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**MEDIUM ENERGY MEASUREMENTS OF N-N
PARAMETERS**

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By

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NARRATIVE

Until 1990, nearly all of the work of the Medium-Energy nucleon-nucleon (N-N) physics program of the University of Texas at Austin was associated with nucleon-nucleon (N-N) research carried out at the Nucleon Physics Laboratory (NPL) of the Los Alamos Meson Physics Facility (LAMPF). This work has been carried out in collaboration with the LAMPF N-N group, headed by M. W. McNaughton, and with others. The overall aim of our N-N experimental program has been the determination of the nucleon-nucleon amplitudes, both for isospin 0 and 1, at medium energies. The required data have included both elastic and inelastic experiments, and in addition the measurement of polarization and polarization transfer parameters. The aims of our program have been achieved, at least for the elastic channels.

In 1989 we began participation in a rare kaon decay experiment at Brookhaven, BNL E791, an experiment designed to study the fundamental electroweak interaction. E791 is now completed, and we are now involved in a second generation rare kaon decay experiment, E871, which completed an engineering test run during the summer of 1993. We are now also members of a proposed experiment, STAR, (Solenoidal Tracker at RHIC) to be carried out at the Relativistic Heavy Ion Collider facility, RHIC, at BNL.

We had hoped to extend our LAMPF elastic pp and np elastic work to include a comprehensive study of the inelastic N-N channels. However, in the fall of 1992, a LAMPF experiment, E1097, to study the $np \rightarrow pp\pi^-$ reaction, and on which we spent a large amount of effort during the past three years, was terminated due to funding shortages after we had fabricated and tested the detector, but before data acquisition. Consequently we increased our participation in the rare kaon experiment at BNL, E871. The LAMPF N-N program has now itself been terminated, so that as we complete analyses of our LAMPF N-N data, our research emphasis will shift completely to the BNL rare kaon decay measurement, E871, and to STAR. We expect that STAR, which requires the fabrication of a large colliding beam detector facility, will use an increasing fraction of our research efforts during the next few years.

Our recent nucleon-nucleon experiments have consisted of the following:

(1) p-p elastic absolute differential cross-section measurements at LAMPF energies to an absolute accuracy of 1% [1]. These data have completed the determination of the isospin-1 amplitudes from 500 to 800 MeV, stabilizing the phase-shift solutions and providing an accurate calibration standard to which other data may be normalized.

(2) Spin transfer measurements in np elastic scattering. This experiment consisted of measurements of the four spin-transfer observables K_{LL} , K_{SS} , K_{SL} and K_{LS} [2], and of the observables A_{NO} , P , and K_{NN} [3] at 485, 635, and 788 MeV. These data have proven invaluable in fixing the isospin 0 phase shifts and amplitudes.

(3) New measurements [4] of the spin-transfer parameter $K_{LL}(d)$ at 0° , which clarified a normalization discrepancy in our previous LAMPF np elastic analyzing power.

(4) Forward angle (n,p) analyzing power measurements. By extending our analyzing-power measurements to forward angles, we can tie together the normalization of the forward- and backward-angle peaks and also tie the np to the pp normalization via quasifree measurements. Analyzing-power data are also a sensitive probe of the higher partial waves which are sensitive to isospin-0 inelasticity. These measurements were carried out during the summer of 1993; analyses are just now completed.

(5) n-p inelastic polarization measurements. TRIUMF E372 measured the cross-section and analyzing powers for the reaction $np \rightarrow pp\pi^-$ at a neutron energy of 440 MeV. The Ph.D. dissertation of Mark Bachman was based on this work.

In summary, with the inclusion of our p-p absolute differential cross-section data, Bugg and Bryan report stable solutions for the first time near 650 MeV for both isospin-0 and -1 and near 720 MeV for isospin-1 only. Near 800 MeV the phase-shift solutions agree for the first time with precise measurements of the pp total cross-sections. The determination of the isospin-1 amplitudes can be considered complete from 500 to 800 MeV. Our spin transfer measurements in np elastic scattering (E876) have clarified the renormalization problem, which affects previous LAMPF data, and complete the set needed to extract the nucleon-nucleon scattering amplitudes near 500, 650, and 800 MeV. The forward angle (n,p) analyzing power measurements, completed during the summer of 1993, should provide the cross calibration needed to tie together the normalization of different data sets, and will resolve the problem of the divergence of the energy-dependent A_{N0} fits from the single-energy fits above 500 MeV. The major remaining weakness is with the inelasticities. Although the TRIUMF experiment (E372) was successful, the higher energy $np \rightarrow pp\pi^-$ spin-dependent measurements proposed for LAMPF are badly needed to help resolve our very limited knowledge of $I=0$ inelasticities. With the closing down of the LAMPF N-N program, however, we do not anticipate new relevant experimental data within the next several years. With the analysis and publication of our forward angle (n,p) analyzing power data, the determination of the elastic isospin-1 and -0 amplitudes in the energy range 500-800 MeV can be considered complete.

In the Minimal Standard Model (MSM) the decay $K_L^0 \rightarrow \mu e$ is forbidden by conservation of electron and muon additive quantum numbers. Its observation would be the first direct evidence of physics beyond the MSM. The decays $K_L^0 \rightarrow \mu\mu$ and $K_L^0 \rightarrow ee$ are permitted in the MSM, but are highly suppressed. $K_L^0 \rightarrow ee$ has not yet been seen, and observation of a branching ratio for this process that is significantly above MSM predictions would also be evidence for new physics.

BNL E791, a high sensitivity search for $K_L^0 \rightarrow \mu e$ and $K_L^0 \rightarrow ee$, completed data-taking at the Alternating Gradient Synchrotron facility (AGS) of the Brookhaven National Laboratory in 1990, the year in which our group joined the experiment. The E791 spectrometer provided precise tracking with good (redundant) particle identification. Very high rate capability was achieved using custom built front-end electronics, a large parallel readout architecture, and a multi-level trigger system utilizing SLAC 3091/E emulators. The single event sensitivity to the decay $K_L^0 \rightarrow \mu e$ achieved by E791 is $< 3.3 \times 10^{-11}$ [5]. The E791 collaboration concluded that more running with the same apparatus is not an attractive way to make further gains. Therefore, a new collaboration—with substantial overlap with E791—was formed to perform a new search for $K_L^0 \rightarrow \mu e$ and similar modes. A new proposal was written, E871, "A New Search for Very Rare K_L Decays," (Spokesmen: W. R. Molzon, University of California, Irvine; S. G. Wojcicki, Stanford; and J. L. Ritchie, University of Texas), and was presented to the BNL Program Advisory Committee on November 8, 1990. The aim of BNL E871 is to build on the experience of E791, the most sensitive kaon decay experiment performed to date [5], and to re-use some of the E791 equipment. Through increased acceptance, higher rate-handling capability, and improvements in several detector systems, the experiment should reach a single event sensitivity below 2×10^{-12} . At this sensitivity, a few decays of the type $K_L^0 \rightarrow ee$ should be observed if the decay occurs at the Standard Model level, along with about 10,000 $K_L^0 \rightarrow \mu\mu$ decays. The experiment is possible because of the increased beam flux made available by the AGS Booster.

The two physics Ph.D. graduate students who previously had been working on LAMPF E1097, David Ambrose and Patrick Coffey, are now participating in E871 and expect to complete their Ph.D. dissertation research on this experiment. A successful engineering run was completed in July, 1993, with data runs to follow in 1994 and 1995. Fabrication and testing of detector components are continuing.

Recently we joined a large collaborative group working on the RHIC experiment STAR (Solenoidal Tracker at RHIC) at BNL. The physics goals of the RHIC project are to create and study a new phase of nuclear matter - the *quark gluon plasma*, and to study in detail the properties of nuclear matter at high energy density. For the next several years this project will emphasize the design and fabrication of a very large, complex collider detector. This STAR detector is presently conceived of as a combination of a silicon vertex tracker (SVT), a Time Projection chamber (TPC), a set of trigger scintillators, and time of flight (TOF) counters. There are also an external TPC (XTPC) and some MWPCs. Two graduate students, Jaw-Luen Tang and Ke-Sheng Chan spent the past summer working on STAR TPC software simulation studies at Berkeley, and are continuing this work here at Texas during the fall.

An electromagnetic calorimeter has also been proposed for STAR, which would not only allow the detection of gammas, but would allow for some important measurements of spin dependence at high P_T (>10 GeV/c) with polarized colliding protons that relate to the gluon spin structure functions. Funds for engineering and prototyping for an electromagnetic calorimeter are being sought from DOE within nuclear physics. George Glass has been asked by John Harris, the spokesman of STAR, to join in this development effort and is participating in the design of this calorimeter. The task requires a serious engineering study with major prototyping and testing. Further, a major effort is needed for simulation studies that would establish the detectability of the direct gammas and the associated jets within the plethora of tracks generated in the high luminosity environment anticipated for RHIC.

	1991	1992	1993	1994	1995	1996	1997	1998
LAMPF, Elastic N-N	-----							
LAMPF, E1097	-----							
TRIUMF, E372	-----							
AGS, E791/E871	-----							
RHIC/STAR		-----						
AGS P896 H ₀ Search			-----					

Table 1: The expected time scale for our research projects.

Table 1 shows the expected time scale for our research projects. The transition from our LAMPF and TRIUMF N-N experimental program to rare kaon decay and relativistic heavy ion experiments at BNL is apparent. AGS P896 is a search for a short-lived H_0 dibaryon, short lived strange matter, and the investigation of hyperon production in 11.6 A GeV/c Au-Au collisions. The H_0 search is important not only because physics research at RHIC-STAR will not begin until about the year 2000, but also because P896 may well serve as a testing ground for some of the components of the STAR detector system.

References

1. A.J. Simon *et al.*, Phys. Rev. C48, 256, (1993).
2. M.W. McNaughton *et al.*, Phys. Rev. C44, 2267 (1991).
3. M.W. McNaughton *et al.*, Phys. Rev. C45, 2564 (1992).
4. K.H. McNaughton *et al.*, Phys. Rev. C46, 47 (1992).
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SELECTED PUBLICATIONS, 1991-93. The group has, in addition, 5 manuscripts submitted/accepted

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2. "Absolute Differential Cross Section Measurements for Proton-Deuteron Elastic Scattering at 641.3 and 792.7 MeV," E. Gulmez, *et al.*, *Phys. Rev. C* **43**, 2067, (1991).
3. "np Elastic Spin Transfer Measurements at 788 MeV," M. W. McNaughton, *et al.*, *Physical Review C* **44**, 2267, (1991).
4. "Elastic scattering of N, L. and S-type polarized 794 MeV protons from an ND₃ target polarized in the S-L plane," E. Gulmez, *et al.*, *Physical Review C* **45**, 22, (1992).
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11. "Measurement of $np \rightarrow pp\pi^-$ at 443 MeV," P. J. Riley, *et al.*, invited talk, *RIKEN International Workshop on Delta Excitations in Nuclei*, Riken, Japan, May 27-29, 1993 (to be published).
12. "Improved Upper Limit on the Branching Ratio $B(K_L^0 \rightarrow \mu^\pm e^\mp \tau)$," K. Arisaka, *et al.*, *Physical Review Letters* **70**, 1049, (1993).
13. "Forward angle analyzing power in p-n and p-p quasifree scattering at 643 and 797 MeV," G. Glass, *et al.*, *Physical Review C* **47**, 1369, (1993).
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15. "Absolute differential cross-section measurements for $p+p \rightarrow \pi^+ + d$ reaction at 500-800 MeV," E. Gülmez, *et al.*, *Nuclear Physics A* **551**, 621, (1993).
16. "Energy dependent measurements of the p - p elastic analyzing power and narrow dibaryon resonances," Y. Kobayashi, *et al.*, accepted for publication in *Nuclear Physics*.

Biographical Sketch for each Ph.D. Group Member

Dr. Peter Julian Riley. Born 7/6/33, in Kamloops, British Columbia, Canada. Citizenship: U.S. Married, with 4 children. B.A.Sc., (Engineering Physics), University of British Columbia, Canada, 1956; M.A.Sc., 1958, University of British Columbia; Ph.D., Physics, University of Alberta, Canada, 1962. Assistant Professor of Physics, University of Texas at Austin, 1962-66; Associate Professor of Physics, University of Texas, 1967-75; Professor of Physics, 1976-present. Visiting Staff member, Oak Ridge National Laboratory, 1966-7; Visiting Staff Member, Los Alamos Scientific Laboratory, 1974-75. Program Director, Intermediate Energy Nuclear Physics, National Science Foundation, Washington, D.C., 1984-85 (leave of absence from the University of Texas). Chairman, Department of Physics University of Texas, 1992-present. Current research projects: analysis of TRIUMF and LAMPF N-N polarization data; participation in AGS E871 at Brookhaven National Laboratory - search for rare K_L decay modes; participation in group activities associated with STAR work. His research accomplishments include over 130 articles in refereed scientific journals and two books.

Dr. George Glass. Born 6/15/36 in Austria. Citizenship: U.S. Married, with 4 children. B.S. (Physics), MIT (1959); Ph.D. MIT, (1964). Research Associate, Northeastern Univ., 1965-67. Assistant Professor, Univ. of Washington, 1967-71. Senior Research Associate, Univ. of Washington, 1971-72. Post-Doctoral Fellow, Texas A&M Univ., 1972-73. Research Scientist, Texas A&M Univ. (at Los Alamos National Laboratory), 1973 -1992. Senior Research Fellow, Univ. Texas (at Los Alamos National Laboratory), 1992-present. Research interests and experience: the design, instrumentation, and data analyses of medium and high energy particle physics experiments, with special emphasis on polarization studies in medium energy nucleon-nucleon experiments. Current work emphasizes electromagnetic calorimeter prototyping for the STAR collaboration at Brookhaven National Laboratory. His research accomplishments include approximately 70 articles in refereed scientific journals.

Table I: Ph. D. Graduates 1988-1993

Name: Shen-Wu Xu

Date Ph. D. Received: August, 1988.

Thesis title: *Wolfenstein Polarization Observables for the Reactions $pp \rightarrow np\pi^+$ and $pp \rightarrow pp\pi^0$ at 650 and 800 MeV.*

Current Employment: MCC (Microelectronics and Computer Corporation), Austin, Texas.

Name: Mark Bachman

Date Ph. D. Received: Fall, 1993.

Thesis title: *Measurement of $np \rightarrow pp\pi$ at 443 MeV.*

Current Employment: Post-Doctorate, University of California at Irvine, working at E871 (rare kaon decay) at Brookhaven National Laboratory. Supervisor: Dr. Bill Molzon

Table II: Research Associates no Longer with the Group

Name: David Adams

Period spent with group: 1988

Current Employment: Research Associate Professor, Physics, Rice University, Houston, Texas

Name: Kathleen Johnston

Period spent with group: 1991

Current Employment: Assistant Professor, Physics, Louisiana Tech University, Ruston, Louisiana.

Name: Chau Nguyen

Period spent with group: 1992-93

Current Employment: Seeking industrial employment.

**University of Texas
Nuclear Physics Group
DE-FG05-88ER40446
DOE Review
March 14, 1994**

- I. N-N Elastic measurements at LAMPF**
- II. Inelastic pion production**
 - (a) at TRIUMF (E372) and**
 - (b) at LAMPF (E1097)**
- III. Rare kaon decay at BNL (E871)**
- IV. Relativistic heavy ion physics with STAR at RHIC**

I) NN elastic measurements at LAMPF: Overview

Participants: Peter Riley, George Glass, Kok Heong
McNaughton, David Ambrose, Patrick Coffey

Objectives: To determine the N-N amplitudes, both for
isospin 1 and for isospin 0

Experimental measurements:

- (1) np elastic scattering spin transfer observables K_{LL} , K_{SS} , K_{SL} , K_{LS} , K_{NN} , and analyzing power A_{N0} or A_{0N} at 485, 635, and 788 MeV
- (2) New measurements of $K_{LL}(d)$ at 0° , clarifying normalization discrepancy in previous LAMPF np elastic analyzing power
- (3) Forward angle (n,p) analyzing power measurements
- (4) p-p elastic absolute differential cross section measurements, 500-800 MeV, to an absolute accuracy of 1%.

I) E876: Experimental layout

Figure 2: Detector setup for measuring pp-elastic absolute cross sections

(polarized beam, unpolarized target, measure recoil particle polarization)

Diagram illustrating the optical path of a Janus beam. The beam enters from the left, passes through a point labeled LH_2 , and then splits into two paths: an upper path labeled "up bend (Scylla)" and a lower path. The upper path is deflected upwards by an angle θ_b , and the lower path is deflected downwards by an angle θ . The total deflection angle is θ . The beam is labeled "Janus" and ϵ_c . The power of the upper path is $P_n K_L L \sin \theta$, and the power of the lower path is $P_n K_L L \cos \theta$. The beam is also labeled $A_0 N \cos \theta$ and $A_0 N \sin \theta$.

Figure 3: Spin transfer notation

Figure 4: 788 MeV data for K_{NN} and A_{N0} obtained from E876 in 1992

Figure 5: Measured K_{LL} values for calibration of neutron beam polarization

Figure 6: A_{N0} for 485 and 788 MeV obtained from E1293 during 1993/94

Figure 7: Differential cross sections at 90° cm vs. beam energy

II) E372: Overview

Participants: Peter Riley, Mark Bachman

- First measurement of relative differential cross-section for $np \rightarrow pp\pi^-$ at 443 MeV.
- First measurement of ANO for $np \rightarrow pp\pi^-$ at 443 MeV.
- First measurement of ASO,ALO for $np \rightarrow pp\pi^-$ at any energy.
- Exclusive measurements as functions of several phase-space variables.
- Data provides strong tests for pion production models in intermediate range.
- Data provides constraints for partial wave analyses. In particular, demands partial waves with both protons and pions in relative P -states as well as pions in S -states.
- Found no significant difference in overall ANO with $pp \rightarrow pp\pi^0$ at same energy, suggesting weak or no $I=0$ interferences for most of phase-space.
- Found some indication of $I=0$ interference in the narrow $^1S_0(pp)$ region of phase space.

The measurements significantly add to our database for inelastic pion production in the NN system. This measurement is a full phase-space measurement of spin observables in a 3-body system.

Figure 1. Plot of world cross section data for $np \rightarrow NN\pi^\pm$. Curves reflect fits of σ_{01} and σ_{11} as determined by VerWest and Ardnt [1].

Experimental apparatus

Figure 2. Relevant pictures of the detector: a) Side view of target, tracking detector and timing array; b) view of individual scintillator bar; c) top view of vertex traceback for empty target run, showing target walls and vacuum window; d) response of scintillator showing particle velocity vs. energy deposited in the bar. This information allowed event reconstruction and particle identification.

Beam line

Figure 3. Coordinate system defining pion CMS angle and proton angles.

Figure 4. Relative differential cross sections. Cross sections are normalized to $100 \mu\text{b}$. Data are corrected for detector acceptance; error bars are estimates of systematic error. Key to curves: a) detector acceptance; b) phase-space prediction; c) Klot-Lomon prediction.

Figure 5. Analyzing powers A_{SO} , A_{NO} , A_{LO} for angular variables defined in figure 3. Also shown are predictions from the model of Kloet and Lomon. Not shown are A_{SO} and A_{LO} for $\cos\theta$ and $\cos\psi$ which are zero everywhere.

II) E1097: Overview

Participants: Peter Riley, George Glass, Kok Heong
McNaughton, David Ambrose, Patrick Coffey

Objectives

- to measure differential cross sections and spin observables for single pion production, $np \rightarrow pp\pi^-$ at 500-800 MeV.
- to carry out a partial wave analysis of the $I=0$ inelastic amplitudes.
- to complement other studies of $np \rightarrow pp\pi^-$; TRIUMF E372 (438 MeV) and Terrein at Saturne (572,1134 MeV).

Schedule

- Phase 0 - engineering runs, 1991 and 1992; run parasitically to E876.
- Phase 1 - measure observables A_{NO} , A_{LO} , A_{SO} ; LH_2 target, scheduled for 1993
- Phase 2 - measure spin correlation parameters A_{SL} , A_{NL} , A_{LL} and observable A_{OL} ; frozen spin LH_2 target, scheduled for 1994
- E1097 was terminated by LAMPF November, 1992, due to a shortage of funds.

Detection Setup

- Cylindrical drift chamber
- Vertical acceptance $\pm 60^\circ$; Horizontal acceptance 360° .
- Three track events for 50% of phase space.
- ADCs for charge division (vertical track position).
- TDCs for drift time (horizontal track position).

II) E1097: Overview

The experiment, LAMPF E1097, using the LAMPF polarized neutron beam facility, proposed to measure the differential cross section, σ , and the spin observables A_{NO} , A_{LO} , A_{SO} , A_{OL} , A_{SL} , A_{NL} , and A_{LL} for the single pion production reaction $np \rightarrow pp\pi^-$ at neutron beam energies in the range 500–800 MeV. These data should allow a first order partial wave analysis of the $I = 0$ inelastic amplitudes. E1097 was to run in three separate phases, the first of which (Phase 0) was an engineering phase completed in 1992. Phase 1, planned for 1993, would use a polarized neutron beam and a liquid hydrogen target to measure the observables A_{NO} , A_{LO} , and A_{SO} . Phase 2, expected to have run in 1994, would have used a polarized frozen spin hydrogen target to enable the spin correlation parameters A_{SL} , A_{NL} , and A_{LL} , as well as the observable A_{OL} , to be measured. The Phase 1 measurements are the same as those of TRIUMF E372 at lower energy (438 MeV), and many of the E372 collaborators have also participated in E1097. In addition, the Saturne group under Y. Terrien, also studying this reaction, have measured asymmetries A_{NO} at several neutron beam energies between 572 and 1134 MeV, using a polarized neutron beam, but not a polarized target.

The detection system consists of an array of scintillator bars surrounding a cylindrical drift chamber, at the center of which is the target. The detection system is shown schematically in Figure 1.1. In Phase 1 of the experiment, a liquid hydrogen target was to be used, and in the second phase a polarized hydrogen (frozen spin) target. The vertical acceptance of the detector system is approximately $\pm 60^\circ$. There are no constraints on the horizontal acceptance of the drift chamber. The chamber, the primary component of the detector, is designed to be able to detect all three charged particles for $>50\%$ of phase space, measuring positions perpendicular to the wires by measuring the drift time, and along the wires using charge division. We read the charge from each end of the wire with ADC's, while timing the pulses relative to the start of the event with a TDC. The second element of the detector system consists of a thin, curved scintillator (S1), mounted between the target and wire chamber, and a large array of 21 vertical scintillator bars, placed behind the chamber, used for the event trigger. Additionally, we measure the phototube signals from the scintillator array with ADC's to provide particle identification.

E1097 Apparatus

II) E1097: Chamber construction

The wire chamber is a 1.1 meter long cylinder of 16.4 cm inner and 54 cm outer diameter with 1792 high voltage (HV) wires and 448 sense wires, arranged in four cylindrical layers of 2 sense rings each, running vertically inside. The cylindrical walls are ~2 mm thick carbon, fabricated from epoxy-impregnated carbon fiber tape. The HV wires are made of gold-coated stainless steel, 4 mils in diameter. The sense wires are 1.3 mils diameter stablohm with an internal resistance of 1600 ohms per meter. Two 60 cm diameter aluminum end caps, 1 1/4 inch thick, hold the wires and cap the cylinder at both ends.

The aluminum endplates were designed at the University of Texas and built in the UT Physics machine shop with a computer-controlled mill. They were each cut from 1.25 inch aluminum jigplate, 60 cm in diameter with 8 cm diameter holes in the centers. Two circular grooves, 3 mm wide and 4 mm deep, which hold the carbon fiber walls, were cut 8.2 cm and 27 cm from the center of the plate.

A total of 2240 holes, each drilled and reamed to 0.126 inch diameter, are arranged in 20 concentric rings around the center of the plate, and grouped into four groups of five rings each. The rings of sense wires have radii of 9.5 and 10.5 cm, 14.5 and 15.5 cm, 19.5 and 20.5 cm, and 24.5 and 25.5 cm, respectively. Sense wires and high voltage wires, in a ratio of 4 HV to each sense wire, feed through Teflon guides inserted into the holes. The holes of the rings are staggered to produce a hexagonal cell configuration. The results of the tests suggest that this cell shape will produce efficient electron avalanche on the sense wire. Furthermore, the offset pattern of the cells resolves the "left-right" ambiguity associated with drift chambers. The diagram in Figure 2.2 shows the arrangement of the HV wires and sense wires in the hexagonal cells.

For construction of the carbon fiber walls of the chamber, a rod with "half-moon" ribs encased in aluminum served as the mandril. The two mandrils were built at the University of Texas and consist of a 1.27 m long steel pipe, 2 inch outer diameter, with 1.25 inch wall thickness. There are four aluminum ribs which are made of half-moon flanges. This skeleton provides support for the 0.0625 inch aluminum skin rolled and then encased around it. Using this mandril as a mold, 2 mil mylar, then 1 mil aluminized kapton was over-wrapped in a continuous spiral around the aluminum skin rolled and then encased around it. One mm of "pre-preg" epoxy carbon fiber tape was then spiral-wrapped to become the wall of the final piece. A second 1 mil aluminized kapton coat was wrapped around the carbon fiber tape and taped in place at the ends of the cylinder. The entire assembly was placed in an oven and the carbon walls cured at 250° F overnight. After curing, the aluminum mandril and protective mylar were extracted, leaving a cylindrical shell of aluminized carbon fiber, ~2mm thick. The mandril was designed and constructed at the University of Texas, but the application of the mylar, kapton, and prepreg was carried out at the University of Houston Streamer Chamber Facility, SCARF.

II) E1097: Chamber Construction

II) E1097: Chamber electronics

The objective of the chamber electronics was to provide the data acquisition system with an analogue pulse from both ends of each sense wire to obtain a particle trajectory vertical position along a wire using charge division, and a corresponding ECL pulse from each wire to determine a trajectory's horizontal position using the drift times.

Beginning at the chamber, the pre-amps (PA), which were supported by the pre-amp mounts (PM) on the chamber endplates, initially amplified the signal at each end of the wire. Each pre-amp was mounted on a pre-amp board connected to the tops or bottoms of the 16 sense wires.

The amplified signals were sent through 15 ft. of ribbon coax into the shaping amplifiers (SA) housed in power crates. The shaping amplifiers passively coupled roughly 2% of the input from the top and bottom of each wire, and sent the output to the discriminator board (DB). The other 98% of the signal from both ends of each wire was broadened and then sent down a 250 ft. twisted pair shielded flat cable to a receiving board (RB).

We perform the ADC and TDC operations with the LeCroy FERA (Fast Encoding and Readout ADC) system. Each sense wire module uses two 16-channel FERA for the top and bottom ADC's and a TFC(Time to FERA Converter)-FERA combination for the TDC. The TFC feeds the FERA an amount of charge, in the form of a square pulse, linearly proportional to the arrival time of the DB stop signal. A FERA DRV (Driver) provides the FERA modules with gate information, and transfers the ADC output to a memory module (MEM), read by the computer between beam bunches. A single CAMAC high powered crate holds the DRV, MEM, and 18 FERA, bypassing the problem of branching FERA crates found previously.

To link the MEGA electronics with our FERA system, we use a receiver board (RB), which performs 3 basic functions. First, the RB reverses the polarity of the SA output signals before input to the FERA. Next, a capacitor between the FERA signal and ground inputs stops the injected pedestal charge from bleeding to ground. Lastly, a transformer decouples the FERA from the 250' flat cable, to prevent an observed smearing of the pedestal. The LAMPF NMS group, which uses the same flat cable and FERA combination, discovering these receiver board requirements independently, had manufactured 16-channel RB's for that purpose, and allowed us to borrow some of these boards in time for Phase 0 operation.

II) E1097: Chamber electronics

II) E1097: Preliminary tests / results

In Phase 0, the testing and development phase of the experiment, we tested the overall performance and stability of the chamber, specifically its ability to hold high voltage over an extended period of time without breakdown, which had proven troublesome the previous year. We maintained over a third of the chamber for the duration of the summer, learning to diagnose and fix chamber voltage problems quickly and efficiently. These problems usually involved breakdown of the plastic inserts holding the HV wires at either end, which we solved easily by simply replacing the wire.

To test the chamber resolution and efficiency, we ran the chamber in parasitic mode, behind the existing LAMPF E876 apparatus, where a horizontal flux of recoil protons from the E876 LH2 target could pass through the chamber. Eleven modules of sense wires (16 wires each) were added to the eight from the previous year, so that the entire downstream half of the chamber and four upstream modules could be used. The upstream modules, centered between the Phase 2 target insert holes in the chamber walls, allowed the tracking of particles through the entire chamber, as well as testing with a Sr beta source (which cannot penetrate the walls). For the majority of the summer, the number of FERA units available limited us to 10 chamber modules, which we arranged in a way to provide tracking of recoil protons entering and leaving the chamber as well as scattered protons from a block of CH₂ placed in the target area. Additionally, thin horizontal scintillators, placed before and after the chamber and vertically adjustable, provided for testing of the chamber performance along the length of the wires. The majority of events recorded came from single recoil protons or cosmic particles traversing the entire chamber. The tracking software, working on or off-line, proved successful in reconstructing these events. For a few runs, when the beam intensity was high, we observed elastic scattering events from a CH₂ target placed in the chamber center, distinguishable by a 90° separation of the final state particles.

Investigation of the chamber efficiency showed two factors of importance. The first factor results from the proximity of the wires to the chamber carbon walls, which are held at ground and therefore alter the HV field, lowering the wire efficiency as expected. Fortunately, this effect occurs only for the inner and outer sense wire planes, and can be compensated for, somewhat, by raising the HV level in these planes. In general, the inner planes have efficiencies around 97–99%, while the outer planes range from 80–90%. Second, the Z-position of the hits along the wire also affects the efficiency; since the top and bottom chamber plates are, like the walls, held at ground, the HV field and therefore the efficiency should deteriorate towards the chamber ends. However, we found the average efficiency fairly uniform along the wire, up to about 8 cm from the chamber endplates.

II) E1097: Preliminary tests / results

Cosmic Particle Event

Elastic Scattering Event

BNL E871: Overview

Participants: Peter Riley, Chau Nguyen, David Ambrose,
Patrick Coffey

Objective: To set a limit on $K_L \rightarrow \mu e$ at or below 2×10^{-12} , if no signal is observed. At this sensitivity, we would observe a few $K_L \rightarrow ee$ events. The major data-taking will be during the 1994 and 1995 SEB periods.

Table 1: Results from recent $K_L \rightarrow \mu e$ searches.

	BNL780[20]	KEK137[21]	BNL791
$K_L \rightarrow \mu e$ limit	1.9×10^{-9}	9.4×10^{-11}	3.3×10^{-11}
$K_L \rightarrow ee$ limit	1.2×10^{-9}	1.6×10^{-10}	4.1×10^{-11}
$K_L \rightarrow \mu\mu$ sample	~8 events	178 ± 13 events	717 ± 27 events

Table 2: Sensitivity of the new experiment.

	E791 1989 Data	Improvement	E871
$K_L \rightarrow \mu e$ sensitivity (single event)	3.6×10^{-11}	43	8.4×10^{-13}
$K_L \rightarrow ee$ sensitivity (single event)	4.8×10^{-11}	56	8.5×10^{-13}
$K_L \rightarrow \mu\mu$ observed	284 events	34.5	9800 events

III) BNL E871: Overview

The experimental absence of processes which violate separate lepton family number has led to its conservation being formalized in the Standard Model. In a gauge theory, a globally conserved quantity is associated with the existence of a massless boson (as charge conservation is with the photon). Separate lepton number conservation has no associated massless boson and is therefore, according to current theoretical thinking, unlikely to be exact, but highly suppressed in some dynamical process which lies outside the Standard Model. This is the general motivation for searches for separate lepton number violating processes, such as $\mu \rightarrow e\gamma$, $\mu \rightarrow eee$, $\mu^- A \rightarrow e^- A$, (muon-electron conversion in the field of a nucleus), and in the kaon system, the decays $K_L \rightarrow \mu e$ and $K^+ \rightarrow \pi^+ \mu e$. The processes $\mu \rightarrow e\gamma$ and $\mu \rightarrow eee$ only involve leptons, so any interactions depending upon quarks are not probed at all. While the process $\mu A \rightarrow e A$ is a very powerful probe in many models, it also does not involve a generation-change in the quark sector. The small value of Δm_K (3.5×10^{-15} GeV) is a serious constraint in a broad range of models, although a sensitivity of 10^{-12} for $K_L \rightarrow \mu e$ is beginning to be competitive.

The Particle Data Group lists $(5.70 \pm 0.27) \times 10^{-4}$ as the branching ratio for $K_L \rightarrow \gamma\gamma$. Therefore, the unitarity bound is about 6.8×10^{-9} . Recent measurements of $K_L \rightarrow \mu\mu$, which are dominated by E791, are close to this value. The decay $K_L \rightarrow ee$ also receives a contribution from the $2\text{-}\gamma$ process. However, this contribution is helicity suppressed, so that the expected branching ratio is about 3×10^{-12} . The range between this value and the $K_L \rightarrow \mu\mu$ level is a window for observing a new flavor changing neutral current interaction, such as the pseudoscalar leptoquarks that appear in extended technicolor theories.

Three experiments have been searching for the rare modes $K_L \rightarrow \mu e$, $K_L \rightarrow \mu\mu$, and $K_L \rightarrow ee$: BNL E780, KEK E137 (in Japan), and BNL E791. E791 took data in 1988-90, and no $K_L \rightarrow \mu e$ or $K_L \rightarrow ee$ candidates were found. Preliminary values of final results are given in Table 1, along with the final results from both E780 and E137. As is clear from the table, E791 has dominated this research. The new experiment, E871, to be carried out by substantially the same collaboration, will improve upon E791 by more than an order of magnitude. The major data-taking will be during the 1994 and 1995 SEB periods. As Table 2 shows, we expect to set a limit on $K_L \rightarrow \mu e$ at or below 2×10^{-12} , if no signal is observed. At this sensitivity, we would observe a few $K_L \rightarrow ee$ events.

BNL E871: Experimental apparatus

Our approach to the new experiment depends on detector modifications which will provide significantly increased acceptance and the ability to run with a factor of about four more beam (over E791). We will re-use a significant part of the existing E791 detector, thereby moderating the cost and timescale. In addition, improvements to several parts of the experiment will decrease losses due to inefficiencies and deadtimes. Our group is involved in the following key features of the new experiment:

- The E791 lead glass array will be reused, but reconfigured and substantially upgraded.
- A new muon trigger hodoscope will be built. The muon momentum threshold in E871 will be 1.0 GeV (rather than 1.6 GeV in E791), thereby increasing acceptance. The existing E791 muon hodoscope counters will be re-used in several locations throughout the muon steel and muon rangefinder to improve timing resolution for muons.
- The Level 1 Trigger will be improved by adding a parallelism condition to provide a large suppression of semi-leptonic decays, while imposing tighter constraints on particle identification, and reducing accidentals.

The result of these changes will be an experiment with larger acceptance and a capability to run with much higher beam intensity with improved background rejection compared to E791.

BNL E871: Experimental apparatus

BNL E871: Lead Glass array

The principle function of the lead glass is electron identification. The E871 lead glass detector consists of two large arrays of lead glass blocks. The converter array, consisting of 36 blocks covers a horizontal width of 72 inches and a vertical height of 71 inches, while the downstream array of back blocks covers a horizontal width of 84 inches and a vertical height of 72 inches, both arrays centered on the beam centerline. The array has been sized to account for electromagnetic shower spreading.

The experience of building and maintaining the E791 lead glass system, as well as calibrating it and using it for particle identification, has provided several lessons on how to do things better on E871. The single largest improvement was to eliminate photomultiplier tubes (PMT's) whose performance has proved marginal in E791. All 36 converter PMT's have been replaced along with 50 back block PMT's. Other improvements include building new PMT bases (E791 bases were recycled from previous experiments). The new bases will provide more reliable performance and are designed with an additional amplified output (approximate gain of 30) to provide signals for muons in the glass. This will provide a considerably enhanced ability to calibrate the system (muons were effectively inaccessible in E791 for calibration purposes). While we do not expect significant radiation damage of the lead glass in E871, the option of UV curing between E871 runs has been maintained in the construction of the light-tight, temperature-controlled enclosure which houses the array. The roof of the housing allows for removal of the converter blocks, permitting access to the back block array. We have also been making improvements to the laser-based flasher system. The combined effect of these changes is to improve the function and make maintenance of this system significantly easier.

The major endeavor of the engineering run for the lead glass detector was to test the prototype PMT bases. These bases have, in addition to the nominal output, an amplified output for the purpose of observing muon induced signals in the lead glass. The 8-bit ADC precision makes observation of muon signals in the unamplified signal difficult, due to the limited precision at the low-end of the ADC dynamic range where muons appear. The amplified signals will provide an additional means of establishing and monitoring the lead glass calibration and may ultimately be used to identify muons in the rare decay analysis.

During the 1993 engineering run the prototype PMT bases were connected to a 25 block square on the back array plus several upstream converter blocks. The bases were cabled as they will be in future data runs, running both the amplified signal and the nominal output to the ADC's.

BNL E871: Lead Glass array

BNL E871: Muon Hodoscope

Construction and installation of the Muon Hodoscope was completed in June, 1993, and fully tested during the engineering run (Summer, 1993). The MHO consists of 6 planes of scintillators (X0,X1,X2,Y0,Y1,Y2) separated by 26 iron plates and 16 marble slabs. Interspersed and extending beyond the MHO are 49 Muon Range Finder (MRG) gas counters distributed at intervals of 5% in muon momentum. The combined MHO and MRG detectors can determine muon range for momenta between 1.0 and 9.8 GeV/c.

The four MHO planes (X1,Y1,X2,Y2) consist of scintillator bars and phototubes reused from E791, and are placed at muon ranges corresponding to 0.75, 1.5, 2.8, and 5.8 GeV/c. X1 and X2 contain 11 vertical scintillator bars with tubes at each end. Y1 and Y2 have 14 horizontal bars with a single tube. These scintillator planes have much better timing characteristics than do the MRG panels. The MRG system simply provides a latched bit for a 150 ns time window. All MHO phototube outputs go to fast TDC's and the time resolution is about 1 ns. Also, outputs from X1 go to ADC's for independent energy information.

The planes X0 and Y0 are used for the muon trigger. The spatial widths of the individual X0 and Y0 scintillators were chosen so that these counters could be incorporated into a parallel trigger. Thus, the planes are symmetrically divided along the beam axis, with X0 containing 18 vertical bars with phototubes on each end, and Y0 contains 18 single-ended horizontal bars. These planes are located at the position corresponding to a muon range of 1.0 GeV/c.

During the Summer 1993 engineering run, the overall performance of the MHO was evaluated and found to be satisfactory. More detailed investigation involving the offline analysis software is currently underway.

BNL E871: Muon Hodoscope

BNL E871: Level 1 Trigger

The most important innovation of the new E871 trigger electronics is the addition of a parallelism condition for the tracks. This requirement is imposed at the level of the trigger scintillation counter (TSC) trigger, or Level 0, as well as at the particle identification level (in the Cerenkov and MHO detectors).

The L1 trigger is composed of 10 different kinds of custom built CAMAC boards (23 modules in all), as well as other commercial modules. The L0 trigger includes the L0XX boards, which input TSC x-bar hits and perform a programmable degree of parallelism between front and back TSC slats, the L0YY boards providing an OR of the TSC y-bars, and a final L0XY board, which AND's the x- and y-bars. A similar set of boards AND's the x- and y-bars of the MHO, and another interface module inputs drift chamber hits, fanning them into 13 channels. The TSC, CER, MHO, and drift chamber hits then proceed to the TRIG module, which selects the particular drift chambers desired, and the degree of particle identification parallelism. The actual triggers (μe , ee , $\mu\mu$, etc.) are selected with the LRCO (left-right coincidence) board, and prescaled by PRES. A final board CALI selects the various calibrations desired during running and testing of the experiment.

The L0 modules were installed and tested during the 1993 engineering run. Compared with the 1 MHz rates for L0 during E791 (at a 4 Tp beam intensity), the new system had rates (estimated for 15 Tp) to be 375 kHz for non-parallel triggers, and 55 kHz for parallel triggers with ± 2 range.

Currently, the remaining Level 1 boards are being installed and tested. A software package to load the programmable triggers and perform diagnostics on the CAMAC modules is being finalized by our group for use in the 1994 run.

BNL E871: Level 1 Trigger

Trigger Parallelism	Rate (kHz)
non-parallel	375
+/- 1 bar	31
+/- 2 bars	55
+/- 3 bars	86

STAR: OVERVIEW

Participants: Wayne Betts, George Glass, Jaw-Luen Tang, Peter Riley;
STAR Collaboration; J. Harris, spokesman

Objectives: To create and study a new phase of nuclear matter - *the quark gluon plasma* - and to study in detail the properties of nuclear matter at high energy density. Secondary goals include the study of hard QCD parton-parton scattering and subsequent hadronization in dense, excited nuclear matter, and spin physics at high energy. For the next several years the project will emphasize the design and fabrication of a large complex collider detector, STAR, which will provide a flexible system of tracking all charged particles produced at mid-rapidity for central Au + Au collisions at beam energies up to 100 GeV/A, with accurate momentum determination, particle identification, and secondary vertex track reconstruction.

Software Simulation development:

- (1) dE/dx information on TPC tracks and particle identification
- (2) TPC track finding and fitting
- (3) Event visualization of TPC tracks

We are also participants in AGS P896: Search for a Short-Lived H_0 Dibaryon, Short-Lived Strange Matter, and Investigation of Hyperon Production in 11.6 A GeV/c Au-Au Collisions.

The trigger system we will develop and test in this experiment is similar to that proposed for STAR at RHIC.

STAR, Solenoidal Tracker at RHIC

Ke-Sheng Chan, George Glass, Jaw-Luen Tang, Peter Riley;
STAR Collaboration; [J. W. Harris, spokesman]

During late 1992 we joined a large collaborative group working on the RHIC experiment STAR (Solenoidal Tracker at RHIC) at BNL. This project will for the next several years emphasize the design and fabrication of a very large, complex collider detector. The principal efforts of George Glass as well as those of U.T. graduate students will be spent on STAR. Mr. Chan and Mr. Tang, Ph. D. physics graduate students, have become involved in a program of STAR TPC software simulation development, and spent the summer of 1993 working at Berkely. We are also becoming involved in the design and fabrication of STAR hardware components. Mr. Tang and a new Physics graduate student, Wayne Betts, will spend the summer of 1994 at Berkely continuing on software and hardware development work. A proposal to the University of Texas for funds to create a STAR fabrication and staging area adjacent to our physics machine shop has been approved and funded by the University, and its construction will begin shortly.

The RHIC accelerator will collide relativistic heavy-ion beams (with up to 200 GeV energy in the center of mass for the nucleon-nucleon collision) in an attempt to create the quark-gluon plasma (QGP), an unstable state of unconfined gluons and quarks. This QGP, hypothesized by the MIT bag model and QCD lattice gauge theory [1], may be present at the center of neutron stars or have existed shortly after the Big Bang. In addition to heavy-ion collisions, proton-proton and proton-nucleus collisions will also be produced at RHIC to study systems of highly excited, very dense nuclear matter, hard QCD parton-parton scattering (with jet formation) on such systems, and proton-proton collision spin effects (at 500 GeV cm).

Detectors for these experiments must track, identify, and momentum analyze a broad range of particles, including hyperons and strange mesons whose short lifetimes and subsequent decay lengths place difficult requirements on the detector design and construction. The STAR detector, one of two large collider detectors at RHIC, is a combination of a silicon vertex tracker (SVT), a time projection chamber (TPC), time of flight (TOF) counters, an electromagnetic calorimeter (EMC), and an external time projection chamber (XTPC), based around a solenoidal magnet. Supporting these devices will be a system of front-end electronics (FEE), a multi-level trigger, and a data acquisition system (DAQ). Figure 1 shows a perspective view of STAR[2].

Figure 1: The STAR Detector.

Figure 1: The STAR Detector.

The source of spin in the proton has been a major issue recently, and direct photon detection would allow for some important measurements of spin dependence with polarized colliding protons that relate to the gluon spin structure function. Funds for engineering and prototyping for the electromagnetic calorimeter[3] are being sought from DOE by John Harris and Tim Hallman within nuclear physics. The Argonne group has embarked on this phase of development for STAR. George Glass has been asked by John Harris, as well as by Hal Spinka of ANL, to join in this development effort. Beginning in the Spring of 1994 he expects to spend full-time participating in the design, development, and fabrication of this calorimeter. The task ahead will require a serious engineering study with major prototyping and testing. Further, a major effort is needed for simulation studies that would establish the detectability of the direct gammas and the associated jets within the plethora of tracks generated in the high luminosity environment anticipated for RHIC.

Figure 2. Hit patterns in 200 GeV Si+Si interaction

Figure 2: Hit patterns in 200 GeV Si+Si interaction.

The central time-projection chamber (TPC) is a continuous tracking device capable of handling high multiplicity events and is designed to detect and identify charged particles. Two University of Texas graduate students, Jaw-Luen Tang and Ke-Sheng Chan, spent the past summer working at Berkeley under the direction of Marvin Justice and Iwona Sakrejda on STAR TPC simulation, tracking, and particle identification software. They are continuing work on TPC software development back here at UT Austin this fall. Tasks include the calculation and display of hit patterns on the TPC pad-plane, the calculation of dE/dx information for each track from reconstructed TPC tracking data, the investigation of drift velocity and diffusion as a function of fields for different gases in the TPC, and the overall problem of tracking identification and fitting. Figure 2 shows calculated hit patterns on the xz pad-plane by the 200 GeV Si+Si interaction.

Mr. Tang and Mr. Chan also started the development of algorithms for merging TPC track segments where it is necessary to compensate for energy losses along a track. For example, merging techniques become necessary where a particle encounters different

media along its track, resulting in different energy losses, so that its radius of curvature changes.

They also began development of a particle identification (PID) subroutine for the TPC, which takes input from the TP track table and outputs the assigned particle ID for each reconstructed track. Such a PID subroutine is essential for the analysis of experimental data. Several particle identification algorithms have been proposed and primary tests have been evaluated. These are based on comparisons between calculated dE/dx information and the experimental data. Figure 3 shows the dE/dx versus p graph of a simulated 200 GeV Au-Au event where the dE/dx for each track is calculated by truncating only one point on the track with the maximum dE/dx value.

The continued work here at UT Austin of Mr. Tang and Mr. Chan includes the usage of PAW, TAS, and GEANT packages in the development of STAR application programs. The TPC event visualization program will be enhanced and refined. They have developed a program for examining the four-dimensional space-time relationships between tracks of high multiplicity on the STAR TPC. Overall, a major goal is to develop a strong software effort here at UT as part of our contributions to STAR.

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dE/dx from reconstructed tracks for 200 GeV Au+Au event

Figure 3. dE/dx versus momentum for 200 GeV Au+Au event.

AGS P896: Search for a Short-Lived H_0 Dibaryon, Short-Lived Strange Matter, and Investigation of Hyperon Production in 11.6 A GeV/c Au-Au Collisions

Peter Riley; Collaboration: BNL, CERN, Columbia Univ., Johns Hopkins, LBL, Berkeley, Texas, UCLA, Univ. of Catania, Univ. Space Research Assoc., Wayne State Univ.; H. Crawford and T. Hallman, spokesmen

The H_0 is the lowest 6-quark (uuddss) state predicted by the MIT bag model[1]. It is singular among the $A>1$ multiquark states predicted by the bag model, since a wide mass gap separates it from heavier metastable particles and from stable multiquark "strangelet" states.

This experiment will search for the H_0 doubly strange dibaryon and for $A>1$ hyperon bound states produced in nucleus + nucleus ($A + A$) collisions. The experiment enhances similar heavy-ion experiments by extending into regions of shorter H_0 lifetimes; it complements the existing double strangeness exchange search program by offering access to a more probable doorway channel, the coalescence of two L^0 s into a bound di-lambda. The experiment setup, shown in figure 1, includes the following: (1) a strong dipole magnet to sweep away the beam, beam fragments, and most produced charged particles, (2) a low mass tracking detector located inside an analyzing magnet downstream of the sweeping magnet which has a low efficiency for gammas and neutrons, and (3) a fast trigger capable of identifying secondary vertices corresponding to decay lifetimes ranging from that of the L^0 to approximately an order of magnitude longer. This will be accomplished by using a distributed drift chamber (DDC) in which an unambiguous decay signature can be measured in combination with a modern trigger system capable of recognizing V^0 s and kinks in the tracks fast enough to make storage decisions for events of interest. The trigger system we will develop and test in this experiment is similar to that proposed for STAR at RHIC.

References

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Figure 1: A Schematic diagram of the proposed experimental setup for AGS 896.