Collimation Tests in HiRadMat: Overview of HRTM-23 and Plans for Multi-Materials Experiment

Joint WP2-WP5 meeting &
46th Collimation Upgrade Specification Meeting
03.10.2014

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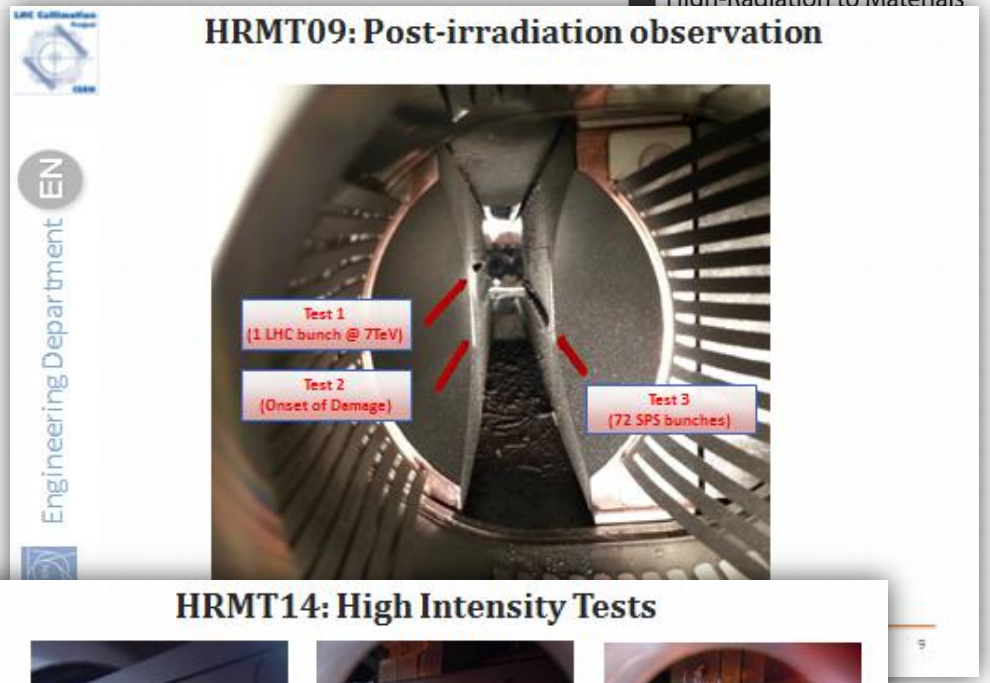
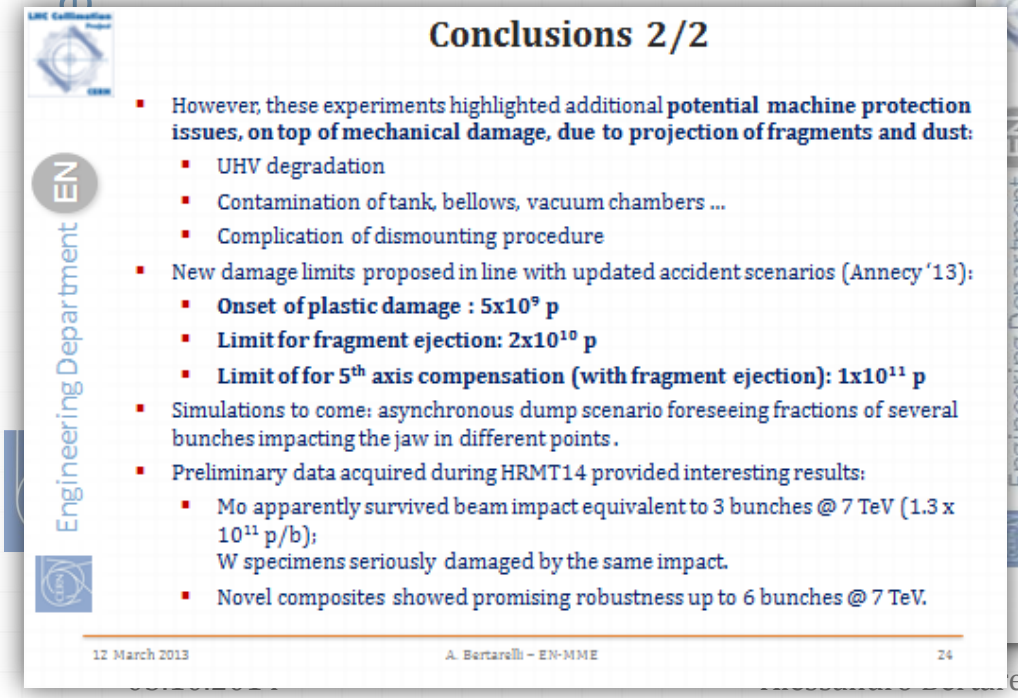
Outline

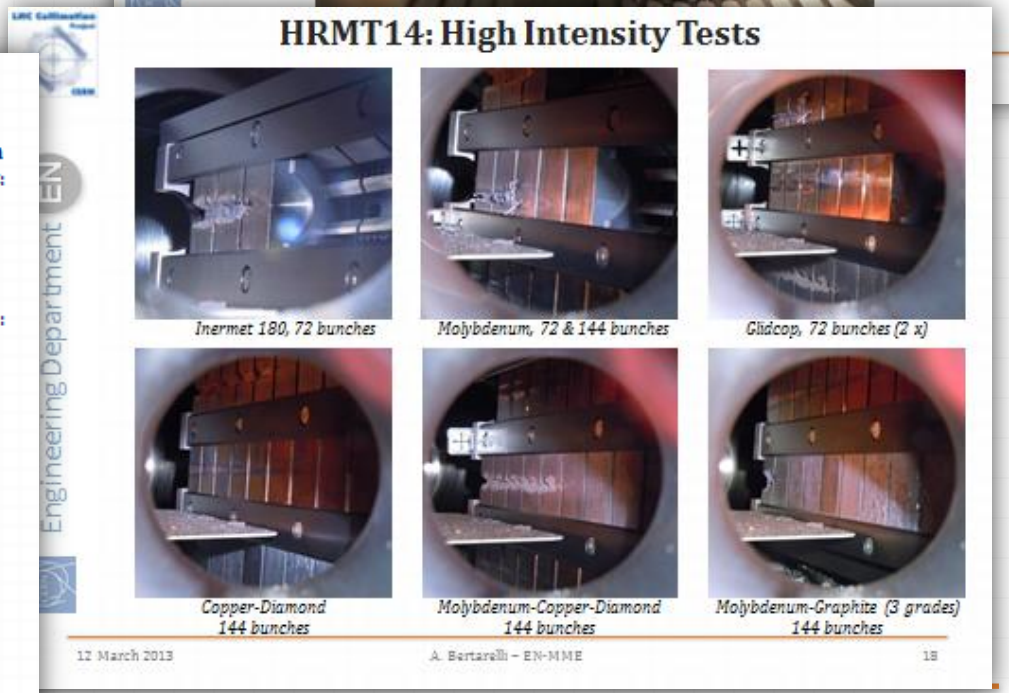
- Context
- Overview of Collimation Experiments in HiRadMat
- HRMT-23 (Jaws) Experiment
  - Preliminary Beam Specifications
  - Design
  - Data Acquisition and Instrumentation
  - Post-irradiation
- MultiMat Experiment Proposal
- Schedule and Proposes Actions
- Conclusions

Context

- **HRMT-09** and **HRMT-14** were very **successful** and **useful** experiments, which among other, allowed to:
  - Confirm numerical simulations
  - Gain confidence in methods
  - Derive operational limits for installed hardware (namely TCTA and TCTP).







Context

Limitations of HiRatMat Run 1 Experiments:

However, a number of **intrinsic limitations** exist for HRMT-14 and/or HRMT-09 experiments:

- Limited online instrumentation for full collimator test (HRMT-09)
- Lack of intermediate options between specimens and full collimator tests
- Intrinsically low signal to noise ratio for resistive strain gauges
- Low signal for low-Z materials (those better surviving the impact …)
- Relatively low resolution / acquisition rate for high speed camera
- Pollution by molten material of viewports
- LDV acquisition on one single specimen per target station.
- Signal attenuation on cables.

And most notably:

- **A number of novel materials not yet tested** …

Context

Overview of Future HiRadMat Experiments for Collimators

Possible future proposal…

HRMT-21 (not covered by this talk)

HRMT-23

As a follow up to HiRadMat run 1, **several Collimation related experiments are proposed** to:

- Integrally **test under full SPS beam** (288 b) **jaws** and **collimators of latest generation** (TCSPM, TCTPx, TCTW, SLAC Phase II …).
- Repeat the test done in 2004/2006 on **Carbon/Carbon collimators** (TT40), with increased intensity (**HL-LHC scenario**) and more extensive and dedicated acquisition devices.
- **Acquire online data** about response of **full jaws** to beam impact.
- **Test samples of novel/advanced materials** for Collimators with little known constitutive equations under highly bright beams (LIU/HL-LHC).
- **Benchmark** not-yet-explored effects such as **code coupling, tunnelling etc.**

Proposal 1415 (MultiMat) submitted to HRM Scientific Board…

HRMT-23 Experiment Goals

- Integrally test under **LIU-SPS beam** (up to **288 b**, ideally **2.3e11 p/b**) jaws for HL-LHC collimators (simulation of ultimate HL-LHC Injection Error)
- Determine damage thresholds for HL-LHC Jaws (if lower than ultimate HL-LHC Injection Error)
- Acquire online data about response of complete jaws to beam impact
- Assess impact consequences on jaws components after irradiation

HRMT-23 (approved by HiRadMat Scientific Committee):
Test of Fully Assembled Jaws

- Main Features:
  - Three superposed jaws in one tank.
  - Jaws equipped with set of strain gauges, sensors, … for online acquisition.
  - Special tank equipped with viewports for optical acquisition, LDV, electric connections etc. and fast dismounting system for glove box post-irradiation observations.

Preliminary Beam Specification

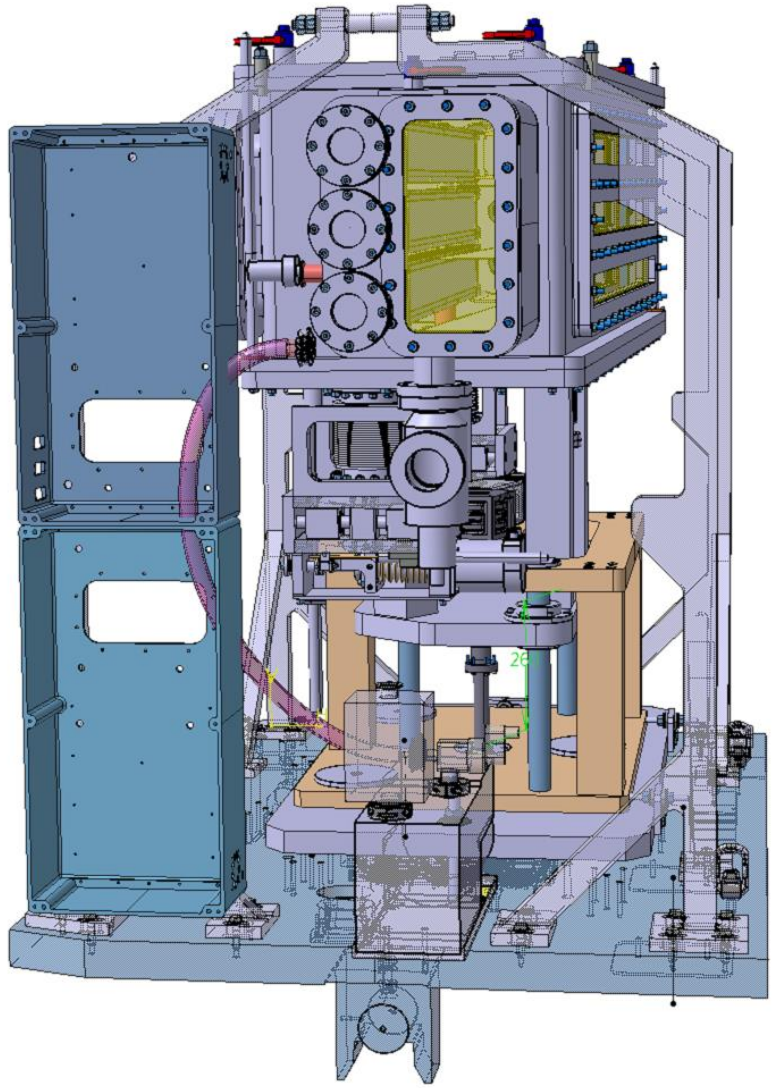
Beam parameters shall be consistent with LIU/HL-LHC injection scheme (ideally reaching up to expected HL-LHC intensity and emittance).

Preliminary beam parameters:

- Beam energy: **440 GeV**
- Bunch spacing: **25 ns**
- Bunches per pulse: **1 to 288**
- Protons/bunch: (desirably) up to **2.3 e11 p/b**
- Beam size**: 2x2 mm^2** down to **0.5x0.5 mm^2 at maximum intensity** (beam size should match expected HL-LHC emittance, however it may be reduced to **0.25x0.25 mm^2** to compensate for possible lack of beam intensity…)
- Impact parameter: **1 to 5 mm**
- Total expected number or protons **~ 6÷8 e14 p**

HRMT-23 Overall Design

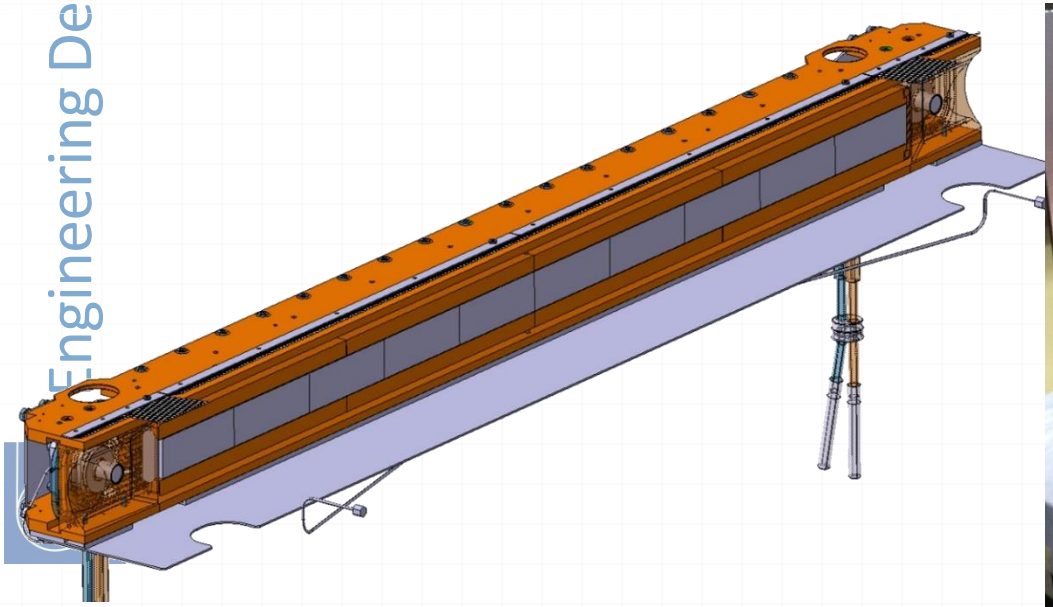
- **3** separate **complete jaws** extensively instrumented.
- **Stainless steel vacuum vessel** ($p > 10^{-3}$ mbar). Quick dismounting system to access and manipulate jaws in a glove box.
- **Be/CFC vacuum windows**: design to withstand higher energy density and intensity
- **Horizontal actuation** inspired by collimator movable tables; Stroke (H): 28 mm
- **Vertical movement of the whole tank**; stroke (V) +/-142 mm. 3 separate beam windows sets for each jaw
- **Control system** derived from HRMT-14
- **Standard HiRadMat support table**:
  - Total envelope: 1.2(H) x 0.4(W)x 2.1(L) m^3
  - Total mass ~ 1600 kg

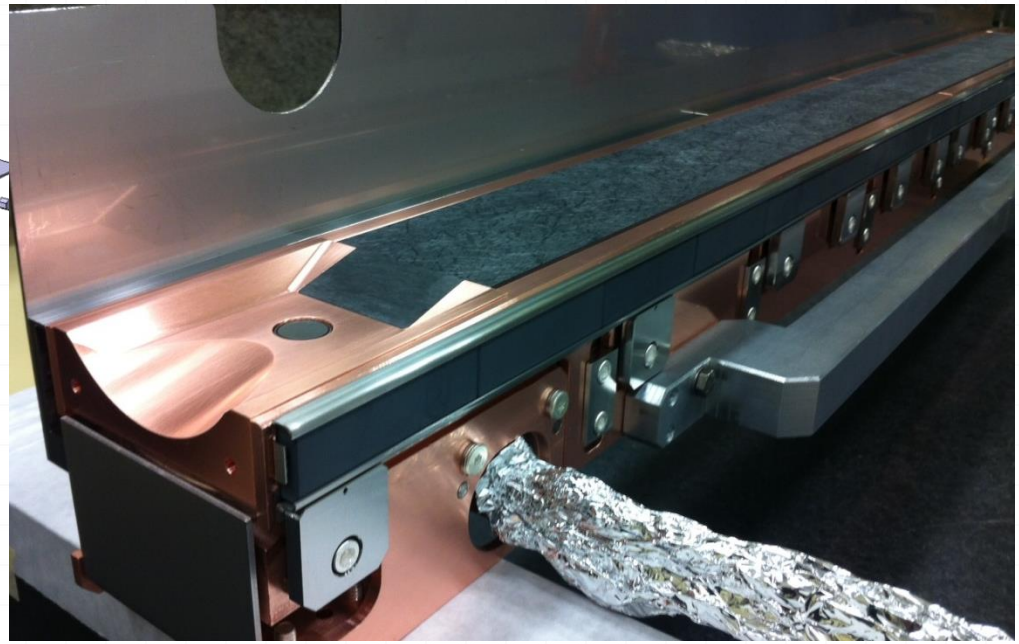


HRMT-23 Jaws To Be Tested

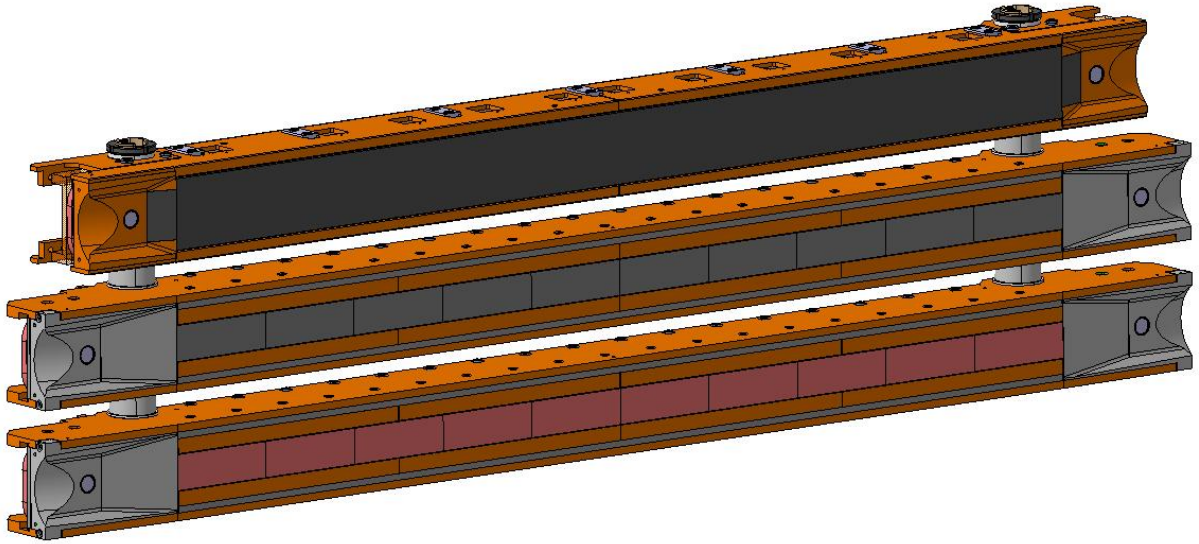
Currently envisaged proposal for Jaws:

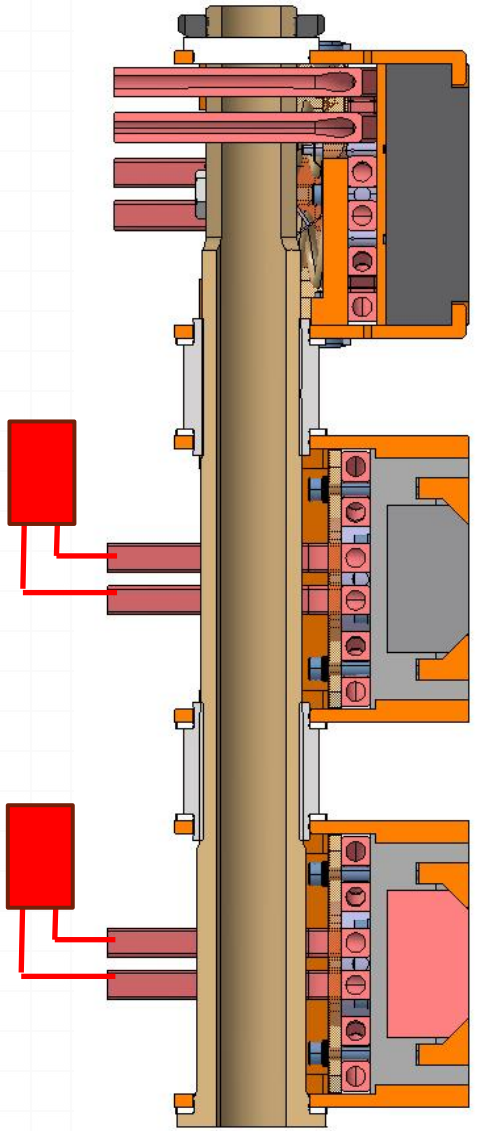
1. **HL-LHC Secondary Collimator Jaw** (TCSPM) with 10 **Molybdenum Carbide – Graphite** inserts (some inserts possibly coated).
2. **HL-LHC Secondary Collimator Jaw** (TCSPM) with 10 **Copper – Diamond** inserts.
3. **TCSP jaw**: to verify the resistance of Phase I C/C jaw to beam injection accident with HL-LHC parameters (double intensity, smaller emittance w.r.t Phase I) …





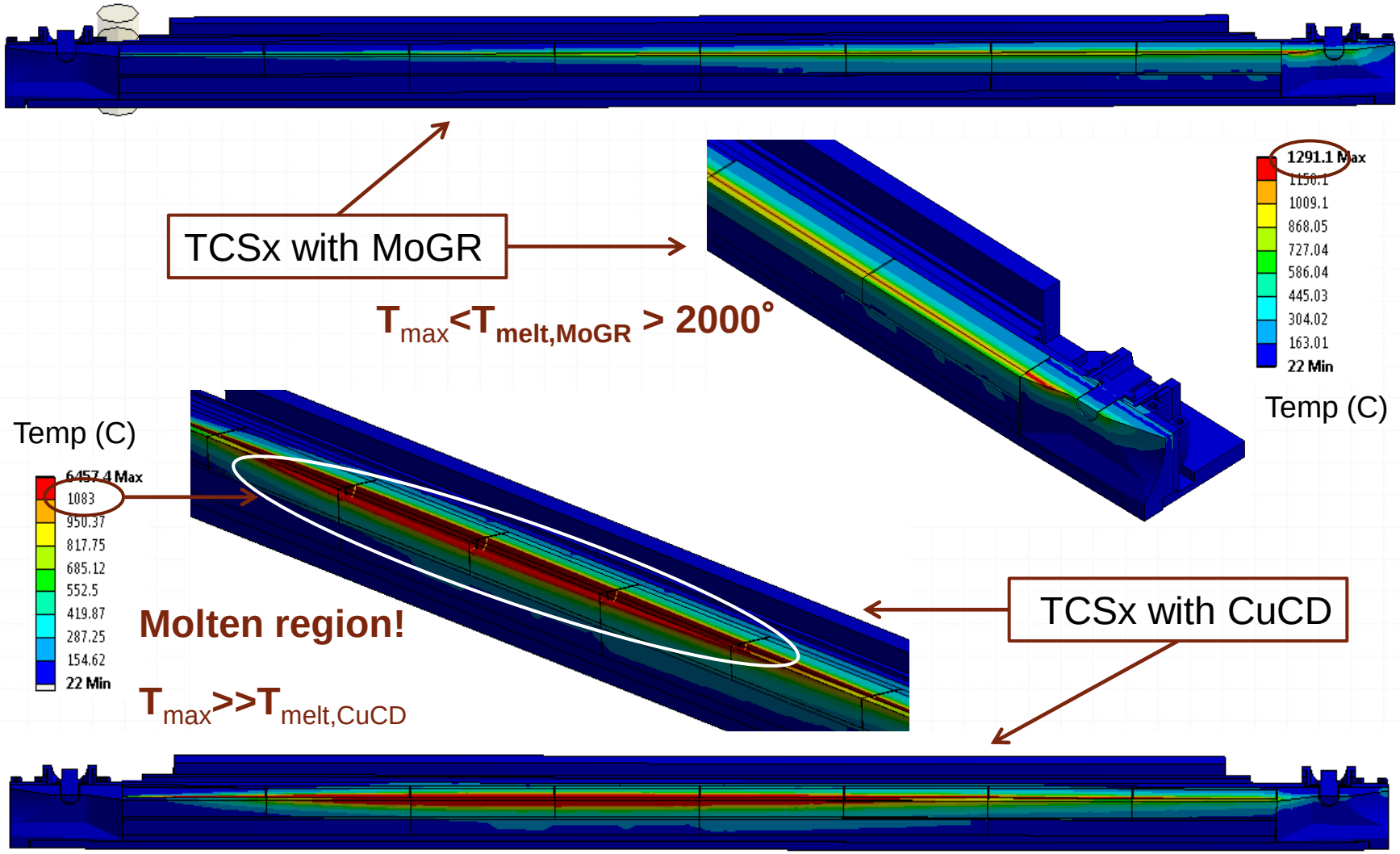
HRMT-23 Jaws Assembly





- Each jaw can be (mounted and) dismounted independently to ease post-irradiation manipulation.
- A small independent water expansion tank will be installed on 2 TCSPM jaws to allow measuring pressure burst in cooling circuits.
- TCSP jaw will be recovered from spare (outgassing) TCSP collimator once new compliant TCSP spares will become available. No possibility to install expansion tank on this jaw.

HRMT-23 Thermal Simulations



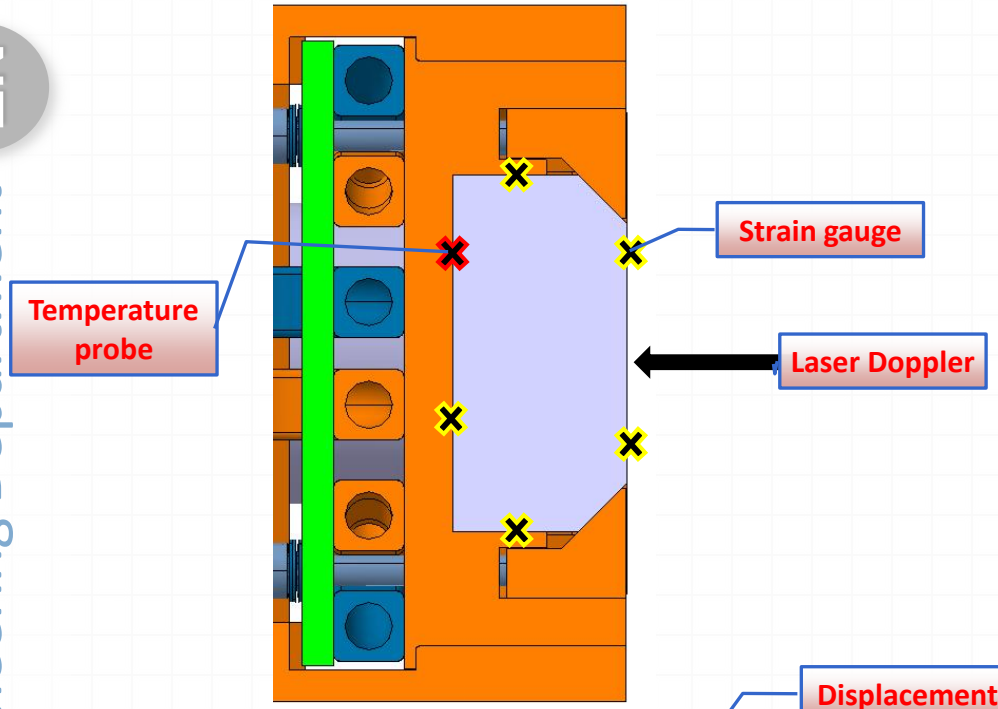
FLUKA energy deposition maps courtesy of S. Lefteris

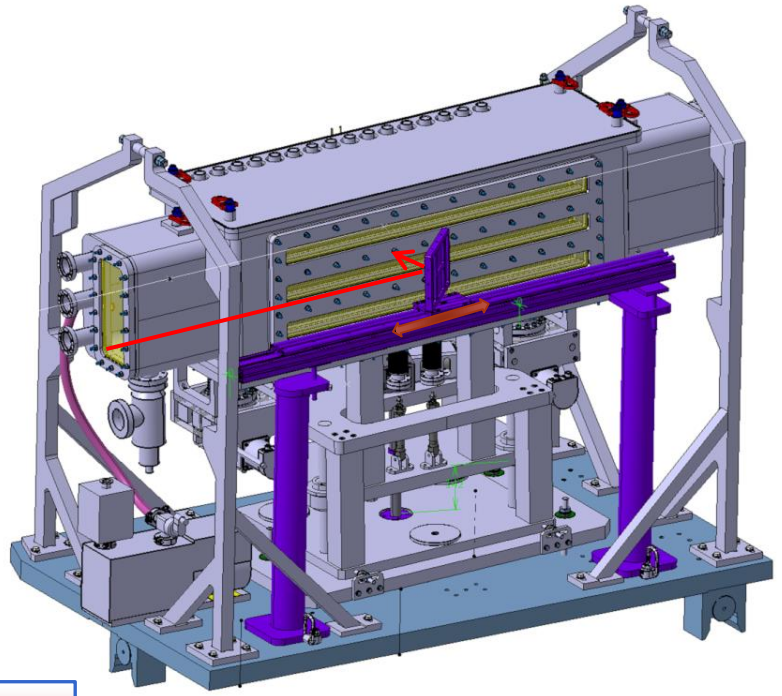
HRMT-23 DAQ and Electronics

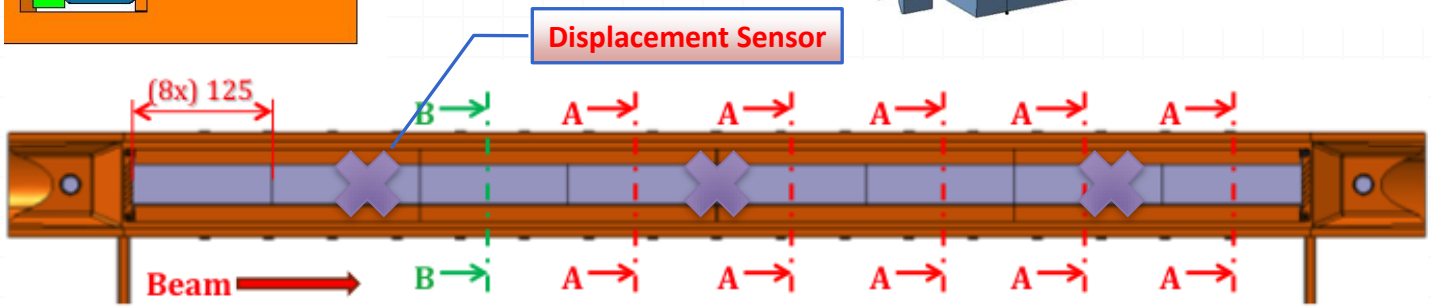
- Instrumentation (MME Mechanical Lab). Main objectives:
  - Acquire online pressure waves on most relevant components (mostly jaw inserts).
  - Acquire online temperatures on relevant locations.
  - Detect online high speed vibrations (pressure wave – induced)
  - Detect online low speed oscillations (full jaw flexural modes)
  - Detect offline (possible) permanent jaw deformation
  - Visually Record (possible) jaw explosion / fragmentation
  - Detect offline (possible) internal material damage (e.g. delamination, cracks, tunneling …)
  - Record online pressure burst in water cooling pipes
- Motorization: controls and hardware compatible with HRMT-14. Updated software interface required. Help by EN/STI/ECE …
- Acquisition System: the DAQ hardware and infrastructure should be designed and implemented with a comprehensive view on a larger spectrum of HiRadMat Experiments ⇨ ***Synergy with and contribution from other experiments and projects***.

HRMT-23 Instrumentation

- Sensor positioning (adjustable)

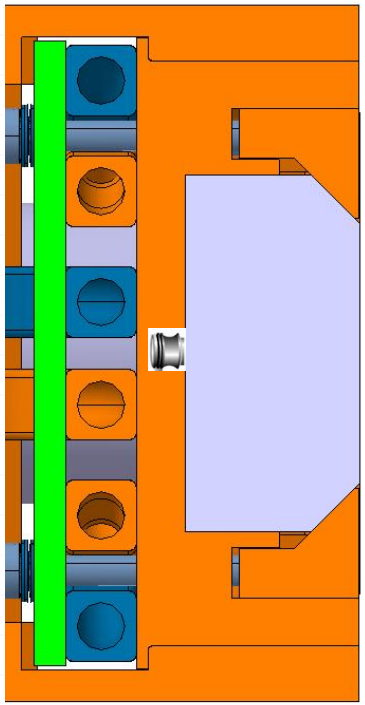






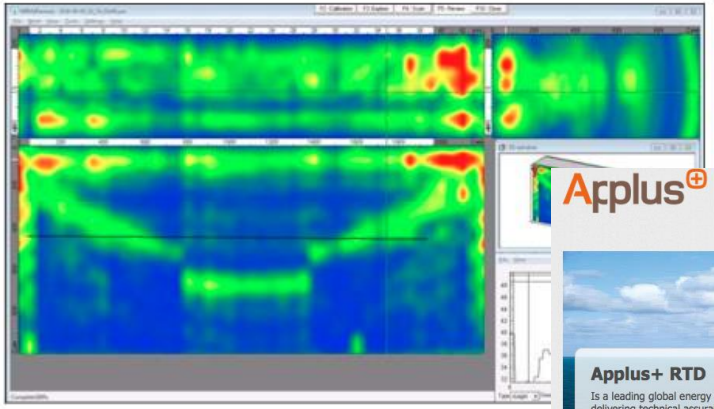
HRMT-23 Advanced Instrumentation

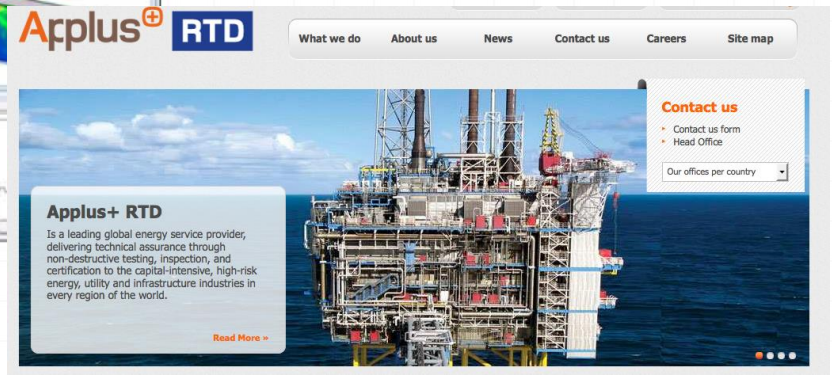
- Ultrasonic non destructive tests. Under study, not yet confirmed.



- Ultrasonic mapping along Z axis
- Cracks and phase changes in the jaws
- Not online… checking between impacts
- Probe compatible with 1000kGy and 350°C

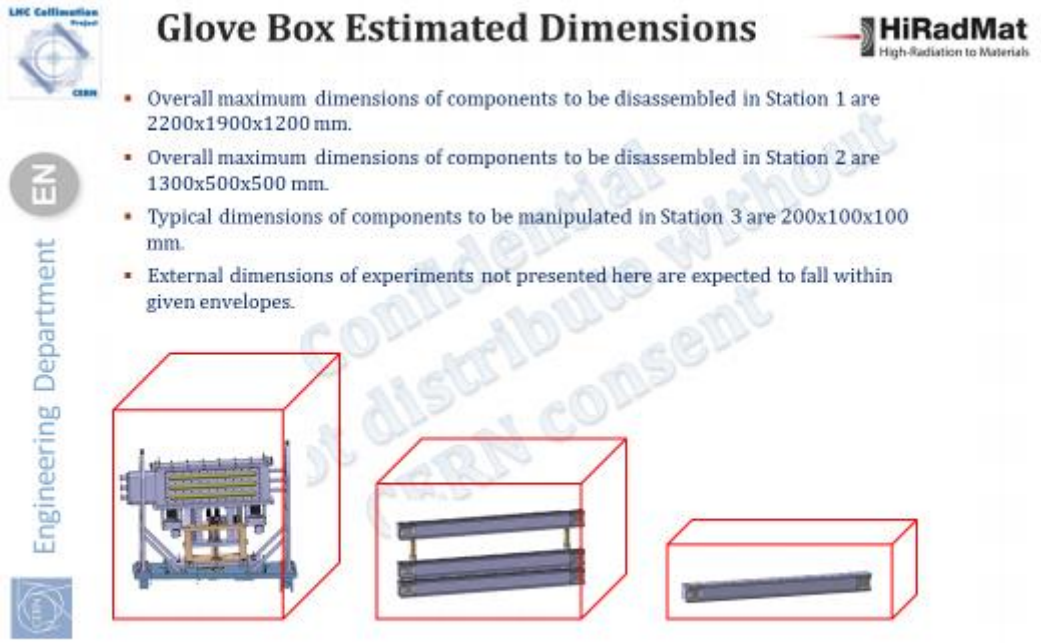
Ultrasonic Pulse Echo Scans Produced By the MIRA





HRTM-23 Post-irradiation

- After irradiation, additional analyses are foreseen. These include:
  - **Remote observation** of impacted jaws through cameras, LDV and ad-hoc viewports (on upstream and downstream sides of vacuum vessel)
  - **Direct observation** and **in-situ measurements** of impacted jaws after dismounting of the tank
  - After appropriate cool-down time, dismounting of collimator components (jaws and jaw part) in a convenient Glove Box.
  - **Cutting** of material specimens in a Glove Box
  - **Metrology**, **NDT** and analysis of **cut samples**
- Waiting for feedbacks from German supplier.



MultiMat Experiment Goals

- Test samples of novel/advanced materials for present and future Collimators under very bright beams
- Acquire online exploitable data particularly for low-Z materials
- Confirm/extend constitutive model for high-Z materials.
- Benchmark not-yet-explored effects such as code coupling

Multi-Material Experiment

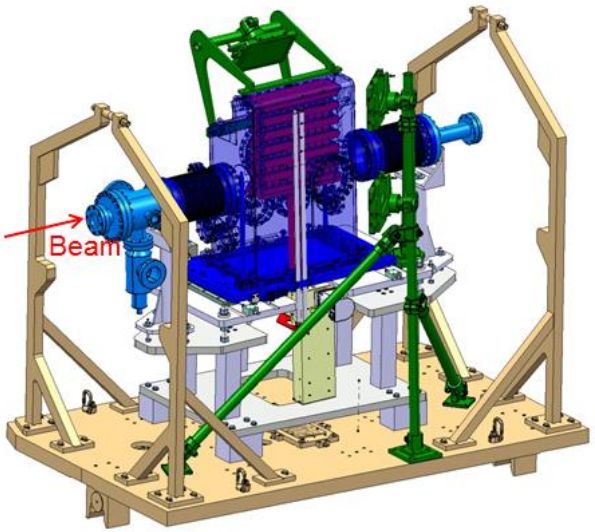
- Initially proposed by Collimation Team at **AdColMat meeting 21.10.2013**
- Derived from HRMT-14. Up to **12 target stations**, each hosting a different material.
- Specimen shape and dimensions to be optimized, possibly varying according to material (disks, cylinders, bars …).
- Specimens and test-bench extensively relying on online and offline instrumentation.

MultiMat Experiment Goals

- Because of its inherently "device-independent" concept, this experiment lends itself to explore material behaviour, benchmark simulations and derive constitutive equations for a **large spectrum of materials.**
- Possibility to create **synergy** with other projects such as **TDI**, **TCDI**, etc.
- Proposal to **join forces**, **optimize resources** and **share costs** between BE/ABP, BE/OP, EN/MME, EN/STI, TE/ABT …
- Materials to be testes may include:
  - Molybdenum Carbide - Graphite
  - Copper - Diamond
  - Other Ceramic-Graphite composites (under development)
  - Carbon/Carbon (both 2D and 3D grades)
  - Graphite
  - Boron Nitride
  - Glidcop
  - Molybdenum
  - Tungsten heavy alloys (Intermet, W-Re etc.)

MultiMat Experiment Proposal

- **Beam time request proposal** submitted to HiRadMat Scientific Committee (Proposal 1415 "MultiMat")
- Test **material specimens** of simplified shape of interest for **LHC collimators, injection** and **dump absorbers, protection devices**, etc.
- Beam intensity up to **288 bunches**, **2.3e11 p/b**, beam size down to **0.5x0.5 mm2** (down to **0.25x0.25 mm²** if LIU intensity cannot be reached)
- Design and instrumentation inspired by **HRMT14 experiment.** 12 target stations each hosting several specimens.



HiRadMat - Experiment Proposal
EDMS No: 1213282
Version 2.0

HiRadMat Beam Time Request Form

Designation	
Experiment Name	to be assigned
Acronym	to be assigned

Date	08.09.2014

General		
Responsible/primary contact		Person completing this beam request
Name	Alessandro Bertarelli	
Home institute	CERN	
E-mail	alessandro.bertarelli@cern.ch	
Phone	+41-22-7672337	
Participating institutes	Politecnico di Torino, Italy Participations from other EuCARD2 partners are also possible.	List of participating institutes, relevant information for EuCARD2 Transnational Access.
Number of team members	At least 2	Estimated number of persons participating to the preparation and/or the experiment with travel/stay at CERN.
Interested in Transnational Access	Yes	More information at http://cern.ch/hiradmat

Scientific description		
Executive summary	Impact tests with beam pulses up to HL-LHC nominal injection parameters (440 GeV, 288 bunches, 2.3e11 p/b) on a several target stations each hosting specimens made of one relevant materials. The experiment includes a comprehensive acquisition system monitoring on- and off-line the response of material specimens to beam impacts.	A very short (couple of phrases) description of the scientific purpose and the experimental setup.
Scientific motivation	During the post-LS1 runs and, even more, in the HL-LHC era, machine components located close to the beam orbit must meet extremely demanding requirements against the consequences of accidental beam impacts, considering the expected increase in beam intensity and brightness.	Extended description of the scientific purpose (couple of paragraphs) including the expected scientific results.

Schedule and Actions

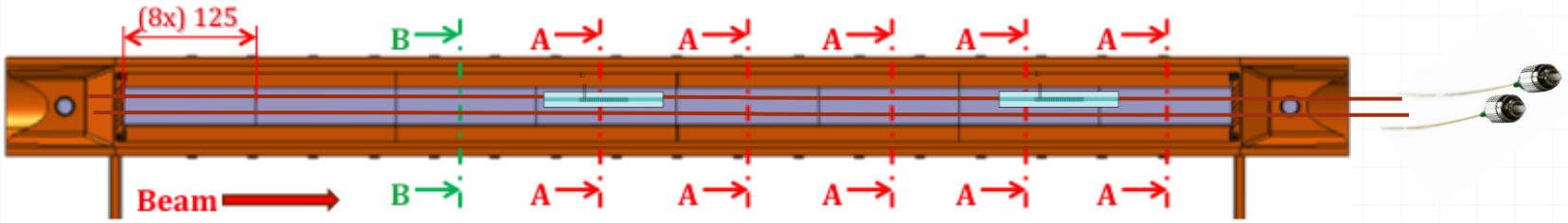
- Schedule of experiments and prototyping is triggered by the requirement to collect feedbacks in time for LHC Run2, well before LS2.
- In particular, HRMT-23 is mandatory to validate installation of a HL-LHC Collimator with qualified materials in LHC for operational tests early 2016.
- HRMT-23 experiment is currently scheduled for spring 2015: go-ahead to material procurement to be given now!
- To optimize resources and maximize benefits to all HiRadMat experiments, infrastructure and electronic equipment are to be designed keeping in mind requirements for future experiments.
- Contributions are required by all concerned groups and projects.
- Go-ahead to TCSPM to be given well ahead of HRMT-23 tests to meet early 2016 installation deadline.
- MultiMat experiment proposal submitted to HRM Scientific Committee: decision to be taken soon on which and how many materials to test.
- MultiMat experiment expected by early 2016.

Conclusions

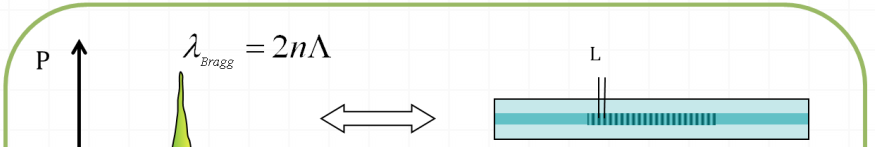
- A number of HRMT experiments in necessary to validate different Collimator designs for the HL-LHC era (new designs, SLAC design, existing designs, BBLRC …)
- Experiment to test 3 complete Collimator Jaws by HRMT SC (HRMT-23) and to test SLAC RC (HRMT-21) proposed and approved.
- HRMT-23 include 2 HL-LHC TCSPM jaws made of CuCD and MoGr (some inserts possibly coated) and one TCSP C/C jaw.
- HRMT-23 procurement to start now in order to meet challenging schedule (spring 2015).
- An experiment to test a large spectrum of materials for Collimators and other BID (TCDI, TDI …) is proposed (MultiMat). Synergy with and contributions from several projects and groups.
- Design of equipment and infrastructure for Acquisition System is on-going and anticipating needs for a number of experiments. Joining efforts and contributions by several stakeholders is necessary.
- Go-ahead to TCSPM prototype to be given well ahead of HRMT-23 tests to meet early 2016 installation deadline.

HRMT-23 Advanced instrumentation

- Distributed strain measurements by FOS. To be studied.



- Beam perturbation should be limited
- No impact on the channel numbers



Performance Properties	
Acquisition Rate[2,3]	2 MHz on four simultaneous channels
Continuous Data Collection	Stream full 4 channel 2 MS/s data to disk in continuous, timed or triggered modes
Strain Range[4]	~40,000 με
Strain Sensitivity[4,5]	~20 με
Detection Bandwidth	-3dB optical BW = 350 kHz (-6dB electrical), 2-pole, Butterworth filter, 20dB/decade
Measurement Repeatability[6]	0.05% of full scale (standard deviation)
Dynamic Range	Total 12 dB loss budget (2x degradation in measurement repeatability 8 dB loss)
Max FBGs per Channel	1
Sensor Wavelength Range	1520 - 1570 nm
Optical Connectors	LC/APC
Optimal FBG Specifications	1.0 nm Bandwidth, > 90% Reflectivity