

Recent results on EW Physics Measurements and Searches for New Physics at HERA

V. Boudry

Laboratoire Leprince Ringuet
Ecole Polytechnique, Palaiseau

Les Rencontres de Physique de la Vallée d'Aoste



1 HERA I & II

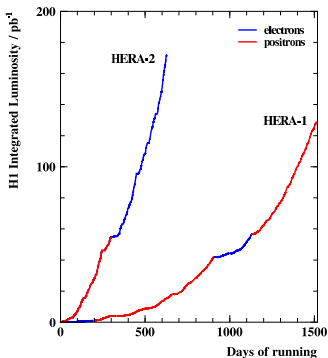
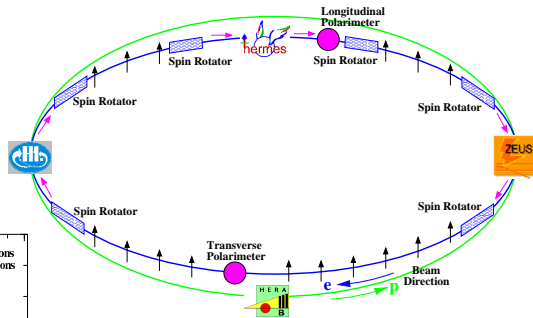
2 EW measurements

- Introduction
- QCD & EW fit
- Polarised $e^+ p$ Cross-Sections
- Differential Polarised Cross-Sections

3 Searches

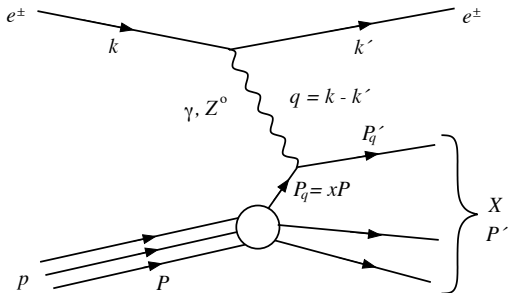
- Isolated leptons
- H1 Multi-leptons

- $E_{e^\pm} = 27.5 \text{ GeV}$
- $E_p = 920 \text{ GeV}$



Lumi per experiment

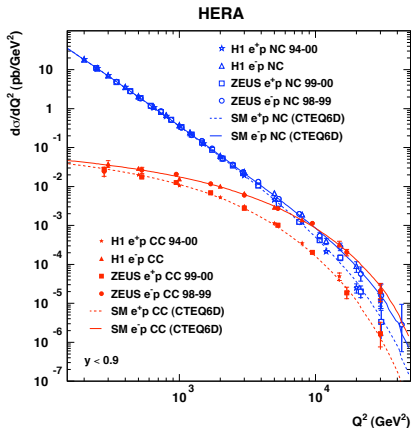
- HERA-I (94–00): $100 \text{ pb}^{-1}(e^+ p)$; $20 \text{ pb}^{-1}(e^- p)$
- HERA-II (02–05): $50 \text{ pb}^{-1}(e^+ p)$; $150 \text{ pb}^{-1}(e^- p)$
polarised e^\pm (unpol. p) equally shared



Neutral or Charged Currents

Kinematics:

- $Q^2 = -q^2 = -(k - k')^2$,
resolution $\simeq 1/\sqrt{Q^2}$
- $x = \frac{-q^2}{2P \cdot q}$ fraction of p's
momentum of involved quark
- $y = \frac{P \cdot q}{P \cdot k}$ inelasticity
- $s = (P + k)^2$
- $Q^2 = sxy$



- H1 HERA-I (94–00): e[±] p: 117.2 pb⁻¹
 - 100.8 pb⁻¹(e⁺ p) + 16.4 pb⁻¹(e⁻ p)
 - unpolarised
- Limited stat at high Q²

$$\frac{d^2\sigma^{CC}(e^\pm p)}{dx dQ^2} \propto \frac{G_F^2}{2\pi X} \left[\frac{M_W^2}{M_W^2 + Q^2} \right]^2 \times \text{PDF's}$$

$$\frac{d^2\sigma^{NC}(e^\pm p)}{dx dQ^2} \propto \left| \frac{A}{Q^2} + \frac{B}{Q^2 + M_Z^2} \right|^2 \times \text{PDF's}$$

⇒ PDF from low Q² CC & NC;

⇒ M_W from high Q² CC; weak couplings from high Q² NC

NC Cross-section break up

$$\frac{d^2\sigma^{\text{NC}}(e^\pm p)}{dx dQ^2} = \frac{2\pi\alpha^2}{xQ^4} Y_+ \tilde{F}_2(x, Q^2) \mp Y_- x \tilde{F}_3(x, Q^2) - y^2 \tilde{F}_L(x, Q^2) \left(1 + \Delta_{\text{NC}}^{\pm, \text{weak rad.}}\right)$$

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

$$\begin{aligned} \tilde{F}_2 &\equiv F_2 - v_e \frac{\kappa Q^2}{(Q^2 + M_Z^2)} F_2^{\gamma Z} + (v_e^2 + a_e^2) \left(\frac{\kappa Q^2}{Q^2 + M_Z^2}\right)^2 F_2^Z \\ x \tilde{F}_3 &\equiv -a_e \frac{\kappa Q^2}{(Q^2 + M_Z^2)} x F_3^{\gamma Z} + (2v_e a_e) \left(\frac{\kappa Q^2}{Q^2 + M_Z^2}\right)^2 x F_3^Z \\ \tilde{F}_L &= 0 \quad \text{in QPM} \end{aligned}$$

$$[F_2, F_2^{\gamma Z}, F_2^Z] = x \sum_q [e_q^2, 2e_q v_q, v_q^2 + a_q^2] \{q + \bar{q}\} [x F_3^{\gamma Z}, x F_3^Z] = 2x \sum_q [e_q a_q, v_q a_q] \{q - \bar{q}\}$$

Renorm.
Schemes:

On-Mass-Shell (OMS)

$$\kappa^{-1} = 4 \frac{M_W^2}{M_Z^2} \left(1 - \frac{M_W^2}{M_Z^2}\right) (1 - \Delta r)$$

in Mod. OMS (MOMS)

$$\kappa^{-1} = \frac{2\sqrt{2}\pi\alpha}{G_F M_Z^2}$$

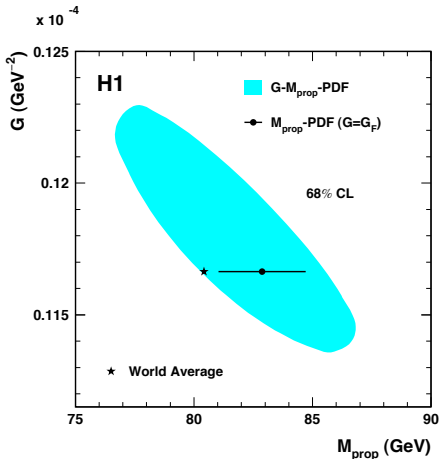
5 PDF are fitted (NLO+DGLAP+ $\overline{\text{MS}}$ +fixed α_s): gluons + 4 q and \bar{q}

Addit'l free parameters in MOMS scheme:

- G_F (= G as norm.) and M_W (= M_{prop} as propagator mass)
- M_W (as propagator mass M_{prop})
 $M_{\text{prop}} = 82.87 \pm 1.82_{\text{exp}} \begin{matrix} +0.30 \\ -0.16 \end{matrix} \Big|_{\text{model}} \text{ GeV}$
- $v_U - a_U - v_D - a_D$ (next slide)

in SM [OMS scheme]:

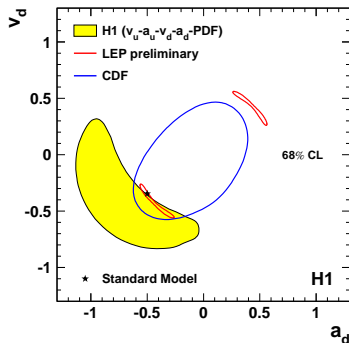
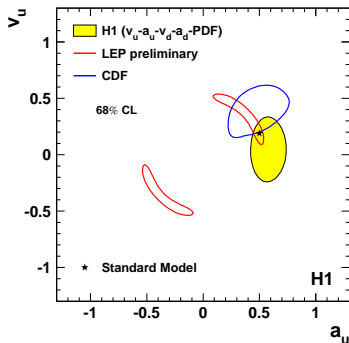
- G_F and M_W
- m_t



EW & QCD Fit – u & d Weak Couplings to Z^0

$$v_q = I_{q,L}^3 - 2e_q \sin^2 \theta_W, \quad a_q = I_{q,L}^3$$

$I_{q,L}^3$ = is the third component of the weak isospin.



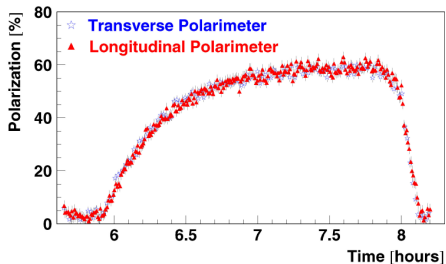
- First measurement of light q weak coupling to Z^0 at HERA
- Sensitive to u and d couplings separately
- No sign or $v_u \leftrightarrow a_u$ ambiguities
- large improvement expected from HERA-II \mathcal{L} and polarisation

Phys. Lett. B632 (2006) 35, hep-ex/0507080

Polarisation

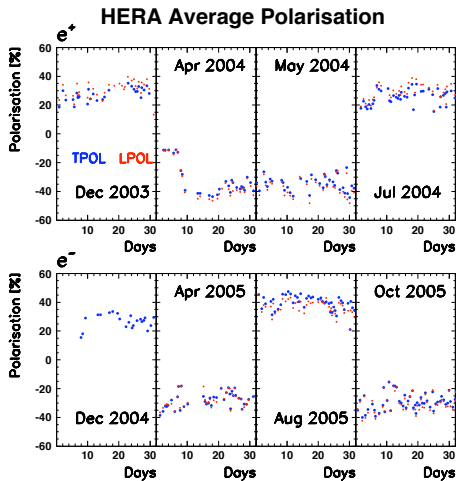
$$P_e = \frac{N_R - N_L}{N_R + N_L}, \quad N_R (N_L) \equiv \text{number of Right (Left) handed particles in the beam.}$$

P_e in a lumi Fill: built-up time ~ 40 min



Relative uncertainty
LPOL $\sim 1.6\%$

TPOL $\sim 3.5\%$



Total Polarised Charged $e^+ p$ Cross-sections – Data Samples & Selection

H1:

- $Q^2 > 400 \text{ GeV}^2, y < 0.9$
- R sample: $\langle \mathcal{P}_e \rangle = +(33.6 \pm 0.7) \%$, $\mathcal{L} = 26.9 \pm 0.6 \text{ pb}^{-1}$
- L sample: $\langle \mathcal{P}_e \rangle = -(40.2 \pm 1.1) \%$, $\mathcal{L} = 20.7 \pm 0.5 \text{ pb}^{-1}$

LPOL used when avail. TPOL otherwise. (run by run)

ZEUS:

- $Q^2 > 200 \text{ GeV}^2, y < 1.0$
- R sample: $\langle \mathcal{P}_e \rangle = +32 \%$, $\mathcal{L} = 12.3 \text{ pb}^{-1}$
- L sample: $\langle \mathcal{P}_e \rangle = -41 \%$, $\mathcal{L} = 11.5 \text{ pb}^{-1}$

Polarimeter with highest Lumi used. (run by run)

Total Polarised Charged e^+p Cross-sections

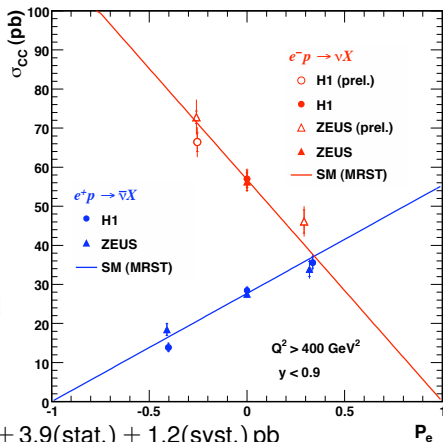
$$\sigma_{CC}(e^\pm p) = (1 \pm \mathcal{P}_e) \sigma_{CC}(e^\pm p)|_{\mathcal{P}_e=0}$$

Largest uncertainties:

- CC+NC: Calorimeter E scale
- NC: Parton Shower scheme

Consistent with SM and no W_R

Charged Current ep Scattering (HERA II)

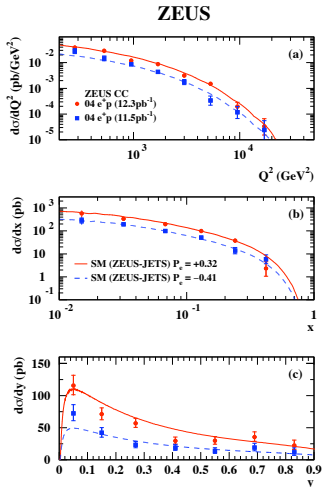


ZEUS:	7.4	$\pm 3.9(\text{stat.}) \pm 1.2(\text{syst.}) \text{ pb}$
H1:	-3.9	$\pm 2.3(\text{stat.}) \pm 0.7(\text{syst.}) \pm 0.8(\text{pol.}) \text{ pb}$
Combined*:	-1.0	$\pm 1.8(\text{stat.}) \text{ pb}$

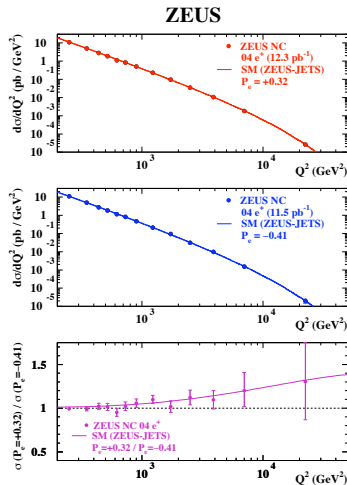
* unofficial fit, correlations not considered

Differential Polarised Cross-Sections

Charged Current



Neutral Current



- CC: Clear difference in all kinematic regions.
- NC: Consistent with SM (\supset ZEUS-PDF's): $\chi^2/\text{data pt} = 0.3$.
 No polarisation dep^{ce} $\Rightarrow \chi^2/\text{data pt} = 1.5$

Small sample: recent results (since last summer)

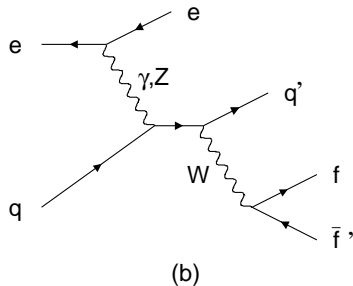
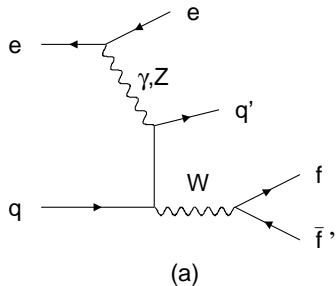
Inclusive

- LeptoQuarks
- Lepton Flavor Violation
- SUSY (Rpv and in SUSY)
- Excited Fermions
- Extra Dimensions
- Quark Radius
- Contact Interactions

Exclusive FS

- **Isolated Leptons** (e, μ, τ)
- **Multi-Leptons**
- Single Top Production
- Double charged Higgs
- Gravitinos
- Magnetic Monopoles
- General Search
- Pentaquarks

In SM single W production



$$ep \rightarrow eWX, \nu WX;$$

$$W \rightarrow l\nu$$

\Rightarrow Isolated lepton (+e) + $P_T^{\text{miss.}}$

ZEUS (re-analysis):

- $e^+ p$
- HERA-I (99–00): 66 pb^{-1}
HERA-II (03–04): 40 pb^{-1}
tot 106 pb^{-1}
- $\ell = e$
- $P_T^e > 5 \text{ GeV}$, $M_T > 10 \text{ GeV}$
- $D_{\eta-\phi}(e, \text{ other track}) > 0.5$
- acoplanarity

H1:

- $e^\pm p$
- HERA-I (94–00): $118 \text{ pb}^{-1}(e^\pm p)$
HERA-II (2003–2005): $53 + 107 \text{ pb}^{-1}(e^+ p + e^- p)$
tot 279 pb^{-1}
- $\ell = e, \mu$
- $P_T^\ell > 10 \text{ GeV}$; $P_T^{\text{calo}} > 12 \text{ GeV}$,
 $P_T^{\text{miss.}} > 12 \text{ GeV}$
- $D_{\eta-\phi}(\ell, \text{ jet}) > 1.0$
 $D_{\eta-\phi}(\ell, \text{ track}) > 0.5$
- “acoplanarity” & large momentum transfert for low P_T events

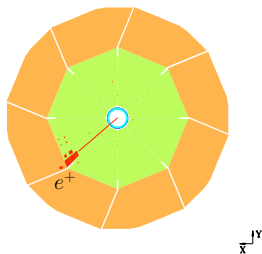
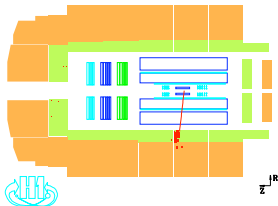
Background: NC & CC DIS

earlier ZEUS analysis on full HERA I dataset (e, μ) published {more background}.

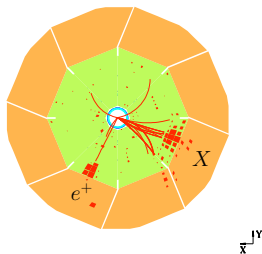
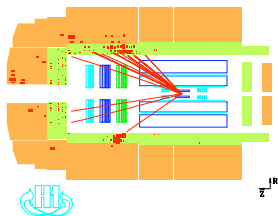
Isolated Leptons – Events

Elastic and inelastic W?

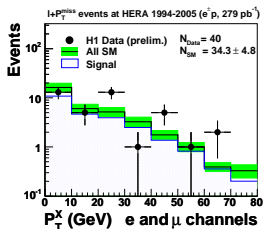
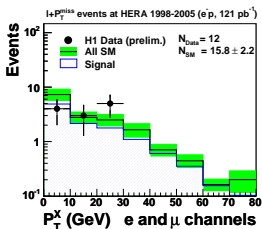
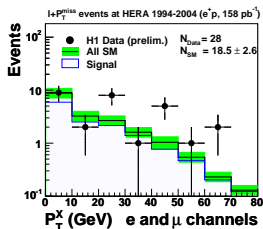
$$P_T^e = 47 \text{ GeV}, P_T^{\text{miss}} = 47 \text{ GeV}$$



$$P_T^e = 37 \text{ GeV}, P_T^{\text{miss}} = 44 \text{ GeV}, P_T^X = 29 \text{ GeV}$$



Isolated Leptons – Results



e: $11\oplus + 6\ominus + 13$ unmeas.

μ : $5\oplus + 4\ominus + 1$ unmeas.

($\sim 2/3\oplus$ expected from SM)

for $P_T^X > 25$ GeV: obs./exp (signal contribution ~ 60 – 80 %)

H1 Preliminary	e	μ	Combined
94-04 $e^+ p$ 158 pb^{-1}	9/2.3 \pm 0.4	6/2.3 \pm 0.4	15/4.6 \pm 0.8
98-05 $e^- p$ 121 pb^{-1}	2/2.4 \pm 0.5	0/2.0 \pm 0.3	2/4.4 \pm 0.7

$\Rightarrow 3.4\sigma$ in $e^+ p$, nothing in $e^- p$.

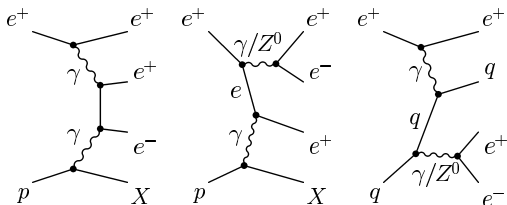
ZEUS summary table:

Isolated e candidates	$12 < P_T^X < 25$ GeV	$P_T^X > 25$ GeV
ZEUS (prel.) 99-00 e^+p (66 pb ⁻¹)	1/1.04 ± 0.11(57%)	1/0.92 ± 0.09(79%)
ZEUS (prel.) 03-04 e^+p (40 pb ⁻¹)	0/0.46 ± 0.10(64%)	0/0.58 ^{+0.08} _{-0.09} (76%)

- Still no excess wrt SM seen by ZEUS in e
- Still an excess for H1, at the same rate as for HERA-I
- Probability(high P_T^X events):
 0.0015 [3.0 σ] (HERA-I, mainly $e^+ p$) → 0.0208 [2.0 σ](all data)
 0.0003 [3.4 σ] for all $e^+ p$ data only.

Multi-Leptons – Introduction

- $\gamma\gamma, \gamma Z^0, Z^0 Z^0$ interactions
 $ep \rightarrow \mu\mu X, eeX, e\mu\mu X, eeeX, (\tau\tau X)$
- Backgrounds:
 - NC DIS
 - QED Compton



- H1: 1994–2005
- $52 \text{ pb}^{-1}(e^+ p) + 105 \text{ pb}^{-1}(e^- p) = 275 \text{ pb}^{-1}(\text{tot.})$
- new data + new topologies ($e\mu$ and $e\mu\mu$)

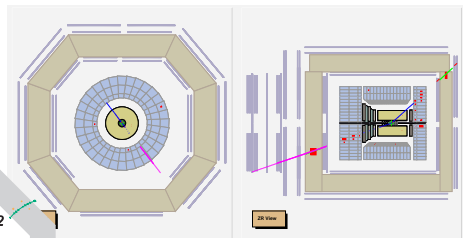
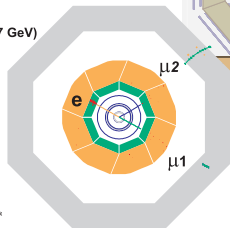
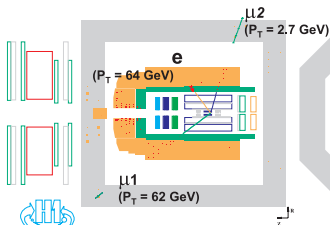
- ZEUS: 1996–2000
- $101 \text{ pb}^{-1}(\text{tot.})$
- $\mu\mu$

H1 Selection

- e with $E > 5 \text{ GeV}$ within $5^\circ < \theta < 175^\circ$
 $D_{\eta-\phi}(e, \ell \text{ or jet}) > 0.5$
- μ with $P_T > 2 \text{ GeV}$ within
 $20^\circ < \theta < 160^\circ$
 $\Delta\theta(\mu_1, \mu_2) < 160^\circ$ (cosmics)
 $D_{\eta-\phi}(\mu, \text{track or jet}) > 1.0,$
 $D_{\eta-\phi}(\mu, \ell) > 0.5$
- $N\ell(20^\circ < \theta < 150^\circ) > 2,$
 $P_T^{\ell 1} > 10 \text{ GeV}, P_T^{\ell 2} > 5 \text{ GeV}$

ZEUS selection

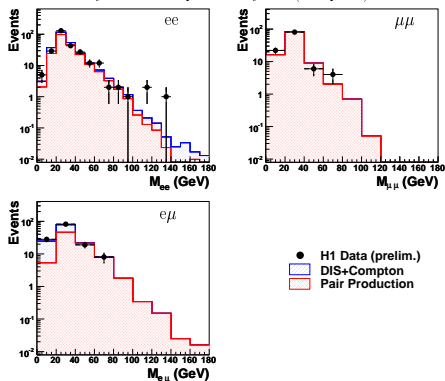
- μ with $P_T > 5 \text{ GeV}, M_{\mu\mu} > 5 \text{ GeV}$
 $12^\circ < \theta < 164^\circ$
 $\Delta\theta(\mu_1, \mu_2) < 174^\circ$ (cosmics)
 $D_{\eta-\phi}(\mu, \text{track}) > 1.0,$



Multi-Leptons – Mass Distributions

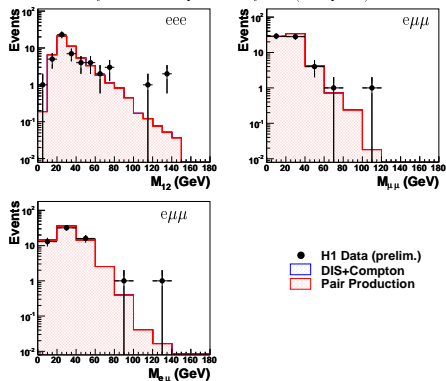
2 leptons (H1)

H1 Preliminary Multi-lepton analysis (275 pb⁻¹)



3 leptons (H1)

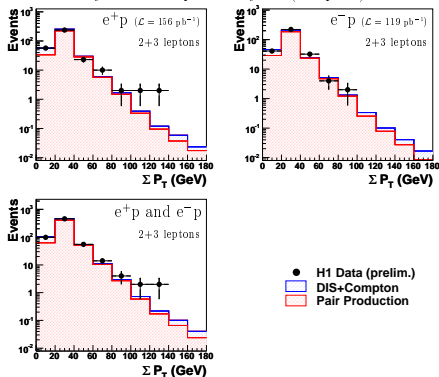
H1 Preliminary Multi-lepton analysis (275 pb⁻¹)



- the 3 ee and the 3 eee events at high mass were seen in the HERA I data.
- no new multi-e event in HERA II data with $M > 100$ GeV
- ZEUS HERA-I $\mu \mu$ signal consistent with SM

Multi-Leptons – Mass Distributions all leptons

H1 Preliminary Multi-lepton analysis (275 pb^{-1})



$\Sigma P_T > 100 \text{ GeV}$

H1 Preliminary 275 pb^{-1} (1994–2005)

Selection	Data	SM	Pair Production	NC-DIS + Compton
e^+p	4	0.6 ± 0.1	0.49 ± 0.09	0.11 ± 0.04
e^-p	0	0.5 ± 0.1	0.37 ± 0.10	0.13 ± 0.04
All	4	1.1 ± 0.2	0.86 ± 0.18	0.24 ± 0.06

Reminder: 2003 ZEUS analysis on HERA-I data didn't show any excess.

- First combined QCD & EW fit of HERA data
 - Results from polarised data will soon be there
- Isolated Leptons (e , μ) always there (H1 & $e^+ p$ only!)
 - waiting for an update on τ from ZEUS.
- Some Multi-Lepton High P_T seen in $e^+ p$

- less than half $e^- \mathcal{L}$ accumulated $\Rightarrow \sim 600 \text{ pb}^{-1}$
- will improve, with polarisation, the EW parameter measurement
- Switching to e^+ in August to have the same amount of Lumi in $e^+ p$ and $e^- p$

Expected Lumi:

