Nuclear structure functions at x>1: Searching for Super-fast quarks

- Inclusive scattering at x>1
  - Quasielastic → SRCs
  - DIS → pdfs at x>1: mapping out superfast quarks
  - JLab6, 12, EIC?

John Arrington, Argonne National Lab,

EIC-NUC2010, April 9th, 2010

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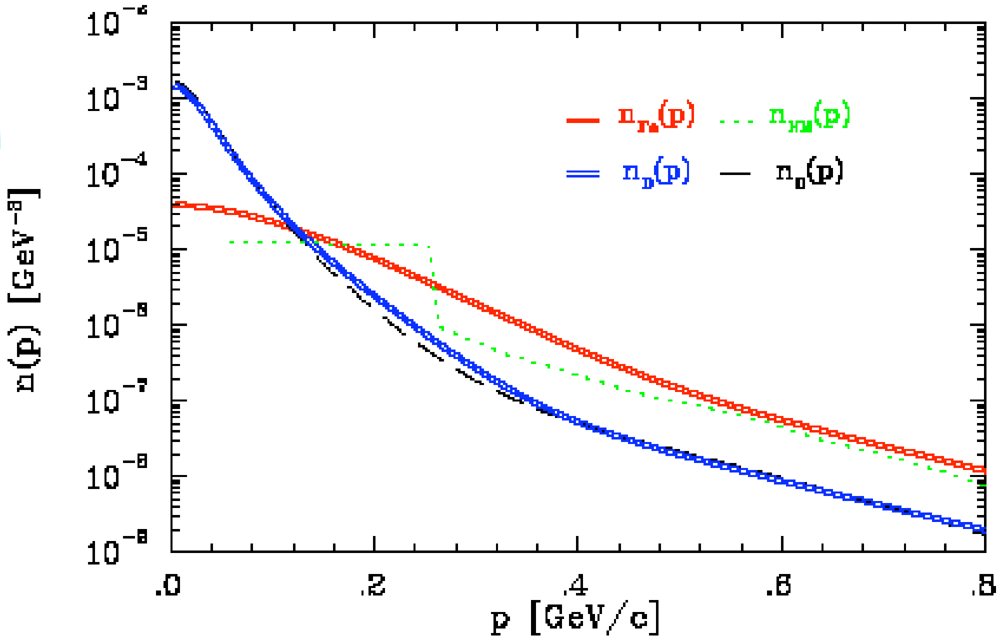
Office of Nuclear Physics Exploring Nuclear Matter - Quarks to Stars

Deuteron and Iron fits to data (y*-scaling)

Deuteron and nuclear matter calculations.



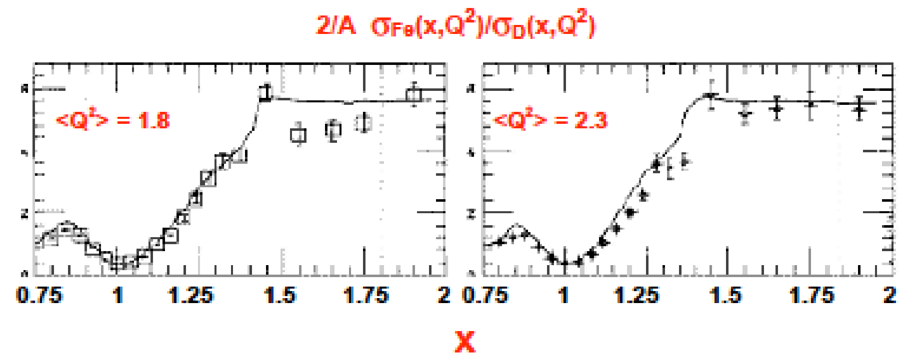
QE scattering, x>1:
high-momentum nucleons,
Short-range correlations

Same high momentum behavior seen is for C, Au (lower quality data)

Distribution at high momentum has same shape for deuteron and heavy nuclei - 2N SRCs appear to dominate.

Same as seen in cross section ratios, σ_A/σ_D at large x.

Fe data from SLAC NE3
^{2}H data interpolated to NE3 kinematics from older SLAC experiments.

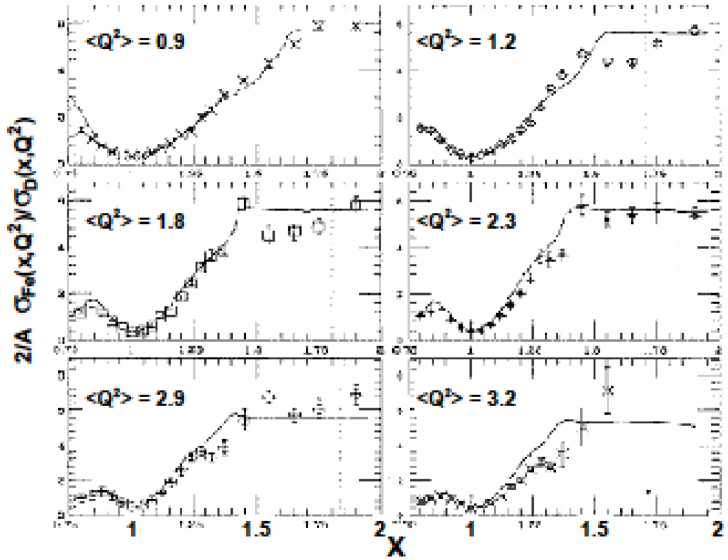


SRCs in σ_A/σ_D Ratios

σ_A/σ_D ratios show that heavy nuclei and deuterium have similar high momentum tails in regions where mean field motion is negligible (x>1.5).

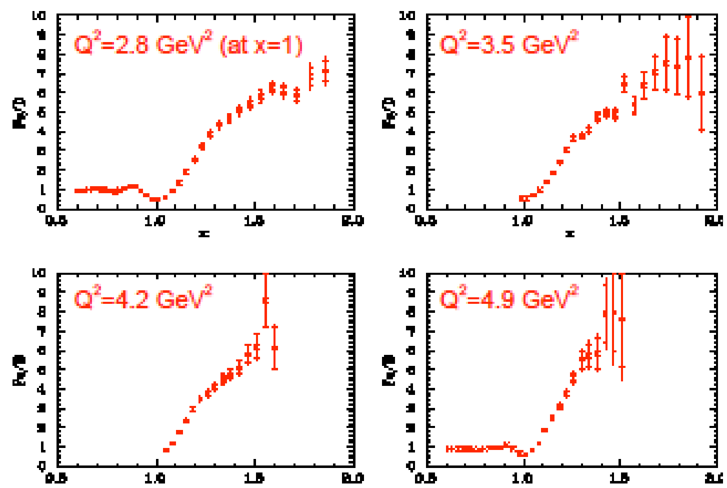
SLAC

Fe data from NE3. Deuterium data is interpolated to NE3 kinematics from previous SLAC measurements.



JLab - Hall C

Ratios limited by lack of high-x deuterium data. (89-008 was a short run focussed on heavy nuclei).



CLAS data, $Fe/^3He$

SLAC – combined deuterium and heavy target data from different experiments

Hall B – Measured ratios of heavy targets to ^3He, rely on measured or calculated $^3He/^2H$

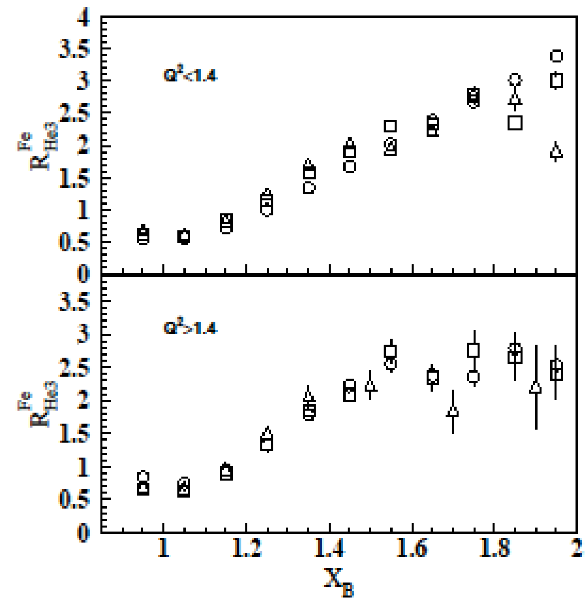
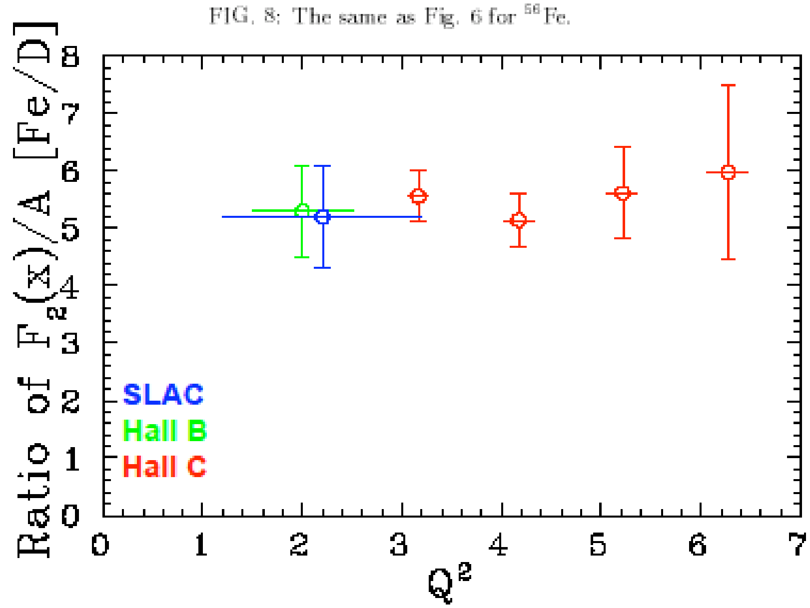


FIG. 8: The same as Fig. 6 for ^{56}Fe.

F_2^{Fe}/F_2^D at large x

Hall C (4 GeV) – Experiment did not focus on deuteron, so x coverage is poor at large Q^2



E02-019 (6 GeV) – ^2H, ^3He, ^4He, and heavy nuclei; paper in preparation

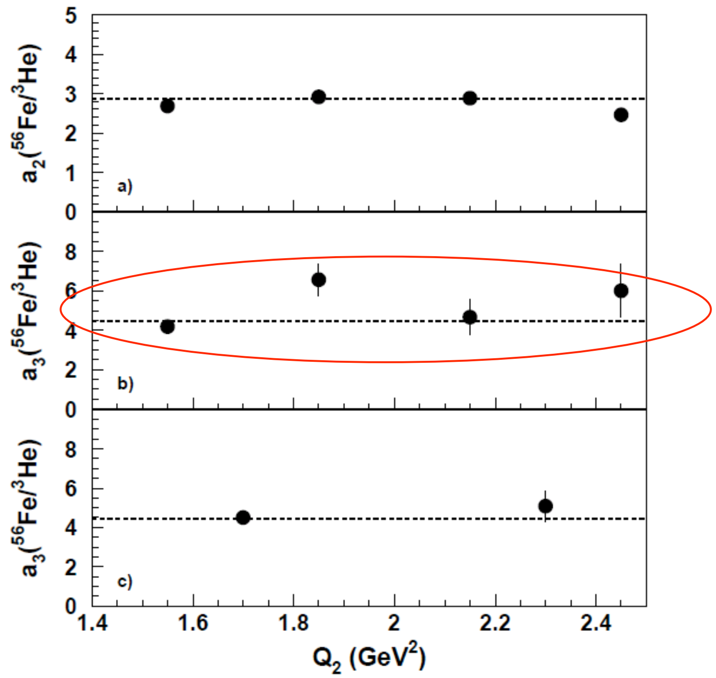
CLAS: 3N-SRCs

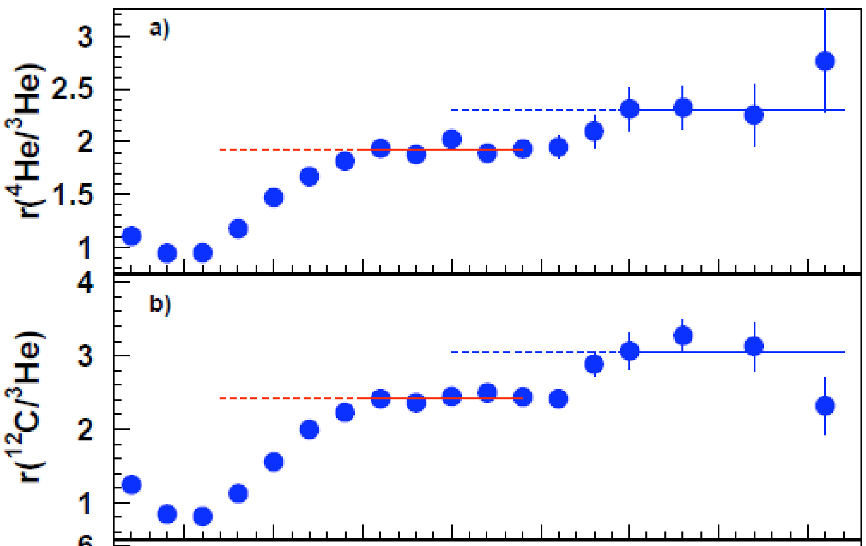
K. Egiyan et al, PRL96, 082501 (2006)

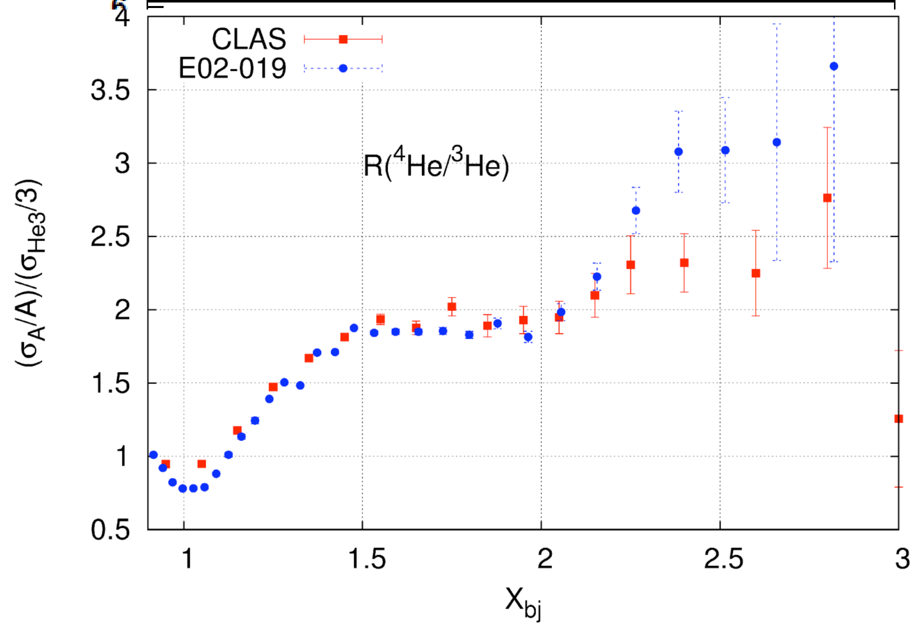
- **A/^{3}He ratios for x>2 should show similar plateau if 3N-SRCs dominate and have A-independent structure**

- **CLAS ratios: first such suggestion of 3N-SRCs**

  Q^2 low (dominated by Q^2<1.7 GeV^2)



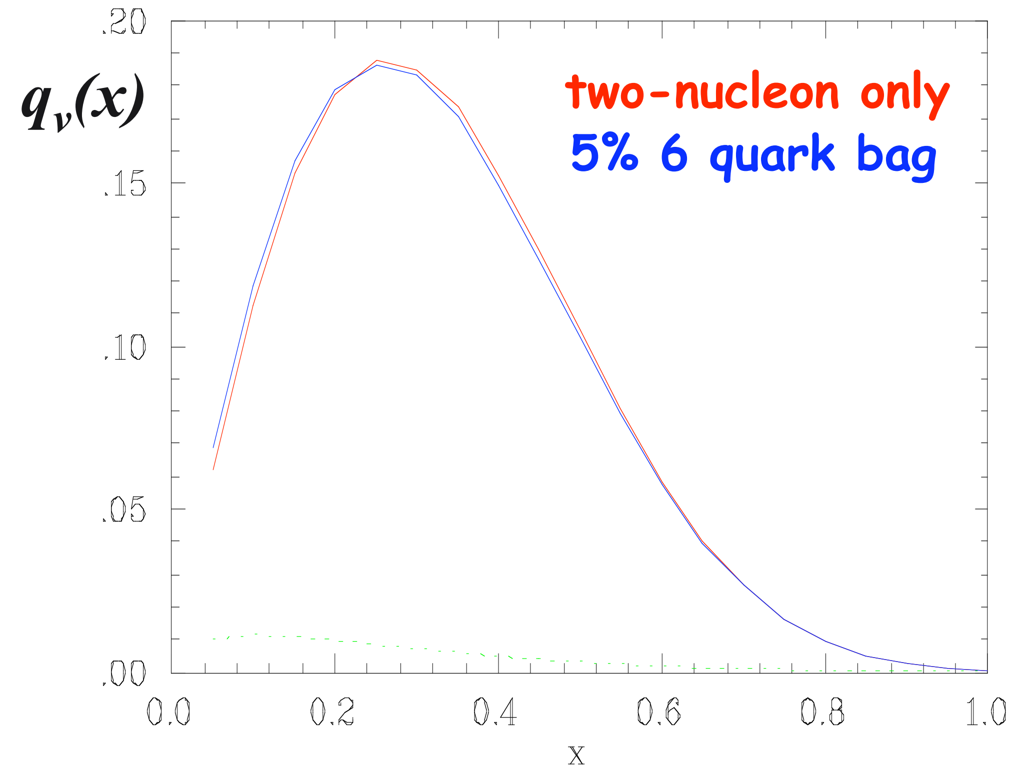


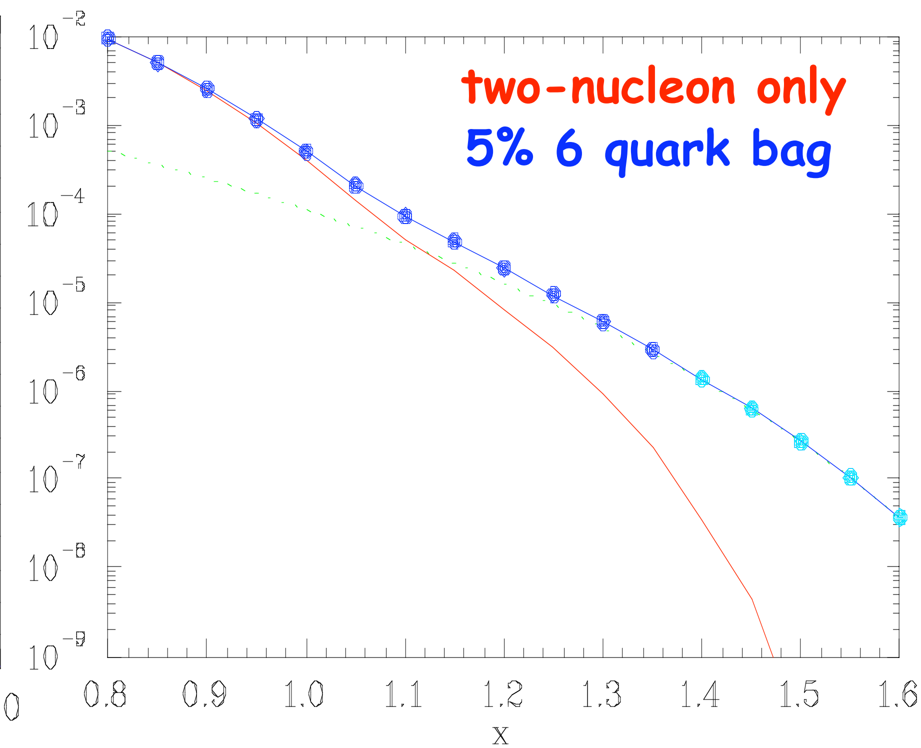


2011: E08-014, dedicated measurements, x>2

DIS at x>1: Superfast quarks, short range structure

- 12 GeV x>1 proposal → DIS-dominated scattering in SRC-dominated kinematics
- Exotic states, where nucleons share momentum (e.g. 6q bag), yield much larger "EMC" effect at x>1





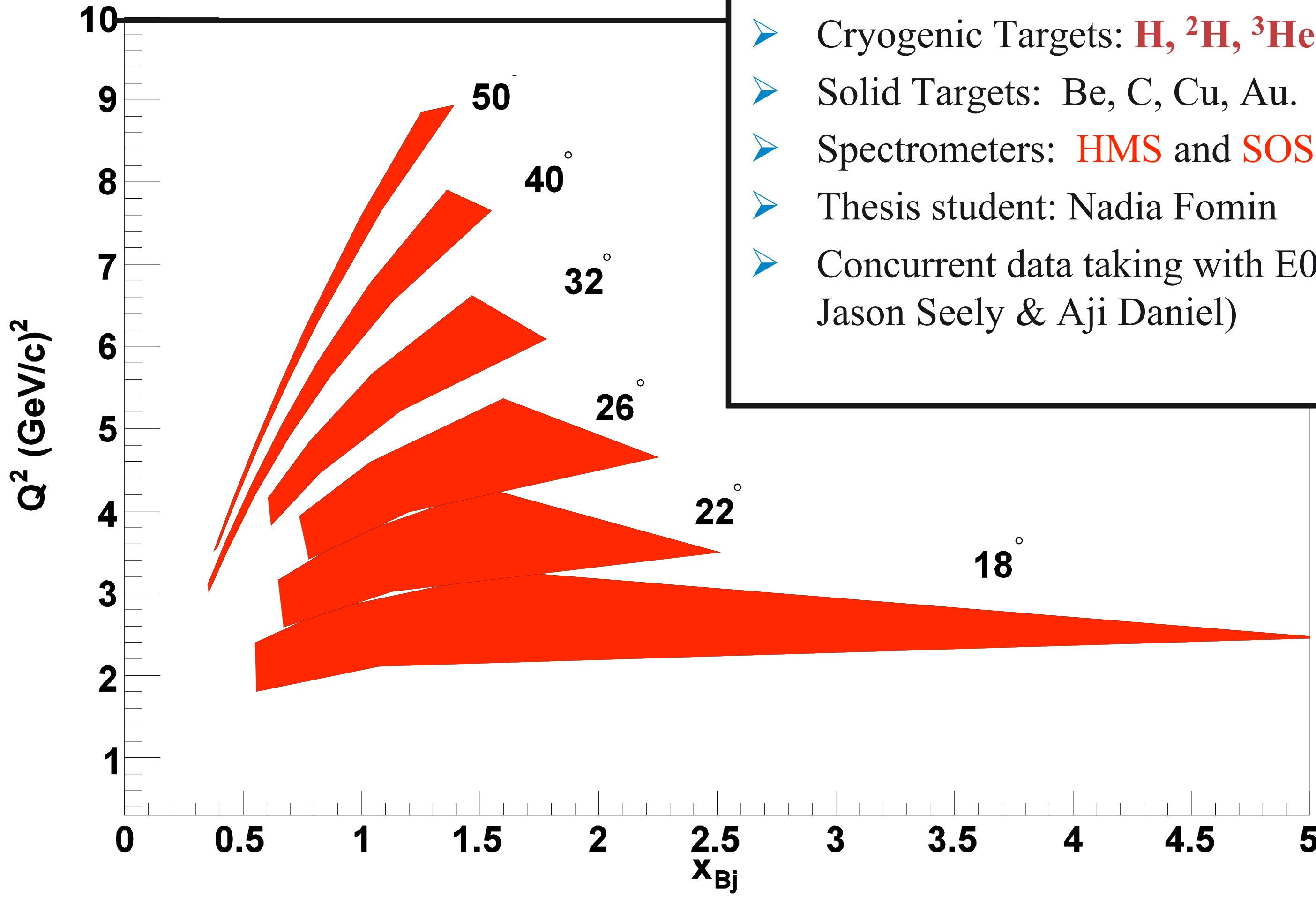
What do we know about superfast quarks?

- 2 results for high x SFQ distributions (**CCFR** & **BCDMS**)
  - both fit F_2 to exp(-sx), where s is the "slope" related to the SFQ distribution fall off.
  - **CCFR**: s=8.3±0.7 (Q^2=125 GeV/c^2) *"very large short range structure"*
    - *Poor resolution in x*
  - **BCMDS**: s=16.5±0.5 (Q^2: 52-200 GeV/c^2) *"little short range structure"*
    - *Low statistics (only upper limits above x=1.05)*

- Plenty of lower Q^2 data (SLAC, JLab E89-008 (4 GeV))
  - Not in DIS region (but not clear how to define for x>1)
  - Expect large higher twist contributions at large x
  - However, even at very low Q^2 (to about 3 GeV^2), the data showed qualitatively scaling vs Nachtmann ξ

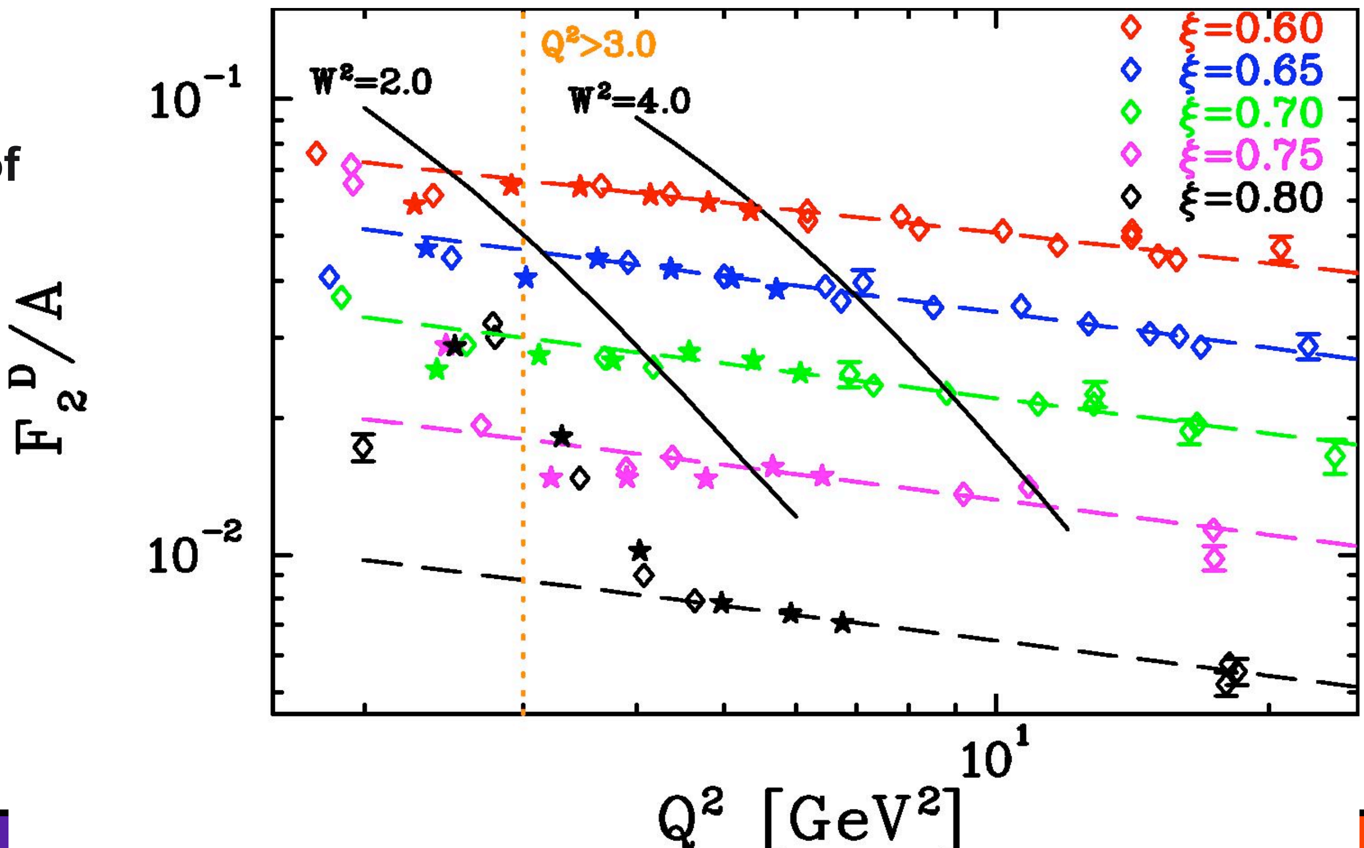
E02-019: Hall C at JLab

- E02-019 ran in Fall 2004
- Cryogenic Targets: **H, ^{2}H, ^{3}He, ^{4}He**
- Solid Targets: Be, C, Cu, Au.
- Spectrometers: HMS and SOS (mostly HMS)
- Thesis student: Nadia Fomin
- Concurrent data taking with E03-103 (EMC Effect – Jason Seely & Aji Daniel)



Scaling of the nuclear structure functions

- **Low Q^2 JLab data** (from E89-008, 4 GeV) **are consistent with extrapolated structure function from high Q^2 SLAC data** [fixed $d\ln(F_2)/d\ln(Q^2)$]
- **Above ξ=0.65, there is a large gap between JLab, SLAC data, but there are indications of scaling up to ξ=0.75**
- **New data fill in the gap up to ξ~0.75, show indications of scaling up to ξ~0.9**



Step 1: Apply target mass corrections

$$F_2^{TMC}(x,Q^2) = \frac{x^2}{\xi^2 r^3} F_2^{(0)}(\xi) + \frac{6M^2x^3}{Q^2r^4} h_2(\xi) + \frac{12M^4x^4}{Q^4r^5} g_2(\xi)$$

Structure function including target mass corrections (i.e. as measured)

"Massless-limit" structure function: corresponds to large Q^2 limit (i.e. to pdfs)

$$h_2(\xi,Q^2) = \int_\xi^1 du \frac{F_2^{(0)}(u,Q^2)}{u^2}$$

$$g_2(\xi,Q^2) = \int_\xi^1 dv(v-\xi) \frac{F_2^{(0)}(v,Q^2)}{v^2}$$

- We want $F_2^{(0)}$, the massless limit structure function as well as its Q^2 dependence
- Need model for $F_2^{(0)}$ to calculate h_2, g_2

$$r = \sqrt{1 + \frac{4x^2M^2}{Q^2}} \equiv \sqrt{1 + \frac{Q^2}{\nu^2}}.$$

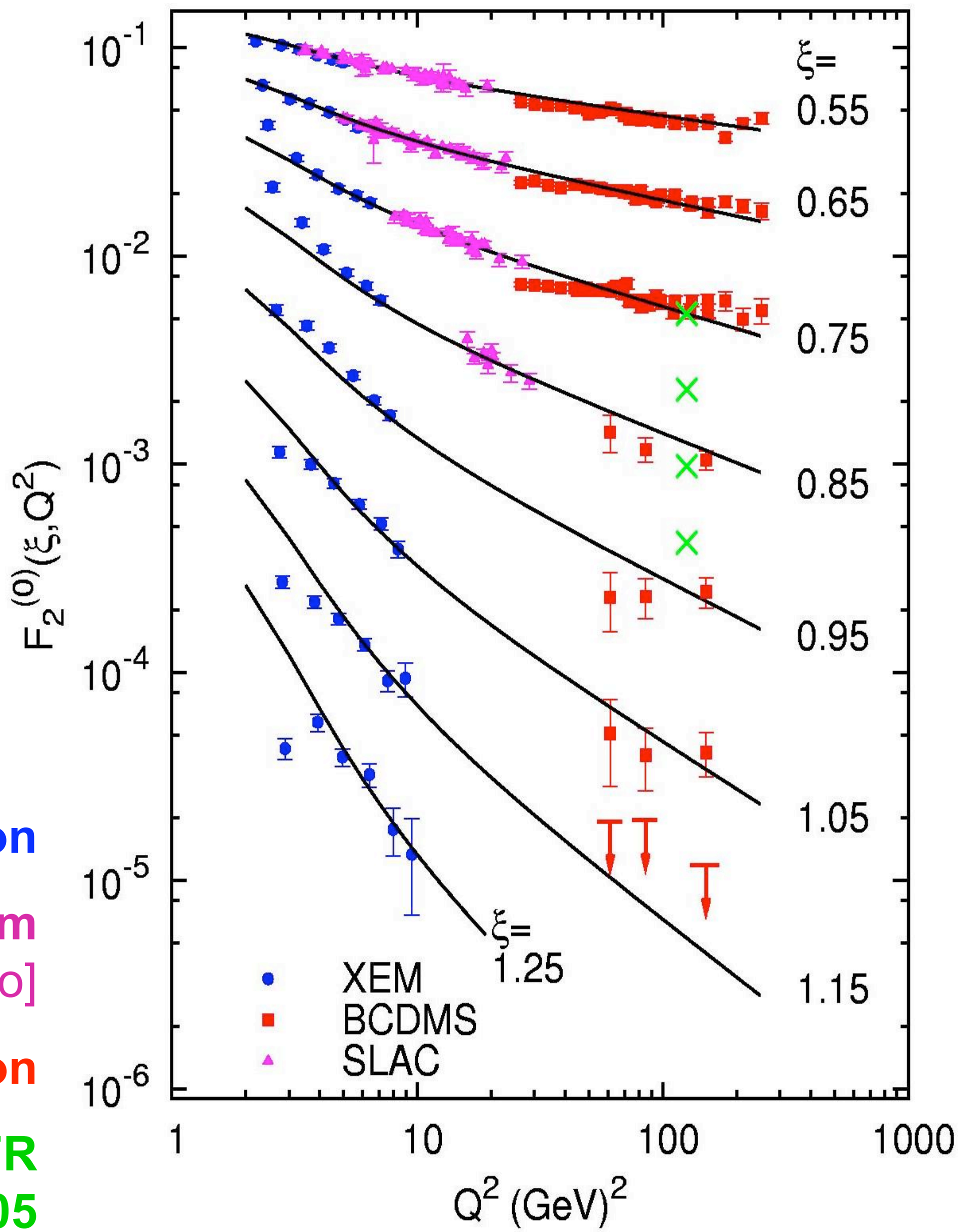
$$\xi = \frac{2x}{1+\sqrt{1+4x^2M^2/Q^2}} = 2x/(1+r)$$

I. Schienbein et al, J.Phys G, 2008

$F_2^{(0)}$ Model for TMCs

- Factorized ξ, Q^2 dependence
- ~logarithmic Q^2 dependence (fit to worlds data at several ξ values)
- For each target, interpolate nearby data to Q^2=7, fit $F_2^{(0)}(\xi,Q^2=7)$

Model then used to apply TMC, estimate ~2% model-dependence

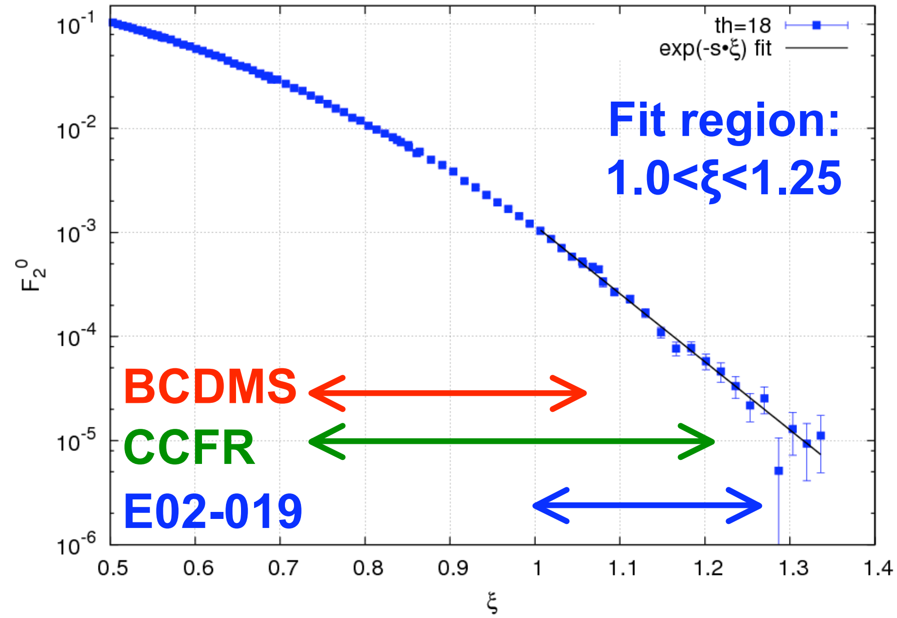


E02-019 carbon

SLAC deuterium
[times SLAC C/D ratio]

BCDMS carbon

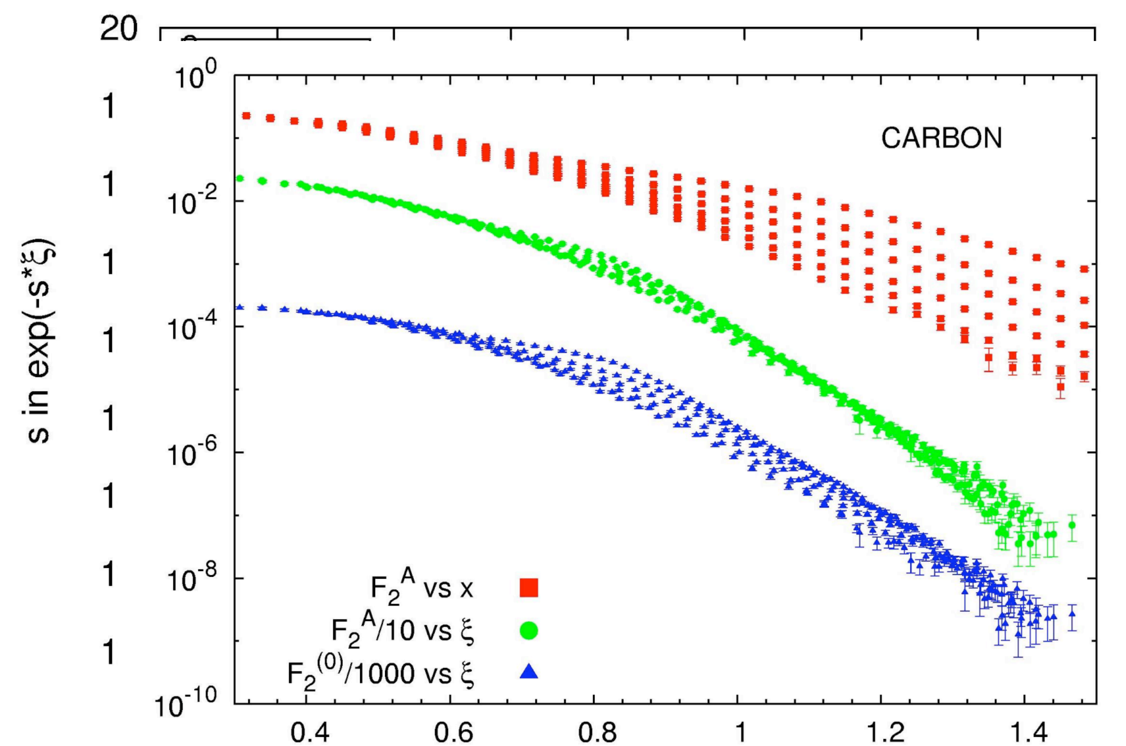
x = projection of CCFR falloff, 0.75-1.05



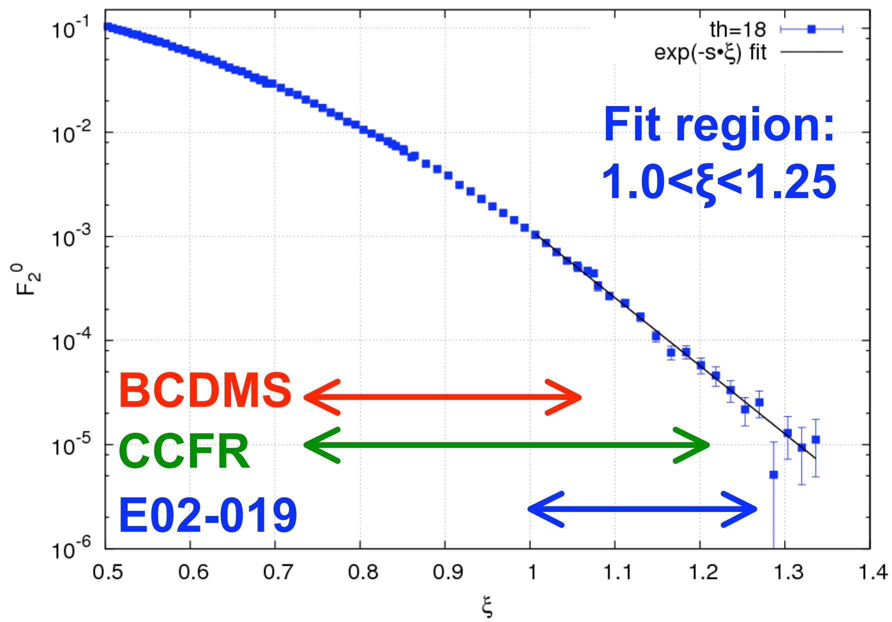
Final step: fit exp(-sξ) to F_2^0 and compare to CCFR and BCDMS

CCFR (Q^2=125 GeV^2)
s=8.3±0.7

BCMDS (Q^2: 52-200 GeV^2)
s=16.5±0.5



Some concerns about the comparisons



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SLAC deuterium
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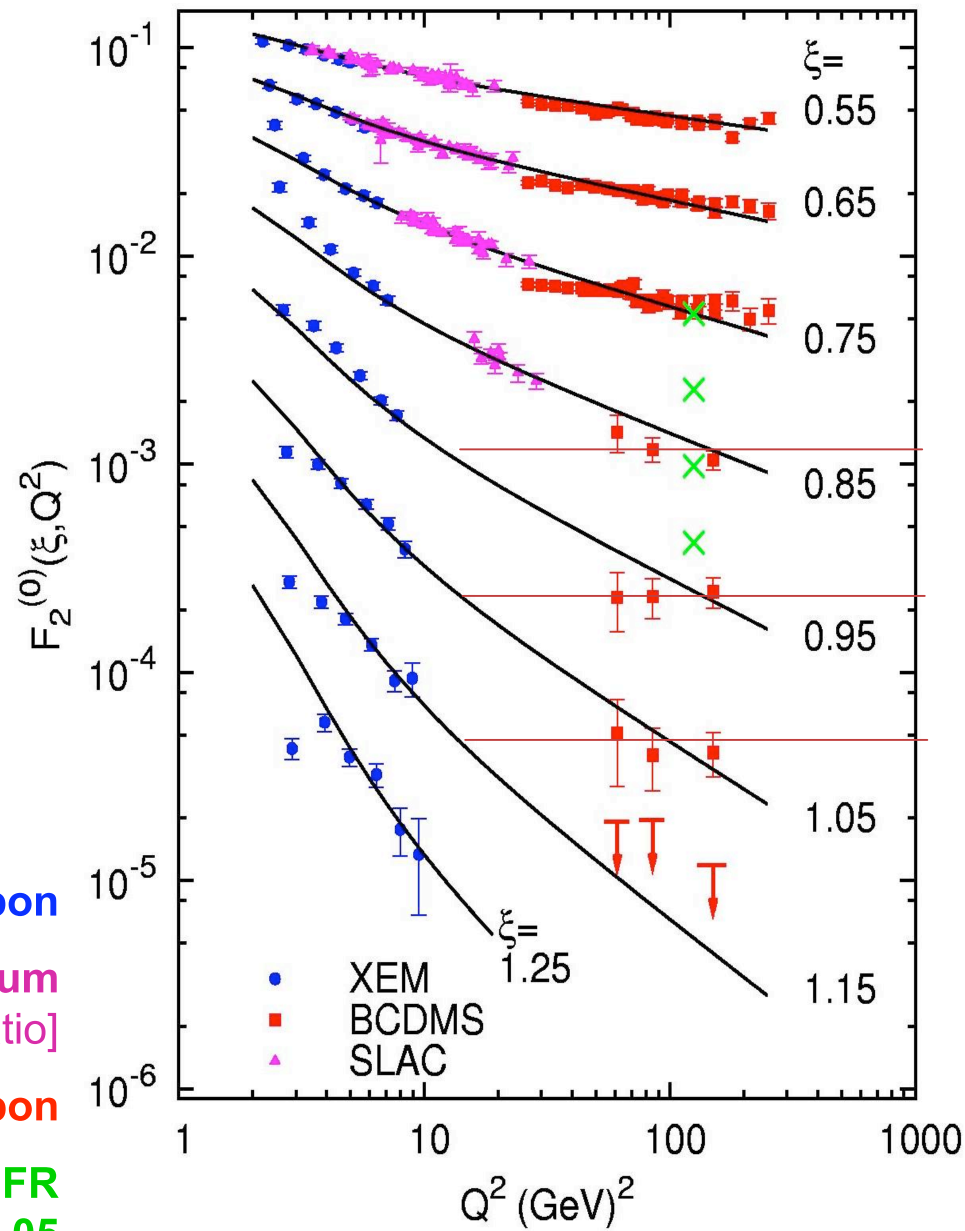
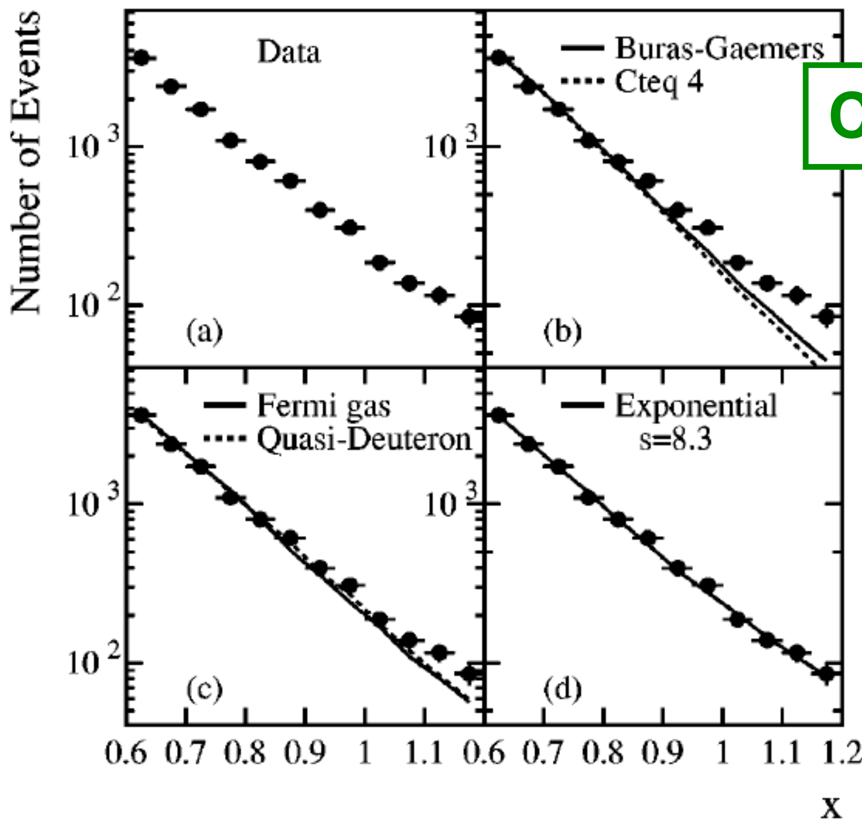




CCFR

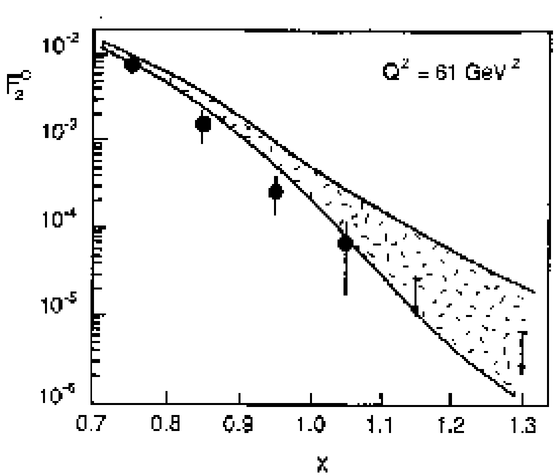
Bottom left fig is CTEQ style PDF convoluted with Fermi gas model: only 20-30% below the high-x data

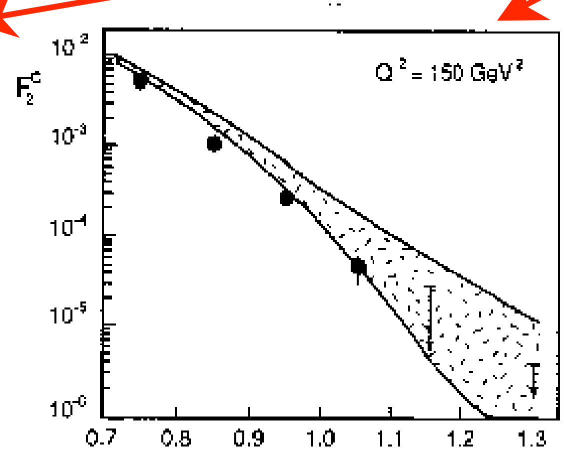
Low Q^2 data at large x suggest that PDFs underestimate F_2 by similar amount

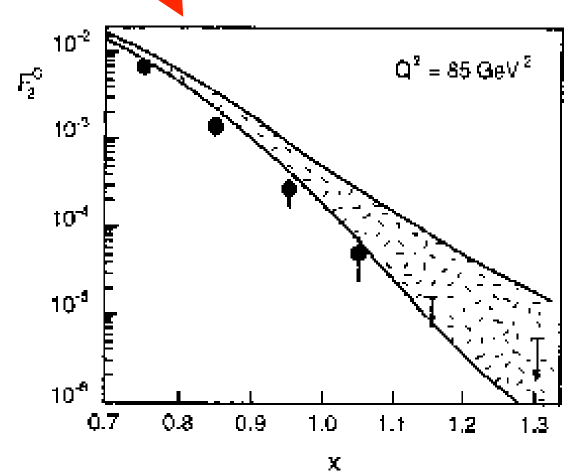
Idea that CCFR data imply very large SRC <u>does not appear to be justified</u>

CCFR, BCDMS may not go to large enough x to interpret slopes in terms of SRCs or more exotic short-range structure

BCDMS







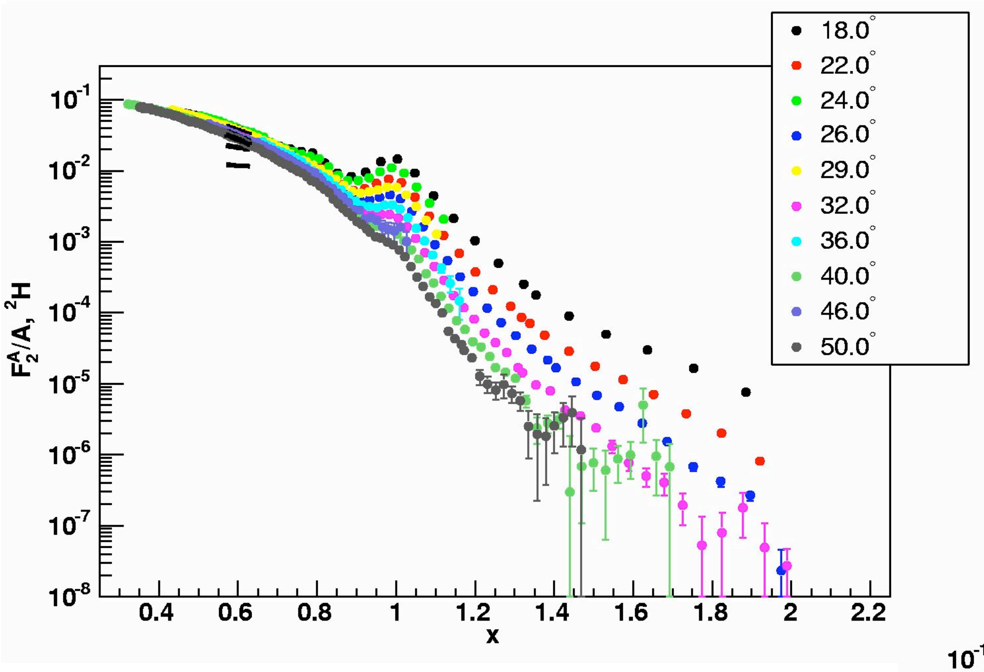
Future

- Apparent consistency of 6 GeV measurements and BCDMS support idea that 12 GeV measurement can constrain superfast quarks
  - Comparison of QCD evolution to our fitted Q^2 dependence will provide more quantitative measure of scaling violations

- (m/M)E®(h)IC limited by cross section
  - For $s=1000$, $L \approx 10^{34}$, statistics running out for $x \approx 0.85$
  - Might be possible to reach interesting x range
    - *Need factor of 10, 100, 1000 to reach $x \approx 1.0, 1.15, 1.30$*
    - *Need to evaluate statistics for lower s*
      - Can one run below the nominal minimum with reduced luminosity?
    - *Not clear just how high in x required to isolate short-range structure that we're intereste in*

Fin

Scaling of the nuclear structure functions



$F_2(x,Q^2)$ consistent with QCD evolution in Q^2 for low x values (x<0.5)

Huge scaling violations at large x (especially for x>1)

$F_2(\xi,Q^2)$ consistent with QCD evolution in Q^2 to much larger ξ values

Scaling violations are mostly the "target-mass" corrections
(plus clear contribution from the QE peak)

→ **Nearly independent of A**