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The gamma ray spectrometer GA.SP

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GA.SP is a general purpose 4π detector array for advanced γ-spectroscopy and, in the same time, a suitable system for reaction mechanism studies. The detector is sited at the LNL Tandem+Linac accelerator and has been built as a joint project of INFN Padova, LNL, Milano and Firenze. The array consists of 40 Compton suppressed HPGe detectors and of a 4π calorimeter composed of 80 BGO crystals. The detector houses a reaction chamber of 34 cm diameter where a charged particles multiplicity filter composed of 40 Si detectors is going to be installed. Evaporation residues produced in the centre of GA.SP can be injected into the recoil mass spectrometer (RMS, named CAMEL) in use at LNL, without the need to remove any of the gamma detectors. The coupled operation of GA.SP, RMS and Si ball will give a unique instrument for identification and study of weak reaction channels.

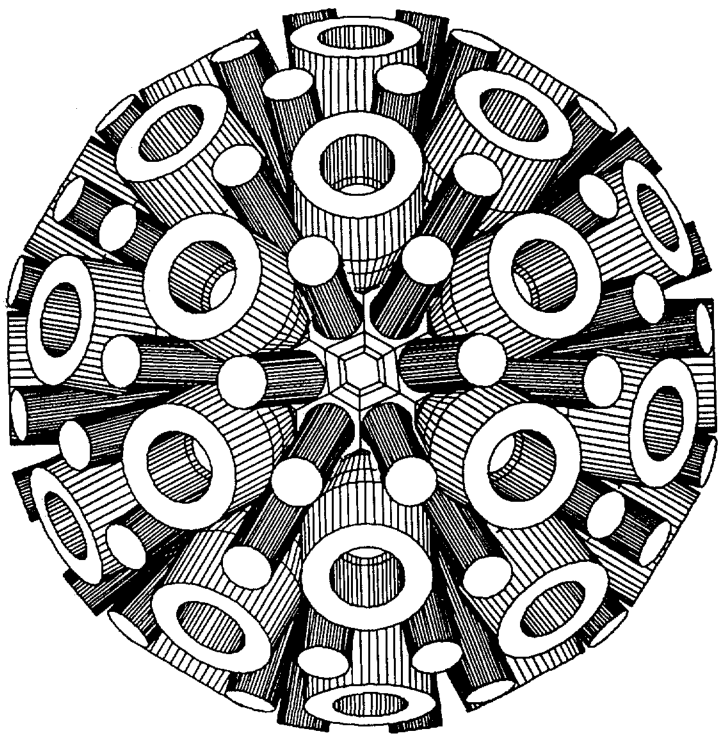

Figure 1: Downstream view of the array (and Logo of GA.SP).

The geometry of the detectors array is based on the polyhedron with 122 faces which can be built starting from the icosahedron or from its dual, the dodecahedron. The inner ball uses 80 of these faces while the remaining 42 faces are used for the beam ports and for the 40 Ge+Ac systems. Fig. 1 shows an artist's view of the array. In order to simplify the drawing only the active parts of the detectors and the photomultiplier tubes of the inner ball are shown.

The 4π γ-detection systems proposed in recent years try to maximize the photopeak efficiency by means of non-standard germanium designs and of shared Compton suppressors. In this respect GA.SP is a detector system of the standard type as it uses individual Compton suppression shields. The increase of efficiency is obtained using the big volume germanium crystals which became available in recent years. Our HPGe detectors are built out of n-type cylindrical crystals of 72 mm diameter and about 82 mm length. The detectors have a taper of 10 degrees on the last 3 cm and are housed in an 87 mm diameter end cup. The mean relative photopeak efficiency of the detectors delivered until the time of this writing (36) is (see Fig. 2) about 83% at 1332 keV. The average energy resolution of these detectors is 2.2 keV.

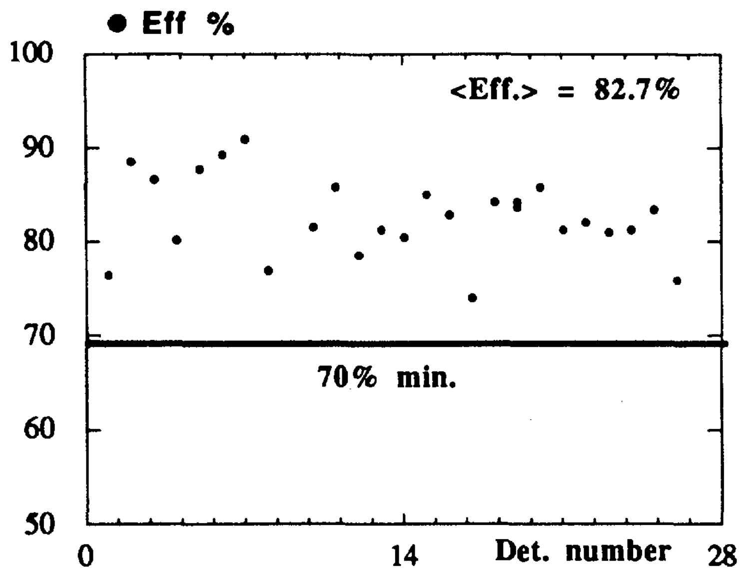

Figure 2: Relative photopeak efficiency at 1332 keV for the first 28 germanium detectors.

Compton suppression is performed by symmetric BGO shields composed of eight 19.5 cm long optically isolated crystals. Each of the 8 pieces has its own photomultiplier tube although the individual anode signals are summed together before being sent to the processing electronics. The dimensions and the cost of the BGO crystals have been optimized by means of extensive Montecarlo calculations exploiting the benefits of the higher intrinsic P/T of the big volume germanium crystals.

When using the inner BGO ball, the germanium detectors are positioned at 27 cm from the target; the detectors of the inner ball act as a partial collimator and the solid angle subtended by the germanium detector is 0.26%. In this situation the calculated absolute photopeak efficiency is 0.086% and the P/T is about 70% at 1 MeV. A measurement of the absolute photopeak efficiency at 1332 keV, performed using the sum energy of the two ^{60}Co lines, has given 0.074% which translates to about 3% for the complete system. Tests performed with the ^{60}Co source have given

Compton suppressed spectra with a P/T of 65%, as shown in Fig. 3. This results confirm that, as planned, GA.SP has the best response function among the arrays being built at present.

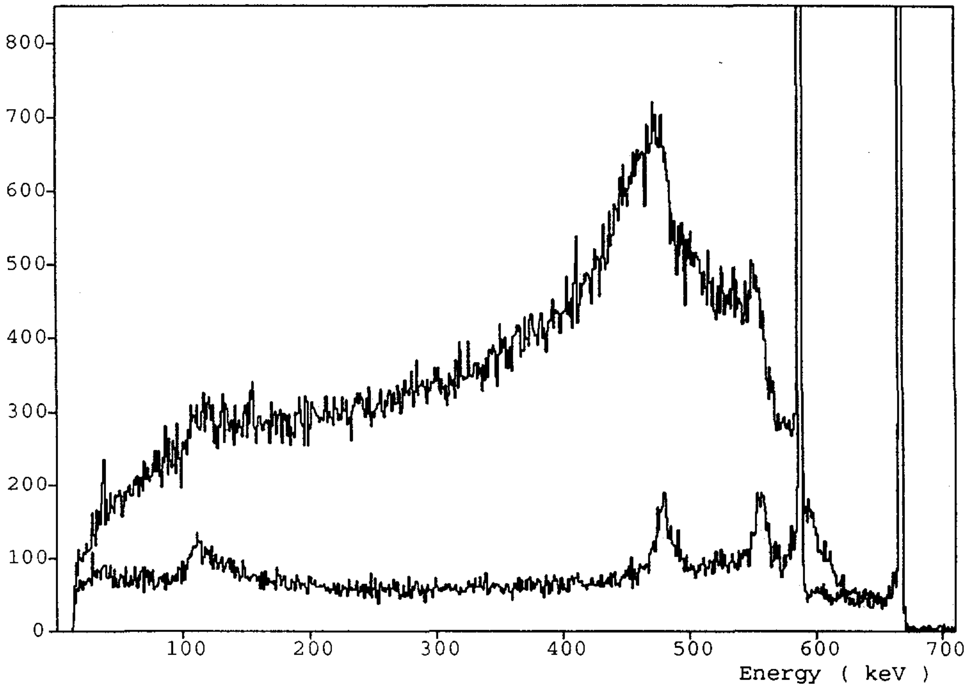

Figure 3: ^{60}Co spectra with (P/T = 65%) and without (P/T = 29%) Compton suppression.

The target-germanium distance can be reduced to 20 cm if the inner ball is removed and if the increased doppler broadening (which, for a recoil velocity of 4% changes, on the average, from 7 keV FWHM to 9 keV at 1332 keV) can be accepted. As in this way one could gain about a factor of two in detection efficiency the holding structure has been designed in order to allow for this option. However the detection efficiency is not the relevant feature and one should better compare the resolving power. This is defined normally as

$$R = \frac{SE_\gamma}{\Delta E_\gamma} \frac{P}{T} \tag{1}$$

where SE_γ is the average separation of the gamma lines, ΔE_γ is the width of the peaks and P/T is full energy fraction of the response function. Under the usual assumptions of a gamma multiplicity of 30, a neutron multiplicity of 4, and a recoil velocity of 4% and a separation energy of 60 keV we have R=4.8 for the configuration with the inner ball and R=3.3 without it. In view of the different efficiency of the two configurations the average fold is 0.84 and 1.4 respectively. Finally if one takes as a figure of merit the expression $R^{<F>}$ and keeping in mind that the affect of the inner ball is estimated to give roughly a factor of two one ends up with about 8 and 5 for the two cases respectively.

For detection of high energy gamma rays the AC+Ge system can be operated in the add-back mode. At 20 MeV the calculated total efficiency is 0.36% ; the full energy peak has a FWHM of 1% and the P/T is about 20% .

The inner ball is built out of 80 hexagonally shaped 6 cm thick BGO crystals of two slightly different shapes but with almost exactly the same efficiency. The ball covers a solid angle of 80% and, according to Montecarlo simulations, it has an absolute efficiency of about 75% at 1 MeV and a resolution of 30% for a cascade of 30 transitions. Tests with radioactive sources are in progress in order to obtain the detailed response function of the BGO ball. In the first phase of operation of GA.SP only a reduced set of parameters will be taken from the inner ball and namely the fold k and the sum energy H. A planned improvement foresees the acquisition of both energy and time for every detector of the ball in order to obtain the details of the hit pattern and of the timing and total energy of the event.

One of the most interesting characteristics of this project is the coupled operation of GA.SP and RMS. As this is achieved without removing any gamma detector we get an increased resolving power without sacrificing detection efficiency.

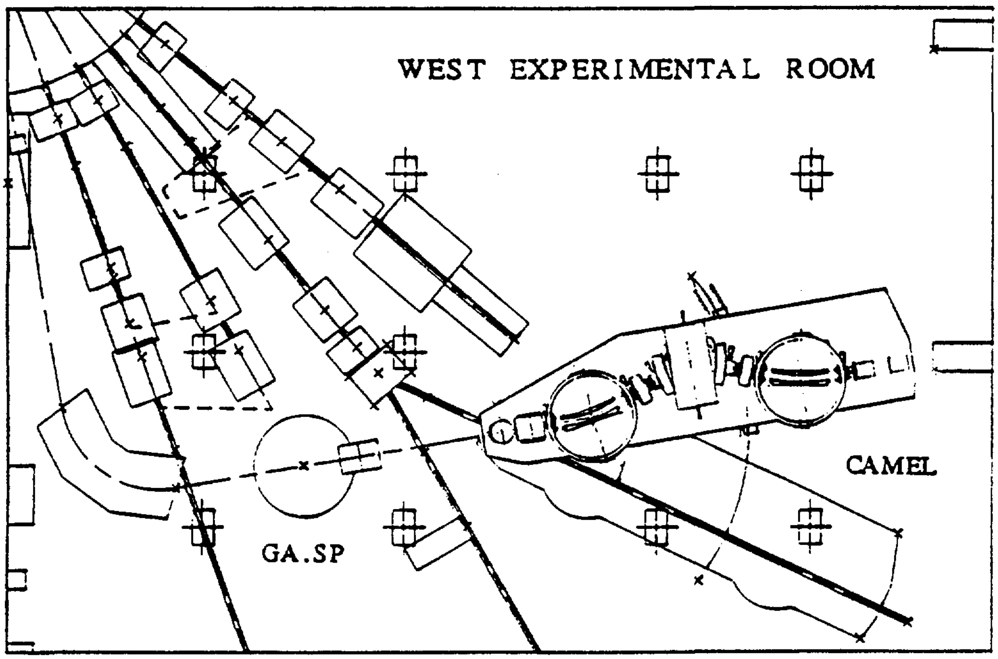

Figure 4: The experimental area with GA.SP and RMS.

The distance between the two spectrometers, as one can see in the layout of the experimental area shown in Fig. 4, is about 4 metres and the coupling of the two instruments is obtained by means of a magnetic quadrupole doublet, positioned at 70 cm from GA.SP, which focuses the recoils on the actual target position of RMS. Ray tracing calculations give an overall acceptance of the coupled system of about 5 msr (compared with 10 msr when the target in the RMS chamber) with $\Delta E/E$ of 10% and a mass resolution of 1/170 for a central mass A=100. This acceptance is sufficient to collect almost 100% of the residues from HI induced reactions with evaporation of only neutrons and protons.

The signals from the 160 gamma detectors are worked out by dedicated electronics and acquisition system. Most of the electronics has been designed and home built with the goal of having a compact and reliable system with computer control of some of the most important features. Among the modules we will just mention the four channels Camac Constant Fraction Discriminator (which contains a Timing Filter Amplifier, the logics to perform the Compton suppression and a Gate and Delay Generator for the output signals) the Linear and Logic Multiplexers, used to inspect the relevant signals without disconnecting cables, and the Linear Gate and Stretcher module which acts as an interface to the ADC system. Considerable effort has been spent in order to obtain the best performances from the germanium detectors both in terms of energy resolution and of throughput. In order to increase the throughput and reduce the effects of pile-up, which are particularly severe for the high folds, it is foreseen that the main amplifier will be operated at a shaping time of $1\mu s$ and that the ballistic deficit will be recovered by an active filter integrator stage placed in the Linear Gate and Stretcher.

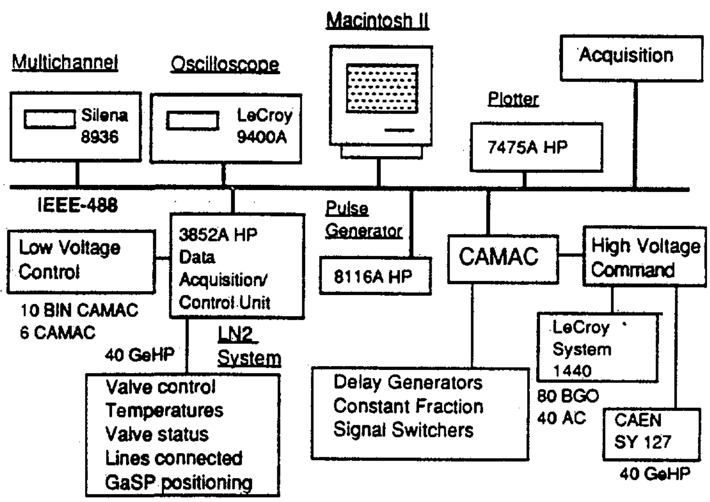

Figure 5: Layout of the control system for the LN2 and the electronics.

The detectors of GA.SP are controlled by a Macintosh based system which, is responsible for the liquid Nitrogen filling and for the HV settings. Beside these two tasks the Macintosh system (as shown in Fig. 5) is used to set up the CFD timings, to control the quality of the signals from the preamplifiers an PMTs and to maintain a data base of the relevant parameters and the history of the used detectors. It is planned that the user can, to a great extent, check and adjust the electronics set-up just by typing commands to the system through a very easy to use and intuitive graphical interface.

The rate of coincidences from the germanium detectors after Compton suppression can easily reach 20-30 kHz for doubles and this corresponds to a data flow in excess of 1 Mbyte per second when considering only the gamma detection part of the system. The aim of the project is to have a reliable on-line analysis of the data, including automatic gain matching and ballistic deficit correction for the germanium detectors. This last will be achieved by taking the peaking time of the linear germanium signal, which is given by the LGS module, and using its empirical correlation to the amplitude loss as determined looking to $E_\gamma - T_{peak}$ matrices. The on-line system should furthermore be able to produce several gamma-gamma matrices in order, for example, to extract information from the two fold coincidences also when only higher folds are written on magnetic tape (usually EXABYTE).

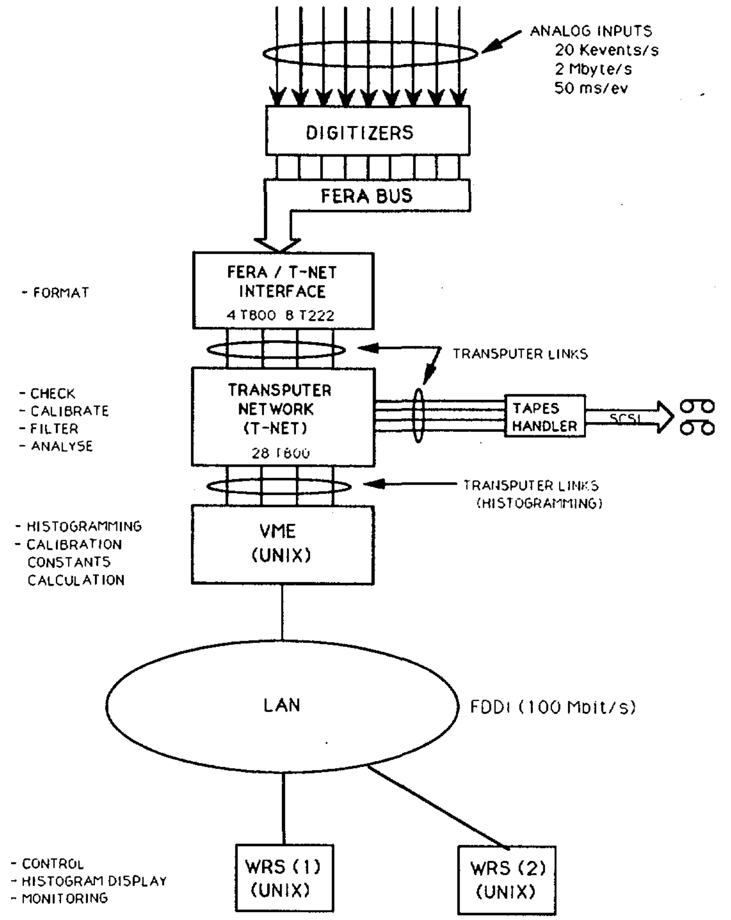

Figure 6: Layout of the Transputer based data acquisition system.

The computer power needed for all these tasks has been obtained with the development of a Transputer based distributed system. Its layout is shown in Fig. 6 : the several chains of transputer modules get the digitized data from the FERA read-out system, format the events in a user defined way, produce projections of the raw data, match the gains, perform the requested on line analysis and store the events on tape.

The user interacts with the system through applications running on a standard UNIX based computer. The building of events and their on-line analysis are performed in the Transputer system which is controlled by programs written in a high level language explicitly defined and implemented for this project. This language (called NEO for Nuclear Events Oriented language) contains primitives for the most common sorting operations and has the main function of hiding the parallel structure of the system to the user. In its present implementations the NEO compiler produces native Transputer code (OCCAM); a C code producing compiler is being presently written in order to use the same sorting language also in the off-line analysis running on standard serial computers.

Installation of GA.SP has begun in late fall 1991 and has been completed in March 1992. Commissioning of the system (using 28 Ge+Ac systems and the full BGO inner ball) has been performed in May 1992. A test of coupled operation of GASP and RMS has also been performed but the detailed study of the matching of the two systems has been moved to the second part of the year. Experimentation has been started shortly after the commissioning runs. Test experiments performed during commissioning(e.g. the $^{105}Pd+^{32}S$ reaction at 155 MeV with a beam current of about 10 pnA such to have 10 kHz of singles in the germaniums) have shown that the system can give about 5 kHz of triple coincidences. Several measurements are now scheduled and the main topics are the search for the linking transitions between superdeformed and normal states, search for hyperdeformation, study of the nuclei of the region around ^{100}Sn, search for octupole deformation and so fort. The detection system should be running in its full configuration for the beam times scheduled for the second part of the year.