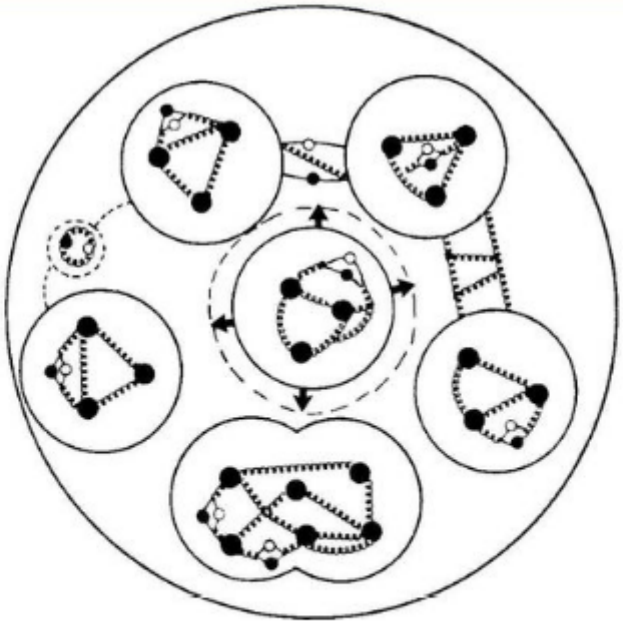
Physicists Just Solved a 35-Year-Old Mystery Hidden Inside Atomic Cores

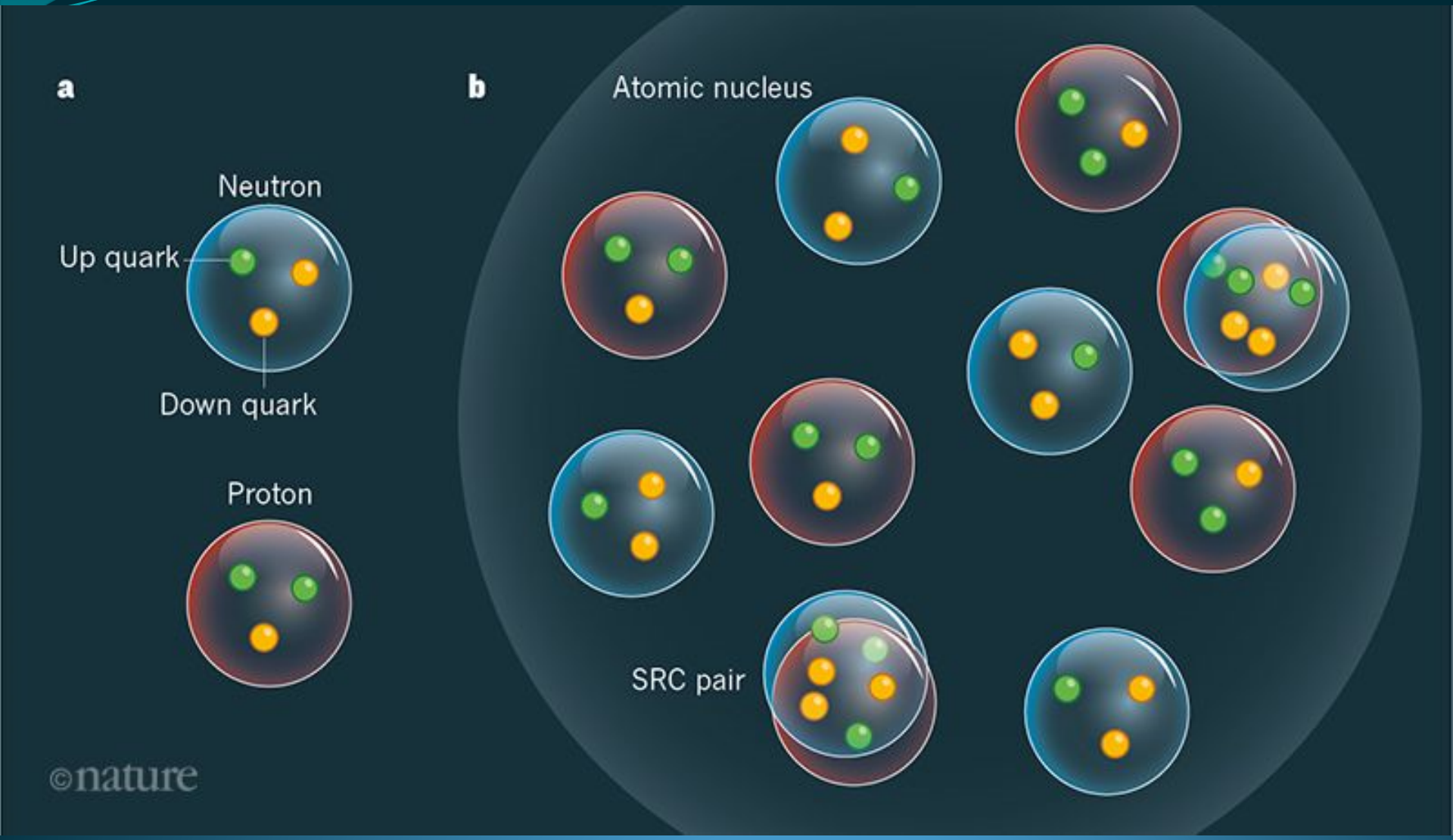
Modified structure of protons and neutrons in correlated pairs

The EMC effect

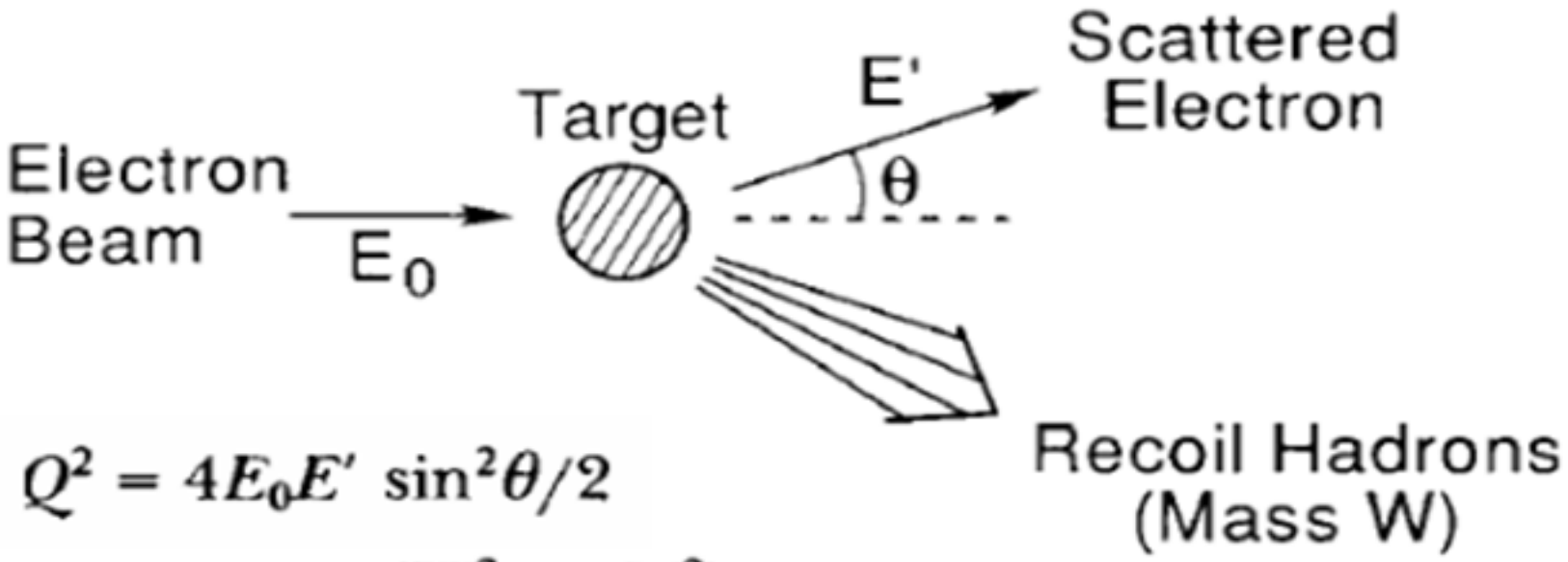
Quark- and gluon-distributions are different for free nucleons and for bound nucleons inside nuclei



Quarks slow down massively once they're confined to a nucleus in a n atom


a
Neutron
Up quark
Down quark
Proton
b
Atomic nucleus
SRC pair
©nature

DIS Kinematics:



$$Q^2 = 4E_0E' \sin^2\theta/2$$

$$E' = \frac{E_0 - \frac{(W^2 - M^2)}{2M}}{1 + \frac{2E_0}{M}\sin^2\theta/2}$$

or, since E' and θ are measured:

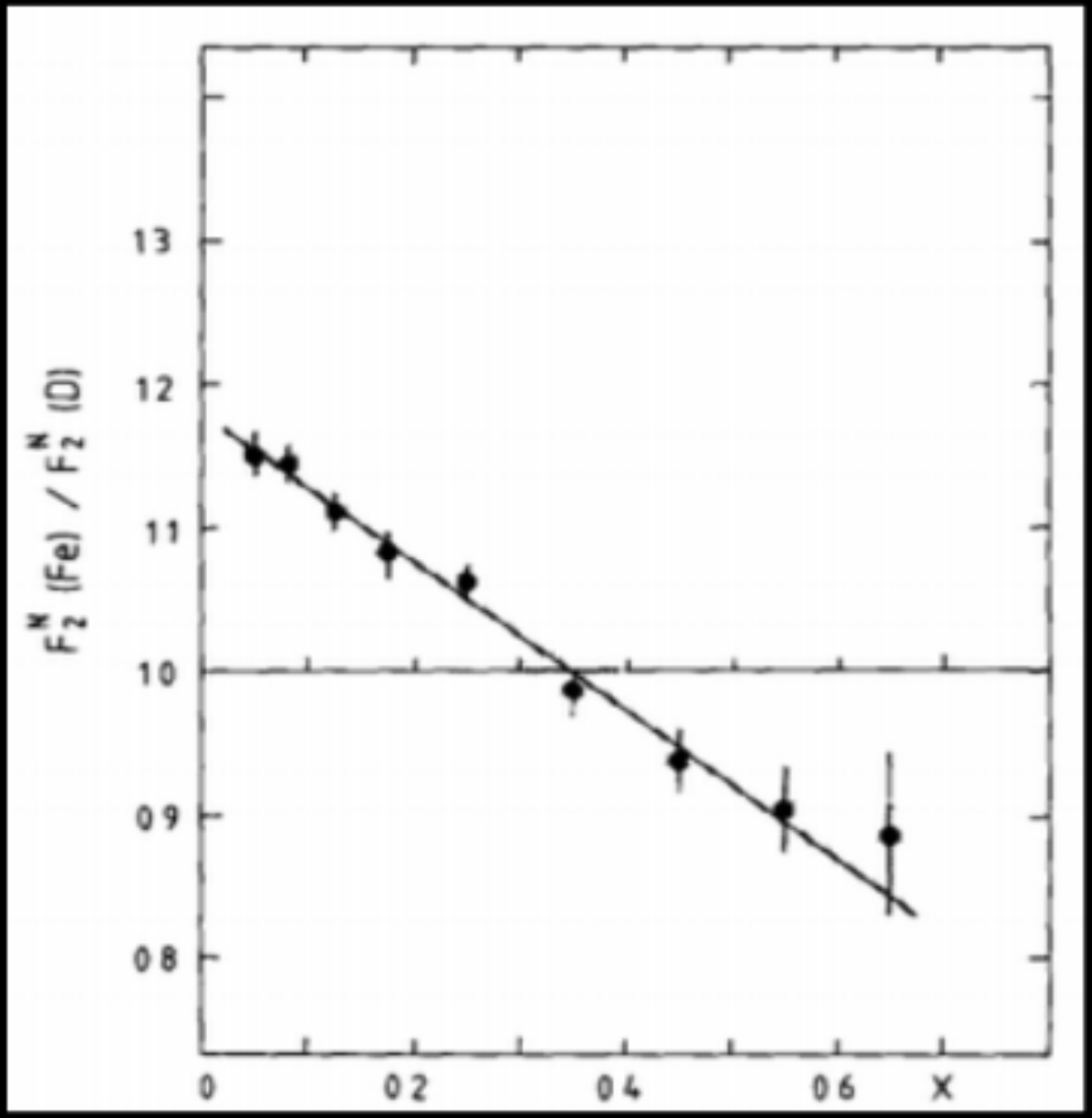
$$W^2 = M^2 + 2M(E_0 - E') - 4E_0E'\sin^2\frac{\theta}{2}$$

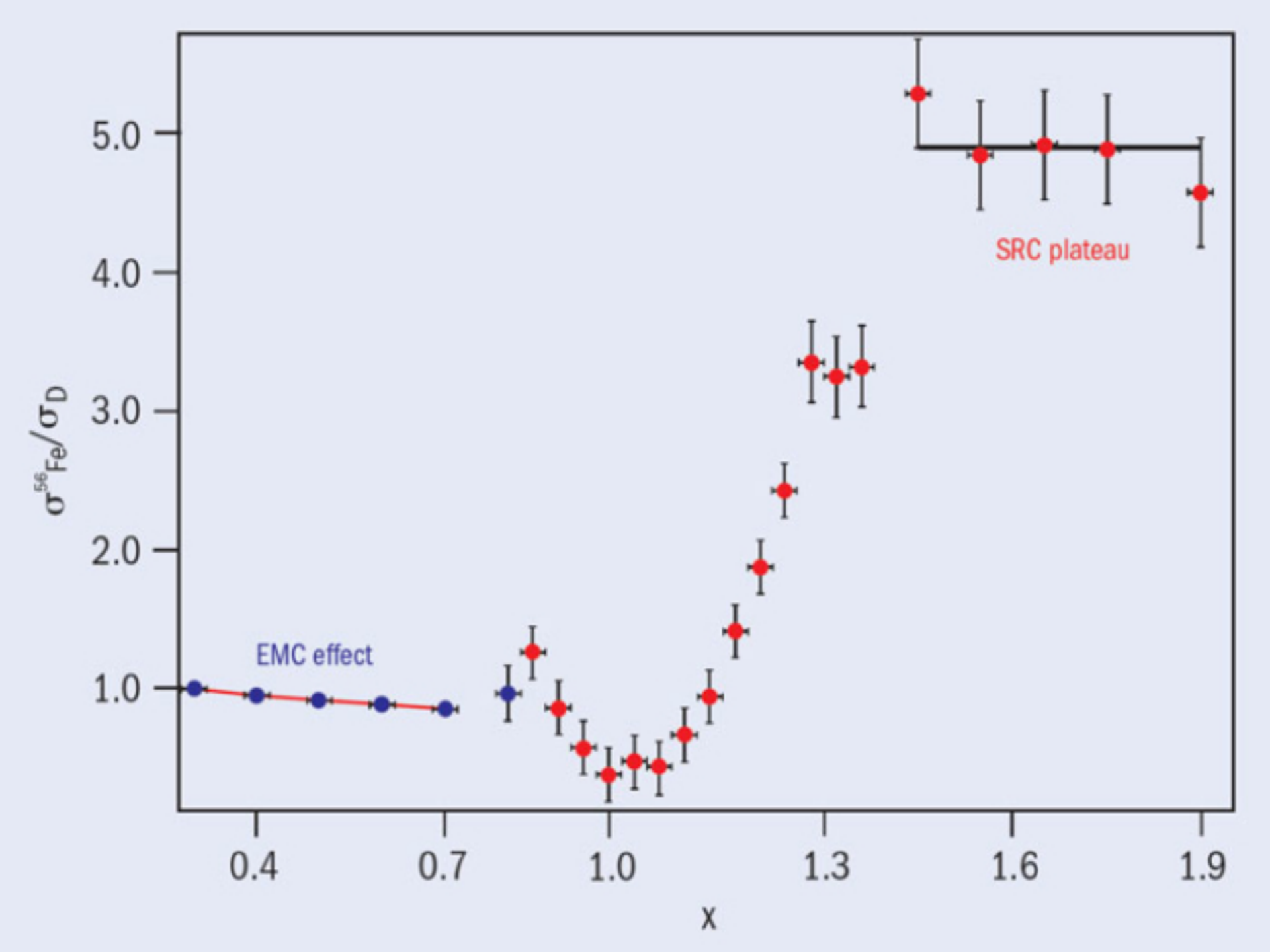
The DIS cross-section on a nucleon can be expressed as a function of a single structure function, $F_2(x_B, Q^2)$.

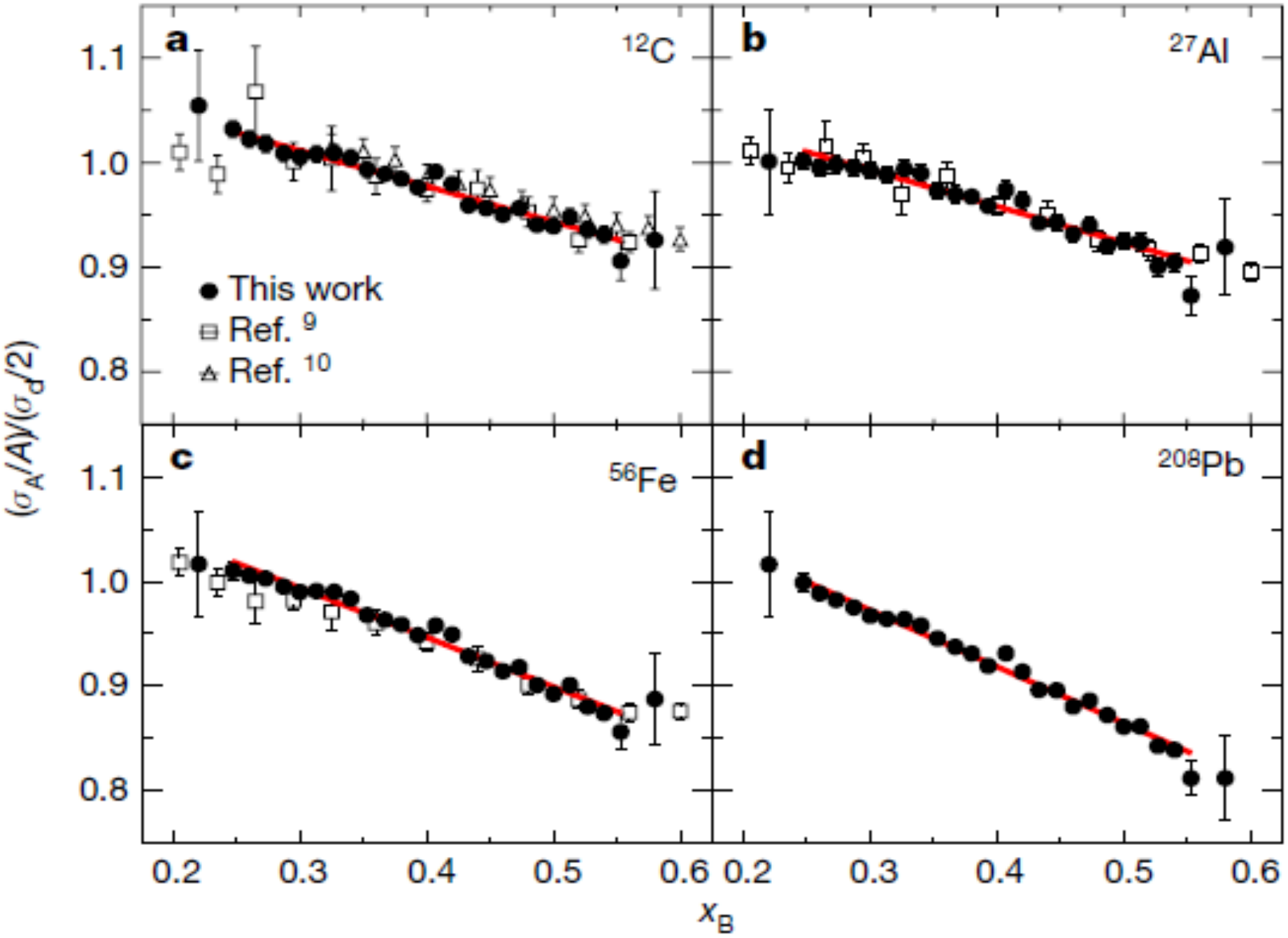
In the parton model, x_B represents the fraction of the nucleon momentum carried by the struck quark.

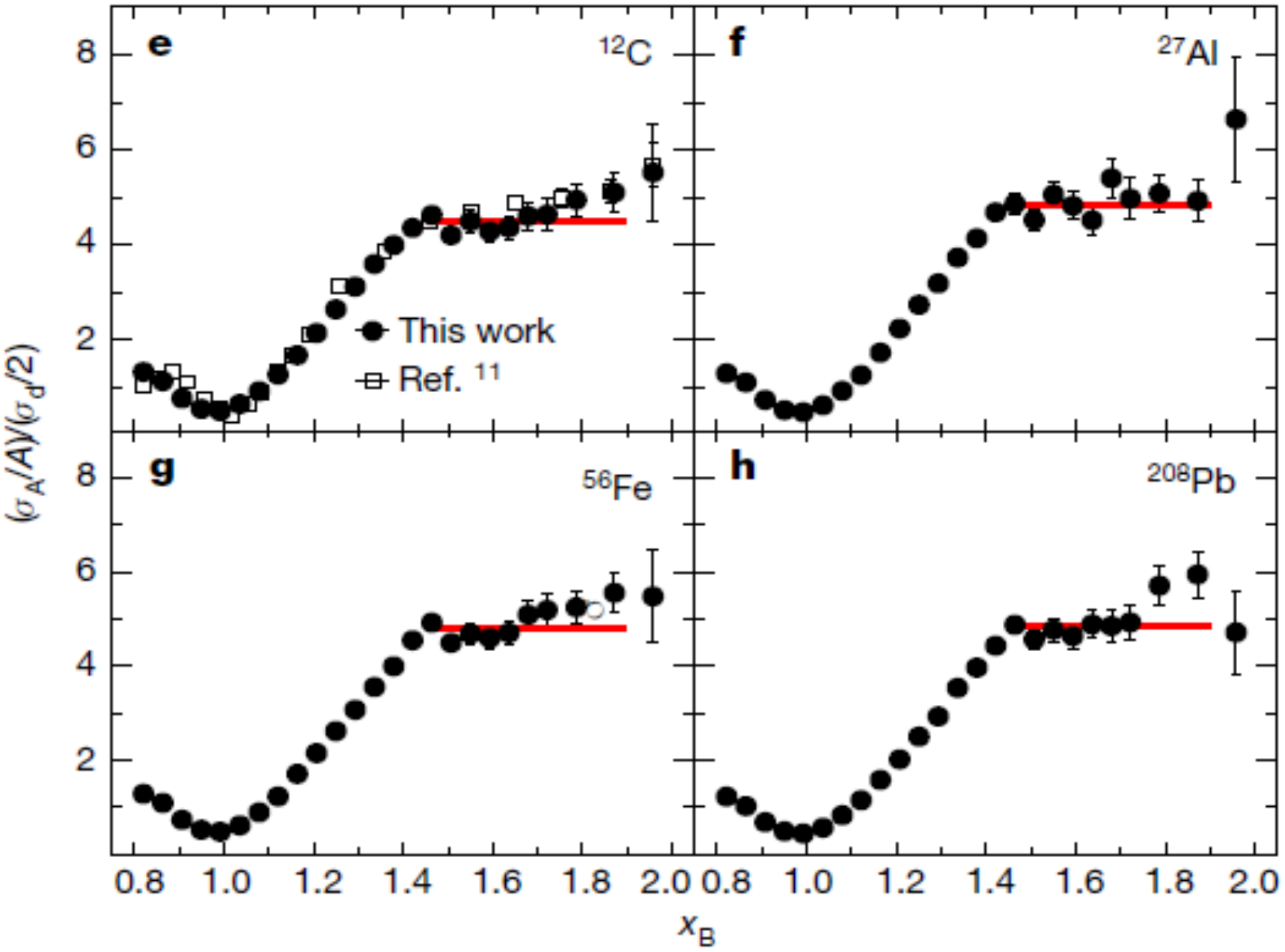
$F_2(x_B, Q^2)$ describes the momentum distribution of the quarks in the nucleon, and the ratio $[F_2^A(x_B, Q^2)/A] / [F_2^d(x_B, Q^2)/2]$ describes the relative quark momentum distributions in a nucleus A with mass number A and deuterium

$$0.3 \leq x_B \leq 0.7$$


F_2^N (Fe) / F_2^N (D)
1.3
1.2
1.1
1.0
0.9
0.8
0
0.2
0.4
0.6
x


5.0
4.0
3.0
2.0
1.0
$\sigma^{56}_{Fe}/\sigma_D$
SRC plateau
EMC effect
0.4
0.7
1.0
1.3
1.6
1.9
x


a
^{12}C
b
^{27}Al
c
^{56}Fe
d
^{208}Pb
This work
Ref. 9
Ref. 10
$(\sigma_A/A)/(\sigma_d/2)$
x_B
1.1
1.0
0.9
0.8
0.2
0.3
0.4
0.5
0.6

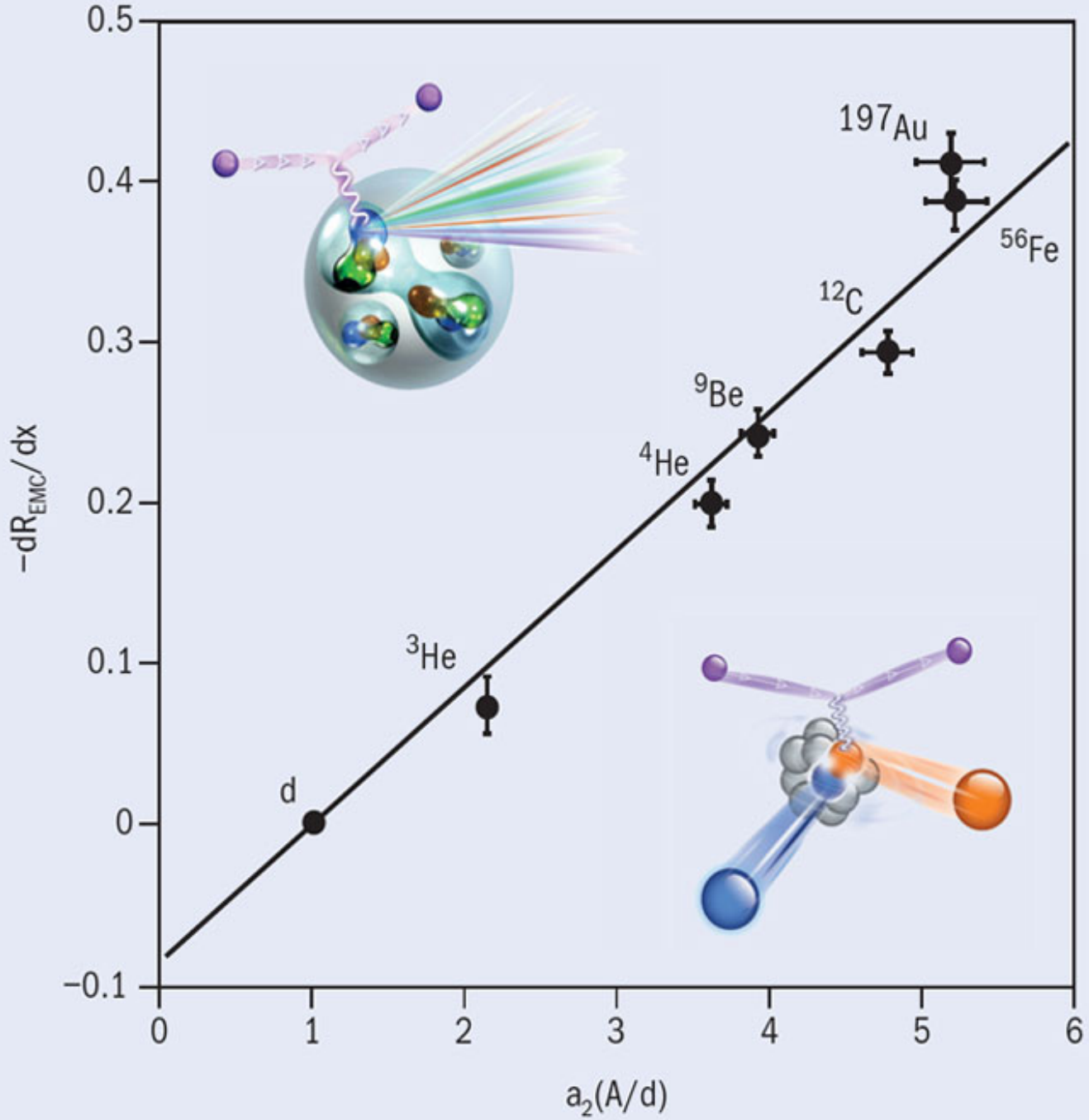

e
^{12}C
f
^{27}Al
g
^{56}Fe
h
^{208}Pb
This work
Ref. 11
$(\sigma_A/A)/(\sigma_d/2)$
x_B
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2
4
6
8

Extended Data Table 2 | EMC slopes

Nucleus	dR_{EMC}/dx_B			Universal Function Slope		
	JLab Hall C	SLAC	This Work	JLab Hall C	SLAC	This Work
^{3}He	0.091±0.028			-0.066±0.019		
^{4}He	-0.207±0.025	-0.222±0.045		-0.080±0.010	-0.086±0.017	
^{9}Be	-0.326±0.026	-0.283±0.028		-0.094±0.009	-0.078±0.010	
^{12}C	-0.285±0.026	-0.322±0.033	-0.340±0.022	-0.082±0.007	-0.092±0.010	-0.097±0.006
^{27}Al			-0.347±0.022			-0.086±0.006
^{56}Fe		-0.391±0.025	-0.472±0.023		-0.094±0.006	-0.115±0.006
^{63}Cu		-0.391±0.025			-0.094±0.006	
^{197}Au		-0.511±0.030			-0.100±0.008	
^{208}Pb			-0.539±0.020			-0.111±0.005

Extended Data Table 1 | SRC scaling coefficients

Nucleus	This work			Ref. [5]		
	a_2	a_2^p	a_2^n	a_2	a_2^p	a_2^n
^{3}He				2.13±0.04	1.60±0.03	3.20±0.06
^{4}He				3.60±0.10	3.60±0.10	3.60±0.10
^{9}Be				3.91±0.12	4.40±0.14	3.52±0.11
^{12}C	4.49±0.17	4.49±0.17	4.49±0.17	4.75±0.16	4.75±0.16	4.75±0.16
^{27}Al	4.83±0.18	5.02±0.19	4.66±0.17			
^{56}Fe	4.80±0.22	5.17±0.24	4.48±0.21			
^{63}Cu				5.21±0.20	5.66±0.22	4.83±0.19
^{197}Au				5.16±0.22	6.43±0.27	4.31±0.18
^{208}Pb	4.84±0.20	6.14±0.25	3.99±0.17			


0.5
0.4
0.3
0.2
0.1
0
−0.1
0
1
2
3
4
5
6
$-dR_{EMC}/dx$
$a_2(A/d)$
^{197}Au
^{56}Fe
^{12}C
^{9}Be
^{4}He
^{3}He
d

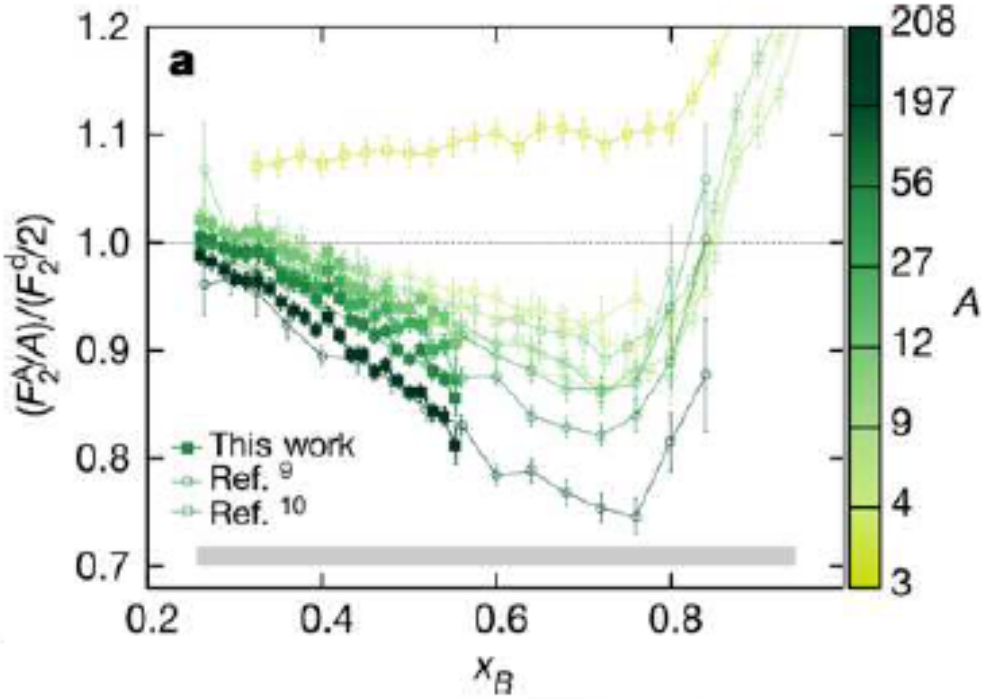
$$F_2^A = (Z - n_{SRC}^A) F_2^p + (N - n_{SRC}^A) F_2^n + n_{SRC}^A (F_2^{p*} + F_2^{n*})$$

$$= Z F_2^p + N F_2^n + n_{SRC}^A (\Delta F_2^p + \Delta F_2^n)$$

$F_2^p(x_B, Q^2)$ and $F_2^n(x_B, Q^2)$ are the free-proton and free-neutron structure functions

$F_2^{p*}(x_B, Q^2)$ and $F_2^{n*}(x_B, Q^2)$ are the average modified structure functions for protons and neutrons in SRC pairs

n_{SRC}^A is the number of *np* SRC pairs in nucleus A



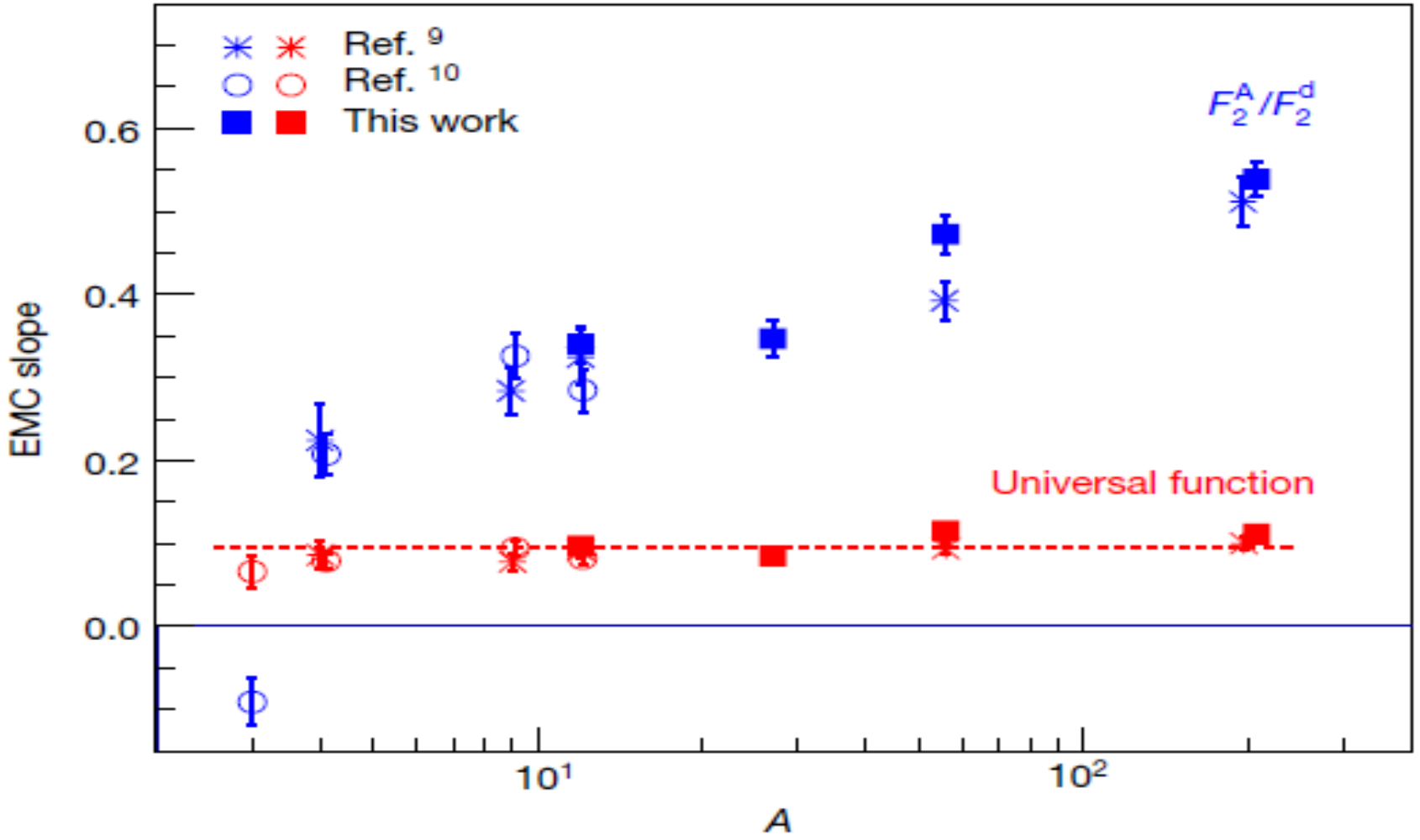


Fig. 3 | EMC and universal modification function slopes. The slopes of the EMC effect for different nuclei from Fig. 2a (blue) and of the universal function from Fig. 2b (red). The error bars shown include the fit uncertainties at the 1σ or 68% confidence level.