On the total cross section for incoherent π^- photoproduction on the deuteron in the threshold energy region

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Deuteron as a way to study neutron

Due to the absence of a free dense neutron target, reactions on a nucleus, primarily on a deuteron, is a source of information about the neutron and about the "elementary" amplitudes of interaction on it.

Plentiful information about the structure of the nucleon can be extracted in the reaction of pion photoproduction on nucleons.

Research motivation

Previously available experimental data described energies above 200 MeV (with a threshold about 150 MeV).

2018: The first measurements of the cross sections of the reaction $\gamma d \to \pi^- pp$ in the threshold energy region $E_\gamma < 160$ MeV (MAX IV laboratory, Lund university).

Kinematics

Let

$$k = (k^0, \mathbf{k}),\ p_d = (\varepsilon_d, \mathbf{p}_d),\ q = (\varepsilon_\pi, \mathbf{q}),\ p_1 = (\varepsilon_1, \mathbf{p}_1),\ p_2 = (\varepsilon_2, \mathbf{p}_2)$$

be the four-momenta of $\gamma, d, \pi^-, p_1, p_2$ respectively;

$$k^0_{lab} = E_\gamma \quad \text{and} \quad k^0_{cm} = \omega = E_\gamma M / W_{\gamma d}$$

are the photon energy in the lab and cm system respectively,
where $W_{\gamma d} = \sqrt{M^2 + 2ME_\gamma}$ is invariant mass, M is the deuteron mass.

Kinematics

It is convenient to take as independent kinematic variables the photon energy, pion momentum and the emission angle of one of the protons in the cm system of the final proton-proton pair.

Equality

$$W_{NN} = 2\varepsilon_P = 2\sqrt{\mathbf{P}^2 + m^2} = \sqrt{(k + p_d - q)^2}$$

allows us to find the proton momentum P. Boost of momenta $\mathbf{P}$ and $-\mathbf{P}$ with a speed $\mathbf{v} = (\mathbf{k} + \mathbf{p}_d - \mathbf{q}) / (k^0 + \varepsilon_d - \varepsilon_\pi)$ gives us the momenta of outgoing protons

$$\mathbf{p}_1 = \mathbf{P} + \gamma \mathbf{v} \left[\frac{\gamma}{1+\gamma} \mathbf{v} \cdot \mathbf{P} + \varepsilon_P\right], \qquad \mathbf{p}_2 = -\mathbf{P} + \gamma \mathbf{v} \left[-\frac{\gamma}{1+\gamma} \mathbf{v} \cdot \mathbf{P} + \varepsilon_P\right], \quad \gamma = \frac{1}{\sqrt{1 - \mathbf{v}^2}}$$

and, therefore, kinematics is totally determined.

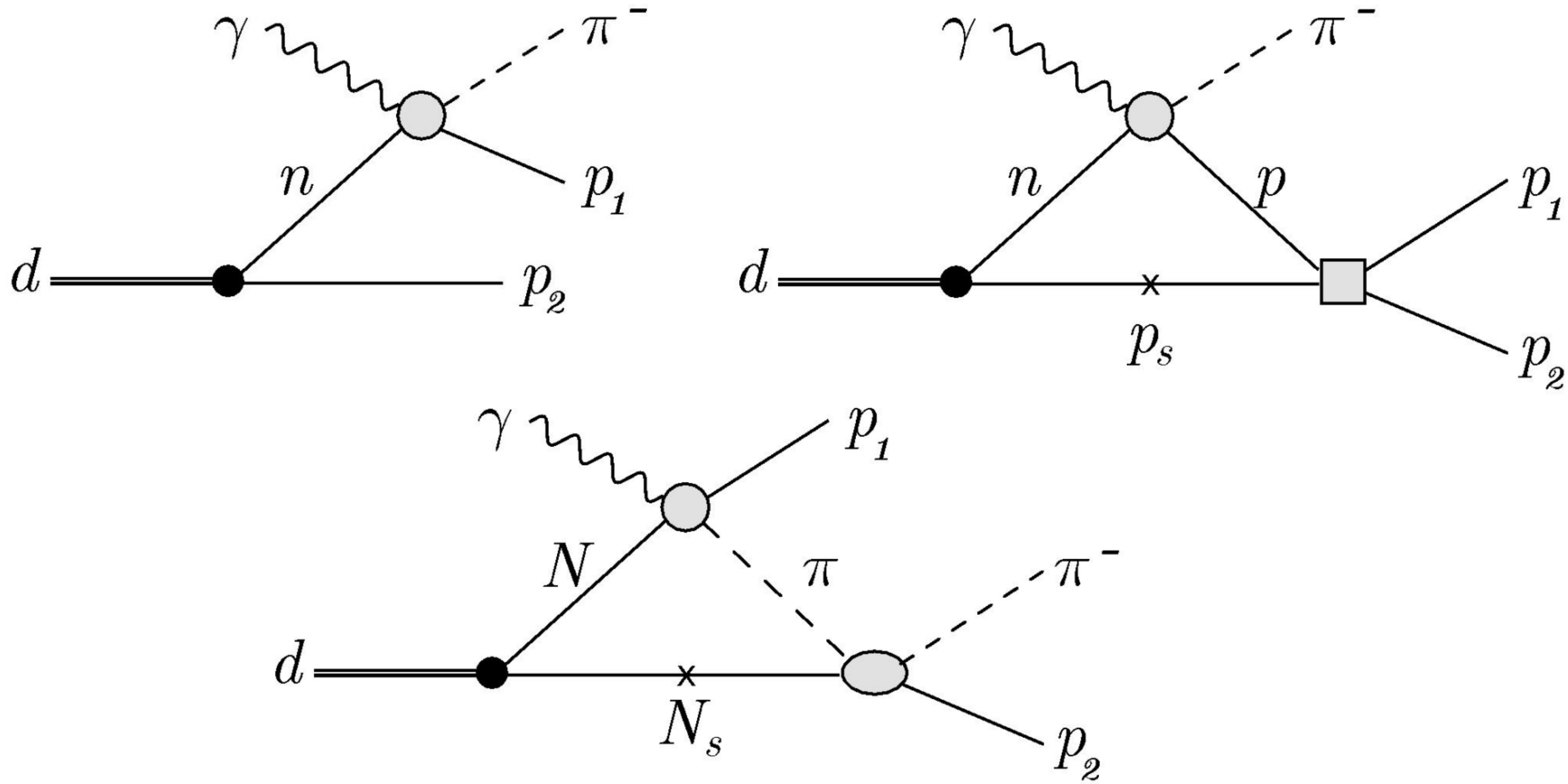
Kinematics

Differential cross section of the reaction is given by

$$\frac{d\sigma}{d\mathbf{q}d\Omega_{\mathbf{P}}} = \frac{1}{(2\pi)^5}\frac{m^2\varepsilon_d\left|\mathbf{P}\right|}{8k\cdot p_d\ \varepsilon_\pi\varepsilon_P}\times\frac{1}{2}\times\frac{1}{6}\left|T\right|^2 .$$

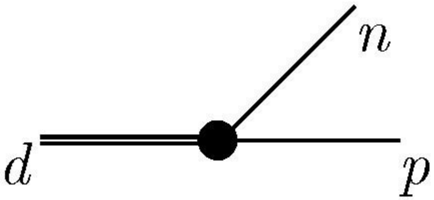
Factor ½ emerges due to identity of the protons, 1/6 emerges due to averaging over the initial spin states of the particles. In $\left|T\right|^2$ we mean the summation over the polarization of the initial and final particles.

Diagrammatic model



Diagrammatic model

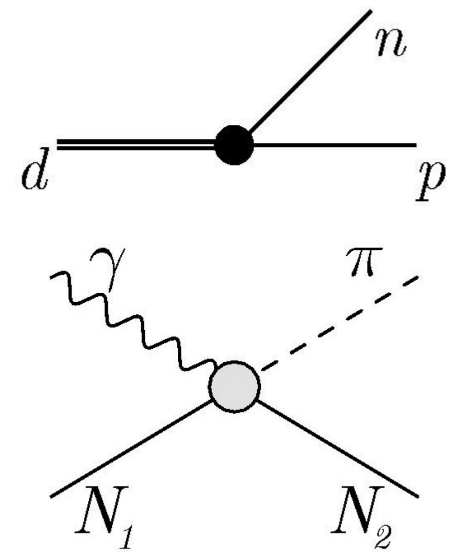
- For the deuteron vertex, the deuteron wave function from CD-Bonn NN-potential is used.



Machleidt, R. High-precision, charge-dependent Bonn nucleon-nucleon potential / R. Machleidt // Phys. Rev. C – 2001. – Vol. 63, № 2 – 024001(32).

Diagrammatic model

- For the deuteron vertex, the deuteron wave function from CD-Bonn NN-potential is used.
- For the pion photoproduction on the nucleon, MAID07 model is used.



A unitary isobar model for pion photo- and electroproduction on the proton up to 1 GeV / D. Drechsel [et al.] //Nucl. Phys. A – 1999. – Vol. 645, Iss. 1 – P. 145–174.

Diagrammatic model

- For the deuteron vertex, the deuteron wave function from CD-Bonn NN-potential is used.
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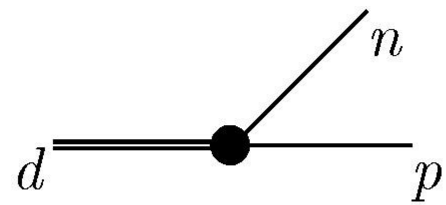
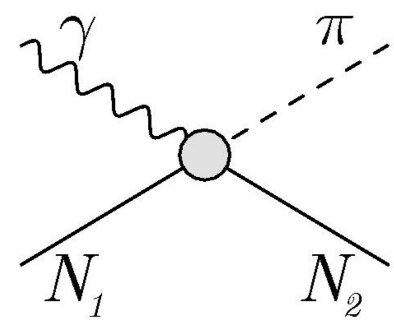
- The pp-scattering amplitude is obtained by solving the Lippmann-Schwinger integral equation for CD-Bonn potential.





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Diagrammatic model

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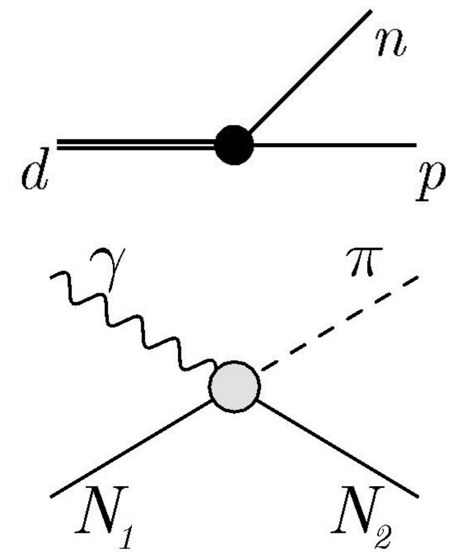
- For the pion photoproduction on the nucleon, MAID07 model is used
- The pp-scattering amplitude is obtained by solving the Lippmann-Schwinger integral equation for CD-Bonn potential.
- The πN-scattering amplitude is the solution of the Lippmann-Schwinger equation for the separable potential constructed in the work



Nozawa S., Blankleider B., Lee T. S. H. *Nuclear Physics A*, 1990, vol. 513, iss. 3–4, pp. 459–510.

Energy dependence of the total cross section of the reaction

Experimental data:

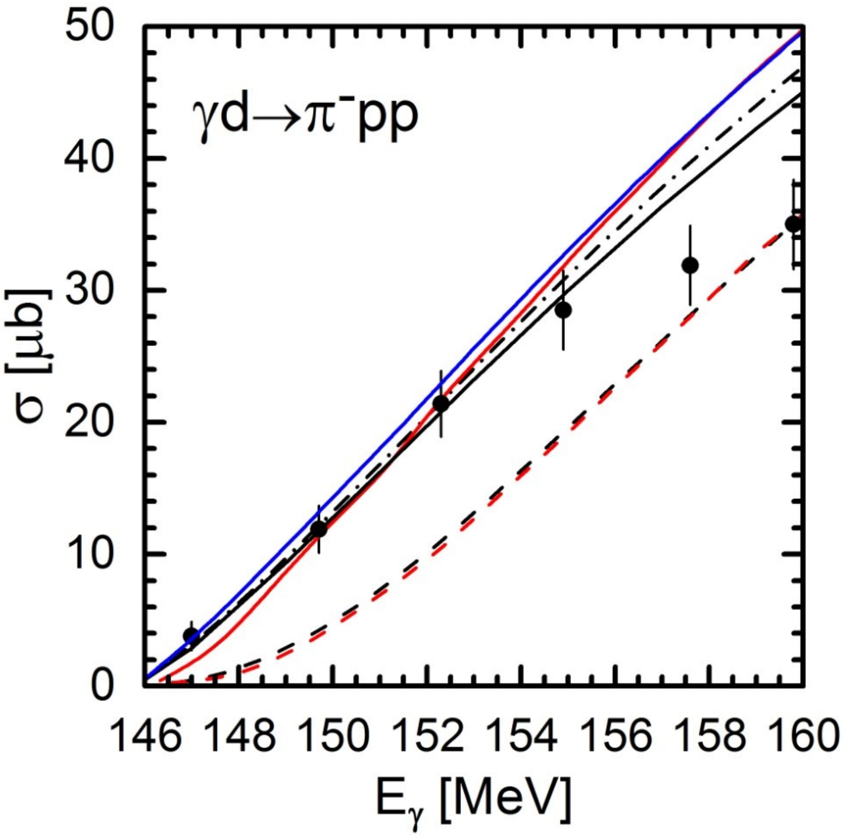
MAX IV Laboratory,
Lund University (2018).

Solid red line:

Near-threshold π^- photoproduction on the deuteron / Strandberg, B. [et al.] // Phys. Rev. C. – 2020. – Vol. 101, Iss. 3 – 035201(1).

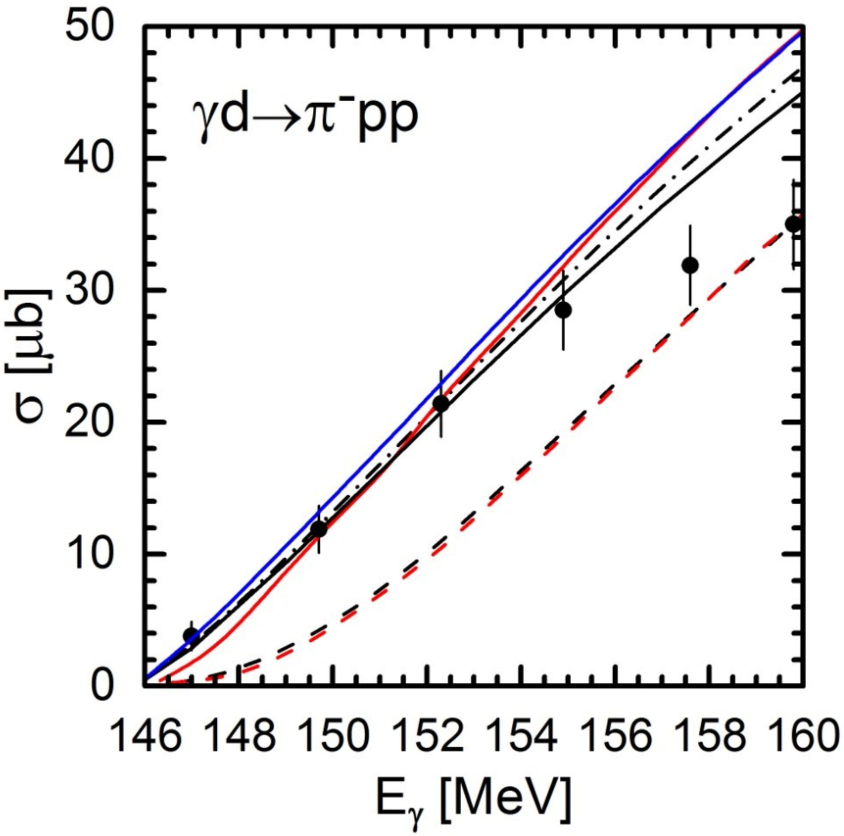
Solid blue line:

Near-threshold incoherent pion photoproduction on the deuteron with final-state interaction effects / E. M. Darwish [et al.] // Annals of Physics – 2019. – Vol. 411 – 167990(26).



Energy dependence of the total cross section of the reaction

It is noteworthy that the behavior of the data on reaction $\gamma d \to \pi^+ nn$ is similar to the given theoretical predictions for the reaction $\gamma d \to \pi^- pp$



$^2H(\gamma,\pi^+)nn$ total cross section from threshold to ΔE=22 MeV
/ E. C. Booth [et al.] // Phys. Rev. C – 1979. – Vol. 20, № 4 – P. 1217–1220.

Thanks for attention!