CBS experiment @ CTF2 (ARTI)

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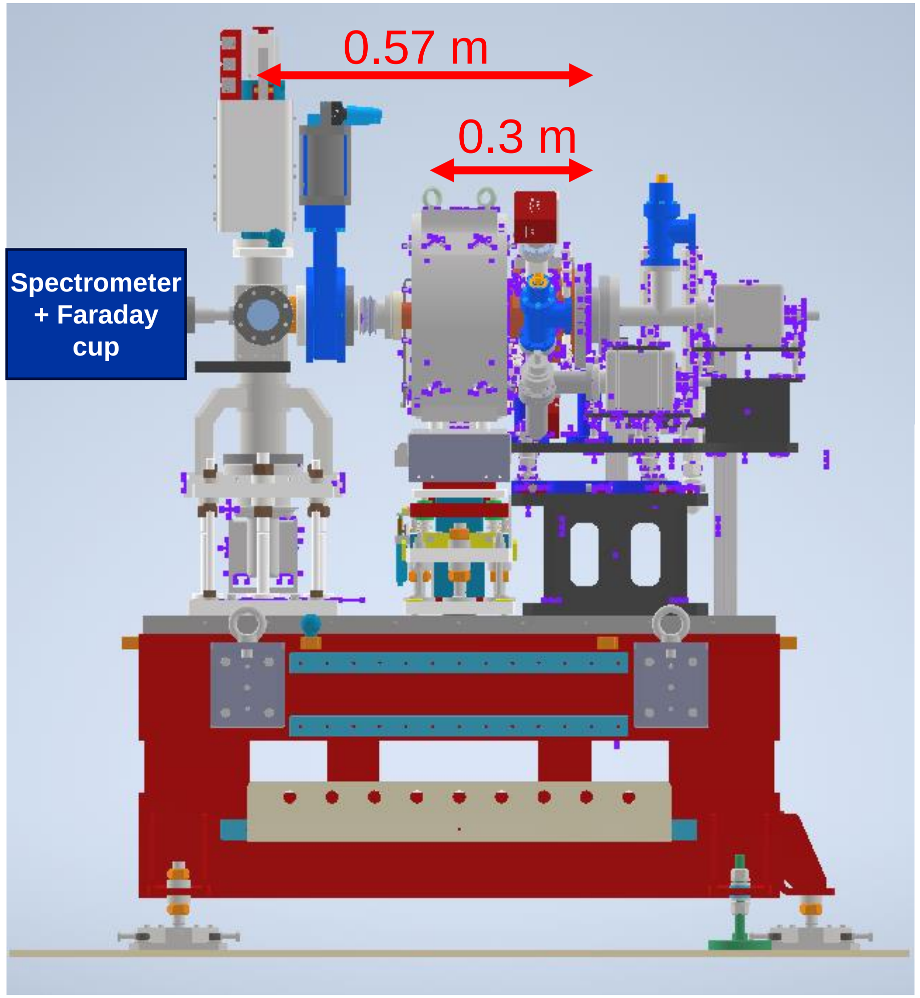
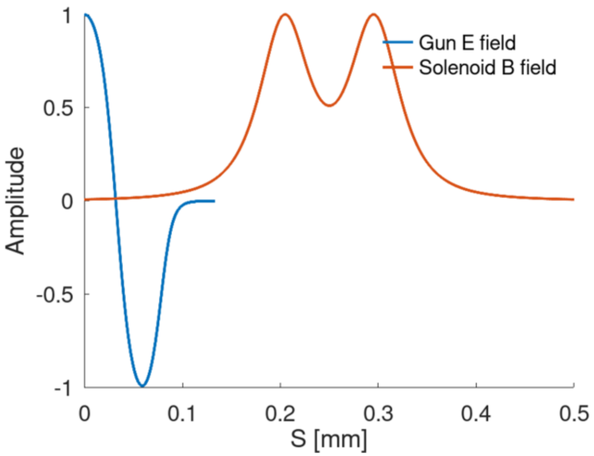
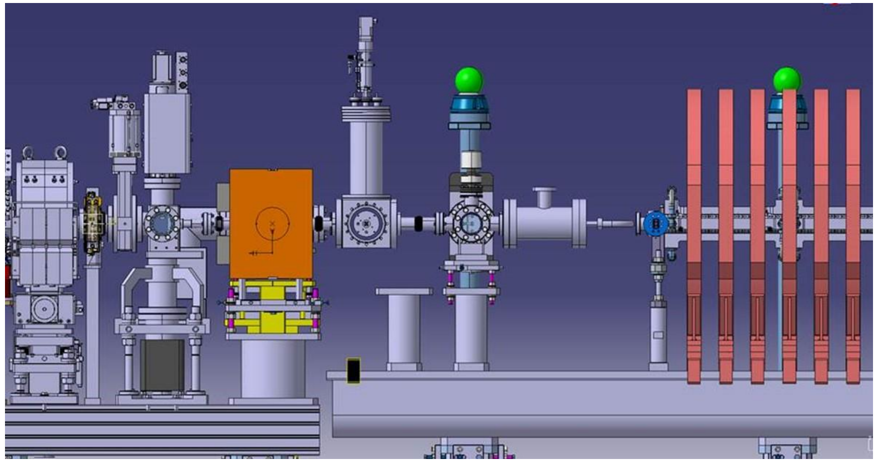
Thanks to: Steinar Stapnes, Richard Scrivens, Federico Roncarolo, Miguel Calderon, Stefano Mazzoni, Alice Michet, Wilfrid Farabolini.

Contents

The CTF2 gun

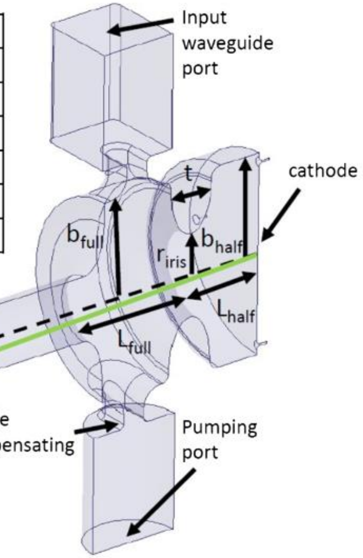






CLINXBT_0001

r_{iris}	18
t	20
b_{half}	43.63
b_{full}	43.18
r_{pipe}	14
L_{half}	33.74
L_{full}	53.04



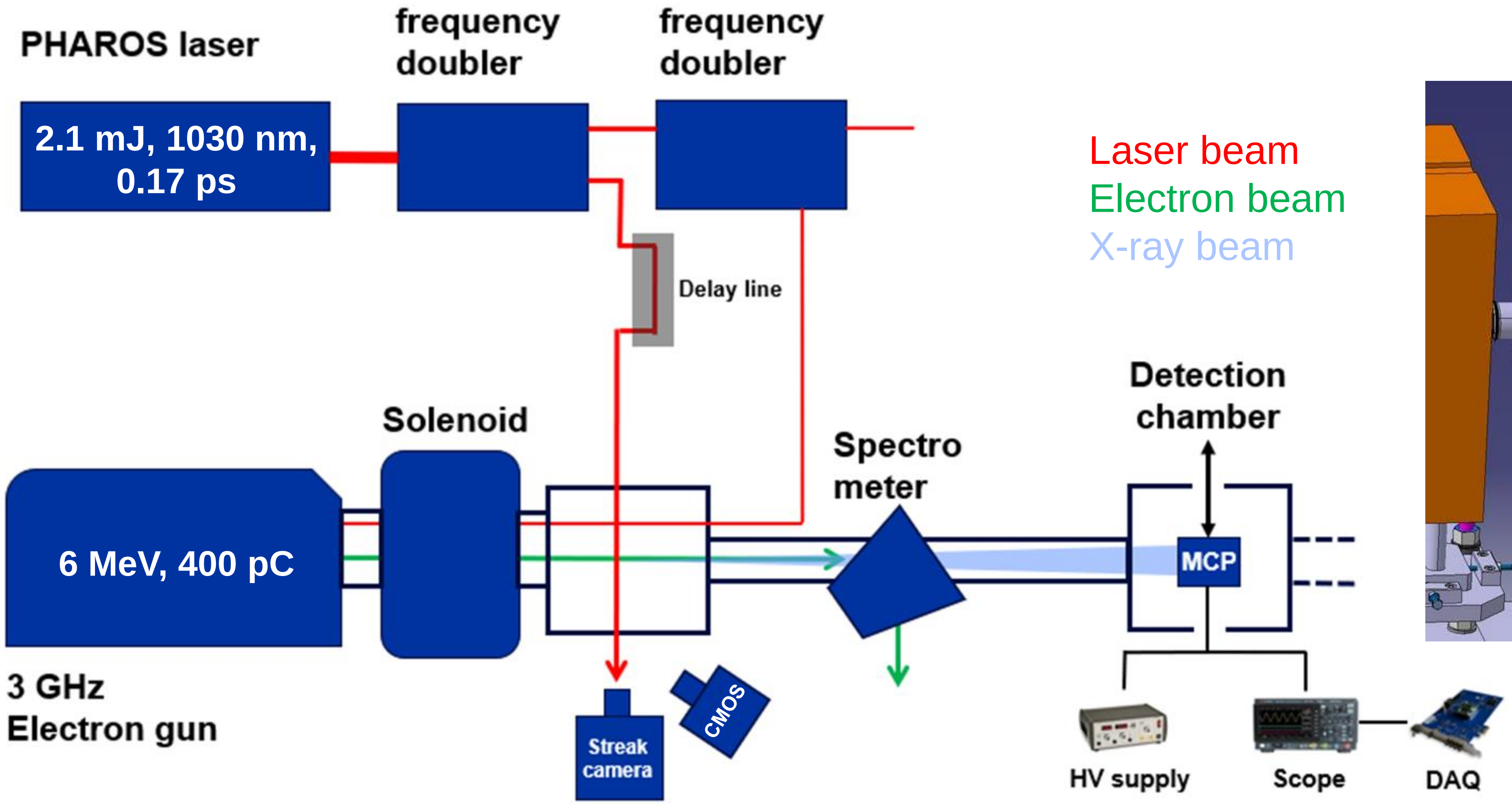
S-band standing wave 1.5 cell RF-gun intended for the new AWAKE injector.

Prototype constructed by INFN-Frascati and commissioned at CTF2.

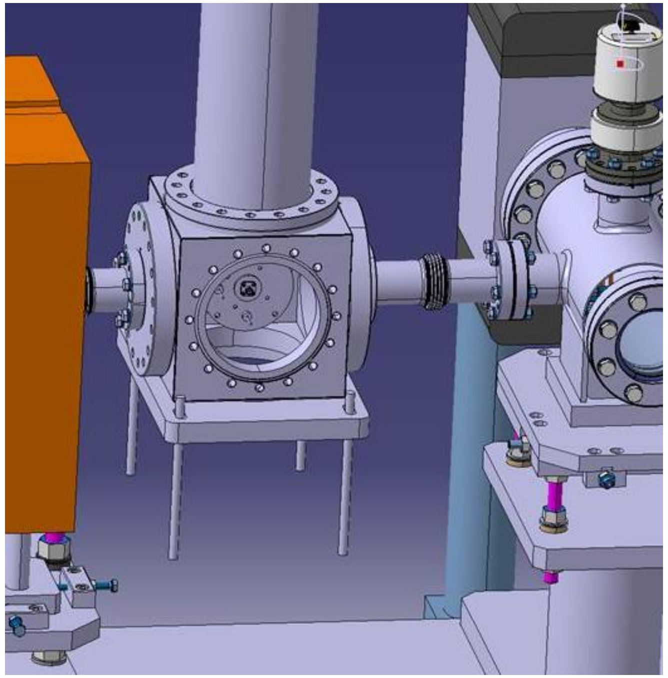
Fabricated with brazing free technology [1].

[1] D. Alesini, et al., PRAB, vol. 21, n. 11, November 2018

Experimental set-up



Laser beam
Electron beam
X-ray beam



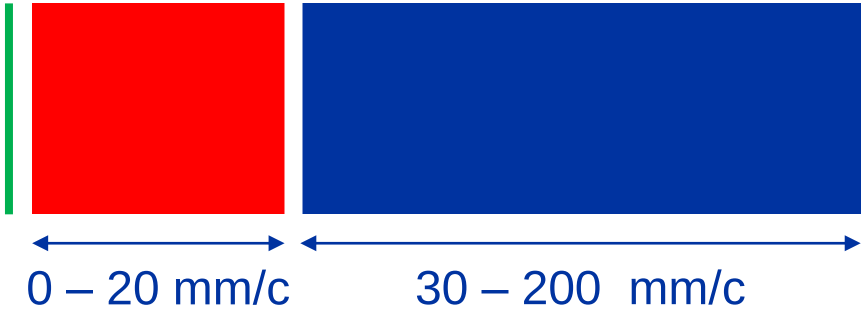
Experimental match with simulations

Simulations of CTF2 injector

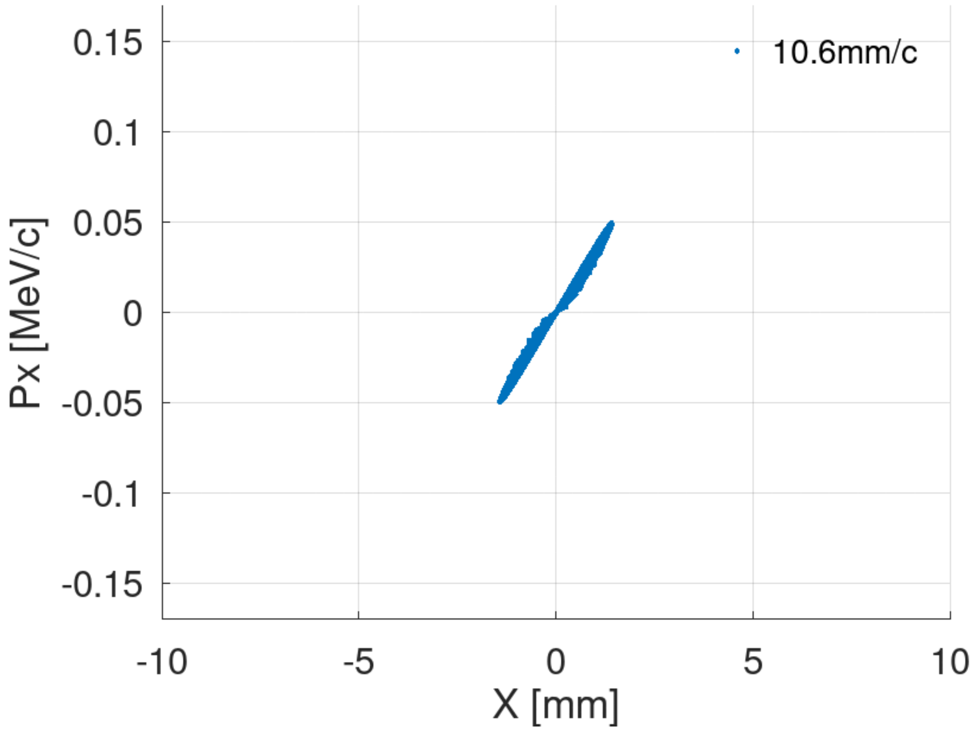
A model of the CTF2 gun was implemented in RF-Track.
The model comprised the cathode, gun, and solenoid.

Optimisation goals:

- **Maximise flux**
- **Minimise background**

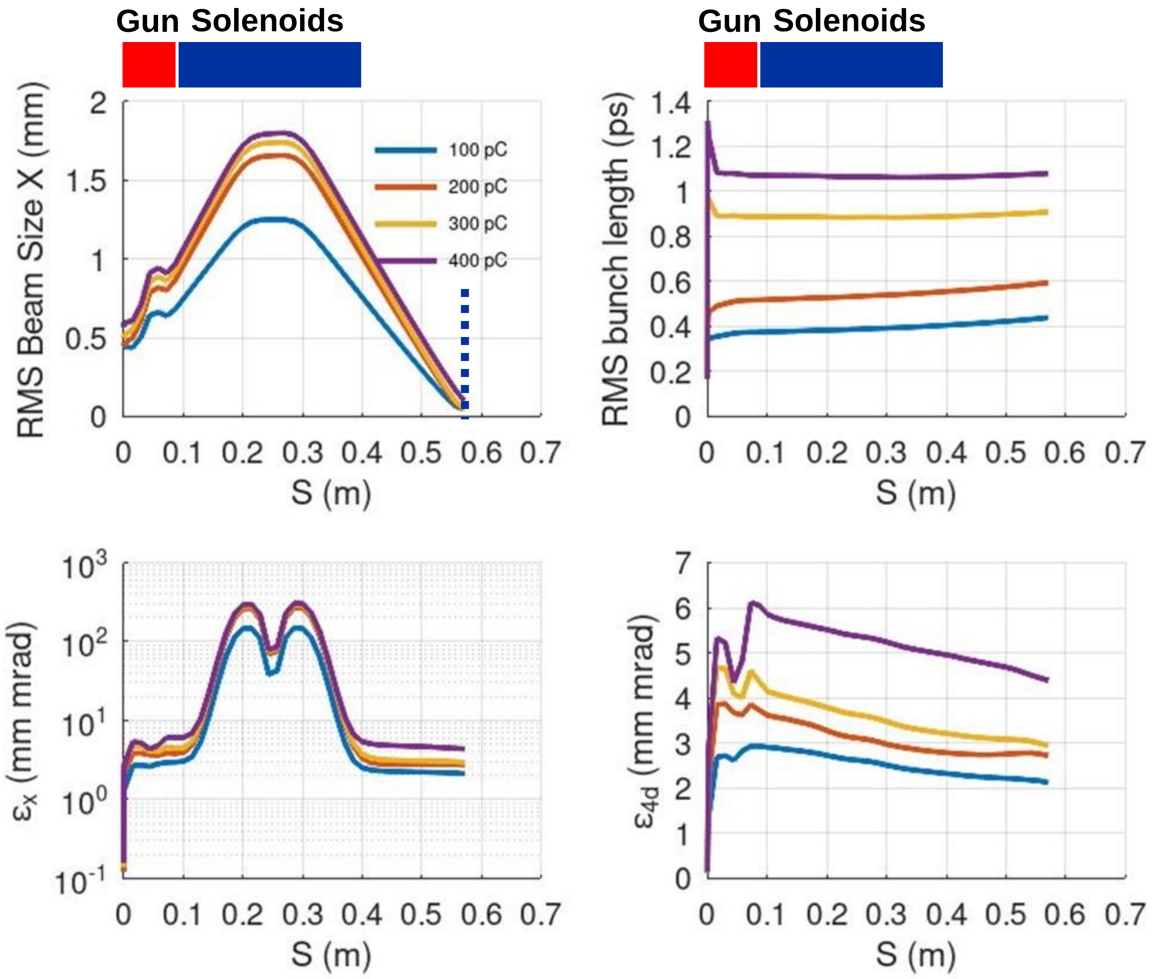


Evolution of the phase space from cathode to screen

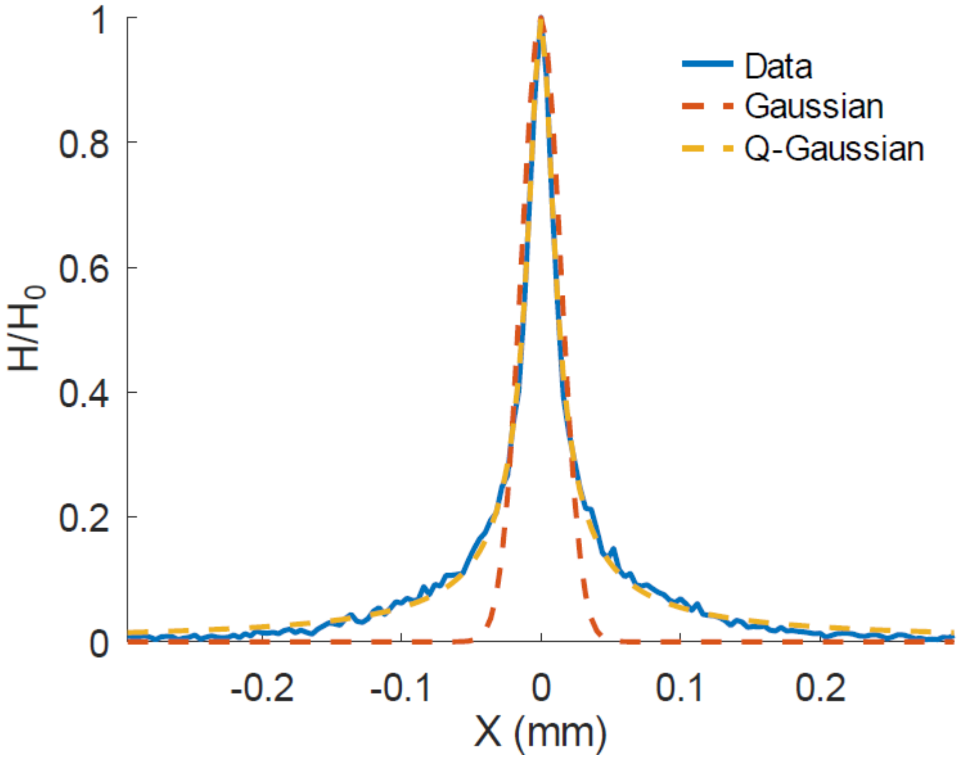


Cathode	Gun	Solenoid
Bunch charge (laser intensity)	RF phase	B field
Laser spot size (Gaussian)	RF gradient	

Flux optimisation (cathode → screen)

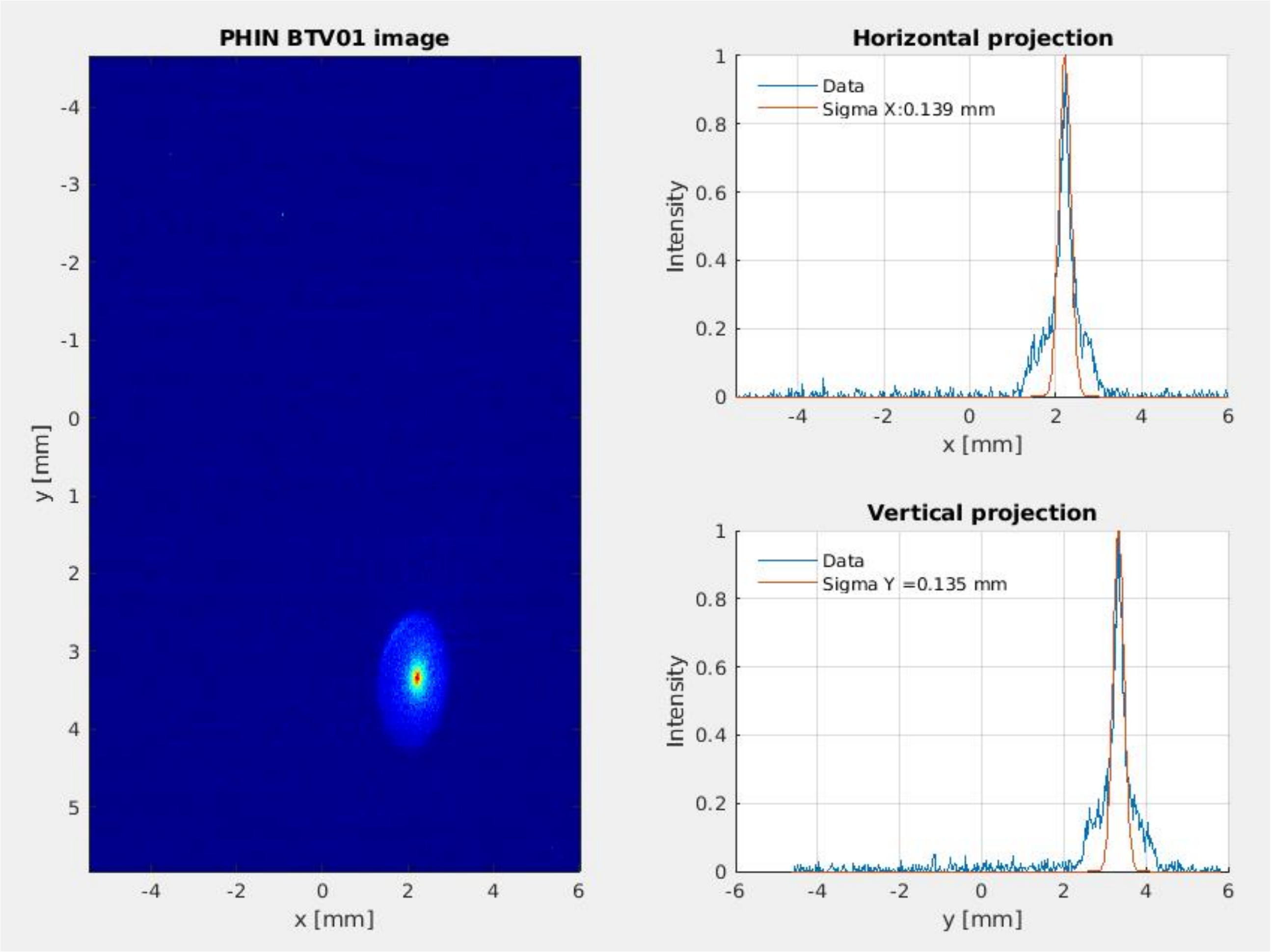


Electron beam profile of the optimised bunch at IP



Parameter at IP	Unit	100 pC	200 pC	300 pC	400 pC
$\sigma^*_{x,el}$	µm	42	46	61	94
Ph/bunch	#	14,000	35,000	37,000	29,000

Small spot working point

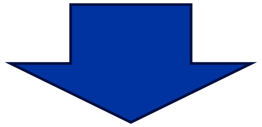


Small spot obtained with a -10 deg RF phase and 200 μm laser spot on the cathode.

An electron RMS spot of 140 μm for a bunch charge of 200 pC.

The beam halo inducing a non-Gaussian beam profile accounts for 77% of charge.

Why the larger measured beam size?

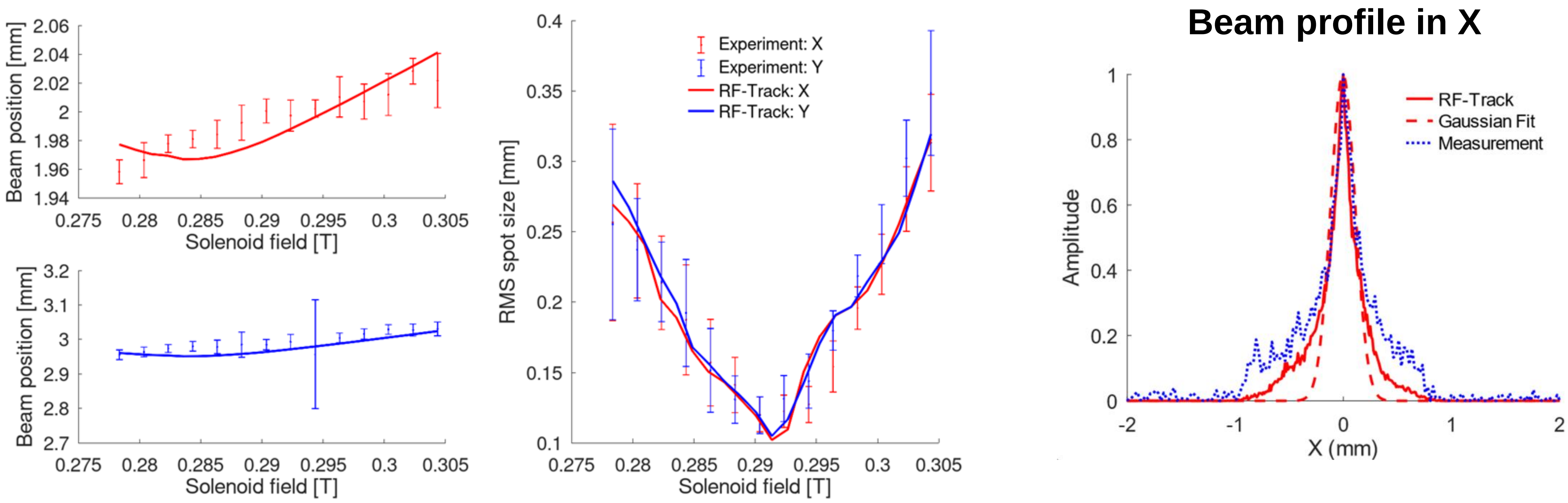


Offsets in the cathode and solenoid alignment

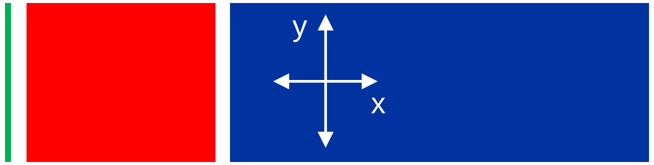
Novel solenoid offset inference method

Can infer the solenoid offset from tracking the electron beam size and position through a solenoid scan.

Offsets lead to an emittance increase → larger beam size at focus. The beam displacement trajectory depends on the alignment of the solenoid with respect to the gun.



Novel solenoid offset inference method

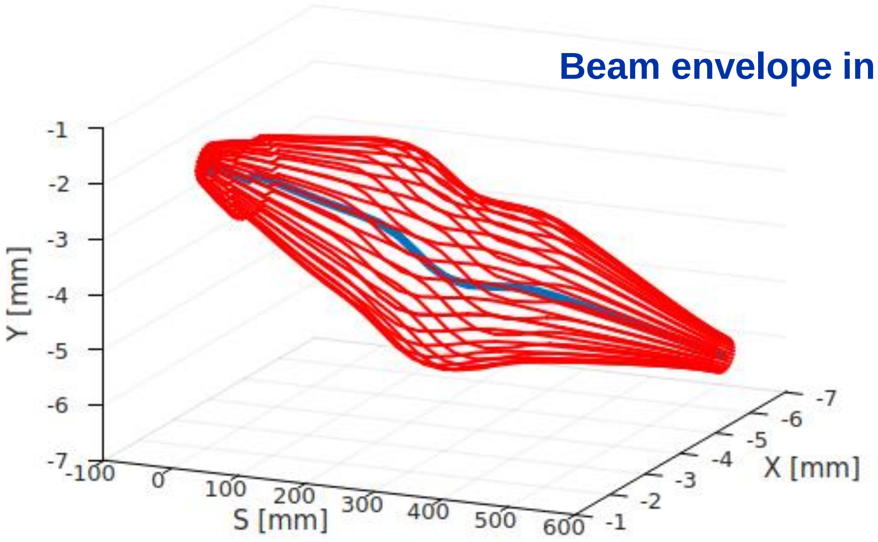


Laser input	Value
Pulse length	327 fs RMS
RMS spot X	160 um
RMS spot Y	230 um

RF input	Value
Bunch charge	53 pC
Gradient	106.7 MV/m
Phase	-20 deg

Offset input	Value
Solenoid offset X	2.66 mm
Solenoid offset Y	3.19 mm
Solenoid pitch	0.625 mrad
Solenoid yaw	0.770 mrad
Cathode offset x	2.30 mm
Cathode offset y	1.33 mm

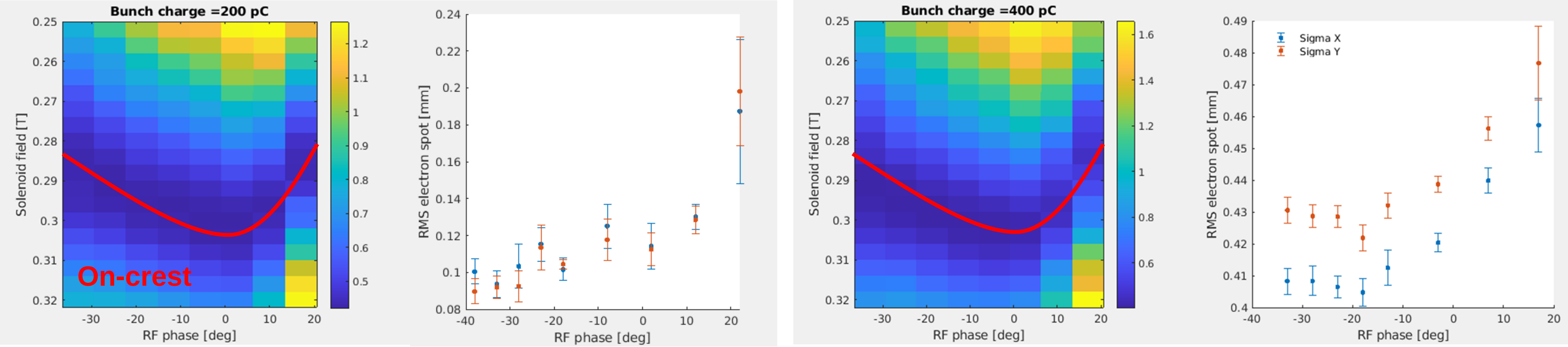
Beam envelope in red



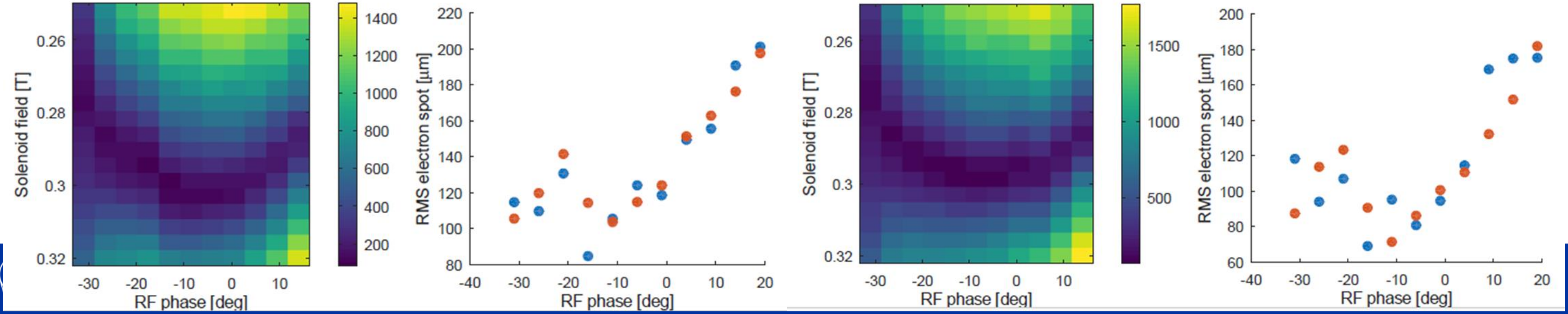
Use the inferred offsets to beam sizes measured for solenoid scans with various RF phases and laser spot sizes.

Electron beam size dependence on RF phase

Experiment: electron beam size from <u>projection</u>

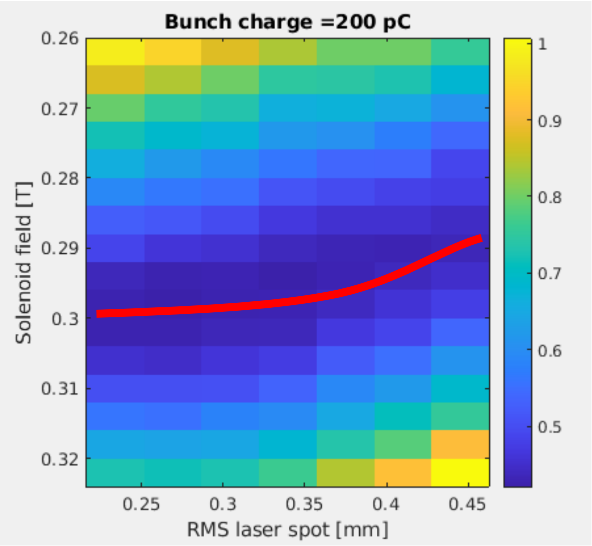


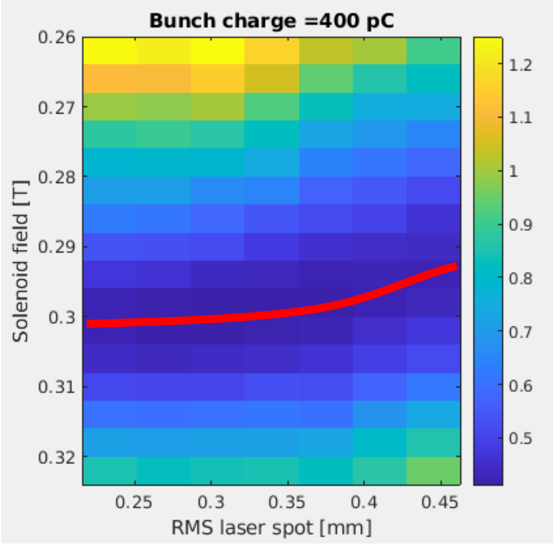
200 pC — **RF-Track: electron beam size from <u>slice</u>** — **400 pC**



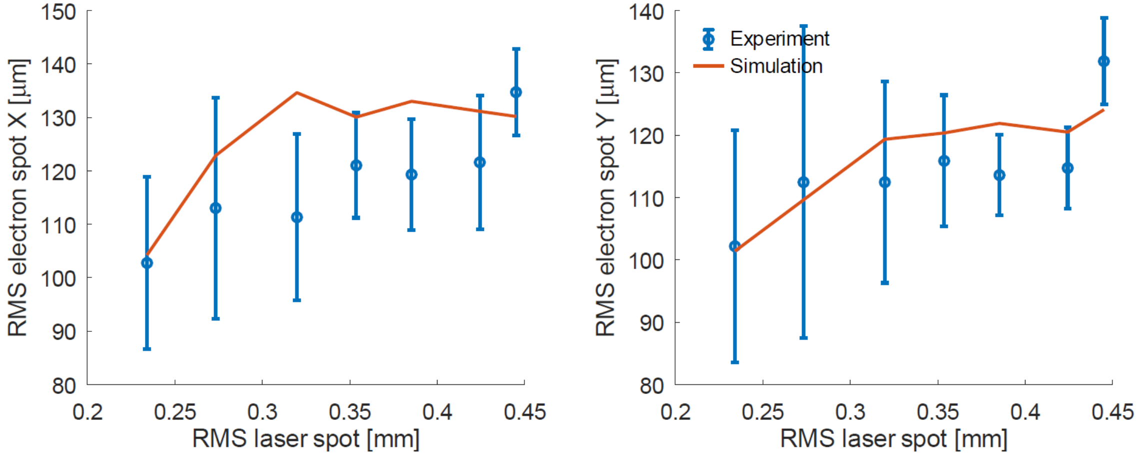
Electron beam size dependence on the laser spot

Experiment

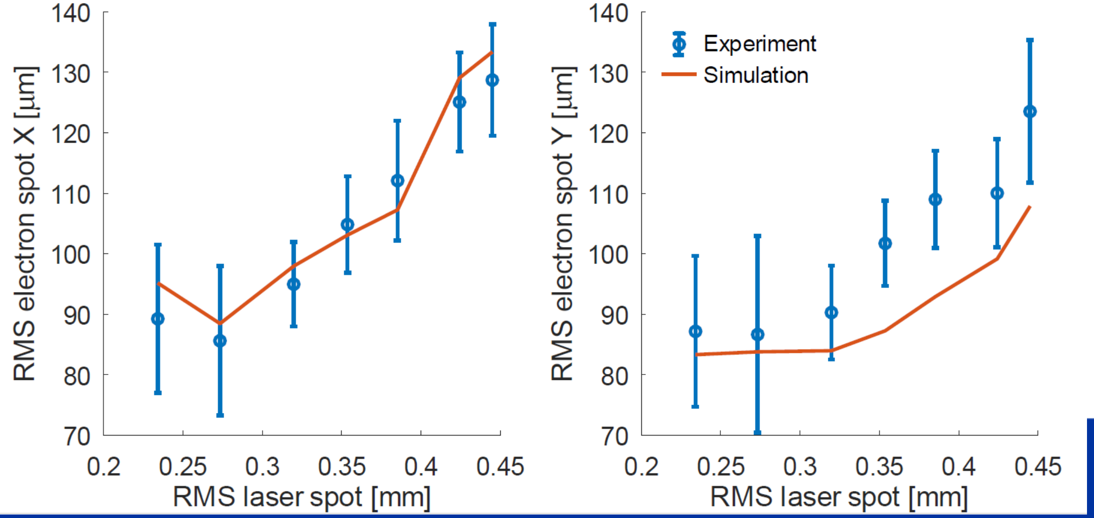




200 pC

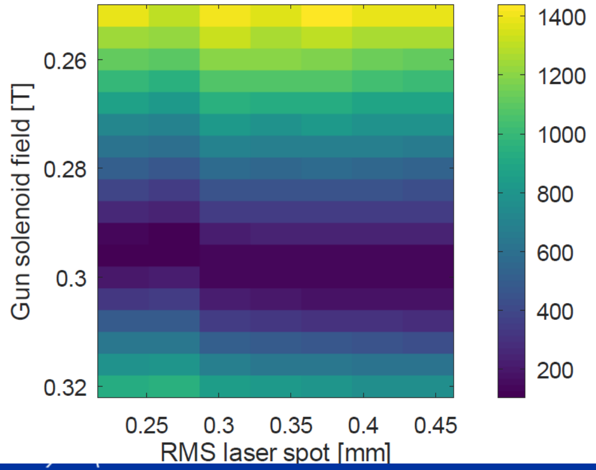


400 pC

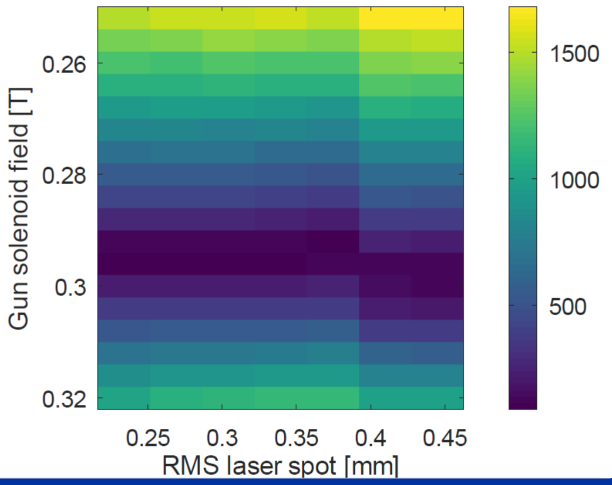


RF-Track

200 pC

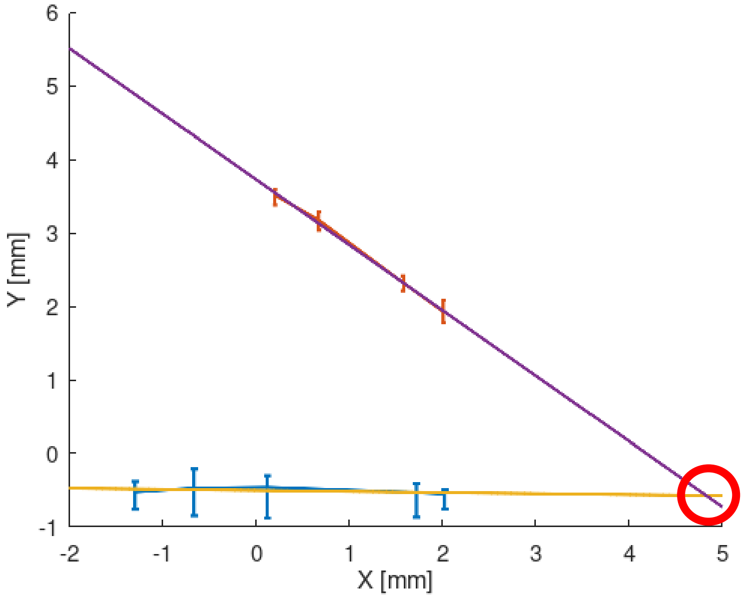


400 pC



Cathode laser and solenoid alignment

Centering the laser on the gun axis



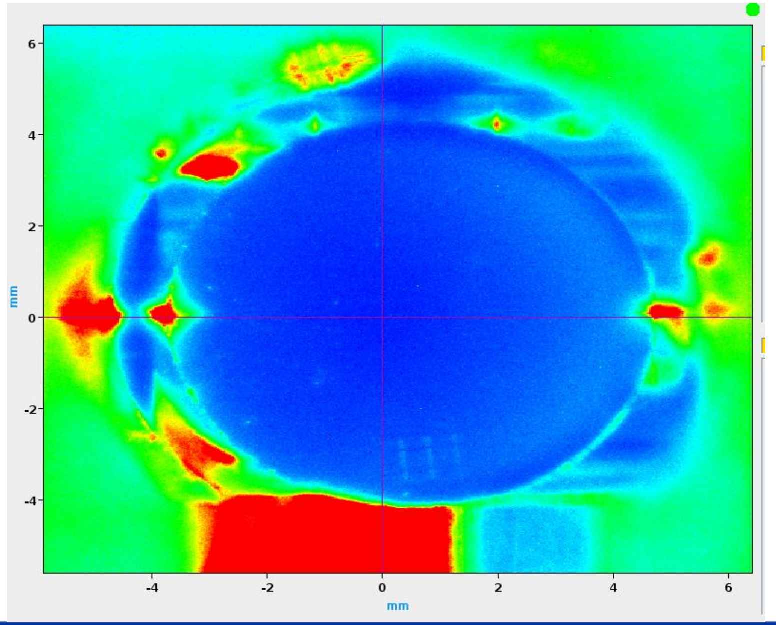
RF focusing was used to have beam with the solenoid off. To achieve this:

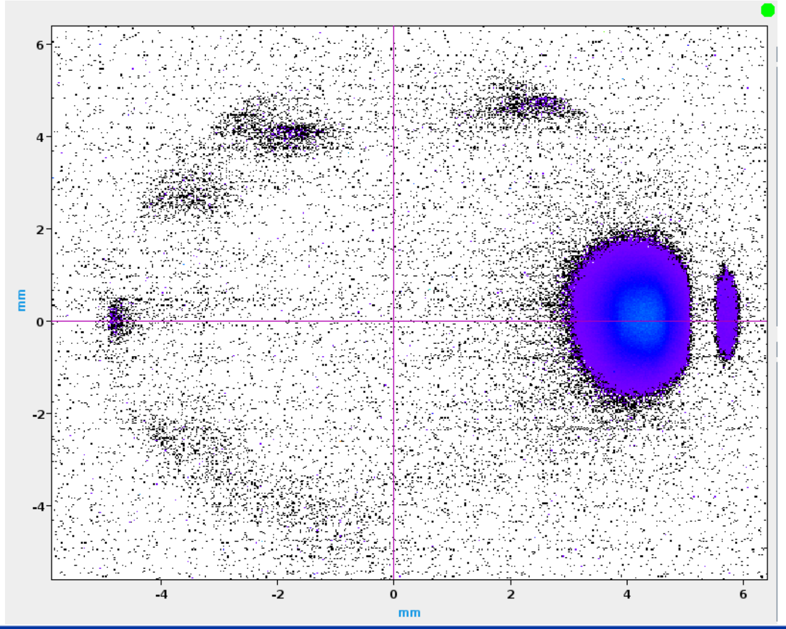
- **Low beam energy (0.7 MeV)**
- **Low bunch charge (5 pC)**

Followed the beam drift across a phase scan for two different laser position coordinates (transverse RF fields). Gun centre is where the two drifts intersect.

Beam centre actually outside the camera aperture -> brought it as close as possible.

Corrected cathode offset was:
X = 160 um
Y = 940 um



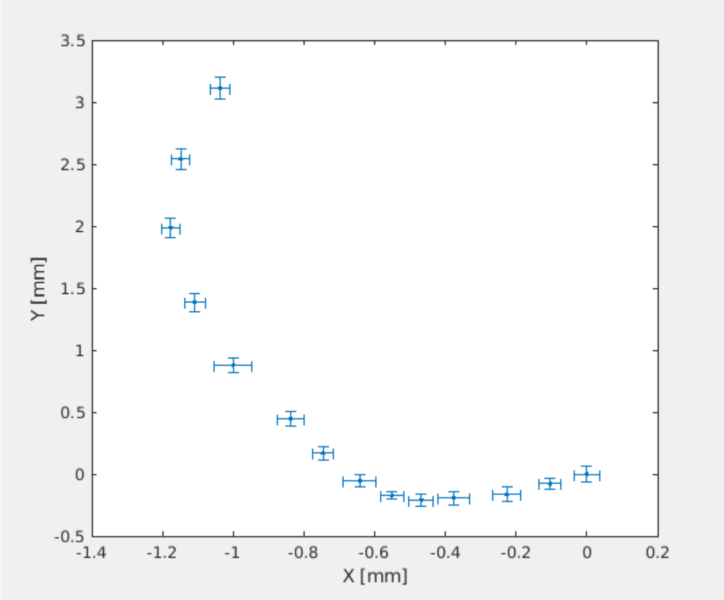


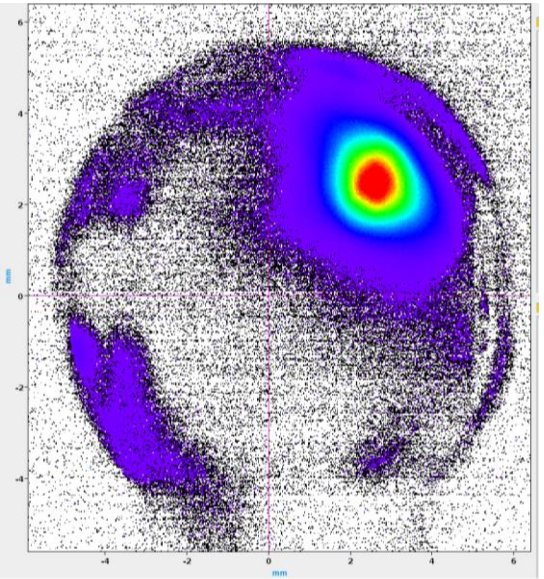
Centering the solenoid

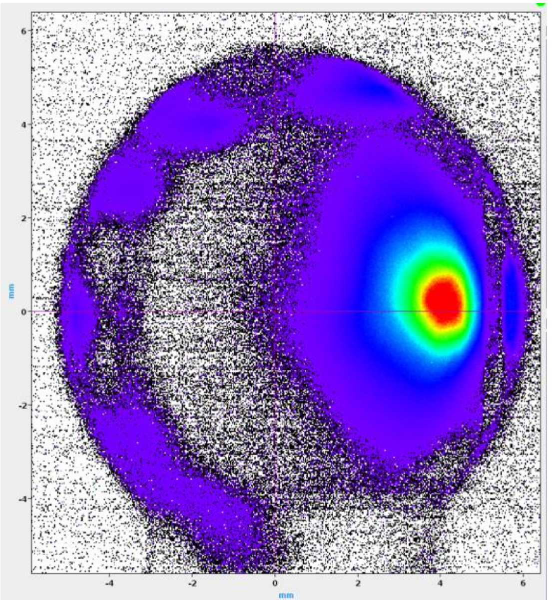
The solenoid was aligned by increasing the solenoid strength (0.02 T) and bringing the drifted electron beam back to its initial position.

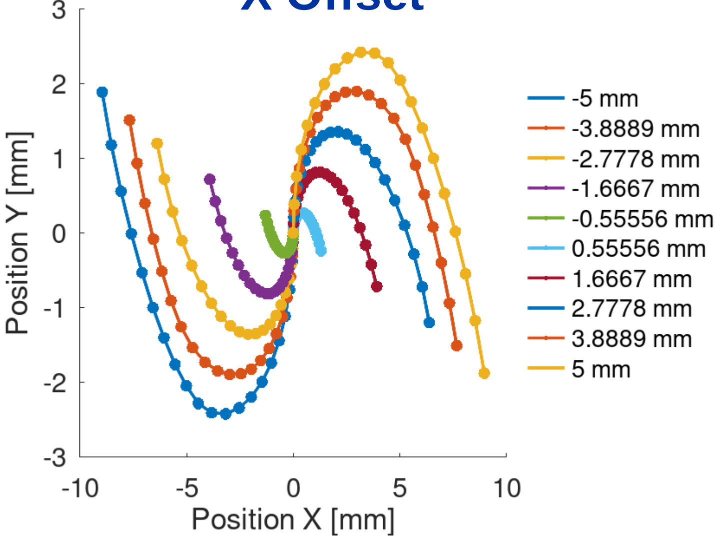
Adjusted solenoid movers according to trajectories seen in simulations.

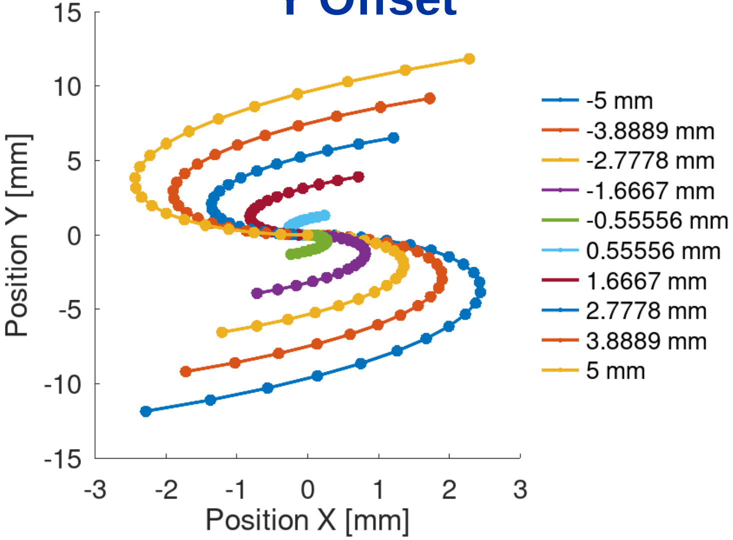
Corrected solenoid offsets
X: 0.818 mm Y: 1.625 mm



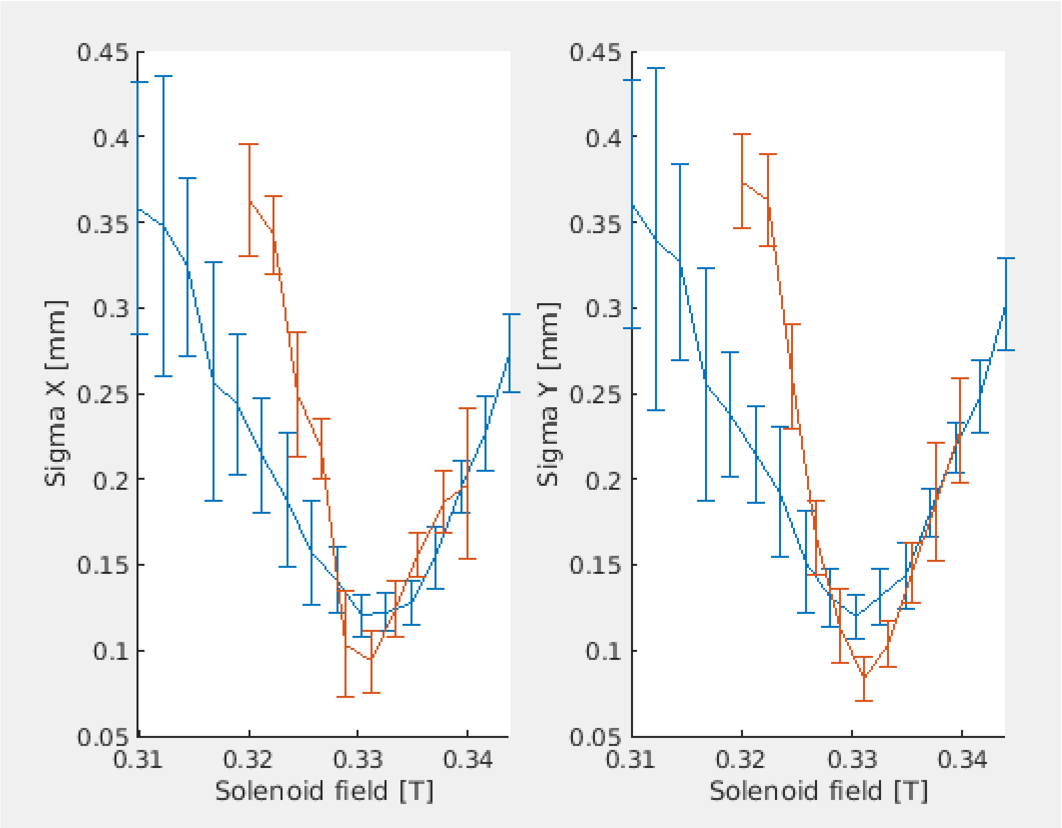








Impact on beam size from solenoid and gun centering

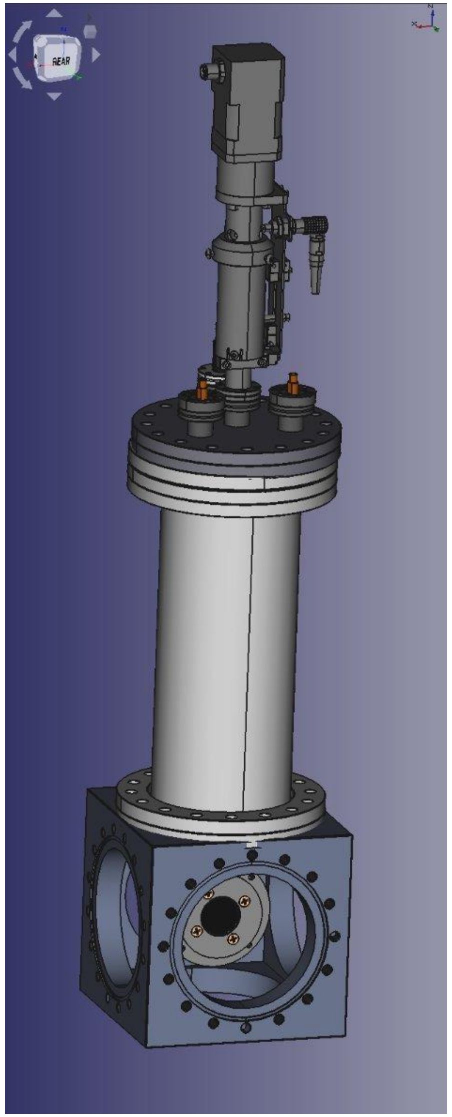


A 40% reduction in beam size was achieved after correcting the solenoid and laser cathode position.

Minimum beam in plot reduced from 120 um to 72 um.

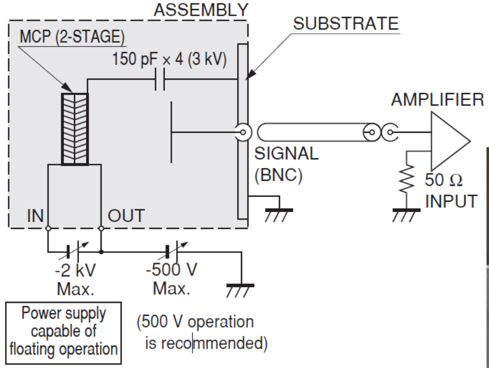
Offsets experimentally corrected (not final):

Cathode	Solenoid
X: 0.160 mm	X: 0.818 mm
Y: 0.940 mm	Y: 1.625 mm

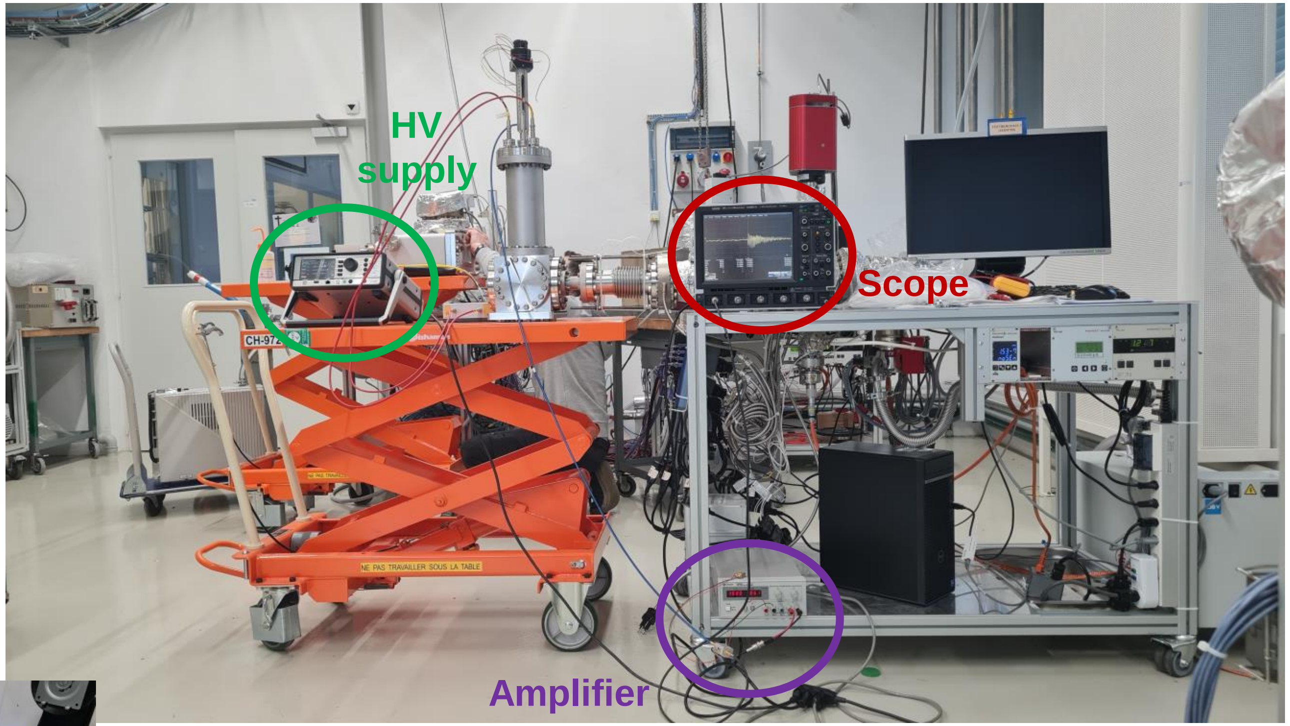


Detection chamber vacuum test

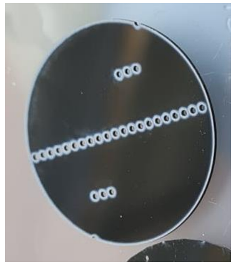
Vacuum test: Detection chamber

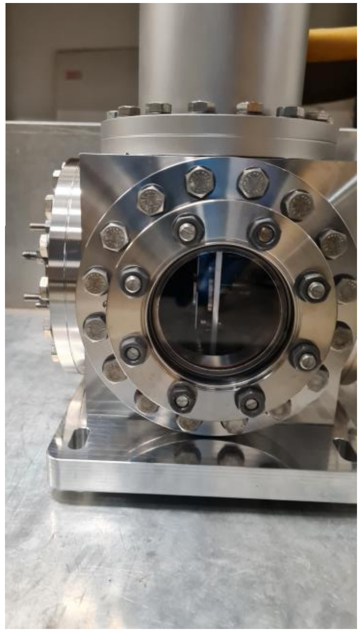


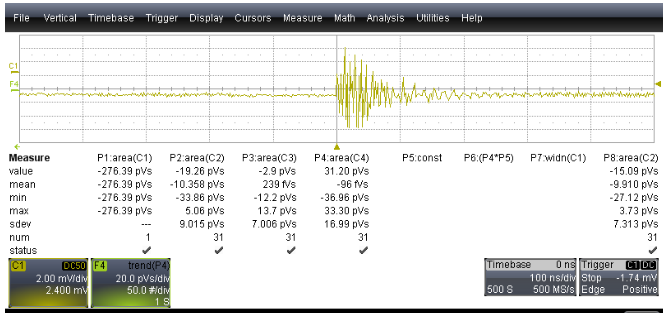
Vacuum test of the detection chamber showed the MCP detector is working as expected. Dark counts (field emission, cosmic muons, residual gas ionisation, local discharge) of 3 per second were observed.



OTR screen







Conclusions & Next steps

- **Simulations of the gun at CTF2 showed that it can be used to generate water window X-rays for a proof of principle experiment.**

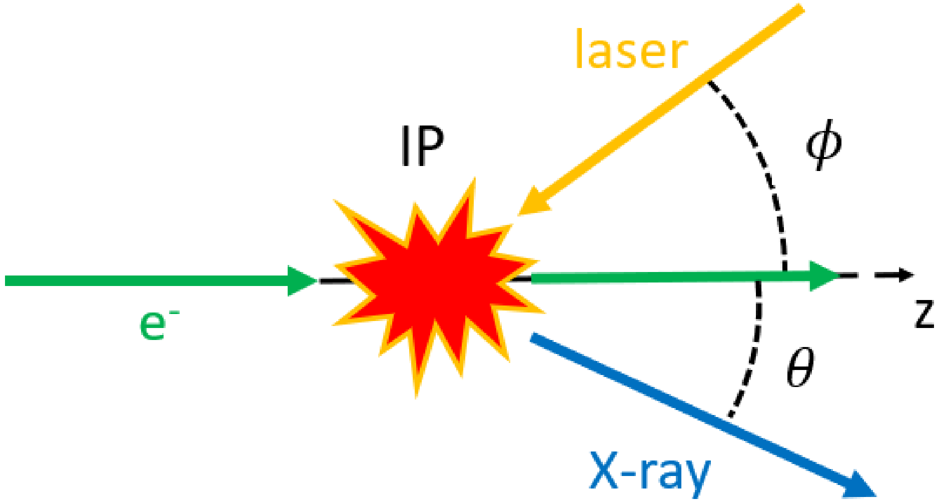
- **The cathode and solenoid offsets have been adjusted, which led to a 40% reduction in beam size.**

- **The detection chamber has been assembled and tested, installation in the next few weeks.**

- **On track to have the experiment in the first half of this year.**

home.cern

Compton backscattering



= The scattering of a low energy photon from an EM field to a high-energy photon (X-ray or gamma ray) during the interaction with a charged particle.

$$N_\gamma = \sigma_c \frac{N_e N_{\text{laser}} \cos(\phi/2)}{2\pi\sigma_{\gamma,y}\sqrt{\sigma_{\gamma,x}^2 \cos^2(\phi/2) + \sigma_{\gamma,z}^2 \sin^2(\phi/2)}}$$

Total flux

$$\mathcal{B} = \frac{\mathcal{F}}{4\pi^2 \sigma_{\gamma,x}\sqrt{\epsilon_x/\beta_x}\,\sigma_{\gamma,y}\sqrt{\epsilon_y/\beta_y}}$$

Average brilliance

$$\frac{\sigma_{E_\gamma}}{E_\gamma} = \sqrt{\left(\frac{\sigma_{E_\theta}}{E_\theta}\right)^2 + \left(2\frac{\sigma_{E_e}}{E_e}\right)^2 + \left(\frac{\sigma_{E_{\text{laser}}}}{E_{\text{laser}}}\right)^2 + \left(\frac{\sigma_{E_\epsilon}}{E_\epsilon}\right)^2}$$

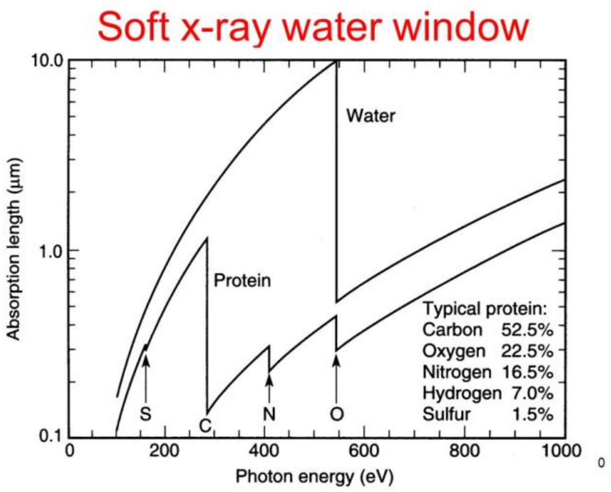
Photon bandwidth

$$E_{\text{X-ray}} = 2\gamma^2 E_{\text{laser}} \frac{1+\cos\phi}{1+\gamma^2\theta^2}$$

Photon energy

Water Window X-ray source

- Water window is a region in the electromagnetic spectrum where water is invisible.
- The region spans the K-edge of Carbon (282 eV) to Oxygen (533 eV).
- Only microscopy allowing for 10 nm range 3D imaging of cellular samples in their near-native state → quantitative characterisation of (sub)cellular organisation in single cells and cell-cell interaction [1].
- Most water window microscopes have been implemented as part of synchrotrons.



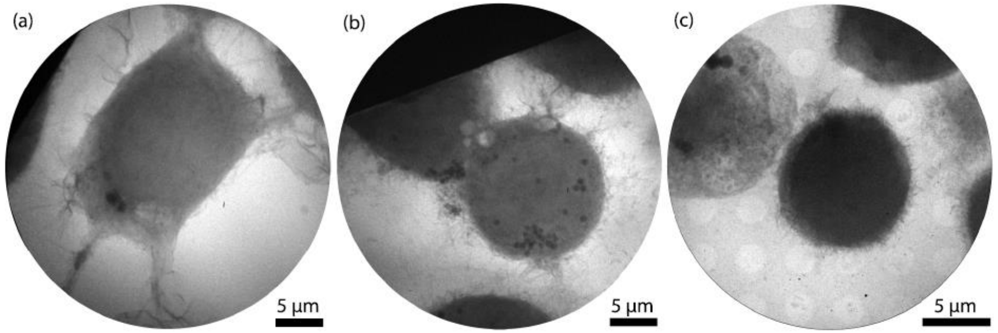
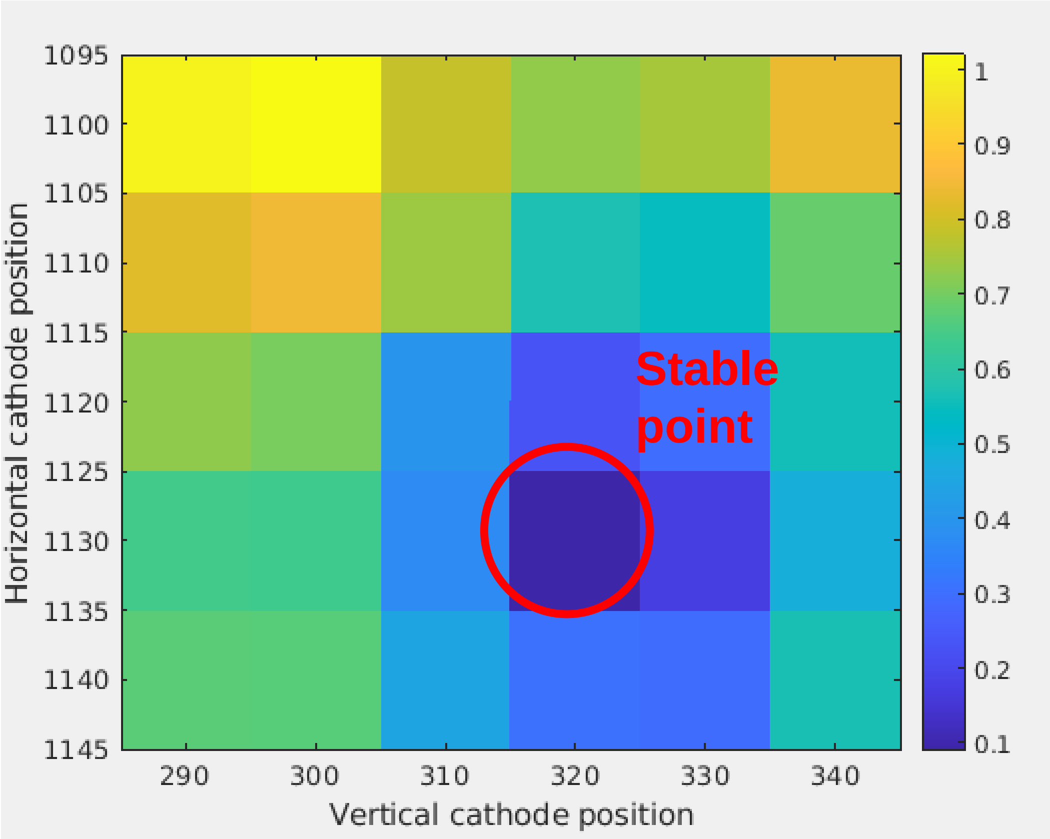


Fig. 9. 2D cryo imaging with laboratory soft XRM. (a) Healthy and adhered HEK 293 T cell, 30 s exposure time; (b) slightly starved and rounded HEK 293 T cell, 20 s exposure time; (c) THP-1 cells with 5 min exposure time. Images (a) and (b) from the Stockholm microscope and (c) from the Berlin microscope.

https://doi.org/10.1364/OPTICA.393014

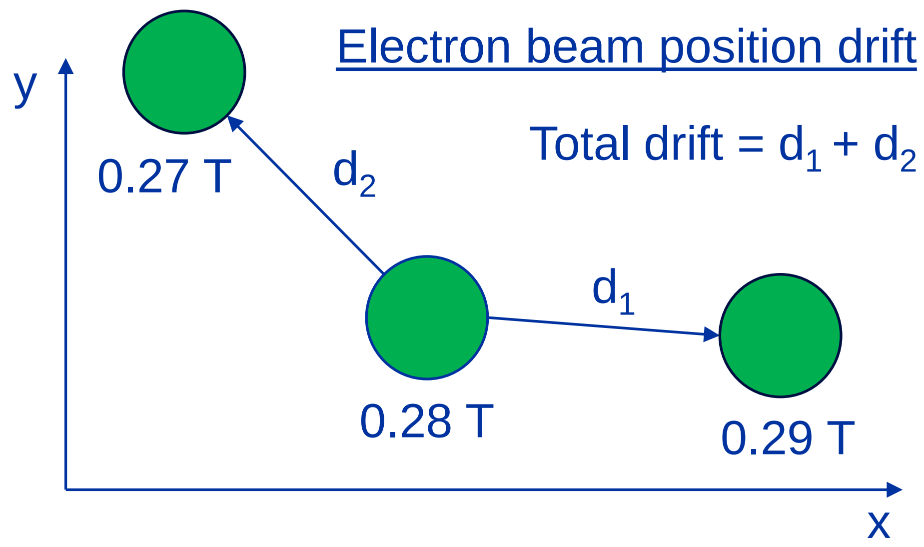
[1] V. Weinhardt, J.-H. Chen, A. Ekman, G. McDermott, M. A. Le Gros, and C. Larabell, “Imaging cell morphology and physiology using x-rays,” Biochem. Soc. Trans. 47, 489–508 (2019).

Alignment of laser spot on cathode wrt the solenoid



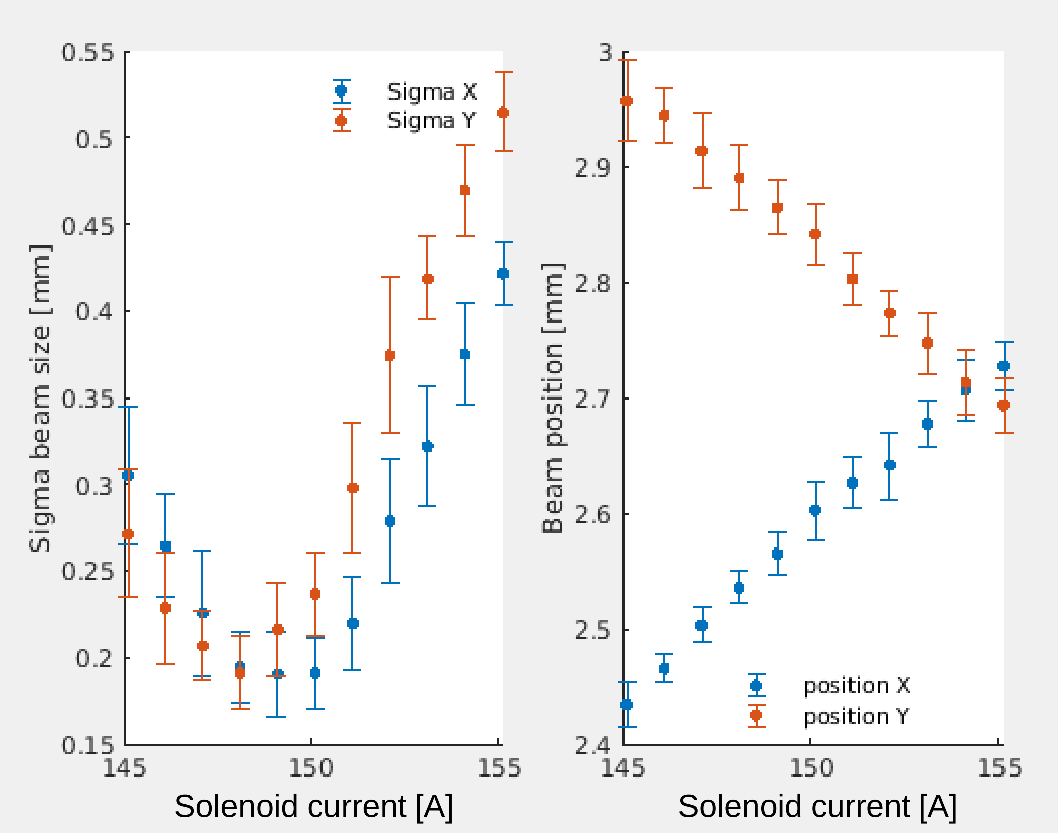
Method: scan the laser position on the cathode, and for each point, made a solenoid scan and determined the beam drift → select laser coordinates with smallest drift.

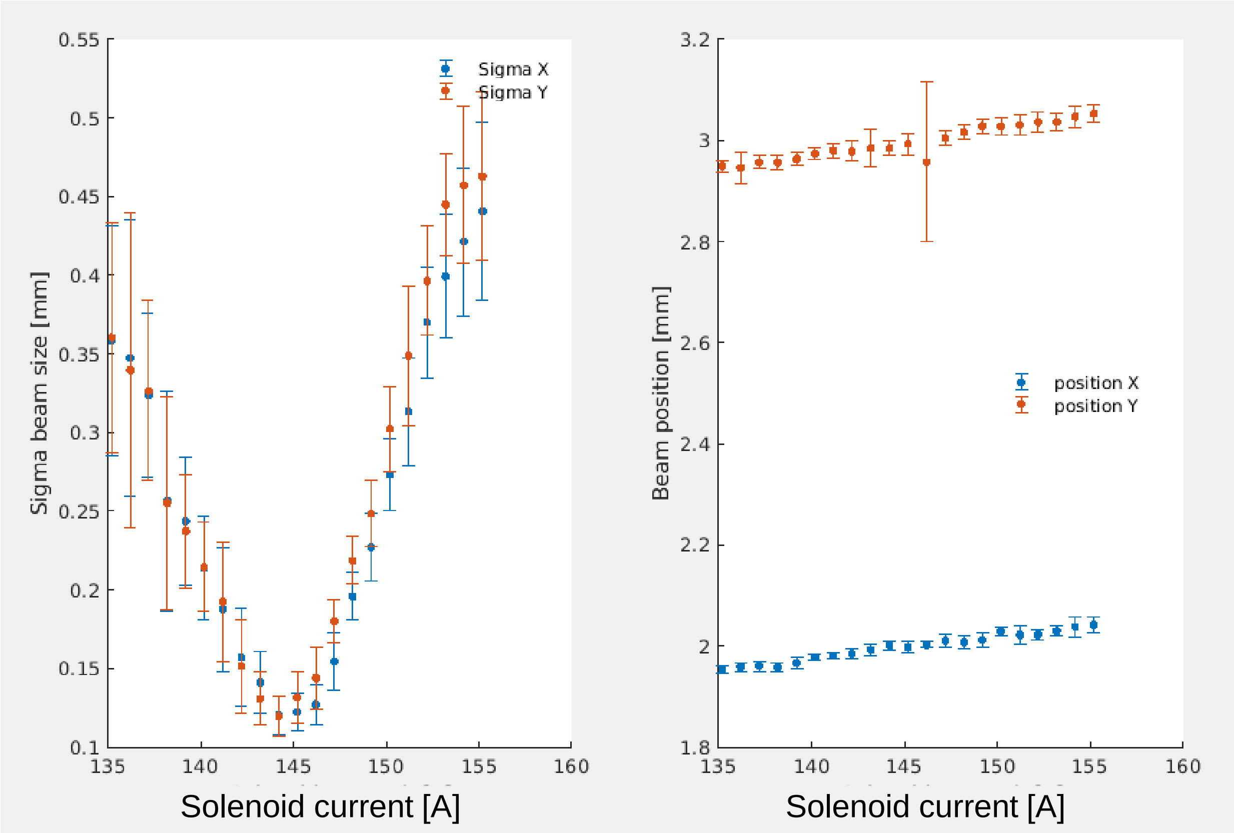
Stable beam region set by laser spot position within 160 µm.



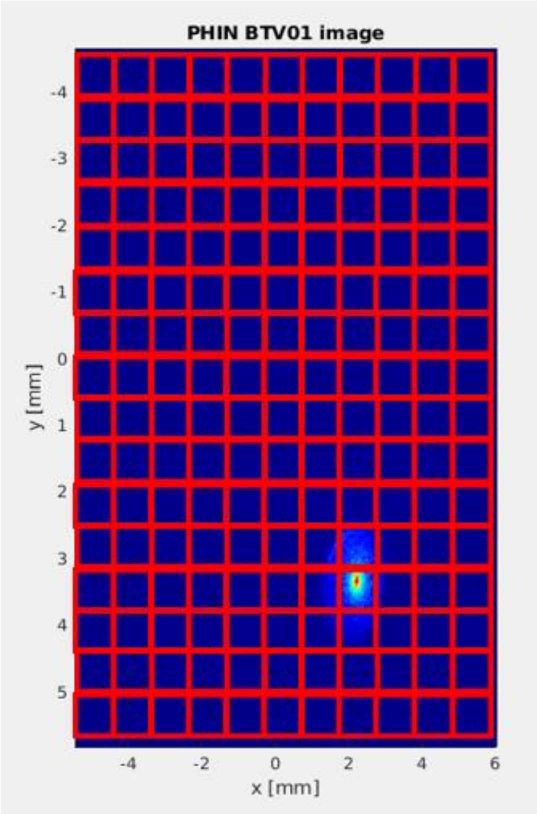
Alignment of laser spot on cathode wrt solenoid

Stable beam for a large range of solenoid strengths was obtained.





Beam size measurement



Three methods used to compute the beam size:

1. From the gaussian fit of projected pixels in X and Y
2. From the gaussian fit of a slice in x and y passing through the beam centre
3. From the weighted mean of the pixel intensities

Pixel projection is standard, however it tends to overestimate the beam size in the case of beam halo.

The weighted mean of the pixel intensities allows for computing the beam size with no fit. However, it is very sensitive to background.

To mitigate this, a pixel slice was used to compute the beam profile. The direct cut showed that beam size was up to 4 times smaller than the on predicted from the projected pixels.