Studies of vacuum discharges in the CLIC accelerating structure

Master's Thesis

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Outline

Goals

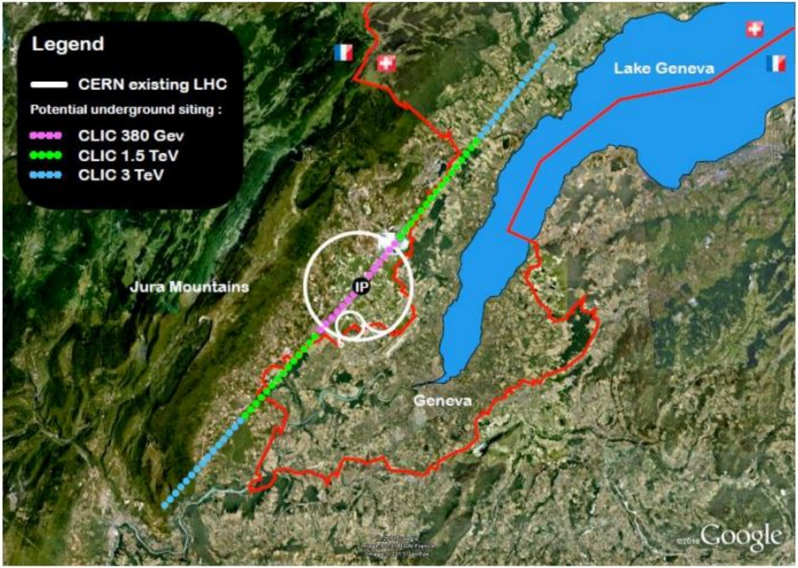
Goals of the project

- Increase the knowledge of breakdown physic inside high gradient structures, by analysing data from the CLIC test stand XBox2.
- Compare old and new positioning methods
- Use images from the Uppsala/CLIC X-band spectrometer for positioning and more
- Characterise features from these images

Introduction

CLIC

What is CLIC?



Introduction
CLIC

CLIC scheme. 140 000 accelerating structures give high demand on the amount of breakdowns inside, to keep luminosity

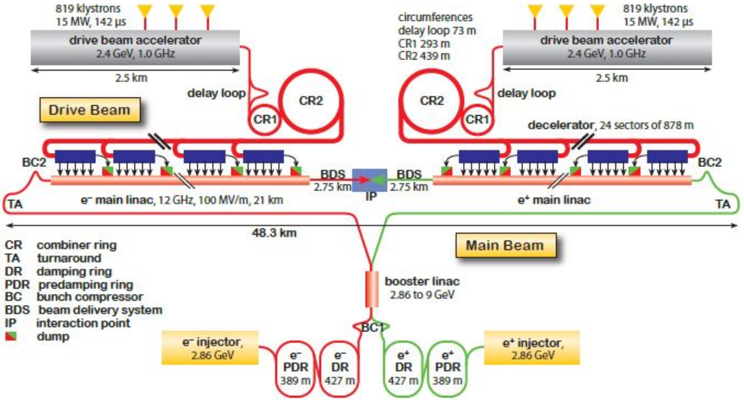


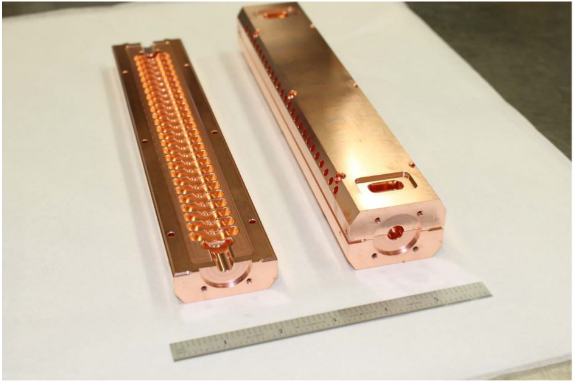
Table: Table with CLIC parameters

Energy	380 GeV, 1500 GeV, 3000 GeV
Length (proposed)	48.3 km
Luminosity	5.9 $\times 10^{34}/cm^2 s$
Gradient	100 MV/m
Repetition rate	50 Hz
Nr of particles per bunch	3.72 $\times 10^9$
Nr of bunches per pulse	312
Bunch length	156 ns
Pulse length	200 ns
Frequency	11.994 GHz
$Emittance_x$	600 nm rad (at linac injection point)
$Emittance_y$	10 nm rad (at linac injection point)

Background and Theory

- Cavities
  - Structure used to accelerate particles with E-field powered by RF power
- Conditioning
  - Process of increasing power but keep the breakdown rate (BDR) constant
- Vacuum discharges/Breakdowns
  - Discharges comes from emitter sites made from the structure material. Charged particles gather until an arc is formed.

Cavity is a structure for accelerating charged particles, with help of RF power

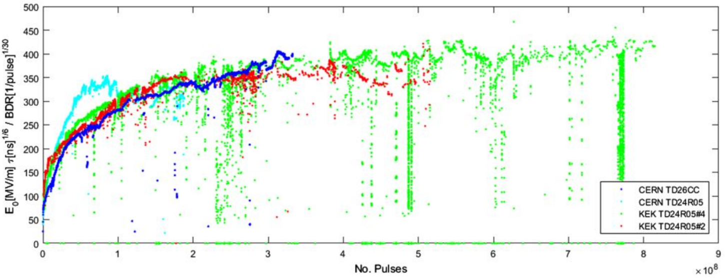


The T24OPEN cavity with travelling wave, before brazing.
Constant gradient structure $\longleftrightarrow$ Different group velocity of the RF-signals through the structure

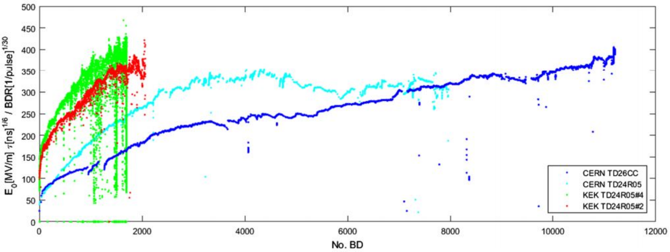
Conditioning Process

- Is a very slow process (couple of months) which purpose is to lower the amount of breakdowns inside the structure. To not destroy the structure itself
- Slowly increase the gradient by increasing the power and changing to longer pulse lengths.
- Conditioning process seems to be correlated to the number of pulses and not the number of breakdowns

Scaled gradient vs Number of pulses



Scaled gradient vs Number of breakdowns



Breakdowns

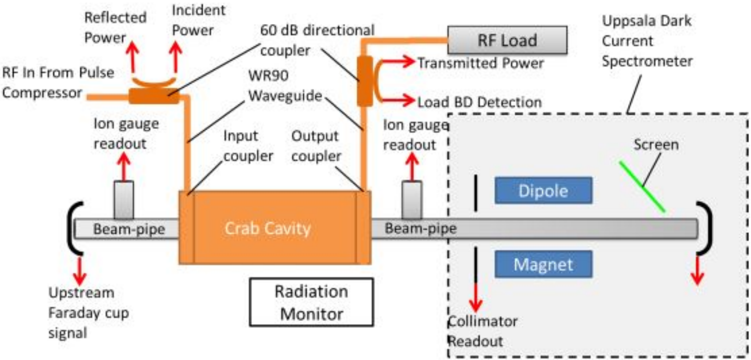
- Ignore gas particle interaction due to vacuum
- Tunnelling of electrons occur when high e-field exists
- Emitters emit while charged particles gather as a plasma until arc is formed. Breakdown occur when this arc is self-sustaining
- Electrons coming from the formed plasma will be going onto the fluorescent screen
- Instruments for studying breakdowns exist

Instruments/Tools

Instruments and tools used for the work

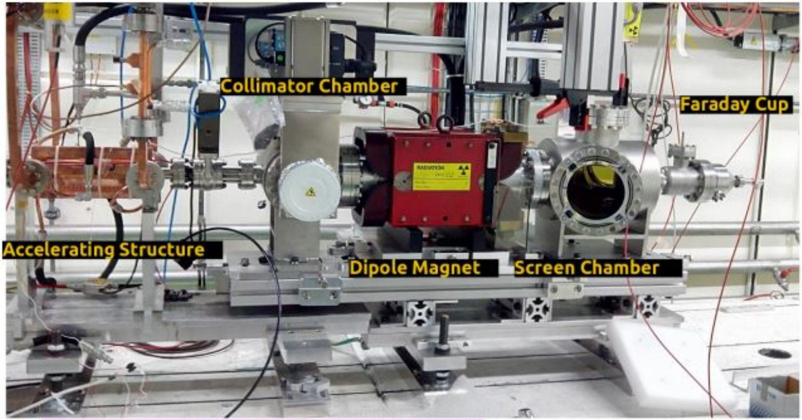
- XBox2 - High gradient test stand. For conditioning cavities while studying breakdowns, with no beam.
- Instrument [**UCXS**]
  - Uppsala/CLIC X-Band Spectrometer
- Choose program [**MATLAB**,LabView,C,Python, etc].

50 MW of power from LLRF-rack, modulator, klystron and pulse compressor into the bunker



Reflected signal appear when the load is unmatched

Photograph of UCXS inside the bunker. Accelerating structure, collimator, dipole and screen chamber



50 Hz and saves both proceeding and preceding images for use as background. Screen is fluorescent and gives images from incoming accelerated electrons

Data analysis

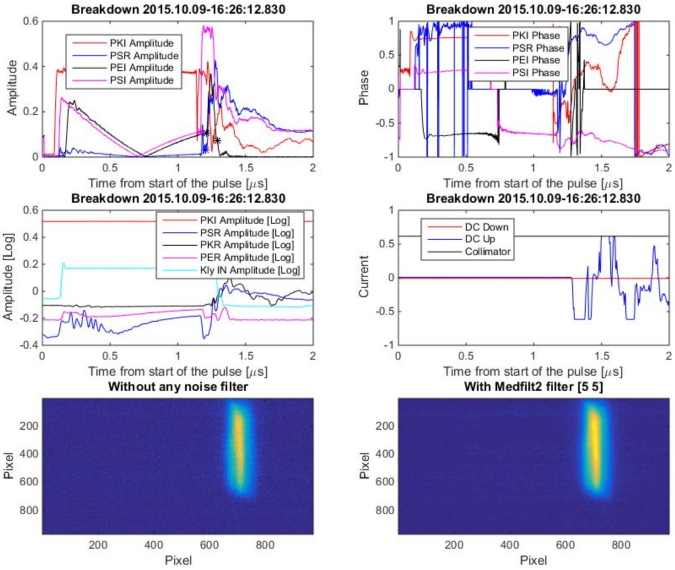
Cross-Check/Different Approach

Initiation phase

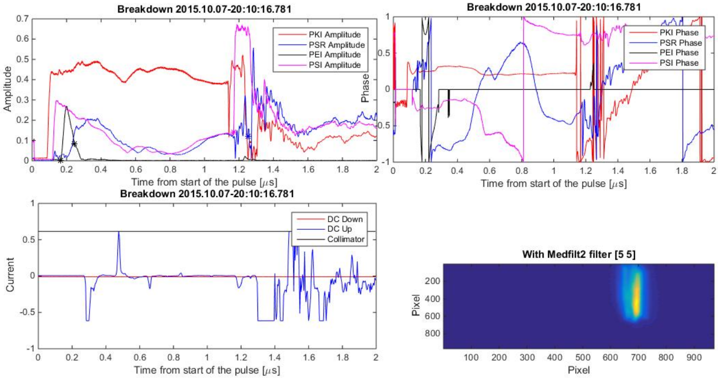
- Methods for longitudinal positioning
  - Edge Method
  - Correlation Method
- Other Methods for positioning
  - Faraday-cup Method
  - Image Method

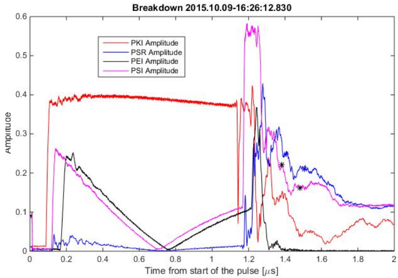
Signals as seen in MATLAB

Normal breakdown signals



Bad breakdown signal



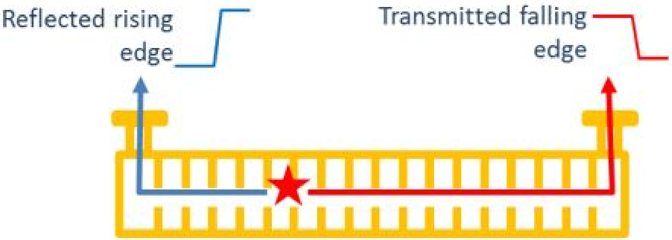


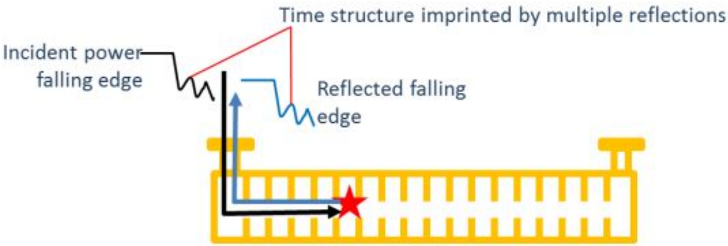
- Faraday-cup method
  - Uses transmitted (90% from max) and the upstream faraday-cup signal.

- Edge method
  - Uses transmitted (80% from max) and reflected (20% from min) signals. Uses background subtraction

- Correlation method
  - Uses input signal (70% from max) and the best correlated reflected signal. Corr function in MATLAB used for calculating correlation between the signal values. No background subtraction

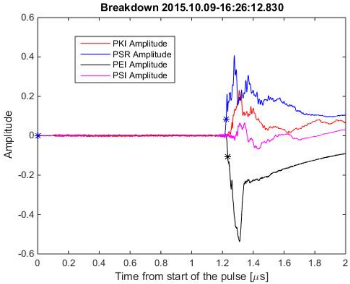
Edge and Correlation method illustrations



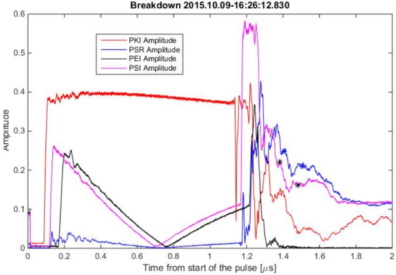


After calculation, signal points are marked

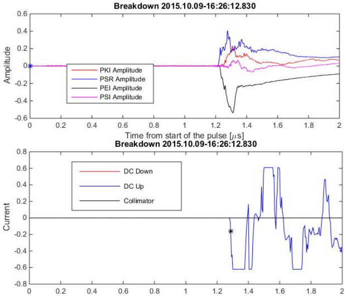
Edge



Correlation

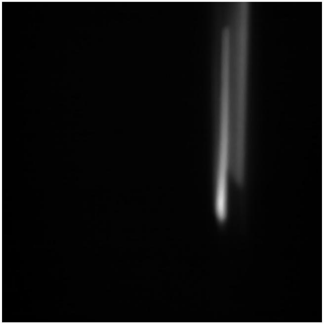


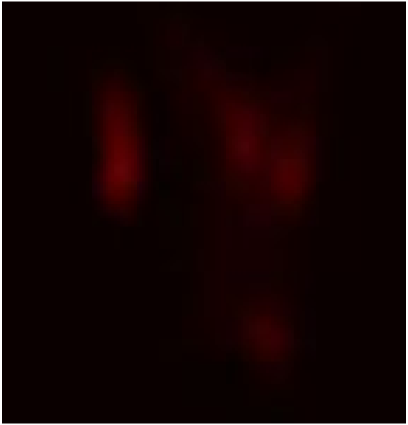
Faraday-cup



Images from UCXS

Collimator have two openings. Slit (10 x 0.5 mm) and pinhole (0.5 mm diameter).





Multiple features if more breakdowns have occurred

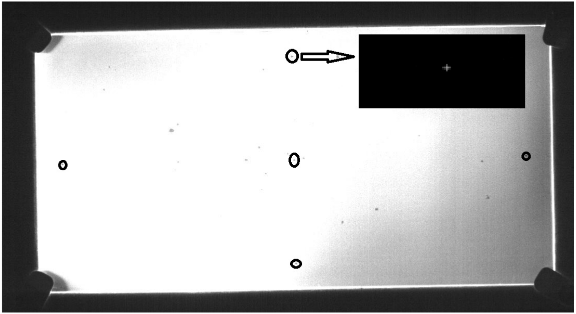
How should we use the images we get from UCXS?

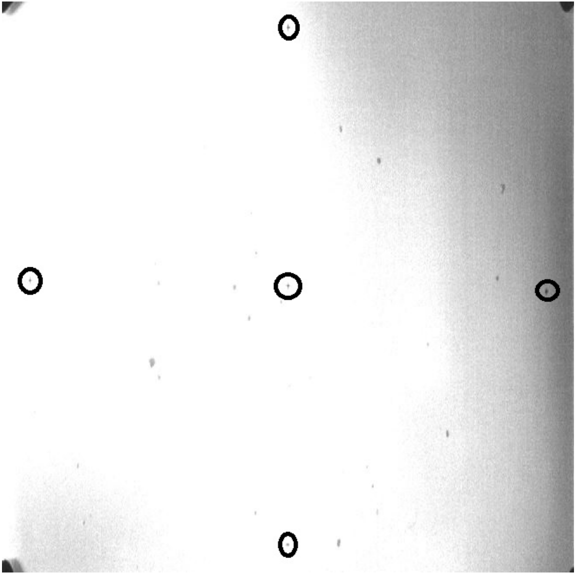
- Calculate position from size of slit/pinhole
- Calculate transversal position from pinhole
- Categorise different features

- First calibration has to be done on the screen. Since the screen is situated with an 30° angle to the beam axis.

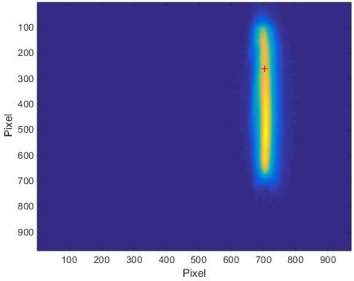
Calibration

Calibration had to be done first From 1100 x 600 $\longleftrightarrow$ 1001 x 1001 for 50 x 50 mm. Making 1 pixel $\approx$ 0.05 mm

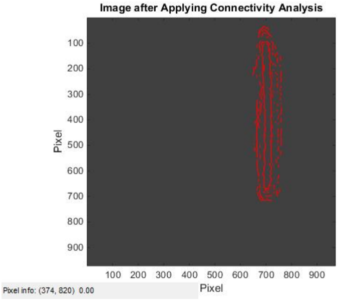




Code to count and find edges of slit image spots

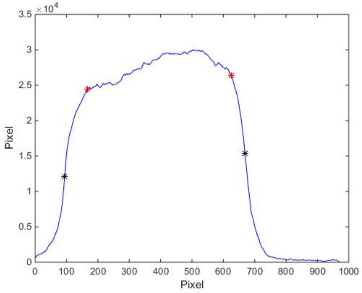


Counting algorithm with cleaning

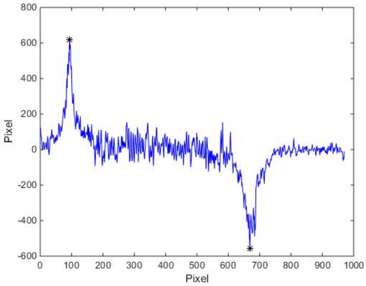


Edges after connectivity analysis

After finding peaks and edges. Calculate the height with the help of row projection



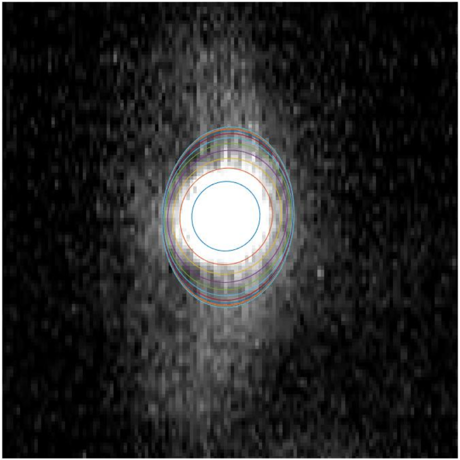
Projection



Derivative

Talk about pinhole images

Ellipse calculated until 2% difference is achieved

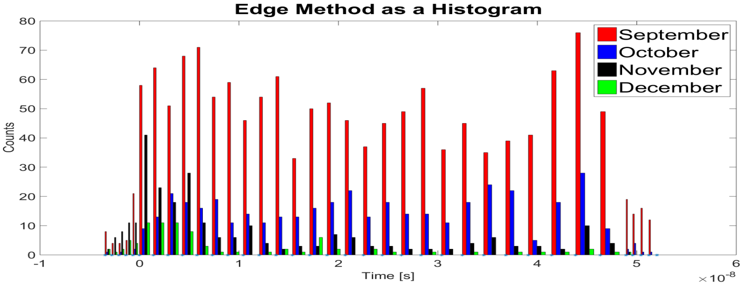


Results Different Methods

- Edge Method: Transmitted Falling Edge vs Reflected Rising Edge.
- Correlation Method: Input signal correlated to the Reflected signal.
- All method use a bin length that varies due to the change in group velocity through the cavity.

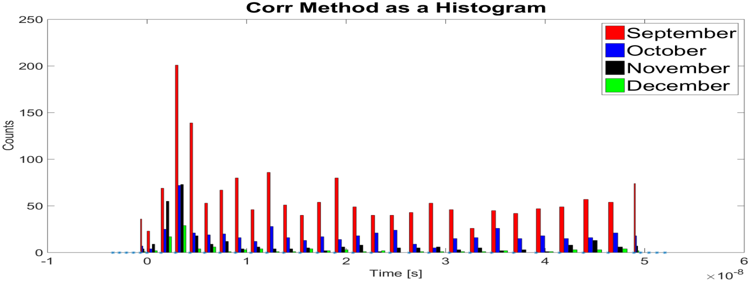
Edge Method

Edge method has an symmetric distribution as is suspected



Correlation Method

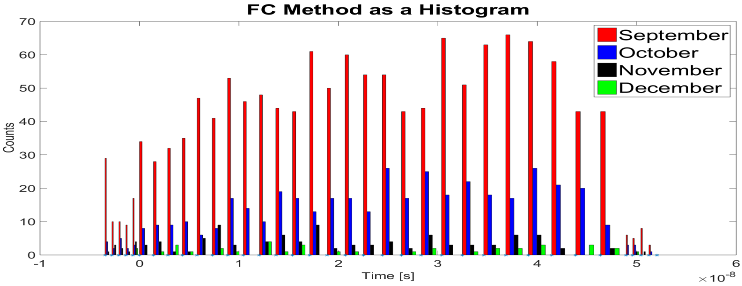
Correlation method have migration towards earlier cells, asymmetric distribution. Why migration?



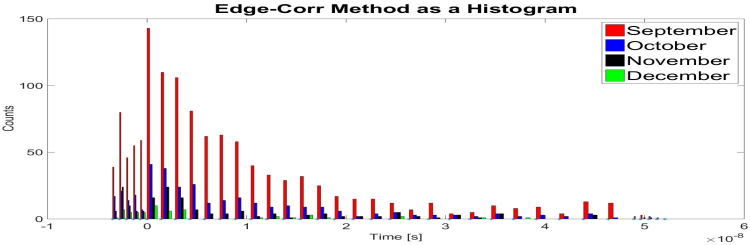
- Turn on time?
- Loss of energy?

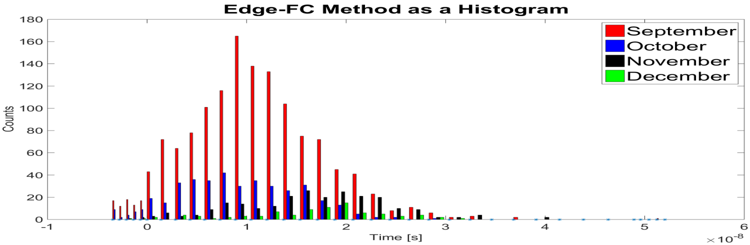
FC Method

Symmetric distribution as well

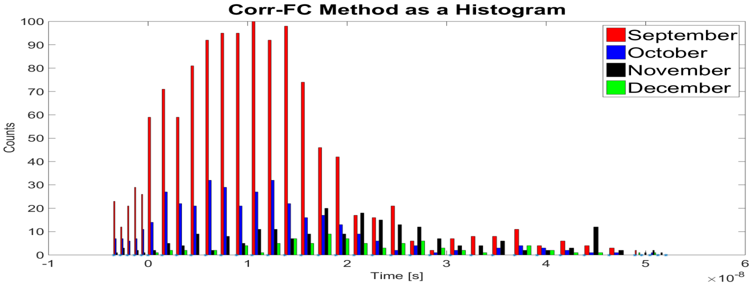


Difference distributions





Difference distribution

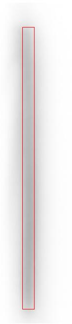


Faraday-cup method seems to have an offset of abut 10 ns. Can be since no alignment is done of the timings. This since no signal is present when there is no breakdown

Table: Method Comparison

Number of spots\Method	Edge	Correlation	FC
1 Spot	18.765 [ns]	24.015[ns]	4.150 [ns]
1 Spot	3.140 [ns]	3.078[ns]	-18.500 [ns]
2 Spot	20.328 [ns]	4.015 [ns]	5.025 [ns]
2 Spot	50.015 [ns]	37.140 [ns]	33.775 [ns]
3 Spot	24.073 [ns]	8.078[ns]	18.150 [ns]
3 Spot	28.765 [ns]	30.890[ns]	25.650 [ns]

Results after algorithm for single spots



Results after algorithm for multiple spots. More inaccurate results

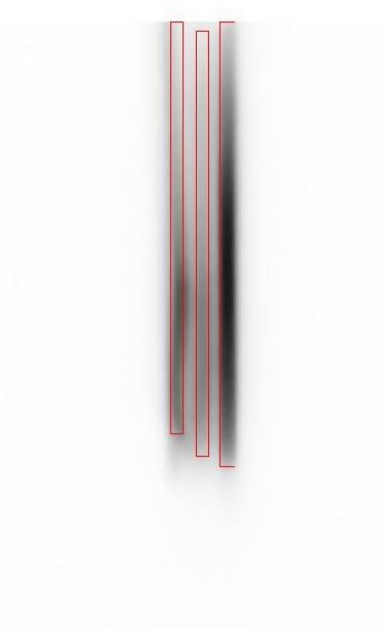


Image tables

Slit

Table: Table over Slit images October 2015

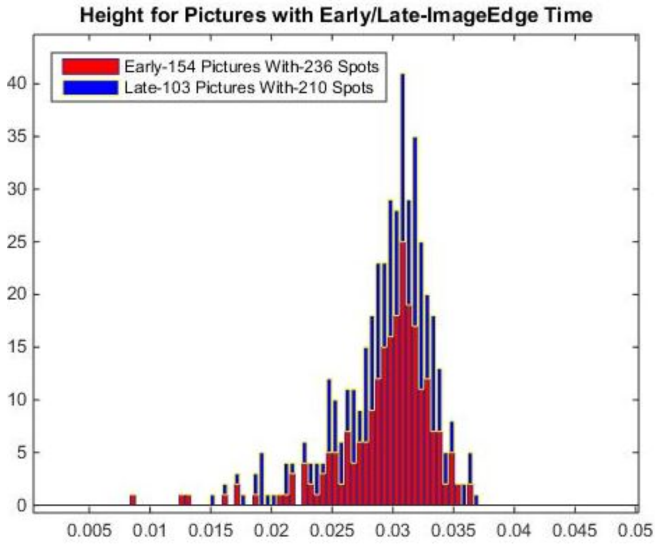
Number of Events	590
Number of Working Events	242
Number of Non-Working Events	348
Number of total Slits	387
Number of total Discarded Slits	265
Number of images with 1 slit	105
Number of images with 2 slit	94
Number of images with 3 slit	39
Number of images with 4 slit	4
Number of images with 5 slit	0
Number of One-Discarded-Slit	82 Slits
Number of Two-Discarded-Slit	51*2 Slits
Number of Three-Discarded-Slit	19*3 Slits
Number of Four-Discarded-Slit	6*4 Slits

Image tables
Pinhole

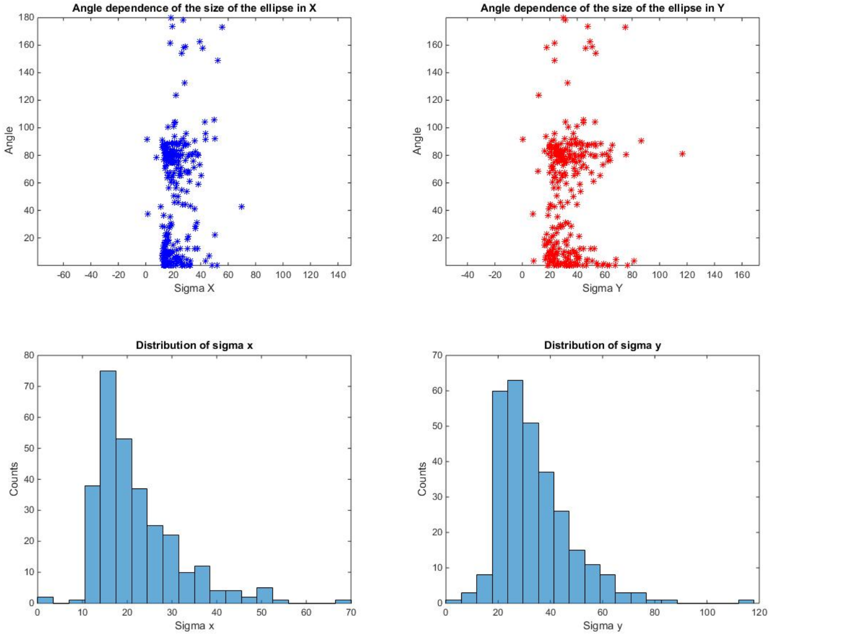
Table: Table over Pinhole images February 2016 - April 2016

Number of Images	448
Number of Black Images	223
Number of Good Images	204
Number of Bad Images	21
Pinhole Spots	340
Pinhole Spots on good Images	292
Pinhole Spots on bad Images	48
Pinhole Images with 1-spot	139 Spots
Pinhole Images with 2-spots	47*2 Spots
Pinhole Images with 3-spots	14*3 Spots
Pinhole Images with 4-spots	3*4 Spots
Pinhole Images with 5-spots	1*5 Spots
Pinhole Images with Higher-spots	0

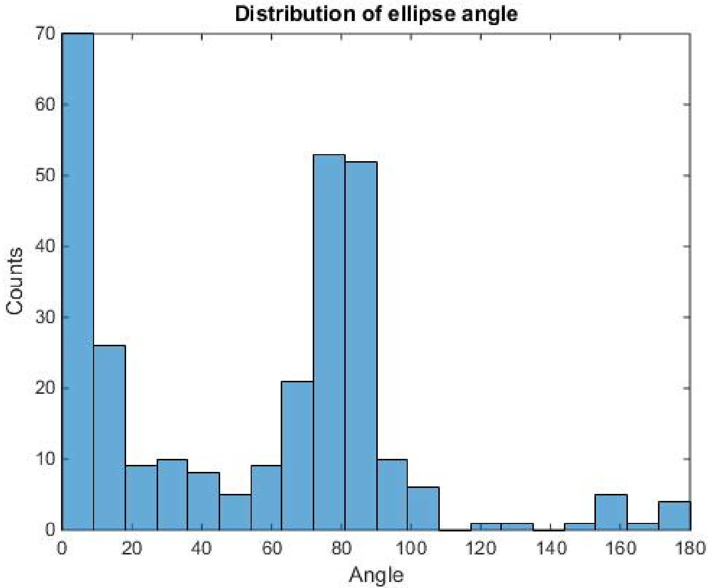
Distribution for slit events under October month



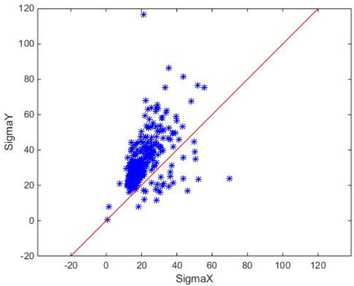
Ellipse angle vs ellipse sigma in both x and y

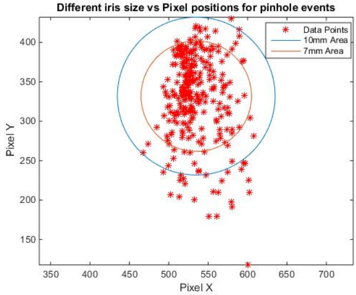


Distribution of the angle



Sigma x vs sigma y together with distribution of the mean value around 2 different iris sizes

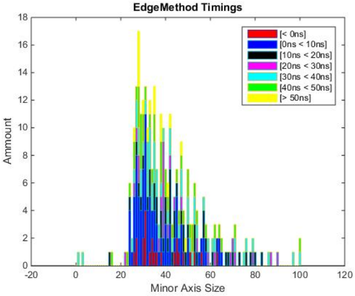


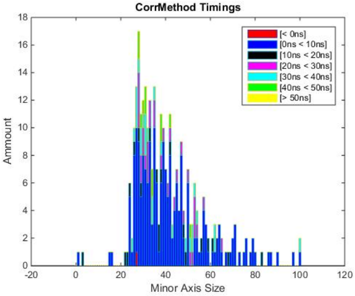


We can see that y-values is more spread in both pictures

7 mm maximum iris size and 10 mm with deviations from pixel positions

Distribution of the minor axis of the ellipses. This to see if there is any correlation between size and timing from both edge and correlation method





Minor axis used since it's the smallest size and goes over iris instead of around

Summation

What have been achieved?

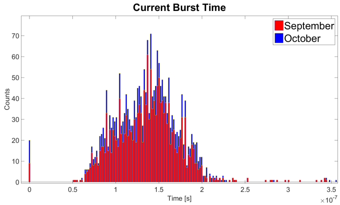
- Results from longitudinal RF signal method shows that there is a difference. Consistent with previous results
- Categorised different image features, both single and multiple features.
- Seen that we probably can't use images for longitudinal positioning, while transversal works better
- Images shows that there probably exists multiple breakdowns that occurs under the same event
- Work have given important knowledge for future tests. For example using dipole magnet after collimator at the UCXS

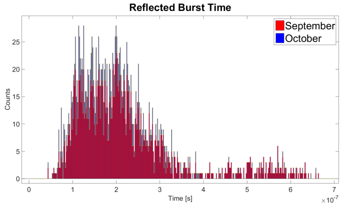
For Further Reading I

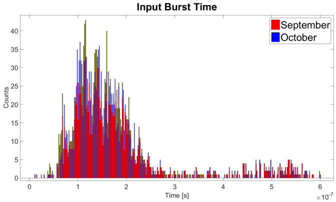
A. Tropp.
Studies of vacuum discharges in the CLIC accelerating structure, June 2016.

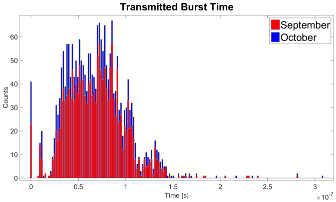
That was all for me. Thank you for listening, Questions?

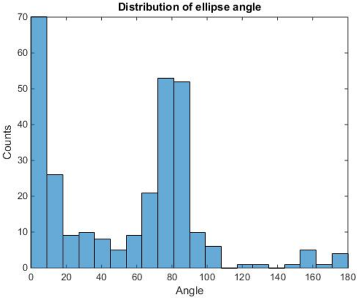
Extra Data

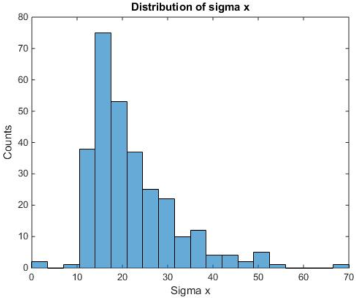

Current Burst Time
September
October
Counts
Time [s]
×10^-7

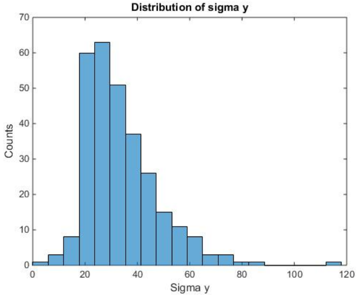

Reflected Burst Time
September
October
Counts
Time [s]
×10^-7

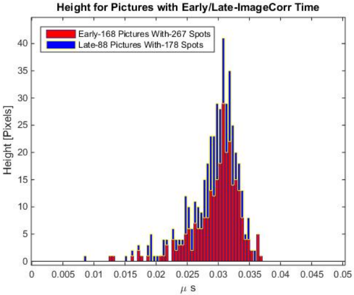

Input Burst Time
September
October
Counts
Time [s]
×10^-7

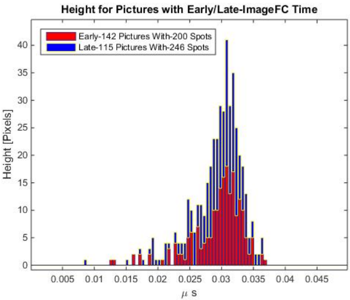

Transmitted Burst Time
September
October
Counts
Time [s]
×10^-7

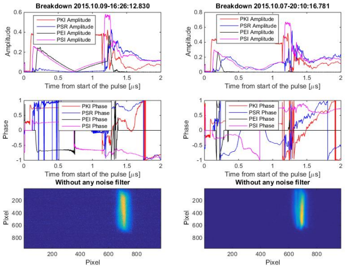

Distribution of ellipse angle
Counts
Angle

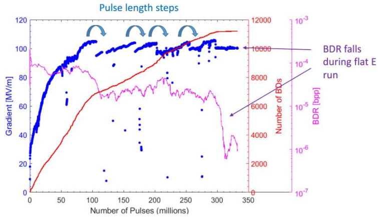

Distribution of sigma x
Counts
Sigma x

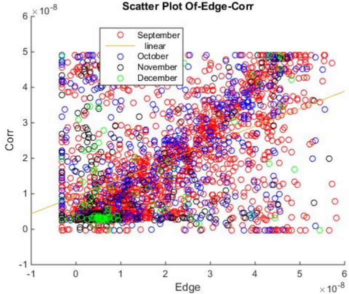

Distribution of sigma y
Counts
Sigma y

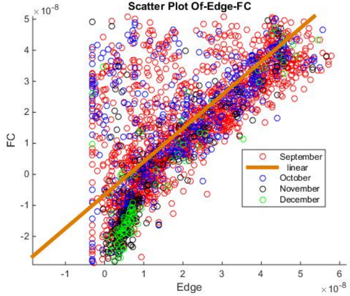

Height for Pictures with Early/Late-ImageCorr Time
Early-168 Pictures With-267 Spots
Late-88 Pictures With-178 Spots
Height [Pixels]
μ s

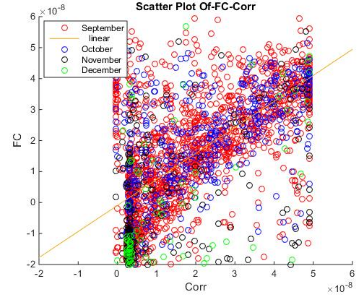

Height for Pictures with Early/Late-ImageFC Time
Early-142 Pictures With-200 Spots
Late-115 Pictures With-246 Spots
Height [Pixels]
μ s

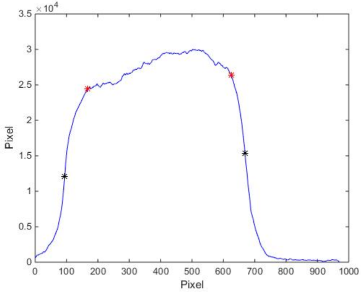

Breakdown 2015.10.09-16:26:12.830
Breakdown 2015.10.07-20:10:16.781
PKI Amplitude
PSR Amplitude
PEI Amplitude
PSI Amplitude
Amplitude
Time from start of the pulse [μs]
PKI Phase
PSR Phase
PEI Phase
PSI Phase
Phase
Without any noise filter
Pixel

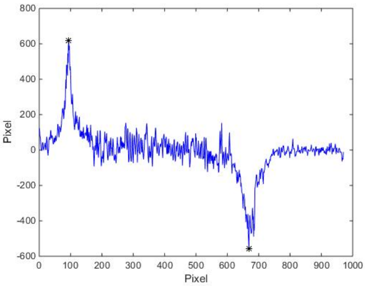

Pulse length steps
BDR falls
during flat E
run
Gradient [MV/m]
Number of BDs
BDR [bpp]
Number of Pulses (millions)

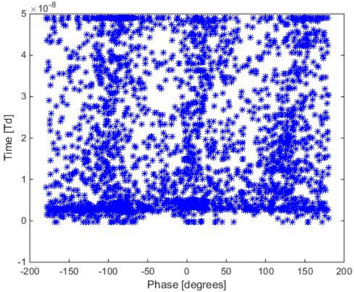

Scatter Plot Of-Edge-Corr
September
linear
October
November
December
Corr
Edge


Scatter Plot Of-Edge-FC
FC
Edge
× 10^-8
× 10^-8
September
linear
October
November
December


Scatter Plot Of-FC-Corr
FC
Corr
× 10^-8
× 10^-8
September
linear
October
November
December


× 10^4
Pixel
Pixel


Pixel
Pixel



×10^-8
5
4
3
2
1
0
-1
Time [Td]
-200
-150
-100
-50
0
50
100
150
200
Phase [degrees]