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

WP4 Managing Innovation
Status of Tasks 4.3 and 4.4

IFAST Steering Meeting
14th December 2023

F. Carra (CERN)
On behalf of IFAST WP4 members

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

- Two technical solutions investigated
  - Metallic windows (tantalum, T91 steel, aluminium alloys)
  - Graphenic windows (thin graphene membranes)

- What's next: **Deliverable D4.3**
  - Manufacture and test of 2 beam-windows prototypes, due date ~~December 2023~~ → June 2024
  - Postponed by 6 months due to beam unavailability in 2023
  - Alternative solution chosen → irradiation at **CERN IRRAD in S2 2023**

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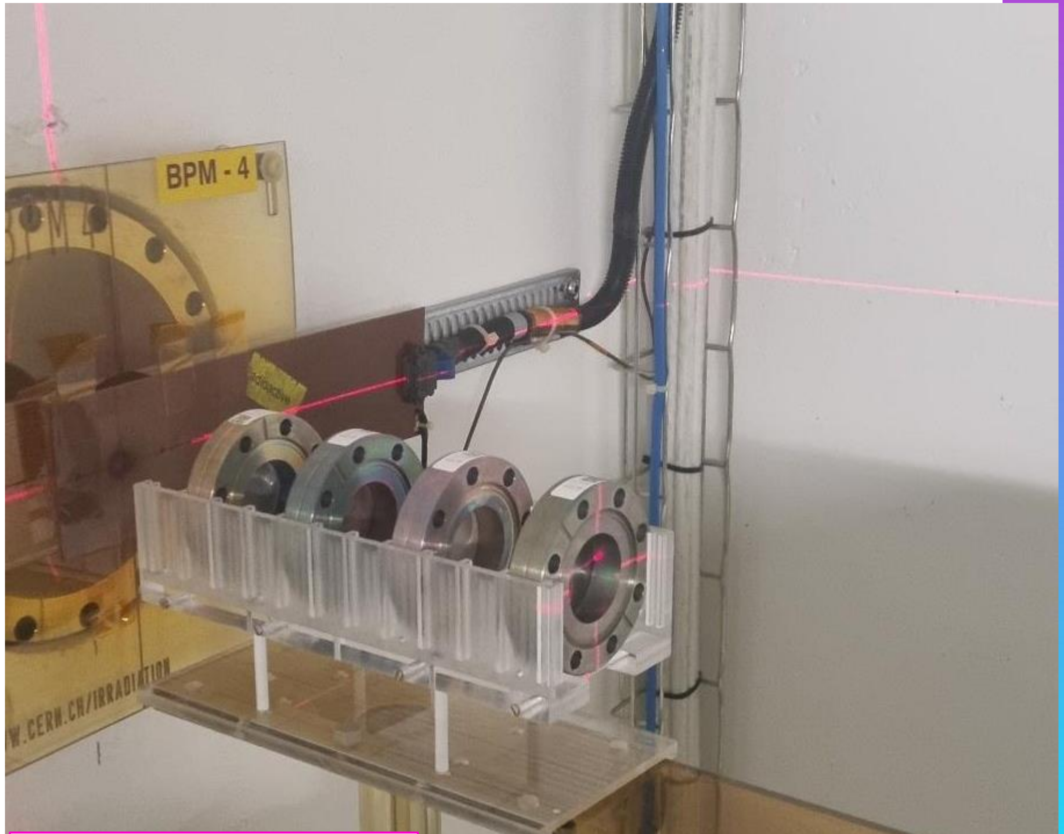
WP4.3 – Metallic windows

- **Facility**: IRRAD (PS proton beam, T8 beam-line at the CERN PS East Hall building 157)
- **Beam**: protons @24 GeV
- **Samples**: thin foils brazed to metallic flange produced by **RHP**
  - **Sample Holder 1** (Irradiation period **6 September – 11 October 2023**, fluence: 1-2E16 p/cm2 20x20 / 10x10 mm^2, 3-5 MGy Si)
    - Sample #7 → Tantalum, diameter 20mm, thickness 0.3mm
    - Sample #15 → Tantalum, diameter 20mm, thickness 0.4mm
    - Sample #13 → T91, diameter 20mm, thickness 0.4mm
    - Sample #10 → T91, diameter 20mm, thickness 0.6mm
  - **Sample Holder 2** (Irradiation period **April – June 2024**)
    - Sample #8 → Tantalum, diameter 20mm, thickness 0.6mm
    - Sample #9 → T91, diameter 20mm, thickness 0.4mm
    - Sample #11 → T91, diameter 20mm, thickness 0.6mm
    - Sample #10 → Graphene, 10x10 mm, thickness 1 um

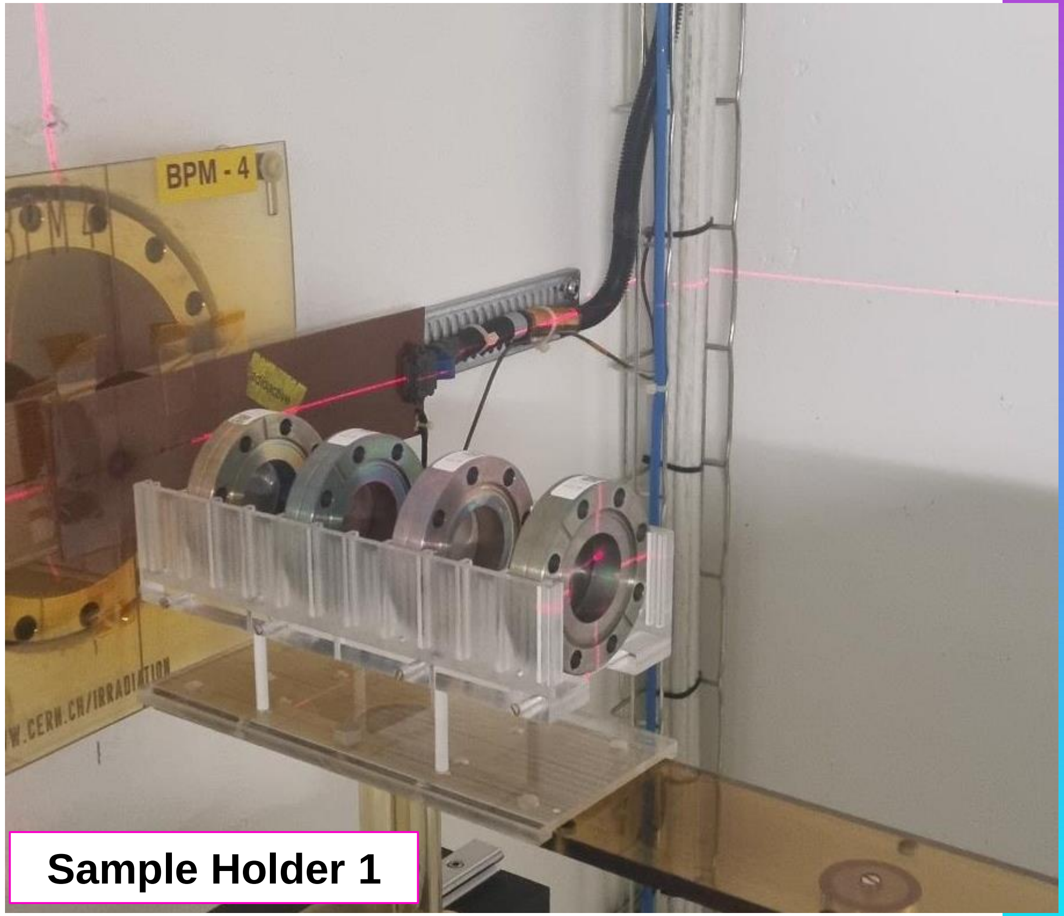
  - D4.3 due by June 2024, so to be ready somewhere in April 2024 → **only Sample Holder 1 will be in its scope**



Sample Holder 1

WP4.3 – Metallic windows

- **Post-Irradiation Examination (PIE)**
  - Samples still at some mSv/h at contact → cooldown until January 2024
  - **January – April 2024**: thermophysical properties testing of irradiated vs unirradiated samples at CERN (MME Mech Lab and MME-MM)
  - Deliverable will include also additional tests done at RHP during production (i.e. dye penetrant testing)
  - We aim at **calculating also DPA** allowing to compare irradiation conditions to operational beam windows in applicative cases, e.g. ADS, muon collider, etc. → CERN FLUKA section contacted
- Aiming at completing deliverable document by the **end of April 2024** for review by project management
- **Extensive scientific production**: 3 papers prepared (1 of which already accepted for publication at PRAB) + 1 Master Thesis + 1 paper planned by the end of the project

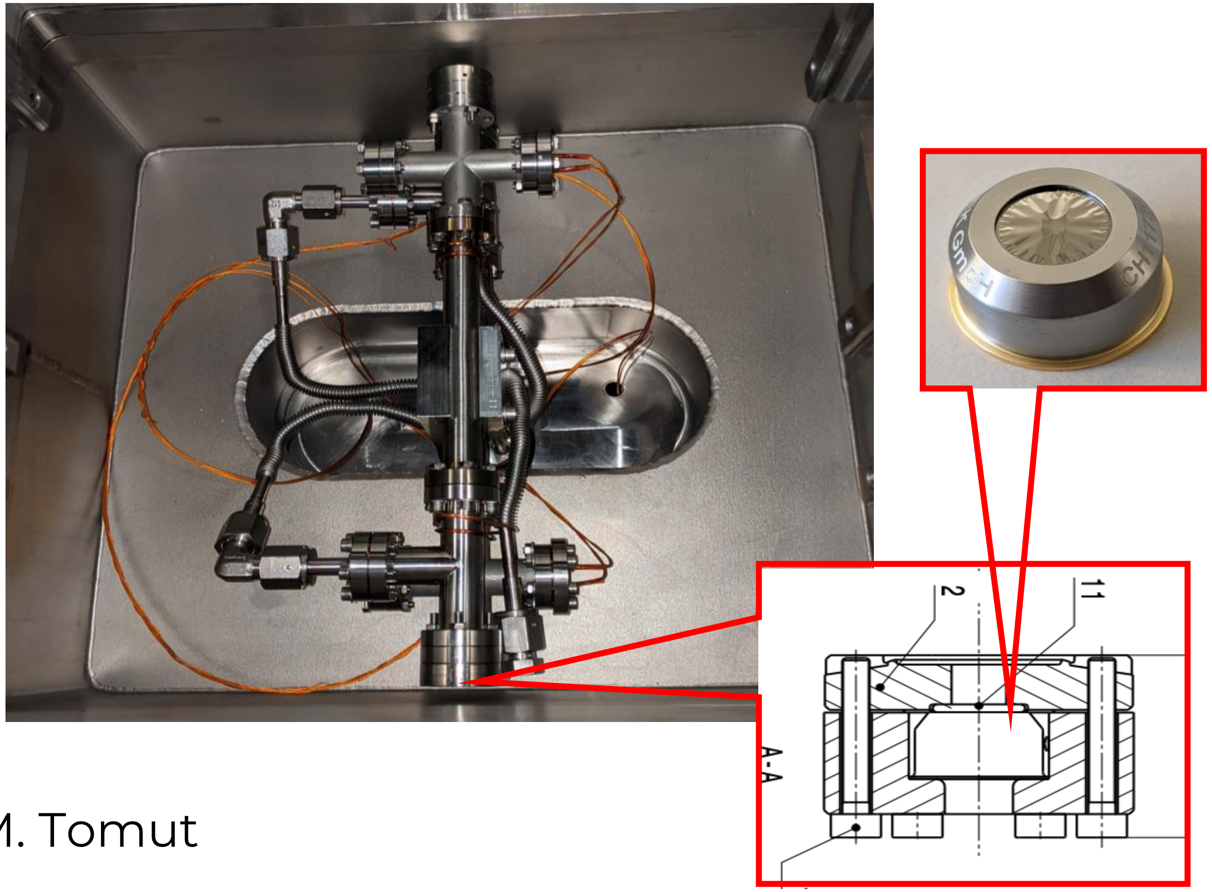


Sample Holder 1

WP4.3 – Graphenic windows

Irradiation of GC at UNILAC, GSI
4.8 MeV/u ^{197}Au

Set up for pressure and leak test of irradiated GC



Courtesy of M. Tomut

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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

- **Milestone MS14** due date August 2022, achieved in **June 2022**
  - Alternative to MoGr proposed and validated → **Chromium-Graphite (CrGr)**
- **Deliverable D4.4** completed in **April 2023**
  - *Produce two large CCM plates (cross section >400 cm^2) in a single sintering cycle*
  - This means: moving from the sintering of Ø170 mm to Ø230 mm plates → **doubling the cross-section** (and: 2 plates per cycle!). **CrGr selected as CCM material for the deliverable**.
  - Sintering run successfully completed in March 2023

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WP4.4 – Carbide-Carbon Materials for Multipurpose Applications

More in F. Carra's talk at 2nd IFAST Annual Meeting

WP4.4 – Carbide-Carbon Materials for Multipurpose Applications

- All milestones and deliverables of I.FAST task 4.4 **have been reached in the first two years of the project**
- However, in the scope of the task objective (reduction of cost of carbon-carbide materials), **several actions are still foreseen in the last two years of I.FAST**:
  - **Complete the in-lab characterization of the CrGr** produced in the scope of deliverable D4.4, and publish the results on an international journal (record achieved in CrGr thermophysical properties and record in a CCM size sintering)
  - Optimize and, if possible, remove production steps related to material **pre-dwell and annealing**
  - Study the machine insulation system to understand if further improvements are needed to **reduce power losses**
  - **Further increase the material volume produced per cycle**: increase the plate thickness (up to 5 cm?) and/or increase the number of plates (up to 4?)
  - Optimize the material composition to **reduce spilling of molten metal**

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Thank you for your attention!

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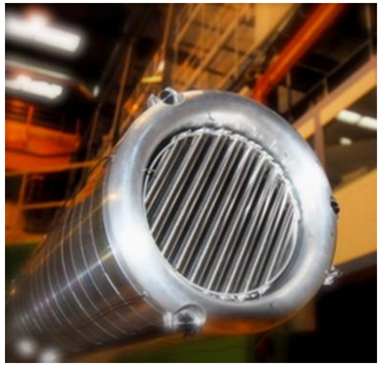
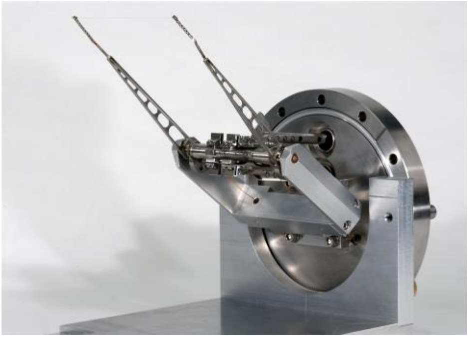
Motivation

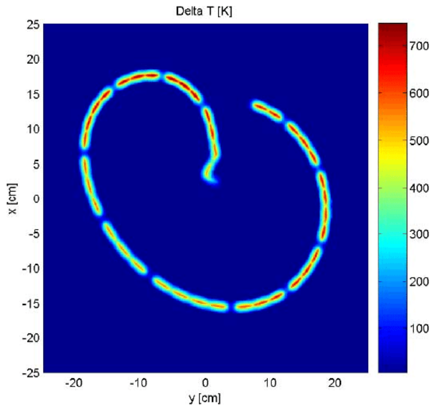
- **Increasing worldwide request for thermal management materials** (high thermal diffusivity and specific heat, low density)
- **Cost still high**: CCM are limited to high-end applications (nuclear energy, particle physics, aerospace, …)
- Decrease of energy consumption, improvement of production cycle **efficiency and sustainability** are also a must
- In particle physics: very interesting for **beam-intercepting devices and beam instrumentation, beam windows, etc.**



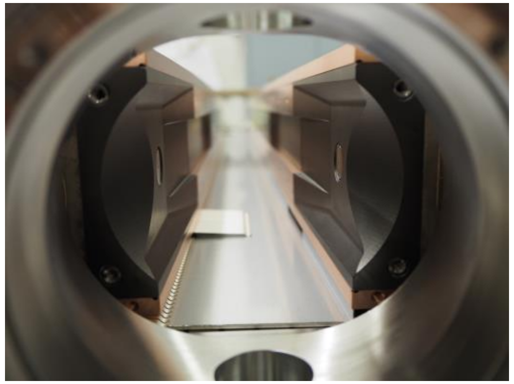
Targets



Beam wire scanners



Dumps



Collimators

Expected figures for the development of the thermal management market in the next years, source: *https://www.marketsandmarkets.com/Market-Reports/thermal-management-market-155049228.html*

Year 1 activities – Technical Specification

- Definition of the **minimum thermophysical properties** for a use in HEP beam-intercepting devices and in thermal-management applications

Property	Specification		
	ll*	⊦	Unit
Density at 20ºC	2.40 – 2.60		[g/cm³]
Specific heat at 20ºC	> 0.6		[J/(g·K)]
Electrical conductivity at 20ºC	> 0.75		[MS/m]
Thermal Diffusivity 20ºC /at 300ºC	> 350/100	> 20/6	[mm^2/s]
Thermal conductivity at 20ºC /at 300ºC	> 500/280	> 35/20	[W/(m·K)]
Volumetric CTE 20-1000ºC	< 7		[$10^{-6}K^{-1}$]
Coefficient of thermal expansion 20-1000ºC	< 2.9	< 15	[$10^{-6}K^{-1}$]
Young's Modulus at 20ºC	35 < E < 75	5 < E < 8	[GPa]
Flexural strength at 20ºC	> 60	> 10	[MPa]
Flexural strain to rupture at 20ºC	> 2500	> 4000	[µm/m]
Dimensional stability*	< 0.05	< 0.25	%

**The dimensional stability shall be ensured after the following thermal cycle: heating of the specimen up to 1950ºC with a ramp of 5ºC/min. Cooling of the specimen down to room temperature with the same ramp.*

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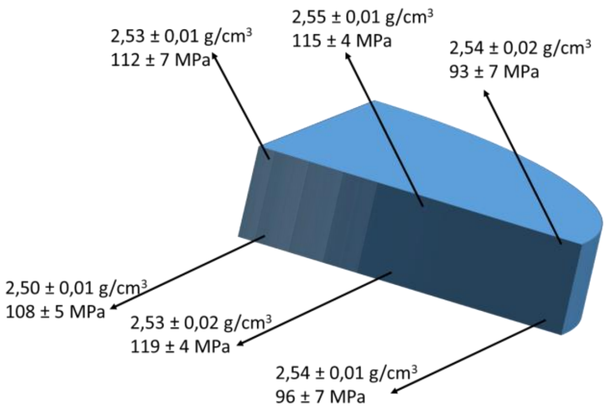
Year 1 – Increase of volume per cycle

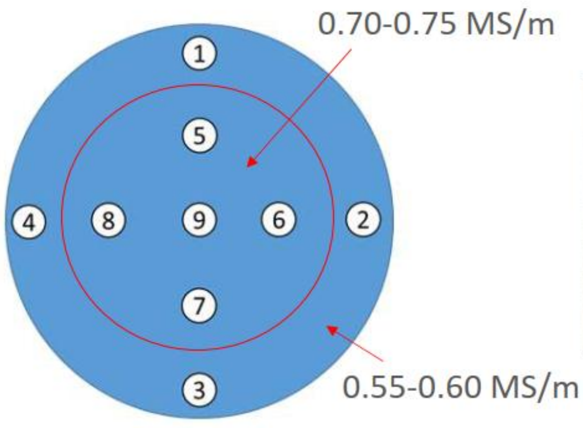
- **Molybdenum-Graphite** (sintered at 2640°C)

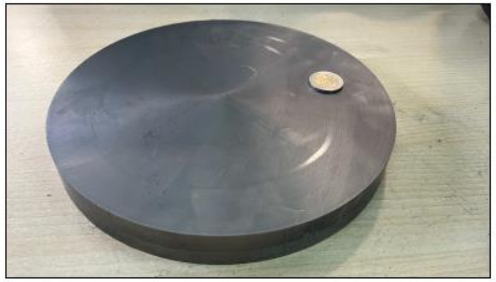
2 plates produced with 230 mm Diameter (2x bigger section than before IFAST)



Disk (230 mm diameter)	Density (g/cm³)	Electrical Conductivity (Mean values on each side) (MS/m)
Plate #1 (p=26 MPa)	2,53	0,6 – 0,63
Plate #2 (p=40 MPa)	2,60	0,65 – 0,68
Specification	**2,3 ÷2,6**	**>0,8**

Lower electrical conductivity values than in the 170 mm diameter disks





Pre-compaction of the green powder:

Maximum Applied Force Uniaxial Hydraulic Press ~ 900 kN

- 170 mm Ø → 40 MPa → 2,00 g/cm³
- 230 mm Ø → 21 MPa → 1,65 g/cm³

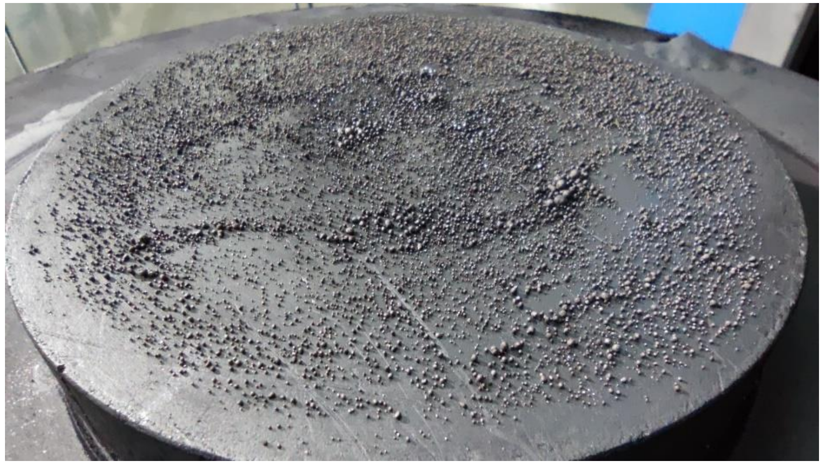
Next: increase the metal content, together with the higher sintering pressure

Year 1 – Decrease of sintering Temperature

- **Chromium-Graphite** (sintered at 2000°C – 1.3x lower T)
- Concept proposed by **Jorge Guardia** within ARIES WP14 & WP17, technically was not demonstrated yet (very poor mechanical properties)

3 plates produced with 170 mm Diameter

Disk (170 mm diameter)	Density (g/cm^3)	Electrical Conductivity (MS/m)
Plate #1	**2,30**	**1,00 – 1,07**
Plates #2 & #3	**2,30**	**0.75/0.81**
Specification	**2,3 ÷2,6**	**>0,8**



Reusable Mold and Parts → Important Cost Reduction

- **Plate #1 produced in a single plate per cycle**, very promising properties, decision for full characterization at CERN
- **Plates #2 and #3 double-plate per cycle**, losing a bit in conductivity → composition and cycle to be optimized

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Year 1 – CrGr Characterization