Determination of Effective Target Thickness and Luminosity from Beam Energy Losses at the ANKE Cluster Target

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The cluster target is one of the four targets in use or to be used at the ANKE spectrometer facility. It provides a 12 mm long and 5 mm wide beam of hydrogen or deuterium vertically crossing the p beam 300 mm in front of the D2 spectrometer magnet [1] The cluster target was first used in Sept. 1999. During the a_0 beamtime in Jan./Febr. 2001, the hydrogen cluster target operated with a very high particle density so that the energy loss of the p beam due to the beam-target interaction was measurable with good accuracy via the shift of the revolution frequency of the p beam.

This was possible because - at least up to now - ANKE experiments are using a coasting beam without stochastic cooling. Since the dispersion at the ANKE position can be minimized due to a special lattice setting, the p beam does not shift away from the target when the beam energy decreases. The beam intensity, however, may fall off after some time when emittance growth and dispersion in the arcs cause particle losses due to the acceptance limits. In the Sept. 2000 run the 1.97 GeV COSY beam could be used in one-hour cycles with only 5% beam losses. In the a_0 run in Febr. 2001 with 2.65 GeV beam energy the intensity started to decrease rapidly already after 5 to 6 min, an indication of very high target density [2]. The cycle time was therefore reduced to 5 min. Due to the sufficiently low vacuum pressure in the ring, mean value ~ 5 x 10^{-9} mbar, the beam losses with cluster beam off were not detectable. The operational status of the cluster target showed up in the vacuum pressure in the ANKE region, increasing from about 10^{-8} up to almost 10^{-6} mbar. The pressure rise is caused by hydrogen gas not completely trapped in the gas catcher. Since the pressure rise in the beam tube is extended over a distance of 10 to 20 m, its contribution to the energy loss has to be examined.

The shift Δf of the revolution frequency f_0 in the time interval Δt, detected by a Schottky pick-up and analyzed by a high-performance fast-Fourier transformer [3], is related to the momentum shift Δp and the energy loss ΔT by the two Eqs. (1). The energy loss dT per a single target traversal, divided by the stopping power and the mass of the proton, Eqs. (2), yield the number n of hydrogen atoms interacting with the proton beam.

$$\frac{\Delta p}{p_0} = \frac{1}{\eta}\frac{\Delta f}{f_0} \qquad \frac{\Delta T}{T_0} = \frac{1+\gamma}{\gamma}\frac{\Delta p}{p_0} \qquad (1)$$

$$dT = \frac{\Delta T}{f_0 \Delta t} \qquad n = \frac{dT}{(dE/dx) m_P} \qquad (2)$$

For the case considered here the following numbers apply:

T_0	= 2.650 GeV	the beam energy,
p_0	= 3.463 GeV/c	the beam momentum,
f_0	= 1.577 MHz	the revolution frequency,
η	= − 0.13	the measured slip factor
γ	= 3.82	the Lorentz factor,
dE/dx	= 4.1 MeV·cm^2·g^{-1}	the stopping power [5],
m_P	= 1.67 x 10^{-24} g	the proton mass.

It should be noted that due to the D = 0 setting in the straight sections COSY is operating above transition energy, T_{trans}= 1.3 GeV. Therefore, the slip factor η is negative and the frequency shift positive.

Figure 1 shows the frequency shift measured at different times during a 5 min cycle. The relation is linear yielding Δf = 198 Hz per 300 s and consequently n = 9.97 x 10^{14} atoms/cm^2.

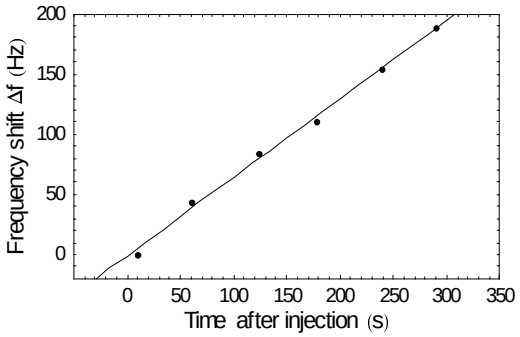

Fig. 1: Revolution frequency shift Δf due to energy loss of the p beam in the hydrogen cluster target at ANKE.

As a systematic correction one has to subtract the fraction of straying hydrogen atoms in the beam tube around ANKE. The estimate based on the measured pressure rise yields at most 10%. The 1σ statistical errors of the slope of the $\Delta f(t)$ relation and of η are 5%. dE/dx may also have 5% error. All other error contributions are negligible. The "effective " areal target density n_T is then given as:

$$n_T = (9 \pm 1) \times 10^{14} \text{ atoms/cm}^2$$

This value, also considering an incomplete beam-target overlap, is more than a factor of 10 higher then expected from earlier runs [1]. If the p beam current is known during the time period of the frequency shift measurement, one may obtain a rather reliable value for the luminosity because n_T contains only those target particles which do interact with the p beam, no matter whether there is a complete beam target overlap.

$$L = i_p \, n_T \qquad (3)$$

In the 5 min period of the reported Δf measurement 3.1 x 10^{10} protons (i_p = 4.9 x 10^{16} p/s) where circulating in the COSY ring (ANKE Run No.3217), resulting in a luminosity

$$L = (4.4 \pm 0.8) \times 10^{31} \text{ s}^{-1} \cdot \text{cm}^{-2}$$

The practical application of this procedure in a long running experiment needs a continous recording and the evaluation of the p beam current and a typical target monitor rate in order to take into account p beam or target beam intensity variations.

References:

[1] H.-H. Adam et al., IKP Annual Report 1999, Jül-3744, p.20.
[2] H.J. Stein , ANKE Collaboration Meeting 2001.
[3] A. Schnase et al., IKP Annual Report 1997, Jül-3505, p. 188.
[4] Physical Reference Data, see http;//physics.nist.gov.