Electroweak precision and New Physics in LHeC

Soumitra Nandi

Dipartimento di Fisica Teorica, Univ. di Torino and INFN,

Sezione di Torino
Torino, Italy

Plan of talk

- Motivation: LHeC
- DIS and Electroweak parameters
- New physics and Electroweak parameters
- Conclusions

Why New Physics?

- History of matter and antimatter in the Universe, can not be accounted for by the KM mechanism

  $\frac{n_B}{n_\gamma} \approx 9.1 \times 10^{-11}$

- Strong CP problem $\Rightarrow$ CP violation in strong interaction is very small

  $\theta_{QCD} \leq 10^{-9}$

- Hierarchy problem
- Dark matter/energy puzzle

Motivation: DIS

- What is the fundamental structure of matter, is there substructure of quarks and leptons?
- Do the fundamental interaction unify?
- What is the dynamics of quark-gluon interaction ?
- What is the quark-gluon structure of the nucleon?

DIS is the cleanest approach $\Rightarrow$ played an important role in understanding the interplay of electromagnetic, weak and strong interactions

HERA VS LHeC

- $27.5GeV \times 920GeV$ *ep* HERA was a high precision machine for QCD and modest precision machine for electroweak Physics
- The LHeC is a proposal for TeV scale DIS with the potential for significantly higher luminosity than HERA $(Lumi \approx 10^{33}cm^{-2}s^{-1})$
  Kinematics: $(140$ GeV $\times$ 7 TeV) machine with $\sqrt{s} = 2TeV$, expected range for Q^2 is beyond $10^6 GeV^2$
- LHeC have considerably more asymmetric beam energy than HERA

Precision Physics and LHeC ?

- LHeC is mainly build to study proton structure new QCD phenomena with great precision
- It has the potential to constrain the proton (and nuclei) PDFs to an unprecedent level of accuracy with important implication for LHC phenomenology
- It also has the potential to constrain the electroweak parameters a_f, v_f with great precision from NC-DIS cross section
- It's also useful to measure M_W mass precisely from CC-DIS cross section

DIS cross section

$$\frac{d^2\sigma^{\rm NC}(e^\pm p)}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}[H_0^\pm + P_e H_{P_e}^\pm] \Rightarrow \text{NC cross section}$$

$$H_{0,P_e}^\pm = Y_+ F_2^{0,P_e} \mp Y_- x F_3^{0,P_e}$$

$$F_2^{0,P_e} = \sum_q x(q+\bar{q}) A_q^{0,P_e} \qquad xF_3^{0,P_e} = \sum_q x(q-\bar{q}) B_q^{0,P_e}$$

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

$$A_q^0 = e_q^2 - 2e_q v_q v_e \chi_Z + (v_q^2 + a_q^2)(v_e^2 + a_e^2)\chi_Z^2$$

$$B_q^0 = -2e_q a_q a_e \chi_Z + 4 v_q a_q v_e a_e \chi_Z^2$$

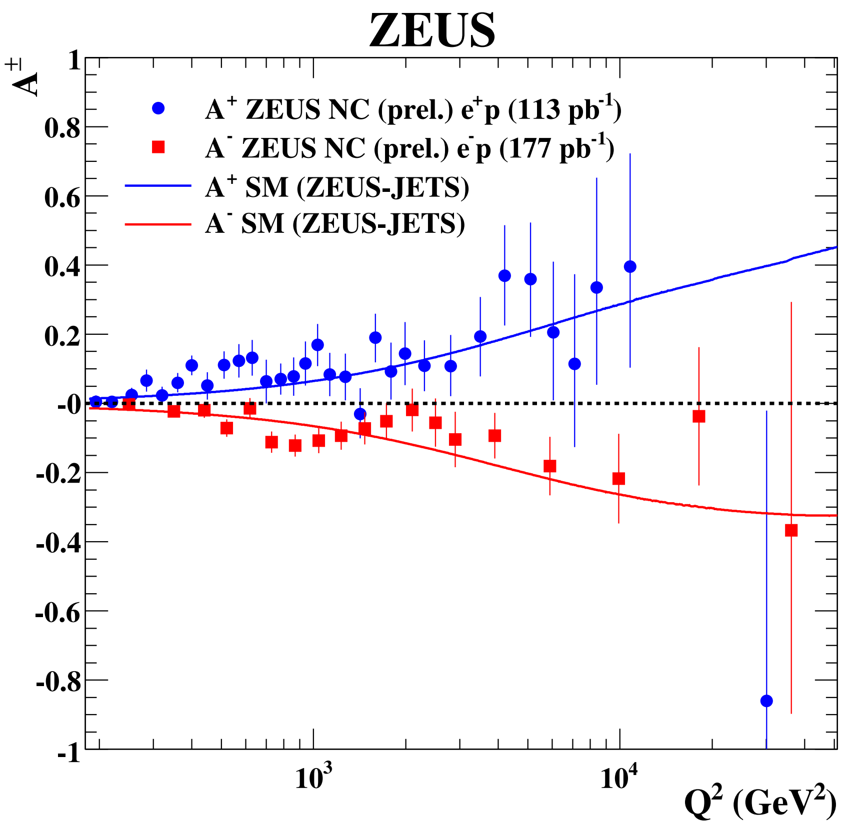
$$A_q^{P_e} = 2e_q v_q a_e \chi_Z - 2(v_q^2 + a_q^2) v_e a_e \chi_Z^2$$

$$B_q^{P_e} = 2e_q a_q v_e \chi_Z - 2 v_q a_q (v_e^2 + a_e^2)\chi_Z^2$$

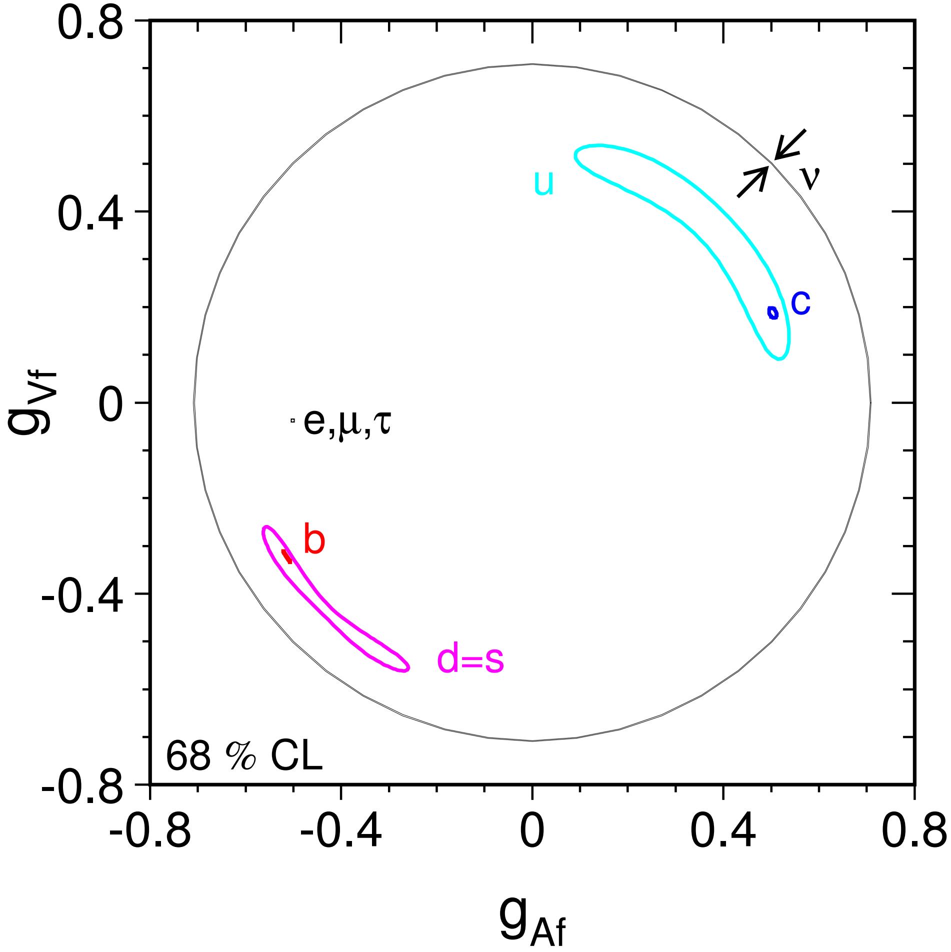
$$\chi_Z = \frac{1}{\sin^2 2\theta_W}\left(\frac{Q^2}{M_Z^2 + Q^2}\right)$$

Polarization asymmetry

$$A^{\pm} = \frac{2}{P_e^+ - P_e^-} \frac{\sigma^{\pm}(P_e^+) - \sigma^{\pm}(P_e^-)}{\sigma^{\pm}(P_e^+) + \sigma^{\pm}(P_e^-)} \approx a_e v_q$$



LEP measurements for a_f and v_f



see talk by Gwenlan at pre LHeC meeting, April, 2009

LHeC scenarios studied

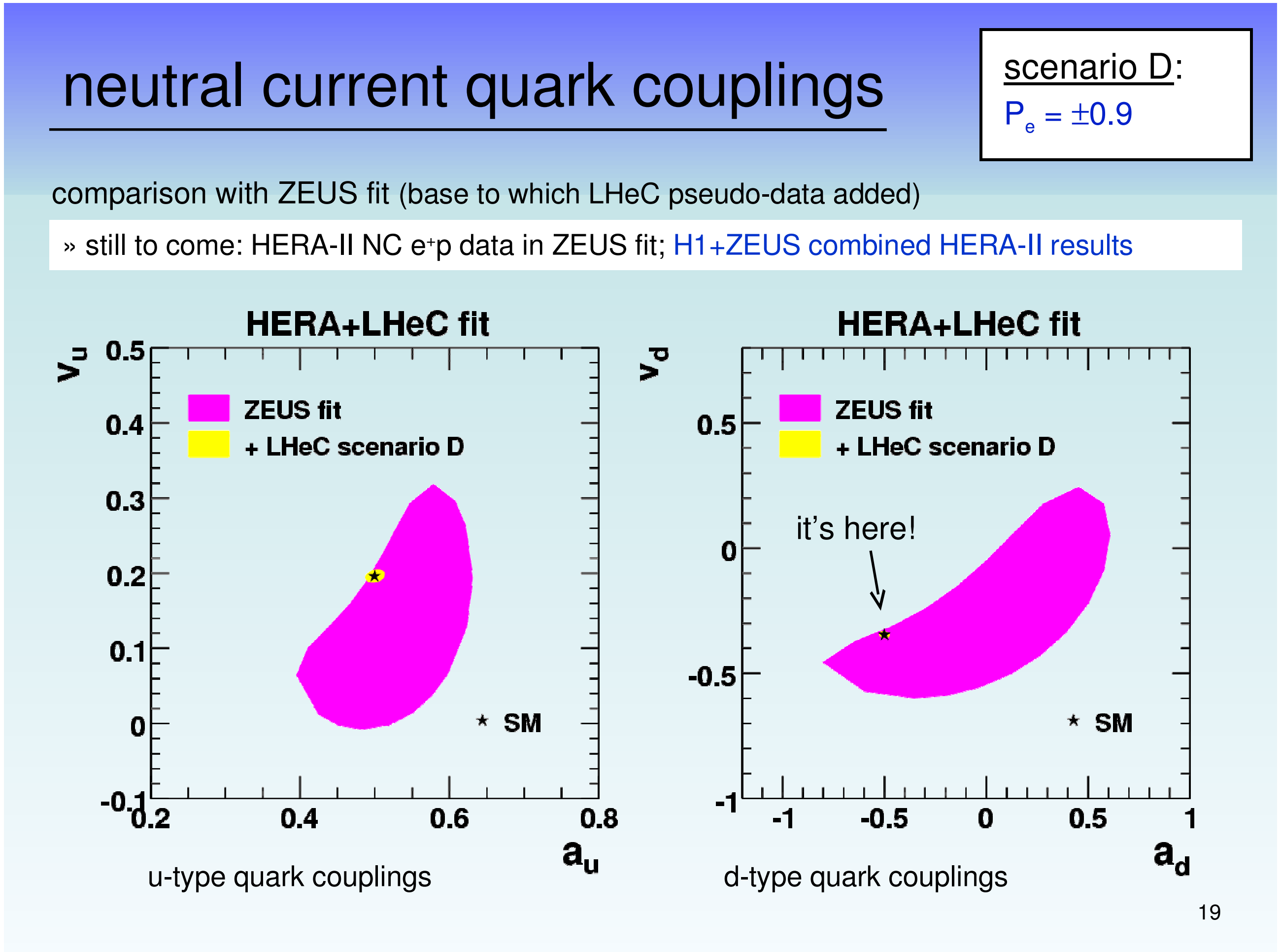
config.	E(e)	E(N)	N	$\int L(e^+)$	$\int L(e^-)$	|Pol|	$L/10^{32}$	P/MW	years	type
A	20	7	p	1	1	-	1	10	1	SPL
B	50	7	p	50	50	0.4	25	30	2	RR hiQ^2
C	50	7	p	1	1	0.4	1	30	1	RR lo x
D	100	7	p	5	10	0.9	2.5	40	2	LR
E	150	7	p	3	6	0.9	1.8	40	2	LR
F	50	3.5	D	0.5	0.5	0.4	0.5	30	1	eD
G	50	2.7	Pb	0.1	0.1	0.4	0.1	30	1	ePb

Scenario D:
$E(e^\pm)$ = 100 GeV
E(p) = 7 TeV
($\sqrt{s}$ = 1.673 TeV)
$P_e = \pm 0.9$

… simulated LHeC data (M. Klein); mainly looked at scenario D (since it was produced first!)
[available at: http://hep.ph.liv.ac.uk/~mklein/simdis09]

6

see talk by Gwenlan at pre LHeC meeting, April, 2009



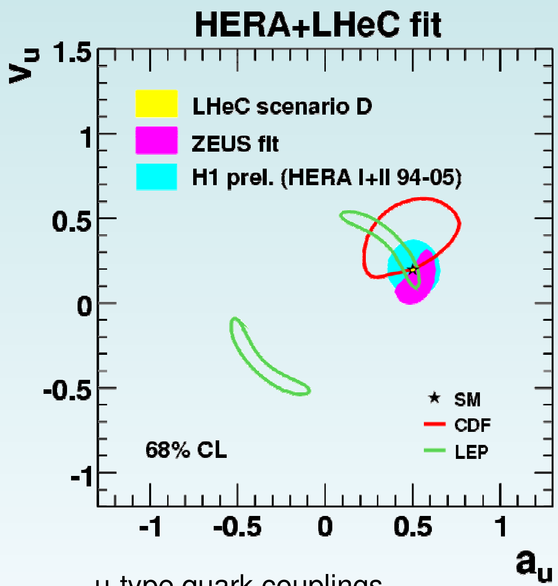
see talk by Gwenlan on pre LHeC meeting, April, 2009

neutral current quark couplings

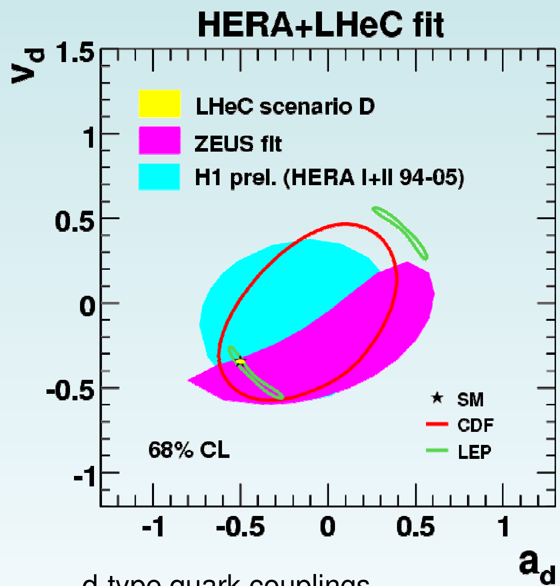
scenario D:
$P_e = \pm 0.9$

comparison with other experiments

» still to come: HERA-II NC e^+p data in ZEUS fit; H1+ZEUS combined HERA-II results



u-type quark couplings



d-type quark couplings

20

Points to be noted...

Analysis based on the following assumptions:

- Quark axial and vector coupling, v_q and a_q, has been taken as free parameters and fitted simultaneously with PDFs $\Rightarrow$ $v_f \to v_f^{SM} + \Delta v_f \qquad a_f \to a_f^{SM} + \Delta a_f$
- Lepton axial and vector couplings, a_e and v_e, has been fixed to there SM values
- Deviations Δv_q and Δa_q do not depend on x or Q^2 $\Rightarrow$ most of the new physics that could modify NC couplings would give rise to Q^2 dependent form factors

This analysis is good to test the SM prediction but not to quantify new physics effect, except few specific scenarios...

Leptophobic Z'

- Extra $U(1)$ gauge group appear naturally in many extensions of the SM
- Particles associated with new $U(1)$ are reasonably massive and have small mixing with the SM *Z* $\Rightarrow$ originating from *E6* and *S0(10)*
- Leptophobic *Z'* $\Rightarrow$ *Z'* does not couple to SM leptons $\Rightarrow$ avoids traditional collider searches $\Rightarrow$ can not be produced in Drell-Yan collisions

$$\mathcal{L}_{NC} = \frac{g}{2\cos\theta_W} \sum_i \left[Z_0^\mu (v_S^i \bar{\psi}\gamma_\mu\psi + a_S^i \bar{\psi}\gamma_\mu\gamma_5\psi) + V_0^\mu (v_N^i \bar{\psi}\gamma_\mu\psi + a_N^i \bar{\psi}\gamma_\mu\gamma_5\psi) \right]$$

$$v_{eff}^f = \cos\zeta\, v_S^f + \sin\zeta\, v_N^f \qquad a_{eff}^f = \cos\zeta\, a_S^f + \sin\zeta\, a_N^f$$

see talk by Gwenlan on pre LHeC meeting, April, 2009

neutral current quark couplings

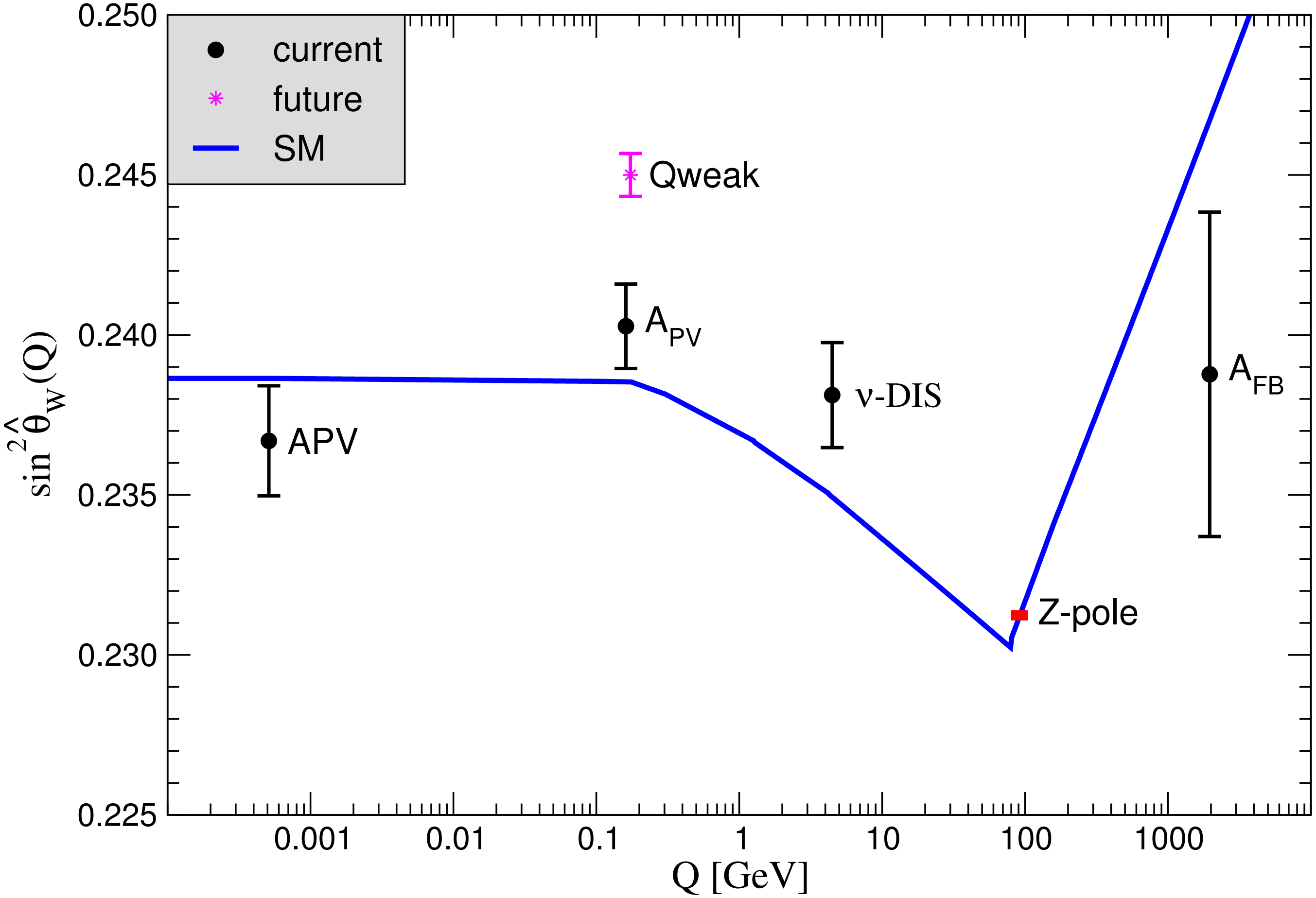
uncertainties on the neutral current quark couplings: $\Delta_{uncorr} \pm \Delta_{corr}$

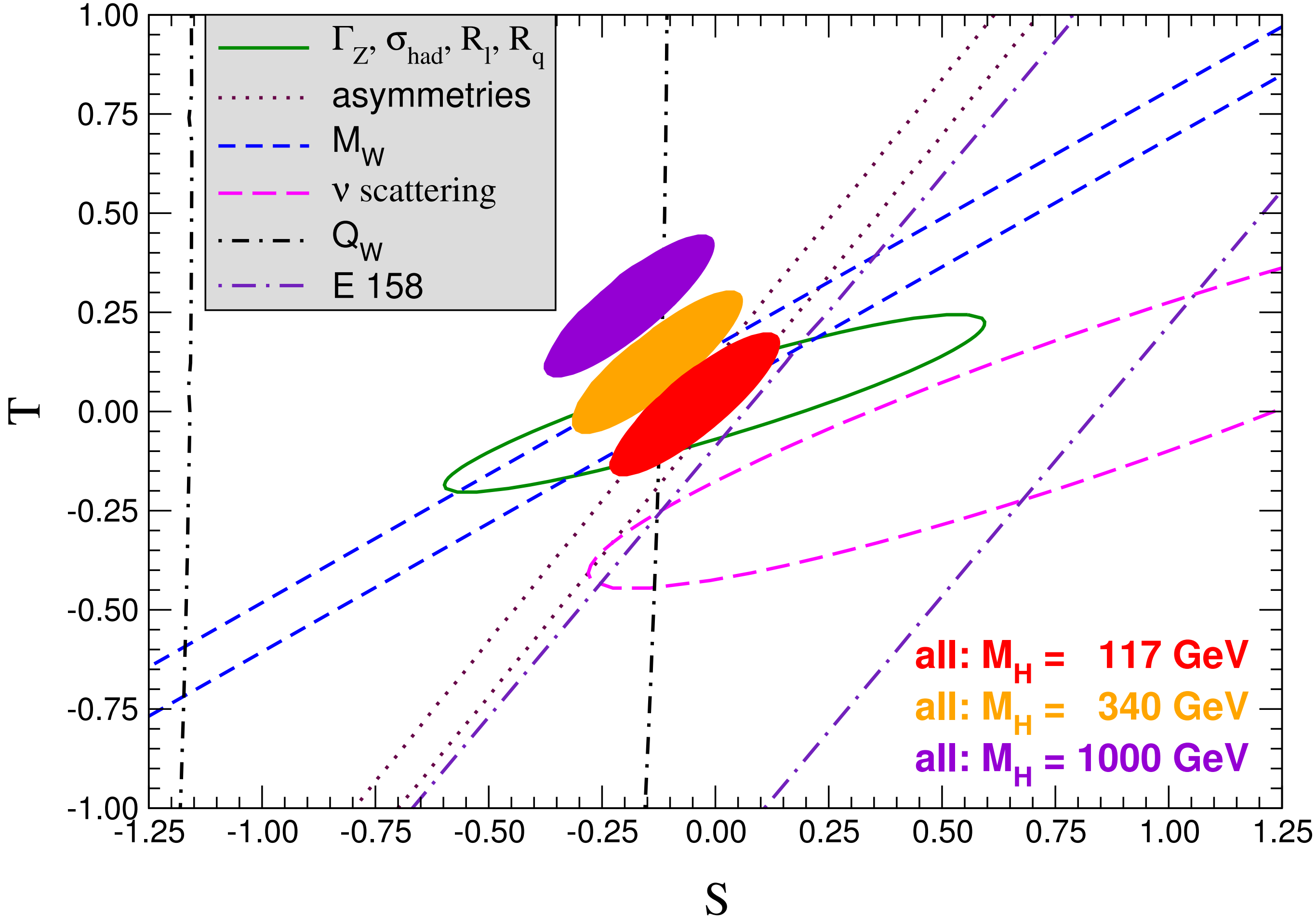
	a_u (0.5)	v_u (0.196)	a_d (-0.5)	v_d (-0.346)
A	0.05 ± 0.09	0.073 ±0.120	0.21 ± 0.44	0.112 ± 0.225
B	0.01 ± 0.01	0.010 ± 0.067	0.01 ± 0.02	0.020 ± 0.010
C	0.02 ± 0.02	0.014 ± 0.007	0.03 ± 0.05	0.030 ± 0.012
D	0.01 ± 0.01	0.003 ± 0.007	0.01 ± 0.02	0.006 ± 0.009
E	0.01 ± 0.01	0.004 ± 0.007	0.01 ± 0.02	0.007 ± 0.009

(note: with LHeC NC and CC included)

44

$\Delta(sin^2\theta_W)$ is $\mathcal{O}(10^{-3})$


current
future
SM
Qweak
A_{PV}
APV
ν-DIS
Z-pole
A_{FB}
$\sin^2\hat{\theta}_W(Q)$
Q [GeV]
0.250
0.245
0.240
0.235
0.230
0.225
0.001
0.01
0.1
1
10
100
1000



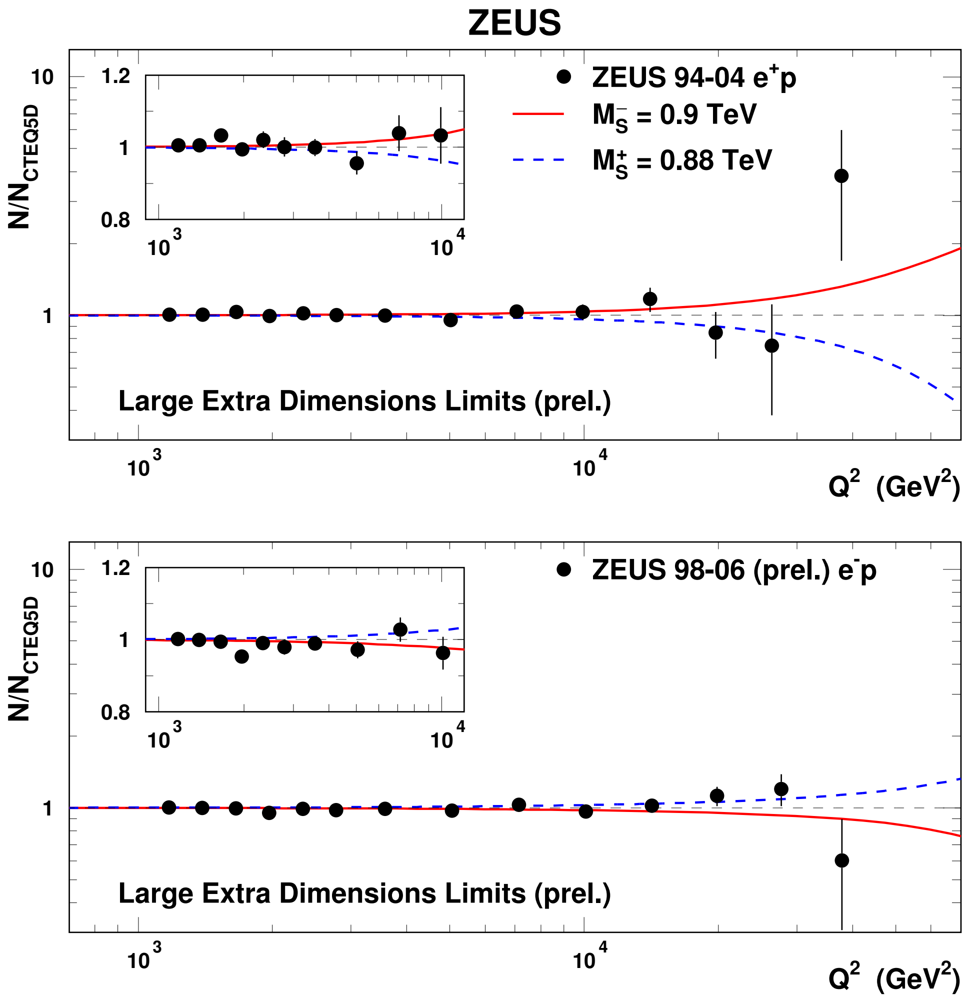
Γ_Z, σ_{had}, R_l, R_q
asymmetries
M_W
ν scattering
Q_W
E 158
all: M_H = 117 GeV
all: M_H = 340 GeV
all: M_H = 1000 GeV
T
S

Contact interactions

- New interactions between electrons and quarks involving mass scale above the center-of-mass energy can modify the DIS *ep* scattering cross section at high Q^2
- Vector four-fermion contact interaction : $\sum_{i,j=L,R} \eta_{ij}^{eq} (\bar{e}_i \gamma^\mu e_i)(\bar{q}_j \gamma_\mu q_j)$
  $\eta_{ij}^{eq} \Rightarrow$ Helicity and flavour structure ($\pm 4\pi/\Lambda^2$)
- Λ has the range, $2.0 to 8.0$ TeV from $ZEUS$ and $1.6 to 5.5$ TeV from $H1$ experiments, based on the analysis of $1994 - 2006$ data

Q^2 distribution of NC DIS in the model with large extra dimension

ZEUS data compared with 95% CL exclusion limits for the effective Planck mass scale in models with large extra dimensions



Thank you !

DIS cross section

DIS cross sections,

$$\sigma_{NC(CC)} = \sigma^{Born}_{NC(CC)}(1+\delta^{qed}_{NC(CC)})(1+\delta^{weak}_{NC(CC)})$$

$\sigma^{Born}_{NC(CC)} \Rightarrow$ Born cross section

Radiative corrections: $\delta^{qed}_{NC(CC)} \Rightarrow$ QED $\quad \delta^{weak}_{NC(CC)} \Rightarrow$ weak

The NC cross section:

$$\frac{\mathrm{d}^2\sigma^{\pm}_{NC}}{\mathrm{d}x\,\mathrm{d}Q^2} = \frac{2\pi\alpha^2}{xQ^4}\left[Y_+\tilde{F}_2 \mp Y_- x\tilde{F}_3 - y^2\tilde{F}_L\right](1+\delta^{weak}_{NC})$$ where

$$\tilde{F}_2 \equiv F_2 - \ v_e\ \frac{\kappa_w Q^2}{(Q^2+M_Z^2)}\ F_2^{\gamma Z} + (v_e^2+a_e^2)\left(\frac{\kappa_w Q^2}{Q^2+M_Z^2}\right)^2 F_2^Z$$

$$x\tilde{F}_3 \equiv -\ a_e\ \frac{\kappa_w Q^2}{(Q^2+M_Z^2)} xF_3^{\gamma Z} + \ (2v_e a_e)\ \left(\frac{\kappa_w Q^2}{Q^2+M_Z^2}\right)^2 xF_3^Z$$

$$\kappa_w^{-1} = 4\frac{M_W^2}{M_Z^2}(1-\frac{M_W^2}{M_Z^2})$$