Dileptons and Photons at the CERN SPS

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CERES, HELIOS-3 and NA38 have observed a significant excess of lepton pairs in collisions of 200 GeV/nucleon S beams with heavy targets in comparison to the expected yield from known hadronic sources. The excess was confirmed by results obtained by CERES and NA50 experiments with the Pb beam of 160 GeV/nucleon. The enhancement is more pronounced in the low-mass region \((m = 0.2 - 1.5 \text{ GeV/c}^2)\) measured close to mid-rapidity and seems to hint at in-medium modifications of the vector mesons and in particular at a decrease of the \(\rho\)-meson mass interpreted as a precursor of chiral symmetry restoration. On the other hand, there is no evidence of a signal in the search for direct photons and the various measurements, carried out by the CERES, HELIOS-2 and WA80 experiments, allow to set an upper limit of the order of 10%. This paper reviews all experimental results on dileptons (electron and muon pairs) with invariant mass \(m < 3 \text{ GeV/c}^2\) and real photons obtained from the CERN SPS heavy-ion program with S and Pb beams, together with the current attempts to understand them.

§1. Introduction

At the 1995 Quark Matter Conference, the three experiments involved in the measurement of dileptons at the CERN SPS—CERES, HELIOS-3 and NA38—presented evidence of a large excess of dileptons—in particular at low-masses \((m = 0.2 - 1.0 \text{ GeV/c}^2)\) but also at intermediate masses \((m = 1.5 - 2.5 \text{ GeV/c}^2)\)—in S-induced collisions at 200 GeV/nucleon. Since then, these results have been at the focus of attention, triggering a strong interest mainly stimulated by the possibility that the low-mass excess could result from the decrease of the \(\rho\)-meson mass as a precursor of chiral symmetry restoration. Recent results obtained with the Pb beam by the CERES and NA50 experiments show also an enhanced production of dileptons at low and intermediate masses confirming at least qualitatively the results with the S beam. This paper gives an overview of all experimental results on dilepton continuum and photons obtained since the beginning of the CERN SPS heavy-ion program and of the current attempts to understand them.

The main goal of ultra-relativistic heavy-ion collisions is the study of hadronic matter under extreme conditions of density and temperature and in particular to search for evidence of the predicted phase transition(s) leading to Quark Gluon Plasma formation—where quarks and gluons are free to move over a large volume compared to the typical size of hadrons—and to chiral symmetry restoration where masses drop to zero. The importance of dileptons \(e^+e^-\) or \(\mu^+\mu^-\) pairs—in this endeavour has been emphasized time and again since it was first proposed by Shuryak in 1978. Since dileptons interact only electromagnetically, their mean free path

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is relatively large compared to the size of the system formed in these collisions; therefore, once produced they can leave the interaction region and reach the detectors without any further interaction, carrying information about the conditions and properties of the matter at the time of their production and in particular of the early stages when temperature and energy density have their largest values. This has to be contrasted with the hadronic observables which are sensitive to the late stages of the collisions at and after freeze-out, i.e. once the hadronic system stops interacting.

The main topic of interest is the identification of dileptons emitted as thermal radiation which can tell us about the nature of the matter formed, the conjectured quark-gluon plasma (QGP) or a high-density hadron gas (HG). The elementary processes involved are $q\bar{q}$ annihilation in the QGP phase and $\pi^+\pi^-$ annihilation in the HG phase. Since the thermal emission rate is a strongly increasing function of the temperature, it is most abundantly produced at the early stages when the temperature and energy density have their largest values, thereby providing a higher sensitivity to identify the thermal radiation from the QGP, if it is formed. This sensitivity increases as the initial temperature of the system increases relatively to the critical temperature of the phase transition. Theoretical calculations have singled out the mass range of 1-3 GeV/$c^2$ as the most appropriate window to observe the thermal radiation from the QGP phase at initial temperatures likely to be reached at RHIC or LHC. At SPS energies, the initial temperature is believed to be close to or below the critical temperature, and therefore one expects the dense hadron gas to be the dominant source of thermal radiation. The window to search for it is at low masses, around and below the $\rho$-meson mass, since the $\pi^+\pi^-$ annihilation cross section is dominated by the pole of the pion electromagnetic form factor at the $\rho$ mass.

The physics potential of dileptons is further emphasized by the capability to measure the vector mesons –which are considered as important messengers of the collision dynamics—through their leptonic decays. Of particular interest is the decay of the $\rho$ meson into a lepton pair since it provides a unique experimental window to observe the effects of chiral symmetry restoration. Due to its very short lifetime ($\tau = 1.3$ fm/$c$) compared to the typical fireball lifetime of 10-20 fm/$c$ at SPS energies, most of the $\rho$ mesons produced in the collision will decay inside the interaction region with a reduced or even zero mass if the temperature and or the baryon density are large enough for chiral symmetry restoration to take place. The situation is very different for the other mesons, $\omega, \phi$ or $J/\psi$ because of their much longer lifetimes; they will be reabsorbed in the medium or they will decay well outside the interaction region where they have regained their vacuum masses.

Together with this brief discussion on the physics interest and physics potential of dileptons, one should also appreciate the difficulties associated with the measurements. The main experimental problem is the huge combinatorial background of uncorrelated lepton pairs originating from the decay of hadronic particles (and also from conversions in the measurement of electron pairs), which strongly increases as the coverage moves to the low-mass and low-$p_t$ regions. Secondly, dileptons can be emitted by a variety of sources and therefore, before one can make a claim on the observation of any new effect, it is absolutely necessary to have a thorough under-
standing of the contribution from all known sources, i.e. the physics background. Drell-Yan and semi-leptonic decays of charm mesons, produced in the primary hard collisions, are the main contributions at intermediate masses. In the low-mass region, the physics background is dominated by the electromagnetic decay of hadrons (Dalitz decays of $\pi^0, \eta, \eta' \rightarrow l^+l^-\gamma$, $\omega \rightarrow l^+l^-\pi^0$, and resonance decays of $\rho, \omega, \phi \rightarrow l^+l^-$) which mostly take place at a late stage of the collision, long after freeze-out. To understand the physics background, the experiments have adopted a systematic approach, performing precise measurements of the dilepton production in pp and pA collisions. These studies provide also the basis for comparison to nucleus-nucleus collisions and to identify any possible deviation from known physics. The results which I will review below show clear evidences of such deviations.

The above discussion is also relevant to real photons, since real and virtual (dileptons) photons are expected to carry the same physics information. However, the physics background for real photons is larger by orders of magnitude as compared to dileptons, making the measurement of photons much less sensitive to a new source.

This paper is organized as follows. Section 2 briefly presents and lists all measurements of electromagnetic observables performed so far. The experimental results are presented in Section 3. Section 4 reviews the current theoretical attempts to understand the various results and Section 5 contains a short summary and discussion on open questions and further work.

### Table I. List of Dilepton Measurements

| Experiment | Probe | System | y  | Mass (GeV/c²) |
|------------|-------|--------|----|---------------|
| CERES      | $e^+e^-$ | p-Be/Au 450 GeV/c | 2.1-2.65 | 0 - 2.0 |
|            |        | S-Au 200 GeV/u     |        |               |
|            |        | Pb-Au 158 GeV/c    |        |               |
| HELIOS-3   | $\mu^+\mu^-$ | p-W,S-W 200 GeV/u | > 3.5 | 0.3 - 4.0 |
| NA38       | $\mu^+\mu^-$ | p-A,S-U 200 GeV/u | 3.0-4.0 | 0.3 - 6.0 |
| NA50       | $\mu^+\mu^-$ | Pb-Pb 158 GeV/u   |        | 0.3 - 7.0 |

### §2. Measurements of electromagnetic probes

The three experiments involved in the measurement of dileptons are listed in Table 1. CERES is the only experiment dedicated to the measurement of low-mass electron pairs, from $\sim 50$ MeV/c² up to $\sim 2$ GeV/c², limited at the upper end by the available statistics. It covers the mid-rapidity region with a very broad range of $p_t$. The other two experiments are dedicated to the measurement of muon pairs. HELIOS-3 measured a very broad mass range from the dimuon threshold up to the $J/\psi$ covering mostly the forward rapidity region. NA38 (and its successor NA50) is mostly focussed in the mass range around and below the $J/\psi$ and covers the mid-rapidity region. The reference measurements on pp and pA performed by each experiment are also listed in Table 1. HELIOS-3 has finished data-taking whereas CERES and NA50 are continuing their physics programme with the Pb beam.
Two experiments are presently involved in the measurement of real photons (see Table 2), WA80 which measures them directly and CERES which uses the conversion method. Both experiments cover almost the same mid-rapidity interval. For completeness, Table 2 also includes HELIOS-2 which has performed the first search of direct photons using the O and S beams of the CERN SPS.

Table II. List of Real Photon Measurements

| Experiment | System       | y     | $p_T$ (GeV/c) |
|------------|--------------|-------|--------------|
| CERES      | S-Au 200 GeV/u | 2.1-2.7 | 0.4-2.0     |
| HELIOS-2   | p,O,S-W 200 GeV/u | 1.0-1.9 | 0.1-1.5     |
| WA80       | O-Au 200 GeV/u  | 1.5-2.1 | 0.4-2.8     |
|            | S-Au 200 GeV/u  | 2.1-2.9 | 0.5-2.5     |

§3. Experimental Results

The three dilepton experiments have reported an excess of dileptons in S-induced interactions over the known sources as measured in pp or pA collisions after scaling them to the S-nucleus case. This excess is confirmed, at least qualitatively, by the results obtained with the lead beam.

The overall picture is beautifully illustrated in Fig. 1 which shows the results of HELIOS-3 in central S-W interactions together with those obtained in p-W at 200 GeV/nucleon. They are presented in the form of muon pairs per charged particle measured in the same rapidity interval. The enhancement covers a very broad mass range including the low-mass continuum ($m = 200 - 600$ MeV/c$^2$), the vector mesons $\rho$, $\omega$ and $\phi$, and the intermediate-mass continuum (above the $\phi$ and below the $J/\psi$).
masses). The figure also displays the well known $J/\psi$ suppression, a topic of much current interest (see the paper presented by D. Kharzeev at this school). In the following we discuss in detail the experimental results on low- and intermediate-mass pairs.

3.1. Low-mass Dileptons

3.1.1. Results with the $p$ and $S$ beams

The low-mass region is systematically studied by the CERES experiment. Fig. 2 shows the low-mass spectra measured in 450 GeV/c $p$-Be (a very good approximation to the $p$-$p$ system) and $p$-Au collisions. The data are normalized to give the pair density per charged particle density within the acceptance of the CERES spectrometer. The lines represent the contributions from the known hadron decays and the shaded area gives the systematic error on the summed contributions. It is assumed that the particle production ratios of these sources is independent of the collision system and consequently, that the $e^+e^-$ production scales with the number of charged particles. One sees that the $p$-induced data are very well reproduced by electron pairs from the known hadronic sources. There is no need to invoke any unconventional or "anomalous" source of lepton pairs (see also ref. 17). The situation is completely different in the nucleus-nucleus case. The measured S-Au mass spectrum, shown in Fig. 3, reveals a dramatic effect; it has a different shape and shows a strong enhancement over the hadronic contributions at masses $m > 0.2$ GeV/$c^2$, reaching even one order of magnitude around $m \sim 0.4$ GeV/$c^2$. The enhancement factor –defined as the ratio of the measured yield integrated over the mass range $m = 0.2 - 1.5$ GeV/$c^2$ to the expected one– is $5.0 \pm 0.7$ (stat.) $\pm 2.0$ (syst.)

The reliability of the results presented in Fig. 3 is affected by the limited statistics of the sample, (a total signal, for masses $m > 200$ MeV/$c^2$, of 445 pairs with
a signal to combinatorial background ratio of 1/4.3). Furthermore, the shape of the excess and the combinatorial background are quite similar for masses \( m > 200 \text{ MeV}/c^2 \) raising the question whether the combinatorial background has been subtracted correctly. However, it seems that the similar shapes is a mere coincidence. The results remain stable within errors all along the chain of rejection cuts and when the cut values are varied by \( \sim \pm 15\% \) around the optimal values.

3.1.2. Results with the Pb beam

Figure 4 shows the recent results of CERES obtained in Pb-Au collisions at 160 GeV/nucleon with an average charge multiplicity of \( \langle dn/dy \rangle = 220 \) corresponding to the top \( \sim 35\% \) of the geometrical cross section. The spectrum is based on a total of 650 pairs with a signal to background ratio of 1/8. The results shown in Fig. 4 are very similar to those obtained in S-Au collisions. The yield is clearly enhanced compared to the predicted one from hadron decays. This is most pronounced in the region from 300 to 700 MeV/\( c^2 \) where the enhancement factor is \( 5.8 \pm 0.8 \) (stat) \( \pm 1.5 \) (syst). The enhancement extends also to higher masses. In the larger mass interval \( 0.2 \leq m \leq 2.0 \text{ GeV}/c^2 \) the enhancement factor is here \( 3.5 \pm 0.4 \) (stat) \( \pm 0.9 \) (syst).

An important aspect to characterize the excess is provided by the multiplicity dependence of the dilepton yield. The thermal radiation emitted either by partons or by pions should exhibit a quadratic dependence with multiplicity for a fixed interaction volume, since the emission rate is proportional to the product of the particle and anti-particle densities. In spite of the limited statistics of the Pb sample an attempt was made to exploit the large range of impact parameters covered by the data to study the yield as a function of the event multiplicity. Fig. 5 shows the pair density per charged particle density integrated over the mass range \( m > 200 \text{ MeV}/c^2 \) for four bins of multiplicity. If hadron decays were to be the only source of electron pairs –as it is the case in pp and pA collisions– the data should scale linearly with multiplicity. Therefore the pair density normalized to the charged-particle density should remain constant at the level determined by pp collisions and shown by the horizontal line in the figure. Although the error bars are large, one observes a clear deviation from the constant hadronic level indicating that the excess increases faster than linearly with multiplicity. This result confirms previous hints of a non-linear scaling observed in the S-Au case.

3.2. Intermediate-mass Dileptons

The excess in the intermediate mass region is best illustrated by the results of NA38 and NA50. Fig. 6 shows their results in p-W, S-U and Pb-Pb collisions. Drell-Yan and semi-leptonic charm decay are the main contributions at masses \( 1.5 < m < 2.5 \text{ MeV}/c^2 \), and they provide a good description of the p-W data. A small enhancement is observed in S-U collisions which appears more pronounced in the Pb-Pb system. In these two cases, the Drell-Yan and charm decay cross sections are

\[ *) \text{The amount of combinatorial background in the } e^+e^- \text{ measured yield is assumed to be equal to the total like-sign yield, } e^+e^+ + e^-e^- \text{, such that the signal is obtained by subtracting the like-sign yield from the unlike-sign yield.} \]
assumed to scale with the product $A_P A_T$ of projectile and target mass numbers. For details on the normalization and extrapolation procedures see refs. 5 and 20.

3.3. Photons

In contrast with the dilepton measurements, there is no evidence for enhancement in the measurement of real photons. The three experiments which have performed measurements of real photons have been able to establish only an upper limit for the production of thermal photons, which is now of the order of 10% of the expected yield from hadron sources.

The CERES and WA80 results on S-Au collisions at 200 GeV/nucleon measured at mid-rapidity are in very good agreement with each other and the absolute yield is very well reproduced by the expectation from hadronic sources as illustrated in Fig. 7 with the CERES results. From this comparison, CERES deduces a photon excess equal to 4% of the total inclusive photon yield from expected sources with systematic errors of +9% and -14% (the statistical errors are negligible), namely an excess which is consistent with zero. WA80 has a similar result, an excess of 5% with smaller errors $\pm 5.8\%$. Previous results on this topic, published by HELIOS-2 and WA80 reached also the same conclusion, although with larger errors. In all these attempts, the sensitivity is actually limited not by the statistical but by the systematic errors, too large to identify a source which is expected to be of the order of a few percent of the total yield (see next section).

§4. Theoretical Interpretations

The results presented in the previous section, and in particular the low-mass dilepton enhancement, have triggered a strong wave of theoretical activity. In this section I shall try to review and summarize the main highlights.

First of all, one may question the validity of the assumption of constant particle production cross section ratios used to scale the expected dilepton yield from the pp to the ion case, although it is certainly a very reasonable one. More specifically, one could ask whether it would be possible to reproduce the low-mass S-Au data of CERES with a modified “cocktail”, using an enhanced production of the $\eta$, $\eta'$ and $\omega$. Inspection of the S-Au spectrum of Fig. 3 reveals that this can fairly well be achieved. However, this would create a contradiction with other existing experimental information. For example, the ratio $\eta/\pi^0$ was measured by WA80 in S- S and S-Au collisions at 200 GeV/nucleon and was found in very good agreement with the ratio measured in pp collisions, thus not allowing the enhancement of the $\eta$ by the factor of 3-5 which would be needed to bring the cocktail close to the data. Alternatively, one would have to enhance the $\eta'$ or/and the $\omega$ yields by at least one order of magnitude; such a dramatic increase would have observable consequences in the real photon yield (since these particles have a large branching ratio to decay into photons) creating a conflict with the data of CERES and WA80 discussed previously. We therefore conclude that it is not possible to explain the observed low-mass dilepton enhancement by a modification of the particle ratios in the cocktail of known hadronic sources (see ref. 37 for upper limits on the $\eta$ and $\eta'$.
The explanation of the low-mass excess requires therefore an additional source, not present in the pp case. The two-pion annihilation channel $\pi^+\pi^- \rightarrow e^+e^-$ which is expected to become important in a high density environment, is an obvious candidate. The characteristic features of the excess –its onset at a mass $m_{ee} \sim 2m_\pi$, its extension to the low-mass region below and around the $\rho$-meson, and the possibility of a quadratic dependence with multiplicity – suggest indeed that the excess is due to this channel. This would then be the first indication of thermal radiation emitted from the dense hadronic matter formed in relativistic heavy ion collisions.

Numerous calculations have been reported, which have all included the pion annihilation channel. As an example, we show in Fig. 8 one of the first calculations by Li, Ko and Brown. One sees that the addition of the $\pi^+\pi^-$ annihilation channel (dashed line in Fig. 8) on top of the hadronic sources listed above (histogram in Fig. 8), leads to a considerable increase of the low-mass electron pair yield particularly near the $\rho$ mass –a direct consequence of the inclusion of the pion annihilation channel which is dominated by the pole of the pion form factor at the $\rho$ mass. However, the calculation fails to reproduce the data in the mass region $0.2 < m_{e^+e^-} < 0.5 \text{ GeV}/c^2$.

The same conclusion was reached by many other authors which have performed similar calculations, including the pion annihilation channel, but treating the reaction dynamics in completely different ways. Among those we quote transport models which explicitly propagate baryons and mesons assuming the formation of a hadronic system in thermal equilibrium or without equilibrium, a standard hydrodynamical model invoking or not invoking the formation of a thermalized QGP and a model based on a thermalized hadronic gas. The common constraint is that the models are required to reproduce experimentally observed hadronic variables like multiplicity, rapidity and $p_t$ distributions. Some of those calculations are shown in Fig. 9 in comparison with the CERES and HELIOS-3 results. A striking feature is that their predictions are very similar –within a factor of $\sim 2$– 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. One sees, as in Fig. 8, that the pion channel accounts for a large fraction of the observed excess. The calculations reproduce well or even overshoot the dilepton yield near the $\rho/\omega$ mass. However, they all fail to reproduce the data at lower masses, in the region $0.2 < m_{e^+e^-} < 0.5 \text{ MeV}/c^2$.

Data in this mass region have been quantitatively explained by taking into account the decrease of meson masses –in particular of the $\rho$ meson– in the hot and dense fireball as a precursor of chiral symmetry restoration. With this approach, first proposed by Li, Ko and Brown, excellent agreement has been achieved with the CERES data, as shown in Fig. 8 by the solid line. Similar observations have been reported Cassing et al. They derive the drop of the meson masses from QCD sum rules and their results are very similar to those of ref. 2. Both groups are also able to reproduce the HELIOS-3 low-mass enhancement. Their results are shown in Fig. 10. The dropping mass scenario also reproduces the enhancement observed in the preliminary Pb-Au results from CERES.
Other authors have investigated a different path, considering modifications of the $\rho$-meson width in the dense medium, due to collision broadening. Although a larger width increases somewhat the yield of low-mass dileptons, the effect is not strong enough to account for the observed yield\(^{26}\),\(^{34}\),\(^{35}\). More recent calculations\(^{41}\),\(^{42}\), have reached a different conclusion using a $\rho$-meson spectral function which includes the pion modification in the nuclear medium and the scattering of $\rho$ mesons off baryons and mesons. This leads to a much larger broadening of the $\rho$-meson shape (see left panel of Fig. 11) and consequently to a considerable enhancement of low-mass dileptons. These calculations are able to reproduce very well the CERES and HELIOS-3 S data (see Fig. 11 right panel), and also the CERES preliminary Pb-Au data, as well as the dropping $\rho$ mass scenario. These results are however not free of debate. Steele, Yamagushi and Zahed\(^{43}\) addressed the same physics of in-medium modifications of the $\rho$ spectral function. Using on-shell chiral reduction formulas and enforcing known constraints, they reached the conclusion that the additional strength is not sufficient to explain the low-mass CERES data.

As discussed in the Introduction, direct photons should provide analogous information to thermal dileptons. Therefore, a simultaneous quantitative description of results on low-mass dileptons and direct photons within a single model would be very decisive in establishing a consistent and reliable interpretation of experimental results. In this context, the lack of signal in the photon data is in striking contrast to the strong enhancement of low-mass dileptons and raises the question of consistency between the two experimental findings. In fact the real question is a quantitative one, namely the level of sensitivity of the two measurements to a new source with respect to their hadronic background. Simple arguments reveal that the level of sensitivity is more than two orders of magnitude lower for photons compared to electrons\(^{1}\). In other words, the enhancement factor of 5 observed in the CERES S-Au data should translate into an enhancement factor of a few percent in the photon measurement. This conclusion has been recently confirmed by calculations performed by Li and Brown\(^{44}\) with the same model of dropping meson masses used to explain the CERES and HELIOS-3 low-mass dilepton results. Their results are shown in Fig. 12 and compared to the WA80 data. The excess of direct photons is predicted to be a few percent of the total hadronic background, in agreement with the experimental results. This sharpens the strict requirement imposed on the experiments to control the systematic errors down to the percent level in order to be able to observe direct photons.

We finally turn briefly to the intermediate mass region. An interesting question is whether the excess in this mass region has the same origin as at low-masses. In the HELIOS-3 data the mass spectrum of the excess has the same slope below and above the vector mesons $\rho$, $\omega$ and $\phi$, suggesting a common origin\(^{14}\). NA38 however, makes the observation that the shape of the excess in the intermediate mass region resembles very much the shape of the open charm contribution suggesting that enhanced charmed production could be at the origin of the excess. One would then need a different explanation for the excess at low masses since charm production has a negligible contribution there. Data on multiplicity dependence and $p_t$ distribution may shed light on this issue.
CERES, HELIOS-3 and NA38 have observed a significant excess of lepton pairs in S-Au collisions at 200 GeV/nucleon over the expected yield of known hadronic sources. The excess is confirmed by results obtained by the CERES and NA50 experiments in 160 GeV/u Pb-Au and Pb-Pb collisions, respectively. Theoretical calculations show that a large fraction of the low-mass (m = 0.2 - 1.5 GeV/c^2) excess originates from the pion annihilation into lepton pairs, \( \pi^+\pi^- \rightarrow \rho \rightarrow l^+l^- \), thereby providing the first evidence of thermal radiation emitted from the dense hadronic matter formed in these collisions. The models achieve an excellent agreement with all data sets by further requiring strong in-medium modifications of the vector mesons, in particular a decrease of the \( \rho \)-meson mass as a precursor of chiral symmetry restoration.

There is no evidence of direct photon emission in these collisions and the various experiments allow to set an upper limit of the order of 10%. The lack of signal is attributed to the lower sensitivity of the photon measurement as compared to dileptons. The same model of dropping meson masses provides a good description of the photon data.

The dilepton experimental results together with the hints of in-medium effects and chiral symmetry restoration have created a considerable excitement. In order to further constrain the models we need more and precise information on the excess: the two key questions are the \( p_T \) distribution and the multiplicity dependence of the observed excess. A considerable progress is expected from the present round of experiments at the CERN SPS with the Pb beam and detailed information on multiplicity and \( p_T \) dependences should be available within a year. Two major new steps are foreseen in a somewhat longer time scale. First, CERES is planning to dramatically improve the mass resolution to achieve \( \delta m/m = 1\% \), by the addition of a TPC downstream of the present double RICH spectrometer. With this resolution, which is of the order of the natural line width of the \( \omega \) meson, it should be possible to directly measure the yield of all three vector mesons \( \rho, \omega \) and \( \phi \) including any possible changes in their properties (mass shift or increased width) thereby providing compelling evidence of the scenarios invoking chiral symmetry restoration. Second, a measurement is proposed 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.

Acknowledgments

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Fig. 3. $e^+e^-$ invariant mass spectra in 200 GeV/nucleon S-Au collisions measured by CERES. Statistical (vertical bars) and systematic (brackets) errors are plotted independently of each other. See text for details.

Fig. 4. $e^+e^-$ mass spectrum measured by CERES in 160 GeV/nucleon Pb-Au collisions.
Fig. 5. Multiplicity dependence of the $e^+e^-$ pair yield normalized to the charged particle density measured by CERES in Pb-Au collisions at 160 GeV/nucleon. The horizontal line indicates the expectation from hadron decays.

$$\frac{dN_{e^+e^-}}{dN_{ch}} \times 10^{-5}$$

0.2 \ less \ than \ 2 \ GeV/c^2
Fig. 6. Di-muon invariant mass spectrum measured by NA38 in 200 GeV/nucleon p-W and S-U collisions and by NA50 in 160 GeV/nucleon Pb-Pb collisions. The dotted, dashed, dot-dashed, thin and thick lines represent the J/ψ, Drell-Yan, ψ', open charm and total contributions, respectively.

Fig. 7. CERES results on inclusive photon $p_t$ distribution from central S-Au collisions and comparison to predictions from hadron decays.
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Fig. 8. Invariant mass spectrum of $e^+e^-$ measured by CERES in S-Au collisions at 200 GeV/u compared to the expected yield from hadron decays (histogram) and to the calculations of Li et al. including in addition $\pi\pi$ annihilation (dashed line) and dropping $\rho$ mass (solid line).

Fig. 9. Comparison of the CERES and HELIOS-3 results with model calculations all including the two-pion annihilation channel.
Fig. 10. Comparison of the CERES and HELIOS-3 results with the calculations of refs. 25 with dropping meson masses.

Fig. 11. The $\rho$-meson spectral function after inclusion of in-medium pion modifications and $\rho$ scattering off baryons and mesons. The curves correspond to fixed momentum ($q=0.5\text{ GeV}$) and chemical potentials ($\mu_B=0.39\text{ GeV}$, $\mu_{\text{meson}}=0$) at temperatures of $T=0.127\text{ GeV}$ (long-dashed), $T=0.149\text{ GeV}$ (short-dashed) and $T=0.170\text{ GeV}$ (dotted) (left panel). Comparison of the resulting dielectron spectrum with the CERES data on S-Au collisions (right panel).
Fig. 12. Comparison of the WA80 photon data (presented as the ratio of the total measured yield to the expected background yield from $\pi^0$ and $\eta$ decays) with the calculations of refs. [44] with (solid line) and without (dotted line) dropping meson masses.