15th LIU PSB Beam Dynamics Working Group

Participants: F. Antoniou, F. Asvesta, H. Bartosik, G. Bellodi, C. Bracco, G. P. Di Giovanni, A. Findlay, J. B. Lallement, B. Mikulec, A. Oeftiger, T. Prebibaj, F. Roncarolo, P. Skowronski

Information: LIU restructuring (Fanouria Antoniou et al)

Fanouria reported on the restructuring of the LIU meetings. The main difference in respect to the WG is the new LIU Beam Dynamics Coordination meeting, chaired by Hannes and Giovanni, to which our WG will report. In this 1st meeting the milestones for this year were presented.

Fanouria and Chiara reported on the PSB Beam Dynamics milestones for 2019/2020 which were presented during the 1st Beam Dynamics Coordination meeting.

***Results on Stripping Foil Tests* (Chiara Bracco et al)**

- Chiara reported on the tests concerning the stripping efficiency of the units. The test bench was described and the beam conditions were explained. In particular, the foil holder can host up to 6 foils at a time, the failed foils could be replaced and they could all be tested one by one.
- Hannes **asked whether the reference position is always around 0, which Chiara confirmed and stressed that the foil needed to always be at the center so there was additional steering whenever needed.**
- Hannes **also asked about the reference of the screen to which Chiara again ensured that it was always such that the beam center corresponded to the reference center adding that it could also be cross-checked with the foils.** To measure the efficiency two cross calibrated BCTs were used, located upstream and downstream of the foils.
- Bettina **commented on position and stressed that it should correspond to the 81 mm height of the chicane + injection painting bump**.
- Chiara presented the foils that were tested showing the materials, thickness and beam time. The thicker Multi-Layer Graphene foils should be favored according to the study since the outcome concerning the efficiency was similar and the thicker ones are easier to use.
- Hannes **commented on the pictures shown and wondered whether one of them was after the test. Chiara said they were all before the test but it corresponded to a thin foil that was very hard to manipulate, that is the main reason that the thicker foils should be favored.**
- Hannes **then asked about the manufacturers of the foils wondering whether there were any manufactured at CERN. Chiara replied that no foils were made at CERN but there were foils from GSI, Japan and Canada.**
- Hannes **asked** Giulia **whether the foils of the LINAC3 were also from GSI and Giulia confirmed for some of them.**
- Gian Piero **commented on the costs of the foils since all non-European companies would be more problematic and the GSI ones are usually cheaper for this reason.**
- The results of the stripping efficiency were presented for all tested foils. All of them had high enough efficiency, above 98%. In the half sector where the H^- monitor could also be used and cross checked with the BCTs, all of the foils were at almost 100%. Hannes **wanted to ensure that this number came from both the BCTs and monitors, which Chiara again confirmed**. No clear correlation between the efficiency and the

losses was observed. The expected behavior would be to have higher losses for higher efficiency (thicker foils) since the foil interacts more with the beam.

- **Piotr commented that since the measurement is done with a device that assumes the beam passes through, it is not possible to measure any scattered particles. Gian Piero commented that these were actually conservative numbers. Chiara mentioned that the stripped electrons were escaping the foil and their charge affected the BCT readout. This was proven by using a steering corrector to bend the electrons away from the proton trajectory, up to a certain strength the current at the downstream BCT increased, then, due to proton losses, it decreased again. Federico then observed that there is some correlation between the losses and the efficiency to which Chiara replied that it is not really understood. Hannes observed that all of the foils are satisfactory in terms of efficiency to which Chiara agreed but suggested further tests concerning the effect on the emittance and again stressed the issue of the thickness of the materials.**
- **Piotr wondered if there were losses without the foils, Chiara said that practically no losses were observed without foils and much higher when using the BTV screen.**
- **Giulia asked if the times shown are lifetimes or testing times. Chiara said they correspond to the time the foils were tested and that none of the failures were connected to the lifetimes of the foils, since the direct interaction with the beam was never responsible for the breakage.**
- Concerning the damage of the foils, some are believed to be caused by bad grounding of the BTV, since there were failures whenever the BTV was used. Once the grounding improved no more foils ended up with damage due to the BTV screen.
- After the impact with the beam the passing point is visible in the foil as a crater is formed. However, the stripping efficiency was not affected by this. The only observable to affect the efficiency was the optics, since the miss steering caused drops in the efficiency. On a different case, a completely burnt foil was found at the bottom of the chamber and the foil holder was highly activated. The reason of this is believed to be the fact that the tests for the grounding of the BTV caused many losses at low energy upstream that affected the holder. In these tests the BTV was exposed to beam for a long time. **Bettina mentioned that there are interlock systems for such failures and Hannes observed that there was almost a factor 4 higher intensity (full 4 rings batch) during the test**. Concerning the GSI foil, even though it was completely deformed after the first impact, the efficiency remained at almost 99.8%.
- **Hannes wondered whether there are enough data concerning the lifetime. Chiara commented that the lifetime of every foil is estimated to be compatible with a full year of operation. Interlocks exist for when the stripping efficiency drops by 10% and the foils are not expected to be changed very often in operation. Bettina commented that this was mainly for study purposes. Chiara added that such problems are not expected and were not even seen on simulations, stressing that the test has more problems than expected during operation.**
- **Jean Baptiste asked if the beam size was larger during the test but there is not a dramatic difference.**
- **Fanouria asked if the large spreads of the GSI and DLC foils are correlated with degradation in time. Chiara replied that there is no indication of degradation. The spread is due to steering errors as the data were not filtered.**

***Wrap-up of L4 2018 autumn run* (Jean Baptiste Lallement et al.)**

- Jean Baptiste started with the reliability of the run that lasted for almost three months. It took almost a month to restart, set-up and take various measurements. In the future it is expected to take around 2 weeks if the source is already running. Some issues were revealed during the run, especially from the low level RF for the first few weeks and from the source and FGCs towards the end of the run. Moreover, the fact that no piquet service was available outside working hours and that Linac4 was not on top priority compared to LHC injectors, the issues took generally longer to resolve. Overall the reliability was at 94.7% close to the aim of 95%.

- **Bettina and Gian Piero commented that 95% was only the first step and the reliability should be further increased. Jean Baptiste stressed that the LINAC4 is a much more complex machine with many differences from the past: almost a factor 4 more cavities and furthermore the H- source is very demanding and very hard to get up to speed, which was also the experience in other similar labs. From this perspective the reliability is quite satisfactory.**

- Jean Baptiste continued with the requirements from the PSB side for the beam quality. The maximum current was limited to 25mA which was known from the start since the source was known and measured to be limited to 27mA (out of the RFQ). All the problems in transmission were localized in the source and the tuning of the RFQ while no losses were observed after those elements. Concerning the flatness of the pulses, it can be tricky since it is influenced by many parameters and especially by the source settings, the space charge compensation and the beam loading in the cavity.

- **Bettina commented that it was also seen on the plots provided and the shot by shot variation was satisfactory but not maintained for long periods. Jean Baptiste explained that it could be achieved if sufficient time is spent to optimize the settings and that it was not asked to maintained stability for long periods during the run. Bettina then suggested to check how the autopilot could affect this behavior. Piotr asked about the particulars of the Feedback loop used. Jean Baptiste commented that so far it is quite basic and only checks the pulse shape coming from the source and added that the Feedback loop was not used during the run. Piotr continued asking about the correlations between the signals and how all these are understood. Jean Baptiste replied that the correlations are understood but so far the optimization is done by playing with the respective knobs. It was stressed that this could be done in a few minutes by experienced operators. Bettina mentioned that machine learning methods should be applied to check the individual parameters and to this Piotr stressed the importance of correlations since this should be the basis for the Feedback. Bettina continued saying that many tests are done also with Daniel Noll to check how it can be achieved. Jean Baptiste concluded that to be fully automatized further studies are needed. Hannes asked how the situation would look like if no modifications are made, to which Bettina replied that it would be very bad. Jean Baptiste agreed saying that the beam parameters out of the source are continuously changing so there is a need for regular re-matching. In his view the autopilot would help keeping the performance of the source constant. Hannes then asked if by using the autopilot one could avoid this regular re-tuning, to which Jean Baptiste agreed that it could be less frequent. Gian Piero and Bettina mentioned that there were discussions concerning the optimizations in other meetings with Alessandra and Verena. Fanouria observed that the optimum of 25mA was not maintained in an everyday basis to which Jean Baptiste responded that it would be possible but it was not required in this run. Hannes further emphasized the importance of the stability of the pulse and Jean Baptiste stressed the need for fine tuning, the autopilot and some margin for the source current. He continued asking for comments on the granularity for the flat pulses to which Bettina responded that it is required turn by turn.**

Hannes wondered whether the data for the full run are available for analysis to check the pulses. Jean Baptiste replied that the data on the pulse shape were not logged continuously. Bettina noted that it was not possible to store all the data during the previous run and Gian Piero added that this should not be any more a problem for the LBE run. Hannes and Federico agreed that it is very important to be made available for the future.

- Jean Baptiste commented on the difference between the intensity coming from the source and the one out of the RFQ. **Hannes wondered whether the difference was coming from high amplitude particles. Jean Baptiste confirmed that those particles were out of the RFQ acceptance. Fanouria then asked if that meant that the emittance out of the source was larger to which Gian Piero said that the RFQ is built based on certain specifications and Jean Baptiste added that since the source was measured at the test stand, it was known that it could provide a maximum current of 27 mA within the RFQ acceptance.**

- Jean Baptiste showed the current drops as the source reaches the limit and stressed to Hannes that a stable pulse requires large margins. **Hannes asked whether the overall beam quality (not only in terms of current) by simply adding the autopilot would be equivalent to the one acquired by optimizing all other parameters individually. Jean Baptiste replied that with enough margin there wouldn't be issues. Hannes further referred to how not intervening for optimizations could affect the shot to shot reproducibility. Jean Baptiste explained that given enough margin from the source one always gets the RFQ acceptance. Piotr wanted some comments on the effect of less power from the source to which Jean Baptiste responded that it would mean less current so it would be best to have more. Piotr continued asking about the drift in current observed in the case of less current. Jean Baptiste replied that it was not really a problem and he wanted to emphasize on the spread. Bettina added that it should be demonstrated that the reproducibility can be maintained over long periods and that running with high power in the source could create problems, to which Jean Baptiste agreed**.

- Jean Baptiste moved on to the energy reproducibility. From the LINAC side the energy is believed to be achieved with an absolute error of less than ±1MeV, which could only be verified by the PSB, but with a very good reproducibility. **Gian Piero replied that on the PSB side there will be the energy matching**.

- Jean Baptiste showed some emittance measurements, in which the RMS emittance was computed. **Piotr asked if these measurements were taken at the end of the LINAC and if the pulse was included. Jean Baptiste confirmed that the data were taken at the end of the machine and that all the pulse was included in this particular case. Since it is known to affect the transverse emittance, more data on different time slots should be analyzed**. **Hannes had some questions concerning the plots and Jean Baptiste clarified that the raw signal was fitted to extract the RMS value so the red and blue profiles correspond to these signals. Hannes then asked if we are actually at the limit of what can be achieved. Federico noted the problems that could arise from the non-Gaussian tails of the profiles. Jean Baptiste said that the measurement was intended to give an idea of the emittance and check the reproducibility of the machine so the real emittance could be slightly different from what shown. Federico stressed that the problem then would be transferred to the Booster where the reproducibility is needed in terms of brightness, Jean Baptiste repeated that the measurement was not intended to give a precise emittance measurement but mainly as a means to check the beam dynamics stability of the LINAC. Hannes asked about differences in the optics and Jean Baptiste replied that the quadrupoles remained unchanged**. **Hannes asked if the wire was passing through pulse after pulse. Federico confirmed. Federico and Piotr further noted the problems arising from**

misalignments and Piotr insisted on the optics effects arising and in particular dispersion, Jean Baptiste would not expect a dramatic change due to misalignments.

- Jean Baptiste presented results concerning the beam chopping. During the run, the chopping efficiency in steady state was satisfactory and the principle was already validated since years. Further improvements can be made by playing with the optics but it would affect transmission. Moreover, the rise time of the chopper is difficult to play with, while the space charge compensation could also be affected. **Bettina asked if it is possible to repeat some measurements and Jean Baptiste assured that measurements are ongoing**. **Piotr asked whether the emittance has been measured with the chopper on and Jean Baptiste said that there are some data but not using the pattern shown since there are issues with the timings as Federico had already mentioned. Federico and Piotr had a discussion concerning the integration timings of the measurements and Federico was unsure whether it would be possible to measure with the SEMs and noted that the timings for the Wire-scanners, especially the sampling rates, would have to be rechecked**.

- Summarizing the criteria for the beam quality **Bettina noted that the margin of the Intensity flatness needs to be improved in an everyday basis. Jean Baptiste was confident that flat pulses can be achieved but the reproducibility would need to be revisited either with tuning or the autopilot**.

- Concerning the beam stability in position and angle, the efforts were on stabilizing the position assuming that the angle would follow. **Hannes mentioned that for this statement to be true the point of measuring would need to be carefully chosen**. The beam is unstable in position during the first few μs due to beam loading. **Piotr asked if it is before or after the bending since the LINAC is fully straight, Bettina commented it is after the bending and Jean Baptiste added that it's observed even before**. The margins in the PSB were further discussed. **Chiara added that these values are required for the LHC, so no painting. Jean Baptiste asked whether this was equivalent to no dispersion and Chiara confirmed and added that there could be profit from the non-zero dispersion and large offsets. Hannes wanted to clarify what is the difference between LHC and non-LHC beams and Jean Baptiste said there was not really a difference on the LINAC side. Bettina added that the energy variation is most important for the LHC beams. Hannes concluded that there should be no real variation since only the residuals would give such numbers. Piotr asked about the effect of the chopper on this and Jean Baptiste noted that no effect on the phasing of the beam is expected by the chopping process**. **Piotr had further comments on the chopper concerning, fill timings, position variation, and possibility to measure since this should be the nominal mode of operation. Jean Baptiste mentioned that the beam chopping transition time is much smaller than the cavity filling time. The 2 us beam holes (between rings) will be transparent to the cavity beam loading and no change of position is expected. Bettina stressed the difference on the calibration of the wires and Jean Baptiste commented on whether it was possible to get the resolution needed. The problem according to Piotr is that there is no way to measure the beam before it enters the Booster. Bettina agreed that it should be discussed in the next weeks. Jean Baptiste added that there are data of chopped beams and Piotr noted that it should be checked whether particles could be in the acceptance of the machine but off-centered.**

- Jean Baptiste concluded the results of the run and mentioned that overall the LINAC4 has surpassed the capabilities of LINAC2 by far, but since it's a very flexible machine it is also very complex.

- **Fanouria asked whether there are plans to work below the 3MeV energy and Jean Baptiste noted that there is a test bench and the work is ongoing, there are considerations on working on the RF system but so far the focus is on the source and the low energy beam transport. He noted that they have already some**

improvements but the results are still preliminary and no decision was taken concerning the source setup that will be used during the LBE.

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Foteini Asvesta