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by

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ABSTRACT

An overview of LAMPF nucleon-nucleon experimental facilities is presented. Particular emphasis is given to simultaneous operation in the three beamlines served by the negative ion beam. Capabilities are described for matching beam parameters, including the beam polarization axis, to experimenters' requirements. Some comments on facility usage are included.

Introduction

This review of LAMPF nucleon-nucleon facilities is intended principally to document the state of the facilities as used in 1981. It is expected that as time goes on our capabilities will grow beyond those described here.

This is a written version of a review presented at the "Nucleon-Nucleon Satellite Program" to the IX International Conference on High-Energy Physics and Nuclear Structure. It supplements information available in the LAMPF Users Manual, which is more specific on beams available in each experimental area. This review gives more of a facility overview, with particular emphasis on the practical constraints of simultaneous beam operation in the three nucleon areas. These constraints arise particularly with polarized beam operation, and this subject occupies most of this report.

People who have made major contributions to these facilities include Phil Chamberlin (injector), Earl Hoffman (800-MeV spin precessor), Mike McNaughton (Janus polarimeter, beam line polarimeter, calibration standards), and John Jarmer (polarized target).

The Accelerator

The LAMPF accelerator is an 800-MeV linac that can deliver 120 beam pulses per second with 9% duty factor. The negative ion beam serving the nucleon area can share the same accelerating rf as the high-current proton beam for the meson areas. The beams are then delivered simultaneously and at the same energy. Beam parameters for single-energy operation are given at the top of Table I.

To deliver a low-energy H^- beam for the benefit of the nucleon experiments, some of the accelerating rf is turned off, so full-energy H^+ cannot be delivered on the same beam pulse. In this mode, typically one beam pulse out of three is low-energy H^- , giving a reduced duty factor, as shown in Table I for dual-energy operation.¹ The polarized beam current then drops from about 15 nA to 5 nA.

Although the beam energy can be changed in 17-MeV steps, scheduling of three simultaneous users tends to channel the energies to a few round numbers.

TABLE I

LAMPF DUAL BEAMS, DUAL ENERGIES

BEAM STRUCTURE

Full Duty, Single Energy: $120 \text{ Hz} \times 750 \text{ } \mu\text{s} = 9\% \text{ df}$

Dual Energy: $\left\{ \begin{array}{l} 80 \text{ Hz for } H^+ = 6\% \text{ df} \\ 40 \text{ Hz for } H^- = 3\% \text{ df} \end{array} \right.$

AVERAGE CURRENTS

H^+ 600 μA 6-9% df

H^- 1-3 μA 3-9%

P^- $\left\{ \begin{array}{ll} 15 \text{ nA} & 9\% \quad \text{Single Energy} \\ 5 \text{ nA} & 3\% \quad \text{Dual Energy} \end{array} \right.$

ENERGIES AVAILABLE

800 MeV - 300 MeV in 30 Steps

Typically Use 50-MeV Steps

Fig. 1. LAMPF H⁻ beam areas.

Beamlines

The H^- beam is delivered simultaneously to three experimental areas, as shown in Fig. 1. Line C has the High Resolution Proton Spectrometer. Line B is used to make neutrons from a deuterium target for the BR channel; alternatively, protons can be delivered directly from Line B into BR. The External Proton Beam line delivers beam to a general-purpose experimental area. Only in EPB can the beam be received as a negative ion beam. The high magnetic fields in Lines C and B prevent H^- transmission.

The beamline transport bends are completely in the horizontal plane. Consequently, vertical polarization appears the same in each beamline. However, the horizontal components of spin are different in each beamline because of the relative beamline angles.

Beams for the three beamlines are split apart by means of strippers and magnetic separation. An adjustable stripper jaw, shown on the right in Fig. 2, provides more than 10^{-4} range in transmitted H^- . In the figure, the unstripped beam is represented by the transmitted square of light. The collimation of the unstripped beam is sometimes undesirable: two effects often noticed are transformation beam position instability into intensity modulation, and unfavorable selection of polarization (polarization-phase-space correlation). Consequently, we are developing a system of sieve or mesh strippers, illustrated on the left, to provide stripping with a uniform sample across the beam. On the other hand, the collimation may be used to produce beams of high brightness, exceeding 100 nA/mm^2 , with low total current, $<50 \text{ nA}$, in EPB.

Fig. 2. Beam stripper assemblies. Adjustable jaw stripper on right, sieve stripper on left. The strippers are illuminated to illustrate partial H^- transmission by transmitted light patterns.

Polarized Beams

The polarized H^- beam originates in a Lamb-shift H^- ion source, shown schematically in Fig. 3. The peak current and polarization for the LAMPF source are typical of the dozen or so Lamb-shift ion sources throughout the accelerator world. A great virtue of the Lamb-shift injector is self-calibration through the quench method. This technique removes, or quenches, the polarized component of the beam but transmits the unpolarized background beam essentially without disturbance. Thus the net polarization can be calculated from the quenched and unquenched beam currents. At LAMPF, a polarized-quenched (PQ) cycle operates continuously with a 60-s period, asynchronously with the usual 130 s spin reversal (NR) cycle. This measure of beam polarization independent of the beamline polarimeters provides a redundant monitor of system performance, permits monitoring of longitudinal polarization when delivered to an experimenter, and has resulted in bootstrapping polarimeter and ion source performance to higher standards of operation.

Fig. 3. Lamb-shift polarized ion source schematic and beam parameters. The current is peak current during the beam pulse. (The fast spin reversal system is not usually used.)

Figure 4a is a sketch of a polarimeter in one of the three beamlines; the polarimeters are all similar and contain counters in the horizontal and vertical planes to measure the transverse polarization. The forward-conjugate acceptance is broad enough to be usable from 300 to 800 MeV without angle change, but tight enough to see only a few percent inelastic events from a polyethelene target. The hydrogen analyzing power at 17° is near 50% over the dual-energy operating range as shown in Fig. 4b.² System refinements with continuous quench calibration permits quite accurate measurement of the analyzing power and beam polarization.

Fig. 4a. Beamline polarimeter schematic.

Fig. 4b. Hydrogen analyzing power vs. beam energy at 17° lab. Complete data references in Ref. 2.

Precession

The horizontal beamline angles among Lines C, B, and EPB generate relative precession angles for the horizontal spin vector. This situation is shown in Fig. 5, where the outer arrows give the relative geometrical orientation of the beamlines, and the inner arrows the spin directions in BR and EP when Line C receives longitudinal (L) spin at 800 MeV. The angle between the spin and momentum is called the relative spin angle in these diagrams.

The nonrelativistic (Ω_0) and relativistic (Ω) precession angles in a beamline bend of θ are

$$\Omega_0 = G^\pm \theta, \quad \Omega = \gamma \Omega_0,$$

where $\gamma = E/m$, $G^\pm = (\pm g_p - 1)$ for $H^\pm$, and $g_p = 2.793$. Ω is additive, even in the case of a beam of H^- being stripped part way through a system of bends. Table II gives the cumulative angles Ω_0 at various places in the LAMPF beamlines.

TABLE II

Beamline angles θ^- for H^- , θ^+ for H^+ , Nonrelativistic Precession Angles Ω_0
(Degrees, Positive Angle Counterclockwise)

From	To	θ^-	θ^+	Ω_0	
Linac	Line X	45	0	-170.685	
Line X	Line C	0	120	215.16	(at Line C polarimeter and HRS target)
Line X	LB-S0	2	2	-4.000	(solenoid position in Line B)
Line X	LB-P0	2	18	24.688	(Line B polarimeter)
Line X	BR	2	34	53.376	(BR channel or deuterium target)
Line X	EPB	0	0	0	

Fig. 5. Relative orientation of the spin vectors in BR and EPB when the spin is L in Line C at 800 MeV. Ω is the angle between the spin and momentum.

Figure 6a. shows the graphs of $\Omega_{EP}-\Omega_C$ and $\Omega_{BR}-\Omega_C$ vs. beam energy; the ordinate is the relative spin angle in EP or BR when HRS has longitudinal polarization. There is no energy within the operating limits where BR is in phase (180° or 360°) with Line C. Near 600 MeV, Ω_C and Ω_B are 90° out of phase, thus S-polarization in Line C appears as L-polarization in BR.

L-polarization in BR is essential for polarized neutron production. To make L-spin in BR when Line C receives the frequently run N-polarization, a solenoid (LB-S0) may be placed in Line B upstream of BR. The solenoid rotates the spin about the beam axis from N to S, then the subsequent 32° beamline bend provides nearly perfect S to L precession over the entire dual energy range, as shown in Fig. 6b. For polarization transfer to neutrons, the L-component of spin, $\cos\Omega_B$, is the important quantity. For N-S-L precession using the solenoid in Line B, a maximum of only 6% of the polarization is lost in the L-projection from 200-800 MeV. Similarly for S to L precession in Fig. 6a (no solenoid), less than 10% of the polarization is lost within the dashed region around 600 MeV.

Fig. 6b. Relative spin angle in BR with N polarization upstream of Line B solenoid.

Fig. 6a. Relative spin angles vs. energy in EP and BR with L spin in Line C.

A more general precessor is available in EPB.³ This device employs a solenoid to provide transverse (NS) precession and a unique system of three dipoles and a stripper to provide horizontal (SL) precession, as shown in Fig. 7. Without the stripper the dipoles would cause no net precession; with stripping, the net precession is $\Omega = -2\gamma\theta q_p$, where θ is the bend angle of H^- in the first dipole (note that the precession of H^- is of opposite sign to bend angle). The middle dipole bends 2θ but for clarity is shown in Fig. 7 as two bends of θ .

Presently there is only one solenoid, LB-SO, to be used in either EP or BR; thus if the spin upstream is N (for HRS), then both EP and BR cannot have L spin. Procurement of a second superconducting solenoid is being considered.

A further restriction is placed upon the EP precessor by the finite dipole apertures and the geometry of the vacuum chamber through the middle dipole, which limits θ to -5° to $+14^\circ$ (positive angles bend beam-left). At 500 MeV, we find that L polarization in HRS gives $\Omega = -330^\circ$ at the beginning of EPB. To obtain S beam in EPB, the precessor must operate with $\theta = -7^\circ$ or $+14^\circ$, which will not adequately transmit the beam. Therefore the effective lower limit for L(HRS) $\rightarrow$ S(EPB) is 550 MeV, or more generally, the relative spin orientation in the horizontal plane between EPB and HRS cannot be made 90° below 550 MeV. Notice that this restriction does not apply for N(HRS) $\rightarrow$ L or S(EPB).

As a final application of the precession equation $\Omega = \gamma G \theta$, we mention a limitation in use of the HRS focal plane polarimeter (similar to the Janus polarimeter, described below). Because of the 150° vertical bend angle in the spectrometer, N polarization in the scattered proton is precessed to longitudinal at 632 MeV. Thus there is a blind spot to the N component at this energy; furthermore, the observable transverse projection $\sin\Omega$ is less than 0.5 from 532-732 MeV.

Fig. 7. EP spin precessor dipole system. L polarization is shown precessed to S.

Neutron Beam

The BR area shown in Fig. 8 is used for both neutrons and protons. The neutron beam may be taken off at several angles through collimators viewing the production target; the zero degree port can also be used for delivery of primary protons. For neutron production a liquid deuterium target may be used. The usable neutron flux is $\sim 3 \times 10^{-7}$ neutrons per primary proton (refer to User's Manual for specifics). The usual beam rf structure is 5 ns; with chopping at the injector, the bunch period can be made 40 ns to permit good neutron energy resolution by time-of-flight to rf. More than a factor of 8 intensity loss is the penalty.

Fig. 8. BR area. Typical experiment sketched in 0° channel, which can deliver primary protons at 0° from Line B, or neutrons from the liquid deuterium (LD₂) target.

However, the charge-exchange reaction at 0° with the deuterium target produces a sharp neutron energy peak just below the incident proton energy, with a well-separated inelastic background, as shown in Fig. 9.⁴ This rather clean neutron spectrum makes elaborate neutron energy measurement unnecessary for some experiments.

The earlier comments on the importance of longitudinal polarization for neutron production is explained in Fig. 10. Longitudinal spin transfer is 64% to the full-energy neutrons at 0° , but the transverse spin transfer is only 15%.⁴ Therefore small transverse polarization in the protons tends to be further washed out in the neutrons. With the present LAMPF polarized beam, roughly 10^4 neutrons/s of ~50% polarization are available on the experimenters target.

Fig. 9. Neutron spectrum at 0° from LD_2 target.

Fig. 10. Longitudinal (K_{LL}) and transverse (K_{NN}) spin transfer coefficients in neutron production by 800-MeV polarized proton beam.

Polarized Targets

The three polarized proton targets usually available at LAMPF are outlined in Table III; however, only one target, using the HERA magnet brought from Saclay, is actually owned by LAMPF. It can operate in the frozen spin mode.

TABLE III

POLARIZED TARGETS AT LAMPF

Owner	Magnet			Target			Free Pol. %
	Supercon?	Field, T	Dir.	Mat'l	Diam., cm	Length, cm	
P-Div. ^a	N	2.5	Vert.	Propanediol			80
ANL/Rice	SC	2.5	Vert.	Propanediol	2	5	75-80
MP-Div. ^a	SC ^b	2.5	L.S.	Propanediol	4	5	75-80
				Propanediol	2	4	

^aDivision of Los Alamos

^bfrom Saclay

Another facility available to experimenters is the Janus recoil polarimeter,⁵ sketched in Fig. 11. This device uses six drift chambers around a carbon analyzer to measure the polarization of scattered particles. Janus has been calibrated directly in the primary beam as well as with scattering reactions. A similar recoil polarimeter is permanently installed on the proton spectrometer in Line C.

Fig. 11. "Janus" Polarimeter for analysis of scattered particles.

Usage

The significance of these facilities to the LAMPF program is shown by a sample of usage. Preliminary or final research reported in the last year, principally in our progress report^{6,7} or in Los Alamos conference proceedings,^{8,9} are shown in Table IV by the facilities used. The "name" column may be spokesman, first author, or simply a knowledgeable person.

Five experiments are shown using polarized protons and polarized targets, six with polarized protons and unpolarized targets, two with polarized neutrons, and several others in other categories. An experiment that illustrates the breadth of this program and the flexibility of the experimental areas is the H^- -laser colliding beam experiment.

Similarly, experiments on scattering reactions on heavy targets are given in Table V. This table is of course dominated by work done on the spectrometer; conversely, the previous table contained only two HRS experiments. A noteworthy non-HRS experiment in the table showing complex targets is the parity violation experiment.

In summary, our nucleon facilities have grown to provide moderate intensity H^- , or low-intensity polarized beam with variable energy. Sufficient instrumentation and controls are available to permit simultaneous beam use in three experimental areas. Of course, in the tradition of the famous laws of Murphy, we find that the experimenters request combinations that are beyond our proven capabilities. But that is to be expected and keeps us challenged. Perhaps a more frustrating result is the increased opportunity for scheduling conflicts produced by some of these advances in our facility.

TABLE IV

NUCLEON + SIMPLE TARGET

Recent Sample of LAMPF Reports
Over ~12 Months

		In	"Physics"	Channel	Exp.	Name	Ref.
POLARIZED PROTON BEAM	POL. TARGET	$\bar{p} \bar{p}$	$\Delta\sigma_L$ (E) 318-800 MeV	EP	498	Wagner	G.C
		$\bar{p} \bar{p}$	$\Delta\sigma_T$ (E), A_{NN} (E, 90° c.m.)	BR	504	Phillips	G.D
		$\bar{p} \bar{p}$	$\rightarrow d\pi^+$ A_{NN} (E, 90° c.m.)	BR	505	Phillips	D
		$\bar{p} \bar{p}$	D_{NN} (E, 90° c.m.)	BR	492	Bonner	G
		$\bar{p} \bar{p}$	A_{NN} (650, 800 MeV)	EP	27	McNaughton	P
	UNPOL. HYDROGEN TAR.	$\bar{p} p$	A (E,0)	EP	27	McNaughton	P
		$\bar{p} p$	D_{NN} , D_{SS} , D_{LS} (650, 800 MeV)	EP	194	McNaughton	P
		$\bar{p} p$	$\rightarrow \pi^0, \pi^+$	EP	336	Mutchler	P,J
		$\bar{p} p$	$\rightarrow \bar{n}X$ at 0°	BR	402	Riley	P
		$\bar{p} p$	Small-angle Coulomb	HRS	15	Igo	D
		$\bar{p} d$	Quasi-free AP, A^n	HRS	395	Hoffman	D
NEUTRON BEAM		$\bar{n} p$	A (300-800 MeV)	BR	65	Newsom	P
		$n \bar{p}$					
		$\bar{n} \bar{p}$	A_{NN} (300-665 MeV)	BR	66	Simmons	P
		$n p$	$\rightarrow pp\pi^{--}$	BR	366	Phillips	D
OTHER		$H^- \gamma$	Atomic Physics	EP	449	Bryant	C
		$\bar{H}^- \rightarrow \bar{H}^0$	Depolarization	EP	530	van Dyck	P
		$\bar{p} C, \bar{p} Be$	Inclusive A	EP	194	Ransome	P

REFERENCES: G = 31 GeV Workshop (Los Alamos)

J = LAMPF Progress Report, June 1980

D = LAMPF Progress Report, December 1980

C = CERN Courier

P = V Pol. Conf. (Santa Fe)

TABLE V

NUCLEON + COMPLEX TARGET
Recent Sample of LAMPF Reports
Over ~12 Months

	In	"Physics"	Channel	Exp.	Name	Ref.
POLARIZED BEAM	$\bar{p}$ Pb	A(θ) analyzing power	HRS	355	Hoffmann	D
	$\bar{p}$ Ca	Q(θ) spin rotation	HRS	479	Igo	D
	$\bar{p}$ Mg	A(θ)	HRS	476	Blanpied	D
	$\bar{p}$ d	$\rightarrow$ ^3He X "ABC"	HRS	---	Gazzaly	D
	$\bar{p}$ A	Parity	EP	137	Nagle	J
UNPOLARIZED BEAM	p p p A	Inclusive spectra	HRS	470	Blanpied	J,D
	p A	σ_{total}	HRS	386	Hoffmann	J
	p Ni	$d\sigma/d\theta$ vs isotopes	HRS	139	Tanaka	J
	p A	A = (2s-1d) nuclei	HRS	178	Hintz	J
	p A	A = deformed nuclei	HRS	183	Hintz	J
	p A	Orbit flip states	HRS	347	Hintz	J
	p Pb	$r_n - r_p$	HRS	355	Hoffmann	J
	p C	High q	HRS	354	Blanpied	D
	p Ca	High q	HRS	352	Whitten	D
	p A	Unnatural parity states	HRS	431	Glashauser	J
	p C	Critical opalescence	HRS	486	Igo	D

REFERENCES: J = LAMPF Progress Report, June 1980
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