HERA-B. Multi-Target Equalizing Steering.

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Abstract

HERA-B experiment requires stable 40 MHz Interaction Rate equally distributed over eight independent targets interacting with 820 Gev protons from the halo of the beam. Different approaches have been tested for the multi-target steering under the request of equal contribution. The results obtained so far by measuring charges borne in the target due to the interaction with the proton beam appear to be the most suitable for reaching the goal.

1 Introduction

HERA-B is an experiment with a fixed target at HERA proton ring with the proton energy of 820 GeV [1]. The internal target is a set of eight isolated ribbons individually moving into the beam in two vertical and two horizontal planes separated in the beam direction by 40 mm. The typical sizes of the ribbons are (50 x 500 x 40000) μm^3 (500 μm is a thickness alongside the beam, while the thickness in the transverse direction is 50 μm). The first test results have been reported elsewhere [2].

To provide correct measurement and monitoring of the Interaction Rate (IR) nearly 70 different scintillator and semiconductor detectors have been installed at different parts of the HERA-B detector position. The purpose of this article is to describe the Three-Component Target Monitoring System as well as to present results related to the Multi-Target Equalizing Steering (MTES) obtained during 1996-1997 HERA-B running period.

There is a general requirement to have on average 1 interaction per proton bunch crossing per every target to have perfect conditions for the track reconstruction. To reach this goal one has to determine the working space for targets operation in the range of 4 - 5 sigma of the proton beam intensity distribution keeping interaction rate close to 40 MHz for the HERA-B and making no essential harm to the other HERA experiments.

2 Monitoring and Calculation of the Interaction Rate.

The absolute value of the Interaction Rate is calculated from the F1-rate measured by 4 Hodoscopes with the total acceptance of 7.8 per cent. Hodoscopes were installed symmetrically around the beam-pipe in vertical and horizontal planes at 9 m distance downstream from targets.

The ring of scintillators around the beam-pipe having a total acceptance of 90 per cent was used to calibrate the IR measured by Hodoscopes.

There are few reasons to have non-linear ratio between the IR and the rates measured by large area scintillator counters at high rates. The physical one is related to the necessity to make corrections for the Poisson distributed number of interactions per bunch crossing. The rate in an individual scintillator-counter at high IR could reach several MHz, which is enough to saturate last dinodes and as a result to spoil the IR measurement [3] . The details of the IR calculations could be found elsewhere [4] . The Target Monitoring System components are based on the counters with comparatively small acceptances (Si-telescopes and Si-pad detectors), while Charge Integrators provide data which do not depend upon any acceptance.

3 Three-Component Target Monitoring System.

The main task for the Target Monitoring System (TMS) is to monitor Target-Beam Interactions and to provide data to the steering code for an equal distribution of the Interaction Rate over all inserted targets.

One has to built the IR monitoring system operating at 40 MHz Interaction Rate equally distributed over eight interaction points created by eight targets moving in the close vicinity (2-3 mm) to the core of the proton beam to keep IR constant at progressively (or occasionally) changing parameters of the proton and/or positron beams as well as of the targets.

Thus, we have for the total IR, IR_{tot} :

$$IR_{tot} \;=\; \sum_{i=1}^{8}(N_i(t,x_i) * I_i(t,x_i)) * \sigma_{in}(p,N) * \Omega_i \;=\; 40\,MHz$$

Where: $N_i(t,x_i)$ –number of nuclei in the target i interacting with the beam at time t and relative beam-target position x_i (subject for some deviations due to temperature and vibration induced deformations, mechanical alignment, thickness inhomogeneity etc.).

$I_i(t,x_i)$ – intensity of protons interacting with individual target (subject for dynamical changes for many reasons (predictable and unexpected ones);

$\sigma_{in}(p,N)$ – inelastic cross-section;

Ω_i - acceptance for each of the targets.

The ideal operation of the target set-up would bring the Luminosity value $L_i(t,x_i)$ produced by every target, which has to be uniformly distributed over all 180 (out of 220) proton bunches and kept nearly constant during the whole experiment [1] :

$$L_i(t,x_i) \;=\; N_i(t,x_i) * I_i(t,x_i) = 4 * 10^{32} cm^{-2} * sec^{-1}$$

Due to the high value of the target efficiency (75 per cent) at the IR = 40 MHz and related to that drop of the proton beam intensity at the rate of 1 mA/h the only chance to keep IR constant is to move targets permanently closer to the beam core in accordance with the Mark Seidel function [5] (ideal time evolution of the relative target-beam position).

Different ways to realize this goal have been considered and tested [1,2,3] by measuring :

- Rates of the Scintillator or Si-pad detectors ;
- Asymmetries by four detectors set at the same polar angle in the plane perpendicular to the beam direction at 0,90,180,270 degrees for the azimuth angle (in the forward or backward hemisphere) ;
- Rates in small p-i-n diodes housed close to targets ;
- Beam-initiated charges in isolated wire-targets ;
- Changes of the wire resistance or temperature (due to the heating by the beam).

We shall concentrate here on the description of Three Component Target Monitoring System consisting of 8 Si-telescopes inside the Target tubes, 8 Charge Integrators connected to each of the targets and 16 Si-pad detectors installed at the exit window of the Vertex Detector Vessel , while other results could be found elsewhere [5].

3.1 8 Si-telescopes inside Target tubes.

The idea was to put small Si pin-diodes in close vicinity to the targets and measure the fragmentation products yield which should be proportional to the Luminosity $L_i(t, x_(i))$ in any case. To make the measured rate well selective to its mother-target one has to built a telescope system with a geometry allowing coincidence rate from the mother-target , mainly (Fig.1).

Each telescope consisted of two Si-detectors produced by Kiev firm 'DETECTOR' with an active area of $(3*3)mm^2$, 300 μm thick , separated by 10 mm distance, packed inside the metal shell and positioned inside the Target tube at the very bottom of it.

The distance between the first detector and the mother-target was in the range of 25 mm. There was a steel (500 μm thick) window and 200 μm thick Al shielding on the way of fragmentation products from the target - proton beam interactions at 820 GeV to the Si-detector.

The evaluated energy region for the protons (fragmentation products) mainly contributing into the coincident rate of a telescope was around 10 - 100 MeV for 50 mV thresholds and used pre-amplifiers and shaping amplifiers, (produced at Kiev INR) with shaping times of 0.5 μs. A typical

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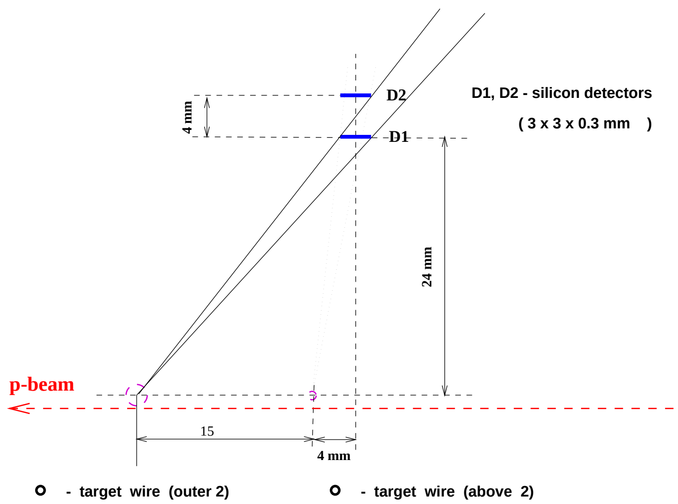
Target monitoring system

Position of silicon detectors



* Position and size of the Si- detectors in TMS are detremined by the goal to monitor contribution of each of the wires.

This is provided by two ways. To disantangle the contribution of two oppoisite wire in one plane we are going to use the asymmetry method. The contribution of wires from different planes is excluded by coincidences between detectors in one target tube (see the Figure).

Figure 1: Geometry layout for the Si-telescope inside the Target tube

rate was in the range of 10-15 kHz for the IR = 40 MHz. The rate shown by each of the telescope counters R_i:

$$R_i \;=\; L_i(t,x_i) * \sigma_{fi} * \Omega_i \;+\; \sum_{k}^{7} L_k(t,x_k) * \sigma_{fk} * \Omega_k \;+\; Bg$$

Where: $L_i(t,x_i)$ – Luminosity value for the mother-target (diagonal elements in calibration matrix);

$L_k(t,x_k)$ – Luminosity being produced by any other target (non-diagonal elements);

$\sigma_{fi,fk}$ – fragmentation cross-sections;

Ω_k, Ω_i – corresponding acceptances of telescopes; Bg - non-target originated background rate.

Due to the modified '97 geometry of the Si-telescopes (the distance between the detectors has been increased up to 10 mm and the targets were positioned exactly at the axis of the target tube) the contribution of the non-diagonal elements has dropped up to the level of a few per cent for all targets but the one lying in the same plane with a mother-target.

Fig.2 illustrates operation of the Si-telescopes and their selectivity to individual targets. Of course, to get proper operation one has to make rather time consuming measurement of the so-called calibration matrix. This is necessary for the correct determination of the individual target contribution , which could be used for the target steering under the request of equal contribution.

The left corner picture of the Fig.2 shows the evolution of the Interaction Rate (Hz) versus time (hours). On average, it has been varying by 1 MHz around 9 MHz with very short spikes by few MHz.

Two targets (INNER1 and INNER2) were moving at that time into the beam (bottom pictures) with their positions shown in (mm) versus the time ($hours$).

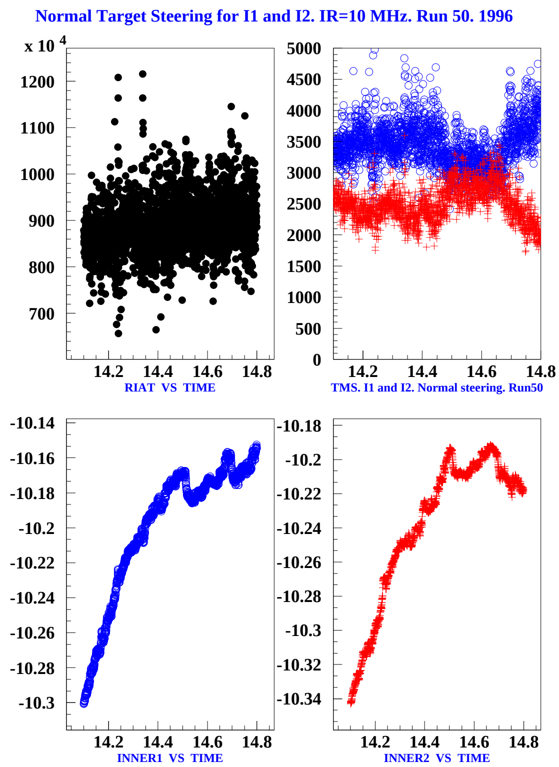


Figure 2: Si-telescopes selectivity to the individual target contributions.

So called normal steering based on the mechanical approach (see below) has been used to move targets for keeping IR constant.

The upper right corner picture of the Fig.2 shows individual target contribution , as it was measured by the Si-telescopes inside the target tubes for the INNER1 (open circles) and INNER2 (crosses). One can conclude that the effective time of the equal contribution was short ($14.5 < t < 14.7$), while the time for adjusting appropriate target positions was considerably larger.

Much better results for the equalization were obtained if the data measured by the Si-telescopes were included into the steering code (Fig. 3).

Here, again at the upper left corner picture one can observe the IR steadily growing up to 20 MHz. In contrast to the Fig.2 Si-telescopes have now fixed an equal contribution of each of the targets (upper right corner picture) at any time. This has also lead to very smooth, regular movement of both targets into the beam (bottom pictures of the Fig.3), as it was expected theoretically [4].

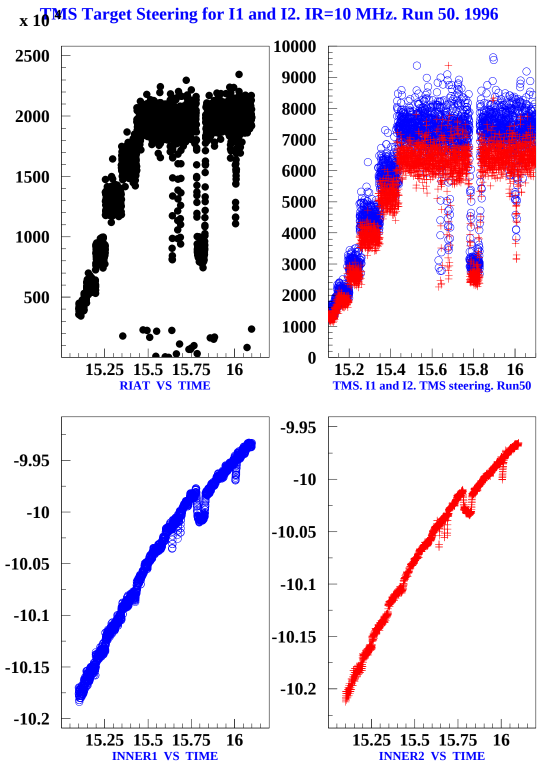


Figure 3: Si-telescopes selectivity to the individual target contributions. Targets steering by the TMS-data.

Thus, the data from Si-telescopes can be used not only for monitoring but also for steering of the targets. Of course, the proper calibration especially for telescopes in the same target planes should be undertaken as well as asymmetry method [1] should be used to determine each target contribution.

One could expect some possible reasons for non-linear or non-reproducible ratios between Interaction Rate measured by Hodoscopes and TMS :

- The target is partially damaged (deformed) to such extent that the Interaction Regionis partially out of the Si-telescope acceptance).
- There are other than the Si-telescope mother-target origins of the contribution into the Hodoscope rate (another target, induced radioactivity, synchrotron radiation from the positron beam, scattered proton beam etc.,)

Concerning the long term reliability of the Si-telescopes part of the TMS detailed analysis should be made related to the stability of the amplifications/thresholds as well as to the radiative hardness of the detectors.

The so far observed variations as well as changes did not exceed 20 per cent level in the corresponding counting rates even under the conditions that leakage currents increased from few nA to hundred nA .

3.2 16 Si-pad detectors.

To provide the Luminosity Monitoring directly related to the contribution of the minimum ionizing particles one has to put the monitoring detectors in the forward hemisphere under the request of the minimum affect onto the HERA-B detector performance. This has lead to the choice of the Si-pad detectors positioned at the very boarders of the HERA-B detector acceptance.

The set of 16 Si-pad telescopes has been positioned at the Outer- Below-Inner-Above sides of the proton beam-pipe at the Vertex Detector System exit window. To reduce the background from the synchrotron radiation and/or induced radioactivity the detectors were installed in pairs creating the telescope structure.

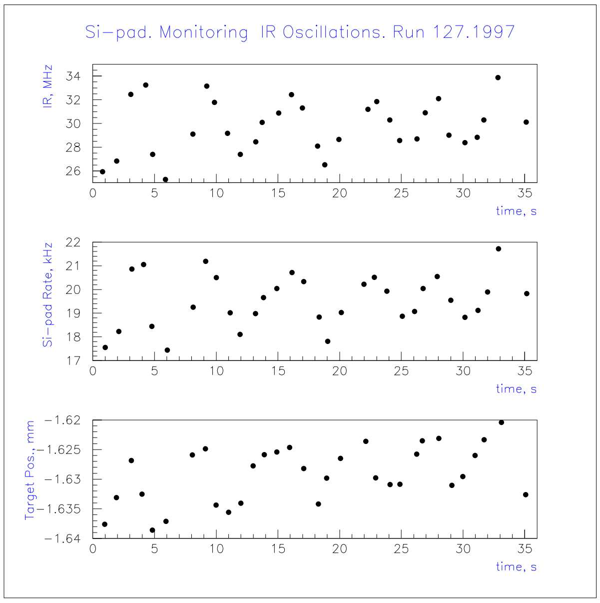


Figure 4: Si-pad monitoring of the Interaction Rate

The ceramic plate supports two Si-detectors with an active area of 29 x 32.5 mm^2 and 380 μm thickness (reached at the negative depletion voltage of 100 V) and built in-situ pre-amplifiers providing 1.3 mV/mip negative signal at their output (signal/noise ratio: 5 - 7). The center vertical line of the first telescope is at the distance of (231 +/- 5) mm from the beam tube axis and 2053 mm from the Z=0 point for HERA-B. The corresponding distances for the second telescope are (261 +/- 5) mm and 2073 mm, respectively.

Fig. 4 illustrates quality of the IR monitoring by the Si-pad detectors. The picture at the top of Fig. 4 shows the IR (in MHz) measured by the Hodoscopes as a function of time for arbitrary chosen 35 s during the Run 127, when the only Target (INNER1) has been inserted in the beam with its position (in mm) shown at the bottom picture of Fig. 4. The Si-pad Rate (in kHz) , shown at the middle picture of Fig.4, develops its value in an exact correspondence with the oscillating feature of the IR measured by the Hodoscopes.

Fig. 5 (bottom picture) shows linear correlation between the Si-pad rate and the rate measured by the Si-telescope installed inside the target-INNER1 tube when the IR (produced at that time again by the INNER1 target, only) was growing up to 35 MHz and down to 0.2 MHz (picture at the top of Fig. 5).

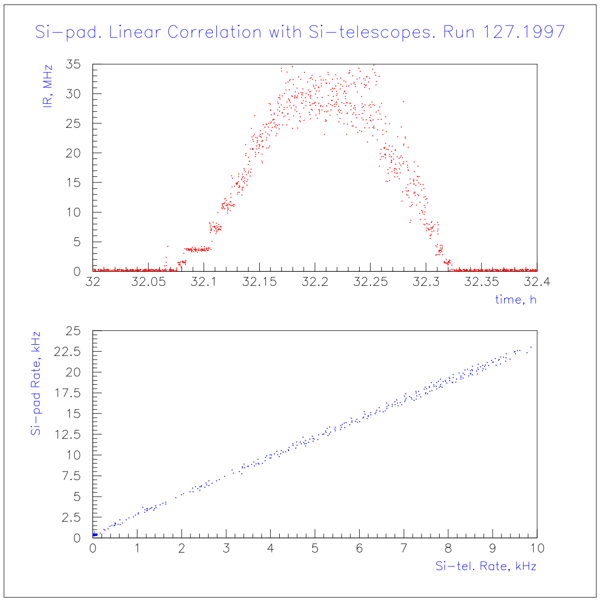


Figure 5: Si-pad - Linear response to the Interaction rate, monitored by Si-tescope inside the tube for the INNER1 target.

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It was rather difficult to get clear mip peak for the detectors operated in a single mode in the real HERA-B environment even at low rates (due to the large background generated by the soft gamma-rays and neutrons). Only providing triggering to ADC from the Trigger scintillator counters we were able to see (also from time to time, only) Si-pad ADC spectra with clear 1 and 2 mips amplitude distributions. hat is why the coincident rates from Si-pad telescopes at the threshold of 1 mip) were taken for the IR monitoring.

Ideally for HERA-B, there has to be a file at the HERA Control Room which brings everything requested by ZEUS, H1 , HERA-B and HERA into the beam vicinity in a coupled way. This needs of course, first of all management efforts, and studies afterwards.

Si-pad data being related to the mips flow from the target provides an additional independent way of Interaction Rate measurement. Si-pad data could also be used for equalization of the Interaction Rate among 4 targets (lying in the same plane)using asymmetry method [1] .

3.3 8 Charge Integrators .

There are few reasons to have an accumulating charge in an isolated target irradiated by high energy protons. The estimate show that each of the 820 GeV proton should knock-out 5-10 δ-electrons from the C - Cu target creating the positive charge.

Another origin of the charge is due to the proton target inelastic scattering (every proton can travel through the target without nuclear interaction , roughly 1000 times , originating charges of both signs (including those due to a β^{+-} - radioactive decay). It is rather difficult to make any accurate calculation of a finally balanced charge in the target due to many uncertainties (cross-section values, absorption, background due to the r/f pick-up, time evolution etc.,).

It was phenomenologically established that the beam-target interaction originated charge has a positive sign and being measured by the Charge Integrator shows the values corresponding to the current of (0.1 - 1) nA linearly related to the IR = (5 - 50) MHz for different targets.

The scheme for the Charge Integrator connections is shown at Fig. 6.

The current being permanently provided by 1.5 V battery through the target to the Charge Integrator allows for to check the stability of its operation as well as to know the status of the target (there was an experience with partially broken targets arriving into the beam).

The measurements done up to now have shown a good performance of the Charge Integrators. Their response is linearly related to the Interaction Rate (Fig.7).

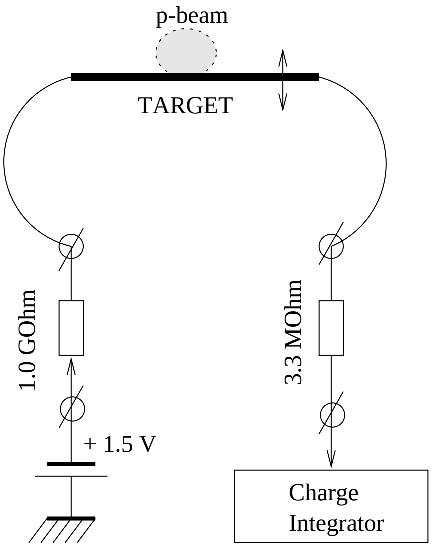

Figure 6: Charge Integrator connections to the Target.

What is essential in the Charge Integrators performance that they respond in a well reproducible way to the corresponding individual target-beam interaction , only (Fig.8). This is an exclusive feature of those devices, which distinguish them as a unique tool for the Multi-Target-Equalizing-Steering (MTES).

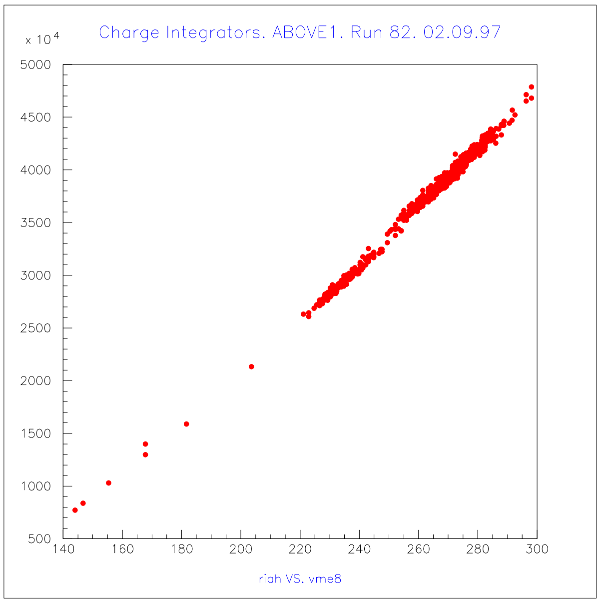

Figure 7: Linear relation between the Charge Integrator rate (Horizontal axis, Hz) and the Interaction Rate (Vertical axis, Hz)

The top (1st) picture of the Fig.8 shows IR measured by the Hodoscopes while different targets were introduced into the beam:

- ABOVE1 for the time interval $23.8h < t < 24.8h$;
- INNER1 $28.1h < t < 29.0h$;
- BELOW1 $21.8h < t < 23.1h$;
- The response of the corresponding Charge Integrators is shown at the 2nd, 3d and 4th pictures of the Fig.8

The permanently present output frequency of the Charge Integrators in the range of 100 Hz corresponds to the calibrating current of 1 nA flowing through the targets. Besides the fact that one can always consider the stability of the Charge Integrators in this way, the status of the target is monitored as well.

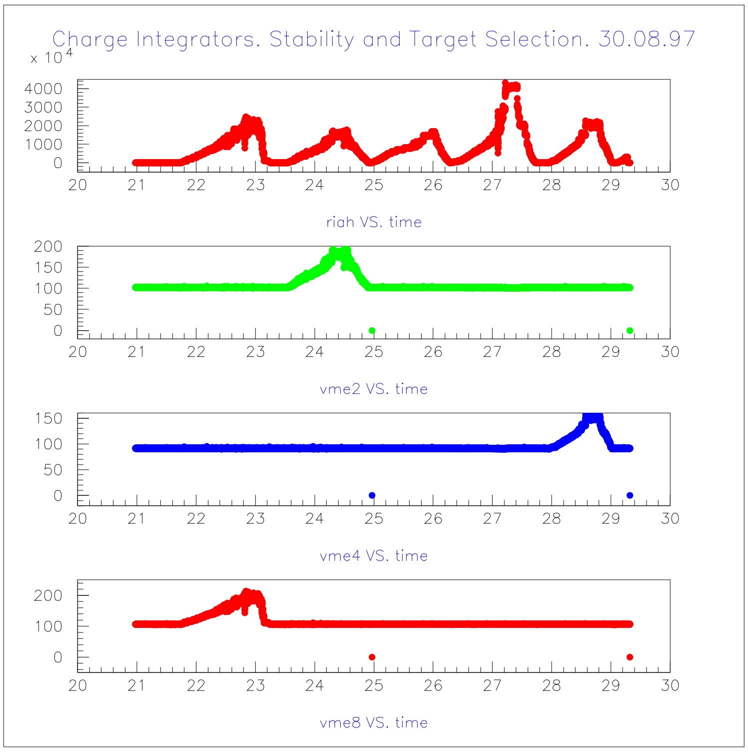

Figure 8: Exclusive selectivity of the Charge Integrators to the contribution of the individual Target

4 Multi-Target Equalizing Steering.

4.1 'Mechanical' Steering

There is a special set of hardware and software stuff related to the Target Steering procedure called Target Control System (TaCoS)[].

The main task for the TaCoS is to provide stable (IR) equally distributed over all (at maximum eight) inserted targets.

The task of reaching any required IR (up to few hundred MHz) is practically solved. Yet, sometimes IR becomes rather unstable, with non-equally populated bunches and/or even non-bunched , continuous time structure. Moreover, the last feature is geometrically dependent being strongly emphasized for the OUTER targets.

The problem of the Multi-Target Equalizing Steering (MTES) has been approached at the very beginning by the attempt to use so-called 'mechanical' algorithm. As the Target Monitoring System (TMS) data show, this approach does not work efficiently. Individual target contribution is not stable, varying chaotically from one target to another one (at most 10 per cent of the time making equal contribution).

It is clear that the running efficiency under the strong request for the multi-target equalization would be rather low (see Fig.2 and Fig.9)

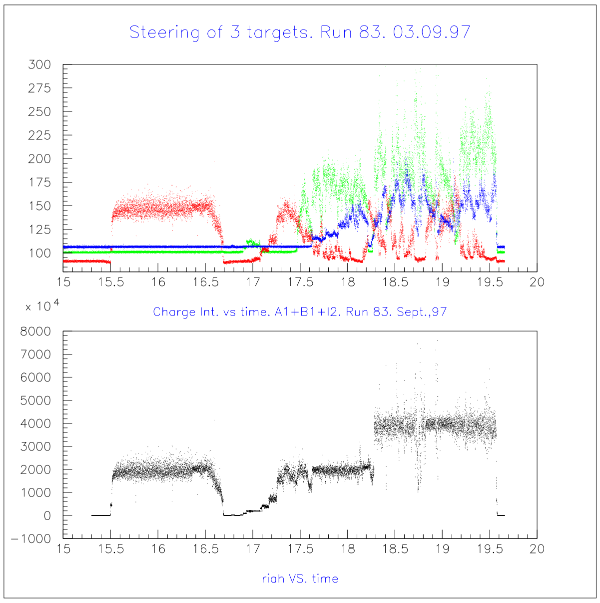

Figure 9: MTES by the 'mechanical' algorithm. Bottom: IR (vertical axis, Hz) vs time, (hours) Top : Charge Integrator rate ,(Hz) vs time: $15.5 < t < 16.5$ - IR = 20 MHz for the single inserted target INNER2; $17.0 < t < 19.5$ - IR up to 40 MHz for three simultaneously inserted targets: ABOVE1, BELOW1 and INNER2.

Fig.9 illustrates the behavior of the Interaction Rate distribution among the three inserted targets under the steering by the 'mechanical' code. One might see that while Hodoscopes were showing rather smooth behavior of the IR, in fact there were order of magnitude varying contributions from individual targets. There were rather short time intervals when Charge Integrator values were indicating equalized target contributions.

The right approach to MTES is to use the TMS data (Charge Integrators and/or Si-telescopes) which correspond to the individual Target contribution. The data show well reproducible results, yet one has to put some efforts to implement those values into a steering code accurately.

The reason for the large Interaction Rate fluctuations obviously belongs to the non-balanced target-beam movement.

There has to be a condition fulfilled for the bunch-independent-steering that the time between steps of any target-beam movement (for instance, caused by high frequency modulated instability in the HERA optics , or due to the neighboring motors induced oscillations) is much larger than the length of the bunch train (21 mus).

4.2 TMS steering

TMS steering provides quite perfect equalization of the individual target contribution. Both approaches based on Si-telescopes (see Fig. 3) as well as Charge Integrators(Fig. 10) have been successfully tested.

Fig. 10 illustrates the performance of the steering procedure made by 'mechanical' approach as well as by the Charge Integrators. Starting with the very top picture (Fig.10.1) one can observe the evolution of the IR (shown in Hz) versus time (shown in hours) measured by the Hodoscopes, while two targets (ABOVE1 and BELOW1) from the first Target station were moved in. Their positions are shown in mm at Fig 10.3 and 10.4, respectively.

The individual target contribution as it was measured by the Charge Integrators is shown at Fig.10.2 (red line - for the target ABOVE1, black line - for the target BELOW1).

The time interval $35.8 < t < 37.9$ corresponds to the steering under the 'mechanical' approach. The overall IR as measured by the Hodoscopes (Fig.10.1) was in the range of 15 MHz at that time, varying by factor of 20 per cent. Yet , the individual contribution has been varying by factor of 5 - 10, reaching more or less stable conditions after nearly one hour of the search ($37.0 < t < 37.9$).

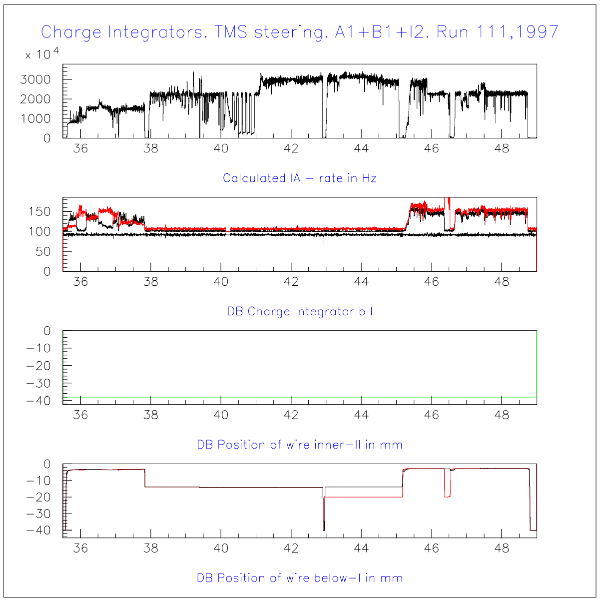

Figure 10: MTES by the Charge Integrators.

At the time interval $45.0 < t < 49.0$ data from the Charge Integrators were used for the target steering. One can clearly see now a smooth and equalized distribution of the rates between the two wires while the overall IR has been kept at the range of 20 MHz.

The characteristic behavior of the steering code is demonstrated at the time interval $46.2 < t < 46.6$, when the target ABOVE1 has been retracted totally (Fig. 10.4), leaving the only contributing into the IR target BELOW1. Namely, this target has been immediately moved in by the steering procedure to compensate the loss caused by the ABOVE1-target retraction. One could see the fall and jump of the rates measured by the corresponding Charge Integrators (red line for the ABOVE1, black one - BELOW1) at the same time interval (Fig.10.2).

As far as Charge Integrators have shown reliable operation and are simple in handling them (easy calibration, permanent check of the stability of their response, control of the target with respect to their even partial damage) they are the preferable devices for the steering of the targets.

Si-telescope data should serve as a back-up for the Charge Integrators ones.

Si-pad data being more related to the mips flows from the target will provide an additional independent way of the Interaction Rate measurement.

5 Interaction Rate Stability

What is finally expected to be provided by the Target sub-system for the HERA-B experiment could be specified as follows:

- Absolute value of the IR;
- IR Distribution over targets;
- Expected IR instabilities;
- Position, size and time evolution of the Interaction Points (IP).

To reach the stable and predictable position of the IPs one has to provide the fast measurement of the parameters for the Steering Procedure to define M. Seidel-function for the current proton beam fill [].

There is clear relation between HERA-B running efficiency and IR instabilities. This is true for both kind of instabilities related to the beam-target relative fluctuations on the large time scale (more than one proton bunch turn) as well as to non-equal bunch population.

Micro-variations of the IR (T less 21.12 mu) will affect the HERA-B running efficiency even worse, brining more problems with the track reconstruction procedure.

There has to be an optimum value for the IR in that case. Its minimum value is defined by the still acceptable time for the data accumulation. Its maximum value will be now dependent not only on the irradiation issues but also on the possibility of the track reconstruction due to the effective increase of the number of interactions/bx.

Among the possible reasons for the IR instability one could account for the following:

- Beam - target relative jumps.
- Target varying thickness.
- Beam varying intensity.

Beam - target relative jumps, as the beam-position monitors (bpm)-data show, reach sometimes value of 5-20 μm which could lead to huge spikes in the IR []. One has to include some or how the bpm-data into the Steering code.

There is a possibility to have some non-controlled target movements due to the mechanical imperfections of the Target system as well as due to the induced by external (vacuum pumps, electric generators, S-bahn phenomena etc.,) and/or internal (beam or r/f induced heating , beam-target Coulomb interaction etc.,) sources vibrations

There could be different reasons for the target varying thickness.

- We have an experience with partially destroyed targets (which was not a simple case to realize it, as far as there was no direct way to observe the target integrity). This has to be excluded as far as one can never reproduce data once observed with the target consisted of many filaments chaotic-ally arriving into the beam.
- Beam heating could lead to dynamically changing deformations up to a partial evaporation of the target material.
- One could consider also transmutation processes under half of a year irradiation by the intensive proton beam.

Beam varying intensity is of course of major importance for the IR instability. Any instability in the beam transporting system would lead to the IR instability. Moreover, high frequency modulated instabilities could modify even bunch population at the HERA-B IP regions, only (as far as peripheral parts of the beam are used for).

Summary

The Target Monitoring System in its three-component shape provides a reliable set of data for the HERA-B Luminosity Monitoring.

Data from the Charge Integrators connected to targets are now the most reliable for the Steering Procedure under the request of Muli-Target Equalization.

Efficiency of further improvements (as well as forthcoming running efficiency) would be the highest if HERA includes in 'LUMI TUNING' procedure specifications for the HERA-B Interaction Rate (absolute value of 40 MHz, 10 per cent rate stability, equal bunch population).

Ideally for HERA-B, there has to be a file at the HERA Control Room which brings everything requested by ZEUS, H1 , HERA-B and HERA into the beam vicinity in a coupled way. This needs of course, first of all management efforts, and studies afterwards.