New High Q^2 Results in ep Collisions at HERA

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for the
H1 and ZEUS Collaborations

Initial Results: Z.Phys.C74(1997), 191,
Z.Phys.C74(1997), 207

Update (94-97): L(H1) = 23.7 pb^{-1},
L(ZEUS) = 33.5 pb^{-1}

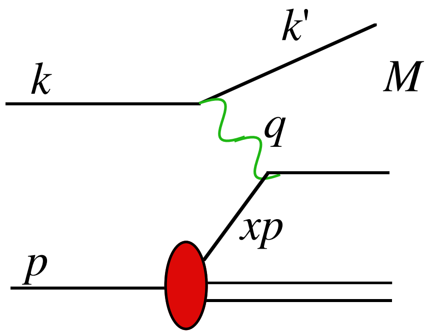
- Introduction
- add: W-Processes
- The Standard DIS Model
- σ_{DIS} in ep Collisions
- Events at High Q^2
- Conclusions

Introduction

HERA:

ep collider

E_p = 820 GeV
E_e = 27.6 GeV



$$s = (k + p)^2$$

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

$$M = \sqrt{sx} = \sqrt{\frac{Q^2}{y}}$$

$$y = \frac{pq}{pk}$$

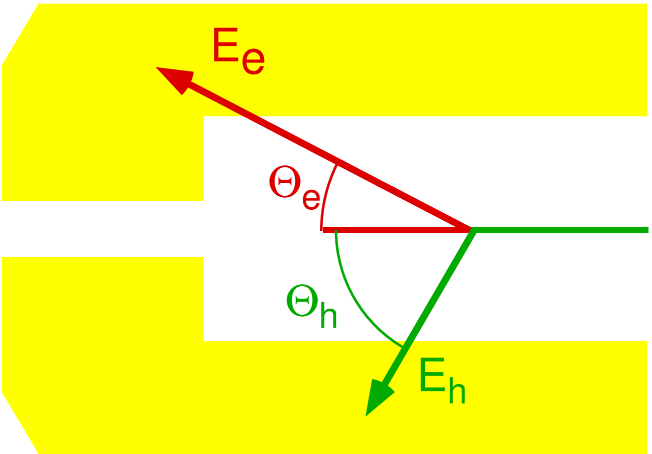
$$y = \frac{1 + \cos\theta^*}{2}$$

is probing the proton at distances down to 10^{-16} cm

- *t*-channel exchange of a highly virtual gauge boson
- *s*-channel resonant production of leptoquarks, squarks, …

⇒ study interaction at highest Q^2.

Remark on Kinematics



Measure (at least) four independent kinematic quantities when two are sufficient to describe the final state (at fixed s):

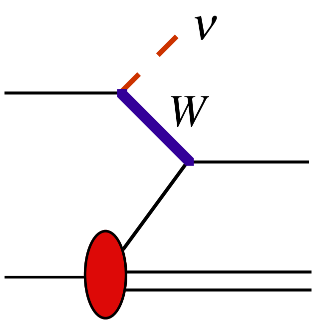
E_e, Θ_e, E_h and Θ_h

Options:

E_e, Θ_e:	e-method, classic DIS
E_h, Θ_h:	purely hadronic (Charged Current)
Θ_e, Θ_h:	double angle method (DA-method), energy scale independent
…	

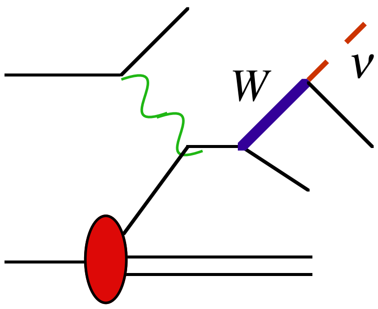
H1	e-method
ZEUS	DA-method

W-Processes

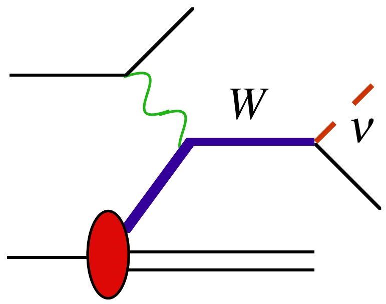


t-channel exchange
in Charged Current
Processes

$\sigma \approx 20$ pb



… + …



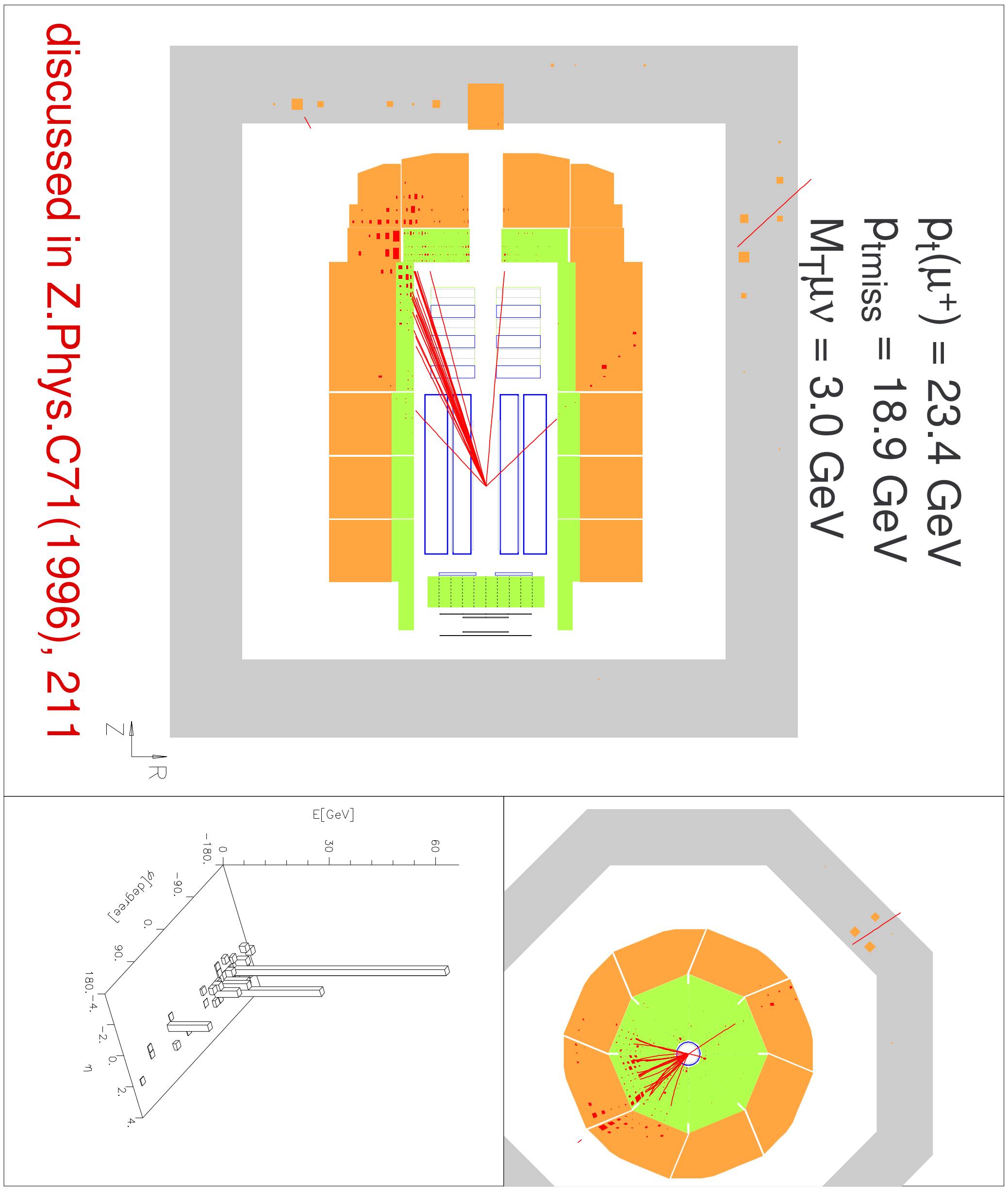
Production of real (and virtual) W
with subsequent leptonic decay

$\sigma \approx 70$ fb

Processes characterized by large missing
momentum in either production or decay.

The first

high p_{tmiss} μ^+ Event



"W"-Selection

Require

- p_{trans}(Calorimeter) > 25 GeV
- CC selection and background filters

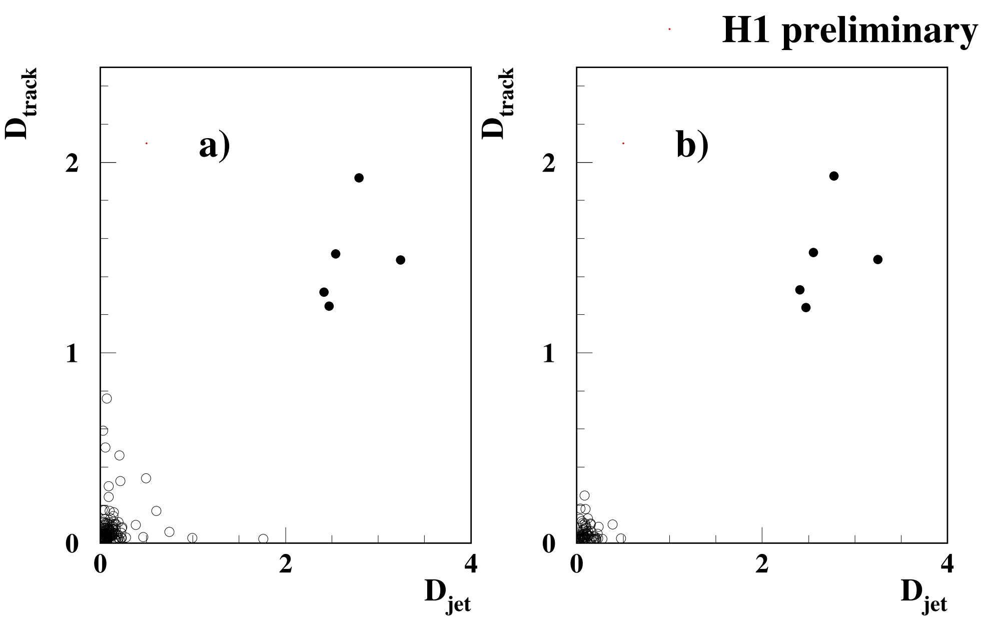
  ➢ 336 events
- isolated charged particle p_{trans} > 10 GeV

Find

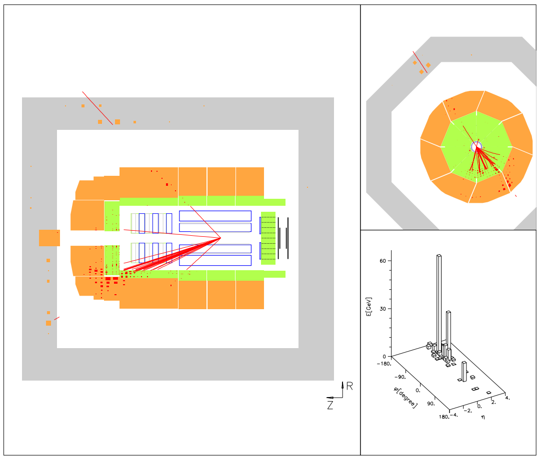
- 2 μ^+, 2 μ^-, 1 e^- candidates (no e^+)

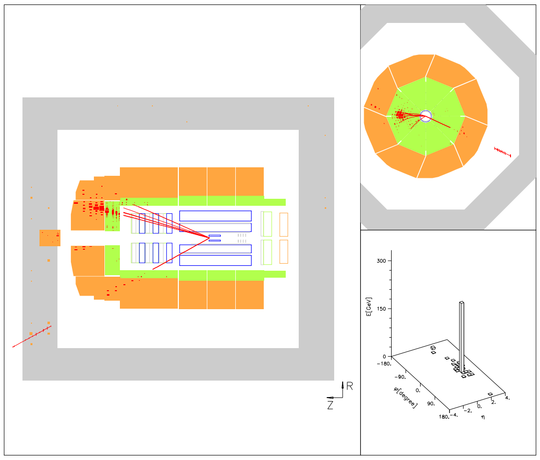
High p_t track Isolation (distance in η–ϕ space)

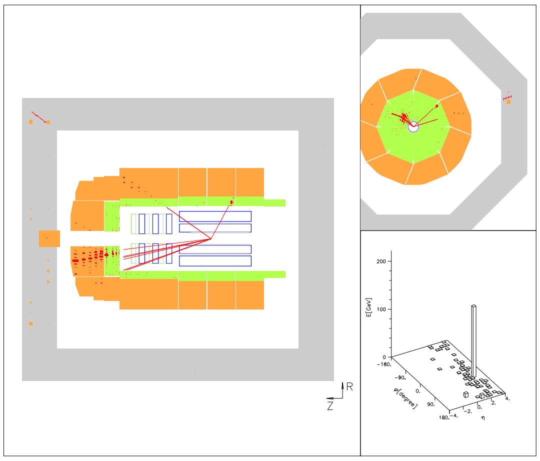
All events Lepton candidates

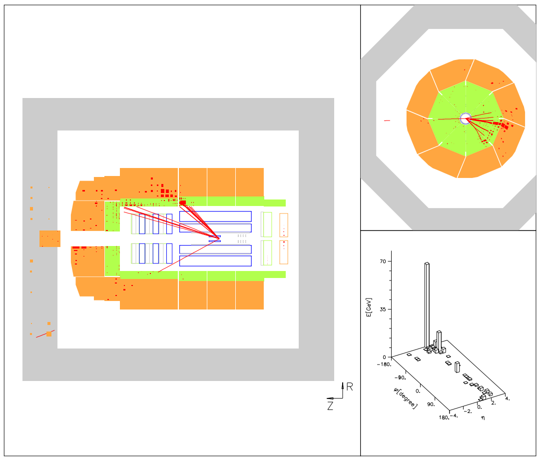


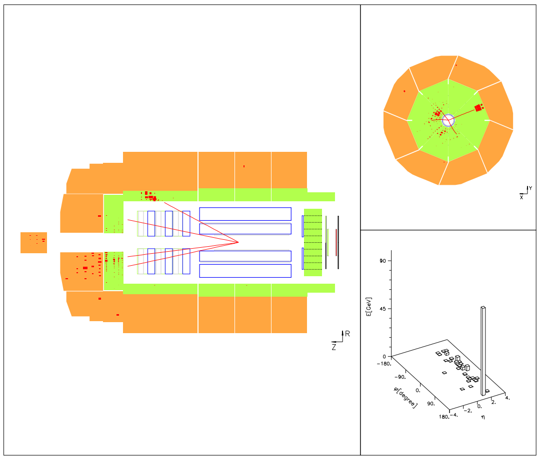
Large p_{tmiss} Events with Leptons











μ^+ μ^+

μ^- μ^-

e^-

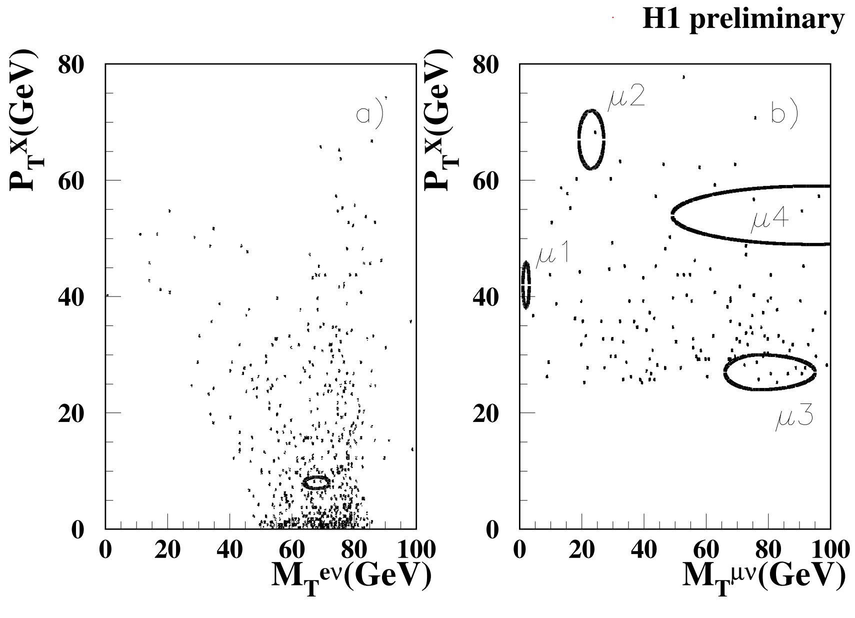
Kinematics of the

5 high p_{tmiss} Lepton Events

Expect:

- small p_t hadronic
- Jacobian peak in $M_T(l\nu)$

e L(MC) = 500 L(H1) μ

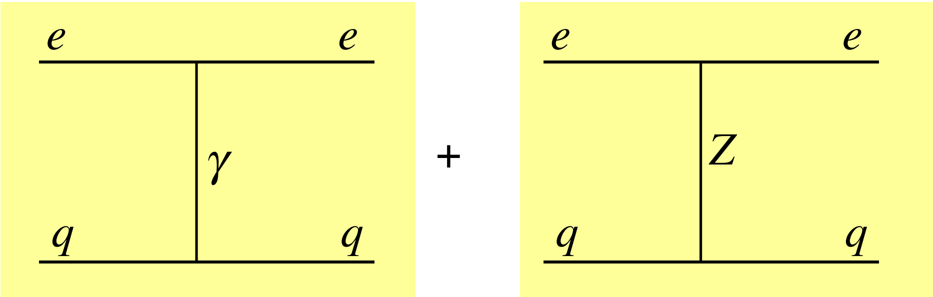


	Events see	Expectation for W Production	
e	1	1.34 ±0.20	
μ	4	0.41 ±0.07	
	(2	0.02 ±0.003	p_t>40 GeV, $M_T(l\nu)$<30 GeV)
		<0.05	backgrounds γp, HQ, $\tau^+\tau^-$,…

Deep-Inelastic Scattering

Cross Sections

Neutral Currents (NC)

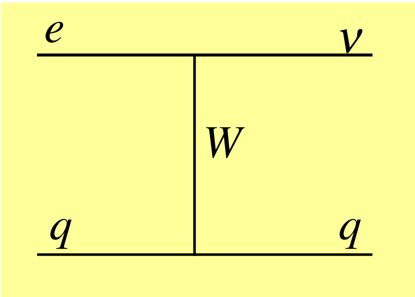


$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}x\,\mathrm{d}Q^2} = \frac{2\pi\alpha^2}{xQ^4}\left[Y_+F_2(x,Q^2) + Y_-xF_3(x,Q^2)\right]$$

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

F_i contain the dependence on the structure of the proton, the propagator terms and the electroweak couplings.

Charged Currents (CC)

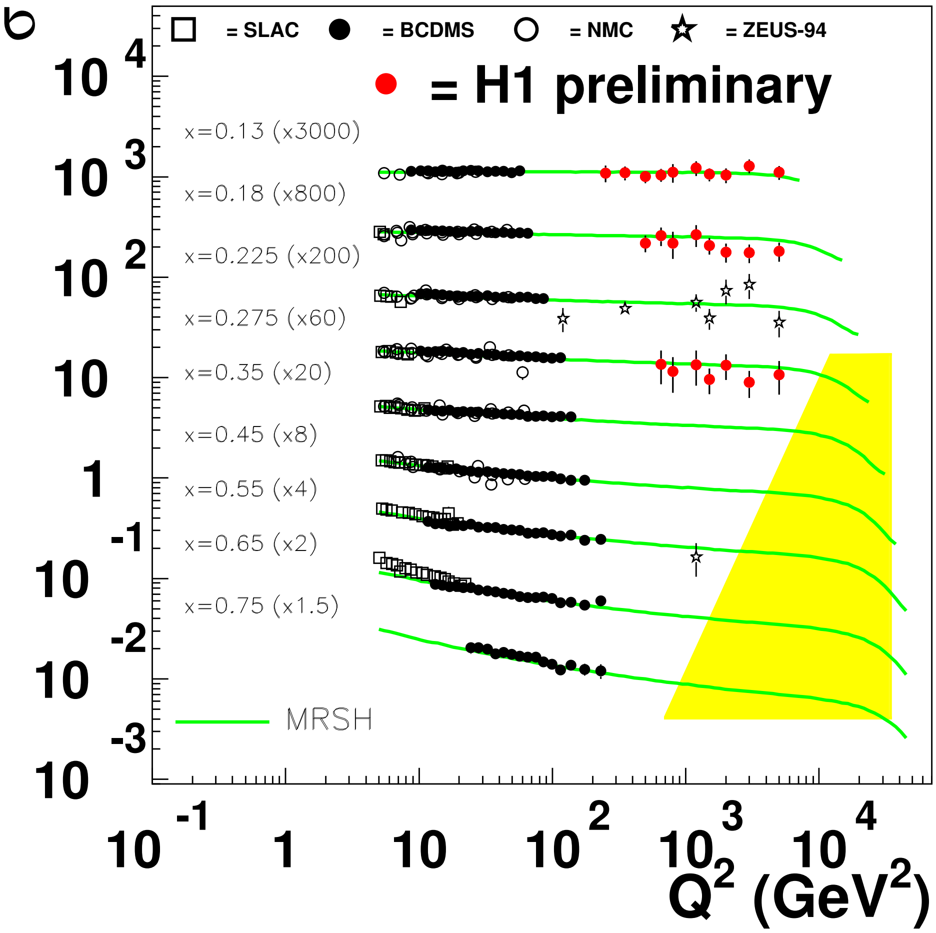


purely weak current.

The Proton Structure –

Reduced Cross Sections

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

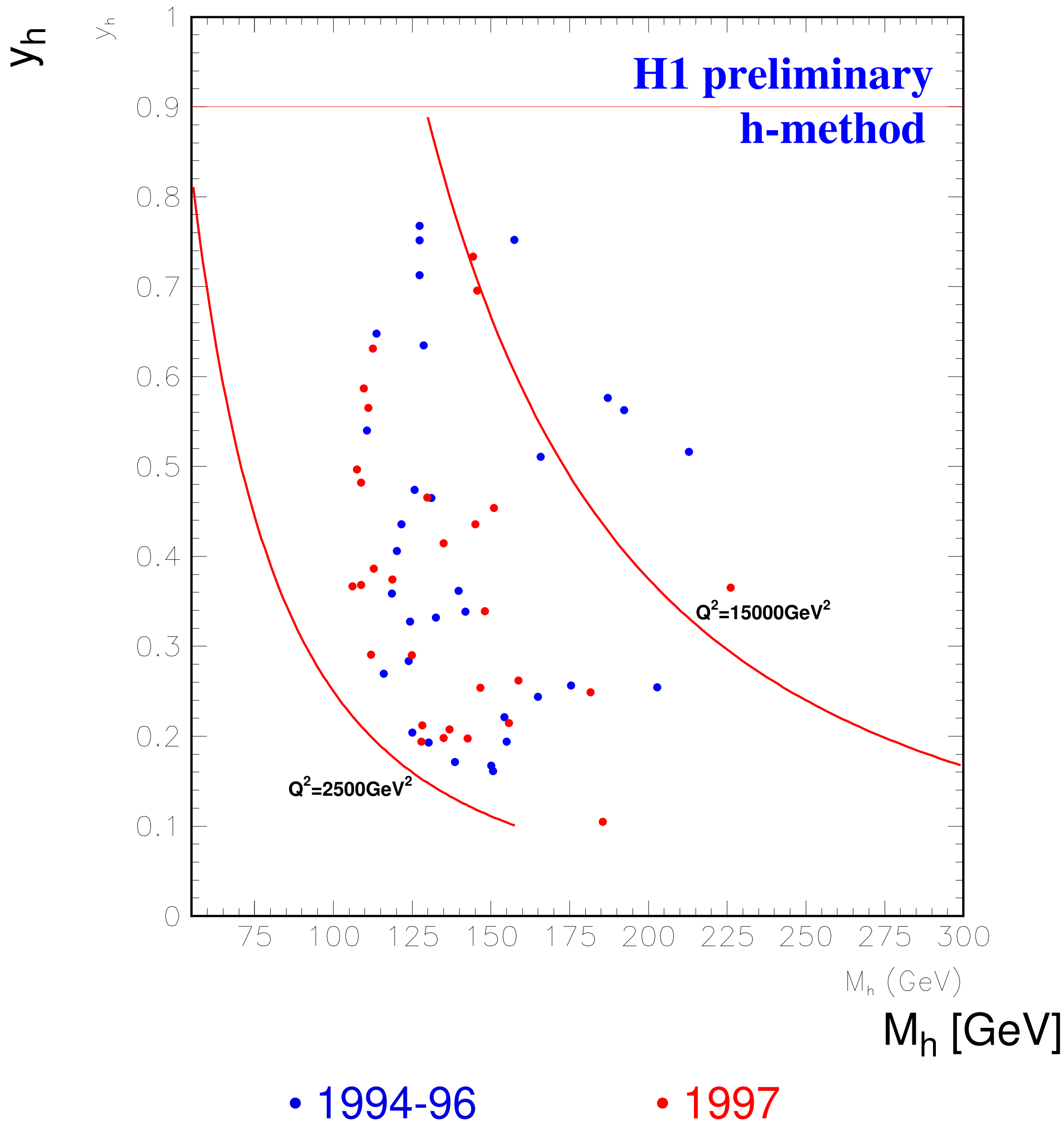


Region now examined in detail

QCD Extrapolation well constrained by low Q^2 data (<6.5%) and low x, high Q^2 data of HERA.

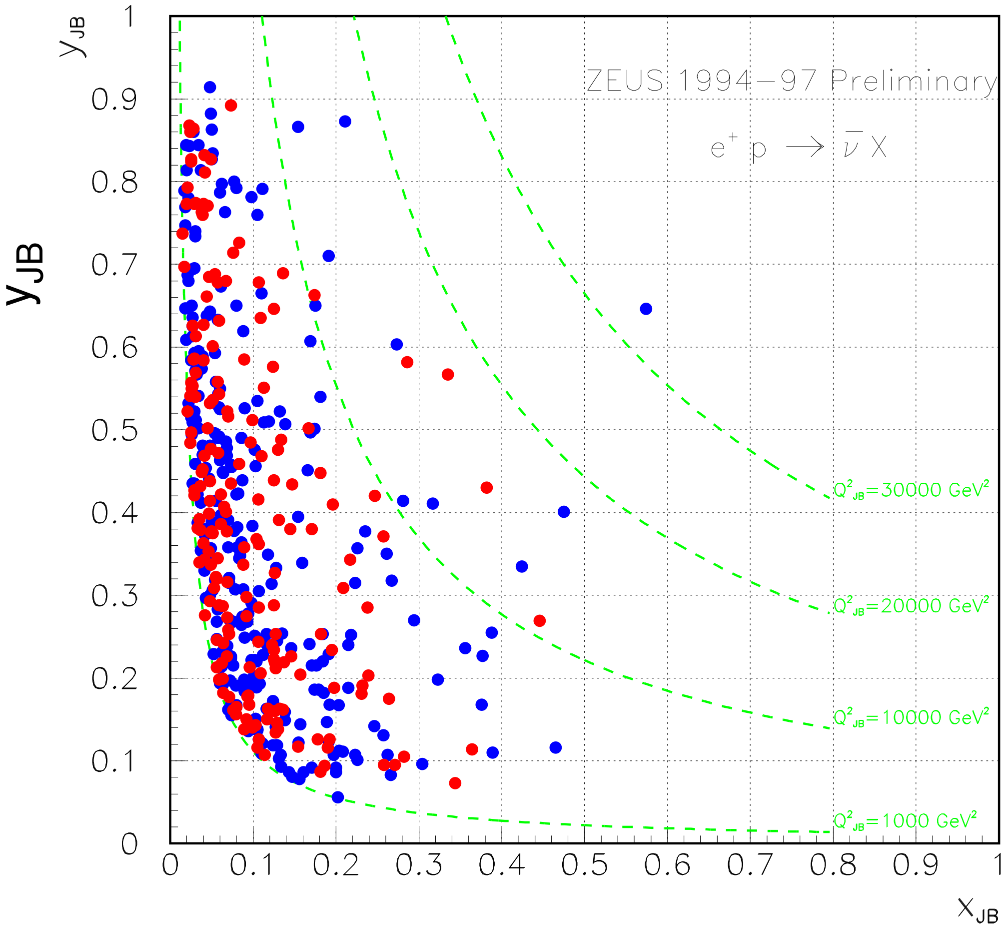
H1 CC

y-M plane



ZEUS CC

y-x plane

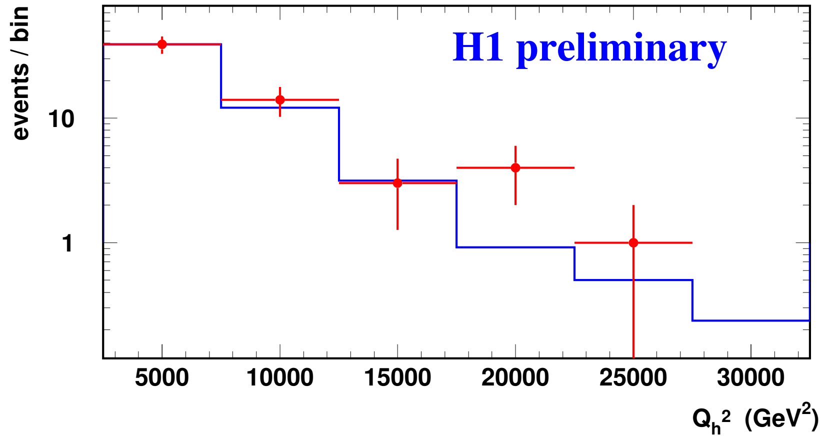


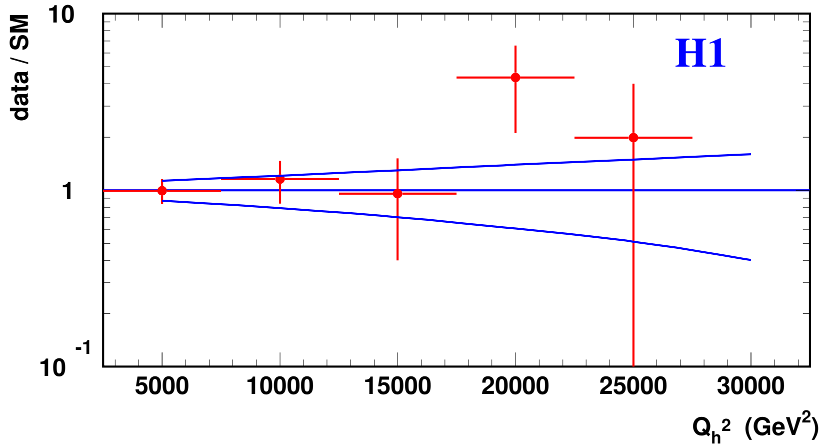
x_{JB}

• 1994-96 • 1997

H1 CC

Q^2 Distribution

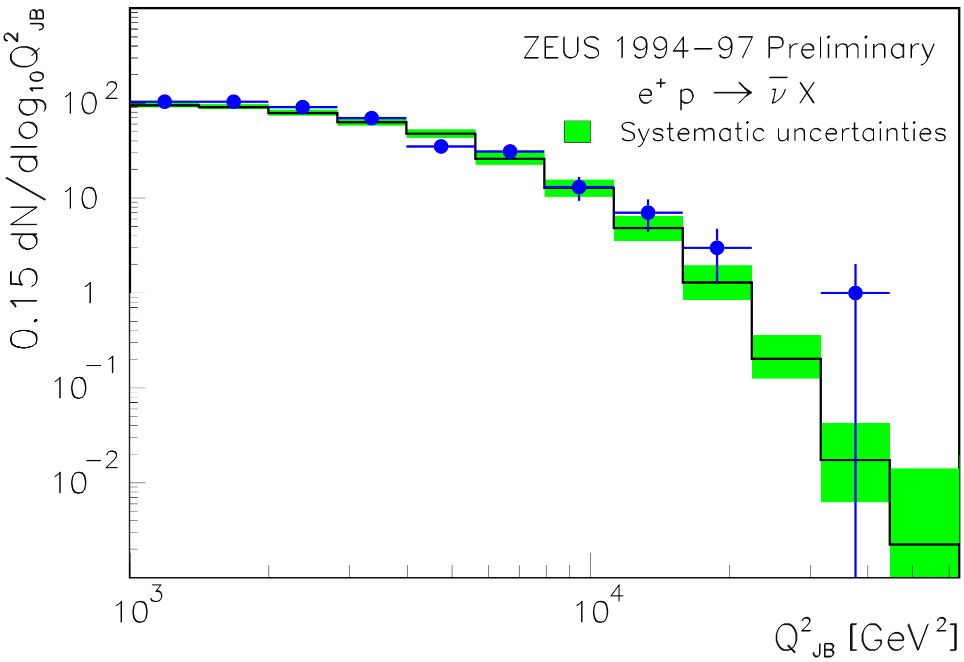




Q^2_{min}	Nobs	Nexp
2500	61	56.30±9.40
5000	42	34.70±6.90
10000	14	8.33±3.10
15000	6	2.92±1.44
20000	3	1.21±0.64

ZEUS CC

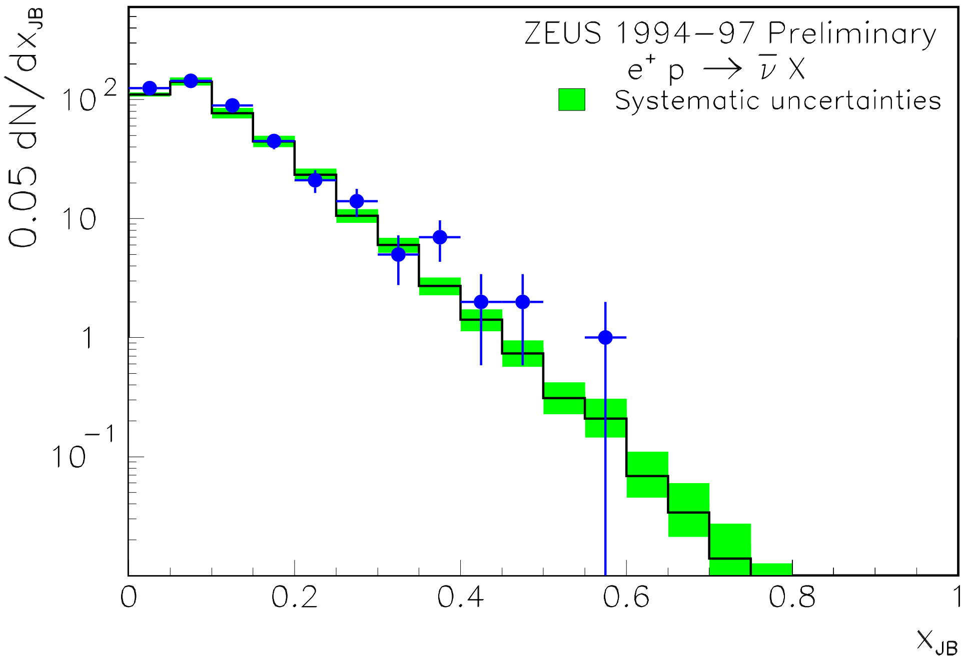
Q^2 Distribution



			Uncertainty	
Q^2_{min}	Nobs	Nexp	EScale	PDF
1000	455	419	13	33
10000	15	9.4	2.5	1.6
15000	5	2.0	+0.81−0.54	0.4
20000	1	0.46	+0.28−0.16	0.10
30000	1	0.034	+0.037−0.016	0.008

ZEUS CC

x Distribution



			Uncertainty	
$x_{jb,min}$	Nobs	Nexp	EScale	PDF
0.1	186	167	8.5	16
0.2	52	45.5	5.0	4.6
0.3	17	11.5	1.9	1.1
0.4	5	2.8	0.6	0.3
0.5	1	0.65	0.2	0.1

Summary

Large p_{tmiss} - Processes

- See 5 events with isolated leptons:

  1 e^-, expect 1.34±0.20 and

  4 $\mu^\pm$, expect 0.41±0.07 events from W-production.

  2 events populate the favoured region of phase space. The backgrounds are small.

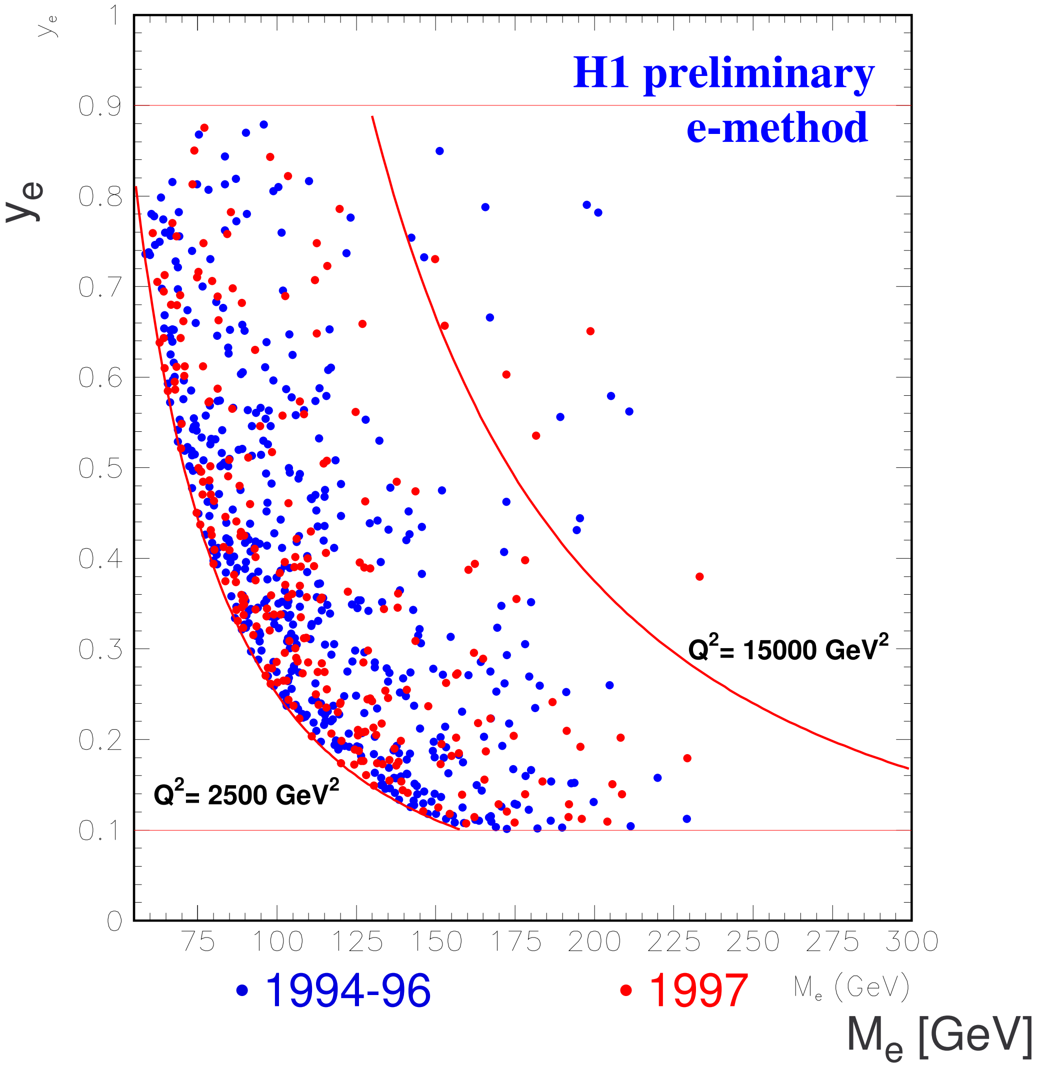
- Data exceed Standard Model DIS expectations for CC at large Q^2.

  For $Q^2 > 10000$ GeV^2 H1 and ZEUS see 29 events where 17.7±4.3 events are expected.

- The uncertainty in the Q^2 reconstruction becomes large at large Q^2 and large y.

H1

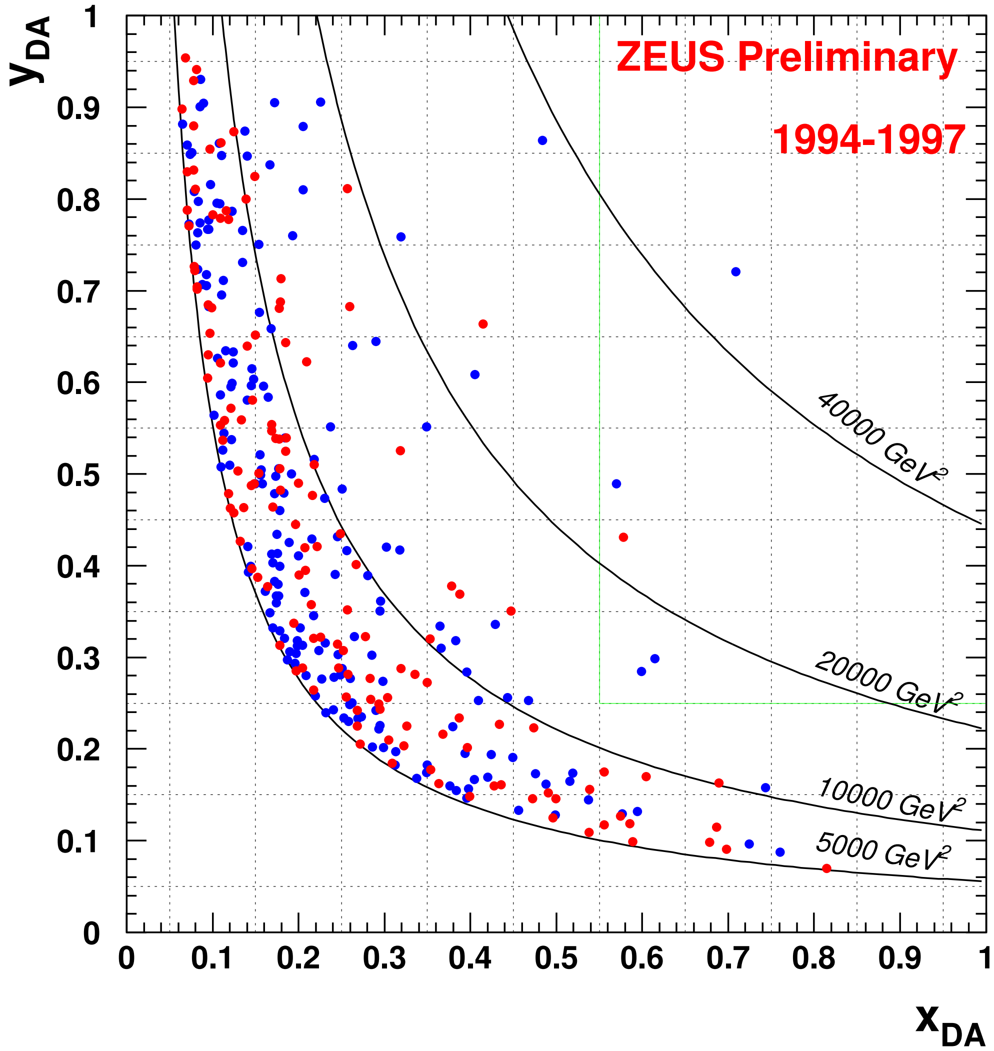
NC M-y plane



Region	Events	Expectation
Q^2>2500	724	714±69
Q^2>15000	18	8.0±1.2

ZEUS

NC x-y plane



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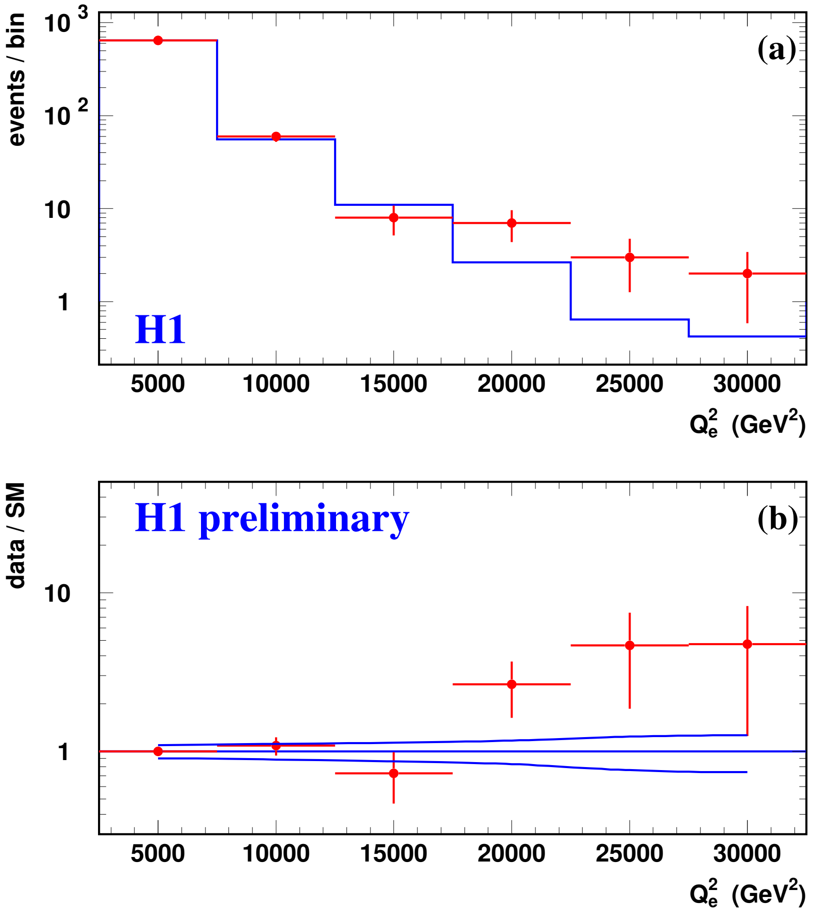
Region	Events	Expectation
$Q^2>5000$	326	328±15
$Q^2>35000$	2	0.242±0.017

H1

NC Q^2 Dependence

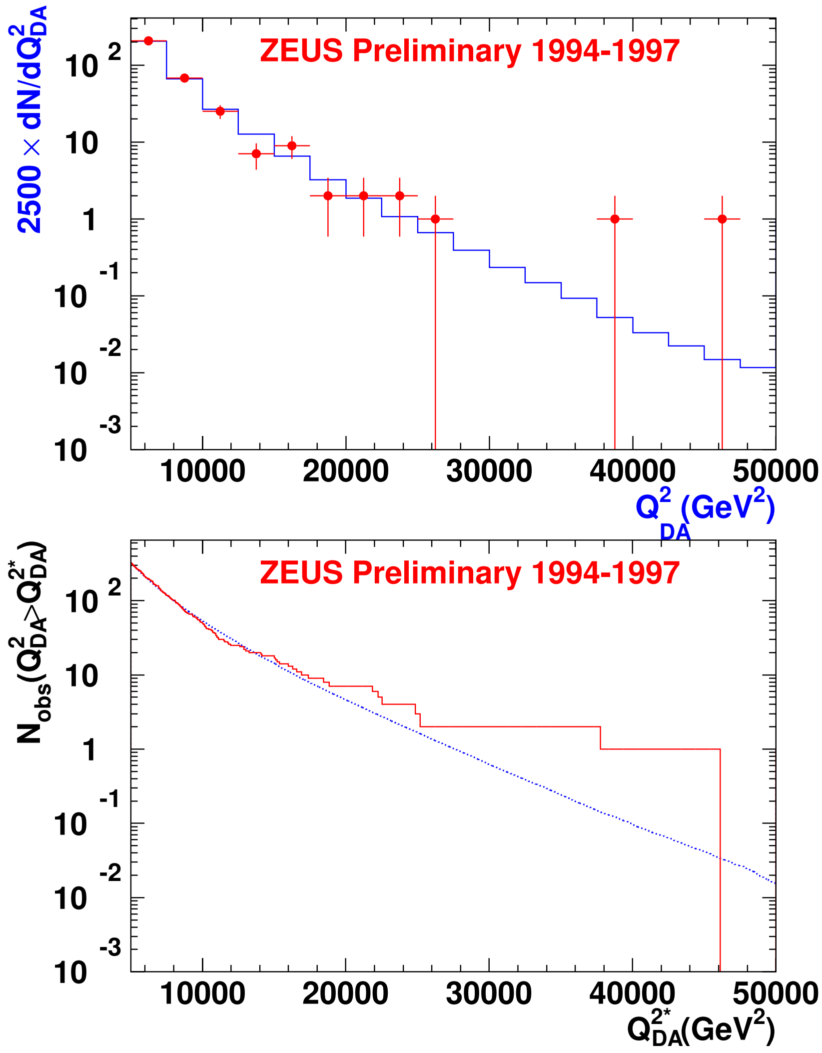


For Q^2_e>15000 GeV^2

See 18, expect 8.00±1.16, P=3.4×10^{-3}

ZEUS

NC Q^2 Dependence

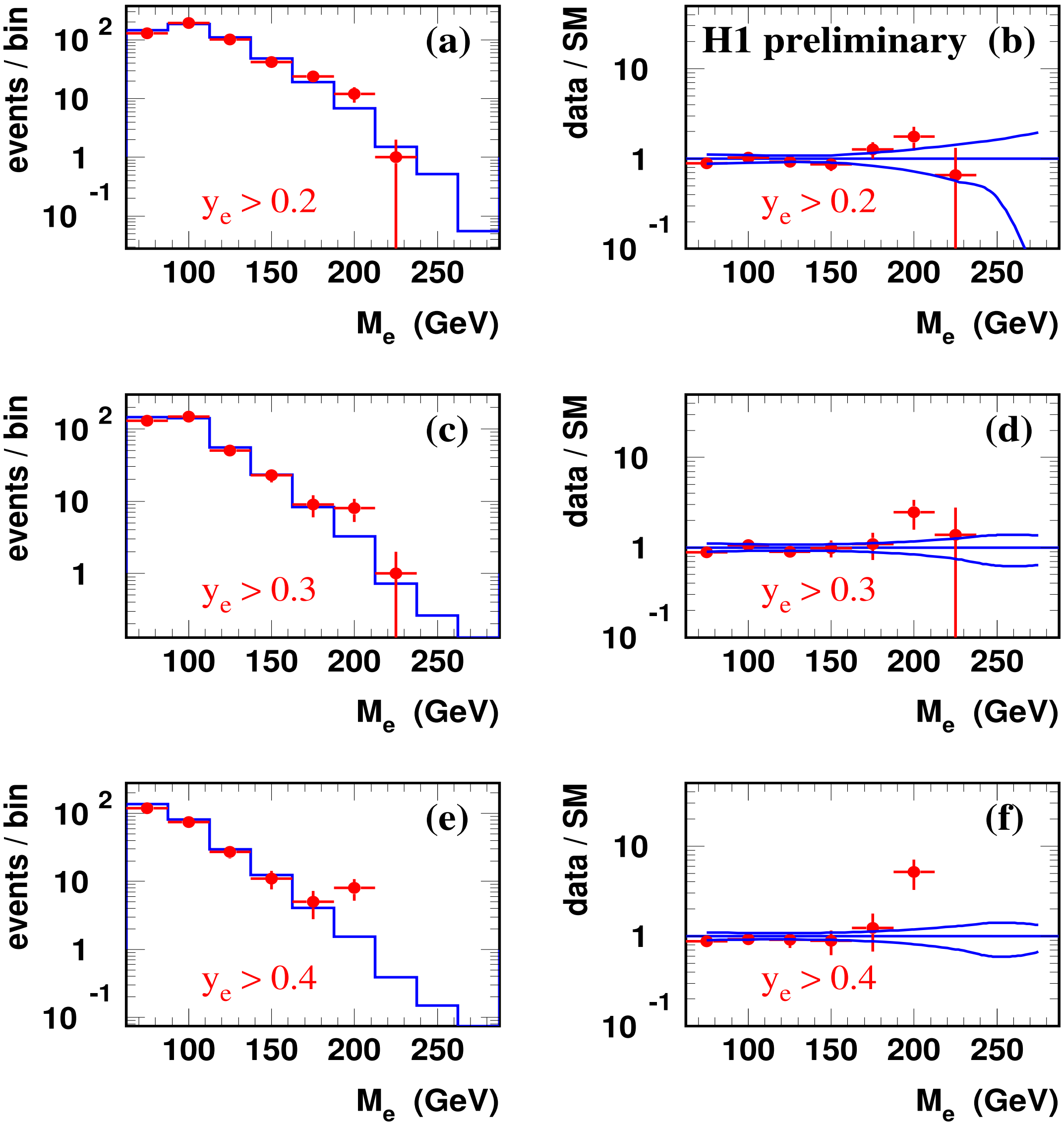


For Q^2_{DA}>35000 GeV^2

See 2, expect 0.24±0.02, P=2.5×10^{-2}

H1

M_e at large y

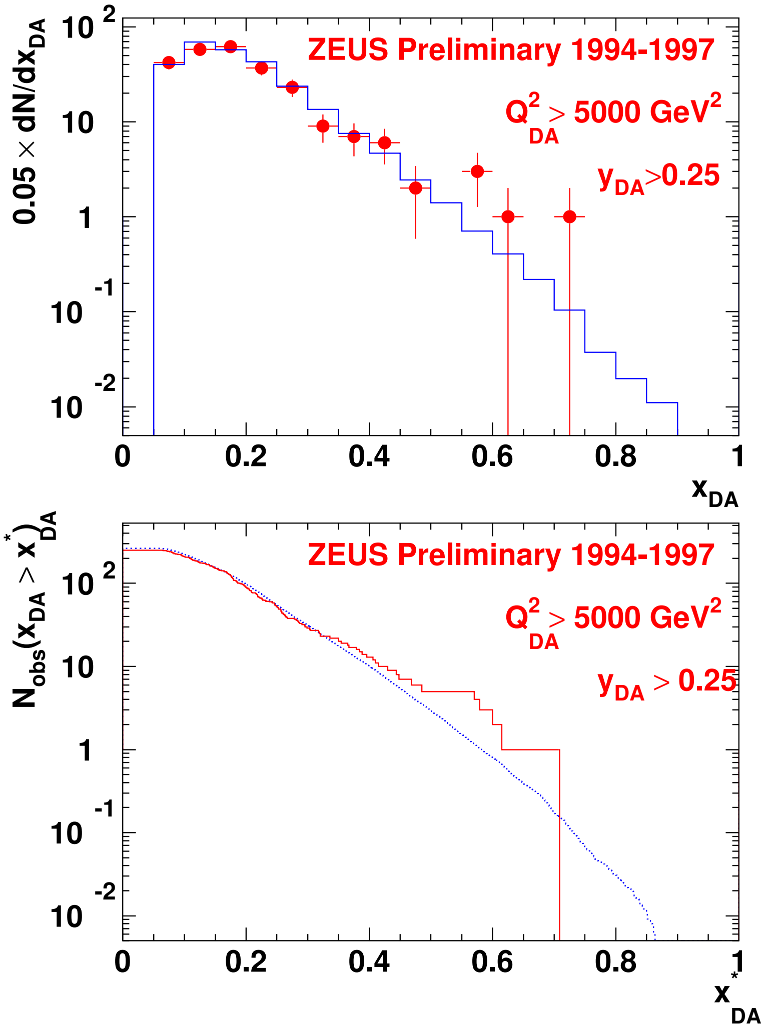


For $187.5 < M_e < 212.5$

See 8, expect 1.53±0.29. $P = 3.3\times10^{-4}$
Probability to see such an excess anywhere in some M_e window is ≈1%.

ZEUS

x_{DA} at large y_{DA}



For $x_{DA}>0.55$ and $y_{DA}>0.25$
See 5, expect 1.51 ± 0.13, P=0.019

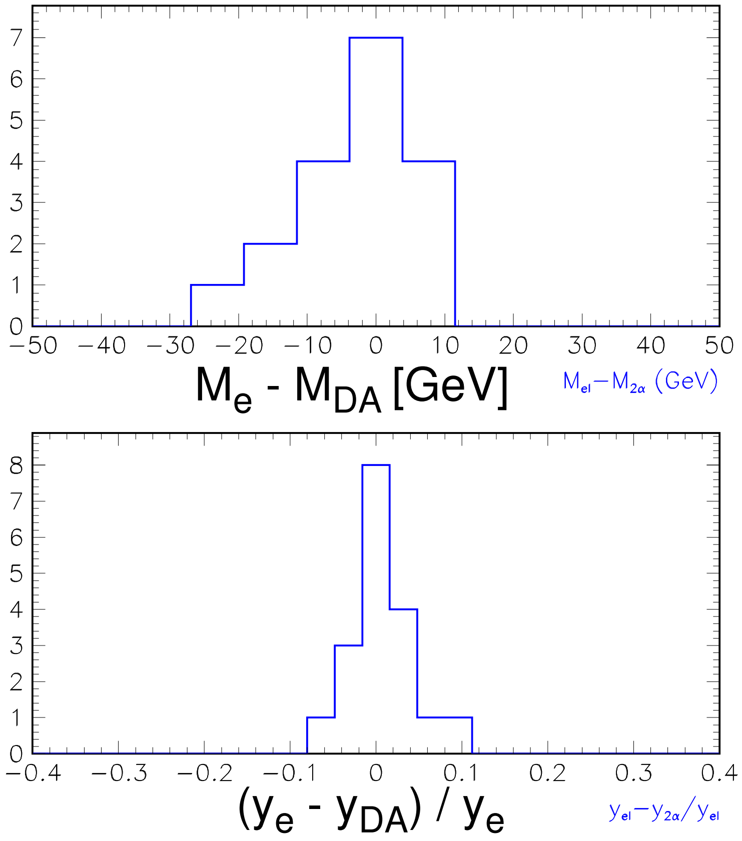
Consistency of kinematic Reconstruction

H1:

Compare DA-reconstruction with e-reconstruction in high Q^2 region.

$Q^2 > 15000\ \mathrm{GeV}^2$

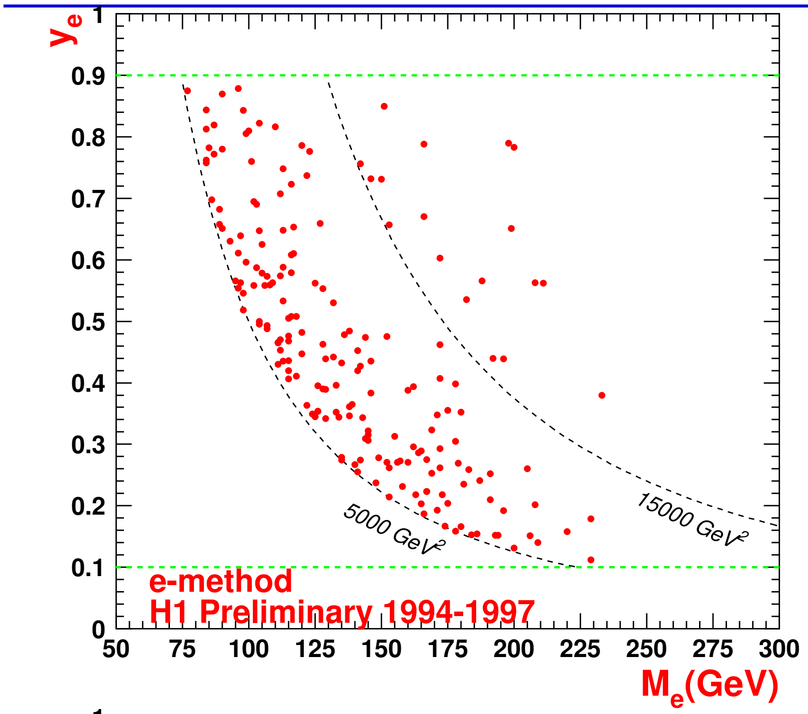
H1 Preliminary



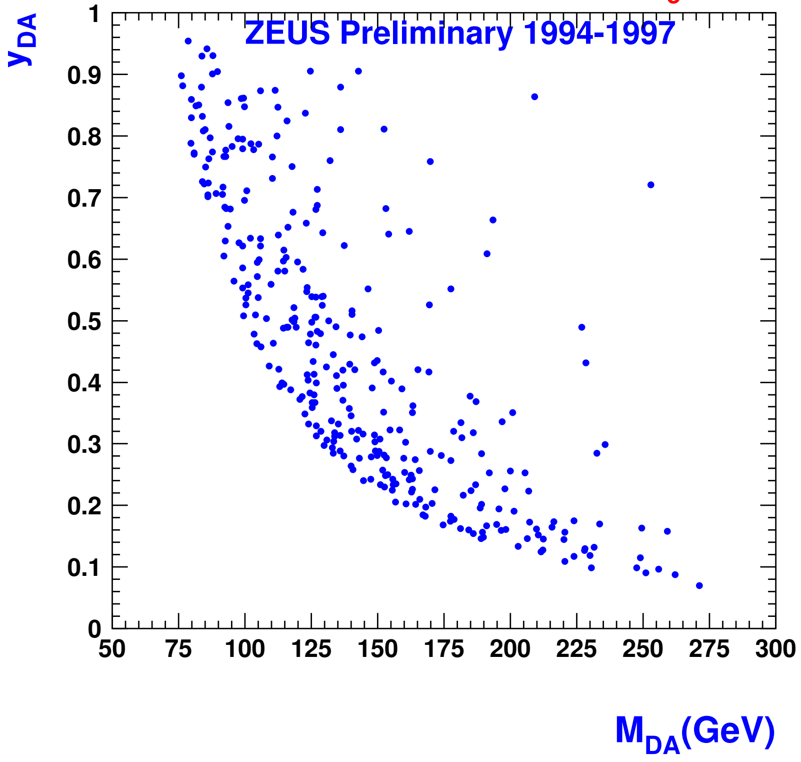
- ➢ good consistency
- ➢ no signs of large QED radiation

NC M-y Plane

for Q^2 > 5000 GeV^2



H1:
e-method

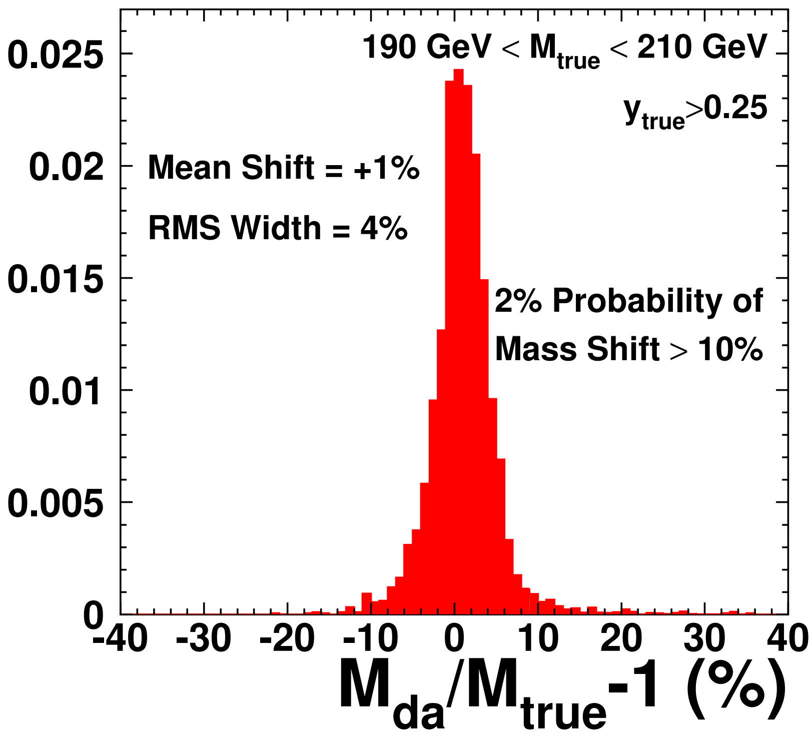


ZEUS:
DA-method

Single Narrow Resonance?

- H1: 8 events at y_e>0.4. at Me≈200GeV ($\sigma_m \approx 5$ GeV)
- ZEUS: 4 events for y_{DA}>0.25, M_{DA}≈229 GeV ($\sigma_m \approx 9$ GeV)

ZEUS
MC Study



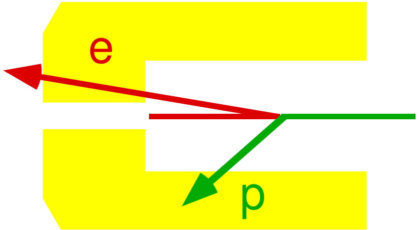
- H1: 3 % E_{em} scale uncertainty ±4 GeV
- ZEUS: hadr. angle reconstruction ±6 GeV

➢ probably not the same enhancement

Cross Section in

Standard DIS Model for y<0.9

H1 uses explicit cut y<0.9:



Region of high x, high y
affected by:

- smaller acceptance
- larger uncertainties in structure functions
- radiative corrections

➢ Measure integrated cross section for y<0.9

Q^2_{min}	DIS SM (Born) MRSH y<1	DIS SM (Born) MRSH y<0.9	H1 σ_{Born}[pb] y<0.9
2500	40.78	38.62	$38.35^{+2.84}_{-2.84}$
5000	9.73	9.03	$8.86^{+1.02}_{-1.02}$
10000	1.64	1.46	$1.40^{+0.30}_{-0.27}$
15000	0.44	0.38	$0.78^{+0.22}_{-0.20}$
20000	0.144	0.117	$0.343^{+0.146}_{-0.125}$
25000	0.052	0.040	$0.210^{+0.112}_{-0.091}$
30000	0.020	0.014	$0.124^{+0.087}_{-0.064}$

Table of

$\sigma(Q^2 > Q^2_{min})$

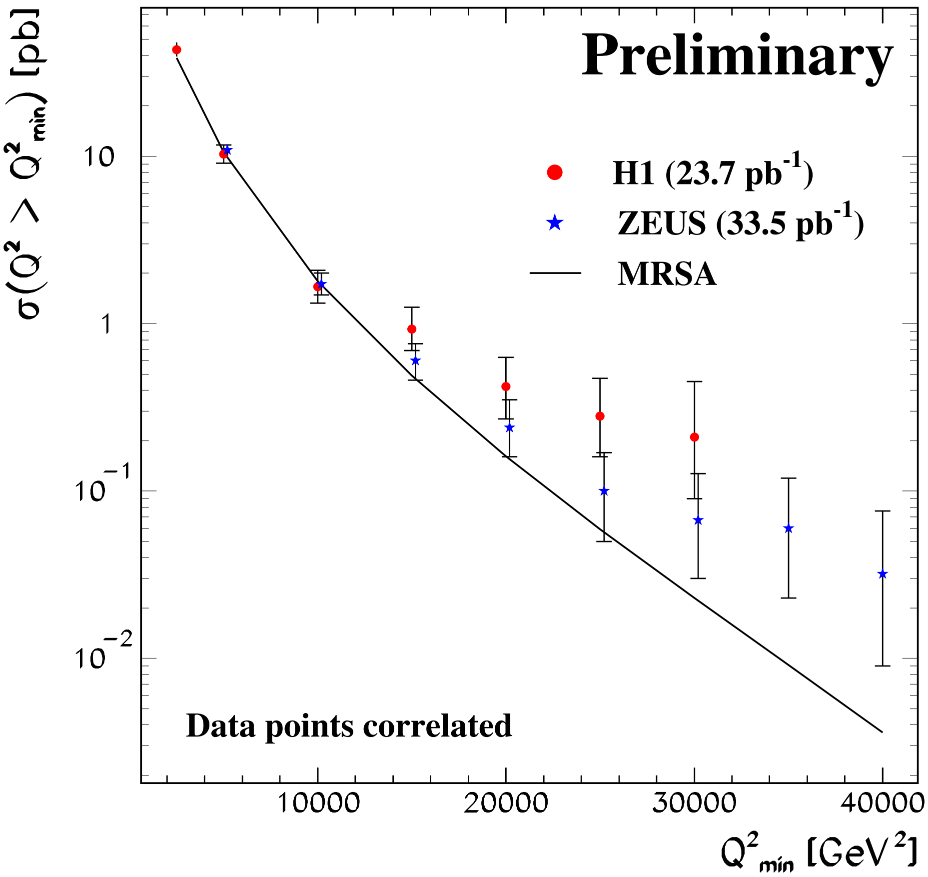
Cross sections for entire kinematic plane (y<1) using the corrections of the DIS Standard Model (hadr. vertex).

Q^2_{min} [GeV^2]	σ[pb] H1	σ[pb] ZEUS	σ[pb] DIS SM
2500	$43.3^{+4.6}_{-3.9}$		43.7
5000	$10.3^{+1.4}_{-1.2}$	$10.9^{+0.8}_{-0.8}$	10.6
10000	$1.66^{+0.42}_{-0.33}$	$1.73^{+0.28}_{-0.25}$	1.79
15000	$0.93^{+0.32}_{-0.24}$	$0.60^{+0.16}_{-0.14}$	0.49
20000	$0.42^{+0.21}_{-0.15}$	$0.24^{+0.11}_{-0.08}$	0.161
25000	$0.28^{+0.19}_{-0.12}$	$0.10^{+0.07}_{-0.05}$	0.059
30000	$0.21^{+0.24}_{-0.12}$	$0.067^{+0.060}_{-0.037}$	0.023
35000		$0.060^{+0.059}_{-0.037}$	0.0091
40000		$0.032^{+0.044}_{-0.023}$	0.0036

Comparison of Cross Sections

in Standard DIS Model

$\sigma(Q^2>Q^2_{min})$ for $y\leq1$ extrapolated within SM.
Data not corrected to Born level.



- H1 and ZEUS consistent
- Good Description at low Q^2
- Data exceed SM at high Q^2

Conclusion

- Charged Current Selection

➢ $W \to \mu\nu$, $W \to e\nu$ candidates:

H1:

See 5 candidates,
2 events are in the favoured region of phase space.

➢ CC Candidates

H1 and ZEUS:

See 29 events for 17.7 ± 4.3 expected for $Q^2 > 10000$ GeV^2

- Neutral Current Selection:

➢ high statistics measurement of cross section at high Q^2 and (not so) low x.

➢ Observe excess of events

H1: most pronounced at $M \approx 200$ GeV

ZEUS: most pronounced $x > 0.55$ and $y > 0.25$

H1 and ZEUS:

Data exceed DIS SM at large Q^2.