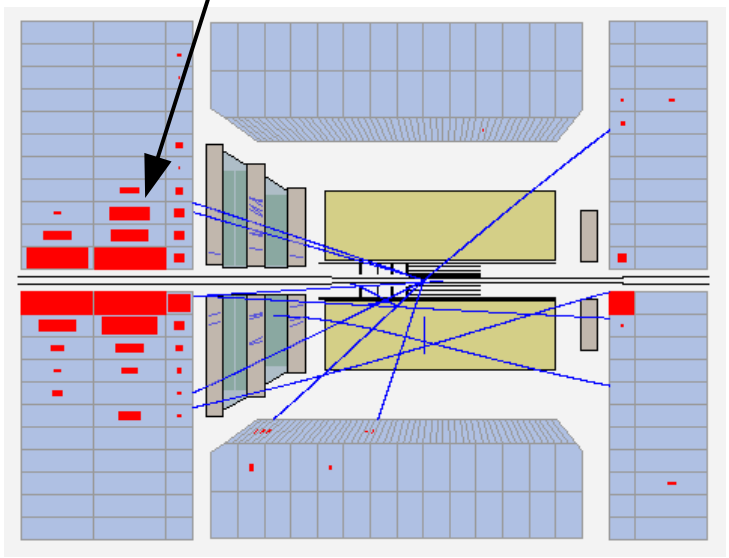
- Multijet sample dominated by QCD background: no Z^0 signal

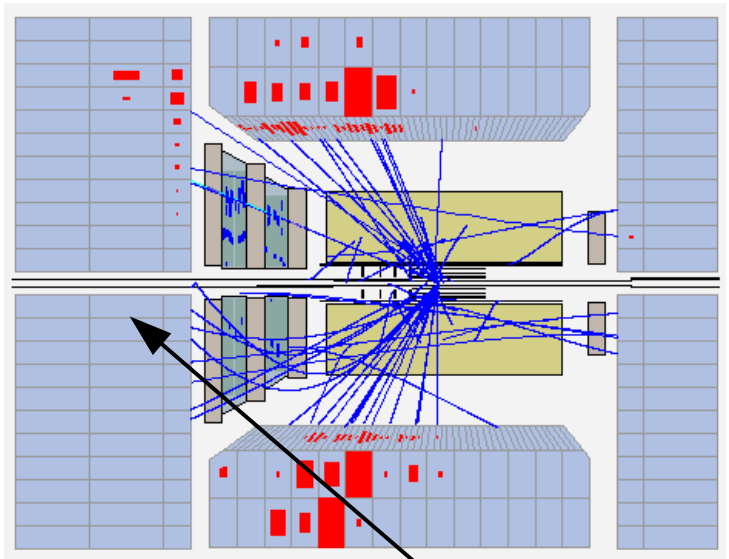


- Use η_{max} for elastic selection:
  - pseudorapidity of the most forward energy deposit in the calorimeter

$\eta_{max} < 3.0$

$\eta_{max} = 4.03$





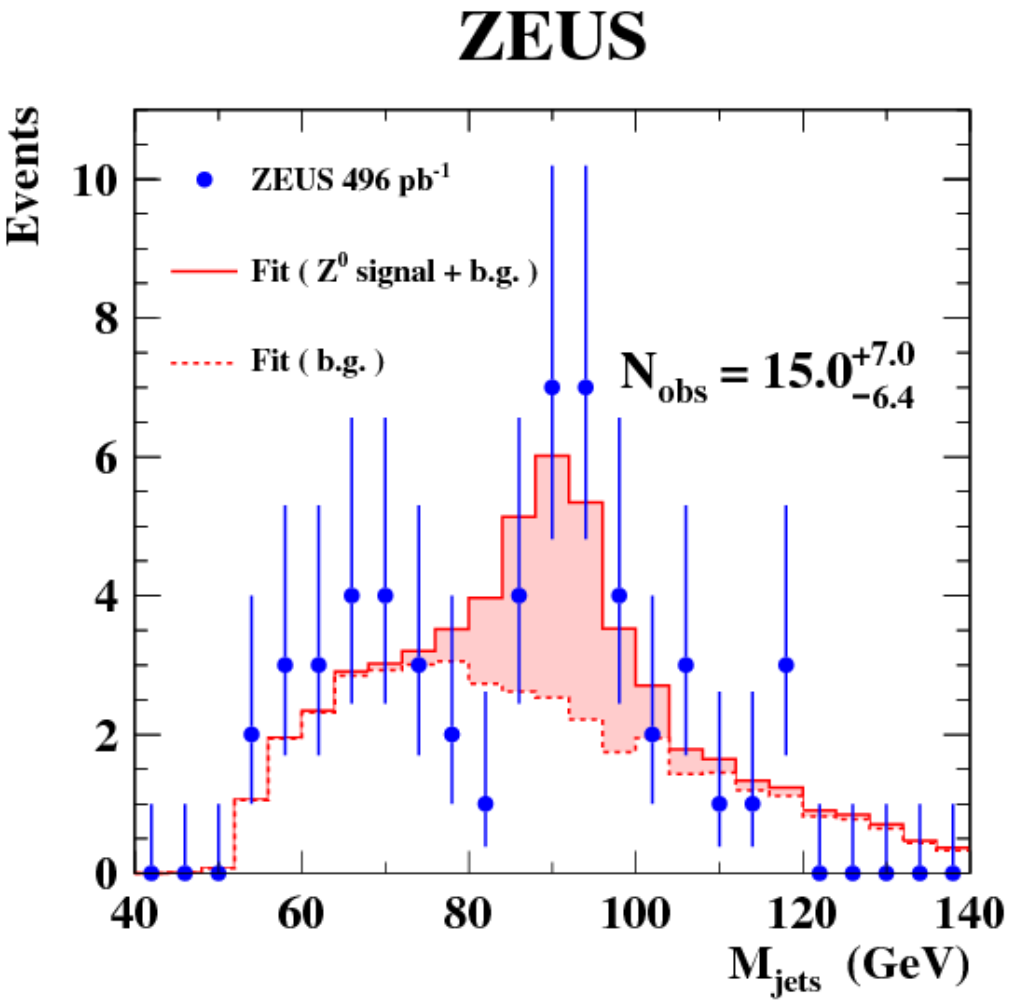
elastic event: $\eta_{max} = 1.24$

Z^0 cross section

0.5 fb^{-1} data collected in years 1996-2007 used

- Z^0 mass peak clearly visible
- shows excellent resolution of ZEUS uranium calorimeter

15 events observed
First measurement @ HERA
Smallest x-section measured @ HERA



$$\sigma(ep \to eZ^0 p^{(*)}) = 0.13 \pm 0.06\,(\text{stat.}) \pm 0.01\,(\text{syst.})\,\text{pb}$$

Consistent with SM elastic cross section $\sigma_{SM}\left(ep \to ep^{(*)}Z^0\right) = 0.16\text{pb}$

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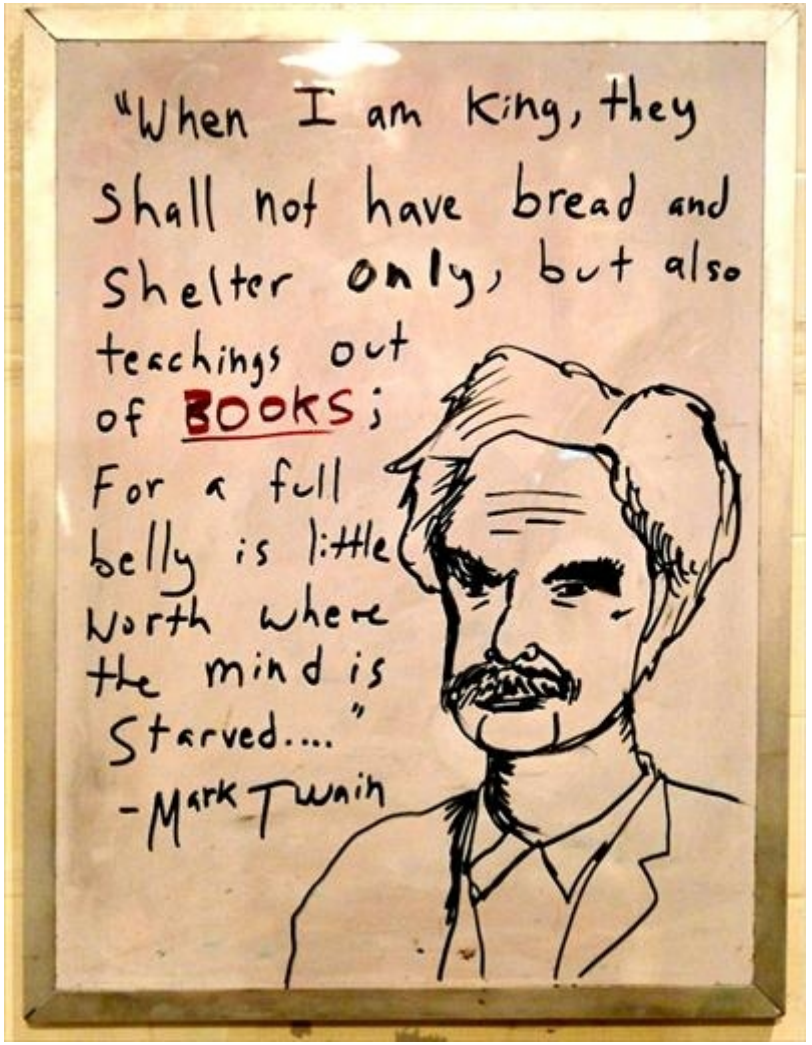

Conclusions

- HERA provides unique window for precise electroweak studies
  - High luminosity
  - Polarization
  - Final results on NC and CC cross sections from H1 and ZEUS
- NC and CC DIS cross sections in very good agreement with SM
  - Also at high Q^2
  - Including polarization and charge asymmetries
- Access to parton densities -> QCD fits
- All EW bosons explored @ HERA, virtual and real