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PROPOSAL

STUDY OF ELECTRON PAIR AND PHOTON PRODUCTION IN LEAD-LEAD COLLISIONS AT THE CERN SPS

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1 Introduction

We propose to perform systematic measurements of e^+e^--pairs and direct photons as a function of the event multiplicity in Pb-Pb collisions using the 160 GeV/c Pb-beams which will be available at the CERN SPS from 1994. The measurements will be carried out starting at low multiplicities in peripheral collisions, resembling S-S, up to the highest multiplicities in central Pb-Pb collisions. This is a continuation of the physics program of the CERES/NA45 experiment [1] which is mainly dedicated to the measurement of electron pairs produced in pp, pA and AA interactions in the mass range from 100 MeV/c^2 up to 1-2 GeV/c^2, in the region $2.0 < y < 2.6$ close to mid-rapidity.

The measurement of lepton pairs and photons in nuclear collisions is generally considered as a unique way to probe the hot early stages of the collision, due to the absence of final-state interactions. It has, in particular, been proposed as a tool to study the quark-gluon plasma which is expected to be formed in ultrarelativistic heavy-ion collisions. CERES will look for continuum radiation by measuring e^+e^--pairs and direct photons. In addition, CERES will address other physics topics associated with the vector meson resonances, the ρ, ω, and ϕ, which will be measured through their e^+e^--decay channel. The spectrometer will also allow high-statistics measurements of QED pairs. Some hadronic observables, high-$p_\perp$ pions and charged-particle rapidity distributions, which are easily obtained as by-products, will also be measured in large samples.

CERES is the only experiment dedicated to the measurement of e^+e^--pairs in nuclear collisions at SPS energies. It uses a novel spectrometer based on two Ring-Imaging Cherenkov detectors and a silicon radial drift chamber. The spectrometer became fully operational at the end of 1991. First data with a 200 GeV/c ^{32}S beam were taken in 1992. High-statistics runs on p-Be and p-Au collisions at 450 GeV/c were completed during 1993. A detailed account of the CERES achievements (including detector performance, first physics results, and a discussion on the pattern recognition performance) is given in the CERES Status Report which is presented to the SPSLC together with this proposal as a separate document [2].

We do foresee experimental difficulties with the present CERES spectrometer, as it stands, in the environment of a Pb-beam. For the continuation of the CERES physics program with Pb-beams, we are therefore planning to upgrade the spectrometer with additional detectors: two silicon drift chambers of an improved design, and a pad chamber behind the spectrometer. They will add redundancy to the tracking system and will help the pattern recognition of the RICH detectors in the environment of the higher multiplicities and higher background expected in central Pb-Pb collisions. In particular, most of the conversion- and π°-Dalitz-pair rejection will be done using the two silicon drift chambers and RICH-1. Furthermore, the excellent position resolution of the silicon detectors together with an increase of the magnetic field by 20% will improve the mass resolution of the spectrometer by a factor of 2. Monte Carlo simulations clearly demonstrate that the performance of the upgraded spectrometer will be substantially improved compared to the original set-up. We should be able to measure e^+e^--pairs produced in central Pb-Pb collisions with a pair-reconstruction efficiency of ~15% and a signal-to-background ratio (S/B) of 0.4. At low charged-particle rapidity densities of $\mathrm{d}n/\mathrm{d}y \approx 160$, the pair-reconstruction efficiency should reach almost 40% with a S/B-ratio of ~2. Compared to the values achieved in S-Au collisions with the original set-up in 1992, the pair-reconstruction efficiency will be improved by a factor of about 2 and the S/B-ratio by almost factor of 10 (referred to the same multiplicity density).

This document is organized as follows. Section 2 gives an account of the physics motivation and the physics program. In Section 3 we discuss the spectrometer upgrade. The expected benefits and performance are given in Section 4 together with a discussion on trigger, rates and sample sizes. Section 5 gives some details on schedule, manpower and responsibilities.

2 Physics Program

The main objective of the forthcoming SPS ion program is to study hadronic matter under the extreme conditions of density and temperature produced in Pb-Pb collisions. If sufficiently high energy densities and temperatures are achieved, a phase transition is expected, leading to a deconfined state of quarks and gluons called the quark gluon plasma. This phase transition is predicted by lattice QCD calculations [3]. CERES will look for thermal and other continuum radiation, emitted during the space-time evolution of the collision system, via the measurement of electron pairs and photons. It will also measure the vector mesons ρ, ω and ϕ, accessible through their e^+e^- decay channel, which can provide additional information on the reaction dynamics. In addition, the CERES spectrometer will easily allow to measure QED e^+e^--pairs and some hadronic observables (high-$p_\perp$ pions, charged-particle rapidity distribution) in large samples. The Pb-beams will offer better conditions for all these studies than the ^{16}O and ^{32}S beams used so far. The interaction volume and the multiplicity range will, of course, be larger, and somewhat larger energy densities are also expected.

2.1 Continuum Radiation: Electron Pairs and Real Photons

The special interest in electromagnetic probes is based on the fact that their mean-free-path is large compared to the interaction volume. Therefore, once produced, they can travel practically unaffected to the detector carrying information about the conditions and properties of the matter at the time of their production. Since these particles can be emitted at different stages of the collision, a careful analysis can in principle uncover the whole space-time evolution of the interaction region. In particular, it can provide information about the dense and hot early stages of the collision, where the virtual photons (dileptons) as well as the real photons are emitted as thermal radiation. In order to observe thermal radiation it is necessary to have a thorough knowledge of the dilepton and photon rates originating from hadronic decays. In addition, the experimental sensitivity has to be matched to the (possibly small) level of the thermal radiation above such other sources. Many calculations have been performed in order to estimate the dilepton and photon thermal yields [4, 5, 6, 7, 8, 9]; their results depend rather sensitively on the initial assumptions, in particular on the thermalization time; the thermal emission is expected to increase with decreasing thermalization time. Some estimates suggest that the most appropriate mass window for thermal radiation would be 1-3 GeV/c^2 (the mass region above the J/Ψ is dominated by hard parton processes). The relative mixture of thermal radiation from partons and hadrons (essentially $\pi^+\pi^-$ annihilation) is theoretically unclear. At low masses, below the ρ/ω in particular, pion annihilation may actually dominate [10, 11, 12]. If so, the thermal continuum would kinematically be cut-off at m $\leq$ 2m$_\pi$, leading to a possibly observable structure in the overall continuum ('pion cusp'). Bremsstrahlung from pions, in itself a process of great interest, may strongly contribute in the low mass region, comparable to the yield from hadronic decays [10, 11, 12]. It is again controversial to what extent bremsstrahlung may mask the pion cusp [10, 11, 12]. In view of all these uncertainties, we take the experimentalists point of view and try to take the best possible data, without prejudices, over the whole mass region, limited only by the accessible statistics at the upper end (above 1 GeV/c^2).

The dependence of the continuum on the associated hadron multiplicity density in the event may help to disentangle different contributions to the radiation. Thermal radiation either from partons or pions should show the unusual feature of a quadratic dependence $\propto (\mathrm{d}n/\mathrm{d}y)^2$ [13], reflecting the emission rate to be proportional to the *product* of the particle- and antiparticle density in the reaction volume (strictly speaking, a variation of $\mathrm{d}n/\mathrm{d}y$ will have to be corrected for a trivial mass number-, volume- and/or impact parameter dependence such as to reflect the variation in *energy density*). Bremsstrahlung, on the other hand, would just be linear in $\mathrm{d}n/\mathrm{d}y$, as is of course the case for the hadronic decay sources. A careful measurement of the associated multiplicity density within the spectrometer acceptance, minimizing all systematical errors to be sensitive to subtle effects, is therefore of great importance.

No clear experimental evidence exists at present for an excess of continuum radiation above the hadronic decay sources from the dilepton measurements carried out so far with ^{16}O and ^{32}S-beams. However, some hints have appeared recently. Preliminary results of dimuon measurements both by NA34/3 [14] and NA38 [14] seem to indicate an excess in the mass region between the ϕ and the J/ψ, i.e. for 1-3 GeV/c^2, above the yield expected from the Drell-Yan continuum and the combinatorial background from open charm decays. In the data of NA34/3, there may also be an anomaly in the region of the ρ/ω and below [14]. Although the analysis of our own electron-pair sample from the S-Au run in 1992 is not yet completed, we doubt whether the statistical accuracy will become sufficient in the future to reach a competitive sensitivity [2].

In the case of direct photons, no solid evidence for any continuum excess above the hadronic decay sources (here dominantly $\pi^0 \rightarrow \gamma\gamma$) exists either. The first generation experiments NA34/2 [15] and WA80 [16] have reported upper limits of order 10%, while the more recent second generation experiments CERES/NA45 [2, 17] and WA93 [18] report again only an upper limit (including a limit on a possible $(\mathrm{d}n/\mathrm{d}y)^2$-dependence [2, 17]), or a 2σ-effect [18], respectively. In all present experiments, the sensitivity is actually limited not by the statistical, but rather by the systematical errors, insufficient to identify a contribution of direct photons which may only be of the order of a few percent [5, 6, 9].

2.2 Vector mesons

The measurement of e^+e^--pairs allows to study other interesting aspects of the collision besides the continuum radiation. The mass region $0.6 < m < 1.2$ GeV/c^2 is dominated by the vector mesons ρ, ω and ϕ which can directly be measured through their e^+e^--decay channels. These mesons are also considered to be important probes of the space-time evolution of the collision.

The ρ has recently been proposed [19] as a tool to study the hadronic phase of the fireball, due to its very short lifetime of 1.3 fm/c. The ρ-yield is expected to increase relatively to the ω if the fireball lives substantially longer than the ρ, so that several generations of (thermal) ρ-mesons would contribute to the spectrum. The ρ-yield can therefore serve as a clock of the fireball lifetime.

The search for the phase transition restoring chiral symmetry is another major topic which can potentially be addressed by the measurements of e^+e^--pairs. The transition is predicted to occur at conditions very similar to those leading to deconfinement. There are specific predictions as the system gets close to chiral symmetry restoration. Already in 1982, Pisarski [20] proposed the ρ as a probe of the phase transition restoring chiral symmetry. In his calculations, as well as in later ones for other mesons [21], both the mass and the width of the ρ are found to change as the critical temperature for chiral symmetry restoration is approached.

The ϕ-meson has a lifetime of $\tau = 48$ fm/c, sufficiently large to decay outside the interaction volume. Consisting of $s\bar{s}$-quarks, it has been proposed as another messenger of quark-gluon-plasma formation [22]. Its production is expected to be enhanced as a result of two factors: (i) an abundant production of $s\bar{s}$-pairs is expected if chemical equilibrium is achieved in the plasma; (ii) the OZI rule which suppresses ϕ-formation in hadron-hadron collisions should be irrelevant in the case of quark-gluon-plasma formation. The ϕ-enhancement is expected to increase as a function of the energy density. Results reported by NA38 [23] as well as NA34/3 [14], which measure the ϕ through its $\mu^+\mu^-$ decay channel, are in qualitative agreement with these predictions. However, like many other proposed signatures, non-quark-gluon-plasma explanations are also possible and a similar enhancement as a function of $E_\perp$ can be obtained via rescattering in a hadron gas [24]. However, the enhancement does require large particle densities as well as a relatively long lifetime and also implies some degree of thermalization, all necessary conditions for quark-gluon-plasma formation.

2.3 QED Pairs

Electron-positron pairs are produced in large quantities by the strong transient electromagnetic fields generated during the collision of heavy nuclei at high energies. This process is generally referred to as QED pair production. It is well known, and the cross sections have been calculated in lowest-order perturbative QED. The availability of heavy ions at ultrarelativistic energies and, in particular, the perspective of the future heavy ion colliders RHIC and LHC have brought a renewed interest in this process from the theoretical point of view. As the energy and the charge of the colliding nuclei increase, the lowest order perturbative approach becomes unjustified, and higher order effects are expected to play an increasing role. This also implies that multiple pair production will start to occur [25]. The process may also play an important role in the production of new particles [26, 27], given sufficiently high ion energies.

Two measurements of this process have been performed at the SPS, using a ^{32}S beam of 200 GeV/u. The study of Vane et al. [28] was limited to the $p_{\perp}$ and angular distributions of inclusive e^{+}. We have measured the invariant mass of the QED pairs produced in S-Au peripheral collisions, using the original CERES spectrometer [2, 29]. The set-up was slightly modified to allow the measurement of electrons with a momentum down to 25 MeV/c and of pair masses down to 10 MeV/c^2. The results were found to be in good agreement with lowest-order perturbative QED calculations. The experience gained from this run showed the CERES spectrometer in its present form to be very well suited for this type of measurement. We therefore propose to extend these measurements to peripheral Pb-Pb collisions, using basically the same set-up (the additional detectors foreseen for the upgrade will not be needed for this purpose).

2.4 Hadronic Observables

The CERES-spectrometer is designed to measure leptonic probes. However, also hadronic observables like high-$p_{\perp}$ pions and rapidity distributions are obtained as a by-product with very high statistics [2].

The RICH detectors which identify electrons by their asymptotic ring radius will also measure pions once they exceed the Cherenkov threshold. Therefore we have the unique opportunity to study the production of π^+ and π^- for $p_\perp > 1$ GeV/c up to 5 GeV/c, where the upper limit is given by the electron/pion separation in the RICH detectors. In general the $p_\perp$-spectra of hadrons from nucleus-nucleus collisions may indicate the degree of thermalization reached, and provide evidence for collective expansion of the highly excited central region. In addition, if hard parton scattering starts to be important, it will influence in particular the high-$p_\perp$ tail of the spectrum. High-$p_\perp$ pions might also add new information to clarifying the question whether events with extremely large average $p_\perp$ as observed in the JACEE cosmic ray experiment [30] at higher energies are already produced in Pb-Pb collision at the CERN SPS.

The necessary event characterization will be provided by the silicon drift detectors, measuring the charged multiplicity within the spectrometer acceptance on an event-by-event basis.

We also like to emphasize the rather unique capability of the doublet of silicon-drift detectors as an instrument of excellent resolving power for charged-particle tracks in the (φ, y) phase space, which opens the perspective to study rapidity correlations. Using effectively a point target, by virtue of the sharply defined vertex, local densities of charged hadrons are measured with high precision in φ (1 mrad or better) and y ($\sim 1 \cdot 10^{-3}$ at $\langle y \rangle$). In addition, a very high level of accuracy is within our reach, with respect to *statistical* errors, taking a sample of $\sim 10^8$ events, as well as with respect to *systematic uncertainties*, being able to reject most of the conversion and δ-electrons, and maintaining a very low level of double interactions.

Fluctuations in rapidity correlations ('intermittency') came to fame recently by methods to filter out statistical noise and study scaling behavior with the size of the rapidity interval Δy [31], or in higher dimension [32]. The physics for AA-collisions is interesting by the sheer fact that the intermittency effects observed (see ref. [33] for a recent review) *cannot* be interpreted by any of the independent collision models and require non-linear effects. Among those that have been proposed ([31]) is the quark-gluon-plasma transition, but we are aware of the inherent problem to treat soft processes in perturbative QCD.

There is a link from fluctuations to the physics of Bose-Einstein (BE) correlations which is well defined and very challenging to pursue. Due to the BE-enhancement, like-sign particles, say two π^-, will be forced to *bunching* [34] in configuration space, the higher the local density is. The mean density will increase roughly in proportion to rapidity density from S-Au to Pb-Pb, and with the event multiplicity as well, since $\langle p_\perp \rangle$ is little affected. The highly non-linear density dependence of the BE-correlation will enhance local fluctuations, an effect analogous to the bunching of photons into *speckles*. The point vital for CERES is that some bunching should persist without momentum and charge analysis on individual particles, and we like to refer to a Monte-Carlo simulation [35] of Pb-Pb events in 'ordinary' y, φ space where BE-correlations produce clusters that stick out by eye. It is the *macroscopic* aspect we are after, which alone carries the BE-enhancement of the full, densely populated multi-particle phase space. The conventional 2-particle correlation functions are sensitive only to a tiny subset of it, and moreover, will be increasingly hard to measure, since the large source sizes expected [36] will require momentum resolution well below 20 MeV/c.

The smallest bin sizes that can safely be employed in the correlation analysis are defined by the smallest cell size for which we are able to distinguish a double hit from a single hit with, say, 90% confidence. This limiting cell size is estimated to be $\Delta r = 250$ μm, corresponding to $\Delta y = 1 \cdot 10^{-2}$, and $\Delta\varphi = 10$ mrad. The 'pictures' to be taken for each event then consist of about $5 \cdot 10^4$ pixels with an average occupancy (statistical) of $1 \cdot 10^{-2}$. The combination of high statistics and excellent resolution seems quite unique, and surely, there is a potential for surprises.

3 The Spectrometer Upgrade

3.1 Motivation of the Upgrade

The original CERES spectrometer consists essentially of two RICH detectors, one (RICH-1) located before, the other (RICH-2) located behind a superconducting solenoid, and a silicon radial drift chamber located close to the target (see Fig. 1). The tracking relies on the capability to identify ring images in the RICH counters without the knowledge of their centers. Electron tracks are identified by the asymptotic Cherenkov ring radius and the common polar angle in both RICH detectors. The vertex is determined afterwards by matching the tracks to the silicon drift chamber. The silicon counter alone cannot serve this purpose since we use an extended target. The rejection of close-pairs (photon conversions and π°-Dalitz decays) is mostly based on RICH-1 exploiting the small opening angle of the two tracks, which remains unchanged in the field free region over the full length of RICH-1, by either recognizing both rings or an unresolved doublet of rings. The silicon drift chamber provides additional rejection by analyzing the $\mathrm{d}E/\mathrm{d}x$-information. (for more details on the overall concept and the pattern recognition see the accompanying Status Report [2]).

This scheme will not be able to cope with the higher background and the higher yield of close pairs anticipated in central Pb-Pb collisions. Two clear features become apparent if we apply the present analysis procedure to simulated central Pb-Pb collisions: The ring-recognition efficiency decreases, and simultaneously the amount of fake rings (random combinations of hits in the RICH detectors) increases with the event multiplicity. These two problems originate from the fact that the location of the ring centers is unknown, and therefore the whole detector area needs to by searched for the presence of rings. This procedure is completely adequate in proton induced collisions where the background is small and the events are rather clean. It is still acceptable for $\mathrm{d}n/\mathrm{d}y$ up to 160, as we have demonstrated for S-Au data [2] where we have measured e^+e^--pairs with a reasonable efficiency, even though our data sample is of limited statistics. The procedure completely fails in the Pb-case. In addition also the close pair-rejection capability of RICH-1 is seriously diminished in Pb-events. With the increasing amount of rings per event, both genuine and fake, it is not possible to achieve enough rejection without seriously vetoing the signal.

The original concept to base the entire measurement on the RICH detectors alone with only very little redundancy and no real tracking in front and behind the magnetic field needs to be revised for the high multiplicities of central Pb-Pb collisions.

3.2 Overall Concept of the Upgrade

In order to cope with the problems discussed in the previous section, we will upgrade the CERES spectrometer. The basic double RICH spectrometer will remain unchanged. Its properties are discussed in refs. [1, 2, 37] and summarized in Tables 1 and 2. The upgrade will include additional detectors which will improve and add redundancy to the tracking, thereby helping the pattern recognition of the RICH detectors. We plan to install *two new* silicon drift chambers of an improved design (which will replace the present silicon drift and silicon pad counters) and a MWPC with pad readout behind RICH-2. We will also use a much thinner (segmented) target with an optimized geometry. The modified set-up is shown in Figs. 1 and 2.

The two silicon drift chambers will allow a very precise vertex reconstruction without needing any additional information from RICH-1. In addition, they will allow a precise pointing into UV-1 such that only a small fraction of the detector area needs to be searched for the location of the ring centers. Using the measured resolution of RICH-1 and the expected one of the silicon drift chambers, we estimate that the fake-ring probability will be reduced by a factor of 20 in central Pb-Pb collisions, i.e. for events with a charged-particle density $\mathrm{d}n/\mathrm{d}y = 500$. The pad chamber behind the spectrometer will fulfill a similar role in RICH-2, i.e. it will provide an a priori knowledge of the ring-center location, thus practically removing the fake-ring problem also in UV-2.

The two silicon drift chambers will also allow a powerful rejection of close pairs. Since a ring in RICH-1 must be matched to a pair of hits in the two chambers, the amount of relevant close pairs is practically restricted to the π°-Dalitz decays and the conversions occurring in the target only; this presents already an important improvement compared to 1992.

The conversions from the target itself are minimized by using a much reduced target thickness compared to the ^{32}S-beam run in 1992. The total thickness is limited to about 200 μm of Pb ($\lambda/\lambda_I = 0.5\%$) to cope with the very much larger cross section of δ-ray production by a Pb-beam; it is chosen such that on average not more than about 15 UV-photons are observed from target δ-electrons entering the radiator of RICH-1. In addition, the target is segmented into 8 individual disks with a diameter of 600 μm and a thickness of 25 μm each (see Fig. 2). The disks are spaced by 2.5 mm such that on average only half a disk (12.5 μm, i.e. $X/X_0 = 0.22\%$) contributes to photon conversions within the acceptance of the spectrometer.

Taking the π°-Dalitz decays and the remaining conversion pairs together, a total of only 2.2 close pairs at a charged-particle rapidity density of $\mathrm{d}n/\mathrm{d}y = 500$ is left within the acceptance. The nearly identical value, 2.1 pairs, was achieved with the original spectrometer in RICH-1 in central S-Au collisions with $\mathrm{d}n/\mathrm{d}y = 160$. In other words, for a given multiplicity, the initial amount of close pairs will be three times smaller with the proposed set-up as compared to the original one. This relatively low level of initial close pairs will be much reduced by the pattern of the tracks defined by the two silicon drift chambers together with the rings in RICH-1: tracks will be rejected (i) as likely a conversion pair if both silicon drift chambers show a double-$\mathrm{d}E/\mathrm{d}x$ signal or if the ring has a large enough amplitude, or (ii) as likely a Dalitz pair if two close rings in RICH-1 are matched to two close hits in the two silicon chambers. Our simulations show (see Section

4) that this approach is now only limited by the π°-Dalitz pairs, while the contribution from conversions can be suppressed to a negligible level. In all, enough rejection can be achieved, while keeping a reasonable efficiency of the signal reconstruction, which will still rely on the two RICH counters.

A weak point of the original spectrometer is its mass resolution. The excellent position resolution of the silicon drift chambers, together with the redundancy of the tracking, will bring a considerable improvement. We are also planning to increase the magnetic field by 20%. The mass resolution of the upgraded spectrometer is thus expected to improve by almost a factor of two.

The upgrade will also include some other steps of more technical nature, like a new first-level trigger, improvements in the pad readout electronics of UV-2, and a new and faster data acquisition system. These will be described below.

3.3 The Radial Silicon Drift Chambers

3.3.1 Outline

We describe here the new silicon drift detectors and their performance in view of the physics needs of the CERES Pb-experiment. The tasks are

(i) Vertex determination

(ii) Tracking of electrons into the spectrometer

(iii) Identification/rejection of close pairs, and

(iv) Event characterization by n_{ch}, rapidity density, and rapidity correlations.

Two closely-spaced large silicon drift detectors will determine with very high precision the vertex location common to the bunch of charged particles traversing them. The tracking of the electron candidates from the vertex point into the spectrometer should be done with such precision that the limiting momentum resolution set by the tracking accuracy after the magnetic deflection (RICH-2 and/or Pad chamber) will be reached. The rejection of close pairs will be even more important than in previous experiments since the double-ring recognition in RICH-1 will deteriorate markedly with increasing charged particle rapidity density.

The most prominent quality criteria are the single-hit resolutions in r and φ, common to all tasks. The efficiency is of outstanding importance for the tasks (ii) and (iii), since we shall require a candidate track to show up in both detectors of the doublet. The hit density will matter because it limits both the signal efficiency and the rejection of late conversions. A good double-hit resolution, eventually, will limit the degree of miscounting n_{ch} (iv), but will also improve the rejection of close pairs.

The design is based on our experience with silicon drift detectors used in CERES over the last three years [38, 39], and the detailed analysis of the data taken [40]. These detectors have not been without fail; some defects emerged from the production, some impairment of the actual performance can now be traced back to approximations used in designing the radial drift geometry, still others have to do with the way we had to operate these detectors in the experiment. We are now convinced to understand most of this in great detail and have developed strategies, with the help of full Monte-Carlo simulations, to assure a highly robust performance of the planned detector system which does not deteriorate markedly should actual parameters deviate from design values, within reasonable limits. To demonstrate the improved performance, we will frequently refer to the old detector and its operation in the previous experiments which has been documented in ref. [2]. The current status of the development of the new silicon drift detectors and their front-end electronics is given in Section 3.3.4.

3.3.2 Geometry and Hit Densities

The geometry envisaged is sketched in Fig. 2. The doublet of silicon drift detectors covers the fiducial spectrometer acceptance with a rather wide margin. That was given for free by the need to comply with the industry standard of 4"-wafers, together with the shorter segmented target compared to 1992, allowing to considerably reduce the hit density in the detector. The average and maximum densities *over the full range* $r_{min} < r < r_{max}$, 0.26 and 0.74 hits/mm^2, respectively, for the rapidity density $\mathrm{d}n/\mathrm{d}y = 500$ of Pb-Pb central, are significantly *smaller* than the corresponding densities of 0.57 and 2.7 hits/mm^2 of the old system for the much smaller rapidity density of $\mathrm{d}n/\mathrm{d}y = 160$ (S-Au central). Once the vertex is known, the hit densities *within the spectrometer acceptance* are even lower, 0.19 at $\langle\theta\rangle = 10.4°$ and 0.34 hits/mm^2 at $\theta = 8°$.

It will be shown in the following that the requirements of resolution in azimuth can be well fulfilled with the 360 anodes we used previously. To increase the resolution, the two detectors are rotated with respect to each other by 1/2 degree. The main properties of the detectors are summarized in Table 3.

3.3.3 Design Strategies for Improved Performance

We discuss the main shortcomings of the previous detector and indicate their cure.

(i) φ-Resolution and Charge Division

The φ-resolution was grossly deteriorated by deviations from a strictly radial geometry of the drift field which had been implemented via field 'rings' of polygonal structure with 120-fold symmetry. The new design uses 360-fold symmetry of the field structure instead, and there will be no more 'focusing' anodes that spoil the resolution (since there is no way to distinguish one from the other). With modern layout software for the lithography masks, the huge files can be handled, though not at ease.

The critical range for charge division is at large radii where the electron cloud, during its short path to the anode, finds no time to spread to a lateral extension that compares to the pad size. We have taken three measures to maintain the desired φ-resolution at large radii: (1) by allowing for an additional drift space between the largest radius r_{max} within the acceptance and the anode radius r_A, (2) by rotating the two drift detectors by half an anode pitch which cuts the effective pad size in half, (3) by designing a split-anode structure which distributes a small fraction of the charge to the neighbors on either side; in the simulations to be presented, the last provision is not contained.

(ii) Efficiency and Charge Collection

The reason for the loss of efficiency at small radii as observed in the operation of the old detector system is the large ballistic deficit, combined with a high detection threshold. The latter was set at about 7 times the equivalent noise charge. This high level was found necessary to prevent excessive event lengths due to pick-up of voltage spikes from the read-out chain of the RICH-1 detector, and no better cure was found.

The operation of the shaping amplifier, by principle, is that of a band pass filter which attenuates signals with rise times longer than those corresponding to the center frequency (and those with shorter rise times as well, by its purpose as an anti-aliasing filter). This happens as the rise time of the charge signal arriving at the anodes increases with drift time, due to diffusion. While the principle can not be fought, its consequences can be strongly reduced. The strategy must be to minimize the *variation* of the diffusion width σ_t^{in} over the acceptance and *adjust* the time constant σ^{elec} of the shaper such that pulses with the average width pass unattenuated. The action to be taken is to use drift velocities (v_d) sufficiently high. The figure-of-merit can be judged from the reduction of the ballistic deficit, and even more important, from the reduction of its variation with r.

The ultimate reason for the importance of charge collection for efficiency is, of course, that hit definition is a matter of the margin by which the charge signal at the output of the readout electronics can be separated from pulses originating from electronic noise. This requires the setting of an amplitude threshold, and usually the threshold level is adjusted in terms of the rms noise such as to reject spurious hits with sufficient power. Adjusting the threshold according to noise proper becomes irrelevant as soon as external disturbances outnumber the noise spikes above a certain threshold. That happened in our previous experiments because of pickup from the read-out sequence of the RICH-1 detector.

The signal charge will be diminished not only by the ballistic deficit but also by the charge sharing among several anodes, thereby reducing the noise margin. To limit excessive charge sharing from hits at small radii, the cure is again to use a sufficiently high v_d.

3.3.4 Design Parameters

Readout chain

We have decided to use the 32-channel front-end chip which has been designed for the read-out of silicon-drift detectors in the ALICE experiment, employing the full custom bipolar process SHPi by Tektronix [41]. A single channel contains a preamplifier, a quasi-Gaussian shaper and a symmetrical line driver. The specifications relevant here are

(i) equivalent noise charge = 350 electrons,

(ii) width of the quasi-Gaussian output pulse for a delta input, $\sigma^{elec} = 21$ ns, corresponding to a peaking time of 45 ns.

(iii) ballistic deficit (see below for definition), specified by

$\delta = 0.763$ for $\sigma_t^{in} = 18$ ns,

$\delta = 0.527$ for $\sigma_t^{in} = 32$ ns.

The signal pulse will be sampled for each channel in parallel by a FADC system at sampling frequencies up to 100 MHz which is within the capability of the system used so far. The detection threshold is given in terms of the Equivalent Noise Charge. A pulse train is generated by the scanner whenever the threshold is surpassed in two adjacent time bins, and it is supplemented by a pre- and post-sample. To avoid loss of resolution due to undersampling, the policy is to have a sampling frequency sufficiently high to ensure that the signal surpasses the detection threshold in a minimum of 3 successive time bins. The optimum sampling frequency is bound to increase with increasing drift velocity. The conversion uses a dynamic range of 6 bit nonlinear, or 8 bit linear.

3.3.5 Performance by Simulations

Drift velocity

MC simulations were performed to find the optimal design values for the new silicon-drift detectors (see Appendix). The effect of increased drift velocity on diminishing the variation of the spread of the signal charge, and of the all-important ballistic deficit, is evident from Fig. 3. The resulting efficiency curves are presented in Fig. 4 for two choices of the detection threshold. With v_d= 10 mm/μs we have a detector with an efficiency equal to 1 within 0.3% at the rather high threshold of 6 times the rms noise.

We are confident that we will be able to solve the above-mentioned pick-up problem since we have to redesign both the target area (an occasion to improve the shielding) and part of the readout (an occasion to reduce the antenna action). The simulated efficiency for a threshold of 9σ of noise is still above 0.98 at the smallest radius.

Single-Hit Resolution

The simulated single-hit resolution in the radial direction is well below 15 μm, even with simple centroid algorithms, and we do not care about it further on. Because of the highly temperature-dependent electron mobility, we foresee precautions against spatial and temporal temperature variations, consisting of an environment stabilized to 0.1 K over some hours, as used previously, supplemented by improved calibration methods (local charge injection).

Of main concern are the azimuthal resolutions. For the doublet, the hit positions are obtained from an error function fit applied *simultaneously* to the signal amplitudes vs. anode number for the two detectors which are rotated by 0.5 anode pad with respect to each other. The single-hit resolution derived is shown in Fig. 5 vs. hit position r for the higher drift speeds, together with the frequency spectrum of deviations for the acceptance region $15 < r < 36$ mm. It is observed that the improvement in σ_φ for the doublet over that of the singlet amounts to more than a factor of 2 (actually a factor of 4 at 3σ threshold), which might have been expected considering one half the effective anode pitch.

3.4 Pad Chamber

The main role of the pad chamber is to help the pattern recognition in RICH-2 by providing the knowledge of the ring-center location. It consists of a MWPC with pad readout. Its characteristic properties are listed in Table 4.

The chamber is placed behind the mirror of RICH-2, at a distance of ~3.3 m from the target, and covers the pseudo-rapidity interval $2.0 < \eta < 2.7$, i.e. slightly larger than the fiducial acceptance of the spectrometer. The MWPC has a structure similar to the multiwire amplification stage of UV-2 [42]. A schematic layout is shown in Fig. 6. The electrodes have an annular shape. The upstream cathode is a stainless steel mesh; the second electrode is the wire anode. It is made of 30 μm diameter gold plated tungsten wires spaced by 3 mm, very similar to the one used in UV-2. The electrode is divided azimuthally in 16 sectors by radial spokes made of G10 (see Fig. 6). The wires within each sector are parallel to the central radius of that sector as shown in Fig. 6b, a scheme successfully employed in the RICH UV-detectors. The downstream cathode is the pad electrode. It has ~50 000 pads with a pad size of $\sim 6 \times 6$ mm^2. It will be constructed similar to the pad electrode of UV-2, which consists of a sandwich of standard printed circuit board, reinforced by a number of ribs, and carrying the pads and plated-through contact holes with soldered plugs receiving the front-end modules without leaving any dead areas. Gas tightness is achieved by an additional G10-sheet toward the inside, carrying a resistive layer transparent to the signals (as for the RICH detectors), or by sealing on the outside with epoxy.

The anode to cathode distance is ~5 mm, i.e. a minimum-ionizing particle will deposit a total primary charge of ~50 e in the chamber, requiring a moderate gain of a few times 10^4. Due to the chamber geometry, the induced signal will have an rms-width of about 0.8 pads, allowing a position resolution of 600 μm with center-of-gravity interpolation.

The readout will be similar to the improved UV-2 pad readout (see next section). The preamplifier modules which cover 121 channels will be identical to UV-2. We will need a total of 400 modules to cover the whole acceptance. A module consists of two low-noise 64-channel CMOS amplifiers (CAMEX64A), mounted on a ceramic hybrid and a carrier board including a protection circuit against sparks. The carriers will be adapted to the slightly changed readout pitch. Pairs of modules will be grouped and equipped with an analog-to-digital interface. A pedestal correction of the pad amplitudes is applied and the information is digitized using an 8-bit FADC. In addition, the interfaces control the readout of the modules by supplying all necessary control signals and channel addresses.

The VME-based system collecting the event via 16 chains (32 modules) will be similar to the one now used for RICH-1 and RICH-2.

3.5 Modifications of the RICH Detectors

The pad readout is used to read out the information from the UV-detectors and the pad-chamber. The backplanes of these gas detectors consist of about 50 000 square metal pads each which pick up induced signals of $\approx 2 \cdot 10^5$ electron charges. Preamplifier modules with low-noise VLSI chips are plugged directly onto the backplanes to read out the analog pulse height of each pad [43]. The front-end modules of UV-2 will be modified following the good experience gained with the second generation of the UV-1 pad readout electronics, which was installed during 1992. The carrier boards which contain the preamplifier modules will be equipped with an improved protection circuit against sparks using low-leakage-current diodes, which ensure much better noise immunity. We will also adapt the digital readout scheme of UV1, replacing the old analog transfer to the counting room. Analog-to-digital interfaces will serve two readout modules (242 channels) and will be plugged directly onto the front-end modules. The pad amplitudes will be corrected for pedestal variations, digitized with 8 bit resolution and then transferred to the counting room. As for UV-1 we expect that these modifications will result in an increase of the signal-to-background ratio by about a factor of two and a reduction of the readout time by one order of magnitude.

Further modifications will be needed for the new DAQ scheme. The pad occupancy in central Pb-Pb collisions is expected to be a factor of 3 larger as compared to S-Au. To avoid an excessive event length especially in UV-1, we will use an online data compression algorithm. For the expected occupancy, this leads to an overall reduction of a factor of 3 compared to the previous setup, i.e. the amount of data going to tape stays rather constant. The compression algorithm is fully implemented by hardware using programmable gate arrays. It requires the construction of new VME boards to receive the digitized data in the control room. The readout is organized in 16 chains (with a maximum of 4096 channels), each using a receiver board. The remaining channels above an individual threshold are now further compressed. They are grouped in lists instead of coding each channel individually with its corresponding 18-bit x and y-coordinate. A compressed event has now the following structure: it contains a list of all amplitudes (4 channels grouped in one longword) and a preceding bit pattern of all channels firing. The compressed data of each receiver board are stored in a FIFO-memory, which is linked to a special backplane connecting all receivers of a detector like a shift-register. The collection of the data of all chains requires rather high speed (1Gbit/s), which prohibits the use of any standard bus system. A special control module buffers the data transmitted via this 'bus'. In addition, it is equipped with a high-speed optical link, which is used to transfer the data of a detector into a fast memory situated in the master crate. This memory will be large enough to buffer the data for one burst.

3.6 First-Level Trigger Detectors

The original setup of the first-level trigger (FLT) will be replaced; the concept will however remain unchanged. The trigger will be generated by the coincidence of a beam particle upstream and a minimum charged-particle multiplicity downstream of the target.

Following our experience of the last years, clean beam conditions, i.e. a minimum amount of upstream interactions, are essential for a good data quality. Upstream interactions produce a large flux of charged particles which traverse the UV-detectors, in particular UV-1, adding a considerable load on them. To avoid upstream interactions as much as possible, the vacuum pipe will be extended up to 1 or 2 cm close to the target. We foresee a thin ($<$ 1mm) plastic scintillator located approximately 60 m upstream of the target to tag the beam. This detector will be integrated in the vacuum pipe; the design will enable us to easily exchange it in case of radiation damage. A veto wall made of scintillators of the size of UV-1, will be positioned approximately 4 m upstream of our experiment and will be used to minimize the amount of upstream events by tuning the collimator and magnet settings of the H8 beam line. In addition, it will allow to reject the remaining upstream events, which can be distinguished by time of flight from backward emitted particles of a target interaction.

During p-nucleus and S-nucleus running, the multiplicity information for the interaction trigger was obtained from a segmented silicon pad detector located 10 cm downstream of the target, with a rapidity coverage matched to the spectrometer acceptance [2]. The upgraded spectrometer will have two silicon drift chambers in that area, instead of only one in the original set-up. Due to the limited space in the target area and the need to minimize the amount of material in front of RICH-1 (to reduce the number of photon conversions), we have decided to remove the silicon pad detector. Instead, we will install a new scintillator array (Fig. 7), downstream of the experiment, to measure the multiplicity for the trigger. It will be segmented in 24 individual counters. It will not cover the acceptance $2.0 < \eta < 2.6$ of the spectrometer, but rather the region $3 < \eta < 4$, in order to avoid the particles from showers occurring in the pad chamber. The different acceptance does not represent a real disadvantage since the particle densities are similar and the multiplicity within the spectrometer acceptance is accurately measured by the silicon drift chambers. On the other hand, the interactions downstream of the target but in front of the multiplicity array can not be neglected when triggering at low multiplicities, in particular since we will use a very thin target of 200 μm. We will use an additional detector close to the target to ensure that the collision originated at the target. A final choice has not yet been made, but several options are being considered, like a small number of silicon detectors positioned at more backward angles ($\eta < 2$) or a thin scintillator at forward angles, read out via an air light guide made of reflecting mylar foils.

3.7 Data Acquisition System

In this chapter we describe the modifications to the CERES data acquisition system (DAQ) necessary to cope with the requirements of data taking with Pb-beams. We will keep the original modular design of the system. It will be therefore rather straightforward to add the new detector components: the pad chamber and the second silicon drift detector. The overall concept of the data acquisition system is shown in Fig. 8. Each detector has a VME crate assigned to it, which is equipped with a CPU and some memory to allow for local control (calibration runs, test). A further VME crate will be used for slow control (e.g. HV control, temperature and gas quality monitoring). All the processors will run under the operating system OS9/68000. They are booted via TCP/IP from a UNIX workstation, which is also their NFS file server; consequently none of them needs any private mass storage device. In addition, each crate has an interface to a high-speed optical link which is used to transfer the data into a fast memory situated in the master crate. These memories (one per detector) will be large enough to buffer the data of the corresponding detector for one whole burst (max. 32 MByte). The necessary modifications for the UV-1/2 pad readout and the pad chamber are discussed in Sections 3.4 and 3.5. The FADC system (DL300) to read out the Silicon drift detectors remains basically unchanged. It is only necessary to build an interface between the scanning modules of the system (one per crate) and the high-speed link to the burst-memory. The data acquisition system will be able to accumulate and buffer about 1450 events of an average length of 80 kByte (this is the maximum length expected in a Pb-Pb central collision event). This leads to a total data volume of 120 MByte per burst which will be transferred to a high-speed tape drive. We intend to use a SONY D1 tape drive which can record at speeds up to 8, 16 or 32 MByte/sec, depending on the model. We are planning to use the medium speed model; the VME to tape interface, with the required speed of 16 MByte/sec, is presently being developed for NA49. With this tape drive one can use tapes which can store up to ∼100 GByte; this corresponds to more than 4 hours of uninterrupted data taking.

4 Performance of the Upgraded Spectrometer

4.1 Overview

The low-mass e^+e^--spectrum ($0.2 < m < 1$ GeV/c^2) originates, in the absence of new physics, from the known hadronic decays (Dalitz decays: $\eta, \eta' \rightarrow \gamma e^+e^-$, $\omega \rightarrow \pi^\circ e^+e^-$, resonance decays: $\rho, \omega, \phi \rightarrow e^+e^-$). The integral yield (for masses $m > 200$ MeV/c^2 and with a $p_\perp$-cut of 200 MeV/c on each track) is of the order of $3 \cdot 10^{-5}/\pi^\circ$. We will refer to those pairs as the hadronic signal or shortly the signal. New physics would have to appear as a deviation from that signal.

The major endeavor of the experiment is to detect this weak source in the presence of an overwhelming yield of pairs originating from photon conversions and π°-Dalitz decays, which are several orders of magnitude more abundant. A huge background of fictitious pairs arises from the combination of tracks that belong to unrecognized conversions and π°-Dalitz decays, if those tracks are not rejected at the level of $\geq$90%. The goal of the experiment is to measure the mass spectrum of the hadronic signal with an accuracy sufficient to reveal possible deviations from expectations. This is a real challenge in central Pb-Pb collisions since the background increases quadratically, whereas the signal increases linearly with event multiplicity. We will denote the conversions and π°-Dalitz decays as 'close pairs' since they have a small opening angle as opposed to the pairs of the signal which have a relatively large opening angle.

The crucial question is how well can one reject the close pairs while keeping at the same time a reasonable efficiency to reconstruct the signal. To answer this question, we use a Monte Carlo simulation code based on the present understanding of the CERES spectrometer. This code generates Pb-Pb events (see next section), which contain the expected amount of close pairs. We superimpose an $\omega \rightarrow e^+e^-$ decay on each event, which we use as a flag, in order to determine the signal reconstruction efficiency. All particles are tracked through the spectrometer using GEANT [44], and special care was taken to generate a realistic response of the RICH detectors using as guidelines our previous S-Au results. The event is then analyzed with a twofold goal:

(i) to assess the rejection of close pairs. The doublet of silicon drift chambers provides most of the rejection handles while the RICH detectors ensure the identification of electrons by their asymptotic ring radius. The remaining single tracks from close pairs, after all cuts, are combined into pairs, and these define the combinatorial background.

(ii) to determine the signal reconstruction efficiency by the success of finding both tracks of the added $\omega \rightarrow e^+e^-$ pair.

The results show that the upgraded spectrometer will allow us to measure low-mass e^+e^--pairs up to the highest multiplicities expected in central Pb-Pb collisions. For comparable multiplicities, the performance is much superior to that achieved in S-Au collisions with the old set-up.

In the following we will give a short account of the Monte-Carlo simulation, the track reconstruction scheme and discuss the pair-reconstruction efficiency, signal to background ratios, mass resolution and the data samples that we expect to achieve. Real photons and QED pairs require dedicated runs and are discussed separately.

4.2 Monte Carlo Simulations

The performance of the spectrometer has been studied using a detailed description of the whole setup in the GEANT framework [44]. The code first generates a Pb-Pb collision event using a simplified event generator. Practically all sources of background tracks are from unrecognized conversions or π^0 Dalitz decays; in order to simulate them it is therefore sufficient to generate pions (π^+, π^- and π^0) according to measured rapidity and $p_\perp$ distributions. Special emphasis was given to reproduce the measured slope in the high-$p_\perp$ region, since high-$p_\perp$ pions – most of them being just above the Cherenkov threshold – are an important source of single Cherenkov photons. In order to make the simulations as realistic as possible, we have taken great care to include our present understanding of the performance, especially of the RICH detectors.

The response of the UV-detectors to single UV-photons is simulated taking into account the single hit resolution, the exponential amplitude distribution of the avalanche and the digitization of the pad readout electronics. In comparing Monte Carlo simulations to the data taken with the ^{32}S-beam, we found that the number of single photons in RICH-2 is very well reproduced, whereas it is underestimated for RICH-1 [2]. Because the origin of this background of single hits is yet unknown, we have added this extra component of single hits according to the measured angle and multiplicity distributions. The measured number of extended hits ("clusters") from densely ionizing charged particles is reasonably well described by the Monte Carlo generator for both RICH detectors. In the simulation, the external tracking was simplified, using the known direction of the particle as a 'predictor' for the ring center, instead of actually performing the full track reconstruction. This approach is justified, since the resolution of the silicon detectors and the pad chamber is much better than the resolution of the RICH detectors.

4.3 Electron Tracks

The general philosophy of the new tracking scheme has already been discussed in section 3.2. The first step in the tracking is to determine the vertex using the two silicon drift chambers. Because of the large number of charged particles within their acceptance, it is possible to determine the spatial position of the interaction with high precision, as the errors decrease like $1/\sqrt{n_{ch}}$. Fig. 9 demonstrates the resolution for events with the lowest multiplicities considered ($\mathrm{d}n_{ch}/\mathrm{dy} = 100$), i.e. the worst resolution. The vertex is resolved to better than 50 μm in lateral direction and to 100 μm along the beam axis.

The reconstructed vertex is the origin of a track that intersects the silicon drift detectors at the hit position (using the information from both detectors) and serves to point at the predicted ring center in RICH-1. Therefore only a small area in RICH-1 has to be searched for rings. If enough photon hits are found within a mask around the asymptotic Cherenkov ring radius, a fitting procedure is applied. We accept an electron candidate track under the condition that (i) the ring survives a number of quality cuts, like a cut on the number of hits, and (ii) that the reconstructed ring center and the original predictor coincide within a window determined by the multiple scattering (which limits the resolution).

The matching between the silicon drift chambers and RICH-1 considerably reduces the number of candidate tracks. The remaining tracks are now extended to the pad chamber. The latter is inspected for a matching hit in a region limited by the deflection in the magnetic field for $p_\perp = 200$ MeV/c and the resolution, which is again completely dominated by multiple scattering. More than one match is found on the average, due to the high charged-particle density. The fraction of random coincidences is 15% at $\mathrm{d}n/\mathrm{d}y = 160$ and $\sim$50% at $\mathrm{d}n/\mathrm{d}y = 500$. With the additional space point, the direction of the track is now fixed behind the magnetic field deflection, which freezes possible ring centers now also in RICH-2. The following ring reconstruction procedure is similar to RICH-1.

By requiring an asymptotic Cherenkov ring radius in both RICH detectors, practically only electron tracks remain ($> 95\%$); most of them are from photon conversions and π°-Dalitz decays. The demanding task will be to discriminate the genuine single electron tracks of the signal against the ones from close pairs.

4.4 Background Rejection

The amount of close pairs is largely reduced by the $p_\perp$-cut already applied in the reconstruction of the track. The number of single tracks per conversion or π°-Dalitz decay which survive this cut is $\sim$20%. For the further rejection of the background of tracks from close pairs, the doublet of silicon drift detectors plays a decisive role.

The close pairs remaining after the $p_\perp$-cut can be characterized according to their signature in the double silicon detectors as follows:

(i) *low-mass Dalitz pairs* mostly from π°-Dalitz decays,

(ii) *target conversions* which take place inside the target and the material between target and the first silicon drift detector,

(iii) *SIDC-1 conversions* occurring inside the first silicon drift detector,

(iv) *late conversions* occurring in the second silicon drift detector or in the material downstream of it, including one half of the gas in radiator 1 (resulting in an – apparently single – electron ring in RICH-1).

Since a ring in RICH-1 must be matched to a hit in both silicon detectors, all late conversions (iv) including a fraction of (iii) are practically eliminated. The inefficiency in the rejection of late conversions is only limited by the probability for accidental hits in the (small) inspection area. The amount of close pairs is therefore reduced to the π°-Dalitz decays, the conversions occurring in the target and a fraction of SIDC-1 conversions which escape a $\mathrm{d}E/\mathrm{d}x$-cut.

Tracks from pairs of classes (i) and (ii) are rejected using the $\mathrm{d}E/\mathrm{d}x$-information of both silicon drift detectors in an area around the intersection point. The track is rejected, if there is more than one hit within a veto area on *both* drift detectors, or if the measured $\mathrm{d}E/\mathrm{d}x$ is twice the value of a minimum ionizing particle in *both* detectors. To illustrate the power of this rejection, Fig. 10 shows the combined information of both silicon detectors for single tracks and for conversions. Using cuts in the 2-dimensional plane as indicated by the solid lines, the rejection can be rather high without loosing efficiency on the signal. Varying the cut in both detectors simultaneously, the resulting efficiency for single $\mathrm{d}E/\mathrm{d}x$ vs. the rejection of double minimum ionizing particles is shown in Fig. 11. However, the signal efficiency is also reduced, due to accidental overlap with a pion track in the veto area. This introduces a multiplicity dependent loss of signal tracks, which is below 15% for central collisions. Due to their larger opening angle, tracks from Dalitz decays are rejected less efficiently; they are recognized by their pattern of two close-by rings in RICH-1.

4.5 Results

The generated Monte Carlo events were fully analyzed, reconstructing electron tracks and rejecting close pairs by the procedure described above. The single tracks from close pairs, remaining after all rejection cuts, are combined to pairs defining the combinatorial background. Since the number of photon conversions and π°-Dalitz decays are described correctly by the Monte Carlo procedure, the background can be determined in absolute terms for a given multiplicity. The $\omega \to e^+e^-$ pair, contained in each event and therefore analyzed under identical conditions, is used to determine the pair-reconstruction efficiency.

To compare the combinatorial background to the expected signal, we have generated the invariant mass spectrum of inclusive $\mathrm{e^+e^-}$-pairs using a generator containing all the hadronic sources, i.e. the π°, η, η', ρ, ω and ϕ. Their $p_\perp$-distributions were generated according to measured pion distributions, assuming $m_\perp$-scaling. The rapidity distribution was a fit to $\mathrm{d}n/\mathrm{d}\eta$ as measured by WA80 [45] for S-Au, modified to reflect the ratio of $\sigma_{central}$ to σ_{tot} measured by NA27 [46]. The Dalitz decays were treated according to the Kroll-Wada expression with the experimental transition form factors taken from ref. [47].

The momenta of the electrons were convoluted with the expected resolution. The result of this cocktail, compared to the combinatorial background, is shown in Fig. 12 and Fig. 13 for peripheral and central Pb-Pb collisions, respectively. It is normalized according to the pair-reconstruction efficiency determined by the Monte Carlo and the event multiplicity.

For peripheral collisions (dn/dy = 160), the pair efficiency is about 40%, resulting in a signal-to-background ratio (S/B) of about 2. The remarkable improvement in the S/B-ratio over that obtained for the S-Au data taken previously [2], is also visible in Fig. 12. It amounts to almost a factor of 10, reflecting the lowering of the initial number of close pairs and the much more powerful rejection provided by the silicon drift chamber doublet. At the same time the signal efficiency has improved by about a factor of 2, basically as a consequence of the ring-center knowledge provided by the tracking system. For central Pb-Pb collisions (dn/dy=500), the S/B-ratio is deteriorated to 0.4. This reflects the linear rise of the signal with the event multiplicity compared to the quadratic increase of the combinatorial background, as well as a reduction of the reconstruction efficiency for the higher multiplicities.

To illustrate this dependence, Fig. 14 shows on the left hand side the pair-reconstruction efficiency for different multiplicities as resulting from the Monte Carlo simulation. The open circles show the efficiency after the track reconstruction. The efficiency is 60% in peripheral collisions and drops continuously to 40% for central collisions as the pattern recognition in the RICH detectors deteriorates more and more with increasing density of background hits. The rejection of close pairs, of course, introduces some degradation of the efficiency, but after applying all rejection cuts, the reconstruction efficiency is still 15% at the highest rapidity density of 500. On the right hand side of Fig. 14 the accompanying S/B-ratios are shown. Here, signal and background are determined as described above, but with an additional mass cut of m> 200 MeV/c^2 for the combinatorial background. While the S/B-ratio is definitively prohibitive for any measurement before rejection, it improves by more than a factor of 10 once all rejection tools are applied, and we reach 2 and 0.4 for peripheral and central collisions, respectively.

4.6 Momentum and Mass Resolution

A good mass resolution is of major importance in order to resolve the vector mesons ρ/ω and ϕ in the invariant mass spectrum of the electron pairs. The capability to also resolve the ρ and the ω is of particular interest since it will determine the sensitivity to a possible mass shift of the ρ expected as one approaches the phase transition restoring chiral symmetry.

The mass resolution was a weak point of the original CERES spectrometer. The momentum resolution (shown as a dashed line in Fig. 15) was given there by the ring-center resolution of the RICH detectors, the effects of multiple scattering (only the material between the two RICH detectors enters) and the φ-deflection of 120 mrad/p (GeV/c). It is limited by multiple scattering at low momenta and by the chromatic dispersion in the radiator gas – dominated by the contribution of RICH-1 – at high momenta (see ref. [2] for details).

We have taken great care to improve the momentum resolution of the new set-up as much as possible. First, an overall improvement is achieved by a 20% increase of the magnetic field. This increase is well within the coil specifications. It was successfully tested in 1993, but, after a serious quench caused by imperfect power feed-throughs to the coils, we decided, as a precaution, not to use it during data taking. This technical problem can be repaired, and we do not see any risk in the field increase. A further improvement of the resolution in the new set-up is due to the tracking scheme which is no longer based on the RICH detectors alone, but includes also the new silicon drift detectors and the pad chamber. At high momenta, the most accurate tracking is given by the silicon drift chambers and RICH-2. This is due to the excellent φ-resolution of the combination of two silicon chambers $\sigma_\varphi \approx 0.7$ mrad as compared to 3.2 mrad from RICH-1. With decreasing momentum, the φ-measurement in RICH-1 becomes the better one, due to the increasing multiple scattering contribution in the silicon chambers. The best momentum resolution at low momenta is achieved by tracking RICH-1 and RICH-2, as in the old set-up, and there is practically no further improvement beyond the one given by the increase in the magnetic field. The pad chamber only plays a minor role in the resolution considerations due to the large multiple scattering. The resulting momentum resolution is shown as the full line in Fig. 15.

The relative mass resolution of the spectrometer as a function of the invariant mass of the electron pair is plotted in Fig. 16. We have assumed $m_\perp$-scaling for the relation between m and $p_\perp$, and applied a $p_\perp$-cut to each track. The resolution of the new set-up is better by almost a factor of 2 over the entire mass range as compared to the original set-up (dashed line in Fig. 15). The resolution is 3.8% (30 MeV/c^2) and 4% (41 MeV/c^2) for the vector mesons ρ/ω and ϕ, respectively. This is completely sufficient to resolve the

ρ/ω and the ϕ-meson. The mass resolution is now substantially smaller than the natural width of the ρ and we are confident, given sufficient statistics, that we are able to also disentangle the ρ and the ω.

4.7 Trigger and Sample Sizes

In this section we discuss our trigger scheme and the expected sample sizes. The major share of the running time will be dedicated to the measurement of low-mass continuum e^+e^--pairs and the vector mesons ρ/ω and ϕ. The measurement of rapidity correlations, high-$p_\perp$ pions, etc., will be performed in parallel. The other observables, direct photons and QED pairs, require dedicated runs with slight modifications of the setup and are therefore discussed separately.

4.7.1 Low-Mass Continuum Pairs and Vector Mesons ρ/ω and ϕ

The interaction rate is dominated by very peripheral collisions. In the first-level trigger, these are suppressed by a threshold on the charged multiplicity. We will select events with $dn/dy > 100$, covering a range from collisions with partial overlap up to central Pb-Pb collisions.

Due to the increased cross-section of the signal for high multiplicities, we can accumulate large samples even without any higher level trigger. At low multiplicities, however, we have the option of using the ring-center information for RICH-1 from the CERES systolic processor array as a second-level trigger. The trigger performance in the S-Au run of 1992 was seriously limited by the readout speed and imperfections of the RICH-1 electronics; nevertheless a reduction factor of 6 at an efficiency of about 50% was reached. In the proton run of 1993, with improved electronics and optimized trigger and running conditions, reduction factors of 110 at an efficiency of 60% were achieved (see ref. [2] for details). Based on that, we expect an enrichment factor (reduction $\times$ efficiency) of >5 for low multiplicity Pb-Pb collisions. We are presently investigating to what extent a correlation of the ring centers of both RICH detectors will improve the trigger and also enable it to cope with the more complex pattern recognition in central collisions. Here we adopt a conservative approach and quote expected rates and sample sizes under the assumption that only the first-level trigger will be used.

The information on target, beam intensity, trigger rates, efficiencies and final sample sizes of e^+e^--pairs is summarized in Table 5. Our estimate is based on a 30 day full-efficiency running period and a beam intensity of $2.5 \cdot 10^6$/burst. We assume a burst length of 4 out of 19 seconds, as in previous ion runs at the CERN SPS. The segmented Pb-target has a total thickness of 200 μm (λ/λ_I =0.5%) as cited before. The first-level trigger corresponds to approximately 40% of the cross-section, estimated from the multiplicity distribution (Fig. 17) determined by the VENUS 4.10 [48] event generator. We arrive at a first-level trigger rate of 5000/burst. The high speed (2 ms/event) of our new DAQ will enable us to write 1450 events/burst to tape.

The sample size quoted is defined as the total yield of e^+e^--pairs, originating from the known hadronic decay sources, with a mass m > 200 MeV/c^2 and a $p_\perp$-cut of 200 MeV/c on each track. For the average multiplicity of 280 we expect an electron-pair production probability of $3.8 \cdot 10^{-4}$/event. Taking into account an average reconstruction efficiency of 28% (compare Fig. 14), we expect a yield of about 20 000 reconstructed e^+e^--pairs within a running period of 30 days.

Based on this sample, we have investigated the statistical sensitivity to any deviation relative to the production rate from known hadronic sources. The results are summarized in Table 6. We discuss the low-mass continuum region $200 < m < 650$ MeV/c^2 and a region around the ω and ϕ vector mesons ($\pm 1.68\sigma_m$) separately for central Pb-Pb collisions and more peripheral collisions 100< dn/dy < 280. For each mass region, the relative yield of e^+e^--pairs as well as the combinatorial background can be obtained from Figs. 12 and 13. We define the sensitivity as a 3σ-limit determined by the statistical error on the 'effective' sample size, which is a sample size of identical statistical errors for a background-free measurement. The results from Table 6 show that in all cases, even for central Pb-Pb collisions, the statistical accuracy will be much better than the systematic errors on the production rates from hadronic sources, which at present are 30% but will certainly be improved by our 1993 p-Be data. In the mass region above the ϕ-meson, the statistics achievable within a running period of 30 days will be marginal; here, the development of an extremely powerful higher-level trigger would be essential.

4.7.2 Direct Photons

All measurements of direct photons in heavy ion experiments have so far been limited by the systematical rather than the statistical errors. It is therefore clear that all efforts have to be made to minimize the former. With that goal in mind we plan to perform a dedicated measurement. As in our previous direct photon measurement in S-Au collisions (see ref.[2, 17]), we will use the conversion method, but rather rely on an external converter instead of the target. The converter will be located between the two silicon drift chambers. This is an ideal location, which allows a positive and rather unambiguous identification of a photon conversion independent of the RICH detectors by the absence of a hit in the first chamber and a double-$\mathrm{d}E/\mathrm{d}x$ signal in the second one. Another advantage is that the converter thickness is known and can be changed as a check. In the data analysis we will apply a single-track $p_{\perp}$-cut of 60 MeV/c; 16% of all conversions within the spectrometer acceptance survive this cut. The pattern recognition in the RICH detectors – the signature for a conversion is a double ring in RICH-1 matched to two rings in RICH-2 – is greatly helped by the external tracking. Our Monte Carlo simulations show that the conversion reconstruction efficiency depends only slightly on the event multiplicity, and we expect to reach an overall reconstruction efficiency of >50%.

Table 7 shows the rates and sample sizes for the real photon measurement using the same assumptions on target thickness, beam intensity and trigger conditions as for the e^+e^--pairs. The entries in the table are self-explanatory; for two days of running time we obtain about $1.4 \cdot 10^6$ and $4 \cdot 10^6$ events for a 1% and 3% converter, respectively.

The sensitivity to detect thermal photons is clearly dominated by the systematic errors. We follow two approaches with rather different errors [2, 17]: In the first, we measure the inclusive photon $p_{\perp}$-distribution and compare it to the expected photon yield, generated with a Monte Carlo generator containing all hadronic sources (dominantly π° and η). In the second, we investigate the photon production rate as a function of the charged-particle rapidity density. Many systematical errors associated with the pattern recognition and the hadronic decay generator are expected to cancel out in this approach, and therefore we expect it to be more sensitive. In our previous S-Au measurements, the systematical errors for both methods were of the order of 10%. Several factors which contributed there will be eliminated or much reduced in the new set-up:

- the Dalitz contamination can be completely eliminated by the external converter and the double silicon drift chamber;
- the charged-particle multiplicity will be accurately measured by the drift chambers, covering the same acceptance as the spectrometer (instead of measuring it with the silicon pad detector and an extended target as done in 1992);

- the converter will have a known and homogeneous thickness such that it will not introduce any error;
- the understanding of the pattern recognition efficiency will be facilitated, since the additional conversion identification by the silicon detectors allows to relax the cuts introduced in the previous analysis to remove fake conversion patterns in the RICH detectors;
- the multiplicity scale can be checked with the RICH detectors within the same acceptance as the conversion pairs.

We also hope to achieve some improvements from better input data to the Monte Carlo photon generator. In particular, our measurements of p-Be and p-Au collisions in 1993 together with the TAPS calorimeter may be helpful in that respect [2]. In all, we are confident to achieve a factor of 5 improvement in the systematical errors of the multiplicity dependence and at least a factor of 2 for the inclusive $p_\perp$-spectra.

4.7.3 QED Pairs

The measurement of the electromagnetic production of e^+e^--pairs in peripheral non-disruptive Pb-Pb collisions requires a slightly modified set-up, in particular of the trigger conditions. We will use a set-up similar to the one which was successfully used in our S-Pt measurements.

The magnetic field will be reduced to 20% of its nominal value. This enables us to reconstruct electrons with energies $E \geq 25$ MeV, close to the Cherenkov threshold of 16 MeV, and pair masses down to 10 MeV/c^2. The ring images of these low-energy electrons are very much distorted by multiple scattering, but they can still be recognized with sufficient efficiency since the events are practically empty. The target area set-up will be replaced by the one used in the S-Pt experiment. A silicon pad counter is used in the trigger. This counter is segmented in 64 pads arranged in eight concentric rings and eight azimuthal sectors [49]. It was part of the standard CERES set-up and has performed very well in the measurements of charged particles in proton and S-induced collisions. Special care will be taken to minimize the amount of material and thus to reduce the production rate of δ-electrons, which is the main background source for this measurement. We will use a 10 μm thick Pt-target, and the gas volume up to the silicon pad counter will be flushed with He. In addition, low-energy δ-electrons (<250 keV) will be stopped in a

240 μm mylar foil mounted in front of the silicon pad counter.

We will use a three step scheme to trigger on e^+e^--pairs produced in peripheral Pb-Pb collisions:

- First the projectile nucleus will be identified downstream of the experiment in a scintillator or a Cherenkov counter of sufficient resolution.
- The first-level trigger will then require 2 or 3 charged particles detected in the silicon pad counter, within the acceptance of the spectrometer, in coincidence with the projectile. This trigger will be generated mostly by δ-electrons, produced upstream of the silicon counter, in spite of the efforts to minimize the amount of material in that region. The yields of δ-electrons per beam particle are given in Table 8 together with the yield of QED pairs per trigger, which was calculated from lowest-order Feynmann diagrams of the process [50]. For comparison we have included in the table the yields of our previous S-Pt run. Since the production of both δ-electrons and QED pairs scale with Z^2 of the projectile, the rate of QED pairs per first-level trigger in Pb-Pb will be very similar to S-Pt.
- As a third step we plan to use the intermediate-level trigger, which performs a fast but coarse ring recognition on the RICH-1 data [2]. It was developed and successfully used for proton running in 1993. We expect that it will reduce the trigger rate by a factor of 3 to 4, rejecting those δ-electrons which are seen in the silicon pad counter but are below the Cherenkov threshold of the CH_4 gas radiator. Its signal efficiency is expected to be $\sim$90%, similar to the efficiency obtained in the proton run of 1993. The corresponding rates are also given in Table 8.

Table 9 shows the sample size expected in 24 hours running time, based on the rates discussed above and using the DAQ in an almost saturated mode. Assuming an off-line pair-reconstruction efficiency of 10%, we estimate a total sample of 4000 pairs per running day. The set-up with the intermediate-level trigger and the faster DAQ system represents a performance (sample size/time) improved by of a factor 70 compared to our previous S-Pt measurement.

5 Manpower, Responsibilities and Schedule

5.1 Manpower

The CERES collaboration has a total manpower of about 30 physicists plus diploma students. Most of them are presently working full-time on the CERES experiment. Several technicians will be available for the next 9-10 months for the hardware tasks of the spectrometer upgrade. These will be carried out at the home institutes, taking advantage of their know-how and their infrastructure (mechanics and electronics).

5.2 Responsibilities

The responsibilities will be shared among the collaborating institutions. The Heidelberg University group will be in charge of the pad readout electronics of the pad chamber, of the modifications of the UV-2 readout electronics and of the DAQ. The Max-Planck-Institute group together with the BNL and the Milano groups will be in charge of the silicon drift chambers and their associated electronics. The Weizmann Institute group will care about the construction of the pad chamber and the target preparation. The Dubna group, which has recently joined the CERES collaboration, will be responsible for the detectors and electronics of the first-level trigger. We plan to construct at CERN some of the parts of the pad chamber.

5.3 Schedule

The hardware development tasks for the upgrade are quite demanding with respect to manpower and financial budget. However, we feel safe to complete successfully the implementation of the major components, based on the large experience accumulated by the collaboration in previous years.

The upgrades of the RICH-2 electronics and the construction of the pad chamber with its read-out electronics, do not require new developments, and can be achieved by some re-design of proven concepts.

Although similar remarks apply to parts of the silicon-detector system, we are facing a (small) risk of production failure; the planning of the production foresees alternatives therefore, should one or the other fail. The design of the lithography masks has been almost completed [51], and the adjustments to the industrial production process(es) have been incorporated. We foresee that tests can start in June. The novel integrated front-end electronics seems rather fail-safe, on grounds of the highly-reliable Tektronix process. The chips will become available for tests in April. The production of the masks and the detector wafers will be financed on a split-order basis between MPI for NA45, GSI Darmstadt and KVI Groningen for the WA98 experiment; that of the front-ends includes INFN as the main promoter.

5.4 Time Schedule

Installation at CERN is foreseen to start in summer, and it will be complete with all major components (possibly save the new DAQ) for the first running period af the Pb beam in November 1994.

5.5 Requests to CERN

We ask CERN to continue its support for the major items, as it did previously: cryogenics (liquid-He supply), power supplies for cold and warm coils, gas systems for the RICH radiators and the detectors (here we will be asking for an additional one for the pad chamber), cabling for the new detectors from the zone to the counting room. Some general technical help from the infrastructure is expected to continue (G10 machining for the pad chamber, etc.). For mounting and inspection of the silicon detectors, a laminar-flow box accessible in a clean room of modest quality is required; the provisions we used will not be acceptable any longer.

To fulfill the proposed research program we require 3 weeks of beam time in 1994 and 8 weeks of beam time for the years 1995 and 1996 each. This request is recommended by the statistics required, and it includes some margin for the effective on-time, as well as for the processes of learning how to use our instrument in the most efficient way.

In addition to the program presented in the main part of this document, we express interest to investigate, at some time in the future, electron pair production in the region of maximum baryon density, i.e. in the stopping regime. Depending on the learning processes from other experiments of the Pb-era, this may require to step down in beam energy, possibly to the lowest for which the SPS can supply a Pb-beam. It would allow us to study the consequences of chiral symmetry breaking inside the highly condensed nuclear medium in the best possible way.

For 1994, the draft schedule foresees 28 days of running for the H8 beam line in the North Area, divided between NA45 and NA52. We consider it quite important to run for the major fraction of this time.

Appendix: Simulation of the New Silicon Drift Chamber

Drift, Diffusion and Shaping

The primary ionization due to a passage of a m.i.p. creates a signal charge of Q_{in}= 25000 electrons, on average. It is taken as a stochastic variable with Landau density, as measured in experiment [2].

We use different values of the drift speed v_d in the range 6-10 mm/μs, and the diffusion constant D= $35 \cdot 10^{-4}$ mm^2/μs. In the previous operation we measured $v_d = 0.66$ cm/μs at the applied drift field of 500 V/cm. A drift field of 760 V/cm necessary to reach the highest value of $v_d = 1.0$ cm/μs used in the simulations will be still safe.

The time spread of the electron cloud as it arrives at the anodes is $\sigma_t^{in}(t) = \sqrt{2Dt/v_d^2}$, or, expressed in distance along the drift coordinate r $\sigma_r^{in}(r) = \sqrt{2D(r_A - r)/v_d}$. In the direction χ perpendicular to r, the spread is $\sigma_\chi^{in}(r) = \sqrt{2D(r_A - r)(r_A/r)/v_d}$.

At the output of the shaping amplifier the time spread of the charge signal is $\sigma_t^{out}(t) = \sqrt{(\sigma_t^{in})^2 + (\sigma^{elec})^2}$. The signal $Q^{out} = \delta(\sigma_t^{in})Q^{in}$ is attenuated by the ballistic deficit $\delta(\sigma_t^{in}) = Q^{out}(\sigma_t^{in}/Q^{out}(\sigma_t^{in} = 0)$ for which we have used a quadratic interpolation of the values specified above.

Sampling, Hit Reconstruction, Threshold and Noise

A pulse train is generated by a scanning algorithm whenever the threshold is surpassed in two adjacent time bins, and it is supplemented by a pre- and post-sample.

The fraction of the signal charge on a given channel (anode) is measured as the *peak value* of the *pulse train*, or deduced as the maximum amplitude of a (quasi-Gaussian) line shape fitted to it. A *hit* is comprised of the pulse trains on adjacent channels (anodes), and the signal charge is the sum of the peak values of the individual pulse trains. The larger the ratio σ_χ/a, a denoting the anode pitch, the more charge will be lost at the wings of its anode distribution because of the threshold.

The noise is added as a Gaussian random variable with standard deviation equal to the Equivalent Noise Charge *independently* to each time bin of the signal to be sampled. This is a simplistic approximation because the noise auto correlation does not die out within one time bin, i.e. the fluctuations of neighboring channels are partly correlated. It is, however, a conservative estimate since both the precision of the time measurement (by way of the centroid of the hit, or by any other algorithm to determine the hit location) as well as the precision of the amplitude measurement (derived from the peak value) is affected in the most pessimistic way.

Tables

Table 1

The RICH Detectors

		RICH-1	RICH-2
θ-range (2/3-rings)		6.4 – 17.4°	8.2 – 15.0°
η-range (2/3-rings)		1.88 – 2.81	2.03 – 2.64
$\Delta\eta$		0.93	0.61
$\langle\eta\rangle$		2.34	2.34
Window		CaF_2	Suprasil
Bandwidth	(eV)	6.1 – 8.5	6.1 – 7.35
N_0 expected	(cm^{-1})	157	75
Effective radiator length	(cm)	90	175
γ_{th} CH_4 50° 0.94 atm.		31.4	32.6
Number observed (resolved hits)		11.2	10.9
Number observed (sum amplitude)		13.7	12.9
Chromatic dispersion	(mrad)	1.13	0.53
Single-electron diffusion	(mrad)	0.37	0.11
Readout accuracy	(mrad)	0.33	0.25
Overall single-hit resolution	(mrad)	1.23	0.60
Ring-center resolution	(mrad)	0.64	0.32

Table 2

Materials within the acceptance

	z (cm)	X	X/X_0 (%)
Pb-Target 25 μm disks	± 1	eff. 12.5 μm	0.22
Air (15°, 0.946 atm)	0	11 cm	0.03
First silicon drift chamber	11	280 μm	0.27
Second silicon drift chamber	12.5	280 μm	0.27
Radiator-1 entrance window 2×50 μm mylar	12	100 μm	0.03
Radiator-1 gas CH_4 (50°, 0.946 atm)	12	90 cm	0.11
Mirror-1 (carbon fiber laminate)	100	1.1 mm	0.41
Intermediate volume He (50°, 0.946 atm)	100	48 cm	0.01
Radiator-2 entrance window 2×80 μm mylar	148	160 μm	0.06
Radiator-2 gas CH_4 (50°, 0.946 atm)	150	175 cm	0.22
Mirror-2 (glass)	325	6 mm	4.88

Table 3

The Doublet of Radial Silicon Drift Detectors

material		4" diam. n-type silicon, (280 ± 20) μm thick
	doping	neutron transmutation
	resistivity	2-5 kΩcm
geometry		SIDC-1,2 110, 125 mm from target
	sensitive region	$14.1 < r < 36.2$ mm in r, 2π in φ
	anode radius	$r_A = 42$ mm
	θ-acceptance[a]	$6.4 < \theta < 16.2^\circ$
	η-acceptance[a]	$2.88 > y > 1.95$, 0.93 units
electron drift	field geometry	defined by structure of 1° polygons
	field	750(600) V/cm
	drift velocity	10.0(8.0) mm/μs
	max drift time	2.8(3.5) μs
	max diffusion	$\sigma_t = 14.0(19.6)$ ns
granularity	in r	given by double-hit resolution
	in φ	360 anodes on outer rim, 733 μm pitch,
		rotation of 0.5° between SIDC-1,2
single-hit resolution	in r, local resolution	$\sigma_r < 15$ μm over entire acceptance
(laser test)	linearity	$\sigma_r^{lin} < 35$ μm
	in φ, local resolution	$\sigma_\varphi < 0.7$ mrad (doublet)
		$\sigma_\varphi = 2.3$ mrad (singlet)
double-hit resolution	in r	$\sigma_r < 260$ μm
	in φ	$\sigma_\varphi < 20$ mrad
occupancy[a]	mean	0.19 hits/mm^2 at $\langle\theta_0\rangle = 10.4^\circ$
	worst case	0.34 hits/mm^2 at at $\theta_0 = 8^\circ$

[a] for center of target

Table 4

Pad Chamber – Properties and Performances

Inner radius	450 mm
Outer radius	890 mm
Distance from target	3300 mm
Angular range	$7.8 < \theta < 15.1°$
Rapidity coverage	$2.0 < \eta < 2.7$
Pad size	6×6 mm^2
Number of pads	50 000
Single hit resolution	0.6 mm $\hat{=}$ 0.18 mrad

Table 5

Electron Pairs

Rates and Sample Sizes

Target disks 8×25 μm Pb	200 μm
λ/λ_I ($\lambda_I = 42.8$ mm)	0.5%
Beam particles/burst (4 s/19 s)	$2.5 \cdot 10^6$
Interactions/burst	12 000
First-level triggers/burst ($\mathrm{d}n/\mathrm{d}y > 100$)	5 000
DAQ lifetime (2 ms)	29%
Events to tape/burst	1 450
$\langle P_{e^+e^-} \rangle$/event	$3.8 \cdot 10^{-4}$
e^+e^--pair sample (30 days)	70 000
$\langle \epsilon_{rec} \rangle = 0.28$	20 000

Table 6

Electron Pairs

Statistical Sensitivity

	Peripheral Pb-Pb dn/dy = 160 $\langle \epsilon_{rec} \rangle = 0.37$				Central Pb-Pb dn/dy = 500 $\langle \epsilon_{rec} \rangle = 0.16$			
Mass range MeV/c^2	e^+e^- pairs	S/B	'effective' sample	sensitivity [%]	e^+e^- pairs	S/B	'effective' sample	sensitivity [%]
200-650	6800	1.5	4000	5	3100	0.3	700	11
720-840	2800	7	2400	6	1250	1.4	700	11
940-1100	550	4	400	14	250	0.8	100	28
> 200	11000	2	6700	4	5000	0.4	14000	8

Table 7

Direct Photons

Rates and Sample Sizes

Target disks 8×25 μm Pb	200 μm	
λ/λ_I ($\lambda_I = 42.8$ mm)	0.5%	
Beam particles/burst (4 s/19 s)	$2.5 \cdot 10^6$	
Interactions/burst	12 000	
First-level triggers/burst (dn/d$y > 100$)	5 000	
DAQ lifetime (2 ms)	29%	
Events to tape/burst	1 450	
Converter	1%	3%
Conversions/event	1.3	3.9
$p_\perp > 60$ MeV/c (track)	0.2	0.6
sample size (2 days each)	$2.8 \cdot 10^6$	$8 \cdot 10^6$
$\langle \epsilon_{rec} \rangle = 0.50$	$1.4 \cdot 10^6$	$4 \cdot 10^6$

Table 8

Rates of δ-Electrons and QED Pairs

(probabilities per beam particle)

Sources of δ-electrons	S-Pt 50 μm	Pb-Pt 10 μm	Pb-Pt with ILT 10 μm
Target	0.105	0.54	0.29
Helium	0.016	0.082	—
Beam pipe window (50 μm mylar)	0.02	0.102	0.054
Total δ/beam	0.14	0.72	0.34
Trigger probability/beam ($\geq$2 δ)	0.009	0.16	0.048
QED pairs/trigger	$1.0 \cdot 10^{-3}$	$1.44 \cdot 10^{-3}$	$4.8 \cdot 10^{-3}$

Table 9

QED Pair Sample Size

Target Pt	10 μm
Beam particles/burst	10^6
First-level triggers/burst	160 000
ILT lifetime (35 μs)	0.54
ILT reduction	3
DAQ lifetime (2 ms)	0.064
Events to tape/burst	1850
Pair sample size (24 h)	40 000
$\langle \varepsilon_{pair} \rangle = 10\%$	4000

Figure Captions

Fig. 1 Layout of the upgraded spectrometer

Fig. 2 Arrangement of the doublet of 4" silicon drift detectors. The spectrometer acceptance for the short segmented target projects onto the radial range between r_{min}= 15 mm and r_{max}= 36 mm and is covered by a wide margin. The charge collecting anode pads at r_A are outside the acceptance to allow for additional drift.

Fig. 3 The rms spread of the signal charge in radial direction (left), in the perpendicular direction, here in terms of the anode pitch a (center), and the ballistic deficit δ (right) vs. radial hit position for three different drift velocities 6, 8, 10 mm/μs, labeled 1, 2, 3, respectively.

Fig. 4 Detection efficiency η vs. radial hit position for three different drift velocities. Threshold is set at 3σ of noise (left) and at 6σ (right).

Fig. 5 Average single-hit φ-resolution in terms of σ/a vs. hit position in r (left) and frequency of deviations $\Delta\varphi$ within the acceptance. Top row for the doublet, bottom row for a single silicon drift detector. Threshold is set at 3σ of noise.

Fig. 6 Layout of the new pad chamber

Fig. 7 Layout of the scintillator array of the multiplicity trigger

Fig. 8 Schematic block diagram of the data acquisition system

Fig. 9 Vertex resolution in the plane perpendicular to the beam axis (left) and along the beam direction (right), using the two silicon drift detectors. The rms values are $\sigma_{x,y} = 50$ μm, $\sigma_z = 100$ μm.

Fig. 10 Correlation of energies deposited in the two silicon drift detectors for single (left) and double (right) tracks, with the 2-dimensional cuts A and B, respectively.

Fig. 11 Resulting single track efficiency and close-pair rejection as a function of the (common) cut indicated in Fig. 10. To the right, an enlargement is shown.

Fig. 12 Expected invariant mass spectrum of the hadronic decay cocktail (histogram) and combinatorial background after rejection, for a multiplicity $\mathrm{d}n/\mathrm{d}y = 160$ (full line). The situation for the 1992 S-Au data of CERES is shown for comparison (broken line).

Fig. 13 Expected invariant mass spectrum of the hadronic decay cocktail and combinatorial background after rejection for a multiplicity $\mathrm{d}n/\mathrm{d}y = 500$.

Fig. 14 Efficiency and signal-to-background vs. multiplicity from the Monte Carlo simulation.

Fig. 15 Momentum resolution of the old and proposed new set-up of the spectrometer

Fig. 16 Mass resolution of the old and proposed new set-up of the spectrometer

Fig. 17 Multiplicity distribution for Pb-Pb collisions at central rapidity ($2.4 < y < 3.4$) generated by VENUS 4.10.

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