Generalized Vector Meson Dominanz
and
Shadowing Effects

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- △ Introduction and Motivation of GVMD
- △ Nucleon Structure Function
- △ Nucleus Structure Function
- △ Momentum Dependence
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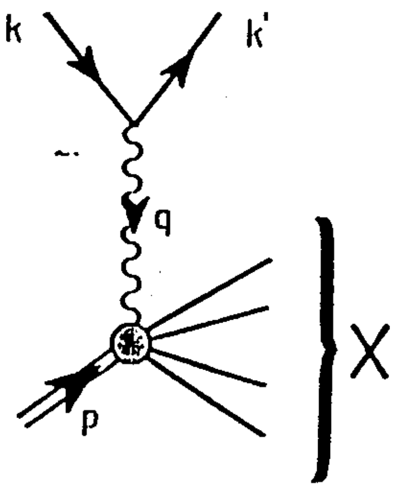
Introduction



$$q = k' - k$$

$$Q^2 = -q^2$$

$$x = \frac{Q^2}{2Mq_0}$$

M: nucleon mass

$$\left.\frac{d^2\sigma}{d\Omega\, dE'}\right|_{Lab} = \frac{\alpha^2}{Q^4}\,\frac{E'}{E}\, L^{\mu\nu} W_{\mu\nu}$$

leptonic tensor   hadronic tensor

$W_{\mu\nu} \longleftarrow$ structure fns. $F_1(Q^2, x)$, $F_2(Q^2, x)$

shadowing: $\dfrac{F_2^A(Q^2, x)}{A\cdot F_2^N(Q^2, x)} = \dfrac{\sigma^A}{A\cdot \sigma^N} < 1$

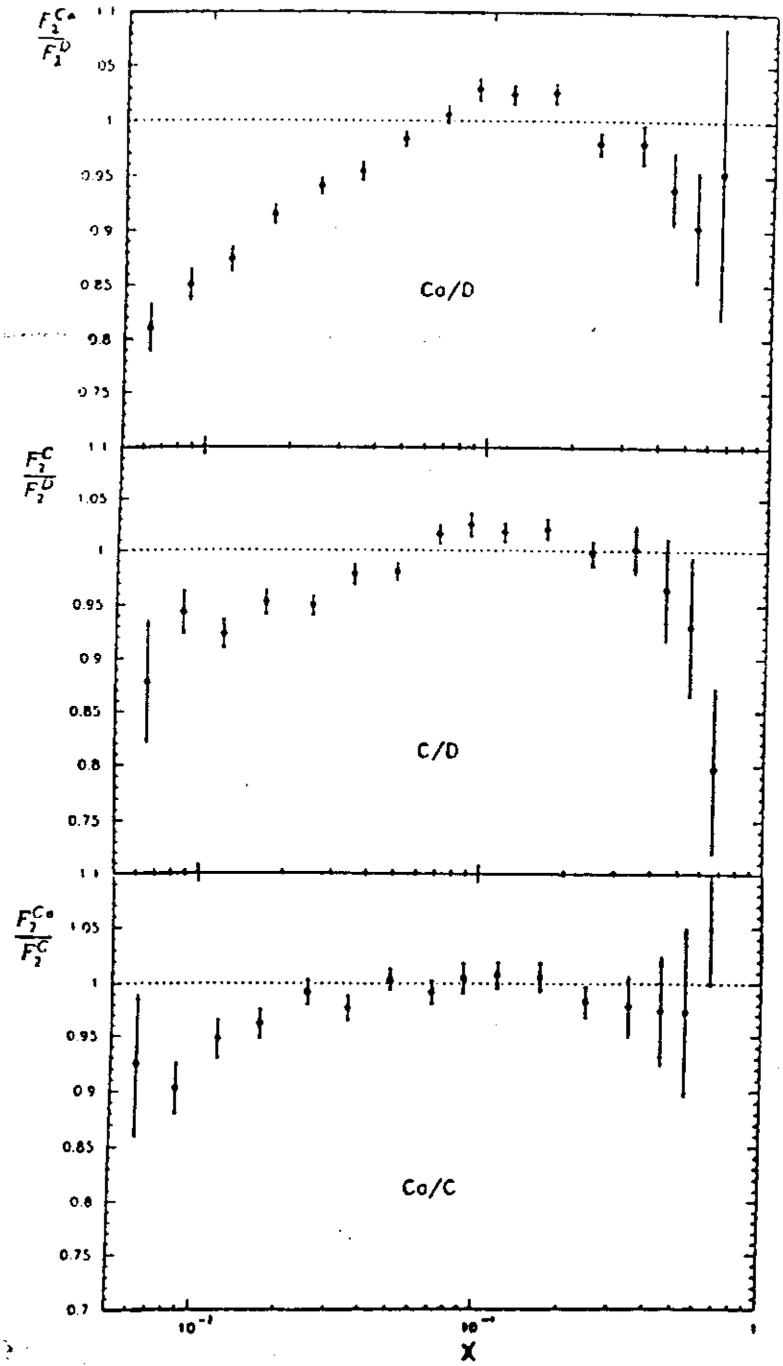
if $R^A_{L/T} = \dfrac{\sigma^A_L}{\sigma^A_T}$

independent of A

Experimental Data:

preliminary results from the NA 37 experiment (NMC) for D, C, Ca target.

beam energy: 90, 120, 200 and 280 GeV



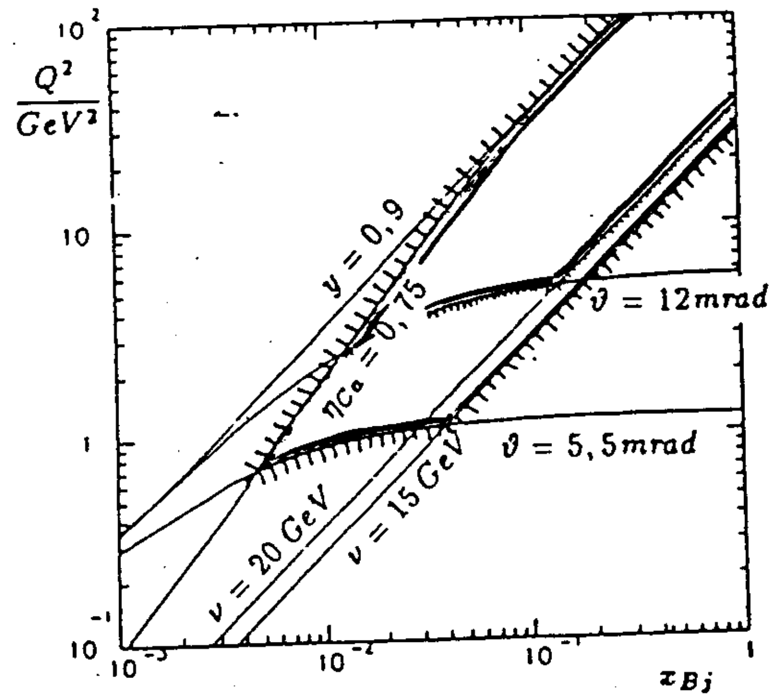
rise in $\langle Q^2 \rangle$!

e.g. for Ca target:

$x \approx 0.004 \quad \langle Q^2 \rangle \approx 0.78\ GeV^2$

$x \approx 0.04 \quad \langle Q^2 \rangle \approx 5.2\ GeV^2$

kinematical cuts :

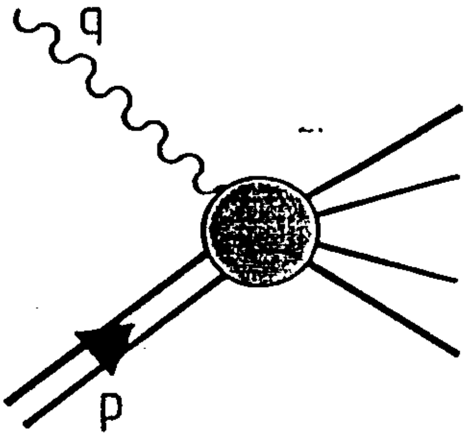


(C. Scholz, Heidelberg PhD Thesis)

	Trigger 1	Trigger 2
ϑ^{Ca}_{min}	12 mrad	5.5 mrad
ν_{min}	20 GeV	15 GeV
y_{max}	0.9	0.9
η^{Ca}_{min}	0.75	0.75

↳ problems in measuring shadowing within a small x-bin over a wide range of Q^2 especially for very small x.

↳ Lack of information on Q^2-dependence naive picture of shadowing:



nuclear mean free path l_γ of the photon:

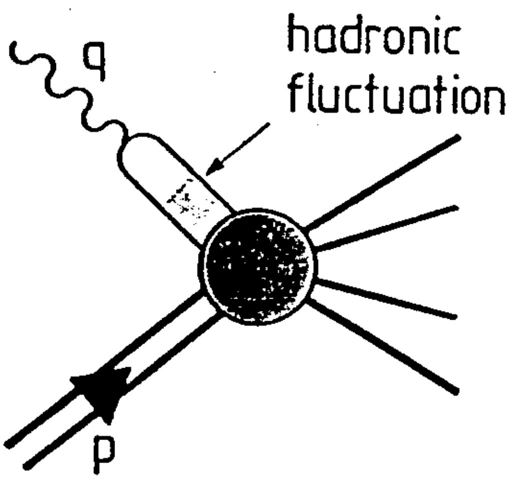
$$l_\gamma \approx \frac{1}{\rho_{nucl.}\,\sigma(\gamma N)} \approx 550\ \mathrm{fm}$$

$$l_\gamma \gg R \approx r_0 A^{1/3} \quad (1\text{–}5\ \mathrm{fm})$$

⇒ if pointlike γ-interactions

$$\sigma(\gamma A) = A \cdot \sigma(\gamma N)$$

<u>**but**</u>: hadronic structure of photon



also hadron-nucleus-processes

e.g.: $\sigma(\rho N) \approx 27\ \mathrm{mb}$

⇒ $l_\rho \approx 2.5\ \mathrm{fm}$

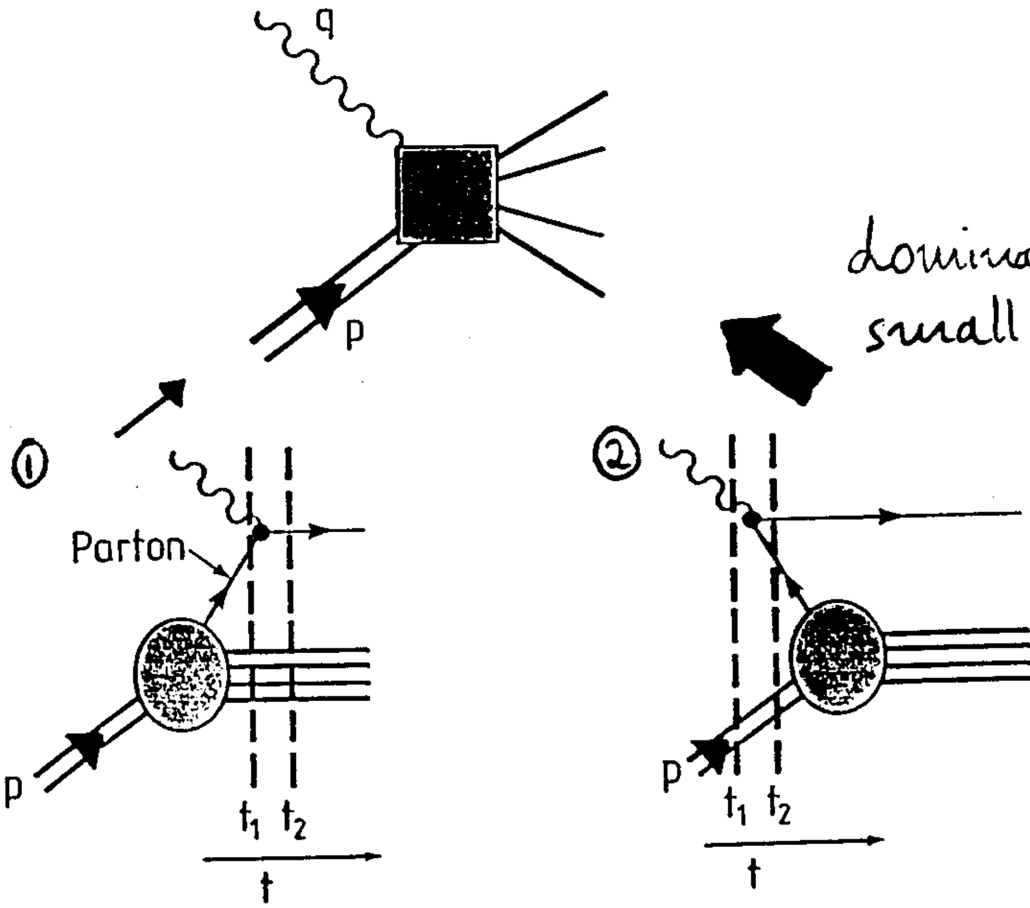
⇒ multiple scattering

⇒ shadowing

Motivation for a GVMD Picture

space - time - picture of DIS

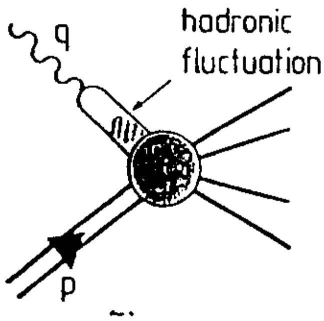
* high photonenergy q_0
* rest frame of the nucleon



dominant at small x

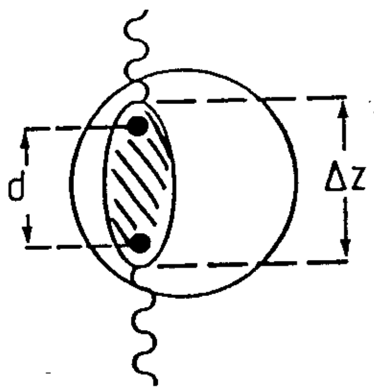
"old fashioned perturbation theory"

$$\boxed{\frac{\Delta E_1}{\Delta E_2} \sim \frac{1}{x}}$$ for small x



QCD-evolution of
$q\bar{q}$ pair → hadronic state

$$\boxed{\text{the nucleon in its rest frame sees at small } x \text{ mainly the hadronic structure of the photon}}$$



side remark: When will shadowing start?

Δz : propagationlength of hadron

d : nucleon-nucleon distance

$$\Delta z \approx \frac{1}{\Delta E} \gtrsim d$$

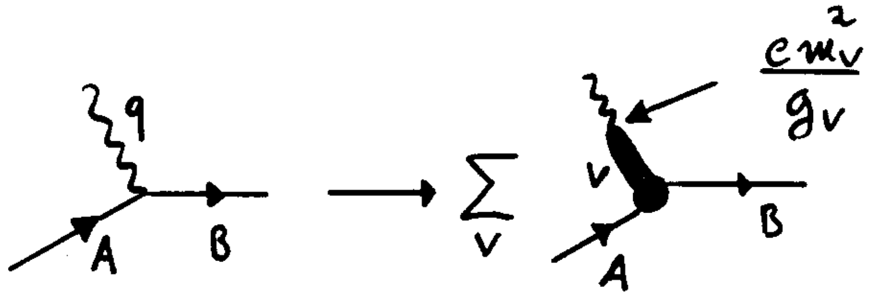
$$\frac{2q_0}{\mu^2 + Q^2} \gtrsim d$$

$$\hookrightarrow \quad \boxed{x \lesssim 0.1}$$

Nucleon Structure Function

$$F_2(Q^2,x) = \frac{Q^2}{4\pi^2\alpha}\,\sigma(\gamma^* N)$$

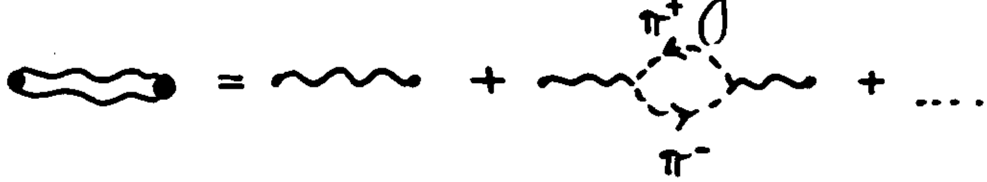
VMD:



$$F_2(Q^2,x) = \frac{Q^2}{\pi}\sum_V \frac{m_V^4}{g_V^2}\left(\frac{1}{m_V^2+Q^2}\right)^2 \sigma(VN)$$

<u>but</u>: no scaling for large Q^2

photon can hadronize into many other states :



$$D_{\mu\nu}(q^2) = g_{\mu\nu}\left(\frac{Z_3}{q^2+i\varepsilon} + \int_{4m_\pi^2}^{\infty}\frac{d\mu^2}{\mu^2}\,\frac{\Pi(\mu^2)}{q^2-\mu^2+i\varepsilon}\right)$$

$\Pi(\mu^2)$: spectral density fns

GVMD: $$\boxed{F_2(Q^2,x) = \frac{Q^2}{\pi}\int_{4m_\pi^2}^{\infty} d\mu^2\,\frac{\mu^2\,\Pi(\mu^2)}{(\mu^2+Q^2)^2}\,\sigma(\mu^2,N)}$$

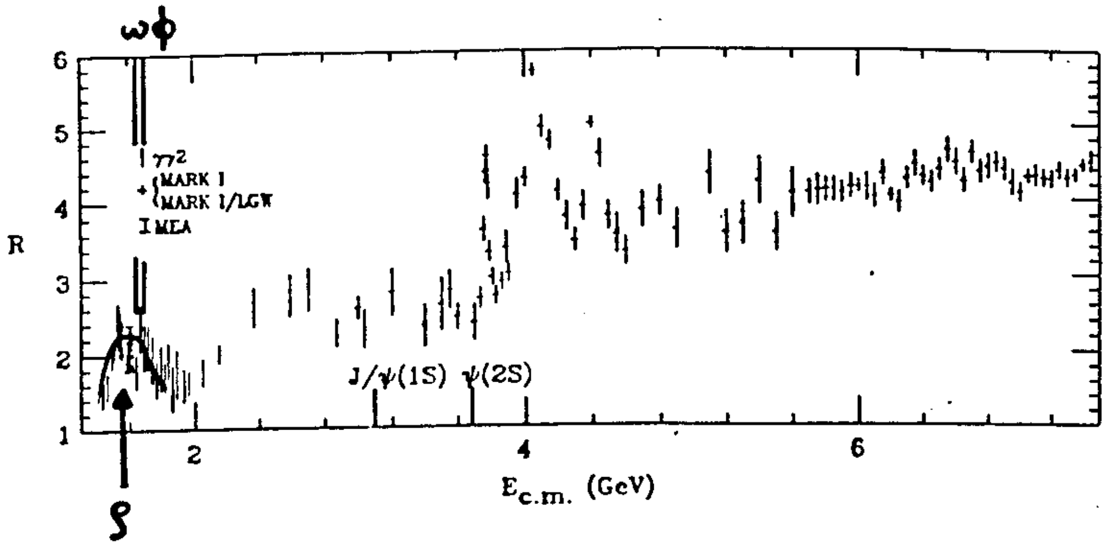
remarks :

- GVMD for small x only !

- in general also off-diagonal contributions $VN \to V'N$,
  strong destructive interference between on- and off-diagonal terms $\longrightarrow$
  remaining effects thought to be absorbed in effective cross section $\sigma(\mu^2, N)$
  (D. Schildknecht et al.)

- $\Pi(\mu^2)$ measured in $e^+e^- \longrightarrow$ hadrons

$$R(s) = \frac{\sigma_{e^+e^- \to hadrons}}{\sigma_{e^+e^- \to \mu^+\mu^-}} = 12\pi^2 \, \Pi(s)$$



choice of the Hadron - Nucleon cross section

$\sigma(\mu^2, N)$:

$\sigma(\mu^2, N)$ depends in general on:

* invariant mass μ^2
* energy $s = 2Mq_0 + M^2 - Q^2 \approx Q^2/x$
  $\sqrt{s}$ in multi GeV range
  ↪ cross sect. flat
  ↪ drop s - dependence

choice: $$\sigma(\mu^2, N) = \frac{16}{\mu^2} \, \mathrm{GeV}^2 \, \mathrm{mb}$$

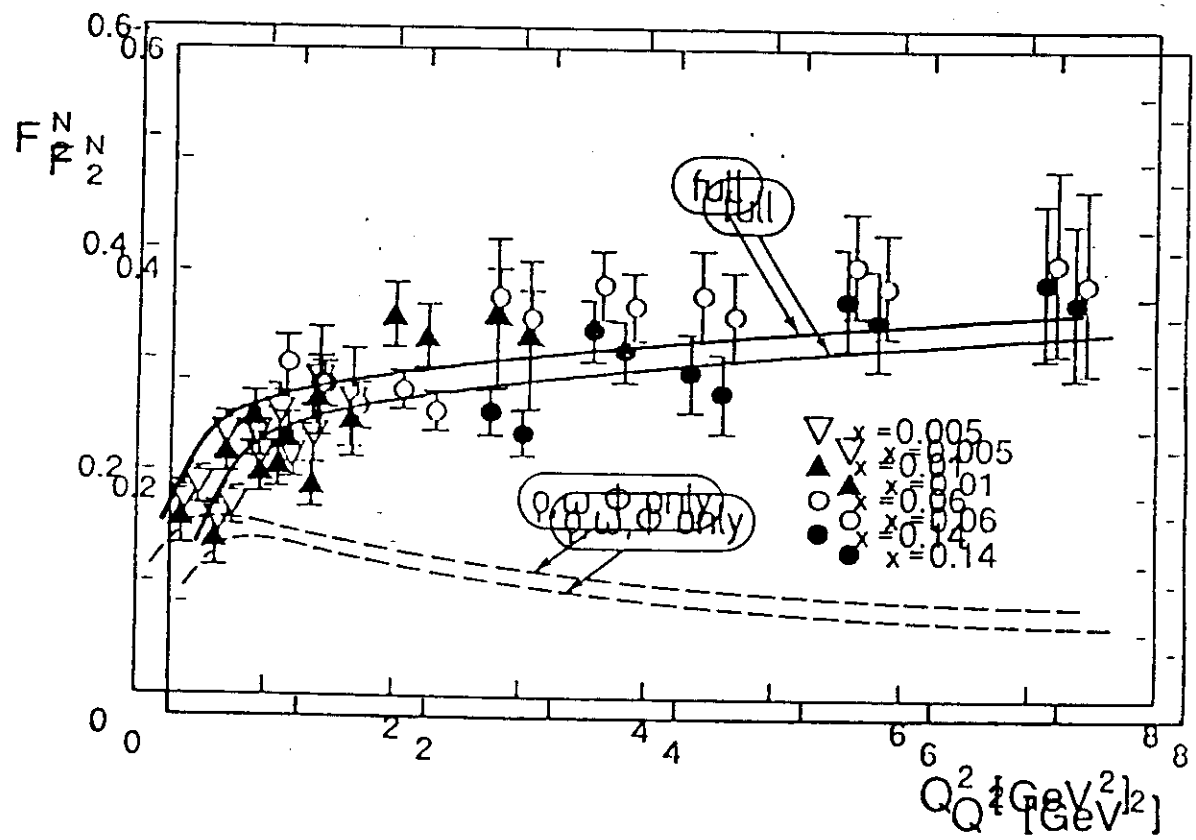
* need $1/\mu^2$ for "scaling" at large Q^2
* fit of $F_2^N(Q^2, x)$ at low x
* reproduces roughly the low mass vector meson cross - sections:

$\sigma(\rho, N) \approx 27$ mb (27 mb)

$\sigma(\phi, N) \approx 15$ mb (12 mb)

$\sigma(J/\psi, N) \approx 1.7$ mb (2 mb)

Nucleon Structure Function at low x :



data : EMC, M. Arneodo et al
Nucl. Phys B 333 (90) 1

Nuclear Structure Function

$$F_2^A(Q^2, x) = \frac{Q^2}{12\pi^3} \int_{4m_\pi^2}^{\infty} d\mu^2 \, \frac{\mu^2 R(\mu^2)}{(\mu^2 + Q^2)^2} \, \sigma(\mu^2, A)$$

* Large photon energy q_0 → eikonal approximation
  Glauber multiple scattering theory connects $\sigma(\mu^2, N)$ and $\sigma(\mu^2, A)$.

* neglect $\mathrm{Re}\, f_N / \mathrm{Im}\, f_N$

* neglect diffractive dissociation terms ($VN \to V'N$) in multiple scattering series (error for σ_A < 5% ; P.V.R. Murthy et al., NP B92 (75) 269)

* finite propagation length $\Delta \ell = \dfrac{2q_0}{\mu^2 + Q^2}$

  → extension by V.N. Gribov (JETP 30 (70) 709)

→ phase factor: $\exp\left[i \cdot \frac{\Delta z}{\Delta \ell}\right]$

$$\sigma(\mu^2, A) = A \cdot \sigma(\mu^2, N) +$$

$$+ \sum_{n=2}^{A} \left(-\frac{1}{2}\right)^{n-1} \binom{A}{n} \left[\frac{\sigma(\mu^2 N)}{A}\right]^n \times$$

$$\times \mathrm{Re}\left\{ \int d^2b \, dz_1 \dots dz_n \; \rho_n(\vec{b}, z_1 \dots z_n) \, e^{i \frac{z_1 - z_n}{\Delta \mathcal{L}}} \right\}$$

* ρ_n : n-particle nuclear density
  ↪ expand up to terms linear in the two-body correlation function

$$\Delta(\vec{r}, \vec{r}\,') = \rho_2(\vec{r}, \vec{r}\,') - \rho(\vec{r}) \, \rho(\vec{r}\,')$$

$$= - j_0(q_c |\vec{r} - \vec{r}\,'|) \, \rho(\vec{r}) \, \rho(\vec{r}\,')$$

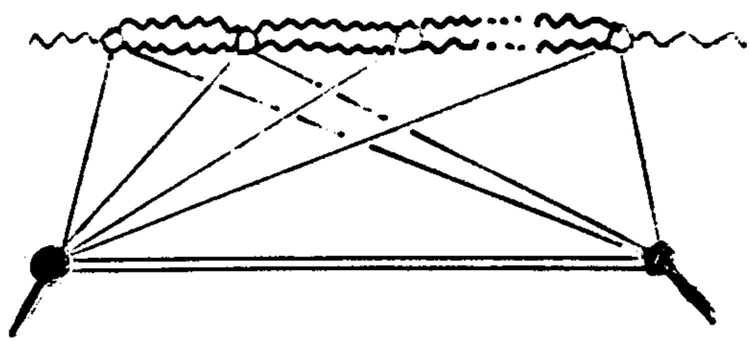
with $q_c = 780$ MeV

* used realistic densities $\rho(\vec{r})$:

$$\rho(r) = \frac{\rho_0}{1 + e^{(r-R)/a}} \left[1 - c \frac{r^2}{R}\right]$$

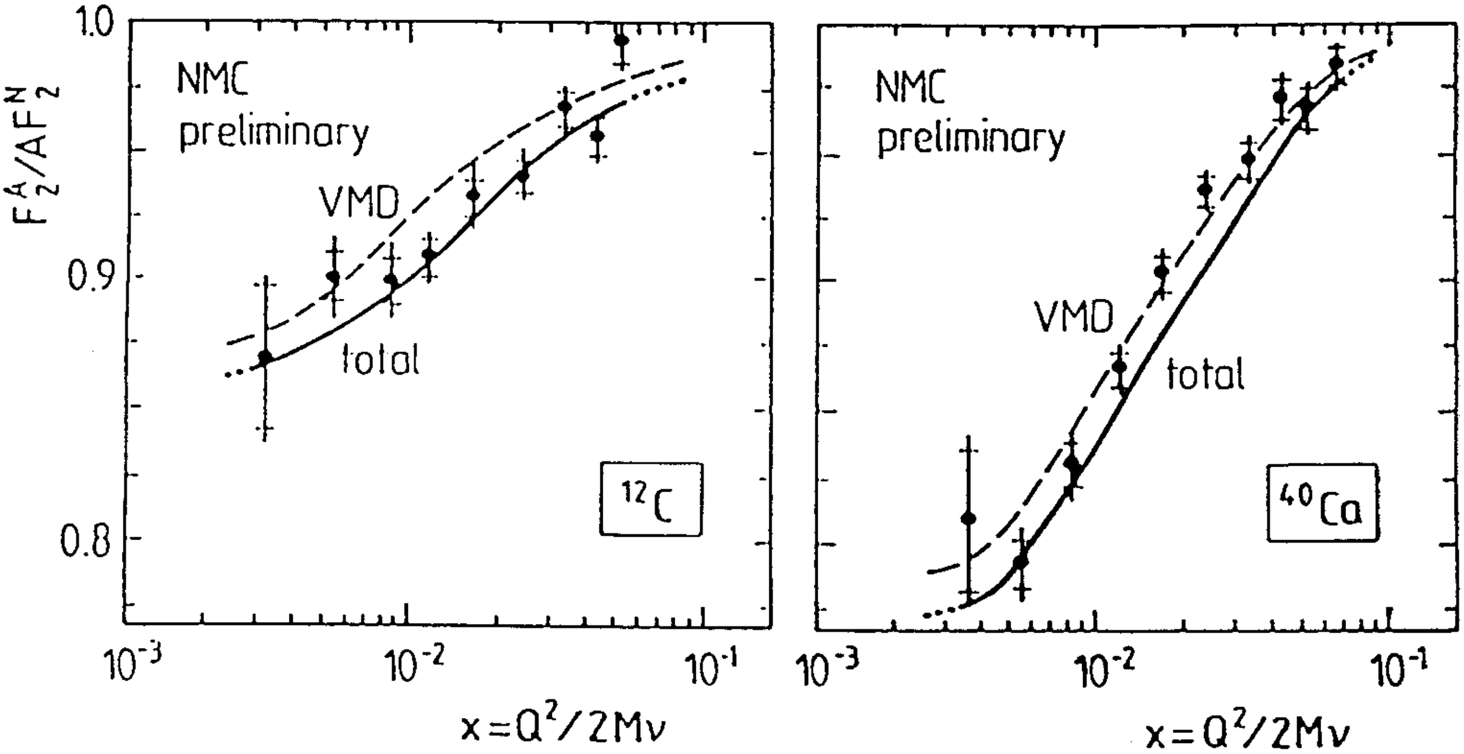
i.e. nuclear structure function is calculated via :

$\sum_{n=1}^{A}$



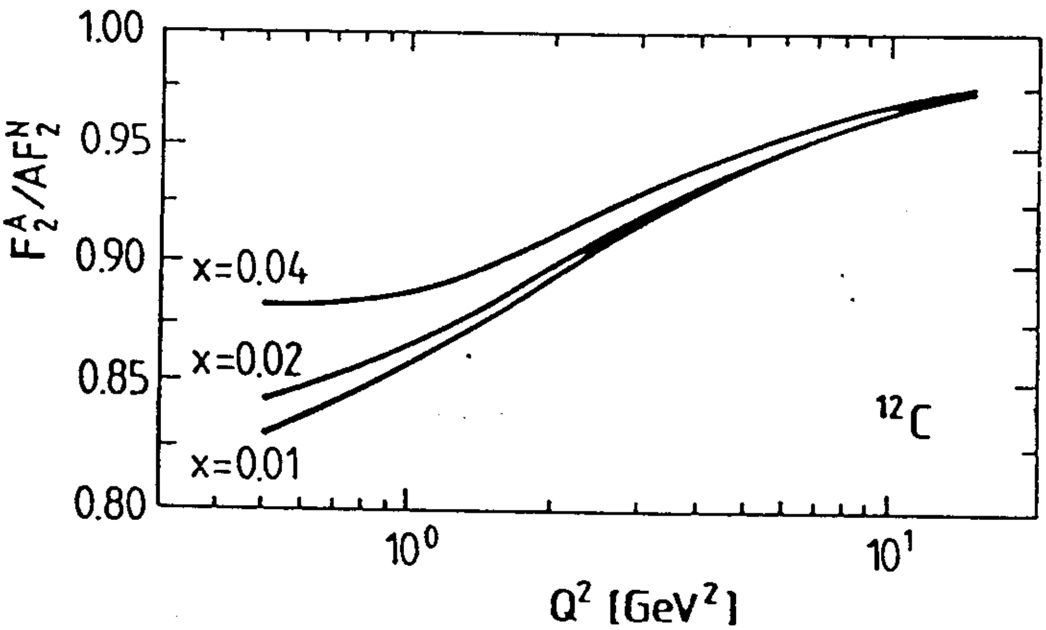
$$\hookrightarrow \quad \boxed{R(Q^2, x) = \frac{F_2^A(Q^2,x)}{A \cdot F_2^N(Q^2 x)}}$$

results for $\frac{F_2}{A F_2^N}$ using realistic nucleon densities :



data: 'NMC preliminary resuls from NA 37

Q^2 dependence of $\frac{F_2^A}{A F_2^N}$ for a ^{12}C target:



~ Logarithmic Q^2 dependence

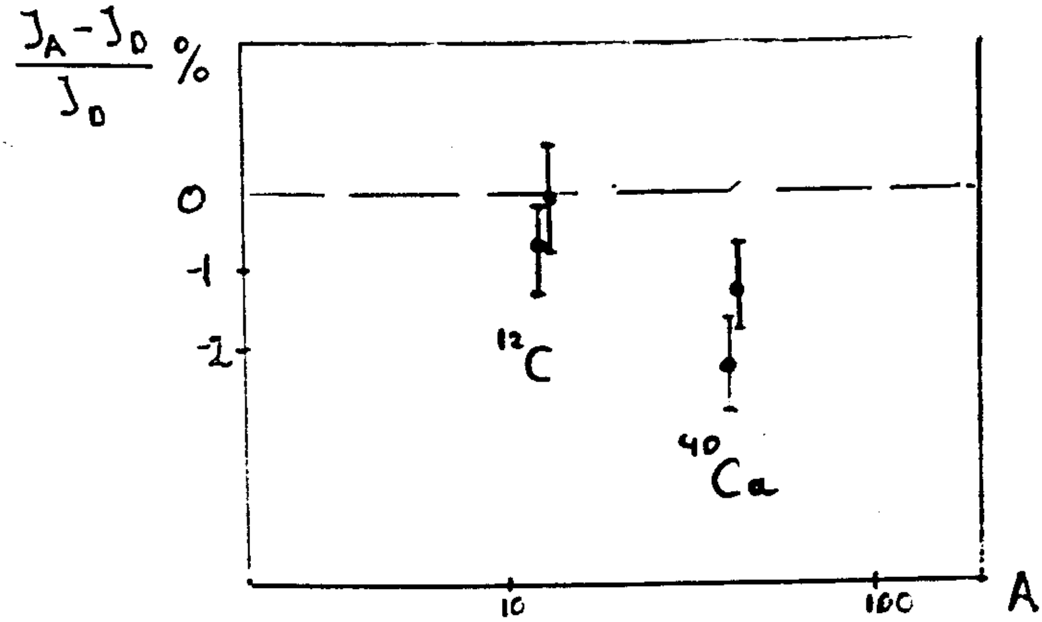
Momentum Conservation

$$J(Q^2) = \int dx \; F_2(x, Q^2) \sim \begin{cases} \text{total long. momentum} \\ \text{of valence- and} \\ \text{sea quarks} \end{cases}$$

sum rule: $\frac{1}{\langle e_q^2 \rangle} \int F_2(x)\, dx + \int x \; G(x)\, dx = 1$

NMC, SLAC - data

(C. Scholz, Heidelberg, PhD Thesis)



|: exact scaling

|: GVMD ($Q^2 \gtrsim 12$ GeV^2)

↳ within GVMD slightly less enhancement of total gluon momentum

Summary

We described the nucleon structure function at small x within a GVMD model taking into account all hadronic fluctuations measured in $e^+e^- \to$ hadrons.

Using the Glauber-Gribov multiple scattering series and implementing short range NN correlations, we get a good description of the observed shadowing phenomena.