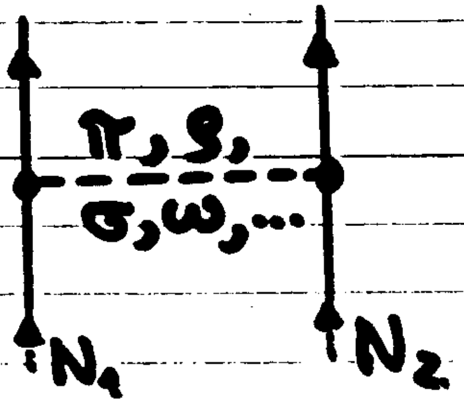
Amand Faessler
Triest; Sept. 1990

The QUARK MODEL, the NUCLEON-NUCLEON INTERACTIO and the DEUTERON FORMFACTO

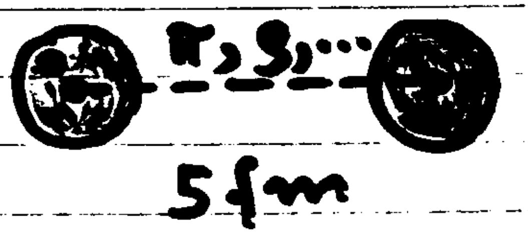
U. Straub, K. Bräuer, [redacted]
[redacted]; [redacted]; Shimizu;
Lübeck; Zang Zong-ye



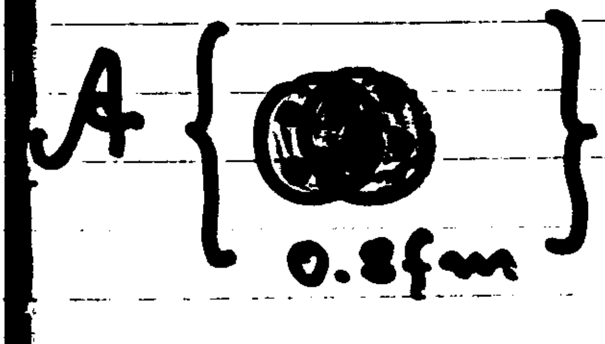
Meson Exchange:

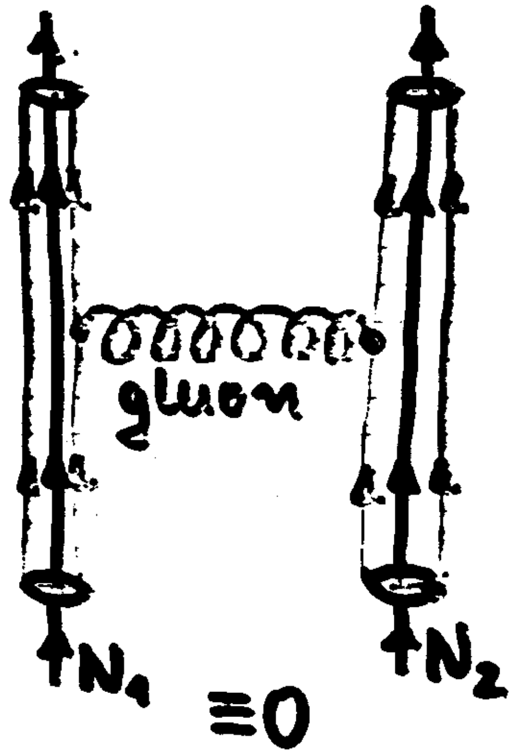
[redacted]

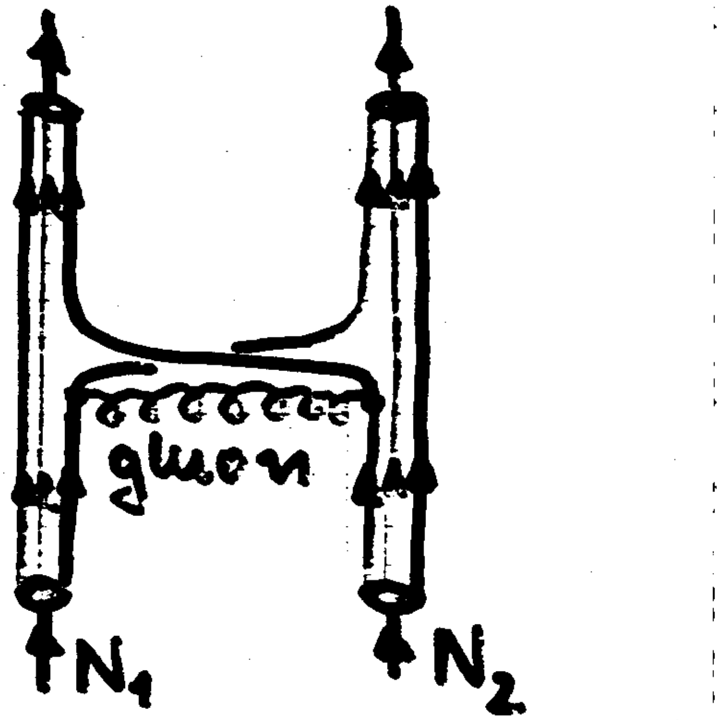
G. Breit ω 1958

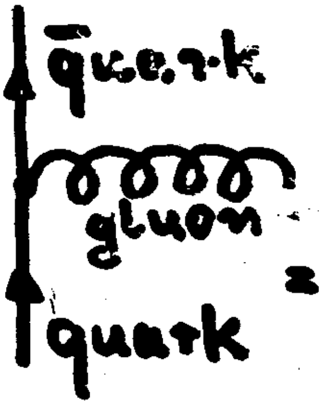


QUARK MODE and NNINTERAC



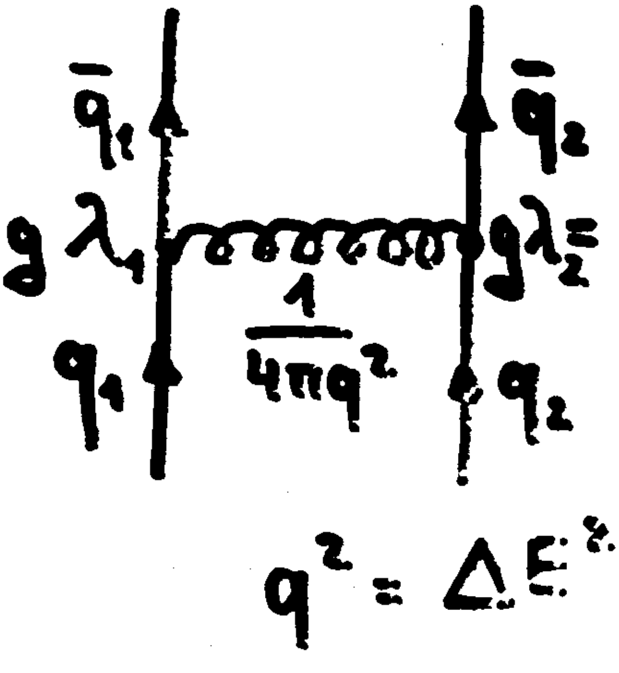




$g\lambda$ 

$$= g\, J^{a}_{\mu} \cdot A^{a\mu}$$

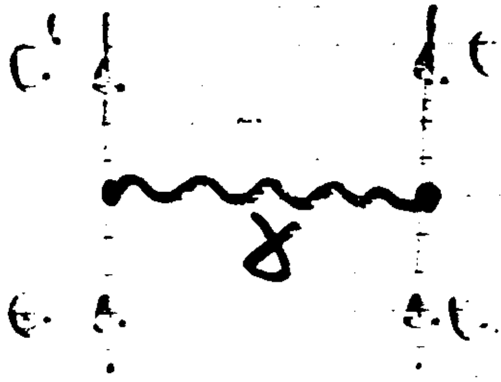
$$= g\{\bar q\, \gamma_\mu \tfrac{1}{2} \lambda^{a}_{qq}\, q\} A^{a\mu}(x)$$



$$= \frac{g^2}{4\pi} \{\bar q\, \gamma^\mu \tfrac{1}{2} \lambda^{a}_{1}\, q\}_1 \frac{1}{q^2} \cdot \{\bar q\, \gamma_\mu \tfrac{1}{2} \lambda^{a}_{2}\, q\}_2$$

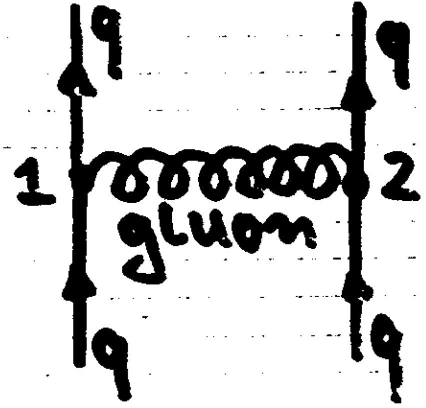
$$q^2 = \Delta E^2 - \vec{q}^{\,2}$$

QED: NON-RELATIVISTIC REDUCTION (Fermi-Breit)



$$\approx \frac{e^2}{4\pi}\left[\frac{1}{r_{12}} + \dots\right]$$

QCD:



$$\approx \frac{g^2}{4\pi}\,\frac{1}{4}\,\tilde{\lambda}_1\cdot\tilde{\lambda}_2\Big[\frac{1}{r_{12}}$$

$$+\frac{\pi}{m_q^2}\left(1+\frac{2}{3}\vec{\sigma}_1\cdot\vec{\sigma}_2\right)\delta(r_{12}$$

+ tensor

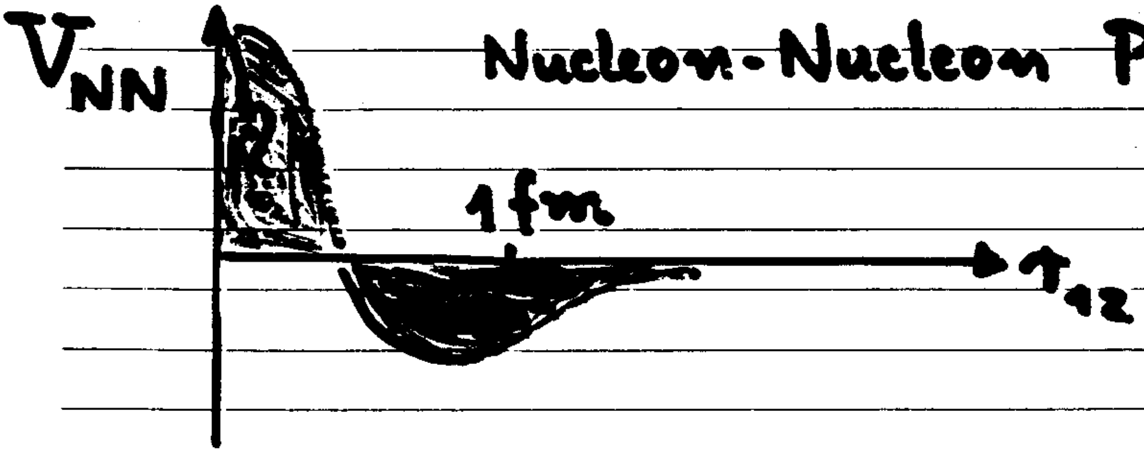
$$+ \text{two-body } \vec{L}\cdot(\vec{S}_1+\vec{S}_2)\,\Big]$$

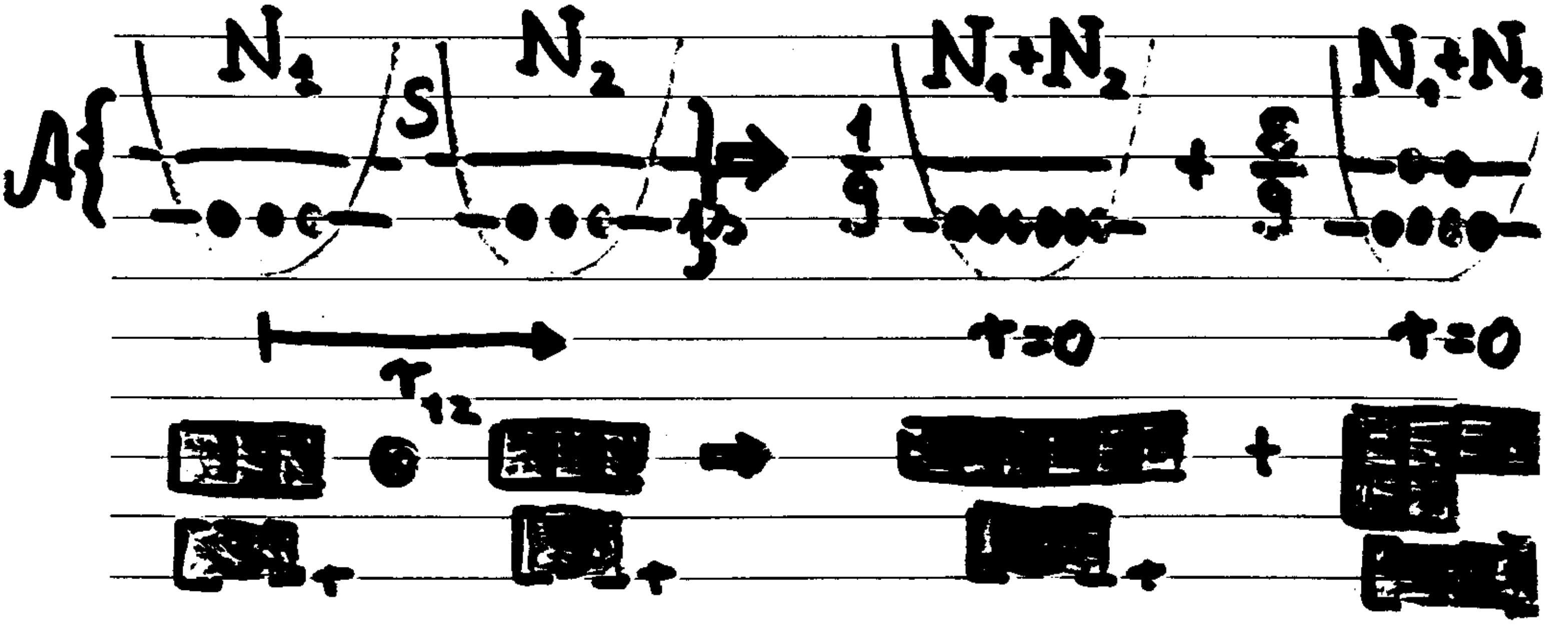
$$H_{chromo} = \sum_{i=1}^{6}\left[m_i + \frac{p_i^2}{2m_i}\right]$$

$$+\sum_{i<j=1}^{6}\left[V_{qq}(i,j) - a\,\lambda_i\cdot\lambda_j\,r_{ij}^2\right]$$

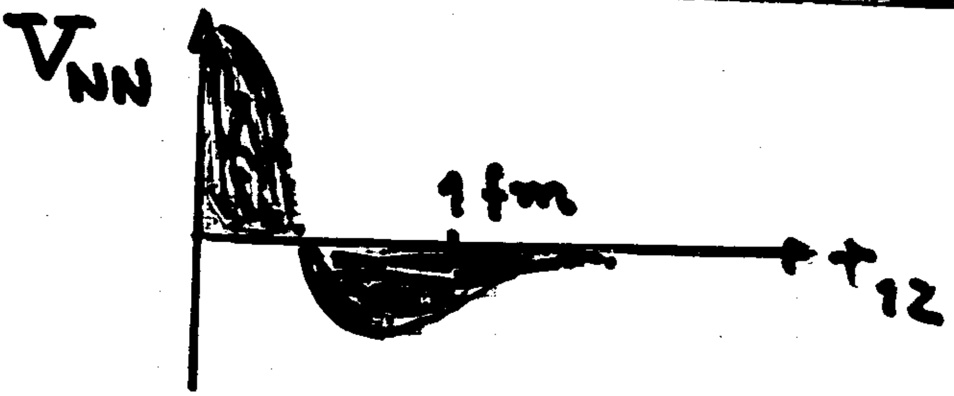
N-N-Interaction:

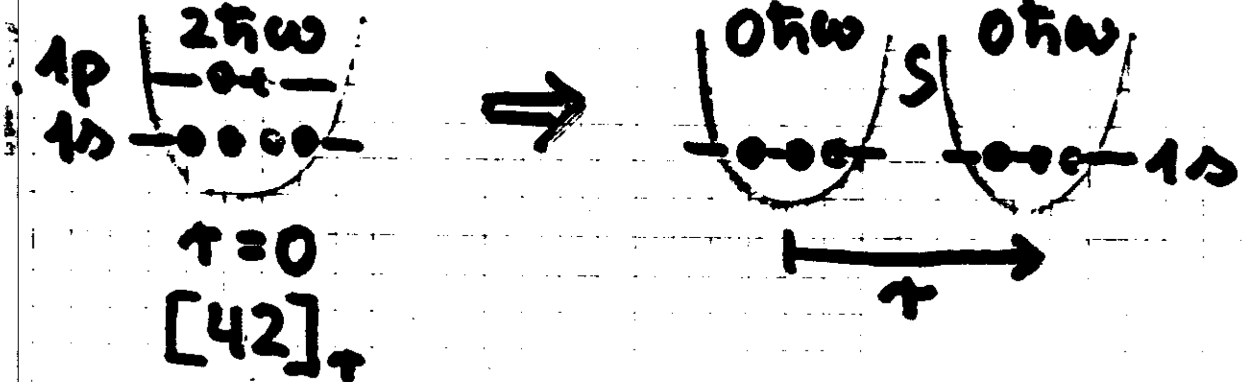
The Nature of the Short Range Repulsion?

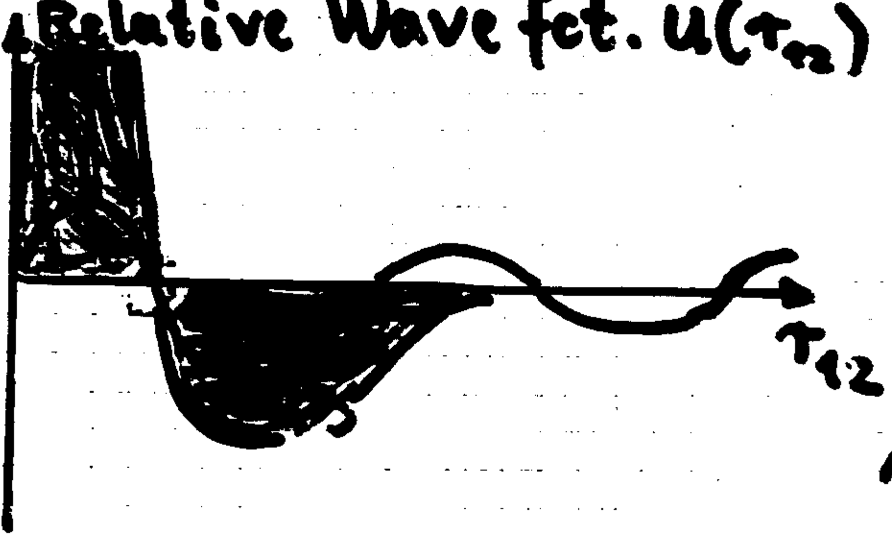

Nucleon-Nucleon Potential

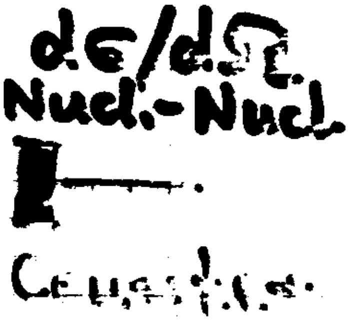


Nature of Short Range Repulsion!









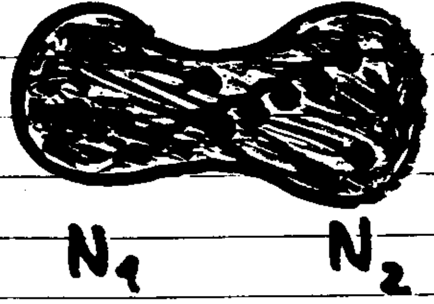
Phase shift

$$u(r_{12}) = \cancel{\alpha_1|1s\rangle} + \alpha_2|2s\rangle + \alpha_3|3s\rangle + \dots$$

forbidden

Short range Part : Nucleon-Nucle

[illegible]



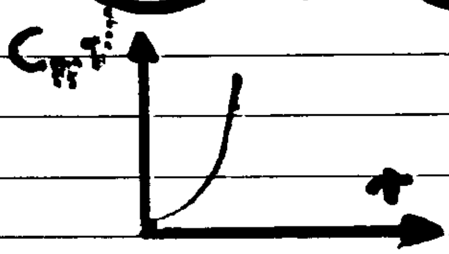
Quark and
Gluon-exchange

■ form facto
■ o-----o
■ $\mathcal{A}\{\quad\}$
■ finite size

Long range Part :

$= g_{\pi qq}(r) = C_\pi$

$\frac{g^2_{\pi NN}}{4\pi} = 14.5$



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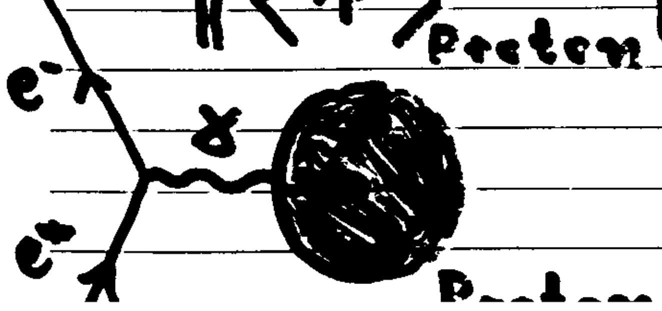
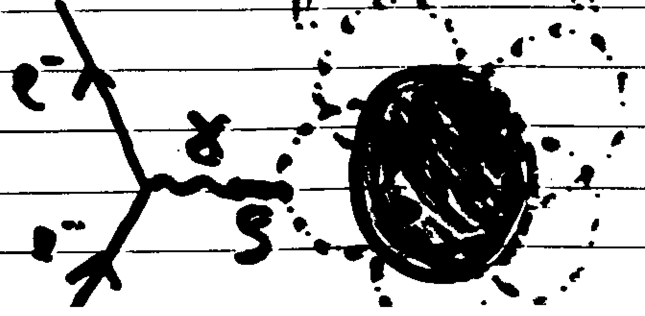
6 Adjusted Parameters by:

m_q
α_s
b, a
$C_{\pi,\sigma}$

$m_N = 938\,\text{MeV}$ $m_\Delta = 1232\,\text{MeV}$
$g^2_{\pi NN}/4\pi = 14.5$ $g^2_{\sigma NN}/4\pi = 3.4$

$\| \langle r^2 \rangle^{1/2}_{\text{Proton}} \|$





Resonating Group Method:

$$\Psi_{6q} = \mathcal{A}\Big\{ |NN, r\rangle \, \underline{u_N(r)} + |\Delta\Delta, r\rangle \, \underline{u_\Delta(r)} + |CC, r\rangle \, \underline{u_C(r)} \Big\}$$

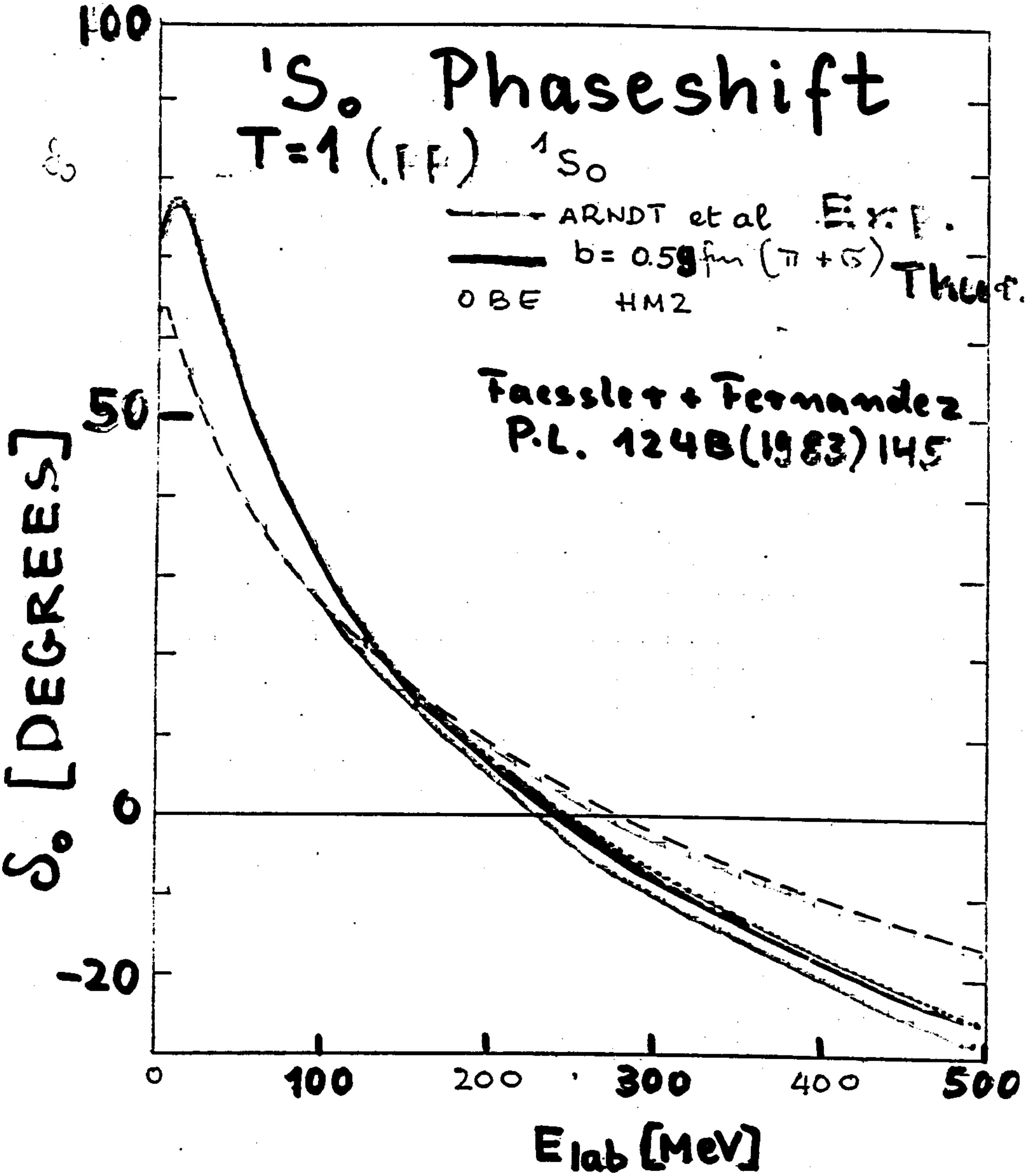
^1S T=1
^3S T=0

$$\langle \delta \Psi_{6q} | \hat{H}_6 + \hat{V}_8 + \hat{V}_6 - E | \Psi_{6q} \rangle = ($$

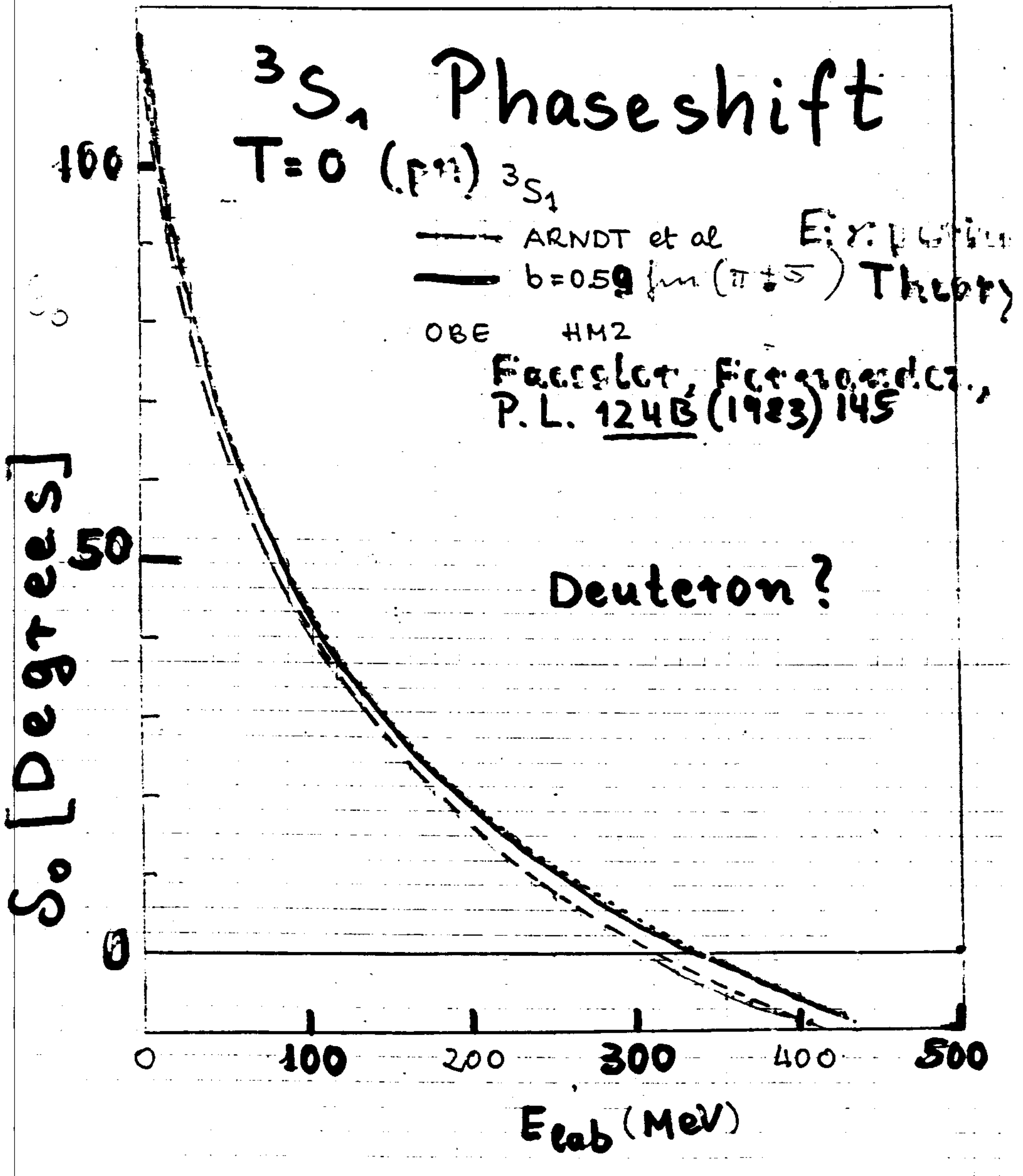
⇝ System of integral equations for:

$\underline{u_N(r)}$, $\underline{u_\Delta(r)}$, $\underline{u_C(r)}$

$\lim\limits_{r\to\infty} \underline{u_N(r)}$ ⇝ Phase shift



^1S_o Phaseshift
T=1 (pp) $^1S_0$
ARNDT et al Exp.
b= 0.59 fm ($\pi + \sigma$) Theor.
OBE HM2
Faessler + Fernandez
P.L. 124B(1983) 145
100
50
0
-20
δ_o [DEGREES]
0
100
200
300
400
500
E lab [MeV]


$^3S_1$ Phaseshift
T=0 (pn) $^3S_1$
ARNDT et al Experim
b=0.59 fm (π+σ) Theory
OBE HM2
Faessler, Fernandez, ..,
P.L. 124B (1983) 145
Deuteron?
δ_0 [Degrees]
100
50
0
0
100
200
300
400
500
E_{lab} (MeV)

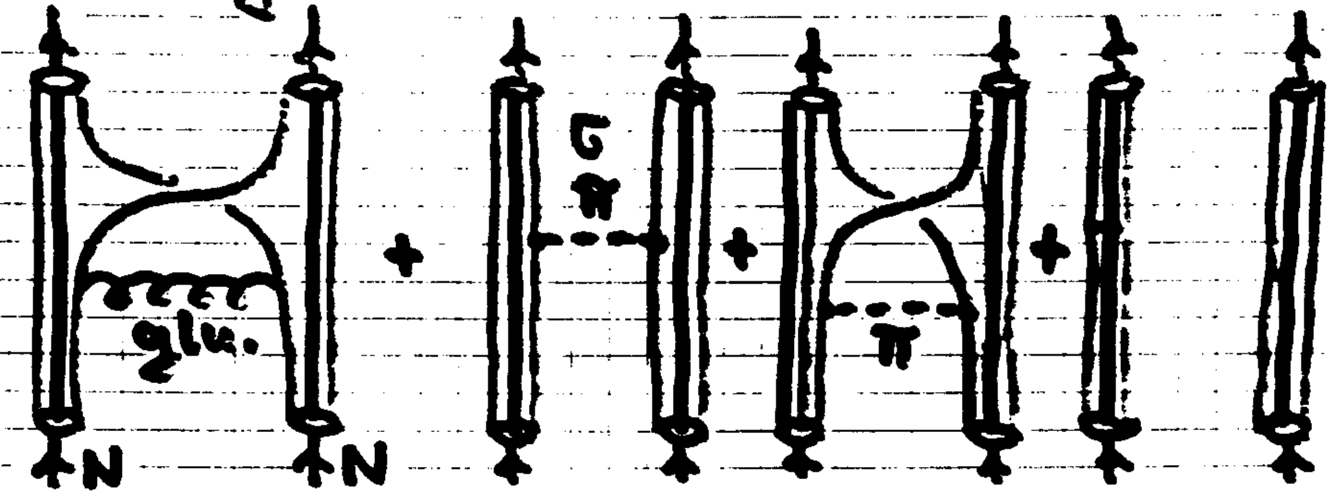
NN scattering:

$g_\sigma^2/4\pi \approx 3.4$

B(Deuteron) = 3.3 MeV

Adjust: B(Deuteron) = 2.2 MeV

$g_\sigma^2/4\pi \approx 2.68$ (instead 3.4)

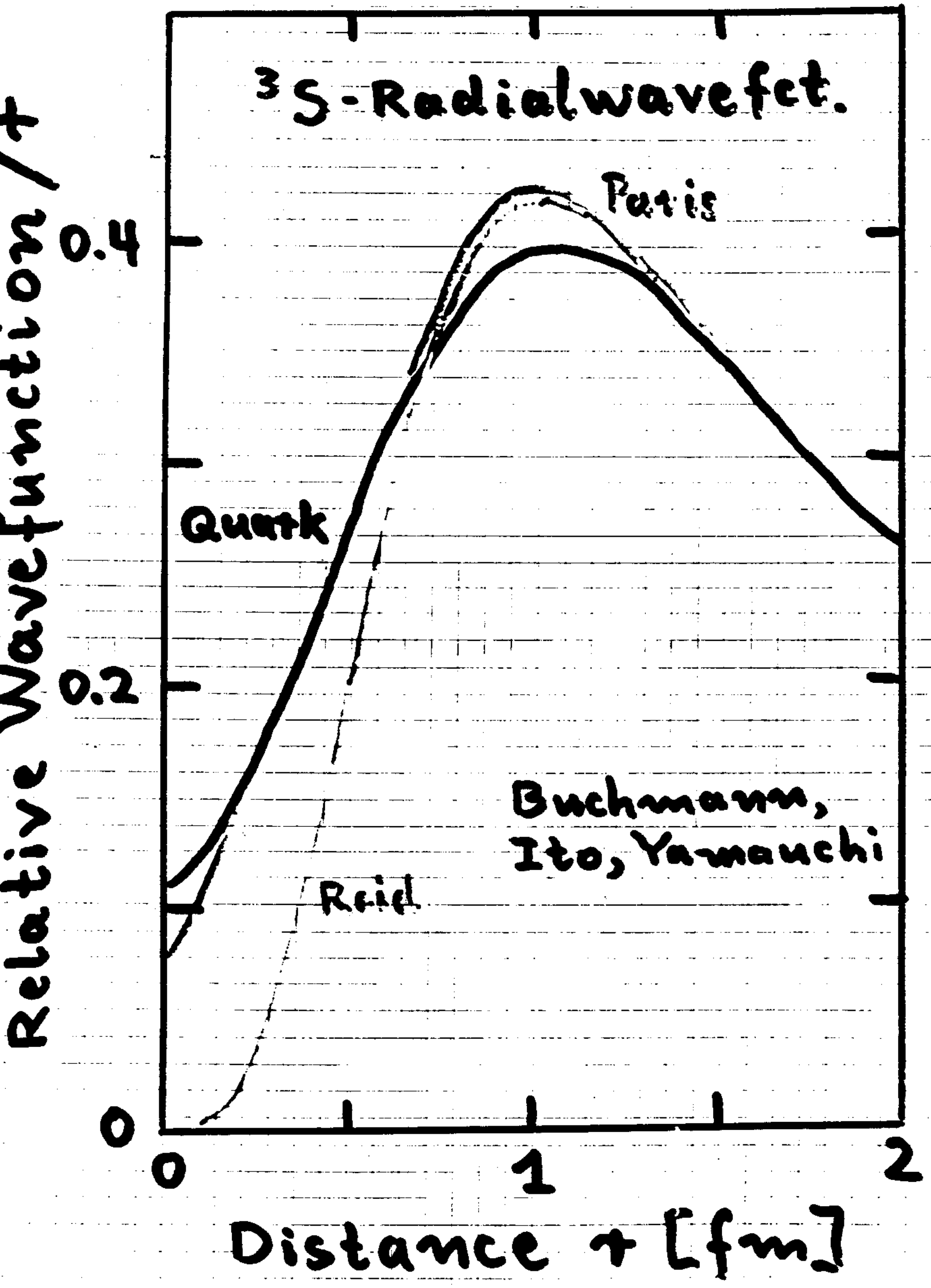


Resonating Group Method

	P_D[%]	$\mu_D[\mu_N]$	Q_D[f
Quark M.	5.23	0.850	0.26
Exp.	—	0.857	0.28

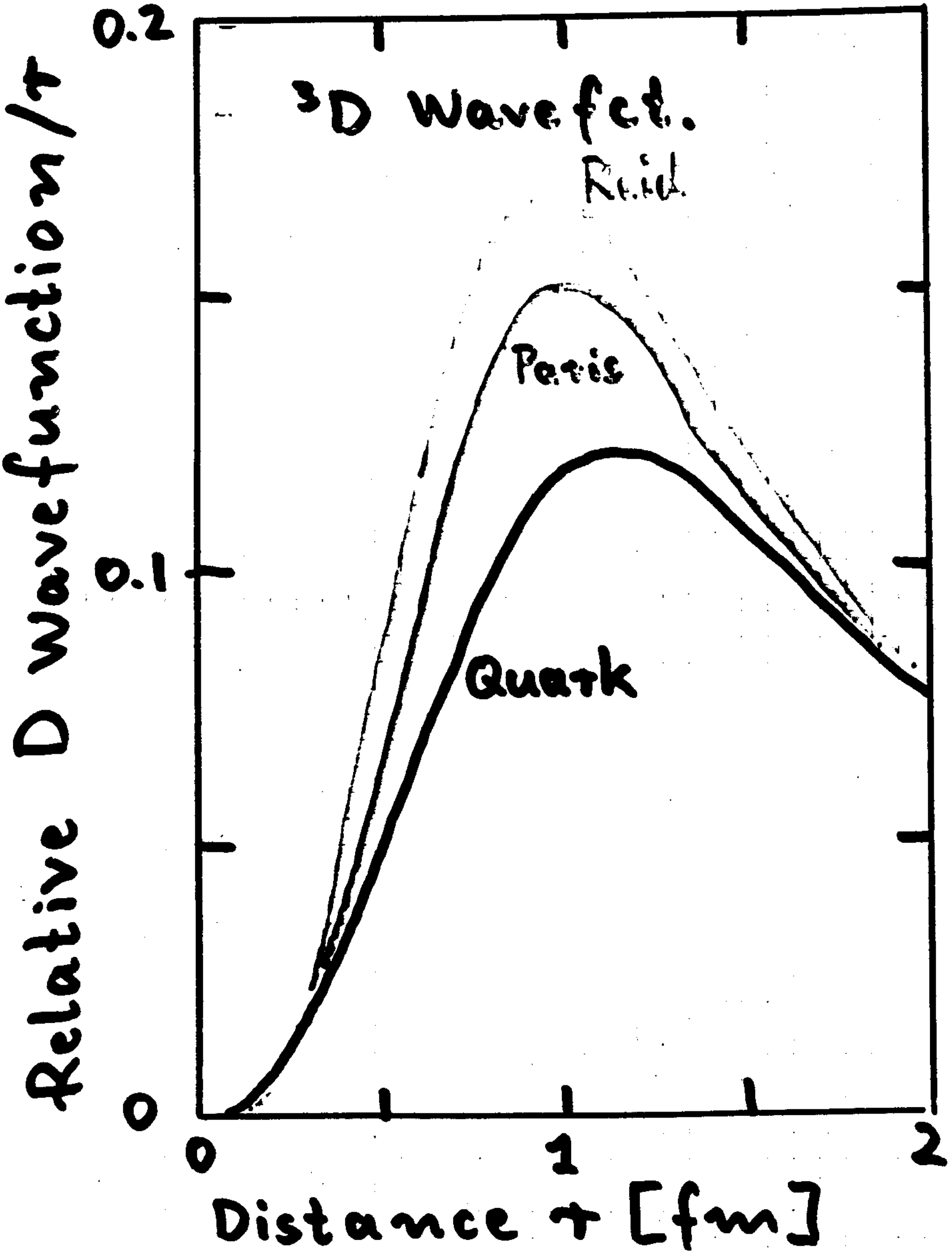
Buchmann, Ito, Yamauchi, Fae
Nucl. Phys. A496 (1989) 621

Deuteron



³S-Radialwavefct.
Paris
Quark
Reid
Buchmann,
Ito, Yamauchi
Relative Wavefunction / r
0.4
0.2
0
0
1
2
Distance r [fm]

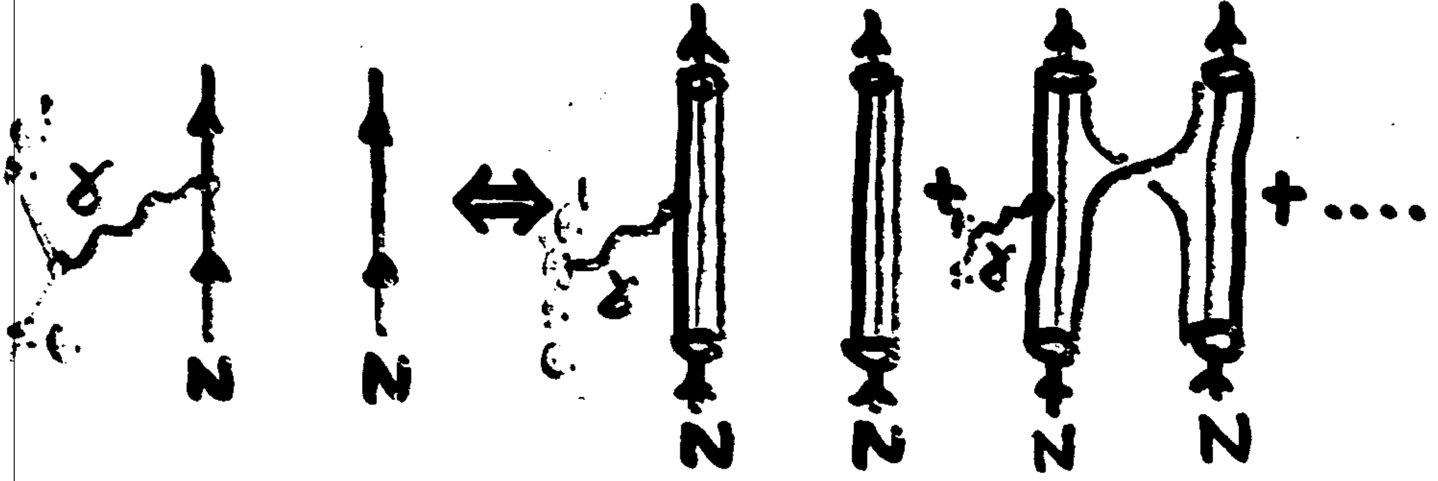
Deuteron


Relative D wavefunction/r
0.2
0.1
0
³D Wavefct.
Reid
Paris
Quark
0
1
2
Distance r [fm]

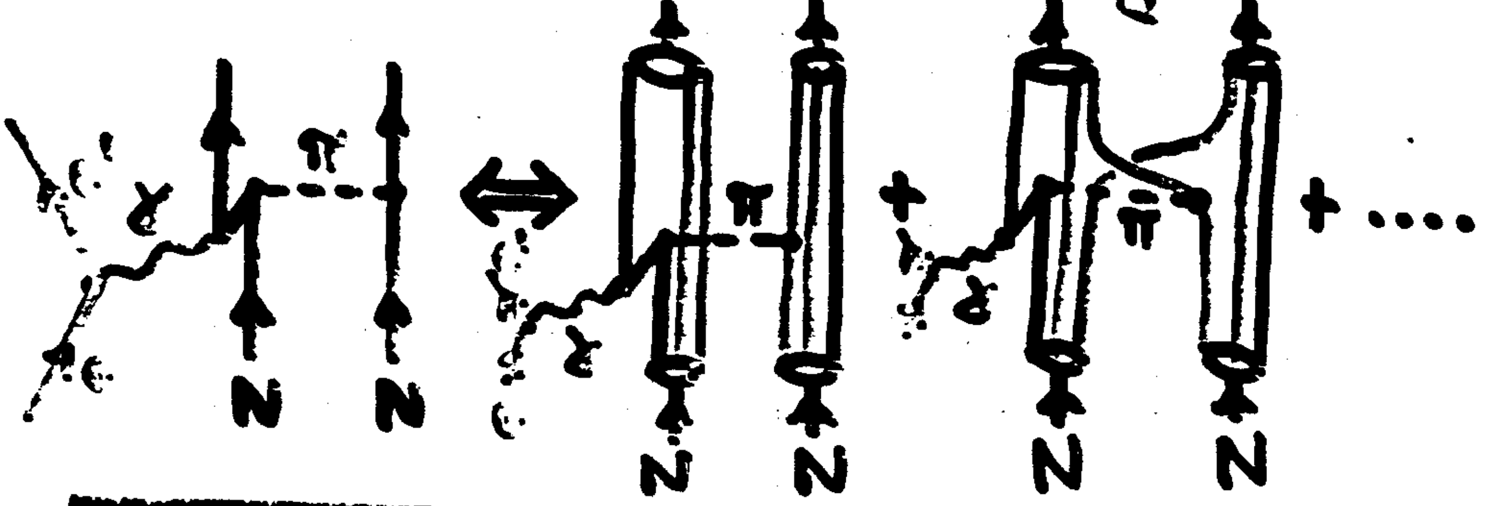
Form Factors:

Electron-Deuteron Scattering

- Impulse Approximation



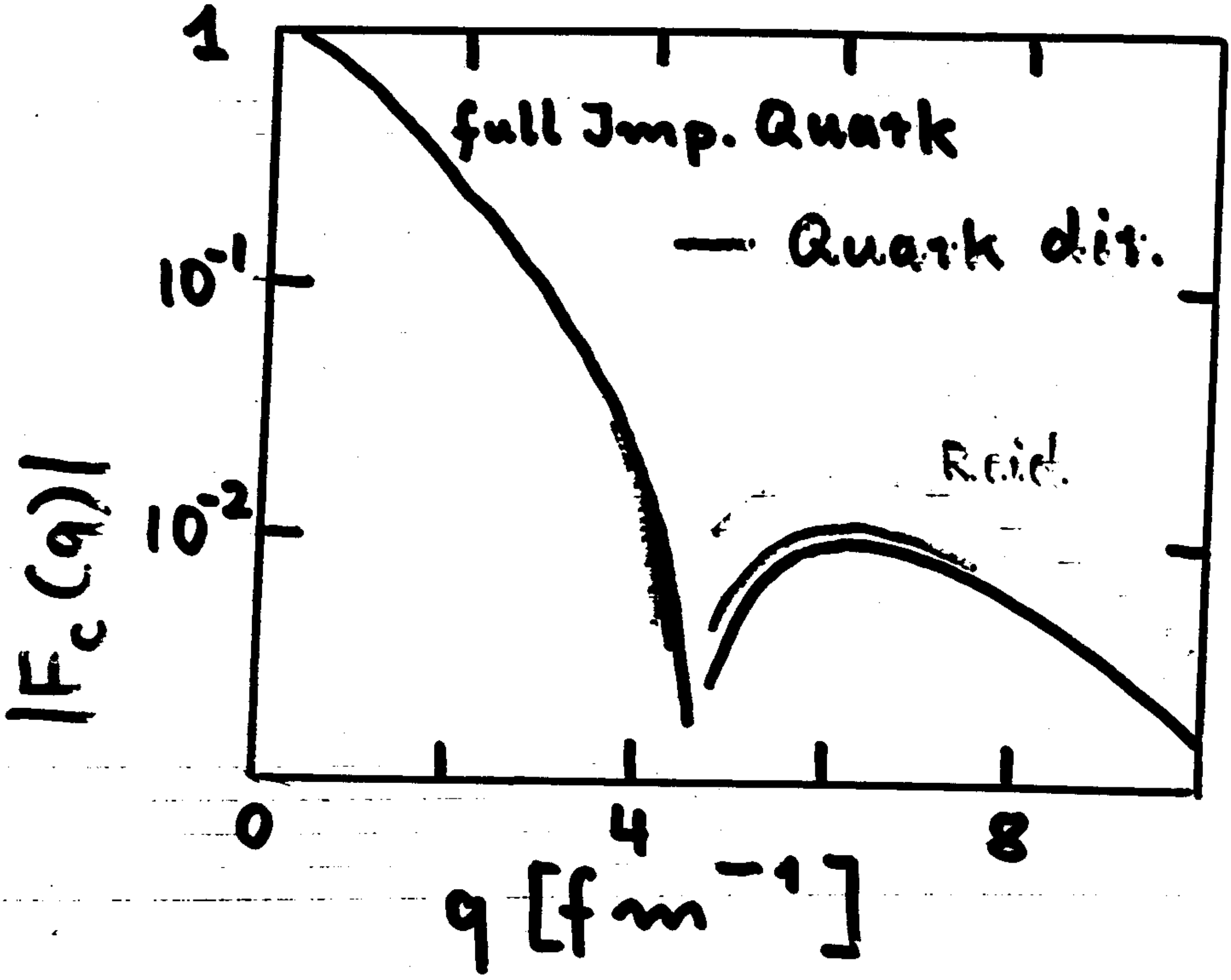
- Plus Meson Exchange Current

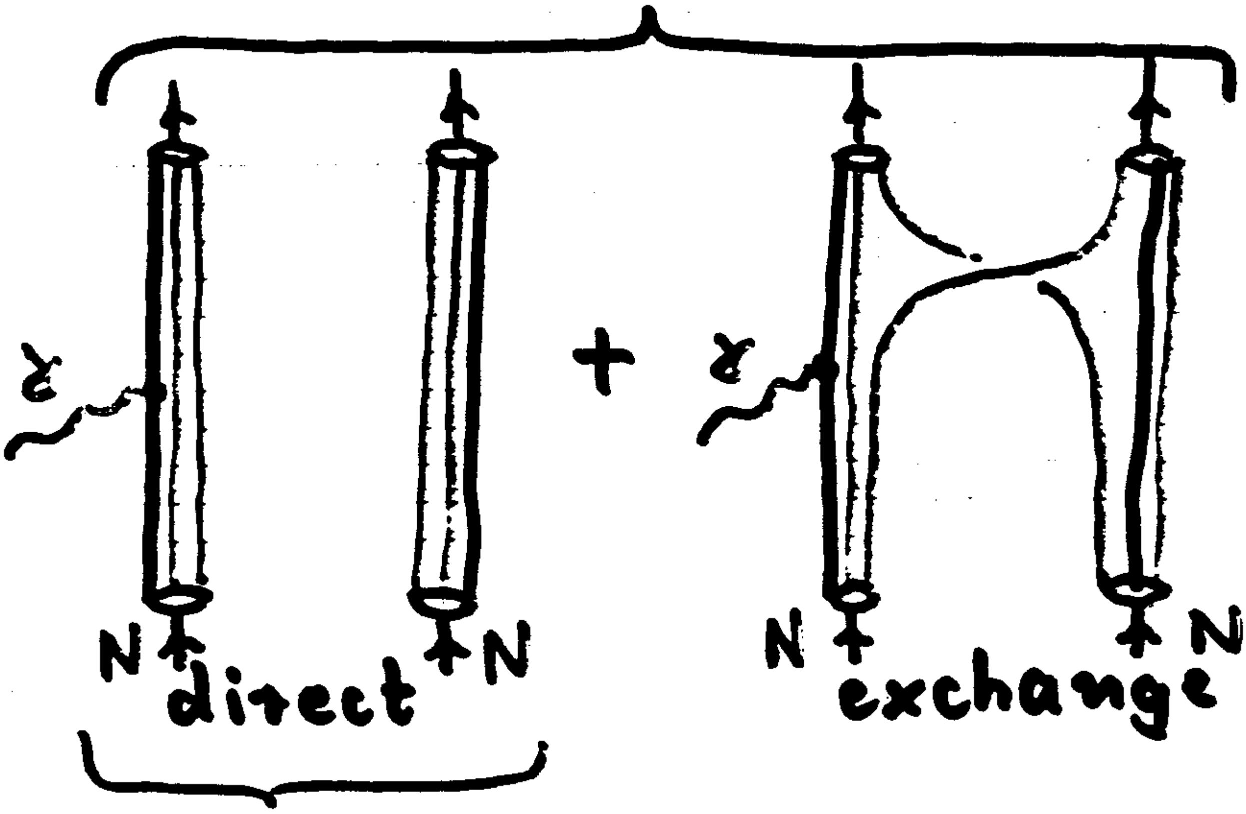


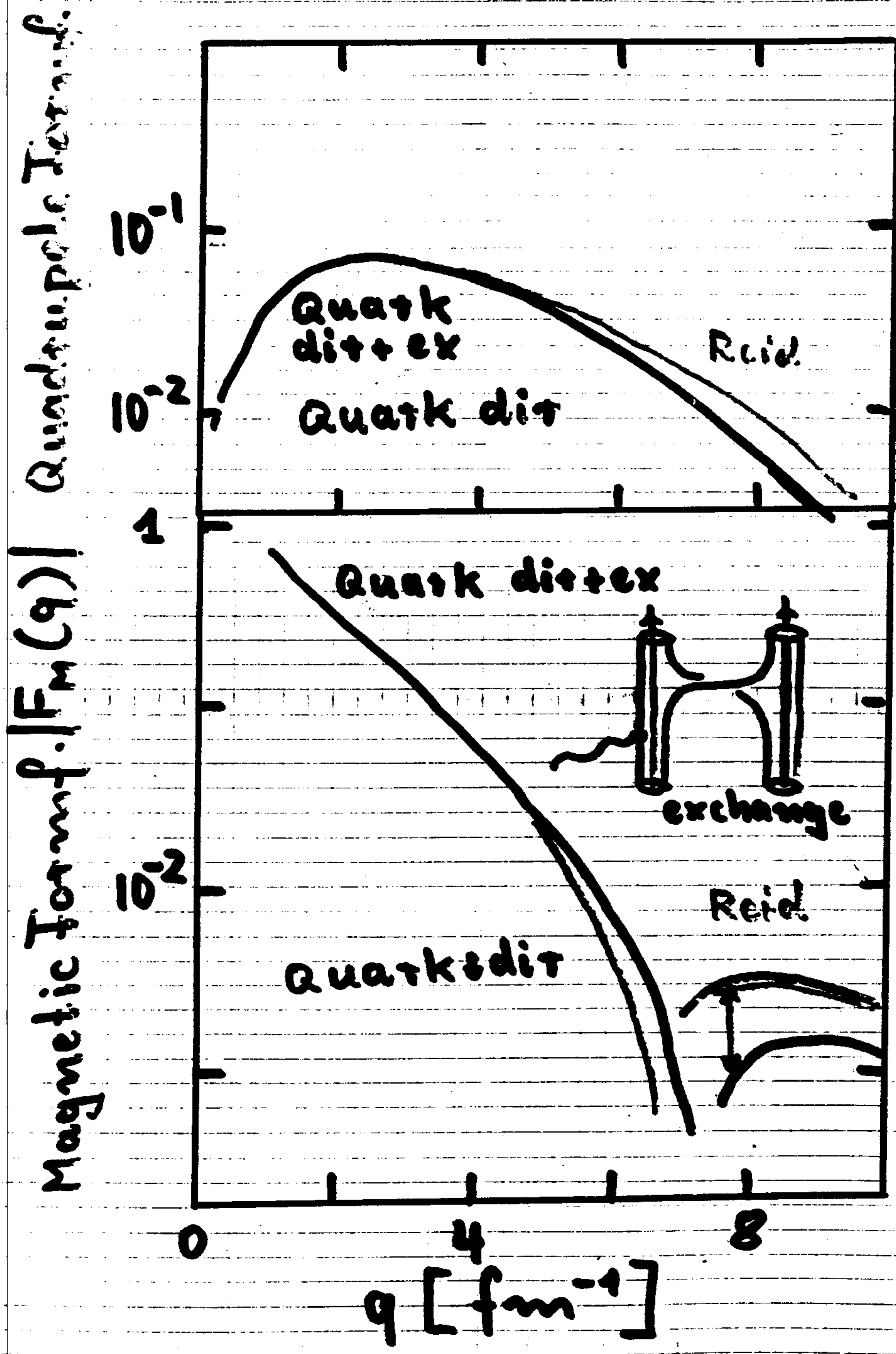
$$\boxed{\frac{d\sigma}{d\Omega_{e.p}} = \frac{d\sigma}{d\Omega_{Mott}}\left[A(q) + B(q)\,tg^2\frac{\vartheta}{2}\right]}$$

$$A(q) = F_c^2(q) + \alpha_1 q^4 F_Q^2(q) + \alpha_2 q^2 F_M^2(q)$$

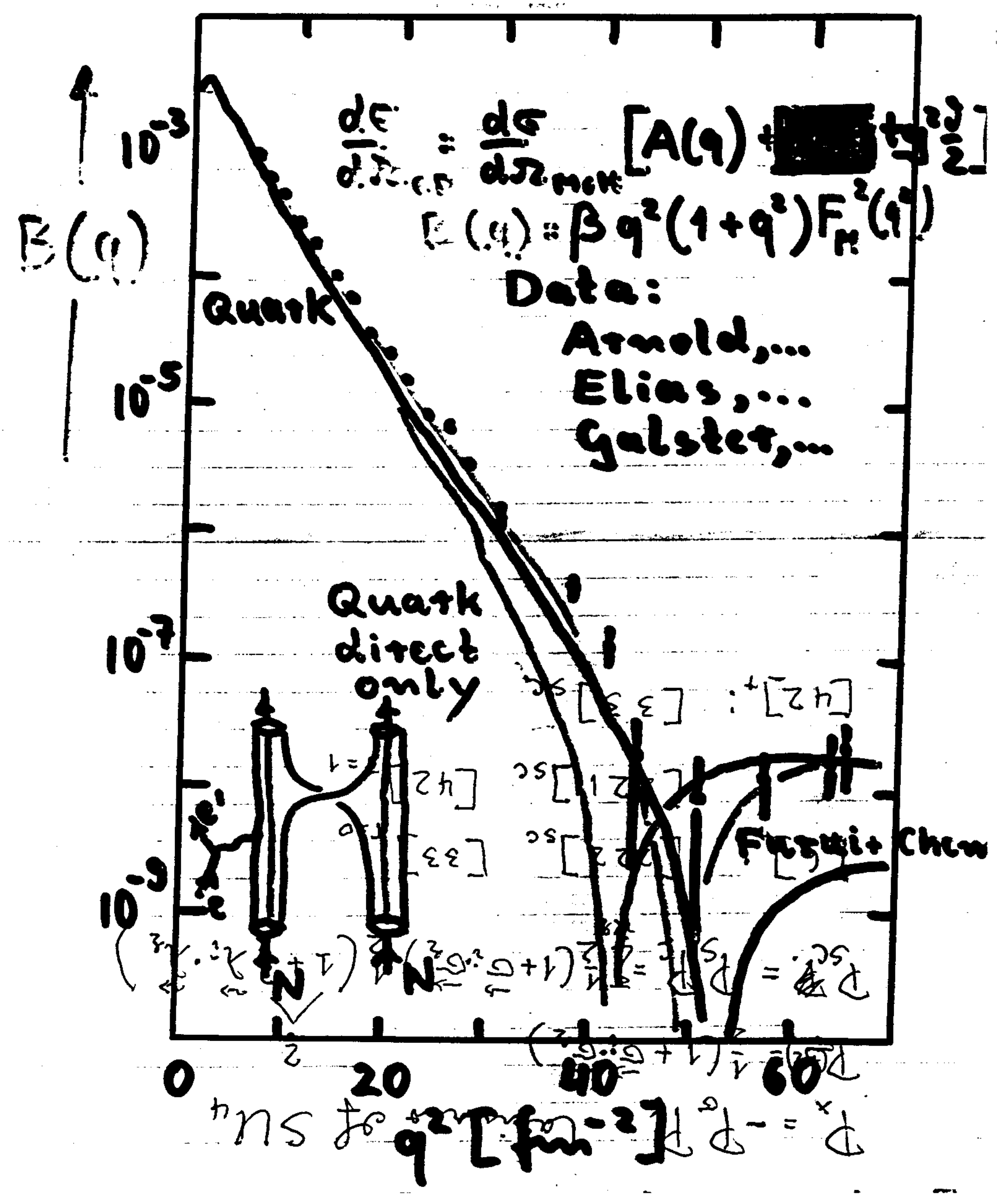
CHARGE MONOPOLE FORMFAC



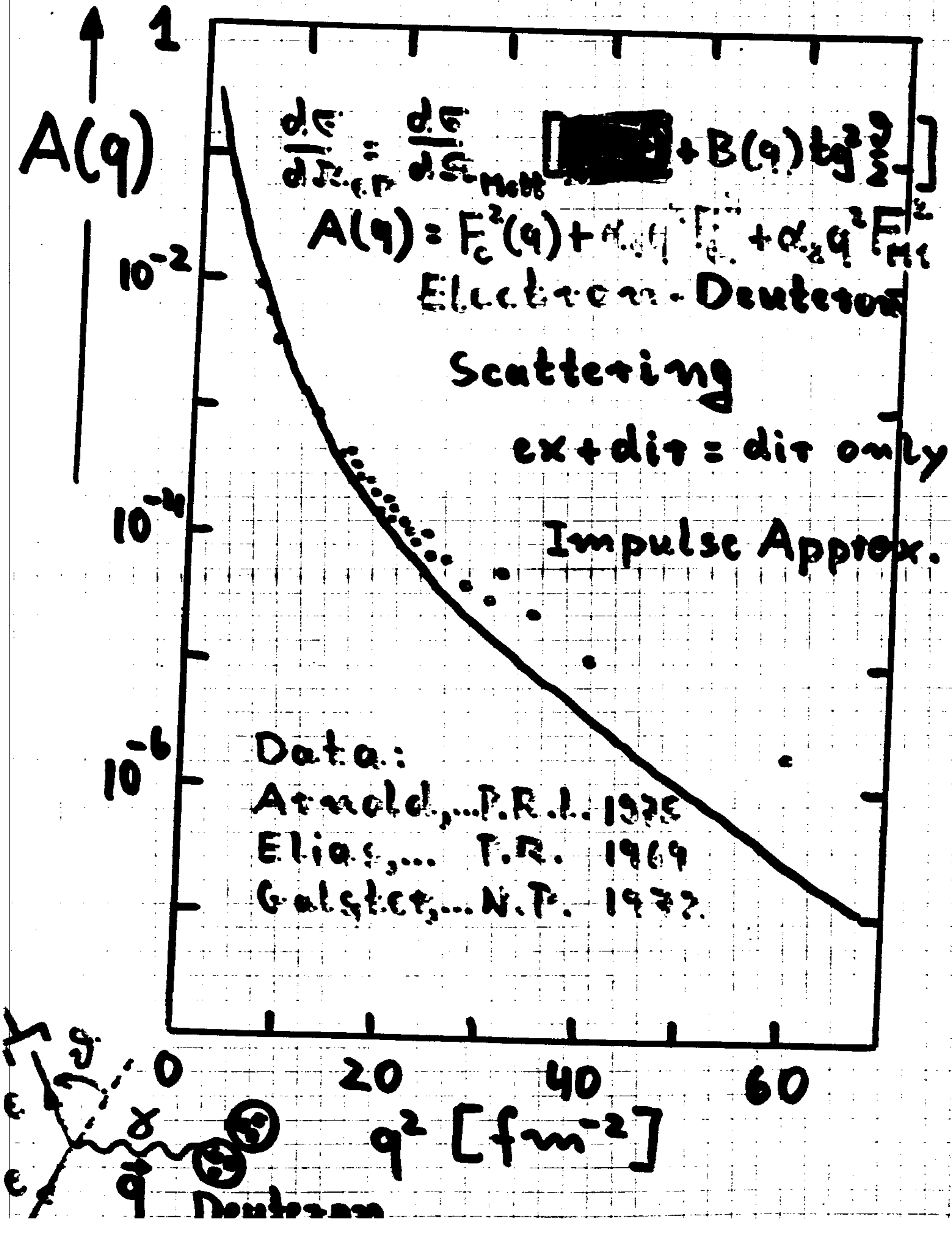



Quadrupole Formf.
Magnetic Formf. |F_M(q)|
10^-1
10^-2
1
10^-2
Quark dit+ex
Reid
Quark dit
Quark dit+ex
exchange
Reid
Quark+dit
0
4
8
q [fm^-1]

Electron-Deuteron Scatterin



Longitudinal Formfactor



$$\frac{d\sigma}{d\Omega_{e.D}} = \frac{d\sigma}{d\Omega_{Mott}}\left[[redacted] + B(q)\, tg^2\frac{\vartheta}{2} \right]$$

$$A(q) = F_c^2(q) + \alpha_1 q^4 F_Q^2 + \alpha_2 q^2 F_{M1}^2$$

Electron - Deuteron Scattering

ex + dir = dir only

Impulse Approx.

Data:

Arnold,... P.R.L. 1975

Elias,... P.R. 1969

Galster,... N.P. 1972.

Tensor-Polarisation: e D

$$T_{2.0}(q^2) = f\left(\frac{F_Q(q^2)}{F_C(q^2)}, \frac{F_M^2(q^2)}{F_C^2(q^2)}; \, tg^2 \frac{\vartheta}{2} \right)$$

Problem: Single Nucleon Formf

Quarkmodel: $e^{-b^2 q^2/6}$

Experiment: $\left[1 + \frac{q^2}{0.71 \mathrm{GeV}^2}\right]^{-2}$

Divide out and multiply

$$T_{20}(\vartheta) = \frac{\left[d\vec{\sigma}/d\Omega\right]_2 - \frac{d\sigma_0}{d\Omega}}{\frac{d\sigma_0}{d\Omega}} \sqrt{2}$$

Impulse Approximation

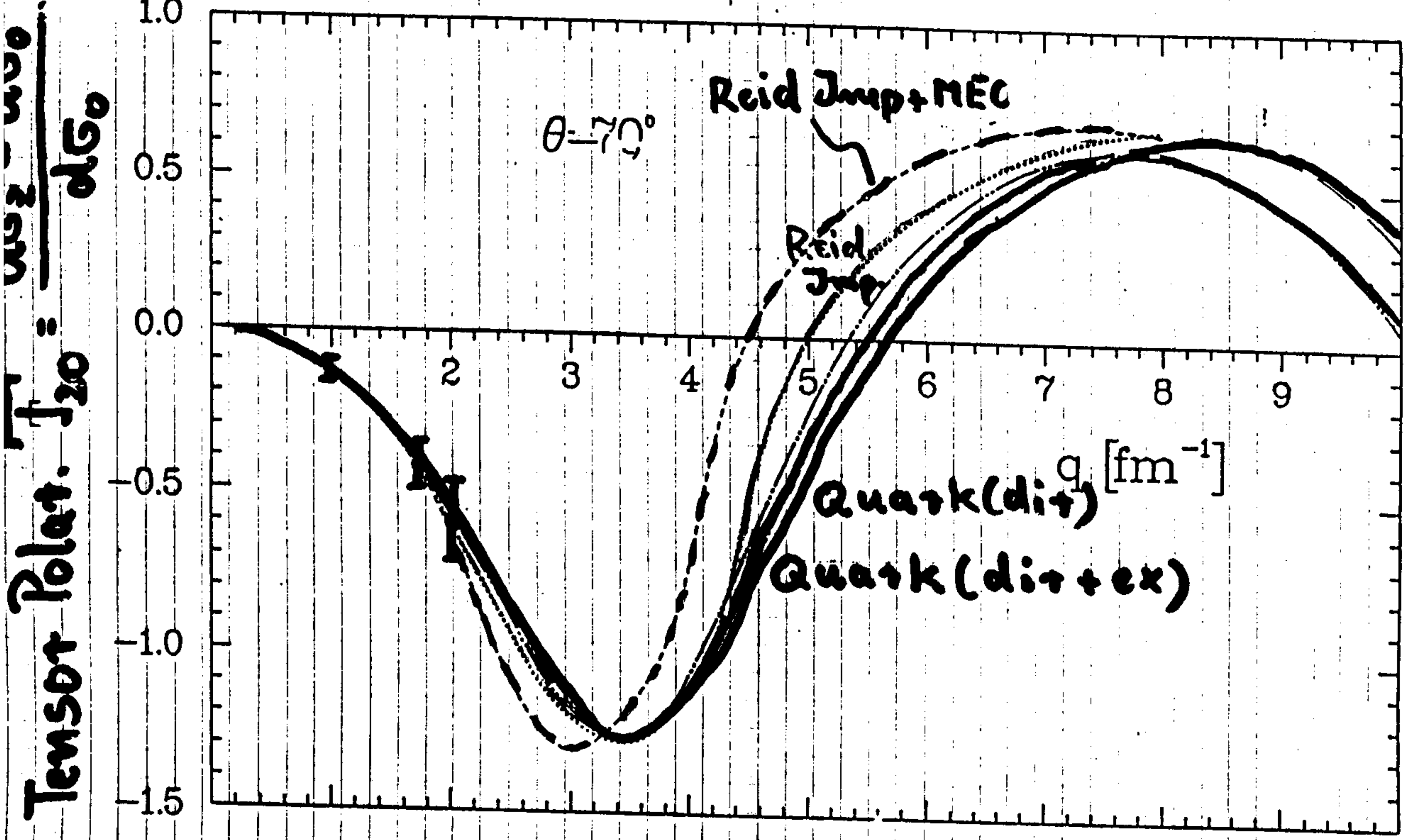


Fig.15

$$\boxed{\frac{d\sigma}{d\Omega}_{e.D} = \frac{d\sigma}{d\Omega}_{Mott}\left[A(q)+B(q)\,tg^2\frac{\vartheta}{2}\right]}$$

$$\begin{cases} A(q) = F_C^2(q) + \alpha_1 q^2 F_Q^2(q) + \alpha_2 q^2 F_M^2(\\ B(q) = \beta q^2(q^2+1)\,F_M^2(q^2) \end{cases}$$

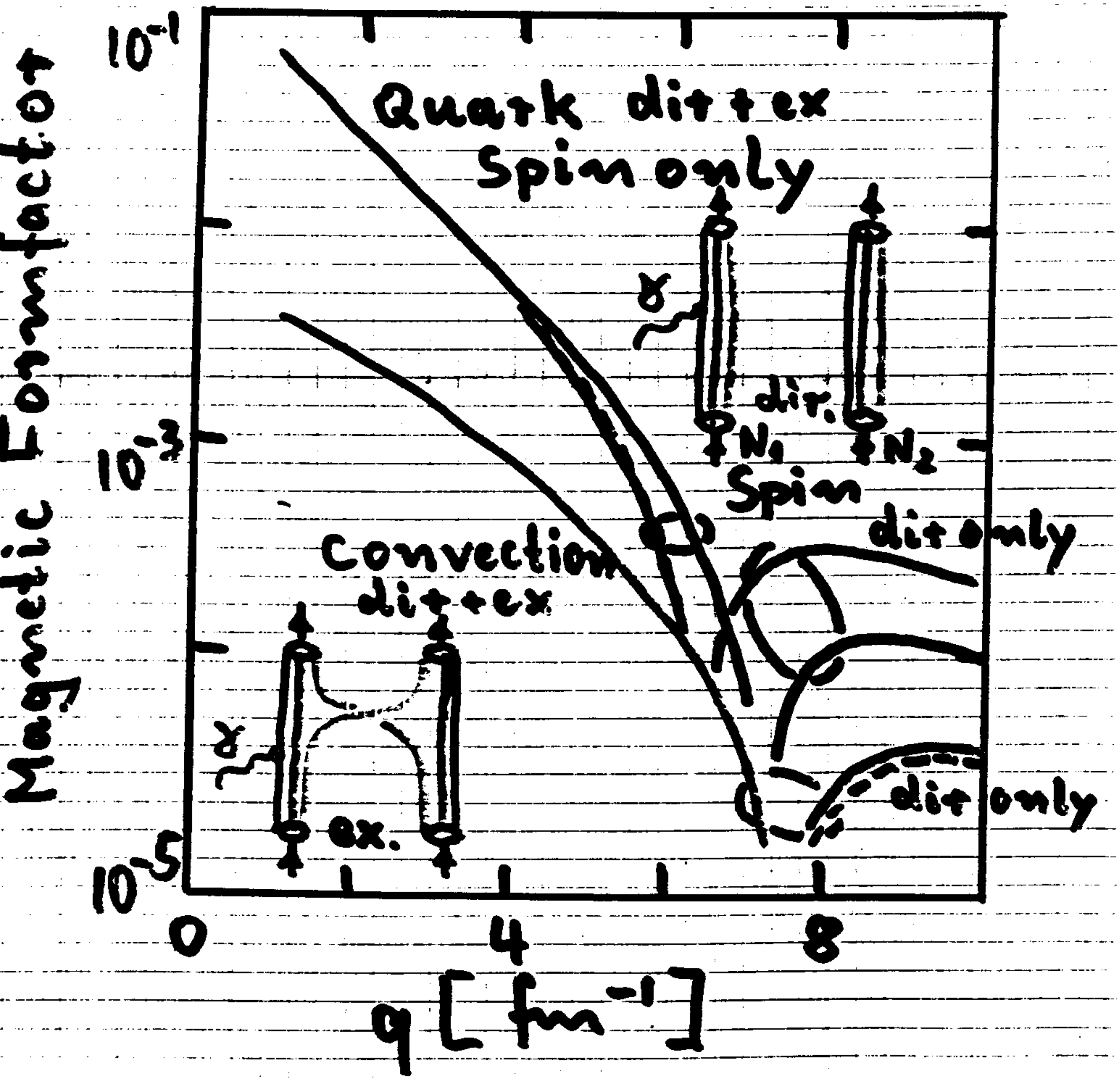
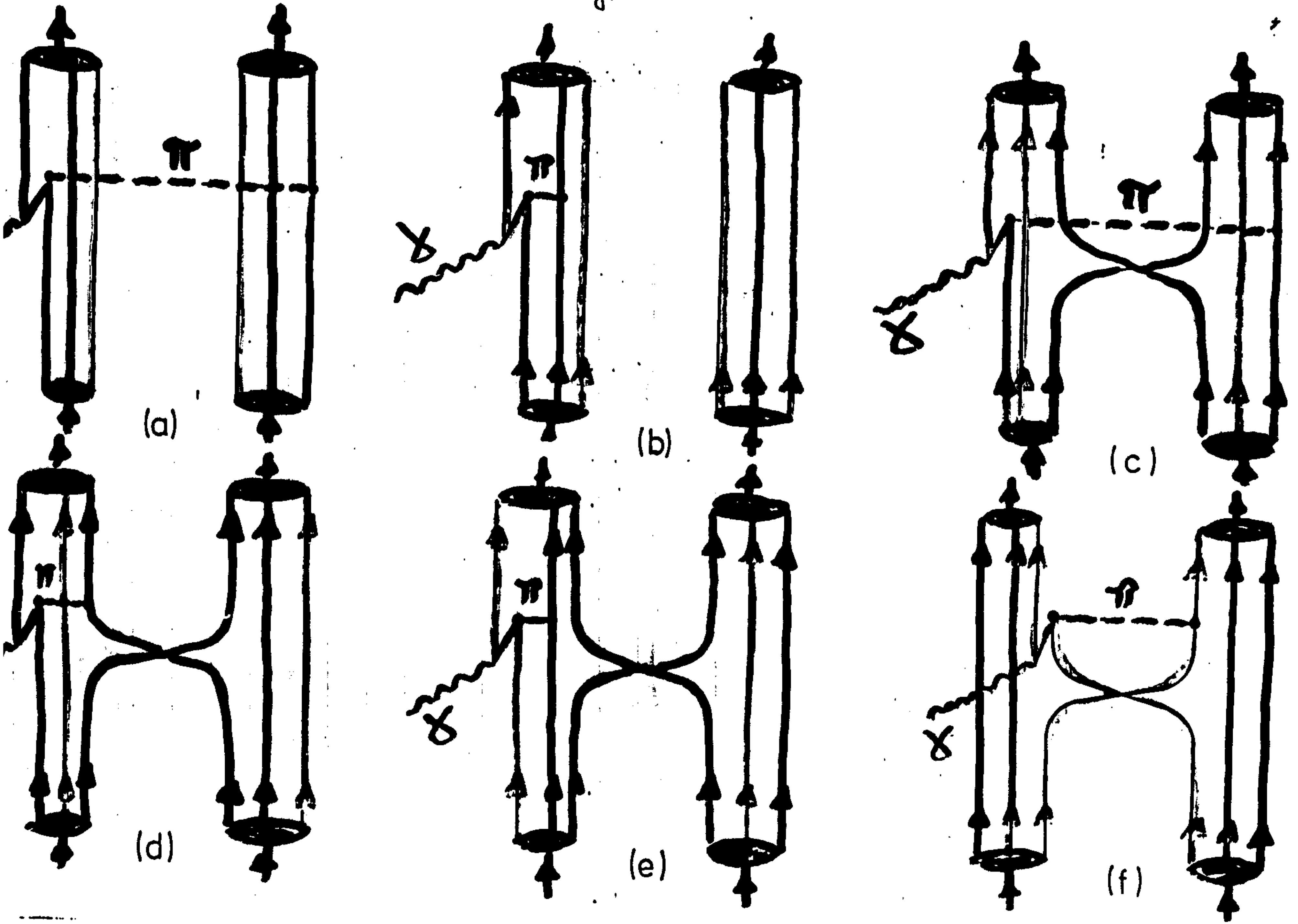
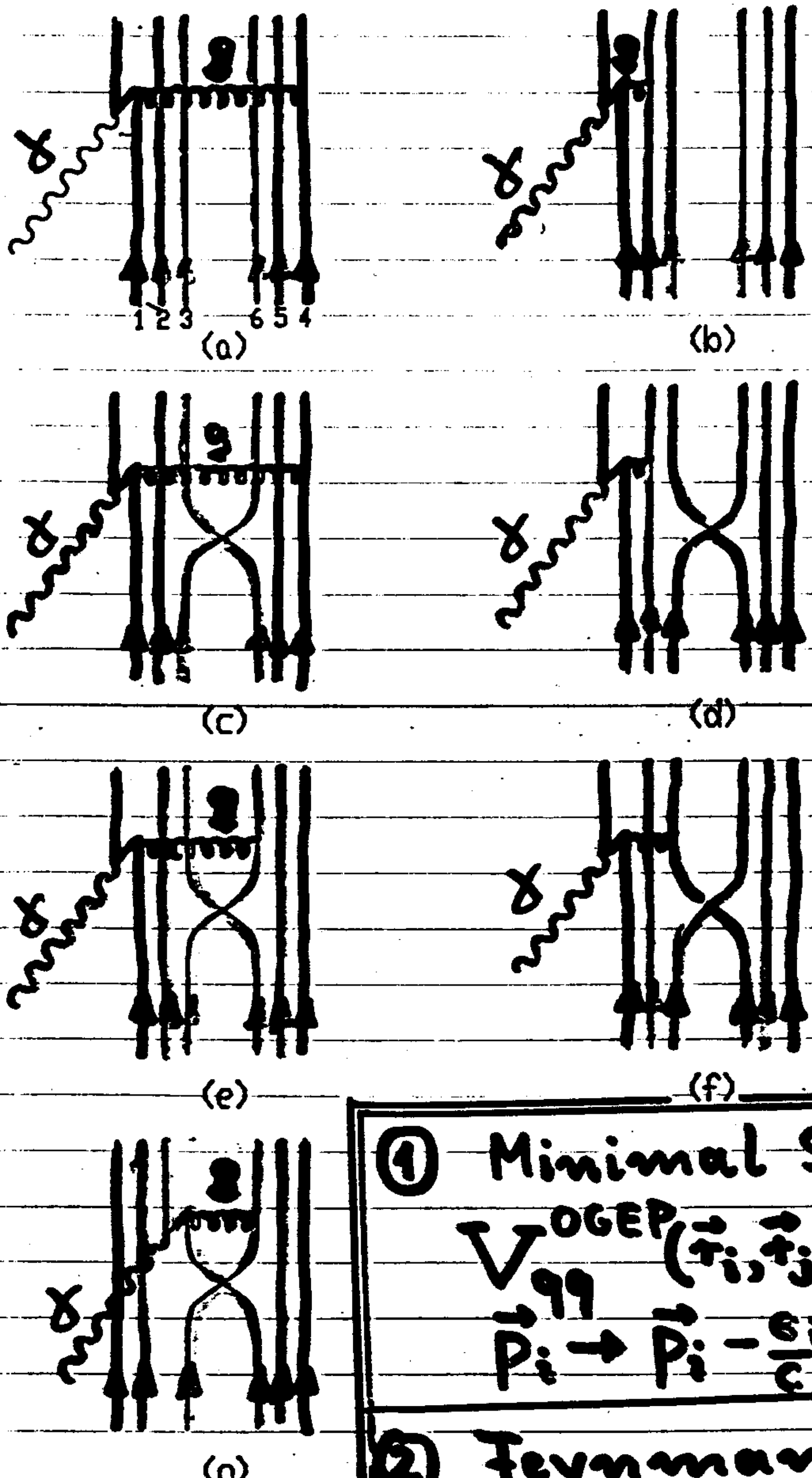


Fig. 1



GLUON Exchange:



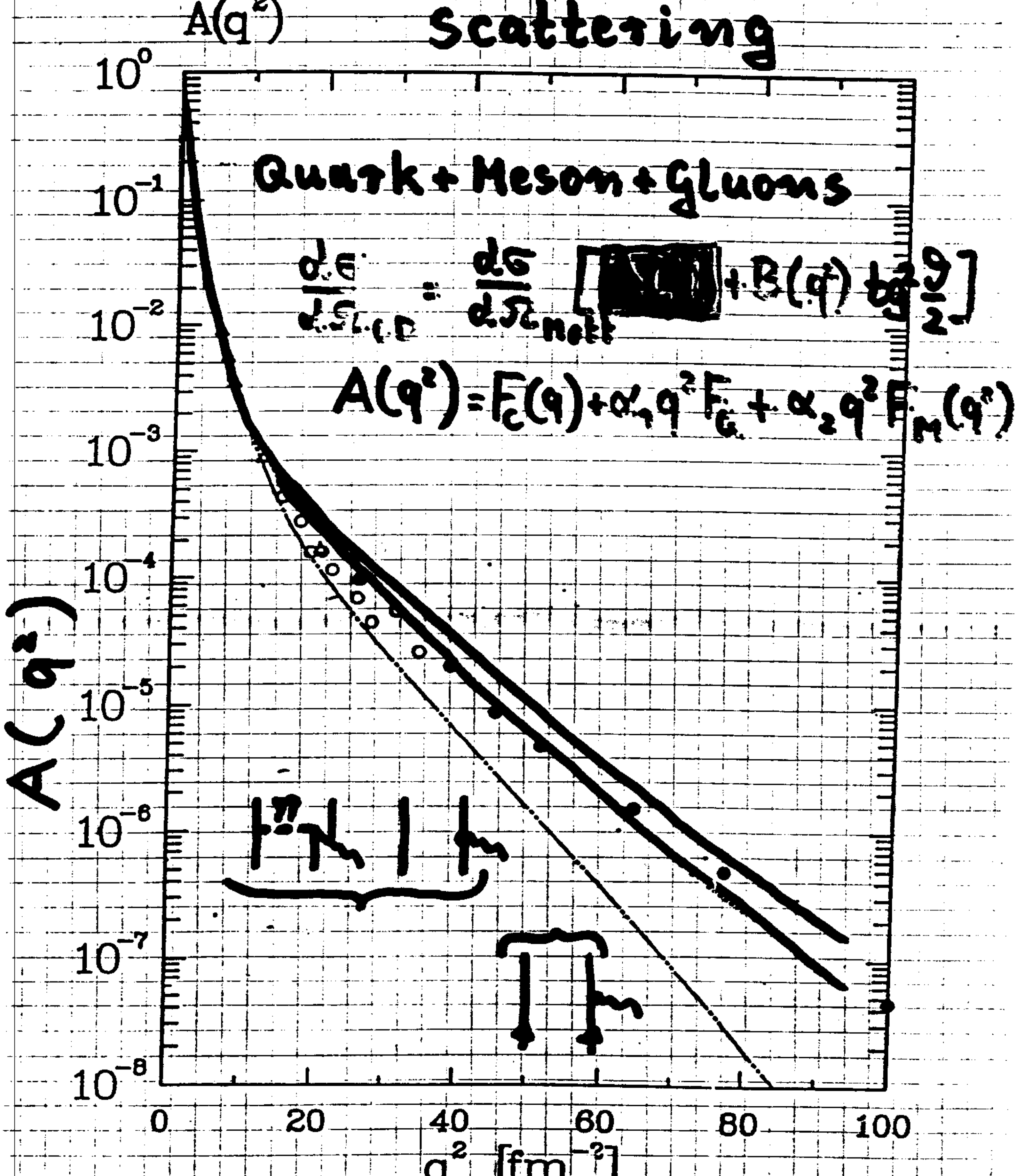
① Minimal Substitut.

$$V_{qq}^{OGEP}(\vec{r}_i, \vec{r}_j; \vec{p}_i, \vec{p}_j)$$

$$\vec{p}_i \rightarrow \vec{p}_i - \frac{e_i}{c}\vec{A}$$

② Feynman rules + non-relativ.

Elastic e-Deuteron Scattering



$$\frac{d\sigma}{d\Omega_{e.D}} = \frac{d\sigma}{d\Omega_{Mott}}\left[[redacted] + B(q^2)\, tg^2\frac{\theta}{2}\right]$$

$$A(q^2) = F_C(q) + \alpha_1 q^2 F_G + \alpha_2 q^2 F_M(q^2)$$

Fig. 13

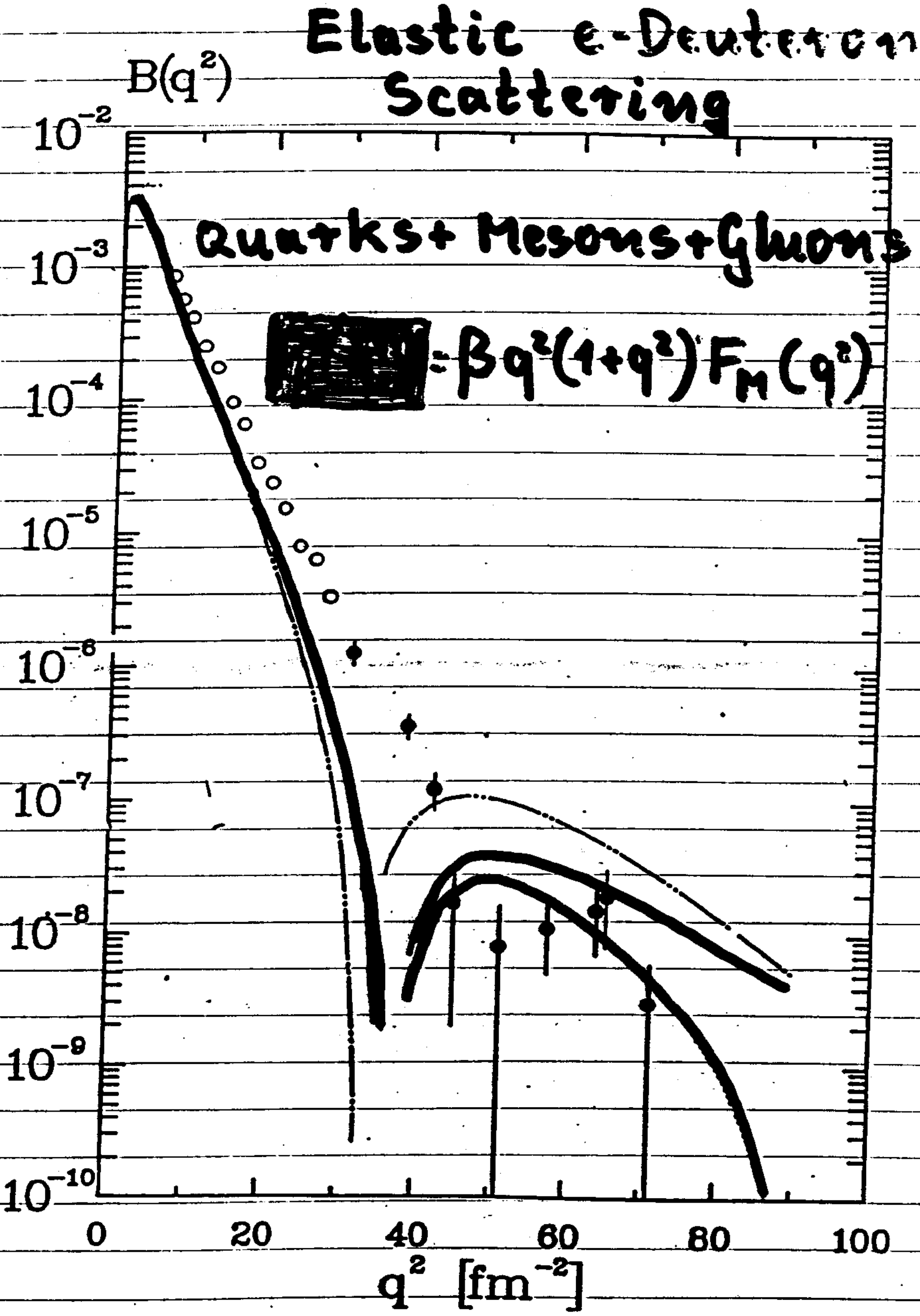
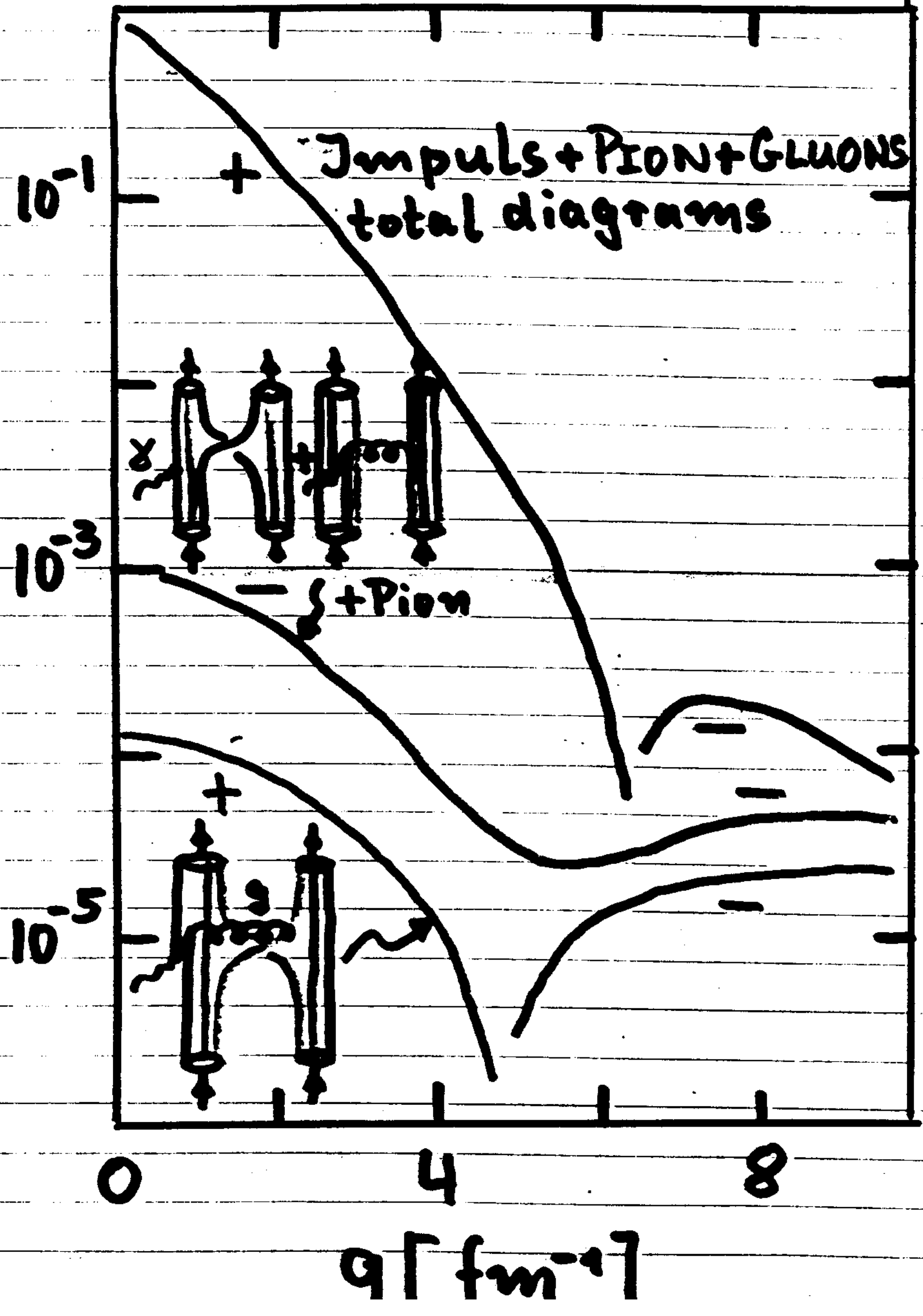
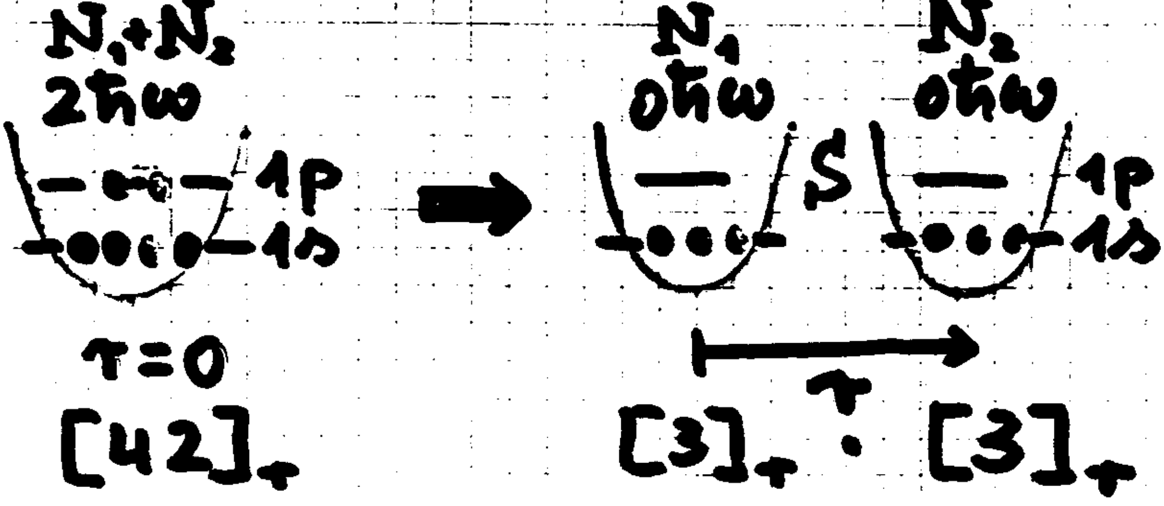

Elastic e-Deuteron Scattering
$B(q^2)$
Quarks+Mesons+Gluons
[redacted] $= \beta q^2 (1+q^2) F_M(q^2)$
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
0
20
40
60
80
100
q^2 [fm^{-2}]

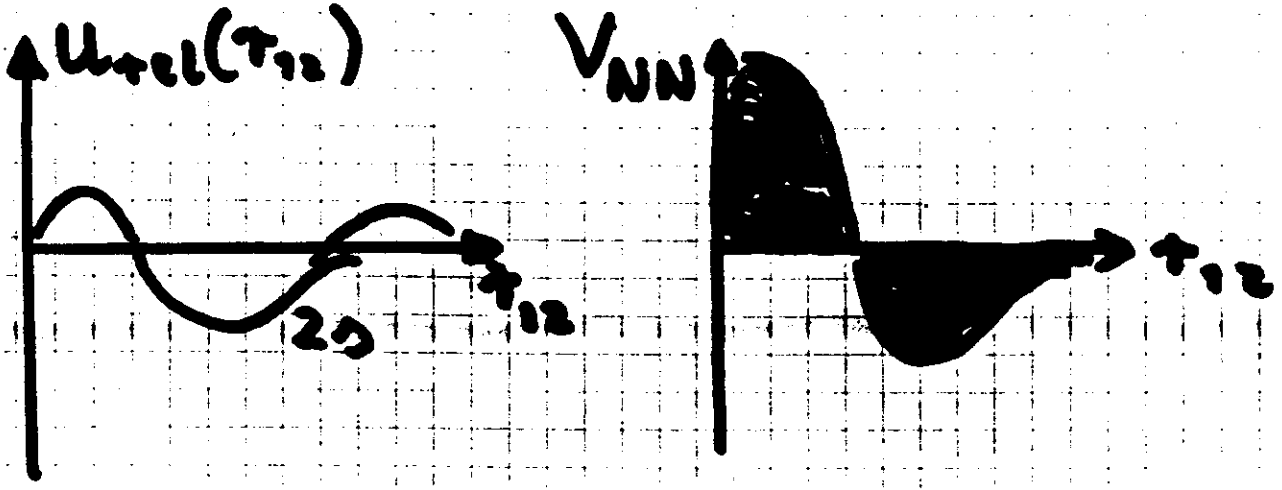
Fig. 14

$|F_M(q)|$ Magnetic Formfactor



SUMMARY:





$m_N ; m_\Delta ; \langle r^2 \rangle^{1/2}_{r.ch.} \; \frac{g^2_{\pi NN}}{4\pi} ; \frac{g^2_\sigma}{4\pi}$

↷ Nucleon-Nucleon

Nucleon-Hyperon

→ Hyperon-Hyperon

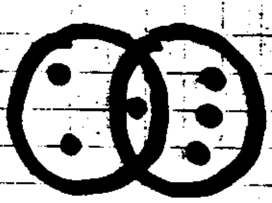
WHAT IS THE NATURE OF SHORT-RANGE REPULSION?

Conclusion: of ②

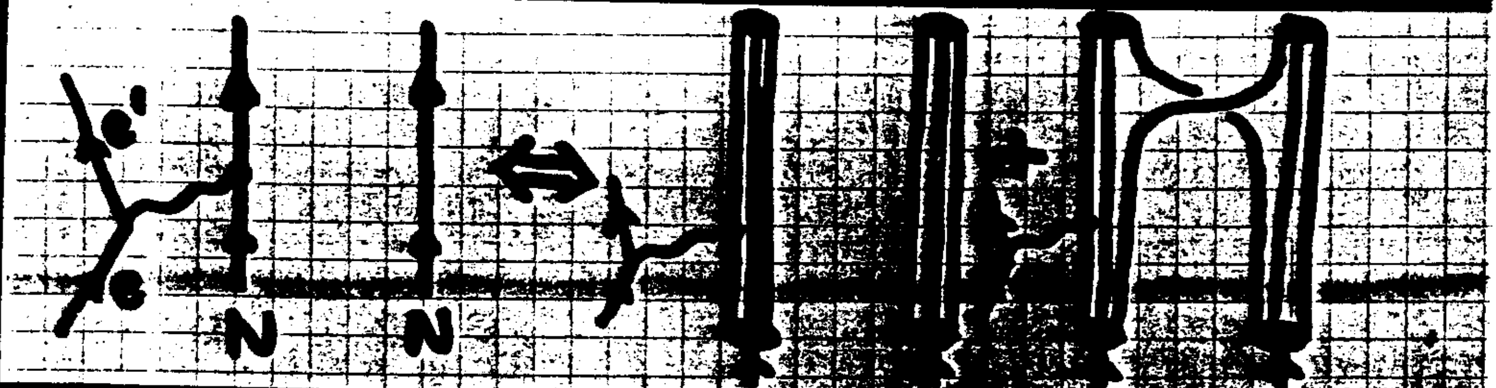
Deuteron Properties

Elastic e^- D Scattering:

NN ⇔



IMPULSE APPROX:



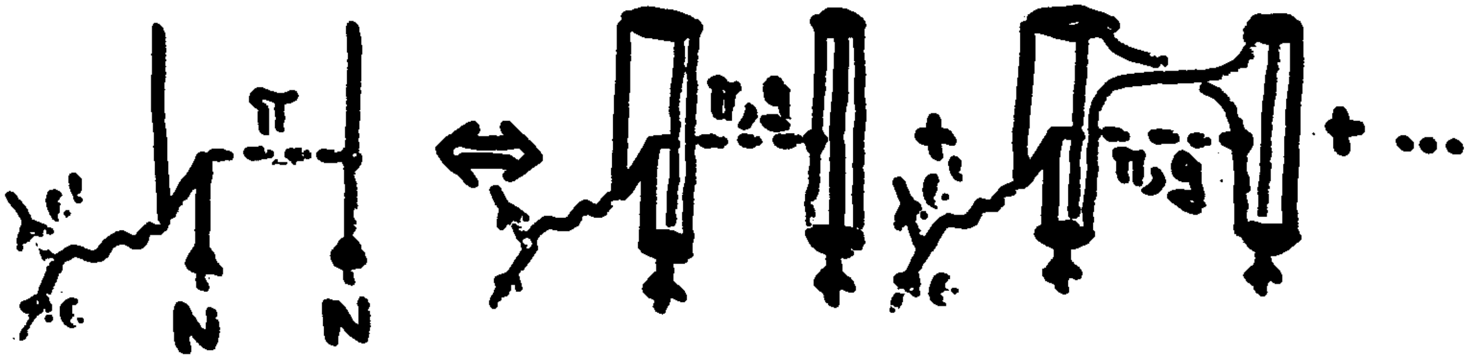
Nucleons ⇔ Quarks

$$F_C(q^2) \approx F_C(q^2)$$

$$F_Q(q^2) \approx F_Q(q^2)$$

$$F_M(q^2) \neq F_M(q^2)$$ in Spin

Meson Exchange Current:



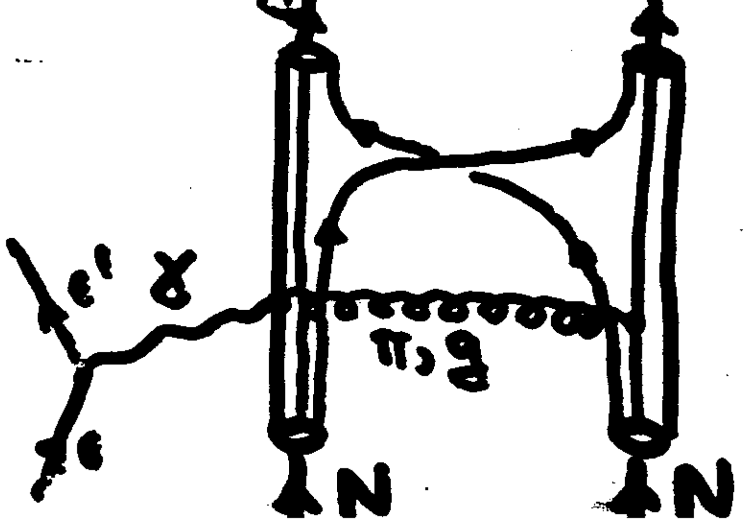
Nucleons ⇔ Quarks

$$\downarrow \quad E_{p+q} = \sqrt{m_q^2 + (\vec{p} + \vec{q})^2} \rightarrow m_q$$

$$E_{p+q} \approx \sqrt{m_q^2 + \vec{q}^2}$$

No large Difference:
ex MEC small.

Magnetic (Transverse) Formfact



Spin part
at high $|\vec{q}|$
large.
+ Pion + Gluon
Exchange