ISTITUTO NAZIONALE DI FISICA NUCLEARE

Sezione di Padova

INFN/BE-90/11
28 Novembre1990

GA.SP Collaboration:

GA.SP EXPERIMENT: PROJECT REPORT OF A GAMMA SPECTROMETER

Servizio Documentazione
dei Laboratori Nazionali di Frascati

INFN - Istituto Nazionale di Fisica Nucleare
Sezione di Padova

INFN/BE-90/11
28 Novembre 1990

GA.SP Experiment

Project report of a gamma spectrometer.

The participants in the project are:

Padova Sect.: D.Bazzacco, F.Brandolini, A.Buscemi, S.Lunardi, G.Nardelli, G.Nebbia, P.Pavan, C.Rossi Alvarez, C.Signorini, F.Soramel e R.Zanon.

L.N.L.: M.DePoli, P.Favaron, G.Maron, G.Montagnoli, G.Prete, P.Spolaore, A.M.Stefanini, G.Vedovato.

Milano Sect.: F.Bortignon, G.Lo Bianco, P.Sala.

Spokesperson: C.Rossi Alvarez

GA.SP Collaboration

Working groups composition

Group 1) **Computer Simulation of the Apparatus**

Chairman: D. Bazzacco
P. Spolaore

Group 2) **Mechanical Structures**

Chairman: A.M. Stefanini
P.Favaron
P. Pavan
G.C. Nebbia
F. Brandolini
F. Soramel

Group 3) **Electronics and Control**

Chairman: C. Rossi Alvarez
G.C. Nardelli

Group 4) **Data Acquisition and Analysis**

Chairman: M. De Poli
G. Maron
G. Vedovato

Group 5) **Detectors**

Chairman: G. Lo Bianco
G.F. Prete
P. Sala
P. Mandò
N. Taccetti
S. Lunardi

Group 6) **Tender Procedures**

Chairman C. Signorini
G. Montagnoli

Participants to parts of the project

Section of Milano
N.Molho
M.Pignanelli

Section of Firenze
A.M.Bizzeti-Sona

Laboratories of Legnaro
D.R.Napoli

I. INTRODUCTION

This document reports on the results of a project for the construction of a gamma spectrometer GA.SP of high energy resolution and efficiency.

The work, started late in 1988, is not yet finished, but allows an estimate of the total cost of the instrument and of the overall expected performances.

The report has been extracted from four other reports that collect the work of the working groups established in October 1988.

The definition of the main characteristics of the first 10 sets of Germanium detectors has been made in agreement with the DECA-HEG experiment as established by the III National Committee. A test of the detectors supplied by the companies has been performed to control fully the expected behaviour of the detectors.

From the point of view of efficiency and resolution power the proposed detector is midway between the biggest existing systems (Nordball or Tessa30) and the future projects (Gammasphere or Euroball).

The chosen solution gives the opportunity to have in a short time a competitive instrument in the Italian Laboratories at a reasonable cost.

A particular effort has been made to satisfy the constraints given by the different research lines that were involved in the project.

In particular, the problems araising from the combined use of the gamma and RMS spectrometers have been solved in a convenient way, that is, maintaining good performances of the acceptance and leaving open the possibility to use the two instruments separately. It will also be possible to use small detector arrays inside the BGO sphere in the 340 mm diameter of free space.

The holes free for the Germanium observation are 40; 30 of them will be occupied by the proposed set, leaving the possibility to further increase, in a second moment, the efficiency of the system.

This report is composed by the following parts:

-Scientific justifications of the detector.

-Description of the proposed structure and computer simulation of the performances.

-Specific characteristics of the proposed germanium detectors, multiplicity filter, and antiCompton shields.

-The coupling between GA.SP and RMS.

-The electronic system.

-The data acquisition and analysis.

-The estimated total cost and time schedule.

II. SCIENTIFIC JUSTIFICATIONS

Nuclear structure research has lead over the last few decades to a deep understanding of such a "small" quantal object with so "many" particles as an atomic nucleus, characterized by single particle as well as collective degrees of freedom.

The properties of the average nuclear potential, of the nucleon correlations, of the vibrational and rotational collective motions have been rather well defined through experimental measurements on the low-lying states of the nucleus ($E_X < 20$ MeV).

In more recent years the construction of new heavy-ion accelerators has disclosed the possibility of studying nuclei formed under extreme conditions of excitation energy and angular momentum, close to the limits of stability of the atomic nuclei.

In such studies, owing to the complexity of the decay trajectories in phase space, significant results can be obtained only with gamma detection systems that offer both high resolution and large geometrical efficiency.

An improvement of the effective resolution depends not only on the intrinsic resolution of the detectors, but also on the peak/total ratio, which is highly improved both by increasing the volume of the detectors and the Compton suppression.

The availability on the market of germanium detectors with effective efficiency of about 80% of a 3"x3" NaI crystal and the possibility of "clustering" such detectors in a suitable array allow one to perform measurements of n-fold γ-γ coincidences with $n>2$ using reasonable amounts of beam-time.

In this perspective we propose to build a large array of Compton-suppressed germanium detectors of large volume to be used possibly in connection with other detection systems, for second-generation gamma-ray experiments.

Some of the new physics to study with spectrometers such as GA.SP is, in the proponent's view, summarized in the following topics:

a) High angular momentum studies (phase transitions connected with the break-down of the pairing correlations, to the onset of superdeformations and to shape changes)

b) Finite temperature effects (giant resonance states in hot nuclei, role of thermal fluctuations, damping of collective vibrational and rotational modes, order-to-chaos transition)

c) Production of exotic nuclei,

d) New insight into the nuclear reaction field (transfer reac-tions, sub-barrier fusion, energy and angular momentum balance in dissipative phenomena).

These topics have been the subject of discussion in the definition of similar projects like Gammasphere (USA, 1988), Deca/heg (Italy, 1988),

Euroball (proposal under way).

In the following we report in some detail a few research lines for which the use of the GA.SP spectrometer would provide a unique tool of investigation.

Additional detailed information on the various research topics is described in the ALPI proposal [1].

Nuclear spectroscopy

The possibility of using an array of 30 Ge detectors with Compton-suppression (CS) will allow to challenge in an efficient way some questions concerning fundamental problems still open in Nuclear spectroscopy such as :

- How and when pairing correlations disappear; it is well known that such peculiarities of the nuclear structure play an important role at low excitation energy and spin.
- How the rotation frequency and the nucleon alignment affect the evolution of nuclear deformations. In some nuclei the rotational band is supposed to end because of the total alignment of the spins of the valence nucleons that should produce an oblate deformation.
- Superdeformed nuclei.

The first evidence of superdeformed states at high spin in a sequence of 19 transitions from 60 to 22 h-bar separated by a constant energy interval of 47 keV [2] has been given in 1987.

The average intensity of such transitions is about 1% and its connection with the low excitation levels is still unknown. The measurement has been possible thanks to the coupling of an array of 12 Ge detectors (CS), with a 50 element multiplicity filter.

For a better understanding of the nature of such super-deformed bands a systematic study is necessary on other nuclei, of the ways of population and de-excitation of these bands.

Moreover, these sequences cannot be found with the usual methods, but rather identifying groups of gammas equally spaced with equivalent intensities.

- Spectroscopy in the neighbour of new unstable magic nuclei and variations of their characteristics in the neighbouring nuclei. Search of new examples of shape co-existence [3].

- Giant resonances [4]

Exclusive measurements of the gamma and/or particle decay of giant resonances are necessary to obtain a precise determination of their microscopic structure. One can thus obtain a strict test of the theoretical predictions based on mean field models and on the description of the damping mechanism of collective motions ("doorway" states, coupling to surface degrees of freedom, etc.).

The evolution of typical parameters (e.g. the width) of the giant dipole resonance excited on single-particle states of nuclei at high excitation energy and spin can provide information on the nuclear shape transitions, on the collectivity of certain temperature-dependent effects (motional narrowing), on the role of thermal fluctuations, on a "close" system as an atomic nucleus, etc.

To shed some light on such open questions one needs a very high efficiency detection system, possibly coupled with a dedicated equipment for the detection of particular events (e.g. large dense crystals to detect high energy gamma rays).

- Isomeric states.

In the framework of the Bohr-Mottelson model, transitions with multipolarity less than ΔK [5] are forbidden.The detection of transitions between these states, as in the case of the Hf nucleus, shows the existence of "mixing". Recent measurements in the W-Os region have revealed unusual features that have been interpreted as barrier penetration close to the nuclear potential minima.

- Octupole shapes.

Recent theoretical calculations [6-10] indicate that some nuclei can have octupole deformations at high spin.

This implies that such nuclei must also have an electric dipole moment,in clear disagreement with parity conservation of the nucleon-nucleon forces that requires zero odd-order electric moments.

The main feature of such a situation would be the existence of alternate close levels of opposite parity with fast E1 transition probability.

The experimental requirements to challenge these problems are the following:

- Possibility to follow the level scheme up to spins of the order of 60-70 h-bar in coincidence measurements at high multiplicity and resolution.

- Determination of lifetimes of high spin states to infer the nuclear deformations; such measurements require high statistics achievable only with high efficiency systems coupled with a "plunger" technique.

- Measurements of dipole and quadrupole moments. Both require high statistics since, especially for the determination of magnetic moments, the angular distributions show an anisotropy at least 5 times smaller than those obtained in coulomb excitation experiments.

In fusion-evaporation experiments the complex populations of the levels make the analysis difficult and because of the very short lifetimes the net expected effect is rather small.

However, with a system of 12 to 24 GeV detectors triggered by a multiplicity signal,one expects to be able to collect significant statistics in a share of one week of beam time.

- The increased solid angle defined by the array that would allow to increase considerably the rate of high fold coincidence events and the efficient coupling to other specific detectors; this would open the possibility of looking for rare events that are normally buried in severe background. Among these possibilities the following are currently taken into consideration:

1- The possibility to perform experiments in coincidence with charged particles and/or neutrons to select particular decay channels. In the case of superdeformations one expects a reduction of the coulomb barrier for charged particles and consequently an effect on the yield and average energy of the latter. To perform such experiments it is necessary to provide an adequate amount of space inside the array to install a small scattering chamber.

2- The possibility to couple the array with the Recoil Mass Spectrometer (RMS) currently located at the L.N.L. In this case the selective trigger given by the RMS also would allow a great reduction of the background and the study in detail of the formation of rare nuclei in fusion reactions.

As an example the identification of the ^{80}Zr nucleus [11] and the measurement of the first levels' excitation energy has been obtained coupling 14 Ge detectors with the Daresbury RMS which allowed to isolate a channel with a cross section of 10 microbarn buried in a background 10^4 times larger.

III. REACTION MECHANISMS

The study of dissipative processes (fusion-fission, deep-inelastic, etc.) induced by heavy ions often requires the use of spectroscopic techniques in order to enlighten or complete the landscape of the possible mechanisms involved in the collisions.

Very often this possibility is overruled either because of the limited efficiency of the gamma detection systems available or owing to their incompatibility with the devices dedicated to the particle detection.

Among all the examples of possible applications of a system like GA.SP coupled with charge particle detectors currently used, at least two are well matched with the current research interests of the groups involved in this project:

1- In the study of the decay of hot nuclei produced in fusion reactions the analysis of the charged particle spectra (p,d,t,alpha) can give detailed information on the structure of fast rotating hot nuclei [12].

In these cases it is necessary to identify carefully the exit channels and thus impose strict conditions upon the decay trajectory in the phase space.

Such a selection, achieved through identification of the final products by spectroscopic techniques, requires extremely high efficiency systems, in particular when dealing with medium-heavy nuclei in which the charged particle decay channels often represent a small fraction of the total cross-section.

Another important aspect of the exit channel selection is represented by the possibility, via gamma multiplicity measurements, to identify regions of different spin in the initial compound nuclei population [13], thus allowing to study separately the influence of temperature and angular momentum on the decay processes.

2- In the study of the limits of stability of atomic nuclei (which will be possible when the accelerating system Tandem+Linac will be operational at L.N.L.), an interesting application of gamma spectroscopy consists in measuring the temperature of the nucleus through the Boltzmann relation which allows to determine thermo-dynamic quantities from the ratio of fragments emitted in an excited state to those emitted in the ground state.

Some pioneering experiments have been performed in this direction [14], however the results are often of rather poor quality because of the limited efficiency of the detection systems.

In fact, triple coincidences being required (emitter-emitted fragment--gamma to perform such experiments) once again an extremely high efficiency system , which can host a series of particle detectors in its interior, is necessary.

The construction of such a system, connected with a high granularity filter capable of event-by-event multiplicity determination, would then not only allow to perform second generation spectroscopy studies, but would also open unprecedented possibilities to the exclusive study of reaction mechanisms.

IV. COUPLING WITH THE RECOIL MASS SPECTROMETER

The possibility has already been mentioned of performing gamma spectroscopy experiments selecting particular events by the RMS, especially in those reactions in which one wants to obtain information about the structure of nuclei far from the line of stability produced in fusion processes between heavy ions.

In fact there have been several attempts (also at the L.N.L. [15,16]) to reach and study nuclei situated around the proton drip line.

The cross-sections for the production of such nuclear species are rather small as compared to the strongest evaporation channels and this once again imposes severe experimental problems.

On one side one needs an efficient high-resolution detection system for gamma rays, on the other one needs an adequate trigger on the decay channel.

As a consequence, we feel that the possibility of selecting the small cross-section events with the RMS, and measuring with high efficiency the discrete gamma transition in coincidence, represents the right solution to the present limitations intrinsic in traditional gamma spectroscopy techniques.

For what concerns the study of nuclei far from the stability valley but on the neutron rich side, good experimental possibilities will be open when the Tandem+Linac system will become available at the L.N.L. and produce very heavy beams at energies of about 5-6 MeV/amu.

It will then be possible to bombard a relatively light target with a heavy projectile and then exploit the so-called inverse kinematic effect that restricts the reaction products into a narrow cone around the beam axis, thus allowing an efficient use of the RMS to trigger the gamma spectrometer on rare events.

2- In the field of reaction mechanisms at Tandem energies, a lot of interest has been raised in the last few years by the studies of sub-barrier fusion phenomena [17].

One of the most important parameters in the theoretical description of such processes is the spin distribution of the compound nuclei whose measure would then allow stringent tests on the current models.

The spin distribution is experimentally accessible through the measurement of the total gamma multiplicity; it is then necessary to have a large efficiency gamma-ray filter with suitable granularity to be coupled with the RMS which will separate the fusion events from the rest of the reaction products (for sub-barrier fusion a typical ratio is 1 to 100).

Transfer reaction around the Coulomb barrier[18] is another field which raises the interest of the scientific community, but is affected by lack of good experimental data especially for the heavy systems.

In this case the transfer mechanism is characterized by a strong coulomb excitation both in the entrance and in the exit channels, so that one expects the nucleons to be transferred between highly excited states at high spin; in particular the transfer of pairs of nucleons will assume particular importance to obtain information about the pairing interaction in conditions of fast rotation or about the rotational pairing bands in superfluid nuclei.

The RMS coupled with GA.SP will be able to give information about the transfer mechanism via the coincident detection of the heavy products and associated gamma transitions.

References

[1] - ALPI Project, Report L.N.L. - INFN 001/87

[2] - P.J.Twin et al., Phys. Rev. Lett. 57 (1986) 811

[3] - S.Lunardi et al., Proc. Int. Conf. on Nuclear Structure with Heavy Ions, Legnaro, Italy, May 23-27 1985

[4] - P.F.Bortignon et al., Proc. First Topical Meeting on Giant Reso-nance Excitation in Heavy Ion collisions, Legnaro, Italy, Sept. 21-29 1987

[5] - A.Bohr and B.R.Mottelson, Nuclear Structure vol. 2, (Benjamin, Reading, Mass., 1975)

[6] - R.R.Chasman Phys. Lett. 96B (1980) 7

[7] - G.A.Leander et al., Nucl. Phys. A413 (1984) 375

[8] - W.Nazarewicz et al., Nucl. Phys. A429 (1984) 269

[9] - P.Bonche et al., Phys. Lett. 175B (1986) 387

[10] - W.Nazarewicz et al., Nucl. Phys. A467 (1987) 437

[11] - C.J.Lister et al., Phys. Rev. Lett. 59 (1987) 1270

[12] - Z.Majka et al., Phys. Rev. C35 (1987) 2125

[13] - M.N.Namboodiri et al., Phys. Rev. C35 (1987) 1495

[14] - D.J.Morrissey et al., MSUCL-Report 4S4-1987

[15] - C.J.Lister et al., Phys. Rev. Lett. 55 (1985) 145

[16] - F.Soramel et al., Proc. Int. Symp. on Weak and Electromagnetic Interactions in Nuclei, Heidelberg, Jul. 1986

[17] - M.Beckerman, Phys. Rep. 129 (1985) 145

[18] - K.E.Rehm et al., Phys. Rev. Lett. 55 (1985) 280

V. BGO FILTER AND AC SHIELDS

The filter

The shapes that were used for the simulation of the filter geometry have been chosen according to the following main considerations:

1- Thickness sufficient to absorb 95% of gammas of 1 MeV.

2- Internal dimensions of the sphere such that it will be possible to house, in its interior, some compact particle detector systems, plungers, etc.

3- Granularity at least 2-3 times larger than the maximum gamma multiplicity expected in a typical fusion reaction.

4- Multiple hit minimization.

5- Shape such that the individual efficiency of each element be as equal as possible.

6- Dimensions compatible with the present production technical limitations.

7- The filter has to act as a partial collimator for the external Germanium-AC system.

At present the design phase of this part of the project is not totally defined, since up to now we do not have definite answers from the crystal factories about the feasibility of growing crystals of the required size.

Moreover the search of optimum of the whole set of design parameters is still under way.

However, on the basis of the answer of one of the largest companies that have been addressed, we have already elaborated a financial plan, having to a good extent defined the design parameters by our simulations.

The read-out of the crystals will be done with standard PMT's; a Photodiode read-out has been discarded since the detection threshold introduced by the high noise and low amplification of such devices would be too severe.

The shields

For the estimate of the AC shield's price we have relied on the recent offers we had acquired for similar systems for the ARA project.

The design proposed for GA.SP, although slightly different, is close enough so that no major changes in the price are expected.

The project group has also considered the possibility of re-designing the entire AC system from scratch and to build it in house for the sake of economy. A final decision will be taken once a complete study of the detector shape, crystal availability and prices is finished.

In order to do so one has explored the possibility of addressing the Ceramic Institute of Shanghai (People's Republic of China) for the supply of BGO crystals following the lines of the L3 CERN collaboration.

This last possibility will have to be carefully inspected by the project group to take into proper account the man power needed for such a task which,on the other hand, is perfectly performed by industrial companies.

VI. GEOMETRY OF THE INTERNAL SPHERE

In the following we report on the considerations applied to define the geometry of the GA.SP apparatus.

First the starting specifications:

- 30 Ge-AC systems with the obvious requirement of having the detectors as close as possible to the target
- shell of scintillators, inside the Ge-AC array, to determine multiplicity and sum energy of the gamma cascade.
- internal room of about 300-400 mm. diameter to install a scattering chamber able to house particle detectors.

These requirements, which turn out to work against each other, have been satisfied choosing a BGO crystal as scintillator, thus keeping the thickness of the shell to 65-70 mm. without giving up efficiency due to the high density of BGO.

The i/o radius of the shell is between 170 and 240 mm.; with this geometry and considering the holes for the Ge detectors one has a total solid angle of 85% with a total efficiency of 80% for 1 MeV. gammas.

The geometry of the individual elements of the filter has been the subject of some study and simulation; a number of elements (with different shapes) between 60 and 120 have been considered, so as to have a sufficient granularity for the multiplicity measurement.

We started the study considering the regular platonic icosahedron (a solid with 20 regular triangular sides), then proceeded to the subdivision of each side into a number of simple parts; the projection of these figures on spherical surface provides the desired solution.

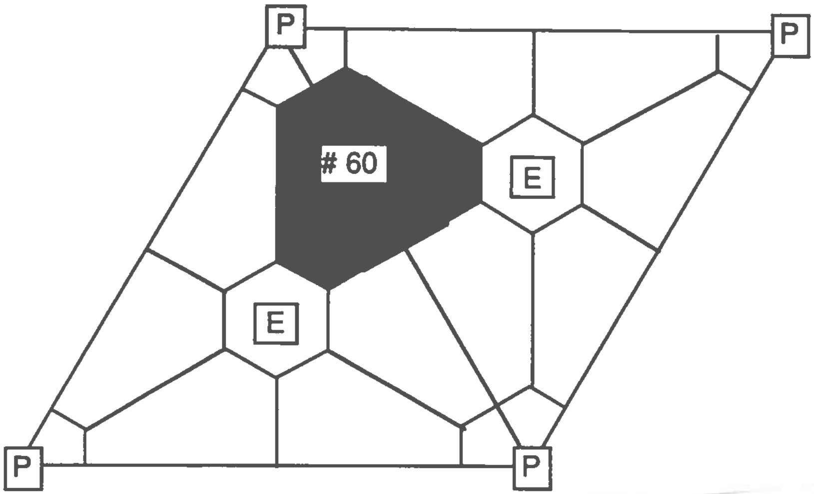
In this way one can construct a typical "soccer ball" simply cutting off the tips of the triangles.

This last solution has been adopted for similar devices like ESSA30 and NordBall.

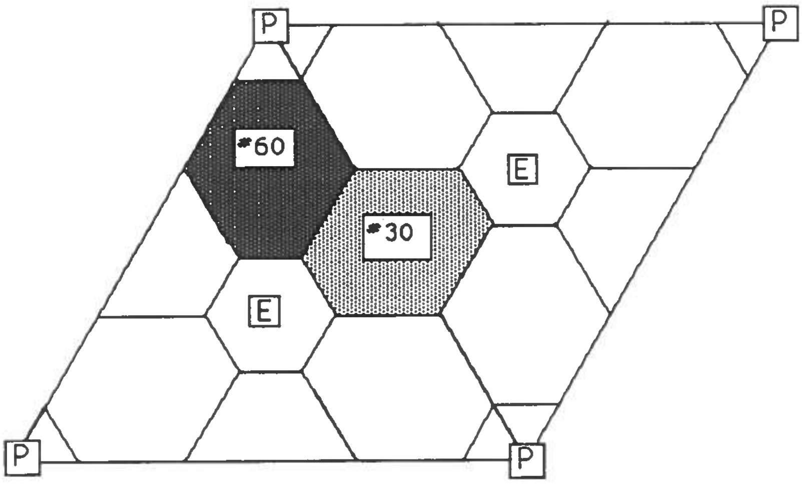
In the following figures three among the various considered configurations are reported.

To show the shape of the detectors we draw two adjacent elements with the relative divisions.

Letters P and E indicate position and shape respectively (pentagon and hexagon) of the access holes for the Ge detectors.

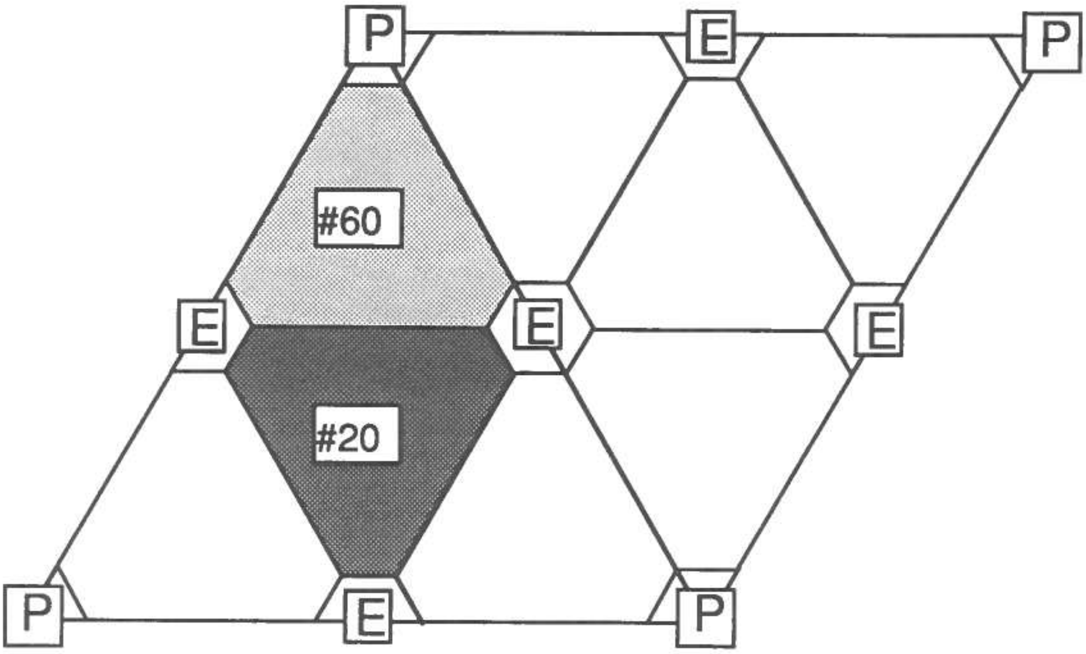


This first solution involves 60 detectors for the scintillator shell, all of the same size and shape, and leaves 20 hexagonal and 12 pentagonal holes for germaniums. This structure is appealing for its high degree of symmetry but unfortunately the size of the single elements is too large for the standard industrial productions, and therefore has been abandoned.



Geometry with 90 BGO 's and 32 holes.

In this case the size of the elements is reduced but they are still at the limit of the industrial standard production.



Configuration with 80 BGO's (two different shapes) and 42 access holes.

The 30 Ge's will be installed in hexagonal holes and (left two apertures for the beam entrance and exit) one has 10 holes more left open.

This last configuration represents the final choice and has the following characteristics:

- sufficiently large number of elements
- symmetry of the whole system
- two (and rather similar) shapes only for the elements
- dimension of the crystals compatible with the industrial standards
- 10 additional holes beside the 32 necessary for Ge and beam
- the Ge detectors are distributed in the proper locations to define groups of 10 detectors in the same plane, this last feature is particularly important for angular correlation measurements.

The next figures give an overview of the total geometry.

Fig. 1

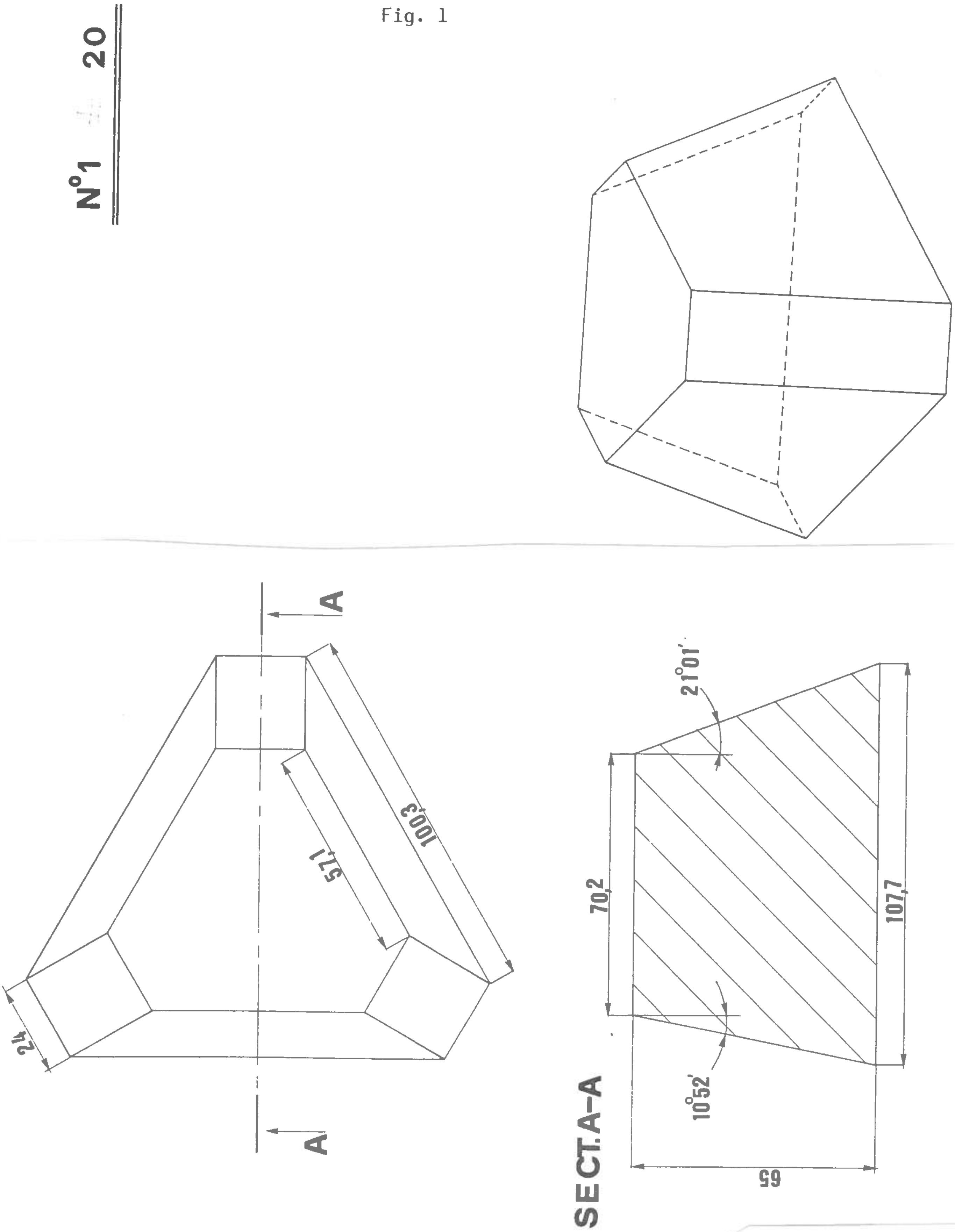
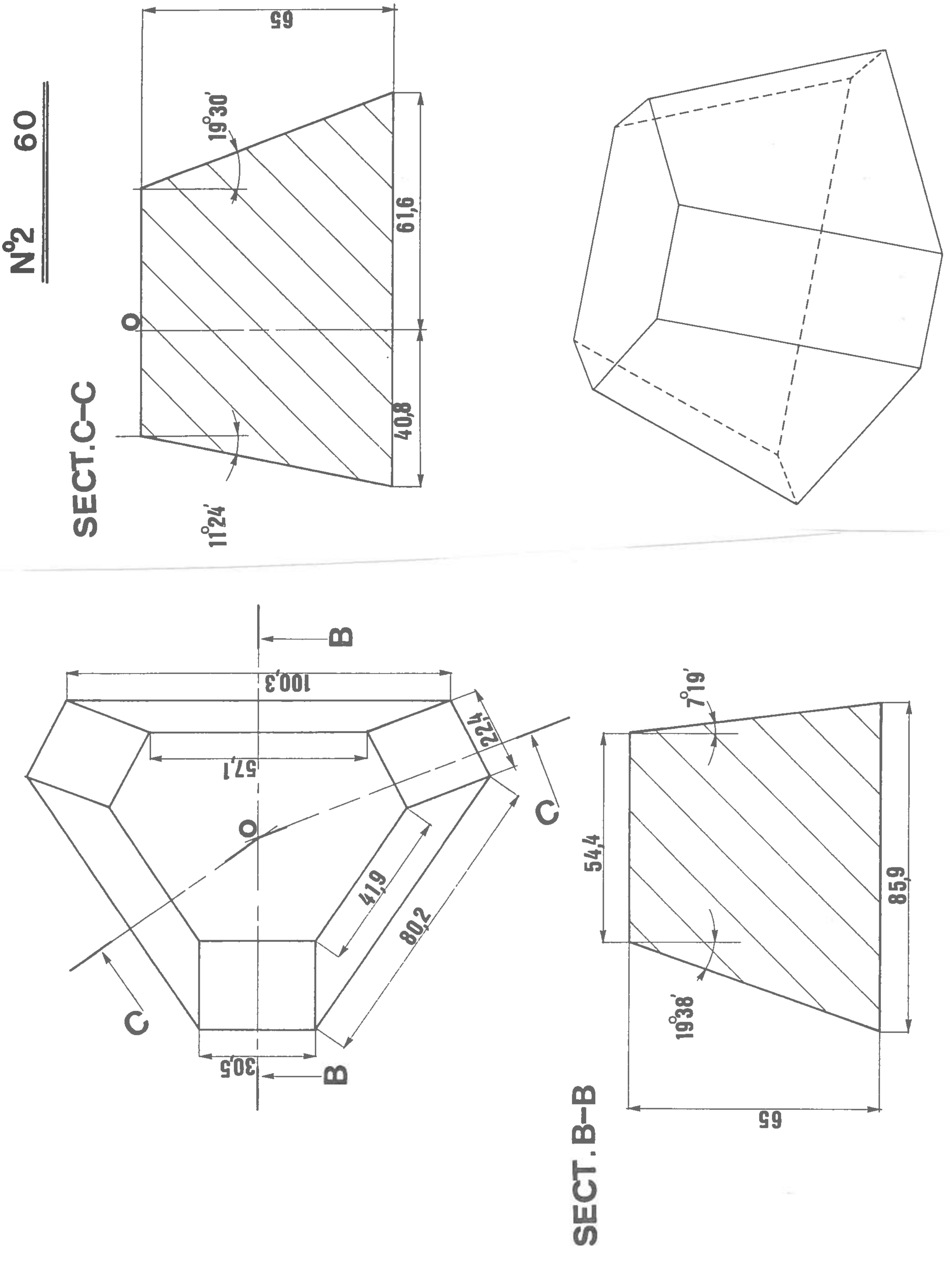
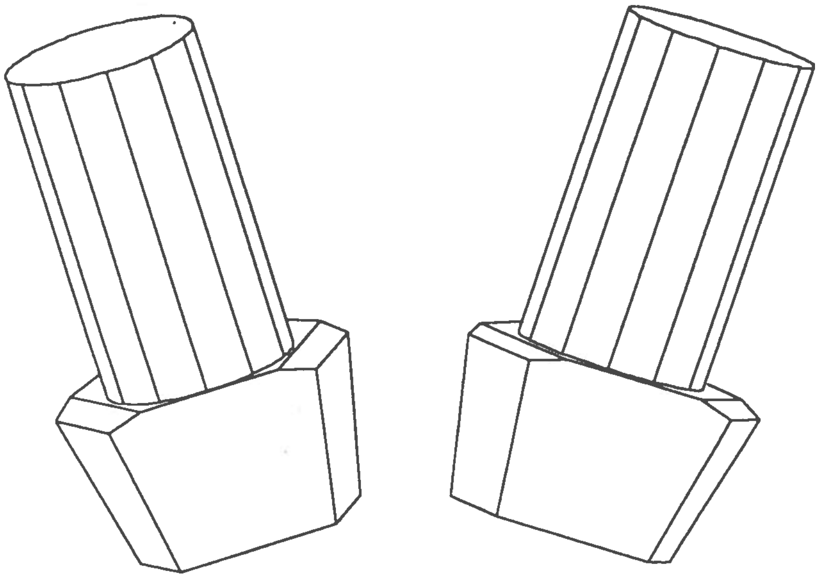


Fig. 2


N°2 60
SECT.C-C
65
19°30'
61,6
40,8
11°24'
O
B
B
100,3
57,1
22,4
C
C
O
41,9
80,2
30,5
7°19'
54,4
85,9
19°38'
65
SECT.B-B



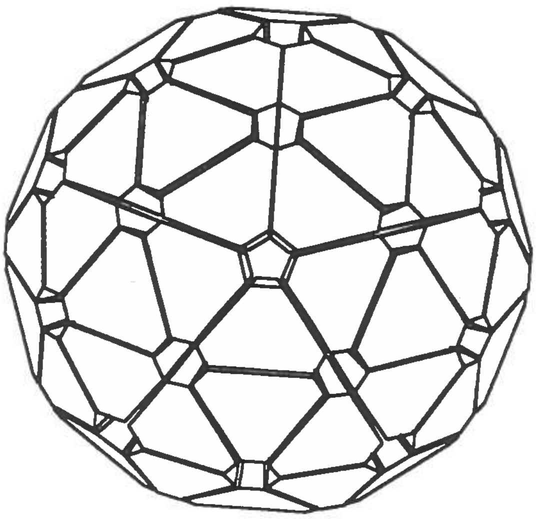


Fig. 3 Perspective view of the shell. External point of view in line with the beam direction.

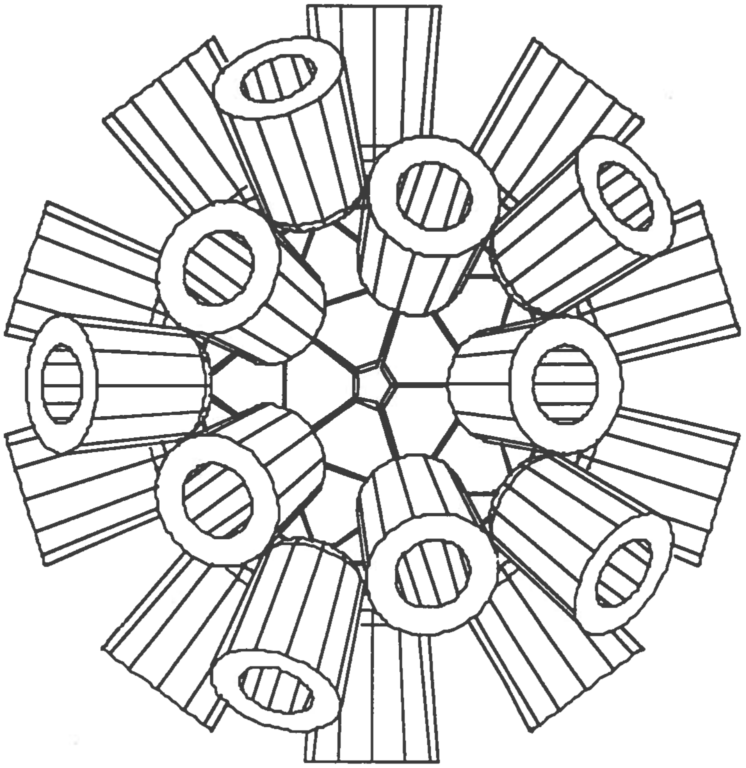


Fig. 4 Overall view of the shell with the AC shields located at the holes. (only the scintillators are shown)

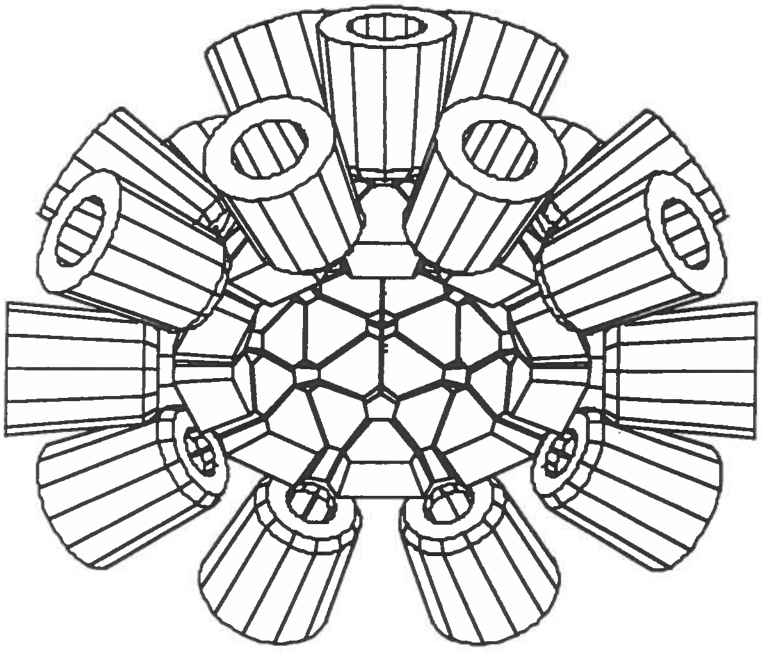


Fig. 5 Internal view of half a shell.

VII. THE ANTICOMPTON SHIELDS

The requirement of leaving an inner space available for a scattering chamber and the necessity of having an internal multiplicity filter imply that the Ge detectors should be located at a distance of the order of 250 mm. from the target; consequently for the sake of efficiency it is necessary to use large volume Ge detectors.

Hyperpure germanium detectors of the last generation can be produced with an efficiency of 70-80% with crystals of 70 mm in diameter and approximately 80 mm in length.

Because of their size the capsule that contains them is incompatible with the AC shields of current use, like e.g. those of the ARA set-up, which have a Ge located in a standard capsule of 72 mm. diameter.

Therefore it is necessary to re-design the AC shields; in order to do so we have considered a safety diameter of 87 mm. taking into account the increased efficiency of the Ge crystal and consequently the possible reduction of the AC suppressor dimension.

The main characteristic of a Ge-AC spectrometer is in fact the full-energy response of the detector; in other words, the parameter to take into account is the so called peak-to-total ratio (P/T).

In coincidence gamma measurements the useful events are those in which the full energy is measured for each detected gamma, whereas everything that corresponds to incomplete energy detection turns out as background.

The following table shows the fraction of good events in multiple coincidence simulations as a function of P/T to stress the importance of such parameter.

	P/T	30%	40%	50%	60%	70%
Fold	2	9	16	25	36	49
	3	2.7	6.4	12.5	21.6	34.3
	4	0.8	2.6	6.2	13.0	24.0
	5	0.2	1.0	3.1	7.8	16.8
	6	<0.1	0.4	1.6	4.7	11.8

One can notice, e.g., that in a triple coincidence measurement less than 3% of the data is useful if one uses detectors with P/T=30%, whereas this quantity grows up to 34% if one uses detectors with P/T=70%.

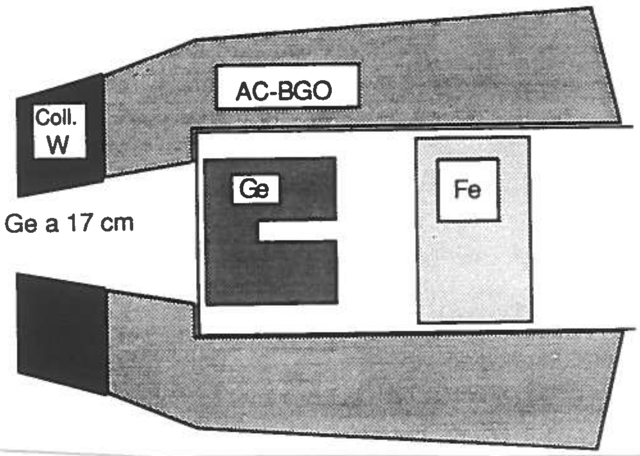
The performances of the AC for the new detectors have been obtained by simulations using the MonteCarlo code based on the SLAC EGS code.

We have noticed that, in order to obtain realistic results, one has to evaluate as closely as possible the geometry of the detection system taking into account non active areas, absorbers, collimation etc.

As shown in the following figures, one includes in the simulation the aluminium end-cup and a block of iron to simulate the scattering of gammas off the cryostat.

In the following we report the two geometries that have been considered:

MIPAD



$\Omega = 0.5\%$ $\varepsilon_{tot} = 0.36\%$ $\varepsilon_{FP} = 0.08\%$ P/T=22% not suppressed

$\varepsilon_{tot} = 0.12\%$ " P/T=67% suppressed

Average suppression $= (0.36-0.08)/(0.12-0.08) = 7$

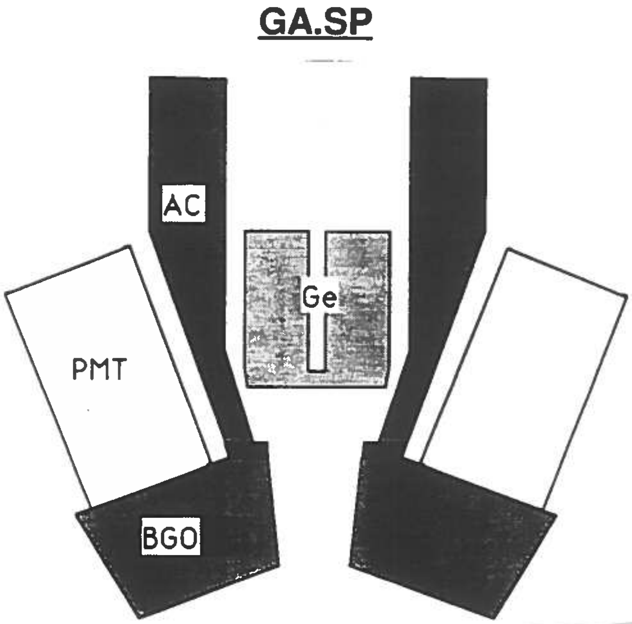
The reported results are in good agreement with the data obtained experimentally with ARA, although one has to be aware that in the actual AC's the front part of the shield is made out of NaI in order to increase the light output for the low energy events produced by Compton backscattering.

To contain the cost of this AC shield closer to the ARA ones, the dimensions of the BGO ring have been maintained within an outside diameter compatible with the ARA's.

In order to check this configuration a shell of BGO has been introduced in the simulation in front of the GE-AC system to reproduce the effect of the multiplicity filter.

The collimation of the gamma radiation is essentially due to the internal filter, the thickness of the real collimator having been greatly reduced.

It is worth noticing that, despite the thinning down of the AC, the suppression factor P/T of the new design is still good.



Ω =0.27% ε_{tot}=0.3% ε_{FP}=0.1% P/T=35% not suppressed

ε_{tot} =0.15% " P/T=69% suppressed

Average suppression = 4.15

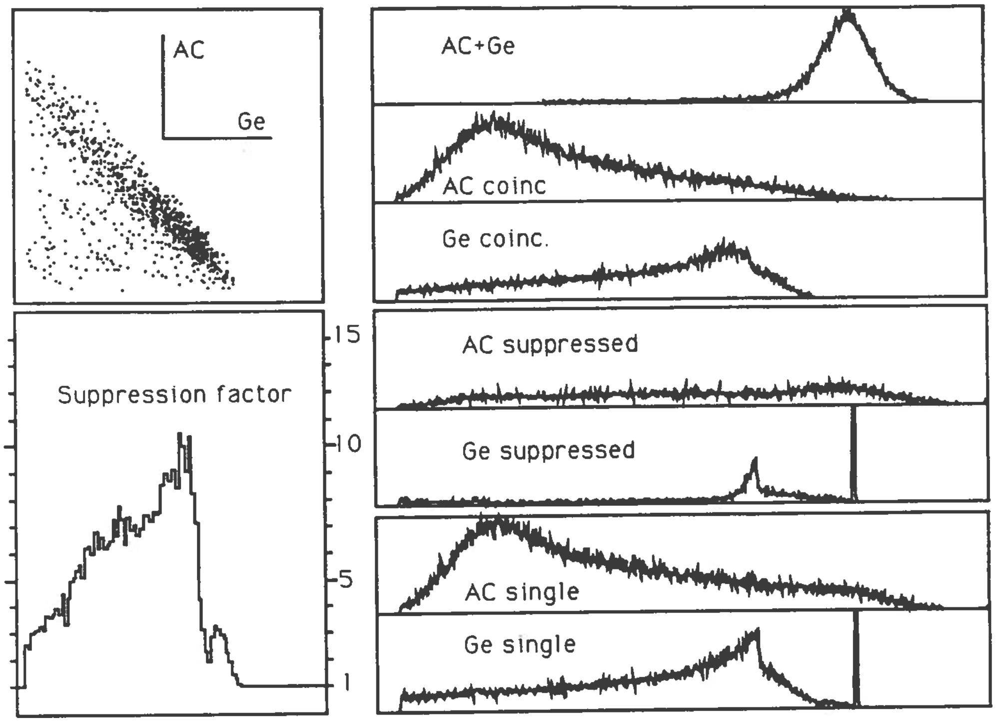
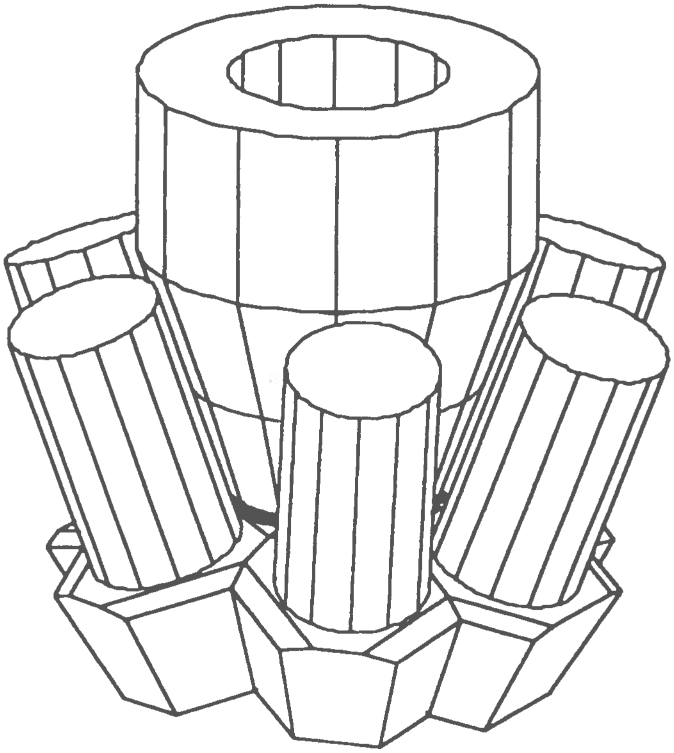


Fig. 6 MonteCarlo calculation of the suppression factor of a Ge-AC system.

The spectra on the right result from various ways of acquiring the signals from the two detectors:

- in singles (low pair)
- in suppression mode (middle pair)
- in coincidence and sum (three spectra on top and dot-ma-trix)

The bottom-left figure shows the suppression factor that one obtains dividing the spectrum into singles by the suppressed one.



VIII. PERFORMANCES OF THE DETECTION SYSTEM

The response of a detection system made of a certain number of detectors of equal efficiency can be obtained by simple combinatorial considerations. One can for example use the following formula

$$1) \qquad P_M^k(N,\varepsilon)=\binom{N}{k}\sum_{i=0}^{k}(-)^{k-i}\binom{k}{i}[1-(N-i)\varepsilon]^M$$

which gives the probability of **detecting k gammas** out of a cascade of **M transitions** using **N detectors** each with **absolute efficiency ε .**

Other useful quantities are:

$$2) \qquad r = 1-(1-\varepsilon)^M$$

which gives the singles counting of one detector

$$3) \qquad s = M\,\varepsilon\,(1-\varepsilon)^{M-1}$$

which gives the "single-hit" counting

$$4) \qquad m=(r-s)/m \sim (M-1)\varepsilon\,/2$$

which gives the "multiple-hit" fraction.

As an example let us consider the response of **N=30** germaniums to a cascade of **M=30** transitions, introducing for the efficiency the value given by the simulation.

The table shows the count rate (in KHz) obtained from 1) with the hypothesis that there are **10^5 cascades per second.**

		ε_{tot}=0.27%	ε_{supp}=0.14%	ε_{FP}=0.10%
k=	2	28.150	23.244	16.603
	3	22.423	9.041	4.531
	4	12.418	2.449	861
	5	5.087	491	121
	r	7.790	4.116	2.957
	s	7.489	4.033	2.914
	m	3.8%	2.0%	1.5%

The extension of this formulation to a system of detectors with different efficiencies is extremely complicated; moreover, in this case the cross-talk of the detectors can only be considered very roughly.

A more realistic response of the system was obtained using a simulation based on the SLAC EGS code.

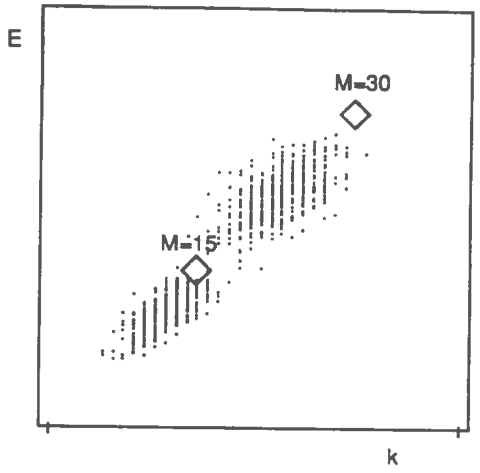
The results reported below were obtained using the shape earlier described for the BGO's and considering a fixed gamma energy of 1 MeV.

The results are tabulated below:

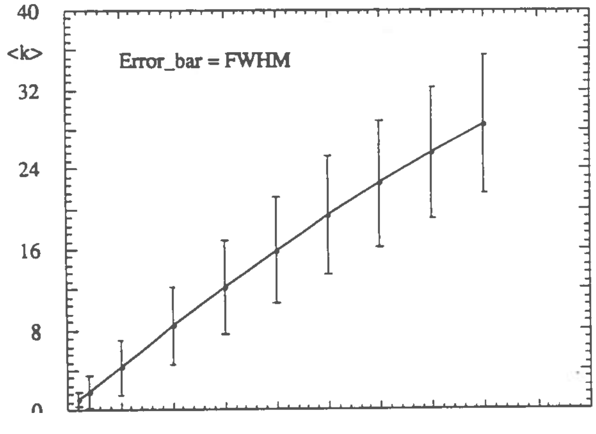
$\Omega = 1.00\%$	$\varepsilon = 0.94\%$	detectors of type '60'
$\Omega = 1.22\%$	$\varepsilon = 1.15\%$	detectors of type '20'
$\Omega = 84.4\%$	$\varepsilon = 79.1\%$	whole ball

The following figure gives an idea of the response,event by event, of the multiplicity filter in case of a M=30 and M=15 cascades.

The symbols in the energy vs. multiplicity plane are the entry points of the two cascades.



The next figure shows the multiplicity response as a function of the real multiplicity M.



IX. GERMANIUM DETECTORS

To determine the characteristics of the Ge detectors, we started from the consideration that the performances of an array for gamma spectroscopy, beside the number of detectors, depend on the total efficiency and on the P/T ratio of the detectors themselves.

In a typical spectroscopy experiment on high spin states the optimum solid angle for each detector is limited, first by the need of minimizing the multiple hits, secondly by the problem of the Doppler broadening on the lines induced by a too large angle covered by a single detector.

Therefore, once the number of detectors is fixed, the total solid angle remains determined and the total efficiency can be improved only by increasing the P/T ratio of the individual detectors.

This requires having Ge detectors with the maximum available dimensions which, among others, presents the following advantages.

First of all a high value of P/T of the individual detectors makes it possible to have a large total P/T, provided a good Compton suppression is made overall.

Secondly, it is possible to increase the distance of the detectors from the target obtaining a large free space inside the "array" which allows to locate other devices close to the target satisfying in this way a primary requirement of the GA.SP project.

For a given volume of the Ge crystal and a given solid angle defined by its front side, it is possible to increase its efficiency abandoning the cylindrical geometry.

A totally tapered crystal, which covers exactly the available solid angle, presents a greater efficiency but a lower P/T compared to a cylinder of the same volume.

The maximum P/T ratio can be obtained for an intermediate configuration in which the crystal is tapered only for part of its total length.

According to some calculations, performed starting from a crystal of 75 mm diameter and 95 mm length, the optimum shape is obtained tapering the crystal for 30 mm at an angle of about 5 deg.

As for the material used, a detector of **n**-type germanium (despite the higher price) is preferable since it is less affected by neutron damaging, it has a smaller passive layer and it can hold a larger number of annealing to remove the radiation damages.

Finally, considering a practical issue, it is desirable to have detectors that can be repaired from the neutron damage simply by heating them for a short time, thus limiting the lithium diffusion from the internal contact.

the p-type equivalent, moreover they worsen as the count rate increases beyond 10-30 kHz.

According with tests recently performed, it is possible to obtain resolutions of the order of 2.5 keV at 1.33 MeV using "Gated Integrators".

Analog circuits have recently been introduced in the market which perform a compensation of the ballistic deficit using the collection time as a parameter for the corrections.

It is possible to operate this correction with software techniques as well, provided that the relation of the time to peak versus energy is known.

With this technique it is possible to improve the resolution by up to 15-20% even in critical conditions of high rate, and low shaping time.

As an example, we report in the following figures some measurements of energy dispersion as a function of collection time for a detector of 80% efficiency.

As one can deduce from the figures, the nominal resolution is strongly conditioned by the contribution of the signals with long collection times, while the resolution for short collection times is much better; in this particular case one goes from 2.6 to 2.1 keV at 1.33 MeV.

In the GA.SP project this possibility has been taken into consideration, thus the electronics for the acquisition of the Ge signals have been designed with these goals.

Keeping in mind the former considerations and after consulting several companies on what is possible to obtain with the present technology, the characteristics of the detectors have been defined as follows:

1 - The detectors will be germanium crystals of n-type.

2 - The energy resolution will be less than 2.4 keV at 1.33 MeV and less than 1.1 keV at 122 keV, obtained according to the constructors specifications, with a shaping time of the main amplifier of 6 microseconds and at a counting rate of 1 kHz.

3 - The crystals will have dimensions of the order of 72 mm of diameter and 80 mm length. They will be tapered at an angle of 10 deg. for a length of 30 mm.

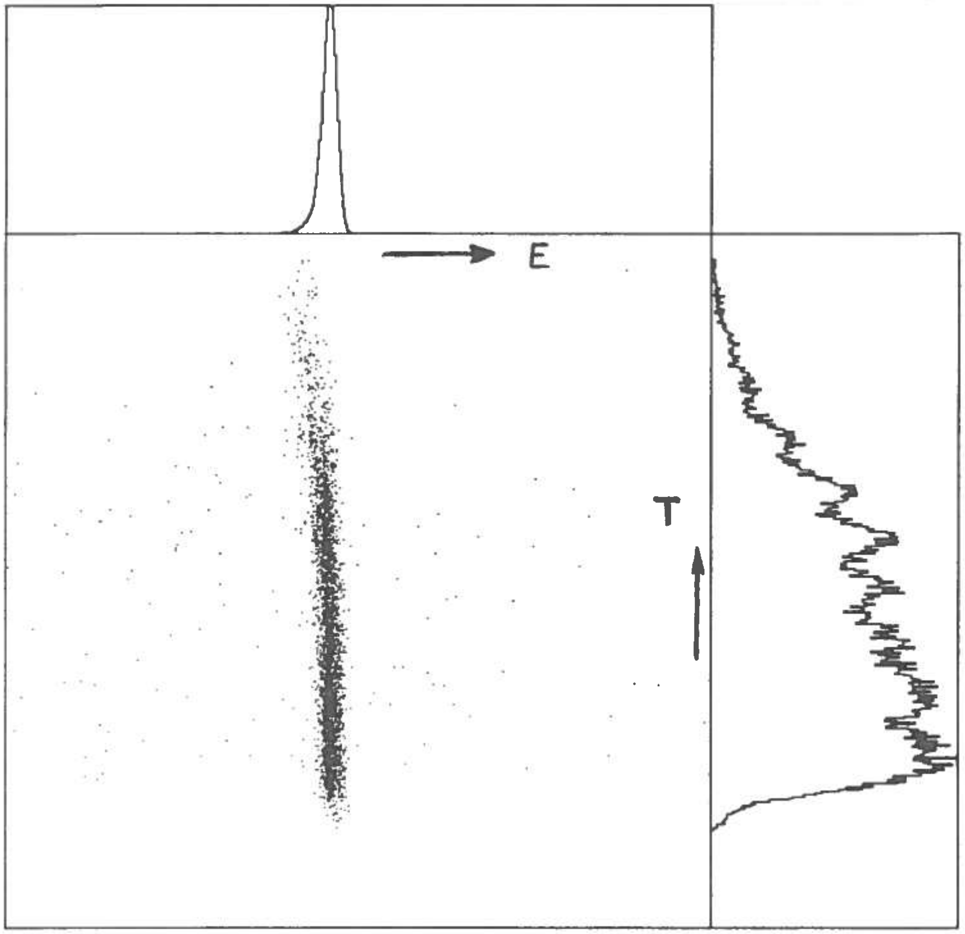
The dimensions of the crystals are not rigidly fixed as long as the required efficiency of 80% with respect to a 3"x3" NaI crystal is preserved, and the crystals will be capsulated into containers with a max. diameter of 87 mm.

4 - It will be possible to repair the detectors on site by annealing at 150 deg. centigrade and check the crystal temperature with continuity.

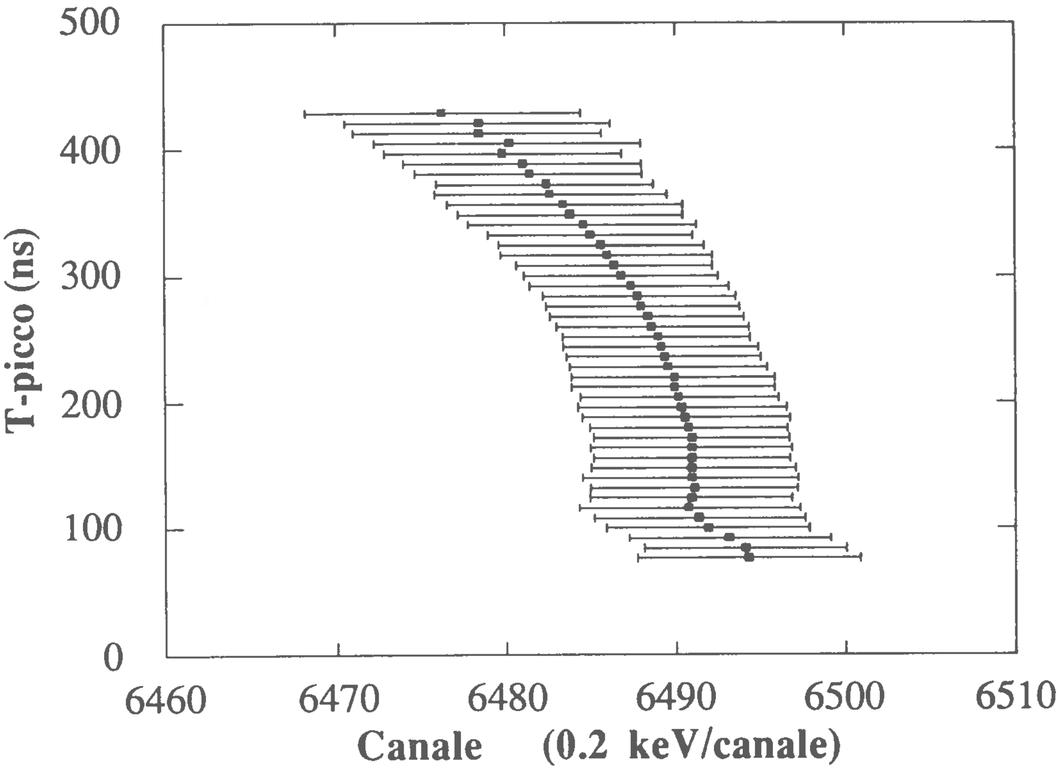
[1] IEEE Transactions in Nuclear Science, Vol. 35, N. 1 (1988) .

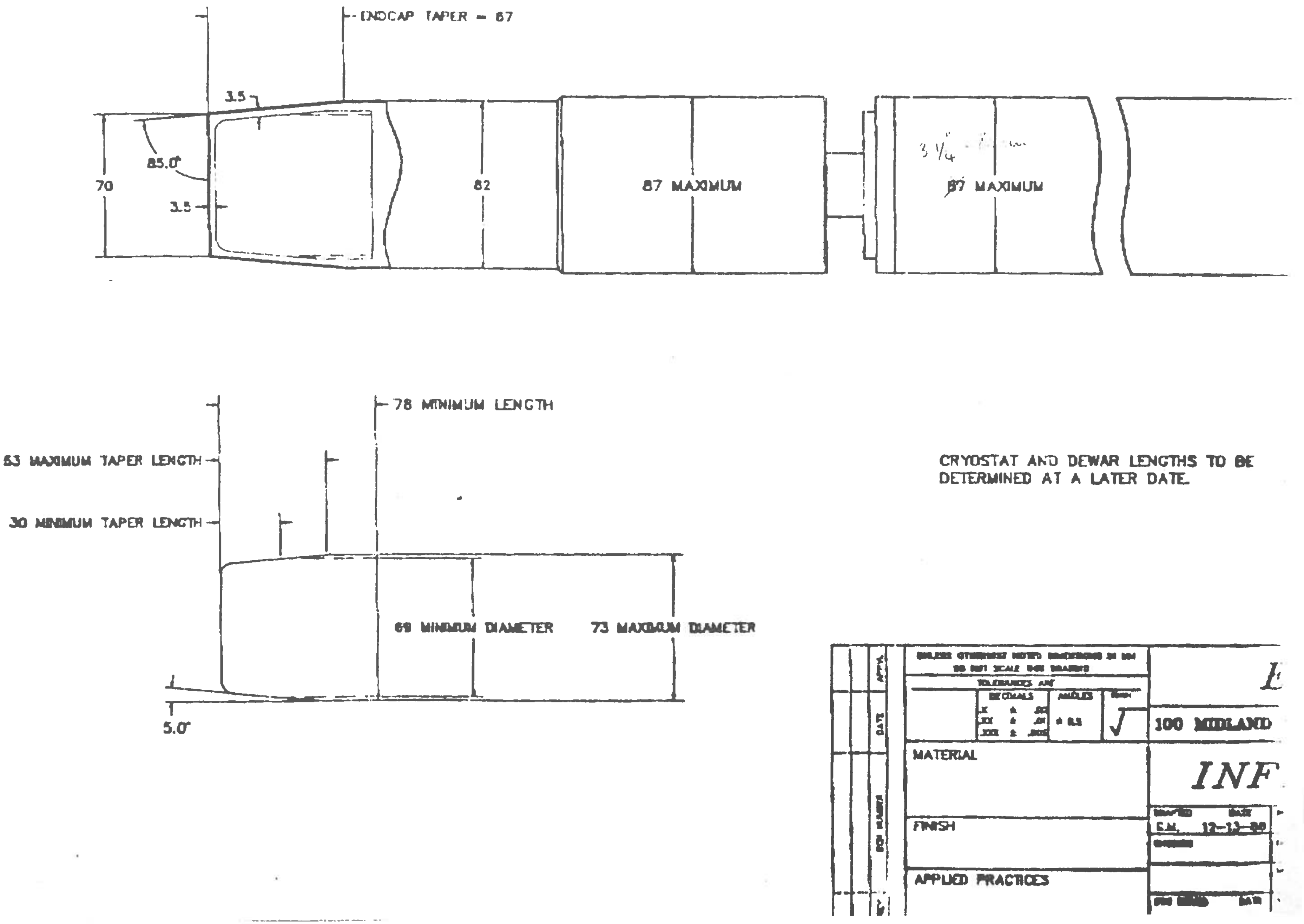
```
NCC,NSUM :

 1  6250  6761
 2     0  8191
 3     0  8191
 4     0  8191
```



```
X-->ADC# 1        6250      6761
Y-->ADC# 2           0      8191
```





CRYOSTAT AND DEWAR LENGTHS TO BE DETERMINED AT A LATER DATE.

X. THE COUPLING OF GA.SP WITH THE RECOIL MASS SPECTROMETER

The main problem of the coupling between the two instruments is of mechanical-geometrical nature.

It is obvious that the best location for GA.SP is the one that allows to have the target as close as possible to the present location in the spectrometer set-up.

However, given the dimension of GA.SP and the amount of space necessary for the operation of GA.SP when not coupled, this solution appears difficult to obtain as it requires a complex mechanical arrangement of the two devices.

One then proposes to keep the two instruments separated and to devise an efficient way to convey the reaction products from the target location inside GA.SP to the RMS.

This solution is shown in fig. 7; GA.SP would be located on the -30 deg. beam line in the west area.

The beam could be sent onto the target in the middle of GA.SP either through the -30 deg. beam line (non coupled operation), or through the -10 deg. beam line and deflected towards the spectrometer by a 90 deg. magnet .

In this case RMS would be rotated of about 40 deg. and be at 0 deg. with respect to the beam outgoing from GA.SP.

It is important to underline the fact that in the proposed solution the spectrometer would be at a fixed angle with respect to GA.SP, but the possibility of a further rotation would imply a very complex and expensive operation, probably not justified by a major interest.

The most delicate problem in this set-up is represented by the adequate transport of the reaction products from GA.SP to RMS.

The performances of the latter will be in fact reduced mainly because of the chromatic aberrations introduced and the reduction of solid angle.

One has to keep in mind that a reduction in solid angle is anyway inevitable since the distance between the target and the firs optical element downstream of GA.SP cannot be shorter than about 800 mm, while in the present RMS set-up it is 300 mm.

On the other hand the future upgrading of RMS programmed in view of the operation of the Linac will involve a reduction of the solid angle as well.

The preliminary calculations have been performed trying to use the minimum number of optical elements between GA.SP and RMS e.g. a doublet of magnetic quadrupoles positioned at a distance of 1 m from the target.

In this configuration a first adjustment of the parameters gives the spectra of fig 8 which represents the lower limit of the performances.

The study of a more complex transport line is under way, which would allow one to improve the acceptance and the resolution compared to the proposed one.

At the end the minimal assembly requires the acquisition of a deflecting magnet of 90 deg. double focussing with a radius of 2 m and max. field of about 1.6 T; a pair of quadrupoles with aperture of 120 mm of diameter and a field of 0.6 T at the surface of the pole, the power supplies for the optical elements and the usual equipment for the beam line.

Fig. 7

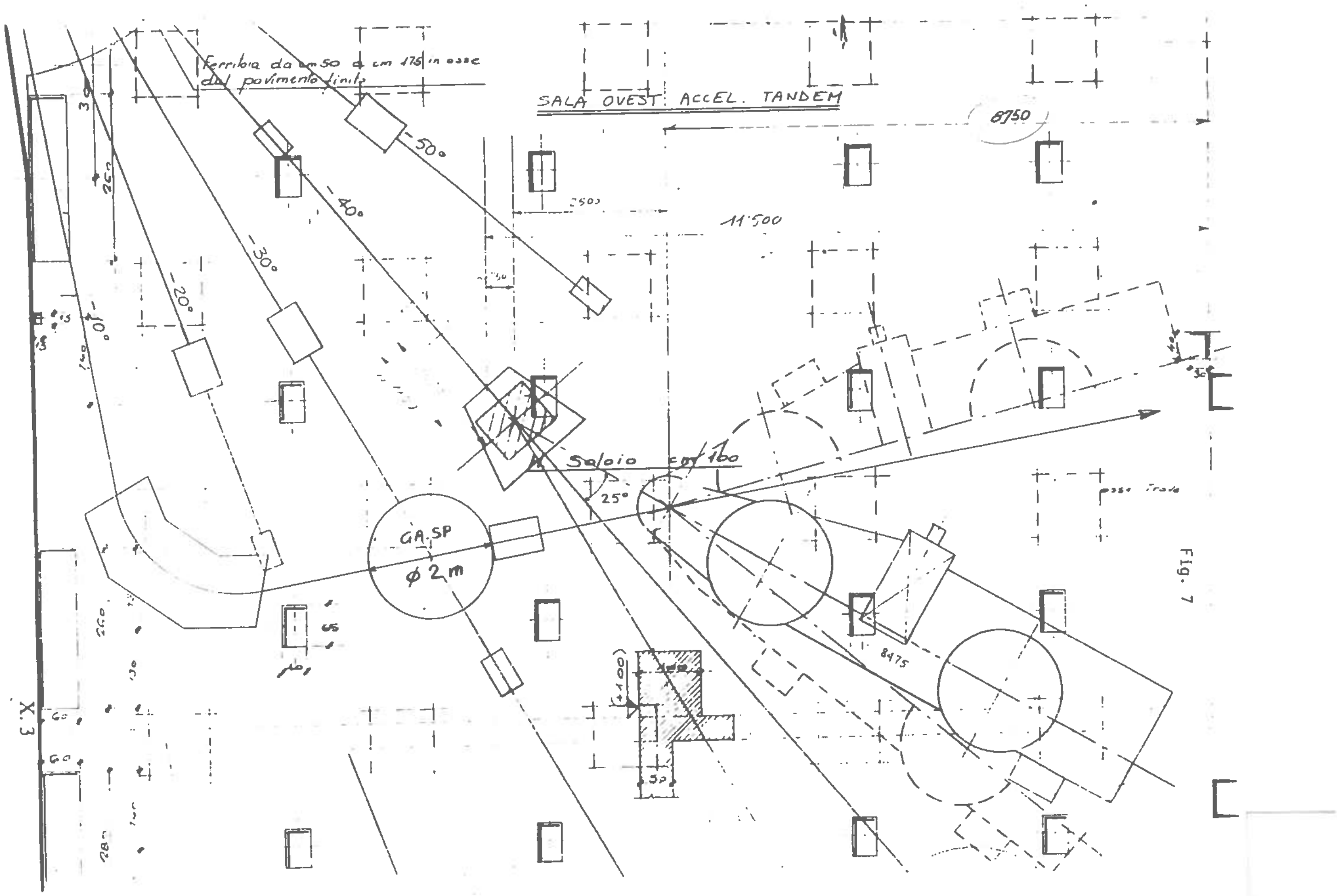
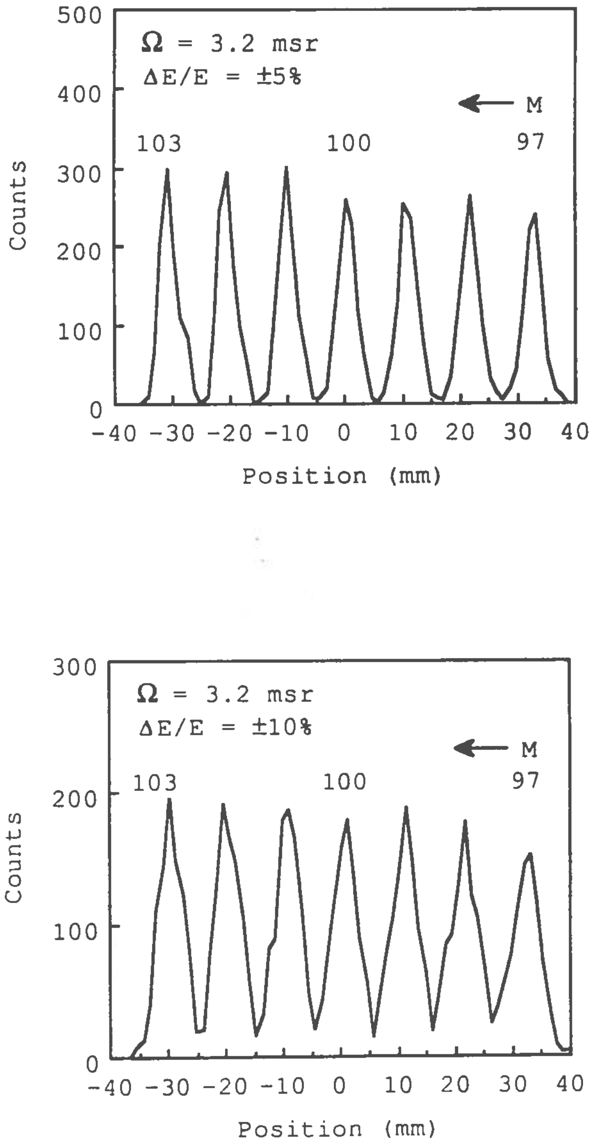


Fig. 8



[1] P.Spolaore et al., NIM A238 (1985) 381

Fig. 7 Possible location of GA.SP in the west area in view of the coupling with the spectrometer.

Fig. 8 Mass spectra calculated at the focal plane of RMS for the set-up indicated in Fig. 1. The mass resolution for the central value of 100 amu is about 1/250 and 1/170 respectively with a ±5-10% change in energy.

XI. ELECTRONICS

To evaluate the needs for electronic equipment we have taken into account the following :

1 - the experience made in the ARA project building home-made electronics on a small scale for the BaF_2 filter.

2 - the standard electronics available on the market is adequate for the Ge-AC systems.

3 - the control and management of the device need a specific project.

4 - The estimated count rates are such that the timing properties of the detectors will not require particular processing. Pile-up problems can limit somehow the expected performances of the array, and as a first approximation they will be faced just by standard pile-up rejector operations.

The approximate electronics scheme is shown in fig. 9.

The multiplicity filter

In the project the filter consists of 80 elements read out by PMT's.

Although the crystals will be of two different shapes, they will be read out with the same kind of PMT which could probably be a 12 dinode type.

This PMT is the same, except for the quartz window, as the ones used in the ARA filter and it could thus be biased trough the same transistorized voltage divider.

The signals thus obtained are already formed to be analyzed by the subsequent electronic chain.

The need to extract both fast information for the multiplicity and slow information for the measurement of the total energy will be met by using two sets of fast and slow amplifiers that could be derived with minor modifications from the existing ones used in ARA and, if possible, integrated in the Linear Gates.

Constant Fraction Discriminators of the CF8000 series produced by EG&G, possibly with remote control, have been considered for their compactness and for the possibility of using their ECL output. A home-made alternative that can solve easily the anticoincidence from the shields will be also taken into account.

The logic signals will be retarded, shaped and sent to a multiplicity circuit that will act as a multiplicity threshold and will deliver an analogic signal proportional to the multiplicity as well as a pattern gate (PGF) for the subsequent linear analysis.

The measure of the total energy will be performed by Linear Gates and a linear sum amplifier where the PGF will select the channels to be summed.

Compton Suppression Shields

These BGO shields will be used in the conventional way, that is with a single output given by the sum of the 8 detectors that form the shield, split into two to give both the veto and the linear signals to determine the sum energy.

In this case too there will be an analogic signal to determine how many detectors are fired independently of the suppression. There will be no multiplicity threshold.

Germanium Detectors

The processing of these signals will be performed using uniquely standard commercial electronics.

That seems to be sufficiently reliable and given the limited number of detectors it is not convenient to develop a specific electronics, except for the implications of the dead time induced by the shaping time needed for optimum resolution.

The only weak points of such a choice are the limited compactness of the ensemble and the lack of remote control on the gain adjustments of the modules. In a second review of the electronics a possible use of remote gain control will be taken into account.

For the Ge detectors there will also be a multiplicity circuit which will establish a threshold on the event multiplicity; this circuit will be fed by the Ge's fast signals after they have passed the anti-coincidence test with the respective AC suppressors.

A programmable Logic Array module fed by the minimum multiplicity event from the GeHP array, the BGO filter and other fast signals from the RMS or charged particle detectors will be responsible for the production of the first level trigger.

A second level trigger will be obtained combining the minimum multiplicity after the linear analysis performed by the Linear Gate and Stretchers and the equivalent information from the other detectors.

The pattern of the event complexity and the second level trigger will address the data acquisition system for conversion of the relevant information.

The acquisition of the analogic multiplicity signal since the individual signals will not be necessary will be acquired on the basis of the pattern gate trigger.

Front end

All the analogic signal, i.e. the energies and timing with respect to the first level trigger of the Compton suppressed Germaniums, the sum signals and the multiplicities will be converted by sets of ADC's and TDC's at high resolution and differential linearity commercially available.

The Ge energy signals and all the linear signals produced by particle detectors or the RMS will be stored after being memorised by Linear Gates and Stretchers for the following purposes:

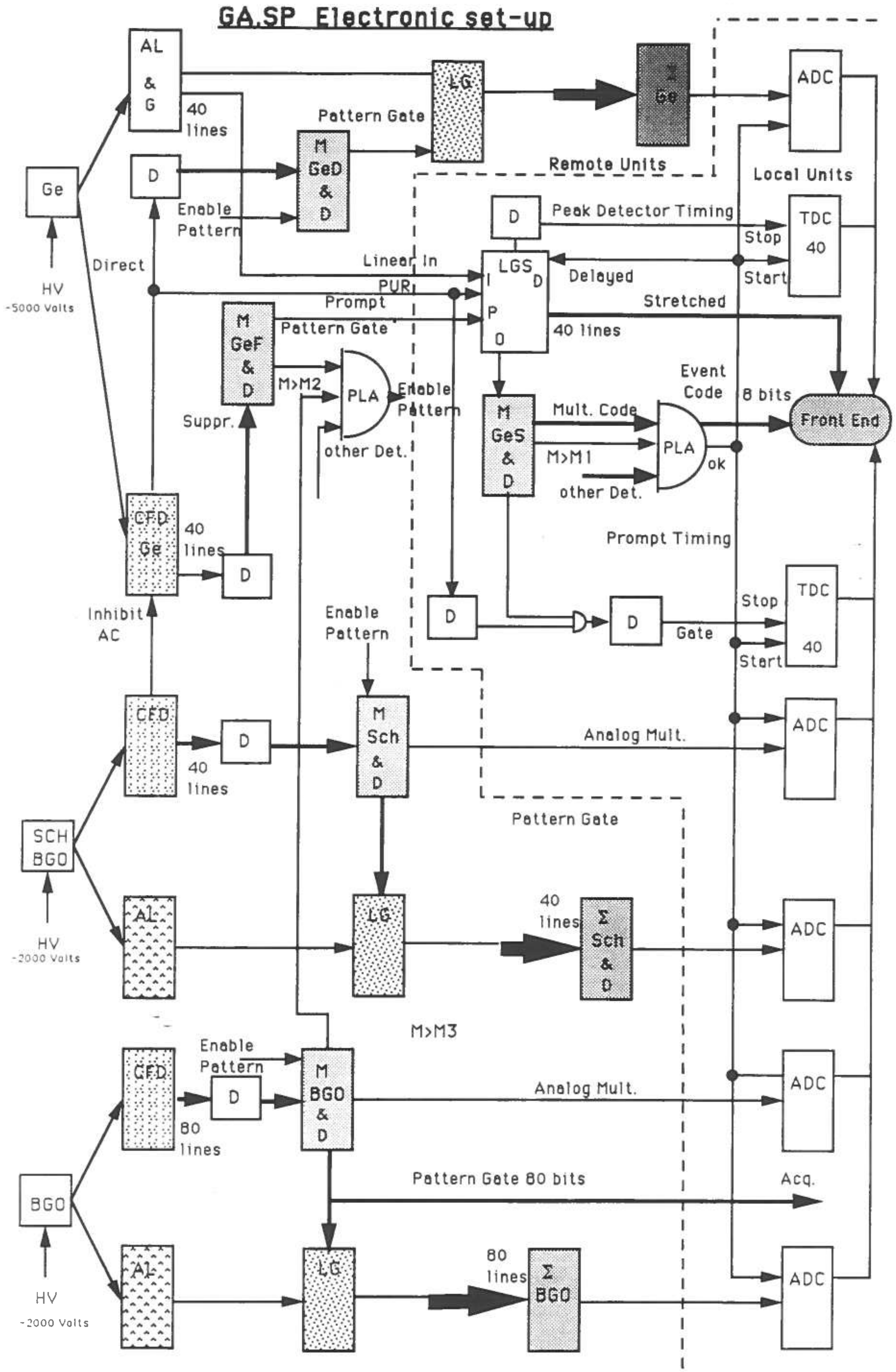
- to allow the storage if the conditions of the trigger logic are satisfied only;
- to furnish a Peak Timing signal equivalent to the rise time signal to correct for the ballistic effect.

The master trigger will be delivered by a logic box which will gather information on the coincidence between the various parts of the device.

Other Components

Beside what has been described above we have estimated approximately the needs concerning power supplies, BIN NIM, BIN CAMAC, and the racks necessary to host all the electronics and the support equipment for the control of the apparatus.

Fig. 9


GA.SP Electronic set-up
Ge
HV
-5000 Volts
Direct
AL & G
40 lines
LG
Σ Ge
Remote Units
Local Units
ADC
D
Pattern Gate
M GeD & D
Enable Pattern
Linear In
PUR
Prompt
Pattern Gate
D
Peak Detector Timing
LGS
I
D
P
O
Delayed
Stretched
40 lines
TDC 40
Stop
Start
M GeF & D
M>M2
PLA
Enable Pattern
other Det.
Suppr.
Event Code
8 bits
M GeS & D
Mult. Code
M>M1
PLA
ok
other Det.
Front End
CFD Ge
40 lines
D
Prompt Timing
Inhibit AC
D
D
Gate
Stop
Start
TDC 40
Enable Pattern
CFD
D
40 lines
M Sch & D
Analog Mult.
ADC
Pattern Gate
SCH BGO
HV
-2000 Volts
AL
LG
40 lines
Σ Sch & D
ADC
M>M3
CFD
Enable Pattern
D
M BGO & D
80 lines
Analog Mult.
ADC
Pattern Gate 80 bits
Acq.
BGO
HV
-2000 Volts
AL
LG
80 lines
Σ BGO
ADC

XII. DATA ACQUISITION

Among the proposed experiments those that impose the most severe conditions to the acquisition system and to the on line are the gamma spctroscopy ones.

Therefore they have been taken into particular account in the project of the data acquisition system without forgetting, of course, the needs of the other experiments.

The simulations presented in the first part of this proposal, give an idea of the general trend that a data acquisition system for GA.SP must follow. It is obvious that, under the assumptions made to obtain the counting rates, they represent only an upper limit for the system. In the following table are reported the estimated rates and the corresponding data flow rate in the hypothesis of an average event length of 60 Bytes (~30 parameters).

Multiplicity	Ge(kEvents/sec)	≈MBytes/sec
2	23	1.380
3	9	0.340
4	2.5	0.150
5	0.5	0.030
total	35	1.933

The project has been developed keeping in mind the current state of art beeing aware that future developments will be considered during the implementation of the system.

The type of technology which has been taken in account is the one based on VME standard which has been already successfully experienced at the LNL. In this environment it is possible to obtain, at a reasonable price, the necessary computing power and memory dimension. Moreover one obtains a good level of standardization of the modules used, in our hypothesis CPU MC68020 or 030. This choice has also advantages in case of failure, since can surely reduce the down time of the system.

The aim of the project is to produce on line matrices (4kx4k) of the same quality of those at present obtained from off line analyses and to store only high quality data rejecting, if requested, any event not interesting for the experiment being performed.

In this perspective the whole system has been developed as a cascade of filters through which the events flow whitout additional dead time. A block scheme of the proposed system is shown in Fig. 10, 11.

Second Level Filters

After the first hardware level filter given by the electronic trigger, we have introduced a many level structure to allow the desired information of interest only to pass to the subsequent analysis (Fig. 12).

In detail, the function of the "pre-filter" will be the collection of the data from the interface (HSM8170 produced by CES) and the elimination, at the very beginning, of incomplete events and/or complete classes of events on the basis of special parameters values, for example, gamma multiplicity.

This section will be made of 2 interfaces operating in ping-pong mode and of one CPU for the pre-filter function.

The "event formatter", consisting of two CPUs working in parallel, whill have the main function to test the full consistency of the event parameters, to eliminate surplus information and reformat the event structure. This rearrangement allows to reduce the event size and to simplify the analysis making the data treatement independent of the acquisition hardware format.

The real filtering section will be the so called "absolute filter" which will reject events unimportant for the particular experiment.

The algorithms to perform fast mono- and bi-dimensional selections, hashing and synonym reduction techniques with large look-up tables, have been altready implemented in the Laboratory.

This section has been divided into two parts in order to allow the subsequent pre-analisys to be fed with a sufficiently high rate (Fig. 13)

Gamma Data Pre-Elaboration

This section has been developed to take into account the peculiarities of the elaboration of the gamma data coming from germanium detectors.

Among the various kinds of corrections one can apply, two of them have been considered essential:

- ballistic effect correction to improve the Ge detectors resolution
- gain and offset renormalization to equalize the data coming from different detectors into a single matrix.

While the first one is straightforward, the second is more involved since one has to extract the correction parameter from the same data that must be corrected.

To solve this problem we have considered two possibilities. The first way is to store temporarily the incoming data to be corrected in order to derive calibration parameters to use. The second solution is to extract the parameters from the data flow and use them to elaborate subsequent data. In our case, estimated event rates are such that this second approximated method can be applied without introducing significant distortions.

In Fig. 3 we show the block scheme of this section, in which on one side the full correction is made while on the other, after ballistic effect reduction and spectra istogramming, the recalibration parameters are calculated and sent to the first part.

Tests were performed on CPUs of the same kind we intend to use. The results, 10-15 kevents/sec, imply the parallel operation of a group of 3 CPUs on one side and 2 on the other.

Data Storage

For the permanent storage of the collected data many solutions are at present available.

In particular, some kinds of magnetic tape cartridges have been taken into account:

type	capacity	rate
IBM	200 MBytes	1.0 MBytes/sec
8mm	2300 MBytes	0.25 MBytes/sec

Optical discs have also been considered but the present technological level and media price capacity ratio are not yet of great interest.

It is important to notice that the total amount of information required for the experiments we are dealing with is of the order of 10^9 10^{10} events, i.e. about 60-600 GBytes. This fact imposes severe conditions on the kind of media to be used. On the other hand, calculations made on the real information content of events show that in various cases 60% of the media contain only the 30% of the global information.

Finally, we have to take into account the general policy of INFN for computing facilities to allow an easy data exchange and complete compatibility among the Laboratory and the various Universities.

For these reasons we do not take any decision at the moment but indicate, for budget purposes, the amount of money necessary for a 1MByte/sec solution.

On-Line Analysis and Histogramming

As mentioned, before the aim of the whole system is to produce on line matrices and, of course, one dimensional spectra.

Moreover, especially for particle detectors, it is necessary to allow for the extraction of new parameters from the elaboration of event data.

For this purpose, a two-stage final section (Fig.14) has been introduced in which the user can perform either multiple sorting of the data, with the same technique used for the absolute filter, or calculation of new parameters.

The final results from the whole chain will be fed into a large histogramming memory, some 200 MBytes, controlled by hardware DMI units.

User Interface

For the user interface we suggest a full graphic system based on X-WINDOW and commercially availabe graphics packages to reduce software development time.

The tentative configuration will be composed of two graphic stations: the first with acquisition system set-up and measurement control purposes; the second, directly connected via VME to the histogramming memory, will be devoted to spectra mono- and bi-dimensional display and standard elaborations.

An indication of the required computing speed is given by actual elaboration software and by the necessity to give the user graphics responses in reasonable time, i.e. a few seconds.

All this leads to a choice of the work stations in the class commercially known as 3D-stations.

For these components of the system also, owing to the fast evolution of this field, we think it better to delay a definitive choice and insert in the budget the amount actually necessary for two stations of standard performances.

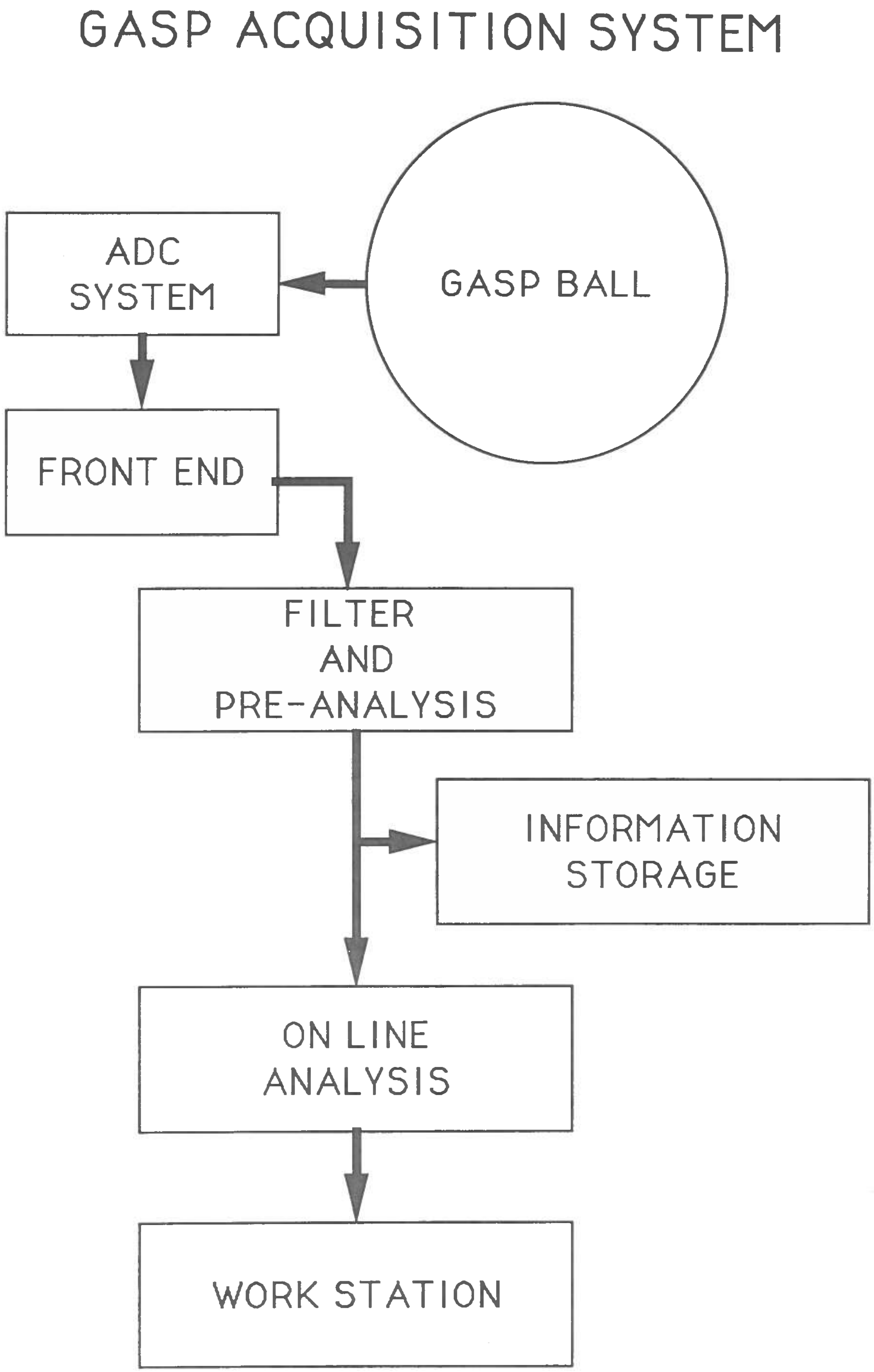

GASP ACQUISITION SYSTEM
ADC SYSTEM
GASP BALL
FRONT END
FILTER AND PRE-ANALYSIS
INFORMATION STORAGE
ON LINE ANALYSIS
WORK STATION

Fig. 10

GENERAL ACQUISITION SCHEME

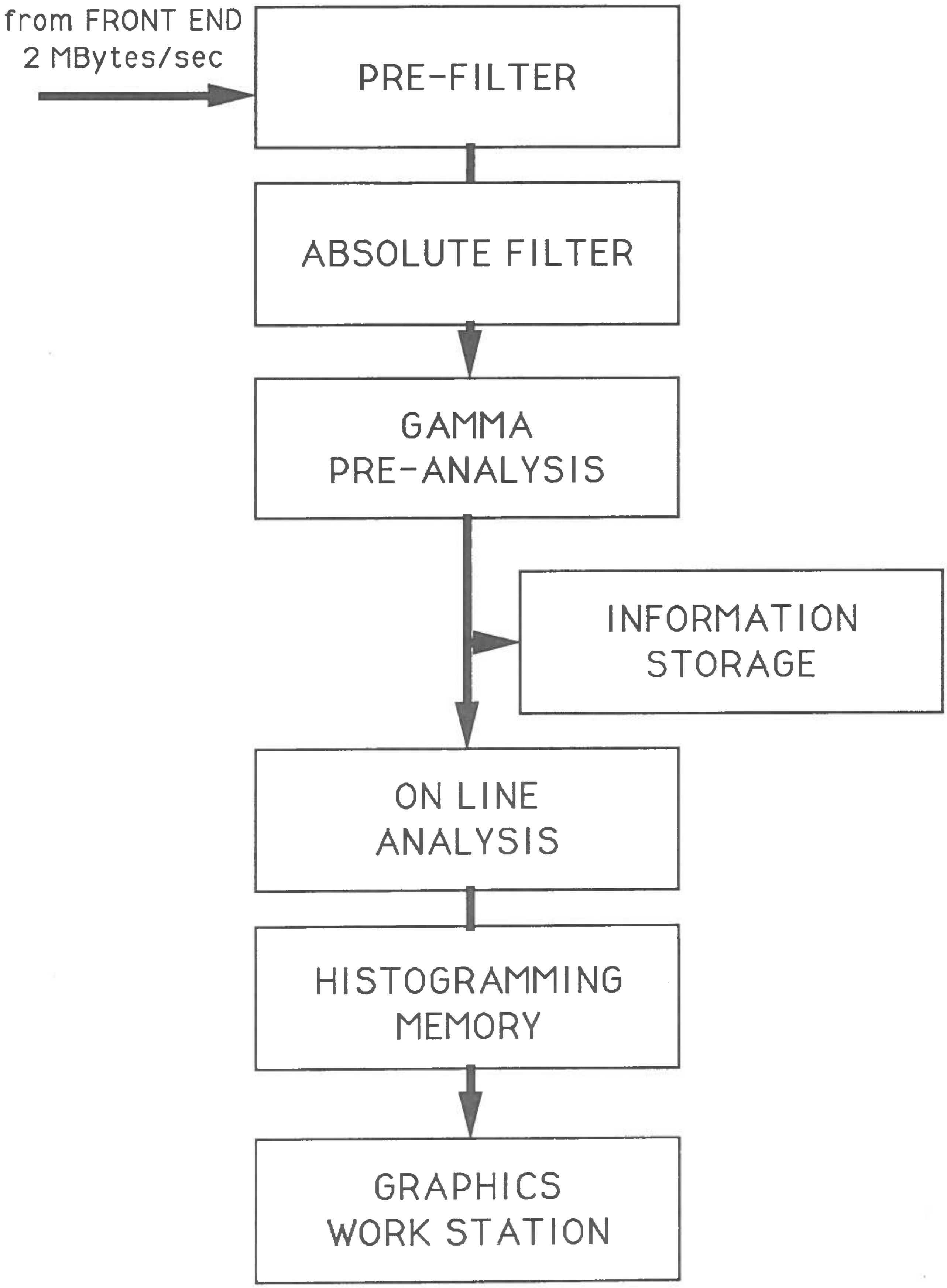
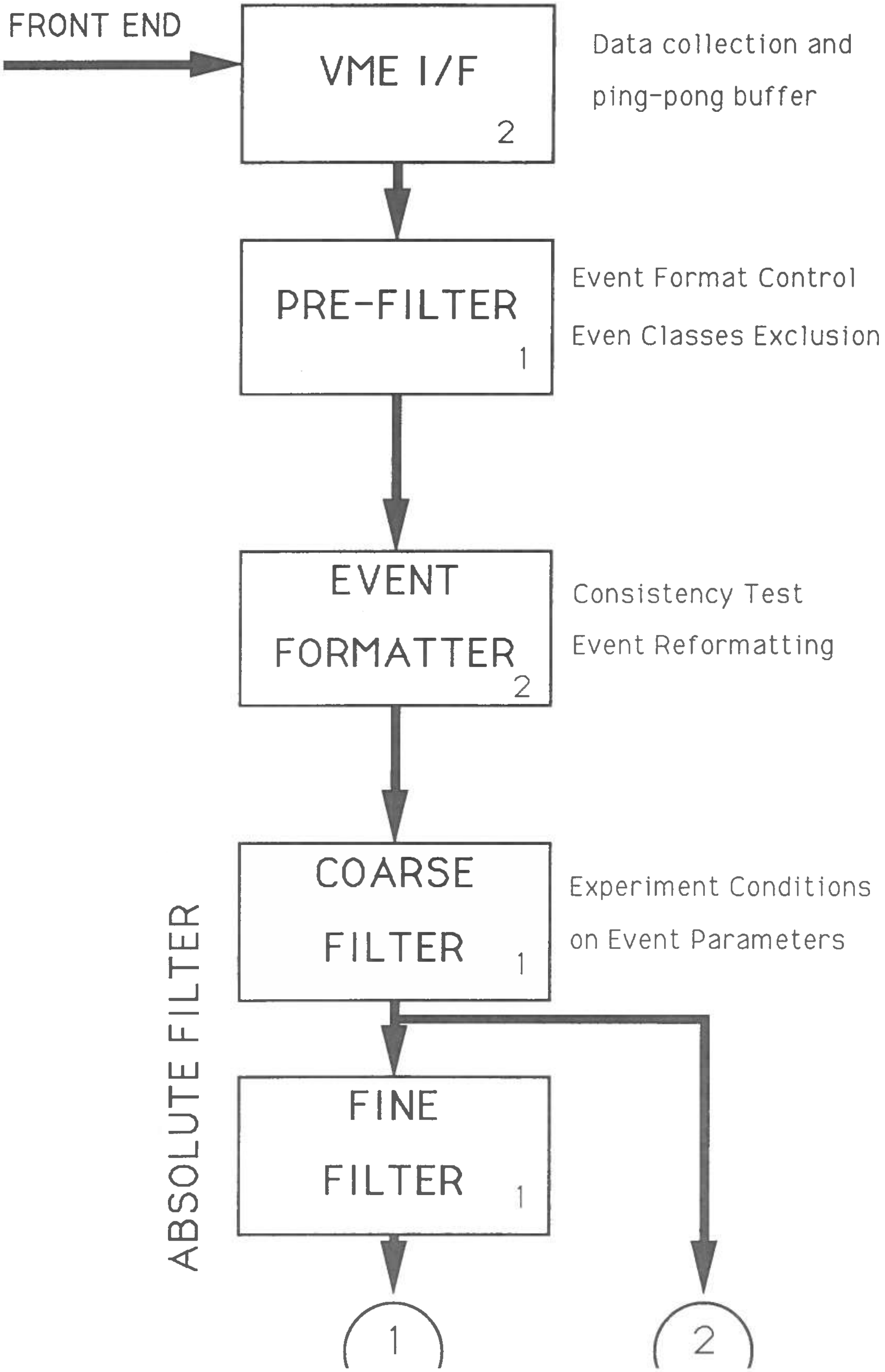


Fig. 11

ACQUISITION SYSTEM
INITIAL FILTERS



ACQUISITION SYSTEM
GAMMA PRE-ANALYSIS

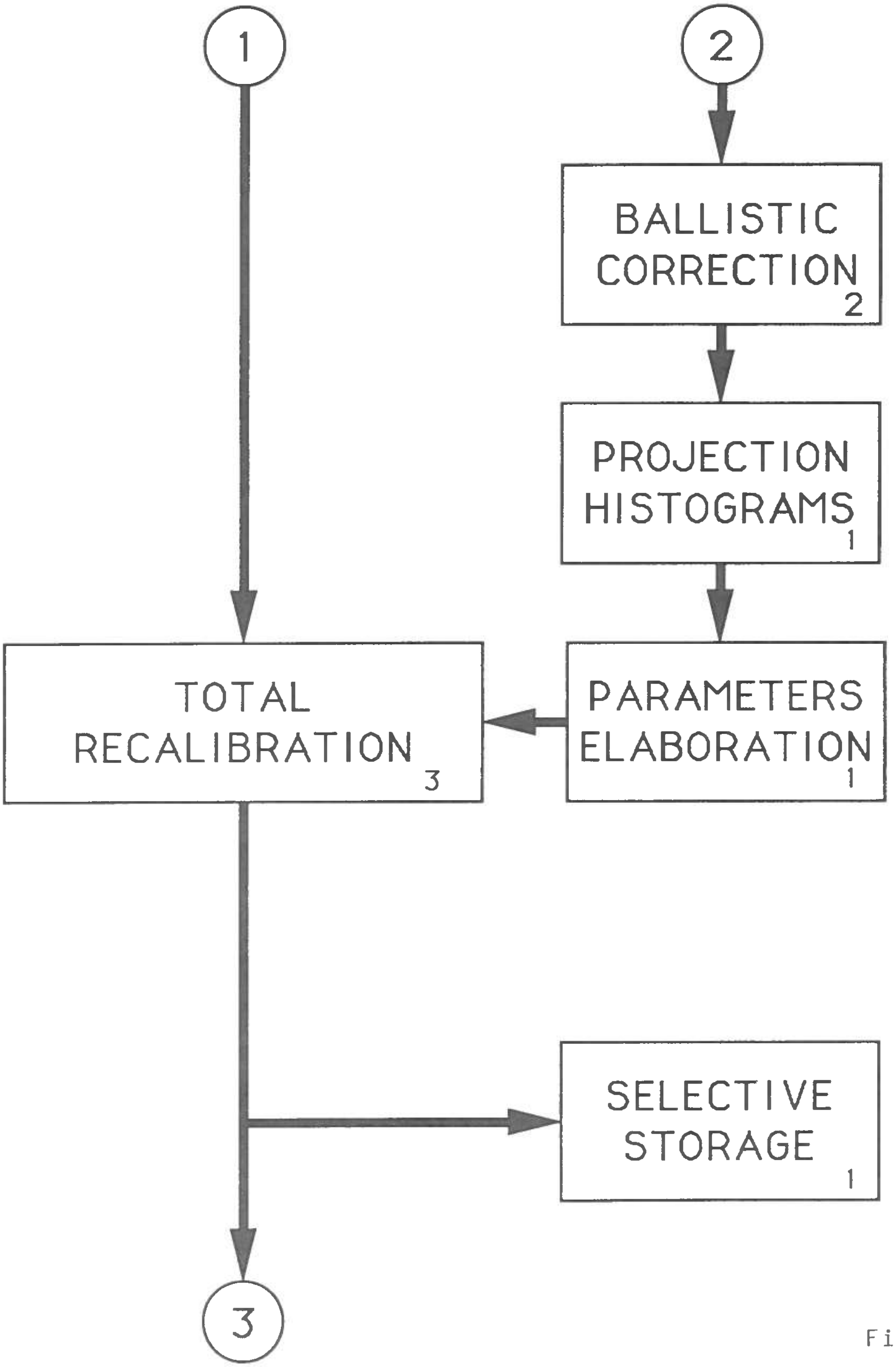
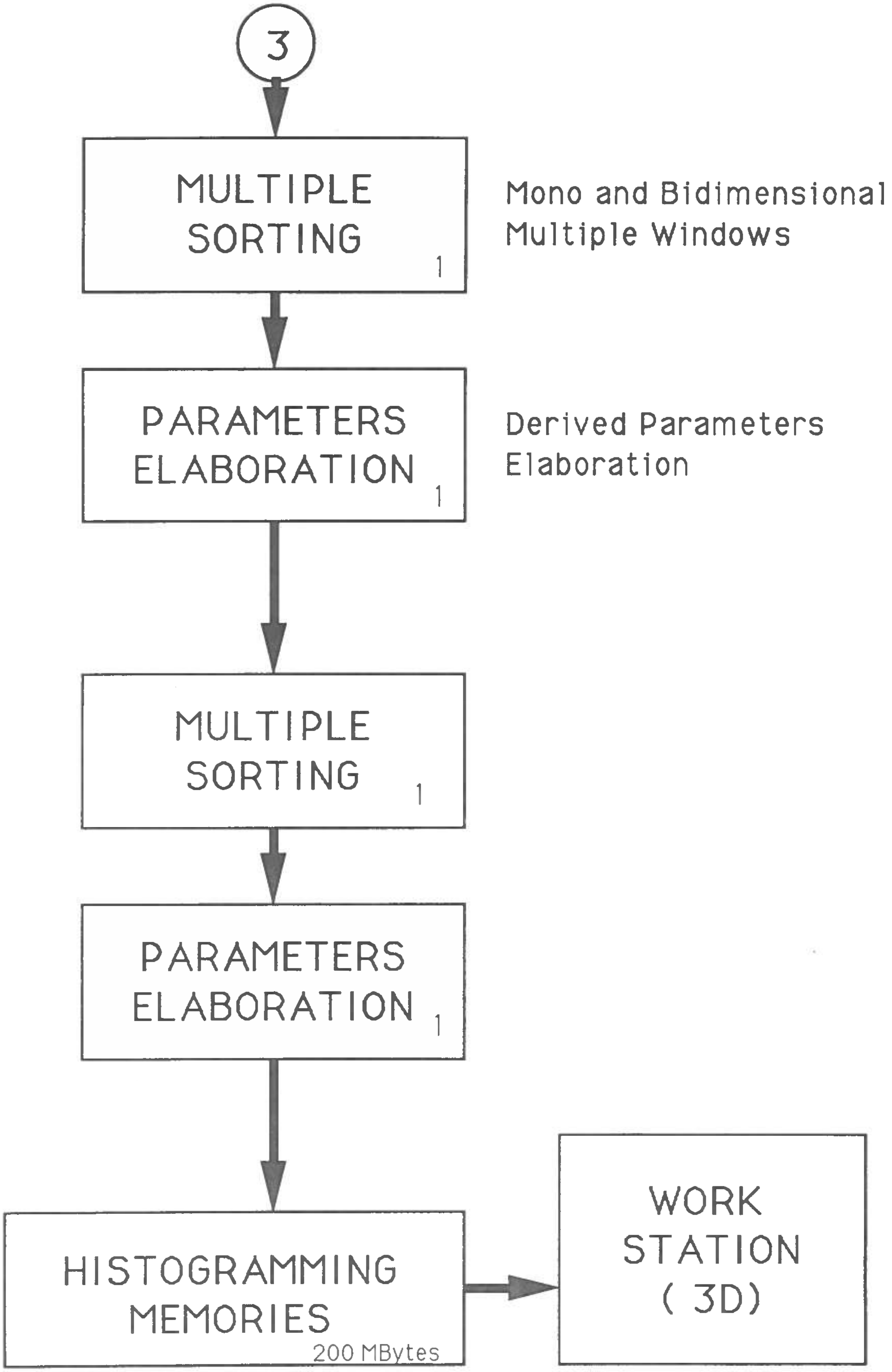


Fig. 13

ACQUISITION SYSTEM ON-LINE ELABORATION



3

MULTIPLE SORTING 1

Mono and Bidimensional Multiple Windows

PARAMETERS ELABORATION 1

Derived Parameters Elaboration

MULTIPLE SORTING 1

PARAMETERS ELABORATION 1

HISTOGRAMMING MEMORIES

200 MBytes

WORK STATION (3D)

XIII. MECHANICS

A large effort has been devoted to the definition of GA.SP's mechanics.

Particular attention has been given to the flexibility of the system in the various experimental set-ups and in connection with other detectors.

The whole had to be thought of in order to allow the easiest access to the target and to the individual filter elements.

One should be able to substitute or remove the Ge detectors as well as the AC shield and the system has to rotate around the target position in order to inject the reaction products at 0 deg. into RMS.

The composition of the system has thus been conceived as follows:

1- Central shell of BGO crystals

2- External spherical structure to hold the Ge detectors with the relative AC shields and cryostats

3- Main frame capable of sliding along the X axis common to the two preceding structures

4- Main frame capable of sliding along the Y axis and rotating around Z

5- Structure for small adjustments and alignments

A drawing of the ensemble is shown in fig. 15.

Central BGO Sphere

The structure could consist of cast aluminium with a shape similar to a soccer ball which presents on the surface some cavities where crystals are to be located.

In this way, one could obtain sites to hold the elements with a wall thickness (and thus a distance between crystals) of about .2-.3 mm and an extremely small tolerance (given the possibility to machine the cast). Then, with an adequate choice of the coating technique, one will reduce to a minimum the dead space due to the crystal capsule.

The sphere will be divided into two parts, which will be opened along a line of separation of the crystals.

A suitable thickening of the external side of the structure will allow one to lock the crystal in place.

The two hemispheres will be mounted on rails and will slide by means of ball bearing to allow a translation as well as the aperture of the detector to grant access to the internal scattering chamber.

External Spherical Structure

To increase the flexibility of the system the structure that holds the Ge detectors with the LN_2 leads and the AC shields is completely separated from the previous one.

One can then imagine a structure concentric to the one of the BGO's conceived as a geodetic figure with suitable openings for the PMT's and the cables coming from the BGO sphere.

The technique of construction of this second structure will be similar to the former, the Ge with relative AC shield will be mounted on rails, to make it possible sliding them out if necessary.

Onto two external structures two Valve-Boxes will be located to distribute the liquid nitrogen to the cryostats.

The necessity of using such a distribution system comes from the large daily consumption of nitrogen, while the division of the distribution between two units comes from the need to simplify the splitting of the structure to access the chamber; each of the two boxes would have a separate inlet and valves for each detector to feed.

With this solution the movements of the structure and the substitution of some parts will be performed in the simplest way, disconnecting the element to repair only and leaving the rest filled with nitrogen.

Main Frame X Movement

This first structure will hold the guides that sustain the two spheres on which the sliding will be realized along a direction perpendicular to the beam to split the system into two.

The main structure could be made of metallic tubing with a walking platform made of aluminium sheet to keep it as light as possible.

The whole will be connected with a structure below with sliding rails to allow sliding along the Y direction (parallel to the beam).

The dimensions for this structure are roughly:

4000 mm in the opening direction (X axis)

3000 mm in the orthogonal direction (Y axis)

Main Frame Y Movement and Rotation

As mentioned above, below the first structure there will be another frame which will hold the fixed part of the Y-axis rails and allow rotation around Z.

This will be made of metal tubing and will have a central hinge and a circular rail to distribute the load.

Main Frame Positioning

This last structure will hold all the preceding ones and will be mounted on adjustable screws to allow careful positioning and alignment of the device.

The whole system, as it has been described, will then satisfy the project requirements:

- Slight movements along the Z axis to align the system
- Rotation around the vertical axis
- Movement along the axis parallel to the beam ±500 mm
- Independent movement of the two hemispheres along the X axis to gain access to the internal chamber.

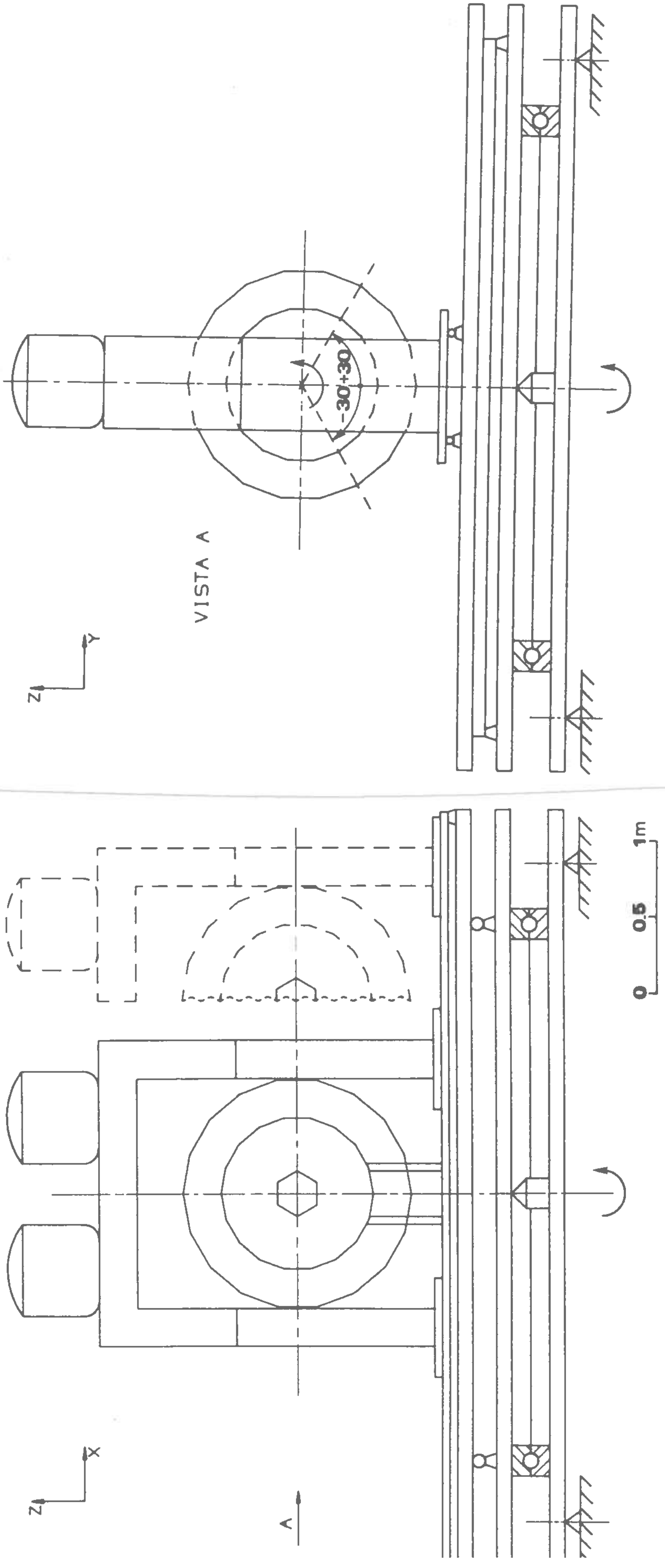


Fig. 14

Table of annual costs

in ML

Year	Ge	Elettr.	BGO	Mech.	Comp.	Others	Total
1989	-	260	-	200	-	100	560
1990	650	180	1230	140	170	260	2630
1991	650	140	1190	100	230	200	2510
1992		100	-	100	90	150	440
1993	150	80	-	-	-	170	400
TOT	1450	760	2420	540	490	750	6540