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Breakdown currents from CLIC crab cavity commissioning

UCXS
Uppsala/CLIC X-Band Spectrometer

Marek Jacewicz

On behalf of Uppsala Accelerator Group

FREIA

Uppsala/CLIC X-band Spectrometer (UCXS) for Xbox Klystron Based Tests Stand(s)

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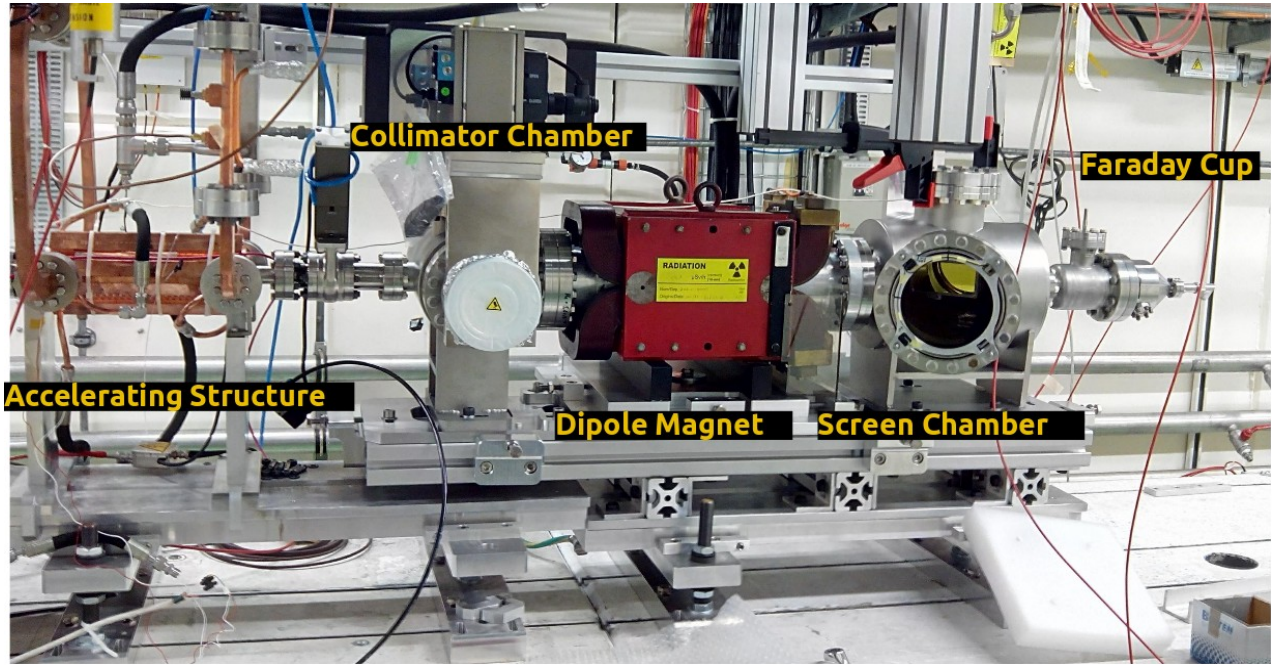
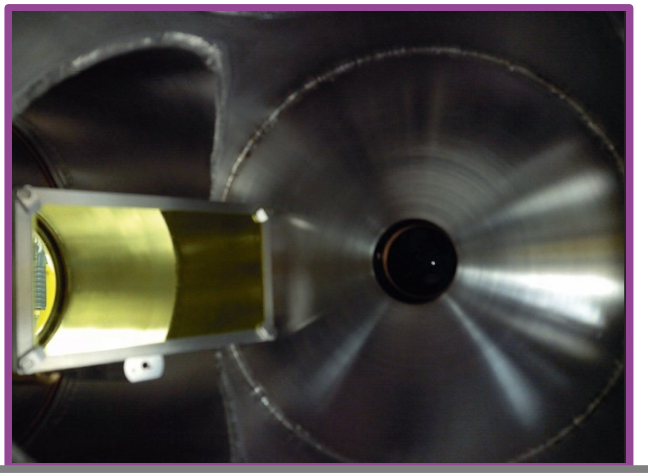
general-purpose system for detection and measurements of dark and breakdown currents during structure conditioning



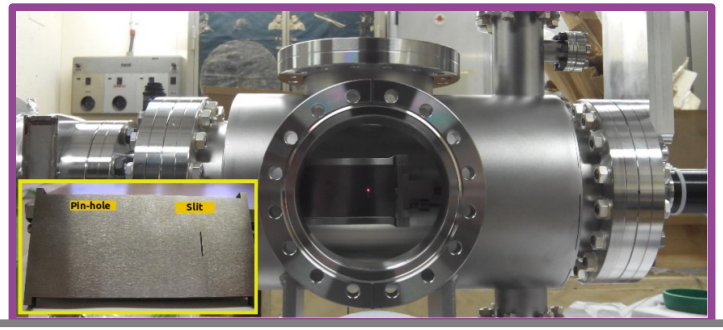


Screen (100x50x0.5 mm YAG:Ce)

linear actuator (fully retractable)

30 degrees angle w.r.t. the beam axis

2M pixel, 50fps camera with focuser



Collimator (5 mm tungsten plate)

linear actuator (fully retractable), place for two patterns, presently: **pin-hole** 0.5mm and **slit** 10x0.5mm

[2]Electrically insulated (for use as a Faraday cup)

Energy resolution with dipole magnet

Maximum electron energy <20MeV

Rel. energy spread (single slit) 10% - 25%

Full energy coverage with magnetic field scan

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UCXS - presently at XBox2

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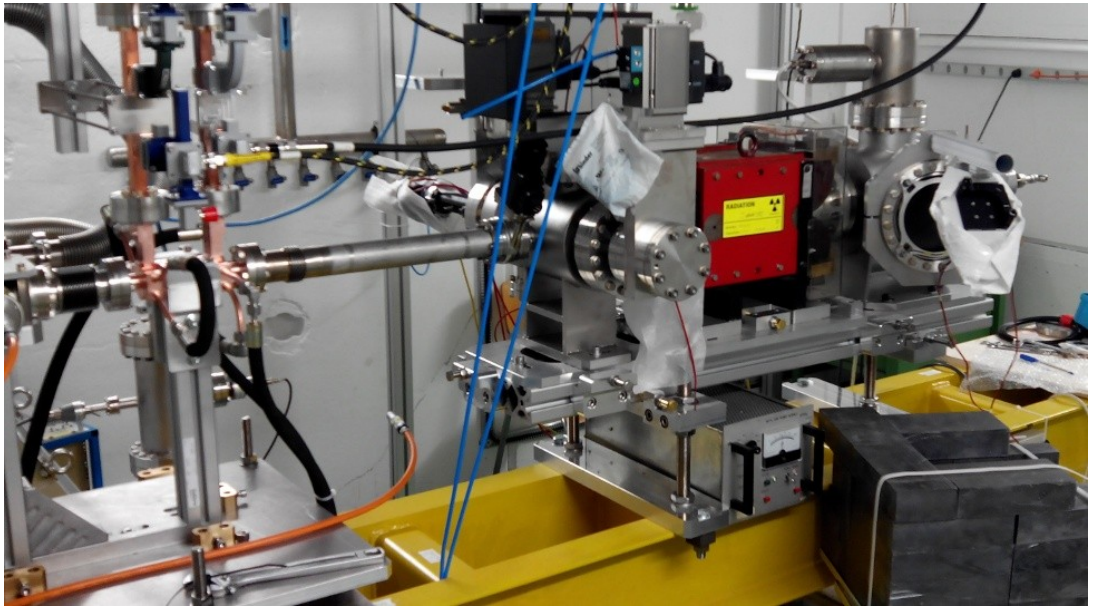

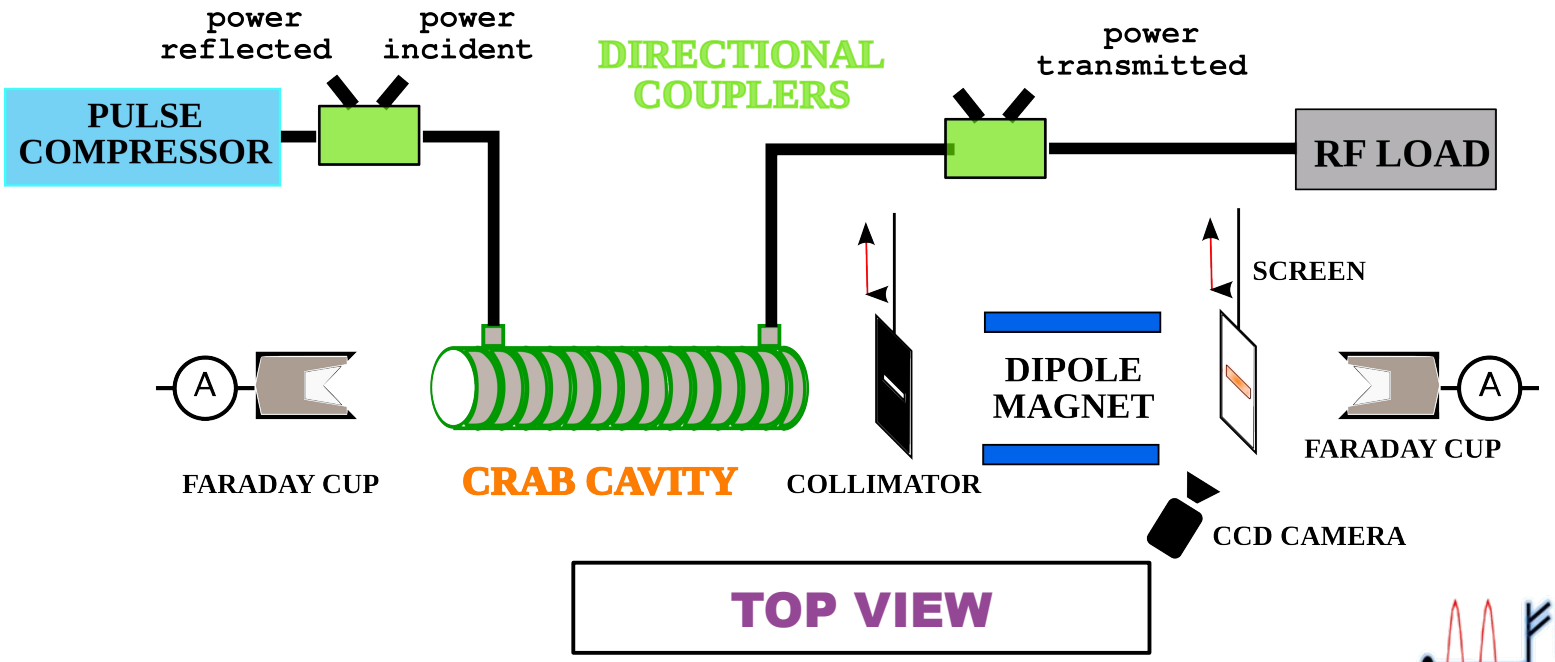

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Spectrometer commissioning

- Operation at 50 Hz with 12bit pixel depth with minimal supervision
- Exposure time (min 24 µs) set to 250 µs
- On trigger from the main system, preceding and following pictures are saved (typically 2)
- All diagnostics information available for the breakdown events was combined with images from the camera.
- High camera gain needed at the moment resulting in high noise content (should be different for an ACS)
- The magnet was tested but not used during the commissioning

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Some typical events with the **slit**

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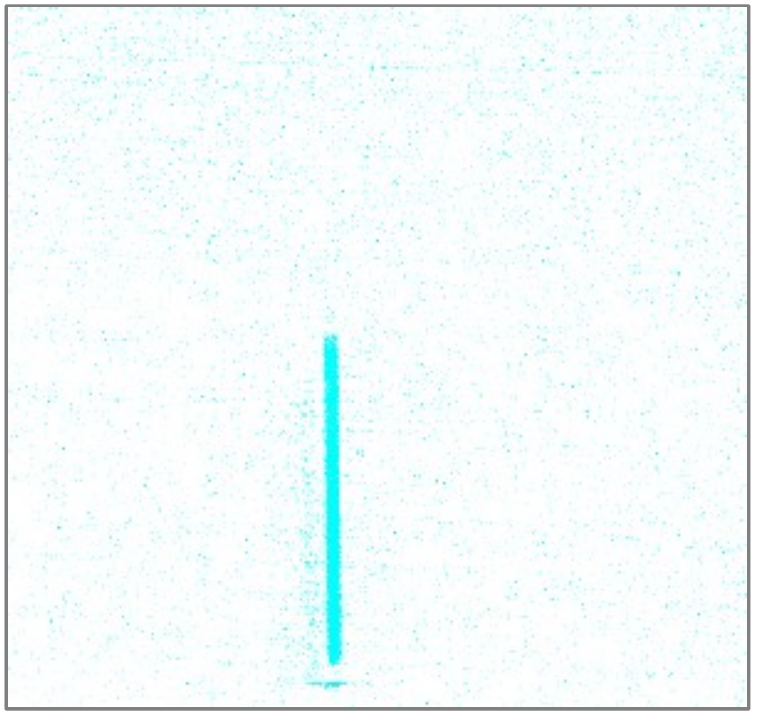
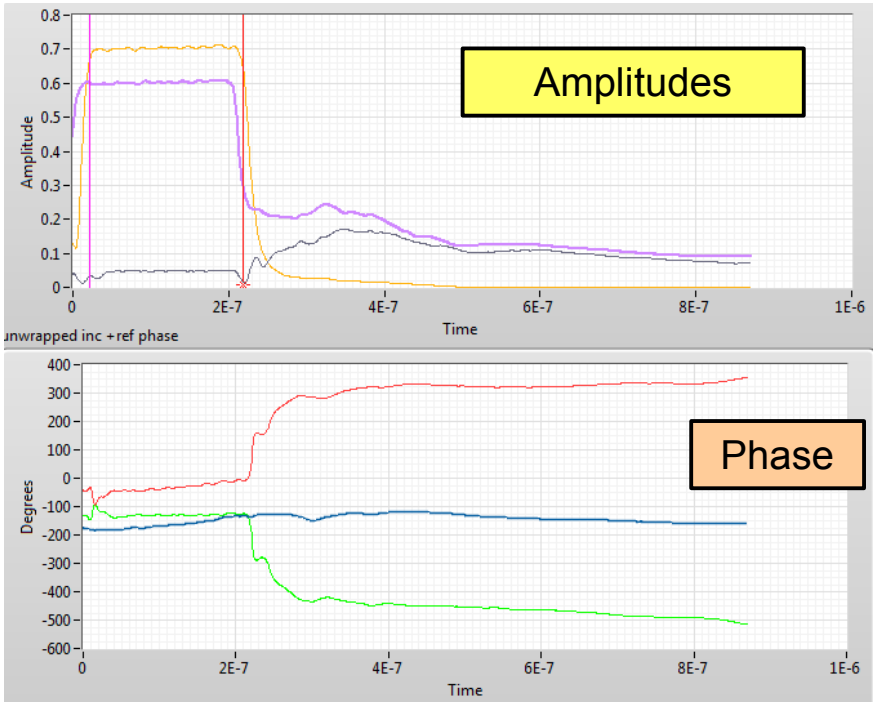




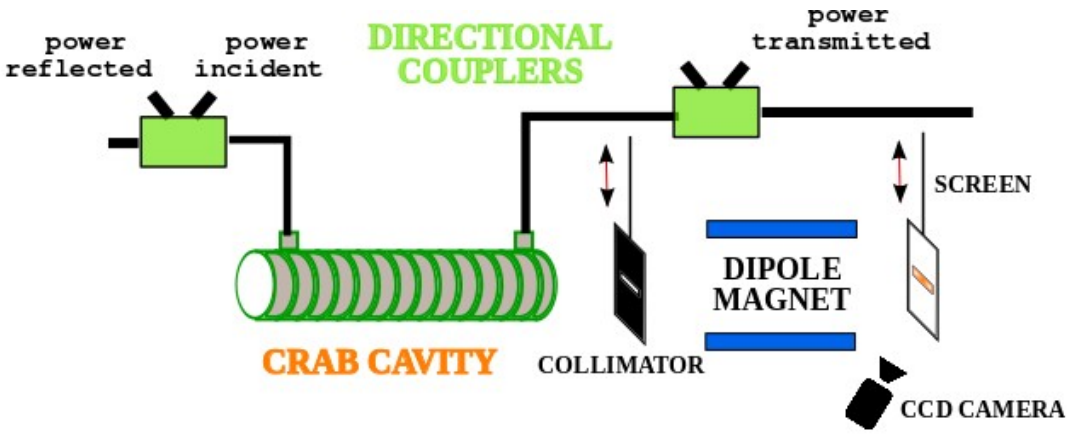
Amplitudes:
- RF In
- RF Transmitted
- RF Reflected

Phase:
- RF In
- RF Reflected
- In - Reflected

One would naively expect most of the events to look like that

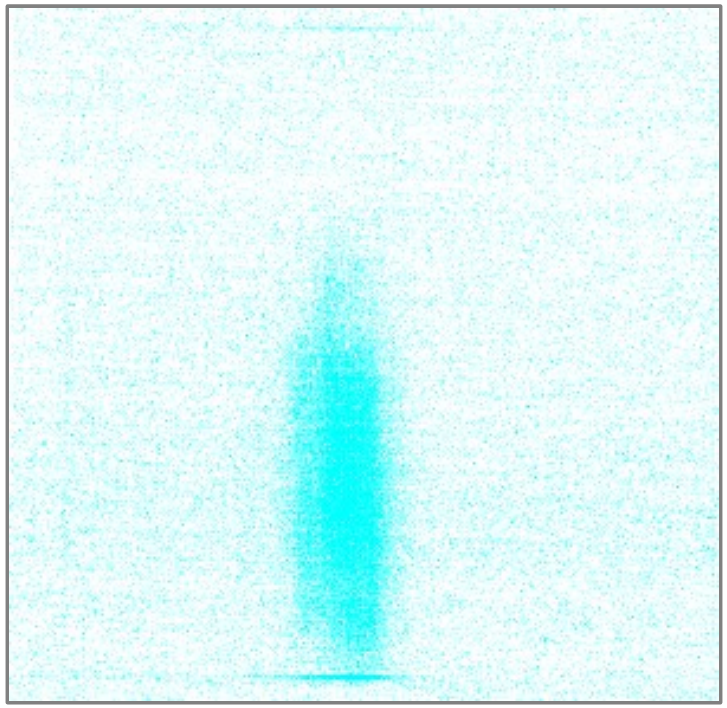
single slit image

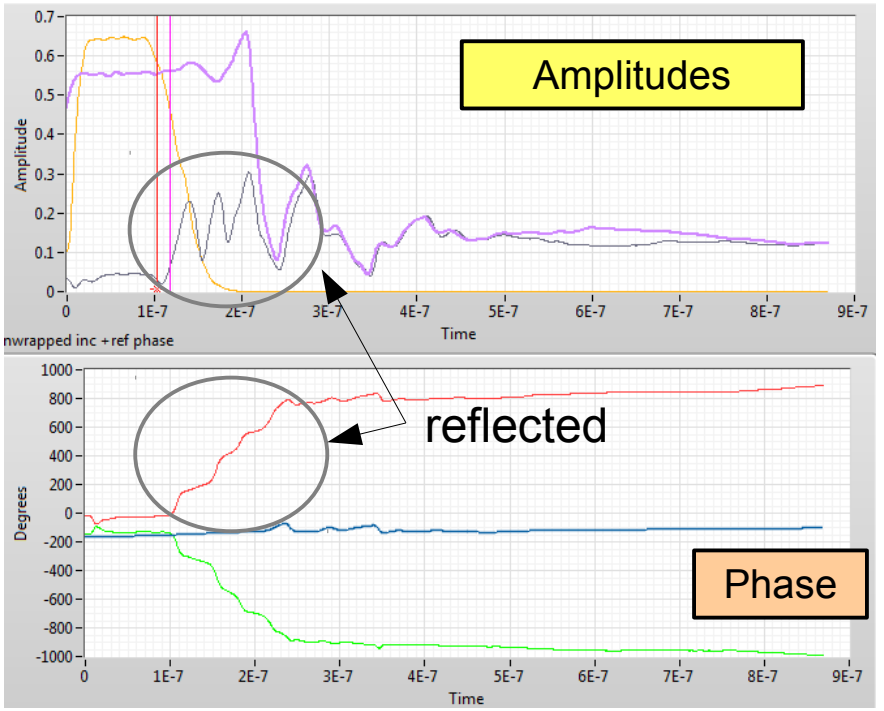
but it is not the case



FREIA

Some typical events with the **slit**





LEGEND

Amplitudes:
RF In
RF Transmitted
RF Reflected

Phase:
RF In
RF Reflected
In - Reflected

Often rich structure of the reflected signal

From amplitude spectrum we conclude that the energy is lost – breakdown is “feeding” from the power

The time and phase difference can give us information about translation of the BD site

Some typical events with the **slit** **and** **pin-hole**

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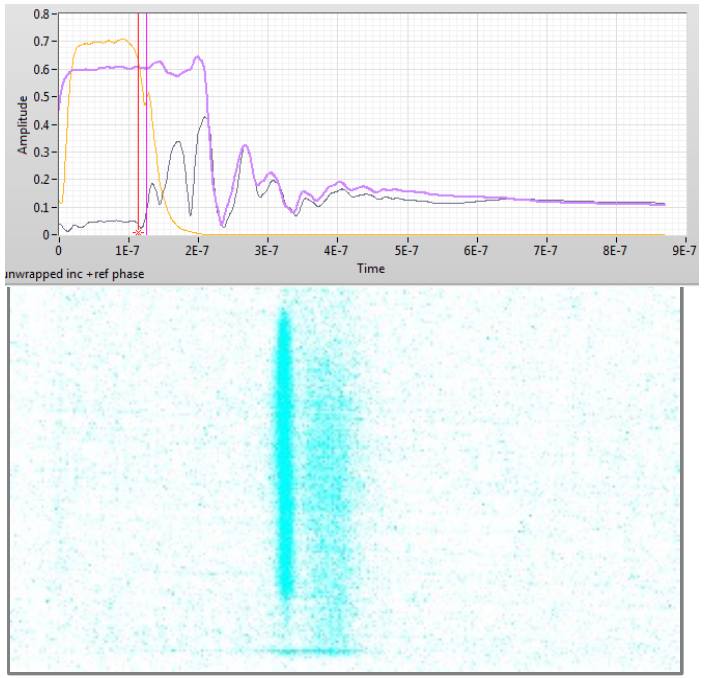

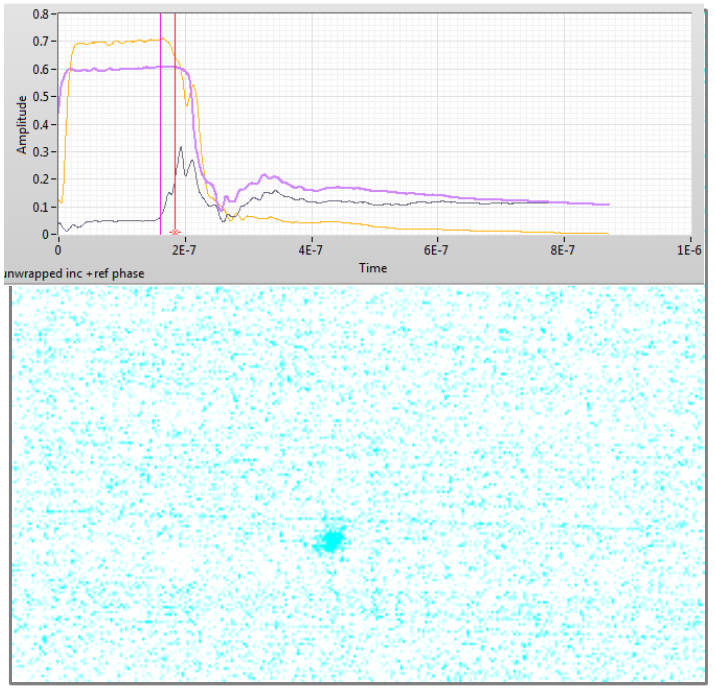

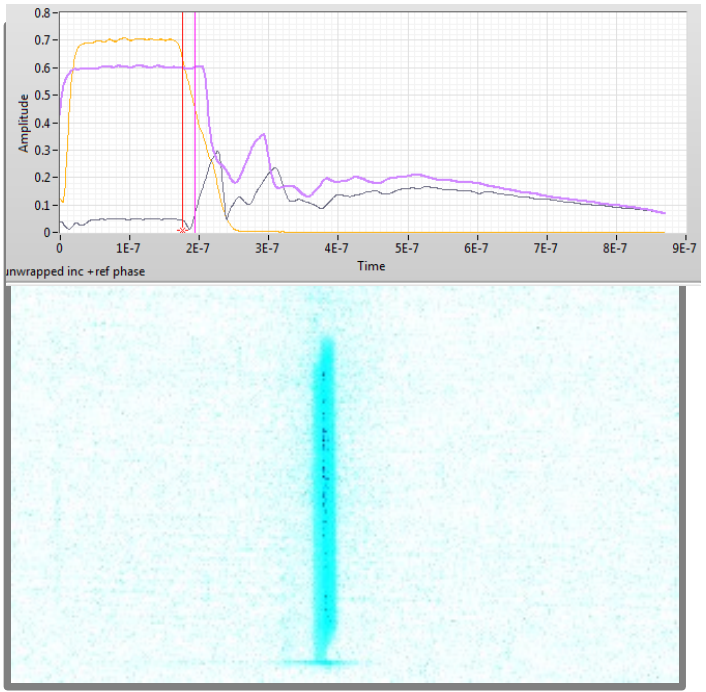

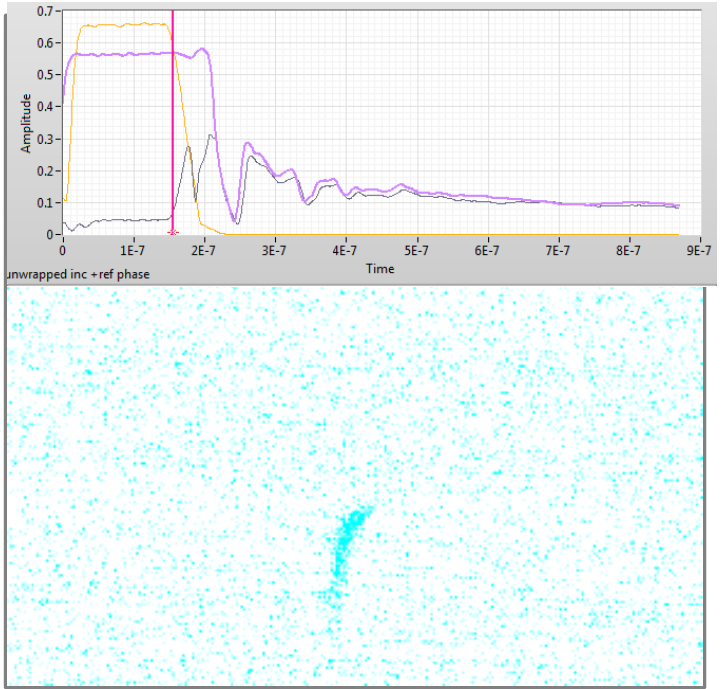

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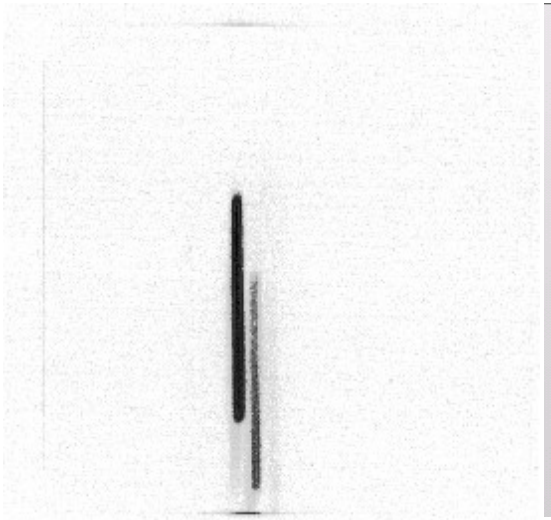
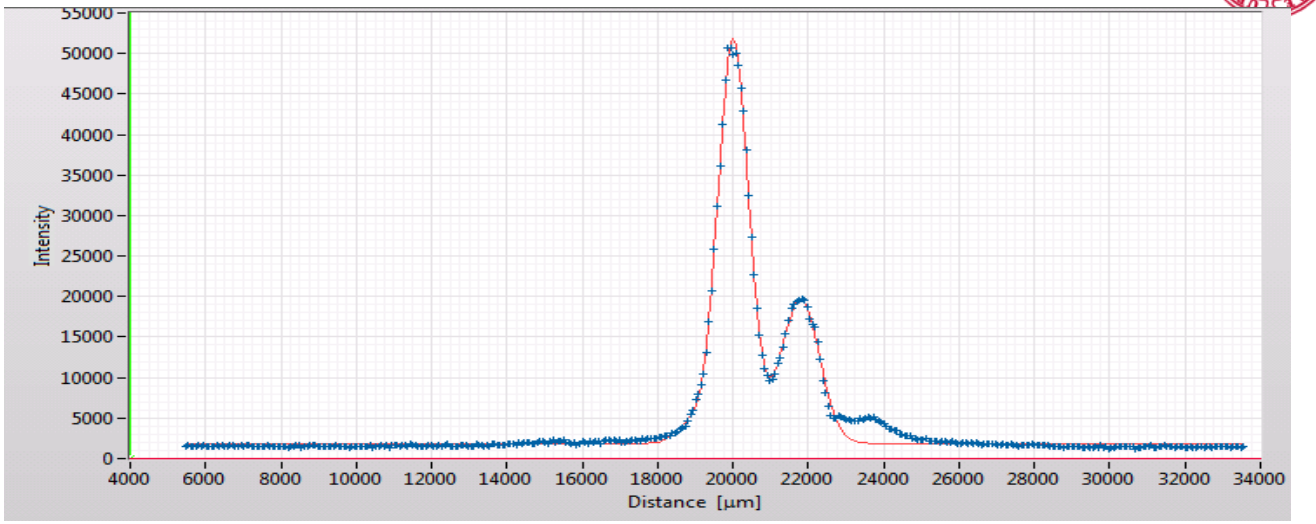
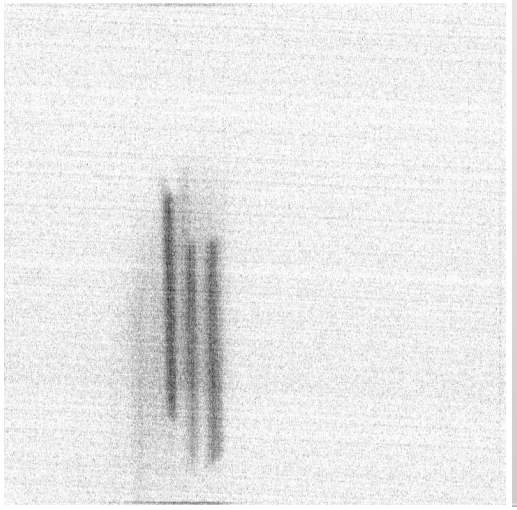
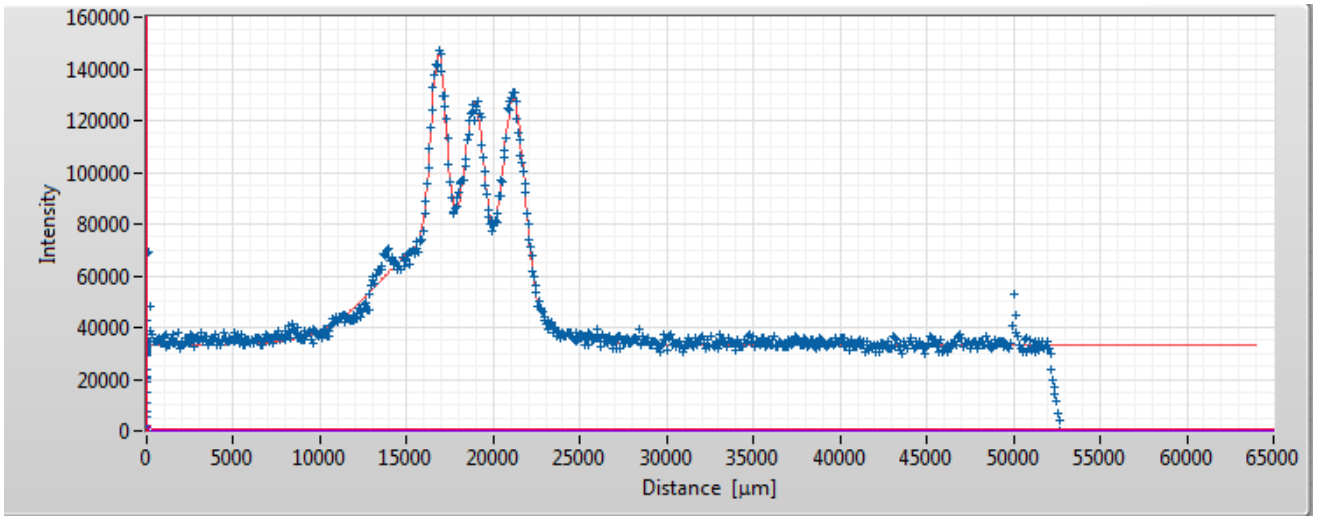
Feature extraction





Fit parameters (in mm): Pos_1 = 19.6 σ_1 = 0.463, Pos_2 = 21.8 σ_2 = 0. 504

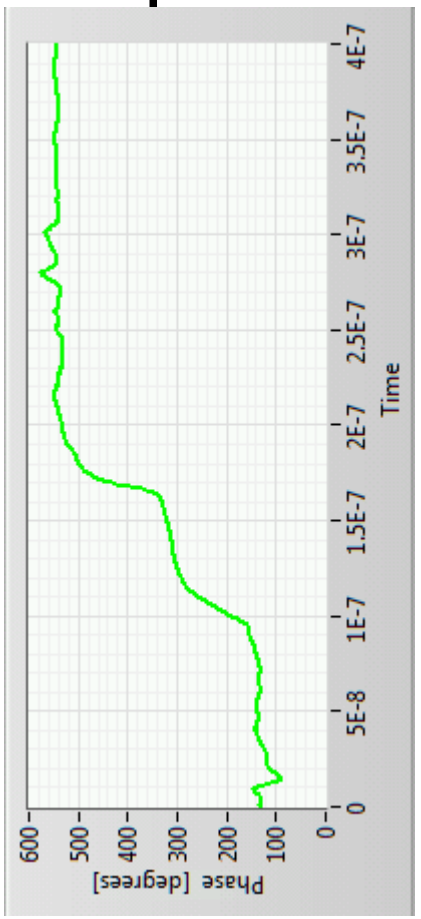




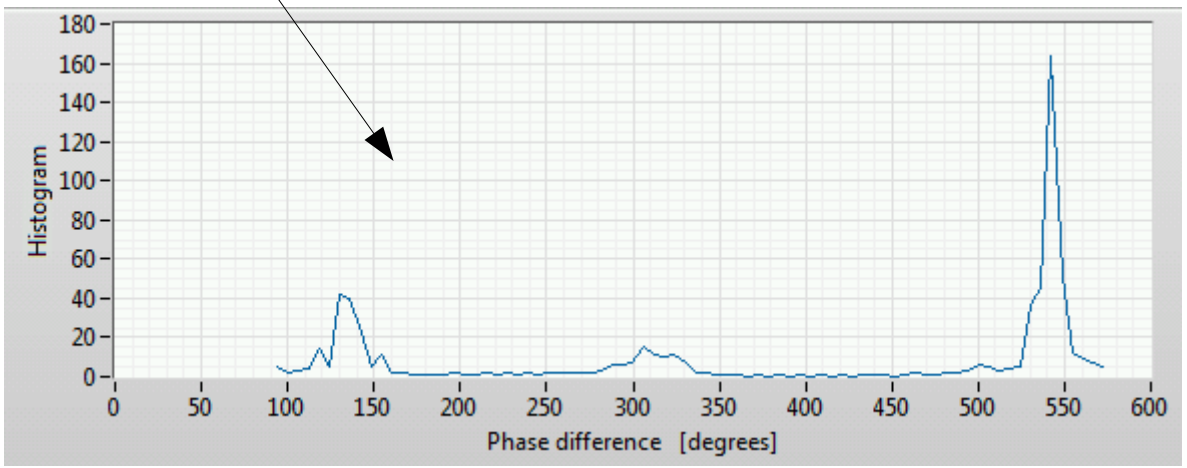
Fit parameters (in mm): Pos_1 = 14.8 Pos_2 =16.9 Pos_3 = 18.9 Pos_4 = 21.2

all Δ ≈ 2.2mm → 2 mm

Structure of the phase difference

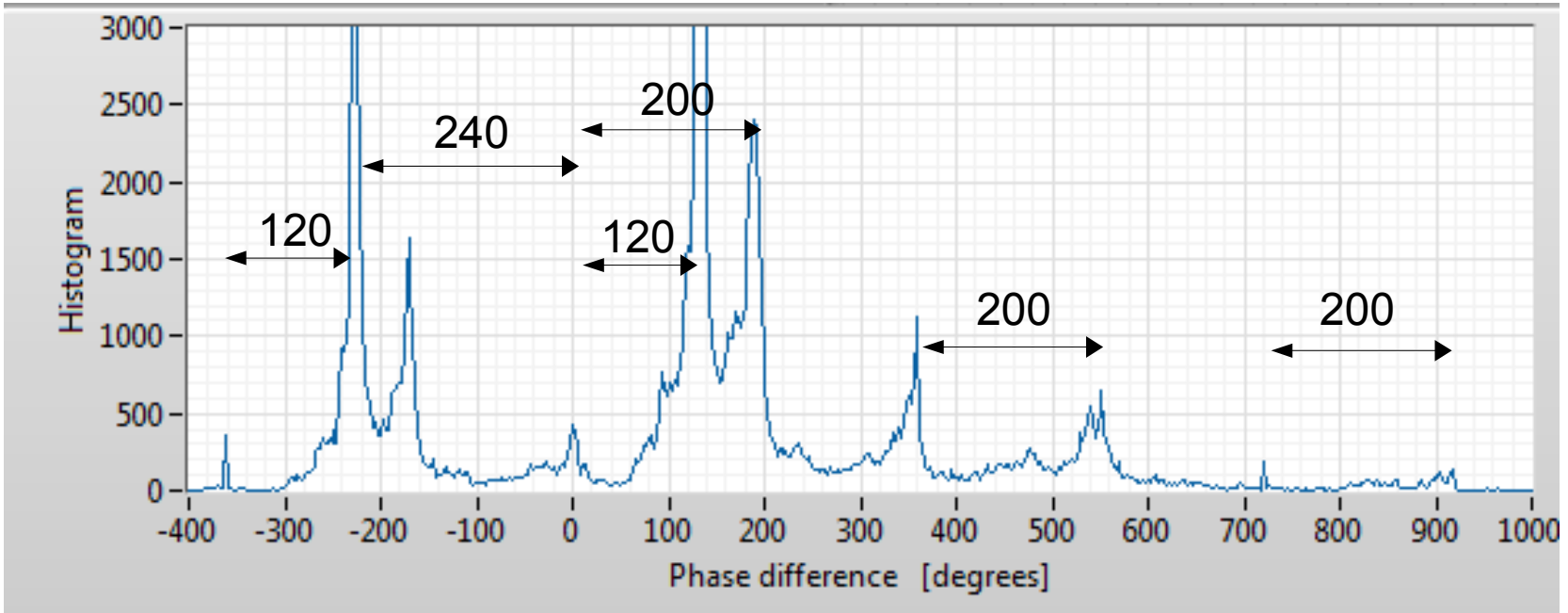


Project the phase difference to a histogram



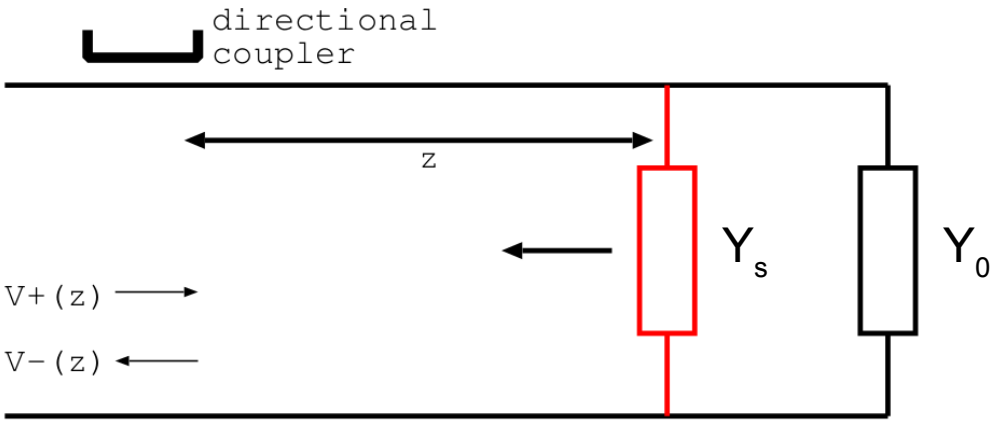
And repeat ~300 times

Structure of the phase difference



Structures in the phase difference.
Peaks are separated by multiples of 100° to 120° –
phase advance of the structure –
suggesting that BD jumps between consecutive irises

Longitudinal discharge dynamics

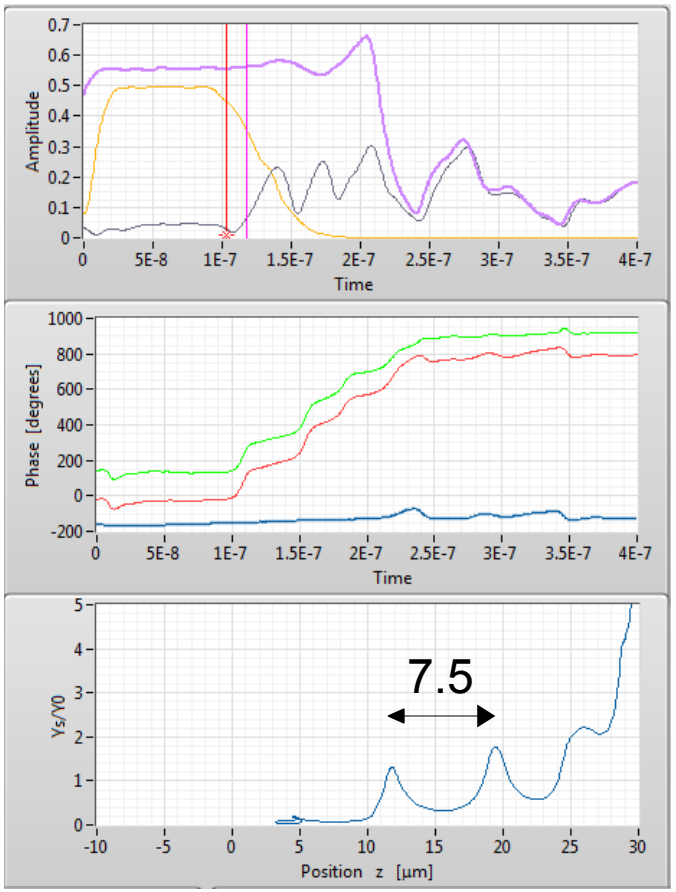


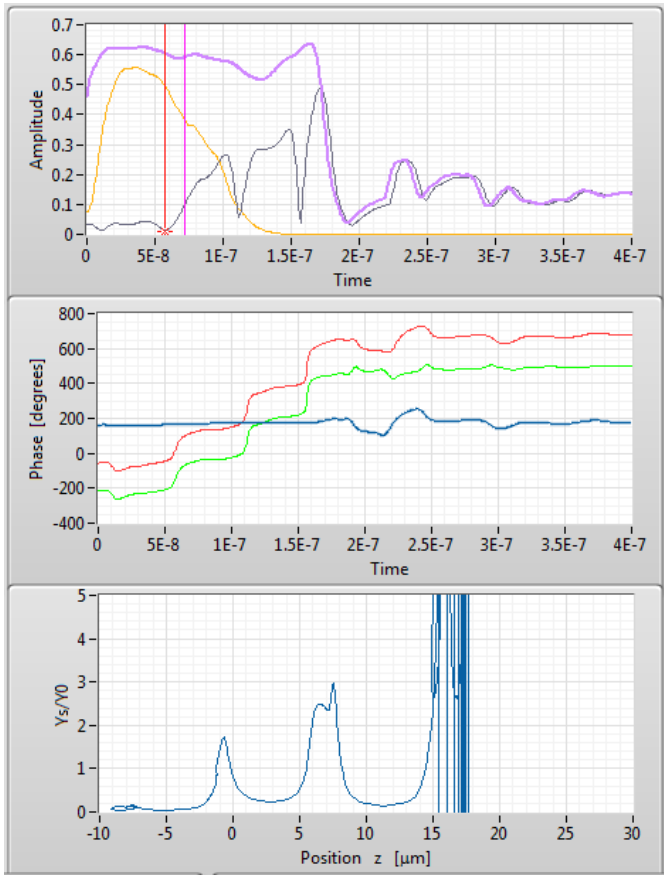
Field reflection can be seen as reflection on a mismatched load in the structure

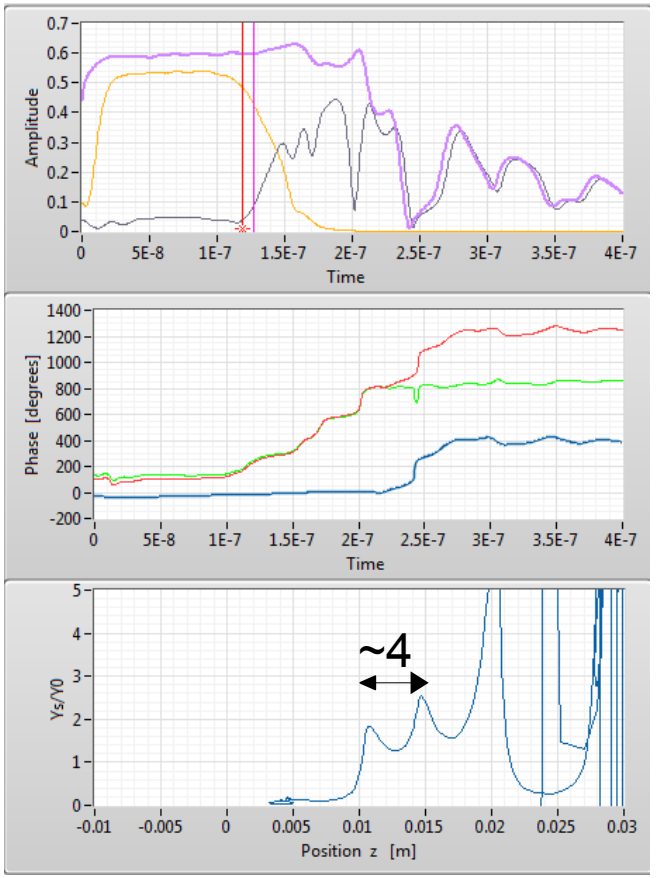
Simple model → mismatched in the load can be interpret as plasma growth

- the ratio of conductances Ys/Y0 is related to amplitude ratio of incoming (V+) and reflected (V-) signals – plasma density
- breakdown position z is related to the phase difference between the incoming and reflected signals – position of the plasma

Longitudinal discharge dynamics







The ratio of the amplitudes of the conductance is often more than 2
The peaks often spaced about 7.5 mm apart (cf with distance between the iris of a 2π/3 structure – 8.3 mm) (sometimes half that distance)

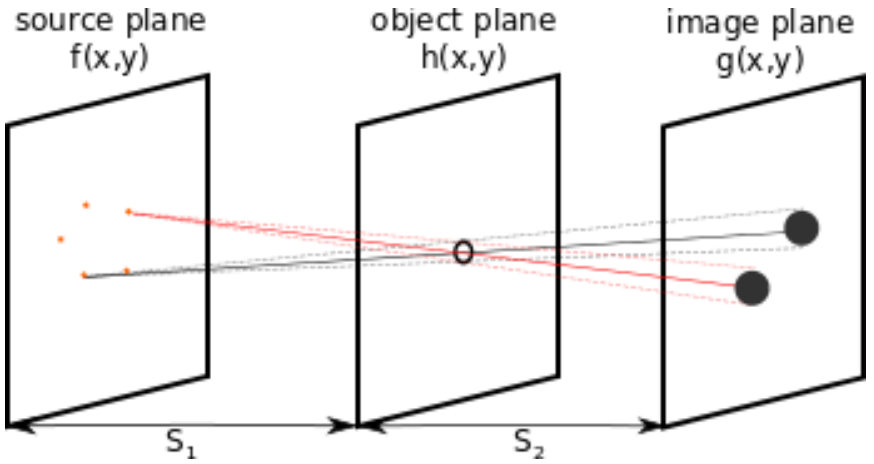
$$A(t)e^{2\mathrm{jkz}} = \frac{V^{refl}(z)}{V^{inc}(z)} = \frac{-e^{2\mathrm{jkz}}}{1+2\,Y_0/Y_S}$$

Interpretation

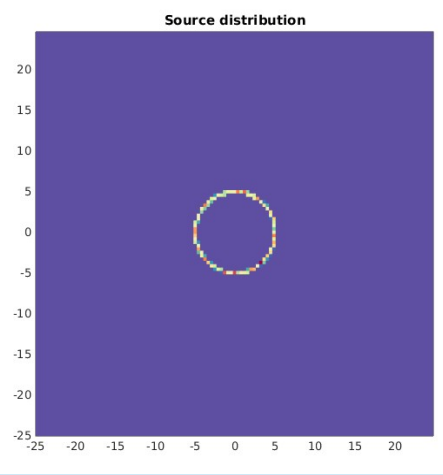
- Simple model with plasma build-up gives inside to longitudinal dynamics
- RF reflected signal shows clear indications of multiple breakdowns – both on amplitude and phase
- Multiple phase jumps indicate longitudinal movement of the discharges. Is it a cascade or separate build-up at a new site?
- The activity on the spectrometer screen reflects the activity on the reflected pulse – in terms of intensity and visible features
- No signal on the preceding/following images
- The images indicate movement of the discharges / creation of new BD sites – this will be investigated next

Can we extract source distribution from the image?

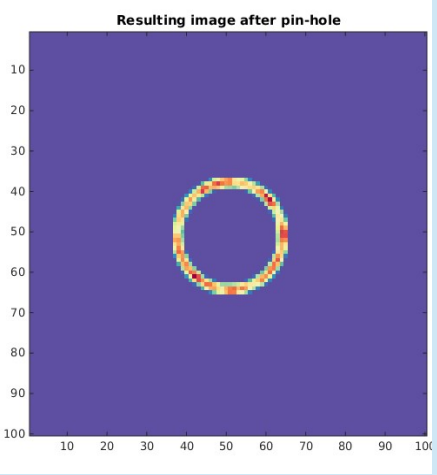
Treating setup as a linear system – analytic solution



Source distribution from circular iris



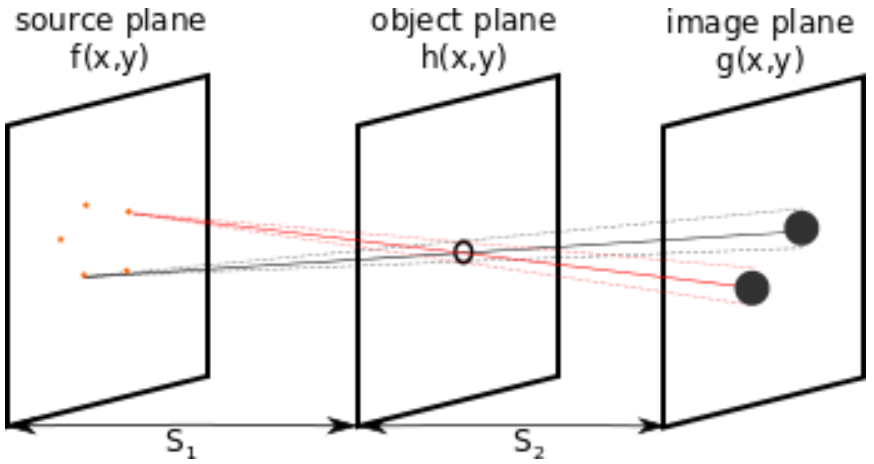
Resulting image after pin-hole



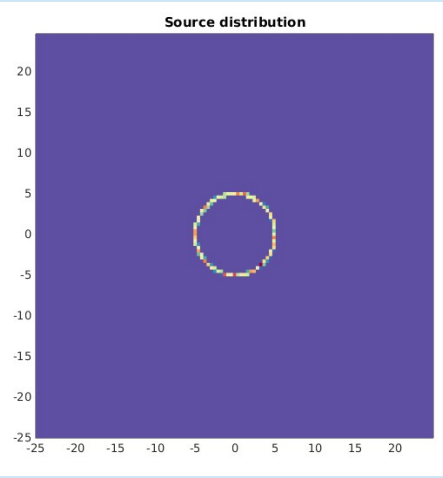
Convolution

$$g(x,y) = f(x,y) \otimes h(x,y)$$

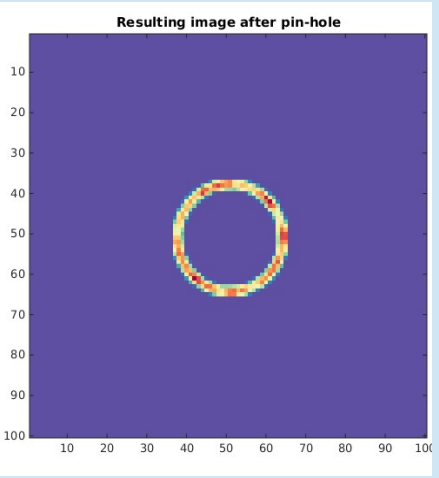
Treating setup as a linear system – analytic solution



Source distribution from circular iris



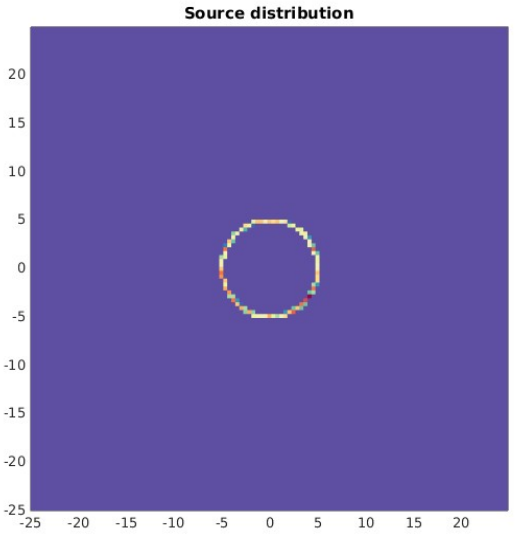
Resulting image after pin-hole

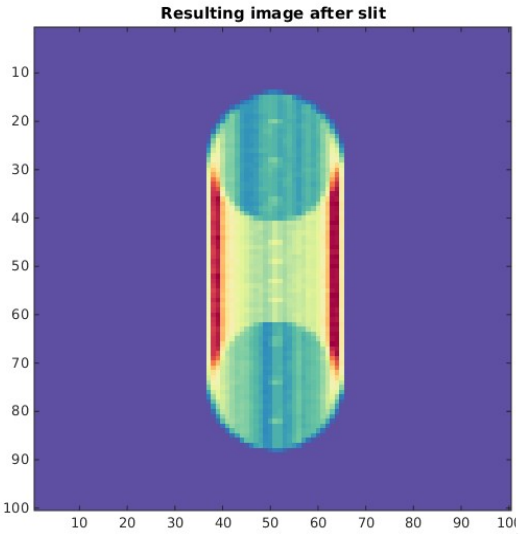


Convolution

$$g(x,y) = f(x,y) \otimes h(x,y)$$

Same distribution at source
But image is form through a slit





Simulation/reconstruction – analytical formula

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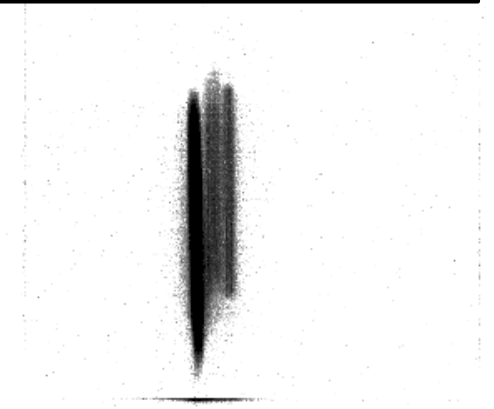
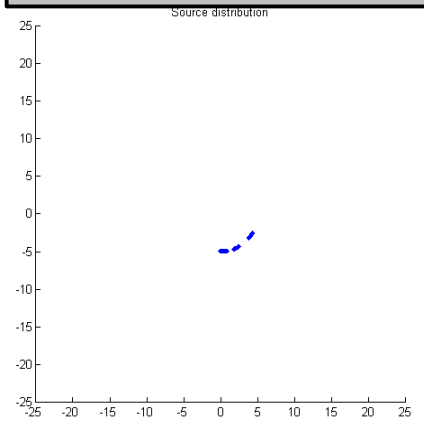
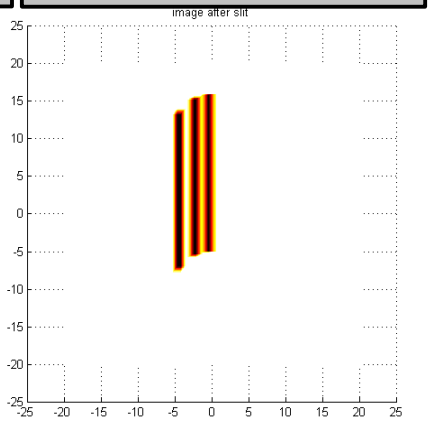
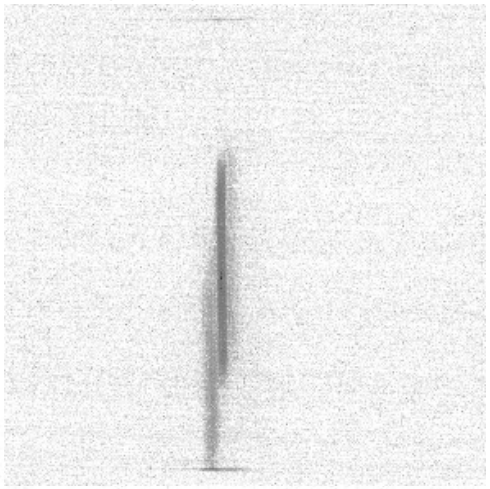
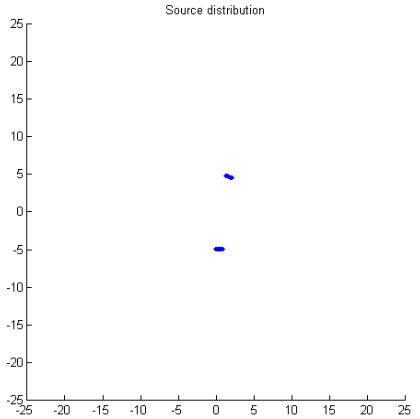
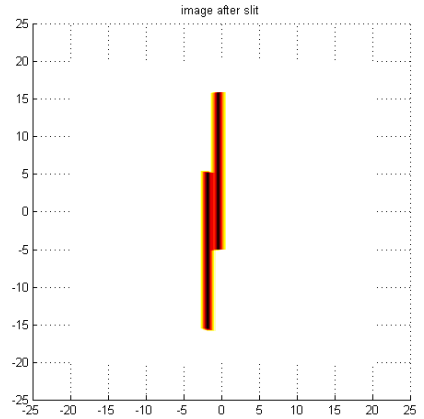
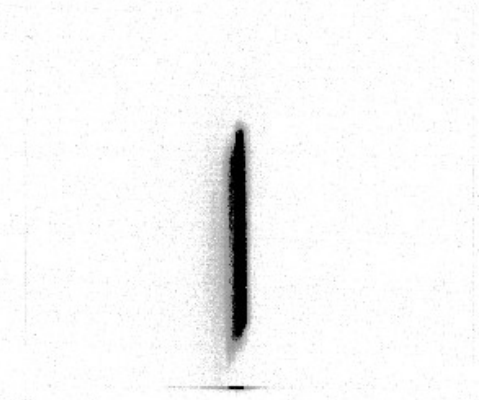
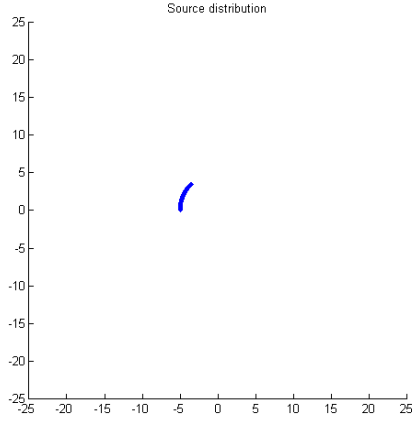
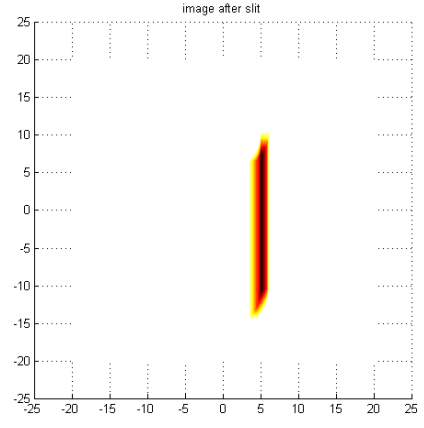
Three examples

Creating image by projecting source distribution through a slit

Experimental images	Source distribution on iris	Distribution after slit
		
		
		

Transverse position reconstruction

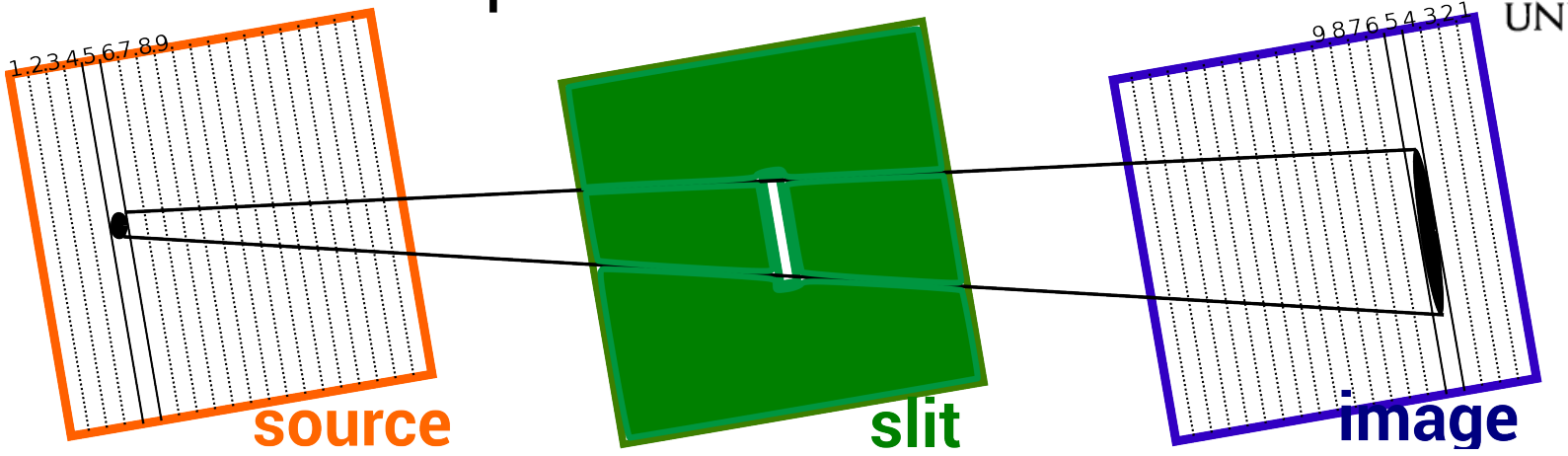
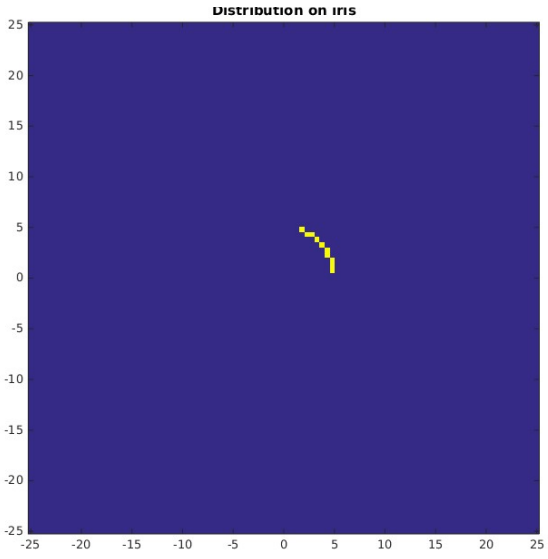
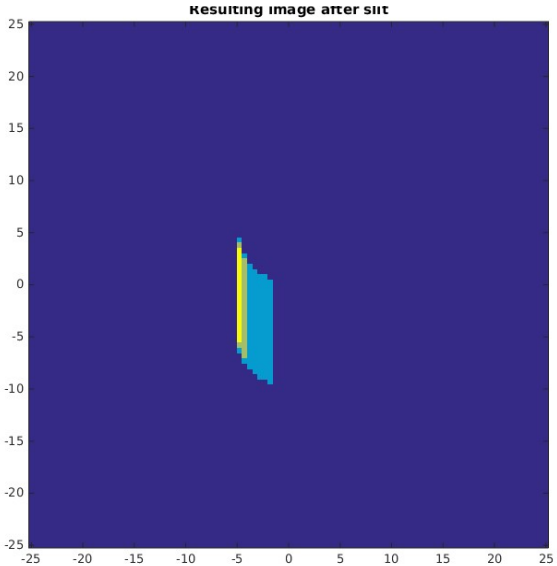
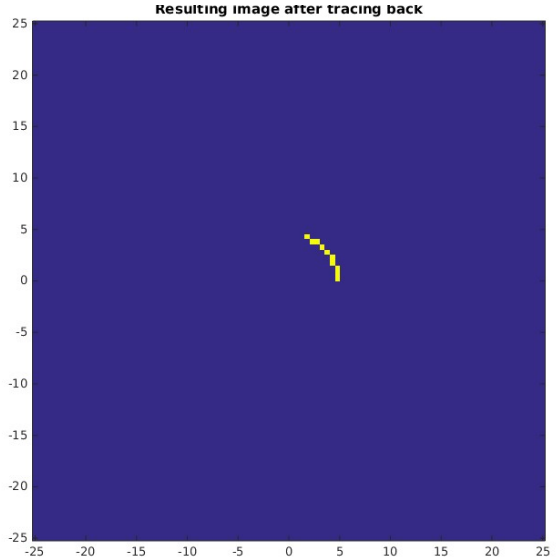


Image is created by calculating a series of 1D convolutions - each column of the source distribution with slit function

Simulation







This way we avoid the influence of the slit's width on the constructed image

Price to pay – lower resolution

Back-reconstruction is done in the same way, by starting from the registered image and deconvolution in 1D the source column

This method proved most robust with the presence of the noise than any 2D convolution methods

Transverse position reconstruction

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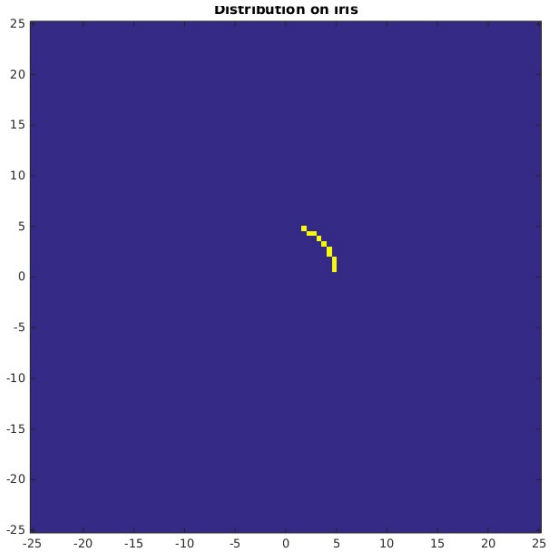
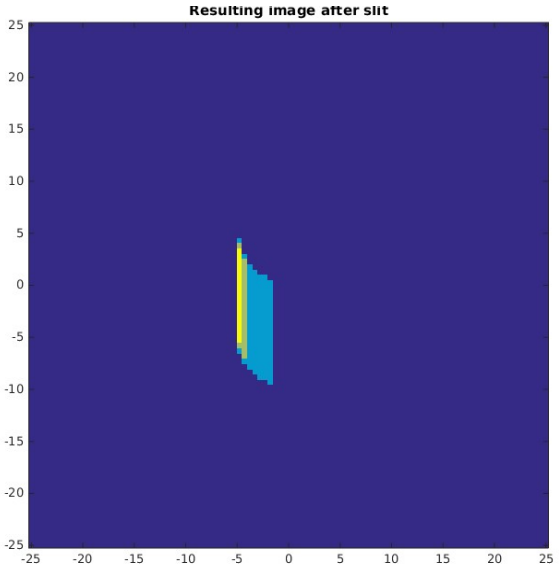
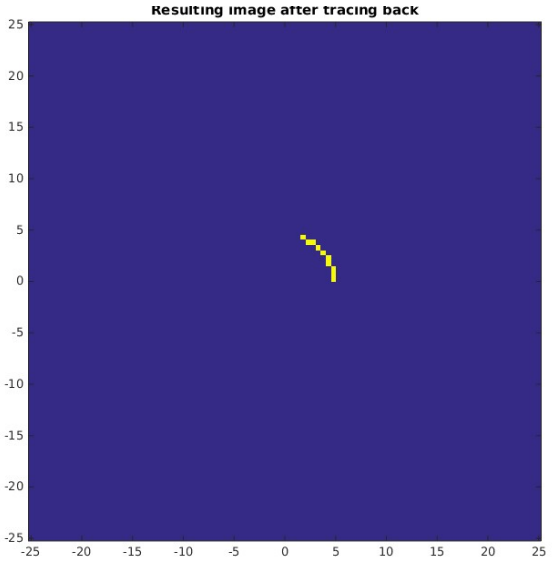
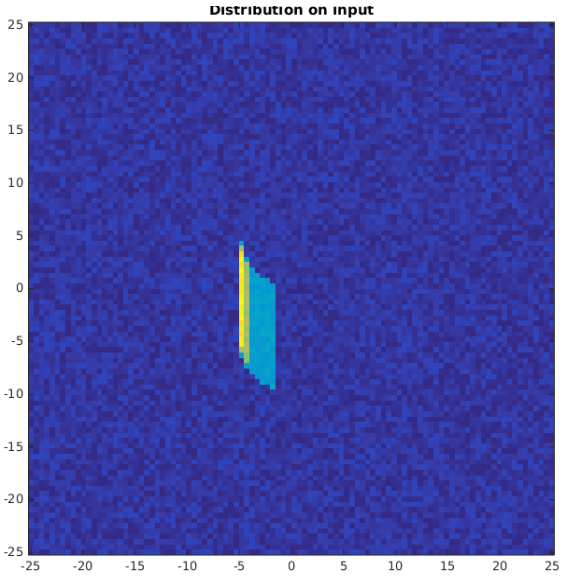
Deconvolution with slit transfer function - simulation

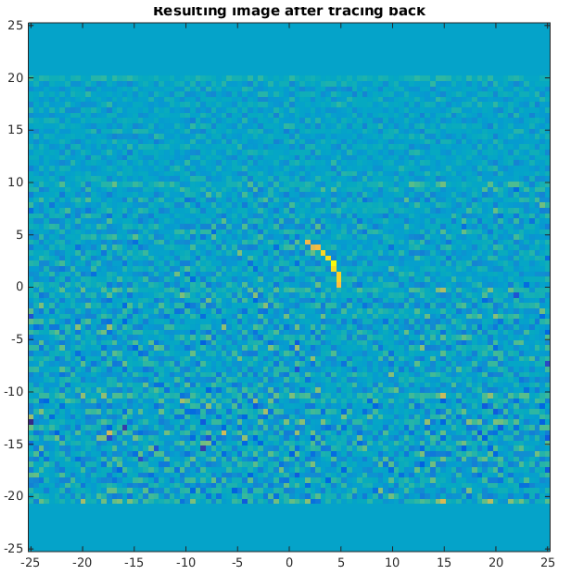






With added
25% noise





Transverse position reconstruction

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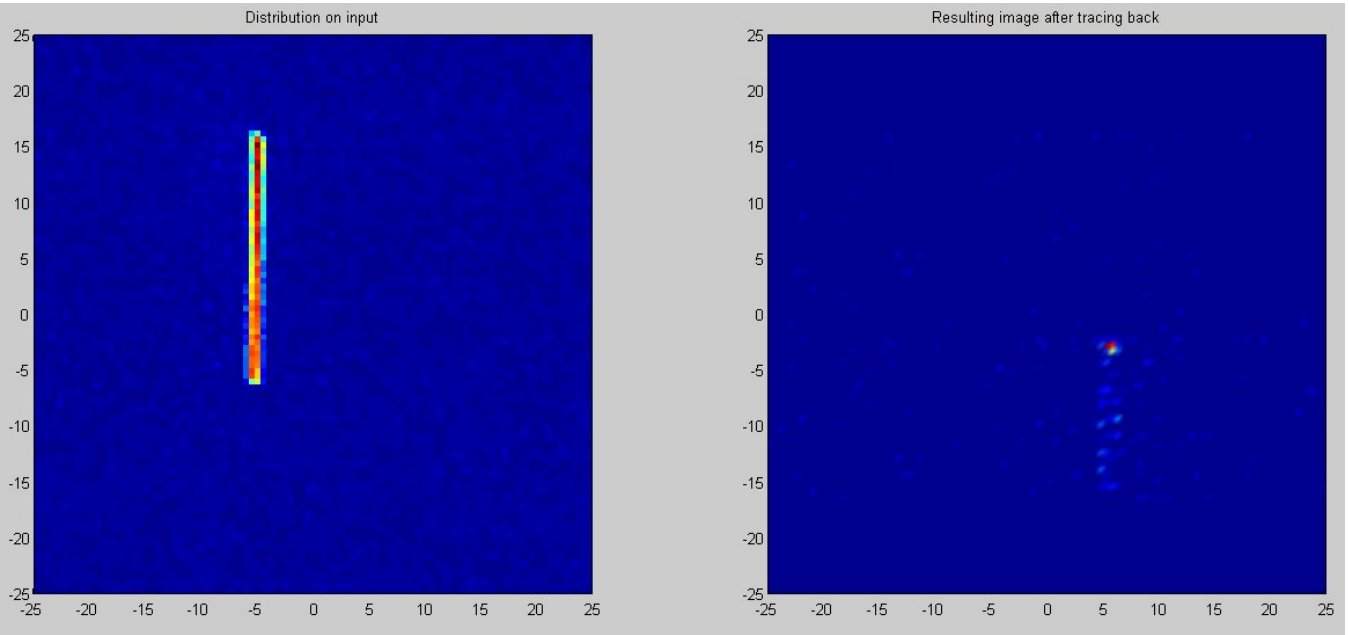
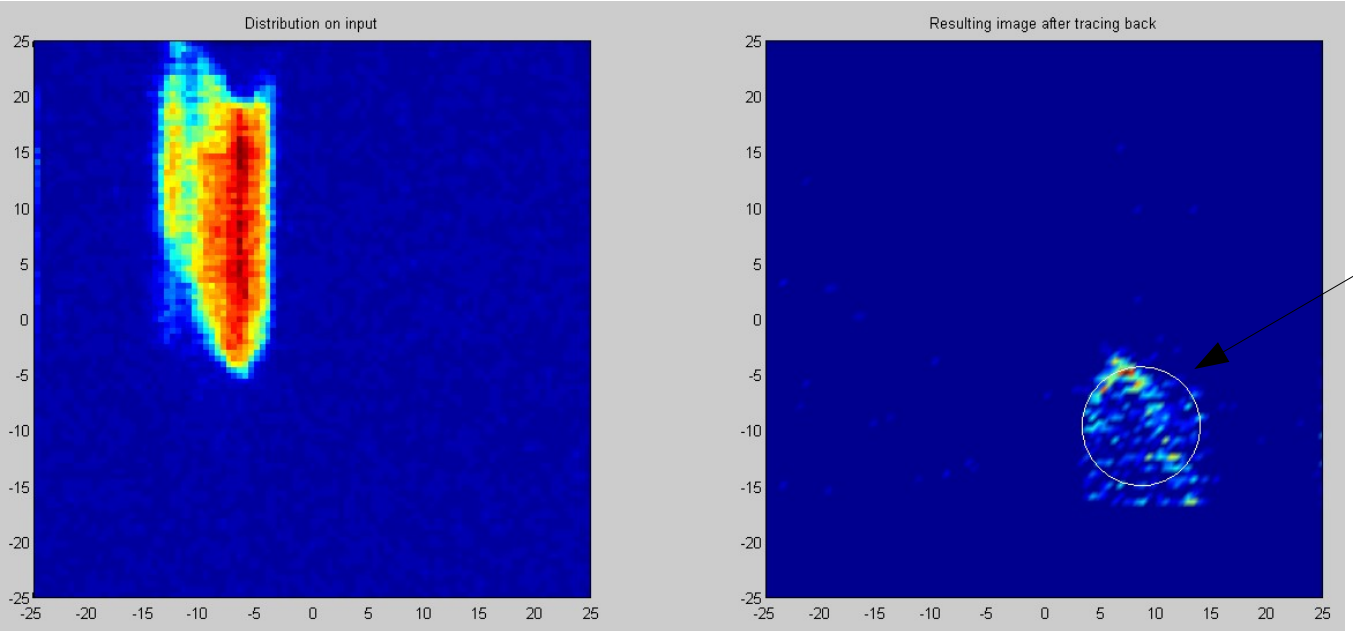
Deconvolution with slit transfer function – experimental images

Pixel size reduced to match the slit's width = 0.5mm



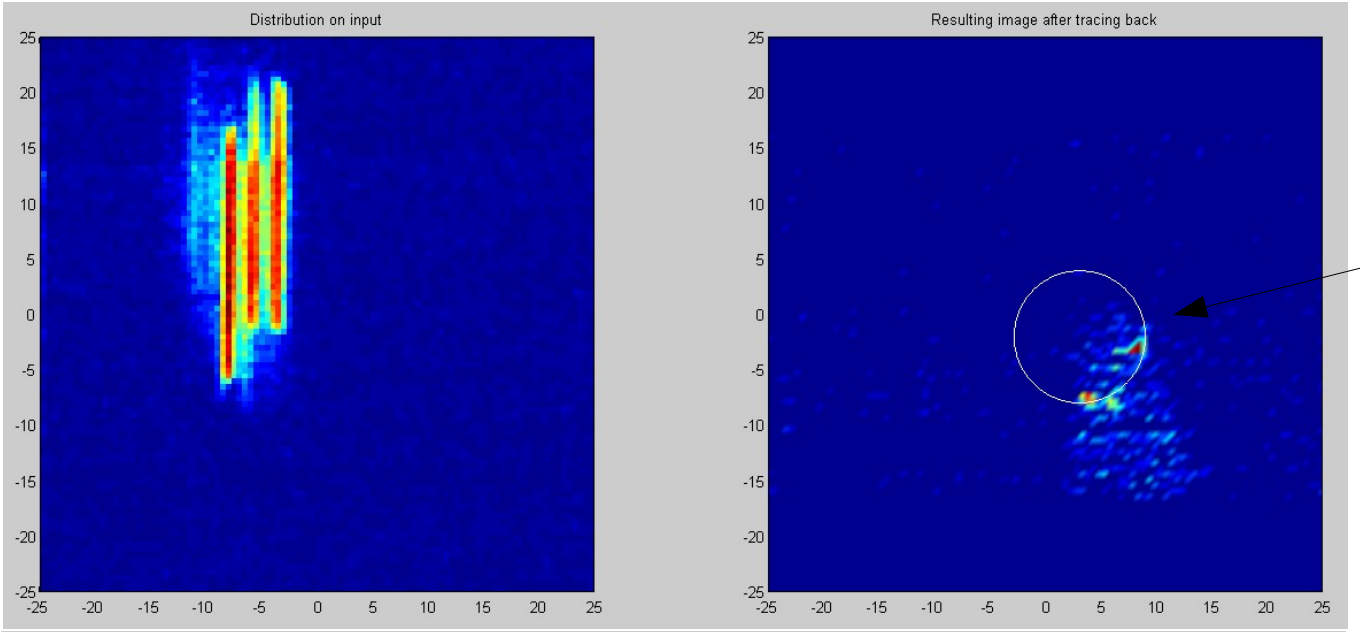


Single slit resulting in a single spot at the source

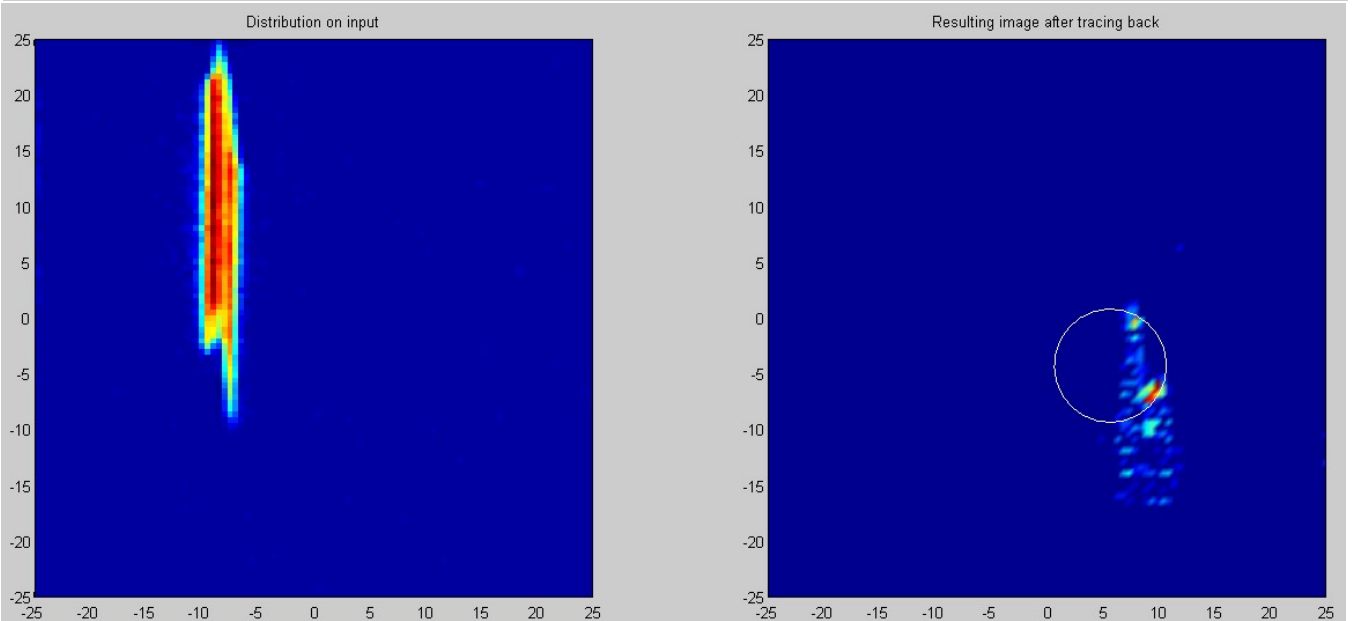
Circle with Φ =10mm

Transverse position reconstruction

Deconvolution with slit transfer function – experimental images



Circle with Φ =10mm



Summary

- Good and stable performance of the UCXS during commissioning
- UCXS fully synchronized with conditioning system
- Information on the **size** and **displacement** of the discharges during RF pulse could be available for the first time:
  - Longitudinal BD position from phase jumps/timing
  - Transversal BD position from deconvoluted images
- More information about plasma (density) can be extracted from impedance model
- Correlations of image intensity with other BD parameters under investigation
- Xbox2 restarting with a T24 CLIC accelerating structure.

  UCXS is ready for it!

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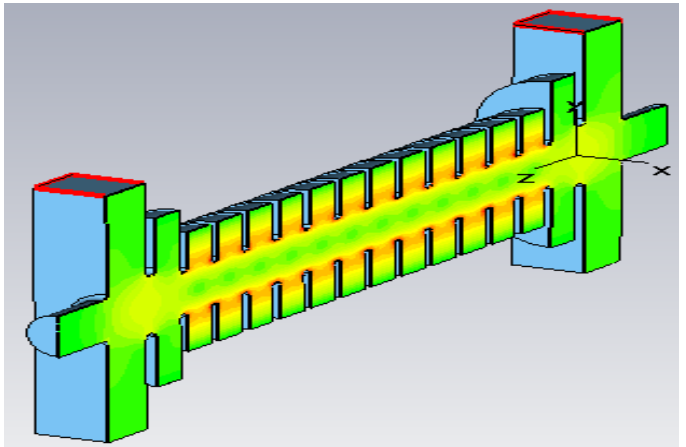
Acknowledgement

MANY THANKS TO XBOX TEAM!

In particular to Ben Woolley for the discussions and technical support!

FREIA

Spares



Parameter	Value
Transverse kick (20 mrad)	2.553 MV
Frequency, phase	11.9942 GHz, 2π/3 rad
Total length	150 mm
Active length	83 mm (10 cells)
Iris radius, group velocity	5 mm, 2.92 %
Input power	16.05 MW (11.6 MW for 12 cells)
Peak surface electric field	102 MV/m
Peak surface magnetic field	352 kA/m
Peak pulsed heating, ΔT	27 K (242 ns pulse)

Courtesy of G. Burt, et. al.

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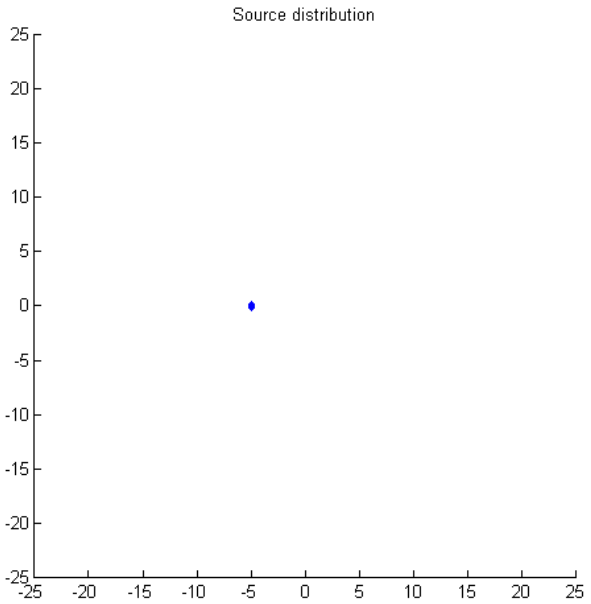
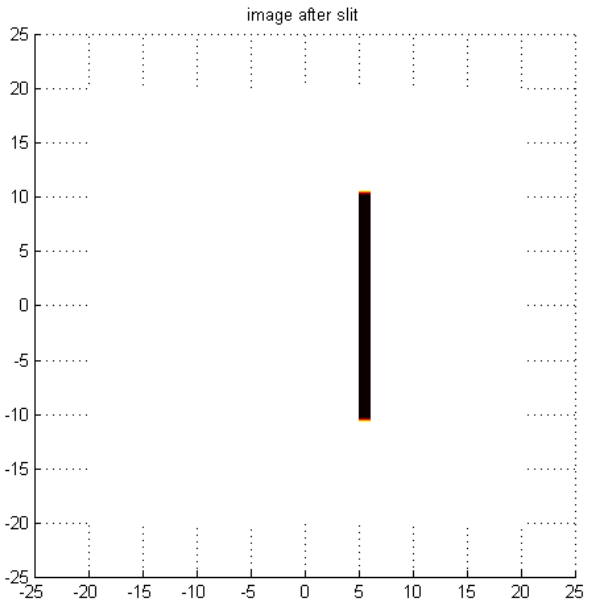
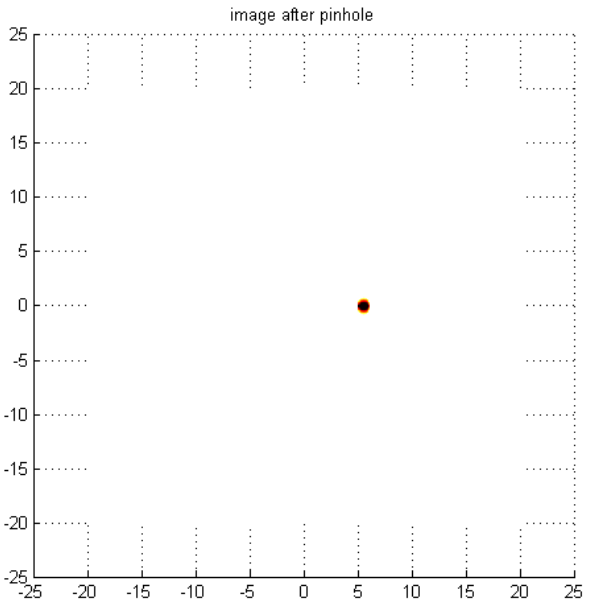
Can the recorded pattern be explain by longitudinal translation?

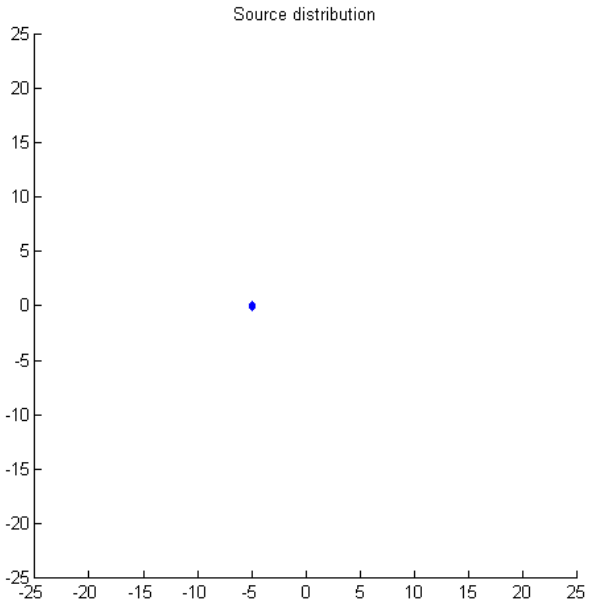


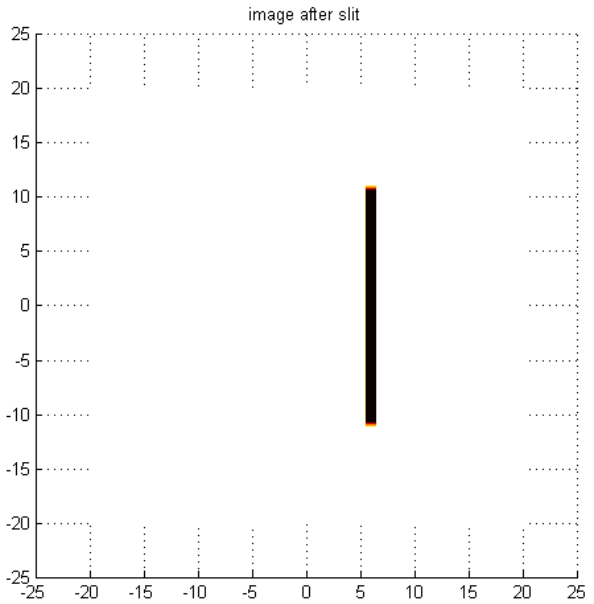


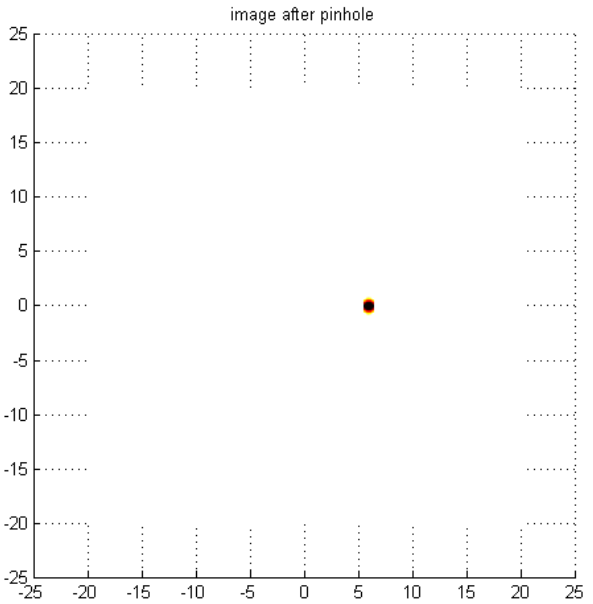


Simulation with a small source at the middle of the crab cavity

Can the recorded pattern be explain by longitudinal translation?

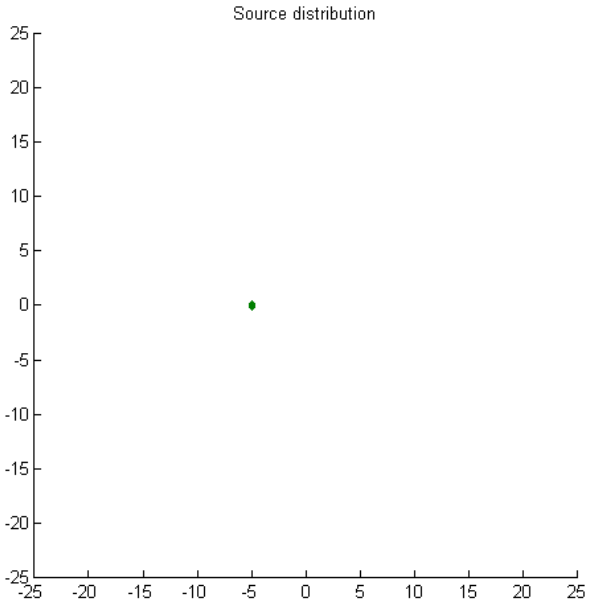


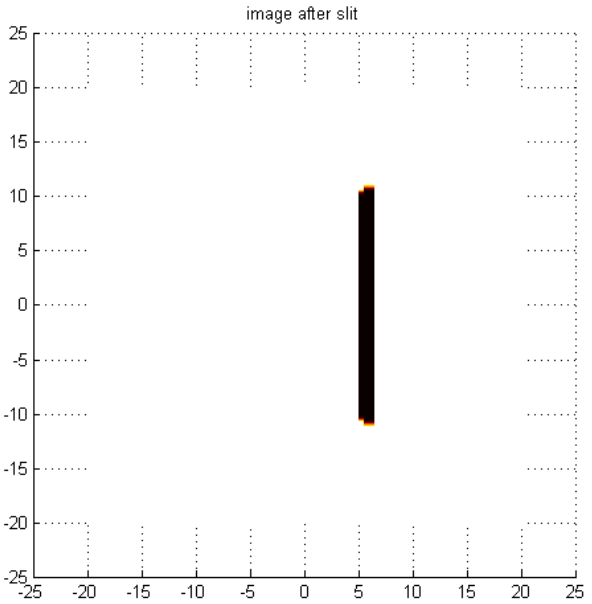


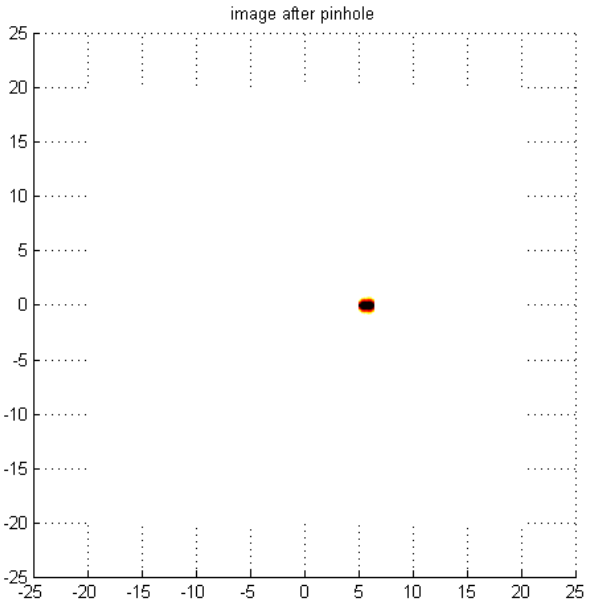


Simulation with a small source at the beginning of the crab cavity – 50 mm shift

Can the recorded pattern be explain by longitudinal translation?







Together on the same plot

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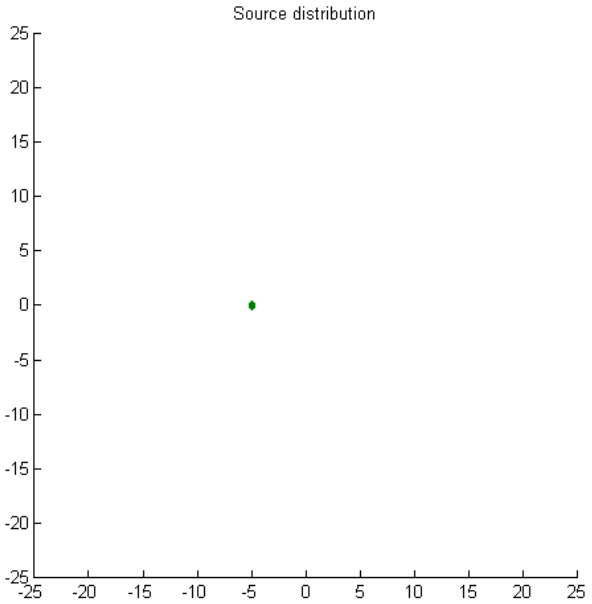
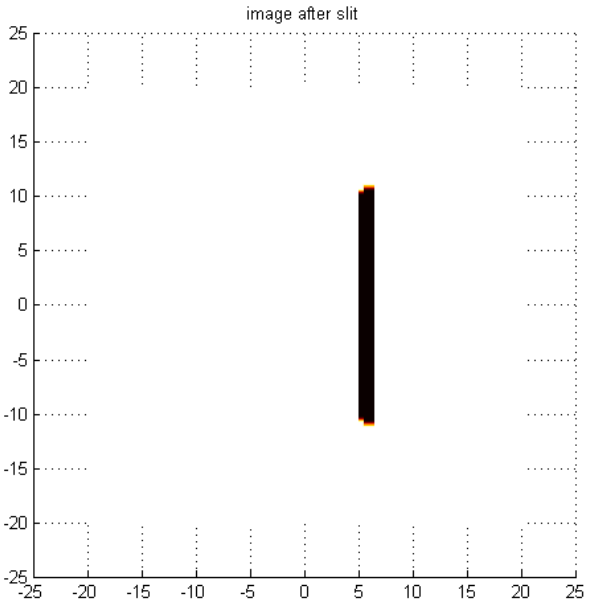
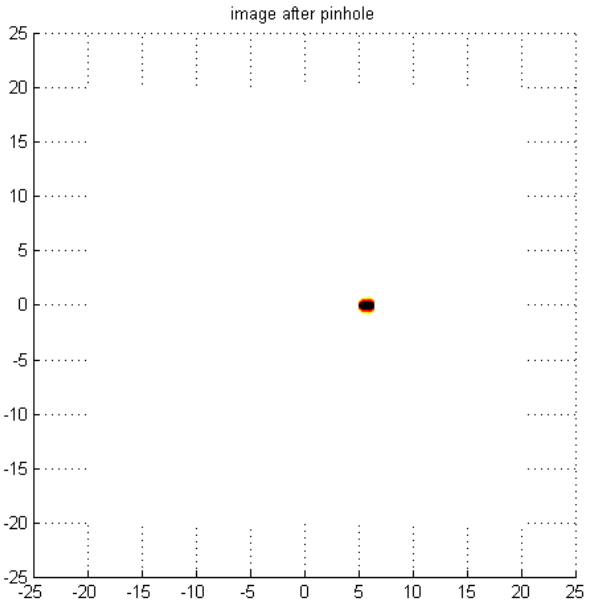
Can the recorded pattern be explain by longitudinal translation?







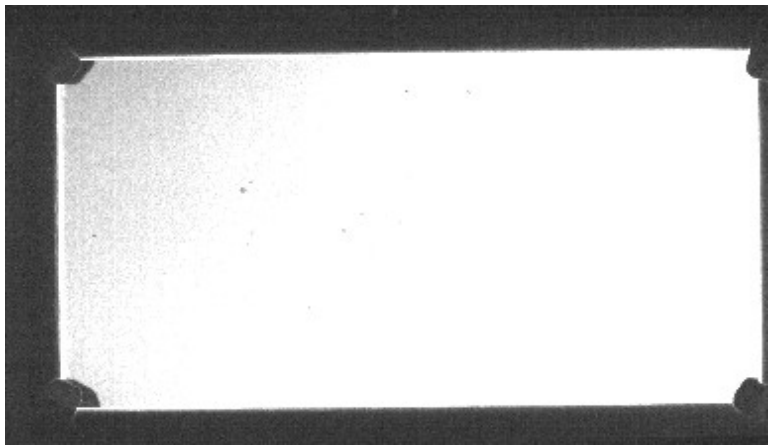
Together on the same plot

The answer is : **NO**

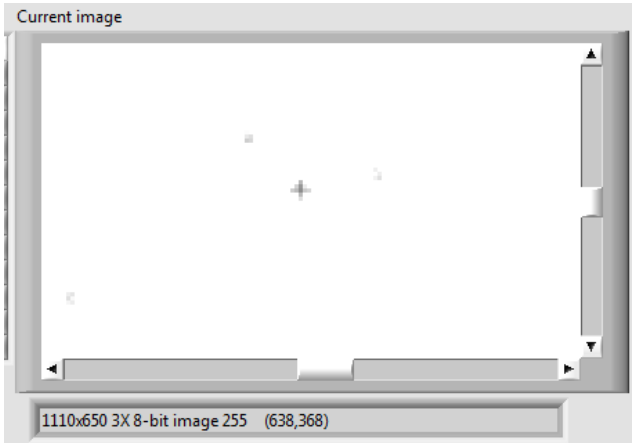
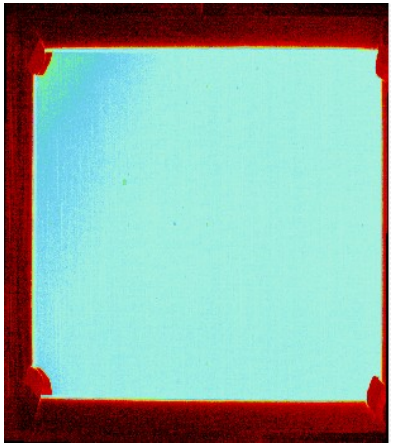
In addition:
The magnet was off during the commissioning and remnant field was measured to be max 0.11 mT (cf with Earth mag. field 0.03-0.06 mT)

Calibration

Using events without collimator (fully extracted)



Five markers 0.5 x 0.025 mm



After calibration