Preliminary Draft Summary 2nd BBLR MD in 2003, Friday 4 July

J.-P. Koutchouk, J. Wenninger, F. Zimmermann, J.-J. Gras, …

Sequence of Events

The beam was dumped 4200 ms after injection (the total length of the MD cycle was 4650 ms). We obtained 8-9x10^{11} protons in 12 LHC bunches (beam type TSTLHC). Less intensity was not available from the PS.

11:13 The transverse dampers were turned off. They remained off throughout this MD. The tune was measured using the multi-Q application. The horizontal tune was 0.176+/-0.001, close to the value of 2002 (0.172). It was flat through the cycle. There was a +500 micron position drift in the horizontal plane, mainly occurring between 3500 and 4200 ms. The vertical tune was found at 0.135+/-0.001. It was changed to 0.152+/-0.001 (last year's value was 0.154). The chromaticity settings were supposed to correspond to 0.03 in both planes. We measured ξ_H~-0.05, slightly negative, and trimmed it to ξ_H **~+0.05** (confirmed by measurement). The vertical chromaticity was ξ_V**~+0.03** as expected. We **corrected the horizontal orbit drift by radial steering** (11:57). The final orbit drift was of the order of 10 micron, within the noise of the measurement.

12:00 We switched on the wire with negative current. This corresponds to an attractive force, for which the vertical tune shift is negative. The flat part of the excitation lasted from 12720 to 14860 ms (the start of the cycle was at 11225 ms) or from about 1500 to 3600 ms after injection. This was the same setting as in the previous MD. We took reference orbits at 1000 ms.

The scraper should move by 20 mm in 100 ms. The beta function at the scraper is β_V =45.6 m (to be checked?). One has to 'disable/enable' in the scraper acquisition to see the BCT & PMT data. Parking position of the scraper was set to 10.196 mm. **Losses were measured for two different scraper positions,** as shown in Table 1.

Scraper position from beam-pipe center $y_{scraper}$	Factor of intensity reduction *(1-f)*
1.25 mm	4.6/8.0=0.575
2.843 mm	6.6/7.4=0.892

Table 1: Intensity loss versus position of scraper.

The wire current was -10 A, at this stage. No losses were observed when the scraper was off.

BWSV41420 was the only operational vertical wire scanner that was not burnt in the preceding MD with LHC beam. The wire-scanner filter was set to 2, and voltage to 1000 V. The beta function should be β_V=21.7 m. The Y emittance was 1.760 micron with the IN scan and 1.472 micron with the OUT scan. For the horizontal plane we used BWSH41677, filter 4, and 800 V. β_H=37.9 m, and D_x=-0.2 m. The emittance was 1.4 micron (IN) and 1.18 micron (OUT), for a timing difference of 3000 ms. We next selected the same time except 100 ms for IN and OUT scan to observe the difference between IN and OUT scan, and we got 1.43 (IN) and 1.28 micron (OUT). The FWHM bunch length was 1.3 ns, from the PS.

We needed to **blow up the transverse emittance** so as to become sensitive to the expected effect of the wire. To this end, we created injection oscillations by steering in TT10 using V-Delta-123. A 5 mm change (cycle# 330405) gave $\gamma\varepsilon_V$=1.772, 1.516 micron. Another 5 mm change, resulted in $\gamma\varepsilon_V$=3.265, 1.906 (selected same time, but did not get it), 2.626, 2.042, 2.610, 1.978 (selected 100 ms difference for IN and OUT scan, but the actual difference was 200 ms or larger). *We observed strong damping of Y oscillations, within 500 turns (10 ms). Why? Turning damper on or off made no difference.* Timing of IN and OUT scan was now stuck, and IN-scan timing completely wrong, occurring long before start of the cycle. 13:08 Re-initializing to previous settings with a large delay and changing the desired IN timing enabled us to get back to the original situation. We measured $\gamma\varepsilon_V$=3.3 (IN, 300 ms), 2.0 (OUT, 3300 ms). Due to the injection error, the beam intensity dropped by a factor of 2. These losses were considered too large.

We went back to the initial injection configuration, and we now **changed the strength of the last D quadrupole in the transfer line** instead of introducing injection oscillations. The initial setting of this quadrupole (QID1011) was 132.065 A. We lowered it by 12 A (or about 10%): $\gamma\varepsilon_V$=3.2 (IN, 3000 ms), 2.5 (OUT, 3500 ms). We next reduced the quadrupole current by another 12 A (cycle# 330529), $\gamma\varepsilon_V$=2.8 (IN, 3000 ms), 2.4 (OUT, 3500 ms), but the losses became too large. We backed off by 6 A(total change –18 A), from cycle# 330536.

We also corrected the small injection oscillation, that might have been introduced by the change of the quadrupole strength (cycle# 330540). The intensity of the stored beam was only $5x10^{11}$, or half the original, though there were no visible losses on the ring loss monitors. Results of vertical and horizontal emittance measurements for different timings are summarized in the two tables below.

IN/OUT timing [ms]	Vertical emittance [micron], BWSV41420
3000, 3500	3.2, 2.6
100, 600	3.7, 3.2
100, 600	3.7, 2.8
3000, 3500	3.1, 2.5

IN/OUT timing [ms]	Horizontal emittance [micron], BWSH41677
100, 600	1.7, 1.5
100, 600	1.7, 1.4 (cycle# 330592)

We bumped exactly –8.2 mm at the BBLR from cycle# 330616 (this would give 12.1 mm separation between wire center and beam, corresponding to the latest simulations). The interpolated position with wire off was –8.6 mm. The spread in the BPM readings was about +/-0.2 mm. We observed a small loss at 518 near the BBLR, following the shape of the bump, which was created synchronously to the wire-current excitation (ramp up from 1000 to 1500 ms, ramp down from 3600 to 4200 ms). The wire current was only -10 A. Nevertheless, the losses were high, about $3x10^6$ at the 3rd PMT (last year we had about 10^6 as the maximum integrated reading).

Emittances measured at various times, after and before the orbit bump and the –10 A wire excitation, are listed in the table below.

IN/OUT timing [ms]	Vertical emittance [micron], BWSV41420
3000, 3500	2.7, 2.3
4200, 4400	2.8, 2.6
100, 300	3.3, 2.8

The multi-Q measures the tune every 30 ms. A small variation in the vertical tune with a total magnitude of 0.005 was seen; the tune varied between 0.1575 and 0.1525.

Now the adopted strategy was to change the wire current in steps and to correct orbit and tune for each step. For each wire current we performed several wire scans and saved PMT data. Wire profiles were saved to /usr/tmp/ WSV-BBLR-90A-100ms.data etc.

Wire current was set to –90 A from cycle# 330691. More losses were seen on the BLM, but not on PMT. MICADO correction of BBLR (cycle# 330697) reduces losses from 25 to 21 units at BLM 518. Measured tune shifts were ΔQ_H=+0.006, ΔQ_V=-0.006 after orbit correction. (for 12.1 mm distance between beam and wire centre, I expected +/-0.008 tune shift, using JPK's numerical formula from the second MD; *the 30% difference between the observed and the expected tune shift could indicate that the beam-wire distance was about 13.9 mm and not 12.1 mm;* however, in the following I keep the number 12.1 mm for now). Next we corrected the tunes through the cycle. First QH was corrected to be flat (from cycle# 330714), then QV (cycle# 330730). Still ~10-20% losses on the BCT, and the PMT reading remained high, around $2.8x10^6$. Emittance $\gamma\varepsilon_V$=2.2 (IN, 3000 ms), 1.8 (OUT, 3500 ms).

The table below summarizes the **vertical emittance measurements for different wire excitations** (always after correcting the orbit and tune). The timings for the IN/OUT scans were held constant at 100, 3100 ms. *These results confirm the observation from the previous MD, that the wire excitation reduces the beam size* (presumably, by removing the particles at larger amplitudes).

Wire excitation	Vertical emittance [micron], BWSV41420
-90 A	3.6, 1.8 (int. losses $2.8x10^6$)
(cycle# 330730)	3.5, 1.8
	3.3, 1.7
-180 A	3.8, 1.6 (int. losses $3.3x10^6$)
(cycle# 330832, ~14:40)	3.5, 1.5
	3.7, 1.6
	3.7, 1.5
-267 A	3.6, 1.5
(cycle# 330884)	3.6, 1.4
	3.6, 1.4
	3.7, 1.4
-1 A	4.1, 2.8
(cycle# 330945, 15:20)	3.4, 2.5
	3.5, 2.5
	3.6, 2.6
	3.6, 2.6
-45 A	3.8, 2.1
(cycle# 331003, 15:32)	3.6, 1.9
	3.5, 2.2
-23 A	4.3, 2.3
(cycle# 331042-331069, 15:48)	3.5, 2.1
	3.9, 2.1
	4.1, 2.4
-12 A	3.6, 2.4
(cycle# ~331070, 15:54)	3.6, 2.6
	4.6, 2.8
	4.7, 2.8
	5.0, 2.8
	3.3, 2.1
	3.6, 2.0

Table 2: IN and OUT emittances for different wire excitations.

Questions raised during the MD: *Where are the particles lost? Is the BBLR the aperture limit? Why does the PMT signal not increase when the wire is excited (always around $3x10^6$ integrated loss)?*
That the **PMT signal** is not sensitive to excitation could be evidence for saturation.

16:05 BBLR at –1 A; reduce bump and look at PMT. 16:13 +1.1 mm (total bump –7.1 mm), cycle# 331141, losses $2x10^6$ global sum. PMT signal vs. time looks reduced. 16:10 +3.3 mm (-4.9 mm total bump), cycle 331159, global sum lower, only $=6x10^5$ now. 16:20 + 4.3 mm (-2.9 mm net), cycle 33116, no signal on PMT! Emittance $\gamma\varepsilon_V$=3.4 (IN, 100 ms), 2.3 (OUT, 3100 ms). Even with 267 A excitation, still no signal in this position. But when going back –2.0 mm (~-5 mm net bump), we saw a huge signal (this position corresponds to a distance of 14 mm to the edge of the BBLR). *This indicates that for a -5 mm bump the BBLR becomes the aperture limit.*

16:37 **Scraper measurements**. Scraper parking at 10 mm. Scraped at 6.86 mm first. Timing at 1800 ms (note that scraper is located outside of bump region). Scraping at 2.16 mm gives a 25% beam loss. Wire scan shows emittance reduction from $\gamma\varepsilon_V$=3.0 (IN, 100 ms) to 1.4 (OUT, 3100 ms). *Beam profile looks Gaussian after scraping.* No diffusion (re-emergence of PMT signal) was visible after this scraping at 2.16 mm (wire current was still at 267 A). Next, scraping at 3.26 mm (16:48)and at 6.6 mm (cycle# 331270). Parking position was changed to 14 mm in cycle# 331273. In cycle 331285 we scraped early, before the wire excitation, but no flash was seen.

We notice that enabling the scraper, even if it is out, has a huge effect on the PMT signals during most of the cycle and even before the orbit/wire-current bump!

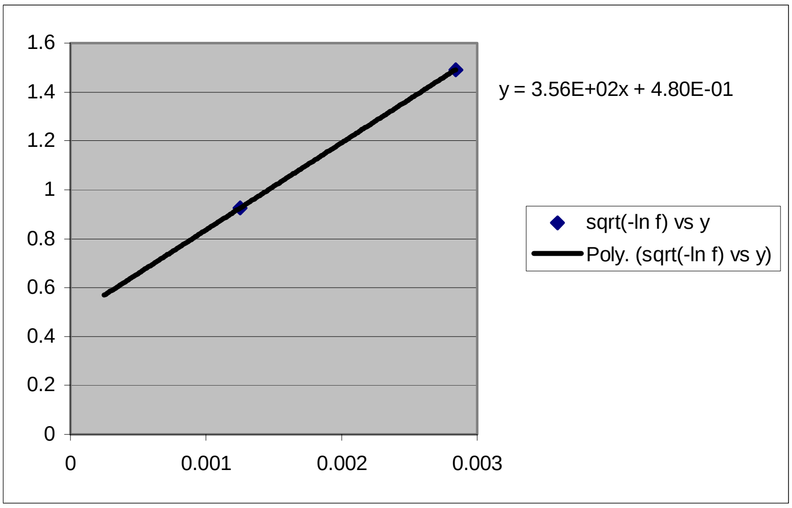
17:22 scraper disabled. We tried to measure diffusion without the scraper, by reducing the orbit-bump amplitude by 2 mm from 1600 to 1700 ms. Specifically, we took data for bump amplitudes of –7/-5 mm and –9/-7 mm.

We finally kicked the beam without damper, first at 2500 ms, then at 500 ms. We generated kick amplitudes up to 8 mm, but there was no signal on the usually employed PMT, but on some of the others. (The extreme variation in the signals of different PMTs is worrying.)

For an 8 mm kick, BLM losses were recorded only at 3 locations around the ring: at 122, 215 and the BBLR. *This might prove an alternative method for identifying the SPS aperture limits.*

Some Analysis

From the numbers in Table 1 we can **get an alternative estimate for the vertical emittance**. Denoting by *f* the fraction of beam lost due to the scraping, and supposing the beam is of Gaussian shape the emittance should be $\gamma\varepsilon_{\mathbf{scraper}}\mathbf{= -\gamma y^2/(2\ ln(f)\ \beta_V)}$, where *y* is the distance between the scraper and the beam centre, and β_V the beta function at the scraper. For the two measurements from the table above we extract 0.54 micron and 1.1 micron, respectively, if we assume that the beam is at the center of the pipe. These numbers are quite different, indicating that the beam was not centered with respect to the scraper. Therefore, we should better deduce the real relative beam position by requiring consistency. To this end, we plot SQRT(-Ln(f)) as a function of y, which is shown in the figure below. The fitted line intersects zero at $y_{scraper}$= -1.35 mm. Including this offset, both measurements above consistently yield the same emittance value 2.3 micron. *This is about 30% larger than the emittance from the wire scan* (1.76 micron for IN scan).



The square root of the lost beam fraction versus scraper position. The zero intersection should give the actual center of the beam.

We computed the average OUT emittance for different wire excitations using the numbers of Table 2. The result is displayed in Fig. 2. We expect the diffusive aperture to decrease as x_{da}~x_{sep}- const Sqrt(I_w), i.e., with the square root of the wire current. We also know that the emittance is proportional to the square of the maximum oscillation amplitude. Thus, in Fig. 3 we plot **the square root of the average final emittance as a function of the square root of the wire excitation**, and find **the expected linear dependence.**

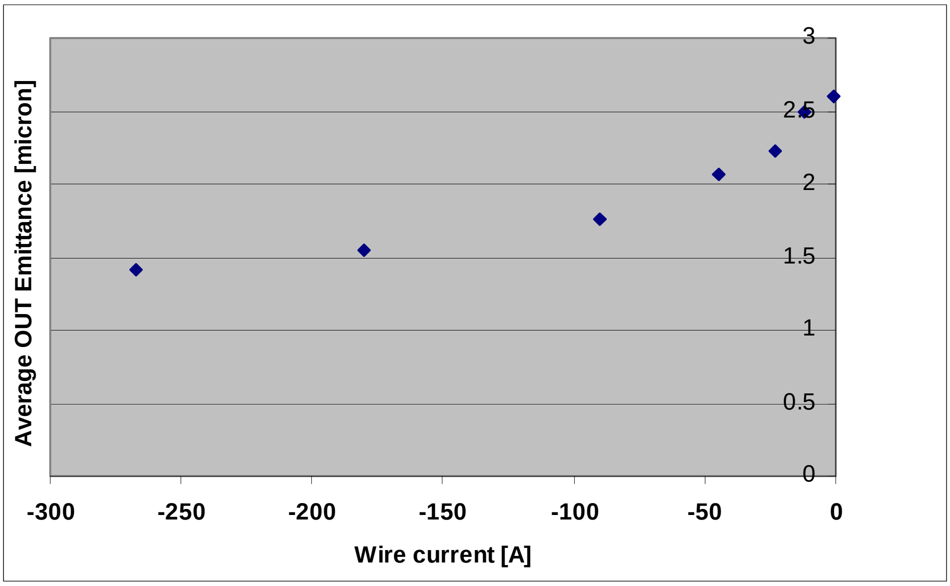


Figure 2: Average OUT emittance for different wire excitations.

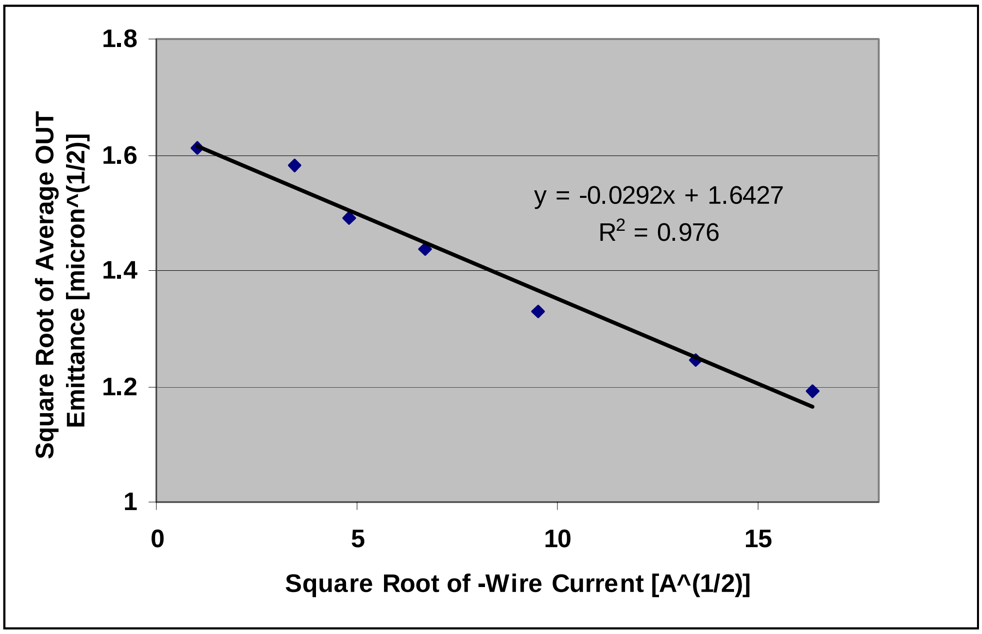


Figure 3: Square root of average OUT emittance as a function of the square root of the wire excitation.

Taking into account the 1.35 mm offset between beam and scraper found earlier, we infer that physically scraping at an amplitude of 3.51 mm yields an apparent measured normalized emittance of 1.4 micron. The 3.51 micron maximum amplitude at a beta function of 45.6 m corresponds to a maximum normalized single-particle emittance of 7.3 micron. So the measured rms normalized emittance is almost exactly a factor of 5 smaller. Using this **calibration factor**, and assuming that it is constant for all amplitudes, we can roughly convert the measured emittances for different wire excitations into maximum transverse amplitudes, which should be estimates of the diffusive aperture. The result of this exercise is illustrated in Fig. 4. The **measured decrease of the diffusive aperture with increasing wire current is somewhat weaker than expected**. This could be partly due to a non-constancy of the scale factor (why is the wire-scanner profile Gaussian anyhow?) and to an intrinsic offset for the OUT scan (not the same as the IN scan). Note that the diffusion process which causes the Gaussian shape might be amplitude dependent. If the latter is not due to an (additive?) uncertainty of the wire scan, that would also have to be taken into account in the data analysis.

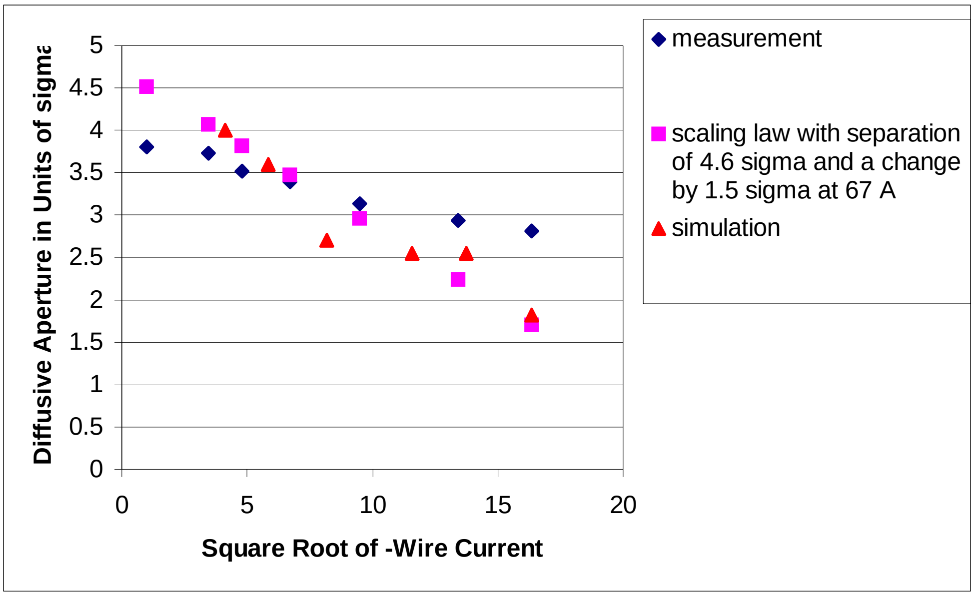


Figure 4: Diffusive aperture as a function of the square root of the wire excitation, according to (1) a rough estimate from the wire profile measurement (using the scale factor 5 obtained from a wire scan after scraping), (2) simple scaling law, and (3) weak-strong simulation.

Figure 5 shows a superposition of **wire-scanner profiles** for different wire excitations.

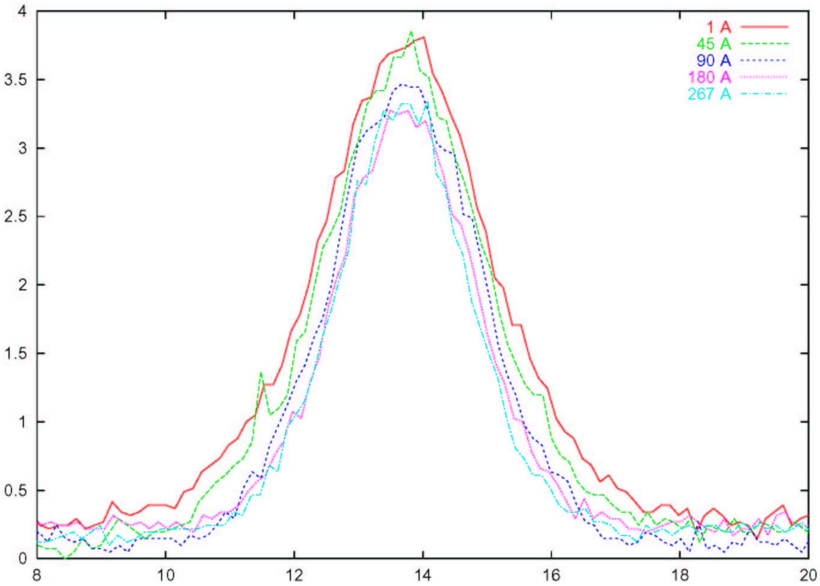


Figure 5: Vertical wire-scanner profiles obtained for different wire excitations; bump amplitude was –8.2 mm, and the estimated distance between beam and center of the wire 12.1 mm.

Redo some analysis for different wire-scan calibration factor (~1.3?)?