Title
PROBING NUCLEAR MATTER WITH DILEPTONS

Author
Schroeder, L.S.

Publication Date
1986-06-01

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

Presented at the VIII International Seminar on
High Energy Physics Problems, Relativistic
Nuclear Physics and Quantum Chromodynamics,
Dubna, USSR, June 19-24, 1986

PROBING NUCLEAR MATTER WITH DILEPTONS

L.S. Schroeder

June 1986

NUCLEAR SCIENCE DIVISION

Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

PROBING NUCLEAR MATTER WITH DILEPTONS

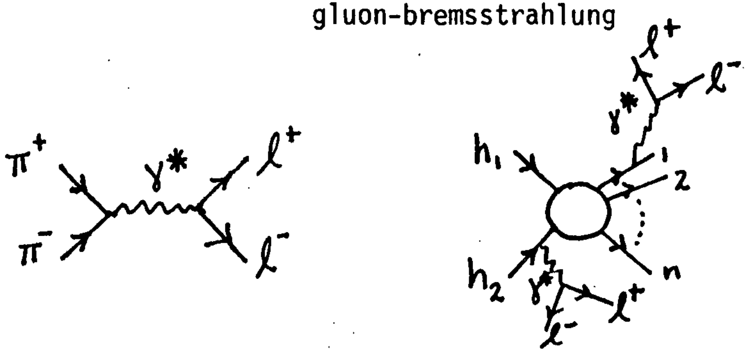
L. S. Schroeder

Nuclear Science Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720
USA

1. *Introduction*

Dileptons have a long and distinguished history in particle physics, e.g., the discovery of the J/ψ and its impact on QCD. In nuclear science dileptons are now being employed to study many interesting features associated with pA and AA collisions at intermediate and high energies. From a theoretical point of view, dileptons are particularly interesting since at high energies they can arise from basic quark-quark or quark-antiquark processes as shown in Fig. 1 (a,b,c)--as such they can be used to probe the quark "degrees-of-freedom" in the collision. In addition, there are other potential sources of dileptons, such as the π^+-π^- annihilation and hadronic(both baryons and mesons) bremsstrahlung processes indicated in Fig. 1 (d,e). We shall see these are also of interest in helping probe extreme conditions of temperature (T) and density (ρ) in nuclear matter. From the

a) q-$\bar{q}$ annihilation b) annihilation & gluon-bremsstrahlung c) q bremsstrahlung



d) hadronic annihilation e) hadronic bremsstrahlung

Fig. 1 Examples of processes yielding dileptons (e^+e^- or $\mu^+\mu^-$) in hadron-nucleus and nucleus-nucleus collisions.

experimental side, leptons and dilepton are felt to be particularly useful since they interact weakly with matter and therefore serve as relatively undistorted probes of various stages (pre-equilibrium, equilibrium and the late frozen phase) of the collision process.

In the remainder of the talk I will:

a) Briefly describe what's known experimentally about dileptons,

b) Review their use in upcoming experiments with light ions at the CERN SPS[1,2]--possible signatures of quark matter formation,[3,4] and

c) Discuss their use in an upcoming experiment with a new spectrometer at Berkeley--probing the nuclear matter equation of state (EOS) at high T, ρ.

2. *Some Features of Dilepton Spectra*

Fig. 2 displays the dimuon mass spectrum as measured by the Chicago-Princeton group in π^--nucleon collisions at 225 GeV/c.[5] The solid curve represents the estimates of the Drell-Yan hard quark-antiquark scattering process. A rich spectrum of resonances are observed above an apparently smooth background. The Drell-Yan process provides an adequate explanation of the data for $M_{\mu\mu}>3$ GeV, i.e., in the region where perturbative QCD is expected to be valid. However, it completely underestimates the yield at lower masses. The region below a few GeV then appears to have an "anomalous enhancement" of dileptons. At present, there is no adequate explanation for these low-mass pairs; although such things as the decay of heavy mesons and quark/hadronic bremsstrahlung processes have been considered--and must provide a portion of the observed signal. In Fig. 3 we see that pair masses in this region (< few GeV) scale as $\sim 1/M^2$, where M = dilepton mass. Also the yield appears to be relatively insensitive to energy and projectile type between 13-225 GeV/c.[6-9] A more detailed discussion of dileptons and direct leptons (whose source should be dileptons) can be found in the review article by H. Specht in the Proceedings of QM'84.[10] Since the dilepton spectrum is sensitive to the quark "degrees-of-freedom," and because dileptons can exit the interaction volume unscathed, they have been high on the list of experimental observables in the search for the quark-gluon plasma (QGP).[3,4] Recently, L. McLerren has provided a summary[11] of the physics that one is sensitive to for various ranges of dilepton masses. This is summarized below:

Dilepton Pair Mass	Physics Probed
a) < 50 MeV	coherent emission from local charge fluctuations
b) 50-500 MeV	QGP emission plus hadronic decays
c) 500-3000 MeV	QGP emission
d) 3000-10000 MeV	Drell-Yan, perturbative QCD

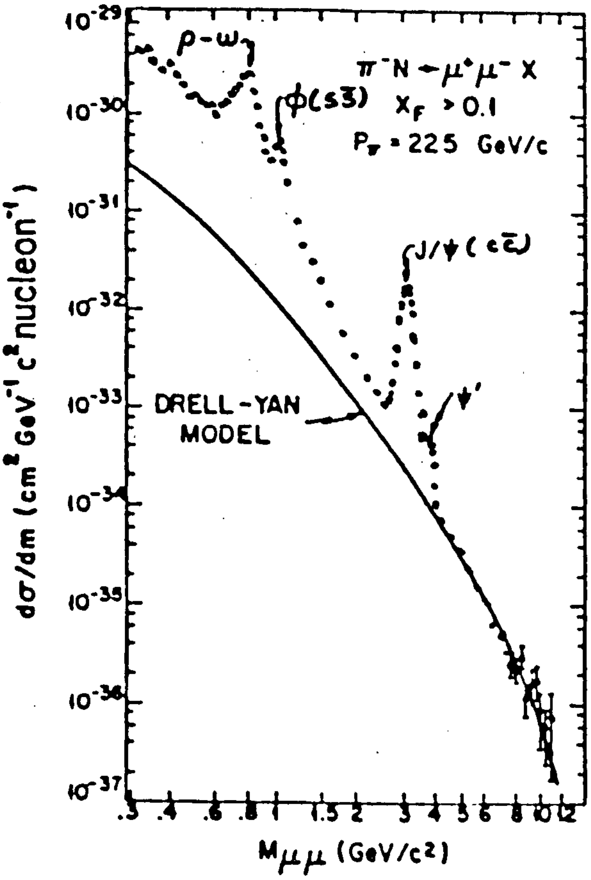


Fig.2 Dimuon mass spectrum measured by Chicago-Princeton group (Ref. 5) Solid curve is Drell-Yan prediction.

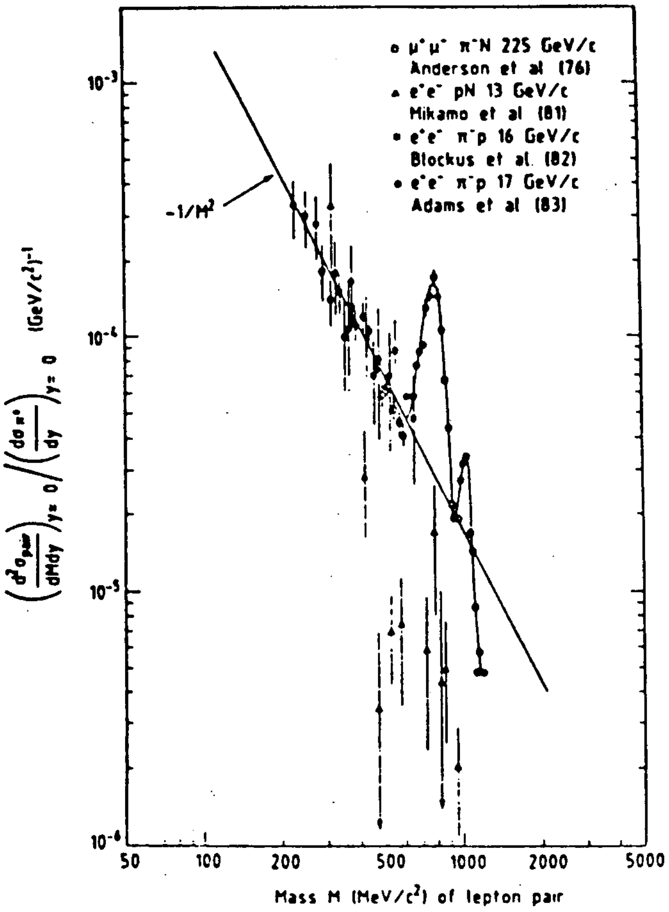


Fig. 3 Compilation of dilepton mass spectrum from several experiments (Refs. 6-9).

The region below 3 GeV is clearly a region of non-perturbative QCD and is the one receiving the most experimental attention in the upcoming high energy light ion program at the CERN SPS.

3. *Dilepton Program at the CERN SPS*

Beginning in November 1986 there will be a major 17 day running period with ^{16}O ions for physics studies at 60-200 GeV/nucleon at the CERN SPS.[1] This is to be followed by an additional period in September-October 1987. Simultaneous with this, light ions (up to ^{32}S) will be available at the Brookhaven AGS at 14 GeV/nucleon.[12] For the future, Brookhaven is planning a dedicated Relativistic Heavy Ion Collider (RHIC) which would feature Au+Au collisions at 100 GeV/nucleon in <u>each</u> beam. The central thrust of studying nucleus-nucleus collisions at high energies is to produce and study the QGP. In this talk I will be discussing only the CERN program on dileptons.

High energy nuclear beams at the CERN accelerator complex have been made possible by the addition of an ion source (built by Geller) and a RFQ (built by GSI and LBL) which are used to inject an existing linac at the PS. Ions are accelerated in the PS, transferred and accelerated to the desired energy in the SPS, and finally extracted into the North and West experimental halls for physics studies in a variety of detectors.[1] Six major experiments and several smaller ones, involving ~300 nuclear and particle physicists are poised to carry out this program. Two of these experiments (NA34 and NA38) have the capacity of measuring the spectrum of dileptons. To give you a feeling for the scale of these measurements, Fig. 4 shows the NA34 setup. It consists of five different

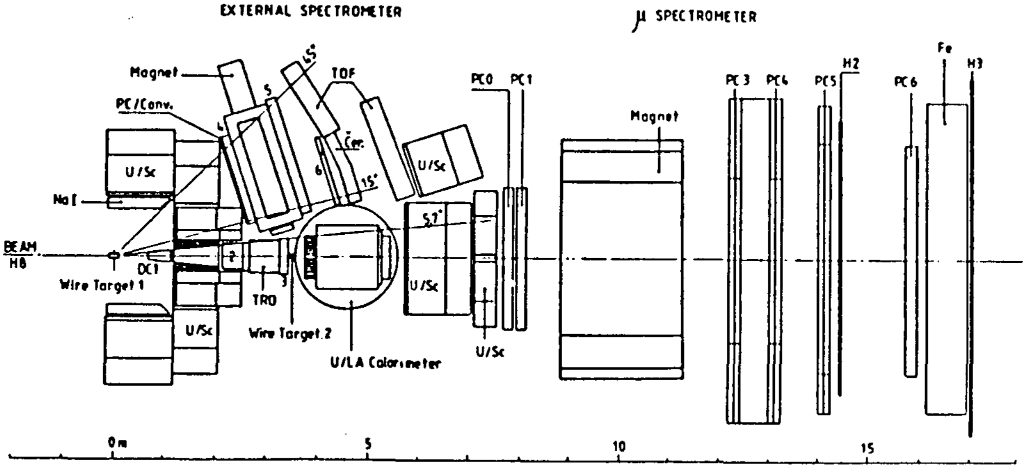


Fig. 4 Schematic of the NA34 experiment at the CERN SPS.

elements:[2] 1) target + vertex detector system, 2) 4π calorimeter with separate EM and hadronic sections, 3) compact forward electron spectrometer (M_{ee} < 1000 MeV), 4) forward muon spectrometer (formerly NA3) covering from 250 MeV to beyond the J/ψ and 5) wide angle external spectrometer. Strong filtering (~10 interaction lengths) is used after the target to remove hadrons and limit decays of π's and K's into muons. In this way they expect to reduce the problems arising from high multiplicities (expect events with ~100-1000 particles at 200 GeV/nucleon), lepton identification, and combinatorics. The question of individual electron tracking and identification is made particularly difficult in the front-end of the system by the 1-2 e-pairs expected from π^0-Dalitz decay alone (they anticipate ~100-200 π^0's for central collision events). A wide angle pair spectrometer is being designed, but will not be available for the first round of experiments. Clearly NA34 has undertaken a very ambitious plan to search for the QGP. As in all the CERN experiments, one will not look for a single signature but must look at correlations within a given event, e.g., dilepton mass spectrum correlated with high multiplicity (M) or high transverse energy flow (E_T), correlations between strange particle production and global observables (M, E_T, dN/dy,...), etc.

Before leaving this section a word is in order on what we might expect from dilepton measurements at SPS energies. Fig. 5 shows a dimuon mass spectrum as

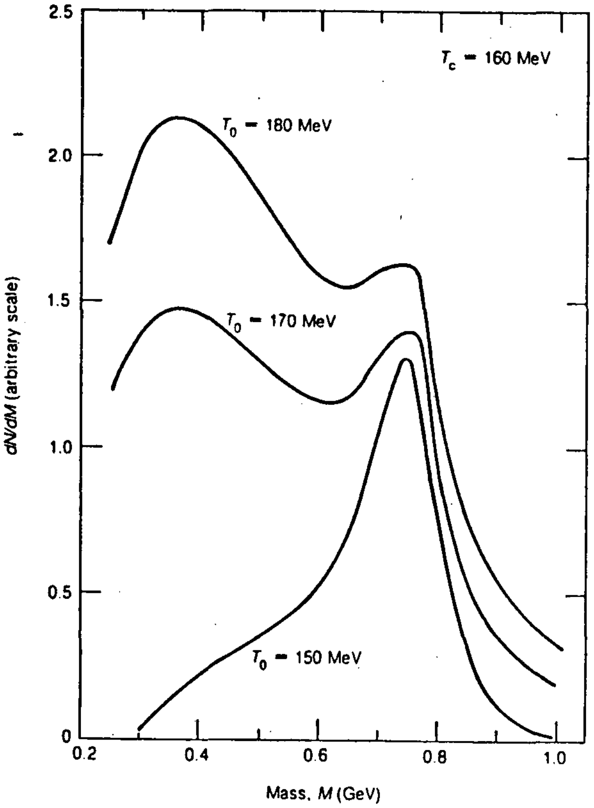


Fig. 5 Shape of dilepton ($\mu^+\mu^-$) low-mass spectrum (calculated by Ref.(3) for different values of the temperature of the source (T_0 = 150, 170, 180 MeV) for a fixed critical temperature of T_c = 160 MeV.

calculated by S. Chin[13] assuming only two contributions: 1) π^+-π^- annihilation and 2) a thermalized QGP with a critical temperature of T_c = 160 MeV. For a source at T_0 = 150 MeV, only the annihilation process (dominated by the ρ-form factor) contributes but above T_c =160 MeV the QGP provides a substantial yield, particularly for $M_{\mu\mu}$ < 500 MeV. Note that the strong roll over at ~400 MeV is due to the finite muon mass, and would not be there for the case of e^+e^- production. Clearly such a calculation is meant to be illustrative at best since it neglects many other potential sources of dileptons. But it does indicate that the low-mass region is of particular interest if one is searching for effects due to the QGP. As a further experimental handle on detecting quark matter, one would want to study the mass spectrum of Fig. 5 for increasing projectile mass, since the QGP should be sensitive to the volume ($\propto A$), while the annihilation process should be more of a surface term ($\propto A^{2/3}$) associated with the later hadronic phase of the collision.

4. *Dileptons at the Bevalac*

Over the last two years an LBL/Clermont-Ferrand/Johns-Hopkins/Louisiana State/Northwestern/UCLA collaboration[14] has undertaken the design and construction of a major new system called the Dilepton Spectrometer (DLS). The DLS will measure the effective mass of e^+e^- pairs at Bevalac energies. At 1-2 GeV/nucleon in the laboratory one does not expect dileptons to arise from formation of the QGP, but rather as the emission of bremsstrahlung (virtual $\gamma \rightarrow e^+e^-$) from cascading baryons in the hot, compressed stage of the collision process (see Fig.1e) and from π^+-π^- annihilation (see Fig. 1d). Just as in the high energy case, at Bevalac energies dileptons serve as excellent probes since they can exit the interaction volume without being distorted. Kapusta[15] has indicated that the region from 20-250 MeV should be sensitive to the hadronic bremsstrahlung (both initial and final state particles), while above 280 MeV (~2 m_π) the π^+-π^- annihilation contribution can be studied. A very preliminary estimate of the expected production yield per unit volume per unit mass for these two processes is shown in Fig. 6 for nucleus-nucleus collisions at Bevalac energies. Two fireball temperatures (T = 50 and 100 MeV) were assumed at a baryon density of $2\rho_0$. At 50 MeV the π^+-π^- annihilation process will be undetectable, but by 100 MeV it should be observable. In addition, the annihilation contribution should be sensitive to the pion dispersion relation in hot, compressed matter. Experimental data on dileptons (e^+e^- at Bevalac) will then be compared with various theoretical models to gain more insight into the EOS of nuclear matter at high T, ρ.

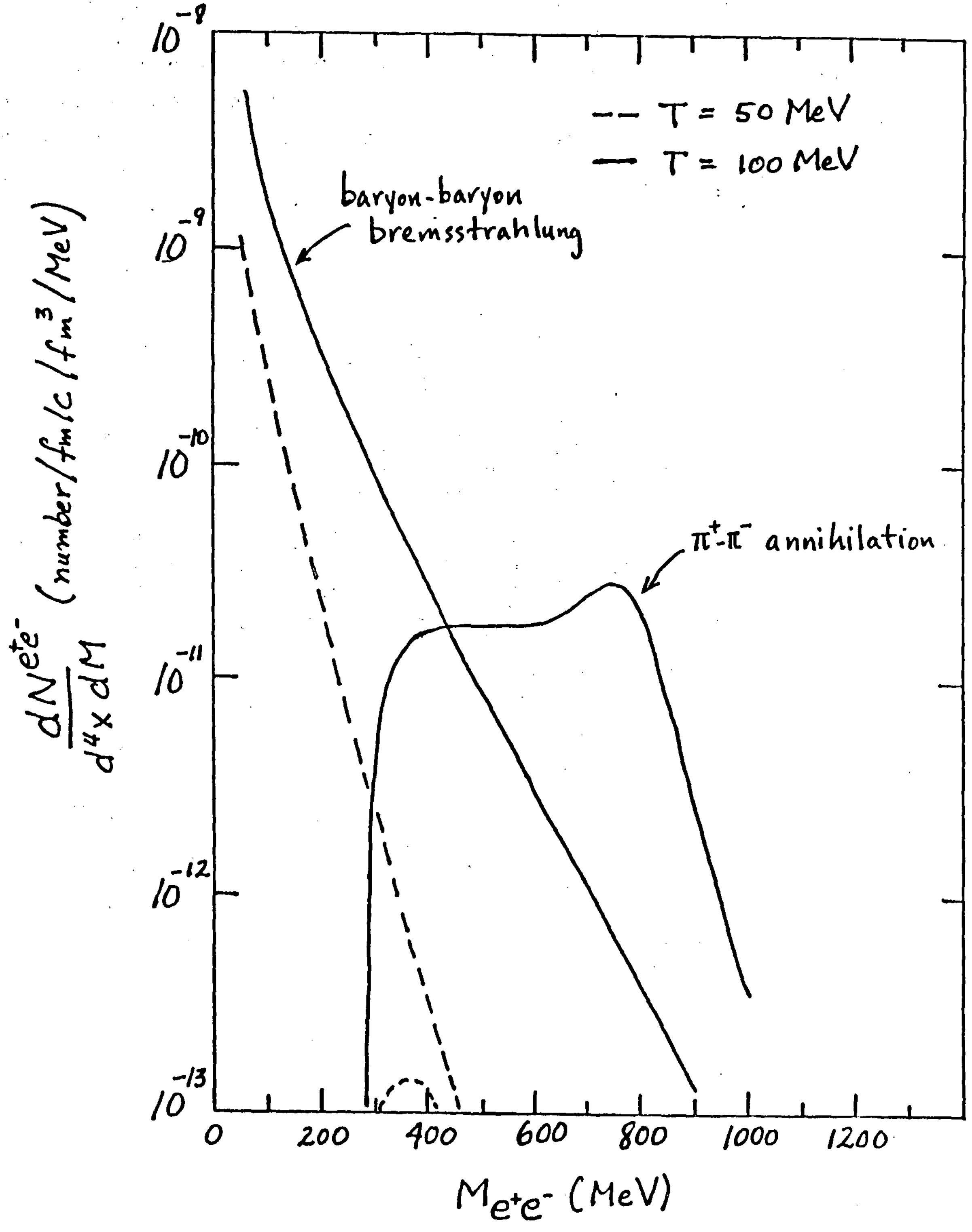
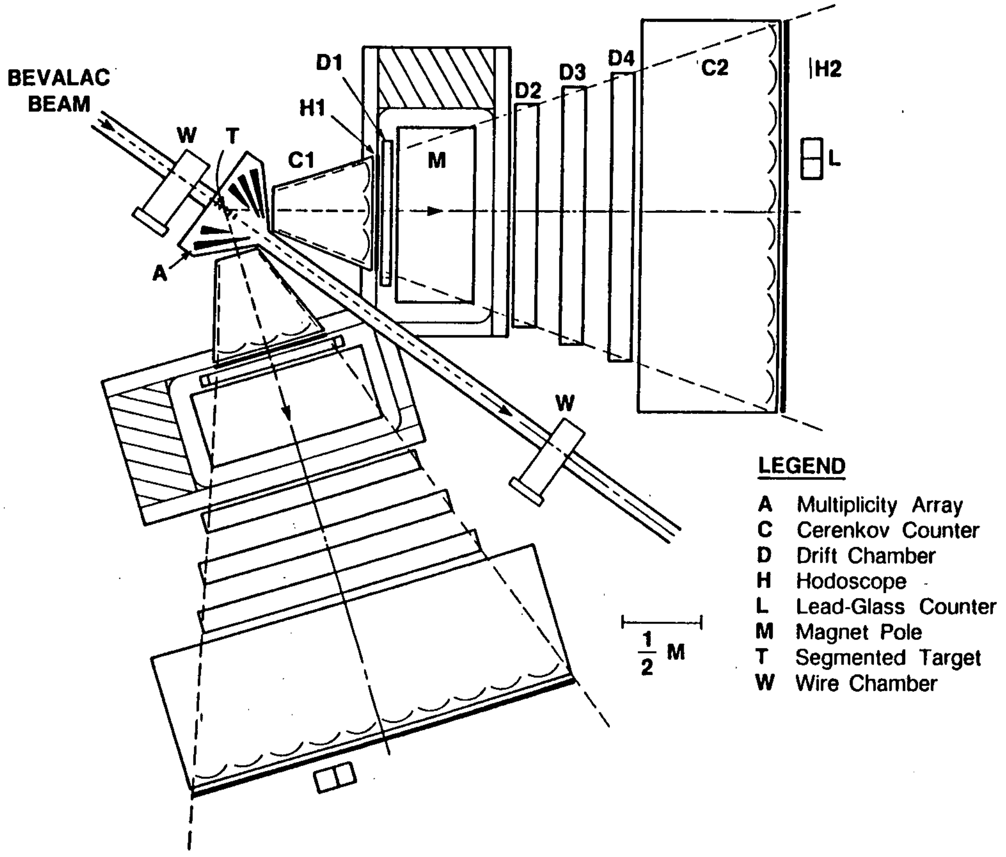


Fig. 6 Preliminary estimate (Ref. 15) of the rate of dilepton (e^+e^-) emission in nucleus-nucleus collisions at Bevalac energies. Two source temperatures are assumed (solid = 100 MeV, dashed = 50 MeV).

Fig. 7 shows a plan view of the DLS. It consists of two identical magnetic arms each of $\Delta\Omega \sim 170$ msr. Each arm contains: 1) a large aperture dipole ($B_{max} \sim 5$ kG), 2) segmented gas cerenkov counters (front and back of magnet) to identify electrons and positrons, 3) scintillation hodoscopes to provide fast electronic signals, and 4) drift chambers in front and back of the magnet for tracking the $e^{\pm}$'s. Segmented targets are located inside a scattering chamber.



XBL 8512-9590

Fig. 7 Plan view of the DLS.

This chamber is surrounded by a multiplicity array to help distinguish between central and peripheral events. The DLS has had one test run (May 1986) and will commence full-scale operation in late 1986/early 1987.

A fundamental limitation to our e^+e^- studies at Berkeley lies in the fact that the Bevalac intensity for masses > 56 is insufficient for a systematic dilepton program. But it is precisely the heavier masses that one needs to produce high T, ρ nuclear matter. Berkeley has recently proposed a Bevalac Upgrade[16] whereby the Bevatron's main ring would be replaced by a modern synchrotron such as that shown in Fig. 8. Such a device would be capable of providing increased beam currents of ~100-1000 over those presently available and would serve as the focus of a very broad-based nuclear science program. In particular, for the DLS program the Bevalac Upgrade would provide:

a) 10^9/sec for heavy (A >100 beams),

b) Enhance data rate (~10X),

c) Permit e^+e^- measurements to lower energies and to $d\sigma/dM \sim$ nb/GeV level (presently expect 1-10 μb/GeV at the Bevalac),

d) Allow data at higher $P_\perp$'s (~1 GeV/c) for e^+e^- pairs, which should help distinguish between different production mechanisms.

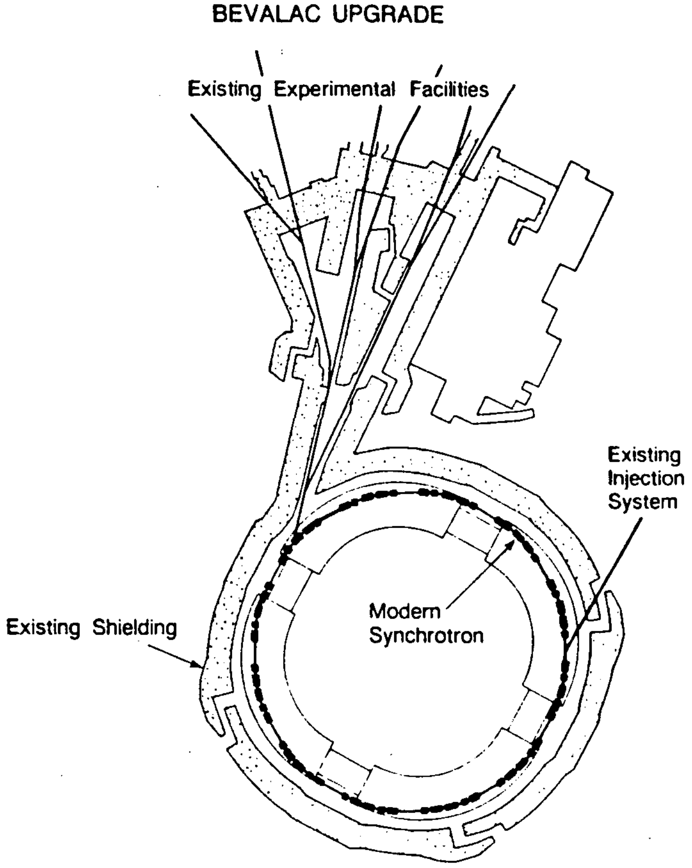


Fig. 8 View of Bevalac Upgrade showing replacement synchrotron and existing experimental halls.

5. *Summary*

Dileptons are widely considered as one of the fundamental tools available for gaining insight into nuclear matter under extreme conditions--whether in the quest for the QGP or learning more about the EOS of nuclear matter at high T, ρ.

At Berkeley by mid-1987 we expect to have our first results on pA → e^+e^- + x(~2.1 GeV/nucleon). On the same time-scale several groups should have early results on the e^+e^- and $\mu^+\mu^-$ mass spectra in ^{16}O+A collisions at 60-200 GeV/nucleon at the CERN SPS. These will be eagerly awaited for at the next Quark Matter meeting (August 1987) as perhaps our first inkling of the QGP. There is no dedicated experiment at the Brookhaven AGS to measure dileptons at present, but experiments are expected later--particularly when the heavy beam capability (AGS booster) is realized (~1989). Finally, several groups are looking at dilepton possibilities for RHIC (physics in the 1990's). The future for this probe looks promising!

6. *Acknowledgments*

My thanks to the members of the DLS collaboration for many stimulating discussions on dileptons (particularly J. Carroll and G. Roche). I wish to thank Professor Baldin and the other members of the Organizing Committee for inviting me to speak at this conference and for their hospitality during the stay in Dubna.

This work was supported by the Director, Office of Energy Research, Division of Nuclear Physics of the Office of High Energy and Nuclear Physics of the U.S. Department of Energy under Contract DE-AC03-76SF00098.

References

1. R. Stock, Nuclear Physics *A447*, 371 (1985).
2. H. Specht, Nuclear Physics *A447*, 387 (1985).
3. L. van Hove, Nuclear Physics *A447*, 443 (1985).
4. Quark Matter '84, Proc. of the 4th Intl. Conf. on Ultra-Relativistic Nucleus-Nucleus Collisions, Helsinki, Finland, 17-21 June 1984, ed. by K. Kajantie, Lecture Notes in Physics 221, Springer-Verlag (1985).
5. A.J.S. Smith, Moriond Workshop on Lepton Pair Production, Les Arcs-Savoie-France, Jan. 25-31, 1981.
6. K.J. Anderson *et al.*, Phys. Rev. Lett. *37*, 799 (1976).
7. S. Mikamo *et al.*, Phys. Lett. *106B*, 428 (1981).
8. D. Blockus *et al.*, Nucl. Phys. *B201*, 205 (1982).

9. M.R. Adams *et al.*, Phys. Rev. *D27*, 1977 (1983).

10. H.J. Specht pg. 221 in Quark Matter '84, Proc. of the 4th Intl. Conf. on Ultra-Relativistic Nucleus-Nucleus Collisions, Helsinki, Finland, 17-21 June 1984, ed. by K. Kajantie, Lecture Notes in Physics 221, Springer-Verlag (1985).

11. J. Carroll *et al.*, Report of the Working Group on Penetrating Probes at Fixed Target Facilities, pg. 45 of the proc. of the Workshop on Detectors for Relativistic Nuclear Collisions, Lawrence Berkeley Laboratory, Berkeley, California, March 26-30, 1984, ed. by L. Schroeder, LBL-18225 (UC-37, CONF-8403137).

12. T. Ludlam, Nuclear Physics *A447*. 349 (1985).

13. S.A. Chin, Phys. Lett. *119B*, 51 (1982).

14. DLS collaboration--LBL: G. Claesson, R. Fulton, D. Hendrie, G. Krebs, E. Lallier, H. Matis, J. Miller, T. Mulera, C. Naudet, D. Nesbitt, H. Pugh, G. Roche, L. Schroeder, A. Yegneswaran, Z. Wang. Clermont- Ferrand: G. Landaud. Johns-Hopkins: T. Hallman, L. Madansky. Lousiana State: S. Christo, Y. Du, J.-F. Gilot, P. Kirk. Northwestern: D. Miller. UCLA: J. Bystricky (on leave from IN2P3, Fr.), J. Carroll, J. Gordon, G. Igo, P. Ouillataguerre, S. Trentalange.

15. J. Kapusta private conversations and invited talk given at the 1986 Bevalac Users' Meeting (April 1986).

16. The Bevalac Upgrade, LBL PUB-5166 (March 1986).