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ADDENDUM to PROPOSAL SPSLC/P280

# STUDY OF ELECTRON PAIR AND PHOTON PRODUCTION IN Pb-Au COLLISIONS AT THE CERN SPS

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**Abstract**

We propose to extend the physics program of CERES/NA45 to the year 2000. A major effort will be undertaken to (i) install a TPC for momentum analysis to improve the mass resolution to $\delta m/m \approx 1\%$ at the $\rho/\omega$ resonance and (ii) significantly increase the rate capability of the experiment and update our second-level trigger scheme. The motivation for this effort stems from the recent observation, by the CERES and HELIOS/3 collaborations, of a new source of low-mass dilepton pairs. Its physics origin may be the onset of the restoration of chiral symmetry in hot and dense matter. With pair samples dramatically superior in size and quality to those previously collected, a systematic study of dependencies of production of continuum pairs and the vector mesons on multiplicity, transverse momentum and baryon density should enable us to scrutinize this exciting physics perspective.

# 1 Introduction

CERES is an experiment dedicated to the measurement of low-mass $e^+e^-$ pairs emitted in p and ion induced collisions at SPS energies, covering the mid-rapidity region and a very broad range of $p_t$ [1, 2, 3]. For that purpose, CERES has developed a spectrometer whose essential components are two RICH detectors, located in front of and behind a short superconducting solenoid, with external tracking provided by two silicon radial drift detectors and a pad chamber. In a systematic approach, CERES has measured electron pairs emitted in p-Be, p-Au and S-Au collisions and has just started the extension of its programme with the Pb beam. The first production run took place in the fall of 1995.

In this Addendum, we report on the present status of the CERES experiment and its physics program and outline our plans for the future. We start with a brief reminder of the main result with the S beam and its theoretical implications, give an account of the 95 run with the Pb beam, present very preliminary results of that run, and reiterate our goals for the near future with the Pb beam. We finally present an upgrade plan of the CERES set-up. The upgrade will be principally in two areas: first we plan to upgrade the data acquisition and trigger system to improve the rate capability of the experiment. Second, we propose to add a TPC downstream of the present double RICH spectrometer. The main purpose of the TPC addition is to dramatically improve the mass resolution thereby allowing, in addition to the continuum measurement, precision spectroscopy of the vector meson resonances $\rho$, $\omega$, and $\phi$. We expect the upgrades to be ready within two years and then wish to continue our Pb programme by new measurements at the full energy of 160 GeV/nucleon and by a measurement at the lowest energy attainable at the SPS, at about 40 GeV/nucleon, where the effect of baryon density on the vector meson masses is expected to be largest.

# 2 Results and Physics Perspectives

## 2.1 The S-Au Results and Present Understanding

CERES has observed a significant excess of low-mass electron pairs in S-Au collisions at 200 GeV/nucleon over the known hadronic sources (Dalitz decays of the $\pi^o$, $\eta$, $\eta$', $\omega$, and decay of the resonances $\rho$, $\omega$, and $\phi$) estimated by scaling from pp collisions [4]. This is illustrated in Fig. 1 where the CERES results are compared to the 'hadronic cocktail' of these sources (hatched histogram).

The characteristic features of the excess –its onset at a mass $m_{e^+e^-} \sim 2m_\pi$, its extension to the region around the $\rho$ meson and the indications, when combined with data from the HELIOS/3 collaboration, of a quadratic dependence with multiplicity– suggest that the excess is due to (enhanced) $\pi^+\pi^-$ annihilation into $e^+e^-$. This would be the first indication for thermal radiation emitted from the dense hadronic matter formed in relativistic ion collisions.

This excess and a corresponding one (but of smaller magnitude) observed by HELIOS/3 in the low-mass dimuon spectrum [5, 6] have triggered intense theoretical activities [7-17]. The pion annihilation channel has been included in most of the calculations, on top of the hadronic sources listed above. The collision dynamics has been treated in a variety of approaches, including transport models which explicitly propagate baryons and mesons assuming the formation of a hadronic system in thermal equilibrium [7] or without equilibrium [8, 9, 10], a standard hydrodynamical model invoking the formation of a thermalized QGP [11] and a model based on a thermalized hadronic gas [12].

Some of those calculations are shown in Fig. 1. A striking feature is that predictions from models not incorporating new physics (such as in-medium mass shifts) lead to similar results despite their different assumptions on collision dynamics, indicating that the results are not very sensitive to the details of the space-time evolution of the collision. The observed dilepton excess near the $\rho/\omega$ mass is well reproduced, a direct consequence of the inclusion of the $\pi^+\pi^-$ annihilation channel which is dominated by the pole of the pion form factor at the $\rho$ mass. However, all calculations fail to reproduce the data in the mass region $0.2 < m_{e^+e^-} < 0.5$ GeV/c$^2$.

Data in this mass region have been quantitatively explained by taking into consideration a decrease of meson masses –in particular of the $\rho$ meson– in the hot and dense fireball as a precursor of chiral symmetry restoration [18, 19]. With this approach, excellent agreement with the CERES data has been achieved by Li et al. [7] as shown in Fig. 2. The same calculation also reproduces the low-mass enhancement found in the HELIOS-3 dimuon data. Similar observations have been reported by Cassing et al. [8].

In conclusion, in spite of numerous theoretical efforts for alternative explanations, the S+Au data are sofar only reproduced quantitatively if in-medium modifications of the vector mesons are incorporated into the calculations. However, the uncertainties in the data are too large to convincingly rule out other more conventionel explanations. This makes it imperative to continue the experimental studies with heavy beams with the particular goals to reduce the systematic errors of the data and to provide the dependence of the $e^+e^-$ yield on other variables of the system such as multiplicity.

## 2.2 Preliminary Pb-Au Results

The first run with the Pb beam took place in November 1995. The whole upgrade programme as outlined in our proposal for Pb beams [2] was implemented in time for this run. In particular, we installed two radial silicon drift detectors (instead of one in the original CERES set-up) upstream of RICH-1 and a large MWPC with pad read-out behind the spectrometer. These detectors allow to track the electrons in front of and behind the double RICH spectrometer, practically eliminating the problem of accidental tracks even in the highest background events of central Pb-Au collisions. A new data acquisition system, about a factor of four faster than the one used in the '92 run with S beam, was successfully operated.

Taking into account time for start-up of the experiment and commissioning of the new DAQ system and the pad chamber, and mostly because of an unusual sequence of critical days, data taking in 1995 was limited to 9 full days of production with an about

80 % efficiency. During this relatively short run, a total of 17 million events of Pb-Au collisions were recorded on tape, with a charged particle rapidity density $dn_{ch}/d\eta > 100$. This event selection corresponds to the most central 40 % of the geometric cross section. The analysis of these data is not yet completed. Preliminary results, however, confirm that an excess of low-mass electron pairs (compared to the scaled 'hadronic cocktail') is also present in the Pb-Au system. The continuum signal $-e^+e^-$ pairs with mass m > 200 MeV/c$^2$– extracted so far (based on an analysis of 10 million events) is about 650 pairs with a signal to background ratio of 1/15. The corresponding invariant mass spectrum is shown in Fig. 3. The enhancement is similar in shape and magnitude to that observed in the S+Au case. Since the data do cover a large range of centralities, the centrality dependence of the effect can be studied. First results indicate a scaling of the signal about quadratic in charged particle multiplicity.

# 3 Plans for Further Running with the CERES Apparatus

The exciting possibility that first hints of chiral symmetry restoration might have been observed in the S and Pb data needs to be quantitatively explored. Our plans therefore call to:

1. Substantially increase the statistics of the dielectron continuum sample.
2. Improve the resolution of the apparatus such that possible mass shifts or changes in width of the vector mesons $\rho$, $\omega$, and $\phi$ can be observed directly along with a simultaneous measurement of the continuum.

## 3.1 Running in 1996/1997

The main goal for this running period is to achieve the luminosity necessary to quantify accurately the dilepton enhancement and to study its properties in more detail which could not be done from the S-Au sample; the multiplicity dependence and $p_\perp$-distribution of the new source are two key questions which can be answered soon. It is our strong wish to complete this goal with sufficient running time in the 1996 run and to only run again with the upgraded CERES experiment in 1998.

The actual performance of the spectrometer in 1995 and the data sample expected after further improvements of the offline analysis are summarized in the first column of Table 1. The preliminary analysis of 1995 data presented above was based on tools developed for the S-Au data analysis and did not yet exploit all possibilities of the apparatus. In particular, a consequent use of the new tracking detectors in Cherenkov-ring reconstruction, as outlined in our proposal [2], will increase the pair reconstruction efficiency by a factor 2-3 to $\sim 20\%$ and at the same time one hopes to obtain a factor of 2 improvement in the ratio of signal to combinatorial background from photon conversions and $\pi^0$ Dalitz-decays. Although the DAQ operated close to its design performance only 50% of the anticipated event rate could be reached in 1995. The reason was an unexpected large sensitivity of RICH-1 to $\delta$-electrons originating from random beam pile-up within the 5 $\mu$s integration time of the readout electronics. In order to avoid pile-up the beam intensity was limited to $5{\cdot}10^5$/burst. At that beam rate about 25% of the events taken had to be removed in the offline analysis because a second beam particle came too close after a valid event. We are currently investigating how to overcome this limitation by suppressing $\delta$-electron production in the target area and within the first radiator as much as possible. But we also request that every effort be made to obtain a flat spill structure. Independently, the external tracking may enable us to analyse most of the pile-up events without significant efficiency loss. The numbers quoted in Table 1 for 1996 are based on an upper limit of 100 % of usable beam particles and the same, relatively low, beam intensity as in the 1995 run. To reach the desired luminosity under these circumstances, we are planning to implement the first step of the revised DAQ scheme, discussed in detail below as part of the upgrade suggested in this addendum, already in 1996. The rate capability will be increased by introducing a pipeline DAQ scheme which decouples the rather slow data storage via VME from the much faster front-end readout. In the first step, the dead time per event will be reduced from presently 3.5 ms to $\sim 300\mu s$. The full upgrade of the DAQ including a higher-level trigger is planned for 1998.

The steps foreseen for this running period will double the rate capability of the spectrometer. Based on a necessary set-up time of the experiment of about 5-6 days and an efficiency of 80% during production a 6-week run will give the necessary increase of the luminosity by about one order of magnitude. A detailed break-down of this estimate is given in the second column of Table 1.

| | 1995 | 1996 |
|---|---|---|
| beam particles/burst | $5 \cdot 10^5$ | $5 \cdot 10^5$ |
| 80% on target | $4 \cdot 10^5$ | $4 \cdot 10^5$ |
| 2.5 $\mu$s before protection | $3.2 \cdot 10^5$ | – |
| interactions/burst ($\lambda/\lambda_I$=0.83%) | 2600 | 3200 |
| first level trigger (38% of $\sigma_{inel}$) | 1000 | 1250 |
| dead-time per event | 3.5 ms | 300 $\mu$s |
| stored by DAQ | 530 | 1150 |
| pair reconstruction efficiency | .2 | .2 |
| fraction left after rejection of beam pile-up | .75 | assume 1.0 |
| $e^+e^-$-pairs from expected hadron decays/day ($m > 200$ MeV/c$^2$) | 130 | 380 |
| scaling hadron decays from pp: | | |
| pair sample 9 days (80% run efficiency) | 950 | – |
| pair sample 30 days (80% run efficiency) | – | 9000 |
| based on an enhancement factor of 3 in PbPb | | |
| pair sample 9 days (80% run efficiency) | 2800 | – |
| pair sample 30 days (80% run efficiency) | – | 27000 |

Table 1: Sample size expected for 1996 running based on the experience of the 1995 Pb-run.

## 3.2 Plans for the Period 1998-2000

In our memorandum for the 1995 Cogne meeting of the SPSLC [3], we presented our first ideas concerning the CERES plans beyond 1997. These ideas are now better defined and more focussed towards answering specific questions raised by our results and the recent theoretical implications as discussed previously. We were then considering the addition of a high-resolution electromagnetic calorimeter to improve on the mass resolution. This, however, would be a very costly solution. Instead, we are now proposing the addition of a TPC and a magnet behind the spectrometer. This option, which is much more cost effective and faster to implement, is described in the following section. At the same time we are taking steps to increase the data taking speed and to implement an $e^+e^-$ trigger, also described in the following section.

# 4 Proposed Upgrade of the CERES Experiment

## 4.1 Physics Motivation for the Upgrade

### 4.1.1 Running at Full SPS Energy

To make a qualitatively new step, the CERES collaboration proposes to improve the mass resolution of the spectrometer with the goal to achieve $\delta m/m = 1\%$ at $m = 1$ GeV/c$^2$. With this resolution which is of the order of the natural line width of the $\omega$ meson it will be possible to perform precision spectroscopy of the behavior of the $\rho$, $\omega$, and $\phi$ mesons in addition to the continuum measurement. In particular, the lifetimes of the $\rho$, $\omega$ and $\phi$ mesons are 1, 23, and 44 fm/c, respectively. This implies that essentially all $\rho$ mesons will decay inside the fireball, while the $\omega$ and $\phi$ mesons will decay partly inside, partly outside. With the upgraded CERES apparatus we therefore seek to obtain direct evidence of chiral symmetry restoration by determining experimentally whether or not the observed enhancement in the continuum is due to a modification of the vector mesons in the hot and dense medium. With the simultaneously planned upgrade in rate capability it should be possible to directly measure the yield for all three vector mesons $\rho, \omega$, and $\phi$ including their possible suppression as well as any possible changes in their properties. The observation of mass shifts or increased widths for the $\rho, \omega$, and $\phi$ mesons will provide compelling evidence for the scenarios invoking effects due to the onset of restoration of chiral symmetry.

### 4.1.2 Running at Lower Energy

To test whether the observed enhanced dielectron continuum is due to the (at least partial) restoration of chiral symmetry and its concomitant reduction of the masses of the vector mesons $\rho, \omega$, and $\phi$ in the hot and dense medium formed in the collision we propose to run the (upgraded) CERES experiment at lower beam energy (about 40 GeV/nucleon for Pb). The arguments for this are as follows:

1. The transition from normal hadronic matter to a state in which chiral symmetry is restored is influenced much more strongly [1] by baryon density than by temperature (or pion density) [21]. For example, the temperature (T) and baryon density ($\rho_B$) dependence of the quark condensate and with it the vector meson masses is predicted [22] to be very different:

$$\frac{m^*}{m} = [1 - (\frac{T}{T_c})^2]^{(1/3)}[1 - 0.2\frac{\rho_B}{\rho_0}]. \quad (1)$$

   Although there is still debate about the detailed form of this mass dependence, there is a consensus about its qualitative features. In view of this it would be very important to repeat the measurement of the dilepton continuum and of the vector meson resonance yields at a beam energy where the ratio of maximum baryon density to maximum temperature (or energy density) is significantly different from that at full

[1]We note that these considerations assume that the transition temperature $T_c$ is not actually reached or crossed in these experiments. If the system spends a considerable time at $T_c$, one can expect even more dramatic effects.

SPS energy. Lowering the beam energy from CERN energies will *decrease* the maximum energy density along with the corresponding pion density and temperature. Simultaneously, however, the baryon density will *increase*. This is supported by comparison of experimental results from the AGS and SPS heavy ion program, as well as by theoretical studies. As a first observation we note that the pion/nucleon ratio increases from about 1:1 at AGS energies to about 6:1 at SPS energies. Cascade codes such as RQMD [23] or codes based on hadron string dynamics [8] which generally account well for the global features of particle production at both energies can be used to predict the beam energy dependence of the maximum baryon density. In Fig. 4 we show the result of such a calculation [24].

Inspection of this figure demonstrates that, near 30 GeV/nucleon, the number of baryons $N_B$ near midrapidity and in a spatial region of the fireball with $\rho_B > 3\rho_0$ is maximum. At this beam energy, the baryon density, integrated over the time of the high-density phase of the collision, is at least a factor of 2 higher than that at 160 GeV/nucleon. Furthermore, results from the Frankfurt group [25] show that, at 30 GeV/nucleon, the lifetime of this high-density state is of the order of 4 fm/c, *i.e.* significantly longer than the lifetime of a (free) $\rho$ meson. At higher energies both baryon densities and lifetimes decrease. Coupled with the production rates for the vector mesons, which still increase with beam energy, this determines the choice of an energy near 40 GeV/nucleon.

2. Theoretical studies of the equation of state of hot baryonic matter and of its transition to quark-gluon matter indicate that the 'softest' point, *i.e.* the point where the ratio of pressure P to energy density $\epsilon$ is minimal, is reached in a heavy ion collision at an energy somewhere near 30 GeV/nucleon [26]. Hydrodynamic calculations [26] imply that at this softest point the pressure gradients are lowest, leading in turn to large system life times. We note that this effect which is not incorportated into the cascade codes lends further support to our choice of beam energy.

In summary, the key argument for a run at low energy is that is will provide a second point at clearly different values of temperature (energy density) and baryon density. Since both parameters influence dilepton production significantly and in different ways comparison of data from the low and high energy run will enable us to perform a stringent test of models and the way chiral symmetry is restored as function of these two parameters.

It should also be recognized that the search for in-medium mass changes of vector mesons is pursued now in several laboratories world-wide. At the CEBAF facility, there is an approved experiment to study, with high resolution, the photoproduction of vector mesons off nuclei [27] at energies of a few GeV. At GSI, a dedicated experiment is presently being built to measure, with a high acceptance, high resolution spectrometer, the production of low mass $e^+e^-$ pairs produced in nucleus-nucleus collisions, as well as in $\pi$ nucleus and p nucleus collisions [28]. Both experiments complement the present proposal, and their existence indicates the importance of questions related to chiral symmetry restoration and in-medium mass changes of vector mesons.

## 4.2 Proposed Upgrade of the Spectrometer

### 4.2.1 Outline of TPC Project

The resolution in opening angle of the $e^+e^-$ pair obtainable by measurement in the Si drift detectors is already good enough to achieve the $\delta m/m = 1$ % goal (see Fig. 12 below). Consequently, the mass resolution presently obtainable in the CERES spectrometer is dominated by the accuracy of the momentum measurement. The momentum resolution, in turn, is limited by the relatively small deflection in the magnetic field after RICH 1 compared to the multiple scattering (in particular in the mirror of RICH 1). In order to achieve the significant improvement necessary we propose to separate the electron identification in the CERES detector from the momentum measurement by adding, behind the second RICH detector, a set of coils and a high resolution TPC. This is schematically described in Fig. 5.

The upgrade comprises a cylindrical TPC with radial electric drift field, similar to that recently proposed for the external TPC's of the STAR detector at RHIC, and a set of coils with currents running in opposite direction to provide the (dominantly radial) magnetic field for particle deflection. The whole new setup is located at a distance of 3.5 m to 5 m downstream of the target. The resulting field lines at and near the position of the proposed TPC are shown in Fig. 6.

In Fig. 6 it is also shown (dashed-dotted lines) that the acceptance of the TPC covers the polar angular range $8° < \theta < 15°$ with full coverage in azimuthal angle, implying that the acceptance of the original CERES setup remains unchanged by the addition of the TPC, whose active volume extends from 3.5 - 5 m downstream of the target.

As can be seen from inspection of Fig. 7, this field configuration produces a deflection predominantly in azimuth $\phi$. Precise measurement of this $\phi$ deflection in the TPC yields the determination of the momentum of the particle. However, the track measurement in the $\phi$ direction is influenced by the Lorentz angle of the drifting electron cloud. Resulting trajectories are shown in Fig. 8 at different z-positions. The relatively modest deflection from straight lines in the radial direction implies that high precision track measurement in the $\phi$ coordinate is possible.

The maximum drift distance obtained from the Lorentz angle and the inner and outer radius of the TPC is 90 cm. As TPC gas we propose to use pure ethane ($C_2H_6$) which has a nearly constant drift velocity of $v_{drift} \sim 5\,cm/\mu s$ over a rather large range of electric fields. The corresponding maximum drift time is 18 $\mu s$, implying that the TPC can be run at about 30,000 interactions per second without significant loss of events due to multiple interactions, a fact which is important for the luminosity upgrade described elsewhere in this document. The relatively large drift velocity also leads to rather small diffusion broadening of the electron cloud in transverse direction of $\sigma_t \sim 1.8\,mm$ for the maximum drift distance. In addition, the divergence of the electric field lines (see Fig. 9) leads to further broadening (for the maximum drift distance) of $\sigma_t \sim 3.0\,mm$. The broadening of the electron cloud by diffusion along the drift direction is only half as large ($\sigma_l \sim 1.7\,mm$).

For the accurate determination of the position of the charge cloud we plan to measure the charge induced on cathode pads distributed at the outer surface of the TPC. The resolution in $\phi$ direction (see above) which is relevant for the momentum measurement depends mainly on three factors:

1. The amount of primary ionization (number of primary electrons).
2. The position resolution obtainable with pad read-out, which is typically, under realistic experimental conditions, limited to about 2% of the pad size [29].
3. The transverse diffusion of the electron cloud, varying with the drift distance.

All three factors were studied in detail and the results are shown in Fig. 10. From this figure one concludes that it is possible to achieve a resolution of $\sigma_\phi \sim 270\,\mu m$ with pads of size 4 cm by 1 cm.

To achieve the goal of a 1% mass resolution at 1 GeV it is necessary to obtain a momentum resolution of about 1-2 % in the momentum range 1-2 GeV/c, where the distribution of lepton momenta from the low mass continuum and from the decay of the vector mesons $\rho, \omega$, and $\phi$ peaks with the acceptance of the CERES spectrometer. The momentum resolution is determined mainly by the following factors:

1. the resolution in azimuthal direction ($\sigma_\phi \sim 270\,\mu m$);
2. the deflection in the magnetic field of the particle track in azimuthal direction;
3. the number of position measurements in $z$ direction;
4. the accuracy of the position measurement in radial direction, determined in the radial TPC by the number of time slices in the digitalisation of the track.

In the simulation whose results are exhibited in Fig. 11 we have optimised all (mutually dependent) parameters such that the 1% mass resolution can be achieved over the full acceptance of the TPC with a realistic technical effort and within reasonable financial boundaries. To achieve this momentum resolution we have assumed 14 measurements in $z$ direction. With the above discussed pad size this implies 10,000 pads, which need to be digitised in about 300 time slices each.

The 14 measurements in $z$ direction can also be used to determine the specific energy loss of the particles via the magnitude of the charge induced on the pads. Extrapolating from results obtained with similar TPC's (see, *e.g.* results from the NA49 TPC [30]) one obtains a resolution of $\sigma(dE/dx)/dE/dx \approx 8\%$. This will allow additional electron identification at about the $4\sigma$ level in the momentum range $2 < p < 3$ GeV/c, leading to a further improvement of the electron/pion separation in the CERES detector.

In Fig. 12 we have calculated the resulting mass resolution for lepton pairs within the CERES acceptance for Pb+Au collisions at 158 GeV/nucleon. The hadronic cocktail used to generate the components of the mass spectrum shown in Fig. 12 was taken from [4]. In the upper two panels we have not included the natural line widths of the $\omega$ and $\phi$ meson to explicitely exhibit the influence of the angular and momentum resolution on the mass measurement. Inspection of Fig. 12 makes it clear that the proposed upgrade of the CERES spectrometer will allow measurements of the mass spectrum which are sensitive to details of the order of the natural line width of the $\omega$ meson.

The installation of the TPC will not change the current operation of the CERES spectrometer. However, the TPC will generate a data volume which will roughly double the volume presently read out per event in the CERES experiment. For 14 measurements along $z$ and 750 pads per $z$ slice the TPC will have about 10,000 pads. From the above mentioned drift velocity of 5 cm/$\mu s$ and the maximum drift distance of 90 cm we obtain a maximum drift time of 18 $\mu s$. To determine the tracks well in radial direction one has to distribute the charge measurement over at least two time slices. To match to the diffusion of about 1cm (corresponding to 200 ns) along the track we propose to use 70 ns wide time slices, corresponding to 256 time slices for a drift length of 90 cm. The total number of read out pixels of the TPC is therefore $2.6 \cdot 10^6$. For the amplitude measurement we need an 8 bit ADC to cover the necessary dynamical range of 8:1 with a signal/noise ratio of about 20:1. The necessary electronics is similar to that currently being developed at LBNL for the STAR TPC. To achieve an (ultimately desired) event rate of about 2000/s one needs a conversion time of about 300 $\mu s$ per channel, which would require to clock the LBNL chip at 150 MHz and to make any effort to reduce the settling time between conversions. Prior to zero suppression the data volume from the TPC is 2.6 MB/event. With the expected occupancy of about 300 charged particles in the TPC, we expect a reduction of a factor of 50 after zero suppression. Taking the present NA49 experience as guideline for the expected noise contribution the addition of the TPC will about equal to the present data volume from the CERES apparatus and would bring the total event size to 100 - 150 kByte.

The realisation of the upgrade project will be carried out by the CERES collaboration. A corresponding request for funds has been submitted to the German BMBF and is currently under consideration. Here we list briefly the different components and estimated costs:

**Magnets:** The magnetic field will be generated with Cu coils built in collaboration with the Dubna group under Y. Panebrattsev. First design calculations have been completed. The necessary current densities imply that building the coils including the necessary mechanical support should be rather straightforward. The main cost of the coils is in the about 30 tons of Cu. Including cost sharing with the Dubna group we estimate total magnet costs of about DM 300,000. In addition, there will be costs of about DM 200,000 for the power supply. Such a power supply might be available at CERN and we are requesting CERN assistance in procuring this power supply.

**Mechanical Construction of the TPC Gas Container and Field Cage:**
The TPC gas container will consist of two concentric cylinders made from Stesalit, and connected with thin windows. A similar construction was used for the Helitron gas detector of the FOPI experiment at GSI [31]. The voltage divider for the field cage will be set up along the windows. The detectors with the field and multiplication wires and pad planes will be connected to the outer Stesalit cylinder. Design and construction should take place within 1 year from now. Following the cost of the Helitron we estimate a total cost of about DM 100,000.

**Pad Detectors:** Prototypes for the pad detectors are currently being developed and should be fully tested by summer 1997. This test includes also the electronics chain. For this purpose we plan to use existing chips from the STAR TPC electronics. Cost for each of the necessary 24 pad detectors including frame, pad plane, wire grids, and HV connections is estimated to be about DM 4,000. This estimate is based on experience with similar pad detectors developed within AGS experiment E877. Final construction of the pad detectors should be complete by the end of 1997.

**TPC Read-out Electronics:**
We plan to use as much as possible the electronic chips (preamp, shaping, SCA, ADC) developed for the STAR TPC [32]. After discussions with electronics experts at LBNL we assume that the necessary changes, including increase of the clock frequency (to a maximum of 150 MHz), reduction of the number of time slices to 256, and change of the digitalisation accuracy to 8 bits, will be achievable without change of the chip (in fact, a joint test is planned later this months a LBNL). Taking advantage of the currently running chip production for STAR we will be able to purchase 10,000 (tested) channels for $ 18 per channel from LBNL over the period of the next year. The receiver boards as well as the connection of the TPC electronics to the CERES data acquisition system will be developed by the CERES DAQ group within the coming 18 months. Since the largest cost item for the electronics will be in STAR TPC chip, we estimate total channel costs at DM 50 (in line with NA49 actual cost and with envisioned cost for STAR), implying that the TPC read-out cost will be DM 500,000 overall.

### 4.2.2 Time and Cost Estimate for the TPC Upgrade

The total costs of the TPC upgrade are as follows:

| Item | | Costs |
|---|---|---|
| Magnet Coils and Frame | DM | 300,000.- |
| Power Supply[a] | DM | 200,000.- |
| TPC Gas Container and Field Cage | DM | 100,000.- |
| Pad Detectors | DM | 96,000.- |
| Read-out Electronics | DM | 500,000.- |
| Gas System | DM | 80.000.- |
| High Voltage System | DM | 20,000.- |
| Laser Calibration | DM | 20,000.- |
| Mechanical Support for the TPC | DM | 30,000.- |
| Total | DM | 1,346,000.- |

[a] requested from CERN

The time scale for the upgrade is such that commisioning should start in 1998 both with proton and with Pb beams and the full production will start as soon as this is completed. Our goal is to achieve this during the 1998 heavy ion run.

## 4.3 Improvement in the Rate Capability of the Experiment

As will become clear from the rate estimates presented below the full benefit of the improved momentum resultion of the experiment can be reaped only of this goes hand in hand with a corresponding increase in luminosity, i.e. an increased rate capability of the experiment. We intend to achieve this by a combination of an increase in speed of readout/DA system and a selective dielectron trigger.

### 4.3.1 Readout Electronics and Data Acquisition

In the present readout concept, the rate is limited by the storage of the global event information, which is performed by several CPU's in VME. The introduction of a pipeline module in the analysis chain offers a substantial increase in the event rate. This decouples the local, hardware-controlled frontend readout of the detector components and trigger from the global event storage by the CPU's in VME. In this concept, the rate is not limited by the storage of the global event information but instead by the shorter readout time of the detector components. After complete readout of all detector components the multiplicity trigger is reactivated and the next event can be recorded without waiting for the global event storage. The data of each detector component are temporarily stored in a pipeline module which operates as an interface between the local hardware eventbuilders and the data acquisition. Events rejected by a higher-level trigger (see below) are removed from the pipeline and not transferred to the global data acquisition. The pipeline storage depth be designed to be arbitrarily expandable by a modular concept; the required depth is determined by the global data acquisition storage time and the higher-level trigger latency.

In the present configuration, the Silicon drift detector readout is the slowest component with a readout time of about 1.2 ms/event. This will be reduced by a factor of 4 by a redesign of the scanner system that reads the DL300 FADC's. The new design comprises, apart from new scanner modules with a readout speed increased by a factor of 2 - 3, a doubling of the number of scanners (two per crate) and a new DL300 backplane accommodating these changes, and a new hit compression algorithm with $\sim$30%

reduction.

The global data acquisition is based on several VME CPU's which read the data arriving in VME storage modules, one for each detector component, in VME D64 block transfer mode. The rate is limited by the capacity of the VME bus, which is about 60 Mbyte/s in this mode. The pipeline concept allows to fully exploit this rate during burst without operating the spectrometer with a high dead time (which is undesirable with respect to detector performance). This result in a total data volume of about 240 Mbyte per 4 s burst, which will be written to tape between bursts (14 s). According to present estimates this corresponds to 1500 - 200 events per burst. The increased volume requires upgrading the present two VME CPU's to 3 CPU's, each with 128 Mbyte memory. A recently available new generation of tape drives (DLT 'digital linear tape') offers 1.5 Mbyte/s data rate and 20 Gbyte capacity, this will allow to store the foreseen data volume on 12 DLT drives, 4 per CPU.

### 4.3.2 Trigger

The readout speed of the frontend of about 300 $\mu$s per event cannot be fully exploited without a higher-level trigger. With a beam intensity of $2 \cdot 10^6$ (assuming that the pile-up problem of $\delta$–electrons in the UV detectors is solved), about 6500 events can be taken per burst while only 1500 to 2000 events can be transferred to tape. Consequently, a reduction by a factor of about 4-5 should be achieved by the trigger. In the analysis of the 1995 data, the requirement of two electron tracks ($p_t > 175$MeV/c) leads to a reduction of about 40, so in an online version implementing the essential analysis steps it should be possible to reach a reduction factor of 5.

The concept of the trigger is essentially based on ring reconstruction in the RICH detectors. The second-level trigger employed in the 1992 sulfur and the 1993 proton running was based on a massively parallel pattern recognition algorithm carried out on a systolic array for *one* RICH. With the performance achieved in these runs, the ring reconstruction efficiency was not inferior to the more elaborate offline analysis; the main deficiency was the rate of fake combinatorial rings due to random hit patterns, steeply rising with multiplicity. This problem can be solved by *correlating* ring candidates with the second RICH and with the other external tracking devices (Silicon drift detector and pad chamber hits).

Online hit reconstruction for the tracking devices needs a CPU power not offered by commercial processors. Instead, a custom multiprocessor array is planned in continuation of the previous developments and experience for RICH trigger processors in CERES. For the hit reconstruction (pattern recognition, centroid and amplitude evaluation), an ASIC will be designed. Presently available CMOS integration densities, say, 0.6 $\mu$m technology on a 150 mm$^2$ chip, allow two-dimensional arrays of processors performing the needed arithmetic operations – even with floating point operands – in parallel. The concept is closely related to published digital filtering techniques employed in telecommunication. The project will be carried out within the EUROPRACTICE Initiative of the European Community which provides access to development tools and production techniques of the European semiconductor industry.

The algorithms used for the extraction of trigger information from the individual detector components are well known and lend themselves easily to implementation in specialized processors. The correlation of this information and resulting track reconstruction, however, requires a more flexible architecture. Specific problems are, e.g. the intercalibration of the components and the resulting tuning of the cut parameters used in the track reconstruction. High-performance digital signal processors (DSP's) in a multiprocessor configuration are the proper choice here. A collaboration with the University of Frankfurt (Experiment NA49) has already been initiated. Heidelberg will design and build the modular, scalable multiprocessor hardware, Frankfurt will develop the rather complex, parallel algorithms. The DSP foreseen is DSP-TMS320C80 (Texas Instruments). In addition to the CERES application, this system offers capabilities needed in ALICE, specifically for data compression and online track recognition for the third-level trigger.

### 4.3.3 Rate estimates

Table 2 outlines how, with the upgraded rate capability of the experiment, a 30 day production period will yield an expected event sample of close to $10^8$, inspecting an equivalent of $3 \cdot 10^8$ untriggered collisions. In order to achieve our physics goal of a quantitative measurement of shape and yield of the vector mesons $\rho$, $\omega$, and $\phi$ we base our estimate of needed production running on the extrapolation based on the pp rates and a sample of 20,000 to 25,000 pairs with invariant mass greater than 200 MeV/$c^2$ (see Table 3). Enhancements or disappearance of vector meson peaks due to special effects in heavy ion collisions (see above) can be judged then on the basis of the expected yield of vector mesons given in Table 3. The present preliminary observation of a factor 2-3 enhancement in the dilepton yield in Pb + Pb collisions at 160 A GeV/c would e.g. yield a pair sample of 50,000 - 60,000. We note that the production period is typically preceded by a 6 day period of set-up, special runs and systematic checks.

| | /burst | /30 days 80% run efficiency |
|---|---|---|
| beam particles | $2 \cdot 10^6$ | $2 \cdot 10^{11}$ |
| interactions ($\lambda/\lambda_I$=0.83%) | 16600 | $1.7 \cdot 10^9$ |
| first level triggers (38% of $\sigma_{inel}$) | 6300 | $6.3 \cdot 10^8$ |
| events stored by DAQ (300 $\mu$s) | 4300 | $4.3 \cdot 10^8$ |
| max. number of events transfered to tape | 1700 | $1.7 \cdot 10^8$ |
| triggered (R=5, $\epsilon$ = .7) events written to tape | 850 | $8.5 \cdot 10^7$ |
| equivalent untriggered events | 3000 | $3 \cdot 10^8$ |

Table 2: Sample size obtainable in a 30 day production period.

# 5 Schedule and requests from CERN

## 5.1 Beam Time Requests

To run with the fully upgraded CERES apparatus we request the following beam times:

1. 1998: 2 $\times$ 2 weeks of proton running for commissioning of the new components. This would be followed by 30 days of running with Pb beam at full energy (160 GeV/nucleon) to commission with Pb beams and for initial production.
2. 1999 30 days of production running with Pb beams at 40 GeV/nucleon.
3. 2000 Further running with Pb beams at full energy for a high statistics $\omega, \phi$ production measurement to achieve the goal as stated in Table 3. The lenght of this run would depend on the performance and the outcome in and from the 1998 run.

| beam energy | 160 GeV | 40 GeV |
|---|---|---|
| $dN_{ch}/dy$ (38% $\sigma_{inel}$) | 270 | 200 |
| $e^+e^-$-pairs/event, $m > 200$ MeV/c$^2$ (from hadron decays) | $3.8 \cdot 10^{-4}$ | $2.9 \cdot 10^{-4}$ |
| pair reconstruction efficiency | 20% | 25% |
| pair sample (from hadron decays) | 23000 | 21500 |
| expected yield from vector mesons: | | |
| $\rho$-mesons | 1700 | 1250 |
| $\omega$-mesons | 2600 | 2000 |
| $\phi$-mesons | 575 | 450 |

Table 3: Expected sample size for a 30 day production period as quoted in Table 2

The sequence of the high and low energy running could be reversed should this be desirable for other reasons.

## 5.2 Requests from CERN

For the upgrade of the CERES spectrometer we request from CERN the power supply for the magnetic coils which produce the field for the TPC. For the data analysis run from the 1995 data sample we have used for the first time the CERN CS2 cluster and after initial investment in setting up all necessary procedures this has proven essential for speedy analysis of the data. We request similar usage of the CS2 cluster for future data analysis.

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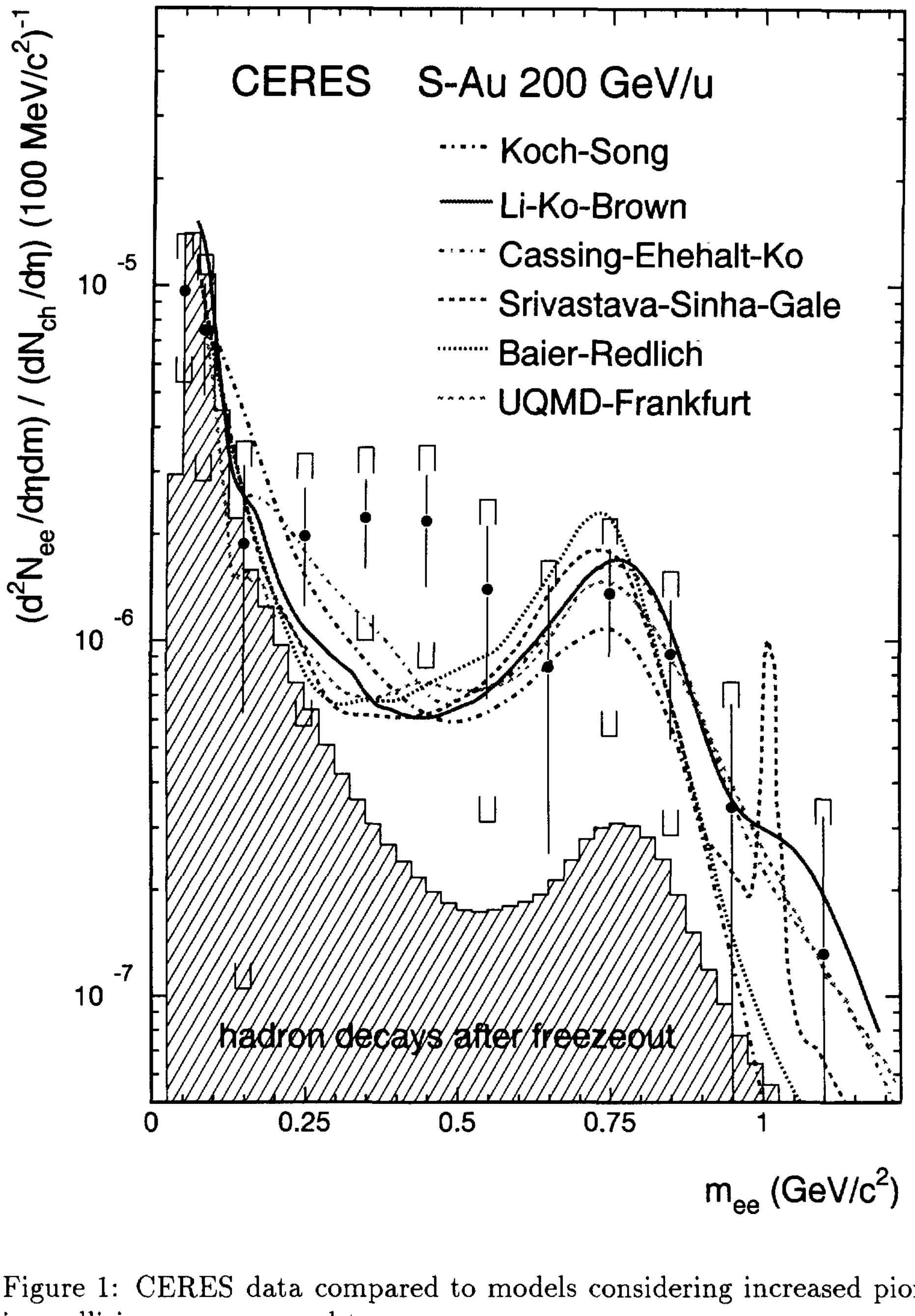


Figure 1: CERES data compared to models considering increased pion annihilation in heavy ion collisions as compared to pp.

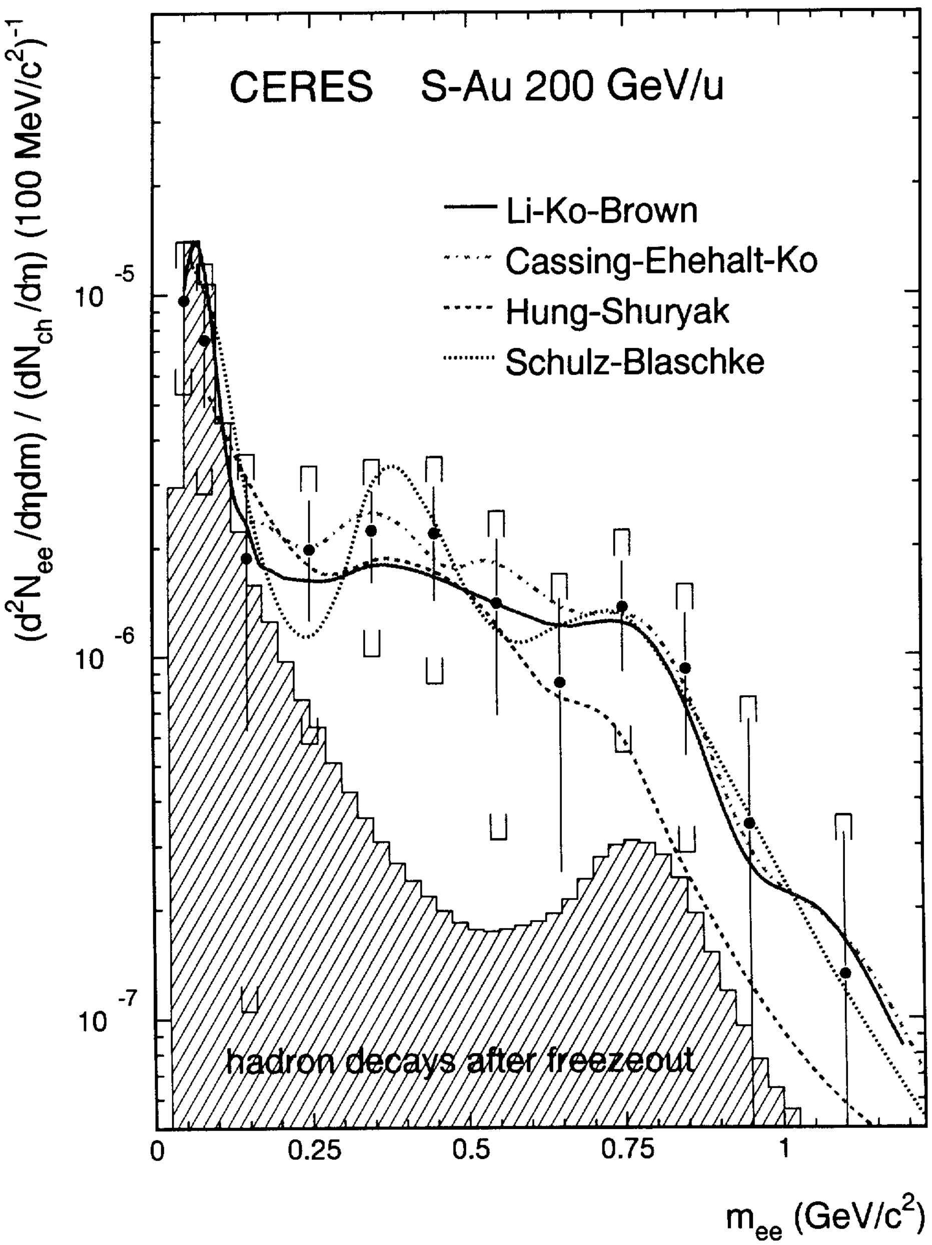


Figure 2: CERES data with model calculations incorporating baryon density dependent mass shifts of the vector mesons

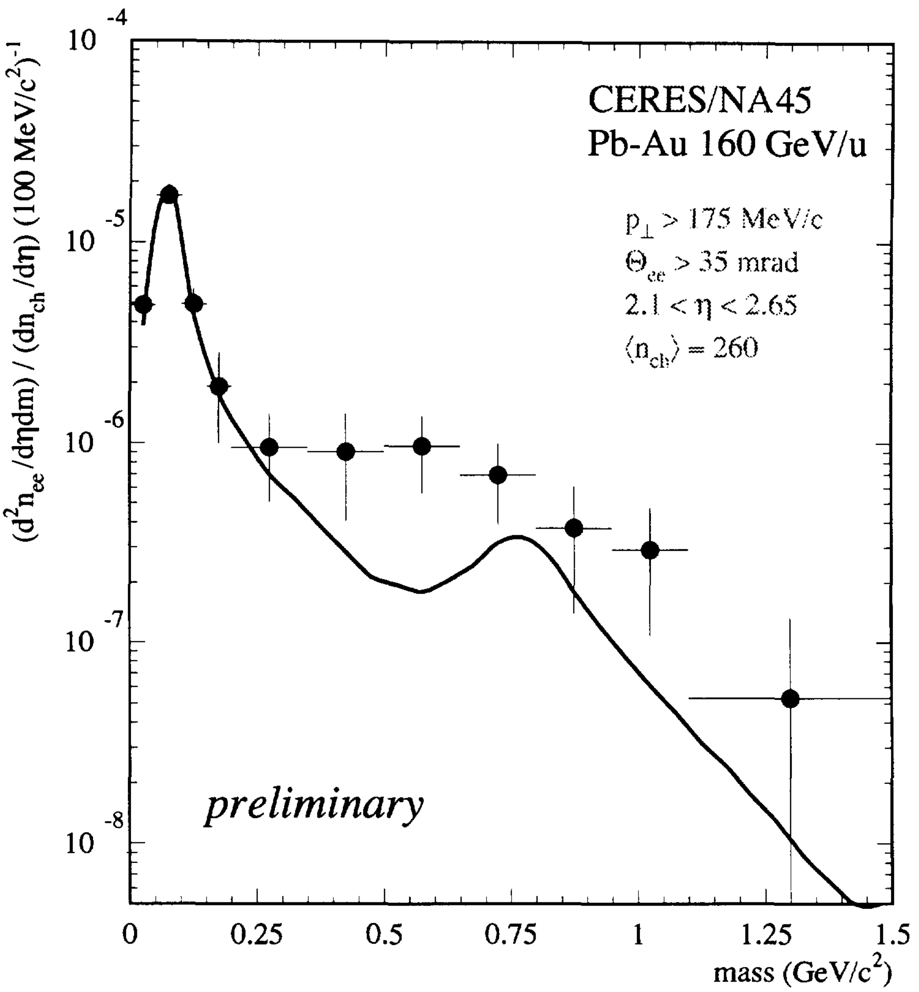


Figure 3: First CERES data for Pb + Au collisions together with the expected contribution from known hadronic sources [20].

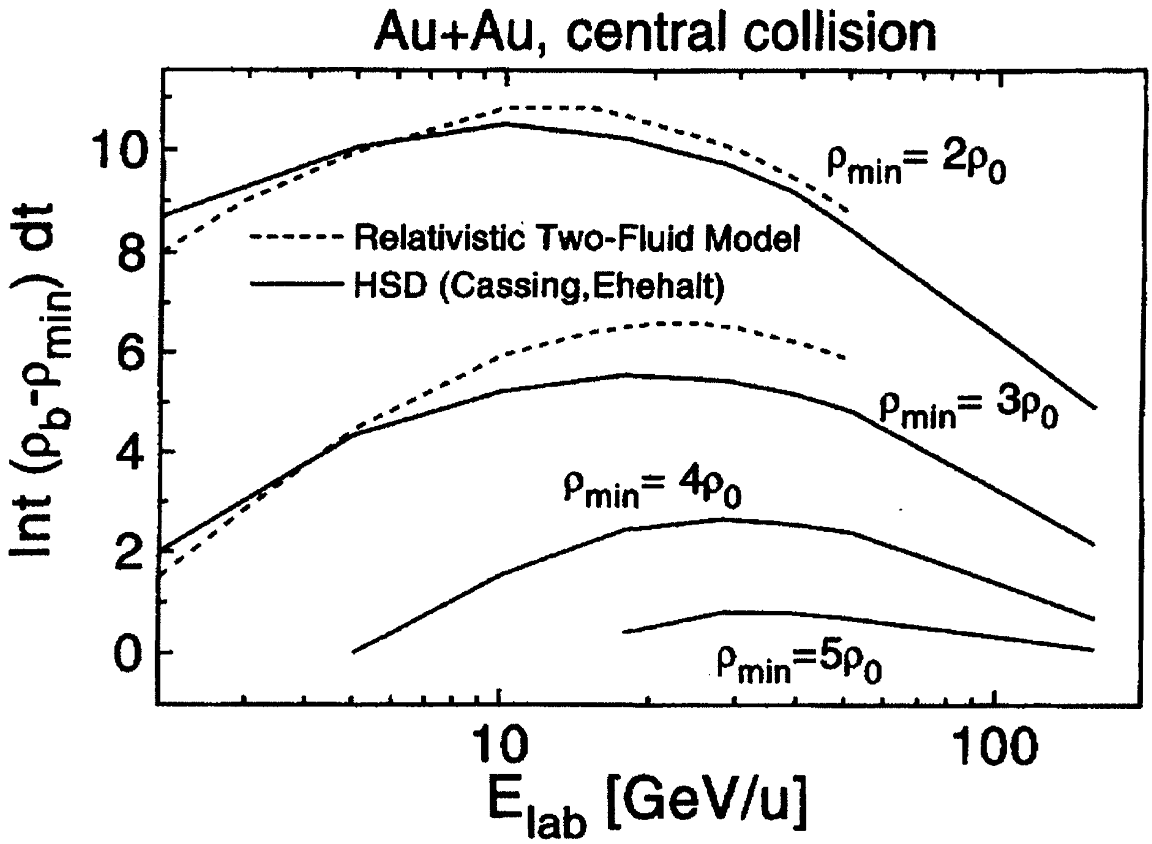


Figure 4: Calculated beam energy dependence of the number of baryons (time integral of the baryon density $\rho_b$ times a central volume) in a region with $\rho_b > \rho_{min}$. Calculations were performed both within a string model (HSD) and within a hydrodynamic scenario (Two-Fluid Model).

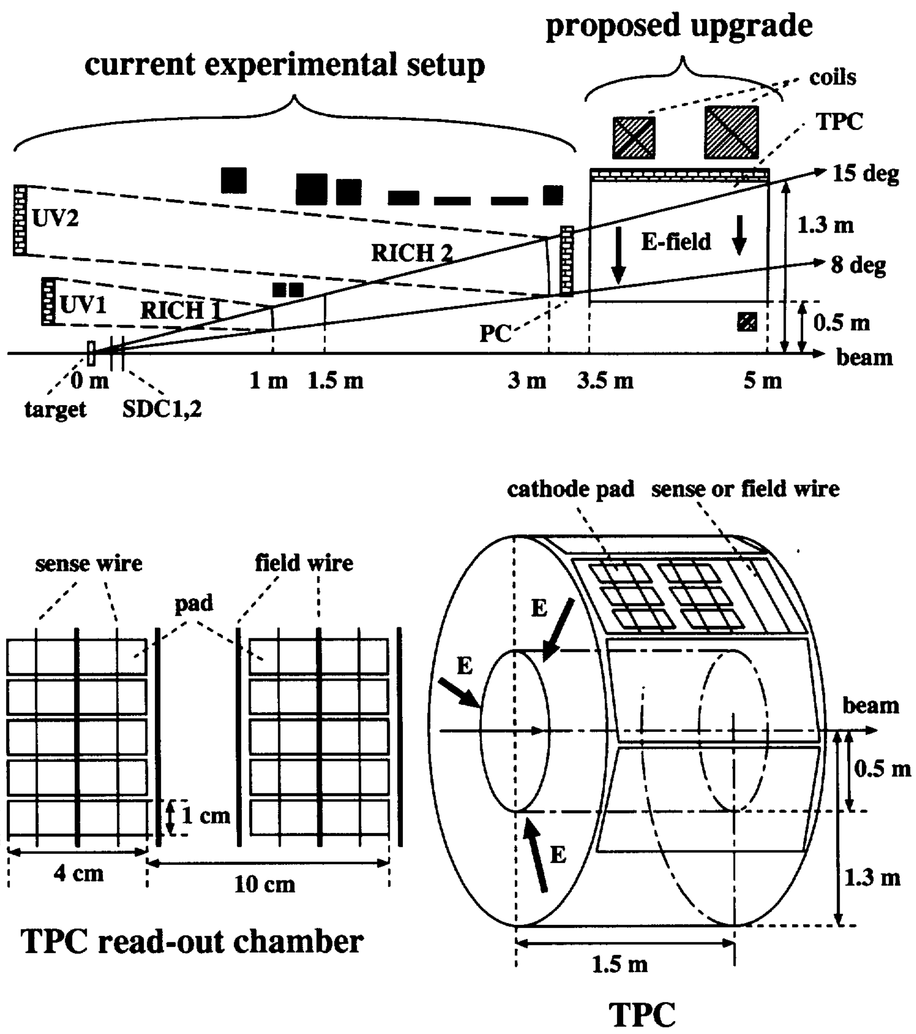


Figure 5: Proposed CERES Upgrade

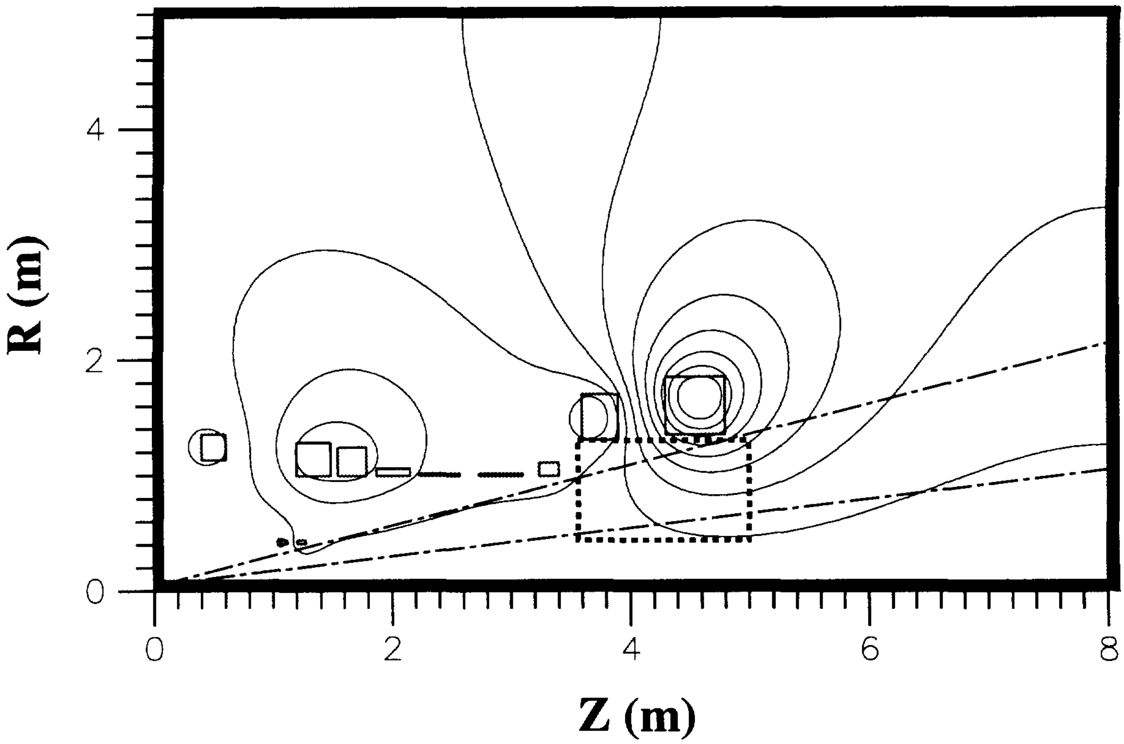


Figure 6: Magnetic field lines near the proposed TPC, whose position is shown by the dotted line.

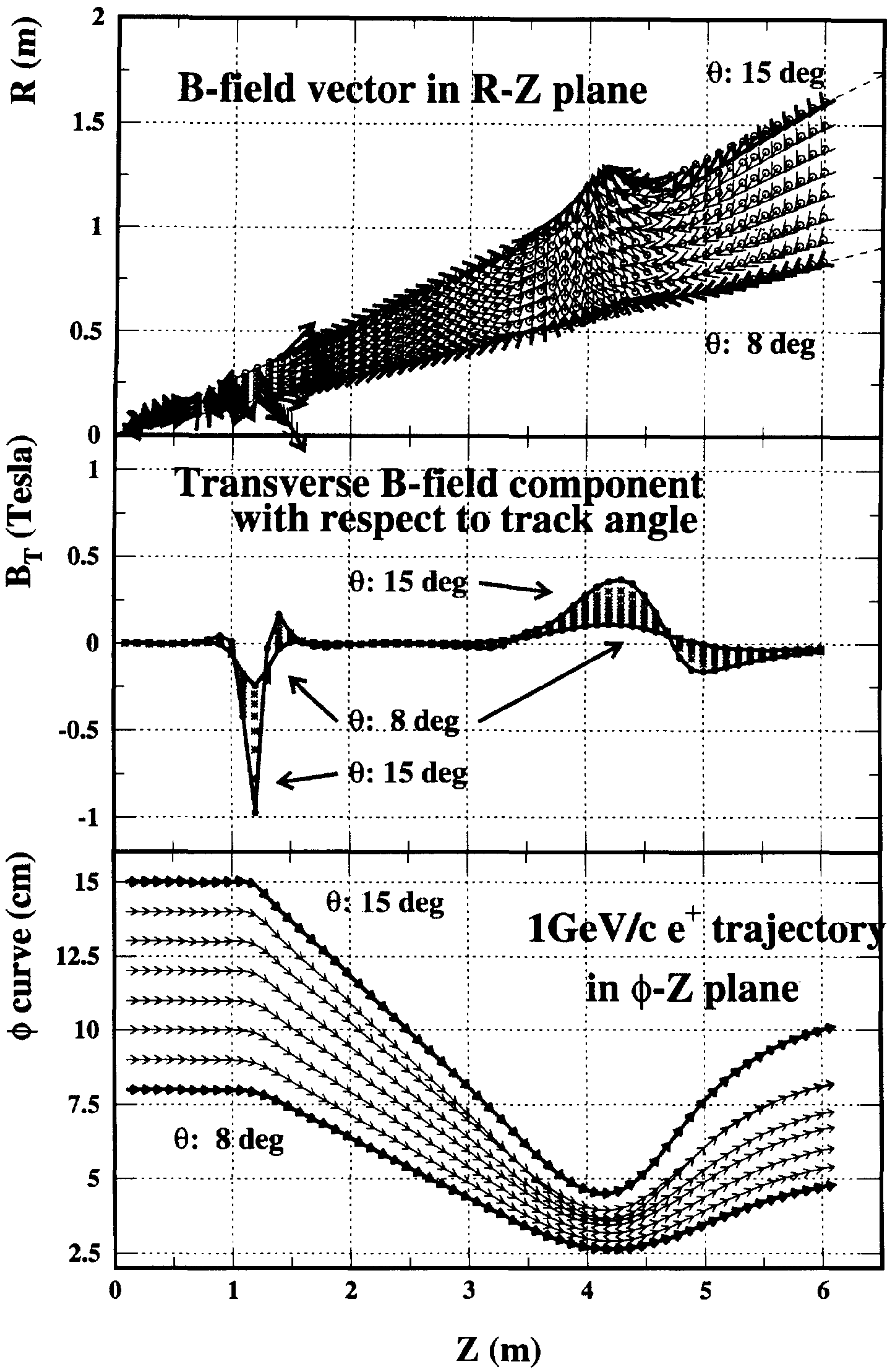


Figure 7: Components of the magnetic field for different polar angles $\theta$ in the $r - z$ plane (top), relative to particle tracks (middle), and in the $\phi - z$ plane for a momentum of 1 GeV/c.

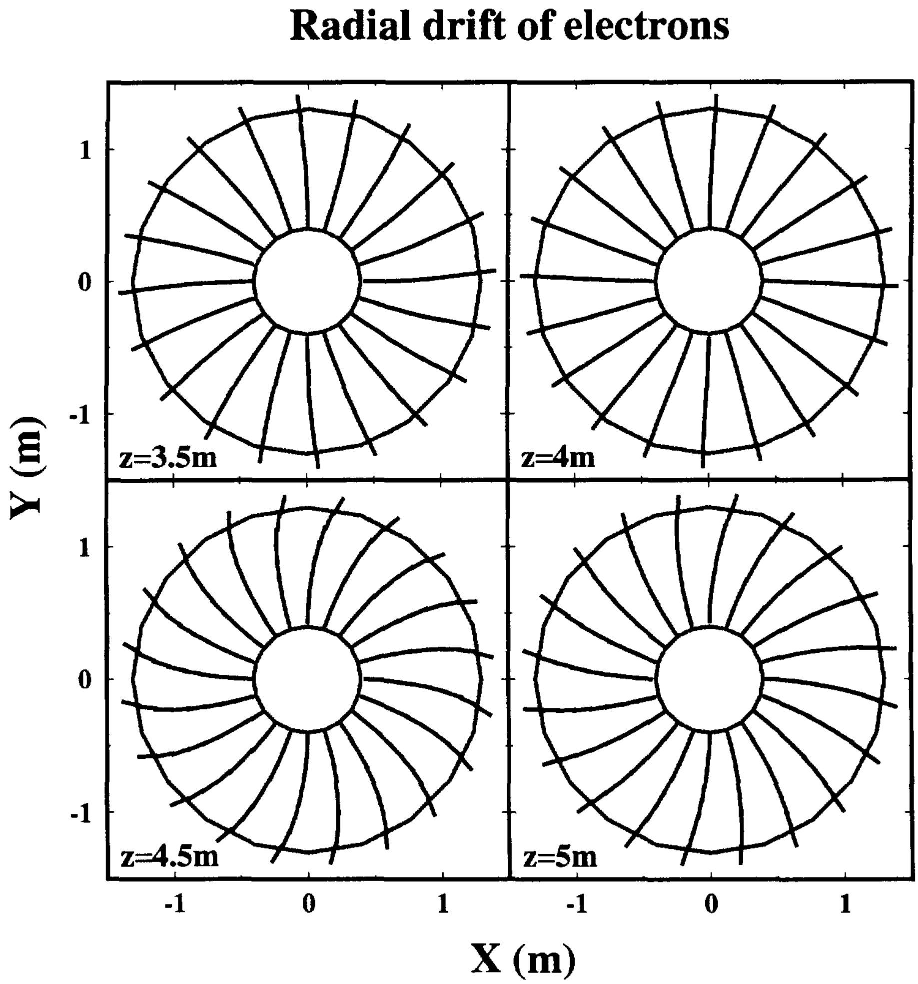


Figure 8: Trajectories of electrons drifting in the crossed E and B fields at different z-positions in the TPC

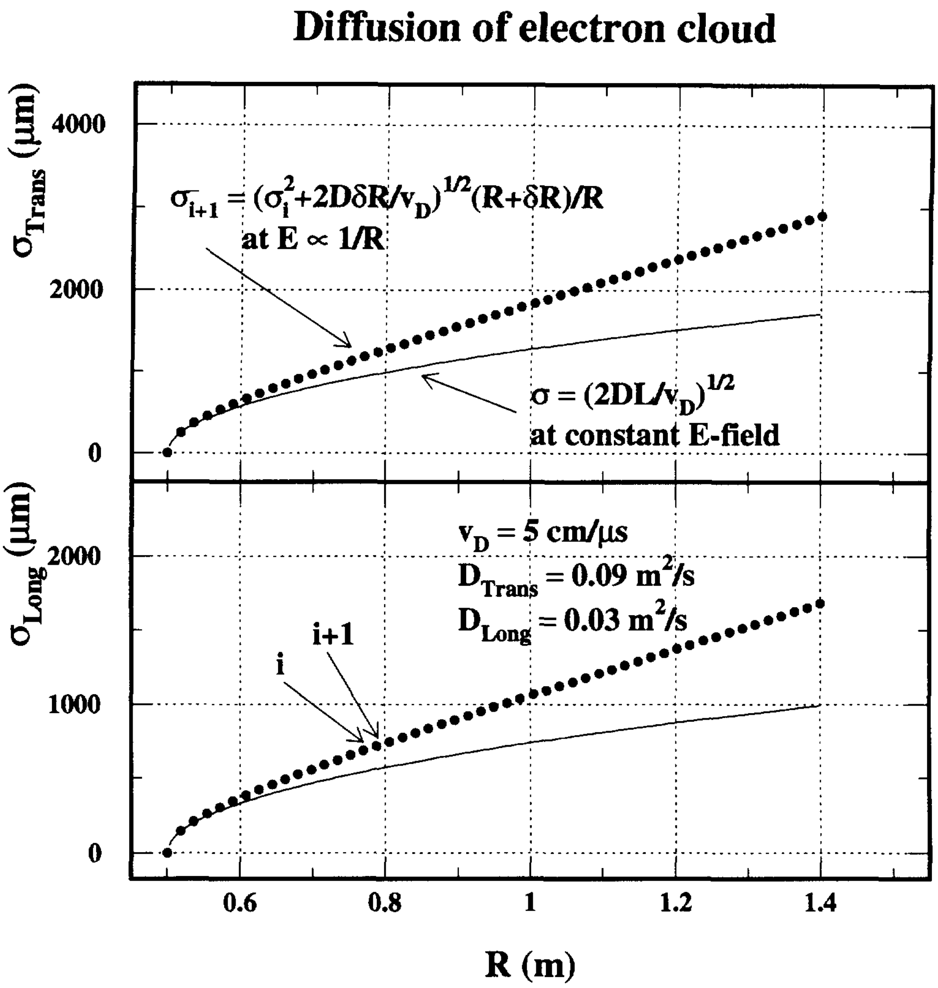


Figure 9: Diffusion along and transverse to the drift direction of an electron cloud starting at the inner radius of the TPC.

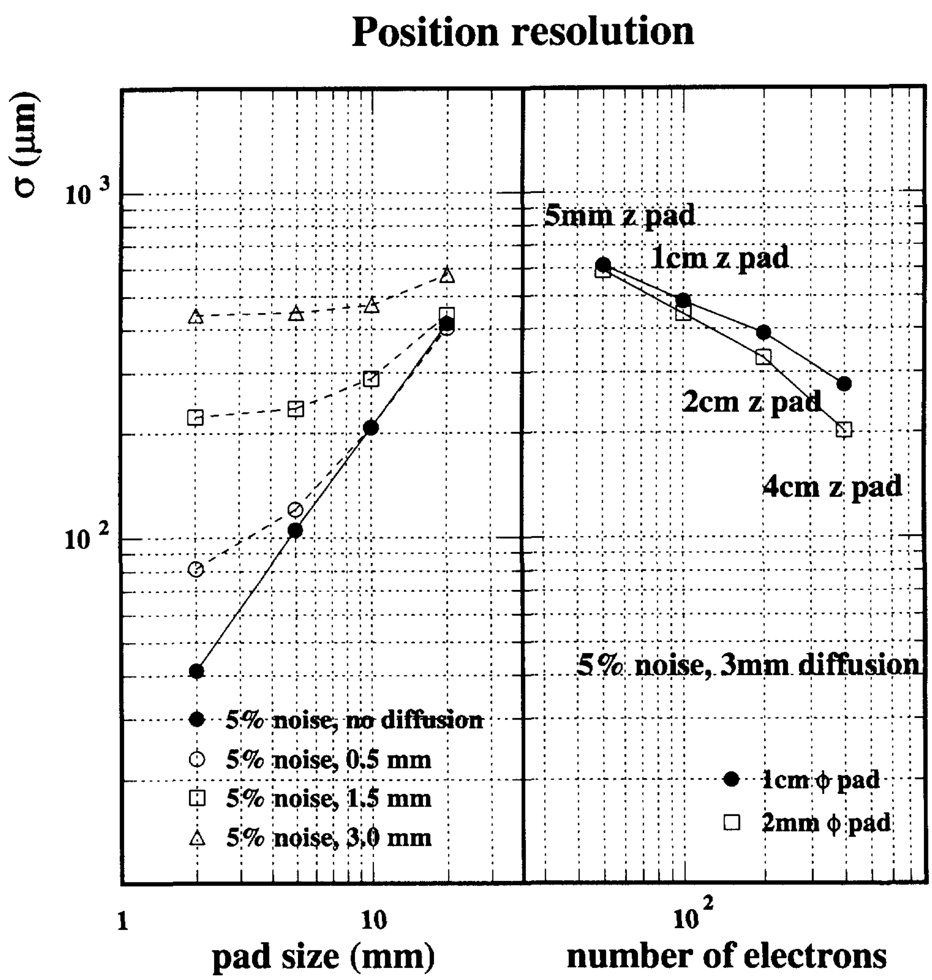


Figure 10: Resolution obtainable with pad read-out: the left panel contains the dependence on pad width for different values of transverse diffusion and a longitudinal pad size of 1 cm. The right panel shows the resolution as function of the length of the pads in longitudinal direction, i.e. as function of the primary electron statistics.

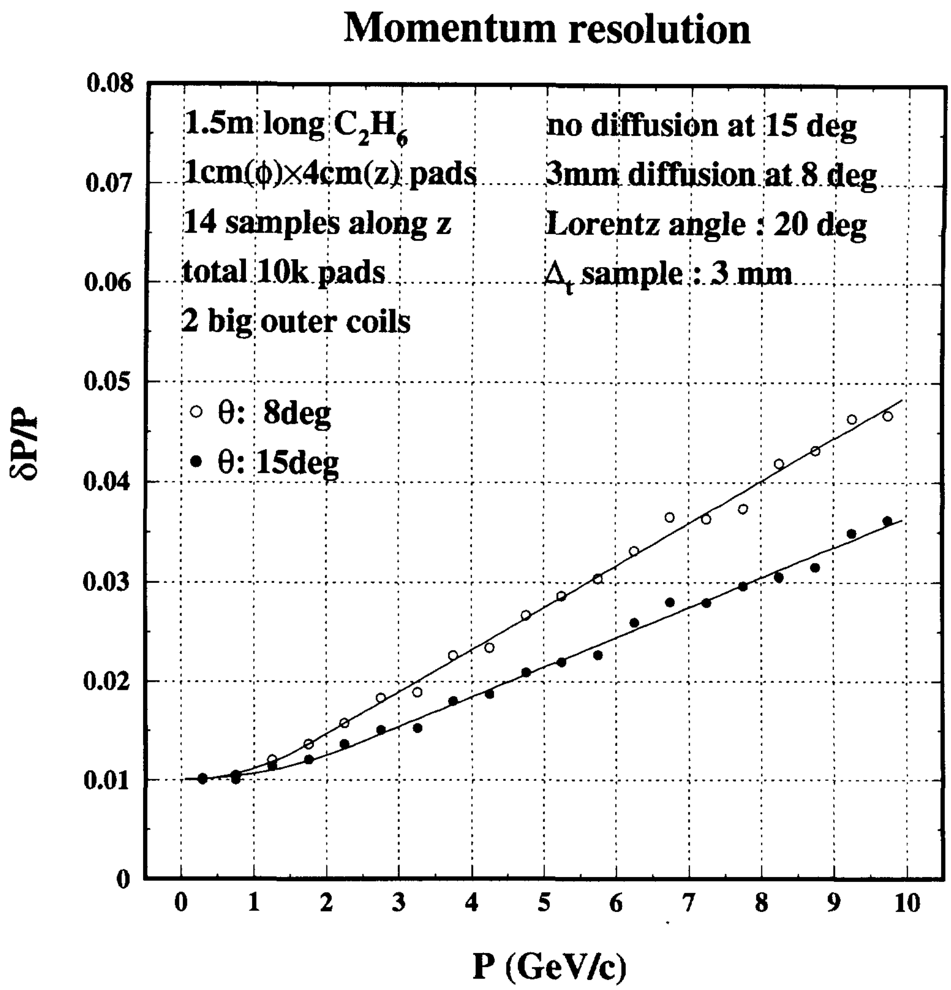


Figure 11: Momentum resolution with the proposed TPC.

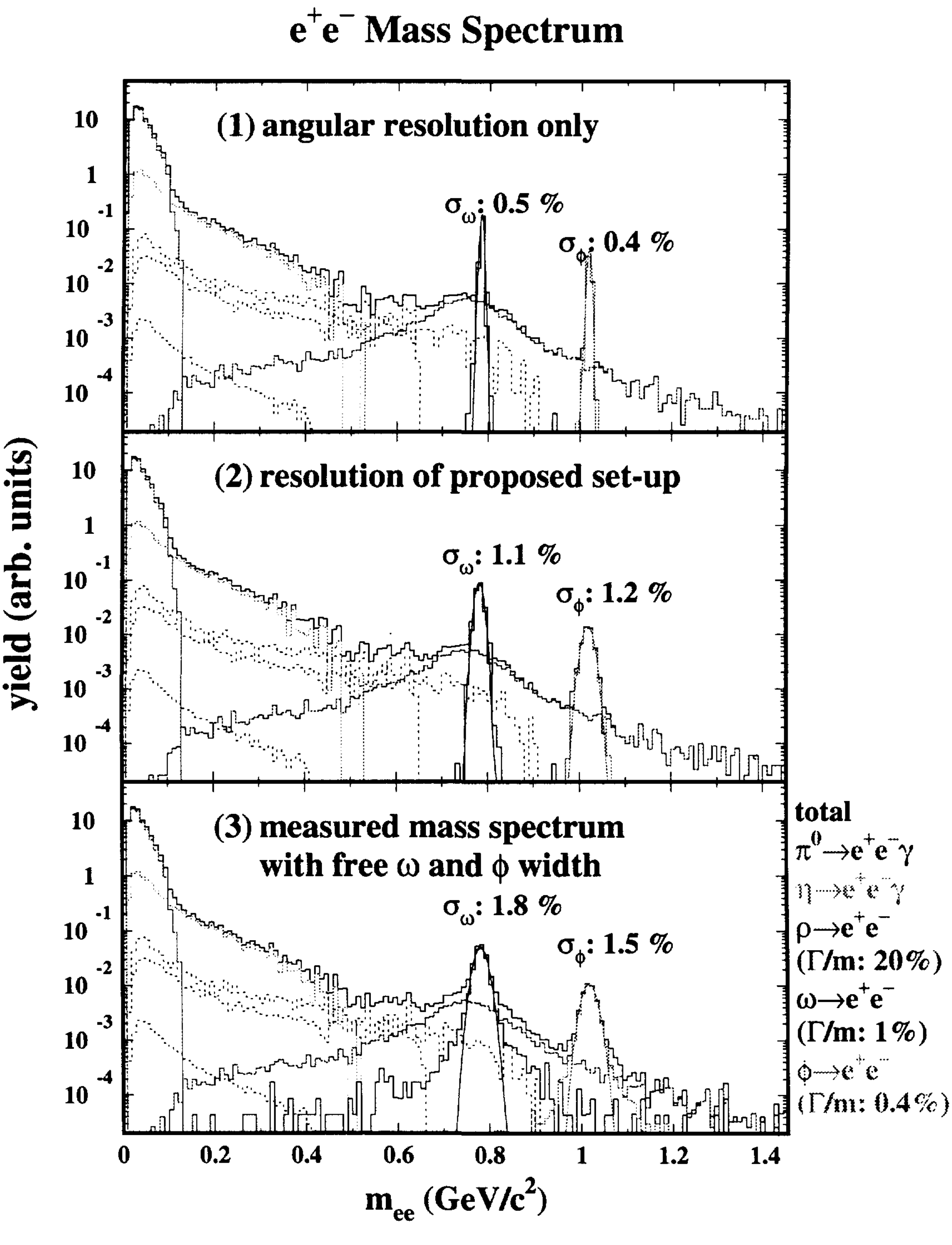


Figure 12: Lepton pais mass resolution achievable with the upgraded CERES spectrometer. The top part shows the influence of the angular resolution. The middle panel shows the expected mass resolution including angular and momentum resolution. The bottom panel exhibits a mass spectrum with the natural width of the $\omega$ and $\phi$ meson included.