AN ENERGY LOSS MEASUREMENT AT HERA-p

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Abstract

Energy loss due to synchrotron radiation for particle beams with a moderate low relativistic energy is not yet measured with sufficient precision to verify the predicted suppression of the radiation in the presence of a conducting vacuum chamber. An understanding of this suppression is important for simulation of coherent synchrotron radiation effects of short bunches in an electron bunch compressor scheme. We describe a setup to measure the suppression of synchrotron radiation in the vacuum chamber of the HERA proton ring. HERA has been chosen for this measurement because of its good vacuum condition and its sufficient beam lifetime to facilitate long-term measurements. The energy loss is measured from the revolution frequency of the coasting beam after switching off the acceleration voltage. A first order correction is applied by considering the drift of the dipole field in the super-conducting coils as measured in a reference magnet using NMR probes.

1 INTRODUCTION

Synchrotron radiation is well known and measured for highly relativistic particles like electrons and positrons at several GeV (Lorentz factor γ of order several thousand). The spectrum is dominated by hard (ultraviolet or x-ray) photons, emitted in the forward direction in a narrow cone of roughly $1/\gamma$ opening angle. The total energy loss scales as E^4 or, equivalently, the relative energy loss $\Delta E/E$ as γ^3 (where γ is the Lorentz factor). The aim of this experiment is a measurement at moderately relativistic energies (γ of order hundred). The synchrotron radiation at these energies is dominated by rather soft photons, corresponding to wavelengths of order mm and emitted in a larger cone. Already in 1945, J. Schwinger predicted, that the low energy spectrum of the synchrotron radiation would be suppressed due to the presence of conducting materials (like the beam pipe) [1]. The shielding of soft synchrotron radiation appears to be poorly known with little or no experimental data. Recently, it gained importance in the context of coherent synchrotron radiation for short bunches. Measurements of the total energy loss including synchrotron radiation of moderately relativistic protons and lead ions have been performed previously in the SPS [2]. The beam was left coasting, with the radio frequency turned off. The energy loss of the debunched beam was observed as shift in revolution frequencies on a Schottky monitor. The SPS-measurements are limited in precision by a relatively poor quality and knowledge of the vacuum (of order 10e-8 mbar). It was therefore suggested to perform similar measurements at HERA-p, where the vacuum conditions are much more favourable.

2 SCHOTTKY SIGNAL DETECTION

At HERA-p no dedicated longitudinal Schottky monitor is installed which could be used for an accurate measurement of the revolution frequency. But sufficient Schottky signal measurements have been performed using a standard wall current monitor [3], although this monitor has a rather poor sensitivity for an unbunched beam. The signal processing is concentrated on the 1268th revolution harmonic at 60 MHz using a crystal filter with a few kHz of bandwidth. This needs high amplification and excellent noise suppression. For spectral analysis with FFT the Schottky signal has to be down converted into the baseband and the absolute stability of the reference frequency used for this task has to be stable in the order of 1e-9 during one measurement cycle of about 2 hours.

3 BEAM PREPARATION

In order to resolve a frequency shift from the measured spectrum, the spectral density must be high. To achieve such good signal conditions, the longitudinal emittance of the proton beam should be preserved during the injection process, the energy ramp, and during the preparation for debunching. The coasting beam has been produced by debunching an initially bunched beam in HERA-p. The debunching procedure starts with an adiabatic reduction of the 208 MHz RF voltage down to a value matched to the 52 MHz voltage of the second RF system. Then the driving power of the 208 MHz is switched off and the cavity impedance stays compensated due to the fast feedback system. The 52 MHz voltage is now reduced also adiabatically to a value where the lifetime begins to drop. For technical reasons the 52 MHz system could not be switched off with the impedance compensation staying active. This may have an influence on the overall parasitic mode loss. The resulting spectral distribution of the unbunched beam can be seen in the upper pictures of Fig.1. The two curves in these pictures show the spectral distribution at the beginning and at the end of the study periods for the three different energies.

4 REVOLUTION FREQUENCY MEASUREMENT

Before debunching the beam, the beam spectrum at the output of the Schottky monitor was shifted into the centre of the FFT frequency span by tuning a reference frequency (60 MHz) which is used for the transformation of the 1268th revolution harmonic into the baseband. The FFT frequency span is chosen from 0 Hz to +200 Hz overlapping the spectrum of the coasting beam and containing 1600 display lines resulting in a resolution of 0.125 Hz.

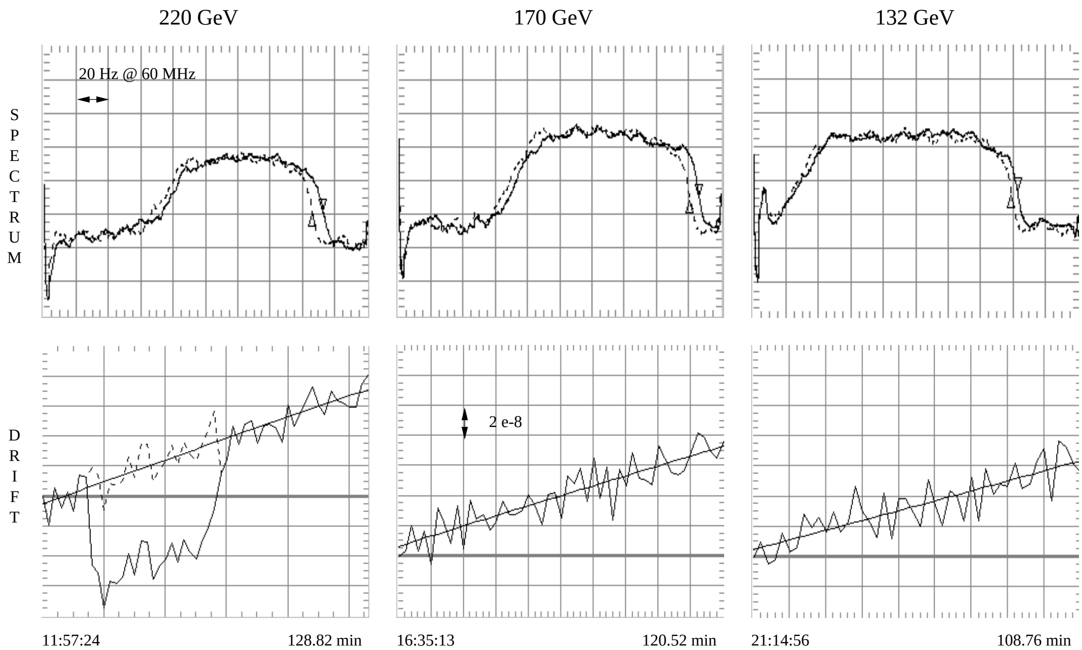

Figure 1: Schottky spectra of the unbunched beams measured at the 1268th harmonic of the revolution frequency which is about 60 MHz. The upper pictures show the spectral density in logarithmic scale (dBV) at the beginning and at the end of the measurement. A mean of 50 data points surrounding every display point was taken to smooth the curves. The horizontal scale is 20 Hz/div. The relative frequency drift of the spectrum (centre of gravity) versus time is shown in the lower pictures. A tripping power supply for some correcting coils was the reason for a temporarily deviation from the normal drift at 220 GeV in the lower left picture. The vertical scale is 2e-8/div for all energies and the horizontal scale indicates the starting time and the duration of the measurement.

The frequency drift of the spectral distribution versus time is shown in the lower pictures of Fig.1. In this case the centre of gravity of the spectrum is used to define a representation for the drift.

5 DIPOLE FIELD MEASUREMENT

The revolution time of the protons depends on their energy and on the strength of the dipole field. In order to deduce the energy loss from the measured revolution frequency, one needs to take into account possible drifts of the dipole fields. At HERA such drifts are mostly due to power supply regulation and persistent currents in the super-conducting coils. In two types of reference magnets (ZANON, ABB) NMR probes are installed for precise field measurements. The magnetic field drift as recorded by these probes is shown in Fig.2. The ZANON values appear to be more noisy and were not available at 132 GeV. Originally it was planned to have the lowest energy at 120 GeV, but it turned out that at this energy, neither the ABB nor the ZANON probe were locking. At the two higher energies, the long term drift recorded by both probes looks rather similar. It appears therefore reasonable to assume, that the drift as recorded by the ABB-NMR approximately represents the change of the field integral in the whole ring.

6 BEAM ENERGY LOSS

The energy loss of the unbunched protons in HERA changes the revolution frequency to higher values. At energies above 200 GeV synchrotron radiation has the main contribution. The time dependence of the energy loss due to synchrotron radiation in free space is

$$-\frac{1}{E}\frac{dE}{dt} = 6.42\cdot 10^{-18}[m]\cdot\frac{f_0\gamma^3}{\rho},\, f_0 = 47\,kHz, \rho = 584\,m$$

where f_0 is the revolution frequency and ρ is the bending radius.
The real change of the proton energy can be estimated from the measurement of the revolution frequency and the dipole field applying the following relation for the relative momentum change:

$$\frac{\Delta p}{p} = \frac{\alpha}{\eta}\cdot\frac{\Delta B}{B} - \frac{1}{\eta}\cdot\frac{\Delta f}{f}\ , \qquad \alpha = 1.28\cdot 10^{-3},\ \ \eta = \alpha - \gamma^{-2}$$

With α the momentum compaction factor and η the slip factor.
In Fig. 3 the results of the measured $\Delta p/p$ per hour are displayed in comparison with synchrotron radiation calculated from the upper formula.

7 CONCLUSION

A very small but still significant energy loss of coasting protons was observed in HERA at three energies of about

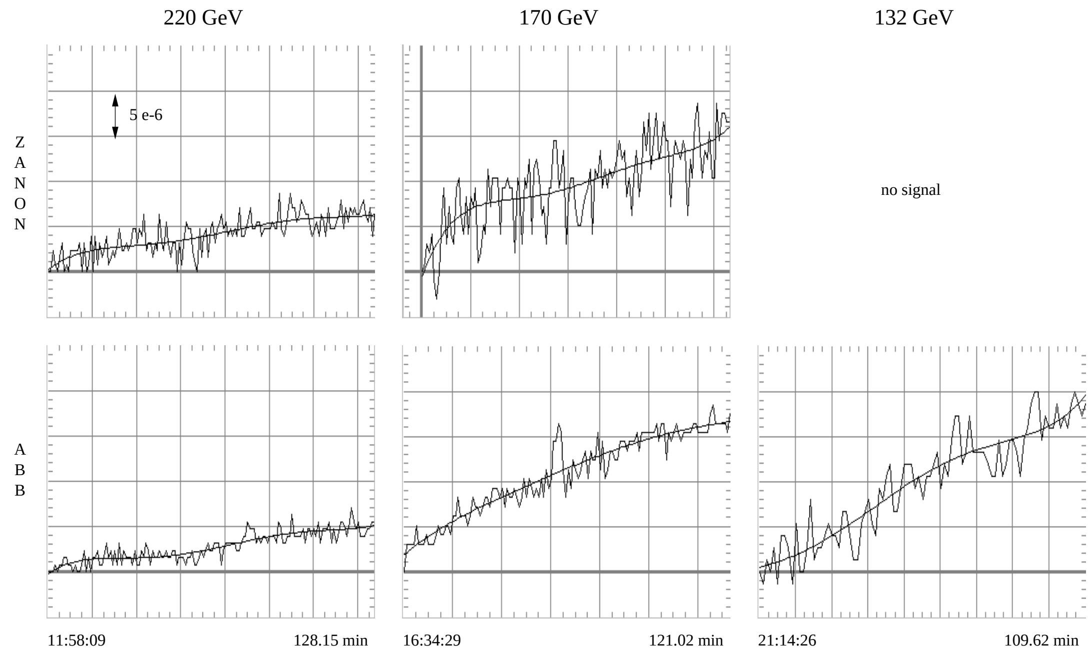

Figure 2: NMR dipole field measurements. The vertical scale is 5e-6/div of relative field change for all pictures. In correspondence with the frequency measurement, the starting time and the duration is indicated at the horizontal scale. With ramp times at 7:55 at 220 GeV, 15:40 at 170 GeV and 20:09 at 132 GeV, there was much more time for persistent currents to decay at 220 GeV than at the lower energies. This matches the observation with larger drifts at the two lower energies. The ABB data are used applying a polynomial fit for representing the total drift of the HERA-p dipole fields during the measurement.

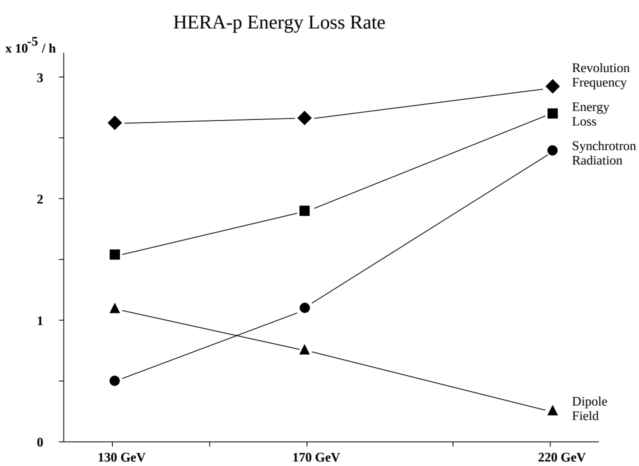

Figure 3: The measured change of the revolution frequency divided by the slip factor η and the change of the dipole field times the momentum compaction factor α divided by η is normalized to one hour and displayed over the energy of the protons. The energy loss is calculated from their difference. For comparison the synchrotron radiation in free space for HERA-p is also shown.

132, 170 and 220 GeV. The total energy loss clearly increased with the beam energy and is compatible with being largely due to synchrotron radiation. The complete analysis with an estimate of the energy loss by other sources (scattering on the rest gas, resistive wall losses etc) and an estimate of all systematic uncertainties is still in progress, and it will be premature to draw any definite conclusions. Still, it is already interesting to see in Fig. 3 that the increase in the total measured energy loss appears to be similar to the increase in free space synchrotron radiation. It will be very interesting to continue the detailed analysis and to attempt to obtain first limits on the amount of shielding. Even if this first attempt to measure the small energy loss of the coasting beams in HERA has already been quite promising, it is also likely that the uncertainty could still be further improved by a more dedicated longitudinal monitoring and an improved magnet drift monitoring or simpler longer measurement times in particular at the lower energies.

8 REFERENCES

[1] J. Schwinger, 'On Radiation by Electrons in a Betatron', Preprint from 1945, transcribed by M.A. Furman in 1998, available from http://www.lbl.gov/∼miguel/. LBNL -39088 and CBP Note-179, LBL, January 1998.

[2] J. Arnold, T. Bohl, H. Burkhardt, R. Cornali, K. Cornelis, G. Engelmann, R. Giachiono, A. Hofmann, M. Jonker, T. Linnecar, M. Meddahi, L. Normann, E. Shaposhnikova, A. Wagner, and B. Zotter, 'Energy loss of proton and lead beams in the CERN-SPS', in *Proceedings of the 1997 Particle Accelerator Conference*, M. Comyn, M. Craddock, M. Reiser, and J. Thomson, eds., vol. 2, pp. 1813–1815.

[3] W. Kriens, M. Minty, 'Longitudinal Schottky Signal Monitoring for Protons in HERA', EPAC 2000, Wien, Austria, 26-30 June 2000