X-Box Discharge Experiments at CERN

M. Jacewicz, R. Ruber , V. Ziemann, T. Ekelöf
FREIA Laboratory, Uppsala University

EuCARD2 WP12 meeting
14/03/2017

UPPSALA UNIVERSITET

Motivation

To develop high-gradient equipment we need to look into major limiting phenomenon – vacuum breakdowns

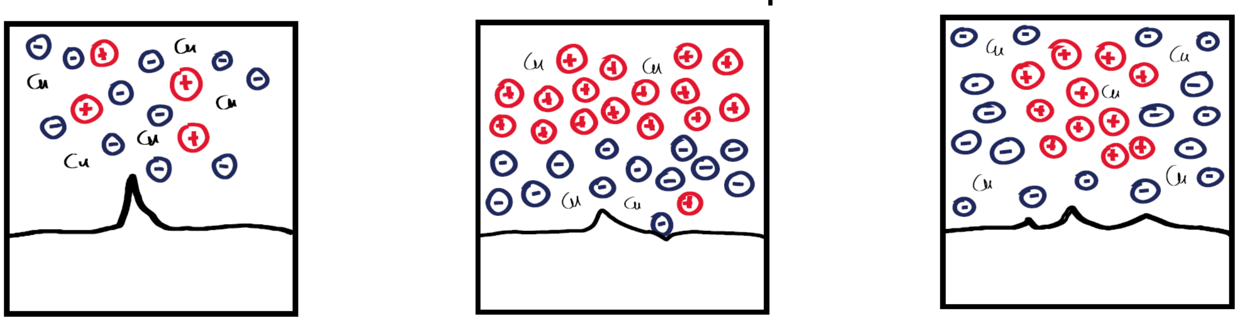
New cavitiy has to be conditioned to achive CLIC specs: 100 MV/m @ 200 ns with BDR~ 10^{-7} bpp/m
Take time and costs – we can optimize the process if we understand it

Continuous progress in understanding e.g. from study of long term trends we believe that the number of pulses, but not with the number of breakdowns conditions the structure

Why? Not sure …
Different models are put forward to understand this hardening process
(i.e. surface can resists more power with increasing number of pulses)

But models need verification by experiment

Phases of breakdown process



Onset
dark current (DC)

Plasma

Discharge
breakdown current (BD)

Drawings by A.Palaia

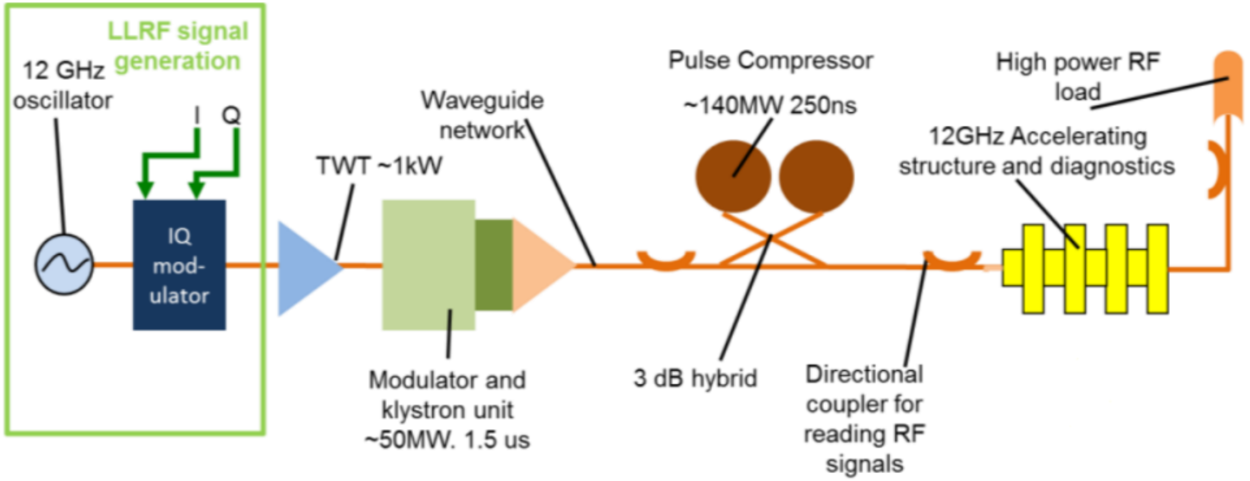
FREIA

Xbox 2 @ CERN

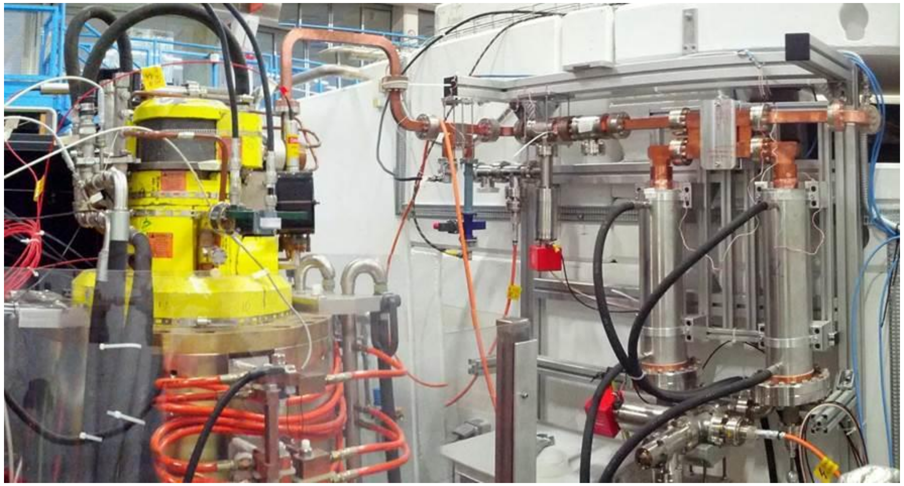
UPPSALA UNIVERSITET

CLIC ACS tests require:

→ 40-45 MW power
→ pulse length ≤ 250 ns
Conditioning process speed related to number of pulses:
→ high rep rate ≥ 50 Hz



XBox2
Solid state modulator (Scandinova) +
a single 50 MW klystron +
pulse compressor

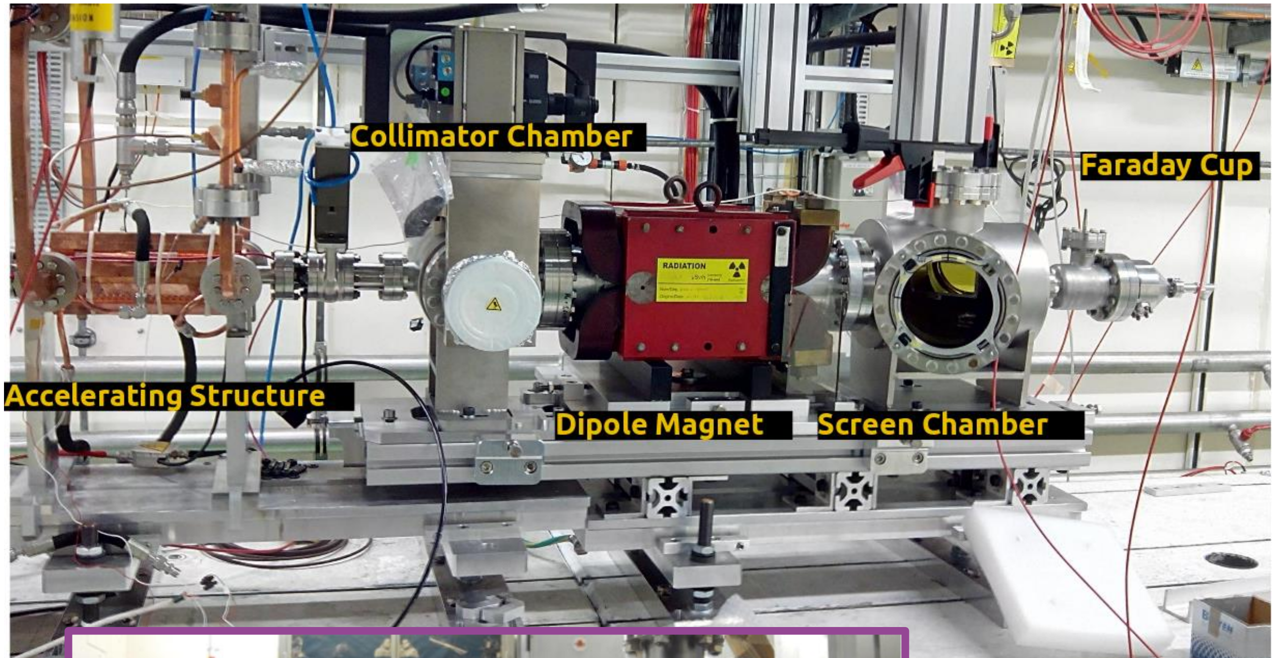


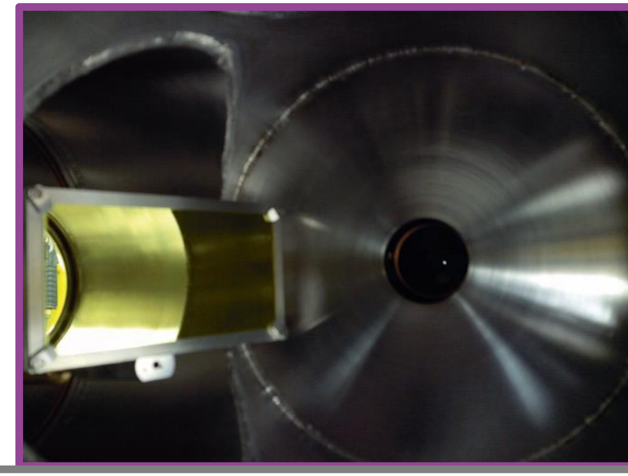
B. Woolley

Uppsala/CLIC X-band Spectrometer (UCXS)

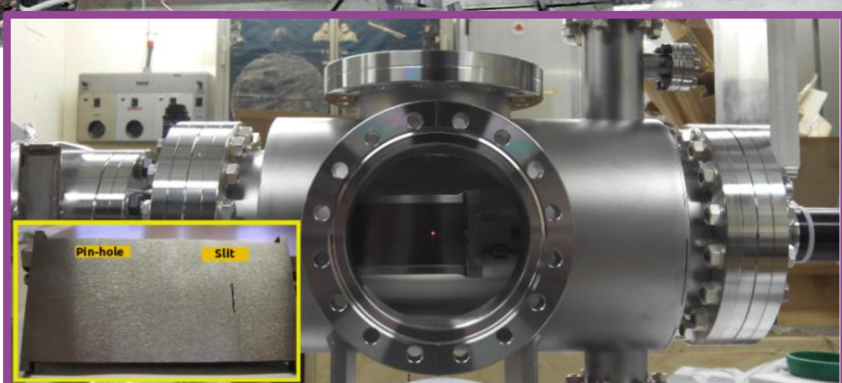
general-purpose system for detection and measurements of dark and breakdown currents during structure conditioning

UPPSALA UNIVERSITET





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



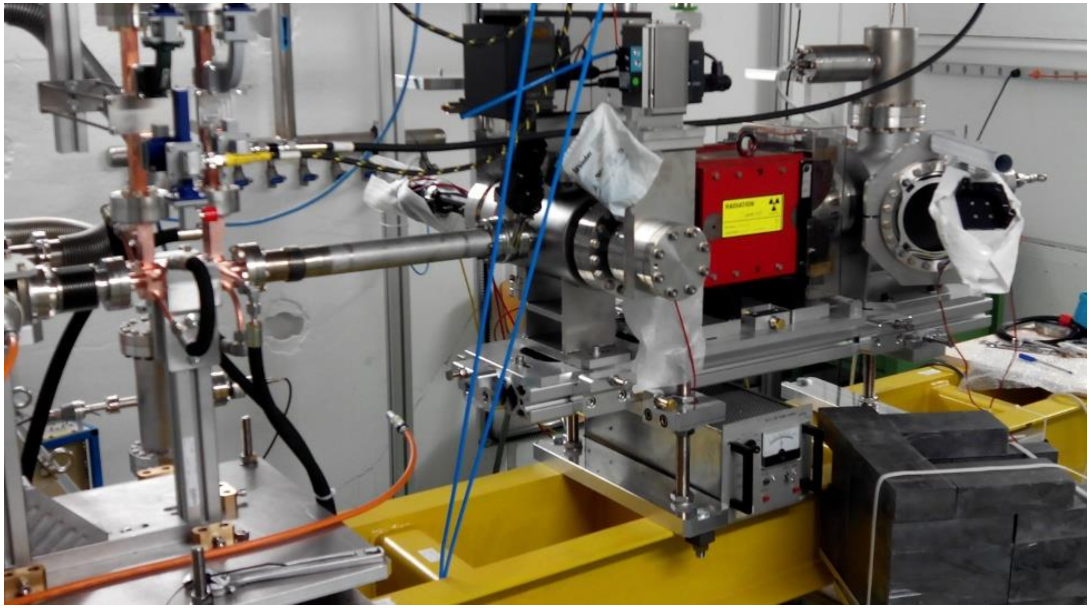
Energy resolution with dipole magnet	
Maximum electron energy	<20MeV
Rel. energy spread (single slit)	10% - 25%
Full energy coverage with magnetic field scan	

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

FREIA

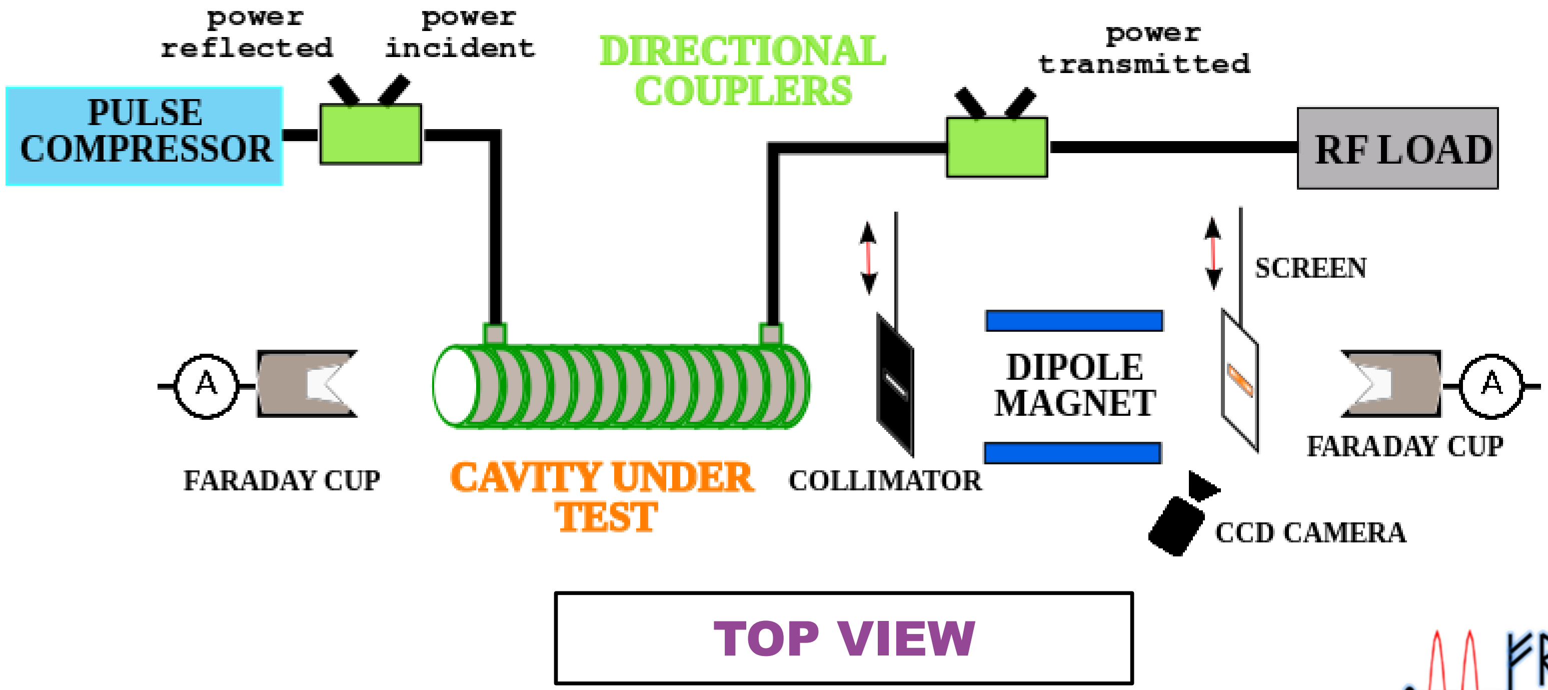
Instrumentation at XBox2

UPPSALA UNIVERSITET



All diagnostics information available for the breakdown events is combined with images from the camera (including images from before and after BD)

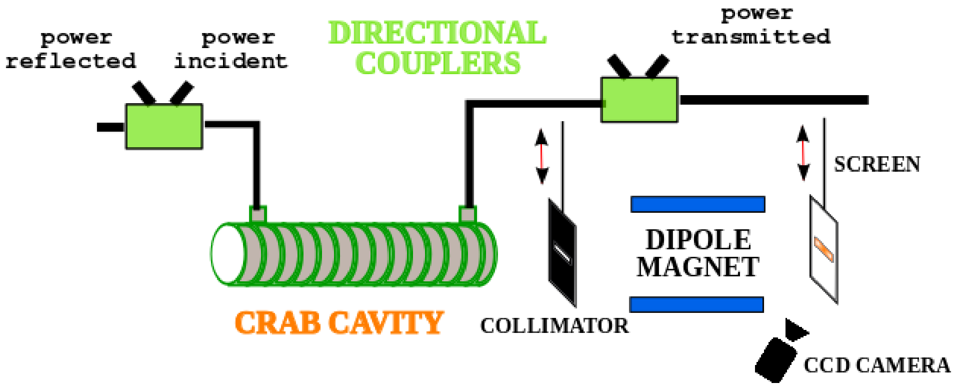
50 Hz operation

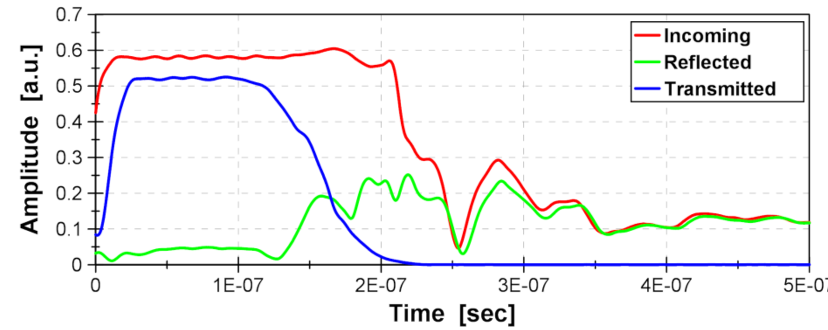


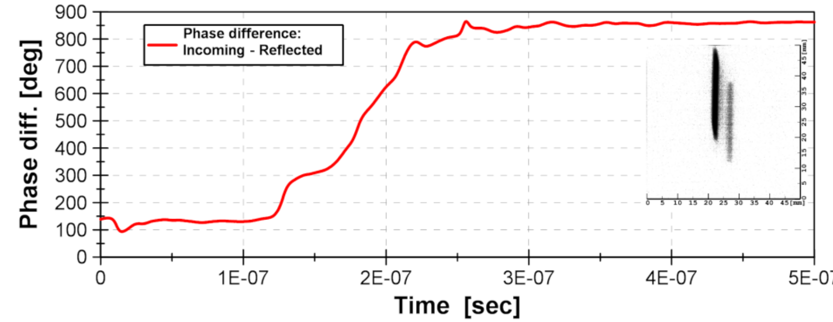
FREIA

Example of collected signals – BD events

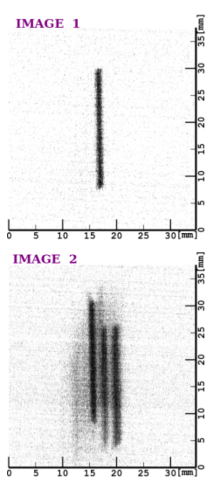
UPPSALA
UNIVERSITET

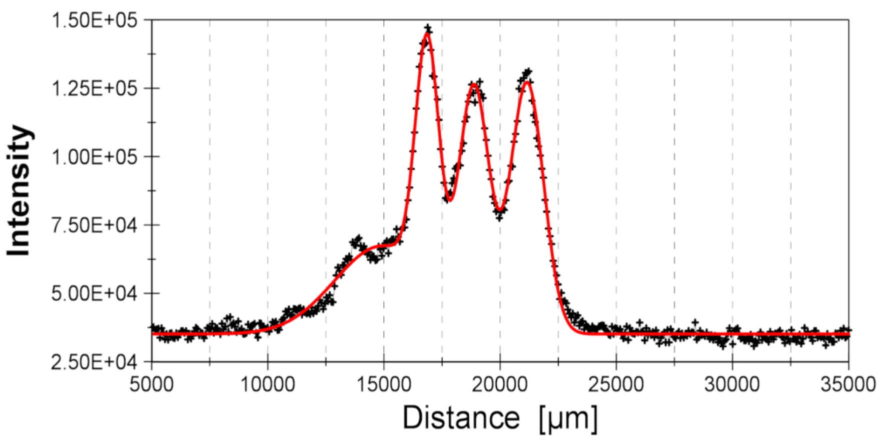






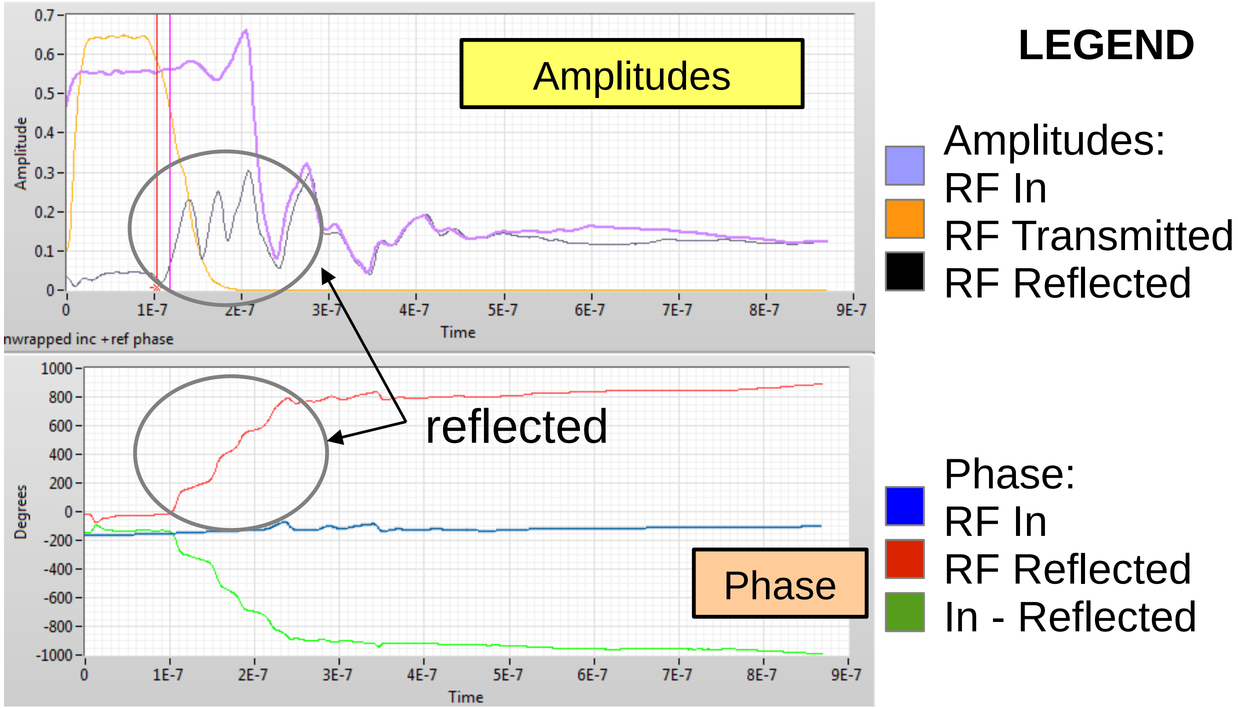
Example of images after the slit





RF signals

UPPSALA UNIVERSITET



→ 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 position of the BD site

FREIA

BD position

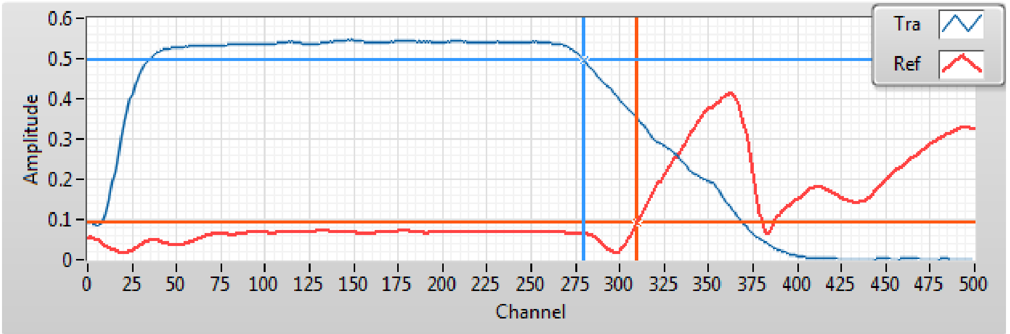
UPPSALA UNIVERSITET

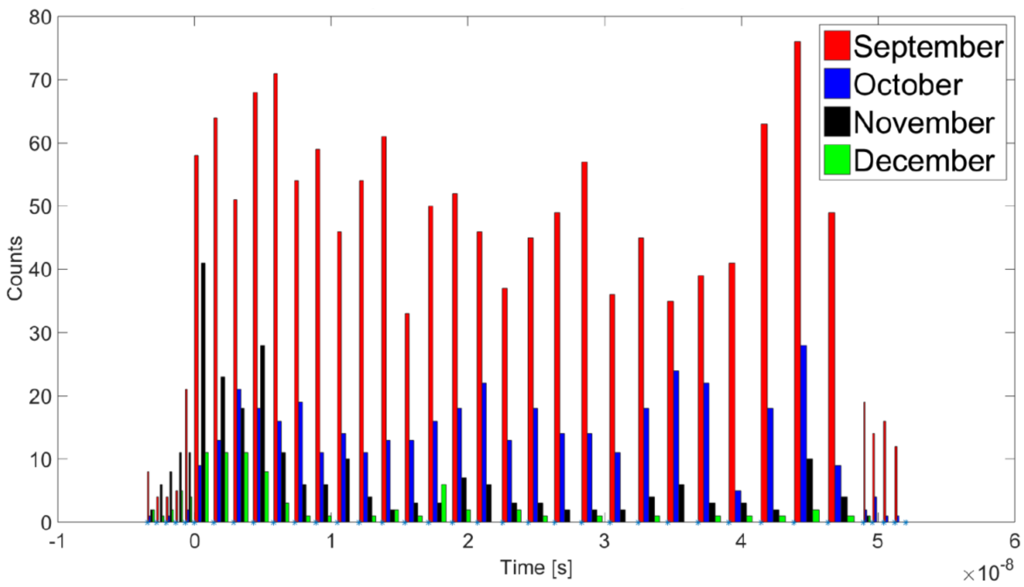
BD detected when:

1) Drop in transmitted power due to plasma formation
2) Power reflected back

<u>Difference in time between the transmitted power falling and the reflected power increasing to find the BD cell location. *)</u>

The phase of the reflected signal is used to pinpoint cell location.



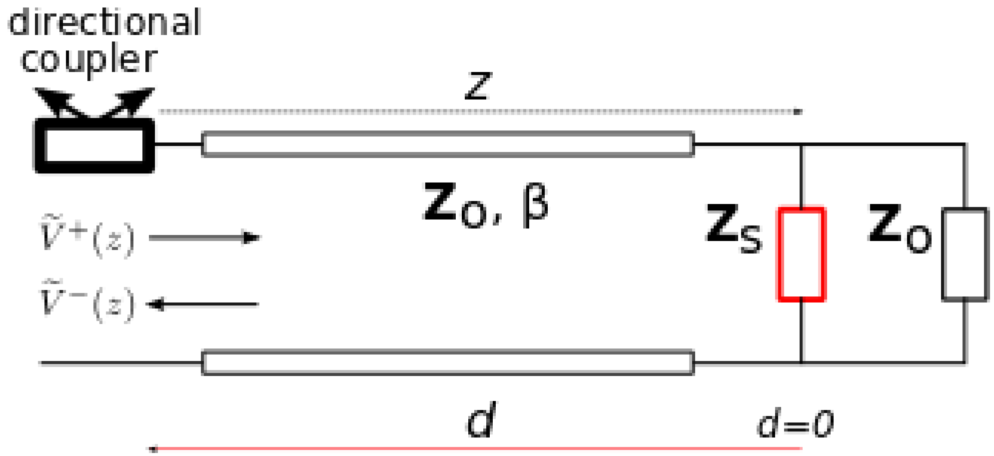


<u>Static information (single value), while BD is a dynamic process</u>
<u>Can we do better?</u>

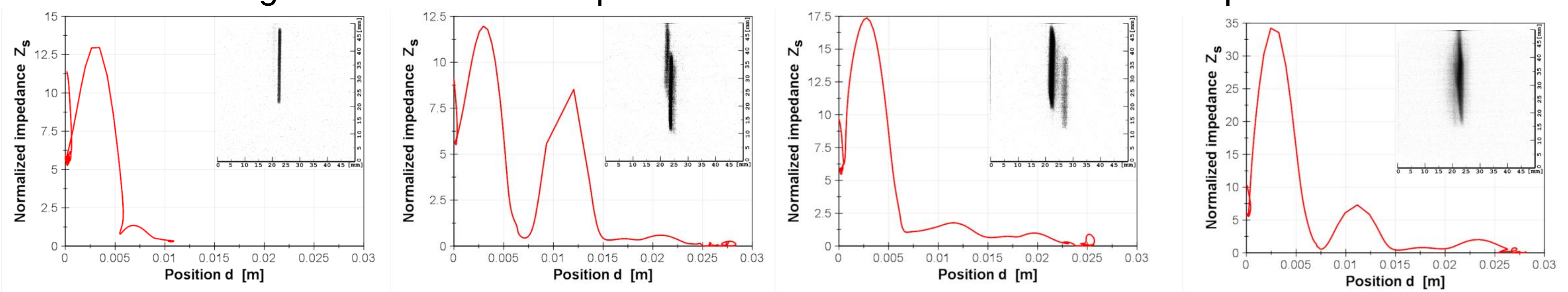
*)There are other methods that use RF signal timing to extract BD position.

Longitudinal discharge dynamics

UPPSALA UNIVERSITET



Field reflections can be seen as reflection on a mismatched load in the structure
→ In a simple model we interpret the mismatch as plasma growth
→ Combining phase and amplitude information from Incoming and Reflected waves we can get relation between position of the wave and the relative impedance



Peak separation in agreement with cell length of 8.3 mm

This supports the theory of breakdown migrations during the RF pulse

FREIA

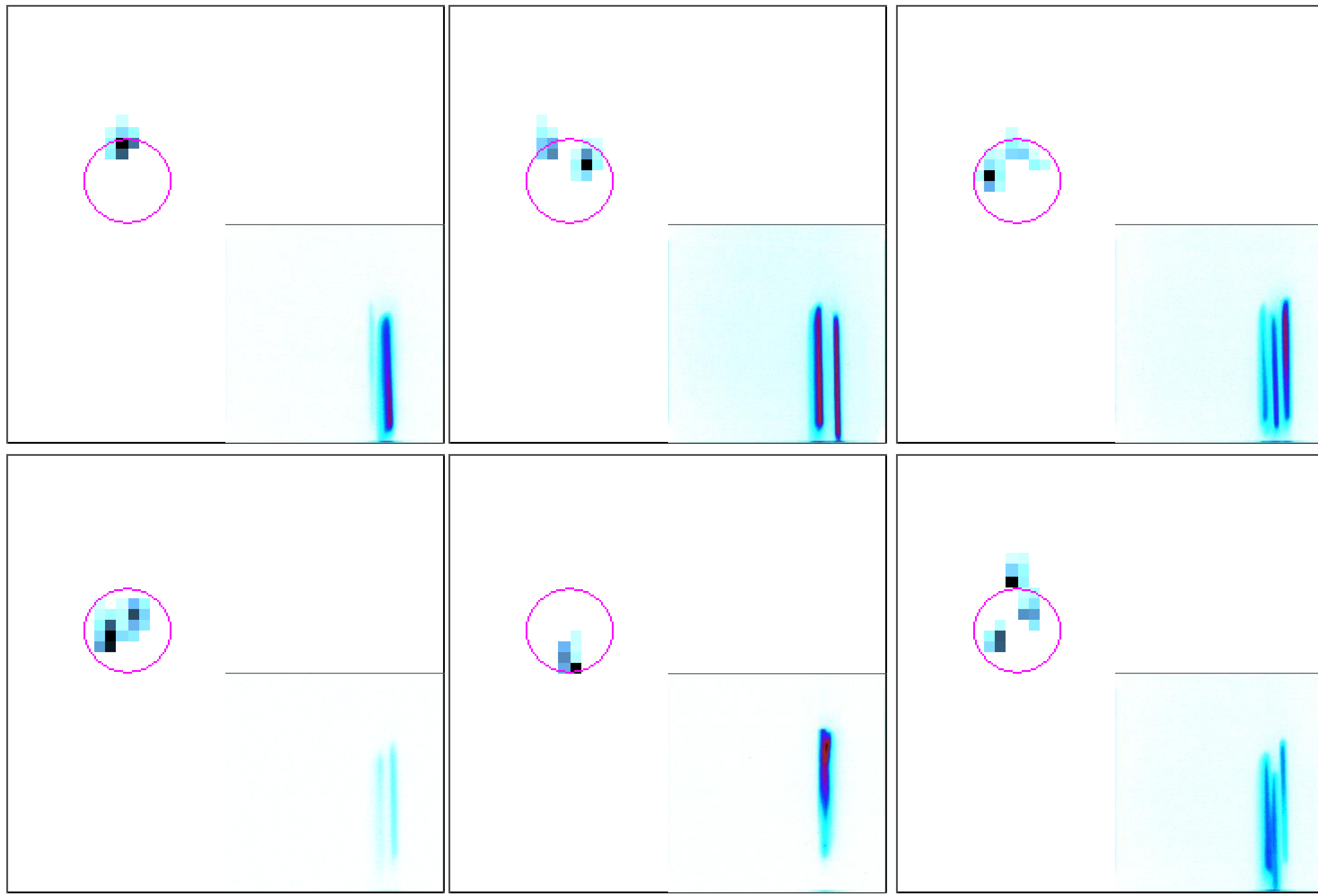
Information from the images

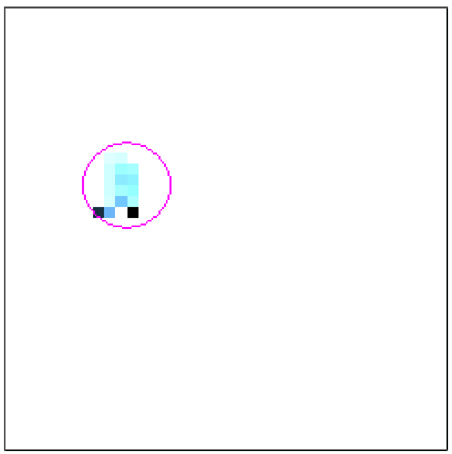
Breakdown transverse position – SLIT

75 ns pulses

Deconvolution with slit transfer function

Single events - recorded images and reconstructed source positions





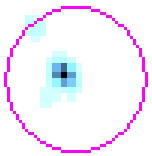
Single events
(animated preview)

Breakdown transverse position – PINHOLE

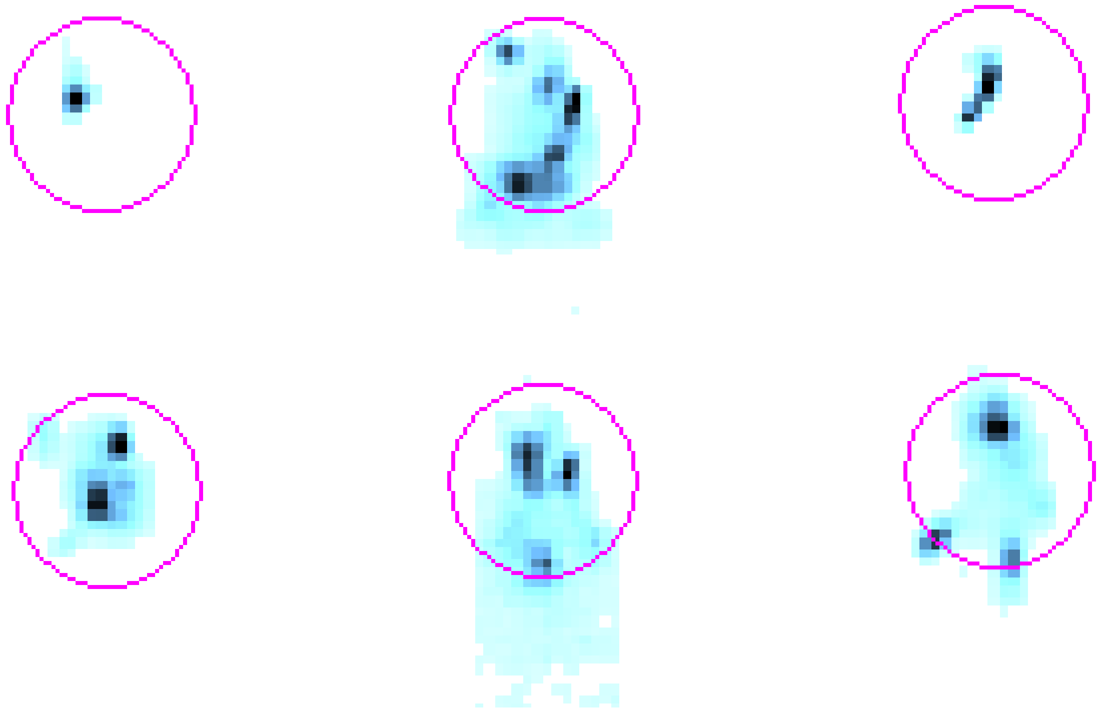
200 ns pulses

Deconvolution with slit transfer function

Single events - recorded images and reconstructed source positions



Single events
(animated preview)



**Qualitatively more features in data –
longer pulse, more time to develop new breakdown**

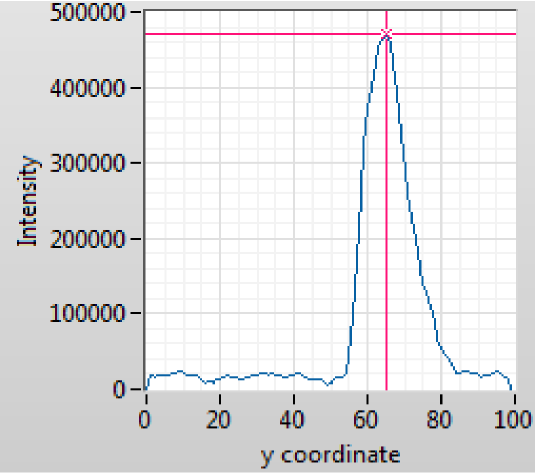
Breakdown transverse position – PINHOLE

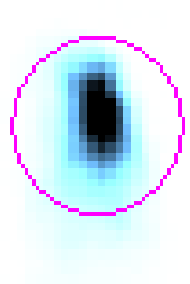
200 ns pulses

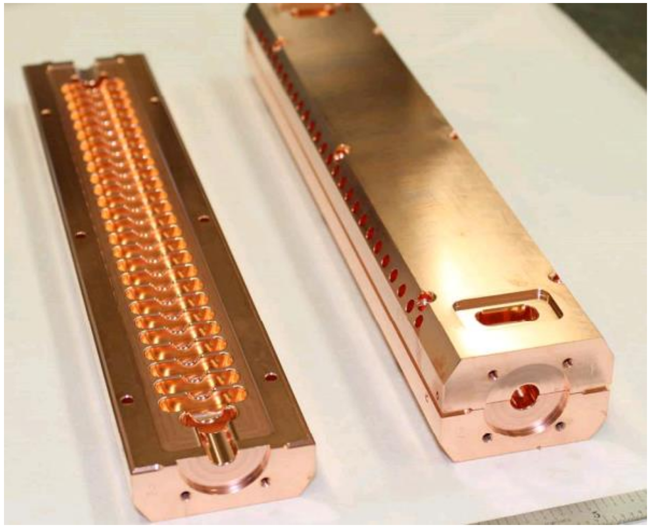
Combined image from 199 events

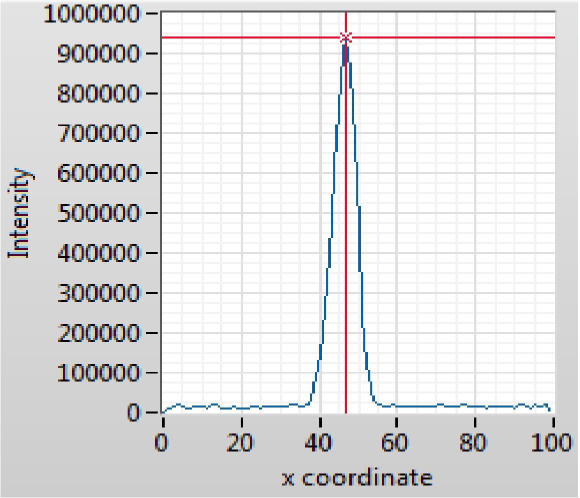
Asymmetry and excess events in vertical direction

Due to special type of structure under test?



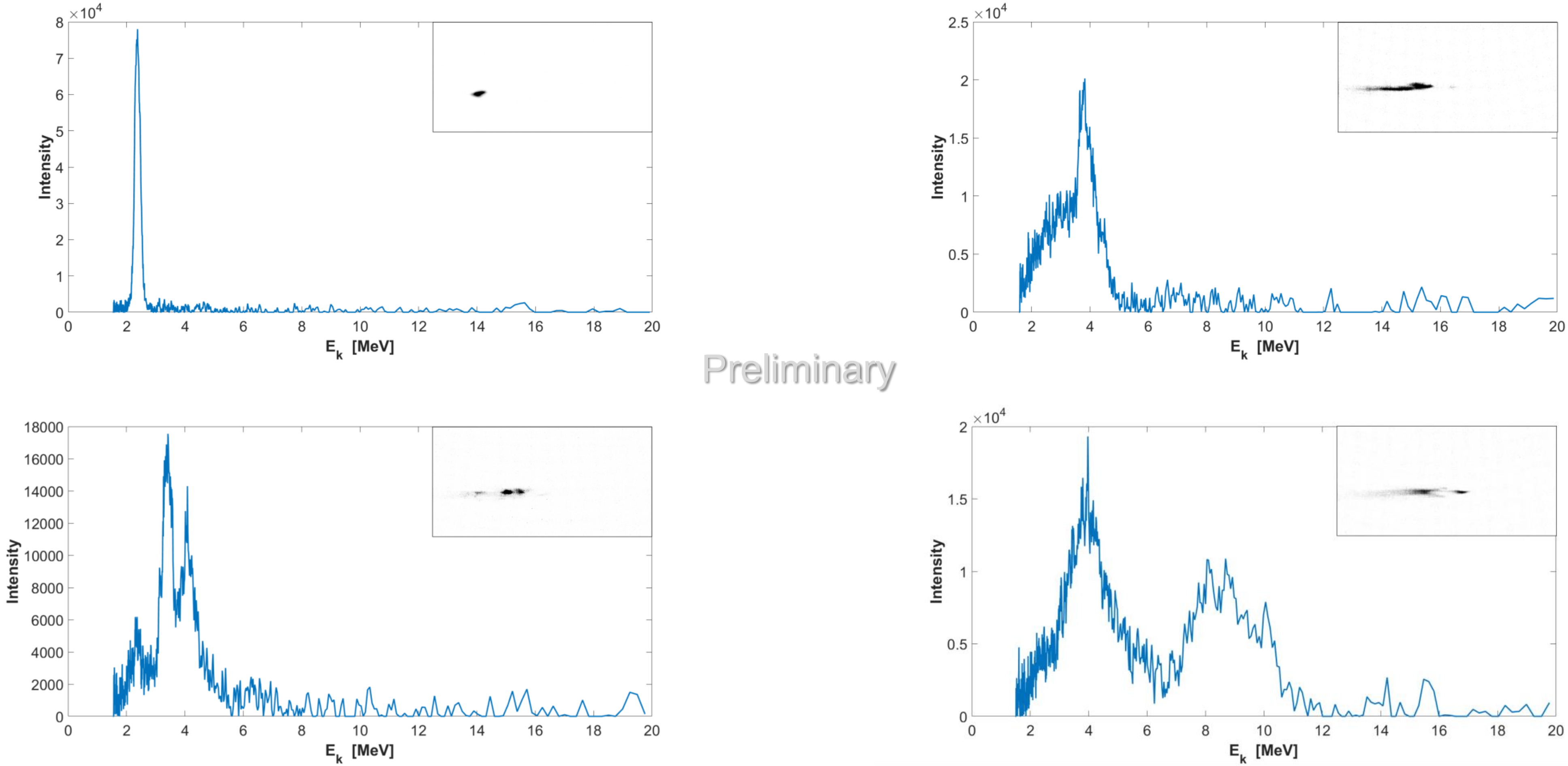






Energy spectra from BD events

UPPSALA UNIVERSITET



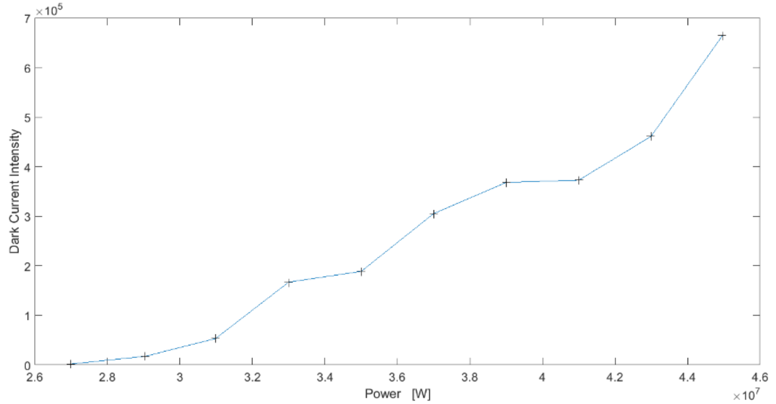
Electrons with well defined energies

→ maximum in agreement with the given power/gradient in the structure

Next step: combining energy information with other signals and compare with simulation

Dark current

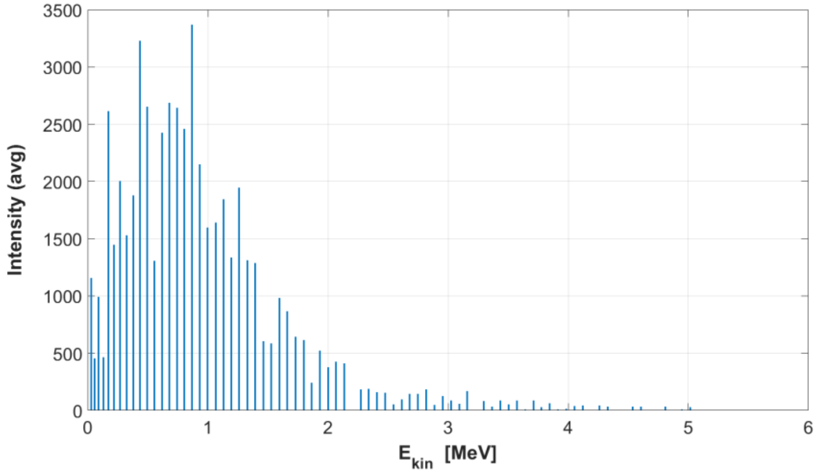
Dark current :
→ precursor of RF breakdown, input to many models
can we predict that BD approaches?
→ Information about structure hardening process
→ Causes RF power loss, radiation, possible backgrounds



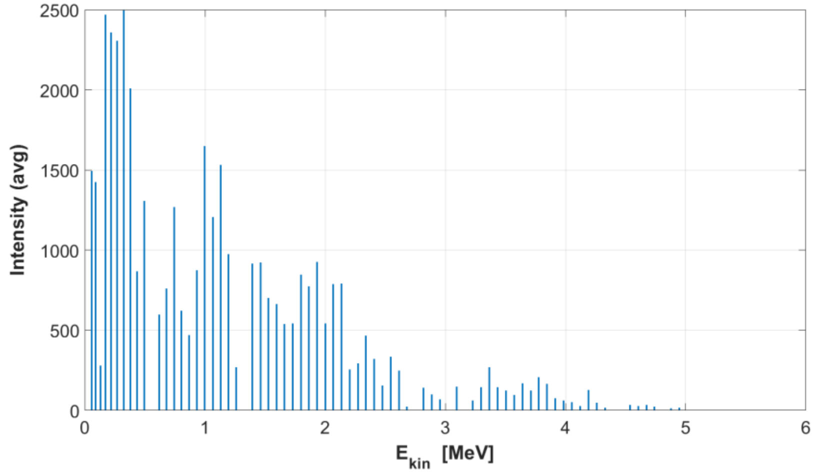
Preliminary

DC scan with power

@ 26 MW inc. power



@ 30.5 MW inc. power



Broad energy spectrum – continuum from electrons in dark current
example here from 50 consecutive pulses (1 second)

Next step: comparison with other detectors i.e. Cherenkov fiber detectors, Faraday cup to look at which structure parameters affect the dark current production

Summary

UPPSALA UNIVERSITET

With data from test stands we better understand the conditioning process

→ We gain in time and cost and ensure the proper performance ACS in a accelerator

During the conditioning we:

- learn about the hardening process by looking at which parameters (pulse shape, power, pulse length etc) affect the dark current behavior
- check with BD localization the "health" of the structures, uniformity, "hot-spots"
- Benchmark theoretical models to understand the changes in metal surfaces under high gradients, applicable outside accelerator physics in fusion devices, satellites etc

UPPSALA UNIVERSITET

Acknowledgement

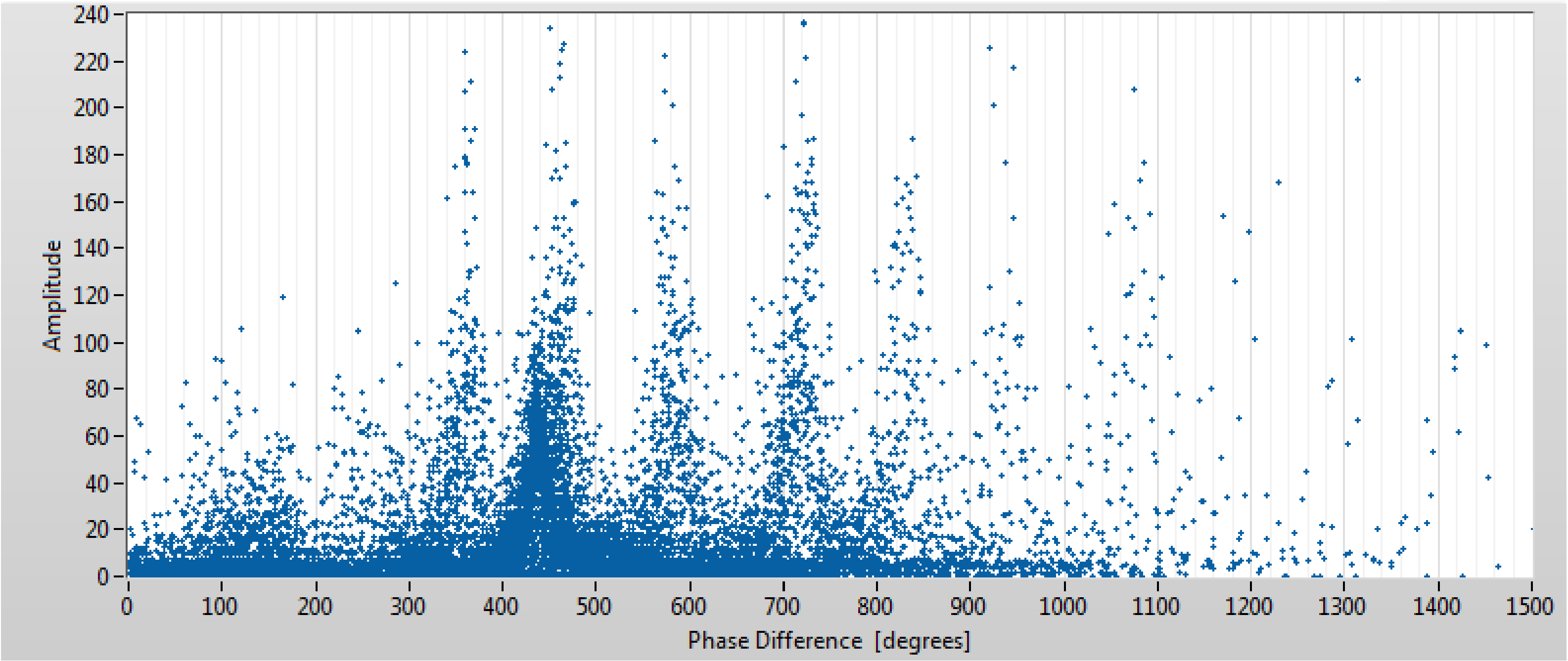
Many thanks to Ben Woolley and

RF group at CERN for the efforts in

constructing and running the XBox

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

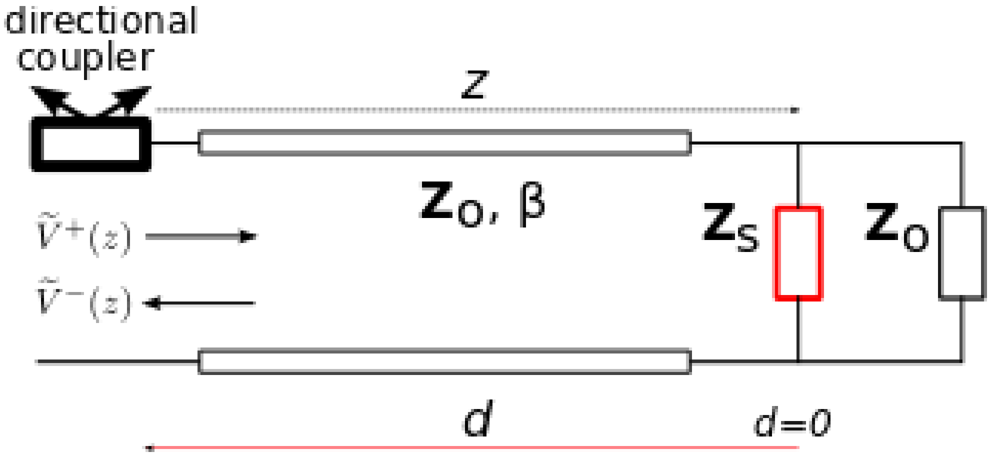
UPPSALA UNIVERSITET



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

FREIA

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

Relative impedance $\widetilde{Z}_S$ is related to ratio of incoming (V+) and reflected (V-) signals - plasma density

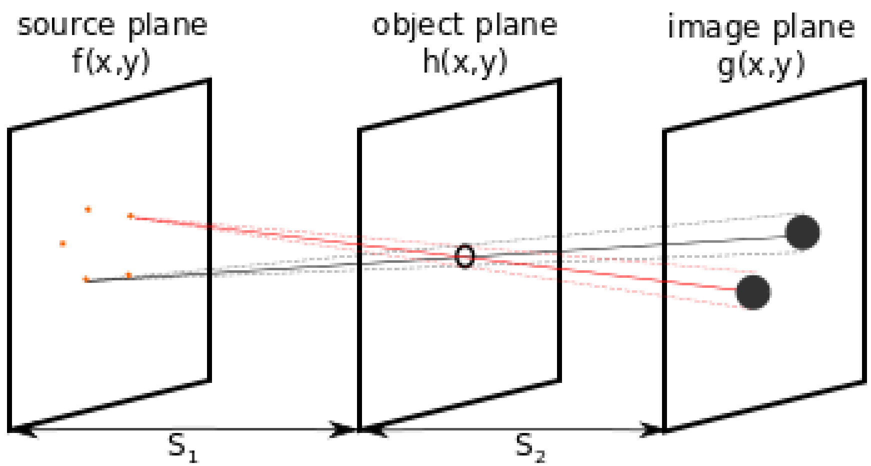
$$\widetilde{Z}_s = \frac{Z_s}{Z_0}$$

Breakdown position *d* related to RF phase

$$\frac{V^{refl}(t)}{V^{inc}(t)} = A(t)e^{j\Delta\phi} = \frac{-e^{2j\beta d(t)}}{1+2\widetilde{Z}_S(t)}$$

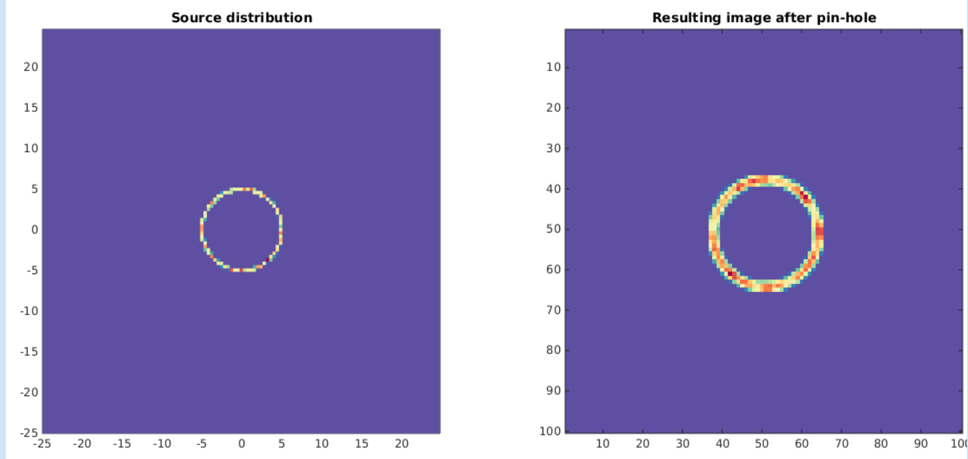
UPPSALA UNIVERSITET

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



Source distribution from circular iris

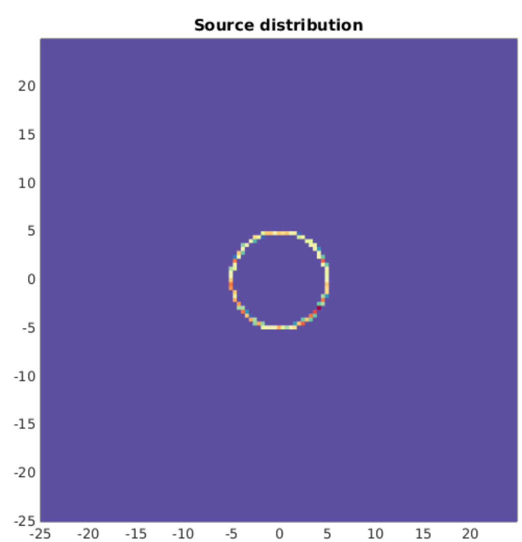
Resulting image after pin-hole

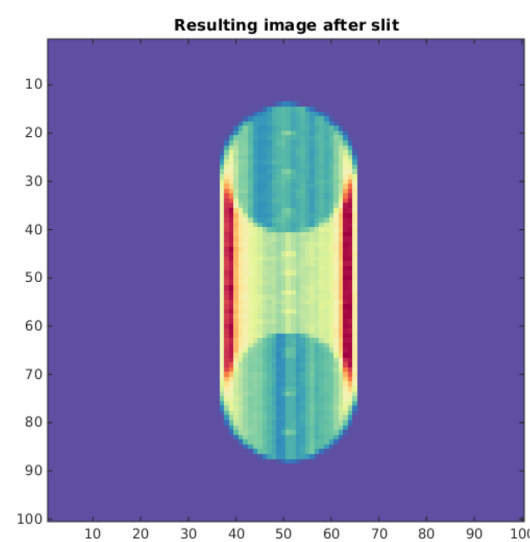


Convolution

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

Same distribution at source
But image is formed through a slit





Deconvolution - breakdown ”tomography”

UPPSALA UNIVERSITET

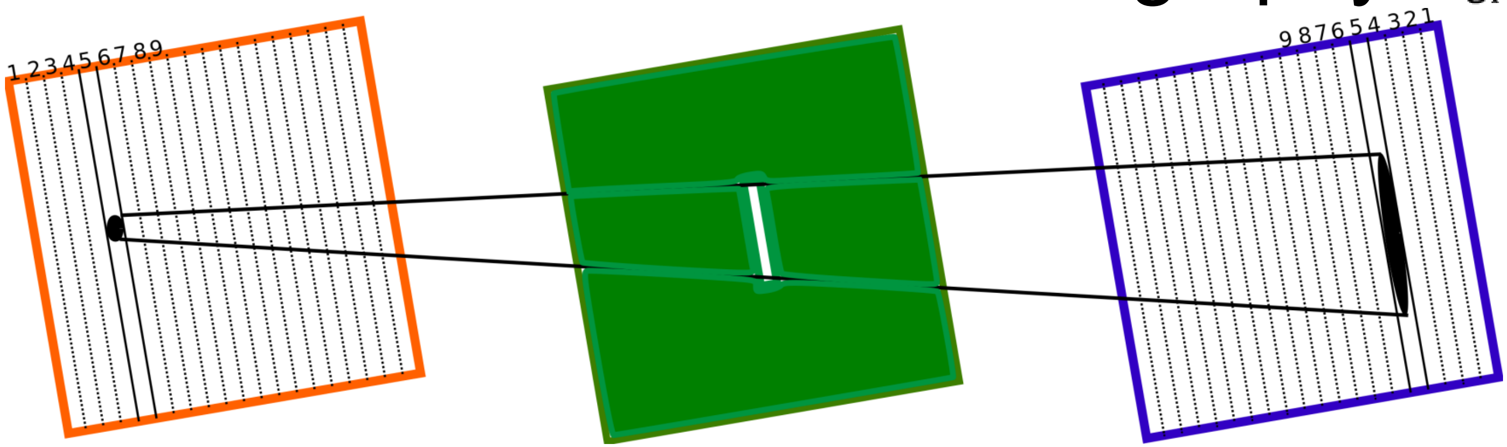
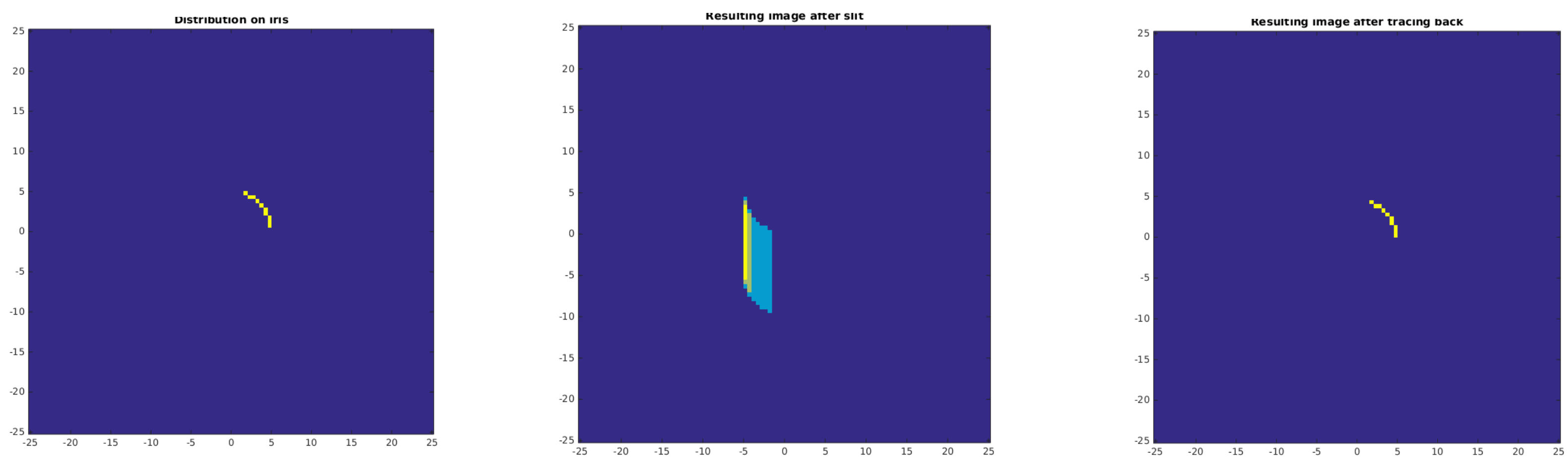


Image is created by calculating a series of 1D convolutions

Image is divided into columns with the width corresponding to the width of the slit
Each projection from the column is taken to directly solve the inverse problem,

Simulation



This way we avoid the influence of the slit's width on the constructed image
Price to pay – lower resolution

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