Notes from the meeting on the LIU-PSB injection (13/10/2014)

Present: J. Abelleira, E. Benedetto, C. Bracco, G.P. di Giovanni, V. Forte, B. Jones, M. Kowalska, A. Lombardi, M. Meddahi, B. Mikulec, G. Rumolo

Introduction: Reminder of the post LS2 beam parameters

- **Linac4 baseline and alternative scenario (cases to be studied) – Alessandra**
  Injection parameters, alphas and betas can be easily tuned according to the needs of the PSB injection. The peak current should be assumed to be **40 mA** (**chopped 26 mA**) within **0.35 um**. It is estimated that 100 turns would provide at least an increase by 20-30% of the intensity for ISOLDE beams. Chopping is needed to avoid losses at 160 MeV of the protons injected out of the bucket size. Alessandra suggests that the need for chopping could be revised because lot of beam is lost with it. However chopping seems needed if losses in the PSB at 160 MeV also need to be minimized.

- **Baseline LHC and HIE-ISOLDE beams @ Booster injection – Giovanni**
  LHC beams after all the LIU upgrades are expected to have the parameters summarized in the EDMS document 296306 v.1 (LIU-PM-NOT-0011 v.1).
  To note:
  The longitudinal parameters come from the fact that a longitudinal emittance of 1.4 eVs after capture means that 80% of the bucket is full. In principle, larger longitudinal emittances could be also acceptable for the production of standard LHC beams (since the expected longitudinal emittance at PS injection is 3.0 eVs), but there is only little margin for the production of BCMS beams.
  The transverse parameters are derived from the assumption that Linac4 will be able to make double brightness beams at the PSB extraction, compared to the beams coming from Linac2. Ideally, we would need to calculate a brightness curve from Linac4 covering the full intensity range from 8e11 to 3.4e12 (25 and 50 ns from "old" nominal intensities to HL-LHC values). Concerning the HIE ISOLDE beams, the spec on beam intensity delivered to ISOLDE after intensity/energy upgrade has to be fully clarified yet (at one of the forthcoming IEFC). The original target was stated to be doubling the present intensity, i.e. at least 1.8e13 p/ring extracted. However, some limitations exist. For instance, not more than 1.4e13 p/ring can be accelerated in the PSB if C02+C04 are only upgraded and not replaced by the new Finemet system. Besides, another limitation comes if the distributor pulse length is changed from 600 to 450 ms. In this framework, it would be important to have predictions of the deliverable current to ISOLDE for the scenarios with 100, 120 and 150 turns injected and 30, 50, 80 mA source currents (covering baseline source and possibly future magnetron source). **Action: Chiara and José.** The transverse emittance is not an issue for ISOLDE beams, the only limit is PSB acceptance and losses at injection.

Consistency checks of the 'simplified' beam line model when compared to the full model – Chiara in collaboration with Alessandra

The goal of this study is mainly to produce a MAD-X version of the BI-TL optics up to the injection point of all 4 PSB rings (including the vertical deflection from the distributor). This will be a handy tool for quick checks of aperture and steering without having to repeat the full space charge calculation each time. Besides, it can be used as a crosscheck for the PATH optics, defining the effect of space charge, as well as for layout checks (quads positions, etc.).
The optics all the way from BHZ20 to the PSB was therefore recalculated with MAD-X (quad strengths and initial conditions given by Alessandra). The differences with respect to PATH are obviously due to the fact that MAD-X does not include space charge. The distributor bump, checked for Ring 3, was found not to bump back the beam on axis as should be, but 0.4 mm off-axis. Dispersion matching to zero at the stripping foil did not work. In principle, both dispersion and its derivative should have been zero downstream from BHZ30. In future, after the present issue with matching and dispersion is sorted out, the optics for the four rings needs to be done in MAD-X for different cases. **Action: Chiara**

It would probably be better to compare MAD-X and PATH with space charge after BHZ40, so that the divergence due to space charge is less important because of the shorter part of the line being analysed with MAD-X.

Recently Jan Hansen wanted the envelope in the last 3 m of the line (main contributions from dispersion and possible offset e.g. for longitudinal painting) and the request was quite urgent because he needs to buy the vacuum chambers. Since we need to be sure about the results before getting the chambers in production and there is little safety margin in the BHZ magnets, it is important to be sure of the results before giving a definite answer to this question. **Action: Chiara**

Tracking studies with the LHC beam – Elena

The goal of this study is to simulate the injection of future LHC beams into the PSB and produce a possible "minimum" brightness curve emittance vs. intensity that we can obtain with Linac4 (similar to the one measured for the PSB and currently used for the analysis of the beam transport through the LHC injector chain). The tool used for the study is PTC-ORBIT.
The study started with a transversely matched Gaussian distribution, which is left to evolve over 7ms during the fall of the chicane bump. The initial longitudinal distribution is a rectangle (680 ns x 600 keV), which filaments in the longitudinal phase space in the typical PSB h1+h2 bucket. For the tracking with space charge, quadrupolar errors at the BSW, eddy currents as well as the time varying compensation with the separated trim quads QDE3 and QDE14 were included. No other errors were included in the analysis. The final average transverse emittance (H+V divided by two) seem to get to 1 um for an intensity of 350e12, whatever is the initial emittance below this value. If the initial value is higher, the emittance remains constant. Other intensities were simulated, yielding a preliminary emittance vs. intensity line, which has half slope than the one so far assumed in the estimation of the LIU beam parameters. More studies will be performed with different tunes and the longitudinal distribution also

needs to be improved (and the longitudinal emittance quantified). **Action: Elena and Vincenzo**

The existing PSB brightness line was calculated for a fixed longitudinal emittance of 1.2 eVs, the one for Linac4 should be similarly calculated for a given longitudinal emittance of 1.4 eVs after capture in the PSB. One important point is that these simulations should take into account the real dynamics of the injection with the parameters from Linac4 and scattering on the foil by starting from an initial distribution that is actually the injected distribution (both transverse and longitudinal) in different scenarios. The injected energy spread is tunable through the debuncher and can be adjusted to obtain the wanted longitudinal emittance in the PSB, however it is not clear whether the adjustment can be applied in PPM (which is important because other beams may have different requirements). **Action Alessandra**: find out whether the debuncher tuning is PPM.

It would be interesting to use the same simulation tool used for this analysis also to try to reproduce the present PSB brightness curve. Vivien Raginel already carried out this study, concluding that the number of knobs available in this exercise was such that the experimental results could always be matched. **Action: Bettina**

Another question concerns the validity of the model of the errors used in the analysis. The ongoing space charge/machine model MDs at the PSB could be used to create a better modeling of the PSB to be used in these simulations. **Action: Elena and Vincenzo**

Injection studies for High intensity beam – José

Simulations of the injection of future ISOLDE beams into the PSB have been performed with ORBIT (efforts are ongoing to migrate to PTC-ORBIT, which would also make it easier to interface with the subsequent machine tracking). The goals of the study are to define the optimum KSW waveforms for ISOLDE, add aperture tolerances (± 1 mm) and check impact on injection losses, check if any improvement is obtained combining a horizontal offset and painting, provide Elena and Magda with the best distribution for their subsequent tracking studies, vary beta_x of the initial distribution from 5.6 m to 2.5 m and see if, by varying the KSW waveform, any improvement is achievable, vary the horizontal tune (ISOLDE).
First, injection of the 2012 nominal LHC beam has been simulated, showing the emittance growth over the 20 turns of the injection (due to scattering against the stripping foil) and a weak linear growth in the subsequent 80 turns. Since simulations with 5k and 500k macroparticles deliver the same results, space charge plays probably a minor role over the 100 simulated turns. Injections of ISOLDE beams with 1.6e13 (100 turns assuming 26 mA average current from Linac4) and 1.95e13 (120 turns) were simulated including longitudinal painting. A vertical offset of 10 mm was found to be optimal and a certain trim function of the horizontal bump decreasing linearly from 40 to 20 mm within the first 20 turns and then staying constant at 20 mm over the next injected turns was

considered. The final transverse emittances are 13 and 8 um in H and V, respectively, irrespective of the number of macroparticles used in the simulation (again indicating that the injection process is not dominated by space charge). The bunch distributions in x and y are quite flat rather than Gaussian. The injection losses are in the order of a few percent and therefore not tolerable. The H offset has been changed by 2 mm both during the first 20 turns and over the flat part of the waveform, and does not appear to cause large changes. In the future, it is planned to move to PTC-ORBIT and continue the studies. **Action: José**

It was remarked that maybe one of the causes of the high beam losses during injection could, be the relatively large offsets used for painting. However, it seems that most of the losses happen during the time when the bump is flat.

Tracking studies with high intensity beam – preliminary results – Magda

The main goal of this study is to determine the best beam profile in terms of emittance and intensity preservation, i.e. to reduce the halo and to minimize the losses. The study was conducted with PTC-ORBIT at constant energy. (10^4 turns @160MeV). Different super-Gaussian distributions were considered with exponents from 2 (traditional Gaussian) to 10. It was found that losses decrease with increasing N, and also the tune footprint is covers a smaller region of the tune space. The emittance evolution follows the loss pattern. It is planned to feed now these simulations with the injected distribution from Chiara and José to have a more realistic estimation of losses and emittance evolution. **Action: Magda.** The needed input is the optimized waveform of the injection bump in order to start the simulation from the injection with PTC-ORBIT. **Action: Chiara and José**

Next meeting: Monday 27 October, 16h to 17h, 865-1B03