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GRAAL : a polarized γ-ray beam at ESRF*

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Abstract

The GRAAL facility produces a highly polarized gamma-ray beam by Compton scattering of laser photons on the electrons of the European Synchrotron Radiation Facility (ESRF) at Grenoble. Preliminary results have been obtained with the LAGRANGE detector showing its excellent performances.

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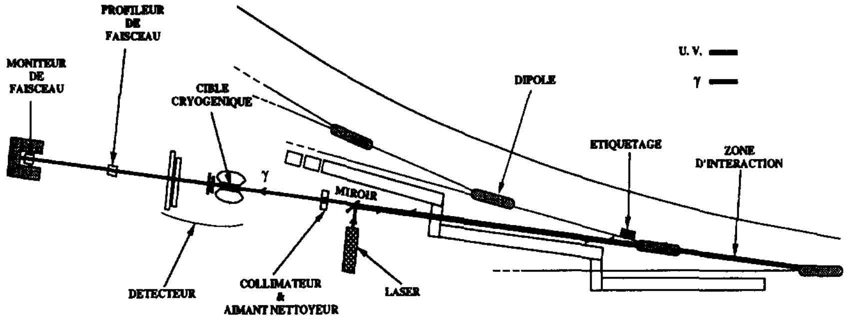

Fig. 1. *Layout of the GRAAL beam line (not in scale).*

1 The polarized gamma-ray beam

The GRAAL facility has recently become operational. It produces a tagged and polarized gamma-ray beam (400-1500 MeV) by Compton scattering of laser photons on the 6 GeV electrons stored in the ring of the ESRF in Grenoble, France.

The photon beam line is installed at a bending magnet port with a modified vacuum pipe which allows the tagging of the gamma-rays and the monitoring of the laser beam (Fig.1). The interaction region is located between two bending magnets over a distance of 6.5 meters. The argon laser produces photons in the u.v. (351 nm or 3.5 eV) with a power of 8 W, while the visible line at 514 nm is produced with a power of 12 W. The backscattering of these photons on the 6 GeV electrons of the storage ring produces gamma-rays with a maximum energy of 1.5 GeV and an intensity of 6.10^5 $\gamma.s^{-1}$. w^{-1}. The intensity of the gamma-ray beam is limited by the ESRF (preservation of the electron beam half-life) at $3.10^6\gamma.s^{-1}$, which corresponds to 2.10^6 $\gamma.s^{-1}$ at target.

The tagging system is located at the exit of the bending magnet. The electrons which have interacted with the photons and lost part of their energy are separated from the normal trajectory by at most 56 mm (maximum energy for the Compton γ-ray). The tagging detector is thus very close to the electron beam (14 mm minimum distance, i.e. 400 Mev for the Compton gamma-ray) and needs to be extremely well shielded from a very intense X-ray flux. The detector for tagging consists of silicon microstrips (300 μm step) and scintillators to obtain the fast timing of the experiment.

As compared to the bremsstrhalung method, Compton scattering provides two main advantages. Firstly, the gamma-ray energy distribution is rather flat and the low energy

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photons can be significantly reduced by collimation, resulting in a maximal flux at the Compton edge. Secondly, thanks to the small spin-flip amplitude, Compton scattering allows to produce highly polarized gamma-rays. The degree of polarization is ≈ 100% at the Compton edge for both linear and circular polarization and then decreases with energy (≈ 50% at $E_{max}/2$ for linear) (Fig. 2). The degree of polarization can be kept higher than 70% in the energy range 900-1500 MeV if one uses successively the u.v. lines around 351 nm (maximum energy for the γ-ray: 1.5 GeV) and the visible line at 514nm (maximum energy for the γ-ray: 1.1 GeV).

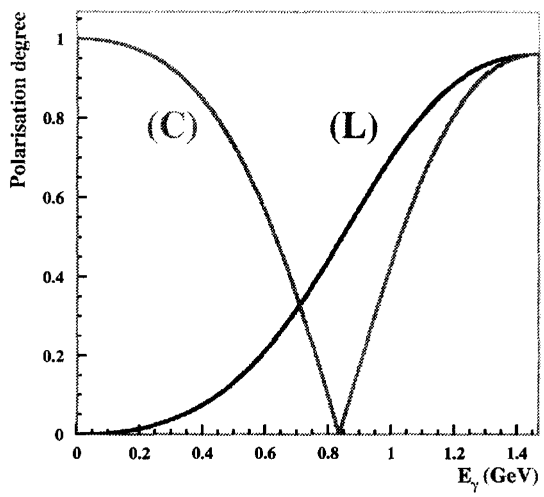

Fig. 2. *The GRAAL photon beam polarization; C: circular polarization, L:linear polarization.*

2 The experimental set-up

Approximately 30 meters downstream of the intersection region is located the GRAAL detection set-up (called LAGRANGE). The detector has a maximum solid angle coverage and has been optimised to measure intermediate energy photons and identify charged particles (protons, kaons, pions).

The calorimeter is composed of 480 BGO crystals[1] (each of them is 24 cm long corresponding to 21 radiation lengths); they are housed in 24 carbon fiber baskets (containing each 20 crystals separated mechanically and optically) that minimize the thickness of non sensitive material. The energy resolution of the BGO ranges between 3% at 1.2 GeV and 6% at 300 MeV, an important feature to analyse the multi-photon final states resulting from the pseudo-scalar mesons decays.

Inside the BGO calorimeter (20 cm diameter central hole) a tracking and particle identification system is installed (Fig. 3). It is composed of two cylindrical MWPC and 32 dE/dx plastic scintillators. The cathodes of the cylindrical chambers are stripped and the position of a charged particle should be given with an accuracy around 0.6 mm. The liquid hydrogen target is at the center of the system (3 cm to 10 cm active length for 30 mm diameter) inside a 10 cm diameter cylinder. The target can be liquid hydrogen or deuterium and a polarized target (HD, frozen spin) is under development.

The forward angles (between 0° and 25°) are not covered by the BGO calorimeter. The charged particles emitted in these directions are tracked by two plane MWPC and a large scintillator wall, located at 3 meters from the target, measures their time-of-flight. Behind the scintillator wall an electromagnetic shower detector, made of layers of lead and scintillator, detects gamma-rays and neutrons (with ≈10% efficiency).

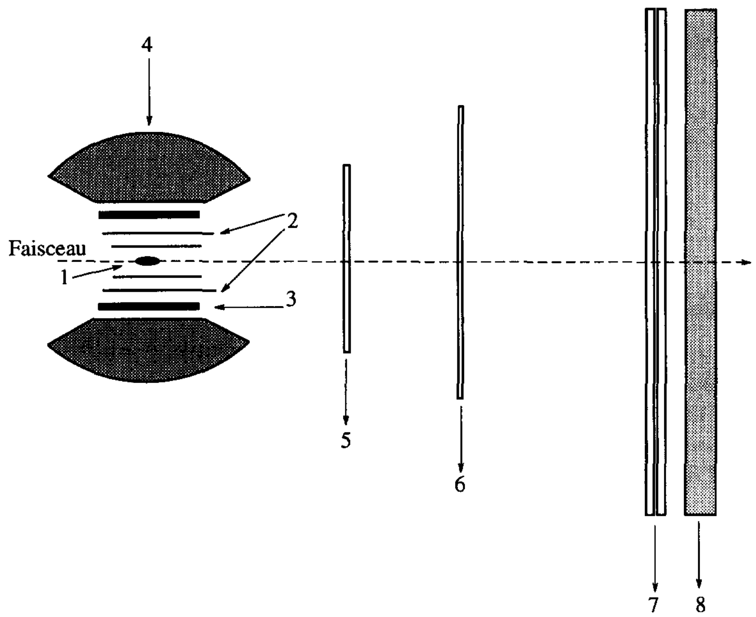

Fig. 3. *The LAGRANGE detection set-up: 1)Target. 2)Cylindrical wire chambers. 3)Plastic scintillators. 4)BGO calorimeter. 5)6)Plane chambers. 7)Scintillator wall. 8)Shower detector.*

3 Experimental program

The initial program is focused on the η photoproduction. The polarization observables are known to be very sensitive to check the theoretical models and the reaction mechanism. The observable Σ represents the beam polarization asymmetry and is expressed

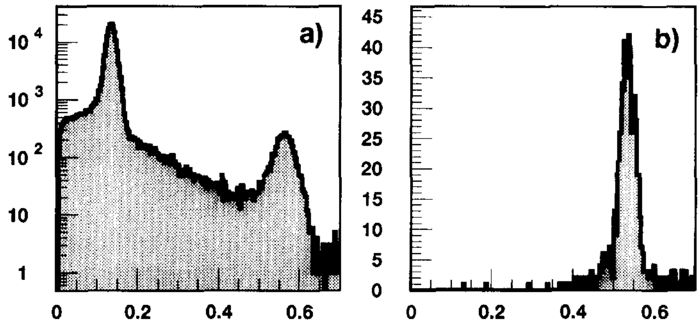

Fig. 4. *Invariant mass for a) two photons b) six photons in the BGO.*

by:

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_o (1 - P_\gamma \Sigma \cos 2\phi_{lab}) \tag{1}$$

where $\frac{d\sigma}{d\Omega}$ represents the differential cross section for a given state of polarization, $\left(\frac{d\sigma}{d\Omega}\right)_o$ the unpolarized differential cross section, P_γ the degree of linear polarization of the beam and ϕ_{lab} the azimuthal angle of the reaction plane in the laboratory. This distribution is easily accessible thanks to the cylindrical symmetry of the detector and great improvements in the rather sparse existing data are expected. The η meson can be identified through their 2γ decay in coincidence with the recoil proton in the forward direction. A preliminary 2γ invariant mass obtained during the first experimental runs is shown in fig. 4. A very clean η peak is observed with negligible background. The quality of the data that can be gathered with this detector is clearly demonstrated when the 6γ invariant mass ($\eta \rightarrow 3\pi_o \rightarrow 6\gamma$ is calculated; the η peak clearly shows up with no background events.

The next experiment will be the study of strangeness photoproduction through the channel: $\gamma + p \rightarrow K^+ + \Lambda$. The polarization observables P (asymmetry of Λ decay) and Σ can be measured together with the double polarization observables O and C. With a polarized target a complete set of polarization observables could be obtained. With a polarized target and a circularly polarized beam the GDH sum rule can also be tested.

The preliminary data analysis[2] of the π° photoproduction has been performed and the asymmetry Σ has been calculated as a function of energy and angle. These results, in very good agreement with the expected behaviour, are too preliminary to be presented.

4 Conclusion

The GRAAL facility is starting a large experimental program devoted to cross section and polarization observables measurements for the pseudo-scalar meson photoproduction reactions. The characteristics of the beam and of the experimental set-up are very well suited for the study of final states with many intermediate energy photons or with three charged particles. In the future the GDH sum rule could be tested when the polarized target will be available.

References

[1] P. Levi Sandri et al., *Nucl. Instr. and Methods* **A370** (1996) 396.

[2] P. Calvat, *Thèse de l'Université de Grenoble* (1997).