Electron Trajectory Prediction using Matching

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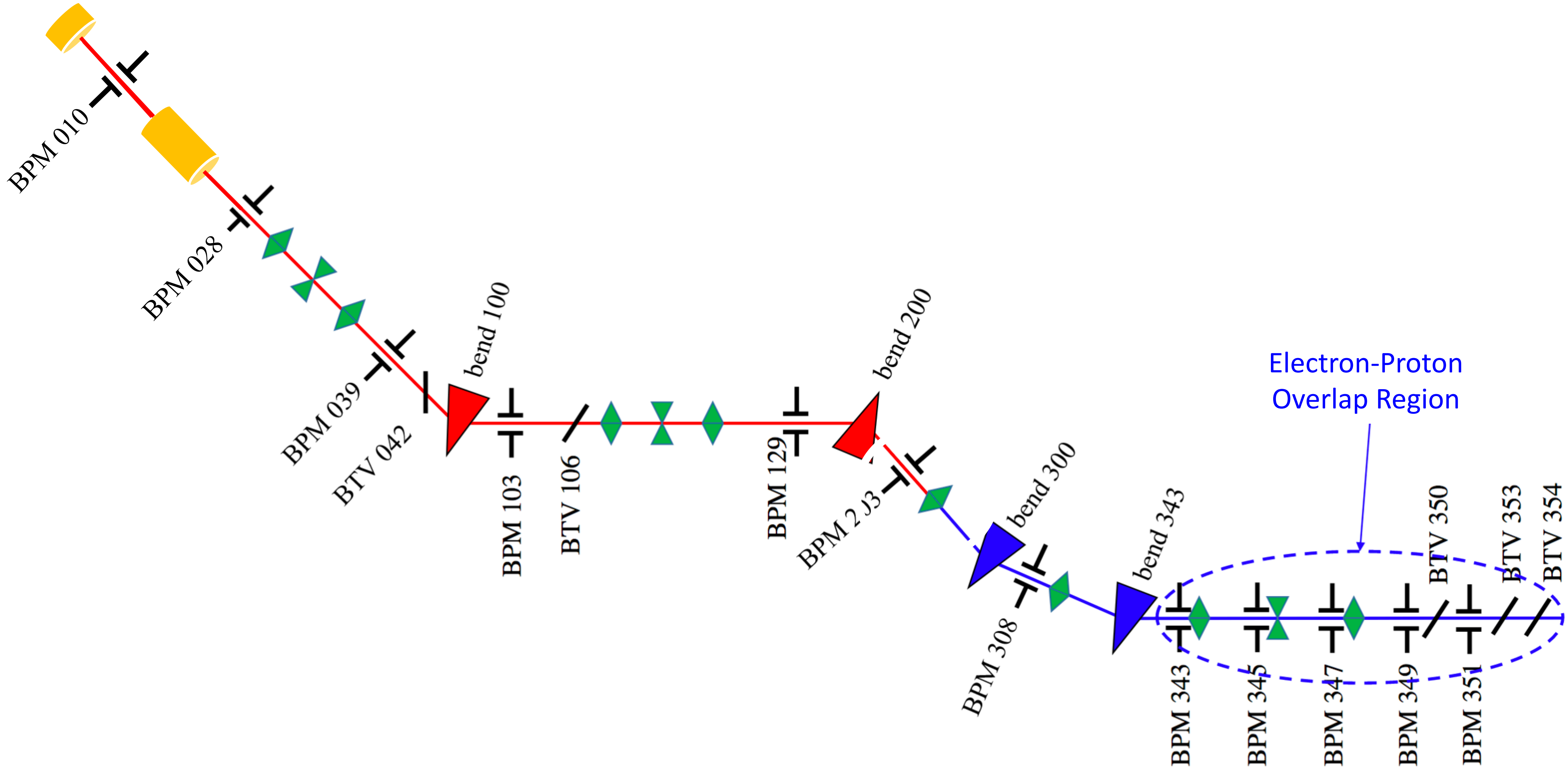
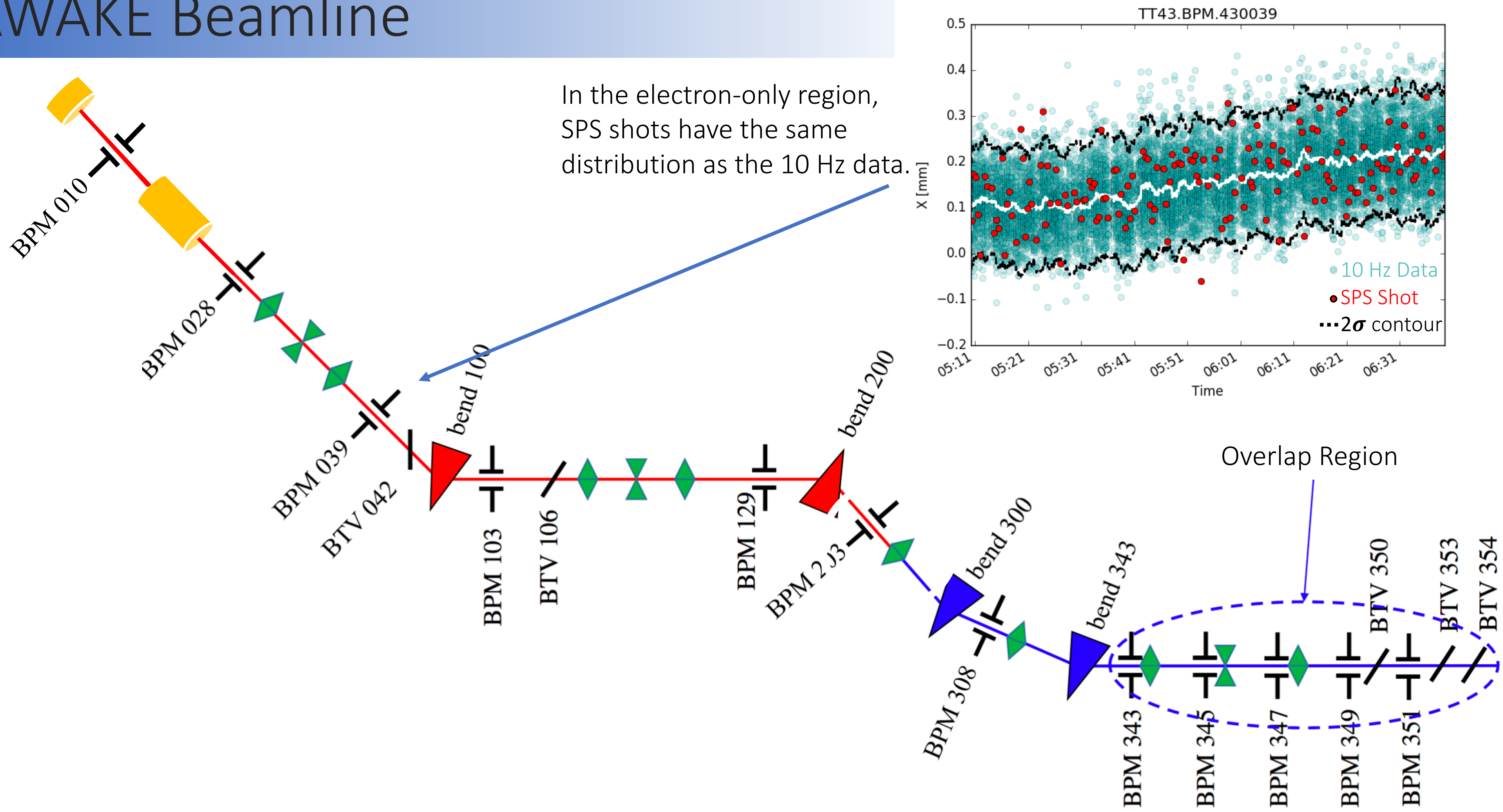
19.12.18

AWAKE Beamline



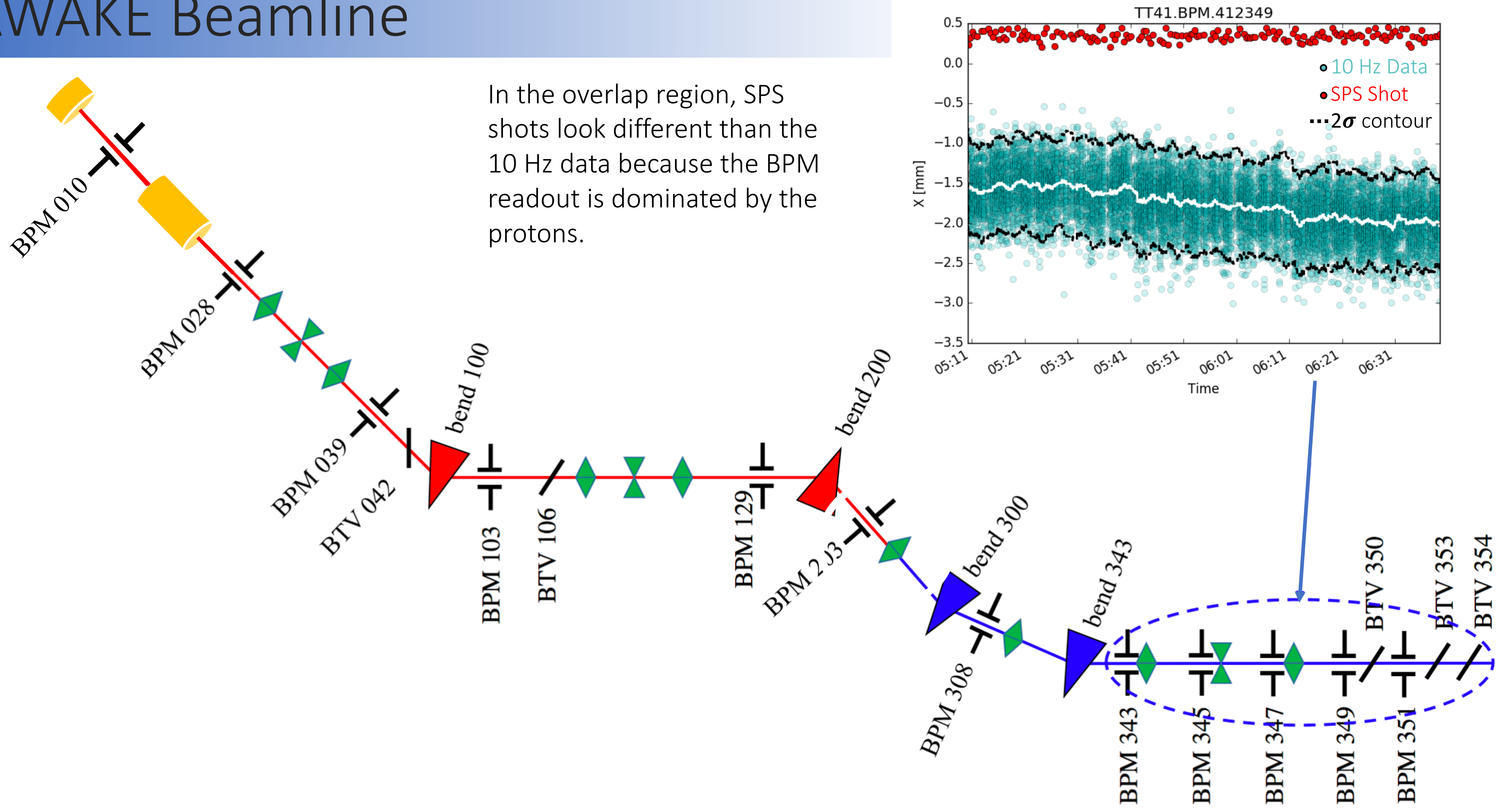
AWAKE Beamline

In the electron-only region, SPS shots have the same distribution as the 10 Hz data.



AWAKE Beamline

In the overlap region, SPS shots look different than the 10 Hz data because the BPM readout is dominated by the protons.



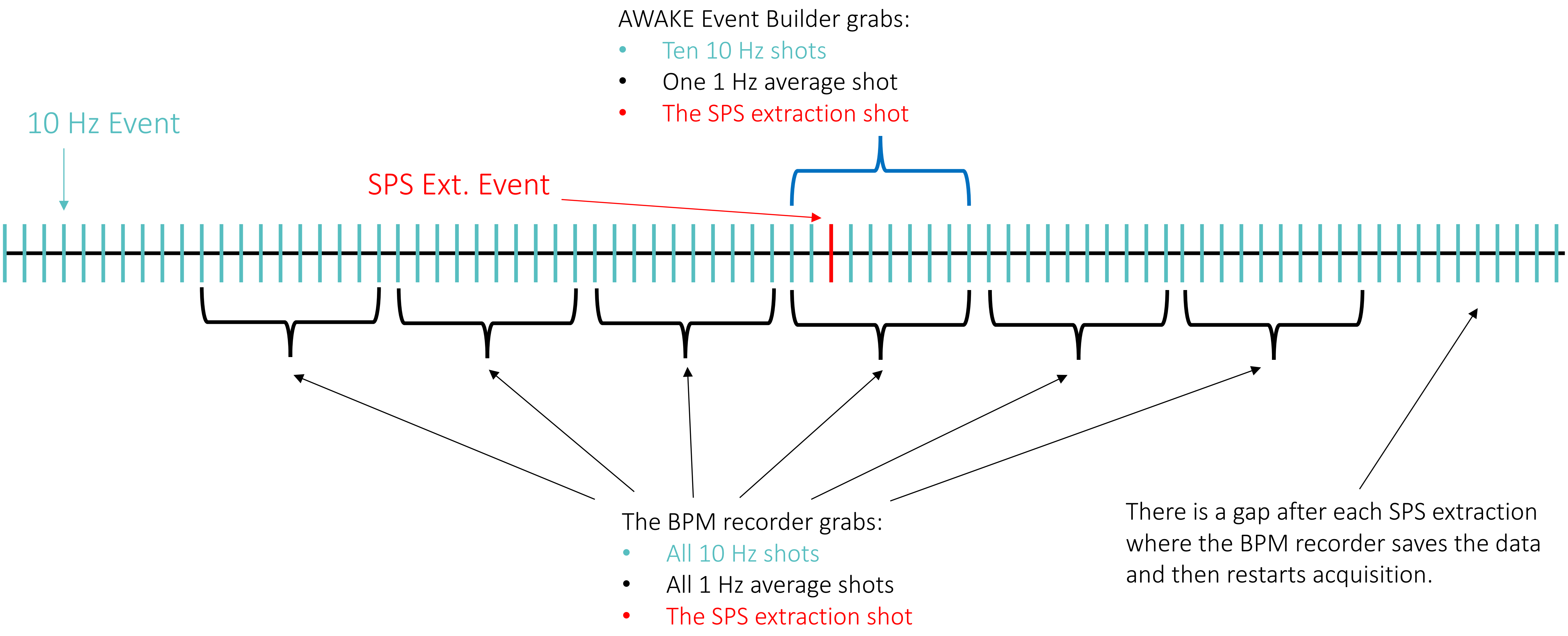
Objective

Can we use the BPM data in the electron-only region to predict the electron trajectory in the overlap region?

Can we do this prediction without using a model?

Data Acquisition

From 10-12 November, an additional process ran in the background to store 10 Hz BPM data "between" AWAKE events.



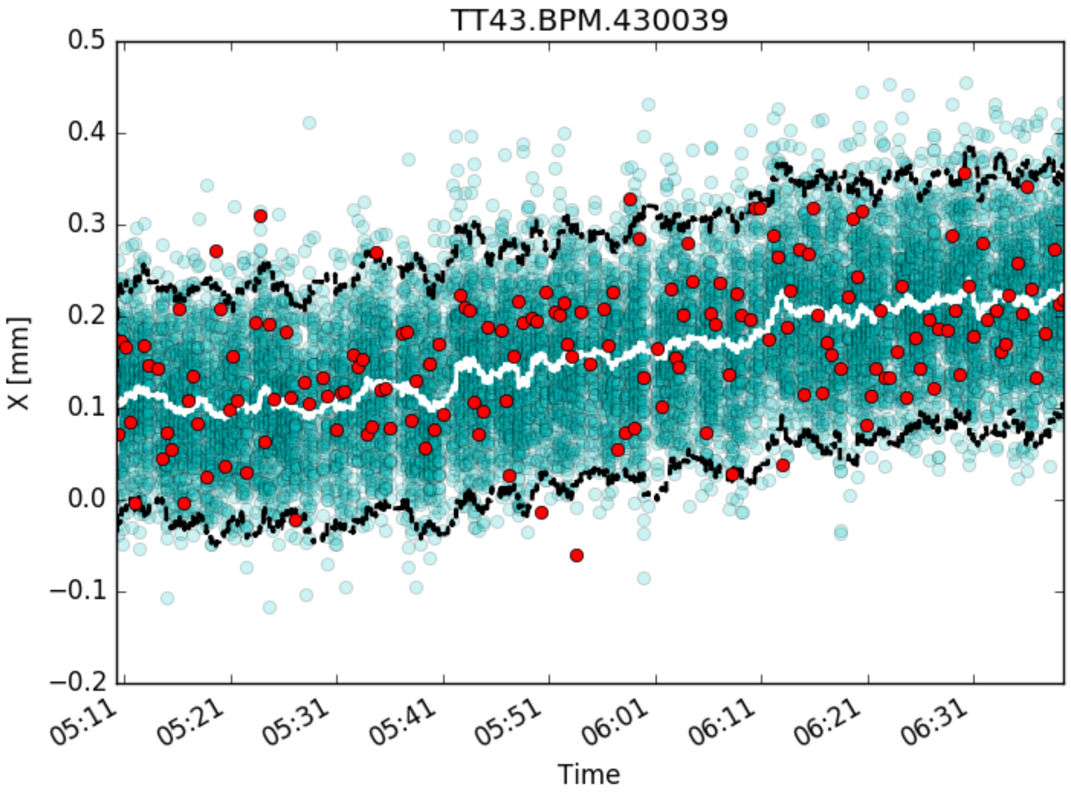
Dataset for this analysis

For this analysis, I use a 90 minute sample between 05:10 and 06:40 on 11.11.18.

During this time, the correctors and quadrupoles did not change.

After applying quality control to the data (more on this later), I am left with:

- 165 SPS extraction trajectories
- 12473 10 Hz trajectories (no protons)



Analysis

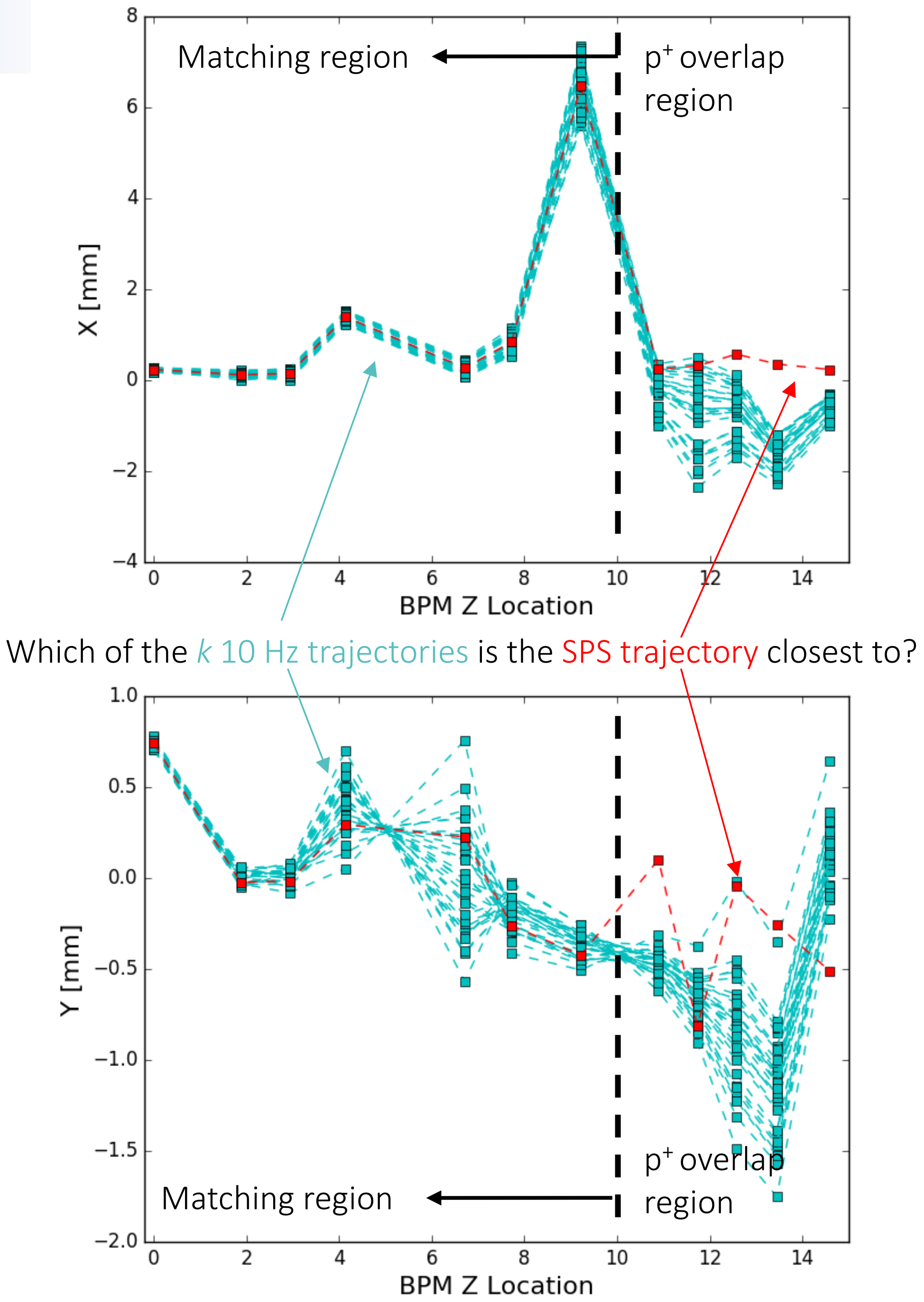
1. Select 1 SPS trajectory.
2. For each of the 10 Hz trajectories in the data set, compute the cost χ by summing the difference squared of the the SPS trajectory with each of the *k* 10 Hz trajectories over the first 7 BPMs (non-overlap region):

$$\chi_x^k = \sum_i^{n=7} (x_i^{SPS} - x_i^k)^2 \qquad \chi_y^k = \sum_i^{n=7} (y_i^{SPS} - y_i^k)^2$$

3. Minimize the cost simultaneously for both the *x* and *y* trajectories to find the matching trajectory *k*:

$$k_{match} = \text{argmin}(\chi_x^k + \chi_y^k)$$

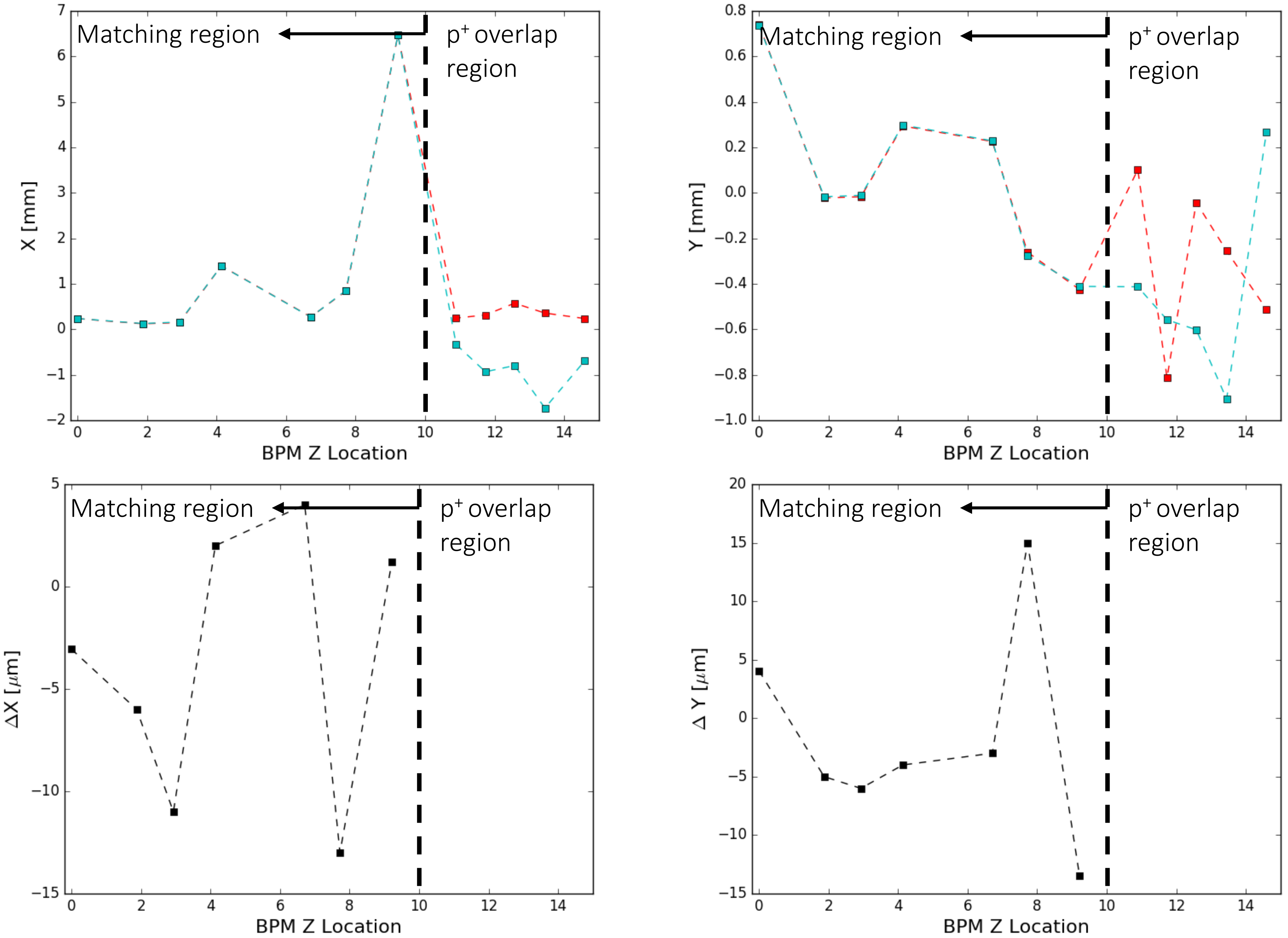
4. Repeat for all 165 SPS trajectories.



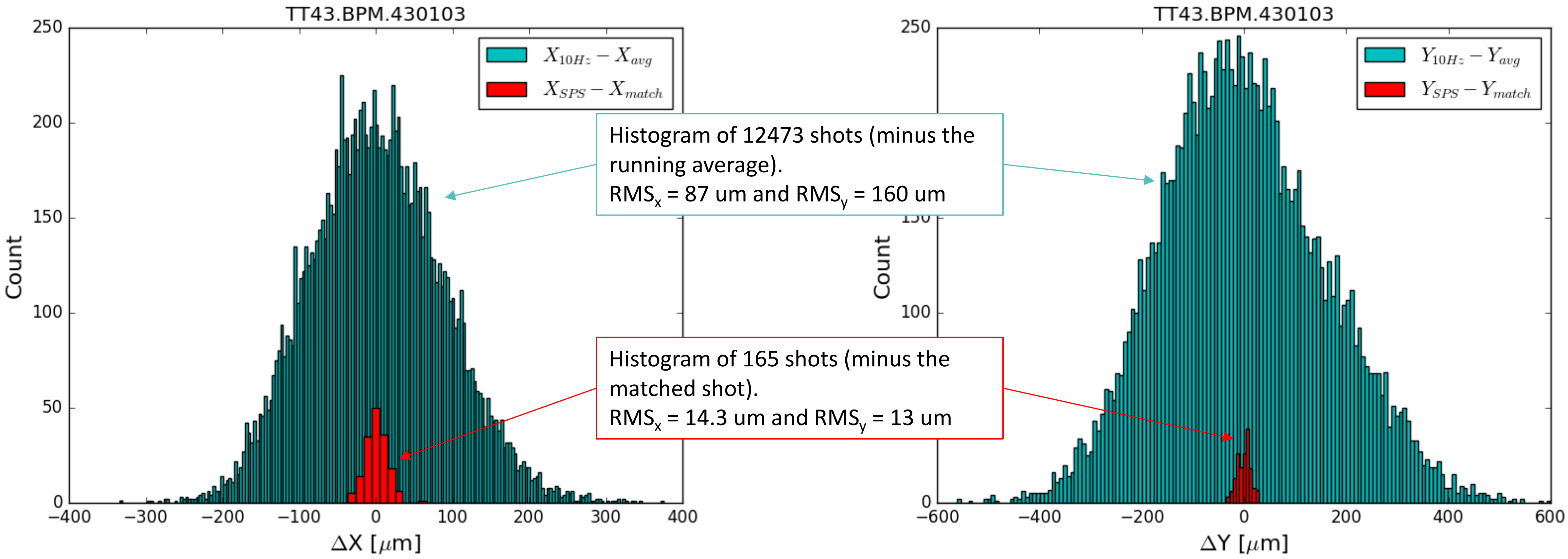
Example Outcome

In this example (shot 81 of 165), we see the selected 10 Hz trajectory plotted on top of the SPS trajectory.

The bottom plot shows the difference between the two trajectories in *microns* at each of the first 7 BPMs.



Quantifying the results



For each BPM, we can ask:

"What is RMS of the 10 Hz values (minus the running average) vs. the RMS of the *difference* between the SPS values and the matched values?"

Results

	TT43.BPM.430010	TT43.BPM.430028	TT43.BPM.430039	TT43.BPM.430103	TT43.BPM.430129	TT43.BPM.430203	TT43.BPM.430308
10 Hz RMS_x [μm]	29.5	52.9	68.4	87.1	114.4	168.5	493.5
Match RMS_x [μm]	15.8	25.9	15.6	14.3	14.9	19.4	23.9
10 Hz RMS_Y [μm]	15.6	27.3	30.0	160.3	301.9	74.7	50.1
Match RMS_y [μm]	12.7	17.9	13.0	13.0	19.4	16.6	17.13

The RMS of the matched value is always smaller than the RMS of the 10 Hz data. This is especially the case at the dispersive BPM 309 (in X) and 129 (in Y).

Validation

This technique *appears* to work: we can always find a trajectory close to the SPS trajectory that we are interested in.

Is there away to convince ourselves that it is *actually* working?

Assume that the distribution of the 10 Hz electron trajectories is the same as the distribution of the SPS electron trajectories.

- This assumption would be invalid if, for example, the proton beam deflects the electrons.

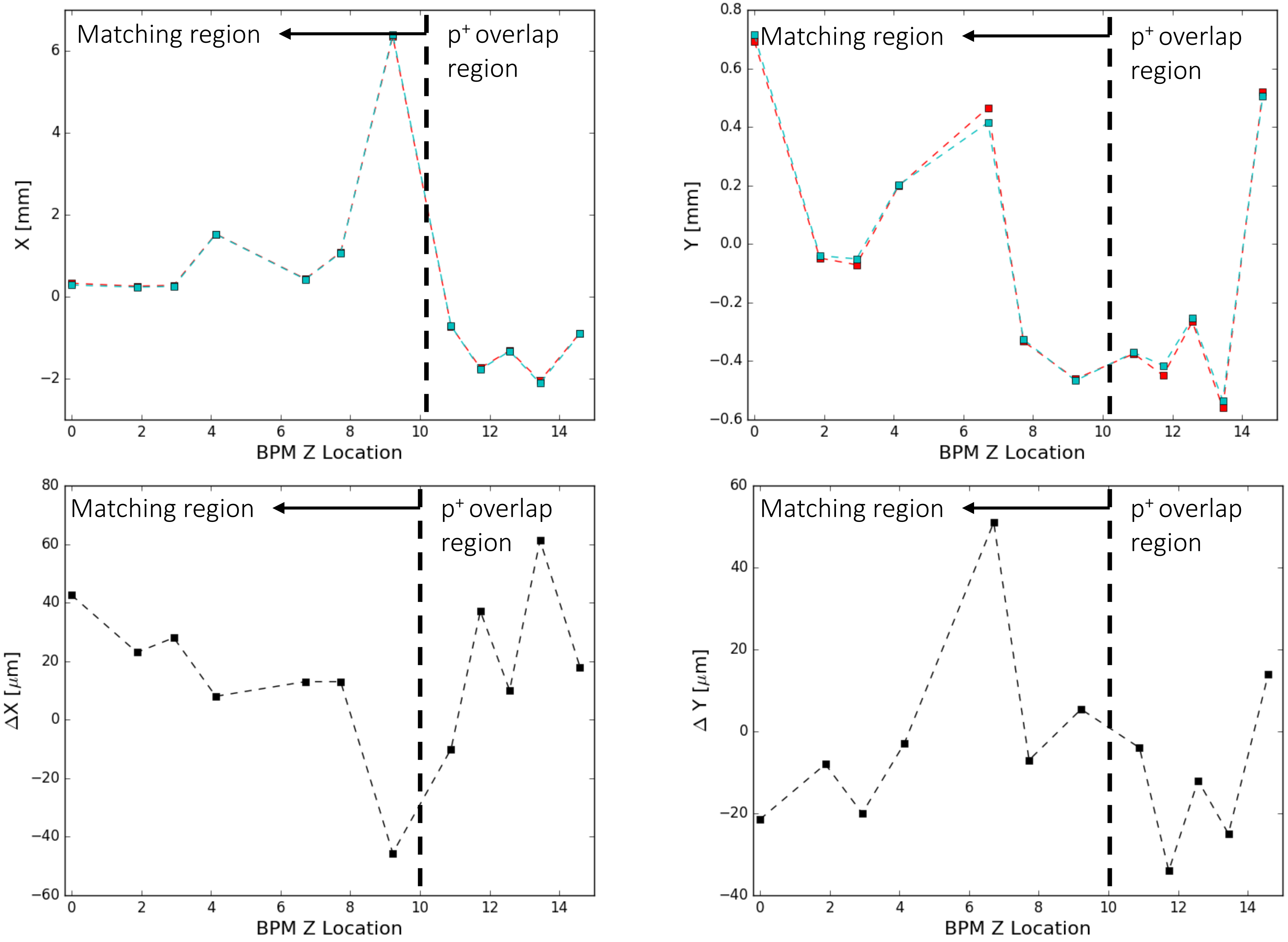
At random, choose a 10 Hz trajectory from the sample, remove it from the 10 Hz data set, and apply the same methodology for that shot using only the first 7 BPMs.

If the match trajectory on the final 5 BPMs is close to the actual trajectory for that shot, we can be reasonably sure that the method is working.

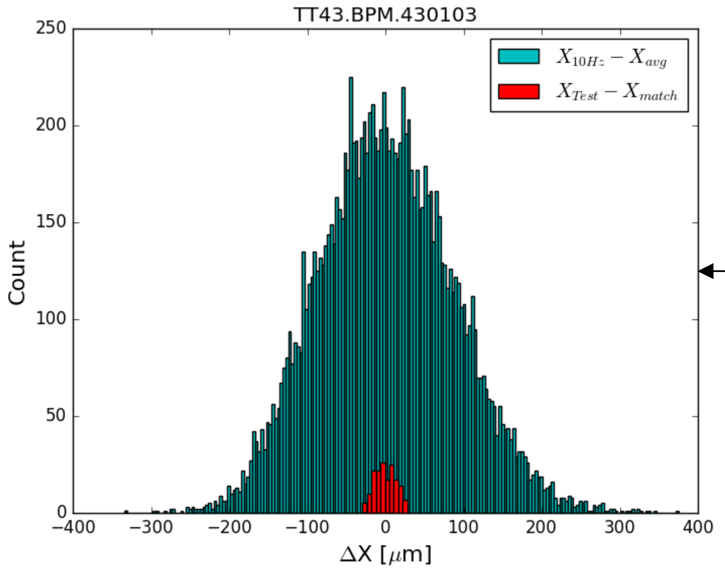
Rinse and repeat 165 times.

Example Validation Result

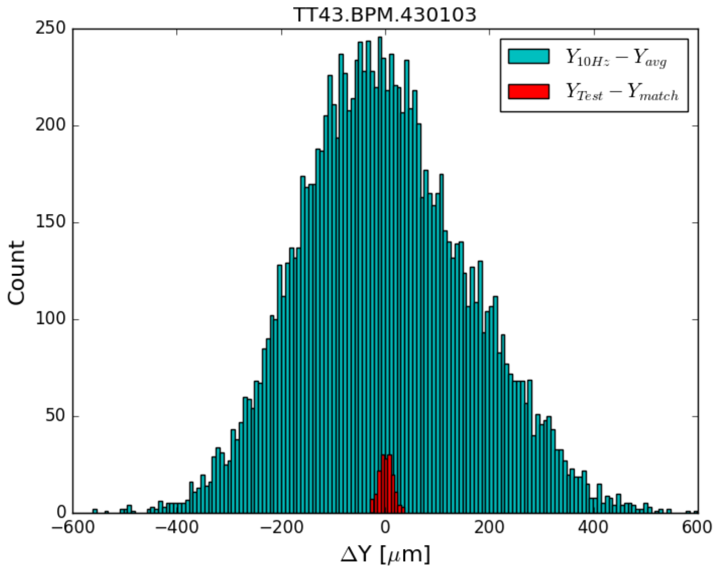
It works!

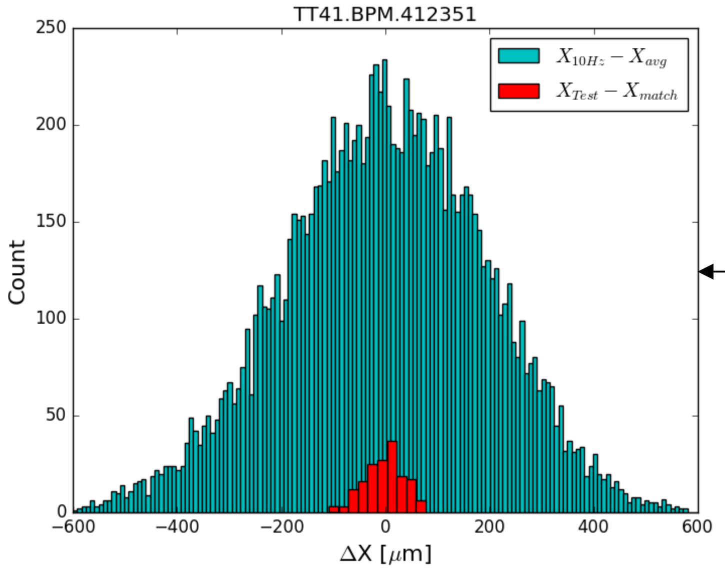


Distribution of Validation data

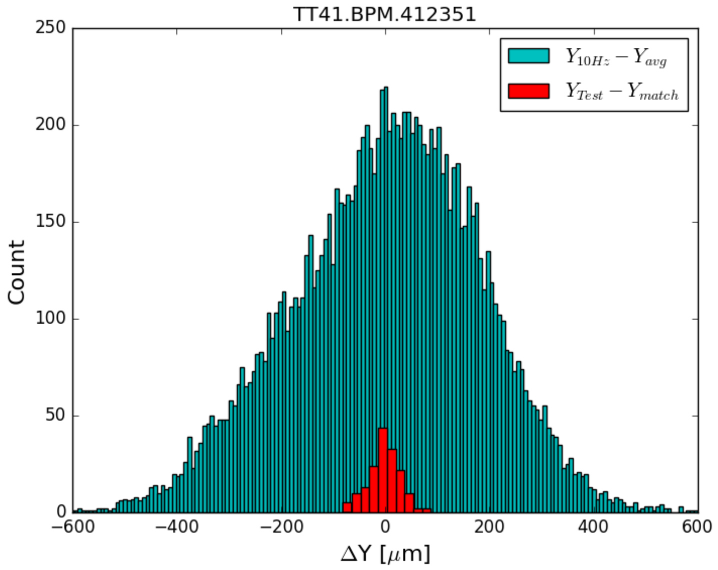


Matched BPM





Predicted BPM



Validation Results

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10 Hz RMS_y [μm]	15.6	27.3	30.0	160.3	301.9	74.7	50.1
Match RMS_y [μm]	11.7	18.3	14.2	13.0	22.5	17.2	15.1

	TT41.BPM.412343	TT41.BPM.412345	TT41.BPM.412347	TT41.BPM.412349	TT41.BPM.412351
10 Hz RMS_x [μm]	365.0	775.3	490.6	308.5	195.4
Pred. RMS_x [μm]	55.2	111.7	75.9	51.0	37.7
10 Hz RMS_y [μm]	55.3	116.2	290.7	285.2	180.0
Pred. RMS_y [μm]	21.8	29.0	39.4	40.5	31.0

Results with matching are nearly identical to what we had when using the SPS trajectories (see slide 11).

The results with the prediction are excellent. Note how large the jitter is in the common line due to the large beta function.

Conclusions

This technique works (assuming we can neglect trajectory changes when the proton beam is present).

This technique should be cross-checked against Felipe and Francesco's reconstruction method which uses a beamline model.

The data used here represents a small subset of the available data from 10-12 November.

- There are lots of issues in the saved BPM date. I will explain in the future how I determine which BPM data are usable.

Assuming that the technique is validated by Felipe and Francesco, we can generate a predicted trajectory for every SPS extraction event from 10-12 November.

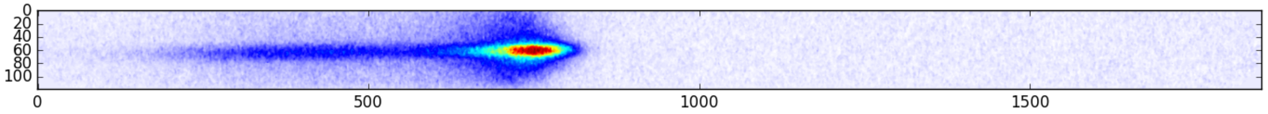
It is not yet clear how to extrapolate this technique to data when we do not have the excess 10 Hz events saved.

- We can discuss options at next analysis meeting.

Bonus

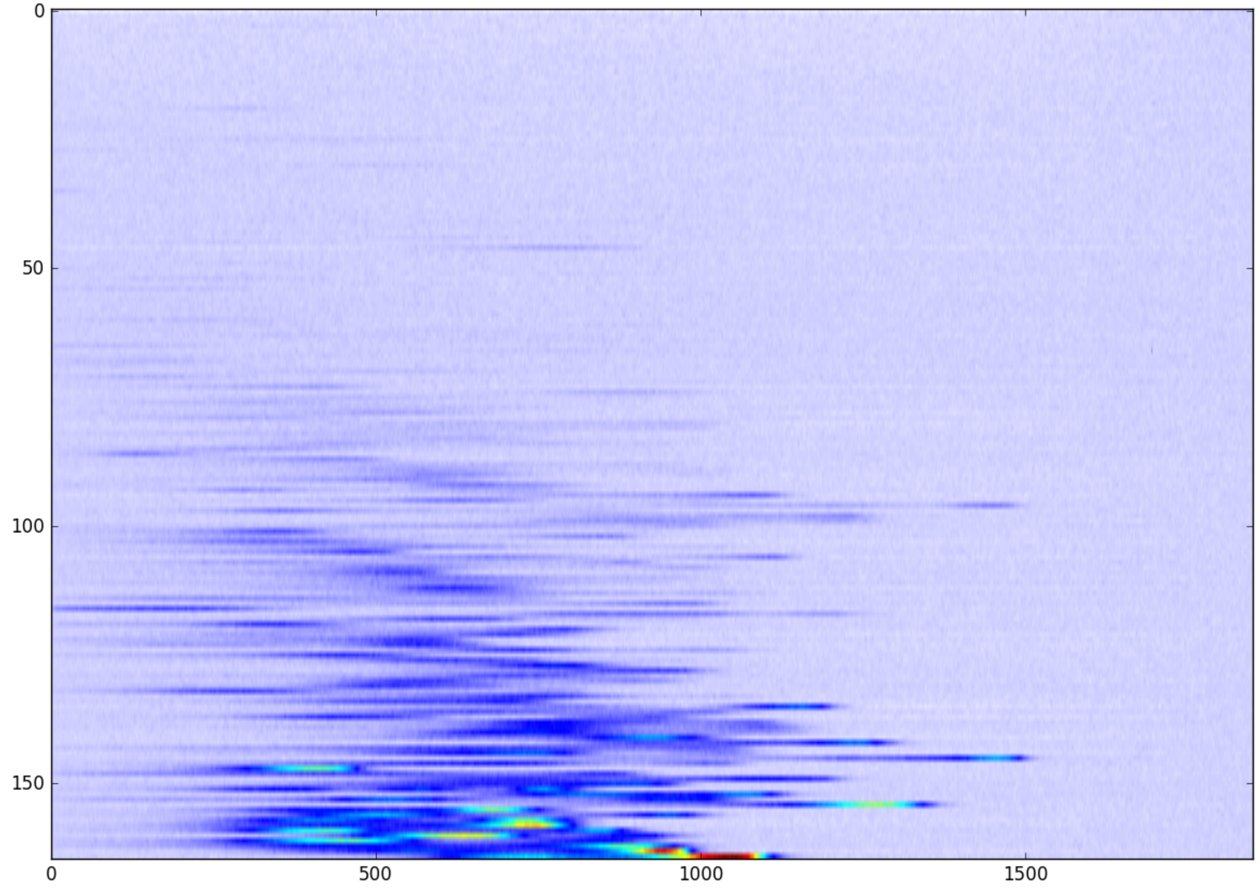
Do Beam Trajectories correlate with Acceleration?

These 165 SPS events include some high charge capture shots like this one.

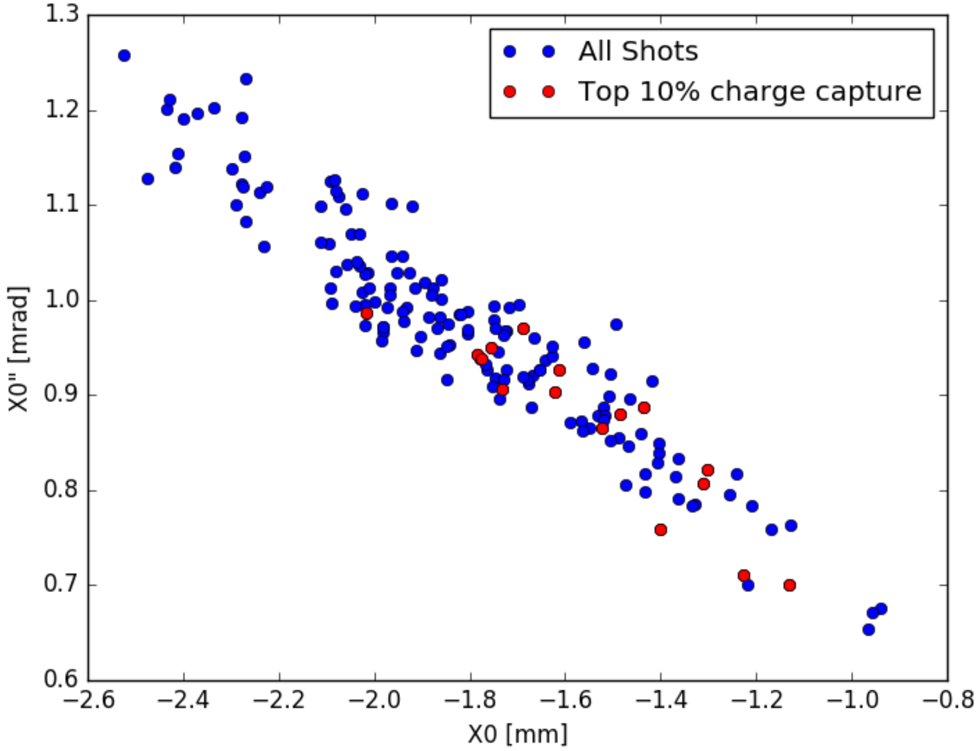


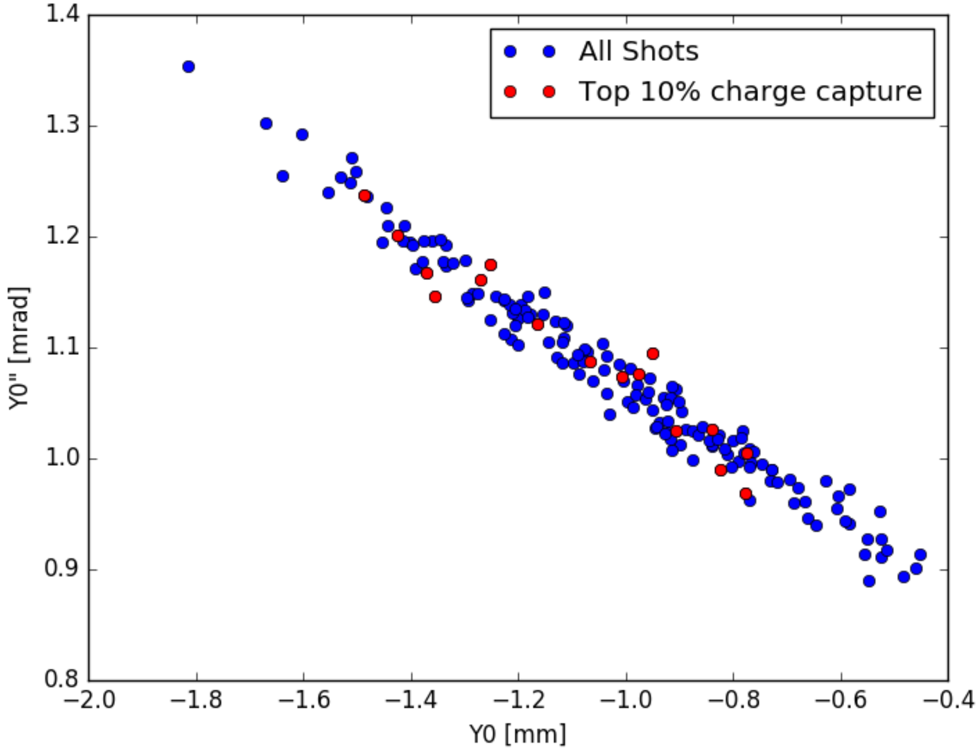
In the waterfall plot, the data is sorted by charge capture (just a pixel sum).

Does the predicted trajectory correlate with the amount of charge capture we see?



Do Beam Trajectories correlate with Acceleration?





These shots show the predicted X0, X0’, Y0, and Y0’ for all 165 shots.

There does not appear to be a correlation between the predicted trajectory and high charge capture shots . . . 😞