Targets for a neutral kaon beam

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A secondary beam of neutral kaons is under consideration for Hall D at Jefferson Lab to perform spectroscopic studies of hyperons produced by K_L^0 particles scattering from proton and deuteron targets. The proposed physics program would utilize the GlueX detector package currently installed in Hall D. This contribution looks at potential targets for use in the new facility, paying close attention to the existing infrastructure of GlueX and Hall D. Unpolarized cryotargets of liquid hydrogen and deuerium, as well as polarized solid targets of protons and deuterons are examined.

I. INTRODUCTION

A proposal is currently under consideration to expand Jefferson Lab's program of hadron spectroscopy and develop a secondary K_L^0 beam in experimental Hall D [1]. The kaon beam will be produced from photoproduction on a beryllium target located about 85 m downstream from the Hall D radiator for Bremsstrahlung photons. Photons escaping the beryllium target will be absorbed by a lead shield, while charged particles will be removed by a sweeper magnet. The K_L^0 flux, collimated into a 6 cm diameter beam, is expected to be of order 10^4 s^{-1}, along with a similar rate of high energy neutrons. The existing GlueX detector package and its 1.8 T superconducting solenoid would be utilized for the program.

This contribution examines possible targets for the neutral kaon beam facility, both unpolarized and polarized hydrogen and deuterium. Emphasis is placed on the former, and in particular on straightforward modifications to the existing GlueX cryotarget that will make it suitable for a large diameter beam of K_L^0.

II. LIQUID HYDROGEN TARGET

If possible, the proposed experimental program will utilize the existing GlueX liquid hydrogen cryotarget (Fig. 1), modified to accept a larger diameter target cell. The GlueX target comprises a kapton cell containing liquid hydrogen (LH_2) at a temperature and pressure of about 20 K and 19 psia. The 100 ml cell is filled through a pair of 1.5 m long stainless steel tubes (fill and return) connected to a small vessel where hydrogen gas is condensed from two room temperature storage tanks. Inside the vessel is a large condensation surface for the gas, consisting of numerous copper fins that are cooled by a pulse tube refrigerator (PTR) with a base temperature of 3 K and cooling power of about 20 W at 20 K. A 100 W temperature controller regulates the condenser at 18 K.

The target assembly is contained within an "L"-shaped, stainless steel and aluminum vacuum chamber with a 1 cm thick Rohacell extension surrounding the target cell. The start counter for the GlueX experiment fits snugly over this extension. The vacuum chamber, along with the hydrogen storage tanks, gas handling system, and control electronics, is mounted on a custom-built beam line cart for easy insertion into the Hall D solenoid. A compact I/O system monitors and controls the performance of the target, while hardware interlocks on the target temperature and pressure and on the chamber vacuum ensure the system's safety and integrity. The target can be cooled from room temperature and filled with liquid hydrogen in about 5 hours. For empty target runs,

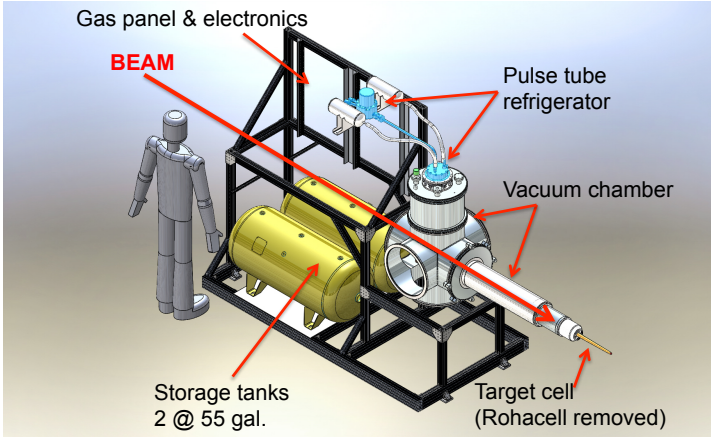

FIG. 1. The GlueX liquid hydrogen target.

the liquid can be boiled from the cell in less than twenty minutes. The cell remains filled with cold hydrogen gas for these runs and can refilled with liquid in about forty minutes.

The GlueX cell (Fig. 2) is closely modeled on those used for experiments in Hall B at Jefferson Lab for more than a decade [3]. It is a horizontal, tapered cylinder about 38 cm long with a mean diameter of 2 cm. A 2 cm diameter reentrant beam window defines the length of LH_2 in the beam to be about 30 cm. Both entrance and exit windows on the cell are 75 μm kapton while the cylindrical walls are 130 μm kapton glued to an aluminum base. In normal operation the cell, the condenser, and the pipes between them are all filled with liquid hydrogen. In this manner the liquid can be subcooled a few degrees below the vapor pressure curve, greatly suppressing the formation of bubbles in the cell. In total, about 0.4 liter of LH_2 is condensed from the storage tanks, and the system is engineered to safely recover this quantity of hydrogen back into the tanks during a sudden loss of insulating vacuum, with a maximum allowed pressure of 49 psia [2].

A conceptual design for the neutral kaon beam target is also shown in Fig. 2. The proposed target cell has a diameter of 6 cm and a 40 cm length from entrance to exit windows, corresponding to a volume of about 1.1 liter. The inventory of gas required to operate the target with this cell will be about 1500 STP liter, which can be stored in the existing tanks at about 50 psia. The JLab Target Group will investigate alternative materials and construction techniques to increase the strength of the cell.

The GlueX target system is expected to operate equally well with liquid deuterium (LD_2), which condenses at a slightly higher temperature than hydrogen: 23.3 K versus 20.3 K at atmospheric pressure. Because the expansion ratio of LD_2 is 13% higher, the storage pressure will about 60 psia. The new target cell will therefore be engineered and constructed to accomodate either H_2 or D_2.

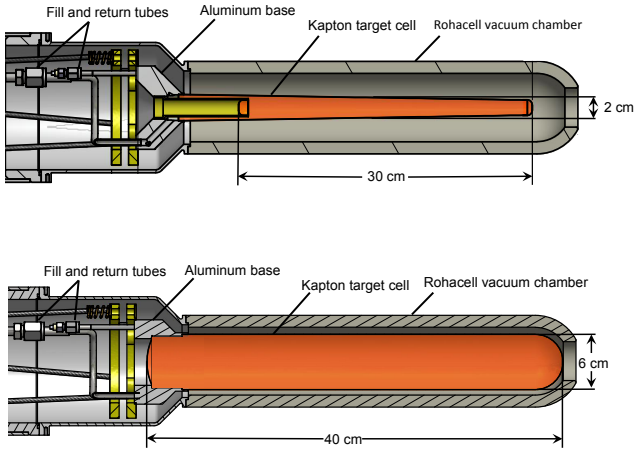

FIG. 2. Top: Kapton target cell for the GlueX LH_2 target. Bottom: Conceptual design for a larger target cell for the proposed K_L^0 beam in Hall D.

III. SOLID POLARIZED TARGET

Dynamically polarized targets were successfully utilized in each of Jefferson Lab's three experimental halls (A, B, and C) during its 6 GeV era [4]. It is natural then to contemplate their use in Hall D as well. We can expect the Hall D solenoid and its accompanying cryogenic facility to play significant roles in the target's design and operation.

To realize dynamic nuclear polarization (DNP), a solid dielectric material is doped with paramagnetic radicals. The unpaired electrons in these radicals are polarized at low temperature and high magnetic field, and microwave-driven spin flip transitions transfer the electron's polarization to nearby nuclei in the material. The nuclear polarization is then transported through the bulk via spin diffusion.

DNP targets generally fall into one of two categories: continuously polarized and frozen spin. In the former case the DNP process is maintained continuously throughout the scattering experiment, while frozen spin targets are polarized intermittently, and the scattering data is acquired while the polarization slowly decays. Continuously polarized targets require a highly uniform polarizing magnet of 2.5–5 T whose geometry limits the acceptance of scattered particles. A similar magnet is also required to polarize a frozen spin target, but the target sample can then be removed from the high field and maintained by a much less massive "holding" magnet during data acquisition, provided it is cooled to a temperature of 50 mK or less. For this reason frozen spin targets are limited to particle beams no greater than about 10^8 s^{-1}, while continuously polarized targets have

operated up to $\sim 10^{12}$ s^{-1}. Because of its high resistance to radiation damage, irradiated ammonia (NH_3 or ND_3) continuously polarized at 1 K and 5 T is the usual choice for electron beams up to 140 nA. Chemically doped butanol ($C_4H_{10}O$) has become the material of choice for frozen spin targets, thanks to its ease of production and handling, and its lack of polarizable background nuclei other than hydrogen. Protons in either ammonia or butanol can be dynamically polarized in excess of 90%. Deuterated ammonia can be polarized to about 60%, and deuterated butanol to 80–90%.

At the expected K_L^0 rate of the proposal, either type of polarized target is suitable. However, the 1.8 T field of the Hall D solenoid is too weak and too inhomogeneous (0.25 T/m) to act as an effective polarizing magnet for DNP. It would serve as an excellent holding magnet for a frozen spin target though. Polarization decay times up to 4000 hours were observed with the FROST target in Hall B using a 0.5 T holding field [5]. From these results we anticipate relaxation times exceeding 10,000 hours at 1.8 T. The target would be polarized outside the Hall D solenoid using a warm-bore magnet similar to the one used for the FROST target and moved to the GlueX solenoid for data acquisition. A small transfer coil would be incorporated inside the target cryostat to maintain the polarization while the target is moving.

The size of the polarized target sample will be critical. For best results, the polarizing field should be uniform to about 100 ppm over the sample volume. The cost of a magnet suitable for a 6 cm sample diameter will be significant, so smaller diameters should be considered. Approximately 2 mW/g of microwave power is necessary for DNP at 2.5 T. Thus the sample volume will also determine the refrigeration capacity of a frozen spin target. Frozen butanol consisting of 1–2 mm beads has a density of 1.1 g/cm^3, a packing fraction of about 0.6, and a dilution factor of 0.135. A target sample 2 cm in diameter and 23 cm long would provide a similar proton luminosity as the 30 cm long LH_2 target. Dynamic polarization of the 50 g sample would require about 0.1 W of microwave power at 2.5 T and 0.3 K. A ^{3}He-^{4}He dilution refrigerator similar to FROST's would be suitable for this application, operating at a ^{3}He circulation rate of 30 mmol/s during polarization and 1–2 mmol/s during frozen spin mode.

A frozen spin target consumes liquid helium at a rate of a few liters per hour to operate the dilution refrigerator. The Hall D cryogenic plant may not be able to provide this volume of LHe to a polarized target and maintain the GlueX solenoid at the same time. In this case the polarized target will require a separate source of LHe, and should be designed to economize ^{4}He consumption. Alternatively, one may consider a so-called "cryogen-free" dilution refrigerator (CFDR), where the circulating ^{3}He is condensed by a small cryocooler such as the PTR utilized for the GlueX cryotarget [6]. Unfortunately, present day CFDRs cannot provide the cooling power

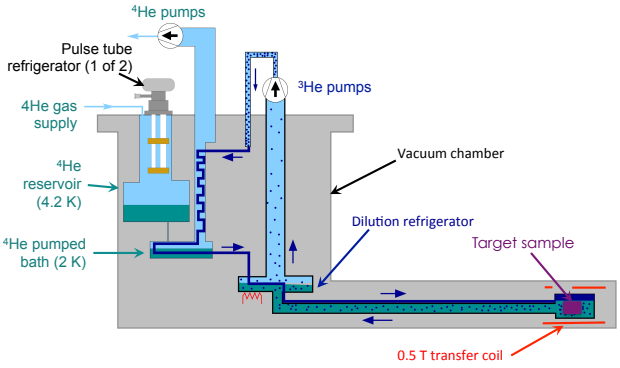

FIG. 3. Schematic drawing of a hybrid cryogen-free frozen spin target. See text for details.

necessary to polarize a 50 g target sample. In its place, we can consider a hybrid system using two pulse tubes (Fig. 3). Together these can condense ^{3}He at a rate sufficient for frozen spin operation and simultaneously condense 5–10 l/day of ^{4}He into a 50 liter reservoir within the target cryostat. Once sufficient liquid is accumulated, it would support an increased ^{3}He circulation rate long enough to polarize the sample, about 8 hours. The ^{4}He level in the reservoir would naturally decrease during this time but recover during the week or more of frozen spin operation.

IV. SUMMARY

Possible targets for a neutral kaon beam in Hall D have been examined. It is found that the existing GlueX cryotarget can be modified to accept liquid hydrogen or deuterium cell diameters up to 6 cm, with some R&D required to increase the working pressure of the current GlueX cells. For polarized target experiments a frozen spin target of butanol is indicated. It will be more difficult to realize a 6 cm diameter sample in this case, due to the magnetic field and cooling power requirements necessary for dynamic polarization. Instead a 23 cm long sample with 2 cm diameter is considered.

V. ACKNOWLEDGEMENTS

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