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Breakdown Tomography with Emitted Electrons

UCXS
Uppsala/CLIC X-Band Spectrometer

M. Jacewicz, R. Ruber and V. Ziemann

FREIA

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Outline

- The instrument
- Example of BD events as registered with setup at XBox2
- Breakdown location methods
  - Longitudal
  - Transversal
- Summary

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

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

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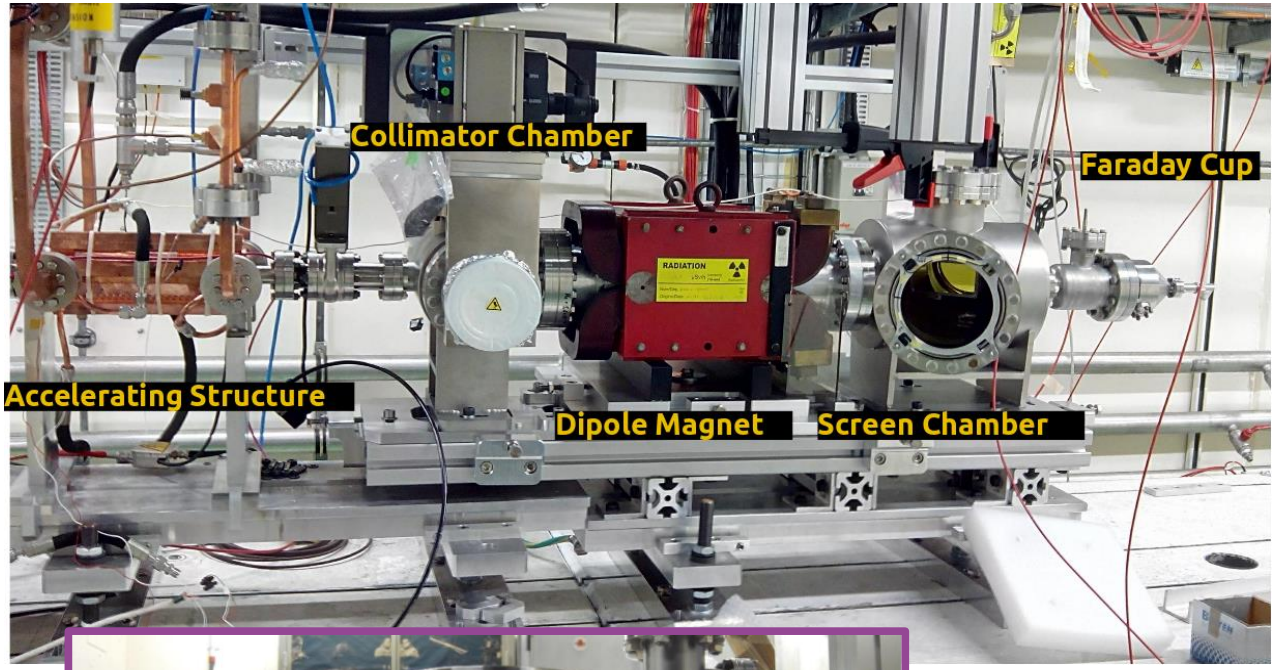
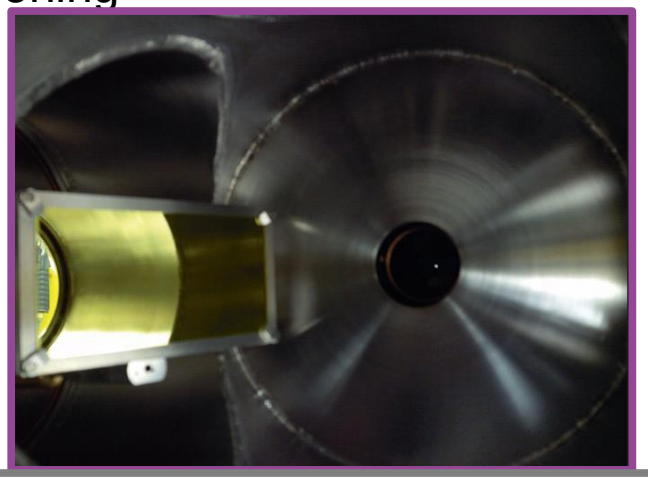
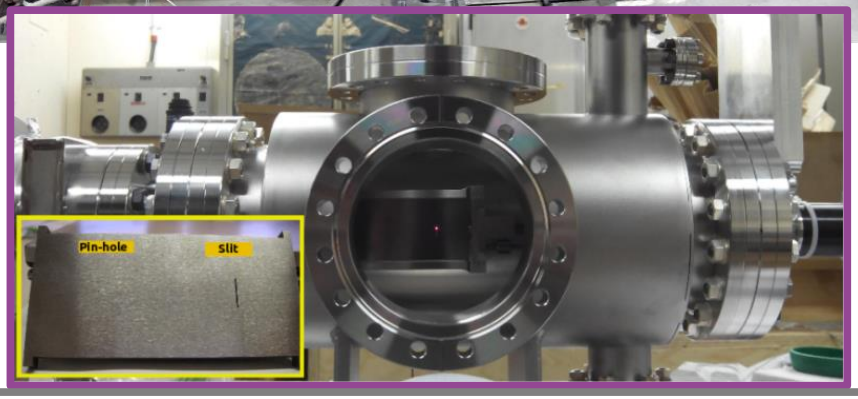




Screen (100x50x0.5 mm YAG:Ce)
linear actuator (fully retractable)
30 degrees angle w.r.t. the beam axis
2M pixel, 50fps camera with focuser



Energy resolution with dipole magnet

Maximum electron energy	<20MeV
Rel. energy spread (single slit)	10% - 25%

Full energy coverage with magnetic field scan

Collimator (5 mm tungsten plate)
linear actuator (fully retractable), place for two patterns,
presently: **pin-hole** 0.5mm and **slit** 10x0.5mm
Electrically insulated (for use as a Faraday cup)

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UCXS - presently at XBox2

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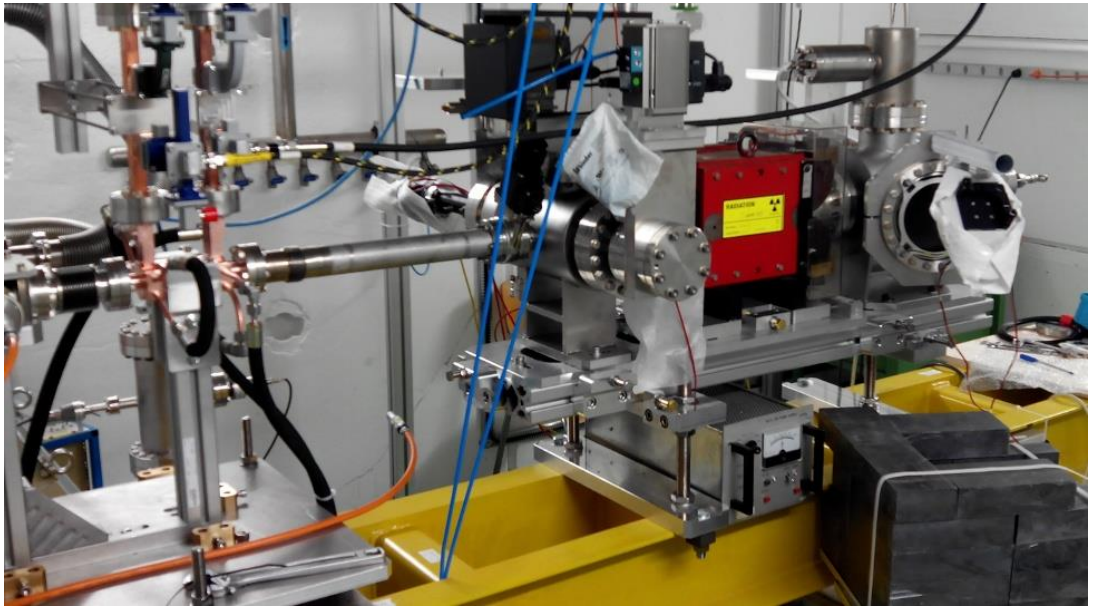

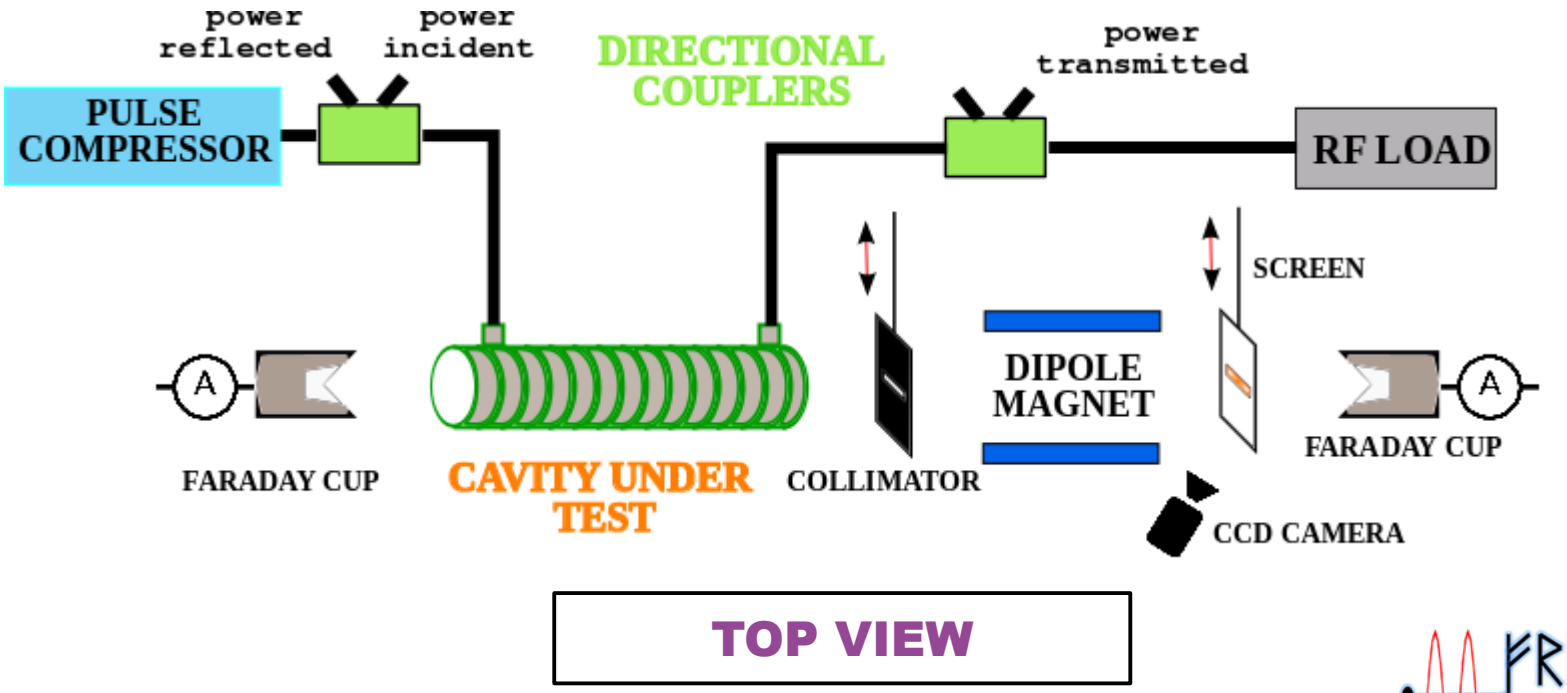

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Status

- Spectrometer commissioned with Crab Cavity in Spring 2015 **(CC)**
- Presently operates with CLIC-G-OPEN ACS T24 **(T24)**
- All diagnostics information available for the breakdown events is combined with images from the camera, 50 Hz operation
- The magnet was tested but not used so far

Some typical events with the **slit (CC)**

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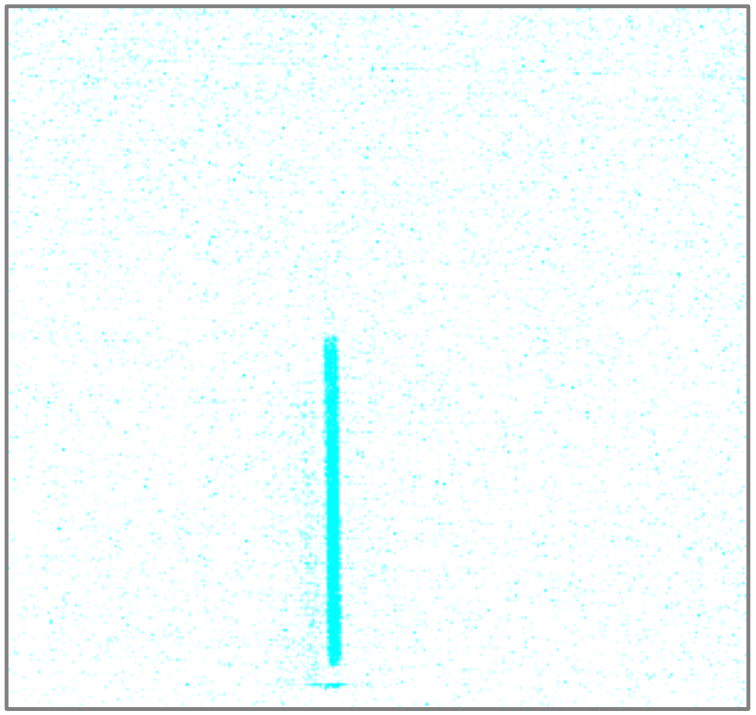
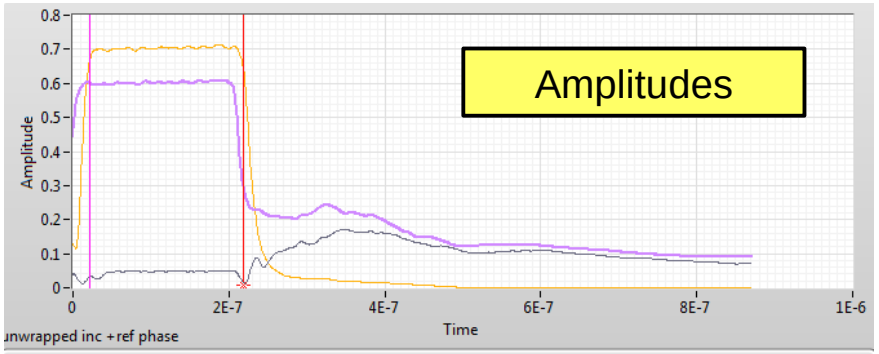
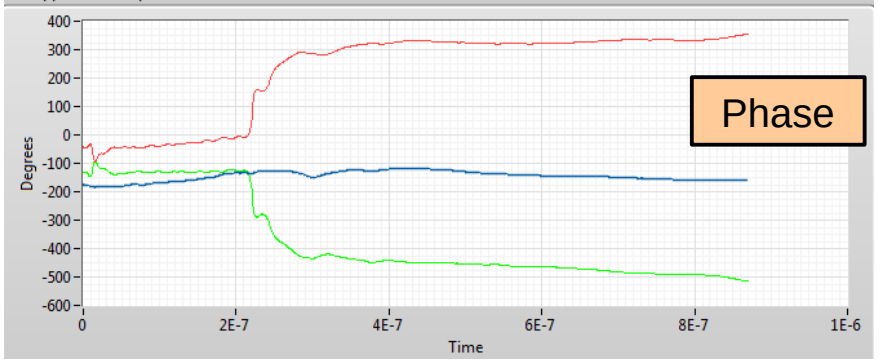






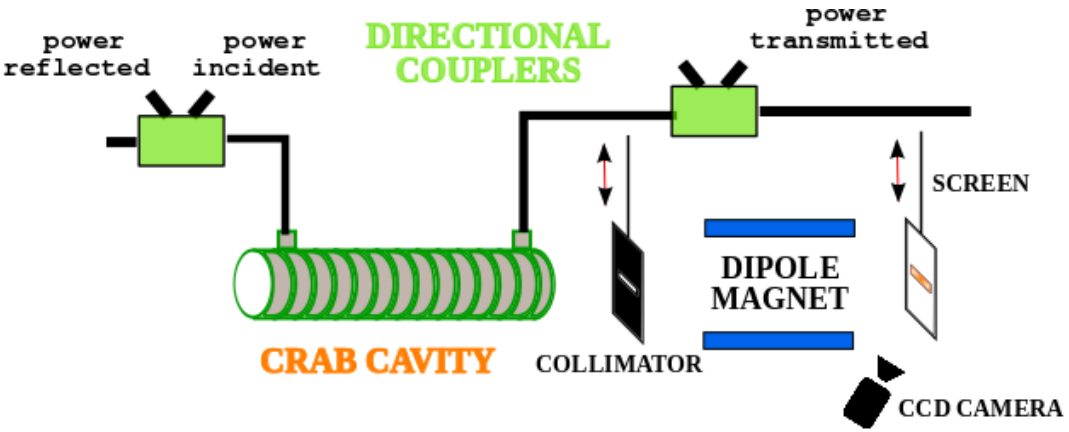
Amplitudes:
RF In
RF Transmitted
RF Reflected

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



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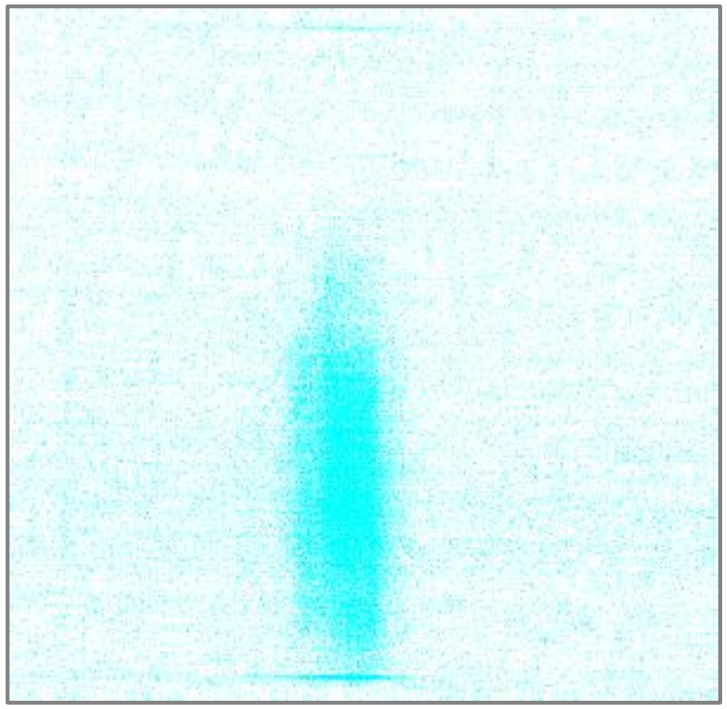
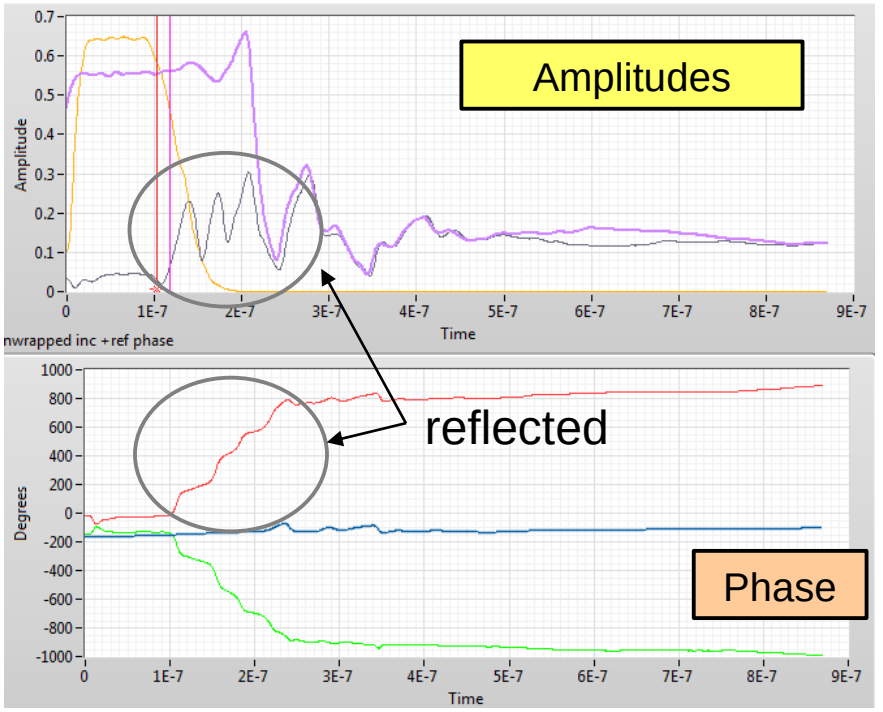
Some typical events with the **slit (CC)**





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** (CC)

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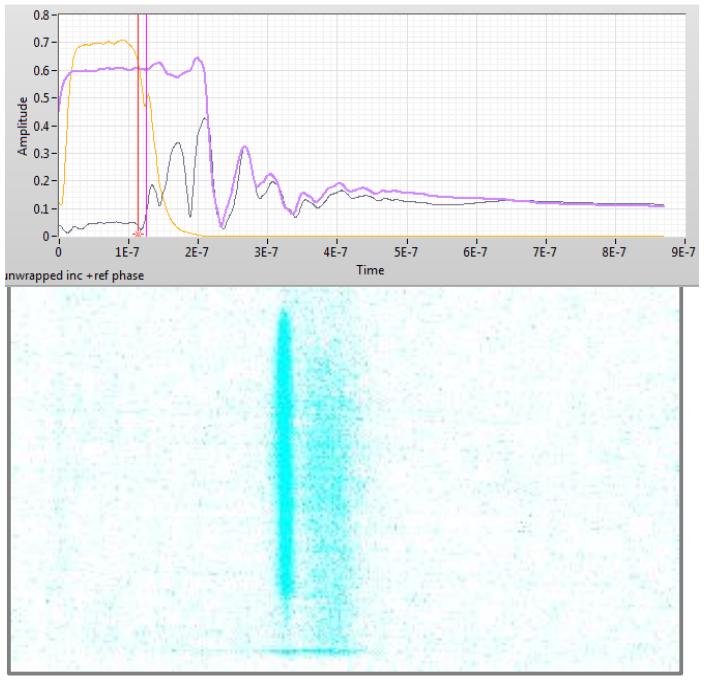

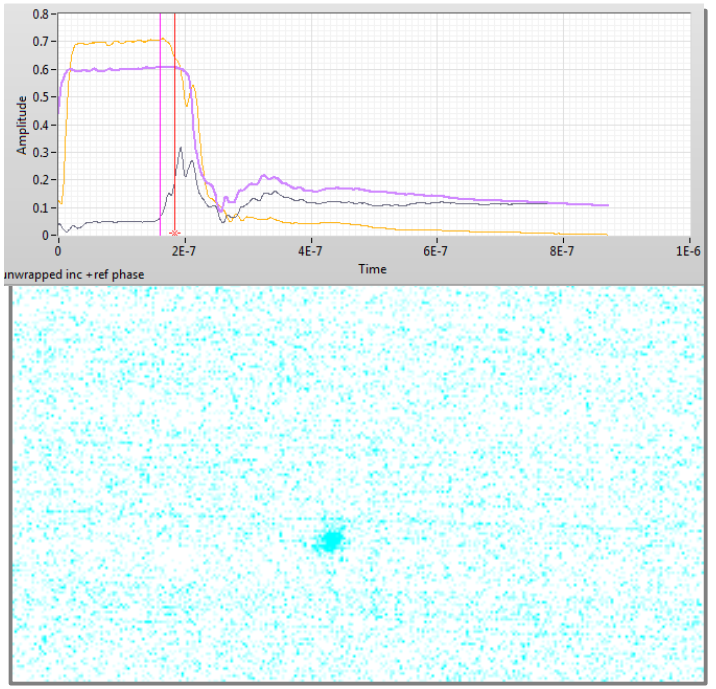

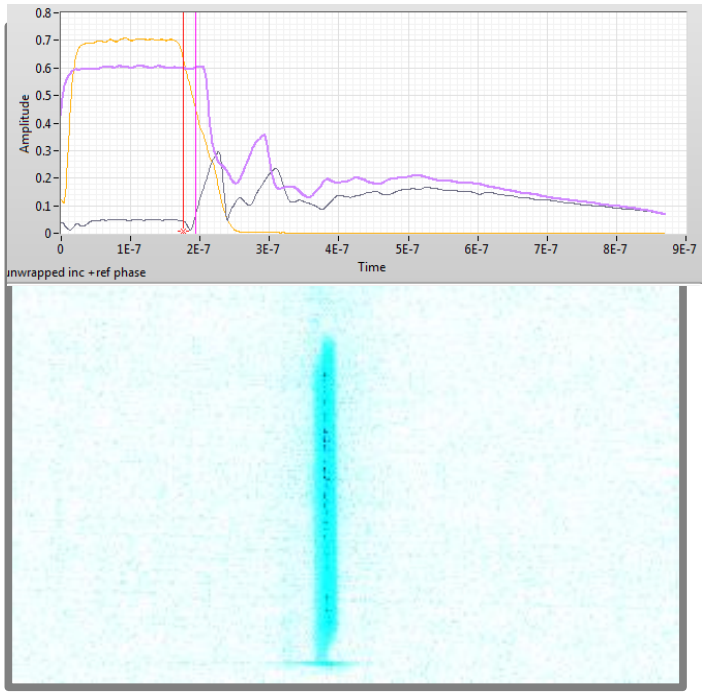

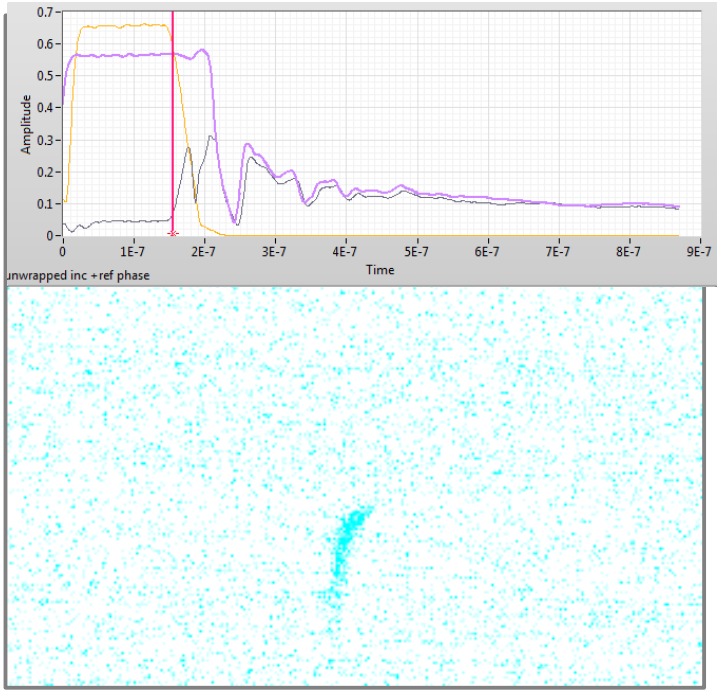

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Feature extraction (CC)

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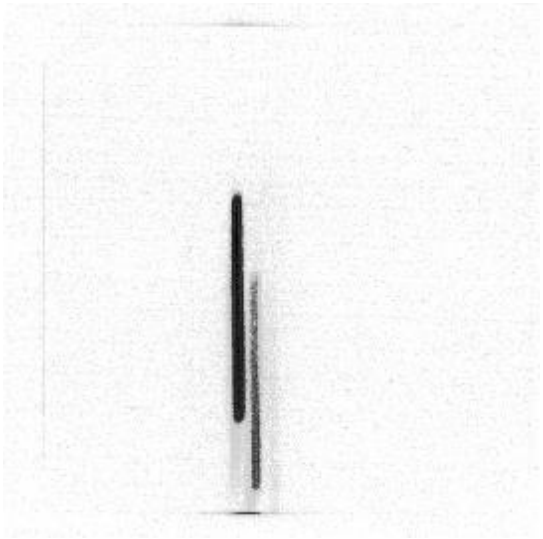
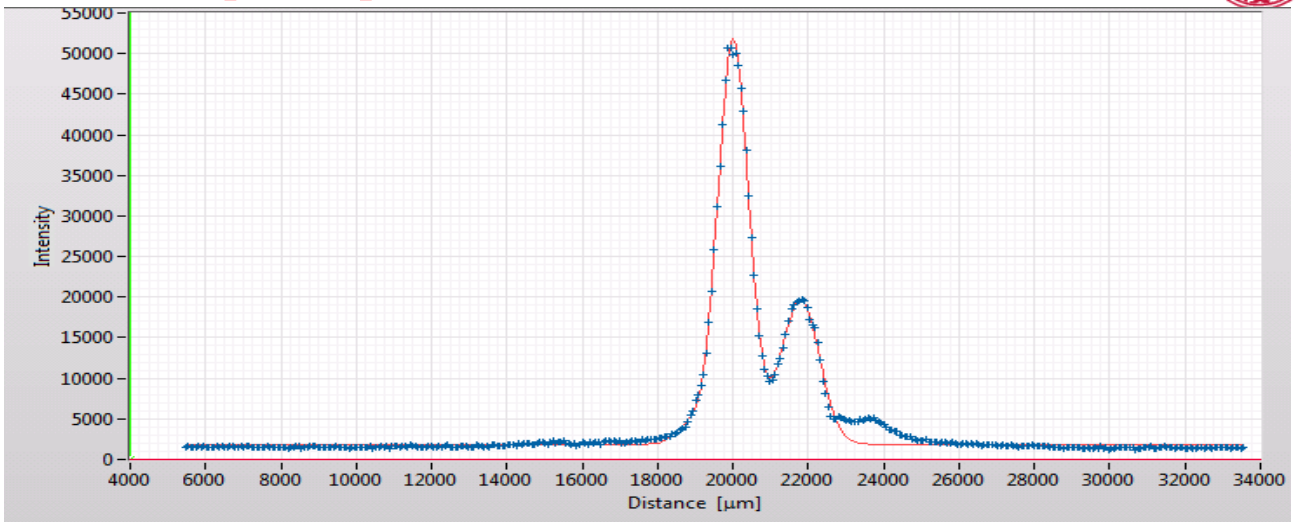
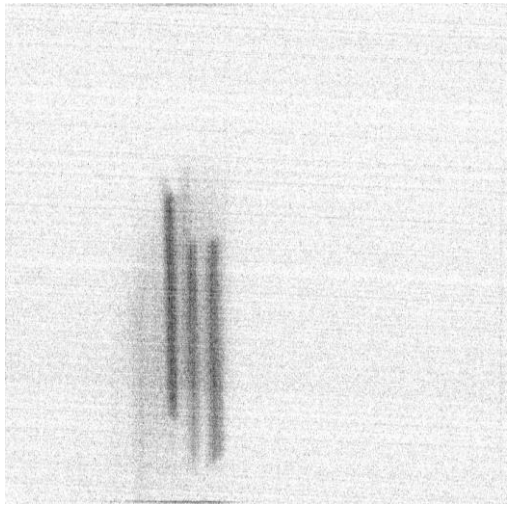
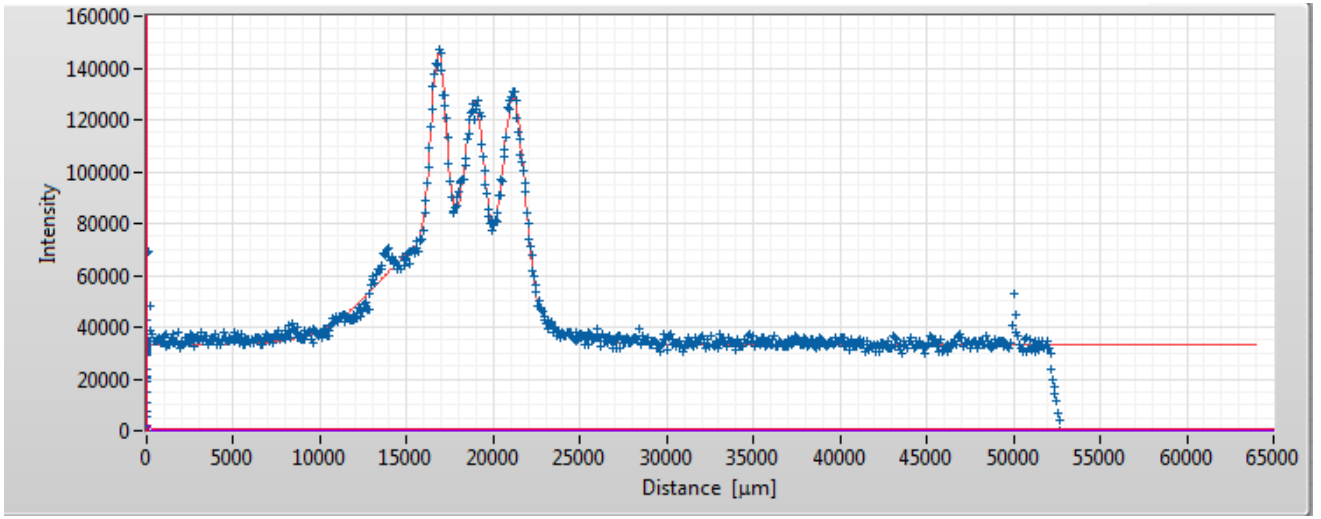




Fit parameters (in mm): Pos_1 = 19.6 σ_1 = 0.463, Pos_2 = 21.8 σ_2 = 0. 504

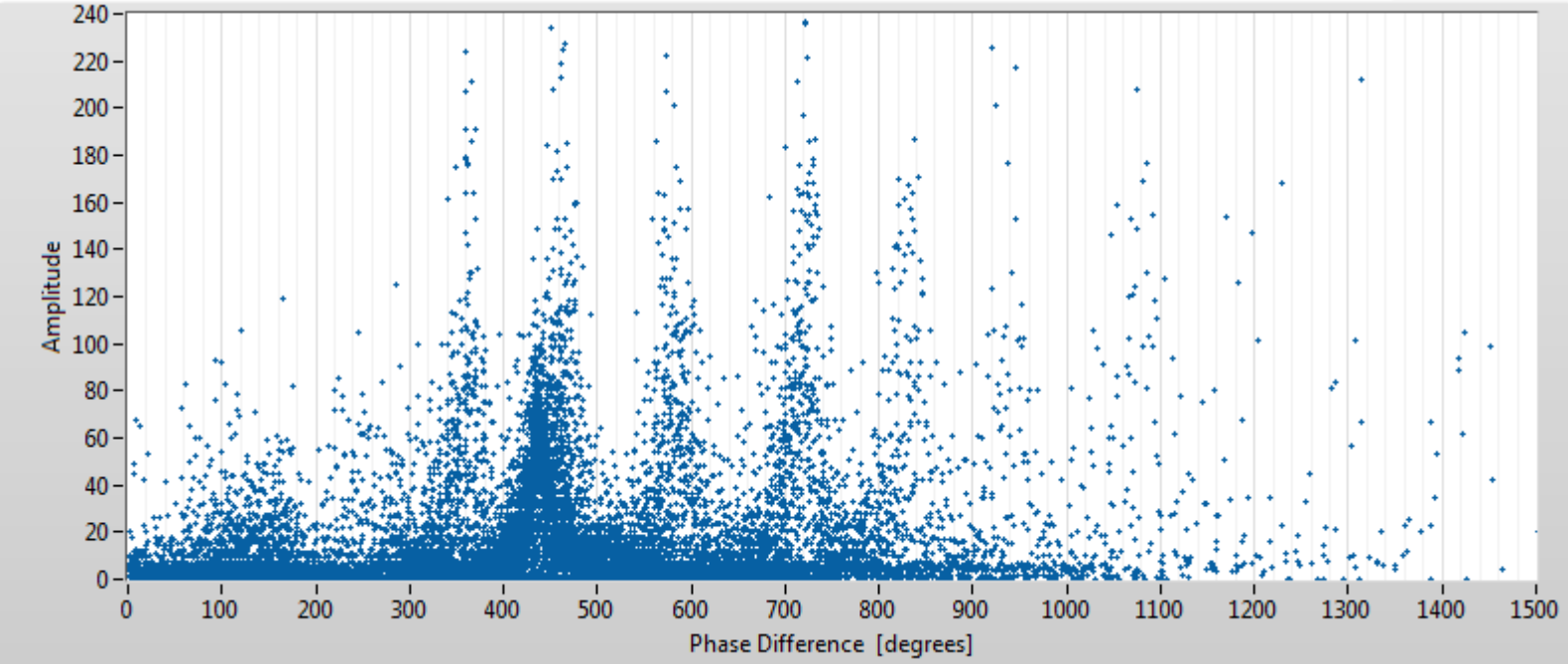




Fit parameters (in mm): Pos_1 = 14.8 Pos_2 =16.9 Pos_3 = 18.9 Pos_4 = 21.2

all Δ ≈ 2.2mm → 2 mm

Correlating images with other parameters
RF phase difference Inc - Refl **(T24)**



Structures in the phase difference (~300 events)
Peaks are separated by multiples of 120º –
RF phase advance of the structure –
suggesting that BD jumps between consecutive irises

Correlating images with other parameters
BD position from RF (CC) (T24)

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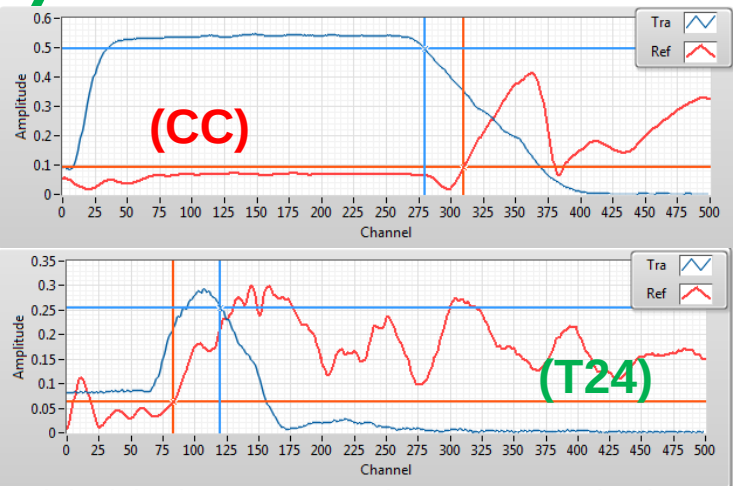
Two main methods, giving in general different information:

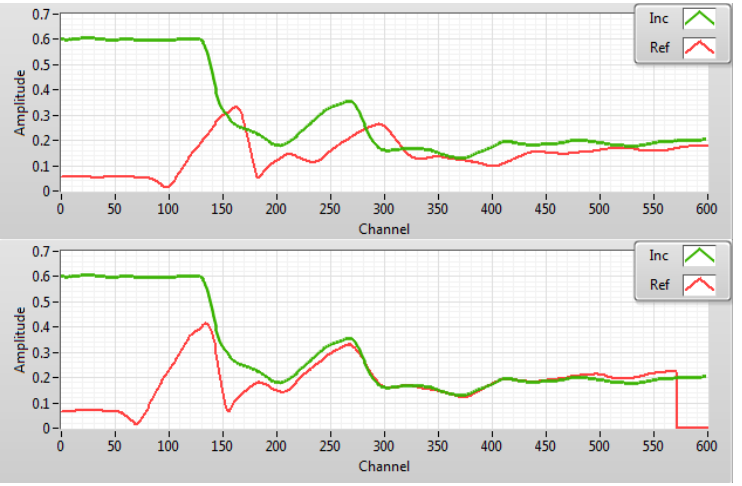
Edge method - Location at BD onset



Difficult in data from T24 due to many reflection

Correlation method - Location at the end of RF pulse due to BD migration

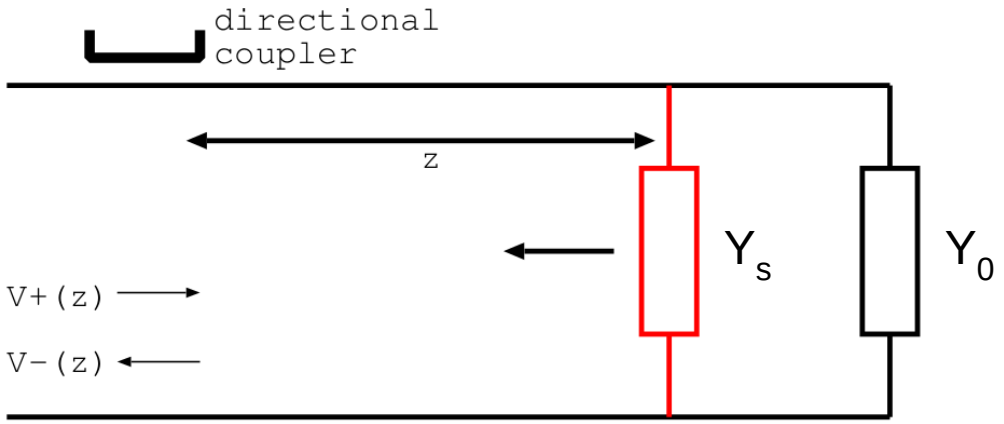
(CC)



<u>Static information, while BD is a dynamic process</u>
<u>Can we do better?</u>

BD location with acoustic signals - not yet available

Longitudinal discharge dynamics

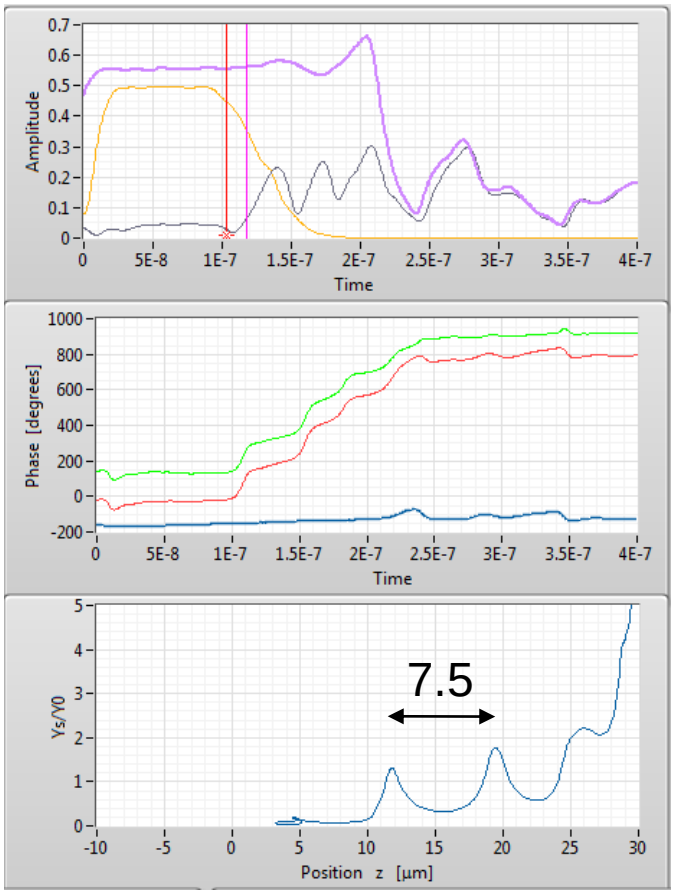


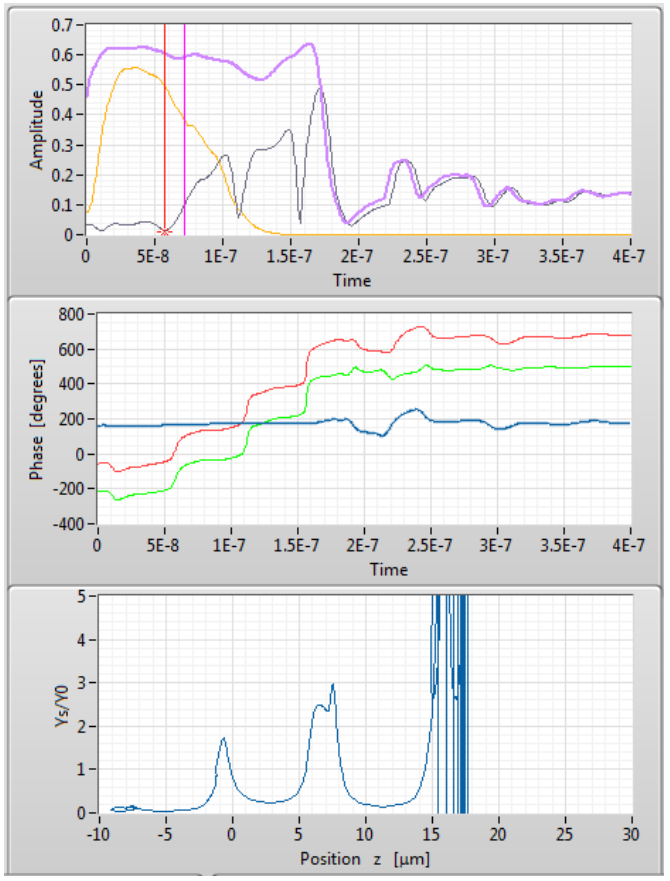
Field reflection can be seen as reflection on a mismatched load in the structure

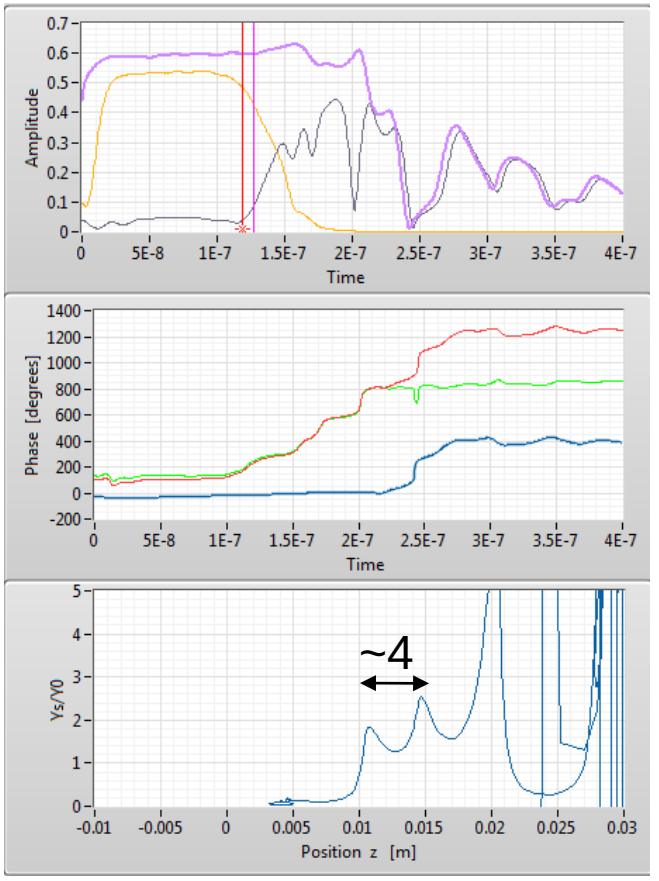
Simple model → mismatch in the load can be interpret as plasma growth

- 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 RF phase difference between the incoming and reflected signals – position of the plasma

Longitudinal discharge dynamics (CC)



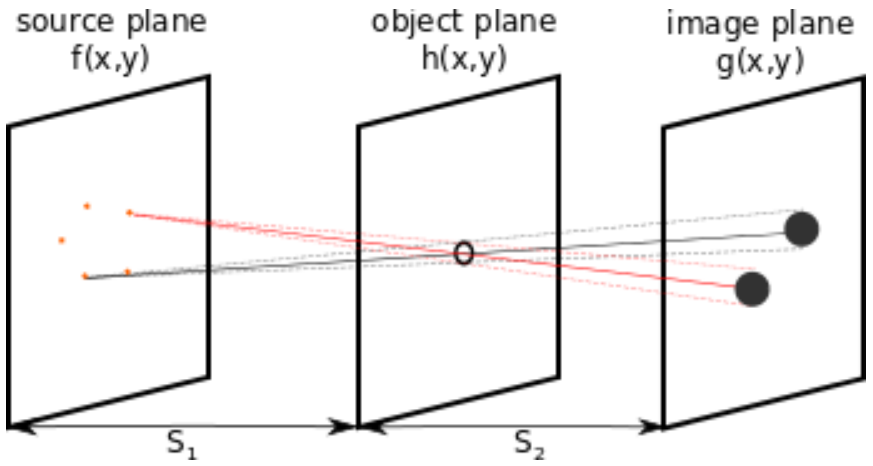




The ratio of the amplitudes of the conductance is often more than 2
The peaks often spaced about 7.5 mm apart (cf with distance between the iris of a 2π/3 structure – 8.3 mm) (sometimes half that distance)

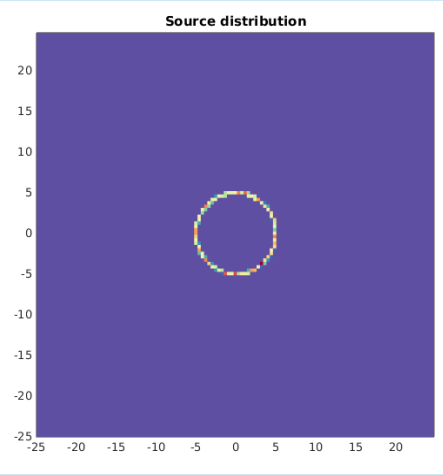
$$A(t)e^{2jkz} = \frac{V^{refl}(z)}{V^{inc}(z)} = \frac{-e^{2jkz}}{1+2Y_0/Y_S}$$

Can we extract source distribution from the image? Treating setup as a linear system – analytic solution

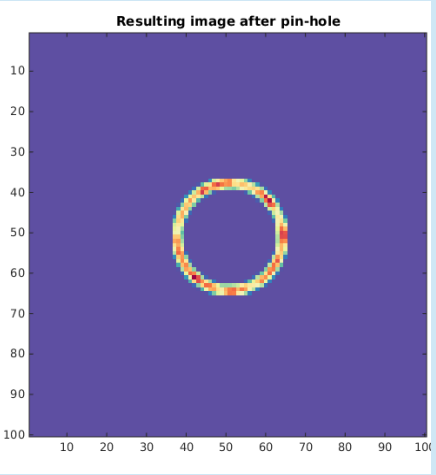


Convolution
$g(x,y) = f(x,y) \otimes h(x,y)$

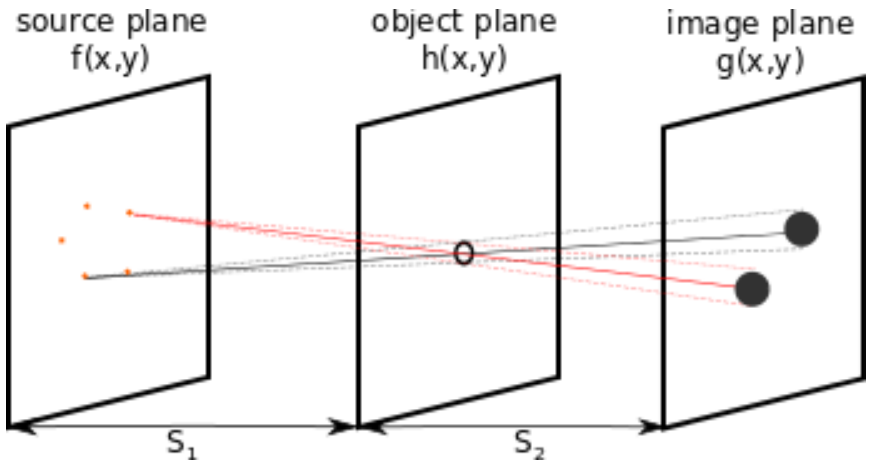
Source distribution from circular iris



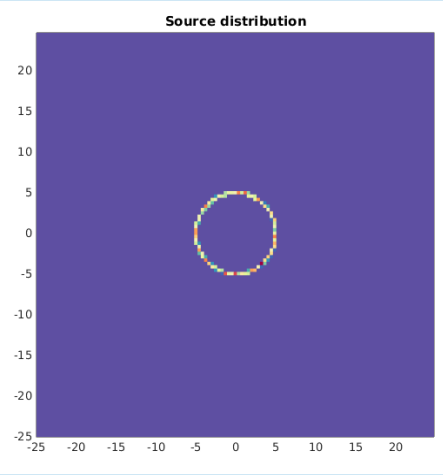
Resulting image after pin-hole



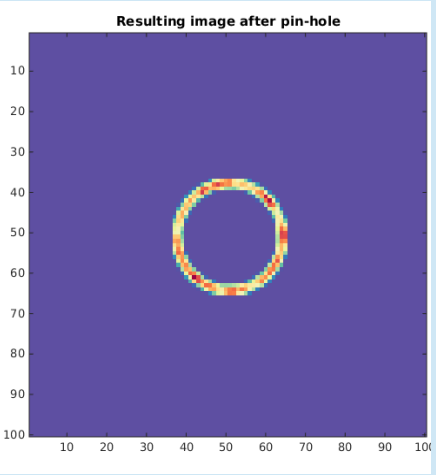
Can we extract source distribution from the image? Treating setup as a linear system – analytic solution



Source distribution from circular iris

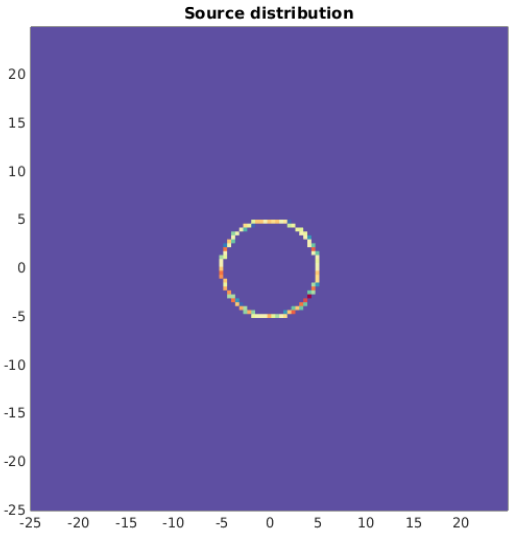


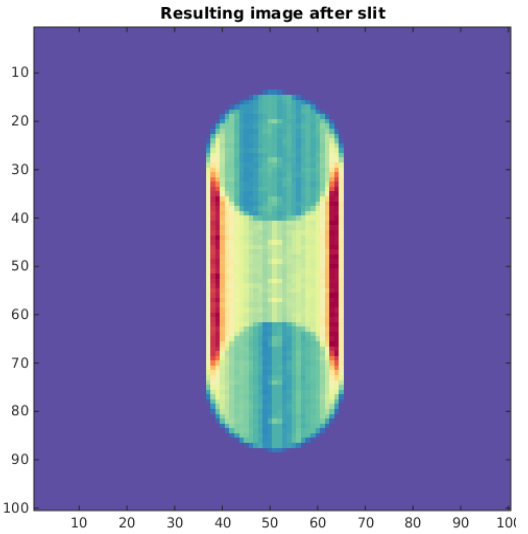
Resulting image after pin-hole



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

Same distribution at source
But image is formed through a slit





Simulation/reconstruction – analytical formula

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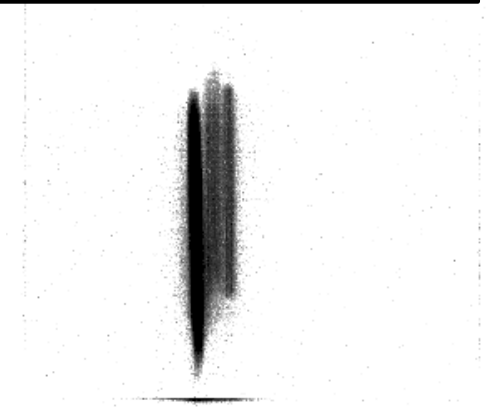
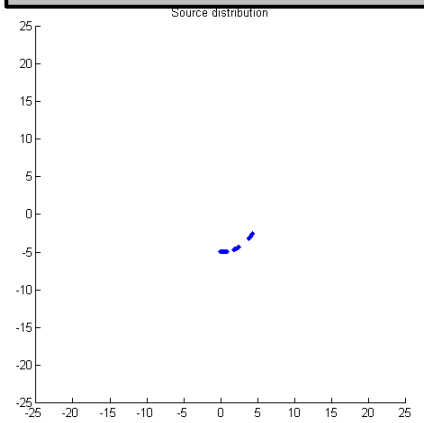
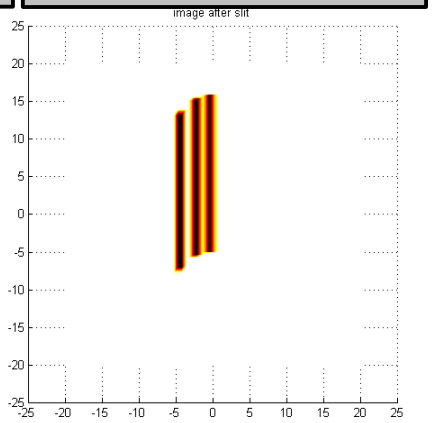
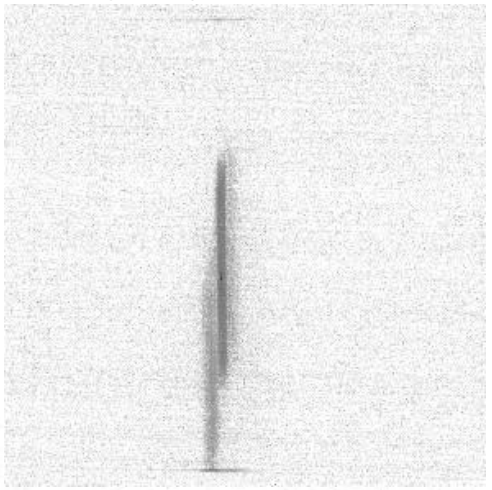
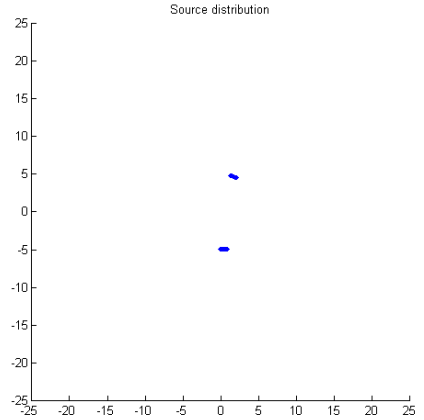
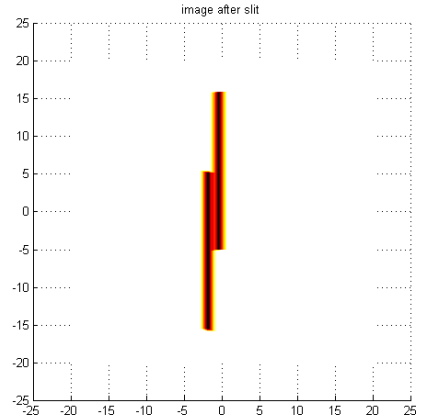
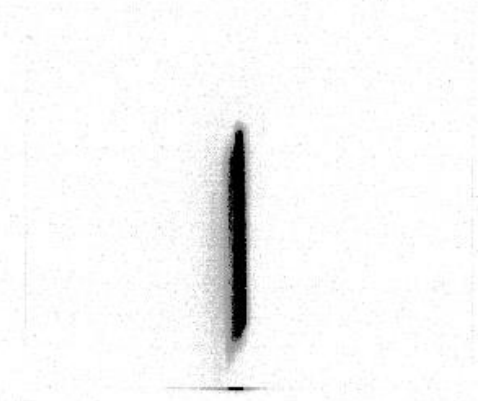
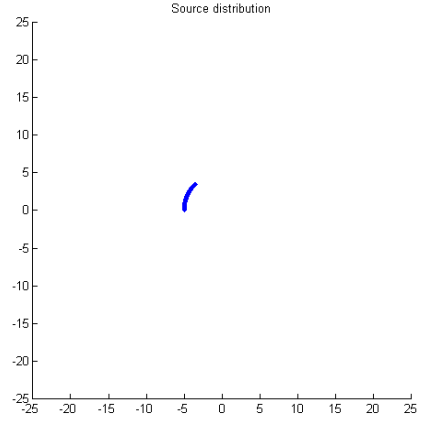
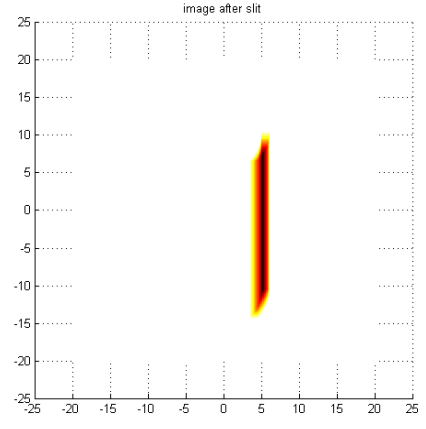
Three examples

Creating image by projecting source distribution through a slit

Experimental images	Source distribution on iris	Distribution after slit
		
		
		

Breakdown Tomography

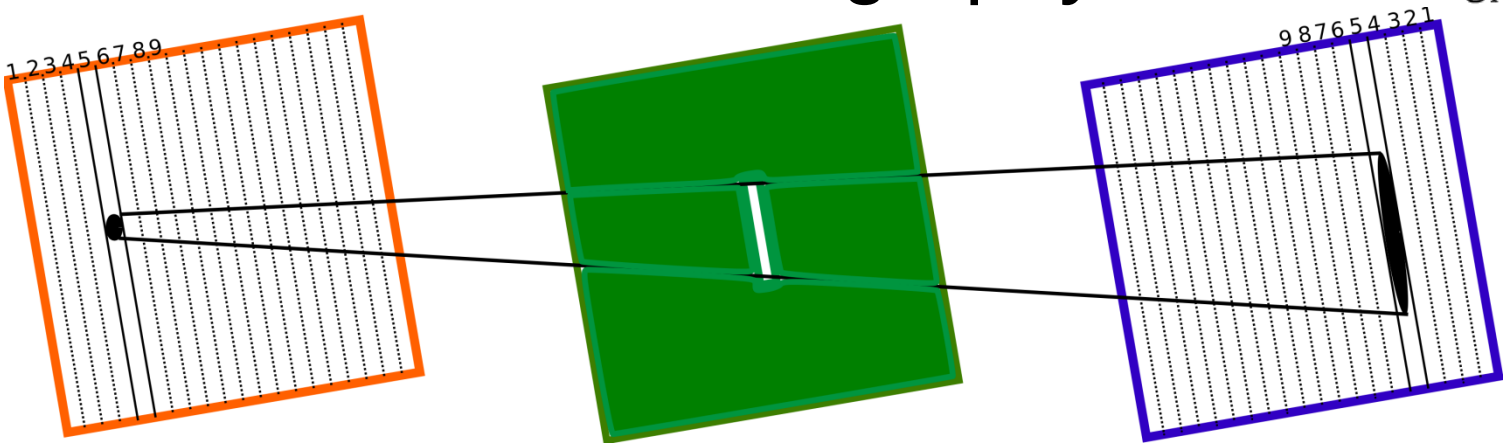
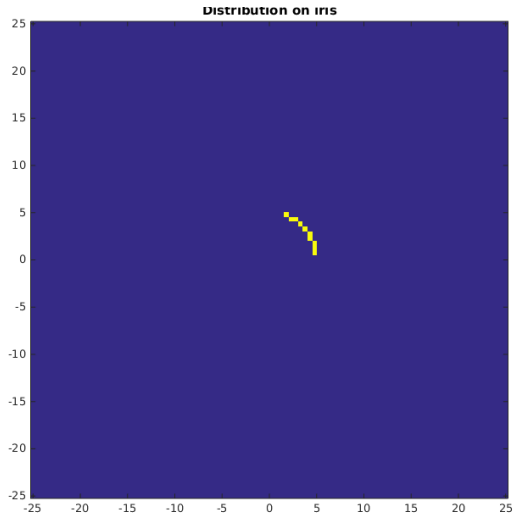
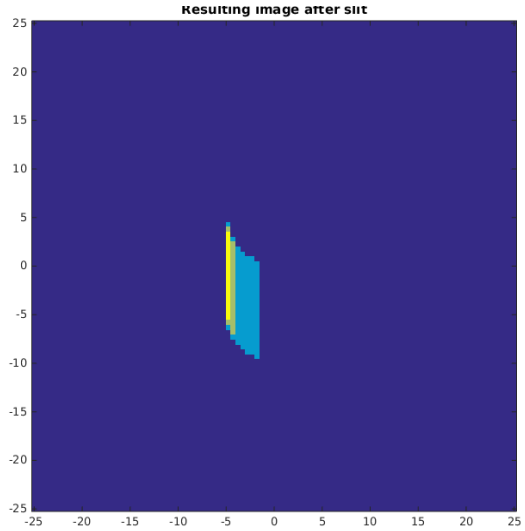
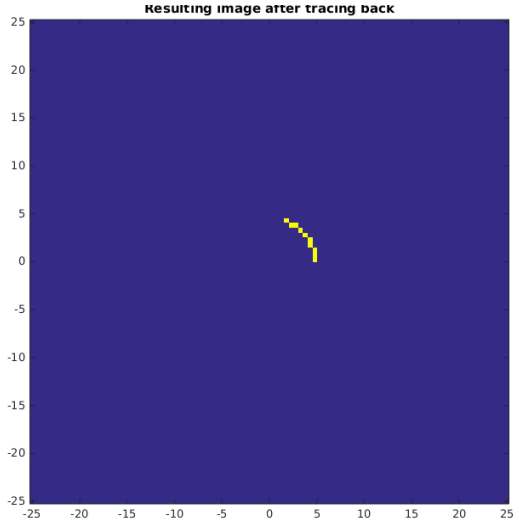


Image is created by calculating a series of 1D convolutions - each column of the source distribution with slit function

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

Breakdown Tomography

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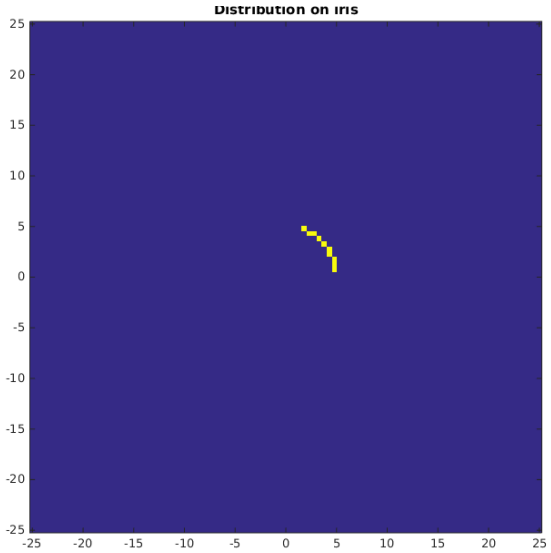
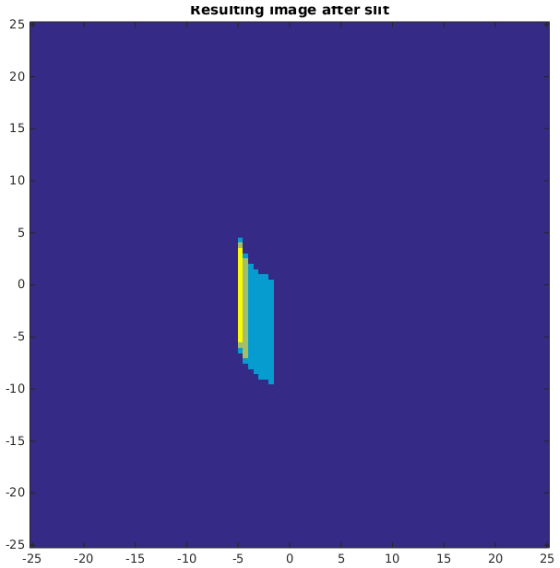
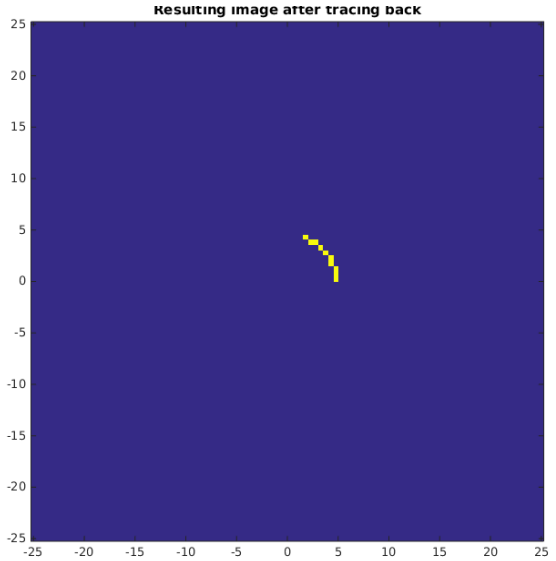
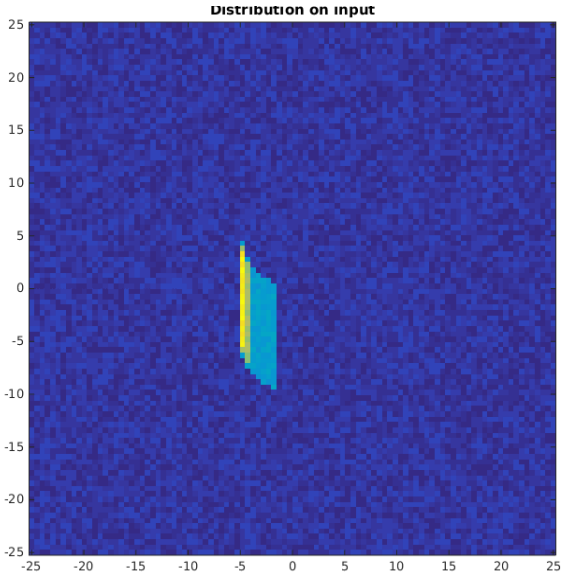
Deconvolution with slit transfer function - simulation

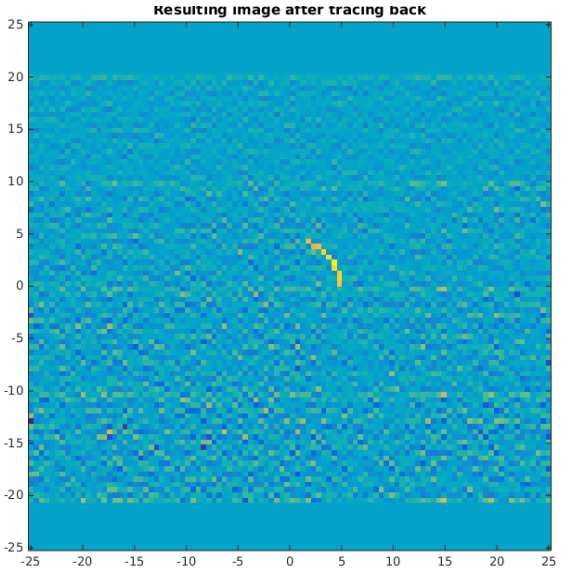






With added
25% noise



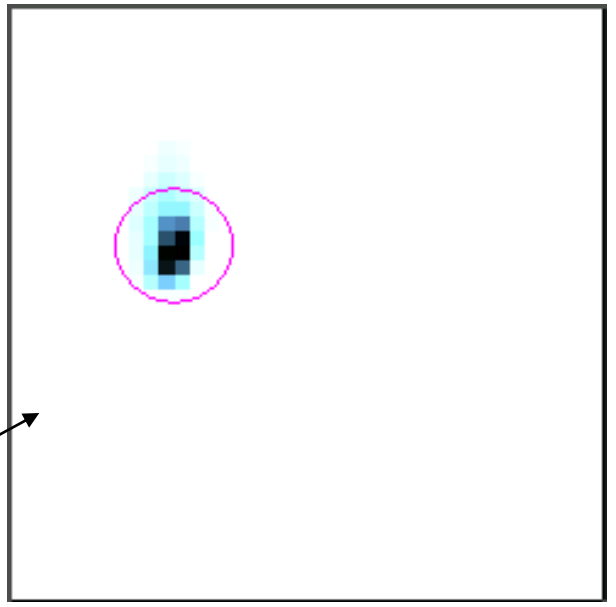


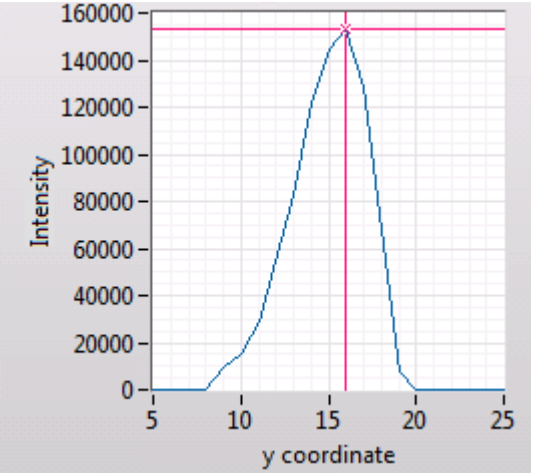
Breakdown Tomography
Experimental data October ’15 (T24)

Deconvolution with slit transfer function

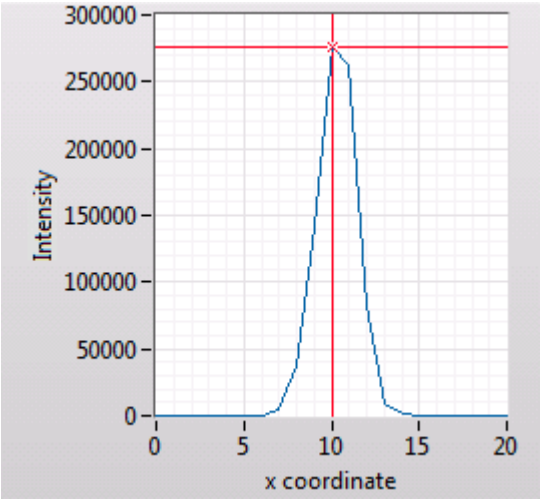
Combined image from 279 events

(from 592)





Circle with Φ =10mm
Max iris size Φ ~7 mm
Pixel size = 1.25mm



Excess events in vertical direction – along the joint between two halves?

Position inside structure is not taken into account at the moment

Breakdown Tomography
Experimental data October ’15 **(T24)**

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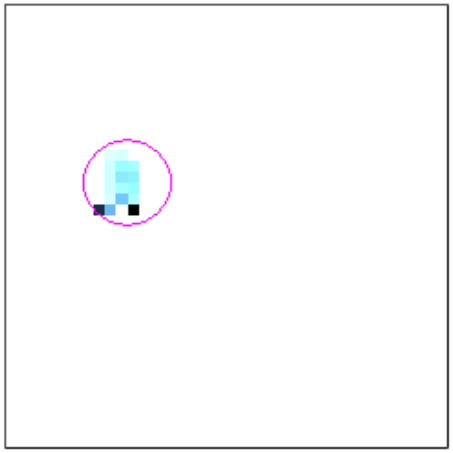
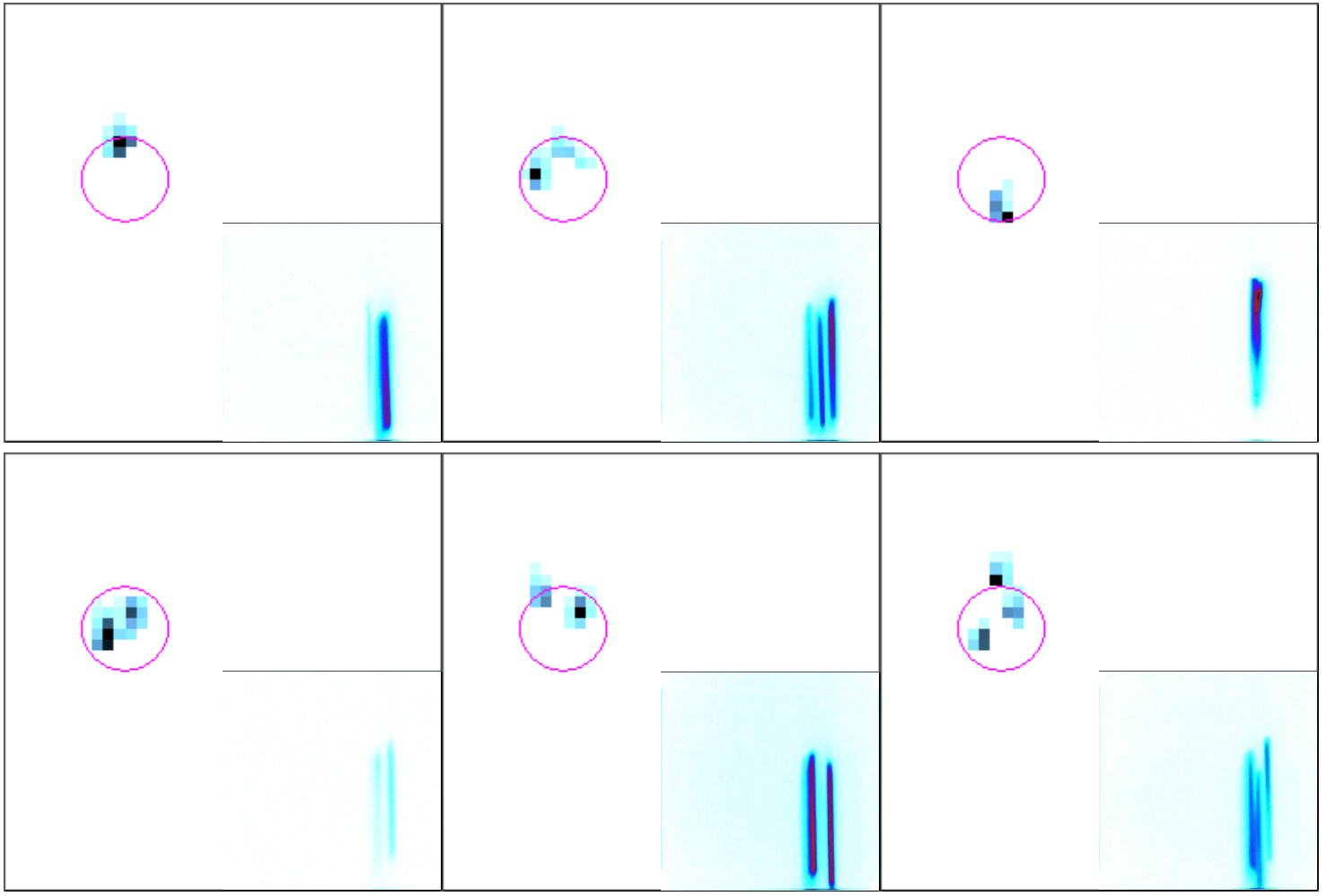
Deconvolution with slit transfer function

Single events - recorded images and reconstructed source positions



Single events
(animated preview)

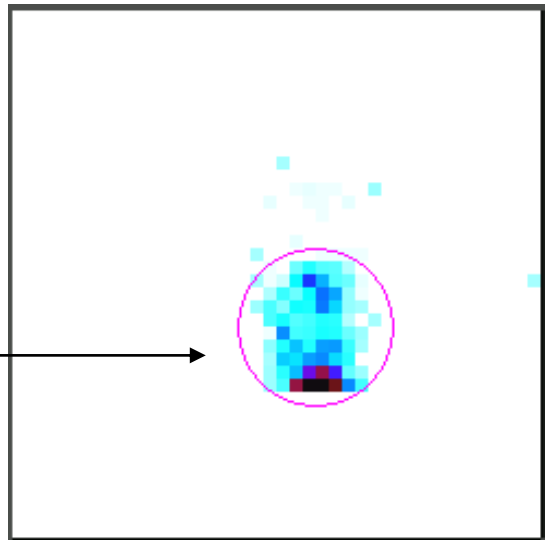


Position inside structure is not taken into account at the moment

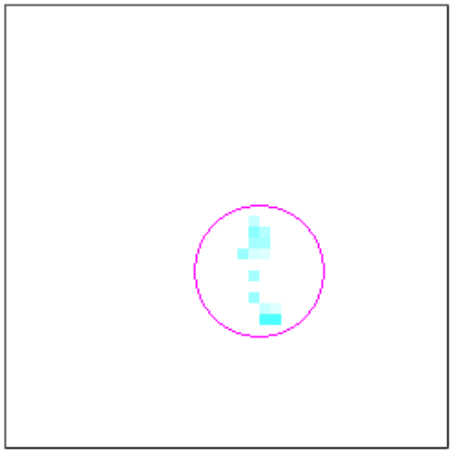
Breakdown Tomography
Experimental data April'15 **(CC)**

Deconvolution with slit transfer function - combined image from 27 events (from 394)

Circle with Φ =15mm
Max iris size Φ =10mm
Pixel size = 1.25mm



Single events
(animated preview)



Position inside structure is not taken into account at the moment

Breakdown Tomography
Experimental data April'15 **(CC)**

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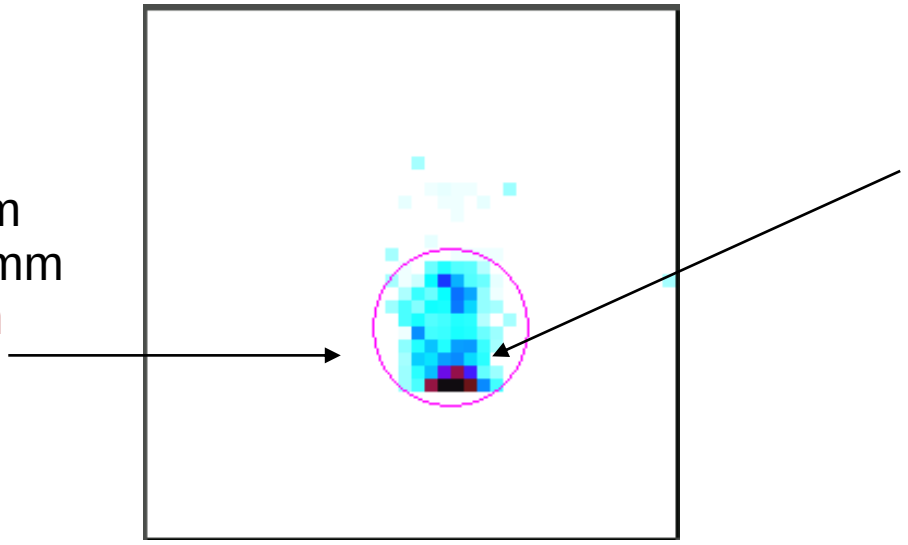
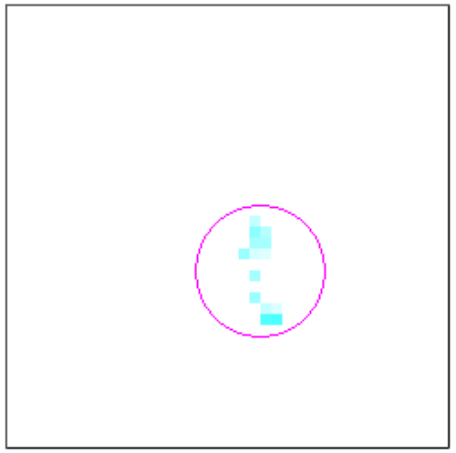
Deconvolution with slit transfer function - combined image from 27 events (from 394)

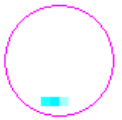
Circle with Φ =15mm
Max iris size Φ =10mm
Pixel size = 1.25mm



Excess events due to edge effect

Single events (animated preview)



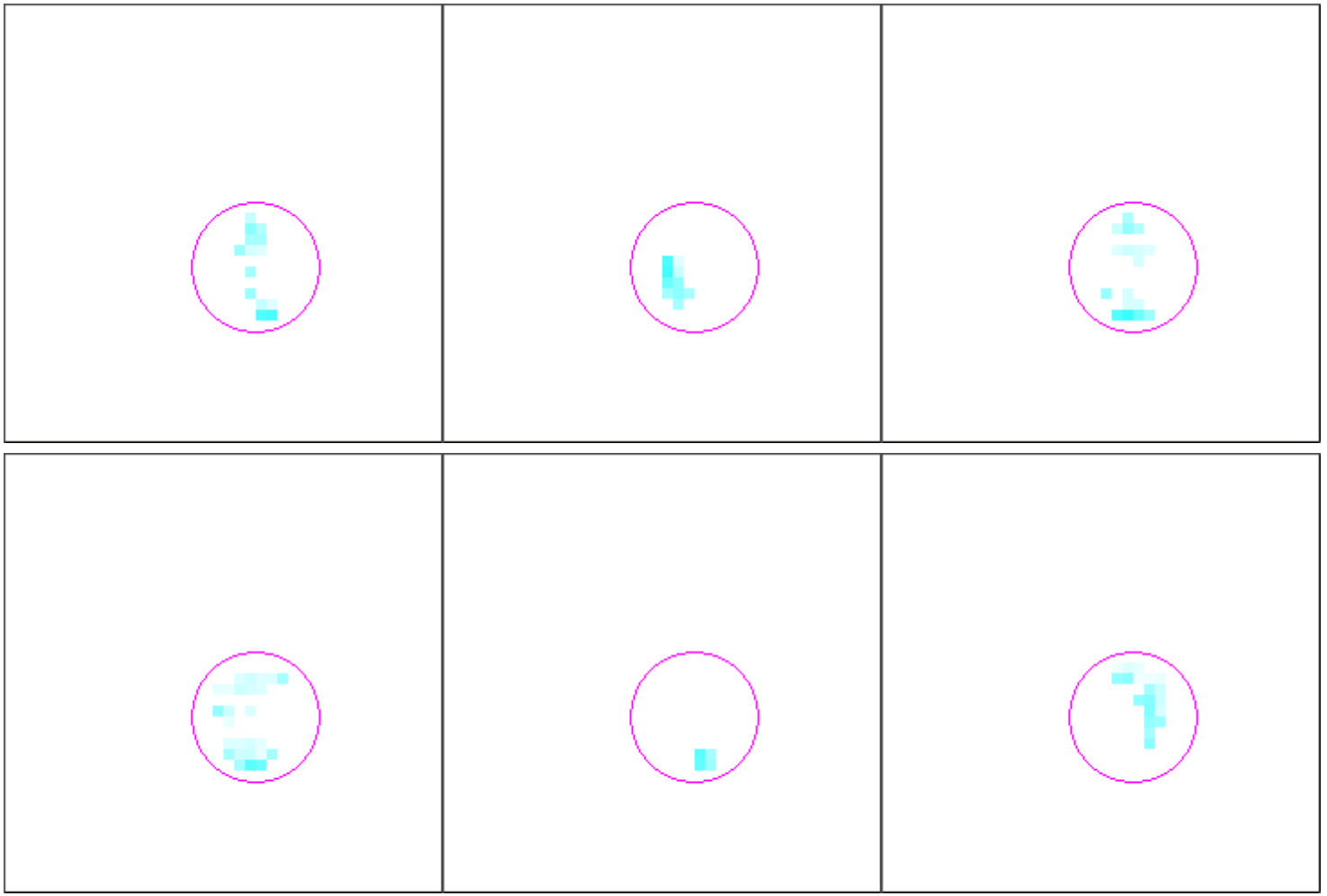


Position inside structure is not taken into account at the moment

Breakdown Tomography
Experimental data April'15 (CC)

Deconvolution with slit transfer function

Single events



Circle with Φ =15mm
Max iris size Φ =10mm
Pixel size = 1.25mm

Position inside structure is not taken into account at the moment

Summary

- Good and stable performance of the UCXS at XBox2
- UCXS fully synchronized with conditioning system
- Data from Crab cavity are fewer and with higher noise level (higher camera gain, further distance, non-accelerating cavity)
- Plenty data from T24, but more difficult to interpret RF signals (transients, reflections)

- Activity on screen reflects activity on the reflected pulse – in terms of intensity and visible features
- No signal on the preceding/following images, dark current not visible
- A lot of information on the **size** and **displacement** of the discharges during RF pulse available for the first time:
  - Longitudinal BD position
    - Edge method – onset location (difficult for T24 data)
    - Correlation method – location of plasma edge
    - Impedance tracking – model with plasma build-up giving inside to longitudinal dynamics (BD migration)
  - Transversal BD position from deconvoluted images via robust algorithm
- More information about plasma (density) can be extracted from impedance model

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FREIA