Post-Mortem analysis: SEM imaging review

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EN-MME-MM

CLIC workshop 2015 – Geneva

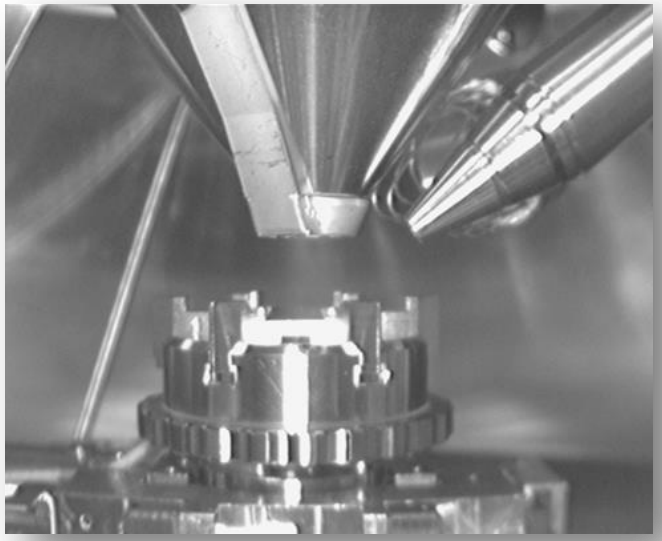
Outline

- ***Introduction***
- ***What does a hot cell look like?***
- ***Have we made progress joining disks? (B-field arcs)***
- ***How do DC and RF BDs compare?***
- ***Catalogue of features related with BD activity***

Introduction

The aim of the SEM observations is:

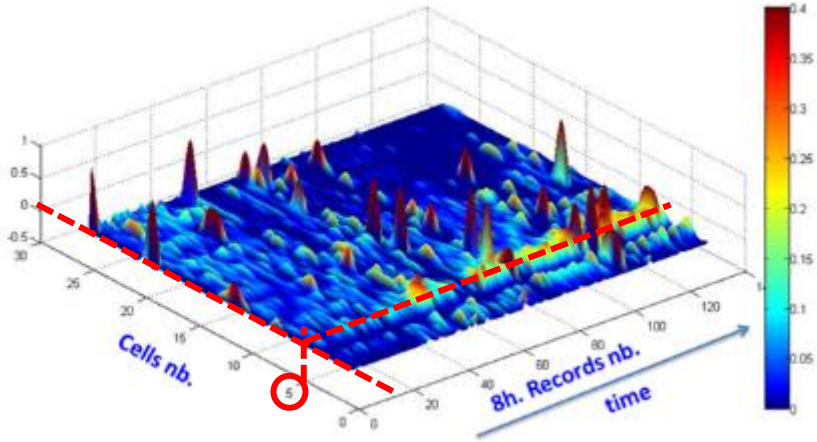
1. To identify the machining quality (machining marks, burrs) and the general surface quality of AS before operation at high power;
2. To characterize the surface after operation.
3. To compare and if it is possible to put in relation individual post mortem features with features observed before operation;

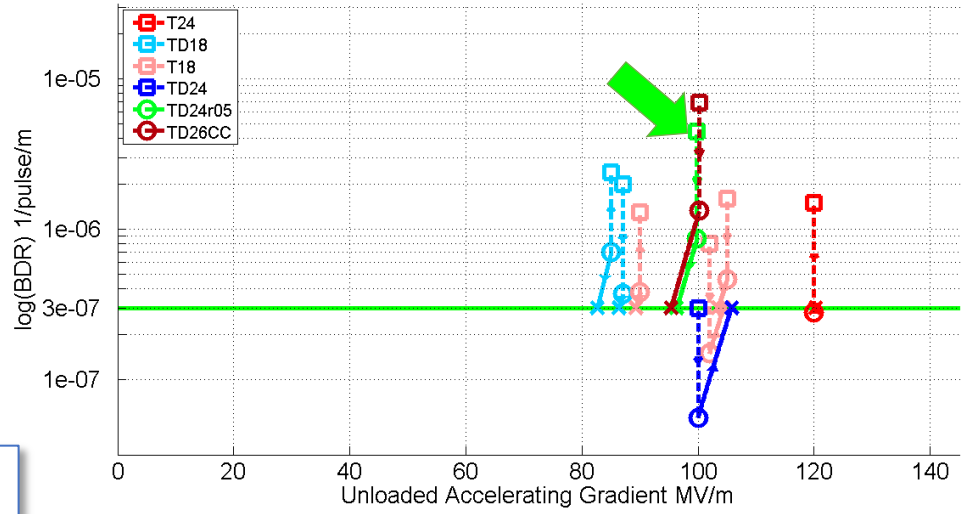


What does a hot cell look like?

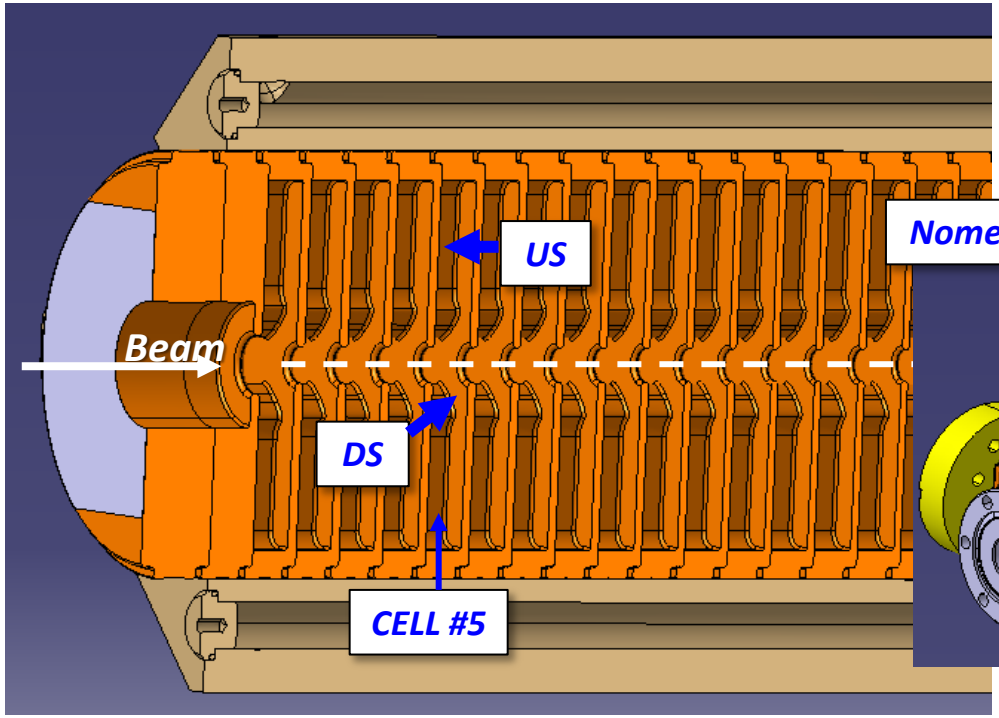
Most recent example: TD24R05 tested at CERN

High gradient summary

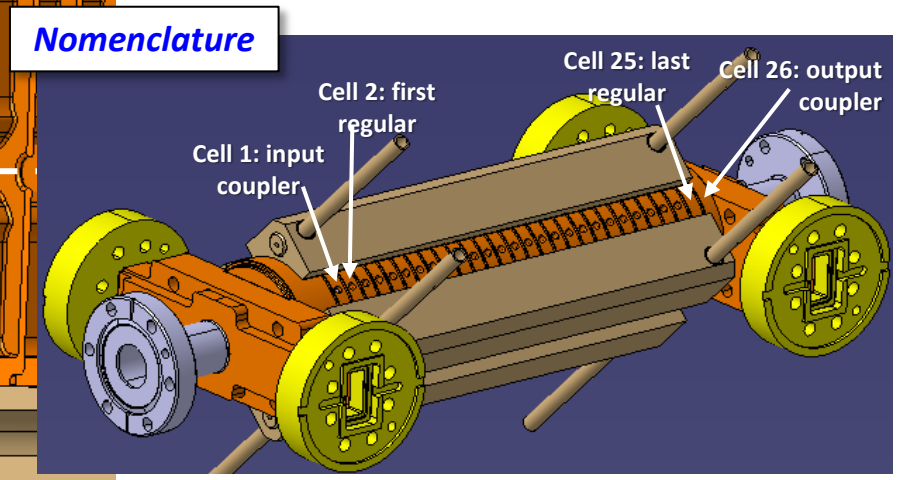




Cell 5 → hot cell/ iris developed during high power operations (W. Farabolini)

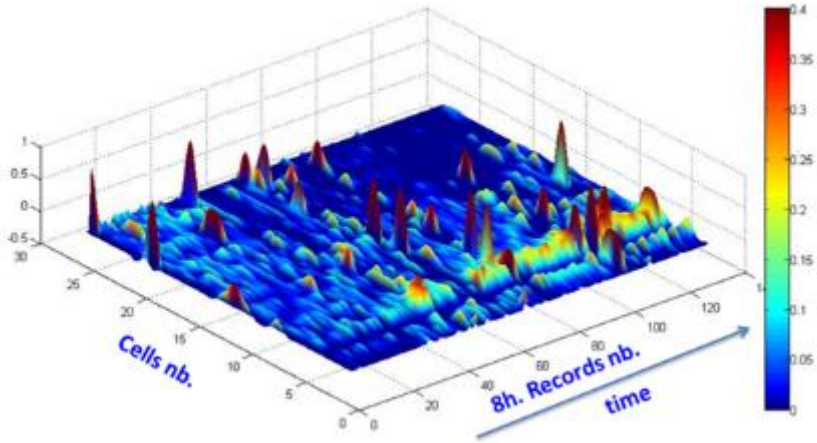


TD24 R= 0.5 mm, is the radius between bottom part of waveguide and it's wall

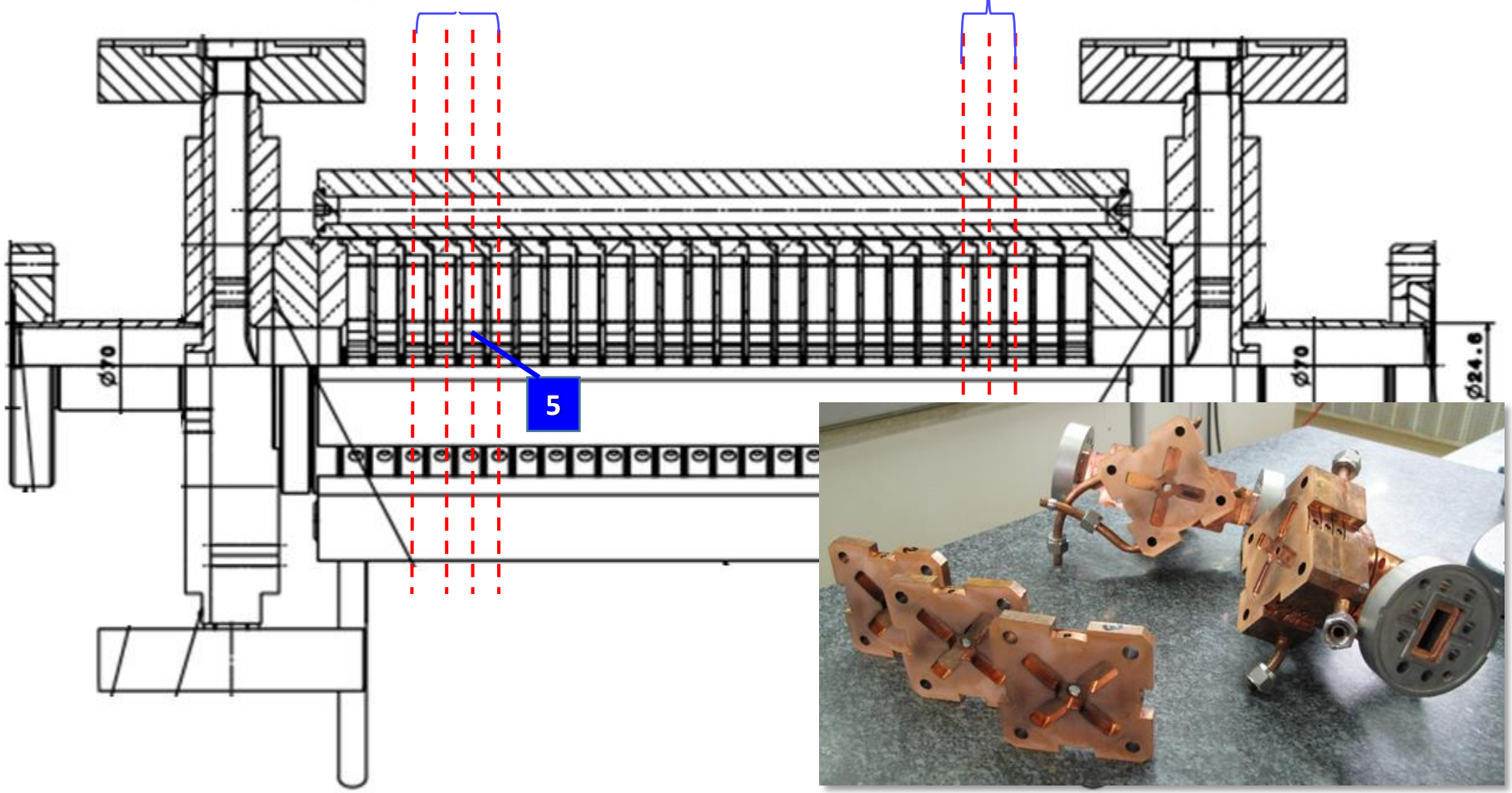


EDM wire cutting at CERN*

Transverse cutting of the two extremities
g of cells number 4-5-6 & 22-23 for iris inspection by SEM
Cell 22 (cutting in quarters) → sent to collaborators



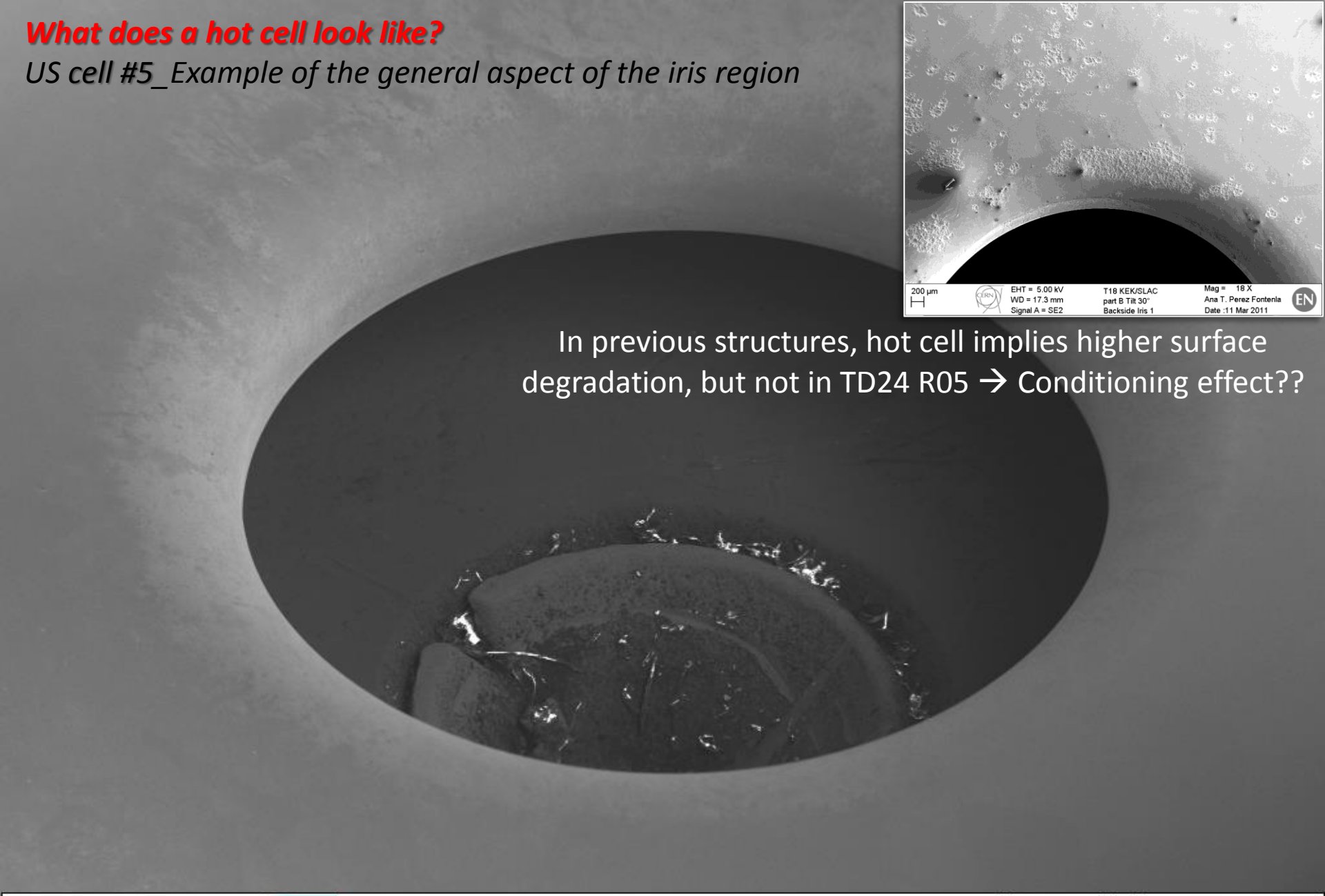
SEM CERN & CLIC collaborators

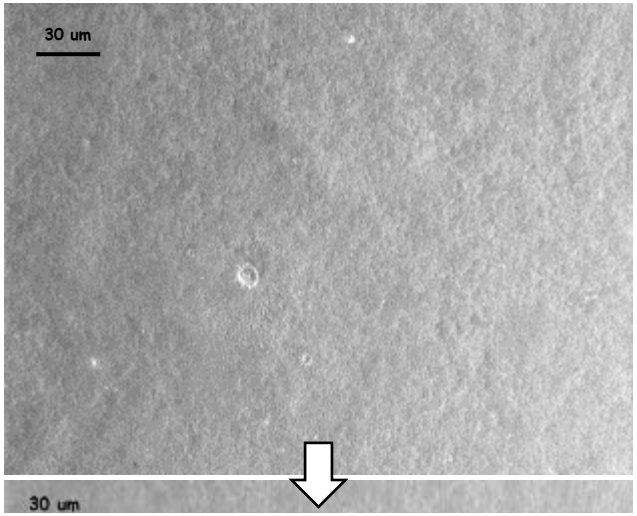


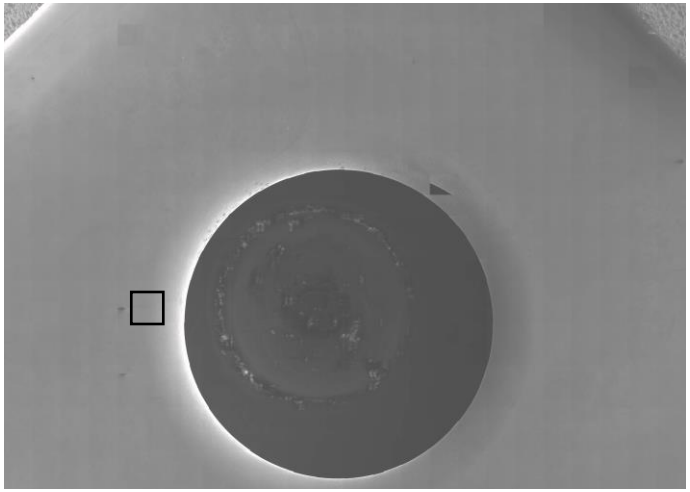
What does a hot cell look like?

US cell #5_Example of the general aspect of the iris region

In previous structures, hot cell implies higher surface degradation, but not in TD24 R05 → Conditioning effect??

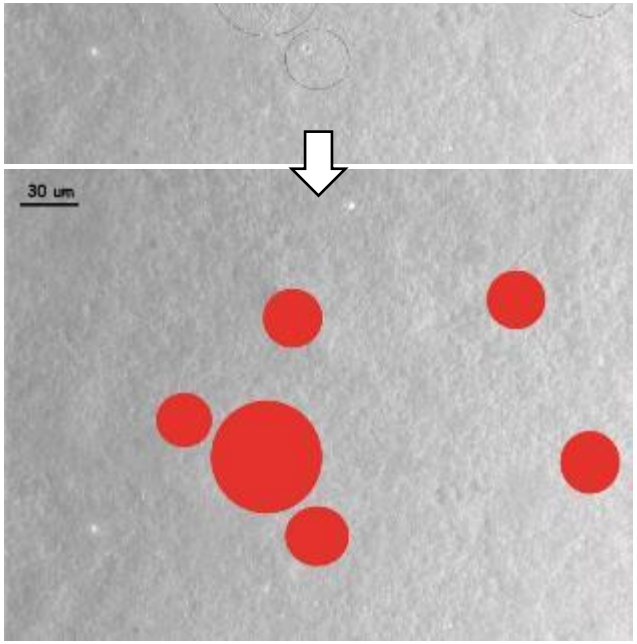


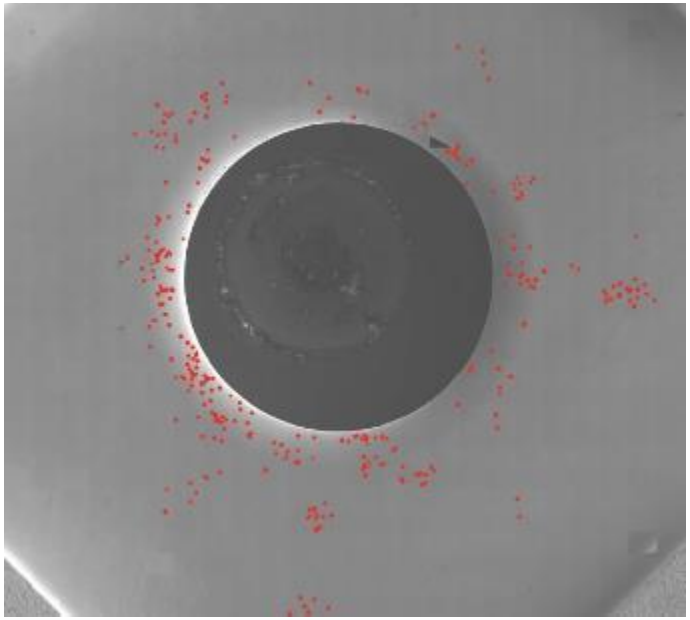


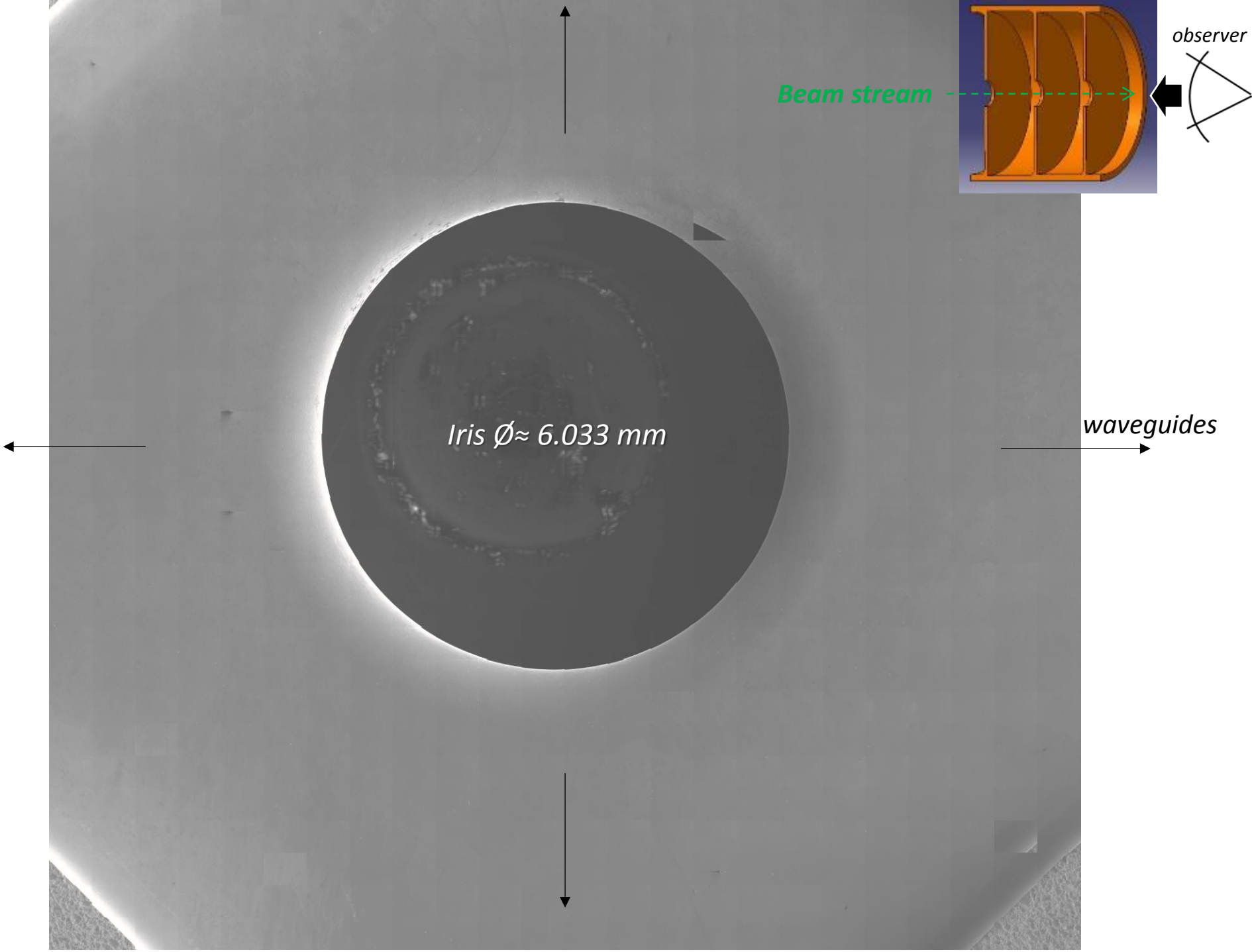


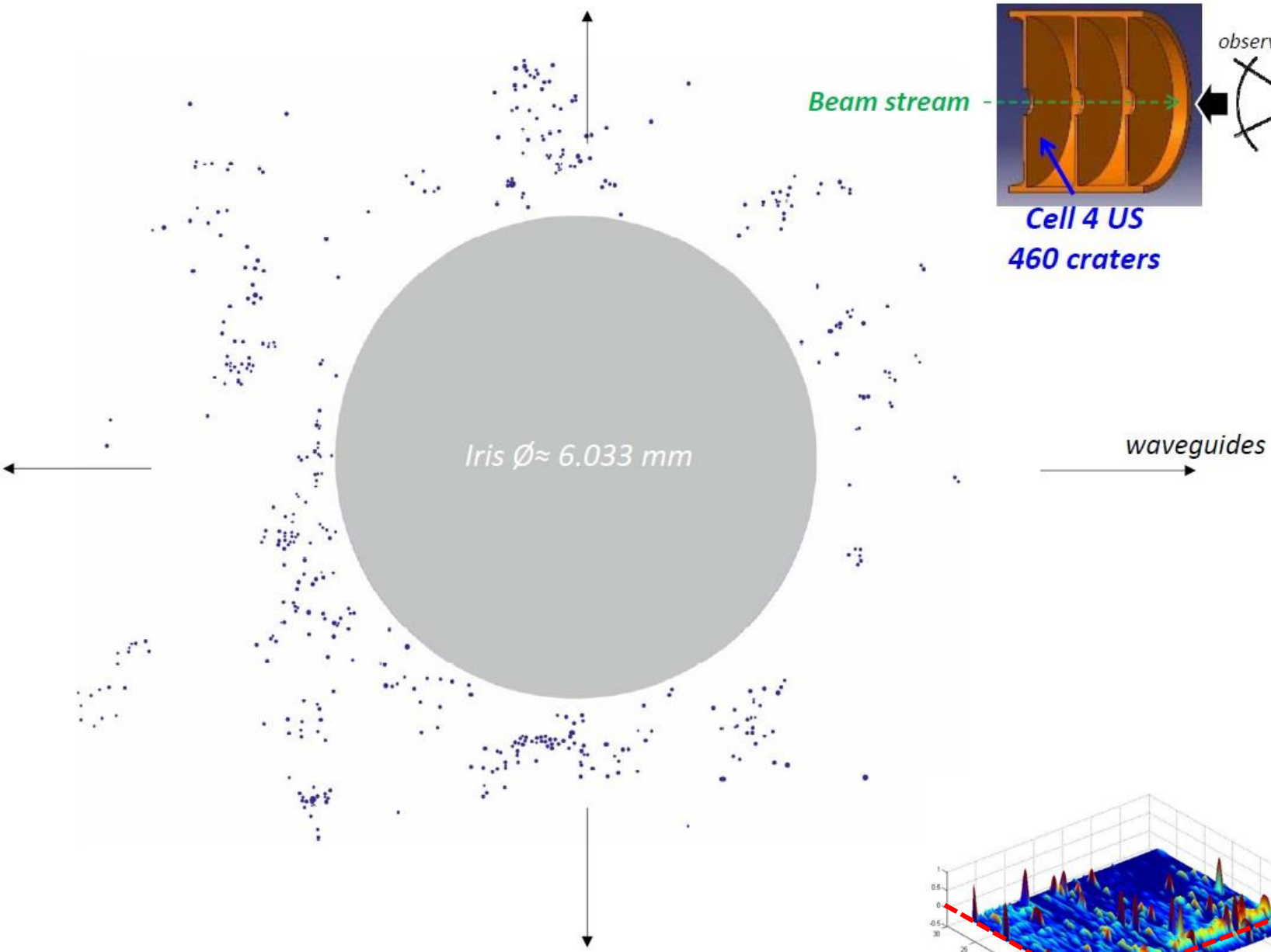
- The marking and counting of craters and affected sites was done manually due to the current absence of an automatic analysis software that can recognize the variable shapes and sizes.

- It’s important to remark that the proximity between craters and their overlapping, can result on a conservative estimation of the total number.

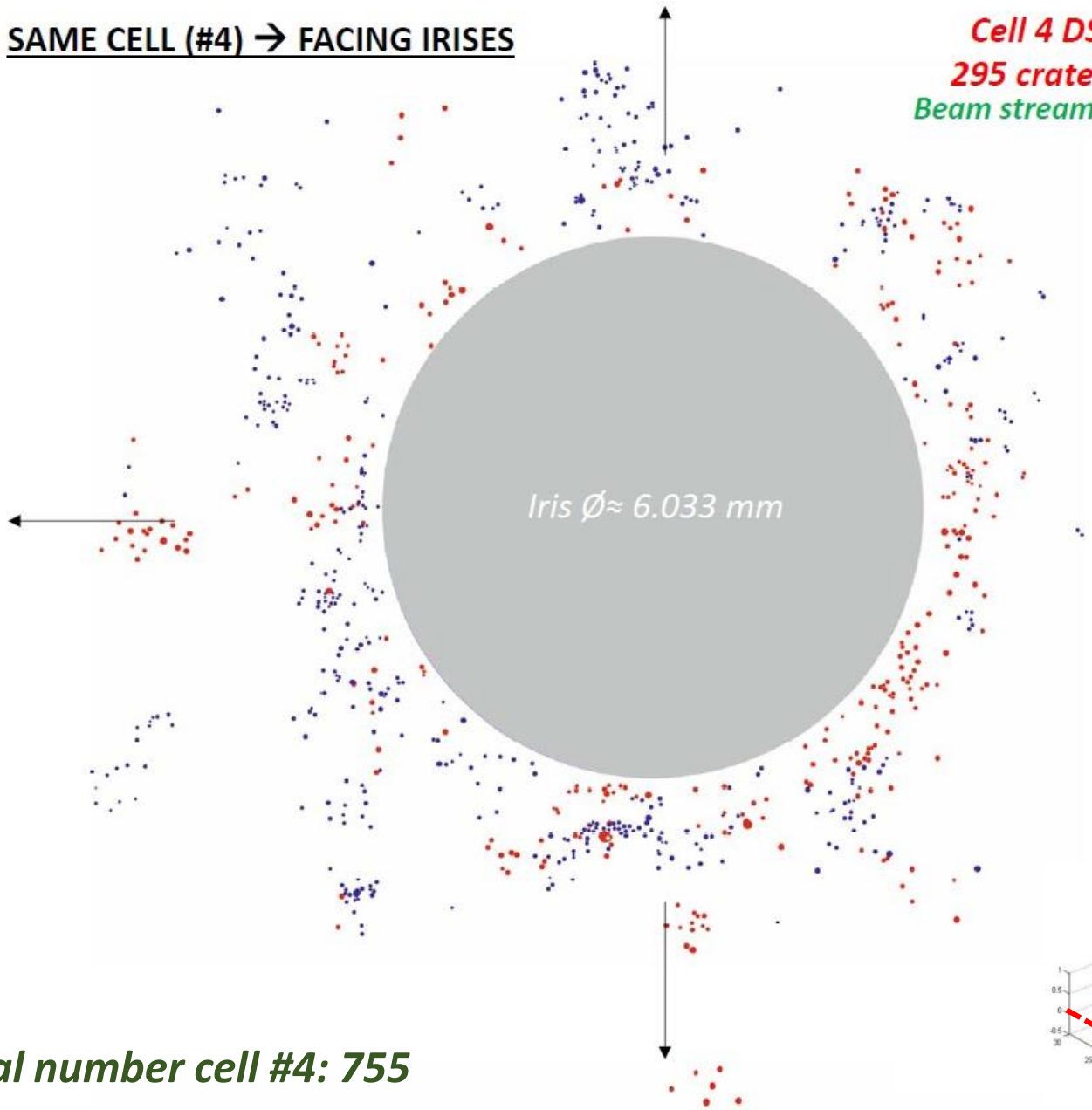


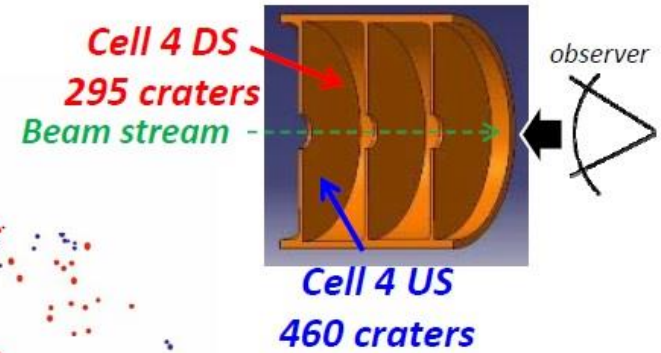


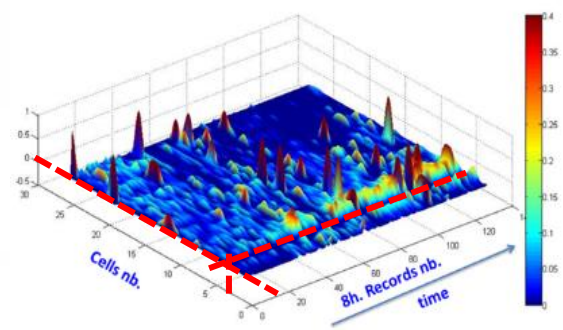

Beam stream
observer
Iris Ø≈ 6.033 mm
waveguides


Beam stream
observer
Cell 4 US
460 craters
Iris Ø≈ 6.033 mm
waveguides
Cells nb.
8h. Records nb.
time

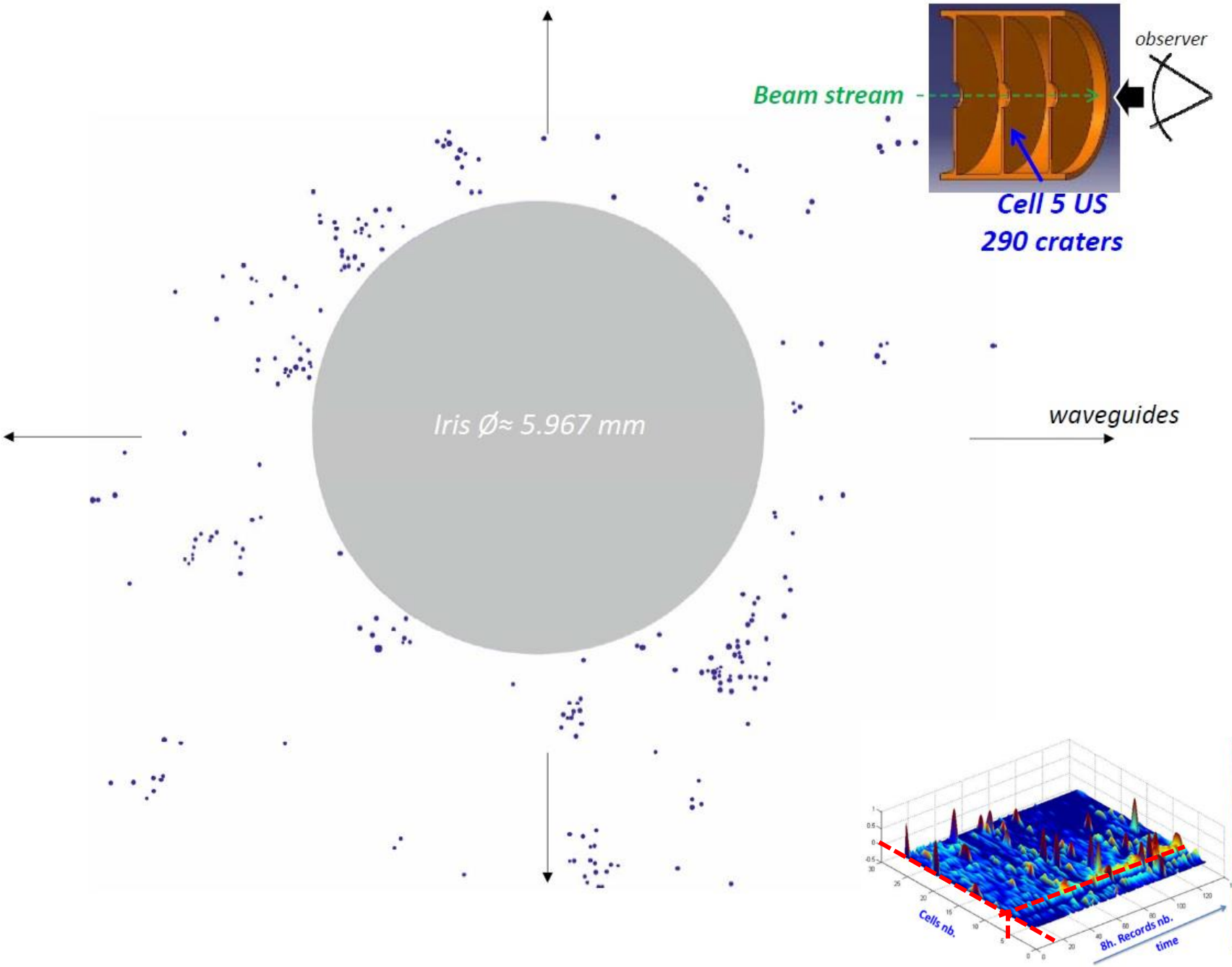
SAME CELL (#4) → FACING IRISES



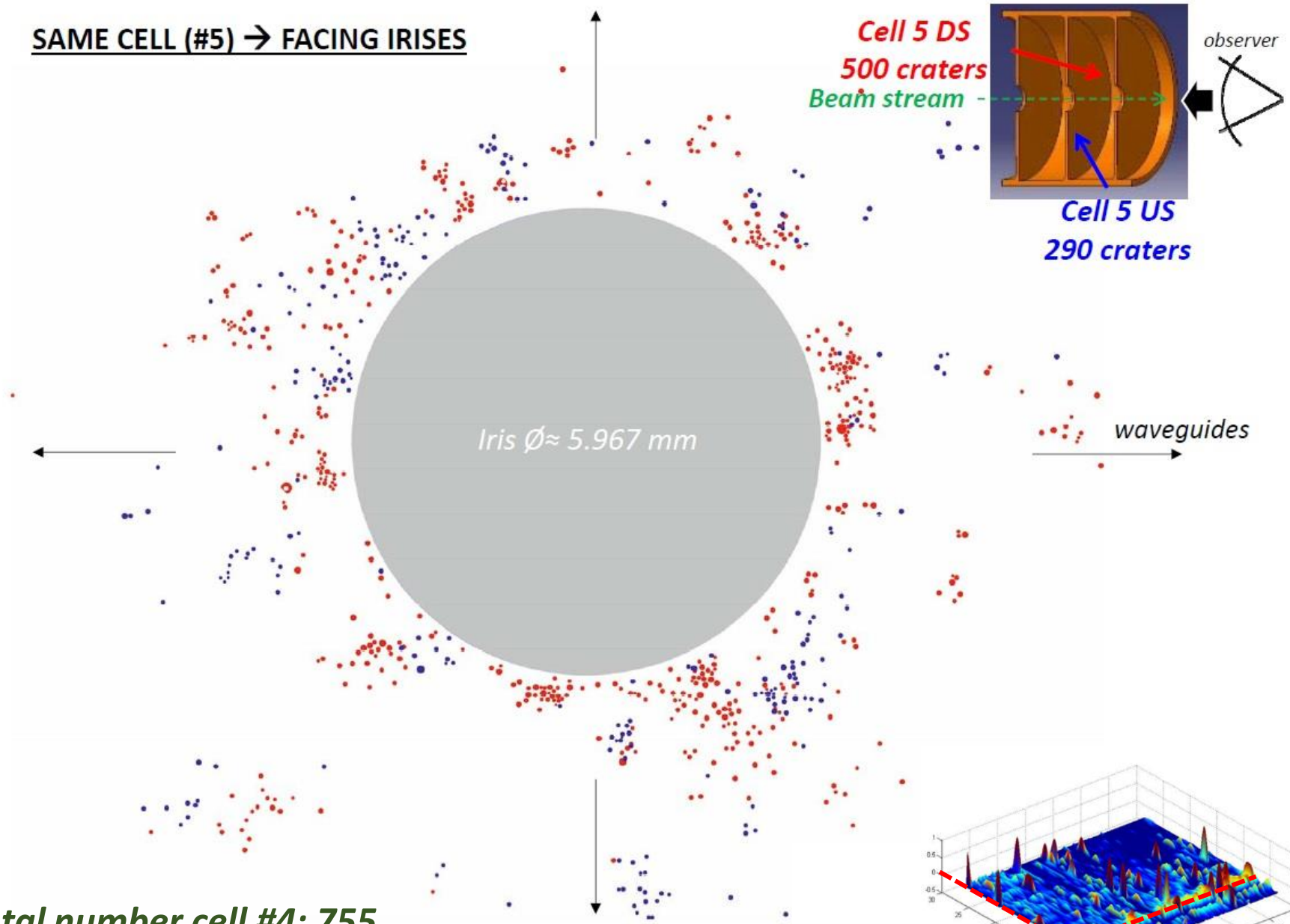


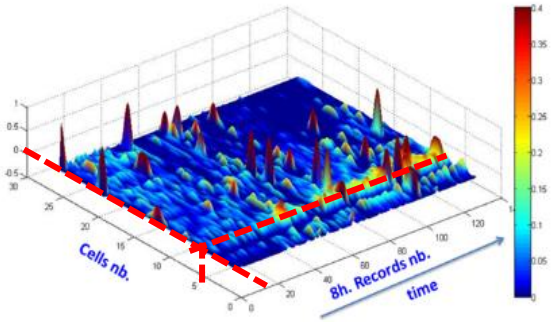


Total number cell #4: 755


observer
Beam stream
Cell 5 US
290 craters
Iris Ø≈ 5.967 mm
waveguides
Cells nb.
8h. Records nb.
time

SAME CELL (#5) → FACING IRISES



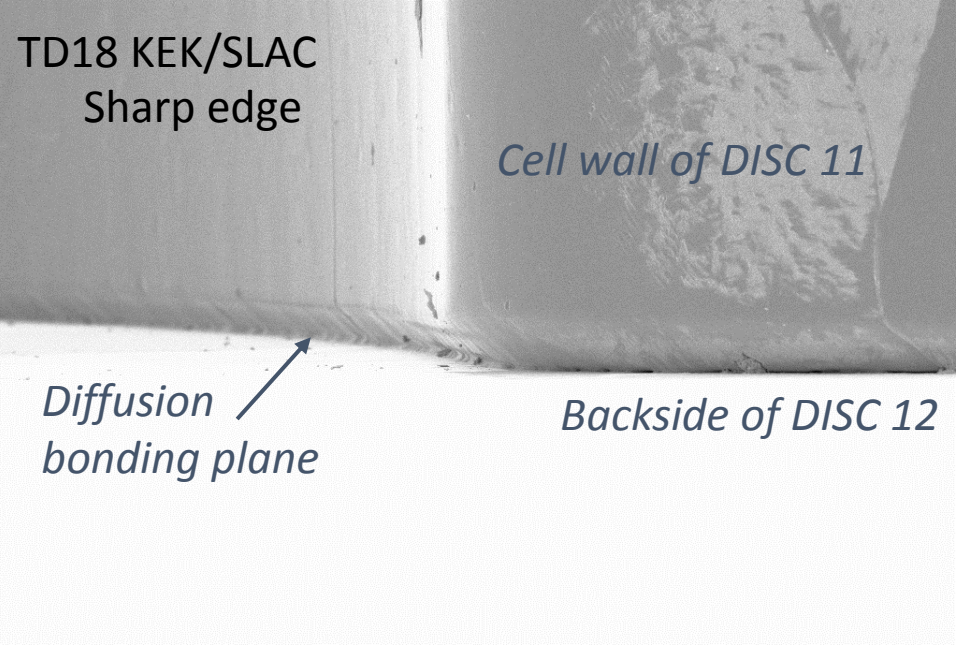


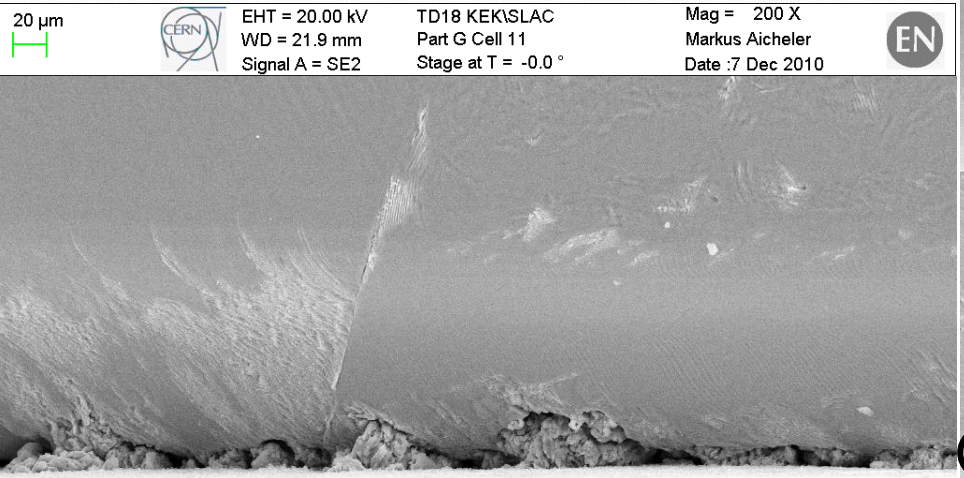
Total number cell #4: 755

Total number cell #5: 790 (Hot cell?)

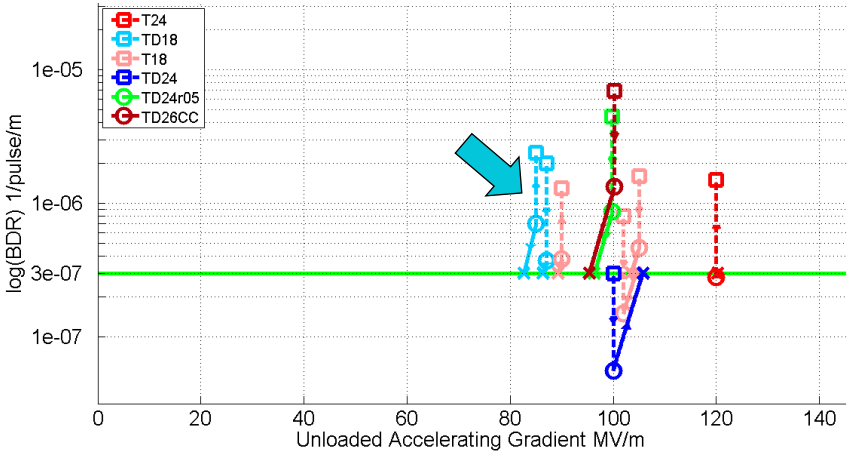
Have we made progress joining disks?

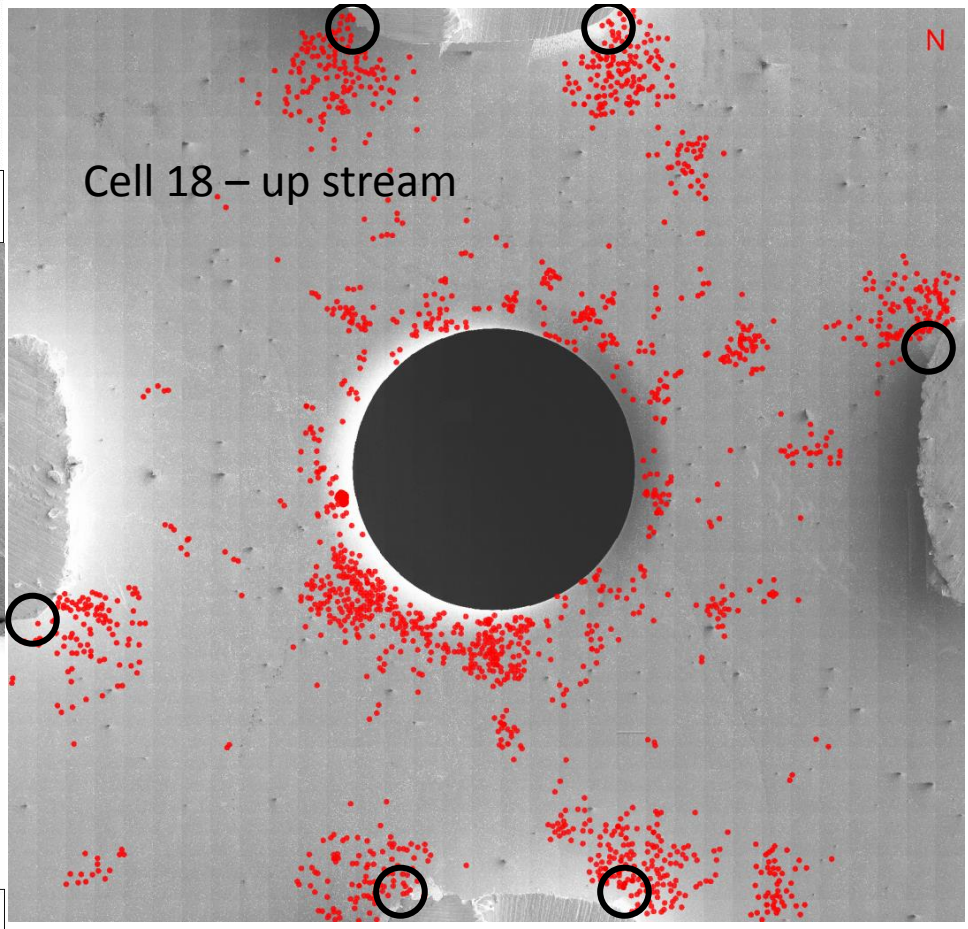
B-field arcs

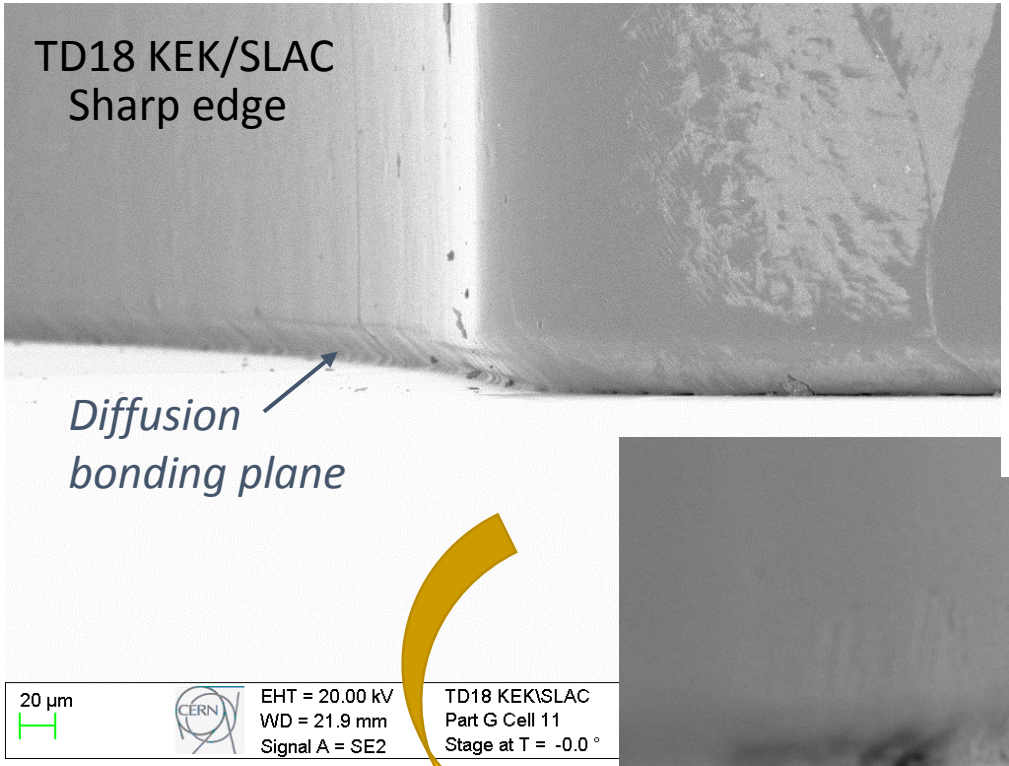

TD18 KEK/SLAC
Sharp edge
Cell wall of DISC 11
Diffusion
bonding plane
Backside of DISC 12

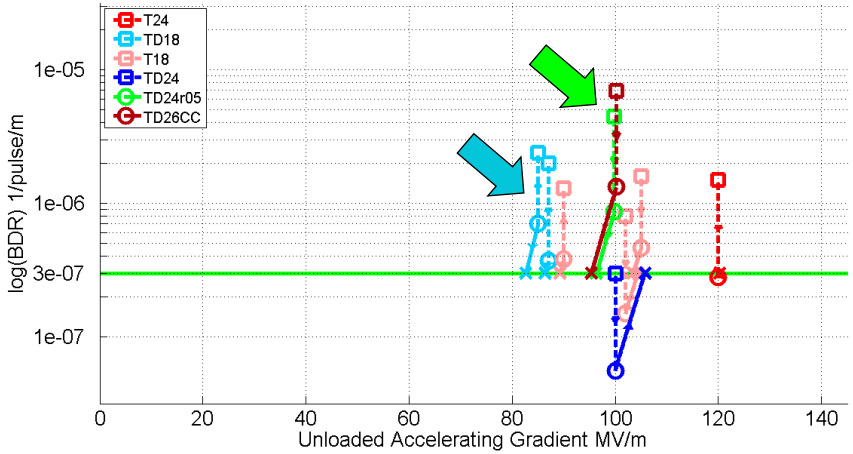

20 µm
EHT = 20.00 kV
WD = 21.9 mm
Signal A = SE2
TD18 KEK\SLAC
Part G Cell 11
Stage at T = -0.0 °
Mag = 200 X
Markus Aicheler
Date :7 Dec 2010
EN

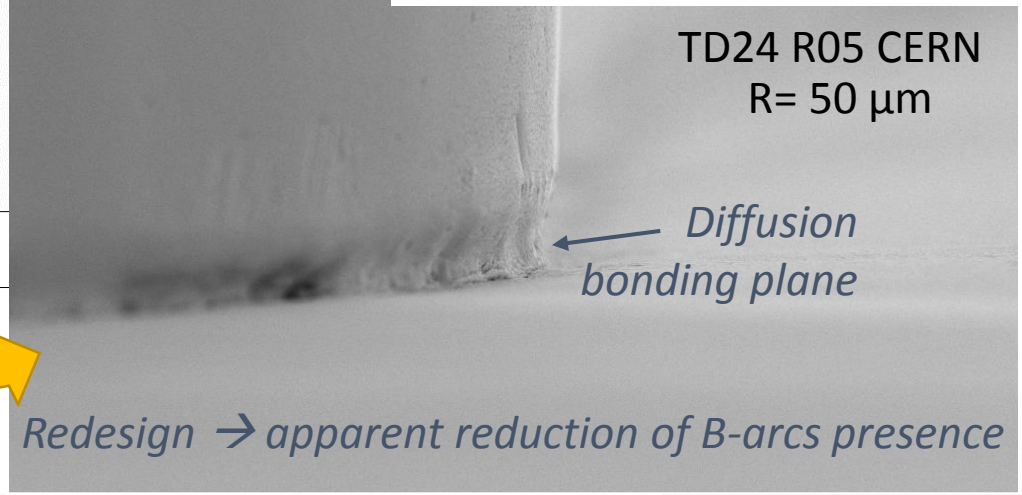
10 µm
EHT = 20.00 kV
WD = 21.5 mm
Signal A = SE2
TD18 KEK\SLAC
Part G Cell 11
Stage at T = -0.0 °
Mag = 1.00 K X
Markus Aicheler
Date :7 Dec 2010
EN

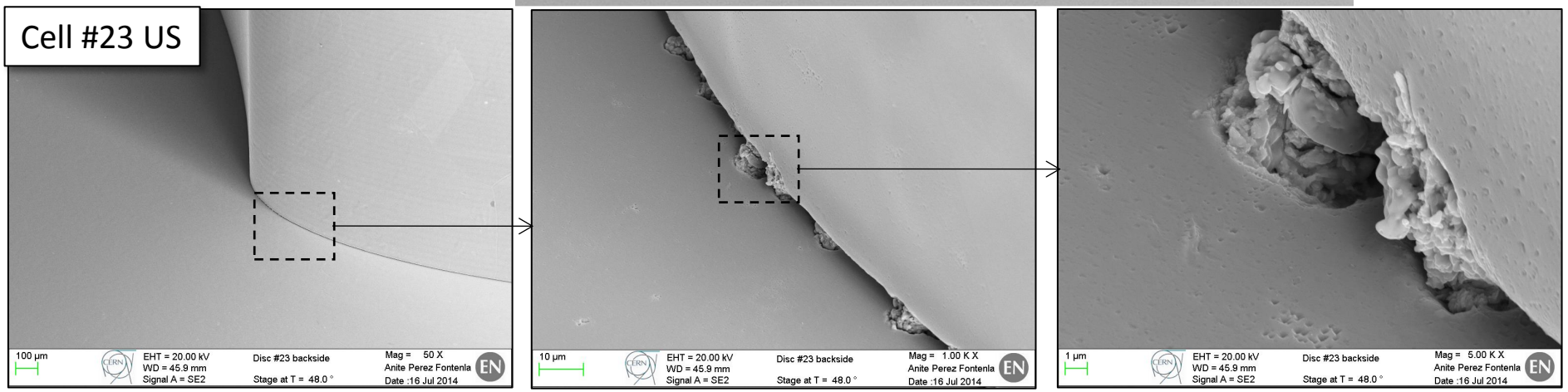

T24
TD18
T18
TD24
TD24r05
TD26CC
log(BDR) 1/pulse/m
1e-05
1e-06
3e-07
1e-07
0
20
40
60
80
100
120
140
Unloaded Accelerating Gradient MV/m


Cell 18 – up stream
N


TD18 KEK/SLAC
Sharp edge
Diffusion
bonding plane
20 µm
EHT = 20.00 kV
WD = 21.9 mm
Signal A = SE2
TD18 KEK\SLAC
Part G Cell 11
Stage at T = -0.0 °


T24
TD18
T18
TD24
TD24r05
TD26CC
log(BDR) 1/pulse/m
1e-05
1e-06
3e-07
1e-07
0
20
40
60
80
100
120
140
Unloaded Accelerating Gradient MV/m

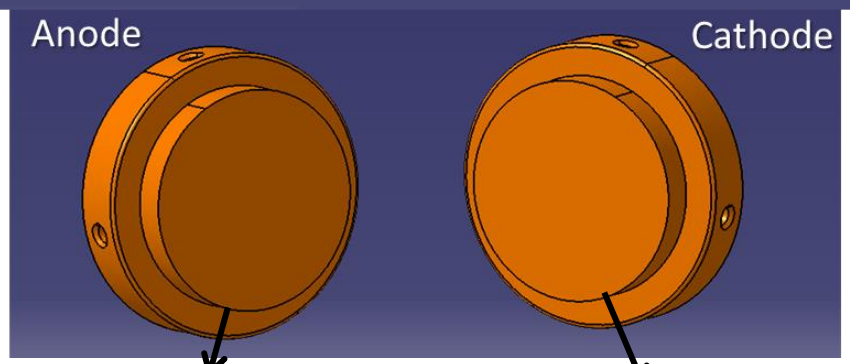

TD24 R05 CERN
R= 50 µm
Diffusion
bonding plane
Redesign → apparent reduction of B-arcs presence

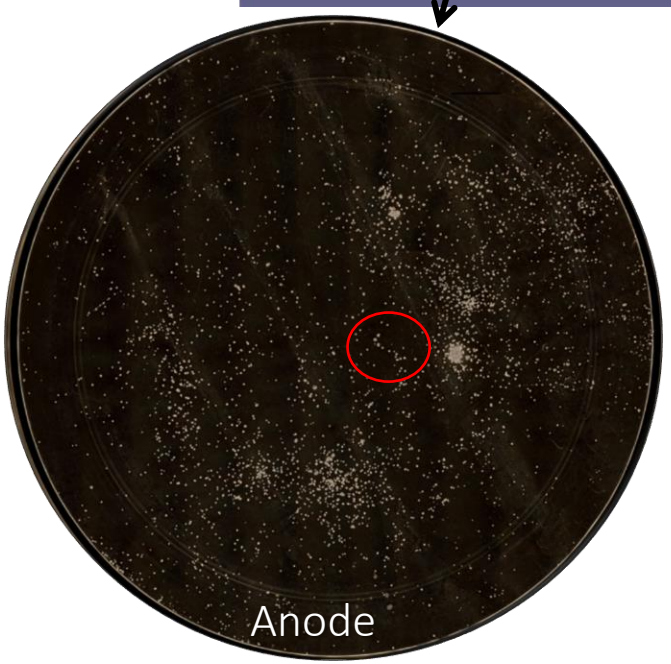

Cell #23 US
100 µm
EHT = 20.00 kV
WD = 45.9 mm
Signal A = SE2
Disc #23 backside
Stage at T = 48.0 °
Mag = 50 X
Anite Perez Fontenla
Date :16 Jul 2014
10 µm
EHT = 20.00 kV
WD = 45.9 mm
Signal A = SE2
Disc #23 backside
Stage at T = 48.0 °
Mag = 1.00 K X
Anite Perez Fontenla
Date :16 Jul 2014
1 µm
EHT = 20.00 kV
WD = 45.9 mm
Signal A = SE2
Disc #23 backside
Stage at T = 48.0 °
Mag = 5.00 K X
Anite Perez Fontenla
Date :16 Jul 2014

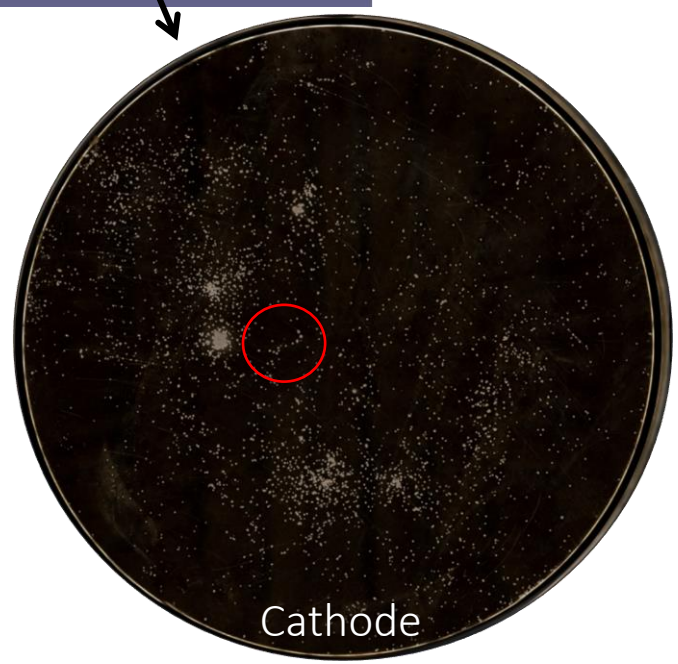
How do DC and RF breakdowns compare?

DC-Spark testing, FGS…

BD's nr and distribution in large electrodes:







Automatic "particle" analysis performed with AxioVision SE64 Zeiss software

Anode BD's nr ≈ **3.400**
Affected area≈ 2.5%

≈

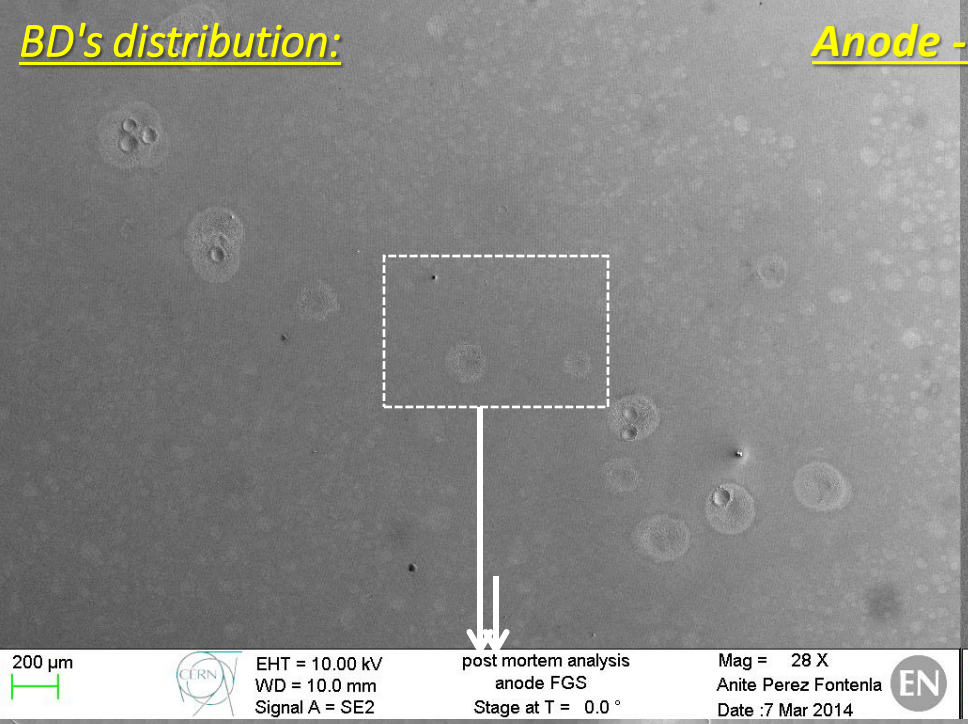
Cathode BD's nr ≈ **3.550**
Affected area≈ 2.7%

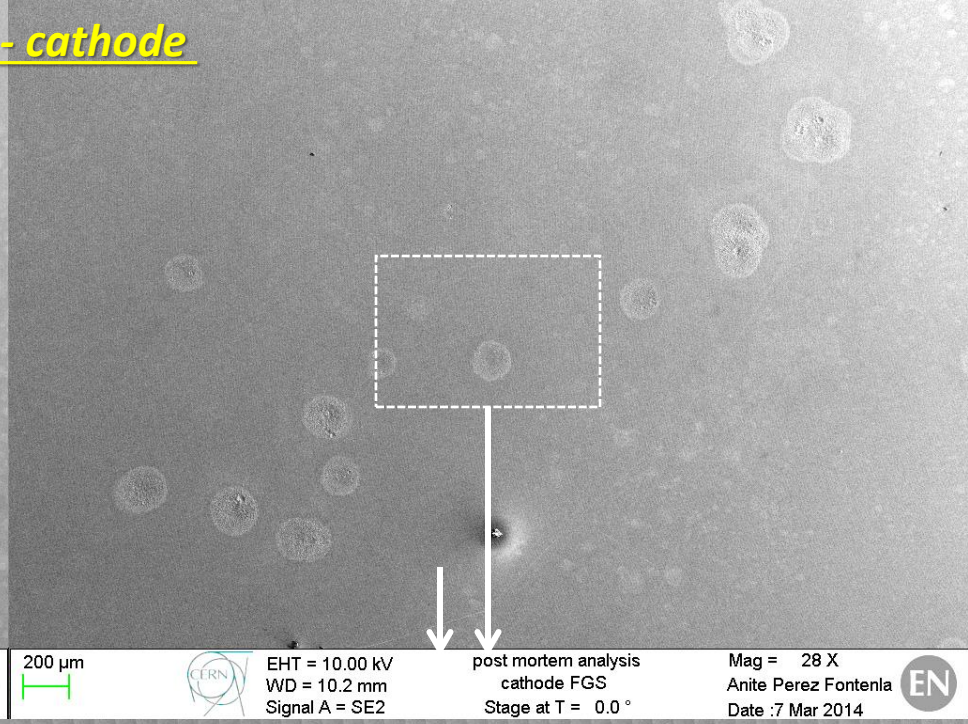
>

Measured nr of BKD during the testing ≈ **2.500**

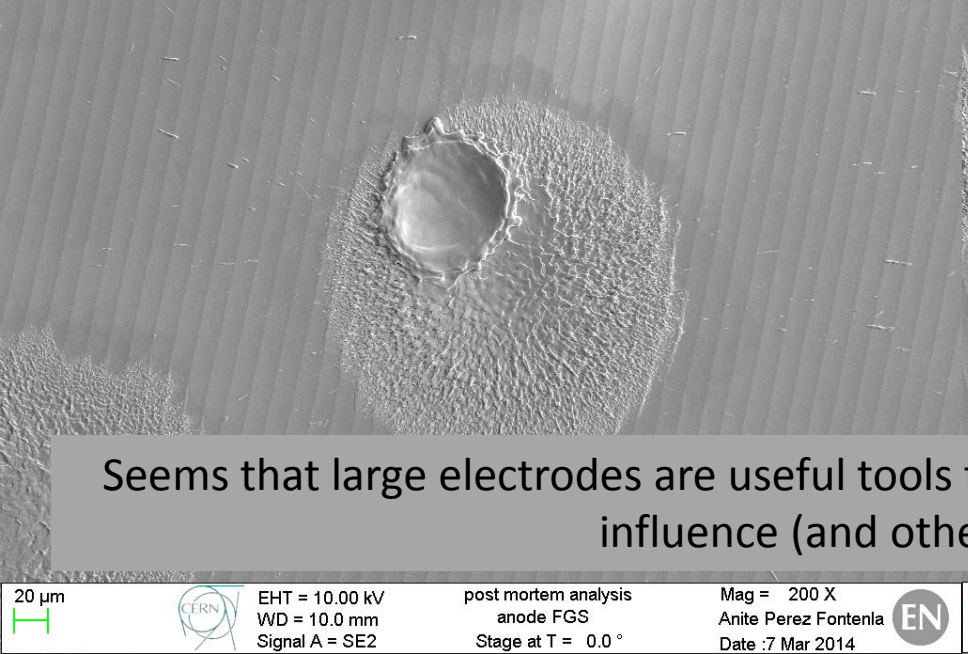
(Data from N. Shipman)

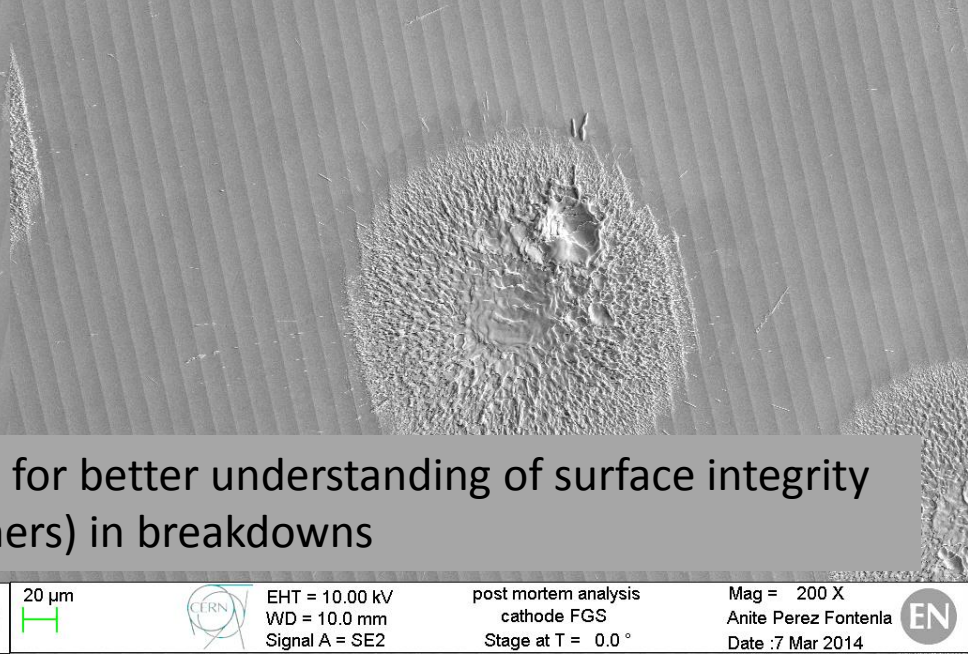
BD's distribution: Anode - cathode



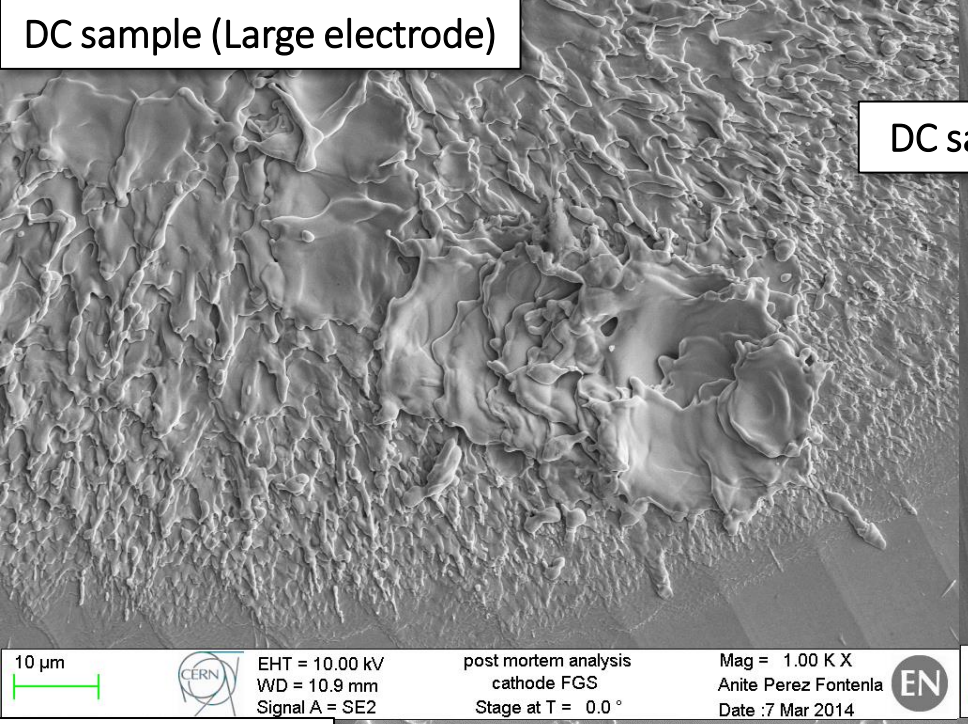


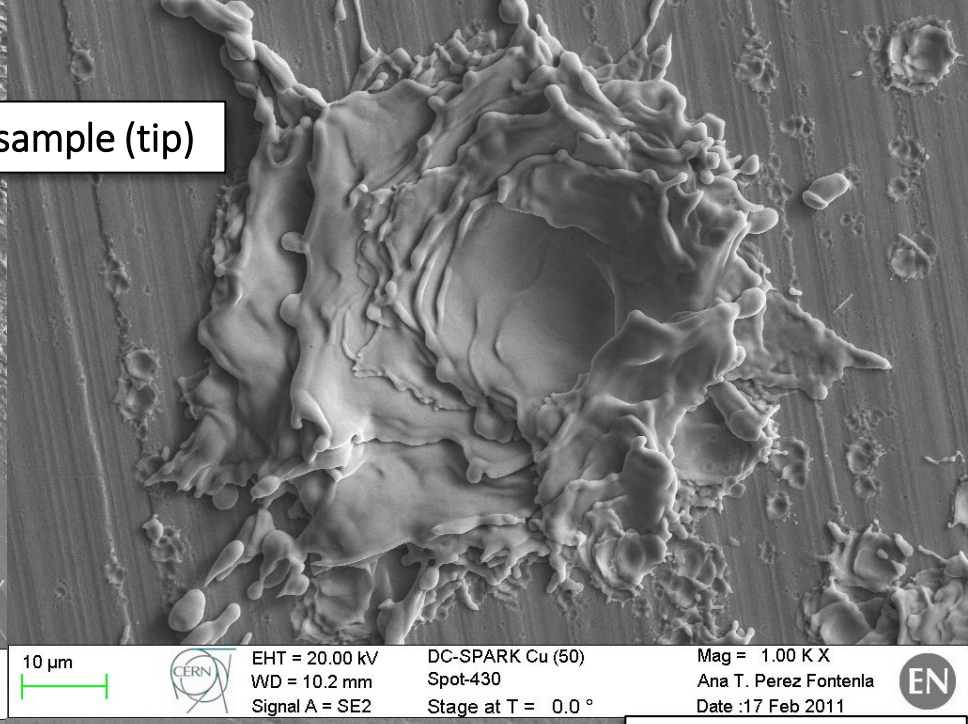
Spots have identical distribution and size in both electrodes (Ø ≈ 200um)

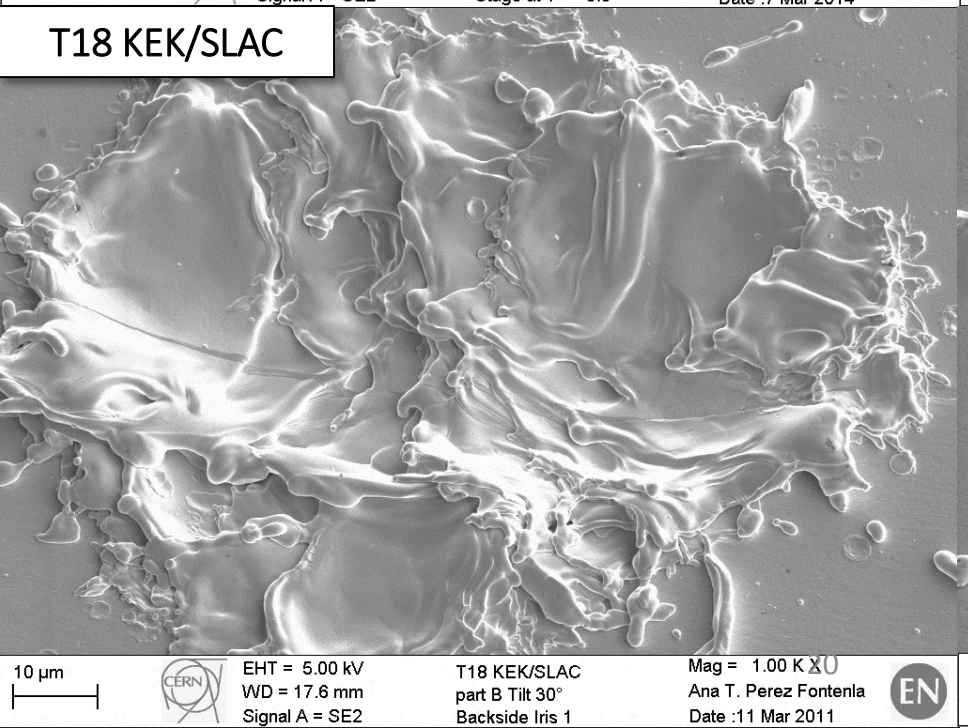


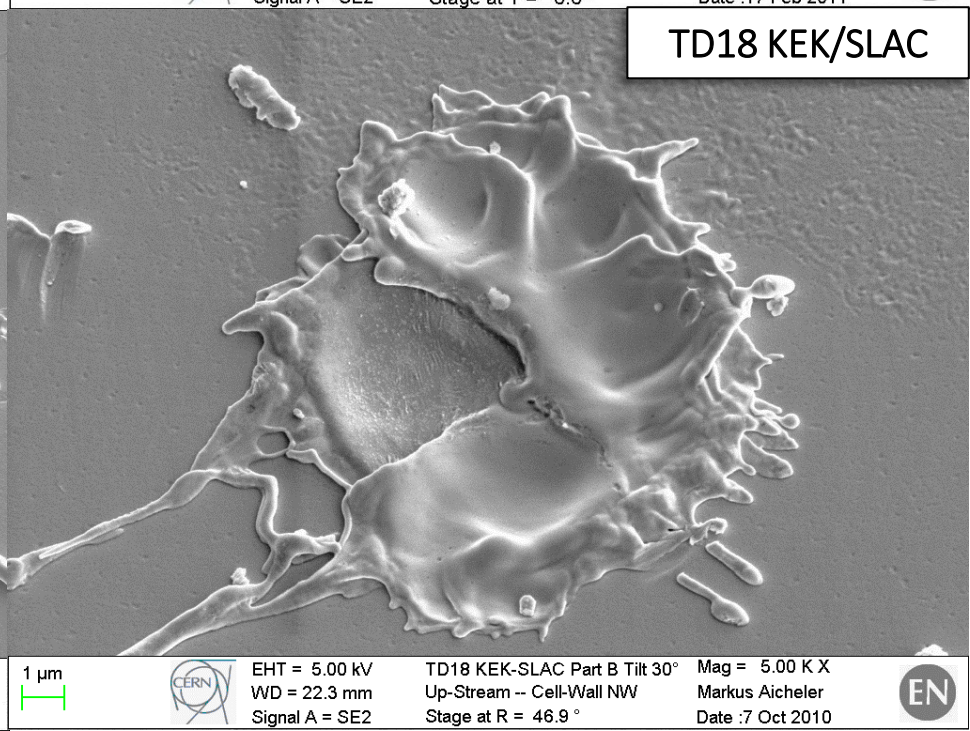


Seems that large electrodes are useful tools for better understanding of surface integrity influence (and others) in breakdowns


DC sample (Large electrode)
10 µm
EHT = 10.00 kV
WD = 10.9 mm
Signal A = SE2
post mortem analysis
cathode FGS
Stage at T = 0.0 °
Mag = 1.00 K X
Anite Perez Fontenla
Date :7 Mar 2014
EN

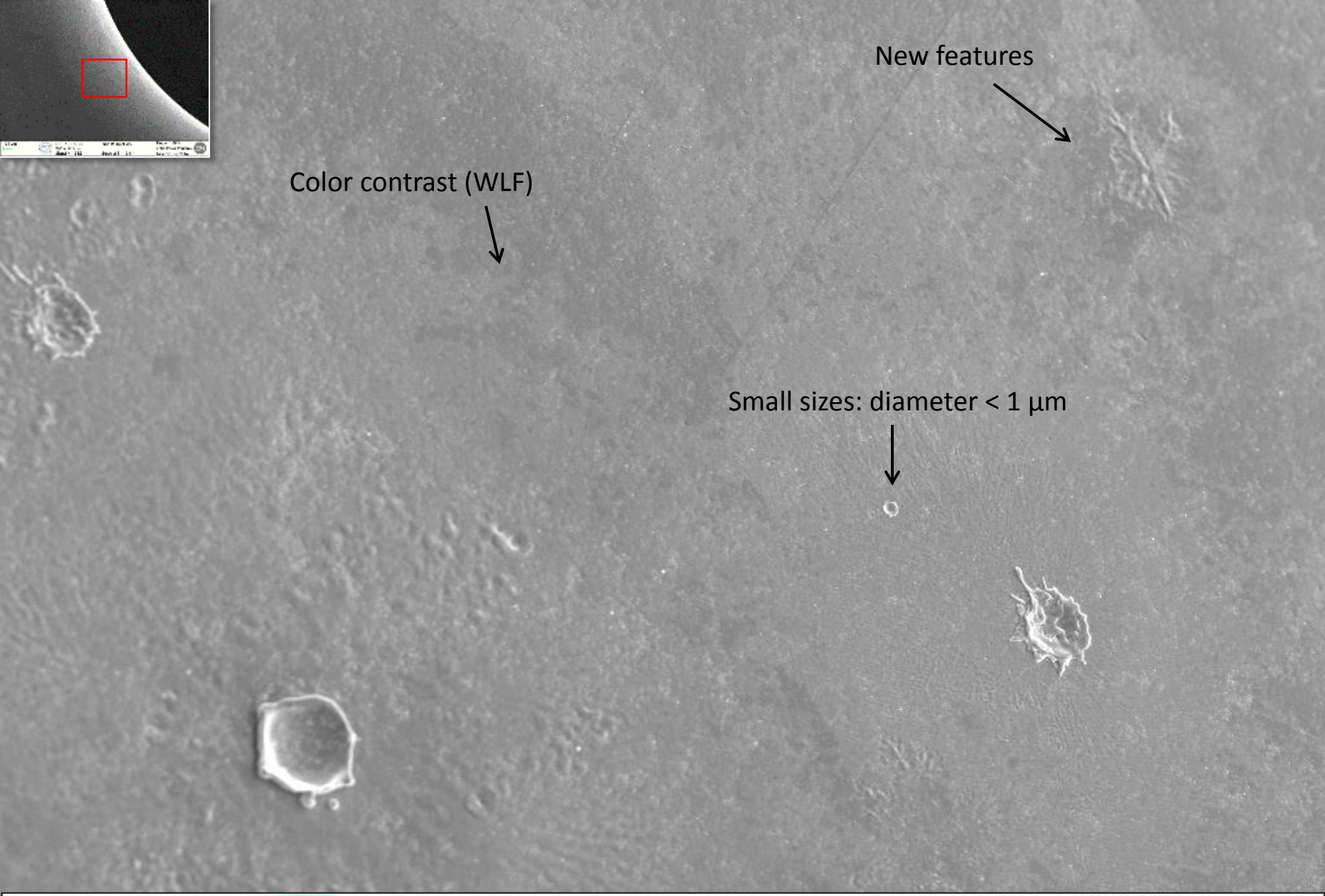

DC sample (tip)
10 µm
EHT = 20.00 kV
WD = 10.2 mm
Signal A = SE2
DC-SPARK Cu (50)
Spot-430
Stage at T = 0.0 °
Mag = 1.00 K X
Ana T. Perez Fontenla
Date :17 Feb 2011
EN


T18 KEK/SLAC
10 µm
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
EN

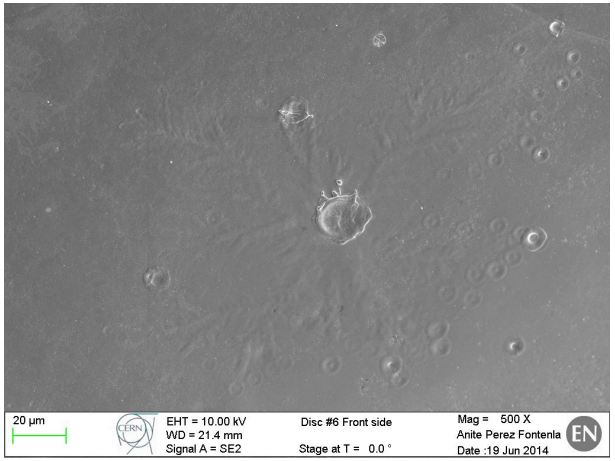

TD18 KEK/SLAC
1 µm
EHT = 5.00 kV
WD = 22.3 mm
Signal A = SE2
TD18 KEK-SLAC Part B Tilt 30°
Up-Stream -- Cell-Wall NW
Stage at R = 46.9 °
Mag = 5.00 K X
Markus Aicheler
Date :7 Oct 2010
EN

Catalogue of features related with BD activity

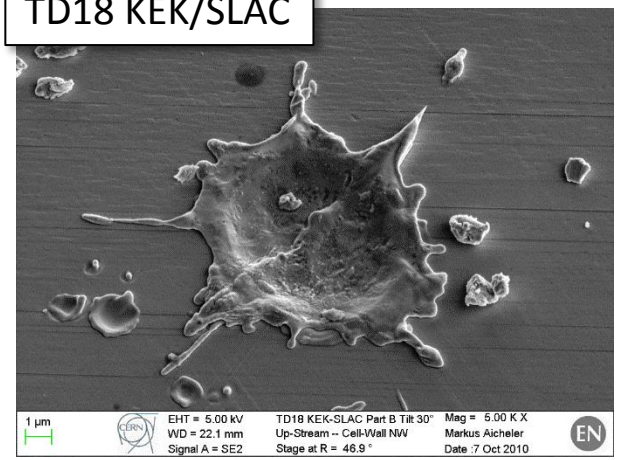
Craters, WLF…


New features
Color contrast (WLF)
Small sizes: diameter < 1 µm
10 µm
EHT = 10.00 kV
WD = 17.5 mm
Signal A = SE2
Disc #5 front side
Stage at T = 0.5 °
Mag = 1.00 K X
Anite Perez Fontenla
Date :18 Jun 2014
CERN
EN

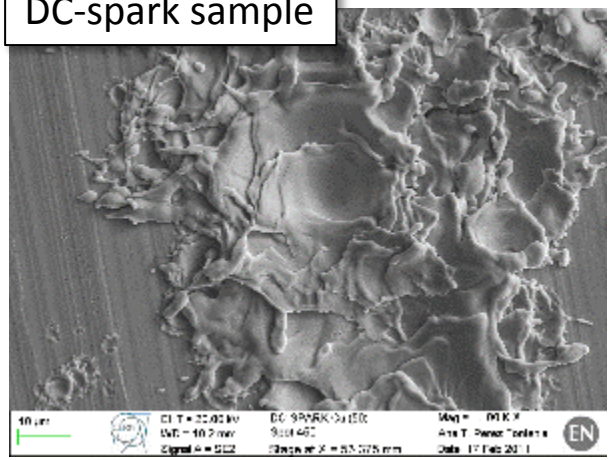
Prelude of craters or a form of very soft breakdown?



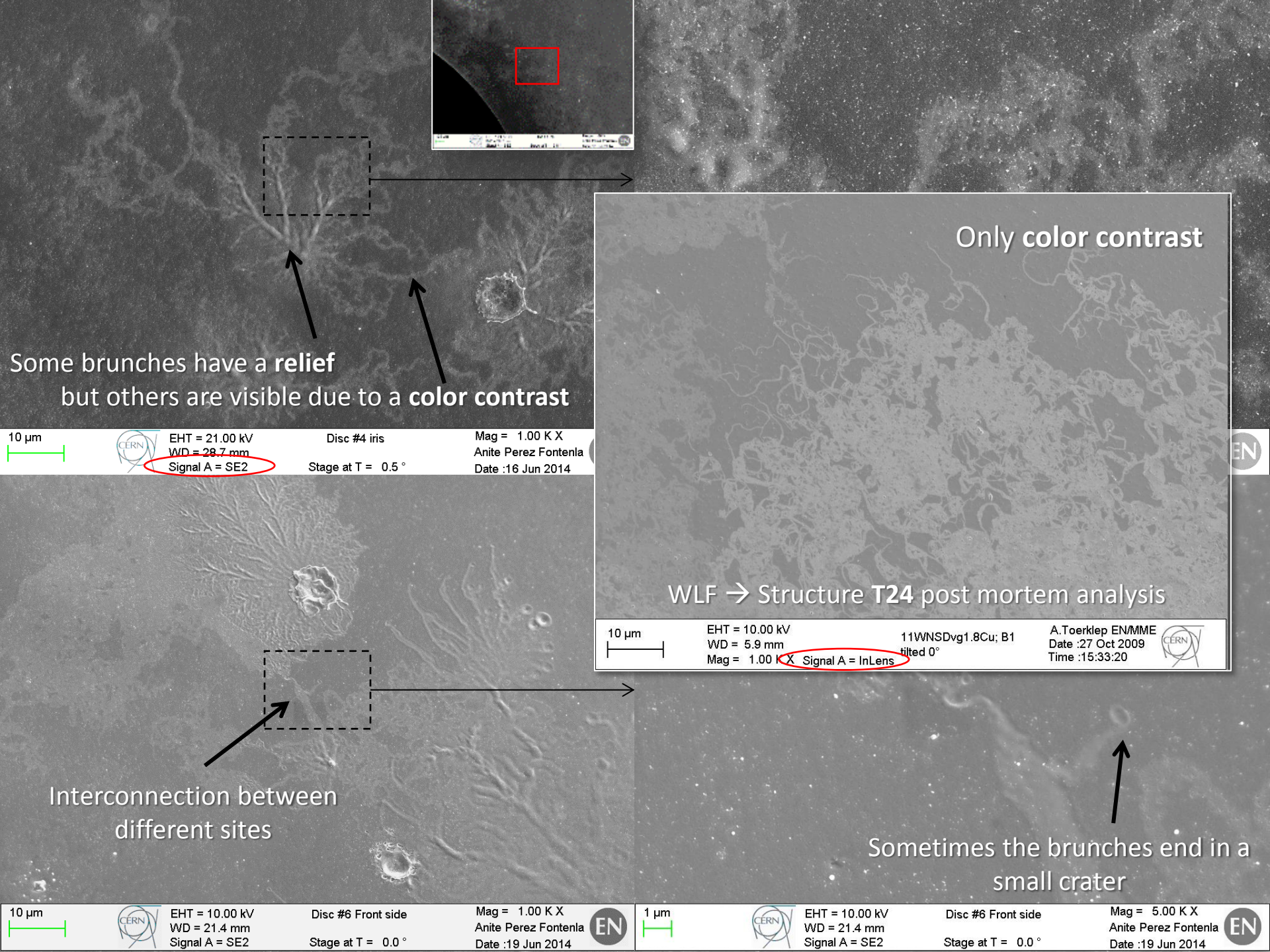
TD18 KEK/SLAC



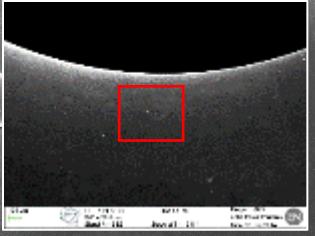
DC-spark sample



“Satellites”: Already observed in AS post-mortem analysis or DC-Spark tested samples

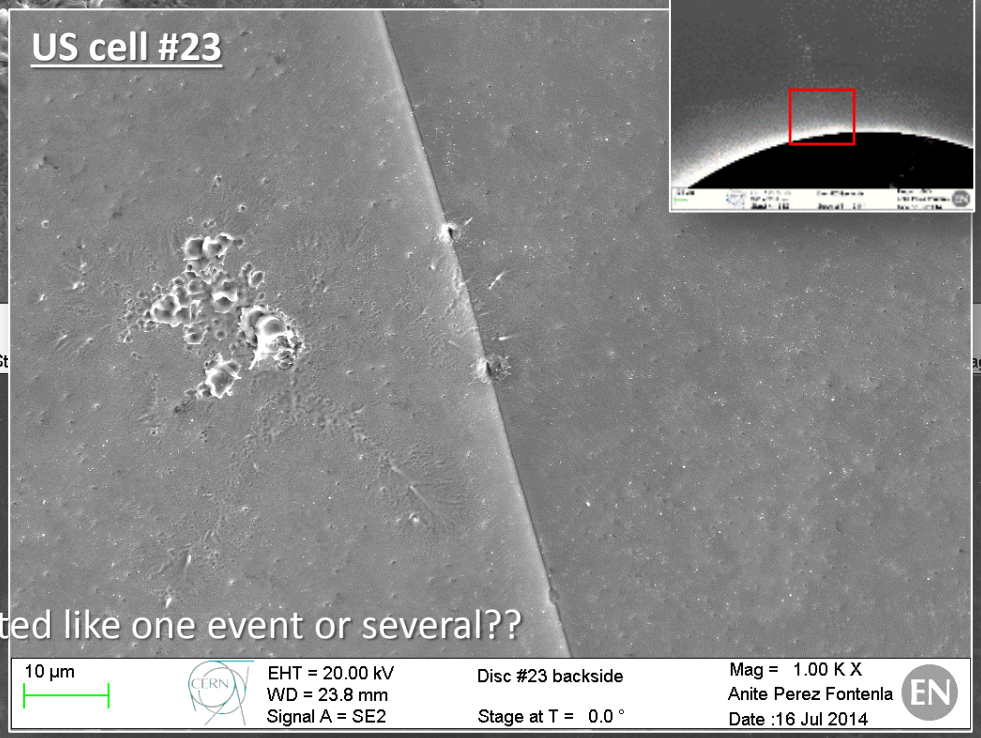

Some brunches have a **relief**
but others are visible due to a **color contrast**
10 µm
EHT = 21.00 kV
WD = 28.7 mm
Signal A = SE2
Disc #4 iris
Stage at T = 0.5 °
Mag = 1.00 K X
Anite Perez Fontenla
Date :16 Jun 2014
Only **color contrast**
WLF → Structure **T24** post mortem analysis
10 µm
EHT = 10.00 kV
WD = 5.9 mm
Mag = 1.00 K X
Signal A = InLens
11WNSDvg1.8Cu; B1
tilted 0°
A.Toerklep EN/MME
Date :27 Oct 2009
Time :15:33:20
Interconnection between different sites
Sometimes the brunches end in a small crater
10 µm
EHT = 10.00 kV
WD = 21.4 mm
Signal A = SE2
Disc #6 Front side
Stage at T = 0.0 °
Mag = 1.00 K X
Anite Perez Fontenla
Date :19 Jun 2014
1 µm
EHT = 10.00 kV
WD = 21.4 mm
Signal A = SE2
Disc #6 Front side
Stage at T = 0.0 °
Mag = 5.00 K X
Anite Perez Fontenla
Date :19 Jun 2014

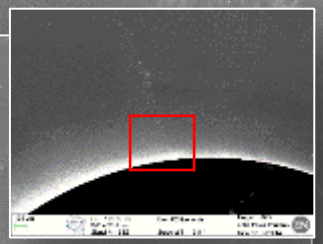
Different features in the same iris (DS cell #3)



Craters in clusters

Isolated crater





Counted like one event or several??

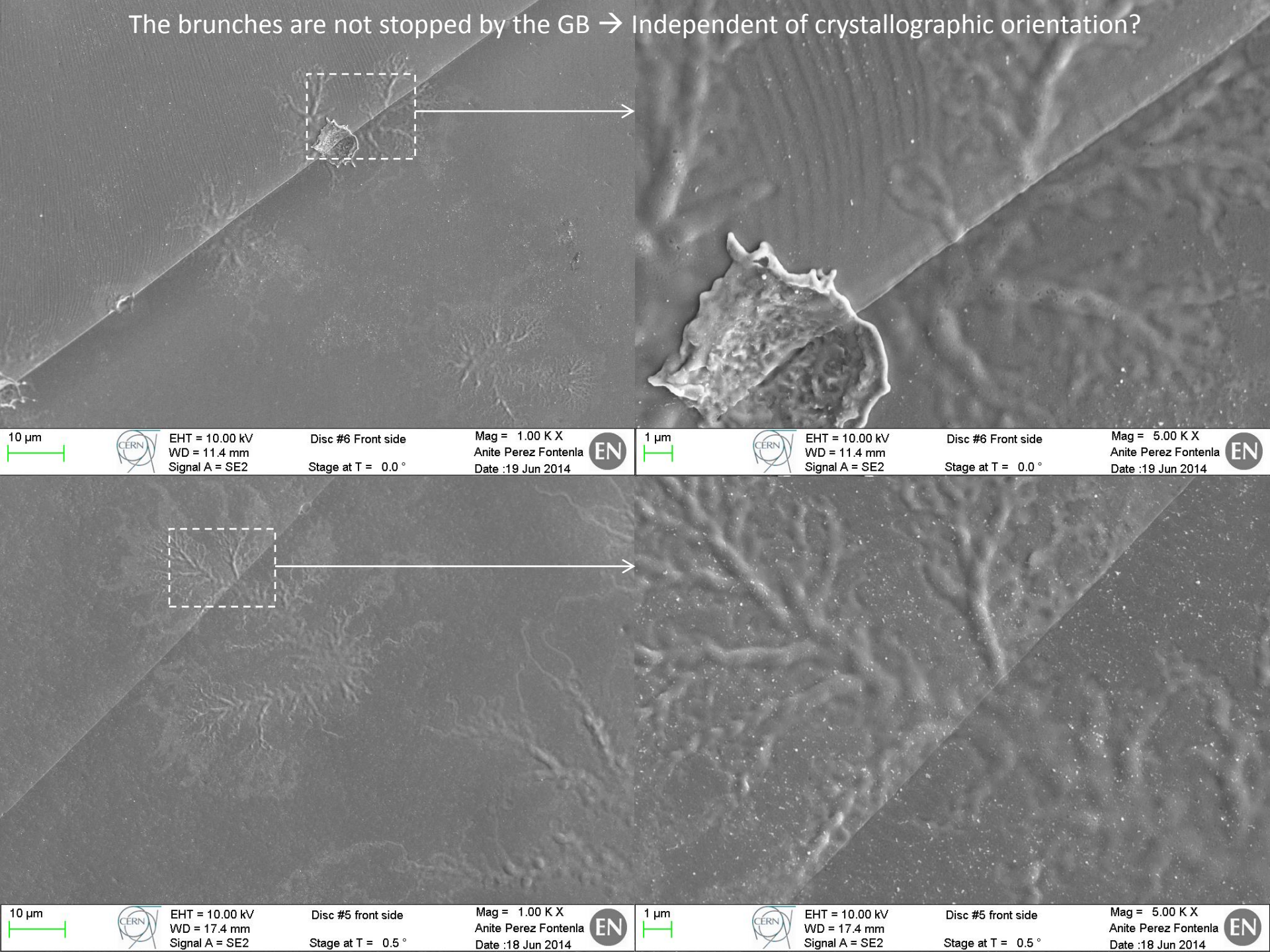
10 µm | EHT = 21.00 kV | WD = 28.8 mm | Signal A = SE2 | Disc #4 iris | Stage at T = 0.5 ° | Mag = 1.00 K X | Anite Perez Fontenla | Date :16 Jun 2014

Sites without central crater → What's the chronology??

10 µm | EHT = 21.00 kV | WD = 28.7 mm | Signal A = SE2 | Disc #4 iris | Stage at T = 0.5 ° | Mag = 1.00 K X | Anite Perez Fontenla | Date :16 Jun 2014

20 µm | EHT = 21.00 kV | WD = 28.7 mm | Signal A = SE2 | Disc #4 iris | Stage at T = 0.5 ° | Mag = 510 X | Anite Perez Fontenla | Date :16 Jun 2014

The brunches are not stopped by the GB → Independent of crystallographic orientation?



Summary:

- ✓ The post-mortem study allows us to compare post mortem features with features observed before operation.
- ✓ In the specific case of the structure TD24 R05:
  - ✓ The **hot cell** presented **same surface damage** as surrounding cells;
  - ✓ **Changes in design** resulted in a **better join** and lower presence of B-field arcs (at least in studied cells) → Important progress
  - ✓ SEM observation confirmed the presence of a **great variety of BD morphologies** consistent with features **observed previously in DC samples**;
  - ✓ New observed features: **Changes in the conditioning process** could be the origin of this **form of very soft breakdown**

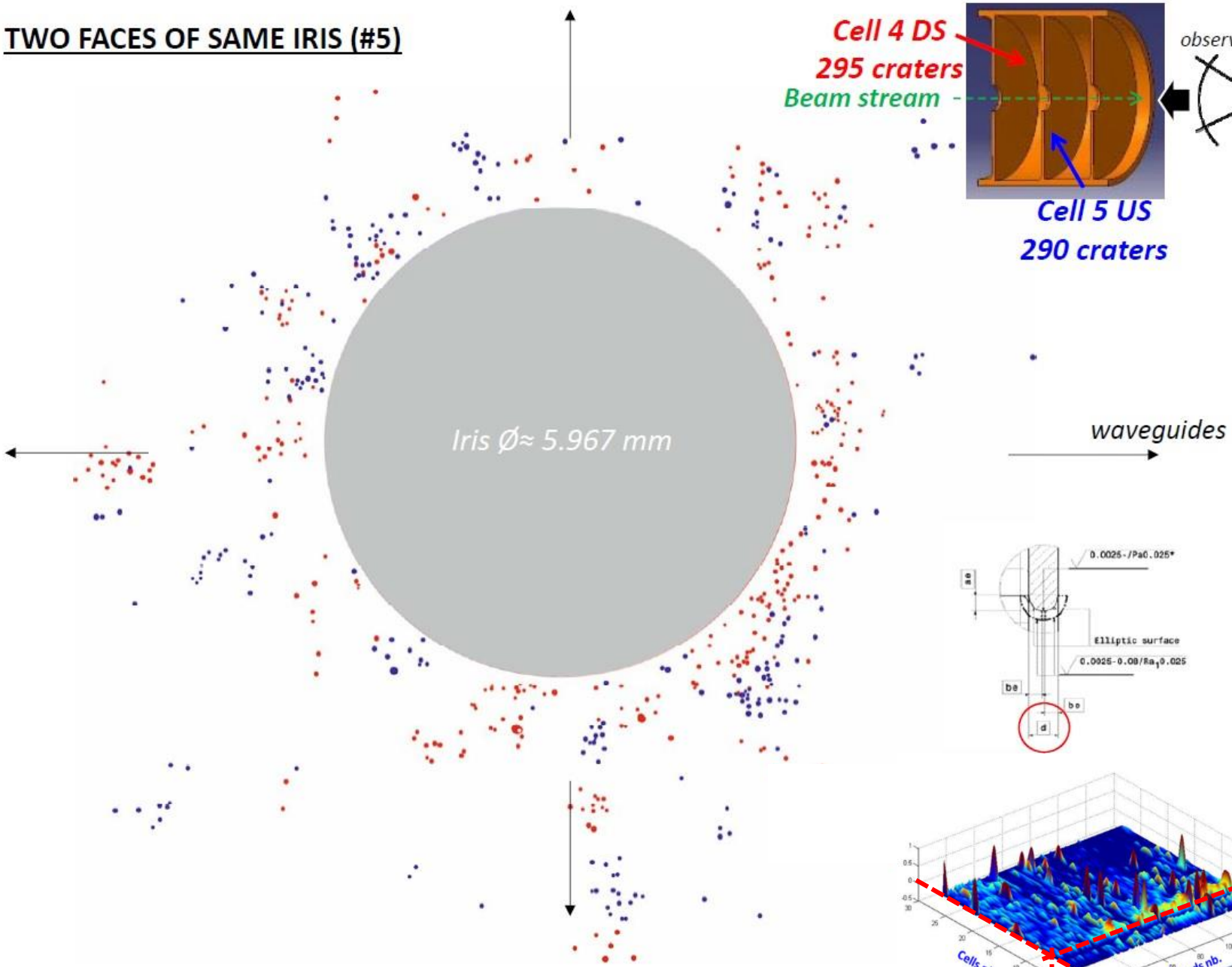
Thank you for your attention.

Questions?

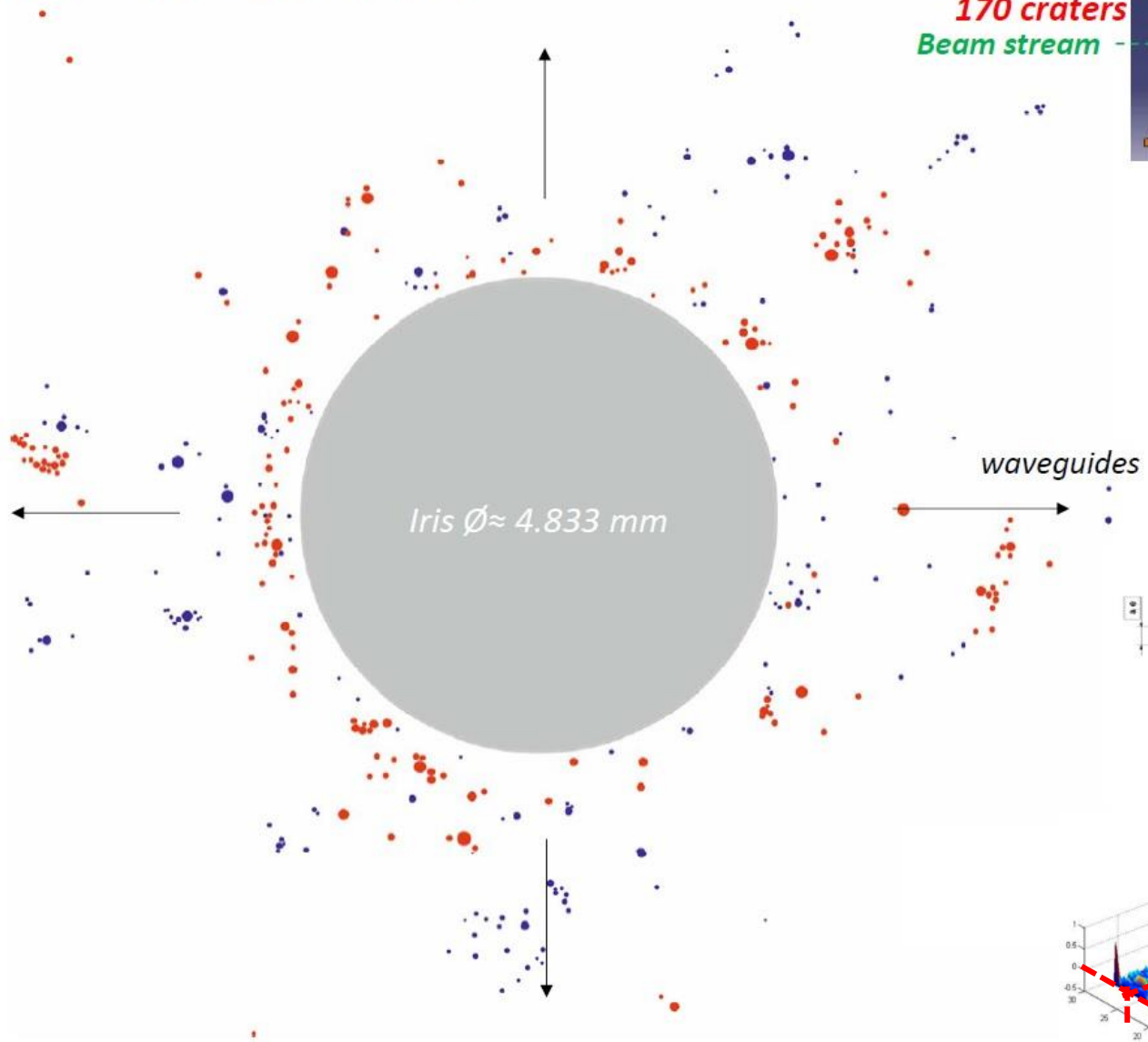
CERN | 60 YEARS/ANS CERN | EN ENGINEERING DEPARTMENT

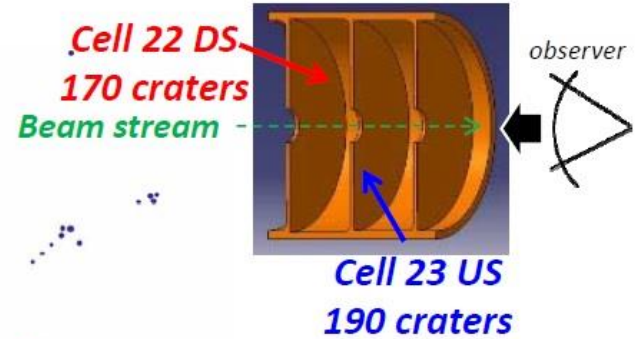
Backup

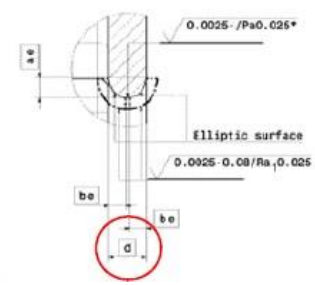
TWO FACES OF SAME IRIS (#5)

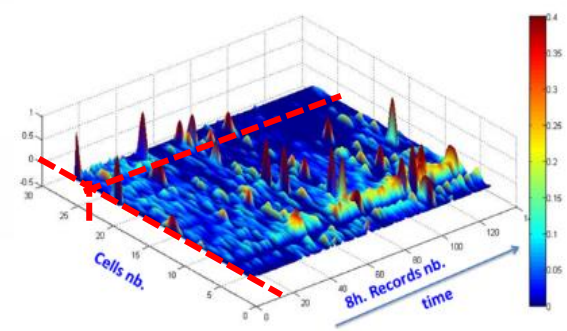


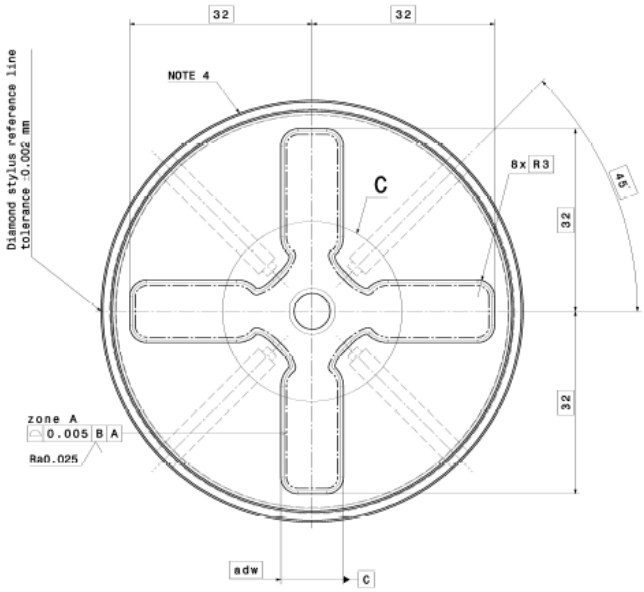
TWO FACES OF SAME IRIS (#23)

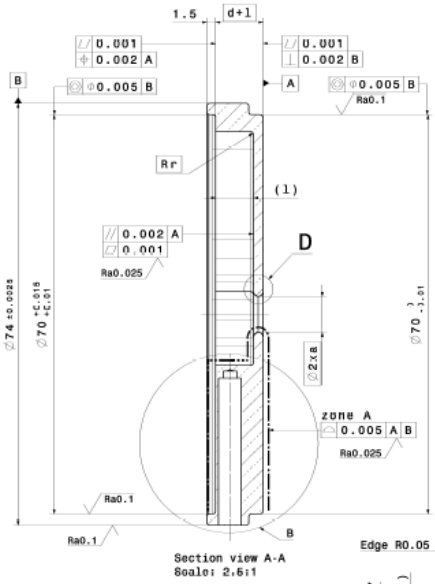




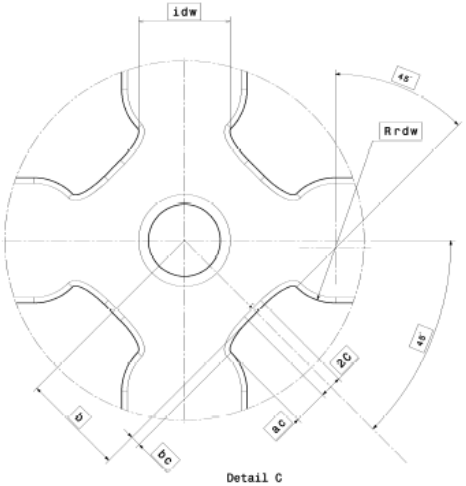




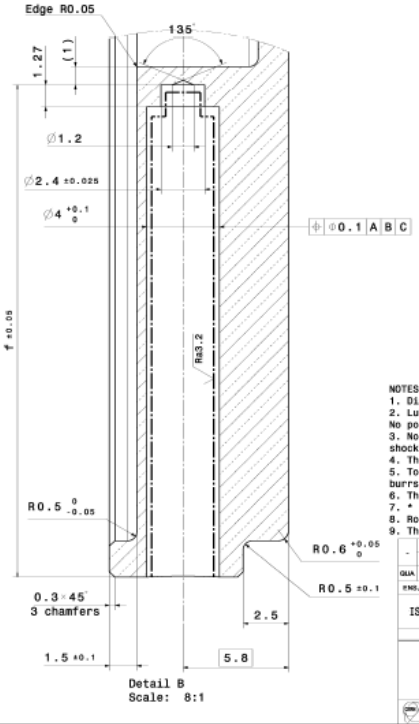




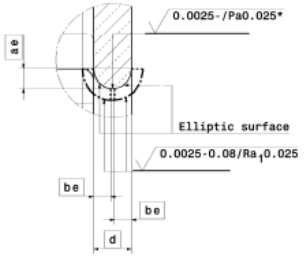
Section view A-A
Scale: 2.5:1



Detail C
Scale: 5:1



Detail B
Scale: 8:1



Detail D
Scale: 10:1

N	Cell	a (mm)	d (mm)	b (mm)	c (mm)	l (mm)	eow	be (mm)	ae (mm)	adw (mm)	idw (mm)	r (mm)	bc (mm)	ac (mm)	rdw (mm)	f (mm)
1	MATCH CELL A	3.15	1.67	8.9417	1	6.662	3.4	0.7515	0.877020583	11	8	0.5	0.898128004	3.053635212	4.809069481	27.0583
2	REGULAR CELL 1	3.1167	1.6421	8.6149	0.6267	6.676	3.3958	0.738945	0.861603249	11	8	0.5	0.917859924	3.116868729	4.801830696	27.3851
3	REGULAR CELL 2	3.0833	1.6142	8.602	0.62	6.7039	3.3875	0.72639	0.846199557	11	8	0.5	0.918297219	3.110731829	4.800927309	27.398
4	REGULAR CELL 3	3.05	1.5862	8.5893	0.6133	6.7318	3.3792	0.71379	0.830742258	11	8	0.5	0.918815941	3.104862828	4.799991263	27.4107
5	REGULAR CELL 4	3.0167	1.5583	8.5768	0.6067	6.7597	3.3708	0.701235	0.815355214	11	8	0.5	0.919412146	3.099154463	4.799014542	27.4232
6	REGULAR CELL 5	2.9833	1.5304	8.5645	0.6	6.7876	3.3625	0.68868	0.799982661	11	8	0.5	0.92009604	3.093822933	4.798011623	27.4355
7	REGULAR CELL 6	2.95	1.5025	8.5524	0.5933	6.8155	3.3542	0.676125	0.784617447	11	8	0.5	0.920863695	3.088761006	4.796974519	27.4476
8	REGULAR CELL 7	2.9167	1.4746	8.5406	0.5867	6.8435	3.3458	0.66357	0.769263738	11	8	0.5	0.921751347	3.083995656	4.795880876	27.4594
9	REGULAR CELL 8	2.8833	1.4467	8.529	0.58	6.8714	3.3375	0.651015	0.753925501	11	8	0.5	0.922729325	3.079609122	4.794759444	27.471
10	REGULAR CELL 9	2.85	1.4188	8.5177	0.5733	6.8993	3.3292	0.63846	0.738595959	11	8	0.5	0.923834133	3.075628594	4.793587741	27.4823
11	REGULAR CELL 10	2.8167	1.3908	8.5066	0.5667	6.9272	3.3208	0.62586	0.723220172	11	8	0.5	0.925021844	3.07181254	4.792371542	27.4934
12	REGULAR CELL 11	2.7833	1.3629	8.4958	0.56	6.9551	3.3125	0.613305	0.707920115	11	8	0.5	0.926343235	3.068511967	4.79111141	27.5042
13	REGULAR CELL 12	2.75	1.335	8.4852	0.5533	6.983	3.3042	0.60075	0.692630299	11	8	0.5	0.927754121	3.065485167	4.789813321	27.5148
14	REGULAR CELL 13	2.7167	1.3071	8.4749	0.5467	7.011	3.2958	0.588195	0.677354681	11	8	0.5	0.929291748	3.062759743	4.788453996	27.5251
15	REGULAR CELL 14	2.6833	1.2792	8.4648	0.54	7.0389	3.2875	0.57564	0.662097014	11	8	0.5	0.93092545	3.060417417	4.787063341	27.5352
16	REGULAR CELL 15	2.65	1.2513	8.4548	0.5333	7.0668	3.2792	0.563085	0.646851347	11	8	0.5	0.932610367	3.058215915	4.785647602	27.5452
17	REGULAR CELL 16	2.6167	1.2233	8.4451	0.5267	7.0947	3.2708	0.550485	0.631563289	11	8	0.5	0.934425231	3.056318047	4.784168334	27.5549
18	REGULAR CELL 17	2.5833	1.1954	8.4355	0.52	7.1226	3.2625	0.53793	0.616353139	11	8	0.5	0.936297301	3.054669944	4.782671105	27.5645
19	REGULAR CELL 18	2.55	1.1675	8.4262	0.5133	7.1505	3.2542	0.525375	0.601157017	11	8	0.5	0.938305825	3.053434814	4.781117188	27.5738
20	REGULAR CELL 19	2.5167	1.1396	8.417	0.5067	7.1785	3.2458	0.51282	0.585978702	11	8	0.5	0.940364464	3.052234978	4.779527487	27.583
21	REGULAR CELL 20	2.4833	1.1117	8.408	0.5	7.2064	3.2375	0.500265	0.570821752	11	8	0.5	0.942524139	3.0514219	4.777903318	27.592
22	REGULAR CELL 21	2.45	1.0838	8.3993	0.4933	7.2343	3.2292	0.48771	0.555681174	11	8	0.5	0.944823526	3.05102413	4.776220233	27.6007
23	REGULAR CELL 22	2.4167	1.0558	8.3908	0.4867	7.2622	3.2208	0.47511	0.540503282	11	8	0.5	0.947217848	3.050799244	4.774483912	27.6092
24	REGULAR CELL 23	2.3833	1.0279	8.3825	0.48	7.2901	3.2125	0.462555	0.52540649	11	8	0.5	0.949716208	3.050963318	4.772711188	27.6175
25	REGULAR CELL 24	2.35	1	8.3745	0.4733	7.318	3.2042	0.45	0.510328802	11	8	0.5	0.952357943	3.051545322	4.770877034	27.6255
26	MATCH IRIS B	4.253	1	8.62136	0.85	7.332	3.2	0.45	0.483334748	11	8	0.5	0.898791096	2.876131508	4.790173923	27.37864

IND.	DATE	NOM/NAME	ZONE	MODIFICATION
C	2011-01-18	A. SOLODKO		add parameter "f" in the table
B	2010-11-04	A. SOLODKO		change radius
A	2010-10-12	A. SOLODKO		add parameter "be" in the table

NOTES:
1. Dimensions in this drawing are at 20°C in free state.
2. Lubricant based on Chlorine or Sulfur should be avoided. No polishing is allowed.
3. No deformations admissible due to stress release or shocks during and after machining.
4. The product should be marked with present drawing
5. To be protected against scratches and marks of any nature, burrs are not allowed.
6. The product must be individually packed inside a main delivery box.
7. * - Evaluation length is equal to (d-2*be) mm
8. Roughness is according to ISO 1302
9. The present drawing is based on KEK drawing XK1401-01

QUA	DESCRIPTION	POS	MAT.	OBSERVATIONS	REF.CERN
-		1	CU-OFE		
RMS/ASS				S-RMS/S-ASS	

ISO 2768-fH-E Ra 0.8 ISO 13715 -0.02 +0.02

CLIC accelerating structure at 12 GHz

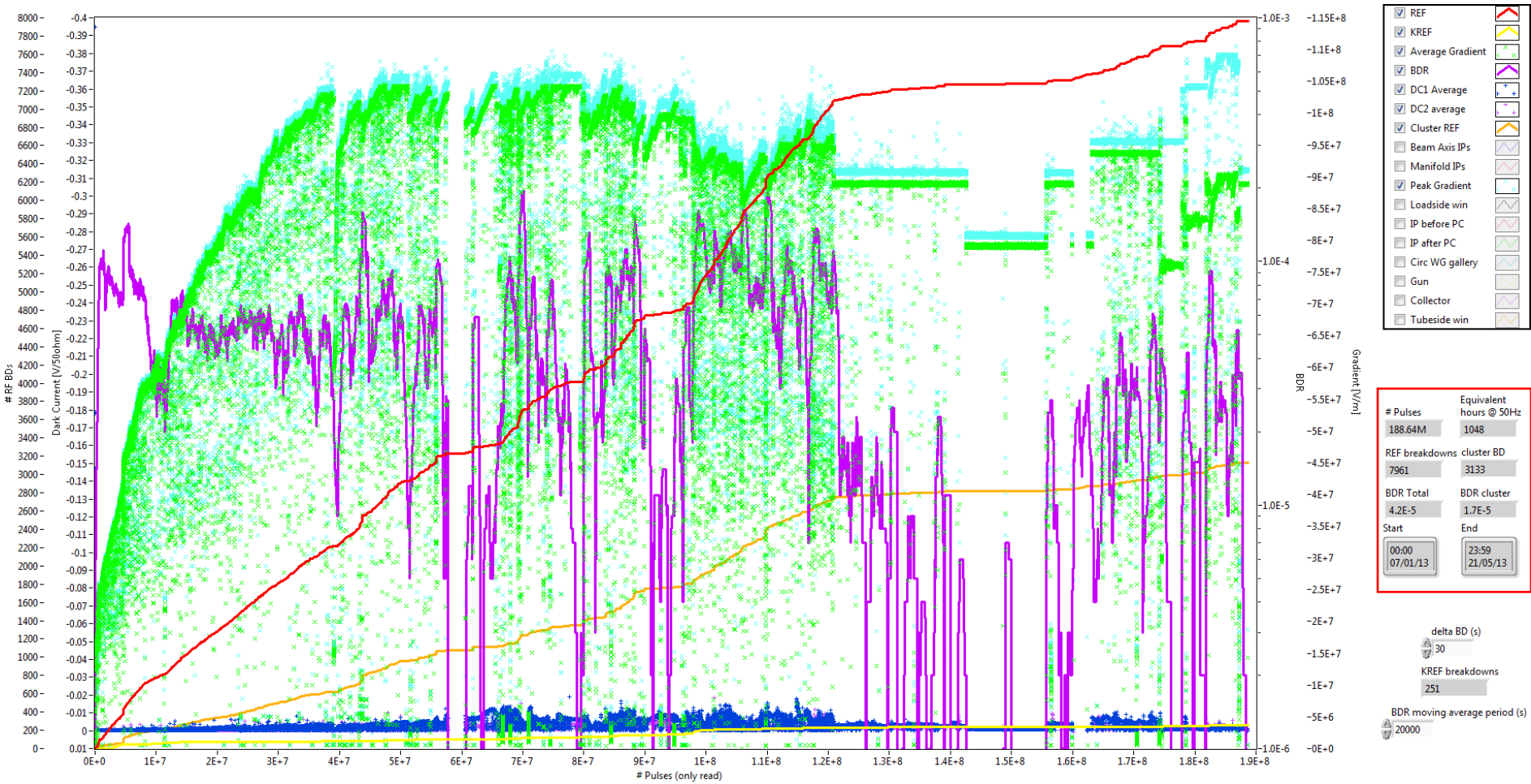
12WDSDVG1.8 R05
STANDARD CELL

DES/DRA	A SOLODKO	2010-06-09
CONTROLLED	S ATECH	2011-01-12
RELEASED	G RIEDONE	2011-01-12
APPROVED		

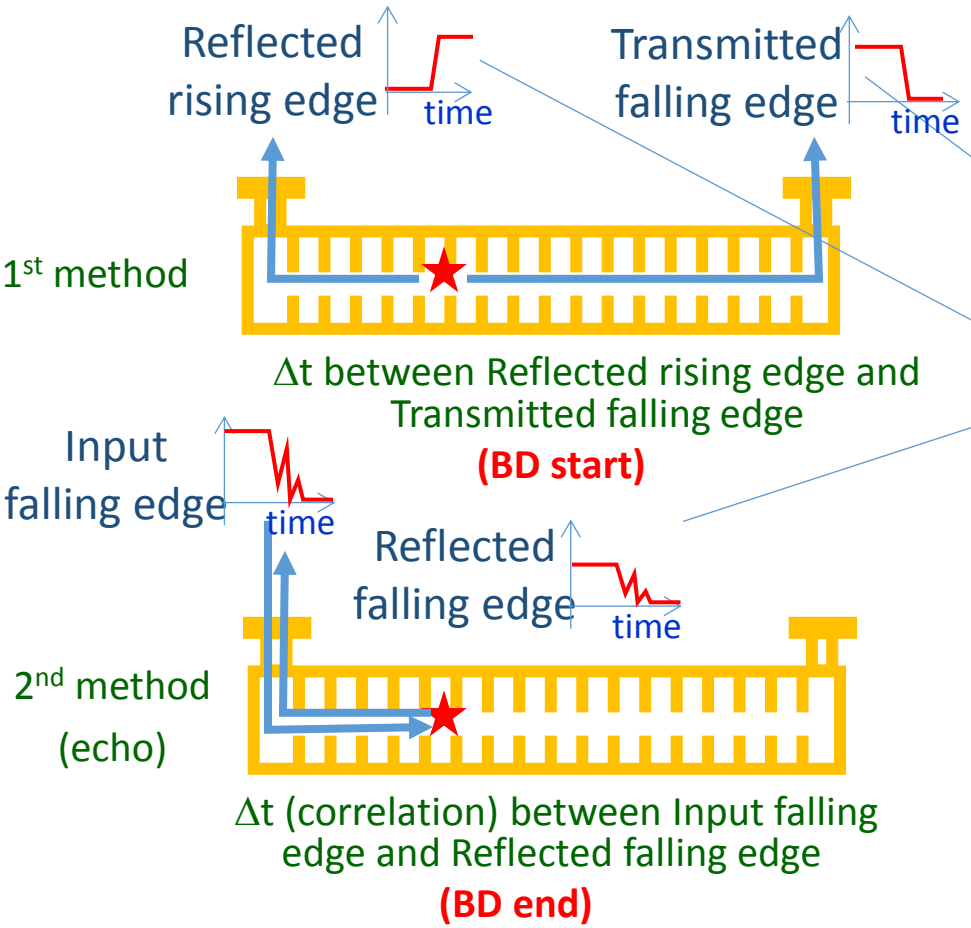
SCALE 2.5:1
CAD Document Number ST0292658_02
REPLACES

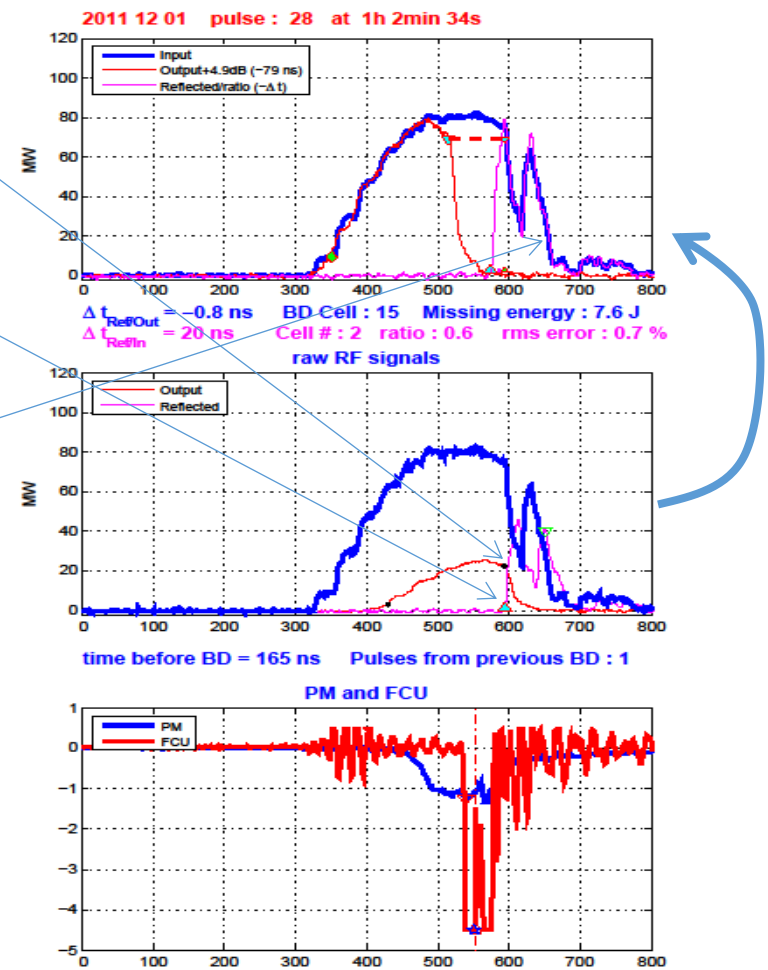
RELEASED BY PROJECT ENGINEER | FOR INFORMATION | SUC. - | CLIAAS120077 | SIZE 1 | IND. C

TD24R05 tested in Xbox1
History plot



BD location determination





- Edge detection is always tricky especially for the transmitted signal (BD ignition time)
- Cross-correlation method is much more robust but possibly biased (needs strong and structured Reflected signal)

BD location histogram for all files

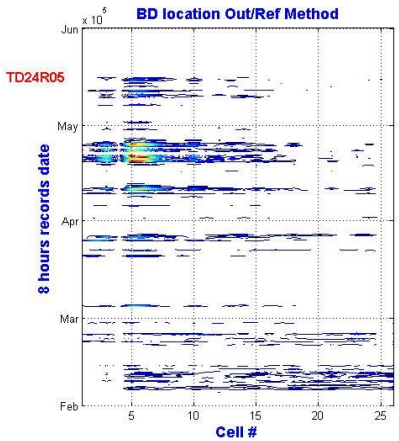
https://indico.cern.ch/event/245702/

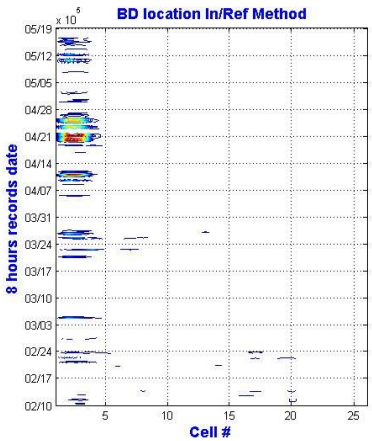
W. Farabolini – 11.09.2013

- No hot cell so far

TD24R05 :

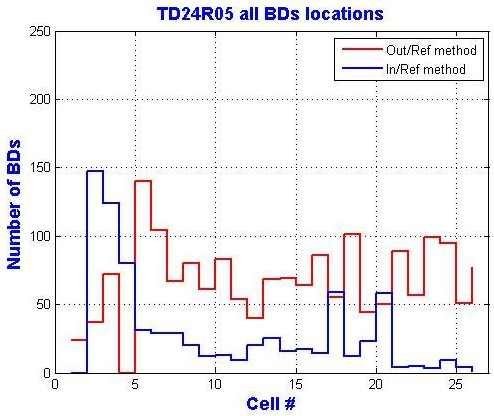
slide 4



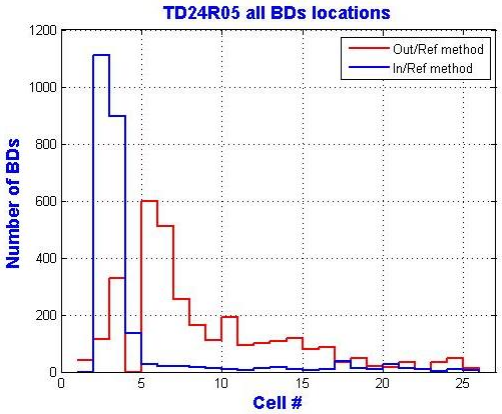


- Really no hot cell (nor cold one !)

slide 5



TD24R05 Feb. & Mar.



TD24R05 May. & Jun.