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Dilepton (e^+e^-) Production Recent pp and pd Studies with DLS at Berkeley

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DILEPTON(e^+e^-) PRODUCTION
RECENT p-p AND p-d STUDIES WITH DLS AT BERKELEY*

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ABSTRACT

The use of dileptons as probes of hot, dense hadronic matter is described. Preliminary results on dileptons produced in p-p and p-d interactions at the Bevalac are presented along with potential ramifications for existing model calculations of dileptons at these energies. Future directions of the dilepton program at Berkeley are outlined.

1. Introduction

A detailed understanding of the production mechanisms and resulting spectra of particles formed in hot, dense hadronic matter is of direct interest to the production and identification of quark matter in heavy ion collisions. This comes about because particles will be emitted over the complete cycle of the nucleus-nucleus collision process, including hadronic, mixed hadronic and quark, and quark matter phases.

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In order to study the time development of the collision, appropriate experimental probes must be developed that can isolate selected features of the interaction. As shown in Figure 1, strongly interacting hadrons are generally felt to reflect the surface features of the hadronic matter produced in the collision. However, dileptons (decay products of virtual photons) and photons, because of their relatively weak interaction with matter, are useful probes of the early hot, dense stage of the collision. At Bevalac energies, where quark degrees-of-freedom are not expected to play a central role, sources of dileptons (e^+e^-) result from a variety of processes, including hadronic bremsstrahlung, radiative decay of the Δ (Ne^+e^-) and pion-nucleon and pion-pion annihilation. Other processes, such as the Dalitz decay ($e^+e^-\gamma$) of π^0's and η's, form an experimental background that must be disentangled before such probes can be sensitive to the extreme conditions of temperature (50–100 MeV) and baryon density ($\rho = [2\text{–}4] \times \rho_0$) expected in collisions at incident kinetic energies up to a few GeV/nucleon. Dilepton production at Bevalac energies has received considerable theoretical attention recently[1–9]. Such calculations demonstrate that dileptons are sensitive to the temperature and density achieved in nucleus-nucleus collisions and may provide unique information on the dynamics of pions in hot nuclear matter.

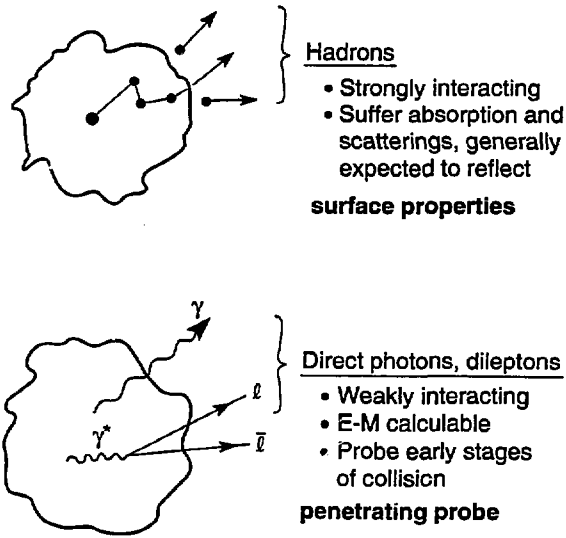

Figure 1. Probes of nuclear matter (hadronic, electromagnetic).

2. DLS Program (p-p and p-d)

At the end of 1986 the DLS collaboration initiated a systematic program of dilepton (e^+e^-) measurements in p-A (p-Be at 1.0, 2.1, and 4.9 GeV) and A-A (1.0 and 2.1 GeV/nucleon Ca-Ca) collisions at the Bevalac. For details of these early results[10–13] and a description of the experimental setup[14] the reader is referred elsewhere. It is worth noting that a positive signal, for direct dilepton production above that expected from such things as the Dalitz decay of the π^0, was observed in all cases. However, the dilepton yield is found to decrease rapidly as the incident energy is lowered.

Recently, p-p and p-d measurements have been added to complement the earlier DLS results. Preliminary results from these measurements are the subject of this paper. There are a number of reasons why measurements of dilepton production in p-p and p-d interactions are an important component to any heavy ion effort studying extreme conditions in nuclear matter. Firstly, in order to understand the production of dileptons in p-A and A-A collisions, it is absolutely necessary that adequate data on the elementary processes (p-p and p-d) be available at the same energy to aid in distinguishing nuclear effects from those that are already present at the nucleon-nucleon level. Secondly, high quality data are needed as input for model calculations of the p-A and A-A interaction yielding dileptons. Thirdly, one wants to learn about the role of hadronic bremsstrahlung, which may result from the many interacting nucleons present in a central nucleus-nucleus collision, through a comparison of p-p and p-d data. Model calculations which have been carried out often assume that the p-n term dominates the p-p term (in the framework of the soft-photon approximation). These calculations suggest that the bremsstrahlung component is strongly dependent on incident energy and may actually dominate hadronic contributions (e.g., radiative decay of the Δ and pion-pion annihilation terms). They further indicate that the ratio of e^+e^- production in p-p and p-d should increase with energy. Based on these calculations the ratio, $R = pd/pp \cong 1 + pn/pp$, for e^+e^- production should vary between about 3 at 1 GeV and increase to a value of 6 or larger at 4.9 GeV.

Figure 2 shows preliminary results of the mass spectrum for p-d (top left panel) and p-p (lower left panel) interactions at 4.9 GeV. The sum of these two data sets (4600 pairs in p-d, 2900 pairs in p-p) represents about an order of magnitude increase over the statistics of the earlier DLS data for p-Be at 4.9 GeV. The upper data points in the two left panels are the opposite sign (+-) pairs, while the shaded area is for like-sign (++ + --) pairs. The subtracted distributions, representing the "true signal" are indicated in the right-hand panels. The ρ-ω region is prominent in both distributions of Figure 2. Figure 3 shows the ratio, R, as described earlier, for the 4.9 GeV data. It is seen to have little or no dependence on the invariant mass of the pair (for pair masses >100 MeV). The preliminary yield ratio, averaged over invariant mass, is found to be 1.64±0.05 at 4.9 GeV. Very preliminary results, based on a small sample of pairs at 1.0 GeV, yield a value of 2.0±0.4, suggesting a relatively weak energy dependence to the

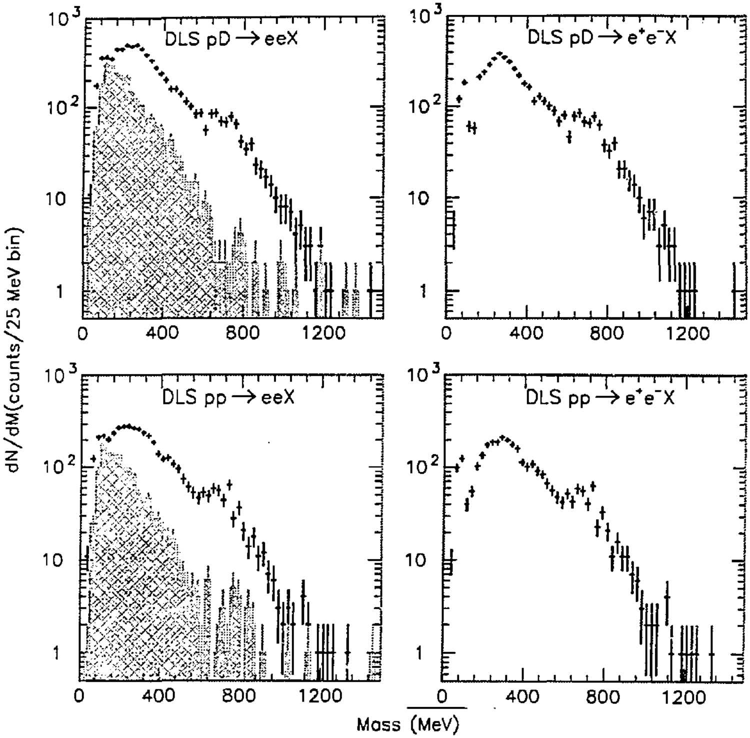

Figure 2. Preliminary results for dielectron mass spectrum from DLS for 4.9 GeV p-d (upper) and p-p (lower). Subtracted (opposite sign-same sign) distributions (right panels) are "true pairs."

ratio. Thus, these preliminary results, for the ratio are in sharp contrast with initial expectations based on theoretical calculations employing the soft-photon approximation. Values of the ratio near 2 would be expected if hadronic sources were to be dominant over bremsstrahlung. This simple ratio needs to be better understood, both experimentally and theoretically, before definite conclusions can be drawn about dilepton production in p-A and A-A collisions at these energies. One possible approach lies in the observation that the omission of particle production (implicit in the soft-photon approximation) is inconsistent with the fact that the nucleon-nucleon cross section is highly inelastic at these energies. Viewed in a slightly different light, the virtual photons responsible for

Ratio of e+e− Yield in p+d and p+p Collisions

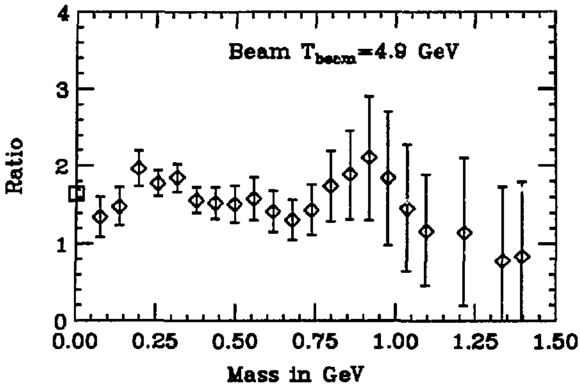

Figure 3. Preliminary value of the ratio (R = pd/pp) of the yields for e^+e^- pair production at 4.9 GeV. Average value of R indicated by square.

the final state e^+e^- pairs are really quite massive (0.1–1.2 GeV), thereby leading to highly inelastic final states.

3. Future Program with the DLS

Data from the DLS collaboration and the theoretical calculations carried out to explain these results have provided a first glimpse into using dileptons as probes of the hot, dense phase of the collision process at incident energies as low as a few GeV/nucleon. Over the next few years the DLS program at the Bevalac will consist of two elements. The first part will involve the completion of the liquid target (p-p and p-d) studies. Higher statistics will be acquired at 1.0 GeV and data will also be obtained at 1.6 (just above η-meson threshold) and 2.1 GeV to complement the existing high statistics 4.9 GeV data set discussed in this paper. The final phase of the DLS program will involve a high statistics study of e^+e^- pair production in Ca-Ca collisions at 1.0 GeV/nucleon. We expect to improve upon our previous measurements by acquiring over an order of magnitude more events (up to about 3000 pairs). Particular attention will be given to the high mass region where pion annihilation may play a prominent role. In addition, with the capability of multiplicity selection in A-A collisions now available with the DLS, new data will be studied as a function of the centrality of the event. *Wolf et al.*[9] have suggested that the contributions from pion annihilation and hadronic bremsstrahlung may be sensitive to impact parameter. Multiplicity selection of the data could provide a means of adjusting the relative strengths of these contributions. In order to carry out this program, substantial amounts of dedicated beam time are required.

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