Deuteron Compton Scattering in a potential model

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A few words about polarizabilities

The electric polarizability

$$\alpha = 2\sum_{n>0} \frac{<n|ez|0>}{E_n - E_0}.$$

In a few particular cases the summation can be performed analytically. For instance, in the case of the hydrogen atom one obtains a well known result

$$\alpha({}^1H) = \frac{9}{2} a_B^3,$$

where $a_B = 1/(em_e)$ is the Bohr radius.

The spin averaged Compton scattering amplitude on a nucleon target is of the following form

$$T(\omega) = -\frac{Z^2 e^2}{M_N}\mathbf{e}\cdot\mathbf{e}'^{*} + 4\pi\,\alpha\,\omega^2\mathbf{e}\cdot\mathbf{e}'^{*} + 4\pi\,\beta\;[\mathbf{k}\times\mathbf{e}]\cdot[\mathbf{k}'\times\mathbf{e}'^{*}] + O(\omega^3)$$

where α and β are the electric and magnetic polarizabilities.

The Baldin sum rule constrains $\alpha+\beta$

$$\alpha+\beta = \frac{1}{2\pi^2}\int_0^\infty \frac{\sigma_{tot}(\omega)}{\omega^2}\,d\omega$$

Numerically

$$\alpha_p+\beta_p = 14.0\pm 0.3, \quad \alpha_n+\beta_n = 15.2\pm 0.5$$

(units are 10^{-4} fm^3).

PDG2012 gives

$$\alpha_p - \beta_p = 10.1\pm 0.6$$

The deuteron is a natural source of neutrons. There are two reactions to study the neutron polarizabilities.

$$\gamma d \to \gamma np$$

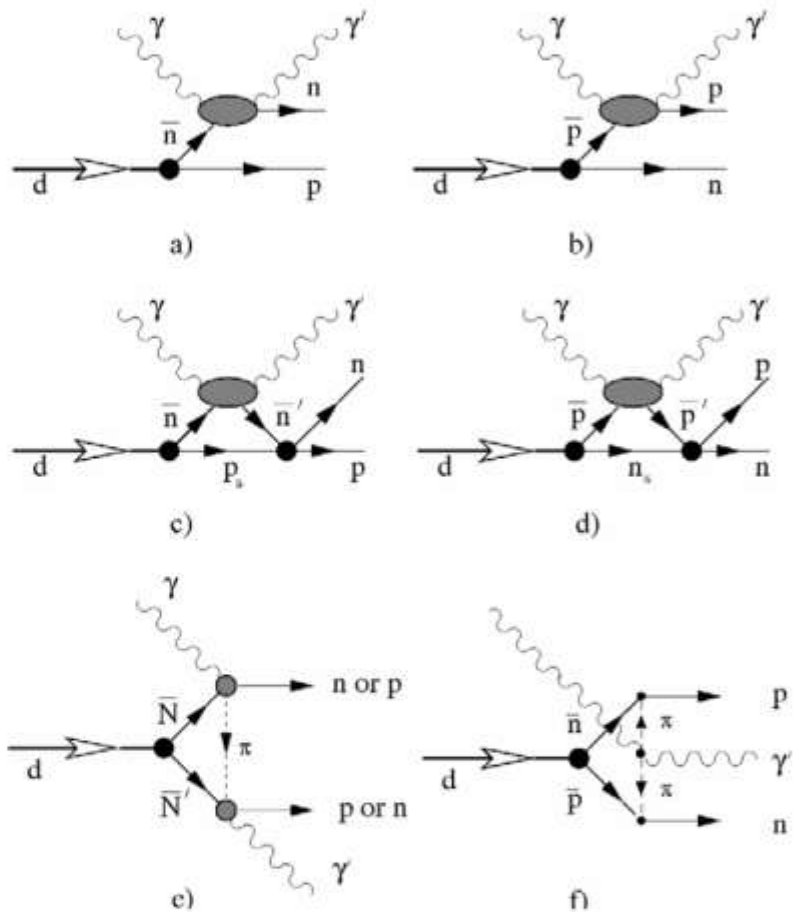


Fig. 1. Main graphs contributing to the reaction $\gamma d \to \gamma' np$.

n ELECTRIC POLARIZABILITY α_n

Following is the electric polarizability α_n defined in terms of the induced electric dipole moment by $\mathbf{D} = 4\pi\epsilon_0\alpha_n\mathbf{E}$. For a review, see SCHMIEDMAYER 89.

For a very complete review of the "polarizability of the nucleon and Compton scattering," see SCHUMACHER 05. His recommended values for the neutron are $\alpha_n = (12.5 \pm 1.7) \times 10^{-4}$ fm^3 and $\beta_n = (2.7 \mp 1.8) \times 10^{-4}$ fm^3, which agree with our averages within errors.

VALUE (10^{-4} fm^3)	*DOCUMENT ID*		*TECN*	*COMMENT*
11.6± 1.5 OUR AVERAGE				
$12.5\pm 1.8^{+1.6}_{-1.3}$	[16] KOSSERT	03	CNTR	$\gamma d \rightarrow \gamma p n$
$8.8\pm 2.4\pm 3.0$	[17] LUNDIN	03	CNTR	$\gamma d \rightarrow \gamma d$
$12.0\pm 1.5\pm 2.0$	SCHMIEDM...	91	CNTR	n Pb transmission
$10.7^{+3.3}_{-10.7}$	ROSE	90B	CNTR	$\gamma d \rightarrow \gamma n p$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
13.6	[18] KOLB	00	CNTR	$\gamma d \rightarrow \gamma n p$
0.0 ± 5.0	[19] KOESTER	95	CNTR	n Pb, n Bi transmission
$11.7^{+4.3}_{-11.7}$	ROSE	90	CNTR	See ROSE 90B
8 ± 10	KOESTER	88	CNTR	n Pb, n Bi transmission
12 ± 10	SCHMIEDM...	88	CNTR	n Pb, n C transmission

n MAGNETIC POLARIZABILITY β_n

VALUE (10^{-4} fm^3)	DOCUMENT ID		TECN	COMMENT
3.7±2.0 OUR AVERAGE				
$2.7 \pm 1.8 ^{+1.3}_{-1.6}$	[20] KOSSERT	03	CNTR	$\gamma d \rightarrow \gamma p n$
$6.5 \pm 2.4 \pm 3.0$	[21] LUNDIN	03	CNTR	$\gamma d \rightarrow \gamma d$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
1.6	[22] KOLB	00	CNTR	$\gamma d \rightarrow \gamma n p$

[20] KOSSERT 03 gets $\alpha_n - \beta_n = (9.8 \pm 3.6^{+2.1}_{-1.1} \pm 2.2) \times 10^{-4}$ fm^3, and uses $\alpha_n + \beta_n = (15.2 \pm 0.5) \times 10^{-4}$ fm^3 from LEVCHUK 00. Thus the errors on α_n and β_n are anti-correlated.

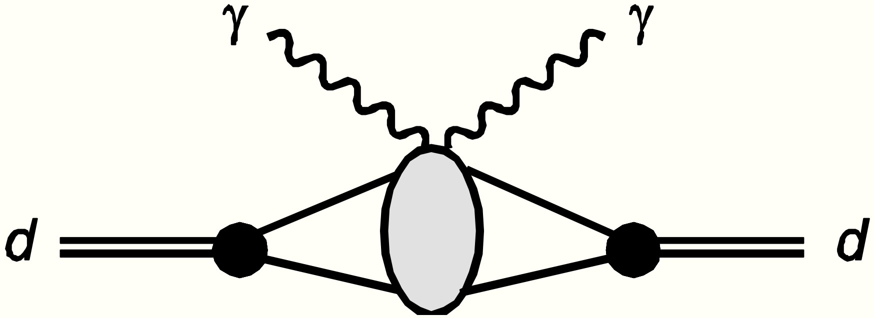
[21] LUNDIN 03 measures $\alpha_N - \beta_N = (6.4 \pm 2.4) \times 10^{-4}$ fm^3 and uses accurate values for α_p and α_p and a precise sum-rule result for $\alpha_n + \beta_n$. The second error is a model uncertainty, and errors on α_n and β_n are anticorrelated.

[22] KOLB 00 obtains this value with an upper limit of 7.6×10^{-4} fm^3 but no lower limit from this experiment alone. Combined with results of ROSE 90, the 1-σ range is $(1.2–7.6) \times 10^{-4}$ fm^3.

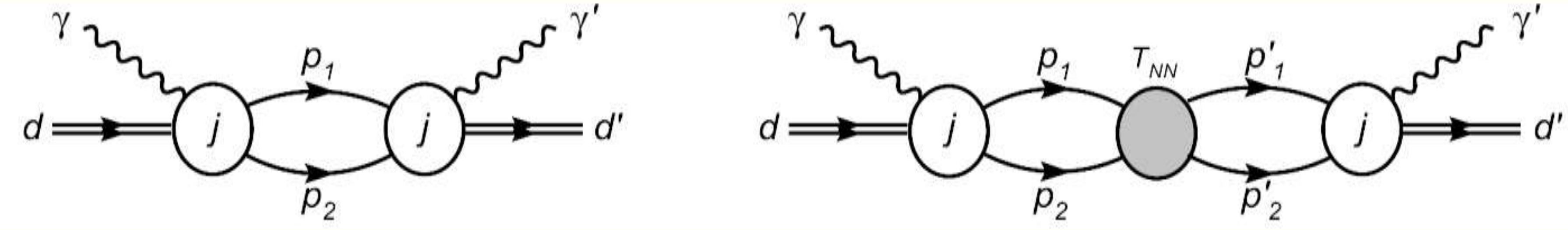
Deuteron Compton scattering is another reaction to study the neutron polarizabilities.

$$\gamma d \to \gamma d$$

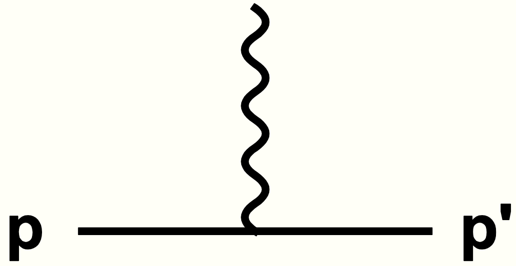
A potential model for this reaction was built by A.I. L'vov and M.I.L. in Nucl. Phys. A 674, 449 (2000). Recently it has been updated.



Resonance diagrams

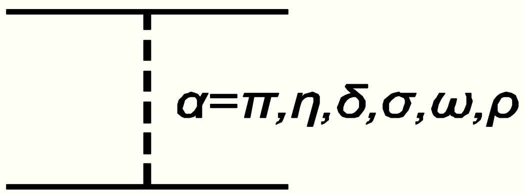


One-body current



$$\boldsymbol{\epsilon} \cdot \boldsymbol{j}^{[1]}(\mathbf{k}; \mathbf{p}', \mathbf{p}) = -\frac{eZ}{2M}\, \boldsymbol{\epsilon} \cdot (\mathbf{p} + \mathbf{p}') - \frac{e}{2M}(Z + \kappa)\, i\omega \boldsymbol{\sigma} \cdot \mathbf{s} - \frac{e}{8M^2}(Z + 2\kappa)\, i\omega \boldsymbol{\sigma} \cdot \boldsymbol{\epsilon} \times (\mathbf{p} + \mathbf{p}')$$

Bonn OBE potential



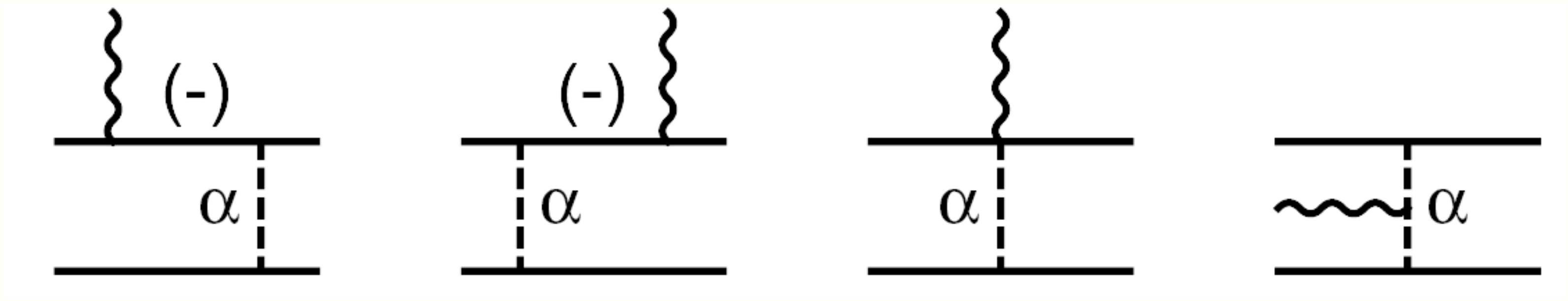
One pion exchange term

$$V_\pi(\vec{q}) = -\frac{g_\pi^2}{4M^2}\ \vec{\sigma}_1\cdot\vec{q}\,\vec{\sigma}_2\cdot\vec{q}\,\vec{\tau}_1\cdot\vec{\tau}_2\,G_\pi(\vec{q}),$$

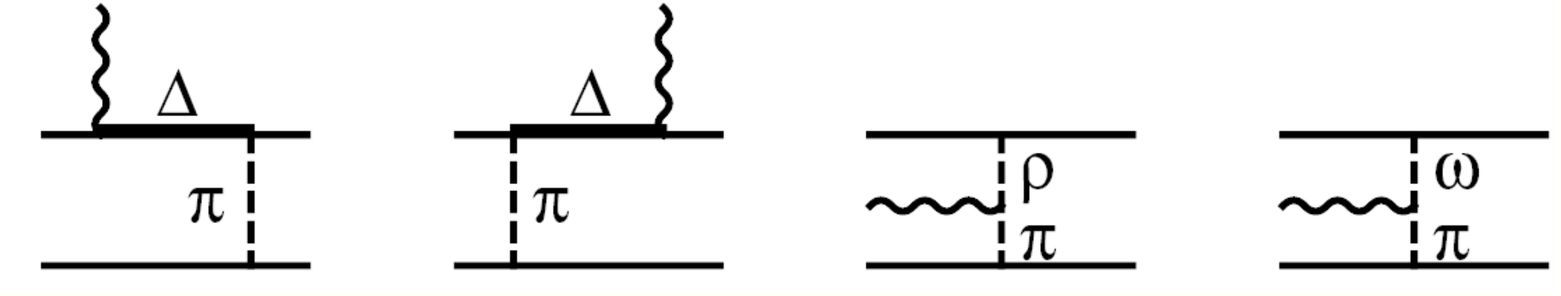
$$G_\pi(\vec{q}) = \frac{F_\pi^2(\vec{q})}{\vec{q}^2 + m_\pi^2}, \qquad F_\pi(\vec{q}) = \frac{\Lambda_\pi^2 - m_\pi^2}{\Lambda_\pi^2 + \vec{q}^2}.$$

The meson exchange current (MEC) operator

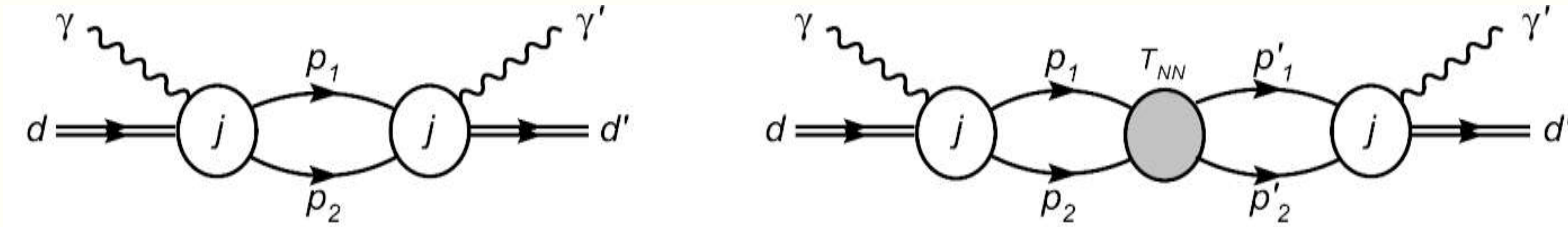
Potential contributions



Nonpotential contributions



Again about the resonance diagrams



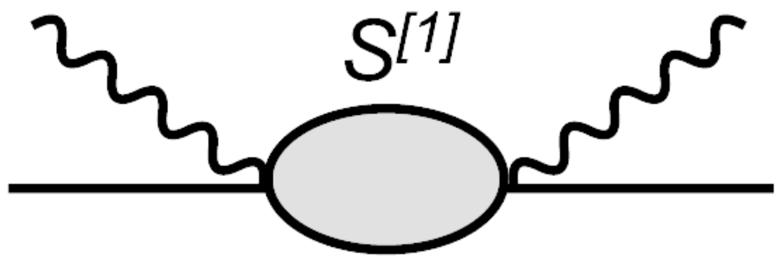
The amplitude of deuteron photodisintegration $T_{\gamma d \to pn}$ was built by M.I.L. in Few-Body. Syst. 19, 77 (1995). The model provides good description of available experimental data both for the direct and inverse reactions.

There was a bug in the computer code at evaluation of the resonance diagrams with the Δ-excitation.

The amplitude T_{NN} was calculated for a separable approximation of the Paris potential rather than for the Bonn OBEPR.

Seagull operators

One-body seagull



$$\epsilon'^{*\mu}\epsilon^{\nu} S^{[1]}_{\mu\nu}(-k',k) = -\frac{e^2 Z^2}{M}\,\boldsymbol{\epsilon}\cdot\boldsymbol{\epsilon}'^{*} + \frac{e^2 Z}{4M^2}(Z+2\kappa)(\omega+\omega')\, i\boldsymbol{\sigma}\cdot\boldsymbol{\epsilon}'^{*}\times\boldsymbol{\epsilon}$$
$$+ 4\pi\omega\omega'(\alpha+\delta\alpha_0)\,\boldsymbol{\epsilon}\cdot\boldsymbol{\epsilon}'^{*} + 4\pi\omega\omega'\beta\,\mathbf{s}\cdot\mathbf{s}'^{*} + \epsilon'^{*\mu}\epsilon^{\nu}\delta S^{[1]}_{\mu\nu}(-k',k)$$

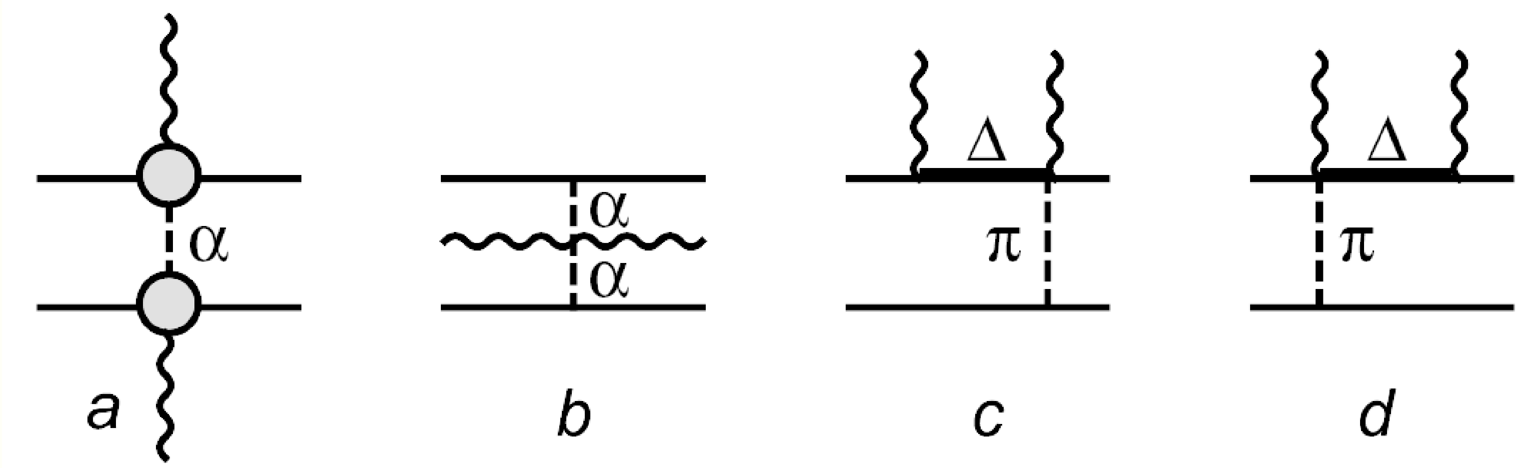
where

$$\delta\alpha_0 = -\frac{e^2}{4\pi}\,\frac{\kappa^2 + Z\kappa}{4M^3} = \begin{cases} -0.85, & \text{proton,} \\ -0.62, & \text{neutron} \end{cases}$$

is a relativistic correction.

$S^{[1]}$ contains the polarizabilities as parameters.

Two-body seagull $S^{[2]}$



Results

The Thomson limit

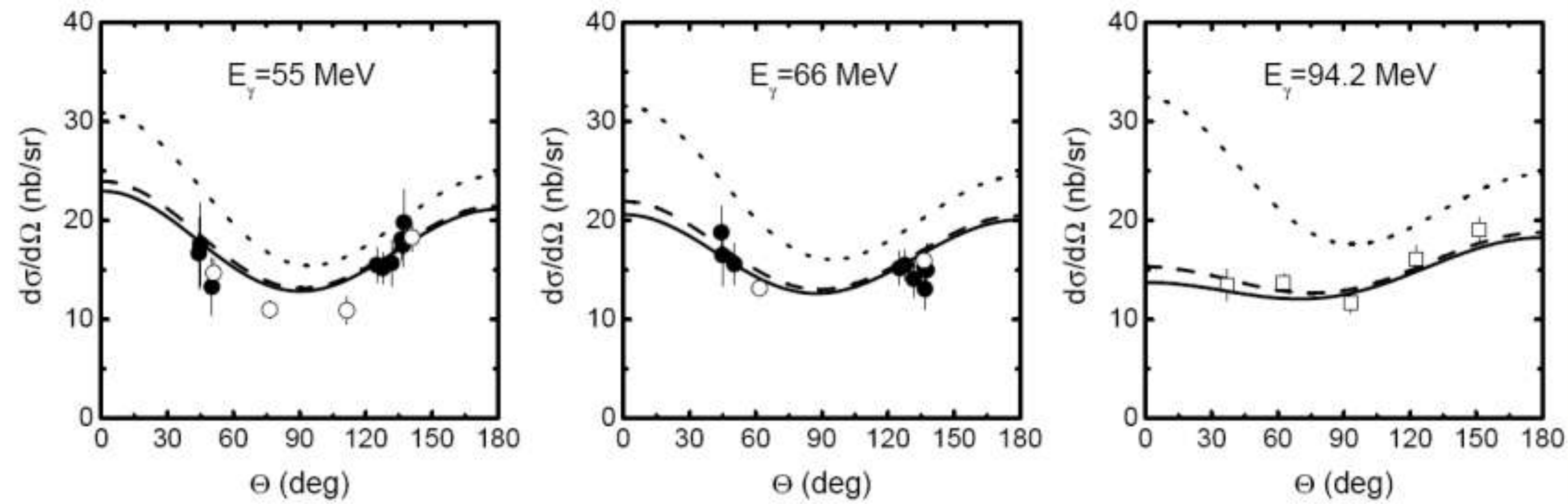
$$T(\omega = 0) = -\frac{e^2}{M_d}\,\mathbf{e}\cdot\mathbf{e}'^*$$

There was -0.94 instead of -1.

Separate contributions:

resonance diagrams without rescattering	+1.68
resonance diagrams with rescattering	-0.20
one-body seagull	-2
two-body seagulls	-0.48
Putting together all these numbers we obtain	-1 !!!

Extracted polarizabilities



Two-parametric fit:

$$\alpha+\beta=16.9\pm1.5,\quad \alpha-\beta=10.5\pm1.7,\quad \chi^2=33/(29-2)$$

One-parametric fit (the Baldin sum rule gives $\alpha+\beta=14.2\pm0.5$):

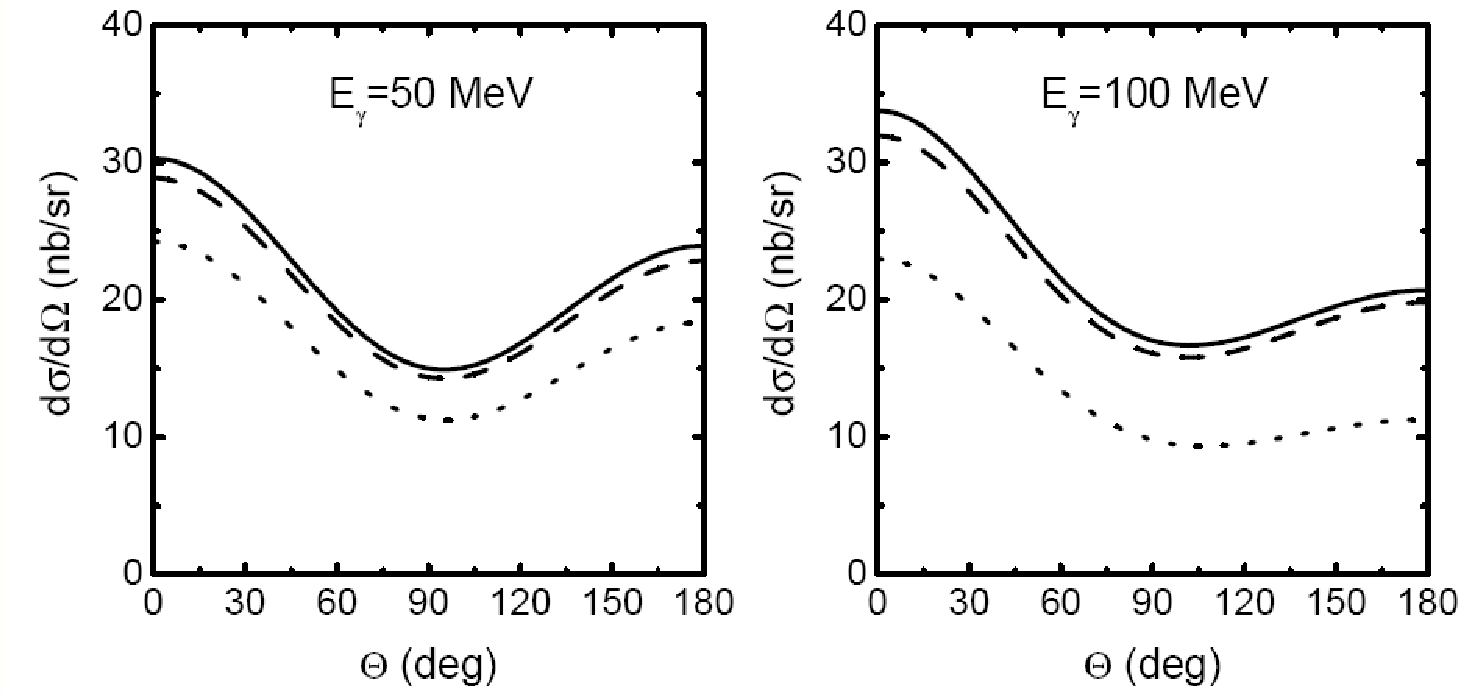
$$\alpha-\beta=9.4\pm1.6,\quad \chi^2=35/(29-1)$$

Proton value

$$\alpha_p-\beta_p=10.1\pm0.6$$

There is no visible isovector component in nucleon polarizabilities!

One has to estimate theoretical uncertainties!



•••• contributions from one-body current and seagull

– – – contributions from pion current and seagull are added

— contributions from heavy meson currents and seagulls are added

Thank you for your attention!