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WP4 Managing Innovation: Beam Windows and Composite Materials

I.FAST Period 2 Review

15th July 2024

F. Carra (CERN), M. Tomut (University of Munster, GSI)

With contributions from WP4.3 & WP4.4 members, CERN IRRAD and FLUKA teams

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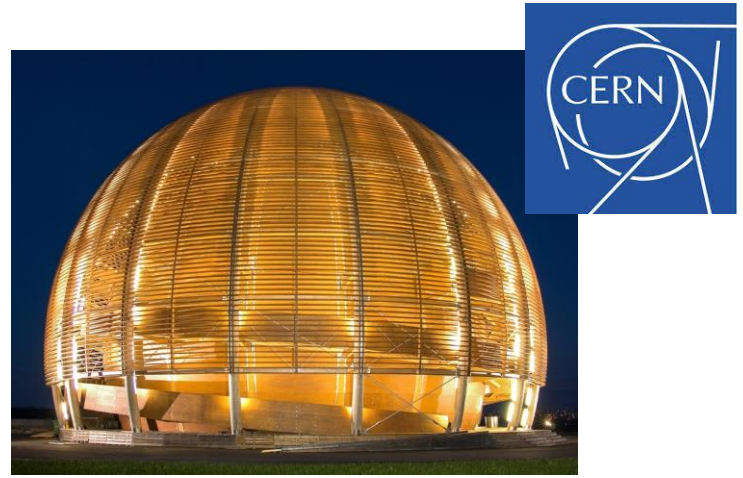
Outline

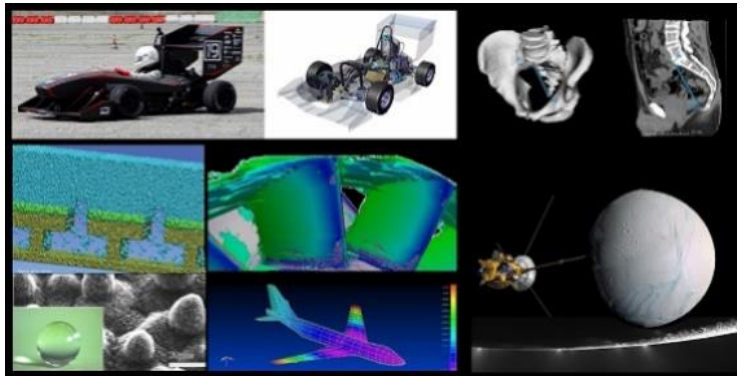
- Status of WP4.3 – Innovative beam windows for high-power accelerator applications
- Status of WP4.4 – Carbide-Carbon Materials for Multipurpose Applications
- Conclusions

(with focus on Period 2 activities)

WP4.3 – Innovative beam windows for high-power accelerator applications

- **Beam window**: separating environment at different pressures (vacuum/atmosphere or differential vacuum levels)
- Two technical solutions investigated within WP4.3
  - **Metallic windows** (tantalum, T91 steel, aluminium alloys)
  - **Graphenic windows** (thin graphene membranes)
- Task participants: **GSI (DE), RHP (AT)** and **CERN** + collaboration with **La Sapienza University - DIMA (IT)**





WP4.3 – Innovative beam windows for high-power accelerator applications

Milestone/Deliverable Number	Title	Lead beneficiary	Type	Dissemination level	Due Date (in months)
MS13	First characterisation of beam windows materials under thermomechanical load and extended radiation damage	GSI	Report	Public	18
D4.3	Manufacturing and testing of two beam-windows prototypes	CERN	Demonstrator	Public	32 → **38**

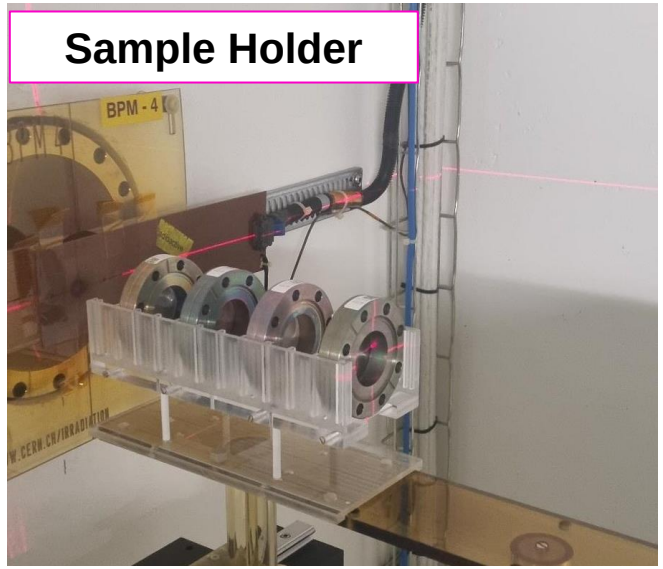
Deliverable D4.3

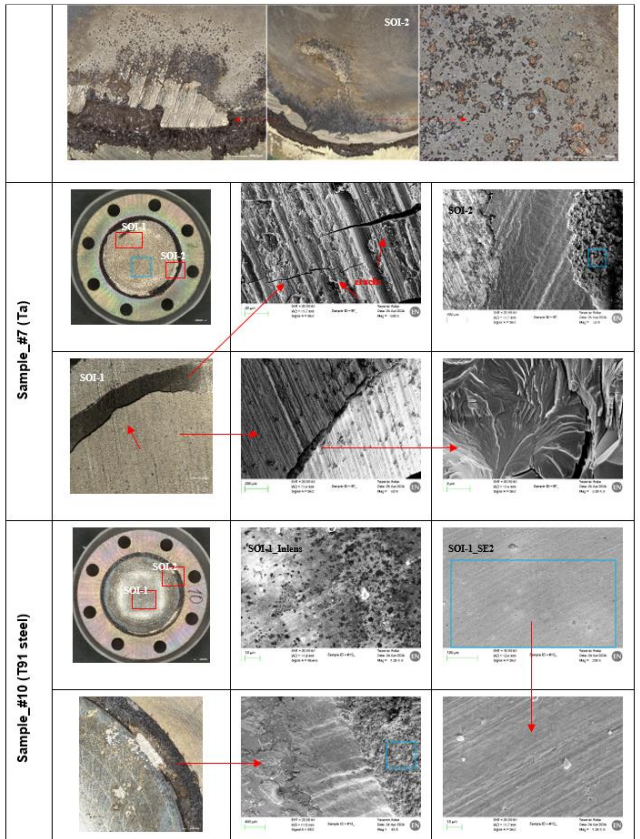
- Postponed by 6 months (June 2024) due to beam unavailability at GSI in '23
- Alternative solution found → **proton irradiation at CERN IRRAD in Sep-Oct '23**
- Samples cooldown until March '24 → **followed by thermomechanical characterization**
- **Deliverable completed and submitted in June '24**

D.3 in a nutshell

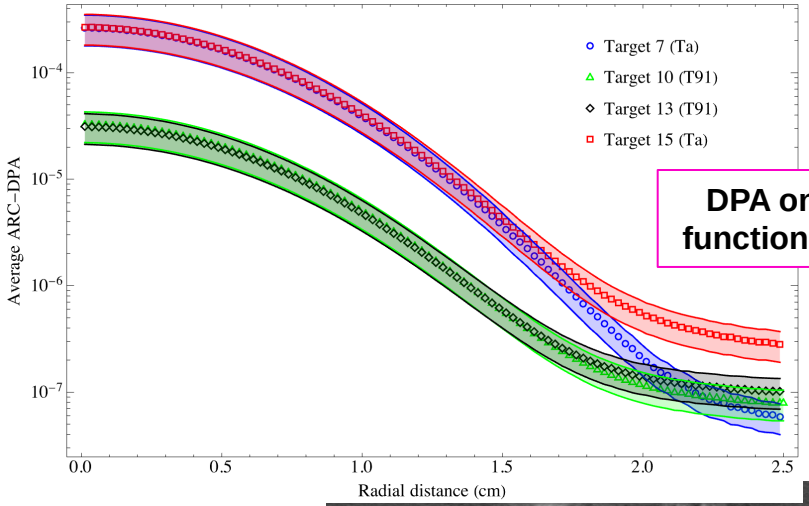
- **Facility**: IRRAD (PS proton beam, T8 beam-line at the CERN PS East Hall building 157) ***www.cern.ch/ps-irrad***
- **Beam**: protons @24 GeV/c
- **Samples**: thin foils brazed to metallic flange produced by **RHP**
- **Post-Irradiation Examination** showed qualitatively and quantitively that **materials well resisted to a radiation equivalent to ~1e-3 displacements-per-atom (DPA)**

Sample Holder



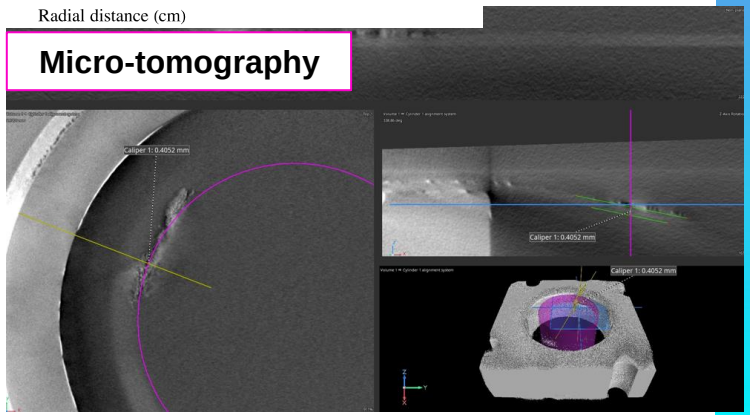


Microscopy



DPA on target as a function of the radius

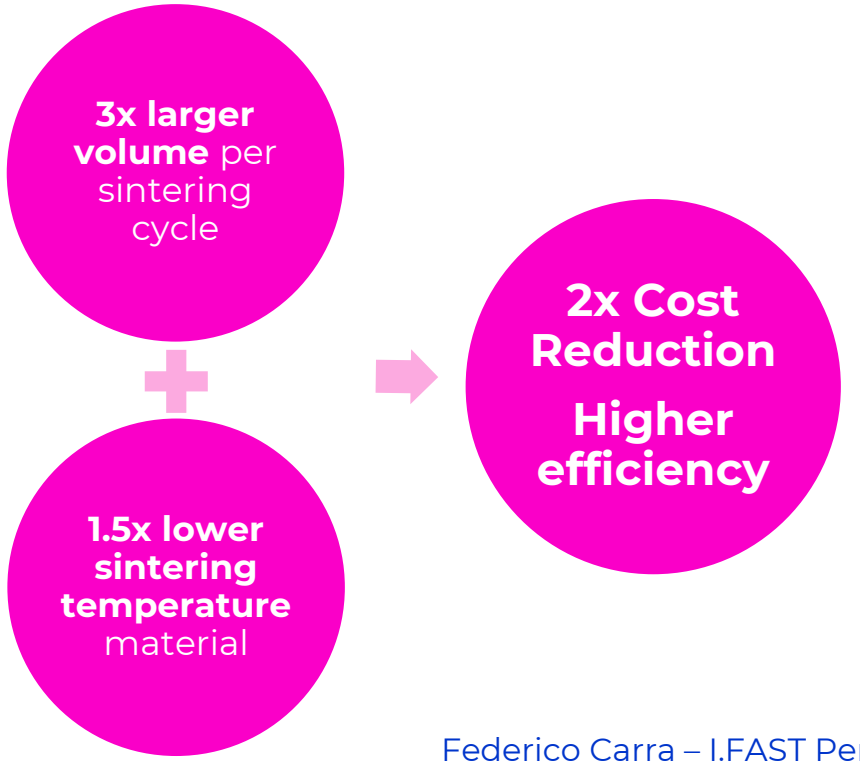
Micro-tomography



v 2, 15 July 2024

WP4.4 – Carbide-Carbon Materials for Multipurpose Applications

- Large scale Carbide-Carbon Materials for multipurpose applications (M1 – M48)
  - **Promote the use of carbide-carbon materials (CCM)** in future particle physics facilities and open up the market to commercial applications (thermal transfer, aerospace light components, fusion, etc.)
  - Thermal conductivity 2-3 times higher than Cu! Stronger, low density
- How?



- Who?

WP4.4 – Carbide-Carbon Materials for Multipurpose Applications

Milestone/Deliverable Number	Title	Lead beneficiary	Type	Dissemination level	Due Date (in months)
MS14	Evaluation of a CCM alternative to Molybdenum-Graphite	CERN	Report	Public	16
D4.4	Production of large-size CCM plates	CERN	Demonstrator	Public	24

D4.4 ***achieved in 2023*** *(**link**)*

- **Two big (Ø230 mm) Chromium-Graphite disks produced in a single machine cycle** (doubling of disk cross-section, decreasing of the sintering temperature wrt MoGr)
- Presented at the 2nd IFAST Annual Meeting (see ***here***)

Conclusions

- **WP4.3 Beam Windows:**
  - Beam windows assemblies prepared by RHP and irradiated at CERN at IRRAD in 2023
  - Cooldown completed in April 2024 and post-irradiation characterization + DPA / gas production calculations concluded in May
  - Results included in deliverable D4.3
  - **What's next**: ongoing irradiation of a 2nd sample holder at 10x higher fluence
- **WP4.4 Carbide Materials:**
  - MS and D completed, but additional activities already agreed / ongoing or under discussion
  - Main one is the thermomechanical characterization of the two big disks of Chromium-Graphite → ongoing at CERN mechanical laboratory
- **Extensive scientific contribution** through master thesis and papers already produced and some more is coming!

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Thank you for your attention!

From: F. Carra, C. Belei, M. Kitzmantel, M. Pasquali, M. Tomut, N. Vejnovic, J. Swieszek, S. Rivera, C. Gutierrez, L. Notari, S. Marin, F. Salvat Pujol, F. Ravotti, G. Pezzullo, I. Aviles, S. Hoell, J. Guardia Valenzuela, C. Accettura, O. Sacristan, L. Puddu, M. Losasso, and I'm probably forgetting someone…

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under GA No 101004730.

WP4.3 – Innovative beam windows for high-power accelerator applications

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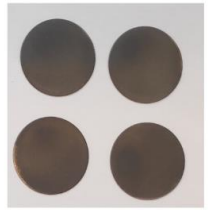
Milestone MS13 ***achieved in 2022*** (***link***)

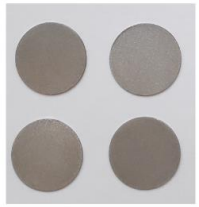
- **Ion irradiation of window foils** of different materials at GSI M-Branch UNILAC → T91 steel, Titanium grade 23, Inconel 718, Aluminium 6082 T6, graphene
- **Online and post-mortem characterization** of mechanical and thermal properties
- Well documented in **Marilena's** ***talk*** at 2nd IFAST Annual Meeting
- **Scientific production** on top of milestone report (**L. Notari** master thesis, international papers → *see "Scientific Contributions" in backup slides*)

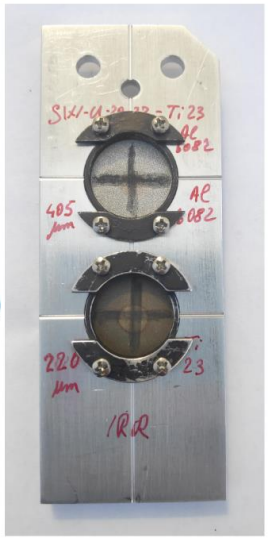
Courtesy of M. Tomut (GSI), L. Notari (La Sapienza)

Titanium Grade 23 (0.22 µm thickness)



Aluminium 6082 T6 (0.405 µm thickness)





WP4.4 – Carbide-Carbon Materials for Multipurpose Applications

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MS14	Evaluation of a CCM alternative to Molybdenum-Graphite	CERN	Report	Public	16
D4.4	Production of large-size CCM plates	CERN	Demonstrator	Public	24

Milestone MS14 ***achieved in 2022*** *(**link**)*

- **Chromium-Graphite** (CrGr) proposed (and produced) as a valid alternative to MoGr
- Presented at the 1st IFAST Annual Meeting (see ***here***)

D4.4 ***achieved in 2023*** *(**link**)*

- **Two big (Ø230 mm) Chromium-Graphite disks produced in a single machine cycle** (doubling of disk cross-section, decreasing of the sintering temperature wrt MoGr)
- Presented at the 2nd IFAST Annual Meeting (see ***here***)

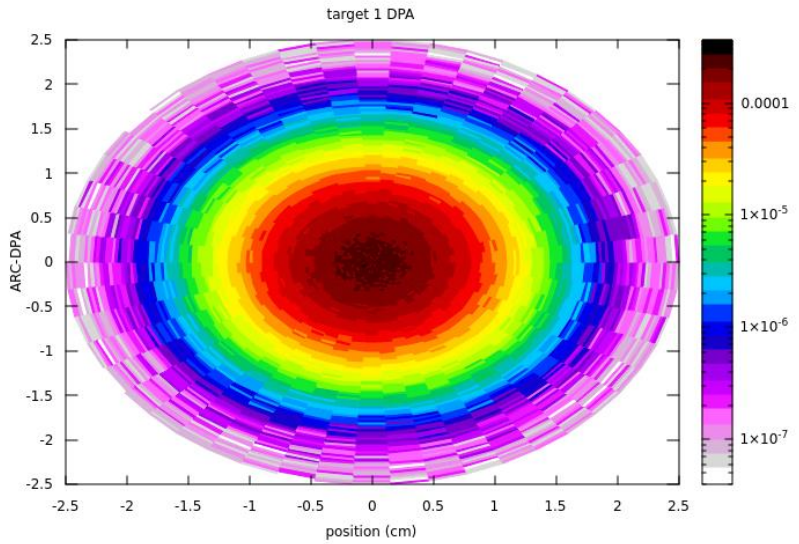
Scientific Contributions

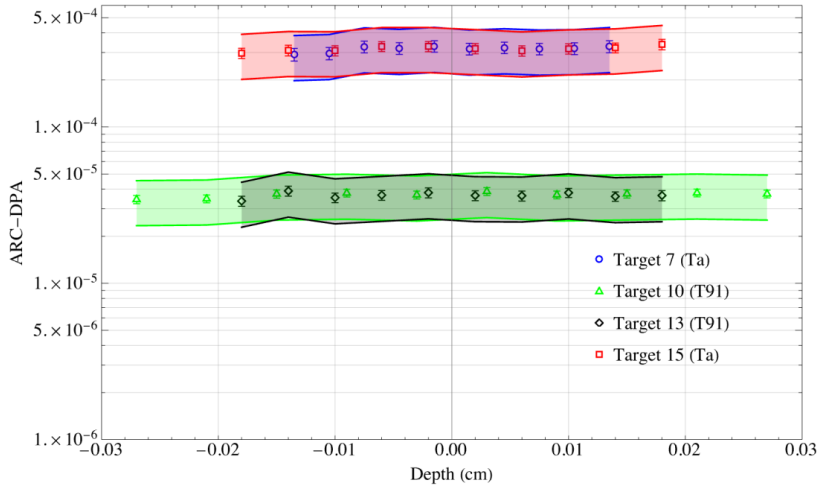
- L. Notari, "*Dynamic radiation effects induced by short-pulsed U-ion beams in metallic targets*", Master Thesis, 10.5281/zenodo.7484054
- L. Notari, M. Pasquali, F. Carra, M. Losasso, M. Tomut, "*Materials adopted for particle beam windows in relevant experimental facilities*", https://zenodo.org/uploads/10964349
- L. Notari, M. Pasquali, F. Carra, M. Losasso, J. Guardia-Valenzuela, M. Tomut, "*Dynamic response to short-pulsed U-ion beams of material candidates for vacuum beam windows manufacturing*", submitted to Heliyon and under review.
- Additional paper "wishlist":
  - L. Notari on simulations of 2022 windows irradiation – ongoing
  - F. Carra on 2023/24 windows irradiation
  - M. Tomut on graphenic windows
  - J. Guardia on Chromium-Graphite

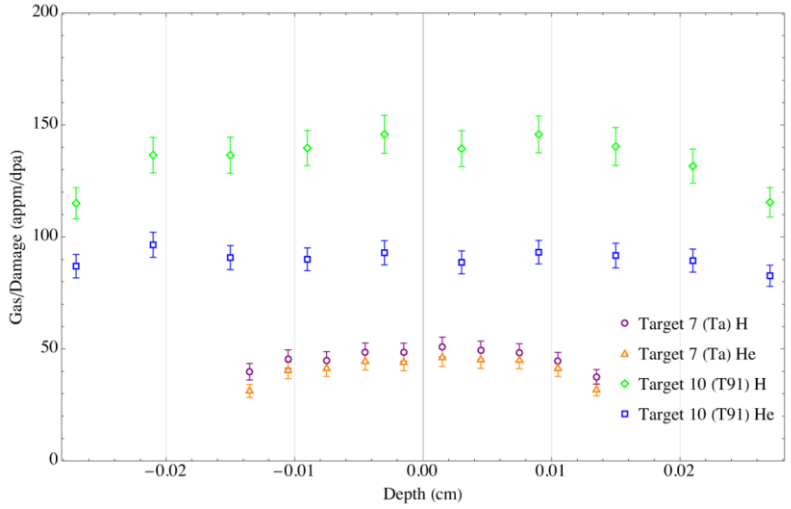
WP4.3 – Innovative beam windows for high-power accelerator applications

- Change in the thermomechanical properties will be correlated to the **estimated displacement-per-atom (DPA) and gas production** (big thanks to the FLUKA team at CERN SY-STI!)
- FLUKA simulations also allow to estimate the **temperature during irradiation** (preliminary: looks to be close to T_{room})
- Highest level of DPA in Sample Holder 1 **~5e-4 DPA** (ONGOING / PRELIMINARY ESTIMATION)

Courtesy of S. Marin, F. Salvat Pujol (CERN)
PRELIMINARY RESULTS!



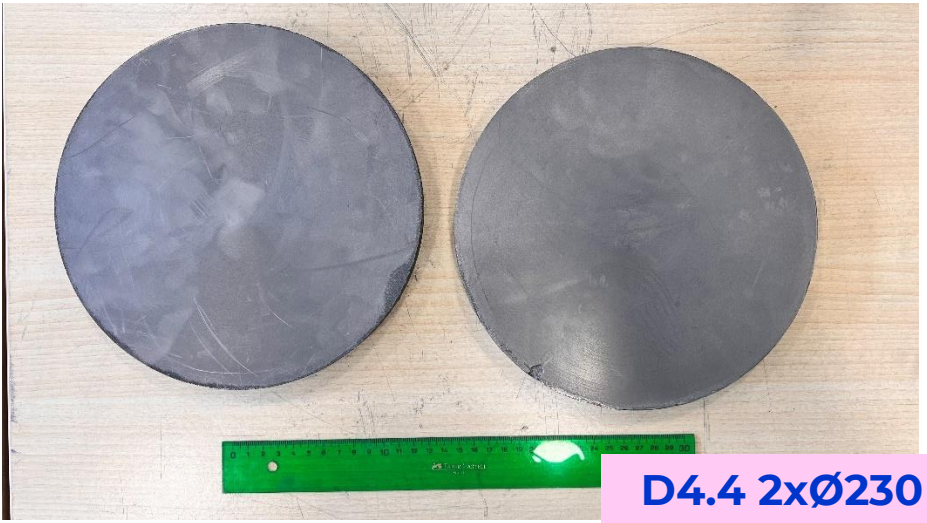


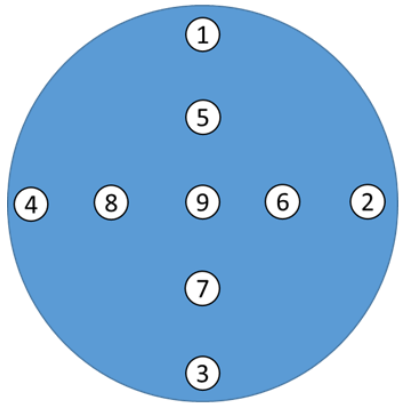


WP4.4 – Carbide-Carbon Materials for Multipurpose Applications

Possible additional activities until the end of the project

- **Already ongoing:** in-lab characterization at CERN of the full thermomechanical properties in temperature of the CrGr big disks (thanks to Nanoker for cutting > 100 samples!)
- One more sintering test with **increased disk thickness** (> 30 mm) to achieve record volume sintered per cycle?
  - Potentially followed by fine machining + metrology + UHV test?
- Scientific paper on CrGr → never disclosed in an international journal so far!





Conductivity (MS/m)		
Position	Side 1	Side 2
1	1,04	0,74
2	1,02	0,75
3	1,03	0,79
4	1,04	0,78
5	1,08	0,89
6	1,06	0,94
7	1,01	0,88
8	1,09	0,96
9	1,05	1,00
Average	**1,05**	**0,86**

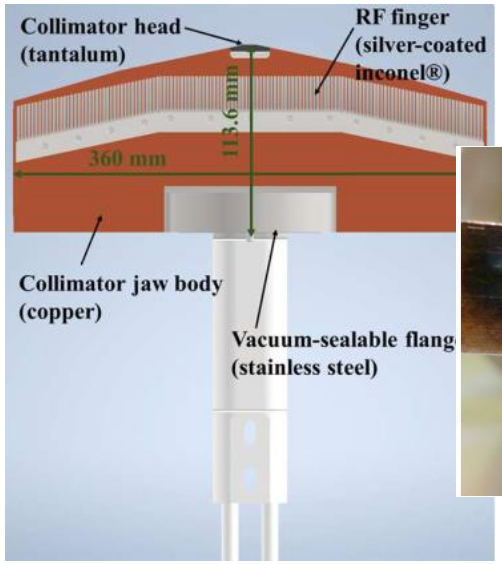
Conductivity (MS/m)		
Position	Side 1	Side 2
1	0,95	0,92
2	0,94	0,93
3	0,94	0,90
4	0,95	0,88
5	0,93	0,91
6	0,93	0,93
7	0,93	0,92
8	0,94	0,91
9	0,92	0,93
Average	**0,94**	**0,91**

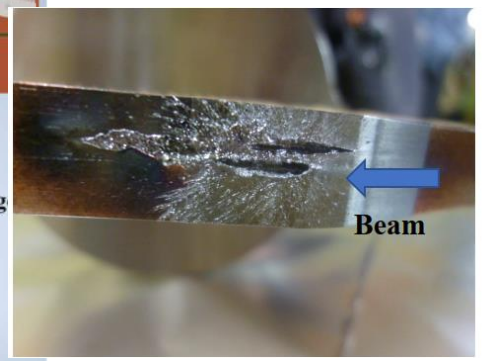
D4.4 2xØ230 mm CrGr plates

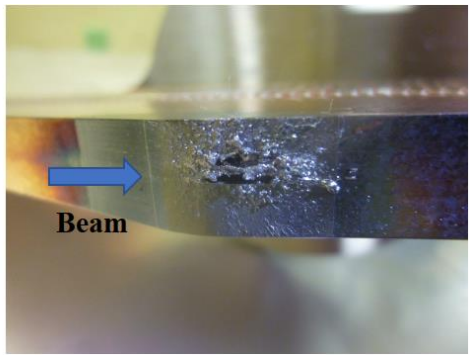
SAC recommendations and TRL

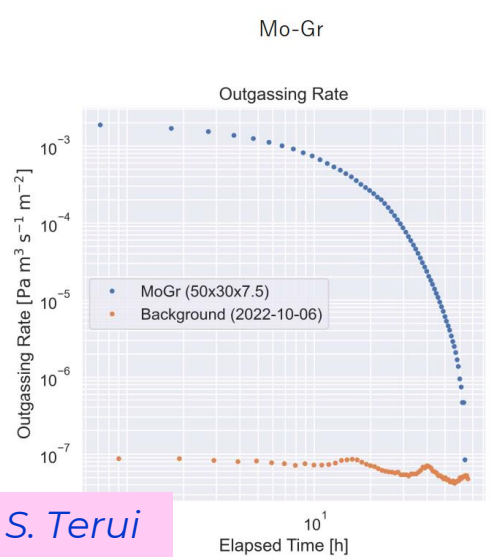
- **SAC Feedback from 2nd annual meeting:**
  - Carbide materials: it is a very successful development work good for HL-LHC at CERN and also for KEK-SuperKEKB.
- **15 HL-LHC collimators with MoGr already operating** in the LHC, CrGr development can provide cheaper solution
- **KEK collaboration via IFAST**: several material samples sent to KEK for study on SuperKEKB collimators

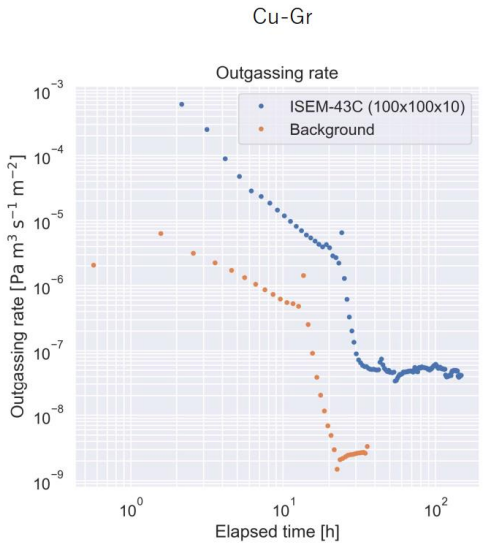
Big MoGr block for KEK studies, courtesy of S. Rivera











Fede

Studies at KEK, courtesy of S. Terui

SAC recommendations and TRL

- **SAC further (general) suggestions**
  - I.FAST technologies should be critically assessed with regards to a realistic pathway to identified markets and the time scales required.
  - For each technology, it would be good to get idea of technology readiness level (TRL) as not all developments seem to have the same level of market-readiness.

Technology	TRL	TRL definition	Time until market readiness (TRL=9)*	Comments
Ta and T91 beam windows	**6**	Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)	**2 years**	Assembly (window + flange bonding) requires optimization and testing at higher does / flux
Molybenum-Graphite	**9**	Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)	**–**	Installed in 12 HL-LHC collimators, currently under operation!
Chromium-Graphite	**4**	Technology validated in lab	**2 years**	Based on the experience with MoGr

**in presence of budget and a driving application scenario concretizes*