Application of Muon Radiography to Blast Furnaces: the BLEMAB project

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Muon radiography is a non-invasive imaging technique that exploits cosmic ray muons to explore the content of large, dense and otherwise inaccessible volumes. The European project BLEMAB (BLast furnace stack density Estimation through on-line Muon ABsorption measurements) represents an exemplary application of this technique in the industrial field: the aim of the project is indeed to investigate the capability of muon radiography to scan the inner part of active iron-making blast furnaces. In particular, the focus of the study is the characterization of the so-called "cohesive zone", which could be of great interest for steel-making companies. The project foresees the construction of a dedicated muon imaging detector, that will be installed at the blast furnaces in the ArcelorMittal site in Bremen (Germany). This paper describes the status of the project, including the development of software simulations and the manufacturing of the detector.

KEYWORDS: BLAST FURNACE, IMAGING, MUON RADIOGRAPHY;

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inspection, a certain number of muons will be absorbed. A dedicated muon detector can be placed downstream of the target volume to get a measurement of the muon flux: by comparison with the measurement of the muon flux in the same direction but in the absence of the target (free-sky) and with numerical simulations, a 2-dimensional map of the density distribution of the target can be obtained. By repeating the measurements from different angles (or equivalently by using more muon detectors at once), a 3-dimensional reconstruction can also be performed.
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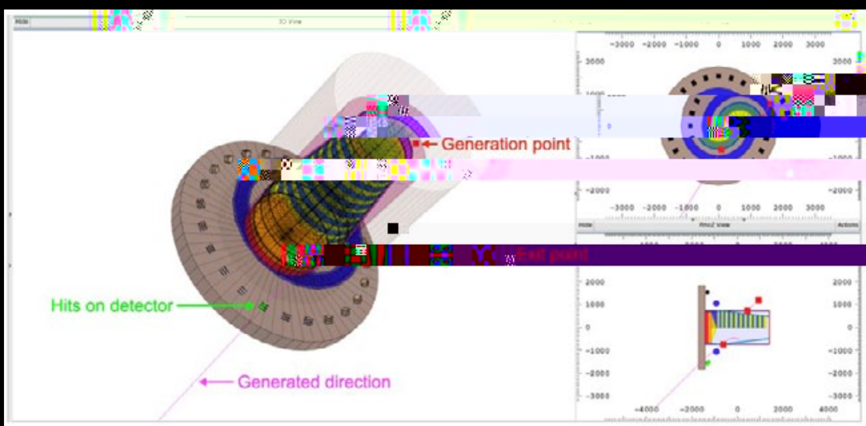

Fig.2 - Disp

In the BLEMAB project software simulations are implemented for two main reasons: firstly, to get a preliminary estimate of the muon rate, so that the characteristics of the experimental apparatus can be defined, and secondly, to perform a comparison with the experimental data and obtain the density distribution of the material inside the blast furnace. To address these issues, two different implementations has been developed: a fast simulation tool and a full Monte Carlo (MC) simulation tool.

The fast simulation tool is used for the evaluation of the feasibility of the experiment; it has been developed starting from a software already available and successfully used in other muon radiography applications [20]. This simulation contains the geometry of the blast furnace and a realistic muon generator, that was developed on the basis of the measurements conducted with the ADAMO magnetic spectrometer in Florence [21], so that the simulated muons reproduce the same energy and angular distribution of the observed ones. In this tool, the interactions of muons with the matter are not simulated, and the detector is simplified to a point-like object. Fig. 1 shows the CAD model of the furnace used for fast simulations and the expected muon counts after 24h of data-taking.

Fig.3 - (Left) Design of the BLEMAB detector: the muon tracker is made of three modules, each of them giving the (x,y) coordinates of the muon trajectory. (Center) The detector will be enclosed in an aluminum box and mounted on a rotating platform that allows to setup its inclination. (Right) The metal frame housing the detector and the cooling system is shown only partially in yellow. / (Sinistra) Design del rivelatore BLEMAB: il tracciatore è costituito da tre moduli, ognuno dei quali fornisce le coordinate (x,y) della traiettoria del muone. (Centro) Il rivelatore sarà racchiuso in un involucro di alluminio e montato su una struttura che consentirà di impostarne l'inclinazione. (Destra) In giallo è indicata la struttura metallica, qui

i[illegible]led downstream of the object to be studied. For the E[illegible]MAB application, two independent muon trackers will be constructed: they could both be installed at the same blast furnace, in order to get a measurement of the object from two points of view and perform a 3D reconstruction; otherwise they could be placed at two different furnaces at the same time, so that a comparative analysis of the two plants could be carried out.

The muon trackers will be developed with the same technology already used for the MURAVES [27] and the MIMA [28] projects: each of them will be made of three 80 x 80 cm^2 tracking modules equally spaced. Each module will be composed by a double layer of 64 scintillator bars, a material that emits light at the passage of ionizing particles such as muons, the two layers being orthogonally oriented to give the measurement of the muon hit on a xy plane. The scintillator bars are 80 cm long and have a triangular cross-section with a 2.5 cm base and a 1.25 cm height. The light emitted by the scintillator bars will be collected by Silicon Photomultipliers (SiPM) and transformed into electrical signals. Each tracking module will be read out by four custom data acquisition (DAQ) slave boards, housing a 32-channel Extended Analogue SiPM Integrated Read-Out Chip (EASIROC 1B [29]) and an application specific integrated circuit (ASIC) to control the transmission of data to a central custom DAQ master board, where the trigger logic and the data collection are implemented. A Raspberry PI [30] computer will be connected to the DAQ master to control the electronic chain and to write data on a physical support. The network connection provided at the ArcelorMittal site will allow online control of the detector and data synchronization on a remote network.

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dology to get a direct information of the inner state of the furnace and to control the burden process for a stable and efficient operation, thus it could be of great interest for steel-making companies.
For this purpose, software simulations and a dedicated muon tracking system, described in the previous sections of this work, are under development; a preliminary detector prototype has already been realized and tested to provide experimental validation of the apparatus. The installation of the tracking system at the blast furnaces in the ArcelorMittal site in Bremen (Germany) is scheduled for late 2022: the detectors will collect data for several months and the results obtained with the muon radiography technique will be compared for validation with the measurements of a new eMPVP and mathematical blast furnace models.

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PAROLE CHIAVE: ALTOFORNO, IMAGING, RADIOGRAFIA MUONICA;

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