SIMULATION OF PELLET TARGET EXPERIMENTS WITH BETACOOL CODE

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Abstract

In last years at GSI (Germany) new accelerator complex project FAIR is being realized. One of the most important goals of this project is caring out an experiment with internal target PANDA [1]. The only way to achieve design luminosity value is to use a pellet target. However, such a target is coming up with short-scale luminosity variation. Peak to mean luminosity ratio can reach a big value unacceptable for detector.

A numerical simulation of this experiment is connected to two different time-scale processes. The first one is the short-time process, which describes luminosity variations while one pellet is crossing the beam. This process can be about tenths microsecond long. The long-time process of the beam parameter evolution (particle number, transverse and longitudinal profiles) are defined by the beam losses and equilibrium between target heating and electron cooling.

This article presents the numerical simulations with BETACOOL code [2] which allows solving both these tasks.

INTRODUCTION

While the beam is crossing a pellet target, transverse scattering of the particles on the nucleus field has place to be. That leads to loses of the particles on acceptance (single scattering on large angle) and to growing emittance because of the multiple scattering on small angles. Loses of the particle energy that come due to target atom ionization lead to decreasing average energy and changing revolution frequency of the beam. Fluctuation of energy loses may bring particles losing on longitudinal acceptance due to single interaction with a target.

Ionization loses of the average energy are compensated by accelerator gap if RF system is switched on. To avoid large bunching factor of the beam a non-sinusoidal RF wave (so called burrier bucket system) can be used. Application of the burrier bucket system is planed for PANDA experiment and it was used at the experiments on COSY storage ring [3].

All things described above can be easily modeled using BETACOOL code. General goal of the BETACOOL program is to simulate long term processes (in comparison with the ion revolution period) leading to variation of the ion distribution function in 6 dimensional phase space. In the case of pellet target simulation the existing algorithm is based on assumption that during one step of the integration a large number of the pellets cross the beam. This algorithm does not take into account short-scale luminosity variations. Such variations can be unacceptable for the PANDA detector, therefore numerical simulation of this effect is of great importance.

At the frame of the PANDA collaboration [4] an additional algorithm was developed and implemented into the BETACOOL. It calculates luminosity time dependencies at the time scale sufficiently shorter then time that takes a pellet to get through the beam.

For benchmarking of the BETACOOL algorithms, data from experiment with pellet target WASA [5] at COSY storage ring was used. During the COSY run from June 21 to July 5 2008 a luminosity value and different beam parameters were recorded as functions of time. Modeling of the experiment was made using the BETACOOL program. The purpose of modeling was a comparison of calculated luminosity variations in the storage ring while every pellet is crossing the beam with experimental data.

At the frame of COSY experiment two working modes were applied - RF is switched *off* and *on*. Main parameters of COSY experiments are presented in Table 1.

Table 1. Main parameters of the experiment.

Deuterium beam	
Momentum, GeV/c	1.2
Energy, MeV/u	177
Particle number	2×10^{10}
Horizontal emittance, π mm mrad	1
Vertical emittance	0.5
Initial momentum spread	2×10^{-4}
Deuterium target	
Pellet radius, μm	15
Pellet flux radius, mm	2.5
Mean distance between pellets, mm	10
Rate of pellet generation, kHz	7
Deuterium density, atom/cm^{-3}	6×10^{22}
COSY	
Circumference, m	183.4728
Momentum slip factor, η	0.533
Horizontal acceptance, π m rad	2.2E-5
Vertical acceptance, π m rad	1E-5
Acceptance on momentum deviation	$\pm1.2\times10^{-3}$

RF IS SWITCHED OFF

The presented pellet parameters are approximate, so the mode with RF switched off was used to verify them. The results of measurements are presented on the Fig. 1. One can see long trace cut at the end (bottom of the picture).

This reflects a displacement of beam mean energy. Cutting of the trace can be explained by longitudinal acceptance limitation. Profile of the beam which is shown inside a circled area of the picture is displaced from the centre and cut from the left.

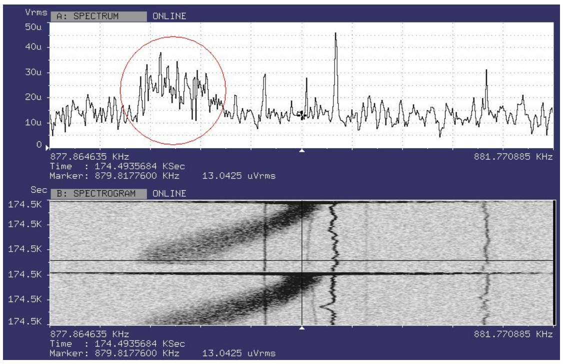

Fig. 1. Longitudinal Schottky noise of the beam after 43 s of the experiment (upper plot) and evolution of the spectrum during two subsequent injections.

On the Fig.2 BETACOOL modeling of the beam energy decreasing is presented. Relative momentum shift corresponds to about 4 «sigma», the sigma in the plot is equal to initial momentum spread.

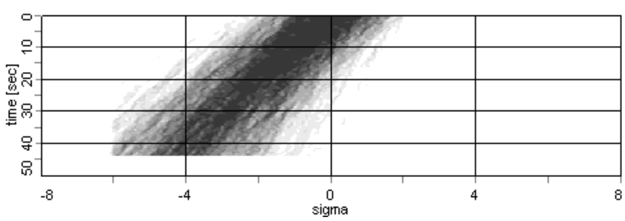

Fig. 2. Simulation of the momentum spread evolution. Burier bucket is switched off.

To compare this result with experiment data one needs to calculate the momentum shift from the Fig.1 in accordance with the formula:

$$\frac{\Delta p}{p} = \frac{1}{\eta}\frac{\Delta_f}{n f_0}; \qquad (1)$$

Here f_0 = 879.82 kHz is initial revolution frequency, Δ_f = 0,977 kHz is the frequency shift of the distribution centre, n=1 is the harmonic number. The formula 1 gives momentum shift 8.1×10^{-4} that is a good agreement with the simulation.

The particle distribution on momentum deviation obtained in the simulations (Fig. 3) reproduces the shape of the beam Schottky spectrum measured in the experiment (circled curve at the upper plot in the Fig.1)

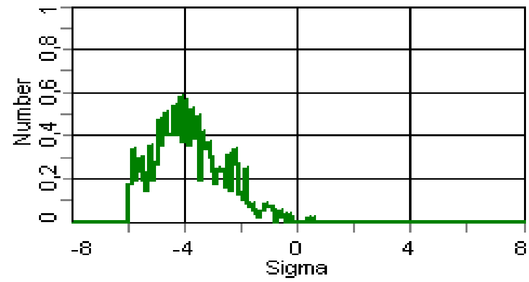

Fig 3. The simulated beam profile after 40 sec of the experiment. Burier bucket is switched off.

The good agreement between simulations and experiment tells that the pellet target parameters and effective target density are fitted correctly.

RF IS SWITCHED ON

Applying of the barrier bucket makes particle loses more slowly as it is shown on the Fig.4. (black line). When the barrier bucket is switched on the RF noise does not permit to measure Schottky noise spectrum like on fig.1.

On the Fig.4 signals from storage rings detectors are presented: black line shows particle number in the storage ring, yellow and green lines corresponds to the pellet number, other colour lines are count rate values from different detectors which are proportional to the luminosity value.

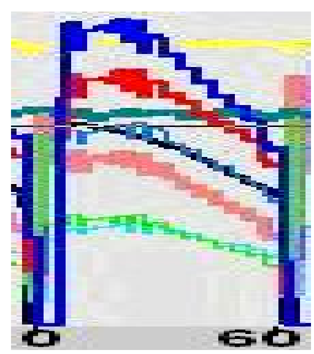

Fig. 4. Count rate values and particle number during experiment with RF on as functions of time in seconds (horizontal axis).

On the Fig.5 the BETACOOL modeling of the particles number is presented as a function of time. As example of BETACOOL modelling opportunities luminosity modelling picture is presented (Fig.6). Simulation results have a good agreement with experimental results on Fig.4.

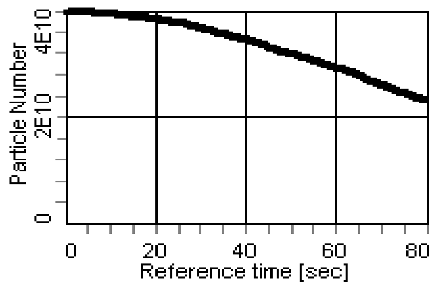

Fig 5. Simulation of particle loses on. Burier bucket is switched on.

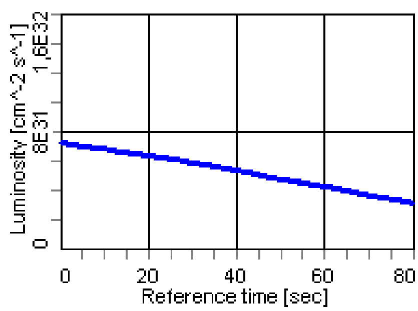

Fig. 6. Simulation of luminosity on time. Burier bucket is switched on.

LUMINOSITY VARIATIONS ALGORITHM

One of the experiment goals was benchmarking a new algorithm for calculating luminosity variation that comes up with every pellet going through the beam. WASA detector can measure the signal from each pellet in short-time scale. The picture with experimental data is presented on Fig.7. The distance between peaks is defined by the rate of pellet generation (Table 1). The variation of signal amplitudes exists due to the horizontal position of the pellet and the real profile distribution of the ion beam.

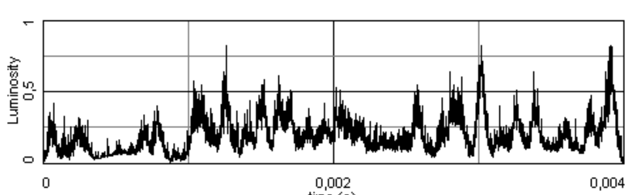

Fig. 7. Experimental luminosity variation.

In the process of the BETACOOL algorithm working, profiles of the beam are saved to hard disk drive. The new algorithm generates a flux of pellets and moves pellet flux through the beam. The flux moving the beam profiles is considered to be constant on each integration step. At every step of algorithm the density of the particles is calculated for every pellet using the beam profiles.

On the Fig. 8 simulated luminosity variations is presented as a function of time.

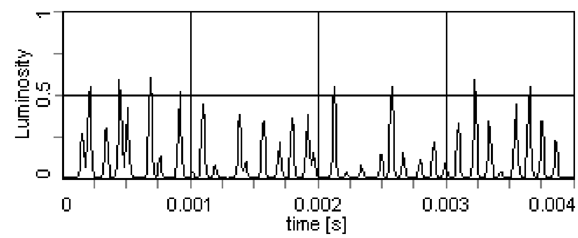

Fig. 8. Simulation of the luminosity variations

Results of the short-time scale simulation of the luminosity variation are in a good agreement with experimental measurements. The new algorithm can be used for the simulation of the effective luminosity in the experiments with pellet target which is very important for PANDA project.

CONCLUSION

The comparison of simulations and experiments with the internal pellet target WASA @ COSY shows a good agreement. A new algorithm for short-time process of the luminosity variation was implemented in the BETACOOL code and was benchmarked with the experiments at COSY. This new algorithm is being developed for the effective luminosity simulation when peak to mean luminosity ratio can reach a big value unacceptable for detector.

REFERENCE

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