Luminosities in ANKE experiments with heavy nuclear targets

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The A-dependence of proton induced subthreshold K^+-production was studied at ANKE in experiments with strip targets of C, Cu, Ag and Au [1]. It is expected that for targets of nuclear charge $Z \geq 6$ the lifetime of the circulating beam is limited by Coulomb-scattering. Scattering angles scale roughly with Z^2. Thus the luminostiy integrated over the beam life time should decrease with Z as $LT \equiv \int Ldt \sim 1/Z^2$. However in the ANKE experiments a weaker dependence was observed: $LT \sim 1/Z^{1.2}$ [2], suggesting that other particle-loss mechanisms contribute. In order to accomplish optimal accelerator conditions in future K^+, K^-experiments a better understanding of energy loss in the target is needed.

A rough estimation of LT can be obtained from integral formulae, which yield a Gaussian distribution of multiple scattering through small angles and the mean energy loss (Bethe-Bloch). The calculation shows that for the relevant COSY ring parameters and for a particle momentum acceptance of $\Delta p/p<0.3\%$ particle loss through energy degradation may occur for targets of $Z \leq 6$. Recently the energy loss induced by the ANKE H_2 clustertarget could be measured directly [3]. Beam life times deduced fom the integral formulae alone may differ significantly from reality as the tails of the probability distributions ($1/\theta^3$ for the scattering angle θ, $1/\Delta E^2$ for the energy losses ΔE) are not reproduced. In particular the coupling of transversal and longitudinal phase space is missing. Dispersion somewhere in the ring reduces the accepted transversal phase space. E.g. for a beam momentum shift dp/p=0.2%, a dispersion D=20m, and a free beam tube diameter of 120 mm the beam axis is shifted by 40 mm, which reduces for the x-acceptance to 1/9 of the value relevant for dp/p=0 particles.

More precise luminosities are obtained through MC simulations, in which the full probability distributions for energy loss and angular scattering for thin targets are reproduced. Starting from routines which were used in the design phase of ANKE for the study of the beam target interaction [4] a C program has been developed in which particle deflection by the target follows from the sum of elementary scattering processes. The Coulomb cross section is given by

$$\sigma_{Cb} = 4\pi \, (Z_1 \cdot Z_2 \cdot e^2 / p \cdot c \cdot \beta \cdot \alpha)^2$$

with Z_1, Z_2: nuclear charge numbers, p: particle momentum, β: particle velocity, α: atomic screening angle. Single scattering angles Θ are deduced from a random numbers RN (0<RN<1) through $\Theta = \alpha\sqrt{1/RN - 1}$ [5]. Energy loss is chosen according to the Landau distribution [6].

The calculations show, that for typical thin solid state targets (10 to 1000 µg/cm²) LT is independent of target thickness and geometry. Therefore -for certain target and ring parameters- LT can be determined through MC calculations assuming a thin target of any geometry.

The following parameters were used for the heavy target luminosity calculations:

- beam energy: T=1 GeV
- beta functions at target: βx=4m, βy=5m
- transv. accept. of COSY: Ax=50, Ay=16π· mm· mrad
- figure of merit [4]: $FM=1/(\beta x/Ax+\beta y/Ay)=2.5$
- target thickness: 1mg/cm²
- injection: ring filled to transversal ring acceptance
- acceleration: beam emittance shrinks with 1/p
- momentum acceptance: $\Delta p/p$ = 0.1% or = 0.3%
- compens. of mean energy loss in target: ON or OFF

The ANKE experiments were made with a coasting beam. Thus energy loss was not compensated. Results of the calculations are given in table 1.

Target	Z	LT $cm^2/10^{20}$ dp/p=0.3% with dE compens.	LT · Z^2 $cm^2/10^{24}$ dp/p=0.3% with dE compens.	LT $cm^2/10^{20}$ dp/p=0.1% without dE compens.	LT · $Z^{1.2}$ $cm^2/10^{20}$ dp/p=0.1% without dE compens.
C	6	1130	4.1	270	2320
Cu	29	56	4.7	39	2220
Ag	47	25	5.5	19	1970
Au	79	9.8	6.1	8.4	1590

Tab. 1: Calculated integrated luminosities LT per circulating particle for the ring momentum acceptance dp/p=0.3% with compensation of the mean energy loss for each target crossing and for dp/p=0.1% without compensation of the mean energy loss.

LT changes roughly as expected for $Z \geq 6$, if the mean energy loss in the target is compensated (column 4). If energy loss is not compensated (coasting beam) and if the momentum acceptance of the storage ring is low (0.1%) luminosities are strongly reduced for Z=6 targets (factor of 4) and slightly reduced for Z=29 targets (factor of 1.4, column 5). The luminosity obtained with an Au-target is only reduced by a factor of 1.16. The observed Z-dependence of LT is roughly given by $Z^{-1.2}$ (column 6). The precise value of the exponent was not determined, because it has no physics relevance. It depends on COSY beam optics which probably will change in different beam experiments.

The conclusion of the present study is, that for experiments with coasting beam energy loss in the target must be taken into account for targets of $Z \leq 29$. In future experiments energy loss compensation should be applied, if maximum luminosity is desired.

References:

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