

CLIC Crab Cavity Post-Mortem analysis

*Ben Woolley
(CERN)*

*Enrique Rodríguez Castro
(University of Vigo)*

23. 03. 2016



Outline

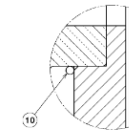
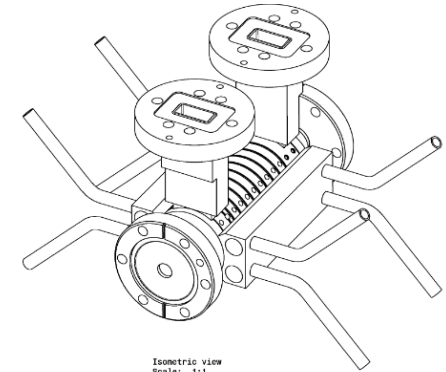
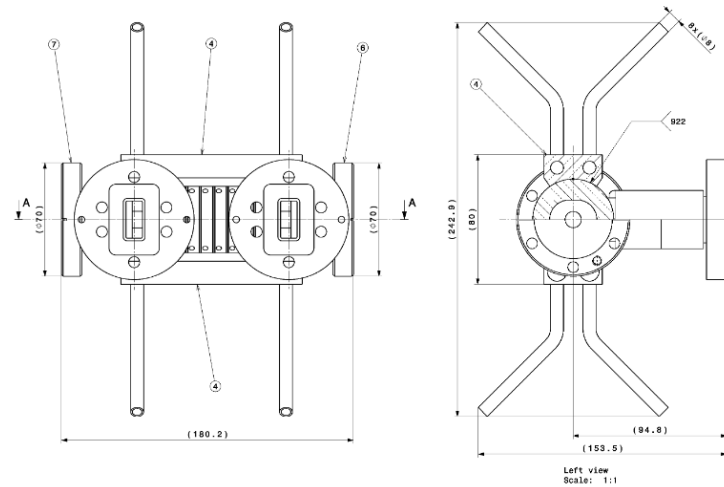
- **Introduction**
- **Objective**
- **Cutting and Nomenclature**
 - Marks and pollution induced by Post-Mortem cutting
 - Cleaning (degreasing)
 - General appearance of the surface after cleaning
- **Distribution**
 - BD distribution in the iris
 - BD location Vs E-Field
 - BD location Vs H-Field
 - BD location Vs Sc-Field
 - Facing irises (same cell)
- **Acquisition**
 - Imaging
 - Marking
 - Counting
- **Catalogue of features related with breakdown activity**
 - Comparison with other tested structures
 - Craters
 - Worm Like Features (WLF)
- **Summary of observations**

Outline

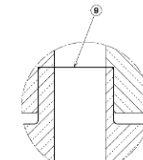
- **Introduction**
- **Objective**
- **Cutting and Nomenclature**
 - Marks and pollution induced by Post-Mortem cutting
 - Cleaning (degreasing)
 - General appearance of the surface after cleaning
- **Distribution**
 - BD distribution in the iris
 - BD location Vs E-Field
 - BD location Vs H-Field
 - BD location Vs Sc-Field
 - Facing irises (same cell)
- **Acquisition**
 - Imaging
 - Marking
 - Counting
- **Catalogue of features related with breakdown activity**
 - Comparison with other tested structures
 - Craters
 - Worm Like Features (WLF)
- **Summary of observations**

CLIC Crab Cavity

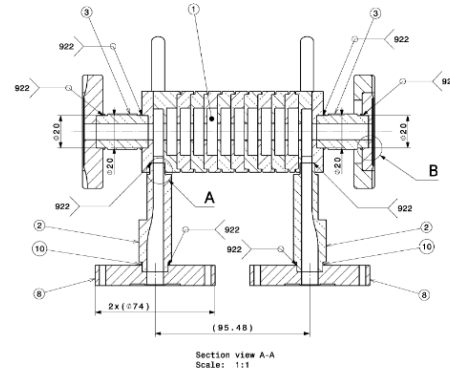
- Tested at Xbox 2
- Finished in June 2015



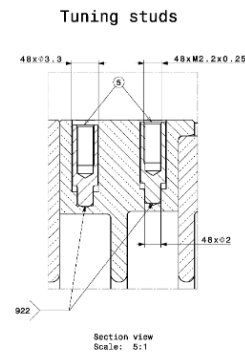
Detail B
Scale: 5:1



Detail A
Scale: 5:1



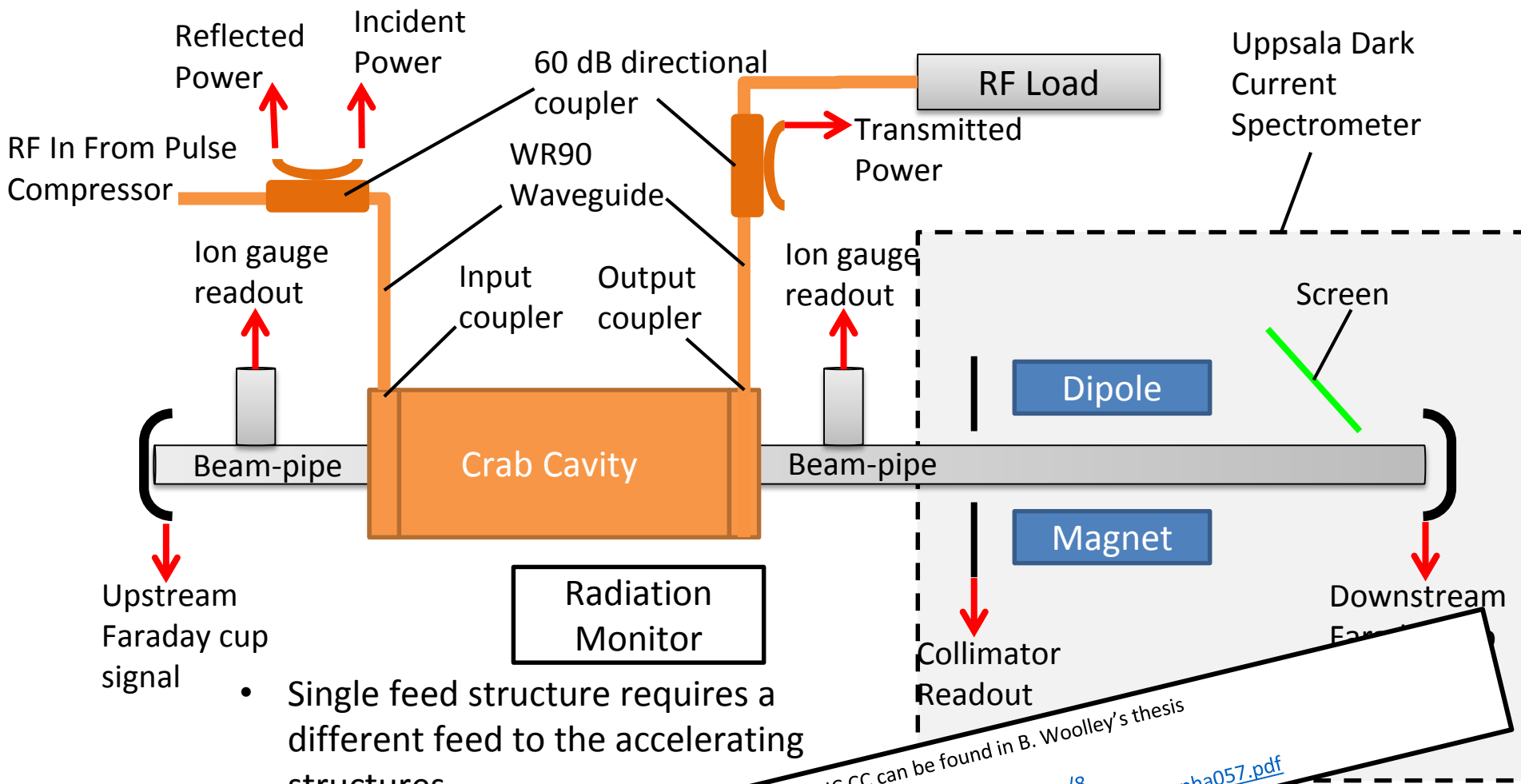
Section view A-A
Scale: 1:1



Section view
Scale: 5:1

NO	DESCRIPTION	QTY	UNIT	QTY	REF. CODE
1	BRACING WIRE (Ø1.5)	1	M		
2	CLIC LHM RP FLANGE	4			
3	ØW 40 LHM FIXED FLANGE	2			
4	ØW 40 LHM ROTAT. FLANGE	2			
5	TUNING STUD	4			
6	COOLING BLOCK ASSEMBLY	4			
7	SEW PFC	2			
8	WINDSHIELD (BRAC. MOUNTING)	2			
9	BEK STACK (Ø10x15)	1			
10	BEK STACK (Ø10x15)	1			
DRAWN: S. RODRIGUEZ CASTRO CHECKED: S. RODRIGUEZ CASTRO DATE: 2015-06-15 SCALE: 1:1 REF. CODE: CRAB CAVITY ASSEMBLY					

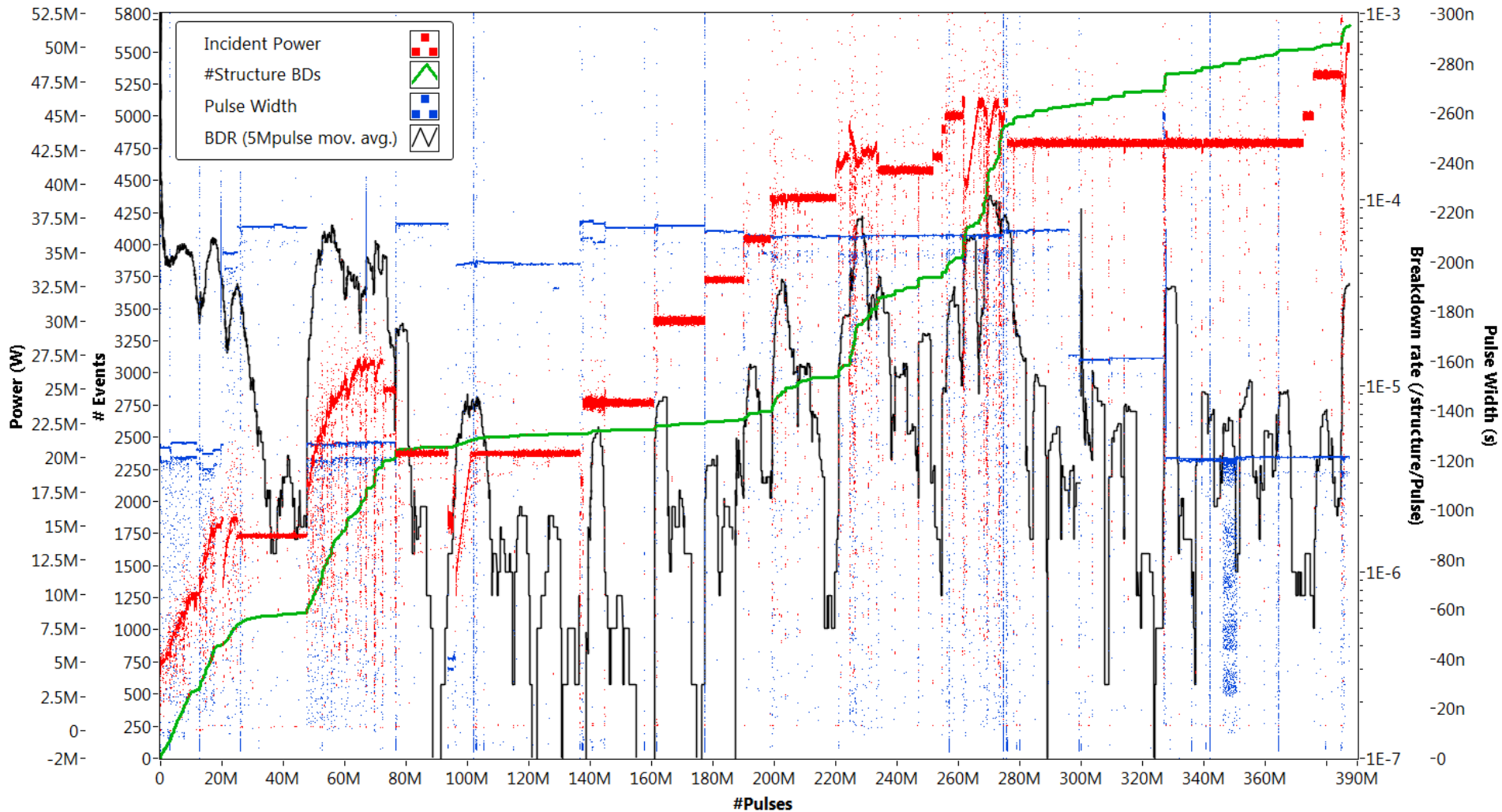
Xbox-2 Diagnostics



- Single feed structure requires a different feed to the accelerating structures.
- We can take advantage of these diagnostics with the current spectrometer

More information about CLIC CC can be found in B. Woolley's thesis
<http://eprints.lanacs.ac.uk/76926/>
 or <https://indico.cern.ch/event/358352/contribution/8>
 or <http://accelconf.web.cern.ch/AccelConf/IPAC2015/papers/wepha057.pdf>

Full Processing History



Structure has seen almost 390 million pulses with over **5700 breakdown events**.
 Performed well above the operating limit of 13.35 MW: 43MW, 200ns flat-top, BDR 3e-6.
 Peak power reached: 51 MW, 100 ns flat top, BDR 3e-5.

Outline

- **Introduction**
- **Objective**
- **Cutting and Nomenclature**
 - Marks and pollution induced by Post-Mortem cutting
 - Cleaning (degreasing)
 - General appearance of the surface after cleaning
- **Distribution**
 - BD distribution in the iris
 - BD location Vs E-Field
 - BD location Vs H-Field
 - BD location Vs Sc-Field
 - Facing irises (same cell)
- **Acquisition**
 - Imaging
 - Marking
 - Counting
- **Catalogue of features related with breakdown activity**
 - Comparison with other tested structures
 - Craters
 - Worm Like Features (WLF)
- **Summary of observations**

Objective

- Breakdown features (BDs) observation.
 - Are they similar to those in monopole structures.
- Macroscopic observation of BDs.
 - How are they distributed in the iris?
 - Distribution relation in the cell
 - Comparison against E-field, H-Field and Sc-Field

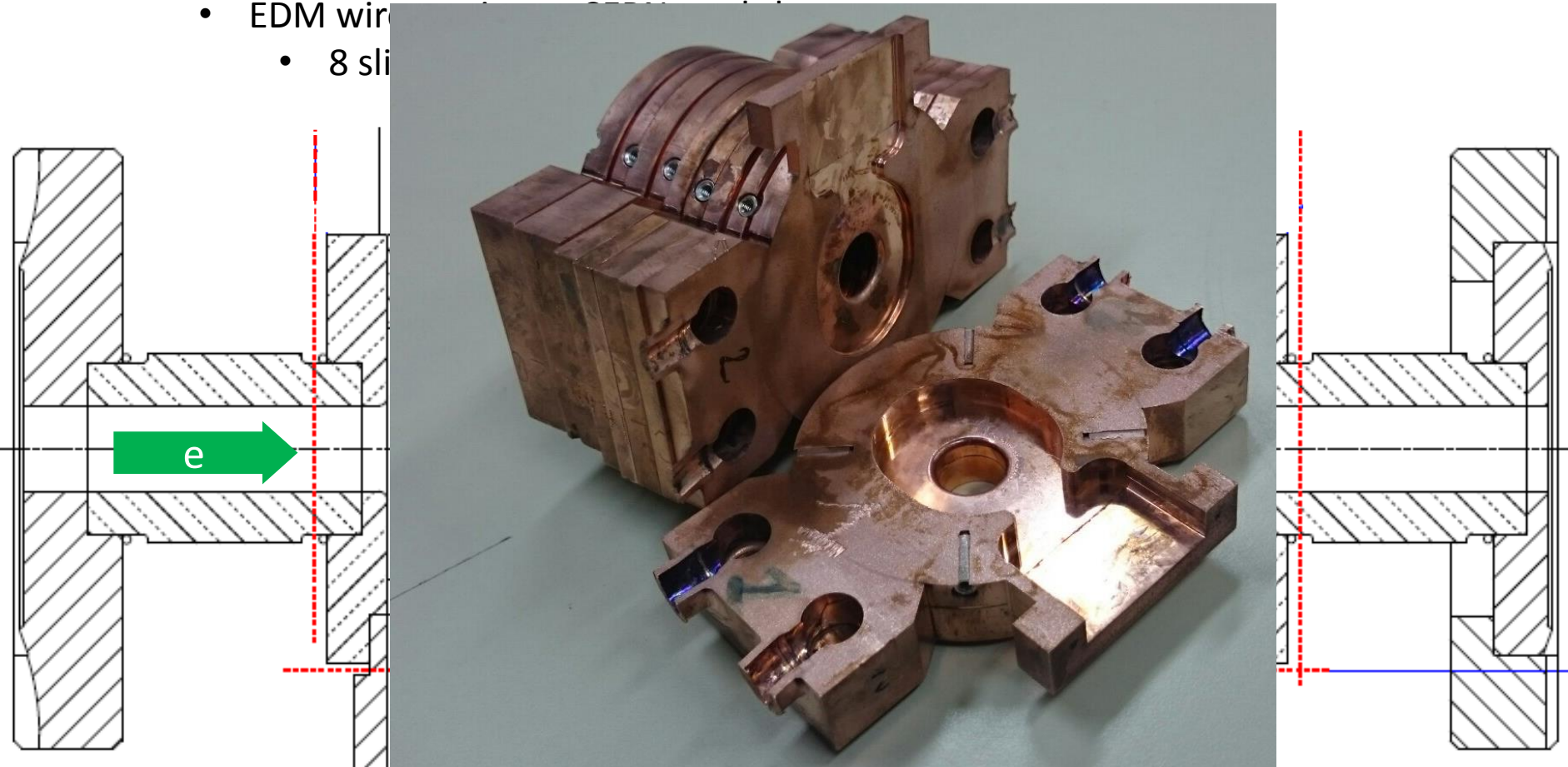


Outline

- **Introduction**
- **Objective**
- **Cutting and Nomenclature**
 - Marks and pollution induced by Post-Mortem cutting
 - Cleaning (degreasing)
 - General appearance of the surface after cleaning
- **Distribution**
 - BD distribution in the iris
 - BD location Vs E-Field
 - BD location Vs H-Field
 - BD location Vs Sc-Field
 - Facing irises (same cell)
- **Acquisition**
 - Imaging
 - Marking
 - Counting
- **Catalogue of features related with breakdown activity**
 - Comparison with other tested structures
 - Craters
 - Worm Like Features (WLF)
- **Summary of observations**

Cutting and nomenclature

- EDM wire
- 8 slices



OUTPUT

INPUT

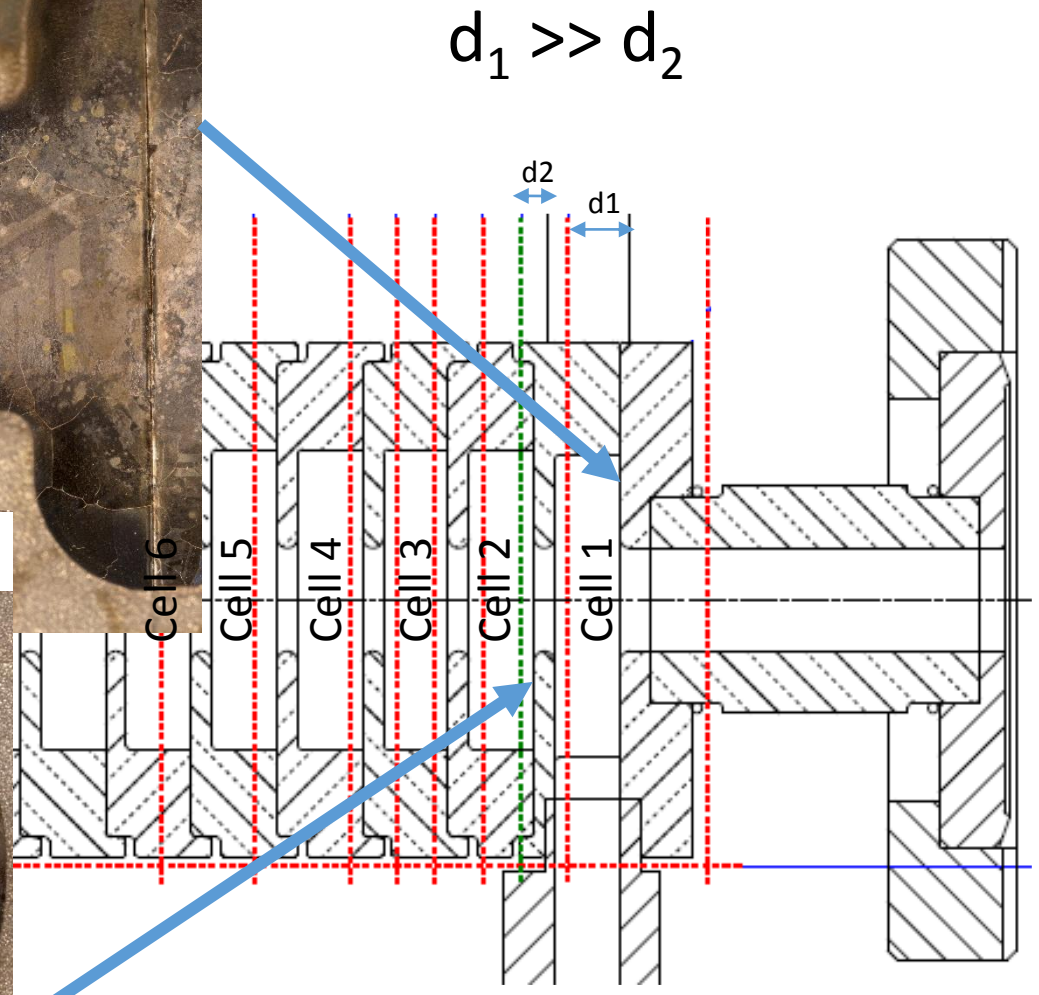
Iris 1 = Iris in the INPUT side
Iris 2 = Iris in the OUTPUT side

➔ Example: Cell 4 – Iris 1
B. Woolley/E. Rodriguez Castro

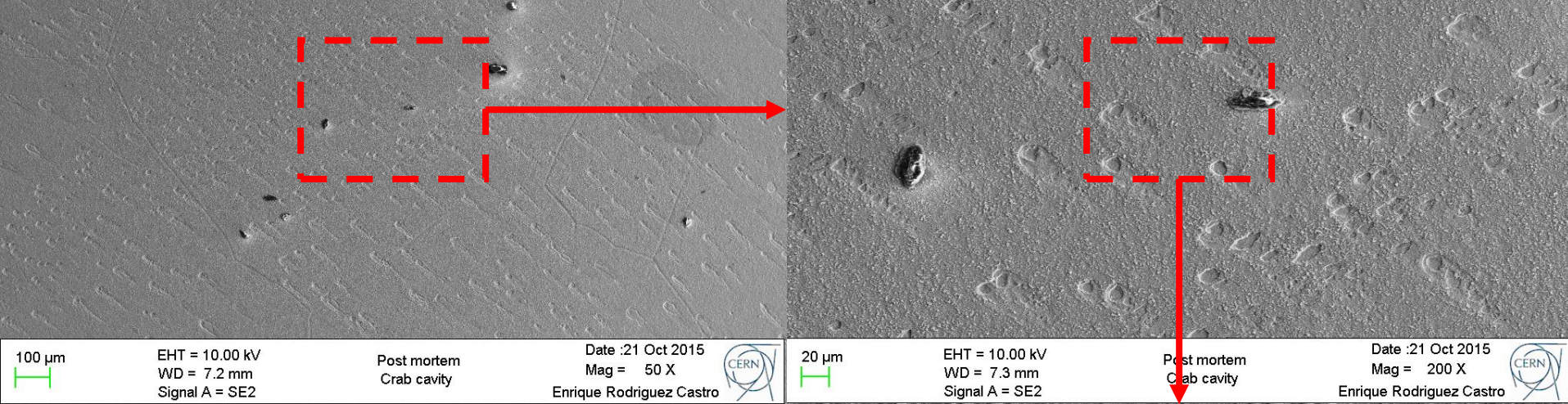
Cell 1 Iris 1 (Far from wire during cutting)



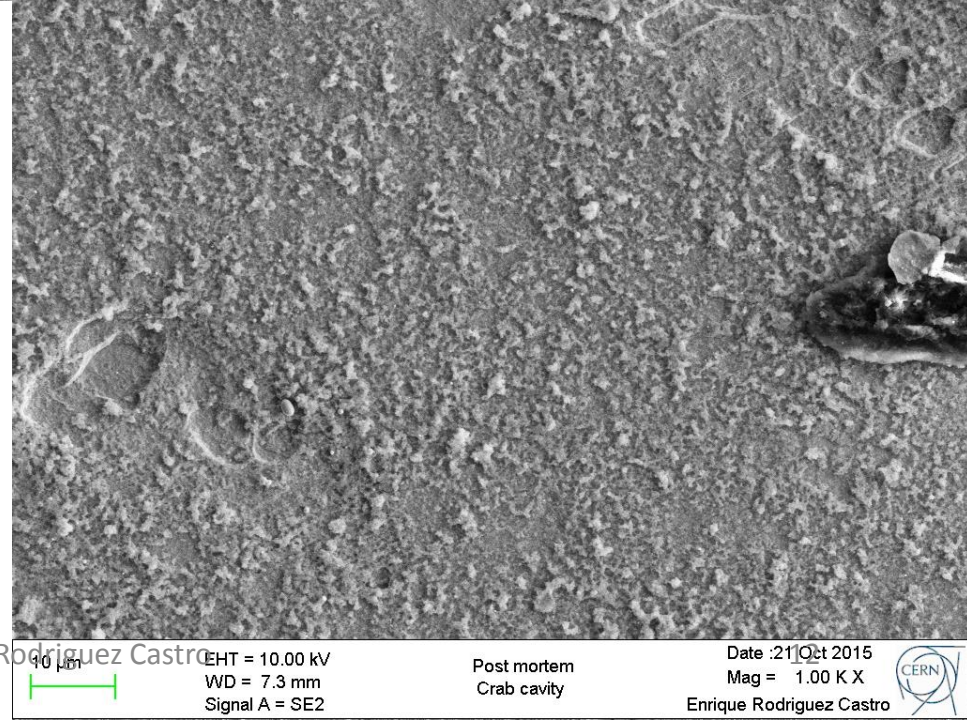
Cell 2 Iris 1 (Close to wire during cutting)



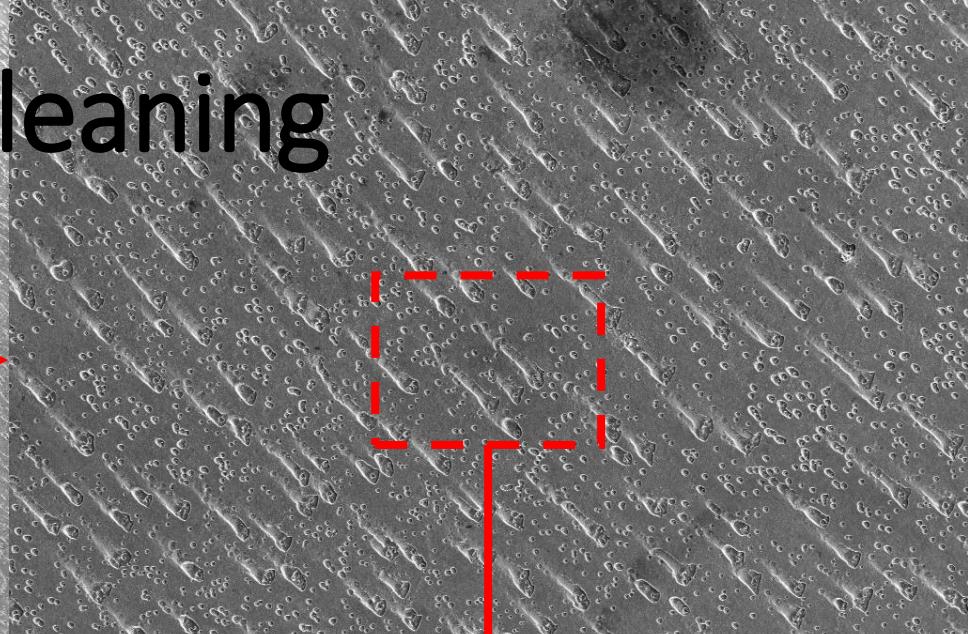
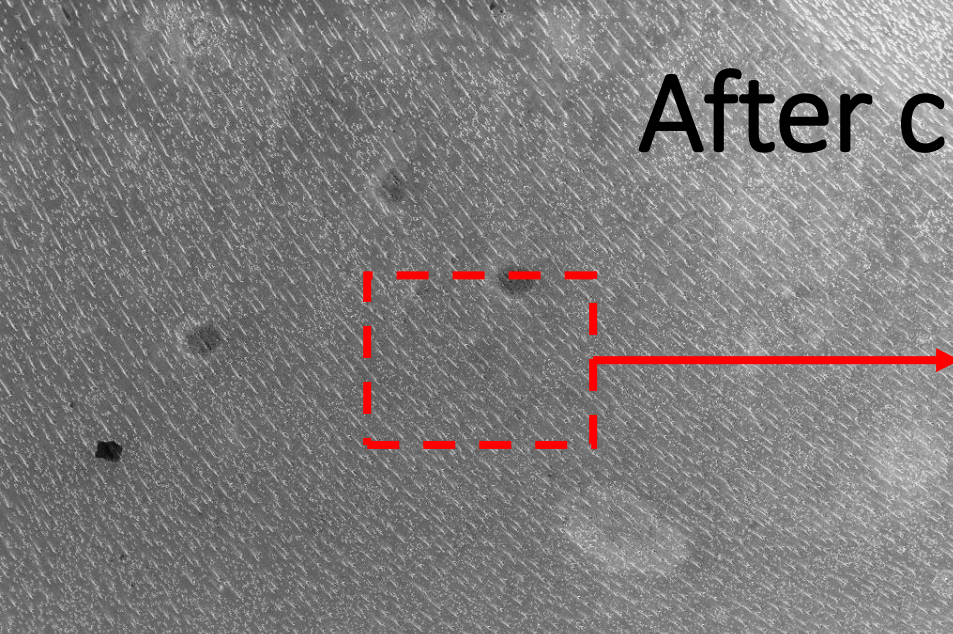
Marks and pollution induced by Post-Mortem cutting



Pollution on the surface → degreasing



After cleaning

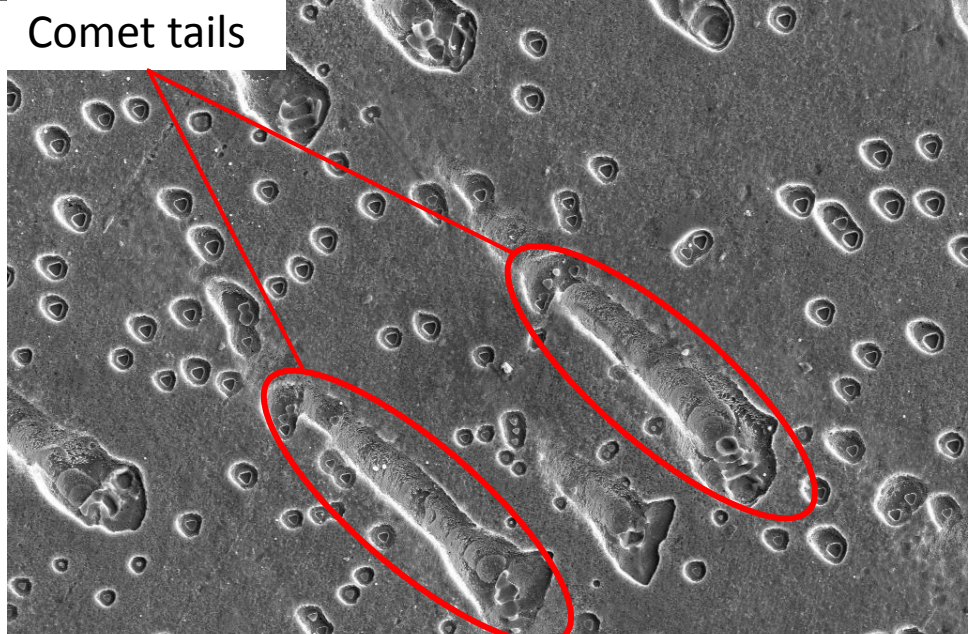


100 μm EHT = 20.00 kV Port Mortem - Crab Cavity Date :1 Dec 2015
WD = 15.2 mm Cell 1 - Iris 2 Mag = 50 X
Signal A = SE2 Smatstich Enrique Rodriguez Castro

20 μm EHT = 20.00 kV Port Mortem - Crab Cavity Date :1 Dec 2015
WD = 15.2 mm Cell 1 - Iris 2 Mag = 200 X
Signal A = SE2 Smatstich Enrique Rodriguez Castro

- Comet tails covering all the surface.

Comet tails



B. Woolley/E. Rodriguez Castro

10 μm EHT = 20.00 kV Port Mortem - Crab Cavity Date :1 Dec 2015
WD = 15.2 mm Cell 1 - Iris 2 Mag = 1.00 K X
Signal A = SE2 Smatstich Enrique Rodriguez Castro

General appearance of the surface after cleaning



100 μ m



EHT = 20.00 kV
WD = 15.2 mm
Signal A = SE2

Port Mortem - Crab Cavity

B. Woolley/E. Rodriguez Castro

Cell 1 - Iris 2

Smatstich

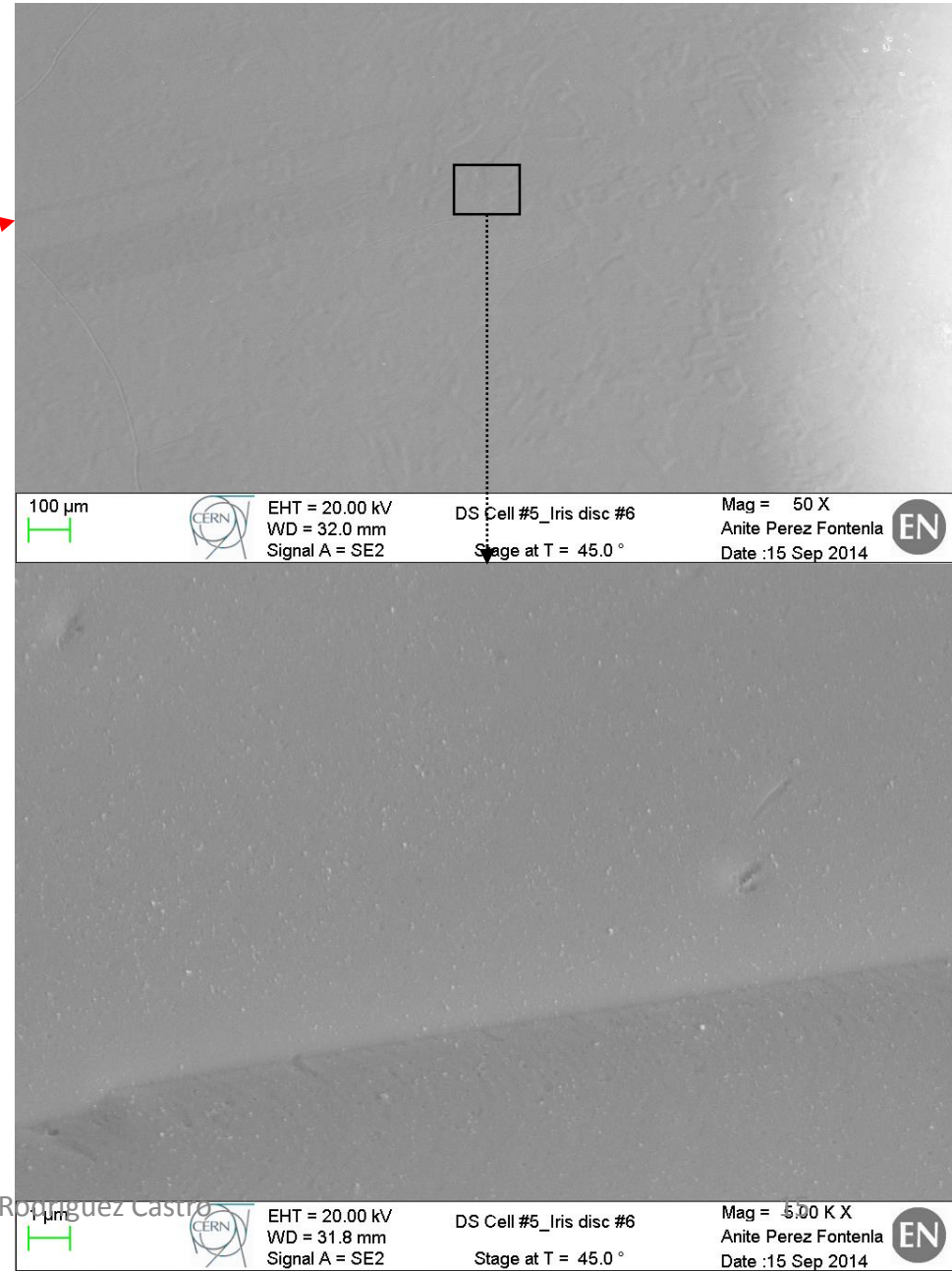
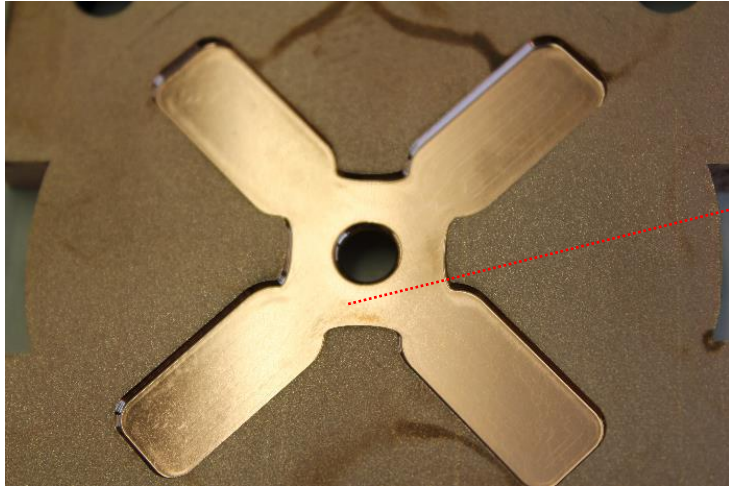
Date :1 Dec 2015

Mag = 50 X

Enrique Rodriguez Castro

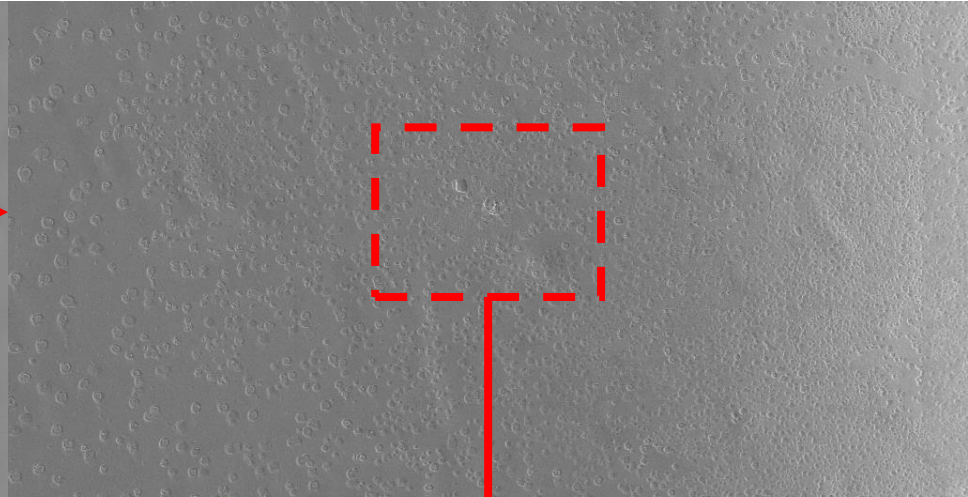
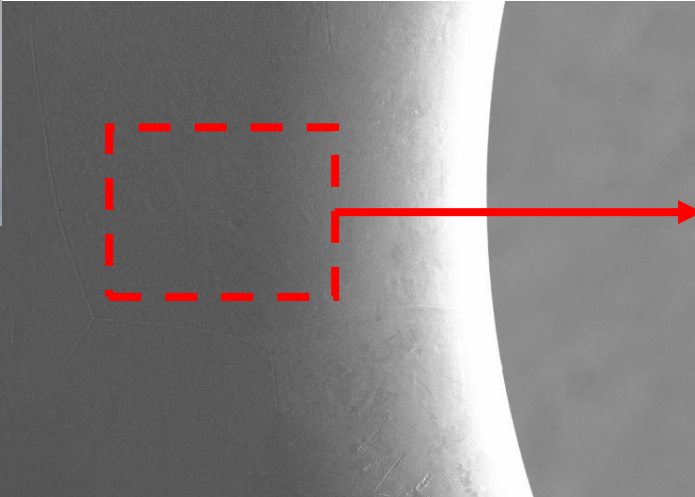




TD24 R05





- EDM wire cutting (2014 Post Mortem analysis TD24 R05)

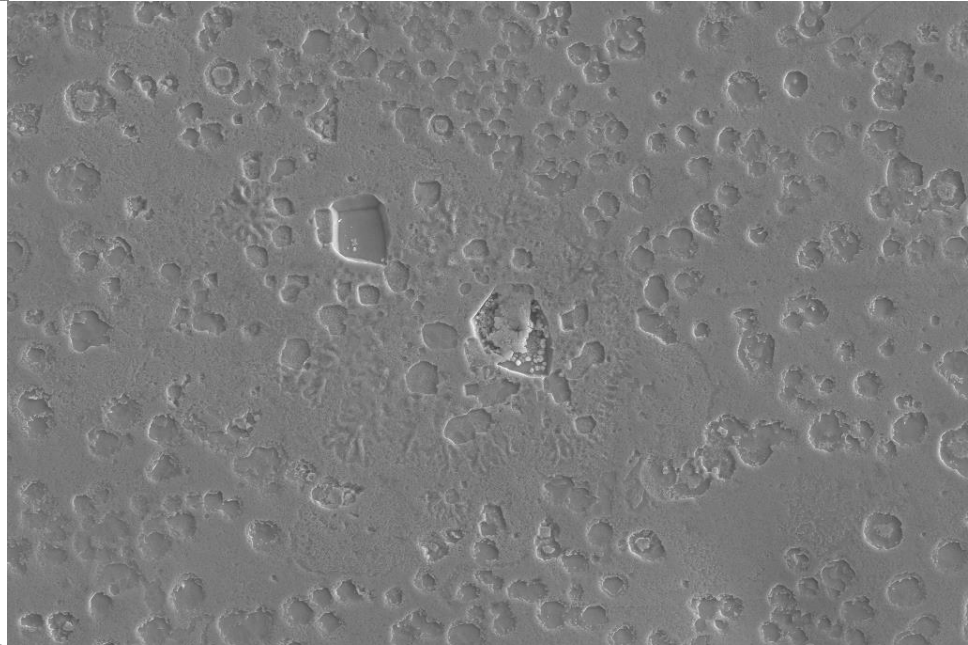
TD24 R05





100 μm  EHT = 20.00 kV
WD = 9.5 mm
Signal A = SE2
disc 22 DS
TD24 R05 p-m analysis
Stage at T = 0.0 °
Mag = 50 X
Anite Perez Fontenla
Date :30 Oct 2014 

20 μm  EHT = 20.00 kV
WD = 9.5 mm
Signal A = SE2
disc 22 DS
TD24 R05 p-m analysis
Stage at T = 0.0 °
Mag = 200 X
Anite Perez Fontenla
Date :30 Oct 2014 

- Marks induced by subsequent cuttings performed by EDM wire cutting (2014 Post Mortem analysis TD24 R05)



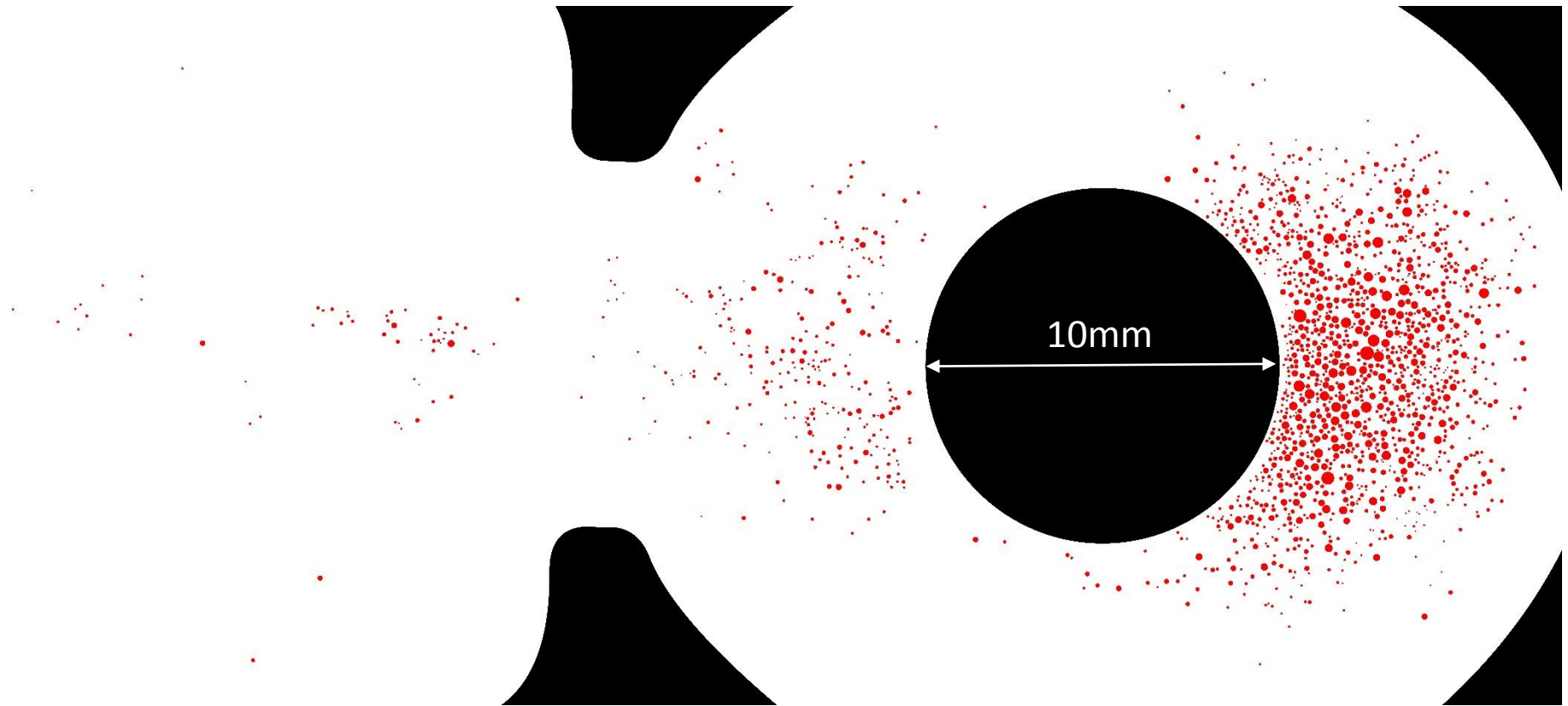
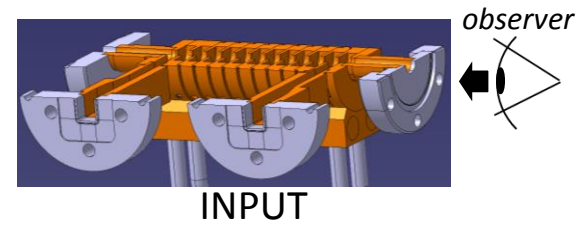
B. Woolley/E. Rodríguez Castro

10 μm  EHT = 20.00 kV
WD = 9.5 mm
Signal A = SE2
disc 22 DS
TD24 R05 p-m analysis
Stage at T = 0.0 °
Mag = 400 K X
Anite Perez Fontenla
Date :30 Oct 2014 

Outline

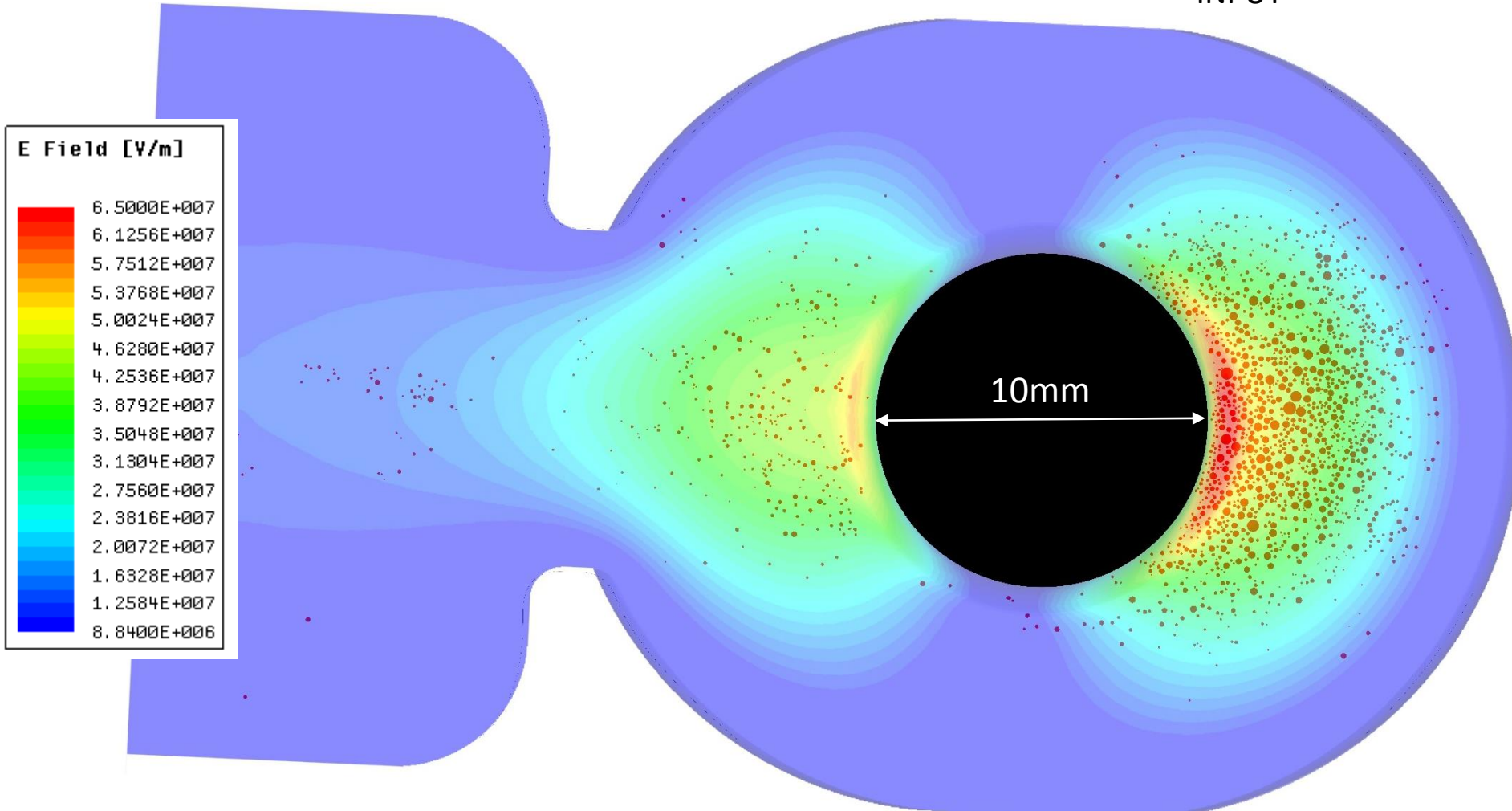
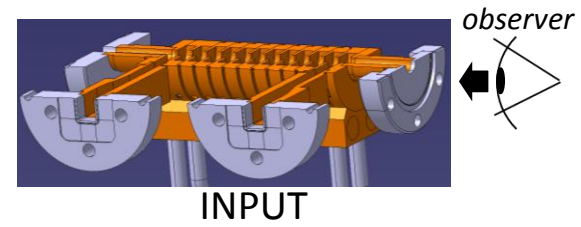
- **Introduction**
- **Objective**
- **Cutting and Nomenclature**
 - Marks and pollution induced by Post-Mortem cutting
 - Cleaning (degreasing)
 - General appearance of the surface after cleaning
- **Distribution**
 - BD distribution in the iris
 - BD location Vs E-Field
 - BD location Vs H-Field
 - BD location Vs Sc-Field
 - Facing irises (same cell)
- **Acquisition**
 - Imaging
 - Marking
 - Counting
- **Catalogue of features related with breakdown activity**
 - Comparison with other tested structures
 - Craters
 - Worm Like Features (WLF)
- **Summary of observations**

Cell 1 – Iris 1

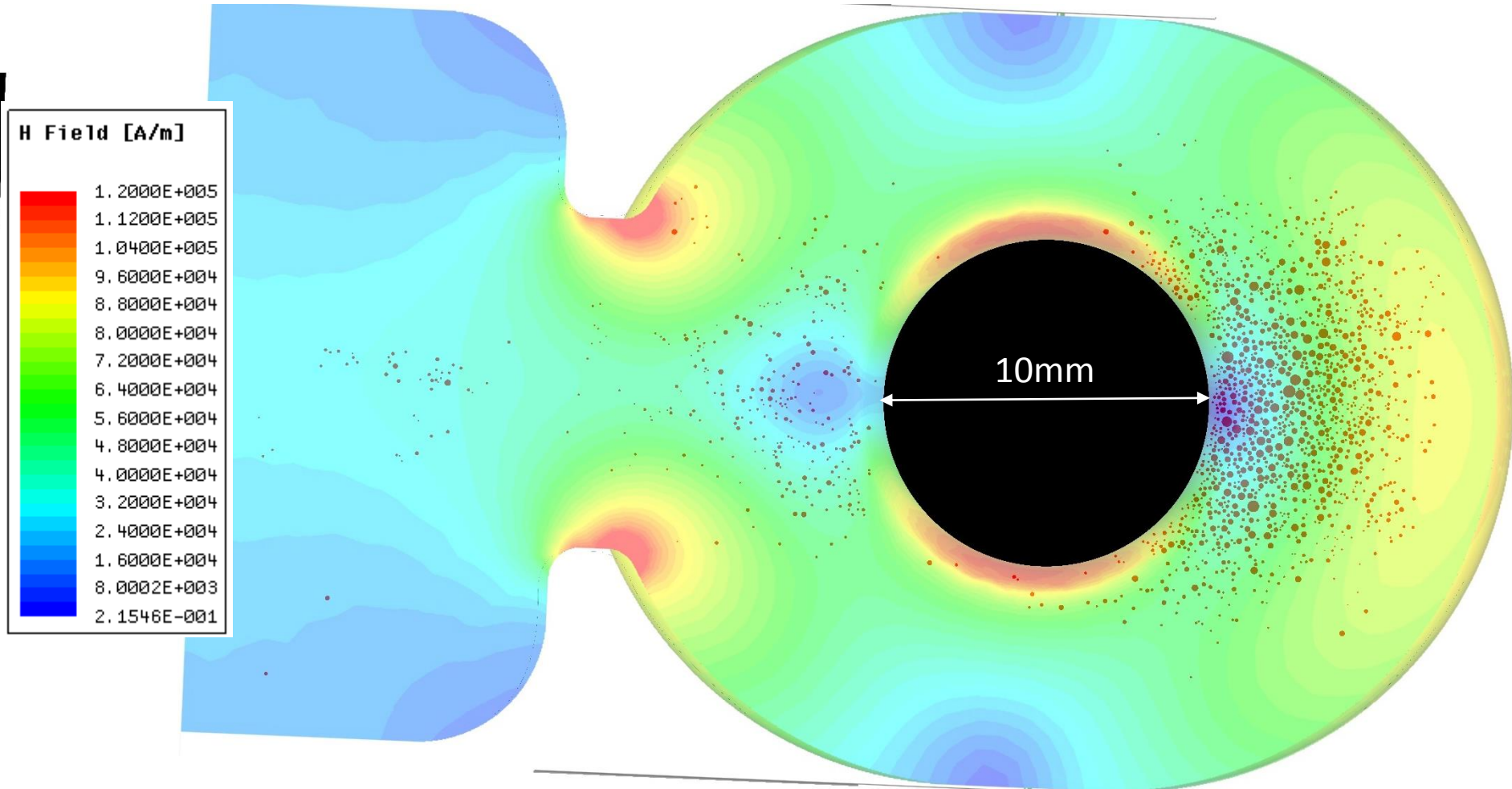
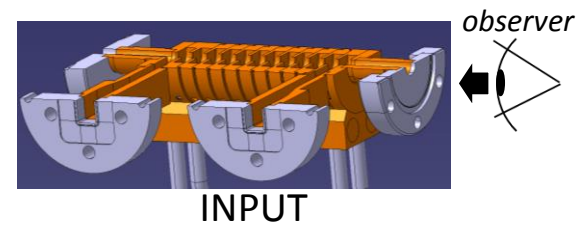


Number of sites BD sites = 1681

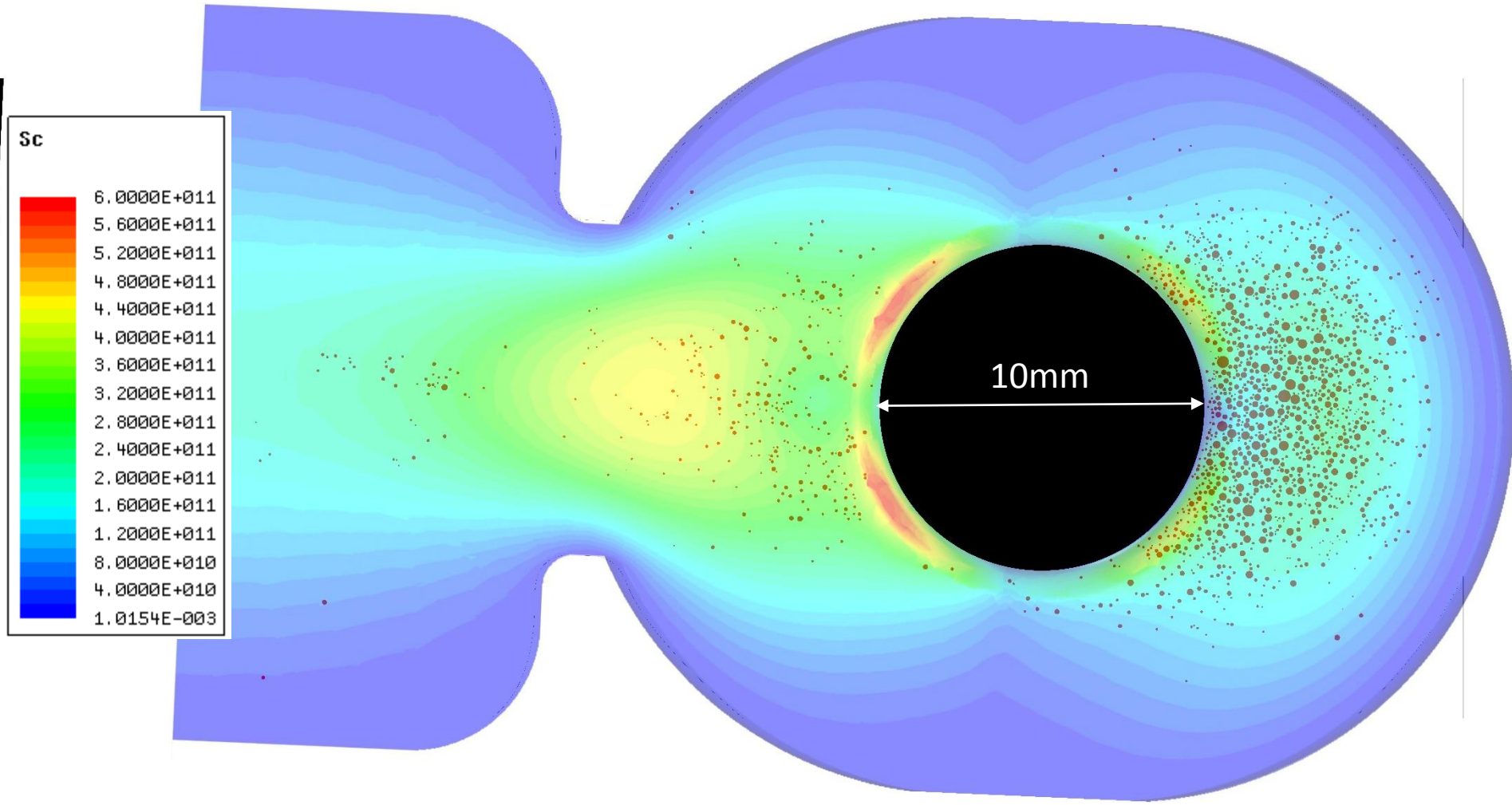
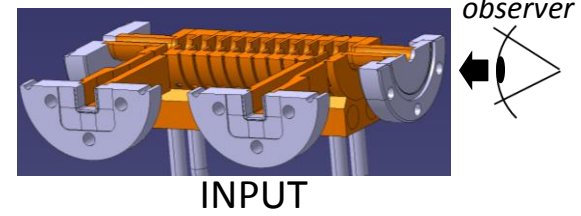
Cell 1 – Iris 1 Vs E-Field



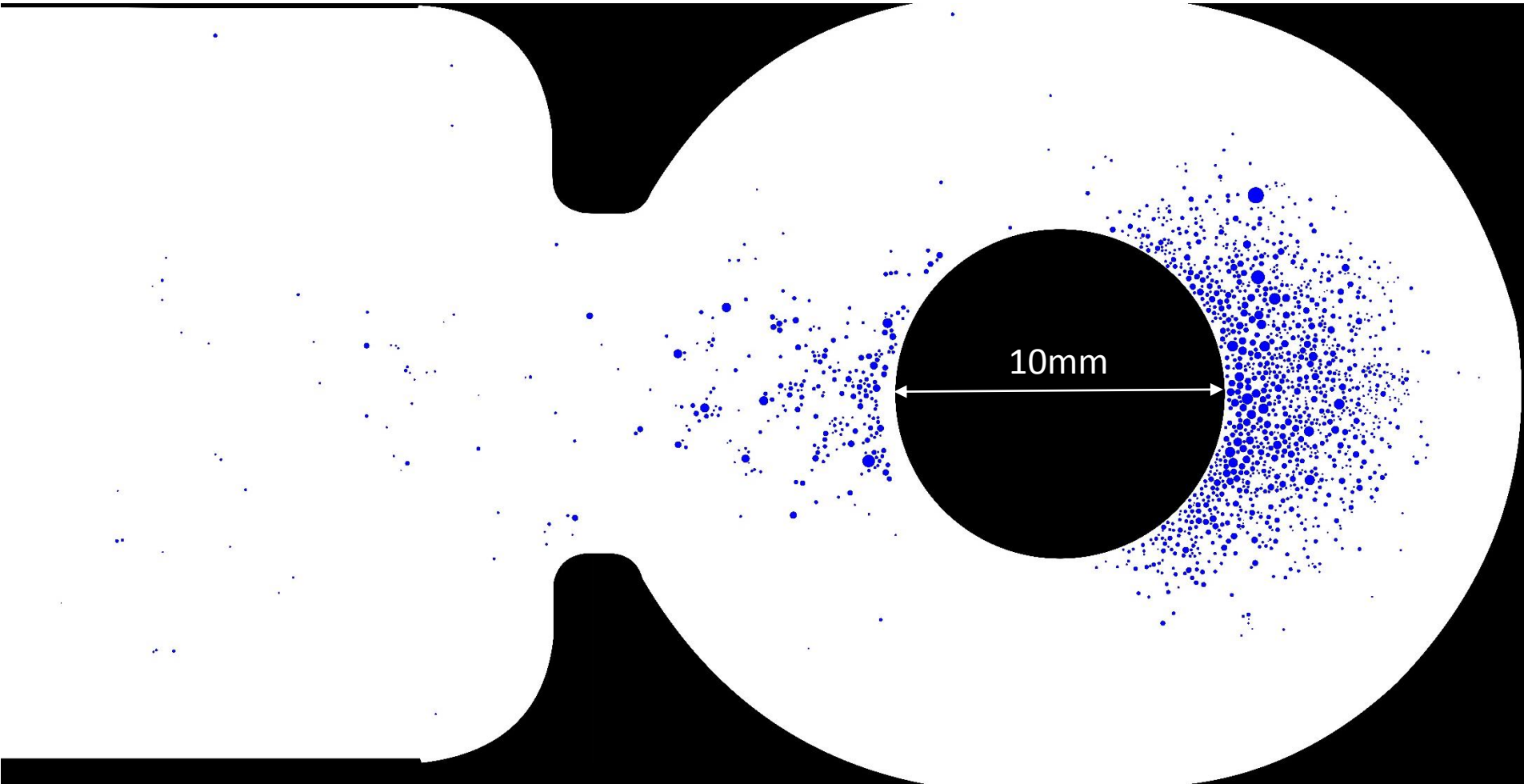
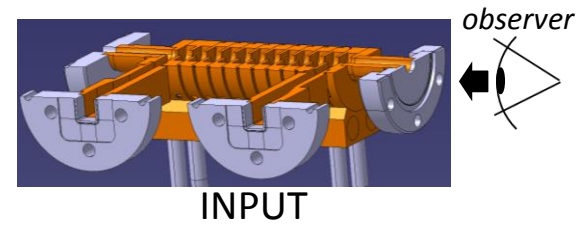
Cell 1 – Iris 1 Vs H-Field



Cell 1 – *Iris 1* Vs Sc-Field

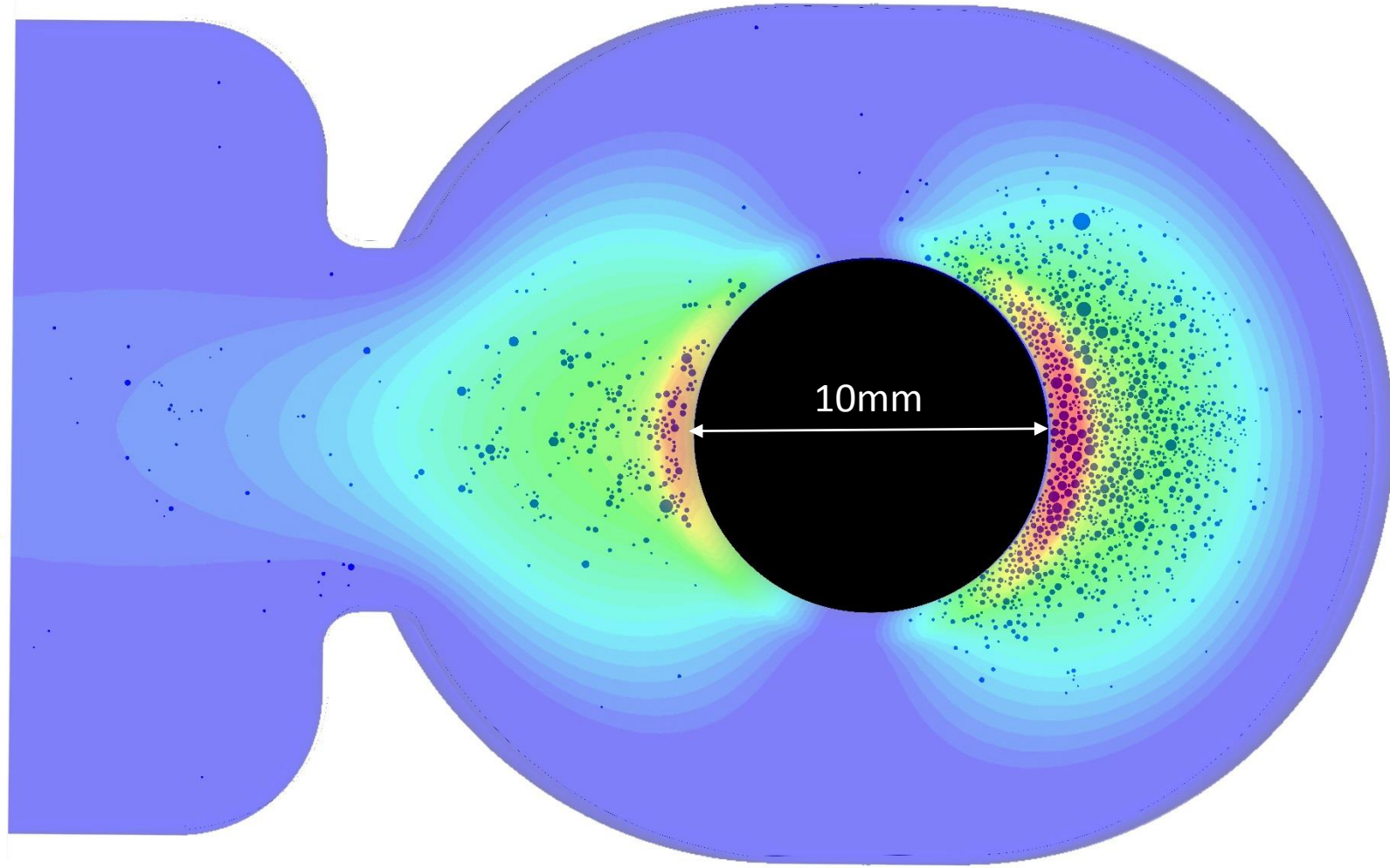
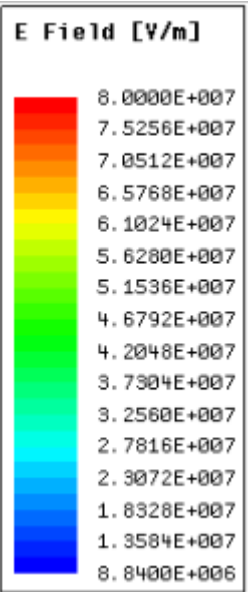
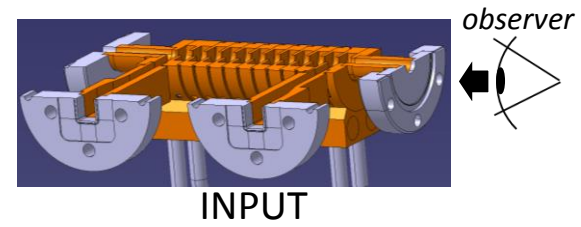


Cell 1 – Iris 2

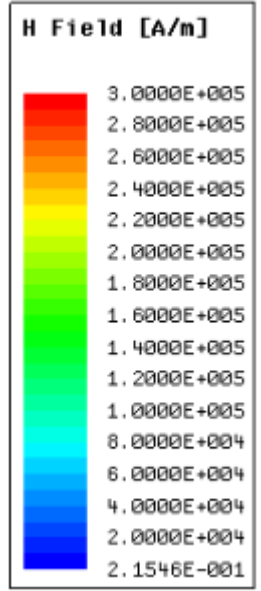
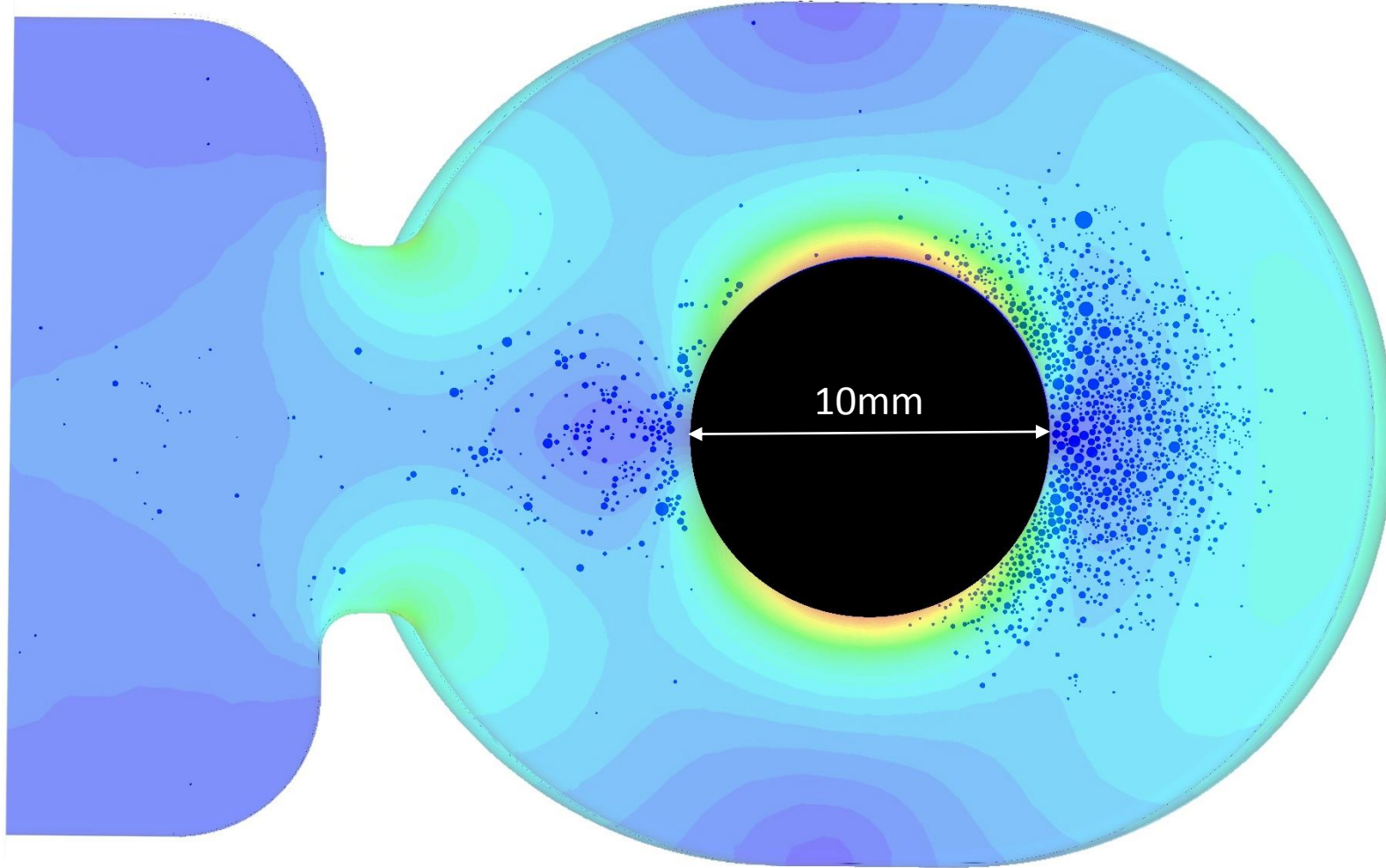
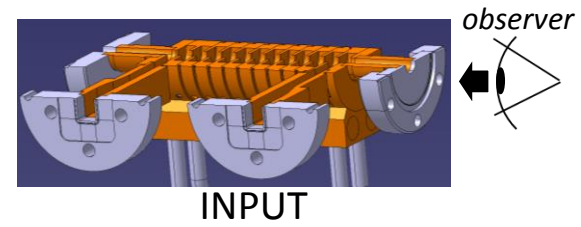


Number of sites BD sites = 1573

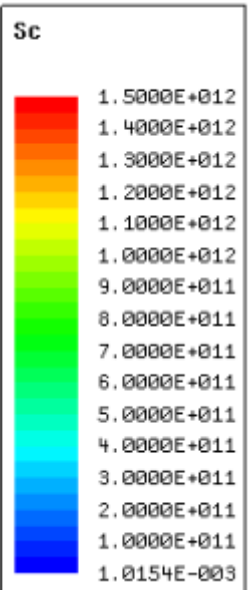
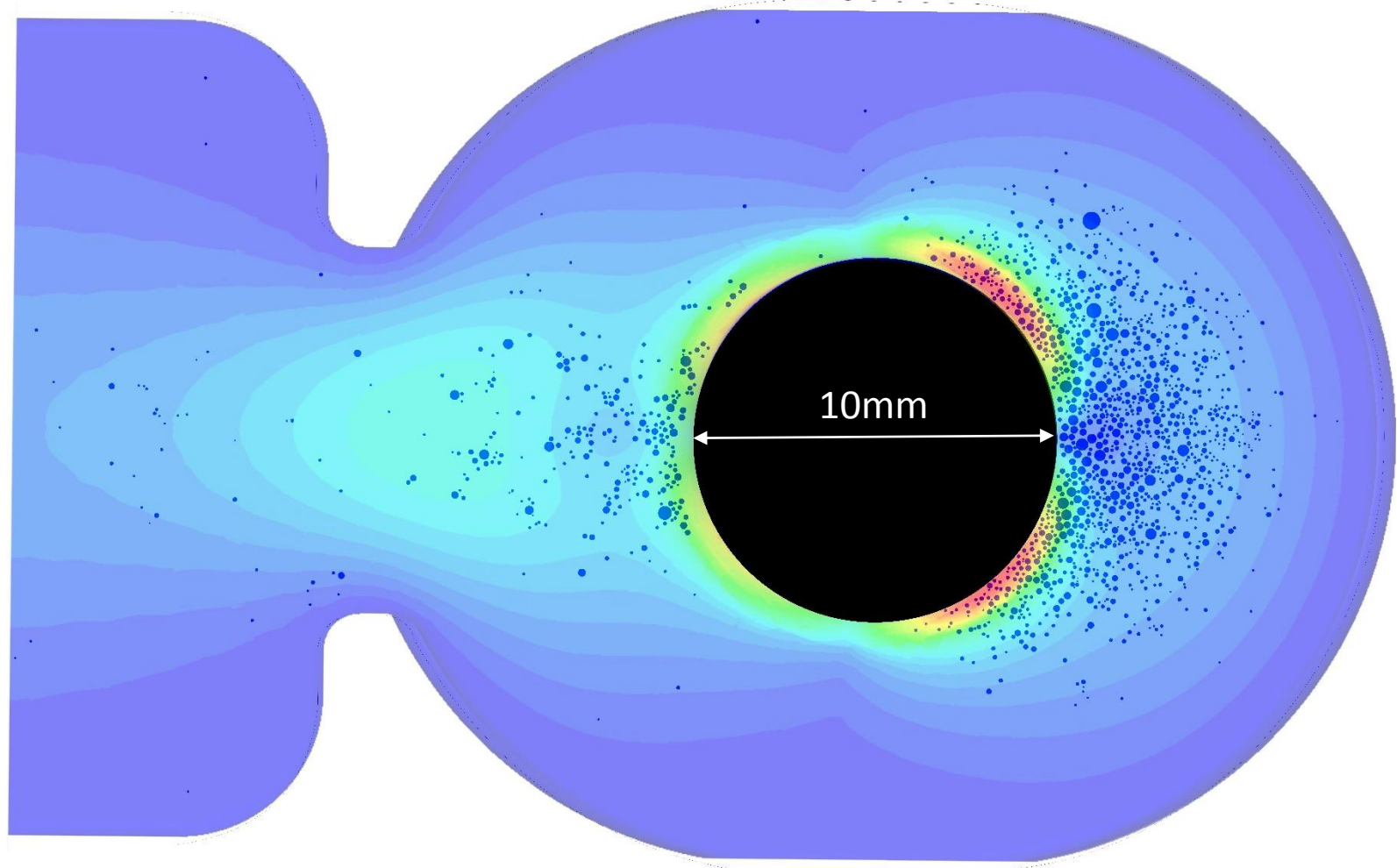
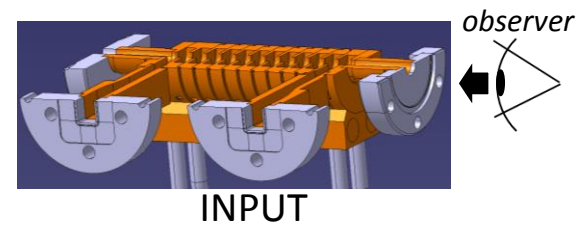
Cell 1 – Iris 2 Vs E-Field



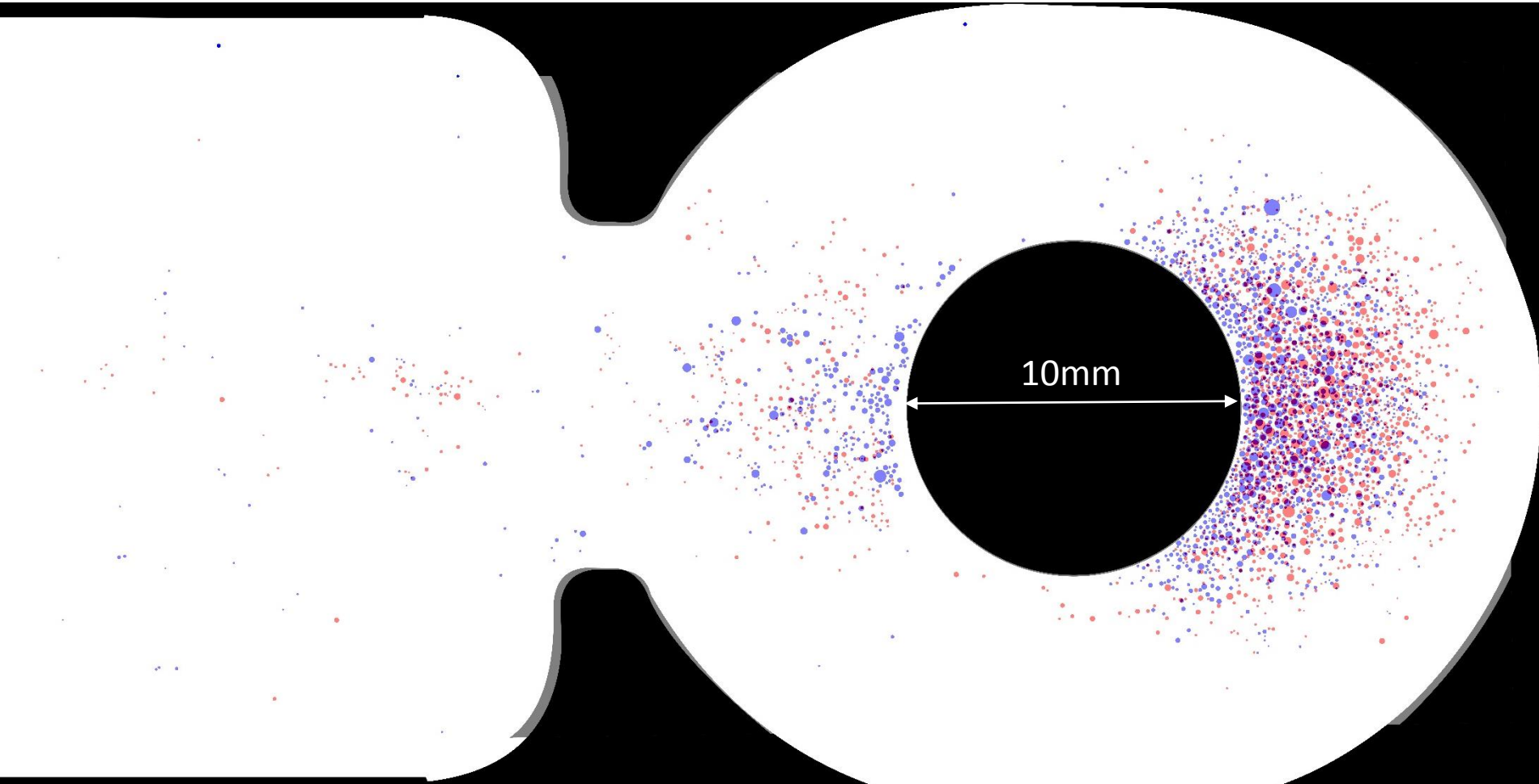
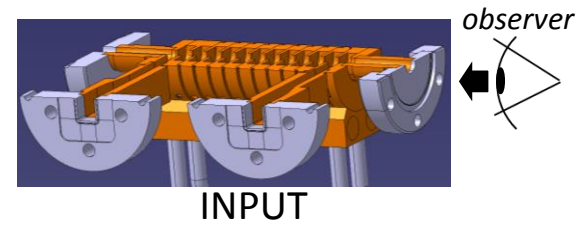
Cell 1 – Iris 2 Vs H-Field



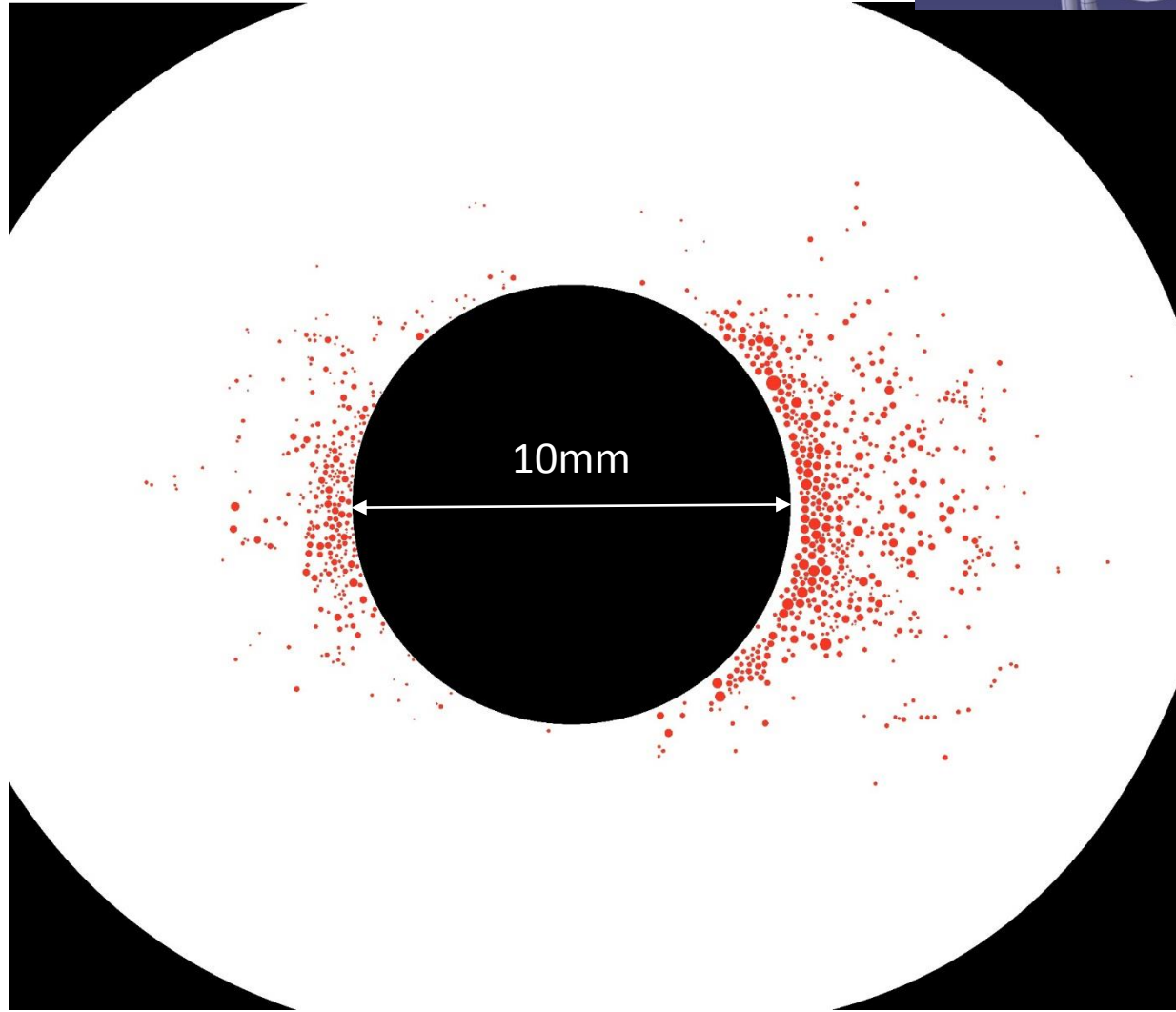
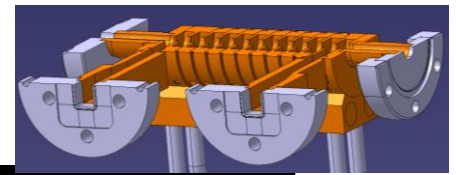
Cell 1 – Iris 2 Vs Sc-Field



Cell 1 – Iris 1 Vs Cell 1 – Iris 2

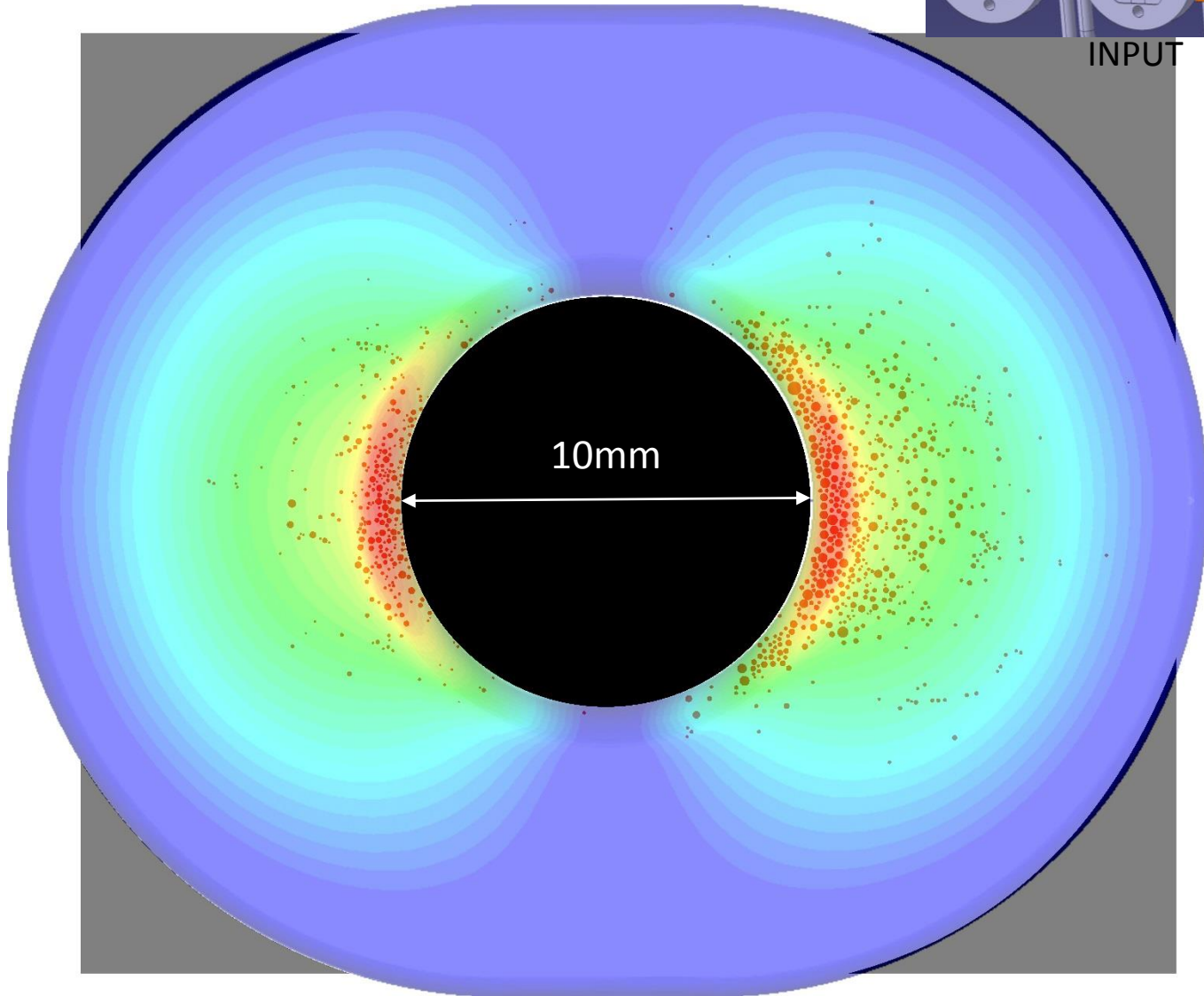
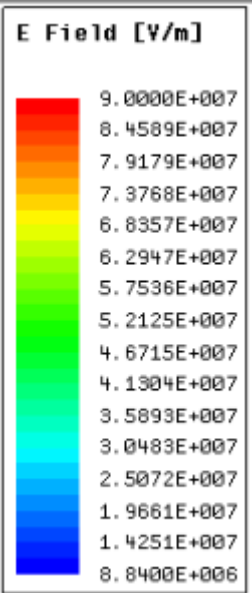
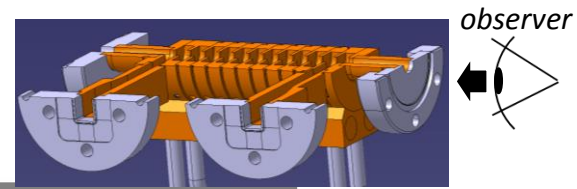


Cell 2 – Iris 1

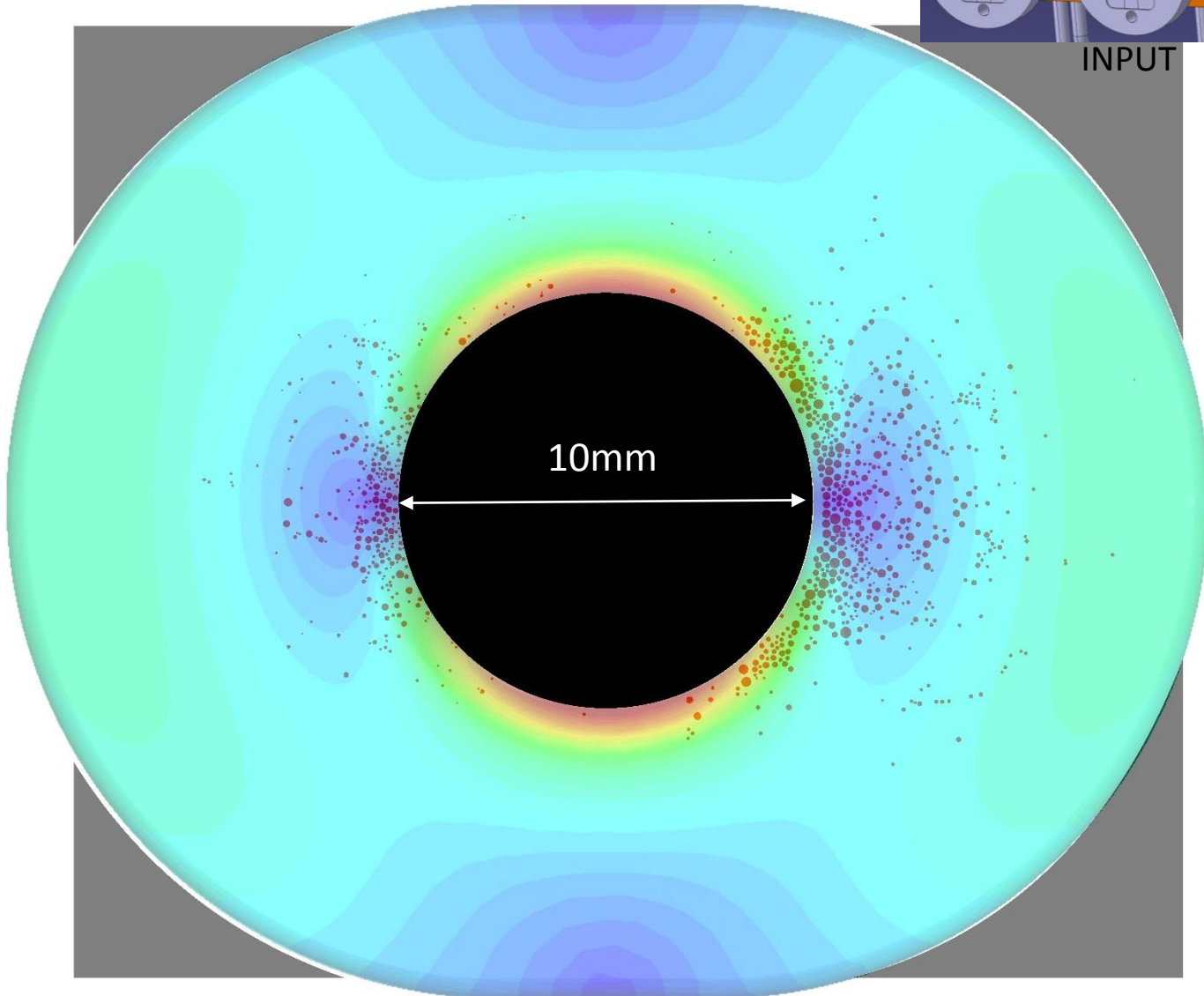
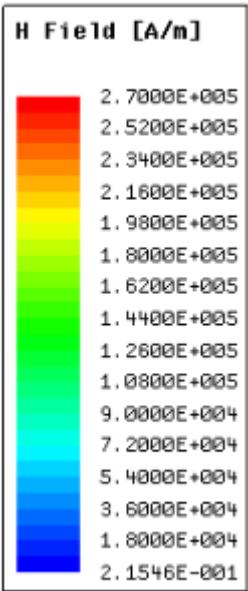
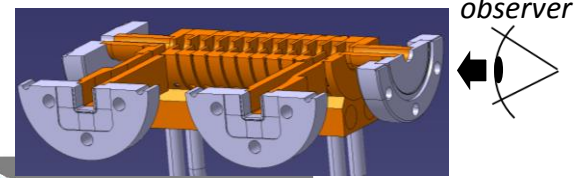


Number of sites BD sites = 917

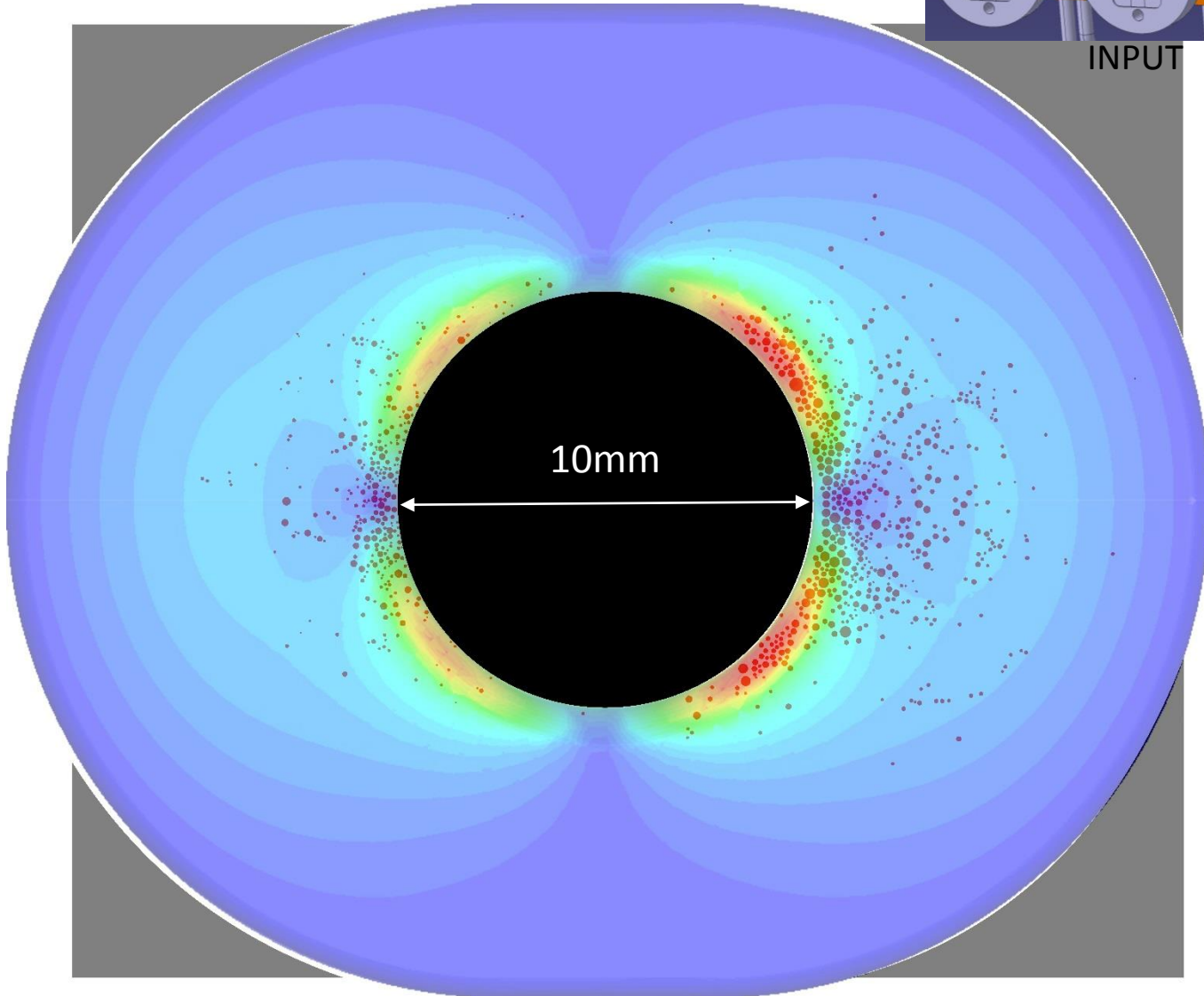
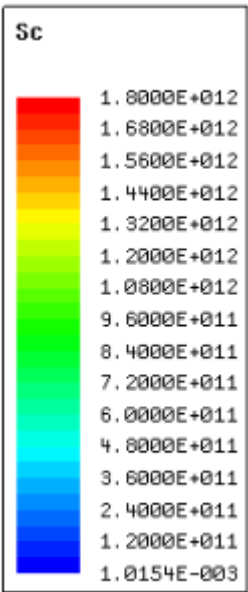
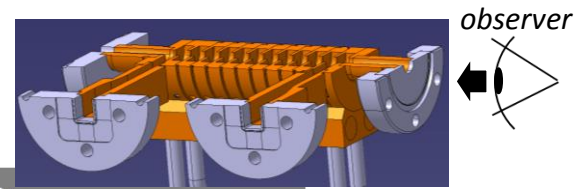
Cell 2 – Iris 1 Vs E-Field



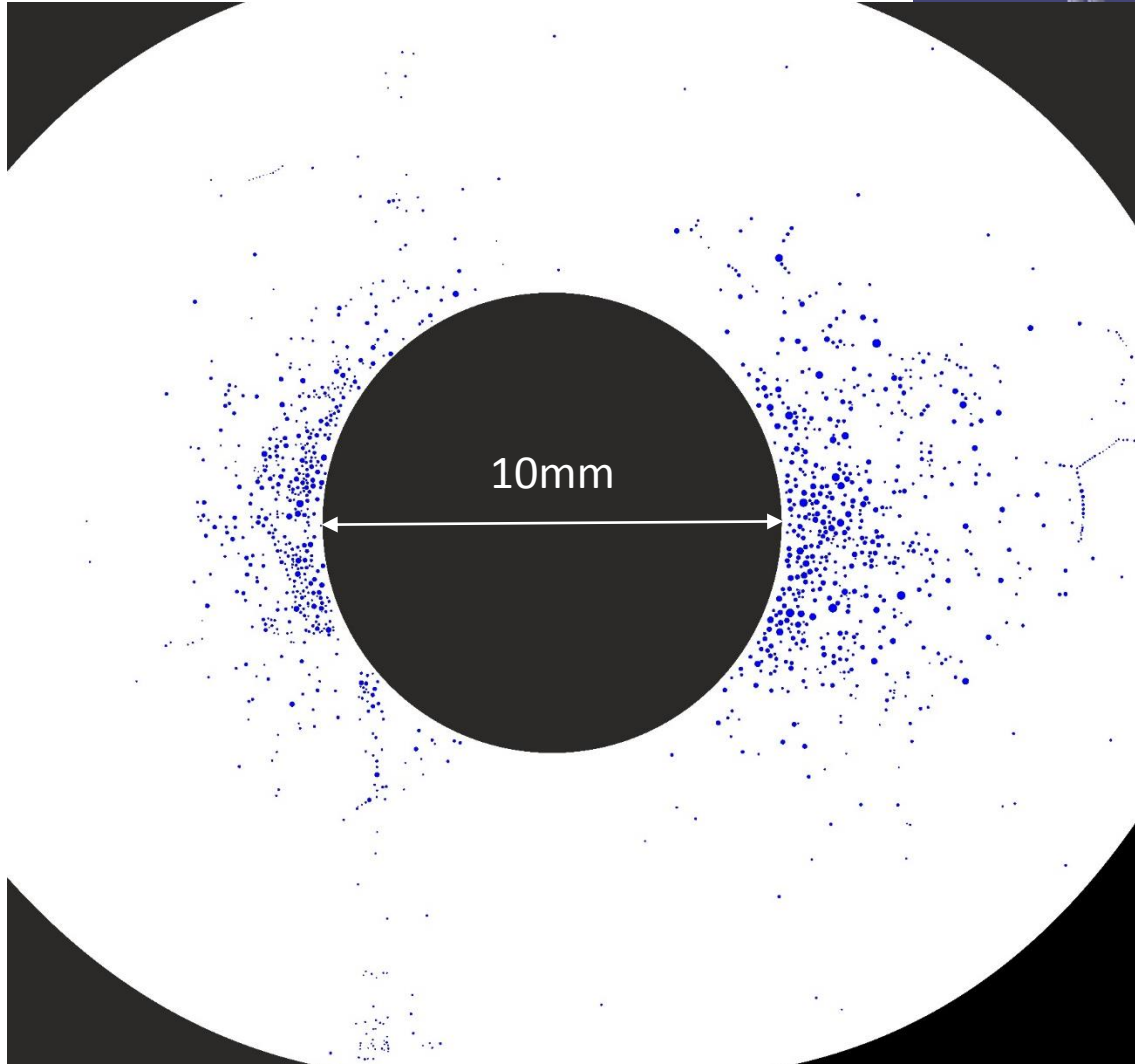
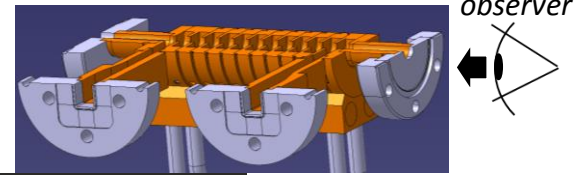
Cell 2 – Iris 1 Vs H-Field



Cell 2 – Iris 1 Vs Sc-Field

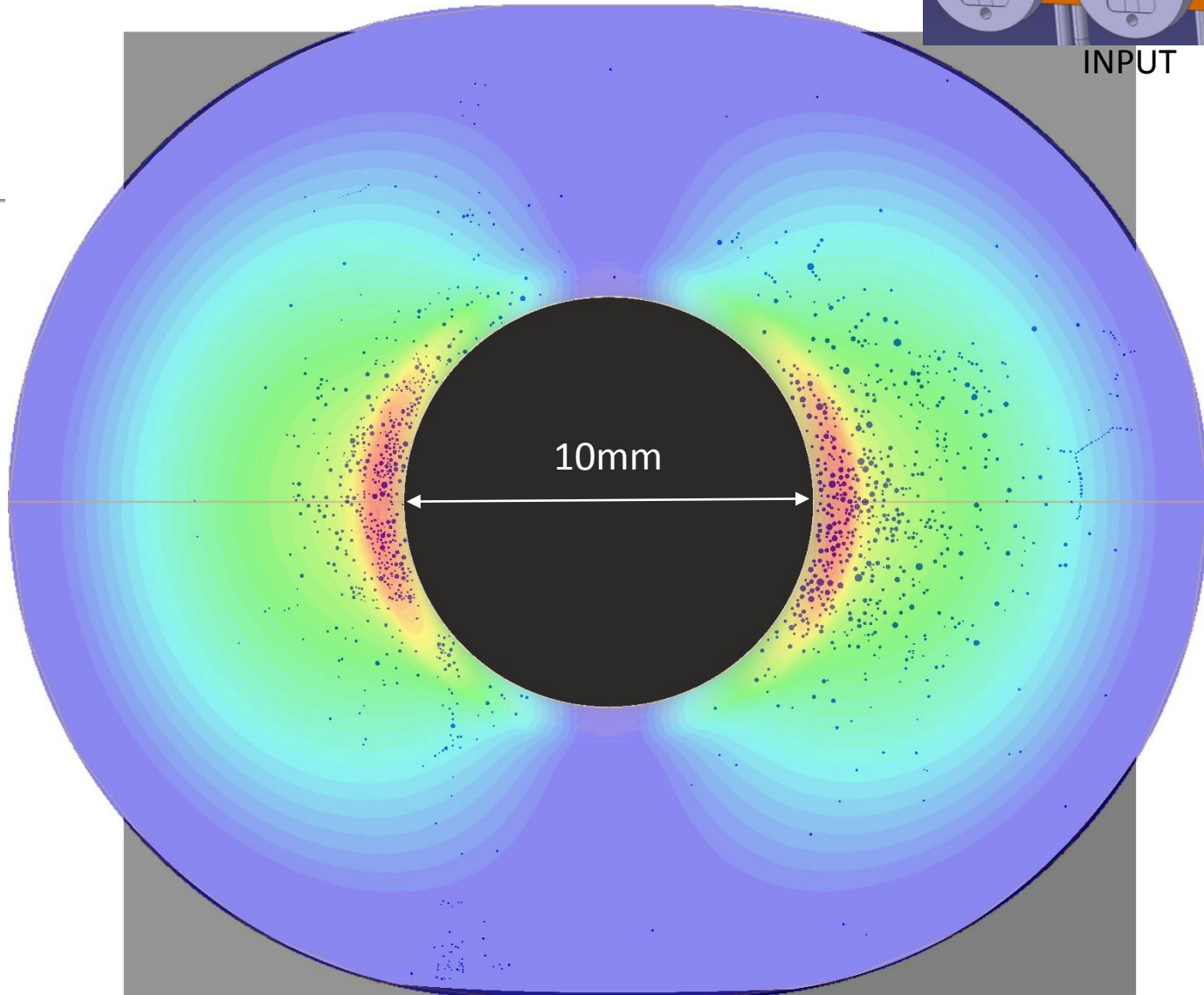
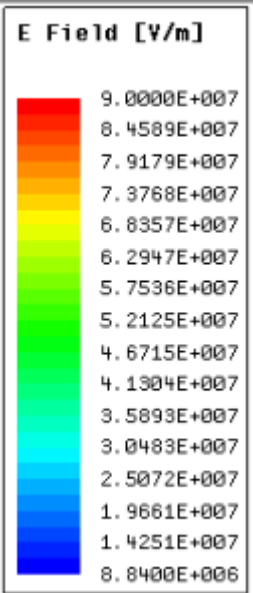
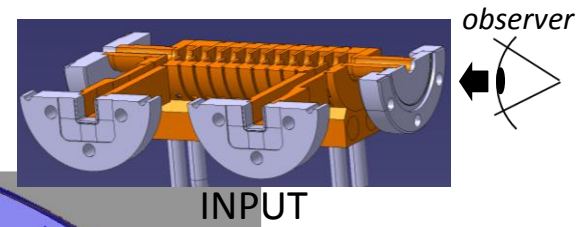


Cell 2 – Iris 2

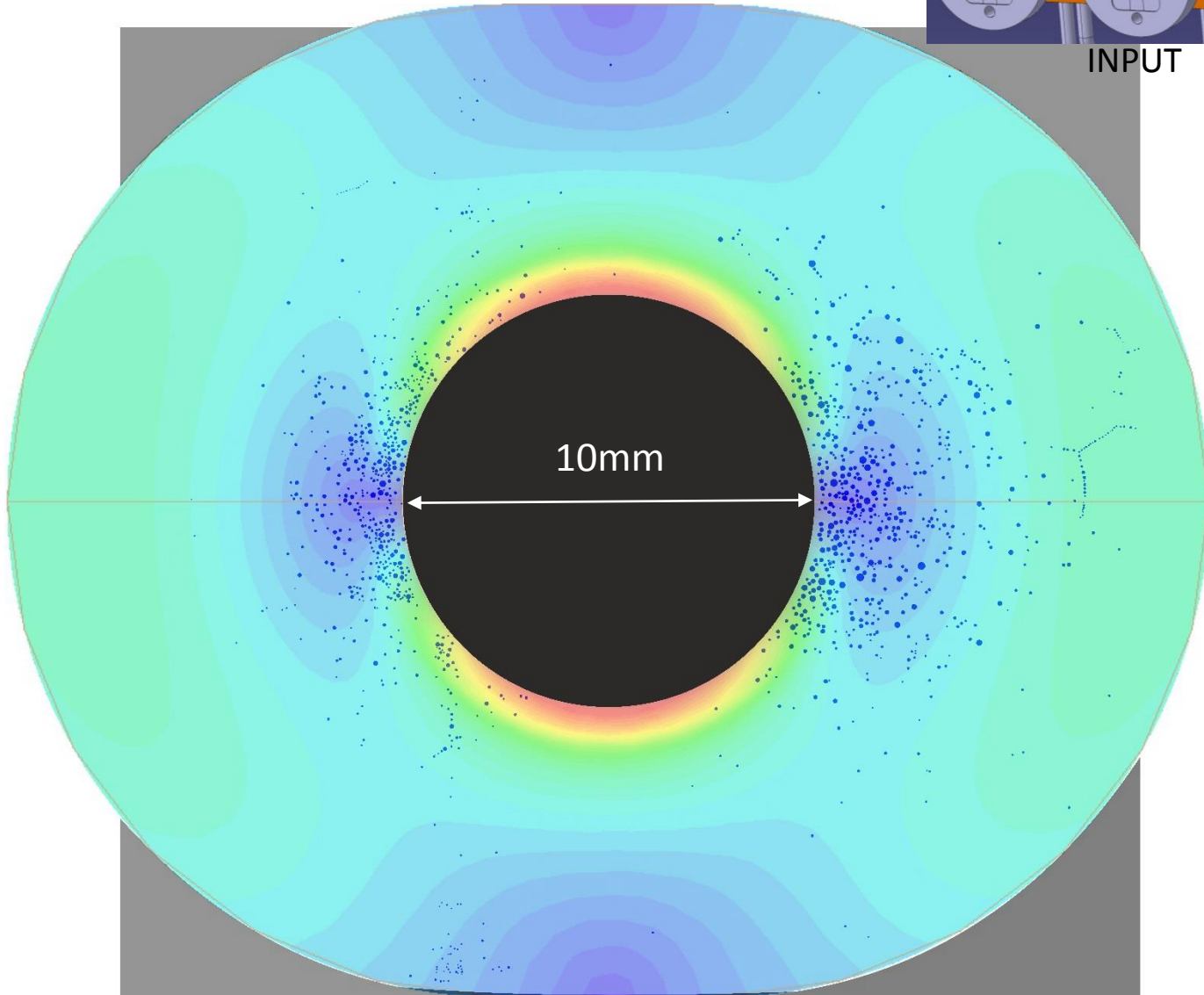
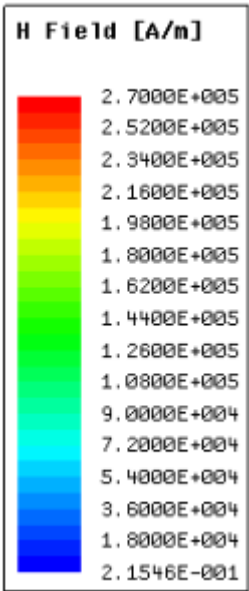
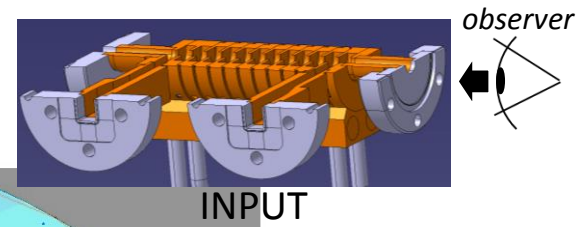


Number of sites BD sites = 1305

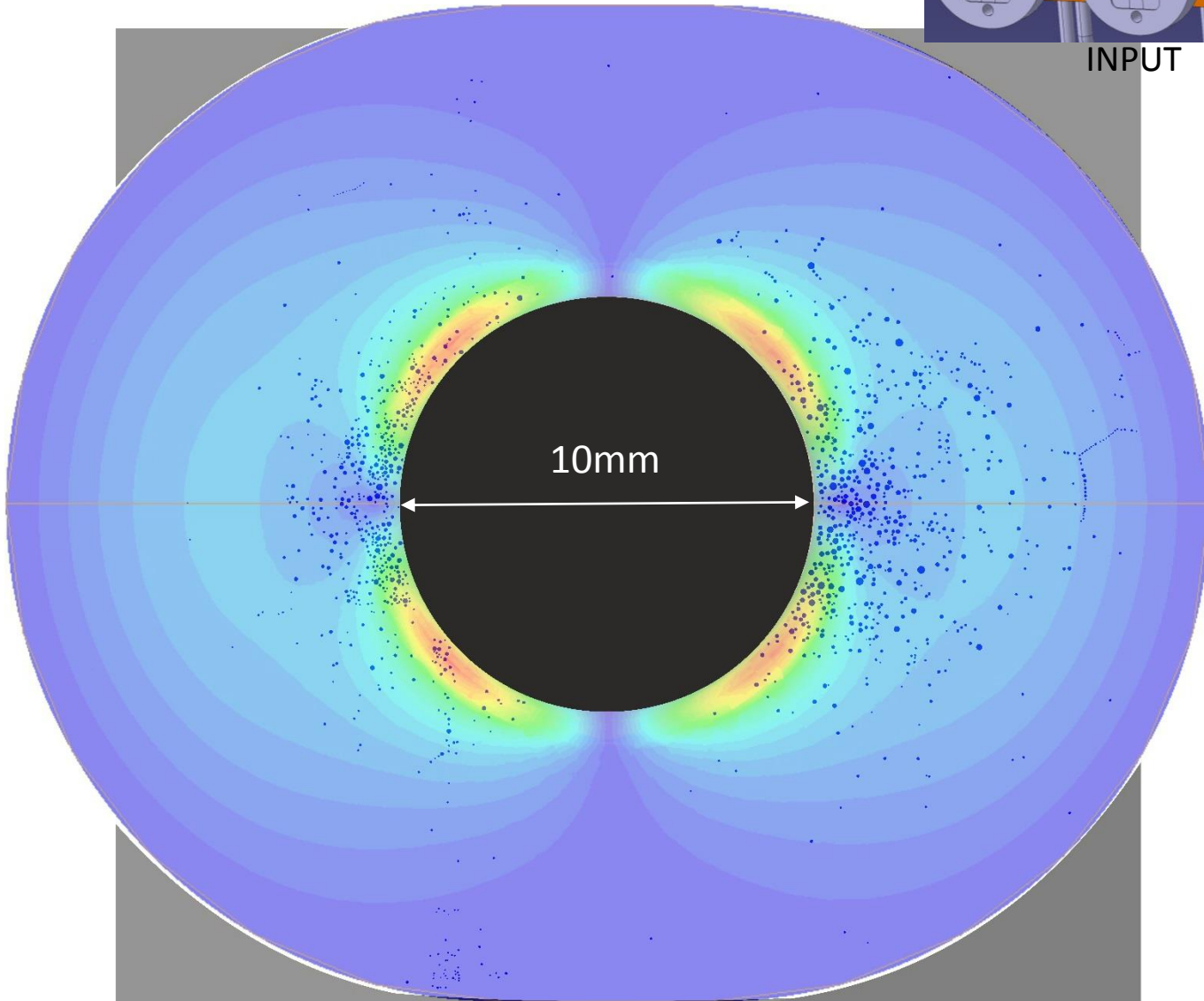
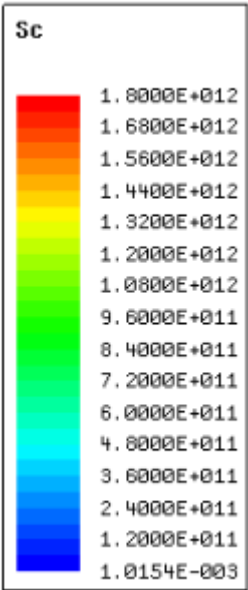
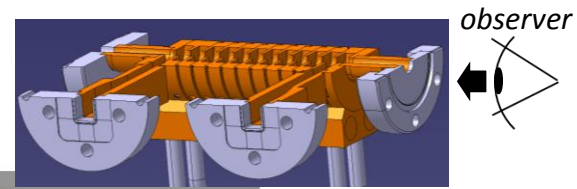
Cell 2 – Iris 2 Vs E-Field



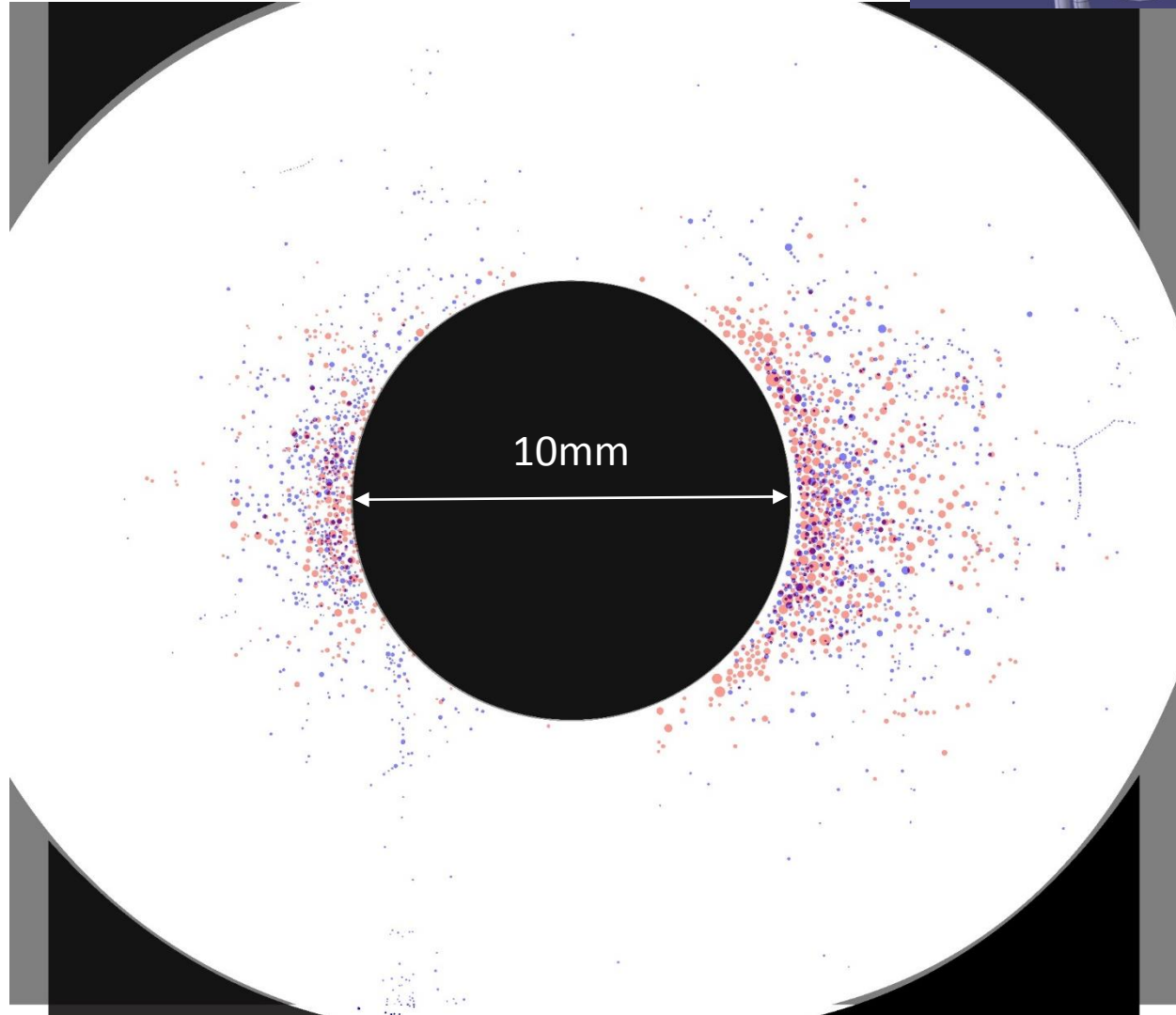
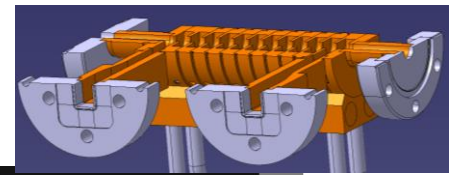
Cell 2 – Iris 2 Vs H-Field



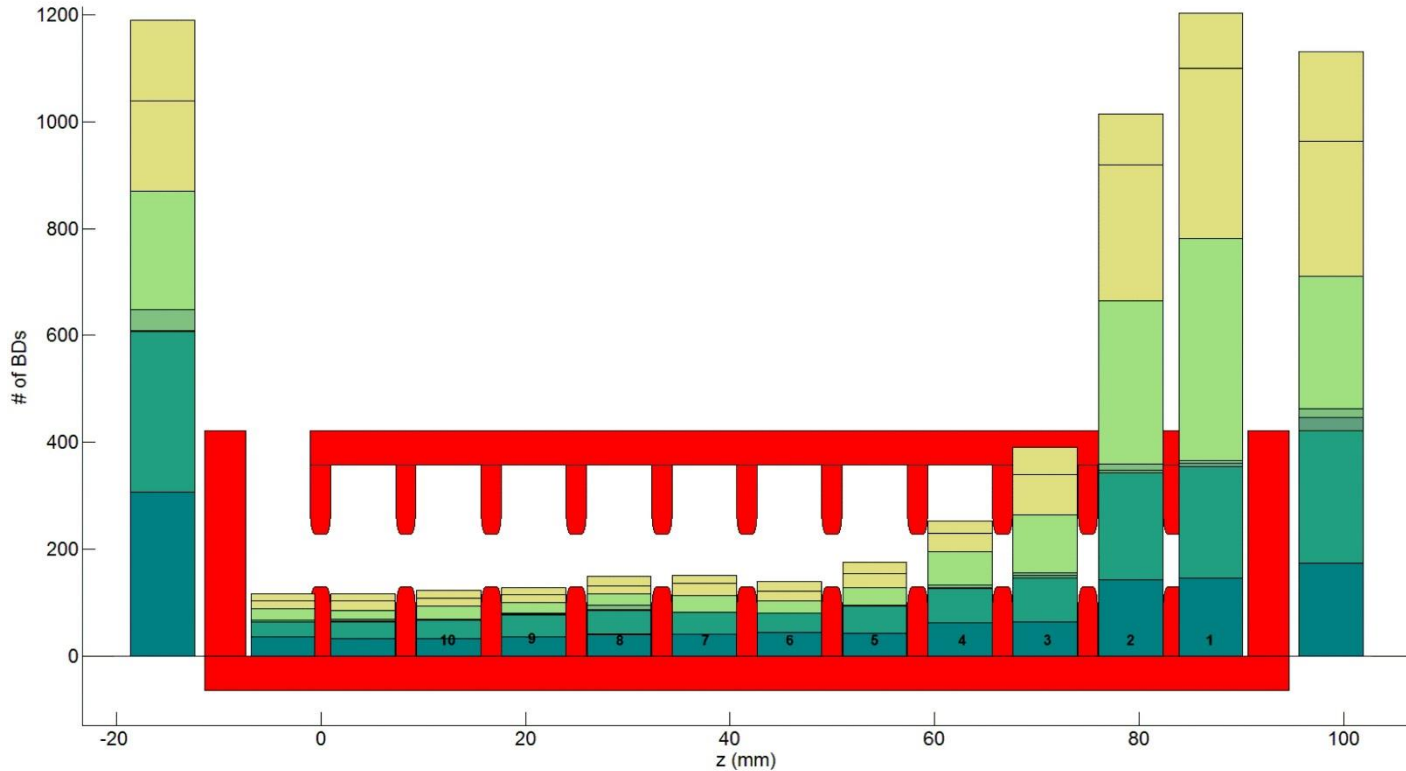
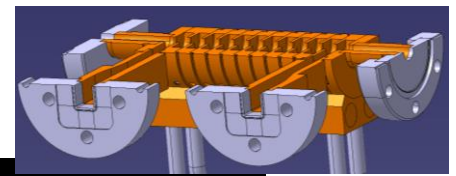
Cell 2 – Iris 2 Vs Sc-Field



Cell 2 – Iris 1 Vs Cell 2 – Iris 2



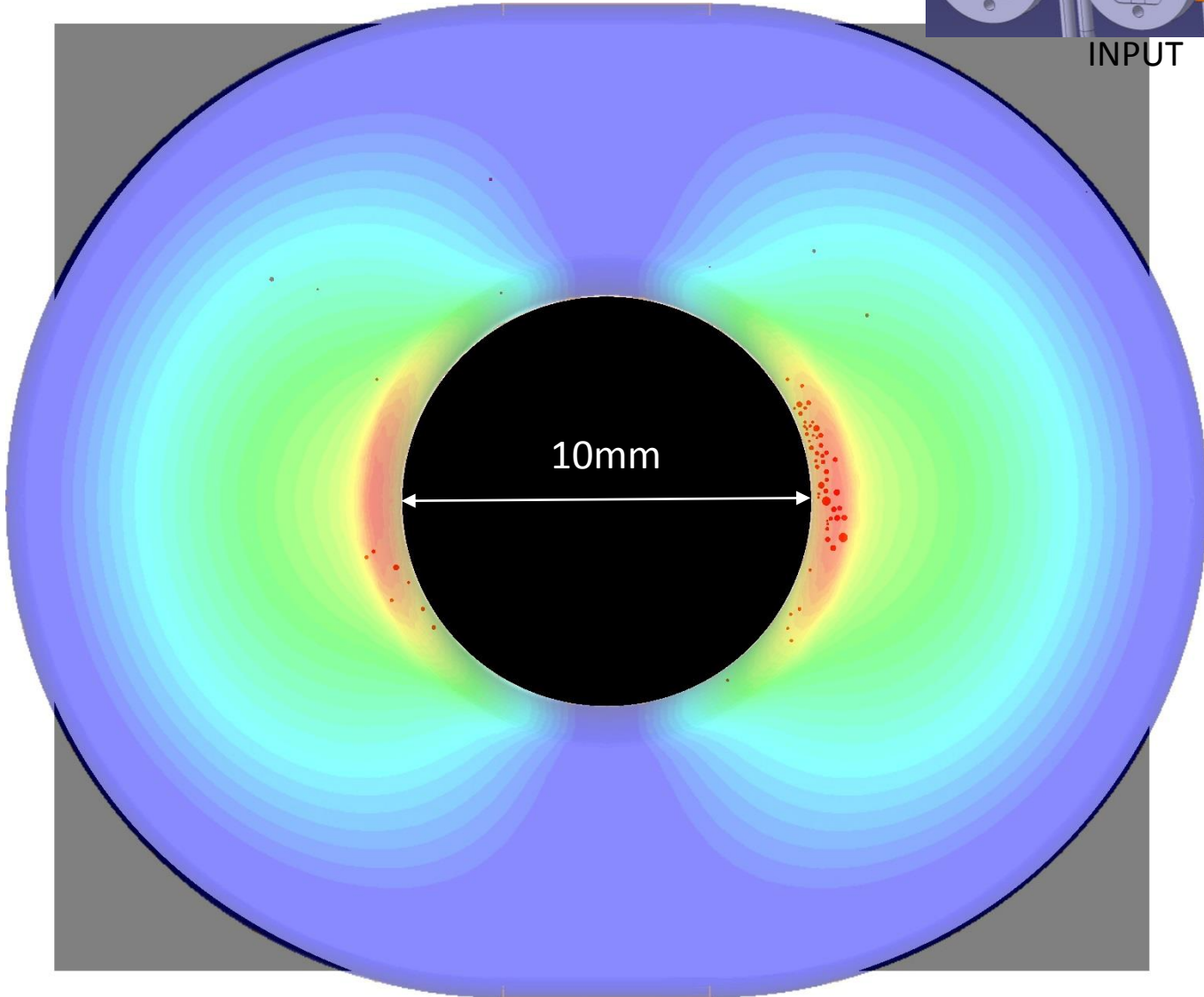
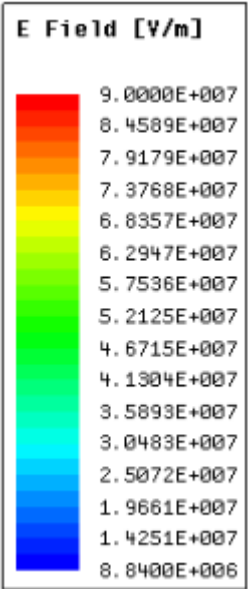
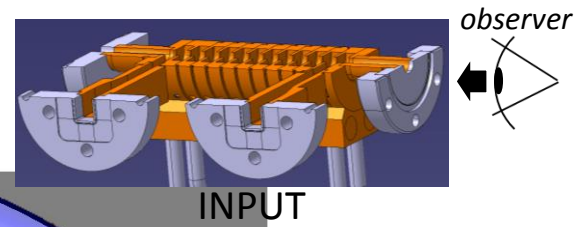
Cell 3 - Iris 1



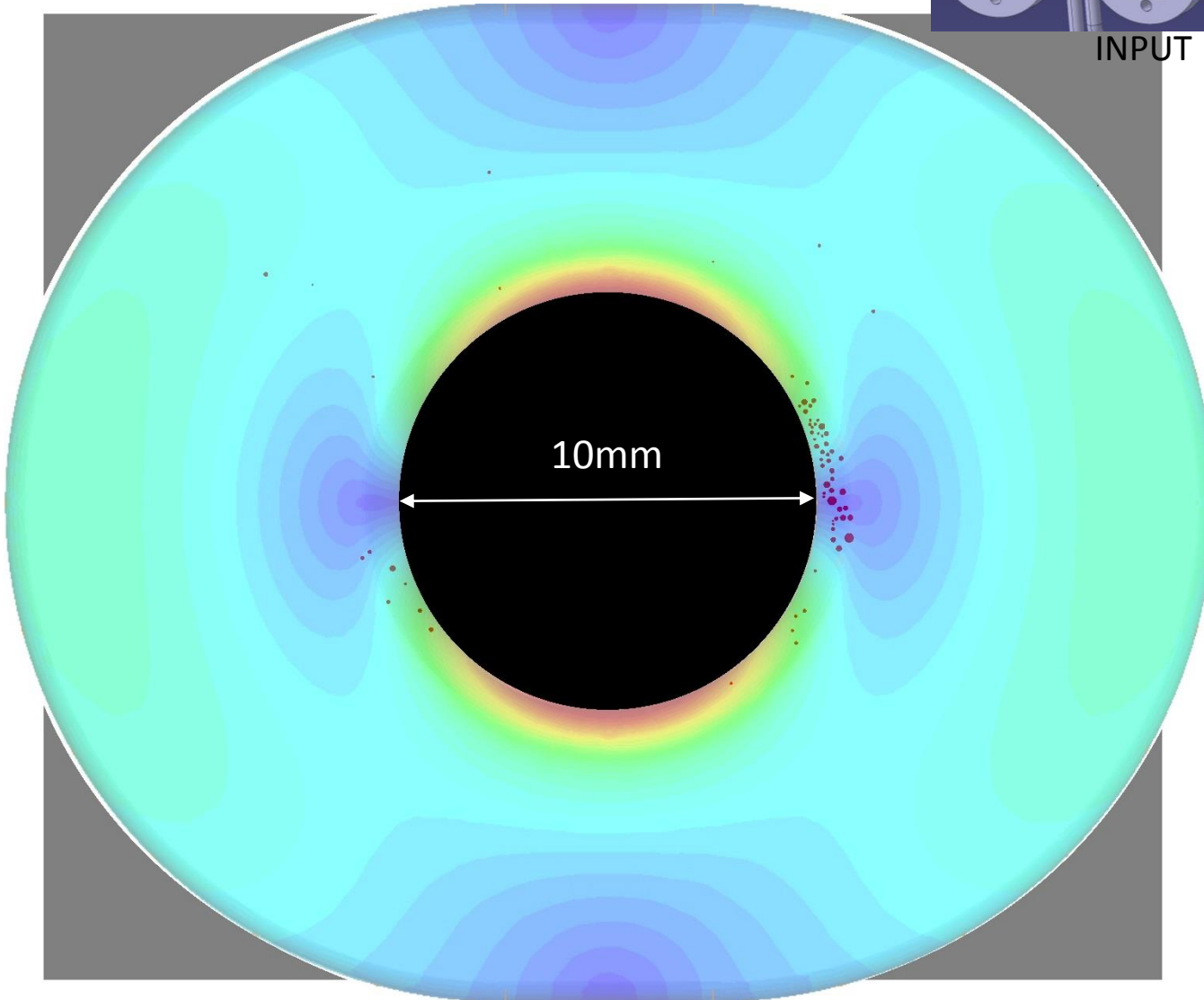
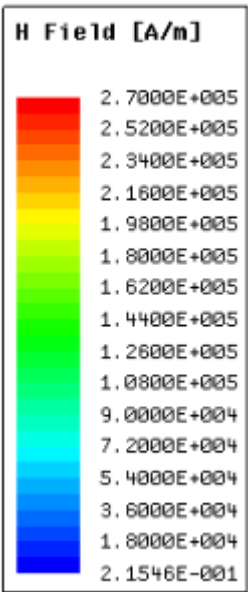
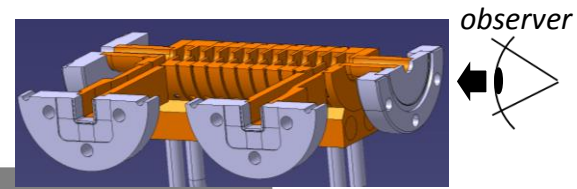
Histogram of the BD cell location, along with the month in which the BD occurred.

Number of sites BD sites = 69

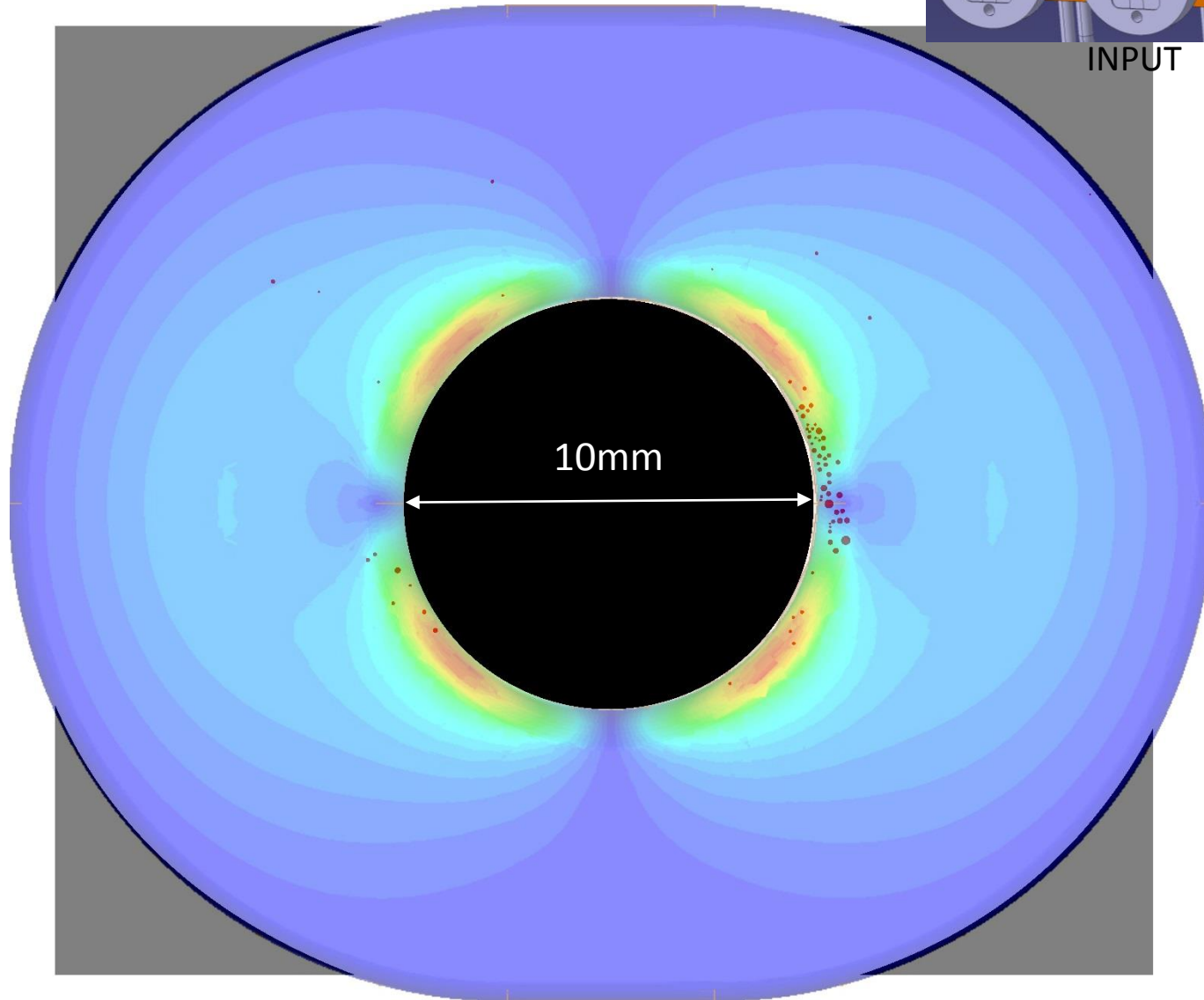
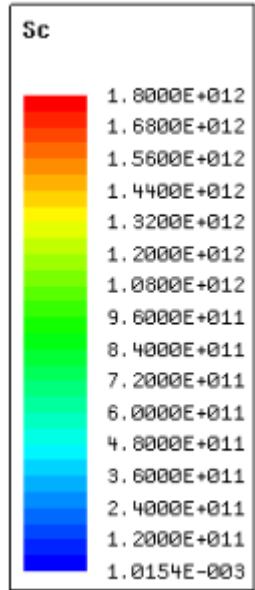
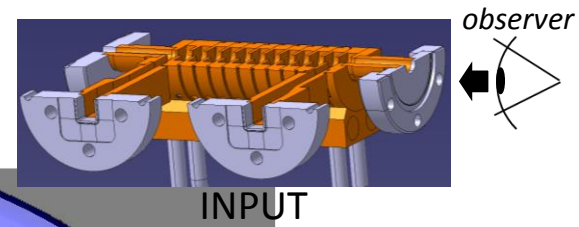
Cell 3 – Iris 1 Vs E-Field



Cell 3 – Iris 1 Vs H-Field



Cell 3 – *Iris 1* Vs Sc-Field



Outline

- **Introduction**
- **Objective**
- **Cutting and Nomenclature**
 - Marks and pollution induced by Post-Mortem cutting
 - Cleaning (degreasing)
 - General appearance of the surface after cleaning
- **Distribution**
 - BD distribution in the iris
 - BD location Vs E-Field
 - BD location Vs H-Field
 - BD location Vs Sc-Field
 - Facing irises (same cell)
- **Acquisition**
 - Imaging
 - Marking
 - Counting
- **Catalogue of features related with breakdown activity**
 - Comparison with other tested structures
 - Craters
 - Worm Like Features (WLF)
- **Summary of observations**

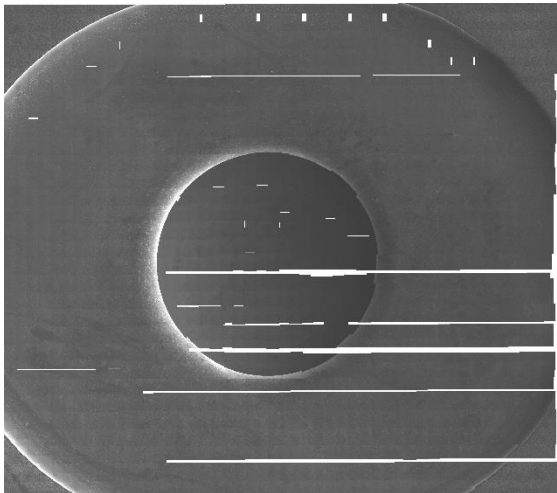
Acquisition of Images



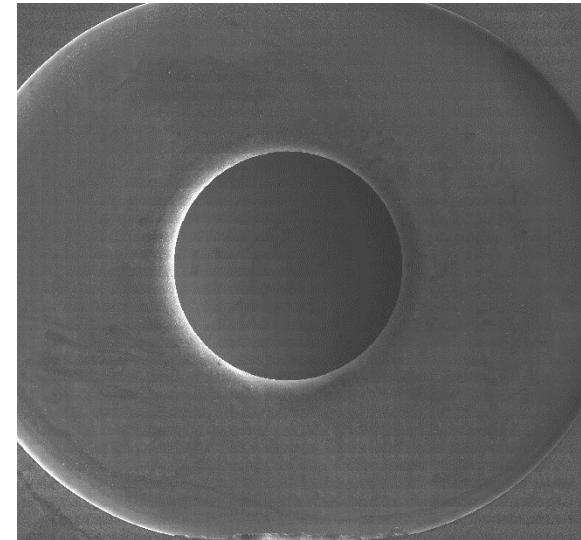
Multi-Scan with SEM

Acquisition of each global image ($\approx 16\text{h}$ to 24h):

- Input Cell 5000 images/Iris
- Rest of Cells ≈ 3000 images/iris

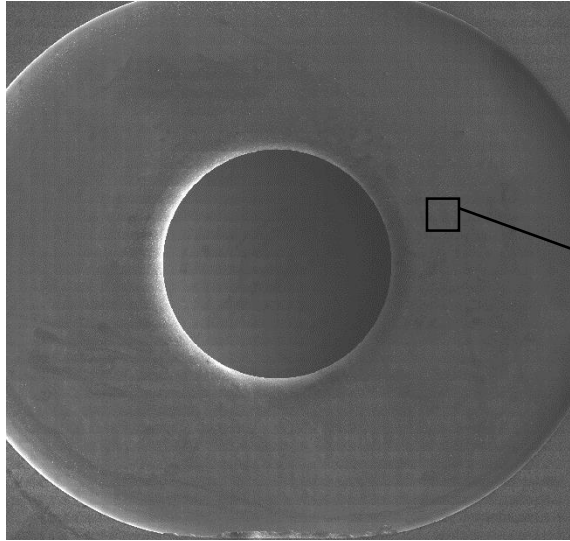


SmartSEM-SmartStitch
ZEISS



Stitching with MATLAB

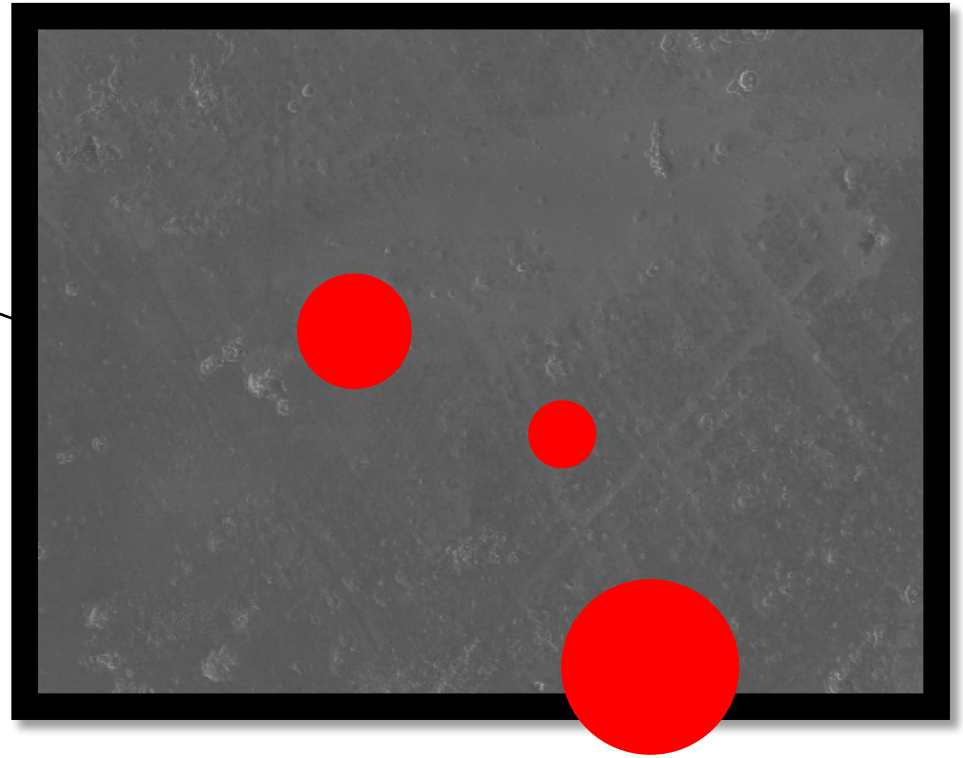
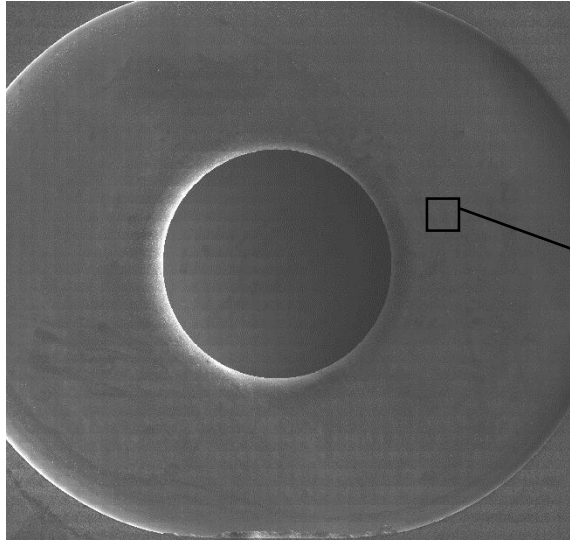
Counting of features



Limitations

- Manually
- Thousands of sites
- Conservative counting due to BD overlapping / various in the same site...
- Difficult due to surface state

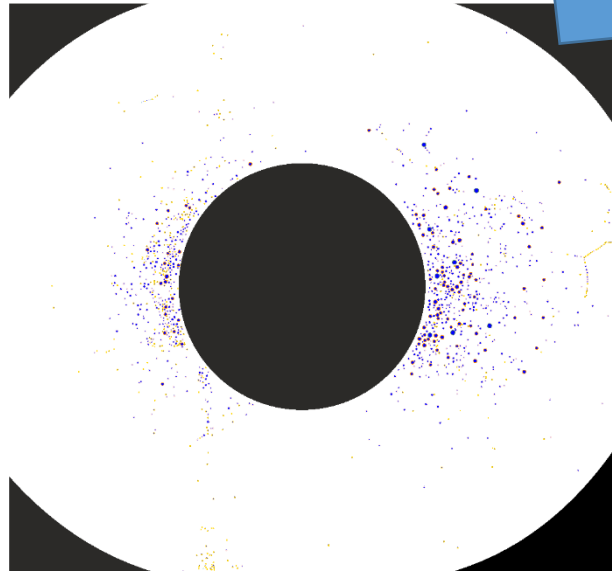
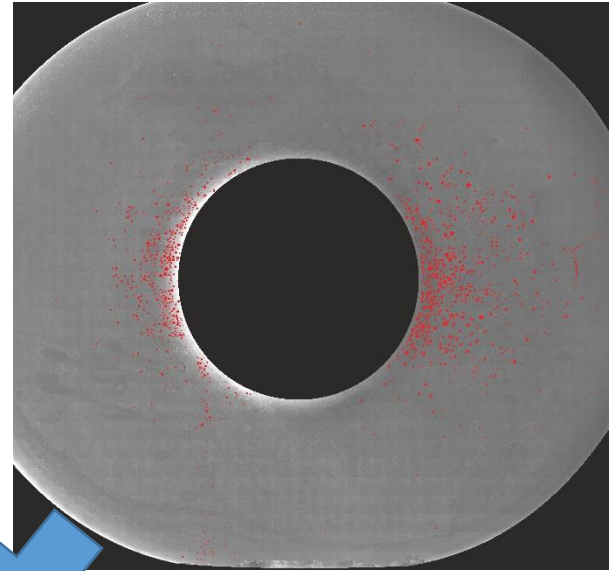
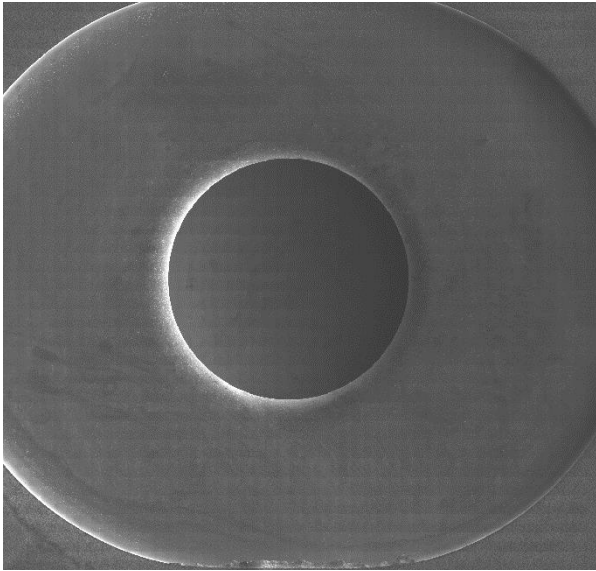
Marking



Limitations

- Manually
- Thousands of sites
- Conservative counting due to BD overlapping / various in the same site...
- Difficult due to surface status

Counting

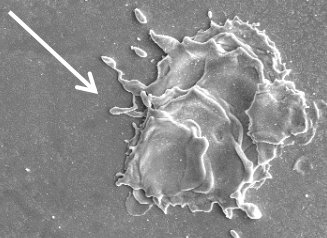


Analysis of the mask with *Zeiss Axio Visio – Particle analyser* for an automatic counting of the features

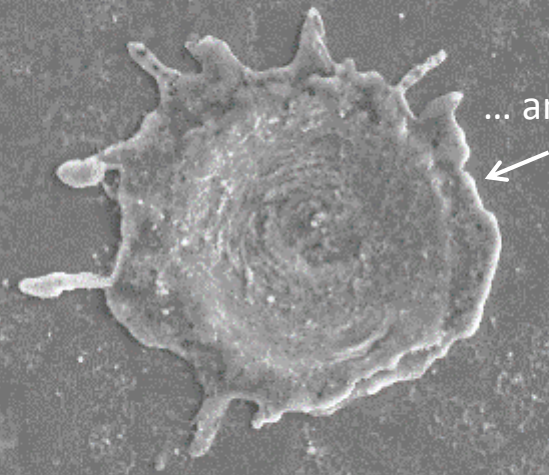
Outline



- **Introduction**
- **Objective**
- **Cutting and Nomenclature**
 - Marks and pollution induced by Post-Mortem cutting
 - Cleaning (degreasing)
 - General appearance of the surface after cleaning
- **Distribution**
 - BD distribution in the iris
 - BD location Vs E-Field
 - BD location Vs H-Field
 - BD location Vs Sc-Field
 - Facing irises (same cell)
- **Acquisition**
 - Imaging
 - Marking
 - Counting
- **Catalogue of features related with breakdown activity**
 - Comparison with other tested structures
 - Craters
 - Worm Like Features (WLF)
- **Summary of observations**

Overlapped sparks...



... and isolated

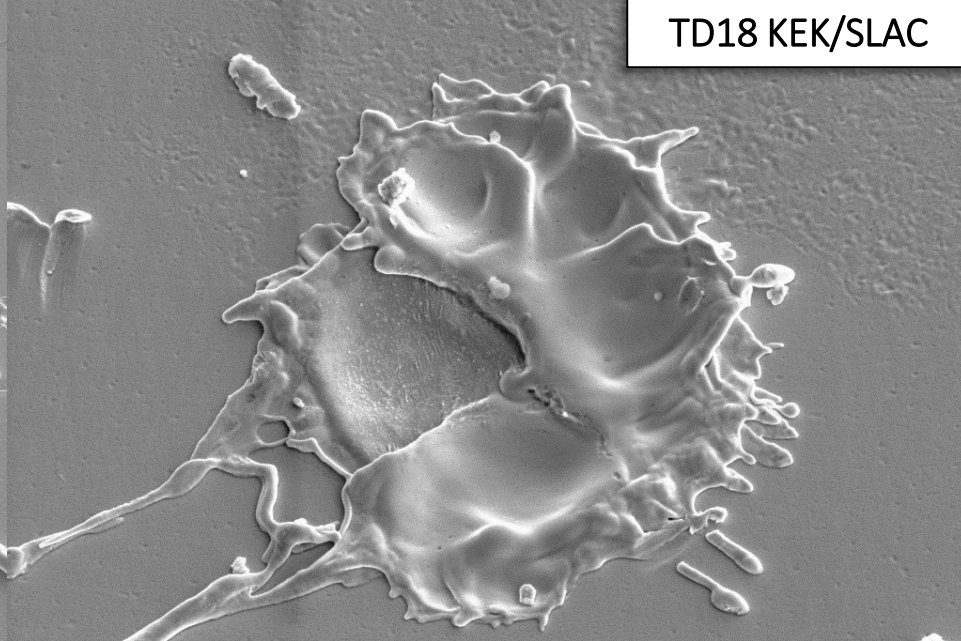
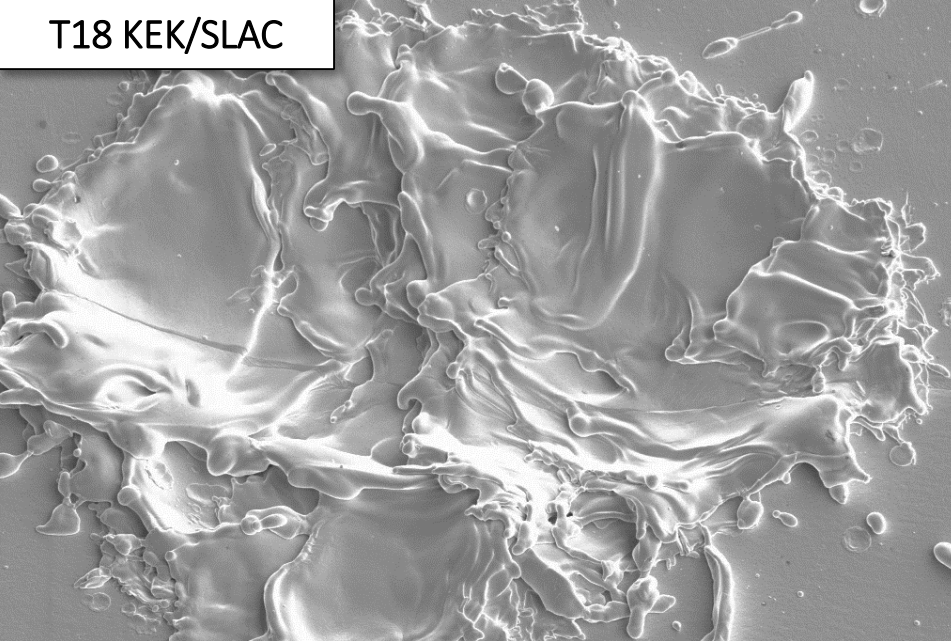




10 μ m   EHT = 10.00 kV
WD = 17.4 mm
Signal A = SE2
Disc #5 front side
Mag = 1.00 K X
Anite Perez Fontenla
Date :18 Jun 2014



1 μ m   EHT = 10.00 kV
WD = 19.4 mm
Signal A = SE2
Disc #4 backside
Mag = 5.00 K X
Anite Perez Fontenla
Date :18 Jun 2014

T18 KEK/SLAC



TD18 KEK/SLAC





10 μ m   EHT = 5.00 kV
WD = 17.6 mm
Signal A = SE2
T18 KEK/SLAC
part B Tilt 30°
Backside Iris 1
Mag = 1.00 K X
Ana T. Perez Fontenla
Date :11 Mar 2011

1 μ m   EHT = 5.00 kV
WD = 22.3 mm
Signal A = SE2
TD18 KEK-SLAC Part B Tilt 30°
Up-Stream -- Cell-Wall NW
Stage at R = 46.9°
Mag = 5.00 K X
Markus Aicheler
Date :7 Oct 2010

Overlapped BDs craters

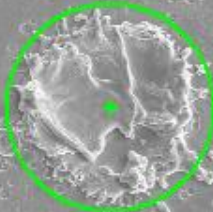
20 μ m EHT = 20.00 kV Post Mortem - Crab Cavity Date :14 Jan 2016
 WD = 24.8 mm Cell 1 - Iris 1 Mag = 200 X 
Signal A = SE2 Stage at T = 0.0° Enrique Rodriguez Castro

Isolated BDs craters

20 μ m EHT = 20.00 kV Port Mortem - Crab Cavity Date :1 Dec 2015
 WD = 15.0 mm Cell 1 - Iris 2 Mag = 200 X 
Signal A = SE2 Smatstich Enrique Rodriguez Castro



Da 1 = 62.52 μm
Db 1 = 3070. μm^2

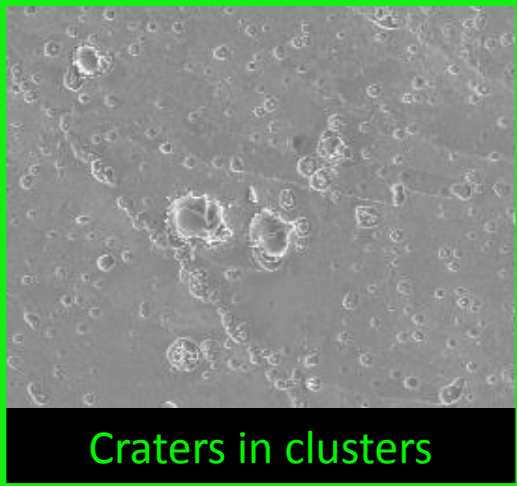


Da 1

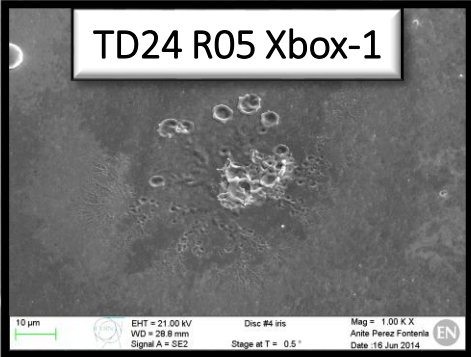


Da 2

Da 2 = 29.03 μm
Db 2 = 661.8 μm^2



Craters in clusters



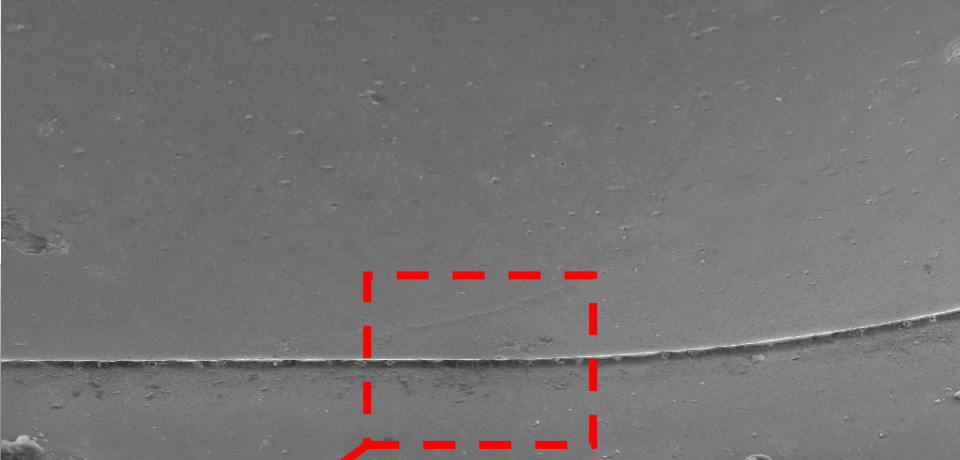
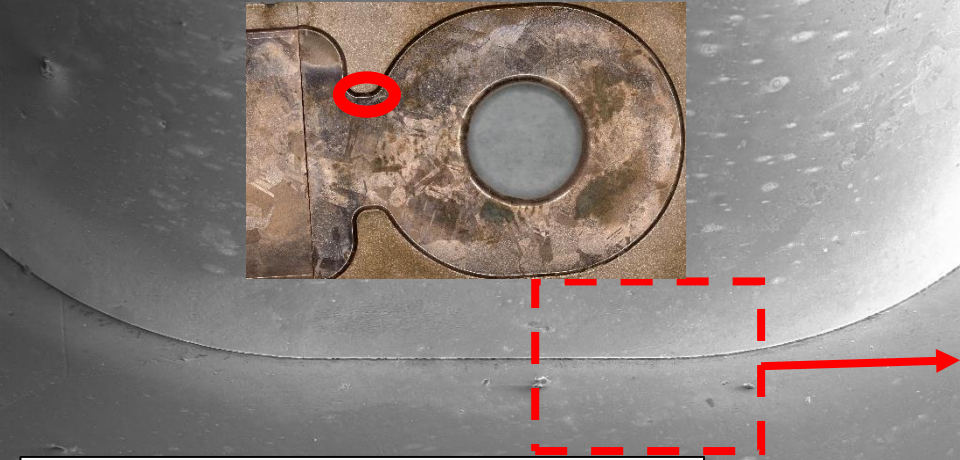
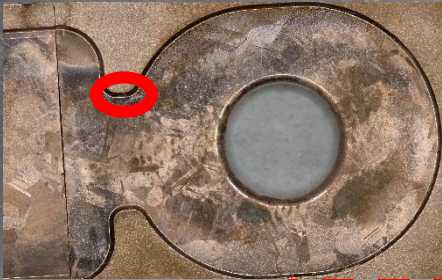
20 μm

EHT = 20.00 kV
WD = 24.5 mm
Signal A = SE2

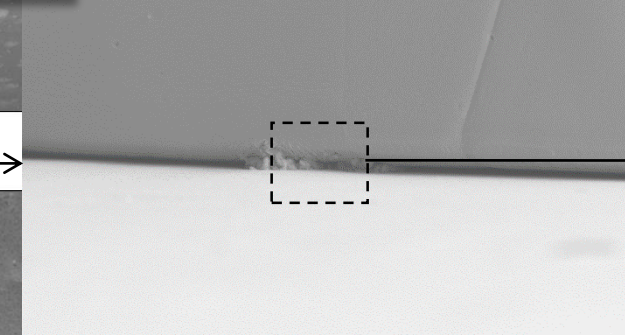
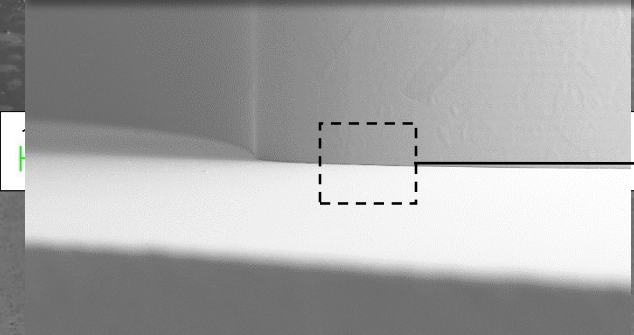
Post Mortem - Crab Cavity
Cell 1 - Iris 1
B. Woolley/E. Rodriguez Castro
Stage at T = 0.0°

Date :14 Jan 2016
Mag = 200 X
Enrique Rodriguez Castro





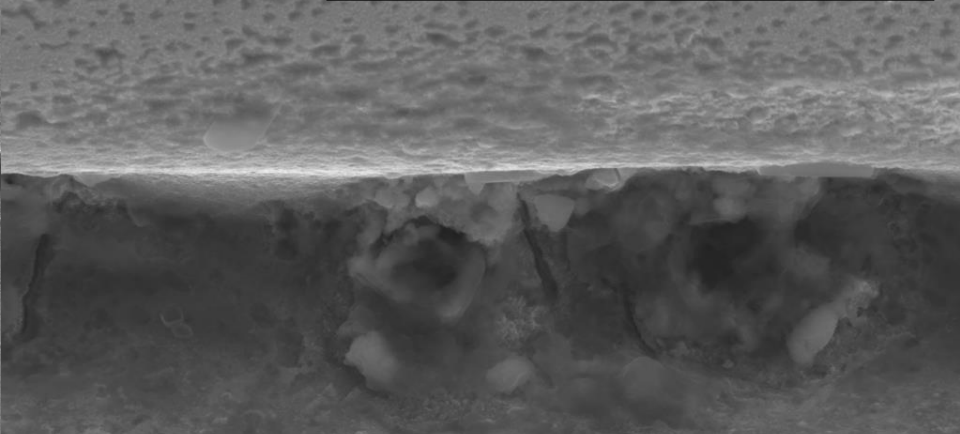
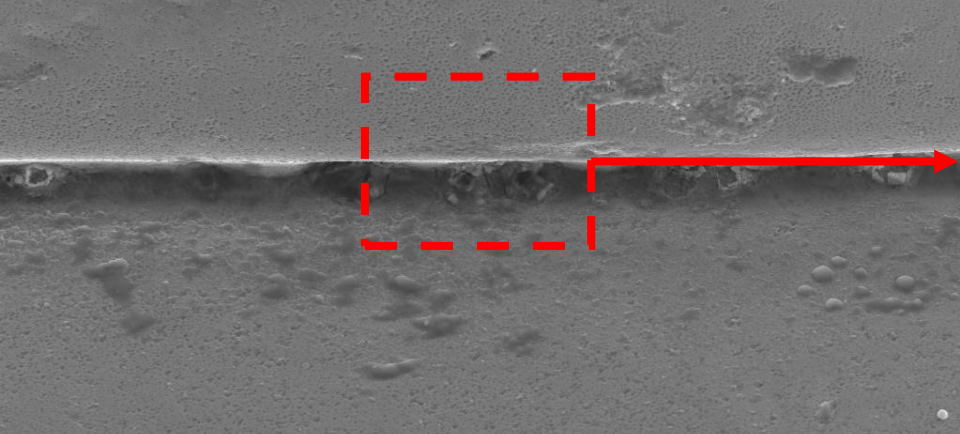
TD24 R05 N1 Cell #22 US_Quarter F3



100 μ m
 EHT = 20.00 kV
 WD = 11.2 mm
 Signal A = SE2
 Disc #22
 Stage at T = 86.0°
 Mag = 50 X
 Anite Perez Fortenla
 Date :17 Jul 2014
 EN

10 μ m
 EHT = 20.00 kV
 WD = 11.2 mm
 Signal A = SE2
 Disc #22
 Stage at T = 86.0°
 Mag = 1.00 K X
 Anite Perez Fortenla
 Date :17 Jul 2014
 EN

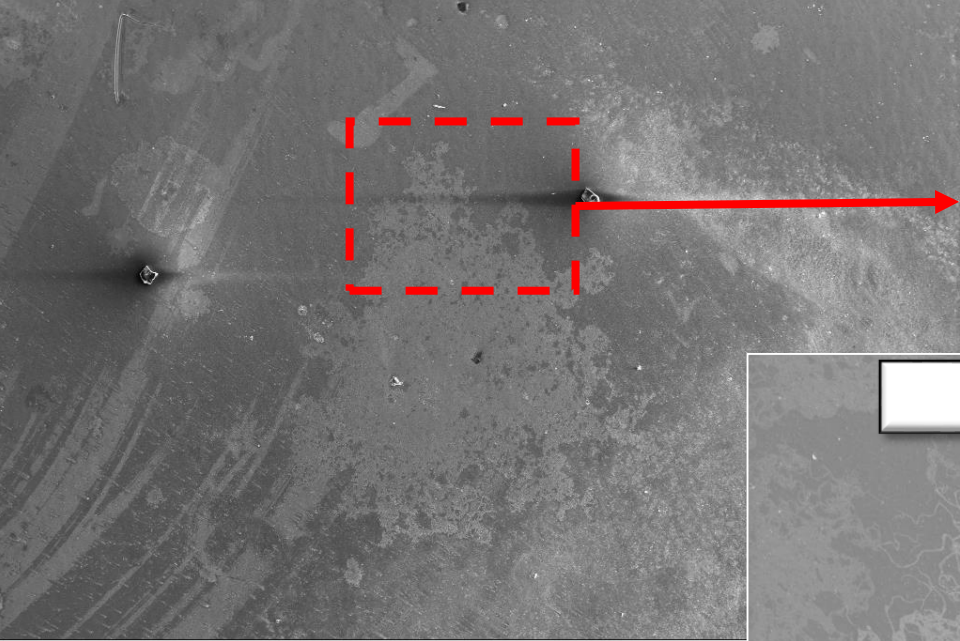
1 μ m
 EHT = 20.00 kV
 WD = 11.2 mm
 Signal A = SE2
 Disc #22
 Stage at T = 86.0°
 Mag = 5.00 K X
 Anite Perez Fortenla
 Date :17 Jul 2014
 EN



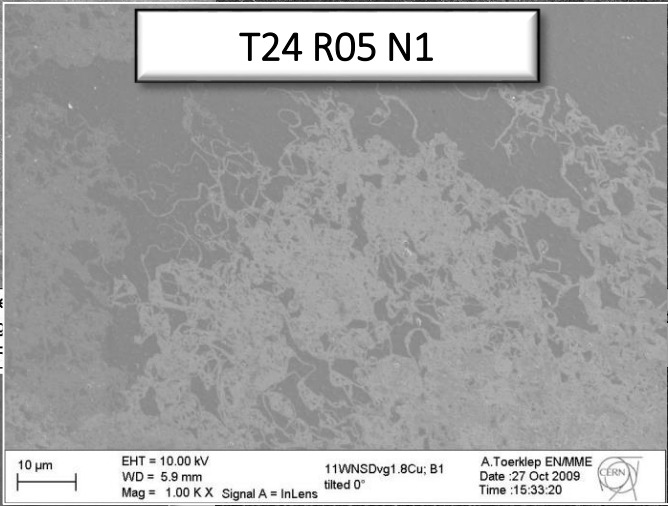
10 μ m
 EHT = 20.00 kV
 WD = 31.8 mm
 Signal A = SE2
 Post Mortem - Crab Cavity
 Cell 1 - Iris 1
 Stage at T = 45.0°

14 Jul 2016
 Mag = 1.00 K X
 Enrique Rodriguez Castro
 EN

1 μ m
 EHT = 20.00 kV
 WD = 31.8 mm
 Signal A = SE2
 Post Mortem - Crab Cavity
 Cell 1 - Iris 1
 Stage at T = 45.0°
 Date :14 Jul 2016
 Mag = 5.00 K X
 Enrique Rodriguez Castro
 EN



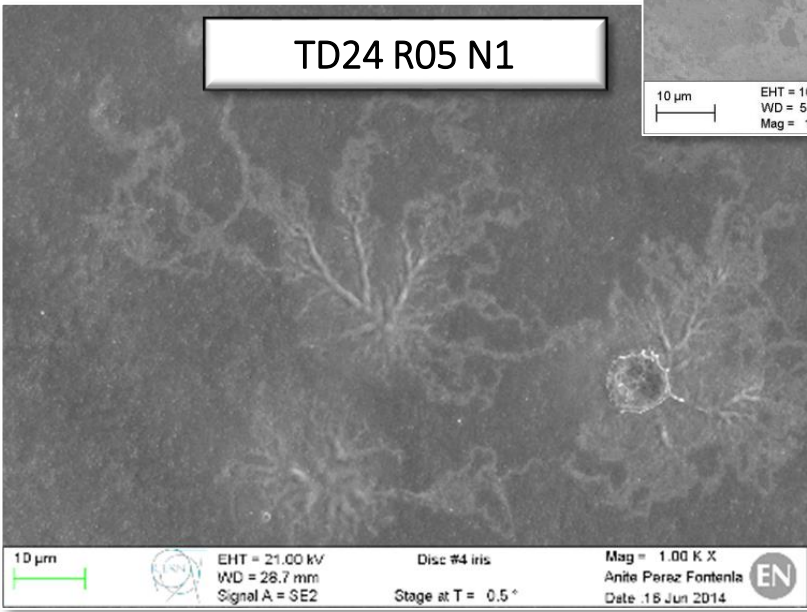
T24 R05 N1



100 µm EHT = 20.00 kV Post Mortem - Crab Cavity Cell 1 - Iris 1 Date :14 Jan 2016 Mag = 200 X Signal A = SE2 Enrique Rodriguez Castro

Date :14 Jan 2016 Mag = 200 X Enrique Rodriguez Castro

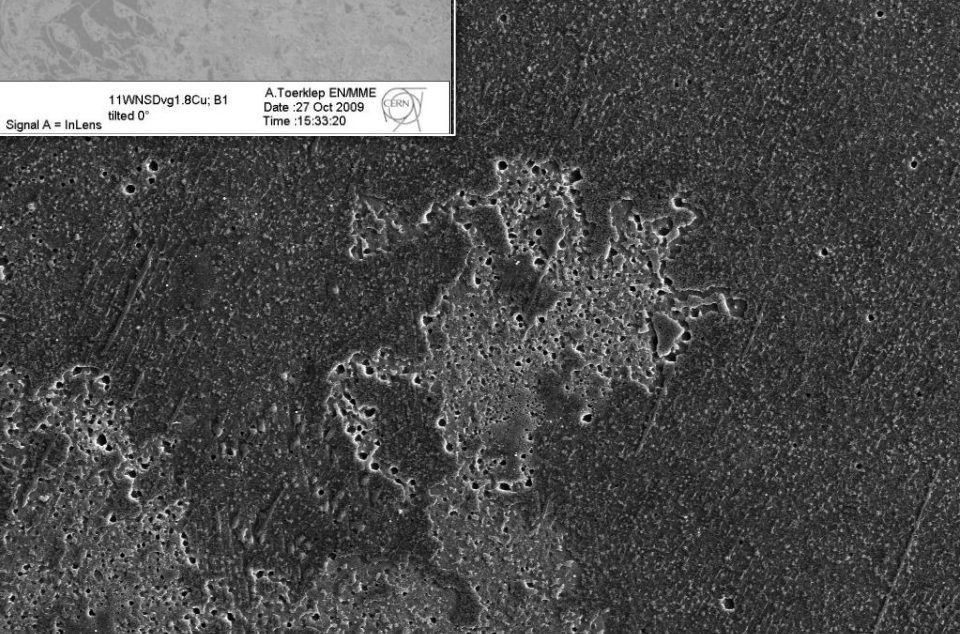
TD24 R05 N1



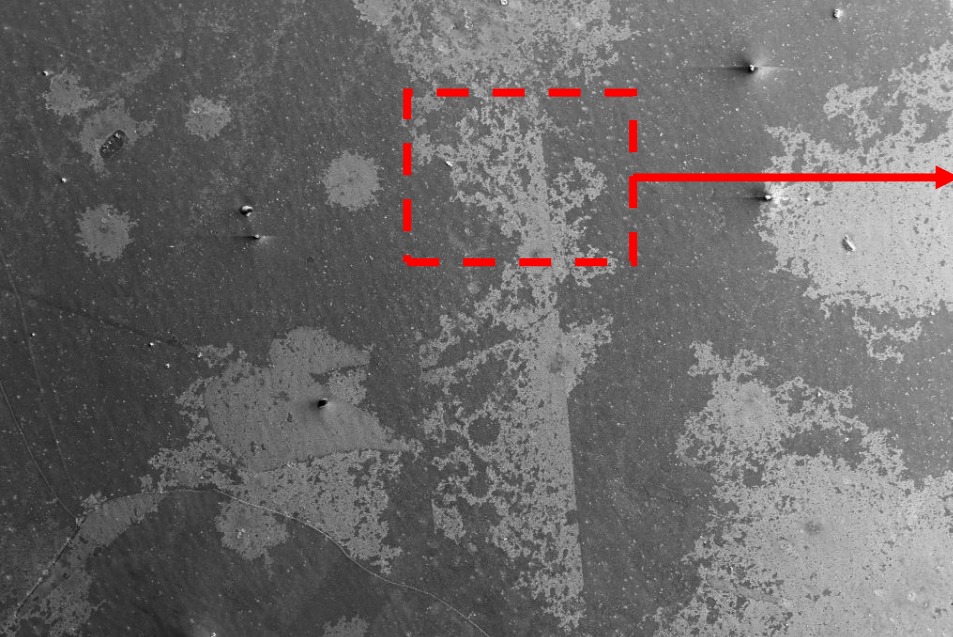
10 µm EHT = 10.00 kV 11WNSDvg1.8Cu; B1 A.Toerklep ENMME Date :27 Oct 2009 Time :15:33:20 Mag = 1.00 K X Signal A = InLens tilted 0°

10 µm EHT = 21.00 kV Disc #4 iris Mag = 1.00 K X Anite Perez Fontela Date :16 Jun 2014 Signal A = SE2 Stage at T = 0.5°

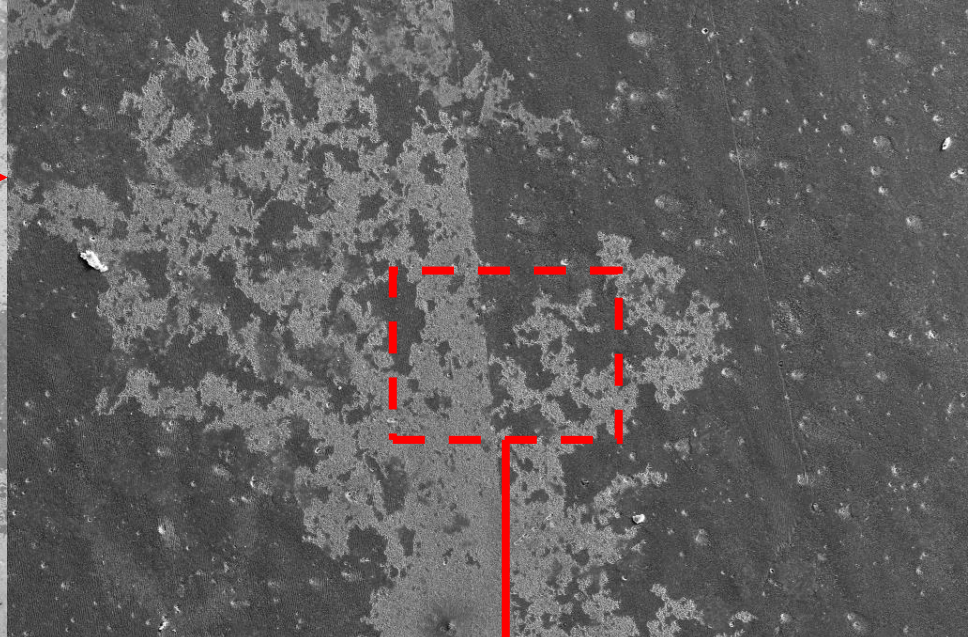
B. Woolley/E. Rodriguez Castro



10 µm EHT = 20.00 kV Post Mortem - Crab Cavity Cell 1 - Iris 1 Date :14 Jan 2016 Mag = 1.00 K X Signal A = SE2 Enrique Rodriguez Castro

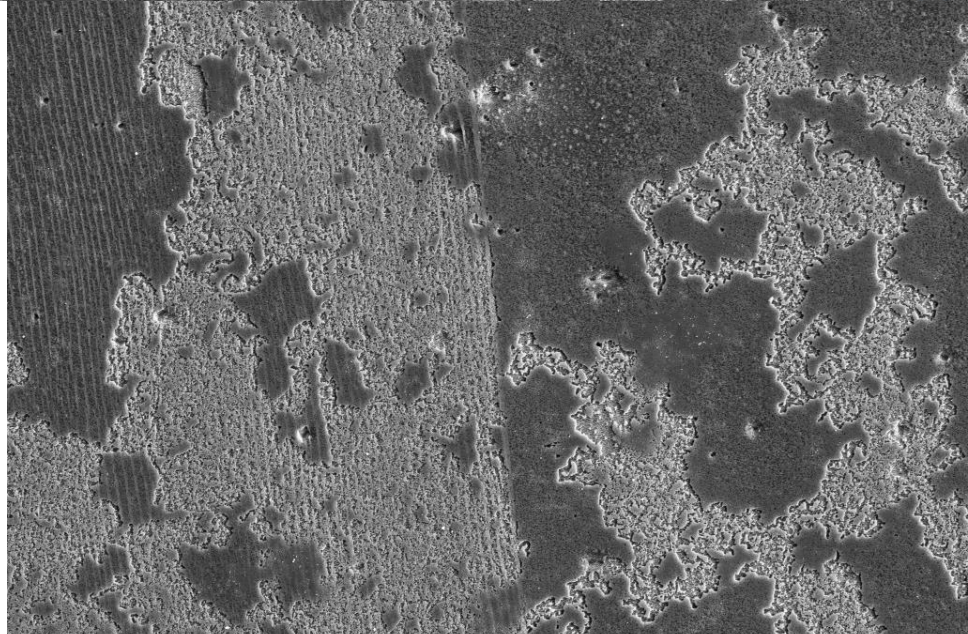


100 μm EHT = 20.00 kV Post Mortem - Crab Cavity Date :14 Jan 2016
WD = 14.3 mm Cell 1 - Iris 1 Mag = 50 X
Signal A = SE2 Enrique Rodriguez Castro



20 μm EHT = 20.00 kV Post Mortem - Crab Cavity Date :14 Jan 2016
WD = 14.3 mm Cell 1 - Iris 1 Mag = 200 X
Signal A = SE2 Enrique Rodriguez Castro

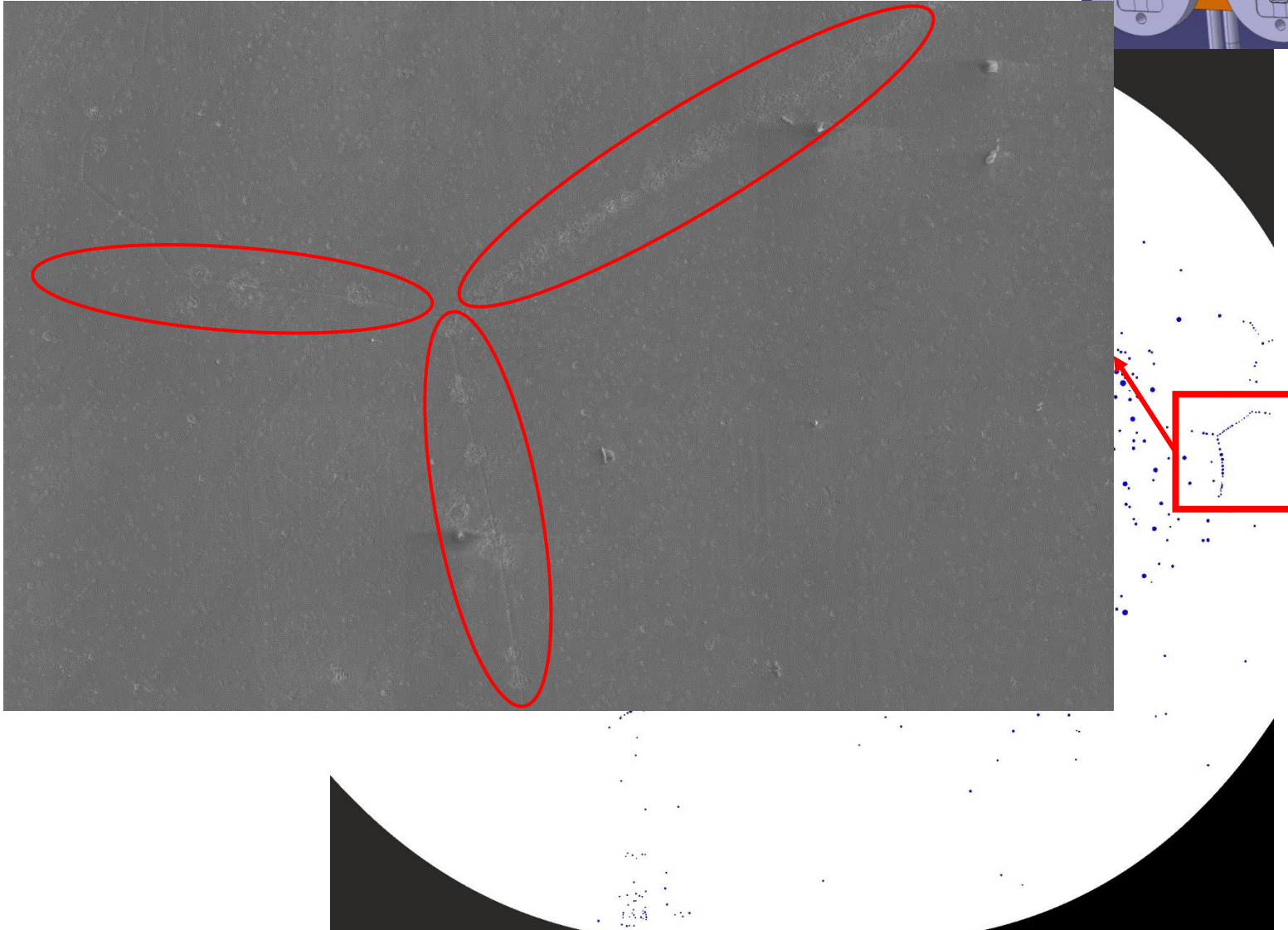
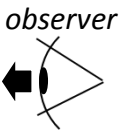
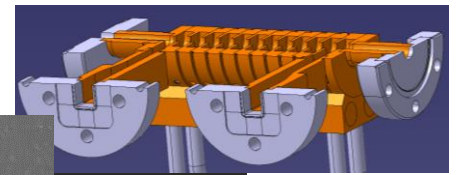
Stopped in grain boundary



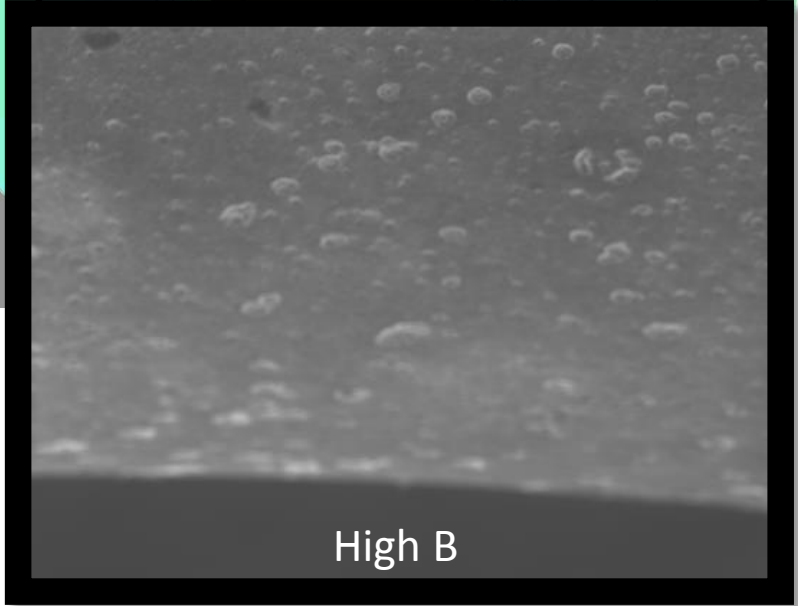
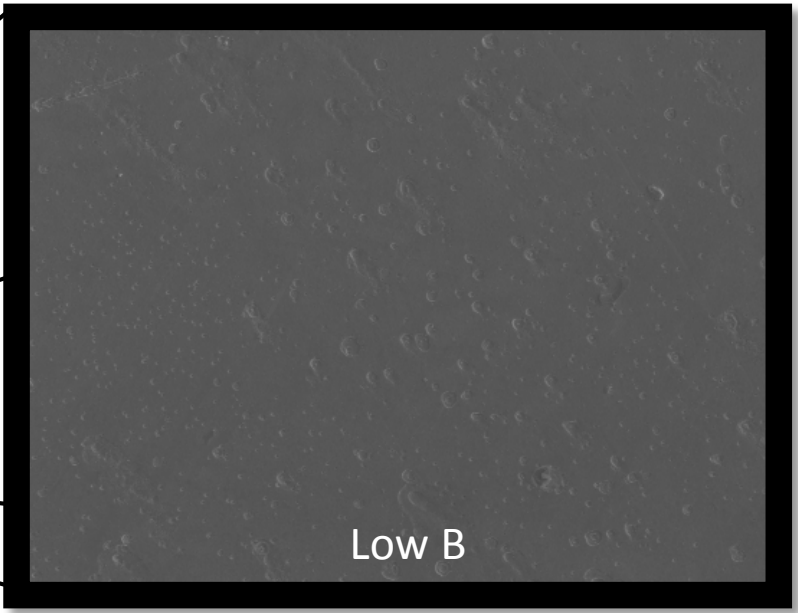
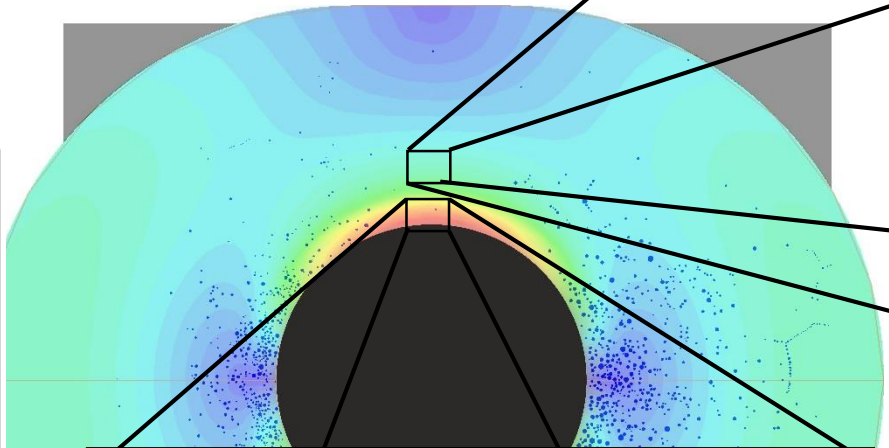
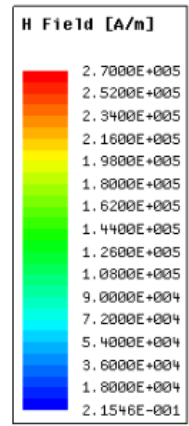
10 μm EHT = 20.00 kV Post Mortem - Crab Cavity Date :14 Jan 2016
WD = 14.3 mm Cell 1 - Iris 1 Mag = 1.00 K X
Signal A = SE2 Enrique Rodriguez Castro

B. Woolley/E. Rodriguez Castro

Cell 2 – Iris 2



Number of sites BD sites = 1305



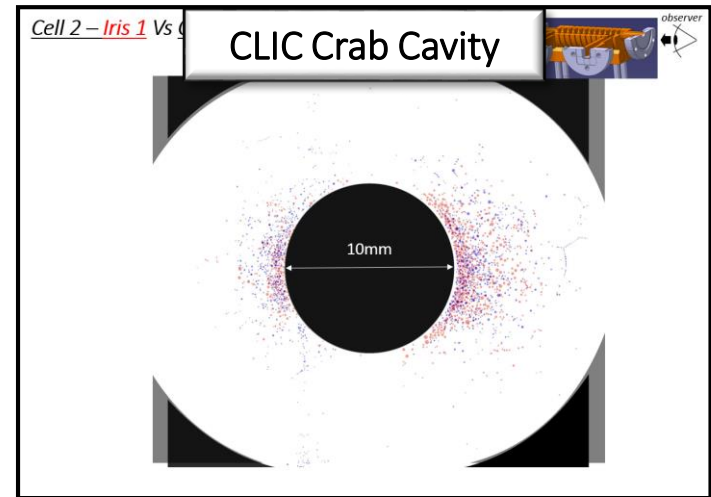
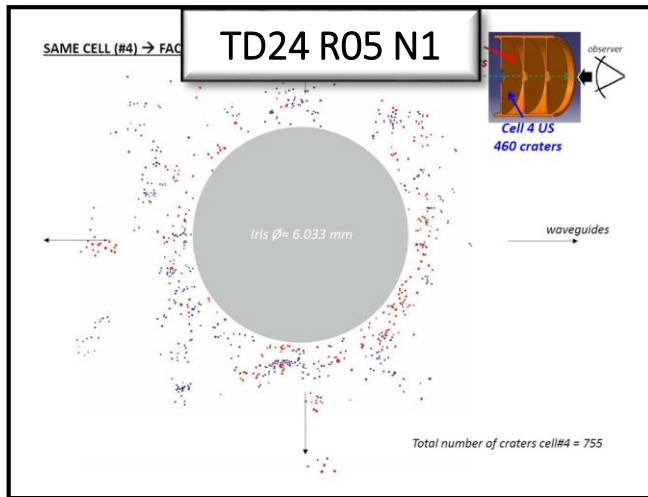
No fatigue signs in surface

Outline

- **Introduction**
- **Objective**
- **Cutting and Nomenclature**
 - Marks and pollution induced by Post-Mortem cutting
 - Cleaning (degreasing)
 - General appearance of the surface after cleaning
- **Distribution**
 - BD distribution in the iris
 - BD location Vs E-Field
 - BD location Vs H-Field
 - BD location Vs Sc-Field
 - Facing irises (same cell)
- **Acquisition**
 - Imaging
 - Marking
 - Counting
- **Catalogue of features related with breakdown activity**
 - Comparison with other tested structures
 - Craters
 - Worm Like Features (WLF)
- **Summary of observations**

Summary of observation

- Distribution of BDs is different than in monopole structures



- Craters and features have same morphology that those in monopole structures
- BDs number drops significantly after firsts cells
 - To be confirmed with the complete observation (on going)

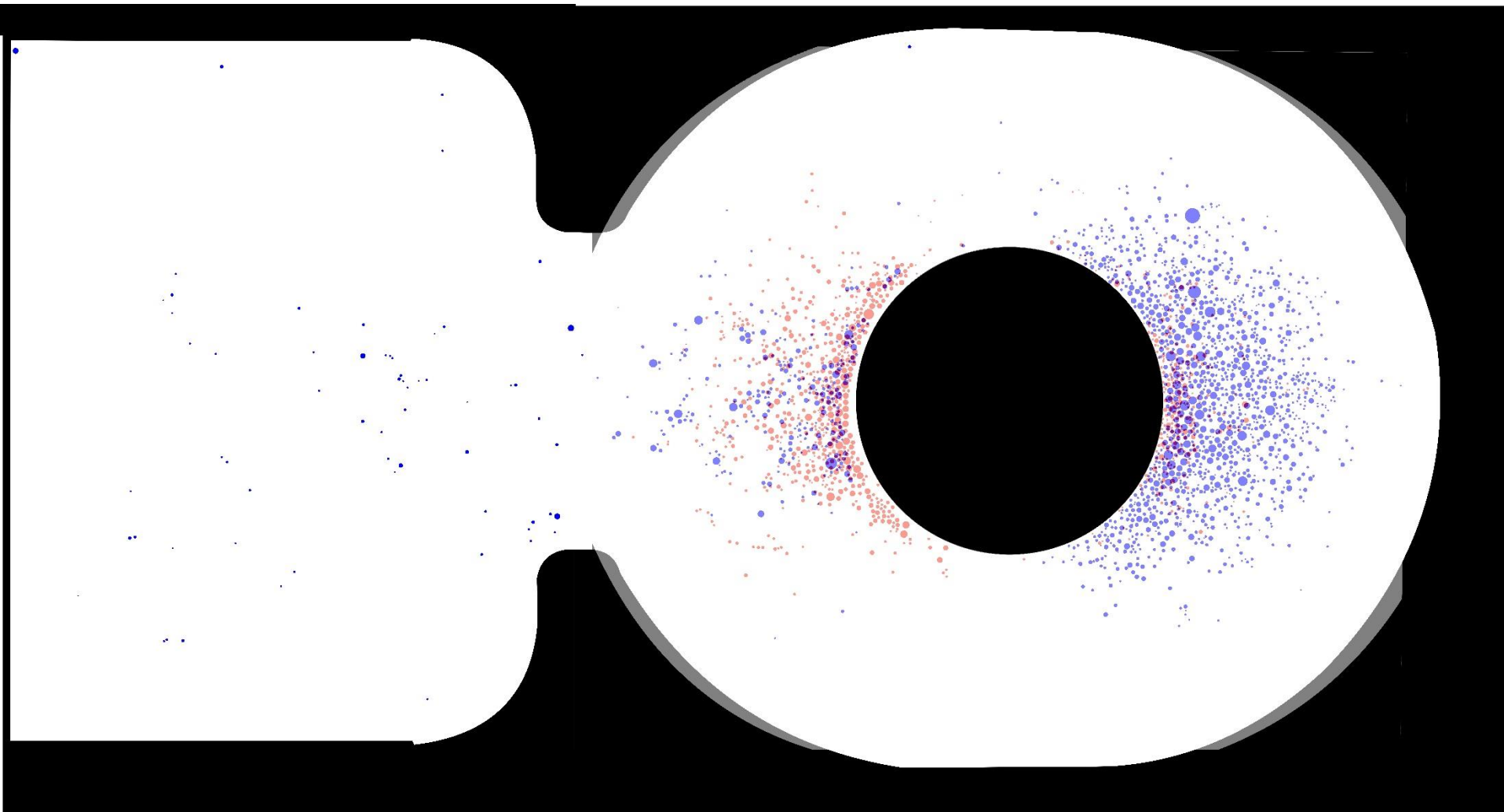
Thank you for your attention.

Questions?

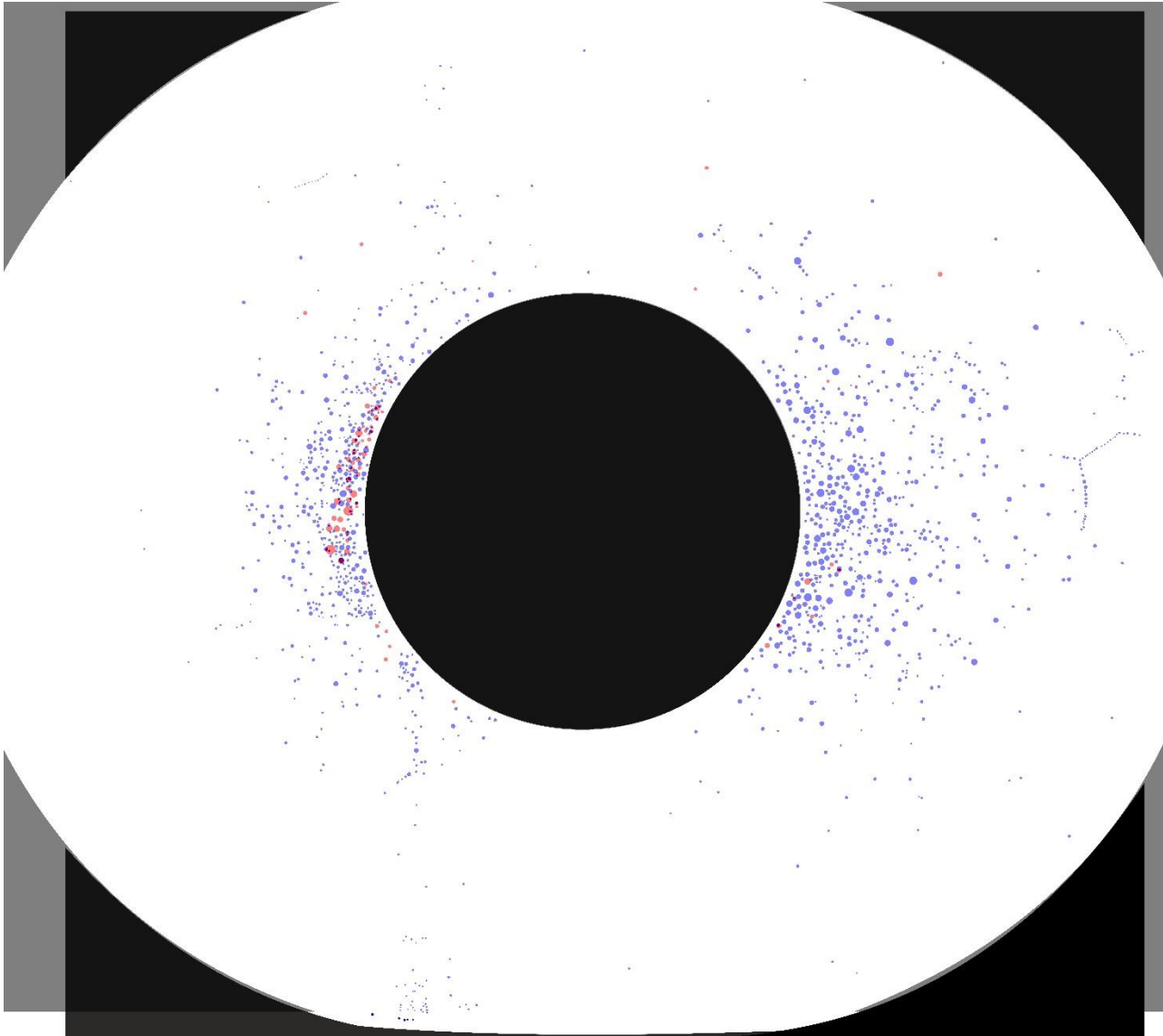


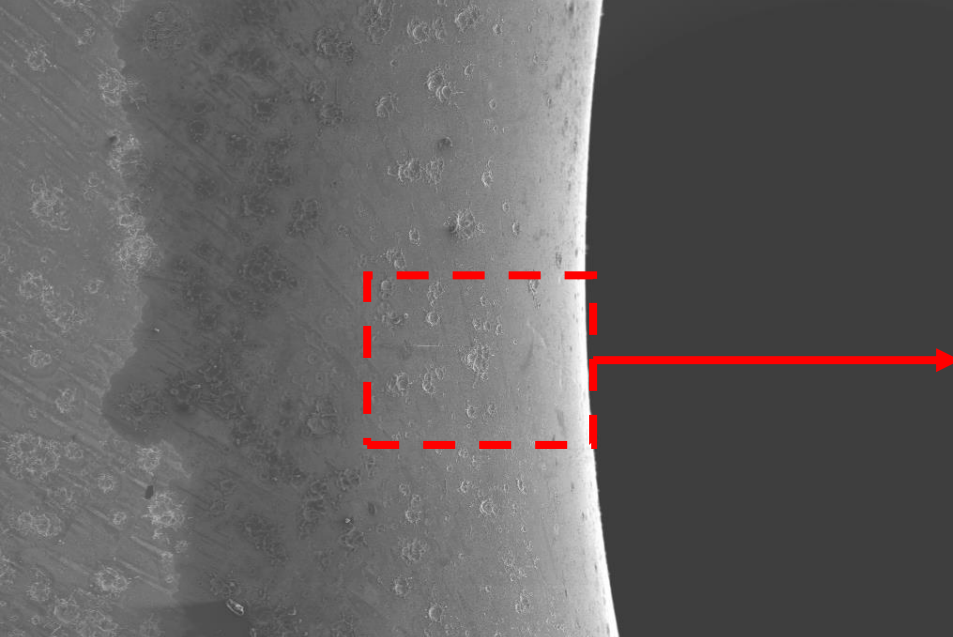
Extra Slides

Cell 1 – Iris 2 Vs Cell 2 – Iris 1

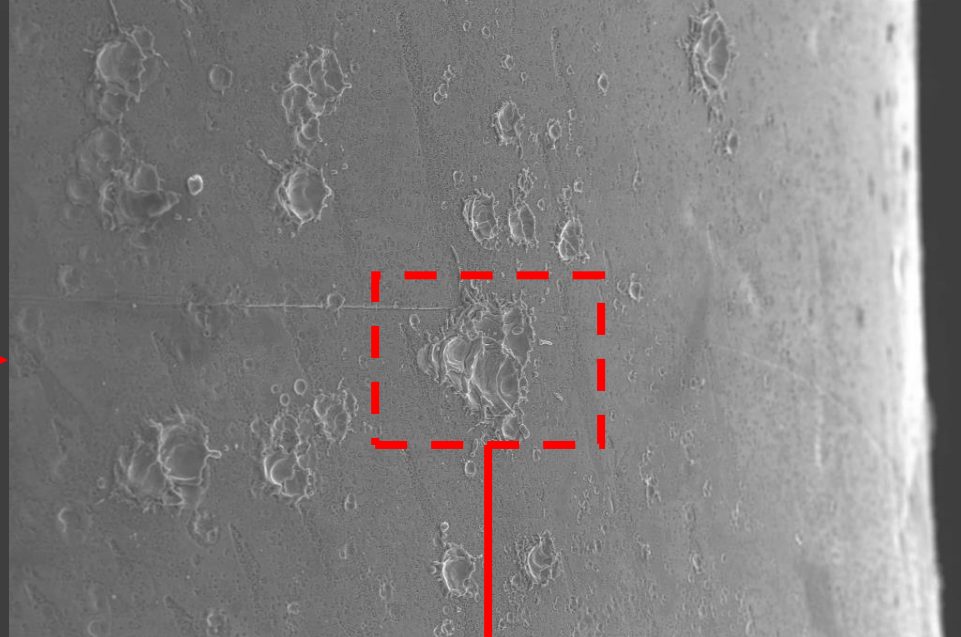


Cell 2 – Iris 2 Vs Cell 3 – Iris 1

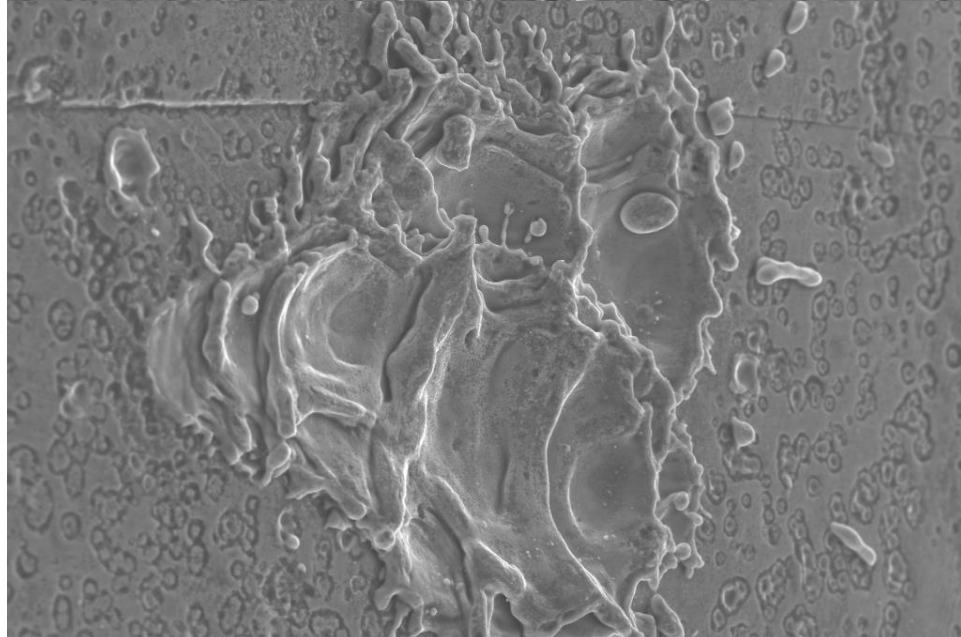




100 μm EHT = 20.00 kV Post Mortem - Crab Cavity Date :14 Jan 2016
WD = 24.8 mm Cell 1 - Iris 1 Mag = 50 X
Signal A = SE2 Stage at T = 0.0° Enrique Rodriguez Castro



20 μm EHT = 20.00 kV Post Mortem - Crab Cavity Date :14 Jan 2016
WD = 24.8 mm Cell 1 - Iris 1 Mag = 200 X
Signal A = SE2 Stage at T = 0.0° Enrique Rodriguez Castro



10 μm EHT = 20.00 kV Post Mortem - Crab Cavity Date :14 Jan 2016
WD = 24.8 mm Cell 1 - Iris 1 Mag = 1.00 K X
Signal A = SE2 Stage at T = 0.0° Enrique Rodriguez Castro

B. Woolley/E. Rodriguez Castro