Fit of EW Parameters using Polarised DIS H1 Data

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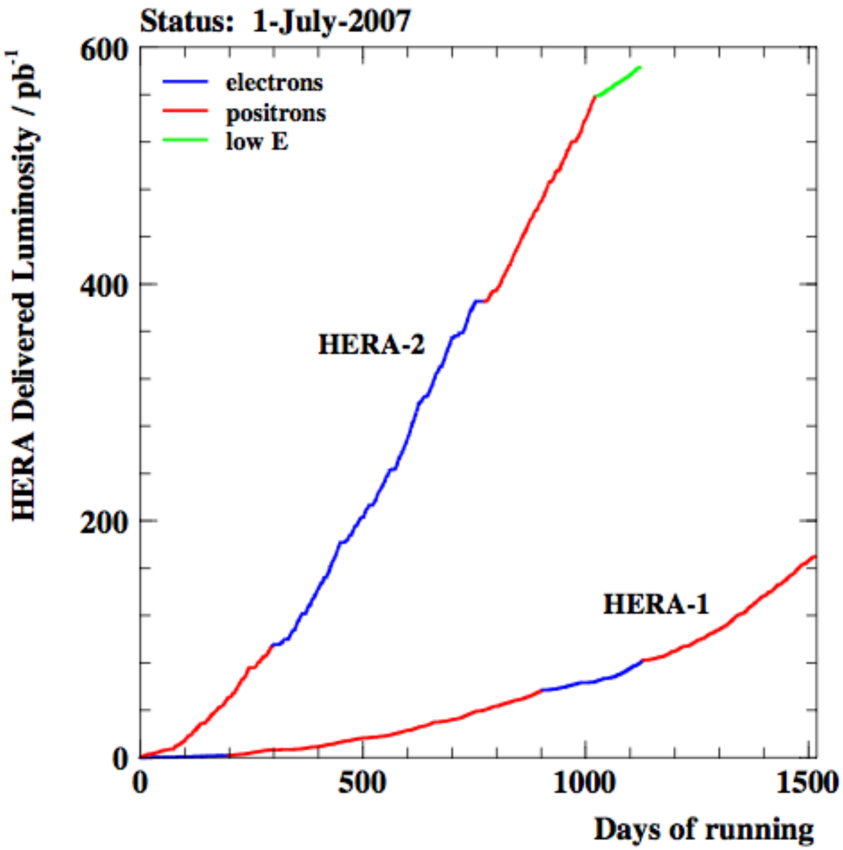
Outline

- Introduction
- New constraints from HERA-2 Data with P_e
- Results
- Summary

Introduction

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

Both NC and CC inclusive cross sections were precisely measured



HERA-1 (1992-2000):

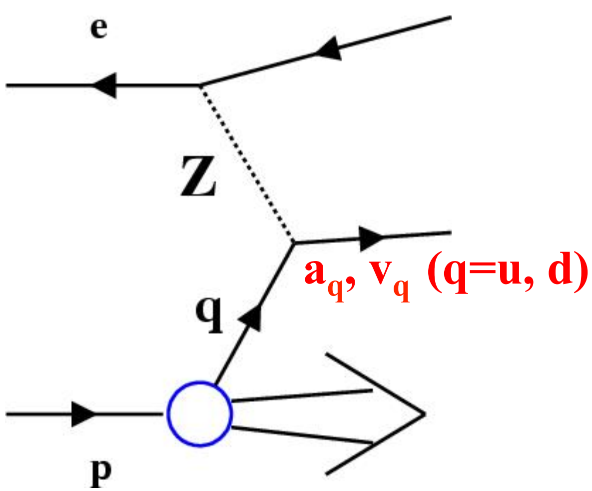
Combined HERA-1 data primary input for all modern PDF sets:

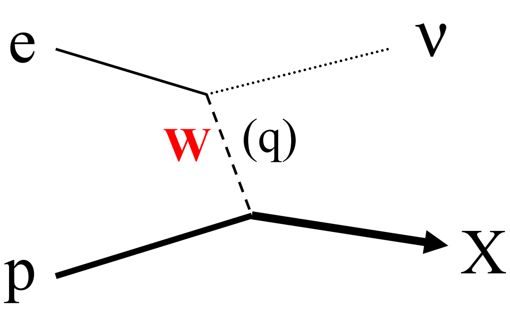
- CTEQ
- MRST
- NNPDFs
- HERAPDF1.0
- ……

HERA-2 (2003-2007):

- Increased lumi (x10 e-, x2 e+)
- Long. polarized e beam
- Full combination HERA-1 & -2

Neutral and Charged Current DIS Interactions





NC interactions sensitive to light quark couplings to Z

Event kinematics:

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

x: momentum fraction of struck parton

$y = Q^2/sx$: inelasticity

Coupling Sensitivity with Unpolarised HERA-I Data

$$\frac{d^2\sigma^{\pm}_{\rm NC}}{dxdQ^2} \sim Y_+\tilde{F}_2 \mp Y_- x\tilde{F}_3 \qquad \text{with} \quad Y_\pm = 1 \pm (1-y)^2$$

$v_e \sim 0$, ➔ some of the terms are negligible

$$\tilde{F}_2 = F_2 - \cancel{v_e\kappa_Z F_2^{\gamma Z}} + (\cancel{v_e^2} + a_e^2)\kappa_Z^2 F_2^Z$$

$$x\tilde{F}_3 = -a_e\kappa_Z xF_3^{\gamma Z} + \cancel{2v_e a_e\kappa_Z^2 xF_3^Z}$$

$$F_2^Z = x\sum_q \left(v_q^2 + a_q^2\right)\{q + \bar{q}\}$$

$$xF_3^{\gamma Z} = 2x\sum_q e_q a_q \{q - \bar{q}\}$$

➔ a_q mainly constrained by $xF_3^{\gamma Z}$

➔ v_q constrained by F_2^Z

$$\kappa_Z^{-1} = \frac{2\sqrt{2}\pi\alpha}{G_F M_Z^2}\frac{Q^2 + M_Z^2}{Q^2}$$

In on-mass-shell scheme:

$$G_F = \frac{\pi\alpha}{\sqrt{2}M_W^2}\left(1 - \frac{M_W^2}{M_Z^2}\right)^{-1}(1+\Delta r)$$

$$\Delta r = \Delta r(\alpha, M_W, M_Z, m_t, m_h, \cdots)$$

First determination performed by H1 PLB 632 (2006) 35

Additional Sensitivity with Polarised HERA-II Data

Polarized e beam (P_e) ➔ Additional terms

Structure function formulae given for e^-p scattering, for e^+p, $P_e \to -P_e$

$$\tilde{F}_2 = F_2 - (v_e - P_e a_e)\kappa_Z F_2^{\gamma Z} + (v_e^2 + a_e^2 - 2P_e v_e a_e)\kappa_Z^2 F_2^Z$$

$$x\tilde{F}_3 = -(a_e - P_e v_e)\kappa_Z xF_3^{\gamma Z} + \left[2v_e a_e - P_e(v_e^2 + a_e^2)\right]\kappa_Z^2 xF_3^Z$$

$$\left[F_2^{\gamma Z}, F_2^Z\right] = x\sum_q \left[2e_q v_q, v_q^2 + a_q^2\right]\{q + \bar{q}\}$$

$$\left[xF_3^{\gamma Z}, xF_3^Z\right] = 2x\sum_q \left[e_q a_q, v_q a_q\right]\{q - \bar{q}\}$$

➔additional constraint on v_q by $F_2^{\gamma Z}$

Used Data Sets

	Data set	Q^2-range [GeV^2]	$\sqrt{s}$ [GeV]	No. of data points	Polarization [%]
HERA-I	e^+ Combined low-Q^2	(0.5) 12 – 150	319	81 (262)	–
	e^+ Combined low-E_p	(1.5) 12 – 90	301	118 (136)	–
	e^+ NC 94–97	150 – 30 000	301	130	–
	e^+ CC 94–97	300 – 15 000	301	25	–
	e^- NC 98–99	150 – 30 000	319	126	–
	e^- CC 98–99	300 – 15 000	319	28	–
	e^- NC 98–99 high-y	100 – 800	319	13	–
	e^+ NC 99–00	150 – 30 000	319	147	–
	e^+ CC 99–00	300 – 15 000	319	28	–
HERA-II	e^+ NC L HERA-II	120 – 30 000	319	137	-37.0 ± 1.0
	e^+ CC L HERA-II	300 – 15 000	319	28	-37.0 ± 1.0
	e^+ NC R HERA-II	120 – 30 000	319	137	$+32.5 \pm 0.7$
	e^+ CC R HERA-II	300 – 15 000	319	28	$+32.5 \pm 0.7$
	e^- NC L HERA-II	120 – 50 000	319	138	-25.8 ± 0.7
	e^- CC L HERA-II	300 – 30 000	319	29	-25.8 ± 0.7
	e^- NC R HERA-II	120 – 30 000	319	139	$+36.0 \pm 0.7$
	e^- CC R HERA-II	300 – 15 000	319	28	$+36.0 \pm 0.7$

For the first 2 data sets, only data above 12GeV^2 are included

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

Fit Strategy

- Fits performed with log-normal based likelihood function

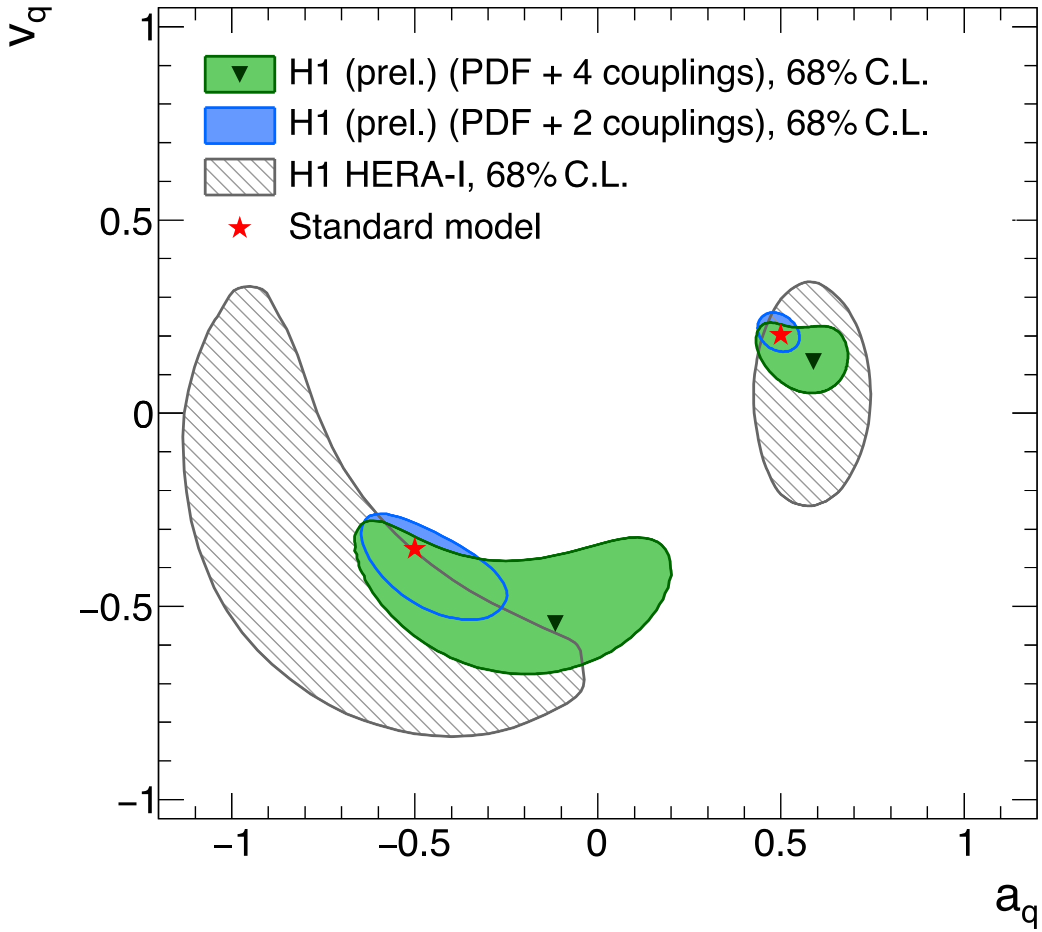
$$\chi^2 = \sum_{ij} \log \frac{d_i}{\tilde{\sigma}_i} V_{ij}^{-1} \log \frac{d_j}{\tilde{\sigma}_j}$$

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

- Fit-1: Quark couplings + PDFs
  - 4 or 2 couplings + 13 PDF parameters
  - chi2 value: 1370.5/(1388-21)=1.0

- Fit-2: M_W + PDFs (chi2 value: 1372.3/(1388-18)=1.0)
  - Translate to $\sin^2\theta_W$ in on-mass-shell scheme by using known M_Z
  - Divide data sets in several Q^2 ranges
  - $\sin^2\theta_W$ extracted at different scale $\mu = \sqrt{Q^2}$
  - chi2 value: 1365.3/(1388-24)=1.0

Fit-1 Results



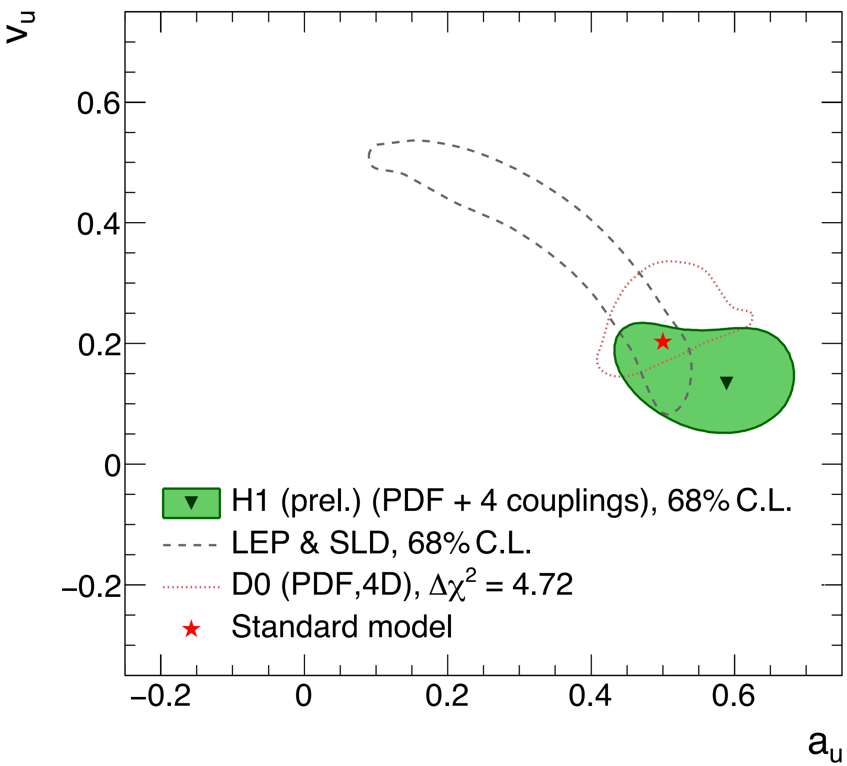
Fixing

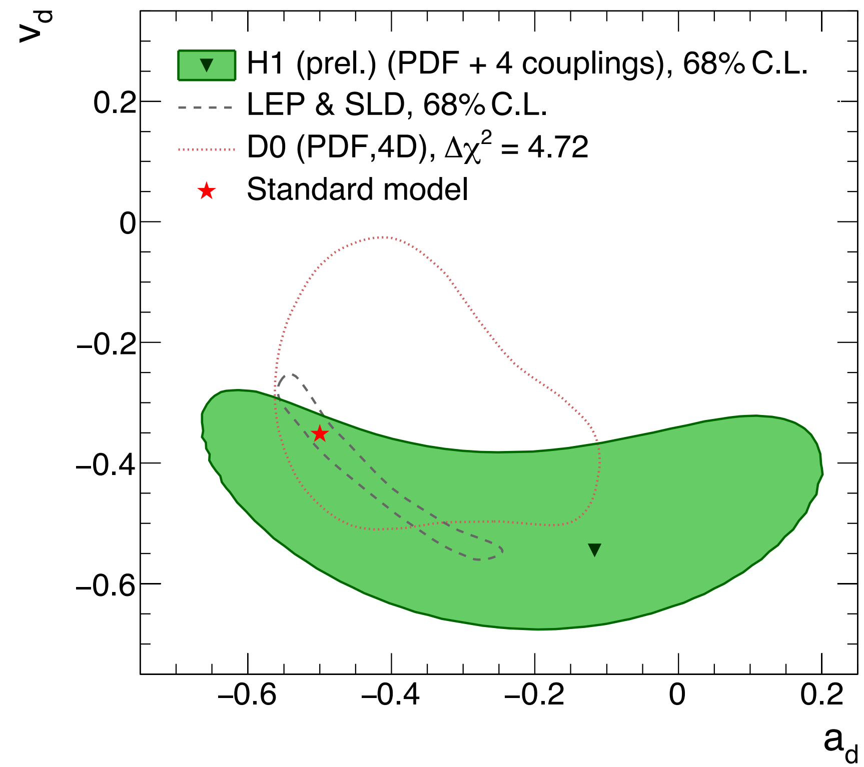
α, M_Z, M_W in NC

G_F, M_W in CC

- Significant improvement over HERA-I determination
- 2 coupling fit is more precise due to the reduced correlation

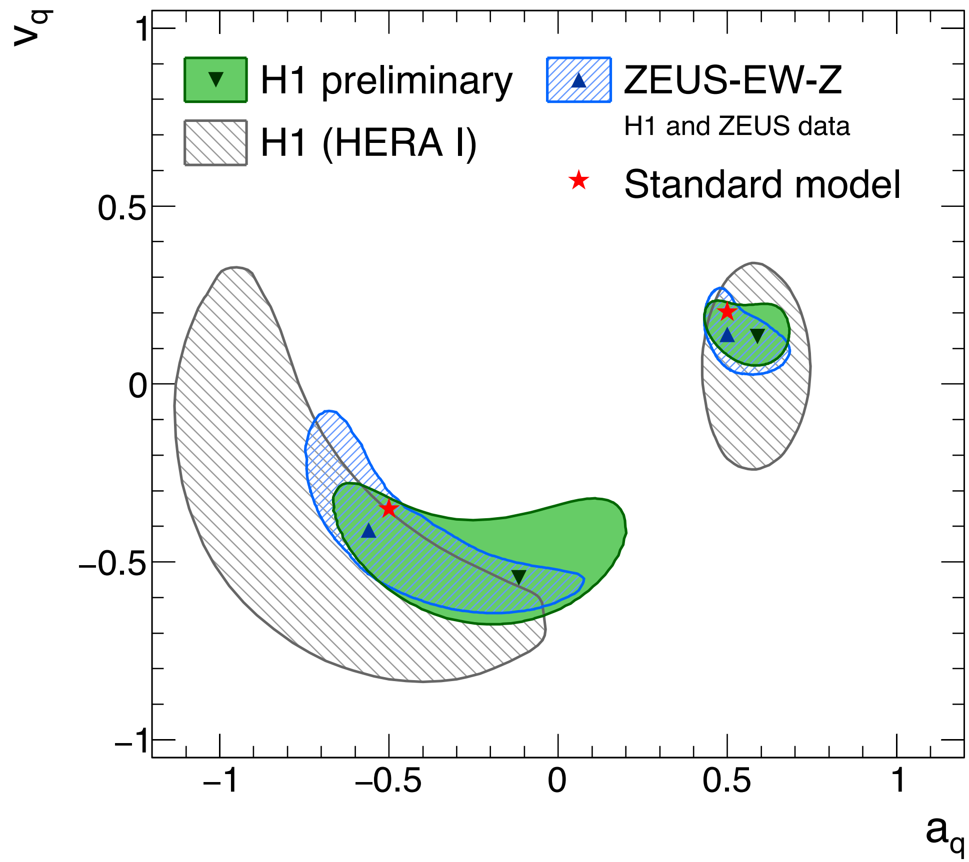
Comparison with LEP and Tevatron Results





- Precision (in particular for a_u, v_u) competitive with LEP & D0
- LEP determinations have ambiguity in sign

Comparison with ZEUS Results



- This result comparable with a similar one from ZEUS (previous talk)
- ZEUS fit included HERA-I and -II data sets from H1 with P_e=0

ZEUS: PRD 93 (2016) 092002

Fit-2: M_W + PDFs

SM overconstrained

- at HERA, W boson appears as a virtual boson exchange
- Probing space-like momentum transfers
- M_W determined in on-mass-shell scheme by fixing α, M_Z, m_t, m_h
- Correlation with PDFs properly taken into account

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

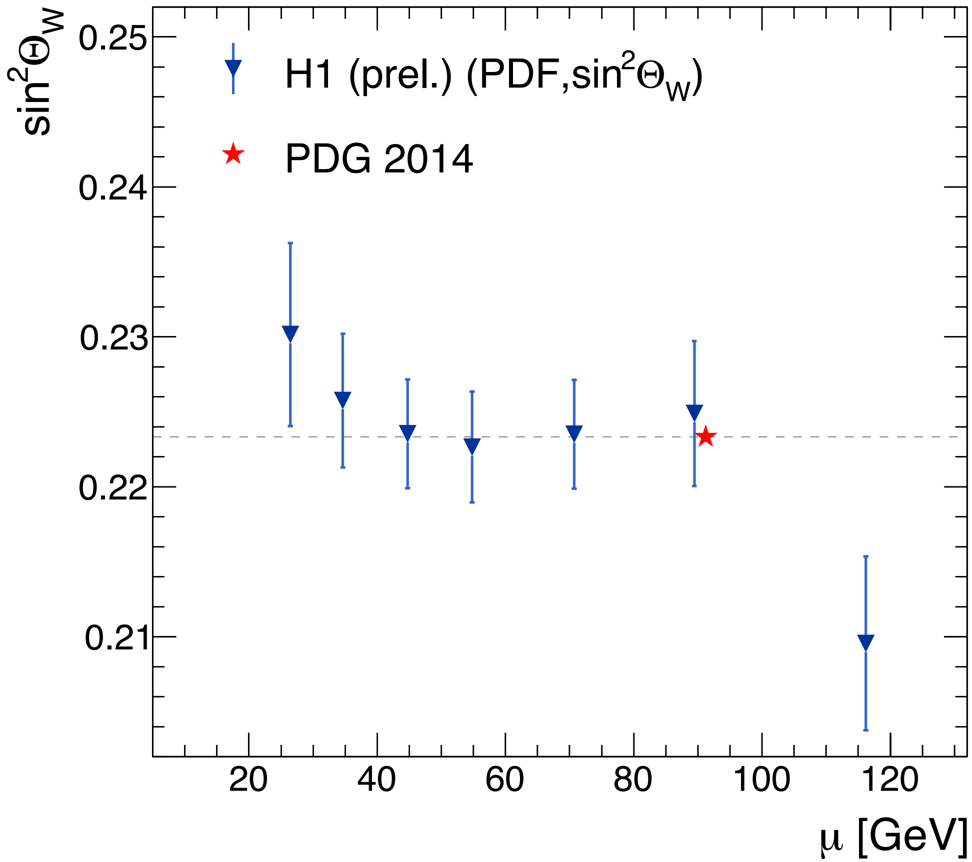
to be compared with HERA-I result:

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

⇒ A factor ~2 improvement!

⇒ Extract $\sin^2\theta_W(\text{on-mass-shell}) = 1 - \dfrac{M_W^2(\text{fit})}{M_Z^2(\text{input})}$

Fit-2: Weak Mixing Angle versus Q^2



- $\sin^2\theta_W$ showing no strong scale dependence as expected
- Results consistent with precise Z-pole measurements

Summary

- ❒ (Light) quark couplings determined with much improved precision, thanks to
  - ➤ the new sensitivity with polarised e^+/e^- beams at HERA-II
  - ➤ more HERA-II high Q^2 cross section measurement

- ❒ A M_W (and $\sin^2\theta_W$) determination
  - ➤ A factor of 2 improvement in precision over HERA-I

- ❒ The final results (including 1-loop EW corrections) will be published soon