Measurements of F_2 at large x

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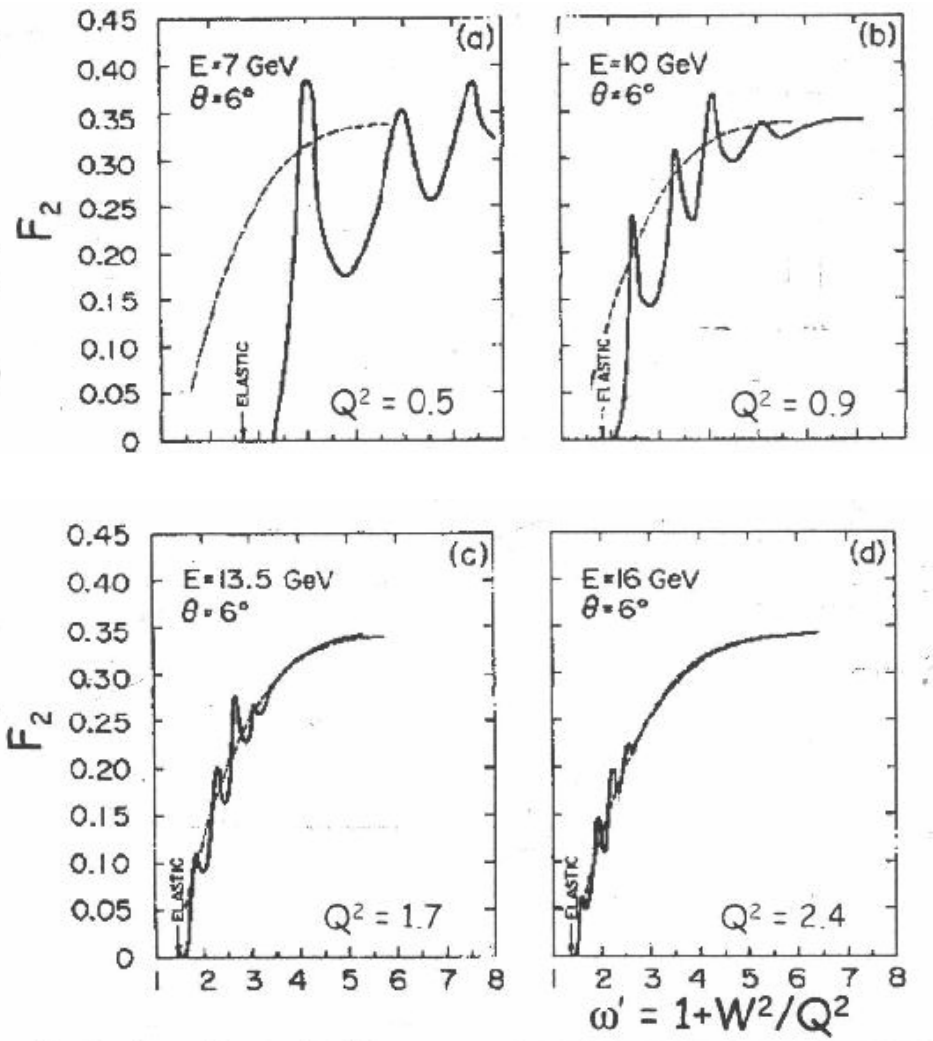
Outline

- **Quark-hadron duality**
- **Physics motivation for E00-116**
- **F_2^p at high x from E00-116 data**

Bloom-Gilman duality



'70- Bloom and Gilman observed that the prominent **resonances** in e-p scattering **do not disappear with increasing Q^2** relative to the "background" under them **but follow the DIS scaling limit curve** falling at roughly the same rate as *any "background"*.

Finite energy sum rule:

$$\frac{2M}{Q^2}\int_0^{\upsilon_m} \upsilon W_2\left(\upsilon, Q^2\right) d\upsilon = \int_1^{\left(2M\upsilon_m + m^2\right)/Q^2} \upsilon W_2\left(\omega'\right) d\boxed{\omega'}$$

'76- A QCD based explanation by de Rujula Georgi and Politzer: in the ***resonance regime*** the ***higher twist*** effects are ***small or cancel*** → **duality**

Duality in the F_2 Structure Function

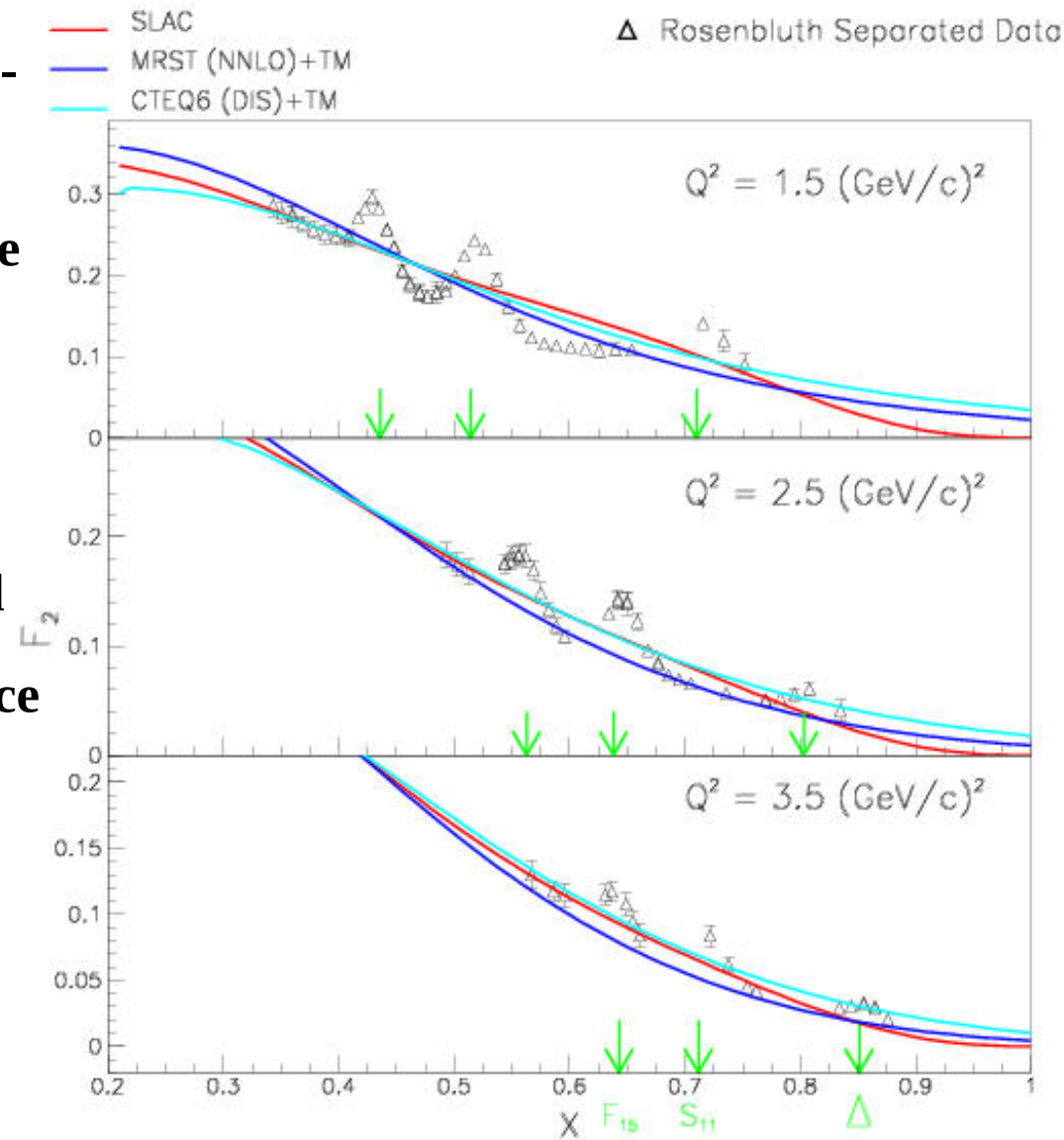
Use Bjorken x instead of Bloom-Gilman's ω'

Empirically, DIS region is where logarithmic scaling is observed: $Q^2 > 5$ GeV^2, $W^2 > 4$ GeV^2

Duality: Averaged over W, logarithmic scaling observed to work also for $Q^2 > 0.5$ GeV^2, $W^2 < 4$ GeV^2, resonance regime

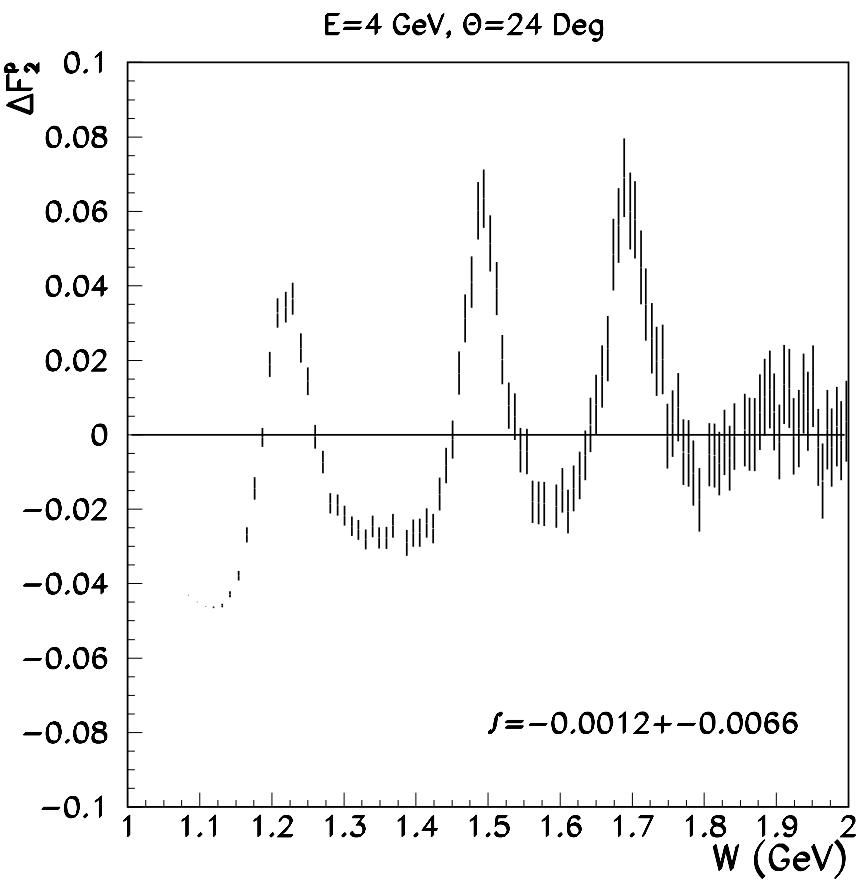
(note: $x = Q^2/(W^2-M^2+Q^2)$)

JLab results: Works quantitatively to better than 10% at surprisingly low Q^2

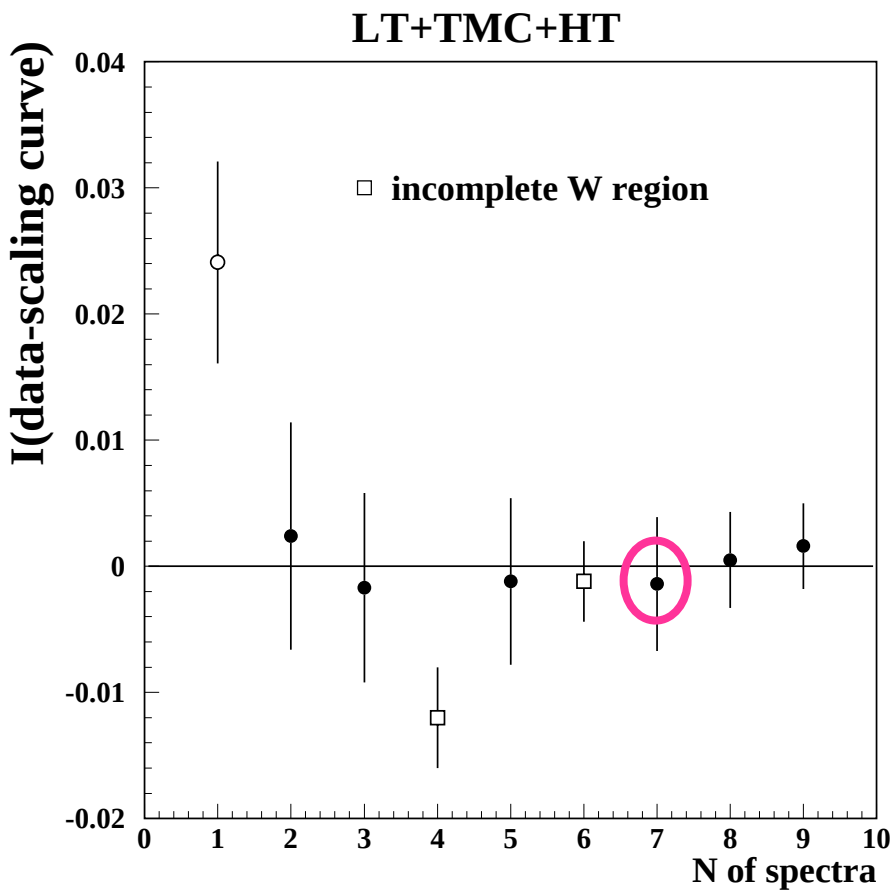


Quantification: Resonance Region F_2 w.r.t. Alekhin NNLO Scaling Curve

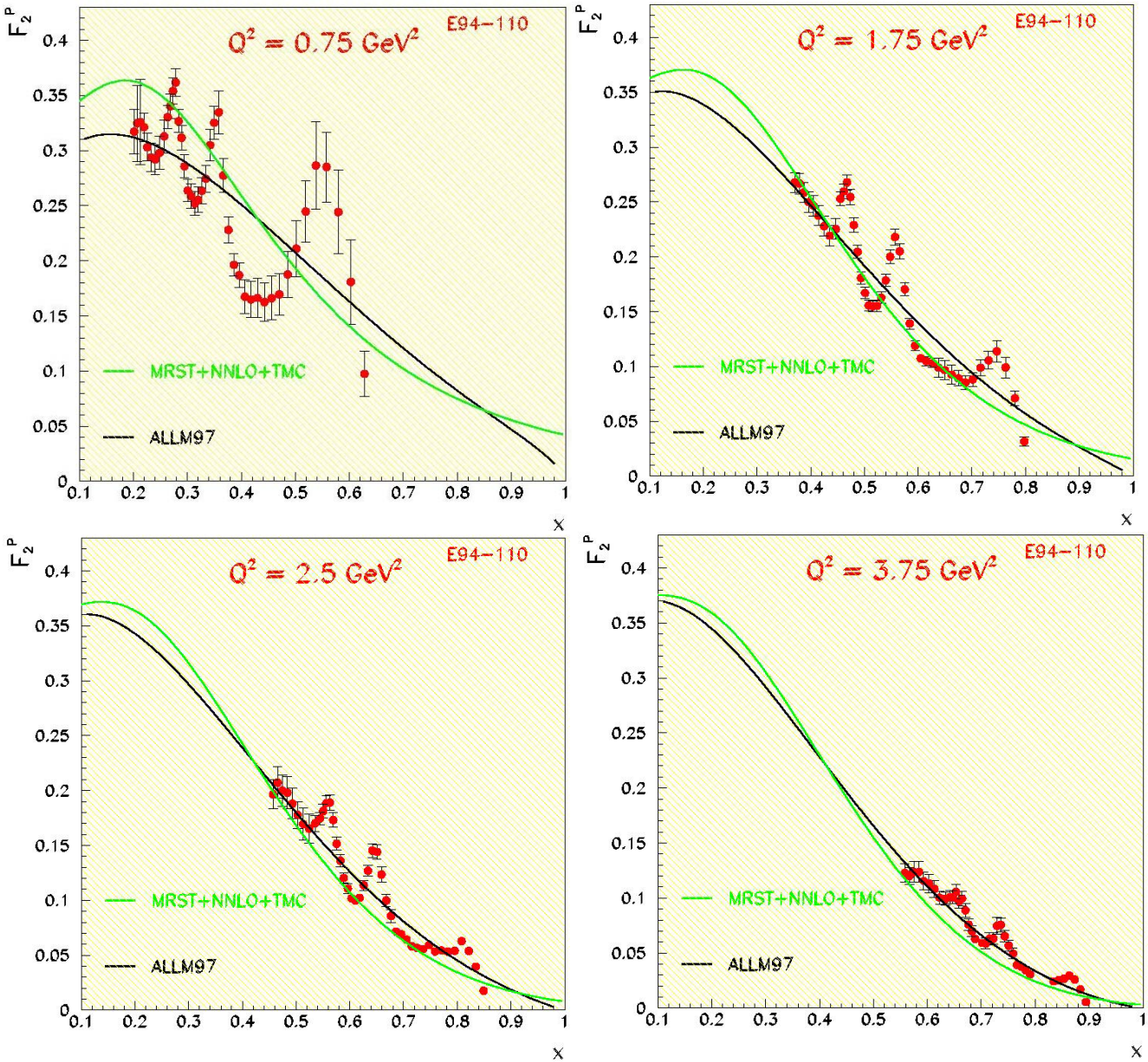
(Q^2 ~ 1.5 GeV^2)



Difference between Alekhin NNLO curve (formed from lepton-nucleon scattering only) and resonance data, *integrated for many spectra*



E94-110 Rosenbluth separated data



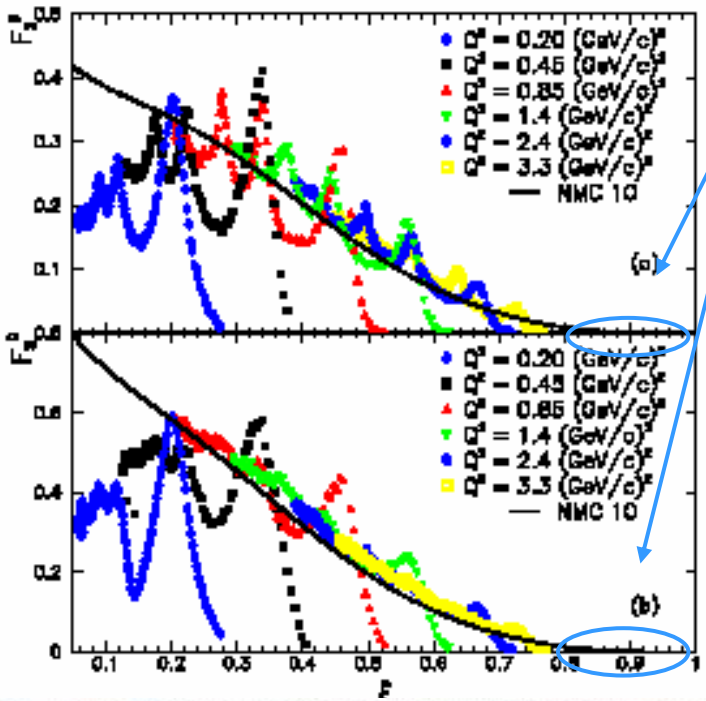
With increasing Q^2 the resonances slide towards higher x on *ALLM97* curve while pdf curve MRST+NNLO+TMC starts undershooting the data.

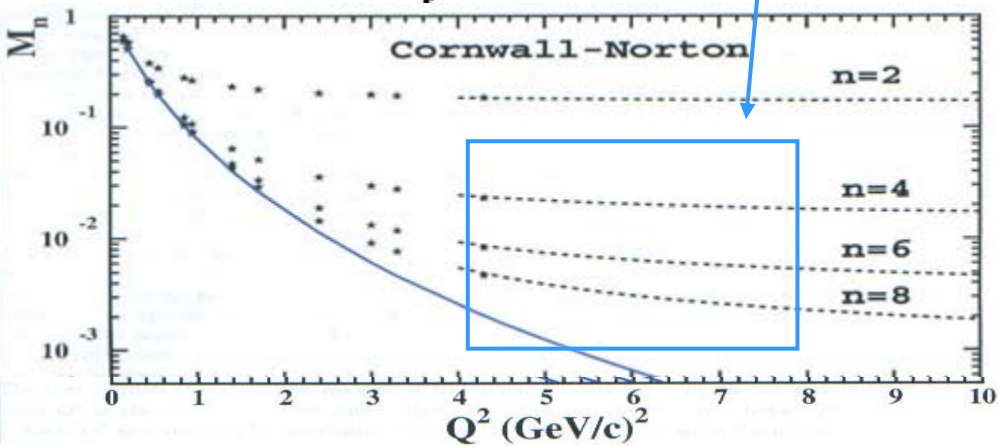
Higher Q^2/x data needed to get more information ...

E00-116 physics motivation

resonance data

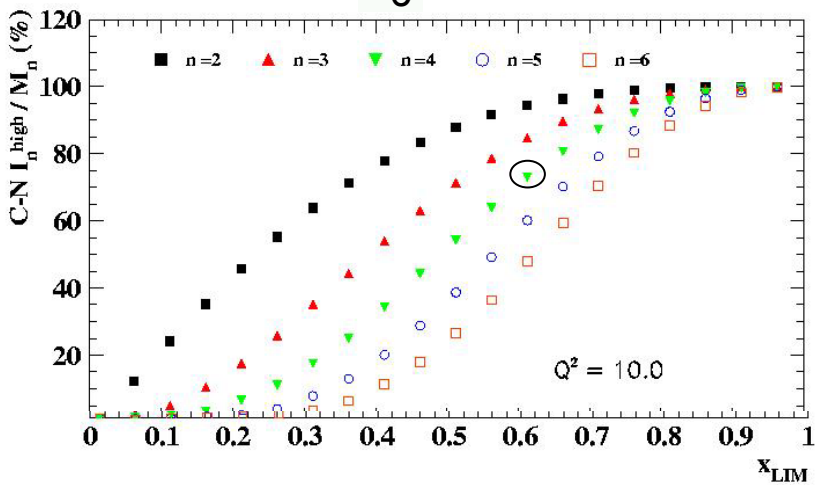
high x





- **Constrain higher moments**

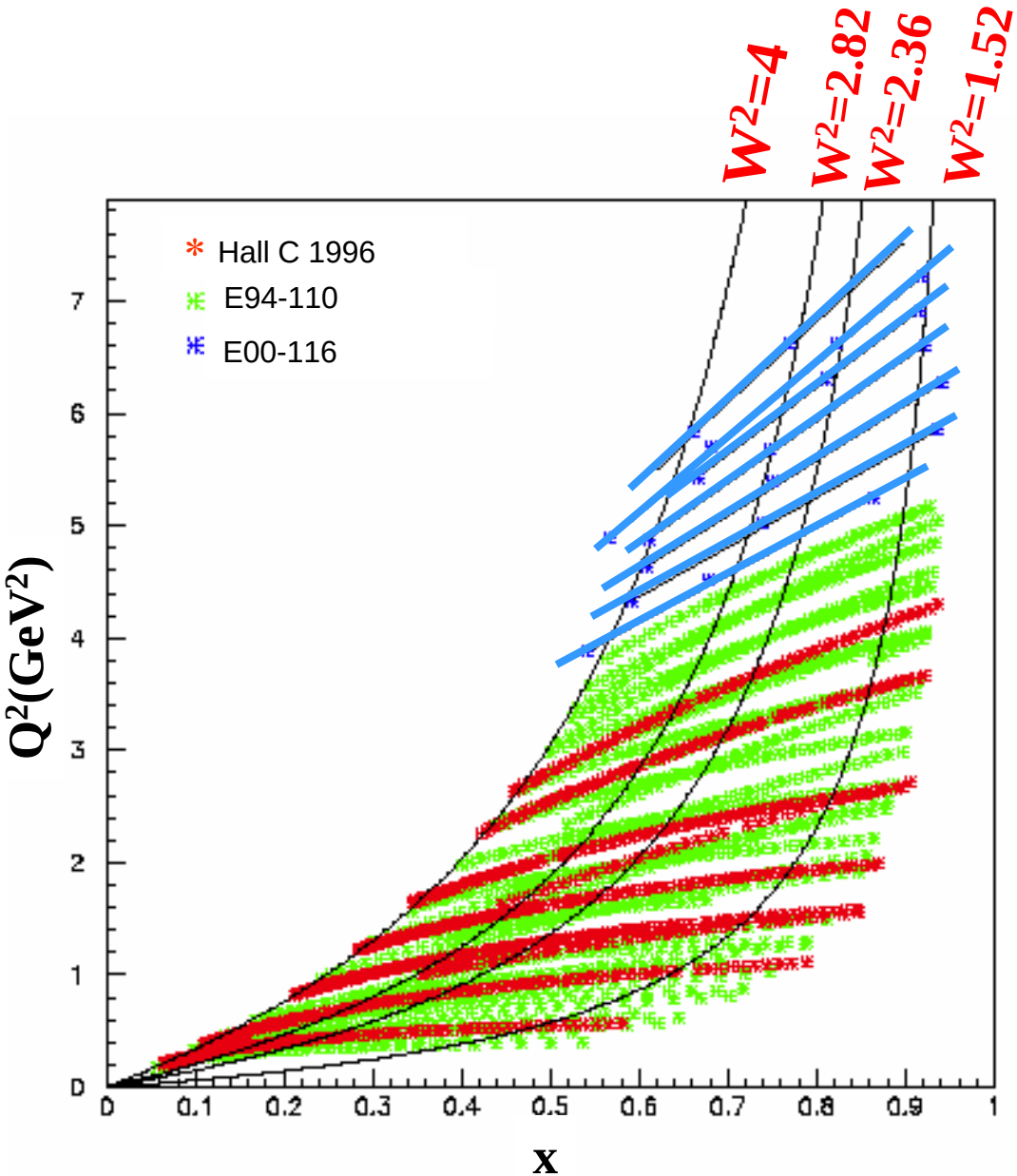
$$M_n(Q^2) = \int_0^1 dx\ x^{n-2} F(x,Q^2)$$



- **Higher twist extraction**

- **High x pdf evolution**
- **F_2^d / F_2^p ratio at large x**

E00-116 kinematics



37.93° { $Q^2 \in (3.88 - 5.25)$, $x \in (0.54 - 0.87)$

41° { $Q^2 \in (4.32 - 5.85)$, $x \in (0.59 - 0.94)$

45° { $Q^2 \in (4.63 - 6.27)$, $x \in (0.61 - 0.94)$

50° { $Q^2 \in (4.88 - 6.59)$, $x \in (0.61 - 0.92)$

55° { $Q^2 \in (5.43 - 6.91)$, $x \in (0.67 - 0.92)$

60° { $Q^2 \in (4.89 - 7.21)$, $x \in (0.56 - 0.92)$

70° { $Q^2 \in (5.83 - 6.62)$, $x \in (0.66 - 0.77)$

Background analysis

Charge symmetric background: **These are electrons coming from γ and π^0 produced in the target.** $\gamma \longrightarrow e^+e^-$ while $\pi^0 \longrightarrow \gamma\gamma \rightarrow e^+e^-$ $e^+ e^- \gamma$

The background electrons are symmetrically produced in pairs with positrons that can be detected and used for background subtraction.

We used SOS for H,D (e, e+) measurement.

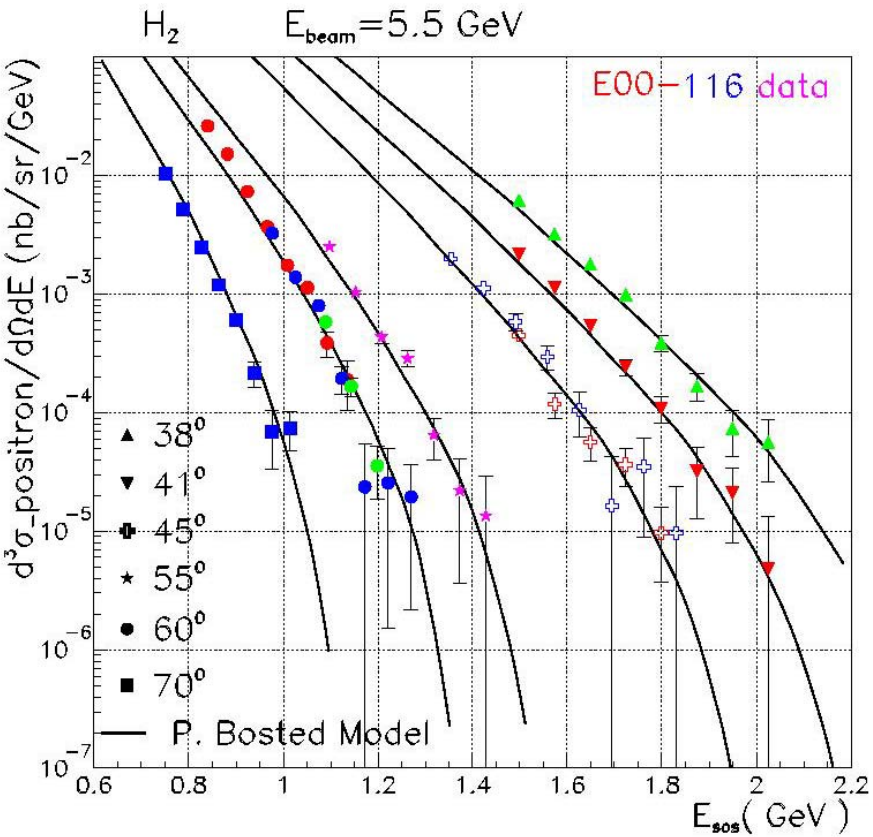
SOS has a larger acceptance than HMS. (e, e+) cross sections is varying strongly as a function of θ and E' . Therefore we need to disentangle θ and E' dependence in order to do the subtraction.

For positron cross section calculation, spectrometer acceptance corrections were applied and P. Bosted model was used for bin centering correction.

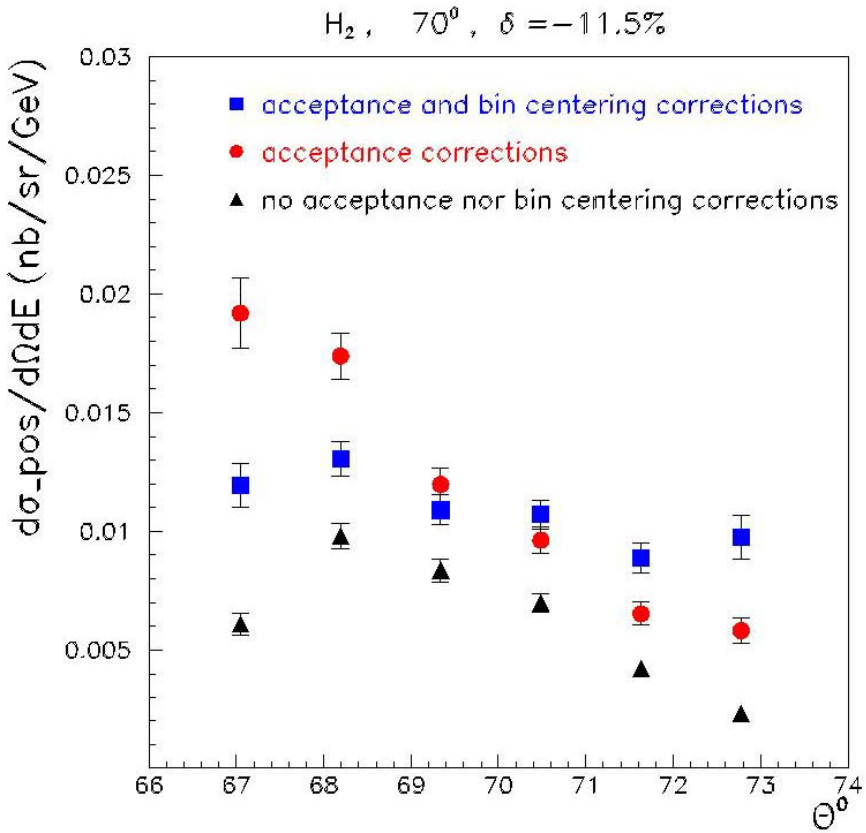
The background was subtracted as difference on a theta/momentum grid.

Background analysis

Positron cross sections for e00-116 kinematics on h_2 target as a function of momentum.



An example of positron cross section across angular acceptance before / after corrections: acceptance and bin centering corrections.



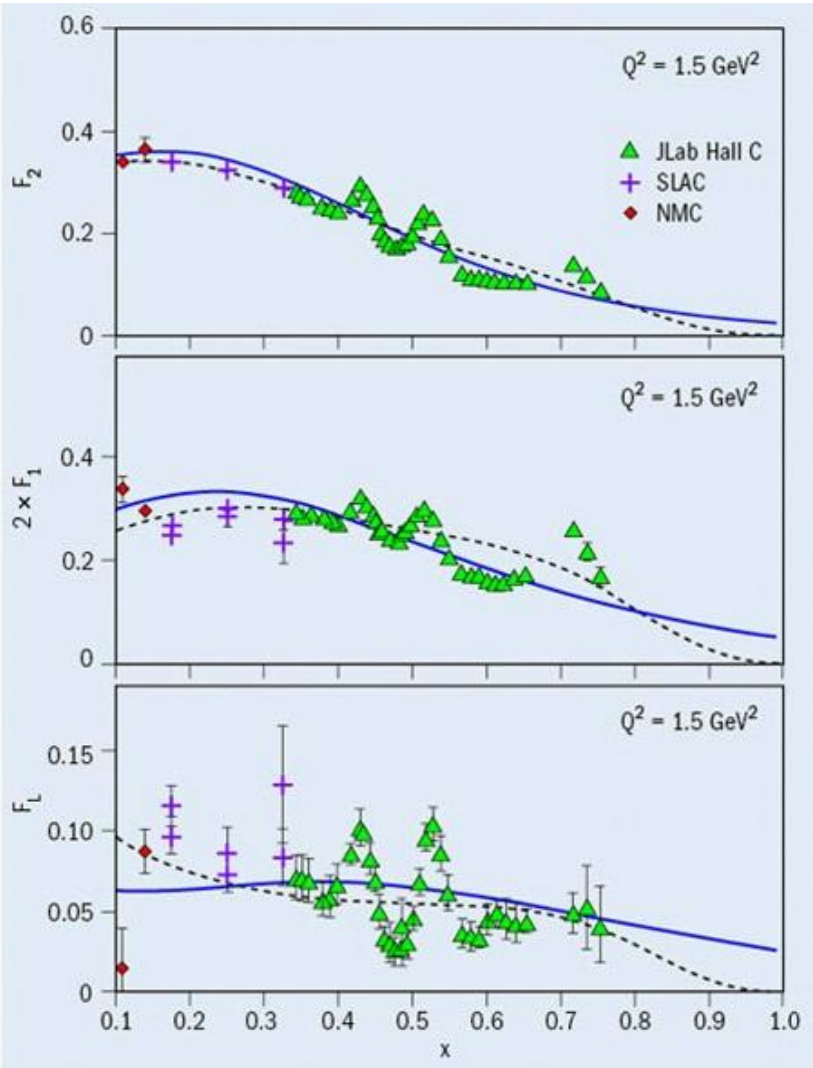
F_2 extraction

$$F_2 = \frac{d^3\sigma}{d\Omega dE'} \boxed{\frac{1+R}{1+R\varepsilon}} \frac{K\upsilon}{4\pi^2\alpha} \frac{1}{\Gamma} \frac{1}{1+\upsilon^2/Q^2}$$

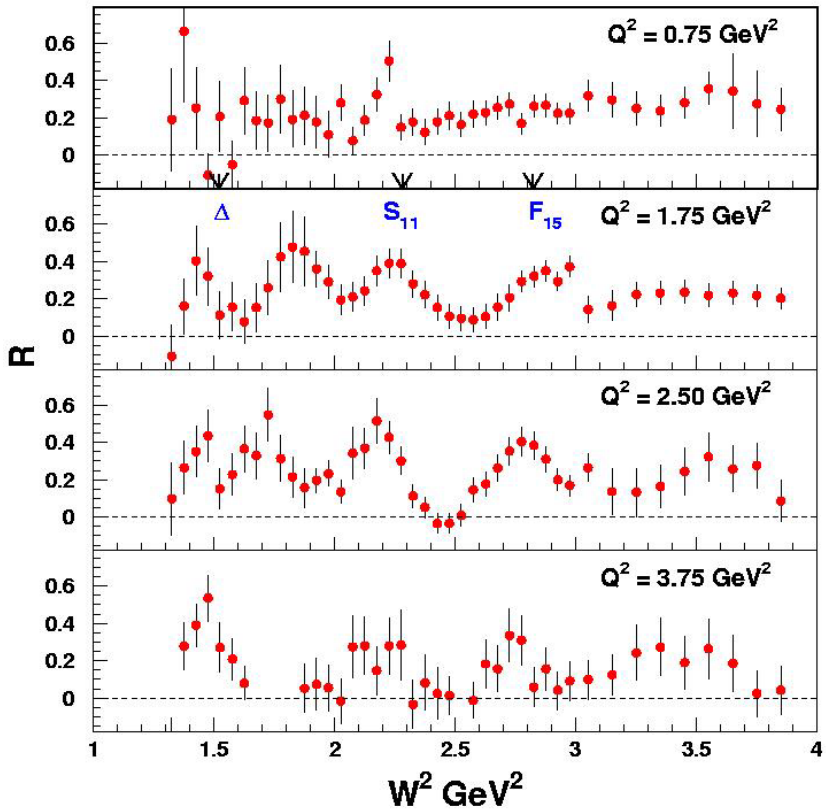
E00-116 measures $\frac{d^3\sigma}{d\Omega\, dE'}$

We wish to construct F_2 but have not measured R.

E94-110 : Separated Structure Functions



Duality works well for $2xF_1(F_T)$, F_L and works for R.



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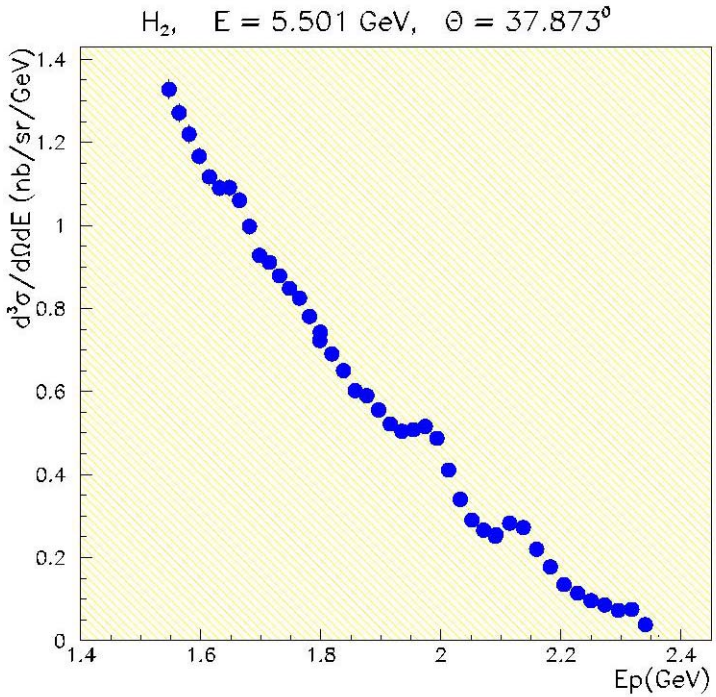
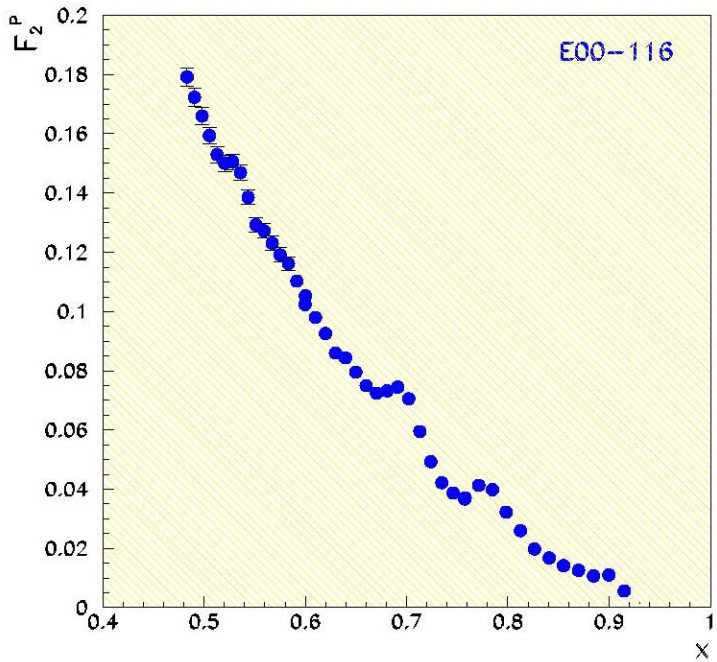
$$F_2 = \frac{d^3\sigma}{d\Omega dE'} \boxed{\frac{1+R}{1+R\varepsilon}} \frac{K\upsilon}{4\pi^2\alpha} \frac{1}{\Gamma} \frac{1}{1+\upsilon^2/Q^2}$$



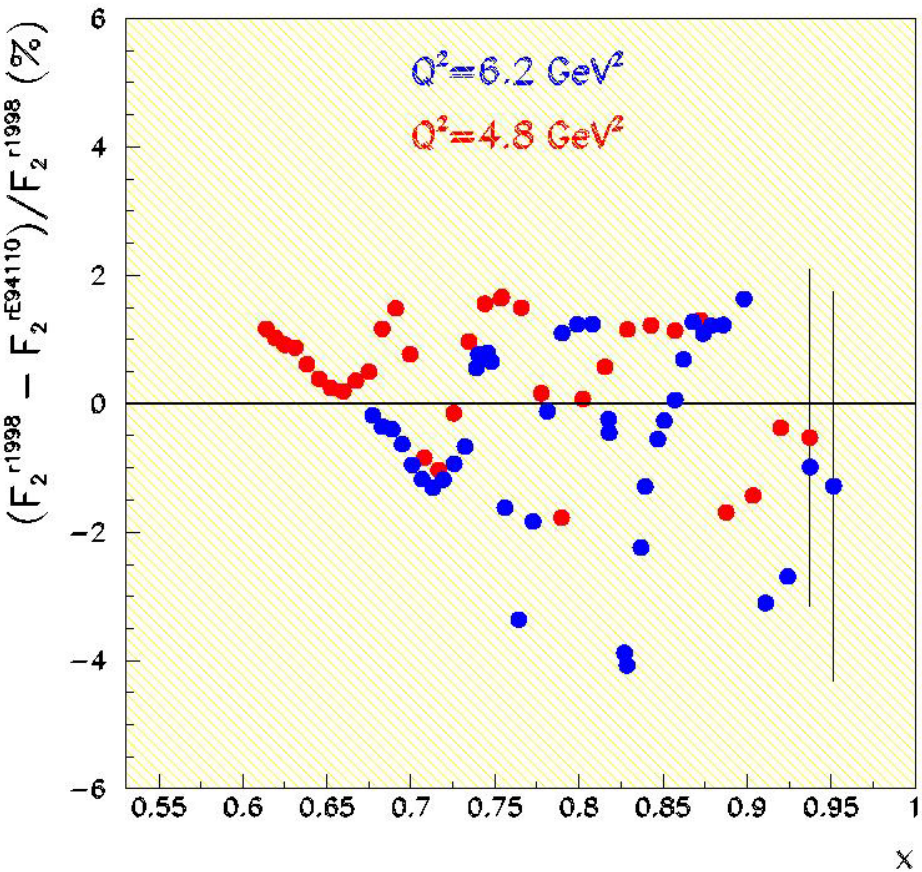
R1998

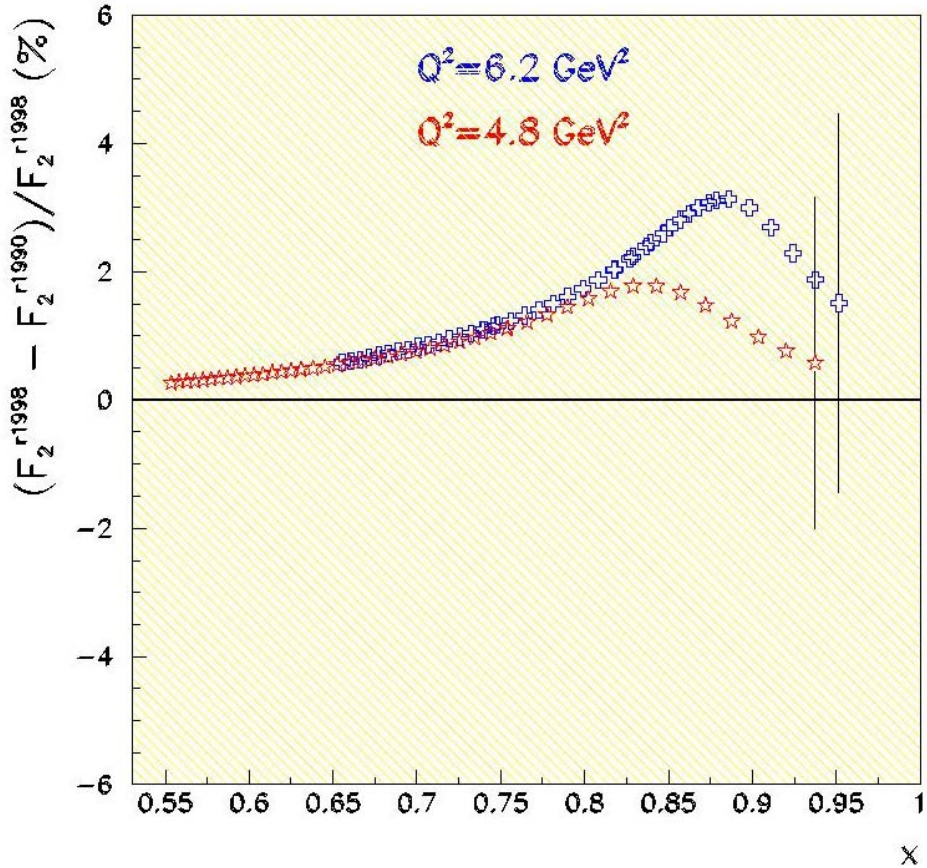


For F_2 extraction R1998 was used.

F_2 sensitivity to R parameterization

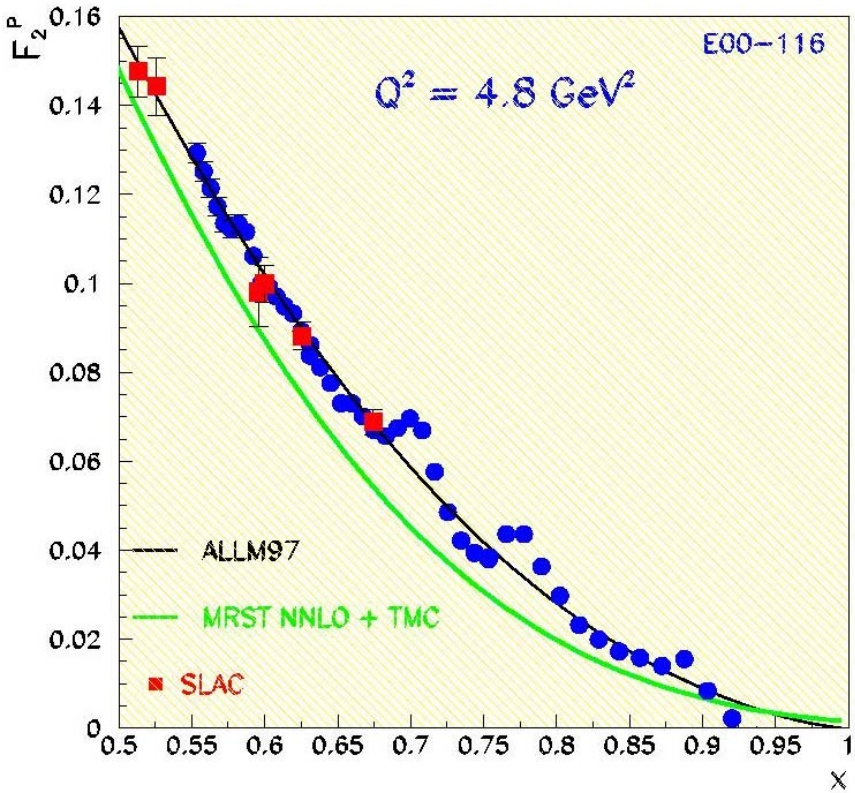
R1998 was used to extract F_2 from the data. The relative difference in F_2 when using R94-110 or R1990 as opposed to R1998 is ~ 2%. So the estimated uncertainty on F_2 originating from the R parameterization used is 2%.

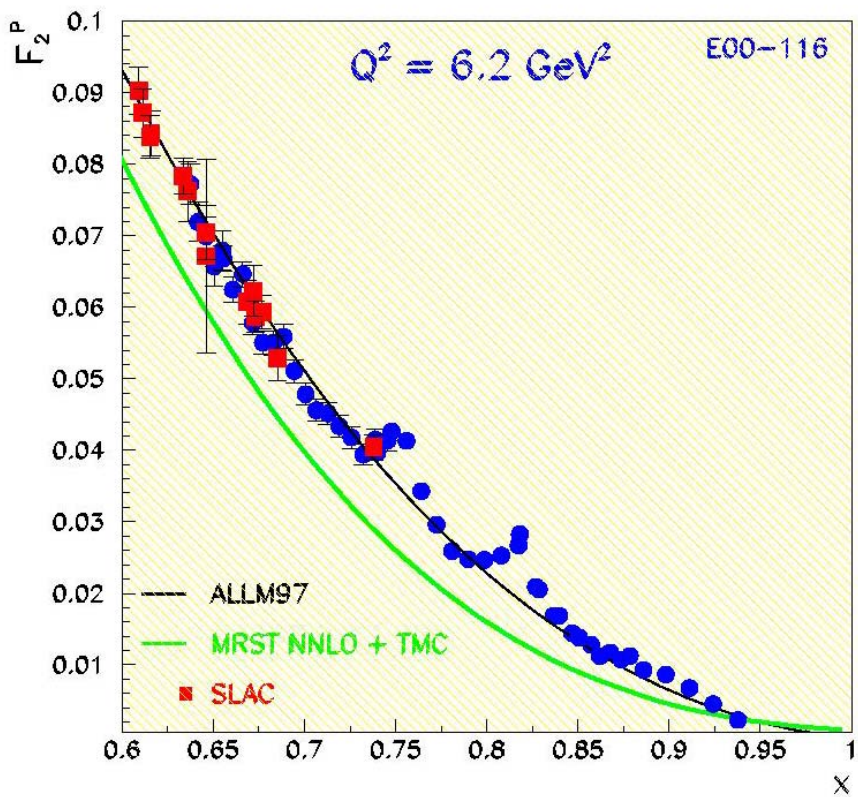




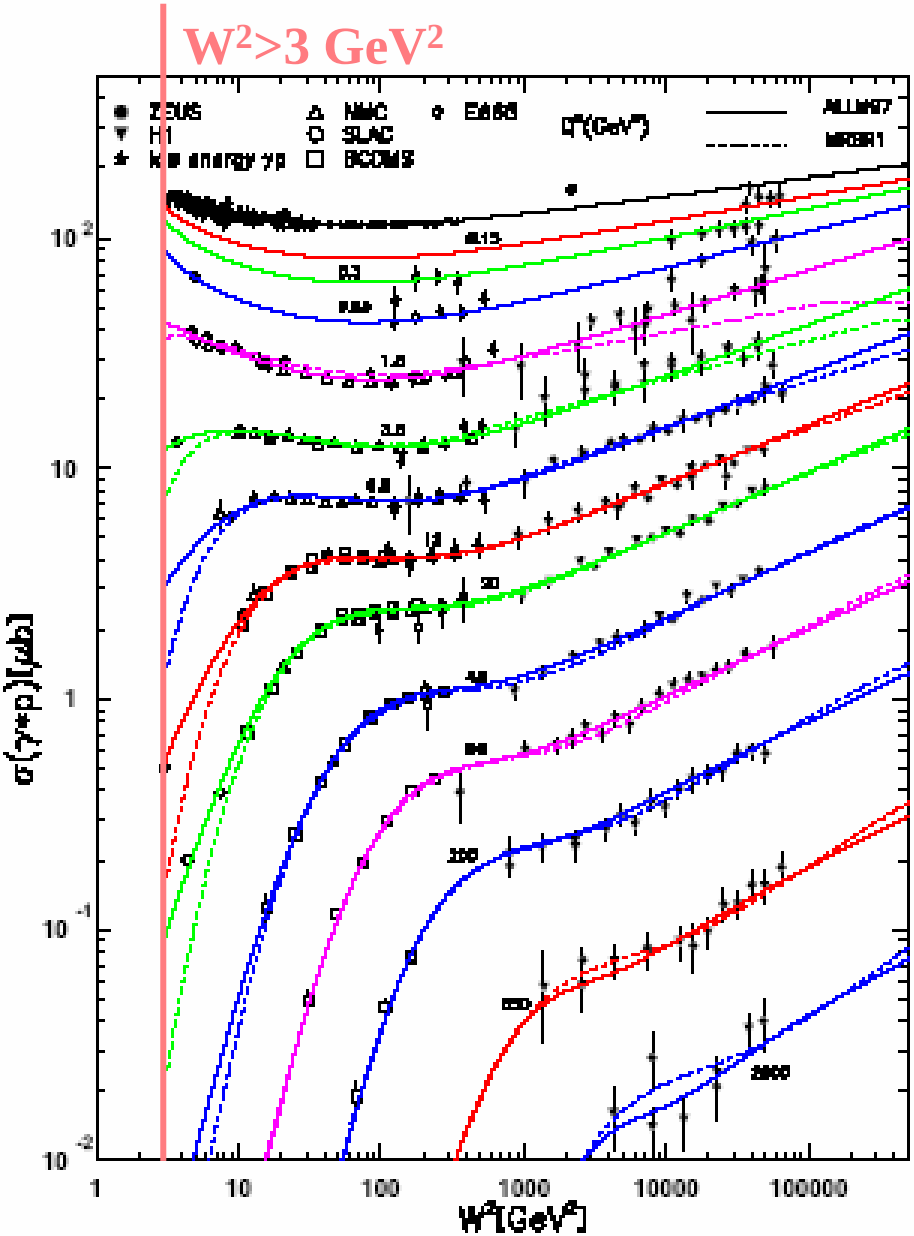
F_2^p from E00-116 data

- As observed from E94-110 , MRST pdf evolution curve undershoots the data at intermediate Q^2 , high x.
- ALLM97 fit behaves , to a certain degree, as a "scaling curve" for the resonance data.





What is ALLM97 ?



ALLM97 (Abramowicz,Levin,Levy,Maor) is a fit to a wide range of γ^*p scattering data(all existing data by 1997) with $W^2>3$ GeV^2 including also photoproduction data (γp).

The fit form assumed for F_2 is the product of:

- $Q^2/(Q^2+m_0^2)$
- $c_{P,R}(t)*x_{P,R}^{a_{P,R}(t)}*(1-x)^{b_{P,R}(t)}$

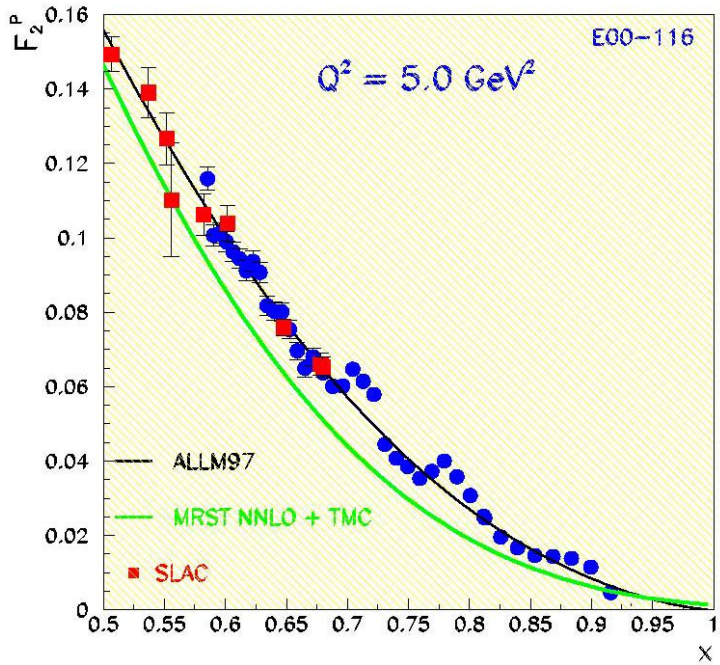
where $t = \ln\left\{\frac{\ln[(Q^2+Q_0^2)/\Lambda^2]}{\ln(Q_0^2/\Lambda^2)}\right\}$

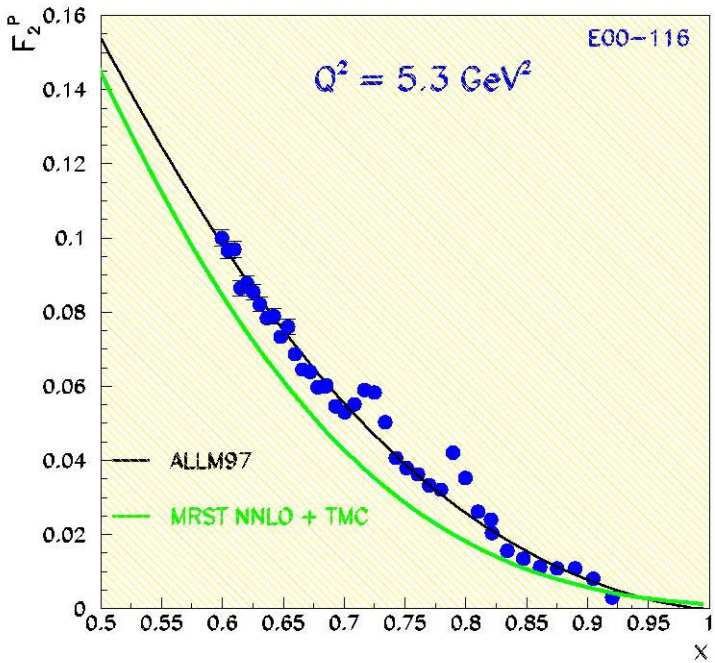
$x_{P,R}$**=modified Bjorken x**

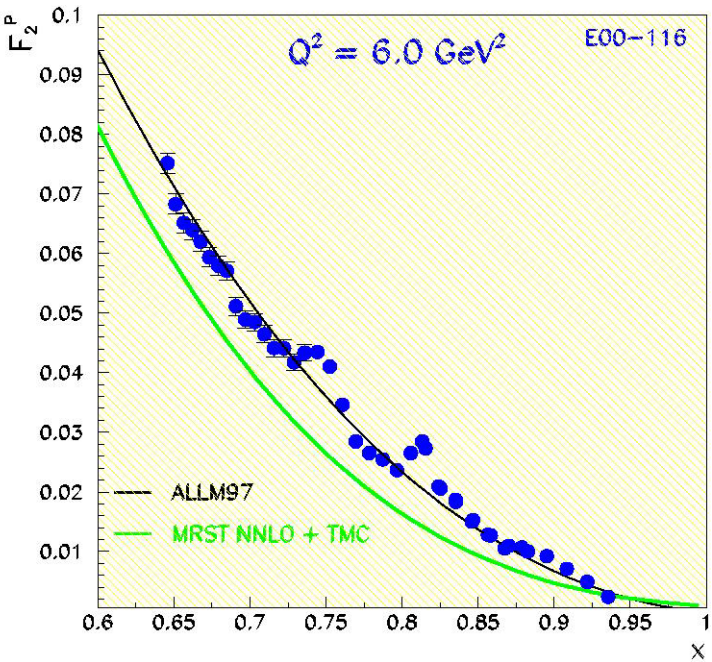
$1/x_{P,R}=1+(W^2-M^2)/(Q^2+m^2_{P,R})$

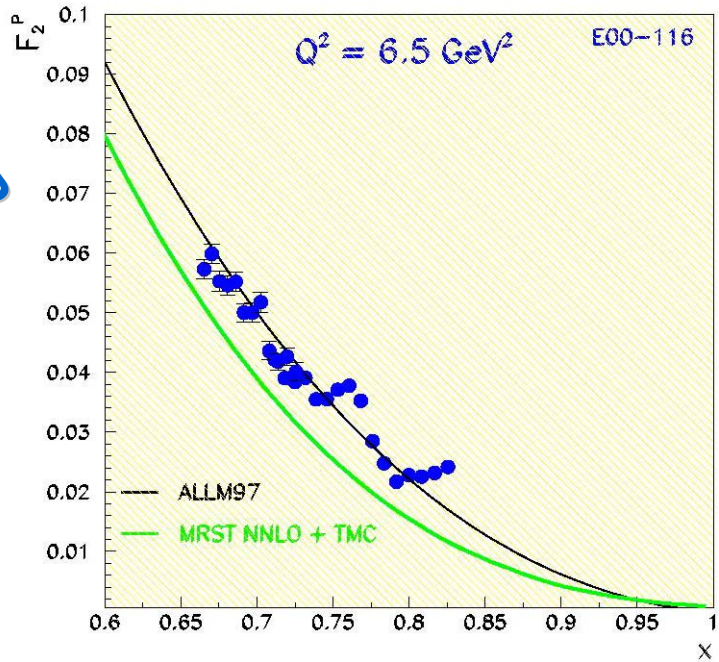
Remaining spectra of

E00-116 F_2^p



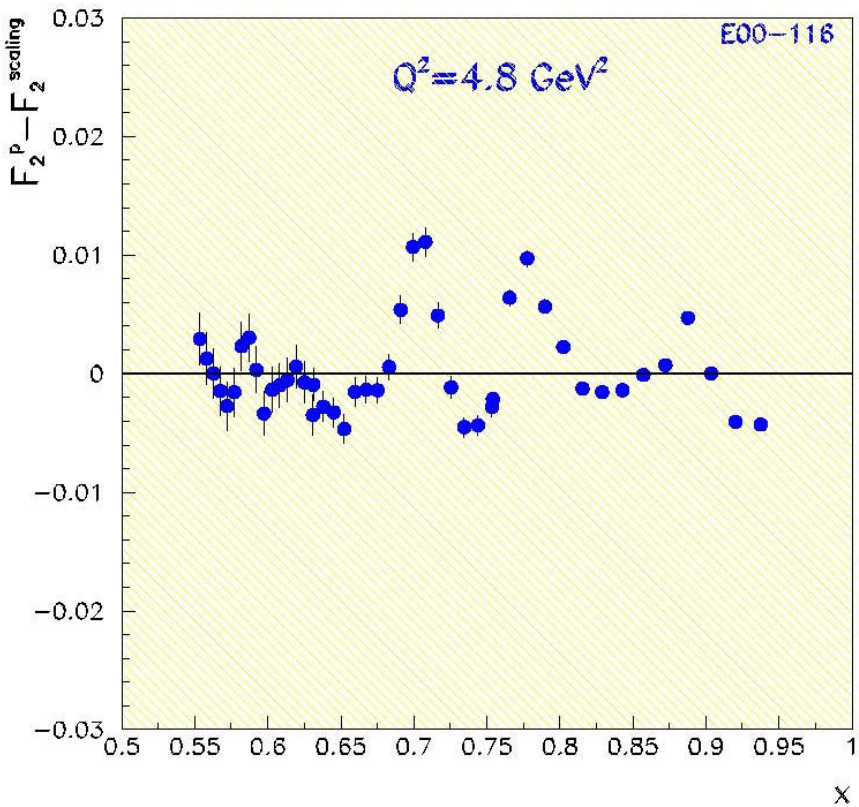


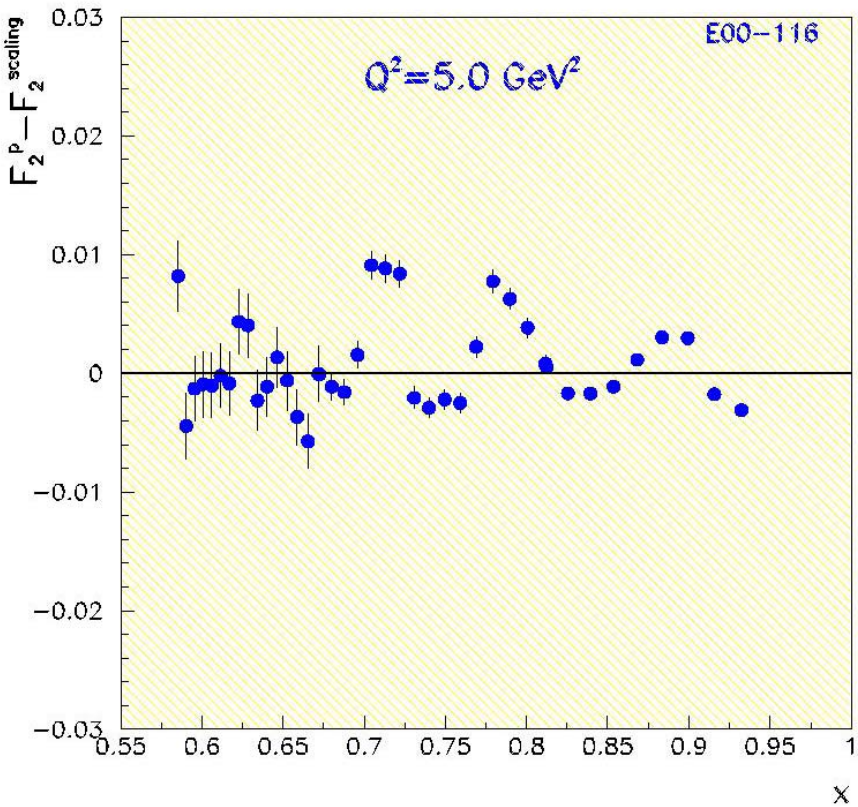




“Duality studies”

ALLM97 fit was used, at this stage, as scaling curve for “duality studies”.



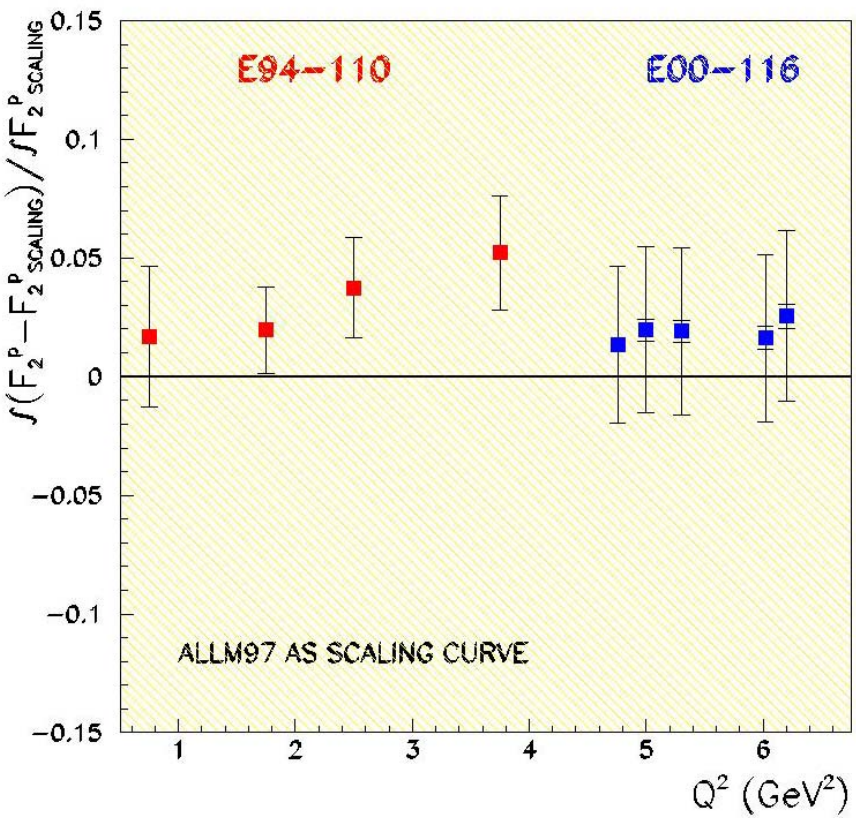


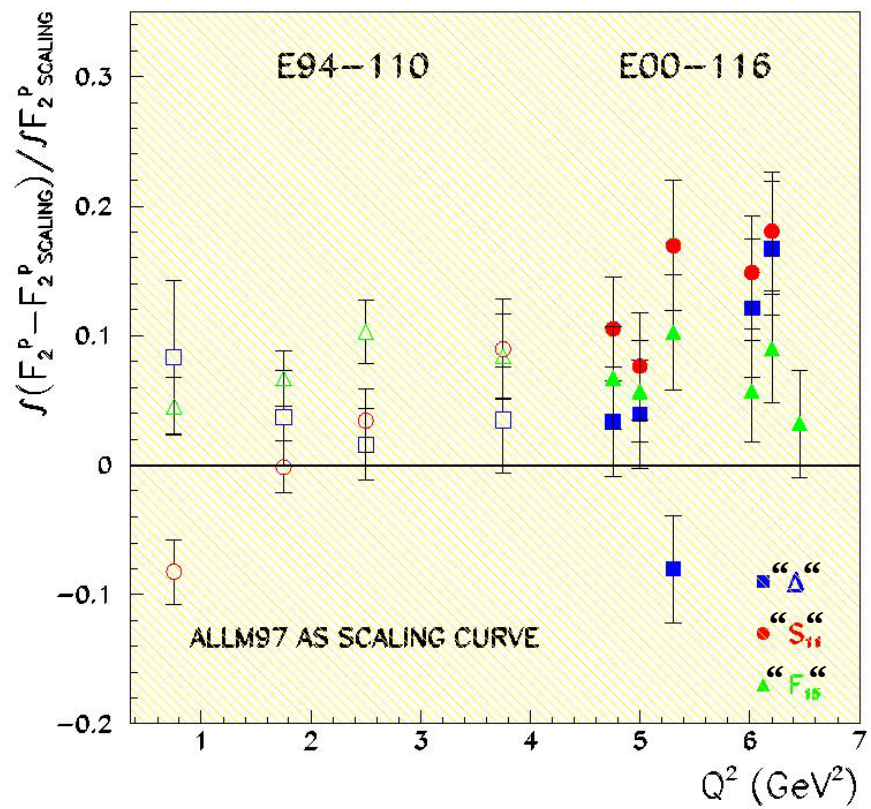
"Duality studies"

Global duality: when integrating over the entire spectrum - resonance + DIS region – with ALLM97 as scaling curve, duality holds up to 2% .

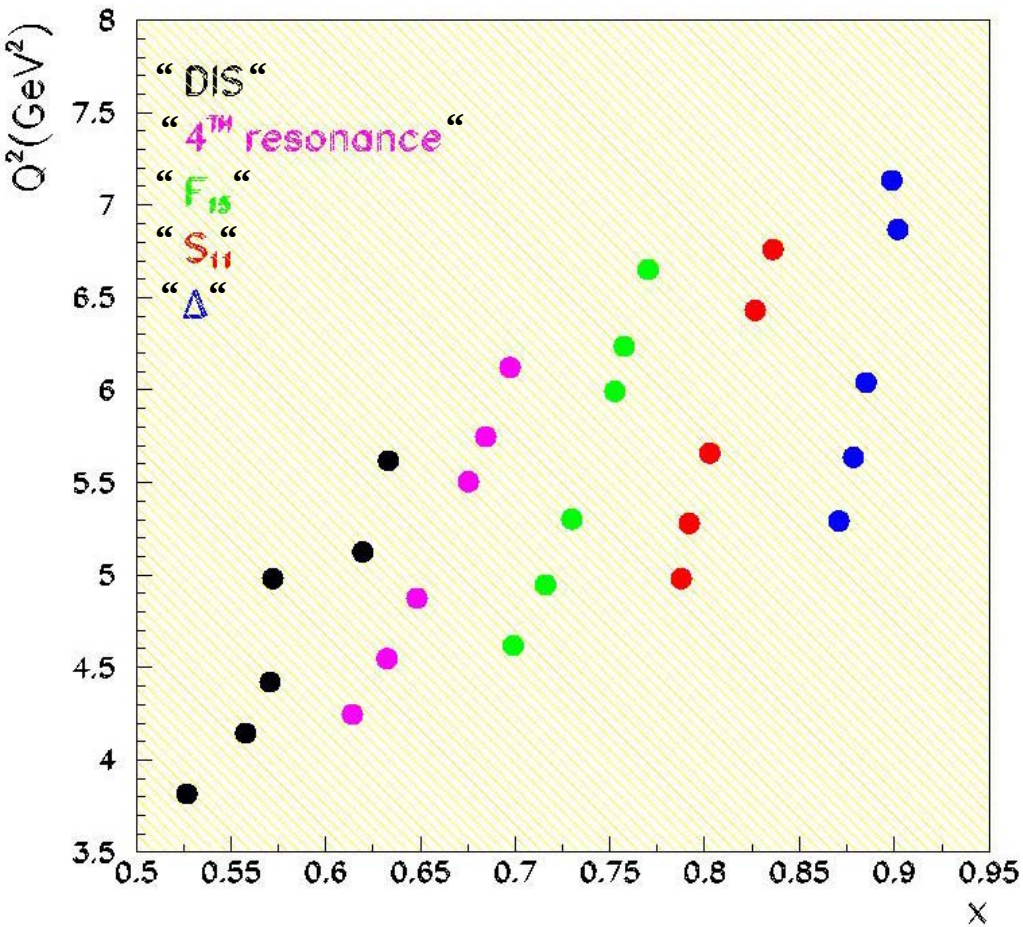
Local duality: when integrating region by region the resonances *seem* 10% higher than ALLM97 fit, on average.

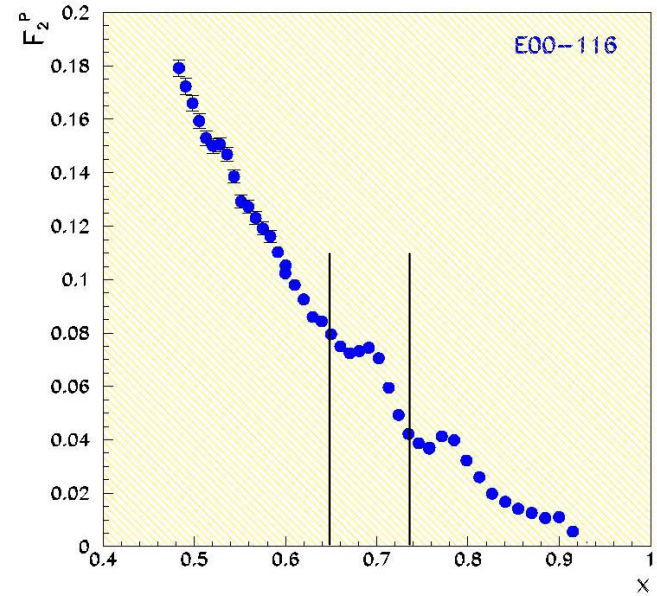
W^2 cuts:
- **Δ → (1.3 – 1.9) GeV^2**
- **S → (1.9 – 2.5) GeV^2**
- **F → (1.9 – 3.1) GeV^2**





$F_2^p(x,Q^2)$ "kinematics"





These

↓

W^2 cuts:

- Δ → (1.3 – 1.9) GeV^2
- S → (1.9 – 2.5) GeV^2
- F → (1.9 – 3.1) GeV^2
- 4th → (3.1 – 3.9) GeV^2
- DIS → (3.9 – …) GeV^2

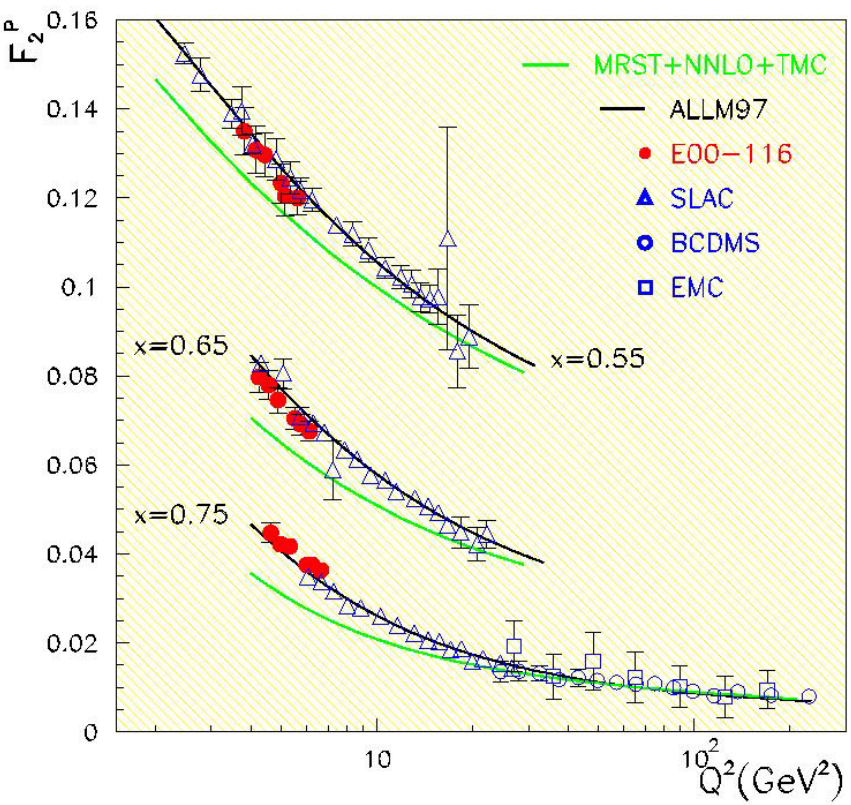
↓

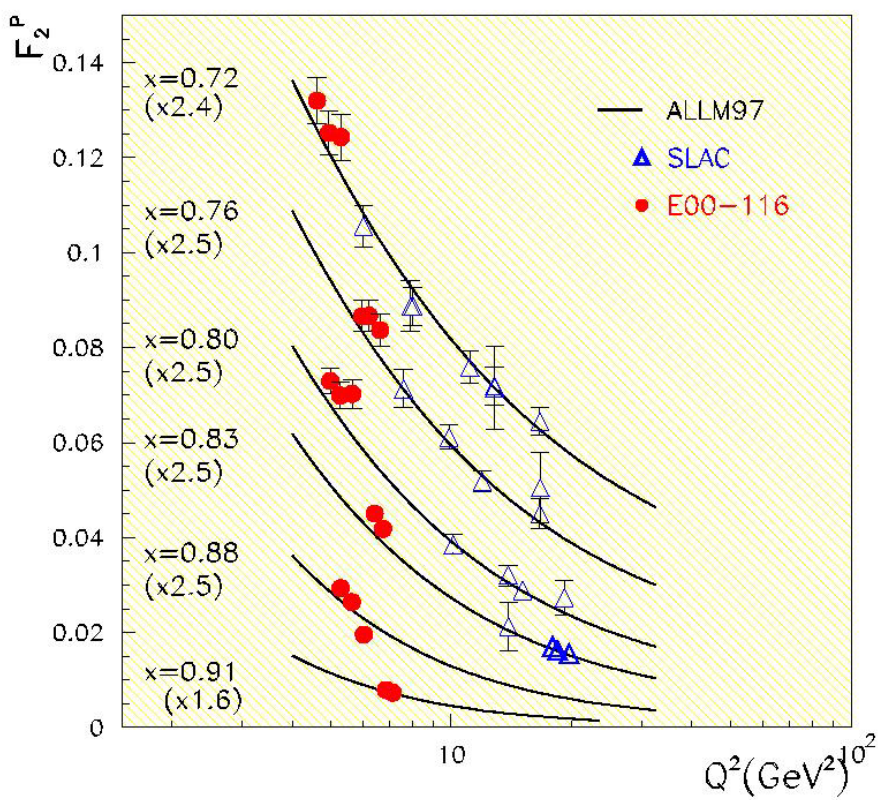
were used to average over each dis / resonance region, for a given scan, in order to obtain $F_2^p(x,Q^2)$.

Then…

F_2^p dependence of $Q^2 \Longrightarrow F_2^p(Q^2)|_{x=const.}$

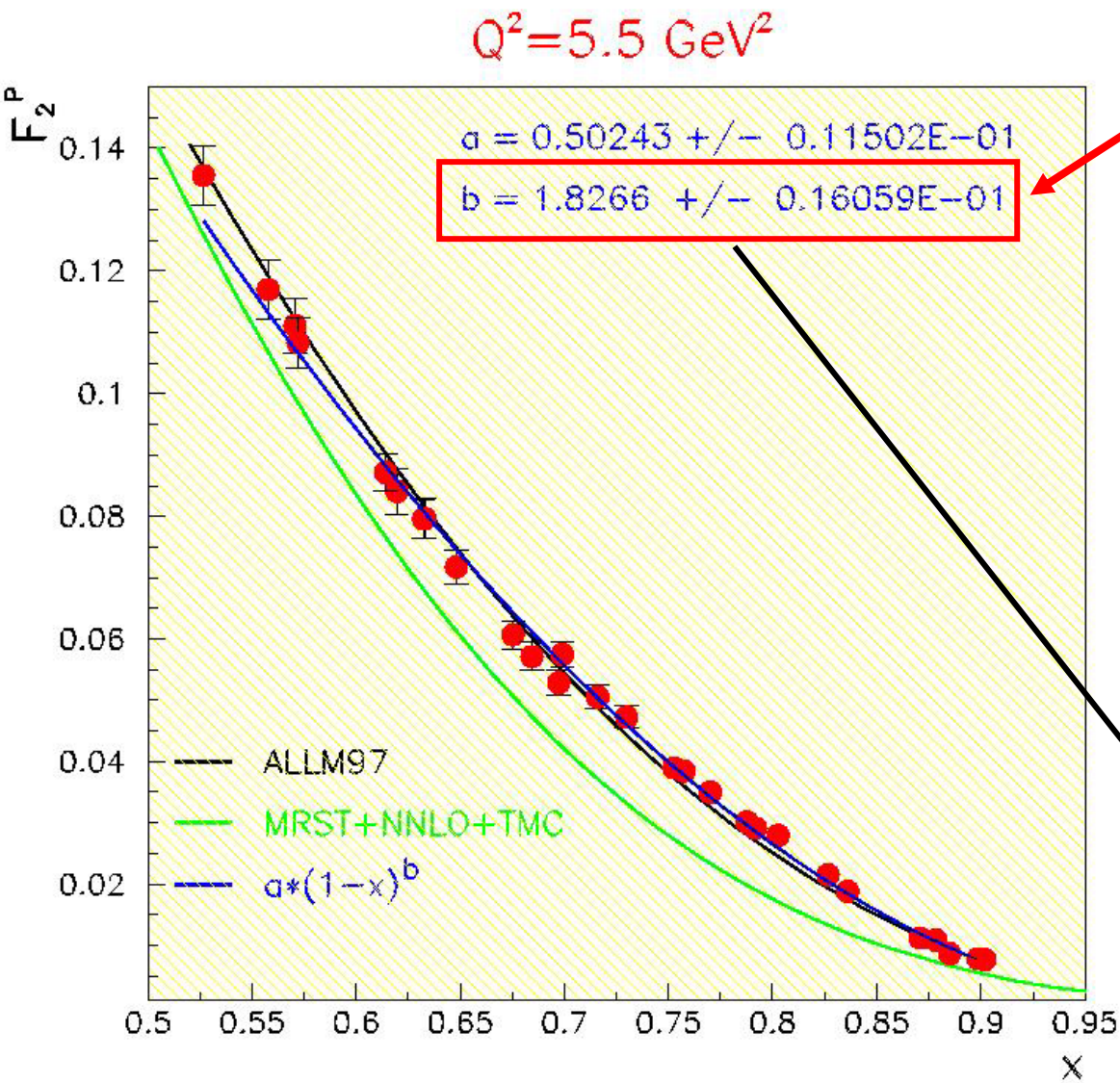
ALLM97 fit was used to bin-center $F_2^p(x,Q^2)$ "points" at different kinematics where world data exist.
E00-116 data were compared to world data (where found) and they follow overall the same Q^2 behavior as ALLM97.





$F_2(x)|_{Q^2=const.} \sim (1-x)^b$

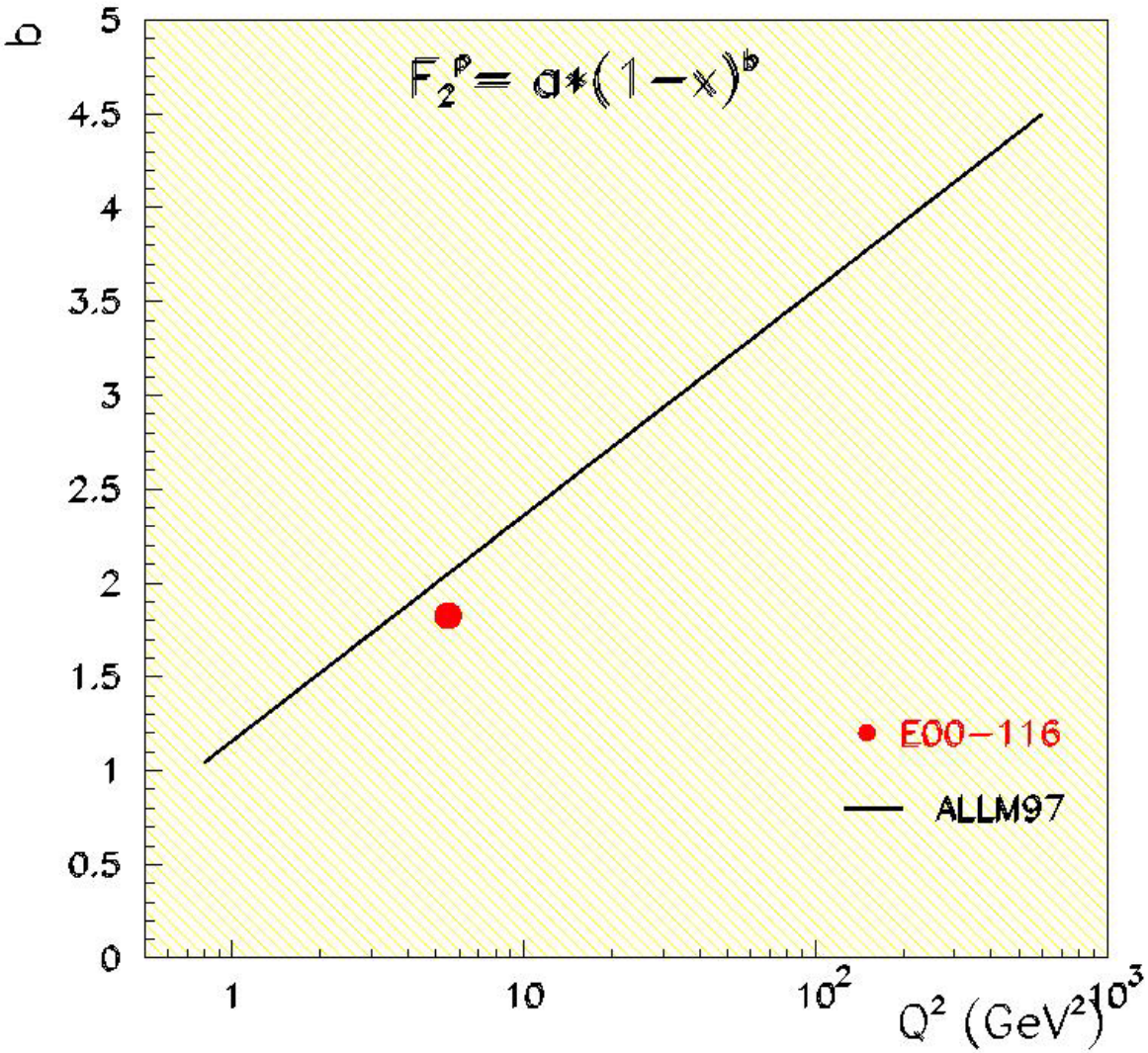
?



For a fixed Q^2, the F_2 dependence of x goes like $(1-x)^b$.

E00-116 F_2^p "points" were centered at a fixed $Q^2 = 5.5$ GeV^2 and the x dependence of F_2^p was fitted.

If compared to ALLM97…



If fitting the x dependence of <u>F_2^p-ALLM97</u> for <u>various Q^2</u>, a ALLM parameterization for <u>"b power" as a function of Q^2</u> is obtained.

E00-116 is in agreement with calculation of "b power" dependence of Q^2 using ALLM97.

Summary

- **F_2^p extracted from E00-116 resonance data were shown. With increasing Q^2/x they slide on ALLM97 curve but are becoming systematically higher then MRST+NNLO+TMC curve.**

- **Global and local "duality studies" were shown with ALLM97 as scaling curve but a W^2 cut study needs to be done for an accurate quantitative estimation of local duality.**

- **F_2^p dependence of Q^2/x for E00-116 data were checked against world data, ALLM97 fit and MRST+NNLO+TMC. E00-116 data follow the Q^2 / x behavior of ALLM97 fit.**

- **All the studies are preliminary since iteration for both H_2 and D_2(not shown here) data still needs to be done.**

- **F_2^d extracted from E00-116 D_2 data will follow soon…**

- Moments of the Structure Function $M_n(Q^2) = \quad dx\ x^{n-2}F(x,Q^2)$

  If n = 2, this is the Bloom-Gilman duality integral!

- Operator Product Expansion

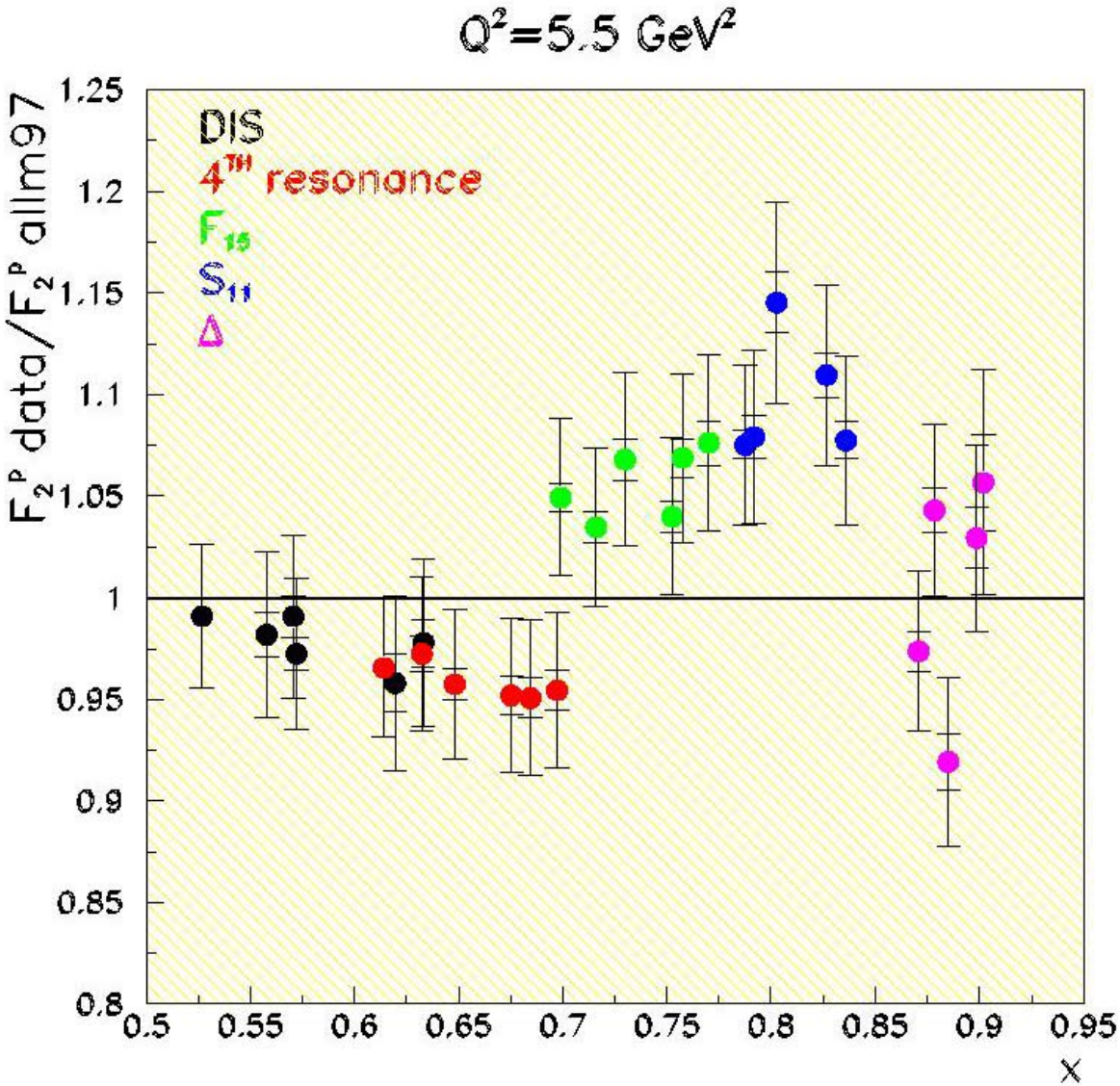
$$M_n(Q^2) = \sum (nM_0{}^2/\ Q^2)^{k-1}\ B_{nk}(Q^2)$$

higher twist logarithmic dependence

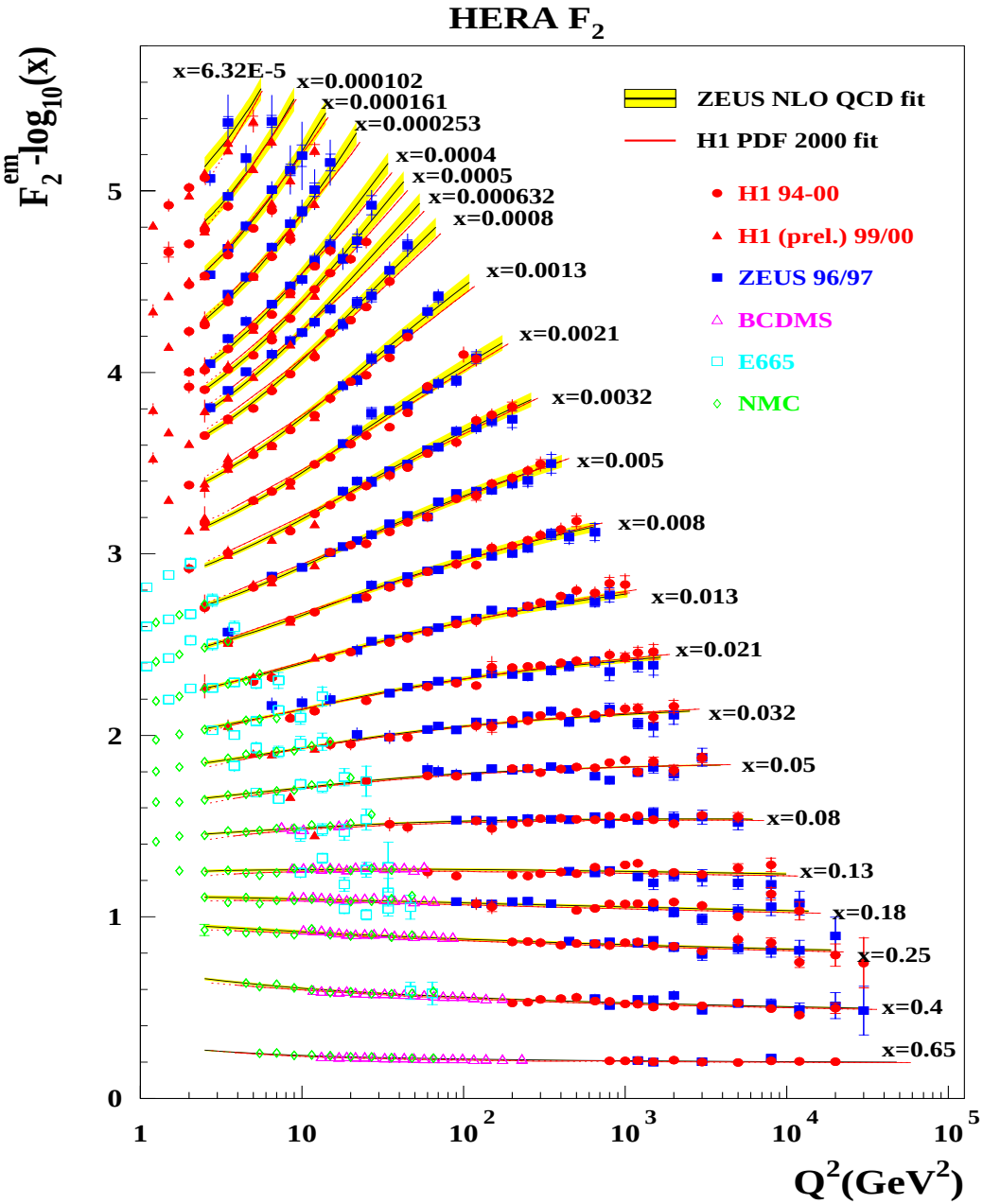
- Duality is described in the Operator Product Expansion

  as higher twist effects being small or canceling

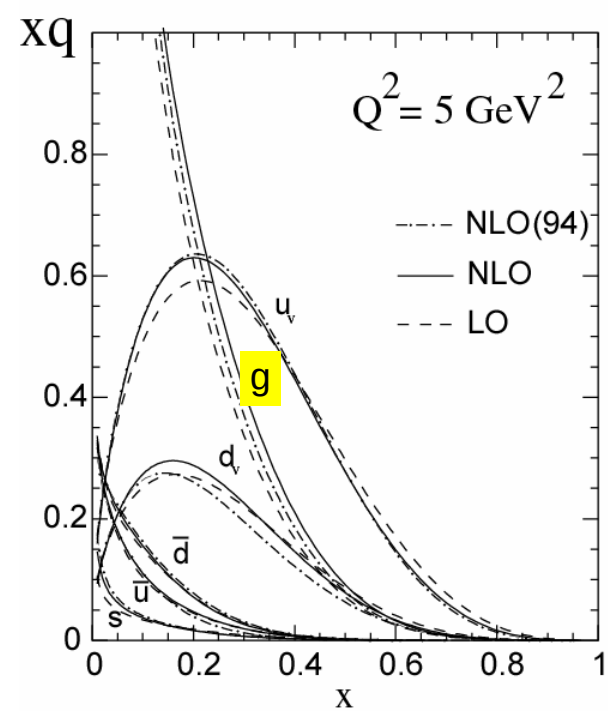
  DeRujula, Georgi, Politzer (1977)

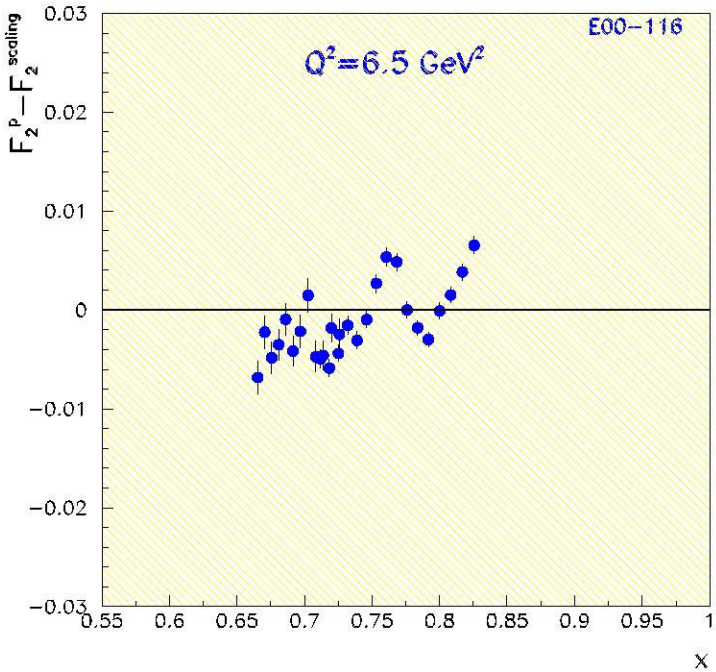

Q^2=5.5 GeV^2
DIS
4TH resonance
F_{15}
S_{11}
Δ
F_2^p data/F_2^p allm97
1.25
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
0.5
0.55
0.6
0.65
0.7
0.75
0.8
0.85
0.9
0.95
x

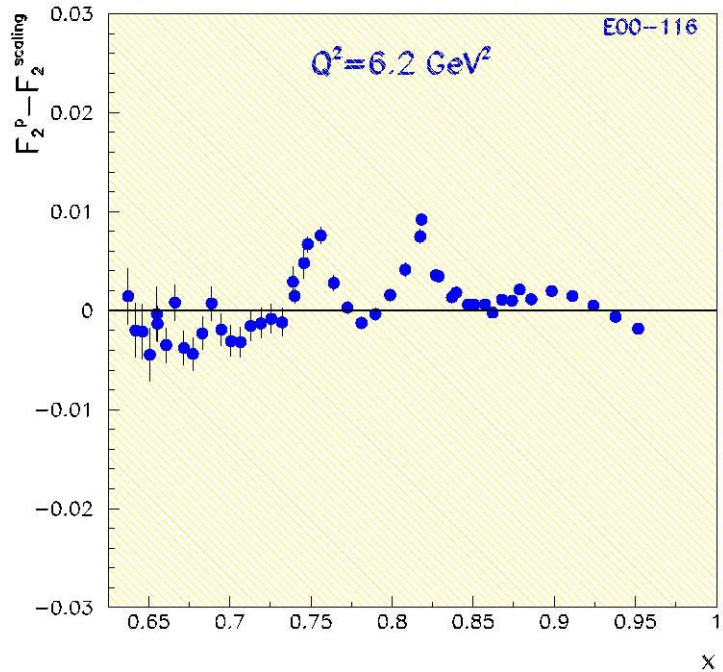
World Data on F_2^p Structure Function

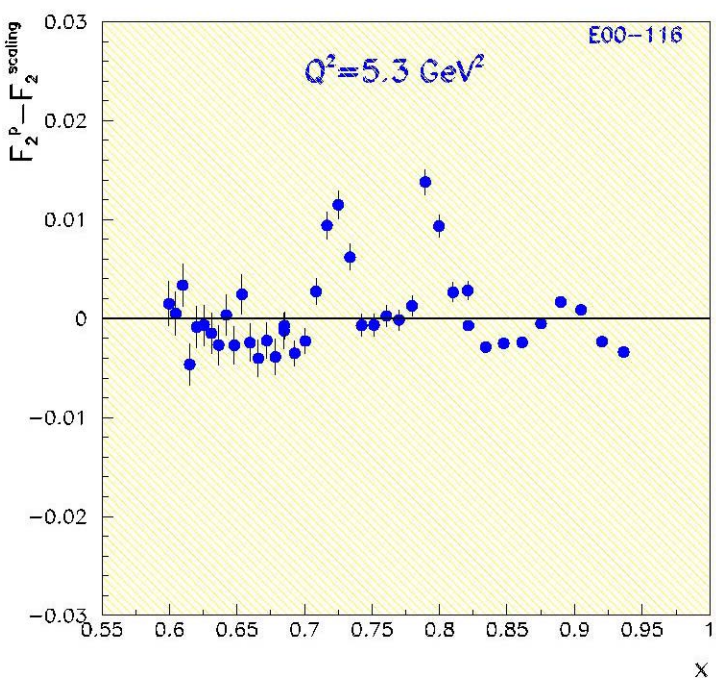


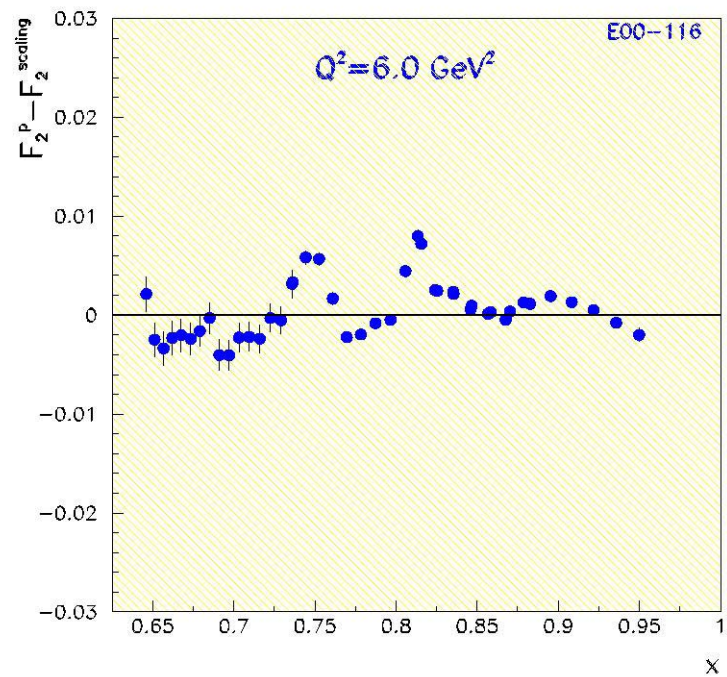
In general, Next-to-Leading-Order (NLO) perturbative QCD (DGLAP) fits do a good job of reproducing the data over the full measurement range.




E00−116
Q²=6.5 GeV²
F₂ᵖ − F₂ scaling
x


E00−116
Q²=6.2 GeV²
F₂ᵖ − F₂ scaling
x


E00−116
Q²=5.3 GeV²
F₂ᵖ − F₂ scaling
x


E00−116
Q²=6.0 GeV²
F₂ᵖ − F₂ scaling
x