EuCARD / ColMat

Kick-off Meeting

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17th June, 2009

A. Bertarelli, A. Dallocchio

CERN EN-MME

Task Structure of ColMat

Task 1 → **ColMat Coordination and Communication.**

R. Assmann (ColMat coordinator) & J. Stadlmann (deputy)

Task 2 → **Modelling, Materials, Tests for Hadron Beams.**

A. Bertarelli

Task 3 → **Collimator Prototyping & Testing for Hadron Beams.**

P. Spiller, R. Assmann

Objectives of ColMat

Task 2. Modelling, Materials, Tests for Hadron Beams.

- Identify and fully characterize in experiment and simulation materials that are adequate for usage in high power accelerators.
- Predict residual dose rates for irradiated materials and their life expectancy due to accumulated radiation damage.
- Design, construct and test a collimator prototype for upgraded LHC performance.
- Design, construct and test one cryogenic collimator prototype for use in FAIR and possibly LHC.
- Develop crystal engineering solutions for collimation.

Description Task 2.1

Task 2. Modelling, Materials, Tests for Hadron Beams.

- **Sub-task 1: Halo studies and beam modelling.**
    - Nature, magnitude and location of beam losses in modern accelerators.
    - Dynamics of the beam halo and proper diffusion models.
    - Design and optimization of multi-stage collimation systems.
    - Simulation of multi-turn collimation processes, including nuclear interactions of halo particles in the collimator materials (e.g. **simulation of metal-diamond composites, ceramics and multilayer materials…**).

Description Task 2.2

Task 2. Modelling, Materials, Tests for Hadron Beams.

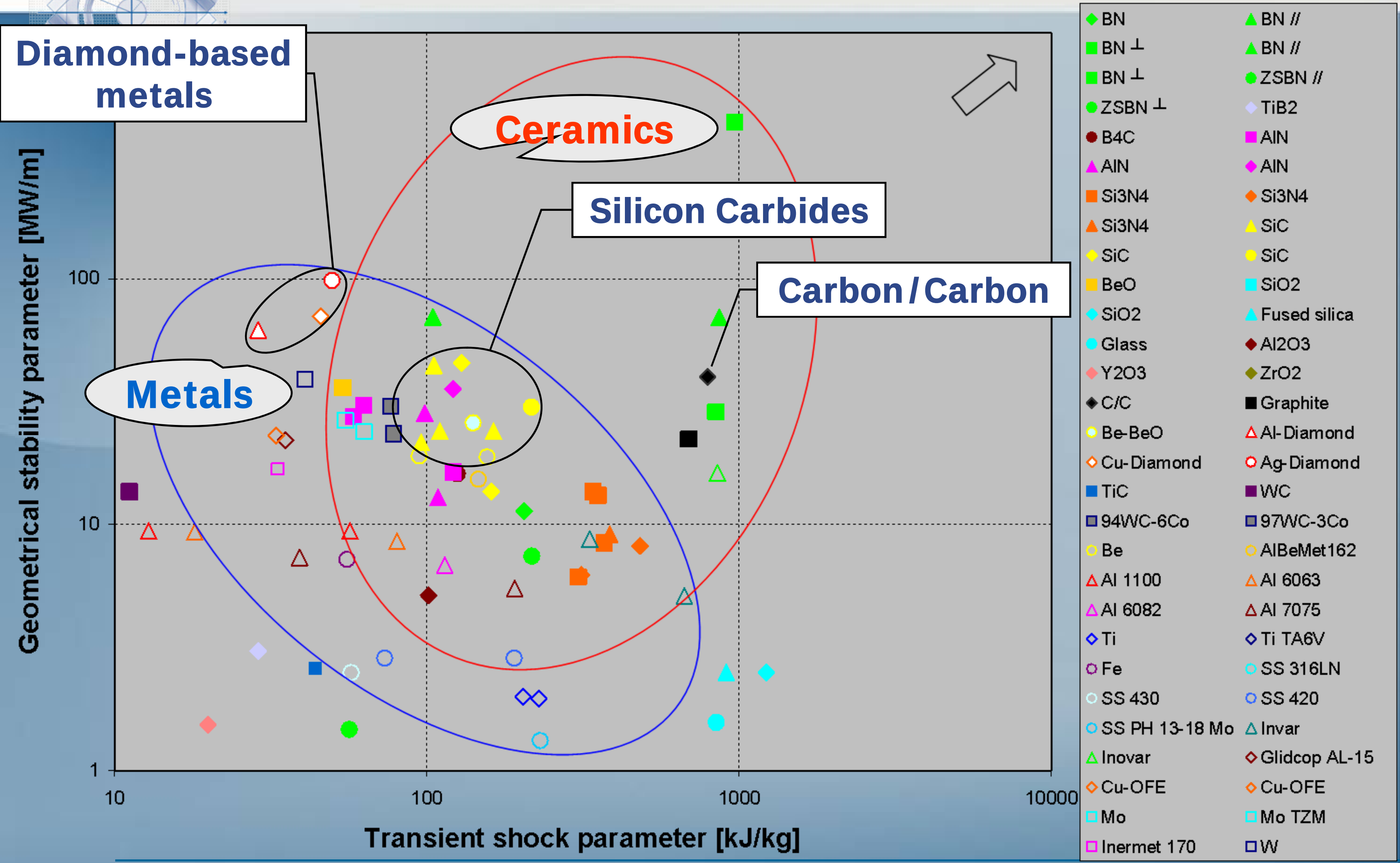
- **Sub-task 2: Energy deposition calculations and tests.**
  - Showering models with protons and ions in the relevant energy range.
  - Modeling of the accelerator geometry and materials.
  - Energy deposition calculations for various operational assumptions.
  - Calculation of residual dose rates.
  - Modelling radiation-induced displacements per atom (dpa).
  - The following institutes contribute to this work: **CERN and GSI.**

Description Task 2.3

Task 2. Modelling, Materials, Tests for Hadron Beams.

- **Sub-task 3: Materials and thermal shock waves.**
  - Selection of candidate materials for usage in high intensity accelerators. This includes also special materials, like advanced composite materials and crystals.
  - Mechanical, electrical and vacuum characterization of materials.
  - Simulations of thermal shock phenomena induced by impacts of beam particles (transient stresses, shock waves, change of phase)
  - Experimental tests to simulate material resistance to beam-induced thermal shock waves.
  - Modelling of beam shock-induced damage of accelerator materials.

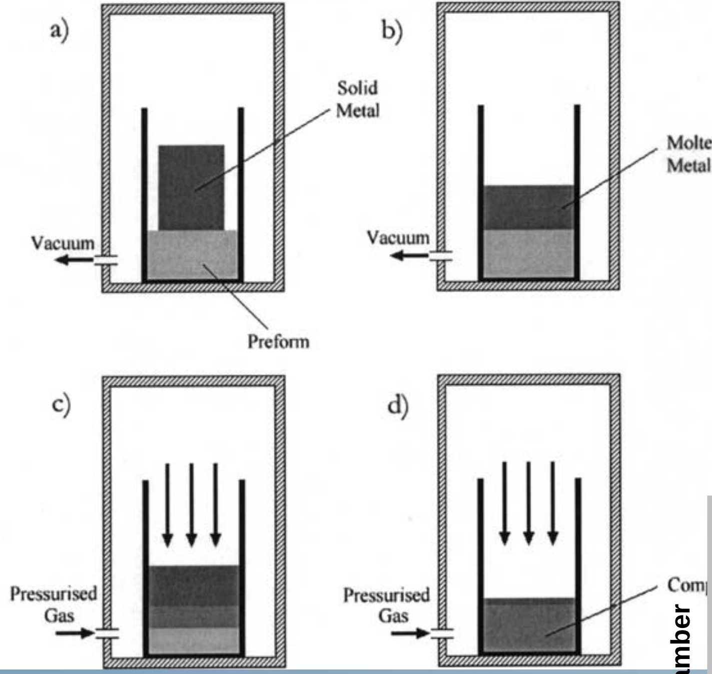
Description Task 2.3

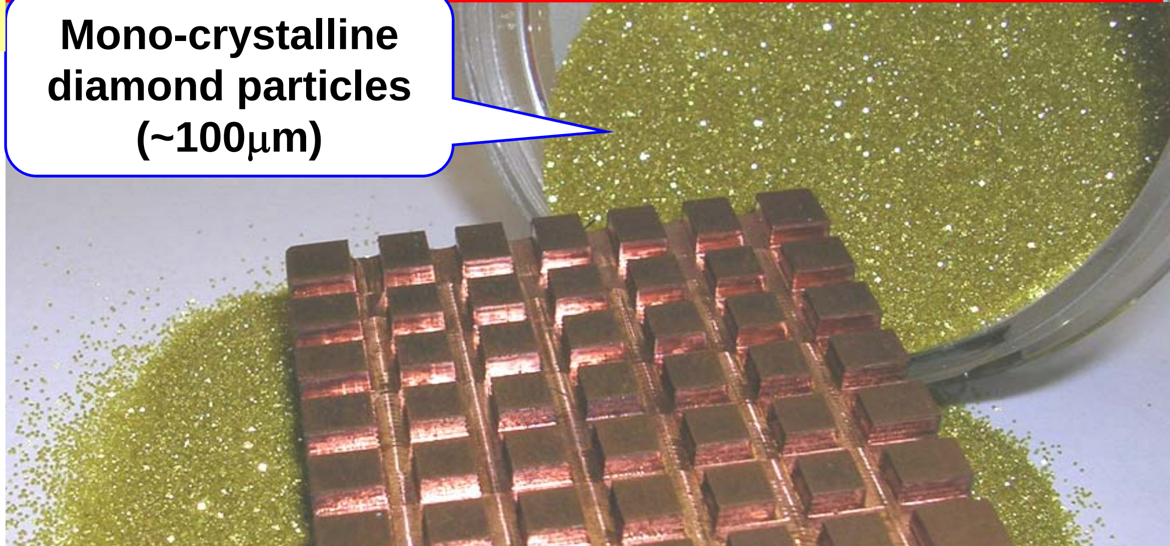


Description Task 2.3

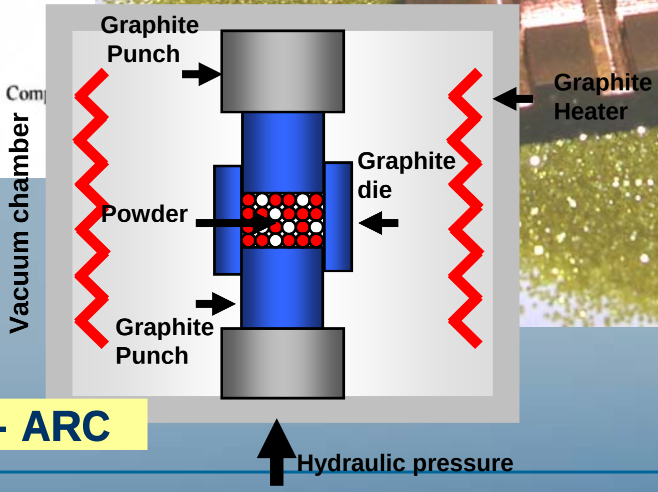
Diamond-metal composites are advanced thermal management materials usually obtained by liquid metal pressure infiltration or hot pressing…

Courtesy L. Weber – EPFL





Mono-crystalline diamond particles (~100μm)



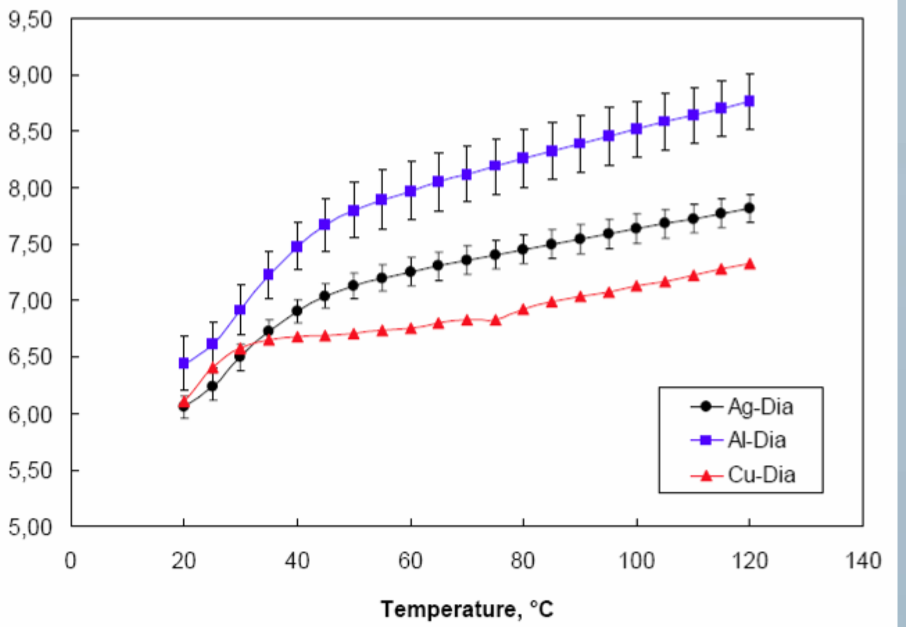
Courtesy E. Neubauer – ARC

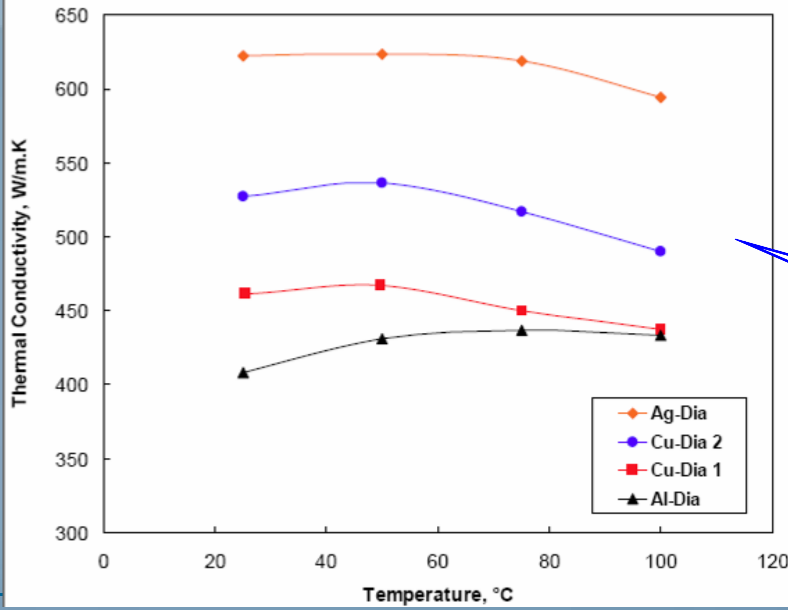
Description Task 2.3

Diamond-metal composites combine excellent Thermal conductivity (higher than Cu) with particularly low CTE …**it is a promising candidate!**

Coefficient of Thermal Expansion

(factor 2÷3 less than Cu)





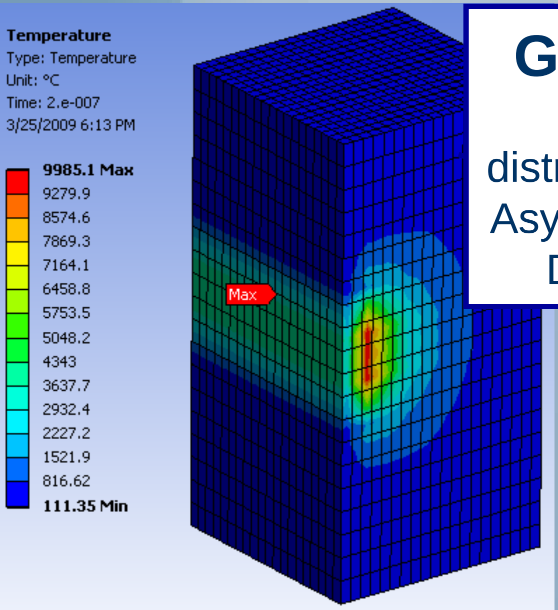
Thermal conductivity

(factor 1.5÷2 more than Cu)

Source: Plansee AG – Reutte (AT)

Description Task 2.3

Preliminary simulations of direct 7 TeV beam impact (200 ns): SiC gives promising results (no melting as opposed to Glidcop jaw). **Simulations with hydrodynamic codes + dynamic characterization of the materials + HiRadMat tests are mandatory (See I. Efthymiopoulos talk).**

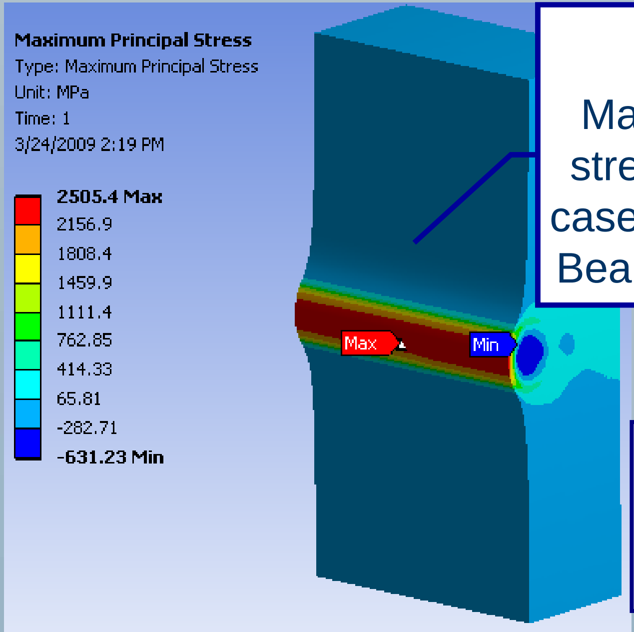


Glidcop Jaw

Temperature distribution in case of Asynchronous Beam Dump at 7 TeV

Max Pressure increase of cooling water:

~60bar



SiC Jaw

Maximum principal stress distribution in case of Asynchronous Beam Dump at 7 TeV

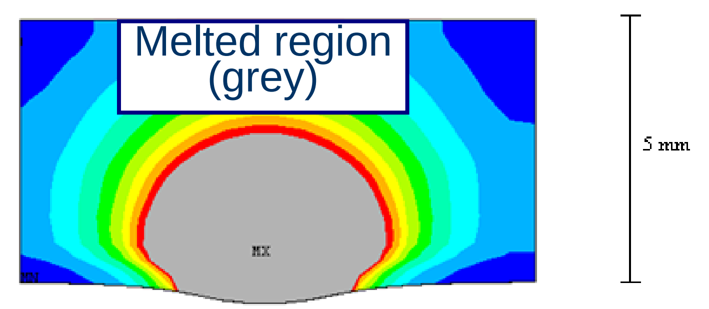
Max Pressure increase of cooling water:

~25bar

Description Task 2.3

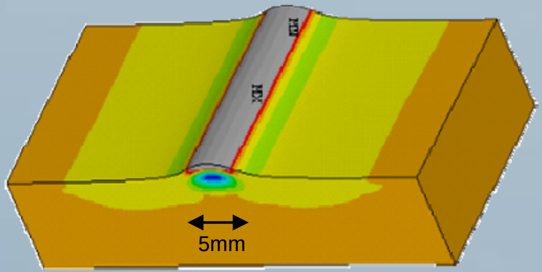
Preliminary simulations of direct 7 TeV beam impact (200 ns): SiC gives promising results (no melting as opposed to Glidcop jaw). **Simulations with hydrodynamic codes + dynamic characterization of the materials required.**

Glidcop



Melted region (grey)

SiC



Affected region (grey):

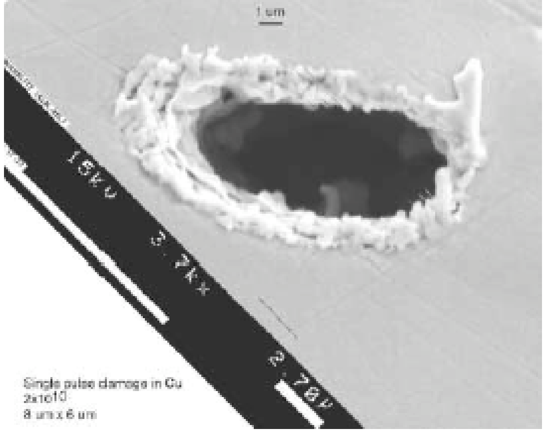
Thermal stresses exceeding tensile strength

5th D.o.F. motor allows to move all the vacuum tank by ± 10mm.

Collimators should withstand up to 5 accidents.

Exact Nature & Extent of Damaged Region still not really known well. We need beam tests with prototype.

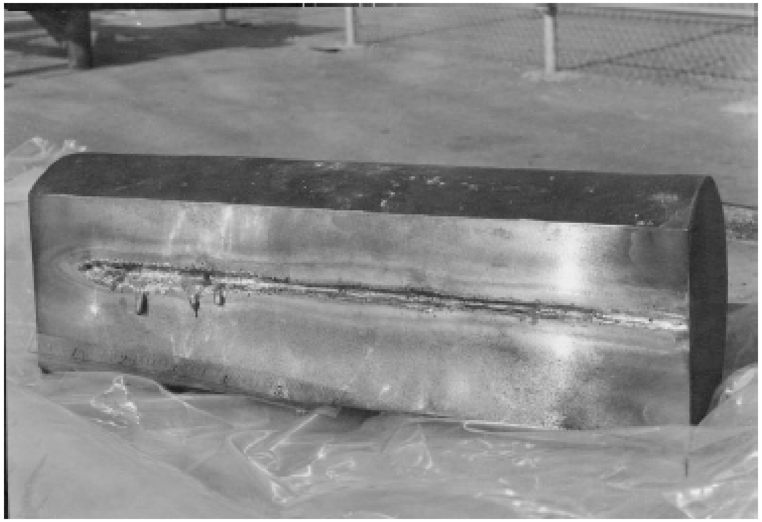
Thin Cu sample in FFTB electron beam at SLAC
Hole = Beam Size



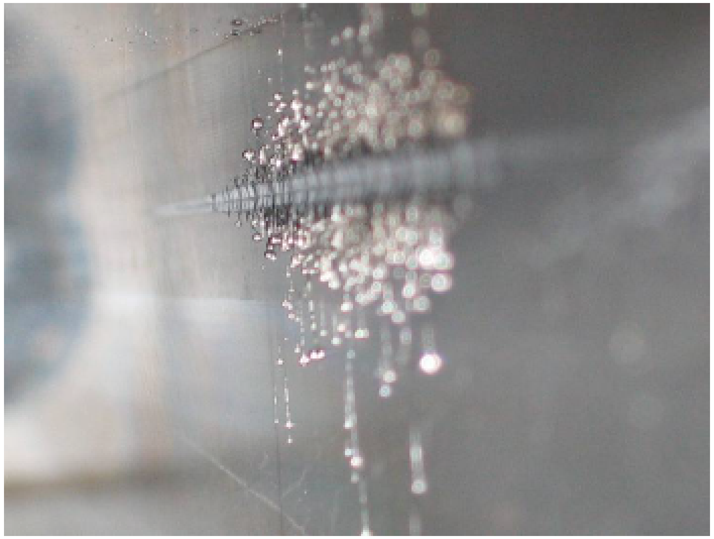
Single pulse damage in Cu
2×10^{10}
8 um x 6 um

Thermo-structural FEM analyses including hydrodynamic effects (phase changes, shock waves…) are required!

2000um 500 kW 20 GeV e- beam hitting
a 30cm Cu block a few mm from edge
for 1.3 sec (0.65 MJ)



FNAL Collimator with .5 MJ



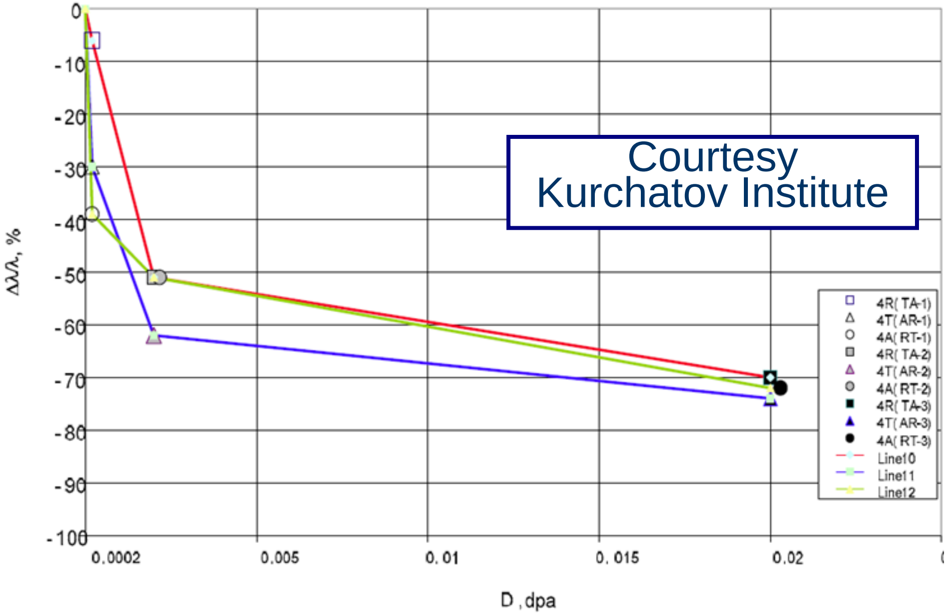
Description Task 2.4

Task 2. Modelling, Materials, Tests for Hadron Beams.

- **Sub-task 4: Radiation damage.**
  - Experimental tests on material resistance to beam-induced radiation.
  - Modelling of radiation damage for accelerator materials.
  - Prediction of material life expectancy in accelerator environment.
  - The following institutes contribute to this work: **CERN, GSI** and **RRC KI.**

Description Task 2.4

Radiation hardness is a critical aspect for the lifetime of C-C jaws used for Phase I collimators …



Courtesy
Kurchatov Institute

Fig.51. The relative change in thermal conductivity of samples for AC-150 material depending on the doses.

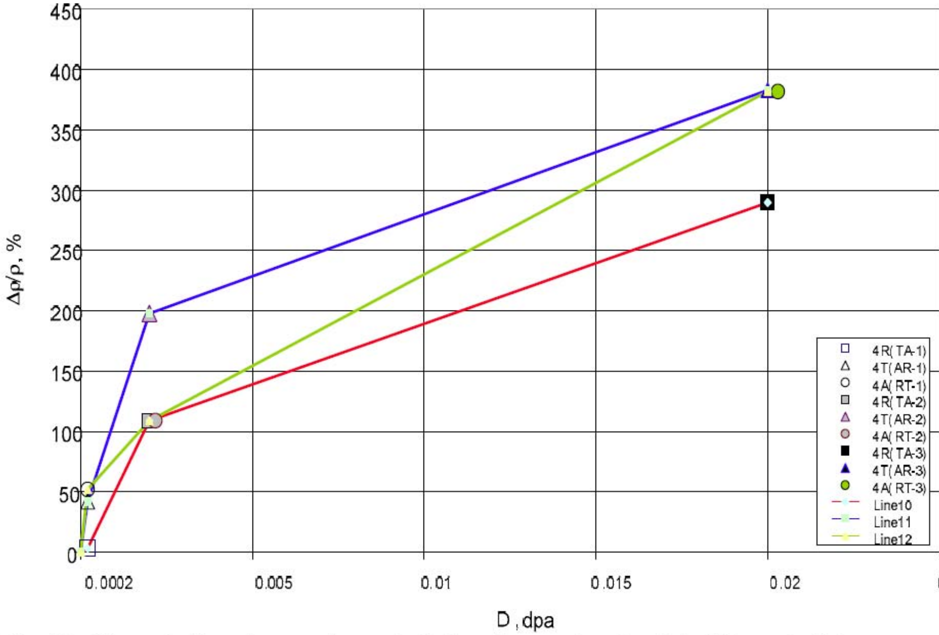
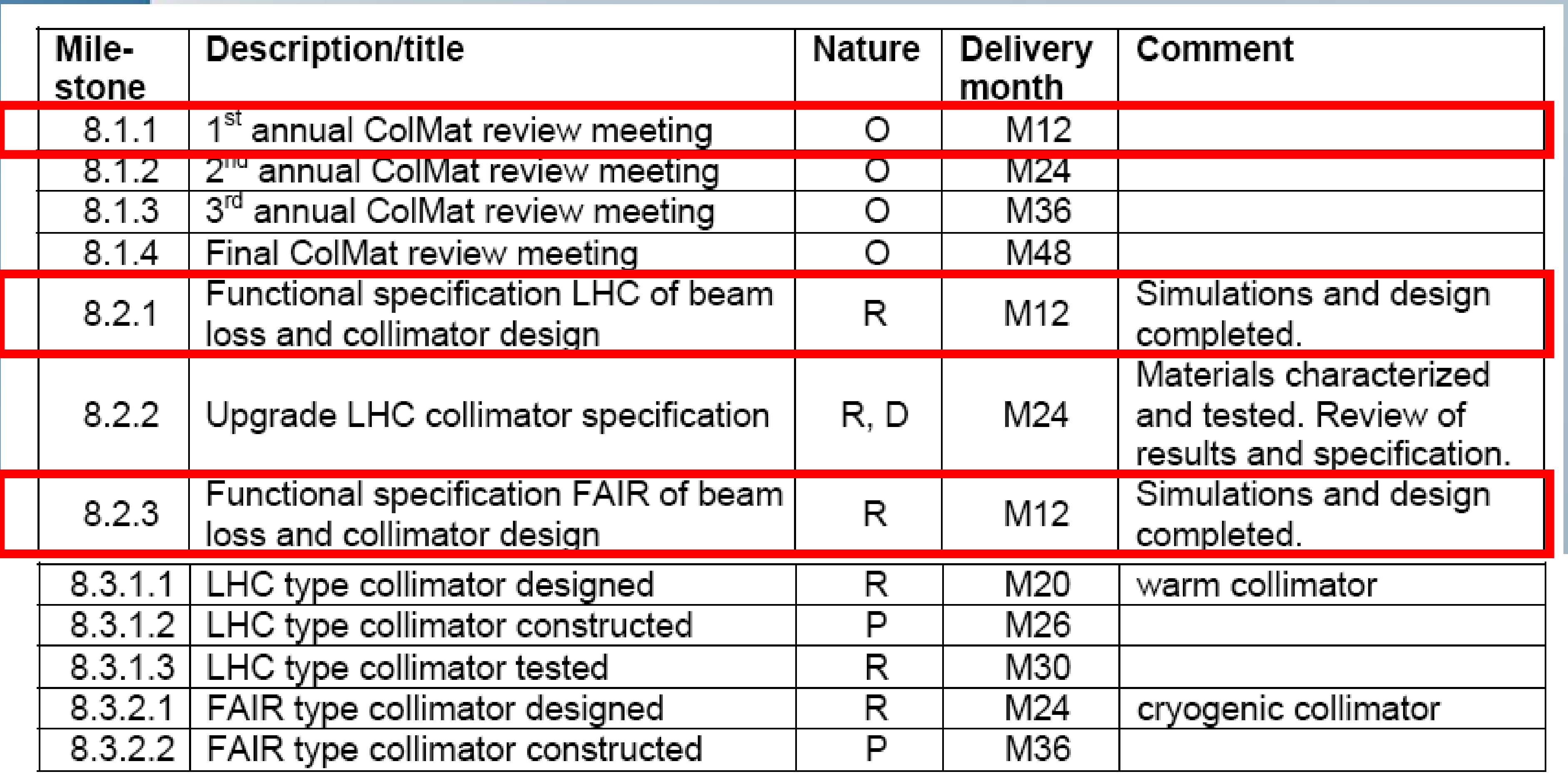


Fig. 50. The relative change in resistivity of samples for AC-150 material depending on the doses.

- According to data available in literature all potential materials (SiC, Copper, Diamond) exhibit good behaviour against radiation …
- Lower doses on surrounding equipment will extend lifetime of critical components (e.g. Warm Quadrupoles)

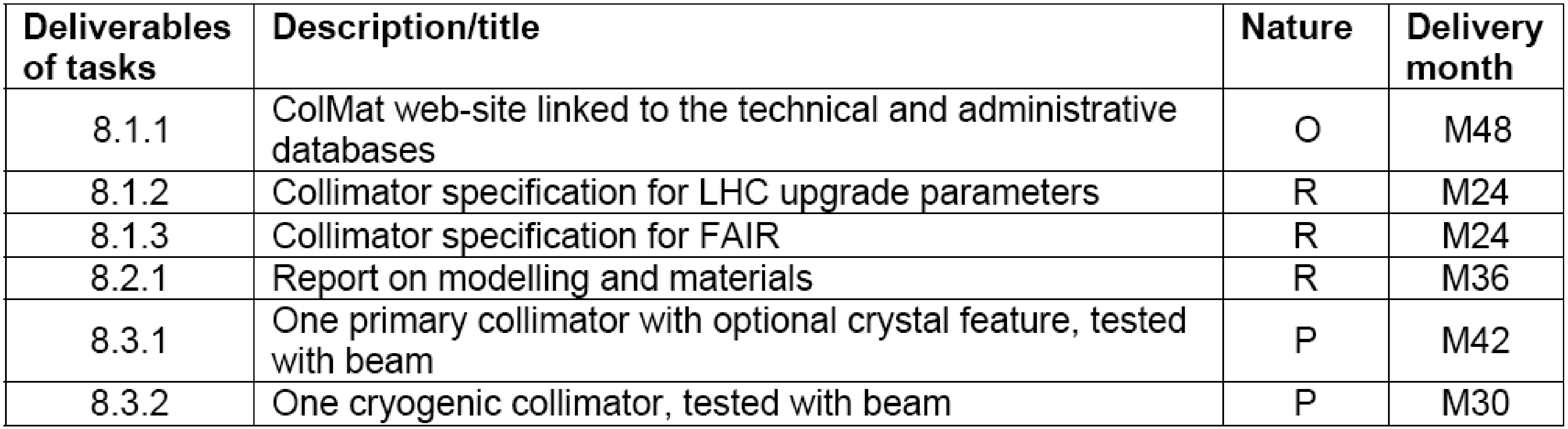
Milestones - Schedule

Task 2. Modelling, Materials, Tests for Hadron Beams.



Mile-stone	Description/title	Nature	Delivery month	Comment
8.1.1	1^{st} annual ColMat review meeting	O	M12	
8.1.2	2^{nd} annual ColMat review meeting	O	M24	
8.1.3	3^{rd} annual ColMat review meeting	O	M36	
8.1.4	Final ColMat review meeting	O	M48	
8.2.1	Functional specification LHC of beam loss and collimator design	R	M12	Simulations and design completed.
8.2.2	Upgrade LHC collimator specification	R, D	M24	Materials characterized and tested. Review of results and specification.
8.2.3	Functional specification FAIR of beam loss and collimator design	R	M12	Simulations and design completed.
8.3.1.1	LHC type collimator designed	R	M20	warm collimator
8.3.1.2	LHC type collimator constructed	P	M26	
8.3.1.3	LHC type collimator tested	R	M30	
8.3.2.1	FAIR type collimator designed	R	M24	cryogenic collimator
8.3.2.2	FAIR type collimator constructed	P	M36	

Deliverables - Schedule



Deliverables of tasks	Description/title	Nature	Delivery month
8.1.1	ColMat web-site linked to the technical and administrative databases	O	M48
8.1.2	Collimator specification for LHC upgrade parameters	R	M24
8.1.3	Collimator specification for FAIR	R	M24
8.2.1	Report on modelling and materials	R	M36
8.3.1	One primary collimator with optional crystal feature, tested with beam	P	M42
8.3.2	One cryogenic collimator, tested with beam	P	M30

Actions I

- Material R&D
  - Feasibility study of large dimension metal-diamond components.
  - Joining techniques to integrate metal-diamond and ceramic components into the jaw assembly.
  - Processing (machining, coating, drilling) analysis.
  - Investigation of small series production.
- Beam halo simulations
  - Simulation of multi-turn collimation processes, including nuclear interactions of halo particles in the collimator materials (metal-diamond composites, ceramics and multilayer materials…).
  - Design and optimization of multi-stage collimation systems including cryogenic collimators.
- Energy deposition
  - FLUKA simulations including steady-state and accident working conditions.

Actions II

- Thermo-mechanical characterization
  - Thermal and mechanical tests (quasi-static)
  - Possibility of reproducing a thermal shock by equivalent high strain-rate mechanical tests.
  - How to extract information from HiRadMat experiments in order to create reliable material models (including EOS, shock waves, phase changes…)
- Thermo-mechanical simulation
  - FEM simulation of 7TeV beam impact on collimators: Choice of simulation codes, methods and material modelling.
- RF characterization
  - Electrical characterization of materials for optimal RF performances.

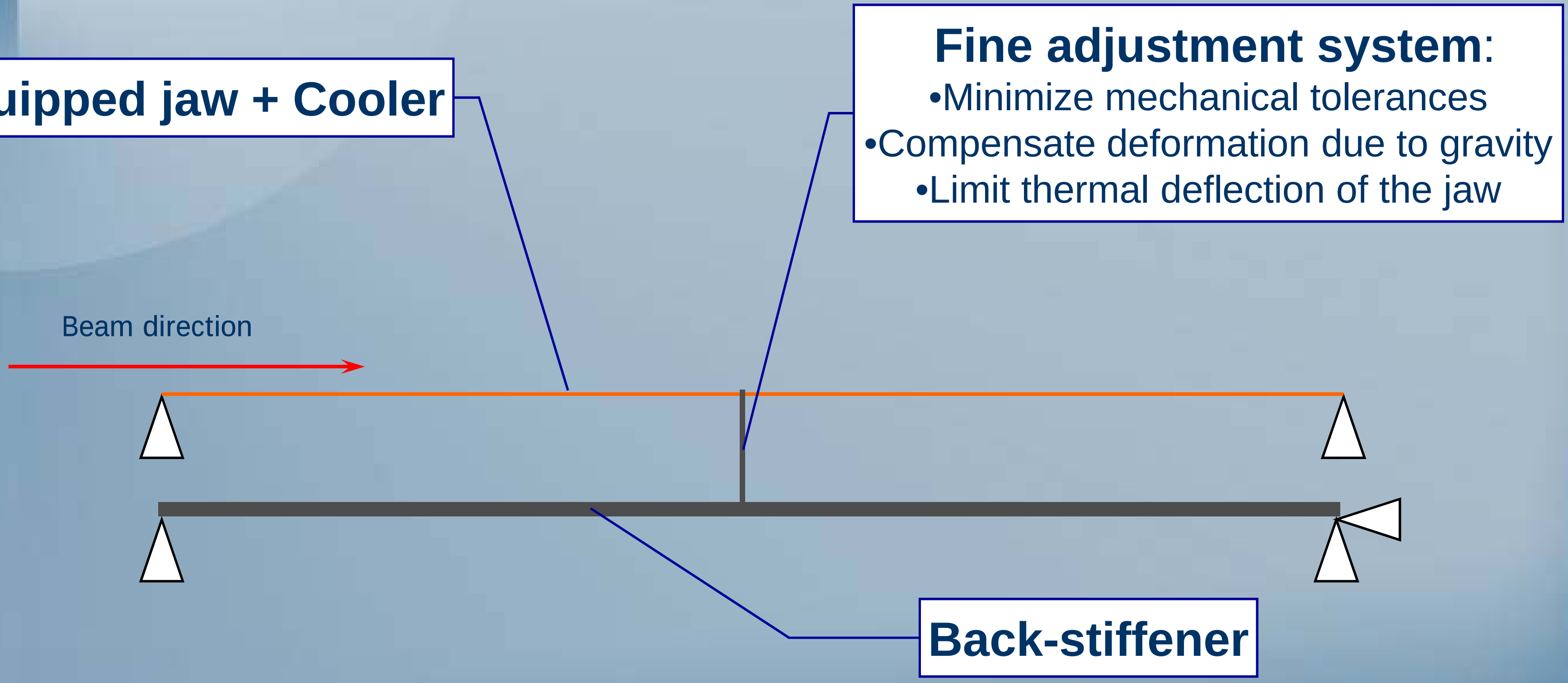
Thank you for your attention!

Phase II Design Features

- **Jaw design**
  - **Modular design (a common baseline for the jaw assembly allows the use of alternative materials for the jaw).**
  - **Back-stiffener concept to allow maximum geometrical stability (improves collimator efficiency).**
  - **Adjustable system to allow jaw flatness control and compensate gravity sag (2 versions being studied …)**
  - **Optimized internal cooling circuit to absorb higher heat-loads.**
  - **Integrated BPMs to minimize set-up time.**
- **Jaw materials (goals)**
  - **Tailored electrical conductivity to improve RF stability.**
  - **High thermo-mechanical stability and robustness.**
  - **Higher density (high-Z) to improve collimation efficiency.**
  - **Strong resistance to particle radiation.**

Phase II Design Baseline

Preliminary design is based on the concept of a rigid back stiffener remaining at almost uniform temperature and ensuring high **geometrical stability** to the jaw surface under thermal load.



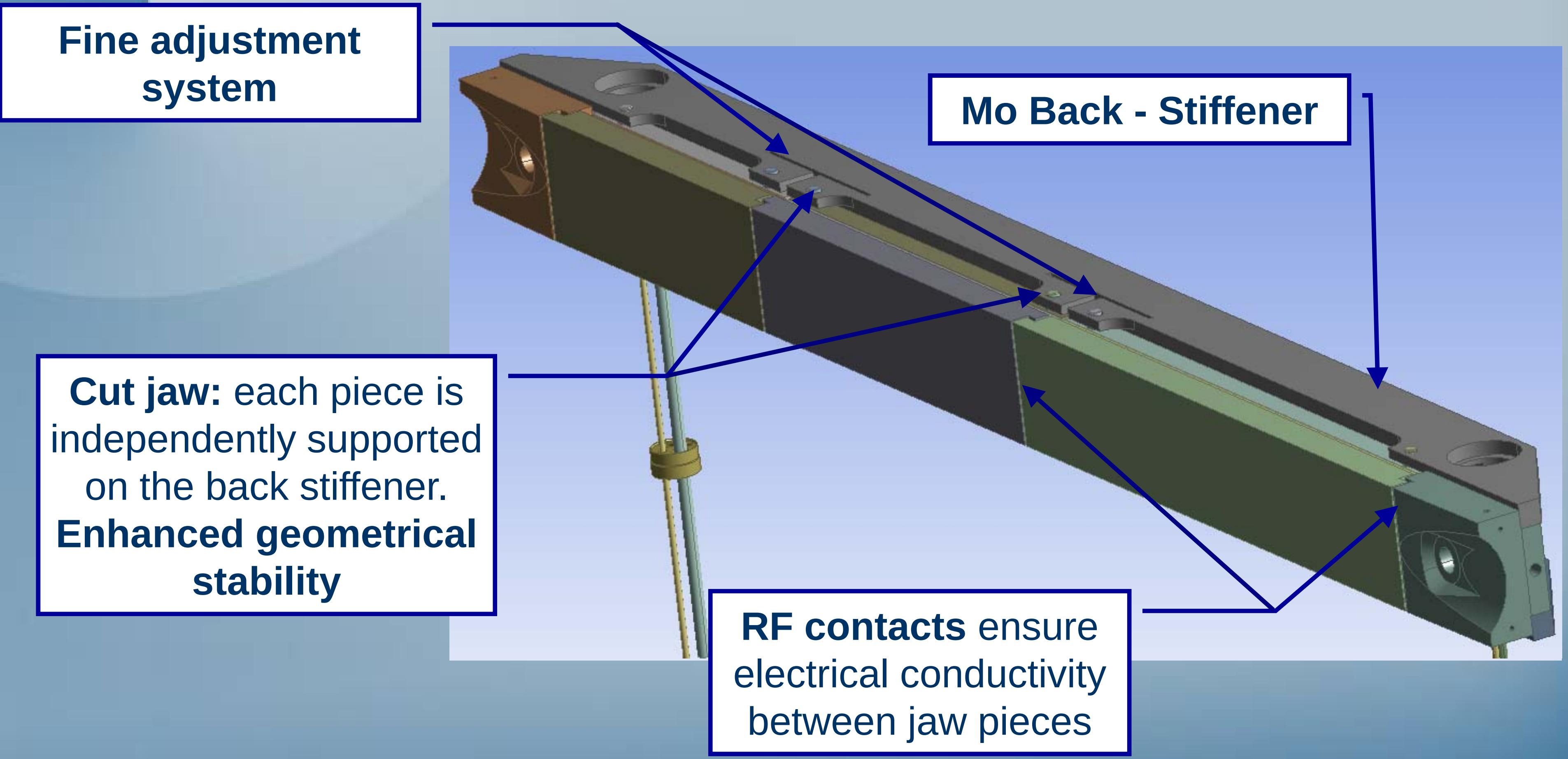
Equipped jaw + Cooler

Fine adjustment system:
- Minimize mechanical tolerances
- Compensate deformation due to gravity
- Limit thermal deflection of the jaw

Back-stiffener

Design Baseline (v2)

Alternative design of equipped jaw based on 2 intermediate adjustable supports …



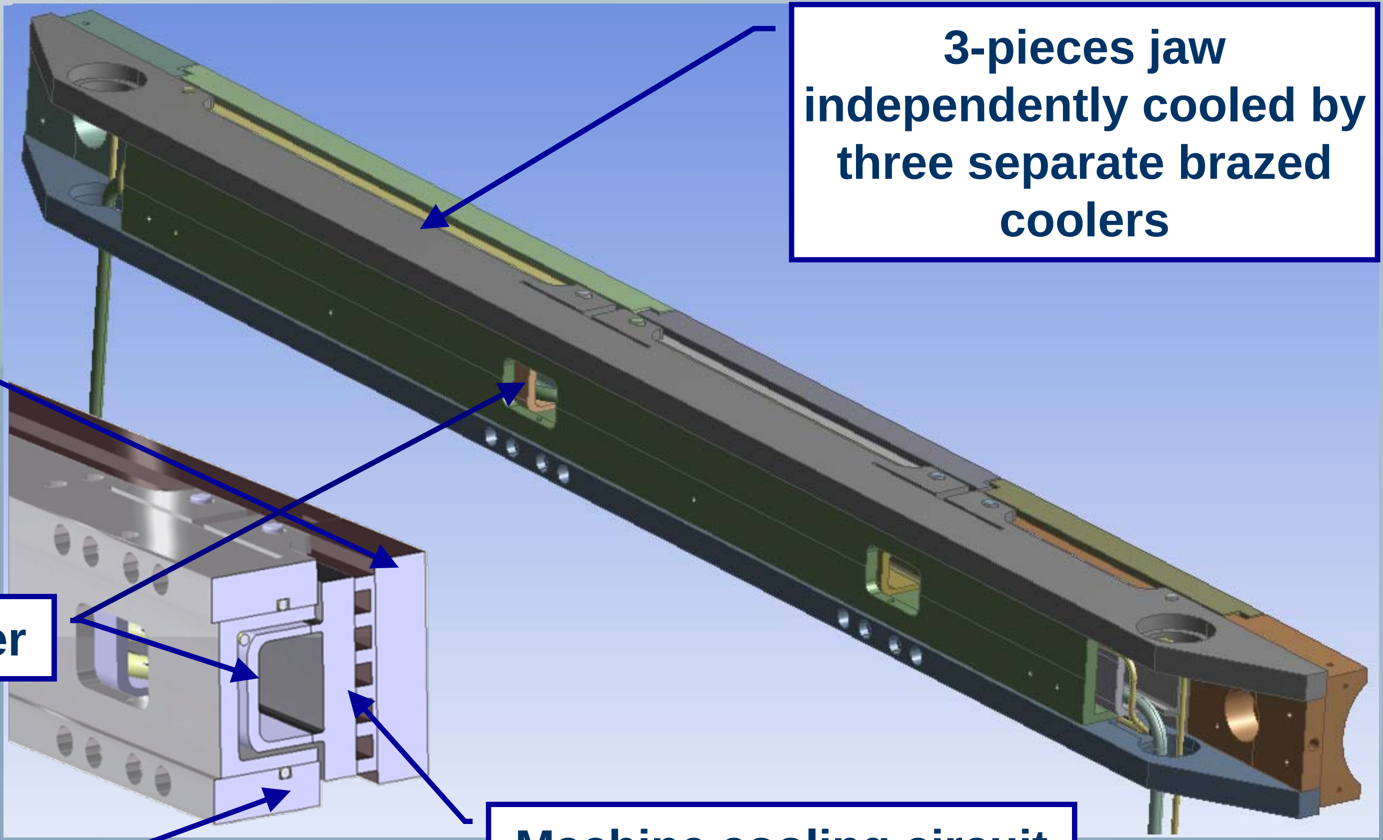
Fine adjustment system

Mo Back - Stiffener

Cut jaw: each piece is independently supported on the back stiffener. **Enhanced geometrical stability**

RF contacts ensure electrical conductivity between jaw pieces

Design Baseline (v2)



3-pieces jaw independently cooled by three separate brazed coolers

Jaw

Jaw - Stiffener

Back - Stiffener

Machine cooling circuit with brazed covers

Alternative Materials

Metal jaw (high electrical conductivity) vs. **Ceramic jaw** (non-conductive) on metal conductive support...