Proton beam measurements

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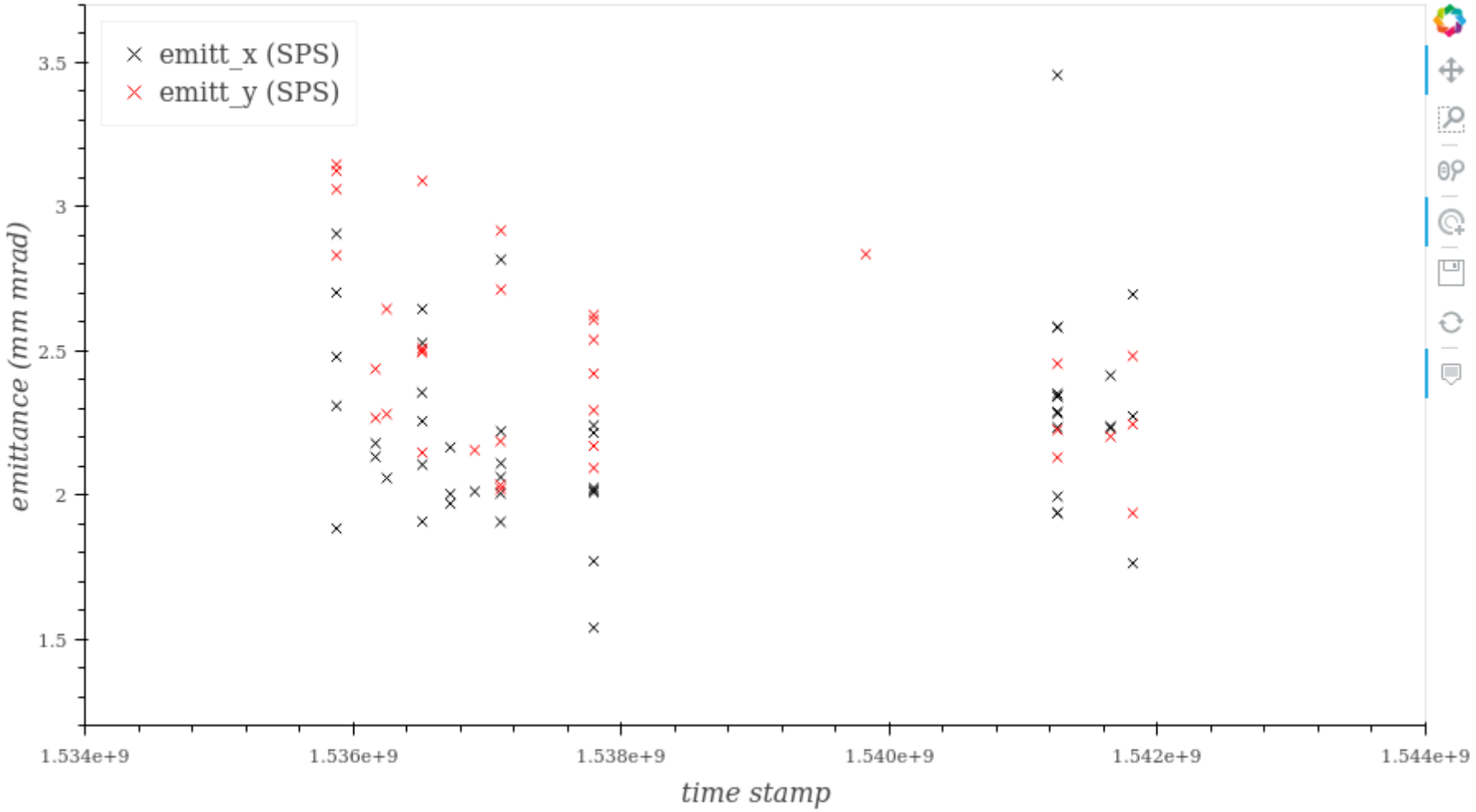
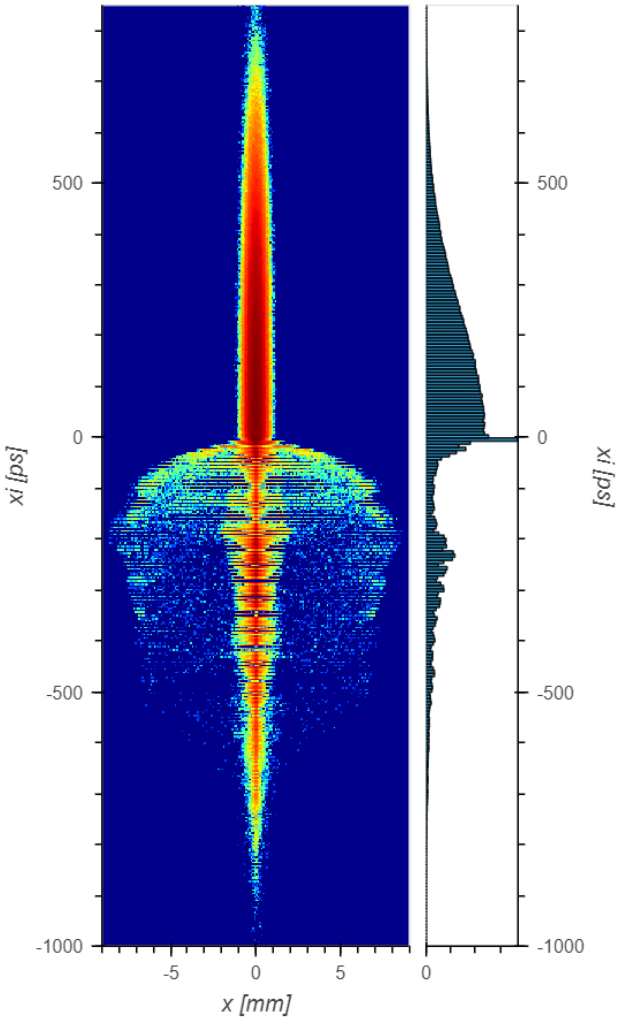
SPS measurements show significant fluctuations of the beam emittance

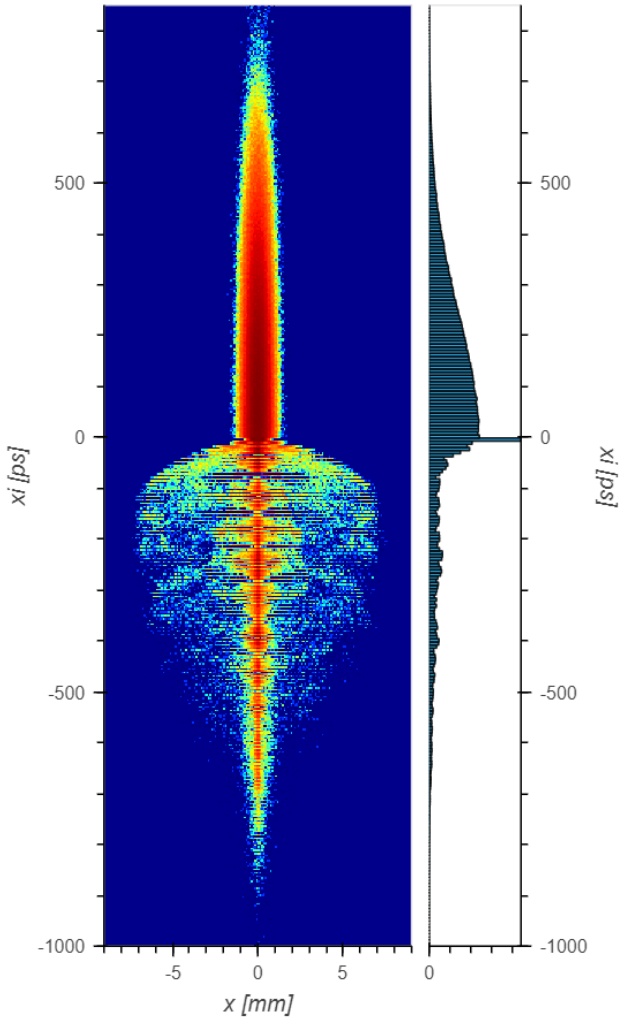


Result of simulations is sensitive to input beam size (emittance)

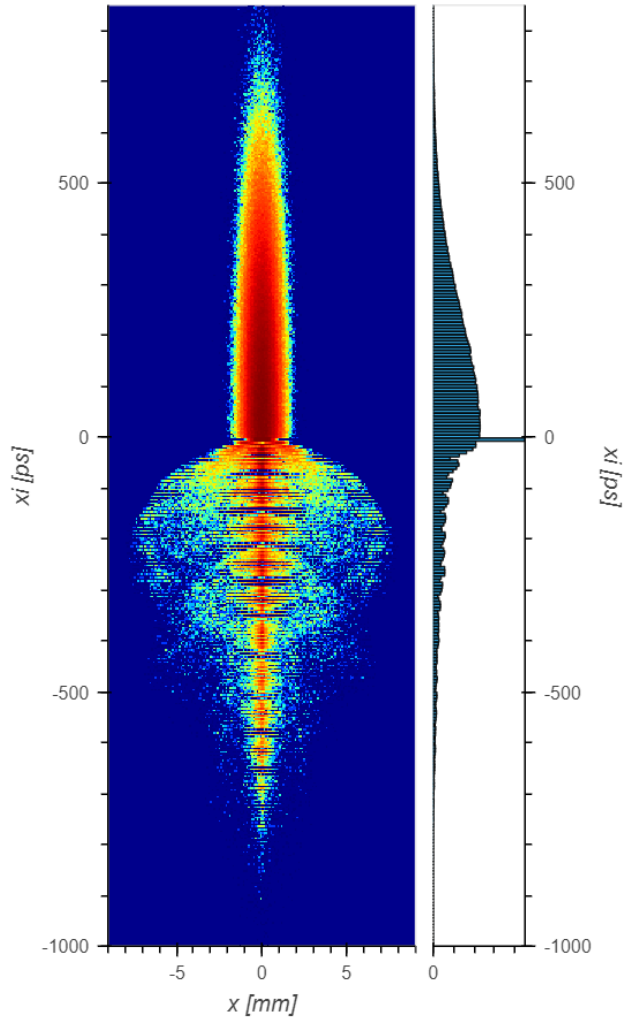
$\sigma_r = 100\ \mu m$
$(\varepsilon_n = 1\ mm \cdot mrad)$
$r_{max} = 8.86\ mm$



$\sigma_r = 150\ \mu m$
$(\varepsilon_n = 2\ mm \cdot mrad)$
$r_{max} = 7.74\ mm$



$\sigma_r = 200\ \mu m$
$(\varepsilon_n = 3.5\ mm \cdot mrad)$
$r_{max} = 8.07\ mm$



Overview

Goal: Construct the model based on the proton beam measurements that predicts parameters of the bunch close to the plasma cell entrance. These parameters should further be used as input parameters for the simulations.

Strategy:

- Measure transverse profiles of the proton bunch using BTVs

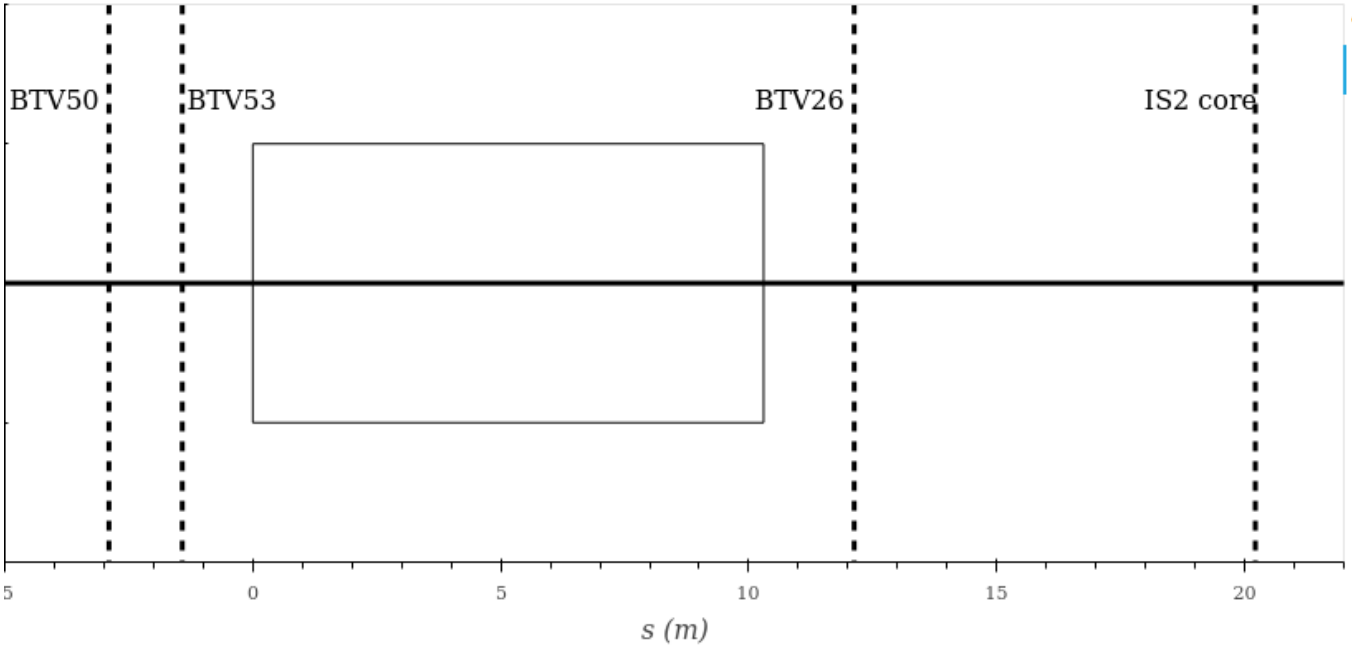
- Construct statistical model
- Test the model with MCMC

- Extract beam size directly from BTV images
- Construct simplified analytical model

Use calculated beam parameters for the simulations

Measurements

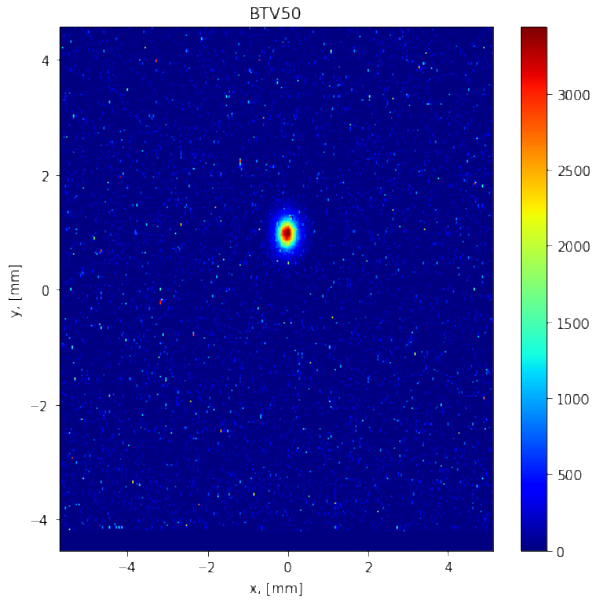
1. BTV50
2. BTV53
3. BTV26
4. IS2: Core Camera

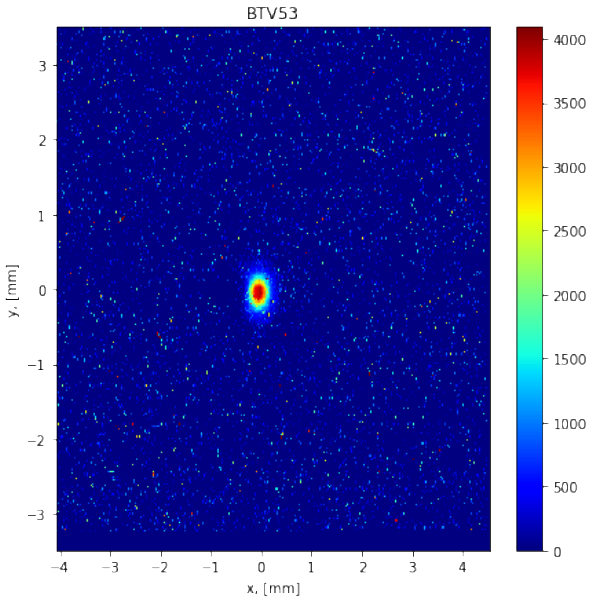


Data that has been collected:

- Set #1: Charge 3e11 [p], Bunch rotation ON (120 events).
- Set #2: Charge 3e11 [p], Bunch rotation OFF (120 events).
- Set #3: Charge 1e11 [p], Bunch rotation ON (120 events).
- Set #4: Charge 1e11 [p], Bunch rotation OFF (120 events).

Typical signal from BTVs





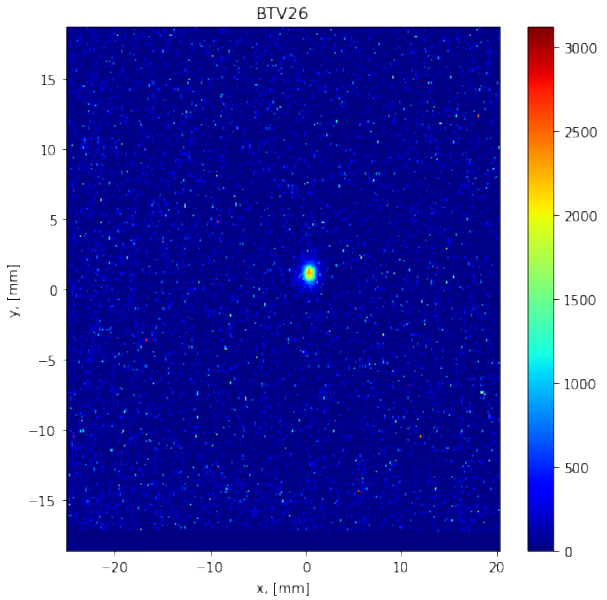
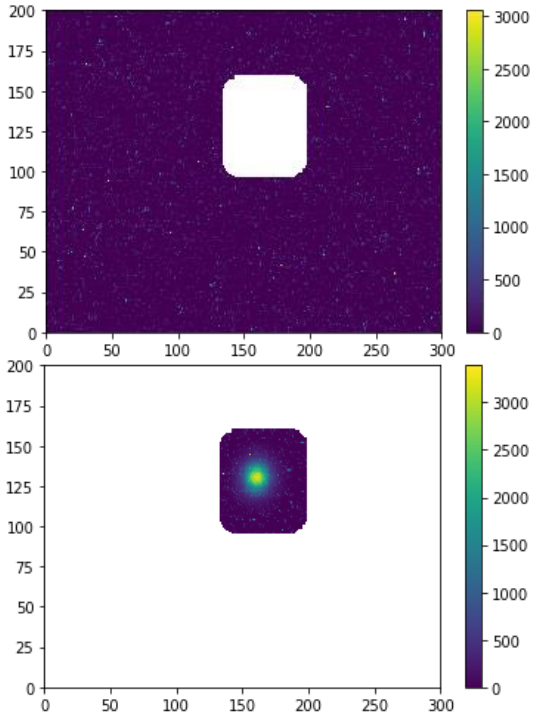
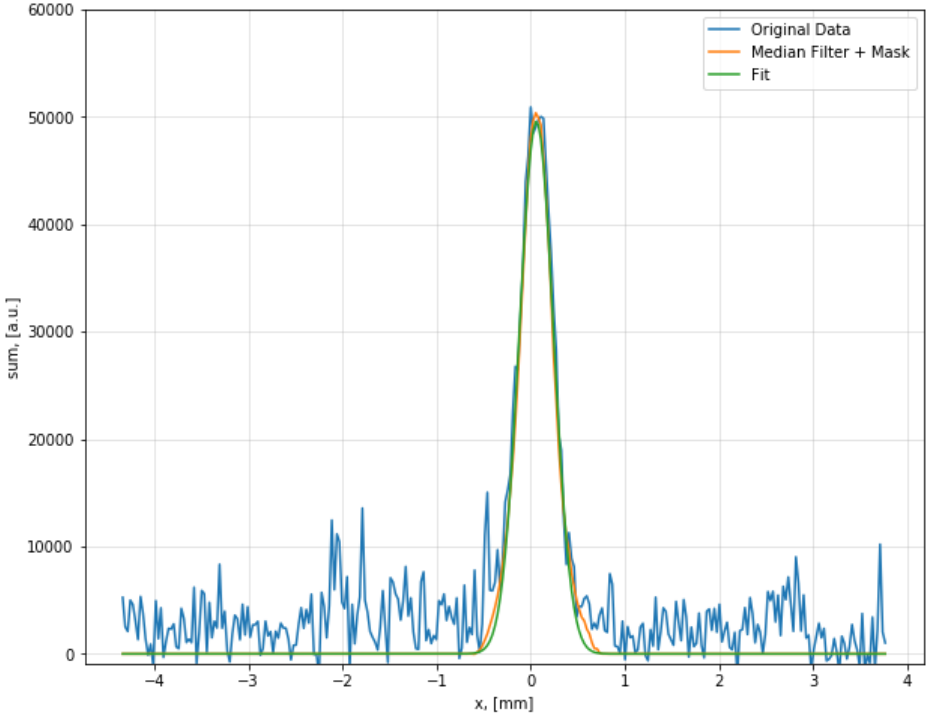
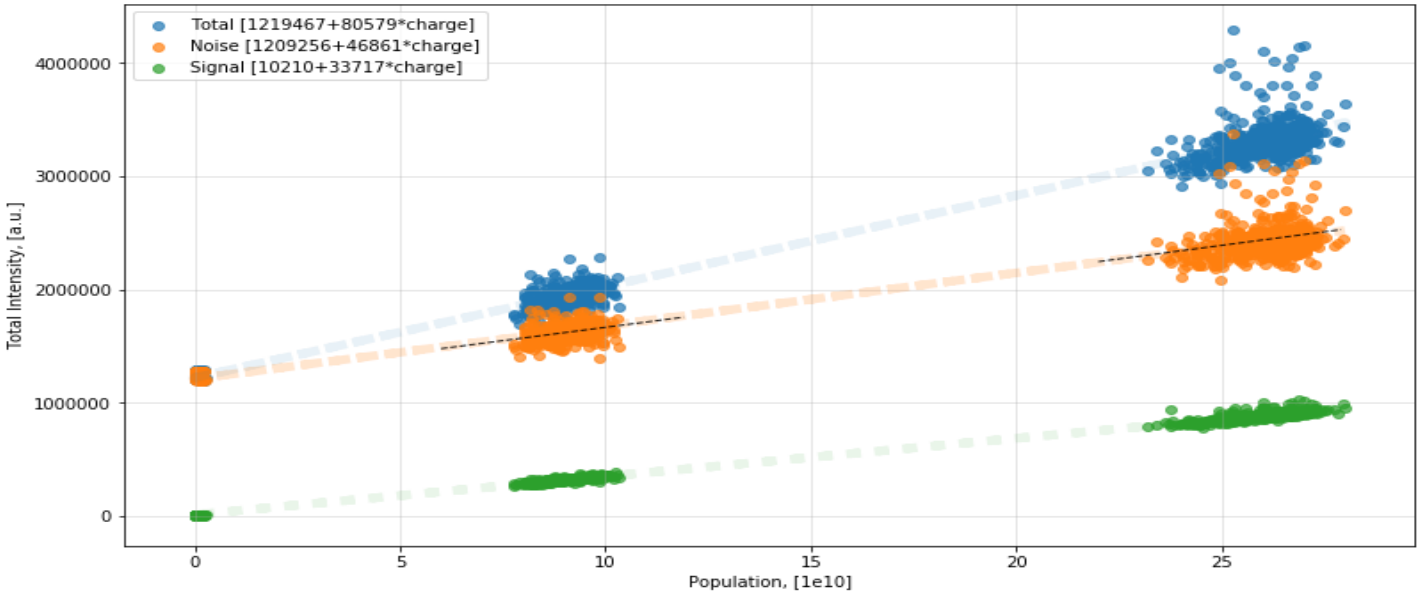


Image processing







Beam dynamics in vacuum

- Assume there are no forces acting on each proton:

$$x'' = 0 \quad \Rightarrow \quad x' = const \qquad \varepsilon_{RMS} = \sqrt{< x^2 >< x'^2 > \; - < xx' >^2} = const$$

- Square and average the law of motion to get formula for beam envelope:

$$x = x_0 + x' \cdot s \qquad < x^2 > = < x_0^2 > + 2 < x_0 x' > s + < x'^2 > s^2$$

- Extracting $< x_0 x' >$ term from ε_{RMS} define the waist position s_{waist}:

$$s_{\text{waist}} = -\frac{\sqrt{< x_0^2 >< x'^2 > \; - \varepsilon_{RMS}^2}}{< x'^2 >} \qquad < x^2 > = < x_0^2 > \; - 2 s_{waist} < x'^2 > s + < x'^2 > s^2$$

We know:

$< x_0^2 >, < x_1^2 >, < x_2^2 >, s_0, s_1, s_2$

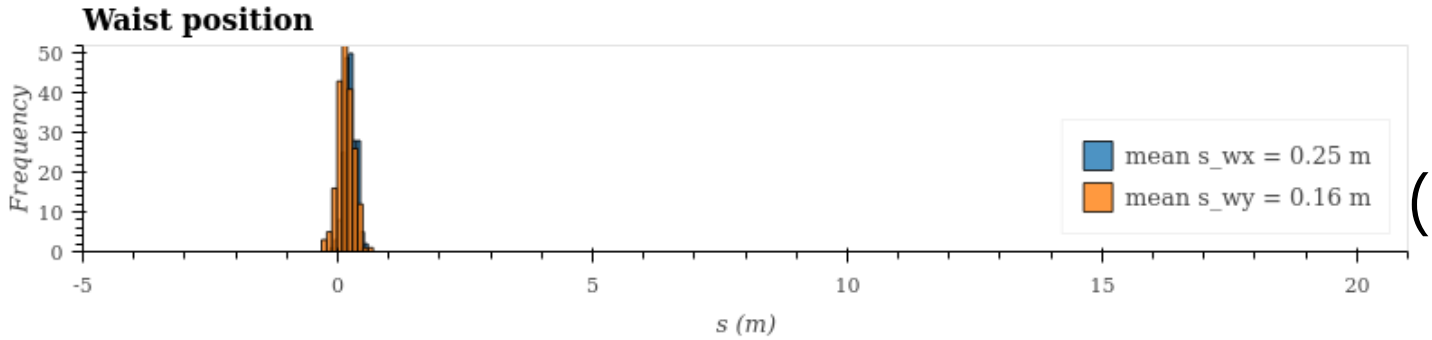
$$< x_0^2 > = < x_0^2 >$$

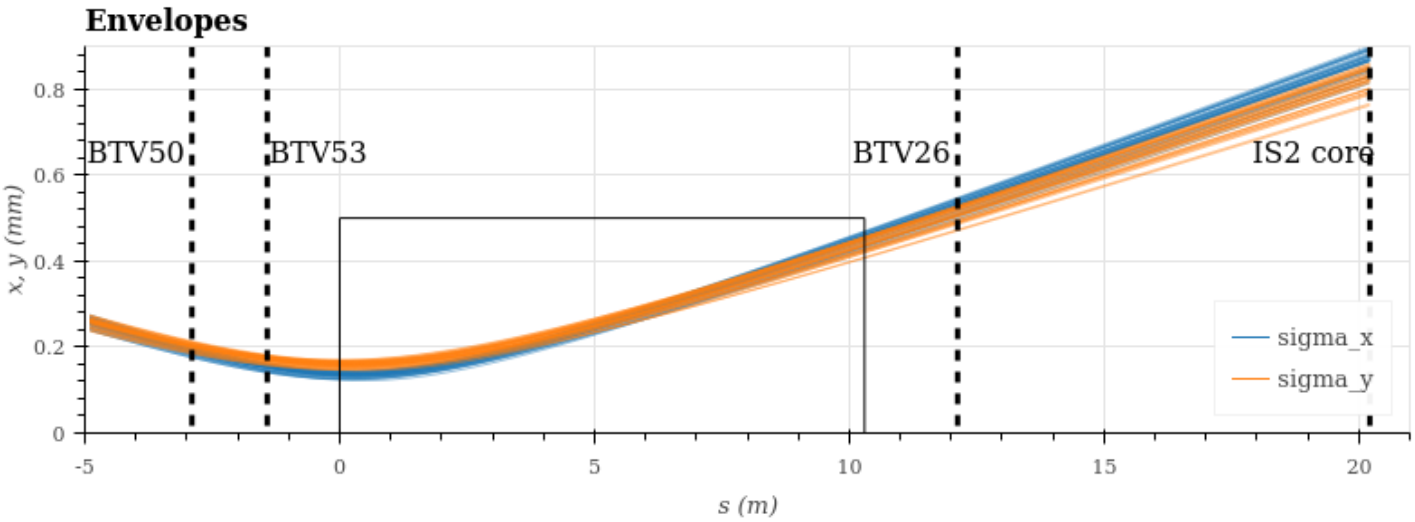
$$< x_1^2 > = < x_0^2 > \; - 2 s_{waist} < x'^2 > s_1 + < x'^2 > s_1^2$$

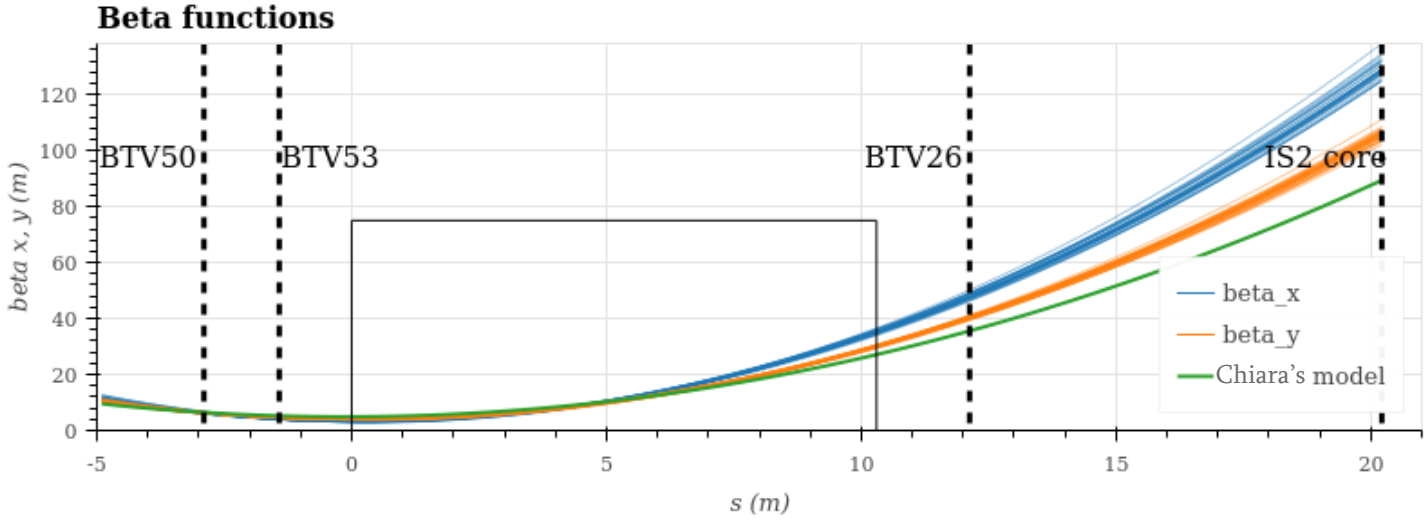
$$< x_2^2 > = < x_0^2 > \; - 2 s_{waist} < x'^2 > s_2 + < x'^2 > s_2^2$$

We want to know:

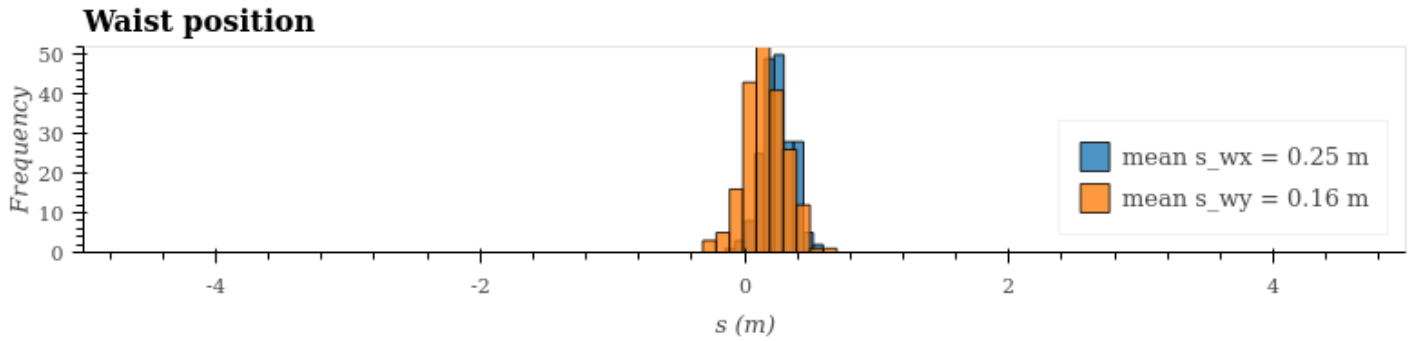
$\varepsilon_{RMS}, \; s_{waist}, \; < x'^2 >$





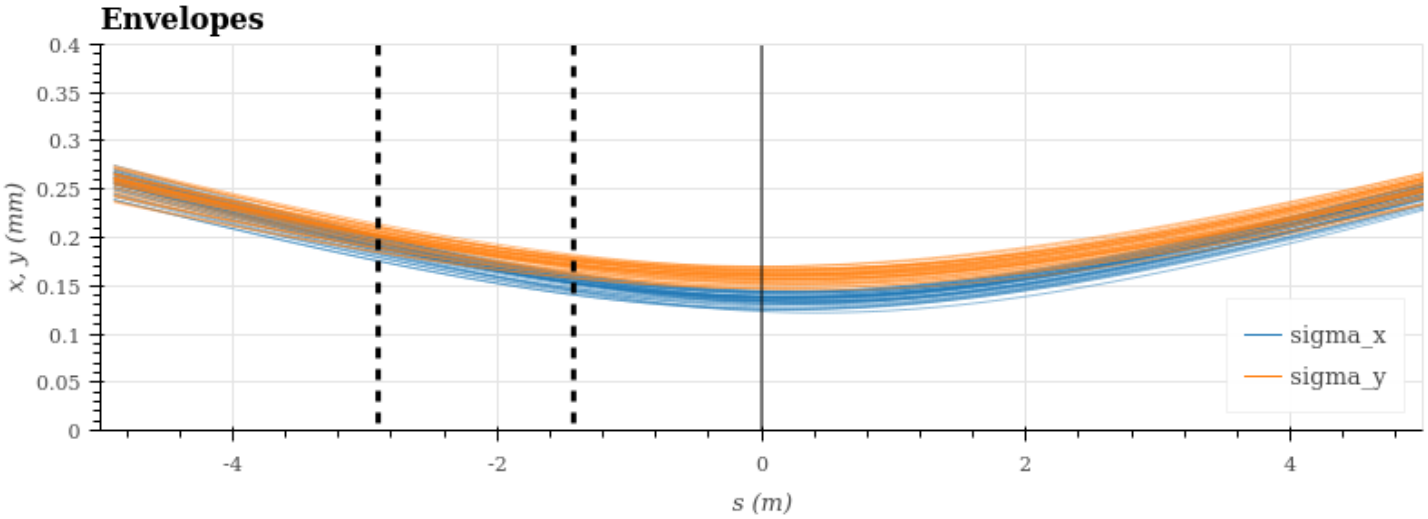


Set #1 (High charge)

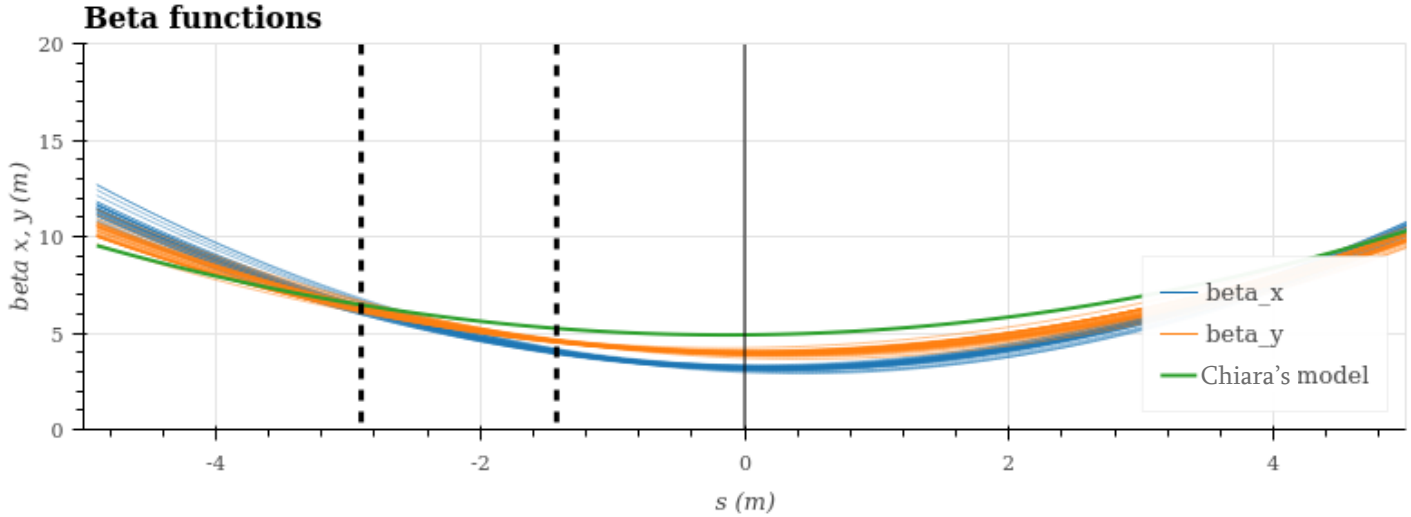


Near the iris:

$s_{waist} \approx 0 \pm 20$ cm



$\sigma_x \approx 0.14$ mm
$\sigma_y \approx 0.16$ mm

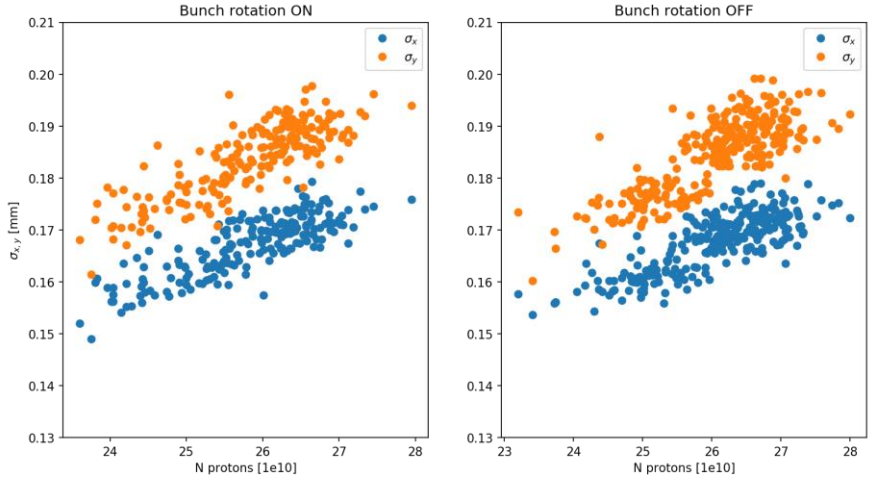


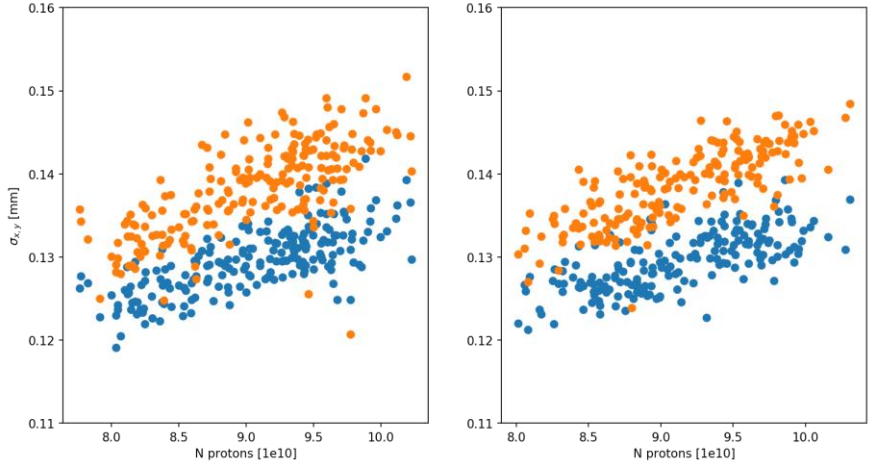
Chiara's model:
$\beta(s = 0) = 5$ m

Our calculations:
$\beta_x(s = 0) = 3.25$ m
$\beta_y(s = 0) = 3.9$ m

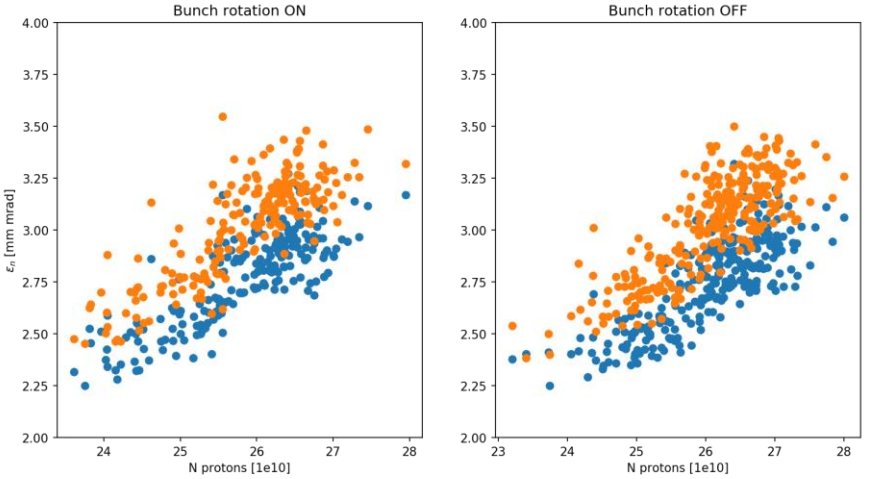
Beam sigma and emittance vs. population using data from BTV26

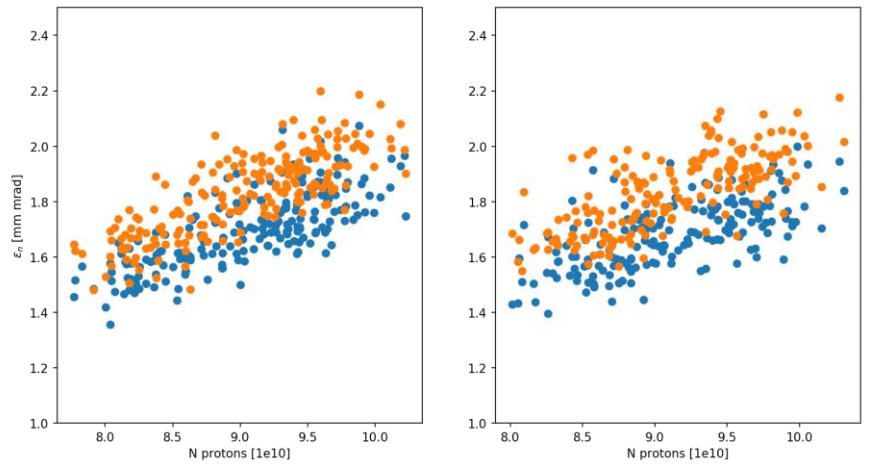
Sigma





Emittance

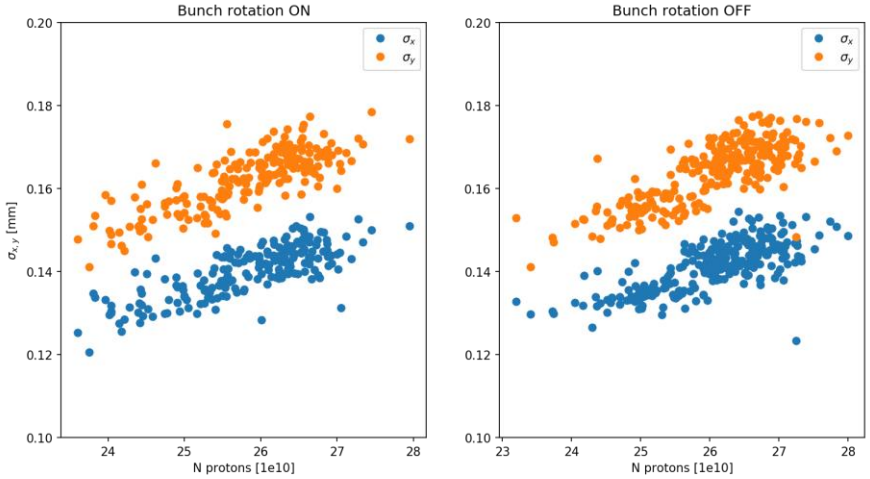


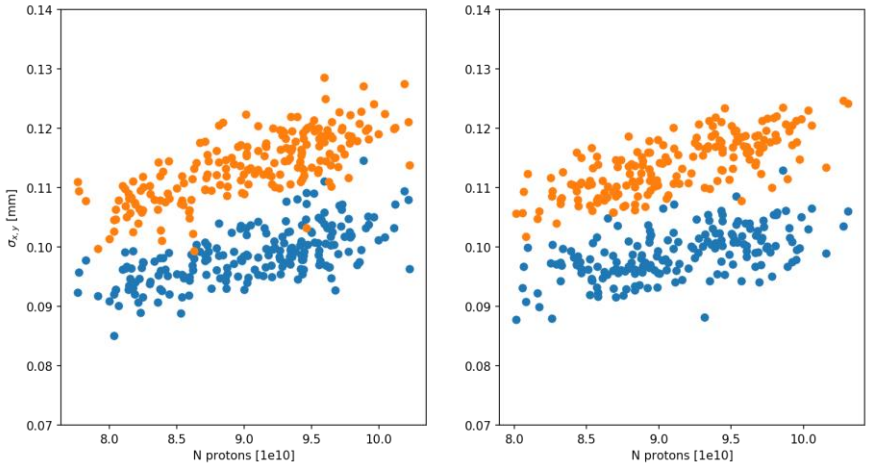


x – blue, y – orange

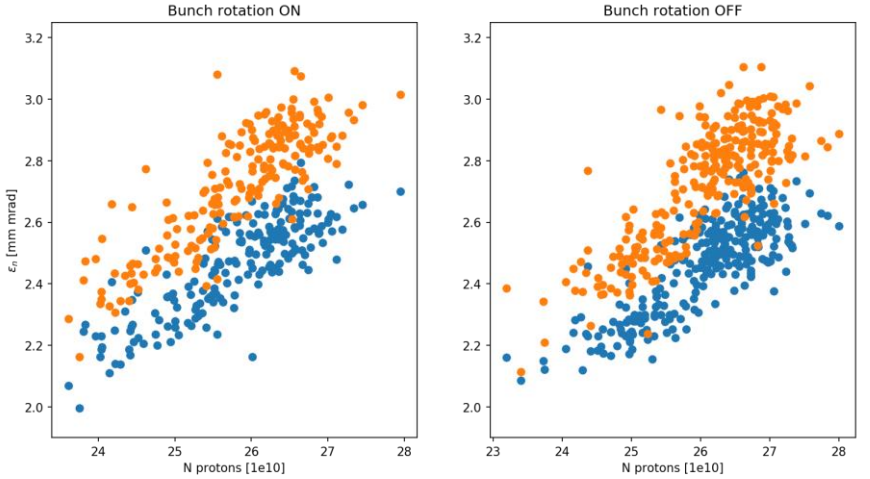
Beam sigma and emittance vs. population using data from IS2 core camera

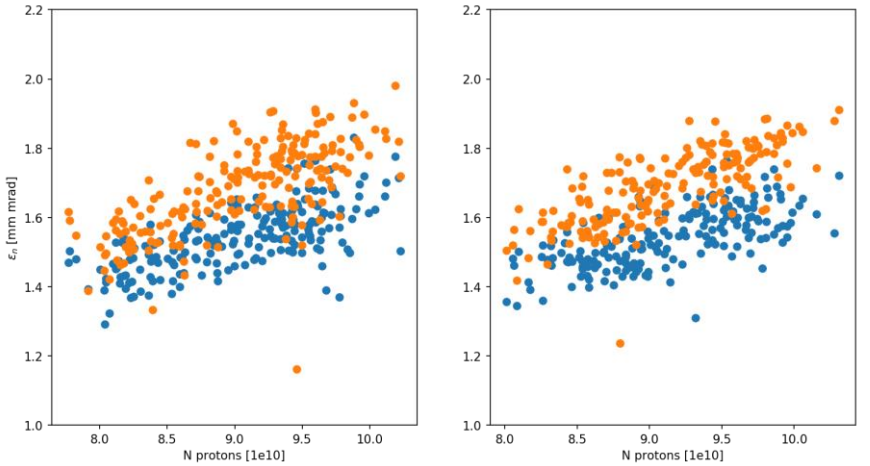
Sigma





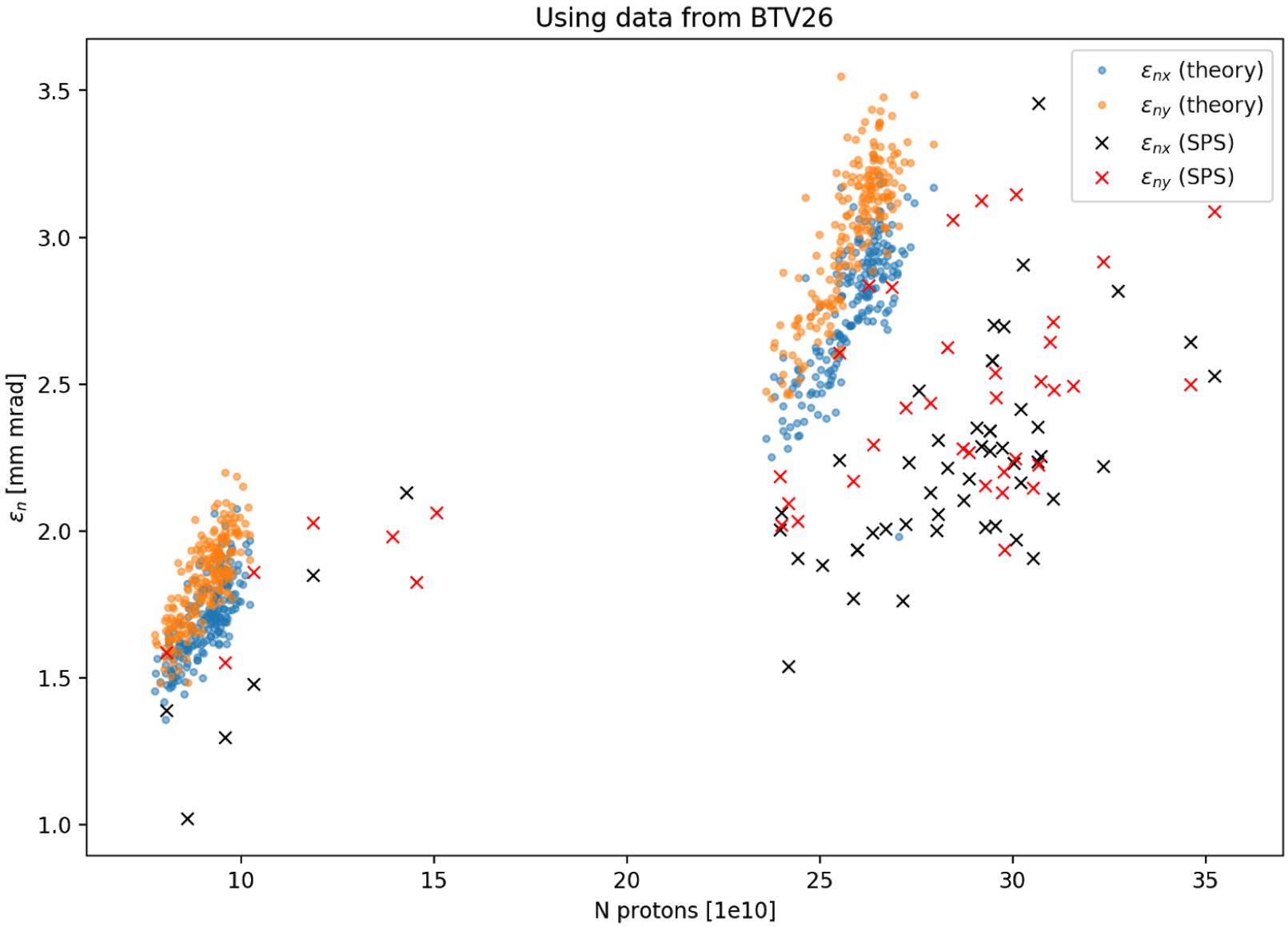
Emittance



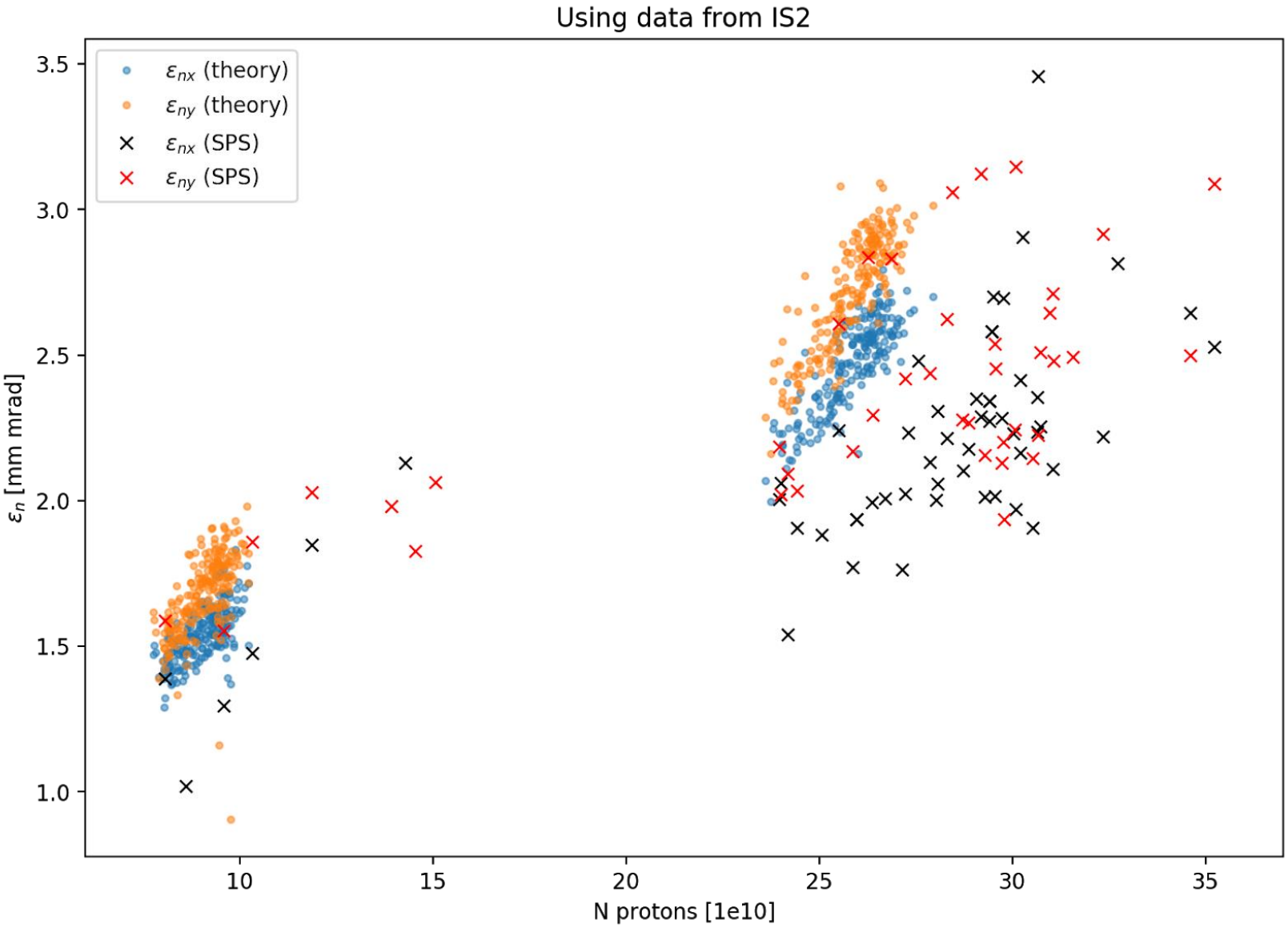


x – blue, y – orange

Comparison of calculated emittance with SPS measurements



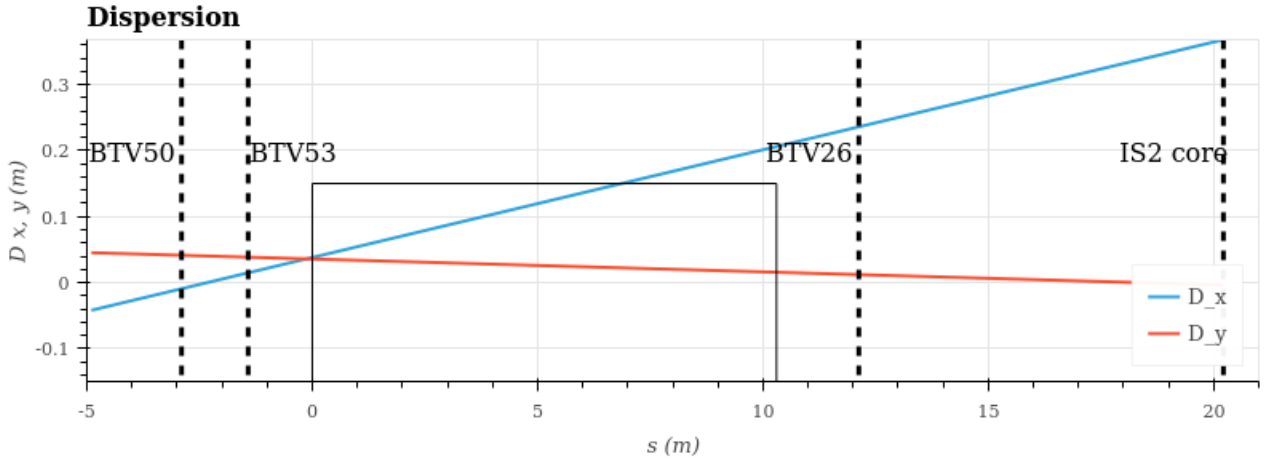
Comparison of calculated emittance with SPS measurements



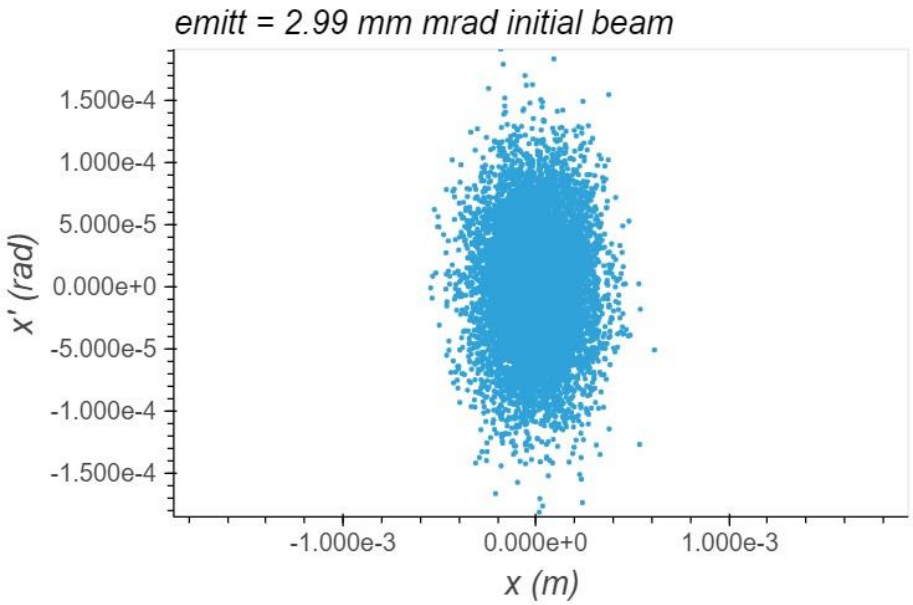
Can be emittance overestimated because of dispersion?

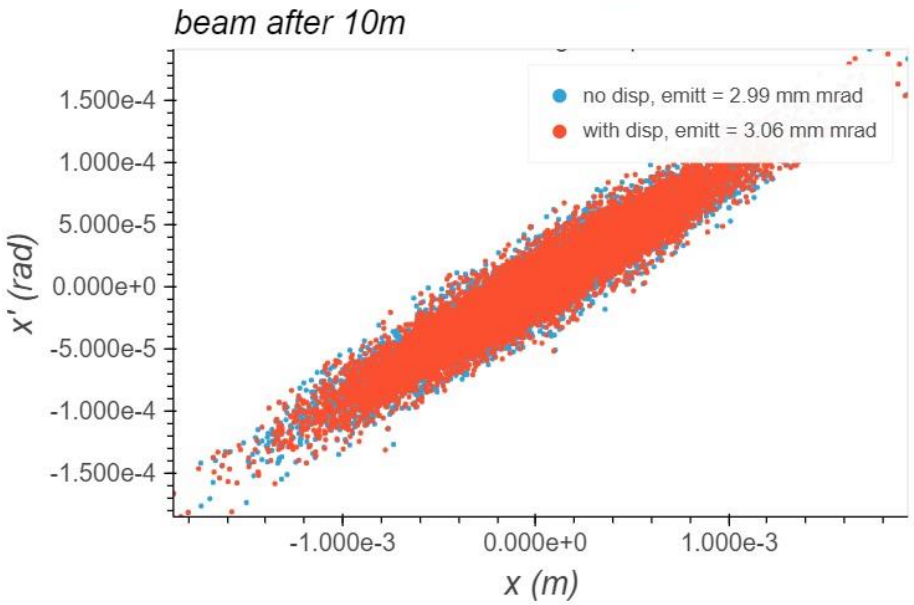
$$x = x_0 + x'_0 \cdot s + D(s) \cdot \frac{\Delta p}{p}$$
$$x' = x'_0 + D'(s) \cdot \frac{\Delta p}{p}$$

$$\frac{\Delta p}{p} \sim 6 \cdot 10^{-4}$$



Additional RMS angular spread = 2.34 %
Additional RMS size = 2.20 %





Summary

- Calculations show strong correlation between the bunch charge and beam size/emittance and have relatively low spread. We can use this fact in order to reduce the uncertainty of the input value of emittance for the simulations.

- Likely, at the plasma entrance the beam is smaller then we expected especially in low charge case.

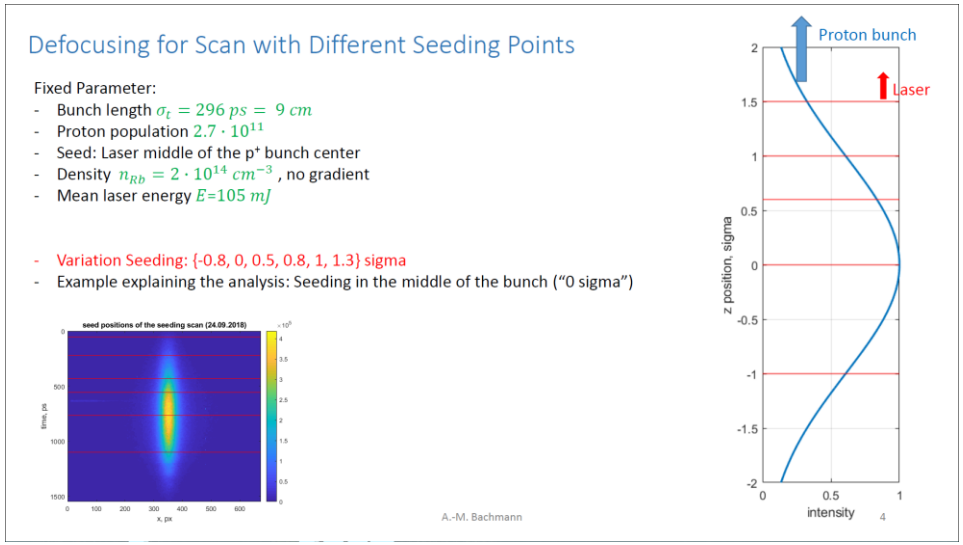
- There is no significant influence of the bunch rotation and dispersion on transverse beam dynamics.

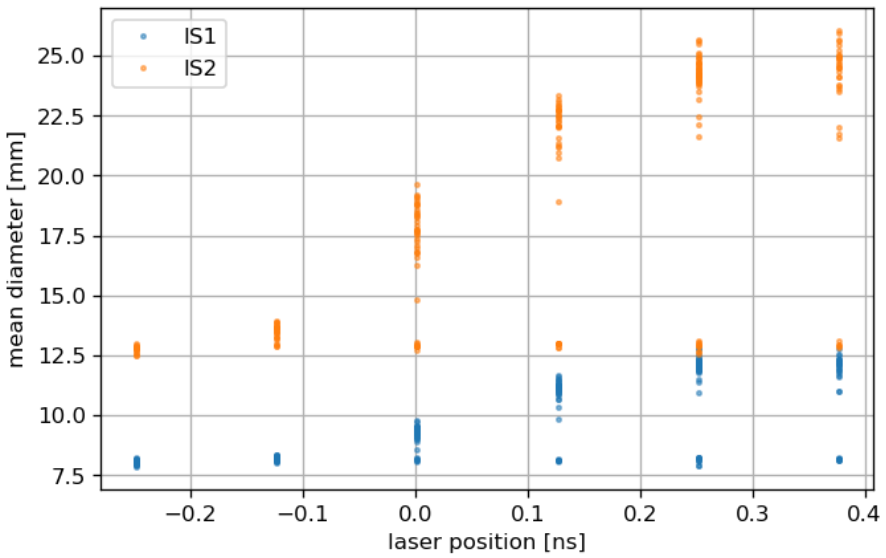
- Calculated emittance may be overestimated because of blurring of the beam image on BTVs and IS2 core camera.

- That also may be a reason why using the data from BTV26 and IS2 core camera gives a bit different results.

Next steps

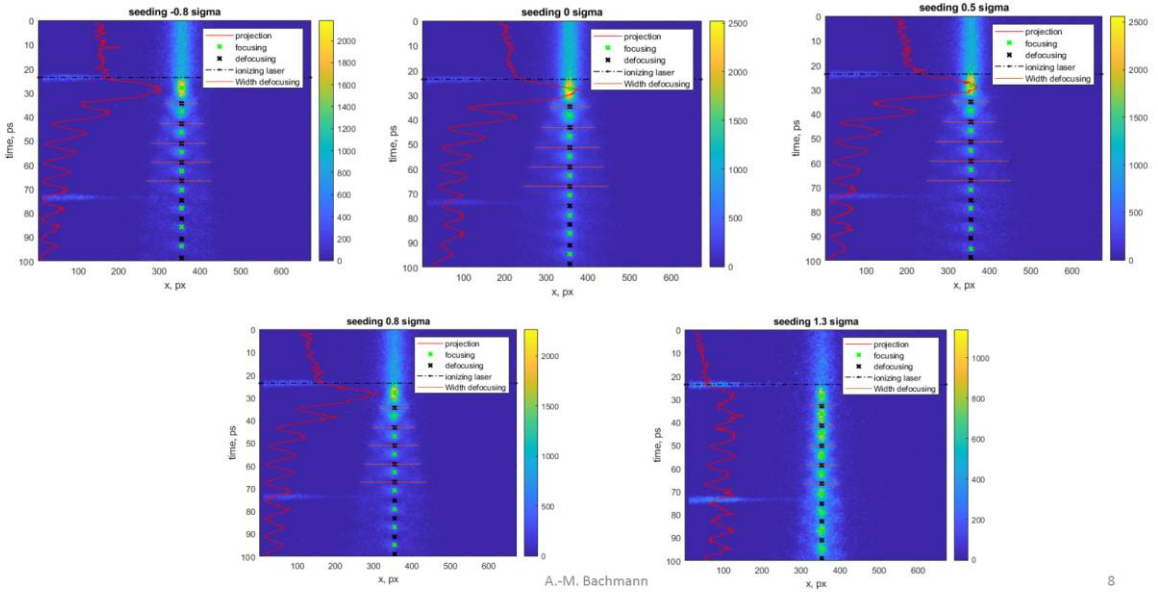
- Simulations for seeding scans





Thanks

Comparison of Determined Width with the Stitched Image



Scan from
September 24-25, 2018

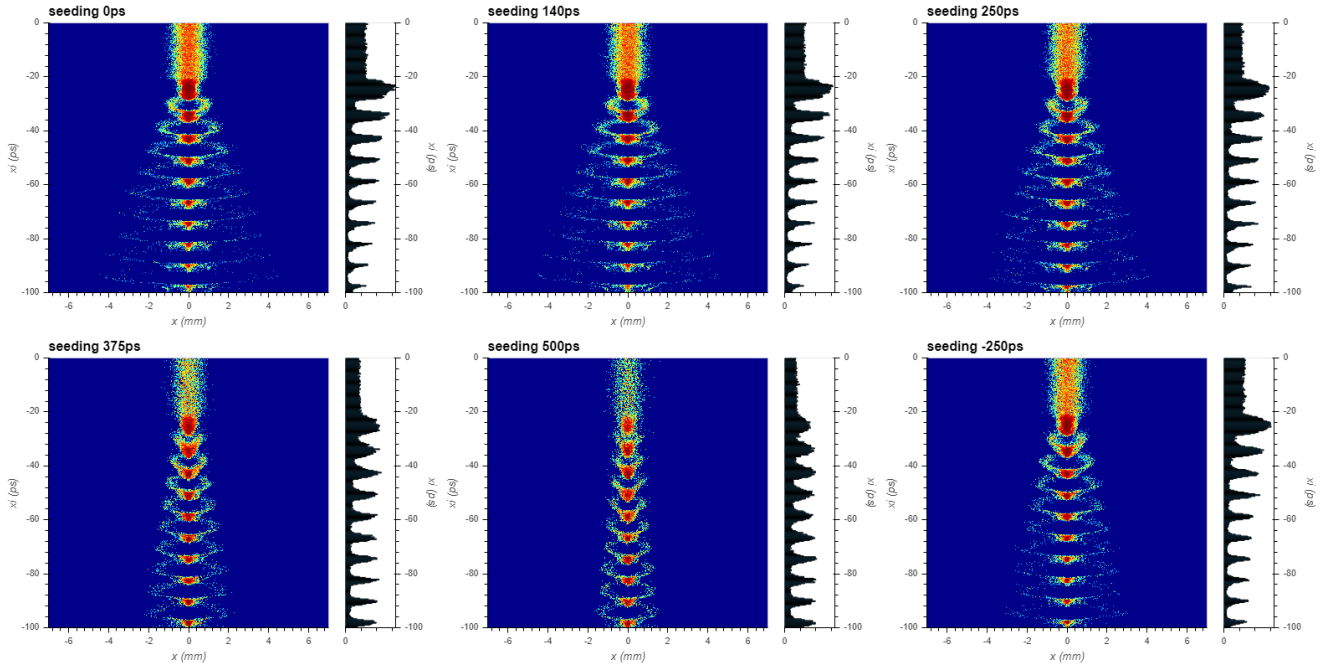
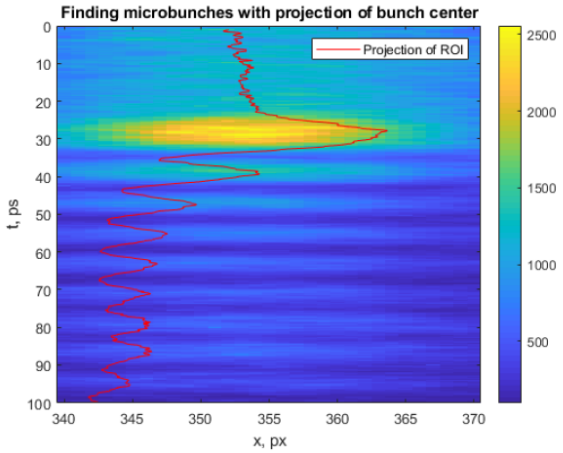
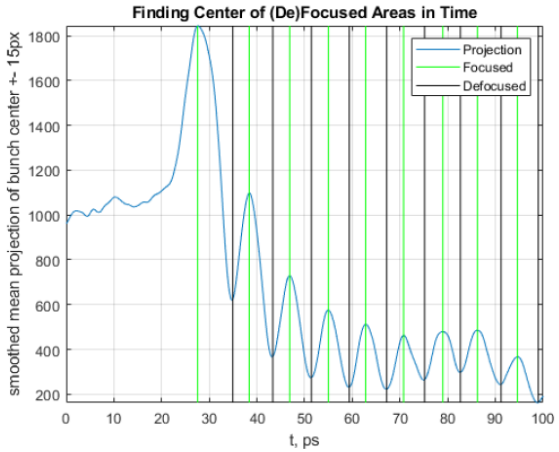


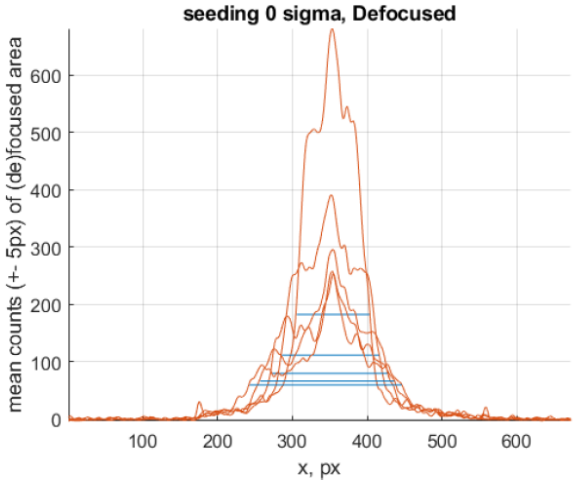
Image Processing



3. Finding the Micro Bunches by Calculating a Mean Projection of the center of the bunch (340<x<370)



4. Defining the Center of a Micro Bunch in Time: Search for the maxima and minima of the smoothed mean projection



5. Profile along x for the (de)focused areas (mean for determined center +-5 px in time) and determination of the width of RMS