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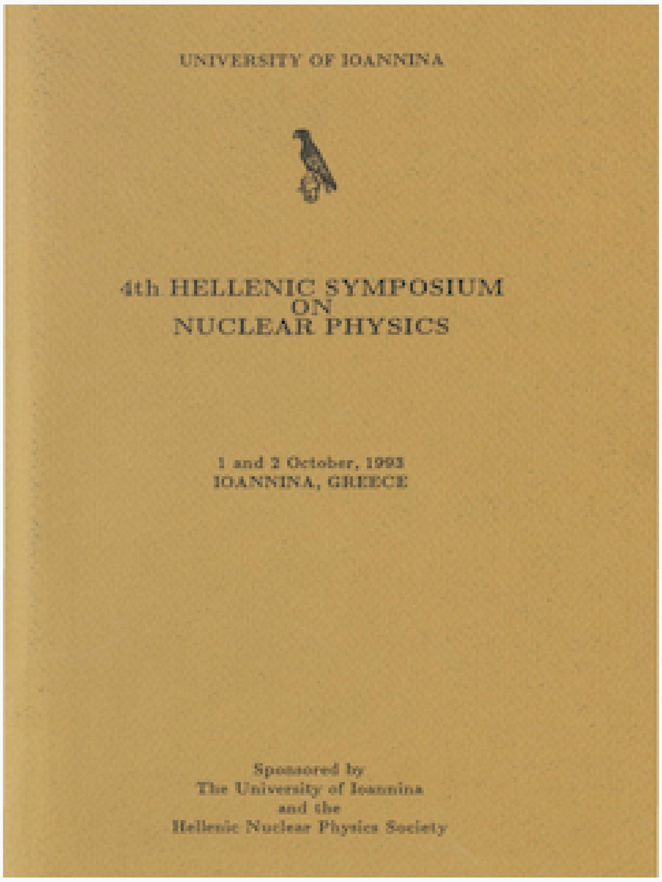

PTOLEMEOS: A 4π γ-detection system for Nuclear Astrophysics

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PTOLEMEOS: A 4π γ-detection system for Nuclear Astrophysics [1]

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Abstract

A new 4π detector system, called PTOLEMEOS, especially designed for the study of (p,γ) and (α,γ) reactions of astrophysical interest is presented. Technical data of the target system designed for PTOLEMEOS are also given.

1 Introduction and Motivation

Nuclear astrophysics, an interdisclipinary field of astronomy and nuclear physics, has mainly devoted itself to the explanation and understanding of the distribution of the elements and their isotopes observed in the universe: The reproduction of the so called *universal abundance curve* is one of the most interesting tasks for nuclear astrophysicists. This task can be partly carried out by studying the element-synthesizing processes in the laboratory, i.e. by determining the cross sections and reaction rates of different nuclear reactions. According to the famous paper of B^2FH [1] the element synthesizing processes can be categorized as:

- Hydrogen burning,
- Helium burning,
- C-,O-,Si-burning,
- r-process,
- s-process, and
- p-process.

The universal abundance curve and the mass regions, where each of the above processes is the dominant element-sysnthesizing mechanism, are shown in fig. 1.

[1] Presented by S. Harissopulos

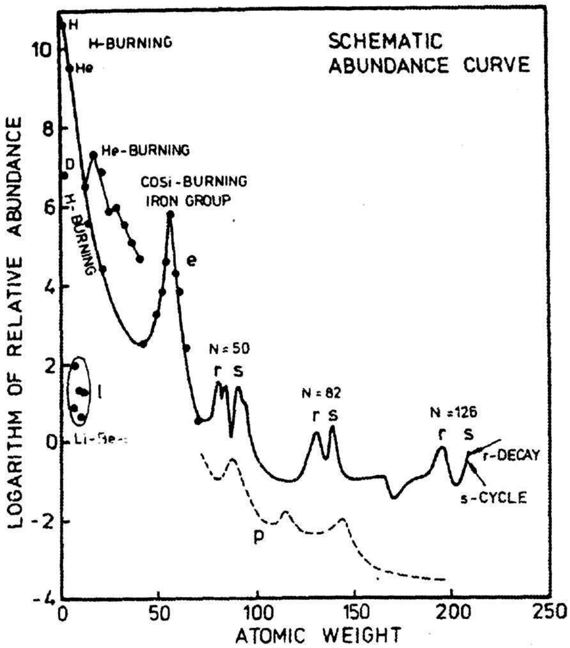

FIG. 1: Abundance curve of the universe (from ref. [1])

A detailed description of the element synthesizing proccesses is given in ref. [2]. Here, we will only refer to some basic principles of the p-process. This mechanism is responsible for the production of some nuclei above Iron, which are characterized as *proton rich* nuclei and are located on the left-hand side of the stability curve. These nuclei are produced mainly by proton capture i.e. (p,γ)-reactions and/or photo-nuclear reactions. A chart of the proton rich nuclei is given in fig. 2.

The γ-ray detection system PTOLEMEOS presented here is designed to measure cross sections of (p,γ) and (α,γ) reactions of astrophysical interest. The main motivation hereby was the fact that the p-process has not been so far intensively investigated due to the very small cross sections involved. The data which can be obtained from measurements with PTOLEMEOS could serve as input parameters for reproducing theoretically the abundances of the observed p-nuclei.

2 Description of PTOLEMEOS

2.1 The operation principle of PTOLEMEOS

In a typical (p,γ) or an (α,γ) reaction the produced nuclei are at some excited state. As it shown in fig. 3a, these nuclear states can decay to the ground state via different γ-cascades. The γ-spectrum measured with a common "small" γ-ray

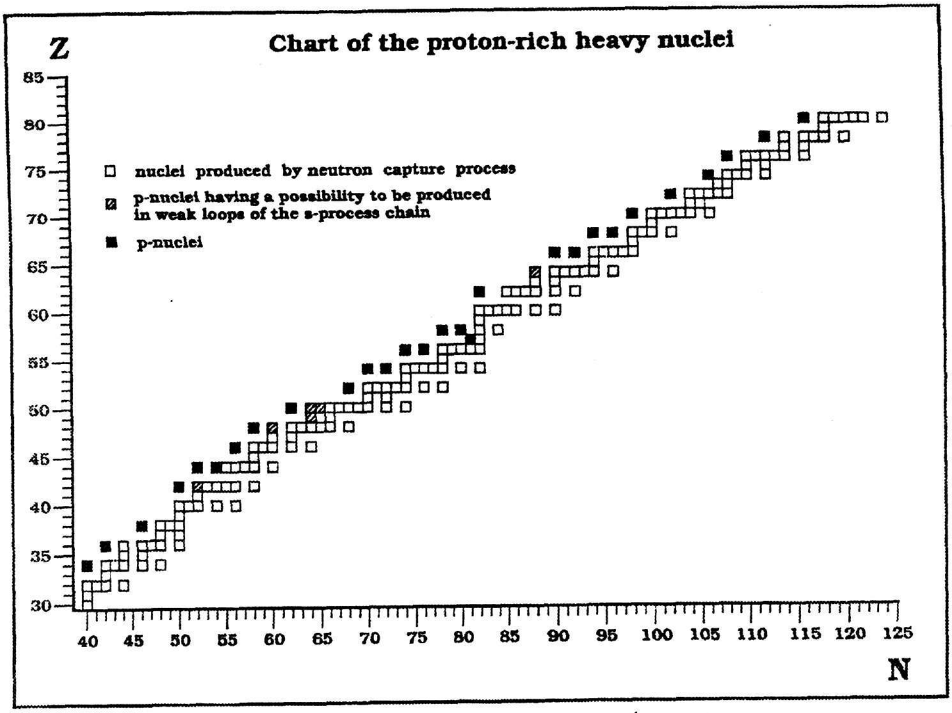

FIG. 2: Chart of the proton rich nuclei (from ref. [3])

detector contains all the γ-rays deexciting the compound nuclei and, due to the respective Compton background, can be rather complicated (see fig. 3b).

In order to determine the total cross section of a given (p, γ)-reaction it is necessary to measure the intensities of _all_ γ-lines of the spectrum which belong to the nucleus of interest. This task is not always simple because of the complexity of the spectrum. Furthermore, by taking into account that the intensity of a γ-ray depends on the detection angle, an extra angular distribution measurement has *also* to be carried out for _each_ γ-line of the spectrum. These problems however can be avoided by using a detector, which:

1. Covers a 4π-geometry. Then, no angular distribution measurements are needed.
2. It is large enough, so that no γ-rays escape from inside. In this case the Compton background is eliminated and therefore the measured spectrum is rather simple to be analyzed.

A detector fulfiling t: above conditions, often called 4π calorimeter, would provide a rather simple spectrum like this of fig. 3c; Such a calorimeter simply sums all the γ-rays absorbed by it and instead of "seeing" n γ-lines of different energy, i.e. $\gamma_1(E_1)$, $\gamma_2(E_2)$, $\gamma_3(E_3)$, ..., $\gamma_n(E_n)$, it "sees" only one γ-ray [2] having an energy E equal

[2] Hereby, it is assumed that the time needed by the detector to distinguish between two different γ's, i.e its *rise time*, is longer than the time intervall between emmission and absorbsion of one γ. This condition is almost always fulfiled as the rise time of the detectors lies in the μs - ns region.

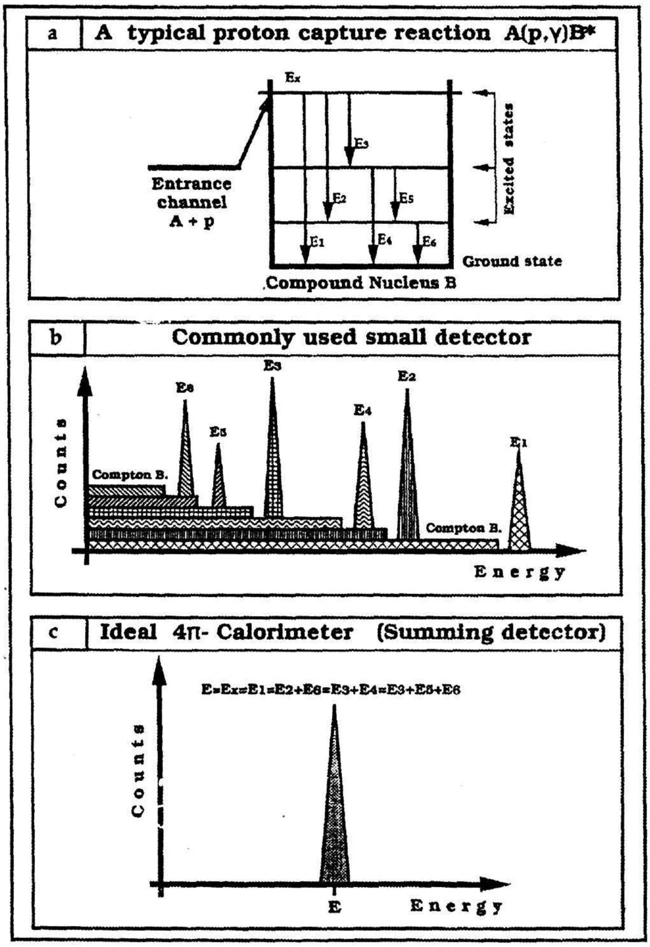

FIG. 3: The operation principle of PTOLEMEOS

to the excitation energy E_x of the highest state populated by the reaction. For the case shown in fig. 3 this means that $E = E_x = E_1 = E_2+E_6 = E_3+E_4 = E_3+E_5+E_6$

2.2 The crystal barrel

The main component of PTOLEMEOS is a "barrel" of about 80 Kgr weight, which is sketched in fig. 4. It is consisted of two large NaI(Tl) crystals (Ø305 × 152.5 hgt) of cylindrical shape. As shown in fig. 5, each of them has a bore along its symmetry axis and is segmented in 4 equal parts (*segments*). The barrel is also bored (Ø83 mm) vertical to its symmetry axis in order to allow the installation of two extra NaI(Tl) detectors. Hence, by putting a target at the centre of the barrel, a 4π geometry can be covered for the γ-rays deexciting the compound nuclei produced in the target.

Energy and time signals from the 8 segments with typical rise time of about

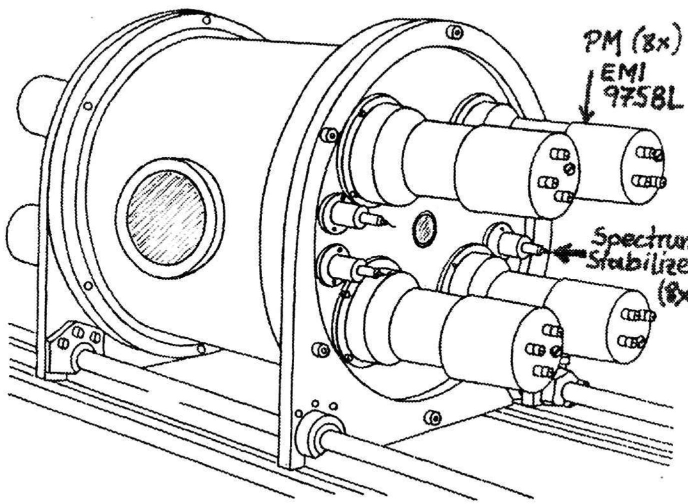

FIG. 4: The crystal barrel of PTOLEMEOS

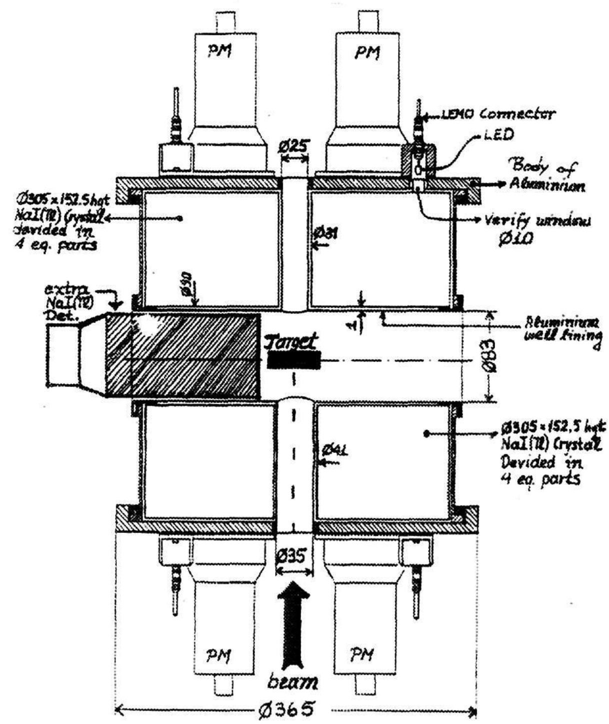

FIG. 5: Technical drawing of the crystal barrel: "bird view"

2 μs and 100 ns respectively are taken via 8 photomultipliers of type EMI 9758L. In addition 8 LEDs of type MONSANTO MV 5252 are coupled to the 8 segments serving as spectrum stabilizers. The energy resolution of the segments varies between 9-10 %. In order to achieve the desired 4π geometry 2 extra NaI(Tl) detectors are used, with a typical energy resolution of 6%. These extra detectors can be replaced by Ge detectors for other types of experimets. In the latter case the crystal barrel could serve as an anticompton shield in order to reduce the compton background in the spectra taken with the Ge detectors. A photo of the crystal barrel with one extra NaI(Tl) detector and one Ge detector is shown in fig. 6. A "bird" view of the system with 2 extra Ge detectors is shown in fig. 7.

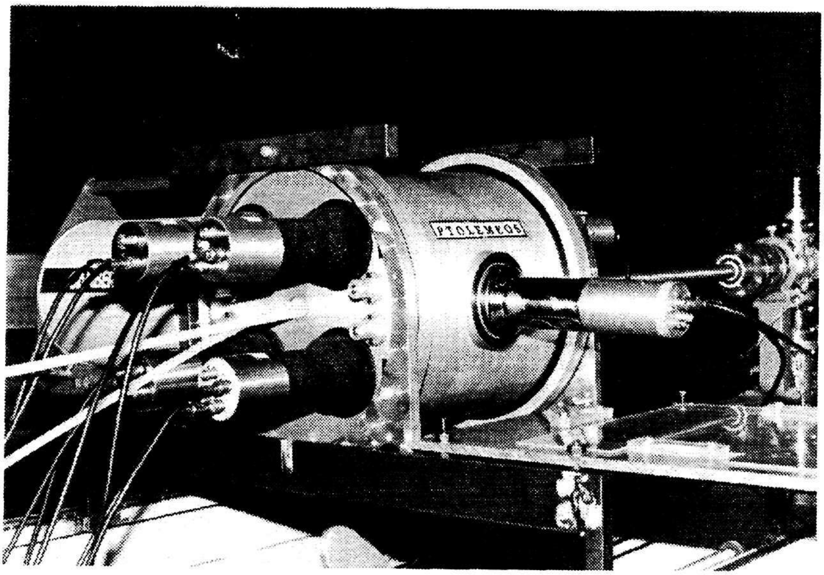

FIG. 6: Side view of PTOLEMEOS

The whole detector system is placed on a railway fixed on an iron frame which "seats" on a wagon. This frame can be aligned to all directions via ten independently rotating screws. The height of the wagon from the floor can be also easily adjusted via 4 independent jacks. A photo of the whole system is shown in fig. 8.

2.3 Beam line and target system

The experimental study of the p-process is in most cases a difficult task due to the very small cross sections involved. In order to carry out a (p,γ) or an (α,γ)

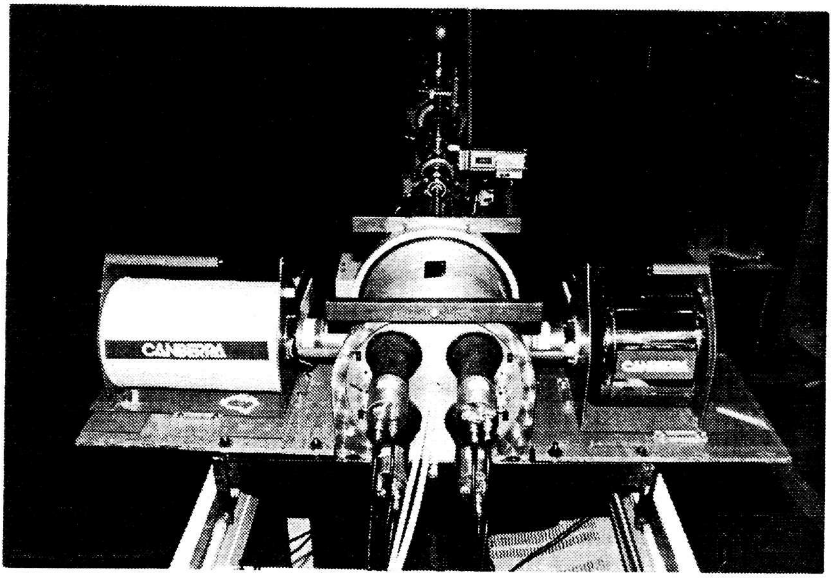

FIG. 7: Bird view of PTOLEMEOS

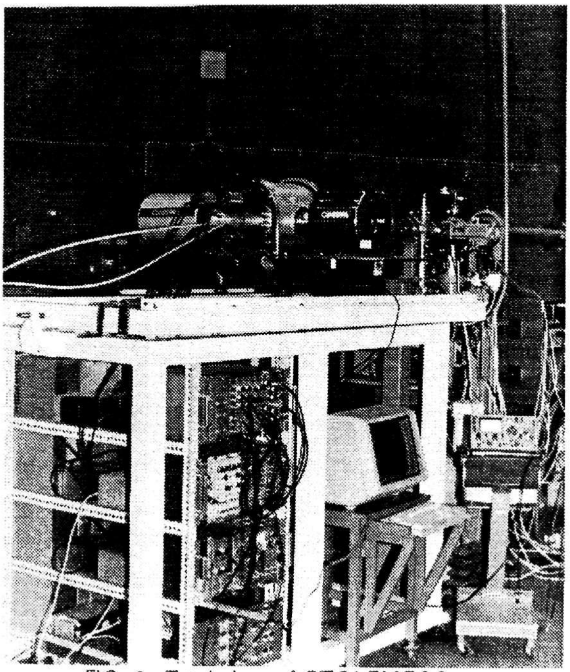

FIG. 8: Total view of PTOLEMEOS

was chosen. According to ref. [4] it has sufficiently low outgasing rate comparable to that of glazed porcelain. For the beam collimating part of the target system 4 viton rings were necessary to act as insulators. This part, however, will be replaced with a new one in which only metal and ceramics will be used.

In the target system the target holder is actually the "back side" of the cooling part of the system. The cooling system was necessary to avoid destruction of the target due to the heat deposited on it by the high beam current. As the target could also be destroyed by the high pressure apllied on it by the projectiles, it has to be backed.

The cooling system can be mechanically mounted on the target tube by tightening a hollow brass cyclinder. As vacuum sealing material between the target holder and the tube, a lead ring of about 1 mm thickness was used. This ring has been proved quite sufficient for sealing: Up to now, an "off beam" vacuum of 0.5×10^{-8} Torr has been achieved, without using the 3 cooling traps of the beam line. This vacuum is comparable to this achieved when using Indium instead of Lead. Indium has been used by other experimentalists [5,6] quite succesfully. In our case however lead was chosen not only because of its good "sealing ability" but also due to its price, which is much lower than this of Indium. A photograph of the target system of PTOLEMEOS is shown in fig 10. A view of the target system placed in the crystal barrel is shown in fig. 11.

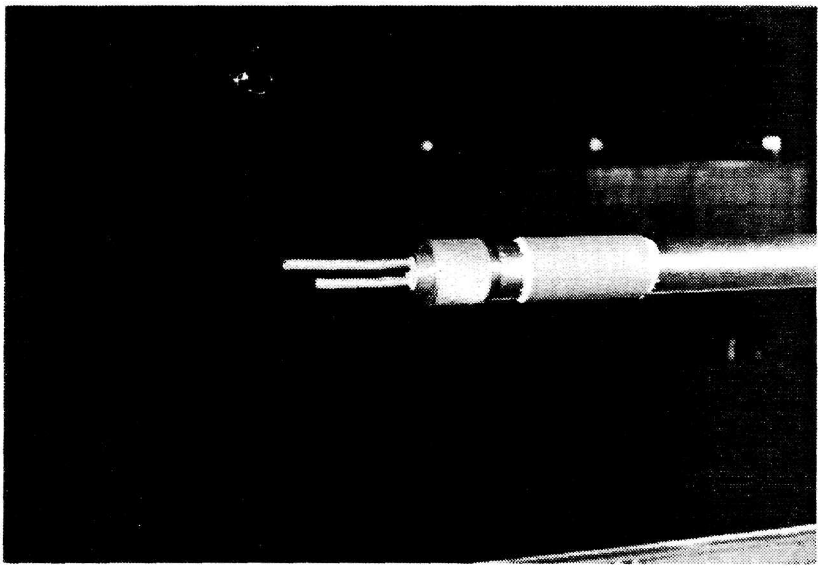

FIG. 10: Photo of the target system of PTOLEMEOS

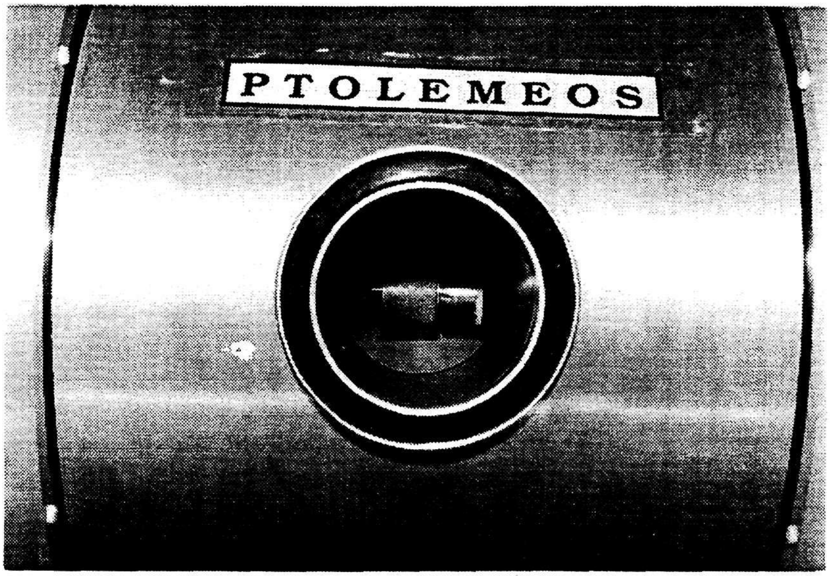

FIG. 11: The target system in the crystal barrel

3 Preliminary tests of PTOLEMEOS and further tasks

In order to check the ability of PTOLEMEOS in summing γ-rays we used a ^{60}Co source and "added" the energy signals from the 8 segments. This "addition" was performed via the simple circuit shown in fig. 12. Before summing the signals from the 8 segments, they have been all gain matched using the potensiometers of the 8 Photomultipliers and, fo- fine gain matching, the 5 $K\Omega$ potensiometers of the summing unit of fig. 12. The resulting spectra of ^{60}Co when adding signals from a) one half of PTOLEMEOS (4 segments) and b) all the 8 segments are shown in fig 13a and 13b respectively. The sum peak shown in fig 13b. does not correspond to the maximum "summing efficiency" of PTOLEMEOS since no 4π geometry was covered; The two extra NaI(Tl) detectors were hereby not used.

Before starting carrying out experimets with PTOLEMEOS the following tasks have to be completed.

1. Efficiency calibration of PTOLEMEOS: For this purpose theoretical calculations using the code GEANT [7] are in progress.

2. Shielding of PTOLEMEOS against natural radioactivity and cosmic rays: For the shielding, a lead "inner box" of about 5 mm thickness will cover PTOLEMEOS

measurement "efficiently" the following experimental conditions have to be fulfiled:

1. *High beam current.*
2. *Very good vacuum.*
3. *Elimination of every kind of background.*

In order to work with a good vacuum, a beam line including 3 cooling traps and 4 turbo pumps was chosen. Three of these pumps have a volume flow rate R=170 l/s (for N_2) and one has R=50 l/s. The latter pump is located at the entrance of the target system at a distance of about 1.2 m from the target position.

The beam line chosen for PTOLEMEOS is O-ring free. This is very crucial since the beam can easily split hydrocarbons outgased by the O-rings; The resulting cruckproducts and/or carbon can be deposited on the target causing carbon induced reactions. This problem was taken into account when designing the target system, which is shown in fig. 9: As sealing material and/or isolating material hard PVC

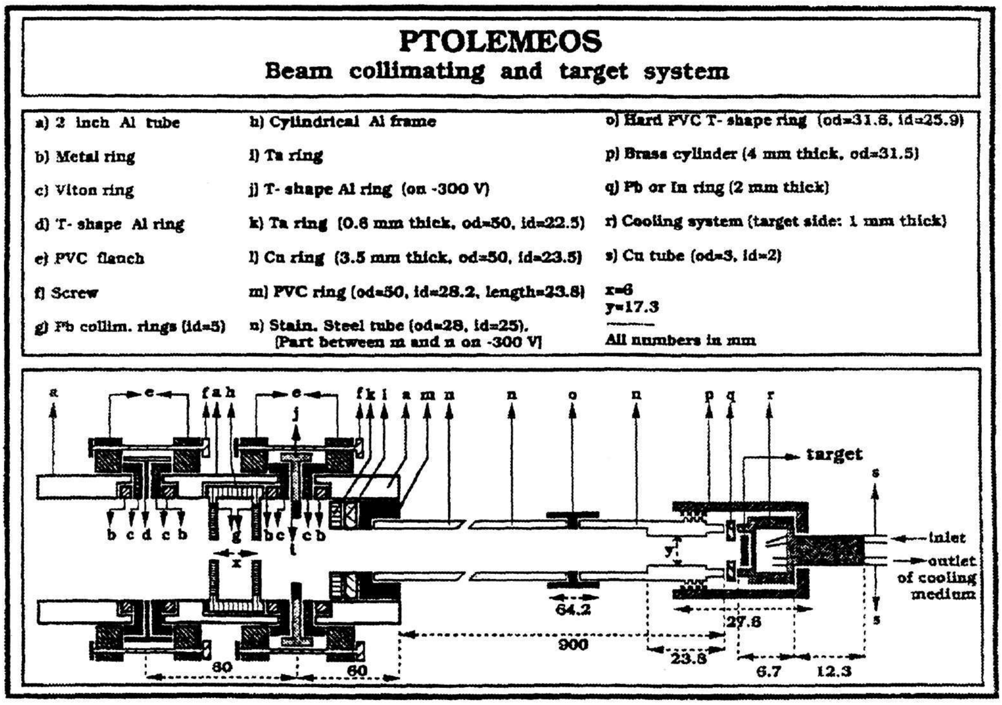

FIG. 9: The target system designed for PTOLEMEOS

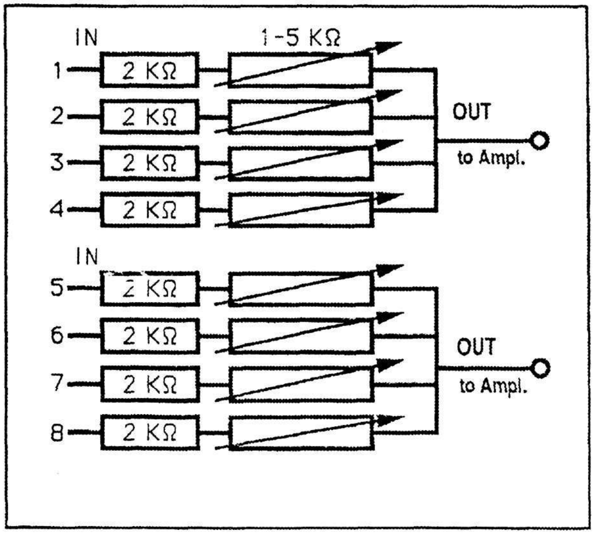

FIG. 12: The electronic unit for summing energy signals from the segments of PTOLEMEOS

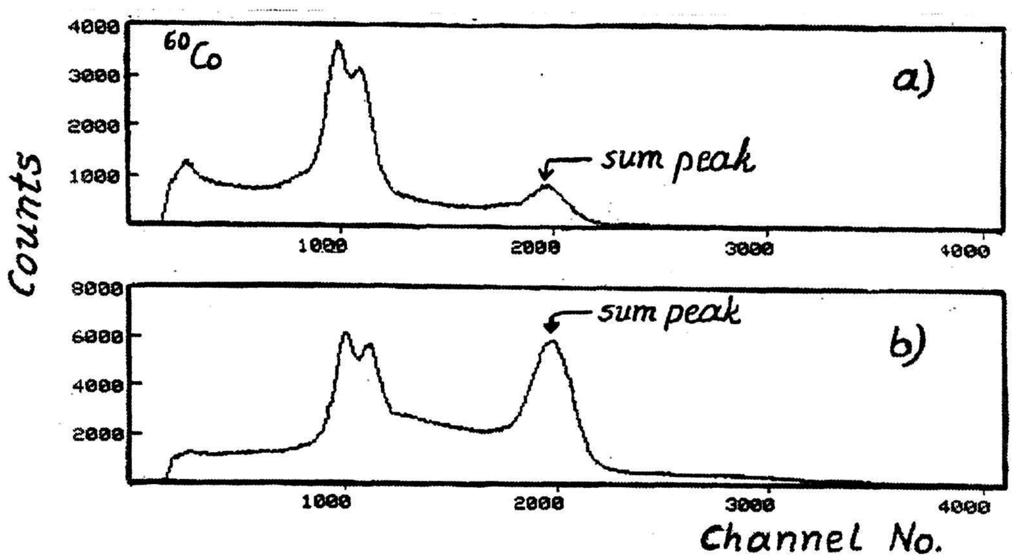

FIG. 13: "Sum" spectra of ^{60}Co taken with PTOLEMEOS

completely. This box will be surrounded by 6 plastic scintillators, each covering a side of the inner box. In addition an outer lead box will also cover the scintillators. The frame for this construction, which has to be relatively easy to translate when a target change has to take place, will be about 2 tons heavy and is under design.

Summing up, PTOLEMEOS is a new 4π detector system for measuring cross sections of nuclear reactions involved in the p-process. Preliminary tests have shown that PTOLEMEOS works properly. After efficiency calibrating the system it is expected to run the first experiments in summer 1994.

REFERENCES

[1] E.M. Burbidge, G.R. Burbidge, W.A. Fowler and F. Hoyle, Rev. Mod. Phys. 29(1957)547

[2] C.E. Rolfs and W.S. Rodney, Cauldrons in the Cosmos, (The University of Chicago Press, Chicago, 1988)

[3] K. Ito, Prog. Theor. Phys. 26(1961)990.

[4] N.T.M. Dennis and T.A. Heppell, Vacuum System Design, (Chapman and Hall, London, 1968) p.128

[5] T. Schange, Diplomarbeit, Münster, 1990, unpublished

[6] M. Junker, Diplomarbeit, Münster, 1992, unpublished

[7] Code GEANT, Vers. 3.16, Cern Library (CERN)