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Memorandum to the S

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From: PS207 collaboration
Beam-time request LEAR 1996

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ZAMPAGLIONE
Patricia AS

In a first measuring period, experiment PS207 was set up and run using the 105 MeV/c beam of LEAR. For the first time, antiprotonic X-rays were observed with a crystal spectrometer.

The main results from the set-up measurement in ***1994*** are:

- The incoming antiprotons were stopped to 90% in the center of the cyclotron trap at 30 mbar gas pressure.
- The size of the X-ray source, i.e. the diameter of the stop volume, has been measured with the crystal spectrometer to be ≤20 mm (FWHM) for 30 mbar hydrogen.
- Several hundreds of $L\alpha$ X-rays both from antiprotonic hydrogen and deuterium have been observed with the Bragg crystal spectrometer (fig. 1).
- With the spherically bent quartz and silicon crystals having a diameter of 10 cm, resolutions close to the limits as calculated from crystal diffraction theory have been achieved.
- The broadening of the $L\alpha$ transitions in hydrogen and deuterium due to the multiplet structure of the 2p levels is clearly seen when compared to the calibration lines from antiprotonic helium and neon.
- A 1 cm^2 CCD detector installed close to the stop volume in the bore hole of the magnet was able to operate up to a rate of about $2 \cdot 10^5$ incoming antiprotons per second.
- The pressure dependence of the Balmer series has been measured from 1.3 to 30 mbar showing large effects from Stark mixing even at the lowest pressure.

In ***1995***, upgraded CCDs and crystals are being installed. The Bragg crystal surfaces have been etched to improve on the performence at the $L\alpha$ energies, i.e. to approach closer to the theoretical limit of reflectivity and resolution. The read-out cycle of the CCD mounted in the bore hole of the magnet is now shortened by a factor of 3.2.

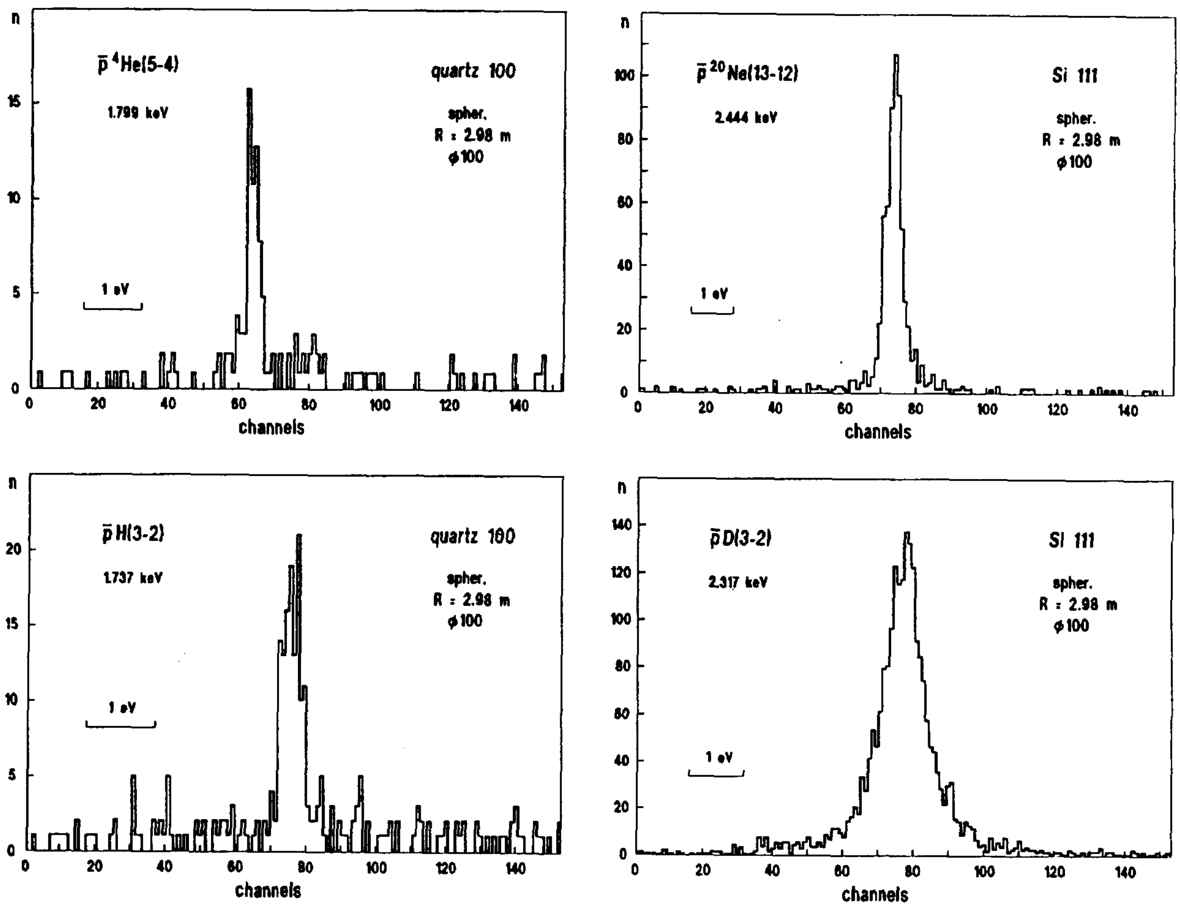

Fig.1: Energy spectra of the CCD mounted on the crystal spectrometer showing the Lα transitions of antiprotonic hydrogen and deuterium. The X-rays were reflected in first order by a sperically bent quartz and silicon crystal, respectively. Also shown are the transitions 5$\rightarrow$4 of antiprotonic ^{4}He and 13$\rightarrow$12 of antiprotonic ^{20}Ne, which are used to determine the corresponding response functions of the apparatus. At 1.8 and 2.4 keV resolutions of 230±30 and 360±40 meV were measured. The theoretical limits including geometrical broadening are 170 and 310 meV.

For the measurement of the hydrogen isotopes in ***1996***, new techniques are foreseen to be used both for the detection of the Lα transitions with the crystal spectrometer and the direct detection of the Kα X-rays in the bore hole.

Crystal spectrometer ('Lα' measurement)

The resolution of the crystal spectrometer can be improved using ***asymmetric cut Bragg crystals***. For asymmetric cut crystals, the reflecting planes have a finite angle with the surface of the mirror. In test experiments performed in collaboration with the ILL (Grenoble) and the Friedrich-Schiller-University at Jena, for the first time the reduction of the reflection width could be established for spherically bent asymmetric cut crystals (at an energy of 5.4 keV).

In the case of the Lα transition in hydrogen, a decrease of the rocking curve width to 60% is predicted by theory of crystal diffraction (tab. 1). At present, asymmetric cut quartz crystals are being prepared in collaboration with the ZEISS company in Oberkochen, Germany. Furthermore, special etching procedures are applied to obtain very clean and homogenuous surfaces for all new crystals. (The duration of the full production cycle is about 6 months.)

For the case of the deuterium, a decrease of the rocking curve width by a factor of 2.5 is possible by changing from Si to asymmetric cut quartz crystals (tab.1). The preliminary result from our measurements in 1994 for the spin-averaged width of the 2p level is 260^{+150}_{-40} meV indicating that at least some of the hyperfine transitions are narrower than expected from the calculation of Wycech, Green, and Niskanen (Γ_{2p}=400-500 meV)[1]. On the other hand, scaling the prediction for the ground state of Latta and Tandy[2] to the 2p level yields $\Gamma_{2p} \approx 100$ meV. So, an improvement on the resolution by a factor of 2.5 considerably improves the significance of the data.

It is planned to have a complete set of asymmetric cut crystals ready beginning of 1996.

Direct X-ray detection ('Kα' measurement)

A fully depleted ***pn-CCD*** is being set up as a dedicated high-rate detector to improve on the measurement of the Kα line shape. Such a device can be red out faster by a factor of 100 than the CCD presently used in the bore hole of the cyclotron trap. The energy resolution is 200 eV at 9 keV. About 2000 detected Kα X-rays from antiprotinic hydrogen are expected per 10^9 incoming antiprotons.

In addition, due to a depletion depth of 300 μm the detection efficiency is about 80% even at an energy of 12 keV. With such a detector, the observation of the Kα transition in antiprotonic deuterium should be feasible which is beyond the present detection limit. Assuming a line broadening of 3 keV and a 2p level width of 300 meV, about 20000 Kα X-rays should be detectable in one week yielding an accuracy of about 10% and 30% for the hadronic shift and the broadening, respectively.

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[1] S. Wycech, A.M. Green, and J.A. Niskanen, Phys. Lett. 52B (1985) 308
[2] G.P. Latta and P.C. Tandy, Phys. Rev. C 42 (1990) R1207

Because the pn-CCD is illuminated from the rear, the detection of X-rays down to 0.7keV is possible. That means, that the energy range of the M series of antiprotonic deuterium (0.81-1.85 keV) is fully covered by the detector.

Table 1: Comparison of the symmetric and the asymmetric Bragg case.
The cut angle α is the angle between the crystal surface (Miller indices in parenthesis) and the reflecting plane. ΔE is the width of the crystal rocking curve as calculated from diffraction theory for flat crystals. For curved crystals, an additional geometrical broadening occurs, which is calculated by means of a Monte-Carlo ray-tracing code to be of the order of $\approx$ 15% (see fig. caption 1). The X-ray rate estimates per 10^9 incoming antiprotons (about 1 spill) are for the simultanuous use of two crystals.

symmetric Bragg case			asymmetric Bragg case		
crystal cut angle α	ΔE /meV	$n/10^9\,\bar{p}_{in}$	crystal cut angle α	ΔE /meV	$n/10^9\,\bar{p}_{in}$
quartz 100 α=0°	148	35	quartz 100 (101) α=38.2°	87	20
Si 111 α=0°	270	80	quartz 101 (100) α=38.2°	110	50

To achieve a sufficient accuracy for the fits to the data, about 5000 events per Lα transition are necessary summing up to **1½ weeks** beam time for the hydrogen and **1 week** for the deuterium measurement. (We assume 10^{11} antiprotons from LEAR per week.) A reduction of the total beam time from three to two weeks would require to choose between hydrogen and deuterium.

BEAM PARAMETERS and BEAM TIME REQUEST for 1996

The PS207 collaboration asks for beam time in 1996 to measure antiprotonic hydrogen and deuterium using the new techniques described abvove.

Set-up parameters:

- set-up in area S3 at LEAR
- beam momentum 105 MeV/c
- main user at maximum intensity ($\geq 10^9$ incoming antiprotons per spill)
- spill duration of 20 min for the measurement with the crystal spectrometer
- beam time request: **3 weeks main user**

Schedule foreseen for a measuring period of 3 weeks:

- beam line set-up, optimization of injection into the cyclotron trap, and set-up of crystal spectrometer — 2 days
- hydrogen — 10 days
- deuterium — 8 days

Changing the set-up from hydrogen to deuterium takes 6-12 hours.

For the PS207 collaboration

D. Gotta