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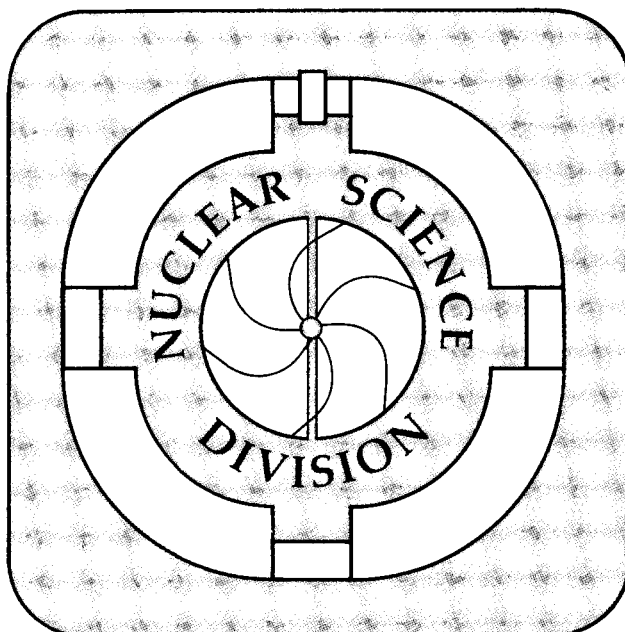
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Production of Lepton Pairs at the LBL Bevalac

G. Roche

June 1989



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PRODUCTION OF LEPTON PAIRS AT THE LBL BEVALAC

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PRODUCTION OF LEPTON PAIRS AT THE LBL BEVALAC

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ABSTRACT

We discuss the physics objectives of the DLS program with some emphasis on the possible use of dileptons as a probe of pion dynamics in nuclear matter. Data on p-Be reactions at 1.5 GeV and Ca-Ca at 1.2 A GeV are presented. The observation of a structure at about twice the pion mass in the e^+e^- invariant mass spectra above 2 GeV beam energy and the excitation function for the p-Be reaction suggest that pion annihilation is a significant dielectron source above 2 GeV. The dielectron mass spectrum from Ca-Ca at 1 A GeV exhibits an inverse slope larger than the one from p-Be at the same beam energy.

INTRODUCTION

I am going to present the work done by the Dilepton Spectrometer (DLS) Collaboration^b on the production of lepton pairs at the LBL Bevalac. This study is relevant to *nuclear matter* and has nothing to do with quark matter, except perhaps that it may give some indication on the backgrounds that could be experienced in the search for the quark-gluon plasma. The energy domain is about 1 A GeV.

The DLS program deals more precisely with the production of electron pairs (dielectrons) in p-p, p-nucleus and nucleus-nucleus collisions:

$$A + B \longrightarrow e^+e^- + X \text{ (multiplicity measurement),}$$

Multiplicity information was not recorded with the first data presented herein.

I will start with a brief review of the experiments at the beginning of the DLS program and give the physics motivations with some emphasis on the aspects relevant to pion dynamics in nuclear matter. The experimental set up will be described and results obtained so far on p-Be and Ca-Ca collisions will be presented. I will end the talk with some first conclusions and a brief discussion of the possible developments of the program.

STATUS OF EXPERIMENTS AT THE BEGINNING OF THE DLS PROGRAM

At the beginning of the DLS program, there was obviously no data on nucleus-nucleus collisions. Dilepton production had been extensively studied in hadron-nucleon and hadron-nucleus collisions above 10 GeV beam energy while there was no data between 1 and 10 GeV. A low energy experiment¹ on p-p at 256 and 800 MeV found no evidence for direct^c single electron production, at the level of 10^{-6} of the pion production rate for the 800 MeV measurement. Thus, there was a possibility for the existence of a threshold in between 1 and 10 GeV beam energy.

Fig. 1 shows a typical dimuon mass spectrum measured in high energy hadronic collisions². It exhibits peaks corresponding to the various meson resonances and a continuum. The high mass region of the continuum is well interpreted in term of the Drell-Yan hard quark-antiquark annihilation process, while the low mass region, sometime referred to as "the anomalous dilepton continuum", is not well understood. Several experiments have been devoted to the study of the dilepton low mass continuum, and we list in Table 1 those performed with electron pairs at energies closer to the Bevalac domain. The KEK dielectron mass spectrum³ is shown in Fig. 2. The estimated background due to η and ω^0 Dalitz decays cannot account for the dielectron yield. The soft parton model calculation of V. Černý *et al.*⁴ or the quark-gluon plasma model of E.V. Shuryak⁵ are not in very good agreement with the data points. Also shown in Fig. 2 is a fit to the data using a functional form from K. Kinoshita *et al.*⁶. We will use this fit for a comparison to the DLS data later on.

At the Bevalac, we are evidently limited to the dilepton mass region that corresponds to the anomalous dilepton continuum and the DLS results should help to clarify the situation.

PHYSICS MOTIVATIONS

p-N and p-nucleus Collisions

The DLS program aims to establish the existence of direct electron pair production in the few GeV beam energy domain and help clarify the production mechanism(s).

Nucleus-nucleus Collisions

When we submitted our first proposal five years ago, there was no theoretical study precisely relevant to the Bevalac energy range. We were relying on general arguments as follows. Dileptons should be a good probe of the primary hot stage of the fireball. They present three advantages; (i) they are a penetrating probe and do not interact much in going out of nuclear matter, (ii) their production rate is biased toward the high density phase of the collision, and (iii) their coupling to other particles is very well known so accurate calculations are in principle possible. However, they present the disadvantage of low production rates due to the smallness of the fine structure constant α (there is roughly one e^+e^- pair produced per ten thousand NN collisions). This disadvantage actually makes the experimental difficulty quite

Fig. 1. Dimuon mass spectrum measured by the Chicago-Princeton group and contribution of the Drell-Yan process².

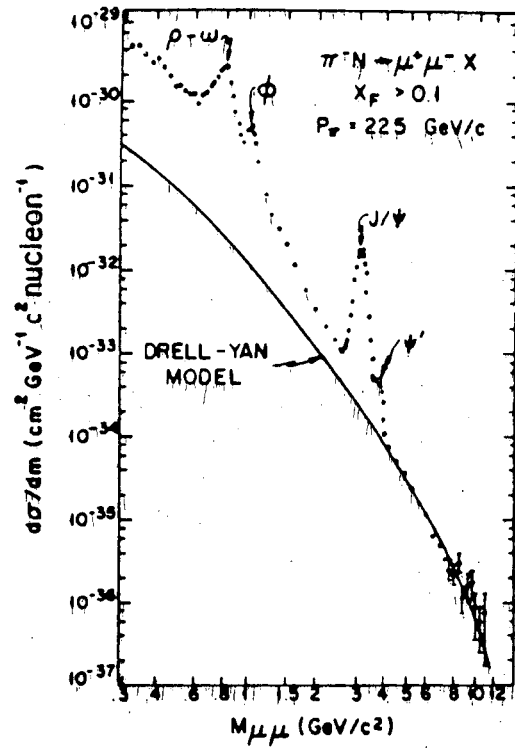
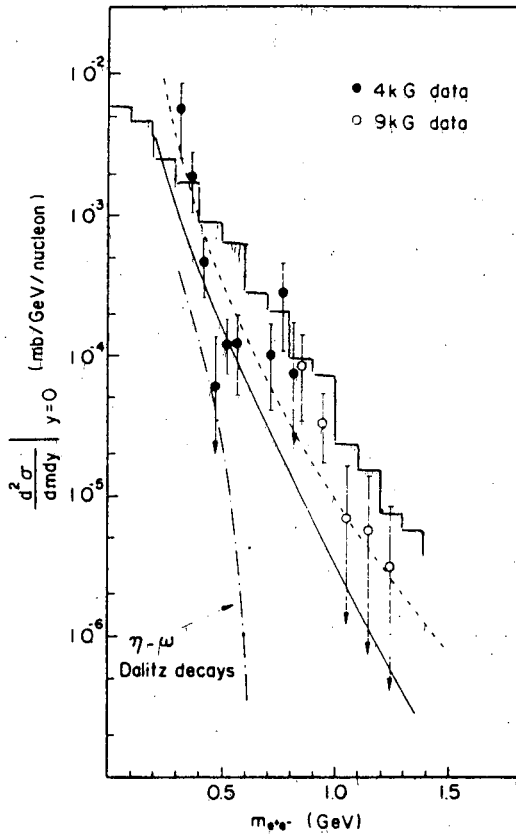


Fig. 2. The KEK dielectron mass spectrum³, p-Be at 12.1 GeV. The dot-dashed curve is the estimated background due to η and ω^0 Dalitz decays. The histogram is the soft parton model of V. Černý *et al.*⁴, the solid curve is the prediction of E.V. Shuryak⁵ and the dotted curve a fit to the model of K. Kinoshita *et al.*⁶.

Table 1.

Existing data at the beginning of the DLS project
(electron pairs)

KEK ³	p-Be at 12.1 GeV	144 true pairs
SLAC ⁷	π^- -p at 15.9 GeV	107 true pairs
BNL ⁸	π^- -p at 16.9 GeV	165 true pairs
LAMPF ¹	(single electron experiment) p-p at 800 MeV	no signal at the level of $e/\pi \sim 10^{-6}$

serious. The use of real photons would provide the same advantages as dileptons, with in general^d a much higher production rate ($\sim 1/\alpha$ higher), but it is then difficult to subtract the copious gamma ray yield from π^0 decay. In the case of dileptons, the combinatorial background (false pairs) can be measured directly from the like-sign pair yield, and the true pair Dalitz decay background is only important at very low masses, below about 100 MeV.

Later on, C. Gale and J. Kapusta⁹ have made calculations applicable to the Bevalac energy domain and pointed out possible interesting effects relevant to the pion dispersion relation in hot-dense nuclear matter. This study is generalized by L.H. Xia *et al.*¹⁰ who include the expansion of the fireball and consider dileptons as a probe of pion dynamics in heavy ion collisions. G. Brown¹¹ discusses the interest of dilepton measurements in connection with the subjects of the nuclear equation of state and pion condensation. M. Schäffer *et al.*¹² compute the pn bremsstrahlung contribution in p-Be collisions at 1 GeV. Very recently, a preprint by S. Pratt¹³ seems to raise a controversy about the effect of pion dispersion on the dilepton mass cross section.

There are several theoretical talks at this meeting on the subject of dilepton production in the 1 A GeV energy range, so I would like to only briefly discuss the possibility of using dileptons as a probe of pion dynamics in nuclear matter.

Pion Dynamics in Nuclear Matter

Two possibly dominant processes of dilepton production in the 1 A GeV range are shown in Fig. 3. When dealing with pion dynamics, $\pi^+\pi^-$ annihilation is of most interest and pn bremsstrahlung is a background. The propagation of pions in nuclear matter is described by the following dispersion relationship:

$$\omega^2 = \mathbf{k}^2 + m_\pi^2 + \Pi(\omega, \mathbf{k}),$$

where ω is the pion total relativistic energy and \mathbf{k} its vector momentum. The effect of the nuclear medium is introduced through the term $\Pi(\omega, \mathbf{k})$. It is both temperature and density dependent, the strongest dependence coming from the baryon density. There is little experimental information on the pion dispersion relation and it is mostly constructed on theoretical arguments.

A kinematical domain of special interest corresponds to lepton pairs emitted back-to-back in the center-of-mass frame of the collision. In that case, the total vector momentum of the pions is

$$\mathbf{q} = \mathbf{k}_1 + \mathbf{k}_2 = 0.$$

It results that

$$\omega_1 = \omega_2 = \omega$$

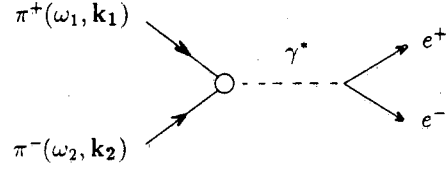
and

$$M_{e^+e^-} = 2\omega.$$

There is an almost one-to-one correspondence between a point of the dielectron mass spectrum and a point of the pion dispersion curve. In that kinematical domain, the pion dispersion effect on the dielectron mass spectrum can be expected to be the strongest and is clearly seen in Fig. 4 from L.H. Xia *et al.*¹⁰. The pn bremsstrahlung

Fig. 3. Two possibly dominant processes of dilepton production in the 1 A GeV range.

$\pi^+\pi^-$ annihilation



pn bremsstrahlung

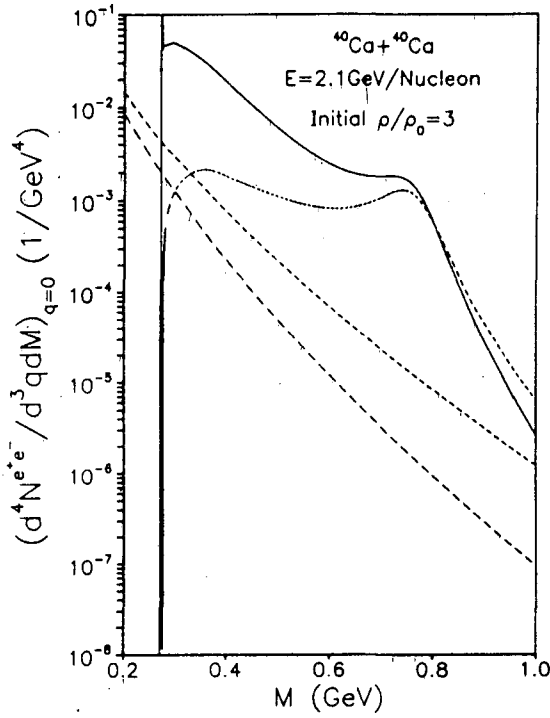
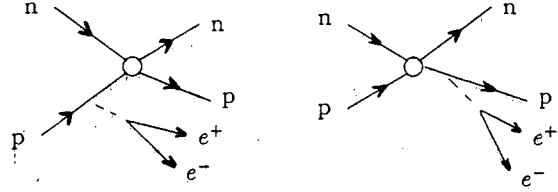
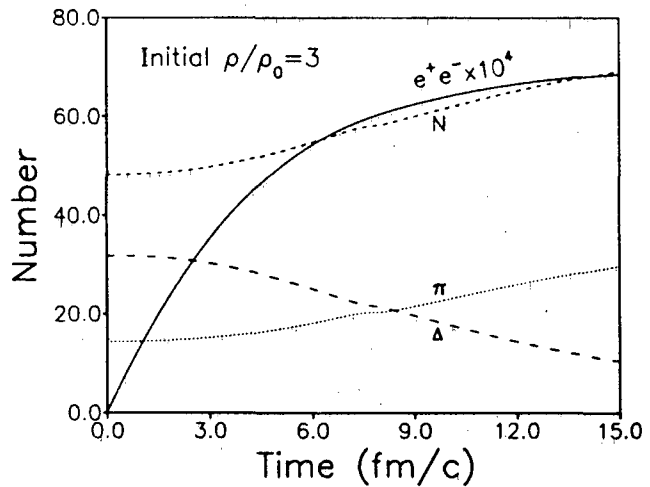


Fig. 4. The effect of the pion dispersion relation on the dielectron production rate, solid curve. The dotted curve is the $\pi^+\pi^-$ annihilation contribution without dispersion effect. The other two curves are the contribution from pn bremsstrahlung computed in the soft photon approximation with phase space included (long dashed curve) or without (dashed curve). The figure is from ref. 10.

Fig. 5. Time evolution of the number of nucleons, deltas, and pions in the fireball for the same reaction as in Fig. 4. The solid curve is that for the density in momentum space of dileptons with zero total momentum. The figure is from ref. 10.



contribution is also shown in the figure. The effect of the pion dispersion amounts to an enhancement of the mass region just above the $\pi^+\pi^-$ annihilation threshold by more than an order of magnitude. Also, the same authors quantitatively establish that dileptons are created during the first stage of the nucleus-nucleus collision, within the first 6 fm/c for Ca on Ca at 2.1 A GeV (see Fig. 5).

As a conclusion to this part of the talk, I can say that *dileptons should be a good probe of pion dynamics in nuclear matter*. Notice that the same dispersion relation concept should actually apply to both p-nucleus and nucleus-nucleus collisions. The subject of pion condensation, which received much attention in the 1970's, is also regaining interest. Finally, the dilepton study is also useful in the more general framework of the nuclear equation of state for it should provide information (density, temperature) on the early hot-dense stage of heavy ion collisions.

EXPERIMENTAL SET UP

Design Considerations

There are some numbers that are important to better understand the experimental set up and the data. The direct electron yield as measured in high energy experiment is very low. It is usually reported as the ratio of direct electrons to pions at a given transverse momentum p_t :

$$e/\pi \sim 10^{-4}$$

(the ratio goes up to about 10^{-3} at very low p_t 's of about 100 MeV/c as measured at the CERN ISR¹⁴). The dielectron yield can also be expressed as the ratio of dielectrons to dipions and high energy experiments give the value

$$(e^+e^-)/(\pi^+\pi^-) \sim 10^{-5},$$

the DLS data actually providing the same value (see below). Thus, the experimental set up must fulfill the following requirements: (i) an extremely good hadron rejection power ($\gtrsim 10^5$), and (ii) a large acceptance and/or high interaction rate capability.

The main backgrounds result from π^0 decay:

$$\begin{array}{llll} \pi^0 \rightarrow \gamma\gamma & \xrightarrow{\text{conversion}} & e^+e^- & BR \simeq 1 \\ \pi^0 \rightarrow \gamma e^+e^- & (\text{Dalitz decay}) & & BR \simeq 10^{-2}. \end{array}$$

Difficulty can be anticipated (i) for low dielectron masses ($\lesssim 100$ MeV) and (ii) because of a combinatorial background (false pairs).

The Dilepton Spectrometer

The DLS experimental set up is shown in Fig. 6. The target is segmented to reduce the combinatorial background from gamma ray conversion. The two large aperture dipole magnets offer each an angular acceptance of 170 msr. The electron identification with adequate hadron rejection power is provided by two gas Cherenkov counters in each arm. Tracking is achieved with drift chambers and scintillator hodoscopes provide trigger flexibility and redundant information. Details can be found

in ref. 15. The multiplicity array was not yet implemented when we collected the first data presented below. The kinematical domain under investigation is approximately 0.1-1.2 GeV in invariant mass, 0.0-0.8 GeV/c in transverse momentum and 0.5-1.9 in units of laboratory rapidity (y).

The central ray of each arm is set at 40° to the beam direction, which is an adequate value for beam energies 4.9 GeV (p-Be reaction) and 2.1 A GeV (p-Be and Ca-Ca reactions). For these two beam energies, mid-rapidity electrons are emitted (in the laboratory) at 31.7° and 43.4° , respectively. However, for the lowest beam energy of 1.0 A GeV that has been used, the mid-rapidity laboratory angle of 53.9° does not match well the DLS rapidity acceptance and back-to-back pairs for instance are detected with a low efficiency.

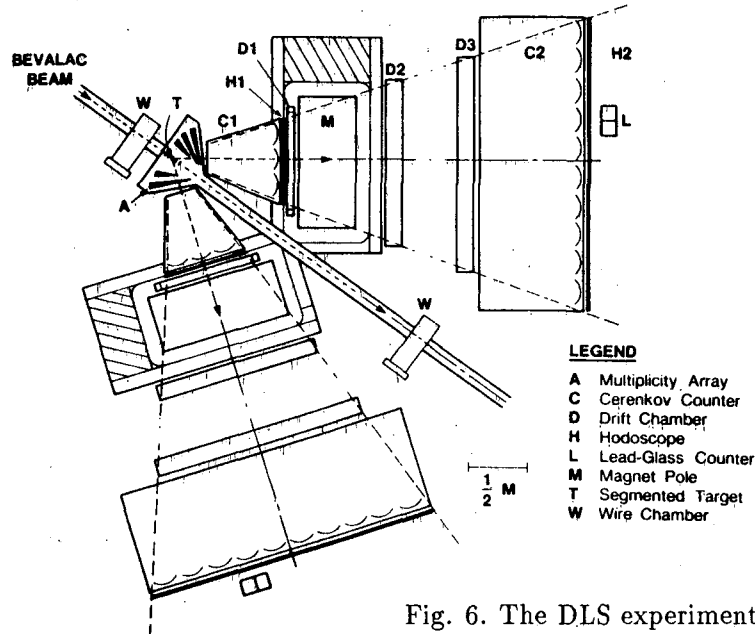


Fig. 6. The DLS experimental set up.

False Pair Subtraction

A significant combinatorial background (false pairs) originates when two uncorrelated electrons are detected, one in each DLS arm, these two electrons being mostly produced through the decay of π^0 's, either directly from the Dalitz mechanism or by the conversion of their γ -ray products in the target or surrounding materials. These uncorrelated electrons are always produced in pairs and there are some cases when the two members of Dalitz or conversion pairs go through the whole system on one arm. Then we just remove the corresponding events. The presence of two electrons before one magnet can also be detected from the ADC^e information of the front Cherenkov counters. The hodoscope and drift chamber information also helps. Therefore, a false pair mostly results when all ADC, TDC^e, time-of-flight and reconstruction conditions are fulfilled and that we miss one member of a Dalitz or conversion pair in one arm, on both sides. However, due to the charge detection symmetry of the two arms (and the symmetry is improved by collecting data for the four field polarity combinations in the magnets over equal periods of time), the opposite-sign false pair sample is equal to the like-sign sample and the true pair signal is simply obtained by subtraction of

the like-sign pairs from the opposite-sign pairs. Evidently, the statistical accuracy on the true pairs depends on the amount of false pairs. The false pair yield increases as the square of the pion multiplicity and, depending on the origin of the true pairs, the true to false ratio can get worse when going to heavier target/projectile systems.

Notice that Dalitz pairs can be emitted with wide opening angles and detected by the system. These will not be subtracted but estimates of their contribution to the true pair signal will be given.

RESULTS ON p-Be AND Ca-Ca COLLISIONS

Table 2 gives the running conditions and Table 3 the pair statistics for the data taken so far. The interaction rates go from about 3×10^5 up to 3×10^7 . The low number of reconstructed events compared to the number of recorded events is only partly due to the very simple trigger that we have been using (an eight-fold coinci-

Table 2.

DLS running conditions
(for p-Be at 1.0 GeV, the star refers to the same analysis as Ca-Ca at 1.0 A GeV)

Reaction	Average beam int. (proj./spill)	Acq. time (hours)	Target thick. (col. leng.)	# of recorded events	# of recons. pairs
4.9 GeV p-Be	1.2×10^8	34	0.1	1.4×10^5	933
2.1 GeV p-Be	2.3×10^8	16	0.1	7.7×10^4	715
2.0 A GeV Ca-Ca	2.5×10^7	30	0.01	2.8×10^5	139
1.0 GeV p-Be	3.0×10^8	26	0.1	7.3×10^3	130
					374*
1.0 A GeV Ca-Ca	1.0×10^8	83	0.02	2.0×10^5	1207

Table 3.

DLS pair statistics
(for p-Be at 1.0 GeV; the stars refer to the same analysis as Ca-Ca at 1.0 A GeV)

OS= number of opposite sign pairs, LS= number of like sign pairs,

F= number of false pairs in the OS sample ($F=LS$),

T= number of true pairs ($T=OS-LS$), $\sigma_T=\sqrt{OS+LS}$.

Reaction	OS	LS	T	T/F	T/ σ_T
4.9 GeV p-Be	732	201	531 \pm 31	2.6	17.4
2.1 GeV p-Be	567	148	419 \pm 27	2.8	15.7
2.0 A GeV Ca-Ca	94	45	49 \pm 12	1.1	4.2
1.0 GeV p-Be	111	19	92 \pm 11	4.8	8.1
	263*	111*	152 \pm 19*	1.4*	7.9*
1.0 A GeV Ca-Ca	731	476	255 \pm 35	0.5	7.3

dence of the signals from the hodoscopes and Cherenkov counters). It also results from the large acceptance and the severe background conditions, and translates the difficulty of the measurements. The data is much cleaner for the lowest beam energy of 1.0 A GeV which allowed the use of looser cuts in the analysis (needless to say that the efficiency of the cuts is corrected for). The true to false ratio is about three times better for p-Be than for Ca-Ca collisions, independently of the analysis cuts and the incident energies. The existence of a dielectron signal down to 1 A GeV is established to a high level of statistical accuracy and the first goal of the DLS program is achieved.

p-Be Data

The cross section per nucleon (assuming an $A_t^{2/3}$ dependence, where A_t is the target mass) for p-Be as a function of the dielectron invariant mass is shown in Fig. 7 for the three beam energies 4.9, 2.1 and 1.0 GeV. The general shape of the 4.9 and 2.1 GeV distributions for masses above 300 MeV are similar to that seen at higher energies. For comparison to the KEK 12 GeV p-Be data³, the fit given in Fig. 2 is plotted as a solid curve in Fig. 7(a). An enhancement in the ρ/ω region is seen in the mass spectrum from p-Be at 4.9 GeV. At 2.1 GeV, the maximum energy available in the nucleon-nucleon center-of-mass frame is 850 MeV, just barely above the ρ/ω threshold. The total Dalitz decay contributions to the dielectron cross sections (see ref. 16 for details) are shown as dashed curves in Fig. 7 for all three beam energies. The significant contributions are from π^0 and η at 4.9 and 2.1 GeV, while π^0 and $\Delta(1232)$ contribute at 1.0 GeV. At 4.9 and 2.1 GeV, the Dalitz decay background is approximately an order of magnitude smaller than the measured yield for masses above 200 MeV, in agreement with the higher energy results. For the 1.0 GeV data, the Dalitz decay contribution is less accurate due to the uncertainty in the $\Delta(1232)$ production cross section and our systematic errors.

The new observation is the structure at about 300 MeV (twice the pion mass) in the 4.9 and 2.1 GeV spectra. We have been much concerned with it, trying to answer the two questions: its statistical significance and the possibility of an experimental bias. An experimental bias could come from the acceptance due to the fact that it gets limited in y and p_t at low mass and thus more difficult to evaluate. In fact, we know that the very first mass bin (the tip of the acceptance domain) is not reliable and it is given only for a *qualitative* understanding of the mass spectra. We believe that the acceptance bias is negligible above $M = 150$ MeV and the second mass bin should already be reasonably accurate¹⁷. Evaluation of the statistical significance assumes the choice of a structureless model. Taking a softer functional form (such as an exponential) yields a lower statistical significance, while using a steeper functional form (such as power laws, M^{-2} or M^{-4} , reasonable for bremsstrahlung or soft parton models) yields a very high statistical significance. We finally decided not to give any number and let the readers decide. It is interesting to notice that a recently presented data¹⁸ on very low mass dielectron production in p-p at a center-of-mass energy of 63 GeV is not inconsistent with the DLS result (see Fig. 8).

The cross section (per nucleon) for producing the low mass dielectron continuum, $200 \lesssim M \lesssim 700$ MeV, is plotted in Fig. 9 as a function of the available center-of-mass energy. The brackets around the DLS data points represent the systematic normalization errors of approximately +70/-20%. We first notice that the DLS cross

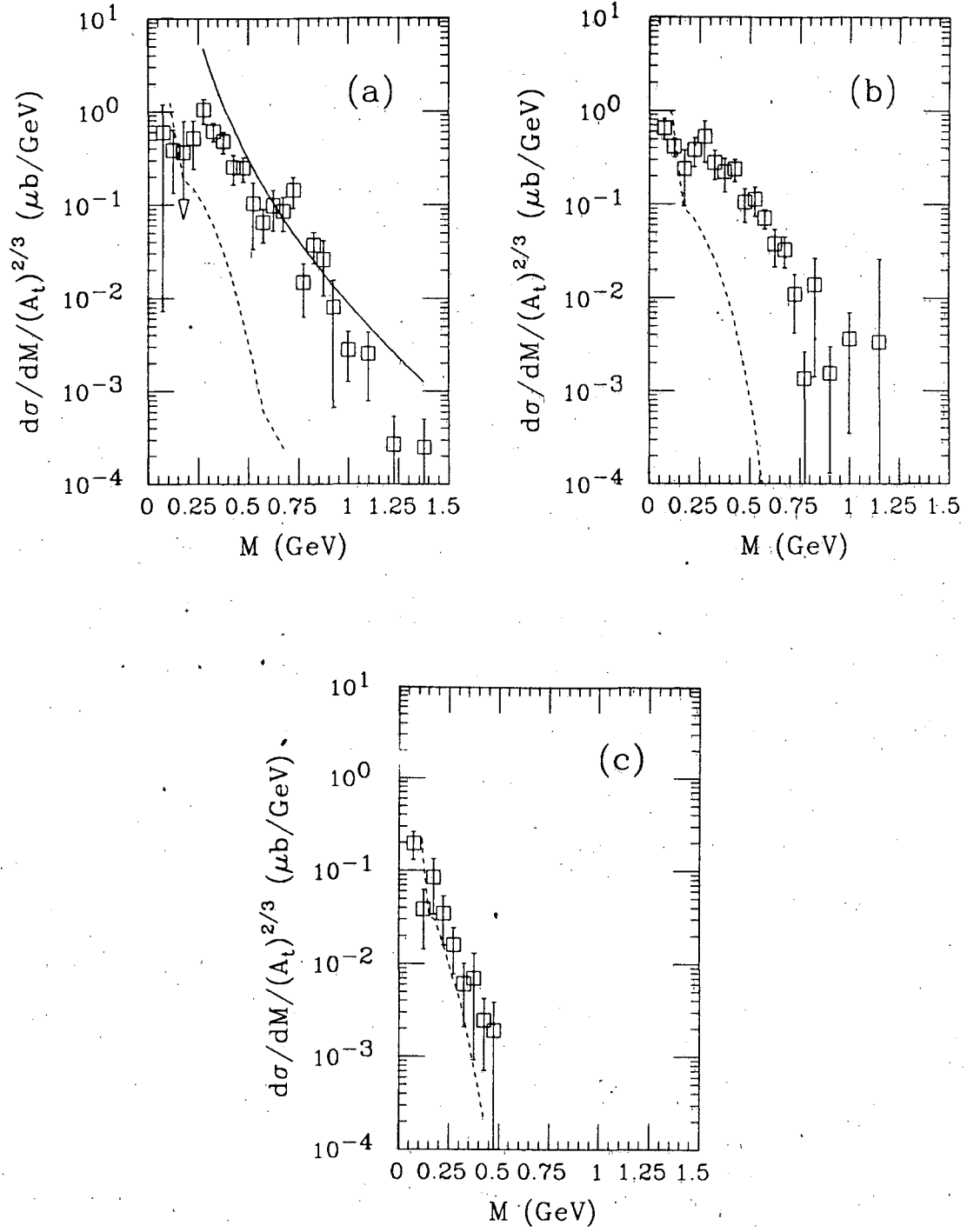


Fig. 7. The dielectron invariant mass spectra from the p-Be reaction at beam energies of (a) 4.9, (b) 2.1 and (c) 1.0 GeV. The first data point on all three spectra is qualitative. The dashed curves are the total Dalitz decay contributions. The solid curve is the fit to the KEK 12 GeV p-Be data³ for comparison.

Fig. 8. Dielectron invariant mass distribution from p-p at 63 GeV center-of-mass energy¹⁸.

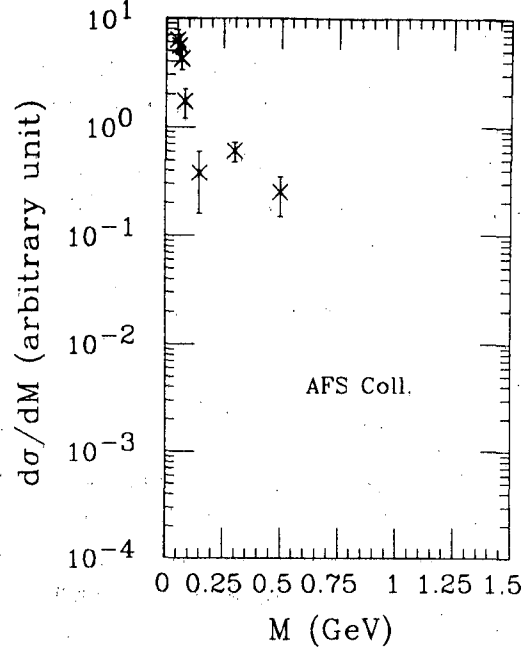
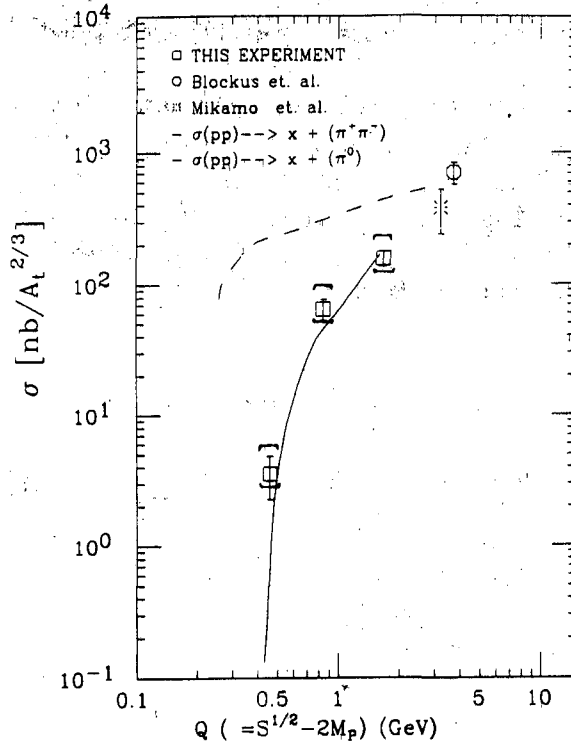


Fig. 9. The total dielectron production cross section as a function of the available NN center-of-mass energy: circle, D. Blockus *et al.*⁷ π^-p at 16 GeV; star, S. Mikamo *et al.*³ $p+Be$ at 12.1 GeV; squares, DLS data. The solid and dashed curves show the $\pi^+\pi^-$ and π^0 total cross sections¹⁹ respectively, scaled down by 1.33×10^{-5} .



sections are in agreement with the higher energy results from KEK³ and SLAC⁷, and probably also with the lower energy measurement at LAMPF¹. The e^+e^- and $\pi^+\pi^-$ cross sections are found to have similar threshold behavior while the π^0 excitation function is much flatter in the same range of available center-of-mass energy. The dielectron to dipion ratio is about 10^{-5} .

Both the mass structure at about twice the pion mass and the excitation function suggest that *pion annihilation* is a possible dominant mechanism of dilepton production for proton beam energies above 2 GeV. However, other mechanisms may also have significant contributions (e.g., Dalitz decay of the $\Delta(1232)$ resonance, bremsstrahlung).

Fig. 10 shows the dielectron invariant mass spectra for the reaction Ca-Ca at 2.0 and 1.0 A GeV. The Dalitz decay contributions shown as dashed curves in the figure have been scaled from the previous p-Be calculations and their estimated uncertainties are within $\pm 50\%$. These contributions cannot account for the dielectron yield for masses above 200 MeV. The first mass bin in both spectra is again qualitative. The statistical accuracy is not good enough to draw a conclusion on the existence of a structure around twice the pion mass, even though subtraction of the Dalitz contributions would significantly change the shapes of the distributions in the low mass region. We have not performed this subtraction yet as more accurate estimates may become available (e.g., Dalitz decay of the $\Delta(1232)$ resonance²⁰).

For comparison to the more accurate Ca-Ca data at 1.0 A GeV, a preliminary calculation by C.M. Ko²¹ for the same reaction is shown in Fig. 11 (same type of a calculation as in Fig. 4). The features of the computed spectrum (the brake at twice the pion mass and the ρ enhancement) are not seen in the experimental distribution, perhaps due to the reduced statistical accuracy as indicated above. Thus we may just compare slopes. Hand-made exponential fits to the two components in Fig. 11 give inverse slopes^f of 95 and 69 MeV for pion-pion annihilation and pn bremsstrahlung respectively, while the exponential fit to the DLS spectrum above $M = 200$ MeV yields an inverse slope of 125 ± 16 MeV, see Fig. 12(a). Of course it must be reminded that the calculation is performed for back-to-back pairs and integration over p_t and y may somehow wash out the pion dispersion effect.

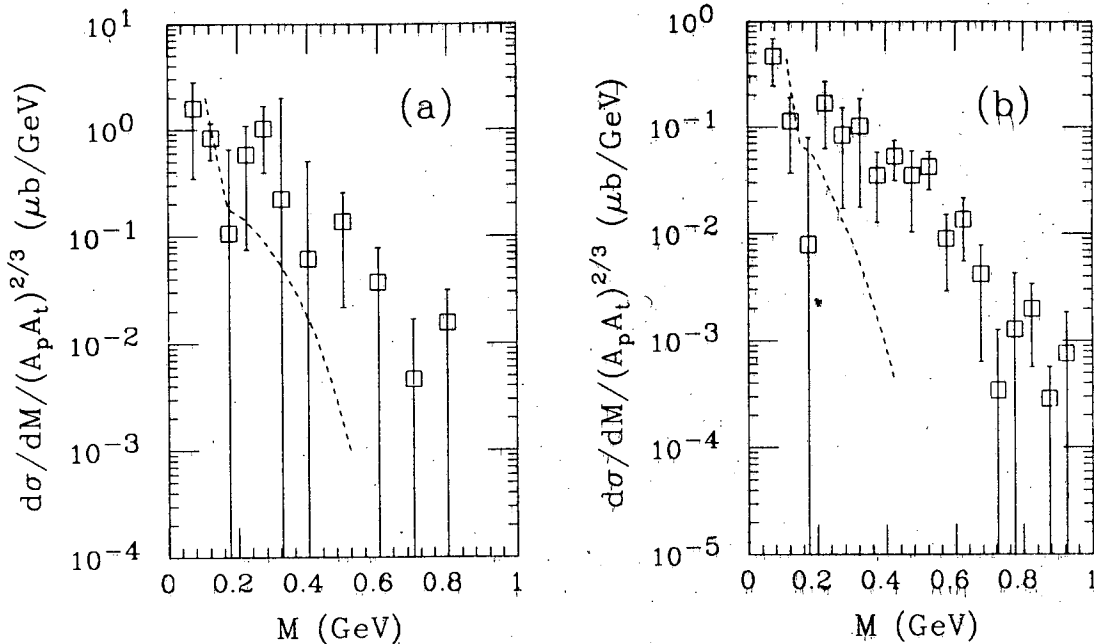


Fig. 10. The dielectron invariant mass distributions (per nucleon) from the Ca-Ca reaction at (a) 2.0 and (b) 1.0 A GeV. The first data point on both spectra is qualitative. The dashed curves are the Dalitz decay contributions.

Fig. 12 compares the dielectron mass spectra for both Ca-Ca and p-Be reactions at 1.0 A GeV. There is a higher yield at higher masses in the Ca-Ca spectrum compared to p-Be. The exponential fit to the p-Be data above $M = 200$ MeV yields an inverse slope of 71 ± 18 MeV, much lower than the Ca-Ca inverse slope of 125 ± 16 MeV. A first estimate indicates that this large difference in slope cannot be explained from Fermi motion.

Fig. 11. The rate of back-to-back pairs computed for pion-pion annihilation and pn bremsstrahlung²¹; the dotted lines are hand-made exponential fits to the annihilation and bremsstrahlung components.

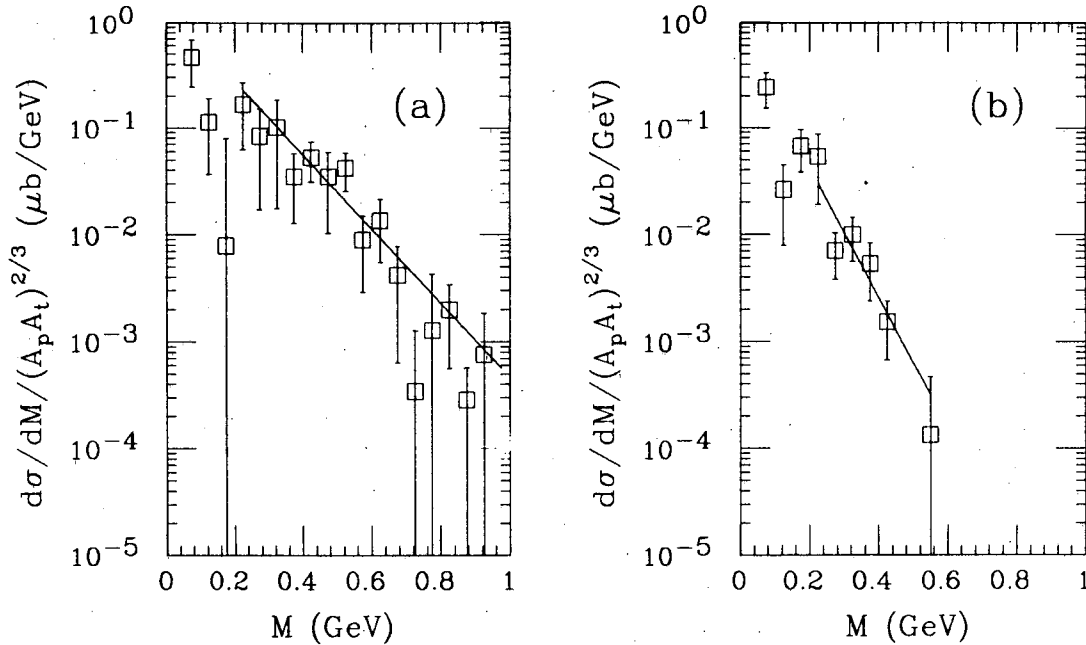
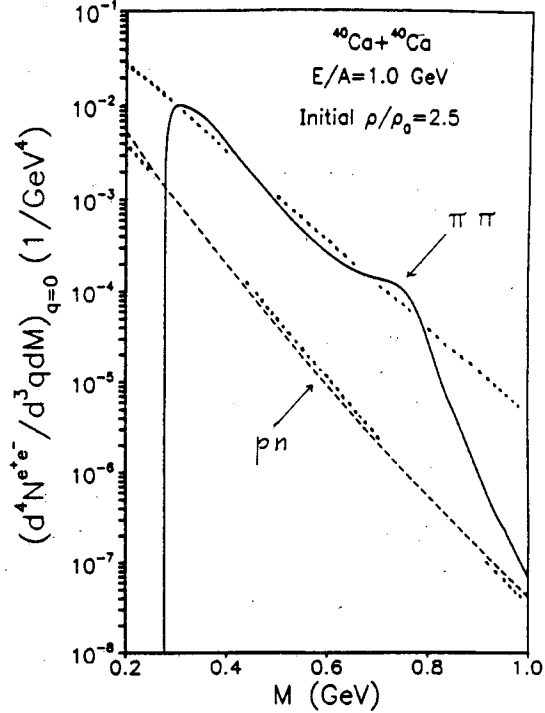


Fig. 12. Comparison of the dielectron mass distributions for both (a) Ca-Ca and (b) p-Be reactions at 1.0 A GeV. The solid lines are exponential fits to the data.

CONCLUSION

I have restricted the DLS data presentation mostly to the mass distributions. We actually measure the triple differential cross section $d\sigma/(dMdp_t dy)$ and more data is available, being published or in the process of publication, e.g., p_t distributions^{15,16,22}, p_t vs. M in p-Be at 4.9 GeV¹⁷. These should be of interest to check the model calculations. The conclusions below refer to the whole data set.

We have established the existence of a dielectron signal down to 1 A GeV incident energy.

In p-Be collisions above 2 GeV, the mass distributions ($M > 300$ MeV), p_t distributions and yields $((e^+e^-)/(\pi^+\pi^-) \sim 10^{-5})$ are similar to those obtained at higher energies. The observation of a structure in the mass spectra at about twice the pion mass and the excitation function suggest that pion annihilation is a possible dominant production mechanism, even though other processes may have significant contributions.

Comparison of the Ca-Ca and p-Be data at 1 A GeV shows a large difference in the slopes of the mass distributions, the Ca-Ca spectrum being much flatter. The production yields are consistent with a projectile/target mass dependence as $A_p A_t$.

The DLS results show the *feasibility* of experiments using dileptons as a probe of nucleus-nucleus collisions in the 1 A GeV range. There is hope to obtain information on pion dynamics in nuclear matter but it needs more work, both theoretical and experimental.

Developments of the program

The multiplicity detector has just been implemented and we have collected data on Ca-Ca at 2.0 A GeV and Nb-Nb at 1.0 A GeV. In the very near future, we are going to take data on p-p and p-d reactions to gather information on the basic processes and further study the 300 MeV mass structure. On a longer term basis, the project will develop toward higher projectile/target masses at 1 A GeV beam energy. It will need setting the two DLS arms at 54° and upgrading the electron identification system, e.g., Ring Imaging Cherenkov counters in front of magnets and full calorimetric coverage behind each arm. An ultimate goal of the program should be a high statistics study of the back-to-back pairs at 1 A GeV with the heaviest beams, but the Bevalac beam performance may then create limitations.

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FOOTNOTES AND REFERENCES

- ^aOn leave from the Université de Clermont II, France.
- ^bLawrence Berkeley Laboratory: G.F. Krebs, A. Letessier-Selvon, H.S. Matis, C. Naudet, G. Roche, L. Schroeder, P.A. Seidl, A. Yegneswaran; University of California at Los Angeles: S. Beedoe, J. Carroll, J. Gordon, G. Igo; The Johns Hopkins University: T. Hallman, L. Madansky, R. Welsh; Louisiana State University: P. Kirk, Z.F. Wang; Northwestern University: D. Miller; Université de Clermont II (France): P. Force, G. Landaud.
- ^cIn the language of high energy physics, direct leptons are those not originating from the decay of known particles or resonances.
- ^dIn the case of $\pi^+\pi^-$ annihilation, dielectron and real photon production rates are of the same magnitude (see next lecture by C. Gale).
- ^eThe abbreviations ADC and TDC stand for analog-to-digital converter and time-to-digital converter, respectively. Signals from phototubes (hodoscopes and Cherenkov counters) are split and sent to both ADC and TDC channels which allows to record the amplitude (energy) and time information of a given signal.
- ^fThe inverse slope is the parameter M_0 in the exponential fit $\exp(-M/M_0)$.
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