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TetraBall: A single-moderator neutron spectrometer for HL-LHC

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ABSTRACT

This contribution presents a novel single-moderator neutron spectrometer, named "TetraBall", developed at INFN and optimized for characterizing the neutron field in the CMS experimental cavern. The TetraBall condenses the functionality of several Bonner Spheres (BS) in a single moderator and it is equipped with 42 SiC radiation-hard detectors organized in a tetrahedral geometry designed to be insensitive to incident gammas and charged particles. Thanks to lead inserts, it can respond up to GeV energies. It works in single exposure mode, suitable for real-time monitoring. It is designed to be used as neutron monitor during the High-Luminosity LHC data taking.

1. Introduction

This paper illustrates the main features of an innovative neutron spectrometer, the so-called "TetraBall", being developed at INFN (Italy) and tailored to be used as neutron monitor in the CMS BRIL (Beam Radiation, Instrumentation, and Luminosity) Upgrade Project [1] during the High-Luminosity LHC data taking period, providing fully unfolded neutron spectra. The aim of such a spectrometer is to benchmark FLUKA simulations [2] with real data, providing reliable predictions of the radiation environment in the CMS cavern and to inform future maintenances and upgrades.

The main challenges for this novel radiation-hard neutron spectrometer are (see Fig. 1):

- An accurate measurement of the neutron component in a mixed-field condition where non negligible fractions of gammas and charged particles are present;
- Being sensitive to a wide energy neutron spectrum ranging from eV to GeV.

The TetraBall design, allowing to tackle these challenges with a single-moderator neutron spectrometer, is described in the following section.

2. The TetraBall design

Bonner Spheres (BS) are still the "state of the art" for radio protection measurements: they can cover ten, or more, decades in energy and they are characterized by simple operation, isotropic response and fluence determination with better than 5% uncertainty. Nevertheless, they require sequential irradiations that are very time consuming and this makes BS unsuited for real time monitoring. The Tetraball condenses the functionalities and the performance of several Bonner Spheres in a single moderator. The design of the TetraBall is illustrated in Fig. 2 and it profits of the experience matured in INFN in the past decade [3–5].

A single High Density Polyethylene (HDPE) sphere is equipped with 42 SiC rad-hard detectors [6] organized in 21 "sandwiches" each made by two SiC detectors where one is made sensitive to neutrons by a micrometric coating of ^{6}LiF and the other is not. The coated SiCs are individually calibrated in ENEA and INFN HOTNES reference thermal neutron fields. A picture of a single uncoated SiC detector is shown in Fig. 3. The 21 "sandwiches" are disposed along the axes of a tetrahedron to guarantee isotropic response.

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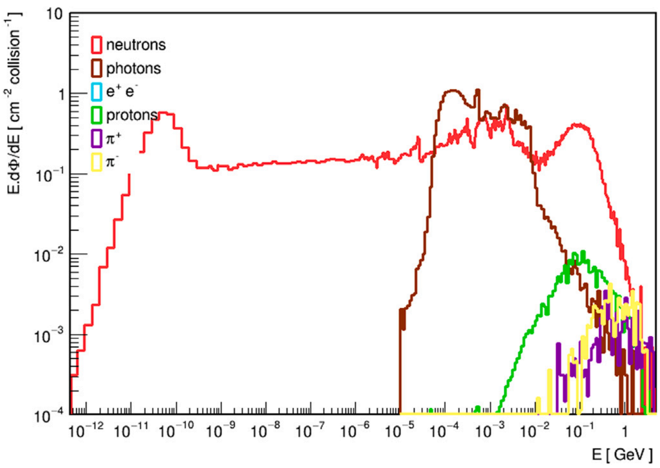

Fig. 1. FLUKA simulation of particle fluences normalized to LHC single proton–proton collision, in a reference location in the CMS cavern.

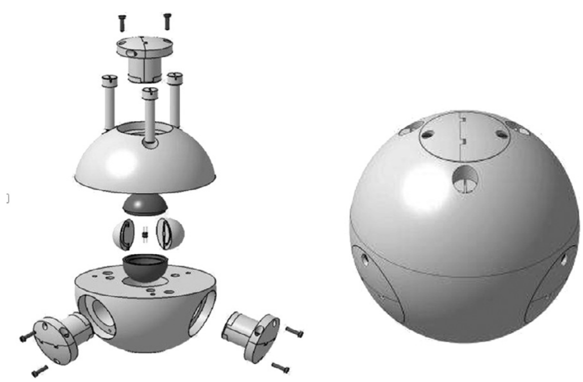

Fig. 2. Open (left) and closed (right) TetraBall geometry. The HDPE parts are shown in light gray, while the lead spherical insert is shown in black.

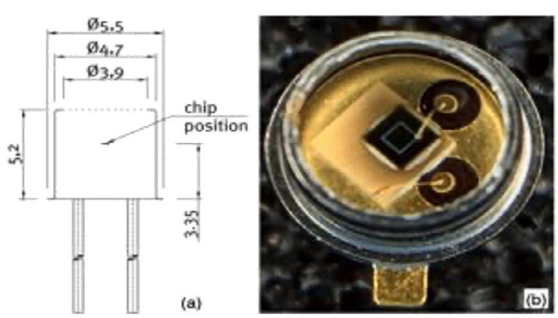

Fig. 3. A 7.6 mm^2 SiC detector used in the TetraBall.

Moreover they are disposed at different depths in the single moderator sphere to mimic different BS radii. Thanks to a lead spherical insert the TetraBall can respond up to GeV energies.

Each detector is readout through custom analog and digital boards designed at INFN and optimized for the CMS BRIL upgrade project. The difference in counts of the two detectors of the same "sandwich" allows to extract the "pure" neutron contribution. Indeed the contribution of the uncoated SiC is small because the reverse bias is tuned to reduce the noise and to produce a limited depleted volume that maximizes the neutron signal and makes them almost insensitive to gammas and to charge hadrons. The design of the TetraBall, its geometry and the position of the detectors inside the sphere has been optimized using MCNP6

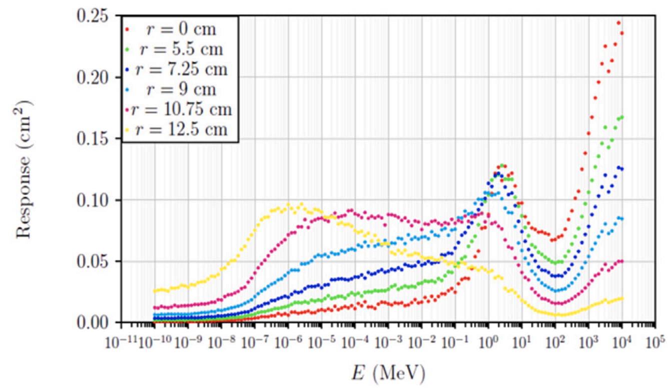

Fig. 4. The TetraBall's detectors neutron response functions calculated using MCNP6. The parameter r represents the distance from the center of the HDPE sphere. A lead spherical insert surrounds the r =0 detector and makes the spectrometer sensitive up to GeV neutrons.

simulation code. In Fig. 4 the neutron response functions (normalized to unit incident fluence) of the detectors at different distances from the center of the TetraBall, as a function of the incident neutron energy, is shown.

A detailed and accurate calibration of the whole TetraBall in a reference facility will be needed. The calibration will consist of many irradiations with monoenergetic neutron beams in a wide energy range in order to validate the response functions of the instrument. This will enable to reconstruct the absolute neutron fluence rate of the measured spectrum at CMS.

3. Conclusions

The TetraBall spectrometer is a novel single-moderator neutron spectrometer developed at INFN, tailored to characterize the complex neutron field in the CMS experimental cavern. It is part of the CMS BRIL upgrade project and it aims to become the CMS BRIL Neutron Monitor for the HL-LHC phase.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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