Quark-Hadron Duality Studies in Structure Functions

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- Concept of Duality
- Review of Experimental Situation in Unpolarised & Polarised Case
- Studies of Q-H Duality in Unpolarised & Polarised Structure Functions
- Conclusions & Outlook

Concept of Duality (1)

DUALITY = RELATION BETWEEN DIS AND RESONANCE REGIONS

Bloom & Gilman, PRL 25 (1970) 1140; PR D4 (1971) 290

"The smooth scaling curve measured in DIS processes at high Q^2 is in average equal to the curve measured in the nucleon resonance region at lower Q^2 for a fixed range of the Bjorken variable scaling x"

Q-H Duality $\Longrightarrow$ Complementarity quark and hadron description of observables

At 'enough' high energy:

Hadronic Cross section averaged over appropriate energy range $\simeq$ Perturbative Quark-Gluon Theory
$\Longrightarrow$ Transition from strongly interacting matter to perturbative QCD

Concept of Duality (2)

- High Energy $\Longrightarrow$: interactions between quarks and gluons become weak (*asymptotic freedom*) $\rightarrow$ description in terms of quarks

- Low Energy $\Longrightarrow$: effect of confinement make strongly-coupled QCD highly non-perturbative $\rightarrow$ description in terms of collective degrees of freedom (mesons and baryons)

- Duality between Quark and Hadron descriptions: $\Longrightarrow$ Description of physical phenomena in terms of hadrons or quarks
  - reflects relationship between *confinement* and *asymptotic* freedom
  - intimately related to nature and transition from non-perturbative to pQCD

- Breakdown of Duality at sufficiently low Q^2
- Duality expected to be process dependent

Close & Isgur, PL B509 (2001) 81; Isgur *et al.*, PRD 64 (2001) 054005

Check of Duality

Comparison between SF integrals in RES $\&$ DIS regions, in the same x interval

$$I^{res}(Q^2) = \int_{x_m}^{x_M} F_2^{\text{Res}}(x)\, dx \qquad I^{DIS}(Q^2) = \int_{x_m}^{x_M} F_2^{\text{D}IS}(x)\, dx$$

$$I_1^{res}(Q^2) = \int_{x_m}^{x_M} g_1^{\text{Res}}(x) dx \qquad I_1^{DIS}(Q^2) = \int_{x_m}^{x_M} g_1^{\text{D}IS}(x) dx \qquad g_1 = A_1 \cdot \frac{F_2}{2x(1+R)}$$

$(x_M - x_m)$ delimited by $\Delta \mathrm{W}^2$ region

$R = I^{res}/I^{DIS} = 1 \longrightarrow$ Duality fulfilled

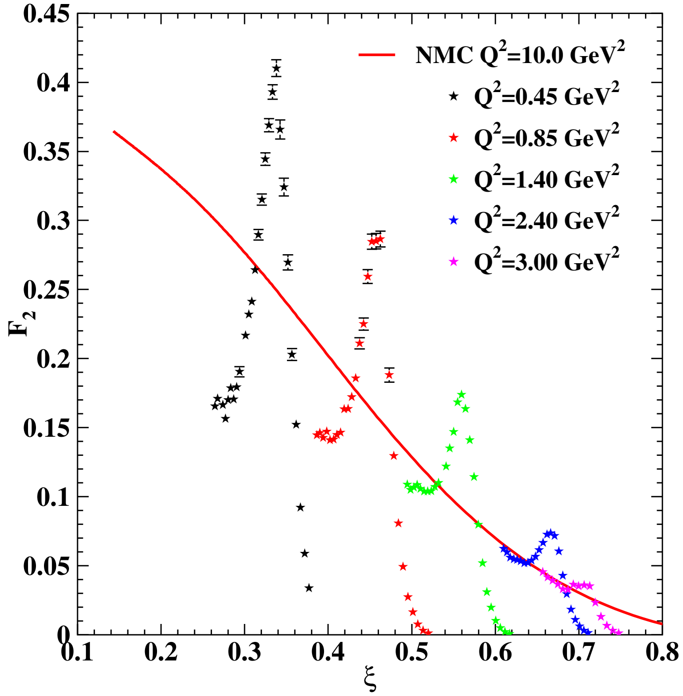
- Resonance region can be described in terms of quark degrees of freedom
- Distinction between resonance & DIS region is artificial

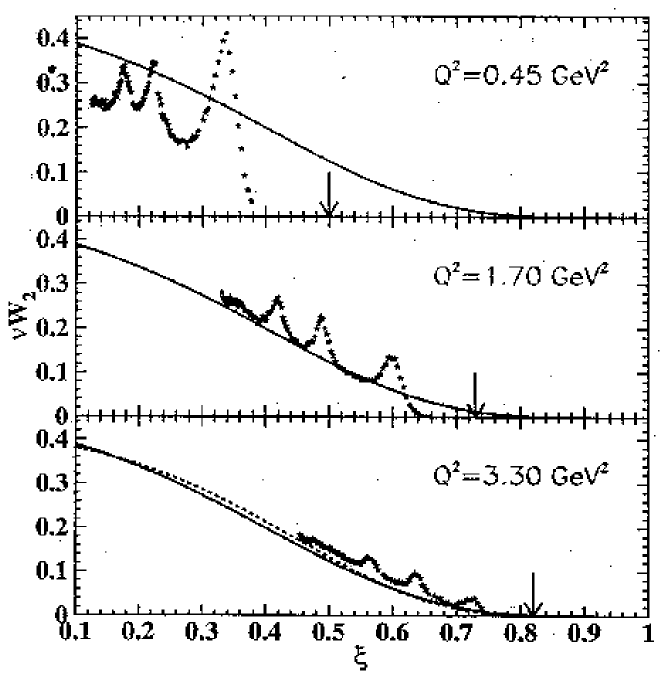
$\Longrightarrow$ Duality provides extended access to large x regime

Duality in Unpolarised case

$R =$ const. (inside of errors) for Q^2 > 4 GeV^2 Carlson & Mukhopadhyay, PR D47 (1993) 1737

Data from JLAB Hall C (1996) Niculescu *et al.*, PRL 85 (2000) 1182; PRL 85 (2000) 1186





Duality does not holds on top of the peak
Averaging over W^2 region, RES $\simeq$ DIS

Resonance spectra at different Q^2 appear at different x (or ξ) on DIS curve, which averages data

JLAB E94-110: Preliminary results on QH Duality in Long. and Transverse SF

Duality in Polarised case (1)

Interest for Duality in Polarised case started in late '90

O. Rondon PR-95-005; PR-96-002 (approved) $\rightarrow$ E01-006: data in 2002; Carlson & Mukhopadhyay, PR D58 (1998) 94029

"Data with polarised structure functions in the resonance region at higher Q^2 can throw significant new light on the issue of duality. Facilities such as TJNAF, SLAC and HERMES can all contribute over a significant range in Q^2 and W^2."

$g_1^{\mathrm{p,n}}$ and $A_1^{\mathrm{p,n}}$ in RES region + DIS measurements $\Longrightarrow$ test Quark-Hadron Duality

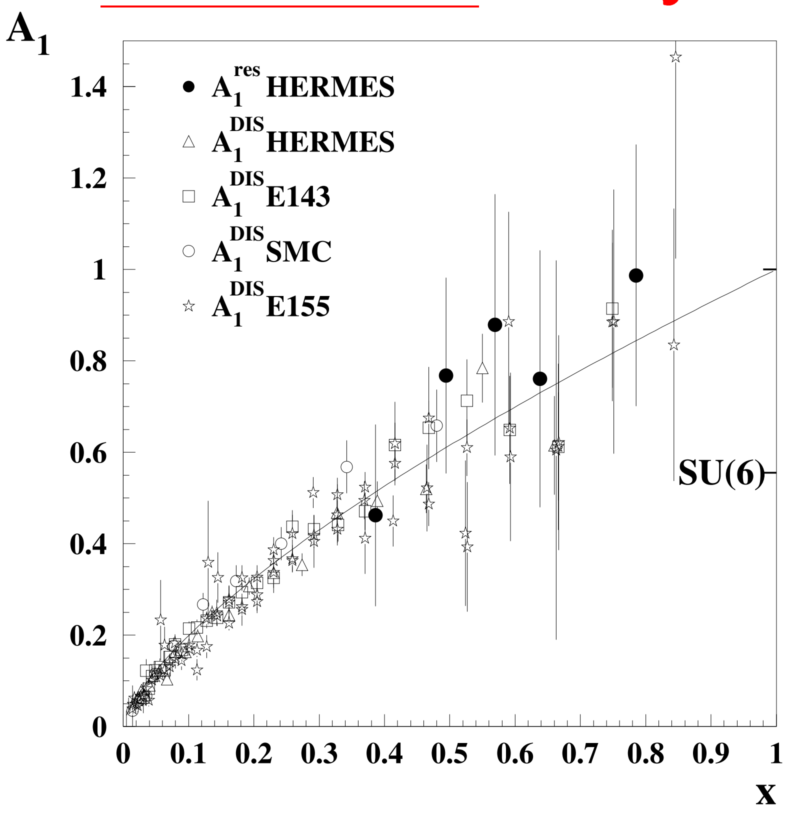
Several experiments ongoing, several experiments planned...

- final HERMES data A_1^p, preliminary JLAB EG1 g_1^p
- $A_{\parallel}^{p,d}$, $A_{\perp}^{p,d}$ measured in JLAB Hall C
- JLAB Hall A will measure A_1^n for $1.0 < Q^2 < 5.4$ GeV^2
- $A_1^{p,n}$ at high x planned/proposed (E=6/12 GeV)

BIG INTEREST

Duality $\rightarrow$ tool for studying high x region

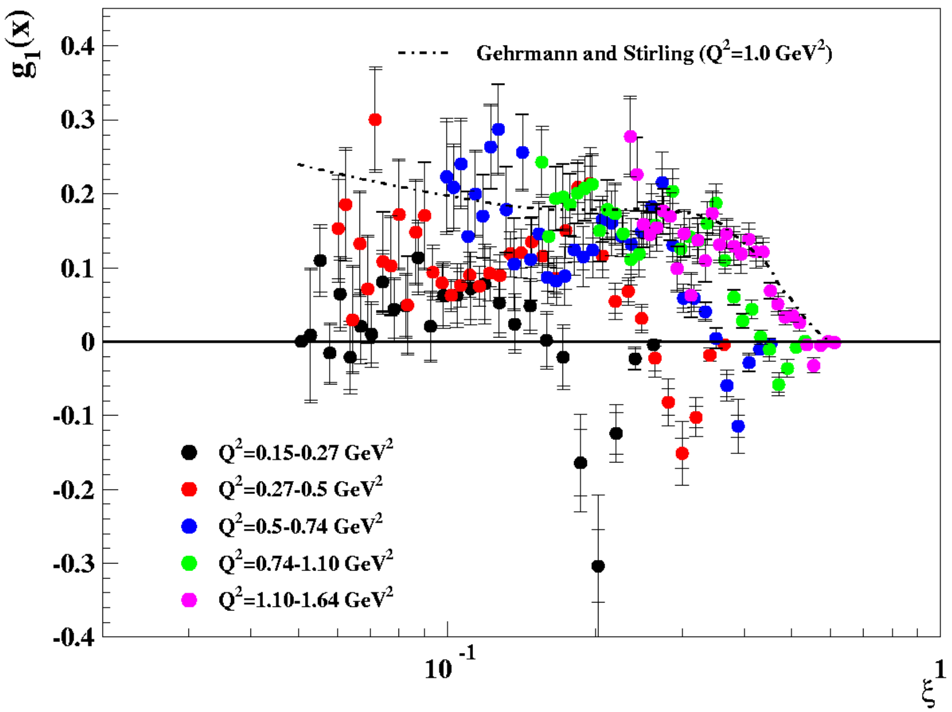
Duality in Polarised case (2)



HERMES Collaboration, PRL 092002 (2003)

$< A_1^{res}/A_1^{DIS} >= 1.11 \pm 0.16 \pm 0.18$

Description of A_1 in terms of quarks degree of freedom valid also in the RES region for $Q^2 > 1.6$ GeV^2



Preliminary CLAS data EG1:

Apparent Duality in the highest Q^2 bin ($1.10 < Q^2 < 1.64$ GeV^2)

Duality in Structure Functions

A quantification of Quark-Hadron Duality is still elusive

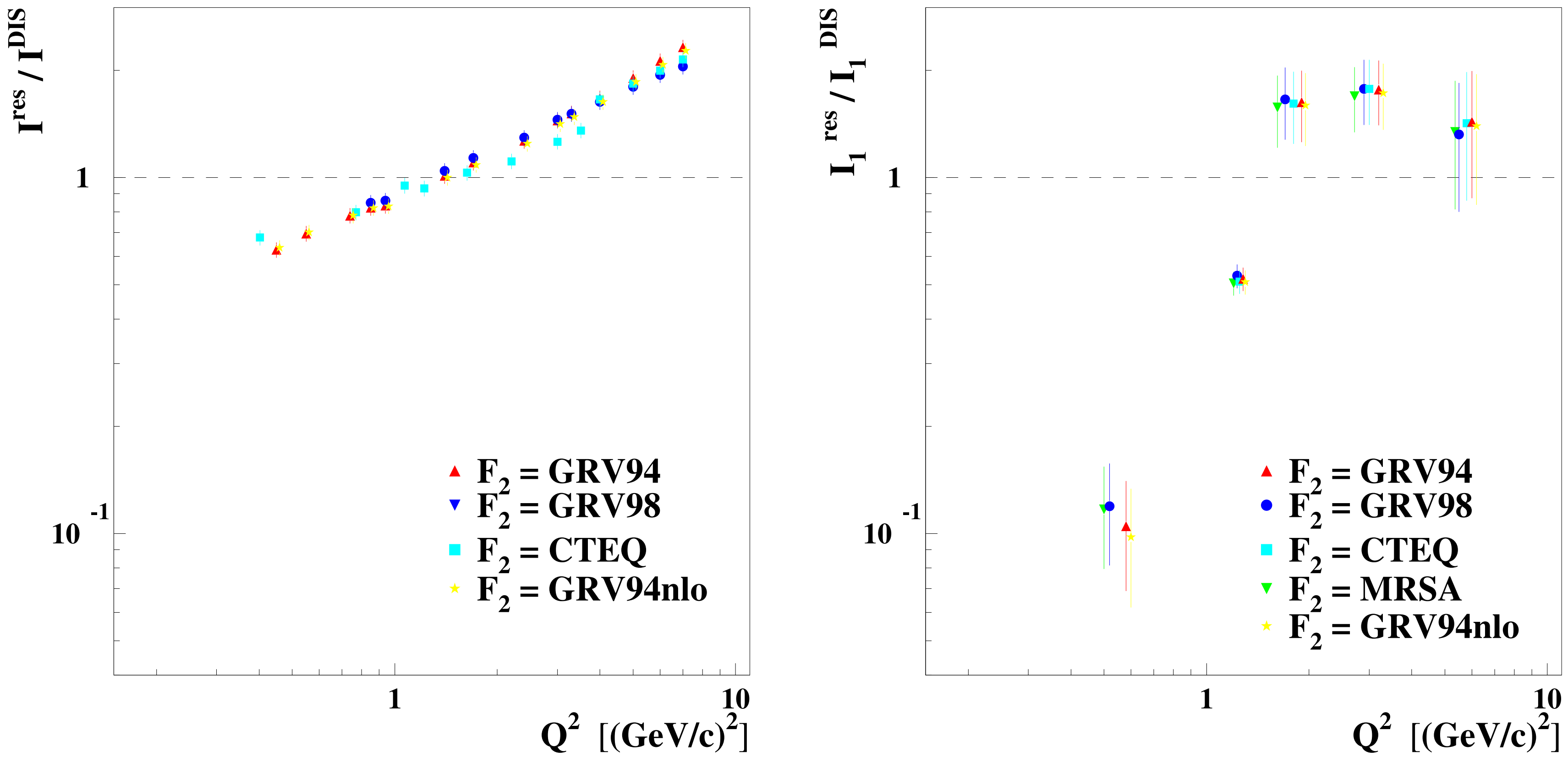
Large $x \longrightarrow$ scaling violations very large

Quark-Hadron Duality studies of SF throught different parameterisations of F_2^{DIS}

- PDF (LO & NLO) - Parton Distribution Functions:
  pure DIS param. evolved to $\langle Q^2_{meas} \rangle$ with QCD evolution (i.e. DGLAP equations)
  - GRV94, GRV98, CTEQ, MRS

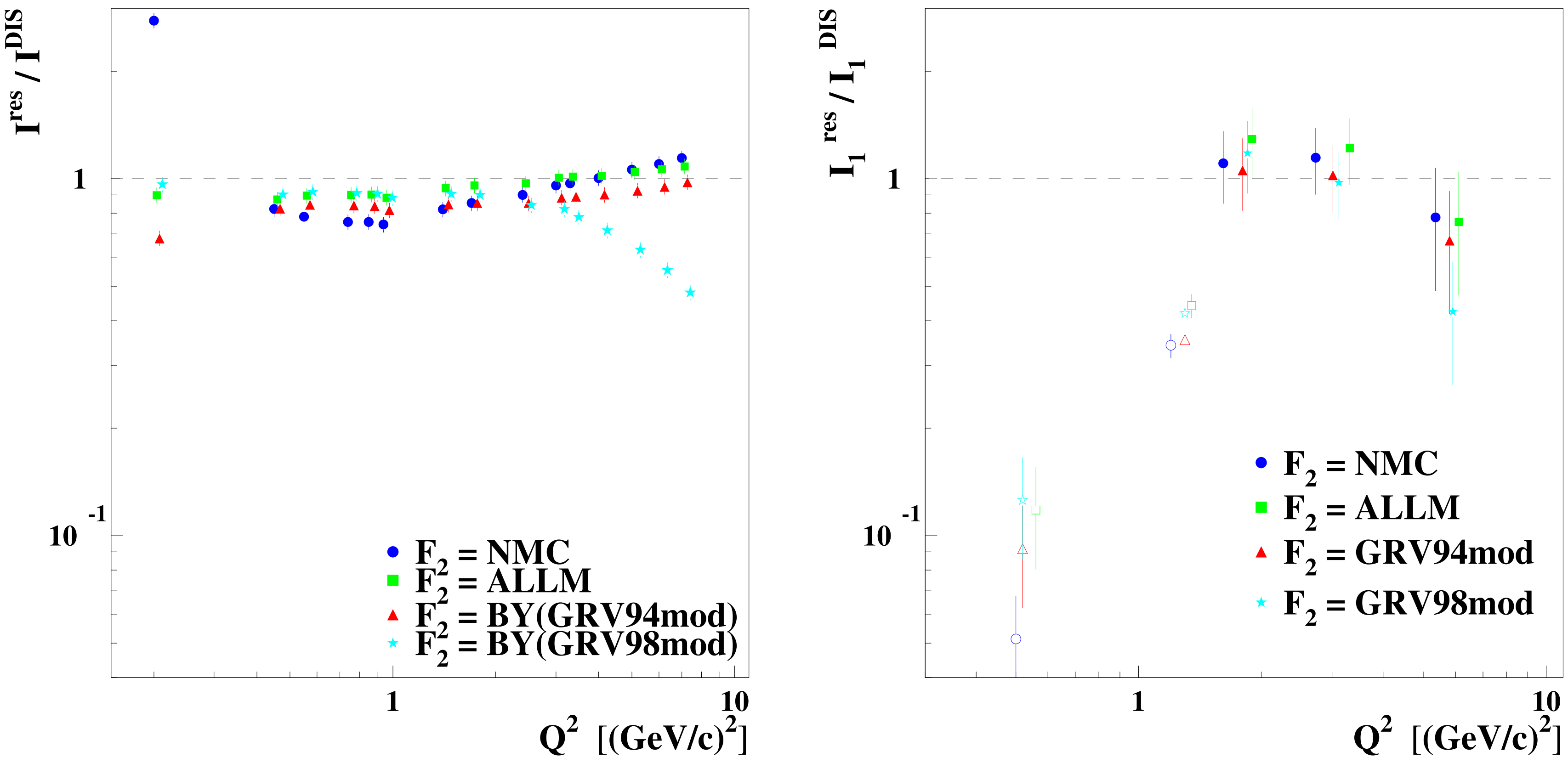
- Phenomenological Parameterisations (HT + TM) obtained fitting DIS data even in a low Q^2 region $\Longrightarrow$ contain implicitely higher twist effects or non-perturbative contributions:
  - NMC, ALLM
  - BY(GRV94mod,GRV98mod) (Bodek & Yang: hep-ex/0203009, hep-ex/0210024)

$F_2^{\rm DIS}$ from PDF (LO & NLO)



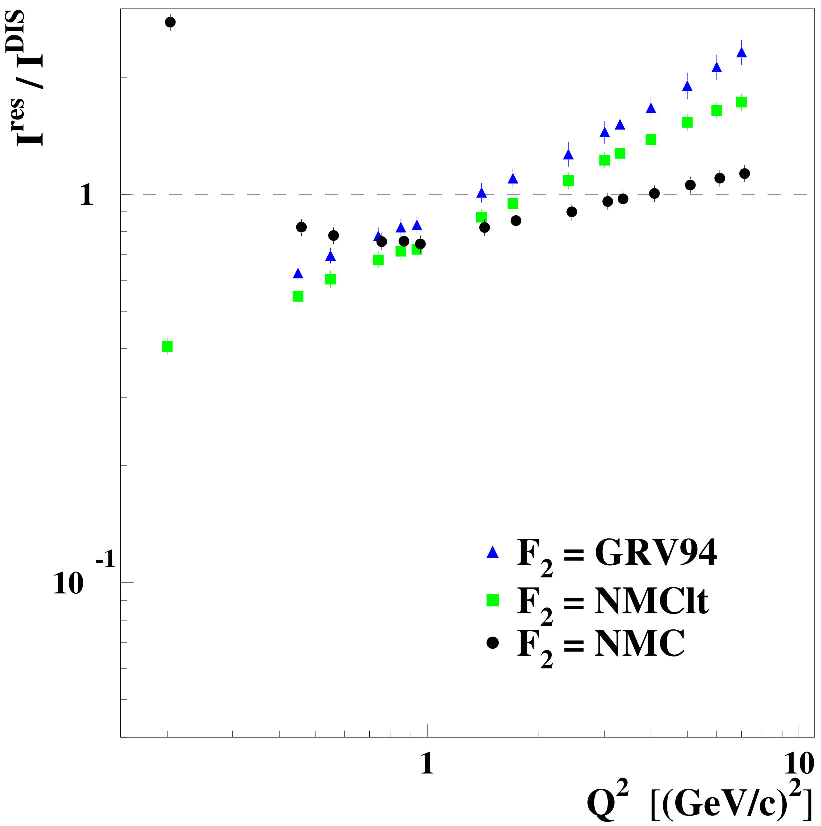
Quark-Hadron Duality NOT fulfilled by PDF at LO and even NLO

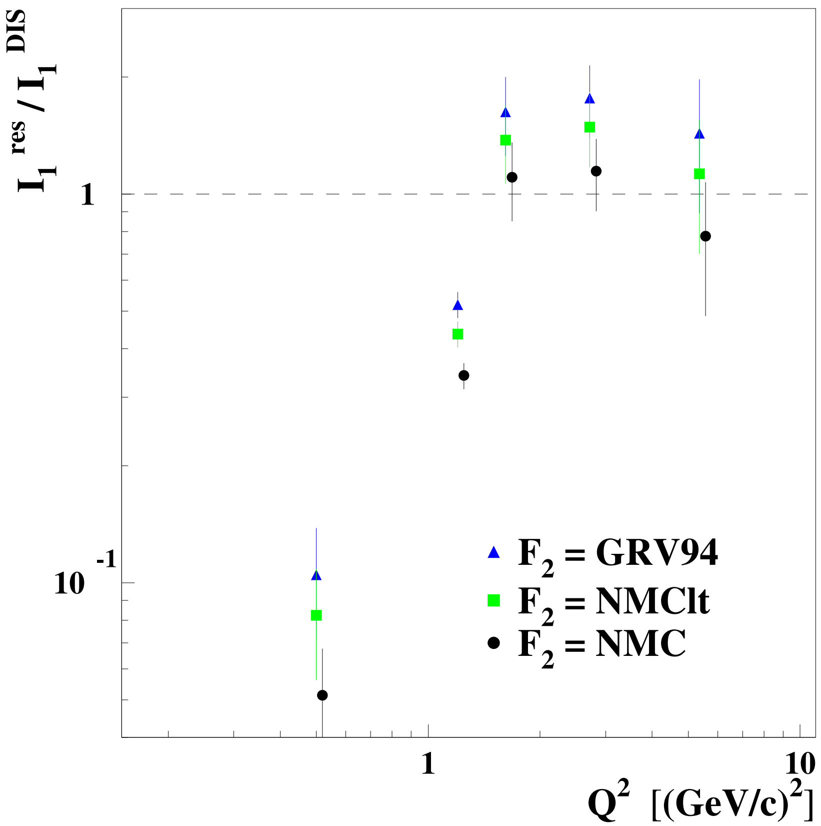
$F_2^{\rm DIS}$ from Phenomenological Parameterisations



- ∘ NMC & ALLM contain implicitely HT effects
- ∘ BY(GRV94mod, GRV98mod) are PDFs modified by Bodek & Yang including:
- \- Target Mass effects (x_w and ξ_w respectively)
- \- possibility to use fit down to photoproduction limit

F_2^{DIS} from Different Parameterisations





- Including terms $\rightarrow$ Duality is approaching
- Still something left... to be investigated
- Difference between Unpolarised and Polarised case

Work in progress

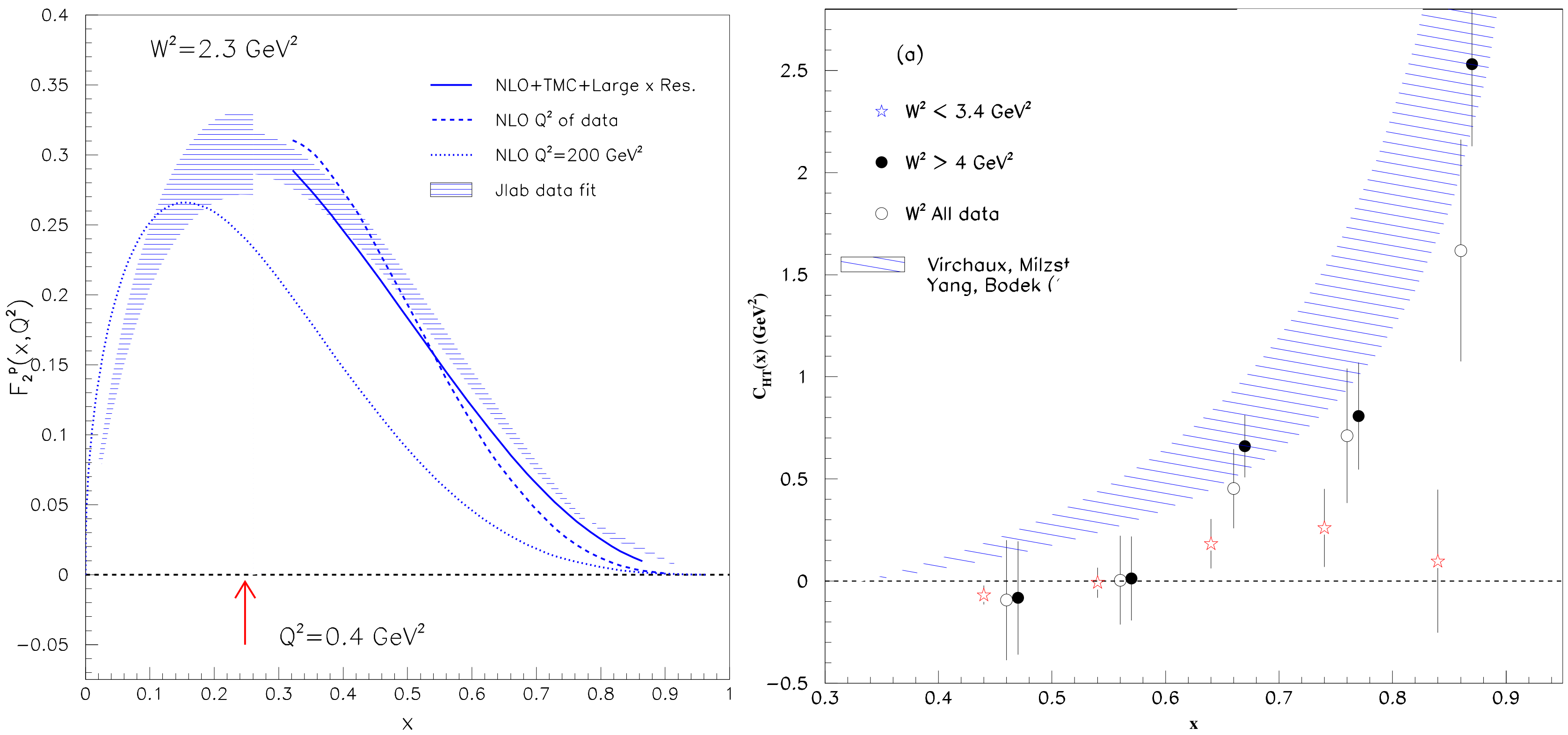
- Make an assessment based on current data, of the extent to which pQCD works in the few GeV region, both in polarised and unpolarised scattering

- pQCD definition of Q-H Duality based on NLO analysis which includes:
  - Target Mass Correction
  - Large x Resummation
  - Evaluation of Power Correction (HT) $1/Q^2$, $1/Q^4$ ...

- pQCD-defined Quark-Hadron Duality violated in unpolarised DIS (richer Q^2-dependence at low Q^2 and W^2?)

- Similar conclusions in polarised scattering cannot be reached at present

NLO + TMC + Large x Resummation + HT



$$F_2^{\mathrm{exp}}(x,Q^2) = F_2^{\mathrm{pQCD+TMC}}(x,Q^2) + \frac{H(x,Q^2)}{Q^2} + O(\frac{1}{Q^4})$$

$$H(x,Q^2) = F_2^{\mathrm{pQCD+TMC}}(x,Q^2) \cdot C_{HT}(x)$$

S. Liuti *et al.*, PRL 89 (2002) 162001

Conclusions

- Study of Quark-Hadron Duality in Unpolarised and Polarised $e - p$ scattering

- Unpolarised and Polarised data compared with:
  - pQCD analyses using global Parton Distribution Functions (GRV, CTEQ...)
  - pQCD based fits to the DIS ep data ($\mathrm{NMC}_{\mathrm{lt}}$)
  - pQCD based fits + HT terms (NMC)
  - phenomenological fits with non-perturbative contributions (ALLM, BY)

$$\Downarrow$$

- Duality not fulfilled using PDF at LO and NLO

- HT,TM corrections need to be included (Phenomenological Parameterisations)

- Slightly different behavior between Unpolarised and Polarised Case

- Quantitative analysis including TMC, HT and Large x Resummation is in progress