Parton distribution functions in nuclei

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- Contents -

Introduction

- parton distributions in the nucleon
- parton distributions in nuclei

EMC effect, shadowing

Parametrization of nuclear parton distributions

1. functional form of $f_i^A(x)$
2. constraints: A dependence, conservation laws
3. χ^2 fitting to experimental data
4. results: optimum nuclear parton distributions

Summary

Purposes

Determination of parton distributions

- unpolarized distributions in the nucleon

  3 major groups (CTEQ, GRV, MRS)

- polarized distributions in the nucleon

  several groups (GS, GRSV, ..., AAC)

- distributions in nuclei

  no χ^2 analysis! (see Eskola, Kolhinen, Ruuskanen)

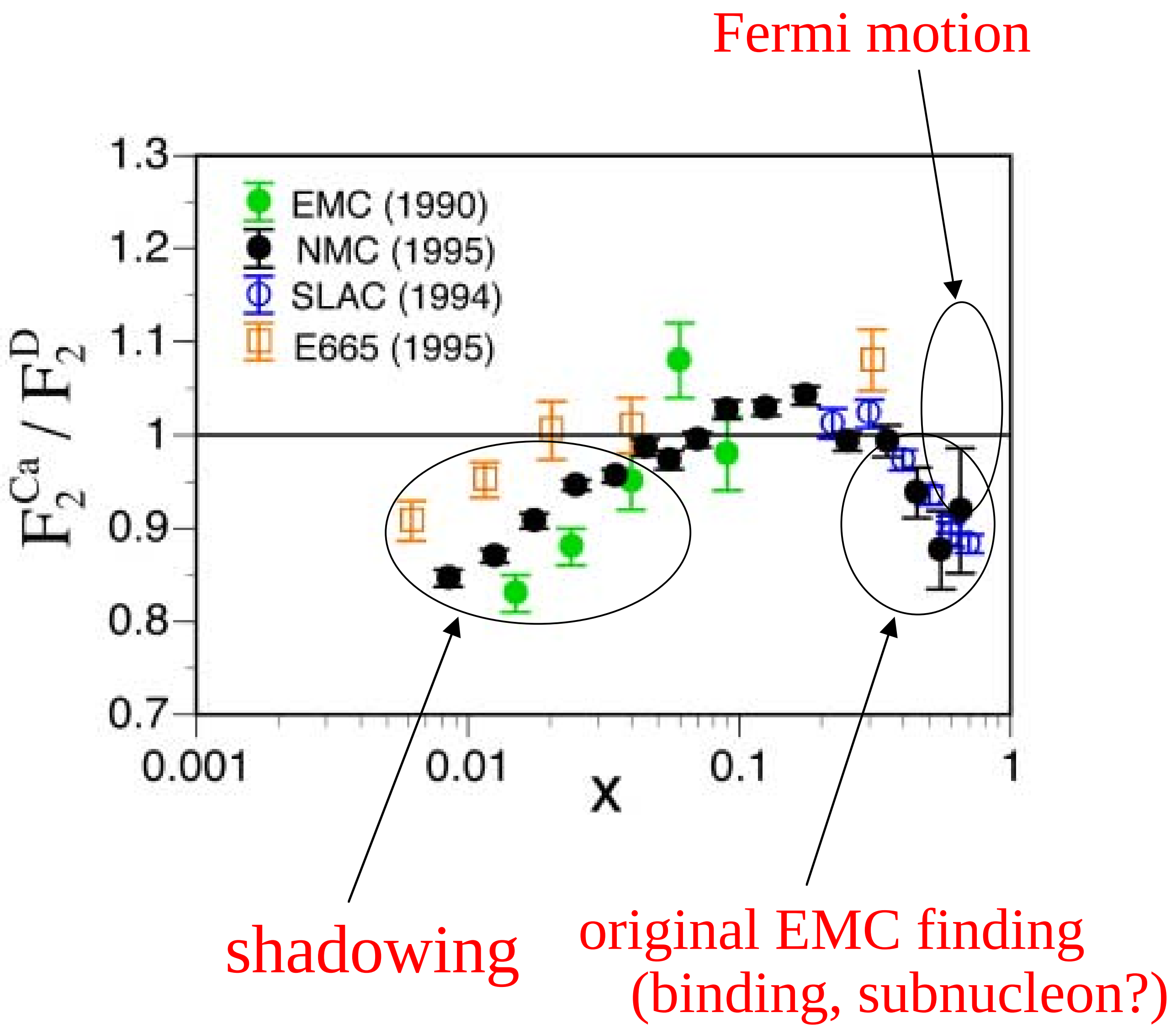
  $\rightarrow$ **for understanding nuclear mechanisms in the high-enegy region**

  $\rightarrow$ **for heavy-ion physics**

• parton distributions in nuclei

Nuclear modification of F_2^A / F_2^D is well known in electron/muon scattering.

$$F_2^A = \frac{1}{9}\, x \left[4\, u_v(x) + d_v(x) \right]_A + \frac{2}{9}\, x\, S_A(x)$$



Parametrization of

nuclear parton distributions

without relying on models!

- Nuclear parton distributions (per nucleon)
  if there *were* no modification

$$A\, u^A = Z\, u^p + N\, u^n, \quad A\, d^A = Z\, d^p + N\, d^n$$

Isospin symmetry: $u^n = d^p \equiv d\,,\ \ d^n = u^p \equiv u$

$$\rightarrow u^A = \frac{Z\,u + N\,d}{A}, \quad d^A = \frac{Z\,d + N\,u}{A}$$

- Take into accont the nuclear modification by the factors $w_i(x,A)$

$$u_v^A(x) = w_{u_v}(x,A)\ \frac{Z\,u_v(x) + N\,d_v(x)}{A}$$

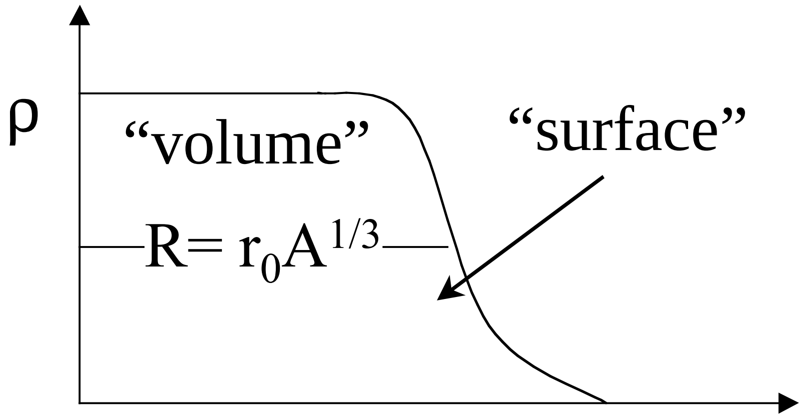
$$d_v^A(x) = w_{d_v}(x,A)\ \frac{Z\,d_v(x) + N\,u_v(x)}{A}$$

$$\bar{q}^A(x) = w_{\bar{q}}(x,A)\ \bar{q}(x)$$

$$g^A(x) = w_g(x,A)\ g(x)$$

A dependence

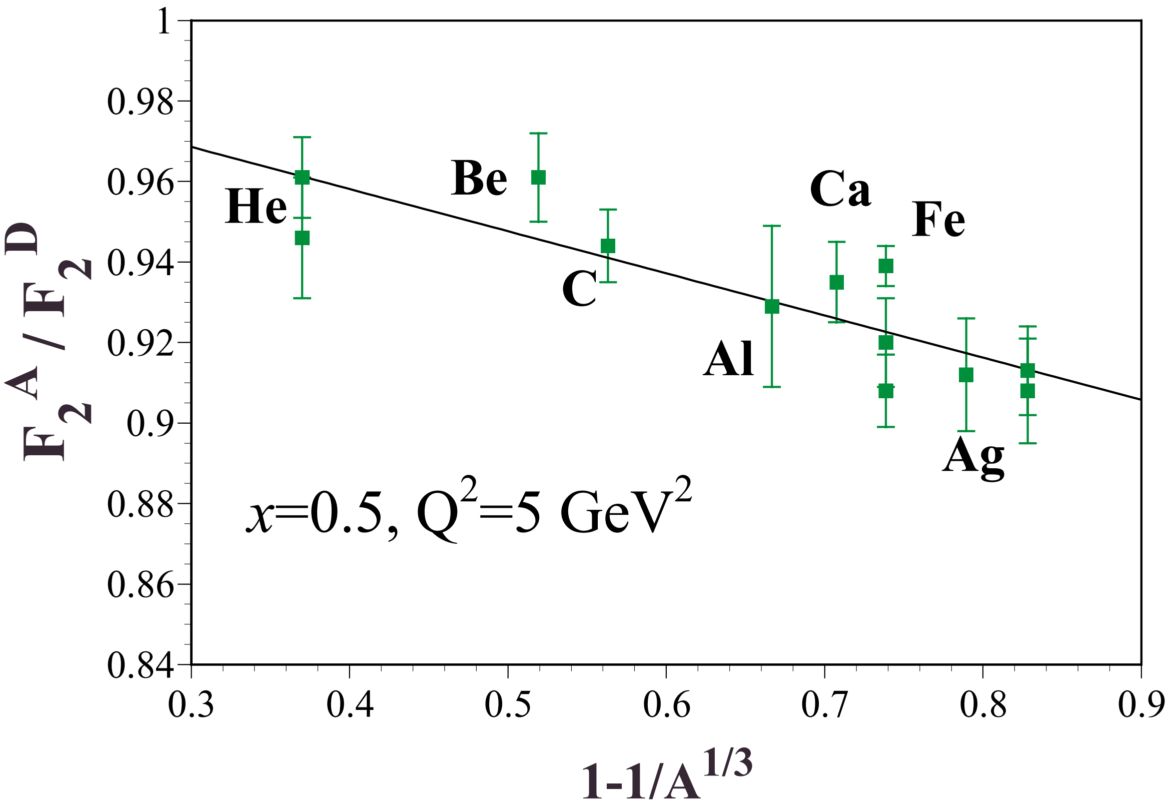
Ref. I. Sick and D. Day, Phys. Lett. B 274 (1992)



roughly speaking $\sigma_A = A\,\sigma_V + A^{2/3}\,\sigma_S$

$$\rightarrow \frac{\sigma_A}{A} = \sigma_V + \frac{1}{A^{1/3}}\,\sigma_S$$

$\sim \frac{1}{A^{1/3}}$ dependence



Functional form of $w_i(x,A)$

$$f_i^A(x) = w_i(x,A)\, f_i(x), \quad i = u_v, d_v, \bar{q}, g$$

first, assume the A dependence as $1/A^{1/3}$

then, use

$$w_i(x,A) = 1 + (1-1/A^{1/3}) \frac{a_i + b_i x + c_i x^2 + d_i x^3}{(1-x)^{\beta_i}}$$

a_i, b_i, c_i, d_i, β_i: parameters to be determined by χ^2 analysis

Fermi motion: $\frac{1}{(1-x)^{\beta_i}} \to \infty$ as $x \to 1$ if $\beta_i > 0$

Shadowing: $w_i(x \to 0, A) = 1 + (1-1/A^{1/3})\, a_i < 1$

Fine tuning: b_i, c_i, d_i

Constraints

- **Nuclear charge**

$$Z = A \int dx \left[\frac{2}{3}(u^A - \bar{u}^A) - \frac{1}{3}(d^A - \bar{d}^A) - \frac{1}{3}(s^A - \bar{s}^A) \right]$$

$$= A \int dx \left(\frac{2}{3} u_V^A - \frac{1}{3} d_V^A \right)$$

- **Baryon number**

$$A = A \int dx \frac{1}{3} (u_V^A + d_V^A)$$

- **Momentum**

$$A = A \int dx\, x (u_V^A + d_V^A + 6\, \bar{q}^A + g^A)$$

Three parameters can be determined by these conditions.

Structure function in leading order

$$F_2^A = \sum_i e_i^2 \, x \, (q_i^A + \bar{q}_i^A) = x \left(\frac{4}{9} u_V^A + \frac{1}{9} d_V^A + \frac{12}{9} \bar{q} \right)$$

$$f_i^A(x) = w_i(x,A) \cdot f_i(x)$$

$$w_i(x,A) = 1 + (1 - 1/A^{1/3}) \frac{a_i + b_i x + c_i x^2 + d_i x^3}{(1-x)^{\beta_i}}$$

parameters: a_{u_V}, a_{d_V}, b_V, c_V, d_V, β_V,
$a_{\bar{q}}$, $b_{\bar{q}}$, $c_{\bar{q}}$, $d_{\bar{q}}$, $\beta_{\bar{q}}$, a_g, b_g, c_g, d_g, β_g

// : nuclear charge, baryon #, momentum

× : $d_V = d_{\bar{q}} = d_g = 0$ in the quadratic fit

: $d_g = 0$ in the cubic fit

/ : $\beta_{\bar{q}} = \beta_g = 1$: $\bar{q}$ & g cannot be determined in the large x region at this stage

\ : $b_g = -2 c_g$, g(x) shape cannot be determined at medium and large x

7 or 9 parameters for 309 data points

Experimental data on F_2^A/F_2^D

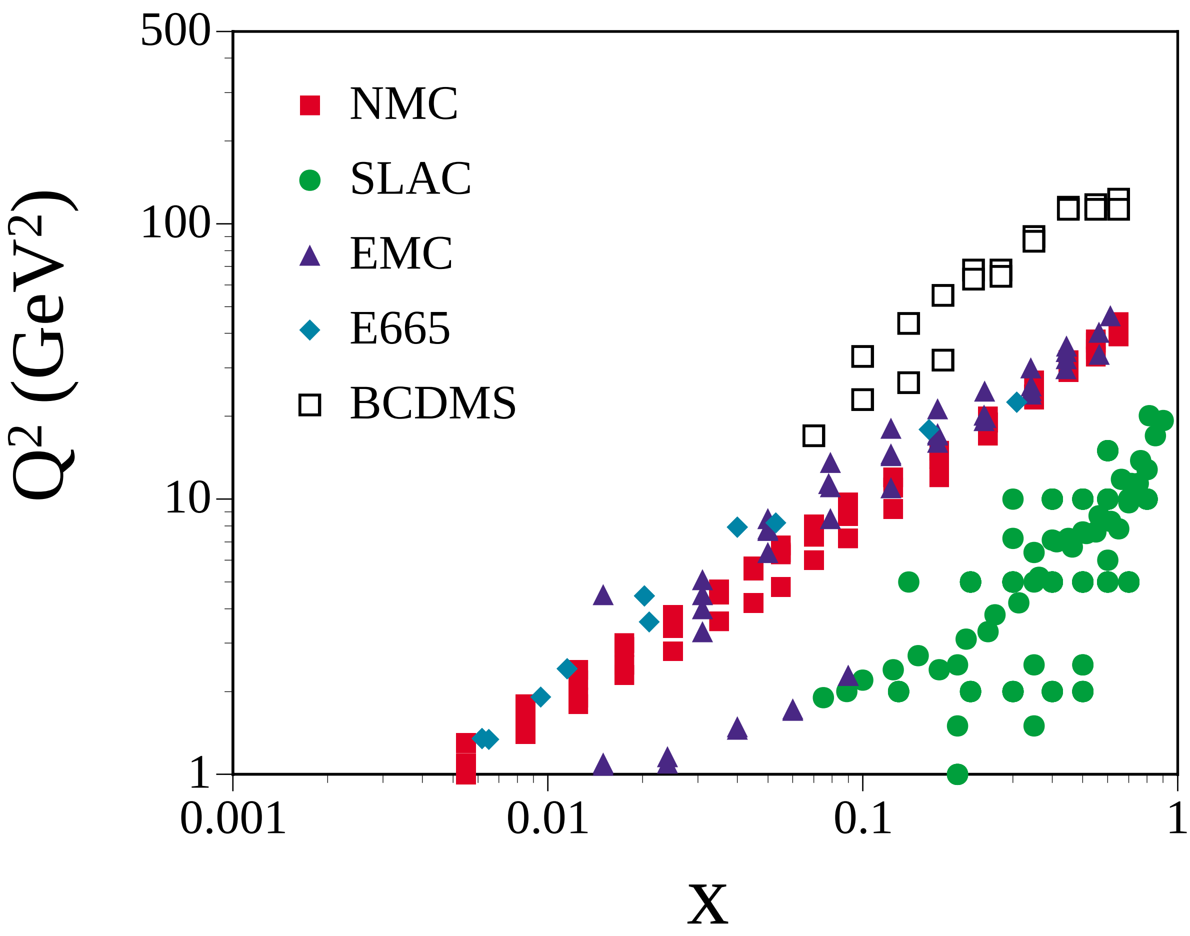
NMC: He, Li, C, Ca

SLAC: He, Be, C, Al, Ca, Fe, Ag, Au

EMC: C, Ca, Cu, Sn

E665: C, Ca, Xe, Pb

BCDMS: N, Fe



Analysis conditions

- parton distributions in the nucleon

  MRST98 - LO (Λ_{QCD}=174 MeV)

- Q^2 point at which the parametrized distributions are defined: $Q^2 = 1\ \mathrm{GeV}^2$

- used experimental data: $Q^2 \geq 1\ \mathrm{GeV}^2$

- total number of data: 309

- number of flavor: $n_f = 3$

- subroutine for the χ^2 analysis: CERN - Minuit

$$\chi^2 = \sum_i \frac{(R_i^{data} - R_i^{calc})^2}{(\sigma_i^{data})^2}$$

$$R = \frac{F_2^A}{F_2^D}, \qquad \sigma_i^{data} = \sqrt{(\sigma_i^{sys})^2 + (\sigma_i^{stat})^2}$$

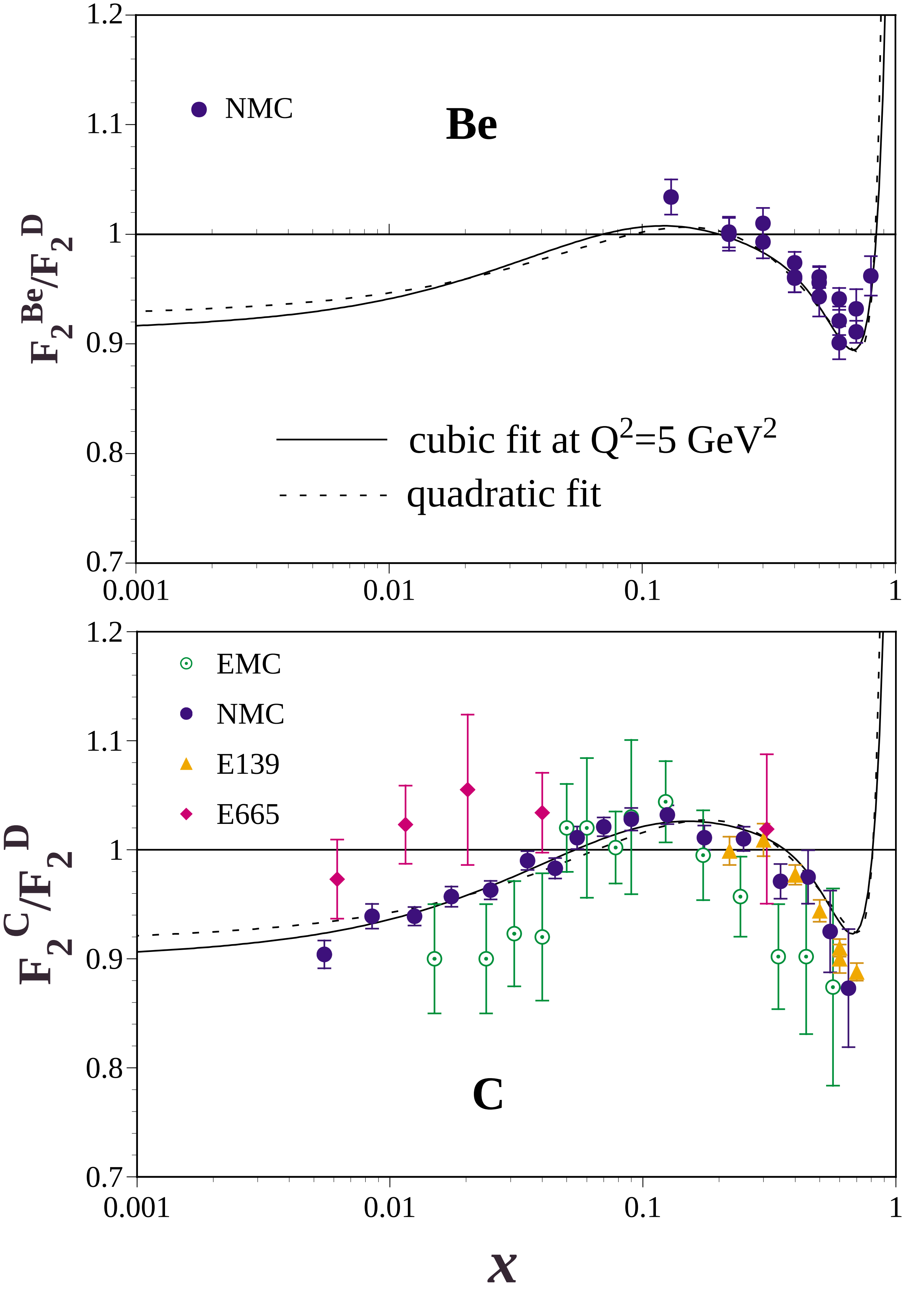
→ obtained χ^2_{min}/d.o.f. = 583.7 / 302 (quadratic)

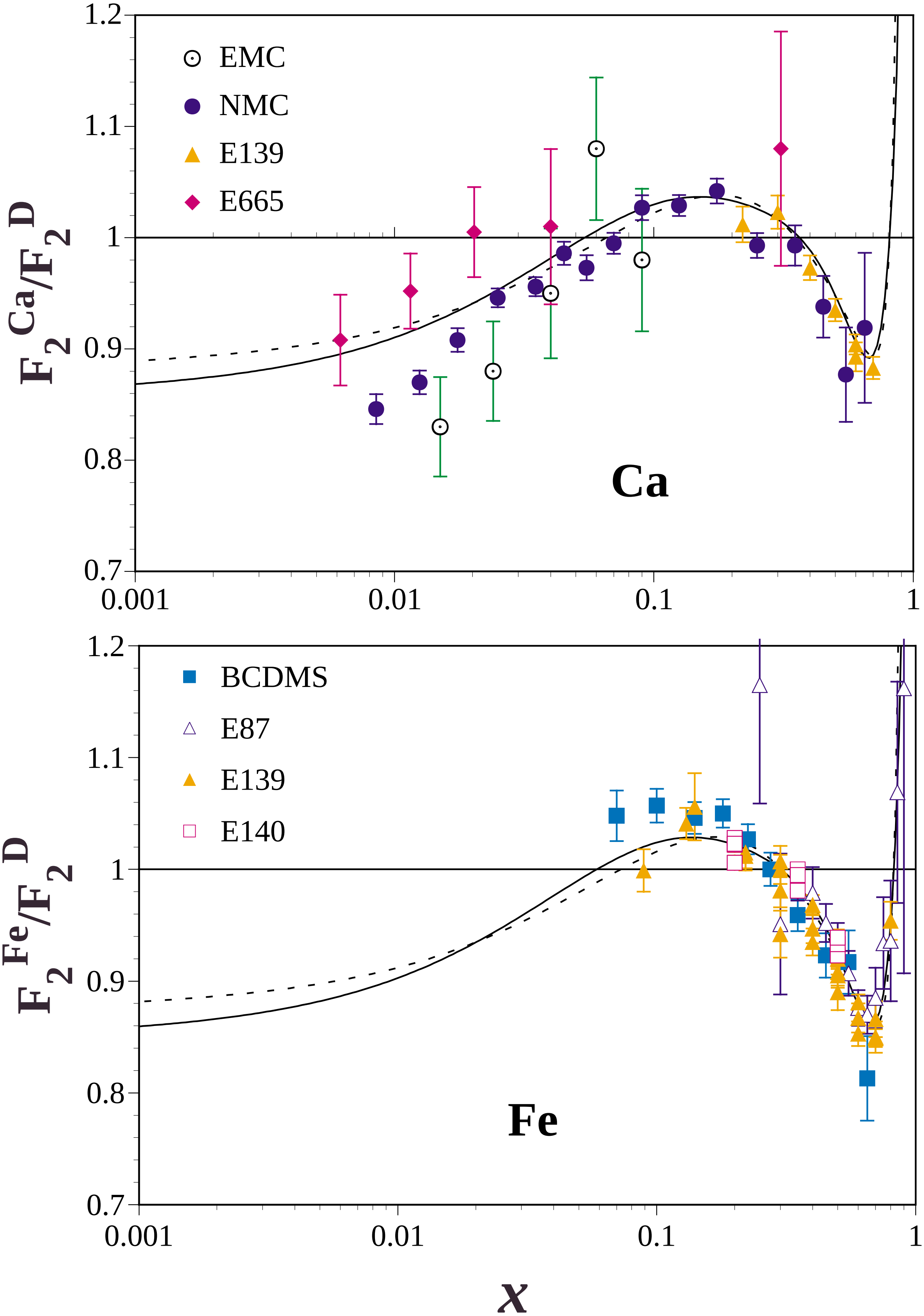
= 546.6 / 300 (cubic)

χ^2 contributions

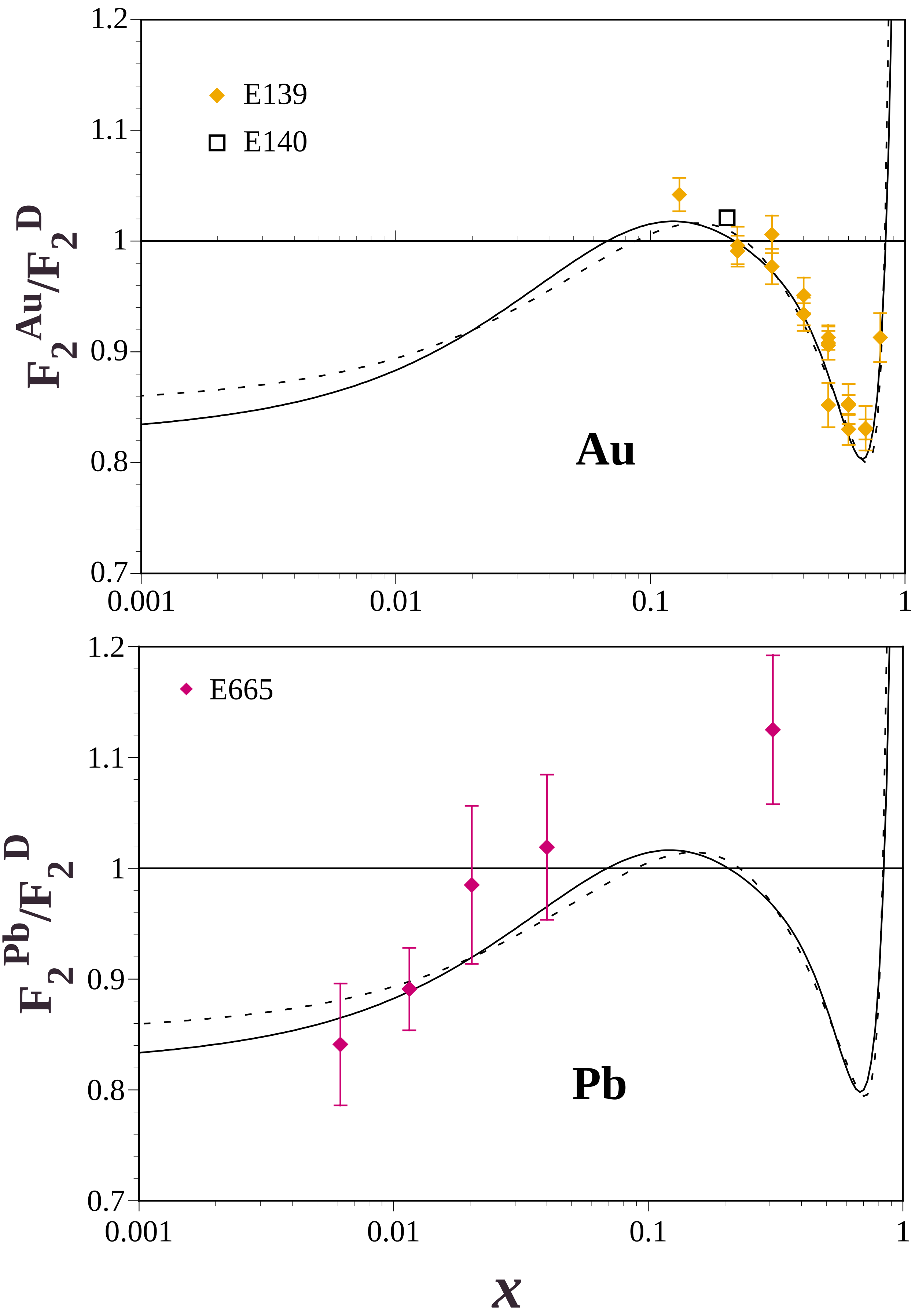
A	# of data	χ2 quad.	χ2 cubic
He	35	55.6	54.5
Li	17	45.6	49.2
Be	17	39.7	38.4
C	43	97.8	88.2
N	9	10.5	10.4
Al	35	38.8	41.4
Ca	33	72.3	69.7
Fe	57	115.7	92.7
Cu	19	13.7	13.6
Ag	7	12.7	11.5
Sn	8	14.8	17.7
Xe	5	3.2	2.4
Au	19	55.5	49.2
Pb	5	7.9	7.6
total	309	583.7	546.6

Analysis results





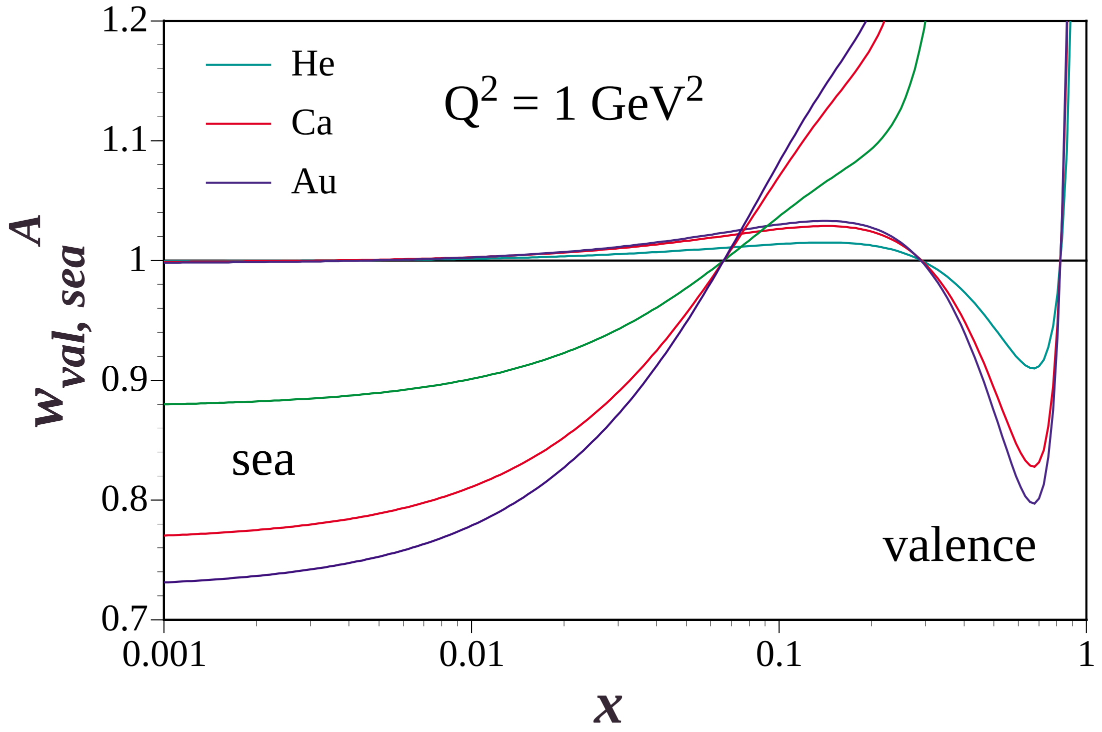
EMC
NMC
E139
E665
Ca
BCDMS
E87
E139
E140
Fe
F_2^{Ca}/F_2^D
F_2^{Fe}/F_2^D
x
1.2
1.1
1
0.9
0.8
0.7
0.001
0.01
0.1
1

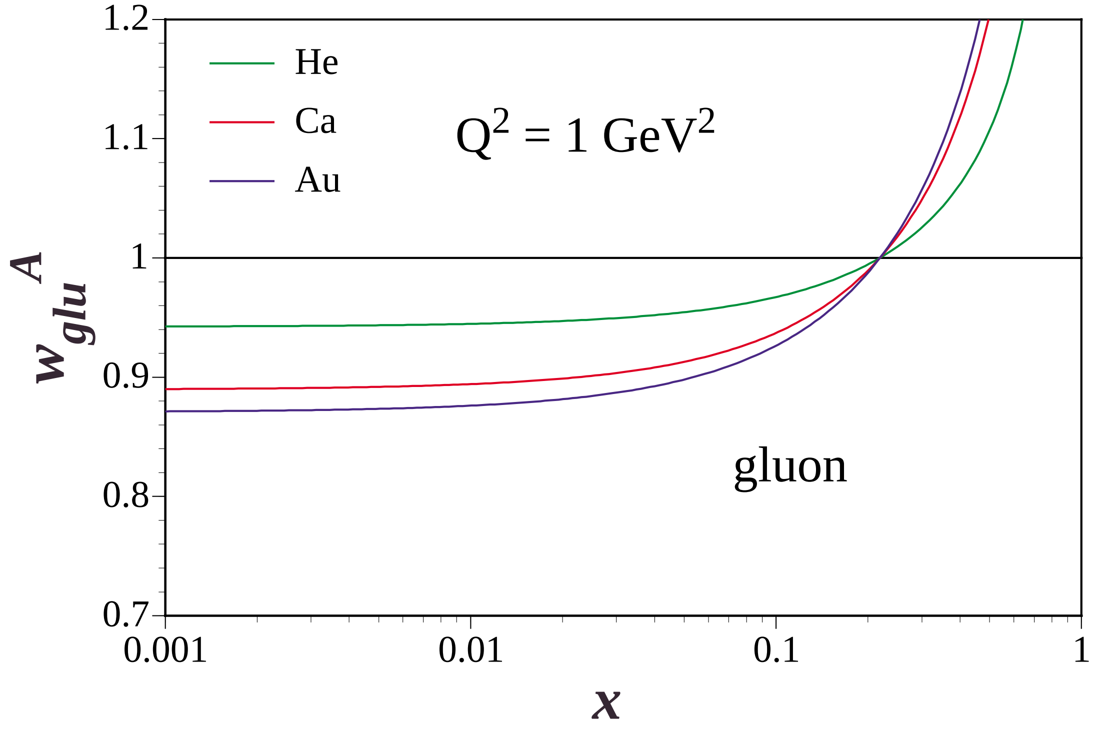


E139
E140
Au
F_2^{Au}/F_2^D
E665
Pb
F_2^{Pb}/F_2^D
1.2
1.1
1
0.9
0.8
0.7
0.001
0.01
0.1
1
x

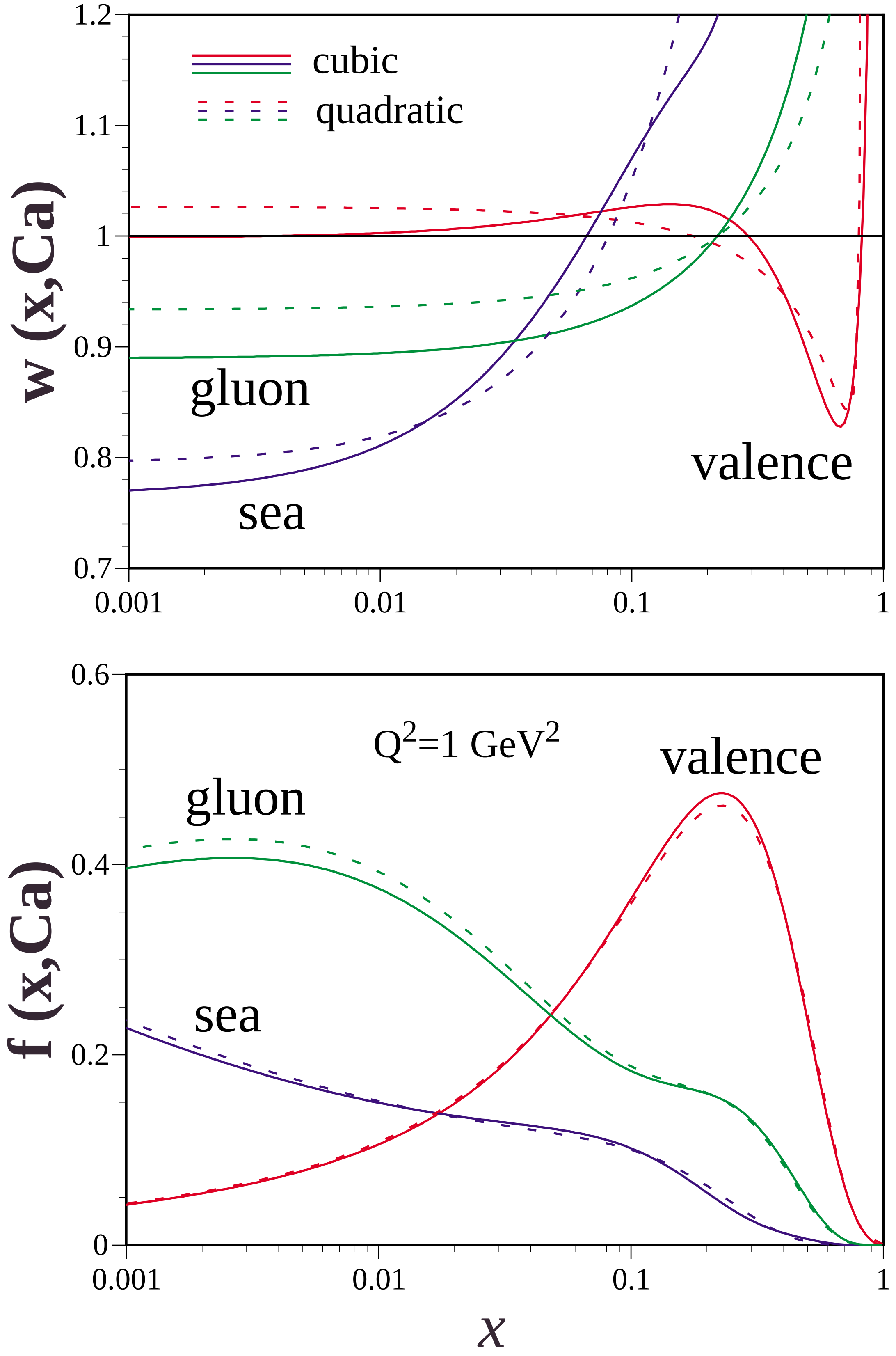
Weight functions $w_i(x,A)$ for He, Ca, Au

"cubic fit"





Weight functions and parton distributions for Ca



Summary

- first χ^2 analysis

  for the nuclear parton distributions

- reasonably good fit with

  χ^2_{min} = 583.7 (quad.), 546.6 (cubic)

- $g^A(x)$ cannot be well determined

- $\bar{q}^A(x)$ at medium x ?

- need analysis refinement

- need a variety of data

  → Drell-Yan, direct γ, ν scattering, ...

- relation to heavy-ion physics

- computer codes could be obtained from

  http://www-hs.phys.saga-u.ac.jp