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Background Measurements at HERA near the H1 Detector

by

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Abstract: We report on background measurements at HERA during the summer and autumn runs in 1992. A sample of 8 beam loss monitors (BLM) with small silicon photodiode detectors has been installed near the H VETO WALL at $z \sim -650\,cm$. The radial distance of the BLM from the beam is between $r = 18\,cm$ and $r = 47\,cm$. The results of the BLM measurements are compared with those of larger photodiodes inside the H 1 detector ($z = -136\,cm$ and $r = 11 - 14\,cm$). A good correlation between doses measured by both systems is found for proton injections. Every particle detected by the BLM corresponds to a dose of about $1\,\mu Rad$ inside the central tracking detectors. Because of their advantages (no saturation even at high particle fluxes and no pedestal) the BLM provide useful information about doses inside the H 1 detector by measuring particle rates outside the detector.

Additional background measurements were made with TLD dosimeters which were placed on the H 1 beampipe at $z = +20.5\,cm$ and $z = -46.0\,cm$. When scaled to the HERA design currents an integrated dose of $3 - 40\,kRad/y$ near the beampipe ($r \sim 10\,cm$) is expected. This is in agreement with estimations made in [EWERT 1992].

1 Introduction

In a previous report [EWERT 1992] one of the authors has described dose measurements during the HERA luminosity run in summer 1992 (June 29th - August 3rd). Silicon photodiodes with a sensitive area of $1\,cm^2$ were used to measure the integrated dose from different HERA operation states, for example beam injections, inside the H 1-detector. The diodes were installed at $z = -136\,cm$ and at a radial distance $r = 11 - 14\,cm$ from beam position. A total of 152 HERA processes were investigated. Amongst them were 30 proton beam injections, 49 electron beam injections and 33 beam losses. The aim of [EWERT 1992] was to estimate the expected total dose in one year of HERA operation at full currents. The total dose inside the H 1 detector ($r = 11 - 14\,cm$) has been estimated to $4 - 12\,kRad/y$ with additional $1 - 35\,kRad/y$ due to HERA test operation. This gives an idea of the conditions for the future H 1 silicon vertex detector, which is going to be placed at a position comparable with the one of the photodiodes. More details about the expected doses from different operation states of HERA at nominal currents are shown in table 1.

However, the method of dose determination using the photodiodes has shown certain disadvantages: The ground frequency of the readout system represents a sizeable pedestal and has to be substracted from the measured rate. This leads to uncertainties. A more serious problem is the occasional saturation of the readout electronics, a fact that excludes certain measurements from further analysis, especially beam losses.

No problems of this kind appear when beam loss monitors (BLM) are used, but they are simply too big and massive to be installed inside the H 1 tracking detectors. Therefore a sample of 8 BLM was placed around the beam pipe near the H 1 VETO WALL ($z \sim -650\,cm$). The BLM were operated and read out into the H 1 VETO WALL data aquisition system during the summer run of HERA in 1992. The goal of this note is to find out whether there is a correlation between the doses measured with the photodiodes inside the detector and the rates of the BLM outside the detector. Since the evaluation of the BLM rates is easier, one would in this case have an additional instrument for background measurements which is even better to handle. In a way, this note is a supplement to [EWERT 1992], since the measurements of identical HERA operations are compared, regarding both, the H 1 photodiodes and the BLM at the H 1 VETO WALL.

We also report on integrated doses measured with thermoluminescense dosimeters (TLD) during the summer and autumn run of 1992, which allow consistency checks on the results of [EWERT 1992].

In section 2 the beam loss monitors and their readout are described. In section 3 the evaluation of data is discussed. Sections 4 and 5 give the results.

	Integrierte Gesamt–Dosis	Skalierung
Protonen- Injektionen	5 - 69 $mrad/mA$	$160 \times 200 \times 1$
	0.2 – 2.2 krad/y	
Elektronen- Injektionen	4 - 25 $mrad/mA$	$60 \times 200 \times 4$
	0.2 – 1.2 krad/y	
Offene Kollimatoren	31 - 70 $mrad/mA$	$60 \times 200 \times 4$
	1.5 – 3.4 krad/y	
Protonen- Strahlverluste	5 - 50 $mrad/mA$	$160 \times 200 \times 1$
	0.2 – 1.6 krad/y	
Elektronen- Strahlverluste	5 - 50 $mrad/mA$	$60 \times 200 \times 4$
	0.2 – 2.4 krad/y	
Gespeicherte Strahlen bei Luminositätsbetrieb	$\leq 0.014\,rad/h$	$20 \times 24 \times 200$
	≤ 1.3 krad/y	
SUMME	**3.6 – 12.1 krad/y**	
Zusätzliche Belastungen durch Testbetrieb (2 Monate/Jahr)		
Protonen- Injektionen	86 $mrad/mA$	$16 \times 60 \times 5$
	0.4 – 8.3 krad/y	$160 \times 60 \times 10$
Elektronen- Injektionen	46 $mrad/mA$	$6 \times 60 \times 5$
	0.1 – 1.7 krad/y	$60 \times 60 \times 10$
Offene Kollimatoren	320 $mrad/mA$	—
	0 – 11.5 krad/y	$60 \times 60 \times 10$
Protonen- Strahlverluste	100 $mrad/mA$	$16 \times 60 \times 5$
	0.5 – 9.6 krad/y	$160 \times 60 \times 10$
Elektronen- Strahlverluste	100 $mrad/mA$	$6 \times 60 \times 5$
	0.2 – 3.6 krad/y	$60 \times 60 \times 10$
SUMME	**1.2 – 34.7 krad/y**	

Table 1: Expected doses at nominal HERA current as deduced from the measurements of [EWERT 1992]

2 The beam loss monitor (BLM)

The BLM has been described in detail in two reports: [SCHLGL 1992] and [MORRE 1992]. At this point only the most important features are listed.

Original application: The BLM were developed by the HERA machine group PKTR to provide an instrument which can be used to detect beam losses of the HERA proton beam [WITTBG 1990]. This is important to avoid so-called quenching of the supraconducting magnets.

Fundamental way of function: In principle the BLM is a particle counter. The heart of the detector consists of two small PIN silicon photodiodes[1], each with a sensitive area of $2.75 \times 2.75\,mm^2$. They are operated in $24\,V$ reverse bias mode, that means both diodes can work as independent particle detectors but are normally used in coincidence mode: a particle is only recorded if it crosses both diodes.

Characteristics: The BLM is a fast detector. Its amplifier has a relaxation time $t < 96\,ns$ so that the BLM can record and distinguish particles from every HERA bunch crossing. Assuming that due to the very small detector area of $0.0756\,cm^2$ at most one particle crosses the detector during one bunch crossing, no problem with saturation is expected. Furthermore, the operation in coincidence mode provides measurements with hardly any background: the dark pulse rate is less than $0.01\,Hz$. Every detected particle is converted to a TTL-signal that can easily be processed with additional counters.

Experimental setup

Fig. 1 shows a top view of the 8 BLM. In table 2 the coordinates of the BLM are summarized. Fig. 2 shows a side view of the H1 detector. The photodiodes inside the detector at $z = -136\,cm$ and the BLM around the VETO WALL at $z = -570\ to - 700\,cm$ are marked in fig. 2. It is important to point out that monitors 95 and 96 are placed in a way that the sensitive area of the photodiodes is parallel to the beam axis in contrast to the orientation of the other monitors. These diodes are perpendicular to the beam axis. Detectors 95 and 96 are placed directly on and below the magnet surface, respectively ($r = 27\,cm$). Monitors 94 and 97 are placed inside the gaps between the magnets and are at a distance $r = 18\,cm$ from the beam. Finally, monitors 90 to 93 are placed between the large scintillators of the VETO WALL and the steel plate at $z = -650\,cm$. Their radial distance from the beam is $r = 47\,cm$.

BLM	r [cm]	x [cm]	y [cm]	z [cm]
97	18	0	+18	−573
94	18	0	+18	−704
95	27	0	+27	−625
96	27	0	−27	−625
90	47	−44	+16	−633
93	47	+44	+16	−633
92	47	−44	+16	−667
91	47	+44	+16	−667

Table 2: Coordinates of the photodiodes of the beam loss monitors (BLM); (z is the distance from the interaction point)

Readout: Two NIM-modules are necessary to provide the readout of the TTL-signals: Together with the BLM the first readout unit is near the VETO WALL. It supplies the monitors firstly

[1] Siemens BPW34

with a 24 V voltage as reverse bias for the photodiodes and secondly with 5 V control voltages[2]. The TTL-signals from the beam loss monitors reach the second module[3] via a 60 m coaxial cable for each monitor. They are converted into NIM-signals and fed into a CAMAC counter module which is read out every two seconds (via the same processing path as described in detail in [EWERT 1992]). The sensitive counting time within this interval is approximately 1.5 sec, i.e. there is a deadtime of about 25 %.

3 Measurement of different HERA processes

In order to measure the integrated dose of a particular HERA process the same evaluation method as for the photodiodes inside the H 1 detector is used: During one process all rates are added up and finally the total number of detected particles is multiplied with a calibration factor. This is at the same time done for all monitors and gives the integrated dose for the relevant process. The calibration factor was determined in [MORRE 1992] to

$$6.9 \cdot 10^{-6} \, Rad \text{ per detected particle}$$

with an error of 20 30%. A complete injection process in HERA lasts between 10 *minutes* and 4 *hours*. With a dark pulse rate of 0.01 hz there is in the worst case an uncertainty of about 1 $mRad$ which can be neglected.

This note deals with 22 proton injections, 41 electron injections and 14 beam losses[4]. The injection processes are those which are also used in [EWERT 1992], except for those with saturation in order to make a meaningful comparison possible. Since every beam loss with a clear effect led to saturation in the H 1 diodes, a comparison with BLM data for these processes is not possible. Hence only the measured doses are given.

Examples: Fig. 3 shows a complete proton injection which took about 4 *hours*. After several unsuccessful attempts a proton beam of 850 μA is achieved (see upper part of the figure). The beam loss monitor 94 detected 204703 particles which corresponds to about 1.4 Rad. When comparing the rates from the photodiodes and the BLM, please note that the first ones are plotted on a linear scale and the latter ones on a logarithmic scale. An equivalent example of an electron injection is shown in fig. 4. In 30 *minutes* an electron beam of about 2.4 mA is injected. This leads to an integrated dose of 22 $mRad$ in monitor 94. Fig. 5 finally shows a total proton beam loss which occurs in several steps (the delay of the beam current display beyond the first arrow has technical reasons). During the first 4 *minutes* the stable proton beam produces no background. After the loss of about 80 % of all protons the remaining beam is unstable and produces high rates in the beam loss monitors. In the end the whole beam is lost.

4 Results from BLM

Proton beam losses: In fig. 6 the measured doses from 14 proton beam losses are shown for monitor 90 as an example for $r = 47\,cm$, for monitor 95 as an example for $r = 27\,cm$ and for the monitors 94 and 97 at $r = 18\,cm$. Except for the latter the measured doses are less then 100 $mRad$ per lost mA proton current. The values from the monitors near the beampipe are between 100 *and* 1000 $mRad/mA$ — about a factor of ten above the values measured with the photodiodes in [EWERT 1992] inside the H 1 tracking detectors. However, because of the problem of their saturation a direct comparison is not possible here.

[2] In addition to the coincidence mode either photodiode can be used in single detection mode. With a switch on the second NIM-module one can change between the two modes. However, since single mode leads to problems with non-constant dark pulse rates, the single mode has not been used in summer 1992

[3] This module also provides the supply voltages for the first module.

[4] p-inj.: all except ID 8/10/18b/20b/22/5/6/9;
e-inj.: all except ID 46/56/59/2/6/9/57/58;
beam losses: all except ID 4/8/9/16/18/22/10/19/26.

Proton injections: Fig. 7 shows the correlation between the doses derived from the BLM and from the photodiodes inside the H 1 detector. A *plus* in the pictures corresponds to one of the 22 injection processes. Fig. 7 clearly shows a proportionality between the doses from the photodiodes and the BLM. The doses measured with the BLM are about 5 *to* 10 *times* higher than those measured with the photodiodes. In the case of diode 3 the proportionality constant is about 7 for monitor 94 and about 5 for monitor 97.
The high doses of the BLM could be explained with an inconsistency of the calibration factor (see [MORRE 1992])[5]. Alternatively one could argue that the BLM are exposed to a higher amount of incident proton beam halo. This halo might get partially absorbed by the endcaps of the H 1 detector before reaching the photodiodes.
To be independent of a particular BLM calibration one has to compare the measured rates with the doses of the photodiodes: This gives a conversion factor which allows interpreting the rates of the BLM as doses. In the case of diode 3 and monitor 94, 100 $mRad$ in the diode correspond to 700 $mRad \equiv 101449$ *counts* in monitor 94. Thus, one detected particle in monitor 94 corresponds to about 1 μRad at the position of diode 3 inside the detector. Table 3 lists the conversion factors of the monitors 94 and 97 for all photodiodes.

	diode 6	diode 7	diode 3	diode 5	diode 2
monitor 97	0.6	0.9	1.4	1.2	1.7
monitor 94	0.5	0.8	1.0	0.9	1.4

Table 3: Conversion factors (units are μRad *per count*)

Electron injections: The same correlations as above are shown for 41 electron injections in fig. 8. In contrast to proton injections the BLM doses are about two times smaller than those of the H 1 diodes and the correlation between both systems is weak. This can be explained with a shielding of the BLM since background of the electron beam reaches the BLM after penetrating the H 1 detector. Additionally, operation of the BLM in coincidence mode prevents the detection of photons from synchrotron radiation. Hence meaningful conversion factors between BLM and H 1 diodes cannot be given for electron injections or electron beam losses.

Radial distribution of background: Since the sensitive area of monitors 95 and 96 is parallel to the beam axis there are only two measuring points left: monitors 94 and 97 at $r = 18\,cm$ and monitors 90 to 93 at $r = 47\,cm$. We observe a clear decrease of dose at large radial distance from the beampipe. However, quantitative statements on the functional form[6] of the radial distribution of background cannot be made.

5 Total doses measured with standard TLD dosimeters

During the HERA summer run (May to August 1992) and the autumn run (September to November 1992) background measurements were also made with TLD dosimeters[7]. With such dosimeters only integrated doses can be measured. The BLM cannot be calibrated with the TLD dosimeters, because the BLM are insensitive to synchrotron radiation whereas the TLD were exposed to all kinds of radiation all the time.
Table 4 summarizes the doses measured with TLD dosimeters at the positions of the BLM[8].

[5] E. Morré has compared measurements of his BLM with those obtained by other ZEUS background detectors. There is still a discrepancy between this comparison and the calibration factor, i.e. the latter is about a factor of *five* higher than the value evaluated by the comparison.

[6] The ZEUS collaboration has measured a radial dependence of $\propto 1/r^2$ during test measurements at HERA in November 1991 (see [LOHRMA 1992]).

[7] These dosimeters are prepared and evaluated by the DESY radiation protection group.

[8] The TLD were fixed on the housing of the BLM.

Two sets of TLD were used: the first one during the summer run and a second one during the autumn run. Remarkably high doses were measured during the autumn run near the beampipe ($r = 18\,cm$). High electron currents with corresponding high levels of synchrotron radiation at the end of the autumn run can explain these values.
To get an idea of the corresponding total doses expected at full currents, the measured values have to be scaled. Since typical electron and proton currents in 1992 were about $3\,mA$ (design value $= 60\,mA$) and $2\,mA$ (design value $= 160\,mA$), respectively, the appropriate scaling factor for the measured doses is between 20 and 80. The last line in table 4 gives the resulting doses which are expected in one year ($\equiv$ 200 *days*) of HERA operation at full currents. Since the summer and the autumn run lasted for a total of about 200 days and the measured radiation represents typical HERA operations including luminosity runs and test operation, only the beam currents have been scaled. The expected total dose near the beampipe ($r = 18\,cm$) is in the same order of magnitude as the results given in [EWERT 1992] (see section 1).

TLD dosimeters were also placed directly on the beampipe of the H 1 detector ($r = 10\,cm$). The positions of the dosimeters are shown in fig. 9 and summarized in table 5. These dosimeters were irradiated during both the summer and the autumn runs. The measured dose is about a factor of 2.0 *to* 2.5 higher on the inner side of the HERA ring. This effect has also been observed in [EWERT 1992] and can be explained with scattered and reflected synchrotron radiation. Scaling these values to the HERA design currents gives the total expected doses (see last line of table 5). Again the results are in agreement with those in [EWERT 1992].

For comparison we present here also results from TLD's placed on the outer wall (z = -257 cm) of the H1 "nitrogen shield" (close to the inner surface of the iron yoke) at a radial distance of r=30 cm at various azimuthal positions. Fig. 10 shows the total doses deposited in the autumn run (Sept. - Nov. 1992). Three TLD's recorded doses between 300 and 500 Rad; three other TLD's had readings between 1200 and 2000 Rad.

One explanation for the high doses recorded (as compared to doses in table 5) is the incidence of backscattered synchrotron radiation from a narrow waiste of the beam pipe inside quadrupoles QL and QK occuring during electron injections, while collimators C3 and C6 are fully open. The waiste is indicated by the letter w in figure 11. Can one understand the large variations of the observed doses at different azimuthal positions? The effect is certainly not due to systematic errors of the TLD's, which are of the order of 5%. Daniel Pitzl (Zürich) has pointed out that the distribution of material around the beam pipe near collimators C5 and C6 is quite uneven. This might contribute to the observed anisotropy. He also pointed out that the TOF scintallator counters between the BEMC and the nitrogen shield observe very high rates during injection when collimators C3 and C6 are open. This confirms the assumption that backscattered synchrotron radiation can cause relatively high doses in the volume between the BEMC and the iron yoke of H1.

Similar observations were made inside the ZEUS detector. Four TLD's of type R1T were placed at z $\approx$ - 290 cm in the horizontal plane (y = 0). The readings for the full year 1992 were as follows [LÖWE 1993]:

No.1	z $\approx$ - 285 cm, x = 5 cm	91 000 Rad
No.2	z $\approx$ - 285 cm, x = 9 cm	3 200 Rad
No.3	z $\approx$ - 300 cm, x = 5 cm	6 700 Rad
No.4	z $\approx$ - 300 cm, x = 9 cm	2 100 Rad

	$r = 47\,cm$				$r = 27\,cm$		$r = 18\,cm$	
	(m90)	(m91)	(m92)	(m93)	(m95)	(m96)	(m94)	(m97)
summer (Rad)	2.8	3.5	3.8	2.4	3.2	2.7	37	28
autumn (Rad)	2.3	2.5	4.9	1.9	2.0	2.0	205	192
total (Rad)	5.1	6.0	8.7	4.3	5.2	4.7	242	220
total (year) at full currents ($kRad/y$)	0.1 - 0.4	0.1 - 0.4	0.2 - 0.8	0.1 - 0.4	0.1 - 0.4	0.1 - 0.4	4.8 - 19.4	4.4 - 17.6

Table 4: Doses measured with TLD dosimeters at the positions of BLM

	$z = +20.5\,cm$		$z = -46.0\,cm$			
	inside	outside	inside up	inside down	outside up	outside down
dose (Rad)	491	213	298	293	150	163
total (year) at full currents ($kRad/y$)	10 - 40	4 - 16	6 - 24	6 - 24	3 - 12	3 - 12

Table 5: Doses measured with TLD dosimeters on the H 1 beampipe ($r = 10\,cm$)

6 Conclusions

1. We have demonstrated that radiation doses from *proton injections* measured with beam loss monitors about $6.5\,m$ away from the interaction point are proportional to corresponding doses measured inside the H 1 central tracking detectors. In the present setup one detected particle in the BLM is equivalent to 0.5 *to* $1.7\,\mu Rad$ inside the H 1 detector, depending on the particular photodiode. Similar proportionality is expected for *proton beam losses* since background, in particular muon background, from proton beam losses has a similar penetration potential as background from proton injections. We conclude that the BLM located around the H 1 VETO WALL are well suited for estimating the radiation doses from proton background inside the central chambers.
2. This is much less the case for background from electron injections and electron beam losses. The BLM are shielded by the BEMC calorimeter, the tail catcher and the compensating magnet against electron showers originating inside the central tracking chambers. Additionally, because of their coincidence mode the BLM are insensitive to synchrotron radiation. For future monitoring of electron and synchrotron radiation background inside the central tracking chambers medium sized photodiodes or scintillators with a nonsaturating readout have to be developed.
3. The biggest uncertainty in the extrapolated doses at design currents stems from the HERA test operations. A continuous monitoring should be implemented inside the experiments in order to prevent "surprises".
4. During the luminosity operation the most prominent source of background is synchrotron radiation entering the detector after electron acceleration, when collimator C3 is still open (see [EWERT 1992]). Measures should be taken to attempt acceleration with closed or partially closed collimators or to ensure that the collimators are fully closed immediately after acceleration.

5. The total annual radiation dose deposited inside the H1 central detector in 1992 has been determined by two different methods. The TLD's at r = 10 cm and z = +20.5 cm and z = -46 cm recorded doses of 160 - 490 Rad, consistent with measurements by photodiodes positioned at z = -136 cm and r = 11-14 cm. The extrapolated annual doses at nominal HERA currents are estimated to 3-40 kRad. The upper value would be uncomfortably high for the new H1 silicon vertex detector. A careful design of the new beam pipe and the related collimators is mandatory.

Acknowledgements

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7 Figures

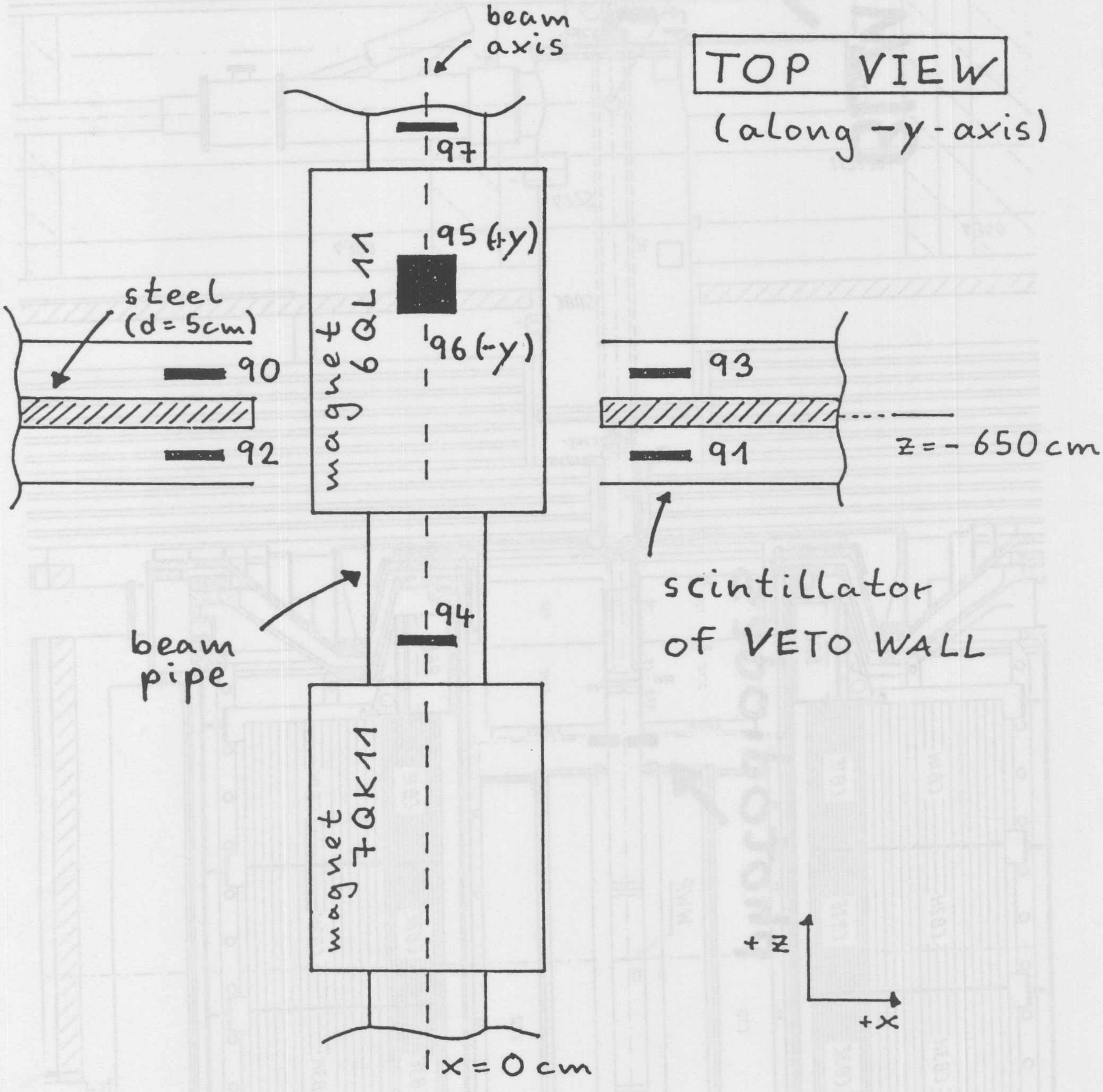

Figure 1: The beam loss monitors (BLM) around the beam pipe

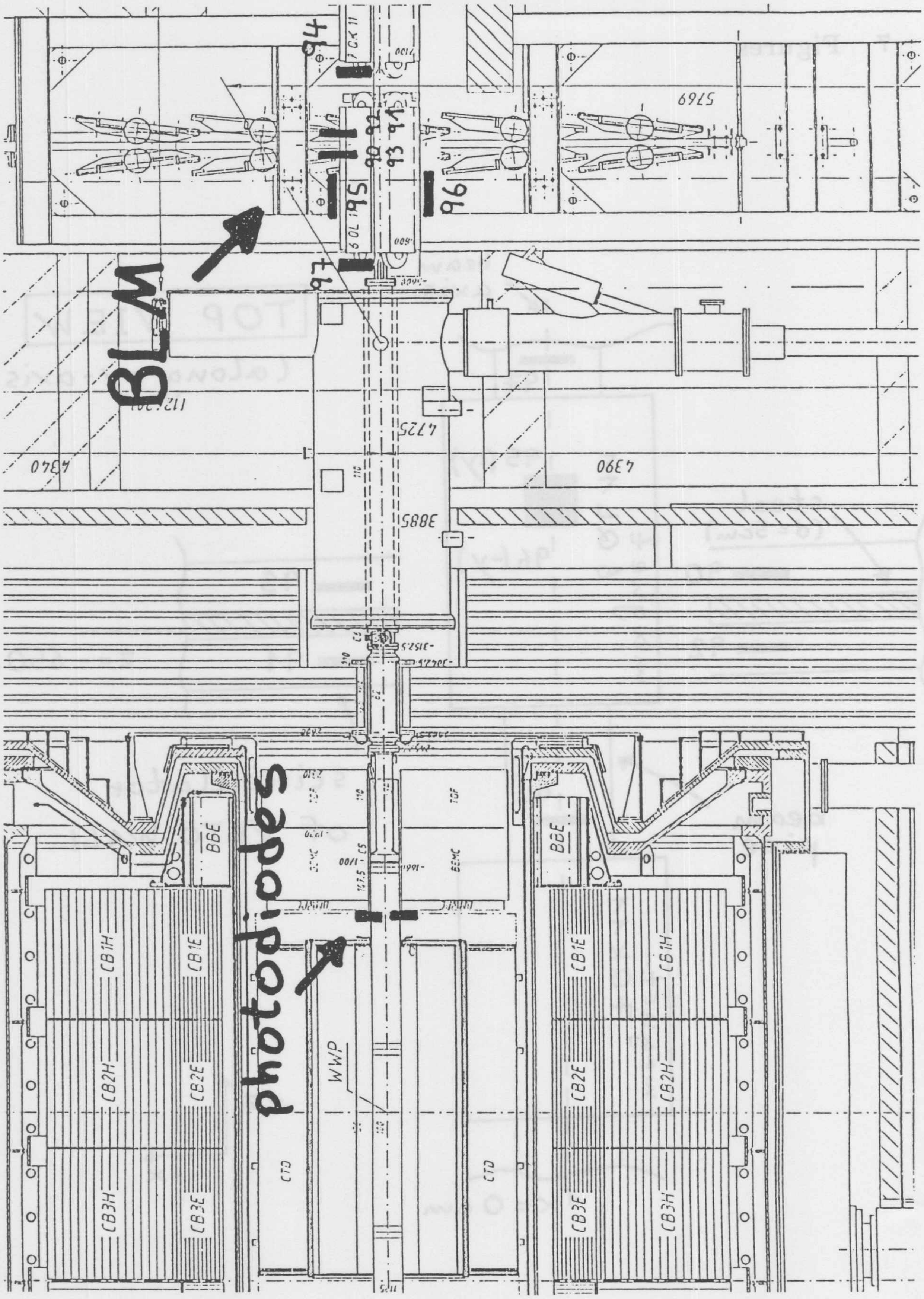

Figure 2: Side view of the H 1 detector with inner photodiodes and BLM near the VETO WALL

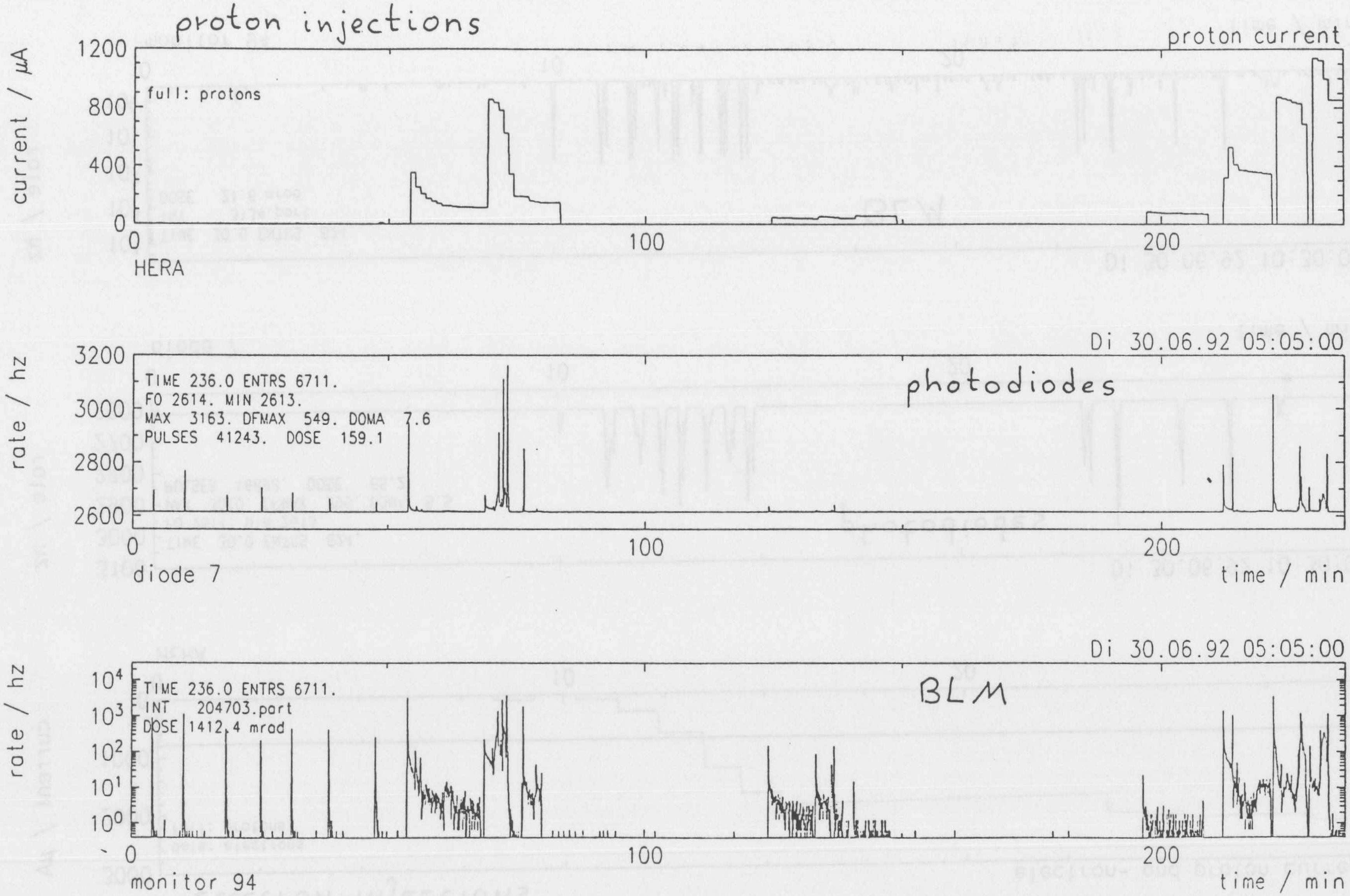

Figure 3: Example of a proton injection

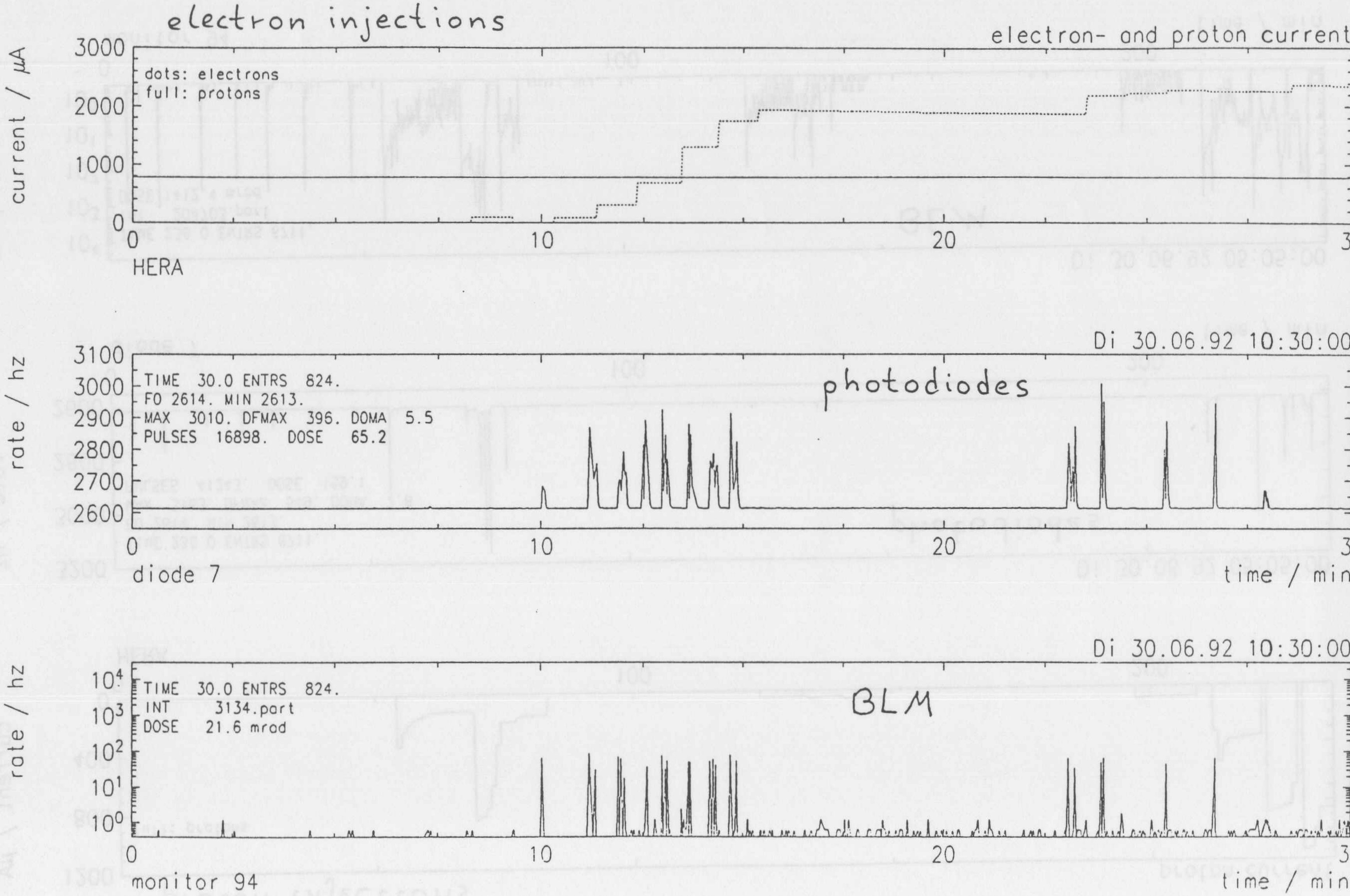

Figure 4: Example of an electron injection

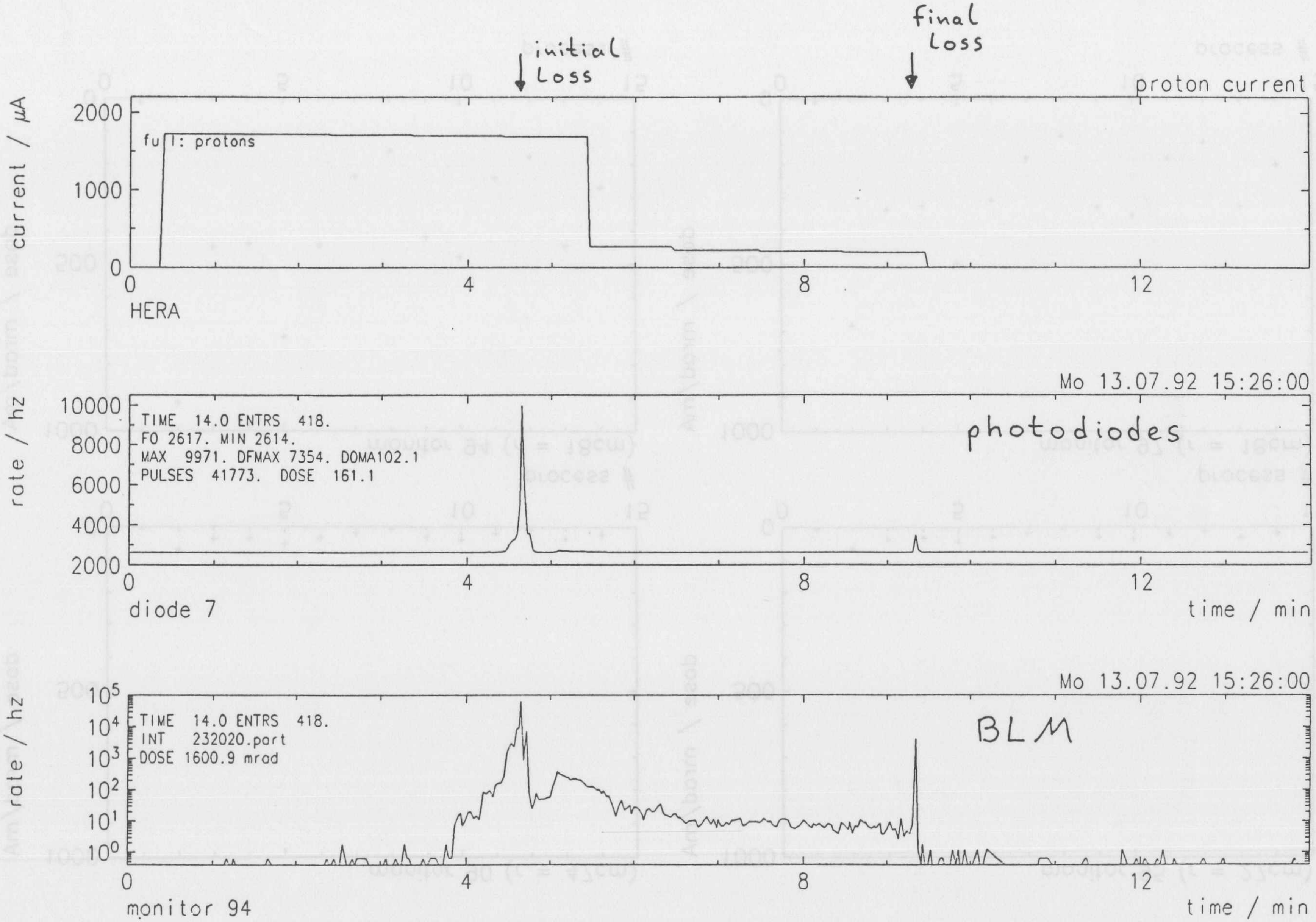

Figure 5: Example of a proton beam loss

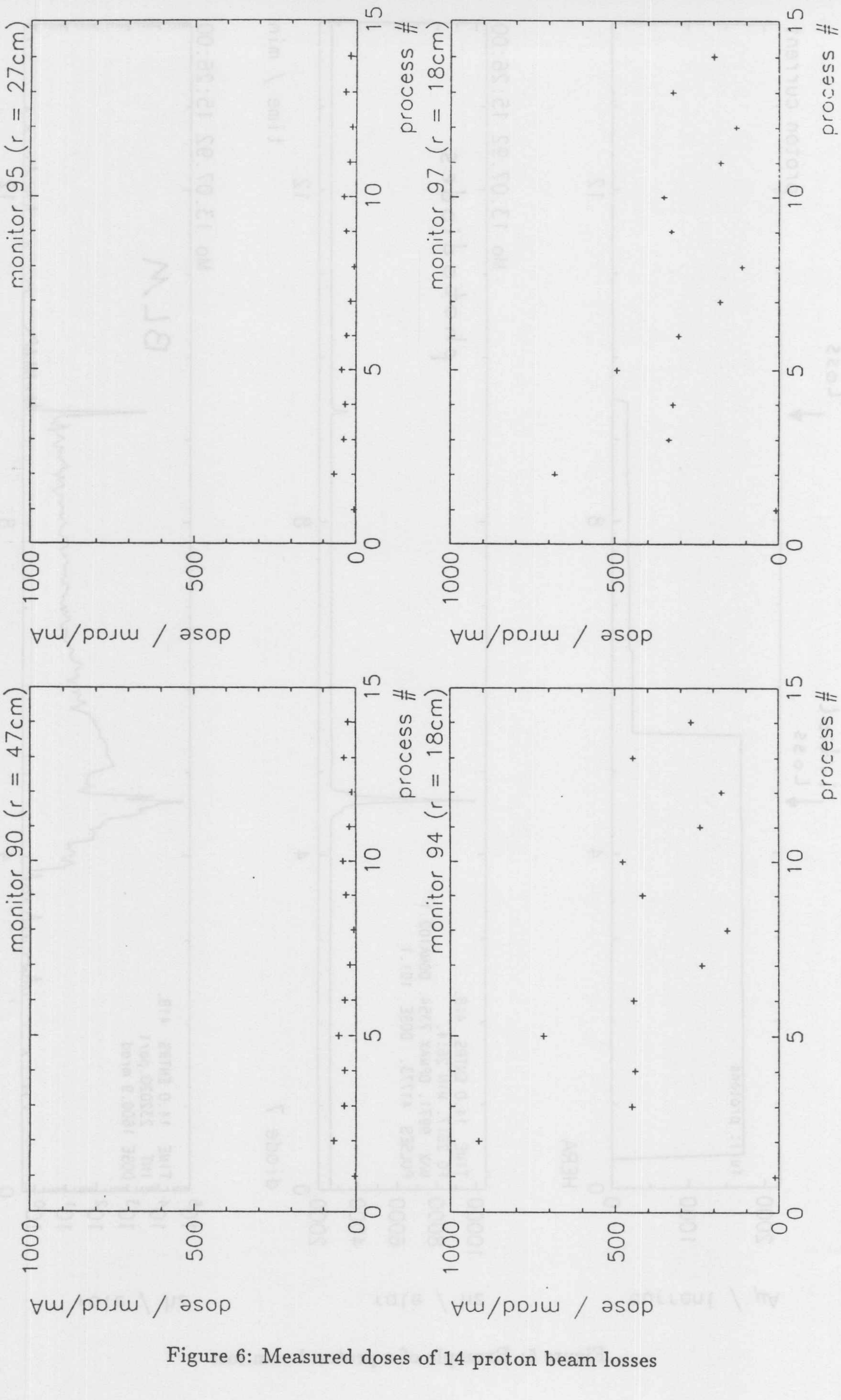

Figure 6: Measured doses of 14 proton beam losses

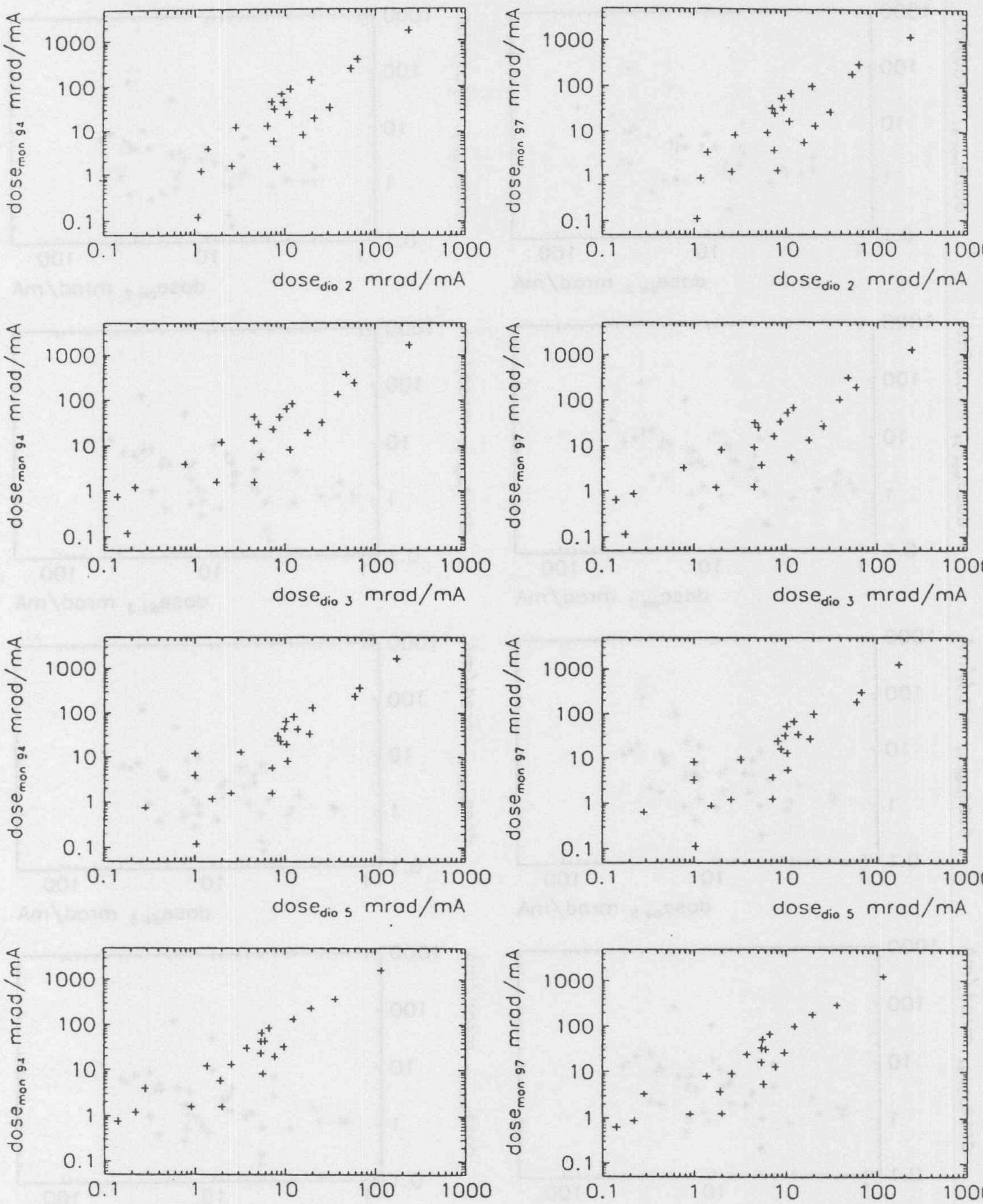

Figure 7: Correlation between doses from photodiodes and BLM for proton injections

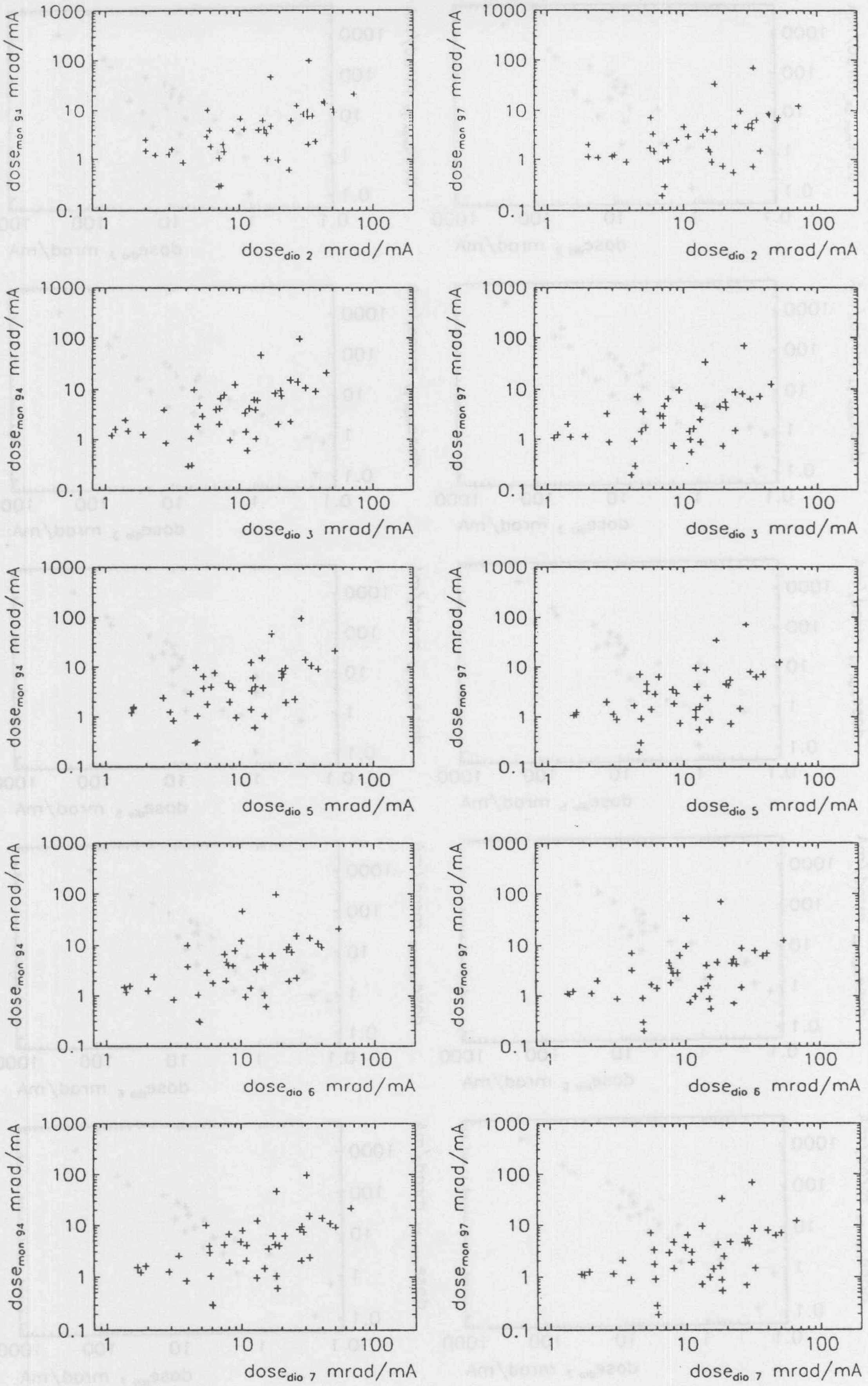

Figure 8: Correlation between doses from photodiodes and BLM for electron injections

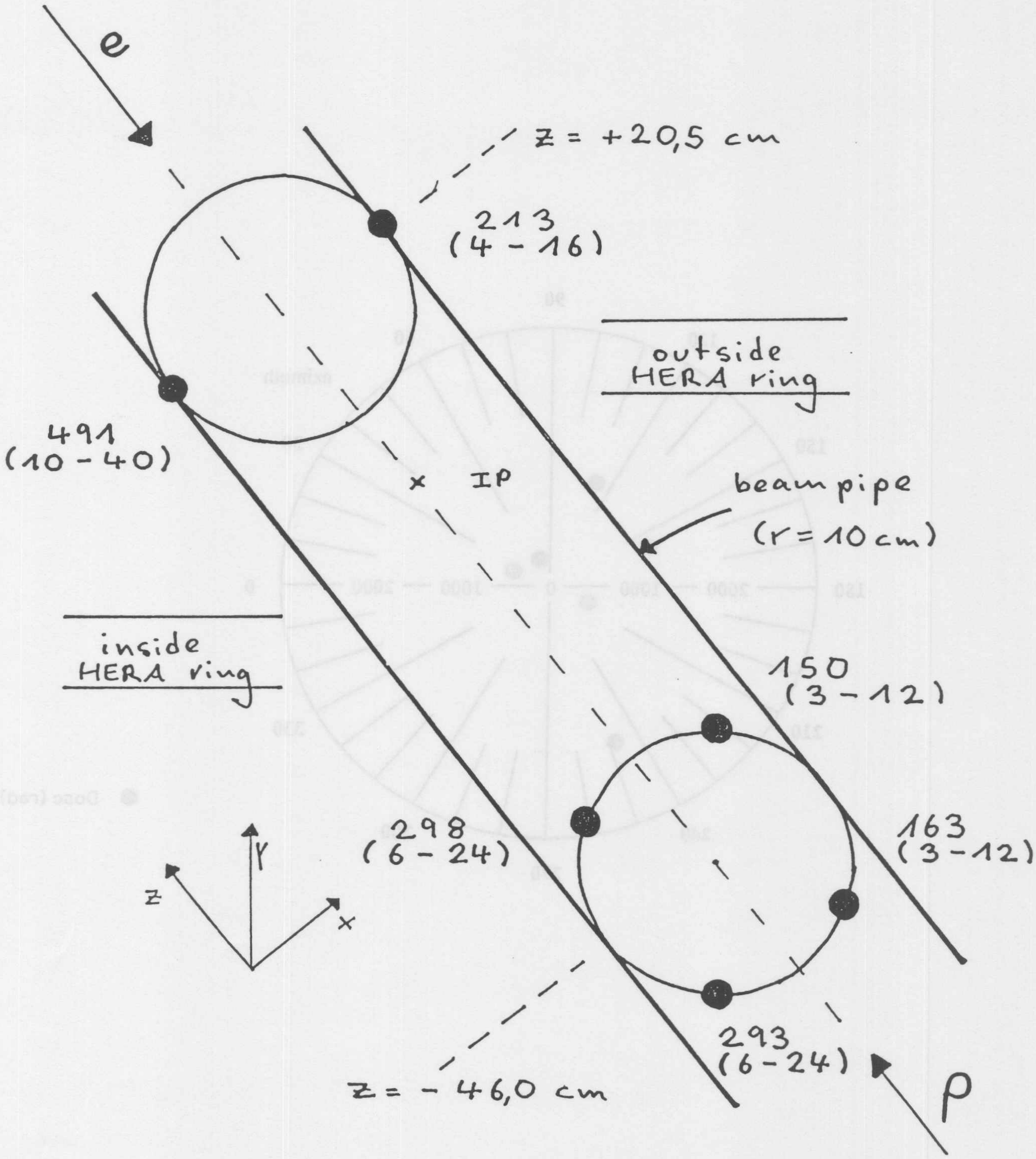

Figure 9: TLD dosimeters on the beampipe inside the H 1 detector (numbers are explained in the text)

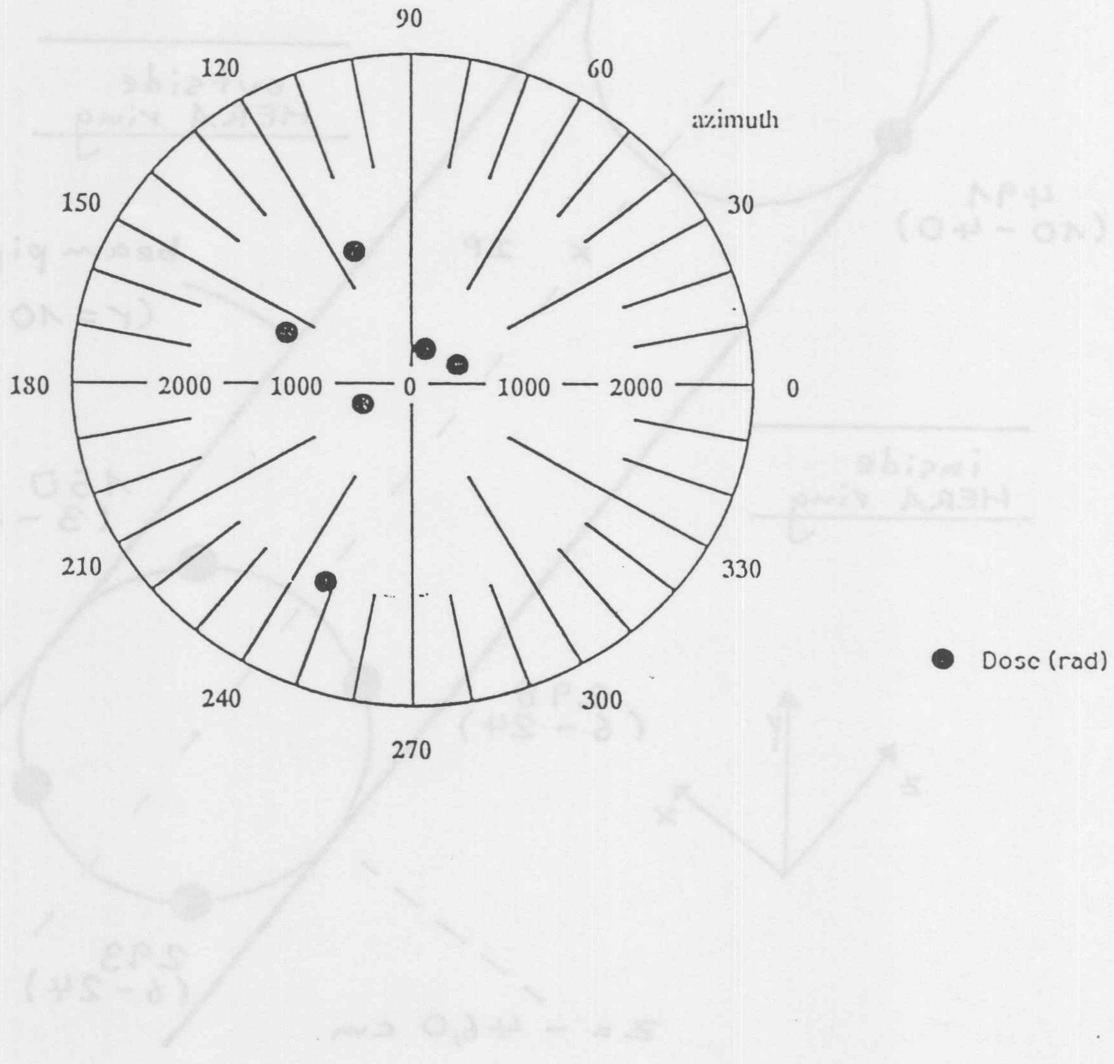

Figure 10: Radiation doses measured with TLD's at z = -257 cm and a radial distance of r = 30 cm for various azimuthal positions. The dosimeters were installed from 14. August - 30. November 1992, i.e. they were also exposed to the "high current" test operation of HERA in November 1992

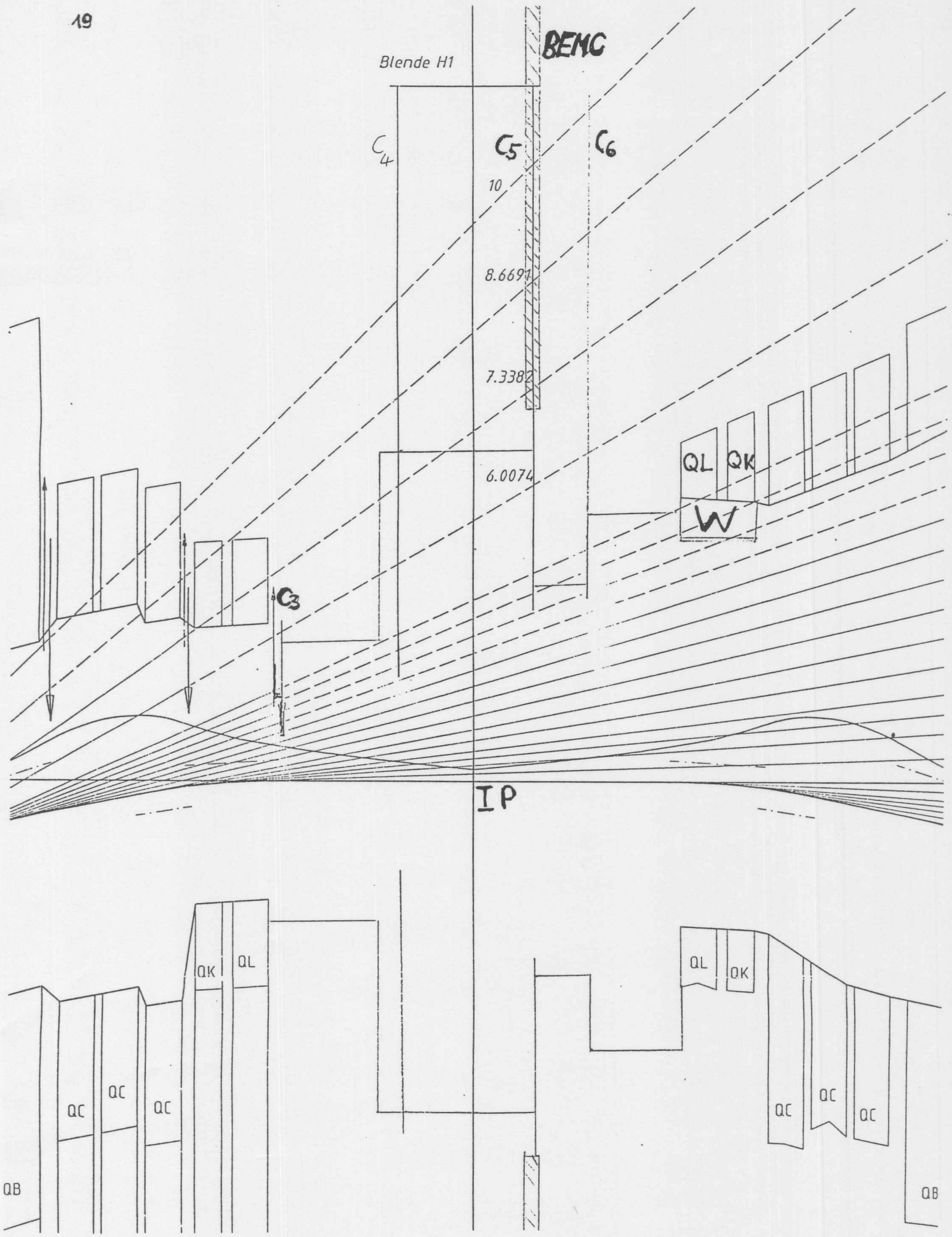

Figure 11: Synchrotron radiation cones near the interaction point (IP) of the H1 experiment