PR12-06-105

Inclusive Scattering from Nuclei at x>1 in the quasielastic and deeply inelastic regimes

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PAC 30 , Jefferson Lab, August 24, 2006

Outline

- Goals of the Experiment
- Physics Background and Motivation
- The Experiment
- Request to PAC
- Institutional Committments

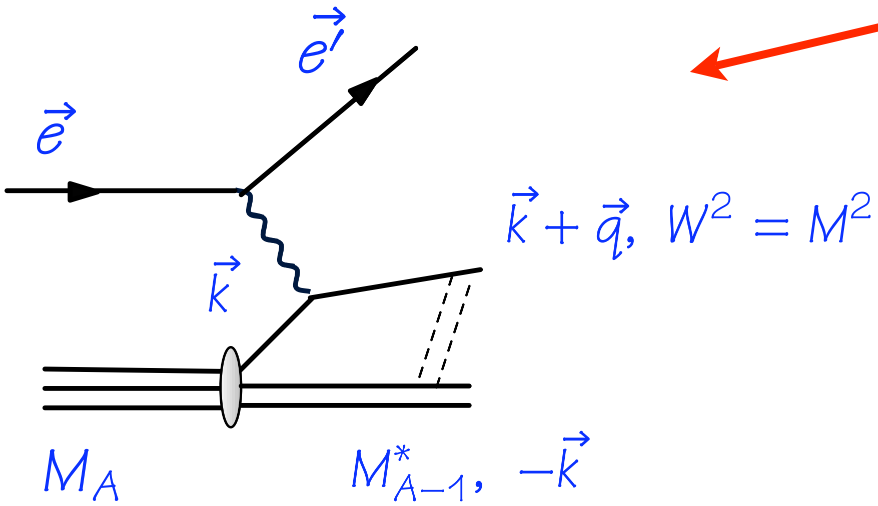
Overall Goals

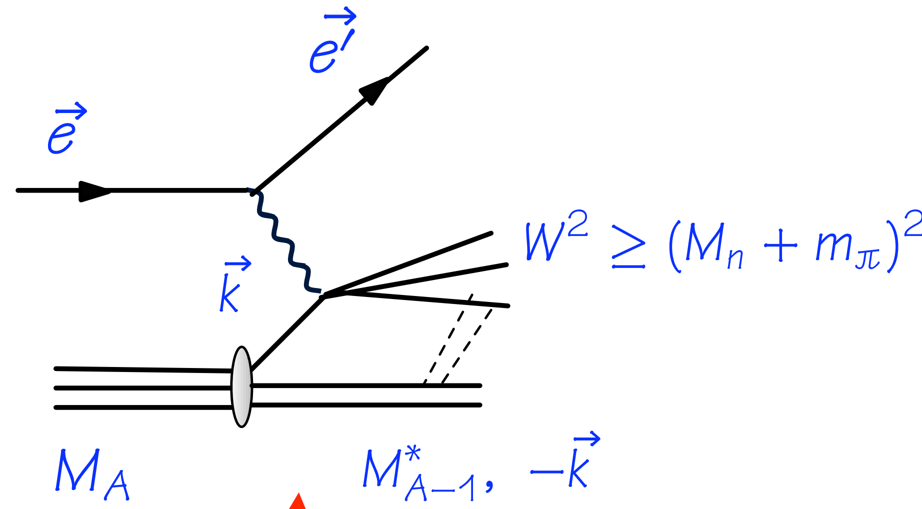
- Take data for light and heavy nuclei in a unique kinematic region that is largely unexplored
- Obtain precise ratios of heavy to light nuclei to expose role of multi-nucleon correlations
- Examine a regime that is sensitive to high momentum constituents (quarks or nucleons) generated by high density configurations
- Capture signatures of medium modifications in high density configurations
- Reach scaling region ($Q^2 > 15$) out to very large x (1.4).

Inclusive Quasielastic and Deep Inelastic Scattering at High Momentum Transfers

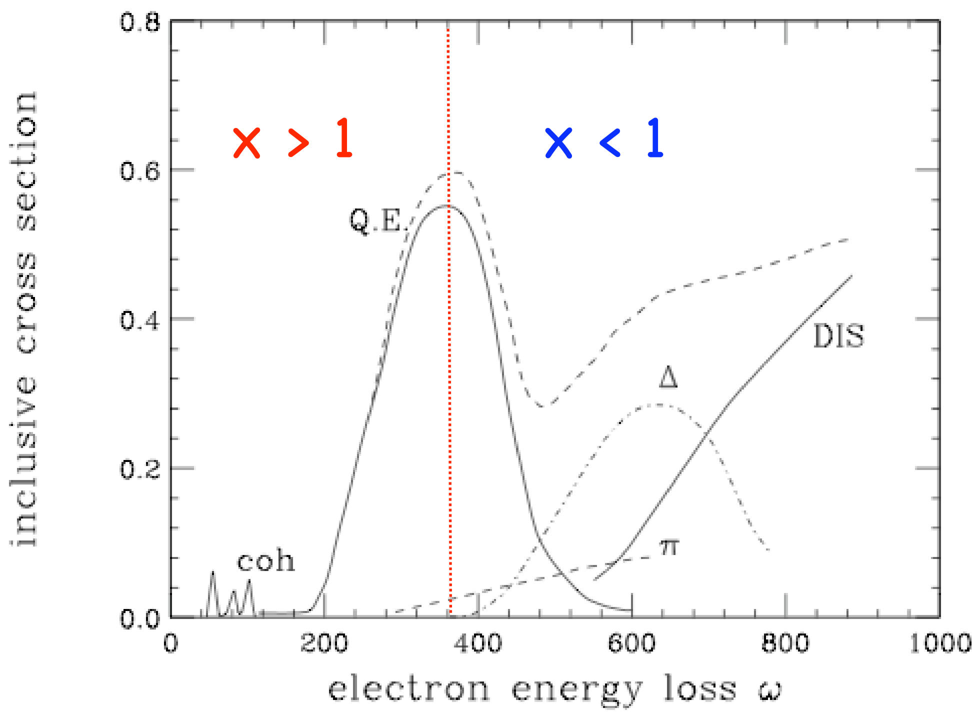
Two distinct processes

Quasielastic from the nucleons in the nucleus

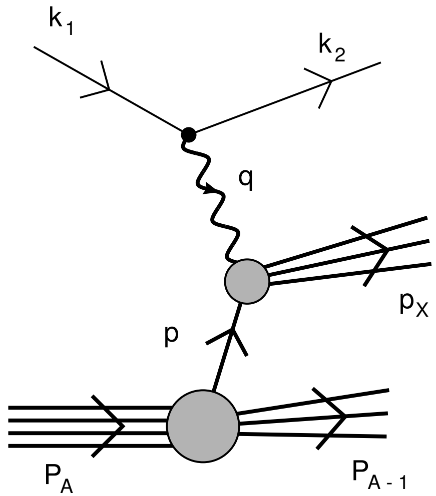




Inelastic, Deep Inelastic from the quark constituents of the nucleon.



Inclusive final state means no separation of the two dominant processes



Nonetheless there is a rich, if complicated, blend of nuclear and fundamental QCD interactions available for study from these types of experiments.

The two processes share the same initial state

QES in PWIA $$\frac{d^2\sigma}{d\Omega d\nu} \propto \int d\vec{k} \int dE \sigma_{ei} \underbrace{S_i(k,E)}_{\text{Spectral function}} \delta()$$

$$n(k) = \int dE \; S(k,E)$$

DIS $$\frac{d^2\sigma}{d\Omega d\nu} \propto \int d\vec{k} \int dE \; W_{1,2}^{(p,n)} \underbrace{S_i(k,E)}_{\text{Spectral function}}$$

However they have very different Q^2 dependencies

σ_{ei} goes as the elastic (form factor)^2

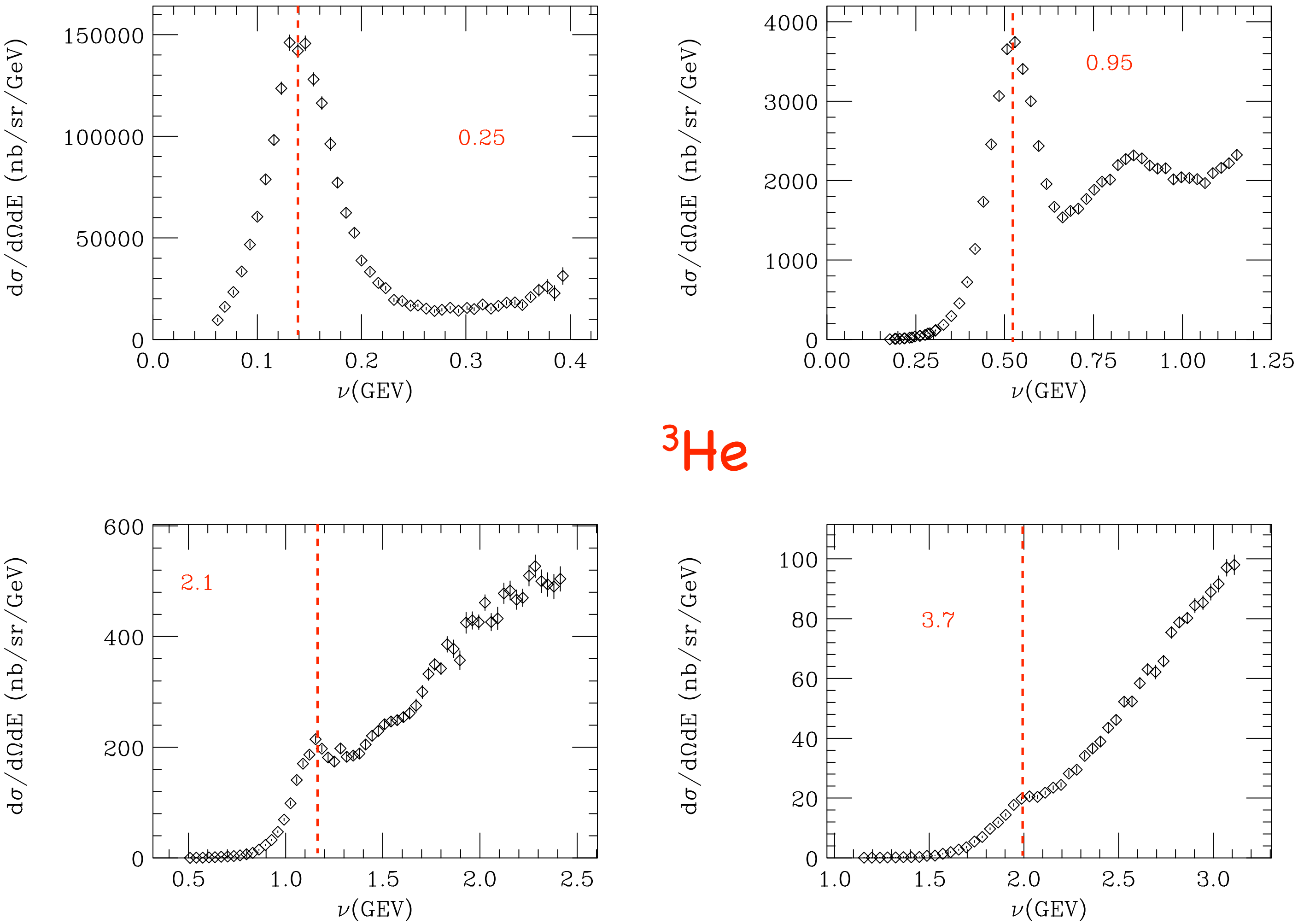
$W_{1,2}$ scale with ln Q^2 dependence

Exploit this Q^2 dependence

Physics Topics

- Short Range Correlations and Multi-nucleon correlations
  - Ratios of heavy to light nuclei
  - Absolute cross section measurements
- Momentum distributions and details of the spectral function S(k,E).
  - Absolute cross sections of multiple few-body systems allow comparison to 'exact' calculations
  - Constrain role of FSI
  - Range of A allows extrapolation to NM
- Nuclear Structure functions at large x
  - Distributions of `super-fast quarks'
  - High Sensitivity to non-hadronic configurations in nuclei - EMC effect, quark clusters ...
- Scaling of the nuclear structure functions at large x - duality

Q^2 dependence

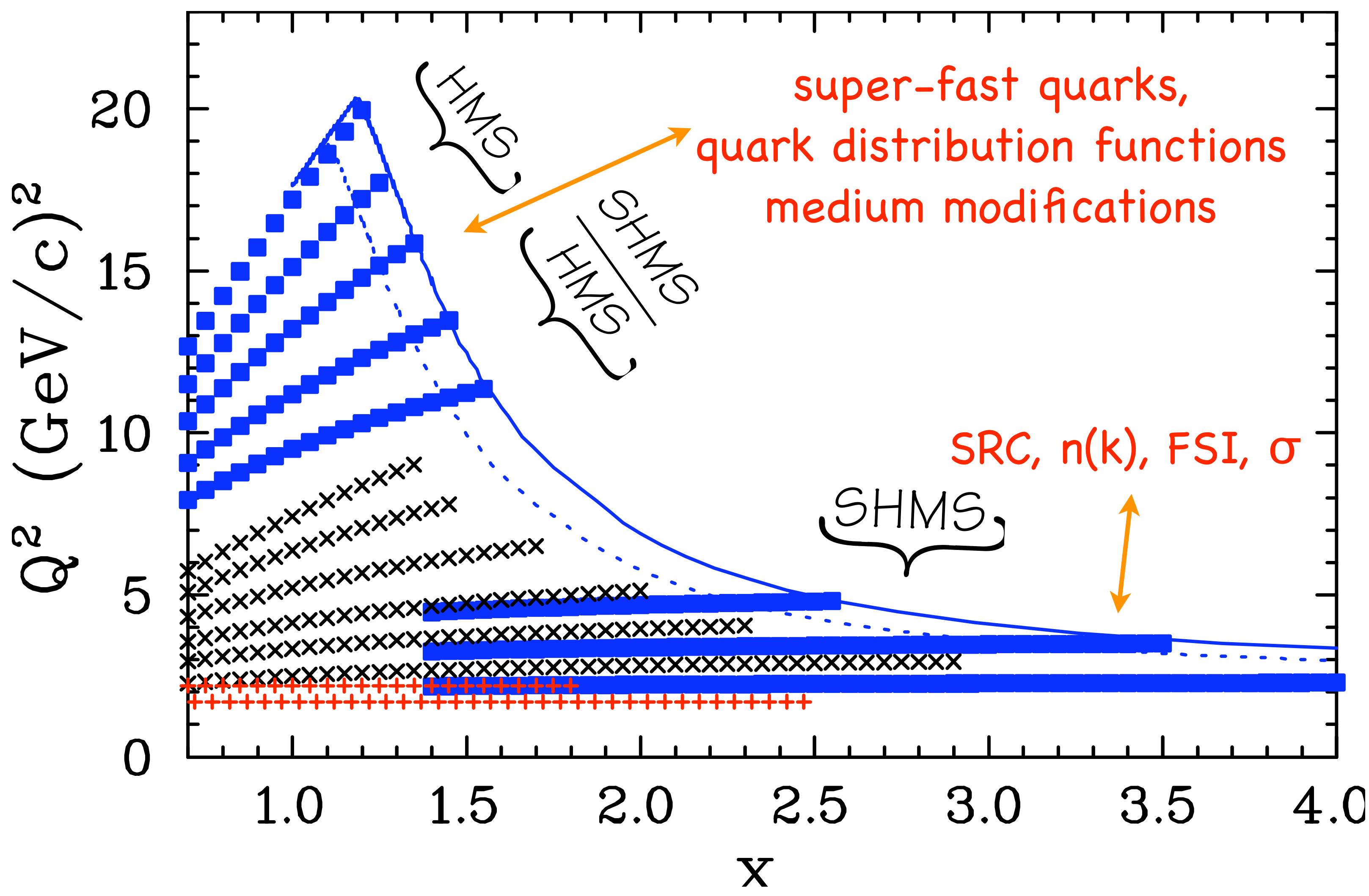


In nuclei, the quasielastic peak (QE) is broadened by the Fermi-motion of the struck nucleon.

At low energy loss (ν) the quasielastic contributions dominates the cross section even at moderate to high Q^2.

We can use x and Q^2 as knobs to dial the relative contribution of QES and DIS.

Kinematic range to be explored



Black - 6 GeV, red - CLAS, blue - 11 GeV

Short Range Correlations (SRCs)

Mean field contributions: $k < k_F$

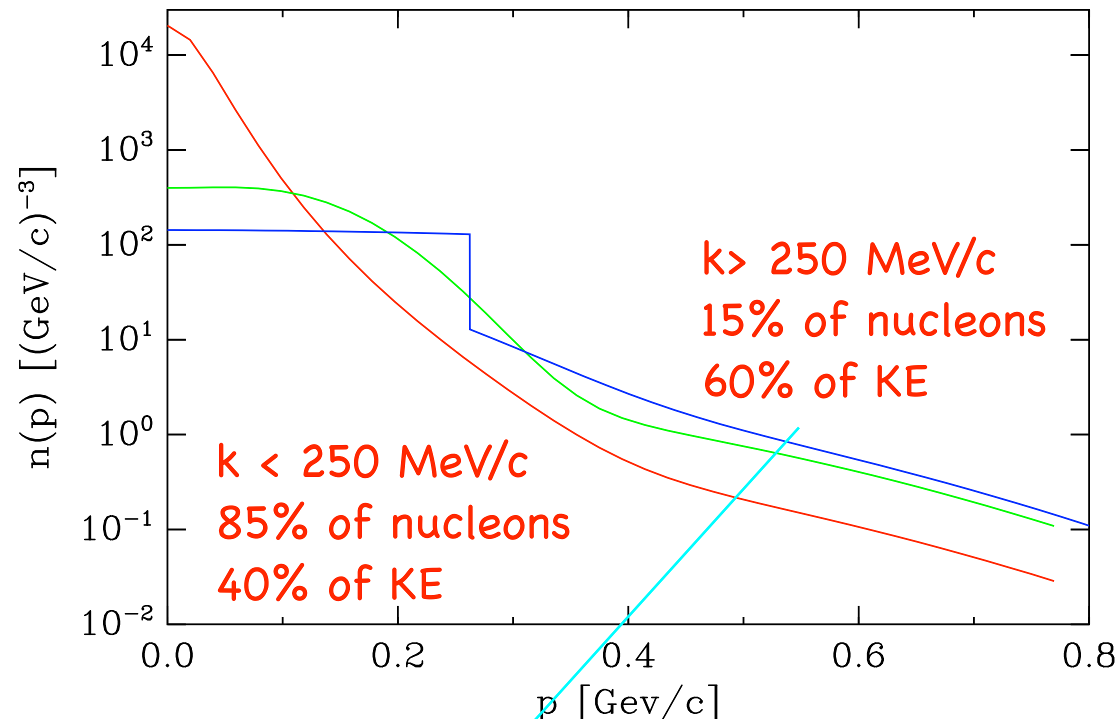
Well understood

High momentum tails: $k > k_F$

Calculable for few-body nuclei, nuclear matter.

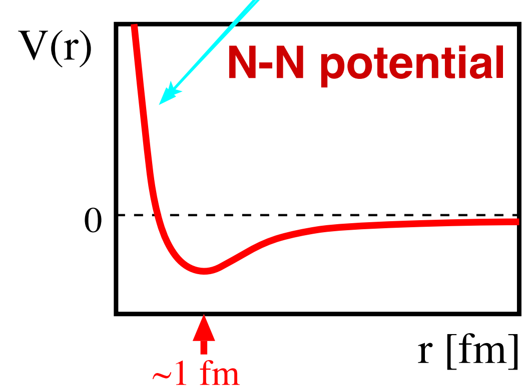
Dominated by two-nucleon short range correlations

Isolate short range interactions (and SRC's) by probing at high p_m



Poorly understood part of nuclear structure

Sign. fraction have $k > k_F$

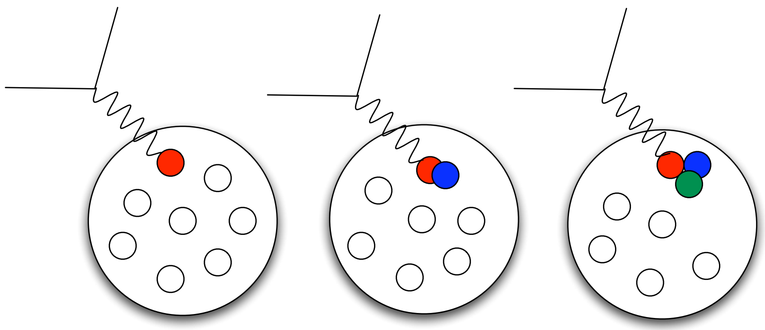


Uncertainty in SR interaction leads to uncertainty at $k >> k_F$, even for simplest systems

Short Range Correlations

In the region where correlations should dominate, large x,

$$\sigma(x,Q^2) = \sum_{j=1}^{A} A\frac{1}{j}a_j(A)\sigma_j(x,Q^2)$$
$$= \frac{A}{2}a_2(A)\sigma_2(x,Q^2) + \frac{A}{3}a_3(A)\sigma_3(x,Q^2) + \vdots$$



$a_j(A)$ are proportional to finding a nucleon in a j-nucleon correlation. It should fall rapidly with j as nuclei are dilute.

$$\sigma_2(x,Q^2) = \sigma_{eD}(x,Q^2) \text{ and } \sigma_j(x,Q^2) = 0 \text{ for } x > j.$$

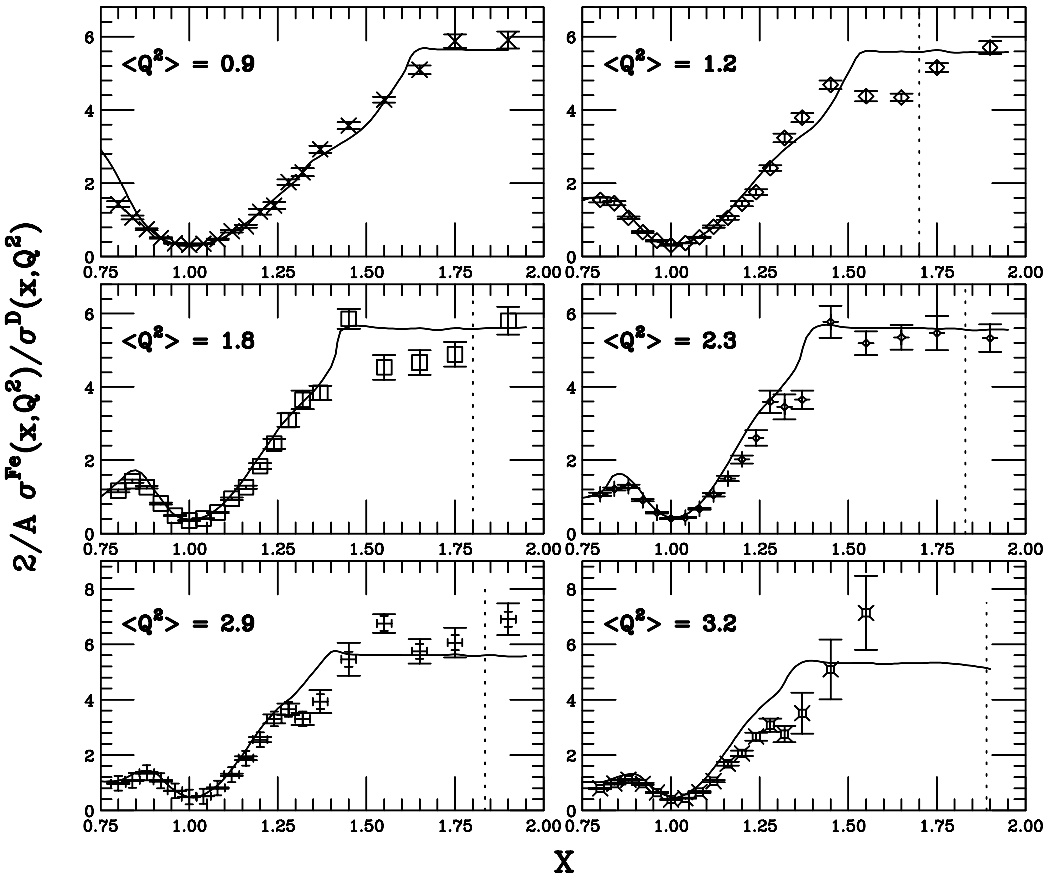
$$\Rightarrow \quad \frac{2}{A}\frac{\sigma_A(x,Q^2)}{\sigma_D(x,Q^2)} = a_2(A)\Big|_{1<x\leq 2}$$

$$\frac{3}{A}\frac{\sigma_A(x,Q^2)}{\sigma_{A=3}(x,Q^2)} = a_3(A)\Big|_{2<x\leq 3}$$

In the ratios, off-shell effects and FSI largely cancel.

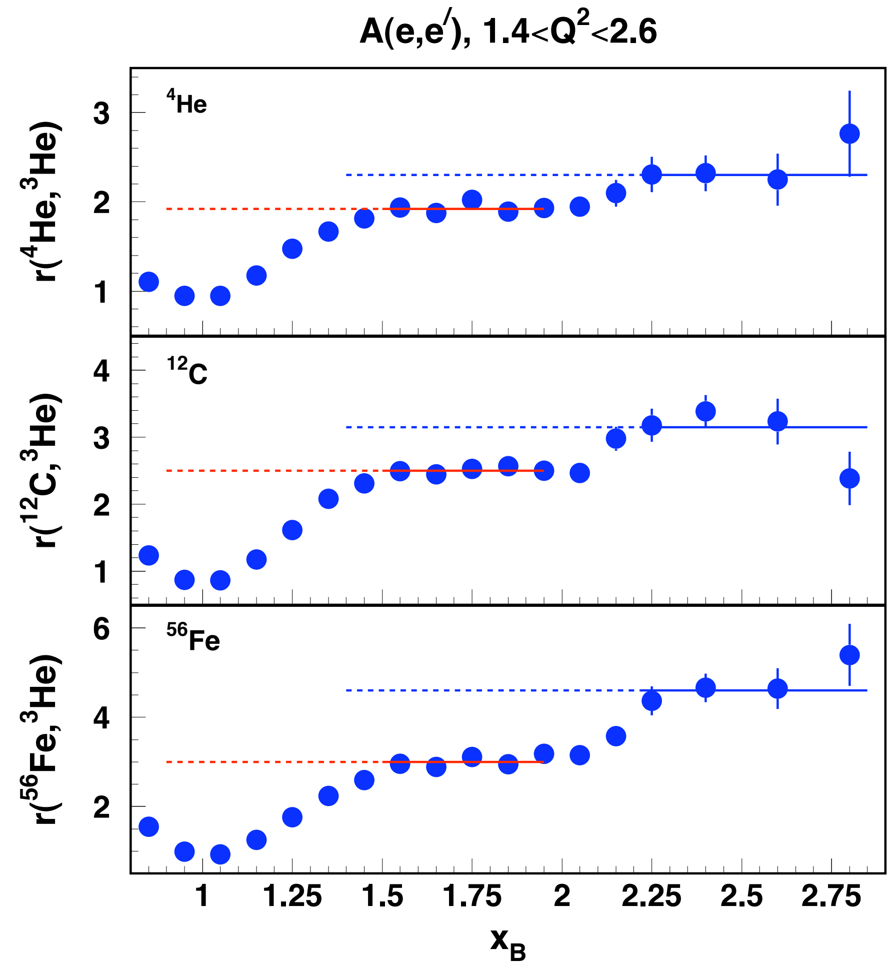
$a_j(A)$ is proportional to probability of finding a j-nucleon correlation

Short Range Correlations



$$\frac{2}{A}\frac{\sigma_A}{\sigma_D} = a_2(A);\ \ (1.4 < x < 2.0)$$

CLAS data



$a_j(A)$ is proportional to probability of finding a j-nucleon correlation

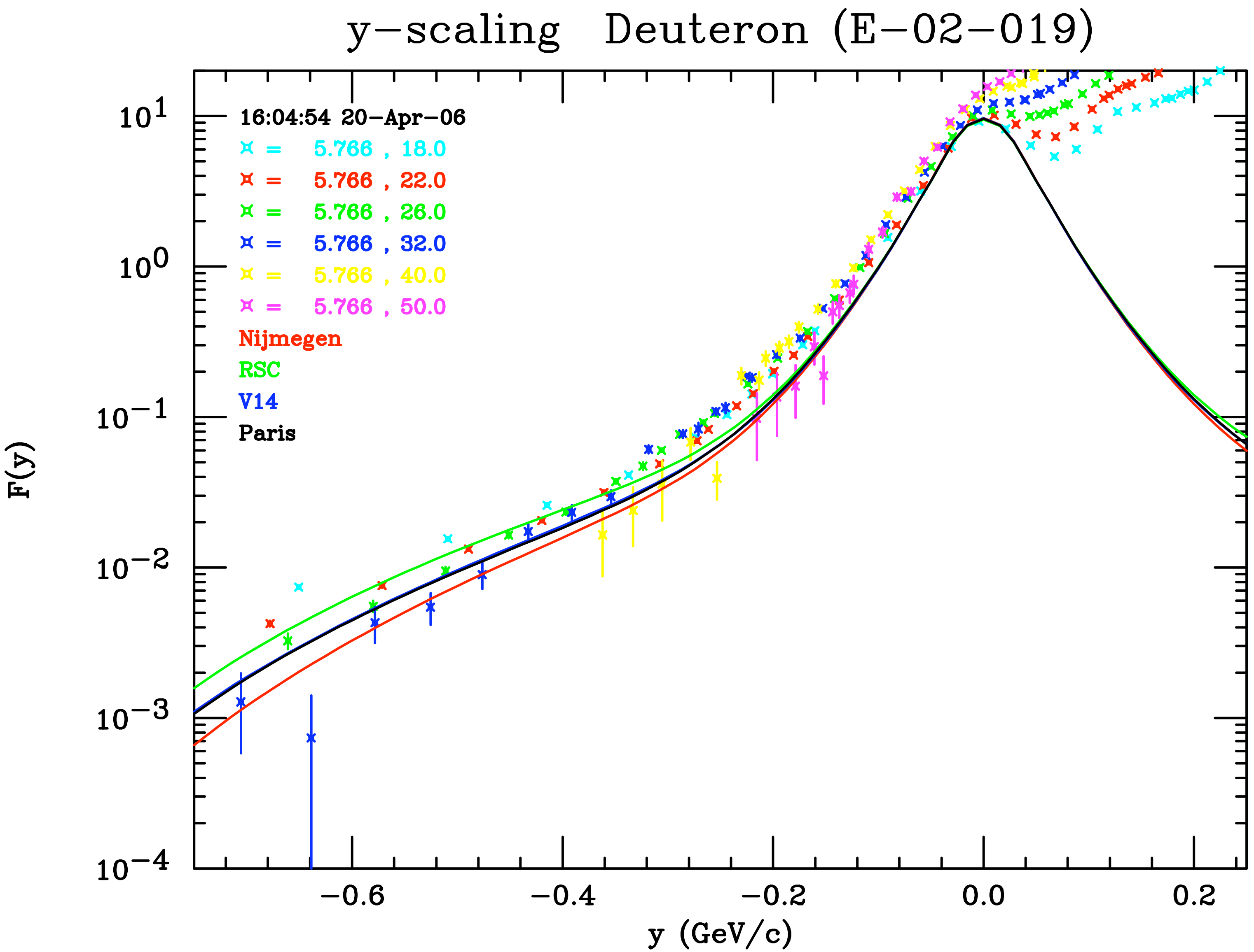
Ratios and SRC

There are suggestions that FSI spoil the analysis of these ratios: Benhar et al.: FSI includes a piece that has a weak Q^2 dependence and is A dependent

This experiment:

- Direct ratios to ^2H, ^3He, ^4He out to large x and over wide range of Q^2
  - Study Q^2 dependence (FSI)
- Absolute Cross section to test exact calculations and FSI
- Extrapolation to NM

Momentum distributions and the spectral function S(k,E).

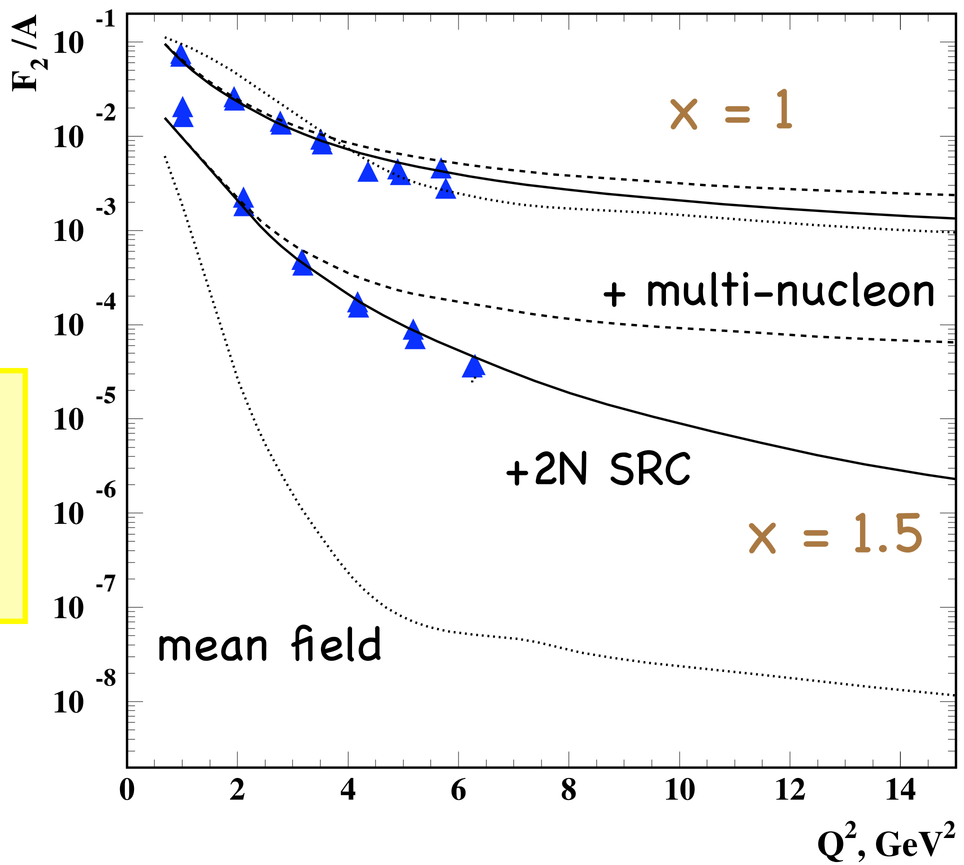


Comparison to exact calculations will allow one to set limits on FSI and extract high momentum piece of gs wave function

Sensitivity to SRC

We want to be able to isolate and probe two-nucleon and multi-nucleon SRCs

Dotted = mean field approx.
Solid = +2N SRCs.
Dashed = +multi-nucleon.



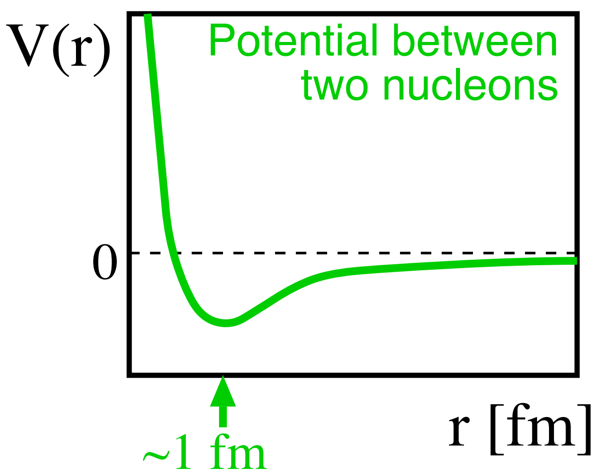
11 GeV can reach Q^2= 20(13) GeV^2 at x = 1.3(1.5)

- very sensitive, especially at higher x values

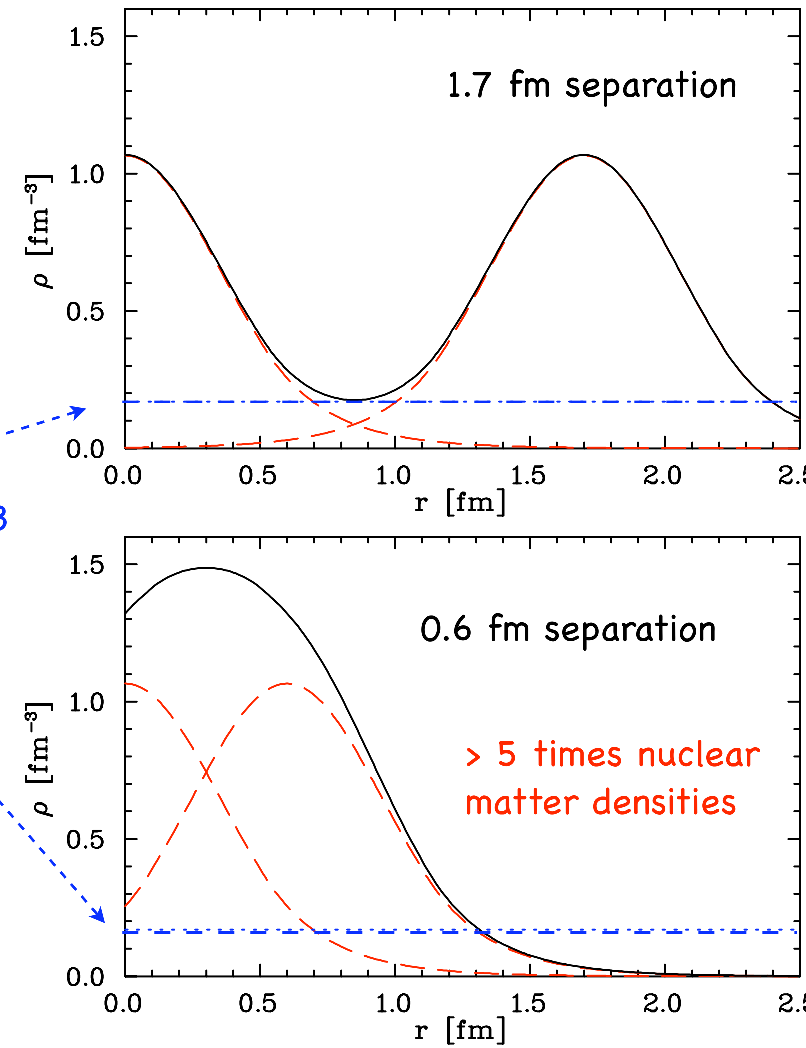
Medium Modifications in high density configurations

Nucleons are already closely packed in nuclei
Ave. separation ~1.7 fm in heavy nuclei
nucleon charge radius ~ 0.86 fm

Nucleon separation is limited by the short range repulsive core



ρ_{NM} =0.17 fm^{-3}

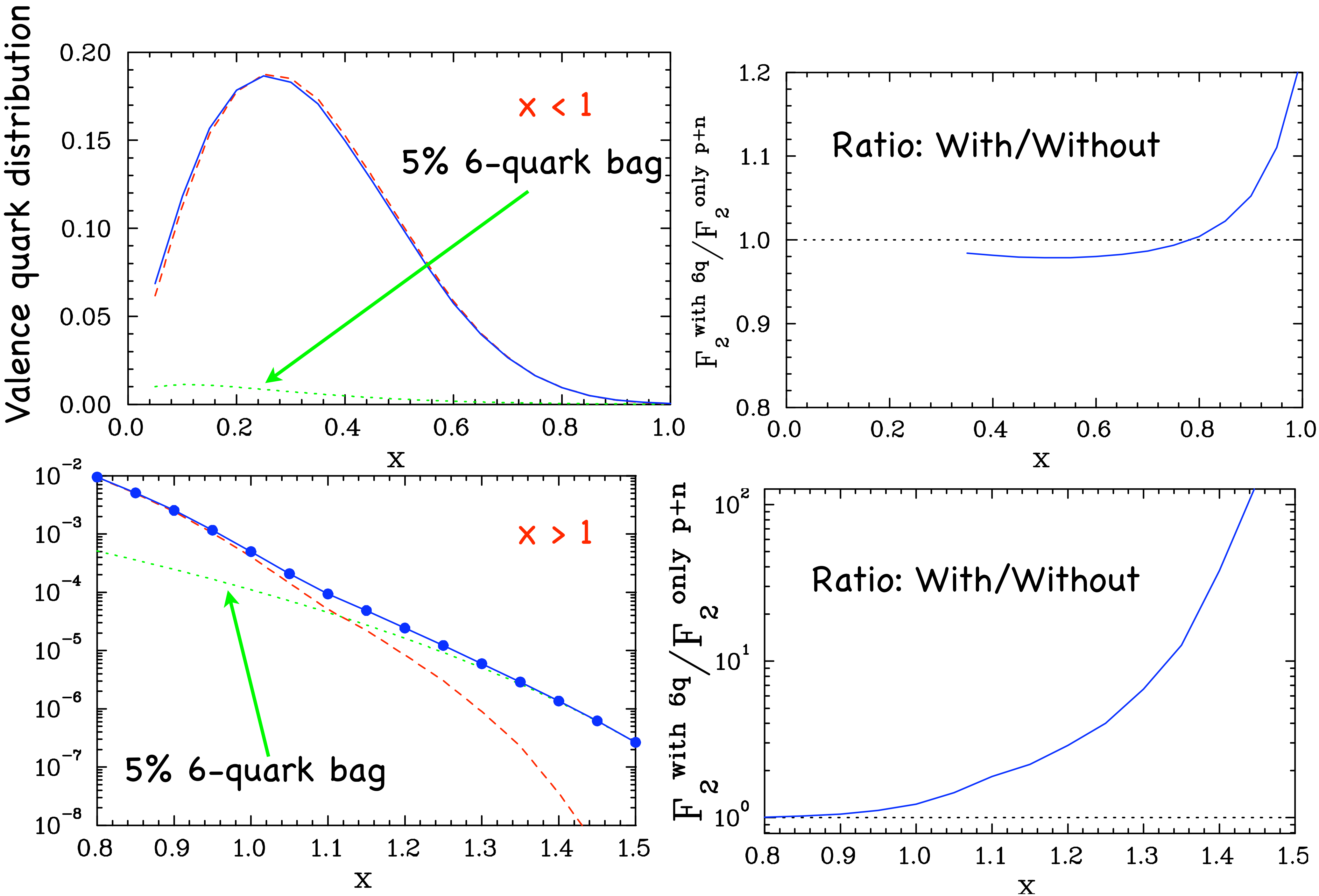


Even for a 1 fm separation, the central density is ~4x nuclear matter

Comparable to neutron star densities!

High enough to modify nucleon structure?

Sensitivity to non-hadronic components

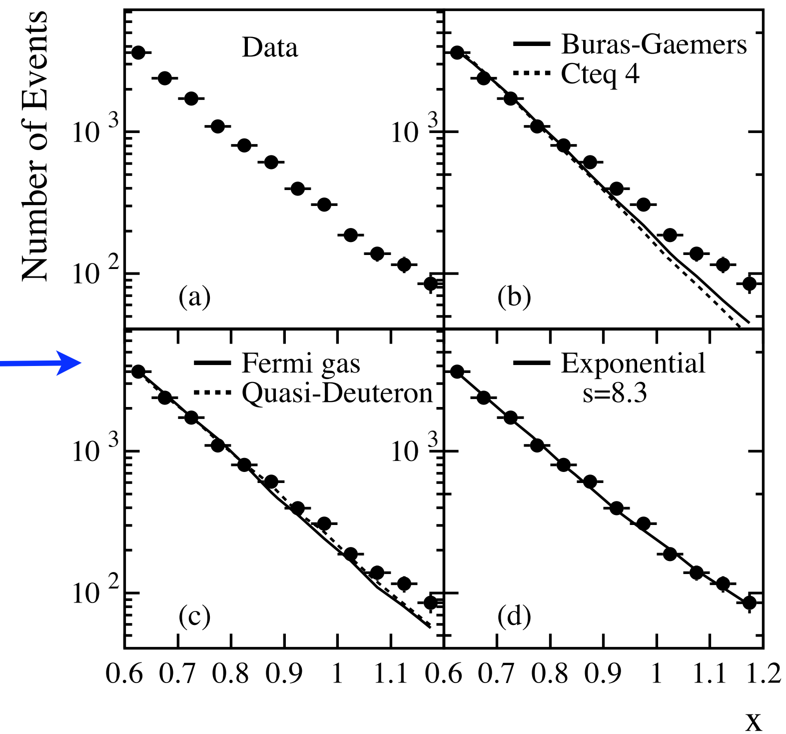


Quark distributions at x > 1

Two measurements (very high Q^2) exist so far:

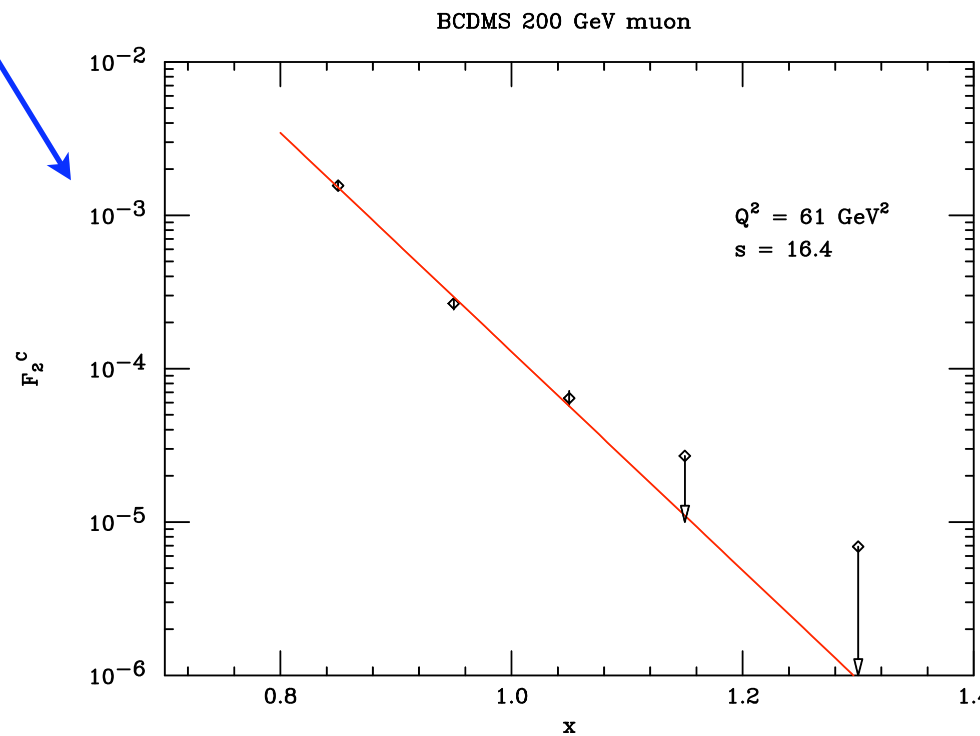
CCFR (ν-C): $F_2(x) \propto e^{-sx}$ s = 8

Limited x range, poor resolution



BCDMS (μ-Fe): $F_2(x) \propto e^{-sx}$ s = 16

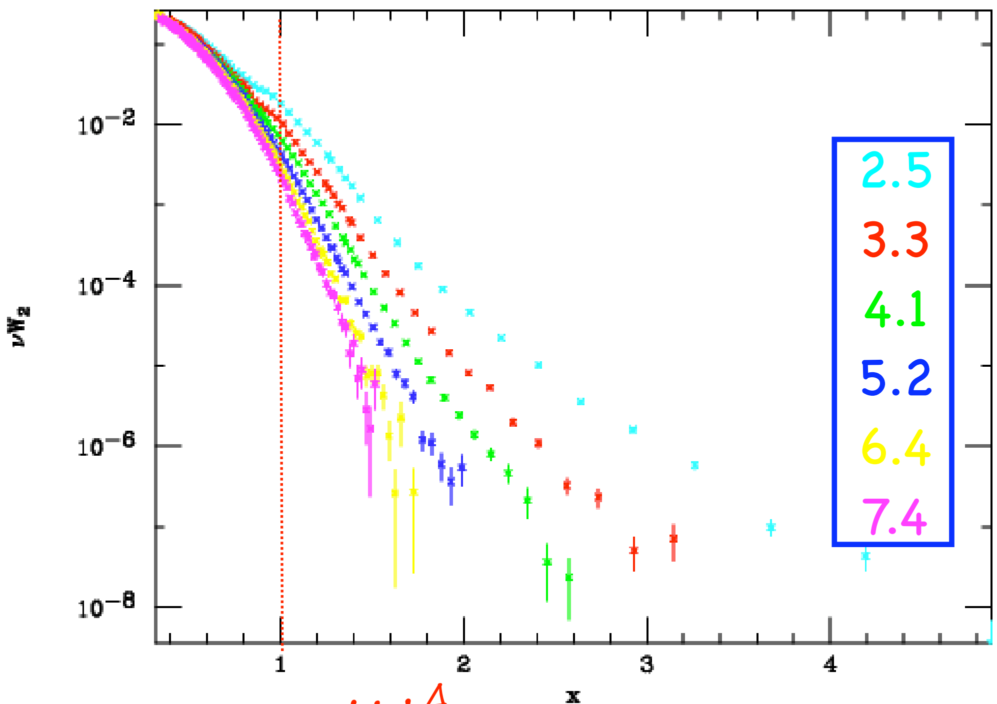
Limited x range, low statistics



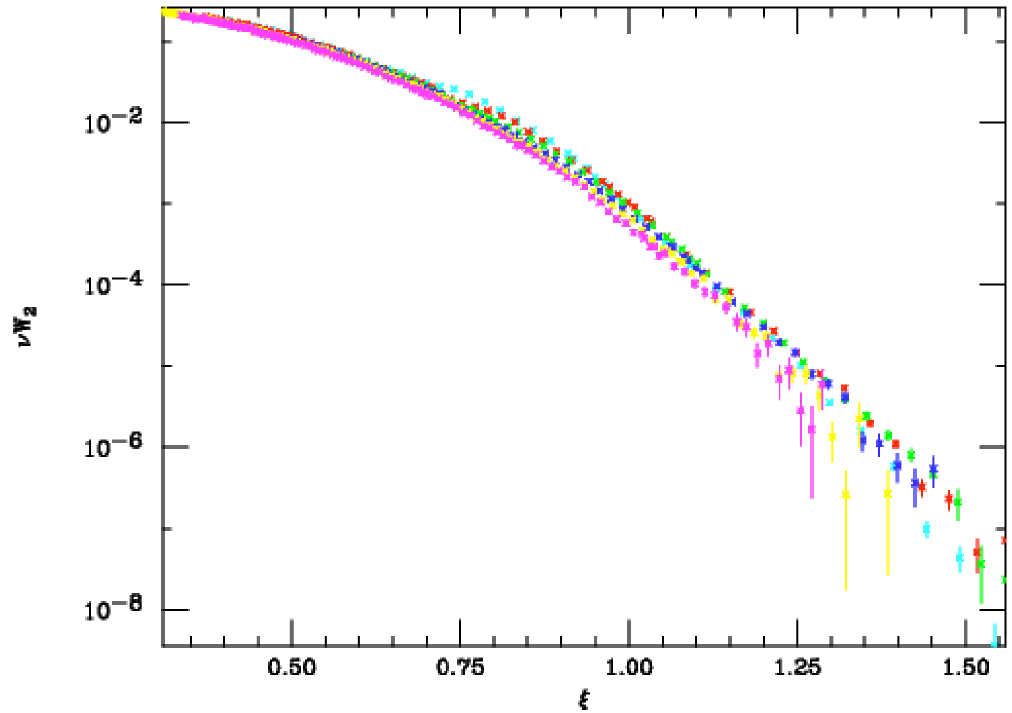
With 11 GeV beam, we should be in the scaling region up to x≈1.4

x and ξ scaling

Carbon E02-019



νW_2^A versus x



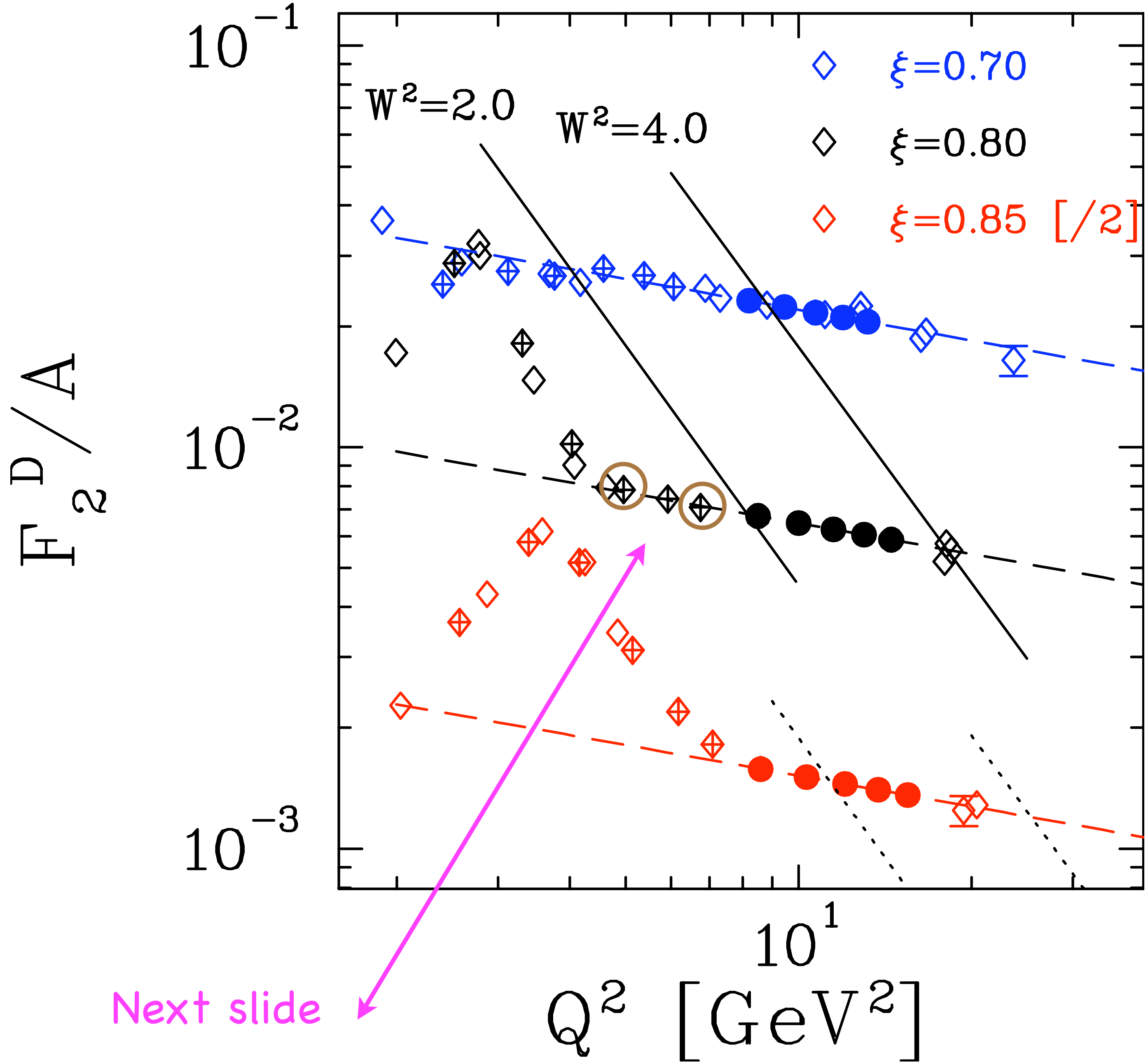
νW_2^A versus ξ

$$\nu W_2^A = \nu \cdot \frac{\sigma^{exp}}{\sigma_M}\left[1 + 2\tan^2(\theta/2)\cdot\left(\frac{1+\nu^2/Q^2}{1+R}\right)\right]^{-1}$$

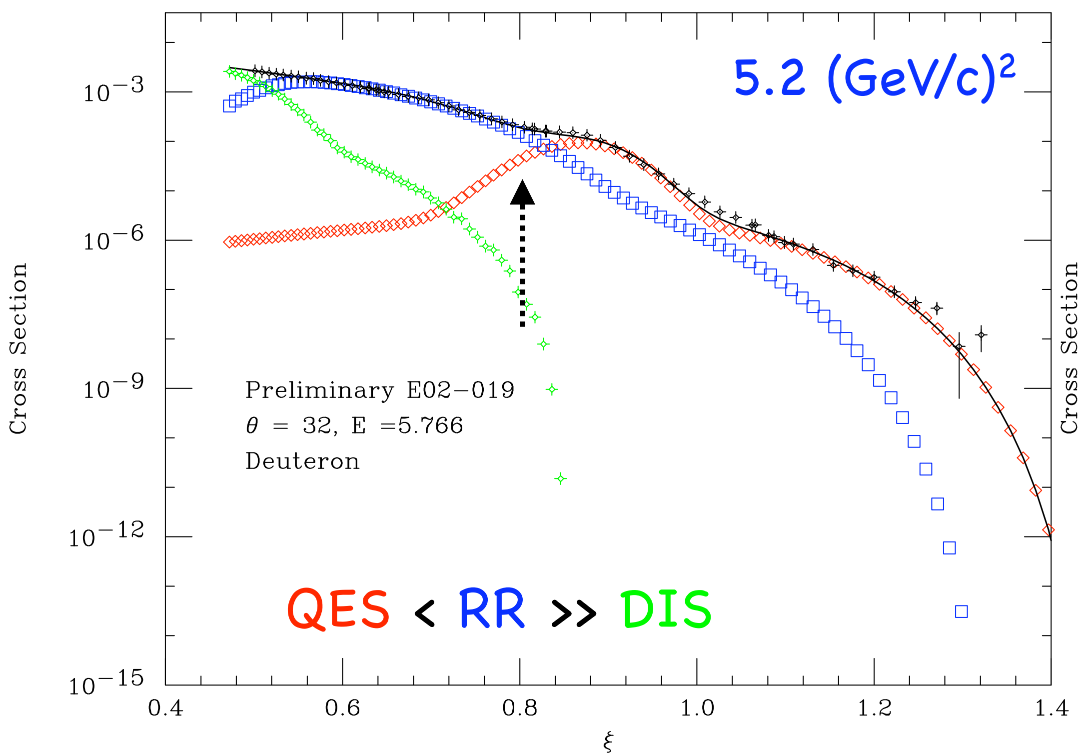
Approach to Scaling - Deuteron

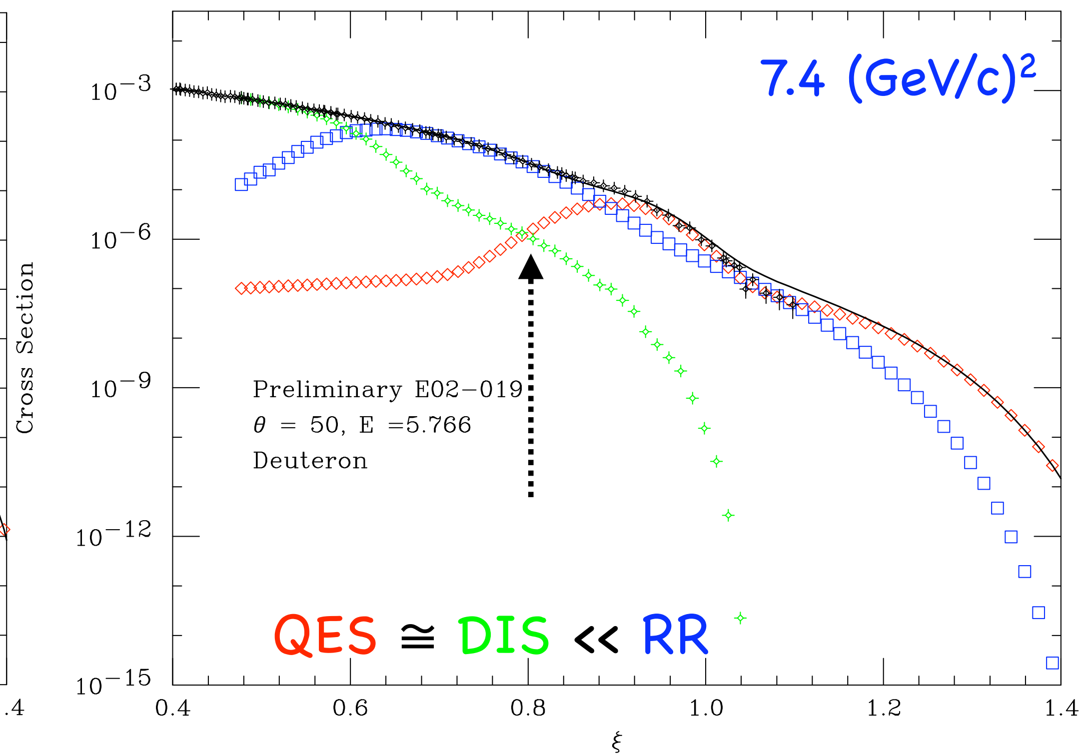
Dashed lines are arbitrary normalization (adjusted to go through the high Q^2 data) with a constant value of $d\ln(F_2)/d\ln(Q^2)$

filled dots - this experiment



Approach to Scaling





Convolution model

QES

RR ($W^2 < 4$)

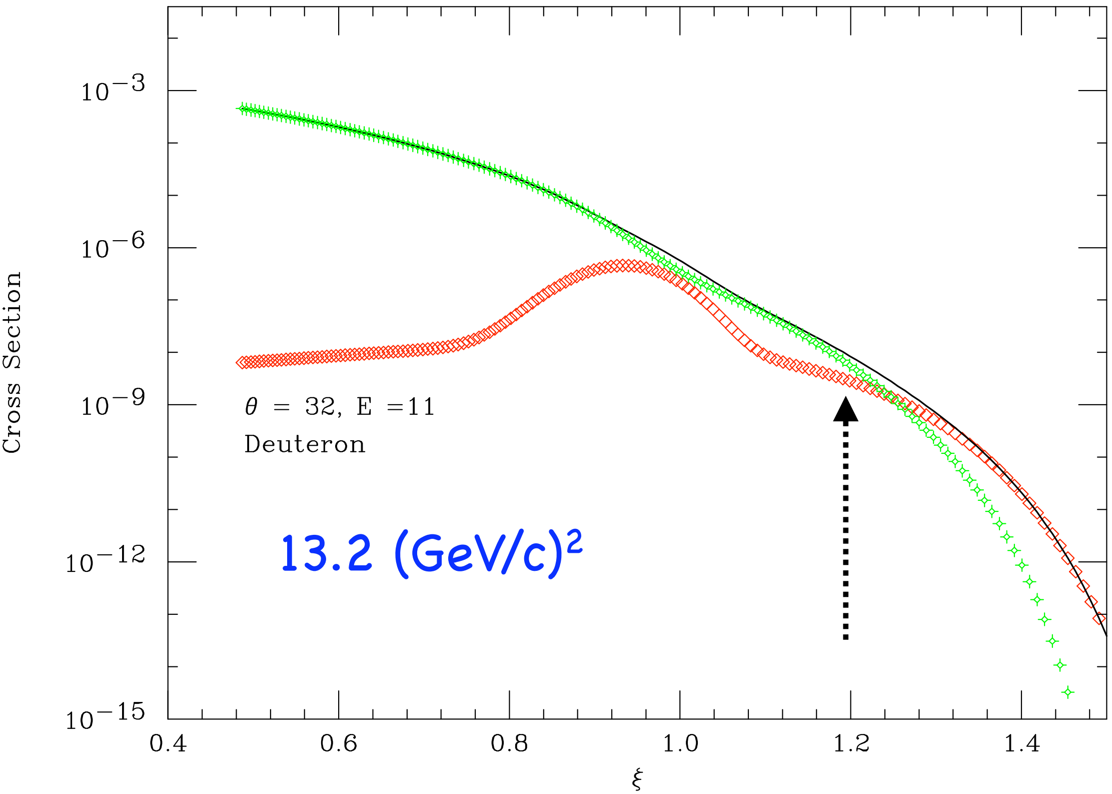
DIS ($W^2 > 4$)

Scaling appears to work well at ξ= 0.8 nearly to the point where QES dominates.

We can expect that any scaling violations will melt away as we go to higher Q^2

Quark distributions at x > 1

Predictions for 11 GeV

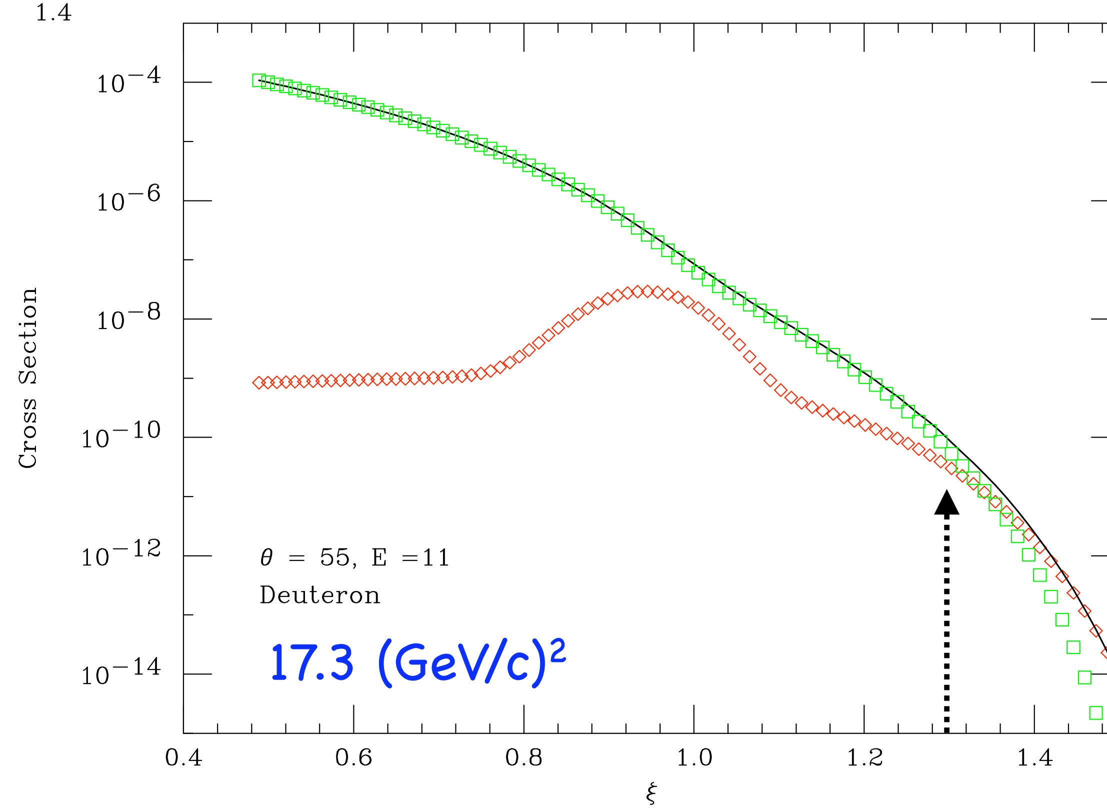


Convolution model

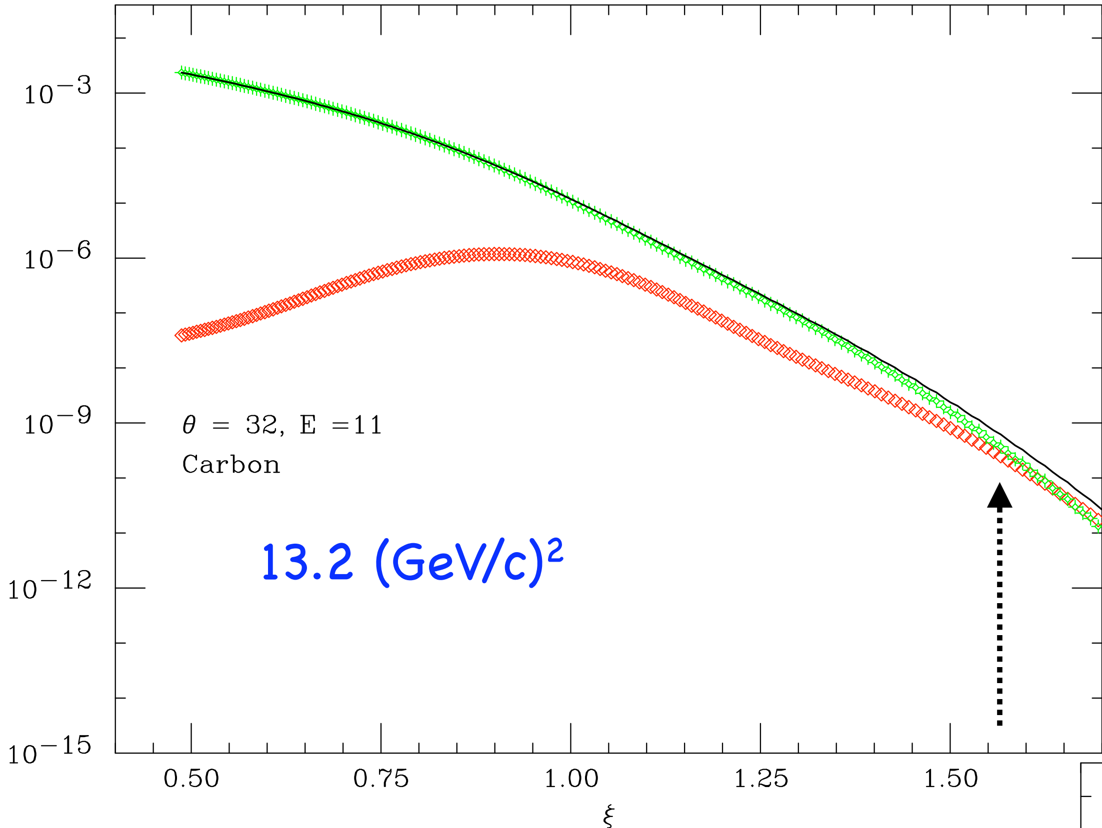
QES

DIS + RR

Deuteron is worst case as narrow QE peak makes for larger scaling violations



Quark distributions at x > 1

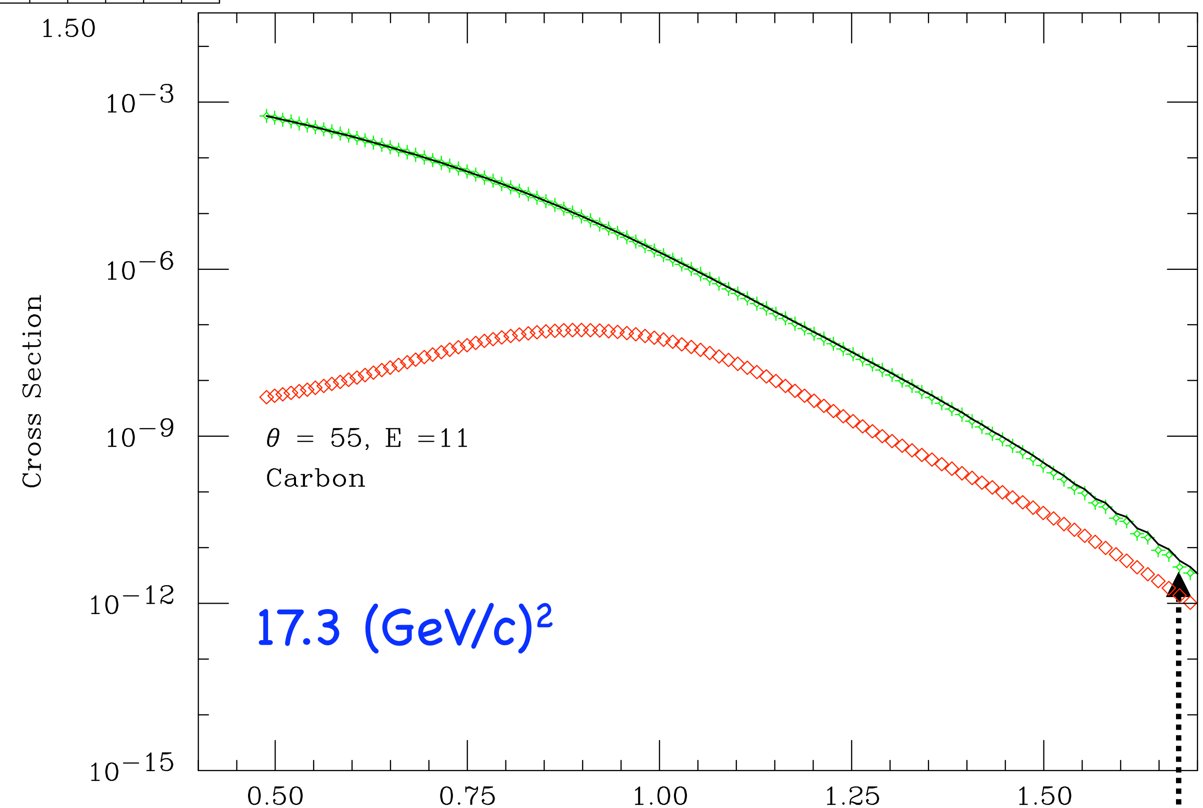


Predictions for 11 GeV

Convolution model

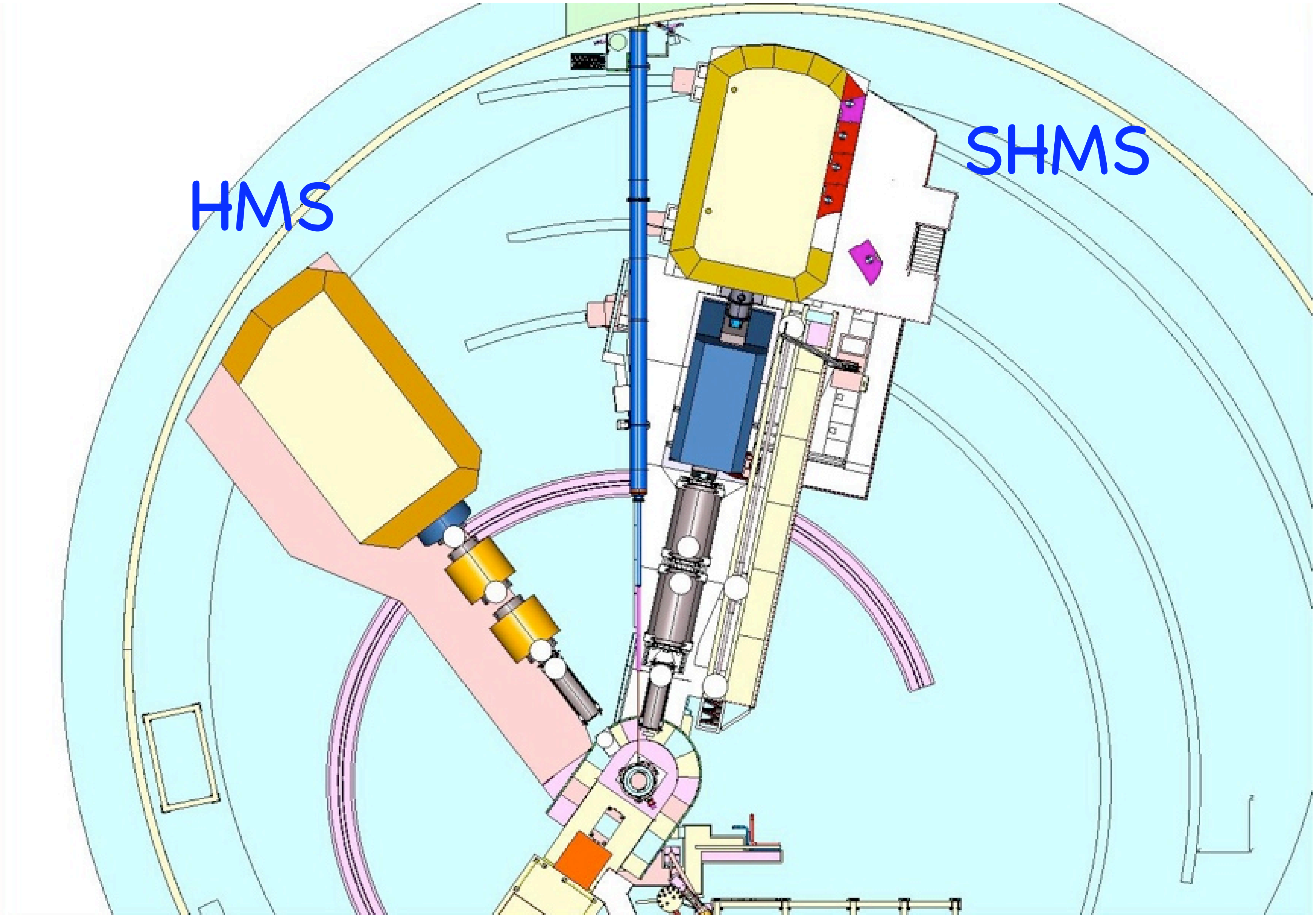
QES

DIS + RR



Experimental Details

- Hall C
- Cryogenic Targets: H, ^{2}H, ^{3}He, ^{4}He
- Solid Targets: Be, C, Cu, Au
- Spectrometers: HMS and SHMS
- Angles: 8-26 (SHMS), 32 -55 (HMS)
- Detector Packages similar
  - Drift Chambers
  - Hodoscopes
  - Good PID
    - Calorimeter
    - Cerenkov



Data taking with both spectrometers simultaneously

Particle ID/Backgrounds/Corrections

E′ (GeV/c)	π/e ratio	Rejection				
		Calorimeter	Cer	Total	Spect	Status
> 5-6	< 50:1	100:1	50:1	5000:1	SHMS	To be Built
< 5	≤ 1000:1	50:1	200:1	10000:1	HMS	Demonstrated

Low-density $\hat{C}$ required for SHMS

PR12-06-101: Fpi
PR12-06-103: pion photo

Charge Symmetric Backgrounds

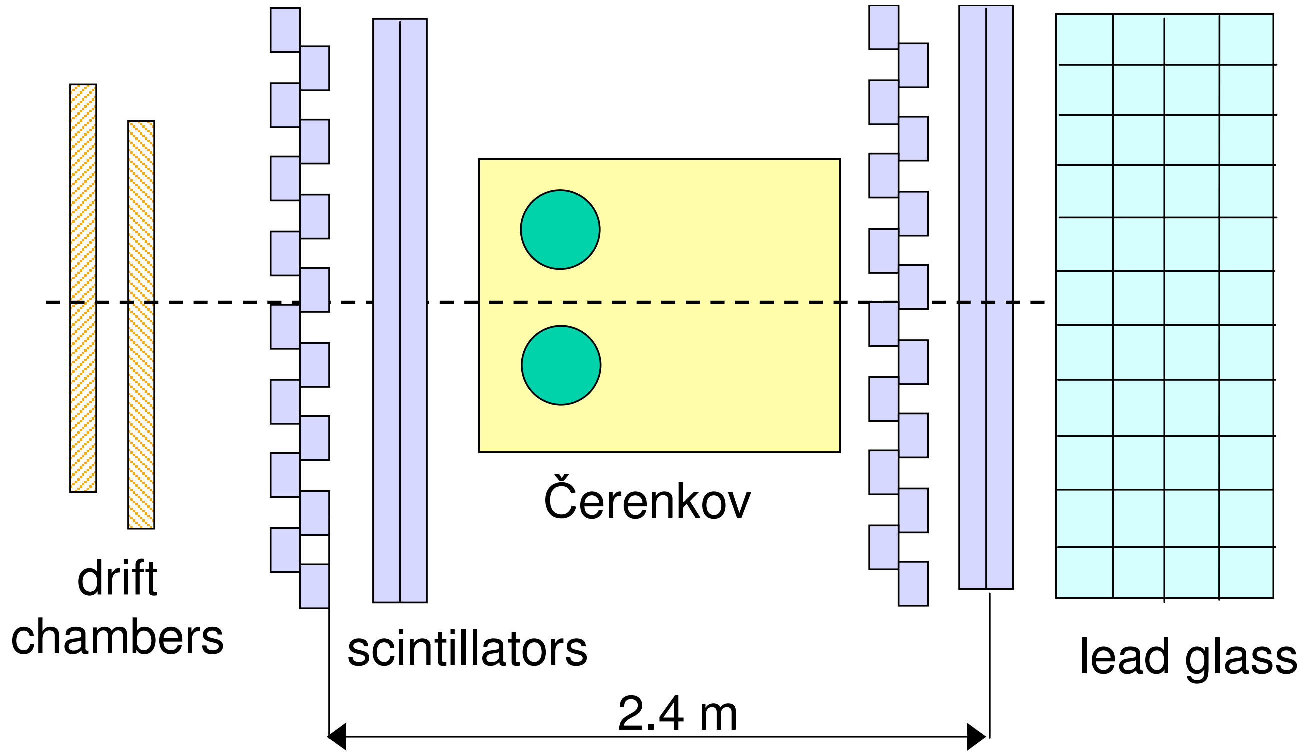
Worst case: 55 degrees and high Z -> 10%

Much better for low Z, decreases rapidly with θ

Coulomb Corrections

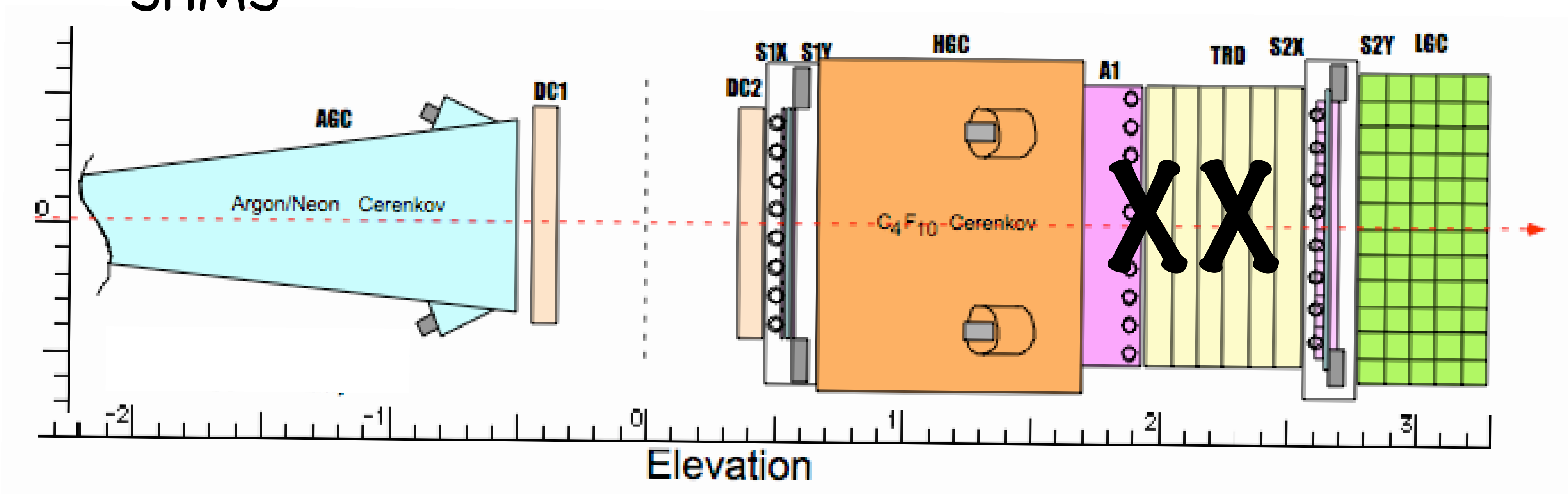
Worst case: < 20% for Au, < 10% Cu, and smaller for lighter nuclei: calculations improving

HMS



drift chambers
scintillators
Čerenkov
lead glass
2.4 m

SHMS



AGC
Argon/Neon Cerenkov
DC1
DC2
S1X
S1Y
HGC
C_4F_{10} Cerenkov
A1
TRD
S2X
S2Y
LGC
Elevation

Beam Request Cu (LD2)

θ (deg)	E' settings (GeV)	x	Q^2 GeV^2	time(hrs) Cu	Notes
8.0	10.6	0.7-4.0	2.1-2.3	10	SHMS (17 hrs. for cryotargets)
10.0	10.4	0.7-3.0	3.0-3.5	10	SHMS (17 hrs. for cryotargets)
12.0	9.8	0.7-2.6	4.0-5.0	10	SHMS (17 hrs. for cryotargets)
22.0	5.7,7.0	0.7-1.55	8.1-12	3+8=11	SHMS
26.0	4.8,6.0	0.7-1.45	9.5-14	3+8=11	SHMS (use HMS for cryotargets)
32.0	3.3,3.9,4.6	0.7-1.35	11-17	(1+5+10)	HMS
40.0	2.4,2.8,3.3	0.7-1.25	12-18	(1+5+10)	HMS
55.0	1.5,1.7,2.0	0.7-1.20	13-20	(2+8+10)	HMS
				12	e^+ data
				6	overhead
				6	dummy targets (cryotargets only)
				70 (87)	Total time for Cu (LD2)

Request to PAC

Activity	Time (hours)
Solid target running	259
Cryotarget running	383
HMS/SHS cross calibration	16
Hydrogen elastics	24
Target Boiling Studies	16
Target Changeover	24
BCM calibrations	8
Beam spot monitoring	4
checkout/calibration	24
Total	758 (32 days)

Summary

- Target ratios (and absolute cross sections) in quasielastic regime: map out 2N, 3N, 4N correlations
- Measure nuclear structure functions (parton distributions) up to $x = 1.3 - 1.4$
  - Extremely sensitive to non-hadronic configurations
- Targets include several few-body nuclei allowing precise test of theory.

Institutional Commitments

- Argonne
  - SHMS optics, field maps and verification
- University of Virginia
  - Atmospheric Cherenkov for SHMS