EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-EP/85-70
8 May 1985

NEW APPLICATIONS OF LIQUID-HYDROGEN TARGETS

PS185 Collaboration

P.D. Barnes[1], R. Besold[4], P. Birien[8], B. Bonner[7], W. Breunlich[10], W. Dutty[5], R.A. Eisenstein[6], G. Ericsson[9], W. Eyrich[4], R. Frankenberg[4], G. Franklin[1], J. Franz[5], N. Hamann[5], D. Hertzog[1], A. Hofmann[4], T. Johansson[9], K. Kilian[2], C. Maher[1], R. Müller[4], H. Ortner[4], P. Pawlek[2], S.M. Polikanov[3], B. Quinn[1], E. Rössle[5], H. Schledermann[5], H. Schmitt[5], J. Seydoux[1], J. Szymanski[1] and P. Woldt[3]

Carnegie-Mellon Univ.[1]–CERN[2]–Darmstadt (GSI)[3]–Erlangen-Nuremberg Univ.[4]–Freiburg Univ.[5]–Illinois Univ. (Urbana)[6]–Los Alamos Nat. Lab.[7]–Saclay (CEN-DPhN)[8]–Uppsala Univ.[9]–Vienna (Akad. Wissensch.)[10]

Abstract: In view of the high performance of LEAR the use of small liquid-hydrogen targets with very thin windows is desirable for various experimental investigations. We discuss here the properties of such an LH_2 target. By optically coupling the target to a Cherenkov-light readout for veto applications, very clean trigger conditions can be obtained. Furthermore, with this Cherenkov-active LH_2 target, Experiment PS185 can measure at LEAR various hyperon–antihyperon production channels in one set-up at the same time.

Presented by K. Kilian at the
Third LEAR Workshop on
Physics in the ACOL Era with Low-Energy Cooled Antiprotons,
Tignes, 19–26 January 1985

1. INTRODUCTION

The extremely good beam quality achieved at LEAR (spot size < 1 mm^2 FWHM, intensity > 5 × 10^5 $\bar{p}$'s per second) permits the use of thin, liquid-hydrogen targets. In a variety of experimental investigations, small target volumes are of considerable interest, e.g.

- in measurements of excitation functions and total $\bar{p}p$ cross-section at low energies, because of increasing energy loss and straggling;
- in high-precision experiments where particle–antiparticle symmetries are investigated (e.g. Y–$\bar{Y}$ [1,2], K–$\bar{K}$), a small target mass helps to reduce systematic errors coming from secondary interactions;
- in experiments calling for a good definition of the interaction vertex, e.g. PS185 [3].

Thin targets (of the order of a few millimetres) require windows that are very thin compared with the thickness of the liquid hydrogen in the container. A good 1 mm LH_2 target should have a Mylar or Hostaphan container with a wall thickness of only a few microns. An additional advantage of reduced window thickness is the possibility to effectively combine the liquid-hydrogen target with a Cherenkov-light readout.

2. TECHNICAL SOLUTION FOR THIN-WALLED TARGETS

Thin windows are possible if the pressure difference across the windows (between target cell and isolation vacuum) is stabilized at a small value in all operational modes. This has been achieved in a prototype developed at CERN[4,5] and shown schematically in Figs. 1 and 2.

Very flexible cylindrical metal bellows are used as a reservoir for gaseous hydrogen. A weight on its top causes a constant pressure difference (0.2 atm) between the hydrogen inside and the isolation vacuum

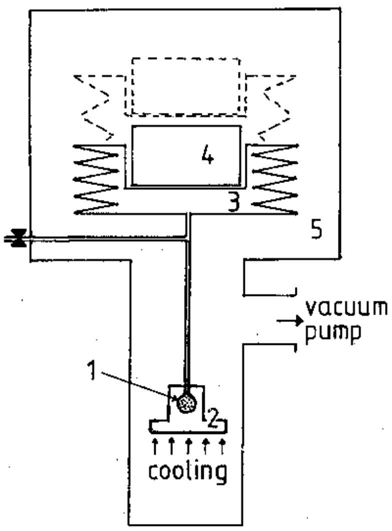

Fig. 1 Schematic view of the LH_2 target prototype: 1. LH_2 target cell with thin windows; 2. copper block connected to refrigerator to condense H_2; 3. H_2 reservoir with variable volume (flexible bellows); 4. weight which defines pressure difference between the inside (3) and outside (5) of the hydrogen container; 5. isolation vacuum.

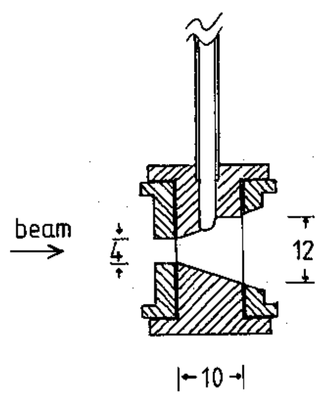

Fig. 2 Cross-section through the cooled copper target cell. The H_2 gas enters through the tube from above and condenses in the conical target volume between two 2.5 μm Hostaphan windows. Dimensions are in millimetres.

outside, independently of the operational status of the system. This closed system contains a fixed amount of hydrogen which is sufficient to fill the target cell with LH_2 when cooled. The 10 mm thick cell has Hostaphan windows of 2.5 μm thickness, with 4 and 12 mm diameter, respectively. The target cell and the reservoir are located in a common isolation vacuum.

3. APPLICATION AS A CHERENKOV COUNTER

Based on positive experience with normal-pressure LH_2 Cherenkov counters built by the LH_2 group at CERN[6], it can be envisaged to use, in addition, the advantages of thin target windows for Cherenkov applications. The transmission of LH_2 Cherenkov light through the windows is improved, and the unwanted emission of Cherenkov light from the windows is largely reduced.

In Table 1 several hyperon–antihyperon production channels accessible in the momentum range of LEAR are listed.

Table 1

$\bar{p}p \to \bar{Y}Y$ reactions accessible in the momentum range of LEAR

Reaction	$\bar{Y}Y$ production mode	Main decay mode	$\bar{p}$ beam momentum at threshold (MeV/c)
1	$\bar{p}p \to \bar{\Lambda}^0\Lambda^0$	$\bar{p}\pi^+p\pi^-$	1435.1
2	$\bar{p}p \to \bar{\Lambda}^0\Sigma^0$ + c.c.	$\bar{p}\pi^+p\pi^-\gamma$ + c.c.	1652.7
3	$\bar{p}p \to \bar{\Sigma}^+\Sigma^+$	$\bar{p}\pi^0p\pi^0$	1853.0
4	$\bar{p}p \to \bar{\Sigma}^0\Sigma^0$	$\bar{p}\pi^+\gamma p\pi^-\gamma$	1870.6
5	$\bar{p}p \to \bar{\Sigma}^-\Sigma^-$	$\bar{n}\pi^+n\pi^-$	1898.4

For the neutral $\bar{\Lambda}\Lambda$ production [reaction (1)], the CERN PS185 experiment is at present using a simple CH_2 transmission target surrounded by a small scintillator veto box. This defines neutral production and suppresses both prompt charged interactions and passing beam particles on line. Background from $\bar{\Lambda}\Lambda$ production on ^{12}C in the target can be fully rejected[7] by off-line kinematical reconstruction of the delayed charged decays $\Lambda \to p\pi^-$ and $\bar{\Lambda} \to \bar{p}\pi^+$. This rejection would be less effective if Σ^0 or $\bar{\Sigma}^0$ hyperons were involved [reactions (2)and (4)] owing to the more complicated ('three-body') decay chains $\Sigma^0 \to \gamma\Lambda \to \gamma p\pi^-$ and $\bar{\Sigma}^0 \to \gamma\bar{\Lambda} \to \gamma\bar{p}\pi^+$. For $\bar{\Lambda}\Sigma^0$ + c.c. or $\bar{\Sigma}^0\Sigma^0$ studies, a pure hydrogen target is therefore needed. Furthermore, when investigating charged $\bar{\Sigma}^{\pm}\Sigma^{\pm}$ hyperon production [reactions (3) and (5)] a scintillator veto box can no longer be used.

Both these problems can be solved by the use of a 1 × 1 × 1 cm^3 LH_2 target with Cherenkov-light readout, as sketched in Fig. 3. The possible target arrangement shown in Fig. 4 will allow Experiment PS185 to measure simultaneously all the hyperon–antihyperon production channels listed in Table 1. A clean enough on-line trigger can be provided by using Cherenkov light to veto charged prompt annihilations in the

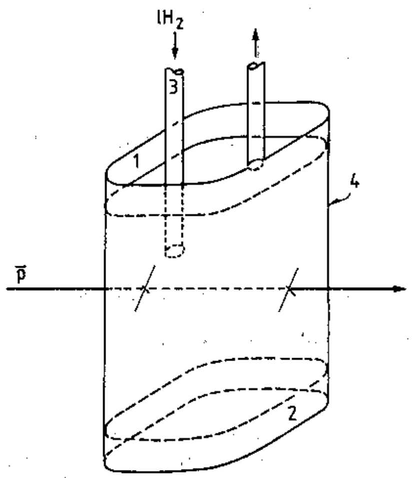

Fig. 3 Schematic view of the LH_2 target cell for Cherenkov-light readout: 1. top cover (steel) with LH_2 inlet and outlet; 2. bottom cover (steel); 3. LH_2 inlet; 4. Mylar foil.

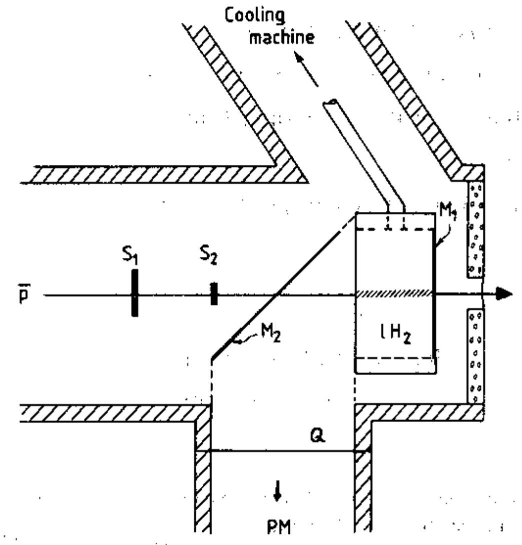

Fig. 4 Arrangement in the target region. The LEAR $\bar{p}$ beam comes from the left, passes through beam-defining scintillation counters (S_1, S_2), and enters the LH_2 target cell. Cherenkov light is collected by Al-coated Mylar foils (M_1, M_2) and is viewed by the photomultiplier through a quartz window (Q).

target. The LH_2 refraction index, $n \simeq 1.11$ (threshold velocity $\beta \simeq 0.9$), corresponds to threshold momenta for the particles involved, as given in Table 2. None of the wanted $\bar{p}p \to \bar{Y}Y$ reactions or their delayed-decay products (Table 1) produces a Cherenkov veto. The passing beam is vetoed by a small scintillator far downstream.

Table 2

Cherenkov threshold momenta of the reaction products involved in $\bar{p}p \to \bar{Y}Y$

Particle	Cherenkov threshold momentum (MeV/c)
π^+, π^-	290
$p, \bar{p}$	1948
$\Sigma^+, \bar{\Sigma}^+$	2469
$\Sigma^-, \bar{\Sigma}^-$	2485

The suppression of background from multipion annihilations has been estimated using a Monte Carlo simulation; some of the results are listed in Table 3. The basic assumptions were the following:

- An LH_2 cell of dimensions $1 \times 1 \times 1\ cm^3$, and a light-collection efficiency such that a 1 cm long track of a 700 MeV/c pion gives two dynode electrons in the photomultiplier. (This corresponds to the sensitivity obtained in Ref. 6. In the set-up foreseen for PS185 the light collection can be better by at least a factor of 2.)
- $\bar{p}p \rightarrow m\pi$ interactions produced by a 1.7 GeV/c $\bar{p}$ beam passing through the centre of the target cell.

Table 3

Results of a Monte Carlo simulation of $\bar{p}p \rightarrow m\pi$ for 1.7 Gev/c $\bar{p}$ beam momentum and a $1 \times 1 \times 1\ cm^3$ LH_2 target cell with Cherenkov-light readout (see text)

Multipion final state [1]	Fraction of events with no $\pi^{\pm}$ above Cherenkov threshold (%) [2]	Events with Cherenkov light: Mean number of electrons produced [3]	Events with Cherenkov light: Veto inefficiency (%) [4]	Total Cherenkov-veto inefficiency (%) [5]	Fraction of events triggering Cherenkov × 1 charged with $\theta_{charged}$ < 30° (%) [6]	Fraction of events triggering Cherenkov × 1 charged with $\theta_{charged}$ < 45° (%) [7]	Cross-section (Refs. 8, 9, and 10) (mb) [8]
$\pi^+ \pi^-$	0.0	2.65	7.0	7.0	2.5	3.9	0.06
$\pi^+ \pi^- \pi^0$	0.0	2.18	11.3	11.3	3.7	5.8	1.19
$2\pi^+ 2\pi^-$	0.0	3.51	3.0	3.0	2.3	2.8	2.15
$\pi^+ \pi^- 2\pi^0$	1.7	1.84	15.9	17.4	5.3	8.1	4
$2\pi^+ 2\pi^- \pi^0$	0.1	2.88	5.6	5.7	3.6	4.8	8.7
$\pi^+ \pi^+ 3\pi^0$	6.0	1.56	21.0	25.7	8.3	13.4	9
$3\pi^+ 3\pi^-$	0.0	3.53	2.9	2.9	2.4	2.5	1.3
$2\pi^+ 2\pi^- 2\pi^0$	0.6	2.35	9.5	10.1	6.4	8.2	
$\pi^+ \pi^- 4\pi^0$	10.9	1.34	26.1	34.2	11.4	18.4	
$3\pi^+ 3\pi^- \pi^0$	0.1	2.84	5.9	6.0	4.9	2.5	2.14
$2\pi^+ 2\pi^- 3\pi^0$	2.2	1.94	14.3	16.2	10.1	13.1	9.2
$\pi^+ \pi^- 5\pi^0$	18.2	1.18	30.8	43.4	16.4	26.1	
$4\pi^+ 4\pi^-$	0.0	2.96	5.2	5.2	3.6	3.6	< 0.04
$3\pi^+ 3\pi^- 2\pi^0$	0.7	2.25	10.6	11.2	8.5	9.3	< 1
$2\pi^+ 2\pi^- 4\pi^0$	5.6	1.59	20.4	24.8	16.9	21.5	< 0.4
$\pi^+ \pi^- 6\pi^0$	26.8	1.02	36.1	53.2	21.9	34.4	

For many multipion annihilation channels (column 1) there is a finite fraction of events (column 2) where no charged pion is fast enough to create Cherenkov light, and which therefore contribute correspondingly to the veto inefficiency. However, the more severe contribution (column 4) comes from the other events; this is because the numbers of dynode electrons produced are statistically distributed around mean values (column 3). Both contributions result in the total Cherenkov–veto inefficiency quoted in column 5. If, in addition to the veto, the on-line trigger asks for at least one charged particle emitted into a forward cone of 30° or 45° half-opening [a kinematical condition which is always fulfilled for reactions (1) to (4) in Table 1], a background suppression of at least 90% can be achieved (columns 6 and 7, respectively). Finally, we note that for the much better optical condition of the foreseen target set-up, a mean number of four dynode electrons can be obtained, and this would give a background suppression of 95% or more.

4. CONCLUSION

Although the veto efficiency is somewhat less than that obtained with a scintillator veto box, the use of a Cherenkov-active LH_2 target in Experiment PS185 has the great advantage that it will enable us to measure at LEAR all hyperon–antihyperon production channels simultaneously in one set-up.

REFERENCES

1) PS185 Collaboration, CERN/PSCC/83-6, M152 (1983).
2) PS185 Collaboration, CERN/PSCC/85-9, M212 (1985).
3) P.D. Barnes et al., Proc. 2^{nd} LEAR Workshop on Physics at LEAR with Low-Energy Cooled Antiprotons, Erice, 1982, eds. U. Gastaldi and R. Klapisch (Plenum Press, Inc., New York, 1984), p. 489 and p. 843.
4) K. Kilian and L. Mazzone, Hydrogen targets with very thin windows, CERN $\bar{p}$ LEAR Note 87 (1980).
5) K. Kilian, L. Mazzone and G. Novellini, A hydrogen target with very thin windows, CERN EP Internal Report 85-02 (1985).
6) K. Kilian, Proc. 2^{nd} Int. Topical Conf. on Meson Nuclear Physics, Houston, 1979, ed. E.V. Hungerford III [AIP Conf. Proc. **54**, 666 (1979)].
7) P.D. Barnes et al., Status and future of Experiment PS185 ($\bar{p}p \rightarrow \bar{Y}Y$) at CERN, these Proceedings.
8) Compilation of cross-sections, CERN-HERA 84-01 (1984).
9) B.Y. Oh et al., Nucl. Phys. **B51**, 57 (1973).
10) R. Armenteros and B. French, *in* High-Energy Physics, ed. E.H.S. Burhop (Academic Press, Inc., New York, 1969), Vol. IV, p. 237.