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PROGRESS REPORT

U.S. DEPARTMENT OF ENERGY

Relativistic Heavy Ion Physics

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TABLE OF CONTENTS

ABSTRACT

In 1991 a proposal by the Iowa State University experimental nuclear physics group entitled "Relativistic Heavy Ion Physics" was funded by the U.S. Department of Energy, Office of Energy Research, for a three-year period beginning November 15, 1991. This is a progress report for the first six months of that period but, in order to give a wider perspective, we report here on progress made since the beginning of calendar year 1991.

In the first section, entitled "Purpose and Trends", we give some background on the recent trends in our research program and its evolution from an emphasis on nuclear structure physics to its present emphasis on relativistic heavy ion and RHIC physics. The next section, entitled "Physics Research Progress", is divided into three parts. First, we discuss our participation in the program to develop a large detector named PHENIX for the RHIC accelerator. Second, we outline progress made in the study of electromagnetic dissociation (ED). A highlight of this endeavor is experiments carried out with the ^{197}Au beam from the AGS accelerator in April 1992. Third, we discuss progress in completion of our nuclear structure studies. In the final section a list of publications, invited talks and contributed talks starting in 1991 is given.

PURPOSE AND TRENDS

The primary emphasis of the Iowa State University experimental nuclear physics program is the study of nuclear matter under extreme conditions of temperature and density by means of relativistic heavy ion collisions. This began in July 1990 when we joined a collaboration to build a di-muon detector for the RHIC accelerator at Brookhaven. Later, as the detector planning evolved, we, along with other members of the di-muon collaboration, joined together with others to build a large detector named PHENIX for RHIC. PHENIX will emphasize the study of photons and di-leptons produced in relativistic heavy ion collisions with a major motivation being to produce and detect signals from the quark-gluon plasma (QGP).

Our group is interested in several aspects of the detector design. It is expected that a major effort of our group will be to help design the trigger for PHENIX in collaboration with the Engineering Services Group of the USDOE Ames Laboratory. That group has extensive relevant experience since they designed the data acquisition system for the Hadron Projection Chamber on the DELPHI detector at the LEP collider at CERN. We also have participated in the RD 10/45 R&D experiment at the AGS accelerator whose purpose is to measure the transport properties of hadrons and muons in various absorbers.

A second aspect of the Ames Program is the study of electromagnetic dissociation (ED) at the Bevalac, AGS, and CERN-SPS accelerators. ED is a process in relativistic heavy ion reactions in which intense electromagnetic fields excite the nucleus through the exchange of virtual photons. ED is predicted to strongly dominate ultrarelativistic heavy ion reactions with heavy projectiles (due to the very intense electromagnetic pulse produced by ultrarelativistic heavy ions), thus it has important implications for the design of experiments and the next generation of heavy ion colliders to be used in searching for the QGP. A proposal, AGS Exp. 862, by our group to extend our ED studies using the 11 GeV/nucleon ^{197}Au beam from the AGS-booster accelerator, was approved in June 1990. Exp. 862 was carried out at the AGS in April 1992 when the first 11 GeV/nucleon ^{197}Au beams became available. At present we are analyzing the extensive data from this run.

In view of our new commitment to relativistic heavy ion physics with future experiments at RHIC as the centerpiece of our program, we are phasing out our efforts in nuclear structure physics. Most of our efforts in that regard are toward completion of the dissertation of Mr. Vo at the 88" cyclotron at Berkeley.

In this report we outline progress made in 1991 and the first six months of our grant (November 15, 1991 to May 14, 1991). The grant covers the three-year period from November 15, 1991 to November 14, 1994. Progress expected in the next year and our plans for the future are outlined in a proposal for funding of the second year (November 15, 1992 to November 14, 1993) of our three-year grant.

PHYSICS RESEARCH PROGRESS

A. Participation in RHIC Detector Development

The participation of the Iowa State experimental nuclear physics program with RHIC began in July 1990 when we joined the collaboration to build a di-muon detector. Along with many of our colleagues from the di-muon collaboration we subsequently joined the larger collaboration to design and build the PHENIX detector which will emphasize the study of di-leptons and photons. Our group hosted the final meeting of the di-muon detector collaboration which was held at Ames during September 1991 at about the same time that the concept of the PHENIX detector was introduced.

We also have joined the PHOBOS detector collaboration. This detector is of interest to us since it emphasizes study of low-momentum particles and thus may have an excellent chance of observing mass shifts of the ϕ meson in hot hadronic matter. Also the proposal to put PHOBOS on-line to the AGS before RHIC becomes operational is attractive since it offers the possibility of performing experiments before the first RHIC beams become available in 1997. We have done studies for the PHOBOS collaboration on e^+e^- background due to electromagnetic dissociation, but our major RHIC efforts at present are directed toward development of the PHENIX detector.

It appears that the major contribution of the Iowa State group to the PHENIX detector will be in developing a first, second, and third level trigger. The concept for such a role began in October 1990 when Glenn Young of Oak Ridge visited Ames for discussions with Harold Skank and Bill Thomas of the Ames Laboratory Engineering Services Group (ESG). The ESG is uniquely suited to work on electronics for PHENIX due to their experience in developing the data acquisition system for the hadron projection chamber (HPC) for the DELPHI detector at the LEP collider at CERN. In April 1992 Glenn Young and Leo Paffrath (Brookhaven) visited Ames for two days to discuss the role of our group in electronics and triggering for PHENIX, and details of our contribution are being negotiated. It is expected that our group will have a major input into the Conceptual Design Report (CDR) for PHENIX which is due in Brookhaven in November 1992.

We have been involved in other studies relevant to the design of the PHENIX detector. One of the primary objectives of PHENIX is the study of virtual photon spectra by means of lepton pairs: the central barrel for e^+e^- pairs, the muon endcap for $\mu^+\mu^-$ pairs, and the combination for muon-electron pairs. Since pion production will be more than three orders of magnitude greater than electron pair production, one of the most critical issues for PHENIX is excellent electron identification (e ID). PHENIX will require a good (>90%) efficiency for e ID and an e/π enhancement factor of 10^4-10^5. One of the technologies that will be needed to achieve this high e/π enhancement involves Cherenkov radiation in a Ring Imaging Cherenkov (RICH) detector. A second technology is a Transition Radiation Detector (TRD) which can be incorporated into a gaseous dE/dx detector (for energy loss of charged particles via ionization) by adding many thin foils to

produce TR for electrons above about 1 GeV. We have worked with the e ID in the momentum range 0.3-3.0 GeV/c, which is the range of interest for e^+e^- studies at PHENIX. In collaboration with Ed O'Brien (Brookhaven), we have studied the chromatic aberrations effects (caused by dependence of the index of refraction of the ethane gas upon Cherenkov light wavelength) for the PMTs used to detect the Cherenkov rings. We also calculated the effects of multiple scattering of electrons in the ethane gas on the formation of Cherenkov rings. We have also studied the possibility of measuring the RHIC luminosity using the Van der Meer method. We prepared a primer on the van der Meer method which indicated the considerations relevant to construction of a luminosity monitor.

The Iowa State group joined the RD-10 experiment which was funded through R&D funds for RHIC. The goal of this experiment was to measure leakage of hadrons though a series of filters upstream from a muon detector. The experiments were carried out using test beams from the AGS accelerator of particles (ρ,π,μ,e) in the momentum range from 1 to 10 GeV/c. Hill, Wohn, and our graduate student Ewell participated in both the preparations for and running of the RD-10 experiment in Spring 1991. In March 1992 Ewell spent about two weeks in Brookhaven helping to set up the RD-45 experiment (the successor to RD-10). The experiment will be run at the AGS in May 1992.

We will work with the TRD/tracking group, for which Ed O'Brien is the spokesman, in studies of TRD and dE/dx detectors at the test beam line of the AGS in May-June 1992. This is a continuation of studies done in 1991 using various polypropylene foams and foils for the radiator. Only foils will be used in the 1992 studies, but various gas combinations (xenon plus small admixtures) will be used for the time expansion chamber (TEC) in the 1992 tests. The TEC detects the electrons produced either by ionization (i.e., the usual dE/dx signal that is spread out over the path of the charged particles) or by the electron "burst" that occurs when a TR photon (of several keV) in absorbed by the gas of the TEC. Two types of electronics will be tested (ADC for dE/dx pulse heights and TDC for analysis of the TR "burst"). Part of the test beam run will study pad detectors that will be used for tracking charged particles in the PHENIX barrel. We expect to participate in running shifts during the two weeks of test beam runs and in on-line analysis of the TRD/tracker data. In particular, we will determine how the TRD and dE/dx signals can contribute to the third-level trigger and whether the pad detectors can provide an estimate of the tracked particle's momentum quickly enough for use at the second-level trigger.

B. Studies of Electromagnetic Dissociation (ED)

Late in the 1970s, after Heckman and Lindstrom observed ED at the Bevalac, we realized that the electromagnetic fields generated at the nucleus in relativistic heavy ion (RHI) reactions with high-Z nuclei could become extremely large. A major effort in the Iowa State program has been the study of the charge dependence of the ED process using projectiles with energies between 1 and 2 GeV/nucleon from the Bevalac. The ED cross section is expected to rise dramatically as the charge of the projectile is increased. We thus carried out experiments under Bevalac proposal 878H to measure ED cross sections on ^{197}Au and ^{59}Co targets using 0.96 GeV/nucleon ^{238}U beams.

Our value for the ED cross section for ^{197}Au(^{238}U,X)^{196}Au is 3.16 barns. This is the largest ED cross section yet observed but is significantly smaller than the value of 4.05 barns calculated by us using the Weizsacker-Williams (WW) virtual photon method. Our result for ^{197}Au may mean that the ED cross section increases more slowly with projectile charge than previously calculated, which is good news for builders of the next generation of relativistic heavy ion accelerators such as RHIC. A letter presenting the Au results has been published in Physics Letters (see publication list) and a longer paper describing in detail the ^{238}U experiments is in preparation for Physical Review C.

We have calculated cross sections for the ED process using virtual photon spectra from the WW procedure. The calculations have been updated using the most recent data for the (γ,n) and (γ,2n) reactions on ^{59}Co and ^{197}Au targets. For one-neutron emission, the calculations and the ED experiments nearly agree, but the dependence of the ED cross section on the projectile charge Z_p was found experimentally to be $(Z_p)^{1.5}$ rather than the $(Z_p)^{1.8}$ calculated using the WW procedure.

In addition to studying the ED charge dependence, we are studying the ED energy dependence by experiments at the AGS Heavy Ion Facility (Exp. 819) and the CERN-SPS accelerator (Exp. NA40). The experiments were carried out at the AGS accelerator using 13.4 GeV/nucleon ^{16}O and ^{28}Si projectiles on ^{197}Au and ^{59}Co targets. The CERN-SPS experiments involved 200 GeV/nucleon ^{16}O and ^{32}S and 60 GeV/nucleon ^{16}O projectiles on ^{197}Au targets. Counting of radioactivities from the above bombardments has been completed at Ames and final data analysis is nearing completion.

It is worth noting that our results on ED have generated considerable interest, both because of the interesting physics and because of the implications for experiments and accelerator performance at RHIC. We gave an invited paper on our latest results at the American Chemical Society meeting in New York in August 1991 and have been asked to write a review article for World Scientific on ED. It is also of interest that our four key papers on one-neutron removal due to ED have received a total of 70 citations (self-citations not included); 52 of the 70 citations occurred in 1989-90.

Calculations using the WW method indicate that σ_{ED} can become very large for high-Z projectiles at ultrarelativistic energies. At the energy of 100 GeV/nucleon planned for the RHIC collider, we calculate that the σ_{ED} for the reaction $^{197}Au(^{197}Au,X)^{196}Au$ reaches 56 b for colliding beams. The first opportunity to study large σ_{ED} was in the spring of 1992 when ^{197}Au beams from the AGS became available. Our AGS Proposal 862, entitled "Electromagnetic Dissociation of ^{59}Co and ^{197}Au by ^{139}La and ^{197}Au Projectiles," (approved in June 1990 for 36 hours of beam time) ponted out that our WW calculations indicate a σ_{ED} for $^{197}Au(^{197}Au,X)^{196}Au$ of 10 barns for the 11 GeV/nucleon ^{197}Au beams from the AGS.

For our AGS Exp. 862, the bombardments with the ^{197}Au beam were completed in April 1992 and counting of the bombarded ^{197}Au and ^{59}Co targets is in progress at Ames using techniques developed by us for earlier ED experiments. Due to the large σ_{ED} expected, a few changes were made in the bombardment sequence. We determined the total cross section for the $^{197}Au(^{197}Au,X)^{196}Au$ reaction by counting individual beam particles at reduced beam intensity using a two-element counter telescope. Separate runs at maximum intensity were carried out in order to measure cross sections for deep spallation products needed to determine the nuclear contribution to the total cross section. Mr. Lars Ewell, a graduate student in our group, will earn his PhD working on this project.

We are collaborating with GSI colleagues on experiment SO32, entitled "Inclusive Measurements of Electromagnetic Dissociation Cross Sections", whose spokesman is K. Summerer of GSI. The run was carried out at GSI in June 1991 on the SIS accelerator using 1 GeV/nucleon ^{197}Au beams. The techniques used for bombardment and data analysis were based on those worked out by our group for experiments at the Bevalac. The targets are being counted at GSI and the results will comprise the dissertation of several students. At the present time we do not anticipate carrying out additional experiments at GSI on ED.

C. Completion of Nuclear Structure Studies

One of the last experiments carried out by us with the TRISTAN separator at the HFBR at Brookhaven was the study of the structure of highly deformed ^{102}Zr populated in the decay of low- and high-spin isomers of ^{102}Y. Based on γ singles and $\gamma\gamma$ coincidence measurements, decay schemes for both isomers were deduced. Of special interest were states observed at 894 and 1211 keV that were postulated to be 0_2^+ and 2_2^+, respectively. Interpretation of these newly observed states in terms of β,γ, or spherical bands were given in our paper published in 1991 in Physical Review C (see list of publications).

The highest priority at TRISTAN in recent years has been experiments using the Fast Electronic Scintillator Timing (FEST) system for β-γ-γ coincidence measurements of level lifetimes down to a few ps. In the A=100 region of deformed nuclei we used FEST to directly determine E2 and M1 moments, and thus deduce the deformation and g-factors of rotational bands. In 1991 we published a paper in Nuclear Physics (see list of publications) on the E2 strengths of the first-excited 2^+ states in the spherical even-even Sr nuclei with A=90-96. This paper compared our results with those for the deformed Sr nuclei with A=97-100 and with various predictions. The Sr shape transition from spherical to deformed is so remarkably large and abrupt that it suggests a "phase change" in Sr collectivity. Invited talks on these results were given at the symposium on "Recent Advances in Nuclear Structure" in Atlanta in 1991 and at the symposium on "Physics of Hadrons and Nuclei" in Darmstadt in 1991 (see list of invited talks). In addition, an invited talk summarizing this work will be given at the symposium on "Nuclear Shapes" to be held in Washington, D.C., in August 1992.

The PhD thesis work of one of our graduate students, Mr. Vo, involves the study of very high angular momentum states in heavy nuclei (A=195-199) at Berkeley using the HERA array at the 88" cyclotron. His work is part of a general program to search for superdeformed (SD) bands in nuclei with Z near 80 and N near 110. In doing these searches, many previously unknown rotational bands, excited in heavy-ion reactions at energies near the Coulomb barrier, are discovered. Mr. Vo's research is focused on the heavy bismuth isotopes, for which no SD bands have yet been found. In 1991 he was heavily involved in two HERA experiments. One was ^{181}Ta (^{22}Ne,xn) at 116 and 120 MeV to study ^{197}Bi and ^{198}Bi. From this data he has found new, highly deformed but not SD, rotational bands in ^{197}Bi and ^{198}Bi. In collaboration with Professor W. H. Kelly of ISU, he has also worked on ^{186}W (^{11}B,xn) at 78 and 84 MeV to search for SD bands in ^{197}Au. He will submit a proposal for Fall 1992 for ^{165}Ho(^{36}S,xn) to look for SD bands in ^{196}Bi and ^{197}Bi at higher angular momentum using this reaction.

Mr. Vo has also been involved in experiments using HERA to search for resonant states in e^+e^- scattering via the predicted 2 and 3 photon decays. These resonant states, called photonium, have been predicted to exist by Professor James P. Vary and Dr. John Spence of ISU. Professor Kelly and Berkeley colleagues are also involved in this project. Mr. Vo has been in residence at Berkeley since March 1992 and has subsequently obtained

three weeks of data on the search for photonium using HERA off-line with a 0.1 mCi positron source (^{68}Ga in secular equilibrium with ^{68}Ge) inside a lead sphere. Mr. Vo's thesis will also include this project. We anticipate that the data needed for his thesis will be obtained by the end of 1992 and that he will complete his degree by the end of 1993.

In 1991 a moving tape collector (MTC) was built by us and the Ames Laboratory shops for use with the Frequent Mass Analyzer (FMA) on-line to the ATLAS accelerator at Argonne. The MTC was delivered to Argonne in late 1991 and successfully tested. In March 1992 the MTC had its first run using ^{58}Ni beams from ATLAS and γ-ray spectra from various reaction products were collected. The system operated as anticipated and will be used in future nuclear structure experiments. Although we will not be major participants in this program we have promised to help where needed.

PUBLICATIONS

Published (Journals)

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J. C. Hill, F. K. Wohn, D. D. Schwellenbach, and A. R. Smith, "Observation of Very Large Electromagnetic Dissociation Cross Sections," Phys. Lett. 273B, 371 (1991).

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J. C. Hill, F. K. Wohn, D. D. Schwellenbach, and A. R. Smith, "Coulomb Dissociation in Relativisitic Heavy Ion Collisions," in Relativistic Aspects of Nuclear Physics, ed. by T. Kodama, World Scientific Publishing Co.

D. D. Schwellenbach, J. C. Hill, F. K. Wohn, P. R. Graham, A. R. Smith, and D. L. Hurley, "Electromagnetic Dissociation of ^{59}Co and ^{197}Au Targets by Relativistic ^{238}U Projectiles," Phys. Rev. C.

Invited Talks

"Small $B(E2;0_1^+ \rightarrow 2_1^+)$ Rates in $^{90-96}$Sr; Evidence for Subshell Closure Effects," Symposium on Physics of Hadrons and Nuclei, Darmstadt, April 1991.

"Structure of Neutron-Rich Sr, Y, and Zr Nuclei," Symposium on Recent Advances in Nuclear Structure Research, Atlanta, April, 1991.

"Electromagnetic Dissociation with Relativistic Heavy Ions," Physics Colloquium, Gesellschaft fur Schwerionenforschung (GSI), Darmstadt, July 1991.

"Electromagnetic Dissociation with Relativistic Heavy Ions," Symposium on Nucleus-Nucleus Collision Mechanisms, Fourth Chemical Congress of North America, American Chemical Society, New York, August 1991.

"Coulomb Dissociation in Relativistic Heavy Ion Collisions," Rio de Janeiro International Workshop on Relativistic Aspects of Nuclear Physics, Rio de Janeiro, August 1991.

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Contributions

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7/7/92