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P R O P O S A L

STUDY OF MUON PAIRS AND VECTOR MESONS PRODUCED IN HIGH ENERGY Pb-Pb INTERACTIONS

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1. INTRODUCTION

We propose to make use of the ultrarelativistic heavy ion beam planned for 1993/1994 in order to extend the physics program started in 1986 and intended to detect, experimentally, those signals which are accessible in dimuon production and which are potentially related to the phase transition of ordinary nuclear matter into the Quark-Gluon Plasma (QGP) state. According to theoretical predictions [1], such a phase transition could take place at sufficiently high energy density and temperature. It is expected [2] that Pb-Pb interactions at 160 GeV/c per nucleon will provide thermodynamical conditions more favourable to the formation of QGP than the 200 GeV/c per nucleon oxygen and sulphur beams which are presently available at CERN.

The following signatures, ordered with respect to time in the interaction history, are within the scope of this proposal:

- thermal dimuons, in the mass range 1.4-2.4 GeV/c^2, which carry information on the very early stage of the interaction from which most of them originate;
- the produced vector charmonia (J/ψ and ψ') which are attenuated in the surrounding medium in a predictable way;
- the ϕ meson, the enhancement of which is related to the strangeness enhancement expected for dense media.

Thermal dimuons have not yet been observed but J/ψ and low mass vector meson production has been studied with O and S beams. The abundance of published phenomenological papers in this field speaks for its relevance. Both the observed J/ψ suppression and ϕ enhancement at high transverse energy clearly indicate the effects of a very dense medium at early times. Whether this medium is a kind of QGP or of a hadronic gas is however not clear yet. New data obtained at higher energy densities over more extended volumes and under better thermalization conditions are needed for a better understanding of the involved mechanisms.

We propose, therefore, to measure muon pair and vector meson production (ρ, ω, ϕ, J/ψ and ψ') in Pb-Pb interactions. The detector is based on the NA 38 apparatus upgraded to stand both the higher trigger rate and the higher radiation level. The layout is completed by a multiplicity detector and a Zero Degree Calorimeter (ZDC) which are added with a view of describing more completely the individual events in which dimuons are produced. The addition of the ZDC implies that the beam will pass through the muon spectrometer (at present it is stopped in the hadron absorber).

2. PHYSICS MOTIVATION

2.1 What has been learnt with O and S beams?

2.1.1 The J/ψ

With O and S beams, the production of both the J/ψ and the dimuon continuum around 2 GeV/c^2 has been studied as a function of the energy density ϵ estimated from the measured neutral transverse energy E_{oT}. For U and Cu targets, the ratio of J/ψ's to dimuons in the mass continuum has been found to be smaller by more than a factor 2 at the highest energy density, when compared to proton induced collisions [3]. This holds especially for J/ψ's of low transverse momentum p_T [4]. A suppression of the J/ψ due to Debye screening in a quark-gluon plasma (QGP) was predicted even before the experiment started [5]. Much theoretical activity has been triggered by the NA 38 result. The present belief is that two types of mechanism can account for the observed results:

1. Debye screening, which prevents the formation of the bound state in a hot plasma, at and above T_D, the critical temperature for Debye screening [5], or dissociation by thermal activation below T_D (but above T_c the critical temperature for the phase transition) [6] (see [7] for the characteristic p_T dependence);
2. and/or initial state interactions and final state absorption in dense hadronic matter [8].

2.1.2 The ϕ

While J/ψ production decreases, the ratio of ϕ to continuum production is 2 to 3 times higher at high energy density than in p-induced collisions [9]. This result is in agreement with the general observation of an enhancement of strangeness production in collisions induced by O and S projectiles [10]. These results are indicative of final state interactions significant enough to favour an evolution of the system towards chemical equilibrium, which also implies thermalization. At present, the question remains open whether the quarks undergo final state interactions in a QGP, or whether the produced hadrons do before freeze-out [11]. For comparison, the $(\rho + \omega)$ production stays rather proportional to the continuum, independently of energy density.

2.1.3 The continuum

In order to study the dependence on transverse energy of the production of the various vector mesons, a reference process is needed with a probability depending linearly on the number of effective participant nucleons of both target and projectile [5]. So far and lacking statistics in the Drell-Yan region beyond the ψ', we have used muon pairs in the mass continuum between 1.7 and 2.5 GeV/c^2. Even in this intermediate mass region, the Drell-Yan process is dominant in our data due to experimental acceptance, although charm production is potentially an important mechanism. Indeed, the transverse energy distribution of these dimuons is well reproduced if they are assumed to behave like Drell-Yan [12]. Moreover, their production cross-section σ_c has been found proportional to the projectile and target atomic numbers A_p and A_T, according to $\sigma_c = \sigma_o(A_pA_T)^\alpha$ with $\alpha = 1.01 \pm 0.04$ [13].

2.1.4 Thermal dimuons

The initial purpose of NA 38 experiment was the search for thermal dimuon production which was expected to offer a genuine characterization of the early phase of the collision [14]. Indeed, once produced, muons will emerge without undergoing further interactions. Thermal dimuons would be observed superimposed on Drell-Yan dimuons in the mass region between the ϕ and the J/ψ, where they would cause a steepening of the mass spectrum. Experimentally, the continuum exhibits a Drell-Yan-like behaviour. To the present level of accuracy, no change in the shape of the invariant mass spectrum has been detected neither when going from O to S projectiles nor when varying the energy density. This negative outcome is not surprising in view of the small rates predicted in ref.[14], which are beyond the sensitivity of our experiment.

2.2 What progress can be expected from a Pb beam?

In the difficult quest of the QGP in colliding systems which have neither the spatial extension nor the stability in time of thermodynamical systems, Pb beams offer distinct advantages over the O and S beams used so far:

1. The much larger *reaction volume* of Pb-Pb collisions provides much better conditions for *thermalization*.
2. Higher *initial temperatures* T_i are reached, at least locally. Indeed, the mean energy density $< \epsilon >$ defined by Bjorken [15], i.e. the energy density averaged over the whole interaction volume, reaches roughly the same value of about 2.5 GeV/fm^3 for O-Pb, S-Pb and Pb-Pb central collisions, when extrapolated to Pb-Pb using e.g. VENUS simulations. Nevertheless, at each impact parameter, there is an energy density profile due to the geometry of nuclei, as described in [16] and shown in Fig. 0. For central Pb-Pb collisions, namely for impact parameter b = 0, the local energy density at the very center of the colliding nuclei will be 40 % higher than the energy density averaged over the whole interaction volume, entailing a 10 % excess of the initial temperature T_i [17]. The difference can be important for *threshold phenomena* such as the formation of a QGP, which may thus appear occasionally in Pb-Pb even if it were never reached in S-Pb.

3. For symmetric A-A collisions, the energy density in Bjorken's definition turns out to be almost independent of the transverse energy except for the more peripheral collisions, as shown in Fig. 1. It becomes thus possible, particularly in Pb-Pb where $< \epsilon >$ is expected to be roughly twice that in S-S, to *distinguish experimentally* between *effects which depend on* ϵ, such as the J/ψ suppression (which is expected to be almost E_T-independent in Pb-Pb), and *effects which depend on* E_T, such as the p_T behaviour of J/ψ's.

4. For dimuon experiments which are rather strictly limited to the forward hemisphere in the c.m. (backwards emitted muons stick in the hadron absorber), the Pb beam impinging on a S target effectively allows to explore the *backward hemisphere* (the light ion defining the forward direction). While S-U collisions in NA 38 have covered the rapidity range $-0.15 < y_{c.m.} < 1.05$, Pb-S collisions in the apparatus proposed hereafter would open the complementary range $-1.05 < y_{c.m.} < 0.15$, where particle production is maximum. The y-dependence of J/ψ production over the enlarged range will be different for models which rely on local conditions, e.g. the density of comovers, than for more global QGP models.

The numerical estimates given are very approximate, given the uncertainties of soft collision dynamics calculations. Fig. 2 shows the local initial temperature and energy density for Pb-Pb central collisions across the interaction volume for two rather different assumptions on the number of effective N-N collisions. Other models find considerably higher particle multiplicities in Pb-Pb, and thereby a higher average energy density [18, 19].

As a consequence of the higher temperature which could be reached in the central hot region, one might observe an additional J/ψ suppression originating from the Debye screening effect, super-imposed on the suppression due to thermal activation and/or to collisions in a dense hadronic medium.

One very interesting feature which has hardly been studied so far due to a lack of statistics, is ψ' production. The ψ' is larger in size and is therefore usually expected to be more suppressed than the J/ψ; the differential Debye screening can be quantitatively predicted [20]. Measurements of J/ψ and ψ' production in proton-nucleus interactions are now available [21], showing less difference in ψ' and J/ψ suppression than our own data [22].

Finally, the ϕ production will further increase in Pb-Pb collisions, owing to the additional final state interactions. The two basic mechanisms could become distinguishable since the time scale is shorter for strangeness production in a QGP than in a hadron gas.

3. DETECTOR STRATEGY

To study J/ψ and ϕ production as a function of the detailed characteristics of the collision, the geometry and the energy density have to be measured on an event by event basis. Also, a well known reference process is needed in order to compare the production rates, in particular as a function of transverse energy.

3.1 Collision geometry and event structure

With O and S projectiles, energy density was estimated from the neutral transverse energy E_{oT} divided by the transverse collision area which was obtained from the same E_{oT} via a model. We believe that this procedure, while justified for an exploratory phase with light ions, would not exploit the full potential of the Pb beam. We intend to build and use a *zero degrees calorimeter* (ZDC) in order to measure the energy E_{ZDC} not involved in the collision. The ZDC provides a direct estimate of the number of projectile participants (= 206 - E_{ZDC}/160 GeV), from which the *transverse collision area* is readily derived using the geometry of spherical nuclei. It also gives the *reaction energy* $E_L = E_{BEAM}$ - E_{ZDC}. The measurements of both the multiplicity and the transverse energy, which are less affected by relative fluctuations due to the the high multiplicity of Pb-Pb interactions, are then needed to characterize, on an event by event basis, the way this reaction energy is dissipated in the interaction region. It can be stressed that the estimate of E_L can be made whatever the impact parameter of the reaction as, contrary to the case of two different interacting nuclei as S and U, the interaction of two identical nuclei leads always to the emission of projectile fragments.

The interest of such detailed event characterization is tied to the possibility that *QGP formation may lead to an event structure which is measurably different from ordinary events*, be it because an increased $< p_T >$ modifies the ratio between E_T and multiplicity (which has been almost a constant in all ion experiments done so far at CERN), be it because the y-distribution shrinks (from the $\sigma_y \sim 1.4$ which prevails for all reactions at at 200 GeV/nucleon, to some value closer to the limit of global thermalization producing an isotropic fireball, with $\sigma_y \sim 0.9$). This argument implies that in events with QGP formation, there is a chance that the rather universal correlation noted so far between multiplicity, transverse energy flow, and longitudinal energy could no longer hold.

The *electromagnetic calorimeter* will have its rapidity coverage shifted outside that of the spectrometer. This is needed in order both to safeguard a reasonable life expectancy under the severe radiation conditions expected with Pb-Pb collisions, and to free the solid angle seen by the detected muons from the 13 radiation lengths of the calorimeter, which will improve the *mass resolution* and ease considerably the identification and the study of the narrow vector mesons, in particular the ϕ and the ψ'.

A *multiplicity detector* covering the large pseudorapidity interval $1.5 < \eta < 4.0$ will therefore be associated to the electromagnetic calorimeter reduced to the range $1.5 < \eta < 2.3$, outside the spectrometer acceptance. The E_{oT}-multiplicity correlation is measured in the common range; beyond, E_{oT} will be estimated from the multiplicity under the assumption of unchanged average p_T per particle.

3.2 The reference

Muon pairs in the mass continuum provide the required reference to the fate of the vector mesons. For this purpose, muon pairs with masses between 2.1 and 2.6 GeV/c^2 will be used, similarly to what has been already done in experiment NA 38. However, with the statistics foreseen for the experiment, a reasonable amount of *muon pairs in the mass continuum above the ψ'* will be available. These events, quite exclusively due to the Drell-Yan mechanism and free from any meson decay background, will constitute an additional reference. Their statistical error will be roughly twice as large, but they will be free from systematical errors. The simultaneous detection of both these references will provide the natural link with previous experiments. Furthermore, the high mass sample of Drell-Yan events will be the most stable and accurate reference in the search for thermal dimuons.

4. EXPERIMENTAL PROBLEMS

Experimental difficulties specifically due to the use of a Pb beam are foreseen with the present NA 38 detector as it stands.

4.1 The present NA 38 detector

The detector used in experiment NA 38 is shown in Fig. 3. Its main components and their use are briefly described hereafter :

1. The standard muon spectrometer [25] is operated with a toroidal magnetic field of 1.2 Tm, corresponding to a current of 4000 A. The beam which does not interact in the target is dumped into a 400 cm long W-U plug. This plug is embedded in the most downstream part of an absorber made of 40 cm of Al_2O_3 followed by 480 cm of carbon. The spectrometer accepts muon pairs in the rapidity interval $2.8 < \eta < 4.0$.
2. A 12 cm thick (13 λ_0) calorimeter made of scintillating fibers embedded in lead measures the electromagnetic energy of the reaction in the pseudo-rapidity interval $1.7 < \eta < 4.1$ (see § 4.3). In the high resolution version of the detector, the inner part of the calorimeter which subtends the rapidity interval

$2.8 < \eta < 4.1$ is replaced by a block of Al_2O_3. This removes 11.5 radiation lengths from the very start of the muon tracks and significantly improves mass resolution due to multiple scattering from 120 down to 80 MeV/c^2.

3. A multiple target system made of up to 20 thin (1.7 mm) sub-targets, surrounded by a set of 32 cylindrical scintillators, identifies the sub-target where the interaction has taken place and flags reinteractions when they occur. The central target is located 22 cm upstream from the calorimeter front side. The beam passes through thin (3 mm) quartz Čerenkov counters which are used to precisely monitor the position of the incident beam on the targets, identify big produced fragments and help fighting pile-up problems (see § 9). Another specific quartz Čerenkov counter identifies beam-target interactions (for minimum bias triggers for example) and, with special electronics, provides the best jitterless time reference for the trigger (the measured jitter of the trigger is less than 0.2 ns) and the shape of the pulse, within the reading gate, which is used as a standard to detect an eventual trigger with two close-in-time interacting ions.

4. A beam hodoscope made of two planes of 16 and 14 thin (1 mm) scintillating counters respectively is located 33 m upstream from the target in a region where beam is wide enough and individual counting rates are low. Its transverse position is adjustable by remote control so as to intercept the whole beam. The beam hodoscope is used to identify and count the incident beam and to fight against beam pile-up if necessary.

4.2 Experimental difficulties foreseen for a high luminosity Pb-Pb experiment

Given the goals of the experiment, in particular for the J/ψ and ψ' studies, high luminosity is a must (see §6.6.2). The experiment proposed here has therefore been designed in order to stand a luminosity corresponding to a beam of 5 10^7 Pb-ions per burst (with a 5 s spill) incident on a 18% interaction length target. This nominal intensity limit follows from our past experience. It corresponds to a working point where pile-up is still at a moderate level and can be easily kept under control provided a reasonably good spill quality.

Due to the increase in the hadron multiplicity produced by Lead as compared to Sulphur, the main difficulty will arise from the background originating from π and K meson decay, especially for muon pairs of masses below 2 GeV/c^2. For the rapidity $\eta = 3$, VENUS simulations lead to an average rapidity density $dN_\pi/d\eta = 170$ (resp. 60) for minimum bias reactions and 650 (resp. 210) for central reactions with b < 3 fm corresponding to 3% of the total cross-section, respectively for Pb-Pb and S-U interactions. It follows that, according to VENUS, the backgound would be of the order of 8.3 times higher when going from S-U to Pb-Pb reactions.

On the other hand, extrapolation to Pb of the experimental data obtained in O-U and S-U interactions would indicate a power law closer to $(A_p)^{1.9}$ leading to a factor of 27. In the following, these two cases will be considered as extreme limits and labelled respectively "background1" and "background2". For instance, the comparison of NA 38 data for O and S and their extrapolation to Pb leads to the backgound2/signal ratio given in Fig. 4, if the set-up were the same as used in 1986/1987. With the improved standard set-up used since 1990 and described in § 4.1, the new backgound levels amount to only 60% of these extrapolated values. It is clear that several problems would arise if nothing were done :

1. Illumination of both upstream trigger hodoscopes and proportional chambers of the spectrometer would increase strongly and, potentially, lead to problems.
2. The trigger rate would reach about 48 10^3 triggers/burst, which is clearly unacceptable.
3. Radiation resistance might become a problem for most detectors located near the target (see Appendices 1 and 2 of this Proposal).

In order to test, experimentally, some of the points mentioned above, a set of tests and measurements have been performed in a 6 week proton run during April-May 1991.

4.3 The high intensity proton tests

We have exposed the spectrometer to an intense proton beam, with 32 cm of air left between the target and the front of the Al_2O_3 absorber but, otherwise, as described in § 4.1 above. The intensity ranged from 5 10^7 up to 1 10^{10} protons/burst, with a 2.5 s nominal spill. For each intensity, a comparison was made between running conditions using either no target at all (in that case the effective target was the inner plug of the absorber 165 cm downstream from the nominal target position) or a 5.6 cm long W target (50% interaction length, i.e., 3 times more than what we are proposing here for other specific reasons). Several absorber configurations were tested. Starting with the standard 480 cm of carbon, more and more downstream slabs were replaced by either polyethylene, to reduce the neutron flux emerging from the absorber usually considered as source of problems, or by plain iron or even by a sandwich-type combination of these two materials. Within the limited configurations that could be tested during the 6 weeks of run, the following general observations have been made :

1. The replacement of the downstream carbon slabs of the absorber by the same thickness of iron decreases significantly the illumination rate of the first chamber PC1 and the first trigger hodoscope R1. Quantitatively, this reduction

amounts to a factor of $\simeq$ 2.5 for 80 cm of iron and to $\simeq$ 10 for 160 cm, stopping, in this last case, a significant part of the low momentum muons. With 80 cm of iron and for an intensity of 10^{10} protons/burst the most upstream hodoscope and chamber have multiplicities of about 30 hits per standard muon pair trigger. The first chamber efficiency stays above 92%. This corresponds to a working point not far from that of a run with 5 10^7 Pb ions/burst.

2. The absorption of slow neutrons by the polyethylene slabs is clearly seen in the measurements done downstream from the absorber. Nevertheless, the spectrometer is quite insensitive to this neutron flux given its absolute level downstream from an absorber similar to the one considered in this proposal which includes 80 cm of Fe at its downstream end. For the highest incident flux of 10^{10} protons/burst and for the rapidity $\eta = 3$, the measured neutron level fluxes are 8.5$\pm$1.3 10^4 and 1.5$\pm$0.4 10^5 neutrons/cm^2/burst respectively for fast ($<$ 15 MeV) and thermal ($\sim$ eV) neutrons.

3. The absolute flux of neutrons measured around the target region for the highest incident flux of 10^{10} protons/burst amounts respectively to 3.3$\pm$0.3 10^8 and 6.1$\pm$0.2 10^6 neutrons/cm^2/burst for fast and thermal neutrons which requires the use of radiation resistant detectors.

5. THE Pb-BEAM CONFIGURATION OF THE APPARATUS

As a consequence of the severe environment and specific experimental conditions foreseen with the Pb beam, the following considerations have guided the design of the different detectors and the operation of the spectrometer :

1. The total space allocated to the different detectors must be kept as short as possible, in order to minimize combinatorial background due to meson decays.

2. Mass resolution should be as good as possible in order to separate the ψ' from the J/ψ and the ϕ from the ρ +ω. As a consequence, multiple scattering must be reduced. This will be obtained by replacing the central part of the electromagnetic calorimeter by an Al_2O_3 absorber, which removes 11.5 radiation lengths at the very beginning of the trajectories of the muons accepted by the spectrometer.

3. High luminosity is required for dimuons with mass above 2 GeV/c^2 as their cross-section is small. This is not the main issue for low-mass dimuons and resonances. Their cross-sections are much larger. The requested luminosity is therefore smaller but the set-up should minimize both the background from meson decays and multiple scattering which dominates mass resolution in this kinematical region.

4. Finally, the use of a Zero Degree Calorimeter to complete the multiplicity information requires important changes of the present setup to let the beam fragments pass all the way through the spectrometer.

We are thus led to propose two slightly different setups optimized separately for the low mass resonance region (i.e. for the ω, ρ, ϕ and continuum below the J/ψ) and for masses above 2 GeV/c^2 (including the J/ψ, ψ' and continuum above 4 GeV/c^2) respectively.

The proposed general layout is shown in Fig. 5 and briefly overviewed hereafter.

The most upstream detector, the beam hodoscope (BH), is located 33 m upstream from the segmented active target (SAT) of the experiment. The target is, in fact, made of two sets of 5 thin sub-targets located at 2.5 cm intervals along the beam line. Each set of 5 sub-targets is followed, 10 cm downstream, by one plane of silicon strip detectors (MD) which measure the multiplicity of the charged particles. The second plane is followed, 5 cm downstream, by an electromagnetic calorimeter (ECAL), similar to the present outer part of the NA 38 calorimeter, which measures the neutral transverse energy produced in the interaction. Behind a set of Al_2O_3 and C absorbers is located the muon spectrometer followed, 20 m downstream, by the zero degree calorimeter (ZDC) which measures the energy of the beam spectator fragments.

6. THE J/ψ VERSION OF THE APPARATUS

6.1 The muon spectrometer

We propose the following changes with respect to the layout used in 1990 and briefly described in § 4.1.

1. The spectrometer is longitudinally contracted to adapt it to the beam energy, shifting down its pseudo-rapidity acceptance to the interval $2.70 < \eta < 3.90$ where maximum energy densities are expected. This implies moving the magnet upstream by 160 cm which, in turn, requires shortening the downstream end of the carbon absorber by 80 cm in order to have the minimum space necessary for the upstream chambers and hodoscopes.

2. The last 80 cm of carbon of the absorber, shortened as stated above, are replaced by iron. This leads to a significant reduction of the illumination of the forward telescope as observed during recent tests (see § 4.3 above) and increases, therefore, the upstream chamber efficiencies. It almost does not affect mass resolution, as theoretically expected and confirmed by the test

data for which the J/ψ resolution was found to be constant and equal to 120 MeV/c^2 within the statistical errors.

3. The current of the magnet is increased to 7000 A. This higher magnetic field brings the trigger rate down to an acceptable level by sweeping away the bulk of the background muons. It almost does not affect acceptance for muon pairs with masses above 2 GeV/c^2 (15% relative reduction). As a by-product, the mass resolution needed for J/ψ and ψ' separation is improved as resolution, at a mass of 3.5 GeV/c^2, partially results from the spectrometer magnetic field itself. Increasing the magnetic field of the spectrometer, however, limits the low mass muon pair acceptance but, on the other hand, allows high intensities together with acceptable trigger rates.

4. The spectrometer is bored all the way through to let the beam reach the ZDC located 36 m downstream from the target, at the very end of the experimental hall. For this purpose, the inner plug of the absorber, presently made of 40 cm long W and U cylindrical pieces, has to be replaced by specific steel parts with an inner conical hole matching, at the downstream end of the magnet, the existing central hole between coils of 9.5 cm radius. This should not affect the response of the wire chambers outside the projection of the conical hole but tests will be done during the next periods. If the tests are successful, the 8 wire chambers will be modified so as to let the beam vacuum pipe pass through. This is a major technical intervention. Its practical feasibility has already been assessed and no particular technical problem is foreseen.

6.2 The segmented active target

The luminosity required for the J/ψ and ψ' studies leads to a target of 18% of an interaction length. It is then necessary to identify those events in which reinteractions of fragments can bias the multiplicity and energy measurements. A fragmented target instrumented with detectors to identify the vertex (vertices) of the interaction is then the solution of the problem, in agreement with the criteria that guided the choice of experiment NA 38. Operation of the present NA 38 target may be difficult, if not impossible, with a Pb-beam for the following main three reasons :

1. Slow particles (protons or composite particles originating from target fragmentation) which have been essential for the performance of the active target with light ions are scarce for central Pb-Pb interactions. For this main reason, the vertex identification has to be performed through the mesons produced at the vertex, using geometrical properties, e.g. an angle sensitive device.

2. Secondary heavy fragment reinteractions will be important with the Pb beam. The number of produced mesons and the resulting showering will make it

difficult to detect a reinteraction vertex unless a special device is implemented for this purpose in this new environment.

3. The radiation level will be too high for scintillator detectors as it amounts to 36 Mrad for 1 month of running at the nominal intensity of 5 10^7 Pb ions/burst.

We propose therefore to build a new segmented active target. It will have the possibility to accomodate a maximum of 10 sub-targets, each 0.5 -1 mm thick corresponding to 1.35-2.7% of λ_i, with transverse dimensions 2 x 1 mm^2, placed at 2.5 cm intervals along the beam axis, except for a somewhat bigger spacing of 5.5 cm between the 5^{th} and the 6^{th} sub-target. Each sub-target is followed, 1.5 cm downstream, by two quartz blades (1 mm thick, 4.4 mm wide and 22.5 mm high) located slightly off the beam axis which provide the needed identification of the interaction point, by detecting charged particles emitted in the angular range $50 < \theta < 350$ mrd. Such a device benefits from the angular selectivity of the Čerenkov light and thus significantly improves the reinteraction vertex identification power of the system. It also overcomes the radiation damage problem thanks to the excellent radiation resistance of quartz (see Fig. 6 of Appendix 3). It is described in detail in Appendix 1.

6.3 The multiplicity detector

A full description of the multiplicity detector, made of two planes of silicon strip detectors (see § 5), is given in Appendix 2. Only the main features are indicated here.

The characteristics of the detector are summarized as follows :

1. acceptance of at least $1.6 < \eta < 4.0$ for all sub-targets;

2. granularity of $\Delta\eta = 0.02$ and $\Delta\phi = 10°$ (matched to the spread introduced by multiple scattering in the sub-target and vertex smearing), for a total of 11520 channels;

3. cell occupancy of at most 30% for central collisions;

4. resolution of $\sim$5% for the multiplicity measurement integrated over pseudorapidity.

Each detecting plane is actually subdivided into smaller sub-detectors, arranged in three crowns, with each sub-detector containing between 40 and 60 channels. The innermost and outermost sub-detectors are shown in Fig. 2 of Appendix 2. The reasons for this arrangement are better fabrication yield, convenient modularity and easier coupling to the front-end electronics.

The position of detecting planes with respect to sub-targets is essentially dictated by radiation resistance considerations. With the proposed layout, an integrated luminosity of $2 \cdot 10^{12}$ Pb-Pb interactions (based on $5 \cdot 10^{7}$ ions/burst, 3 bursts/minute, 100% SPS efficiency and 50 days of running) can be taken by the multiplicity detector without problems (see Appendix 2 for details).

The overall scheme of the electronic chain is shown in Fig. 3 of Appendix 2. A digital readout was chosen, both for simplicity and to limit the amount of data to be read out for each event. The preamplifier, with a 30 ns integration time, is a compromise between a charge and a current sensitive one, with AC coupling to the detector; it is followed by a comparator on the same chip. Discriminated signals are then fed into a second chip which acts as digital buffer. After a trigger is received (1.5 μs latency) data are multiplexed and sent to the VME readout. Cost and space considerations impose a design with VLSI chips, one for the preamplifier/comparator stage and one for the digital buffer. The anticipated modularity of the VLSI chips is 64 channels.

Radiation problems for front-end electronics are practically avoided by adopting a fanout on silicon which allows VLSI chips to be placed at the outer edge of each sub-detector crown.

Comparator threshold initial setting will take place for each chip before final assembly at the experiment (a single threshold is foreseen, due to the expected high uniformity of electronic channels on the same chip), and the setting will be periodically redone during data-taking. It may be useful to run periodically a pulser test during data–taking to verify quickly the status of all channels.

Monitoring of events will consist essentially of strip maps which, with our relatively high occupancy, should allow a rather fast detection of dead and noisy channels. The leakage currents of all sub-detectors should also be monitored continuously.

6.4 The electromagnetic calorimeter

As stated above, the new calorimeter will be similar to the one presently in use in experiment NA 38 except that energy will be only measured in the pseudo-rapidity range 1.50$< \eta <$ 2.30, where radiation levels are reasonable, i.e., of the order of 0.4 Mrad for 20 days of run at the nominal luminosity. The central part, subtending the same pseudo-rapidity range as the muon spectrometer, will be made of a passive Al_2O_3 absorber, with a central hole to let the beam and fragments pass through. This is required by the radiation damage that would induce the high rate of Pb-Pb interactions in this severely exposed part of a calorimeter. It is also the convenient choice in order to improve mass resolution. The new calorimeter design will provide a measurement of the neutral transverse energy outside the rapidity range of the spectrometer and a link with the energy density estimated in the present NA 38 experiment.

A very large amount of π^o s, namely several thousands for the most central Pb-Pb interactions, is produced in each collision. We are thus led, like in experiment NA 38, to measure only neutral energy flows, ΔE_o / $\Delta\eta$ and ΔE_{oT} / $\Delta\eta$, i.e. the sum of the (total or transverse) energies of all photons emitted within a pseudo-rapidity interval $\Delta\eta$.

6.4.1 The calorimeter used in 1991.

The calorimeter presently used in experiment NA 38 is an improved version of our first design already used in 1986. The 12 cm thick converter is made of 0.92 mm ϕ scintillating fibers embedded in lead in a 1:2 volumic ratio (L_{rad} = 9.4 mm). The fibers run parallel to the beam. The converter has an inner hole of radius $r_i = 3.7$ mm and an outer maximum radius of r_e = 12 cm. Its front face is located 25 cm downstream from the target center. It covers the pseudo-rapidity interval $1.7 < \eta < 4.1$. The readout is divided into 30 channels (5 rings for each of the 6 sextants). The innermost 3 rings of the converter are independent of the outside part and can be easily removed or replaced.

The intrinsic resolution of the calorimeter, as measured with 5 to 30 GeV electrons, can be written as :

$$\frac{\sigma_E}{E} = \frac{20\%}{\sqrt{E(GeV)}} + b$$

where b depends upon the cell dimensions. As an example, for a cell of the most external ring, $b \simeq 1\% \pm 1\%$.

The relevant resolution of the calorimeter, for the *neutral energy flow* measured in the experiment, is obtained through a Monte-Carlo simulation, taking into account the shower development, the geometry of the converter and the energy due to charged particles. It is given by

$$\frac{\sigma_{E_o}}{E_o} = \frac{1.45}{\sqrt{E_o(GeV)}}$$

for the total neutral energy, and by

$$\frac{\sigma_{E_{oT}}}{E_{oT}} = \frac{0.47}{\sqrt{E_{oT}(GeV)}}$$

for the neutral transverse energy, when measured with the 5 pseudo-rapidity rings of the calorimeter.

During the sulphur runs of 1990, the six sectors of the innermost ring, and therefore the most severely affected by radiation, were exposed to a dose of 0.4 Mrad.

The corresponding signals were continuously monitored and suffered a decrease of 16% during these 18 days of exposure.

6.4.2 The Pb-beam version of the electromagnetic calorimeter.

As already mentioned, the electromagnetic calorimeter will be located downstream of the second plane of the multiplicity detector, from which it will be separated by a plastic sheet. Based on the same general features described above and tested in recent runs, the proposed calorimeter subtends a pseudo-rapidity interval $1.5 < \eta < 2.3$, subdivided into three roughly equal bins. A block of Al_2O_3 replaces the innermost part of the present calorimeter and is used as the front part of the hadron absorber. It subtends the same pseudo-rapidity interval as the muon spectrometer.

According to our measurements and calculations, the luminosity corresponding to $5\ 10^7$ incident Pb ions per burst on a 18% interaction length target will induce, during a period of 20 days, a radiation dose of 0.5 Mrad for an inner sector of the proposed calorimeter, which will therefore behave in acceptable conditions for about one month. Unless harder scintillating fibers are available within two years, this will imply the occasional replacement of all the fibers of the calorimeter, which is not a major problem.

The reduced acceptance of the proposed calorimeter implies two times worse resolution for the same energy released in the reaction. This is somehow compensated by the large increase in the number of photons when going from S to Pb beam, so that the resolution with a Pb beam for this outer calorimeter, although given by

$$\frac{\sigma_{E_{oT}}}{E_{ot}} = \frac{0.9}{\sqrt{E_{oT}(GeV)}}$$

will be quite similar to that obtained with a full rapidity range coverage in the sulphur case.

6.5 The zero degree calorimeter

The design of such a hadronic calorimeter is made very difficult because of the high luminosity of the experiment. Radiation damage is here a main issue as radiation levels will reach 20 Mrad/month. A second constraint originates from the extremely high rate the device will have to stand, i.e., $5\ 10^7$ hits/burst. To solve both problems, we propose a modified version of the modern spaghetti calorimeters. The scintillating fibers will be replaced by quartz optical fibers with the advantage of a much better resistance to radiation damage and a faster response. This calorimeter is described in detail in Appendix 3. Its main features are given hereafter.

The device, as it is designed, measures the Čerenkov light induced by the beam fragments, showering inside the lead converter. All these fragments are contained within the beam divergence. The dimensions of the ZDC are chosen according to the size of the hadronic shower to be measured. It is shown in Appendix 3 that 99% of the total energy of the showers are contained in a cell of $200\times60\times60$ cm^3 which gives the dimensions of the detector. It will be located on the beam axis, 20 m downstream from the end of the muon spectrometer, close to the wall of the experimental area. Because it should measure only beam spectators and not reaction products, the angular acceptance of the ZDC is defined by an upstream 5 m long iron-collimator, through a conical hole, slightly larger than the beam divergence. Between the collimator and the ZDC will be located a thin quartz hodoscope subdivided in 32 elements which will measure the charge and the coordinates transverse to the beam direction of the incoming beam fragments. This hodoscope will also be used to tag and reject piled-up events (see § 9). The quartz fibers are embedded in lead, in a volume ratio of 1 to 40 (quartz to Pb). They are oriented at 40° with respect to the beam according to the value of the Čerenkov angle. The ZDC is divided, along the beam axis, into slices of 28 cm with edges parallel to the fiber planes. Each slice is read by its own photomultiplier. The pulses of the photomultipliers are then added with the correct delays corresponding to the shower propagation. The resulting pulse is narrower than 5 ns so that the ZDC can stand the 10^7/sec rate. Its energy resolution is expected to be about 5% for ^{208}Pb (33.3 TeV) and of 8% for an ^{16}O (2.56 TeV) fragment.

6.6 Expected performances of the apparatus

6.6.1 Acceptance and resolution

In the configuration proposed here, the carbon absorber immediately follows 53 cm of Al_2O_3. With this geometry and the layout described above, the acceptance and resolution of the apparatus have been computed. The overall acceptance for the J/ψ is of the order of 8.0% in the rapidity range [2.5-4.0]. Differential acceptance is given in table 1. Tables 2 and 3 give differential acceptances for muon pairs in the mass continuum. Note that the J/ψ has a bigger acceptance than a dimuon with the same mass, due to different angular distributions.

The J/ψ mass resolution, as given by the simulation program, is 84 MeV/c^2 (FWMH/2.35), which confirms that it is not affected by iron located at the down-stream end of the absorber.

6.6.2 Signal events for the final analysis

The expected numbers of events are deduced from extrapolations from S-U interactions at 200 GeV/nucleon. They are based on the numbers of events detected in the past in similar set-up's used by experiment NA 38. The numbers of such useful[1] events collected in 1987 are shown in table 4.

[1] *Useful* events are those which, after all the cuts, survive up to the final analysis.

y \ Pt	0.25	0.75	1.25	1.75	2.25	2.75	> 3.0
2.55	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.75	0.01	0.01	0.01	0.01	0.01	0.01	0.02
2.85	0.04	0.04	0.05	0.05	0.06	0.07	0.09
2.95	0.09	0.09	0.09	0.10	0.10	0.14	0.10
3.05	0.13	0.13	0.14	0.14	0.14	0.14	0.13
3.15	0.18	0.17	0.15	0.16	0.15	0.14	0.16
3.25	0.21	0.18	0.17	0.17	0.16	0.18	0.18
3.35	0.23	0.19	0.17	0.18	0.15	0.17	0.17
3.45	0.17	0.17	0.16	0.16	0.14	0.14	0.13
3.55	0.14	0.14	0.13	0.13	0.14	0.10	0.12
3.65	0.10	0.09	0.08	0.08	0.08	0.07	0.06
3.75	0.05	0.04	0.04	0.04	0.05	0.03	0.04
3.85	0.01	0.00	0.00	0.00	0.00	0.01	0.00
3.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 1: *Acceptance as a function of rapidity and transverse momentum for the* J/ψ .

M \ y	2.50	2.70	2.90	3.10	3.30	3.50	3.70	3.90
2.00	0.00	0.00	0.01	0.04	0.07	0.05	0.02	0.00
2.40	0.00	0.00	0.03	0.07	0.10	0.08	0.04	0.00
2.80	0.00	0.00	0.04	0.10	0.13	0.11	0.05	0.00
3.20	0.00	0.00	0.05	0.12	0.15	0.12	0.06	0.00
3.60	0.00	0.01	0.06	0.13	0.17	0.12	0.06	0.00
4.00	0.00	0.01	0.08	0.13	0.19	0.14	0.06	0.00
4.40	0.00	0.01	0.09	0.14	0.20	0.14	0.08	0.00
4.80	0.00	0.01	0.10	0.16	0.19	0.16	0.11	0.00

Table 2: *Acceptance as a function of mass and rapidity for muon pairs in the mass continuum.*

M \ Pt	0.25	0.75	1.25	1.75	2.25	2.75	> 3.0
2.00	0.02	0.02	0.02	0.02	0.03	0.04	0.06
2.40	0.03	0.03	0.03	0.03	0.03	0.04	0.05
2.80	0.04	0.04	0.04	0.04	0.04	0.05	0.05
3.20	0.06	0.05	0.06	0.06	0.06	0.07	0.05
3.60	0.07	0.07	0.07	0.07	0.08	0.08	0.06
4.00	0.08	0.08	0.08	0.08	0.06	0.08	0.08
4.40	0.09	0.09	0.09	0.08	0.08	0.11	0.11
4.80	0.09	0.09	0.08	0.09	0.08	0.10	0.15

Table 3: *Acceptance as a function of mass and transverse momentum for muon pairs in the mass continuum.*

Mass region	J/ψ	ψ'	$CL(2.1-2.6)$	$CH(>4.1)$
Signal	1.74	0.026	0.30	0.012
Background	0.048	–	0.64	–
Signal/Bgd.	36	∞	0.47	∞

Table 4: *Signal, background and their ratios for the runs of 1987. CL and CH are low and high mass continuum (mass range as noted). Numbers of events are given per burst for 200 GeV/c per nucleon S-U interactions, for the 7 mm total length target (18% λ_i) and extrapolated to an intensity of* $5\ 10^7$ *S ions/burst.*

Acceptance corrections due to the use of the new set-up described above are handled through the comparison of the corresponding whole Monte-Carlo simulation and reconstruction chain and are quite trustworthy. Physical extrapolations include the change of all cross-sections due to the difference in beam energy and the new value of $\sqrt{s}$, the higher interaction cross-section leading to thinner targets if keeping the same low reinteraction probability, and the projectile and target atomic number dependence of the cross-sections. Taking all these factors into account leads to the number of useful events per burst given in table 5, for a target of 18% of an interaction length, i.e. 7 mm total length, and a beam of 5 10^7 Pb ions/burst.

Mass region	J/ψ	ψ'	$CL(2.1-2.6)$	$CH(>4.1)$
Signal	3.15	0.047	0.56	0.024
Background 1	0.12	–	0.87	–
Background 2	0.36	–	3.07	–
Signal/Bgd. 1	26.20	∞	0.64	∞
Signal/Bgd. 2	8.75	∞	0.18	∞

Table 5: *Signal, extreme background limits and their ratios.CL and CH are low and high mass continuum (mass range as noted). Numbers of events are given per burst for* 160 *GeV/c per nucleon Pb-Pb interactions, for a 7 mm total length target (18%λ_i) and* 5 10^7 *Pb ions/burst.*

6.6.3 Background due to meson decays

The signal/background ratios are given in table 5, for both extreme limits as explained in section 4.2

6.7.4 Trigger rate

Trigger rates can be calculated by adding up the numbers of events given in table 5, extended to muon pairs of mass below 2.1 GeV/c^2 and to like-sign pairs which are exclusively due to background. The number of events obtained this way has then to be multiplied by the reconstruction and analysis overall efficiency, i.e. the ratio between events recorded on tape and useful events kept for the final analysis. An alternative method leading to a good approximation of the upper limit is based on the number of triggers observed in S-U interactions in experiment NA 38, and considered as if they were exclusively due to background. Extrapolation to Pb-Pb interactions leads to 39000 (11900) triggers/burst with the high (low) extrapolation hypothesis, the same set-up, the same number of interaction lengths for the target and the nominal intensity of 5 10^7 Pb ions/burst. Monte-Carlo simulations lead to a reduction of the background by a factor of 23 with the new set-up which finally gives, under the conditions stated above, 1300 (390) triggers/burst.

7. THE ϕ VERSION OF THE APPARATUS

7.1 The muon spectrometer for low mass muon pairs.

The configuration proposed for the spectrometer itself corresponds almost exactly to its high resolution version used in 1990 and briefly described in § 4.1. Its main features are recalled hereafter.

1. The current of the magnet stays at 4000 A. Mass resolution, dominated by multiple scattering for low muon pair masses, is not sensitive to the difference in magnetic field between 4 and 7 kA.
2. The spectrometer is contracted and the carbon absorber shortened according to § 6.1. The absorber is therefore made of 58 cm of Al_2O_3 followed by 400 cm of carbon. No iron is used in place of carbon at its downstream end, as this would reduce the acceptance for low mass muon pairs due to energy loss in iron and subsequent sweeping away by the magnet (80 cm of iron induce a loss factor of $\simeq 1.5$). If trigger rate or chamber illumination were too high, it would be preferable, in this case, to lower the intensity of the beam.

7.2 The target

In order to lower the background as much as possible, one single subtarget is used, 10.5 cm upstream from the Al_2O_3 absorber. A standard target, 0.7 mm thick, will yield convenient rates, as detailed hereafter. If required by luminosity and allowed by trigger rate, the use of a second identical subtarget, 2.5 cm upstream, could be considered with obvious changes to the nominal numbers given below for a single sub-target.

7.3 Expected performances of the apparatus

7.3.1 Acceptance and resolution

With the layout described above, mass resolution for muon pairs of mass less than 2 GeV/c^2 is dominated by multiple scattering. It amounts to 70 MeV/c^2 (FWMH/2.35) for a 1 GeV/c^2 dimuon mass. Overall acceptance for the ϕ in the rapidity range [2.5,4.0] is 1.2%. Differential acceptance is given in table 6.

7.3.2 Number of events

The expected numbers of useful events are extrapolated from those collected in the runs of 1987 shown in table 7.

Under the hypothesis that ρ, ω and ϕproduction increases like pions when going from

Pt / y	0.25	0.75	1.25	1.75	2.25	> 2.5
2.55	0.00	0.00	0.00	0.00	0.00	0.00
2.65	0.00	0.00	0.00	0.00	0.01	0.00
2.75	0.00	0.00	0.00	0.00	0.00	0.01
2.85	0.00	0.00	0.01	0.03	0.05	0.08
2.95	0.00	0.01	0.03	0.06	0.11	0.12
3.05	0.01	0.02	0.04	0.08	0.12	0.13
3.15	0.02	0.02	0.06	0.10	0.13	0.13
3.25	0.03	0.03	0.07	0.11	0.14	0.14
3.35	0.03	0.03	0.07	0.12	0.15	0.16
3.45	0.03	0.04	0.06	0.11	0.17	0.17
3.55	0.02	0.02	0.04	0.10	0.15	0.14
3.65	0.01	0.02	0.03	0.05	0.07	0.00
3.75	0.01	0.01	0.02	0.02	0.00	0.00
3.85	0.00	0.00	0.00	0.00	0.00	0.00

Table 6: *Acceptance as a function of rapidity and transverse momentum in the ϕ mass region.*

Mass region	$\rho + \omega$	ϕ
Signal	18.9	15.3
Background	78.2	56.0
Signal/Bgd.	0.24	0.27

Table 7: *Signal, background and their ratios for the runs of 1987. Number of events are given per burst for* $200 GeV/c$ *per nucleon S-U interactions, for the 7 mm total length target (18% λ_i) and extrapolated to an intensity of* $5\ 10^7$ *S ions/burst.*

S-U to Pb-Pb interactions, i.e., like the square root of the background due to meson decays detailed in § 4.2, the expected numbers of events are obtained taking into account the correction factors due to the change in beam energy, total target length and set-up modifications. They are shown in table 8.

Mass region	$\rho+\omega$	ϕ
Signal 1	2.7	2.1
Signal 2	4.7	3.9
Background 1	12.0	8.7
Background 2	39.1	28.0
Signal 1/*Bgd.* 1	0.22	0.25
Signal 2/*Bgd.* 2	0.12	0.14

Table 8: *Signal, background and their ratios. Number of events are given per burst for* 160 *GeV/c per nucleon Pb-Pb interactions, normalized to the 0.7 mm long single target (1.8%* λ_i*) and for an intensity of* $5\ 10^7$ *Pb ions/burst.*

For an intensity of $5\ 10^7$ incident Pb ions/burst, about 20000 (11300) ($\rho+\omega$) events together with 16700 (9300) ϕ mesons could be collected every day (with 100% running efficiency). Even if for any reason the intensity had to be lowered by a factor of 2 or 3, the experiment would still be feasible in a reasonable amount of time.

7.3.3 Background due to meson decays

It is calculated according to the extrapolation explained in § 4.2, which leads to two extreme limits. It is based on the numbers of background events observed in S-U interactions in 1987, taking into account the change in beam energy, the total target length, and the change of the set-up. The latter includes a factor 2.8 reduction due to the use of only one single target closer to the absorber (see § 7.2) as compared to the set-up of 1987. Final numbers obtained through this procedure are shown on table 8.

7.3.4 Trigger rate

The trigger rate is again deduced from the 1987 runs. The experimental number is corrected for the different absorber configuration (essentially the total empty space close to the target that is now filled up with Al_2O_3) which reduces background by a factor of $\simeq 2.8$. The use of a single target of 1.8% instead of a total of 18% λ_i and the factors giving the two limits for the background extrapolation as detailed in § 4.2 are taken into account. The final trigger rate obtained this way for a nominal intensity of $5\ 10^7$ incident Pb ions/burst is 1500 (450) triggers/burst, i.e. of the same order as expected for the J/ψ runs.

8. BEAM MONITORS

We intend to use two different beam monitors with a manyfold purpose, as in experiment NA 38(see § 4.1). They both identify the incoming ions and provide their accurate (0.4 ns FWHM) time of arrival with respect to the trigger. They count the incoming beam and can be considered as independent beam intensity and spill monitors. Their granularity allows them to be also used as precise beam position and beam shape monitors.

The Beam Hodoscope(BH) is located 33 m upstream from the target, in a region where the beam spot is large enough so that individual incoming ions can be tagged with a detector of reasonable granularity and physical dimensions. It has to be designed so as to stand radiation doses up to 3 Grad, expected with the requested time of Pb-beam (see below). It will therefore be made, in analogy with the corresponding detector of experiment NA 38, of one plane of 16 quartz blades, associated with photomultipliers detecting the Čerenkov light produced in the quartz by incident ions. Due to the good mechanical properties of quartz, an excellent efficiency (>99 %) is reached with only one plane of detectors. The transverse size of the blades is adapted to the beam spot intensity profile so that each individual counter sees about 1/16 of the total incoming beam intensity. Their thickness is 1 mm. They provide plenty of light (40 000 photoelectrons) which will require the use of appropriate filters. The analog signals are recorded by standard ADC's, through specific homemade selective linear gates which allow to select and record total charges within a 10 ns gate [24]. Standard TDC's record the precise time of arrival of all the incident ions within a given gate, appropriately timed with respect to the ion that has triggered the apparatus. This information can be used to tag beam pile-up as will be explained in the next section.

Simulations have been performed in order to study the emission of Čerenkov light by the parallelepipedic blades. The light comes out from the terminal end of the blade which is cut at 45° and is guided to the photomultiplier by quartz optical fibers. The 16 blades are arranged as shown on Fig. 6. The performances of the blades have been studied as a function of the impact of the beam. For instance, as shown in Fig. 7, it can be seen that a 10 mm long by 3 mm large blade, read by 3 fibers of 1 mm ϕ , has a uniform emission of light, with a dispersion smaller than 5% along the blade, except for the 5mm which are closest to the reading edge. This defines the longitudinal size of the blades, taking into account a beam spot dimension of σ_x= 2.5 mm at this point of the beam line.

A 3 mm thick quartz Čerenkov counter (BI for "beam in") is located 90 mm upstream from the first target. It is similar to the one presently in use in NA 38. It has the same function as the BH. At its location, it intercepts a beam spot of very small dimensions, i.e., $\sigma_x = 0.5$ mm and $\sigma_y = 0.6$ mm. It is divided into four independently read quadrants which allows to center the beam on the targets with a 50 μm accuracy.

Finally, use will be made of the three 90° telescopes which continuously monitor the luminosity and targetting efficiency. They provide, at the same time, the best lifetime measurement of the experiment during data taking. Located along three orthogonal radii in a plane perpendicular to the beam axis, each of them is made of three scintillating counters defining a telescope which points to the central sub-target.

9. PILE-UP IDENTIFICATION AND REJECTION

As already stated above, high luminosity is a must for the proposed experiment with the resulting drawback of potential pile-up in all the detectors sitting upstream from the spectrometer absorber as well as in the ZDC. In order to get rid of events where data of two close-in-time interactions do mix up inside the integration time of the detectors, an elaborated procedure of pile-up rejection is implemented, similar to the one satisfactorily used in experiment NA 38.

9.1 Some numbers

Pb beam parameters are expected to be similar to those of the present S beam. With an effective spill of about 3.3 sec, as measured with the S beam in 1990, a reading gate of 20 ns and a signal width of the same value, an incident intensity of $5\ 10^7$ Pb/burst leads in 37% of the cases to an event where more than one incident ion is present within the reading gate. Among them, only a fraction will have two interacting ions and for a 18% interaction length target, we expect only 8% of real pile-up in the detector.

There are two different possibilities to tag and reject events with potential pile-up problems.

9.2 Beam pile-up rejection

Events can be rejected whenever the ion triggering the experiment is accompanied by a second ion in the beam, such that the time interval between the two ions can lead to pile-up problems. When no other condition is required, this rejection is called "beam pile-up rejection" and is effectively implemented using the timing properties of the beam hodoscope. It is a very clean and unbiased rejection although overpaid in statistics as the second incident ion does not interact necessarily (37% rejection instead of 8%, as explained above.)

9.3 Interaction pile-up rejection

When the beam hodoscope has detected more than one incident ion, a second less statistics consuming procedure can be worked out by requiring further, before rejection, that the second ion has effectively interacted in the target. This procedure, called "interaction pile-up rejection", can be implemented with several devices which provide both the needed complementarity and redundancy.

1. A special quartz Čerenkov counter (SPD for Secondary Particle Detector) located just downstream from the target and specifically designed to detect charged secondary particles produced in the interaction can thus be used. It signs the pile-up due to several superimposed interactions through the shape analysis of its own signal. This technique works fine except for the case where the two ions are closer than 5 ns from each other.

2. Another segmented quartz detector (FLD for Fragment Localization Device) located on the beam line, just in front of the ZDC is also able to refine beam pile-up rejection. It is in fact intended to detect beam spectator fragments and can therefore also be used to tag events where the second incident ion has not interacted in the target. It is less efficient in the case of the more peripheral collisions where the heavy spectator fragment can be misidentified as a beam projectile but, on the other hand, its pile-up rejection power is high when the two incident ions are close in time. It thus provides an information complementary of that of the SPD.

It can be pointed out that the segmented active target itself can be used to make up for the inefficiency of the two other detectors, given its capability to detect the reinteraction of fragments which lead to a pattern similar to the one produced by two interacting ions.

The use of all these devices will allow the experiment to run at the foreseen intensity with minimal pile-up losses.

10. THE NEW DATA ACQUISITION SYSTEM

Under the experimental conditions of this proposal, it is foreseen that the nominal acquisition rate will be of the order of 1.5 Mby/s, i.e. 10 to 20 times higher than the usual acquisition rate of experiment NA 38. In order to be able to handle such rates, an entirely new data acquisition system has to be developed both from the hardware and software points of view.

In fact, the present NA 38 data acquisition system, based on a tandem of NORD computers (ND-100, ND-500) sharing a common memory, accepts a maximum rate of 500 triggers in a burst of 4 seconds, for events with an average length of 320 16-bit words. Although the receivers of the multiwire proportional chambers and scintillation hodoscopes are inserted in RMH crates (of intrinsic high speed), the highest level of the acquisition tree is still based on CAMAC. As a consequence, the present 80 Kby/s rate, which corresponds to one tenth of the total CAMAC - NORD link bandwidth, leads to a 10% dead-time, close to the acceptable upper limit. Thus, our goal of handling a 1.5 Mby/s rate cannot be achieved with the present acquisition system. In order to reach the desired performance, the new data aquisition architecture is based on the following hardware features :

1. At the root of the acquisition tree, a VME crate is used with its bus bandwidth of 10 Mby/s, allowing a fast read-out of the front-end electronics into dedicated burst buffers.
2. Data in burst buffers are accessed by a microprocessor which formats the events and performs a 2^{nd} level trigger.
3. Data are transferred during the 15 s long interburst to a VAX central computer, via BI couplers. This central computer accumulates the histograms concerning the detectors, and the electronics and trigger chains.
4. Data are transferred to cartridge units.
5. Routine data taking quality control is done by means of VAX stations connected to the central VAX.
6. For special purposes, individual detectors are also spied and *ad hoc* programs run on their raw data by means of MacIntoshs interfaced with a 2^{nd} VME crate, which allows the direct sampling of the information contained in the burst buffers of the central crate.

To implement the scheme described above, modules already available in the market will be used whenever possible. The specific hardware choices are the following :

1. A front-end processor (FEP), as the MVME167, equipped with a Motorola 68040 central processor, or equivalent, running the multi-task OS-9 operating system;
2. A VME-CAMAC interface : the CAMAC branch driver CBD8210, or the specifically designed VME-Gec Elliot system crate interface;
3. Four 2 Mby burst buffers at the VME bus level, especially designed, storing a specific part of all the events of a burst;
4. A VME module which synchronizes the different parts of each event that are to be read in parallel (also specifically designed);

5. A VME interface with the VAX BI bus : HVR8217/2;
6. A double drive STK4280 cartridge unit.

A schematic layout of this new system is shown in Fig. 8.

The software effort includes :

1. The data acquisition software to be installed in the VAX central computer, based on the MODEL package supported at CERN, and adjusted to the requirements of a very high acquisition rate;
2. The software for the FEP installed in the VME bus, in order to read and decode the events and be able to perform the 2^{nd} level trigger;
3. All the software needed for specific tests, tuning and monitoring of the different parts of the detector, to be run on devoted workstations.

The choice of a VAX/VMS for the central computer is due to the versatility of its operating system and the available technical support in the CERN environment. The final choice of the specific model to be used will be made as late as possible, as the price/performance ratio is a decreasing function of time.

A prototype of this new system is now being tested.

11. BEAM AND RUNNING TIME REQUESTS.

11.1 Data sample and beam time required for the J/ψ runs

The goal of the J/ψ part of the experiment is to collect a sample of events large enough to allow the comparison, as a function of centrality and transverse momentum, between J/ψ and ψ' suppressions, as this study could be of crucial interest in terms of interpretation of the results. This comparison sets therefore the lower limit of the size of the data sample to be collected. A sample of 10 000 ψ' available for the final analysis, i.e. taking into account the overall inefficiency, seems to be the minimal requirement, leading to 600 events in each cell of a 4 x 4 centrality/transverse momentum two-dimensional plot. Assuming 70% overall running efficiency, it follows from table 10 that such a sample can be collected, with 10 sub-targets of 0.7 mm thick each, in 70 days of beam time at 5 10^7 Pb ions/burst.

11.2 Data sample and beam time required for the ϕ runs

From the numbers given in § 7.3.2, the error on the number of ϕ' and (ρ+ω) particles as deduced from the data can be computed, taking into account the errors due to the background subtraction and to the fit procedure. This error, approximately given by $\sqrt{2 \times Background \ / \ Signal} \ / \ \sqrt{Signal}$, is the same in the two mentioned backgound hypothesis and leads to a relative error on the ratio R $= \phi \ / \ (\rho + \omega)$ of 6% for 1 day of data taking. Thus, for a study in 4 bins of transverse momentum and 4 bins in transverse energy or multiplicity, the error on the ratio $\mathrm{R}(\mathrm{E}_T)/\mathrm{R}(\mathrm{E}_0)$ will amount to 12% in 8 days of data taking. In order to reach an accuracy of 6% , 45 days will be needed asuming again a 70% overall running efficiency.

12. ORGANIZATION AND RESPONSABILITIES.

All the new detectors described in this proposal will be built by the institutes of the collaboration, generally using their know-how and their experience in building, tuning and running similar devices in past experiments.

The beam hodoscope, the target complex and the electromagnetic calorimeter will be built under the responsability of the institutes of the IN2P3 - CNRS which will also take care of the changes in the spectrometer with CERN's technical support.

The multiplicity detector will be designed and built under the responsability of the Torino-INFN group.

The ZDC design, its prototype construction and tests will be under the joint responsability of the institutes of the IN2P3 - CNRS and of the Torino-INFN group. This last institute will be furthermore responsible for building the full size detector.

The geometry modifications of the MWPC's will be the responsability of the IN2P3 groups and should be implemented by a technical team with specific experience in the field of large chambers.

CERN will provide the adequate power supply in order to be able to increase the current in the spectrometer magnet up to 7 kA and will shorten the downstream part of the absorber. We plan to borrow from CERN's electronic pool part of the (by 1993) standard electronics for which a new allocation should be considered.

LIP (Lisbon) will be responsible for the new data acquisition system. IN2P3 - CNRS will have the responsability of the readout hardware and of the tuning software developments.

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A P P E N D I X 1

THE SUB-TARGET IDENTIFICATOR SYSTEM

A1.1 PRINCIPLE OF THE SUB-TARGET RECOGNITION

The idea is to use two rows of slabs made of quartz and located on both sides, right and left, of the sub-target assembly, as shown in Fig. 1. An interaction in sub-target i produces charged particles which generate Čerenkov light in the down-stream slabs. The angular properties of the emitted light allow then to determine the vertex of the collision as explained hereafter. The slab angle relative to the beam axis is such that each slab i (left and right) transmits light, by total reflexion on the two parallel faces, to its associated photomultiplier, while, for slabs $j > i$ (left and right), the light is mainly refracted and lost. The system is designed in such a way that :

- in the case of events with only one interaction, the left and right slabs which give the largest signals sign the vertex of the collision (these two slabs will be called, in the following, the "vertex slab"),
- the level of the signals due to mesons produced in the first interaction are low enough in slabs j for an efficient determination of an eventual reinteraction,
- secondary particles originating from showering in successive sub-targets and emitted at small angles generate very weak signals in slabs j.

A1.2 GEOMETRICAL PARAMETERS OF THE DEVICE

The general geometry of the system is shown in Fig. 1. The shape and position of the slabs (Fig. 2) have been settled by Monte-Carlo simulation (only a row of slabs has been considered) using FRITIOF for simulation of Pb-Pb events and GUIDE for tracking the light inside the detectors.

Few parameters have been fixed for this simulation. The distance between sub-targets, the horizontal angular range covered by the slabs relative to their associated sub-target (θ_{min}-θ_{max}) and, finally, the distance between the slabs at minimum angle (θ_{min}) and their associated sub-target are respectively 25 mm, 50-350 mrad and 15 mm. A slab thickness of 1 mm has been chosen in order to minimize the production of secondary particles (Fig. 1).

The remaining free parameters needed to define completely the system are the four side-face angles θ_1-θ_4 of the slabs, their position angle θ, their height h and the height Y of the area through which light is colllected by optical fibers (of opening angle 24 degrees) perpendicularly to edge 1. Their values have been determined in such a way that :

- Čerenkov light on the four side-faces is mainly refracted ($\rightarrow \theta_1$-θ_4),
- the amount of light refracted through vertex slab edge 1 (edge through which light is collected) and included in the opening angle of the collecting fibers (24°) is maximum for the slab and as high as possible compared to the light collected by any of the downstream slabs ($\rightarrow \theta$),
- for the value of θ determined this way, the ratio of light refracted through edge 1 to light reflected on edges 2 and 4 is maximum ($\rightarrow$ h),
- light refracted for readout through vertex slab edge 1 has not been reflected before on edges 2-4 ($\rightarrow$ Y).

After analysis of the results given by the optimization procedure, some compromises have been made and the following geometrical parameters have been chosen : θ=76°, θ_1=48.5°, θ_2=θ_3=θ_4=55°, h=22.5 mm, Y=15.0 mm.

A1.3 RESPONSE OF THE SYSTEM

We have simulated the response of the system using FRITIOF to generate Pb-Pb events, GUIDE to track the light in the slabs and GEANT to generate particle interactions and showering in the sub-targets.

In the simulation, the parallelepipedic sub-targets are 1 mm wide, 2 mm high and either 0.5 or 1.0 mm thick. We define a counter i as the couple of left and right i counters. Their analogical informations are always added, the use of two rows of slabs, instead of only one, leading to higher level signals and reduced fluctuations. The calculations give, for each counter i, the number of photons S_i refracted through edge 1 inside the limited area of height Y (see the previous paragraph) and the optical fiber acceptance angle (24°). In the following, S_i refers either to the signal or to the collected photons. Photocatode efficiency is not included.

A1.3.1 Events without reinteraction

Fig. 3 shows the response of the system made of 15 counters and 10 sub-targets. One Pb-Pb event is generated (impact parameter $\approx$ 3.6 fm, total multiplicity $\approx$ 3000) in the center of the first sub-target. The calculation leads to a number of photons $S_1 \approx 1500$ for the vertex counter and $S_i \approx$ 100-200 for the downstream counters. It remains relatively stable when secondary particles are also taken into account. Moreover, when the sub-target thickness is increased from 0.5 to 1.0 mm, the number of primary charged particles hitting each counter remains constant, as expected, while the number of secondary particles increases up to a factor 3 from counter 1 to counter 15. Nevertheless, the response of the system is stable showing clearly the influence of the geometrical effects. As a consequence, the device should be able to detect not only the vertex of the primary interaction but also the vertex of a reinteraction, if any, in one of the downstream sub-targets.

Fig. 4 shows the response of a system made of 4 counters downstream from the production sub-target. A sample of Pb-Pb collisions is generated in sub-target 1 taking into account a beam spot size of σ_x=0.2 mm and σ_y=0.6 mm. For each event, the signal S_1 given by the vertex counter is plotted against the signals S_1-S_4 given by any of the 4 counters. Up to some threshold which has to be experimentally determined, the largest signal signs unambiguously the vertex of the interaction. It is always given, in this particular case of events without reinteraction, by the counter following immediately the vertex sub-target.

Fig. 5 shows the response of the system to a sample of Pb-Pb events generated, as previously, in sub-target 1. The impact parameter of the collision, as given by FRITIOF, is plotted as a function of any of the signals S_1-S_4 given by the 4 counters. It is an interesting representation which shows the correlation between the performance of the system and the geometry of the collision. The dependence of the vertex determination efficiency as a function of the impact parameter of the collision (estimated, for example, from the measured transverse energy) has still to be experimentally determined during specific tests.

The above results have a rather mild dependence on the geometrical parameters of the system. They are, in particular, insensitive to changes of $\pm$5 mm in the distance between sub-targets. Nevertheless, the performance of the system decreases when the slab minimum angle θ_{min} changes from 50 mrd to 150 mrd ($\rightarrow$ θ_{max}=350 mrd becomes θ_{max}=450 mrd), any other geometrical parameter remaining constant. Fig. 6 (a and b) shows this effect on the number of photons collected by counter 1 relative to those collected by counters 2 to 4 for collisions in sub-target 1 with impact parameters between 9 and 9.5 fm. It shows the advantage of chosing the smallest possible minimum angle and, consequently, a very narrow beam size.

A1.3.2 Events with reinteraction

In the case of events with reinteraction, each primary FRITIOF Pb-Pb interaction (characterized by the number of projectile participants $N^{proj}_{int.}$) is followed, in a downstream sub-target, bythe reinteraction of a fragment. The number of nucleons of the fragment is N^{frag} = 207 - $N^{proj}_{int.}$. Its interaction with a Pb-nucleus is simulated by a FRITIOF Pb-Pb event with a number of incident participants $N^{proj}_{reint.} < N^{frag}$, approximation which gives, in any case, pessimistic results from a pattern recognition point of view. In fact, if the real fragments have the possibility of interacting with any impact parameter (eventually zero), the simulation procedure adopted here imposes that the fragment reinteraction is necessarily peripheral, as it is simulated by a Pb-Pb interaction with a given number of incident participant nucleons, in any case less than 207. Nevertheless, this approach allows a pessimistic study of the response of the system to events with reinteraction.

Fig. 7 shows a typical response of the system made of 7 counters and 4 sub-targets. A Pb-Pb interaction (impact parameter ≈ 7.9 fm, $N^{proj}_{int.} = 47$) in sub-target 1 is followed by the reinteraction of a fragment in sub-target 4, simulated by a Pb-Pb interaction with $N^{proj}_{reint.} = 97$. The signature of the reinteraction from such a pattern seems to be easily obtained. Obviously, an algorithm will have to be established to solve the problem in the practical case, i.e. recognition of the first interaction and determination of the corresponding sub-target on the one hand, detection of an eventual second interaction and determination of the hit sub-target on the other. The corresponding efficiencies will have to be known.

Fig. 8 (a and b) shows the response of the system to Pb-Pb events with impact parameters between 7 and 9 fm and generated in sub-target 1. For each event, the signal S_1 given by the vertex counter is plotted against the signals S_1-S_7 given by any of the 7 counters of the system. Fig. 8 is the result of the simulation without reinteraction (a) and with reinteraction (b) in a downstream sub-target and generated as defined previously. It is clear that a large number of events with reinteraction (b) lie in regions of this plot which are empty in case of no reinteraction (a). At this stage of the simulation, we conclude that the system will be able to tag events with a reinteracting fragment.

A1.4 TECHNICAL CHOICES AND TESTS

The slabs are made of quartz (suprasil quality, produced by Heraeus). To obtain the best efficiency for light propagation and multiplication (the light wavelength covers the range 200-600 nm), we use guides made of 1 mm diameter quartz optical fibers (HCN-M0200U-20 produced by Ensign-Bickford) and multipliers with a quartz window (XP2020Q by Philips). Tests of a prototype made of two rows of 4 slabs and up to 4 uranium sub-targets will be done in October 1991 with a sulphur beam.

A P P E N D I X 2

THE MULTIPLICITY DETECTOR

This Appendix is organized as follows : the geometry of the multiplicity detector and its expected performances are presented in section A2.1; the electronic chain is described in section A2.2; problems of radiation resistance are discussed in section A2.3; and finally, a first concept for the mechanical support is presented in section A2.4.

A2.1 DETECTOR

The multiplicity detector should provide a measurement of N_{ch} with enough resolution to be able to classify events according to centrality and to detect a possible break–up of the multiplicity–transverse energy correlation. Theoretically it is possible to increase the resolution by increasing the granularity, but in practice physical effects (like conversion of photons in the target) and instrumental effects (like noise) limit the resolution which can be achieved.

Practical considerations (mainly yield and cost) call for a detector system which is modular, made by many identical pieces, each one representing a not too big fraction of a silicon wafer.

The charged multiplicity can be obtained with either digital or analog readout. Our past experience with silicon detectors suggests that the only advantage of analog readout is the ability to monitor pedestal and gain shifts continuously during data taking. A digital system has several advantages : the data volume is reduced, the electronics is simpler to design and operate. A digital readout has therefore been chosen.

We have performed extensive studies of the multiplicity detector using the VENUS 3.11 model [1] to generate Pb-Pb collisions at 160 GeV/nucleon, and GEANT 3.14 to track events through our setup. In addition to the physical effects described by GEANT, we have simulated explicitly the vertex smearing, both transverse (a gaussian beam profile with $\sigma_x = 0.3$ mm and $\sigma_y = 0.5$ mm was taken from the known sulphur beam profile at NA38) and longitudinal (the z-coordinate was distributed uniformly across the sub-target thickness). The detector response was simulated by comparing the energy deposition in each detecting element with a threshold set at 1/3 of a minimum ionising particle.

A natural way to specify the detector granularity is to require a given occupancy for Pb-Pb central collisions. However, finite size of target and multiple scattering actually limit the achievable η resolution, especially for higher pseudorapidities. The rms resolution is of the order of 0.02, so that a constant granularity $\Delta\eta = 0.02$ seems to be a reasonable choice. For $\Delta\phi = 10°$ this gives about 30% occupancy for "quasicentral" Pb–Pb collisions (impact parameter < 2 fm), according to our simulations with VENUS.

The proposed layout is shown in Fig. 1. Ten Pb sub-targets, each 0.7 mm thick, 1 mm wide and 2 mm high, are placed at 2.5 cm intervals along the beam line, except for a bigger spacing of 5.5 cm between the 5^{th} and the 6^{th} sub-target. Two planes of silicon detectors are placed 10 cm after the 5^{th} and the 10^{th} sub-target, respectively. The first (resp., second) plane covers the pseudorapidity range $1.6 < \eta < 4.0$ for the first five (resp. the last five) sub-targets. The distance between the first sub-target and the entry face of the absorber is 40 cm.

Each detecting plane, extending from an inner radius of 0.36 cm to an outer radius of 9.4 cm, is actually subdivided into smaller sub-detectors, arranged in three crowns, with each sub-detector containing between 40 and 60 channels. The innermost and outermost sub-detectors are shown in Fig. 2. The total number of channels is 11520, grouped into 216 sub-detectors.

The occupancy for VENUS Pb-Pb events in the proposed setup is shown in Fig. 4, for two sub-target positions (first and last) and for two kinematical ranges (full acceptance and muon spectrometer acceptance). The occupancy for minimum bias events is roughly a factor 4 less than for central events. However, the dimuon trigger tends to favor higher multiplicity events, so that the average occupancy for triggered events will be slightly more than 15% in the proposed setup.

The correlation between detected and generated charged multiplicity is shown in Fig. 5a, for two sub-targets (first and last) and for two kinematical ranges (full acceptance and muon spectrometer acceptance). The detected multiplicity is defined as the number of hits from all charged particles (including secondary interactions, conversions and decays) taking into account the finite granularity of the detector. A deterioration of the correlation at low generated multiplicity is seen for sub-target 1 : this is due to projectile spectators (protons and neutrons) from peripheral Pb-Pb interactions which are allowed to re-interact in the material following the primary interaction point, therefore producing additional charged particles.

Comparing sub-targets 1 and 10 in Fig. 5a, it emerges that the dominant effect on the resolution degradation comes from re-interactions taking place in the sub-targets which follow the main one (and, to a much lesser extent, in the quartz blades). These events should be identified via the sub-target identification system (see §A1.3), and therefore removed from the analysis. We must also mention that the probability of re-interactions is surely overestimated in our GEANT simulation, since the projectile fragment has a smaller chance to interact compared to a collection of protons and neutrons.

We therefore believe that the situation will be more similar to Fig. 5b, in which we show the correlation between detected and generated multiplicity without projectile spectators reinteractions.

The rms resolution of the N_{ch} measurement has been defined as the rms σ_R of the ratio detected/generated multiplicity, divided by the average of the same ratio R, for any given class of events. This definition assumes that a MonteCarlo correction will take care of the fact that the ratio detected/generated is not equal to unity, mainly because of secondary particles (photon conversions) and also because of the occupancy which increases with multiplicity.

The expected resolution in the full kinematical range ($1.6 < \eta < 4.0$) is shown in Fig. 6, for the two extreme cases of sub-target 1 and sub-target 10 (thickness 1 mm). We observe that the resolution reaches values around 6% at high multiplicity, and is no worse than 12% even at such low multiplicities as 100. Fig. 6 also shows the resolution with a sub-target of 0.5 mm thickness, reaching 4% at high multiplicity. For the proposed thickness of 0.7 mm, a resolution of about 5% is estimated.

A2.2 ELECTRONICS

A2.2.1 Overall Architecture

We assume that the detectors will have a fanout, feeding the preamplifiers with a constant pitch. As a provisional rule we assume that this will be 50 μm. The high rate of the experiment requires an integration time as short as possible, also for compatibility with existing fast detectors. We believe that 30 ns can be achieved without problems, while for shorter integration times a significant fraction of the signal would be lost due to the collection time in silicon. The preamp/comparator and the digital buffer should be two separate chips, serving 64 channels, bonded to one another, and thus sitting on a common hybrid, which in principle should support also the detector. A global scheme of the readout chain is shown in Fig.3, in which the dashed lines are the boundaries between chips. This scheme assumes the availability of two external circuits, which do not need to be ASICs. The two VLSI chips will be discussed in separate paragraphs. The 'discrete' ones should provide :

1. The communication with the trigger system, which controls the digital buffer.
2. The driving of the communication line (electrical or optical) to the VME

readout in the counting room. There should be one such driver per readout chip.

3. The processing of the trigger signals, in order to define the address of the valid data belonging to the triggered event in the digital buffer (this task needs to be performed by one processor only for the whole silicon system).

A2.2.2 Preamplifier/Comparator

Among the three possible preamplification schemes, we believe that for this application one should use a design which is a compromise between the charge and the current sensitive ones. Our main concerns are :

1. The capacitance of the detector elements varies by more than an order of magnitude, which rules out a voltage sensitive scheme (and also makes it somewhat more difficult the design of the current sensitive one).
2. The noise level must be kept below 1000 electrons, while remaining compatible with the other two requirements of high speed and relatively low power (hard to do in a pure current sensitive scheme).
3. The input resistance should be relatively low (order of one kΩ or less) to avoid crosstalk between channels. This requires a departure from a pure charge sensitive scheme.

Regarding the coupling detector/preamplifier, we believe that, in view of the severe radiation damage of the detectors, which will lead to very large leakage currents, it should be AC, with coupling capacitors which could be implemented on the preamp chip. (A solution with coupling capacitors on the fanout part of the detector chip has to be investigated, since it would require thin oxide processing, which might not be available).

For the design of the comparator we foresee a self resetting leading edge discriminator, which would provide a constant length output signal. The preamp will be coupled to the comparator via a coupling capacitor, to eliminate common mode drifts which might appear due to radiation effects on the preamplifier.

The threshold for the comparator shall be provided by one common DC level for all the channels on one chip. We are confident that this would be sufficient for good threshold setting, on the basis of our experience in the HELIOS experiment [2], where a common threshold on ALL the channels performed quite satisfactorily

(Fig.7), although the differences from channel to channel were much larger than what can be expected here.

For the design of the preamplifier/comparator chip, we foresee a direct evolution of a design by W.Dabrowski [3] (Fig.8), which utilizes a low noise analog CMOS process, implementing bipolar transistors, which has recently become available from Orbit. This process is not catalogued as radiation hard, yet the specific design considered here should not be very radiation sensitive. This process has some major advantages, namely the low cost and very rapid delivery of a new design, which should allow several prototype rounds to be done in one year. The other main point in favor of this choice is that the existing circuit has characteristics not far from the ones needed here : the integration time is 70 ns (Fig.9) and the noise rms is 580+42*C equivalent noise charge or ENC (Fig.10), where C is the capacitance of the detector element in pF, and the pitch is already less than 100 μm. Taking into account that for our application one can use up to five times more power than in the existing circuit, one can be quite confident that the required performances (namely, 30 ns integration time and 50 μm pitch) can be achieved.

A2.2.3 Digital buffer

The driving constraint on the digital buffer comes from the asynchronous nature of the events and the randomness of the trigger. In other words, it is not predefined the time interval between two events, nor the number of events which take place in the 1.5 μs of the trigger latency.

The first problem makes it necessary to latch the data with an external signal which defines the time of an event. This has to be very fast, in order to match the transit time of the signals through the preamp/comparator. Thus, it has to be generated locally by a fast detector sensitive to an interaction : the quartz Čerenkov detectors seeing secondaries in the target region should do the job in the required limited time of 100 ns. We will refer to this signal as pretrigger in the following (it is indicated as TRIGGER0 in Fig. 3). Of course, this signal should be part of the trigger logic, so that a) no events are taken which do not have a positive response from this detector, which would jeopardize the whole logic, b) there is a well defined time relationship between this signal and the final trigger.

For the digital storage itself, we favor a solution which uses a RAM, coupled with a counter driven by the pretrigger. The pretrigger count defines the writing address for the new event, and is reset by the trigger. The read address is given by the external event address processor, which couples the final trigger with the number of pretriggers elapsed during the latency time.

At readout time, the event would be transferred to a shift register, also sitting on the same chip, and read out serially to the driver. We consider that the option of having also the driver on the chip, although possible, would involve problems of a) large power on the chip, b) crosstalk generated by the large currents needed for the driver. Coming to the choice of techology, we believe that the digital buffer should be CMOS, with the option of having it radiation hard if needed.

A2.2.4 Monitoring

We foresee two monitoring systems :

A rather crude, but simple testing tool shall be a pulsing system, connected to the detector backplane. This would not be suitable for the adjustment of the thresholds, since the capacitive coupling to each element would be different.

The second system will use the implementation of one or several lines on the fanout, capacitively coupled to the signal lines (for example, a polysilicon or metal2 layer on a thick oxide), again pulsed from the outside. This would provide the same input charge to all the preamplifiers, and thus a precise calibration tool for the thresholds. The use of several lines (Fig.11) would allow selective pulsing of every n-th channel, thus verifying the level of crosstalk, and a test of the digital buffer at the same time.

For debugging purposes at assembly time (check of groundings, noise levels, and so on), we envisage one or two channels with both analog output and discriminated output on each chip.

A2.3 RADIATION RESISTANCE

The expected high fluences of charged particles and neutrons, due to the high luminosity necessary for the experiment, impose a careful estimation of radiation resistance on detector and front-end electronics. This has been done in two steps :

- i) evaluation of the effects of radiation damage on detectors and electronics : the recent review by G. Hall [4] has been used extensively here, together with some of our own measurements [5] and parametrizations of available experimental data;
- ii) fluence calculations (using event generators) and/or fluence measurements

(with presently available beams).

A2.3.1 Radiation damage and its effects

The two most important components of radiation, as far as damage to silicon is concerned, are neutrons and charged particles. The effects of radiation are conveniently separated into bulk damage and surface damage.

Surface damage is mainly due to ionising particles (charged particles and γ rays) and affects oxide-silicon interfaces, resulting in increased surface leakage currents, decreased carrier mobility, variation of resistance between elements, lowering of breakdown voltages. The detector elements which are more subject to surface damage are integrated resistors and capacitors. MOS electronics is mainly sensitive to surface damage.

Bulk damage is due to both charged particles and neutrons and involves dislocation of silicon and impurity atoms. The main consequences for detectors are increased leakage current (due to creation of energy levels in the band gap) and change of doping concentration (gradually converting n-type material into intrinsic material and then into p-type). Bipolar electronics is mainly sensitive to bulk damage.

It is well established experimentally that the increase in leakage current per unit volume, J, is proportional to particle fluence, $J = \alpha\Phi$. Table 1 of ref. [4] presents most of the available data as of fall 1990, from which the author estimates damage constants $\alpha_c = 2.9 \cdot 10^{-17}\,\mathrm{A\,cm^{-1}}$ for charged particles and $\alpha_n = 6.9 \cdot 10^{-17}\,\mathrm{A\,cm^{-1}}$ for neutrons at room temperature. These damage constants include already some annealing, since measurements are usually done at least a few days after the end of the irradiation. The damage constant for neutrons without any annealing (i.e. at time zero after irradiation) is $\alpha_n \sim 8 \cdot 10^{-17}\,\mathrm{A\,cm^{-1}}$ [6].

Recent data from neutron irradiations at the ISIS spallation neutron facility of the Rutherford Appleton Laboratory in the UK [5], [7], [8] indicate a value of the damage constant $\alpha_n \sim 3 \cdot 10^{-17}\,\mathrm{A\,cm^{-1}}$ after about a week of annealing.

Here we will assume conservatively $\alpha_c = 4 \cdot 10^{-17}$ A/cm and also $\alpha_n = 4 \cdot 10^{-17}$ A/cm. It may be interesting to consider cooling at 0°C because then the leakage current is 0.16 times its value at room temperature.

We then obtain the expected increase in leakage current for silicon of standard thickness $t = 300\,\mu$m at room temperature :

$$\Delta I = 12 \frac{\mu A\ cm^{-2}}{10^{13} part\ cm^{-2}},$$

separately for charged particles and for neutrons.

The main effect of the increased leakage current will be an increased shot noise due to fluctuations of the current (this is all the more true if fast shaping is used, which we need to do for various reasons). The increase in power consumption for detector biasing must also be considered.

Assuming for example triangular pulse shaping with peaking time T, the equivalent noise charge (ENC) at the amplifier input due to the leakage current I is given by :

$$Q_{n,shot}^2 = \frac{2}{3} q_e I T$$

(q_e is the electron charge). Assuming a peaking time $T = 15\,\mathrm{ns}$ we obtain a noise of 1600 rms electrons (corresponding to a signal/noise ratio of 15 to 1 for a signal of 24000 electrons) for $I \simeq 40\mu\mathrm{A}$.

We consider this to be the absolute limit for the leakage current per detecting element at the end of the detector's lifetime. Assuming instead CR–RC shaping with the same peaking time, we would get 66% more noise for the same current, and therefore a lower current limit for the same noise.

The other major bulk effect, namely the change of doping concentration, is reasonably well described by the law $D = D_0 e^{-c\Phi} - \beta\Phi$ (D_0 being the original doping concentration), with donor removal parametrized by the exponential factor $e^{-c\Phi}$, and acceptor creation parametrized by the linear factor $\beta\Phi$. Since the depletion voltage is proportional to the doping concentration : $V_D = et^2/(2\epsilon)D$, the ultimate limit to detector operation comes in when V_D exceeds a few hundred V, either due to avalanche breakdown or because the operating voltage becomes impractical.

Results of irradiations of test diodes (manufactured by S.I., Oslo) with neutrons at RAL [8] and with protons at LANL [9] are shown in Fig. 12. Neutron data extend up to fluences of $6 \cdot 10^{14}$ neutrons/cm^2. From these data we estimate a practical limit of $1.4 \cdot 10^{14}$ protons/cm^2 or $2 \cdot 10^{14}$ neutrons/cm^2.

The requirements for proper operation of silicon detectors can be summarized as follows :

1. V_D <250 V requires $\Phi_n < 2 \cdot 10^{14}\,\mathrm{cm}^{-2}$ and/or $\Phi_p < 1.4 \cdot 10^{14}\,\mathrm{cm}^{-2}$;
2. Signal/Noise $\simeq$ 15 requires $Q_{n,shot} < 1600\,\mathrm{e}$ or better (depending on other noise sources), i.e. $I_{det} < 40\mu\mathrm{A}$ or better for any detecting element.

A2.3.2 Estimate of fluences

We proceed now to estimate charged particle and neutron fluences in Pb-Pb collisions at 160 GeV/nucleon. A sample of 2000 minimum bias Pb-Pb interactions generated by VENUS 3.11 has been used, together with GEANT 3.14 to simulate secondary effects (photon conversions, interactions) which increase the flux at the detector. The generated dN_{ch}/dy distribution is shown in Fig. 13.

The dimensions of detecting elements (curved strips) are given for various pseudorapidities (referred to the most distant sub-target, placed 20 cm upstream) in table 1 where R_1 stands for the inner radius, R_2 for the outer radius, W for the width, L for the length, A for the area and C for the capacitance of each element.

Table 1

$\Delta\eta$=0.02, $\Delta\phi$=10°, Z=20 cm

η	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
R_1(cm)	9.19	5.40	3.24	1.96	1.19	0.72	0.44	0.26
R_2(cm)	9.39	5.51	3.31	2.00	1.21	0.73	0.44	0.27
W(μm)	2048	1131	663	397	239	145	88	53
L(μm)	16214	9525	5711	3449	2089	1266	767	465
A(cm^2)	0.33	0.11	0.038	0.014	0.005	0.0018	0.00068	0.00025
C(pF)	11.63	3.77	1.33	0.48	0.18	0.06	0.02	0.01

The capacitance is calculated with the parallel-plate capacitor formula C=$\epsilon A/t$, i.e. C=35 pF/cm^2 for t = 300 μm. Linear dimensions scale with Z, while areas and capacitances scale with Z^2.

We have computed expected fluences of particles using the following input :

1. minimum bias Pb-Pb collisions at 160 GeV/nucleon simulated with VENUS 3.11 [1] and tracked through the setup with GEANT 3.14;
2. 5$\cdot 10^7$ions/burst on a 18.9% target;
3. 50 running days with 100% SPS efficiency.

Average charged particle and "direct" neutron fluxes per event have been obtained in a straightforward way using GEANT; the flux of albedo neutrons at the entry face of the absorber (which is very close to detector 2) has been obtained by convoluting the incident hadron spectrum given by GEANT with the distribution of the number and radial profile of neutrons obtained with dedicated measurements [10]. Projectile spectators were allowed to reinteract in this simulation.

In order to express the integrated fluence with a single number, charged particles have been converted to "equivalent neutrons" of 1 MeV kinetic energy, using the non–ionising energy loss for different particles calculated in ref. [11]. In this way we are able to sum up equivalent neutrons with direct neutrons and albedo neutrons.

We show in Fig. 14a the the total "direct" fluence (i.e., equivalent neutrons plus direct neutrons), expressed in neutrons per cm^2, as a function of radius on detector 2 (which is more exposed to radiation damage than detector 1). Vertical lines indicate boundaries between the 3 sub–detector crowns. The contribution of direct neutrons is shown in the dashed histogram, and is seen to be about one order of magnitude less than charged particles in the used kinematical range.

Fig. 14b presents a comparison of the fluence of albedo neutrons with the total "direct" fluence of Fig. 14a. Vertical lines again indicate boundaries between sub–detector crowns. We observe that albedo neutrons are equal to direct particles at a radius of about 2.3 cm, and become dominant for larger radii.

Adopting a limit of $2 \cdot 10^{14}$ n/cm^2, we conclude that detector 2 can stand a 50 day running period, while detector 1 can stand a slightly longer period.

Total particle fluences (neutrons/cm^2) and corresponding leakage currents ΔI per detecting element (at the end of a run) are given in table 2 for detectors 1 and 2. The pseudorapidity value refers to the first and sixth subtargets for detector 1 and 2 respectively.

Table 2

	η	1.5	2.0	2.5	3.0	3.5	4.0
DET. 1	Φ	$2.5{\cdot}10^{11}$	$8.0{\cdot}10^{11}$	$3.0{\cdot}10^{12}$	$1.0{\cdot}10^{13}$	$3.0{\cdot}10^{13}$	$8.5{\cdot}10^{13}$
	ΔI	0.10	0.10	0.14	0.16	0.18	0.19
DET. 2	Φ	$6.0{\cdot}10^{11}$	$2.0{\cdot}10^{12}$	$5.5{\cdot}10^{12}$	$1.7{\cdot}10^{13}$	$4.5{\cdot}10^{13}$	$1.2{\cdot}10^{14}$
	ΔI	0.24	0.26	0.25	0.28	0.27	0.27

Φ in n/cm^{-2}, ΔI in μA

We observe that expected leakage currents are well below 1μA per detecting element, and therefore do not represent a problem for the detector operation.

To check our fluence calculations, they have been repeated for the high intensity proton test (see §4.3), with 450 GeV/c protons on a W target. The predicted values of integrated neutron fluence at three positions corresponding to η =2, 3 and 4 agree within 25% with the values measured with Indium activation technique.

A2.4 MECHANICS

Details of the detector mechanics, which includes cooling and cabling, have still to be worked out. The general concept is the following.

Each ideal detecting plane has to be split in two physical planes staggered along the beam line, because of the required fanout on silicon at the sub–detector level (each physical plane covers 50% of 2π in azimuth). An additional small staggering between the different crowns is required.

Each subdetector will be pre–assembled with its two VLSI chips (preamplifier-/comparator and digital buffer) on a common substrate. These units will then be mounted on the general support, which should be a light structure placed in between two physical planes. It is essential to allow for easy replacement of each sub-detector unit.

Appendix 2. References

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A P P E N D I X 3

THE ZERO DEGREE CALORIMETER

This Appendix describes the simulations which have been made in order to predict the performances of the detector.

A3.1 HEAVY ION FRAGMENTATION MODEL

When a nucleus projectile of atomic mass A_p undergoes a non central collision either in the target or in the ZDC itself, part of its nucleons with total atomic mass A are only spectators in the collision. These spectator nucleons are not emitted as a single fragment and a model for the fragmentation of this residue A is needed. The following inputs are used [1] :

- If the atomic number A is higher than 56, there are two possible fragmentation schemes with equal probabilities :
    1. One big fragment with atomic number A_0 accompanied by the remaining $A - A_0$ nucleons forming the highest number of α particles. A_0 is chosen among the 52 most stable isotopes according to the probability law $P(A_0) = exp(-(A - A_0)/3)$.
    2. 5 to 6 fragments of about equal mass (again chosen among the heaviest most stable isotopes) accompanied by the remaining single free nucleons.
- If $4 < A < 56$, two similar cases are possible but with respective probabilities of 70% and 30% :
    1. One big fragment with atomic number A_0, the complement being α particles.
    2. 2 to 3 fragments of about equal mass plus the remaining free nucleons.

With such a procedure, the number of α particles may be overestimated. In a phenomenological approach, some of these α particles are then broken into deuterons and eventually into neutrons and protons in order to get a resulting number of α's proportional to $A_p^{2/3}$ and an about equal number of deuterons as experimentally observed [2,3,4]. Fig. 1 shows a comparison between experimental observations and simulated data.

A3.2 ČERENKOV EFFECT IN OPTICAL FIBERS

The intersection of a particle trajectory with a fiber is defined by two parameters :

- α, the angle between the trajectory and the axis of the fiber.
- b/R, the reduced impact parameter of the trajectory of the particle on the fiber of radius R.

For a given value of α, b/R and β, the velocity of the particle, a Monte-Carlo simulation calculates the number of produced photons and tracks them up to the end of the fiber. The results of the simulations are memorized in tables for subsequent use by GEANT simulations.

Fig. 2 shows the number of photons obtained for β=1 with the type of fibers foreseen for the detector [5], i.e., numerical aperture of 0.37 and a diameter of 1 mm. Light yield is maximum for $\alpha = 40° \pm 10°$. For this reason, the fibers in the calorimeter will be oriented at 40° with respect to the beam axis.

A3.3 RESULTS OF SIMULATIONS

A3.3.1 Hadronic shower in the ZDC

When a fragment A hits the ZDC, GEANT code determines the point where it interacts. The collision is then described by FRITIOF which gives the number of "elementary" particles produced with their kinematical characteristics and a number of spectator nucleons depending on the impact parameter of the collision. FRITIOF has been modified in order to replace these individual nucleons by fragments following the model described above, giving rise to other "elementary" particles and to other residues. The operation is iterated until no heavy fragment is left. GEANT code tracks all the "elementary" particles and, when they interact in a fiber, calculates the number of photons produced using the memorized tables computed as described in the previous section.

Fig. 3 shows the longitudinal and radial projections of the showers for a proton, an O ion and a Pb ion impinging on the first Pb nucleus of the ZDC (the impact parameter for the Pb-Pb reaction has been arbitrarily set to 11 fm to investigate the effects of heavy fragment production on the total length of the shower : not very important!). The simulation shows that 99% of the shower is contained in less than 200 cm long and inside a transverse radius of 30 cm.

A3.3.2 Linearity

The predicted linearity is shown on fig. 4. It is excellent for the whole mass range as Čerenkov light does not saturate.

A3.3.3 Energy resolution

The energy resolution shown on fig. 4 has been calculated by the simulation of a number N of incident ions (N being indicated close to each point) and doing a least squares fit on the distribution of the N showers collected in the 200 x 60 x 60 cm^3 volume. The resolution depends on the number of fibers per unit volume of lead. A compromise between cost and resolution leads to a design with 1 mm ϕ fibers every 8.8 mm in the z direction and 3.9 mm in the transverse direction. The resulting lead to quartz volumes ratio of 40 seems very high. As a matter of fact, the total number of photoelectrons per nucleon and GeV is only 0.25. The resolution amounts to 50% for a proton, about 10% for a ^{12}C and 5% for a Pb ion. All these ions have an energy of 160 GeV per nucleon and this ZDC can not measure a pion of 10 GeV as the conventional plastic scintillating fiber spaghetti calorimeter does. It is designed specifically to measure ions of 160 GeV per nucleon energy.

A3.3.4 Timing properties

When a projectile hits the calorimeter, the light pulse obtained in one fiber has been simulated as described hereafter. For every couple (α ;- b/R) and each β, the velocities v of the photons produced, projected along the axis of the fiber are calculated. The pulses are created by adding all the photons as a function of their arrival time t = v/x, where x is the length of the projection along the beam axis. The pulses resulting on the anode of the photomultiplier have been calculated taking into account only the properties of the quartz window and the efficiency of the photocathode of the PM Philips XP 2020 Q we intend to use. When α is close to 40^0, the pulse is extremely narrow. If the angle is close to 0^0 or larger than 60^0, t can be quite dispersed, but this case corresponds to a very small number of collected photons.

In order to be able to work at 5 10^7 Pb/burst, we need the best possible time resolution. This is achieved by dividing the calorimeter into individual longitudinal slices, 28 cm thick along the beam axis, with edges running parallel to the fiber planes. Each slice is connected to a photomultiplier. Fig. 5 shows the anode pulse of the 7 photomultipliers, along with the cumulated fraction of the shower which is measured up to that slice. For a shower which is developing at $\beta = 1$ and 1 m long fibers, it can be seen that

- each pulse is $\simeq$4 ns
- each pulse is shifted by 1 ns with respect to the previous one

This technique of segmented reading allows to add up the pulses corresponding to each individual slice with their appropriate delay so that the resulting total pulse is less than 5 ns wide. This pulse is also very clean and does not show the characteristic tail of plastic scintillators. Such a short pulse will be damaged by the 100 m long cable bringing it up to the reading electronics, but its original width can be restored by an adapted filter.

A3.4 RADIATION DAMAGE

We have extensively studied quartz resistance to high radiation doses :

- At GANIL [6], we have irradiated 2 mm Suprasil quartz discs with 100 MeV/n ^{16}O, which have about the same dE/dx, i.e, 1 GeV/cm, than 200 GeV/n ^{32}S. The transparency of the discs has then been measured as a function of the wavelength with a Beckman absorption spectrophotometer. Results are shown in Fig. 6. A small damage for U.V. and red light is observed below 1 Gigarad. For higher doses, a recovery is observed, probably due to annealing [7]. No further evolution is then observable up to doses of 20 Grad.
- In experiment NA 38, the beam detector just before the target is made of Suprasil quartz and has received a dose of about 5 Grad since 1986 without any observable degradation. The core of the optical fibers we plan to use is made of the same quartz quality.

A3.5 TESTS

A prototype of 20 cm long, and 5 x 5 cm^2 transverse dimensions will be studied with the ^{32}S beam in october 1991 and with electrons.

The measurement of the radiation resistance of the cladding of the fiber will be made using 2 MeV e^-. This measurement is important as only pure quartz is radiation resistant and cladding is usually made of doped quartz in order to lower the refraction index. It should be noted that if the cladding were damaged so that its refraction index would slightly change, the resulting effect would nevertheless be extremely small even if the cladding transparency was lost. This is due to the relative small amount of light entering the cladding and the very small and localized extension of the eventual damaged region (a few centimeters).

Appendix 3. References

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Figure 0: Radial energy density profile for Pb-Pb (full line) and S-Pb (dashed line) central reactions (impact parameter b = 0). The rectangular curves correspond to the energy density ϵ_0 averaged over the interaction volume, calculated assuming flat disk shaped nuclei (adapted from [26]).

For Pb-Pb central interactions, the local energy density at the very centre of the colliding nuclei will be 40 % higher than the energy density averaged over the whole interaction volume.

Figure 1: Energy density ϵ vs. transverse energy E_T as a function of the impact parameter b, for O-Pb and Pb-Pb collisions. ϵ and E_T are model-dependent functions of the impact parameter b. The dashed line shows the behaviour for A-A collisions, in the limit of infinite nuclear size (from [22]).

Figure 2: a) Initial temperature T_i and b) energy density ϵ, for Pb-Pb central collisions as a function of the distance to the center of the hot region at a c. of m. energy of 20 GeV for two different assumptions on the number of efficient N-N collisions per unit transverse area (from [17]).

Figure 3: The NA 38 layout. Top) The target region and beam detectors. Bottom) The muon spectrometer.

Figure 4: Background2/Signal ratio (see page 9) as a function of the muon pair mass (in GeV/c^2) for : a) O-U (experimental data), b) S-U (experimental data), and c) Pb-U interactions (extrapolation from a) and b)). d) Ratio between b) and a).

Figure 5: The proposed setup. Top) The target region and beam detectors. Bottom) General layout.

Figure 6: a) Schematic arrangement of the Beam Hodoscope. b) One of the quartz blades (1 mm thick). The beam is along the z-axis.

Figure 7: The signals given by a quartz blade as a function of the impact of the beam. The beam is parallel to the z-axis. Light escapes from the bevel-edge of the blade as shown in Fig. 7. a) Impact at y = 0 cm. b) Impact at y = 0.1 cm.

Figure 8: Schematic general layout of the acquisition system.

Figure captions for Appendix 1 : The sub target...

Figure 1 : Layout of a section of the active target (top) and horizontal cut of an elementary counter (made of left and right slabs) between two successive sub-targets (bottom). Four parameters have been fixed for the simulation. The distance between sub-targets (25 mm), the horizontal angular range covered by the slabs relatively to their associated sub-target (θ_{min}-θ_{max}=50-350 mrd), the distance between the slab at minimum angle (θ_{min}) and its associated sub-target (15 mm) and the slab thickness (1 mm). The light is collected by photomultipliers through optical fibers.

Figure 2 : Front and side view of a left slab and its associated sub-target (top left) and horizontal cut of two successive left slabs and sub-targets (bottom right). The Čerenkov light generated by a particle traversing the slab is reflected on and/or refracted through the slab faces according to its incidence angle. Qualitatively, for an interaction in sub-target 1, the signal collected through side-face 1 of successive slabs is larger for the vertex slab than for the downstream slabs. The values of θ_1, θ_2, θ_3, θ_4, θ, h and Y are chosen as described in the text.

Figure 3 : Pb-Pb collision generated in sub-target 1 (impact parameter $\approx$ 3.6 fm, total multiplicity $\approx$ 3000). Distributions of charged particles N_{ch} (collected photons S_i) through (given by) the counters of a segmented active target made of 15 counters and 10 sub-targets. The counter giving the largest signal signs the vertex of the collision. The production of secondary particles in downstream sub-targets contributes very little to the collected signals.

Figure 4 : Pb-Pb collisions generated in sub-target 1. Response of a segmented active target made of 4 counters. Number of photons collected by counter 1 (S_1) as a function of those collected by counters 1-4 (S_1-S_4). The largest signal signs the vertex of the collision.

Figure 5 : Pb-Pb collisions generated in sub-target 1. Response of a segmented active target made of 4 counters. Impact parameter as a function of photons collected by counters 1-4 (S_1-S_4).

Figure 6 : Pb-Pb collisions generated in sub-target 1 with impact parameters between 9 and 9.5 fm. Response of a segmented active target made of 4 counters. The covering angle range (θ_{min}-θ_{max}) is : a) 50-350 mrd ; b) 150-450 mrd. The sensitivity of the system increases when θ_{min} decreases.

Figure 7 : Pb-Pb interaction in sub-target 1 (47 projectile participant nucleons) followed by a reinteraction (97 projectile participant nucleons) in sub-target 4. Distribution of signals given by the counters of a segmented active target made of 7 counters and 4 sub-targets. The interaction and reinteraction are clearly recognized.

Figure 8 : Pb-Pb interactions in sub-target 1 of a segmented active target made of 7 counters and 4 sub-targets. For each event, the 7 signals S_i are plotted. a) For events without reinteraction, the largest signal signs the vertex and S_2-S_7 are never above the dash-dotted threshold line. b) For events with a reinteraction, the first illuminated counter signs the interaction and the largest signal beyond the threshold line signs the reinteraction vertex.

Figure captions for Appendix 2 : The Multiplicity Detector

Figure 1 : Layout of the new target complex for the J/ψ setup.

Figure 2 : Layout of a) the innermost and b) the outermost of the 3 sub–detectors of the multiplicity detector.

Figure 3 : Scheme of the multiplicity detector's electronic chain. TRIGGER0 is a local pretrigger used to latch discriminator output, TRIGGER1 is the dimuon trigger used to start readout.

Figure 4 : Distribution of the occupancy of the multiplicity detector (fraction of channels which are hit).

Figure 5a : Correlation between detected multiplicity (number of hits) and generated charged multiplicity (mainly primary pions and kaons), with reinteractions of proton and neutron projectile spectators.

Figure 5b : Correlation between detected multiplicity (number of hits) and generated charged multiplicity (mainly primary pions and kaons), without projectile spectators reinteractions.

Figure 6 : Expected resolution in the charged multiplicity measurement.

Figure 7 : Correlation between digital (i.e., discriminator) multiplicity and ADC multiplicity for silicon detectors used in the HELIOS experiment.

Figure 8 : Present version of the preamplifier/comparator chip.

Figure 9 : Present timing characteristics of the preamplifier/comparator chip.

Figure 10 : Measured noise vs. detector capacitance for the preamplifier/comparator chip.

Figure 11 : Scheme for the pulsing lines.

Figure 12 : Depletion voltage of S.I. diodes vs. fluence.

Figure 13 : dN_{ch}/dy distribution for VENUS 3.11 Pb-Pb collisions at 160 GeV/N.

Figure 14 : Integrated fluences/cm^2 for 50 days of beam at 5 10^7 Pb-ions/burst, for : a) equivalent neutrons plus direct neutrons (shaded histogram : direct neutrons only), b) albedo neutrons, as a function of radius on detector 2.

Figure captions for Appendix 3 : The Zero Degree Calorimeter

Figure 1 : Comparison between the simple model used for fragmentation and data from 2.1 GeV/n O^{16} fragmentation (Lindstrom et al. data) and 200 GeV/n S^{32} (WA80 data).

Figure 2 : Top) Geometrical parameters of an optical fiber – particle trajectory system. Bottom) Number of photons produced by Čerenkov effect and collected at the extremity of a fiber (1 mm diameter and numerical aperture of 0.37) intercepted by a charged particle (Z=1, $\beta = 1$).

Figure 3a : Projection of a proton induced shower on the z (left) and R-axis (right). The arrows point to the values where 90% and 99% of the shower is contained.

Figure 3b : Same as Figure 3a for an O^{16} colliding centrally on a Pb nucleus of the ZDC.

Figure 3c : Same as Figure 3a for a Pb^{208} colliding with an impact parameter of 11 fm on a Pb nucleus of the ZDC.

Figure 4 : Linearity of the ZDC. Figure on the top is a magnification of the low mass region. Near each point is indicated the number of events calculated by the simulation program. The error bars correspond to the FWHM energy resolution as deduced from a least squares fit. See text for more details.

Figure 5 : Top) Schematic view showing the seven 28 cm thick slices along the Z-axis. Bottom) The anode pulses from the Čerenkov light from the different slices collected by the different photomultipliers as a function of time for an Oxygen ion of 160 GeV/nucleon. Pulses of adjacent slices are shifted by one nanosecond due to the shower developement along the z-axis with a value of β close to 1. The full shower for this event is contained inside 6 slices. The last pulse is the sum of the six pulses, each of them being delayed by one nanosecond relative to the next one. It is the useful pulse for the experiment.

Figure 6 : Transparency of a 2 mm thick Suprasil quartz disc after different doses of irradiation. The spectral sensitivity of the 2020 Q photomultiplier shows the interesting fact that this wavelength range is the most insensitive to radiation.

Experiment NA51: The DYSSIS muon spectrometer with its Hydrogen/Deuterium target.