Planned HiRadMat Beam Tests on Collimation Materials

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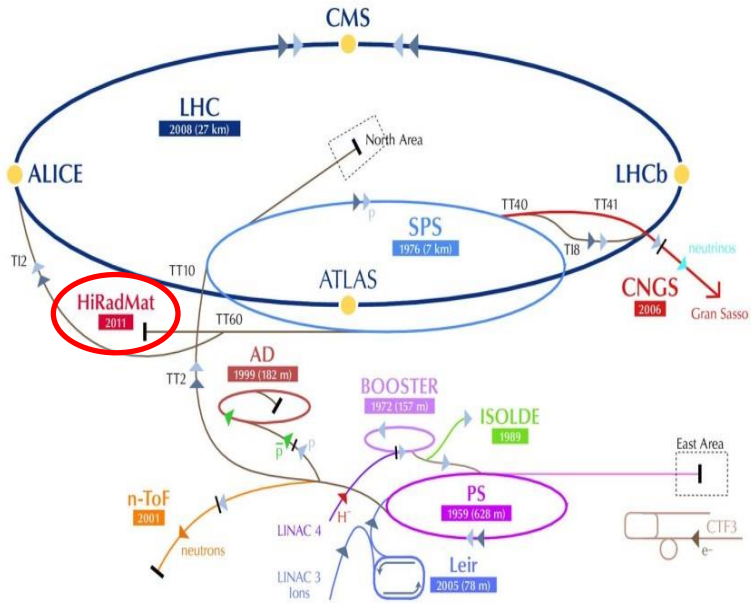
4th Joint HiLumi LHC-LARP Annual Meeting
KEK, Tsukuba, Japan– *19 November, 2014*

Outline

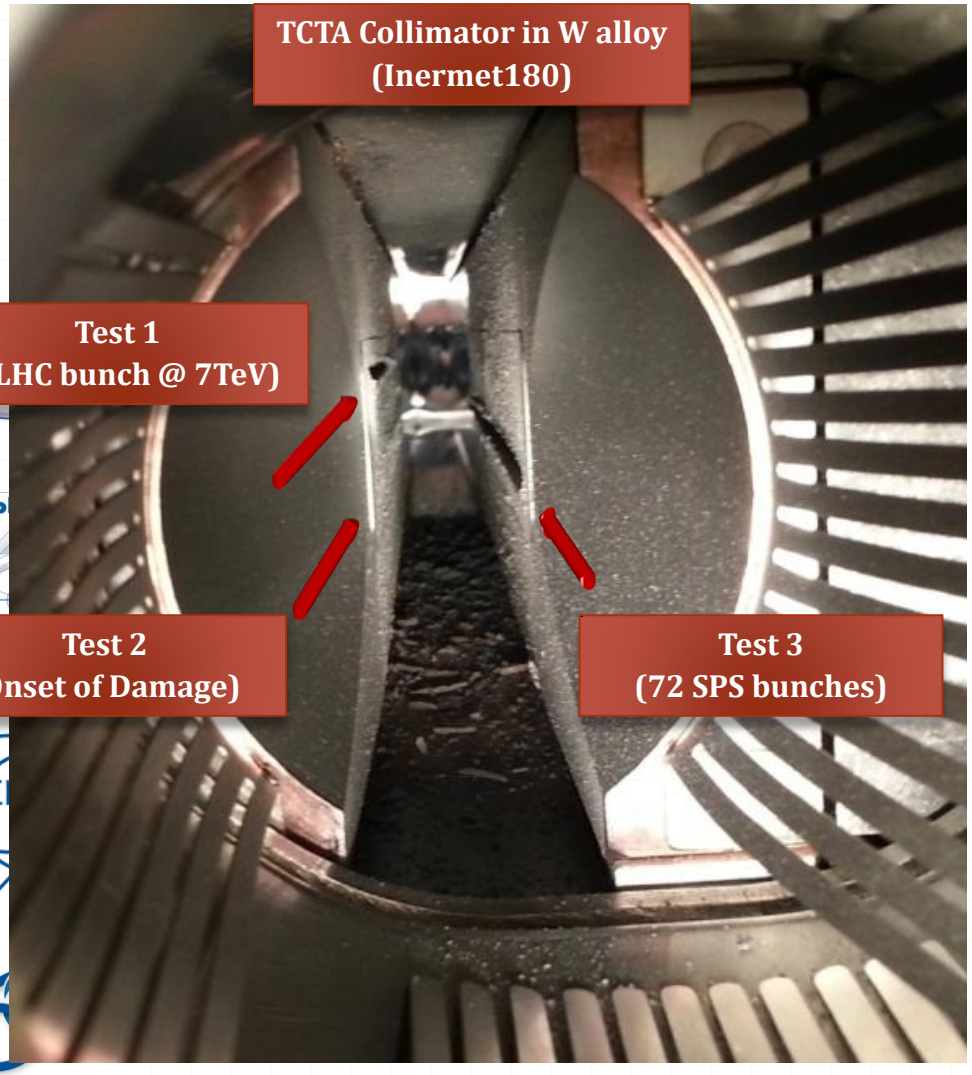
- Context
- Overview of past collimation experiments in HiRadMat
- Future HiRadMat tests:
  - HRMT-23: Collimator Jaws
  - HRMT-21: SLAC Rotatable Collimator
  - MultiMat Experiment
- Schedule and actions

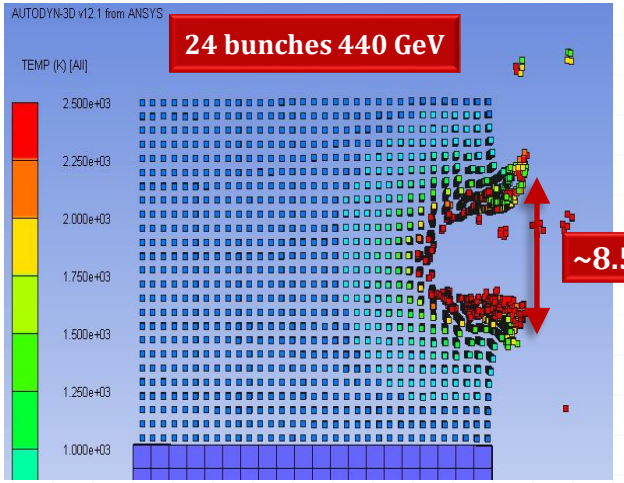
Context

- **2012:** first two experiments (**HRMT-09** and **HRMT-14**) on collimators and collimators materials in the HiRadMat facility
- **HRMT-09** and **HRMT-14** goals:
  - Characterize material response to particle beam impact, benchmarking numerical simulations
  - Gain confidence in prediction methods for damage induced by beam impacts
  - Derive operational limits for installed hardware (namely TCTA and TCTP)



HRMT-09 Experiment



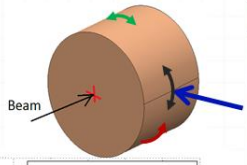


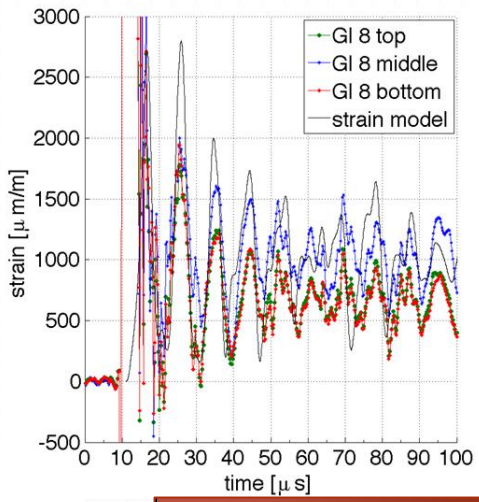
- Three impacts with different objectives:
  - **Test1**: provoke a damage on the jaw equivalent to 1 LHC bunch, 7 TeV
  - **Test2**: determine the onset of plastic damage
  - **Test3**: produce an extensive damage to the W jaw, with plastic deformation of the housing and cooling pipes
- **Good matching between tests and simulations**
- Impressive quantity of **ejected W**
- **Vacuum degraded**
- **Tank contaminated**

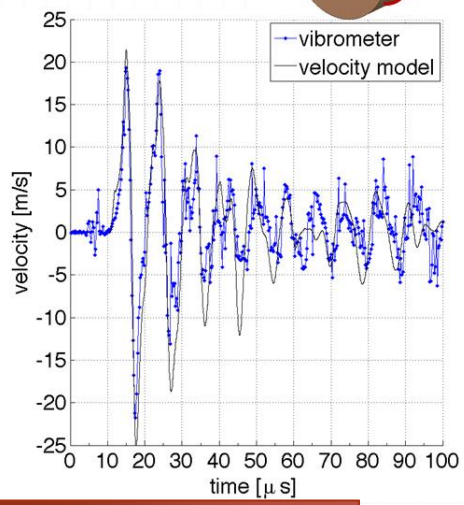
HRMT-14 Experiment

- **Benchmark** advanced numerical simulations and **material constitutive models** through extensive acquisition system.
- Characterize in one go **six existing** and **novel materials** under development: Inermet180, Molybdenum, Glidcop, Mo-CD, Cu-CD, Mo-Gr. **2 sample types, 12 target stations, 88 samples**.
- **Collect**, mostly in real time, **experimental data** from different acquisition devices (Strain Gauges, Laser Doppler Vibrometer, High Speed video Camera, Temperature and Vacuum probes).

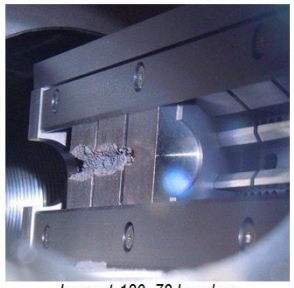
Glidcop Sample – Slot#08
72 b (scraped), Total intensity: 4.66e12 p, σ ≅ 1.3 mm

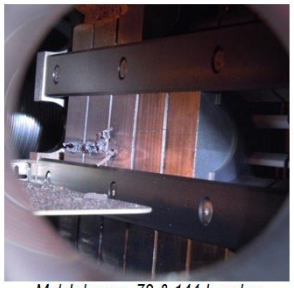


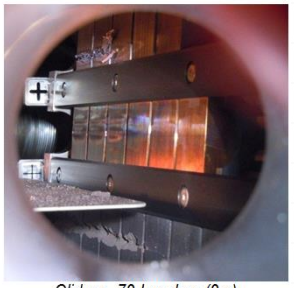


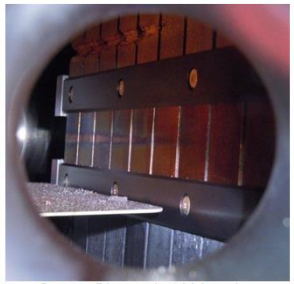


Experimental vs. Numerical benchmarking


Inermet 180, 72 bunches


Molybdenum, 72 & 144 bunches


Glidcop, 72 bunches (2 x)


Copper-Diamond, 144 bunches


Molybdenum-Copper-Diamond
144 bunches


Molybdenum-Graphite (3 grades)
144 bunches

HiRadMat Run1: Summary

- **Both experiments wholly successful.** In particular, all HRMT14 active systems (DAQ, electronics, mechanics) worked properly in spite of the very harsh environment and the technological challenges.
- The experiments confirmed the **effectiveness of numerical methods** and **material models** to reliably predict beam-induced damages…
- **Additional potential machine protection issues** were highlighted (UHV degradation; contamination of tank, bellows, vacuum chambers; complication of dismounting procedure)
- **New damage limits proposed** for TCTA and TCTP in line with updated accident scenarios (Annecy '13 MPP Workshop):
  - **Onset of plastic damage : 5×10^9 p**
  - **Limit for fragment ejection: 2×10^{10} p**
  - **Limit of for 5th axis compensation (with fragment ejection): 1×10^{11} p**
- Further interesting results provided by HRMT14:
  - **Molybdenum** apparently **survived beam impact equivalent to 3 bunches @ 7 TeV** (1.3×10^{11} p/b);
    Inermet180 specimens seriously damaged by the same impact.
  - **Novel composites showed promising robustness up to 6 bunches @ 7 TeV** (equivalent).

HiRadMat Run1: Summary

Limitations of HiRadMat 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** …

Future HiRadMat Tests

Overview of Future HiRadMat Experiments for Collimators

Possible future proposal…

HRMT-21

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 and other BIDs of interest with little known constitutive equations under highly bright beams (LIU/HL-LHC).
- **Benchmark** not-yet-explored effects such as **code coupling, tunneling** etc.

HiRadMat 1421 (MultiMat) submitted to HRM Scientific Board

HRMT-23 Collimator Jaws: Goals

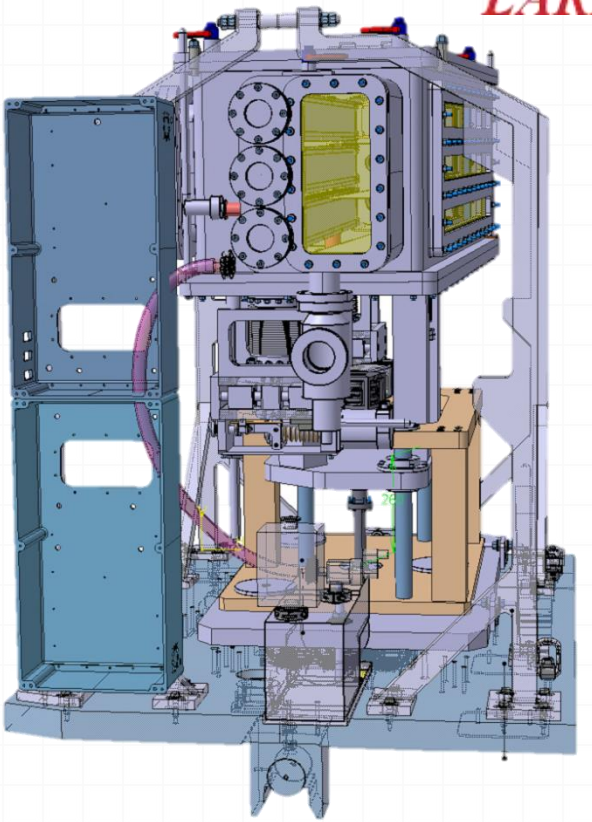
- Simulation of ultimate HL-LHC Injection Error: integrally test under **LIU-SPS equivalent beam** (288 bunches, maximum available intensity - 1.5÷1.7 e11 p/b?? – 0.3x0.3 mm^2 sigma, lower than nominal to compensate for the lower intensity), jaws for HL-LHC collimators
- Determine damage thresholds for 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

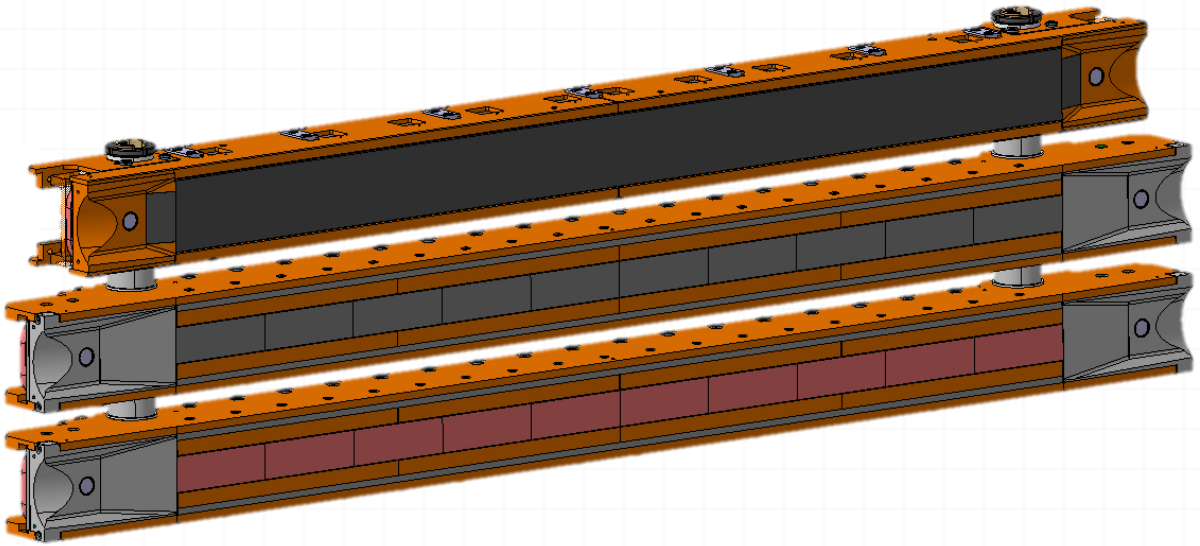
HRMT-23: Test of Fully Assembled Jaws

- 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.

HRMT-23 Experiment

- **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. On a standard HiRadMat table
- **Control system** derived from HRMT-14. Horizontal (jaws) and vertical (whole tank) movement enabled.
- Total expected number or protons **~ 3e14 p**





HRMT-23 Experiment

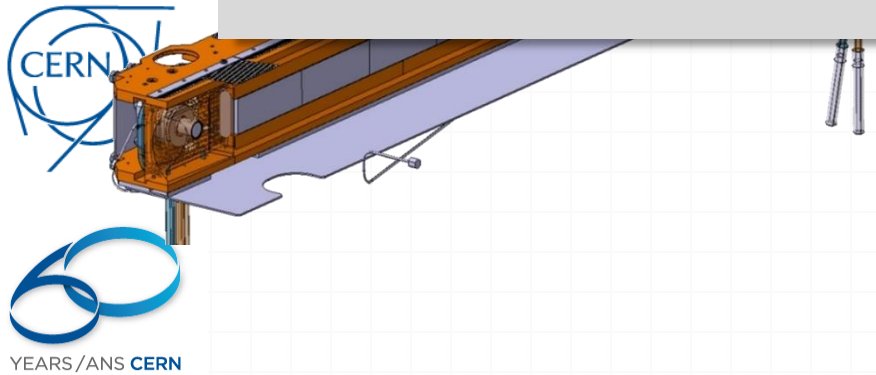
Currently envisaged proposal for Jaws:

1. **TCSPM** with 10 **Molybdenum Carbide–Graphite** inserts (some inserts possibly coated)
2. **TCSPM** with 10 **Copper–Diamond** inserts
3. **TCSP jaw**: to verify the resistance of C/C jaw, metallic taperings and BPM buttons to beam injection accident with HL-LHC parameters

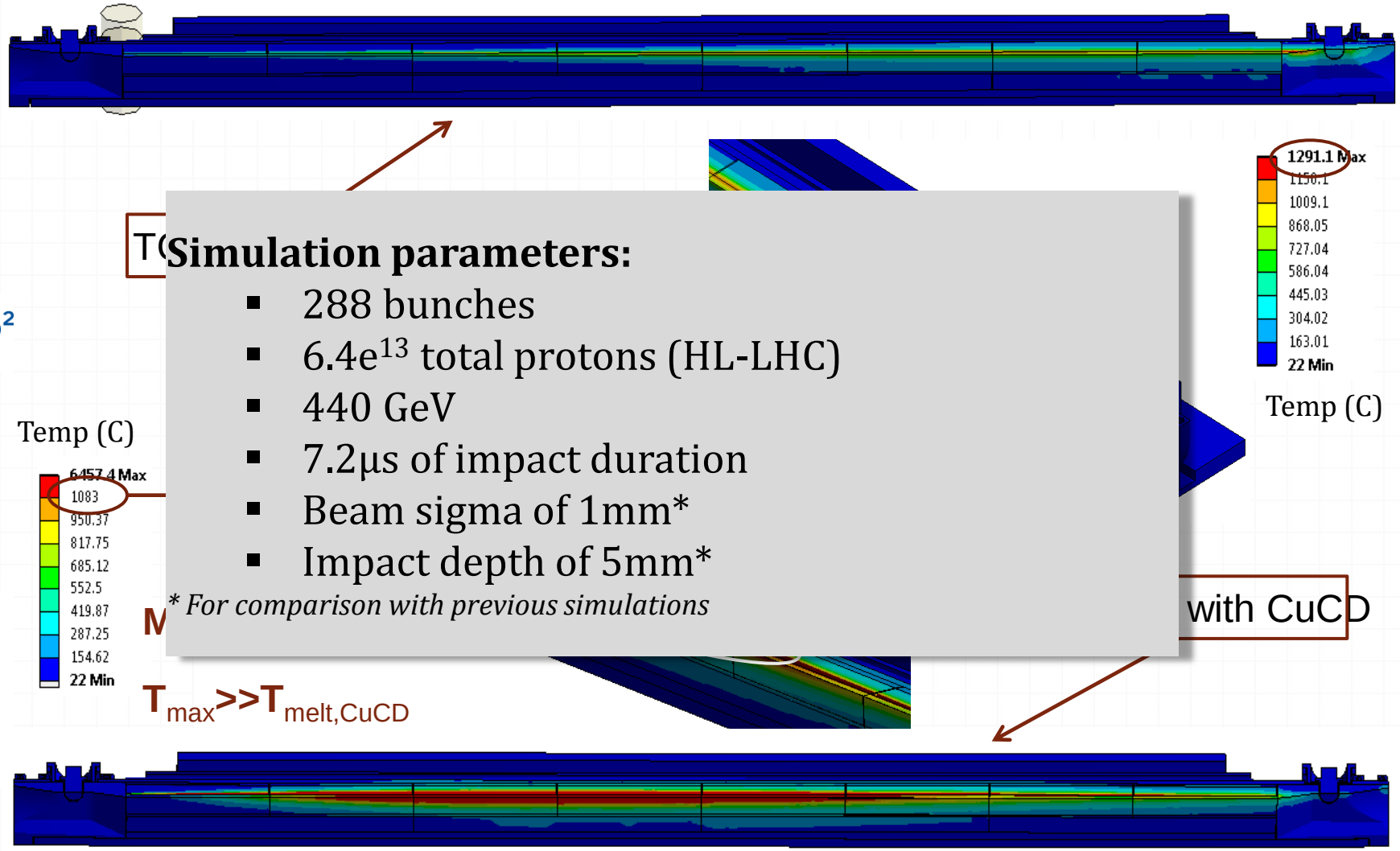
For more details on the TCSPM design see:

"Status of R&D and beam plans for low impedance collimators",

F. Carra et *al.* – WP2/4/5 Session



HRMT-23 Experiment



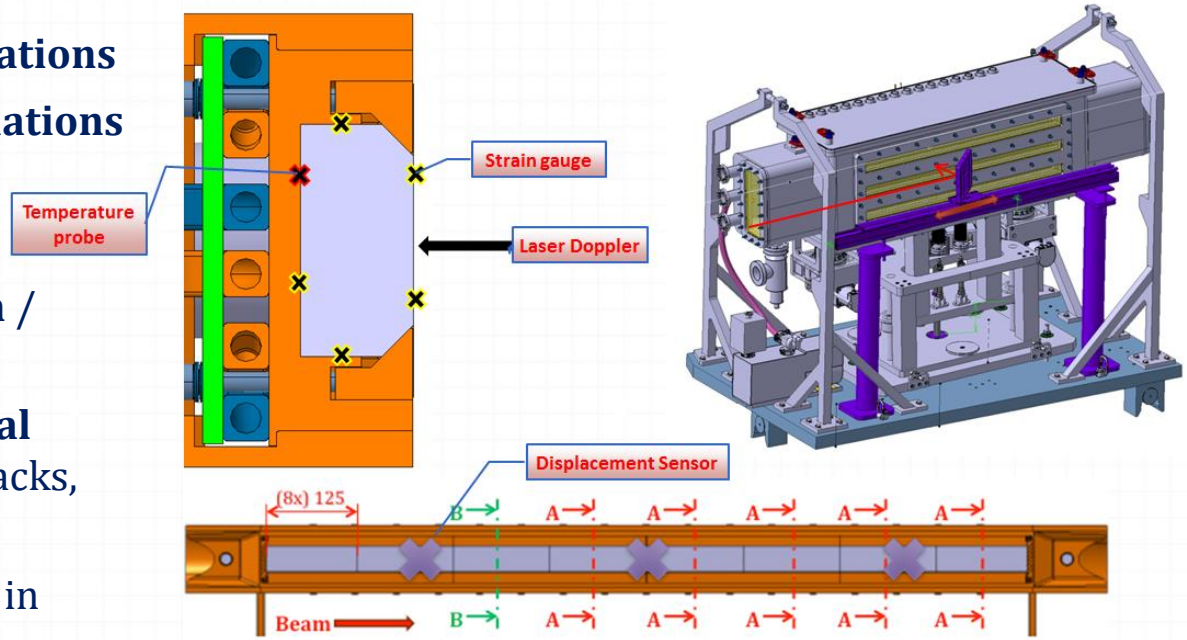
FLUKA energy deposition maps courtesy of S. Lefteris

Ongoing mechanical simulations to estimate residual deflection

HRMT-23 DAQ

Instrumentation objectives:

- Acquire online **pressure waves**
- Acquire online **temperatures**
- Detect online **high speed vibrations**
- Detect online **low speed oscillations**
- Detect offline **permanent jaw deformation**
- Visually **record jaw explosion** / fragmentation
- Detect offline **internal material damage** (e.g. delamination, cracks, tunneling …)
- Record online **pressure burst** in water cooling pipes



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***

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

- Experiment proposed by Collimation Team on 21.10.2013 (**AdColMat** meeting)
- 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 (upgraded version of HRMT-14).

- Test **materi** … **imators, injection** and **dump abso**
- Possibility … etc.
- Proposal t… …een BE/ABP, BE/OP, EN/MME, …
- Beam intens… **…0.5x0.5 mm2** (down to **0.3x0.3 mm**
- Design and … …rget stations each hosting several spec…

HiRadMat - Experiment Proposal
EDMS No: 1213282
Version 2.0

HiRadMat
High-Radiation to Materials

HiRadMat Beam Time Request Form

Designation	
Experiment Name	to be assigned
Acronym	to be assigned

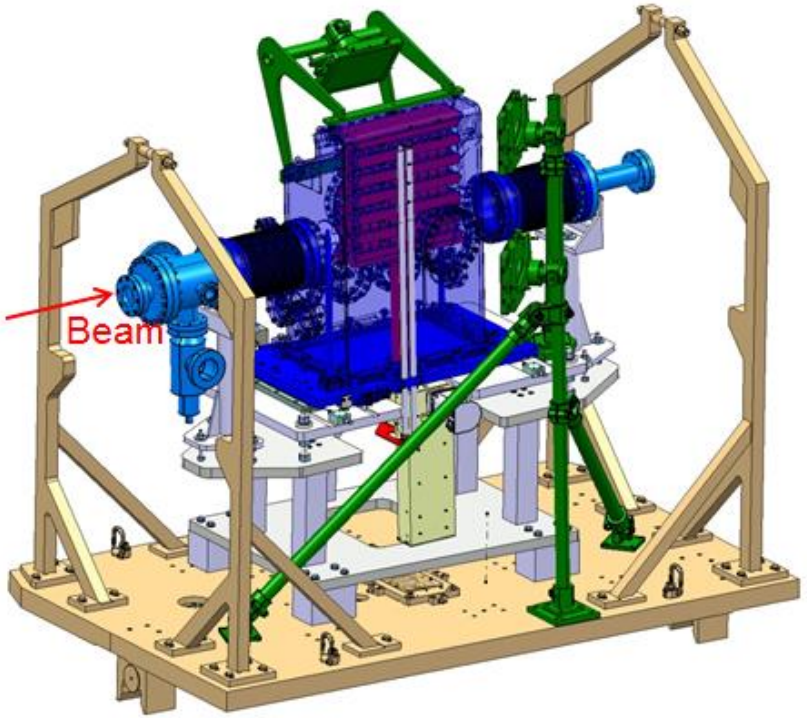
Date	08.09.2014

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.

MultiMat Design Main Features

- Design of the experiment inspired by HRMT14
- HiRadMat standard test stand table
- 2 beryllium/C-C windows withstanding up to 288 SPS bunches, sigma 0.3x0.3 mm^2
- Vacuum Tank (primary vacuum) containing up to 12 target stations
- Each station hosting several specimens (possibly of different shapes) made of one material
- Each stations aligned through 2 DoF actuation system (beam-based alignment). Required position tolerance: ±0.2 mm
- Estimated size: 2100x1200x400mm
- Estimated weight: 1600kg

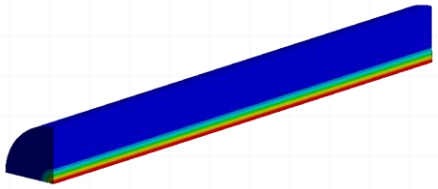


MultiMat Materials

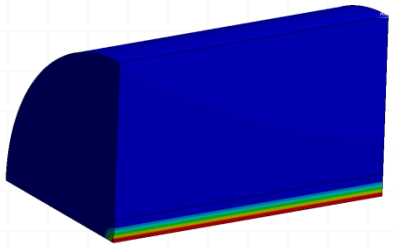
Materials to be tested will likely include:

- 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 (Inermet, W-Re etc.)

Specimen shapes and dimensions under optimization to **improve measurements sensitivity** and **explore different pressure wave regimes**



Ø=30 mm, L=40 mm



Ø=12 mm, L=100 mm

HRMT-21 SLAC Rotatable Collimator: Goals

- To assess damage limits in case of accident scenarios
- To test rotation mechanism functionality to beam impacts with increasing intensity

- Test 1: To assess Glidcop onset of damage (6 shots between 25% and 150% of the expected damage limit followed by 1-3 facet rotation to distinguish damage extension)
- Test 2: To assess functionality after HL-LHC asynchronous beam dump (82b for a total of $1.39e^{13}$ at 440 GeV)
- Test 3: To assess functionality after HL-LHC injection error (288b for a total of $6.62e^{13}$p at 440GeV)

SLAC Rotatable Collimator

- The SLAC RC was built as part of the US-LARP collaboration
- **Objective**: produce a machine-ready prototype for beam tests in SPS/LHC
- **Rotatable jaw concept**: offers up to 20 collimating surfaces in case of beam damage

Test Timeline

➡ 11.2013: SLAC collimat

➡ 02.2014: Tank op

➡ 03.2014: fi

➡ 03.20

sts

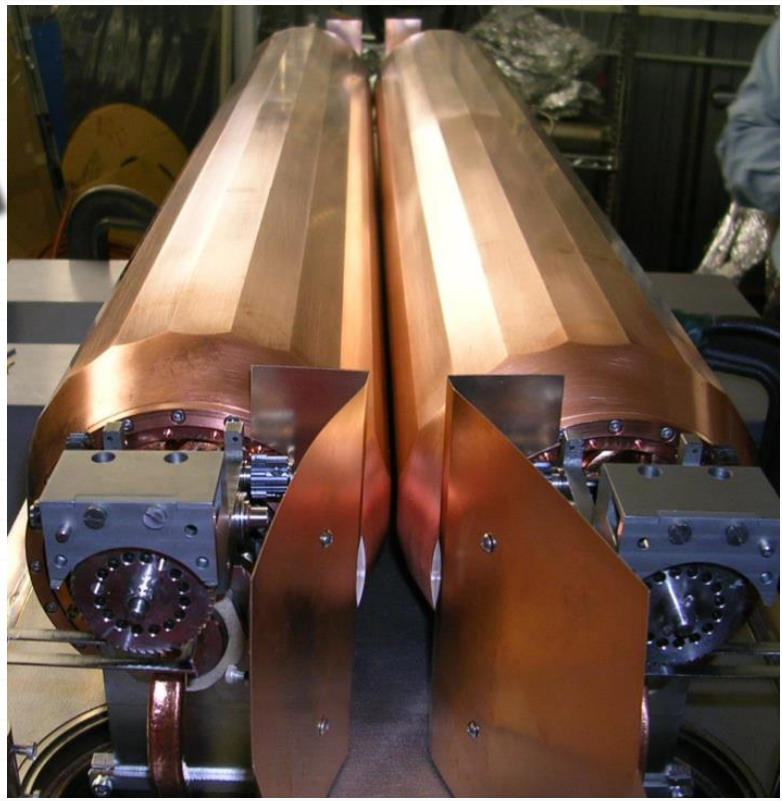
, LVDT, …) tests

compliant

itional controls tests

4: Metrology tests (for positioning)

Compliant with SPS requirements
- MD in the SPS in 2015
- HiRadMat test in 2016



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 TCSPM Collimator with qualified materials in LHC for operational tests early 2016**
- 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
- SLAC RC is proposed for installation in the SPS for **MD in 2015**: ECR prepared and to be circulated soon
- Test of SLAC RC in HiRadMat likely in **2016 (HRMT-21 experiment)**
- **MultiMat experiment** proposal submitted to HRM Scientific Committee; test expected in 2016

Thank you for your attention!