EFFECTIVE LUMINOSITY SIMULATION FOR PANDA EXPERIMENT AT FAIR

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Abstract

In last years at GSI (Germany) the 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]. One of ways to achieve the design luminosity value is to use a pellet target. However, such target is coming up with the short-scale luminosity variation. Peak to mean luminosity ratio can reach a big value unacceptable for detectors. If a detector is overloaded its count rate is not proportional to the luminosity, but depends on electronics design. In this case one can define so called "effective luminosity" as a ratio of the detector count rate to cross-section of the reaction.

Dependencies of the effective luminosity on the pellet target parameters for PANDA experiment simulated using BETACOOL code [2] are presented in this article.

INTRODUCTION

A numerical simulation of the experiment with a pellet target 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 a few tenths microseconds 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. Characteristic time of this process can be of a few minutes or even hours.

The long-time process simulation is the general goal of the BETACOOL program. In the case of a pellet target simulation the algorithm is based on assumption that during one step of the integration over the time a large number of the pellets cross the beam. In the frame of the PANDA collaboration 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, results of experiment with the pellet target WASA at the COSY storage ring were 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 using the BETACOOL program showed a good agreement with the recorded data [3].

This article presents results of the PANDA experiment simulations using the developed algorithms.

DESCRIPTION OF THE ALGORITHM

In the process of the long-time BETACOOL algorithm working, profiles of the antiproton beam are saved to hard disk drive at each step of integration over the time. Typically the integration step is of the order of a few seconds. The beam profile (horizontal or vertical) is a normalized particle density distribution along the corresponding co-ordinate. The beam profiles are calculated from array of model particles by averaging over their betatron oscillations. The new short-time algorithm generates a flux of pellets and propagates the pellet flux through the antiproton beam. When the pellet flux crosses the beam the profiles are considered to be constant on each integration step. The integration step of this algorithm is about 1 µs. At every step of the algorithm the density of the particles in the current pellet position is calculated for every pellet using the beam profiles.

Initially the short-time algorithm generates a pellet array. The pellets from the array are located in a long cylinder which has radius equal to the pellet flux radius. The cylinder height is chosen in accordance with the pellet vertical velocity in order to have required time of the simulation. For instance, the cylinder of 1 m of the height (see Fig. 1, the vertical position of the pellet is indicated as a "longitudinal distance" inside the cylinder) at the pellet velocity of 60 m/s (typical value for the pellet target) the pellet array will cross the antiproton beam during about 15 ms. Across the cylinder the pellets are distributed uniformly. Along the cylinder the pellets distributed in accordance with mean distance between pellets in vertical direction with a given dispersion.

After generation of the pellet array the algorithm propagates this array through the antiproton beam in the vertical direction from top to bottom with given step over time.

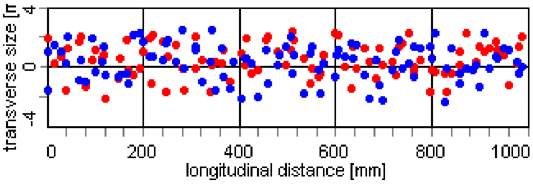

Figure 1: The pellet distribution along the flux: red – horizontal coordinate, blue – vertical.

During the propagation a "weight" value P_{xy} , which is proportional to the antiproton areal density in the pellet position, for each pellet is calculated. The pellet "weight" is evaluated as a product of the horizontal and vertical beam profile magnitudes in the pellet position:

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$$P_{xy} = P_x(x_p)\cdot P_y(y_p),\, P_\alpha(\alpha) = \frac{1}{N}\frac{dN}{d\alpha},\ \alpha = x, y \quad (1)$$

Here P_x, P_y are horizontal and vertical beam profile magnitudes, x_p and y_p are the horizontal and vertical co-ordinates of the pellet. If a pellet is outside of the antiproton beam the pellet weight is equal to zero. It the current version of the algorithm realization it is assumed that all the pellets have the same dimensions, correspondingly the weight values from all pellets are simply summing up:

$$P = \sum_{i=1}^{n} P_{xy_i}, \quad (2)$$

here P_{xy_i} - “weight” value of the *i*-th pellet, *n* – number of the pellets in the pellet array. The luminosity is linearly proportional to this value:

$$L = \rho_p P \pi r_p^2 f_{rev}, \quad (3)$$

where ρ_p is the mean pellet area density in atoms/cm^2, r_p is the pellet radius, f_{rev} is the antiproton revolution frequency.

EFFECTIVE LUMINOSITY

The short-time luminosity variation (Fig.2) is calculated on each integration step of the long-time luminosity calculation (Fig.3). The black curve in the Fig. 2 presents the function *P*(*t*) calculated by the short-time algorithm, this signal averaged over the time (blue line on Fig.2) is proportional to the luminosity calculated with the long-scale algorithm in the corresponding moment of time (blue line on Fig.3).

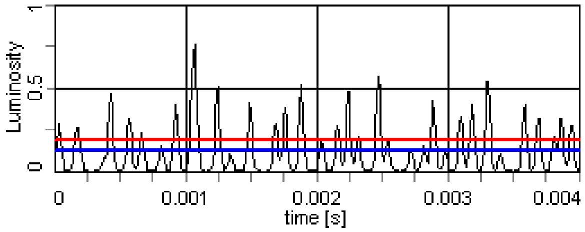

Figure 2. Short-scale signal from pellets: blue line – average value, red line – detector limit.

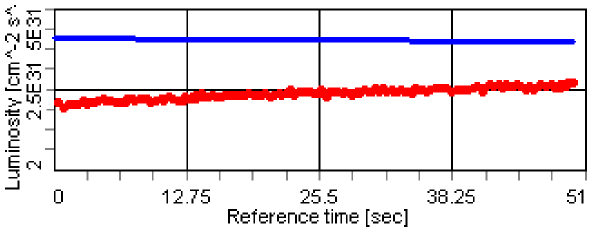

Figure 3: Long-scale luminosity evolution on time and effective luminosity for “top cut” model of detector limit (red line).

The detector is designed for some maximum acceptable event rate. Dividing this event rate by the reaction cross-section one can calculate the maximum acceptable luminosity (or detector limit). An example of the detector limit level is shown by the red line on Fig.2. If the luminosity exceeds this value the detector is overloaded.

In these simulations we consider two ultimate variants of the detector response when it is overloaded: the count rate value is saturated and equal to the detector limit (“top-cut” model on Fig.4 b), the detector is completely closed and can not accept any event – the count rate is zero (“full-cut” model on Fig.4 c). The response of real detector can be in between of these two ultimate cases.

If a detector is overloaded its count rate is not proportional to the luminosity. Ratio between event rate and the detector count rate can be characterized by the effective luminosity. Numerically the effective luminosity is calculated with the following expression:

$$L_{eff} = L_{aver}\frac{I_{cut}}{I_{aver}} \quad (4)$$

where L_{aver} – average luminosity calculated with the long-time algorithm (fig.3, blue line) in the corresponding moment of time, I_{aver} – integral of the total pellet signal (fig.3), I_{cut} – integral of the pellet signal for chosen model of the detector response. An example of the effective luminosity time dependence is presented on fig. 3 (red line) for the “top-cut” model of the detector response.

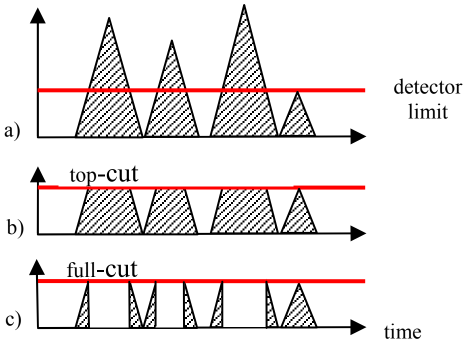

Figure 4: Count rate time dependence: a) event rate from the pellets, the red line is the detector limit b) and c) the detector count rate for two models of the detector response when it is overloaded.

SIMULATION OF PANDA EXPERIMENT

The numerical simulation of the effective luminosity was done for two operational regimes of the PANDA experiment: with high-luminosity (HL) and high-resolution (HR) modes. The typical parameters of the pellet target and antiproton beam are presented in the table 1.

The dependence of the effective luminosity on the pellet size in micrometers for the different detector limit is presented on Fig.5 a, b (HR) and Fig.5 c, d (HL). The detector limit was chosen in the range from the value of the mean luminosity to the value in 10 times larger. The distance between pellets was chosen in accordance with the pellet size to keep the same effective target density.

Simulation results show that for the HR mode the effective luminosity equal to the mean luminosity if the detector limit is defined by the mean luminosity for the

HL mode 2×10^{32} cm^{-2}s^{-1}. A reduction of the effective luminosity for the HR mode can exist if some detectors will be designed especially for the HR mode and the detector limit will exceed the mean luminosity in two times only.

Table 1: The Typical Parameters of PANDA Experiment

Pellet target		
Hydrogen density, atom/cm^3	$4{,}26\times10^{22}$	
Pellet size (diameter), mm	0,028	
Pellet flux radius, mm	1,25	
Distance between pellets, mm	5	
Effective target density, cm^{-2}	4×10^{15}	
Antiproton beam		
Beam energy, GeV	8	
Operation mode	HR	HL
Particle number	10^{10}	10^{11}
Momentum spread	10^{-5}	10^{-4}
Mean luminosity, cm^{-2}s^{-1}	2×10^{31}	2×10^{32}

In the case of the high luminosity mode the effective luminosity is rather different at “top-cut” and “full-cut” models. For the “top-cut” model the maximum pellet size has to be less than 20 µm if the detector limit exceeds the mean luminosity in two times only. For the “full-cut” model the pellet size has to be less than 10 µm and detector limit is sufficiently higher than 2×10^{33} cm^{-2}s^{-1}.

CONCLUSION

Simulation results show that for the high resolution mode the effective luminosity can be equal to the mean luminosity if the pellet size is less than 20 µm and all detectors are designed for the maximum luminosity value of 2×10^{32} cm^{-2}s^{-1} which corresponds to the high luminosity mode. For the high luminosity mode the pellet target can be used for the detector design with “top-cut” mode only. The detector design with “full-cut” mode can not be used for the high luminosity mode due to very large reduction of the effective luminosity.

REFERENCES

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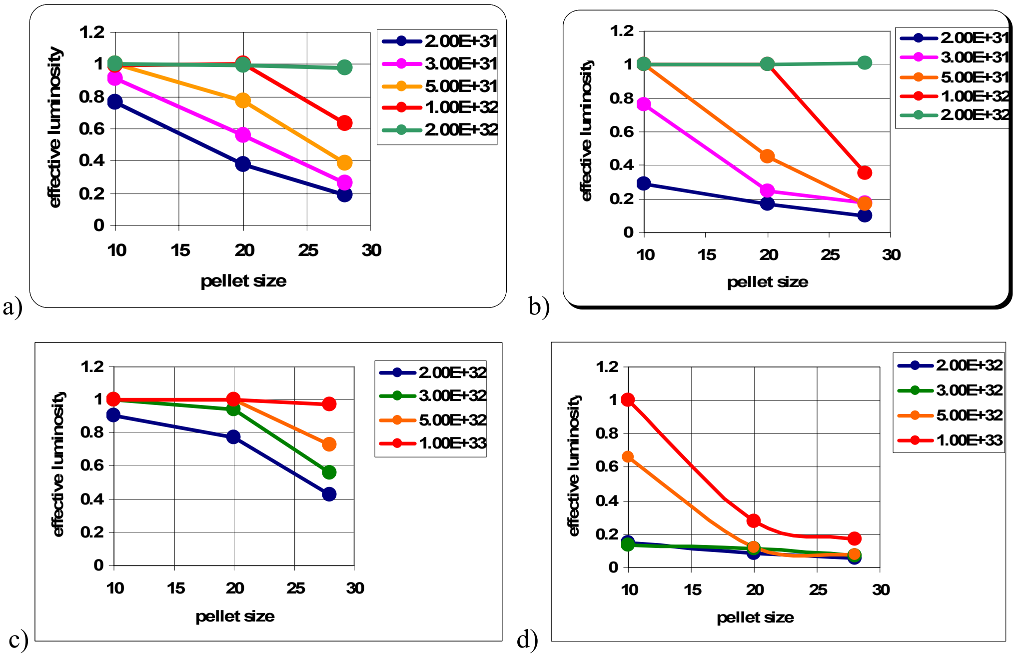
[3] A. Smirnov, A. Sidorin, D. Krestnikov, R. Pivin, D. Prasuhn, M. Wolke. Simulation of Pellet Target Experiments with Betacool Code. Proceedings of RuPAC 2008, Zvenigorod, Russia. http://jacow.org



a) b) c) d)

Figure 5: Effective luminosity simulation for different limits of detectors: high resolution (HR) mode - a) “top-cut” model, b) “full-cut” model; high luminosity (HL) mode - c) “top-cut” model, d) “full-cut” model.