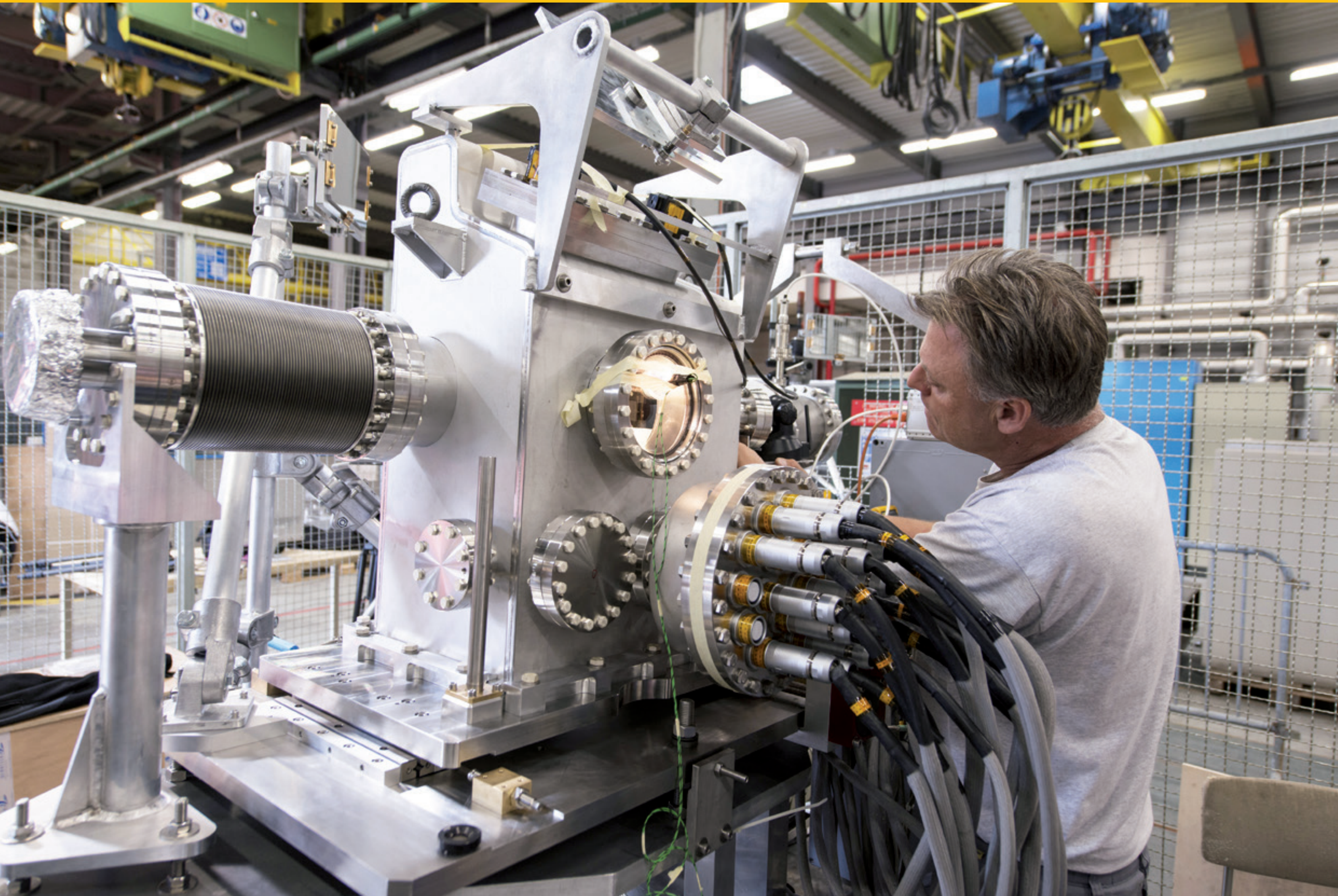
Polytec

Laser Vibrometers for the Roughest Conditions

Material Research at the CERN

Application Note

The introduction in recent years of new, extremely energetic particle accelerators such as the Large Hadron Collider (LHC) at the European Organization for Nuclear Research (CERN) brought about the need for advanced beam cleaning and protection systems in order to safely increase the energy and intensity of particle beams to unprecedented levels.



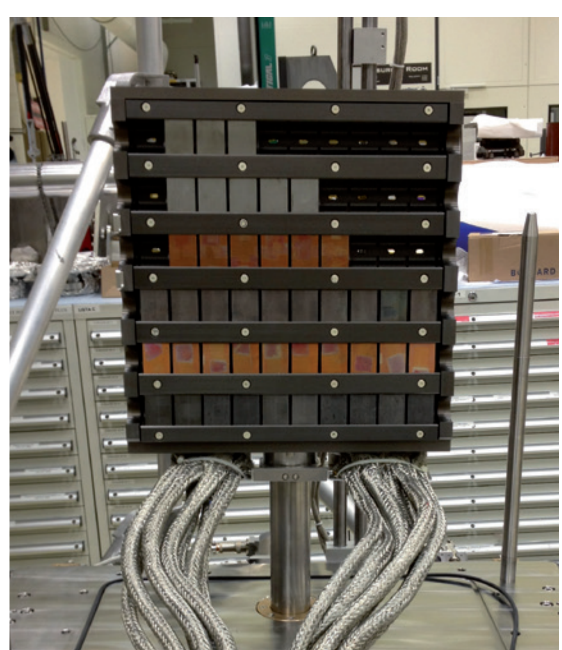
Mission possible

An experiment for the investigation of high-performance materials by bombardment with high-energy particle beams at CERN

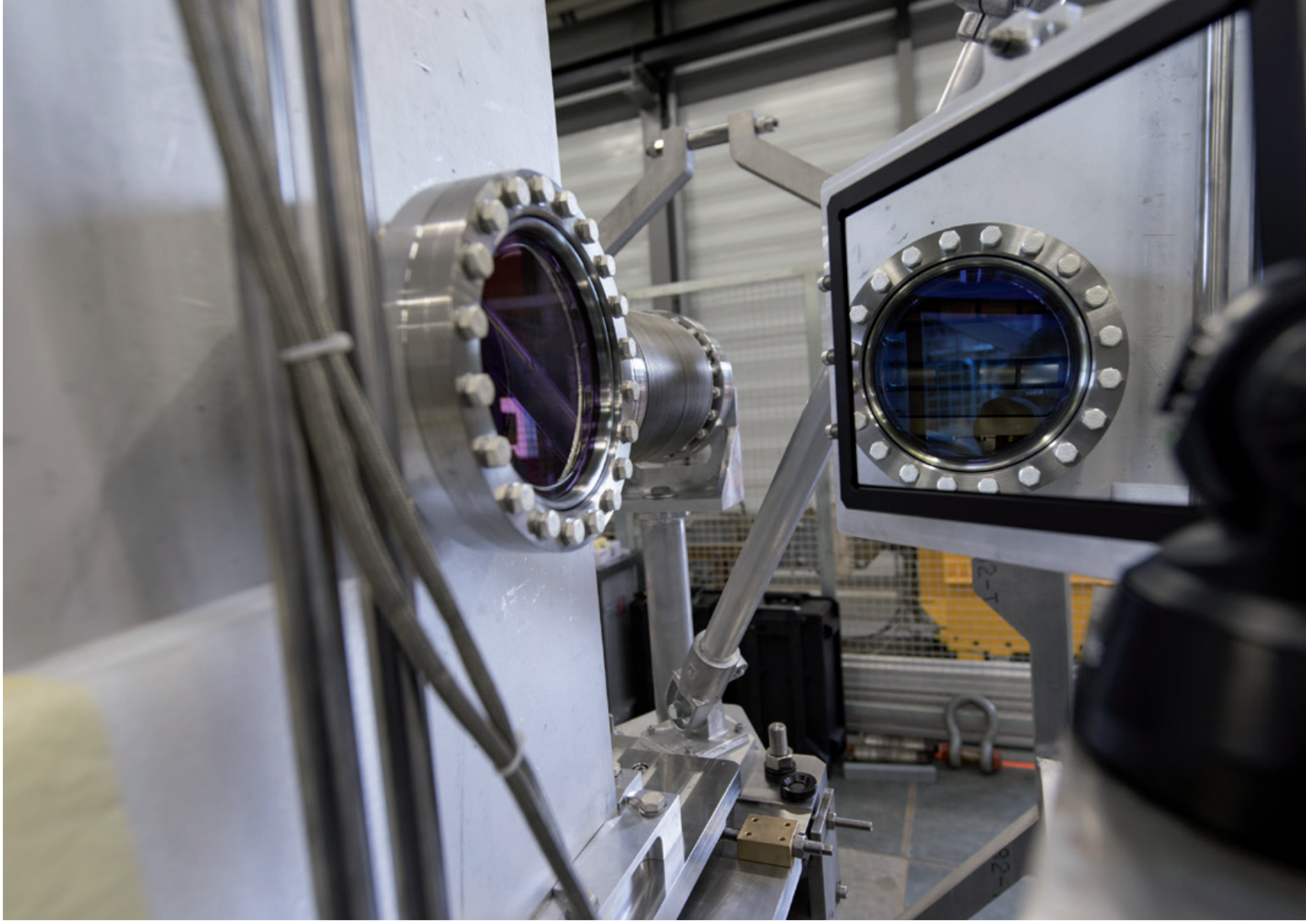
Predicting the consequences of highly energetic particle beams accidentally im pacting protection devices, such as collimators, is a fundamental issue in the design of particle accelerators. Such complex dynamic phenomena, entailing material phase transitions, extended density changes, shock wave propagation, explosions, material fragment projections etc., have been successfully simulated using highly non-linear numerical tools (Hydrocodes). In order to gather experimental data for a comprehensive characterization of relevant materials, a specific test was performed in October 2012 at the CERN HiRadMat (High Radiation to Materials) Facility.

Experimental Setup

The experimental setup consisted of a multi-material sample holder allowing the testing of six different materials (Fig. **1**) under proton beams of different intensity, at an energy level of 440 GeV. The material specimens and their housing were designed and equipped to measure physical quantities in real time such as axial and hoop strains, radial velocity of displacement and temperature necessary to reconstruct material constitutive models. Data were collected at very high sampling rates to fit shock wave profiles with sufficient accuracy. The projection of particles generated by the beam impact was filmed by a high-speed camera. The material sample holder comprises a vacuum vessel and a specimen housing featuring 12 material sample tiers arranged in two rows of six. The specimen housing could be accurately positioned via a two degrees-of-freedom actuation system. Two different specimen shapes were chosen for each material to be tested: a cylindrical geometry for medium intensity tests, to measure simple-shaped shock waves, benchmarking numerical simulation; and cylinders with a half-moon cross section for high intensity tests, allowing extreme surface phenomena (melting, material splashes, debris projections etc.) to be visualized and optically acquired.



1
Sample holder with 6 different materials



2
View of the samples through a Polytec mirror and glass window.

Measurement Instrumentation

Remote optical devices (the RSV-150 laser Doppler vibrometer and a high speed camera) were placed in a radiation-protected bunker, 40 m upstream of the sample holder. The RSV-150 measured the radial velocity on the outer surface of one cylindrical sample per tier. A system of Polytec mirrors (Fig. **2**) was assembled and accurately aligned in order to reflect the laser beam back to the vibrometer, positioned inside the protected bunker. In order to be able to measure the response predicted using beam impact simulations, a RSV-150 was customized to achieve a measurement bandwidth of 2.5 MHz and amplitude range of 24 m/s. The signal output delay of the RSV-E-150-M controller was also a major issue for this measurement (particle beams arrive at a speed close to that of light).

Results and Conclusions

The arriving proton pulse was used to trigger the RSV-150, and the subsequent vibration measurement was collected for 13 ms with a sampling frequency of 4 MHz, although the first pressure wave typically occurs within the first few microseconds. Typical traces of strain and radial velocity raw signals are shown in Fig. **5** below. This event corresponds to the impact of 4.6 x 10^{12} protons on the Glidcop® samples. In this event, the beam impacted the samples at 22 µs (t_0).
The high frequency response and dynamic range of the RSV-150 allows us to evaluate the pressure wave velocity inside the sample (time between t_0 and the first peak at 26 µs). Experimental results confirm the simulation's prediction of a pressure wave velocity around 4,000 m/s in this material. These results also confirm the main advantages of the RSV-150 for this very harsh environment: strain gage signals are lost during the first few microseconds after the impact, possibly due to capacitive coupling effects and electromagnetic phenomena. The RSV-150 data shows only a small perturbation before the impact, probably explained by interference between the controller and beam passing in front of the radiation-protected bunker, or a possible movement of a mirror installed close to the magnets.

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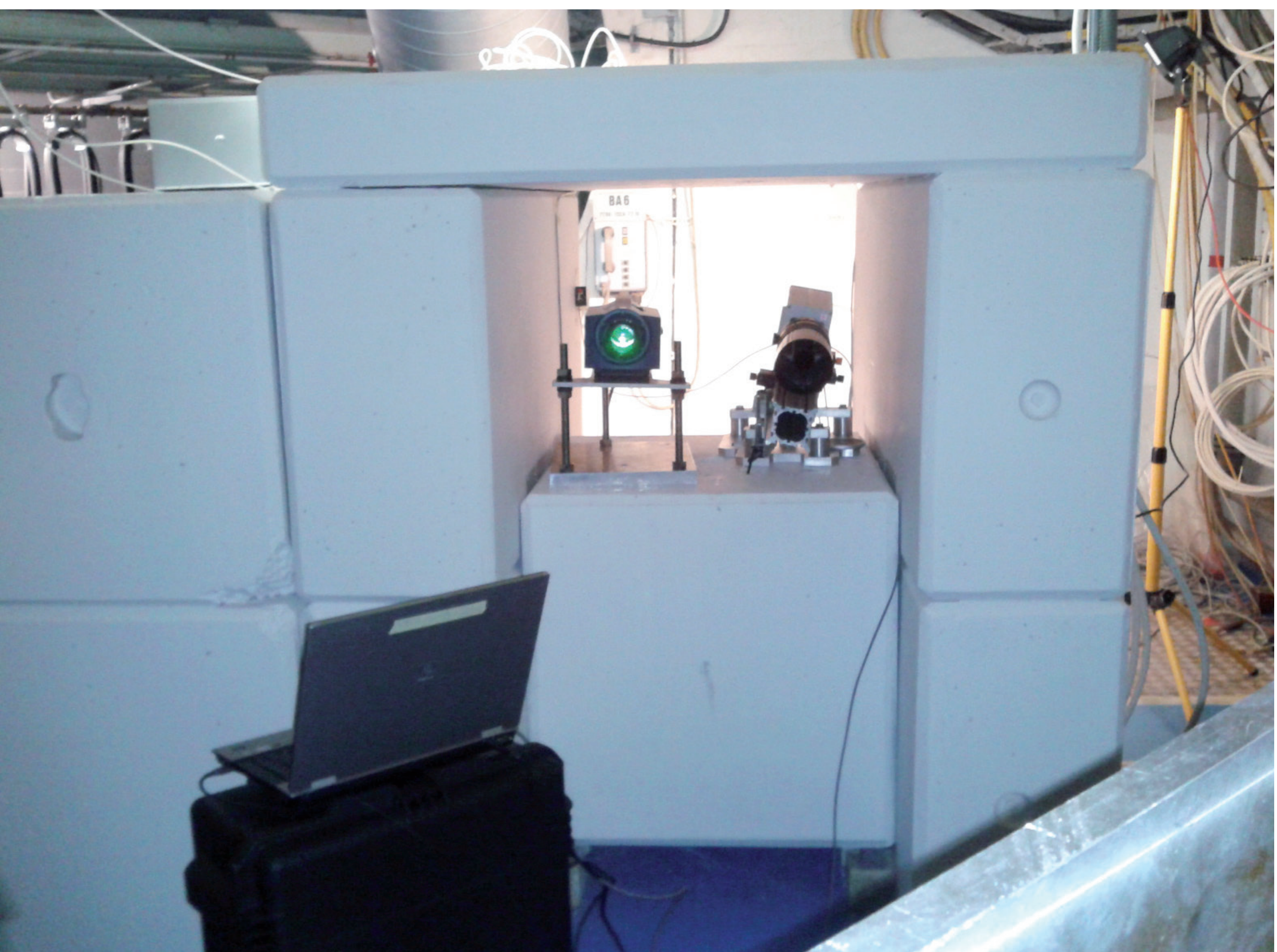
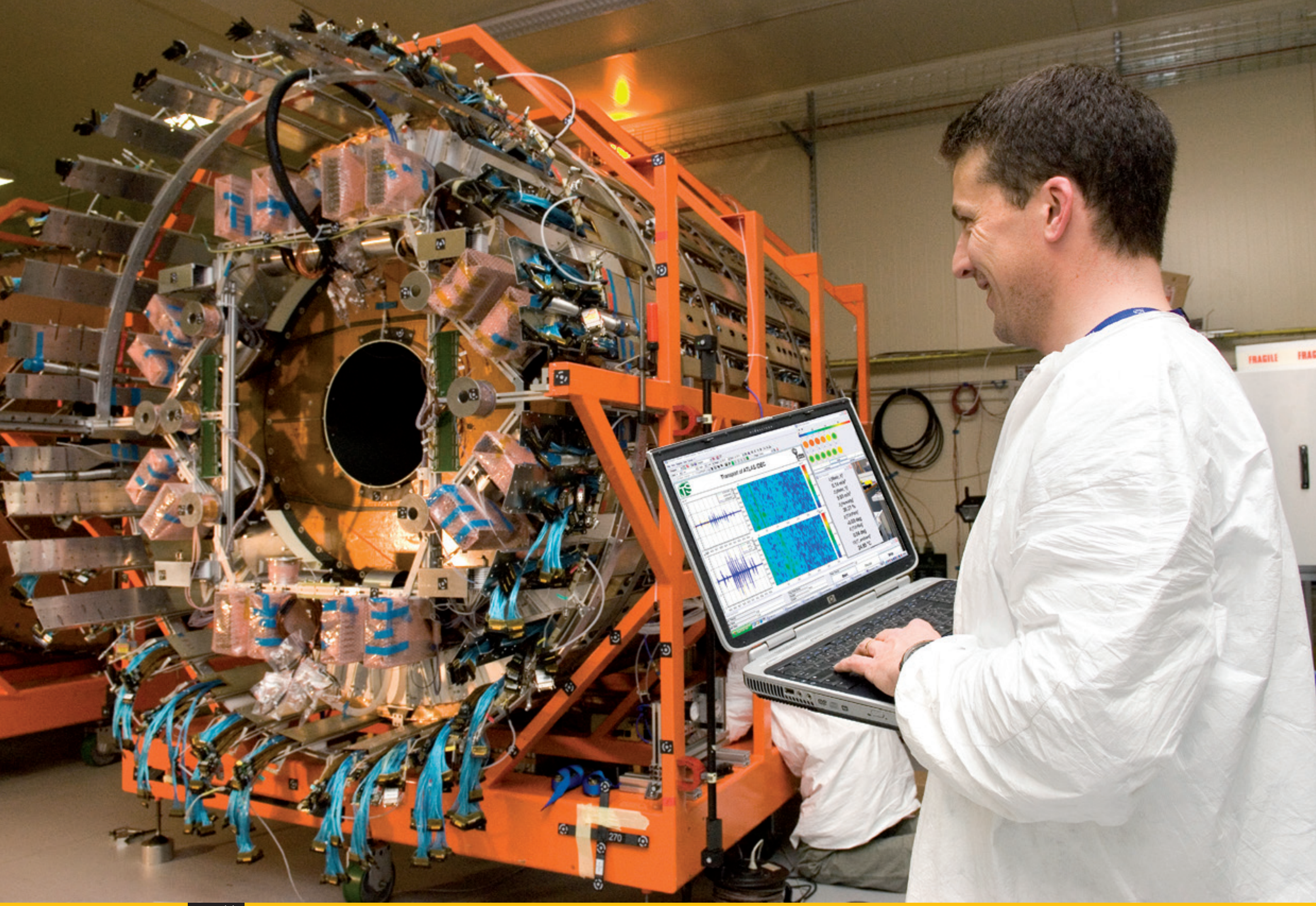
http://jacow.ihep.ac.cn/pls/hb2012/MOP240.PDF

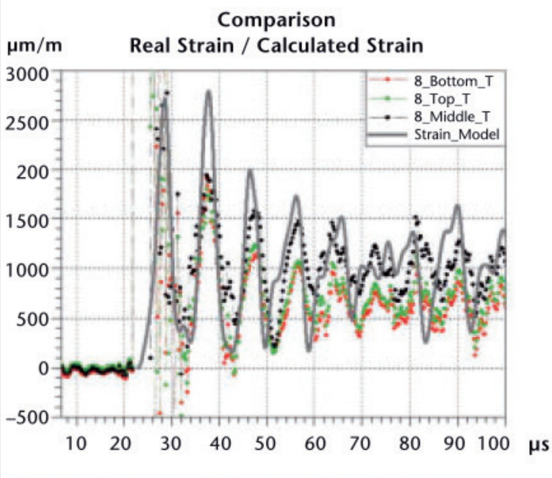
3
RSV-150 laser Doppler vibrometer placed in the bunker.

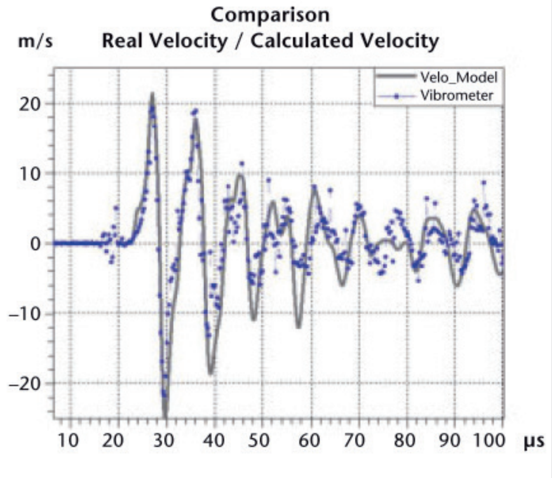


4
View towards the setup from 40 m distance.



»Conditions in which no technology except the laser Doppler vibrometry survived.«





5
Strain and velocity results.

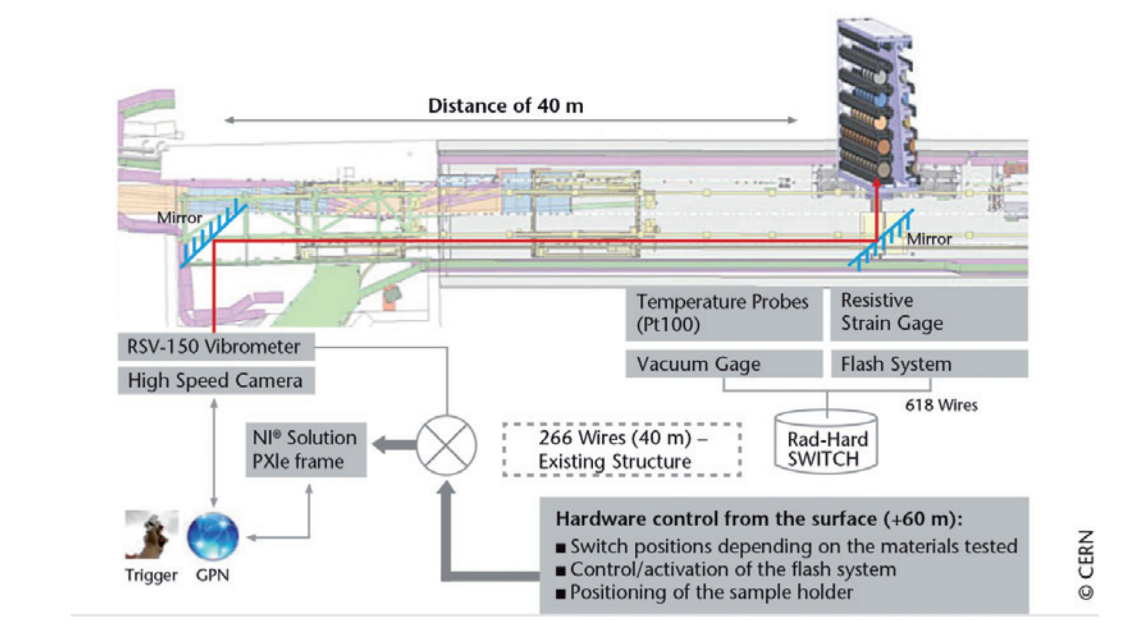
Interview with Michael Guinchard, Responsible for the Mechanical Measurement Lab, Mechanical and Materials Engineering Group, CERN

Mr. Guinchard, how did the laser vibrometer contribute to finding the Higgs particle?
»The RSV-150 has not directly contributed to identifying new particles, but the measurements performed during this experiment on advanced materials will improve beam intercepting devices for the LHC accelerator. These will be used to explore a higher luminosity and energy range.«

How did the vibrometer help in solving or avoiding current problems?
»At CERN, we have a lot of experience measuring mechanical effects in very harsh environmental conditions. However this experiment concentrated many critical conditions such as: vacuum conditions high level of radiation (dose calculations had shown a radiation level of 250 kGy integrated), proton beam a few millimeters away from the sensors, and very fast physical effects. The radial velocity measurement on the samples was also considered crucial information with redundancy provided with strain measurement at the surface of the samples. There are no modern contact sensors able to survive these environmental conditions, and an optical measurement without contact, with remote electronic devices, was the best approach. The RSV-150 fulfilled these requirements.«

What would have been the alternatives to vibrometry?
»As explained before, there are no contact sensors that could withstand these harsh conditions, and the requirement was also very tight. When the beam impacts the sample, the shock wave travels with a speed around 4,000 m/s in the sample and generates a radial velocity at the surface close to 24 m/s with a resonant frequency around 120 kHz. These conditions do not permit using any technology other than laser Doppler vibrometry!«

How was the cooperation and support from Polytec?
»The RSV-150 used for this measurement was customized for this specific application in order to improve the bandwidth up to 2.5 MHz. Polytec provided a lot of support to perform reflectivity tests on the real samples, and preliminary validation tests at CERN using the real distance coupled to the mirrors' positions.«



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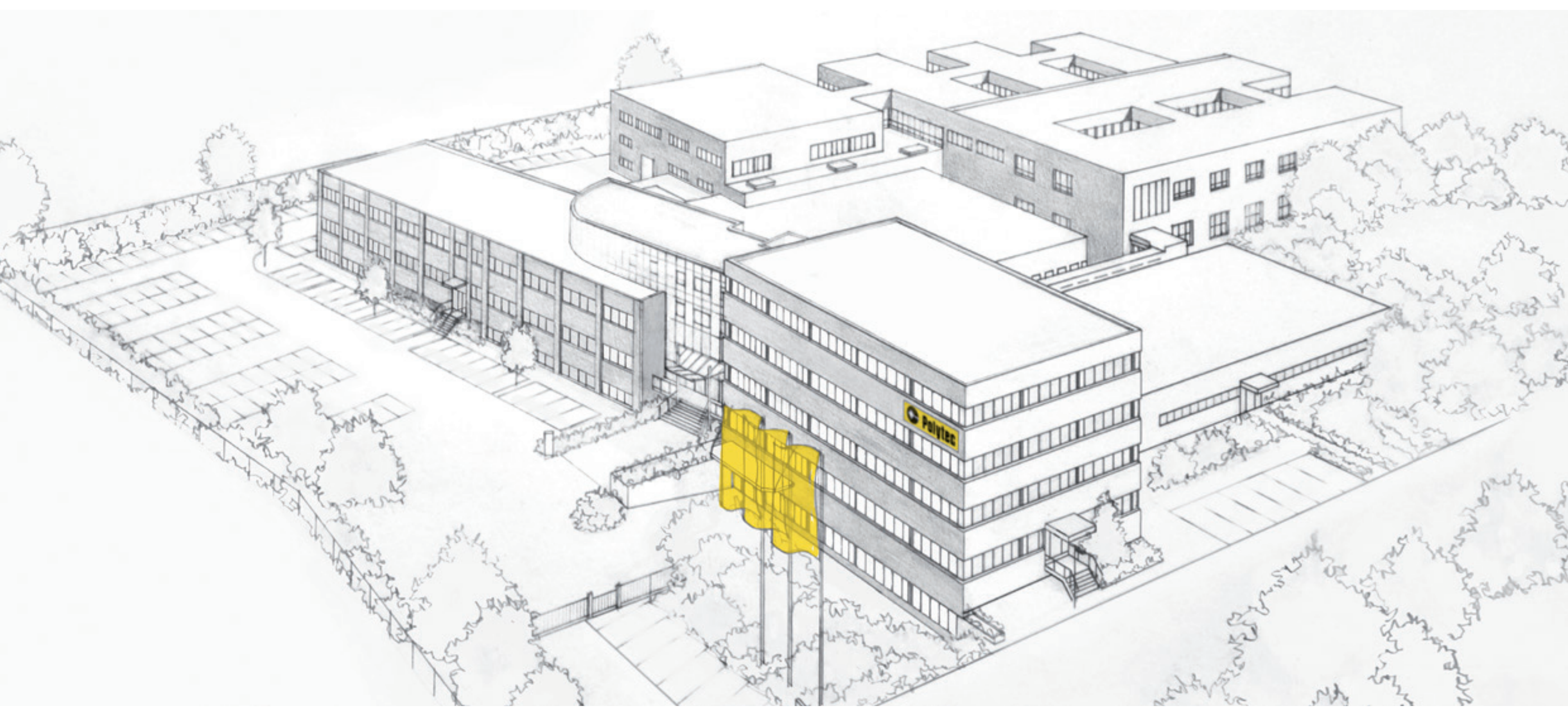
General view of the instrumentation structure.



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