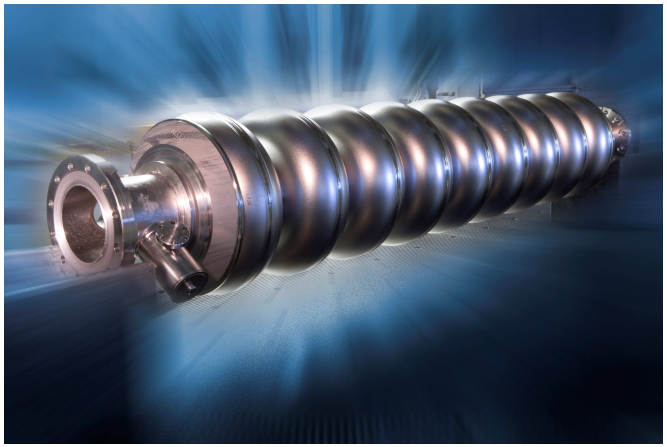
Prospects of automated image processing for characterization of Nb surfaces of superconducting RF cavities

Image analysis and defect recognition



Marc Wenskat
5th Annual Workshop 2011
Bonn, 7-9. Dezember

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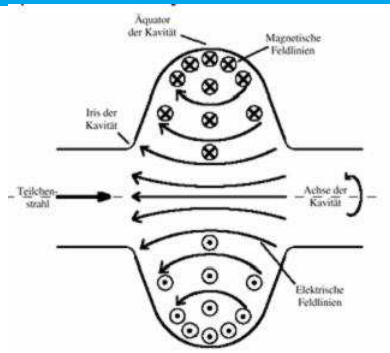
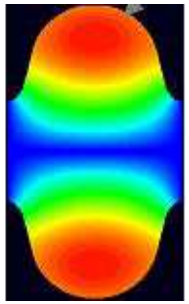
DESY

Motivation

- Superconducting Cavities
  - standing wave operation of cavities
  - low heat dissipation enables long pulse operation and cw-mode
  - low frequency operation (1.3 GHz) results in comfortably sized structures and low beam impedance
  - pure material (RRR Nb) and smooth surface required to sustain superconductivity
  - peak field depends on surface smoothness and geometrical structures
  - verified by in-situ optical inspection with 10 μm^2 resolution

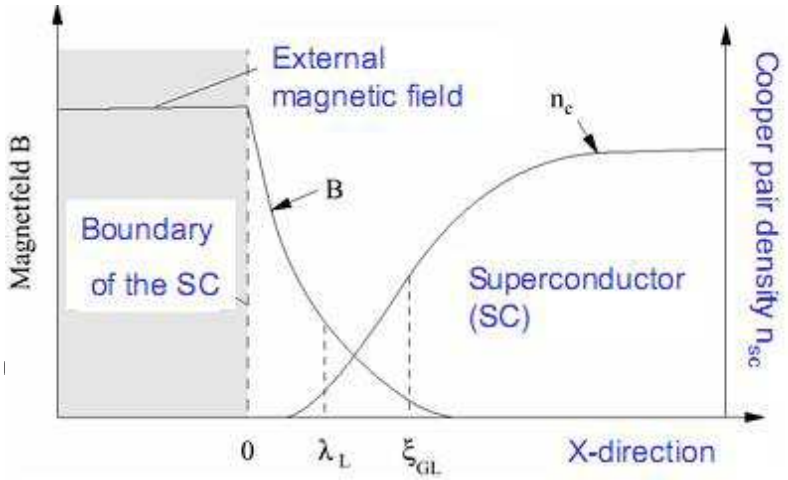
A short reminder – superconducting cavities





Electromagnetic field oscillating inside a volume bounded by superconducting surface.

Surface currents shield the external fields from the bulk niobium (~30nm skin depth).

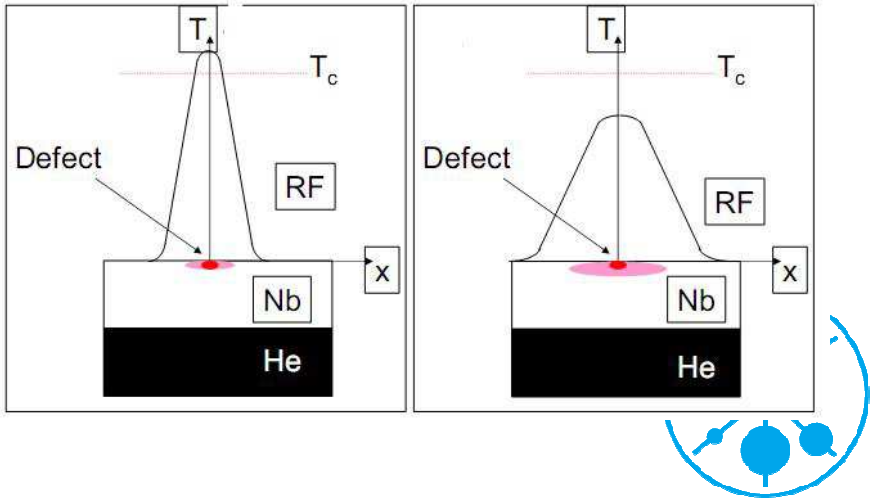


The highest magnetic field is at the equator region.

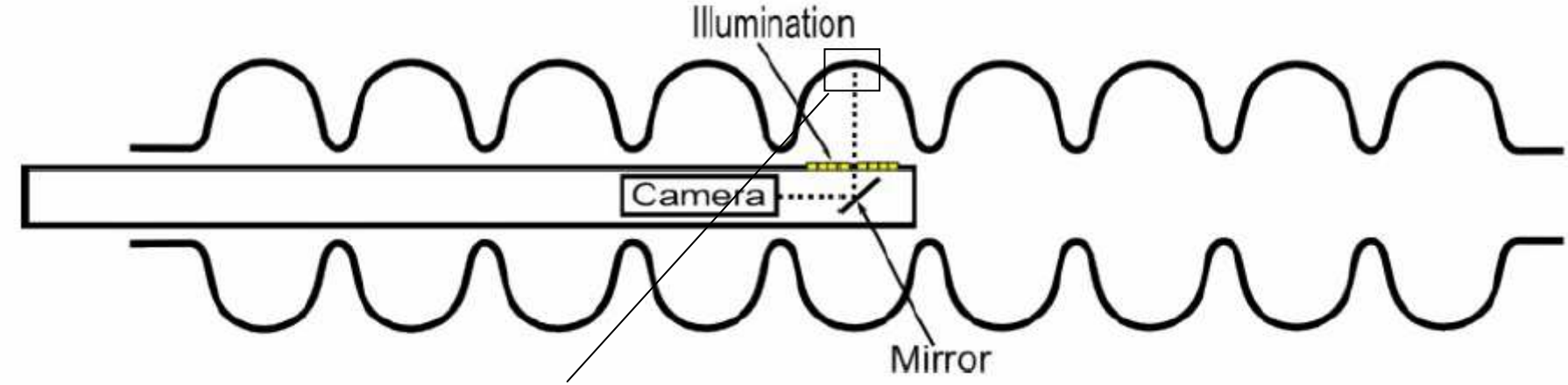
Therefore, the highest current densities are in this region.

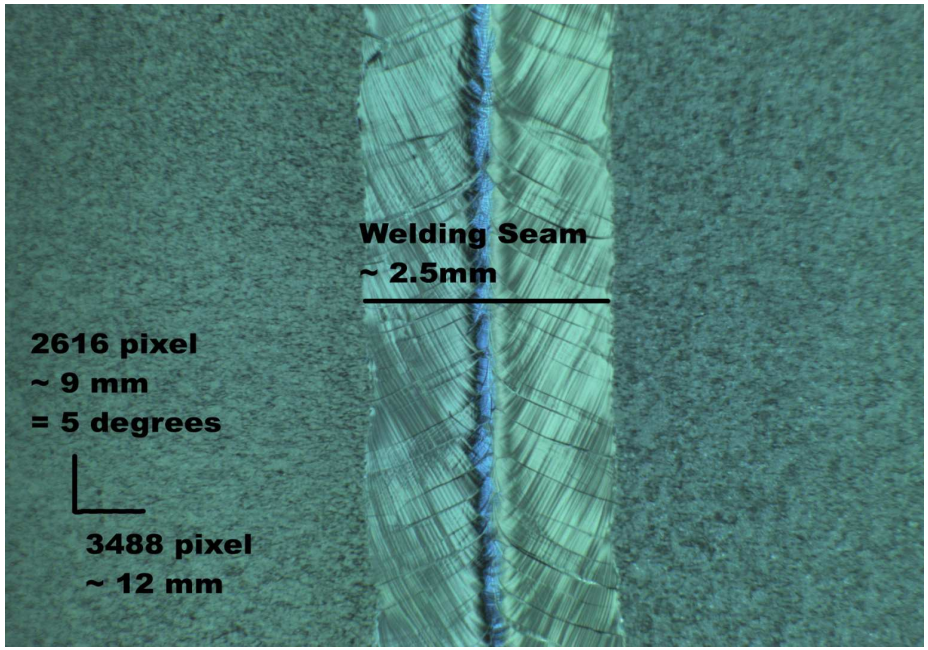
Surface roughness, a geometrical defect or an impurity lead to a local heating of the material.

If the amount of heat can not dissipate fast enough, the local temperature rises above the critical temperature and the cavity will quench.



Optical Inspection: Setup

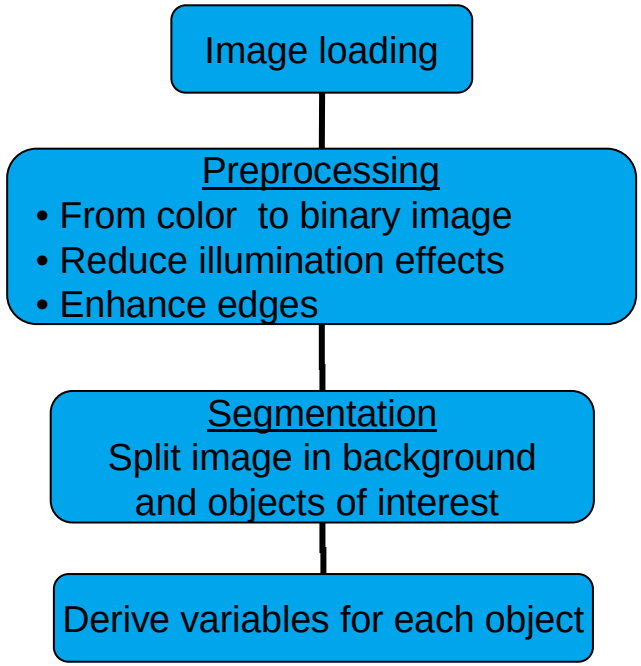


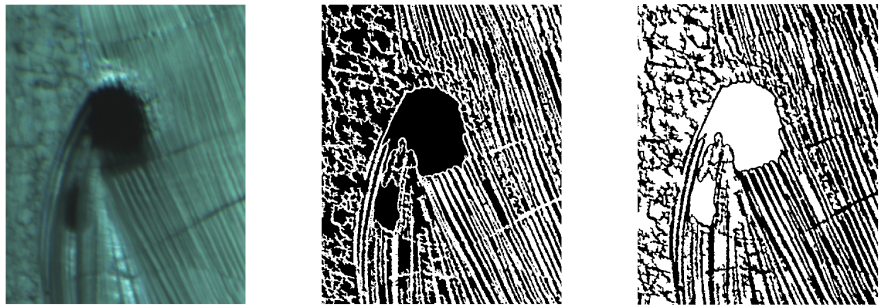


- Effective resolution of 3.5 µm x 3.5 µm per pixel
- Illumination from different angles
- 90 images per equator

(Y. Iwashita et. al., "Development of high resolution camera for observations of superconducting Cavities", Phys. Rev. ST. Accel. Beams 11, 093501 (2008))

Image processing





The original image (left) and the final binary image representations.

These three images are used to derive variables of the objects found in the binary images.

Although, the binary images are just the inverse of each other, they carry different information

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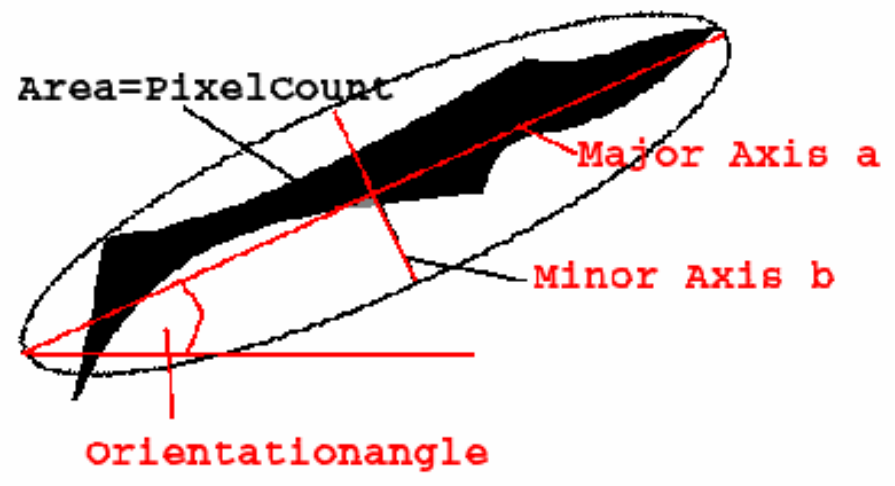
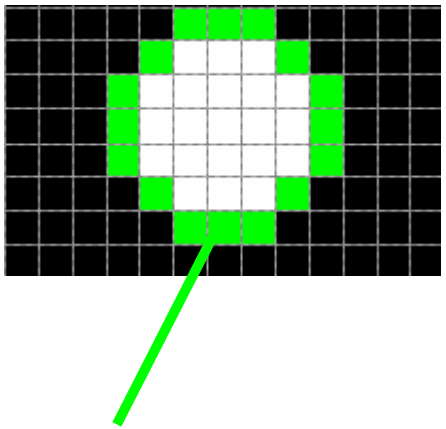
DESY

Measured variables

- Several variables are derived for each representation
- Some are derived from the binary image
  - Area
  - Major & minor axis length
  - Perimeter
  - Orientation
  - Numerical eccentricity



- Some are derived from the original image
  - Surface Roughness R_{dq} ~ Intensity variation in the color image as property of the edges found in the binary image



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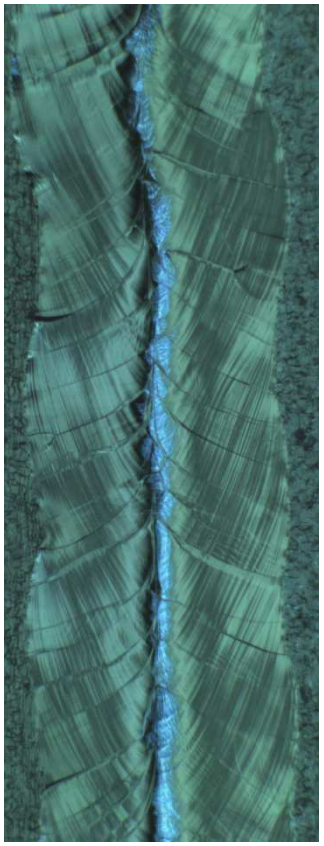
DESY

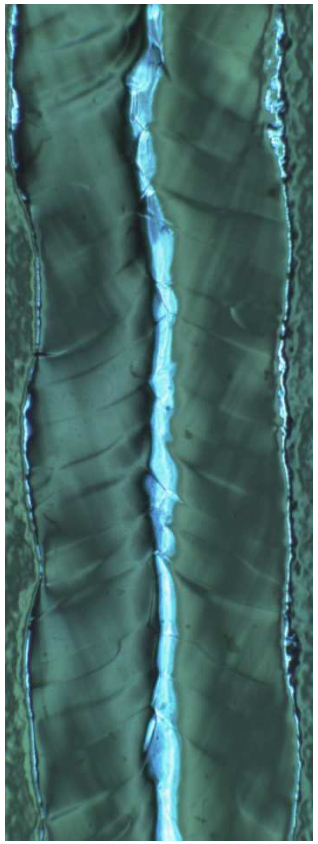
Influence of electropolishing onto the welding seam

- Z161 – Equator 1. Example images: 0° till 4°

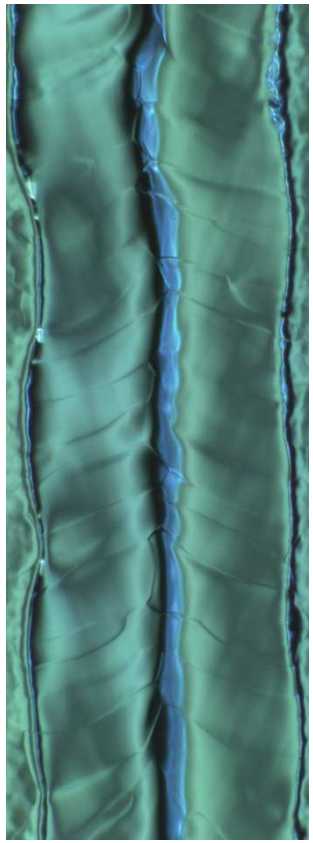
Before EP



After 1st EP



After 2nd EP



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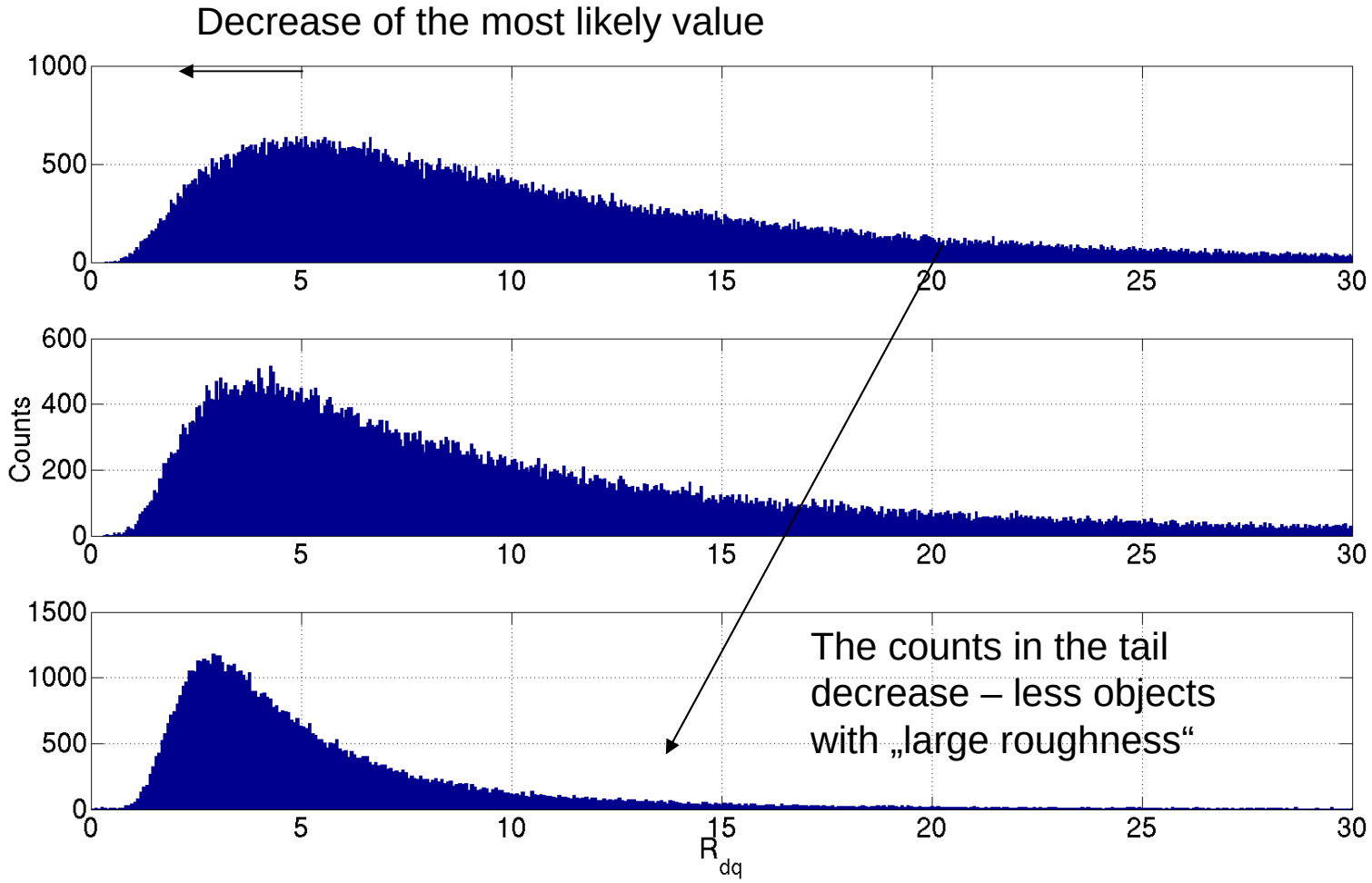
DESY

Influence of electropolishing onto the welding seam



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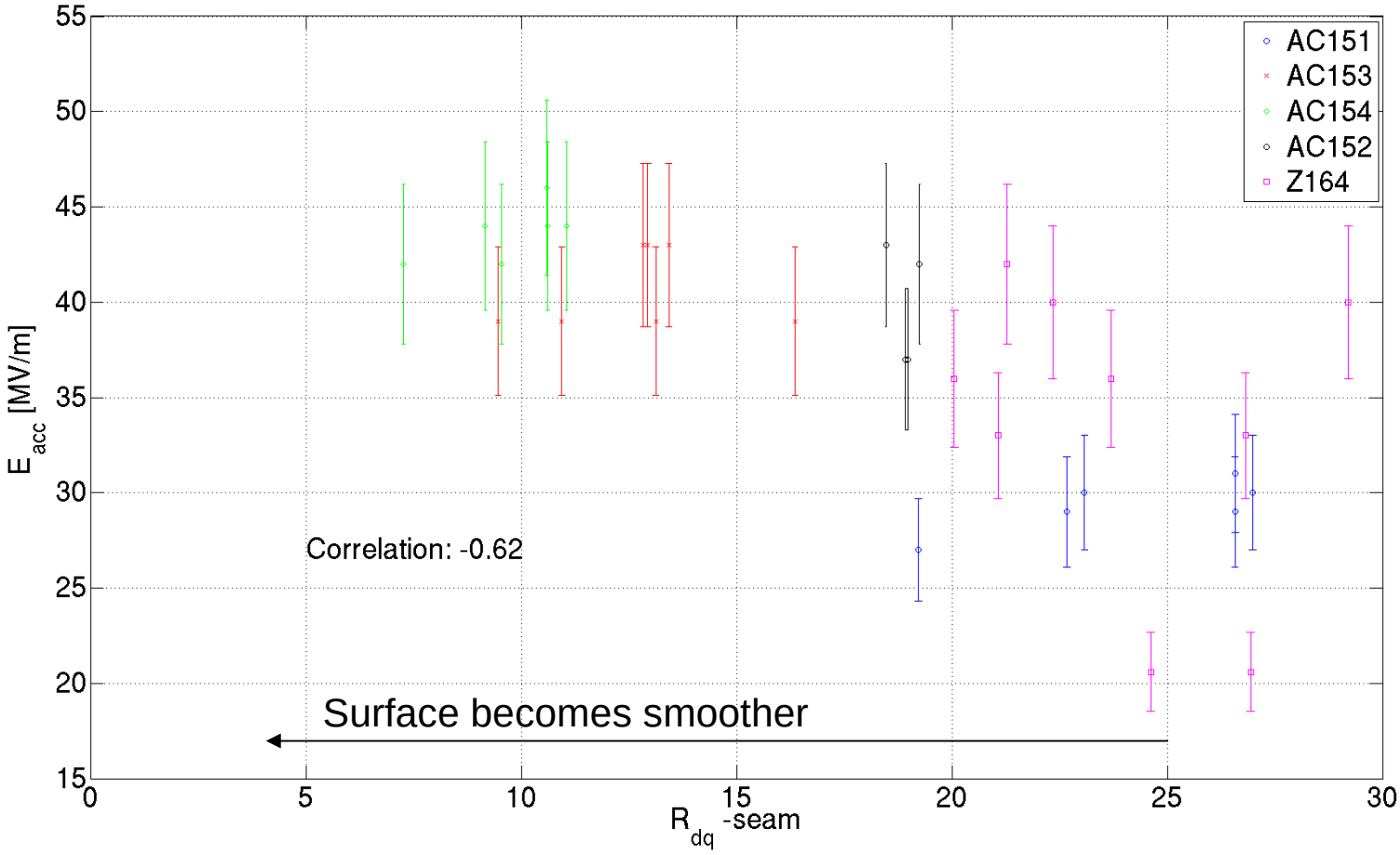
Correlation of surface roughness and gradient



Trimmed mean of R_{dq} for each cell of a cavity

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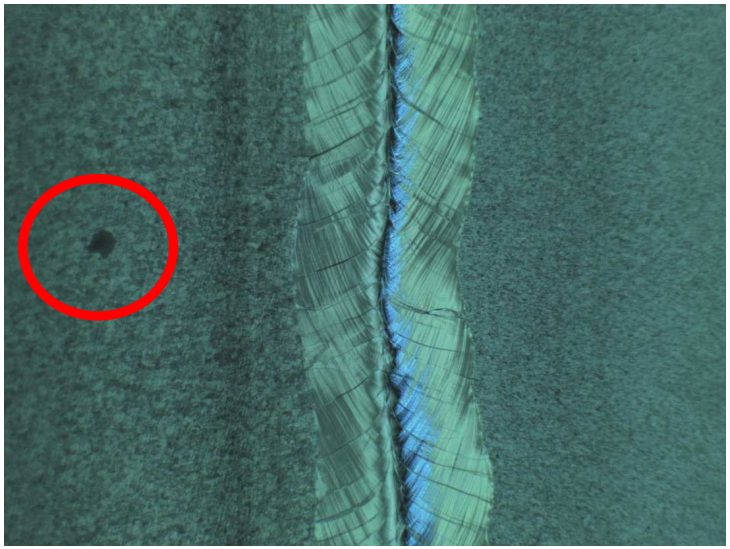
DESY

Defect Recognition

- Variables used to compare an object with the neighborhood
  - Major Axis Length, Eccentricity, Area
- Introduce a metric in n-dimensional phase space where the variable in each dimension is normalized to its typical range of variation (sigma)
- The neighborhood are all objects inside a circle with a radius 3.5 the major axis length
- If the mean distance of a single object compared to the other objects in the neighborhood is above a threshold, mark it as an irregularity



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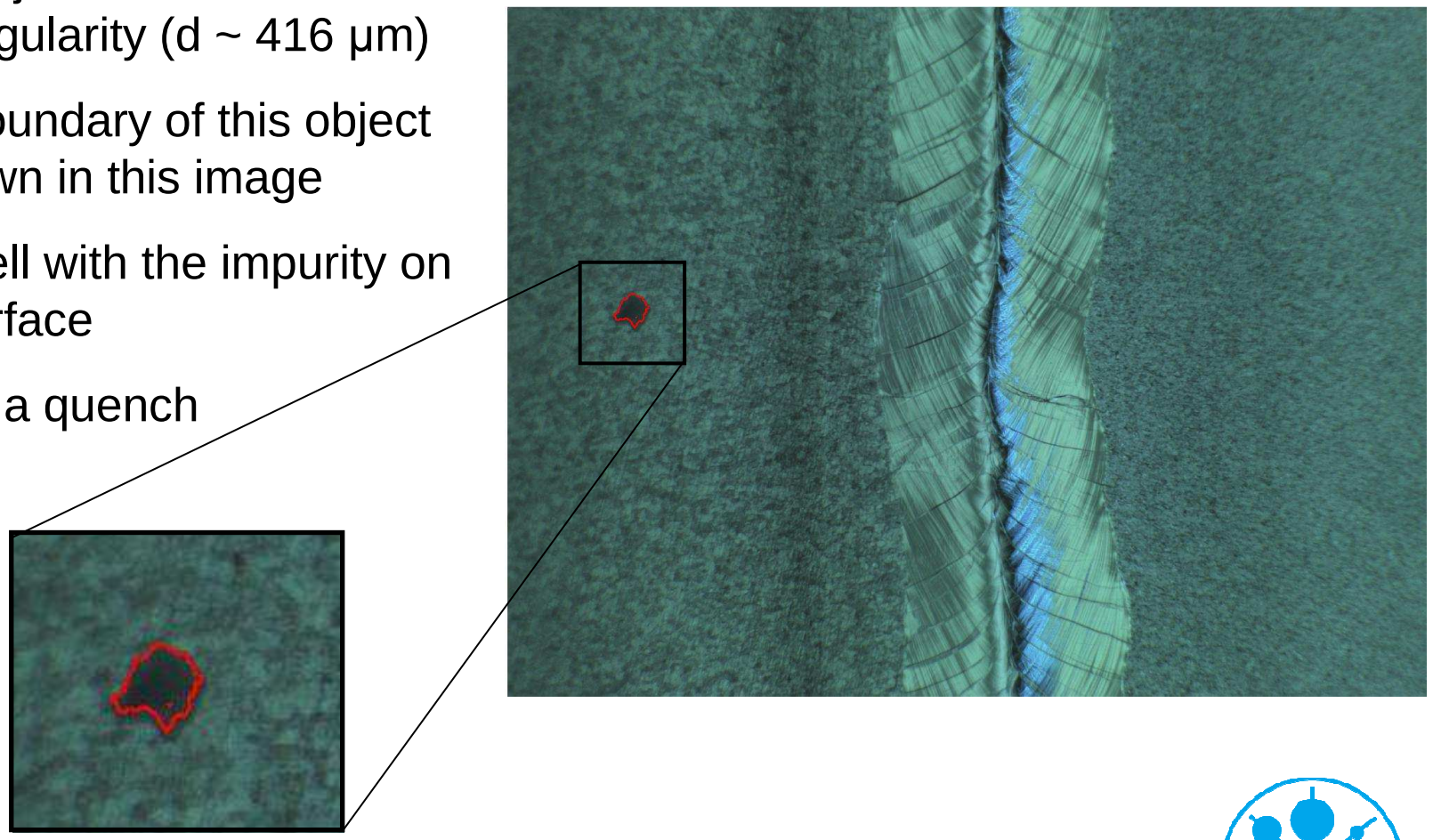
Defect Recognition

- One object was identified as an irregularity (d ~ 416 µm)
- The boundary of this object is shown in this image
- Fits well with the impurity on the surface
- Led to a quench



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DESY

Summary & outlook

- Surface purity and smoothness is paramount to high-field operation of SRF cavities
- Kyoto camera enables optical inspection of the mounted 9-cell cavity
- Automatic image processing allows for classification of surface properties and detection of defects
- A vast amount of cavities for XFEL and ILC-HiGrade will provide the training sample for understanding and feedback


Questions