Inclusive F_2 at low x and F_L measurement at HERA

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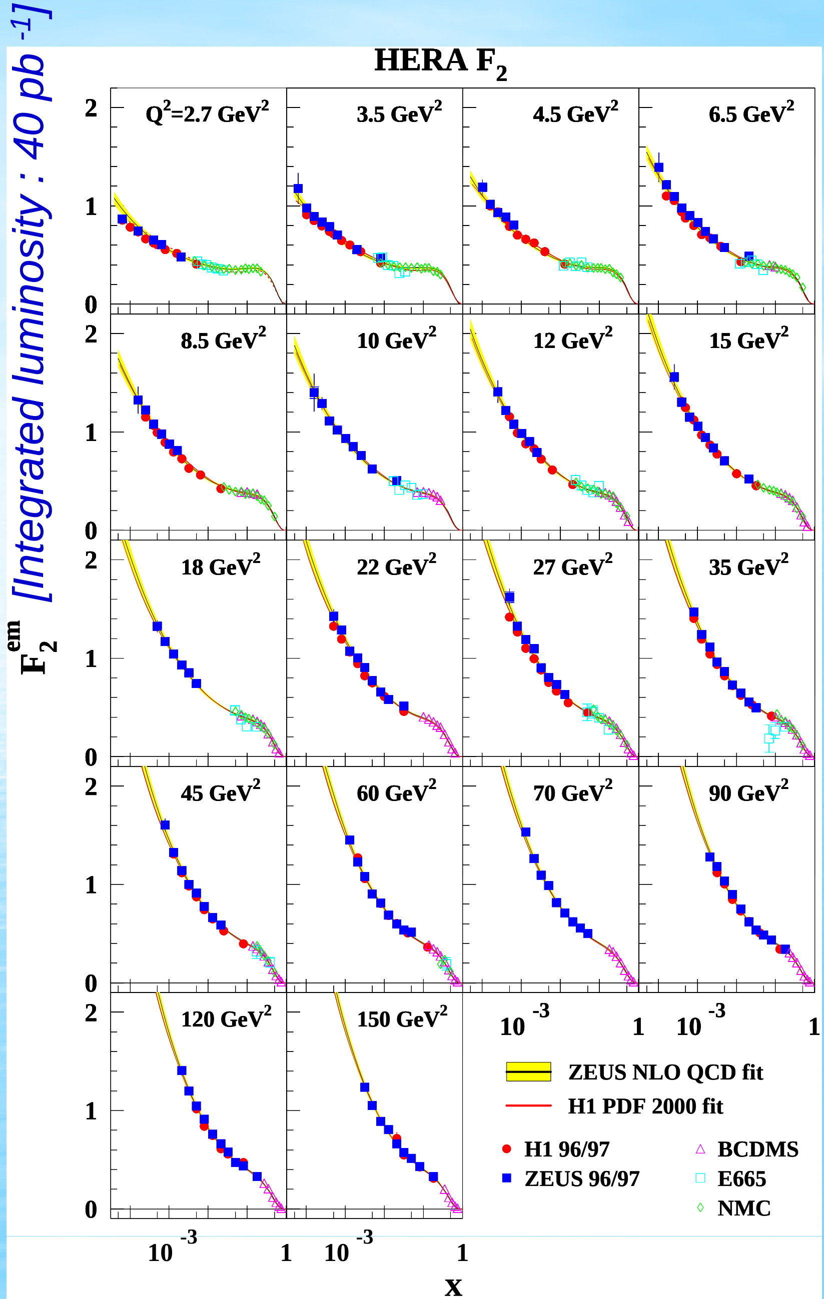
On behalf of the H1 and ZEUS Collaborations

Outlook

- Reminder on published results
- New preliminary H1/ZEUS combination
- New preliminary data
- F_L status and expectations from last data



Inclusive cross section

$$\frac{d\sigma}{dx dQ^2} \propto F_2(x, Q^2)$$

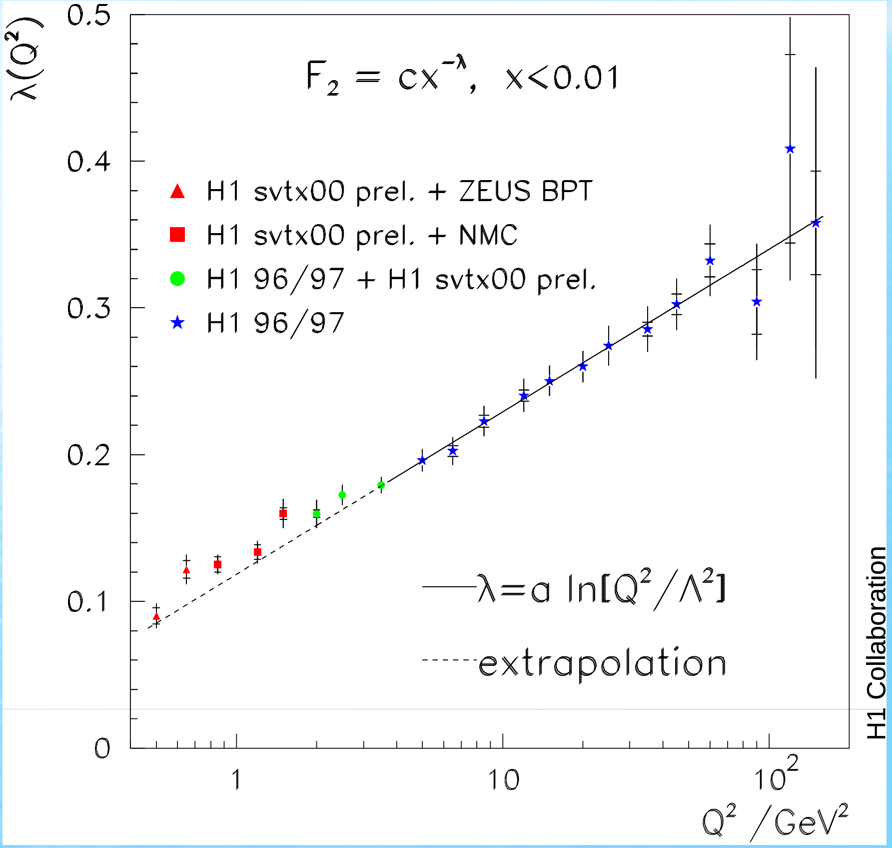
$$F_2(x, Q^2) = \sum_{quarks} e^2 x \left[q(x, Q^2) + \bar{q}(x, Q^2) \right]$$

Impressive rise of F_2 as $x \to 0$

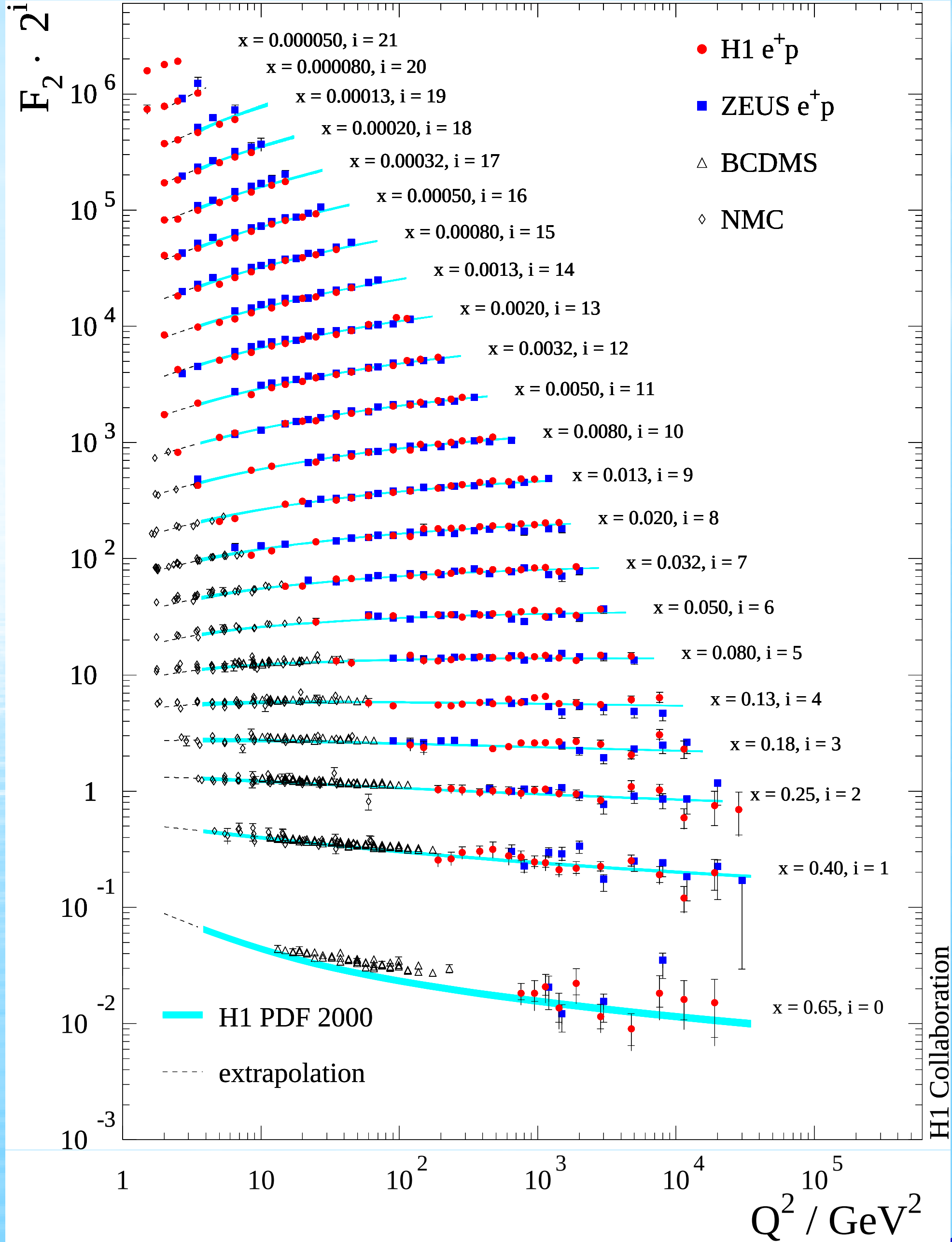
Impressive rise of sea quarks density

The rise increases with Q^2.

Excellent description of data by DGLAP evolution equations. No BFLKL terms required !



No slow down of F_2 rise
No saturation observed yet



Well known pattern of scaling violations :

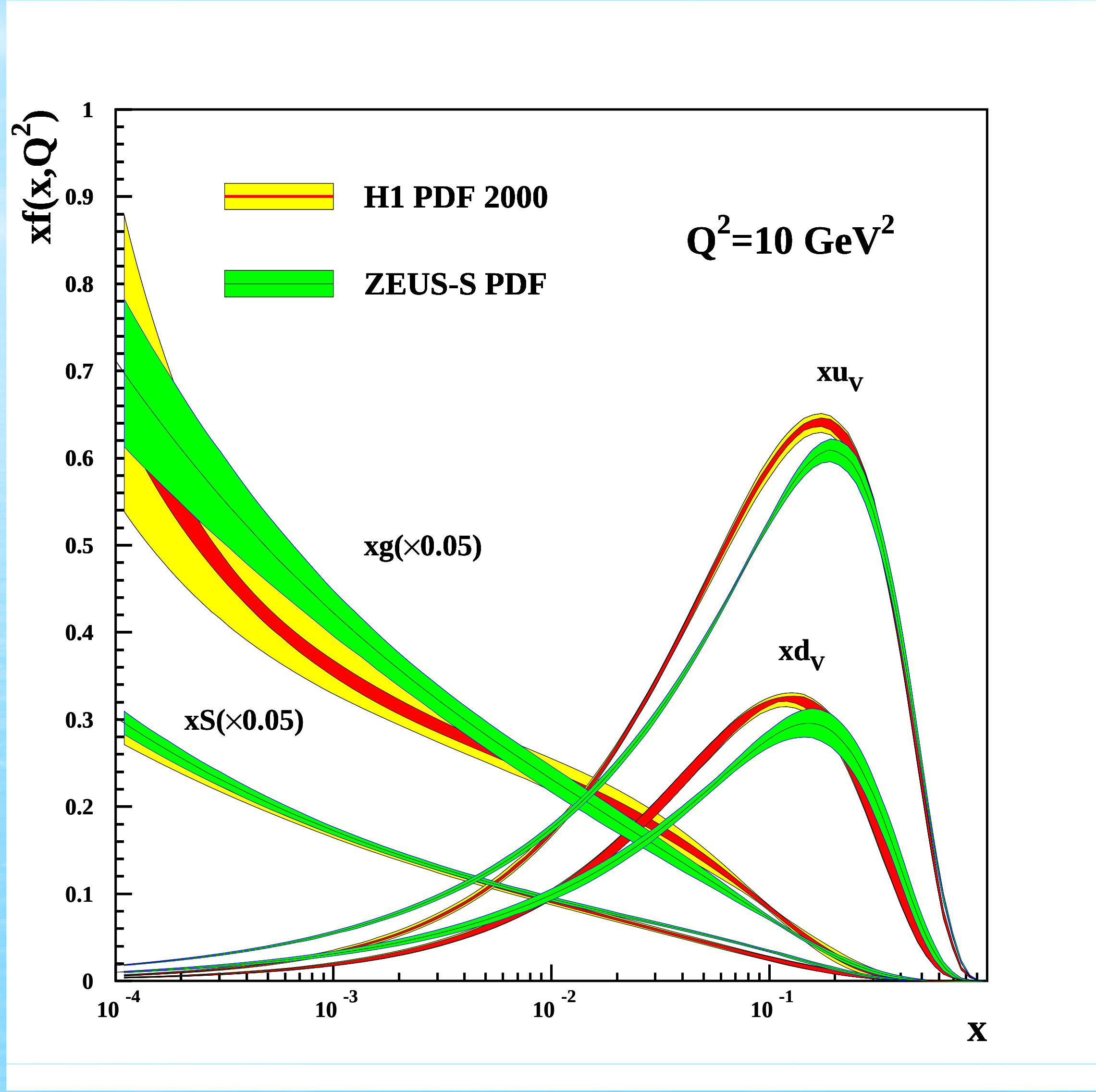
- positive at x<0.08
- negative at x>0.13

At Leading Order (DGLAP) :

$$\frac{\partial F_2}{\partial \ln Q^2} \propto \alpha_s [P \otimes g + P \otimes F_2]$$

low x high x

Well ! But there is still room for improvement !



Combination of H1 and ZEUS DIS Cross Section Measurements

- It should be the ultimate legacy from HERA.
- After a first simple combination of high Q^2 data in 2006, dominated by statistical errors, a coherent approach taking into account systematic correlations and providing cross calibration has been developed.
- To day : preliminary results on HERA I published data taken between 1996-2000 at $Q^2 > 1.5\ GeV^2$

Input Data Sets

data set		x range		Q^2 range (GeV^2)		$\mathcal{L}$ pb^{-1}	ref.	comment
H1 NC min. bias	97	0.00008	0.02	3.5	12	1.8	[5]	NC e^+p $\sqrt{s} = 301$ GeV
H1 NC low Q^2	96 – 97	0.000161	0.20	12	150	17.9	[5]	NC e^+p $\sqrt{s} = 301$ GeV
H1 NC	94 – 97	0.0032	0.65	150	30 000	35.6	[6]	NC e^+p $\sqrt{s} = 301$ GeV
H1 CC	94 – 97	0.013	0.40	300	15 000	35.6	[6]	CC e^+p $\sqrt{s} = 301$ GeV
H1 NC	98 – 99	0.0032	0.65	150	30 000	16.4	[7]	NC e^-p $\sqrt{s} = 319$ GeV
H1 CC	98 – 99	0.013	0.40	300	15 000	16.4	[7]	CC e^-p $\sqrt{s} = 319$ GeV
H1 NC	99 – 00	0.00131	0.65	100	30 000	65.2	[8]	NC e^-p $\sqrt{s} = 319$ GeV
H1 CC	99 – 00	0.013	0.40	300	15 000	65.2	[8]	CC e^-p $\sqrt{s} = 319$ GeV
ZEUS NC	96 – 97	0.00006	0.65	2.7	30 000	30.0	[12]	NC e^+p $\sqrt{s} = 301$ GeV
ZEUS CC	94 – 97	0.015	0.42	280	17 000	47.7	[10]	CC e^+p $\sqrt{s} = 301$ GeV
ZEUS NC	98 – 99	0.005	0.65	200	30 000	15.9	[13]	NC e^-p $\sqrt{s} = 319$ GeV
ZEUS CC	98 – 99	0.015	0.42	280	30 000	16.4	[9]	CC e^-p $\sqrt{s} = 319$ GeV
ZEUS NC	99 – 00	0.005	0.65	200	30 000	63.2	[14]	NC e^-p $\sqrt{s} = 319$ GeV
ZEUS CC	99 – 00	0.008	0.42	280	17 000	60.9	[15]	CC e^-p $\sqrt{s} = 319$ GeV

Method

- Prior to combination, data are :

  - Shifted to a (x,Q^2) common grid (~ no additional error)
  - Moved to 920 GeV

$$\sigma^{e^\pm p}_{NC\ 920}(x,Q^2) = \sigma^{e^\pm p}_{NC\ 820}(x,Q^2) + F_L(x,Q^2)\left[\frac{y^2_{820}}{Y^+_{820}} - \frac{y^2_{920}}{Y^+_{920}}\right] + xF_3(x,Q^2)\left[\pm\frac{Y^-_{820}}{Y^+_{820}} \mp \frac{Y^-_{920}}{Y^+_{920}}\right]$$

$\rightarrow$ Up to 5% uncertainty at high y. It should not be done in the future.

- Average cross section are determined in a simulaneous fit of data. The fit is not physics model dependent !

Chi-2 definition

$$\chi^2_{\text{exp}}\left(M^{i,\text{true}}, \alpha_j\right) = \sum_i \frac{\left[M^{i,\text{true}} - \left(M^i + \sum_j \frac{\partial M^i}{\partial \alpha_j}\alpha_j\right)\right]^2}{\delta_i^2} + \sum_j \frac{\alpha_j^2}{\delta_{\alpha_j}^2}\ .$$

This is the usual χ^2 definition - CTEQ-like
M^i are measurements
$M^{i,true}$ are averaged values
α_j are the j sys errror sources
δ_i are the uncorrelated errors

The Chi-2 is minimised with respect to $M^{i,true}$ and α_j.
The correlated systematics uncertainties are floated coherently, such that each experiment calibrates the other one!

→ Significant reduction of some correlated systematics !

Chi-2 definition : additional (or multiplicative) subtlety

$$\chi^2_{\rm exp}\left(M^{i,\rm true},\alpha_j\right) = \sum_i \frac{\left[M^{i,\rm true} - \left(M^i + \sum_j \frac{\partial M^i}{\partial \alpha_j}\alpha_j\right)\right]^2}{\delta_i^2} + \sum_j \frac{\alpha_j^2}{\delta_{\alpha_j}^2} \, .$$

Most systematic errors are usually estimated as relative error.
But a smaller value of x-section has smaller absolute error.
→ Bias towards smaller averages (checked with toy MC)
Bias can be avoided by modifing Chi-2 definition.

$$\chi^2_{\rm exp}\left(M^{i,\rm true},\alpha_j\right) = \sum_i \frac{\left[M^{i,\rm true} - \left(M^i + \sum_j \frac{\partial M^i}{\partial \alpha_j}\frac{M^{i,\rm true}}{M^i}\alpha_j\right)\right]^2}{\left(\delta_i \frac{M^{i,\rm true}}{M^i}\right)^2} + \sum_j \frac{\alpha_j^2}{\delta_{\alpha_j}^2}$$

In practice a reevaluation of the absolute error after one iteration is sufficient.
The overall effect is small, except for normalisation which is finally taken as relative.

Correlations between H1 and ZEUS data sets

Two clear cut cases:
- Radiative corrections are 100% correlated (same MC progs)
- 0.5% theoretical uncertainty on BH lumi cross section

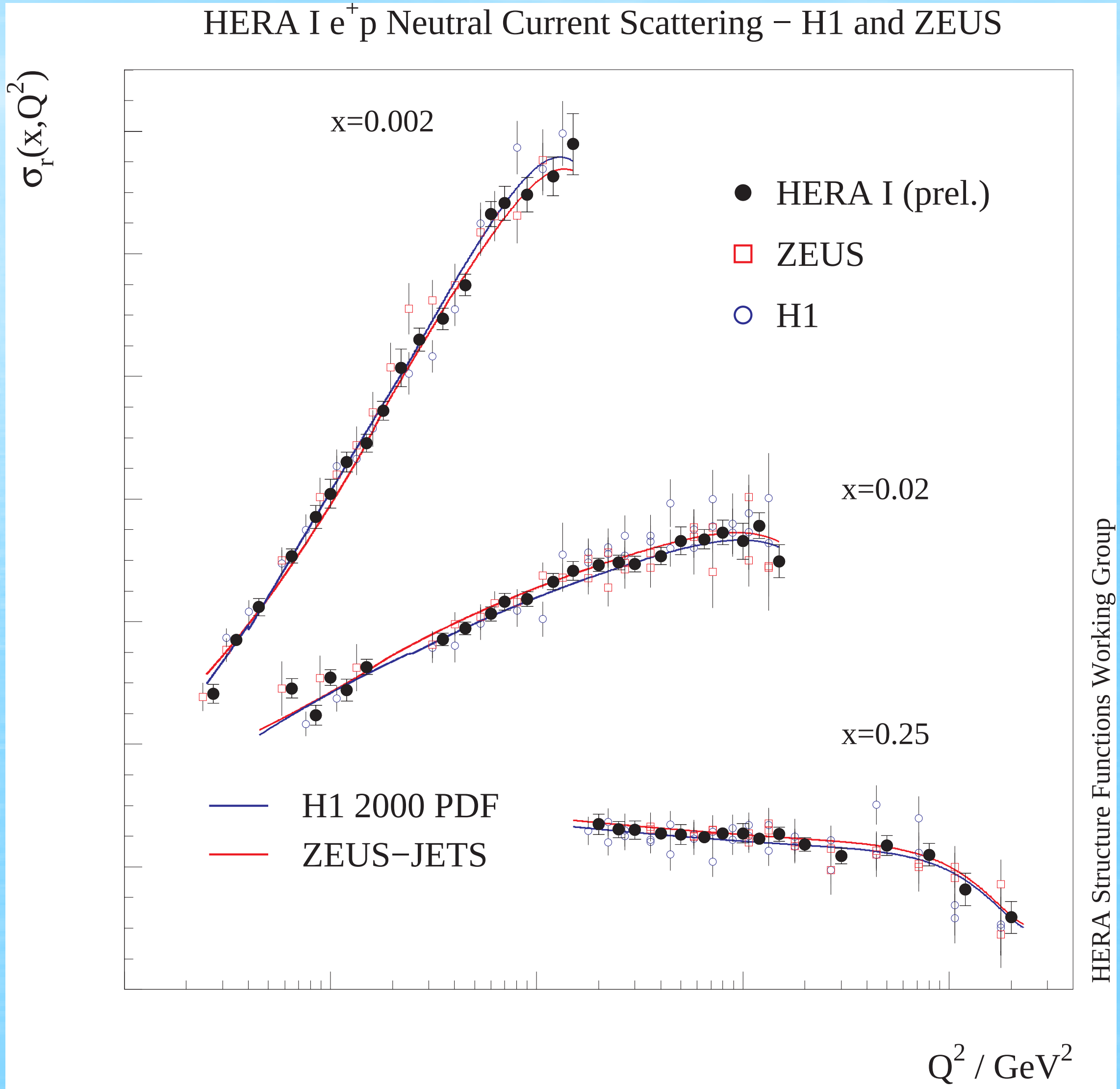
Remainder not clear at all:
- extent of correlation difficult to ascertain
- both use similar methods to calibrate / reconstruct / simulate etc...
- consider rest to be 100% uncorrelated - good approximation

- identify 12 common sources:
  - γp background
  - EM scale (Spa/LAr/RCAL/FCAL/BCAL)
  - Had scale (Spa/LAr/RCAL/FCAL/BCAL)
  - Electron Polar angle

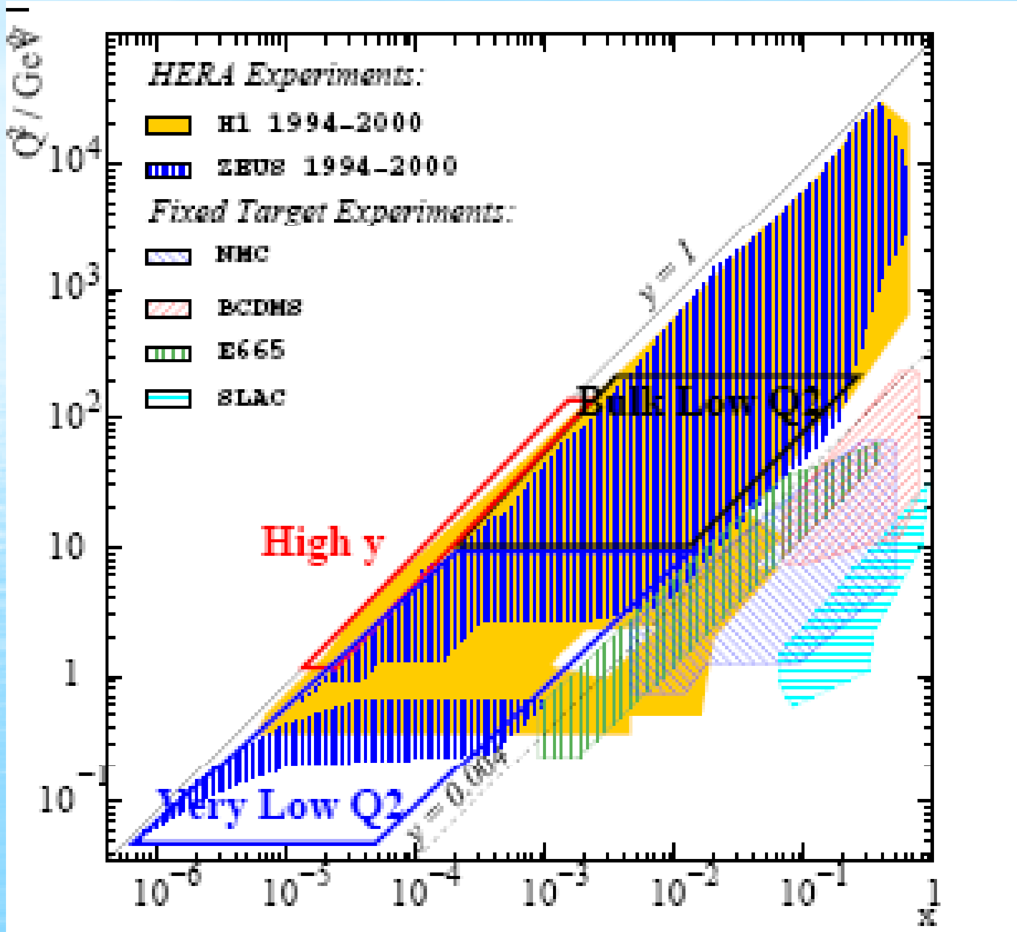
Calculate 2^{12}-1 averages taking all pairs as corr & uncorr in turn
Determine deviations from central value average

Resulting deviations are small ~0.3 % except at low x high y, can be up to 2 %

A visible improvement : reduction of systematics at low Q^2 and reduction of statistical errors at high Q^2



New low Q^2 measurements from H1



At this workshop, preliminary results on :

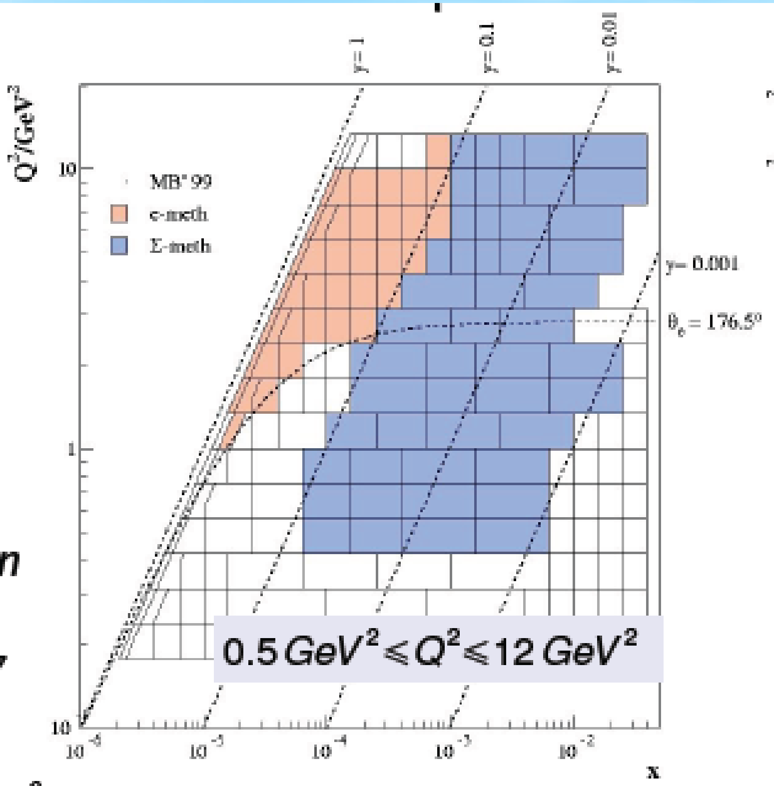
-Very low Q^2 domain
-High y (i.e. low x) domain

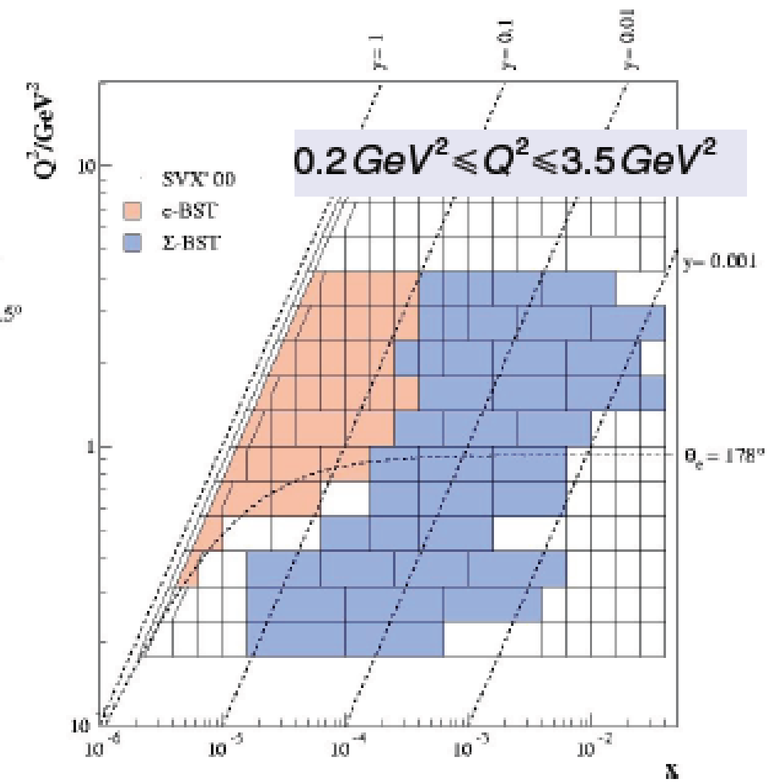
Minimum Bias 1999
MB'99

Shifted Vertex 2000
SVX'00

- MB'99
  $\mathscr{L}=2.1\ \mathrm{pb}^{-1}$
  high y extension
- SVX'00
  $\mathscr{L}=504\ \mathrm{nb}^{-1}$
  low Q² extension
- Published MB'97
  $\mathscr{L}=1.8\ \mathrm{pb}^{-1}$

$1.5\,GeV^2 \leq Q^2 \leq 12\,GeV^2$





$\sqrt{s}=318\,GeV$ MB'99, SVX'00
$\sqrt{s}=300\,GeV$ MB'97

} to be combined

Preliminary results on reduced cross sections

- NC DIS reduced ep cross-section at low Q2:

$$\sigma_r = \frac{Q^2 x}{2\pi\alpha^2 Y_+} \frac{d^2\sigma}{dxdQ^2} = F_2(x,Q^2) - f(y) F_L(x,Q^2)$$

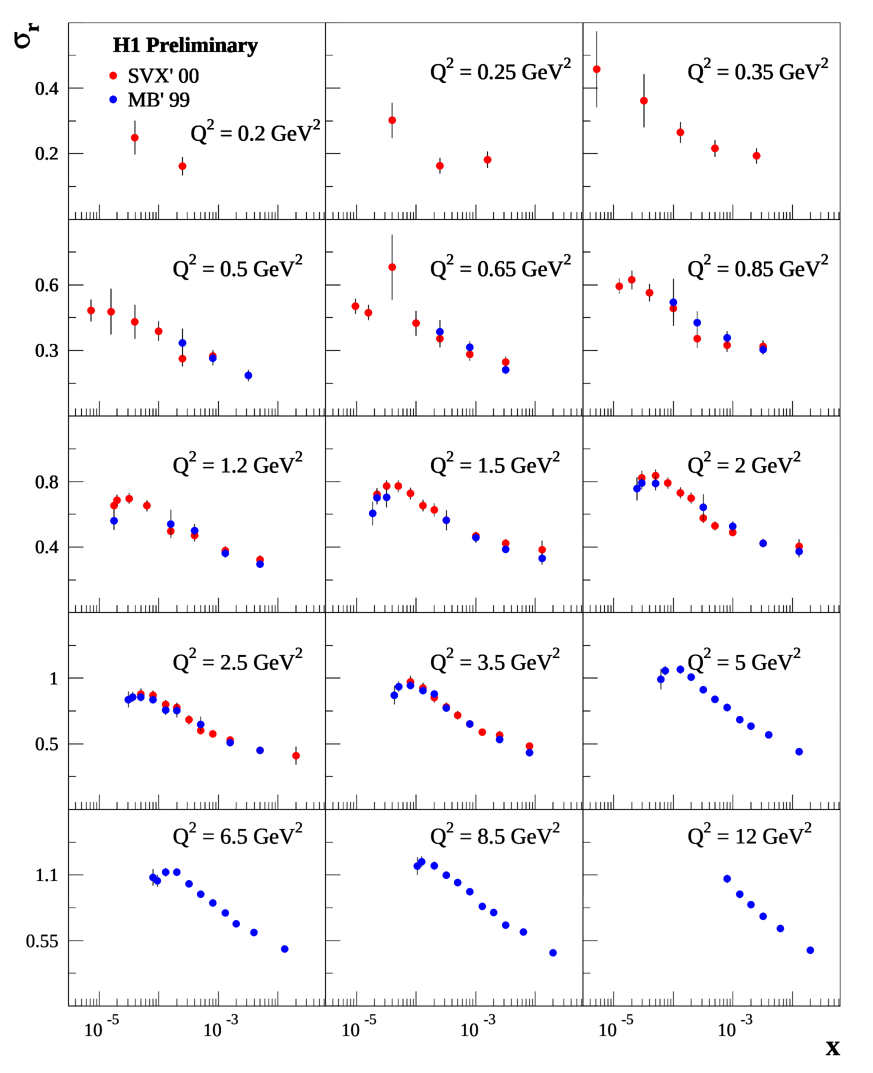
$$Y_+ = 1 + (1-y)^2$$

$$f(y) = \frac{y^2}{Y_+}$$

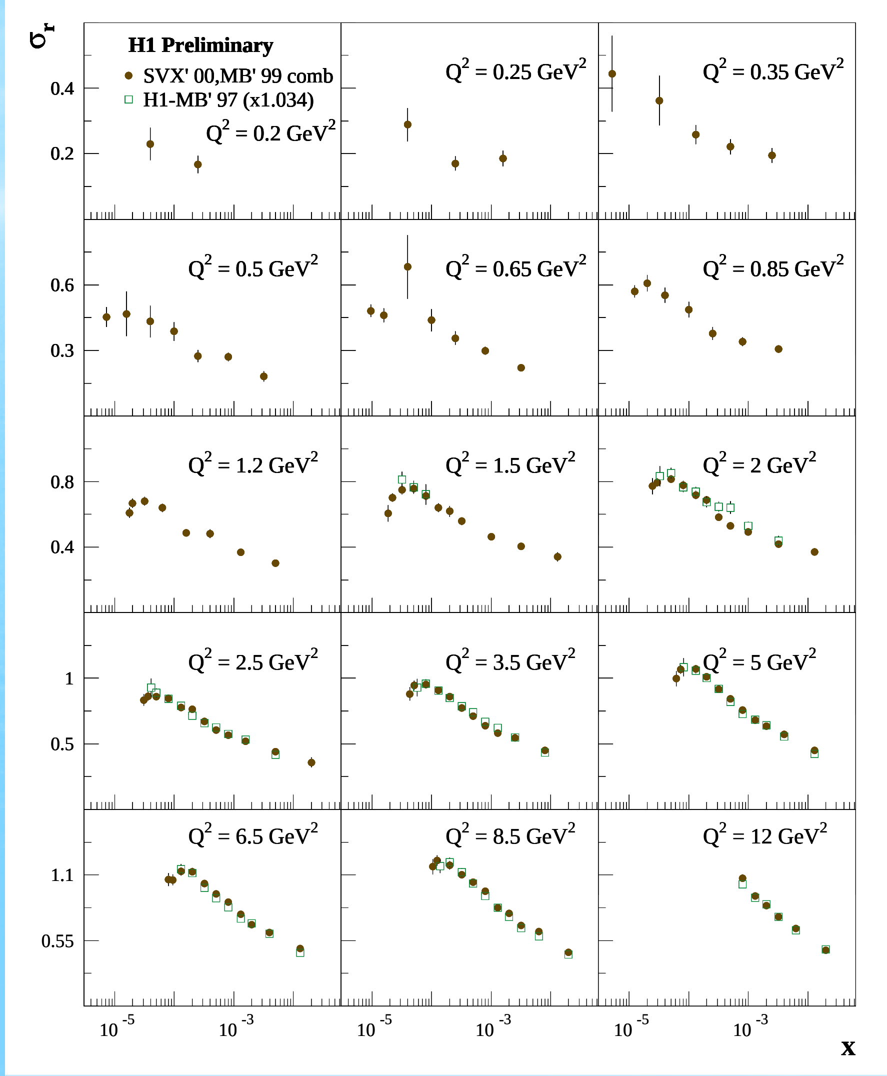
$F_2(x,Q^2)$ → **dominant**

$f(y) F_L(x,Q^2)$ → **sizable only at high y**

MB’99 vs SVX’00

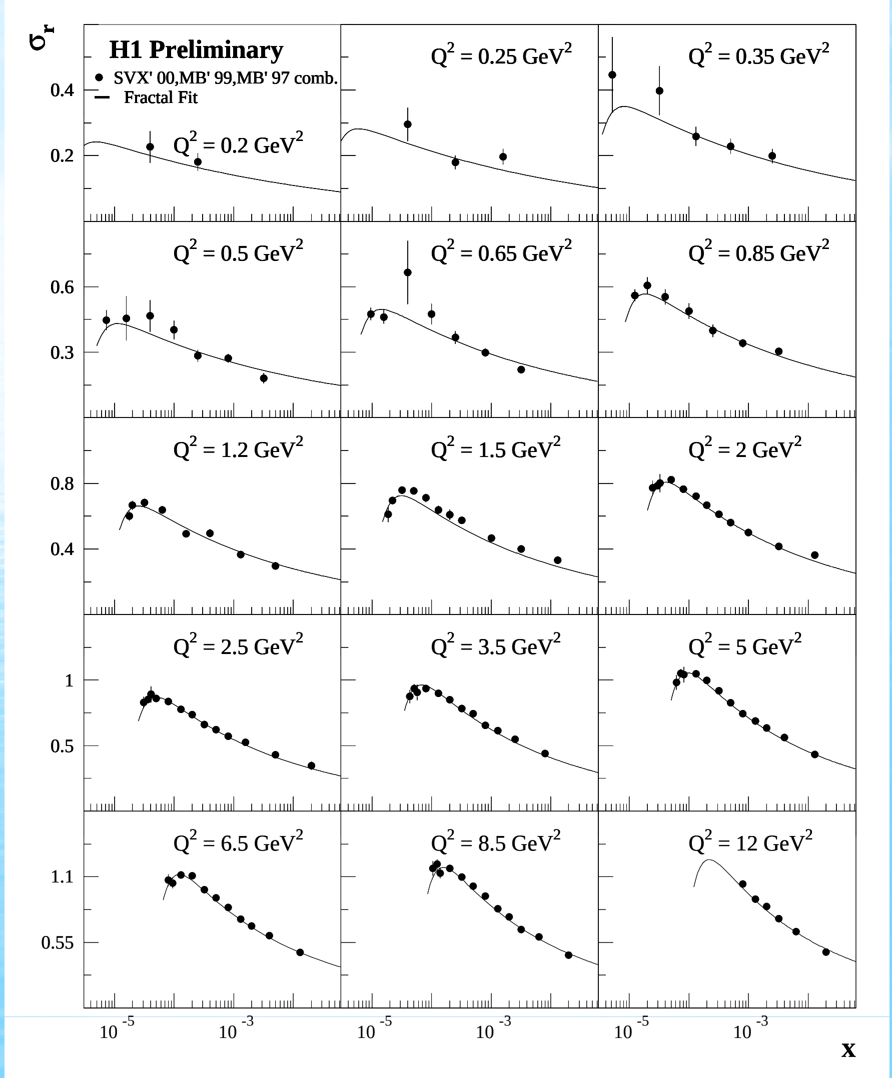


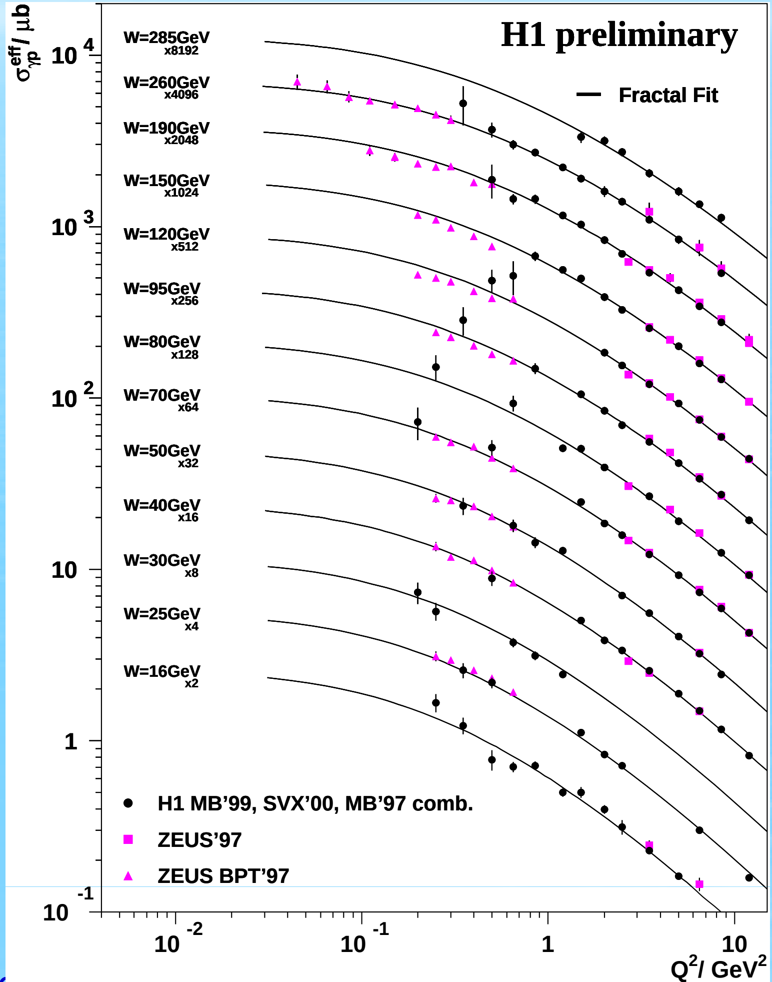
Comb of MB’99+SVX’00 vs renormalised MB’97



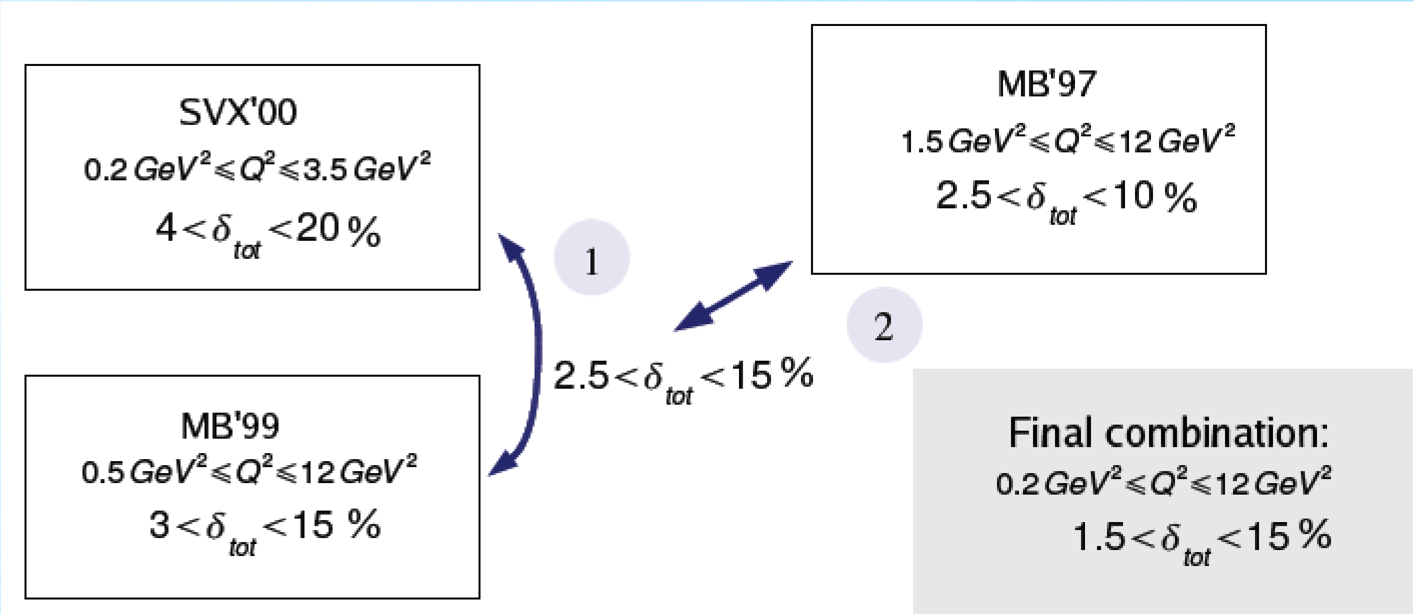
Final (but still preliminary) combination

Data fill the transition region at $Q^2 \sim 1$ GeV^2.
Good agreement with ZEUS.





Combination improvement

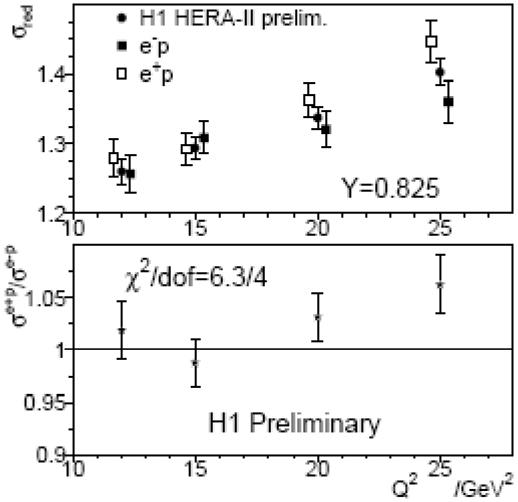


A nice data set for future phenomenological fits

New H1 measurement at low Q^2 high y
$12 < Q^2 < 50$ Gev^2 and $0.75 < y < 0.9$
at Ep= 920 GeV

- It is part of the Q^2,y domain where the F_L measurement is done, but at lower proton beam energies !
- The common experimental challenge is the low scattered electron energy $E'_e > 3.4$ GeV :
  - Calorimeter linerarity (π° and ψ calibration)
  - Trigger efficiency (redundancy)
  - Photo production background (wrong charge track)
  - Radiative correction (measure $2\ E_{beam} = \Sigma\ (E^h - P_z^h) + (E^{e\prime} - P'^e_z)$)
- HERA II data : 51 pb^{-1} e^+p and 45 pb^{-1} e^-p

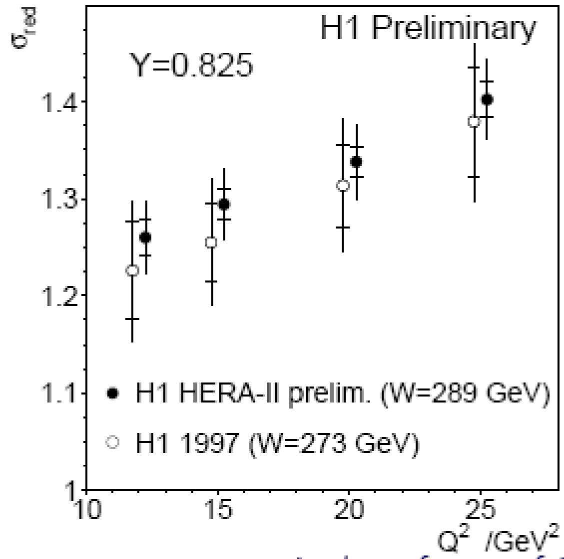
Preliminary cross sections



Only statistical errors shown

→ e⁺p and e⁻p cross section measurement are consistent → an import cross check since the two measurements are oppositely sensitive to the background charge asymmetry.

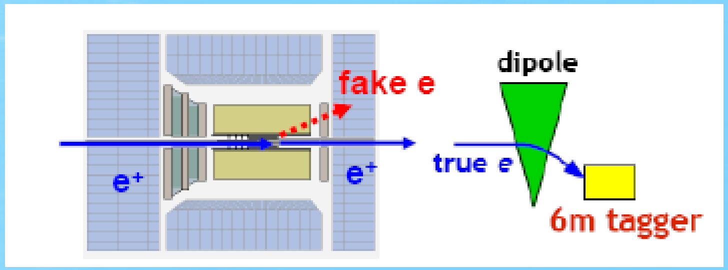
N. Raicevic DIS 2007, 16-20 April, 2007 13



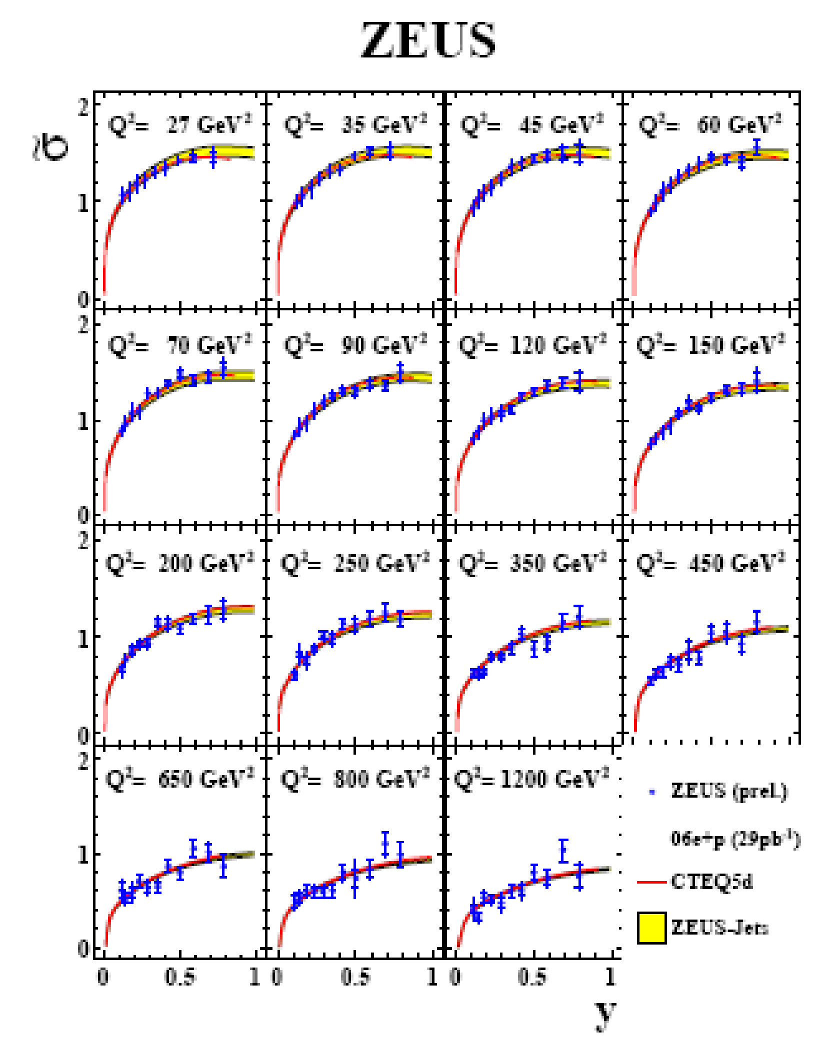
Errors reduced by a factor 2 !

New ZEUS measurement at high y
$25 < Q^2 < 1300$ Gev^2 and $0.1 < y < 0.8$
at E_p= 920 GeV

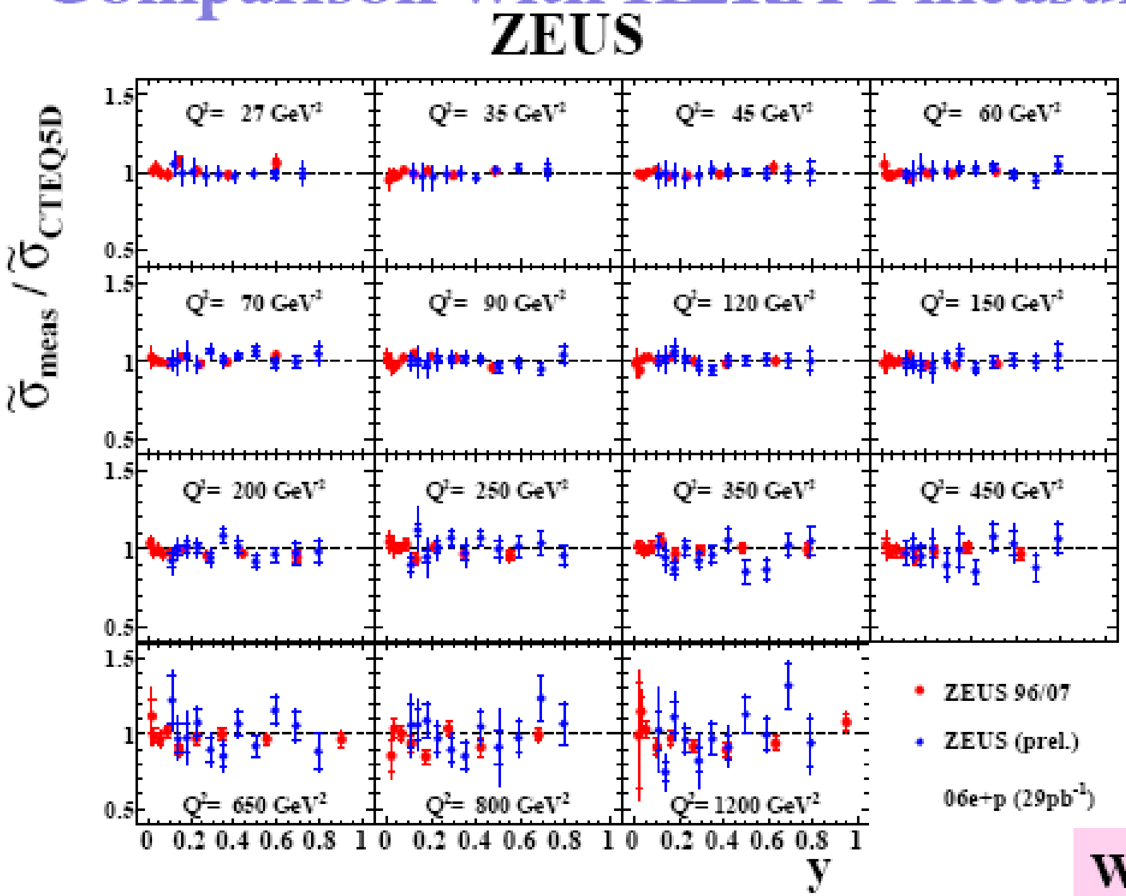
- Same experimental challenges as H1.
- Main differences:
  - E′ > 5 GeV
  - Larger scattering angle (to the electron beam direction)
  - Photoproduction background subtraction mainly from e-tagger events (no charge measurement)



Reduced cross section



Comparison with HERA-I measurement



S.Shimizu
DIS 07

- Measurement is extended to high-y region especially at low Q^2 compared to HERA-I.

We have succeeded to extend the measurement to high-y.

15

Direct measurement of $F_L(Q^2,x)$

$$\frac{d^2\sigma}{dxdQ^2} = \frac{2\pi\alpha^2 Y_+}{Q^4 x}\left[F_2(x,Q^2) - f(y).F_L(x,Q^2)\right] = \frac{2\pi\alpha^2 Y_+}{Q^4 x}\sigma_r$$

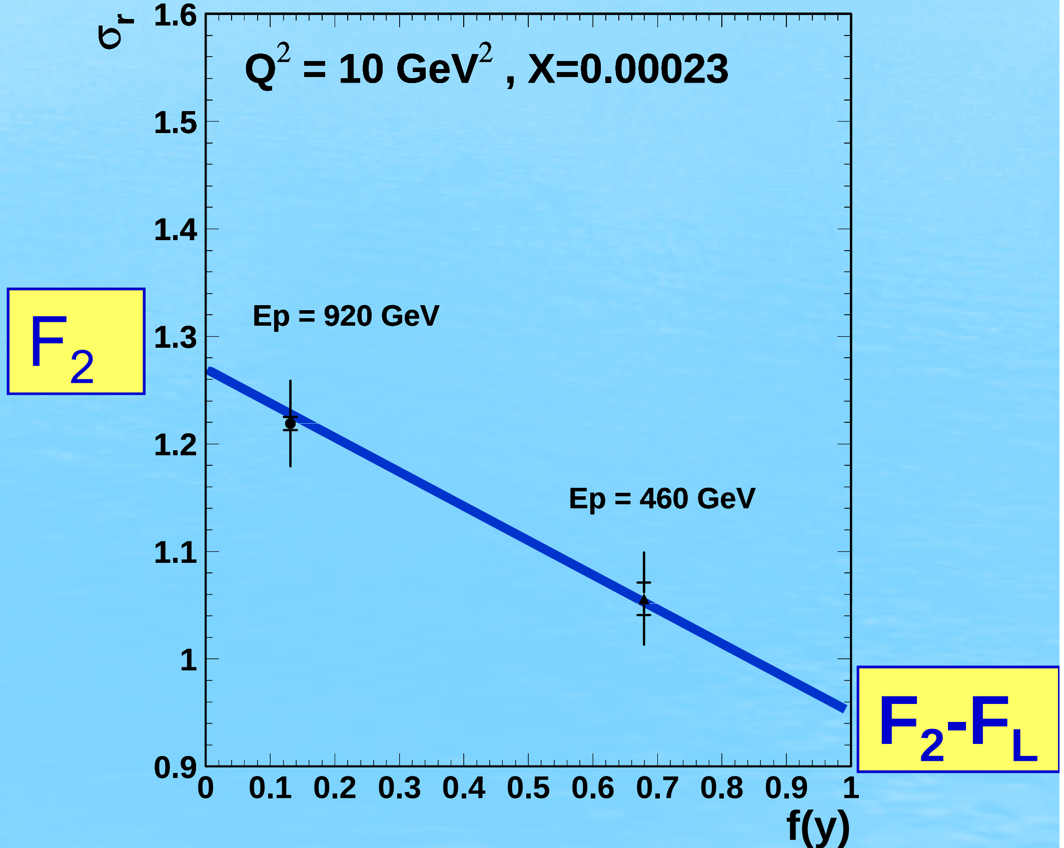
At fixed (Q^2,x), measure cross sections at several beam energies (minimum 2), i.e. at different y.

Perform straight line fit of σ_r to extract F_2 and F_L

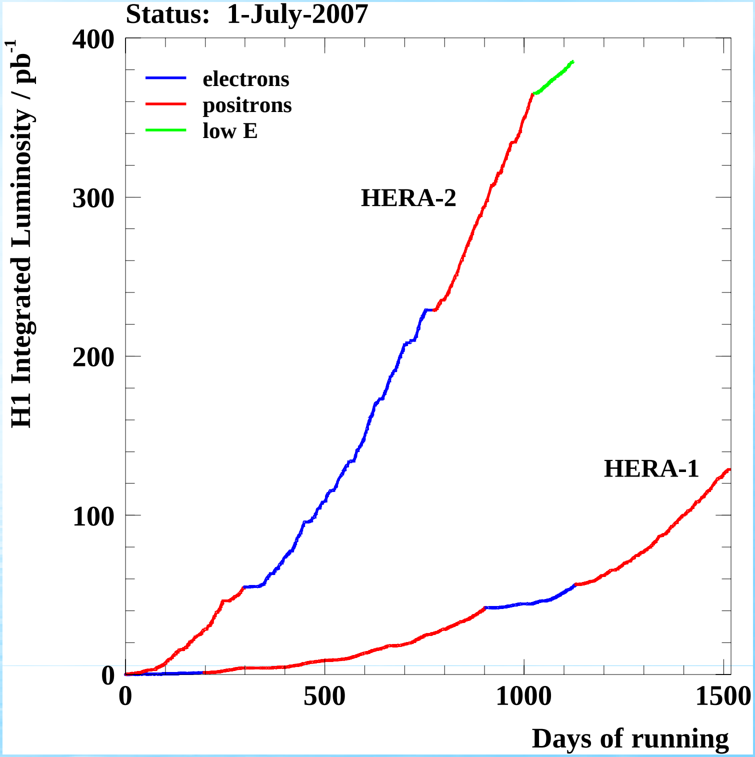
F_L is very sensitive to small relative shifts on cross sections.

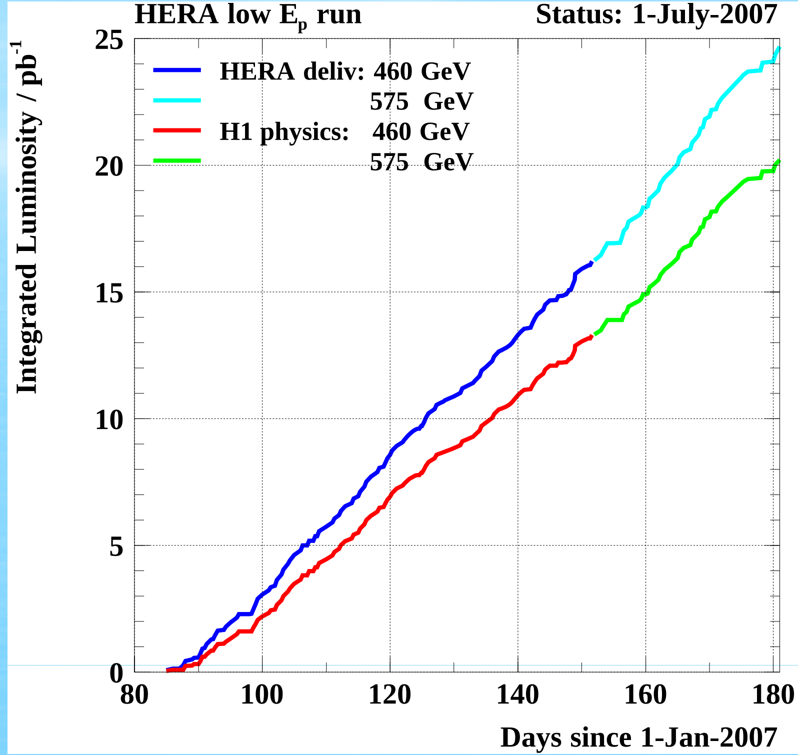
A challenging high y measurement at low E_p.

Reduced cross section



Successful runs of HERA at 460 GeV and 575 GeV

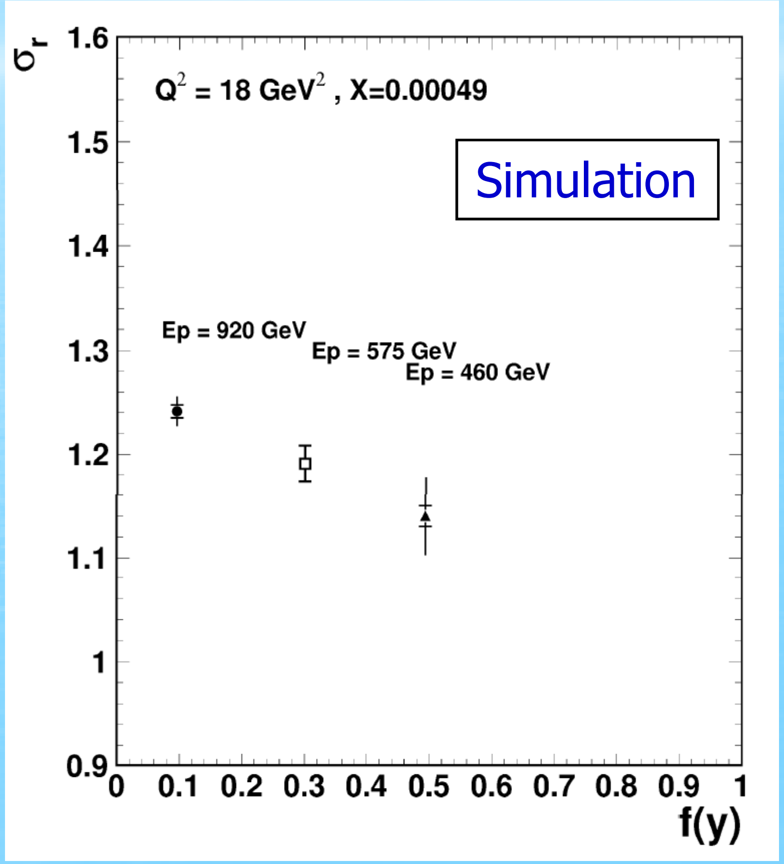




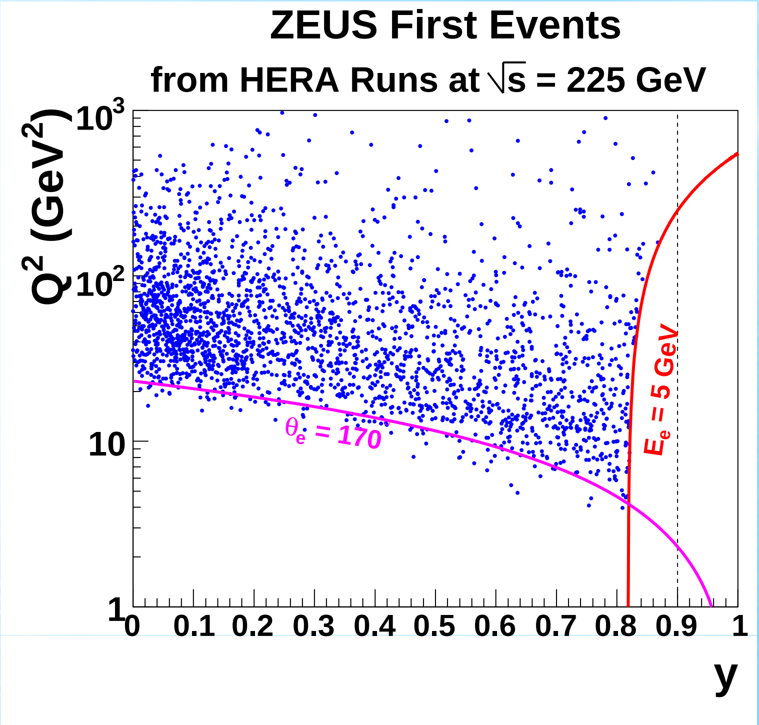
460 GeV
13.6 pb^{-1}

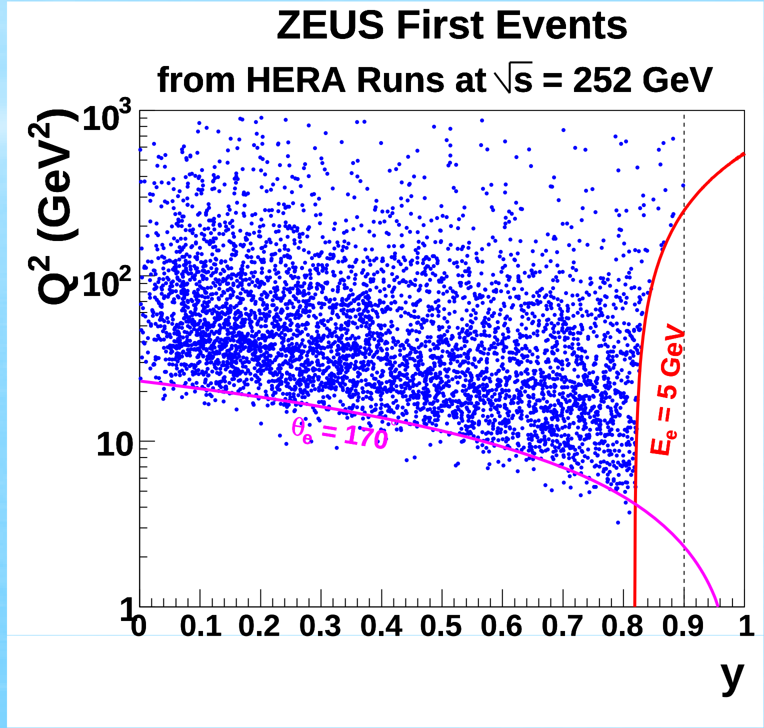
575 GeV
6.5 pb^{-1}

The 575 GeV run : a unique tool to control systematics



Nice data on tape



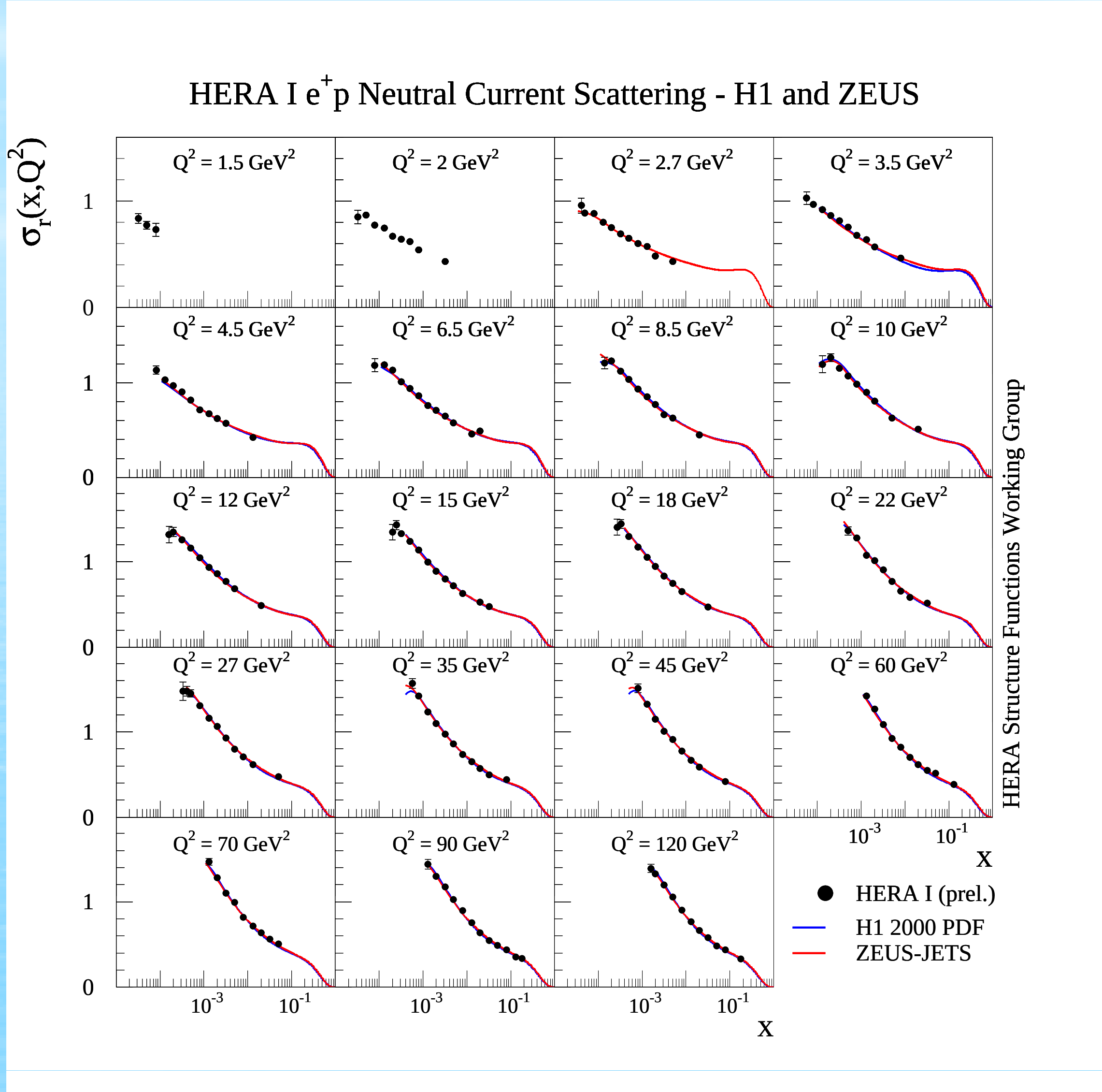


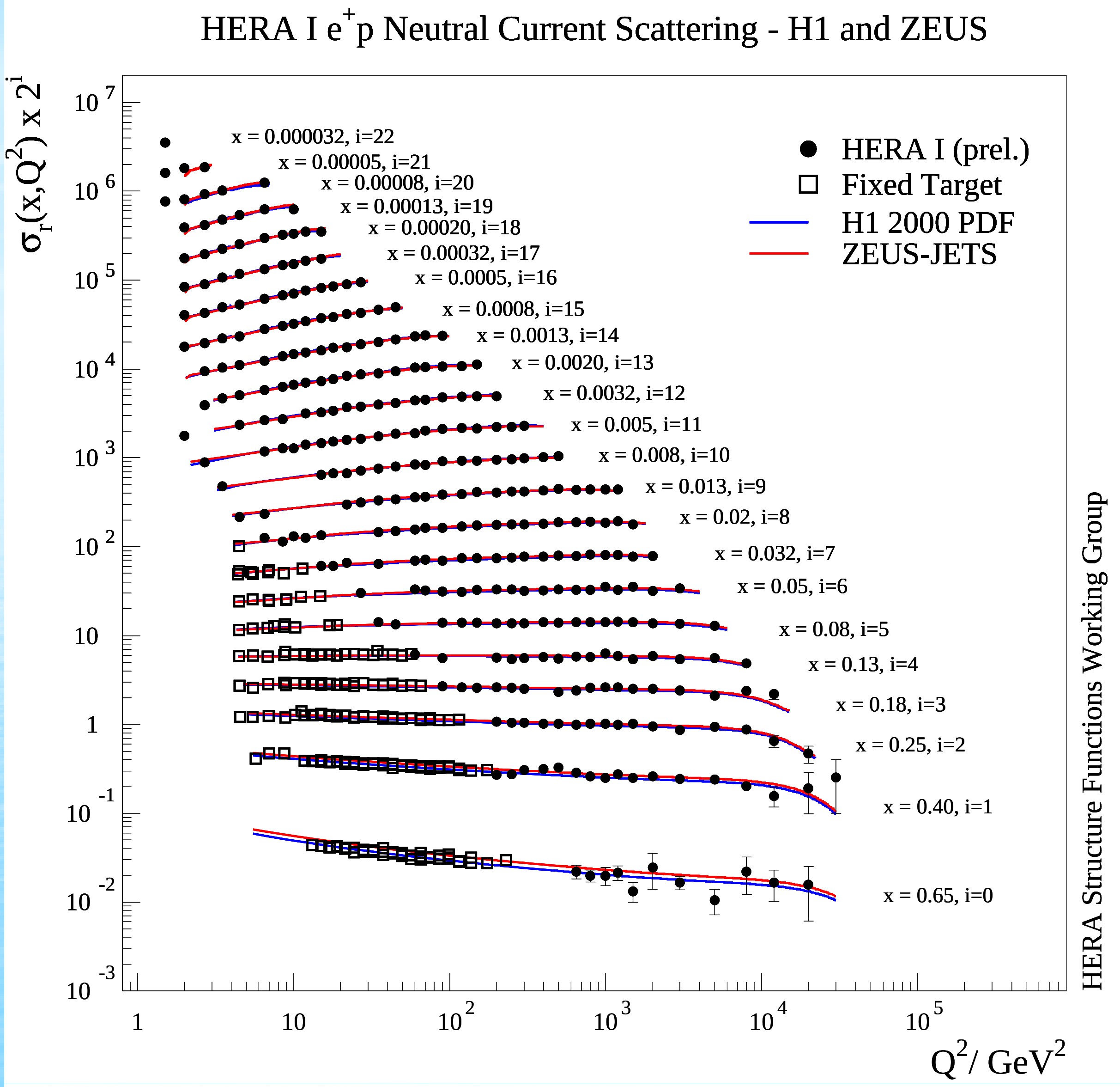
Be patient !

Summary

- New and improved results at low Q^2 (H1) and in the high y domain (H1 and ZEUS) have been presented. New analysis of low Q^2 data are still on going (H1).
- In a fuitful collaboration H1 and ZEUS are well on track to provide high precision (< 2 %) HERA F_2 data at low x. An important input to physics at LHC.
- Successful last runs at low and medium proton beam energies should provide a direct measurement of F_L with an unprecedented good precision. A new handle to the gluon density at low x.

EXTRAS


HERA I e+p Neutral Current Scattering - H1 and ZEUS
σr(x,Q2)
Q2 = 1.5 GeV2
Q2 = 2 GeV2
Q2 = 2.7 GeV2
Q2 = 3.5 GeV2
Q2 = 4.5 GeV2
Q2 = 6.5 GeV2
Q2 = 8.5 GeV2
Q2 = 10 GeV2
Q2 = 12 GeV2
Q2 = 15 GeV2
Q2 = 18 GeV2
Q2 = 22 GeV2
Q2 = 27 GeV2
Q2 = 35 GeV2
Q2 = 45 GeV2
Q2 = 60 GeV2
Q2 = 70 GeV2
Q2 = 90 GeV2
Q2 = 120 GeV2
x
HERA I (prel.)
H1 2000 PDF
ZEUS-JETS
HERA Structure Functions Working Group


HERA I e+p Neutral Current Scattering - H1 and ZEUS
σr(x,Q2) x 2i
x = 0.000032, i=22
x = 0.00005, i=21
x = 0.00008, i=20
x = 0.00013, i=19
x = 0.00020, i=18
x = 0.00032, i=17
x = 0.0005, i=16
x = 0.0008, i=15
x = 0.0013, i=14
x = 0.0020, i=13
x = 0.0032, i=12
x = 0.005, i=11
x = 0.008, i=10
x = 0.013, i=9
x = 0.02, i=8
x = 0.032, i=7
x = 0.05, i=6
x = 0.08, i=5
x = 0.13, i=4
x = 0.18, i=3
x = 0.25, i=2
x = 0.40, i=1
x = 0.65, i=0
HERA I (prel.)
Fixed Target
H1 2000 PDF
ZEUS-JETS
HERA Structure Functions Working Group
Q2/ GeV2

Systematic Error Shifts

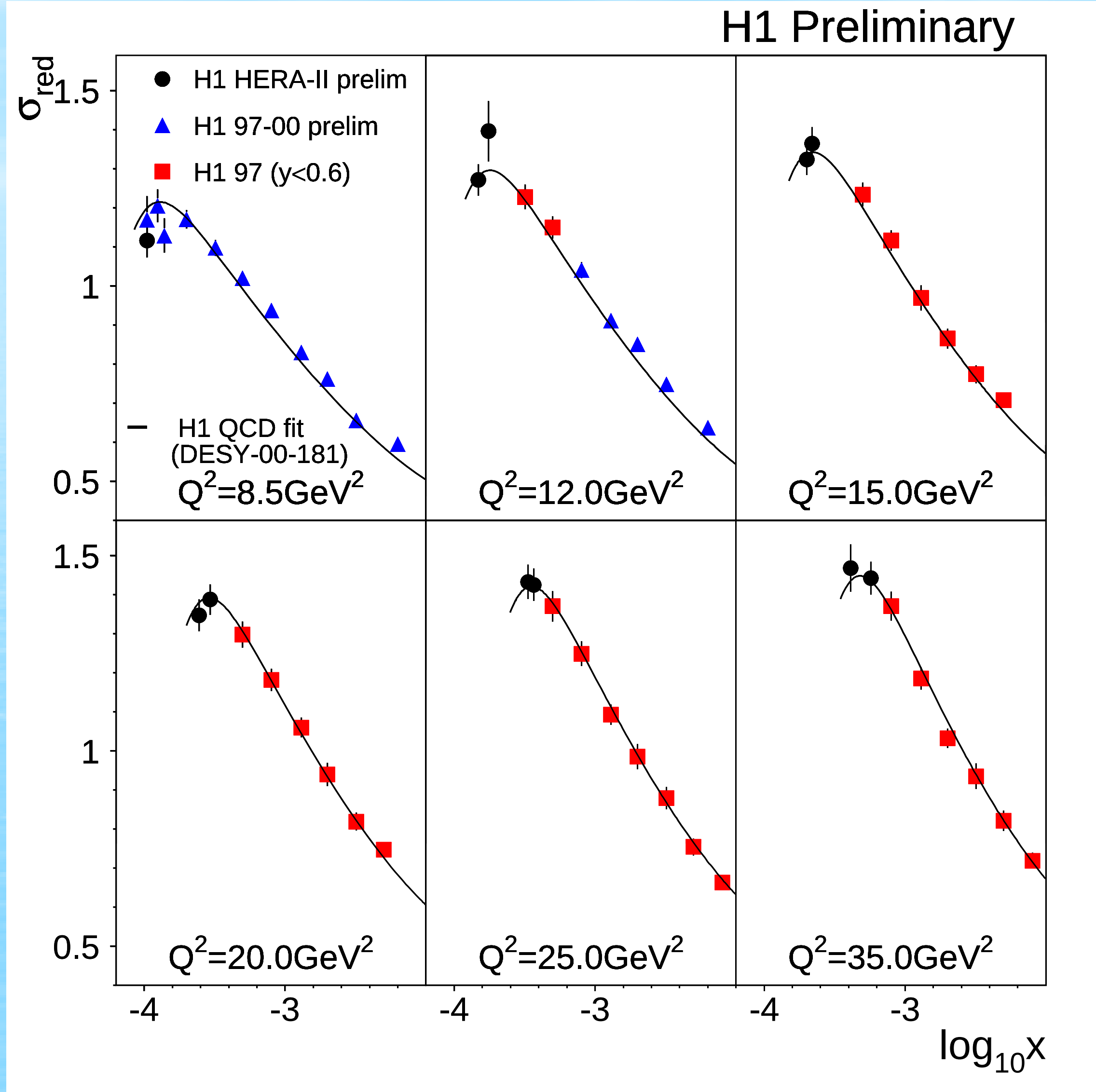
07/08/07

#	Source	Shift	uncertainty (in sigma)
1	zlumi1_zncepl	0.0554	0.5887
2	h2_Ee_Spacal	0.6568	0.3314
3	h3_Ee_Lar_00	-0.3645	0.4448
4	h4_ThetaE_spacal	-0.7437	0.6556
5	h5_ThetaE_94-97	-0.0655	0.7799
6	h6_ThetaE_00	-0.4051	0.5290
7	h7_H_Scale_Spacal	0.4592	0.4755
8	h8_H_Scale_Lar	-0.9265	0.5351
9	h9_Noise_Hcal	-0.5037	0.3645
10	h10_GP_BG_Spacal	-0.5141	0.8179
11	h11_GP_BG_LAr	0.9073	0.8510
12	h12_BG_CC_94-97	0.3389	0.7871
13	h13_BG_CC_98-00	-0.7856	0.8846
14	h14_ChargeAsym	0.0262	0.9993
15	h1lumi1_SPACAL_bulk	1.5543	0.5588
16	h1lumi2_SPACAL_MB	0.8375	0.5984
17	h1lumi3_LAr_94-97_e+p	-1.0706	0.6211
18	h1lumi4_LAr_e-p	-0.0708	0.7778
19	h1lumi5_LAr_2000	-0.7462	0.5982
20	zd1_e_eff	0.4572	0.7486
21	zd2_e_theta_a	0.1576	0.6797
22	zd3_e_theta_b	-0.3849	0.7746
23	zd4_e_escale	0.8342	0.5079
24	zd5_had1	0.3157	0.5906
25	zd6_had2	0.0581	0.6496
26	zd7_had3	-0.7649	0.7413
27	zd8_had_flow	0.6947	0.6619
28	zd9_bg	-0.2358	0.4175
29	zd10_had_flow_b	0.0730	0.2375
30	zd11	-0.4055	0.6174
31	z1nce-_e_scale	0.1777	0.9383
32	z2nce-_bg	-0.4073	0.9178
33	z3nce-_eff1	-0.1819	0.9120
34	z4nce-_eff2	0.5536	0.5544
35	z5nce-_vtx	-0.5180	0.9262
36	z6nce-	0.1218	0.4138
37	z1cce-	0.0296	0.8350
38	z2cce-	-0.0152	0.8680
39	zlumi2_zccem	0.0708	0.7778
40	zd5nc00	0.1386	0.9843
41	zd7nc00	0.1566	0.2093
42	zd8nc00	0.5163	0.9280
43	zluminc00	-0.4854	0.3837

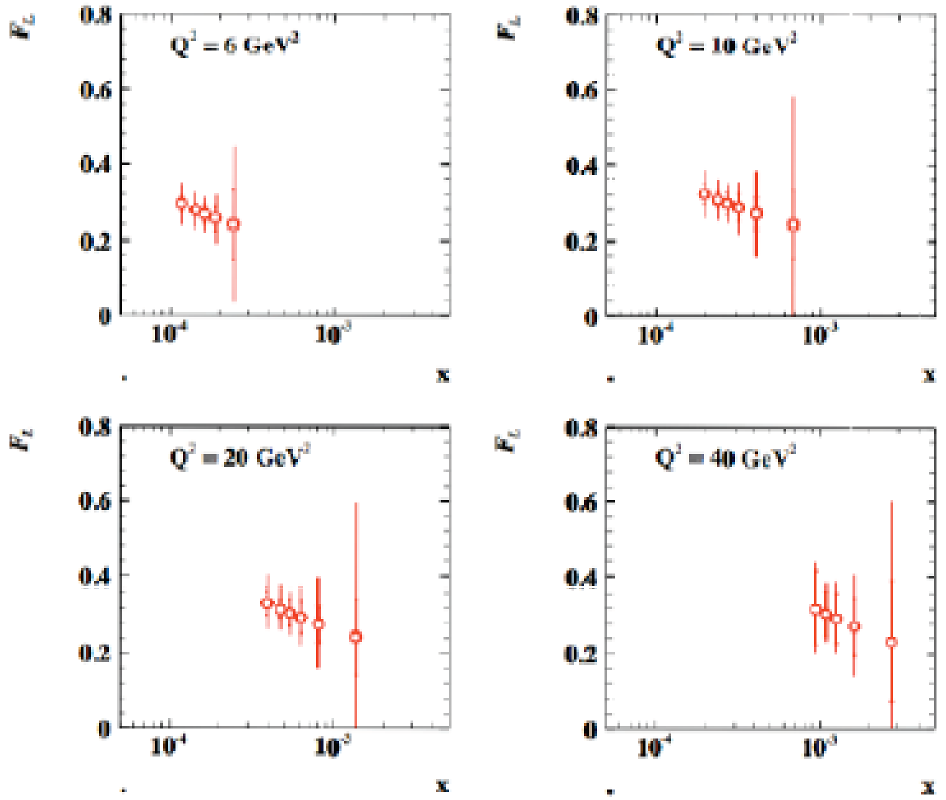
30% correlation to this source

shift ~ 2% upwards
All other shifts within 1σ

High y HERA II compared to smaller y HERA I



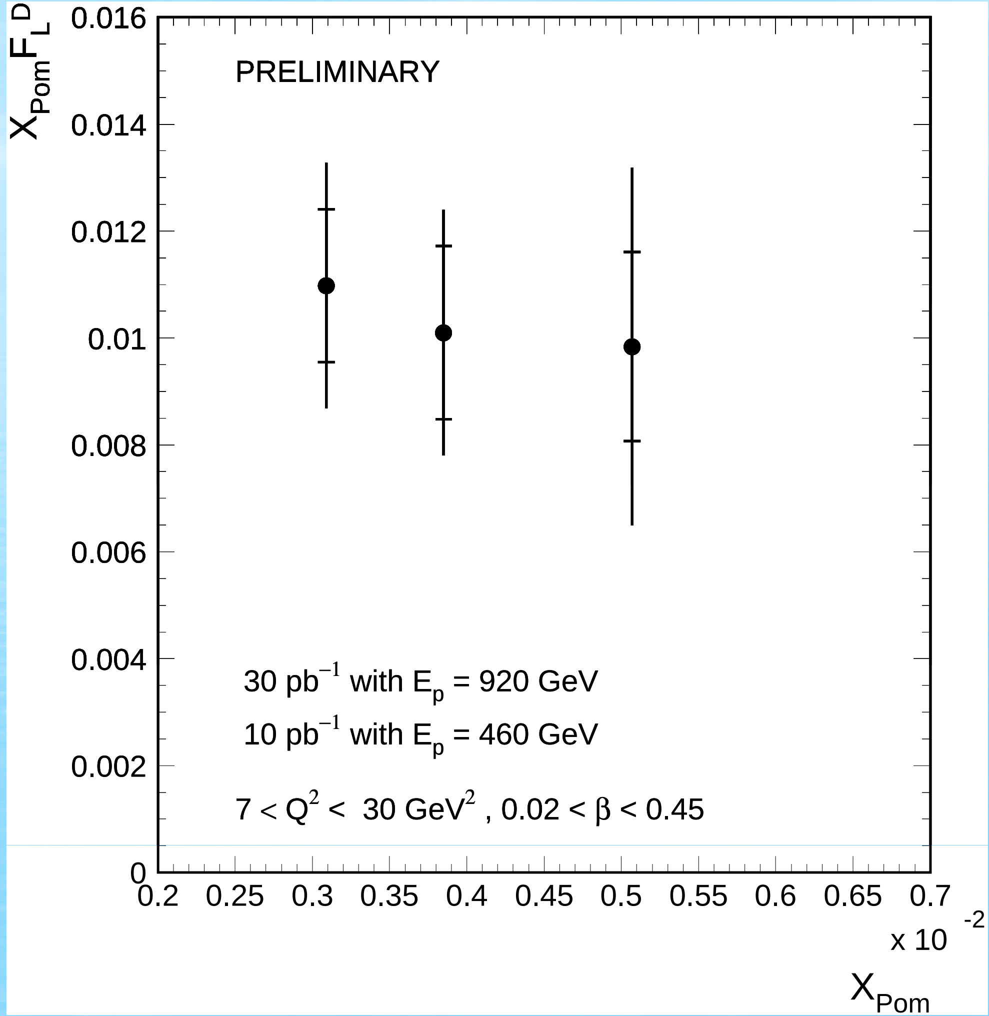
F_L Simulated Data



F_L Simulation

- 30 pb-1 @ 920 GeV
- 7 pb-1 @ 575 GeV
- 10 pb-1 @ 460 GeV

Prospects at low β based on H1 parametrisation



F_L^D at high β

Assuming $\langle F_L^D/F_T^D \rangle = 0.66$
at $0.6 < \beta < 0.9$

Preliminary expectations :

$\langle Q^2 \rangle = 13\ GeV^2$
$\langle x_{Pom} \rangle = 0.0004$
$\langle \beta \rangle = 0.75$

$\langle x_{Pom}.F^{L}{}_{D} \rangle = 0.024 \pm 0.004 \pm 0.006$

With the same assumptions on systematic sources as at low β
measurement at the 3 σ level at high β looks difficult but feasible !