Updates on proton and electron beam lines status

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05/10/2023

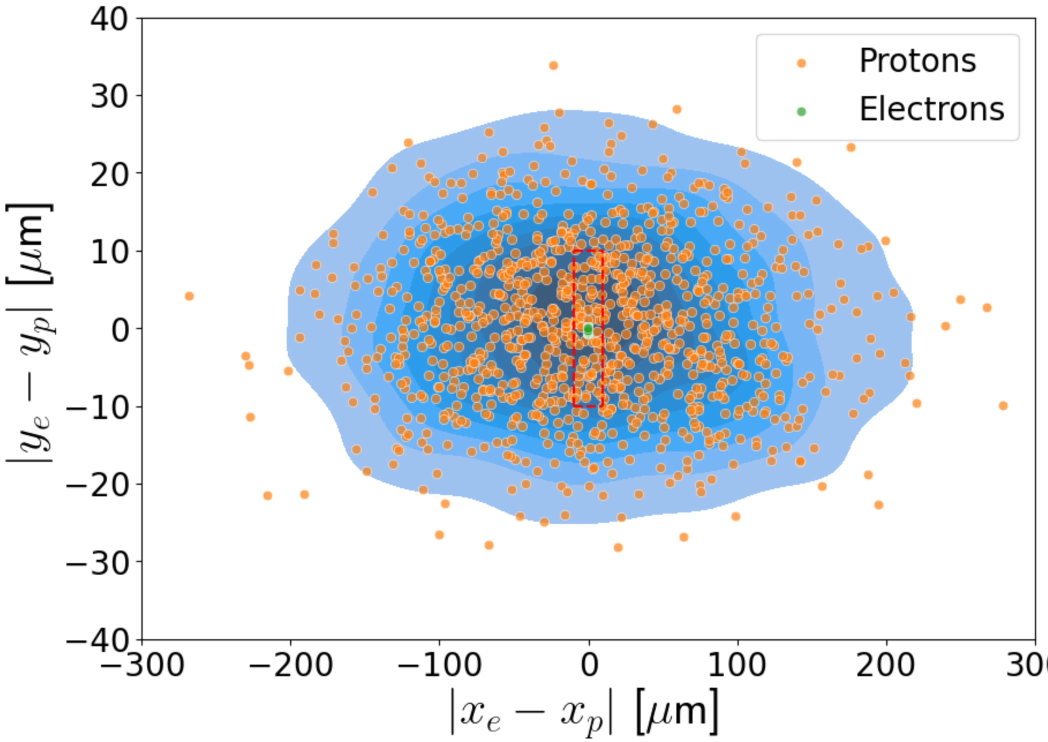
AWAKE Collaboration Meeting

Outline

- Proton beam jitter analysis
  - Power converters ripple
  - Beam jitter measurements
  - What about Run2c?
- Electron beam operations
  - Good news on tomography
  - New optics test
  - Orthogonal steering: last episode

Proton beam jitter

- Proton beam jitter represents the main limiting factor in achieving Run2c nominal parameters.
- It limits the number of good shots to few percent. An upgrade of the power converters is the best option to overcome this limitation and get to an increased number of good shots.



7% good shots

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- The two most critical intervention are related to RBI and MSE circuits, which would involve 350 kCHF investment.

- During a EPC intervention on RBI.410010 and MSE circuits, a problem was found and solved, resulting, in principle, in a reduction in current ripple of a factor 2/3.

- To assess the effect of the intervention two studies were performed:

  - Current ripple analysis in 2022 and 2023 for comparison
  - Beam jitter analysis in 2022 and 2023 to assess effect on proton beam

Power converters ripple

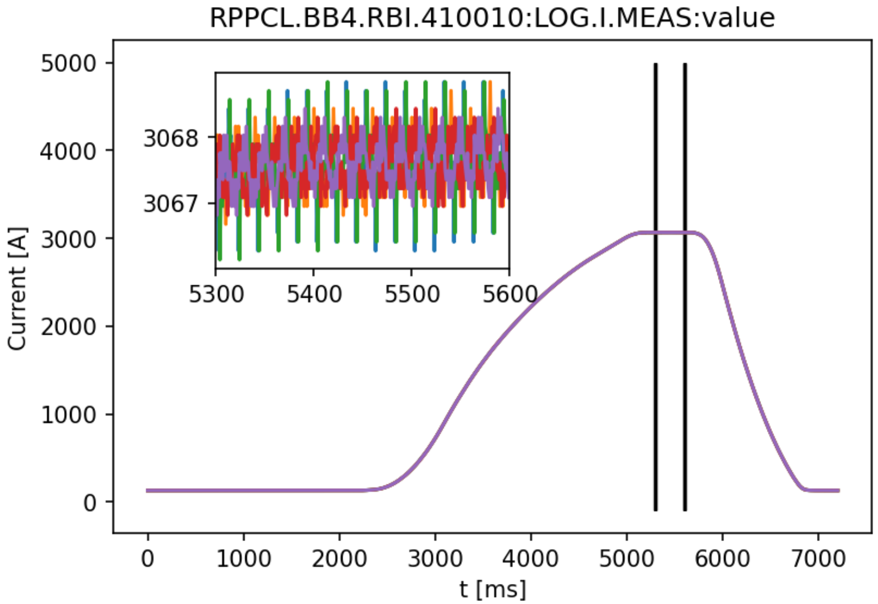
The extracted proton beam randomly falls in the flat-top. It is therefore subject to current oscillations.

For a good estimate of the ripple we consider two quantities

1) **σ(I, single shot) / μ(I, single shot)**: relative ripple within single shot

2) **σ(μ(I, single shot)) / μ (μ(I, single shot):** shot-to-shot differences

The amplitude of the ripple over all shots is given by the ripple in a single shot summed in quadrature with the shot-to-shot difference in mean current.



2022 v 2023: any differences?

- According to the analysis based on Timber data, there were not any major changes in PC ripple.

Dipoles

Timber name	Madx name	Ripple 2022 (ppm, norm to mean)	Ripple 2023 (ppm, norm to mean)
MSE.4183	-	140.53	118.85
RBI.81607	MBG	47.02	75.32
RBI.410010	MBSG	158.86	144.85
RBIH.400107	MBHC	130.37	124.6
RBIH.412133	B190	36.7	42.3

- Maybe readings from Timber are spoiled or incorrect. Can we see something on the beam?

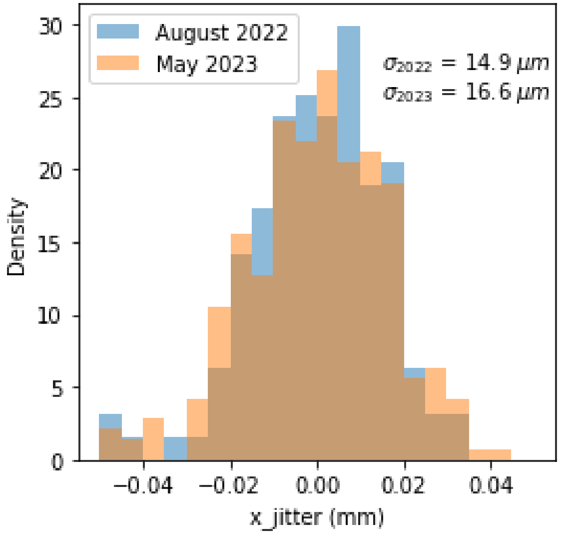
Measurements and analysis

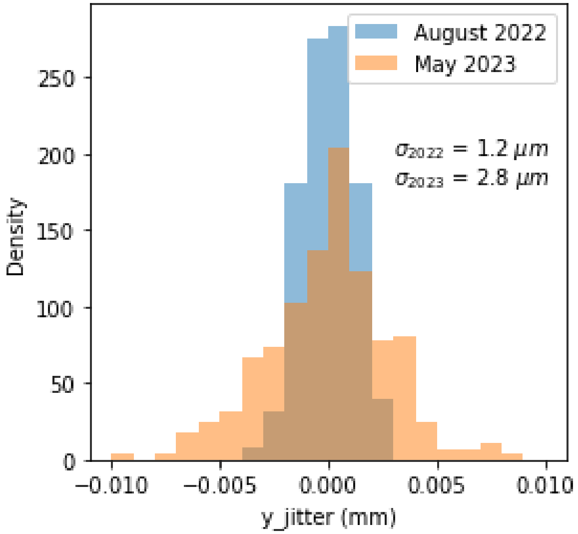
- Main purpose was to assess effect of intervention on TT41 power converters
- Compared data from August 2022 and May 2023 runs

Method:

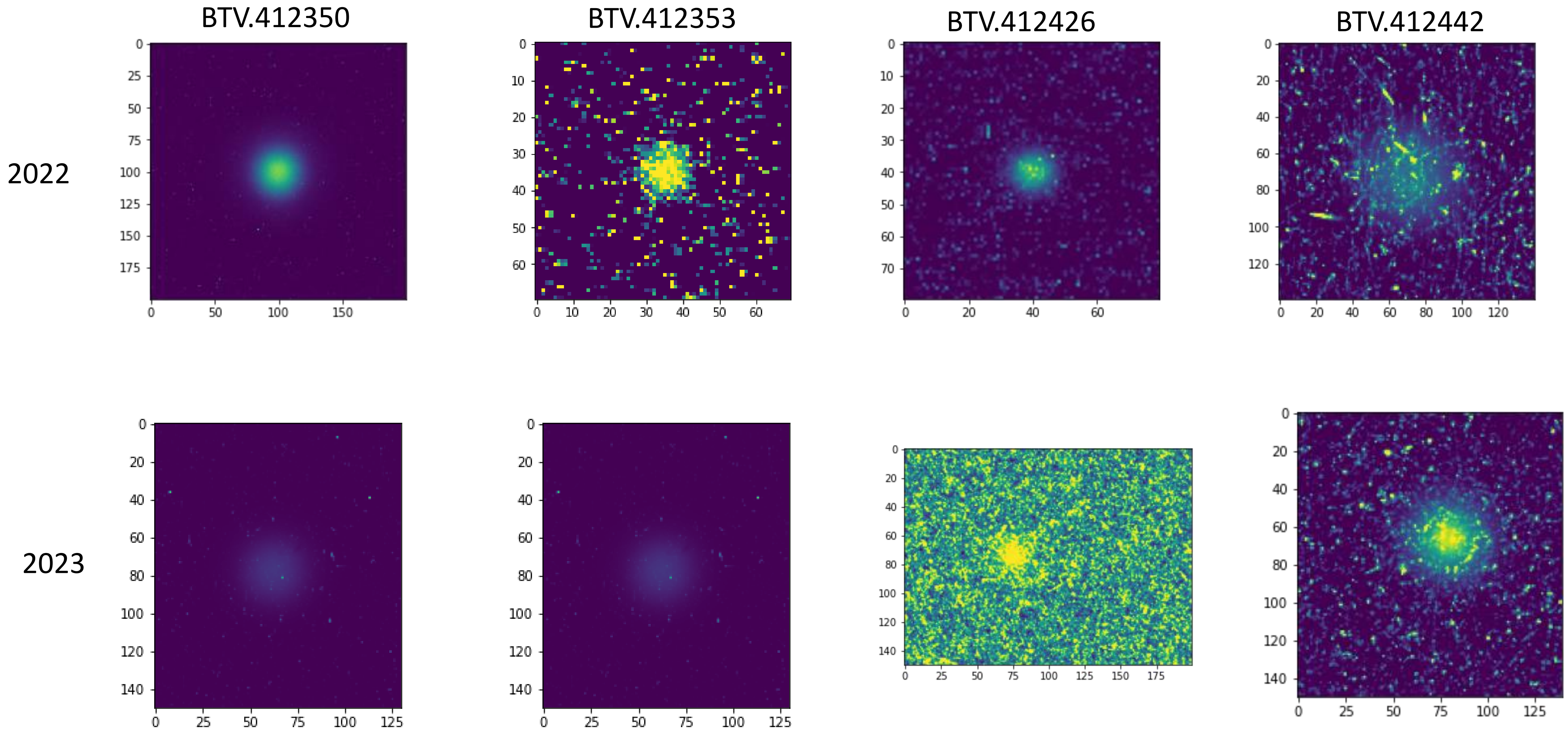
- Cut Roi form images
- Extract projections
- Fit gaussian

- Calculate RMS of beam centers
  ➔ Overall beam jitter
- Calculate mean drift
  ➔ Jitter relative to mean
- Account for uncertainty of fit (more details in backup slides)
- NOISE HAS BIG IMPACT ON FIT QUALITY AND JITTER





Extending to all BTVs



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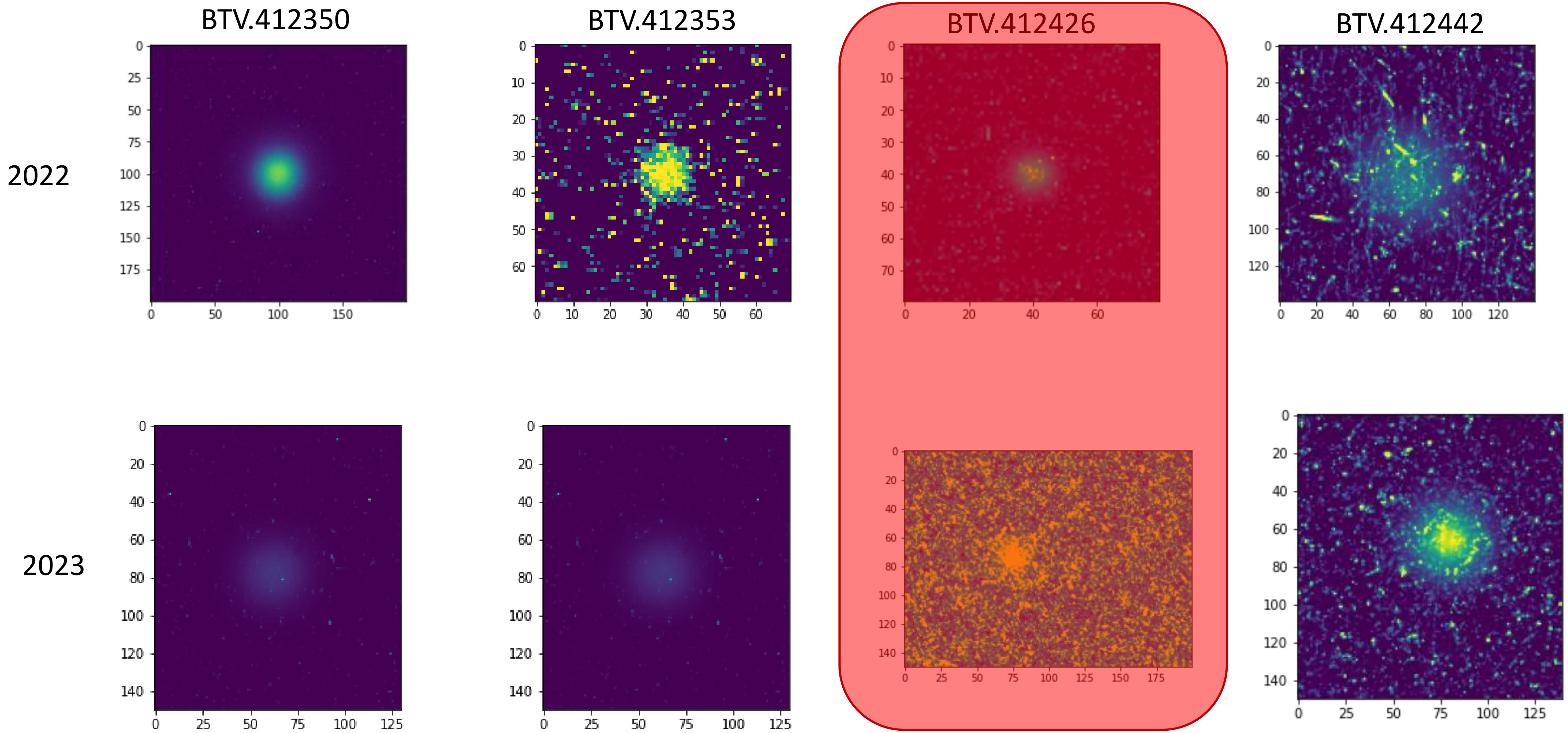

Extending to all BTVs

	2022				2023			
	$\sigma_x\ (mm)$	$\sigma_y\ (mm)$	**Ratio to size x**	**Ratio to size y**	$\sigma_x\ (mm)$	$\sigma_y\ (mm)$	**Ratio to size x**	**Ratio to size y**
BTV.412350	0.020	0.0015	0.113	0.008	0.023	0.0022	0.14	0.012
BTV.412353	0.020	0.0023	0.194	0.09	0.025	0.0014	0.15	0.014
BTV.423426								
BTV.423442	0.079	0.062	0.1	0.08	0.04	0.038	0.1	0.08

- Beam jitter linearly increases with β (and therefore with beam size).
- Ratio between jitter and beam size is introduced to compare measurements at different screens.

Can we simulate this process?

To simulate the process in MADx

- Use measured ripples as input for simulations
- Assume the ripple are distributed as truncated gaussians
- Run 1000 samples and calculate ratio between jitter and beam size
- The ratios are highly comparable
- THIS SIMULATIONS CAN BE USED TO ESTIMATE THE JITTER AT WAIST FOR RUN2C

	Simulations		Measurements	
	Ratio to size x	Ratio to size y	Ratio to size x	Ratio to size y
BTV.412350	0.17	0.02	0.113	0.008
BTV.412353	0.19	0.02	0.194	0.09
BTV.423426				
BTV.423442	0.19	0.02	0.1	0.08

	Ratio to size x	Ratio to size y	Ratio to size x	Ratio to size y
P beam waist	0.21	0.02	0.127	0.017

For 200 um beam

$\sigma_{x,waist} = 24\mu m$

$\sigma_{y,waist} = 4\ \mu m$

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Input for simulations are adjusted to fit the measured values! Many assumptions in the process

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So…what?

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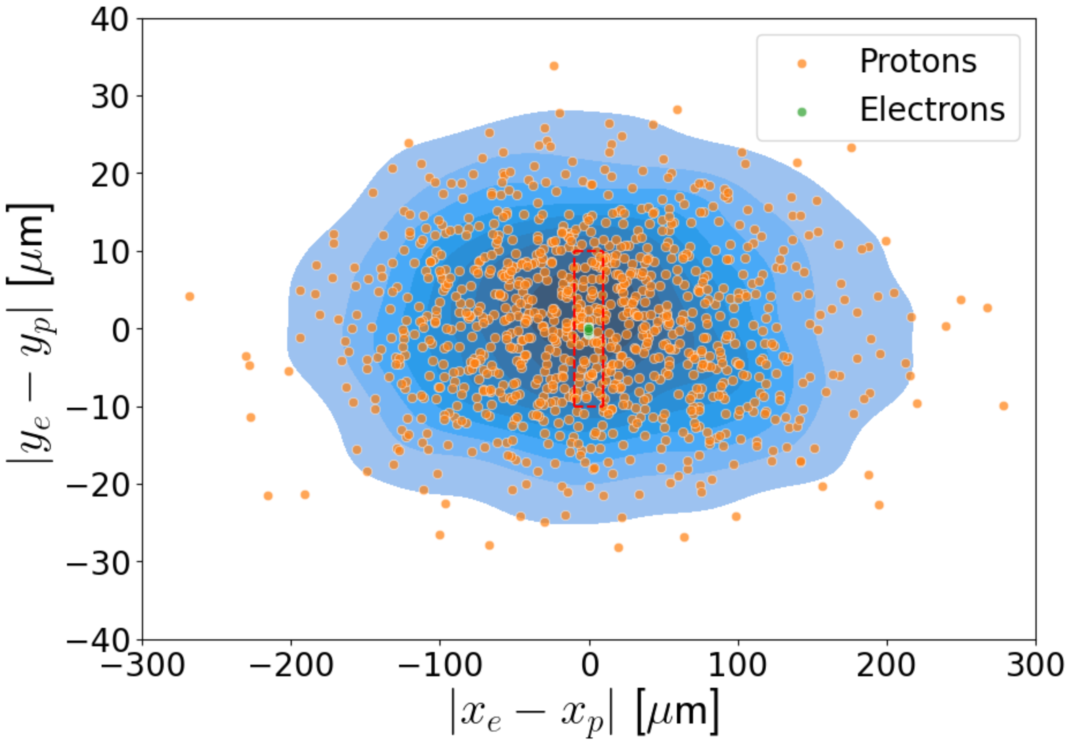
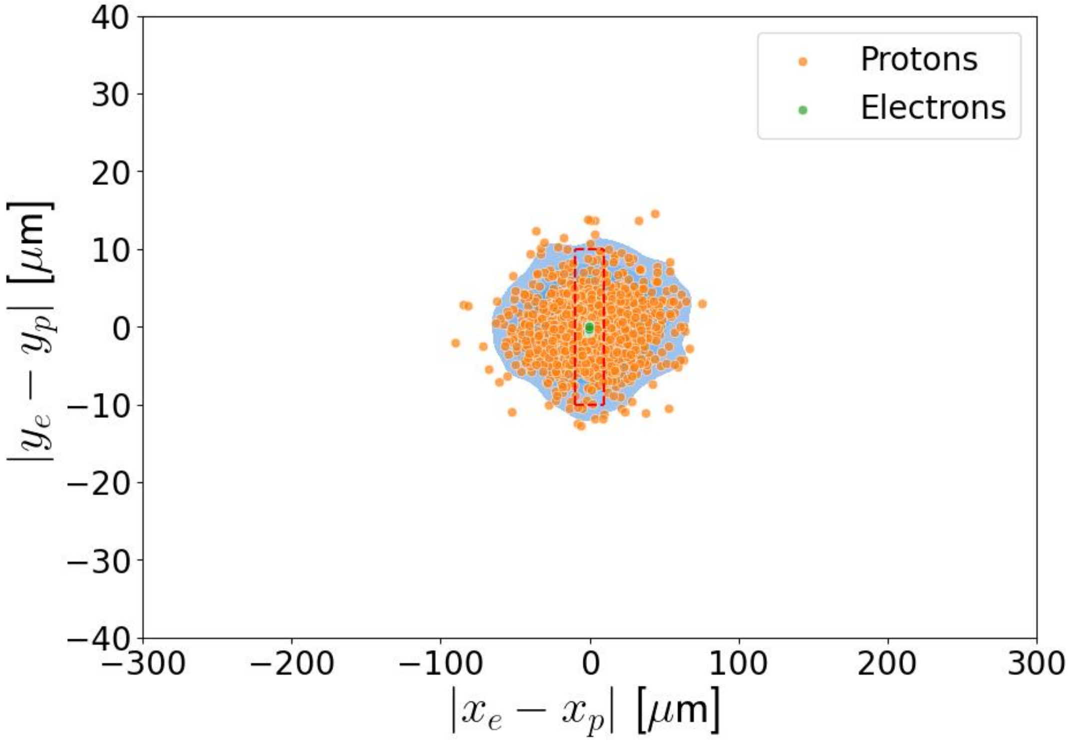
PRELIMINARY+UNDER INVESTIGATION



7% good shots

Data from https://arxiv.org/pdf/2109.12893.pdf



30% good shots

Conclusions of proton jitter

- Both power converters ripple analysis and beam measurements show no improvement between 2022 and 2023
- Simulations behave in same way as measurements providing ratios in the same order of magnitude.
- They can be used to estimate the beam jitter at the beam focus for Run2c.
- Estimated jitter fir Run2c configuration results in ~30% good shots.
- In order to validate the obtained number, further dedicated measurements should be taken.
- Also important to apply analysis method to 10.10.2018 data (used for Vasyl paper).

18 MeV electron beam operations

Introduction

- Electron run between 18 and 25 September.

- Preparing next Run and consolidate operational tools.
  - Take measurements for tomographic reconstruction benchmarking
  - Operational test on orthogonal steering

- Test optics and measure magnetic field for off center injection studies
  - Measure earth magnetic field using three screens
  - Test new optics at different focal points

- Propagation tests
  - Propagate electrons trough plasma cell
  - Check effect of copper plasma heaters on beam position
  - Propagate to spectrometer

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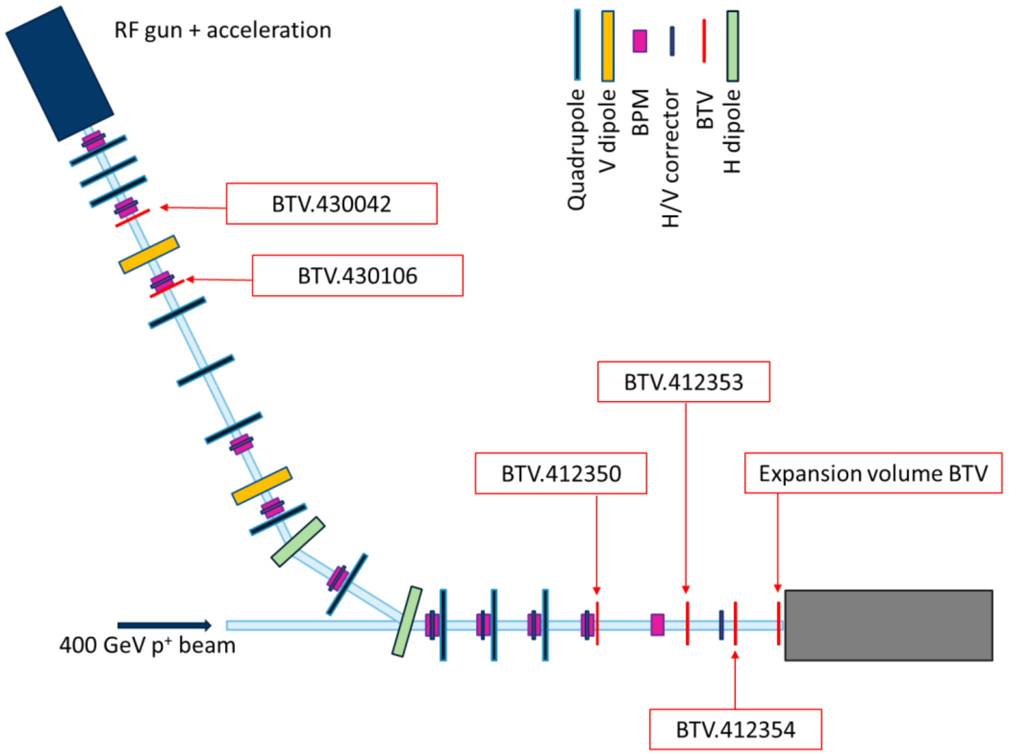
Tomographic reconstruction

To test the validity of tomographic reconstruction:

- Quad scan at BTV.430042 and tomography
- Measure beam distribution at BTVs along the line
- Track reconstructed beam using MADx
- Compare results



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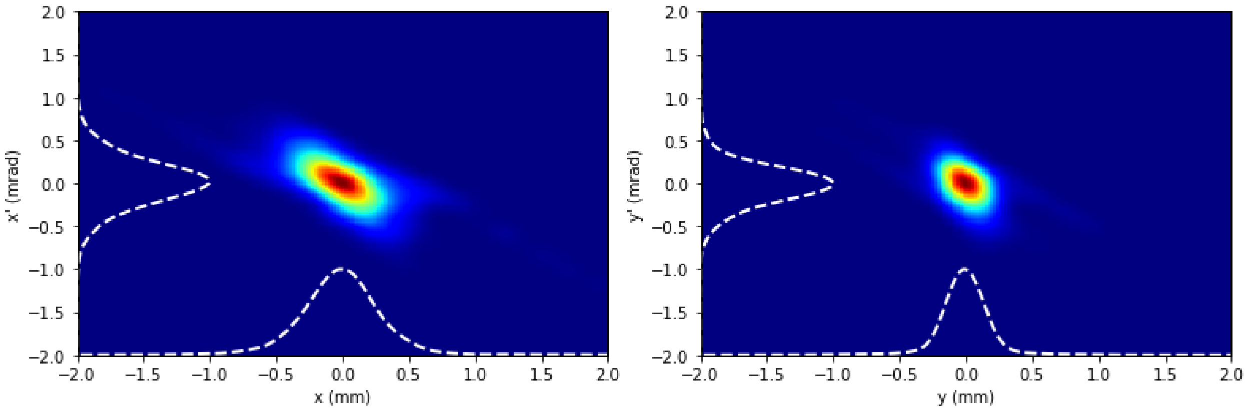

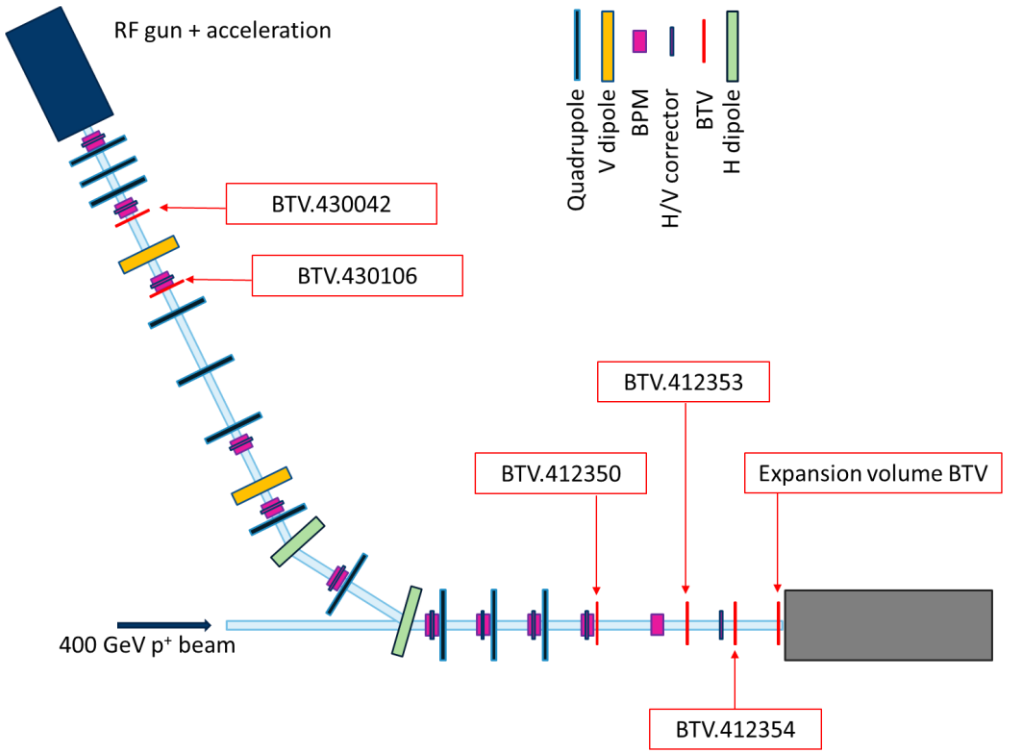

	x	y
$\epsilon_{,norm}\ (mm\ mrad)$	2.51	1.35
$\beta\ (mm/mrad)$	1.19	1.49
$\alpha\ (mm/mrad)$	0.94	0.72

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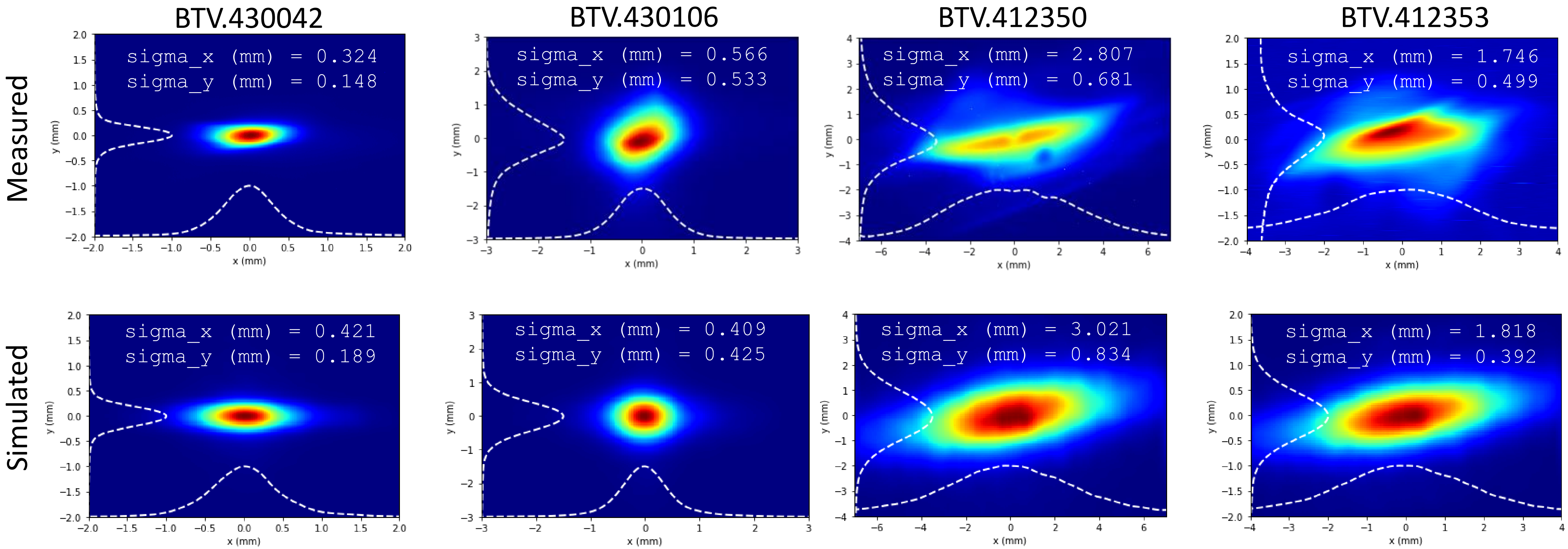

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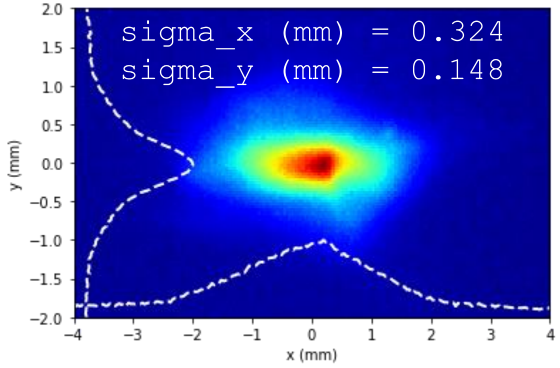
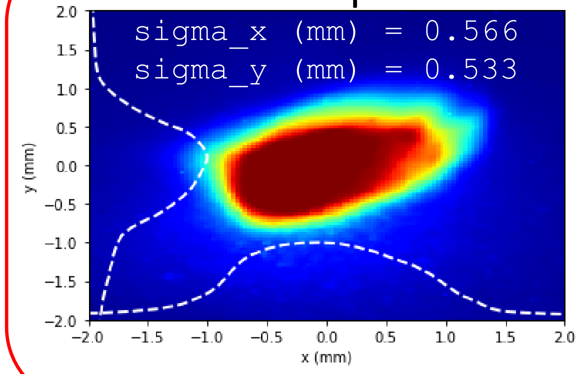
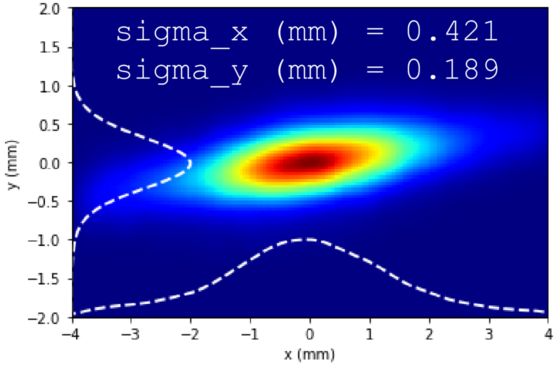
SATURATED

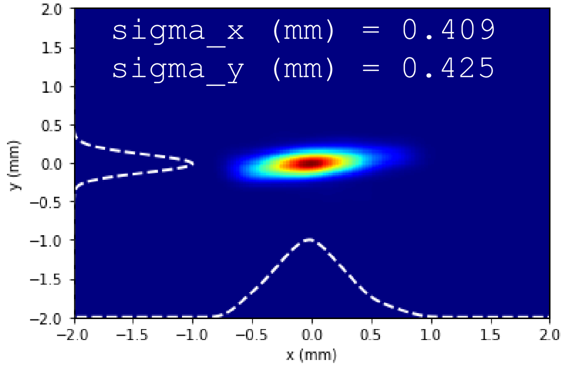
BTV.412354

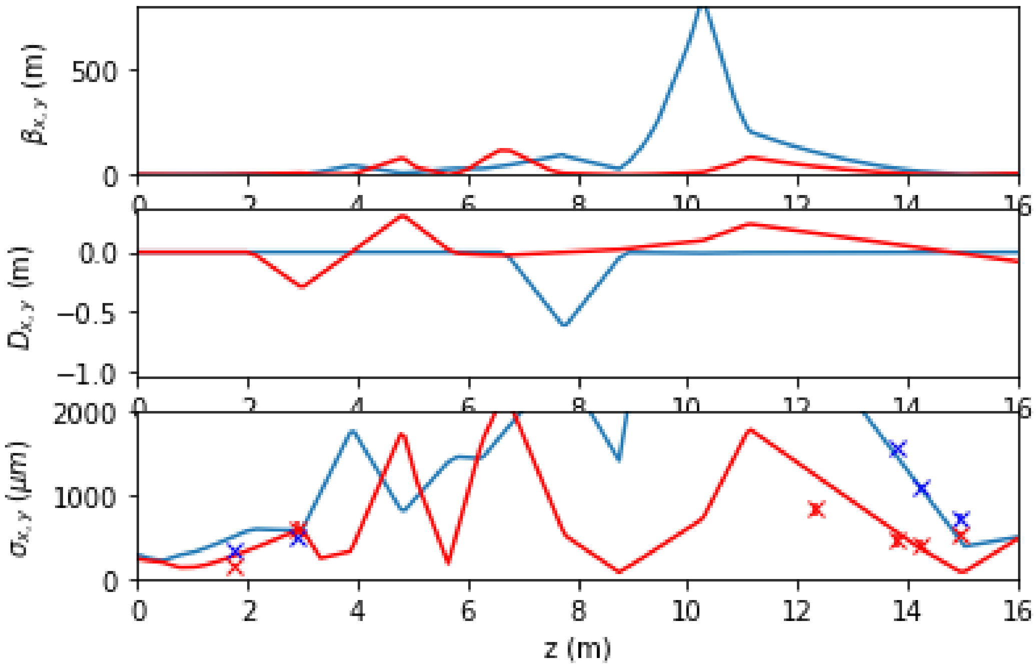
BTV.ExpVol











New optics for side injection

Side injection consist in injecting the electron beam at different points along the plasma cell to quanitify the accelerating gradient of the different sections of the plasma

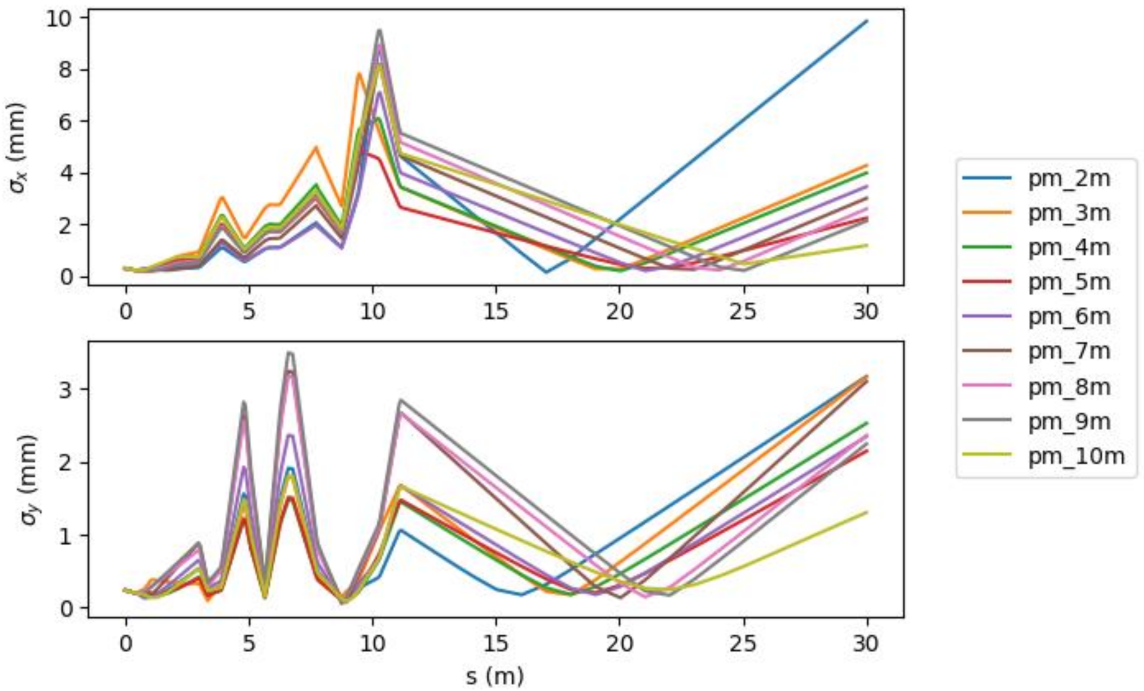
- New optics needed to shift the waist forward in the range between 1m and 10m downstream the iris
- Tomography results used as input for matching
- Matching performed using Genetic Algorithm

This matching procedure changes the first and the last triplet.

Changes in the first triplet have big effect on trajectory

More convenient to keep it at constant strengths.

New procedure using last 4 quads to be implemented



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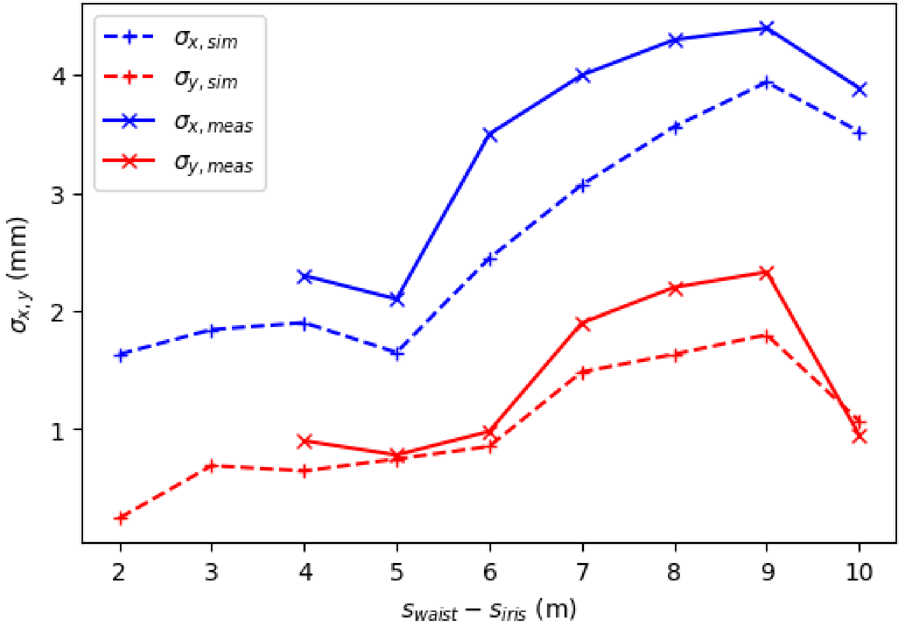
To verify the optics and test them, the beam size at BTV.ExpVol measured for each optics

Measurements compared with simulations

Very nice agreement!

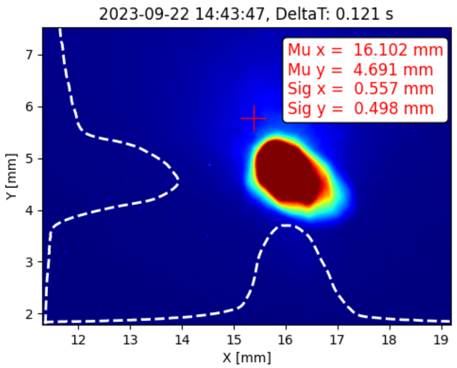


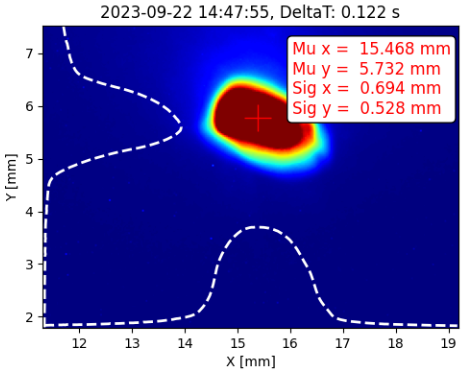
Orthogonal steering: last episode

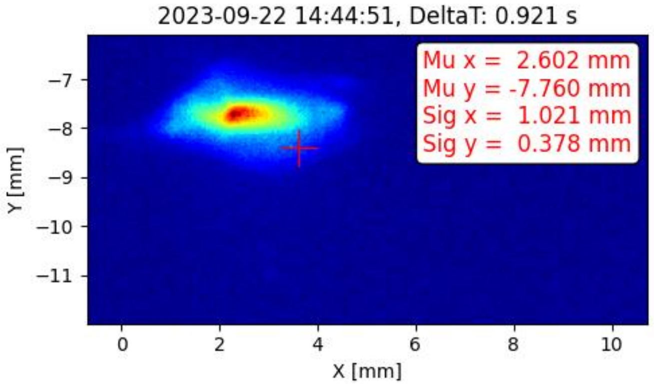
- Solution to orthogonal steering issue was discussed in last CM (slides here)
- The last electron run was the perfect opportunity to test the tool operationally and debug the last details

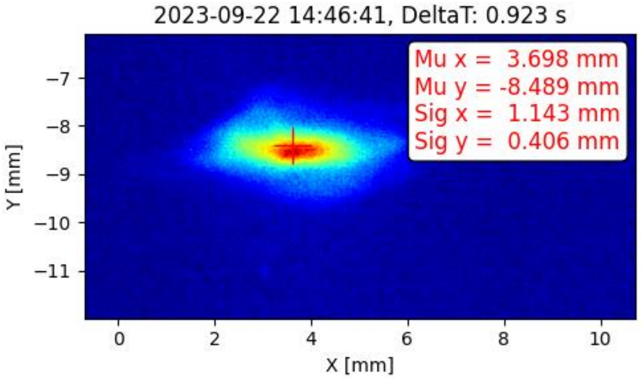
The main results are:

- **Precision**: Orthogonal steering now allows to move to the proton trajectory in a single shot with a precision comparable with central position jitter









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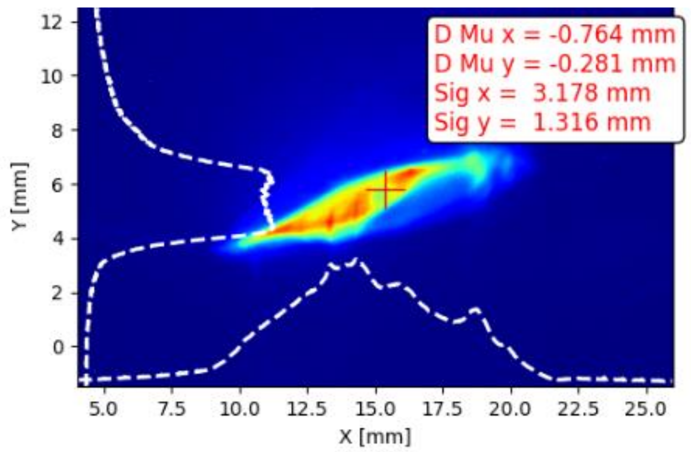
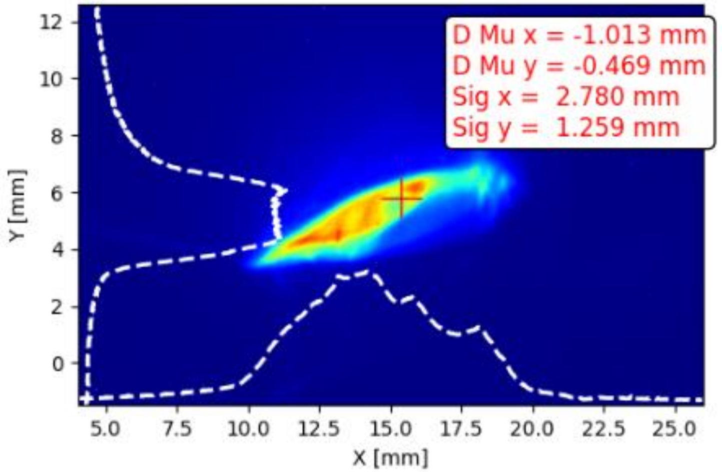
- **Reproducibility:** It can be used ‘blindly’, without checking the screens every time a movement is performed

Before scan



After grid scan (20 moves)



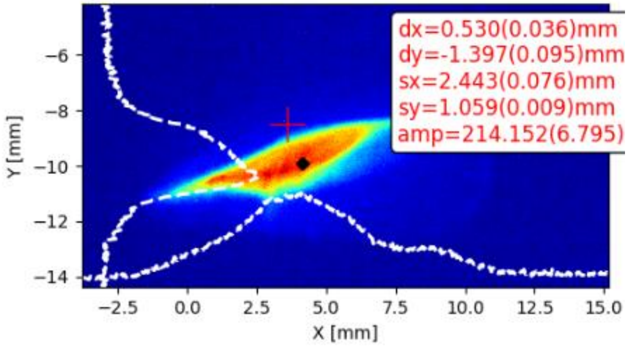
* Single shot measurement – large jitter!

Orthogonal steering: propagation

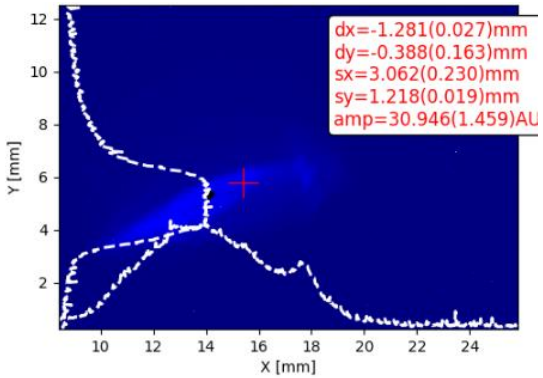
- Orthogonal steering tool allowed to perform an angular scan to find the propagated beam at BTV.412426
- Used new optics to have focus further in plasma cell
- Change position at BTV.412354 and keep it fix at BTV.ExpVol

The scan allowed to find the propagated beam and to optimize the position for maximum transmission…

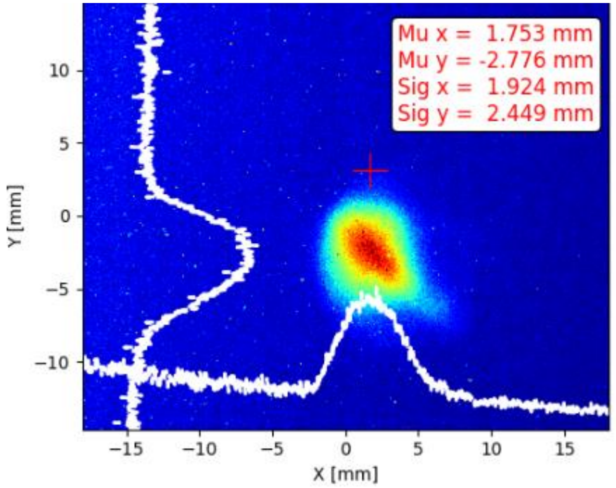
BTV.412354



BTV.ExpVol



BTV.412426



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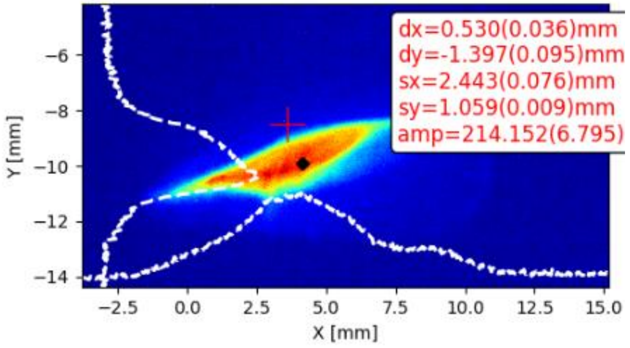
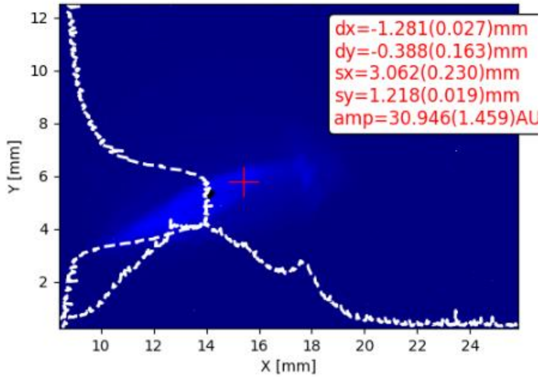
The scan allowed to find the propagated beam and to optimize the position for maximum transmission…

…and to **propagate it to the spectrometer**!

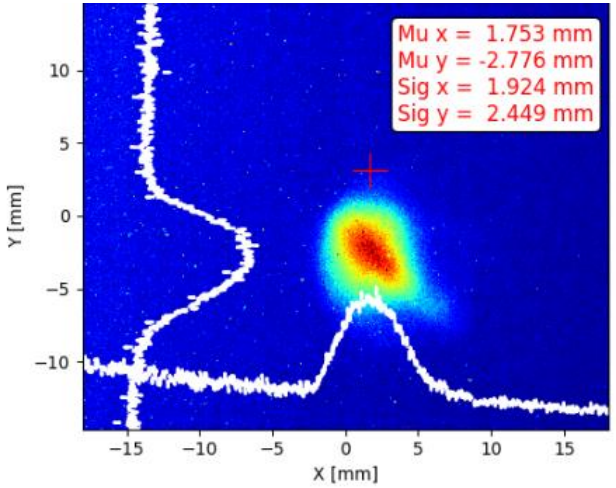
BTV.412354



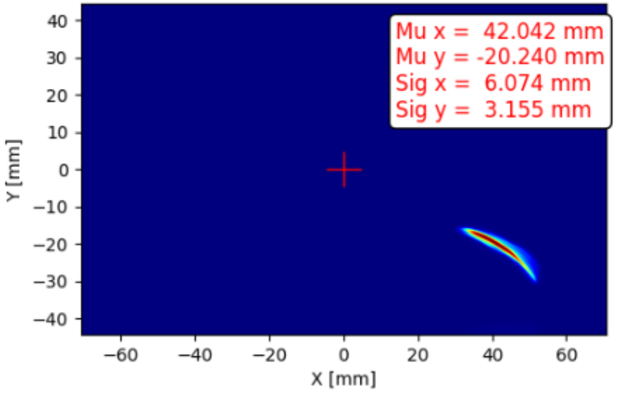
BTV.ExpVol



BTV.412426



Spectrometer



Conclusions

- Tomographic reconstruction proved to be a very useful tool to reproduce the beam development along the electron line
- This allowed to find agreement between simulations and measurements
- The agreement was further confirmed by the test of 9 new optics, which were validated trough measurements
- Orthogonal steering is now a fully operational tool and demonstrated its utility by allowing to propagate electron along the plasma cell without shielding. Not an easy exercise!

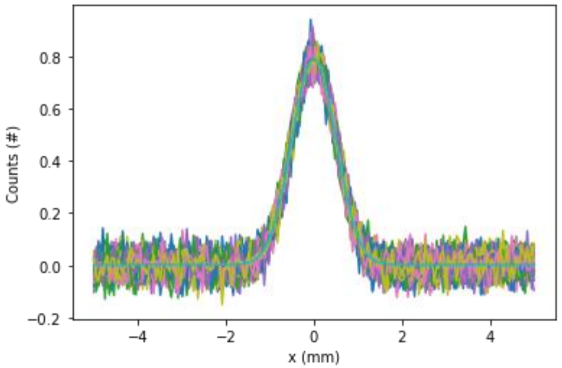
Measurements and analysis

How do we take noise into account?

- The higher the noise, the higher the uncertainty of fit parameters μ and σ.
- To take this into account, we include the uncertainty into the estimation of the beam jitter.

Example:

- Let's consider a gaussian beam with:
  - $\sigma = 0.5\ mm$ (beam size)
  - $\sigma_\mu = 0.01\ mm$ (jitter)
  - Noise = N(0, 0.05)
  - 50 shots



$$\sigma_{uncert.} = 0.0085$$
$$\sigma_{\mu,meas} = 0.013$$

$$\sigma_{jit} = \sqrt{\sigma_{\mu,meas}^2 - \sigma_{uncert}^2} = 0.01$$

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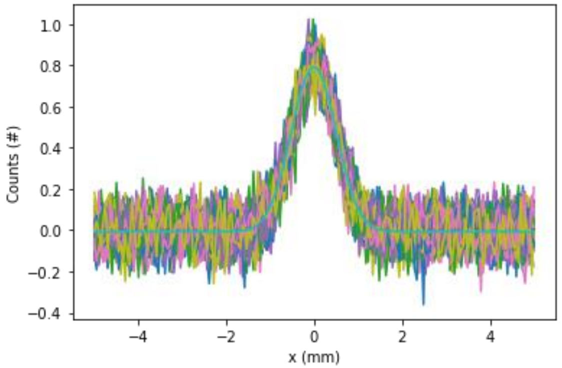
  - $\sigma_\mu = 0.01\ mm$ (jitter)
  - Noise = N(0, 0.1)
  - 50 shots



$$\sigma_{uncert.} = 0.016$$
$$\sigma_{\mu,meas} = 0.021$$

$$\sigma_{jit} = \sqrt{\sigma_{\mu,meas}^2 - \sigma_{uncert}^2} = 0.011$$

The estimate works fine, but…

For noise=0.05
$$\sigma_{jit} = 0.01 \pm 0.002$$

For noise=0.1
$$\sigma_{jit} = 0.01 \pm 0.007$$

Get worse with noise!

MSE considerations

- MSE is composed of 6 module of 2.237m each (magnetic length)
- The total kick to be provided is of 12 mrad
- Let's calculate the angular jitter resulting from the PC ripple

$$B_0 = \frac{p}{\rho_0 e} \qquad \frac{\Delta B}{B_0} = \frac{\rho_0}{\Delta\rho} \qquad \frac{\Delta B}{B_0} = \frac{\rho_0}{\Delta\rho} = \frac{\Delta\vartheta}{\vartheta_0} \qquad \Delta\vartheta = r_{pc}\vartheta_0$$

Angular jitter ($\Delta\vartheta$), PC ripple (ppm) (r_{pc}), Nominal kick (ϑ_0)

$$\vartheta_0 = 12\,mrad$$
$$r_{pc} = ?$$

https://accelconf.web.cern.ch/e00/PAPERS/MOP6B12.pdf

MSE ripple analysis – 2022 v 2023

Going back to our calculations

$$\Delta\vartheta = r_{pc}\vartheta_0$$

$$\vartheta_0 = 12\ mrad$$
$$r_{pc} = 150\ ppm$$

$$\Delta\vartheta = 1.8\ \mu rad$$

What is the effect of such kick jitter on the beam jitter?
Let’s have a look at the simulations

Simulations set up

- Simulations have two main goals:
  - Assess effect of MSE and PC ripples on jitter at waist for Run2b and Run2c
  - Benchmark the results with measurements on Run2b line

- Simulations run using measured jitters.

- We consider three scenarios for old and new line:
  - Run2b
    - Only MSE, no PC ripples
    - Only PC ripples, no MSE
    - Both MSE and PC ripples
  - Run2c
    - Only MSE, no PC ripples
    - Only PC ripples, no MSE
    - Both MSE and PC ripples