High Q^2 DIS Results and Search for Leptoquarks at HERA

Ph. Bruel

LPNHE Ecole Polytechnique

IN2P3-CNRS

On behalf of the

H1 Collaboration

- Introduction
- High Q^2 NC DIS Cross-sections
- New Rates at very High Q^2
- Search for Leptoquarks

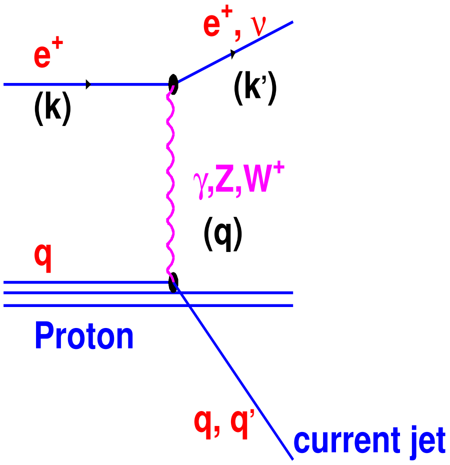
DESY

Introduction: High Q^2 Physics

$$\text{HERA} = \boldsymbol{e}\ (27.5\ \text{GeV}) \rightarrow\leftarrow \boldsymbol{p}\ (820\ \text{GeV})$$
$$\Rightarrow \sqrt{s} = 300\ \text{GeV}$$

Probing the proton at small distances down to 10^{-3}fm ...

- t-channel exchange of a highly virtual gauge boson



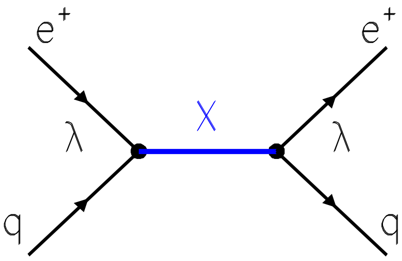
$$Q^2 = -(k-k')^2 = -q^2 = sxy$$

$$x = \frac{Q^2}{2(P.q)} \qquad y = \frac{(P.q)}{(P.k)}$$

$$M = \sqrt{sx} \quad y = \frac{1+\cos\theta_e^*}{2}$$

$$d\sigma/dy\ |_x \propto 1/y^2$$

- Search for s-channel production of new particles coupling to lepton-quark pairs

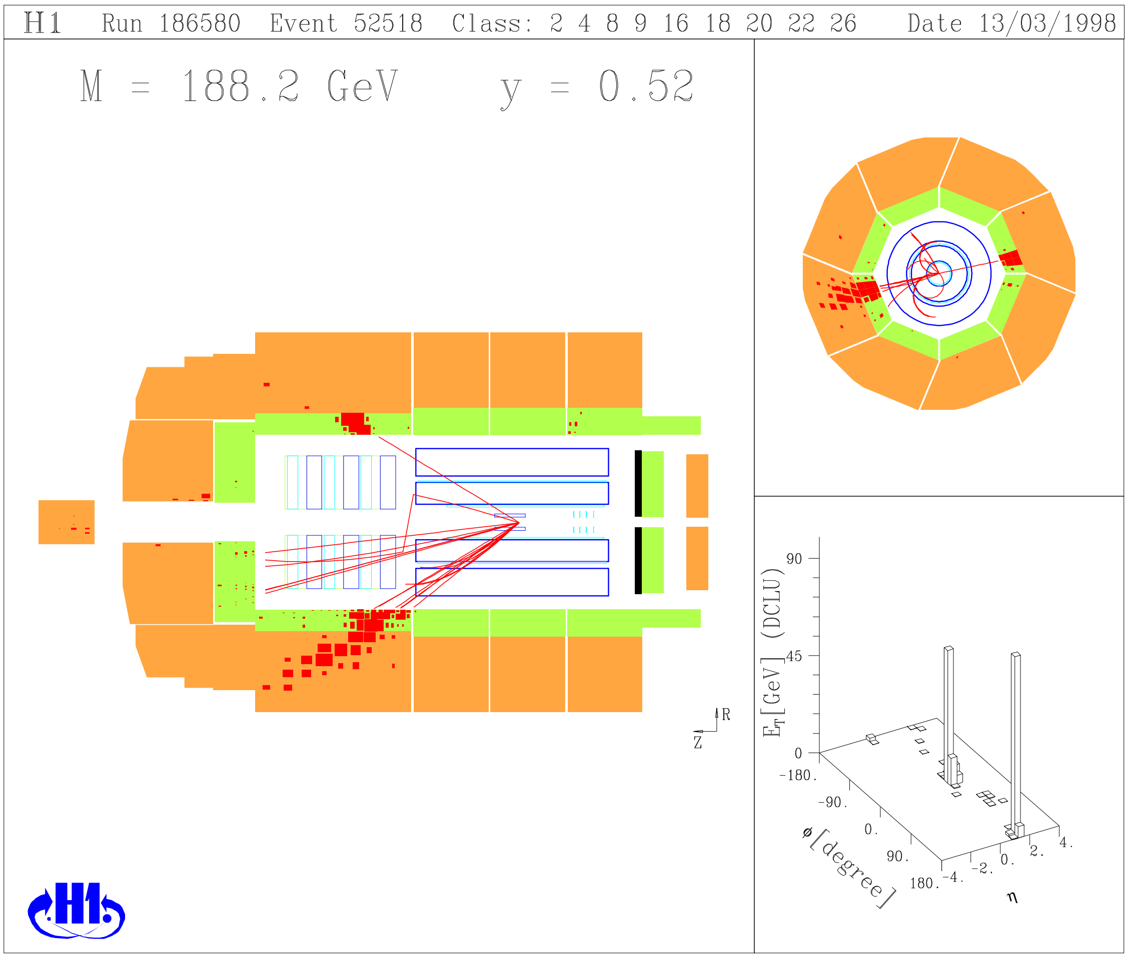


$$M_X \leq 300\ \text{GeV}$$

$$d\sigma/dy \sim const. \qquad (S=0)$$

$$d\sigma/dy \sim (1-y)^2 \quad (S=1)$$

NC DIS Candidate in the H1 Detector



LAr Calorimetry

- Very fine granularity ($\approx$ 44000 cells)
- Optimal for e-identification $\sigma(E)/E \simeq 12\%/\sqrt{E/\text{ GeV}} \oplus 1\%$
- offline weighting for hadrons $\sigma(E)/E \simeq 50\%/\sqrt{E/\text{ GeV}} \oplus 2\%$

Kinematics Reconstruction

θ_e, E_e	"electron" method
θ_e, $\theta_{hadrons}$	"double-angle" method
full information	ω method

What's new ?

- More luminosity

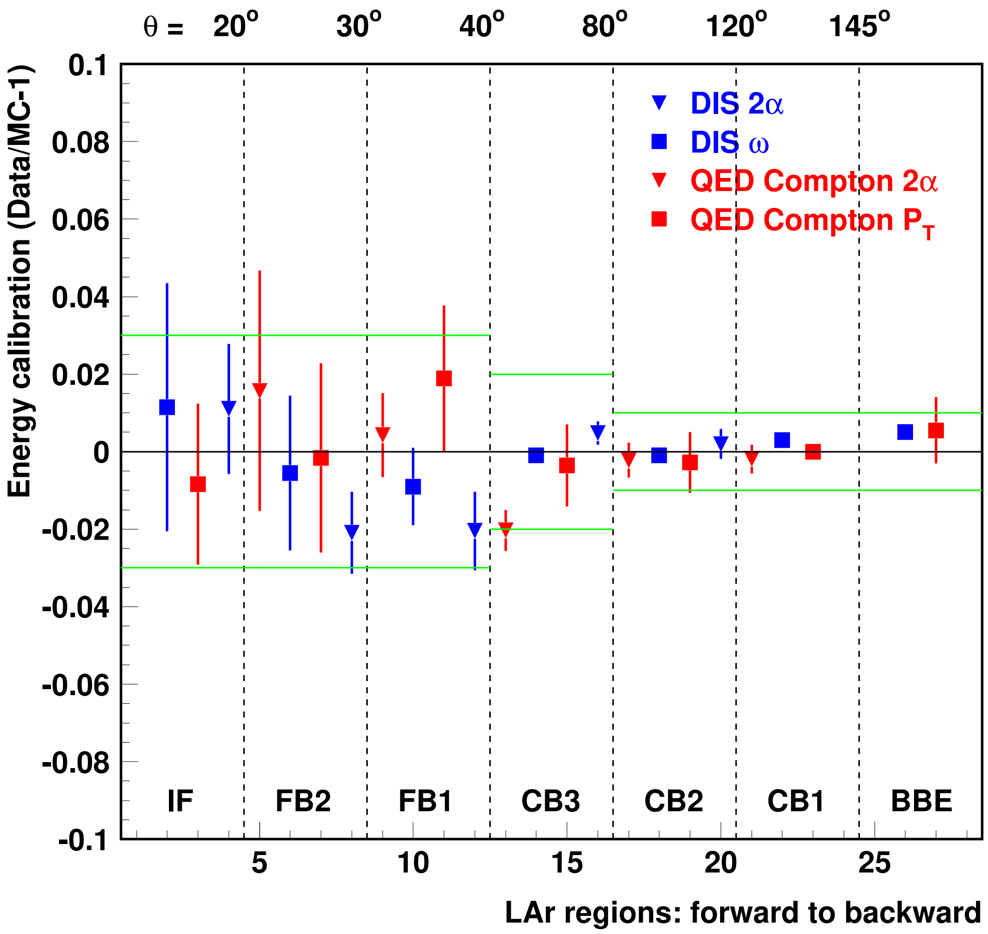
$$14.2 \text{ pb}^{-1} \rightarrow 37 \text{ pb}^{-1}$$

- Improved electromagnetic calibration

In situ calibration now achieved for the LAr_{em} wheels using :

Double-angle method or ω-method for NC DIS

Double-angle method or P_T balance for QED Comptons



Systematics on the LAr em. energy scale:
3% in the forward part to 1% in the backward part.

Standard Model of DIS

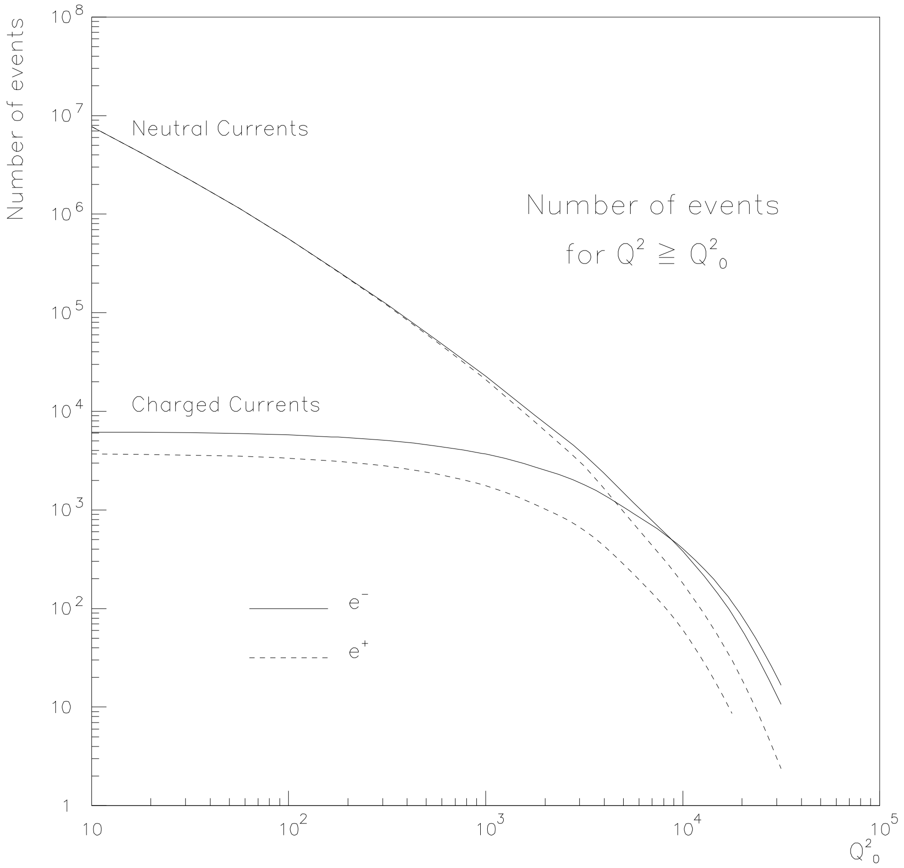
The Born Neutral Current cross-section is:

$$\frac{d^2\sigma}{dx\,dQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left\{Y_+\mathcal{F}_2(x,Q^2)\ -\ Y_-x\mathcal{F}_3(x,Q^2)\right\}$$

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

$$\begin{pmatrix} \mathcal{F}_2(x,Q^2) \\ x\mathcal{F}_3(x,Q^2) \end{pmatrix} = x\sum_q \begin{pmatrix} C_2^q(Q^2)[q(x,Q^2)+\bar{q}(x,Q^2)] \\ C_3^q(Q^2)[q(x,Q^2)-\bar{q}(x,Q^2)] \end{pmatrix}$$

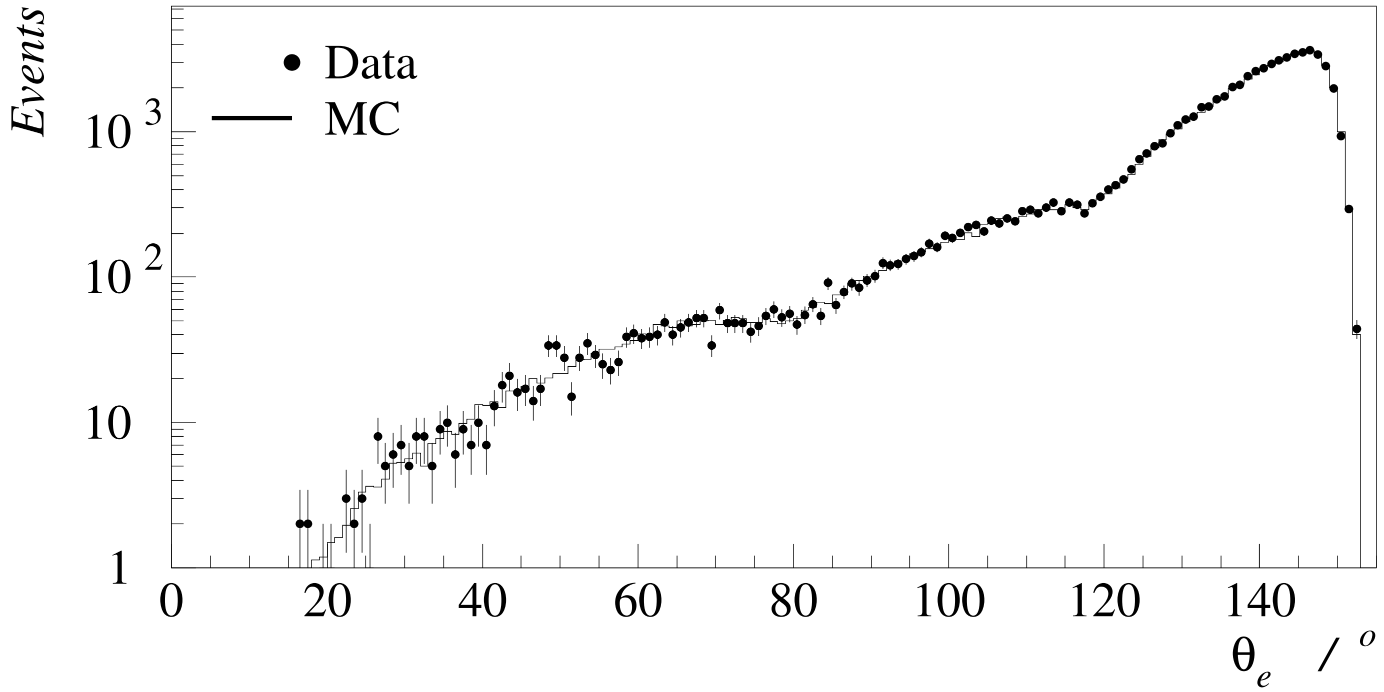
$C_2(Q^2)$ and $C_3(Q^2)$ depending on charges, axial and vector electroweak couplings, $\sin(\theta_w)$ and M_Z.

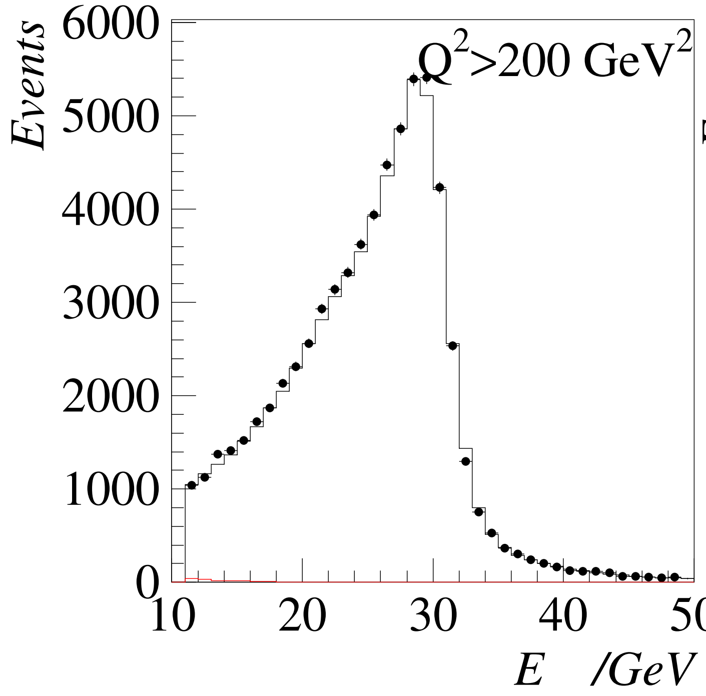


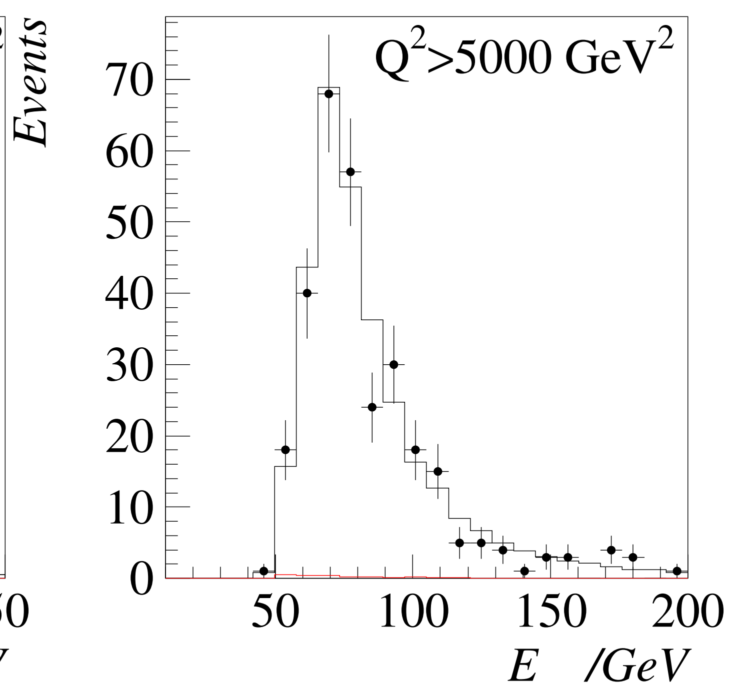
Systematics of 7% on the prediction of the cross-sections at high Q^2

DIS cross-section measurement

kinematical cuts: $E_{el} > 11$ GeV and $y < 0.9$.

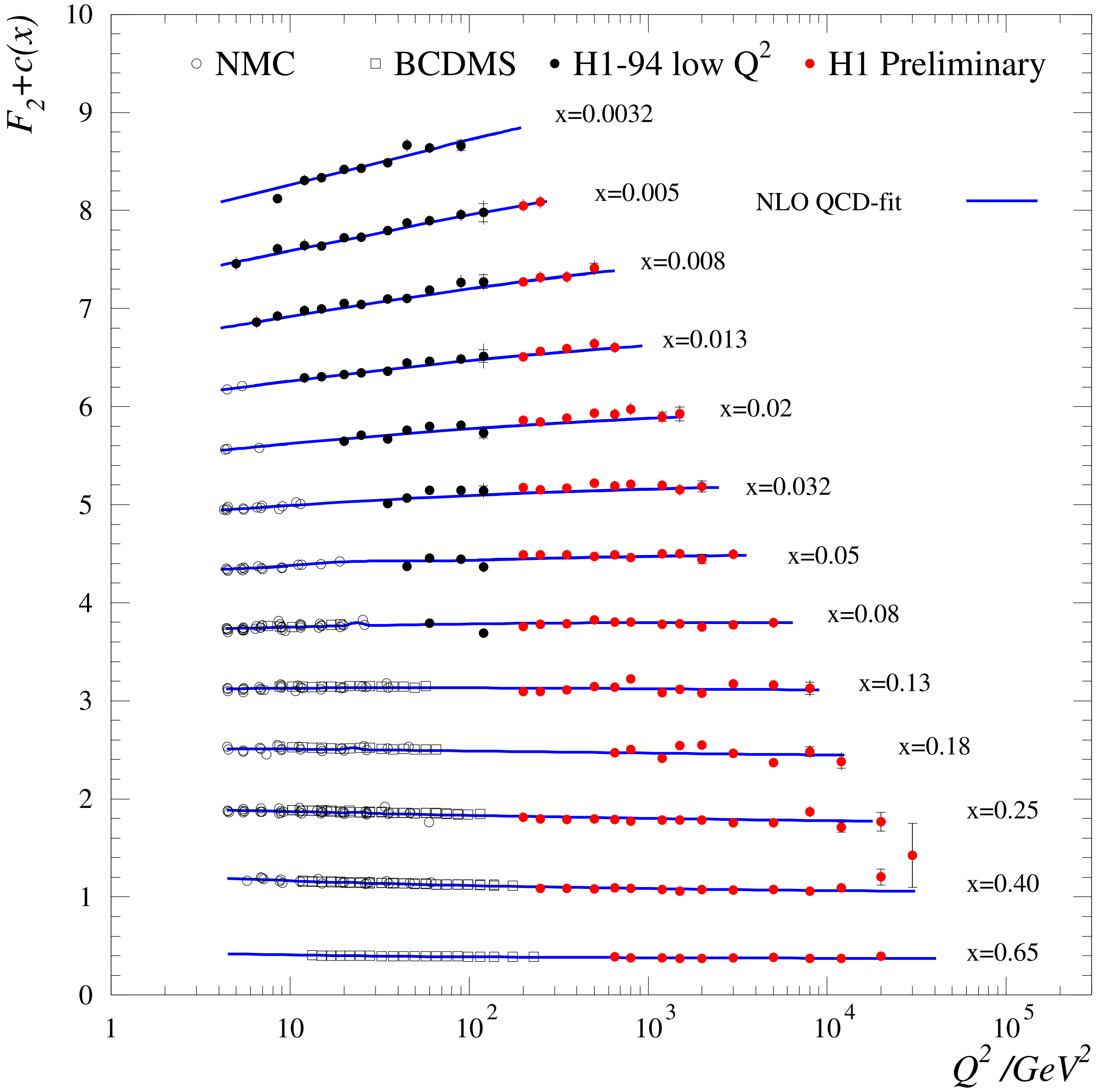






DIS cross-section measurement

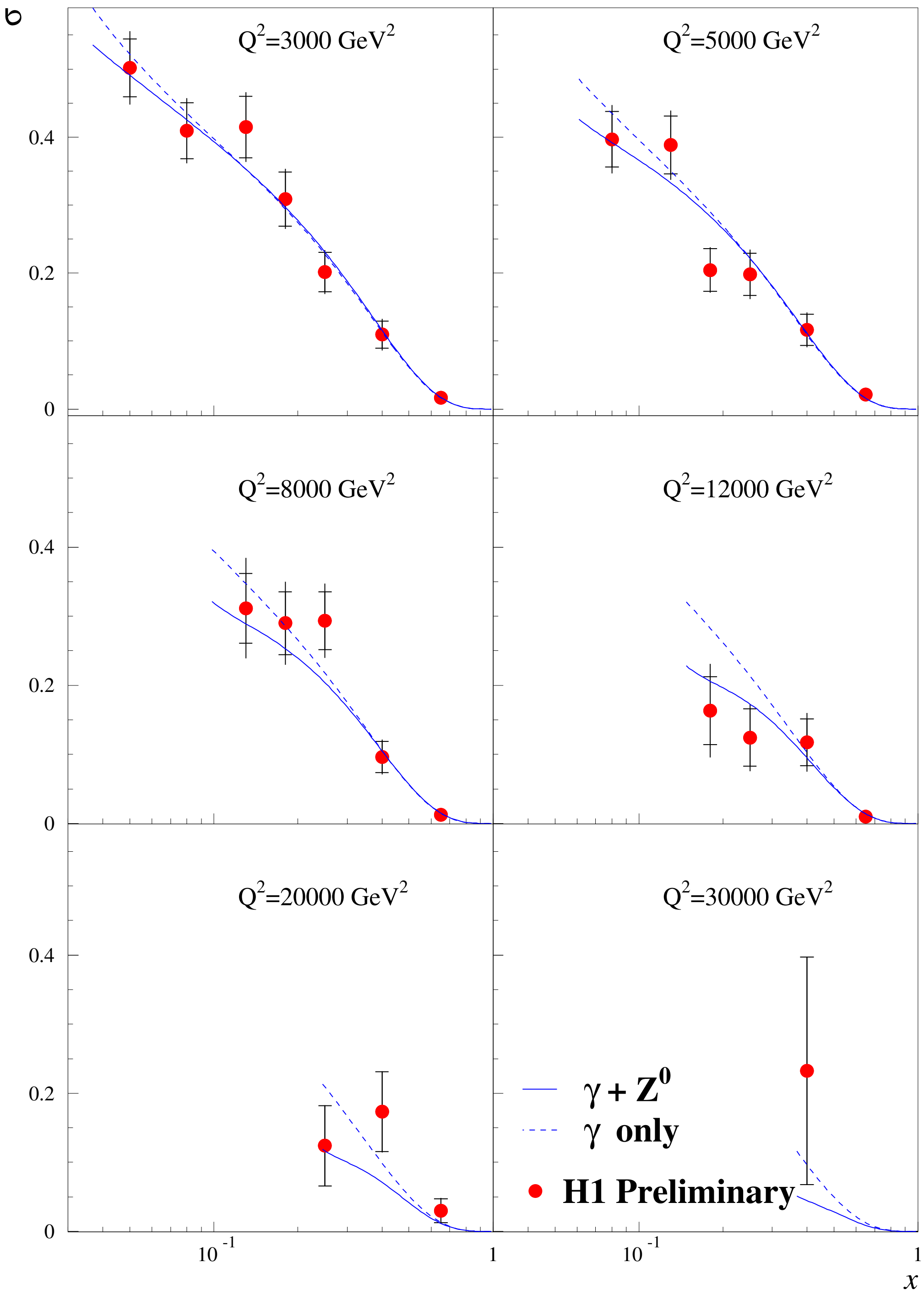
$\mathcal{F}_2(x,Q^2)$ extracted from $\frac{d^2\sigma}{dx\,dQ^2}$ assuming standard $\mathcal{F}_3(x,Q^2)$.



The measured scaling violations are extremely well followed by pQCD evolution (DGLAP) for $Q^2 < 15000$ GeV^2.

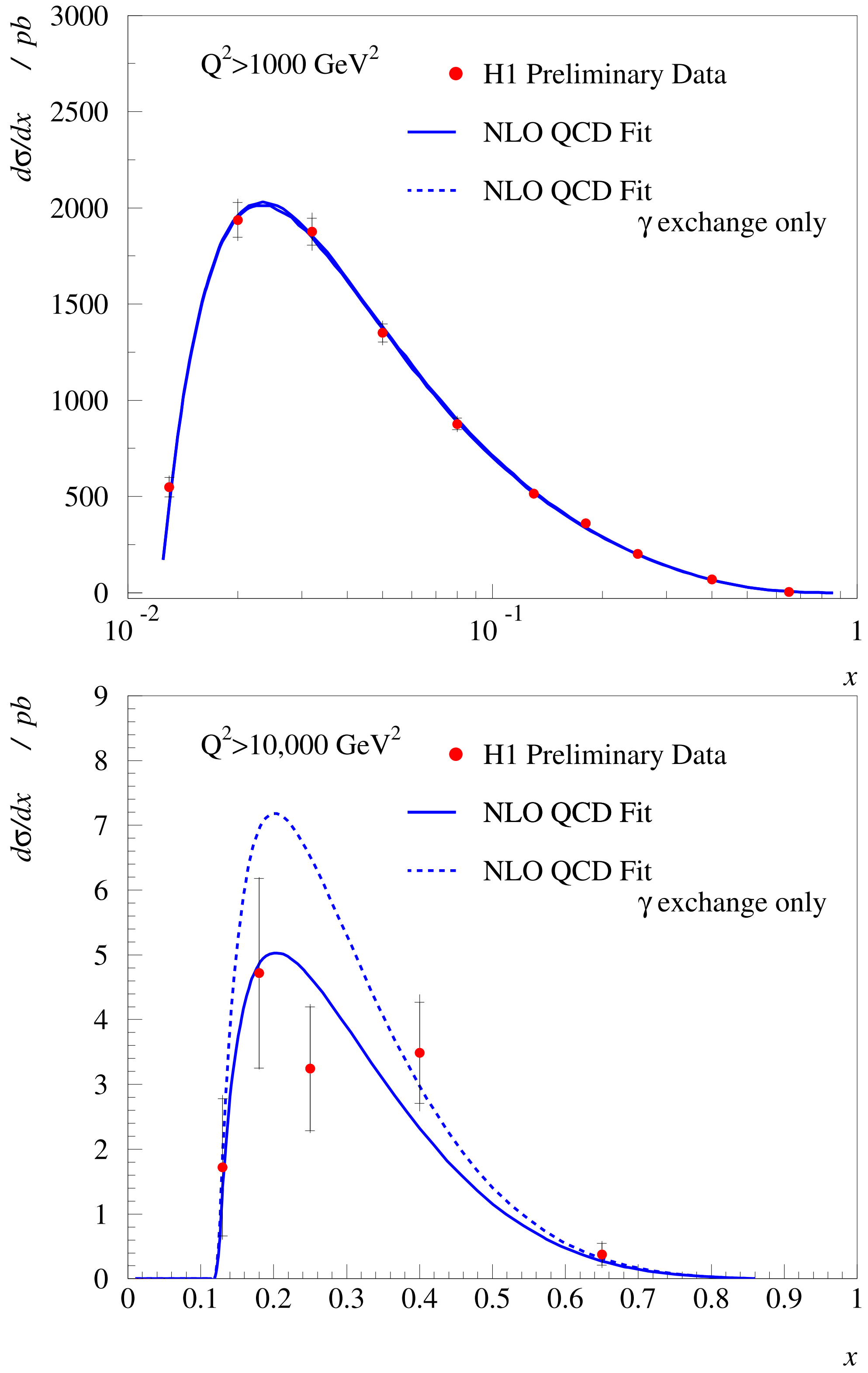
Reduced cross-section

$$\sigma(e^+p) = \frac{xQ^4}{2\pi\alpha^2}\frac{1}{1+(1-y)^2}\frac{d^2\sigma}{dx\,dQ^2}$$



We start to measure in the region sensitive to $\gamma - Z$ interference.

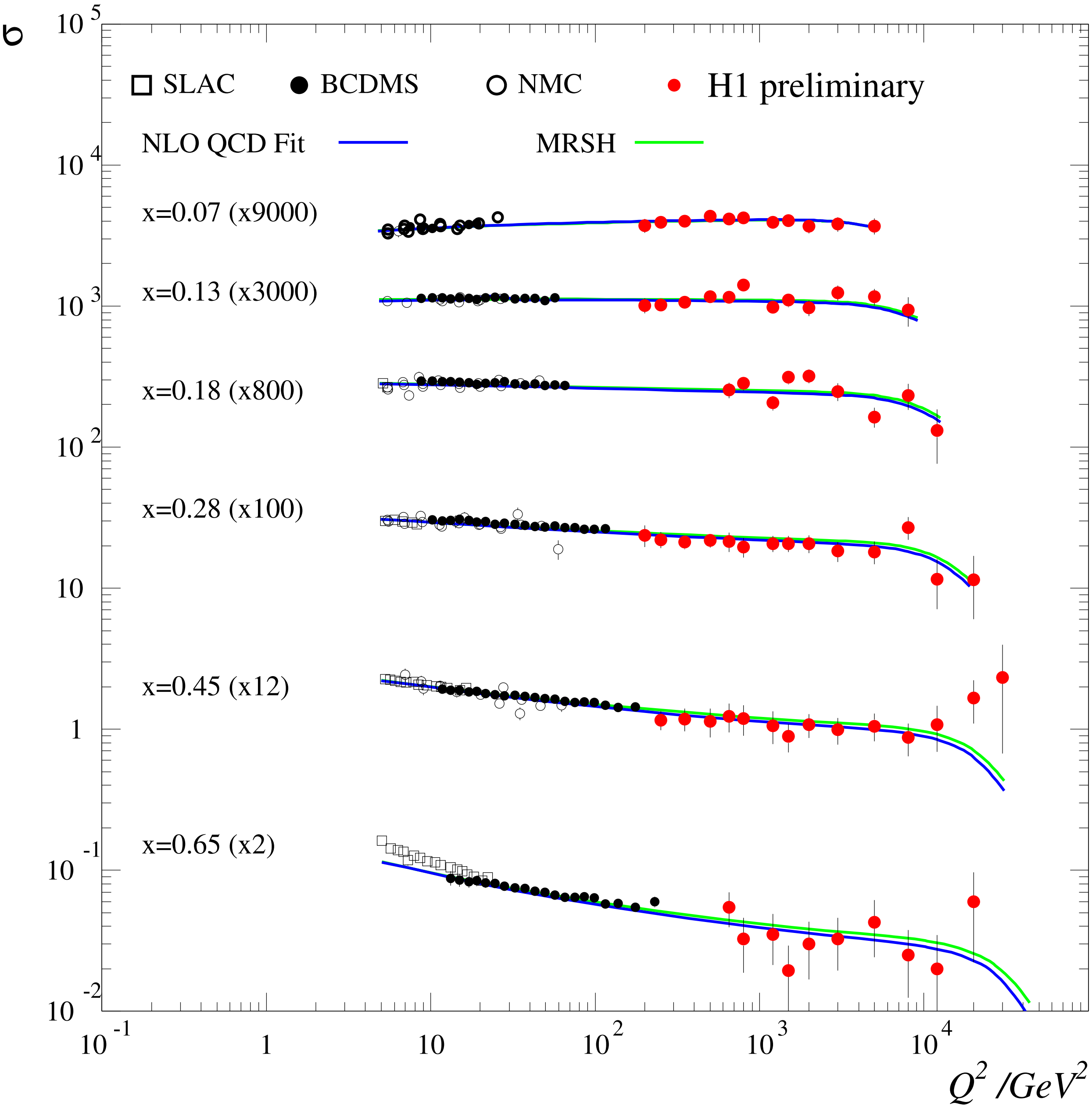
Integrated cross-section $\frac{d\sigma}{dx}$



The data significantly supports the EW (negative interference) contribution to e^+p data.

Reduced cross-section

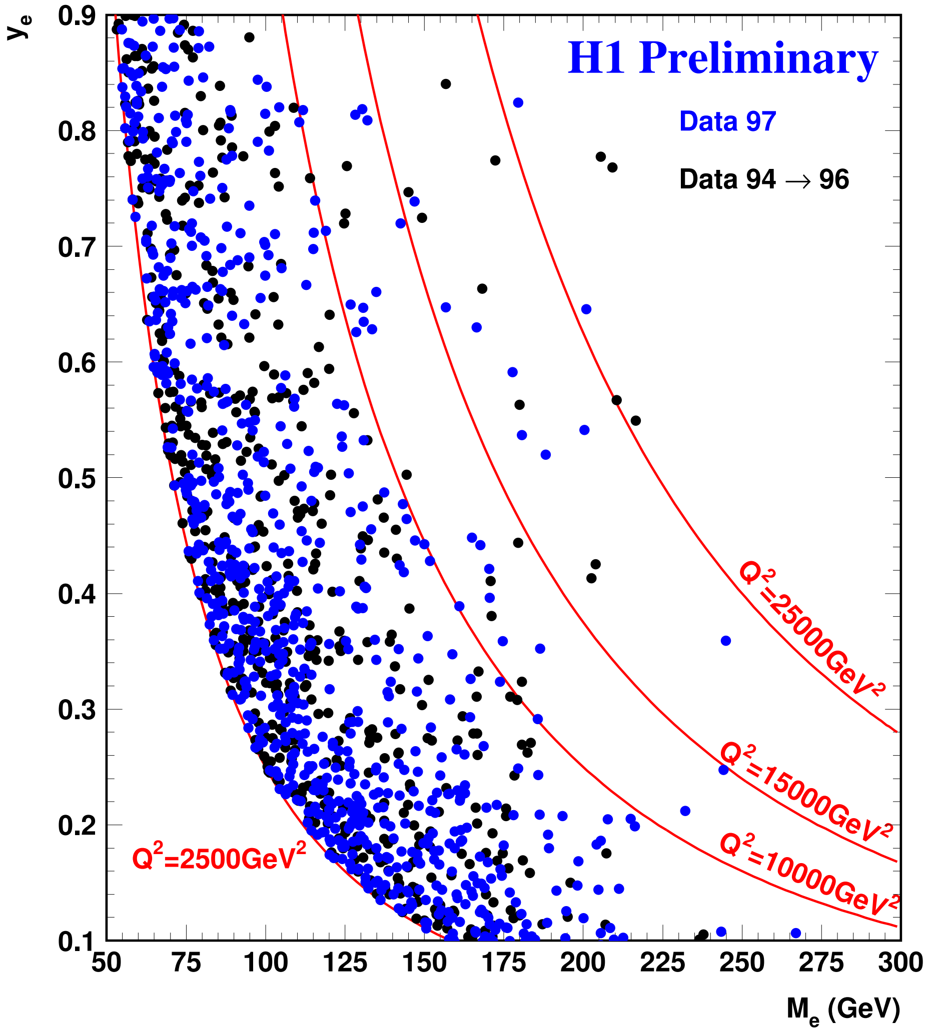
$$\sigma(e^+p) = \frac{xQ^4}{2\pi\alpha^2}\frac{1}{1+(1-y)^2}\frac{d^2\sigma}{dx\,dQ^2}$$



Including new H1 data at high Q^2 would pull the SM QCD fit further down compared to MRSH.

Excess at very high Q^2 and high x_{bj} ...

NC Data Sample in the M-y Plane



H1 NC candidates e-method $\mathcal{L} = 37.04 \pm 0.96\ \mathrm{pb}^{-1}$

$Q_e^2 > 5000\ \mathrm{GeV}^2$ $\qquad$ $0.1 < y_e < 0.9$

Obs. $= 322 \Leftrightarrow$ Exp. $= 336 \pm 29.6$

The acceptance has increased to more than 90% within the y-Q^2 range due to the new selection:

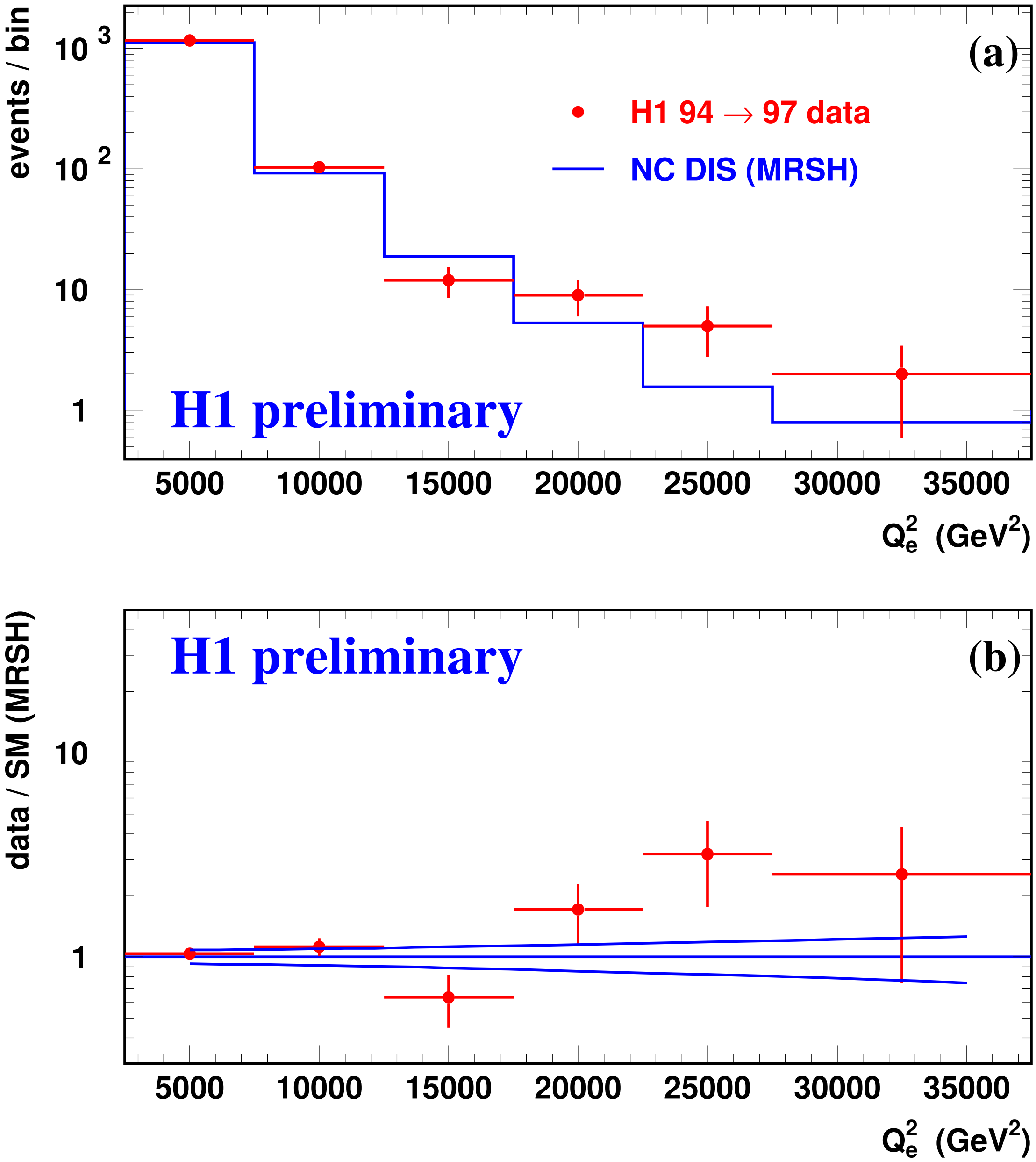
Energy-momenta Conservation:

$$40 < \sum E - P_z < 70\ \mathrm{GeV}$$

Kinematics:

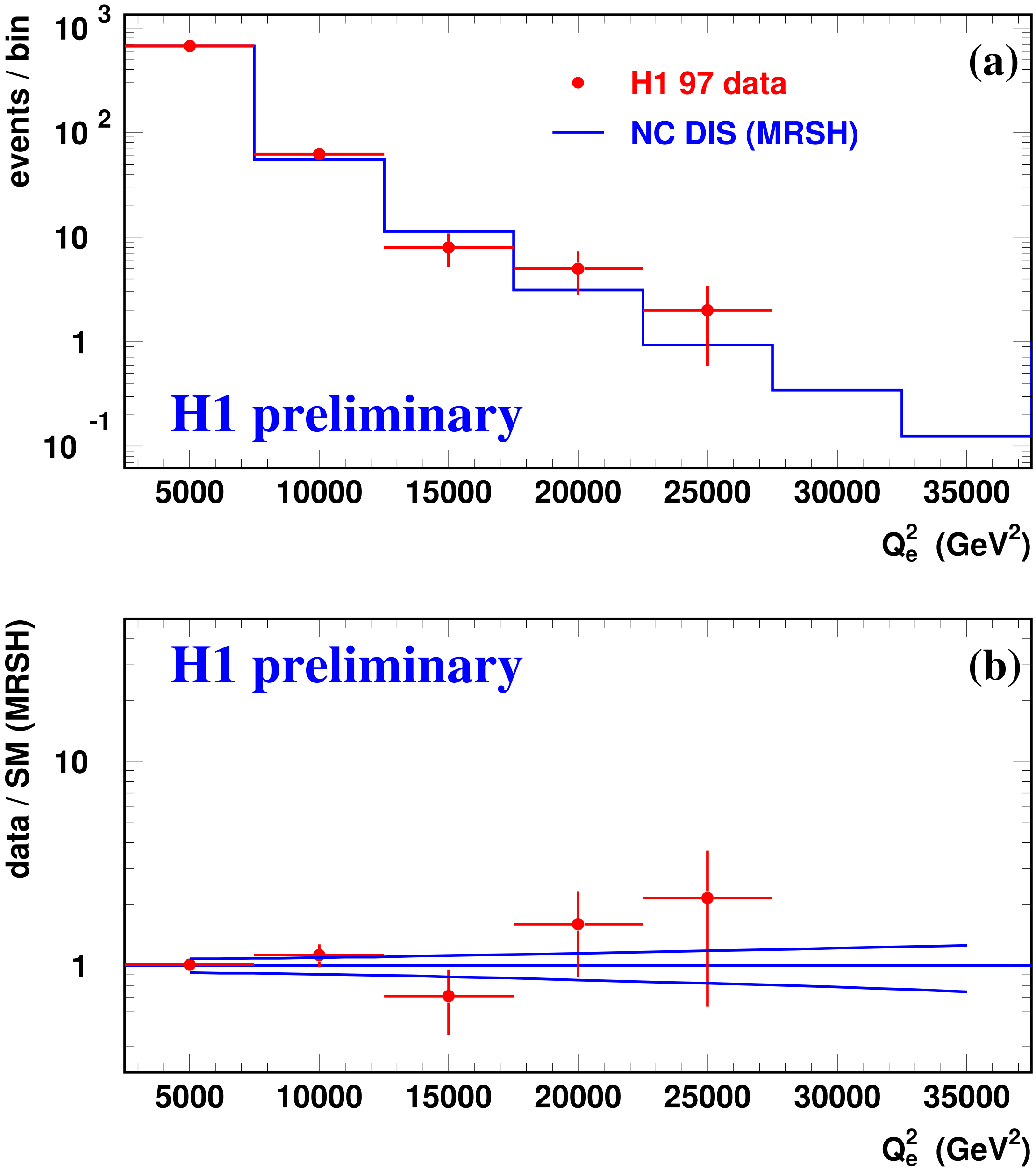
$\boxed{E_{T,e} > 15\ \mathrm{GeV}}$ $\boxed{0.1 < y_e < 0.9}$ $\boxed{Q_e^2 > 2500\ \mathrm{GeV}^2}$

Q^2 Dependence, 1994-97 Data



- Slight deviations from SM expectation observed for $Q_e^2 \gtrsim 15000$ GeV^2 ...
- Excess at highest Q_e^2 less significant than with 1994→96 data only

Q^2 Dependence, 1997 Data Only



- Good agreement with SM expectation for 1997 data
- Only marginal deviations observed for $Q_e^2 \gtrsim 15000$ GeV^2

Q^2 Integrals, e-method

1997 Data, H1 Preliminary						
Q^2_{min}/ GeV^2	2500	5000	10000	15000	20000	25000
N_{obs}	753	178	31	10	4	2
N_{DIS}	758 $\pm$57.9	199.7 $\pm$17.6	32.7 $\pm$3.8	8.77 $\pm$1.26	2.61 $\pm$0.43	0.94 $\pm$0.17
$\mathcal{P}(N \geq N_{obs.})$	53%	83%	59%	38%	27%	24%
All 1994-97 Data, H1 Preliminary						
Q^2_{min}/ GeV^2	2500	5000	10000	15000	20000	25000
N_{obs}	1297	322	51	22	10	6
N_{DIS}	1276 $\pm$98	336 $\pm$29.6	55.0 $\pm$6.42	14.8 $\pm$2.13	4.39 $\pm$0.73	1.58 $\pm$0.29
$\mathcal{P}(N \geq N_{obs.})$	42%	56%	60%	5.9%	1.8%	0.64%

Systematic errors dominate for every Q^2_{min}

- Significance of "anomaly" decrease including 1997 data
- Excess in integrated spectra at $Q^2 \gtrsim 15000$ GeV^2 remains

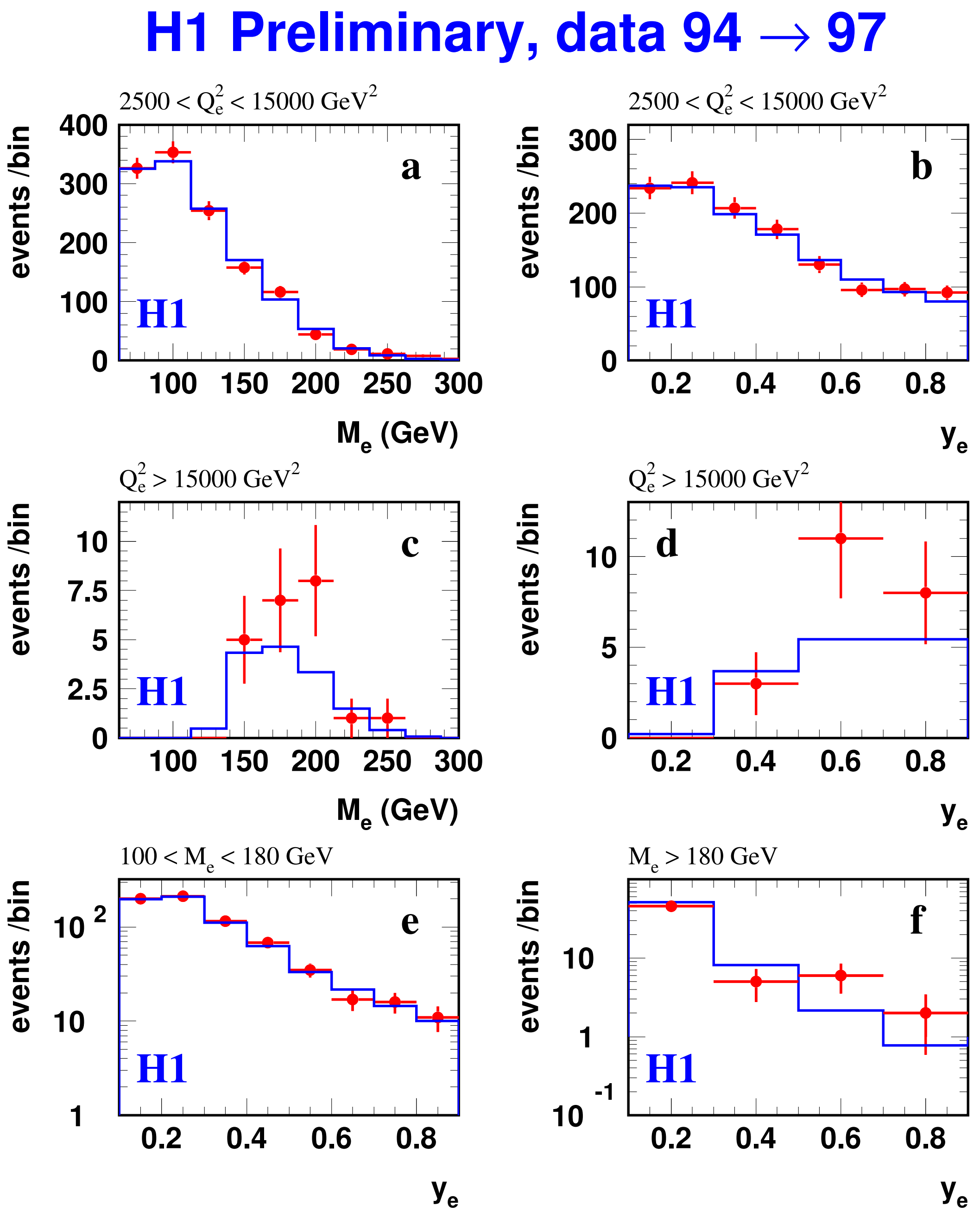
... but only **marginally** supported by 1997 data alone !

- Translation as cross-section corrected to Born level :

σ_{Born} within $(Q^2_0 > Q^2_{min}, y_0 < 0.9)$			
Q^2_{min}	SM (MRSH)	H1 EPS97	H1 Preliminary
5000	9.03	$8.86^{+1.02}_{-1.02}$	$8.69^{+0.77}_{-0.77}$
15000	0.38	$0.78^{+0.22}_{-0.20}$	$0.59^{+0.15}_{-0.13}$
25000	0.040	$0.210^{+0.112}_{-0.091}$	$0.168^{+0.083}_{-0.060}$

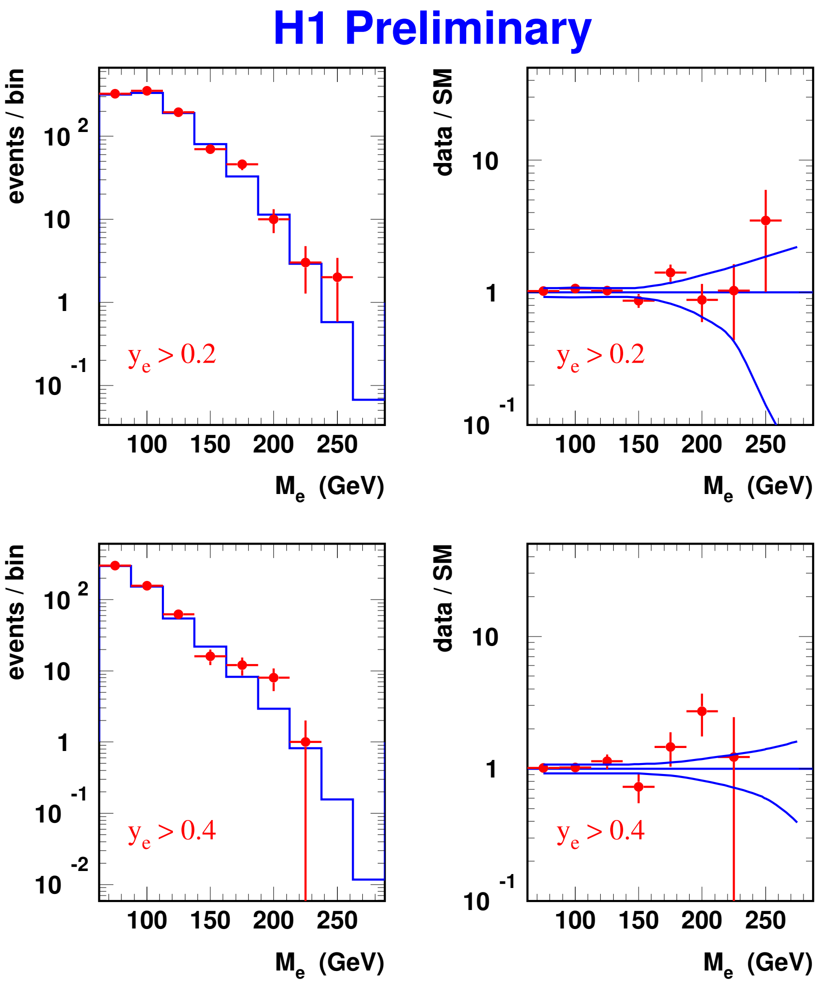
Improved acceptance (and statistics !) since ECHEP97

M and y spectra



- Slight excess remains at large Q^2 (or large M); mostly at large y
- Excess mainly due to 1994→96 data

NC events at Large Masses



Mass Windows at large y_e:

With the 1994-96 data alone (Z.Phys.C74(1997)191):

most significant deviation observed at masses $M_e = 200 \pm 12.5$ GeV:

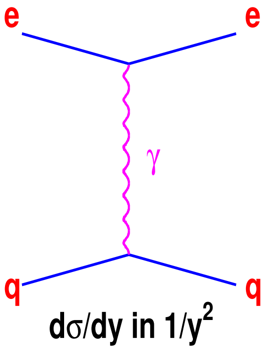
$$N_{obs} = 7 \text{ for } N_{exp} = 0.95 \pm 0.18$$

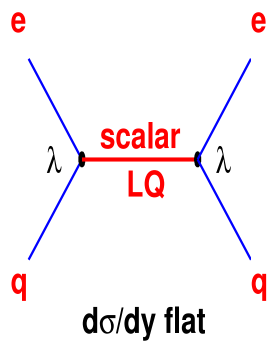
Including the 1997 data:

$$N_{obs} = 8 \text{ for } N_{exp} = 3.01 \pm 0.54 \text{ (new selection/calibration)}$$

- **The 1997 data alone does not confirm the observation of a "clustering" of events around $M_e \simeq 200$ GeV**

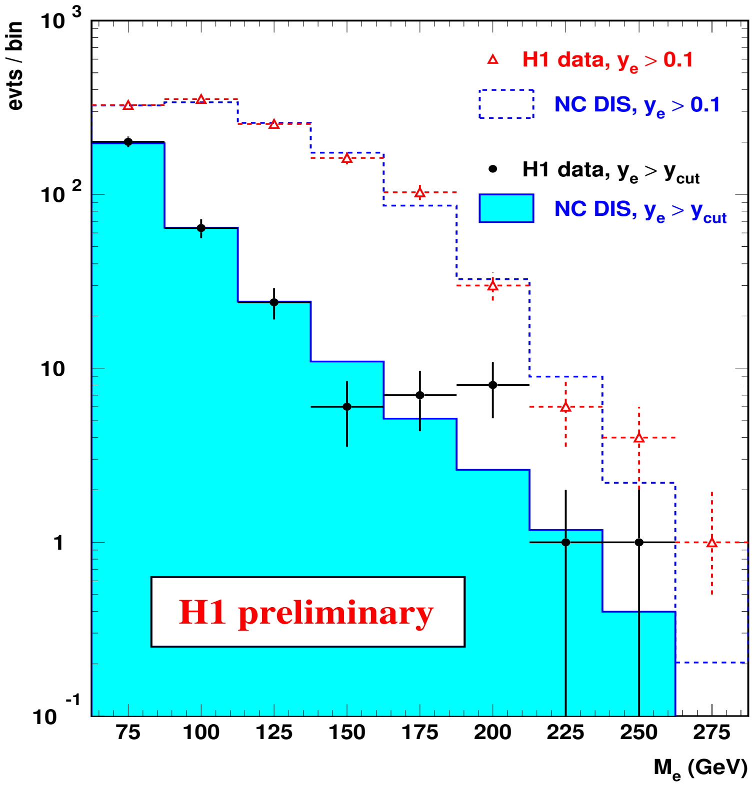
Setting Constraints for Leptoquarks





$\Longrightarrow$ optimized cut $y > y_{cut}$ which maximizes ratio signal / background

$y_{cut} \downarrow$ when $M_e \uparrow$ (e.g. $\simeq 0.4$ at $M_e \simeq 200$ GeV)



Mass spectrum for $y > y_{cut}$ used to constrain $\sigma(eq \to LQ \to eq)$

Parameters :

- LQ mass M_{LQ}
- Yukawa coupling λ

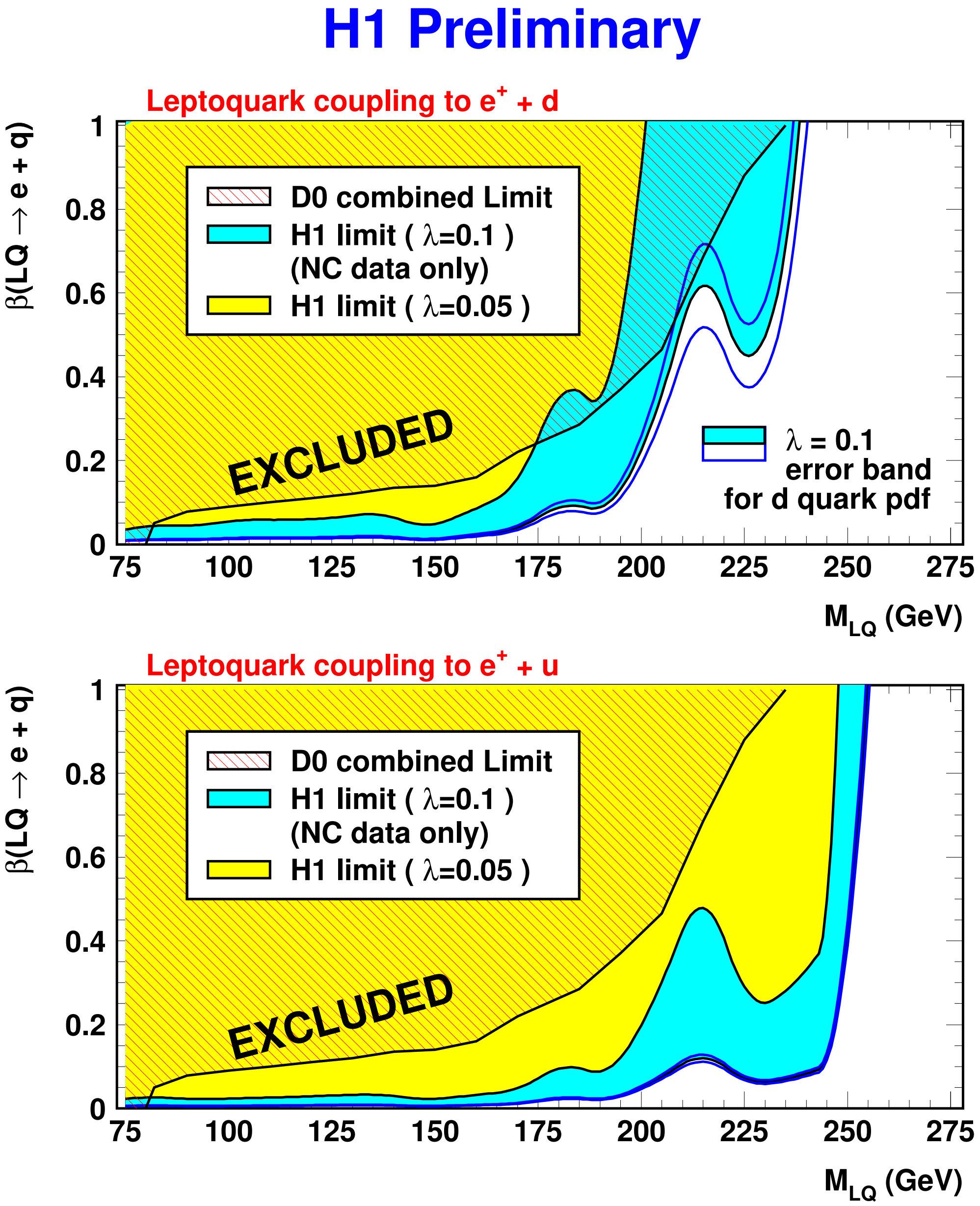
$(\sigma(eq \to LQ) \propto \lambda^2 \times q(x))$

- $\beta = BR(LQ \to eq)$

- either fix λ and set constraints in plane β versus M_{LQ}
- either constrain λ vs M_{LQ} in specific models (β known)

Method : sliding mass window procedure, Poisson statistics (H1 Collab., Phys. Lett. B369 (1996) 173.)

Constraints vs. β for Leptoquarks



Sensitivity drop on β for $M_{LQ} \simeq 210$ GeV :

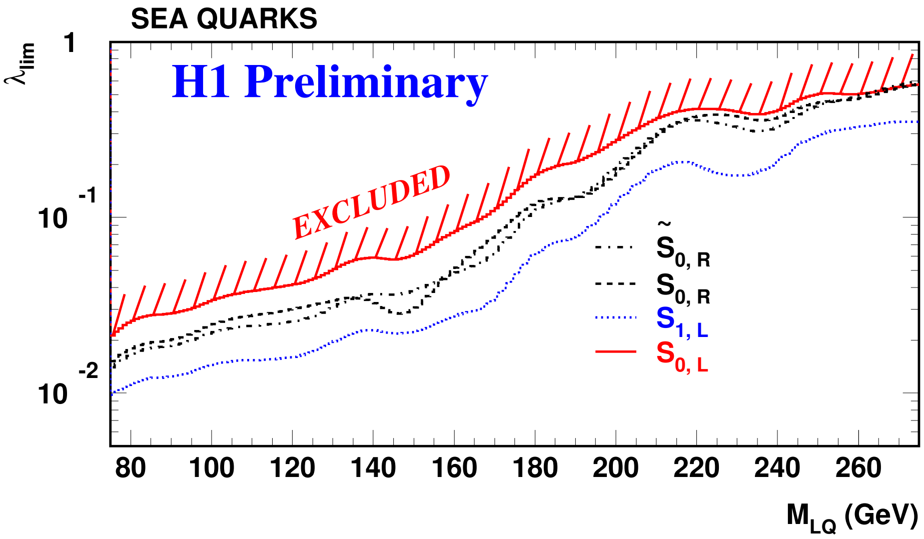
- new calibration $\Rightarrow \simeq +6$ GeV
- M_e underestimates M_{LQ} by $\simeq 4$ GeV

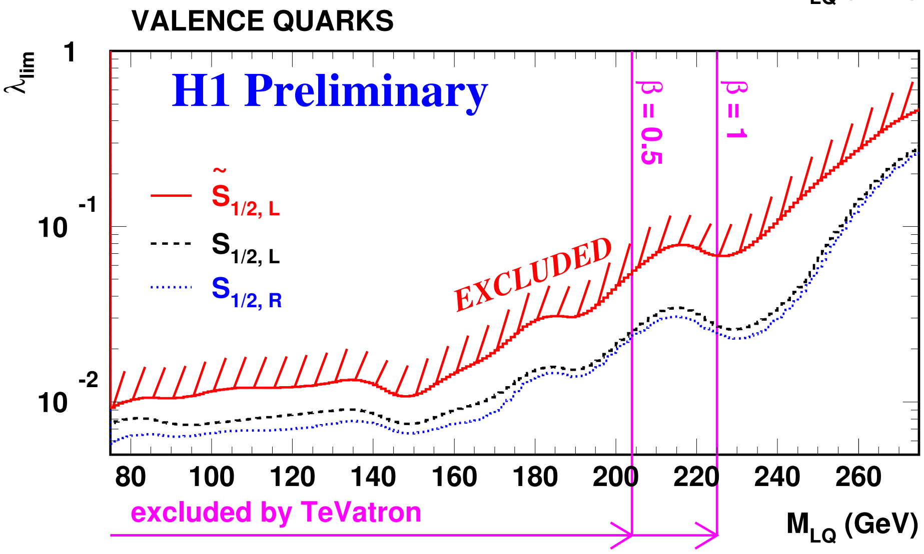
- Unexplored domain covered by H1, even for LQ coupling to e^+d
- Competition with TeVatron ($\lambda = 0.1$ corresponds to $\simeq 1/10 \times \alpha_{em}$)
- Still a high discovery potential at HERA, provided that $\beta << 1$.

Mass-Coupling Constraints for Leptoquarks

Constraints on a specific LQ model (Buchmüller/Wyler)

F=0 or 1 LQ $\rightarrow$ e + q, or ν + q, or both β=1 or 1/2 (pure chiral couplings)	$\Longrightarrow$	7 scalar LQ types



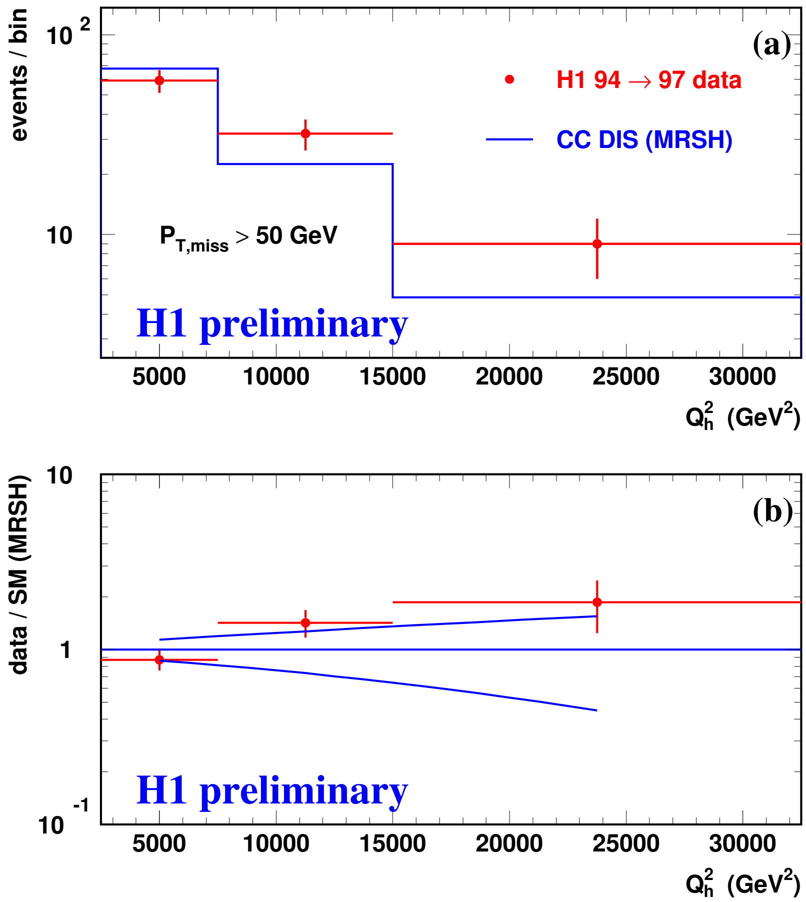


Stringent limits from TeVatron, BUT :

- For $\lambda \simeq \alpha_{em}$: $M_{LQ} > 275$ GeV at 95% C.L.
- Improvement by a factor $\simeq 3$ compared to earlier published results

Update of Charge Current Results

Q_h^2 Spectrum :



Q_h^2 Integrals:

CC DIS, 1994 - 97 Data, H1 Preliminary			
Q^2_{min}/ GeV^2	2500	7500	15000
N_{obs}	100	41	9
N_{DIS}	95.3 $\pm$16.7	27.6 $\pm$8.4	5.07 $\pm$2.8

- Systematic errors dominate for every Q^2_{min}
- Excess in integrated spectra for $Q^2 \gtrsim 7500$ GeV^2
  ... but compatible with SM within errors

Conclusion

- For the first time NC DIS cross-sections are measured:
  - at very high Q^2
  (where $\gamma - Z$ interference can no longer be neglected)
  - at high x_{Bj}
  (where the valence quarks dominate)
  The data are consistent with expectation of a suppression of the cross-section at high Q^2 due to $\gamma - Z$ interference;

- The magnitude of the excess at high Q^2 is reduced when adding 97 data;

- New constraints on Leptoquarks
  (improvement of a factor 3 compared to earlier H1 publication);

- HERA has still a good potential discovery for Leptoquarks !