MAGNETIC FIELD COMPUTATION FOR PMTs SHIELDING OPTIMIZATION

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Abstract

The Photon Array for the studies of Radioactive and Ion Stable beams (PARIS) is a multidetector of clusters. Each cluster is composed of 9 units of two-shells phoswiches of LaBr3/NaI scintillators optically coupled to one photomultiplier tube. PARIS will be used in combination with the VAMOS spectrometer at GANIL. During the experiment, PMTs will be exposed to the constant magnetic fringe fields produced by a quadrupole. Magnetic shielding is essential to efficiently lower the magnetic field inside the PMTs. The design and the optimization of this shield is presented. A comparison is done between the simulated and the experimental values.

INTRODUCTION

PARIS Cluster

A PARIS cluster is a high efficiency detector consisting of 9 two-shells phoswiches for medium resolution spectroscopy and calorimetry of γ-rays in a large energy range [1]. The front-end shell is made of $LaBr_3$. The back end shell is made of NaI. Each phoswich is combined with a photomultiplier tube (PMT) Hamamatsu R7723-100 [2].

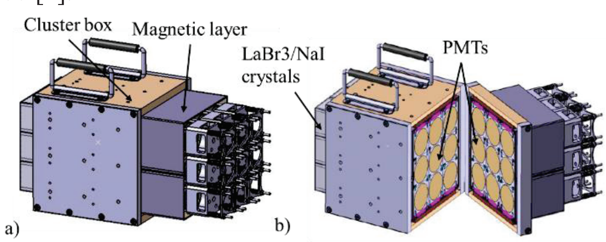

Figure 1: General layout of the cluster (a) and location of the PMTs (b).

The first mechanical support of the cluster is composed of a box and of a magnetic layer. The box is necessary to maintain the phoswiches and to ensure the right position of the cluster. The magnetic layer is used to ensure a PMTs exposure to a magnetic field lower, or equal, to the magnetic field of the Earth, which is about 50 µT. The overall weight of the mechanical support is 11 kg and about 34 kg when loaded with the crystals (Fig. 1).

VAMOS Quadrupole

For the purposes of the nuclear physics experiments, the cluster will be positioned around a spherical nuclear reaction chamber. The center of this chamber is located 0.696 m away from the center of the quadrupole of the VAriable MOde Spectrometer (VAMOS) [3]. The quadrupole has a full aperture of 0.3 m, a physical length of 525 mm and the intensity in the coils is 500 A.

To ensure an efficient propagation of the electric signal from the dynodes of the PMTs during the experiments, the cluster has to be confined into an environment where the magnetic field is close or even below the Earth's magnetic field.

Preliminary Studies

Initial tests and 2D calculations with the POISSON code [4] using a simplified model showed that the magnetic field inside the cluster was significantly above the earth magnetic field. To improve the shielding efficiency, it was then necessary to make further studies, and to use a more detailed 3D model. ANSYS Workbench 15.0 [5] was used to simulate the magnetic field generated by the quadrupole of VAMOS and around the cluster while located as in Fig.2. Experimental values (measured in 2015) and simulations showed to be in good agreement [6].

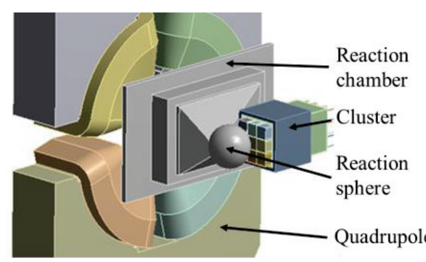

Figure 2: Model used for the simulations.

Under this configuration, the electric signals in the PMTs did not work properly. The maximum field inside the PMTs was then estimated to be of 2-3 mT, 50 times higher than the magnetic field of Earth [6].

SHIELDING STRUCTURE

The PARIS experiment foresees the use of an existing shielding structure made of 7 petals (with extensions) of 3 layers of mu-metal between the cluster and the quadrupole (Fig.3). A layer is 2 mm thick and the layers are spaced by 1 mm gap each other. Other experiments such as EXOGAM array [7] already use such a structure to reduce the magnetic field at the PMTs.

The petals structure was added to the 3D model and several simulations were performed to study the effect of the shielding on the fringe fields.

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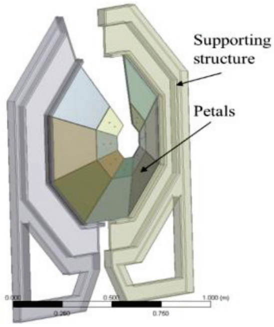

Figure 3: Structure containing the petals of mu-metal.

Fringe Fields After the Petals

First, the fringe fields were estimated from the petals location for two different angles around the reaction sphere. Then these estimations were compared to the experimental values (Fig.4).

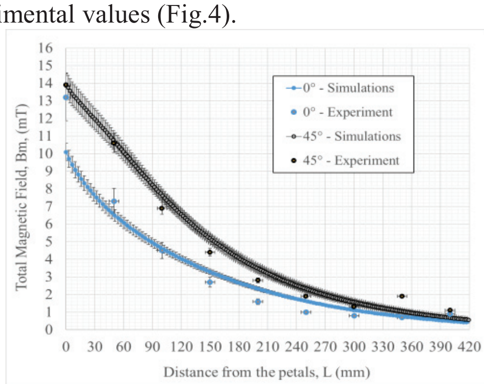

Figure 4: Simulated and measured fringe fields at 0° and 45°. 10% and 5% errors were added on the exp. and simulated values respectively.

Magnetic Field Close to the Petals

The field was then simulated along one single petal (with extension) of the shielding structure over its length (350 mm) and also in 14 points located 3 mm close to the surface of each half part of the 7 petals facing the cluster side, as presented in Fig.5.

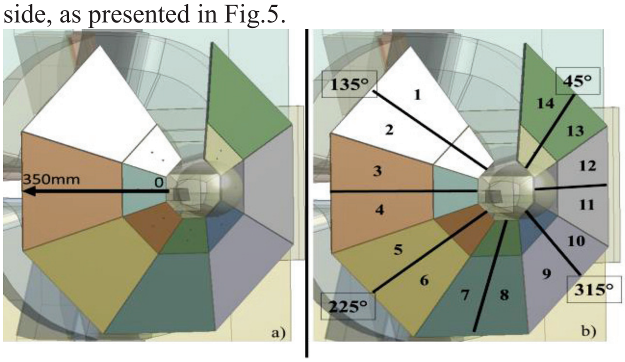

Figure 5: Measurement lines for the field along a petal (a) and close to the surface of each petals (b).

Among the fact that the field peaks are observed at 45°, 135° and 225° and 315° (half petals 13/14, 1/2, 5/6 and 9/10 respectively) the highest peaks are found at the location of the cluster (half petal 11/12). This is due to magnetic reflections of the field between the petals and the cluster shielding.

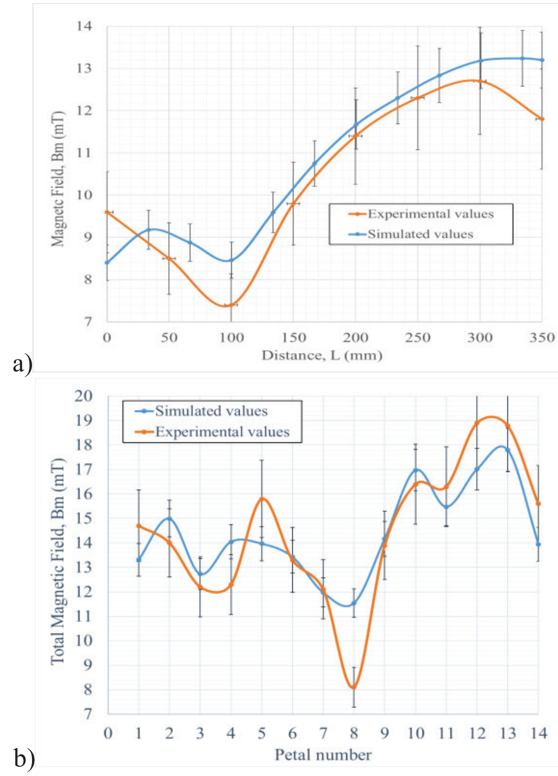

Figure 6: Simulated and measured fields along a petal (a) and after each petal (b). 10% and 5% errors were added on the exp. and simulated values respectively.

The comparisons between the simulated and the experimental results demonstrate again the realistic values estimated by the simulations and their good degree of confidence (Fig.6).

From these conclusions, one could estimate the peak of field inside the PMTs according to its position angle around the reaction sphere and the effect of the petals. For a cluster positioned at 0°, the maximum values of the field inside the PMTs are estimated to be 2320 ± 122 and 4130 ± 206 µT with and without the shielding structure respectively. While at 45°, these values become 2440 ± 117 and 5630 ± 281 µT. Thus the presence of the petals reduces the peak of the magnetic field of a factor 2 in the PMTs. Moreover, as already observed in Fig 4. the field is higher at 45° than at 0°.

The shielding structure does not allow reducing enough the peak of field inside the PMTs. As it can not be improved physically, it was mandatory to optimize the shielding of the cluster itself.

CLUSTER SHIELDING OPTIMIZATION

The magnetic layer of the first developed mechanical support was actually composed of 2 layers of 1 mm thick and 300 mm long each. Those layers are stuck together. The external layer was in non-magnetic material acting as a mechanical support, while the second one was in mu-metal. From the optimization process, the use of a mu-metal layer extended from 300 to 480 mm and thickened from 1 to 2 mm appeared to be the best solution to decrease the peak of magnetic field inside the PMTs (Fig.7).

ISBN 978-3-95450-182-3

Indeed, the maximum value gives 19 ± 1 µT when the cluster is at 0° around the beam axis. However and as expected, higher peak value is observed when the cluster is at 45°: 69 ± 3 µT.

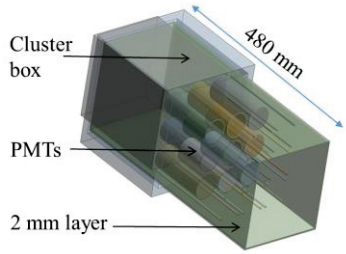

Figure 7: Optimized design of the cluster.

For some reasons related to the physics of the PARIS experiment, it may happen that the cluster must be positioned at 45° around the beam axis. Simulations showed that a cluster box in mild steel (i.e. S1018 type) would decrease further the peak down to 41 ± 2 µT.

Table 1: Summary of the Results from the Simulations

Material				**Max. Field values in the PMTs (µT)**	
Shield type	Cluster box	Layer 1	Layer 2	Cluster at 0°	Cluster at 45°
Initial	n	n	µ	2320 ± 122	2440 ± 117
Initial	S1018	n	µ	142 ± 7	714 ± 35
Optimized	n	µ	µ	19 ± 1	69 ± 3
Optimized	S1018	µ	µ	4 ± 0.2	41 ± 2

n: non-magnetic material; µ: mu-metal

Table 1 summarizes the maximum values of field in the PMTs according to the position angle of the cluster, the shield type and the materials used. The simulations included the petal structure.

The propagation of the field inside the central PMT along its length was also studied (Fig. 8).

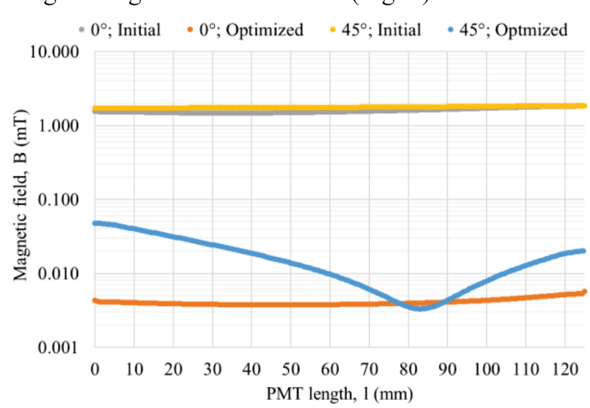

Figure 8: Magnetic field values in the central PMT according to the angle and the version of the cluster (from the anode, 0, to the photocathode, 120 mm).

The use of the optimized version of the cluster decreases the overall field inside the PMT. Moreover, when the cluster is at an angle of 45°, the peak is located at the back of the PMT (anode side) while at 0° it is located at the front of the PMT (photocathode side, which is the worst case) (Fig. 9).

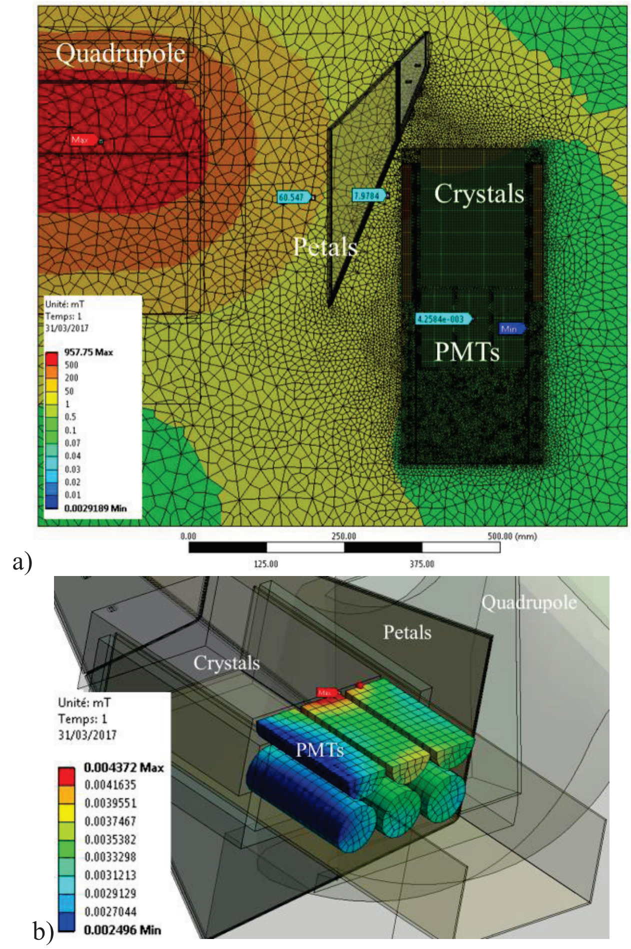

Figure 9: Effect of the optimized version on the propagation of the magnetic field (Cluster at 0°; Horizontal sectional view; I = 500 A): Propagation of field in the whole system (a) and in the PMTs (b).

A prototype of this optimized cluster was tested in Dec. 2016. The PMTs worked properly attesting of the good efficiency of this new version.

ACKNOWLEDGEMENT

The authors thank J. Goupil (GANIL/CNRS) and J. Bettane (IPNO/CNRS) for providing geometry files, for sharing the information and for their availability.

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