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BRIEF REPORTS

Brief Reports are short papers which report on completed research or are addenda to papers previously published in the **Physical Review.** *A Brief Report may be no longer than 3½ printed pages and must be accompanied by an abstract.*

Mass and transverse momentum dependence of the dielectron yield in *p*-Be collisions at 4.9 GeV

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We present the invariant mass and transverse momentum dependence of direct electron-positron pair production in *p*-Be collisions at a beam kinetic energy of 4.9 GeV. The acceptance of our apparatus is shown to have no significant effect for masses above 0.15 GeV. After a correction is made for the available phase space, the transverse momentum dependence of the data is found to be comparable to hadron-hadron observations. A phenomenological calculation involving $\pi^+\pi^-$ annihilation into e^+e^- is shown to be in good agreement with our measurements.

The dilepton spectrometer (DLS) collaboration at the Bevalac has undertaken a program to study dielectron (e^+e^- pair) production in *p*-nucleus and nucleus-nucleus collisions. Previous data[1] have established the existence of low mass, low transverse momentum direct pairs at beam kinetic energies (T) of 12 GeV and above. However, for masses below 3 GeV the continuum is not fully understood. In particular the relative contributions of various mechanisms such as soft parton annihilation, hadronic bremsstrahlung, and pion annihilation, have not yet been well established. Furthermore, in nucleus-nucleus collisions new phenomena could strongly modify the dilepton mass spectrum.[2]

In a previous publication[3] we reported the observation of direct electron-positron pairs in *p*-Be collision at $T=4.9$ GeV. The cross sections were found to be similar to measurements at higher energies except for a structure observed in the mass spectrum at about 0.275 GeV, a mass region not well studied in earlier data. Such a structure at nearly twice the pion mass would suggest that dielectron production through pion annihilation is a dominant mechanism in that region. In the present paper, the double differential cross section $d^2\sigma/dm\,dp_t$ is presented and details of the DLS acceptance are discussed. A description of the DLS can be found in our earlier publications[3,4] and is the subject of a separate paper.[5] The basic concept is a spectrometer made of two identical arms arranged symmetrically with respect to the beam axis. Two large aperture dipole magnets (one in each arm) are powered independently and the data are collected with the four combinations of field polarities for equal length of time. Thus the DLS is a charge symmetric detection device, i.e., the acceptance does not depend on the charge combination of a pair but only on its kinematical variables.

The DLS data are subject to two types of backgrounds. The false pair background, where the detected electrons are uncorrelated, is produced equally with all charge combinations. Since the detection is charge symmetric we have removed this background by subtracting, after the acceptance correction is made, the same-sign pairs from the opposite-sign pairs.[3] The true-pair background, which is primarily from Dalitz decay of mesons and resonances, is estimated[4] to have a small contribution for masses above 0.2 GeV. This background has not been subtracted from the data presented here.

The geometric acceptance of the DLS was computed by a Monte Carlo technique. This simulation, which included a detailed representation of our detector, was constructed using the GEANT software library.[6] We assumed an isotropic production of the electrons in the center-of-mass frame of the pair and computed the acceptance on a three-dimensional mesh as a function of the invariant mass (m) of the pair, the transverse momentum (p_t), and the laboratory rapidity (y). Calculations were limited in phase space to a fiducial volume defined by $\{m\in[0.05,1.25]\ \text{GeV}\}\otimes\{p_t\in[0,0.8]\ \text{GeV}\}\otimes\{y\in[0.5,1.9]\}$. All integrations presented in this paper were done within these limits and acceptance corrections refer to the additional corrections done inside that volume. To date our acceptance is based on 2.2×10^5 accepted pairs corresponding to about 6×10^7 generated events. The results of our calculations are shown as a function of (m,p_t) in Fig. 1. In the (m,p_t) plane our acceptance is roughly limited for $m<0.25$ GeV to a region where $p_t<4m-0.2$ GeV. Although the system has a small region with zero acceptance inside the fiducial volume, it was found that this has little effect on the mass spectrum for masses above 0.15 GeV. As an example we used the parametrization of Kinoshita, Satz, and Schildknecht[7] (KSS):

$$\frac{d^3\sigma}{dm\,dp_t^2dy}=C\frac{\lambda^2 m^{-\beta}}{2(\lambda m+1)}e^{-\lambda E_t}(1-x_0)^{\alpha}\ , \qquad (1)$$

where C, λ, α, and β are constants taken from Ref. 8 ($C=40$ nb GeV^3, $\lambda=6$ GeV^{-1}, $\alpha=3.5$, and $\beta=4$) and where $E_t=(m^2+p_t^2)^{1/2}-m$ and $x_0=E/E_{\max}$. Figure 2 shows the KSS mass spectrum and the result of a calculation from Lichard[9] based on soft parton annihilation. Both distributions are shown with and without the acceptance correction. Above a mass of 0.15 GeV there is no significant distortion introduced by our acceptance in the shape of either of these distributions.

Our 4.9-GeV data are shown in Fig. 3(a) as a double differential cross section per nucleon, $d^2\sigma/dp_tdm$, assuming an $A^{2/3}$ dependence. Data were corrected for acceptance using linear interpolations between the mesh points.[10] One can divide this data set into three main regions corresponding to different data clusters: the low p_t ($p_t<0.1$ GeV) and low mass ($m<0.1$ GeV) where the Dalitz decay of π^0 dominates, the intermediate p_t (0.3 GeV) and mass around 0.275 GeV where the structure is observed in the mass distribution, and finally the $\rho-\omega$ region with $p_t>0.4$ GeV and mass around 0.75 GeV. Figure 3(b) shows the mass distribution for three different p_t slices. One observes that the structure as well as the $\rho-\omega$ resonance are seen only in the highest and the intermediate p_t regions.

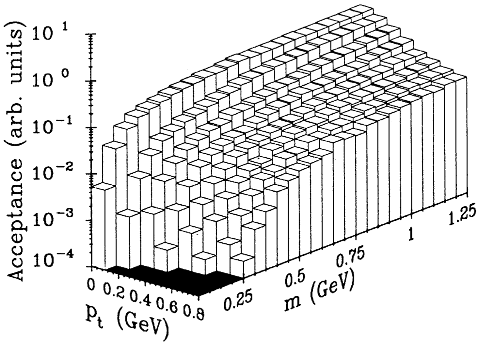

FIG. 1. The acceptance of the DLS as a function of m and p_t. The dark region is an area of zero acceptance. The average acceptance over the fiducial volume is 0.8%.

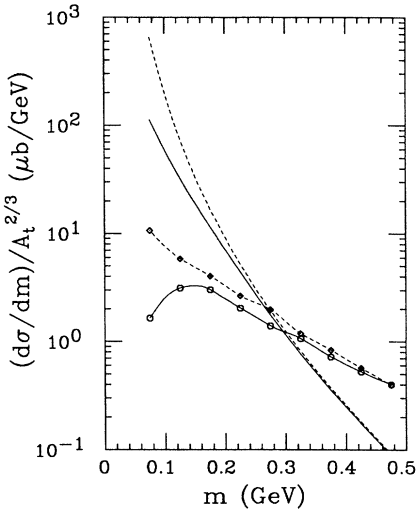

FIG. 2. $d\sigma/dm$ is shown as calculated from Eq. (1) (lines) and from Lichard (Ref. 9, lines with symbols). Solid lines include acceptance corrections, dashed lines do not. For both expressions there are no significant corrections above 0.15 GeV.

This correlation between the invariant mass and the transverse momentum, higher mass pairs being produced at higher p_t, has already been observed in hadron-hadron collisions at higher energies.[7,11] The transverse momentum behavior of a hadronic secondary of mass m_h is well reproduced by

$$\frac{d^2\sigma}{dp_t^2dy\,|_{y=0}}\propto e^{-\lambda E_t},\quad \lambda=6\ \text{GeV}^{-1} \qquad (2)$$

leading to an average p_t as a function of m_h of the form

$$\bar{p}_t(m_h)=\frac{\lambda m_h^2}{\lambda m_h+1}e^{\lambda m_h}K_2(\lambda m_h)\ , \qquad (3)$$

where $K_2(x)$ is the modified Bessel function of the second kind. As pointed out in Refs. 7 and 12, this parametrization agrees well with the existing lepton pair data when one replaces m_h by the invariant mass of the pair.

The average transverse momentum as a function of the pair mass of our p-Be data at 4.9 GeV is compared with the above parametrization in Fig. 4. The dashed line is the prediction of the KSS model corrected for our acceptance. The dotted line represents the predictions of Eq. (2) and includes a phase space correction factor:

$$\bar{p}_t(m)=\frac{\int p_t e^{-6E_t}\phi_3(m,p_t,y)\,dp_t^2dy_{\text{c.m.}}}{\int e^{-6E_t}\phi_3(m,p_t,y)\,dp_t^2dy_{\text{c.m.}}}\ . \qquad (4)$$

The phase space distribution $\phi_3(m,p_t,y)$ is obtained by assuming that the final state contains only two nucleons in addition to the e^+e^- pair:

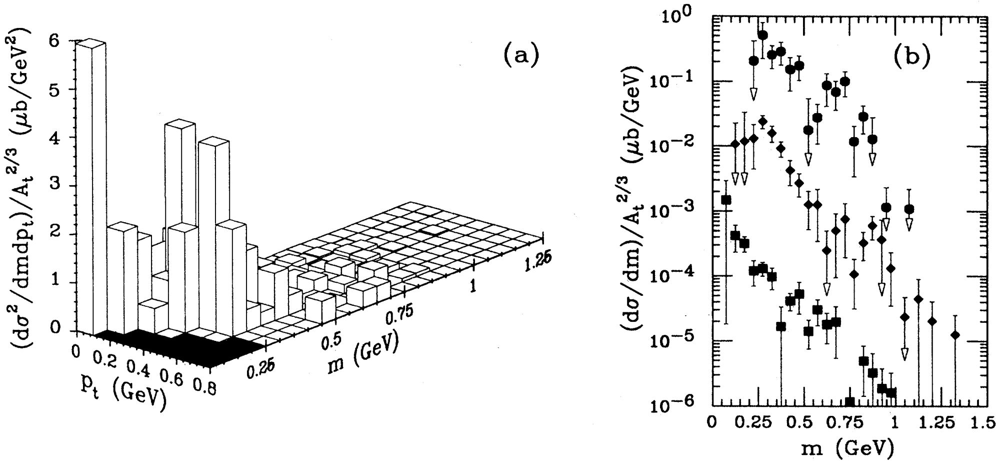

FIG. 3. (a) $d^2\sigma/dm\,dp_t$ is shown in a "lego" plot. The dark region is an area of zero acceptance. (b) $d\sigma/dm$ in p-Be at 4.9 GeV for various p_t intervals ([0,0.1] GeV (solid squares), [0.1,0.3] GeV (solid diamonds), [0.3,0.8] GeV (solid circles)). No structure is observed in the lowest p_t range and the $\rho-\omega$ peak is more pronounced in the highest. From bottom to top scaling factors are $\frac{1}{400}$, $\frac{1}{20}$, and 1.

$$\begin{aligned}\phi_3(m,p_t,y_{\text{c.m.}})&=\frac{\pi(\hat{s}-4m_n^2)^{1/2}}{4\sqrt{\hat{s}}}\,,\\ \hat{s}&=s+m^2-2\sqrt{s}\,m_t\cosh(y_{\text{c.m.}})\,,\end{aligned} \tag{5}$$

where m_n is the nucleon mass, $\sqrt{s}$ is the total c.m. energy, and $m_t=(m^2+p_t^2)^{1/2}$. The solid line in Fig. 4 is Eq. (4) with our acceptance corrections included. Note that the only noticeable difference is in the low p_t region ($p_t<0.2$ GeV).

As shown in Fig. 4, Eq. (4) agrees better with our data than the KSS parametrization. One should, however, note that, when computing $\bar{p}_t(m)$, the explicit m dependence $[\lambda^2 m^{-\beta}/(\lambda m+1)]$ of the KSS model cancels out. Thus the only difference between the two parametrizations lies in the computation of phase space. We have used a three-body phase space whereas the KSS expression uses the function $(1-x_0)^{3.5}$ which is based on high-energy results ($\sqrt{s}>10$ GeV).

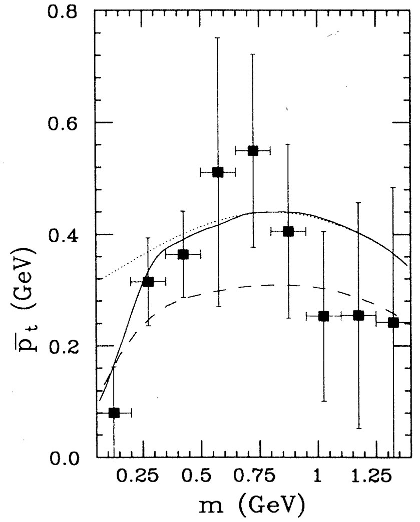

FIG. 4. Average p_t as a function of m. The dotted line is Eq. (4), the solid line is Eq. (4) including acceptance corrections, and the dashed line is the KSS model including acceptance corrections. Note that for all curves the decrease of $\bar{p}_t$ at large masses is due to the limited phase space.

To address more precisely the question of dipion annihilation suggested by the structure observed at $2m_\pi$, and in the spirit of Ref. 7, we have used the KSS parametrization to describe the dipion distribution as follows:

$$\frac{d^3f_{\pi^+\pi^-}}{dm\,dp_t^2dy}=C\frac{\lambda^2m^{-\beta}}{2(\lambda m+1)}e^{-\lambda E_t}\phi_3(m,p_t,y)\,, \tag{6}$$

with $\lambda=6$ and where β is a free parameter. The constant C is taken so that

$$\int\frac{d^3f_{\pi^+\pi^-}}{dm\,dp_t^2dy}dy\,dp_t^2dm=\frac{\sigma_{pp\to\pi^+\pi^-+X}}{\sigma_{pp\to X}}=\frac{13\text{ mb}}{41\text{ mb}}\,. \tag{7}$$

$\sigma_{pp\to\pi^+\pi^-+X}$ was taken from Ref. 13 and $\sigma_{pp\to X}$ from Ref. 14.

Using this parametrization, and assuming that the ratio of p-p cross sections entering Eq. (7) is identical for p-n interactions, the cross section for the reaction $p+N\to e^+e^-+X$ through dipion annihilation will be

$$\frac{d^3\sigma}{dm\,dp_t^2dy}=\sigma_{\pi^+\pi^-}^{e^+e^-}(m)\frac{d^3f_{\pi^+\pi^-}}{dm\,dp_t^2dy}\,, \tag{8}$$

where $\sigma_{\pi^+\pi^-}^{e^+e^-}(m)$ is the cross section for dipion annihilation into an e^+e^- pair:

$$\sigma_{\pi^+\pi^-}^{e^+e^-}(m)=\frac{4\pi}{3}\frac{\alpha^2}{m^2}(1-4m_\pi^2/m^2)^{1/2}|F_\pi(m)|^2\,, \tag{9}$$

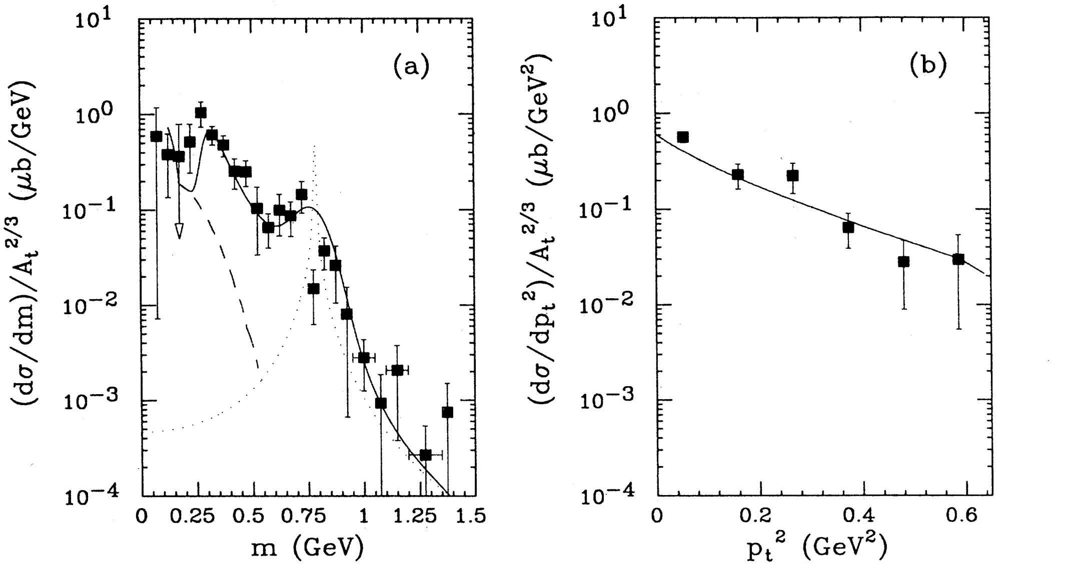

FIG. 5. (a) $d\sigma/dm$ for p-Be at 4.9 GeV (solid squares). The solid curve is the sum of Eq. (8) with $\beta=5$, the Dalitz decay from Ref. 4, and the $\rho-\omega$ contribution. The dashed line is the Dalitz decay contribution, the dotted line is the $\rho-\omega$ contribution before resolution corrections. (b) $d\sigma/dp_t^2$ for p-Be at 4.9 GeV for masses above $2m_\pi$, the solid curve is Eq. (8).

and $F_\pi(m)$ is the pion electromagnetic form factor taken from Ref. 2. The relevant projections including acceptance corrections are shown in Fig. 5. The solid curve in Fig. 5(a) includes the mass resolution of our apparatus, thus $\beta=5$ (rather than $\beta=4$) gives a better fit to the data. Contributions from the Dalitz decay of π^0's and η's[4] (dashed line) and from the decay of ρ's and ω's (dotted line) are shown separately. Note that the $\rho-\omega$ contribution is shown before resolution correction and that we have used a production cross section of 0.07 mb for the ρ and 0.13 mb for the ω. The agreement with our data is good, in shape as well as in magnitude. Equation (8) gives 101 nb for the total cross section to be compared to our measurement of $125\pm15(\text{stat.})^{+70\%}_{-20\%}(\text{syst.})$ nb (for $m\geq 2m_\pi$). We also observed that a reduction of 5% of the pion mass, which lowers slightly the threshold of the dipion annihilation cross section, is sufficient to explain the remaining excess of events observed for $0.2\leq m\leq 0.3$ GeV.[15]

In conclusion, we have shown that for masses above 0.15 GeV the geometrical acceptance corrections do not introduce significant distortions in the cross sections given by the KSS parametrization or by the calculation done by Lichard. We have also shown that the p_t yield as well as the p_t vs m correlation of direct e^+e^- production in p-Be collisions is similar to hadron-hardon measurements at higher energies with a small phase space correction. This correction is compatible with the hypothesis of a final state containing only two nucleons in addition to the e^+e^- pair. Finally, a phenomenological calculation involving $\pi^+\pi^-$ annihilation into e^+e^- was shown to be in good agreement with our measurements.

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