Simulations Techniques at the EN-MME Engineering Unit

Meeting CERN/Université de Liège – F. Carra – CERN EN/MME *(on behalf of the MME Engineering Unit)*

2024-12-06

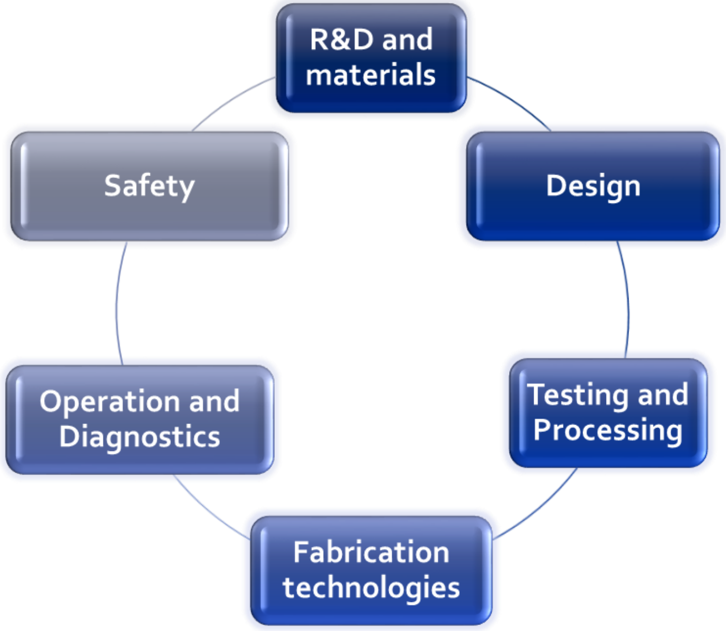
Outline

- **EN/MME Engineering Unit**

- **Analytical & Numerical techniques:**
  - Finite Elements Implicit tools: ANSYS
  - Multiphysics techniques: COMSOL
  - Finite Elements Explicit tools: LS-Dyna & Autodyn

- **Conclusions**

EN/MME Engineering Unit



Scope

- 15 engineers including staff, fellows, students and industrial support
- In charge of **advanced computations and engineering studies** requested by the CERN community (groups, departments, experiments)

Collaborations

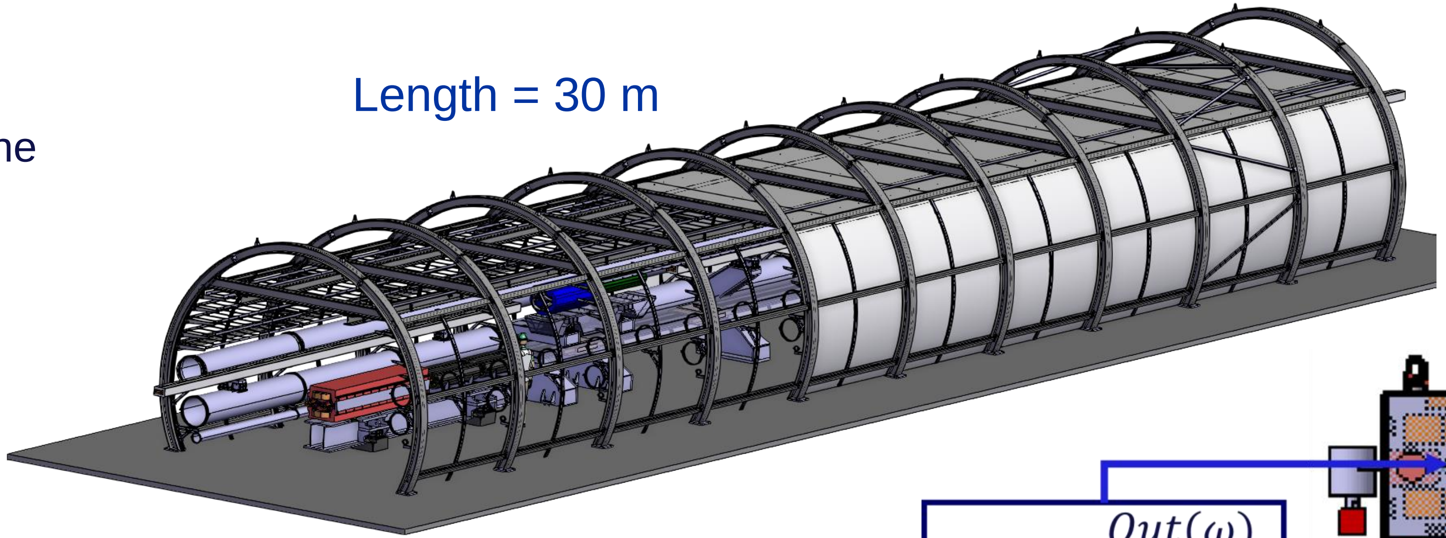
- **Strong synergy** with the other EN-MME poles (design office, workshop, mechanical and material laboratories)
- External collaborators from La Sapienza (IT) & University Carlos III (ES)

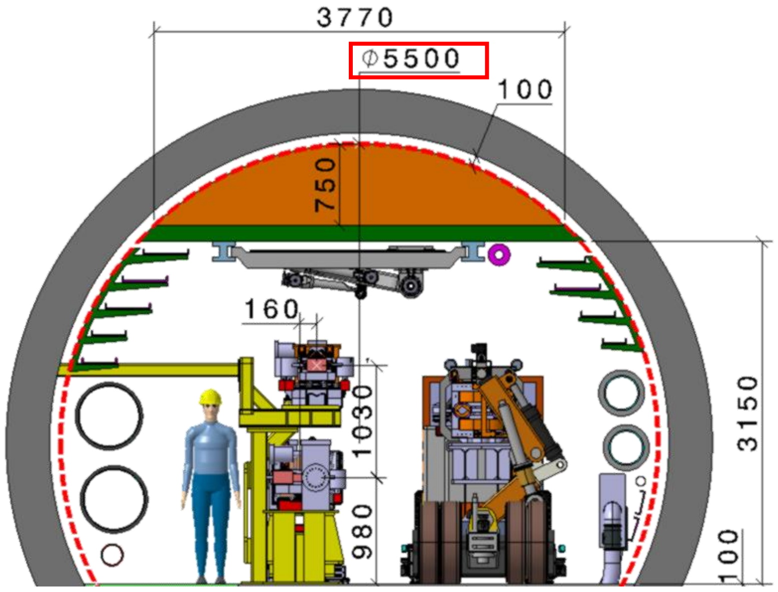
Implicit FE simulations: FCC-ee mock-up

FCC-ee arc half cell mock-up

- **Large metallic structure** representing the most repeatable part of the new FCC-ee accelerator
- **Requires** calculations to demonstrate stability and safety of the installation

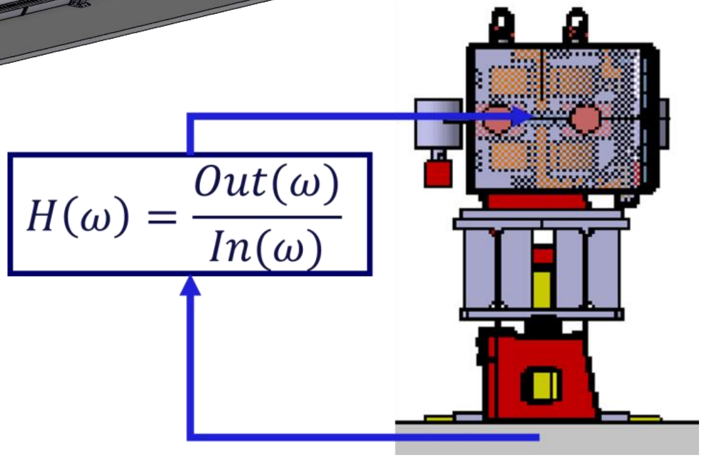
Length = 30 m



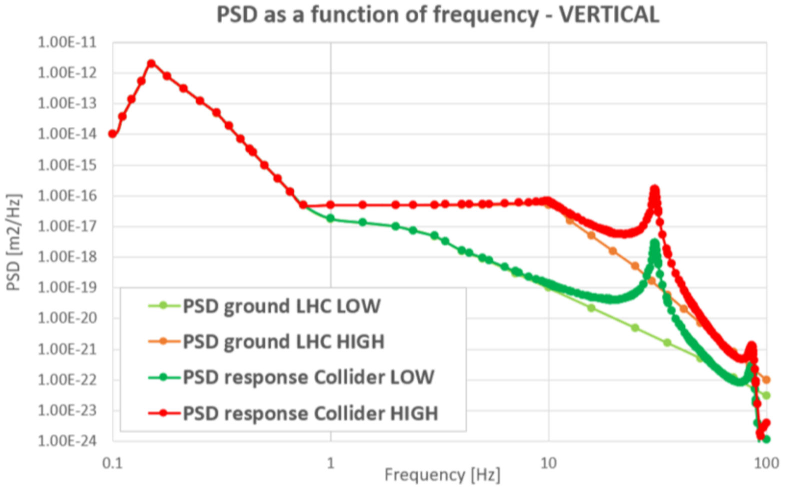


Analytical & Numerical calculations

- **Static and seismic** computations of the frame according to Eurocode 3, EN 13155
- Static + Modal + Random **Vibration analyses** of the short straight sections



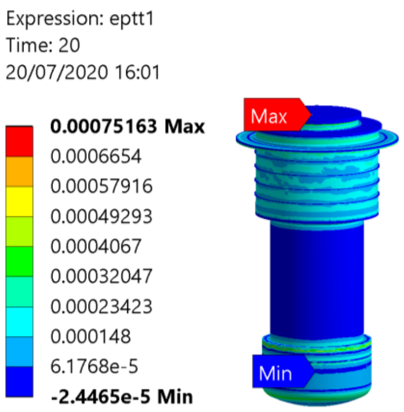
$$H(\omega) = \frac{Out(\omega)}{In(\omega)}$$

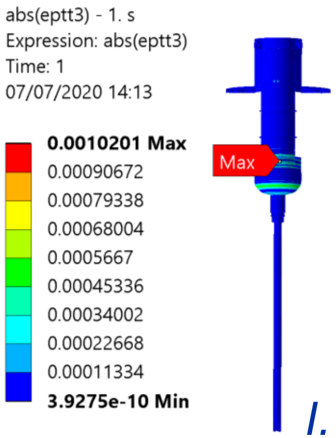


Implicit FE simulations: FRESCA-2

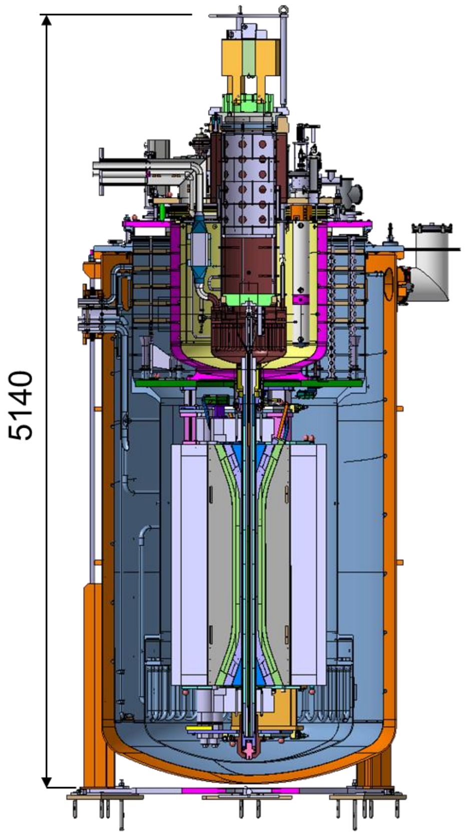
FRESCA-2: Facility for Reception of Superconductive Cables

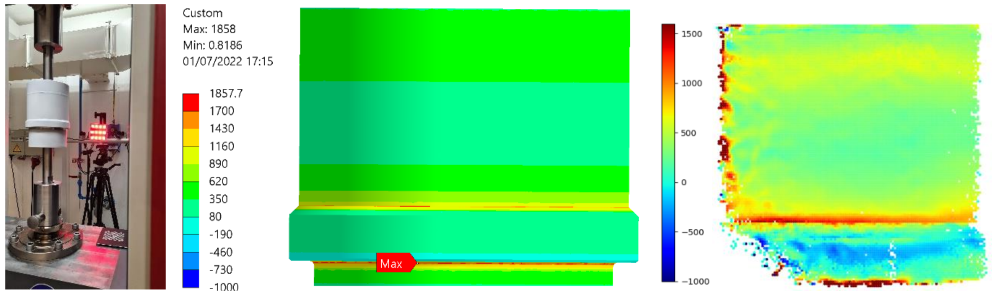
- **Large cryostat** with 13T magnet for superconductive cable measurements
- **Subjected to high loads** (pressure, joints, thermal gradient, EM torque)





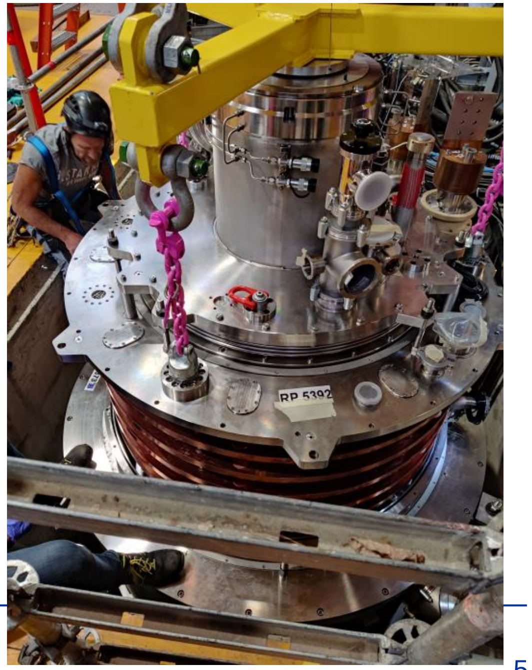
I. Tabian





Numerical calculations

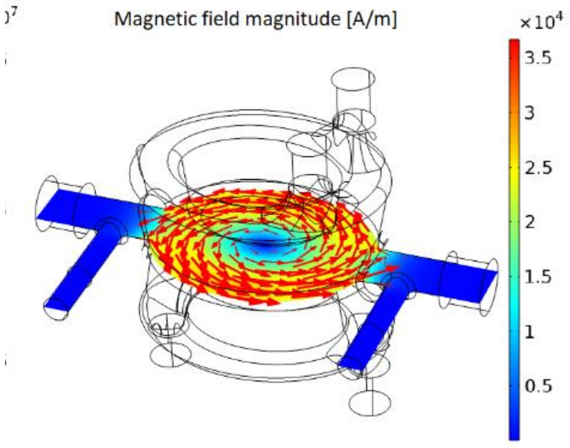
- **Thermo-mechanical** analyses (EN 13445)
- Also **benchmarked with MME Mech-Lab** measurements (DIC)



Multiphysics calculations: Crab cavities

Multiphysics strongly-coupled simulations

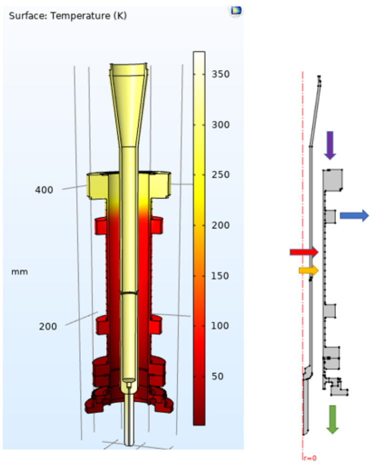
- We use COMSOL when the problem is **strongly coupled**
- e.g. electro-magnetic-thermal, thermomechanical with pressurized contacts, etc.



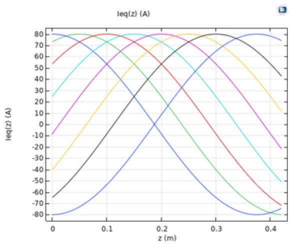
EM-Thermal coupled
T. Guillen Hernandez

FPC RFD, example of results

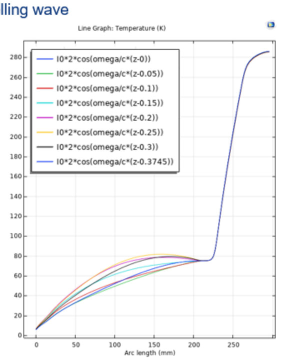
- Coating: 15 μm copper+ 1 μm gold
- One thermalisation point at 75 K
- RF power: 40000 W



RF current travelling wave



Temperature distribution on the inner surface of the FPC tube, considering RF current travelling wave



Heat loss considering RF current travelling wave

move	Qbath [W]	Qrad+P [W]	Qheat [W]	Qterm [W]
0	3.00	-8.82	-39.30	45.12
0.05	3.17	-7.54	-39.43	43.80
0.1	3.82	-6.06	-40.61	42.84
0.15	4.62	-5.51	-42.05	42.94
0.2	5.07	-6.39	-42.80	44.12
0.25	4.76	-7.91	-42.36	45.51
0.3	3.88	-9.00	-41.03	46.14
0.3745	3.00	-8.83	-39.30	45.13

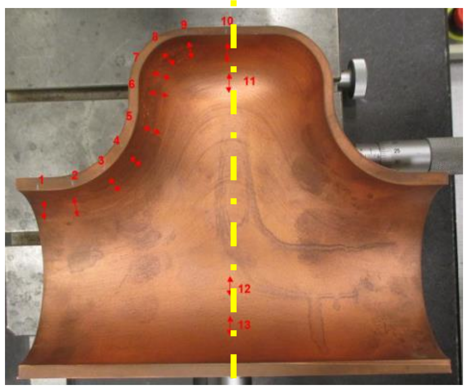
Crab Cavities: Fundamental Power Coupler (FPC)

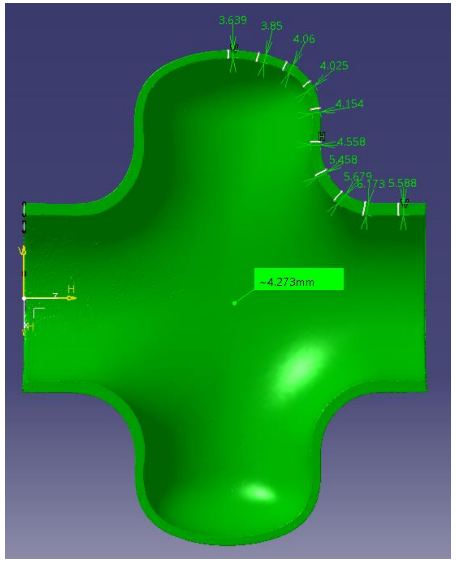
- Thermal dissipation through the FPC line
- Joule effect is a function of space and resistivity, but resistivity is a function of temperature! **Electro-Thermal**
- **Strong coupling needed (COMSOL)**

Explicit FE simulations: LS-Dyna

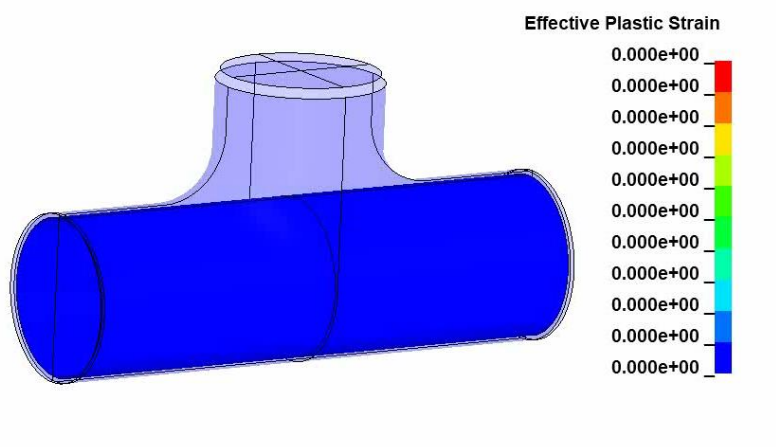
Design for fabrication

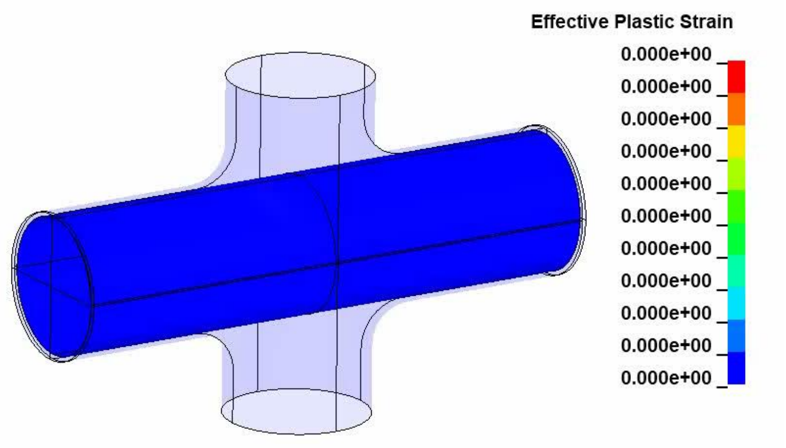
- **Forming, hydroforming, bending, stamping**: high deformations (above 100%!) → **LS-Dyna**
- FE allows to **greatly reduce the number of experimental iterations** during a manufacturing process development
- Examples of application are **SRF cavities, pipe joints, dump cooling circuits, etc.**





Pipe joints





J. Swieszek

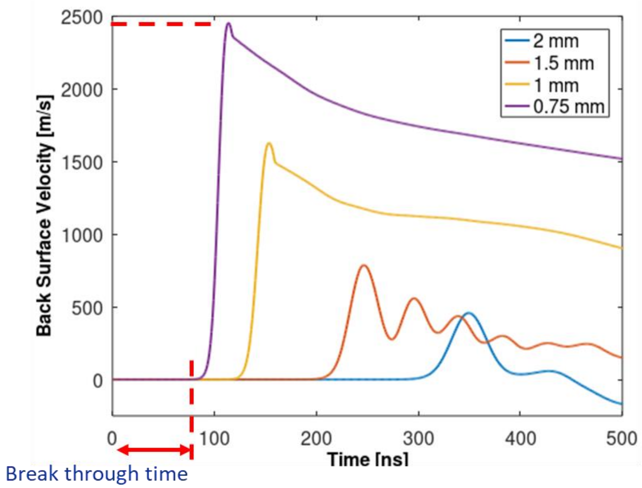
SPS dump, hipping pipe

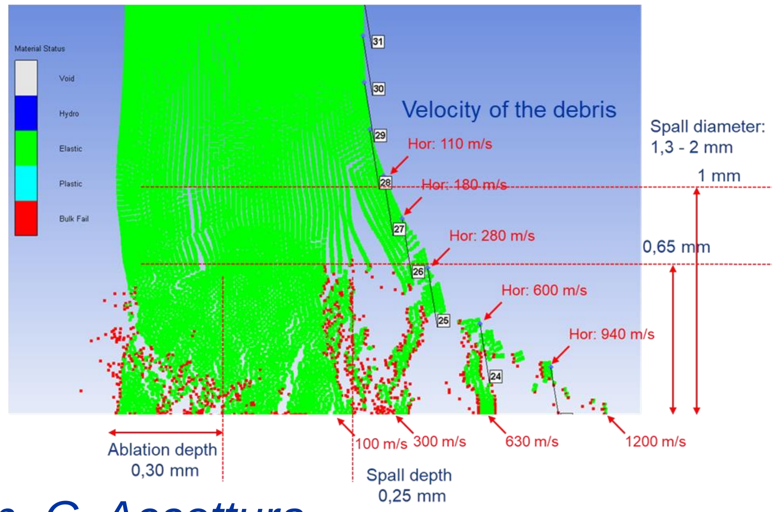
F. Carra

Explicit simulations: Autodyn

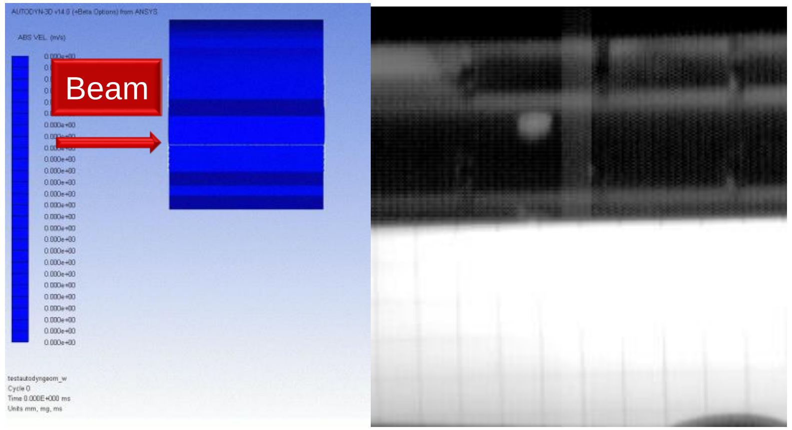
Laser and particle beam impacts

- **Beams impacting on matter** (e.g. dumps, targets, collimators, etc…)
- Quasi-instantaneous heat deposition, expansion prevented by inertia
- **Stress waves, changes of phase, ablation, explosion**, … → **Autodyn**



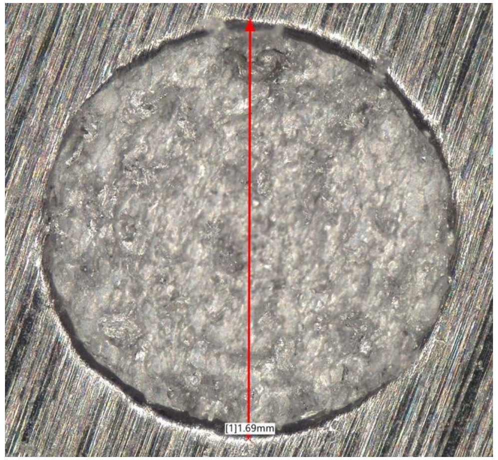


L. Baudin, C. Accettura



Numerical model

- Explicit solver to simulate changes of phase, material fragmentation, etc…
- Can be similarly adapted to **laser impact cases**



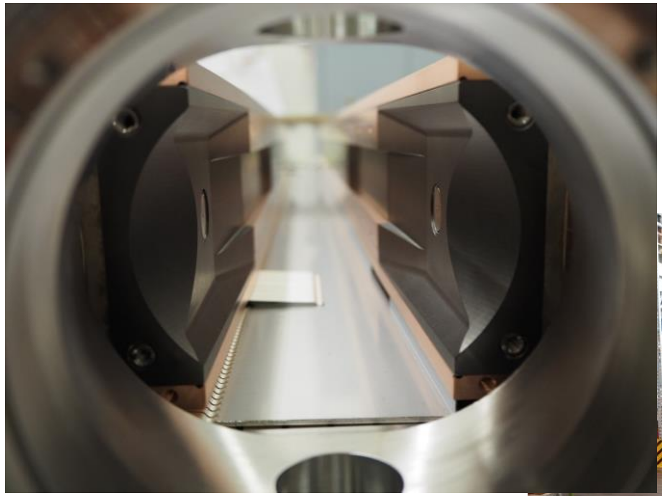
Conclusions

- The **EN-MME Engineering Unit** is a team in charge of engineering studies for the other groups, departments and experiments
- The unit has developed a **core of competences** in the past years including, but not limited to, analytical, semi-analytical and numerical techniques, as well as expertise in the development of advanced composites
- **Young, motivated team** made of Staff, Students, Fellows, IS tightly, **integrated with Design Office, Main Workshop and Mech Lab**
- Very open and **active in collaborations, exchanges, multi-institute projects**

Engineering Department

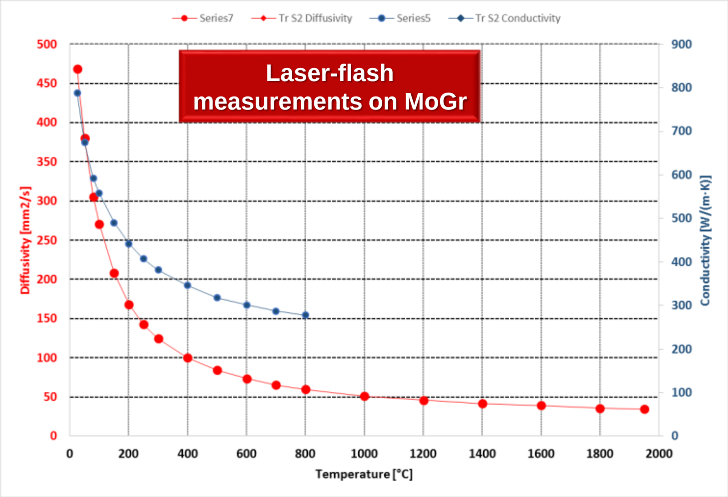
home.cern

R&D on advanced materials



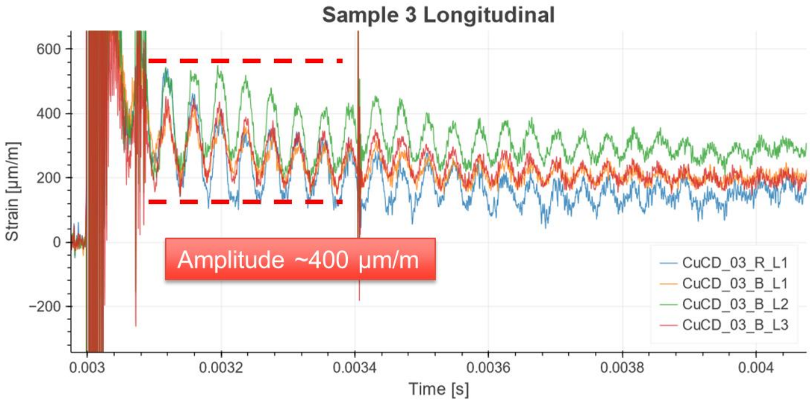
Development of advanced composites

- In collaboration with MME Mechanical Laboratory and EN-MME-MM section
- Originally launched for LHC collimators in 2007, but **exploitable for all beam intercepting devices and for thermal management industrial applications**!
- Explored composites combining the properties of **graphite or diamond** with those of **metals and transition metal-based ceramics**



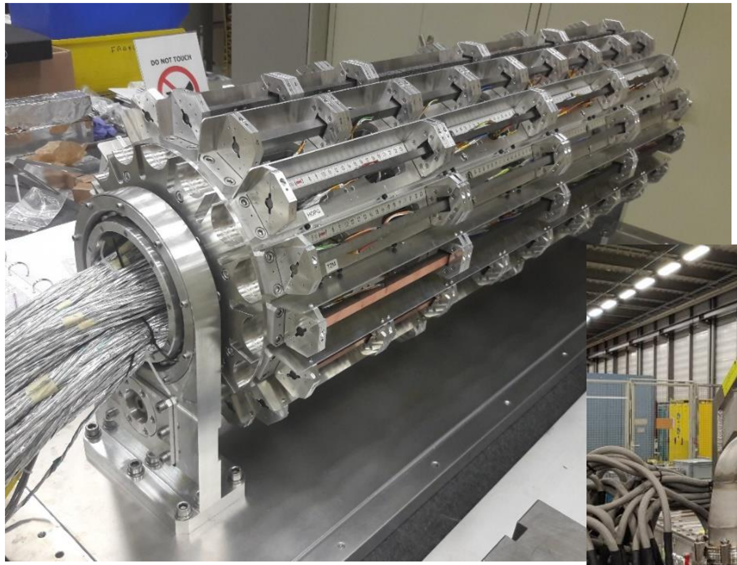
- Development and characterization led to industrialization of **Molybdenum-Graphite (MoGr)** and **Copper-Diamond (CuCD)**
- **MoGr: procured by EN-MME for LS2 collimator series (5 primaries and 10 secondaries)** → multi-MCHF industrial contract with Nanoker (ES)
- **CuCD: industrially procured by EN-MME for IR collimator prototype (TCTPXH)**

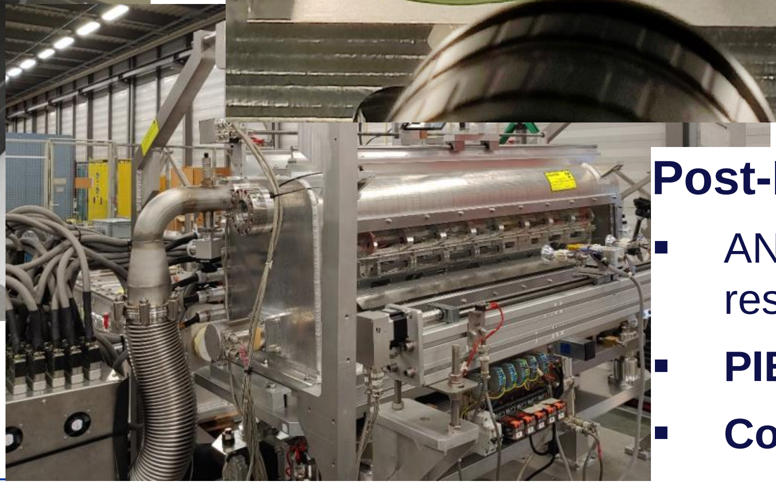
R&D on advanced materials

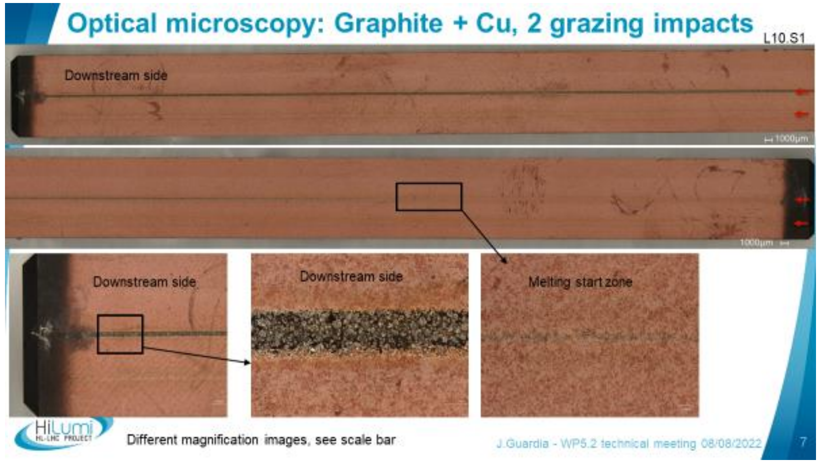


In-beam characterization: HiRadMat → Multimat-2

- EN-MME responsible in 2021 for **validation of MoGr and CuCD industrial solution under beam impact**
- Rotatable barrel allowing testing **up to 16 target stations**, with HL-LHC + KT materials
- Beam time: **September 2021**







J. Guardia, R. Rasile

Post-Irradiation Examination & Numerical benchmarking

- ANSYS simulations performed to benchmark experimental results
- **PIE in 2022** at several CERN facilities (EN-MME-MM, TE-VSC)
- **Confirmation of material choices for the LS3 collimators**