CEBAF PROPOSAL COVER SHEET

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A. TITLE: PROPOSAL ON USING DIFFRACTIVE RADIATION FOR BEAM POSITION MONITORING AND LORENTS-FACTOR MEASUREMENT

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C. THIS PROPOSAL IS BASED ON A PREVIOUSLY SUBMITTED LETTER OF INTENT

[ ] YES

[X] NO

D. ATTACH A SEPARATE PAGE LISTING ALL COLLABORATION MEMBERS AND THEIR INSTITUTIONS

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PROPOSAL ON USING DIFFRACTIVE RADIATION FOR BEAM POSITION MONITORING AND LORENTS-FACTOR MEASUREMENT

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Abstract

We propose to design a Beam Position Monitor, based on the diffractive radiation of relativistic charged particles passing through a round hole or slit. It is shown, that the centre of gravity of the beam can be measured with the accuracy of $\leq 1\mu m$. Compared to the known methods based on the pickup electrodes, the proposed device has the advantage of a better resolution and at the same time it can be used for measuring Lorents-factor $\Gamma=E/mc^2$ of beam particles. In the last case the accuracy is $\Delta\Gamma/\Gamma=10^{-4}$.

Introduction

A number of huge accelerators and colliders are supposed to be built in the forthcoming decade. As a rule in such machines the acceleration and storage of particles are apt to have a Lorents--factor $\Gamma=E/mc^2>>10^3$, whereas the transverse sizes of the beam do do not exceed $r \leq 100\mu m$. It refers to such devices as UNK and VLEPP (USSR), CEBAF and SSC (USA), LHC (CERN) etc. The precise measurement and continous control of the beam position as well as the energy (or Lorents-factor) of beam particles becomes a serious problem. In case of cyclic electron accelerators the synchrotron radiation in the curved parts of beamline helps to solve this problem. However in the straight parts of the beamline the beam position monitoring requires to look for nontraditinal methods, because the known methods based on the use of pickup electrodes or "flying wire" are not able to provide the accuracy required. Methods based on the use diffractive radiation for measuring the centre of gravity of the beam as well as Lorents-factor of the beam particles are suggested below.

Theoretical Background

Already in the 60-ies in a number of works it was shown, that during the passage of charged particles through the round hole or slit in the screen there arises a radiatoin which was called diffractive radiation. In particular, when the particloe is passing through the slit with a width of L in an opaque screen and if the distance between the particle and the edges of the screen are L_1 and L_2 ($L_1+L_2=L$), then the number of photons radiated by each edge is described by the expression

$$\frac{d^2N_{1,2}}{d\lambda\, d\Omega}=\frac{\alpha}{8\pi^2 f^2(f^2+k_y^2)}\{(f^2+k_x^2)[\exp(-4\pi f L_{1,2}/\lambda)-$$

$$\frac{\exp(-2\pi f L/\lambda)}{4\pi^2(f^2+k_y^2)\Gamma^2}[(f^2+k_y^2)\cos(Lk_y)-2fk_y\sin(Lk_y)]\} \qquad (1)$$

where

$$f^2=k_x^2+1/\gamma^2, \qquad k_x=\sin\theta\cdot\cos\Phi, \qquad k_y=\sin\theta\cdot\sin\Phi,$$

θ, Φ and $d\Omega$ are the polar and azimuth angles and the wavelength respectively. The diffractive radiation is distingwished by narrow angular distribution. As it follows from Fig.1 almost the whole radiation is concentrated within the polar angles $1/\gamma \le \theta \le 10/\gamma$. Azimuthal distribution is maximal near $\pm\pi/2$.

It is evident (and it follows from (1)), that this radiation is essential when

$$\lambda\gamma>L. \qquad (2)$$

Otherwise the radiation will be strongly suppressed. Besides if L_1 or L_2 exceed significantly $\lambda\gamma$ then the second (interferense) term in the expression (1) tends to zero and the task comes to the case of radiation of the particle which passes near the edge of semiinfinite screen. At last, the intensity depends on the distance between the particle and the screen's edge as well as on the Lorents factor of the particle exponentialy as it follows from (1).

This very circumstances underlie in the basis of the designed devices for the beam position and Lorents-factor monitoring.

The Method of Beam Position Monitoring

As it follows from the condition (2) the reasonable distances between particles and the edge of the slit ($L = 1\div10$ mm) in the Lorents-factor interval $\gamma=10 \div 10$ can be provided in the optical bandwidth ($\lambda = 200$–800 nm). This essentially simplifies the diffractive radiation registration. Besides, it is evident that the radius r of the beam investigated must be significantly less than L.

Further assume that L= 1mm (the case when the particle passes near the screen edge) the wavelength is $\lambda = 300$ nm, the interval of the waves is $d\lambda/\lambda = 10^{-3}$. The beam parameters will correspond to the conditions of the CEBAF electron accelerator, that is $\gamma=8000$, r.m.s. radius is R= 25 μm, the mean beam current in the accelerator is 100 μA. These data were used for Monte-Carlo simulation of the processes of radiation and its registration.

The dependence of the relative number of photons on the relative shift of the beam's centre of gravity is given on Fig.3. Hence it follows that the shift of the beam position by just 1μm ($\Delta L/L = 10^{-3}$) leads to a sharp change of the photons number ($\Delta N/N = 7\cdot 10^{-2}$). It should be kept in mind that in the traditional method of pickup elestrodes the dependence of the response on the beam position shift is linear [ ], i.e. the value of $\Delta N/N$ will be 10^{-3} under the same conditions.

Another advantage of diffractive radiation is the following. As far as the condition (2) can be satisfied not only in the nearest point of the screen edge, but also in the more remote points. Hence a rather broad region of the screen edge will be radiating. However it is obvious that the radiation intensity will decrease with moving off the central point to the remote ones. It is illustrated in Fig.4, where the spatial distribution of the photons radiated along the edge of the slit is given. The existence of such a dependence can be used for definition of the beam's centre of gravity.

With account of the listed pecularities of diffractive radiation, the following possible versions of the devices are supposed, which are destined for beam position monitoring. The simplest version consists of four radiating screens fixed symmetrically around the beam, an inclined mirror with a hole for deflection of radiation from beamline, a monochromator and four photomultipliers (PM). Under the above-mentioned conditions the shift of the beam's centre of gravity by ΔL [μm] relative to the normal position will lead to the change of the ratio of the two opposite PM's signals by $5{,}8\cdot 10^{2}\cdot \Delta L$. It means that while digitizing the PM's signals to 10 bits, the resolution of monitor will therefor be 0,17 μm [ ] as it is in the case of pickup electrodes.

If the device described above is suplemented with lenses for a parallel transferring of the image of radiating edges in the detector's plane, then the beam itself can be visualized. In this case CCDs as well as optical fibres connected to either multianode PMs or photodiodes can serve as detectors. At last, for this purpose proportional chambers with the photosensitive admixture of TMAE or TEA can be used. This will allow not only to shift into the region of ultraviolet, but as a consequence to increase the accuracy. Thus when =150nm the resolution corresponding to 1 bit under other similar conditions will be 0,07μm.

The absolute value of the number of photons registered in both versions of the proposed devices is of interest. In the first case under the above-mentioned parameters of the beam the number of photons will not be less than $10^{8}s^{-1}$. Taking into account the losses in the optical system and efficiency of PMs the number of photoelectrons in each PM will make $>10^{6}s^{-1}$. This is more than enough for neglecting the statistical fluctuations. In the second case when using the CCD's with the pixel size 10x10μm² the number of photons will correspond to $5\cdot10^{2}\ s^{-1}$ depending on the remoteness of the given pixel from the center of gravity.

It is evident that the versions with the use of PMs combined with FADC are very fast and can be connected in the feedback for the remote control of the beam position.

As a conclusion of this section it must be noted, that the difractive radiation is polarized and this circumstance can be used for suppression of different backgrounds.

Measurement of Lorents-factor of the beam particles

As it follows from expression (1), the intensity of diffractive radiation is strongly dependent upon the Lorents -factor of the particles. It means that in case of the installation shown on Fig.5 the change of Lorents-factor will be accompanied by a similar sharp change in the response of all PMs if the beam is in its normal position. However, it is evident, that the same result can be achieved by changing the intensity of the beam. For the purpose of excluding the influence of beam intensity the radiation can be registered on two different wavelengths, as in this case the dependence of radiation intensity on Γ in accordance with condition (2) is different. For the sake of illustration the dependence of the photon number on the relative change of Lorents-factor at two different wavelengths is shown in Fig.6. The slopes of these dependences strongly differ from each other. Consequently, the change in the Lorents-factor will change the number of photons differently, while the change in the intensity of the weam will lead to the same change in the number of photons for both wavelengths.

Let us estimate the accuracy of the measurement of the Lorents factor of beam particles. In assumption that the signals of the PMs are digitized to 11 bits (i.e. 1 part in 2000) it follows that at $\Gamma=8000$ the accuracy of the measurement will correspond to $\Delta\Gamma/\Gamma=10$. The resolution can be 2-3 times improved by shifting into the region of ultraviolet (=150nm, =175nm).

The extraction of two different wavelength from the radiated spectra offers no technical difficulties, so it won't be discussed hereafter.

Schedules and Manpower

We envision three stages in the development of the Beam Position Monitor. The first stage includes of testing of a simplified version using two photomultipliers. We view this stage as a feasibility test in which we are primarily interested in the basic physics of diffractive radiation. It is anticipated that the early development and construction of the prototype module and readout electronic will occur in Yerevan. Then we will move this equipment to any beam which provides: i) a Lorents-factor of $\Gamma \geq 8000 \div 10000$; ii) the radius of the beam $r \leq 100\mu m$. These conditions can be satisfied at CEBAF, CEBAF,LEP, HERA etc.

The main goal of the second stage is to develop an effective, inexpensive actual module and readout system. These works will be carried out in Yerevan. Later, when we have a working system of the screens and mirror enclosed in an appropriate vacuum chamber, as well as the optics and the detecting system, we plan to move this equipment to CEBAF.

The third stage is the further testing and installing of the monitoring system on the actual beamline.

The collaborators listed on this proposal intend to spend a major part of their reserch efforts over the next 5 years in the above scheduled works. Besides, we intend to take part in the program of CEBAF beam parameters monitoring.

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FIGURE CAPTIONS

Fig.1. The angular distribution of diffractive radiation at different azimuth angles.

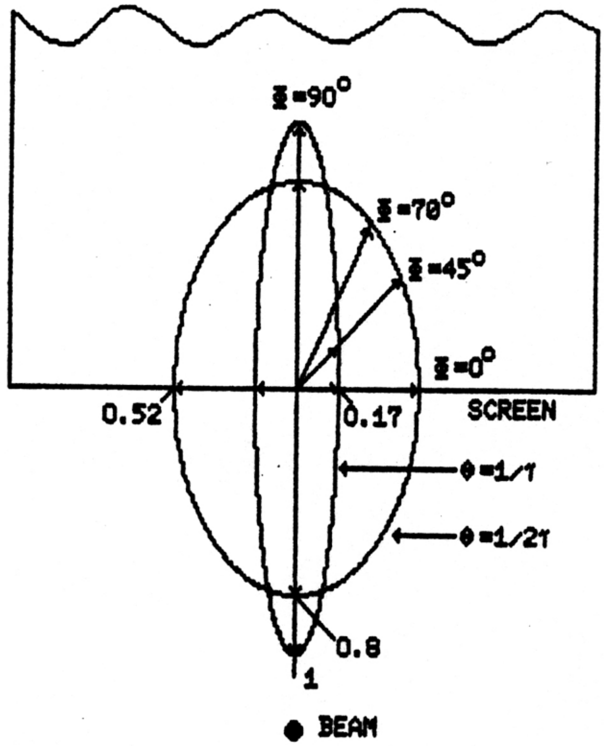
Fig.2. The diagrams of the azimuthal distribution at different polar angles. The figures near the diagrams denote the relative values of intensity.

Fig.3. The dependence of the relative change of photons number on the shift of the beam's centre of gravity.

Fig.4. The spatial distribution of the radiation along the edge of the slit.

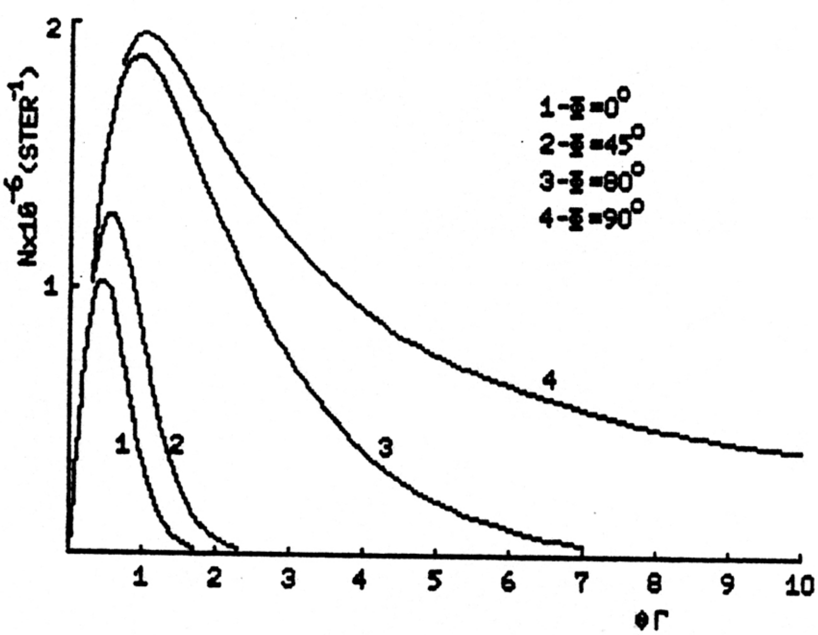
Fig.5. The sketch of the device for beam position monitoring.

Fig.6. The dependence of relative change of photons number on the change of Lorents-factor at two different wavelengths



Φ=90°
Φ=70°
Φ=45°
Φ=0°
0.52
0.17
SCREEN
φ=1/γ
φ=1/2γ
0.8
1
BEAM

FIG.1



Nx10⁻⁶(STER⁻¹)
2
1
1-Φ=0°
2-Φ=45°
3-Φ=80°
4-Φ=90°
1
2
3
4
1 2 3 4 5 6 7 8 9 10
φΓ

FIG.2

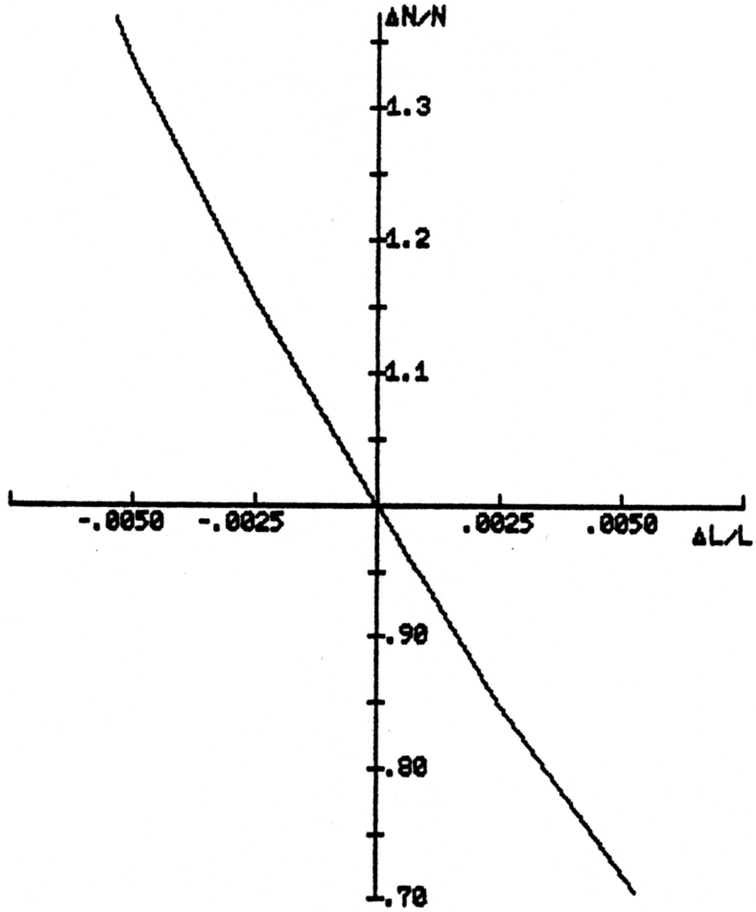

ΔN/N
1.3
1.2
1.1
-.0050
-.0025
.0025
.0050
ΔL/L
.90
.80
.70

FIG.3

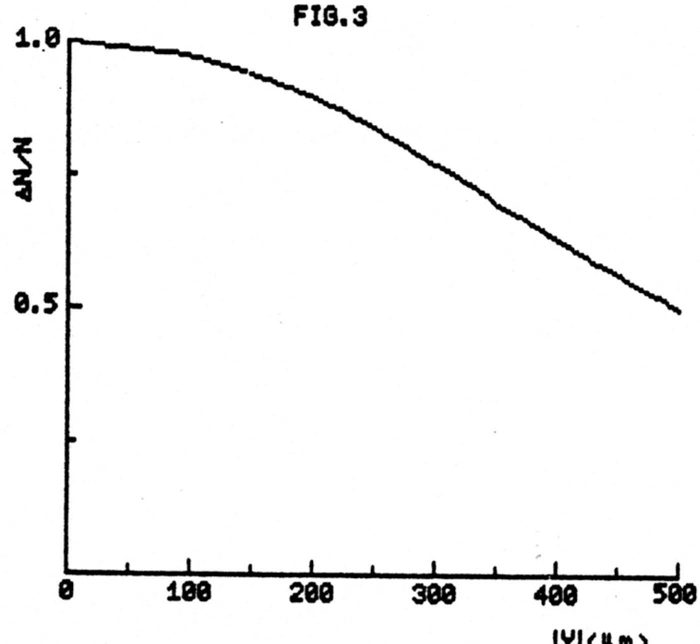

1.0
ΔN/N
0.5
0
100
200
300
400
500
|Y|(μm)

FIG.4

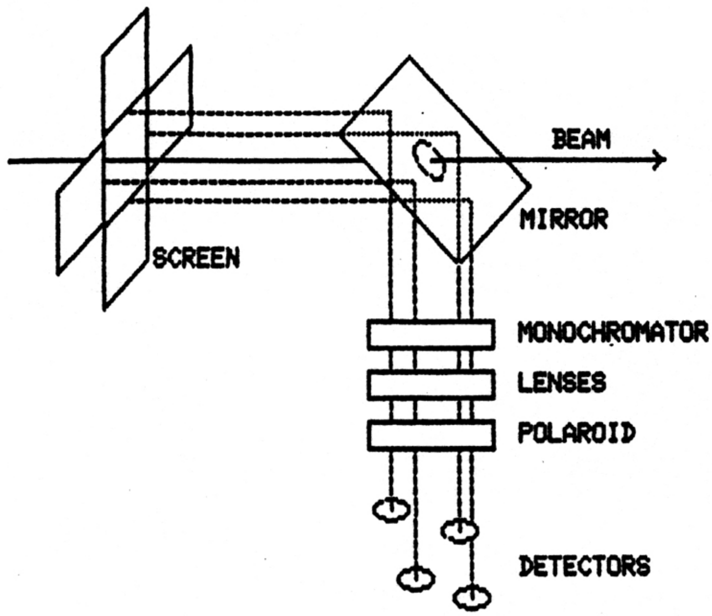

BEAM
MIRROR
SCREEN
MONOCHROMATOR
LENSES
POLAROID
DETECTORS

FIG.5

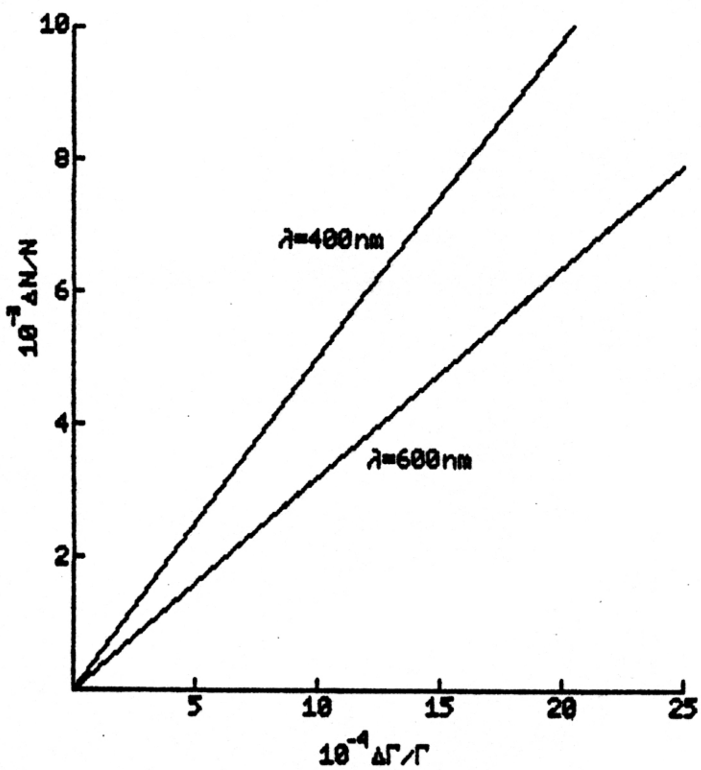

10
8
6
4
2
5
10
15
20
25
λ=400nm
λ=600nm
10^-3 ΔN/N
10^-4 ΔΓ/Γ

FIG.6