

DIRECT LEPTON PRODUCTION
IN HADRONIC AND NUCLEAR COLLISIONS
AT LOW PT AND LOW PAIR MASS

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DIRECT LEPTON PRODUCTION
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ABSTRACT

A brief review of the direct production of single leptons and dileptons in hadronic collisions at low pt and low pair mass is given. Several open questions are pointed out and the universality of lepton production is briefly discussed. The Bevalac Di-Lepton Spectrometer project is presented.

INTRODUCTION

Lepton production has been extensively studied in hadronic collisions from the GeV region up to the highest available energies at Serpukhov, Fermilab and CERN. In ultra-relativistic Heavy Ion collisions, it is considered as a possible signature of the Quark-Gluon Plasma formation. A typical mass spectrum of lepton pairs produced at high energies is shown in Fig. 1. It exhibits peaks corresponding to the various meson resonances and a continuum. The high mass continuum is well interpreted by the Drell-Yan hard quark-antiquark annihilation process, while the low mass continuum, sometimes referred to as "the anomalous dilepton continuum", is not fully understood. Lepton production has also been investigated in inclusive experiments. Here again, there remain questions about the lepton yield at low pt compared to the inclusive pion one, after subtracting known contributions. The copious single lepton yield at low pt and the low pair mass anomaly are frequently considered in connection, even though the issue is not yet completely clear.

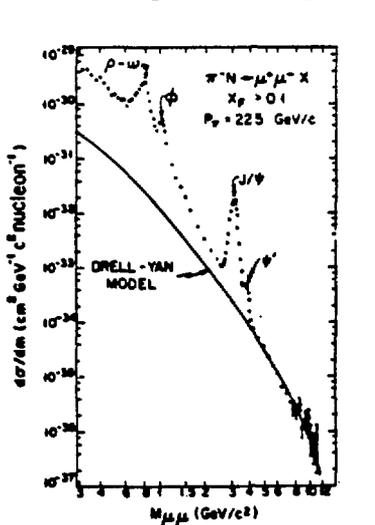


Fig. 1. Mass spectrum of dimuons measured by Chicago-Princeton group and contribution of the Drell-Yan process(1).

I will mostly restrict the talk to low pt and low pair mass direct lepton production (direct leptons are those not produced in the decay of known particles or resonances). There exist previous reviews on the subject(2). I will first summarize existing experimental data and models on dileptons, trying to point out the basic envisioned processes, and then go to single leptons which better leads to the possibility

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of the existence of some universal process from the few GeV domain to the highest energies. Finally, I will present the Bevalac Di-Lepton Spectrometer(DLS) project and conclude with some remarks on the nucleus-nucleus case for which no experimental data exist yet.

THE LOW MASS DILEPTON CONTINUUM

A sample of experimental works on low mass dileptons is contained in ref. 3 to 10. All of these data exhibit an excess of low mass pairs compared to the decay of vector mesons and is not compatible with the Drell-Yan mechanism in a wide range of incident energies and for various hadronic projectiles. A first example was shown in Fig. 1. A second one from Mikamo et al.(3) is given in Fig. 2 with comparisons to some models that we are going to discuss below. The slopes of the mass distributions seem to depend upon the nature of the projectile, proton or pion, and somewhat upon the incident energy, but the characteristics of the cross sections are not well established because of the various kinematical regimes and, most of the time, lack of statistics. In contrast to these data, two CERN-ISR experiments(11,12) report the low mass pair continuum to be in agreement with the Dalitz decay of known mesons or the semi-leptonic decay of charmed particle pairs.

The models that are used to interpret the low mass continuum can be classified into two broad groups, inner bremsstrahlung and soft parton annihilation models, both with or without radiative corrections. Subclasses could be identified depending on the constituents involved in the process and the treatment of the interaction.

Bremsstrahlung models(13) consider the internal conversion of vir-

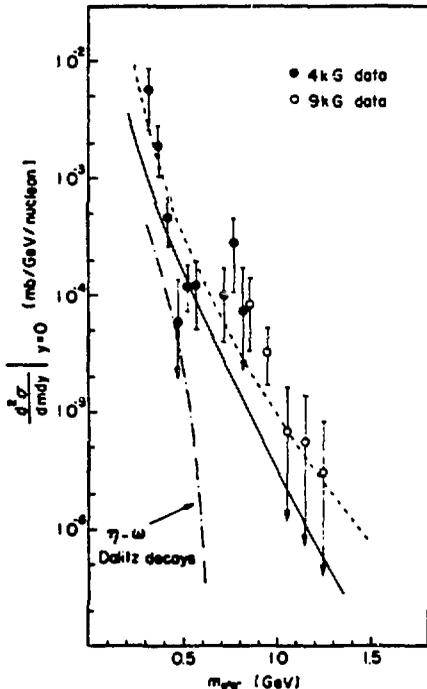


Fig. 2. Dielectron mass spectrum from the KEK experiment at 13 GeV/c. The solid curve is the prediction of Shuryak(17) and the dotted curve is a fit to the model of Kinoshita et al.(18). The dot-dashed curve is the estimated background due to Dalitz decay.

tual photons produced by the bremsstrahlung of charged constituents created during the collision. They suffer difficulties in suppressing real photons and getting the right amount of internal conversion. Besides, the mass distribution of the order of $1/m$ for small masses does not agree with experimental data and yields a wrong e/m ratio.

The soft parton models are somewhat more successful. They were initiated by Bjorken and Weisberg(14) who take into account the presence of the many wee partons and anti-partons created during the collision process and which may reannihilate into leptons before the products of the collision emerge. Latter works consider meson-meson subprocesses (15) or go to the quark level (16). Shuriak(17) considers that dileptons are produced through a created quark-gluon plasma with an initial temperature of the order of 0.5 GeV at high incident energies. The phenomenological model constructed by Kinoshita et al.(18) to unify low mass low pt dilepton and low pt hadron productions is very useful to compare data over the entire incident energy range. It has been found to agree quite well with various experimental data with slightly different parameters.

For the purpose of the DLS design (see a latter section), I have studied the validity of the Kinoshita et al. model that I will refer to as KSS. I checked the model as a scaling law for pion production over a wide range of incident energies. Using the scaling radial variable $x_0 = E/E_{max}$ introduced by Taylor et al.(19), where E is the energy of the detected particle in the center-of-momentum frame and E_{max} the maximum energy kinematically available to the detected particle in the c.m. frame, the following simple relationship was fit to high energy data:

$$E \frac{d\sigma}{dp^3} = C e^{-\lambda E_t} (1-x_0)^\alpha$$

where E_t is the tranverse kinetic energy, $\lambda = 6 \text{ GeV}^{-1}$, $\alpha = 3.5$, and $C = 85$ and $55 \text{ mb}/(\text{GeV})^2$ for positive and negative pions, respectively. This relationship turned out to work quite well all the way down to the GeV region. In the same way, using the radial scaling variable and Mikamo et al. parameters(3), the dielectron cross section can be written as:

$$E \frac{d\sigma}{dm dp^3} = \frac{C}{m^4} (1-x_0)^\alpha \frac{\lambda^2 e^{-\lambda E_t}}{2(\lambda m + 1)}$$

with $C = 1.3 \cdot 10^{-5} \text{ mb} \cdot \text{GeV}^3$ and the other constants being the same as above. I will discuss the agreement of the model with single electron data in the next section.

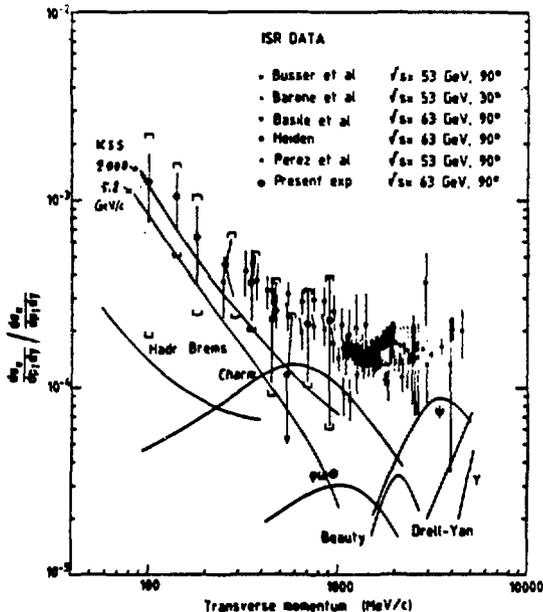
At this stage, the actual source of low mass dilepton might be a superposition of several processes, depending on the incident energies, the projectile particles or the kinematics involved. More experimental data on mass, y and pt distributions, with good statistics, are needed to settle the question.

SINGLE LEPTONS AND THE UNIVERSALITY OF LEPTON PRODUCTION

The yield of single direct leptons is expressed in terms of lepton to pion production ratio as a function of xf or pt . Fig. 3 is a typical representation of the production ratio as a function of pt , here for the CERN-ISR data (20). The e/π ratio is independent of the incident energy and kinematical region (within errors), with a constant magnitude of about 10^{-4} and a rise at low pt . Other works support the same conclusion for other projectiles and for both positive and negative electrons. The figure also shows various known contributions which cannot account for the measured electron yield. The data on single muons are less abundant but they support the same production magnitude without any rise at small pt . This point is important because it may favor the bremsstrahlung origin of the low pt single leptons. Finally, two low energy measurements at 256 and 800 MeV (21) have found no evidence for direct electrons at the 10^{-6} level. This raises the question of a possible threshold effect somewhere below 10 GeV/c.

Most of the works on the low mass dilepton continuum have compared their results to single lepton data (see for instance ref. 3, 5 and 6) by integrating their pair cross sections over the proper kinematical range. These calculations support the hypothesis of the low mass dilepton continuum and the low pt single leptons being of the same origin.

Fig. 3.



However, there is a major difficulty in connecting dileptons and single leptons in the fact that dilepton cross sections have not been measured below 100 or 200 MeV. With a steep dependence at the lowest measured masses, like $1/m^3$, an average assumption, the problem is to find a realistic low mass cut in the integration that would simulate the unknown cross section. Blockus et al. (5) lean on the argument that most of the single-arm spectrometer experiments require one and only one particle in the

spectrometer. This requirement amounts to a cut on mass which is taken at 20 MeV. They note that the computed e/π ratio from the pair cross section would be reduced by a factor of 2 if the mass cut were increased to 60 MeV. Adams et al.(6) use a mass cut of 100 MeV in their calculation. I have studied the question with the KSS model for an incident momentum of 5.8 GeV/c. There is almost an order of magnitude in change when the cut is varied from 50 to 100 MeV, the curves being mostly translated parallel to the vertical axis.

As a consequence, the connection of single electron and dielectron is not straightforward. I mentioned the need for more data. I would then suggest that dielectron measurements might be more useful for the understanding of the processes because they carry more detailed information. In my opinion, the meaning of the mass cut discussed above is a modification in the dielectron cross section behaviour which should get to a peak or at least to a sharp change in slope at low mass. The peak or change in slope suggested by the mass cuts should occur in between 20 and 100 MeV. It is then important to investigate the pair cross section below about 200 MeV which would have a definitive impact on the understanding of the low mass dilepton continuum. To this regard, the problem is different for dimuons which have an inherent threshold of 210 MeV.

I have compared the e/π data with the KSS model and found a good agreement with a mass cut of 100 MeV. As an example, I have plotted a curve on the CERN-ISR data of Fig. 3 (the paper states that contributions from low mass electron pairs less than 100 MeV are eliminated from the data). On the same figure is plotted a curve computed at 5.8 GeV/c incident momentum which show some decrease in magnitude and a slightly steeper slope. This observation might explain the Los Alamos(21) null result by a strong reduction in phase space when going down to 800 MeV. Here again, more measurements in the GeV region would be needed to settle the question of a possible threshold.

Finally, I am getting to the universality of the single lepton data. It is absolutely striking that experimental results (here the ratio $1/\pi$) lie on the same curve over the whole range in energy from 10 GeV up to 2000 GeV (equivalent CERN-ISR incident energy), for different projectile particles and kinematical regimes. In my opinion, it must be a universal basic process which is the source of the phenomenon. It would be very unlikely that contributions from different processes would add up to give a unique behaviour. I would like to quote Cerny et al.(16) who say "if the hadronic origin of the LM (low mass) dileptons is confirmed, then the LM dilepton production could become the simplest hadronic process and as such could be useful for the analysis of more complicated processes of hadron production".

THE BEVALAC DI-LEPTON SPECTROMETER PROJECT

The DLS Collaboration(22) has undertaken an electron pair production study in the few GeV incident energy domain in p-nucleus and nucleus-nucleus collisions at the Bevalac, in order to answer some of the questions mentioned in the previous sections. It also seeks for specific interests in Heavy Ion collisions as will be indicated below. A single electron experiment was first performed(23), the data analysis being still in progress.

The DLS experimental setup is shown in Fig. 4. It consists of a segmented target (about 5 segments) and two symmetric arms, each including a large aperture dipole magnet, two scintillator hodoscopes which provide accurate time of flight information and offer the possibility of using the system in a single arm trigger mode, two segmented gas Cerenkov counters working at one atmosphere for electron identification, and three or four drift chamber stacks for tracking. The conical scattering chamber provides a minimum amount of material along the particle trajectories into the spectrometer together with the use of a multiplicity array detector positioned around the target. Several lead glass blocks behind the detectors will be used for the Cerenkov counter calibration (pion rejection power measurement).

The DLS program will first be exploratory, with data taking in p+Be collisions at 4.9 and 2.1 GeV, then going to Ne+Ne and Ca+Ca at 2.1 GeV/A, and Fe+Fe at 1.7 GeV/A. The development of the program will depend on the first results and might consist in going up in energy or up in mass (therefore, down in energy). The system has been designed to provide suitable acceptance and resolution in mass, y and pt. First detector test runs were just completed and turned out to be quite successful. The data acquisition runs will begin in the fall.

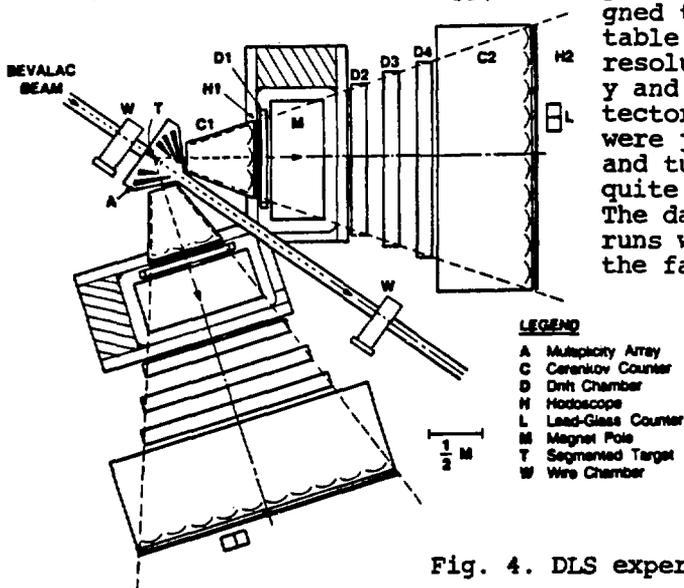


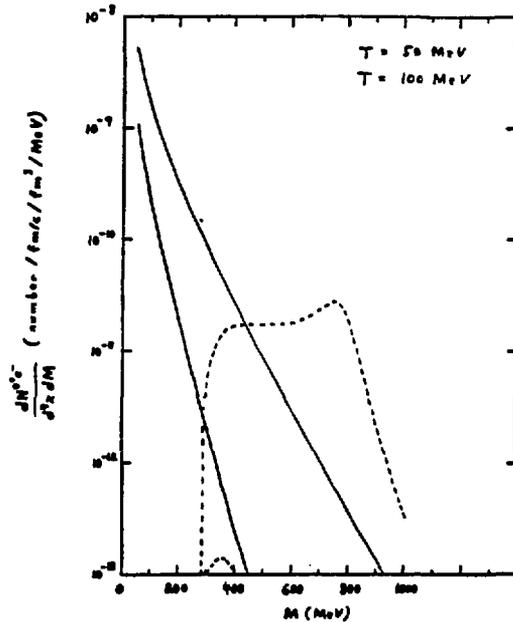
Fig. 4. DLS experimental setup.

Fig. 5. Production yield of dielectrons at Bevalac energies(24) from baryon-baryon cascading (solid) and pion-pion annihilation (dashed).

J. Kapusta(24) has recently presented a first estimate of the dielectron characteristics at Bevalac energies in nucleus-nucleus collisions. Fig. 5 gives the expected production yield per unit volume and per unit mass from pion-pion annihilation and baryon-baryon cascading bremsstrahlung for two temperatures of the fire ball and for a baryon density of twice the normal nuclear density. The curves show that

the pion-pion annihilation would be undetectable at low temperature while it would start to show up at higher temperature. Besides, the annihilation contribution shape depends upon the effective pion mass in the nuclear medium.

The study should bring useful informations on the first stage of the nucleus-nucleus collision, owing to the general property of virtual photons to interact only weakly with the environment, in contrast to hadrons.



CONCLUSION

The low pt single lepton and low mass dilepton productions probably involve some basic and universal process(es) of hadronic interactions but there are still several open questions that must be answered before a good understanding is achieved. I will summarize these questions in three groups:

- the existence of a threshold in single lepton production; data are needed in the few GeV incident energy domain;
- a quantitative connection between single leptons and dileptons still remains to be verified; more lower pt single lepton data and measurements of the dilepton cross section at lower masses would be useful;
- higher statistics experiments on dilepton production, in particular at lower incident energies, would improve our knowledge of the cross section characteristics and our understanding of the low mass continuum origin.

In ultra-relativistic Heavy Ion collision, it is obvious that a good knowledge of the hadronic case must be achieved before trying to extract any possible Quark-Gluon Plasma signature from the low mass dilepton background. On the other hand, M. Danos(25) has described a possible scenario of Quark-Gluon Plasma formation in which plasma "seeds" are initially produced in the hot compressed medium and would then grow or die, depending on the amount of cooling in the system. In this event and according to Shuryak's quark-gluon plasma picture(17), the low mass dileptons might be at the onset of a larger plasma formation.

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