Duality in 12 GeV Era: Projected Results from E12-10-002

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Jefferson Lab

Outline

F_2 at large x (and not only) in the context of Hall C's E12-10-002

- Expected physics output:

  → constraints for PDF global fits

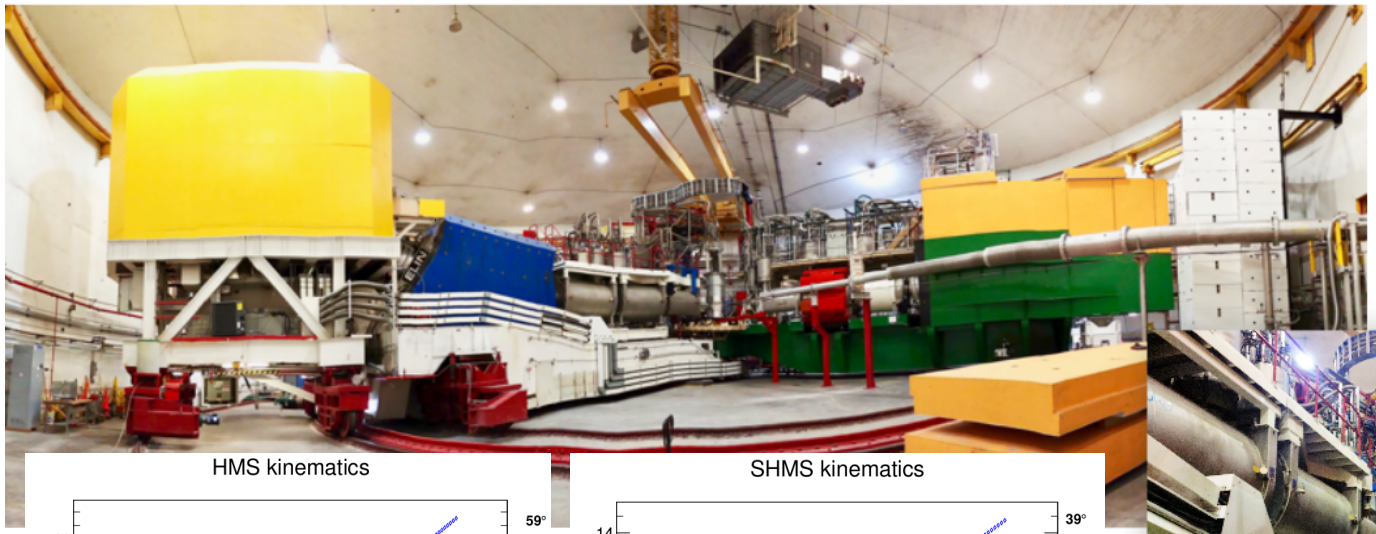
  → quark-hadron duality studies: inspire the theory community to pursue a fundamental understanding of the phenomenon

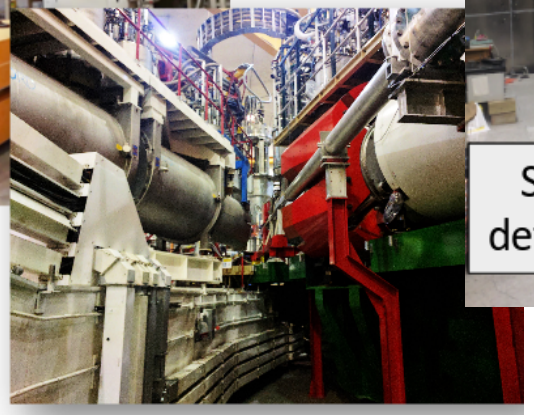
  → non-singlet moments to higher Q^2

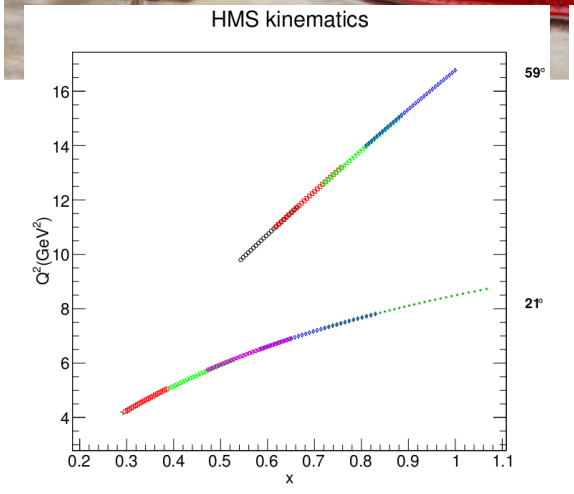
  → modeling of resonance and deep inelastic scattering process

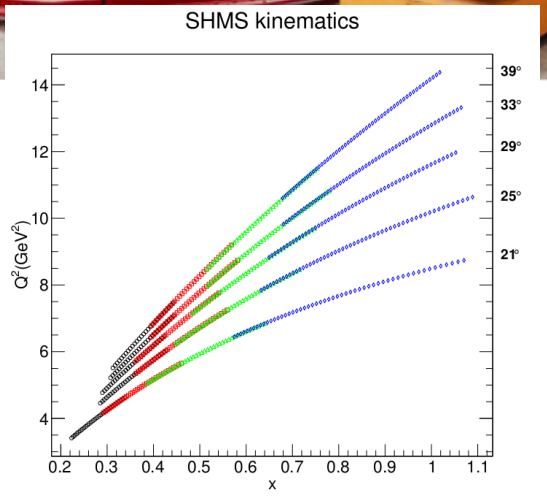
E12-10-002

- Ran at JLab in Hall C February – March 2018 to measure inclusive cross sections for H(e,e'p) and D(e,e'p) in the resonance and deep inelastic scattering regions









→ Beam: 10.6 GeV, unpolarized

→ Targets: LH2, LD2, Al

Constraints for PDFs

Theory-experiment Collaboration: CJ

- Performs global QCD fits of PDFs from data including deep-inelastic lepton-nucleon scattering, proton-proton collisions (lepton pair creation, W-boson and jet production), etc., **with particular focus on the large-x region**

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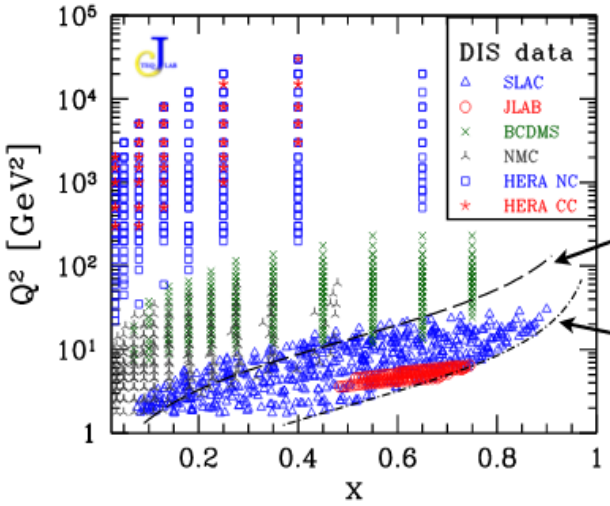

Kinematic cut of almost all other PDF analyses before CJ

$W^2 > 12.25$ GeV^2

$W^2 > 3$ GeV^2

CJ cut includes more data at large x

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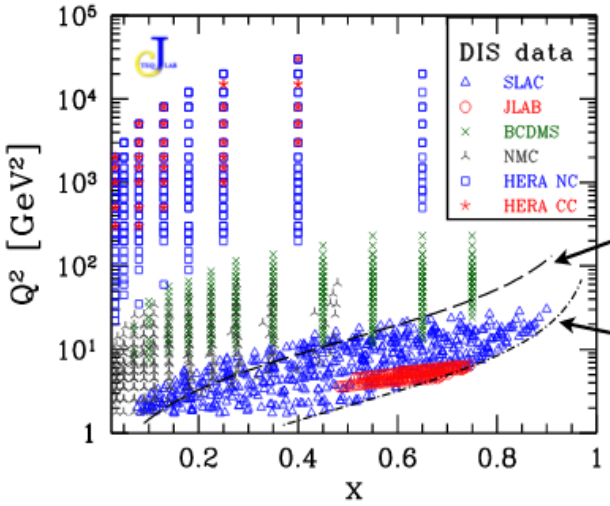

Kinematic cut of almost all other PDF analyses before CJ

$W^2 > 12.25$ GeV^2

$W^2 > 3$ GeV^2

CJ cut includes more data at large x

- Include non-perturbative corrections: data with low W are used
- Include nuclear corrections: **use of deuterium data** requires careful treatment of **nuclear corrections**

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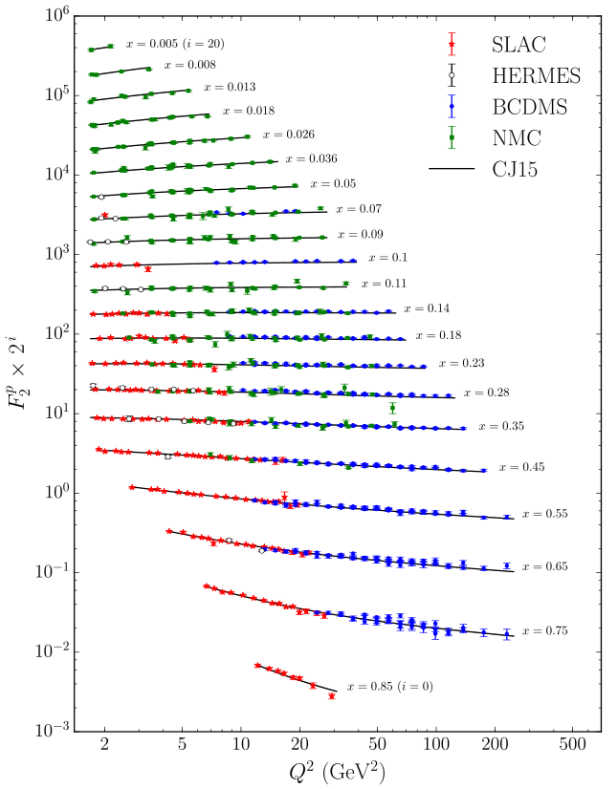

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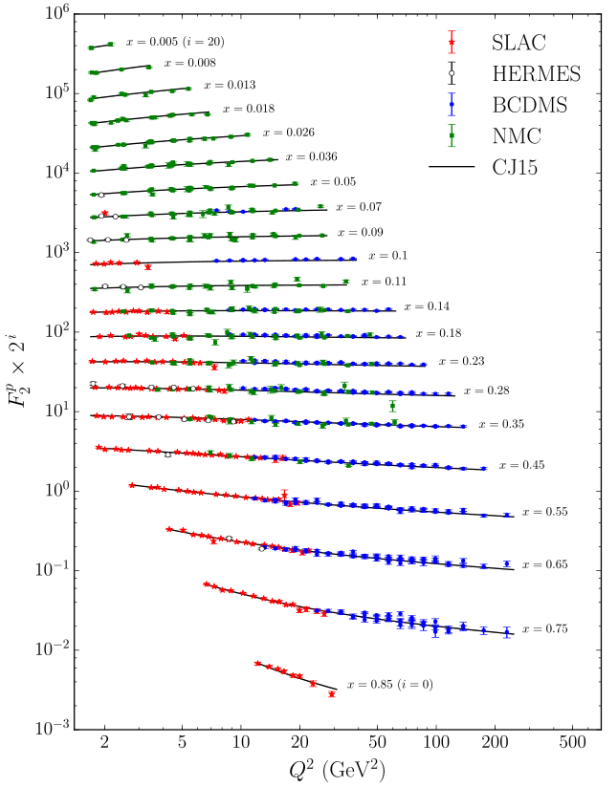

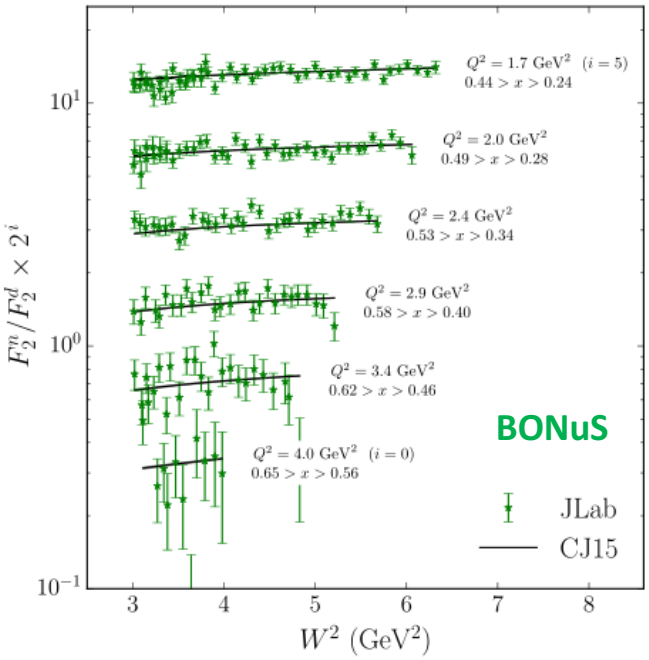

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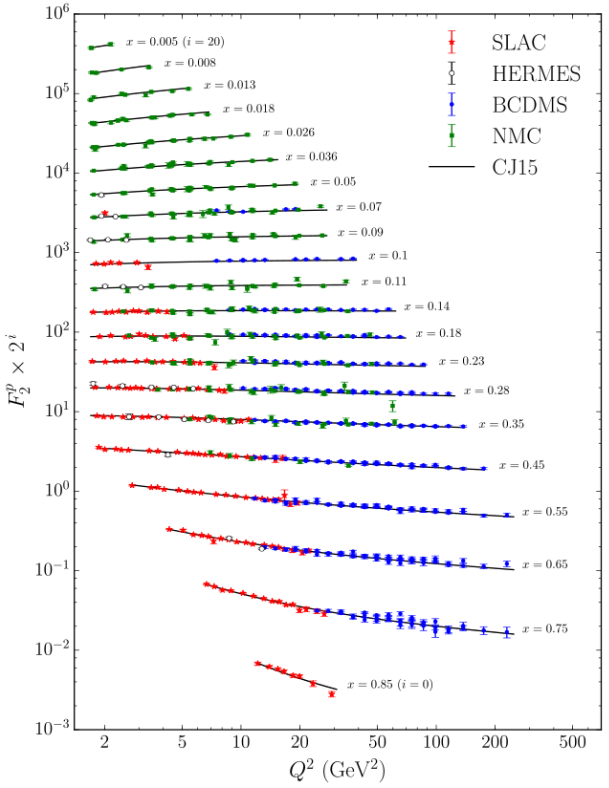
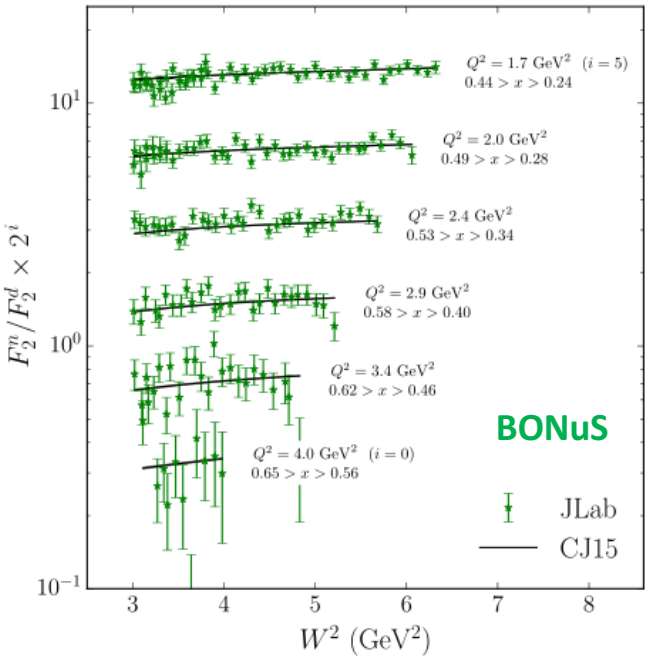
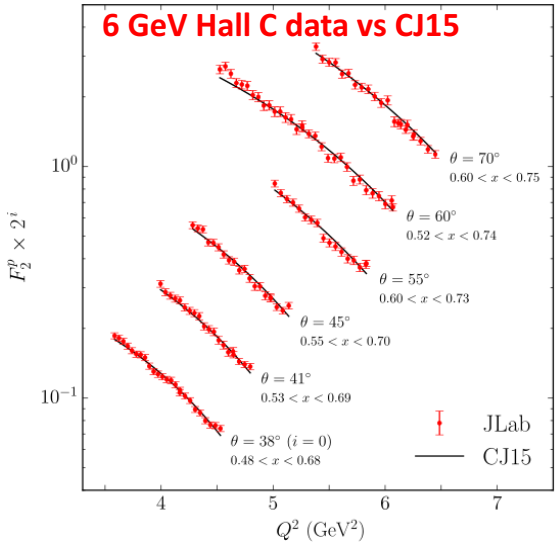


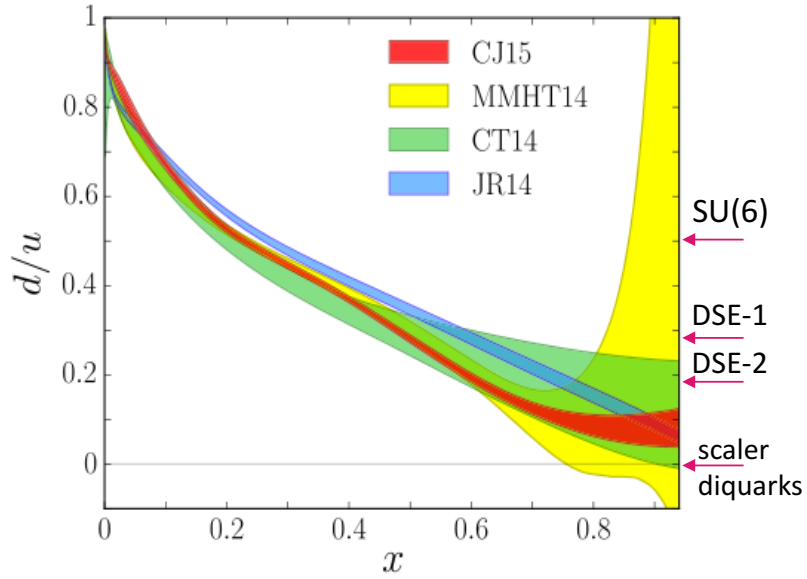




Constraints for PDFs

Theory-experiment Collaboration: CJ

(One of the many) Highlights: Improvement in uncertainty of d/u extraction



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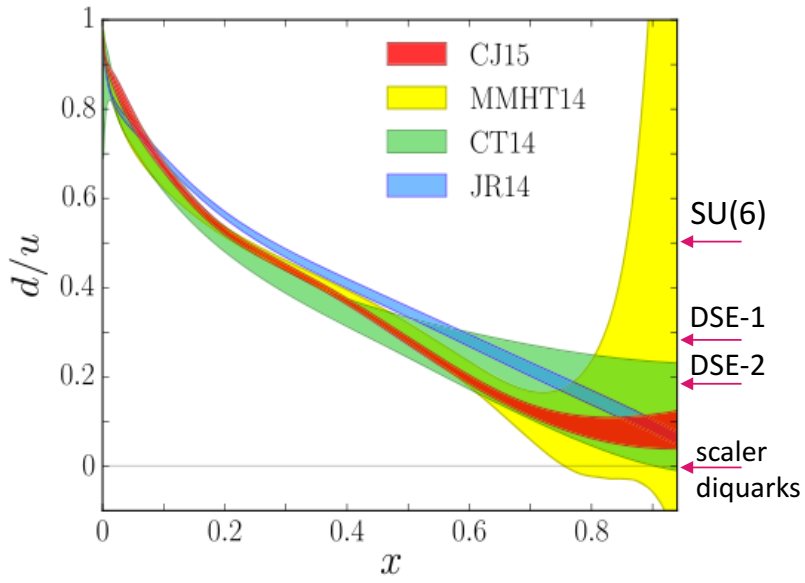
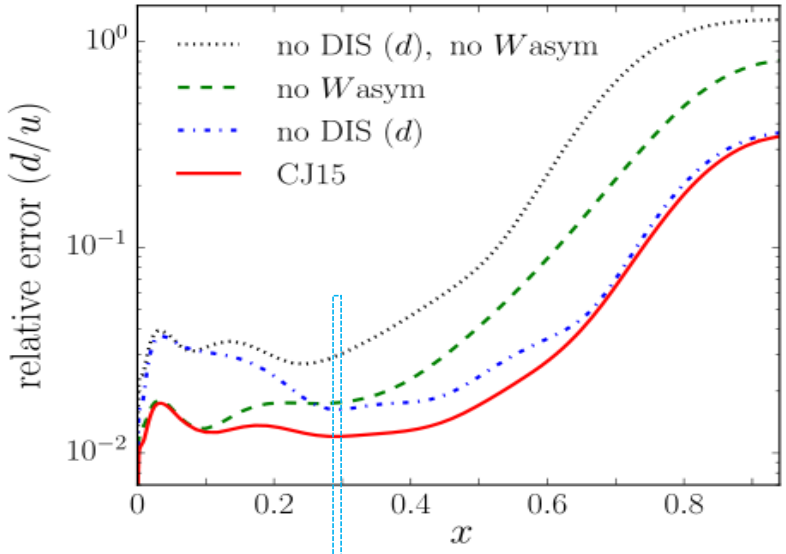




Deuterium data allow for precise determination of d/u

D0 asymmetries determines the "free nucleon" d-quark AND Deuterium data determine the off-shell correction

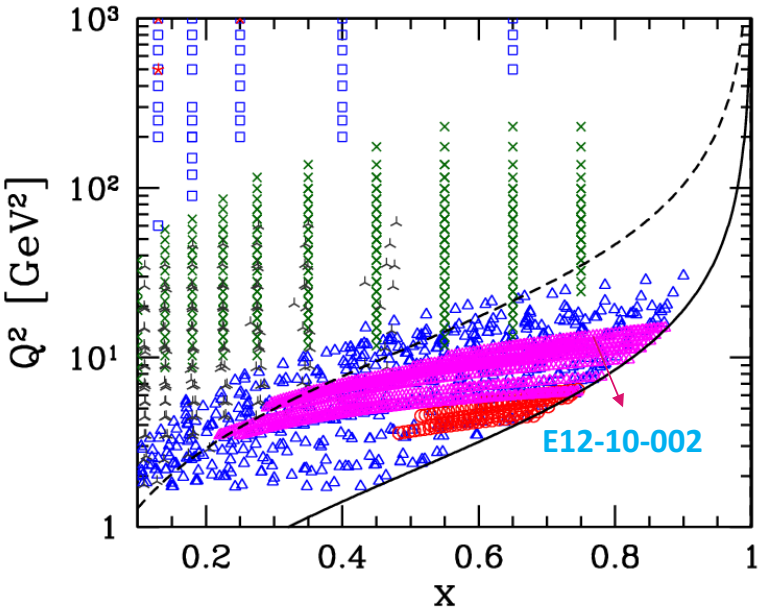
Constraints for PDFs: E12-10-002 Impact

Theory-experiment Collaboration: CJ

- We measured both H and D cross sections (free protons and bound neutrons)
- We not only push to larger x - up to ~0.87 - but we also cover the low x kinematic region – down to ~0.2

→ this should help with constraining the nuclear corrections and the d-quark at the same time

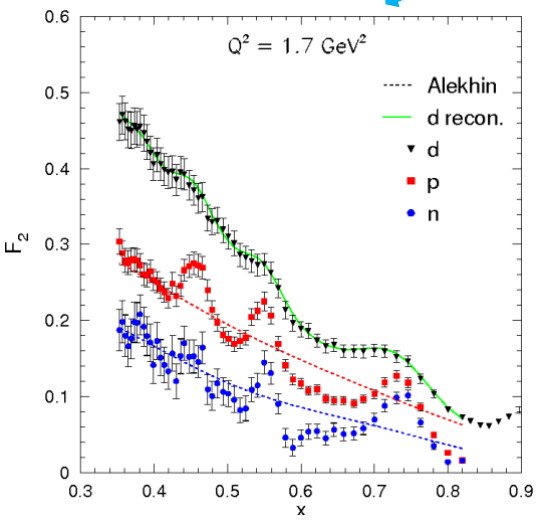
From A. Accardi: "… For the d-quark, at large x this data should be competitive with the D0 W asymmetry data, and at low x it might cut another 50% in the uncertainty. So, I would expect some visible impact when we add these to the whole CJ data set."



Quark – Hadron Duality

- **Quark – hadron duality**: fundamental property of nucleon structure

→ Observed in: F_2^p, F_1^p, F_L^p, F_2^n, F_2^d, F_2^C, F_2^{Fe}, F_2^{Au}, A_1^p, g_1^p, g_1^d, g_1^n, $g_1^{^3He}$, SIDIS



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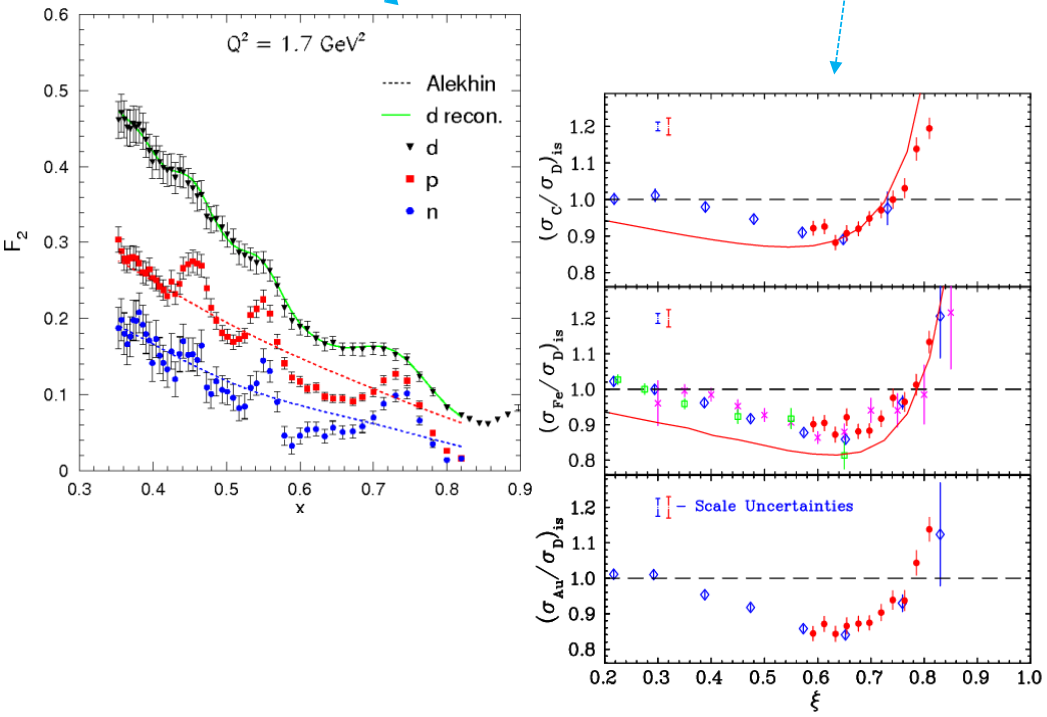

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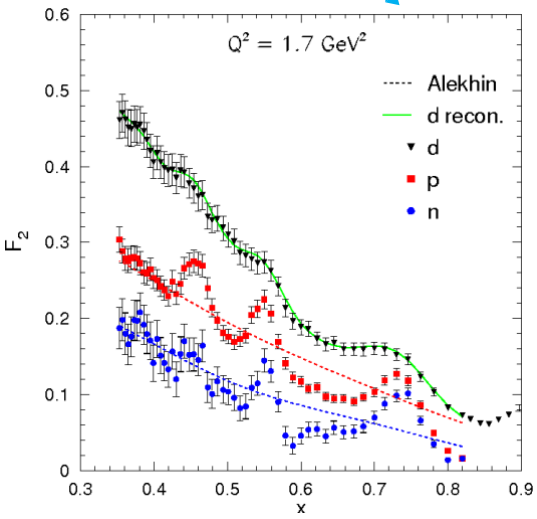

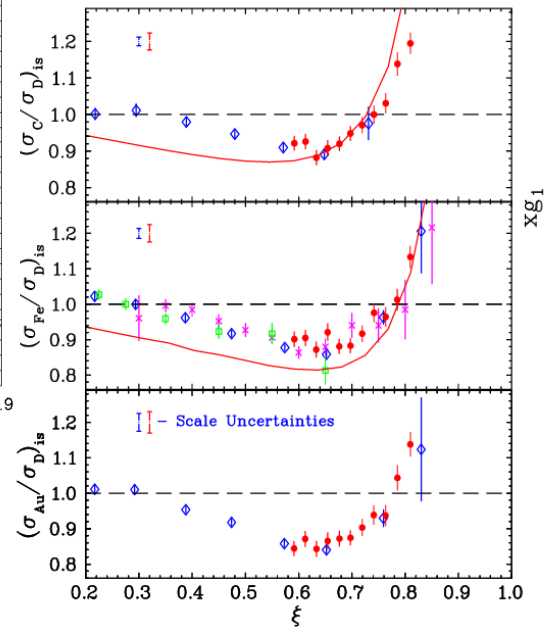

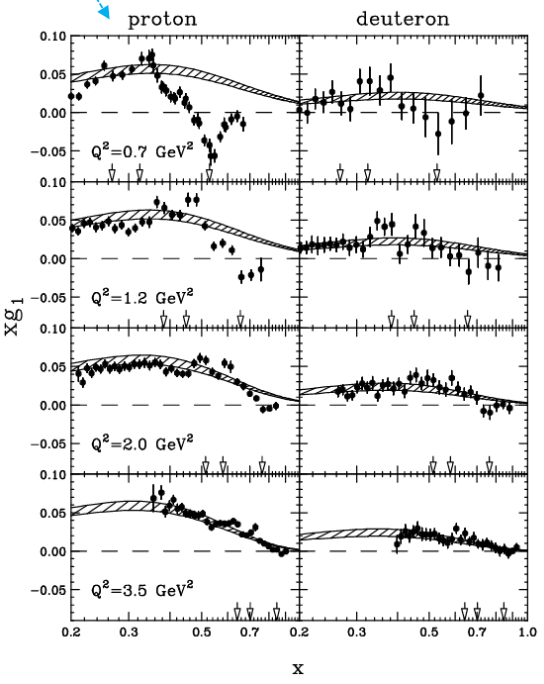

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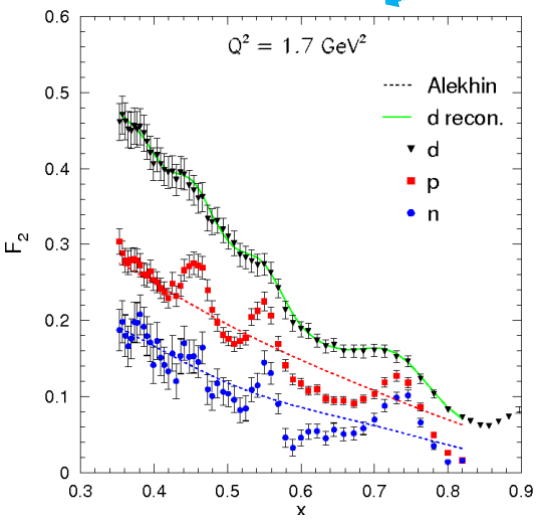
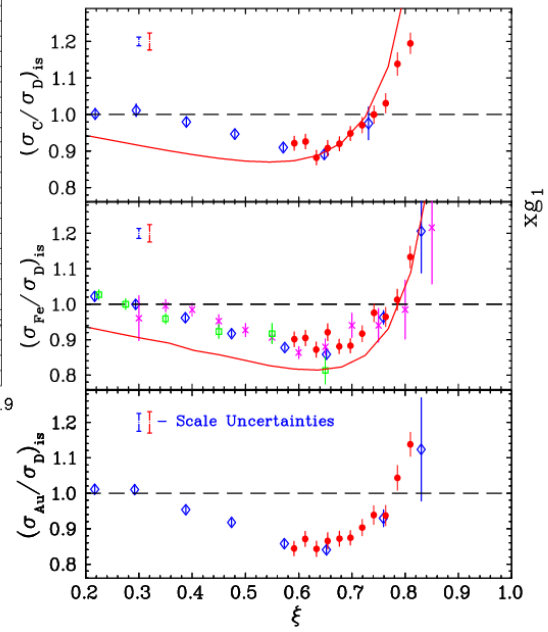
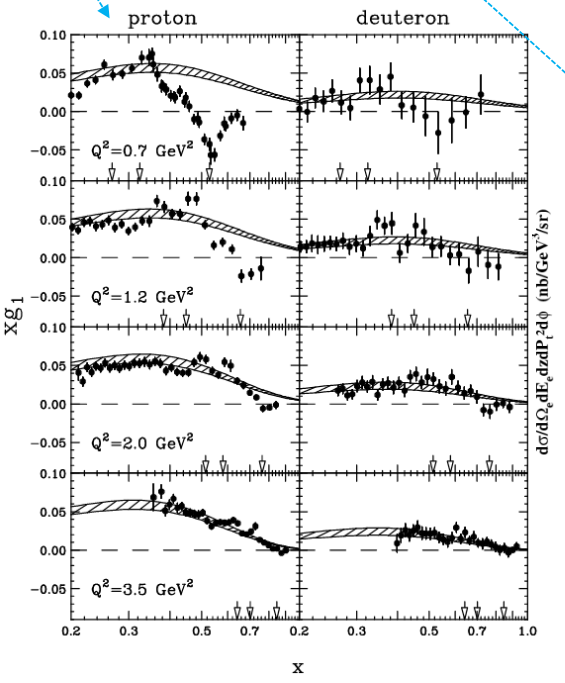
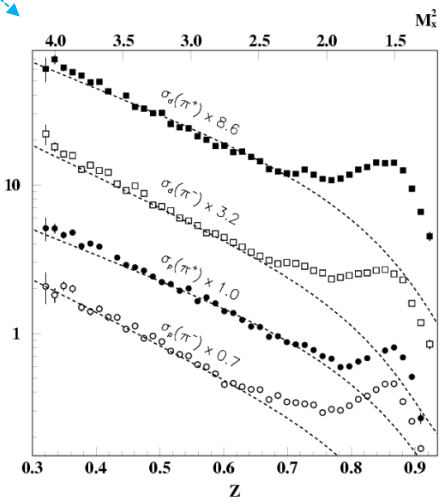






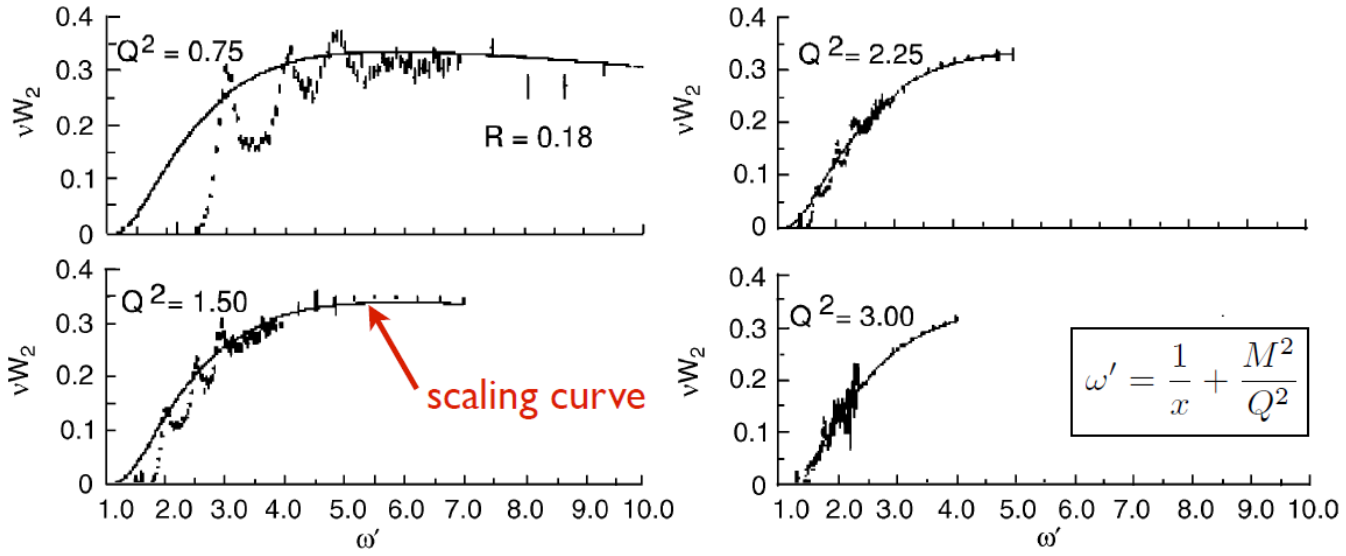


Duality Studies in F_2 - Highlights

- **Bloom-Gilman Duality** in inclusive electron-proton scattering

The resonance region data:
- oscillate around are on average equivalent to the scaling curve
- "slide" along the deep inelastic curve with increasing Q^2

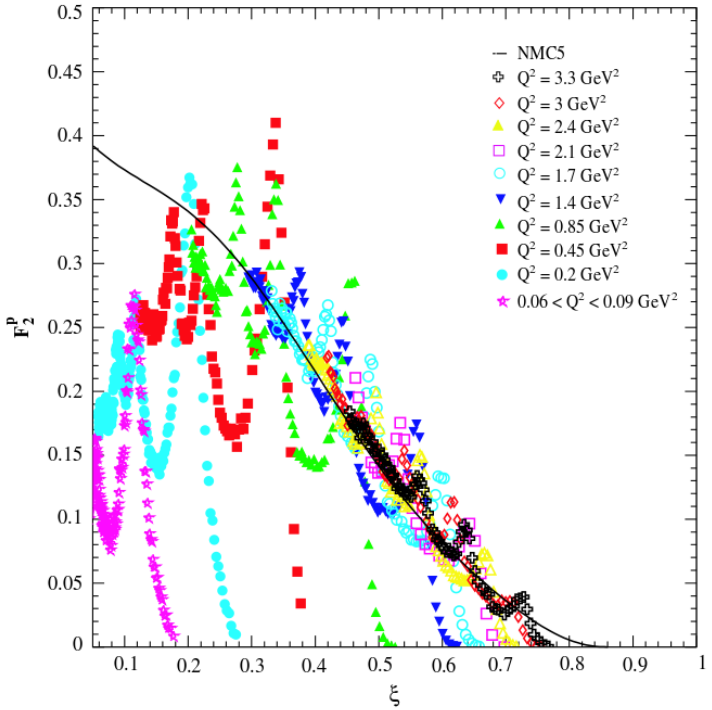
Phys. Rev. Lett. 25, 1140 (1970)

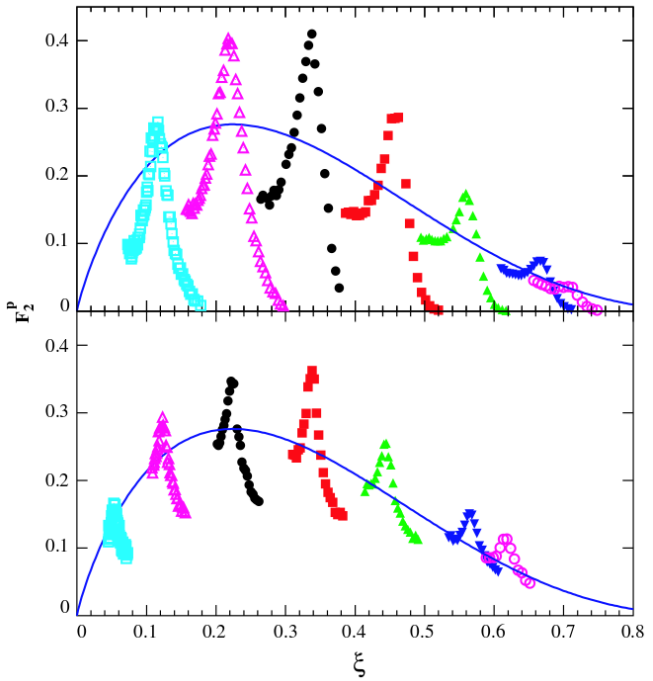


- Quantitatively: relative difference 10% for Q^2=1 GeV^2 to <2% beyond Q^2=2 GeV^2

Duality Studies in F_2 - Highlights

- ξ variable is used to allow comparison of NMC fit - high (W^2, Q^2) DIS data - to the lower (W^2, Q^2) resonance region data at the same ordinate point





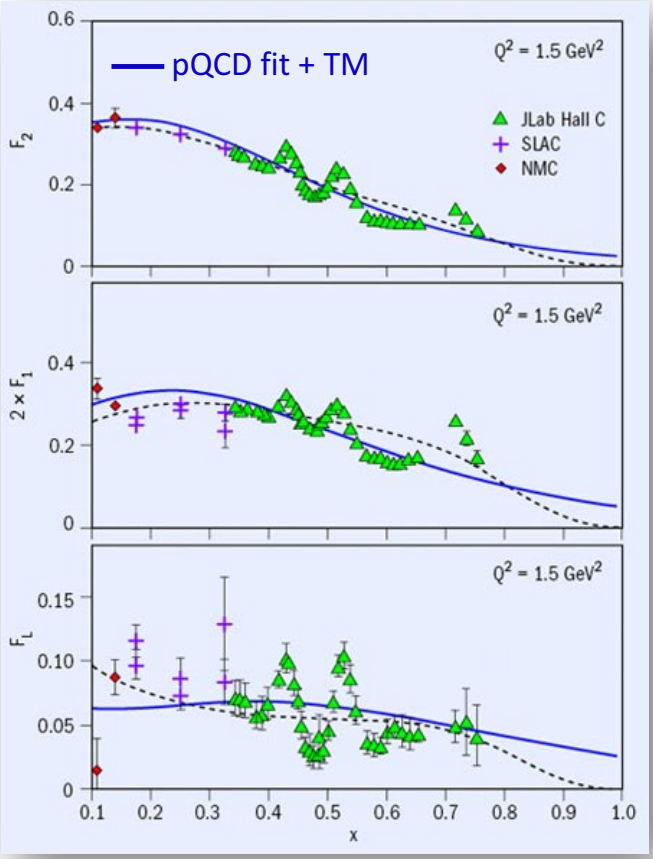
Example: x = 0.6 can correspond to Q^2 = 1.5 GeV^2 in the delta region or to a point in DIS with W^2 = 14 GeV^2 and Q^2 = 20 GeV^2

I. Niculescu *et al.*, Phys. Rev. Lett. 85, 1186 (2000)

I. Niculescu *et al.*, Phys. Rev. Lett. 85, 1182 (2000)

Duality Studies in F_2 - Highlights

- Jefferson Lab experiment, E94-110: duality verified in all separated spin-averaged structure functions



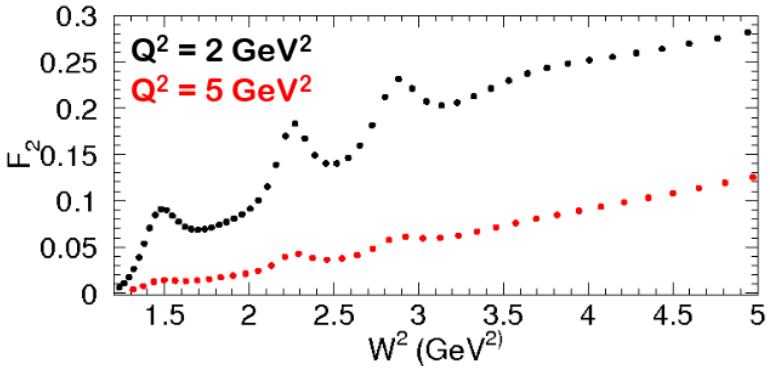
→ Compare resonance region data to pQCD fits with added target mass corrections and use x instead of ξ

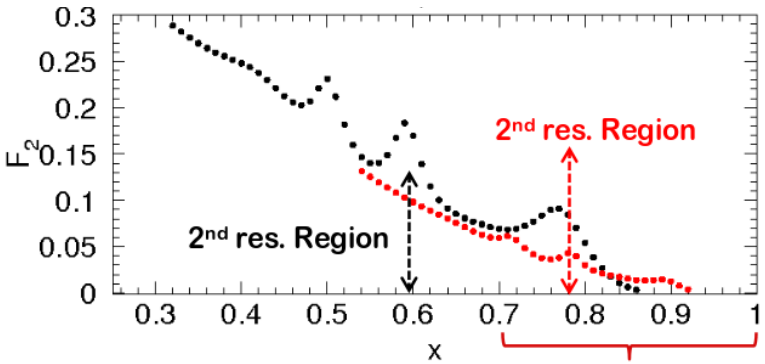
Resonances average to pQCD curve down to a surprisingly low Q^2 not only for F_2 but also for F_1 and F_L

This high-precision experiment pushed duality studies to $Q^2 = 3.5$ GeV^2

Duality Studies in F_2 - Highlights

- Jefferson Lab experiment, E00-116: pushing duality studies to higher Q^2





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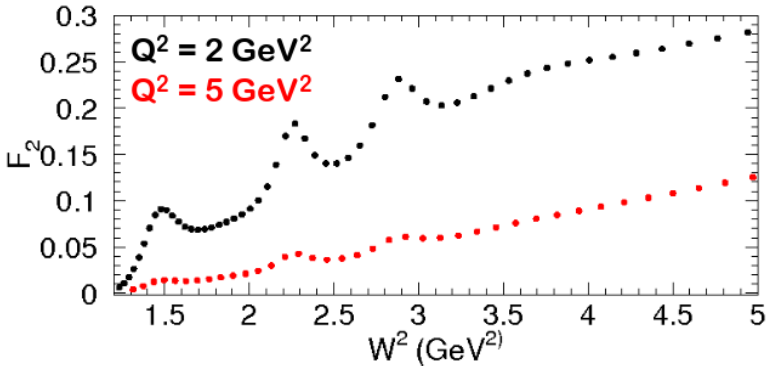
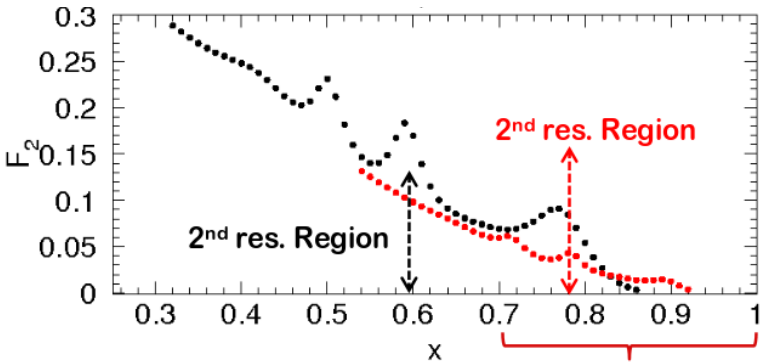
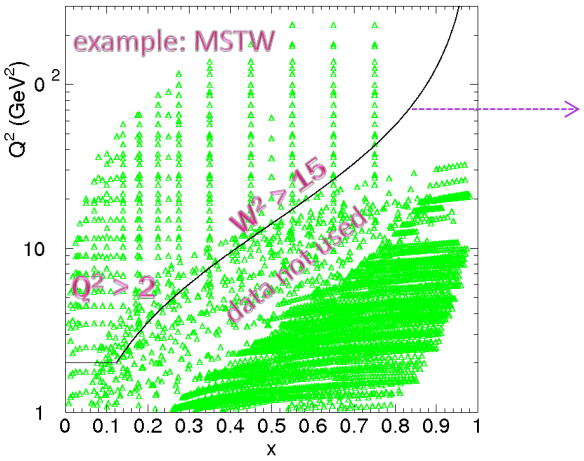
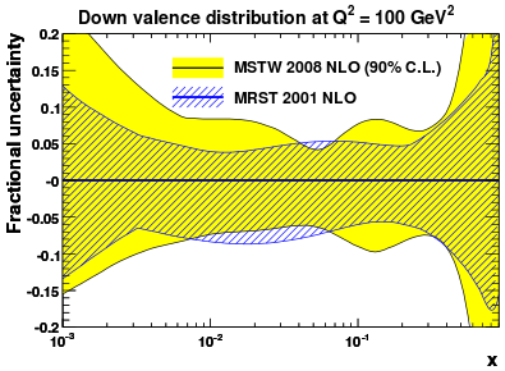




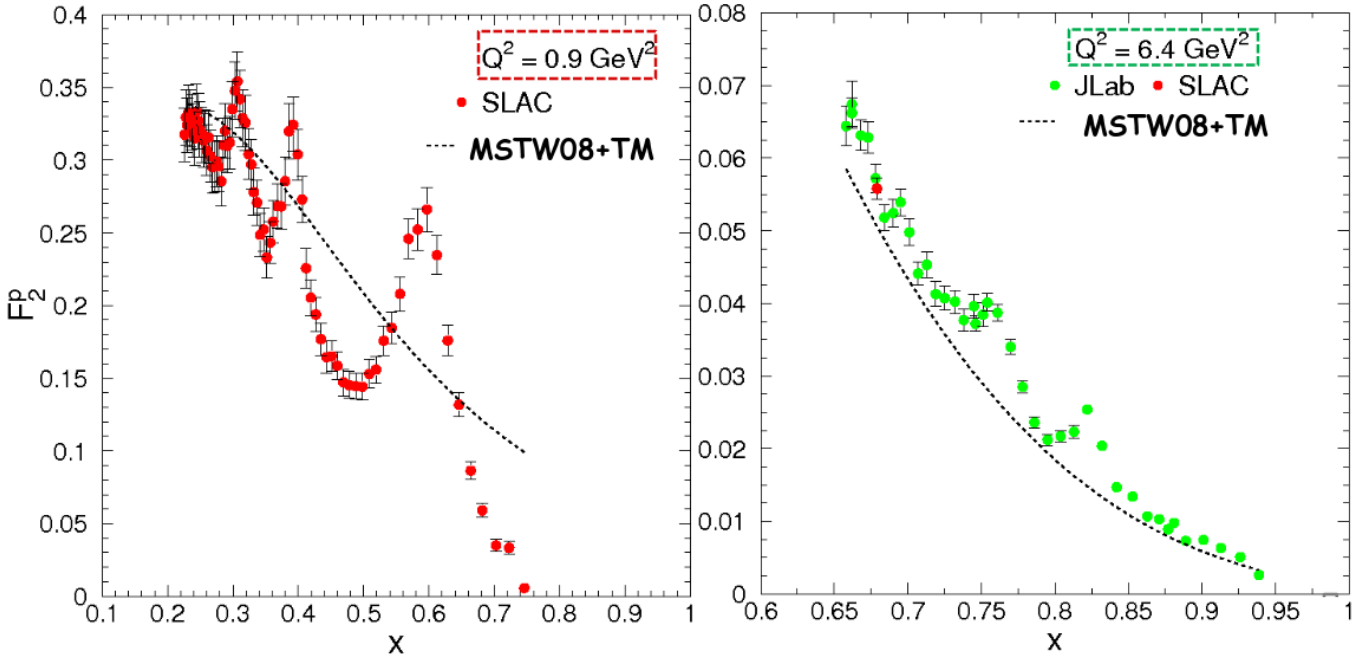




Duality Studies in F_2 - Highlights

- It is not surprising that:

  → though resonances DO average to MSTW08+TM at $Q^2 = 0.9$ GeV^2, x ~ (0.25,0.7)
  → resonances DO NOT average to MSTW08+TM at $Q^2 = 6.4$ GeV^2, x ~ (0.7,0.95)



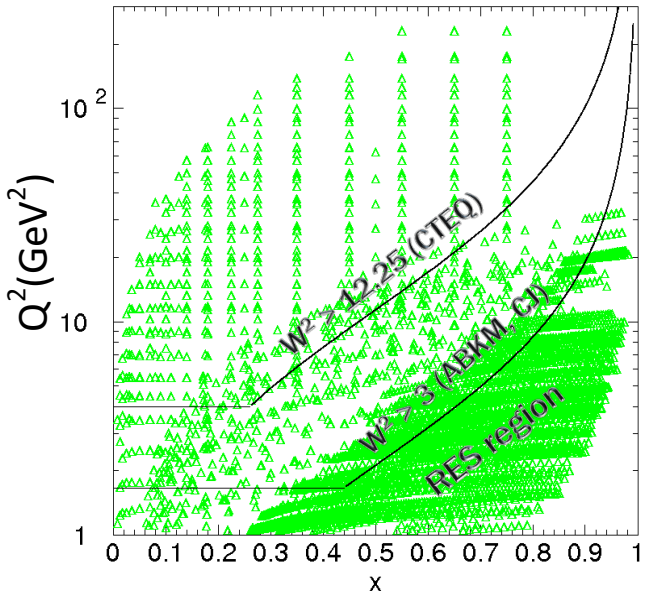
This is not a violation of duality but due to the underestimation of PDFs strength at large x

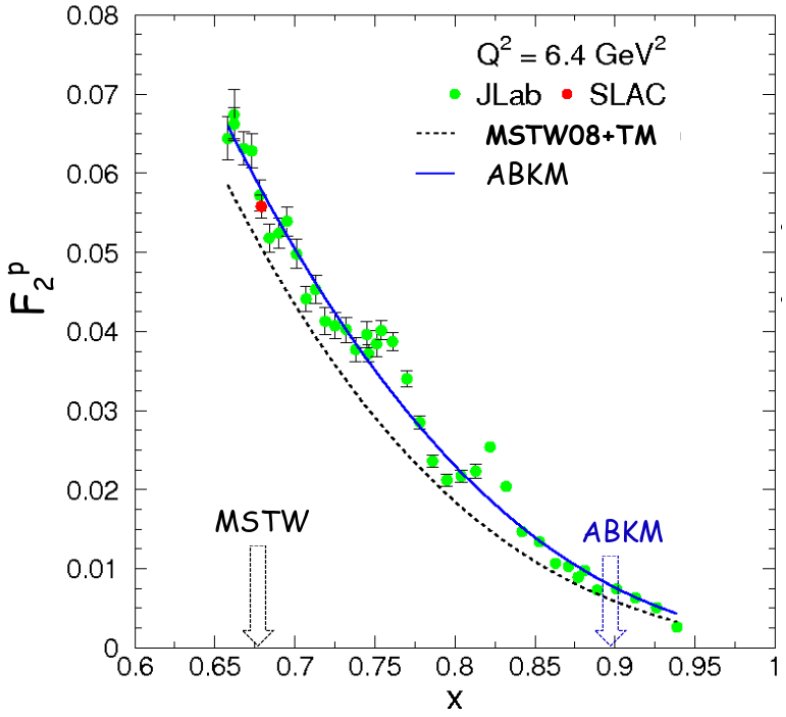
Duality Studies in F_2 - Highlights

- "Duality curve" for verification: PDF fit better constrained at large x

  → Second generation PDF fits extended their PDF extraction to larger x by lowering the W^2 kinematic cuts: ABKM, CJ

  → Curve used for duality verification must be from 2nd generation PDF fits, especially when resonances cover the largest x region





Duality Studies in F_2 - Highlights

- Define duality intervals

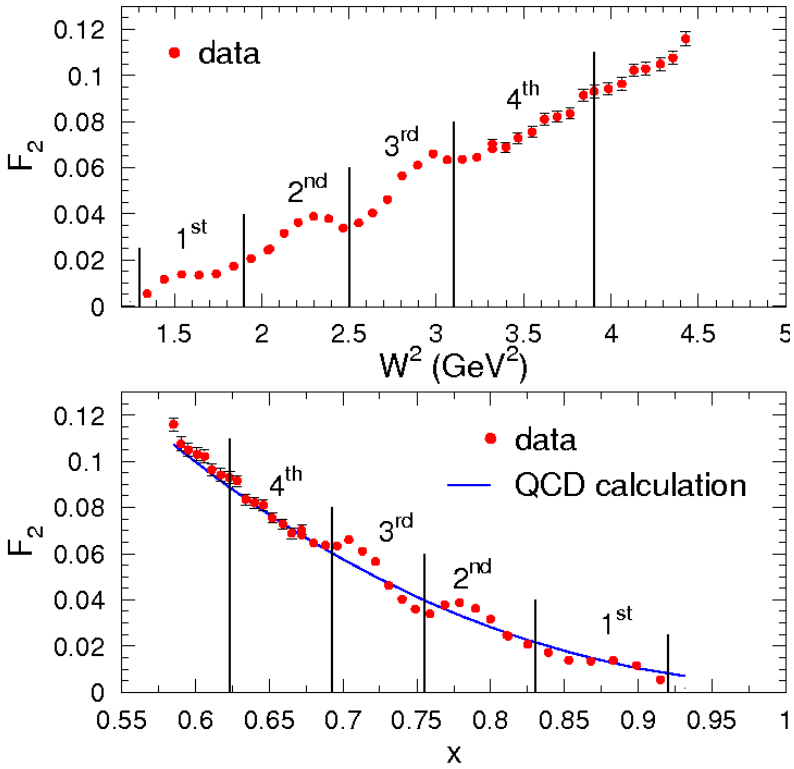
Region	1st	2nd	3rd	4th	DIS	global
W_{min}	1.3	1.9	2.5	3.1	3.9	1.9
W_{max}	1.9	2.5	3.1	3.9	4.5	4.5

→ There is arbitrariness in defining the local W intervals; typically try to catch peaks and valleys within one interval

How well resonance data average to the scaling curve?

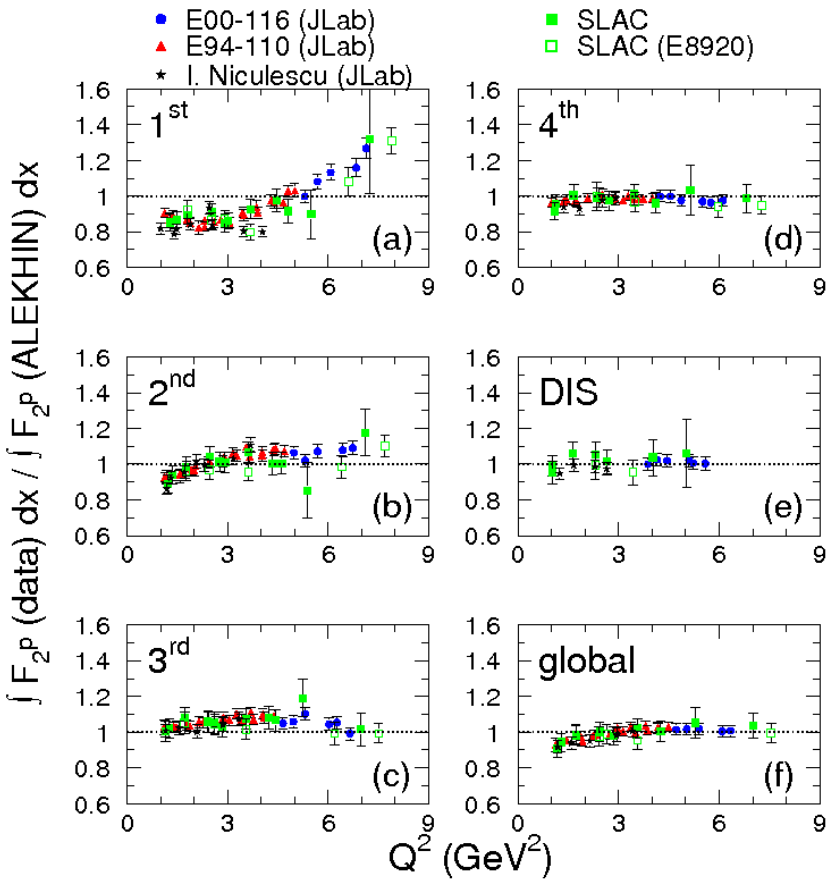
- Calculate ratio:

$$\int_{x_{min}}^{x_{max}} F^{data}(x,Q^2)\,dx \Big/ \int_{x_{min}}^{x_{max}} F^{param.}(x,Q^2)dx$$



Duality Studies in F_2 - Highlights

Duality verified against scaling from ABKM



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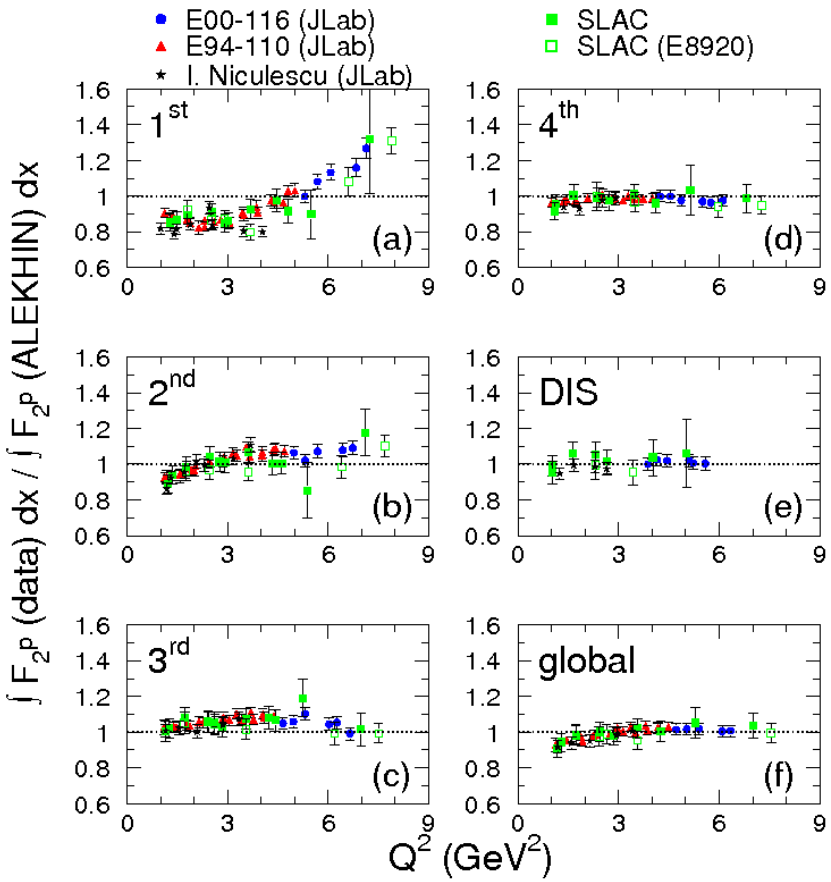
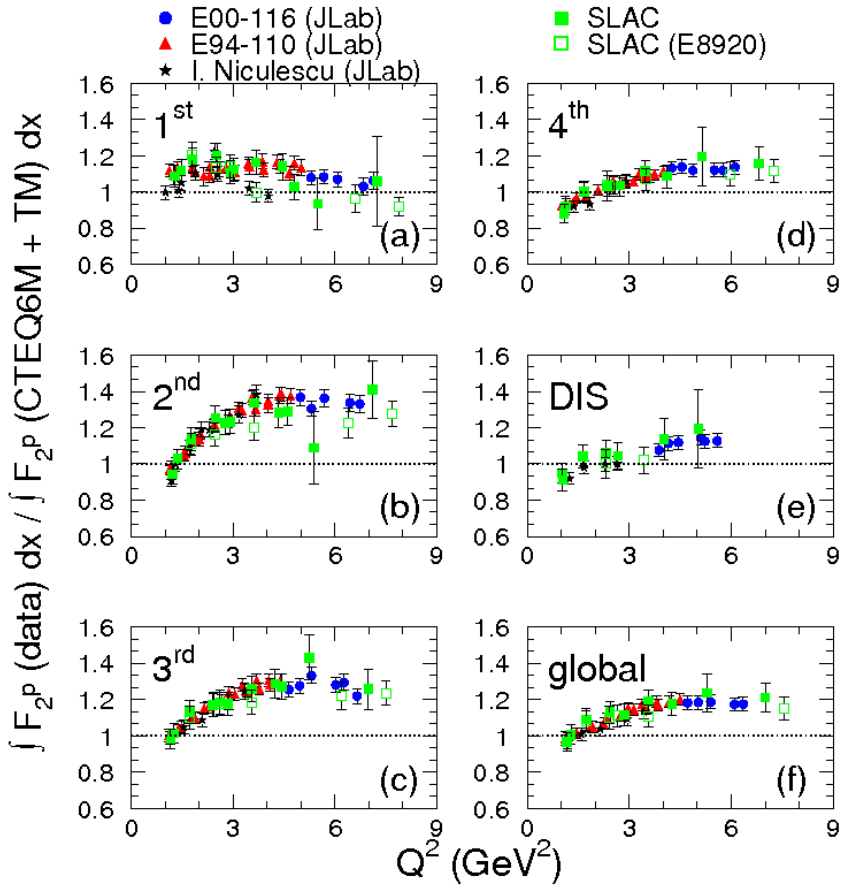
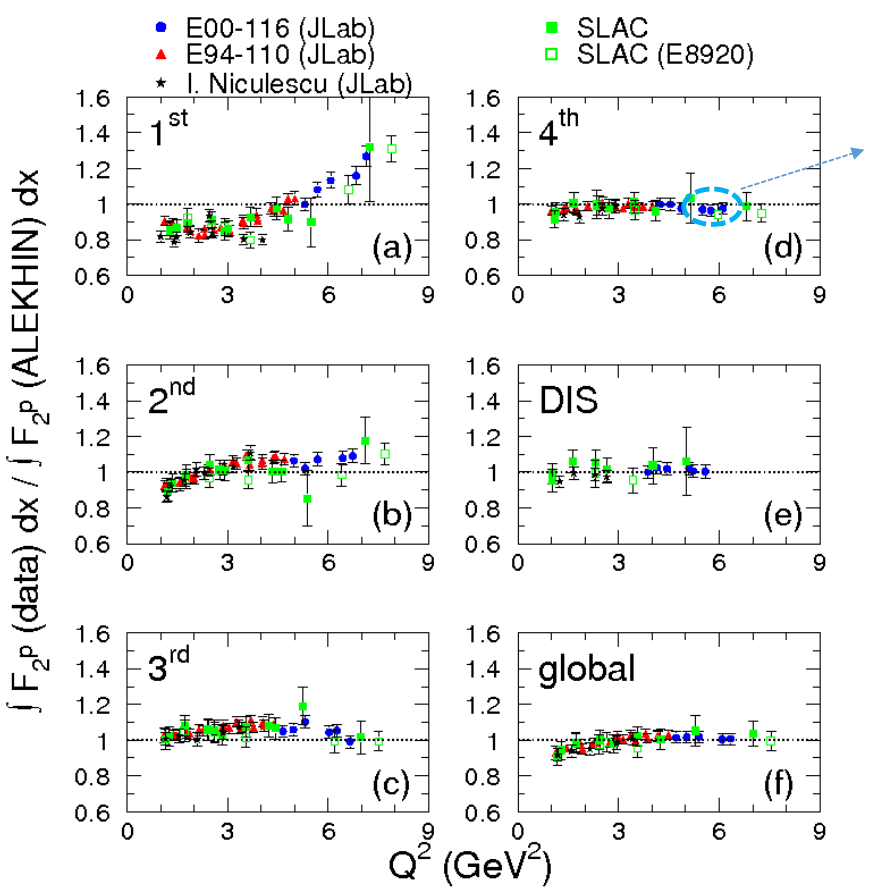


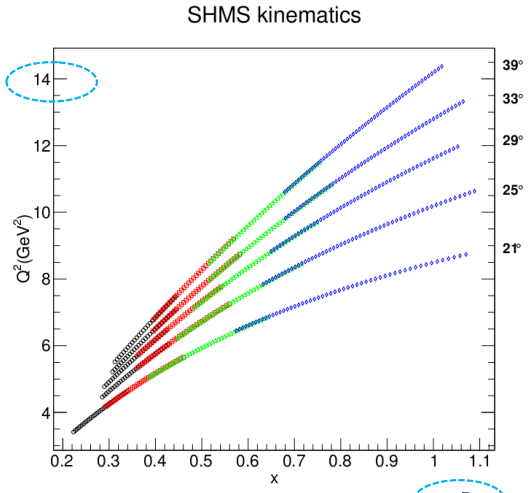
The Q^2 dependence is what matters, right?

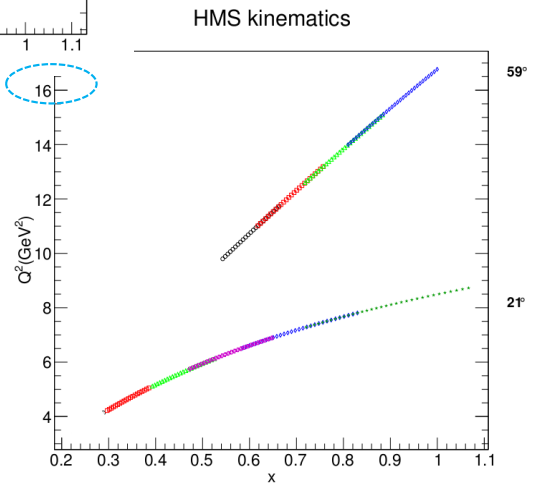


Duality Studies in F_2 - Future

- Jefferson Lab experiment, **E12-10-002**: pushing duality studies to even higher Q^2

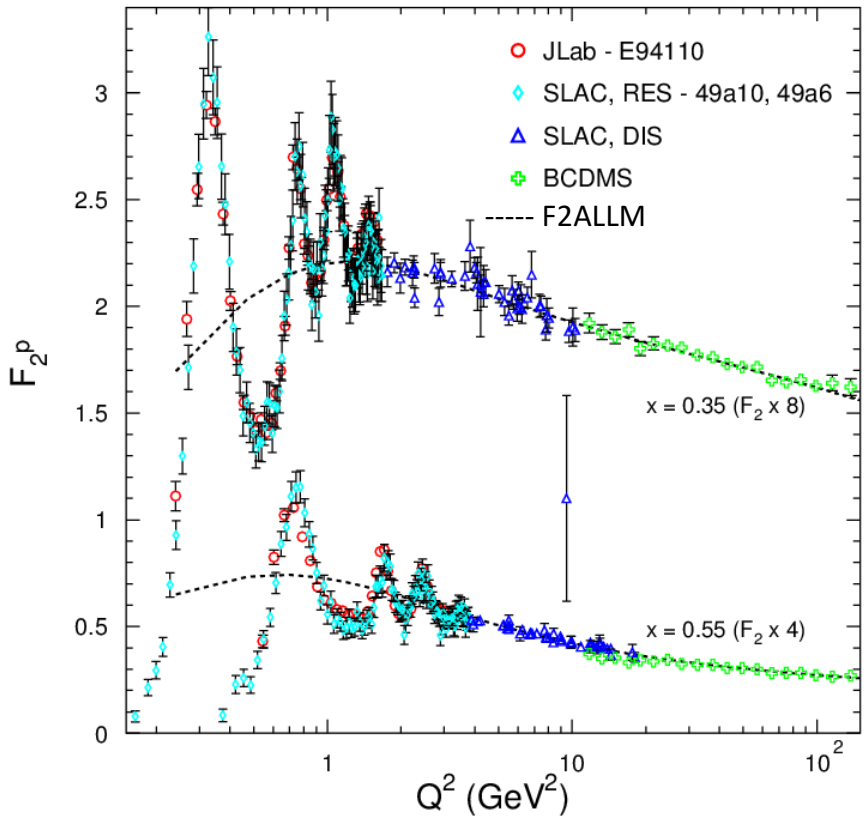


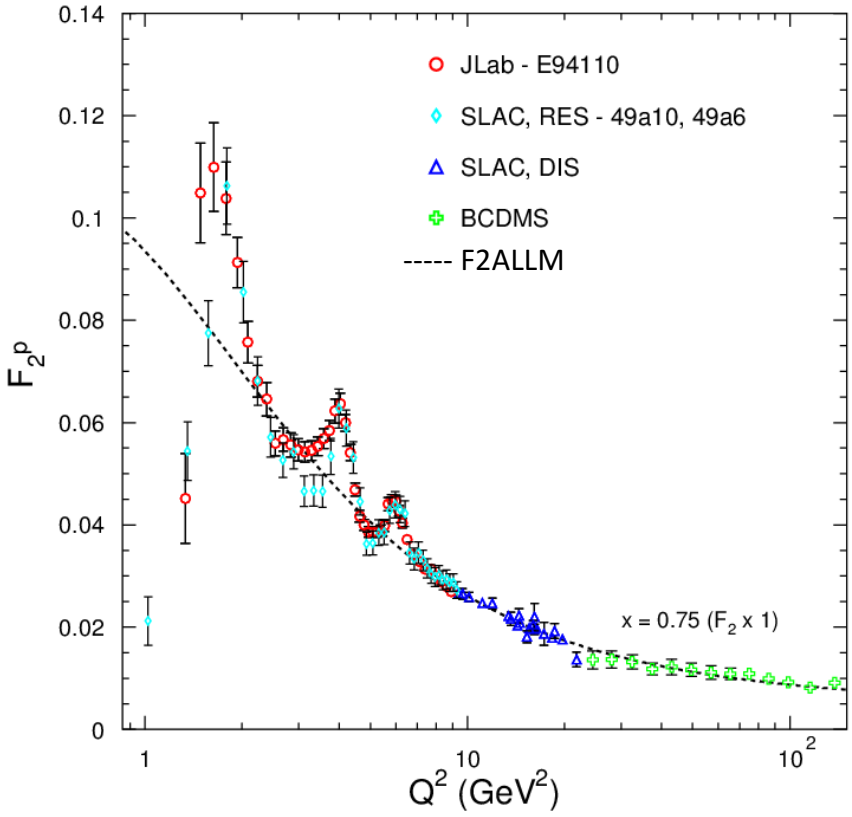




Duality Studies in F_2 - Future

- Another Theory-Experiment Collaboration: develop a different framework to understand the quark-hadron duality – see talk by John Collins





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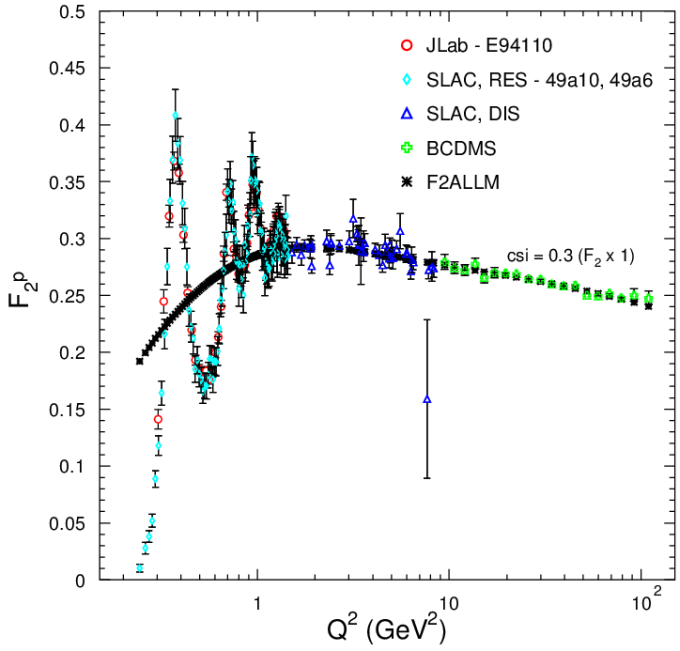
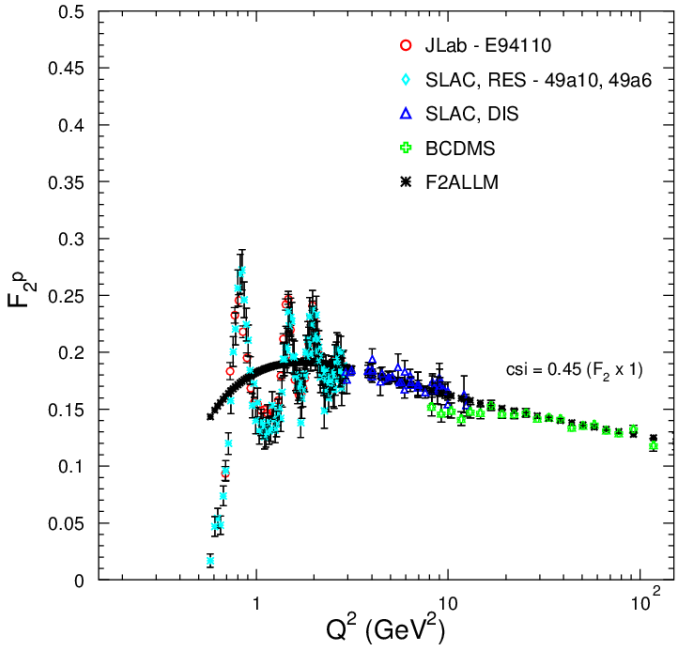
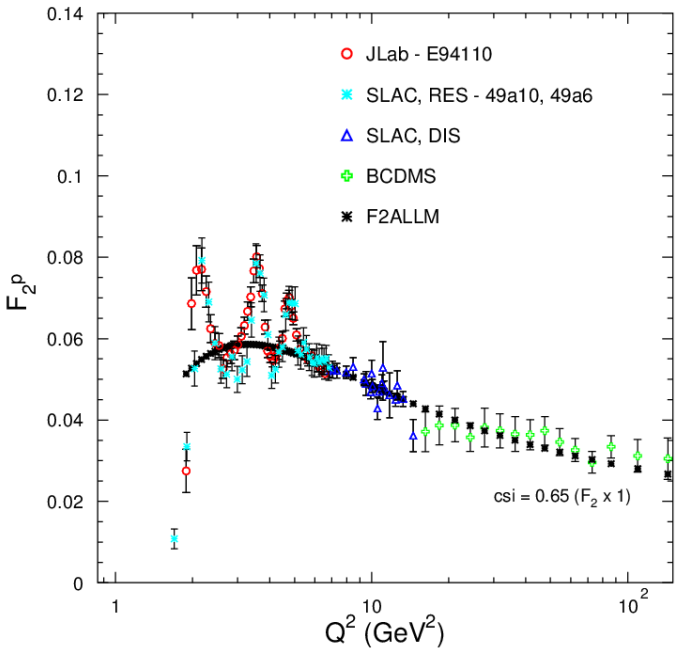
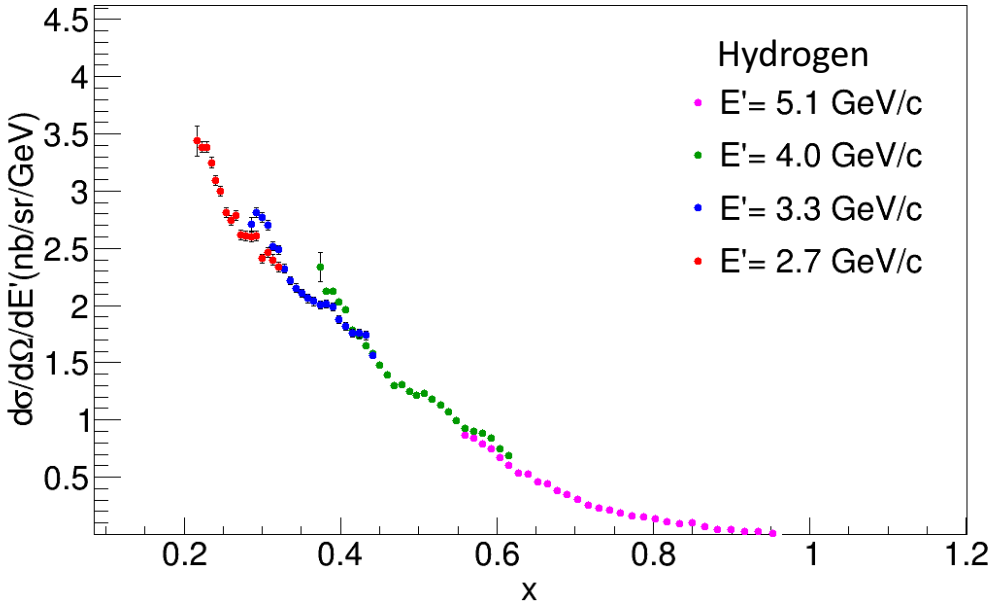


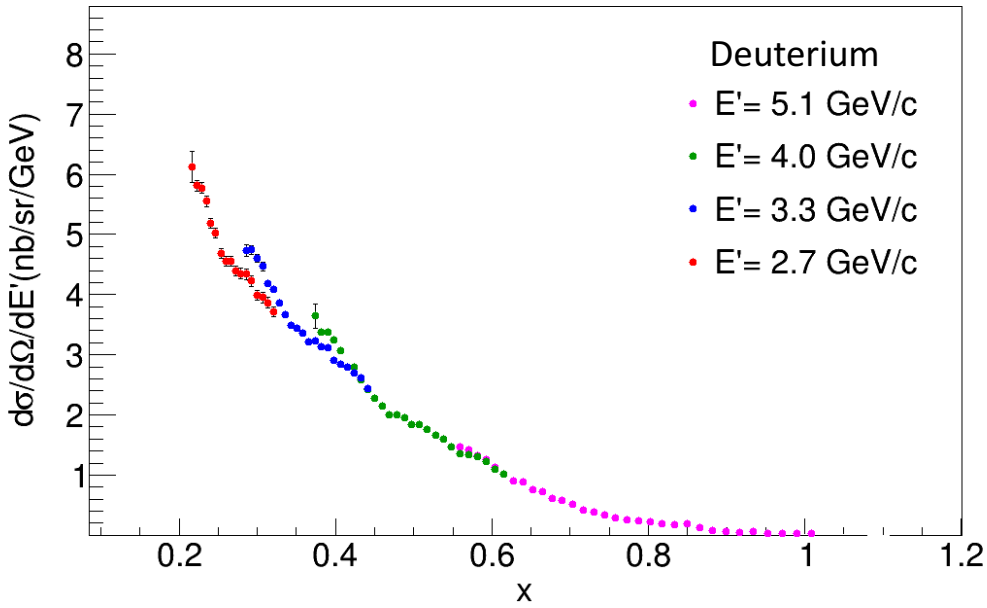




Duality Studies in F_2 - Future

- E12-10-002: very preliminary cross sections from our very first pass





→ Second pass already done (last week), new preliminary cross sections will be available soon

→ Preliminary results on duality checks from the new data will be presented at the SESAPS 2018