Bad Honnef 2003.5.14

Effects of the Dirac Sea on the Gamow-Teller and the Coulomb Sum Rules in Rel. Models

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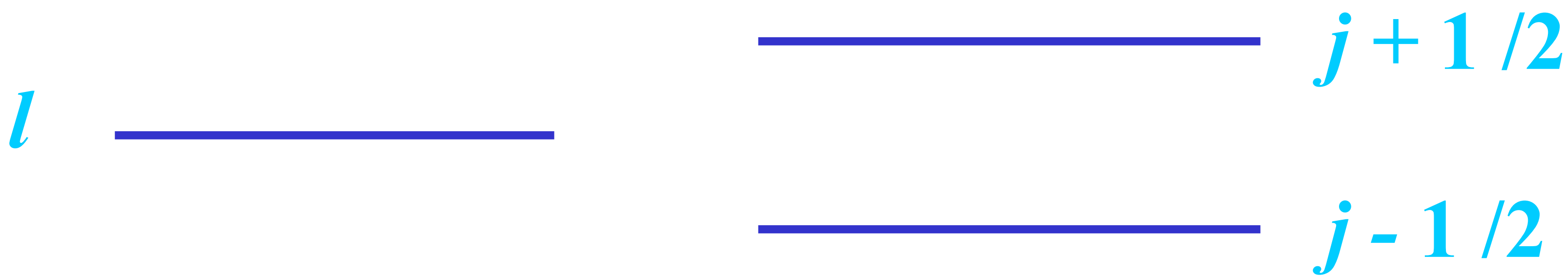
Introduction

The Purpose is

To find nuclear phenomena to show Relativistic Effects

Atom

Relativistic Effect



Bohr

Dirac

2-component (FW)
4-component
any representation

Giant Monopole States

Nishizaki, Kurasawa and Suzuki, Nucl. Phys. **A462** (1987) 687

$$0^+ \quad : \quad \omega_0 = \frac{1}{\epsilon_{\mathrm{F}}} \left\{ \frac{3p_{\mathrm{F}}^2}{\langle r^2 \rangle} \left(\frac{1+F_0}{1+\frac{1}{3}F_1} \right) \right\}^{1/2}$$

$F_0, \quad F_1 \quad :$ **Landau Parameters**

Relativistic Model

Kurasawa and Suzuki, Phys. Lett.**B474** (2000)262

$$F_0 = F_{\mathrm{v}} - \frac{1-v_{\mathrm{F}}^2}{1+a_{\mathrm{s}}F_{\mathrm{s}}} F_{\mathrm{s}} \qquad F_1 = -\frac{v_{\mathrm{F}}^2 F_{\mathrm{v}}}{1+\frac{1}{3}v_{\mathrm{F}}^2 F_{\mathrm{v}}}$$

The denominators come from N$\bar{\mathrm{N}}$-excitations.

H. Kurasawa and T. Suzuki, Phys. Lett. 165B (1985) 234. Bentz, Arima, Hyuga, Shimizu and Yazaki, N. P. A436 (1985) 593. J. F. Dawson and R. J. Furnstahl, Phys. Rev. C42 (1990) 2009. Z. Y. Ma, N. Van Giai, A. Wandelf, D. Vretenar and P. Ring, Nucl. Phys. A686 (2001) 173. J. C. Caillon, P. Gabinski and J. Labarsouque, Nucl. Phys. A696 (2001) 623.

Skyrme Forces

Hernandez etal., N. P. A627 (97) 460

$$f_0 = (1/4)\{3t_0+(1/2)t_3\rho^{\gamma}+\gamma t_3\rho^{\gamma}+(1/4)\gamma(\gamma-1)t_3\rho^{\gamma}\}+\underline{(p_F{}^2/8)\{3t_1+t_2(5+4x_2)\}}$$

$$f_1 = -\underline{(p_F{}^2/8)\{3t_1+t_2(5+4x_2)\}}$$

$$f_0' = -(1/4)\{t_0(1+2x_0)+(1/6)t_3\rho^{\gamma}(1+2x_3)\}-\underline{(p_F{}^2/8)\{t_1(1+2x_1)-t_2(1+2x_2)\}}$$

$$f_1' = \underline{(p_F{}^2/8)\{t_1(1+2x_1)-t_2(1+2x_2)\}}$$

$$g_0 =$$

$$F_0 = N_F f_0$$

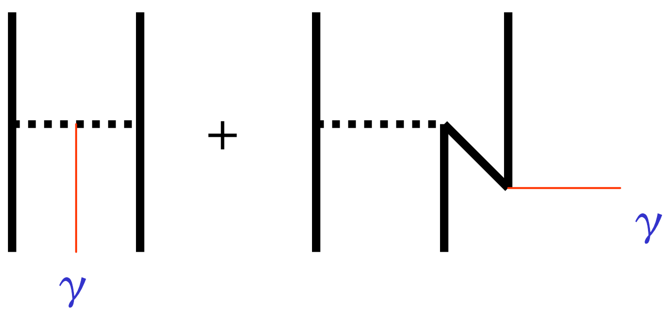
$$g_0' = -(1/4)\{t_0+(1/6)t_3\rho^{\gamma}\}-(p_F{}^2/8)(t_1-t_2)$$

Skyrme Forces SKII, SKIII,・・・・・・・・・・SkM*,・・・・SLy4,・・・SLy7・・・

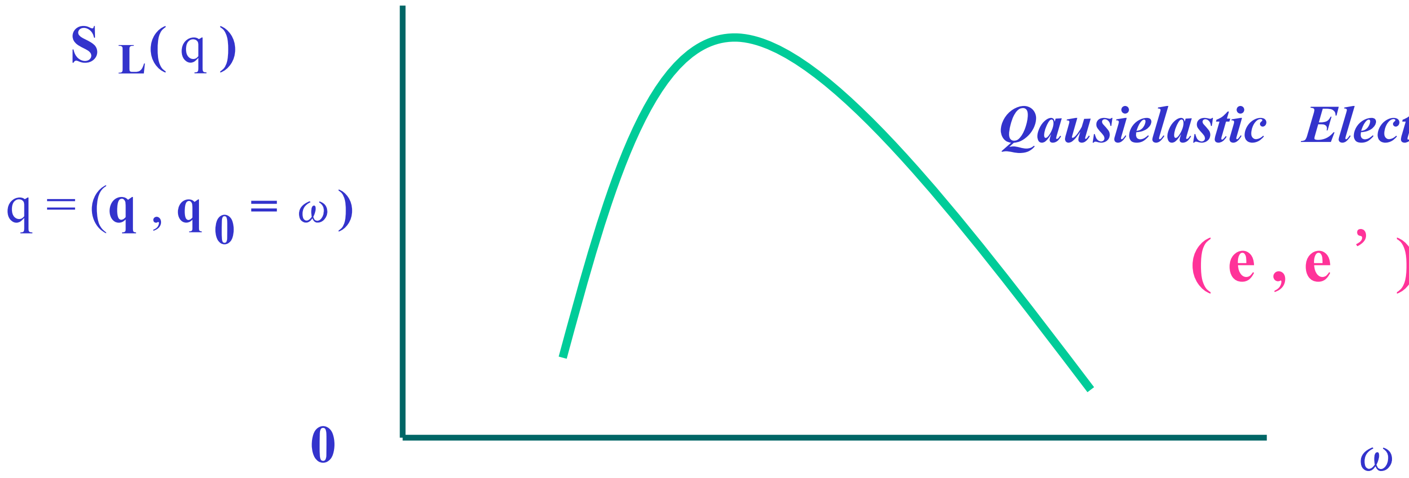
Parameters : t_0 x_0 t_1 x_1 t_2 x_2 t_3 x_3 γ

Role of Antinucleons in Sum Rules

	Classical	Exp	New Deg. of Freedom
γ -abs.	NZ / A	$\sim$ 1.8	π , ρ , $\bar{N}$, Δ
Coulomb sum	Z	$\sim$ 0.7	$\bar{N}$
Gamow-Teller	N - Z	$\sim$ 0.9	Δ , $\bar{N}$



$$\sim \quad [\, V\, ,\ Z\, \tau \,] \quad \sim \quad F'_1$$



Qausielastic Electron Scattering

(e, e')

Coulomb Sum Value

$$\boxed{C(|\boldsymbol{q}|) = \frac{1}{Z}\int_0^{|\boldsymbol{q}|} dq_0 S_{\mathrm{L}}(q)}$$

$$S_{\mathrm{L}}(q) = \sum_n |\langle n|J_0(q)|0\rangle|^2 \delta(E_n - q_0)$$

$$\sim \mathrm{Im}\Pi(J_0, J_0)$$

The longitudinal response function :

$$S_L(q) = \sum_n |< n \mid J_0(q) \mid 0 >|^2 \, \delta(E_n - \omega),$$

$q = q_\mu = (\omega, q), \quad E_n$: Exc. Energy of $\mid n >$

The time component of the nuclear current in nonrelativistic model,

$$\boxed{J_0(q) = \sum_{k=1}^{Z} \exp\{iq \cdot r_k\} G_{E_p}(q),}$$

Z : the proton number

$G_{E_p}(q)$: Sachs form factor of the proton

Since the nucleon form factor is factorized in the nonrelativistic current, one defines

$$R_L(q) = S_L(q)/G^2_{E_p}(q)$$

which depends on the nuclear structure only.

Then, the closure property gives

$$\frac{1}{Z}\int d\omega R_L(q) = \frac{1}{Z}\langle 0|\sum_{k,l}^{Z}\{i\boldsymbol{q}\cdot(\boldsymbol{r}_k - \boldsymbol{r}_l)\}|0\rangle.$$

This provides the **Coulomb sum rule:**

$$\boxed{\frac{1}{Z}\int d\omega R_L(q) \quad \to \quad 1 \qquad (\ |\boldsymbol{q}| \ \to \ \infty\ )}$$

Experimental Results

Saclay   300 MeV $< |\boldsymbol{q}| <$600 MeV ^{3}He to ^{208}Pb

P. Barreau et al., Nucl. Phys. **A402** (1983) 515

Z. E. Meziani et al., Phys. Rev. Lett. **52** (1984) 2130

Z. E. Meziani et al., Phys. Rev. Lett. **54** (1985) 1233

A. Zghiche et l., Nucl. Phys., **A572** (1994) 513

Bates   300 MeV$< |\boldsymbol{q}| <$600 MeV ^{3}He to ^{238}U

M. Deady et al., Phys. Rev. **C33** (1986) 1897

C. Blatchley et al., Phys. Rev. **C34** (1986) 1243

T. C. Yates et al., Phys. Lett. **B312** (1993) 382

C. F. Williamson et al., Phys. Rev. **C56** (1997) 3152

SLAC $|\boldsymbol{q}| \approx 1\mathrm{GeV}$ $^{3,4}\mathrm{He}$, $^{56}\mathrm{Fe}$

D. T. Baran et al., Phys. Rev. Lett. **61** (1988) 400

J. P. Chen et al., Phys. Rev. Lett. **66** (1991) 1283

Z. E. Meziani et al., Phys. Rev. Lett. **69** (1992) 41

World Data

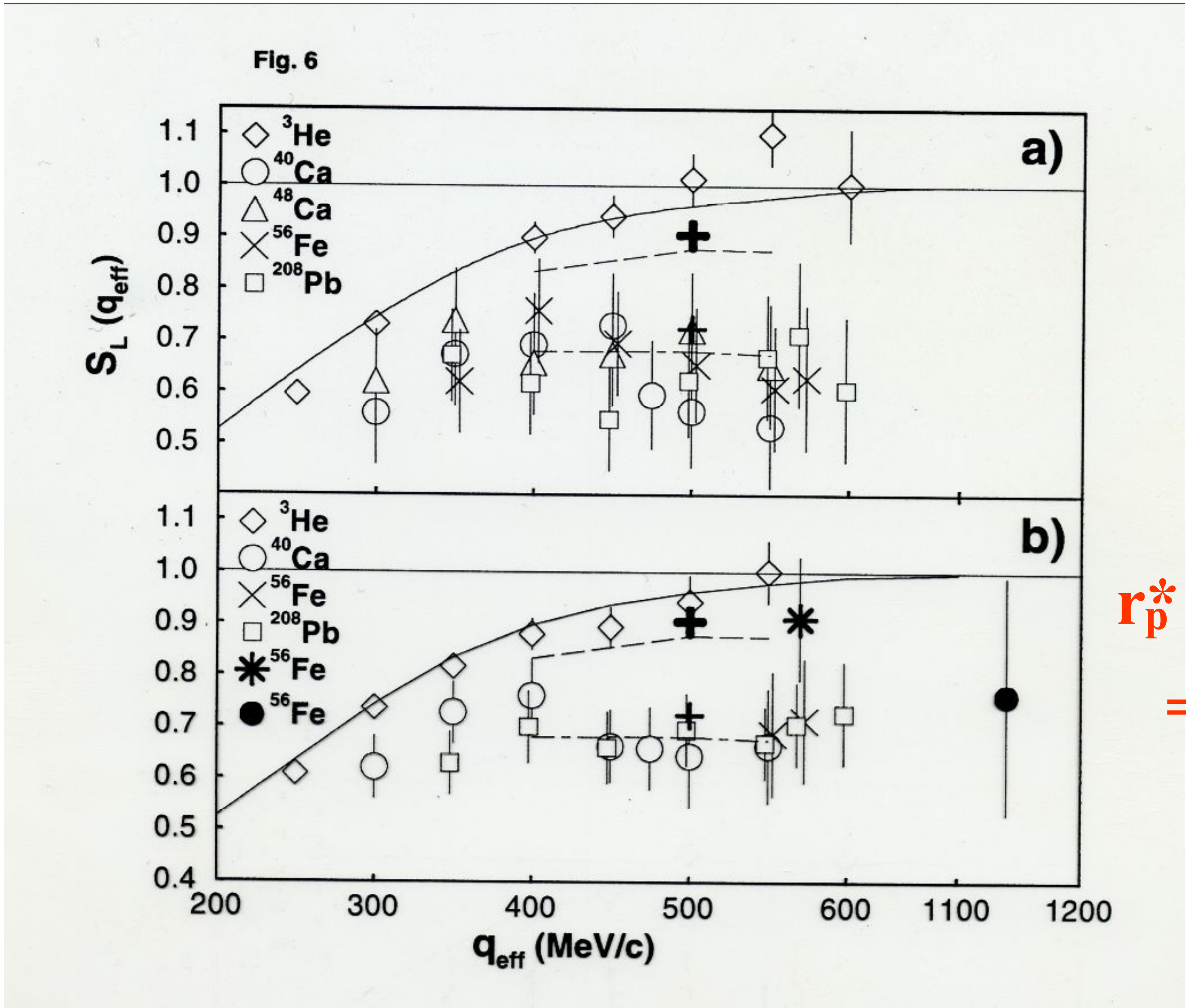
J. Jourdan, Phys. Lett. **B33** (1995) 189

J. Jourdan, Nucl. Phys. **A603** (1996) 117

J. Morgenstern et al., Phys. Lett. **B515** (2001) 269

The Coulomb Sum Values are quenched by $\sim$ 30% in medium heavy and heavy nuclei.

Morgenstern and Meziani, Phys. Lett. B515 (2001) 269



r_p^* / r_p

$= 1 .13\underline{+}0.04$

Fabrocini and Fantoni, N.P. A503 (1989) 375

+ Traini et al., Phys. Rev. C48 (1993) 172

Relativistic Nuclear Current

$$J_\mu(q) \;=\; \underline{F_1(q^2)} \int d^3x \exp(i\boldsymbol{q}\cdot\boldsymbol{x})\bar{\psi}(\boldsymbol{x})\gamma_\mu\psi(\boldsymbol{x})$$

Dirac Current

$$+\underline{F_2(q^2)} \int d^3x \exp(i\boldsymbol{q}\cdot\boldsymbol{x})\bar{\psi}(\boldsymbol{x})\frac{\kappa}{2M} i\sigma_{\mu\nu}q^\nu\psi(\boldsymbol{x})$$

Pauli Current

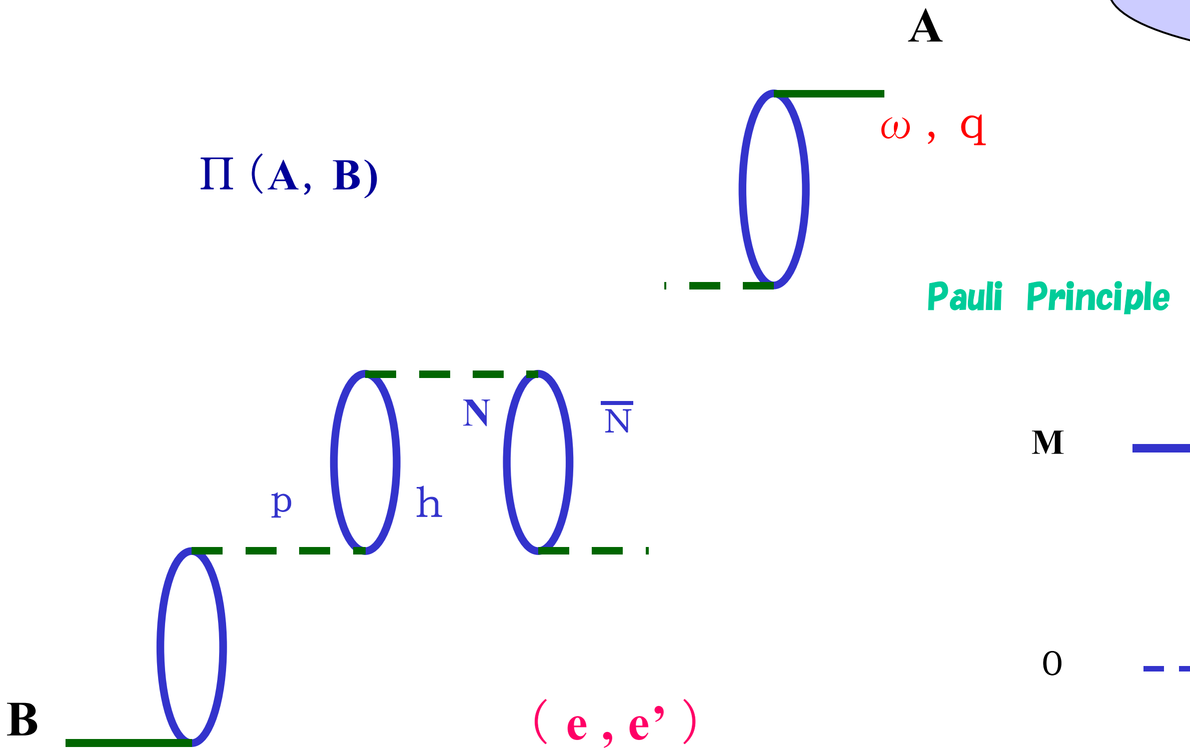
Coulomb Sum Value

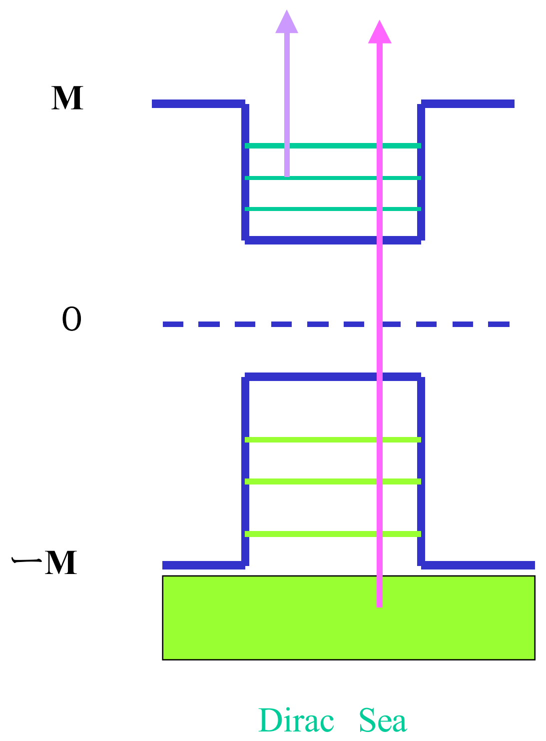
$$C(|\boldsymbol{q}|) = \frac{1}{Z}\int_0^{|\boldsymbol{q}|} dq_0 S_{\mathrm{L}}(q)$$

$$S_{\mathrm{L}}(q) = \sum_n |\langle n|J_0(q)|0\rangle|^2\delta(E_n - q_0) \quad \sim \mathrm{Im}\Pi(J_0, J_0)$$

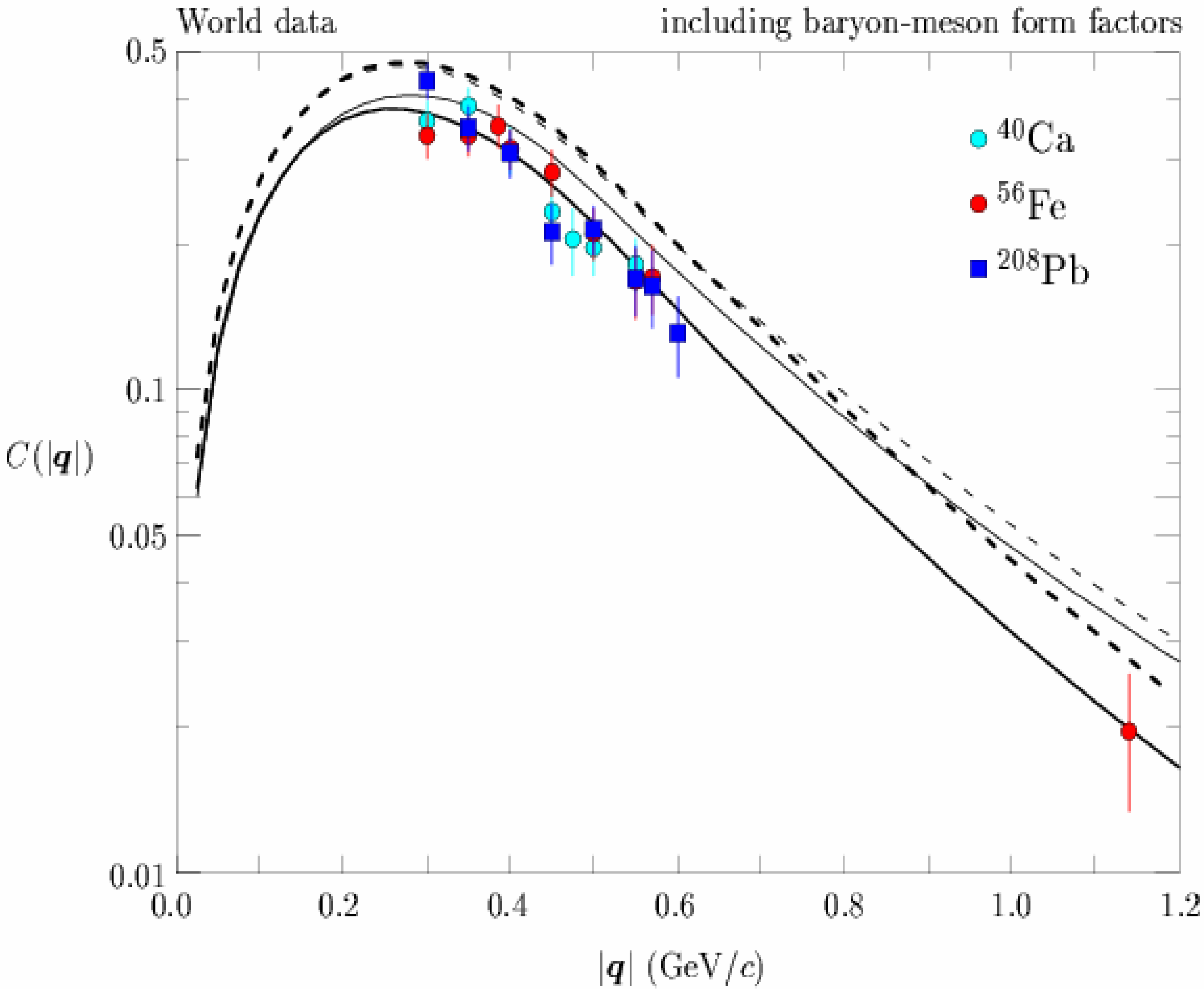
$N\bar{N}$ - Effects on Nuclear Collective States

q → 0





q → high



Hartree＋RPA

Hartree

Mean Field+RPA

Mean Field

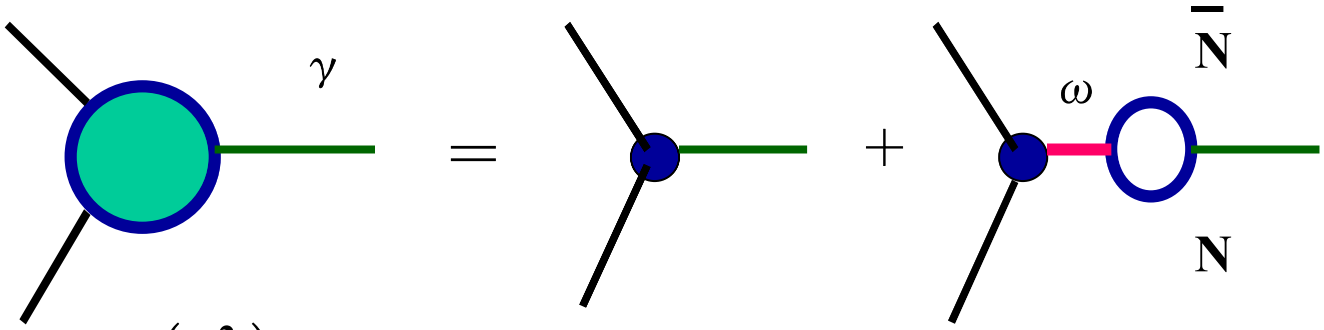
Fig. 2

See also H. Kurasawa and T. Suzuki, N. P. A490 (1988) 571 ; P. T. P. 86 (1991) 773.

C. J. Horowitz and J. Piekarewicz, P. R. L. 62 (1989) 391.

Effects of O(q^2)

Nucleon Form Factor in Free Space



$F_1(q^2)$

Nucleon Form Factor in Nuclear Medium

$$M \longrightarrow M^* = M - U_s$$

$$\langle r^2 \rangle = 6 dF_1(q^2)/dq^2 \, |(q^2=0)$$

Nucleon Form Factor in Nuclear Medium

$$F_1(q^2) \longrightarrow F_1^*(q^2)$$

$$\langle r_{\mathrm{N}}^2 \rangle \longrightarrow \langle r_{\mathrm{N}}^2 \rangle^*$$

For Proton

$$\langle r_{\mathrm{p}}^2 \rangle^* = \langle r_{\mathrm{p}}^2 \rangle + \delta \langle r_{\mathrm{p}}^2 \rangle$$

$$\delta \langle r_{\mathrm{p}}^2 \rangle \approx \frac{1}{\pi^2} \left(\frac{g_{\mathrm{v}}}{m_{\mathrm{v}}} \right)^2 \ln \left(\frac{M}{M^*} \right) > 0,$$

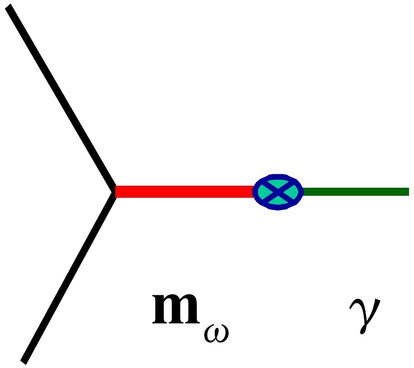
$$\left(\frac{\langle r_{\rm p}^2\rangle^*}{\langle r_{\rm p}^2\rangle}\right)^{1/2} = 1.146 \qquad (M > M^* = 0.731M)$$

$$F_1^*(q^2) \quad < \quad F_1(q^2)$$

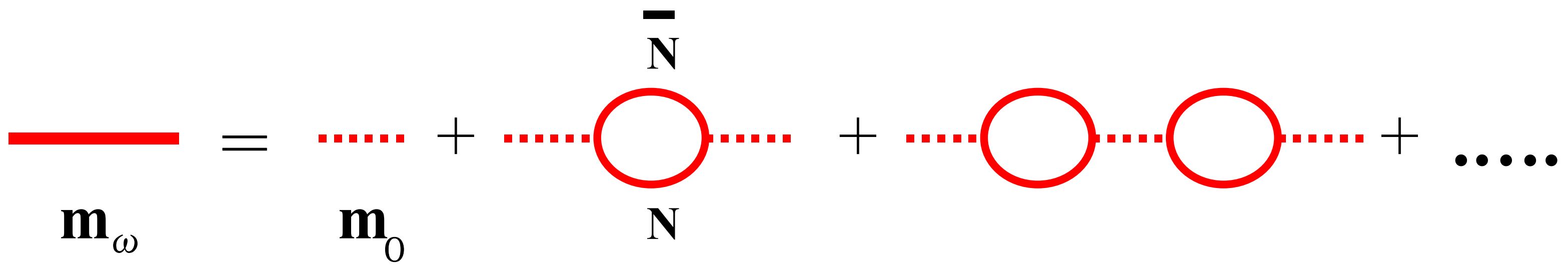
Reduction of the Coulomb Sum Value

Kurasawa and Suzuki,
Phys. Lett. 208B (1988) 160 ; 211B (1988) 500

Vector Meson Dominance Model



$F_1(q^2)$



$M \longrightarrow M^*$

$m_\omega \longrightarrow m^*_\omega$

in Nuclear Medium

$$\delta\langle r_p^2\rangle \approx 3\left(\frac{1}{m_\omega^{*2}} - \frac{1}{m_\omega^2}\right), \qquad m_\omega^* = 0.696\, m_\omega$$

Kurasawa and Suzuki, P.T.P, 84 (1990) 1030

Interpretation

Brown and Rho. Phys. Lett. B222 (1989) 324

$$F_1(q^2) \sim \left(\frac{\Lambda^2}{\Lambda^2 - q^2}\right)^2$$

$$= \frac{1}{2}\left(\frac{\Lambda^2}{\Lambda^2 - q^2}\right)_{\mathrm{s}}^2 + \frac{1}{2}\left(\frac{\Lambda^2}{\Lambda^2 - q^2}\right)_{\mathrm{v}}^2$$

$$\langle r_{\mathrm{p}}^2\rangle = \left(\frac{6}{\Lambda^2}\right)_{\mathrm{s}} + \left(\frac{6}{\Lambda^2}\right)_{\mathrm{v}} = (\,0.811\mathrm{fm}\,)^2$$

$$\Lambda = 840\,\mathrm{MeV} \approx m_\omega = 783\,\mathrm{MeV}$$

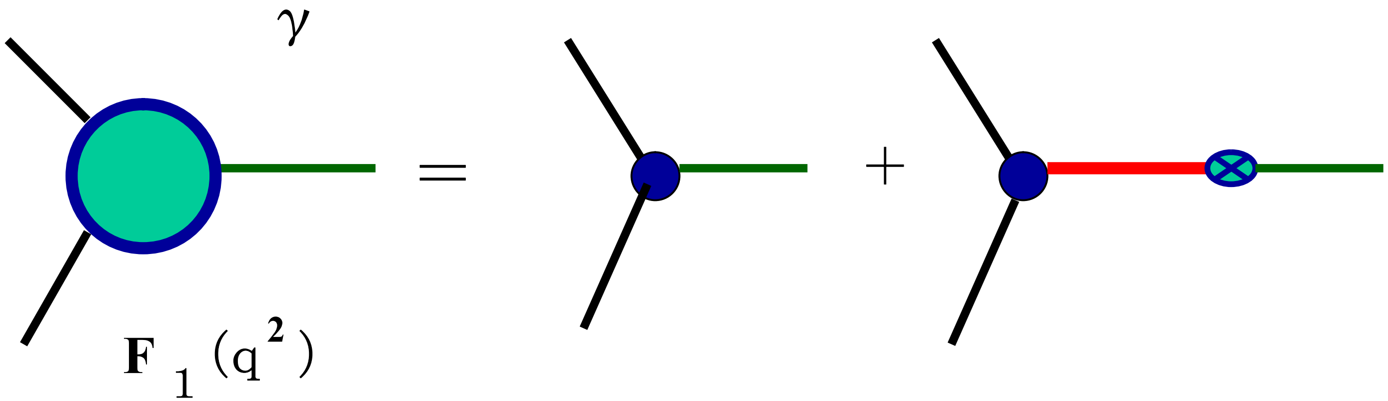
$$\frac{1}{2}\left(\frac{\Lambda^2}{\Lambda^2-q^2}\right)_{\mathrm{s}}^2 \approx \frac{1}{2}\left(\frac{\Lambda^2}{\Lambda^2-q^2}\right)\left(\frac{m_\omega^2}{m_\omega^2-q^2}\right)$$

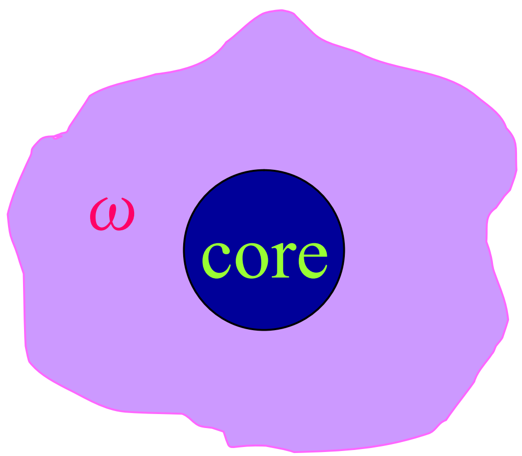
$$= \frac{1}{2}\left(\frac{\Lambda^2}{\Lambda^2-q^2}\right) + \frac{1}{2}\left(\frac{\Lambda^2}{\Lambda^2-q^2}\right)\left(\frac{q^2}{m_\omega^2-q^2}\right)$$

$$\langle r_{\mathrm{p}}^2\rangle = \left(\frac{3}{\Lambda^2}+\frac{3}{m_\omega^2}\right)_{\mathrm{s}} + \left(\frac{6}{\Lambda^2}\right)_{\mathrm{v}}$$

If $m_\omega \rightarrow m_\omega^*$, then

$$\delta\langle r_{\mathrm{p}}^2\rangle = 3\left(\frac{1}{m_\omega^{*2}} - \frac{1}{m_\omega^2}\right)$$


γ
F 1 (q 2)
=
+


ω
core

ELASTIC SCATTERING H. Kurasawa and T. Suzuki, Phys. Rev. C62 (2000) 054303

Nuclear Charge Density for Phase Shift Analyses

$$\rho_c(r) = \int \frac{d^3q}{(2\pi)^3} \exp(-i\boldsymbol{q}\cdot\boldsymbol{r})\langle 0|\hat{\rho}(\boldsymbol{q})|0\rangle$$

Time-component of the Rel. Nuclear Current

$$\begin{aligned}\langle 0|\hat{\rho}(\boldsymbol{q})|0\rangle &= \langle 0|\sum_k \exp(i\boldsymbol{q}\cdot\boldsymbol{r}_k) \\ &\quad \times \left(F_{1k}(\boldsymbol{q}^2) + \frac{\mu_k}{2M}F_{2k}(\boldsymbol{q}^2)\boldsymbol{q}\cdot\boldsymbol{\gamma}_k\right)|0\rangle.\end{aligned}$$

Using the Sachs form factor,

$$\begin{aligned}\langle 0|\hat{\rho}(\boldsymbol{q})|0\rangle &= \int d^3x \exp(i\boldsymbol{q}\cdot\boldsymbol{x}) \\ &\quad \times \sum_\tau \left(G_{E\tau}(\boldsymbol{q}^2)\rho_\tau(x) + F_{2\tau}(\boldsymbol{q}^2)W_\tau(x)\right),\end{aligned}$$

$$(\quad \tau = p, n \quad).$$

nucleon density, $\rho_\tau(r)$ $\boxed{\textbf{spin-orbit density,} \quad W_\tau(r)}$

The nucleon density,

$$\rho_\tau(r) = \sum_\alpha \frac{2j_\alpha + 1}{4\pi r^2} \left(G_\alpha^2 + F_\alpha^2\right).$$

The spin-orbit density,

$$\boxed{W_\tau(r) = \frac{\mu_\tau}{M} \sum_\alpha \frac{2j_\alpha + 1}{4\pi r^2} \frac{d}{dr} \left(\frac{M - M^*(r)}{M} G_\alpha F_\alpha + \frac{\kappa_\alpha + 1}{2Mr} G_\alpha^2 - \frac{\kappa_\alpha - 1}{2Mr} F_\alpha^2 \right),}$$

where

$$\begin{aligned} \mu_p &= 1.793 \qquad \mu_n = -1.913 \qquad M^*(r) = M - U_s(r) \quad \sim \quad 0.6M \\ \kappa_\alpha &= (-1)^{j-\ell+1/2}(j + 1/2). \end{aligned}$$

Nonrelativistic Limit

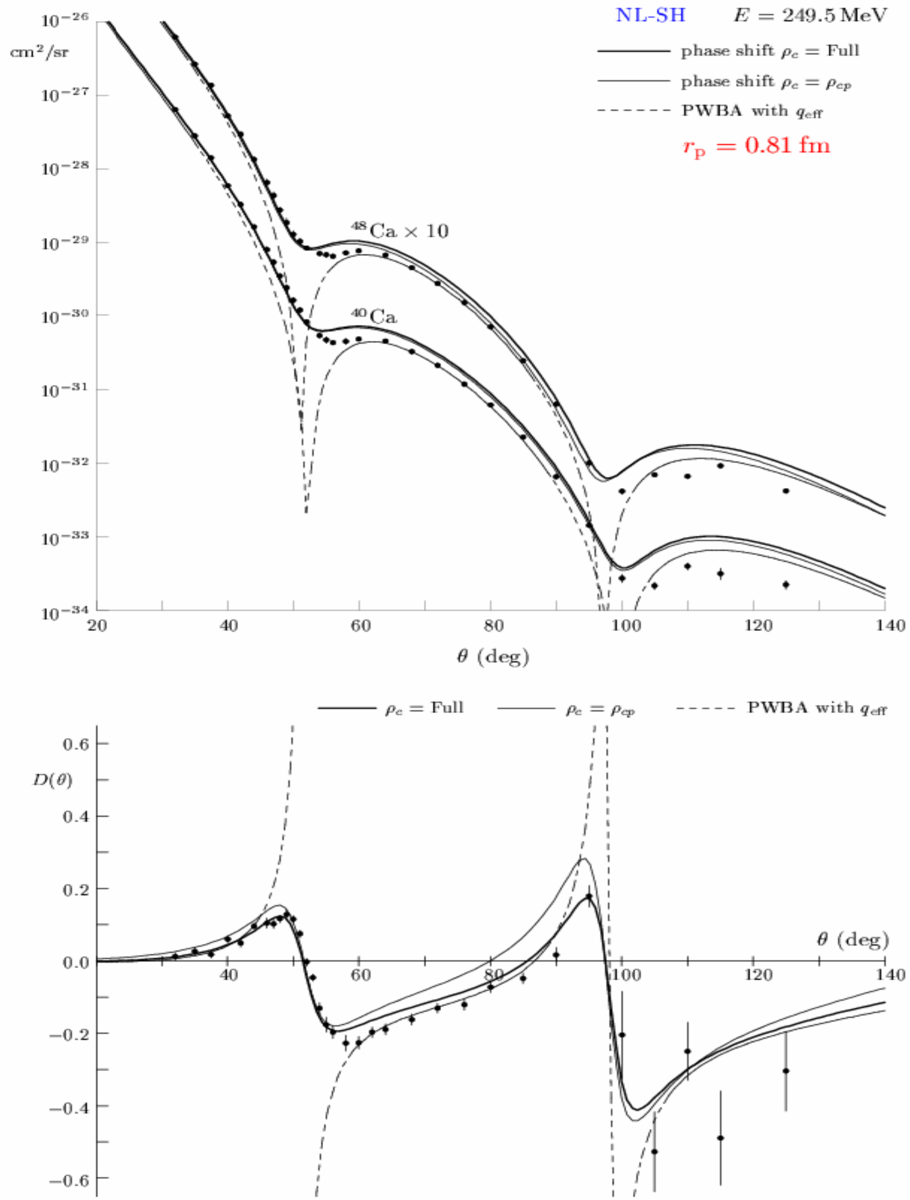
$$F_\alpha \quad \rightarrow \quad 0 \qquad W_\tau \quad \rightarrow \quad O(\tfrac{1}{M^2}) \quad \rightarrow \quad 0$$

Relativistic

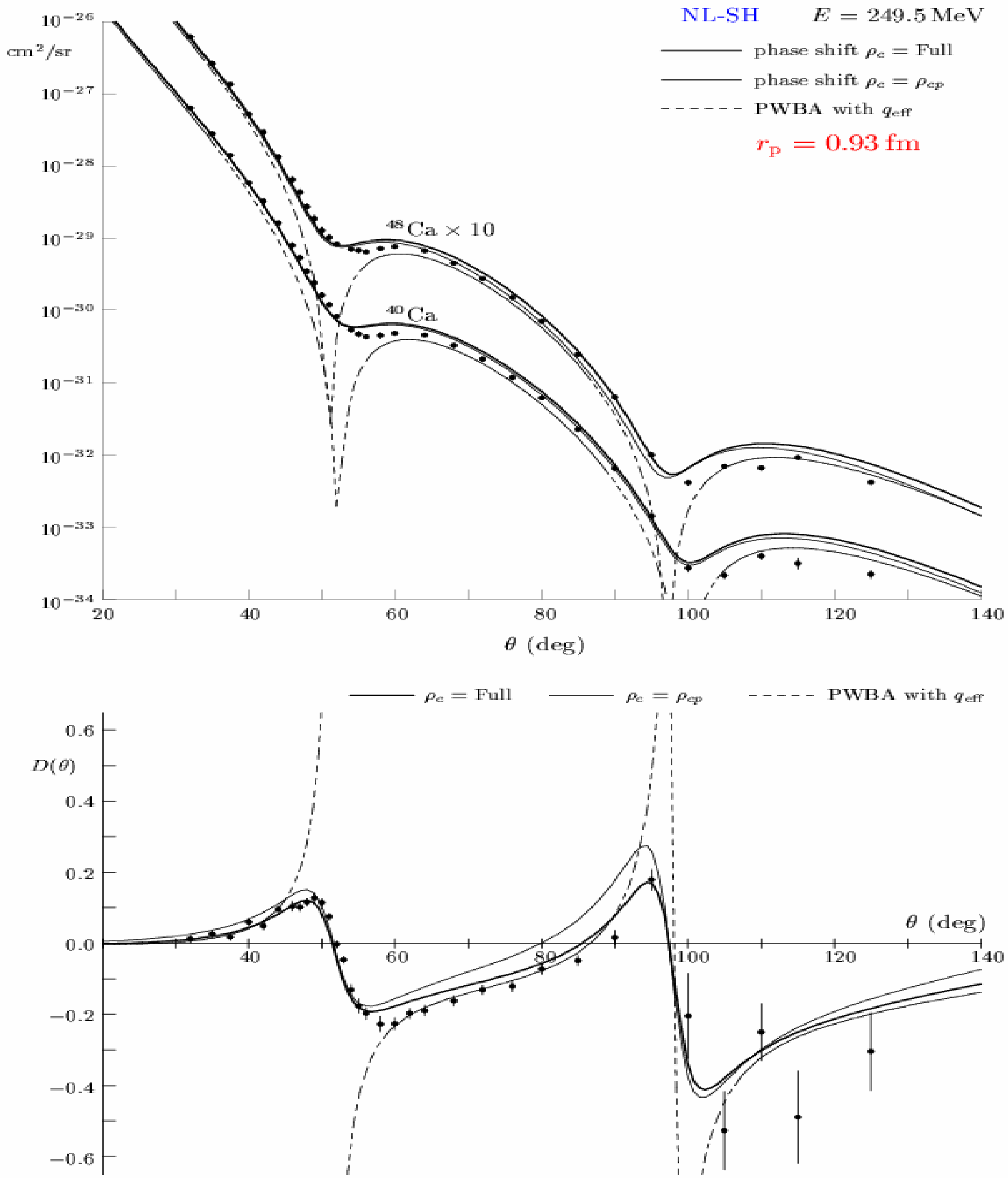
$$W_p(r) \neq 0, \qquad W_n \neq 0$$

W_n **important for Neutron-rich Nuclei**

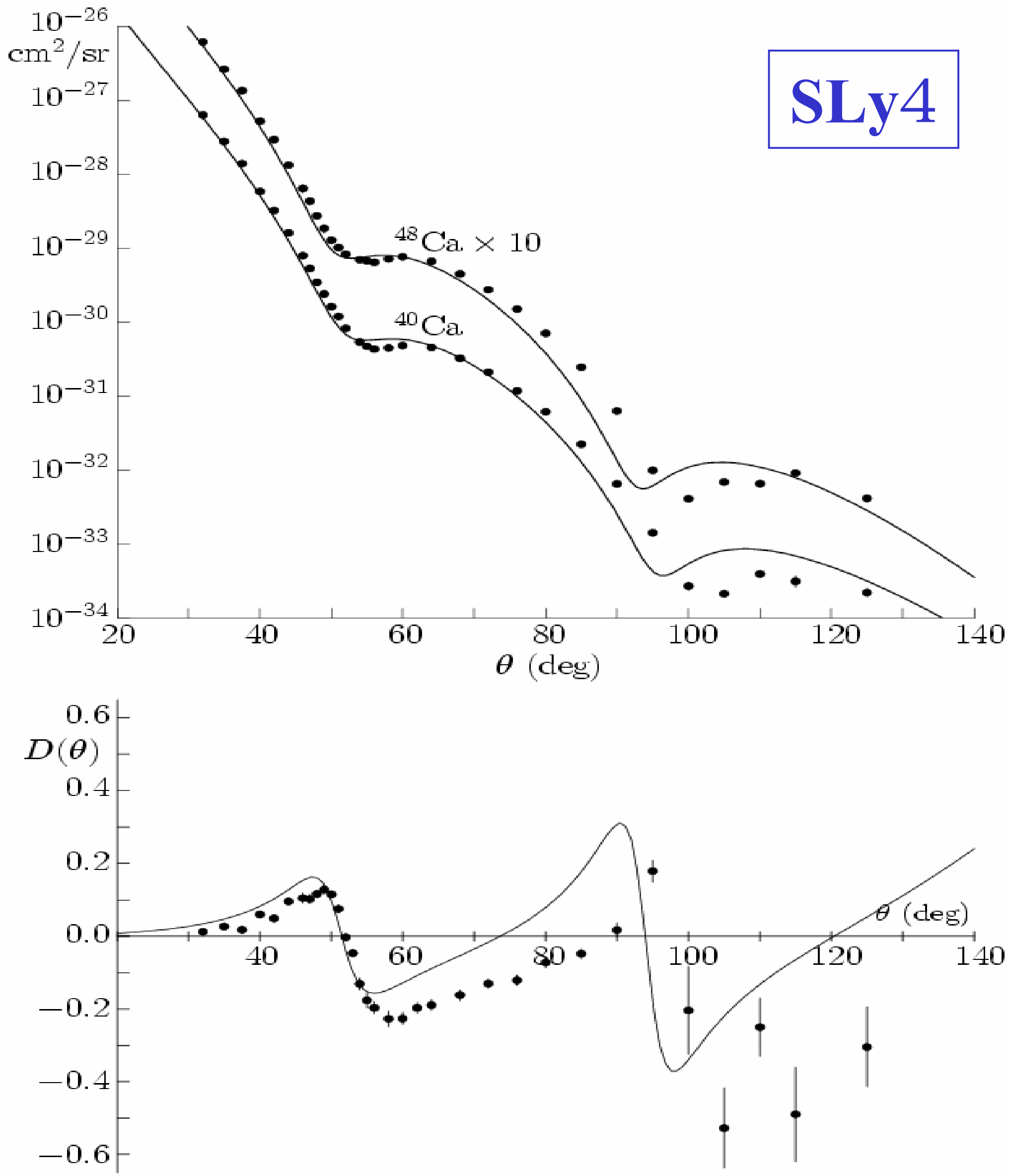
σ



$$\frac{\sigma\,(40) - \sigma\,(48)}{\sigma\,(40) + \sigma\,(48)}$$



NL-SH $E = 249.5\,\mathrm{MeV}$
phase shift ρ_c = Full
phase shift $\rho_c = \rho_{cp}$
PWBA with $q_{\rm eff}$
$r_{\rm p} = 0.93$ fm
^{48}Ca × 10
^{40}Ca
cm^2/sr
10^{-26}
10^{-27}
10^{-28}
10^{-29}
10^{-30}
10^{-31}
10^{-32}
10^{-33}
10^{-34}
20 40 60 80 100 120 140
θ (deg)
ρ_c = Full
$\rho_c = \rho_{cp}$
PWBA with $q_{\rm eff}$
$D(\theta)$
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
θ (deg)
40 60 80 100 120 140


SLy4
10^{-26} cm^2/sr
10^{-27}
10^{-28}
10^{-29}
10^{-30}
10^{-31}
10^{-32}
10^{-33}
10^{-34}
^{48}Ca × 10
^{40}Ca
20 40 60 80 100 120 140
θ (deg)
0.6
$D(\theta)$
0.4
0.2
0.0
−0.2
−0.4
−0.6
40 60 80 100 120 140
θ (deg)

Gamow-Teller Sum Rule

Non-relativistic models

$$Q_{\pm} = \sum_{i}^{A} \tau_{\pm i}\sigma_{yi} \qquad \tau_{\pm} = (\tau_x \pm i\tau_y)/\sqrt{2} \quad , \qquad \tau_0 = \tau_z .$$

Sum Rule for β_- and β_+ transitions

$$\langle \,|Q_+Q_-|\, \rangle - \langle \,|Q_-Q_+|\, \rangle = 2(N-Z),$$

because

$$[\,\tau_+\sigma_y\,,\,\tau_-\sigma_y\,] = 2\tau_z .$$

If we assume

$$Q_+|\,\rangle = 0,$$

we have

$$\langle \,|Q_+Q_-|\, \rangle = 2(N-Z).$$

Relativistic models

The field:

$$\psi(\boldsymbol{x}) = \int \frac{d^3p}{(2\pi)^{3/2}} \sum_\alpha (u_\alpha(\boldsymbol{p}) \exp(i\boldsymbol{p}\cdot\boldsymbol{x})\, a_\alpha(\boldsymbol{p}) + v_\alpha(\boldsymbol{p}) \exp(-i\boldsymbol{p}\cdot\boldsymbol{x})\, b_\alpha^\dagger(\boldsymbol{p})),$$

$$u_\alpha(\boldsymbol{p}) = u_\sigma(\boldsymbol{p})\, |\tau\rangle \;\; (\; \alpha = \sigma, \tau \;)\,, \quad \textbf{etc.}$$

Positive and Negative spinor:

$$u_\sigma(\boldsymbol{p}) = \left[\frac{E_p + M^*}{2E_p}\right]^{1/2} \begin{pmatrix} 1 \\ \frac{\boldsymbol{\sigma}\cdot\boldsymbol{p}}{E_p+M^*} \end{pmatrix} \xi\,, \qquad v_\sigma(\boldsymbol{p}) = \left[\frac{E_p + M^*}{2E_p}\right]^{1/2} \begin{pmatrix} \frac{\boldsymbol{\sigma}\cdot\boldsymbol{p}}{E_p+M^*} \\ 1 \end{pmatrix} \xi$$

$E_p = \sqrt{M^{*2} + \boldsymbol{p}^2}$, $\quad \xi$: Pauli spinor $\quad M^*$: the nucleon effective mass

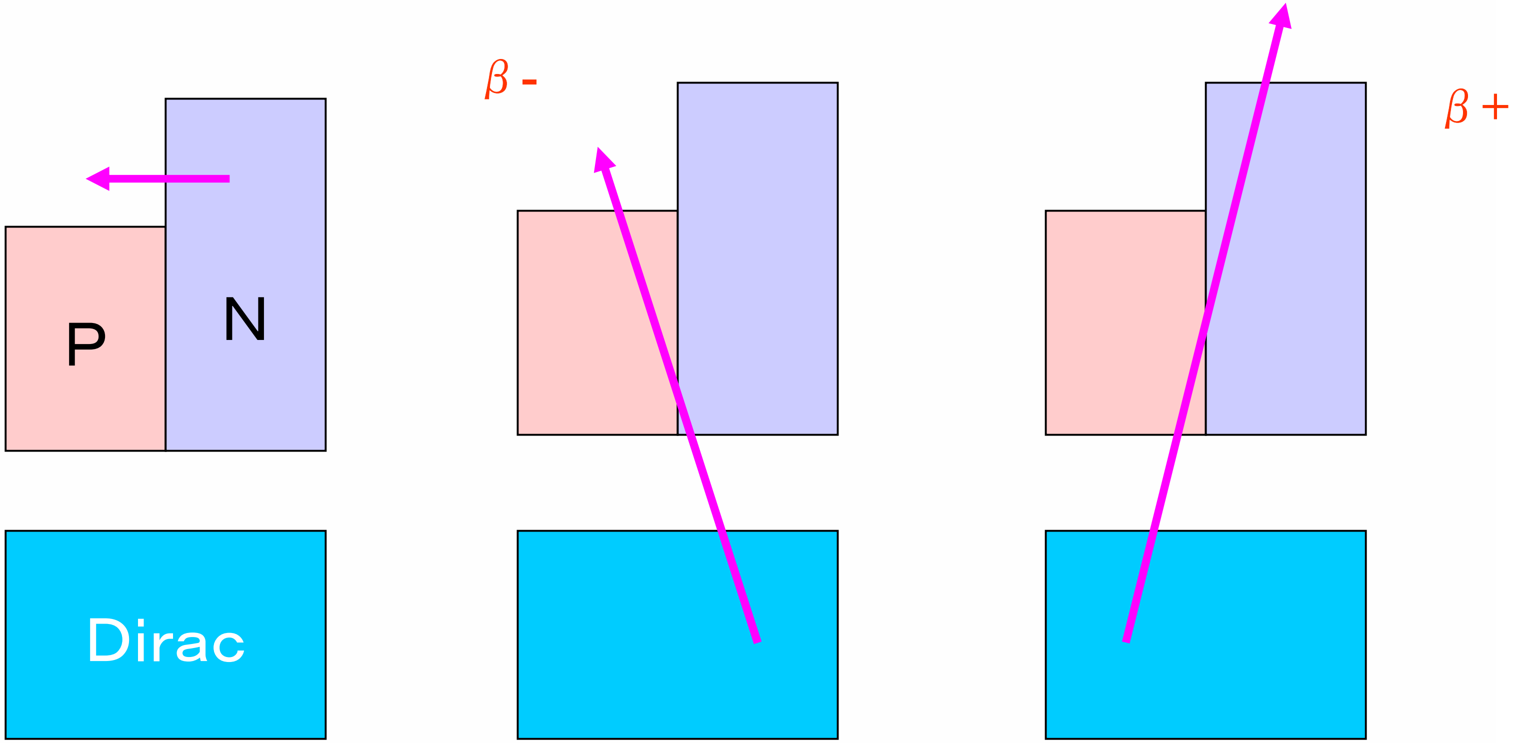
The operator : $F = \int d^3x\, \overline{\psi}(\boldsymbol{x})\, f\, \psi(\boldsymbol{x})$

The β_- and β_+ excitations for ($N > Z$)

$$F_-|\,\rangle = \sqrt{2}\int d^3p \sum_{\sigma\sigma'} \Big(\overline{u}_\sigma(\boldsymbol{p})\Gamma u_{\sigma'}(\boldsymbol{p})\, a^\dagger_{\sigma\mathrm{p}}(\boldsymbol{p}) a_{\sigma'\mathrm{n}}(\boldsymbol{p})$$
$$+\overline{u}_\sigma(\boldsymbol{p})\Gamma v_{\sigma'}(-\boldsymbol{p})\, a^\dagger_{\sigma\mathrm{p}}(\boldsymbol{p}) b^\dagger_{\sigma'\mathrm{n}}(-\boldsymbol{p})\Big)|\,\rangle,$$

$$F_+|\,\rangle = \sqrt{2}\int d^3p \sum_{\sigma\sigma'} \overline{u}_\sigma(\boldsymbol{p})\Gamma v_{\sigma'}(-\boldsymbol{p})\, a^\dagger_{\sigma\mathrm{n}}(\boldsymbol{p}) b^\dagger_{\sigma'\mathrm{p}}(-\boldsymbol{p})\,|\,\rangle,$$

$$(\ \Gamma = \gamma_5\gamma_y\ ).$$



The matrix elements for the β_- and β_+ transitions:

$$\langle \,|\, F_+ F_- \,|\, \rangle = 4\,\frac{V}{(2\pi)^3}\int \frac{d^3p}{E_p^2}\left[\theta_{\boldsymbol{p}}^{(\mathrm{n})}\left(1-\theta_{\boldsymbol{p}}^{(\mathrm{p})}\right)\left(M^{*2}+p_y^2\right)+\left(1-\theta_{\boldsymbol{p}}^{(\mathrm{p})}\right)\left(\boldsymbol{p}^2-p_y^2\right)\right],$$

$$\langle \,|\, F_- F_+ \,|\, \rangle = 4\,\frac{V}{(2\pi)^3}\int \frac{d^3p}{E_p^2}\left(1-\theta_{\boldsymbol{p}}^{(\mathrm{n})}\right)\left(\boldsymbol{p}^2-p_y^2\right).$$

$\theta_{\boldsymbol{p}}^{(i)} = \theta(k_i - |\boldsymbol{p}|)$ for $i =$p and n, $\quad V = A\left(3\pi^2/2k_{\mathrm{F}}^3\right)$,
k_{n} and k_{p} : Fermi momentum of neutrons and protons

Each of them is divergent.
However, the difference gives the sum rule value,

$$\langle \,|\, F_+ F_- \,|\, \rangle - \langle \,|\, F_- F_+ \,|\, \rangle = 2(N-Z).$$

The antinucleon space is necessary.

For the nucleon degrees of freedom only,

$$\boxed{\langle\, | F_+ F_- | \,\rangle \approx 2\left(1 - \frac{2}{3} v_{\mathrm{F}}^2\right)(N - Z)}$$

v_{F} **: Fermi velocity**

The classical sum value is quenched by 12%

for $v_{\mathrm{F}} = 0.43 \;\; (M^* = 0.6M, \quad k_{\mathrm{F}} = 1.36\mathrm{fm}^{-1})$.

The GT strength taken by N $\bar{\mathrm{N}}$ excitations in the time-like rgion:

$$[\langle\, | F_+ F_- | \,\rangle - \langle\, | F_- F_+ | \,\rangle]_{\mathrm{N\bar{N}}} \approx 2\, \frac{2}{3} v_{\mathrm{F}}^2 \, (N - Z)$$

nucl-th/0301074, to be published in Phys. Rev Lett.

GT strengths in Ca 48

n $\rightarrow$ n

$n\ell j$	$n'\ell' j'$	$T_{aa'}$	$g(a:a')$	$f(a:a')$
$1p_{3/2}(-39.41)$	$2p_{3/2}(-3.97)$	0.001	0.0110	−0.0110
$1p_{3/2}(-39.41)$	$1f_{5/2}(-2.09)$	0.002	0.7765	−0.0175
$1p_{3/2}(-39.41)$	$2p_{1/2}(-2.74)$	0.004	0.0323	−0.0091
$1p_{1/2}(-36.23)$	$2p_{3/2}(-3.97)$	0.001	−0.0128	0.0116
$1p_{1/2}(-36.23)$	$2p_{1/2}(-2.74)$	0.001	0.0102	−0.0102
$1f_{7/2}(-10.00)$	$1f_{5/2}(-2.09)$	8.411	0.9592	−0.0150
$1f_{7/2}(-10.00)$	$1f_{7/2}(-10.00)$	6.390	0.9805	0.0195
Total		14.810		

n $\rightarrow$ p

$n\ell j$	$n'\ell' j'$	$T_{aa'}$	$g(a:a')$	$f(a:a')$
$1p_{3/2}(-39.41)$	$2p_{3/2}(-1.09)$	0.000	−0.0113	−0.0116
$1p_{3/2}(-39.41)$	$1f_{5/2}(-1.16)$	0.002	0.8084	−0.0180
$1p_{1/2}(-36.23)$	$2p_{3/2}(-1.09)$	0.005	−0.0360	0.0117
$1f_{7/2}(-10.00)$	$1f_{5/2}(-1.16)$	8.629	0.9715	−0.0148
$1f_{7/2}(-10.00)$	$1f_{7/2}(-9.59)$	6.361	0.9787	0.0200
Total		14.997		

14.997 / 16 = 0.937

GT strengths in Zr 90

$n \to n$

$n\ell j$	$n'\ell' j'$	$T_{aa'}$	$g(a:a')$	$f(a:a')$
$1s_{1/2}(-59.29)$	$2d_{3/2}(-3.19)$	0.000	−0.2874	−0.0032
$1s_{1/2}(-59.29)$	$3s_{1/2}(-3.35)$	0.000	0.0022	−0.0022
$1d_{5/2}(-36.85)$	$2d_{5/2}(-5.08)$	0.002	0.0114	−0.0114
$1d_{5/2}(-36.85)$	$1g_{7/2}(-4.79)$	0.003	0.8668	−0.0194
$1d_{5/2}(-36.85)$	$2d_{3/2}(-3.19)$	0.012	0.0440	−0.0097
$1d_{3/2}(-33.03)$	$2d_{5/2}(-5.08)$	0.004	−0.0242	0.0181
$1d_{3/2}(-33.03)$	$2d_{3/2}(-3.19)$	0.001	0.0105	−0.0105
$1d_{3/2}(-33.03)$	$3s_{1/2}(-3.35)$	0.000	0.0004	−0.0097
$2s_{1/2}(-30.33)$	$2d_{3/2}(-3.19)$	0.001	0.5241	−0.0134
$2s_{1/2}(-30.33)$	$3s_{1/2}(-3.35)$	0.001	0.0116	−0.0116
$1g_{9/2}(-12.52)$	$1g_{7/2}(-4.79)$	11.112	0.9683	−0.0171
$1g_{9/2}(-12.52)$	$1g_{9/2}(-12.52)$	7.520	0.9784	0.0216
Total		18.657		

$n \to p$

$n\ell j$	$n'\ell' j'$	$T_{aa'}$	$g(a:a')$	$f(a:a')$
$1d_{5/2}(-36.85)$	$2d_{5/2}(2.98)$	0.001	−0.0190	−0.0117
$1d_{5/2}(-36.85)$	$1g_{7/2}(1.79)$	0.003	0.8684	−0.0195
$1d_{3/2}(-33.03)$	$2d_{5/2}(2.98)$	0.018	−0.0529	0.0169
$1g_{9/2}(-12.52)$	$1g_{7/2}(1.79)$	11.152	0.9700	−0.0171
$1g_{9/2}(-12.52)$	$1g_{9/2}(-6.13)$	7.515	0.9781	0.0217
Total		18.689		

18.689 / 20 = 0.934

T. Wakasa et al., Phys. Rev. C55 (1997) 2909 ; Phys. Lett. B426 (1998) 257

84 ～ 90 %

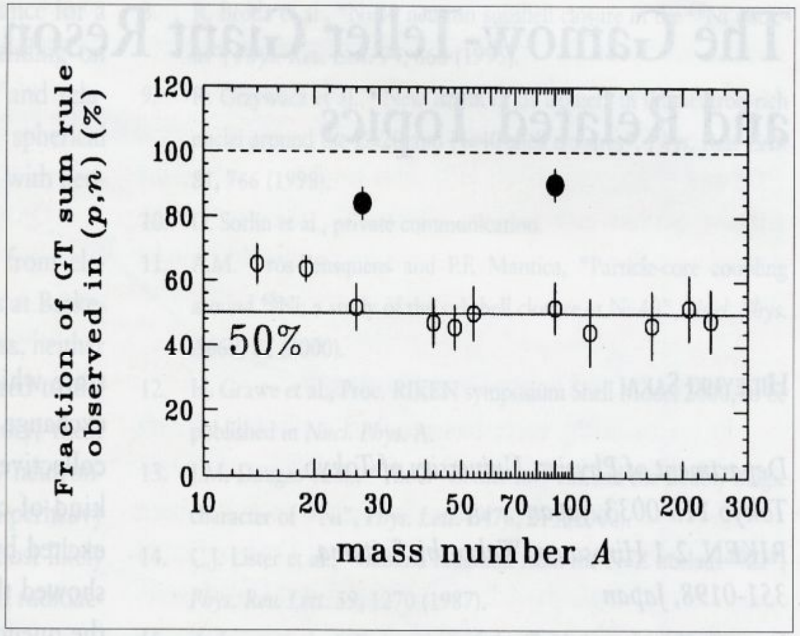


Figure 1. *Fraction of the GT sum-rule value taken from Gaarde [9] (open circle). Solid circles are new measurements taken from [18, 24].*

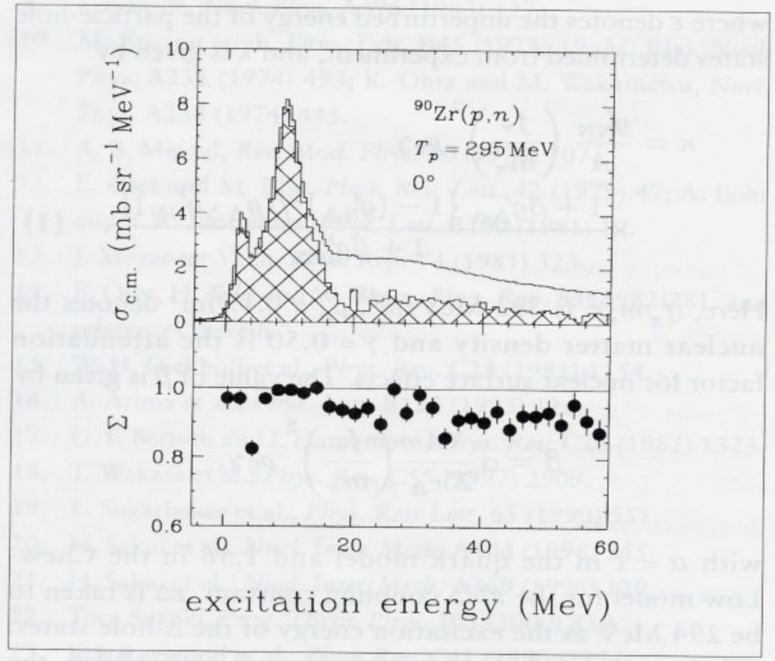


Figure 2. *The energy spectrum (upper) and the total spin-transfer Σ (lower) for the $^{90}Zr(p,n)$ reaction at $T_p = 295$ MeV and $\theta_{lab} = 0°$.*

C. Gaarde, Nucl. Phys. A396 (1983) 127c

Conclusions

1) $\bar{N}$ **is necessary** for the description of both low- and medium- energy phenomena in the present relativistic models.

2) In some low energy phenomena, $\bar{N}$**-effects** are hidden, but appear in the sum rules. **The GT** and **the Coulomb sum values are quenched.**

3) There seem to be possibilities to find **nuclear phenomena to show relativistic effects of the relativistic models explicitly.**