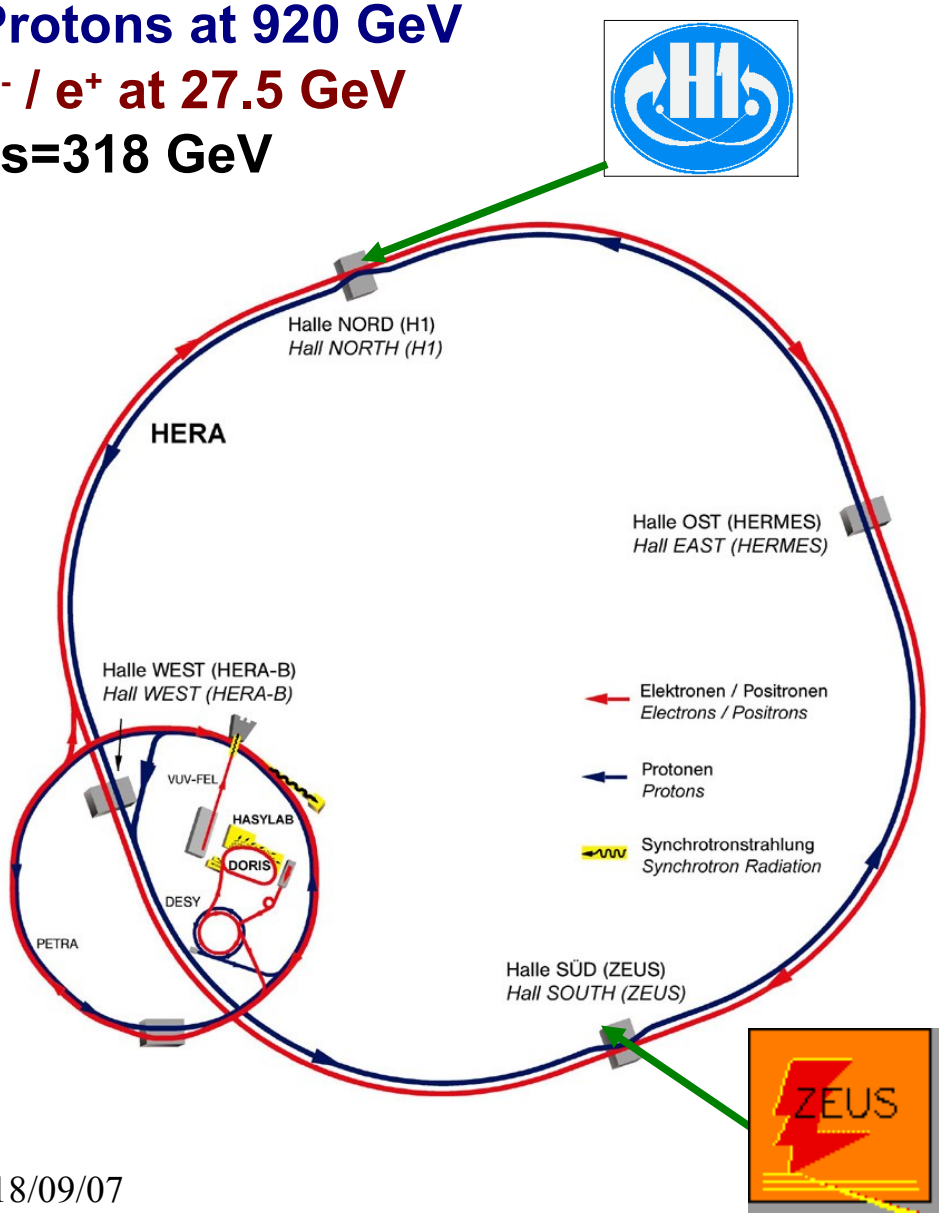
Searches for new physics and electroweak measurements at HERA

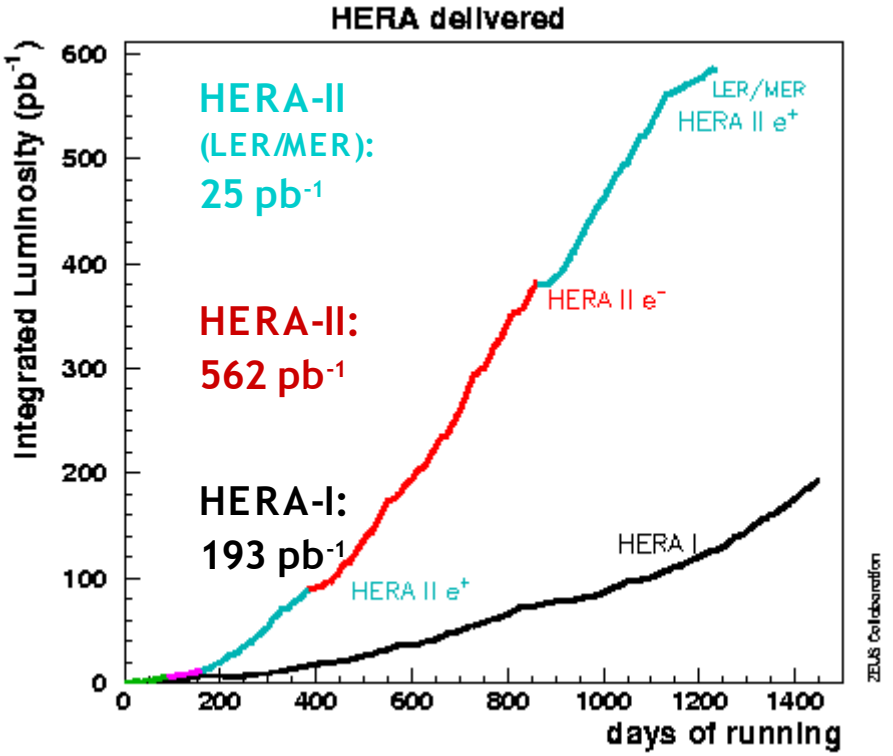
Alessandro Montanari (DESY) on the behalf of H1 and ZEUS

- **Introduction**
  - **Experimental setup**
  - **Deep Inelastic Scattering at high Q^2**
- **Electroweak measurements**
  - **$xF_3^{\gamma Z}$, EW measurements with polarized beams**
- **Beyond Standard Model searches**
  - **Model independent (topology based)**
  - **Model based (excited ν, quark radius, contact interaction)**

HERA: world's only *ep* collider

Protons at 920 GeV
e^- / e^+ at 27.5 GeV
$\sqrt{s}$=318 GeV





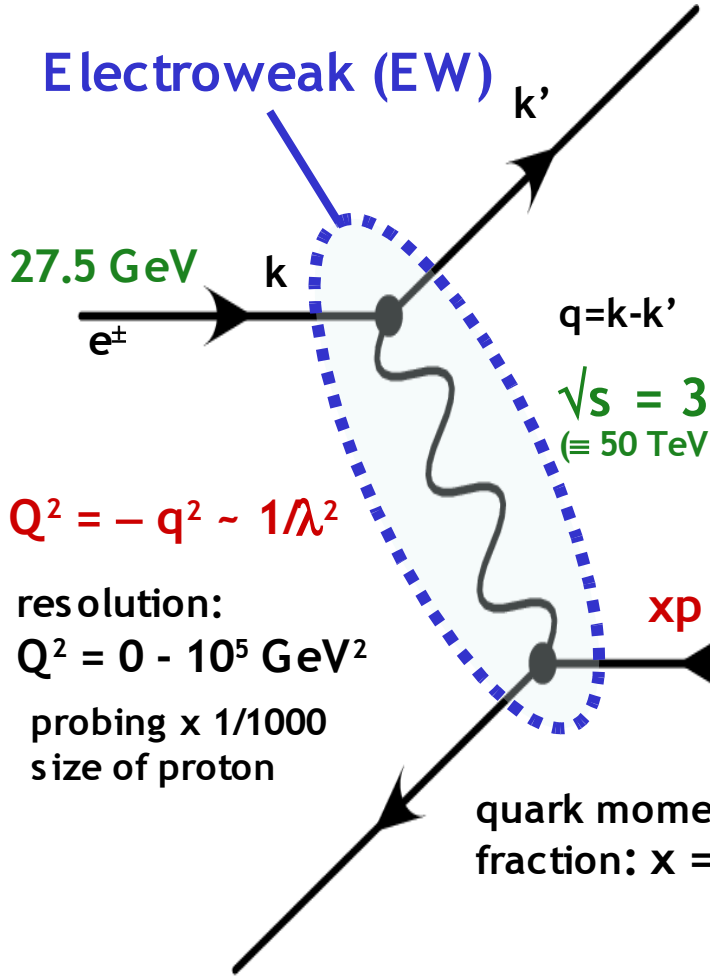
HERA-I: 1993 – 2000

- Precision measurements at low/medium Q^2
  … and a glimpse of high Q2 potential

HERA-II: 2002 – 30 June 2007

- High luminosity → larger statistics for high Q^2
- Polarised e+/e- beams → direct EW sensitivity
- Detector upgrades → heavy flavour
- LER/MER (last 3 months) → FL

Deep Inelastic Scattering at HERA



Kinematic Variables:

- $Q^2 = -(k - k')^2 \sim 1/\lambda^2$: "resolution"
- $x = Q2/2p.q$: quark momentum fraction
- $y = p.q/p.k$: $\equiv (E_e - E_e')/E_e$ in p rest frame

Related via: $Q^2 = s \cdot x \cdot y$ [Reconstructed from scattered e or HFS]

$$\sigma(ep) \sim \sigma(eq) \otimes PDF$$

EW ⊗ QCD

couplings, propagator mass, ... ↗ ↗ proton structure

DIS @ HERA: 1) a "super-microscope" to study Proton Structure (PDFs)

2) sensitivity to EW interaction (in particular when $Q^2 \sim M^2_{W,Z}$)

HERA: Kinematic range

Neutral Current:

$$\frac{d^2\sigma_{NC}(e^{\pm}p)}{dxdQ^2} \sim \frac{2\pi\alpha^2}{x}\frac{1}{Q^4}\left(Y_+ F2 \mp Y_- xF3 - y^2 F_L\right)$$

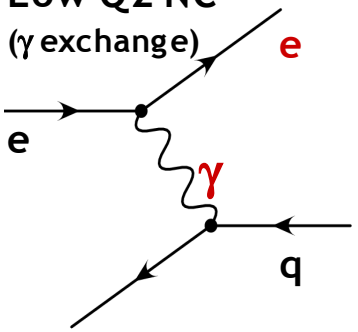
Modified at high Q2 by Z propagator where $Y\pm = 1\pm(1-y)^2$

Charged Current:

$\sigma_{CC}(e^+p) \sim (1-y)^2 (d+s) + (\bar{u} + \bar{c})$

$\sigma_{CC}(e^-p) \sim (u+c) + (1-y)^2 (\bar{d} + \bar{s})$

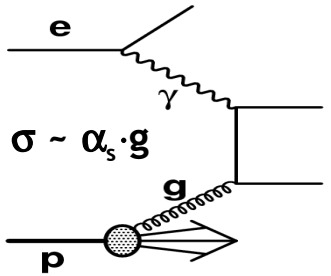
Low Q2 NC
(γ exchange)

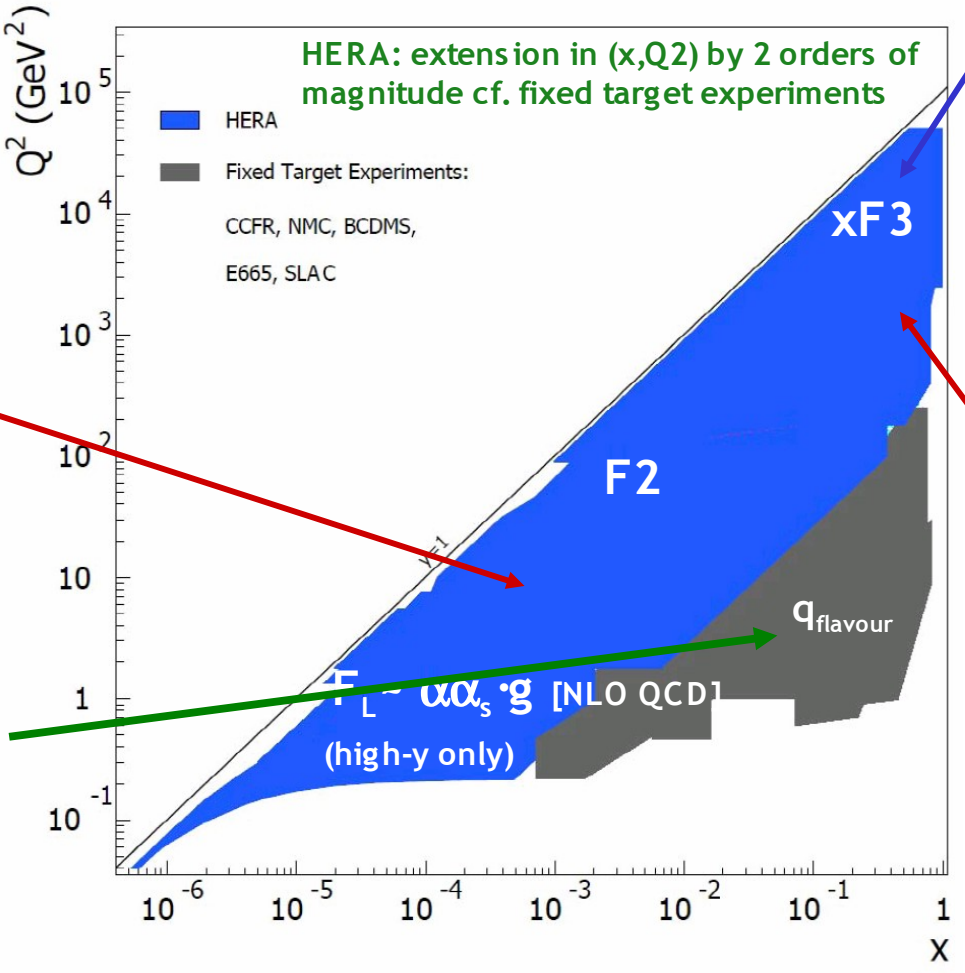


$F2 \sim \Sigma x (q+\bar{q})$

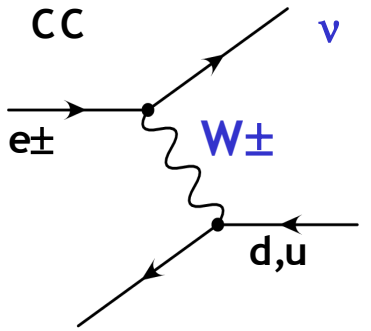
$dF2/d\ln Q2 \sim \alpha_s \cdot g$

Final States:
(Jets, Charm, ...)



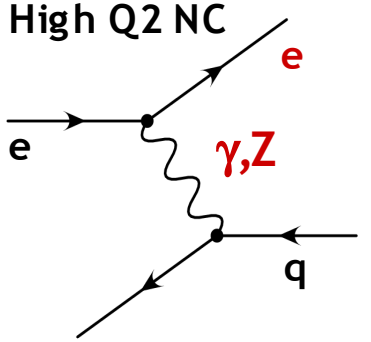


CC



flavour composition
e+: d e-: u

High Q2 NC



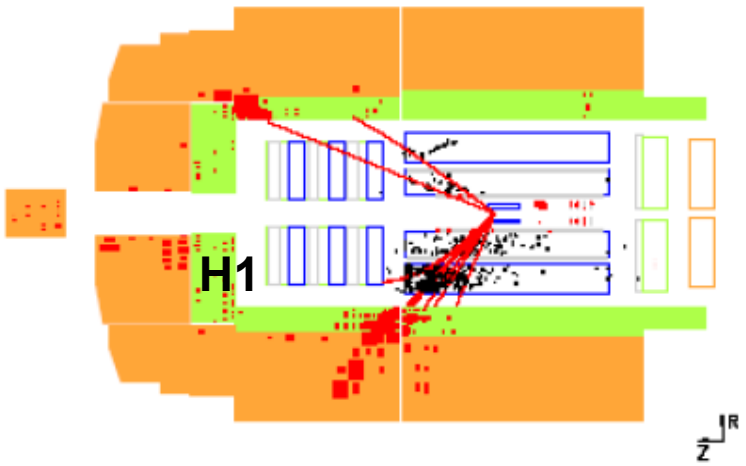
Z Parity Violation

$xF3 \sim \Sigma x (q-\bar{q})$

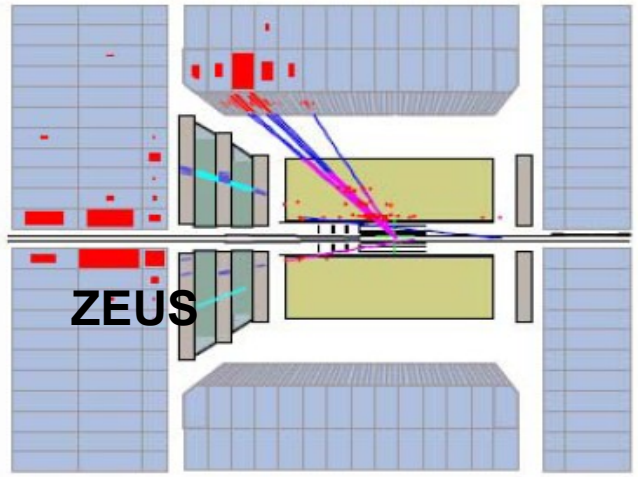
valence

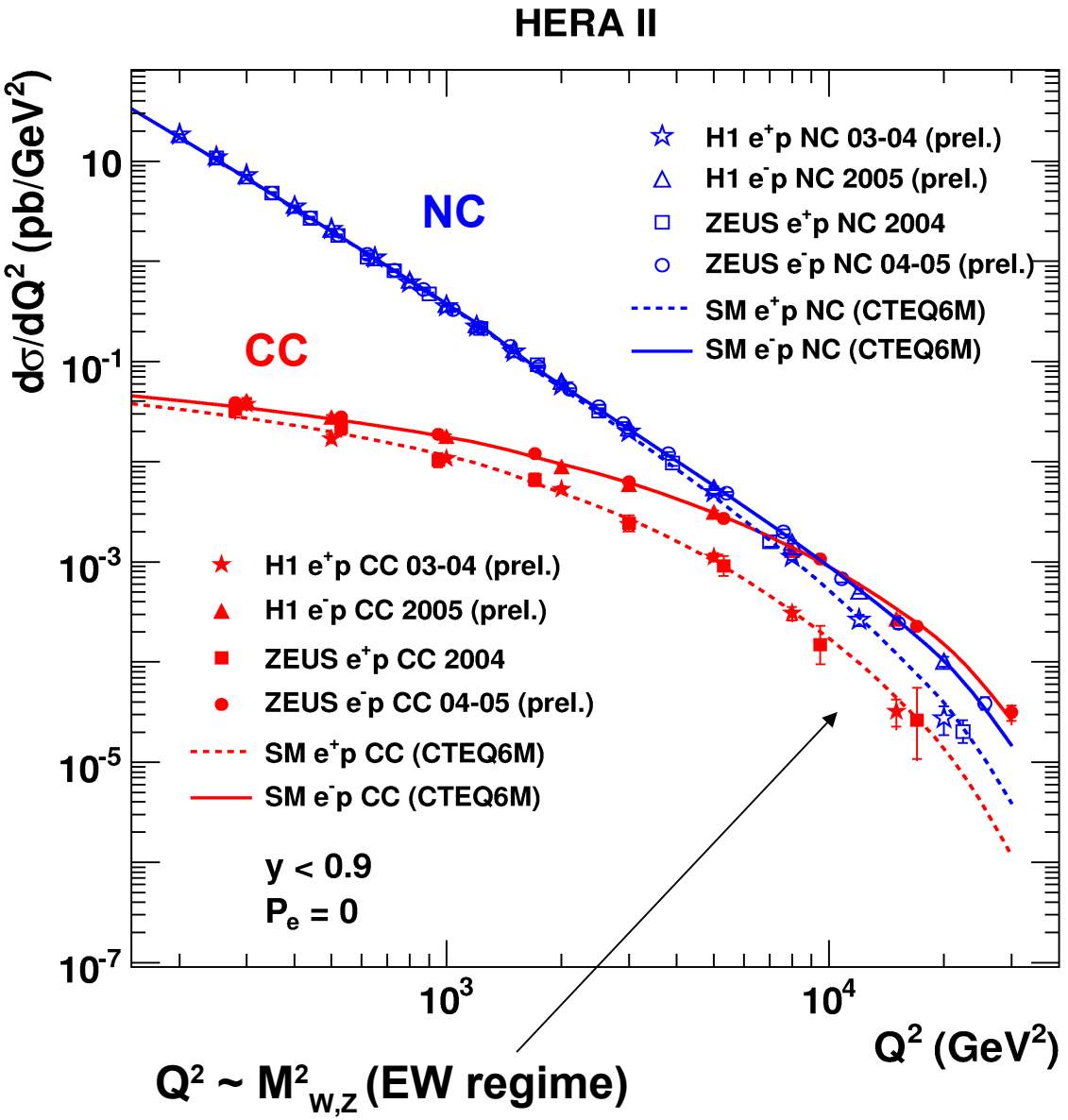
EW Unification

Neutral Current (NC)



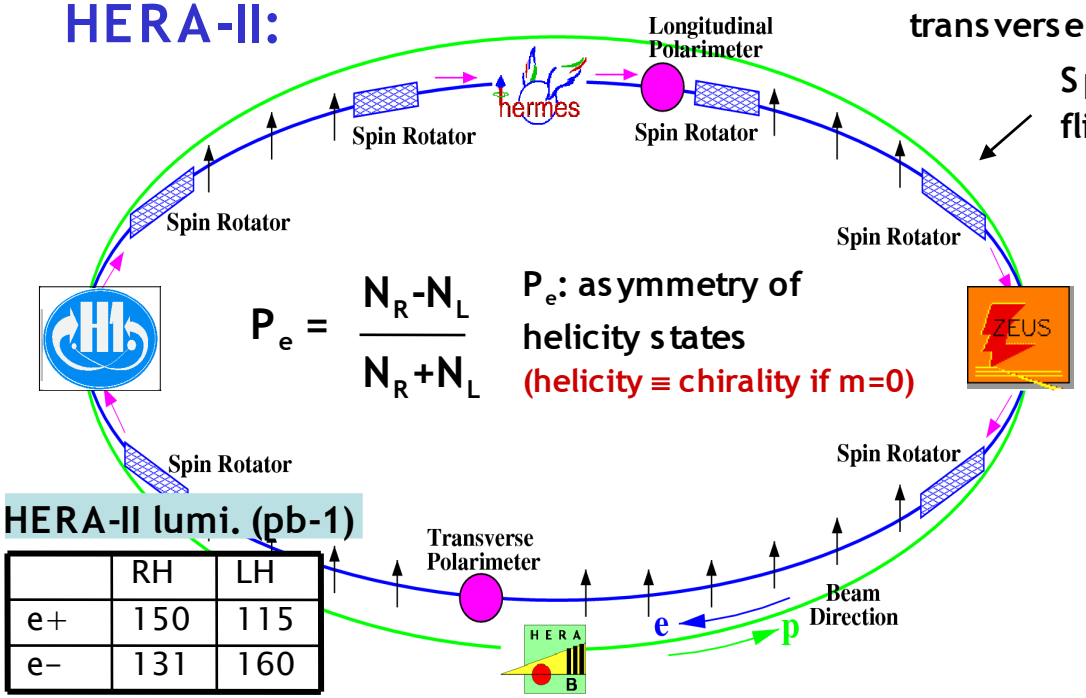
Charged Current (CC)





HERA II: beam polarization

HERA-II:



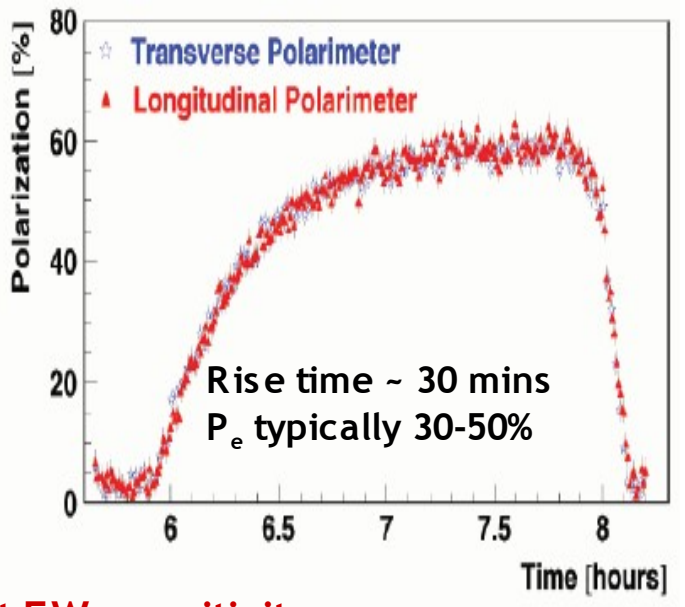
$$P_e = \frac{N_R - N_L}{N_R + N_L}$$

P_e: asymmetry of helicity states

(helicity ≡ chirality if m=0)

Synchrotron radiation off lepton induces transverse polarisation (Sokolov-Ternov effect)

Spin rotators (installed during HERA-II upgrade) flip transverse and longitudinal polarisation



HERA-II lumi. (pb-1)

	RH	LH
e+	150	115
e−	131	160

HERA-II: Longitudinally polarised leptons → direct EW sensitivity

(directly test chiral structure of SM: RH ≠ LH ⇔ parity violation)

CC: pure weak = 100% parity violating in SM → only LH particles (RH anti-particles) interact

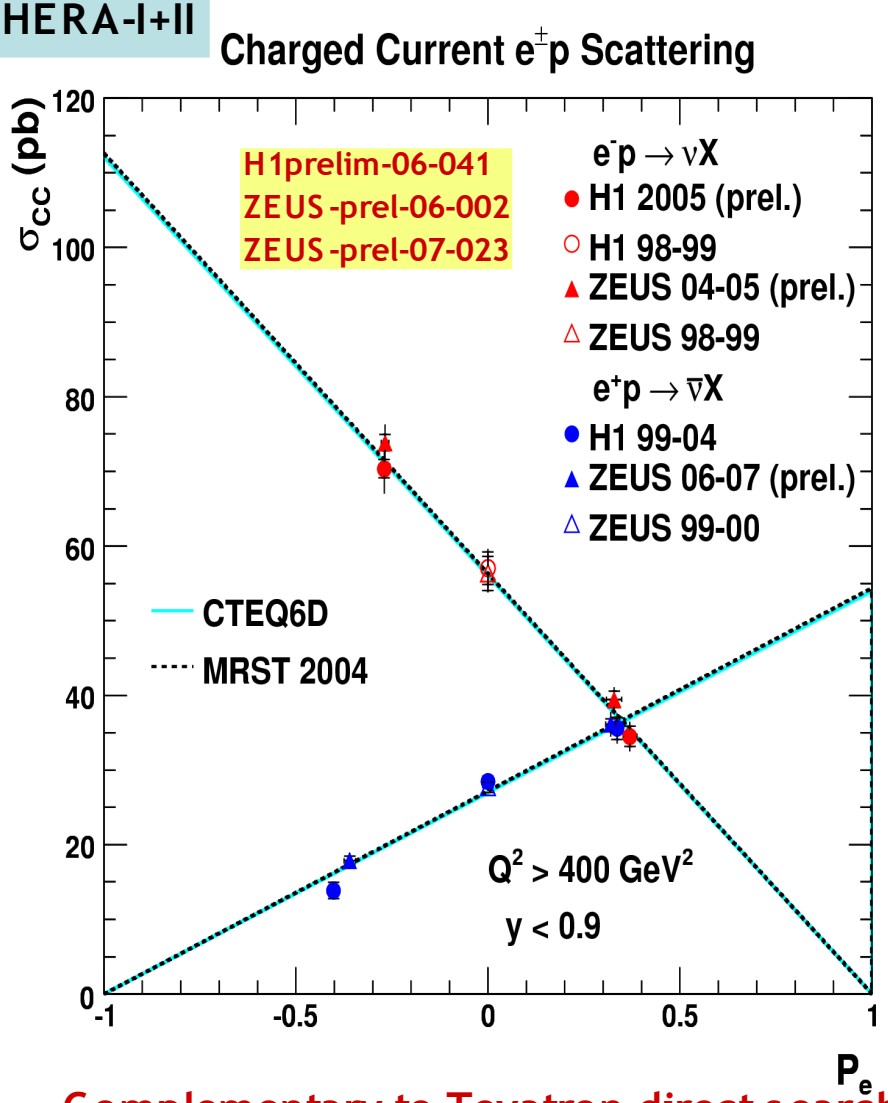
cross section modified by linear scale factor: $\sigma^{\pm}_{CC}(P_e) = (1 \pm P_e) \cdot \sigma^{\pm}_{CC}(P_e=0)$

NC: weak parity violation through γZ interference and pure Z → visible only at high Q^2

(γZ, Z terms contain EW parameters: quark couplings to Z, $\sin^2\theta_W$, M_Z,...)

CC Polarisation Dependence

HERA-I+II



$\sigma^{\pm}_{CC}(P_e) = (1 \pm P_e)\, \sigma^{\pm}_{CC}(P_e=0)$

Linear dependence

Extrapolation to $P_e=\pm1$: limits on RH σ_{CC}

$\sigma_{CC}(e^-p)$ [pb] extrapolated to $P_e = +1$	
H1 (prel.)	$-0.9 \pm 2.9_{stat} \pm 1.9_{syst} \pm 2.9_{pol}$
ZEUS (prel.)	$0.8 \pm 3.1_{stat} \pm 5.0_{syst+pol}$
$\sigma_{CC}(e^+p)$ [pb] extrapolated to $P_e = -1$	
H1 (pub.)	$-3.9 \pm 2.3_{stat} \pm 0.7_{syst} \pm 0.8_{pol}$
ZEUS (pub.)	$7.4 \pm 3.9_{stat} \pm 1.2_{syst+pol}$

Consistent with NO RH Charged Currents!

Convert to 95% CL on heavy W_R boson

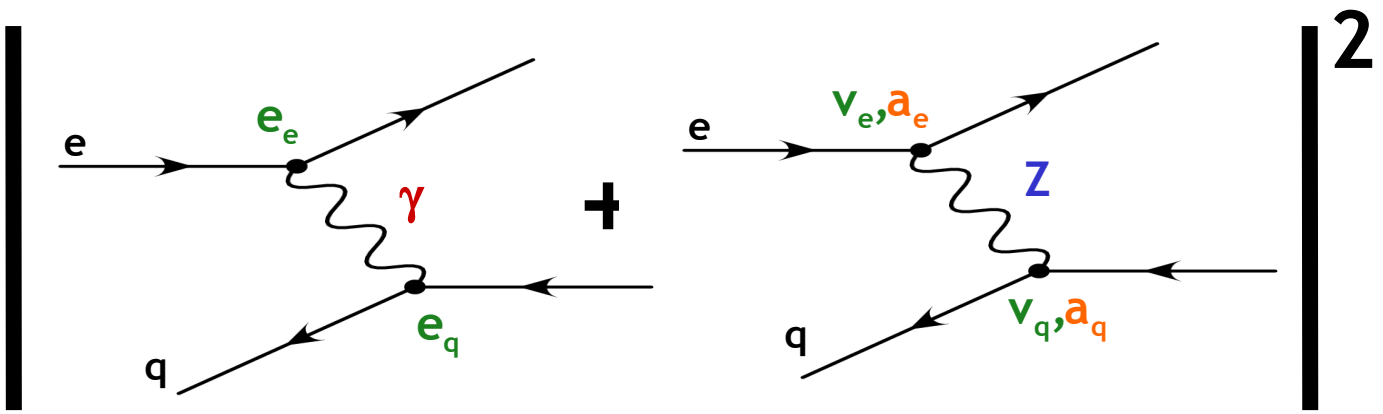
(assuming $g_L=g_R$ and ν_R is light):

- $M_{WR} > 208$ GeV (H1, e+p)
- $M_{WR} > 186$ GeV (H1, e-p)
- $M_{WR} > 180$ GeV (ZEUS, e-p)

Complementary to Tevatron direct searches

cf. W' > 786 GeV by CDF (W' → eν,μν)

Polarisation Effects in NC



Polarisation effects are subtle in NC DIS

Reduced cross section: $\sigma_{NC}(e^{\pm}p) \sim Y_+ F2 \mp Y_- xF3 - y^2 F_L$ $\quad \kappa_Z$ ~ Z propagator

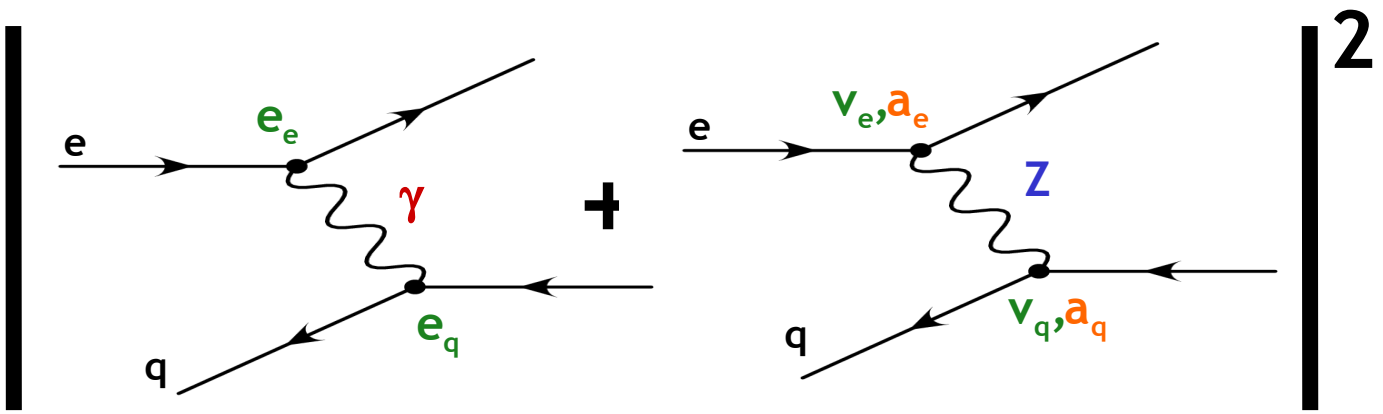
$$F2(\pm Pe) = F2^{\gamma} - (v_e \pm Pe\, a_e)\, \kappa_Z\, F2^{\gamma Z} + ((v_e^2+a_e^2) \pm Pe\, 2v_e a_e)\, \kappa_Z^2\, F2^{Z}$$

$$xF3(\pm Pe) = - (a_e \pm Pe\, v_e)\, \kappa_Z\, xF3^{\gamma Z} + (2v_e a_e \pm Pe\, (v_e^2+a_e^2))\, \kappa_Z^2\, xF3^{Z}$$

Weak parity violating effect though γZ interference and pure Z → high Q2 only

γZ dominates (pure Z suppressed by additional propagator i.e. $\kappa_Z >> \kappa_Z^2$ and $v_e \approx 0.04$)

Polarisation Effects in NC



Polarisation effects are subtle in NC DIS

Reduced cross section: $\sigma_{NC}(e^{\pm}p) \sim Y_+ F2 \mp Y_- xF3 - y^2 F_L$ $\quad \kappa_Z$ ~ Z propagator

$F2(\pm Pe) = F2^{\gamma} - (\pm Pe\, a_e)\, \kappa_Z\, F2^{\gamma Z}$

$xF3(\pm Pe) = - (a_e)\, \kappa_Z\, xF3^{\gamma Z}$

Weak parity violating effect though γZ interference and pure Z → high Q2 only

γZ dominates (pure Z suppressed by additional propagator i.e. $\kappa_Z >> \kappa_Z^2$ and $v_e \approx 0.04$)

Unpolarised: $\sigma(e^+p) - \sigma(e^-p) \rightarrow xF3^{\gamma Z}$

Polarised: $\sigma(P_R) - \sigma(P_L) \rightarrow F2^{\gamma Z}$

EW structure functions in QPM (γZ):

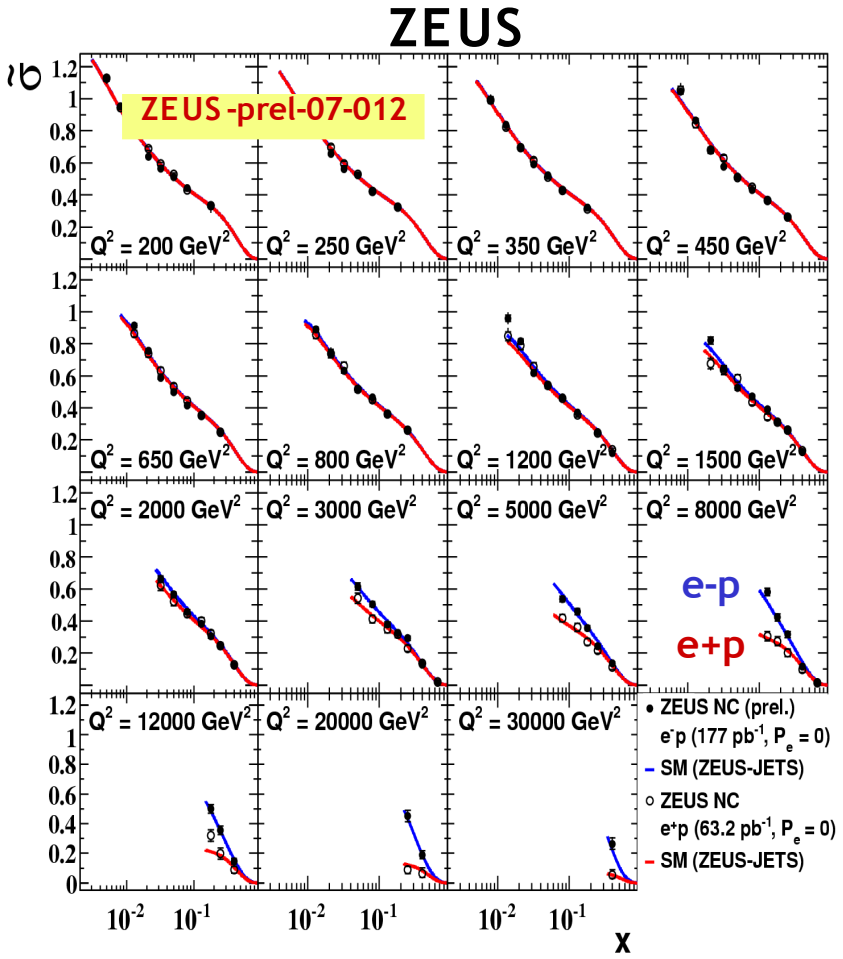
$F2^{\gamma Z} = 2\, e_q\, v_q\, \Sigma x(q+qbar)$

$xF3^{\gamma Z} = 2\, e_q\, a_q\, \Sigma x(q-qbar)$

xF3 and Valence Quarks

$\sigma_{NC}(e^{\pm}p) \sim Y_+ F2 \mp Y_- xF3$ (neglecting F_L)

(γZ interference flips sign ↑)



New HERA-II high precision e-p data at high Q2

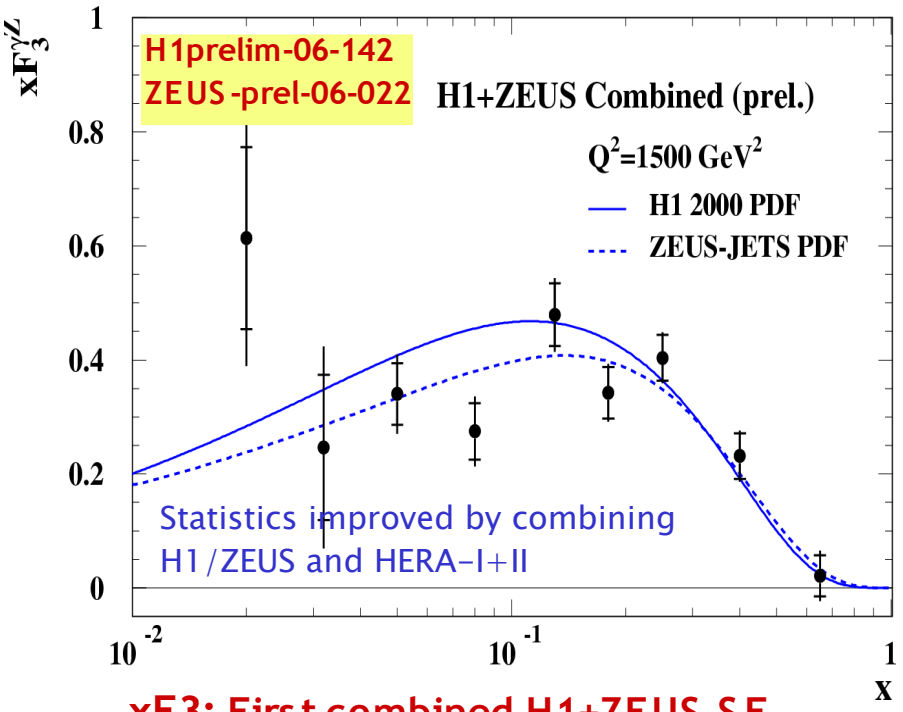
(HERA-II delivered > x10 e-p cf. HERA-I)

- σ(e-p) > σ(e+p) at high Q2 (sign flip)
  → extract xF3 from difference

$xF3 \sim \sigma(e^-p)-\sigma(e^+p) \sim 2/3u_v+1/3d_v$

(assuming SM EW couplings ↑)

- Important information on valence quarks in the proton (x < 0.1)



xF3: First combined H1+ZEUS SF result (using ~ 1/2 full HERA dataset)

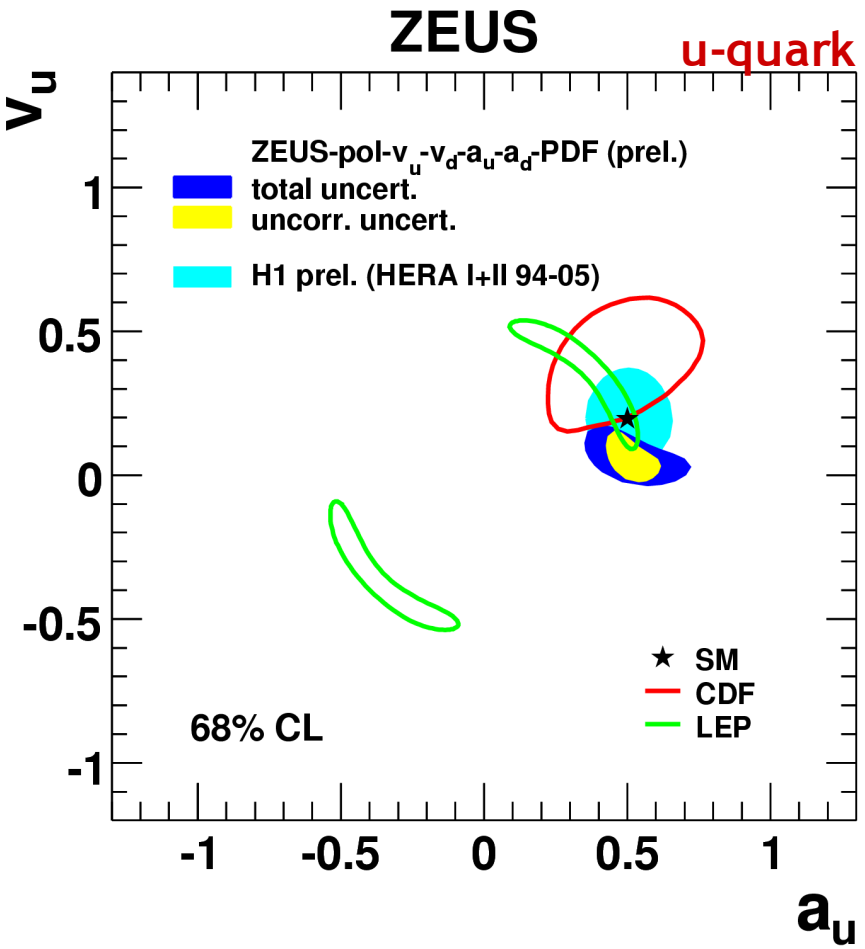
(simple weighted average)

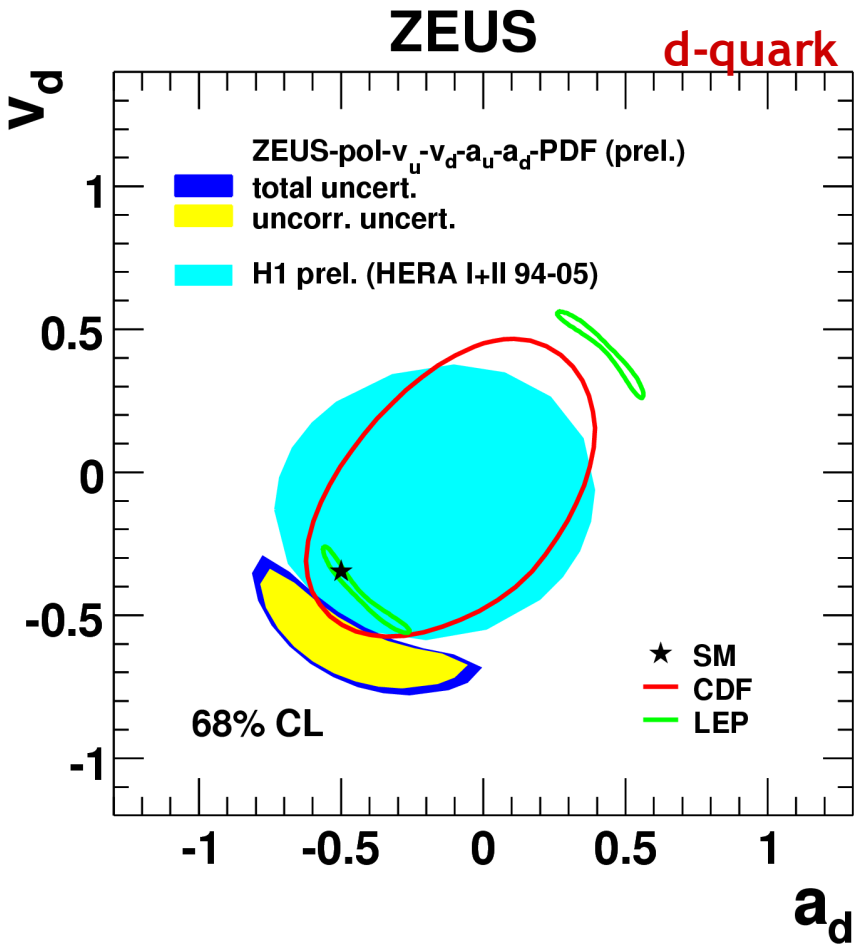
NC Couplings to light quarks

QCD+EW fit: to determine PDFs and u,d quark axial and vector couplings to Z

unpol.: $\sigma(e^+p) - \sigma(e^-p) \rightarrow xF3^{\gamma Z} \rightarrow \propto e_q a_q$

pol.: $\sigma(P_R) - \sigma(P_L) \rightarrow F2^{\gamma Z} \rightarrow \propto e_q v_q$





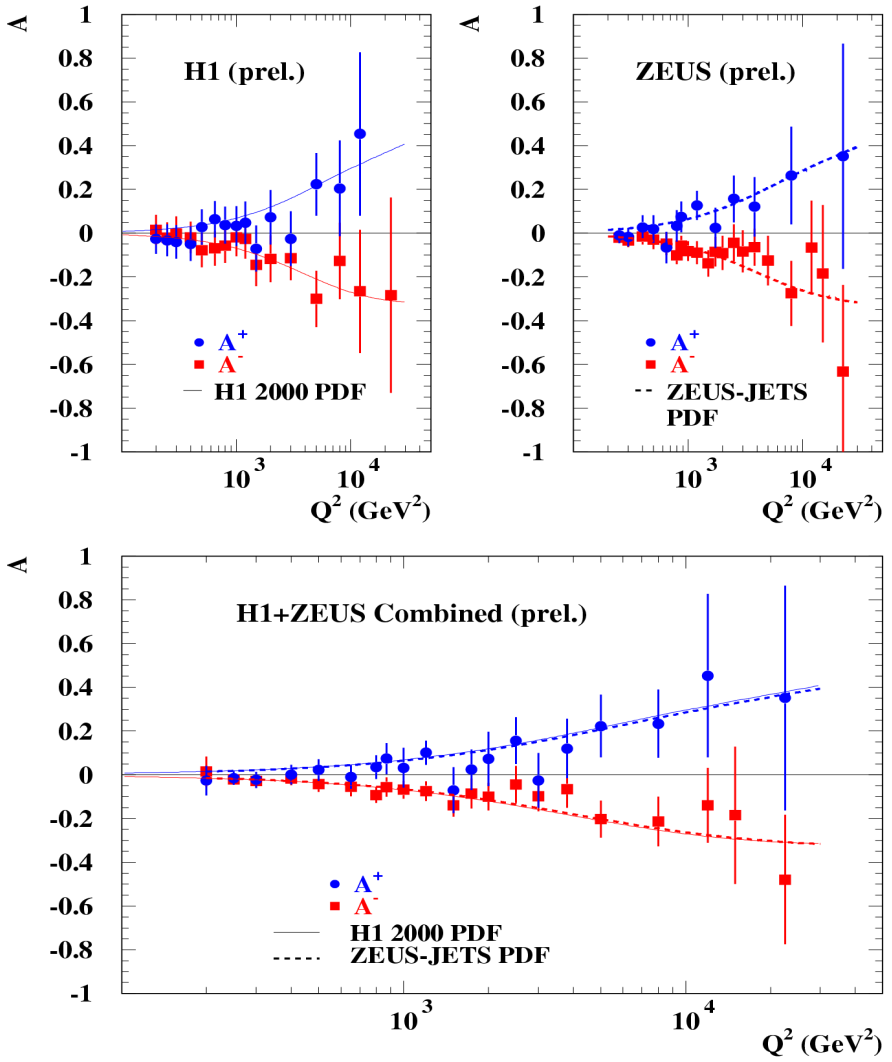
HERA-II greatly improves precision: v_q (polarization) and a_q (luminosity)

NC Cross Section Asymmetry

H1prelim-06-142
ZEUS-prel-06-022

HERA-II

HERA



Asymmetry of RH/LH cross sections:

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

Expect $A^+ \approx -A^-$ in the SM:

$$A^{\pm} \approx \mp \kappa_Z a_e \frac{F2^{\gamma Z}}{F2^{\gamma}} \propto a_e v_q$$

Direct measure of
Parity Violation through $a_e v_q$ term

χ^2 of $\delta A = A^+ - A^- = 0$ is 4.0 (3.1×10^{-3} prob.)

Parity violation observed for the first time @ EW scale

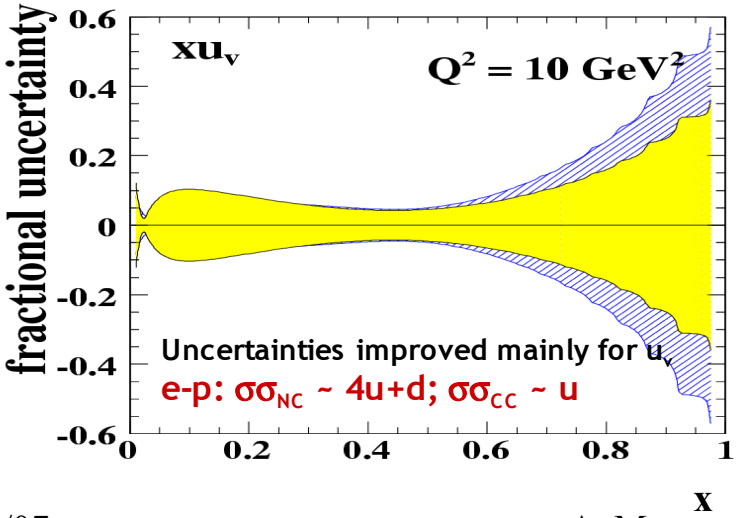
QCD+EW Fits to HERA Data

QCD+EW Fit: to simultaneously determine EW and PDF parameters

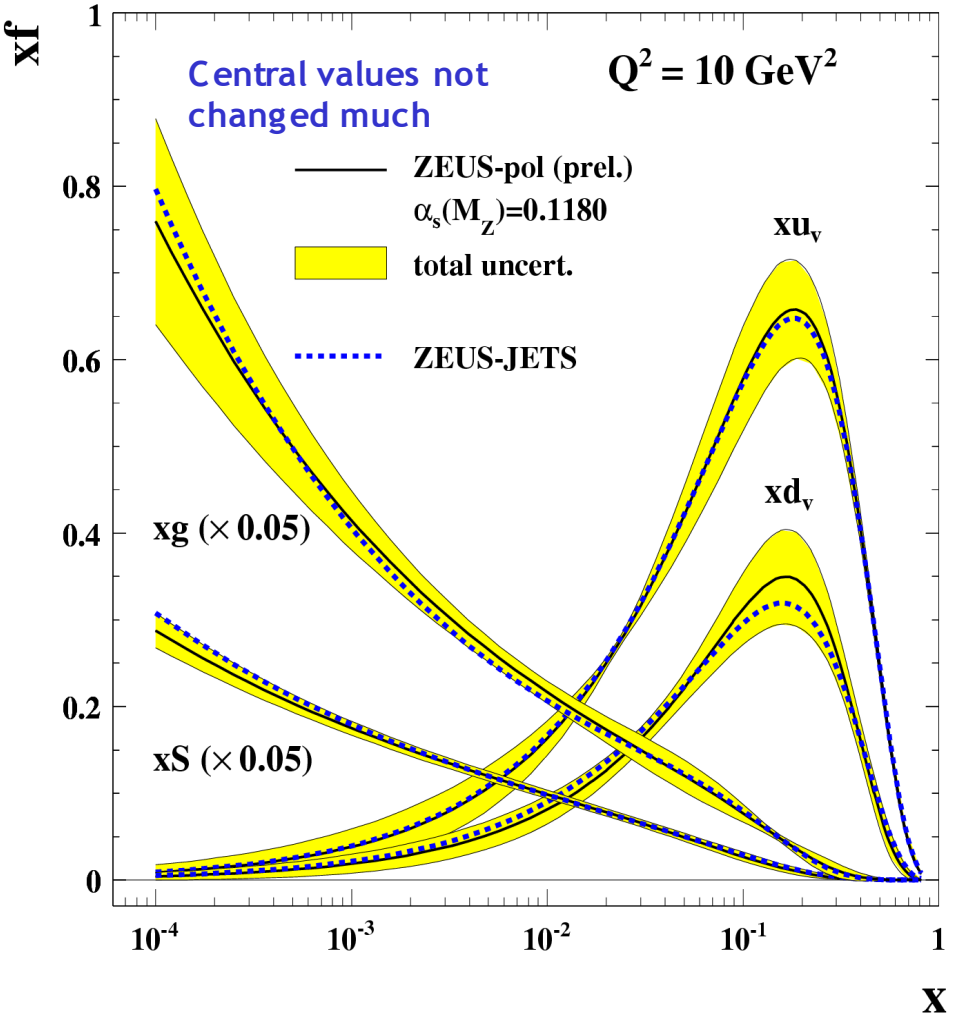
H1 and ZEUS fit to their own data only
(simplifies treatment of systematics)

HERA QCD+EW Fits:

- **H1 fits:**
  HERA-I 94-00 (pub.)
  HERA-I+II 94-05 (prel.)
- **ZEUS-pol fit (prel.):**
  HERA-I+II 94-06 (only e-p for HERA-II)

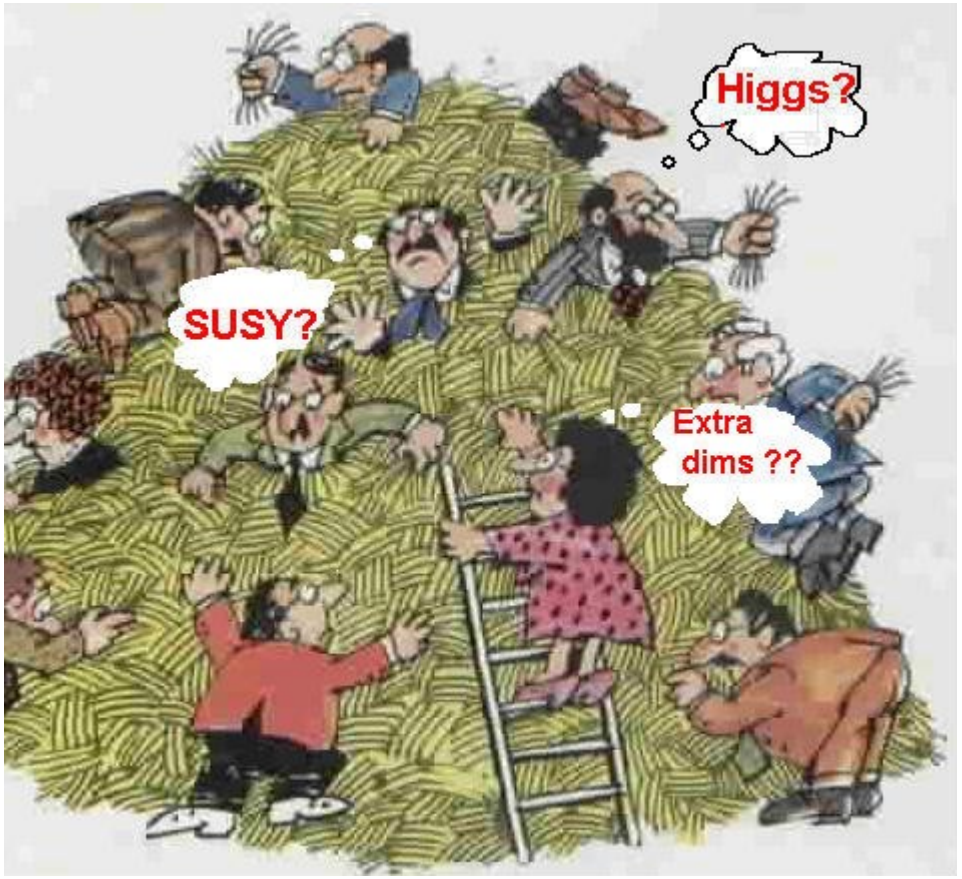


First PDF Fits with HERA-II



Beyond SM Searches

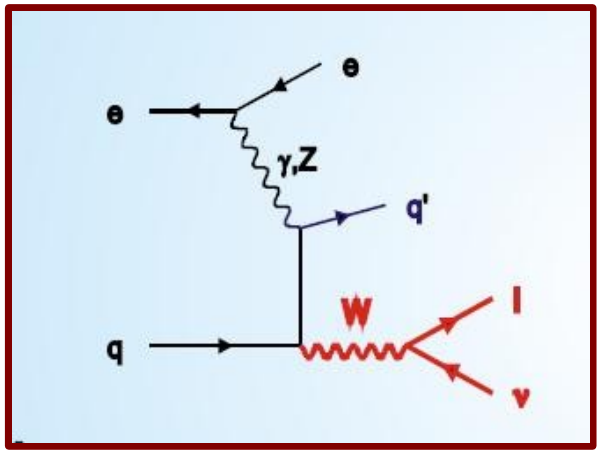
- **Model independent**
  - **Isolated leptons**
  - **Multi-electrons**
  - **General searches**
- **Model dependent**
  - **Excited fermions**
  - **Quark radius**
  - **Contact interactions**



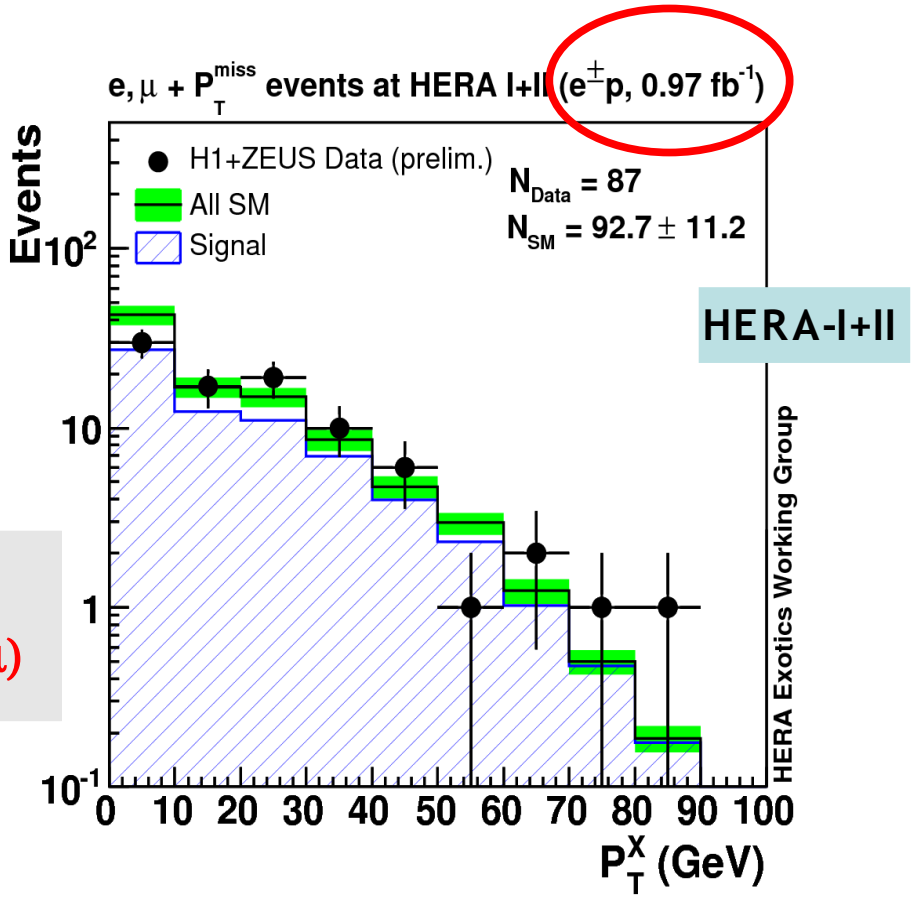
- **Other: leptoquark, SUSY, isolated τ-lepton (not in this talk)**

Isolated Leptons

In the SM, isolated leptons are produced by single W production



Very good agreement for both channel (e,μ)



P_T^X>25 GeV	electrons	muons
e+p (0.58 fb-1)	12/7.4±1.0 (78%)	11/7.2±1.0 (85%)
e-p (0.39 fb-1)	4/6.0±0.8 (67%)	2/4.8±1.0 (87%)
e±p (0.97 fb-1)	16/13.3±1.7 (73%)	13/12.0±1.6 (86%)

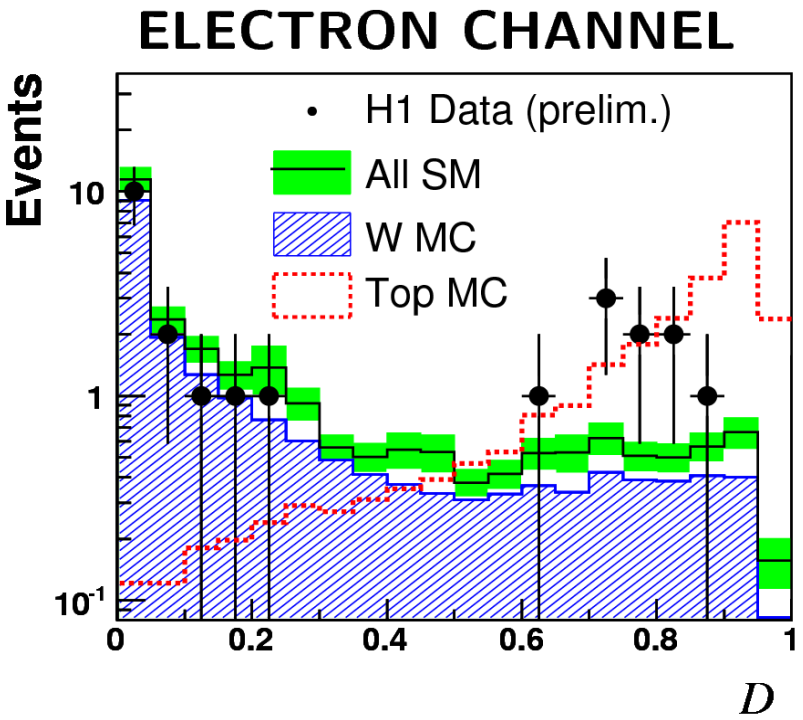
Selection:
- Quark jet with large transverse momentum
- Isolated lepton
- Large missing transverse momentum

Isolated Leptons: single top production(?)

Single top production through anomalous $k_{tu\gamma}$ and $v_{tu\gamma}$ couplings in a FCNC process

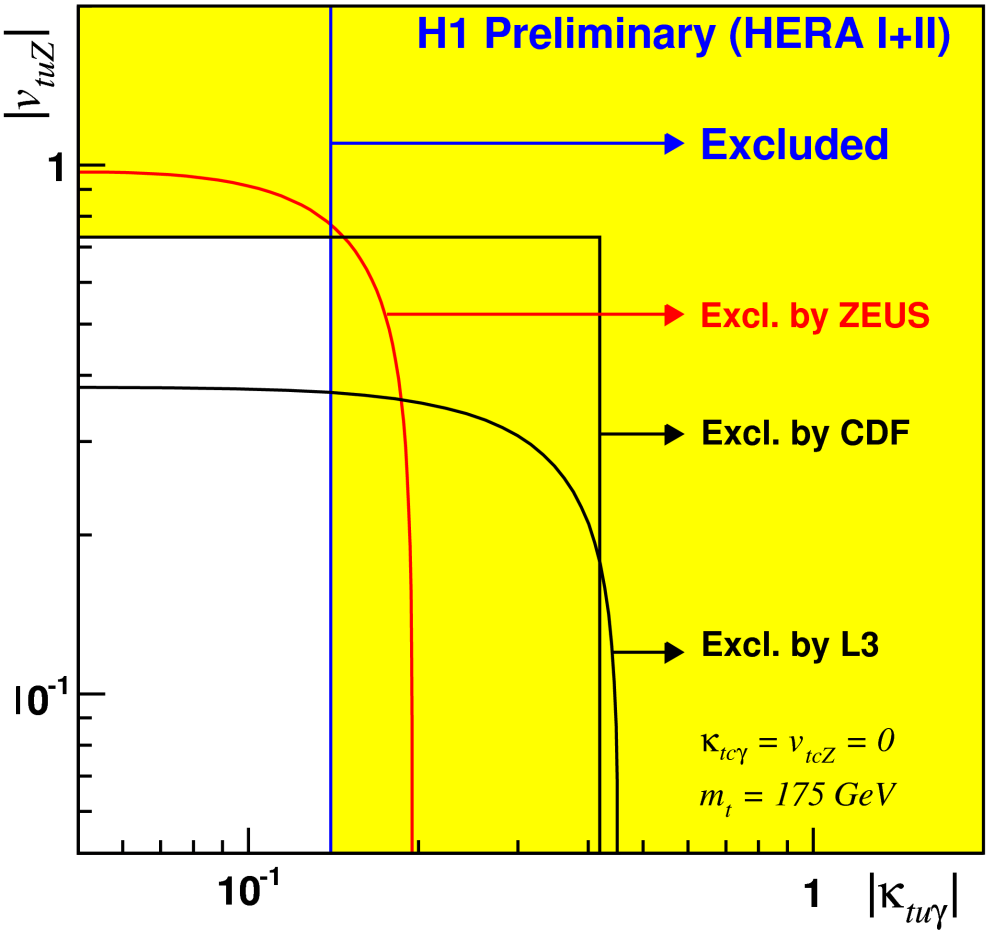
Multi-variate approach to separate signal from SM

→ limits in $|k_{tu\gamma}|$ and $|v_{tu\gamma}|$ plane



$\mathcal{L}$ = 483 pb-1

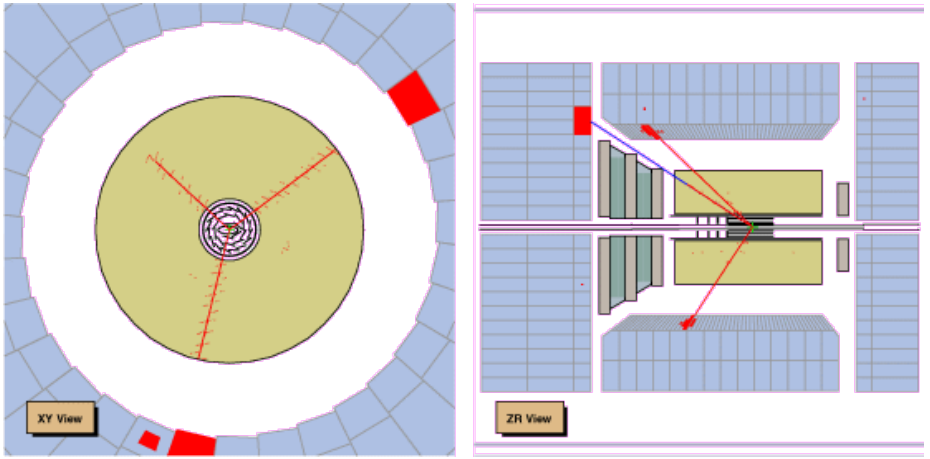
H1-prel-07-163

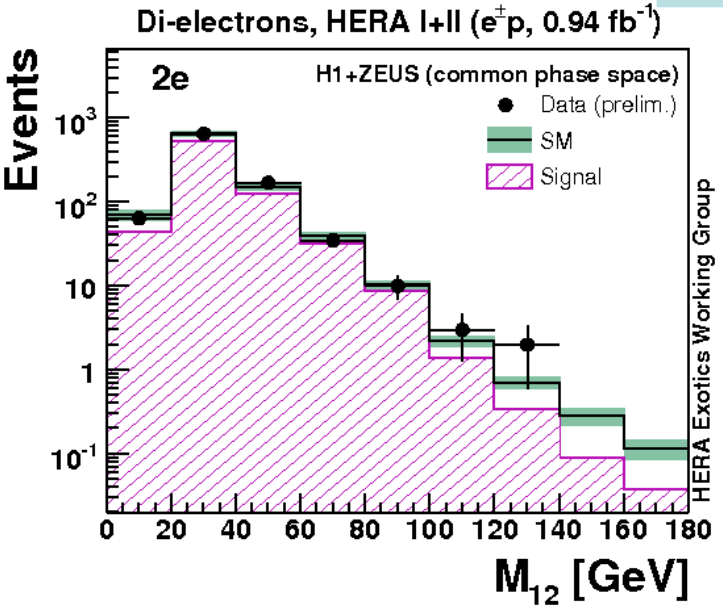


Multi-leptons (positrons and electrons)

HERA-I+II

In the SM, multi-lepton production via $\gamma\gamma$ interaction:

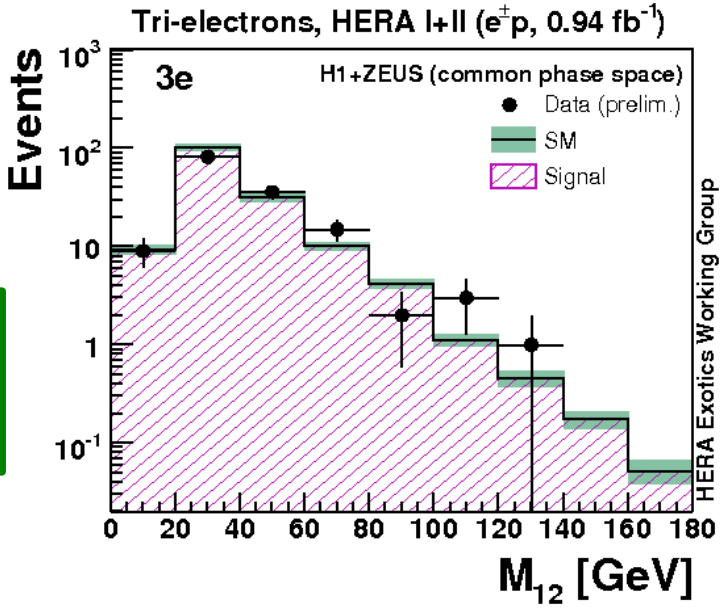




Selection:

- At least 2 candidates (P_T^1>10 GeV, $P_T^{2,3}$>5 GeV)

For ΣP_T > 100 GeV: good agreement!



Data sample	Data	SM	Pair Production	NC-DIS + Compton
e^+p (0.56 fb^{-1})	5	1.82 ± 0.21	1.28 ± 0.16	0.54 ± 0.10
e^-p (0.38 fb^{-1})	1	1.19 ± 0.14	0.79 ± 0.09	0.40 ± 0.08
$e^{\pm}p$ (0.94 fb^{-1})	6	3.00 ± 0.34	2.07 ± 0.24	0.94 ± 0.16

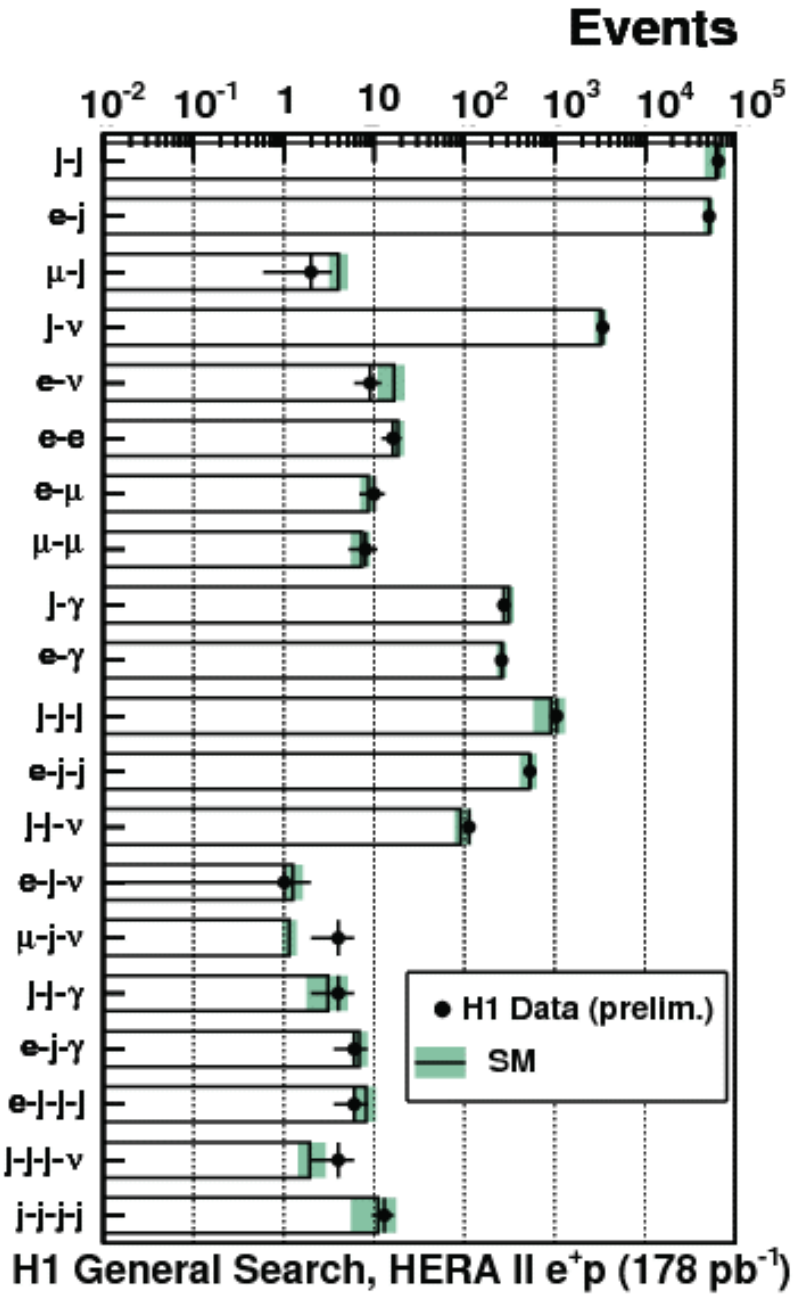
General Searches

A model-independent search for deviation from SM prediction is performed

Inspected 178 pb^{-1} e+p and 152 pb^{-1} e-p data set

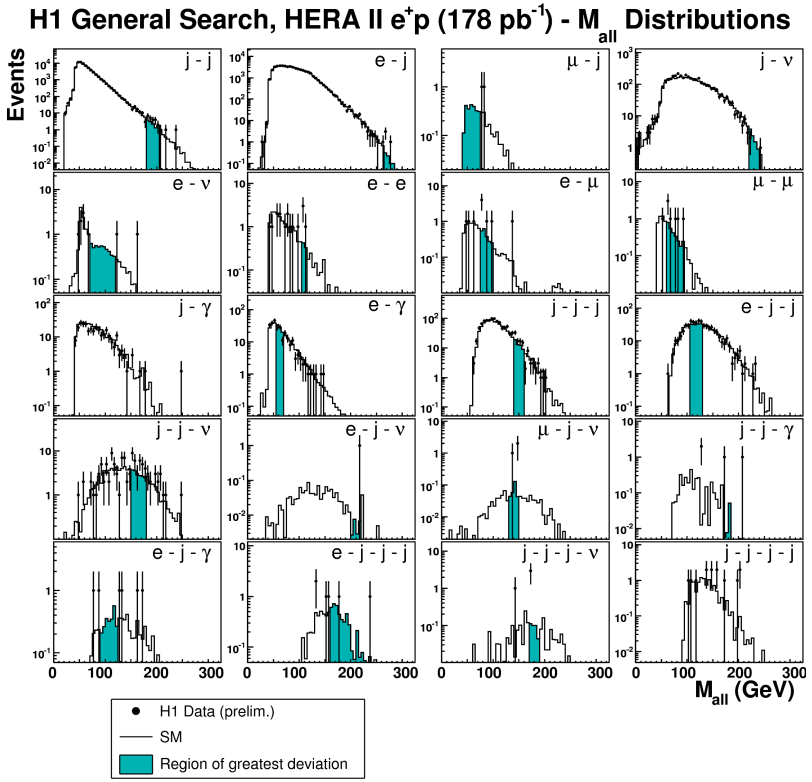
All topologies with:
e, γ ,μ ,ν, jets
with P_T>20 GeV

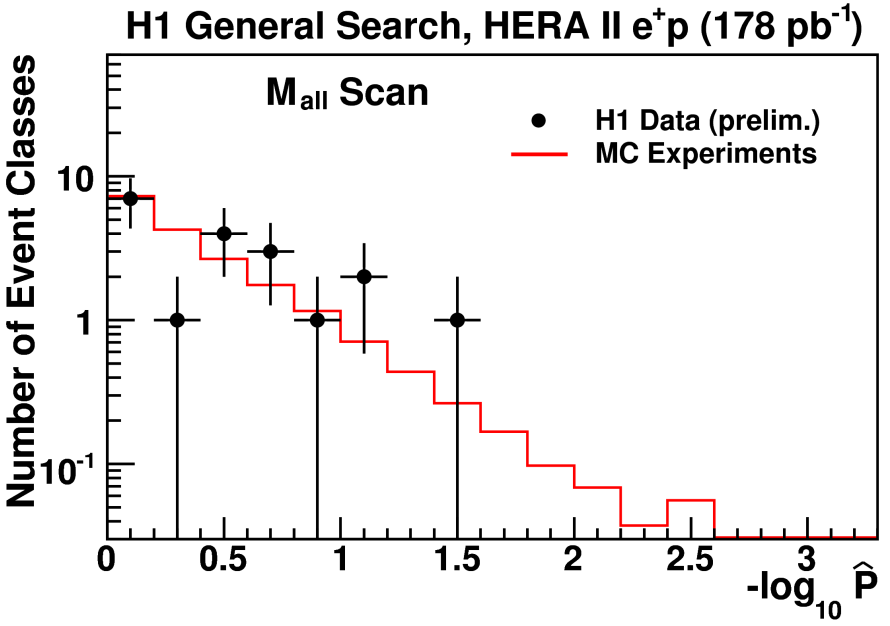
Good agreement between data and SM predictions

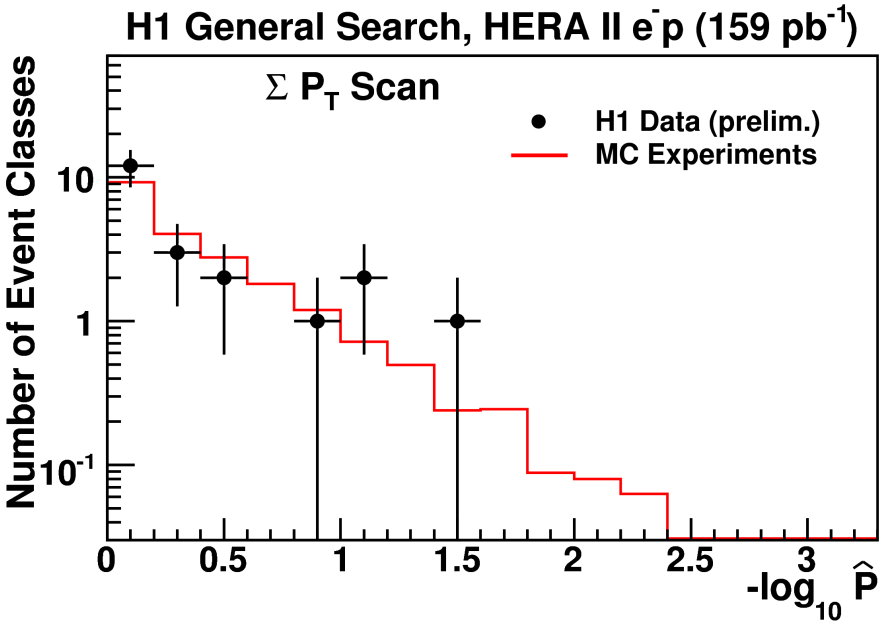


Agreement to SM quantified by looking for maximum deviation in ΣP_T and M_{all} distributions

Observed fluctuations compatible with the SM prediction







Excited Neutrinos

Search for Compositeness scale in neutrino production

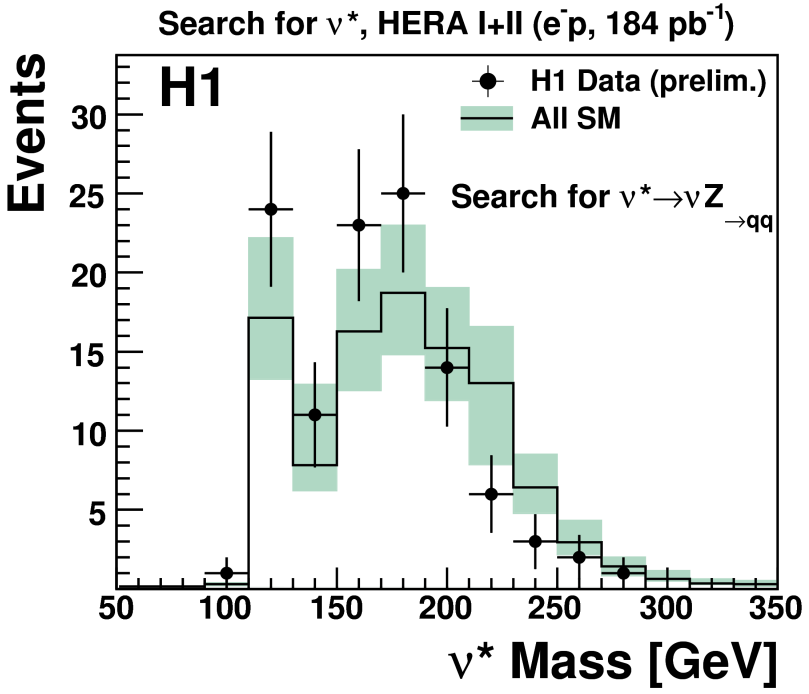
ν* produced through CC interaction in e-p interaction (higher CC cs)

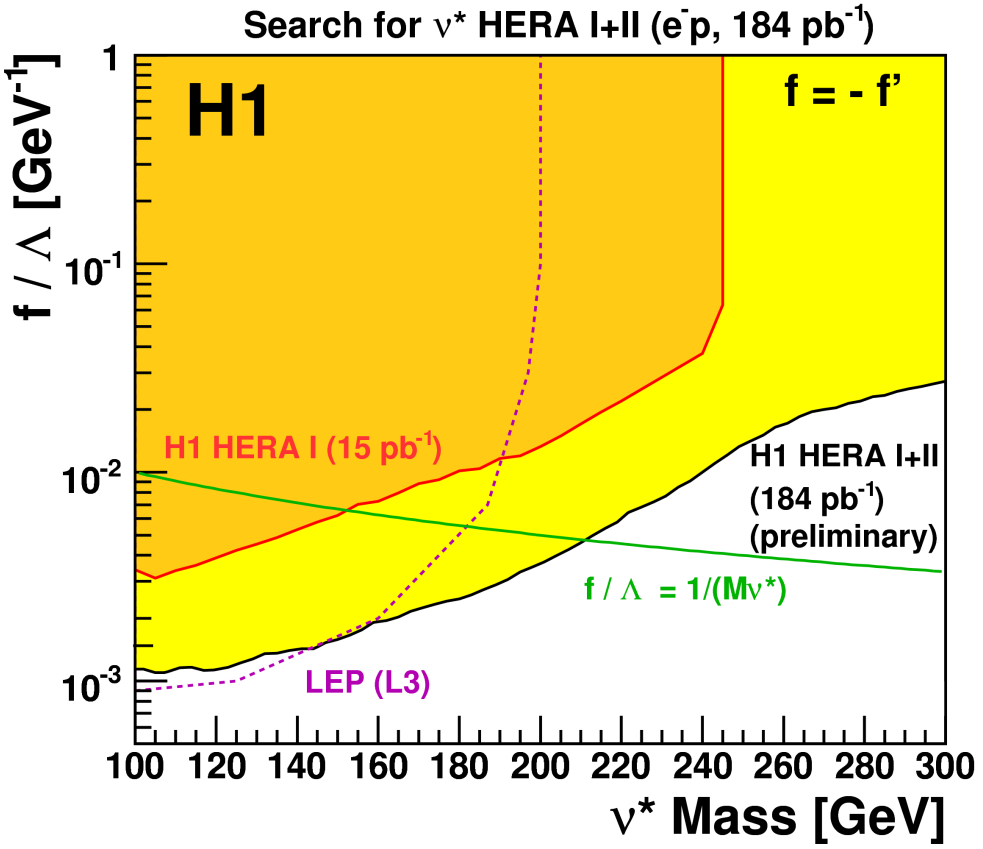
Investigated all the EW decays:
- **ν* → ν γ**
- **ν* → ν Z**
- **ν* → e W**

Used x10 more statistic than the previous publication

Good agreement data with the SM

Limits derived in the context of gauge mediation using the Hagiwara model

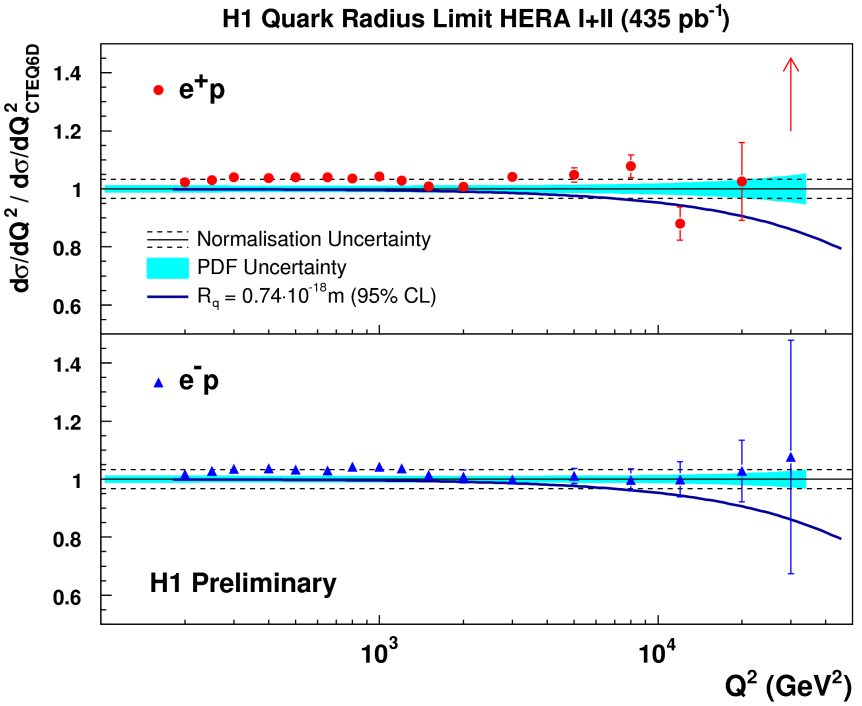


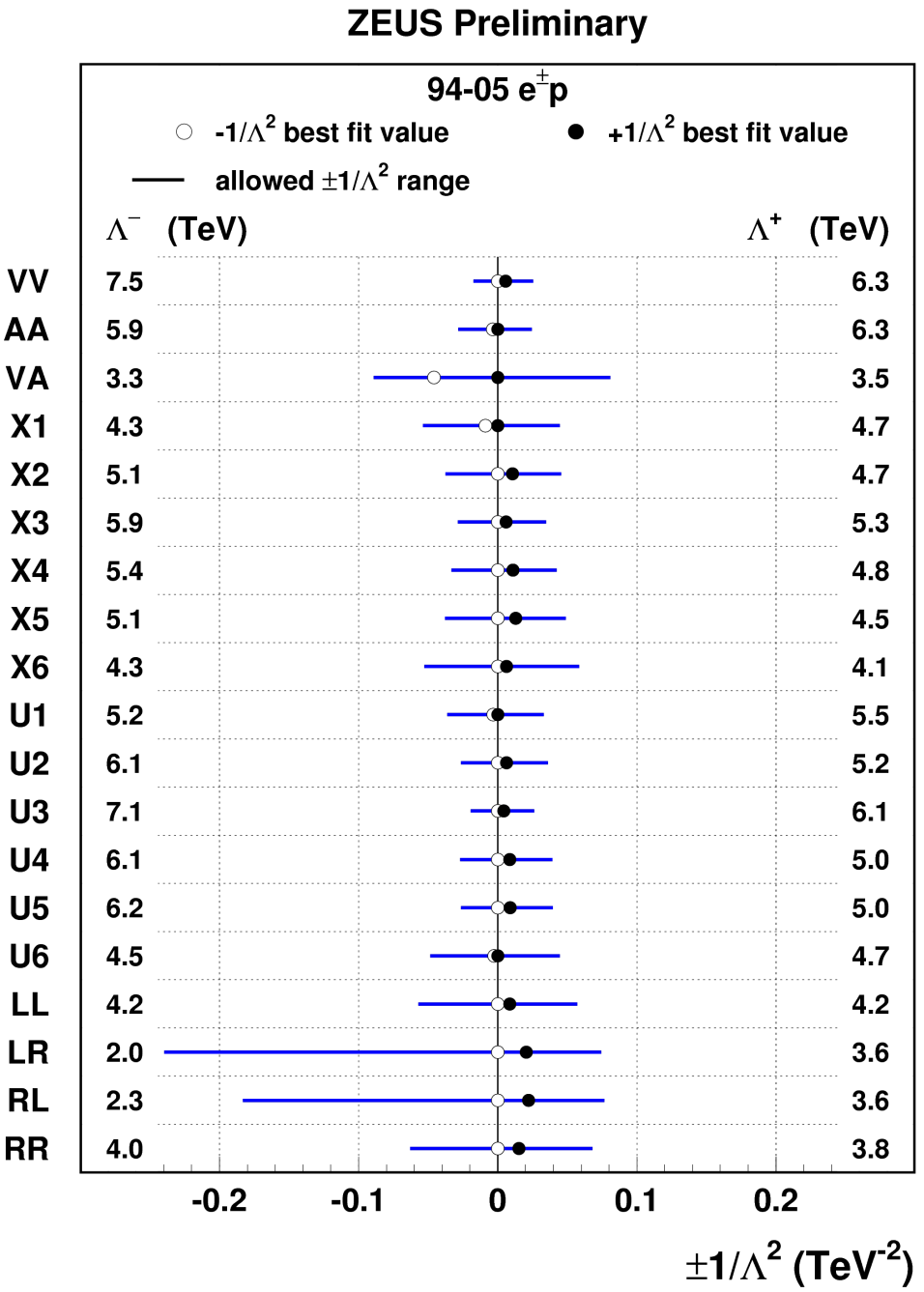


Quark Radius and Contact Interaction

Deviation on the σ_{NC} due to extra terms:

- **Quark radius factor: $(1-R_q^2Q^2/6)$**
  - **ZEUS: 0.67 10^{-18} m**
  - **H1: 0.74 10^{-18} m**
- **Contact interaction coupling Λ: $4\pi/\Lambda^2$**





Conclusions

- HERA has provided, in 15 years of activity, almost 1 fb^{-1} of data (H1 + ZEUS).
- Provided a precision test of EW physics
- Searched for anomaly distributions in particular event topology → limits on several beyond SM models
- Entering an exciting phase of analysis and results combining full H1 and ZEUS data

- Expect the final statements from HERA on EW and BSM in the near future!