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W.K. Wilson and the DLS Collaboration

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DIELECTRON MEASUREMENTS IN P+P AND P+D INTERACTIONS FROM E_{BEAM} = 1.0 TO 4.9 GeV

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ABSTRACT

The first measurements of dielectron production in p+p and p+d interactions at incident kinetic energies from 1.0-4.9 GeV are summarized. The dielectron yield at 4.9 GeV is found to be in excess of that expected from hadronic decays. The beam energy and invariant mass dependence of the dielectron yield in p+d interactions relative to the yield in p+p interactions are also presented. The ratio of the yield in p+d to that in p+p interactions decreases from nearly 9 at 1.0 GeV to ≈ 2 at 4.9 GeV. The large ratio at 1.0 GeV suggests that dielectron production in the p+d system is dominated by a p+n process. The beam energy dependence of the ratio indicates that this p+n contribution decreases with respect to the other dielectron sources as the incident energy is increased.

This talk will summarize the first results of the DLS (Dilepton Spectrometer) proton beam & hydrogen target program at the Bevatron[1,2]. The main goal of this work is to elucidate the processes leading to dielectron production in nucleon-nucleon collisions. However, since this workshop is concerned with the study of nuclear dynamics, it is first necessary to provide the heavy-ion physics motivation for studying dielectrons. My introduction will also outline some of the potential sources of dielectrons in the Bevatron/Bevalac beam energy range. Next will follow a very brief

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overview of the DLS experimental and analysis procedures. We will then compare the dielectron invariant mass spectra obtained from 4.9 GeV p+p interactions with the contributions expected from hadron decay for this system. Finally, we will examine the dielectron yield from p+d interactions relative to that from p+p interactions for clues as to the dominate processes leading to electron-positron pair production.

1. Introduction

Dileptons are useful probes of the hot, compressed nuclear matter produced in the early stages of heavy-ion collisions due to their low interaction cross sections with the nuclear medium[3]. Compared to hadrons, electro-magnetic probes such as dileptons leave the collision zone relatively undisturbed and therefore carry direct information about the conditions within the nuclear fireball. Hadrons, on the other hand, carry information about the conditions following the expansion and cooling of the system, from which the initial evolution of the system must be inferred.

The first measurements of electron pairs produced in Ca+Ca and Nb+Nb collisions for beam kinetic energies from 1-2 GeV/nucleon[4] have proven difficult to interpret due to a lack of knowledge of the fundamental nucleon-nucleon cross sections for the many processes[5,6] which contribute to the dielectron yield. These processes include the production of virtual photons through p+n bremsstrahlung, direct and dalitz decay of hadrons, and pion annihilation. Similar difficulties were also encountered in the various attempts to interpret the dielectron yields observed using the simpler p+Be system[7,8]. The present study of p+p (pp) and p+d (pd) interactions has been undertaken in order to explore the relative contributions of bremsstrahlung and hadronic decay sources to the dielectron cross sections in nucleon-nucleon interactions. This understanding can then be applied towards evaluating the roles of these sources in heavy-ion reactions.

Any process which can produce a real photon can produce a massive virtual photon which decays to an electron-positron pair, albeit with a lower cross section due to the fine structure constant arising from the additional electro-magnetic vertex. Thus bremsstrahlung, which occurs when charges are accelerated during an interaction, produces dielectrons as well as real photons[9]. Similarly, all of the hadrons which decay into gamma rays can also produce virtual photons which then decay to dielectrons. Of course, in this case the mass of the virtual gamma ray and hence the invariant mass of the dielectron will always be less than the mass of the hadron. This property of dielectrons gives them a distinct advantage over real photons since the huge (but largely uninteresting) contribution from π° decay can be filtered out of the data sample simply by restricting the sample to pairs more massive than the pion. It would be very difficult to eliminate the π° background from any study of the real photon continuum in a heavy-ion collision environment when the beam energy is well above the pion threshold. Therefore, despite the difficulties inherent in their detection, dileptons are the electro-magnetic probe of choice at these beam energies.

2. Experimental Setup and Analysis

Proton beams of 1.03, 1.26, 1.60, 1.85, 2.07, and 4.9 GeV kinetic energy were provided by the Lawerence Berkeley Laboratory Bevatron. Electron pairs were detected using the DLS, a twin arm magnetic dipole spectrometer. Their low production cross section make dielectrons difficult to use as probes of nuclear collisions compared to hadrons due to the relatively high beam rates required to achieve a statistically significant sample. Thus, the detector system must be designed to be sensitive to the rare dielectron signal while withstanding a barrage of hadrons. The DLS uses threshold Ĉerenkov gas radiators to preferentially trigger on electrons. For details of the DLS hardware and performance, please see Ref. 10. In the DLS liquid target program, the solid target described in the reference was replaced by a 8.6 cm long cylinder which was filled with liquid hydrogen or deuterium for the pp and pd runs respectively. Like-sign pairs are used to estimate the combinatoric background within the opposite-sign sample. The "true" pair yield is given by subtracting the combinatoric background from the opposite-sign pairs. The yields were normalized by the total number of incident protons in each projectile-target combination and by the densities of the liquid hydrogen and deuterium targets. No correction for the DLS acceptance was applied to the data presented in this talk. Dilepton production cross sections corrected for the DLS acceptance will appear in subsequent papers[11].

3. The Dielectron Yield In p+p Interactions At 4.9 GeV

Measurements of the dilepton yield from p+Be collisions at 450 GeV[12] by the HELIOS collaboration indicate that the Dalitz decays of η and ω mesons may be crucial in accounting for the dielectron yield at masses from 0.1-0.7 GeV/c^2. Although the energy available in the HELIOS experiments is far larger than that in our pp and pd studies, these results suggest that we should carefully investigate the role of hadron decay at Bevalac energies as well. Our estimate of the dielectron yield based from hadron decays, however, does not account for the magnitude of the yield observed in pp interactions at 4.9 GeV. We compare in Fig. 1 the dielectron yield expected from hadron decays to that measured by the DLS group for this system. The electron pairs produced via hadron decay were passed through a GEANT simulation of the DLS and reconstructed using the same software employed in the analysis of the experimental data. Full details of this calculation may be found in Ref. 1 by Huang et al.

4. The p+d To p+p Dielectron Yield Ratio

The ratio of the pd to pp dielectron yields (pd/pp ratio) should clearly indicate the relative importance of hadronic decay with respect to pn bremsstrahlung. In pp interactions, the photons produced by the incoming and outgoing proton lines interfere destructively, yielding a cross section which is traditionally expected to be an order of magnitude smaller than that of pn bremsstrahlung[13]. If bremsstrahlung is the dominant source of dielectrons, the pd/pp ratio [taken as (pn+pp)/pp] would thus

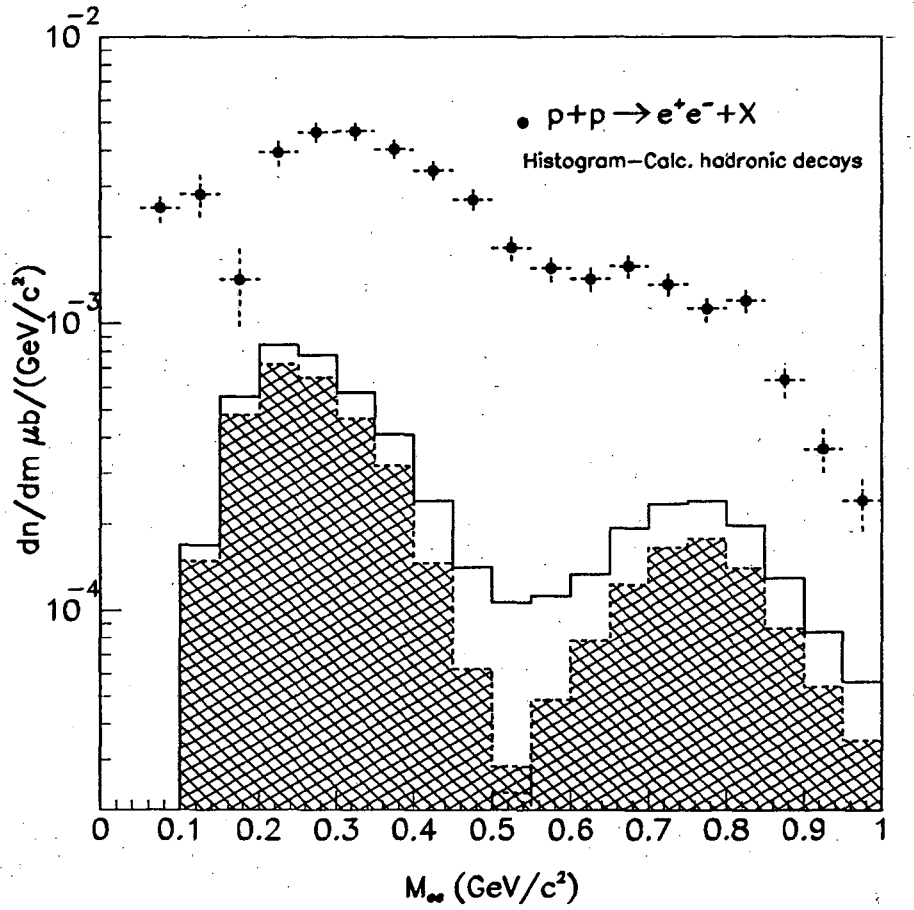

Fig. 1: The dielectron measured in p+p interactions in comparison with the total probable contribution (solid histogram) in the DLS acceptance from decays of the η, ρ, ω, and Δ. The production cross sections were estimated to be σ_η=0.30 mb, σ_Δ=5 mb, and $\sigma_{\rho,\omega}$=0.15 mb. The hatched areas indicate the individual contributions from the Dalitz decay of the η and the two-body decay of the ω, respectively.

be 10 or larger. On the other hand, if most dielectrons are produced through hadronic decays, the pd/pp ratio would have a value closer to 2-4 since hadron production cross sections in pn interactions are typically no more than 3 times larger than those of pp reactions in this energy regime[14].

From an experimental point of view, the pd/pp ratio is a particularly clean observable since the detector efficiency is the same for both systems and thus cancels out of the ratio. We also found that the dielectron mass, transverse momentum, and rapidity distributions were similar enough to cancel the acceptance out of the pd/pp ratio to within the statistical uncertainty of these measurements.

The pd/pp ratio is plotted in Fig. 2 as a function of the invariant mass of the electron pair. Note that in the data for beam energies from 1.0-1.6 GeV, the ratio increases with pair mass. Some of this trend may be due to Fermi motion contributions

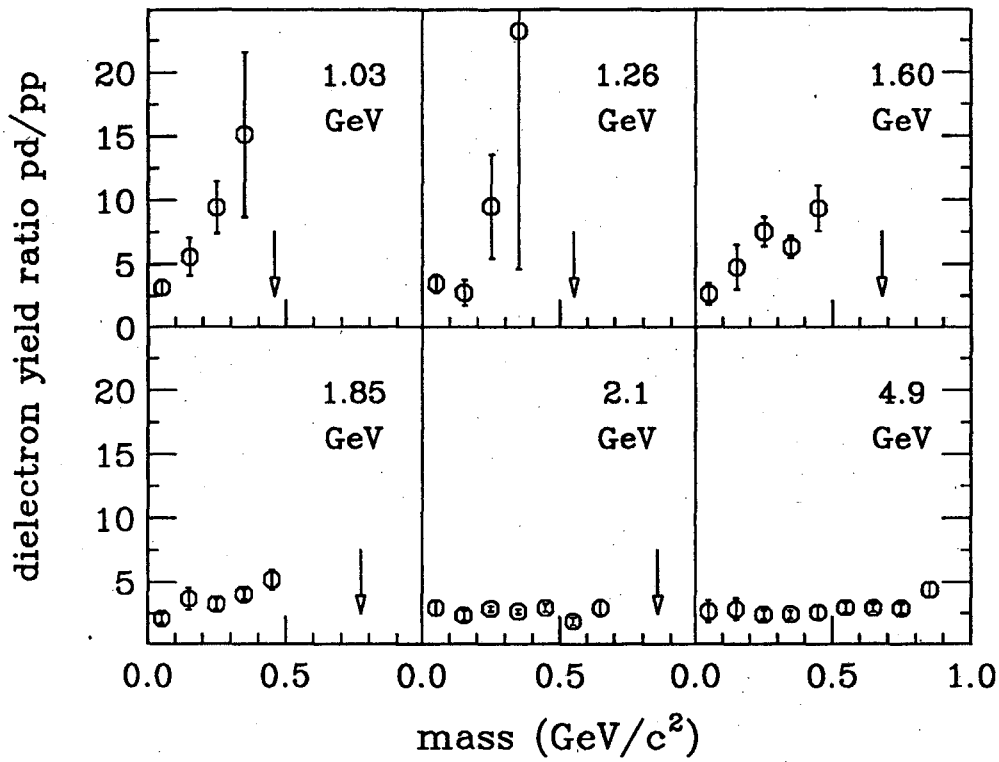

Fig. 2: The pd/pp ratio as a function of the invariant mass of the electron pair.The maximum dielectron mass kinematically allowed in pp collisions is indicated by an arrow for each beam energy except 4.9 GeV, where the limit, m=1.7 GeV/c^2, is off-scale.

to the collision energy in the pd system. At a fixed incident energy, the pd system can create dilepton pairs of greater mass than the pp system, so we would expect an increasing pd/pp ratio when the pair mass approaches the kinematical limit. The arrows in the figure indicate the upper limits on the dielectron masses for pp interactions. However, the mass dependence may also reflect the contributions of different dilepton production mechanisms in pd and pp interactions[6].

Dielectrons with mass less than the pion mass are dominantly produced by the Dalitz decay of neutral pions[8]. As stated earlier, we can eliminate the π° contribution simply by restricting the study to mass range under consideration. The pd/pp ratio in the m$\geq$0.15 GeV/c^2 region, displayed in Fig. 3, is largest at 1.0 GeV incident energy. At this energy, pn bremsstrahlung and Δ Dalitz decay have been predicted to be the dominant sources of dielectrons with masses greater than the pion mass.[15,16] Since the expected cross sections for Δ^+ and Δ^o resonance excitation[14] provide a pd/pp ratio of only 2.7, there must be an additional pn dielectron source such as bremsstrahlung.

Another possible cause of the large pd/pp ratio at the lower beam energies is subthreshold η production. Preliminary reports from the PINOT spectrometer at SATURNE[17] indicate that the pn/pp ratio for η production may be 4-8 near threshold. Together with the knowledge of the Δ production cross sections, the comparison of

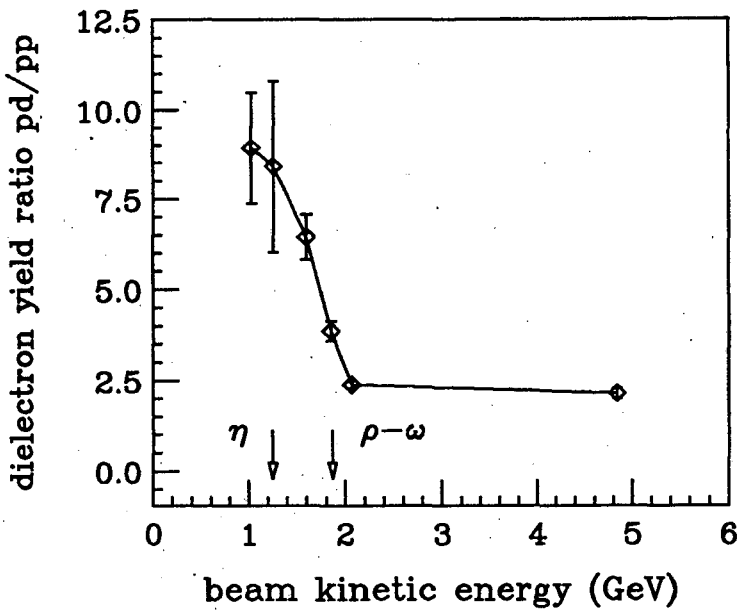

Fig. 3: The pd/pp ratio as a function of the beam energy for pairs with m>0.15 GeV/c^2. The error bars are smaller than the plotting symbols for the 2.1 and 4.9 GeV data. The beam energy thresholds for η and ρ-ω meson production are indicated by the two arrows. The lines are only to guide the eye.

the PINOT η measurements with our pd/pp ratio data should pin down the role of pn bremsstrahlung production of dielectrons at the lower beam energies.

Note that the data displayed in Fig. 3 indicate that the pd/pp ratio of the dielectron yield decreases dramatically with increasing energy. This trend could be due to increasingly important hadronic decay contributions, or an unexpectedly large pp bremsstrahlung contribution at the higher beam energies[13]. In an early theoretical calculation, pn bremsstrahlung was predicted to dominate the other sources of dielectrons in p+Be collisions at 4.9 GeV[15]. This possibility is excluded by the low pd/pp ratio that we observe at beam energies above 2.0 GeV. Full details of the pd/pp ratio measurements may be found in Ref. 2 by Wilson et al.

5. Conclusions

We have measured the ratios of the pd to pp dielectron yields for incident kinetic energies from 1.0-4.9 GeV. The ratio for pairs with invariant masses greater than that of the pion decreases from 8.9±1.5 at 1.0 GeV to 2.14±0.14 at 4.9 GeV. The large pd/pp ratio of the dielectron yield at 1.0 GeV indicates a significant pn contribution to the dielectron yield in p+d collisions. We have also found that the dielectron yield in p+p interactions at 4.9 GeV cannot be accounted for using only the known hadronic decays with their most probable production cross sections.

As the analysis of this data set proceeds, we expect that the dielectron cross sections which will be extracted as a function of the mass, transverse momentum,

and rapidity of the pair will allow more quantitative statements to be made about the sources of dielectrons in these interactions. At the very least, they will provide input into cascade calculations which can then be compared to dielectron measurements in heavy-ion collisions. Thus, we will soon be within reach of the goal which provided much of the original motivation for the DLS project: quantifying the modifications of nucleon-nucleon interactions which occur when the collision takes place within a hot, compressed nuclear medium.

In closing, it is important to note that nucleon-nucleon dielectron production is interesting in its own right apart from its applications to electron pair production in heavy-ion collisions. For example, the coupling of a bremsstrahlung virtual photon to a proton is not known and these pd and pp studies are the only measurements available to address this form factor. Theoretical predictions of the form factor vary from 1.0 to the VDM (vector dominance model) which predicts an enhancement in virtual photon production in the ρ-ω mass region. It is our hope that our measurements can address some of these long-standing questions about fundamental interactions.

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