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HiRadMat Low Intensity Beam Commissioning

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Keywords: HiRadMat, Primary beam line, beam commissioning

Summary

On Wednesday 22 June 2011, proton beam was sent for the first time through the HiRadMat primary beam line, onto the beam dump located in the HiRadMat experimental cavern. The aims of the beam commissioning were to check the beam line geometry and design validity, the correct functioning of all beam line equipment and to verify the beam parameters. At the first trial, the proton beam reached the end of the primary beam line and the preliminary checks allowed confirming that all beam equipment and parameters were within the specification.

1. Introduction

The High Radiation to Materials facility - hereafter HiRadMat - was designed for testing accelerator components, in particular those of the LHC and its injectors, with the impact of high-intensity pulsed beams [1]. The HiRadMat irradiation facility will provide high power LHC type proton and lead ion beams with the maximum SPS energy of 450 GeV and 177.4 GeV per nucleon, respectively. Pulse intensities of up to $5 \cdot 10^{13}$ protons and $3.6 \cdot 10^{9}$ ions will be available. The detailed beam specifications can be found in [2].

The HiRadMat facility is located in the tunnel to the former West Area Neutrino Facility [3], in front of the former neutrino production target. The beam is delivered from the SPS to the HiRadMat facility using the existing TT60 transfer line and the new HiRadMat primary beam line, named TT66.

The design of the proton beam line has been performed in order to fulfil the beam parameter specification, in particular the demanding optics flexibility at the test stand location [4].

The construction of the facility is now complete and two beam commissioning periods are planned (see detailed plans in Annex 1). The first one took place from Wednesday 22 June to 28 June and was performed with low intensity beam. The second period will take place as of 15 August, with high intensity beam. The facility will then be ready for users in October 2011.

2. Layout of the primary beam line

The layout of the TT66 beam line is shown in Fig 2.1. After its extraction from SPS, the beam is first transported by the TT60 transfer line, which is also used for beam transfer to the TI2 injection line of the LHC. After ~200 m from the SPS extraction point, the new TT66 beam line branches off. The switching is performed by 8 powerful dipole magnets. The beam is then transported another ~200 m to the experimental area, where five quadrupoles provide the required focussing onto the test objects.

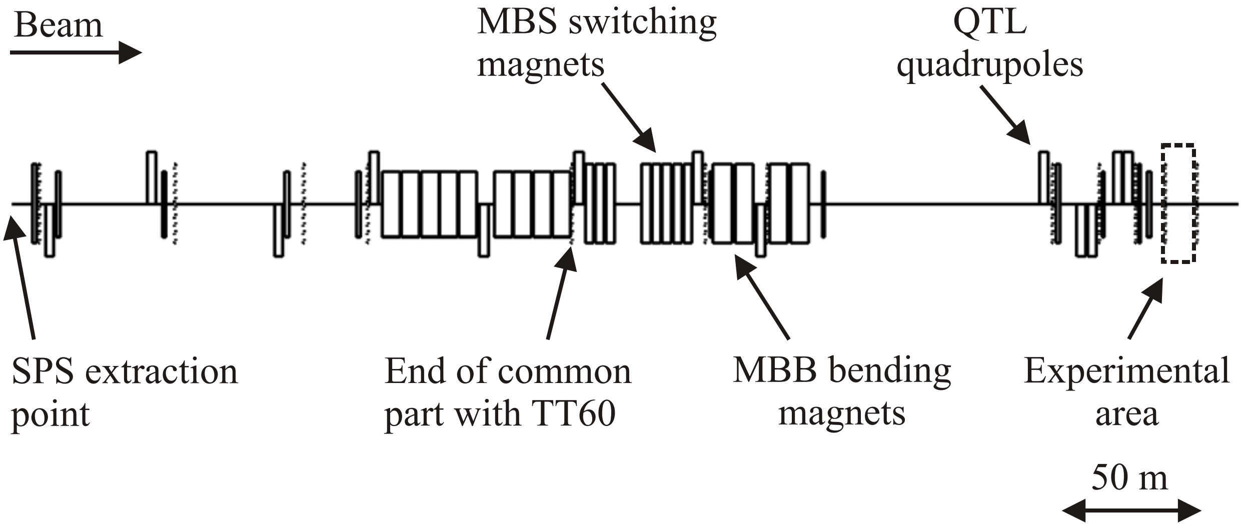


Figure 2.1 Layout of the HiRadMat primary beam line

3. Dry run preparation

And extensive dry run preparation was performed, in order to check the correct functioning of the beam line equipments, without beam. The beam interlock system [5] was also checked, together with the timing and logging system. These extended tests have been very successful and summarised (summary).

4. Beam commissioning

Only LHC Pilot type beam of about 8e9 protons was used during this low intensity beam commissioning. It is to be noted that pulses were only sent on request; a total of ~3.4e12 protons were sent to the HiRadMat beam dump over the whole commissioning period. The checks performed during the beam commissioning are summarised below.

4.1. Beam steering

The first HiRadMat beam was established on Wednesday 22 June. The first pilot sent reached the end of the beam line [Fig.4.1.1].

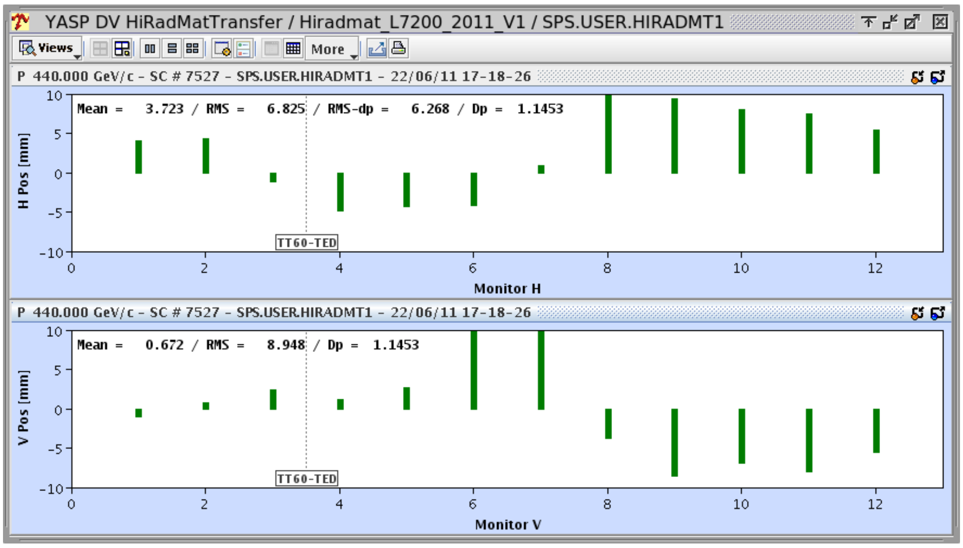


Figure 4.1.1 Horizontal and vertical trajectory of the first pilot beam through TT66

The SPS-TT66 energy matching was then performed (439.2 GeV vs. theoretical 440 GeV) and trajectory corrections done. The resulting trajectory is shown in Fig.4.1.2 and is well within specifications.

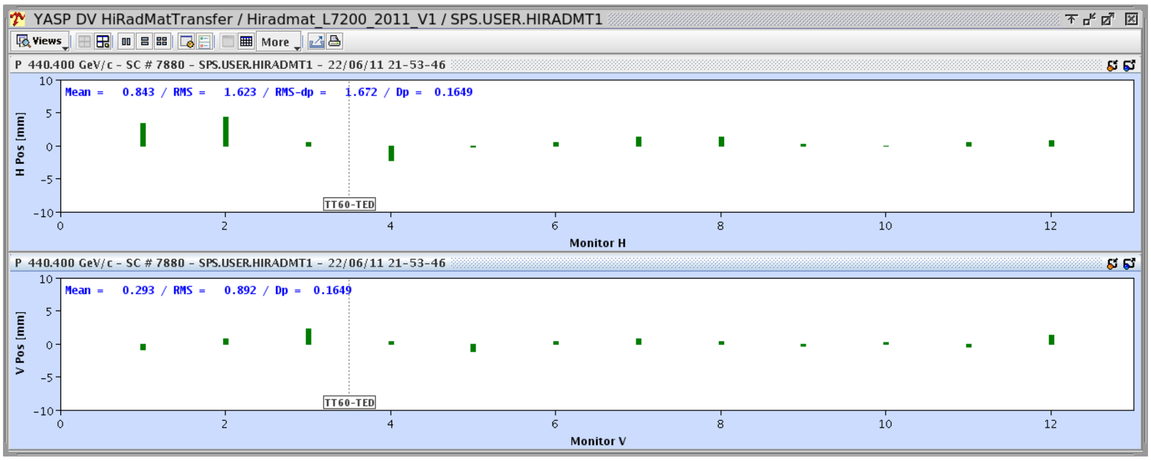
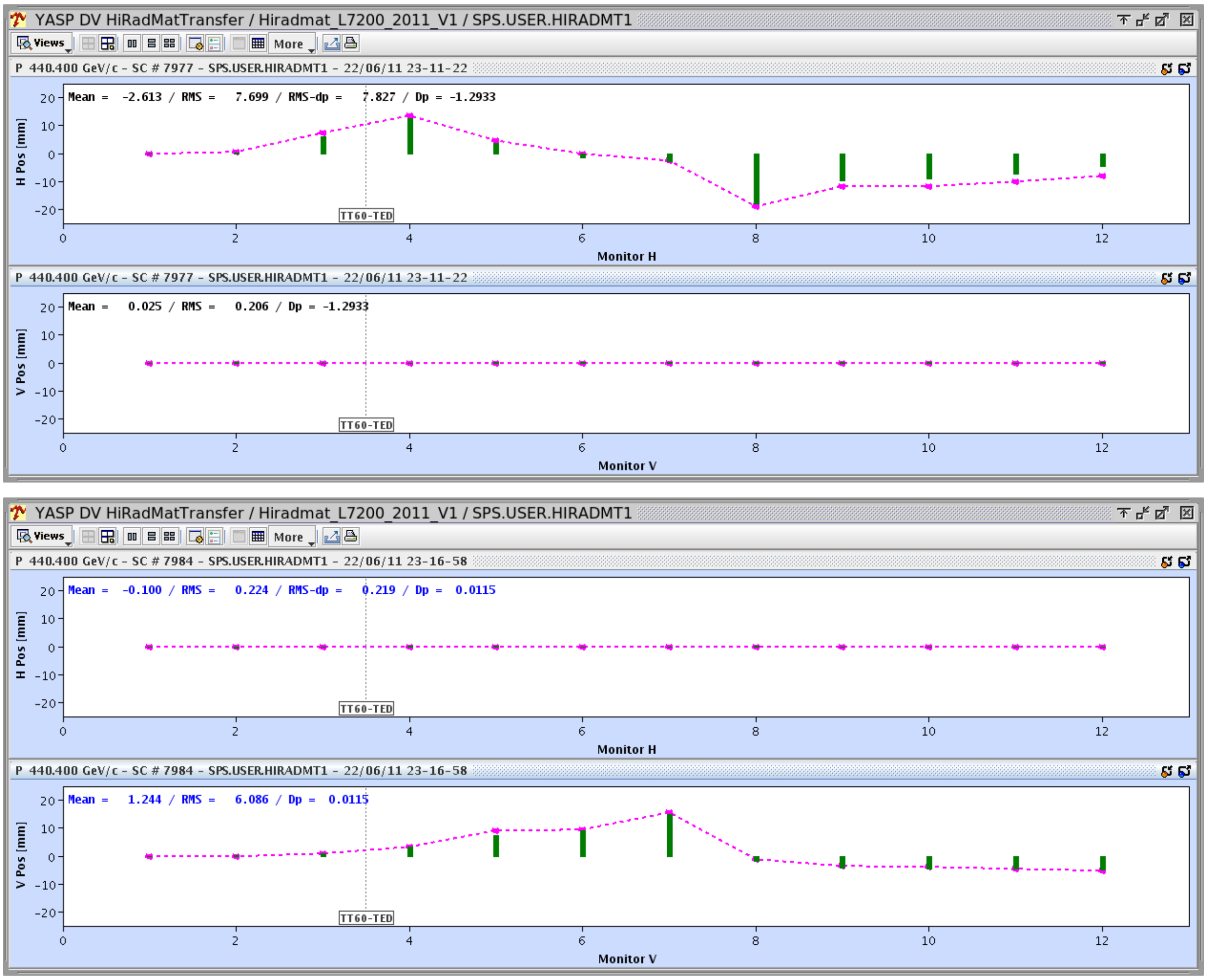


Figure 4.1.2 Horizontal and vertical trajectory after energy matching and trajectory corrections

4.2. Kick response measurements: checking the correct response of the BPM and correctors

Kick response measurements were performed and confirmed that the BPMs polarity signs together with the dipole corrector magnet polarity were correct. No phase advance error is apparent [Fig.4.2.1].



P 440.400 GeV/c - SC # 7977 - SPS.USER.HIRADMT1 - 22/06/11 23-11-22

Mean = -2.613 / RMS = 7.699 / RMS-dp = 7.827 / Dp = -1.2933

P 440.400 GeV/c - SC # 7977 - SPS.USER.HIRADMT1 - 22/06/11 23-11-22

Mean = 0.025 / RMS = 0.206 / Dp = -1.2933

P 440.400 GeV/c - SC # 7984 - SPS.USER.HIRADMT1 - 22/06/11 23-16-58

Mean = -0.100 / RMS = 0.224 / RMS-dp = 0.219 / Dp = 0.0115

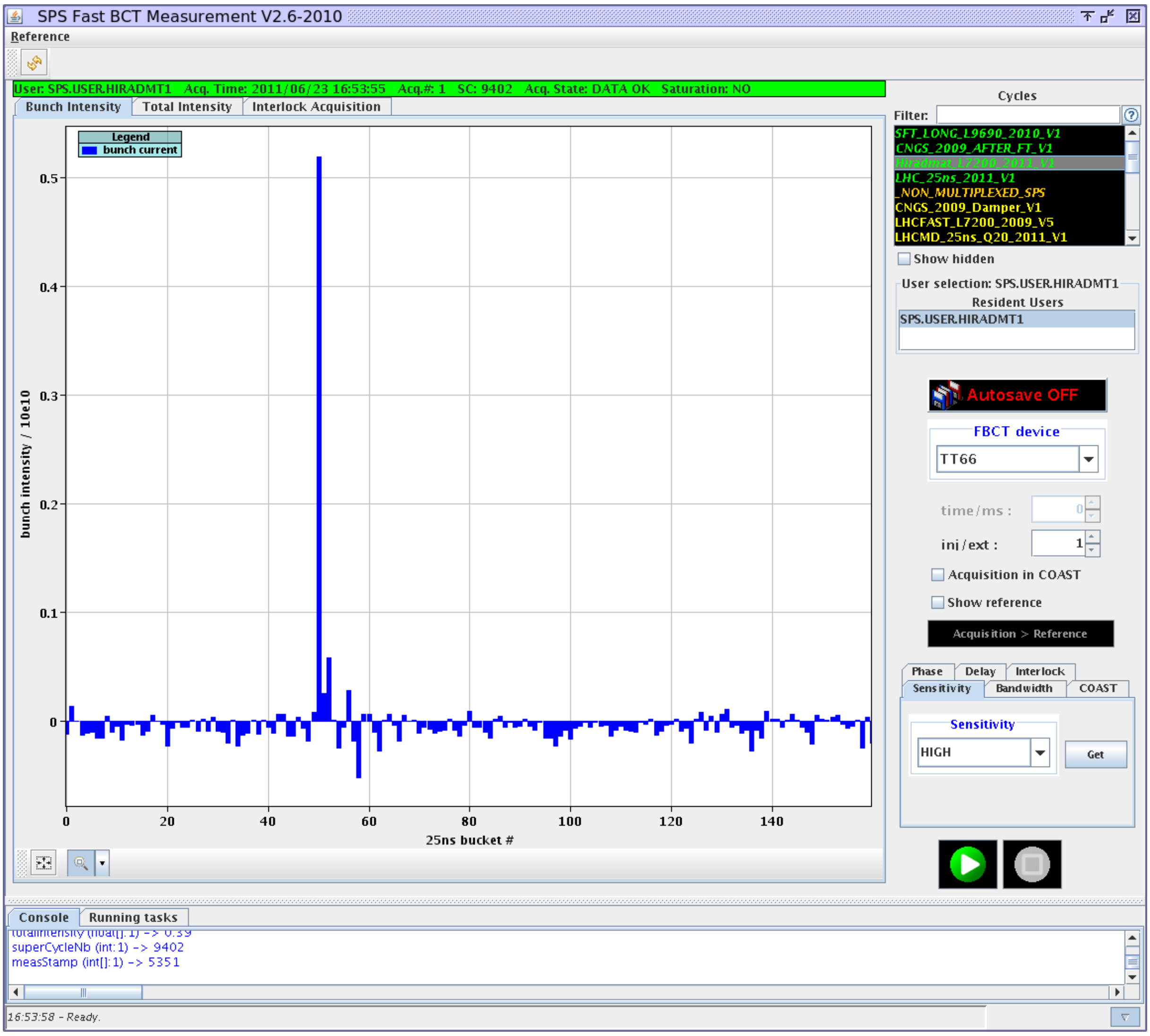
P 440.400 GeV/c - SC # 7984 - SPS.USER.HIRADMT1 - 22/06/11 23-16-58

Mean = 1.244 / RMS = 6.086 / Dp = 0.0115

Figure 4.2.1 Kick response measurements in the horizontal and vertical planes – dotted line is the model and bars are the measurements

4.3. Beam instrumentation response

Beam instrumentation response (BTV, BPM, BLM, and BCT) has been successfully checked. The Fast BCT detector situated towards the end of the TT66 beam line was adjusted for the low intensity beam commissioning. A typical bunch intensity acquisition triggered with the SPS extraction pre-pulses can be seen in figure 4.3.1.



SPS Fast BCT Measurement V2.6-2010

User: SPS.USER.HIRADMT1 Acq. Time: 2011/06/23 16:53:55 Acq.#: 1 SC: 9402 Acq. State: DATA OK Saturation: NO

User selection: SPS.USER.HIRADMT1

FBCT device: TT66

time/ms : 0

inj/ext : 1

☐ Acquisition in COAST

☐ Show reference

Sensitivity: HIGH

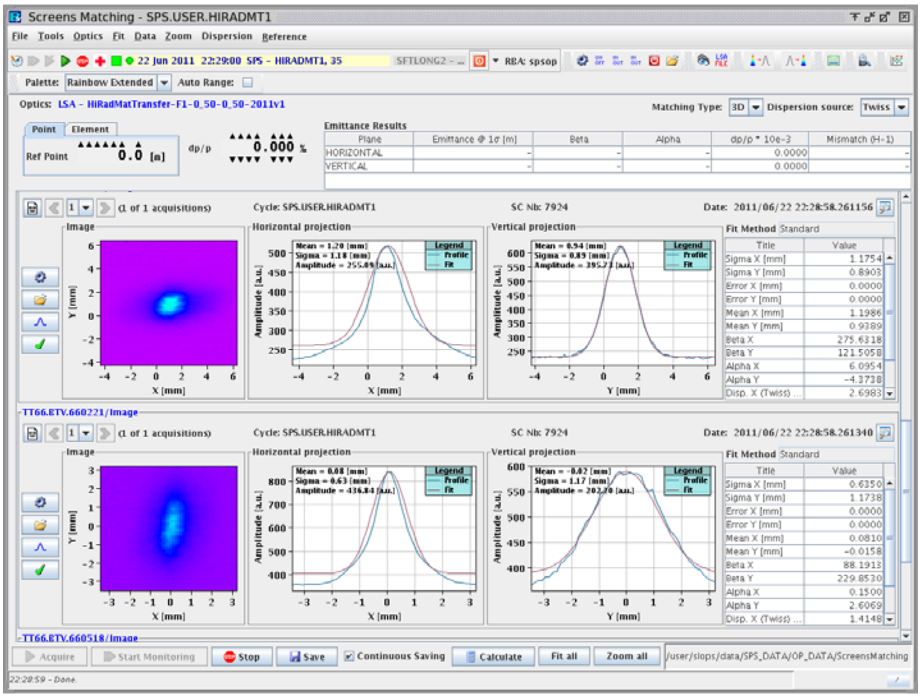
```
totalIntensity (float[]:1) -> 0.39
superCycleNb (int:1) -> 9402
measStamp (int[]:1) -> 5351
```

16:53:58 - Ready.

Figure 4.3.1 Fast BCT response using the dedicated Fast BCT application

The reference for intensity measurements is the DC BCT in the SPS. Due to a wrong configuration of the shot-by-shot logging the corresponding values only became available as of the 23 June 2011. At the same time values from the upstream BCT situated in the common TT60 transfer line was added to the logging. With the low intensity beams it is very difficult to obtain absolute intensity values from the single-pass BCTs. Based on similar systems for the high intensity beam, around 1 % absolute calibration is expected allowing for precise transmission studies.

Three BTV devices are installed along the TT66 beam-line and were used for beam size and centre of mass measurements. An illustration of typical beam images on two of these BTVs is shown in Fig. 4.3.2.



22 Jun 2011 22:29:00 SPS - HIRADMT1, 35

RBA: spsop

Palette: Rainbow Extended

Auto Range: ☐

Optics: LSA - HiRadMatTransfer-F1-0_50-0_50-2011v1

Matching Type: 3D

Dispersion source: Twiss

Ref Point 0.0 [m]

dp/p 0.000 %

Emittance Results

Plane	Emittance @ 1σ [m]	Beta	Alpha	dp/p * 10e-3	Mismatch (H-1)
HORIZONTAL	-	-	-	0.0000	-
VERTICAL	-	-	-	0.0000	-

(1 of 1 acquisitions) Cycle: SPS.USER.HIRADMT1 SC Nb: 7924 Date: 2011/06/22 22:28:58.261156

Horizontal projection: Mean = 1.20 [mm], Sigma = 1.18 [mm], Amplitude = 255.09 [a.u.]

Vertical projection: Mean = 0.94 [mm], Sigma = 0.89 [mm], Amplitude = 395.21 [a.u.]

Fit Method Standard

Title	Value
Sigma X [mm]	1.1754
Sigma Y [mm]	0.8903
Error X [mm]	0.0000
Error Y [mm]	0.0000
Mean X [mm]	1.1986
Mean Y [mm]	0.9389
Beta X	275.6318
Beta Y	121.5058
Alpha X	6.0954
Alpha Y	-4.3738
Disp. X (Twiss) ...	2.6983

TT66.BTV.660221/Image

(1 of 1 acquisitions) Cycle: SPS.USER.HIRADMT1 SC Nb: 7924 Date: 2011/06/22 22:28:58.261340

Horizontal projection: Mean = 0.08 [mm], Sigma = 0.63 [mm], Amplitude = 436.84 [a.u.]

Vertical projection: Mean = -0.02 [mm], Sigma = 1.17 [mm], Amplitude = 202.70 [a.u.]

Fit Method Standard

Title	Value
Sigma X [mm]	0.6350
Sigma Y [mm]	1.1738
Error X [mm]	0.0000
Error Y [mm]	0.0000
Mean X [mm]	0.0810
Mean Y [mm]	-0.0158
Beta X	88.1913
Beta Y	229.8530
Alpha X	0.1500
Alpha Y	2.6069
Disp. X (Twiss) ...	1.4148

TT66.BTV.660518/Image

☑ Continuous Saving

/user/slops/data/SPS_DATA/OP_DATA/ScreensMatching

22:28:59 - Done.

Figure 4.3.2 BTV response using the screen matching application

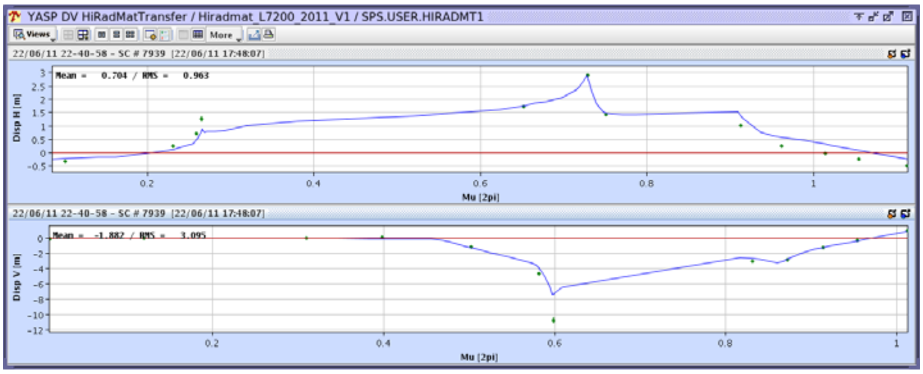
In order to quantify losses along the transfer line, a number of ionisation monitors are installed. The acquisition system for these monitors are connected to the beam interlock system allowing to disable the extraction of beam from the SPS in case loss threshold values are exceeded requiring operator intervention (manual reset). With the low-intensity beam used, the vast majority of acquisitions showed no losses (low gain setting used). During a few extractions towards the end of the commissioning period the monitor in position 660308 showed losses above the noise level; this could be traced to an optics which gave high beam excursions and very little beam on the Fast BCT at the end of the line. When higher intensity beams are used, a resolution of a few 1E-4 [Gy] is expected.

4.4. Logging

Correct logging of all required data has been successfully checked. Logging will again be verified during the high intensity beam commissioning.

4.5. Dispersion measurements

A dispersion measurement was performed (Fig.4.5.1) and preliminary results show that there is no error in the beam line. More data analysis is to be done in order to remove the large energy error measurements at the location with high dispersion, where the BPM response is no longer linear.


YASP DV HiRadMatTransfer / Hiradmat_L7200_2011_V1 / SPS.USER.HIRADMT1

22/06/11 22-40-58 - SC # 7939 [22/06/11 17:48:07]

Mean = 0.704 / RMS = 0.963

22/06/11 22-40-58 - SC # 7939 [22/06/11 17:48:07]

Mean = -1.882 / RMS = 3.095

Figure 4.5.1 Horizontal and vertical dispersion measurements

4.6. Orthogonal steering onto the future test stand location

The orthogonal steering onto the target has been successfully checked. For this measurement the F1-1_0mm-1_0mm optics was used and steering knobs were created for this optics. The beam was then steered independently in both planes within the range +/- 4 mm, as specified in the HiRadMat specs. The beam position on the last BTV screen in the beam line (Fig. 4.6.1) and the trajectories (Fig. 4.6.2) were recorded. The measurements show that the steering is well decoupled in both planes and is possible within the specified range.

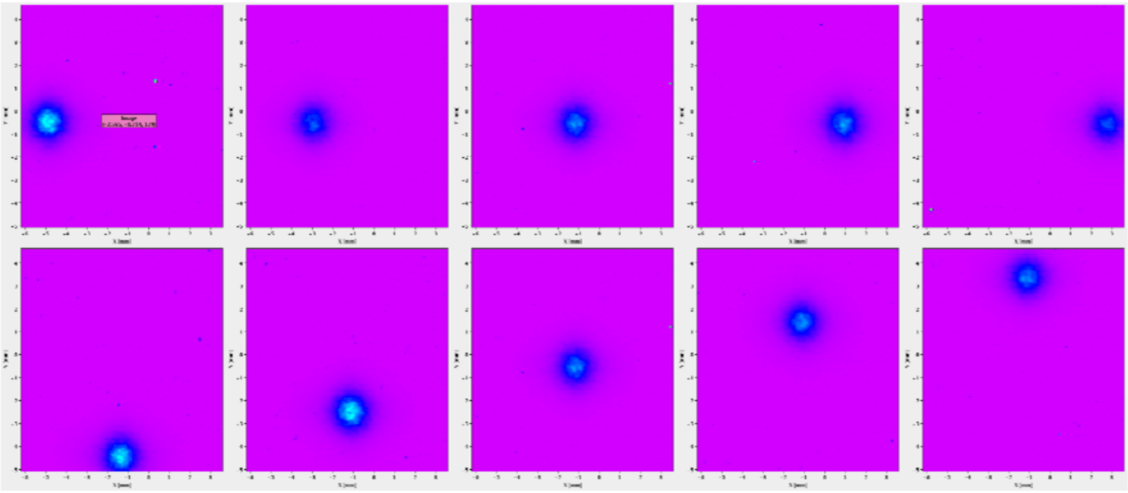
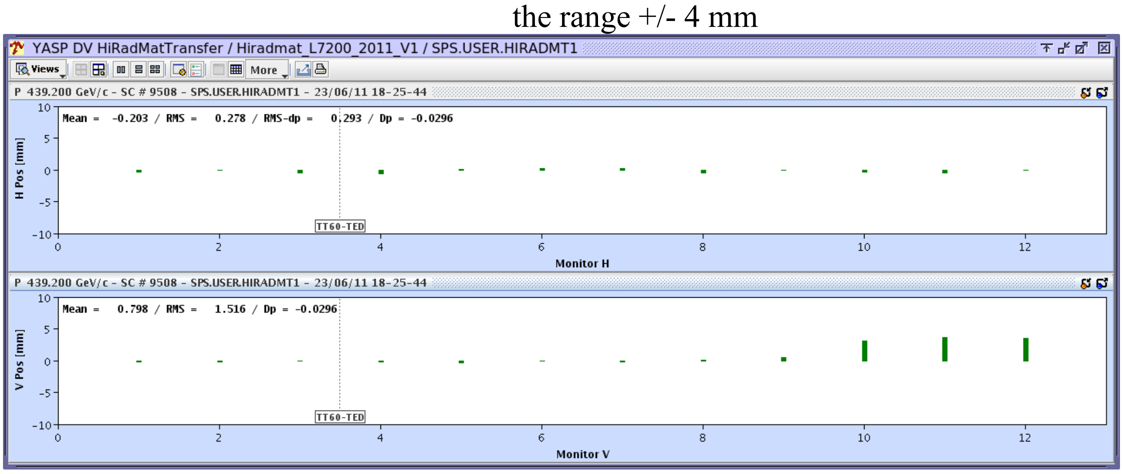


Figure 4.6.1 Steering of the beam on the last BTV screen independently in both planes within the range +/- 4 mm


YASP DV HiRadMatTransfer / Hiradmat_L7200_2011_V1 / SPS.USER.HIRADMT1

P 439.200 GeV/c - SC # 9508 - SPS.USER.HIRADMT1 - 23/06/11 18-25-44

Mean = -0.203 / RMS = 0.278 / RMS-dp = 0.293 / Dp = -0.0296

P 439.200 GeV/c - SC # 9508 - SPS.USER.HIRADMT1 - 23/06/11 18-25-44

Mean = 0.798 / RMS = 1.516 / Dp = -0.0296

Figure 4.6.2 Example trajectory for the case that the beam was steered to +4 mm in the vertical plane

4.7. Horizontal and vertical beam line apertures

Aperture measurements were successfully performed. The F1-0_50 mm-0_50 mm optics was used for all tests.

First of all, 10 shots were used to calibrate the FBCT relation between the signal in TT60 (FBCT.610225) and the one at the end of TT66 (FBCT.660516). Calibration value: mean signal$_{TT60/TT66}$ = 1.018±1.6 %.

Orbit oscillations were induced for both vertical and horizontal planes at the beginning of TT60 line in order to discover all possible bottlenecks along the TT66 line. For the horizontal plane, twelve phases of $n\pi/6$, $0 \leq n \leq 11$ were used. For the vertical plane only $\pi/6$, $5\pi/6$, $\pi/6$, $8\pi/6$, $9\pi/6$ and $10\pi/6$ phases were used, because the power converters for the corresponding correctors were at that time only operating with one polarity. The correctors used for horizontal and vertical plane were MDLH.610104, MDLH.610206, MDAV.610013 and MDLV.610304. Aperture knobs were created for each phase and plane.

Table 4.7.1 and Table 4.7.2 show the beam position offset, in x[mm] and y[mm], with respect to the reference orbit for each test compared to the ones obtained with MAD-X.

Table 4.7.1: Horizontal offsets for tests and MAD-X simulations (unit mm)

Horizontal plane							
Description	BPM.660104.H	BPM.660204.H	BPM.660305.H	BPM.660408.H	BPM.660508.H	BPM.660517.H	BPKG.660529.H
phase30 6.5sigma	7.39	3.24	-5.29	-3.72	-4.20	-4.46	-3.75
MADX	5.96	2.85	-2.68	-2.39	-3.09	-3.19	-3.33
phase30 -10sigma	-9.62	-3.77	10.09	6.85	6.99	7.41	5.80
MADX	-9.17	-4.38	4.13	3.67	4.76	4.91	5.13
phase60 10sigma	3.32	0.50	-8.45	-4.94	-5.04	-4.31	-3.18
MADX	2.30	0.16	-7.62	-5.03	-5.31	-4.77	-4.03
phase60 -10sigma	-1.11	0.73	9.07	5.29	4.77	4.32	3.09
MADX	-2.30	-0.16	7.62	5.03	5.31	4.77	4.03
phase90 10sigma	-5.42	-3.92	-6.12	-2.66	-1.80	-0.53	0.36
MADX	-5.20	-4.09	-9.07	-5.04	-4.43	-3.36	-1.85
phase90 -10sigma	7.98	5.37	6.31	2.96	1.45	0.53	-0.55
MADX	5.20	4.09	9.07	5.04	4.43	3.36	1.85
phase120 10sigma	-14.01	-6.19	-2.25	0.46	1.71	2.45	3.69
MADX	-11.30	-7.26	-8.09	-3.69	-2.37	-1.04	0.83
phase120 -5.5sigma	8.44	4.53	1.36	0.04	-1.18	-1.61	-1.95
MADX	6.21	3.99	4.45	2.03	1.30	0.57	-0.45
phase150 10sigma	-18.40	-7.49	2.21	3.79	5.14	6.06	6.01
MADX	-14.37	-8.47	-4.94	-1.36	0.33	1.56	3.28
phase150 -4.3sigma	8.03	4.49	-1.00	-1.49	-1.69	-2.38	-2.33
MADX	6.18	3.64	2.13	0.59	-0.14	-0.67	-1.41

Table 4.7.2: Vertical offsets for tests and MAD-X simulations (unit mm)

Vertical plane							
Description	BPM.660104.V	BPM.660204.V	BPM.660305.V	BPM.660408.V	BPM.660508.V	BPM.660517.V	BPKG.660529.V
phase0 -10sigma	-9.69	-17.45	1.15	3.69	4.27	4.81	5.09
MADX	-8.33	-13.14	2.39	4.78	4.41	4.74	5.19
phase30 10sigma	1.16	-0.61	-7.86	-11.15	-7.48	-5.76	-3.49
MADX	13.98	25.01	5.85	4.84	1.03	-1.37	-4.74
phase60 -10sigma	4.33	7.60	-0.68	-1.97	-2.31	-2.45	-2.29
MADX	4.43	7.11	-0.88	-2.03	-2.01	-2.26	2.61
phase90 -10sigma	5.45	14.79	15.89	22.30	11.69	7.21	2.72
MADX	6.30	12.68	7.38	8.35	4.52	2.54	-0.23
phase120 10sigma	7.05	16.95	12.82	16.65	8.77	5.32	1.19
MADX	15.35	29.08	11.90	12.44	5.81	2.15	-3.00
phase150 10sigma	-6.72	-13.90	-6.36	-7.22	-3.91	-2.00	0.72
MADX	-20.28	-37.69	-13.23	-13.19	-5.55	-1.18	4.97

The following figures show real and simulated beam oscillations for some of the test cases.

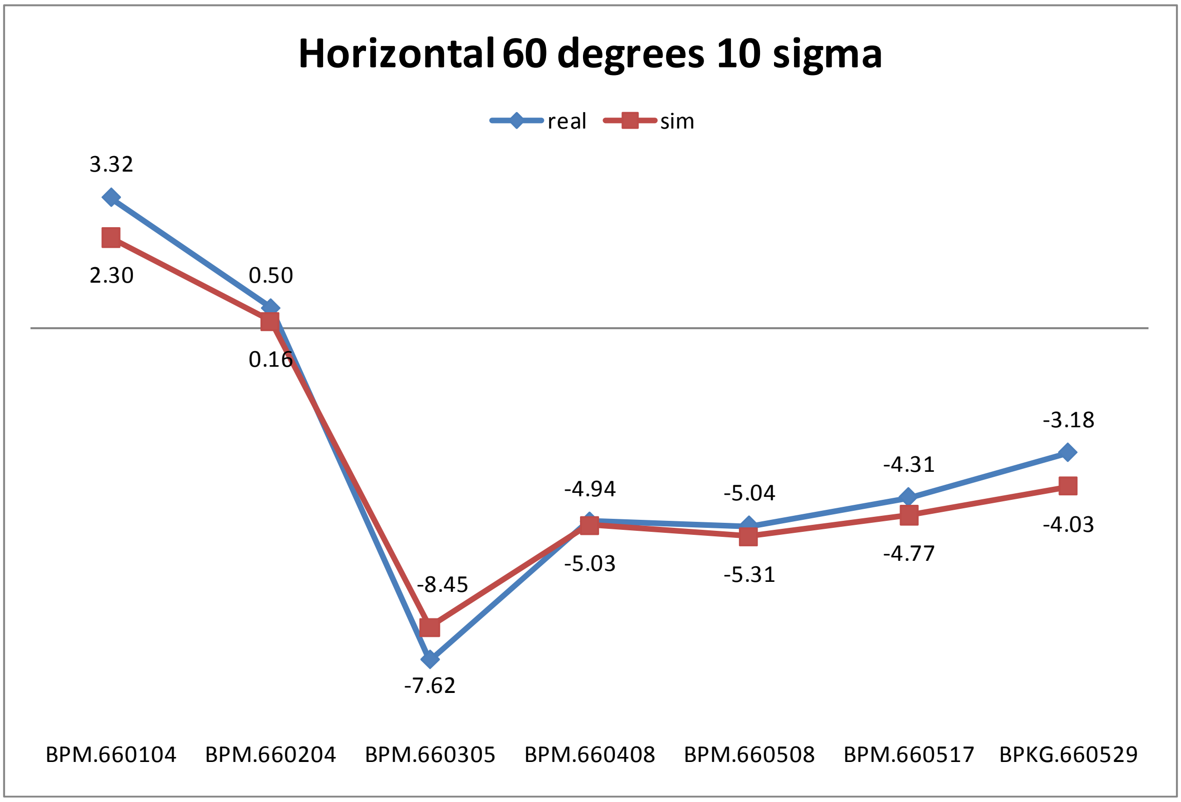


Figure 4.7.1 Horizontal oscillation for phase 60 and 10 sigma (unit mm)

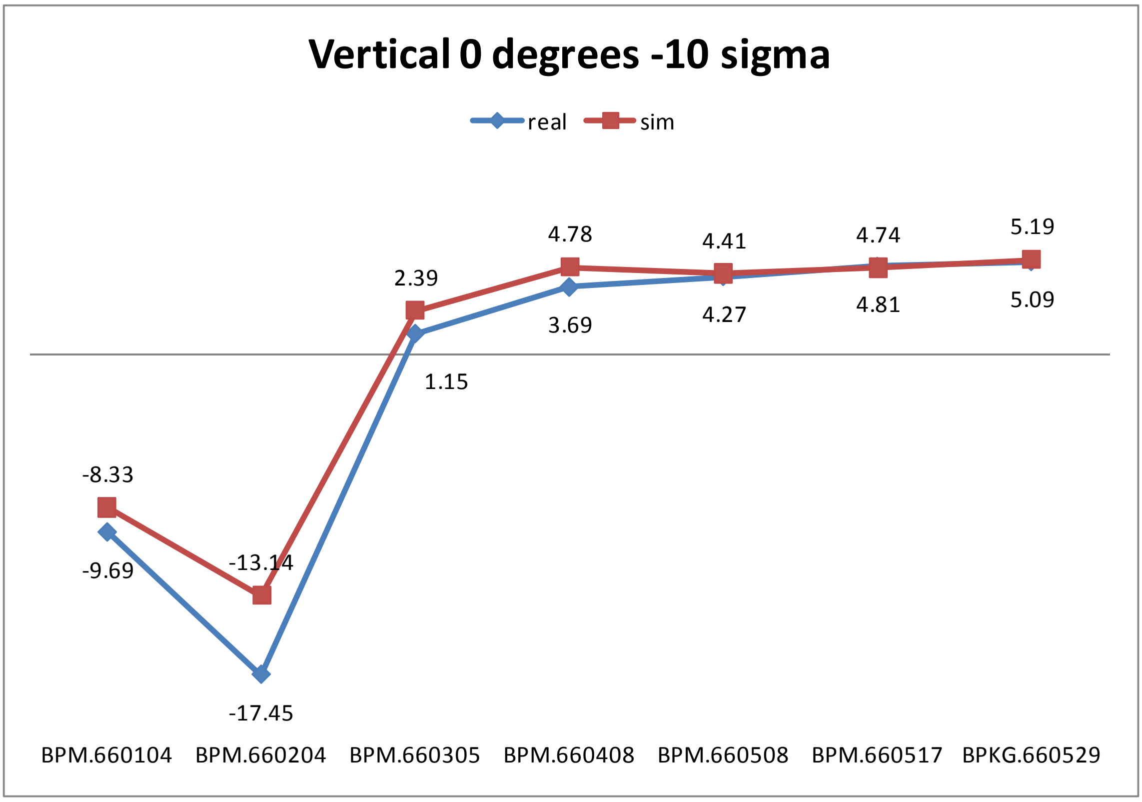


Figure 4.7.2 Vertical oscillation for phase 0 and -10 sigma (unit mm)

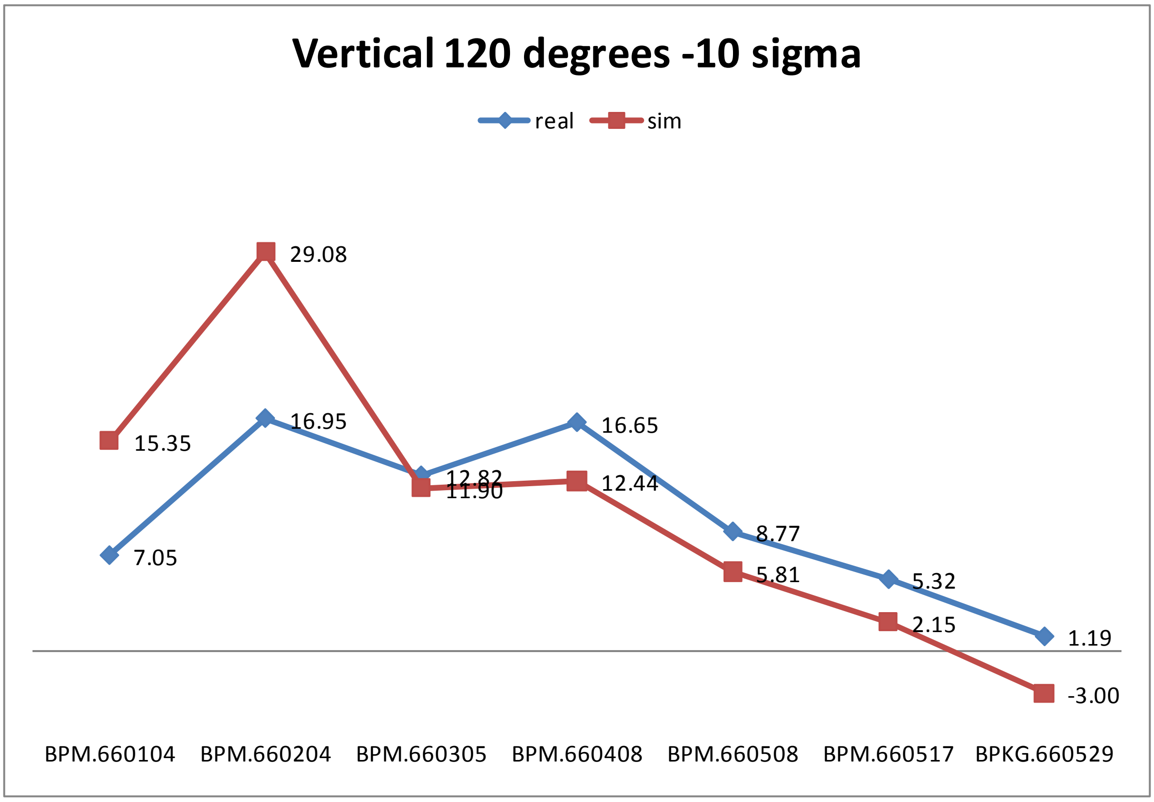


Figure 4.7.3 Vertical oscillation for phase 120 and -10 sigma (unit mm)

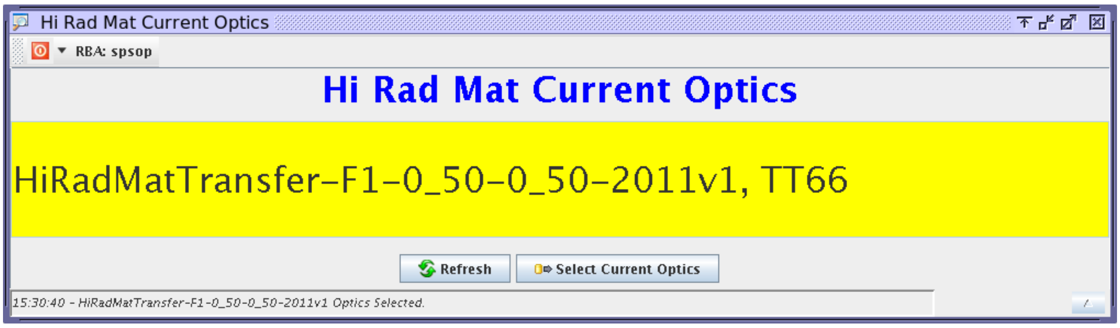
All tests performed in the horizontal plane are in good agreement with the MAD-X simulation. Small discrepancies have been found on the vertical plane. Figure 4.7.3 shows the values for phase 120, -10 sigma and vertical plane.

No significant intensity drop between FBCT.610225 and FBCT.660516 was observed during the tests, meaning that no aperture restrictions were observed. No losses above the background were observed in the Beam Loss Monitors during the test.

All these signals (FBCT current, BLM signal, BPM position, magnet current) were reordered in the logging data base.

4.8. Multiple Optics changes

A special feature of the HiRadMat beam line is its flexibility. It can provide beams with beam radii between σ=0.1 mm and 2.0 mm at different focal point locations. For the different beam sizes and focal points, different optics must be loaded, which is done with a dedicated application (Fig. 4.8.1).

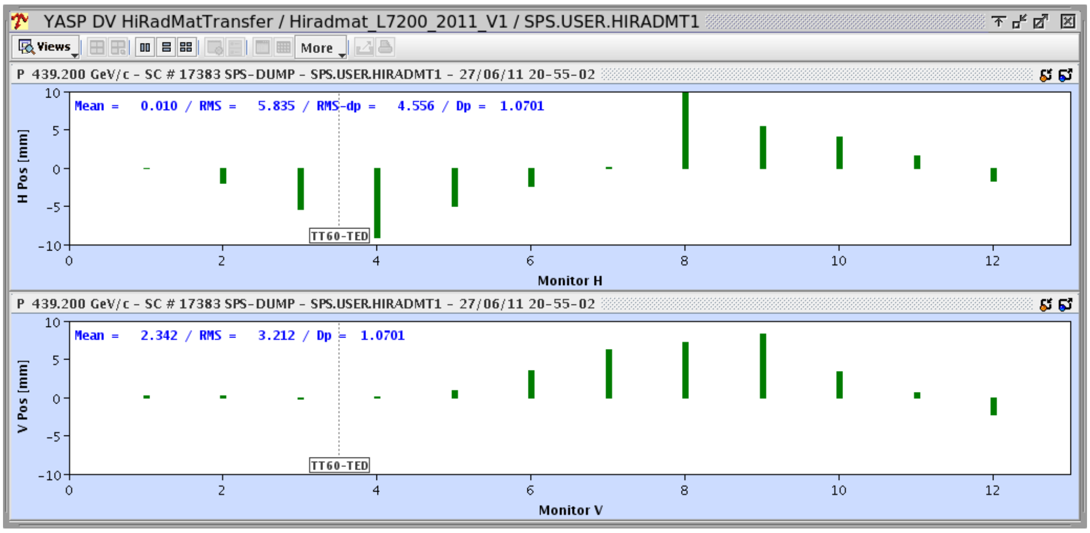


HiRadMatTransfer-F1-0_50-0_50-2011v1, TT66

```
15:30:40 - HiRadMatTransfer-F1-0_50-0_50-2011v1 Optics Selected.
```

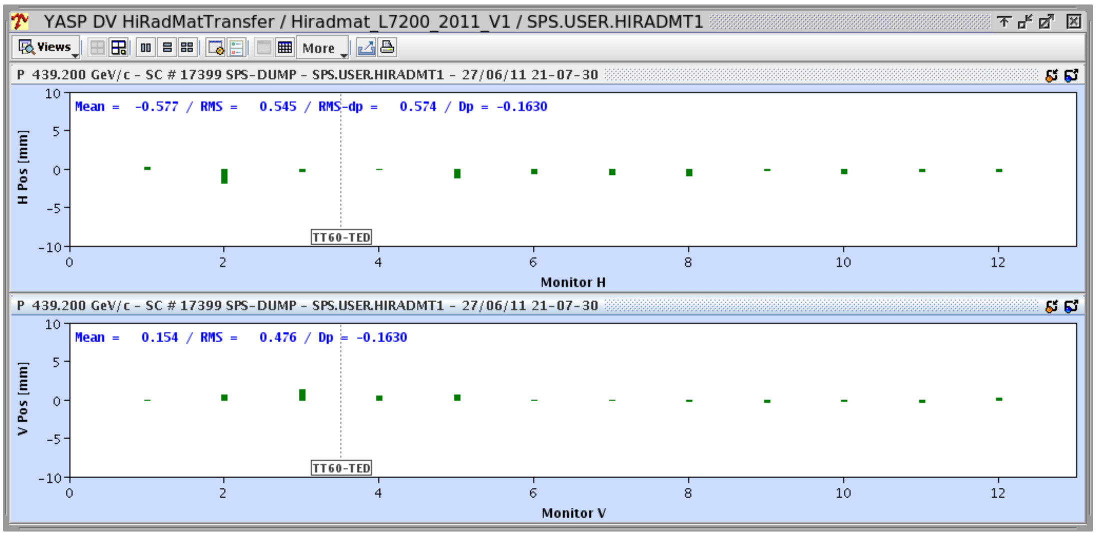
Figure 4.8.1 Control application to load the beam optics

The change of the optics was tested for the different beam sizes at one focal point. These tests showed that the beam line steering must in general be corrected for each optics. See Fig. 4.8.2 and 4.8.3 for an example. These corrections were performed for the tested optics of focal point 1 and mostly saved in the catalog. However, due to the beam availability from SPS, these checks could not fully be completed.



```
YASP DV HiRadMatTransfer / Hiradmat_L7200_2011_V1 / SPS.USER.HIRADMT1
P 439.200 GeV/c - SC # 17383 SPS-DUMP - SPS.USER.HIRADMT1 - 27/06/11 20-55-02
Mean =   0.010 / RMS =   5.835 / RMS-dp =   4.556 / Dp =  1.0701
P 439.200 GeV/c - SC # 17383 SPS-DUMP - SPS.USER.HIRADMT1 - 27/06/11 20-55-02
Mean =   2.342 / RMS =   3.212 / Dp =  1.0701
```

Figure 4.8.2 Difference of the trajectory after changing the optics from F1-0_50 mm-0_50 mm to F1-0_20 mm-0_20 mm



```
YASP DV HiRadMatTransfer / Hiradmat_L7200_2011_V1 / SPS.USER.HIRADMT1
P 439.200 GeV/c - SC # 17399 SPS-DUMP - SPS.USER.HIRADMT1 - 27/06/11 21-07-30
Mean =  -0.577 / RMS =   0.545 / RMS-dp =   0.574 / Dp = -0.1630
P 439.200 GeV/c - SC # 17399 SPS-DUMP - SPS.USER.HIRADMT1 - 27/06/11 21-07-30
Mean =   0.154 / RMS =   0.476 / Dp = -0.1630
```

Figure 4.8.3 New steering for F1-0_20 mm-0_20 mm optics

4.9. Radiation protection

For the radiological surveillance of HiRadMat a set of completely new radiation monitors has been installed in the underground areas of the TNC, TT60 as well as on the surface in the BA7 building. For a complete description of this system embedded in CERN's radiation monitoring system (RAMSES) please refer to Ref. [6]. In addition some older already existing monitors on the surface have been used in a complementary way.

Access to the underground areas of HiRadMat was of course blocked, as it will also be the case for standard operation in the future. But BA7 and its surroundings are classified as non designated areas and thus, are publicly accessible. During the commissioning the readings of especially the surface monitors in and around BA7 have been monitored closely in order to detect any unexpected leakage of radioactivity.

Table 4.9.1 shows a list of monitors which have been used for surveillance during the first phase when the beam had been sent onto the TED.610321, while Table 4.9.2 includes the IDs of the detectors used during the commissioning of the beam line leading into the TNC.

Table 4.9.1: Radiation detectors that have been monitored closely while the beam was sent onto TED.610321

ID	Location	Comment
PAB73	Outside of TT61 in the accessible area	Stray radiation monitor
PMB61	SPS - BA6 surface building	Surveillance of the TED cooling water activation
PMVG172R	Extraction of the ventilation of TT61	Ventilation monitor

Table 4.9.2: Radiation detectors that have been monitored specifically during the commissioning of the HiRadMat beam line

ID	Location	Comment
PMB71	SPS - BA7 surface building	Stray radiation monitor[1]
PAB72	SPS - BA7 surface building	Stray radiation monitor
PMSG72 & PMSN72	SPS – BA7 outside	Environmental stray monitor
PMS072G	SPS – BA7 outside	Environmental stray monitor

In case of problems one would expect the most significant readings from the monitor PAB72 as it is located directly next to the shielded access shaft which leads down to the HiRadMat underground areas (see Figure 4.9.1).

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[1] PMB71 is an old monitor which already existed in BA7 due to its use for previous installations. It was used as well but the more precise and appropriately placed detector for HiRadMat is PAB72.

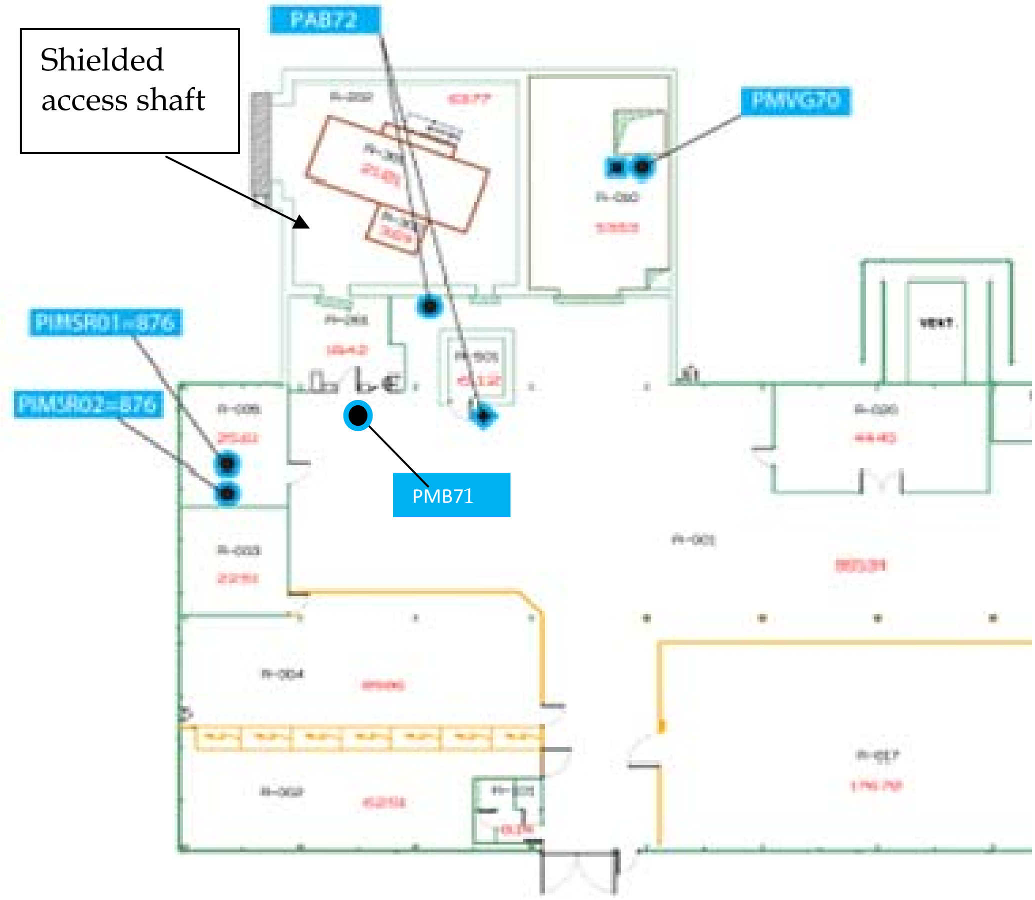


Figure 4.9.1 Location of the radiation protection surface monitor PAB72 next to the access shaft leading to the HiRadMat underground areas [6]

As can be seen from Figures 4.9.2 and 4.9.3 none of the respective monitors listed in Table 4.9.1 showed significant deviations during the time when beam was sent onto TED.610321 on the 22 June between ~17:00 and ~22:00. Subsequently the beam was sent into the dump located downstream of the HiRadMat experimental zone.

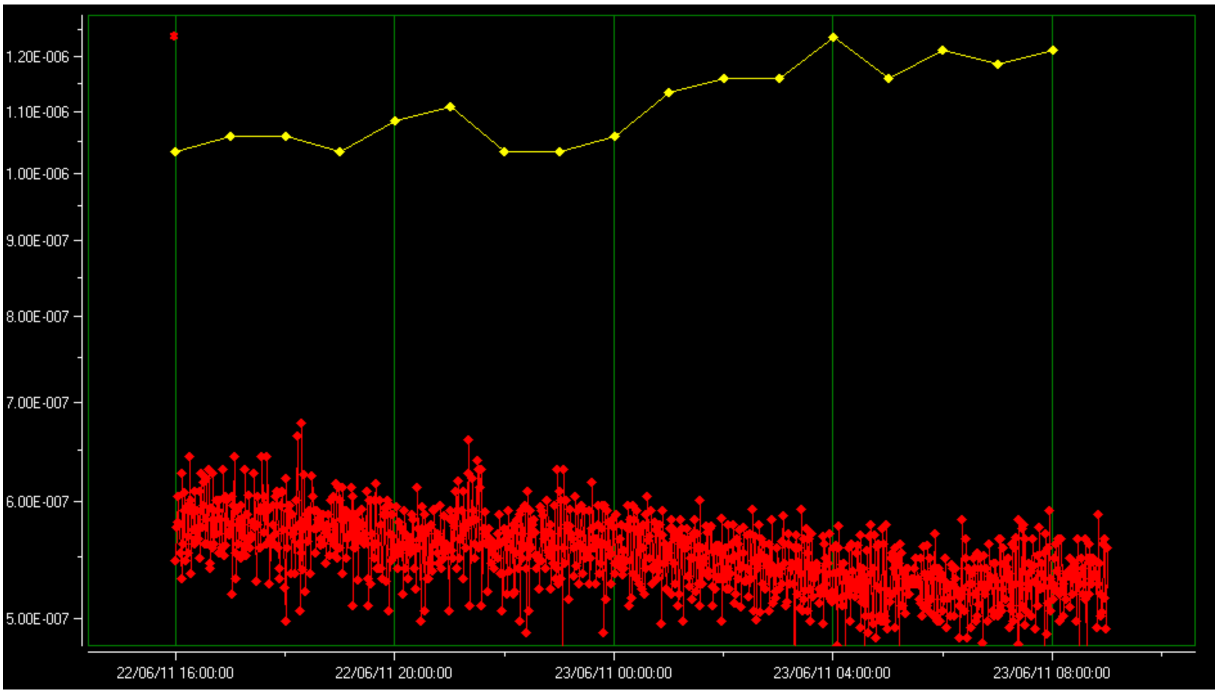


Figure 4.9.2: Readings (Sv/h) of the monitors PAB73 (red) and PMB61 (yellow) which were used for the surveillance during the first phase of the commissioning while beam was sent onto TED.610321. The values are displayed for the period from 22/6/2011 16:00 until 23/6/2011 8:00 to allow for comparison even though the beam was sent onto the TED only from about 17:00 to ~22:00.

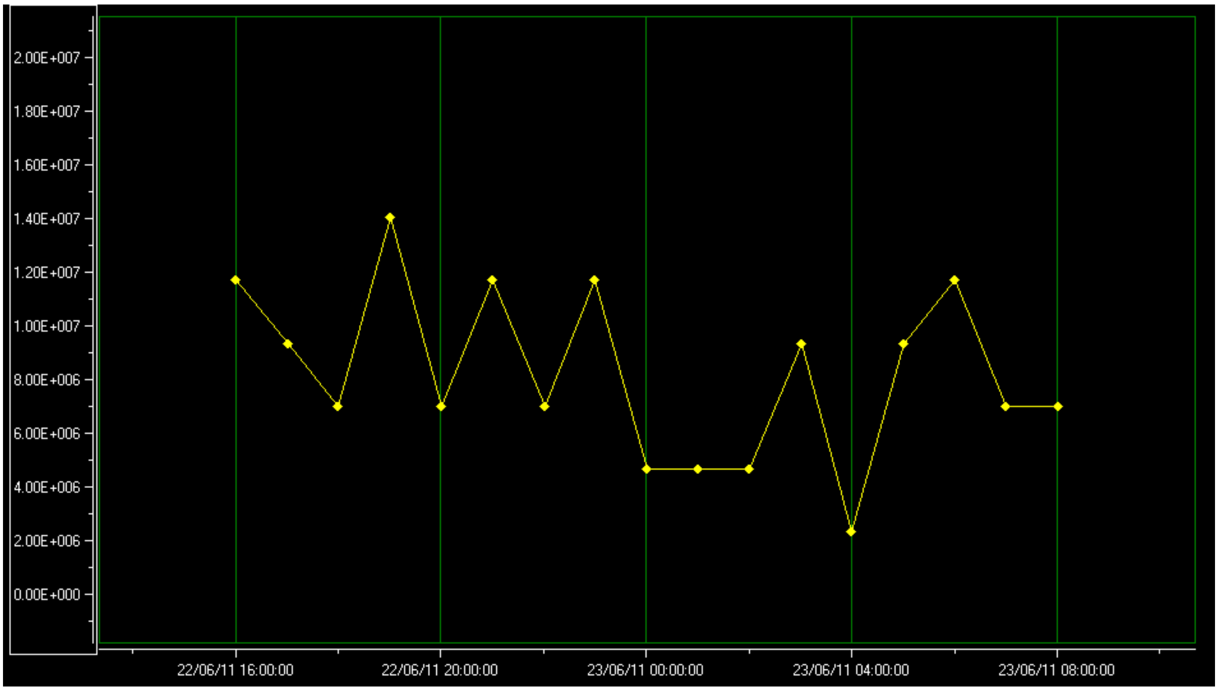
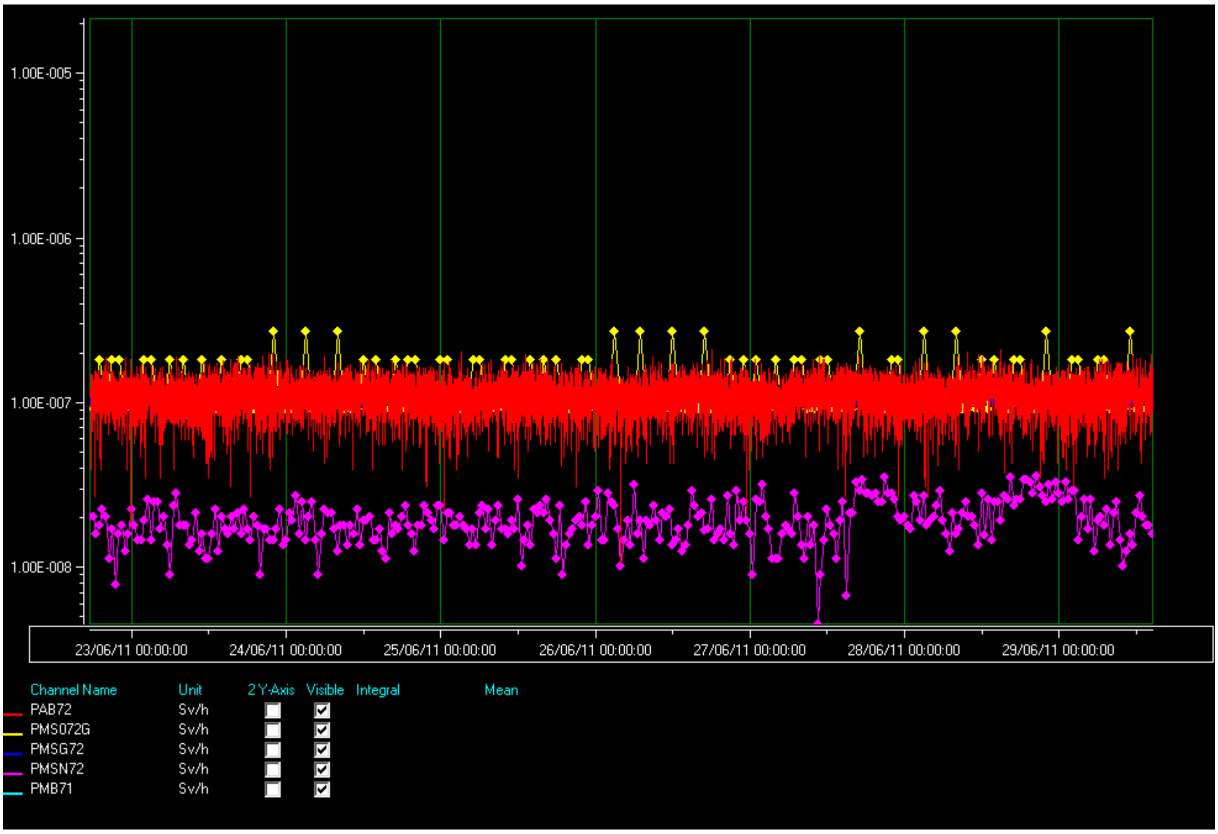


Figure 4.9.3: Readings (Bq/h) of the ventilation monitor PMVG172R which was used for the surveillance of the extracted air from TT61 during the first phase of the commissioning while beam was sent onto TED.610321. The values are displayed for the period from 22 June at 16:00 until 23 June at 8:00 to allow for comparison even though the beam was sent onto the TED only from about 17:00 to ~22:00.

Following the initial setup the beam was sent to HiRadMat during several periods which extended from 22 to 28 June and lasted several hours each. As can be seen from Figure 4.9.4 the values of the monitors listed in Table 4.9.2. did not show any significant deviations during the whole period. The highest values that could be observed were in the order of 300 nSv/h on the environmental detector PMS072G. But these maxima cannot be attributed to HiRadMat as they can be observed also after the commissioning had ended on the 28 June. For HiRadMat especially the monitor PAB72 (shown in red), which is located right next to the shielded access shaft (see Figure 4.9.1), should have indicated unexpected problems due to stray radiation. However, only background could be observed as illustrated in Figure 4.9.4. This clearly shows that the commissioning with low intensity was transparent from the radiological point of view.



Channel Name	Unit	2 Y-Axis	Visible	Integral	Mean
PAB72	Sv/h	☐	☑		
PMS072G	Sv/h	☐	☑		
PMSG72	Sv/h	☐	☑		
PMSN72	Sv/h	☐	☑		
PMB71	Sv/h	☐	☑		

Figure 4.9.4 Readings (Sv/h) of the radiation protection monitors listed in Table 4.9.2 that were used for the surveillance while the beam was sent to the HiRadMat experimental area

It should be noted that the ventilation system was turned off completely during the whole commissioning period as the final configuration was not yet ready and the temporary installation did not include any monitoring of radioactivity released to the environment. First studies had shown that the environmental impact of HiRadMat should be low and especially the low-intensity commissioning should not pose a significant risk due to the restriction of the beam load to a total of 10^{13} protons for the whole period. However, it was decided that it would still be preferable not to have any uncontrolled release of air at all and thus, the ventilation system remained off until 9:00 on 29 June when it was turned on to flush the underground area with fresh air until 13:30. Between the beam stop and the flushing a time span of more than 13 hours had passed. This should have been conservatively sufficient to decrease the dose rate due to potential exposure to activated air in case of an access to the underground area below the applicable limit of 1 µSv/h [7]. The flushing period was completely transparent and no elevated readings have been found on the radiation protection monitors in and around BA7.

During the commissioning the beam has been sent into the dump in the TNC and a number of residual dose rate monitors had previously been installed in that area during technical stops. The one closest to the dump is PMIHR05 and its readings during the period from 19 June to 1 July 2011 are shown in Figure 4.9.5. It can be seen that before the commissioning the residual dose rate was in the order of ~80 µSv/h, which remained unchanged after the commissioning had ended on 28 June. The spikes which are visible in Figure 4.9.5 can be attributed to the prompt radiation due to the particles impinging directly into the dump; they do not originate from residual dose rate.

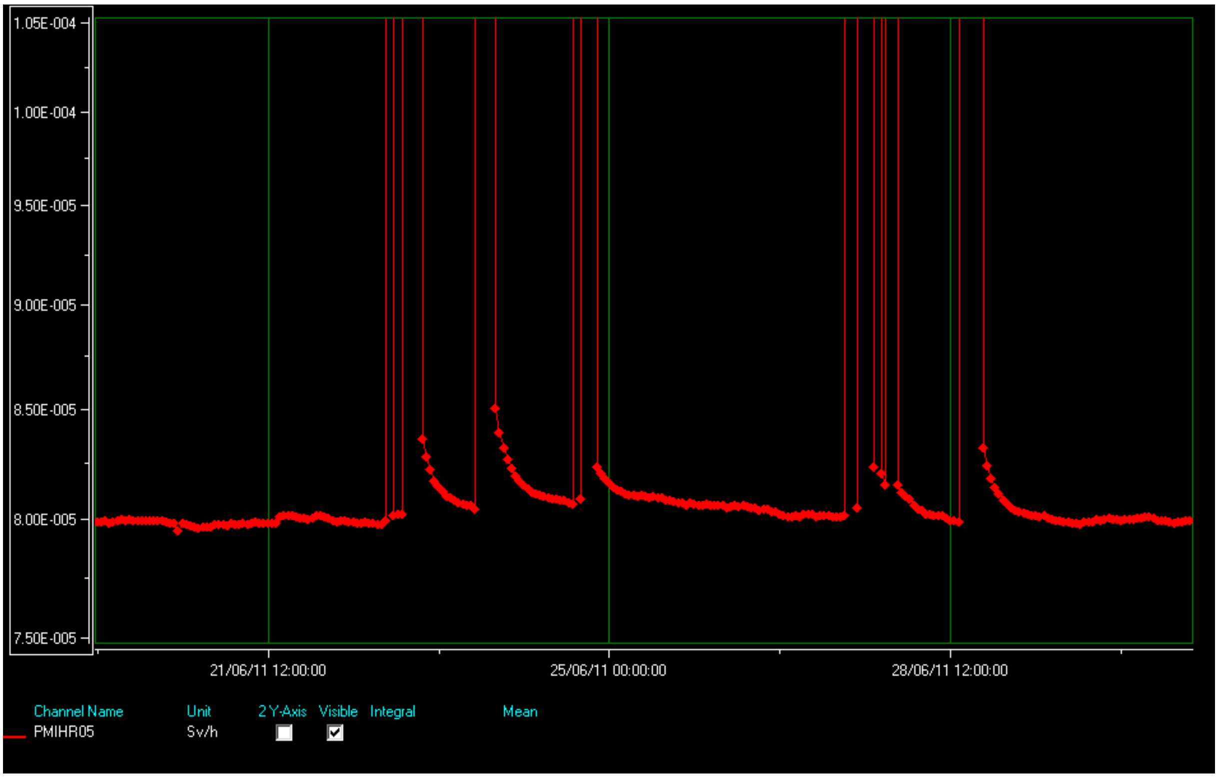


Figure 4.9.5: Readings (Sv/h) of the residual dose rate monitor PMIHR05 installed next to the dump in the HiRadMat experimental area. It can be seen that with the exception of the spikes due to the prompt radiation the residual dose rate before and after the commissioning remained unchanged at ~80 µSv/h.

In summary it can be said that none of the radiation monitors raised any concern and the first commissioning phase of HiRadMat can be considered as a success also from the radiation protection point of view.

5. Summary and conclusions

On 22 June, the first low intensity beam was sent along the HiRadMat primary beam line. All beam line equipment operated as specified and the first proton bunch reach the beam dump located at the end of the primary beam line. Energy matching and beam steering were performed and optics checks did not reveal any optical errors. Aperture measurements confirmed that there were no bottlenecks. Radiation protection monitoring operated as expected and the measurements were within expectation.

The primary beam line is ready for the next beam commissioning phase, scheduled for mid-August, this time with high intensity beam.

6. Acknowledgements

All the members of the primary beam line working groups and the teams involved are sincerely thanked for their dedicated work during the whole life cycle of the HiRadMat project.

The operation crews are thanked for their assistance during all the HiRadMat accesses, the preparation of the beam commissioning and the beam line commissioning.

7. References

[1] The HiRadMat facility at CERN SPS https://espace.cern.ch/hiradmat-sps/

[2] C. Hessler, "HiRadMat Beam Parameters", EDMS document #1054880.

[3] G. Acquistapace et al., "The West Area Neutrino Facility for CHORUS and NOMAD Experiments", CERN-ECP/95-014 (1995).

[4] C. Hessler et al., "The Final Beam Line Design for the HiRadMat Test Facility", IPAC'10, Kyoto (2010).

[5] B. Puccio et al., "Beam interlock system for the HiRadMat facility" https://edms.cern.ch/document/1146094/1

[6] N. Rousset, "Product Requirement Document Activities for RAMSES installation at HiRadMat", EDMS 1070443 v.3, (2010).

[7] H. Vincke, C. Theis, "First RP considerations about the HiRadMat ventilation system", EDMS 1145558, (2010).

ANNEX 1

HiRadMat Beam Commissioning Plan

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The commissioning of the HiRadMat primary beam line is foreseen to be completed in two periods:

- 1st period: 24 h of pilot bunches;
- 2nd period: 4 h of multi-bunches, mostly with 1 batch of 12 bunches.

In case of unforeseen problems (unavailability of beam, etc.) it should be extended by further days if needed.

The tests will mostly be performed using “LHC probe” beams with ~5×10^9 to ~8×10^9 protons per bunch. A few tests will be repeated with higher intensity “LHC2 nominal” pulses with bunch intensities of up to ~1.3×10^{11} p/bunch. These pulses consist of the following number of batches and bunches and will therefore have a maximum of 72 bunches per extraction:

- 1 batch of 12 bunches with 50 ns bunch spacing;
- 2 batches of 12 bunches;
- 1 batch of 36 bunches;
- 2 batches of 36 bunches.

In detail the following tests are planned:

Test	**Beam type**	**# bunches**	**Bunch intensity**	**# shots**	**Max. total intensity**	**Time**
Send beam onto TED.610321						
Test of the extraction from SPS	LHC probe	1	10^{10}	50	10^{12}	2h
Sending beam “LHC Probe” to HiRadMat						
Beam line bare trajectory and steering	LHC probe	1	~8×10^9	90	~7.2×10^{11}	2h
Beam instrumentation (incl. calibration, check response, checks of corrector and pickups)	LHC probe	1	~8×10^9	180	~14.4×10^{11}	4h
Controls, logging	LHC probe	1	~8×10^9	30	~2.4×10^{11}	0.5 h
Steering on target	LHC probe	1	~8×10^9	60	~4.8×10^{11}	1h
Interlocking tests (interlock limits)	LHC probe	1	~8×10^9	30	~2.4×10^{11}	0.5 h
Aperture checks (knobs needed, to be done with 1 reference optics)	LHC probe	1	~8×10^9	240	~19×10^{11}	5h
Beam parameters checks	LHC probe	1	~8×10^9	90	~7.2×10^{11}	2h
Beam size and focal point position adjustment	LHC probe	1	~8×10^9	180	~14.4×10^{11}	4h
Position/intensity stability	LHC probe	1	~8×10^9	60	~4.8×10^{11}	1h

Change of beam line optics + repetition of some tests	LHC probe	1	$\sim 8\times10^{9}$	180	$\sim 14.4\times10^{11}$	4h
Sending beam "LHC2 nominal" to HiRadMat						
Re-check trajectory	LHC2 nominal	12	$\sim 1.3\times10^{11}$	10	$\sim 1.6\times10^{13}$	0.5h
Check beam instrumentation (BTV Ti screens, readings for high intensities, etc.)	LHC2 nominal	12	$\sim 1.3\times10^{11}$	20	$\sim 3.2\times10^{13}$	1h
Beam parameters checks	LHC2 nominal	12	$\sim 1.3\times10^{11}$	20	$\sim 3.2\times10^{13}$	1h
Increase intensity in steps and check consistency of nominal beam with probe beam	LHC2 nominal	24	$\sim 1.3\times10^{11}$	5	$\sim 1.6\times10^{13}$	0.5 h
	LHC2 nominal	36	$\sim 1.3\times10^{11}$	5	$\sim 2.3\times10^{13}$	0.5 h
	LHC2 nominal	72	$\sim 1.3\times10^{11}$	5	$\sim 4.7\times10^{13}$	0.5 h

The estimates are based on a supercycle length of about 1 minute and on a beam availability from the injectors of 100 %. Please note, the given number of shots and time needed for each test is only a rough estimate and depend on the outcome and results of each test.

The maximum intensity for the first period will be $\sim 9\times10^{12}$ protons. The maximum intensity limit for the second period will be $\sim 2\times10^{14}$ protons. The number is conservative and is given as an expected upper limit – only in the case of unanticipated problems (for example an aperture limit requiring more measurement points) could these numbers be exceeded – this will require prior consultation with safety and radioprotection experts.

Beam loss monitors are installed along the TT66 beam line, which will allow the beam losses to be minimized to the absolute necessary. Note that all measurements, which involve losses other than on the TED dumps (aperture scan, calibration of beam loss monitors), will all be carried out with probe bunches.

The extracted intensities, the beam loss measurements and the radiation monitor signals will be logged in the LHC shot-by-shot logging system.