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Measurements of cascade times of antiprotons in molecular hydrogen and helium

OBELIX Collaboration

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Abstract

The Obelix experiment at CERN collected samples of antiproton annihilations at rest in different gaseous targets, such as hydrogen, deuterium and helium. We analyze a set of the Obelix data using a new technique for measuring, for the first time, the cascade times independent of the capture energy and of the antiproton stopping power. We report on measurements of the cascade times for hydrogen at 3.4, 5.8, 9.8 and 150 mbar and for helium at 8.2, 50 and 150 mbar pressure. An estimate of the antiproton capture energy in hydrogen is also presented.

1. Introduction

The Obelix experiment collected data using the antiproton beam produced by the Low Energy Antiproton Ring (LEAR) facility at CERN. The Obelix detector consisted of a cylindrical target filled with different gases and an apparatus to measure the time and reconstruct the vertex of an annihilation inside the target with a resolution of 1 ns and 1 cm respectively. Details about the apparatus and the reconstruction techniques can be found elsewhere [1]. The LEAR machine delivered a monochromatic antiproton beam which passed through some material (a Be window closing the beam pipe, a thin scintillator detector S_o, air and Mylar sheets) before entering the target filled with ultra pure gas (less than 1 ppm of other gases). To maximize the fraction of antiprotons annihilating inside the gas, the beam was degraded to the desired energy by means of suitable thicknesses of material. The degrading system was tuned according to the pressure of the gas inside the target; the higher the pressure the lower the degrading. The antiprotons entering the target at time t_0 (measured by the target entrance scintillator) lose energy in the gas. Some of them, depending on the gas density, were slowed down enough to be captured "at rest" inside the gas, while the others reached the end wall of the target. When captured by the gas atoms or molecules the antiprotons start a cascade process which ends with the annihilation on a nucleus. The mesons from the annihilation give the annihilation time t_a (measured by the scintillator barrel surrounding the target) and permit the vertex reconstruction. The delay time between the antiprotonic atom formation and annihilation is called cascade time (t_{cas}). The cascade time for annihilations in a solid material, such as the end wall of the target, is of the order of picoseconds, thus negligible if compared to the cascade times for annihilations in gas at NTP or at lower density.

In previous works by the Obelix collaboration [1–6], estimates of the cascade times have already been presented. These results depended on the mean kinetic energy of the antiprotons captured ($\overline{E}_{\mathrm{cap}}$) and on the behavior of the stopping power curve[4].

Before the work [7], it had been generally thought that negative-particle capture was almost entirely due to *quasiadiabatic ionization* [8]. This implied values of $\overline{E}_{\mathrm{cap}}$ of the order of some eV. Based on [7,9], new cross sections for capture of the antiproton by H_2 and D_2 molecules have been calculated using fermion molecular dynamics, predicting antiproton capture at energies up to ~ 100 eV.

In this paper we present a new method for measuring the cascade times that allows us, for the first time, to avoid the dependence on the stopping power curve and on $\overline{E}_{\mathrm{cap}}$.

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[4] We recall here that the stopping power is the energy loss per unit path length of a charged particle in traversing matter.

2. Data analysis and results

The time measured by the detector is the annihilation time (t_a) which can be expressed as

$$t_a = t_{\text{end}} + t_{\text{cas}},$$

where t_{end} includes the slowing down and t_{cas} is the cascade time.

For measuring t_{end} we exploit the annihilation time distributions at the end of the target. For explaining such a method let us consider two antiprotons, each one taking the same amount of time to cross the whole target and approaching the end wall with a similar energy, very close to the capture one. Let us suppose that the first one has enough energy to reach the end wall and to annihilate on it, while the second is captured just before the end wall and must undergo the cascade process before annihilating. Since the cascade time in solids is negligible compared with the one in gases, we will "*see*" the second antiproton annihilation after the first, the delay being the cascade time t_{cas}.

We consider the data on hydrogen at 3.4, 5.8, 9.8 and 150 mbar and on helium at 8.2, 50 and 150 mbar. These were the only samples for which we stored the information about annihilations near and on the end wall. The data related to the first three samples, that is hydrogen at low pressure, were taken during 1991 with a primary LEAR beam momentum of 105 MeV/c, while the other samples were recorded during 1992 with a primary LEAR beam of 200 MeV/c. If we plot the annihilation time distribution for the region of the end target wall (see Fig. 1) the events due to in-gas annihilations are clearly visible as a Gaussian at the end of the distribution. This Gaussian form depends upon the energy at which the capture takes place, upon the atomic level of capture and upon the cascade steps.

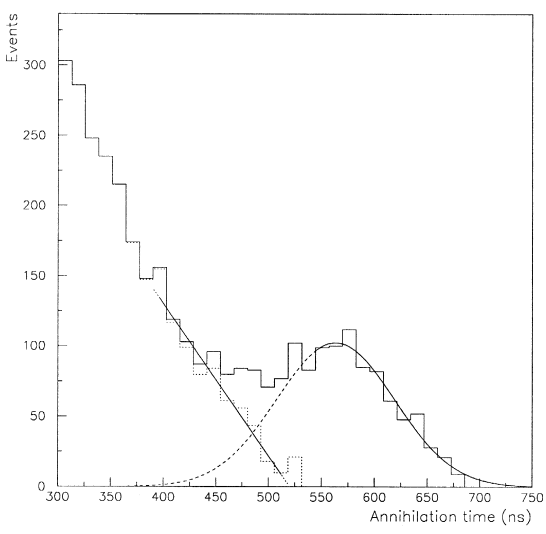

Fig. 1. Hydrogen at 5.8 mbar: annihilation time distribution for annihilations occurring near and on the end target wall. The Gaussian fit to the time distribution due to annihilations in the gas, the subtracted distribution and the linear fit for the calculation of the time of the annihilations on the end wall (t_{end}) are also shown.

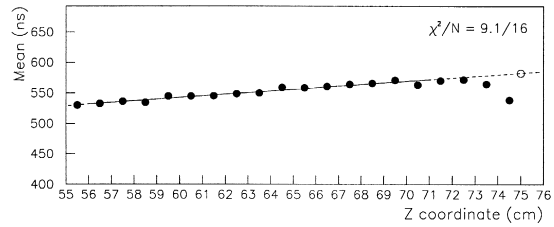

Fig. 2. Hydrogen at 5.8 mbar: annihilation time t_a as a function of the z coordinate. The first order polynomial fit (solid line) superimposed on the data and the linear extrapolation of t_a to the end of the target (dashed line and open dot) are also shown.

We perform a fit of the Gaussian form and consider the tail of the time distributions with the Gaussian subtracted. Indeed these are events that reached the end wall with the lowest possible energy. These events, on average, would have annihilated in gas, if the target had been just slightly longer. We fit the last plot bins with a first order polynomial and consider the extrapolation to "zero events" as a measure of t_{end} (see Fig. 1).

To improve the determination of t_a, we do not consider the Gaussian mean as a measure of the

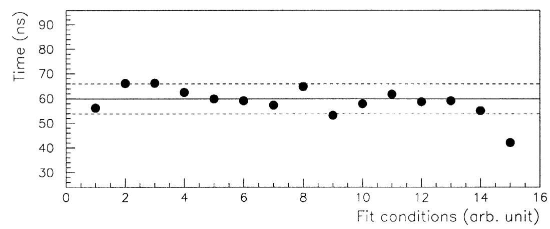

Fig. 3. Hydrogen at 5.8 mbar: cascade time calculations with different fit conditions. The measured value (solid line) and the error band (dashed lines) are also shown.

Table 1
Cascade time for the different gases and pressures

Gas	Pressure (mbar)	Cascade time (ns)
Hydrogen	3.4 ± 0.05	84.1 ± 10.3
	5.8 ± 0.05	59.9 ± 6.0
	9.8 ± 0.05	34.3 ± 2.4
	150 ± 1	6.7 ± 1.1
Helium	8.2 ± 0.05	60.2 ± 8.0
	50 ± 0.1	18.6 ± 2.0
	150 ± 1	10.7 ± 2.0

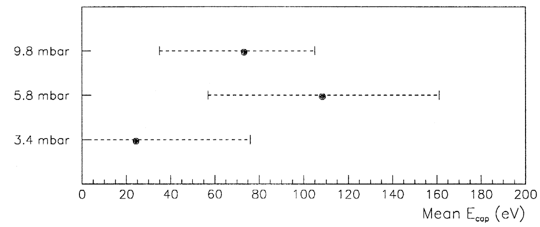

Fig. 5. Mean capture energy range for three hydrogen samples.

average annihilation time of the annihilations occurring in the gas just before the end of the target (t_{gas}). We consider instead the 20 cm preceding the end of the target. For slices of 1 cm width each, the annihilation time distribution has been obtained and then fitted with a Gaussian. We extrapolate the Gaussian averages with a linear fit to obtain the time t_a at the z coordinate of the end wall (see Fig. 2). The last 4 cm were not used to avoid contamination from badly reconstructed annihilations which occurred on the end wall (we recall that the reconstruction resolution was of about 1 cm).

The difference between the extrapolation of t_a (Fig. 2) and t_{end} of Fig. 1 is the cascade time t_{cas}.

To evaluate the total error we consider many different fit conditions for the calculation of t_{end}, such as 10 different bin sizes, 3 different fit regions, 3 different fit curves (first, second and third order polynomial). The cascade time and the error band, along with the different fit condition results, are shown in Fig. 3 for hydrogen at 5.8 mbar.

The results obtained are reported in Table 1 and are also shown in Fig. 4. Cascades of antiprotonic helium and hydrogen were previously studied by [10–12]. If compared with the prediction for hydrogen by [11,12], where molecular effects on the capture of the antiprotons where not taken into account, our values appear to be lower.

To roughly estimate what these results imply for $\overline{E}_{cap}$ we use the technique of [3,4,6] for three of the four hydrogen samples[5]. For each sample we calculate the best fit to the data for the central cascade time value and for the upper and lower limits. The results are summarised in Fig. 5. The errors on the cascade times translate to a large range on $\overline{E}_{cap}$. Nevertheless we can conclude that our results suggest values in the range of some tens of eV and give a first agreement with the predictions of [9]. A more precise evaluation of the capture energy values will be presented in a forthcoming paper with a new analysis of the data collected by the Obelix collaboration in hydrogen, deuterium and helium at 0.2 mbar.

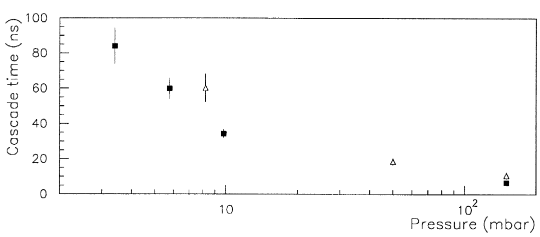

Fig. 4. Cascade times as a function of the target gas pressure: hydrogen (■), helium (△). The pressure scale is logarithmic.

3. Conclusions

Using a set of the Obelix data we measured the cascade time in antiproton-hydrogen and antiproton-helium annihilations at rest at different gas pressures. With a new technique we could measure, for the first time, the cascade times independent of the stopping power curve and of the capture energy. These measurements are important in the light of new theoretical considerations about antiproton capture by molecular hydrogen and deuterium [7,9], and for future experiments planned at the new AD facility at CERN.

[5] The 150 mbar sample was almost non sensitive to $\overline{E}_{cap}$.

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