Identifying Levels of Uncertainty in Longitudinal Tomography in the PS Booster

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1. Abstract

This main objective of this project was to identify the uncertainties in software which are used to do the measurements of a bunch in PS Booster and other CERN accelerators. It is very important to identify these uncertainties and the impact from changes in different parameters to the measured values. This will make it possible to understand the behaviour of the bunch in a more detailed manner and to make an estimate for deviations of the beam from the expected results.

2. Introduction

Measuring characteristics of a particle bunch and estimating the uncertainties for the measurements is vital for understanding machine performances. Measuring the longitudinal emittance value and the momentum spread of the beam in a precise manner is essential to do the further measurements precisely with higher accuracy.

Initially measured data was used to identify the impact of difference on the measurements. Then simulated data was produced using BLonD to investigate the same impacts on data with perfectly known parameters.

The parameters considered were peak RF voltage, dipole magnetic field, gamma transition, lower and upper bound of the phase space for the reconstruction of the tomography. Simulated data were fed with variations of parameters to compare the phase spaces of the original and the reconstructed one from the FORTRAN code

3. Voltage Calibration for Measured Data and Simulated Data

The First test was to study the behaviour of the tomography with different voltages in a range around the measured voltage of one dataset. This lead to the Figure 3.1, result of two minima, observed when looking with high resolution around the peak voltage (2.6 kV) (Figure 3.2).

Simulated data was used to do the same test to determine whether this occurred due to high level of noise embedded in the measured data. This behaviour observed for measured data was not observed with the simulated data, although there was a deviation of the minimum from the expected value which is the original peak voltage for the simulated data as shown in Figure 3.3.

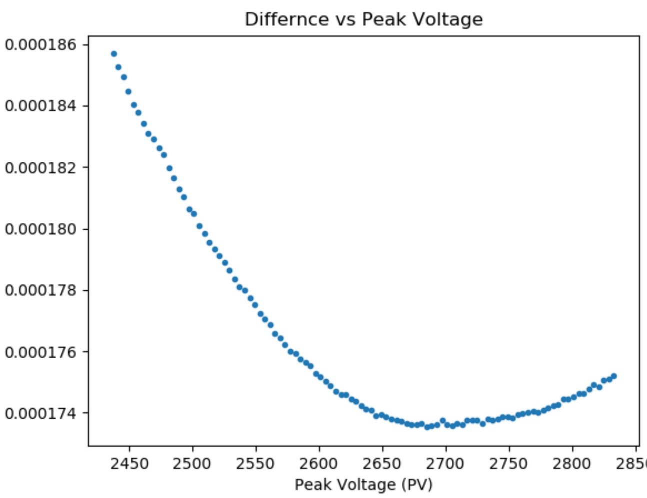

Figure 3.1: Graph of Difference of the reconstruction verses Peak voltage in a range of 400 V around the peak Voltage.

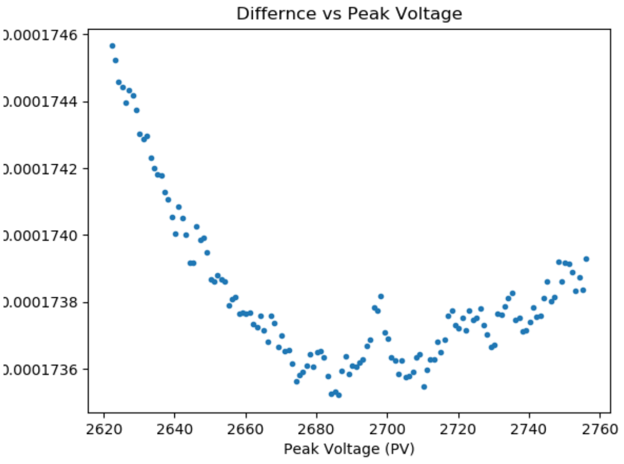

Figure 3.2: Difference versus Peak Voltage in a range of PV-15 V to PV+120 V with a step size of 1 V

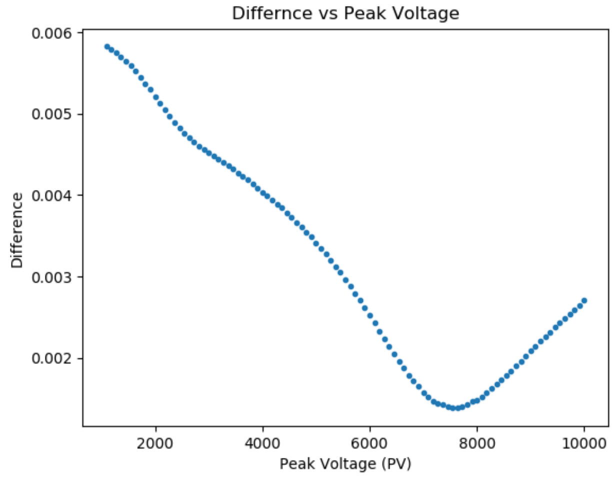

Figure 3.3: Differences versus Peak Voltage calibration for simulated data with 8 kV Peak Voltage

This deviation of the minima was influenced by the boundaries for the waterfall for the reconstruction. This deviation was minimized when the boundaries for the waterfall were selected closer to the edges of the bunch. This result was given in Figure 3.4.

The same calibration was carried out for simulated data with a peak voltage of 4 kV and the observations were similar to the 8 kV case.

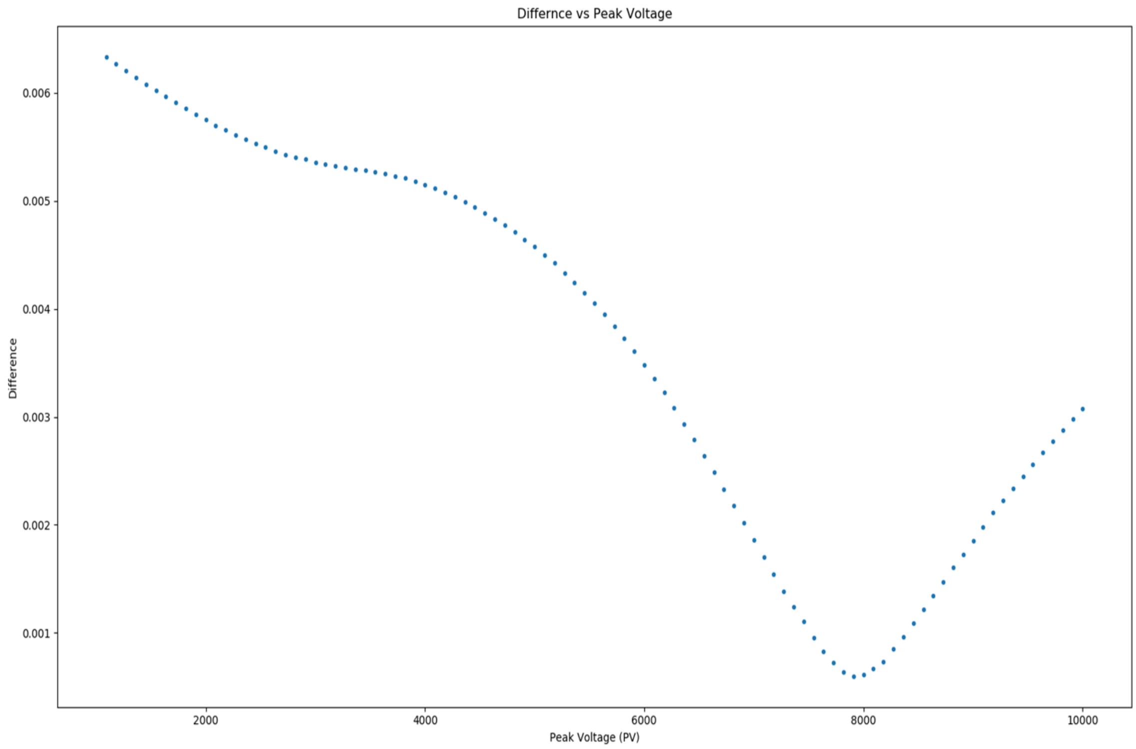

Figure 3.4: Voltage Calibration for 8 kV simulated data with redefined boundaries for the reconstruction

4. Peak Voltage, Magnetic Field and Gamma Transition Parameter Calibration for Measured Data

Parameters which were considered in this run were peak voltage, dipole magnetic field and gamma transition of the measured data. Each parameter was varied from the original value as follows with 20 steps for each range.

- Voltage => [-20% , +20%]
- Magnetic Field => [- 16 G , + 16 G]
- Gamma Transition => [- 0.1 , + 0.1]

According to the results obtained from this search peak voltage had the highest impact towards the reconstruction difference compared to the other two parameters considered here.

The reconstruction difference was much larger as the peak voltage deviates from its original voltage according to the observed results.

Impact for the reconstruction difference for all the combinations of the Magnetic Field and Gamma Transition can be neglected compared to the impact from the peak voltage variation towards the difference.

The histogram of the differences generated by all combinations of the parameters is shown in Figure 4.1.

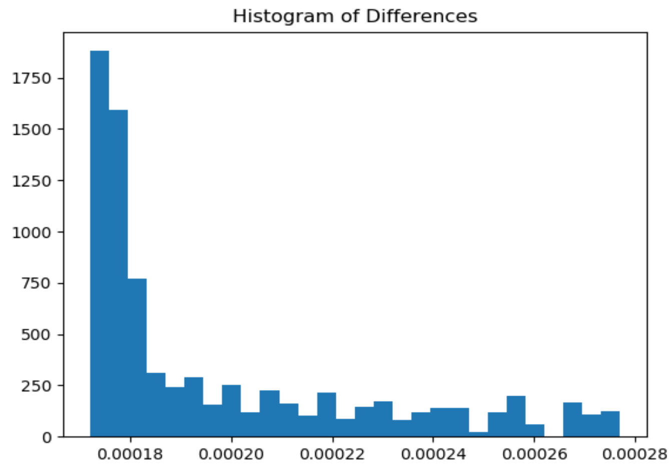

Figure 4.1: Histogram of Differences

5. Upper and Lower bound Calibration for Measured data

This simulation was implemented to test the effect of the upper and the lower bound variation on the FORTRAN reconstruction, using the real data.

According to the outcomes of the simulation, when the boundaries are selected closer to the edges of the bunch, error or the difference of the reconstruction from the original phase space reaches for a minimum.

The following results were produced by varying three parameters peak voltage, upper boundary, lower boundary of the input file from its original values which were 8 kV, 0 and 0.

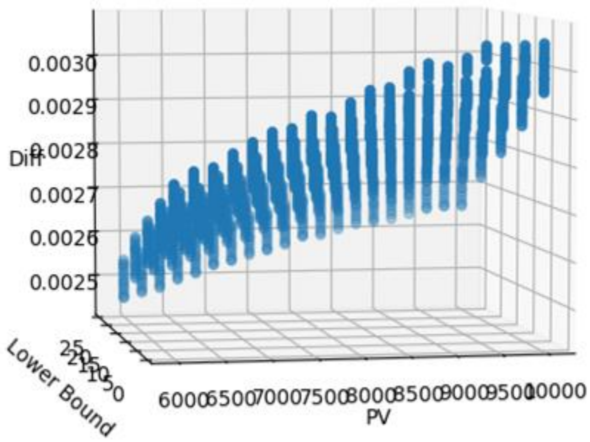

Figure 5.1: 3D graph f Peak Voltage, Lower Bound and reconstruction Difference

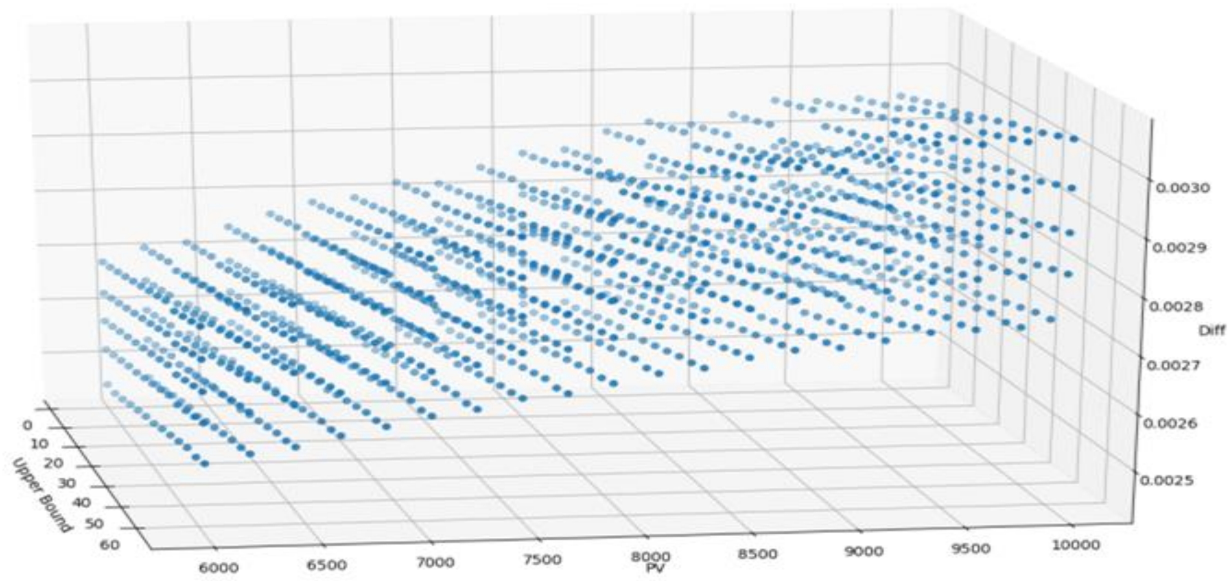

Figure 5.2 3D graph of Upper Bound, Peak Voltage and reconstruction Difference

As it is shown from the Figure 5.2 reconstruction difference highly depends on lower bound.

This behaviour was not intensely observed with the upper bound of the bunch profile. Therefore the effect from the upper bound can be neglected compared to lower bound from the results.

Differences for all the parameter combination are distributed around 0.00275 in a range of [0.0025, 0.0030], which is displayed in Figure 5.3.

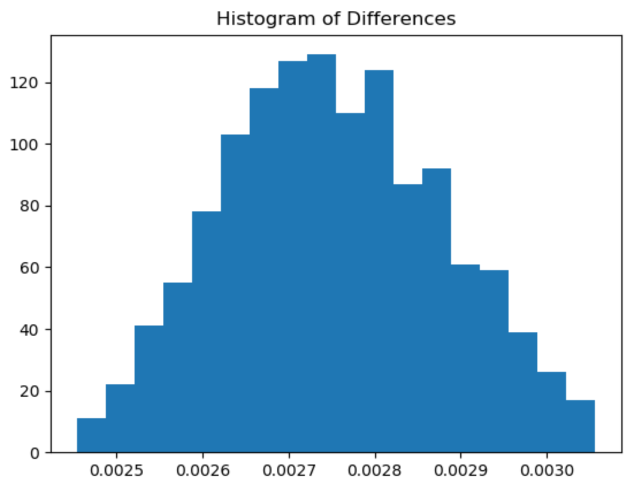

Figure 5.3: Histogram of Differences

6. Upper and Lower Bound Calibrations for BLonD simulated data

The previous implementation included in chapter 5 was implemented for BLonD simulated data with the exact same parameters to understand the above observations under simulated conditions with no measurement error noise.

It was observed that simulated and real data do not behave in the same way. As it is visible simulated data produces minima around the value of the original peak voltage and the reconstruction difference does not have any significant fluctuation over the variation of the lower boundary, as it is observed in measured data.

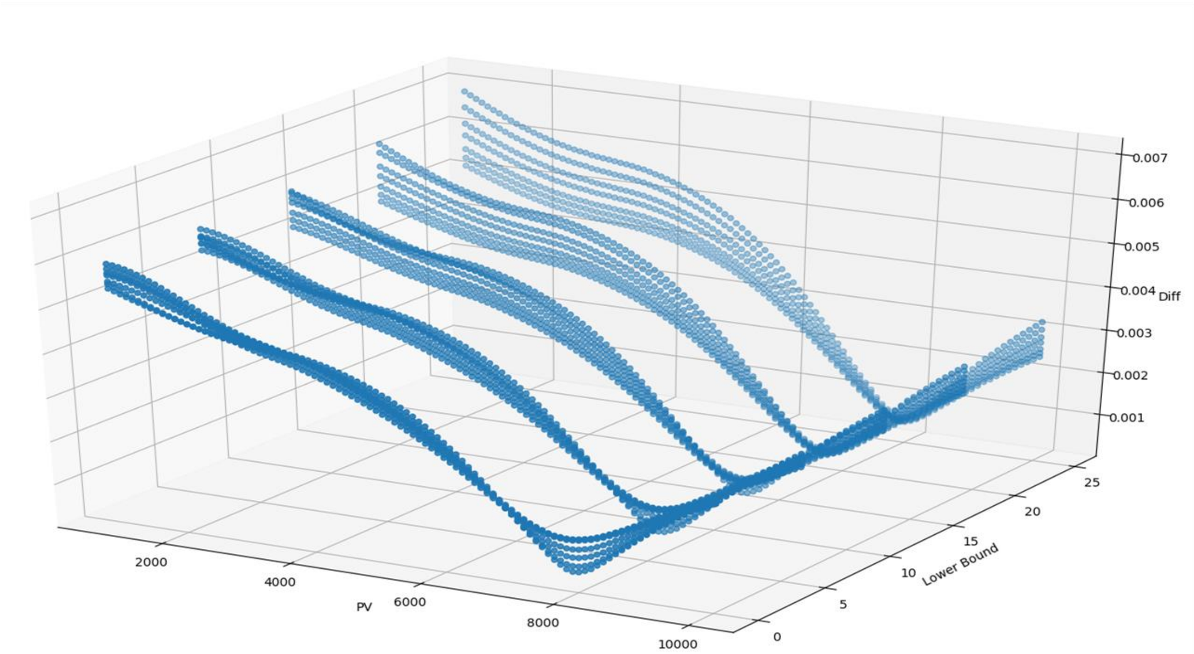

Figure 6.*Error! No text of specified style in document.****.1: 3D graph of Peak Voltage, Upper Bound and Reconstruction Difference***

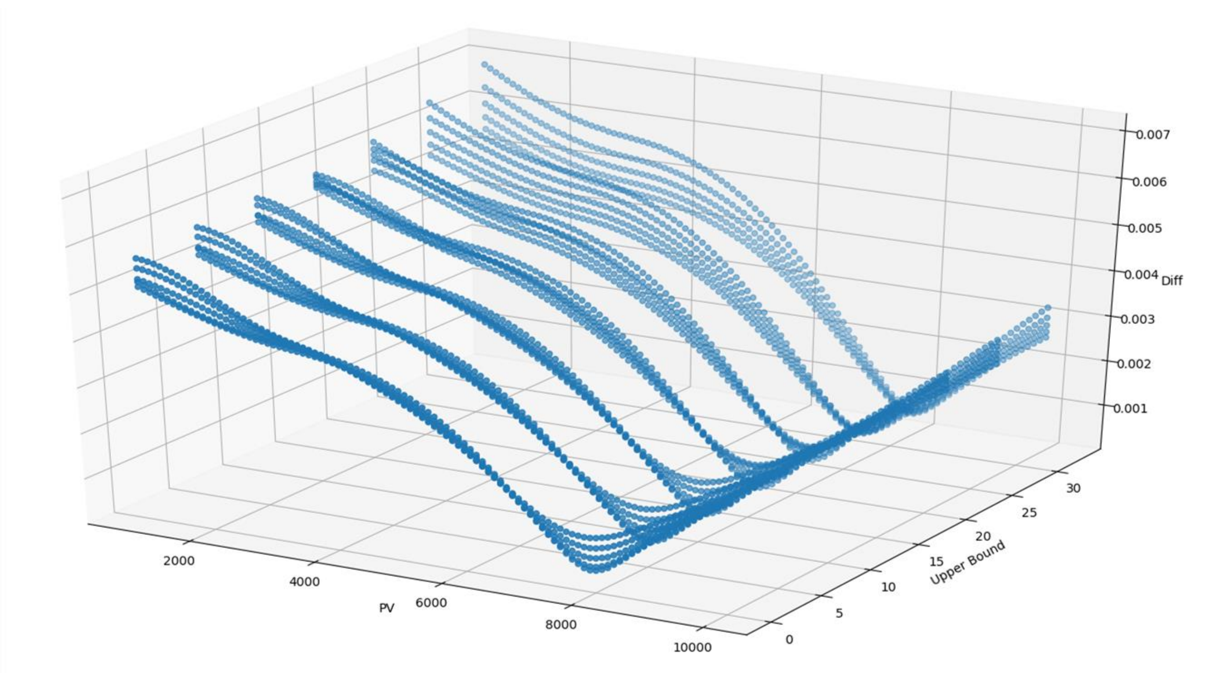

Figure 6.2: 3D graph of Peak voltage, Upper Bound and reconstruction D

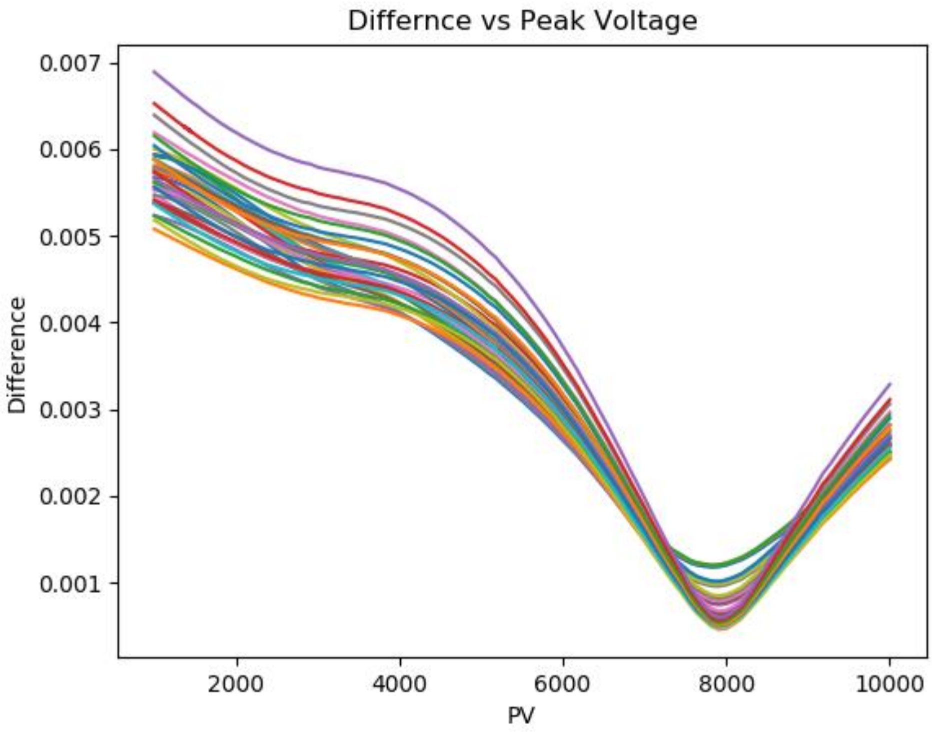

Figure 6.3: Reconstruction Difference versus Peak Voltage

The variation of the upper boundary behaves the same way or no significant effect towards the reconstruction error was observed. This is indicated in Figure 6.2.

The effect of the peak voltage on the reconstruction difference was highlighted by this implementation.

The peak voltage variations for different combinations of parameters are displayed by the following Figure 6.3.

The minimum of the difference for parameter combinations are different according to the above graph. Therefore this conveys us that there is an impact toward peak voltage at the minimum of the reconstructed difference from the lower and upper bound.

7. Comparison of the BLonD Phase Space to FORTRAN reconstructed Phase Space

This was carried out to determine the degree of the accuracy of reconstruction of the tomogram using the existing FORTRAN program. In order to visually display the difference of reconstructed image the difference of the phase phases were graphed with each of their projections over two axes as shown in Following Figure 5.1.

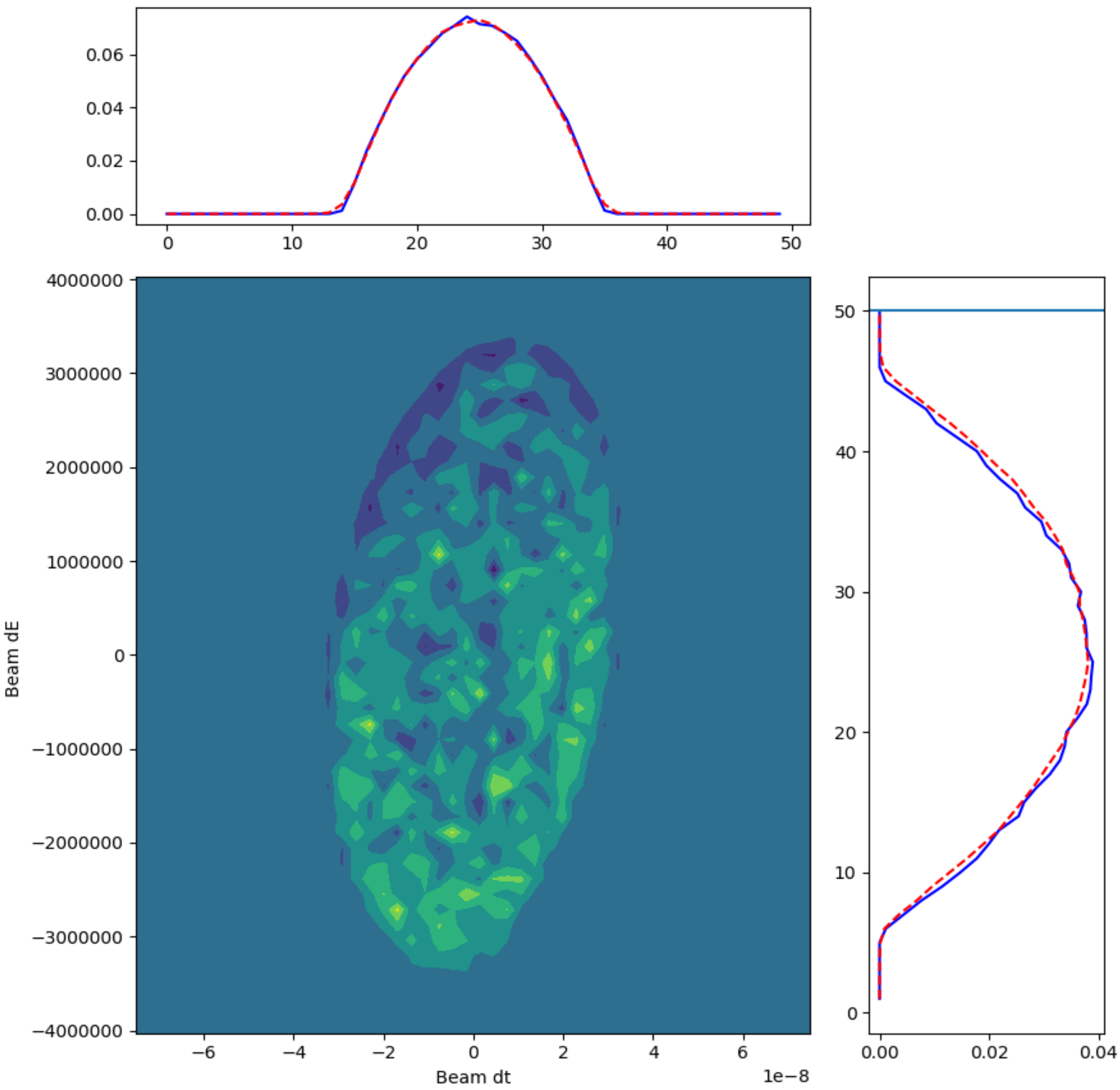

Figure 7.1: Difference of the BLonD phase space and Fortran phase space

8. Conclusions

- Peak voltage parameter has the highest impact towards the reconstruction difference for both simulated and measured data.
- Boundary values influences towards the reconstruction difference of the tomography for simulated data and it determines the voltage that reaches the minimum difference value.
- Magnetic field and gamma transition do not have a significant impact towards the observations compared to the peak voltage.
- The deviation from the original bunch profile depends on the lower boundary for the measured data unlike for BLonD data.

9. References

[1] CERN Beam Longitudinal Dynamics code BLonD http://blond.web.cern.ch

[2] Tomography http://tomograp.web.cern.ch/tomograp/