HiRadMat 28 & 35 TCDI / TDI material tests on ASL 3D Carbon/Carbon and SGL Graphite R7550

7th HL-LHC Collaboration Meeting – 15th November 2017 - Madrid

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Motivations for HRMT28

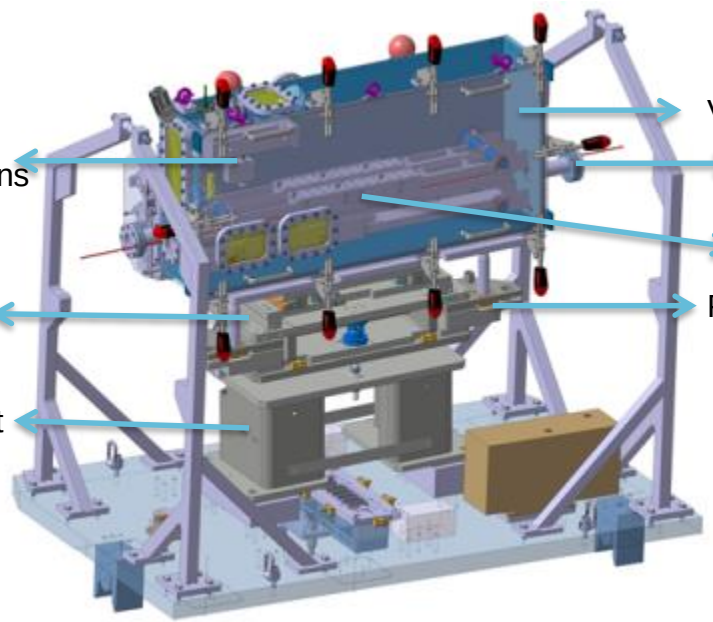
- Assess the Integrity of Graphite for TCDIs and TDIs during Run 3 and test an alternative material: 3D CC. The goal is to reproduce the highest intensity beam that the TCDI and the TDI can see during their life time.

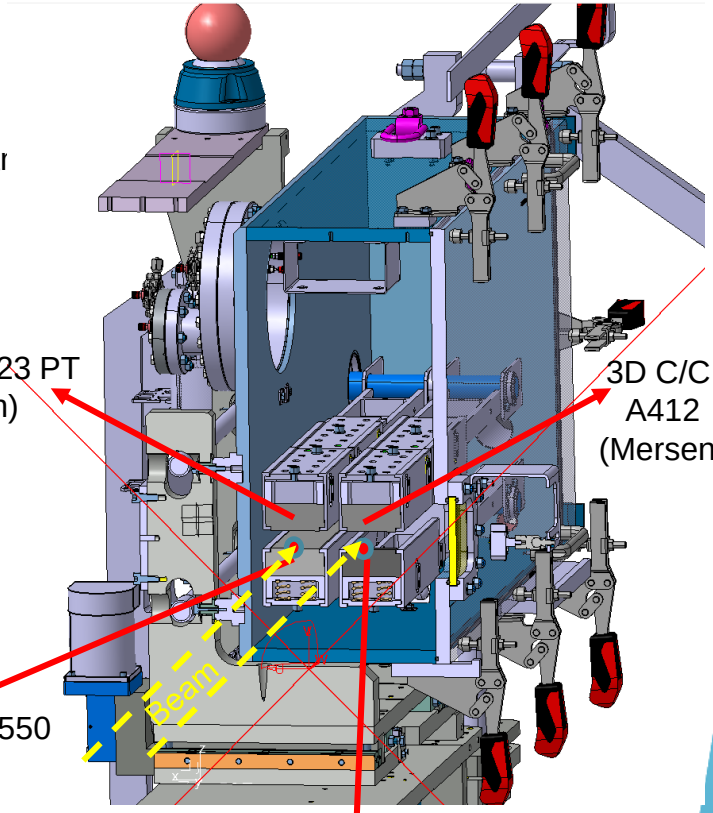
Beam	Intensity	Sig X[mm] × Sig Y[mm]	Max Temperature [°C]	M-C Safety Factor*
Run 3 BCMS	5.76 E13	0.320×0.511	1450	0.8 [~1]
HiRadMat requested beam	3.46 E13 (originally requested 1.3 E11 ppb)	0.313×0.313	1342	0.75 [0.96]
HiRadMat alternative beam (phase II)	2.6 E13	0.25×0.25	1371	[0.97]

- Cross-check simulations.

*The Mohr Coulomb safety factors are calculated with a graphite tensile limit of 30 MPa, and the values between brackets consider a graphite tensile limit of 40 MPa which is the value considered by SGL for the R7550 graphite.

Experimental Set Up

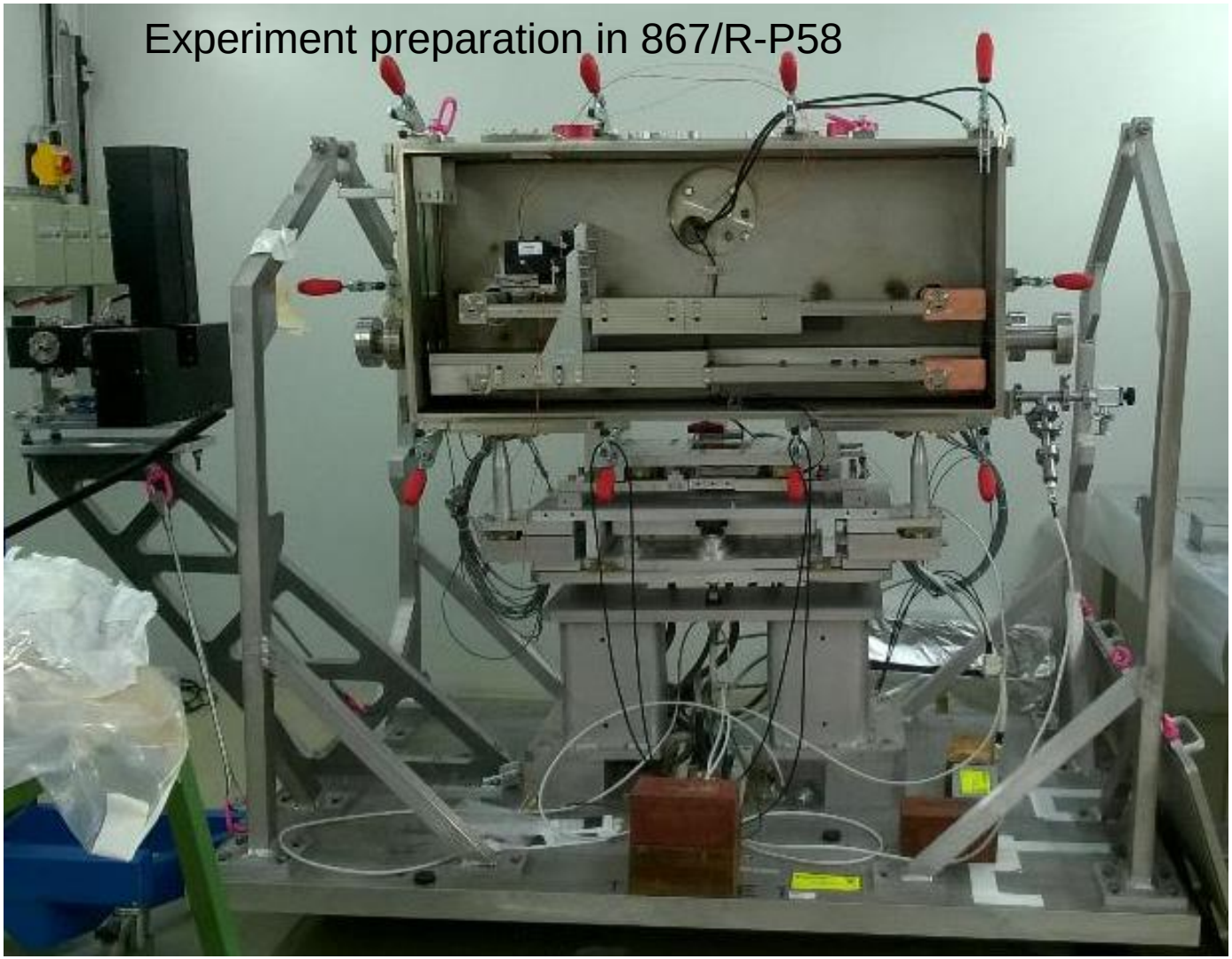




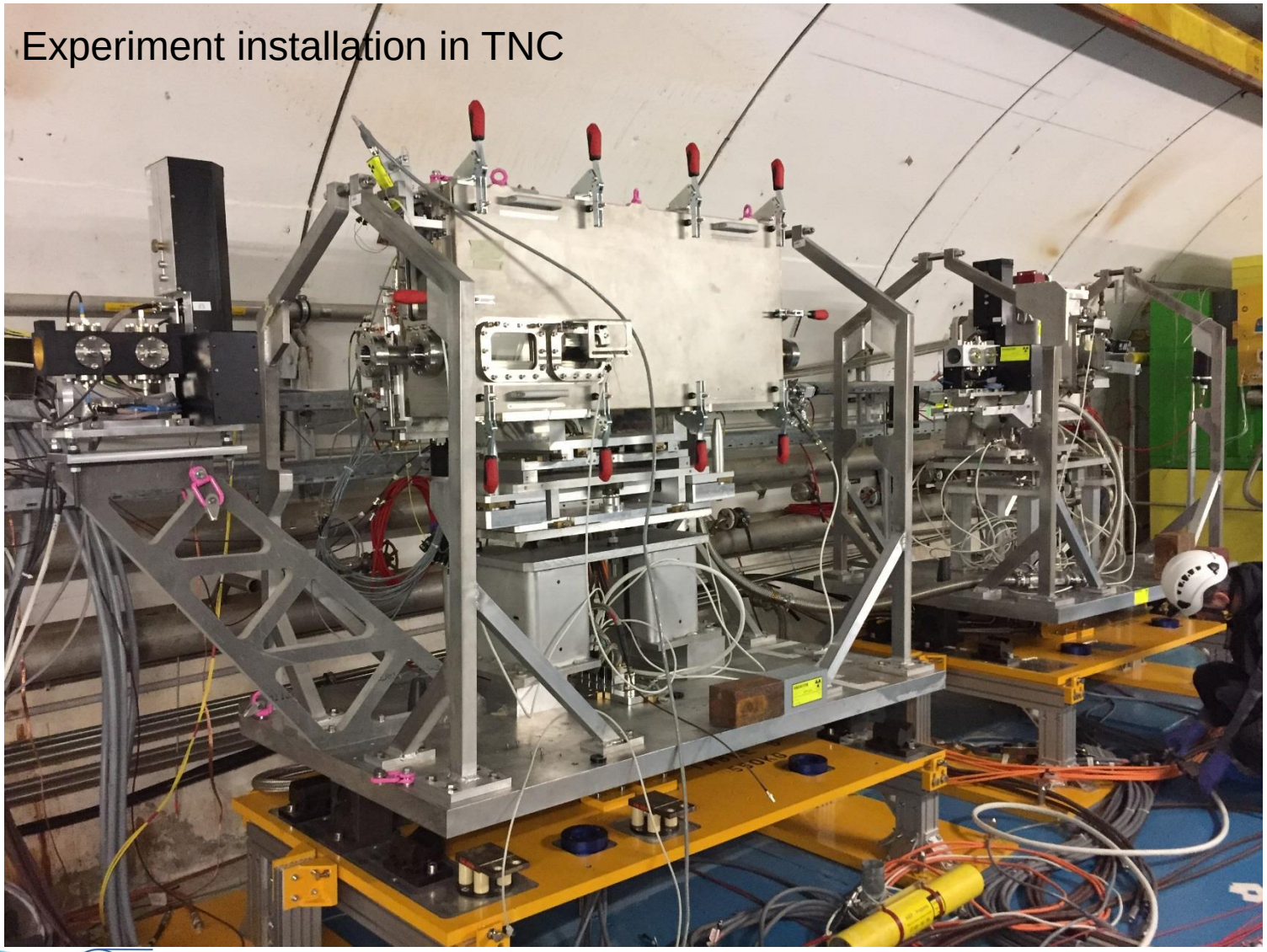
Beam instrumentation:

- BTV, working also for high intensity shots
- BPKG (Working only in the horizontal plane)
- Wire scanner (in SPS ring), working for up to 3 batches

Experimental Set Up



Experimental Set Up



HRMT 28 in a nutshell

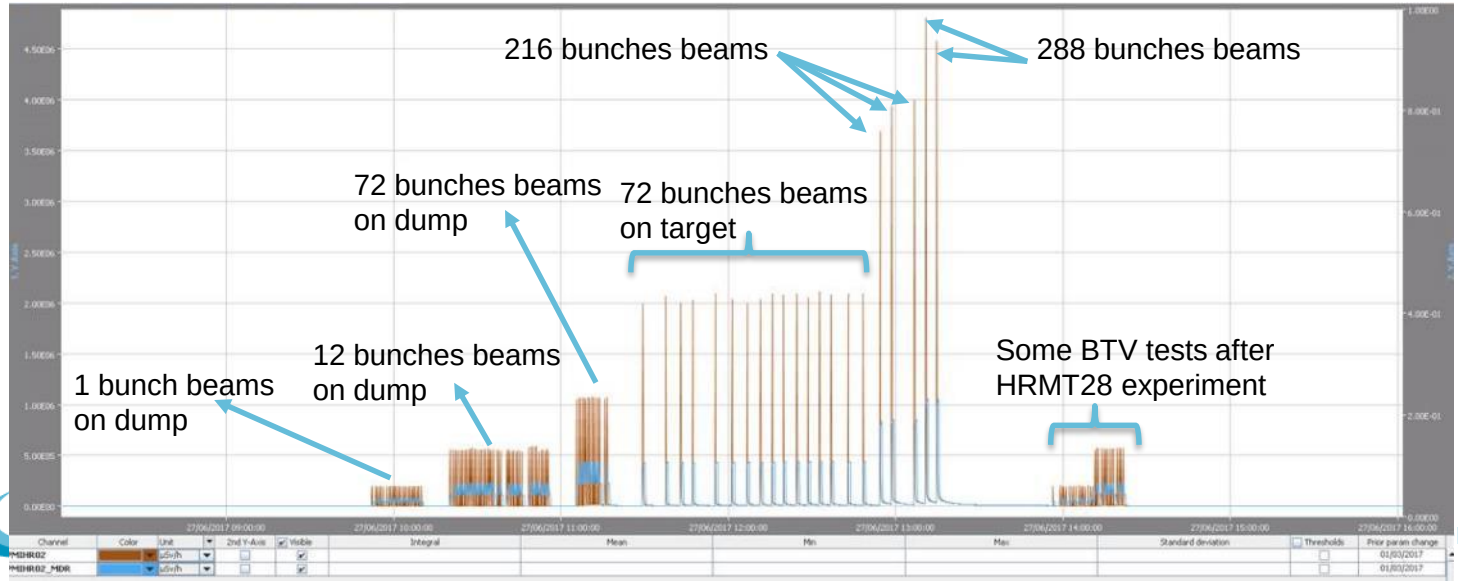
- **4 low density materials** impacted for BID applications;
- About **15 people** involved in the experiment operation itself;
- About **1.12E15** total POT spread over **3 runs**;
- **23 hours spent in the CCC**, aligning the experiment and data acquisition;
- **3 Gb** of collected data;

Residual dose rate	After 9h of cool down	After 44h of cool down
PMIHR02	1 mSv/h	227 µSv/h

High intensity shots on the 27/06/2017

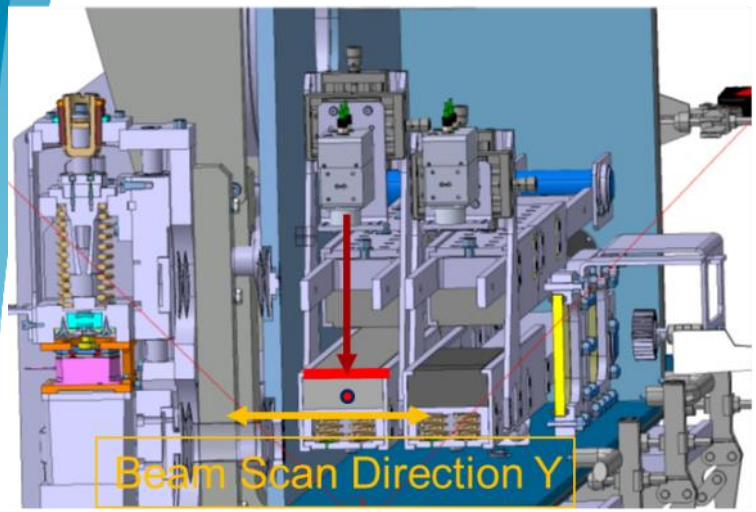
			BTV.524 measurements				
Target	**Time**	**Intensity**	**Sigma X (mm)**	**Sigma Y (mm)**	**Position in X (mm)**	**Position in Y (mm)**	
ASL Sepcarb 3D CC	12h54min02s	2.47E+13	No Signal on BTV				
	12h58min07s	2.49E+13	0.24	0.25	-0.46	0.73	Strange signal on LDV
	13h06min14s	2.50E+13	0.24	0.24	-0.45	0.74	
	13h10min21s	3.35E+13	0.2	0.23	-0.44	0.73	
	13h14min26s	3.34E+13	0.2	0.22	-0.44	0.72	

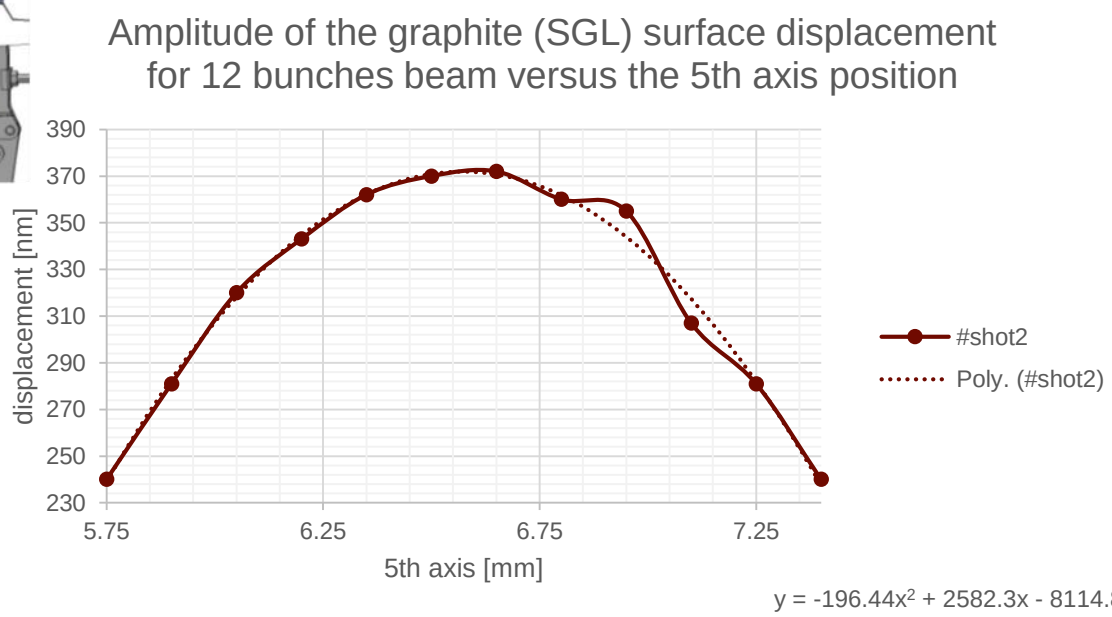
For this run, a red filter in front of the BTV camera in TT61 has been installed



RP Monitor PMIHR02, showing residual dose rate versus time

Optometer alignment with the beam (graphite)

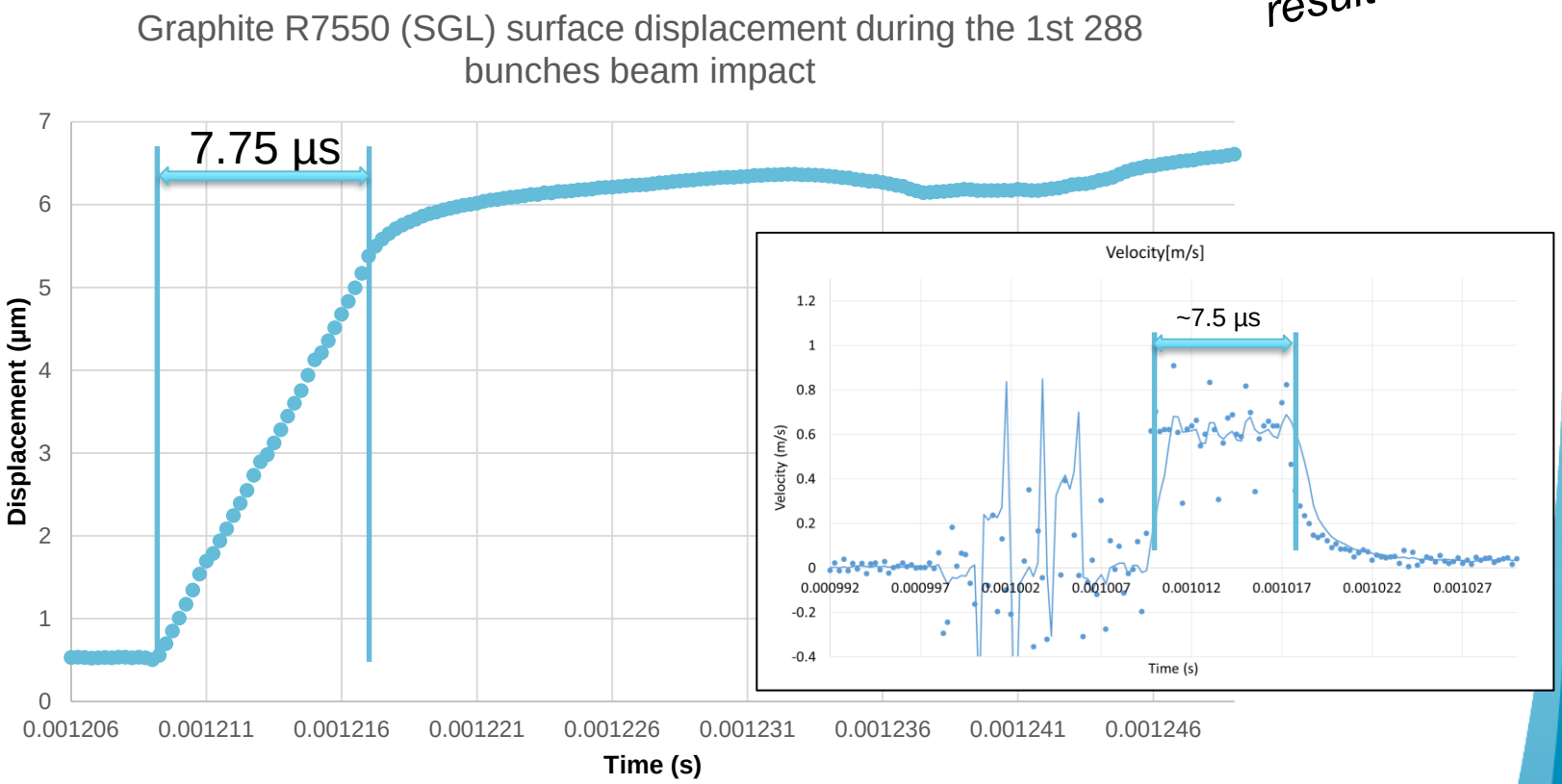




A precise alignment of the LDV with the beam was achieved (better than 0.15 mm)

Graphite (SGL) surface displacement when impacted

Preliminary results

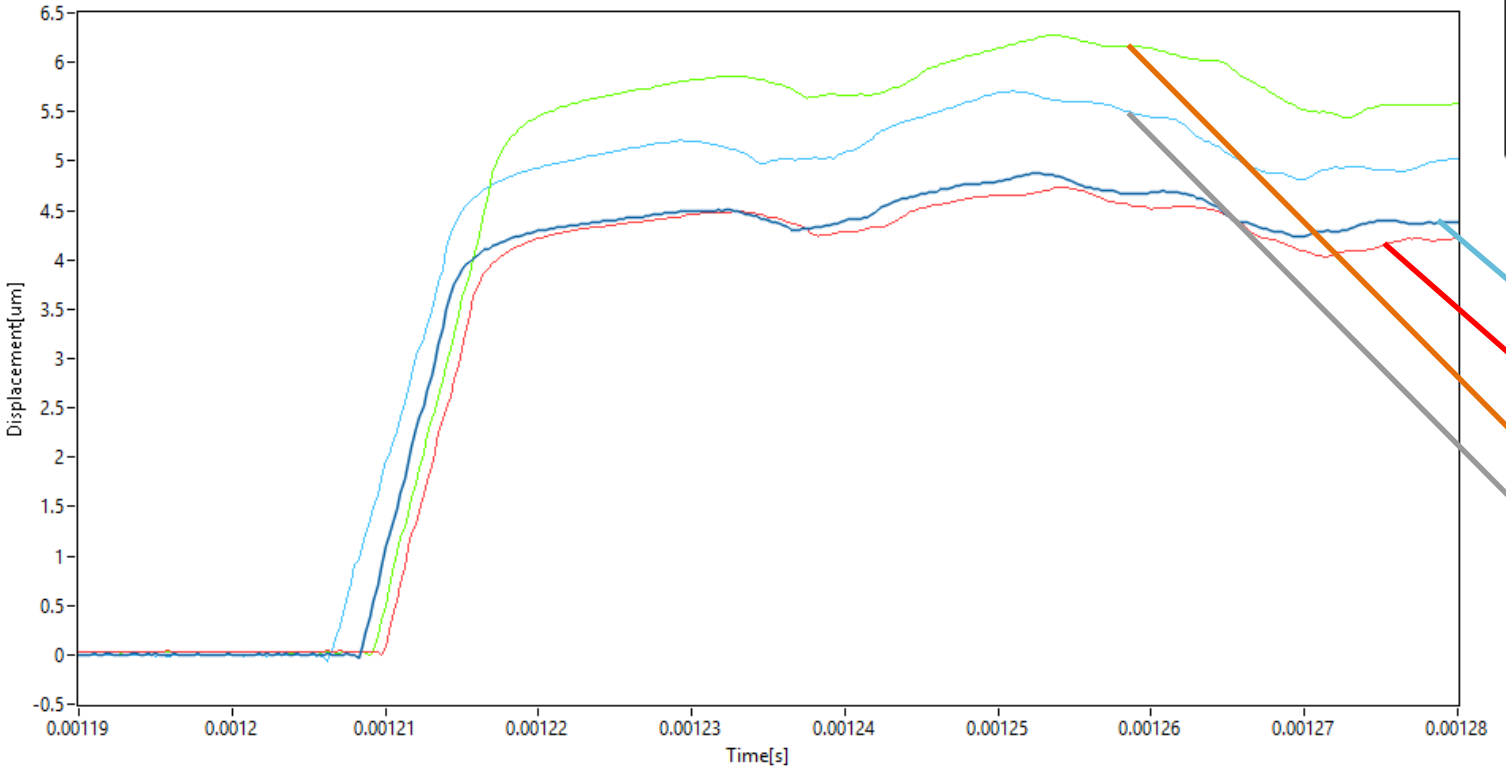


Quick analysis:

- Correct bunch length ✓
- Expected magnitude of the surface displacement (with respect to simulations) ✓
- Corresponds to the measurement got in 2016 ✓

Graphite (SGL) surface displacement for 4 consecutive high intensity shots

Preliminary results

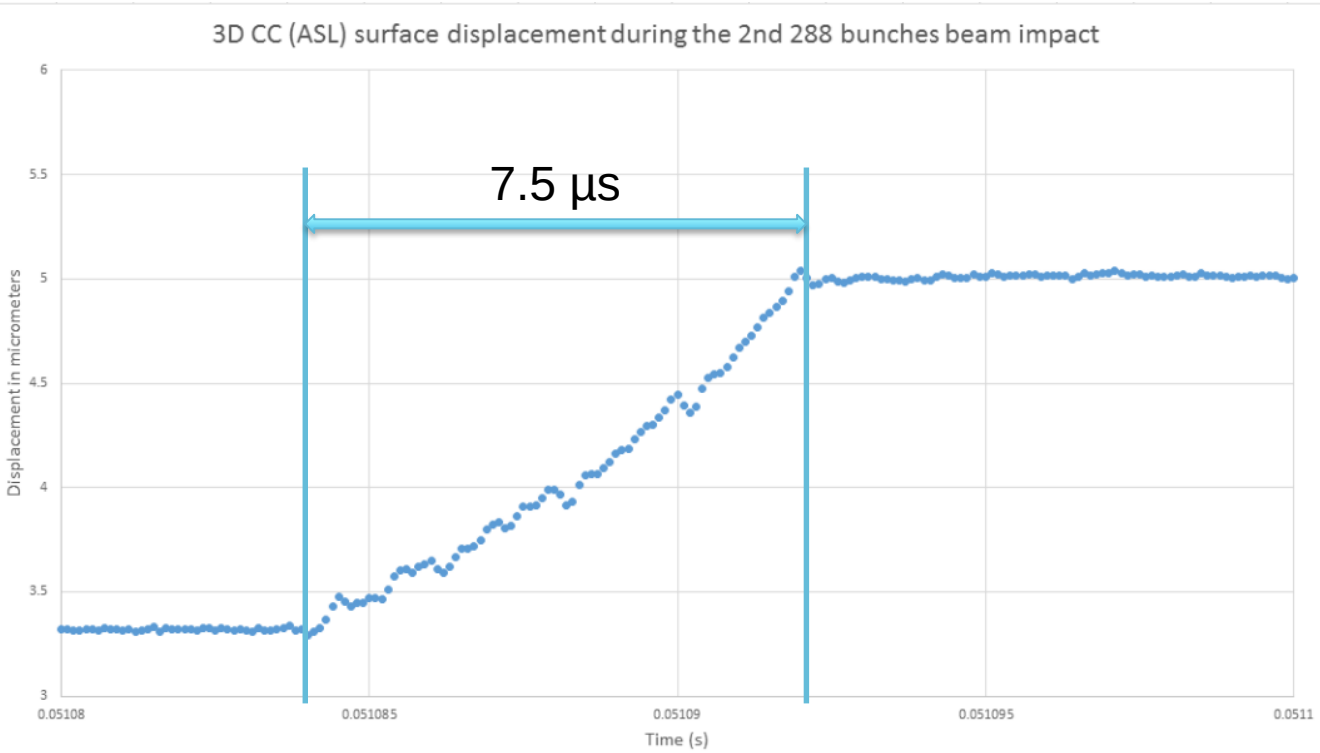


Intensity
2.39E+13
2.37E+13
3.23E+13
3.23E+13

- The very similar (shape) surface displacement curves over time dhows that no beam induced damage occurs on the material, shot after shot;
- The amplitude difference for the last two shots can be due to the impact parameter difference (last pulse is 0.3 mm deeper).

3D CC surface displacement when impacted (LDV 10 MHz)

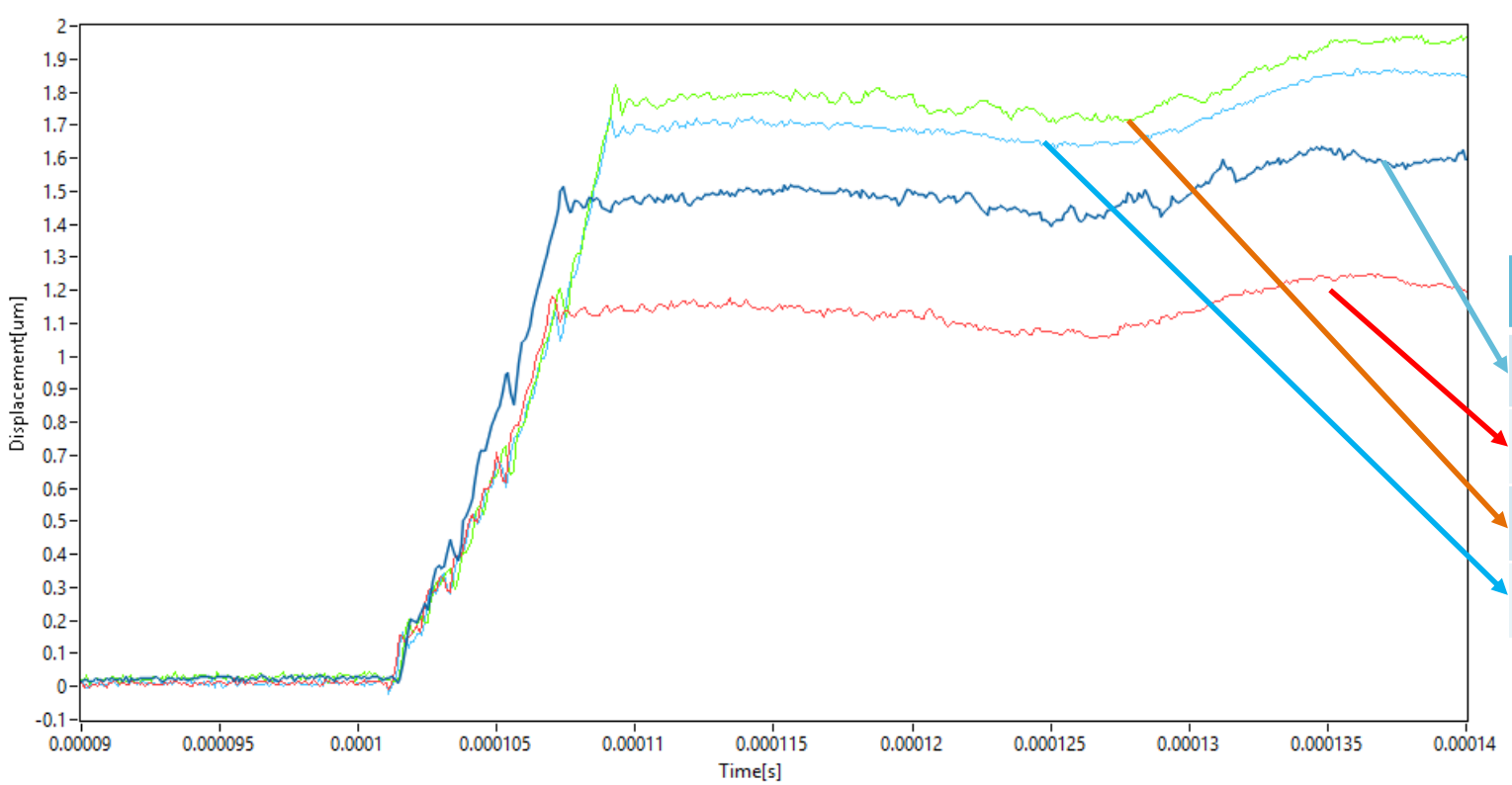
Preliminary results



Quick analysis:

- Correct bunch length ✓
- Expected magnitude of the surface displacement ✓

3D CC (ASL) surface displacement for 5 consecutive high intensity shots (LDV interface 10 MHz), 27-06-2017 (one 216 b shot not recorded)



Intensity
2.47E+13
2.50E+13
3.35E+13
3.34E+13

- The very similar surface displacement curves over time are is an indicator that no beam induced damage occurs on the material, shot after shot.
- The amplitude difference for the 1st and 3rd shots at 216b can be due to a small spot offset in X.

Jaw surfaces (ASL 3D CC and SGL Graphite)

Online pictures

After 2x216 and 2x288 bunches shots on graphite

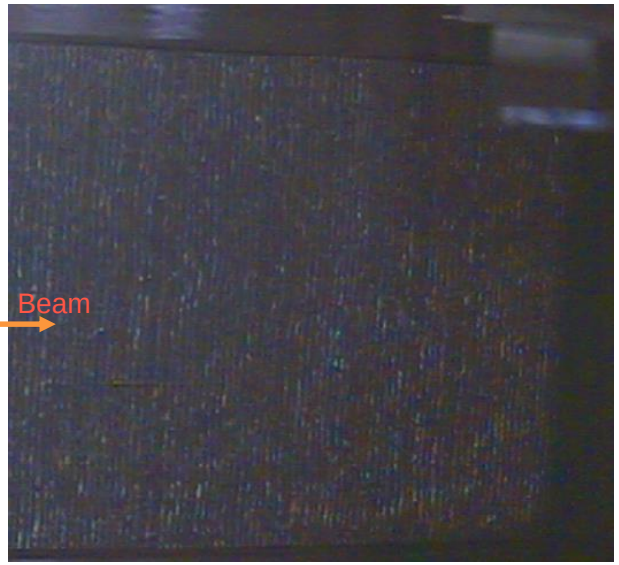
Before impact on graphite

Jaw surface (ASL 3D CC)

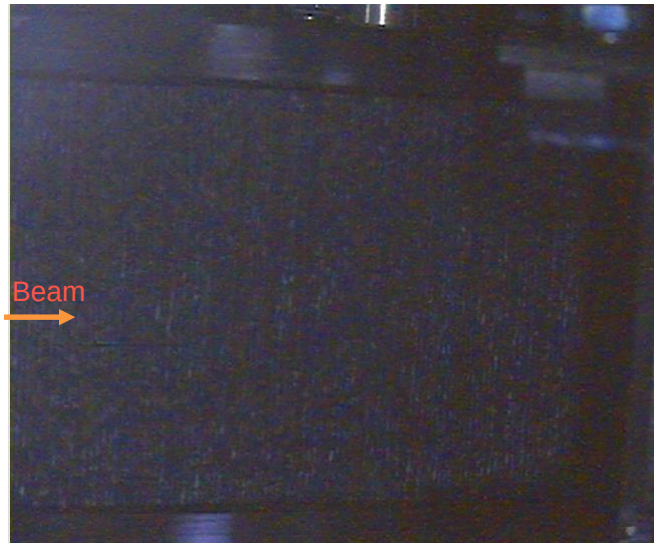
Before impact on 3D CC

Online pictures

After 2x216 and 2x288 bunches shots



After 5x216 and 4x288 bunches shots

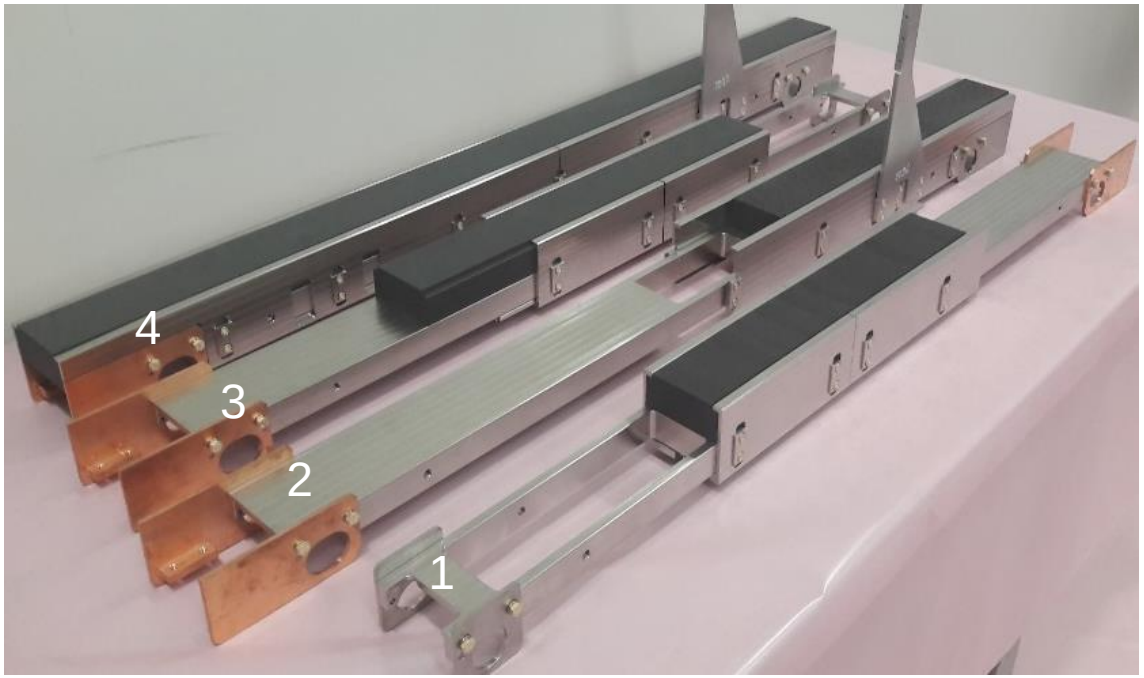


Experiment dismantling in 867/R-P58

Installation in a fully cleaned bunker

The opened vacuum vessel with jaws removed

Targets (jaws) dismounting in 867/R-P58



- RP measurements on the 25.07.17 at 16h45
- 1 / contact: 320 µSv/h, 10 cm: 70 µSv/h, 40 cm: 25 µSv/h
- 2 / contact: 370 µSv/h, 10 cm: 73 µSv/h, 40 cm: 27 µSv/h
- 3 / contact: 280 µSv/h, 10 cm: 52 µSv/h, 40 cm: 15 µSv/h
- 4 / contact: 280 µSv/h, 10 cm: 63 µSv/h, 40 cm: 17 µSv/h

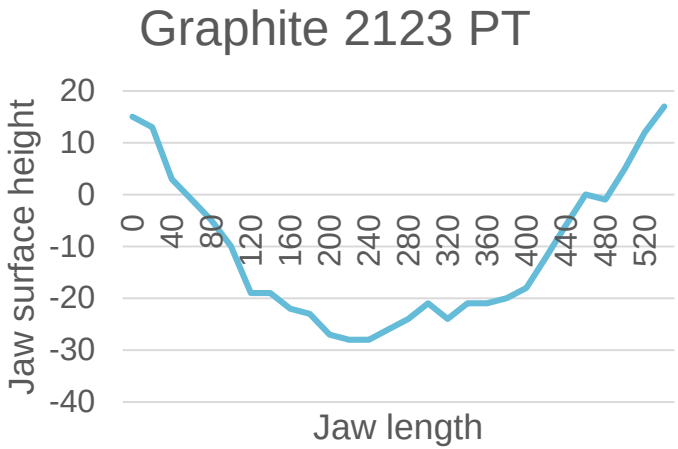
Jaws metrology measurements

Jaw flatness measurement before and after beam impact:

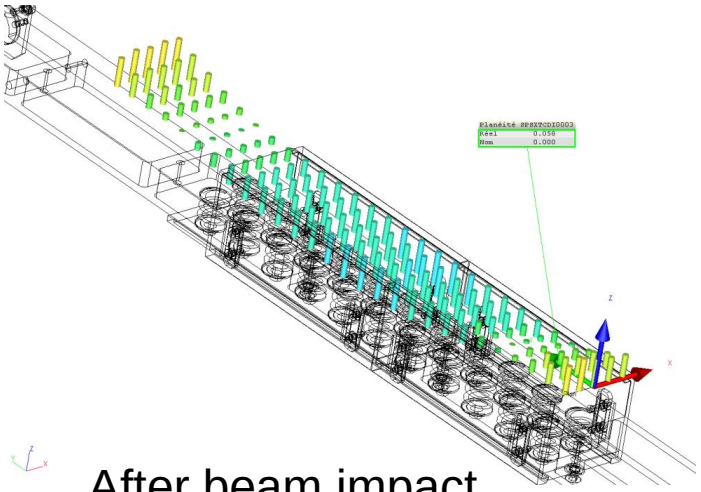
Jaw flatness	Graphite Sigrafine® R7550 (SGL)	Graphite 2123 PT (Mersen)	3D C/C A412 (Mersen)	Sepcarb® 3D C/C (Airbus Safran Launchers)
Before Impacts	**80 µm**	**56 µm**	**128 µm**	**44 µm**
After Impacts	**96 µm**	**58 µm**	**82 µm**	**44 µm**

✓ ✓ ✓

Possible bloc movement during handling



Before beam impact



After beam impact

HRMT-28 Summary (I)

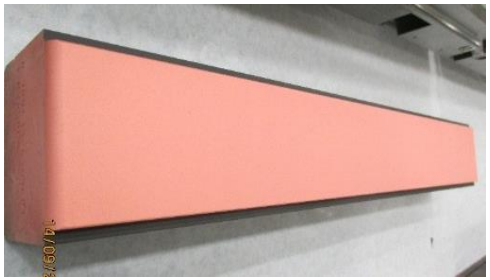
- SGL Graphite and ASL 3D CC are **undamaged** after several high intensity shots, as it was expected by the trend of the surface displacement curves which is very regular from shot to shot;
- After a quick qualitative analysis, SGL Graphite and ASL 3D CC are "*behaving"* as expected by the simulations;
- Metrology is showing the **same global shape before and after impact**;
- Next steps:
  →Detailed comparisons with simulations;
  →Ultrasound tests of the graphite, micro-tomography of the 3D CC.

HRMT-28 Summary (II)

- The jaw material baseline (510 mm of 3D CC and 1590 mm of graphite) is **compliant** with HRMT28 results: both materials are able to survive the beam.
- Graphite has always been considered slightly weaker than 3D CC → experimentally, it's not **yet** possible to determine by how much as **both materials survived all the shots**.
- Installing 3D CC in the machine is also useful to **push this material validation** from the **UHV and mechanical point of views**.
- A TCDIL collimator made of **100% graphite jaws is also suitable** for Run 3 beams.
- TCDIL collimators are expected to withstand grazing to close to grazing impacts.

Motivations for HRMT35

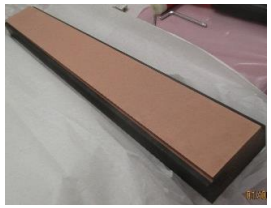
- After dismantling the TDI (10/01/2016), severe damage on the Ti coated surface on the hBN absorbing blocks was found.
- The absorbing blocks of the currently installed TDI are made out of Cu sputtered Graphite R4550.

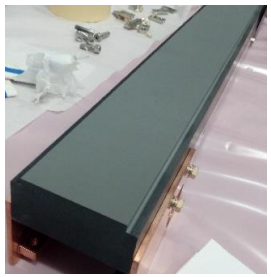


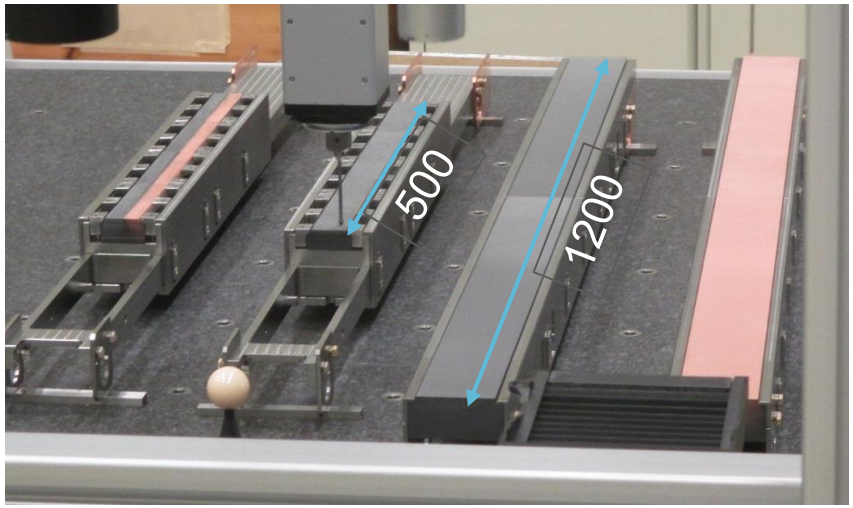
- Given the past issues and the general uncertainties on coatings behavior when grazed by a high intensity proton beam, there is a high priority recommendation by the LHC Machine Committee (LMC#256) to test and validate the sputtered Cu performance under the worst impact conditions that the TDI could face.
- In order to gain important information for future beam intercepting devices such us TCPPM and TCSPM, other coating configurations (by acting on the subtract and the thickness of the deposited layer) were tested on low-Z materials such as R4550, 2D Tatsuno CFC and Molybdenum Graphite (MoGr).

Experimental Set Up

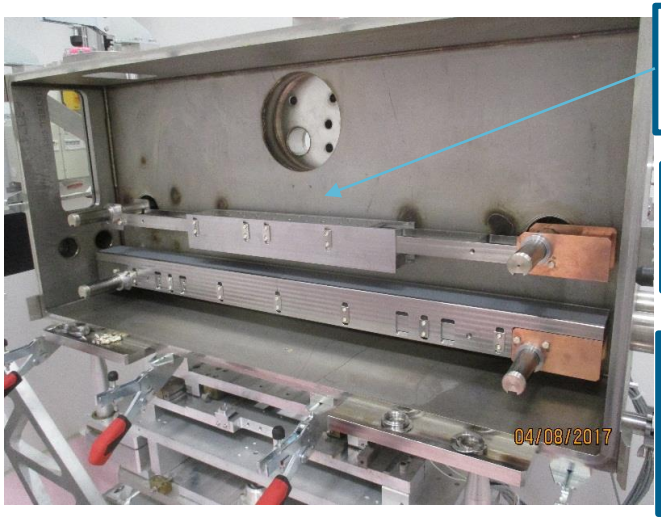
- The HRMT 28 tank and test bench will be used for this experiment
- Modifications will be performed on the jaw configuration in order to host up to 4 different absorbing materials and coating configurations:
  - SGL Graphite R4550 TDI coating configuration with Cu coating;
  - SGL Graphite R4550 TDI coating configuration with Mo coating;
  - Tatsuno 2D CFC in a TCxPM configuration with Mo coating (+SiC-SiC);
  - Molybdenum Graphite (MoGr) with Mo and Cu coating.







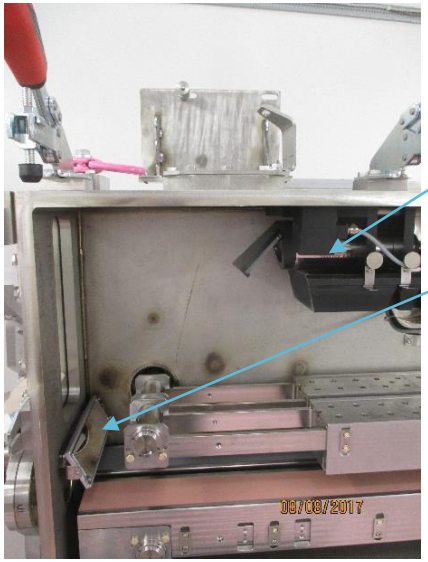
Experimental Set Up



First set of jaws assembly

Second set of jaws assembly

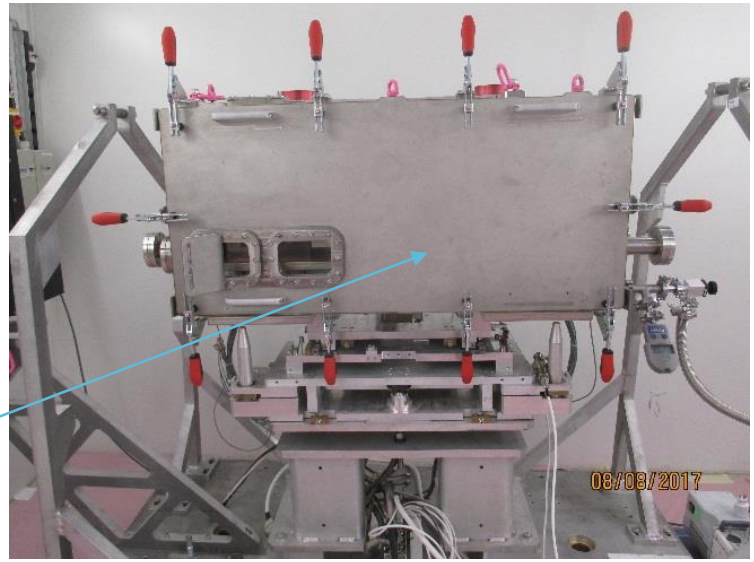
Vertically assy to reduce beam jitter



HD RadHard Camera

Mirror

Closed tank under primary vacuum



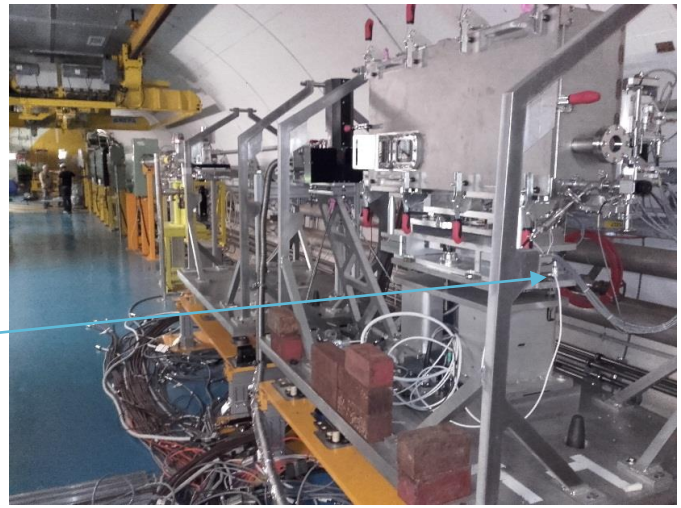
Experimental Set Up

Transport 867-BA7

BA7:
- Alignment
- Electronic tests

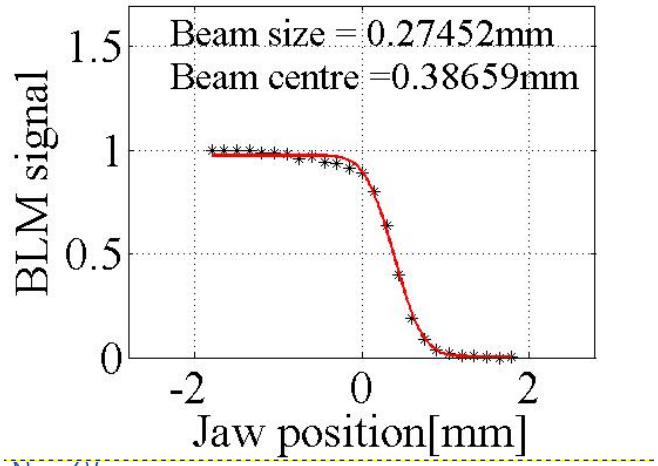
Transport to TNC table 2 position

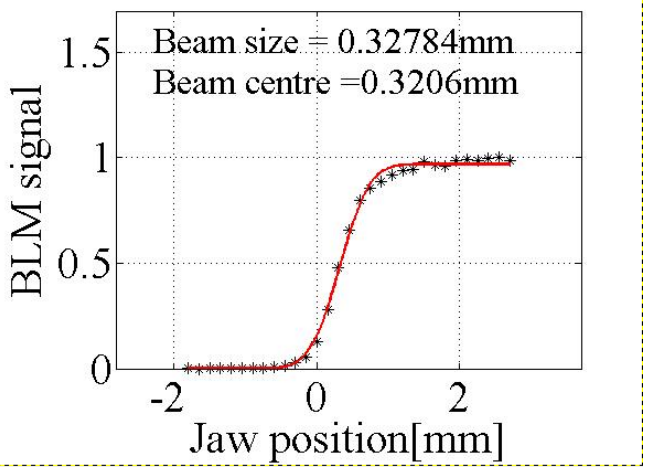
TNC:
- Cameras connection and adjustment
- Vacuum line connection



Alignment Graphite Cu coated jaw

- First BBA took place 21th August 2017:
  - BBA on Graphite/Cu and CFC/Mo jaws with INDIV (~1,2E11ppp, x 50 shots)
    - Left/Top jaw (CFC with Mo Coating)
      - Beam center = 0.387 mm
      - Beam size = 0.275 mm
    - Right/Bottom jaw (Graphite with Cu coating)
      - Beam center = 0.320 mm
      - Beam size = 0.330 mm
  - We assume an average beam center of 0.350 mm and the nominal beam size of 0.3 mm.





Impacts type 1 on Graphite with Cu coating jaw

Time	Number of Bunches	Total Intensity (ppp)	Nominal sigma (mm)	Impact type 1 (sigma)	5th axis (mm)
21/08-21:15	144	1,73E13	0,3	0	110
21/08-21:17	144	1,73E13	0,3	0	110
21/08-21:20	144	1,73E13	0,3	0	110
21/08-21:25	Try to inject 288 bunches. Problems with high intensity beam stability.				
22/08-12:22	Check BBA with few INDIVs.				
22/08-12:38	288	3,53E13	0,3	0	110
22/08-12:40	288	3,56E13	0,3	0,25	110
22/08-12:44	288	3,55E13	0,3	0,5	110
22/08-12:46	288	3,58E13	0,3	0,75	110
22/08-12:50	288	3,53E13	0,3	1	110
22/08-12:53	288	3,53E13	0,3	2	110
22/08-12:56	288	3,54E13	0,3	3	110
22/08-12:59	288	3,58E13	0,3	5	110
22/08-13:01	288	3,59E13	0,3	7	110
22/08-13:04	288	3,58E13	0,3	9	110

Impacts type 2 on Graphite with Cu coating jaw

Time	Number of Bunches	Total Intensity (ppp)	Nominal sigma (mm)	Impact type 2 (sigma)	5th axis (mm)
22/08-13:13	288	3,52E13	0,3	0	100
22/08-13:15	288	3,58E13	0,3	0	100
22/08-13:17	288	3,56E13	0,3	0	100
22/08-13:19	288	3,56E13	0,3	0	100
22/08-13:22	288	3,58E13	0,3	0	100
22/08-13:24	288	3,57E13	0,3	0	100

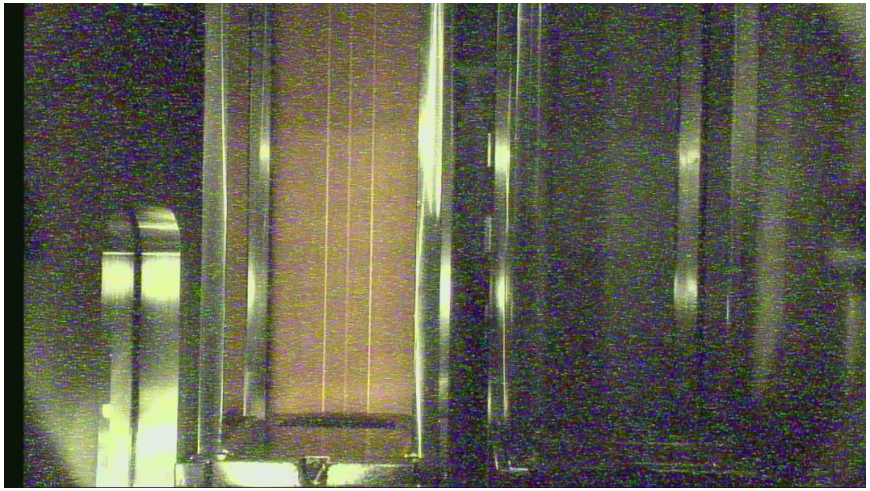
HD RadHard camera any before impact

HD RadHard camera after first impact

Impacts type 3 on Graphite with Cu coating jaw

Time	Number of Bunches	Total Intensity (ppp)	Nominal sigma (mm)	Impact type 3 (sigma and tilt rad)	5th axis (mm)
22/08-13:32	288	3,49E13	0,3	0 and 0	119
22/08-13:36	288	3,50E13	0,3	0 and -300	119
22/08-13:38	288	3,57E13	0,3	0 and -150	119
22/08-13:41	288	3,49E13	0,3	0	119
22/08-13:43	288	3,53E13	0,3	0 and +150	119
22/08-13:45	288	3,58E13	0,3	0 and +300	119

HD RadHard camera after Graphite Cu coating impacts



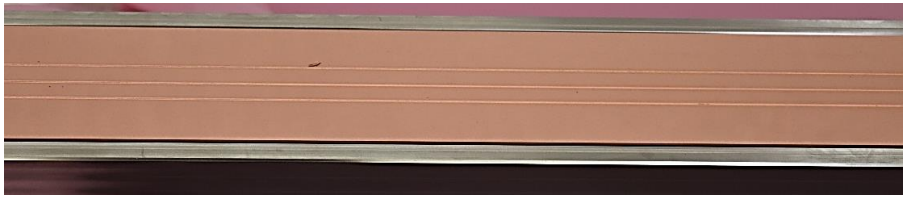
First Visual Inspection of Graphite with Cu coating jaw

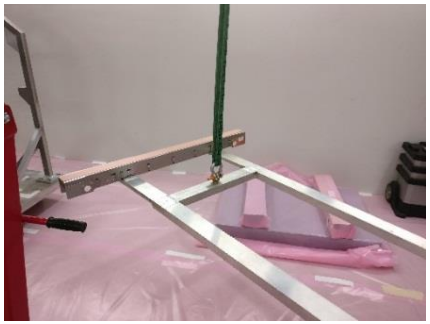
1mSv/h at contact

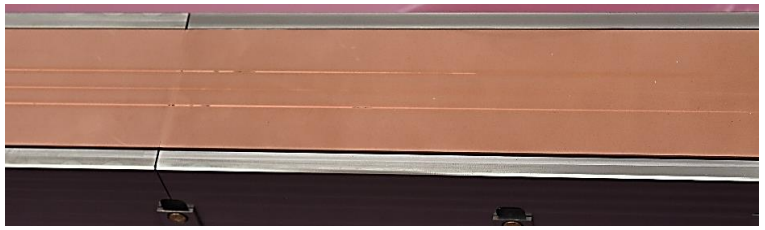
Impact type 2

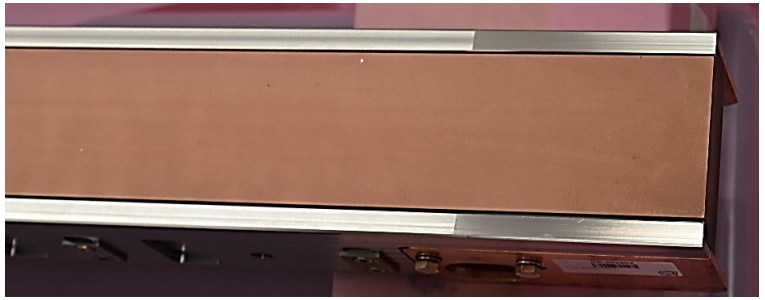
Impact type 1

Impact type 3









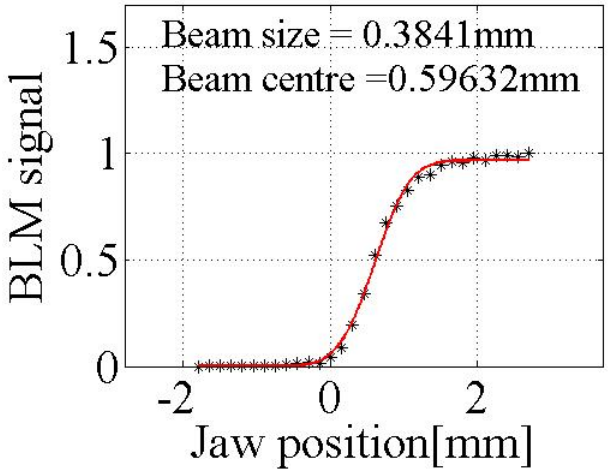
Upstream

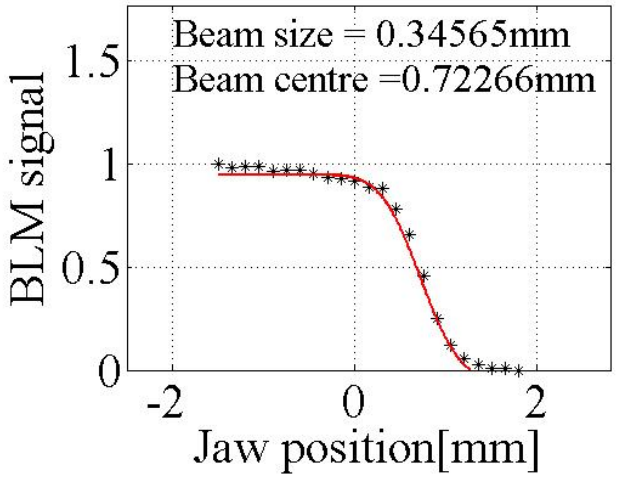
Downstream

Surface CO2 blasted before Cu sputtering ~3 um

Alignment Graphite Mo coated jaw

- Second BBA took place 23th August 2017:
  - BBA on Graphite/Mo and MoGr/Cu/Mo jaws with INDIV (~1,2E11ppp, x 50 shots)
    - Left/Top jaw (MoGr with Mo/Cu coating)
      - Beam center = 0.720 mm
      - Beam size = 0.350 mm
    - Right/Bottom jaw (Graphite with Mo coating)
      - Beam center = 0.600 mm
      - Beam size = 0.380 mm





Impacts type 1 on Graphite with Mo coating jaw

Time	Number of Bunches	Total Intensity (ppp)	Nominal sigma (mm)	Impact type 1 (sigma)	5th axis (mm)
23/08-2:25	288	3,54E13	0,3	0	7
23/08-2:27	288	3,56E13	0,3	0	7
23/08-2:29	288	3,49E13	0,3	0,25	7
23/08-2:31	288	3,48E13	0,3	0,5	7
23/08-2:34	288	3,46E13	0,3	0,75	7
23/08-2:36	288	3,46E13	0,3	1	7
23/08-2:38	288	3,45E13	0,3	2	7
23/08-2:40	288	3,44E13	0,3	3	7
23/08-2:42	288	3,44E13	0,3	5	7
23/08-2:44	288	3,47E13	0,3	7	7
23/08-2:46	288	3,46E13	0,3	9	7

Impacts type 2 on Graphite with Mo coating jaw

Time	Number of Bunches	Total Intensity (ppp)	Nominal sigma (mm)	Impact type 2 (sigma)	5th axis (mm)
23/08-2:53	288	3,48E13	0,3	0	0
23/08-2:55	288	3,49E13	0,3	0	0
23/08-2:57	288	3,47E13	0,3	0	0
23/08-2:59	288	3,49E13	0,3	0	0
23/08-3:31	288	3,48E13	0,3	0	0
23/08-3:33	288	3,45E13	0,3	0	0

Impacts type 3 on Graphite with Mo coating jaw

Time	Number of Bunches	Total Intensity (ppp)	Nominal sigma (mm)	Impact type 3 (sigma and tilt rad)	5th axis (mm)
23/08-3:10	288	3,47E13	0,3	0 and 0	14
23/08-3:12	288	3,50E13	0,3	0 and -300	14
23/08-3:14	288	3,40E13	0,3	0 and -150	14
23/08-3:17	288	3,38E13	0,3	0	14
23/08-3:19	288	3,48E13	0,3	0 and +150	14
23/08-3:21	288	3,48E13	0,3	0 and +300	14

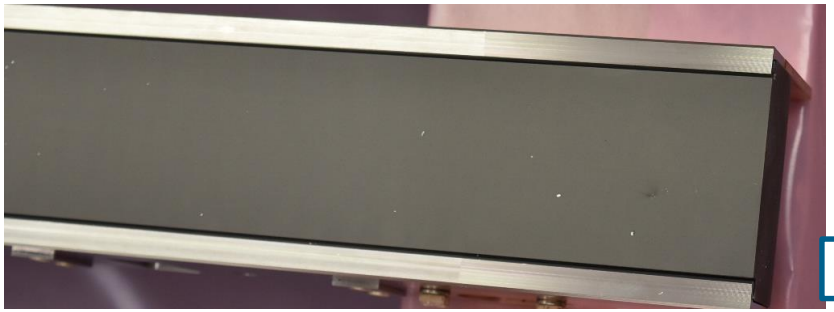
First Visual Inspection of Graphite with Mo coating jaw

1mSv/h at contact

Impact type 2

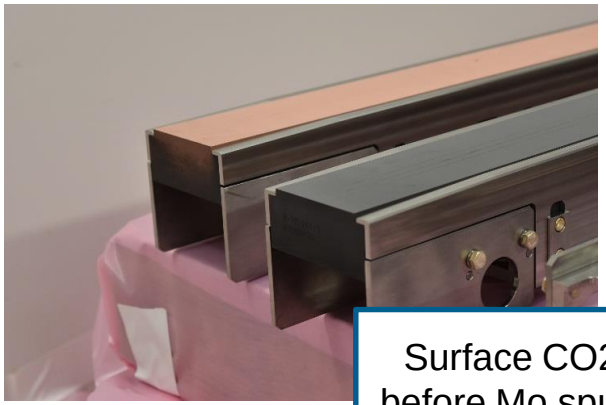
Impact type 1

Impact type 3



Upstream

Downstream



Surface CO2 blasted before Mo sputtering ~3 um

HRMT-35 Summary

- HRMT35 preliminary results indicate quite good coating adhesion with no apparent surface rupture for Cu coated graphite;
- The currently installed TDI and its SGL R7550 graphite blocks sputtered with Cu can perform under the worst impact conditions;
- Further PIE (e.g. coating adhesion tests and tomography) will be performed when residual dose rate will allow;

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HL-LHC PROJECT

Thank you for your attention

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