Determination of EW Parameters Using H1 Data

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Outline

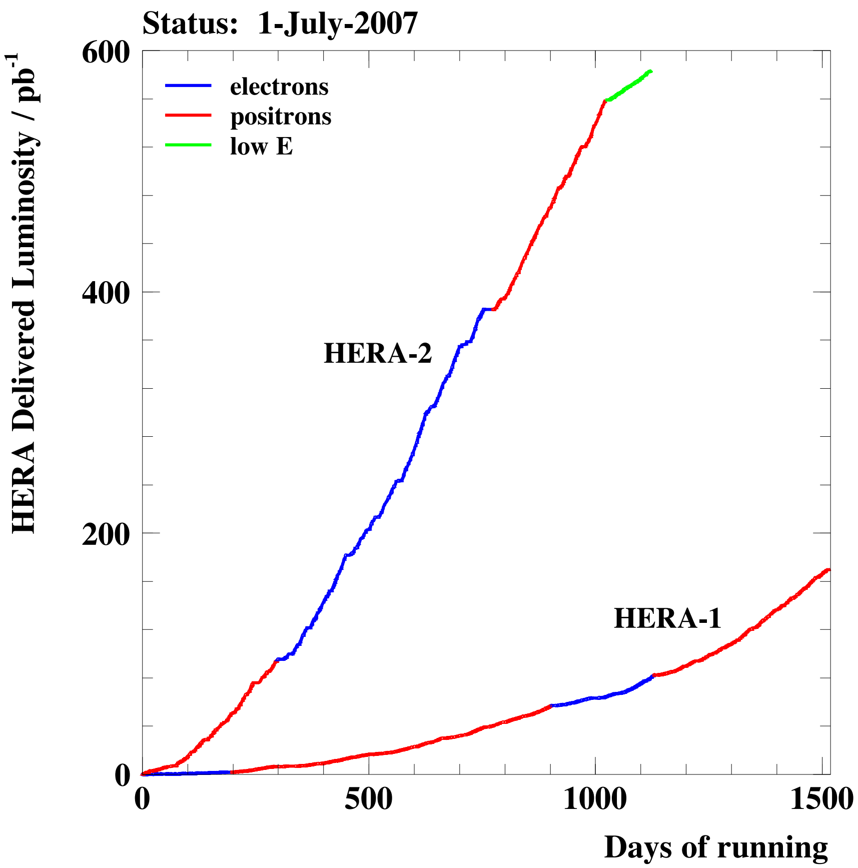
- Introduction
- Analysis strategy
- Results
- Summary

Introduction

ep collider, HERA, used to be the largest electron microscope

A large number of precisely measured inclusive cross sections

These are primary inputs for all modern PDF sets



HERA-I (1992-2000):

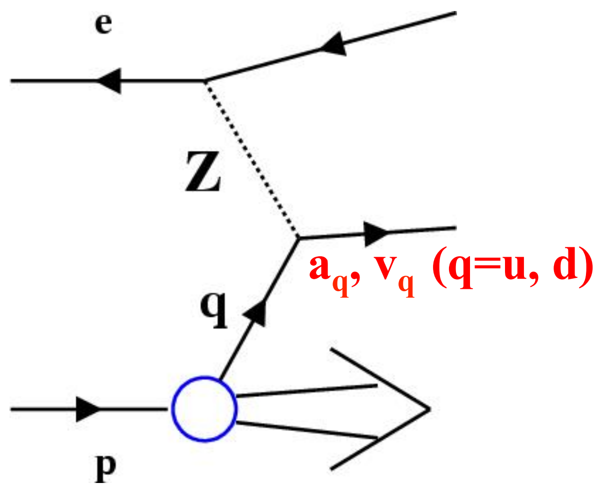
- First EW analysis by H1

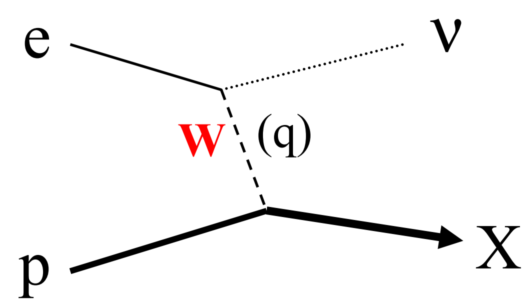
HERA-II (2003-2007):

- Increased lumi (x10 e^-, x2 e^+)
- Longitudinally polarised $e^{\pm}$

This talk reports refined and extended new EW analyses using all HERA-I & -II data

Neutral and Charged Current DIS Interactions





Sensitive to EW parameters (e.g. light quark couplings & W boson mass) in space-like regime

$$a_q \equiv g_A^q, v_q \equiv g_V^q$$

Event kinematics:

$Q^2 = -q^2$: Boson virtuality

x: Momentum fraction of struck partons

$y = Q^2/(sx)$: Inelasticity

$\sqrt{s}$: Centre-of-mass energy

Unpolarised HERA-I NC Data

$$\frac{d^2\sigma^{\pm}_{\rm NC}}{dxdQ^2} \sim Y_+\tilde{F}_2 \mp Y_- x\tilde{F}_3$$

$g_V^e \sim 0$ ➜ some of the terms are negligible

$$\tilde{F}_2 = F_2 - \cancel{g_V^e \kappa_Z F_2^{\gamma Z}} + (\cancel{g_V^e g_V^e} + g_A^e g_A^e)\,\kappa_Z^2 F_2^Z$$

$$x\tilde{F}_3 = -g_A^e \kappa_Z x F_3^{\gamma Z} + \cancel{2 g_V^e g_A^e \kappa_Z^2 x F_3^Z}$$

$$F_2^Z = x\sum_q (g_V^q g_V^q + g_A^q g_A^q)\,\{q + \bar{q}\}$$

$$xF_3^{\gamma Z} = 2x\sum_q Q_q g_A^q\,\{q - \bar{q}\}$$

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

$$\kappa_Z = \frac{Q^2}{Q^2 + m_Z^2}\,\frac{G_{\rm F} m_Z^2}{2\sqrt{2}\pi\alpha}$$

$$g_A^f = \sqrt{\rho_{\rm NC}}\, I_{L,f}^3$$

$$g_V^f = \sqrt{\rho_{\rm NC}}\,(I_{L,f}^3 - 2Q_f \kappa_{{\rm NC},q} \sin^2\theta_W)$$

In on-shell scheme:

$$\sin^2\theta_W = 1 - \frac{m_W^2}{m_Z^2}$$

$$G_{\rm F} = \frac{\pi\alpha}{\sqrt{2}m_W^2}\left[1 - \frac{m_W^2}{m_Z^2}\right]^{-1}(1+\Delta r)$$

$$\Delta r = \Delta r(\alpha, m_W, m_Z, m_t, m_h, \cdots)$$

Polarised HERA-II NC Data

$$\frac{d^2\sigma^{\pm}_{\rm NC}}{dxdQ^2} \sim Y_+\tilde{F}_2 \mp Y_- x\tilde{F}_3$$

$$\tilde{F}_2 \simeq F_2 - P_e g_A^e \kappa_Z F_2^{\gamma Z} + (g_V^e g_V^e + g_A^e g_A^e)\,\kappa_Z^2 F_2^Z$$

$$x\tilde{F}_3 \simeq -g_A^e \kappa_Z x F_3^{\gamma Z} + P_e g_A^e g_A^e \kappa_Z^2 x F_3^Z$$

$$F_2^{\gamma Z} = 2x \sum_q Q_q g_V^q \{q + \bar{q}\}$$

$$xF_3^Z = 2x \sum_q g_V^q g_A^q \{q - \bar{q}\}$$

Longitudinal polarised lepton beams at HERA-II introduces additional terms

P_e: the degree of the longitudinal polarisation

Terms containing g^e_V have been neglected

HERA-I and II CC Data

$$\frac{d^2\sigma^{\pm}_{\mathrm{CC}}}{dxdQ^2} \simeq (1 \pm P_e)\frac{G_{\mathrm{F}}^2}{4\pi x}\left[\frac{m_W^2}{m_W^2 + Q^2}\right]^2 (Y_+ W_2^{\pm} \mp Y_- x W_3^{\pm})$$

$$W_2^- = x\left(\rho^2_{\mathrm{CC},eq} U + \rho^2_{\mathrm{CC},e\bar{q}} \overline{D}\right)$$
$$xW_3^- = x\left(\rho^2_{\mathrm{CC},eq} U - \rho^2_{\mathrm{CC},e\bar{q}} \overline{D}\right)$$
$$U = u + c$$
$$\overline{D} = \bar{d} + \bar{s}$$

Used Data Sets

HERA-I

HERA-II

	Data set	Q^2-range [GeV^2]	$\sqrt{s}$ [GeV]	$\mathcal{L}$ [pb^{-1}]	No. of data points	Polarisation [%]
1	e^+ combined low-Q^2	(0.5) 8.5 – 150	301,319	20, 22, 97.6	94 (262)	–
2	e^+ combined low-E_p	(1.5) 8.5 – 90	225,252	12.2, 5.9	132 (136)	–
3	e^+ NC 94–97	150 – 30 000	301	35.6	130	–
4	e^+ CC 94–97	300 – 15 000	301	35.6	25	–
5	e^- NC 98–99	150 – 30 000	319	16.4	126	–
6	e^- CC 98–99	300 – 15 000	319	16.4	28	–
7	e^- NC 98–99 high-y	100 – 800	319	16.4	13	–
8	e^+ NC 99–00	150 – 30 000	319	65.2	147	–
9	e^+ CC 99–00	300 – 15 000	319	65.2	28	–
10	e^+ NC L HERA-II	120 – 30 000	319	80.7	137	-37.0 ± 1.0
11	e^+ CC L HERA-II	300 – 15 000	319	80.7	28	-37.0 ± 1.0
12	e^+ NC R HERA-II	120 – 30 000	319	101.3	138	$+32.5 \pm 0.7$
13	e^+ CC R HERA-II	300 – 15 000	319	101.3	29	$+32.5 \pm 0.7$
14	e^- NC L HERA-II	120 – 50 000	319	104.4	139	-25.8 ± 0.7
15	e^- CC L HERA-II	300 – 30 000	319	104.4	29	-25.8 ± 0.7
16	e^- NC R HERA-II	120 – 30 000	319	47.3	138	$+36.0 \pm 0.7$
17	e^- CC R HERA-II	300 – 15 000	319	47.3	28	$+36.0 \pm 0.7$
18	e^+ NC HERA-II high-y	60 – 800	319	182.0	11	–
19	e^- NC HERA-II high-y	60 – 800	319	151.7	11	–

For the first 2 data sets, only data above 8.5 GeV^2 are included

Fit Strategy

- EW parameters fitted together with PDFs
  - so that their correlation is properly taken into account
  - the uncertainty of the EW parameters is not underestimated

- Fits performed with log-normal based likelihood function

$$\chi^2 = \sum_{ij} \log \frac{d_i}{\tilde{\sigma}_i} V_{ij}^{-1} \log \frac{d_j}{\tilde{\sigma}_j}$$

Correlation in data (d) taken into account in covariance matrix (V)

- Goodness of the fit (e.g. the PDF alone fit)
  - χ2/ndof: 1435/(1415-17)=1.03

Fit Strategy

❒ 5 sets of PDFs parameterised at starting scale Q_0^2=1.9 GeV^2

$$
\begin{aligned}
xg(x) &= A_g x^{B_g}(1-x)^{C_g} - A'_g x^{B'_g}(1-x)^{C'_g} \,, \\
xu_v(x) &= A_{u_v} x^{B_{u_v}}(1-x)^{C_{u_v}}(1+E_{u_v}x^2) \,, \\
xd_v(x) &= A_{d_v} x^{B_{d_v}}(1-x)^{C_{d_v}} \,, \\
x\bar{U}(x) &= A_{\bar{U}} x^{B_{\bar{U}}}(1-x)^{C_{\bar{U}}} \,, \\
x\bar{D}(x) &= A_{\bar{D}} x^{B_{\bar{D}}}(1-x)^{C_{\bar{D}}}
\end{aligned}
$$

Momentum sum rule and quark counting rules applied to constrain

A_g, A_{u_v}, A_{d_v} (C'_g fixed to 25)

Other constraints applied: $A_{\bar{U}} = A_{\bar{D}}, B_{\bar{U}} = B_{\bar{D}}$

❒ DGLAP evolution & cross section calculations in NNLO QCD and in NLO EW

Determination of W Boson Mass

Determination performed in on-shell scheme:

$$M_W = 80.407 \pm 0.118(\text{exp, PDF-fit}) \pm 0.005(M_Z, m_t, m_h)\,\text{GeV}$$

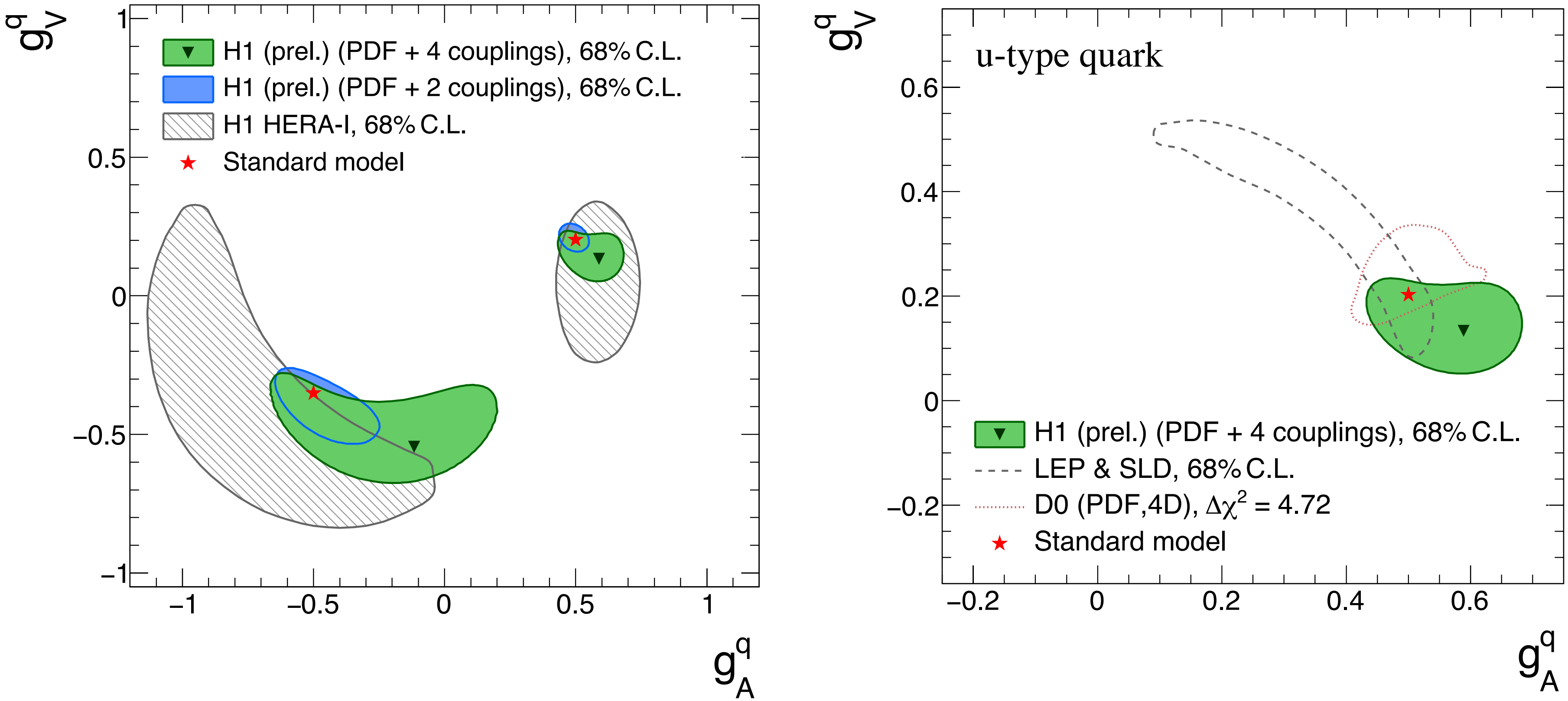
to be compared with HERA-I result:

$$M_W = 80.786 \pm 0.205(\text{exp})^{+0.063}_{-0.098}(\text{th})\,\text{GeV}$$

⇒ A factor ~2 improvement!

- The dominant sensitivity (~120 MeV) comes from the normalisation of the CC cross sections
- The quark and electron couplings to Z boson in the NC cross sections provides additional sensitivity of ~225 MeV
- The W propagator term in CC cross sections provides a sensitivity of ~800 MeV

Light Quark Couplings to Z Boson



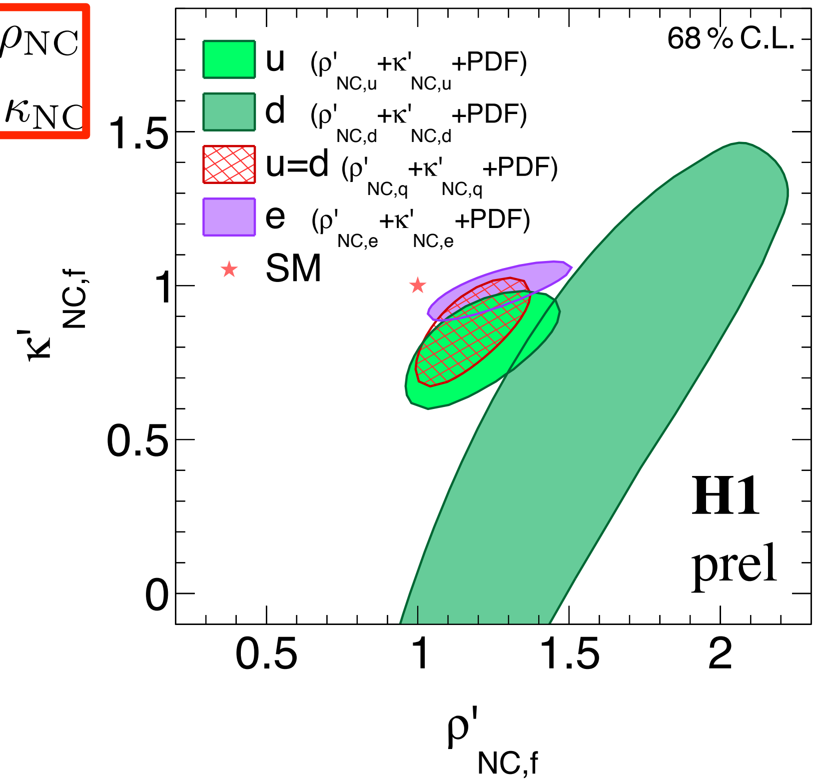
- Significant improvement over HERA-I determination
- 2 coupling fit is more precise due to the reduced correlation
- The results are competitive with other determinations

Study BSM NC & CC Form Factors

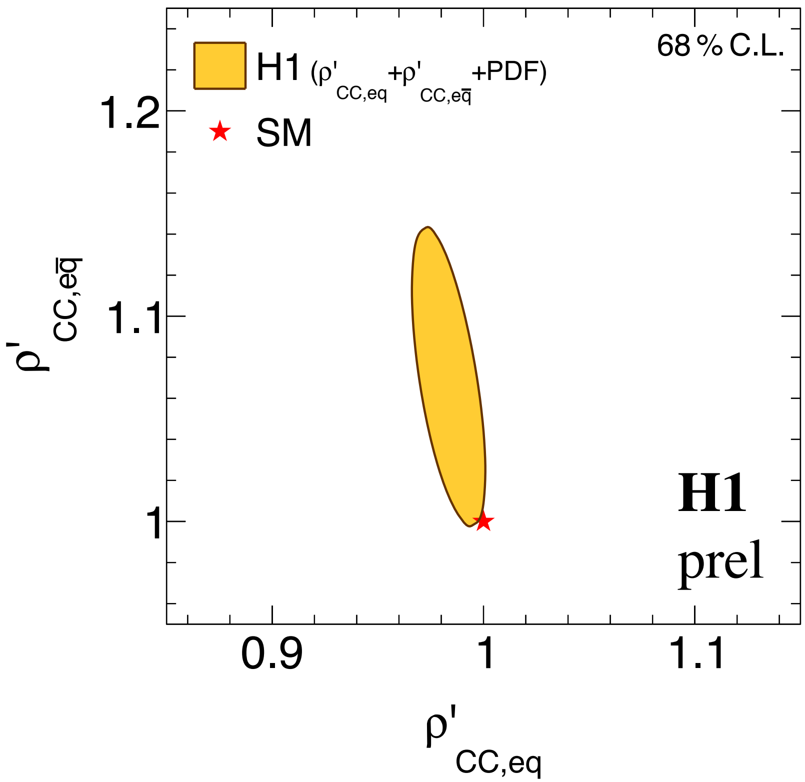
- 4 fits for NC form factors
- 1 fit for CC form factors

(all other parameters are set to their SM values)

$$\rho_{\rm NC} \to \rho'_{\rm NC}\rho_{\rm NC}$$
$$\kappa_{\rm NC} \to \kappa'_{\rm NC}\kappa_{\rm NC}$$



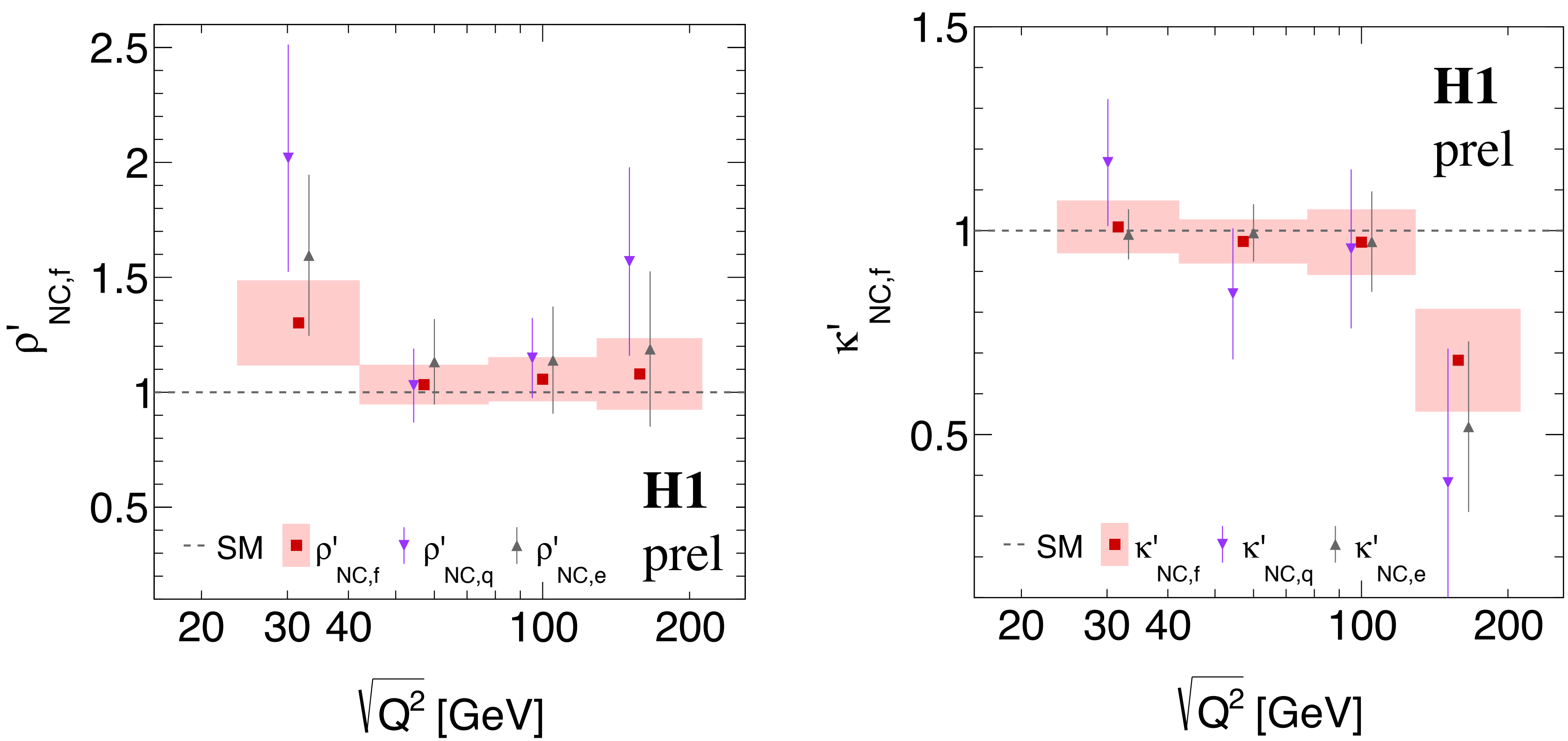
$$\rho_{\rm CC} \to \rho'_{\rm CC}\rho_{\rm CC}$$



- Best constraint for CC form factors, NC form factors for d-type quark less constrained
- No significant deviations from SM

Scale Dependence of BSM NC Form Factors

1. Fit quark form factors + PDFs only (set other parameters to their SM values)
2. Fit e form factors + PDFs only
3. Fit common fermion (e and quark) form factors + PDFs

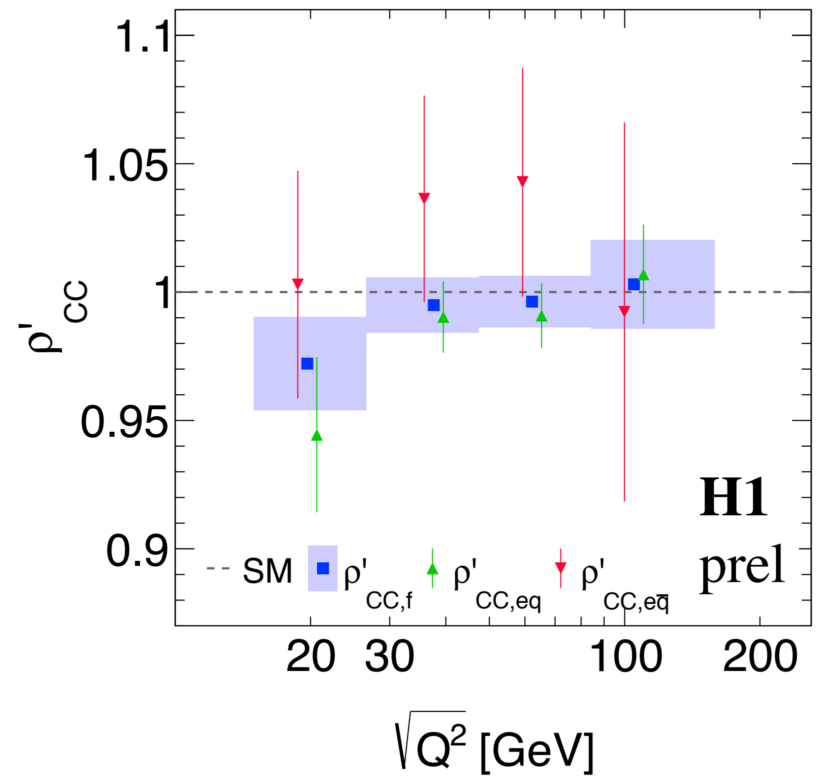


➤ No significant scale dependence and deviation from SM

Scale Dependence of BSM CC Form Factor

1. Fit up-type form factors + PDFs
2. Fit down-type form factors + PDFs
3. Fit common quark form factors + PDFs

(all other parameters are set to their SM values)



➤ First scale dependence study for CC

➤ No significant scale dependence and deviation from SM

Summary

- All HERA-I and HERA-II H1 data used to determine EW parameters together with PDFs
  - Precision wrt to HERA-I results improved by a factor of ~2
  - Thanks to the longitudinal polarised leptons beams and increased statistics precision of HERA-II high Q^2 data
- The light quark couplings to Z boson are competitive to other determinations
  - Complementary test between space-like and time-like regimes
- BSM-like form factors and their scale dependence studied
  - First such study for CC
  - Within the uncertainties, no significant deviations from SM