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THRESHOLD BEHAVIOR OF DIRECT ELECTRON PRODUCTION IN PROTON-BERYLLIUM COLLISIONS

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ABSTRACT

We report measurements of direct electron pair production in p-Be interactions at 1.0, 2.1 and 4.9 GeV kinetic beam energies. The invariant mass and p_t spectra along with the total cross sections are presented. A rapid decrease in the total cross section is observed at the lowest energy.

INTRODUCTION

The study of low-mass electron pairs ($m < 1$ GeV/c^2) in proton-nucleus collisions has been a subject of considerable theoretical and experimental interest. Incisive measurements in the early seventies at Fermilab[1] proved that the low-mass dilepton and low-p_t single lepton yields were not fully understood. To address these questions a series of additional experiments ranging from ISR energies to laboratory beam energies of 12 GeV were pursued [2–7]. It has been determined that the low mass continuum could neither be explained by meson and vector meson decay nor by the Drell-Yan model (naive extrapolation to lower masses yields a underestimate by an order of magnitude). While many mechanisms have been suggested to explain the low mass region such as modified Drell-Yan, hadronic Bremsstralung and soft parton annihilations, this region is still not fully understood. Within the available statistics, the low p_t single lepton yield was found to be consistent with its origin predominantly from low mass pairs[2]. The result of a single-electron experiment[8] which did not observe direct electron production in proton-proton collisions at a kinetic beam energy of 800 MeV suggests a *threshold* between 1 and 10 GeV. We present here the study of e^+e^- production in p+Beryllium interactions at 1.0, 2.1, and 4.9 GeV kinetic beam energies.

EXPERIMENTAL APPARATUS

The data were obtained with the Di-Lepton Spectrometer (DLS) at the Bevalac. Physics considerations guided us to employ a large acceptance spectrometer to compensate for the expected low production rate. Adequate detector segmentation were implemented to discriminate between the hadrons and electrons(e^+ and e^-) in the heaviest system we planned to investigate (ie. Ca+Ca at 2.1 GeV). The experimental apparatus consisted of a segmented Beryllium targets at the vertex of two symmetrical arms, each arm covering an angular range with respect to the beam axis of $17^0 < \Theta < 63^0$ and 14^0 in the transverse plane. This translates into a electron pair kinematic range of approximately .1 to 1 GeV/c^2 in mass, 0 to 800 MeV/c transverse momentum (p_t) and 0.5 to 1.9 units of laboratory rapidity (y). The electrons were identified by using large segmented gas Cerenkov counter's having approximately 95 percent electron detection efficiency and 10^{-5} hadron rejection per arm. The momentum reconstruction in each arm was obtained by use of one wire chamber before and two behind a large dipole magnet. The momentum resolution was balanced in favor of maximizing the acceptance of the low mass pairs by setting the magnetic field at 1.5 kilogauss. This yielded a momentum resolution of 15 percent. A sixteen segmented scintillator hodoscope in front and behind the dipole magnets were used in combination with the cerenkov counters to both trigger the apparatus and to give a first order tracking.

The direct lepton signal (true pairs), which originates from a single elementary process is found by subtracting the same sign pairs from opposite sign pairs. This is because the electron pairs are independently produced thus creating charge symmetry of false pairs. Such electrons may be produced through Dalitz decay of a π^0 or gamma-ray conversion. This removes the main background (false pairs). The segmentation of the target and the designed minimal detector thicknesses reduces the rate of external conversions. In p+Be collisions the false pairs are dominated by Dalitz produced electrons. One wide-angle Dalitz decay however may trigger our system at a very low rate and cannot be removed by this subtraction process. This contribution to the invariant mass cross sections is estimated by using the known meson production cross sections in pp interactions, branching ratios and Dalitz decay mass structure[9]. In this analysis we have included the Dalitz decays of π^0, η, ω, and K_0 and the $\Delta(1232) \rightarrow Ne^+e^-$.

EXPERIMENTAL RESULTS

In an earlier publication[10] this group reported, the existence of a di-electron signal was clearly established at 4.9 GeV kinetic beam energy. The pair statistics of these results along with 2.1 and 1.0 GeV data is shown in Table 1 (the results of the 1.0 GeV data are still considered preliminary at this stage). The existence of the di-electron signal is clearly established at all three energies. Contributions from empty target interactions were significant only in the 2.1 GeV data where we experienced a beam halo problem.

Interaction	Energy [GeV]	Opposite Sign Pairs	Same Sign Pairs	Direct Pairs $D \pm \sigma_D$	R=D/F	D/σ_D
p + Be	4.90	732	201	531±31	2.6	17.4
p + Be	2.10	567	148	419±27	2.8	15.7
p + Be	1.04	204	58	146±16	2.5	9.1

Table 1. Pair statistics for each kinetic beam energy

The absolute cross sections were obtained by applying the acceptance, efficiency corrections and beam normalization factors to the raw data. The acceptance array, the inverse of which weights each event, was generated via Monte Carlo techniques spanning all the accessible phase-space volume in increments of Δp_t, Δy and Δm. The efficiencies (ie. tracking, vertex cuts...) were all established using analysis techniques on both the raw data and Monte Carlo generated events. Two sets of beam hodoscope counters and a calibrated ion chamber monitored the beam flux. The errors in the table reflect only the experimental statistical uncertainty; the overall systematical error is estimated to be approximately ±50 percent. Additional information concerning the detailed acceptance studies and the data analysis may be found in ref. 10.

Figure 1. shows the cross section per nucleon (assuming an $A_t^{2/3}$ dependance) for p+Be as a function of the invariant mass for all three kinetic beam energies. There exist several interesting features to be compared at each bombarding energy. Noticeable at each energy is a sharp increase in the cross section at masses less than 100 MeV. This is seen to be primarily composed of π_0 Dalitz decay with perhaps some additional hadronic bremsstralung. The total contribution of all higher mass meson Dalitz decays is estimated to be 2 orders of magnitude smaller than the observed data[11]. The rho-omega resonance is seen clearly in the 4.9 GeV data around m = .75 GeV/c^2. It is not observed at either 2.1 or 1.0 GeV. However, this is expected since the available center of mass energy at 2.1 GeV kinetic beam energy is .854 GeV barely

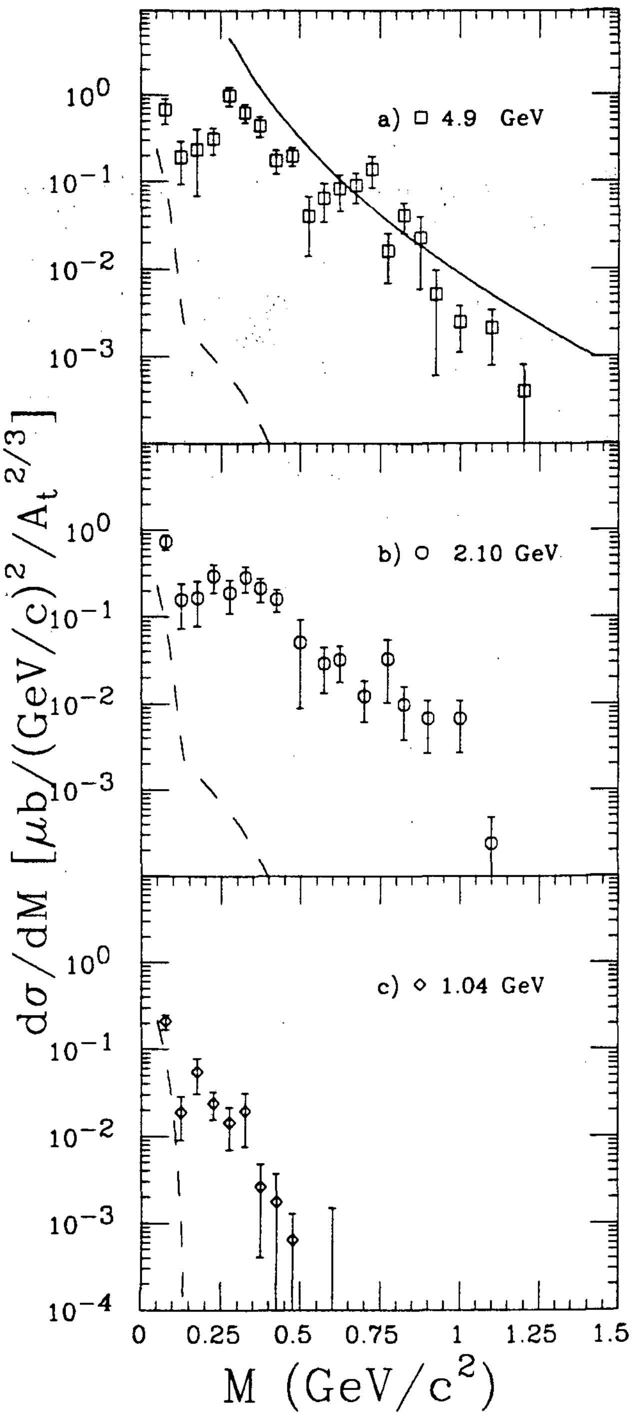

Figure 1. The invariant mass spectra for p+Be at all three kinetic beam energies. (a) The 4.9 GeV DLS data. The solid line is a fit to the KEK 12.1 GeV data.(ref 2) (b) The 2.1 GeV DLS data. (c) The 1.0 GeV DLS data. The dotted line with each figure is the estimated contribution due to the wide angle Dalitz decay at each energy.

above the absolute kinetic threshold for rho-omega production. Comparison with a parameterization of the KEK 12.1 GeV data[2] (the solid curve in Figure 1.(a)) shows that the general shape of the distribution is similar to that at higher energies. For the first time a measurement of the mass structure in regions less than 300 MeV is performed[12]. A structure is observed in both the 4.9 and 2.1 GeV invariant mass distribution near $2m_\pi$. This strongly suggests that a $\pi^+\pi^-$ annihilation mechanisms dominates the production in this energy range. Theoretical studies[13] indicate a thorough understanding of this annihilation structure in heavy systems (ie. Ca+Ca) could yield information concerning the pion dispersion relation and thus information on the density of hot hadronic matter. A rapidly falling cross section is observed in the 1.0 GeV spectra. This is what would be expected for a combination of Dalitz decay, $\pi^+\pi^-$ annihilation and dominating hadronic bremsstralung.

The p_t dependence of our cross section per nucleon, integrated over mass ($m>200$ MeV/c^2) and y as a function of p_t for all three beam energies is shown in Figure 2. The slopes of all three data sets agree well with one another. The data is adequately fit by a form $d\sigma/dp_t^2 = \exp(-\alpha p_t)$ with $\alpha = 6.$. It is interesting to note that this is similar to the higher energy e^+e^- data and the well known low-p_t hadronic dependence.

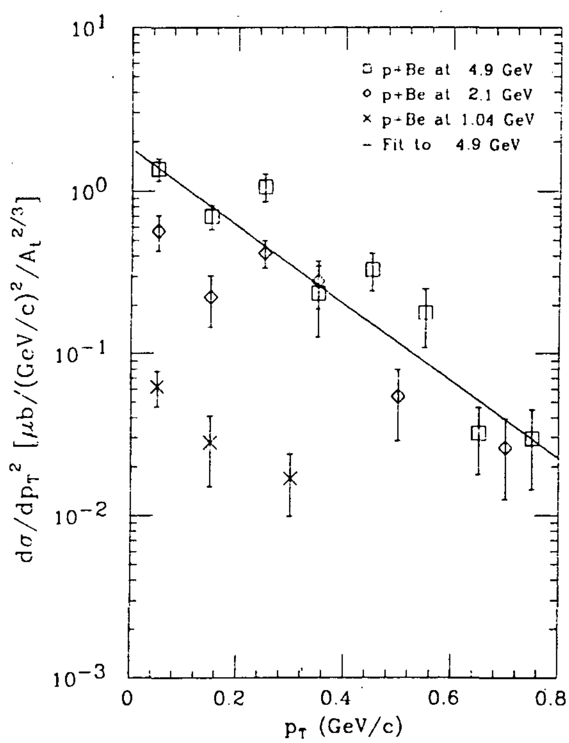

Figure 2. The cross section per nucleon, $d\sigma/dp_t^2$, as a function of p_t for all three kinetic beam energies. The solid line is a fit of the 4.9 GeV data.

The total integrated e^+e^- cross sections per nucleon (200 MeV >m>700 MeV) as a function of the available nucleon-nucleon center-of-mass energy (Q $=\sqrt{s}$-2m_p) is shown in Figure 3. A rapid decrease in the cross section is seen at low energy. Naively one would expect that the Q dependence would be similar to that of the total pp inelastic cross section or perhaps the π^0 production cross section, as the e/π ratio is constant at higher energies. However, both cross sections are approximately constant in the energy range where our experimental data shows a threshold. A comparison with the energy dependence of heavier mesons is not feasible since the data is too meagre at these low energies [14]. From bubble chamber data[15] we have computed the inclusive $\pi^+\pi^-$ production cross section at these low energies. Shown as the solid curve in Figure 3. is the Q dependence of $\pi^+\pi^-$ production, scaled down by 75,000 ($= \alpha^2/4$). Both the e^+e^- and $\pi^+\pi^-$ production cross sections have similar threshold behavior. This evidence also supports the interpretation of $\pi^+\pi^-$ annihilation dominating the dielectron production at these energies.

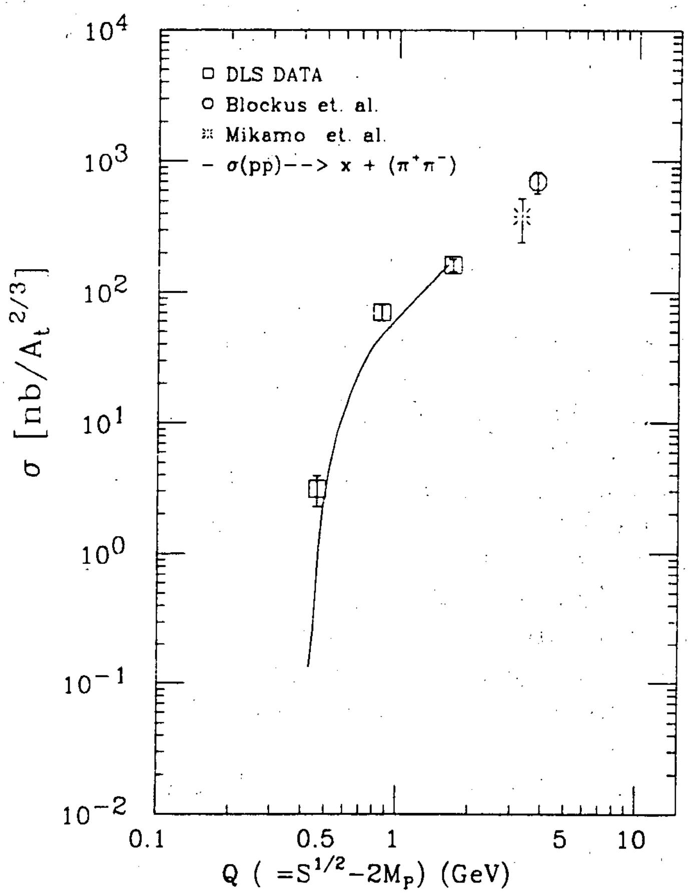

Figure 3. The total integrated e^+e^- production cross section as a function of the available nucleon-nucleon cm. energy. $\sqrt{s}$-2m_p: circle, Blockus et al. (ref. 3); triangle, Mikamo et al. (ref 2); squares this experiment. The solid curve shows the $\pi^+\pi^-$ production cross section (scaled down by 75,000). respectively.

SUMMARY

In summary, dielectron production at 4.9, 2.1 and 1.0 GeV has been observed. The production cannot be explained by meson decays. A unique structure in the invariant mass distribution is observed at twice the pion mass at both 4.9 and 2.1 GeV. The total integrated cross sections are found to rapidly decrease at low energies. Both the mass structure and energy dependence is consistent with the interpretation that the dominant production mechanism is the $\pi^+\pi^-$ annihilation.

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