DATA ANALYSIS AND EVENT IDENTIFICATION OF THE $\gamma + n \to \pi^- + p$ REACTION*

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We present the selection method of events originating from the $\gamma + n \to \pi^- + p$ reaction obtained by bombarding a liquid deuterium target with a polarised γ beam of 0.6–1.5 GeV in the framework of the Graal experiment. We show the effect of bi-dimensional cuts (obtained combining measured quantity and reconstructed kinematic variables) and hardware constraints in order to reduce the contamination coming from the concurrent reaction channels. We describe a new three-dimensional cut based on the Fermi momentum reconstruction able to obtain a great increase of the signal/noise ratio. We determine the reaction vertex by using the precise measurement coming from the multi-wire proportional chambers (MWPCs) detectors: in this way we can reconstruct the shape of the spatial distribution of the beam and its position with respect to the target. By the simulation we estimate the contamination degree due to the other reaction channels so we can test the reliability of our method.

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1. Introduction

Reactions induced by photons, complementary to the ones induced by pions, are an important source of information on nucleon resonances [1] (excitation energy, decay widths, isospin structure, the coupling with photons). The Graal experiment (see detailed description of the experiment in Refs. [2–7]) studies the meson photoproduction by the reaction on

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hydrogen or deuterium targets induced by tagged and polarised gamma produced by Compton back-scattering [8, 9] between the polarised laser beam (uv-line or visible line) and the 6 GeV electrons of the cyclotron of the ESRF-facility in Grenoble. The Graal experiment during the last years produced very precise measurements of beam asymmetry for different reaction channels [2, 3, 5–7, 10, 11]. The extraction of the asymmetry values for $\pi^- n$ photoproduction on the quasi-free neutron allows to complete the isospin study of the pion photoproduction on the nucleon ($\pi^+ p$, $\pi^0 p$, and $\pi^0 n$ measured and published by the Graal Collaboration [2,3,11]), providing the possibility to test the validity of the isospin symmetry and for a precise determination of the three isoscalar and isovector transition amplitudes. The improvement of data analysis allows by increasing the statistics of the selected events to improve the experimental products(electromagnetic probes present low cross section in comparison with others), important in this field of research for the development of theoretical models and to test their prediction reliability.

We present the analysis of data in order to obtain the event identifications of π^- meson photoproduction off neutron in deuterium, in the kinematic conditions where the neutron is protagonist and the proton is the spectator. We show the identification procedure of proton and charged pion in each reaction event and the kinematic cuts used for the determination of the $\gamma n \to \pi^- p$ reaction channel.

2. Identification of the events

The charged particle identification in the central part of apparatus (polar angles between 25 and 155 degrees) was performed by using the bi-dimensional cut on the energy lost in the barrel *versus* the energy measured by the BGO calorimeter (see Fig. 1 (a)), while in the forward direction (for

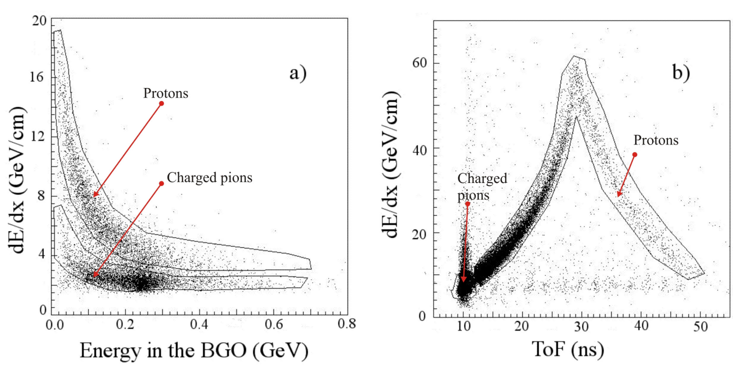

Fig. 1. Panel (a): energy lost in the barrel *versus* measured energy by the BGO; panel (b): energy lost *versus* TOF measured by the plastic scintillator wall.

polar angle less than 25 degrees) it was obtained by using the bi-dimensional cut on energy lost *versus* TOF measured by the plastic scintillator wall (see Fig. 1 (b)). We also applied to each detected charged particle the signal coincidence condition of three charged sensible detectors.

The information coming from direct measurements of the apparatus used in our data analysis are the energy E_γ of the incident photon measured by the tagging detector; the energy E_p of the proton measured in the BGO or by the TOF in the forward wall; the polar and azimuthal angles θ_p and ϕ_p of the proton and θ_{π^-} and ϕ_{π^-} of the pion measured by the planar and cylindrical MWPCs [12], the energy of the pion E_{π^-} obtained by the reaction energy balance neglecting the Fermi energy of the neutron in the deuterium target ($E_{\pi^-} = E_\gamma + M_n - E_p$). The preliminary selection of the events obtained by the constrain to have only one proton and only one charged pion detected in the Graal apparatus shows in simulation [13, 14] that the number of events coming from concurrent channel decreases up to 14%.

3. Reconstruction of the Fermi momentum

We reconstruct the Fermi momentum P_{F} (and consequently the Fermi energy E_{F}) by using the momentum conservation rules

$$\begin{aligned} P_{x\mathrm{F}} &= P_{xp} + P_{x\pi^-} \,, \\ P_{y\mathrm{F}} &= P_{yp} + P_{y\pi^-} \,, \\ P_{z\mathrm{F}} &= P_{zp} + P_{z\pi^-} - E_\gamma \,. \end{aligned} \tag{1}$$

We measure directly all quantities needed for the Fermi momentum reconstruction except the energy of the pion obtained by the energy balance neglecting the Fermi energy.

We try to improve the reconstruction of the Fermi momentum by a recursive procedure: we correct in the nth step calculation the estimation of the pion momentum by using the information of the Fermi energy calculated at the $(n-1)$th step. We stop the calculation loop when the difference $P_{\mathrm{F}}^{(n)} - P_{\mathrm{F}}^{(n-1)}$ will be lower than 10 keV/c (negligible in comparison with the mean value of the difference $P_{\mathrm{F}}^{(n)} - P_{\mathrm{F}}^{(0)}$ see Fig. 2).

In simulation, we observe that the difference between the Fermi momentum calculated at the nth and zero steps of the recursive method is small when we are considering signal events only (see solid line in Fig. 2). However, we find appreciable difference between these two values of Fermi momentum in the case of the concurrent channel (mainly the double charged pion photoproduction), then it is possible to use this quantity in order to distinguish the signal to the noise coming form the other channels (see dashed line in Fig. 2).

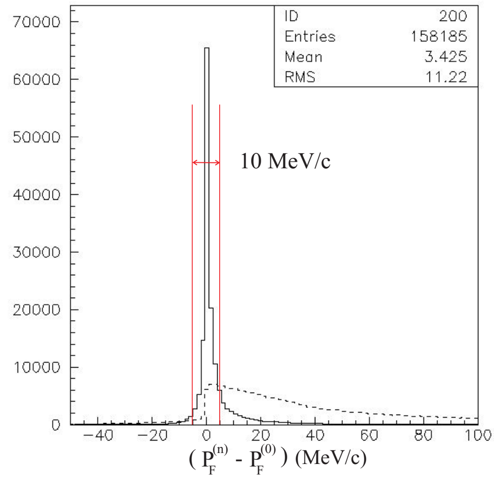

Fig. 2. Difference between the Fermi momentum reconstruction at the nth step of recursive method and at zero-step for the signal (solid line) and for the concurrent channels (dashed line) in simulation.

4. Data analysis

The measured quantities in the Graal experiment provide an overdetermined set of constraints. Then it is possible to calculate all kinematic variables using only a subset of the measured ones. For example, we are able to calculate the polar angle of the pion θ_{π^-} and the energy of the proton $E_p^{\rm calc}$ in the hypothesis of a pure two-body reaction.

We strongly reduced the background of the concurrent channels using different effective constraints:

- we combined the variables $x = \Delta\theta = \theta_{\pi^-}^{\rm calc} - \theta_{\pi^-}^{\rm meas}$ and $y = R_p = E_p^{\rm calc}/E_p^{\rm meas}$ in a bi-dimensional cut (see panels a of Fig. 3) selecting the events according to the condition

$$\frac{(x-\mu_x)^2}{\sigma_x^2} + \frac{(y-\mu_y)^2}{\sigma_y^2} - \frac{2C(x-\mu_x)(y-\mu_y)}{\sigma_x\sigma_y} < \sigma^2\,, \qquad (2)$$

  where $\sigma = 3$, C is the correlation parameter obtained by a combined best fit of x and y with a bi-dimensional Gaussian surface, $\mu_{x\,{\rm or}\,y}$ and $\sigma_{x\,{\rm or}\,y}$ are the mean value and the variance obtained by a Gaussian fit to its experimental distribution. We find the parameters of the cuts by fitting the surface function (Fig. 3(a)) for different energy of gamma and for different periods of data taking [7, 11];

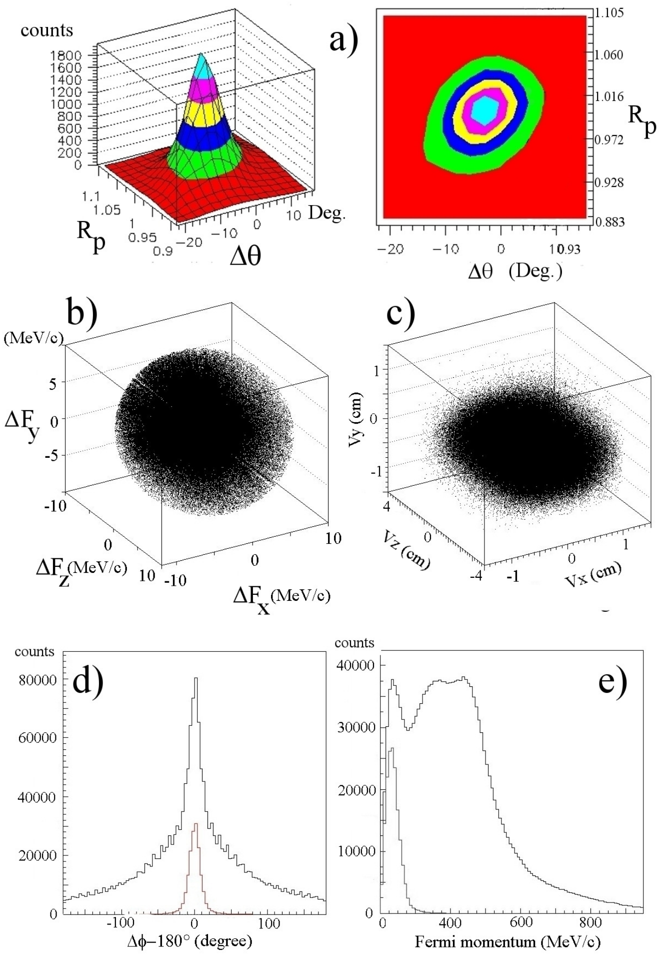

Fig. 3. In data, panels (a): bi-dimensional cut $\Delta\theta$ *versus* R_p; panel (b): three-dimensional representation of the cut defined in formula (3); panel (c): three-dimensional distribution of the reaction vertex; panel (d): coplanarity degree of proton and pion before and after cuts; panel (e): Fermi momentum before and after cut.

- we used the difference between the transverse component of the Fermi momentum neglecting in calculation the Fermi energy and correcting it by the recursive method (see Fig. 3(b)), and selecting the events in agreement with the condition

$$\sqrt{(P_{\mathrm{F}z} - P_{\mathrm{F}z}^{\mathrm{recur.}})^2 + (P_{\mathrm{F}x} - P_{\mathrm{F}x}^{\mathrm{recur.}})^2 + (P_{\mathrm{F}y} - P_{\mathrm{F}y}^{\mathrm{recur.}})^2} < 10\,\mathrm{MeV}/c\,, \quad (3)$$

where the value $10\,\mathrm{MeV}/c$ was suggested by the simulation as the best value in order to obtain the maximum signal-noise ratio (see Fig. 2);

- we applied the condition on the coplanarity of the reaction products $(\Delta\phi - 180^\circ) < 3\sigma_{(\Delta\phi-180^\circ)}$ (see Fig. 3(c)),
- we also reject all events where is present signal coming from neutral particle (signal measured only in neutral sensible detectors).

By the simulation [13, 14] we estimate that after the described cuts the background of the concurrent reaction channel is lower than 2.3%.

We determine the decay vertex distribution [12] of our reaction inside the deuterium target. We find that the reaction vertex of the selected events is correctly inside the target region (see Fig. 3(c)). We show the effect of the cuts on the degree of coplanarity of the reaction products (see Fig. 3(d)) and on the Fermi momentum (see Fig. 3(e)). The cuts realise low Fermi momentum distribution, suitable condition in order to have a quasi-free nucleon reaction. This analysis allows us to produce a very precise measurements of the beam asymmetry Σ of the $\pi^- p$ photoproduction. The theoretical study on our results is in progress.

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