DOE/ER/40413

RECEIVED
JUL 02 1999
OSTI

STUDIES OF RELATIVISTIC HEAVY ION COLLISIONS

Final Report

July 16, 1987 to December 31, 1997

Leon Madansky

Notice

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed or represents that its use would not infringe privately-owned rights.

The Johns Hopkins University
Baltimore, Maryland

1997

PREPARED FOR THE DEPARTMENT OF ENERGY
UNDER GRANT NUMBER DE-FG02-88ER40413

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

MASTER

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

ABSTRACT

As a member of the DLS collaboration, the Hopkins group participated in all aspects of the experiment and the analysis of the results. The recent work involved measurements of dielectrons from p-p, p-d collisions as well as heavy ion Ca-Ca collisions at high densities. These results show the expected effects of bremsstrahlung vector meson decay and Dalitz decay but still show that some varieties of the low mass cross-sections disagree with various theoretical estimates, which could indicate other effects of high nuclear density. The Hopkins group has also been an initial member of the STAR collaboration and helped initiate the proposal for jet searches in the heavy ion experiments at RHIC. The group was instrumental in initiating the first stage of an electro-magnetic calorimeter for these experiments. The group also joined (E896) the Ho experiment. This work was primarily devoted to finding the existence of an elementary system containing strange quarks. An initial experiment was done recently at which Hopkins provided various beam counters. The final work is expected to commence in the fall of '98. Finally, the group has contributed to a number of experiments involving polarization effects in nuclear collisions, searching for production of antimatter, and other aspects of relativistic collisions of heavy ions using the facilities at Brookhaven National Laboratory (BNL).

I:

In a workshop considering heavy ion collisions, LM presented a series of design criteria for measuring lepton pairs resulting from these nuclear interactions. This was reported in a publication (1A). The next year, 1981, a collaboration, which was known as the DLS group, was formed to detect electron pairs and the construction of the apparatus was completed and first data taken in 1986. (1B) describes the dilepton spectrometer, which included two Cerenkov detectors on each arm, a wire chamber system to measure momenta, and various scintillator systems to arrange for triggers and provide a system of time-of-flight measurements. The Hopkins group at the beginning of this work was responsible for the design of the Cerenkov system, the software for taking the data and for the analysis in general. The early experiments involving nucleon-nucleus and nucleus-nucleus collisions were too low in statistic accuracy to evaluate the many sources of pairs. But the experiments showed the feasibility which could yield data that could be compared with theoretical expectations. Around 1990, the first work on reasonably high statistics began with p-p and p-d interactions from 1 GeV to 4.9 GeV. This work was essentially to establish the baseline for evaluation of future nucleus-nucleus collisions in the sense that the p-p and p-n interactions could be summed up in a nuclear-nuclear collision by assuming a hadron gas collision. After work in subsequent years on Ca-Ca, α -Ca and d-Ca, and C-C, work essentially brought the program to its present status. Two of the latest publications (1C and 1D) represent the evaluation of our data.

In studying nucleon-nucleon data, we found that the shape of the spectrum could be understood with the usual "cocktail" distribution of dilepton sources. These include in the low mass range, bremsstrahlung, Dalitz pairs from π^0 decay and in decay of lepton pairs from vector mesons, and a contribution from Δ can contribute to intermediate mass ranges. In addition, the effect of p-p annihilation in the intermediate mass range ~ 400 MeV was a possibility in nucleus-nucleus collisions. Since the dilepton spectrometer only samples a fraction of the rapidity region and azimuthal coverage, several assumptions have to be made about the acceptance. The data seems to follow these general sources but are somewhat larger in cross-section than predicted by this "cocktail" assumption in the region of ~ 400 MeV. A summary of the evaluation of the nucleon-nucleon data is presented below.

The conclusions from the nucleon-nucleon data taken from publication (1C) report our best conclusions drawn from the data. We have presented differential cross-sections as a function of mass, transverse momentum, and rapidity for pp and pd collisions from $T=1.04$ to 4.88 GeV. The integrated cross-section is found to be rapidly increasing with beam energy from $T=1.04$ to 4.88 GeV, as was also found to be the case in our previous studies of the pBe system. The shape of the mass spectra from pp collisions changes as the beam energy crosses over the threshold for η meson production, indicating the importance of the η Dalitz decay component. The shape of the pd mass spectrum at 1.04 GeV is found to be nearly identical to that of dCa at 1.0 A GeV, but the pp mass spectrum falls off much more rapidly with increasing mass. At 4.88 GeV we observe a clear peak at the ρ - ω mass, but there is no obvious indication of a similar peak at 2.09 GeV. This may indicate a breakdown of VDM, but the interpretation is complicated by

uncertainty in the strong T matrix which can modify the shape of the mass spectrum.

The rapidity spectra for the pp collisions reflected about mid-rapidity suggests that the cross-section for dileptons with masses greater than $0.25 \text{ GeV}/c^2$ peaks at mid-rapidity, particularly for the highest beam energies. The shapes of the transverse momentum and rapidity spectra for pp and pd collisions are similar. The contribution from π^0 Dalitz decays appears primarily at low transverse momentum and high rapidities within our acceptance.

The pd/pp ratio decreases with increasing beam energy. This indicates that although the dielectron production cross-section in pp and pn collisions at 4.88 GeV are nearly equivalent, there is a large enhancement of pd relative to pp at the lower beam energies. This asymmetry has been attributed to the additional energy available in the pd system due to its Fermi momentum, destructive interference between dileptons created from bremsstrahlung and Δ Dalitz decay in the pp system at high mass, and, in the case of the 1.27 GeV data, the observed enhancement in η cross-section in pn collisions relative to that of pp collisions near the η production threshold.

These data should provide a useful test of theoretical predictions of the relative importance of various dielectron sources in the following manner. At 1.04 GeV in the pp system, only Δ Dalitz decay and pp bremsstrahlung are expected to contribute. Of the two, the Δ Dalitz decay is consistently predicted to dominate the dilepton production in this system. As the Δ production cross-section is constrained by pion measurements, this system should provide a first test of the various bremsstrahlung calculations. If Δ decay is found to account for the pp data, the next test would be pd at 1.04 GeV. This should provide a stronger test of the bremsstrahlung models since they predict that bremsstrahlung will dominate here. The possible contribution of subthreshold η production could be a complicating factor, but substantial body of data for η production near threshold exists. The trend in the pp and pd data as the beam energy is increased over the η threshold should provide additional tests of the η contribution. The comparison should then be extended to $T=2.1 \text{ GeV}$ where models which utilize the VDM form factor in the virtual photon to proton interaction predict an enhancement or should at the ρ mass. Finally, the proposal that decays of heavy baryon resonances will produce ρ mesons with reduced masses due to phase space limitations which will fill in the dilepton cross-section between η and ρ mass can be tested in the evolution of the dilepton cross-section from $T=2.09$ to the 4.88 GeV. The transverse momentum and rapidity spectra should provide additional constraints, so that comparisons should not be limited to the mass spectra alone. Once a model adequately reproduces the pp and pd data, it may be used to investigate the latest DLS nucleus-nucleus data to search for any deviations from simple superposition of free hadron-hadron interactions caused by the presence of the nuclear medium.

The best data at 1 GeV for nucleus-nucleus reactions is given in (1B). Here we find that the low mass cross-sections for lepton pairs in the Ca-Ca system exceeds what one expects from the "cocktail" assumption, assuming that the eta production follows the so-called TAPS data. The low mass cross-sections from these four data sets reveal a mass-independent scaling of $d\delta/dn \propto A_p A_t$ suggesting similar dynamics for the dominant source mechanisms in reactions ranging from d+Ca to Ca+Ca. While the values of the low mass cross-sections disagree with

an extrapolation of a simple model used to interpret the TAPS results, and with recent model results, we point out that the shape of the data can be approximated by pair distributions characteristic of π^0 and η Dalitz decays. At higher pair mass, the ratio of $\text{Ca}+\text{Ca}$ to $\text{C}+\text{C}$ cross-sections is much larger than the $A_P A_T$ ratio, indicating that a density-dependent mechanism(s) may be exhibited in this mass region.

We indicate in the Bibliography the publications from 1987 to the present which are related to dilepton work. Drs. Timothy Hallman, R. Welsh and W. Christie, who were postdoctoral fellows at Hopkins, made major contributions to the DLS program. TH was instrumental in designing the Cerenkov system and was influential in the overall construction of the DLS spectrometer. RW played an important role in the analysis of the data and the theoretical evaluation, especially involving bremsstrahlung effects. WC was also helpful in the evaluation of the data when he was a postdoctoral fellow.

Although the experiment at LBL was completed several years ago, a complete review of the project will be prepared under the leadership of Dr. Jim Carroll. Finally, the lepton pair work at this energy is being taken over in Darmstadt by the HADES apparatus, which essentially will cover a complete azimuthal coverage and an extensive rapidity range. This would be helpful in finally establishing the effects of high density nuclear matter that can be seen by lepton pairs.

REFERENCES:

- 1A. Lepton Pairs from Relativistic Heavy Ion Collisions: Some Design Criteria, L. Madansky, Johns Hopkins University. Contribution to a Workshop on Lepton Pair Production in Heavy Ion Collisions. Held at Berkeley, California, May 18-22, 1981.
- 1B. The Dilepton Spectrometer. A. Yegneswaran et al., Nucl. Instr. & Meth. A290, 61 (1990).
- 1C. Inclusive Dielectron Cross Sections in p+p and p+d Interactions at Beam Energies from 1.04 to 4.88 GeV. W.K. Wilson et al., LBNL-39973 UC413, preprint, July 1997. Submitted to Physical Review C.
- 1D. Dielectron Cross Section Measurements in Nucleus-Nucleus Reactions at 1.0A GeV. R.J. Porter et al. (DLS Collaboration), Phys. Rev. Letters, 79, 1229 (1997).

II:

A series of experiments were done in collaboration with the 810 group at BNL. These involved both heavy ion experiments at AGS energies as well as experiments using polarized proton beams to find the asymmetry of final state systems.

The basic instrument for these experiments was the TPCs in a large gap magnet which gave excellent momentum measurements. The use of detectors for selecting the impinging heavy ion beam, as well as systems for time-of-flight and particle identification, were also part of the system. Papers 2A and 2B describe the effects of good track reconstruction with very high multiplicity events. This work gave a great deal of encouragement for the later TPCs (e.g., the STAR system) since the very high energy and use of Au beams would create very high multiplicities as well. In addition, the effect of high beam rates (as much as 10^7 minimum particles per second) could be studied and the effect of positive ions was minimal.

A number of heavy ion reactions were studied at energies around 14 GeV with silicon beams. The production of strange particles over a large rapidity region was performed and gave a baseline to understand the possible high density effects which are expected in the forthcoming experiments at RHIC. Publications 2C through 2G present the results and were compared with cascade models that were developed during that time. Typically, the strangeness production was in excess of the predictions. A measurement of low transverse mass in the production of K_S^0 mesons was found in contradiction to the enhancement seen in some of the work.

The Hopkins group prepared some of the detectors and joined in the initial on-line analysis of the work, and allowed us to use the system for subsequent work which will be described in Sections III and IV.

REFERENCES:

- 2A. Modular TPCs for Relativistic Heavy-Ion Experiments, A. Etkin et al., Nucl. Instr. & Meth. in Physics Research A283, 557 (1989).
- 2B. Effects of high beam rates on TPCs, A. Etkin et al., Nucl. Instr. & Meth. in Phys. Research A323, 224 (1992).
- 2C. Rapidity distributions of K_S^0 's and Λ 's produced by 14.6xA GeV/c Si beams on Si and Pb targets, S.E. Eiseman et al., Physics Letters B 297, 44 (1992).
- 2D. Neutral V production with 14.6xA GeV/c silicon beams, S.E. Eiseman et al., Physics Letters B 248, 254 (1990).
- 2E. E^- production in heavy ion collisions at the AGS, S.E. Eiseman et al., Physics Letters B 325, 322 (1994).
- 2F. Recent Results from E-810, K.J. Foley (E-810 Collaboration), Nucl. Phys A544, 335c (1992).
- 2G. Measurement of low $M_T K_S^0$ production from 14.6A GeV/c Si beams on a Pb target, S. Ahmad et al., Phys. Rev. C52, R2289 (1995).

III: Antiproton Nucleus Reactions

A series of experiments involving incident antiprotons on nuclei were begun in 1990. A search was conducted to find if antiprotons could create a high temperature environment due to annihilation in a system of nuclear density. This would contrast with relativistic heavy ion collisions where high densities were expected. Experiment E854 at BNL was designed to look at the final production and compare the results with normal hadron cascade calculations. Paper 3A describes the experimental apparatus. A second paper, 3B, gives the results between 5 and 9 GeV of antiproton nucleus reactions. This search for multiplicities of inclusive Λ , $\bar{\Lambda}$ and K_S^0 production was measured on a light nucleus like C and heavier nuclei, Cu and Pb. The final results are shown in 3C. Essentially, results involving intranuclear cascade calculations reproduce the main features of these experiments so that no compelling evidence for the production of exotic phenomena was seen. Clearly, evidence for the production of quark-gluon plasma requires both higher density and temperature in the reactions of nuclei.

REFERENCES:

- 3A. Measurements at 0° of Negatively Charged Particles and Antinuclei Produced in Collision of 14.6A GeV/c Si on Al, Cu and Au Targets, M. Aoki et al., Phys. Rev. Lett. 69, 2345 (1992).
- 3B. Anti-Proton Nucleus Interactions at 5, 7 and 9 GeV/c, S. Ahmad et al., Nucl. Phys. A585, 193c (1995).
- 3C. Strangeness Production in Antiproton Nucleus Interactions at 5.2, 7.0 and 8.8 GeV/c, S. Ahmad et al., to be submitted for publication.

IV:

Our group collaborated in Experiment E878 at BNL to find the possibility of heavy ion reactions which could produce new metastable particles such as strangelets. This experiment investigated particle production using a zero degree 2-segment focussing baseline spectrometer examining 2×10^{12} Au+Au interactions at a beam momentum of 10.8A GeV/c. These experiments, done in 1995, produced upper limits for such strangelets as the H_0 , etc., whose lifetime was greater than 100 nanoseconds. An experiment to look for strangelets shorter than this lifetime was begun in 1997, and will be described in a later section of this report. This work, however, would produce cross-sections for antiproton production and limits on higher antinuclei. Publications 4A, 4B and 4C are reports of these results. The Hopkins group helped set up the experiment and provided a portion of the on-line analysis. An extensive paper (4D) was prepared giving the results of antiproton production with Au beams on several nuclear targets. The data were measured for a wide range of centralities and rapidities using a spectrometer described above and a high rate centrality detector for triggering. The data were compared with various models exploring the physics of antiproton production and annihilation.

REFERENCES:

- 4A. Search for New Metastable Particles Produced in Au + Au Collisions at 10.8A GeV/c, D. Beavis et al., Phys. Rev. Lett. 75, 3078 (1995).
- 4B. Centrality Dependence of Antiproton Production in Au + Au Collisions, D. Beavis, et al., Phys. Rev. Lett. 75, 3633 (1995).
- 4C. High rate multiplicity detector for relativistic heavy-ion collisions, D. Beavis et al., Nucl. Instr. & Meth. in Phys. Research A357, 283 (1995).
- 4D. Antiproton distributions in Au + nucleus collisions, M.J. Bennett et al., Phys. Rev. C56, 1521 (1997).

V:

The Hopkins group joined a collaboration with a group at Rice University and Brookhaven to study the spin effects of particle production using incident polarized proton beams. The motivation of our group was to understand the result of the proton spin in the behavior of the spin of final state hadrons and/or asymmetries as a baseline for production of similar hadrons in heavy ion reactions. Although the experiments concentrated on the polarization of inclusively produced lambdas, results were also given for the analyzing power of pions and neutral kaons. This work was done at Brookhaven with the MPS magnet system, utilizing 13 to 18 GeV polarized protons. The results of this work (5A, 5B, 5C) showed that the predominate mechanism for lambda production was the extraction of a strange quark from the sea, combining with a di-quark from the incident proton, yielding a polarized lambda similar to the result for the unpolarized case. Careful measurements of the effect of Σ production were taken into account. (Experiments at 200 GeV incident protons begin to show deviation at higher momenta transfers) Measurements of the analyzing power in the same experiment for charged pions and K_S^0 mesons were taken up to transverse momentum ranging up to 2 GeV/c. The results indicate that sizeable effects are present at high x_F and also persist in the hard scattering region. A zero value, however, of the analyzing power was observed for π^- production in contrast to that of π^0 's.

The Hopkins group took advantage of the experiment involving silicon beams at the MPS to measure the polarization of Λ^0 hyperons produced in central collisions. Although these statistics were marginal, the results show a definite reduction in the polarization of the Λ compared to proton nucleus collisions, indicating a marked difference between the mechanism applied in the lower density case. These unpublished reports were presented in the August, 1993 Annual Report of the Hopkins group.

REFERENCES:

- 5A. Spin Transfer in Hyperon Production, B.E. Bonner et al., Phys. Rev. Lett. 58, 447 (1987).
- 5B. Spin-parameter measurements in Λ and K_S^0 production, B.E. Bonner et al., Phys. Rev. D38, 729 (1988).
- 5C. Analyzing power of inclusive production of π^+ , π^- , and K_S^0 by polarized protons at 13.3 and 18.5 GeV/c, B.E. Bonner et al., Phys. Rev. D41, 13 (1990).

VI: The H_0 (Hexaquark) Search

The H_0 is the most plausible multiquark state comprising a combination of six quarks (uuddss) with baryon 2 and spin parity $J^\pi = 0^+$ and strangeness 2. It is a unique object distinct from a bound state of two Λ particles, a deuteron-like system. As a continuation of the program searching for systems involving a strange particle created by collisions of heavy ions, a collaboration was formed to study this new system. There was some hint from previous work of the E810 collaboration concerning the search for strange particles (6A). No candidates were found, but subsequent data with the silicon beam at 14.6xA GeV/c found several H_0 candidates. These were observed in the Σ^-p decay (6B) indicating the possibility of the production of the H_0 . However, the backgrounds and trajectories of the H_0 candidates were very difficult to match to the initial reaction point (6B).

A collaboration (Experiment E896) was formed to study the possibility of H_0 production in an experiment especially designed to clarify the origins of the decay production. The experiment relies on a very high magnetic separator to remove most of the charged particles from the interaction and the decay produced within a wire chamber system with its own magnetic field. The magnet, manufactured by the Oxford Company in England, was delivered last year but its performance at the necessary peak field was diminished by various technical difficulties. Nevertheless, some data were taken in the fall of '96 to ascertain the properties of the trigger and detection systems. An excellent review was presented by W.J. Llope and is shown in "Advances in Nuclear Dynamics 2", and also reported as publication 6C. The final runs are scheduled for the spring of '98 with the full apparatus in place. We expect the data will either show the existence of H_0 in the range and lifetimes available (approximately Λ^0 lifetime), or no bound state at all, which would, therefore, put limits on the mass of such an object.

The Hopkins group was responsible for developing the quartz Cerenkov detector for defining the initial beam (Au nuclei), and a system of shower secondaries to indicate the impact parameter for the collision. Both aspects were used in the trigger.

Although the possible existence of H_0 dibaryon has many consequences for cosmology and particle physics, and is the prime purpose of this search, the study of Λ production itself is of interest, as was indicated in a previous comment, since the polarization in the heavy ion collisions was seen to be very minimal, indicating a different mechanism for the so-called sea, giving rise to Λ production in hadron-nucleus collisions in the past. We expect to be involved in this study as well.

REFERENCES:

- 6A. Results from E-810 Concerning Strange Particles and Strangelet Search, R.S. Longacre et al., Nuclear Physics A566, 167c (1994).
- 6B. H_0 candidates from the decay $H_0 \rightarrow \Sigma^-p$, observed in heavy ion collisions with 14.6xA GeV/c Si beam on Pb target, Ron Longacre et al., Nucl. Phys. A590 (1995).
- 6C. The BNL-AGS Experiment 896, W.J. Llope et al., Adv in Nucl. Dynamics 2, 19 (Plenum Press, 1996).

VII: Heavy Ion Collisions with the STAR Apparatus

In a workshop on detectors for relativistic nuclear collisions (7A), LM discussed ways of utilizing penetrating probes of nuclear matter which would involve the detection of photons or leptons with transverse momenta larger than 3 GeV; the basic idea being that the initial parton scattering would involve quarks and gluons that would have to penetrate the high density matter created in the collision. Bjorken (7B,7C) estimated that the energy loss of these secondary partons would be different as they traverse a quark-gluon plasma in contrast with a high density hadron gas. The detectors for such experiments would involve the detection of jets, di-jets and gamma-jet systems to measure the spectra and compare that with nucleon-nucleus reactions. A recent paper by J. Harris et al. (7D) describes the STAR experiment.

The Hopkins group joined the STAR collaboration when it was clear that the proposed detector would have the capability of measuring jets by the use of an electro-magnetic calorimeter. Although the fluctuations of high momentum particles in the reaction could be rather severe it seemed that one could overcome these problems with sufficient spatial and energy resolution. Our group was instrumental in studying simulations of jet physics using various forms of EM-calorimeters and helped in the studying of prototypes prepared by the Argonne group at test beams at BNL. The EM-cal system was recently approved and will be constructed as an add-on several years after the baseline system of STAR is in place. However, a smaller system of calorimeters will be in place soon after the experiment begins where the EM-cal can be used for triggering and observing the nature of particle production in the collisions.

It is interesting to note that the STAR system including the full EM-calorimeter (7E) would be ideal for studies with polarized proton beams. The nature of the spin arrangements of all the partons and protons (quarks, gluons) can be studied with the EM-cal through the gluon Compton effect and the usual jet-jet physics. Although the EM-calorimeter will be completed some 2 or 3 years beyond the start-up of RHIC, it should be ready to accomplish the polarization work at that time. The Hopkins group was a member of the spin collaboration at RHIC, being a natural extension of our work with polarized protons and hyperons polarization, etc.

LM has made arrangements to travel to Brookhaven to help in the start up experiments with STAR and, eventually, to collaborate on work involving the EM-calorimeter.

REFERENCES:

- 7A. Proceedings of the 1984 LBL Workshop on Detectors for Relativistic Nuclear Collisions (L. Schroeder, ed), T. Ludlam et al., LBL-18225, p. 115 (1984).
- 7B. J.D. Bjorken, Fermilab 82/59/59-THY (1982); J. Appl. Phys. Rev. D33, 717 (1986).
- 7C. X.N. Wang and M. Gyulassy, Phys. Rev. Lett. 68, 1480 (1992).

- 7D. The STAR Experiment at the Relativistic Heavy Ion Collider, J.W. Harris (STAR Collaboration) Nucl. Phys. A566, 277c (1994).
- 7E. The Electromagnetic Calorimeter for the Solenoidal Tracker at RHIC, A Conceptual Design Report, The STAR EMC Collaboration, LBL PUB-5380 (1993).

VIII: General Remarks

The Hopkins group in the past ten years has been involved in studies of heavy ion collisions at projectile energies between 1 and 15 GeV to look for phenomena indicating the difference in the physics of high density and high temperatures of the nucleon system at these energies. In general, the results involving lepton pairs, polarization of Λ 's, etc. essentially showed that the behavior involved is one of nucleon-nucleon collisions and, therefore, represented a baseline to indicate deviations at much higher energies (such as RHIC). The possible existence of a quark-gluon plasma in which the final freeze-out products would be different from those at low energies could be significant. In the near future, we are looking forward to these experiments and we (LM and JM) expect to contribute to these studies.

RESEARCH STAFF DURING THE GRANT PERIOD:

Professor Leon Madansky, Principal Investigator

Dr. John Mitchell, Visiting Research Scientist

Dr. T. J. Hallman, Research Associate 1983-1990

Dr. W. Christie, Research Associate 1992-1993

Dr. R. C. Welsh, Postdoctoral Fellow 1992-1994

Also the following part-time research staff:

Dr. M. E. Beddo, Postdoctoral Fellow

Dr. R. Fletcher, Postdoctoral Fellow

PHD GRADUATE DURING GRANT PERIOD:

R. C. Welsh 1992 "Observation of dilepton production in Ca-Ca collisions
at 2.1 GeV/nucleon"

BIBLIOGRAPHY

Lepton Pairs from Relativistic Heavy Ion Collisions: Some Design Criteria, L. Madansky, Johns Hopkins University. Contribution to a Workshop on Lepton Pair Production in Heavy Ion Collisions. Held at Berkeley, California, May 18-22, 1981.

First Observations of Dielectron Production in Proton-Nucleus Collisions below 10 GeV, G. Roche et al., Phys. Rev. Lett. 61, 1069 (1988).

Mass and Transverse Momentum Dependence of the Dielectron Yield in p-Be Collisions at 4.9 GeV, Letessier et al., Phys. Rev. C40, 1513 (1989).

Dielectron Production in Ca+Ca Collisions at 1.0 and 2.0A, G. Roche et al., Phys. Lett. B228 (1989).

Threshold Behavior of Electron Pair Production in p-Be Collisions, C. Naudel et al., Phys. Rev. Lett. 62, 2652 (1989).

The Dilepton Spectrometer, A. Yegneswaran et al., Nucl. Instr. & Meth. A290, 61 (1990).

Low-Mass Dileptons in pA and AA Collisions, P.A. Seidl et al., Nucl. Phys. A525, 299c (1991).

Dilepton (e^+e^-) Production at Bevalac Energies, Lee S. Schroeder et al., Nucl. Phys. A257, 625c (1991).

Measurement of dielectron production in niobium-niobium collisions at 1.05 GeV/nucleon, S. Beedoe et al., Phys. Rev. C47, 2840 (1993).

Relative dielectron yields in p+p and p+d interactions from $E_{\text{beam}}=1.0-4.9$ GeV, W.K. Wilson and the DLS Collaboration, Phys. Lett. B316, 245 (1993).

Mass and transverse momentum dependence of dielectron production in p+d and p+p collisions at 4.9 GeV, H.Z. Huang and the DLS Collaboration, Phys. Rev. C49, 314 (1994).

Dilepton production from p-p to Ca-Ca at the Bevalac, H.S. Matis and the DLS Collaboration, Nucl. Phys. A583, 617 (1995).

Inclusive Dielectron Cross Sections in p+p and p+d Interactions at Beam Energies from 1.04 to 4.88 GeV. Submitted to Physical Review C.

Dielectron Cross Section Measurements in Nucleus-Nucleus Reactions at 1.0A GeV. R.J. Porter et al., (DLS Collaboration), Phys. Rev. Lett, 79, 1229 (1997).

Invited Talks

Dilepton Production in Nucleus-Nucleus Collisions, Presented at Ninth Winter Workshop on Nuclear Dynamics, Key West, Florida, February 1993 (R. Welsh).

BIBLIOGRAPHY (continued)

Recent Results from Dilepton Experiments at LBL, Presented at the Topical Workshop on Meson Production in Nuclear Collisions, GSI Darmstadt Germany, May 1993 (R. Welsh).

Comparison of Dilepton Rates as Calculated via an Intra-Nuclear Cascade with Experimental Nucleus-Nucleus Data, Presented at Particles and Nuclei International Conference, PANIC93, Perugia, Italy June 1993 (R. Welsh).

Modular TPCs for Relativistic Heavy-Ion Experiments, A. Etkin et al., Nucl. Instr. & Meth. in Phys. Res. A283, 557 (1989).

Effects of high beam rates on TPCs, A. Etkin et al., Nucl. Instr. & Meth. in Phys. Res. A323, 224 (1992).

Rapidity distributions of K_S^0 's and Λ 's produced by 14.6x A GeV/c Si beams on Si and Pb targets, S.E. Eiseman et al., Phys. Lett. B297, 44 (1992).

Neutral V production with 14.6x A GeV/c silicon beams, S.E. Eiseman et al., Physics Letters B248, 254 (1990).

E^- production in heavy ion collisions at the AGS, S.E. Eiseman et al., Physics Letters B325, 322 (1994).

Recent Results from E-810, K.J. Foley (E-810 Collaboration), Nucl. Phys. A544, 335c (1992).

Measurement of low $M_{tK_S^0}$ production from 14.6 A GeV/c Si beams on a Pb target, S. Ahmad et al., Phys. Rev. C52, R2289 (1995).

Measurements at 0° of Negatively Charged Particles and Antinuclei Produced in Collision of 1.46 A GeV/c Si on Al, Cu and Au Targets, M. Aoki et al., Phys. Rev. Lett. 69, 2345 (1992).

Anti-Proton Nucleus Interactions at 5, 7 and 9 GeV/c, S. Ahmad et al., Nucl. Phys. A585, 193c (1995).

Strangeness Production in Antiproton Nucleus Interactions at 5.2, 7.0 and 8.8 GeV/c, S. Ahmad et al., to be submitted for publication.

Search for New Metastable Particles Produced in Au + Au Collisions at 10.8 A GeV/c, D. Beavis et al., Phys. Rev. Lett. 75, 3078 (1995).

Centrality Dependence of Antiproton Production in Au + Au Collisions, D. Beavis et al., Phys. Rev. Lett. 75, 3633 (1995).

High rate multiplicity detector for relativistic heavy-ion Collisions, D. Beavis et al., Nucl. Instr. & Meth. in Phys. Res. A357, 283 (1995).

BIBLIOGRAPHY (continued)

Antiproton distributions in Au + nucleus collisions, M.J. Bennett et al., Phys. Rev. C56, 1521 (1997).

Spin Transfer in Hyperon Production, B.E. Bonner et al., Phys. Rev. Lett. 58, 447 (1987).

Spin-parameter measurements in Λ and K_S^0 production, B.E. Bonner et al., Phys. Rev. D38, 729 (1988).

Analyzing power of inclusive production of π^+ , π^- , and K_S^0 by polarized protons at 13.3 and 18.5 GeV/c, B.E. Bonner et al., Phys. Rev. D41, 13 (1990).

Results from E-810 Concerning Strange Particles and Strangelet Search, R.S. Longacre et al., Nucl. Phys. A566, 167c (1994).

H_0 candidates from the decay $H_0 \rightarrow \Sigma^- p$, observed in heavy ion collisions with 14.6xA GeV/c Si beam on Pb target, Ron Longacre et al., Nucl. Phys. A590 (1995).

The BNL-AGS Experiment 896, W.J. Llope et al., Adv in Nucl. Dynamics 2, 19 (Plenum Press, NY 1996).

Proceedings of the 1984 LBL Workshop on Detectors for Relativistic Nuclear Collisions (L. Schroeder, ed), T. Ludlam et al., LBL-18225, p. 115 (1984).

J.D. Bjorken, Fermilab 82/59/59-THY (1982); J. Appl. Phys. Rev. D33, 717 (1986).

X.N. Wang and M. Gyulassy, Phys. Rev. Lett. 68, 1480 (1992).

The STAR Experiment at the Relativistic Heavy Ion Collider, J.W. Harris (STAR Collaboration) Nucl. Phys. A566, 277c (1994).

The Electromagnetic Calorimeter for the Solenoidal Tracker at RHIC, A Conceptual Design Report, The STAR EMC Collaboration, LBL PUB-5380 (1993).