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INJECTION SEPTA POSITION AND ANGLE OPTIMISATION IN VIEW OF THE 2 GEV LIU UPGRADE OF THE CERN PS

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Abstract

In the framework of the LHC Injector Upgrade (LIU) project the CERN PS injection kinetic energy will be upgraded from 1.4 to 2 GeV. The injection equipment, which is already operating close to its limit, is being redesigned to cope with 30% increase in the beam rigidity. In this paper we present the experimental results from Machine Development (MD) studies on the present septum to explore its operational hardware limits with respect to aperture restrictions, beam losses and kick strengths in view of the LIU upgrade.

INTRODUCTION

As part of the LIU project the injection kinetic energy of the CERN PS will be upgraded from 1.4 to 2 GeV to double the beams brightness. The BT-BTP transfer line and the PS injection scheme have been redesigned to have more flexibility and allow the injection at 2 GeV. Nevertheless PPM compatibility with beams at 1.4 GeV has to be ensured. The present layout of the injection region is presented in Fig. 1 which shows the bumper 42 and the septum between the main unit 41 and 42. The main features of the new injection system are: a five bumpers scheme, instead of the present four bumpers scheme, which gives a better control on the beam displacement in the injection area, and a low beta insertion for High Intensity (HI) beams with quadrupoles installed in SS33 and 49 to reduce the beam envelopes in the injection region and hence losses and hardware irradiation. The duration of the bump will be also halved from 2 to 1 ms. A new eddy current septum has been designed [1] and it will installed in SS42, the physical length of new septum is 940 mm whereas the present septum is 620 mm. The bumper 42 will be a septum-like magnet and it will be hosted in the same vacuum vessel due to reduced longitudinal space availability. The new layout of the straight section 42 is presented in Fig. 2. Optics simulations on the beam envelopes of 2 GeV HI beams during injection [2] have shown that to minimise losses on the septum blade for the injected and circulating beams the optimal position of the future septum is 1 cm closer to the ring orbit with respect to the actual position (from 64 to 54 cm). These results triggered the interest to study the performance of the present septum position and angle and their relation with the observed losses due to the injection area aperture restrictions for HI beams and to verify that the LIU septum position is compatible with the more stringent requirements of HI beams at 1.4 GeV.

PS INJECTION BUMP AT 1.4 GEV

The PS injection scheme for proton (Fig. 3) is performed with a four bumpers scheme to control the orbit displacement and the slope of the bumped orbit. The septum bends the beam from BT-BTP line by 55 mrad (nominal value) and then it goes through the bumper 43 and 44, a kicker in SS45 operated in terminated mode gives the final 4.3 mrad kick to place the beam on the closed orbit. For a given position and angle of the injected beam at the septum flange the bumpers 43, 44 are matched to steer the injected beam with zero horizontal orbit displacement in the kicker 45. The bumpers 40 and 42 are then matched to close the bump for the circulating beam. Operationally the strength of the septum, kicker and bumpers are optimised for each different beam to minimise losses, injection oscillations and the bump closure. The present injection septum design has operated reliably since last PS injection energy upgrade from 1 to 1.4 GeV in 1999. The designed position of the septum was 56 mm from the ring closed orbit but it was moved to 64 mm in the following years to reduce losses during injection of HI beams [3]. For the experiment we used a TOF beam with currents and kick angles of the injection bumpers reported in Table 1.

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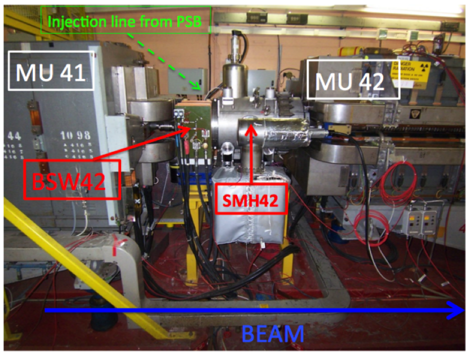

Figure 1: Present layout of SS42. From left to right: the MU41, the bumper 42, the septum 42 and the MU42.

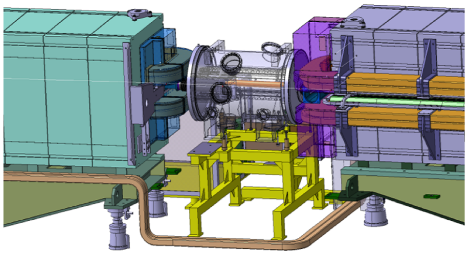

Figure 2: Layout of the SS 42 for the 2 GeV injection, the new eddy current septum in the centre and the main magnet unit 41 (on the left) and 42 (on the right).

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Table 1: Currents and relative kick angles of the bumpers for TOF beam.

Element	BSW40)	BSW42	BSW43	BSW44
I [A]	846.52	3500.9	3131.75	1384.69
Θ [mrad]	3.32	13.72	12.27	5.43

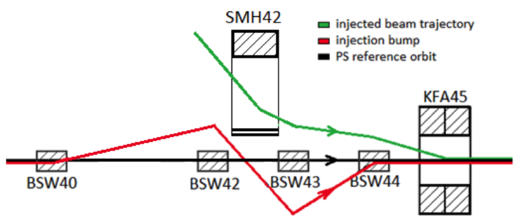

Figure 3: A schematic of the four bumpers injection at 1.4 GeV with $\pi/2$ phase advance between BSW40 and BWS44 [not to scale]. The injected beam trajectory from the transfer line in green and the bumped orbit in red.

THE MD: SETUP AND MEASUREMENTS

To study the effect of the septum position and angle on the beam passage through the injection apertures a dedicated MD has been performed on July 13^{th} 2016. A TOF beam with an intensity of 800 10^{10} ppb was chosen to explore the highest emittances and intensity which impose the most stringent requirements regarding aperture restrictions. The intensity evolution during the magnetic cycle is shown in Fig. 4 where the cyan line represents the intensity. The initial slope of the curve represents the injection losses, about 5% for HI beams. The measurements of the longitudinal phase space with the tomoscope and the horizontal emittance with the wirescanner are presented in Fig. 5 and 6, respectively. The longitudinal emittance is 2.75 eV s and the horizontal emittance is 17.4 mm mrad. The MD strategy has been to move the septum position and angle while adjusting the injection bump and recording the losses measured by the BLM42 due to the transverse beam tails scraped by the septum blade. A fast diamond BLM installed on the main unit 42 was also connected to an OASIS channel to record the fast losses generated by the injected beam on the inside part of the septum blade. The position of the fast BLM on the main unit 42 is shown in Fig. 7. An optimisation of the strength of the septum and kicker 45 was done by using the YASP injection steering tool in order to minimise the amplitude oscillation in the BPMs and, hence, to improve the bump closure. An example of orbit acquisition of the BPMs during injection after optimisation is shown in Fig. 8. The large oscillation signal is due to a malfunctioning pickup whereas the green line starting from -30 mm is the pickup signal in the SS43, which shows the amplitude-varying bump.

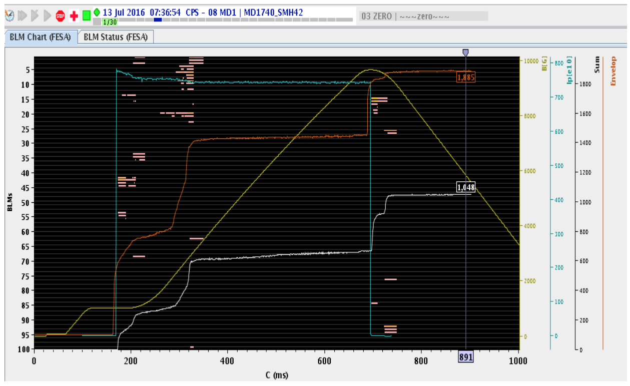

Figure 4: Intensity evolution (cyan line) during the magnetic cycle (yellow line) for TOF beam.

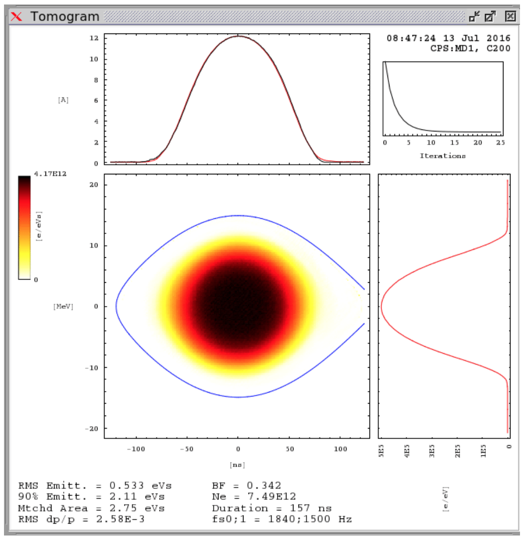

Figure 5: Longitudinal phase space for TOF beam as reconstructed by the tomoscope. The longitudinal emittance is 2.75 eV s.

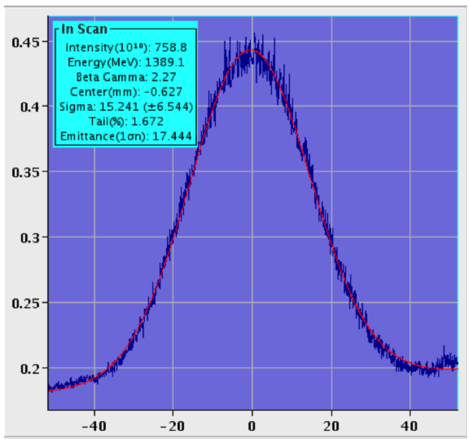

Figure 6: Wirescanner emittance measurement for TOF beam. The horizontal emittance is 17.44 mm mrad.

RATIONALE, PROCEDURE AND MEASUREMENT RESULTS

The rationale of the MD was to produce a map of losses

Figure 7: The white arrow in the picture indicates the position of the fast BLM on the top of main unit 42.

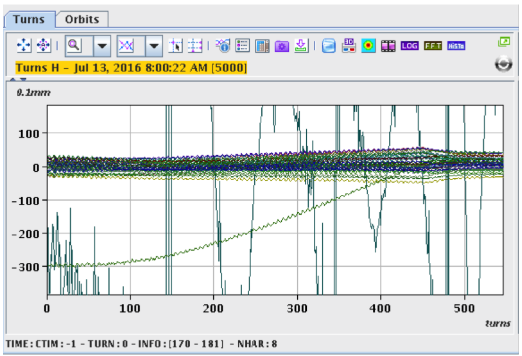

Figure 8: Example of horizontal turn-by-turn trajectory acquisition for TOF beam. Each line represents the acquisition of different pickups along the ring. The large oscillation signal is due to a malfunctioning pickup whereas the green line starting from -30 mm is the pickup signal in the SS43, which shows the amplitude-varying bump.

timization of the injection. The procedure was to move the septum from the original horizontal position of 64 mm towards the minimal value of 53 mm from the beam axis while recording the BLMs signal along the ring and the fast diamond BLM42 connected to an OASIS channel (e.g. Fig. 9). Then the trajectory of the injected beam was optimised with the septum and kicker to minimise losses. At the same time we lowered the bump height to reduce losses of the circulating beam. The measured scanned position and angle of the septum during the MD are presented in Fig. 10, the currents in the bumpers, kicker and septum in Fig. 11 and the recorded signal in the BLMs in Fig. 12 . A total of about 3 thousand acquisitions were recorded in the 5 hours MD. The acquisitions are divided in 9 areas: (1) The first tens of acquisitions were done for the nominal setting of 64 mm and 10 mrad position and angle of the septum. The average signal in the BLM 42 was 23 ADC bits. (2) The angle of the septum was moved to its minimum value of 1 mrad, higher losses were recorded while decreasing the angle indicating that the beam was scraped on the inside part of the septum blade. (3) After that the angle was set to 13 mrad and the position was reduced to 54 mm with 1 mm step. During the scan the BLM42 signal reduced down to 10 ADC bits and then it increased again at a position of 54 mm and an angle of 10 mrad. (4) At this point the fast diamond BLM was connected to the OASIS channel and we tested it by using the PS internal dump to disentangle the losses from the injected beam. (5) The acquisitions with the internal dump can be identified in Fig. 12 as the places where the BLM42 signal goes to zero and the signal from BLM 47 increases. An example of the OASIS signal acquisition is shown in Fig. 9, where the green line indicates the fast diamond BLM signal whereas the yellow line indicates the BLM 42 signal. (6) At 9:30 we reduced the bump height by lowering the strength of the bumpers and optimising the septum and kicker 45 currents. The bumper strength was reduced by 25% and the septum strength was increased by 4.2% while the kicker 45 was increased by 10%. The reduction of losses in the BLM42 is visible around 10:30 indeed for an angle of 10 mrad and the position varied from 54 to 60 mm the BLM42 indicates a constant value of 8 ADC bits. (7) For position higher then 60 mm the BLM42 signal starts to increase up to 40 ADC bits. (8) Acquisitions between 10:50 and 11:50 were done to see the effects on the BLM42 with the optimised bumpers, kicker and septum strengths. (9) We performed an automatized scan on septum position and angle. In Fig. 13 we present the results of the scan using the entire range of the BLM42. It shows that positions between 55 and 60 mm give the lowest BLM values. The same results with the data filtered to values below 8 ADC bits are presented in Fig. 14. The plot indicates that for positions between 57 and 59 mm and angles between 8 and 11 mrad we get the lowest BLM read of about 6 ADC bits. The same analysis has been done with the fast diamond BLM and the integrated signal in OASIS. The results shown in Fig. 15 and 16 confirm that losses are reduced for a lower position of the septum.

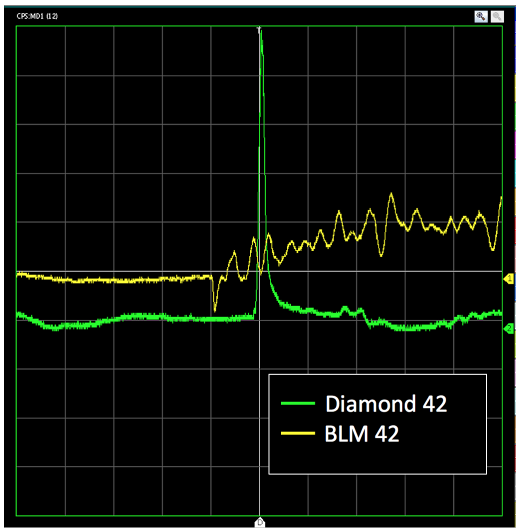

Figure 9: Acquisition example of Oasis slow BLM42 signal (yellow line) and diamond fast BLM42 (green line).

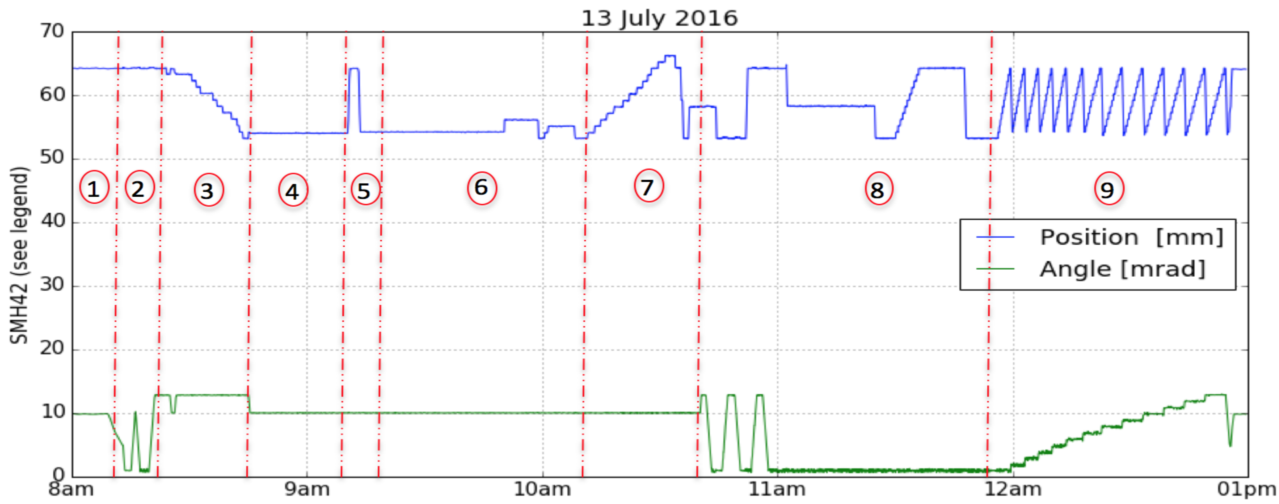

Figure 10: Acquisition of the septum position and angle variations during the MD for TOF beam.

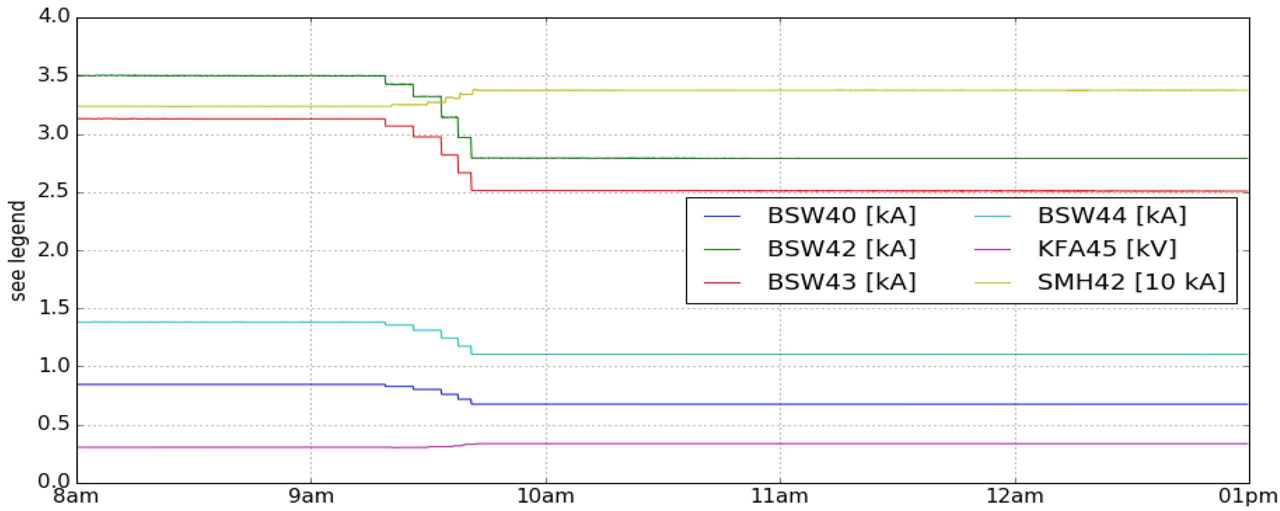

Figure 11: Bumpers, kicker and septum currents during the MD for TOF beam.

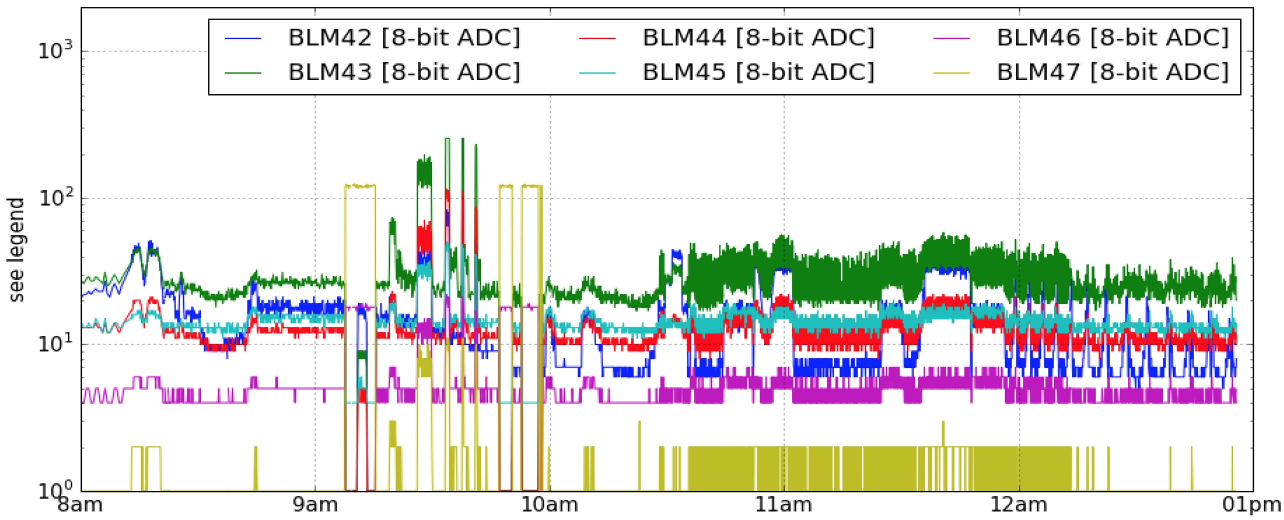

Figure 12: Measured losses in the BLMs downstream the injection section 42 for TOF beam.

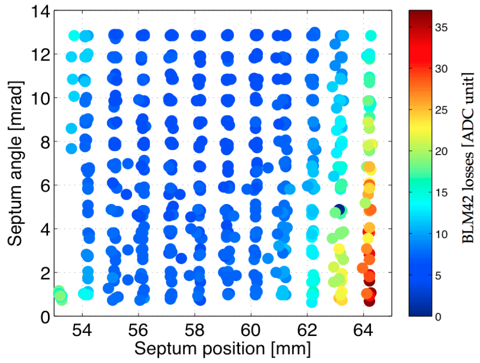

Figure 13: Results of the scan in position and angle for TOF beam. The colour scale is the BLM42 signal.

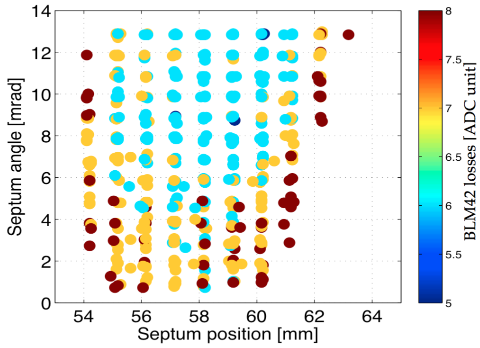

Figure 14: Results of the scan in position and angle for TOF beam. The colour scale is the BLM42 signal. The data have been filtered between 5 and 8 ADC bits.

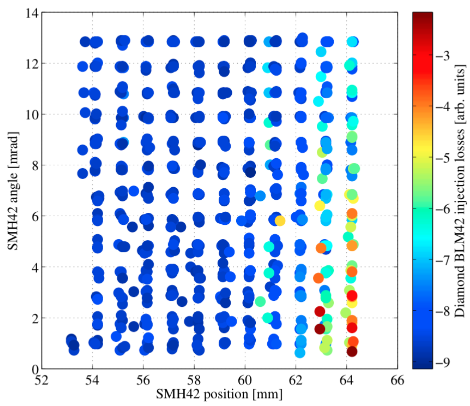

Figure 15: Results of the scan in position and angle for TOF beam. The colour scale is the Diamond BLM42 signal.

EFFECTS ON OTHER BEAMS IN THE PS: SFTPRO AND AD TYPE BEAMS

During the dedicated MD we decided to keep all the production beams in the cycle and measure the beam losses due to the septum position and angle. The septum, kicker and bumpers strengths were not optimised for these beams. The scanned positions and angles, the injection elements strength and the BLM readings for SFTPRO beam are presented in Fig. 19, 20 and 21, respectively. The colour map scan is

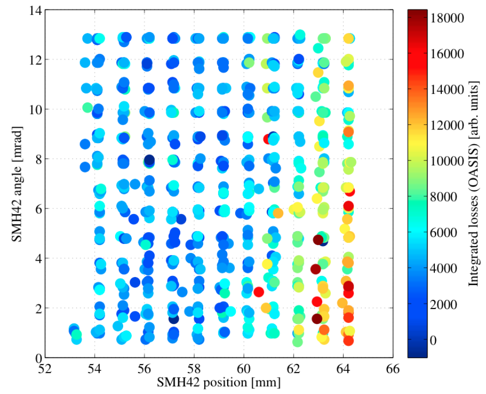

Figure 16: Results of the scan in position and angle for TOF beam. The colour scale is the integrated losses in OASIS.

shown in Fig. 17 and the same plot with filtered BLM data in Fig. 18. The averaged signal of 40 ADC bits is reduced to about 20 for a septum position between 54 and 58 mm and an angle between 8 and 12 mrad. Results of the scan for AD beam are shown in Fig. 22, 23 and 24. The colour maps scan presented in Fig. 25 shows that the BLM signal increases for a septum position of 53 mm and low angles.

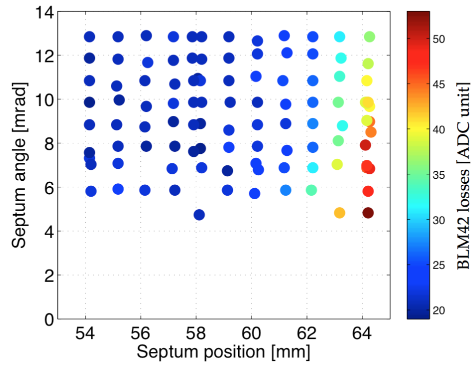

Figure 17: Results of the scan in position and angle for SFTPRO beam. The colour scale is the BLM42 signal.

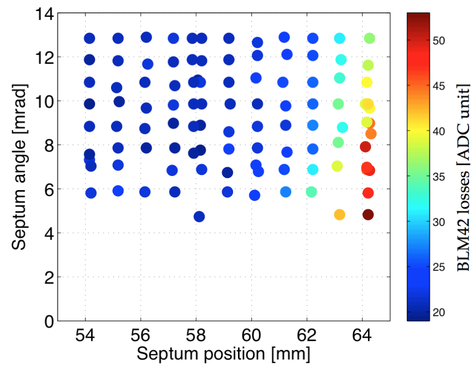

Figure 18: Results of the scan in position and angle for SFTPRO beam. The colour scale is the BLM42 signal. The data have been filtered between 19 and 25 ADC bits.

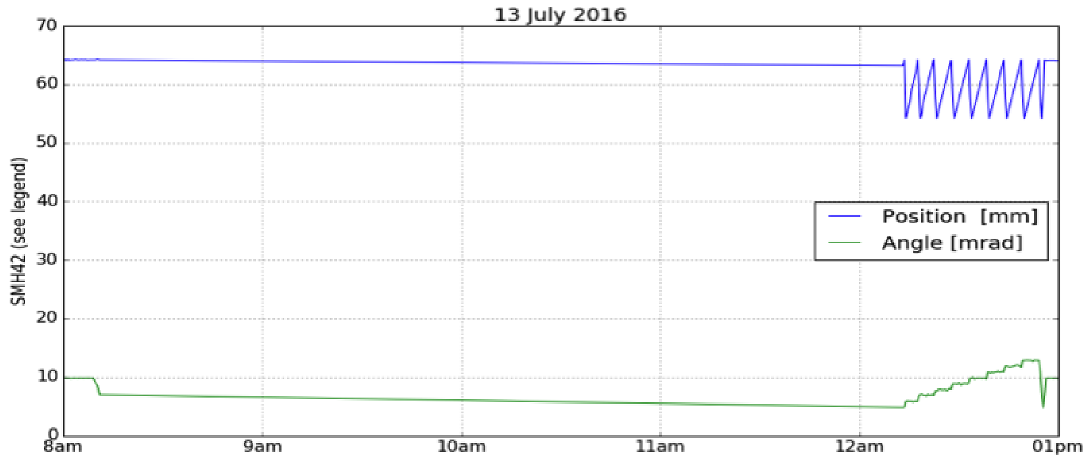

Figure 19: Acquisition of the septum position and angle variations during the MD for SFTPRO beam.

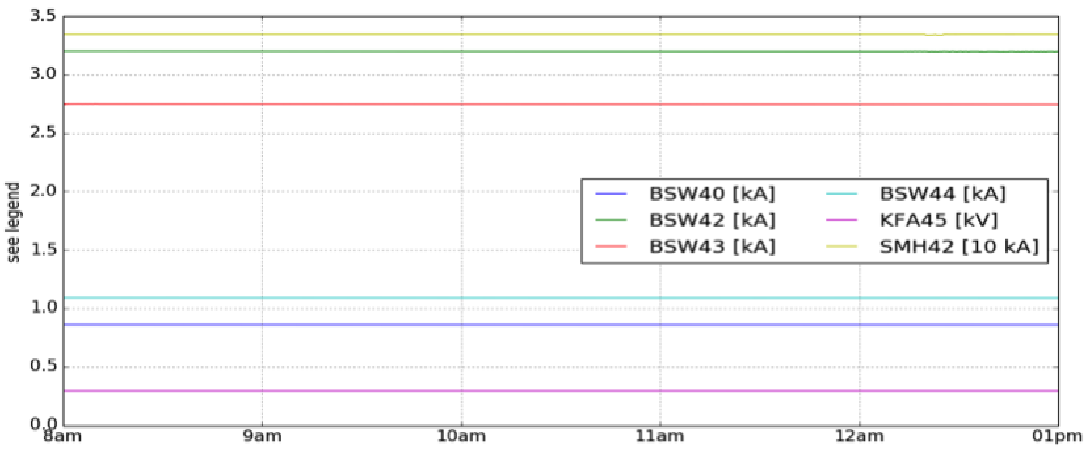

Figure 20: Bumpers, kicker and septum currents during the MD for SFTPRO beam.

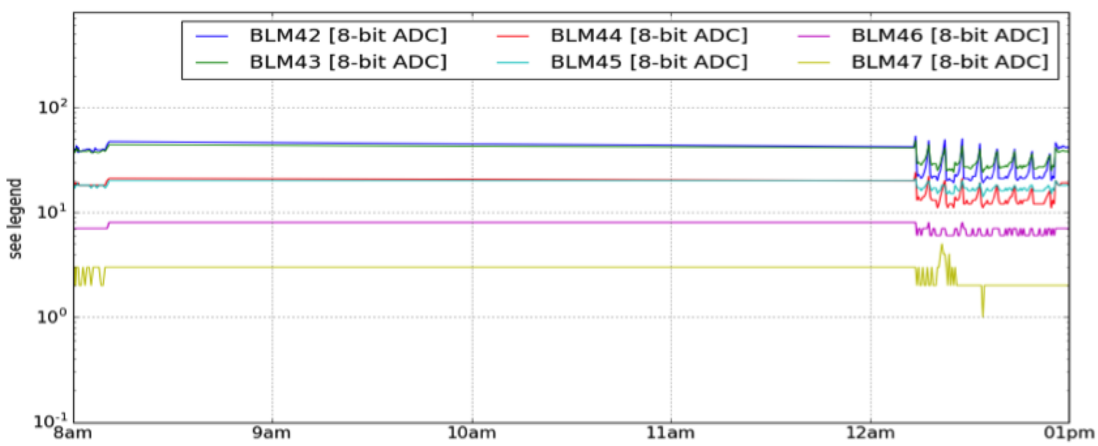

Figure 21: Measured losses in the BLMs downstream the injection section 42 for SFTPRO beam.

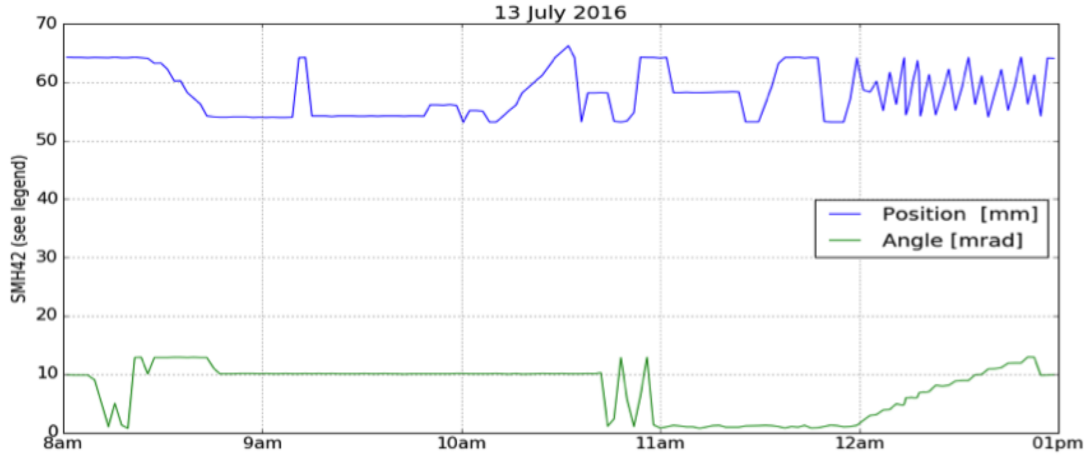

Figure 22: Acquisition of the septum position and angle variations during the MD for AD beam.

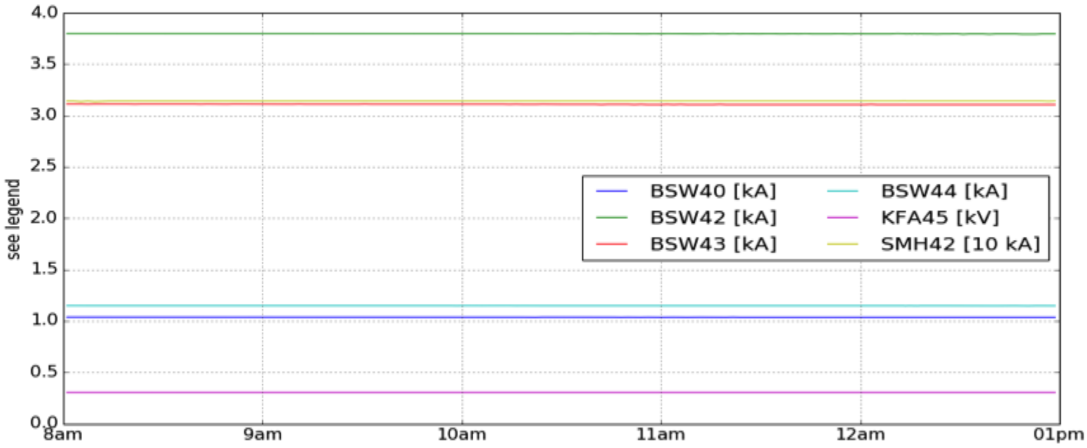

Figure 23: Bumpers, kicker and septum currents during the MD for AD beam.

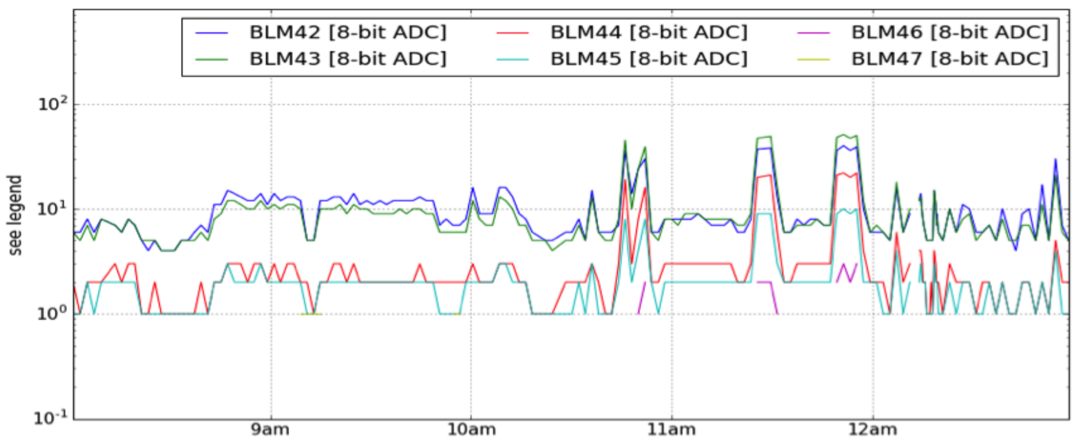

Figure 24: Measured losses in the BLMs downstream the injection section 42 for AD beam.

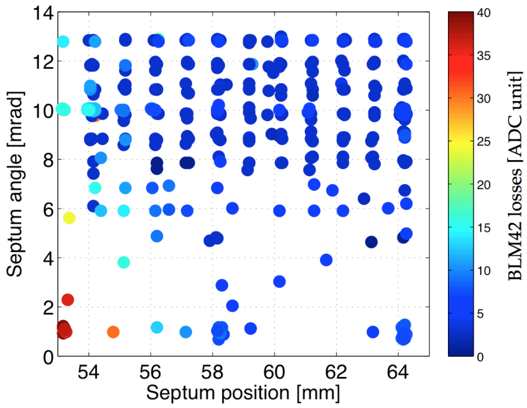

Figure 25: Results of the scan in position and angle for SFTPRO beam. The colour scale is the BLM42 signal.

CONCLUSION

A dedicated MD has been performed to optimise the septum position and angle in view of the LIU upgrade. The results were very positive. They show that lowering the position of the septum and adjusting its angle it is possible to reduce losses in the injection area of the PS ring. This solution could be also applied to the present system with the drawback of increasing the septum strength by 4.2% and push it close to its maximum value.

ACKNOWLEDGEMENT

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REFERENCES

[1] J. Borburgh *et al.*, "Specification for the 2 GeV PS Proton Injection Septa" in *EDMS*, 1477011

[2] J. Abelleira and M. Serluca, "PS Injection Septum Position and Injection Bump at 2.0 GeV" in *EDMS*, 1557577 rev. 1.1

[3] J. Borburgh, private communication, Jun. 2016.