Recent Results from the Graal and LEGS Beams

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Recent Results from the Graal and LEGS Beams

Presented by Carlo Schaerf for the Graal [1] and LSC collaborations [2]

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Abstract. The polarized and tagged Graal gamma-ray beam is obtained by backward Compton scattering of laser light on the high-energy electrons circulating in the ESRF storage ring. This technique, first developed for the Ladon beam on the storage ring Adone at LNF [1], provides gamma-ray beams with linear or circular polarizations close to one and well known. The Graal beam covers the energy region between 600 and 1500 MeV thus allowing the study of baryon resonances up to an energy of 1916 MeV, in large part by precision measurements of beam polarization asymmetries in meson photoproduction on the nucleons.

Keywords: Polarized photons, meson photoproduction, polarization observables
PACS: 13.60.Le

The differential cross section for the photoproduction of mesons with linearly polarized γ-rays on unpolarized nucleons is:

$$\frac{d\sigma(k,q,\phi)}{d\Omega} = \frac{d\sigma_0(k,q)}{d\Omega} \left[1 + P_\gamma\, A(k,\theta)\, cos(2\phi)\right] \qquad (1)$$

where $\frac{d\sigma_0(k,q)}{d\Omega}$ is the cross section for unpolarized γ-ray beam (function of k, the γ-ray energy, and θ the polar angle of the meson in the CMS), ϕ the azimuthal angle between the polarization and reaction planes, $P_\gamma(k)$ the polarization of the γ-ray beam as function of k, and $A(k,\theta)$ the beam polarization asymmetry (function of k and θ).

The Graal detector [2] has been designed to have cylindrical symmetry around the beam axis and we have collected data with two orthogonal orientations of the polarization plane exploiting the feature of Ladon beams that the polarization of the γ-ray beam is in the same direction of that of the laser and therefore can be easily rotated with optical half-wave plates. Graal has produced high quality asymmetries for the reactions:

in Hydrogen

$$\vec{\gamma} + p \rightarrow \pi^0 + p\ , \quad \vec{\gamma} + p \rightarrow \eta + p\ , \quad \vec{\gamma} + p \rightarrow \pi^+ + n$$

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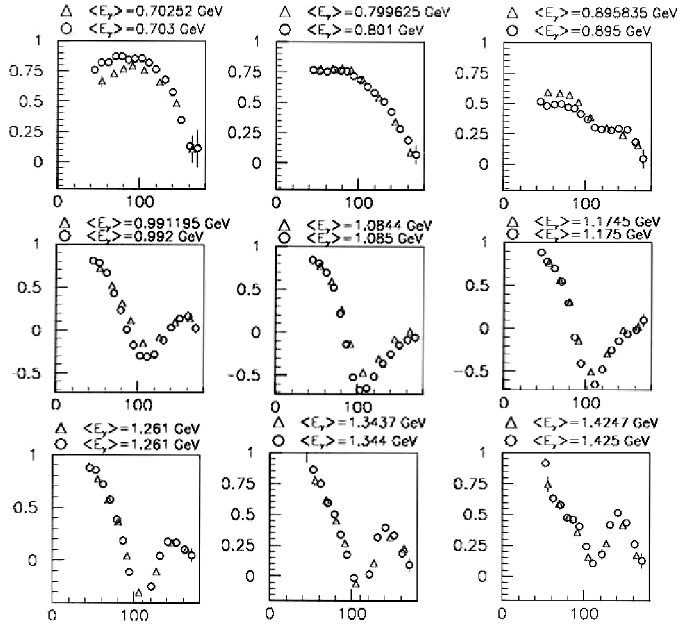

FIGURE 1. Beam polarization asymmetries Σ for π^0 photoproduction on free (open circles) and quasi-free proton (triangles). The results are almost identical with some smoothing of the quasi-free curves near maxima or minima probably due to Fermi motion of the target nucleon.

$$\vec{\gamma} + p \to \pi^0 + \pi^0 + p \ , \quad \vec{\gamma} + p \to \pi^0 + \eta + p$$
$$\vec{\gamma} + p \to K^+ + \Lambda \ , \quad \vec{\gamma} + p \to K^+ + \Sigma^0 \tag{2}$$

in Deuterium

$$\vec{\gamma} + d \to n + p$$
$$\vec{\gamma} + p(n) \to \eta + p(n) \ , \quad \vec{\gamma} + n(p) \to \eta + n(p)$$
$$\vec{\gamma} + p(n) \to \pi^0 + p(n) \ , \quad \vec{\gamma} + n(p) \to \pi^0 + n(p) \tag{3}$$

A Deuterium target has been used to study the reactions on the neutron. To compare the experimental results obtained by us on a neutron bound in the deuteron with the available theoretical results for a free neutron, we have compared the asymmetries obtained for the free proton in Hydrogen with those obtained for the bound proton in Deuterium. This comparison is indicated in figures 1 and 2 for π^0 and η photoproduction, respectively. Figures 3 and 4 present a comparison of the results for the quasi-free neutron with those for the quasi-free proton for π^0 and η, respectively.

In Fig. 6 we have indicated the tantalizing enhancement of the η-n yield compared to that for η-p above the peak of the S11 resonance. This anomalous peak at an invariant mass around 1.68 GeV, first discovered at Graal [5] and successively confirmed by the Bonn cross section measurements [6], has been interpreted in various ways [7]. As

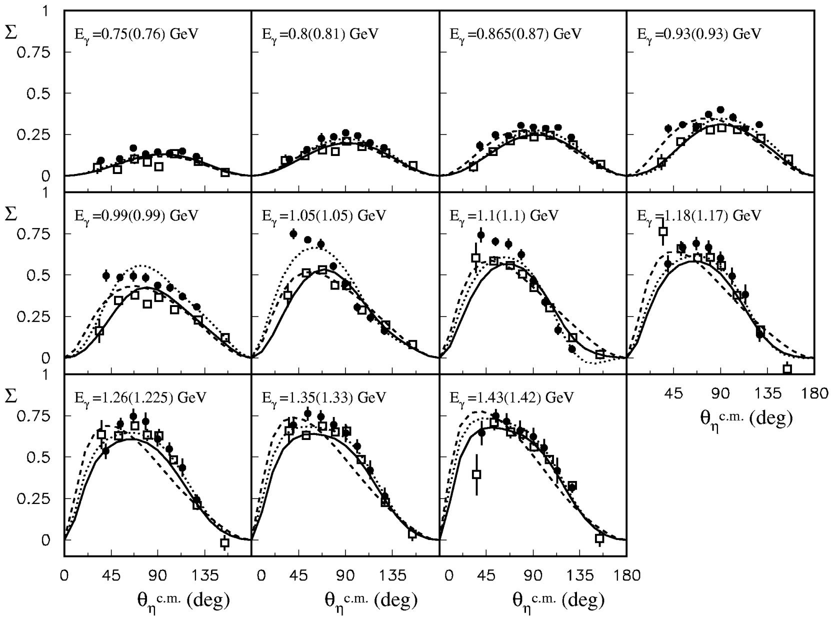

FIGURE 2. Beam polarization asymmetries Σ for η photoproduction on free (full dots) and quasi-free proton (open squares). The different results between 900 and 1100 MeV coincide with the minimum of the cross section and have been explained with the Fermi motion of the target nucleon. The energy values outside and inside parenthesis indicate the mean value of the bin for quasi-free and free protons respectively. Dotted and solid lines are the predictions of Maid2001 [3] for the free and quasi-free protons respectively while the dashed lines are those for the reggeized model of ref. [4].

function of γ-ray energy its width can be explained completely as due to the Fermi motion of the neutron in the deuteron while as function of the η-n invariant mass its width ($\simeq$ 40 MeV FWHM) is due entirely to the experimental resolution of our apparatus. No lower limit of the width can be derived from these experiments.

The production of strange particles in the reactions

$$\vec{\gamma} + p \to K^+ + \Lambda \ , \quad \textit{and} \quad \vec{\gamma} + p \to K^+ + \Sigma^0 \tag{4}$$

allows the measurement of double-polarization beam-recoil observables by the asymmetries in the weak decay of the strange baryons. Fig. 7 compares our preliminary results [8] for the angular distributions of the beam-recoil observables O_x and O_z with the theoretical Coupled Channel calculations of Bonn [9] and the Regge Plus Resonance calculations of Ghent [10]. Beam-recoil double-polarization asymmetries for the same reaction have been measured at CLAS with a circularly polarized γ-ray beam producing the C_x and C_z observables. The consistency of the Graal and CLAS results can be tested comparing the angular distributions of a combination of the observables measured by each experiment. We must have:

$$(1 + T^2 - \Sigma^2 - O_x^2 - O_z^2)^{1/2} = (P^2 + C_x^2 + C_z^2)^{1/2} \leq 1 \tag{5}$$

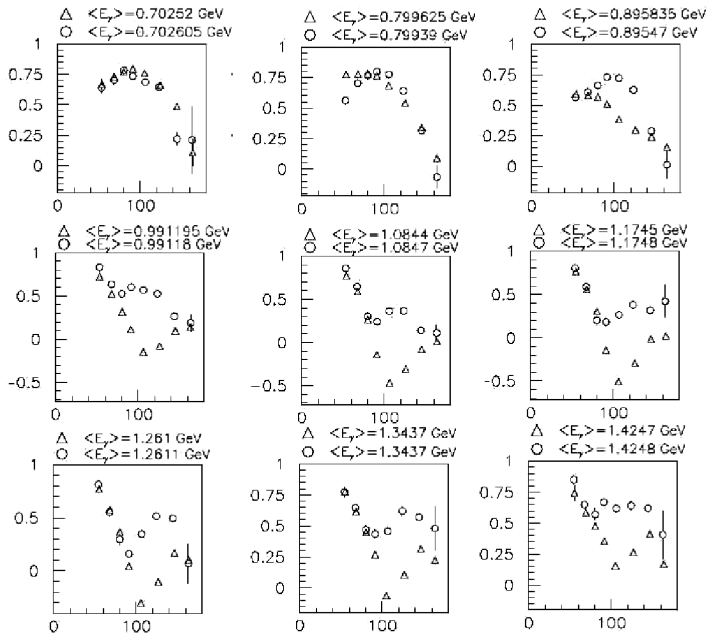

FIGURE 3. Sample of beam polarization asymmetries Σ for π^0 photoproduction on quasi-free neutron (open circles) and quasi-free proton (empty triangles). The striking differences between the two nucleons is due to isospin T=1 of the π^0.

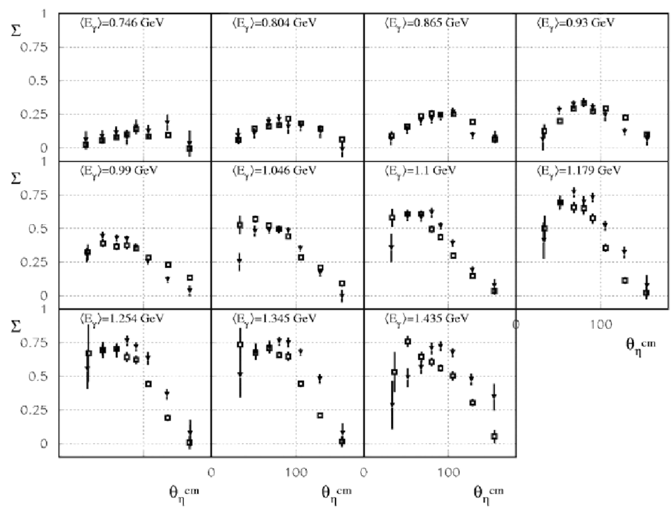

FIGURE 4. Beam polarization asymmetries Σ for η photoproduction on quasi-free neutron (full triangles) and quasi-free proton (open squares). The main differences between the two nucleons are at forward angles and at energies above 1 GeV where the proton has a peak while the neutron exhibits a more symmetric behavior around 90^o.

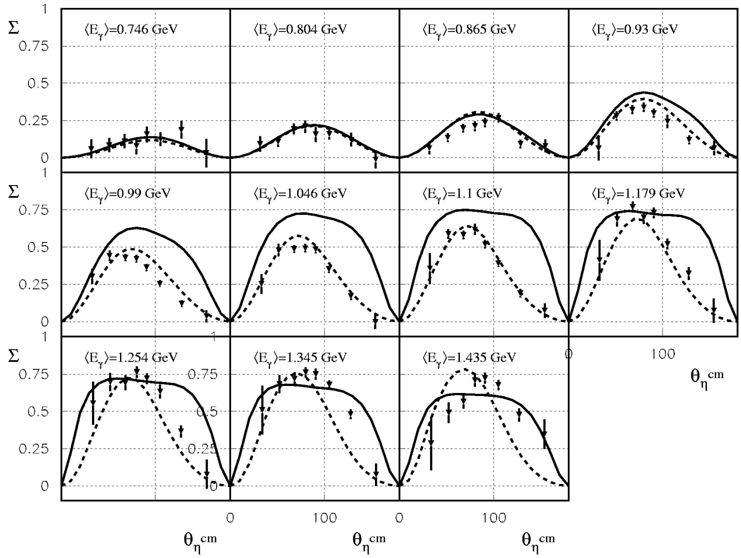

FIGURE 5. The same data of Fig. 4 for η on quasi-free neutron (full triangles). The mean energies for each bin are indicated. The solid and dashed lines illustrate the predictions for neutrons of Maid2001 and the reggeized model of ref. [4].

where the first quantity has been obtained with the Graal results and the last with those of CLAS. As indicated in Fig. 8 both conditions are reasonably satisfied.

The LEGS Spin Collaboration (LSC) has successfully operated a frozen-spin polarized HD target on the polarized and tagged Ladon beam installed on the NSLS storage ring at BNL. The HD molecule allows the independent polarization of its p and d nuclei. Figure 9 indicates the p and d polarizations during its 2004 and 2005 runs.

The LEGS tagged beam provides γ-ray with an energy between 180 and 421 MeV in the region of the Δ_{33} pion-nucleon resonance. Therefore the LSC collaboration has focused on the measurement of the E double polarization observable using a mainly circularly polarized beam on a longitudinally polarized target to verify the Drell-Hearn-Gerassimov sum rule on the nucleons. Fig. 10 provides a sample of the results obtained for the π^0 and π^+ yields as a function of the missing energy in the reconstructed kinematics when the spins of the target and the beam are oriented parallel or antiparallel. The angular distribution of the difference between the parallel and antiparallel cross sections are shown in Fig. 11. The LSC are compared with those of Mainz.

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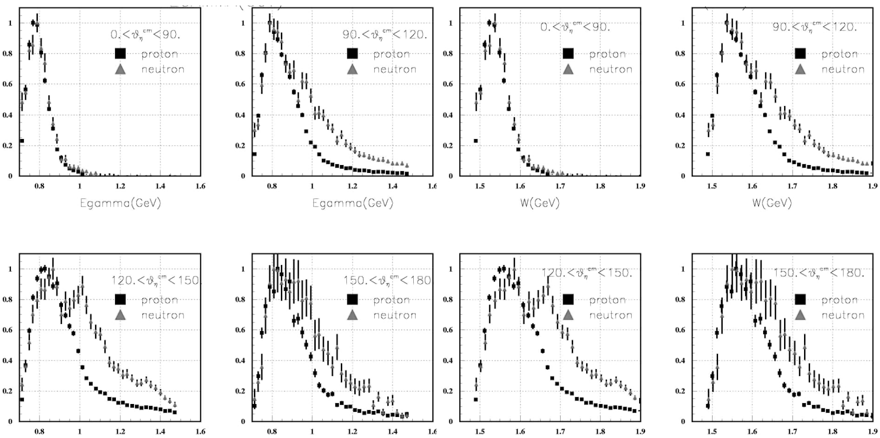

FIGURE 6. The yield for η photoproduction on the neutron (triangles) and the proton (squares) at different angles. The four picture on the left are plotted as a function of the γ-ray energy assuming a neutron at rest while those on the right are plotted as function of the invariant mass of the η-n system calculated from the measured kinematical variables of the two particles.

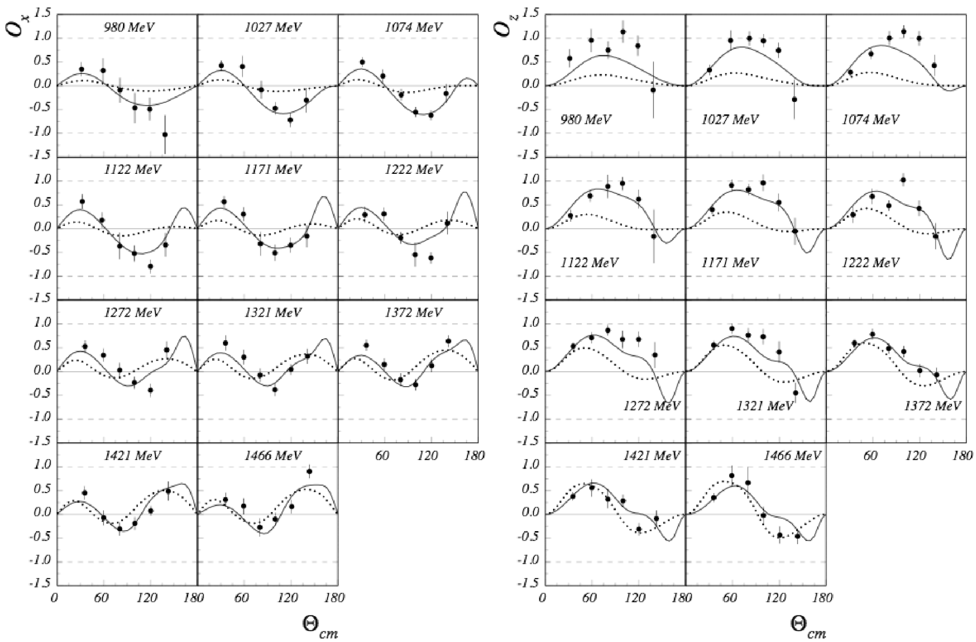

FIGURE 7. The beam-recoil double-polarization observables O_x and O_z are compared with the theoretical calculations of Bonn (solid lines) and Ghent (dotted lines) as indicated in the text.

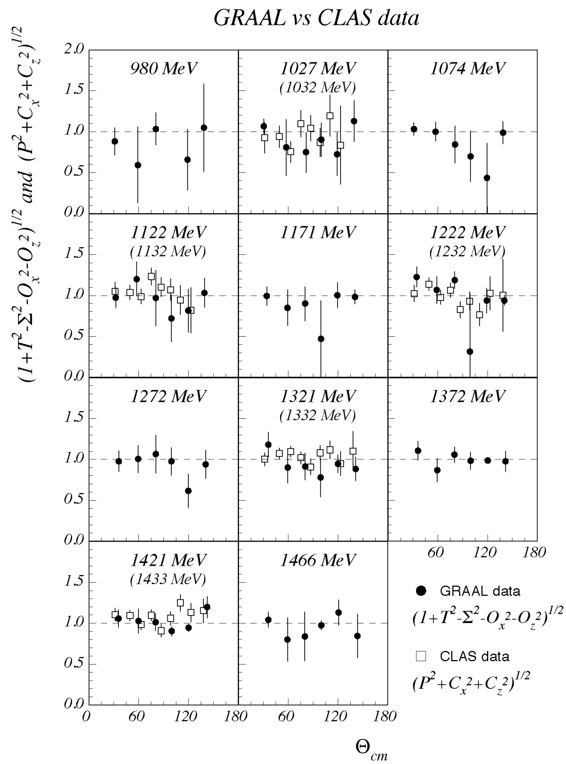

FIGURE 8. Angular distribution of the quantities: $(1+T^2-\Sigma^2-O_x^2-O_z^2)^{1/2} = (P^2+C_x^2+C_z^2)^{1/2} \leq 1$ For a comparison between the Graal and CLAS results. The combination of Graal data is indicated by full points while that of CLAS by empty squares. The Graal energies are indicated above and those of CLAS below in parenthesis.

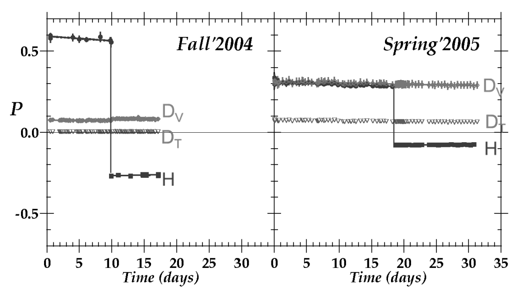

FIGURE 9. Polarizations of H (**full dots**) and D (**gray diamonds**-vector and **full squares**-tensor) nuclei in HD during the two data collection periods. Mid-way through each, the H polarization was flipped using a RF transition.

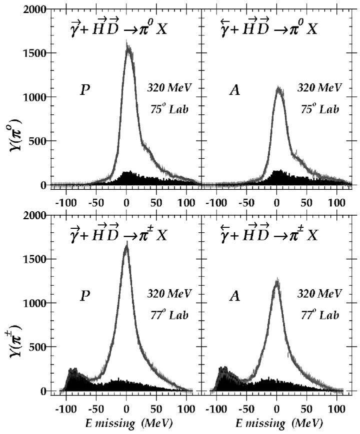

Figure 10. Differences between 2-body kinematics and the measured energy for π^0 (top panels) and $\pi^{\pm}$ (bottom panels), in the cases of parallel (left panels) and anti-parallel (right panels) beam and target spin alignments. The simulated energy differences are shown as the solid curves.

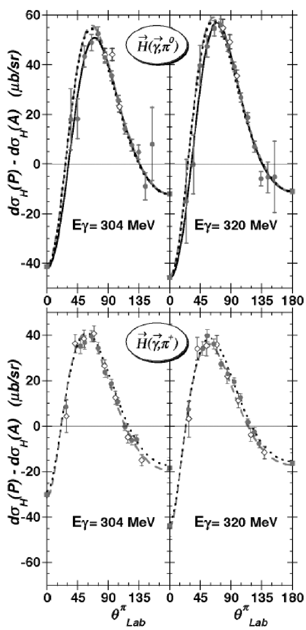

Figure 11. Angular dependence of the $[d\sigma(P) - d\sigma(A)]$ spin-difference cross section for polarized H at beam energies near the Δ peak. The full data from Fall'04 and Spring'05 are shown as solid circles. Unpolarized limits (solid squares) at 0^o and 180^o are the mean of SAID [8] and MAID [9]. Open diamonds are results from Mainz [11] at 310 MeV (left) and at 330 MeV (right). Predictions from SAID and MAID are shown as dotted and dashed curves, respectively. The solid curves in the top panels are a Legendre fit to the new data.

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