Beam Physics Note
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Longitudinal Beam Profile Measurement using a Localized Isochronism Excursion

Thomas Planche, Rick Baartman

TRIUMF

Abstract: One December 21st, 2021, we used the standard "u-turn" triplet — constituted of trim coils #29, #36, and #42 — to create an adjustable localized isochronism bump in the TRIUMF cyclotron. We measured the beam transmission to 480 MeV as a function of the amplitude of the bump, and deduced from it the phase profile of the beam at radius ∼230" (E ∼200 MeV). This proof-of-principle measurement shows promising results. We shall, however, need some more beam time to mitigate the few sources of systematic and stochastic errors that we have identified.

1 The Measurement

The principle of this measurement was suggested by simulation studies carried out by Yi-Nong between 2017 and 2018 [1, 2]. We chose to use the trim coils [3] triplet 29-36-42 with the ratio devised by Yi-Nong (-52% and -39%) to create a localized B_z field excursions, see Fig. 1. First we had to trade off between adjacent trim coils to give ourselves enough headroom on

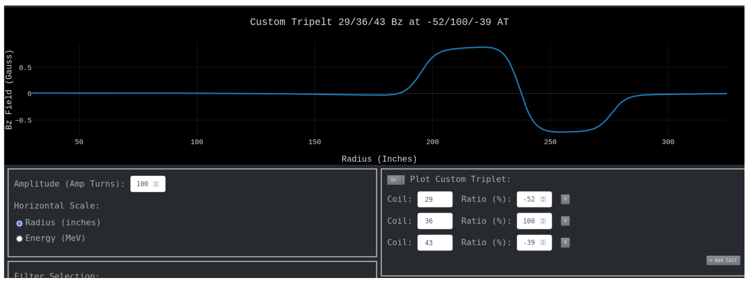

Figure 1: Screen capture of the trim coil binder app (beta.hla.triumf.ca/trimcoilbinder) showing the effect of the B_z triplet used in all the measurements reported in this note.

these 3 trim coils. Then we opened fully (to 0.3" actually) the ISIS emittance defining slits, and tuned the cyclotron for maximum transmission to BL2A (the only beamline receiving beam at the time). We achieved about 27 µA measured on BL2A extraction foil, at 9.5% duty factor, and with 43 µA measured on the fast target (last Faraday cup before injection). This translates to ≈63% transmission and ≈285µA equivalent at 100% duty factor.

Then we turned off both bunchers in the injection line, and measured 4.2 µA in BL2A, i.e. less that 10% transmission, which should have alarmed us since we normally get around 12% transmission with the bunchers off. But we overlooked this fact, and proceeded directly to take our measurements. Retrospectively, I (Thomas) think that this lower-than-usual transmission can be explained by the unusually large transverse emittance of the beam injected into the cyclotron at the time, given that the ISIS slits were essentially fully open. But Rick disagrees, and we will have to repeat the measurement to test my hypothesis.

Anyhow, with the unbunched beam, we varied the trim coil one way, until we lost all the beam to BL2A, and then we varied it back the other way, until we lost all the beam again. We repeated the same measurement with both bunchers on. A screen capture of the xstrip used to collect the data is shown in Fig. 2.

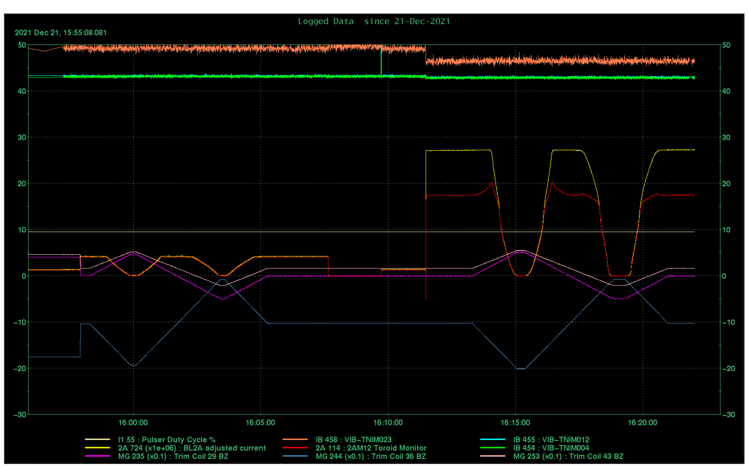

Figure 2: Screen capture of the xstrip used to collect the data, showing the measurement with bunchers off, followed by the measurement with bunchers on.

2 Data Processing

I transferred the data from the CCSCS2 (VMS) cluster using the FTP command:

```
ftp/username=tplanche␣<my␣IP␣adress␣here>
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packaged and splined the data using xst:

beamphys.triumf.ca/ tplanche/cyclotron/xstrip_translate

and manipulated the data using a python script:

beamphys.triumf.ca/ tplanche/cyclotron/2021/20211221-acceptance . And here we go. The raw data looks like this:

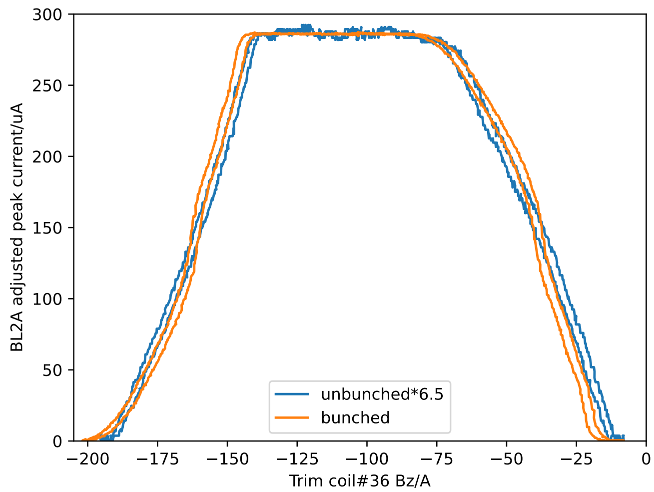

Figure 3: Raw data, plotting BL2A current as a function of the setting of the central trim coil of the triplet. Note that I have scaled the current in the "unbunched" case by a factor 6.5 to allow direct visual comparison.

Note how the curves on the right-hand side look to be a doubly-mirrored image of the curve on the left-hand side. This is explained by the fact that the slope on each side reflect the beam profile, and that the profile is taken twice: a first time when the trim coil is varied from -200 A.turn to 140 A.turn, and second time when it is varied from -75 A.turn to -5 A.turn. To extract the corresponding beam profile, we need to take a numerical gradient, which requires a very low level of noise in the data. Since the data is somewhat noisy (we took it relatively quickly, not necessarily choosing the optimum range for the electronics) we must smooth out the data. This is done using a simple moving window average, see:

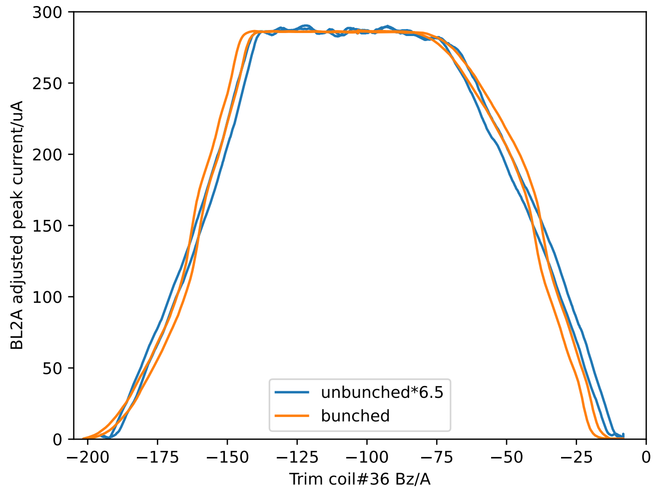

Figure 4: Same data as in Fig. 3 but smoothed out using a moving window average of size = 12 data points.

Taking the derivate and flipping the sign of the derivative for TC#36 settings above -100 A.turn we obtain Fig. 5. Note that the A.turn to beam phase conversion was found by setting the distance between the midpoint of the upward and downward slopes to be 180 degrees. Most importantly, note that I have assumed a linear relation between the triplet setting and the reduction in phase acceptance: an assumption which may not be justified. We need to run Yi-Nong's model to verify it. We can also test it experimentally, injecting a low-transverse-emittance and unbunched beam, which should yield a rectangular beam profile.

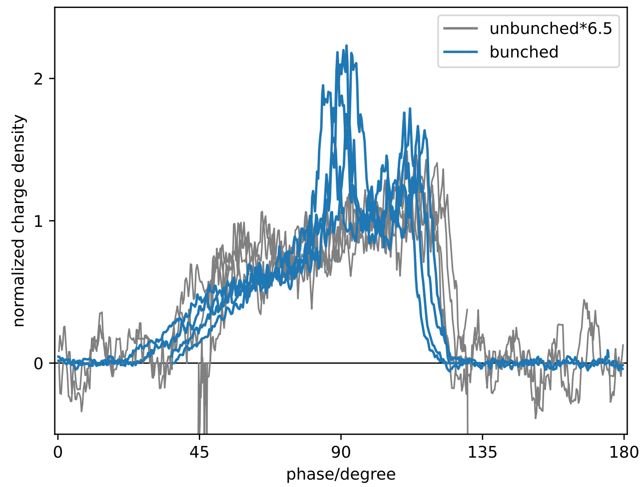

Figure 5: Numerical gradient of the data shown in Fig. 4, with some sign changes, and a calibration of the x-axis as explained above.

The apparent phase of the beam seems to have been drifting around by a few degrees throughout the measurement. We will need more beam time to reproduce and understand this effect. Anyhow, I have cheated, and shifted by hand each profile by a few degrees to align them on their sharpest side (the right-hand one).

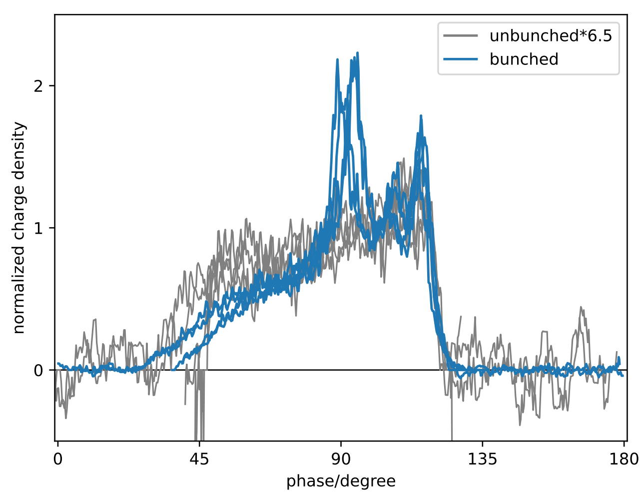

Figure 6: Same data as in Fig. 5 but with each profile manually shifted by a few degrees to make the right-hand edges overlap.

3 Conclusion

The beam profile with high-space charge, i.e. bunchers on, shows two important features: (1) a reduction of the phase acceptance of the machine, and (2) a structure that may be attributed to vortex-motion-driven beam breakup. The next steps includes:

- Running simulations to investigate the A.trun to degree conversion.
- Running simulations to convert phase acceptance measured at 200 MeV to phase acceptance at injection.
- Verifying experimentally the triplet ratios, in particular in the low energy section, using LE probes time of flight signal.
- Repeating the data taking with lower noise data (more beam, optimum gain setting, more data points).
- Investigating the origin of the observed phase drift.
- Retaking data, including the case of a low-transverse-emittance unbunched beam.
- Using other triplets to take similar measurements at different radii.

References

[1] Y.-N. Rao, Triumf u-turn around 206 mev, Tech. Rep. TRI-BN-17-22, TRIUMF, http://lin12.triumf.ca/text/design_notes/Note_on_TRIUMF_UTurn.pdf (2017).

[2] Y.-N. Rao, TRIUMF U-Turn around 480 MeV, Tech. Rep. TRI-BN-18-17, TRIUMF (2018).

[3] L. Root, Review of the TRIUMF Trim Coil Data, Tech. Rep. TRI-DN-08-26, TRIUMF, https://lin12.triumf.ca/design-notes/2008/TRI-DN-08-26.pdf (2008).