On the feasibility of using an extracted polarized antiproton beam of the HESR with a solid polarized target

On the feasibility of using an extrac
polarized target

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Introduction

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Here we do not consider the problems connected with antiproton production and depolarization during acceleration.

A. Lehrach et al., SPIN2004, p. 742.

Introduction

It is known that high-energy protons can be efficiently extracted from the beam halo in a storage ring (collider) using channeling in a bent crystal.

R. Carrigan et al., Phys. Rev. ST - AC 1 (1998) 022801.

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The main beam and thus collider experiments would be undisturbed, and the extracted protons are only those which would otherwise be lost.

Introduction

The experiments at the Tevatron (FNAL) at an energy of 900 GeV confirmed computer simulation and provided the extraction coefficient ≈ 10^{-6}, which for 10^{12} circulating protons resulted in the extracted beam of 10^{6} protons/s.

R. Carrigan et al., Phys. Rev. AB 5 (2002) 043501.

Introduction

The similar results were received at the CERN SPS. With a 120 GeV circulating beam of 5×10^{11} protons typically 6×10^{5} protons/s were extracted.

K. Elsener et al., Nucl. Instr. & Meth. B 119 (1996) 215.

Introduction

But for heavy negative particles (antiprotons) the method of beam deflection by a bent crystal does not work due to fast dechanneling.

V.P. Koshcheev, O.E. Krivosheev., Russian Phys. Journal. 38 (1995) 493;

N.F. Shul'ga, I.V. Kirillin, V.I. Truten',

Phys. Lett. B 702 (2011) 100.

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Phys. Lett. B 702 (2011) 100.

Instead, a stochastic mechanism of multiple scattering of negative particles on the bent chains of crystal atoms was proposed.

Introduction

Experiments at CERN confirmed the computer simulation results of the stochastic mechanism for negative pion beam deflection by a bent crystal.

W. Scandale et al., Phys. Lett. B 680 (2009) 301.

Introduction

We propose to extract the halo antiprotons of the HESR, which can not be utilized by the PANDA facility by means of the bent silicon crystal and/or magnetic septum.

The initial direction of polarization is vertical. If necessary, it can be rotated with the spin rotator in the horizontal direction before the polarized target.

Introduction

We refer to the authors

N.F. Shul'ga, I.V. Kirillin, V.I. Truten‘, http://iap.sumy.org/attacments/files/Kharkov2014/12.pdf.

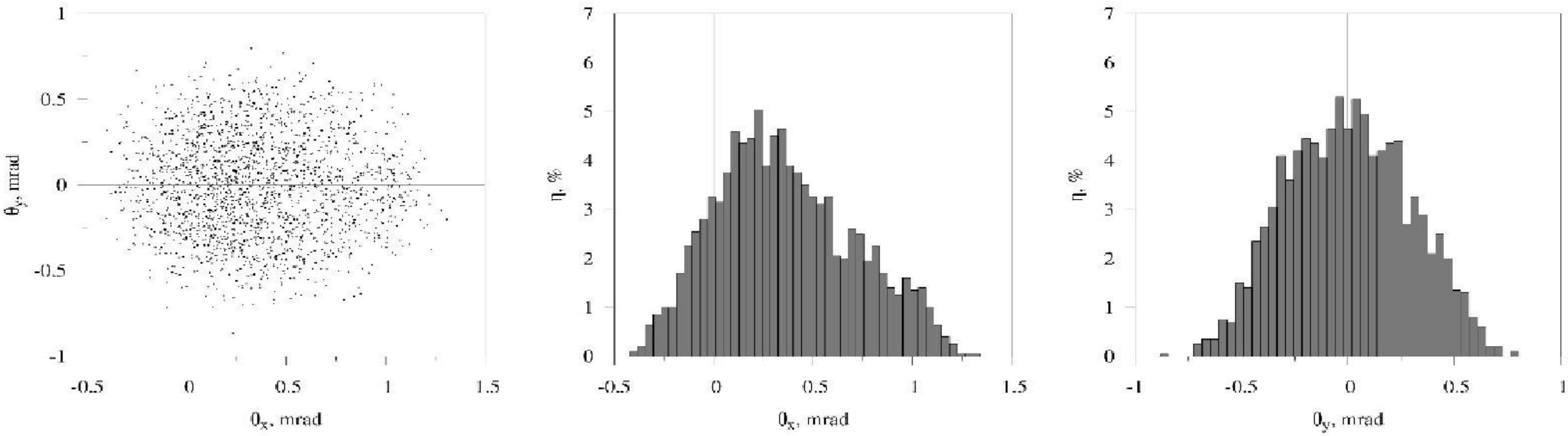
which consider that the stochastic mechanism could be applicable for beam extraction from an antiproton storage ring.

Introduction

The simulation had been carried out for a beam of 2000 antiprotons with an energy of 10 GeV incident on the silicon crystal in the direction of the <110> axis.

Beam divergence was taken equal to ≈10 μrad, a bending radius R = 1 m, crystal thickness L = 1 mm, bending angle α= L/R = 1 mrad.

2000 antiprotons, E=10 GeV, L=1 mm, R=1 m, Si <110>, ψ_c=145 μrad, $\alpha=\frac{L}{R}$=1 mrad



Stochastic beam extraction.

E_{ap} = 10 GeV, L = 1 mm, R = 1 m, α = L/R = 1 mrad, Si <110>

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In this case the maximum of the distribution of the beam deflection reaches 0.3 mrad and the FWHM = 1 mrad.

For the crystal with a thickness L = 4 mm one has two maxima with 0.3 and 1 mrad with FWHM 2 mrad.

Introduction

In the HESR

(FAIR Project (subproject HESR) Technical Report. http:// www.gsi.de\\/fairreports/btr-e.html)

the planned internal coasting beam could reach ≈10^{11} antiprotons in the momentum range 1.5-15 GeV/c (energies 0.83-14.1 GeV).

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the planned internal coasting beam could reach $\approx 10^{11}$ antiprotons in the momentum range 1.5-15 GeV/c (energies 0.83-14.1 GeV).

The beam lifetime in the working mode with the use of hydrogen pellets changes from 0.5 hour at the minimum energy to 2 hours at the maximum energy.

A. Lehrach et al., Nucl. Instr. \& Meth. A 561} (2006) 289.

Introduction

Furthermore, the mechanism of halo formation in the HESR is different in comparison with the case of the Tevatron where the beam lifetime reached 70 hours. This implies, that the extraction coefficient for the HESR could turn out essentially higher than for the Tevatron.

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We consider two possibilities for obtaining an extracted antiproton beam in the HESR with the purpose to use it independently for the study of polarization effects.

Slow resonant extraction

1) Since the accumulated antiprotons in the HESR are not utilized entirely, it is feasible to extract them slowly at the end of the cycle and send to the polarized target.

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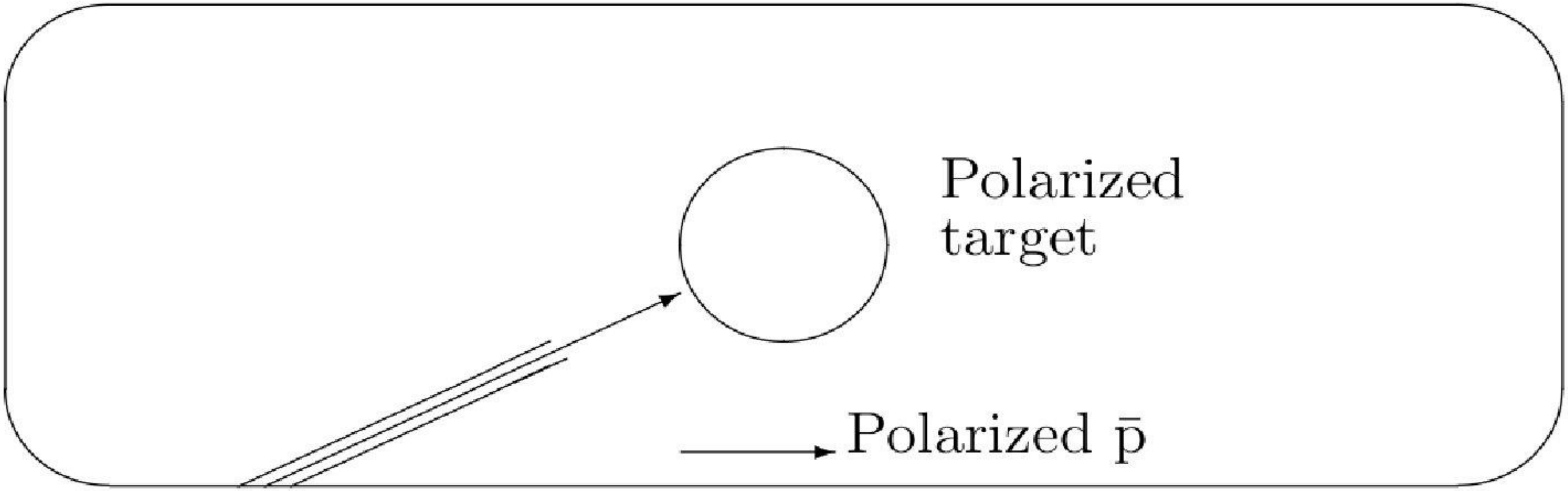
Since the accumulated antiprotons in the HESR are not utilized entirely, it is feasible to extract them slowly at the end of the cycle and send to the polarized target.

For example, at slow variation of the radial betatron oscillation frequency the particles get to the instability region and end up in the septum due to the resonance build-up of the oscillation amplitude.

Slow resonant extraction



Scheme of the polarized antiproton extraction.

Slow resonant extraction

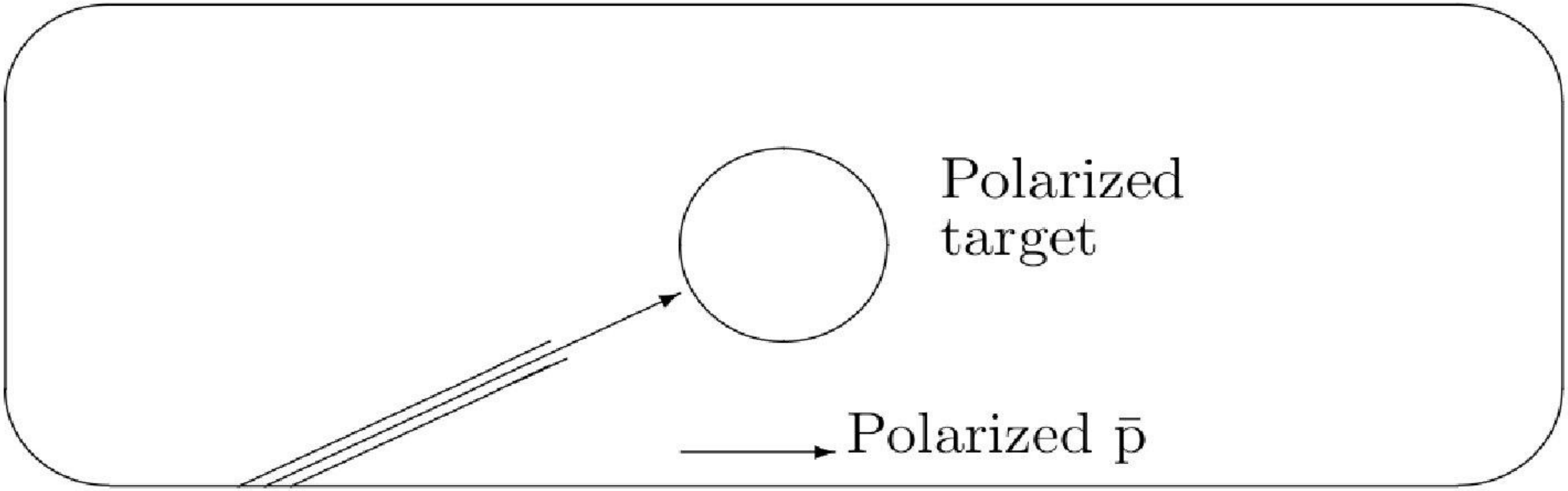
Let the data acquisition stops when the number of particles drops by an order of value, i.e. down to 10^{10} or 10^{9} (depending on the chosen regime).

If the particles are extracted for 10 s with the efficiency of 10%, then for the cycle duration equal to 1 hour an average intensity will be 10^{6} – 10^{5} antiproton/s, which, for the typical 10 cm long polarized target, corresponds to the luminosity 10^{30} - 10^{29} cm^{-2} s^{-1}.

Extraction with a bent crystal

2) At the HESR one might try to extract halo antiprotons, which can not be utilised by the PANDA facility, with the assistance of a magnetic septum and, possibly, bent Si crystal.

Extraction with a bent crystal



Scheme of the polarized antiproton extraction.

Extraction with a bent crystal

It should be noted that the halo formation mechanism in the HESR differs from that of the FNAL storage ring, where intra-beam scattering was the main process.

At the HESR, at low momenta the main contribution comes from Coulomb scattering, while at high momenta – from nuclear processes

A. Lehrach et al., Nucl. Instr. & Meth. A 561 (2006) 289}).

Extraction with a bent crystal

The beam lifetime for the HESR is about 1 hour, while for the FNAL it was about 70 hours.

It can be expected, that in the HESR the substantial share of antiprotons lost due to the interaction with the pellets comes to the halo.

Extraction with a bent crystal

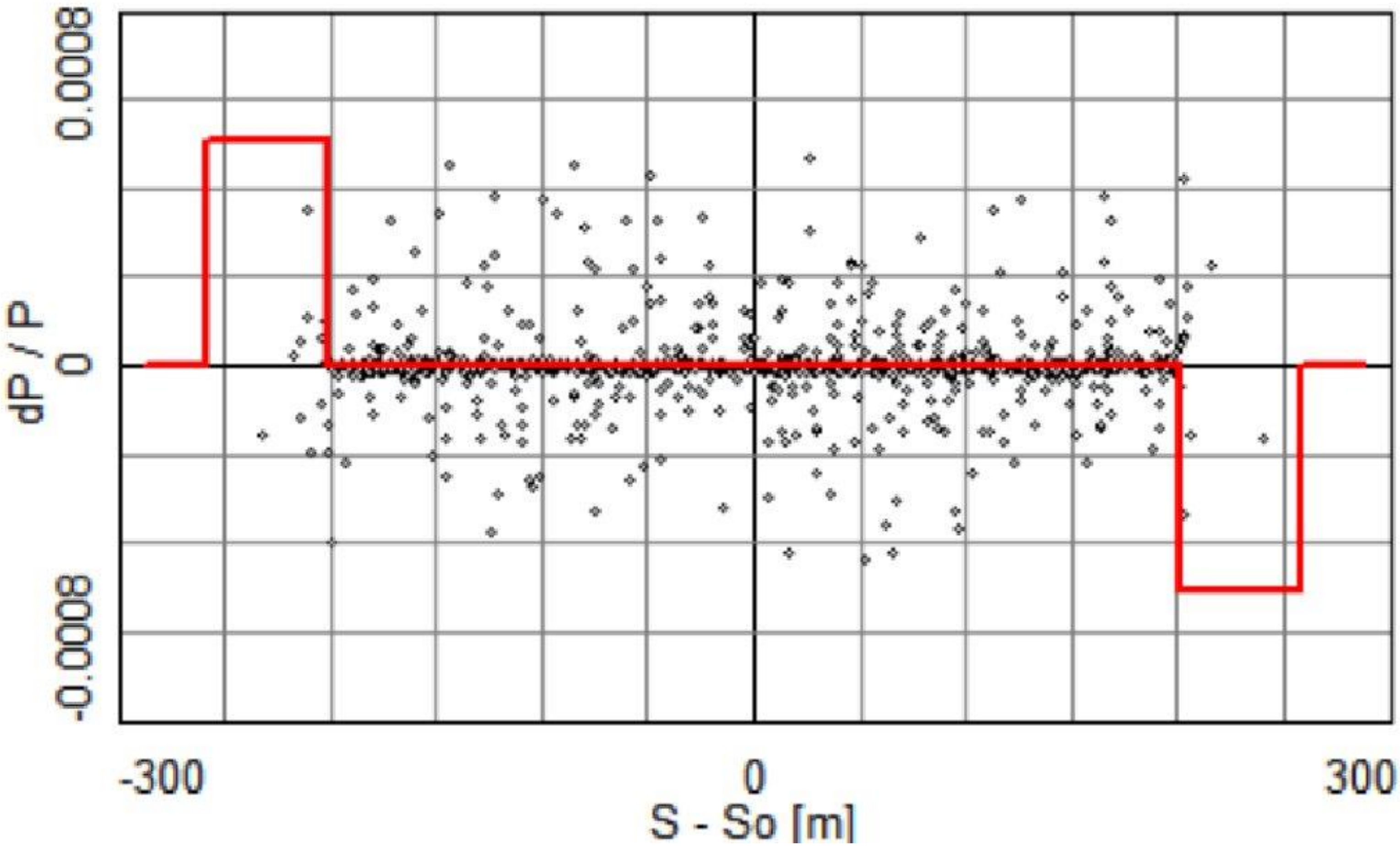
The simulation was done with BETACOOL code (http://betacool.jinr.ru) for PANDA parameters with use the barrier bucket and electron cooling system.

A. Smirnov, A. Sidorin, D. Krestnikov., Effective Luminosity Simulation for PANDA Experiment at FAIR. Proceeding of Workshop on Beam Cooling and Related Topics (COOL09). Lanchzhou, China (2009). http://jacow.org.

The main simulation parameters are presented in the following Table.

Simulation parameters

Antiproton beam, storage ring	
Energy, GeV	8
Particle number	10^{10}
Initial emittance, π mm mrad	0.039
Initial momentum spread, dp/p	1.3×10^{-4}
Longitudinal acceptance, dp/p	5×10^{-4}
Barrier bucket system	
Amplitude, kV	0.4
Barrier width, % of circumference	10
Barrier gap, % of circumference	70
Effective barrier height, dp/p	5×10^{-4}
Electron cooling system	
Electron cooler length, m	20
Electron beam radius, cm	0.5
Electron current, A	0.2
Electron temperature, eV (tran/long)	$1.0/5 \times 10^{-4}$
Hydrogen internal target	
Effective density, cm^{-2}	3.67×10^{15}
Pellet size, mm	0.028
Beta functions, m (hor/ver)	
Beta functions, m (hor/ver)	8/8
Cross-section, barn	0.055



Particle distribution (dots) and barrier buckets (red line) on the longitudinal phase space.

Extraction with a bent crystal

The longitudinal acceptance was chosen equal to the effective barrier bucket height.

It means that particles will be lost after interaction with the target pellet if the energy decreasing is larger than the barrier height.

Extraction with a bent crystal

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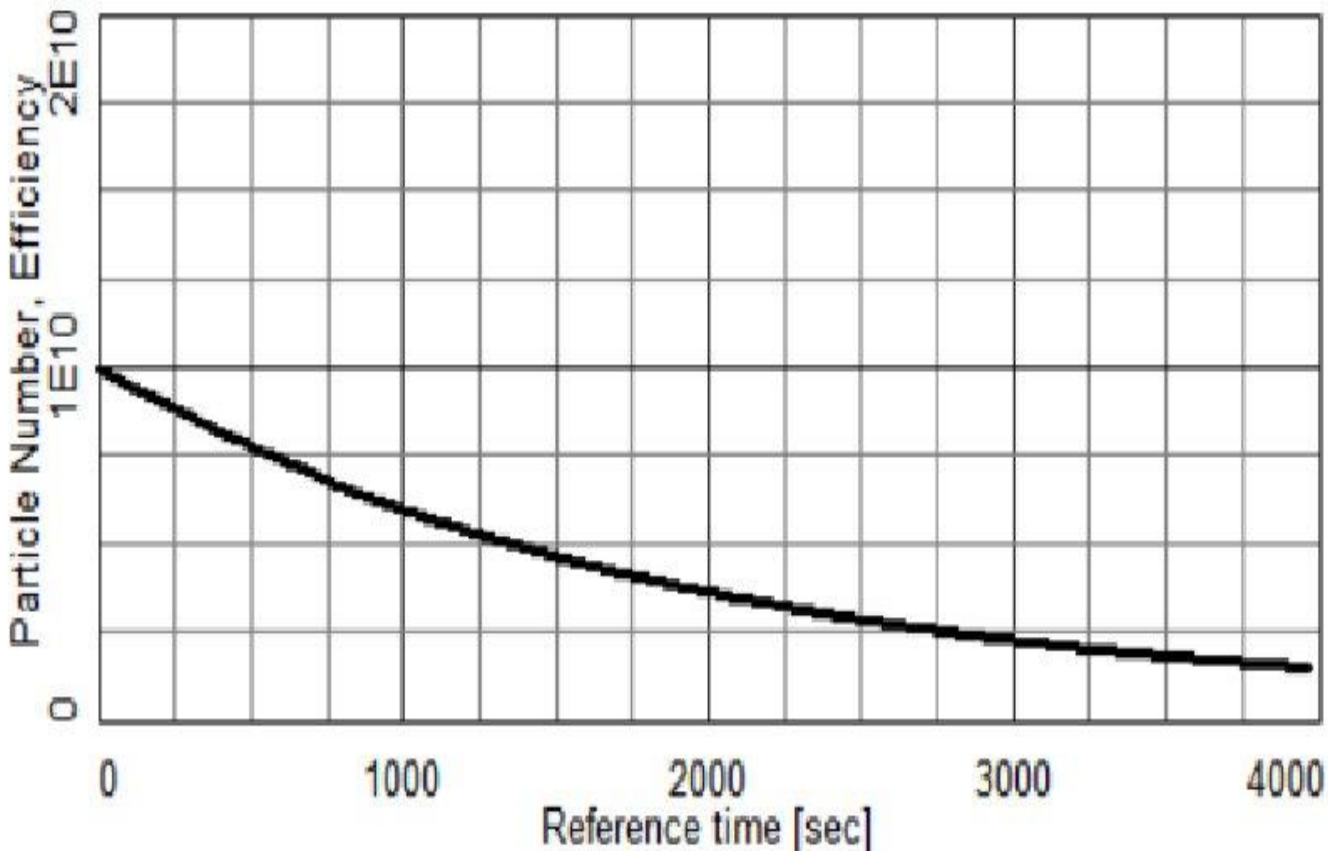
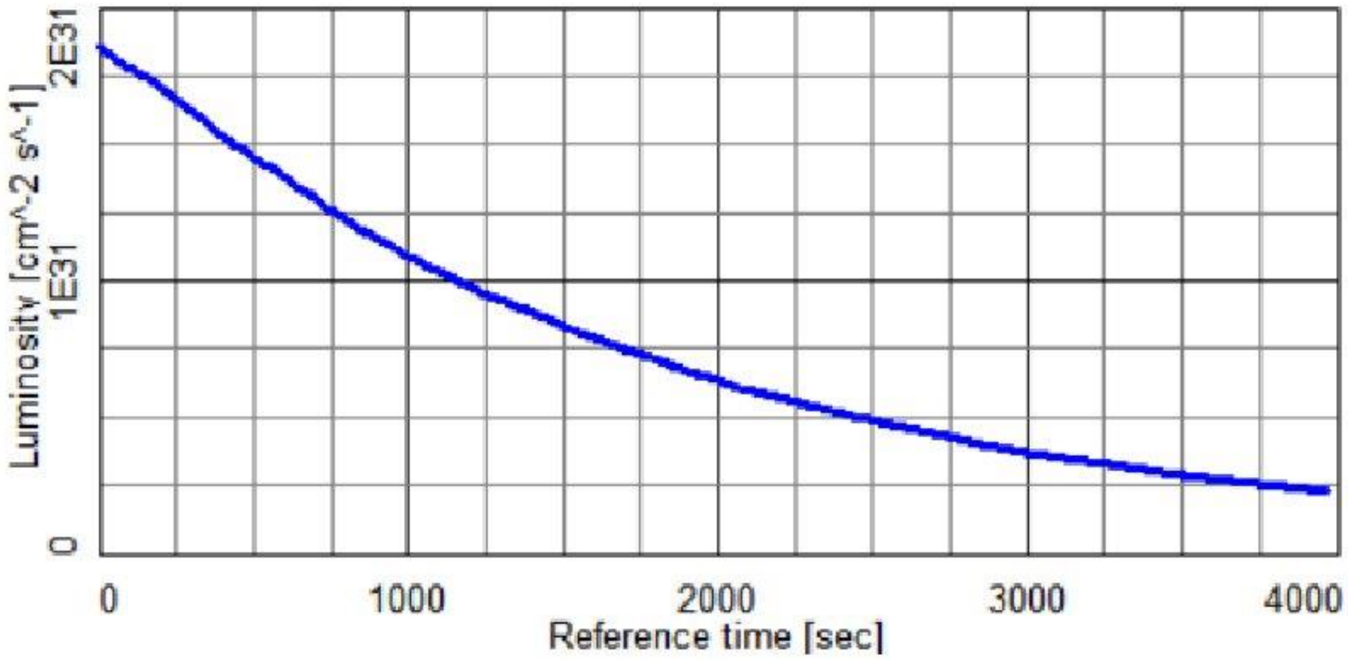
It means that particles will be lost after interaction with the target pellet if the energy decreasing is larger than the barrier height.

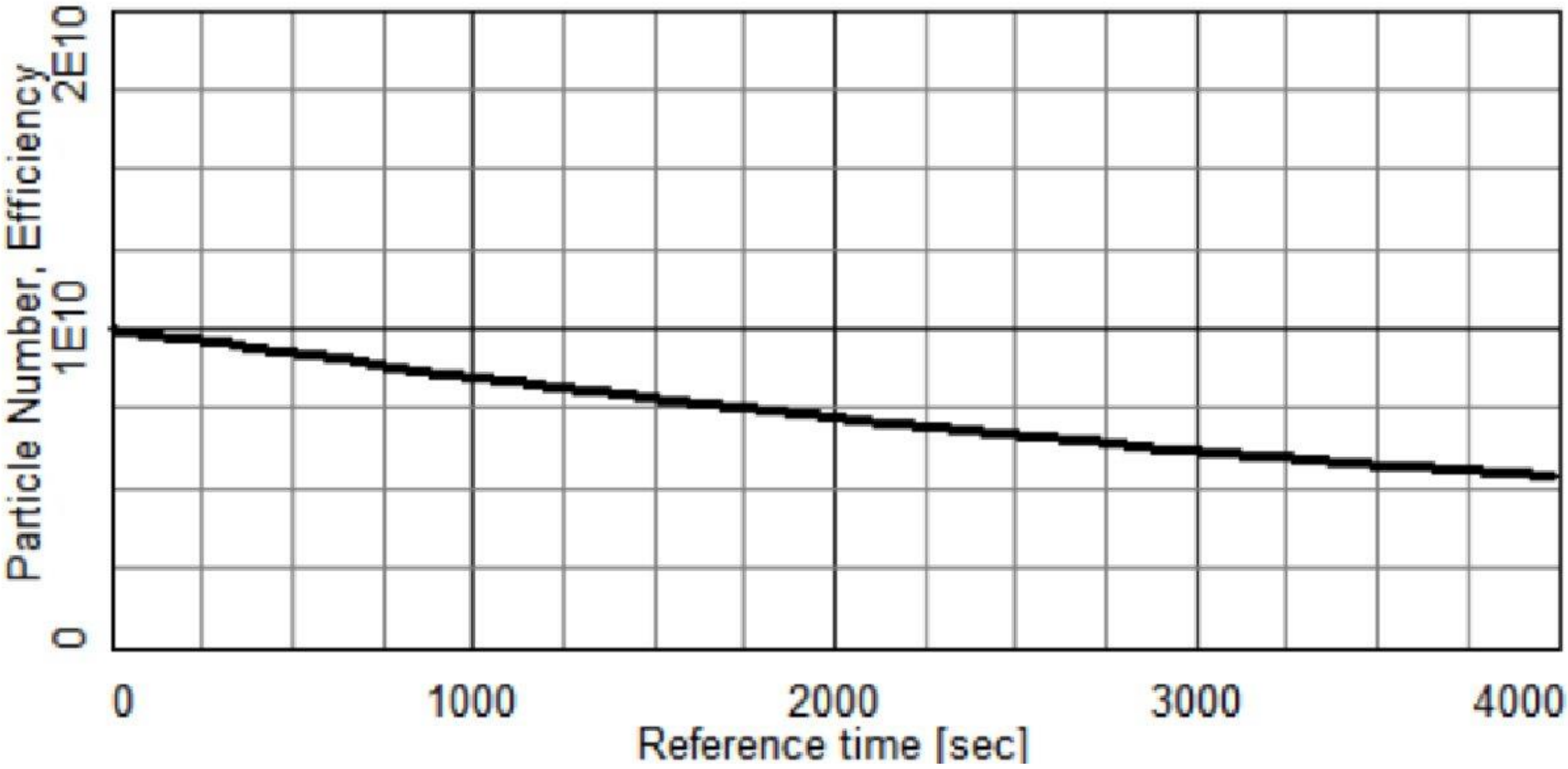
If the particle losses are defined by the longitudinal acceptance and by hadronic interaction in the internal target (cross section is (51-100) mbarn, maximum value at 1.5 GeV/c), than the loss rate is about 4×10^6 particles/s.



Particle number versus time.
Particle losses due to the longitudinal acceptance and hadronic interaction in the internal target.



Luminosity evolution due to the longitudinal acceptance and hadronic interaction in the internal target.



Particle number versus time.
Particle losses due to the longitudinal acceptance.

Extraction with a bent crystal

In the case when the particle losses are defined by the longitudinal acceptance only, the particle losses rate can be estimated at the level about 10^6 particles/s.

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This value can be used as the simple estimation of the intensity of the slow extracted beam for the chosen parameters. Note, that the HESR horizontal dispersion function has mainly positive values. It means that the particles usually can be extracted to the inner side of the storage ring.

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This value can be used as the simple estimation of the intensity of the slow extracted beam for the chosen parameters. Note, that the HESR horizontal dispersion function has mainly positive values. It means that the particles usually can be extracted to the inner side of the storage ring.

But the barrier bucket permits to extract the beam to the external side also.

Extraction with a bent crystal

For a 10 cm long polarized target with a nucleon density of 10^{24} cm^{-3} the luminosity will be about 10^{30} cm^{-2} s^{-1}.

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For a 10 cm long polarized target with a nucleon density of 10^{24} cm^{-3} the luminosity will be about 10^{30} cm^{-2} s^{-1}.

For the estimation of the real intensity of the slow extracted beam, the BETACOOL program can be modified in the accordance with necessary physical and geometrical models (beam and target parameters, extraction kicker parameters, etc.).

Extraction with a bent crystal

The particle losses rates (extracted beam intensity) can be controlled with the different parameters of the barrier bucket and electron cooling system which will define the quality of the slow extracted beam also.

Summary

In summary, an extracted antiproton beam obtained by the use of one of the described methods could be employed in combination either with an dynamically polarized target (DPT) or frozen spin target (FST), depending on the parameters of the beam which will be reached as a result of joint efforts of scientists from Dubna and Mainz.

Of course, coauthors propose here only the principle way, but the realization of a similar project is a serious technical problem which could be solved by a close co-operation of all relevant experts solely.