A Proposal for Betatron Mismatch Detection in the DESY Proton Accelerators

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Abstract

Emittance preservation in the DESY proton accelerators is an important issue for the success of the Luminosity upgrade (Ref. 1) of HERA. To minimize all sources of emittance degradation in the accelerator chain, the detection of betatron phase space matching at injection into the circular proton accelerators will become important. Some diagnostic techniques for HERA, PETRA and DESY III[1] are discussed in this report.

1. Introduction

The emittance budget of the HERA proton accelerator chain has to be kept very tight to achieve high luminosity in the HERA collider. A common source of emittance blow up in each accelerator is a mismatched injection into the beam optics of the circular machines. A position offset results in betatron oscillations and can easily be detected by turn by turn beam position measurements. A mismatch of the betatron phase space will result in transverse shape oscillations, at least for some ten turns, before the different phases of the protons lead to a filamentation of the beam and to an emittance blow up. Fig. 1a shows the phase ellipse at a certain location in a circular accelerator. The ellipse is defined by the optics of the accelerator with the emittance e and the optical parameters β = betafunction, $\gamma = (1 + \alpha)/\beta$ and the slope of the betafunction $\alpha = -\beta'/2$. Fig. 1b-d shows the process of filamentation after some turns.

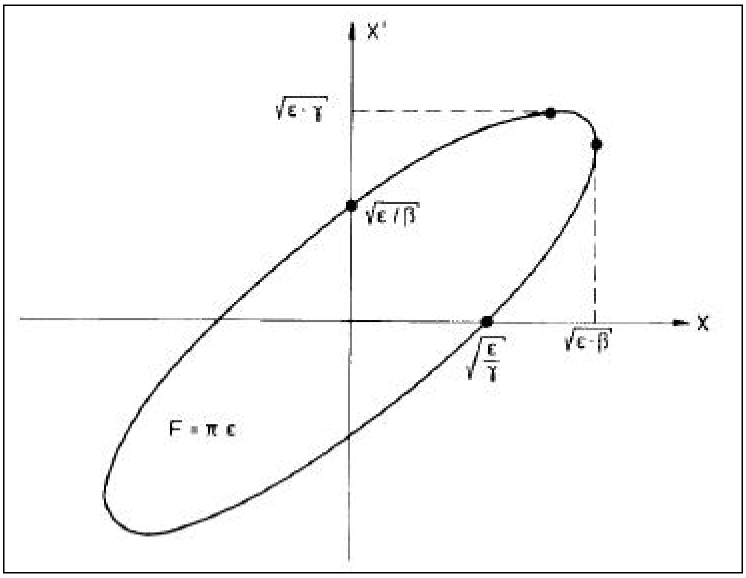

Fig 1a: A phase space ellipse of a circular accelerator, defined by α, β, γ, ε

[1] DESY III: 0.31 – 7.5 GeV/c proton synchrotron, PETRA II: 7.5 – 40 GeV/c proton ring, HERA: 40 – 920 GeV/c proton ring.

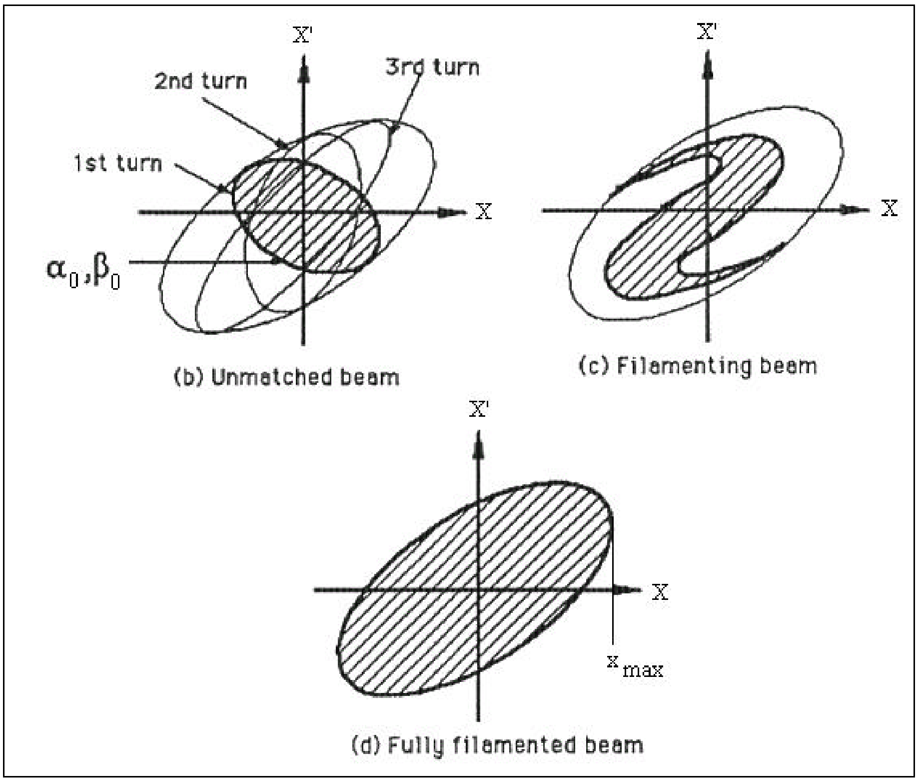

Fig. 1 b-d: Filamentation of an unmatched beam (from Ref. 2)

Assuming a beam is injected into the circular machine, defined by β_0 and α_0 (and therefore γ_0) with a given emittance e_0. For each turn i in the machine the three optical parameters will be transformed by

$$\begin{pmatrix} b_{i+1} \\ a_{i+1} \\ g_{+1} \end{pmatrix} = \begin{pmatrix} C^2 & -2SC & S^2 \\ -CC' & SC'+S'C & -SS' \\ C'^2 & -2S'C' & S'^2 \end{pmatrix} \cdot \begin{pmatrix} b_i \\ a_i \\ g \end{pmatrix} \quad (Starting\ with\ i=0)$$

where C and S are the elements of the Twiss matrix ($\mu = 2\,\pi$ q, q = tune):

$$\begin{pmatrix} C & S \\ C' & S' \end{pmatrix} = \begin{pmatrix} \cos m + a \cdot \sin m & b \cdot \sin m \\ -\,g \cdot \sin m & \cos m_i - a \cdot \sin m \end{pmatrix}$$

Without any mismatch, the three parameters will be constant while a mismatch will result in an oscillation of the parameters with twice the betatron frequency. The oscillation of β_i can easily be measured by the turn by turn oscillation of the beam width $x = ve_0 \cdot \beta$. The following fig. 2 shows a simulation for the first 10 turns in HERA. A 10% β- or α– mismatch lead to a shape oscillation of up to 2 mm (2 σ).

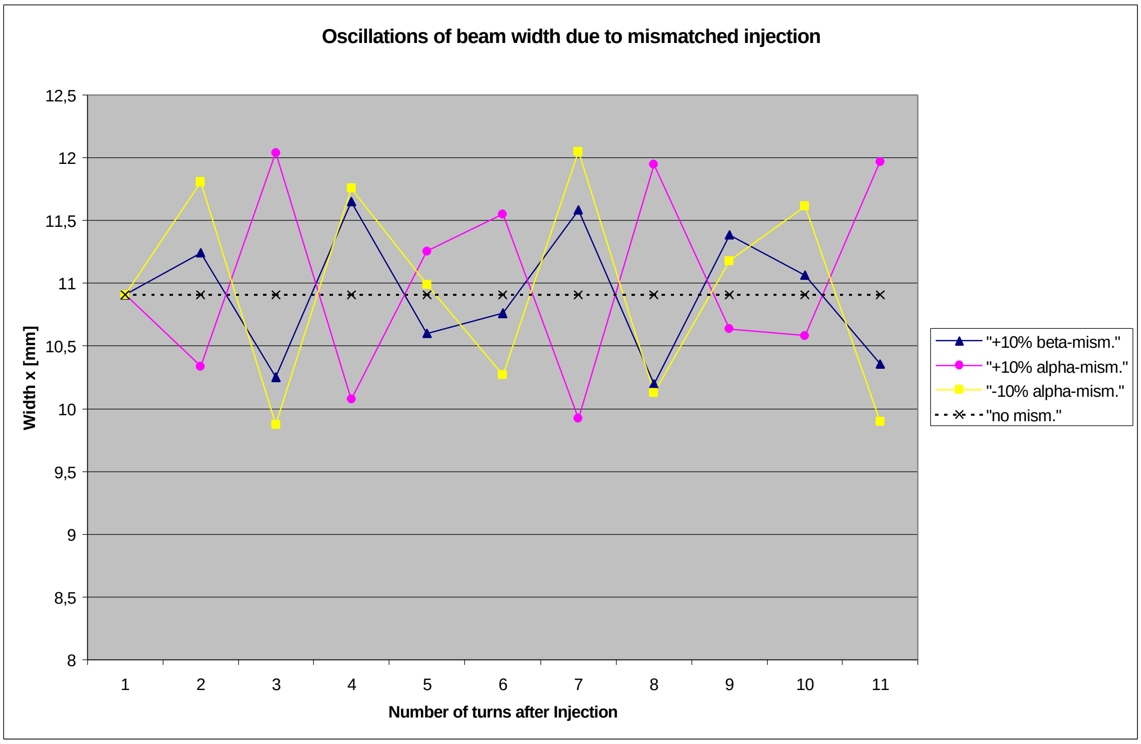

Fig. 2: Beam width oscillation due to a 10% β_0- or α_0- mismatch at injection with $\beta = 238$ m, $\alpha = -2.2$, $\gamma = (1+\alpha^2)/\beta$. The injected beam was assumed to have an 2 σ emittance of $e_0 = 5 \cdot 10^{-7}$ ($e_n = 20\ \pi$ mm mrad)

A +10% β– and -10% α- mismatch leads to roughly the same amplitude of the shape oscillation, while the oscillation phase is shifted by 180^0 in case of a +10% α-mismatch. Therefore the detection of shape oscillations cannot easily distinguish between a mismatch in β and in its slope $-\alpha$.
The emittance blowup due to the betatron mismatch can be calculated with the following formula derived from Ref. 3, 4[2]:

$$e_{filamented} = e_0 \cdot (1 + 0.5 \cdot |\det(\Delta J)|) \quad with \quad J = \begin{pmatrix} a_0 - a & b_0 - b \\ -(g_0 - g) & -(a_0 - a) \end{pmatrix}.$$

The emittance blow up, defined by $\Delta\varepsilon = (e_{filamented} - e_0)/e_0 \cdot 100$ % is plotted in fig. 3. In this example a 10% mismatch leads to an emittance blow up of about 3%. This means, that a measurement of width oscillations at injection is a very efficient method to detect an optical mismatch that increases the emittance in the circular accelerator.

[2] Note that in the present report the subscript 0 refuse the injected beam in contrast to the references! The parameters without subscript refuse to the optic of the circular accelerator.
A simplifying calculation of the blow up can be found in the Appendix 1.

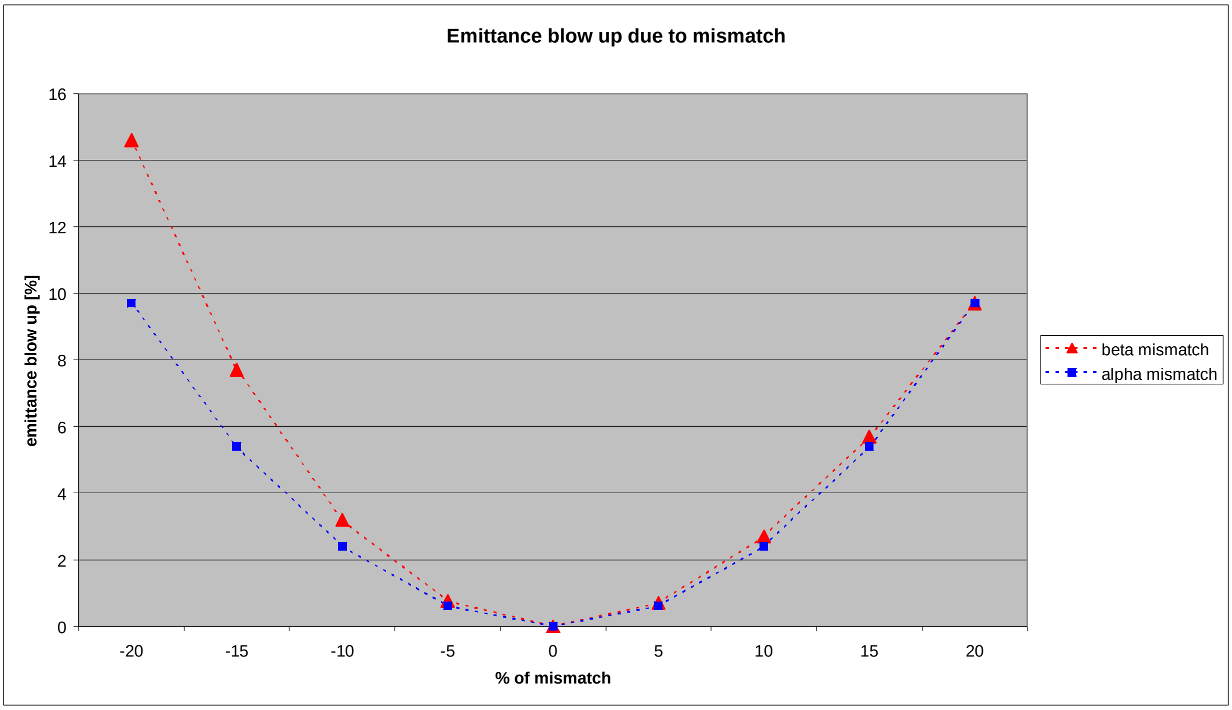

Fig. 3: Emittance blow up $\Delta\varepsilon = (e_{filamented} - e)/ e \cdot 100$ % due to mismatch

2. Devices to measure beam-shape oscillations

This report will focus on monitors that can be used to measure the beam width directly. Not covered are the so-called quadrupole pickups which can in principle measure the quadrupole oscillations of the beam (Ref. 5, 6). Such a monitor is already installed in HERA with some unsatisfactory, up to now, results. The main problem with such a device is the suppression of the beam harmonics from the very weak quadrupole oscillation signal.

2.1. Proposed Devices

A device that should detect injection mismatch oscillations has to measure the beam width turn by turn, for example every 21 µs in HERA. In the following, three possible methods will be discussed, 1) Residual Gas Ionization Profile Monitor (IPS), 2) OTR screen and 3) SEM grid.

2.1.1. IPS

A sketch of the monitor used in HERA is shown in fig. 4.

An electrical potential of -2 kV and +2 kV is applied to the grid G1 and G2, respectively. Between them are 5 pairs of equal spaced field forming electrodes, which are connected with resistors (R) to the grids. The very homogeneous extraction field is responsible for the separation of the electrons and ions produced in the ionization of residual gas by the proton beam. The ions are accelerated to the micro channel plate, which multiplies the number of electrons up to a factor of 10^4 depending on the voltage across it. These electrons are accelerated to the anode where they strike a phosphor screen. The screen is viewed by a video camera through a vacuum window. This provides continues observation of the beam. The primary electrons are not used. They supply a very bad resolution (see Ref. 6). Using a SIT video camera the sensitivity of the monitor is just as good as one then can ‘see' a beam with intensities of a little less than 0.01 µA at a vacuum of about 10^{-8} mbar.

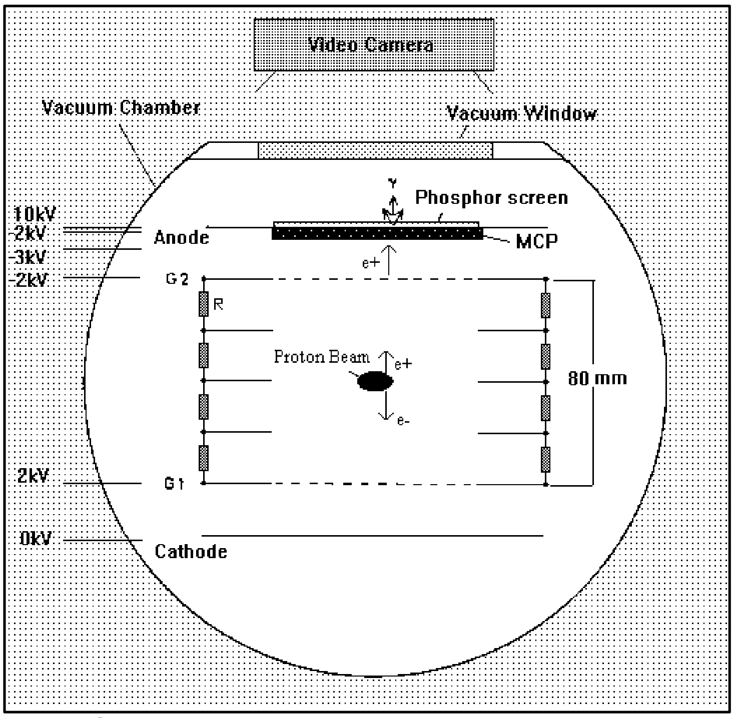

Fig. 4: The IPM in HERA

Preliminary studies have been done in DESY III (Ref. 7) and in HERA to define the improvements which are needed for a turn by turn readout of the existing monitor (Ref. 8):
The present readout is done with a TV-video camera with an integration time of 40 ms and is therefore much to slow. Since only one dimension of the image is of interest one can replace the camera by a much faster linear image sensor. Based on the first tests in DESY III one may conclude that a vacuum pressure of about 10^{-9} mbar is needed to measure turn by turn profiles with an image sensor with a pixel size of 36 µm x 2.5 mm. To check these parameters, we installed a new and fast linear image sensor (Type: EG&G RL0128SBF-011) at the horizontal IPM in HERA. It provides a large area pixel size (25 mm x 2.5 mm) and a fast readout[3]. We measured profiles at the following two different conditions:

Beam Momentum	39 GeV/c	39 GeV/c
Vacuum Pressure at the monitor location	$5 \cdot 10^{-11}$mbar	10^{-9}mbar
Readout time	42µs (2 HERA turns)	42µs (2 HERA turns)
Light collect time	50msec	1.75 msec
Beam current	5.01 mA	55.1 mA

Tab. 1

Fig. 4 and 5 show the beam profiles measured under these conditions.

[3] The proposed maximum clock frequency was 10 MHz and therefore an a readout frequency of 78 kHz was expected, which was sufficient for a turn by turn readout at HERA. Unfortunately the company had changed the technical specification for the sensor to a maximum clock frequency of 5 MHz during delivery.

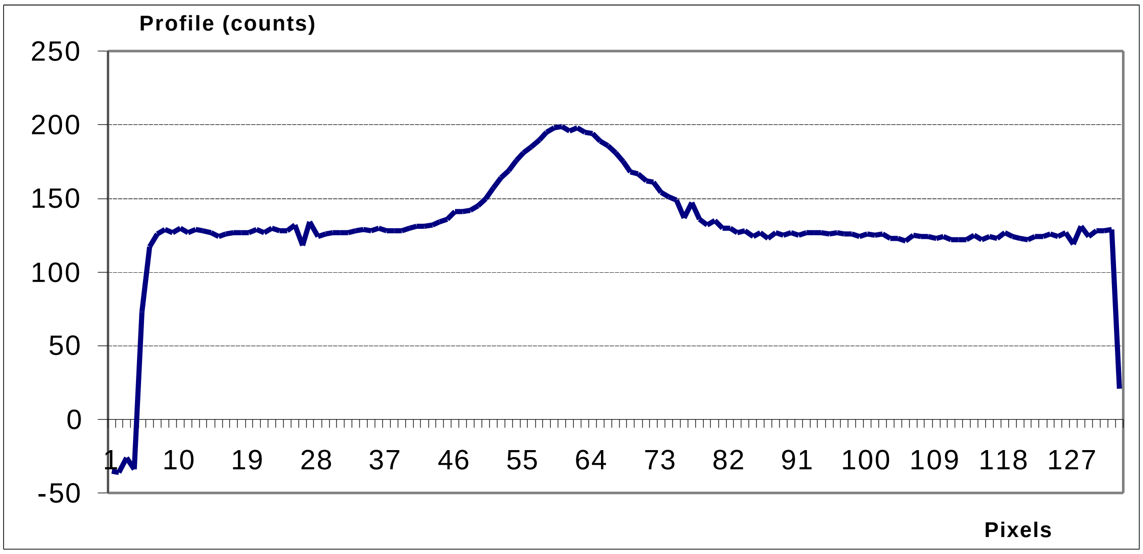

Fig. 4: Measured beam profile after injection at 5 mA beam current and an integration time of 50 ms and a vacuum pressure of $5 \cdot 10^{-11}$mbar. The beam width is about $\sigma = 5$ mm

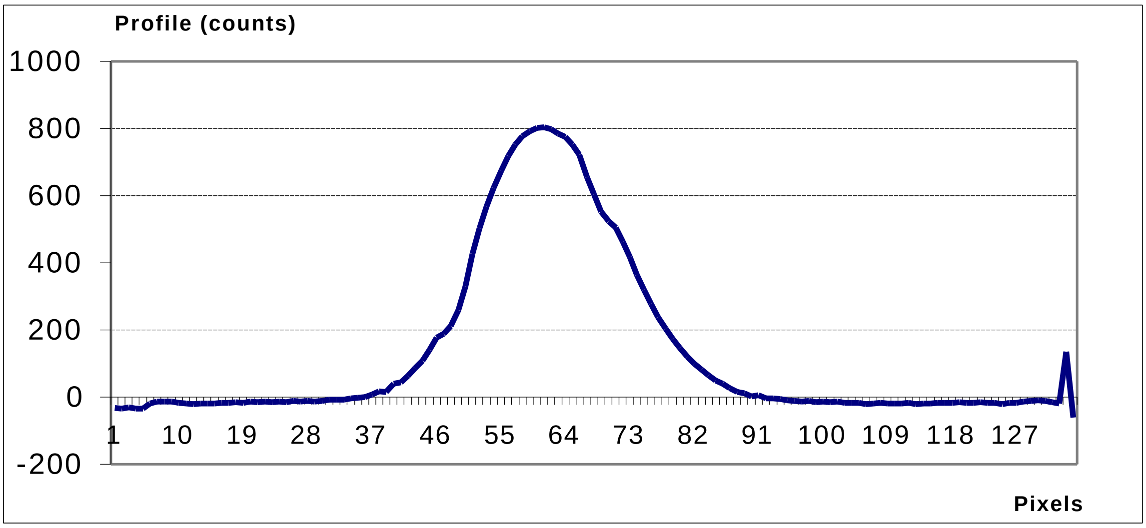

Fig. 5: Measured beam profile after injection at 55 mA beam current and an integration time of 1.75 ms and a vacuum pressure of 10^{-9} mbar. The beam width is about $\sigma = 5$ mm

Within the errors of the vacuum pressure readings (50%), the signal is linear with respect to the pressure, the integration time (light collection time) and the beam current. The linear dependence of the signal on the integration time was confirmed in laboratory measurements. From the measurements shown above, one can conclude that an additional gain of about 1000 is needed to measure reliably turn by turn profiles at injection (5 mA in 10 bunches at 21 µs) at a vacuum pressure of $5 \cdot 10^{-11}$ mbar. Two ways to reach that gain are discussed in the following: 1) increasing the light amplification by an image intensifier and 2) increasing the vacuum pressure.

1) From Ref. 9 it follows that the ionization rate in the beam center is about $2.4 \cdot 10^5$ electron-ion pairs/s/mm^2 at 10^{-9} mbar vacuum pressure and at 170 mA beam current. For a 10 bunch injection (5 mA) and a pressure of $5 \cdot 10^{-11}$ mbar follows an ionization rate of $R_{turn} = 7.2 \cdot 10^{-3}$ /turn/mm^2. With an optical magnification of 18.75, used for the measurements above, one pixel of the linear scanner observes an area

of A = 4.8 cm x 0.48 mm = 23.1 mm^2. Therefore the pixel observes S = $R_{turn} \cdot A$ = 0.17 ions/turn. Even with a very high light amplification, this rate is much to low to observe turn by turn oscillations.

2) Increasing the vacuum pressure by three orders up to $5 \cdot 10^{-8}$ mbar, the rate of ions/turn will increase by the same order to 170 ions/turn. This rate is sufficient for a beam width analysis. A rate of about 400 ions/pixel was received during the light collection time for the results presented in Fig. 4.

The enhancement of the vacuum pressure is necessary only for a short moment at injection. Therefore it will not disturb any machine operation. Such a short pressure bump can be easily achieved by pulsing a piezoelectric valve between two vacuum pumps. The first tests in DESY III were very successful (Ref. 7). The same pressure bump, but with some longer time scale, can be used for another non-destructive and continuous profile measurement, namely the beam induced gas scintillation (BIGS, Ref. 10). The first tests with this type of monitor in the SPS were very promising (Ref. 11).

The readout frequency of large area linear image sensors is presently limited to about 50 kHz/128 pixels. Therefore they cannot be used in smaller circular accelerators like PETRA or DESY which have higher revolution frequencies.

2.1.2. OTR screen

A thin OTR screen which can be moved into the beam at injection will give sufficient light to analyze the beam spot by a fast frame transfer CCD camera (Ref. 12, 13). This screen has the advantage that the resolution of the readout is better than with the IPM.

The disadvantage is, that the screen will blow up the emittance of the beam: The protons receive a mean kick at each traverse through the screen resulting in an additional angle θ.

$$q = \frac{0.014}{p \cdot b} \cdot Z \cdot \sqrt{\frac{d}{l_{rad}}}\left[1 + \frac{1}{9}\log_{10}\left(\frac{d}{l_{rad}}\right)\right] \quad \textit{in radians}$$

where p is the momentum in GeV/c and Z=1 the charge number of the proton, β = v/c the velocity, d the thickness of the foil and l_{rad} the radiation length of the material of the foil. This formula describes the gaussian approximation of the mean scattering angle of the protons after one traverse. The change of the emittance δε for every turn can be calculated by:

$$d\varepsilon_{rms} = \sqrt{2 \cdot p} \cdot q^2 \cdot b$$

which adds quadratically to the 1 σ - emittance of the previous turn. The emittance blowup is shown in Fig. 6 for a 10 µm thick titanium foil as the source of OTR radiation. In addition a betatron mismatch of 10% is assumed.

The figure shows a small growth of the beam width due to the foil, which does not affect the beam width oscillation. The growth rate is small compared to the oscillation amplitude. The faster growth rate in PETRA is a result of the smaller momentum of the injected protons and therefore a larger scattering angle in the foil. This angle will become much larger in DESY III (p=310 MeV/c, β = 0.3), so that the beam width will become unacceptably large within one turn and the loss rate will increase drastically (in Fig. 6 the line for DESY III extend the border of the figure within 3 turns even with a 1 µm screen).

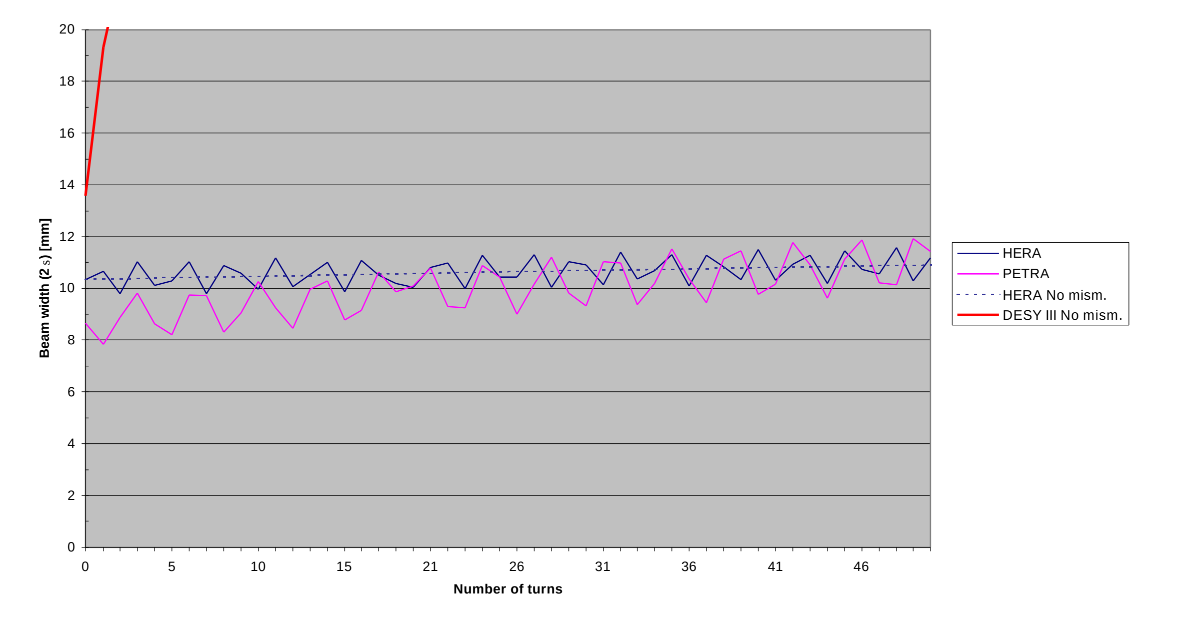

Fig. 6: Emittance growth due to a d = 10 µm Titanium foil at injection energy of HERA and PETRA ($\alpha = -2$ m, $\beta = 40$ m, $\varepsilon_n = 14\,\pi$ mm mrad, q = 0.14, p = 7.5 GeV/c) and DESY III (with a foil-thickness of d = 1 µm (!))

<u>Losses in the screen</u>

The relative proton losses per turn dN/N0 in the foil (thickness d) is given by the nuclear interaction length L_{nuc}:

$$\frac{dN}{N_0} = \frac{d}{L_{nuc}} \qquad with \qquad L_{nuc} = \frac{A}{r \cdot N_A \cdot s_{nuc}}$$

L_{nuc} depends on the total nuclear cross section of the nuclear interaction σ_{nuc}, the density ρ of the foil and the Avogadro constant $N_A = 6.0225 \cdot 10^{23}$ mol^{-1}. The nuclear cross section σ_{nuc} depends on the proton momentum and on the material of the foil and is shown for different materials in Tab. 1 between a momentum of 0.3 < p < 40 GeV/c:

Material A [g/mol] ρ [g/cm³]	Momentum [GeV/c]	σ_{nuc} [mb]	Reference	L_{nuc} [cm]	relative loss/turn $dN/N_0 \cdot 100$ [%] with d = 10 µm
Carbon	0.3	280	16	31.5	$3 \cdot 10^{-3}$
12.01	7.5	360	14/15	24.5	$4 \cdot 10^{-3}$
2.26	40	330	14	22.5	$4.4 \cdot 10^{-3}$
Aluminum	0.3	550	16	30.2	$3.3 \cdot 10^{-3}$
26.98	7.5	700	14/15	38.4	$2.6 \cdot 10^{-3}$
2.70	40	640	14	35.1	$2.8 \cdot 10^{-3}$
Copper	0.3	950	16	12.4	$8.1 \cdot 10^{-3}$
63.546	7.5	1350	14/15	17.6	$5.7 \cdot 10^{-3}$
8.96	40	1260	14	16.4	$6.1 \cdot 10^{-3}$

Tab. 2: Nuclear total cross sections, interaction length and particle losses

The loss rate is negligible small at the injection energies of the DESY proton machines and will not influence the mismatch measurement.

Readout rate

The readout frequency of an OTR screen should be the revolution frequency of the accelerator: HERA f_{rev} = 47 kHz, PETRA f_{rev} = 130 kHz and DESY III f_{rev} = 315 kHz. Such fast CCD cameras already exist: For example the camera SMD 64K1M has a 1MHz frame rate with 256x256 pixels and a pixel size of 56 x 56 µm and an internal storage of 16 successive frames (Fig. 7); storage of 64 successive frames is in preparation.

SMD-64K1M

- One milliom frames per second
- 256 x 256 pixels
- 16 consecutive frames

Silicon Mountain Design's SMD-64K1M digital camera provides 256 x 256 images at up to one million frames per second (fps) with true 12 bit dynamic range. The SMD-64K1M is a solid state CCD camera using a progressive scan CCD to achieve outstanding resolution and gray scale characteristics.

The SMD-64K1M's 12 bit RS-422 digital signal output is perfectly suited for interfacing with external image processing systems. Special interface cables are available for connecting directly to Datacube image processing system.

Fig. 7: The very fast CCD camera SMD-64K1M (Ref.: http://www.smd.com and http://www.catalinasci.com/silicon.htm)

The number of photons per proton N emitted by OTR and received at the camera is given by (Ref. 17):

$$N = \frac{2 \cdot \alpha}{\pi} \cdot |\ln(2 \cdot \gamma) - 0.5| \cdot \ln \frac{\lambda_1}{\lambda_2}$$

with $\alpha = 1/137$, γ = momentum and $\lambda_{1,2}$ = optical wavelength observing interval (typ. 350 – 800 nm).

γ	N [photons/proton]	N_{tot} [photons/turn] with 10^{12} protons =10 bunches	emission angle $\sim 2/\gamma$ [rad]
7.5	$8.5 \cdot 10^{-3}$	$8.5 \cdot 10^{9}$	0.27
40	$15 \cdot 10^{-3}$	$15 \cdot 10^{9}$	0.05
450	$24 \cdot 10^{-3}$	$1.2 \cdot 10^{9}$ ***	0.004

Tab. 3: OTR parameters for HERA and PETRA, *** for SPS with $5 \cdot 10^{10}$ protons!!! (Ref. 17)

Ref. 17 claimed from their measurements, that profile measurements will be possible with $5 \cdot 10^{10}$ protons at 450 GeV/c when using a SIT-camera. The main difference at lower energies is the larger opening angle of the radiation. This has to be taken into account for the light optic design. For comparison one has to note that the SIT camera might be about 10 times more sensitive than a modern CCD camera. Ref. 17 had measured the response of a CCD camera to OTR. The Fig. 8 shows their results and an interpolation for 10^{12} protons. Assuming a typical noise of a CCD camera of a few mV, it can be expected from the interpolation that profiles of some mm (σ) will be observable.

Of course, this kind of measurement can also be used to study the effect of the space charge in PETRA.

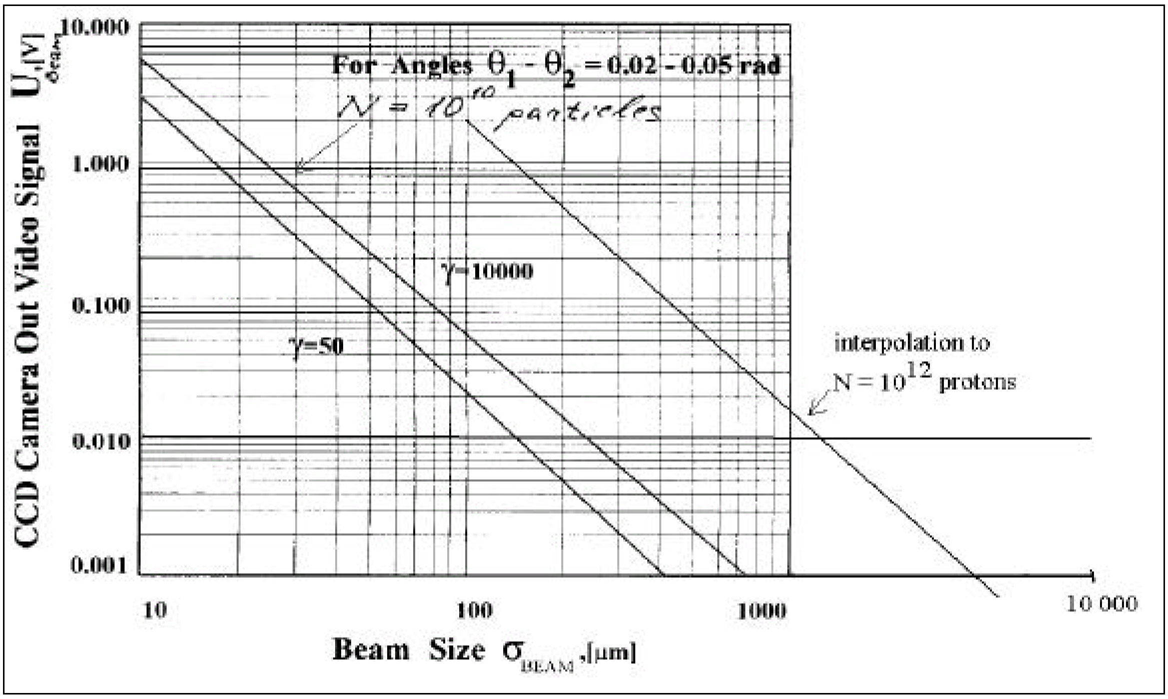

Fig. 8: CCD response to OTR (from Ref. 18). The interpolation was done by the authors ($\gamma = 50$).

2.1.3. SEM-Grids

The emittance blow up in DESY III due to a thin foil is much too large. A harp of thin wires produces less emittance blow up. Assuming a harp of 20 µm titanium wires at a separation of 1 mm, the blowup can be calculated like a 0.2 µm foil. Fig. 9 shows the beam oscillation due to a 10% mismatch in DESY III together with the blowup due to these wires. The secondary emission (SEM) current created in the wires can be read out by fast ADCs turn by turn (315 kHz). Such a readout schema is applied in the PS-Booster at CERN (Ref. 19).

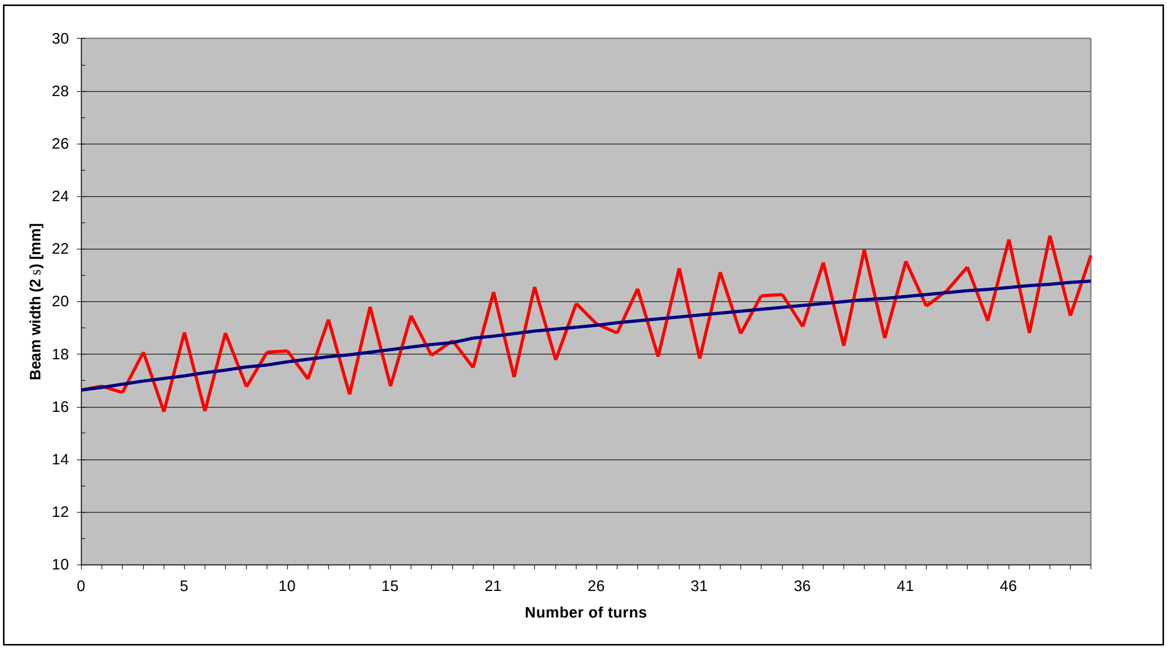

Fig. 9: Simulation of the beam width versus turns as measured by SEM grid with and without a +10% beta mismatch in DESY III (α = -1.7 m, β = 14.3 m, ε_n = 6 π mm mrad, q = 0.28, p = 310 MeV/c)

Signal

Only a small fraction of the beam will produce secondary electrons on the wires. The fraction of protons hitting the wire F is given by:

$$F_i = \int_{-d/2+i\cdot s}^{d/2+i\cdot s} \frac{1}{s \cdot \sqrt{2 \cdot p}} \exp\left[\frac{x^2}{2 \cdot s^2} \right] dx$$

where $i \in N$ is the position of the wire at $i \cdot \sigma$. The secondary electron yield is about η = 5% for titanium wires (Ref. 20) for a wide range of impact energies. The number of electrons/bunch created then is:

$$N_i = F_i \cdot \eta \cdot N_{bunch}$$

where N_{bunch} is the number of protons inside the bunch. Tab. 2 give the number of secondary electrons created, for a 20 µm wire at different positions of the wire for a bunch with 10^{11} protons and a width of 2σ = 16.6 mm:

Wire position	N_i [electrons/bunch]
beam center (i=0)	$24 \cdot 10^5$
1 σ (8.3 mm) (i=1)	$14.5 \cdot 10^5$
2 σ (16.6 mm) (i=2)	$3.3 \cdot 10^5$
3 σ (24.9 mm) (i=3)	$0.25 \cdot 10^5$

Tab. 4: Number of SEM electrons / bunch at different wires of the harp.

One has to find an acceptable compromise between the thickness of the wire (~ signal) and the emittance blow up.

The construction of such a harp and its readout is somewhat expensive because each channel needs its own feedthrough and its own fast readout and one harp per plane will be needed. However, such a fast observation of the beam profile in DESY III will be most helpful to study the behavior of the beam in the presence of the strong space charge at injection and during the first steps of acceleration. It might be, that the emittance blow up due to the space charge is somewhat larger than due to the betatron phase space mismatch, or that a mismatch is needed to reduce the space charge force.

3. Conclusions

Three devices to measure beam width oscillations due to betatron phase space mismatch at injection were discussed. The ionization profile monitor (IPM) in HERA can be used in combination with a gas bump of about $5 \cdot 10^8$ mbar. The same gas bump can be used for a profile monitor based on gas scintillation. An OTR screen can be used in PETRA as well as in HERA. The profile resolution will be better than with the IPM, but it will blow up the emittance. But probably, mismatch measurements will need some dedicated machine time and a small emittance blowup can be accepted. The low momentum of the proton beam at injection in DESY III will allow a sparse harp only. It keeps the emittance blow up to an acceptable growth rate. The proposed devices have given already some successful results at DESY as well as at CERN. They will surely detect minimal beam width oscillations in the range of less than a millimeter that corresponds to about 5% β– or α– mismatch and about 1% of emittance blow up due to the mismatch.

Acknowledgements

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Appendix 1

A perfectly matched beam gives an emittance of $e = x^2/\beta = e_0$ (x = beam width, see Fig. 1a). With mismatch, the resulting phase ellipse of Fig. 1d after filamentation gives an emittance of $e = x_{max}^2/\beta$, which is too large, because only a small fraction of the particles will fill the whole outer region of the ellipse. However, they will contribute to the measured beam width. Assuming gaussian distributions, the difference $(x_{max} - x)$ may add two times (because of the two ends of the ellipse) quadratic to x to give the beam width of the fully filamented beam:

$$e_{filamented} = \frac{(x_{\max} - x)^2 \cdot 2 + x^2}{b}$$

The emittance blow up, defined by $\Delta\varepsilon = (e_{filamented} - e_0)/\, e_0 \cdot 100\ \%$ is plotted in Fig. A1 for the upper assumption and for a formula derived from Ref. 3, 4. The agreement is quite good.

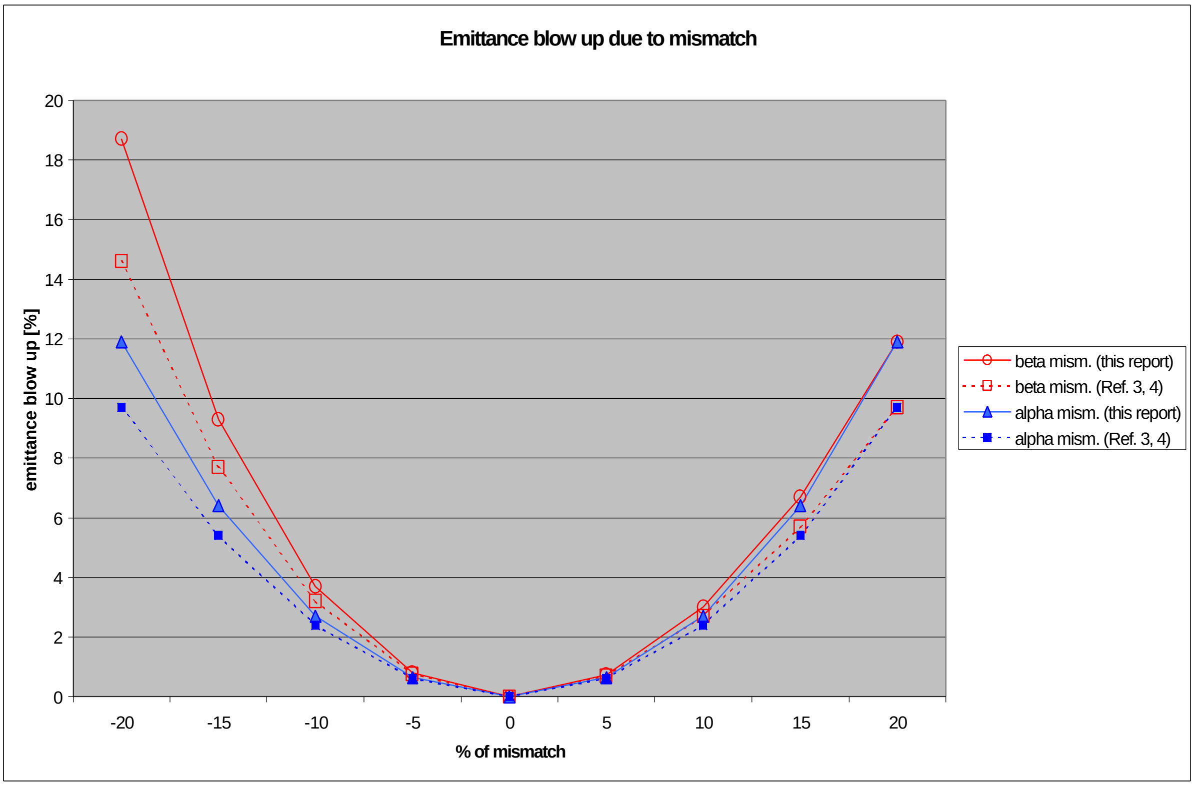

Fig. A1: Emittance blow-up due to mismatch. A comparison between Refs. 3, 4 and the simplifying calculation from above.

References

Ref. 1: U. Schneekloth, (ed.) **The HERA Luminosity Upgrade.**
By (DESY). DESY-HERA-98-05, Jul 1998. 199pp.

Ref. 2: P.J. Bryant; **Beam Transfer Lines**,
Proc. 5th CERN Accel. school, 7-18. Sept. 1992, CERN 94-01 Vol. 1.

Ref. 3: M.J. Syphers, T. Sen; **Notes on Amplitude Function Mismatch.**
SSCL-604-mc, Oct 1992. 19pp.

Ref. 4: Syphers, M.J.; **Injection mismatch and phase space dilution**
Fermilab-FN-458, June 1987

Ref. 5: V. Chohan, F. Pedersen, S. van der Meer, D.J. Williams (CERN**); Measurement of coherent Quadrupole Oscillations at injection into the Antiproton Accumulator.**
In *Nice 1990, EPAC 90, vol. 1* 320-322.

Ref. 6: G. Lopez, DESY, privat communication, and
A Quadrupole Envelope Oscillation Monitor for HERA-p,
talk and report 1998, unpublished

Ref. 7: K. Wittenburg, DESY; **A Non Destructive Way to measure Betatron Mismatch at Injection**
Proc. DIPAC 97, Frascati, Italy

Ref. 8: K. Wittenburg, DESY, **Emittance Measurement in the Proton Accelerators at DESY,**
Talk and report, International workshop on Particle Dynamics in Accelerators -- Emittance in Circular Accelerators -- 21 - 26 November 1994, Tsukuba, Japan

Ref. 9: G. Samulat, **Stahlprofilmessungen in den HERA-Protonen-Beschleunigern unter Ausnutzung der Restgasionisation,**
Diploma thesis, DESY-HERA 89-18,

Ref. 10: F. Hornstra; **A Beam Induced Gas Scintillation (BIGS) Profile Monitor**
DESY-HERA 89-04

Ref. 11: J. Camas, R. Cornali, G. Ferioli, R. Jung, J. Koopman, R. Maccaferri; **First Test in the SPS of gas scintillation beam profile monitor**,
SL-Note-98-037 MD and talk DIPAC99, Daresbury

Ref .12: C. Bovet, R. Jung (CERN); **A new Diagnostic for Betatron Phase Space Matching at Injection into a circular Accelerator.** CERN-SL-96-34-BI, Jun 1996. 3pp. Talk given at 5th European Particle Accelerator Conference (EPAC 96), Sitges, Spain, 10-14 Jun 1996. In *Sitges 1996, EPAC 96* 1597-1599.
CERN-LHC-PROJECT-REPORT-003-REV, Jun 1996. 14pp. Revised version.

Ref. 13: R.J. Colchester, R. Jung, P. Valentin (CERN); **Torwards the Limits of Frame Transfer CCDs in Beam Instrumentation.** CERN-SL-96-10-BI, May 1996. 8pp. Talk given at 7th Beam Instrumentation Workshop (BIW
96), Argonne, IL, 6-9 May 1996.

Ref .14: N.V.P. Murthy et al.; **Neutron total cross section on nuclei at Fermilab energies.**
Nuclear Physics B92 (1975) pp. 269

Ref. 15: E.F. Parker et al.; **Neutron Nucleus total cross section at 5.7 GeV/c.**
Physics Letters Vol. 31B, Nr. 4 (1970) pp. 250

Ref. 16: J.H. Atkinson et al.; **5 BeV Neutron cross section in H and other Materials.**
Phys. Rev. 123 Nr. 5 (1961) pp. 1850

Ref. 17: L Bosser, J ; Mann, J ; Ferioli, G ; Wartski, **Optical transition radiation proton beam profile monitor**; Publ. in Nucl. Instrum. Methods Phys. Res., A : 238 (1985) 45-52 . (23 p)

Ref. 18: V. P. Novikov; **Studies on a TV Profile Monitor for High Energy Beam with a small size using optical Transition Radiation**; Protvino 1995, not published.

Ref. 19: C. Bovet, R. Colchester, C. Dutriat, G. Ferioli, J.J. Gras, R. Jung, P. Knaus, U. Raich, J.M. Vouillot (CERN); **First Results from Betatron Matching Monitors installed in the CERN PSB and SPS.** CERN-SL-98-037-BI, Jun 1998. 4pp. Presented at 6th European Particle Accelerator Conference (EPAC 98), Stockholm, Sweden, 22-26 Jun 1998.

Ref. 20: J. Krider, C. Hojvat, **A Multiwire Secondary Emission Beam Profile Monitor with 20 Microns Resolution**; FERMILAB-Pub-85/176, Nucl. Instrum. Methods Phys. Res., A : 247 (1986) 304.