Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

Presented at the Winter Workshop on Nuclear Dynamics V, Sun Valley, ID, February 22–26, 1988

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March 1988

NUCLEAR SCIENCE DIVISION

Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

LBL-25019

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This paper discusses recent results on the production of di-leptons measured by the Di-Lepton Spectrometer (DLS) collaboration.[1] Results are reported from observations made on p + Be collisions with proton beams from 1.0 to 4.9 GeV and on Ca + Ca collisions with calcium beams of 1.0 to 2.0 GeV/A. All of this data were taken at the LBL Bevalac.

A di-lepton, which arises from the decay of a virtual photon, is produced by the electromagnetic interaction at one of its vertices, while hadronic states are generated completely by the strong interaction. The electromagnetic process is in principle calculable and consequently should be much easier to understand. While this has proven to be correct for the quark hard scattering process, Drell-Yan, the low mass behavior of pairs and the low P_t behavior of single leptons are not understood well.[2] In experiments ranging from about 10 GeV fixed target set-ups to colliding beam detectors at the ISR, there are large, poorly understood yields at both low mass for pairs and at low P_t for single leptons. The difficultly with measuring di-leptons occurs because of their low rate for production as they are produced by electromagnetic interactions. To compensate for the low rates, a large acceptance spectrometer is needed to measure the two-body final state so that the data will have sufficient statistical accuracy.

Di-leptons are thought to be one of the significant signals for the quark-gluon plasma. A virtual photon, which is produced in the interior of a collision, decays inside the volume of that interaction. The decay leptons interact with only the electromagnetic interaction and consequently they are only weakly affected by the other quarks and gluons. Therefore, they are a probe of the interior of hot hadronic matter, while hadronic probes are thought to probe the surface. They are thought to be a probe of the temperature of the interaction. Furthermore, if chiral restoration occurs, then measurable effects such as the changing of the shape or position of vector-mesons could happen. In addition to these processes, an increase in the rate of production of the continuum could occur.

Even though there is broad theoretical interest in di-lepton production, the experimental behavior is completely unknown below 12 GeV. It is important to know and understand the low energy behavior of di-leptons so that observations at higher energies can be used to detect a phase transition.

To measure di-leptons, our collaboration has designed a two-arm spectrometer to detect electrons. Electrons were chosen to be measured because it is feasible, at Bevalac energies, to separate them from pions at a level of about 10^{-5} with Cerenkov counters. Muons are unsuitable to be detected in this energy range because their mass is too similar to pions to use this technique. In addition, because of the higher mass of the muon, it is not possible to study the mass region below 200 MeV.

The apparatus used in this experiment has been described in Ref. 1. Each arm of the spectrometer was constructed identically. Drift chambers before and after the magnet were used to measure the trajectories and consequently the momenta of particles which interacted in the target. Cêrenkov counters, located before and after the magnet, were used to distinguish electrons from pions. Scintillation hodoscopes, in conjunction with the Cêrenkov counters were used to trigger the experiment, and to establish whether the electrons detected in each arm were produced by the same interaction.

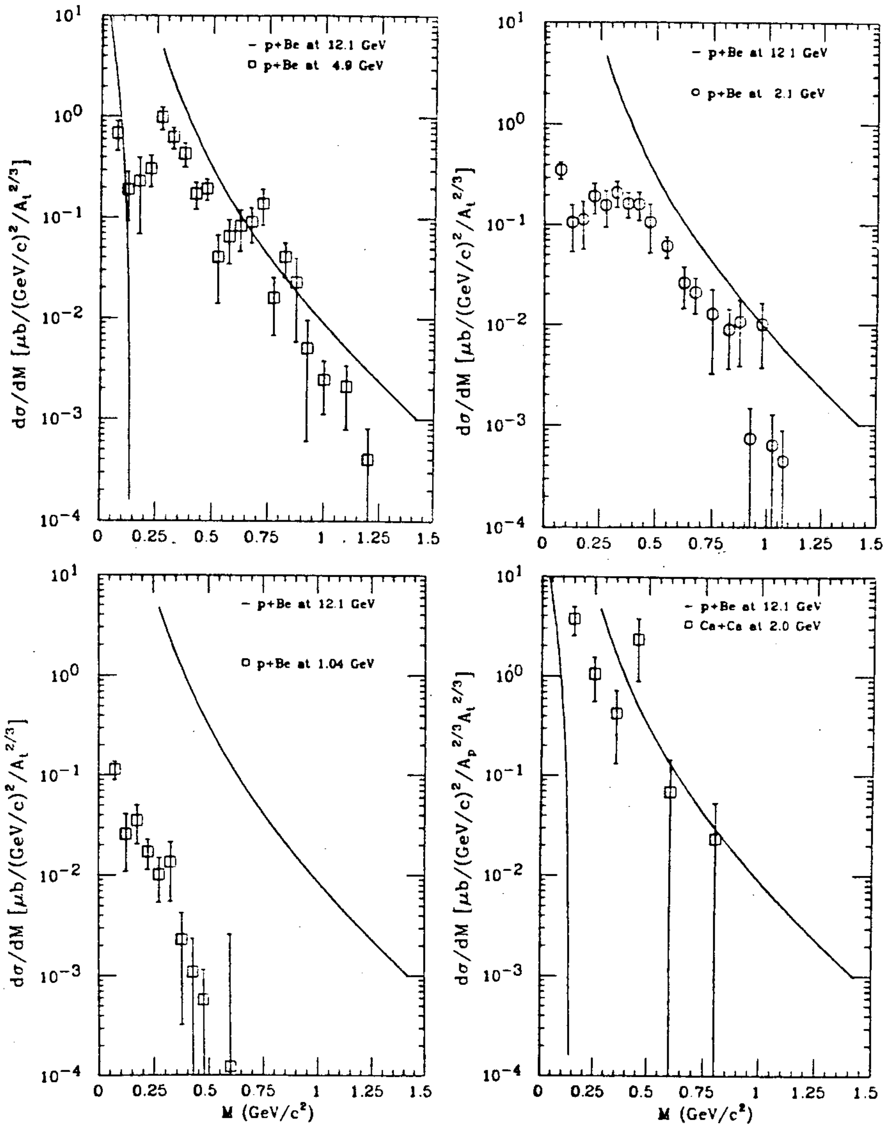
In order to measure the number of direct lepton pairs, it is necessary to subtract the background of pairs, which are produced by non-direct processes, from the data. The dominant production of electrons occurs when a π° decays into a photon and electron pair (the Dalitz decay of a pion) or when a photon interacts in the target or surrounding materials and produces an electron pair. The pair of electrons generated by these mechanisms are usually at low energy and at low mass, so that they will be rejected by the detector. However, it is possible for two separate pairs to be produced in one event and for each arm to only see a lepton from a separate pair. Fortunately, this background produces an equal amount of like-sign and unlike-sign pairs. Therefore, by subtracting the like-sign pairs from the measured data, one is able to measure the direct pair signal.

Fig. 1 shows the mass spectra for a number of reactions measured by the DLS. The final acceptance and normalization corrections have not been made for these spectra. Therefore, these results should only be viewed as preliminary. Only qualitative conclusions should be interpreted from these results.

With this caveat, a number of observations can be made from the data. First, production of di-leptons have been observed at 1.0 GeV. Secondly, some structure in the cross section at about 300 MeV is observed in both the 2.1 and 4.9 p-Be data. Previous electron-pair measurements do not show data in this mass-region. Goldman et al.[3] and Gales and Kapusta[4] have shown that the annihilation of pions produce such a behavior. The ρ meson can clearly be seen in the 4.9 GeV data. In addition, the rise at low mass in both the 2.1 and 4.9 data can be explained by the well known Dalitz decay of a π°. The overall shape of the cross sections are remarkably similar to those measured at much higher energies. The mass range between the Dalitz and π-π annihilations should be dominated by hadron bremsstrahlung. When the contribution of the Dalitz pairs are subtracted from the data set, then one would be able to see if the bremsstrahlung term can be measured. Further study of the threshold of the π-π annihilation could provide information on the density of the hot-hadronic matter.

Also, shown in this figure is the mass spectra for 2.0 GeV/A Ca-Ca collisions. The data are similar to the proton data. It will be necessary to make a careful check of the normalizations and efficiencies to make a detailed comparison of the two data sets. Not shown on this figure is a recent

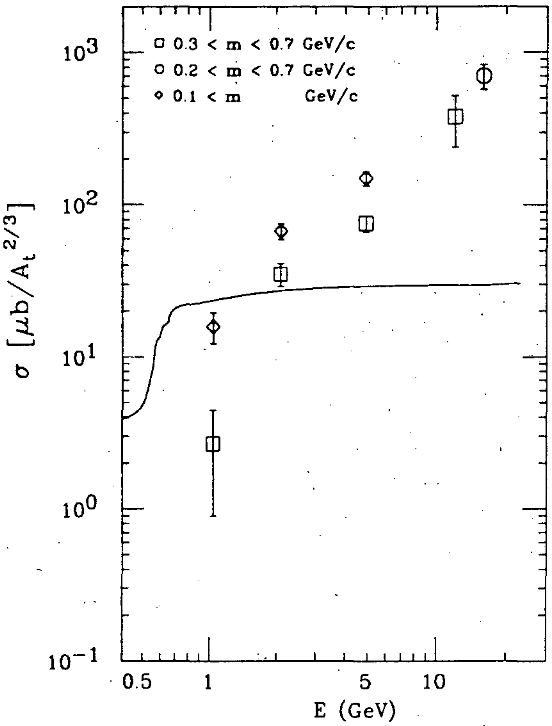
Fig. 1 Mass spectra of di-electrons for p-Be collisions at 1.0, 2.1, and 4.9 GeV and for Ca-Ca collisions at 2.0 GeV. Two curves are shown in this figure. One show a fit (ρ region excluded) to some 12 GeV data. The other curve shows the expected yield of di-leptons from π° decay. Note, the normalizations of our data is preliminary.



measurement of a cross section for pairs with a 1.0 Ca/A beam, where a clear pair signal has been measured.

An excitation curve for production of di-leptons is shown in Fig. 2. With the caveat that there is an uncertainty in the normalizations, several conclusions are apparent. First, at the very lowest energy there is a very rapid increase in the cross section. This increase can not be explained by the p-p inelastic cross section which is superimposed on that figure. This rise is inconsistent with the otherwise successful phenomenological KSS model in which pion and electron yields are proportional. It probably would be better to compare with the multi-pion production cross section as a large component of the cross section could come from virtual or real π-π annihilation. Furthermore, as the pair cross section does not track the inelastic cross section, then the e/π ratio must decrease with energy from the usual 10^{-4} value measured at higher energies. An extrapolation of the data shows that di-leptons should be measurable at 800 GeV, where a previous experiment[5] did not find any measurable cross section of single electrons. However a careful check of the normalization, and a check to determine whether there are

Fig. 2 The total cross section for di-electrons for p beams. Data from other experiments including one which used a pion beam is shown. The pion inelastic cross section divided by 1000 is shown on the curve for reference.



differences between p-p collisions and p-nucleus collisions needs to be done to determine whether the two experiments are in disagreement.

In summary, di-leptons have been measured at Bevalac energies. The shape of the distributions are similar to that at higher energies. The low mass cross section appears to be explained by π-π annihilation, but detailed calculations are needed to substantiate that hypothesis.

I would like to thank G. Roche, the spokesman of the experiment, and J. Carroll for discussing this paper with me. I would also like to thank other members of the collaboration: D. Hendrie, G. Krebs, E. Lallier, A. Letessier-Selvon, C. Naudet, L. Schroeder, P. Seidl, A. Yegneswaran, Z. F. Wang, J. Bystriky, J. Gordon, G. Igo, T. Hallman, L. Madansky, S. Christo, P. Kirk, D. Miller and G. Landau. In addition, I would like to thank J. Kapusta for several very interesting conversations.

This work was supported by the Director, Office of Energy Research, Division of Nuclear Physics of the Office of High Energy and Nuclear Physics of the U.S. Department of Energy under Contract DE-AC03-76SF00098.

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