Tackling the challenges in beam intercepting devices and target systems technologies for the High Energy Frontier

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Beam intercepting devices such as collimators, absorbers and particle producing targets are essential accelerator systems components for the execution of high energy physics programs. The European Laboratory for Particle Physics (CERN) operates up to 250 devices of this type, which are operating under harsh environment, most of the times under ultra-high vacuum conditions as well as with micrometric precision movements and at the same time having to operate with large reliability.

The Large Hadron Collider (LHC) [1] – which has operated with a stored beam energy of up to 300 MJ until end of 2018 – will see the stored energy increase up to 700 MJ at the completion of the High-Luminosity LHC Project [2], foreseen in 2027. This is coupled by extremely small transversal beam sizes, which leads also to significant energy densities, up to 6 kJ/cm^3 [3] or even higher. Average dissipated power is also a challenge, sometimes ranging up to 350 kW, such as for the SPS internal beam dump [4]. These conditions, already are very challenging for the design and operation of beam intercepting devices, ranging from the choice of the absorbing material, lubricants for movable parts, radio-activation, etc. are currently being dealt within the framework of the LHC Injectors Upgrade Project [5] and HL-LHC.

The recent release of the European Strategy for Particle Physics Update [6] has identified the Future Circular Collider (FCC) machine [7] [8] as well as the ILC [9] as priority machines for the future of Particle Physics. The development of these machines, apart from their sizes and technical challenges, will require significant R&D and validation in order to assess the performances of protection devices that will have to cope with the function of protecting the delicate components, such as detectors, magnets as well as personnel. This is true whether they will be leptonic machines (ILC and FCC-ee) or hadronic ones (FCC-hh). The challenges of designing reliable beam intercepting devices will be enormous: as an example, the stored energy per beam – which will have to be absorbed regularly by dedicated devices – will increase more than tenfold with respect to HL-LHC, reaching 8.4 GJ for FCC-hh [7]: the latter requirement will certainly need the development of a new class of graphite-based materials, sufficiently robust as to resist multiple impacts and with reasonable electrical and thermal conductivity. A plan of R&D is being defined within the FCC study team at CERN.

The possibility of muon colliders [10] in order to reach high beam energies with “compact” machines, also highlight the importance of beam intercepting and generally of “targetry” research and development work. Muon colliders require MW-class proton drivers and respective target systems, capable of dealing with the generated thermal power and radiation, while having to optimize the capture of wished muons. Alternative solutions for muon production involve the use of positron drivers, such as in the LEMMA scheme [11], but

open even more challenging targetry technologies to deal with extremely thin targets and very high energy densities.
Radiation damage studies on how high energy charged particle beams irradiation modify the thermal and mechanical properties of target materials are an essential component of these studies; an example of notable efforts are those managed within the framework of the RaDIATE Collaboration [12].

All the mentioned developments require ad-hoc and detailed FEA (both implicit and explicit) as well as CFD techniques, coupled with a detail knowledge on the material properties at the operational regimes, both in terms of temperature, strain rates, environmental conditions, radiation damage, etc. Monte Carlo techniques are also essential for generating – amongst other parameters – the realistic energy density map which is the primary ingredient of the FEA/CFD simulations: the new energy regime of FCC-hh will also require new developments of physics models and relative simulations packages. Significant progress has been made in the last decade in simulating beam intercepting devices, but the projects mentioned above will need significant new progresses in order to be able to reliably predict the devices response as well as to provide accurate estimation of the systems' lifetimes.

As demonstrated by the operating record of facilities such the Spallation Neutron Source, post-irradiation examination (PIE) techniques have demonstrated to be needed to advance the state of the art in predicting the operability and reliability of beam intercepting devices [13] [14]. Similar efforts are starting also at CERN [15] and shall be pursued accordingly, with direct impact for the design of devices required in the context of HL-LHC. Further expansion of this technique is deemed required in order to reach the stated goals.

In conclusion, a significant R&D program is to be established in the medium term in order to tackle the challenges associated with the high energy physics long-term goals of FCC, ILC and muon colliders endeavors.

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