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The Need for an Intense Polarized Source at LAMPF

**Report on a Workshop Held at Los Alamos,
November 9, 1983**

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by

M. W. McNaughton, R. R. Silbar, O. B. van Dyck

ABSTRACT

We report on a workshop to consider the need for an intense polarized source at LAMPF. The primary justification for such a source comes from the nucleon-nucleon program; neutron-proton scattering is seriously underdetermined and cannot be satisfactorily completed without such an intense source. Further justification comes from nuclear $(\vec{n},p)$ and $(\vec{p},\vec{n})$ reactions, as well as from traditional nuclear physics at the LAMPF high resolution spectrometer. We recommend that a source capable of providing a few μA beam on target be built as soon as possible.

I. INTRODUCTION

Polarized-source technology has progressed to the point that it may now be possible for us to replace the present LAMPF polarized H^- ion source with a new source giving of the order of 1 μA average current at 800 MeV. The director of LAMPF, Louis Rosen, thus called for a workshop to be held at LAMPF to consider (and document) the physics justification for, and constraints on, such a source.

The workshop was held in the LAMPF auditorium on November 9, 1983, the day after the annual LAMPF Users Meeting. The agenda and list of participants appear in Appendices A and B. Early talks addressed the present source technology (Appendix C) and competing facilities (Appendix D). The report on the major conclusions of the workshop follows. The

physics is discussed in Secs. II through V (with further details in the Appendixes), source requirements are in Secs. VI and VII and the main conclusion is in Sec. VIII (p. 6).

II. NEUTRON-PROTON ELASTIC SCATTERING

The major justification for an intense polarized source comes from the neutron-proton program. This is examined in more detail in Appendix E. It is generally agreed that when the measurements presently under way are completed, the np data will still not be sufficient to adequately determine the $I=0$ phase shifts and amplitudes. The required experiments cannot be done without an intense polarized source and are not likely to be done elsewhere within the foreseeable future (Appendix D).

When the present series of np experiments (E665, E770) is complete (1985-6), the np data set will be comparable to (though less precise than) the pp data set that existed in 1980. At that time some optimists believed that the pp phase shifts were well determined and further pp elastic measurements were assigned "moderate" priority.¹ The new pp data presented at Santa Fe in 1980² changed the phase shift predictions by up to five standard deviations (e.g., D_{LS} from 0.4 to 0.2 and K_{LS} from 0 to 0.25). The primary reasons were (a) some of the theoretical input to the phase shift fits was not well founded, and (b) some of the data were wrong. Even below 500 MeV, where inelasticity is small and extensive data from TRIUMF exist, more np data may be required.³ The workshop concluded that sufficient data should be accumulated to overdetermine the amplitudes (as a check against incorrect data) without requiring theoretical input to the phase shift fits. This conclusion is addressed in more detail in Appendix E.

The present series of experiments to measure A_{LL} , A_{SS} , and A_{LS} for np elastic scattering was assigned H^+ priority by the PAC, the highest priority ever given by the NPL Committee. The PAC agreed⁴ "that the free np elastic scattering experiments are of the most fundamental importance and should have the highest priority." These measurements are expensive, however, requiring a polarized target with superconducting magnet, a

120-ton, 0.5-MW magnet with 1.6-m^2 aperture, a 3-m-wide drift chamber, and 3 years of beam time. (The experimental event rate is limited solely by the beam intensity.) If we estimate the cost of measuring these three parameters by dividing the LAMPF operations budget by the number of beamlines, the price is about \$10M. Excluding beam time, incremental costs are about \$4M (physicists \$2M, polarized target \$0.7M, cryogenics and liquid helium \$0.6M, engineering and support \$0.6M, power \$0.3M).

Bugg⁵ and Leluc³ agree that, in addition to the above, spin transfer data will be needed to determine the np elastic phase shifts. Bugg points out that the "spin depolarization" parameters (D_{NN} , etc., which could be measured with intense unpolarized neutrons on a polarized target or with quasifree scattering, see Appendix E) are not adequate. The sensitive "spin transfer" experiments (K_{NN} , etc.) require an intense polarized beam. The workshop therefore concluded that the $I=0$ nucleon-nucleon measurements could not be completed adequately unless an intense polarized source is built.

III. NEUTRON-PROTON INELASTIC REACTIONS

With pp elastic scattering well determined, attention at LAMPF, SIN, TRIUMF, and SATURNE has turned to the (more difficult) pp inelastic reactions. It is now clear that only a careful study of the inelastic processes will elucidate the energy-dependent structure ("dibaryons") observed at medium energies. The recent measurement⁶ of $\Delta\sigma_L(I=0)$ indicates that there may be very interesting behavior in the $I=0$ channel, perhaps indicative of a 1F_3 dibaryon resonance. Such a resonance, if it exists, would be very difficult to understand in terms of conventional models with mesons and baryons; it would almost necessarily require an explanation invoking new quark structures. However, the issue is clouded because the $I=0$ information is extracted from the pd data only after a long and precarious theoretical journey.

If further np measurements substantiate this $I=0$ structure, we can expect strong interest in np inelastic measurements. The workshop did not examine np inelastic experiments, but did note that with an intense

polarized beam, experiments on $np \rightarrow pp\pi^-$ (with three charged particles in the final state) are easier than $pp \rightarrow p\pi^+n$ or $pp \rightarrow pp\pi^0$. Furthermore, the absence of a strong inelastic threshold (Δ production) in $I=0$ should make interpretation more straightforward.

IV. SYMMETRY MEASUREMENTS

In the past, tests of charge symmetry at LAMPF have largely been by-products of other experiments and have only marginally challenged the theories.⁷ With an intense polarized beam, meaningful symmetry tests will become possible at LAMPF. Tests on the following reactions were suggested:

$np \rightarrow np$
 $np \rightarrow d\gamma$
 $np \rightarrow d\pi^0$
 $nd \rightarrow {}^3\text{H}\gamma$
 $nd \rightarrow {}^3\text{He}\pi^-$
 $n {}^3\text{He} \rightarrow {}^4\text{He}\gamma$
 $n {}^3\text{He} \rightarrow {}^4\text{He}\pi^0$

Of these, $np \rightarrow np$ seems the most immediately attractive. Such experiments are presently in progress both at TRIUMF⁸ (500 MeV) and IUCF⁹ (200 MeV). LAMPF proposal number 847 is similar to these experiments (but at 800 MeV, the energy dependence is important) and specifically requests an intense polarized ion source.

V. NUCLEAR PHYSICS

Let us grant that the primary justification for an upgrade of the LAMPF polarized proton ion source will be a concerted attack on the neutron-proton interaction. Nonetheless, are there other physics uses of a more intense polarized proton beam at LAMPF? The answer is an unequivocal "yes."

At the workshop we learned of two types of nuclear physics experiments that would be done if more polarized proton beam intensity became available. One of these is to push the HRS program measuring spin observables to much larger angles (momentum transfers) than can be presently measured. One purpose of such measurements is to compare with predictions of the recently developed relativistic Dirac phenomenology for proton-nucleus scattering. The differences between this theory and the nonrelativistic Schroedinger phenomenology are enormous at laboratory angles of 60 to 90°. Only a modest increase in intensity (perhaps a factor of 10) is possible at HRS before background problems become limiting. However, future upgrades may make higher intensities feasible.

Another kind of experiment which has been done at IUCF, but has not been attempted at LAMPF energies, is the measurement of polarization transfer in ($\vec{p}, \vec{n}$) reactions on nuclei. Such experiments might give information on whether the nuclear structure functions are affected by the presence of excess pions in nuclei (as opposed to free nucleons--we are referring here to the so-called "EMC Effect"). Such experiments would require approximately a factor of 10 increase in polarized beam intensity.

LAMPF proposal number 823 proposes to build a facility (beam plus spectrometer) to add nuclear (n,p) data to the (p,n) data discussed above. The proposal discusses only cross-section data using the present unpolarized beam of order 1 μ A. It seems certain that if an intense polarized beam were available, then polarized ($\vec{n}, \vec{p}$) experiments would follow. Such experiments would require at least 1- μ A polarized beam at 800 MeV.

VI. TIME SCALE

Near the beginning of the workshop, one speaker stated that work on the desired intense source might be begun in 1986 and completed in 1989. After the workshop, others indicated that a 1984 start and 1986-7 completion would be more realistic. In light of a long history of delays, the original statement greatly dampened the spirit of the

meeting. However, the participants agreed that even in 1989 the important physics with intense polarized beams would not be complete, though most were not prepared to wait this long. It was agreed that a modest increase in intensity, say a factor of 20 (to 0.4 μA), would be sufficient for many new experiments, and that this increase might be desirable if such a source could arrive soon and be upgraded to higher intensities (few μA) later.

VII. SOURCE REQUIREMENTS

Many experiments discussed in this report will be limited by the beam intensity even with 10 μA on target, and for these P^2I is the figure of merit. The polarized beam is, however, shared by experiments in other beamlines, which generally cannot use all the intensity available. For these experiments, the figure of merit is P^2 . It seems unwise, therefore, to build a source with a polarization much lower than that presently available.

No other constraints on the source were noted at the workshop, though the present authors note that loss of the quench ratio facility will require a substitute method for monitoring L-spin polarization (for example, the Low Energy Polarimeter, LEPO, currently under development,¹⁰ or the proposed Line B spin precession system).¹¹ The workshop also noted that bunching to allow time-of-flight measurements without appreciable intensity loss would still be an important addition even with an intense source.

VIII. CONCLUSION

The NN interaction is basic to the problem of nucleon structure, and this statement will remain true even when we understand how, and to what extent, the underlying quark structure of nucleons is to be seen in nuclear properties. It is also the fundamental input required for the interpretation of the proton-nucleus scattering experiments, a much larger LAMPF program. The need for precise medium-energy nucleon-nucleon information has become especially urgent in recent months as we have been

going through a small revolution which explains the spin-dependence in nucleon-nucleus scattering experiments in terms of a relativistic Dirac phenomenology rather than the nonrelativistic Schroedinger approach. Nuclear physics, as it is now being practiced, simply cannot afford to be without the nucleon-nucleon interaction being known.

The workshop noted that TRIUMF, SIN, and SATURNE all have polarized intensities $>10\times$ LAMPF, yet all are embarking on programs to increase this intensity still further (see Appendix C). The cost of such a source seems small compared with the cost of complex nucleon-nucleon experiments requiring years of beam time. The workshop concluded that an intense polarized source should be acquired as soon as possible.

APPENDIX A

WORKSHOP ON INTENSE POLARIZED BEAM - NOVEMBER 9, 1983

AGENDA

0830	Introduction - Mike McNaughton
0845	Survey of the Competition - Olin van Dyck
0900	What Ion Sources are Available - Phil Chamberlin
0915	np Experiments at LAMPF - Hal Spinka
0945	Discussion
1015	COFFEE BREAK
1030	SIN Experiments - Catherine Lechanoine-LeLuc
1100	SACLAY Experiments - Charles Newsome
1115	Symmetry Experiments - Ben Nefkens
1130	Discussion
1200	LUNCH
1330	KEK Experiments - Yuji Ohashi
1345	HRS Experiments - Bjarne Aas
1400	Polarization Transfer in (p,n) and (n,p) Reactions - Tom Carey
1430	Discussion
1530	TEA/COFFEE
1600	Summary - Dick Silbar
1630	Discussion
1730	End

APPENDIX B

ORGANIZING COMMITTEE AND PARTICIPANTS

ORGANIZING COMMITTEE

M. W. McNaughton

B. E. Bonner

G. Igo

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APPENDIX C

CHOICES FOR A POLARIZED SOURCE

The neutron program as foreseen does not establish a definite threshold requirement for beam current, but rather shows a path of wider possibilities with each step upward. A realistic discussion of a new source, therefore, tends to refer to performance, cost, and time scale, as well as impact on the research program. Some of these technical and other practical issues are briefly addressed here.

Polarized ion sources have been under development for more than 20 years. All processes on hand lend themselves to discussion in four steps:

1. Initiate a beam, either thermal neutrals or charged 0.5-5 keV.
2. Spin-polarize a valence electron (in hydrogen or donor material).
3. Transfer electron polarization to proton.
4. Add electron (or ionize) to form H^- (or H^+).

New methods under development tend to mix techniques which were once distinct between the two traditional methods. Figure C-1 is a simplified "family tree" showing some of the major relationships in polarized-source technology.

Fig. C-1. Principles of polarized sources.

The "atomic-beam source" follows the top line in the figure from the H_2 dissociator thermal-beam source through Stern-Gerlach (sextupole magnet) spin separation and rf hyperfine transition zone. H^- may be obtained via the colliding or crossed-beam method (Haeberli) or via ionization to H^+ and acceleration into a two-electron donor vapor (the ETHZ-Grubler method).

The cryogenic beam method (MIT-Kleppner and Greytak, second line down in figure) is a proposed new version of the atomic-beam source. A cryogenically cold neutral beam can be electron-spin-polarized by a strong solenoidal field. This technique is embryonic and would require several major developments to be made usable. It is interesting to note that cryogenic beam cooling also benefits the standard atomic-beam source, so there is some convergence of technologies here.

The optically pumped polarized source, third line of the figure, passes a 5-keV proton beam through a donor vapor which has been electron-spin-polarized by a laser beam. The resulting energetic neutral beam is converted to H^- in another adder cell, an easier process than in the corresponding step with a thermal beam. Use of an ECR (trapped electron ionizer) proton source instead of a duoplasmatron is essential for adequate beam brightness and polarization.

The Lamb-shift method traditionally uses a beam formed in a duoplasmatron; an ECR beam source may be superior and may be examined at TRIUMF. The choice of ~ 500 -V beam energy and use of cesium in the first adder cell are practically required for efficient atomic metastable production. The spin filter, which is very efficient, may pass one hyperfine state in the metastable beam and quench three, or it may pass two states and be followed by a Sona transition. The use of argon in the second adder cell is constrained by the need to optimize pickup by the metastable component of the neutral beam. Thus, there does not seem to be much room for development in these areas.

As seen now, the two realistic choices to upgrade LAMPF are the atomic-beam source, an established technology for polarized beams with several laboratories contributing developments, and the optically polarized source, a latecomer which has rapidly shown potential for delivery of high currents. LAMPF has experts available for work on either source. At this point, neither source is able to deliver anything close to $P^2 I = 200\text{-}\mu\text{A}$ peak, an ambitious target figure for LAMPF, but both are thought to have good potential for improvement. Thus, the choice tends to focus on practical considerations, some of which are shown in Table C-I.

The ~60% polarization in the optically pumped source is apparently not yet well measured nor has an adequate optimization been done. It is believed that increasing laser peak power will raise the polarization. Higher duty factor for LAMPF, 10% vs 0.1% at KEK, will require higher ECR duty factor (TRIUMF will need 100% duty). Both sources require additional development of the adder cell with alkali vapor or evaluation of an adequate substitute such as Xenon; adder cell operation is a troublesome area which tends to limit source current and run duration. Similarly, both sources would benefit from continued development of an ECR system for beam formation or development of an adequate substitute. The use of an ECR ionizer may also be investigated. In the case of the atomic-beam source for modest currents, component choices of proven design exist as starting points for LAMPF.

However, until more engineering studies are done, it is not clear whether the atomic-beam source can be made to fit the present Faraday cage, whether the small extra length needed for the beam-bunching apparatus could also be included, and whether the output beam energy spread would permit efficient bunching. Faraday cage modification would add substantially to time and cost. This factor is balanced against the earlier stage of development of the optically polarized source. These uncertainties and the promise of impending developments suggest continued study.

Appropriate plans for the immediate future appear to be

- (1) Monitoring, possibly participating in, developments at other laboratories;
- (2) Investigating the effect of beam parameters such as energy spread on the efficiency of beam bunching; and
- (3) Evaluating the impact of the beam buncher on source installation and possible Faraday cage installation, and other similar considerations.

TABLE C-I

COMPARISON OF OPTICALLY POLARIZED AND ATOMIC-BEAM SOURCES

	<u>Optical Pumped</u> Few weeks (est)	<u>Atomic Beam</u> Few weeks
Run Time		
H ⁻ Current (peak)	20 μ A	6 μ A
Polarization, %	60 $\pm$ 8	80
Reliability	Unknown	High
Gas Flow	0.1 cm ³ /min	60 cm ³ /min
Pumping	3000 l/s	15,000 l/s
New Dome	No	Yes (?)
Component Interdependence	Low	High
Commercially Available	No	H ⁰ Portion from SENTEC
Diagnostics	Easier	Harder
Rapid Spin Rev.	Maybe	Yes
Devel. Req'd.	ECR Source Adder Cell	Ionizer-Adder Cooling
Track Record	None	Established (H ⁺ Sources)
Time Scale	?	~2 yr after Funding

APPENDIX D

SURVEY OF COMPETING FACILITIES

An evaluation of new facilities for LAMPF should include consideration of comparable plans and present activity at other laboratories. This "survey of the competition" includes the two other established meson factories and three higher energy synchrotrons with nucleon physics programs. The survey will look at polarized beam facilities and usage and a more subjective reading of their planned investment in nucleon physics.

Table D-I compares the polarized beam facilities at SIN, TRIUMF, and LAMPF. Both cyclotrons have a substantial edge in duty factor and beam current over LAMPF; however, dual-beam operation gives LAMPF a big advantage in usage by multiple experiments.

Ironically, the facility with the highest current (SIN) has least shared usage, nor does SIN use its high intensity for polarized neutron production. Part of the story behind the SIN anomalies lies in the drive for these facilities coming principally from outside user groups. The polarized beam running time on the PM1 channel is multiplied by usage in secondary-beam mode, although the polarization is cut by one-half. Variable-energy operation is achieved by degraders which cost intensity and beam quality. The SIN nucleon program, although limited, is well focused and is executed by durable collaborations.

SIN expects to increase its polarized beam intensity to 10 μ A and to implement a time-shared dual-energy capability through duty-factor division. This will enable a polarized neutron channel addition to PM1 (like the proton-neutron conversion of our BR channel). This reconfiguration and other facility upgrades will shut down PM1 for more than two years. The nucleon program upgrade also competes with planning for the 2-GeV ASTOR ring.

With only a 280-nA polarized beam, TRIUMF cannot usefully exploit its capability for simultaneous dual-energy extraction. Thus, the accelerator is run $\sim 2/3$ of the time for meson users and $1/3$ of the time for nucleon users (calendar time sharing). The polarized beam is usually shared between a proton line (with precessor) and a neutron production target; the proton line can serve a spectrometer target station (like our HRS) or a general purpose target area (like our EPB).

TRIUMF is a little ahead of LAMPF in planning a polarized-source upgrade. It is our understanding that Mori from KEK is likely to spend some time at TRIUMF in 1984 assisting with the construction of an optically polarized source. TRIUMF also has active plans for a Kaon Factory.

In the low-energy dual-beam mode, LAMPF time-shares polarized beam macropulses in a 1:2 ratio with H^+ for the meson area. This gives many more beam hours, if not microampere hours, to the nucleon users; they in turn have partially adapted to the loss in duty factor by improved technology. The low beam current has been adequate for most proton experiments but makes neutron channel experiments difficult and expensive. LAMPF has a big investment in precession equipment and technical and administrative apparatus to support three-way use of the polarized beam.

The polarized-source upgrade at LAMPF competes with PSR preparations and other initiatives, making 1985 a pivotal year.

Table D-II gives a similar comparison of three synchrotrons active in this field, representing France, USA, and Japan.

Saturne II, situated like LAMPF in a big diverse laboratory, has the stated goal of "unequalled facilities for intermediate-energy hadronic physics." Polarized proton and neutron beams have been a central part of this program, so a neutron beam, derived from the polarized deuteron beam, has always been planned. Unfortunately, only one major nucleon-nucleon beamline with a precessor is available, and the proton-neutron changeover is so difficult that it has not yet been done. A

polarized neutron beam has been used on another beamline with the IKAR detector (small-angle scatters). Once again, low current makes polarized beam operation unpopular, although recent user demand drove scheduling up to 1 to 2 months/year. There is a strong in-house nucleon voice and many outside collaborators, including LAMPF associates. Proton scattering experiments have covered a wide energy range, often heavily overlapping meson factory data.

The MIMAS accumulator ring, now funded, will result in a ten-fold intensity improvement for polarized beam and a much greater intensity increase for heavy-ion beams. Thus, interest in MIMAS is driven by both programs, although competition for running time will become more severe as heavy-ion operation improves.

The AGS might be considered the dark-horse entry in this field. The termination of CBA construction, consideration of a heavy-ion collider, a proposed accumulation/booster ring, possible AGS upgrade, and a new polarized ion source all add up to some uncertainty in Brookhaven's future course. The present direction is to bring on the polarized beam program with low current in 1984, while starting construction of the Accumulator/Booster to give a ten-fold increase of polarized beam current. The A/B, with 1- or perhaps 2-GeV acceleration at 10-Hz rep rate, will also permit nucleon physics in this energy range without the AGS, although this is not a feature of the A/B proposal. Apparently, this new machine is funded as an AGS accelerator improvement for not much more than \$10M. The polarized beam program competes with AGS operation for high-energy users (highest current and energy for secondary-beam production) and new heavy-ion initiatives at Brookhaven.

KEK is in a similar position with a polarized beam source under construction and nucleon physics in competition with other initiatives. At KEK the priority is clearly in favor of the TRISTAN collider machine. How fully the optically polarized source will be developed and exploited is a question. KEK already has a booster synchrotron, but its energy range is covered by all three meson facilities.

Each laboratory discussed here finds some internal competition over beam time and/or capital resources which might be used for polarized nucleon physics. The meson factories all balance high-current operation for meson production vs low polarized current, and each has a high-energy upgrade in view with an uncertain future for polarized beam. LAMPF also has another aspect to its program, the PSR, which will begin operation in 1985. KEK apparently is heavily committed to high-energy physics. At Saturne, heavy ions compete with nucleons; the AGS is still uncertain on this issue. The AGS does have a program to reconcile high-energy vs polarized beam operation by increasing polarized beam intensity; it might possibly also implement stand-alone use of the booster machine.

At best, this internal competition produces better physics and helps laboratory durability through diversity. At worst, the facilities are less effective because resources are spread too thin. For adequate payoff on a new polarized beam source at LAMPF, the investment cannot be too little or too late.

TABLE D-I

MESON FACTORY POLARIZED PROTON BEAMS

	SIN	TRIUMF	LAMPF
Source	Atomic Beam (Jaccard, Grubler)	Lamb Shift (Schmor)	Lamb Shift (Chamberlin)
Accel	51 MHz CW Cyclo. 590 MeV 1 μ A 100% Duty	23 MHz CW Cyclo. 180-520 MeV Dual 280 nA 100% Duty	200-800 MHz Linac 212-800 MeV 200-400 nAp 3-9% Duty
Beamlines	PM1 Channel Either: Primary 80% Pol or Secondary 40% Pol Precessor No $\vec{n}$ Yet	BL4 A and B BL4B: Protons (share w/spectro) Precessor BL4A: LD ₂ $\vec{n}$	3 Simultaneous EPB: H ⁺ /H ⁻ with Precessor HRS: 50 keV resol. BR: LD ₂ $\vec{n}$
Annual Use	Primary - small (2.5 yr. PM1 shutdown)	$\sim 1/3$ Schedule $\vec{P}$	4 mo. ($\sim 100\%$ of Schedule)
Upgrades	Source Upgrades Via ETHZ $\vec{n}$ in 1987 Time-shared Dual Beams (Pol + Unpol) ASTOR 2 GeV	Start Opt. Pol. in '84 Kaon Factory	Start new source 0.3 - 3 μ Aa Booster, LAMPF II

TABLE D-II

SYNCHROTRONS WITH POLARIZED BEAMS

	SATURNE	AGS	KEK
Source	Atomic Beam (ANAC)	Atomic Beam (ANAC) + Cs ⁰ Collider In progress	Opt. Pol. in progress (Mori) In progress
Accel	H ⁺ Injection 3 GeV 0.7 nC/sec D ⁺ 2.3 GeV 0.3 nC/2 sec	H ⁻ Injection 26 GeV ~1 μ C / 2 sec	12 GeV ~1 μ C / 2.5 sec (500 MeV 20 Hz Booster)
Beamlines	2 Extracted lines Simultaneous Spectrometer SPES $\vec{d} \rightarrow \vec{n}$ beam possible	Variety	Variety of Internal + external beams (Booster beamlines)
Annual Use	Recently 2 mo.		
Upgrade	MIMAS Accumulator "Unequalled facilities for intermediate energy hadronic physics"	A/B 1 GeV Accum-Booster ~\$11M, will give x 10 pol. intens. Also use A/B Stand-alone 10 Hz	

APPENDIX E

FREE np ELASTIC SCATTERING

It is well known that $I=0$ elastic scattering may be described by five complex amplitudes (if charge independence is assumed). If the overall phase is undetermined, then at least nine spin-dependent parameters must be measured. If the inelasticity is small, then theoretical constraints may be used to reduce this number; on the other hand, some experiments may have systematic errors, so it may be wise to increase this number.

The simplest experiment, the spin-independent cross section, has been measured at LAMPF.¹² The next simplest is the "one-spin" experiment P (which is a single parameter if time-reversal invariance and charge symmetry hold).² The "two-spin" parameters are divided into four spin correlation parameters "A" (two initial state spin measured), five spin depolarization parameters "D," and five spin transfer parameters "K" (one initial state and one final state spin measured). It has been shown¹³ that the more difficult "three-spin" parameters are not essential.

The "two-spin" measurements require two out of the following three facilities: 1) polarized neutron beam, 2) polarized proton target, 3) high-efficiency polarimeter.

The present polarized neutron beam has an intensity of 2×10^4 neutrons/sec at 800 MeV (with the present 1-in. collimator) and has a polarization of about 0.5 at 500, 650, and 800 MeV.¹⁴ The spin direction may be precessed into any one of three orthogonal directions, N, S, or L. The intensity is directly proportional to the intensity of the polarized proton beam incident on the (25 cm) neutron production liquid deuterium target. With present technology, it seems possible to increase the intensity by a factor of about 100.

Existing polarized targets at LAMPF are suitable for use with an intense neutron beam. Different targets are needed for vertical (N) spin and horizontal (S or L) spin. Polarized targets, however, create more

than 10 times as much background as a liquid hydrogen target and are expensive to build, operate, and maintain.

High-efficiency polarimeters for protons have been built¹⁵ and calibrated¹⁵ at LAMPF. The small cross section and analyzing power for the second scatter result in an effective loss in rate of about 100, i.e., 100 times the beam flux is required for the same statistical accuracy. A polarimeter for (final state) neutrons would be at least a factor of 10 less efficient than those for protons.

The status of the LAMPF np data has been reviewed by Spinka.¹⁶ In about 1985-6, the six high-rate experiments will be approximately complete. There will be holes in the data set (e.g., A_{NN} has not been measured at 800 MeV and the proposal, Number 861, requires the intense polarized source), and the uncertainty will be about an order of magnitude greater than for pp.

It was the conclusion of the workshop that these data will not be an adequate determination of np scattering. Errors of five standard deviations have been found in the pp data set so that overdetermination seems necessary. The next step appears to be to add to the spin transfer (or depolarization) data set as has been requested by Bugg⁵ and LeLuc.³

Spin depolarization experiments require unpolarized neutrons (rarely scheduled at LAMPF) and a polarized proton target (expensive). Polarized targets create a lot of background (from the propane-diol, steel vacuum jackets, etc.). Thus, a neutron detector is needed, which decreases the event rate by about a factor of 5 to 10. LAMPF E590 performed such an experiment at forward angles. Alternatively, quasifree scattering could be used to supplement the free np data. The workshop was unable to decide how reliable these data are. Theoretical arguments and empirical evidence indicate that at larger angles the correction for the presence of a spectator nucleon is small. However, the recent measurement⁶ of $\Delta\sigma_L$ for $I=0$ which was extracted from pd is regarded with suspicion. Furthermore, the Fermi motion of the nucleons in deuterium smears out energy-dependent structure significantly. When confronted with the

question of extracting np data from pd, Hans Bethe stated,¹⁷ "I would not trust experiments using pd scattering."

However, Bugg points out that the "spin depolarization" parameters that are measured by the above techniques are insensitive and will not be adequate to determine the np phase shifts. The sensitive "spin transfer" parameters can only be measured with an intense polarized neutron beam incident on a liquid hydrogen target. With the cleaner liquid hydrogen replacing the polarized target, the experiment could use either a spectrometer or a neutron detector (E590 used both) with a consequent rate advantage. LAMPF E403 performed such an experiment at forward angles (with marginal statistical precision, ± 0.1) using the present polarized beam. At larger angles, however, the cross section decreases by a factor of 30.

The measurement⁶ of $\Delta\sigma_L$ ($I=0$) from pd suggests a 1F_3 "dibaryon" resonance. Experiment 683 seeks to check this result with free np scattering but is deferred awaiting beam bunching or an increase in polarized beam intensity. E683 proposes to obtain ± 2 -mb uncertainty at 3 energies, which will do no more than check the gross features observed with the previous pd measurement. A complete experiment, comparable to the pp experiment, would require both bunching and intense beam. If the energy-dependent structure were confirmed, then a lengthy program of np inelastic measurements would undoubtedly become important.

In summary, the basic np program that we foresee with an intense beam is as follows (not necessarily in the following order):

1. Measure $\Delta\sigma_L$ ($I=0$) and $\Delta\sigma_T$ ($I=0$) with free neutrons (i.e., E683 expanded to include more energies, ± 1 -mb precision, and transverse spins). Evaluate the np inelastic program in light of what is observed.

The elastic experiments (2 to 4 below) should concentrate on 650 and 800 MeV with some cross checks at 500 MeV. If unexplained structure

is observed in $\Delta\sigma(I=0)$, then further data at 575 and 725 MeV will be required.

2. Complete the present program of polarized target measurements (A_{SS} , A_{LL} , A_{SL} , and A_{NN} , i.e., E665, 770, and 861). (E861 requires an intense beam.)
3. Measure spin transfer parameters in $\vec{n}p \rightarrow n\vec{p}$ (E403 extended to backward angle).
4. Improve the precision of early experiments (E65, 66, 403, 665, 770).

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