

Characteristics of magnetic shields for protection PMT in the LHCb hadron calorimeter

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Abstract. CERN is preparing the new experiment aimed at the detection of weakly interacting massive long-lived particles. The experiment was called SHiP. The instrumental and technological solutions successfully used in experimental setups ATLAS, LHCb and others will be applied in experimental setup SHiP. One of these units is a hadrons calorimeter. It uses several thousands photomultiplier tubes (PMT) placed in protective magnetic shields because PMTs are located near strong permanent magnets. Taking into account that since the creation of the experimental setup LHCb has been passed more than 10 years and there are new manufacturing techniques of magnetic screens appeared, we investigate the characteristics of shielding screens used in the LHCb, and proposed the recommendations to magnetic screens' designs for SHiP experiment.

1. Introduction

A new experiment at the CERN SPS (Super Proton Synchrotron) accelerator [1] is proposed that will use decays of charm mesons to search for Heavy Neutral Leptons (HNLs), which are right-handed partners of the Standard Model neutrinos [2, 3]. The experiment was called SHiP (Search for Hidden Particles) [4]. The experimental instrumentation consists of a target, a hadron absorber, a muon shield, a decay volume and two magnetic spectrometers, each of which has a magnet, a calorimeter and a muon detector (figure 1).

It is planned that the experimental setup SHiP will be created with the use of instrumental and technological solutions successfully applied on to existing installations at CERN ATLAS [5] ALICE [6] and the LHCb [7]. This will significantly reduce the cost of the experiment and accelerate its realization. The sketch of the experimental setup detecting part SHiP is shown in figure 1. Hadron and electromagnetic calorimeters contain electronic photomultiplier tubes (PMT), which are usually located near sources of static magnetic field. Residual (scattered) field of these magnets can have a negative impact on PMT operation. For this reason, they have to be protected with special screens.



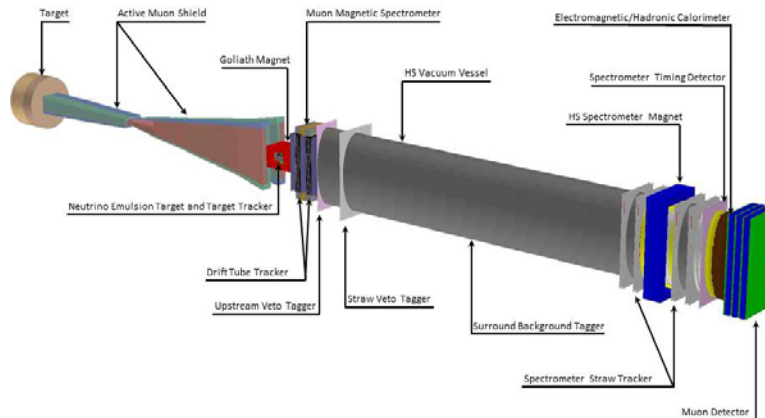


Figure 1. Three-dimensional sketch of the experimental setup SHiP.

However, we must bear in mind that these settings were created over 10 years ago and during this time, new technologies [8] and detectors [9] have emerged. This also applies to screens to protect against static magnetic fields. The hadron calorimeter in the SHiP is similar in its aims and characteristics of a hadron calorimeter the LHCb experiment, which used a PMT protected by magnetic screens. Here we investigate the characteristics of shielding screens used in the LHCb, and proposed the recommendations to magnetic screens' designs for SHiP experiment.

2. Technique

The hadron calorimeter LHCb experiment applies a PMT, protected by Permalloy shield and placed in a (soft magnetic steel) shell. It is known that in the case of cylindrical screen configuration, the magnetic field is weakened in its more significant if it is perpendicular to the longitudinal axis of the screen (radial field) than if the longitudinal orientation [10]. For this reason, in the experimental apparatus the photomultiplier is positioned so that a magnetic field which affects them was directed perpendicular to the longitudinal axis of the screen and the photomultiplier respectively. Therefore, in this paper we focus on the research of the shielding efficiency only in the radial magnetic field.

It should be noted that the Helmholtz coils allow to obtain high field homogeneity. Magnetic induction measured by the Hall sensors. In place of the PMT location in LHCb experiment, the magnetic field strength of the order of 1 mT [7]. Our measurements have been carried out in the range of 0.21 to 2.10 mT that corresponds to the expected experimental SHiP the magnetic field strength [4]. Magnetic shields to protect the PMT in the hadron calorimeter LHCb experiment consists of a screen (permalloy) and steel shell (figure 2).

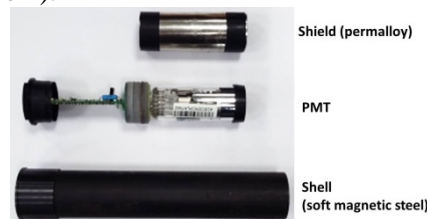


Figure 2. Shield, shell and PMT in the LHCb Hadron Calorimeter.

2.1. The measurement of the magnetic field inside the permalloy shield

For this measurement permalloy shield (5 layers of foil, 0.5 mm total thickness) was installed so that its axis is located in the center of the Helmholtz coil system and the magnetic field was perpendicular to its longitudinal axis. In this case the screen was located in completely homogeneous magnetic field created by the Helmholtz coils. Photo of the experimental setup is shown in figure 3. The magnetic field strength was measured simultaneously in the center of the screen, and from the outside at a

distance of 5 mm from the surface of the screen. Sensors were rigidly interconnected so that they are placed opposite each other and, respectively, moved simultaneously.

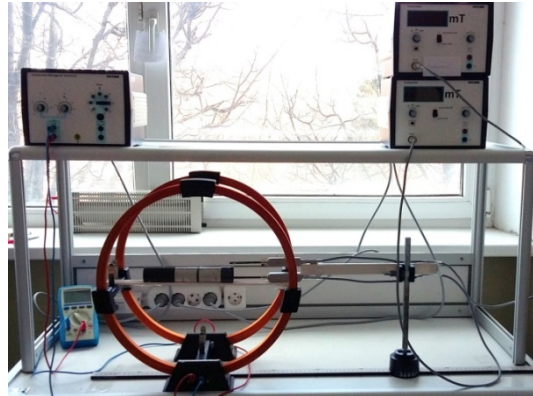


Figure 3. Experimental setup.

2.2. The measurement of the magnetic field inside the steel shell

For this measurement the steel shell was positioned on the site of the Permalloy screen. The steel shell has been set so that if it was Permalloy screen inside, it would be on the same place as in the previous measurement. This means that the magnetic field in this area was uniform. However, the edge of the steel shell was located outside the homogeneous magnetic field, so the measurement did not carried out in this area

2.3. The measurement of the magnetic field inside the system permalloy shield + steel shell

For this measurement inside the steel shell set in Helmholtz coils system as described above, permalloy shell was placed on its standard location.

3. Results

In figure 4 shows the results of the measured values of the magnetic field strength as a function of the coordinates (along the axis of screens) for the experiments described above.

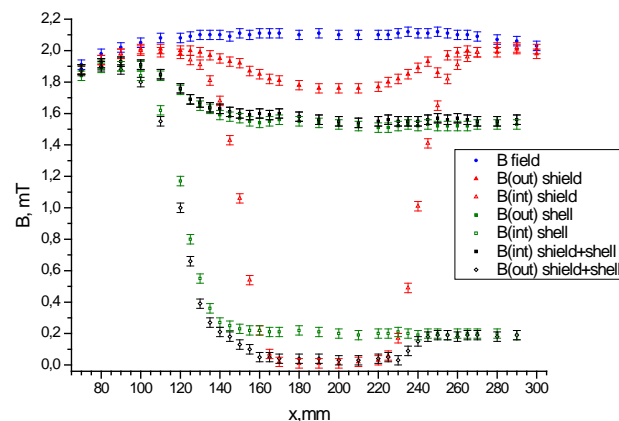


Figure 4. Dependence of the intensity of the radial field of coordinates for magnetic field strength 2,14mT. Location of the permalloy shield corresponds to the range 160-240 mm, and location of the steel shell corresponds to the range 130-325 mm.

From the above measurement results it is possible to note that the permalloy shield used alone protects the PMT better than in case, when it is used together with the steel shell. For a more evident representation of these results the calculated value of the screening $k = B_{out}/B_{int}$ in the central region of the sample ratios, where the screened field is sufficiently homogeneous, for each value of the magnetic field used are shown in figure 5.

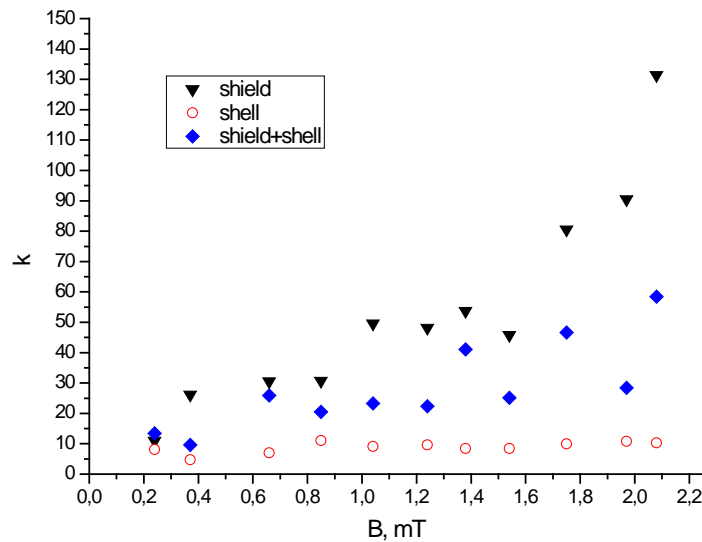


Figure 5. The dependence of the shielding ratio on the strength of the radial field B . Experimental errors are located within the experimental points.

From these results it can be concluded that it is not good solution to use steel for shell as it deteriorates the efficiency of permalloy shield, and also has a large weight. This effect is explained as follows. When we use them together, the steel shell reduces the magnetic field that is applied to the permalloy shield. This leads to a decrease of permalloy magnetic permeability (quite significant) and accordingly to a decrease of the coefficient of shielding. As a result of the combined effect of screening can be worse than the screening separately taken permalloy screen that takes place in this case. The optimal option to protect a PMT from magnetic fields, taking into account the latest technological advances, can be aluminum housing with a multilayer film screen deposited on it.

4. Summary

For providing high coefficient of PMT protection its housing should not produced from magnetic material (steel). The optimal option to protect a PMT from magnetic fields, taking into account the latest technological advances, can be aluminum housing with a multilayer film screen deposited on it [11, 12].

Tandem screening *shield+shell* is less effective than screening alone a "strong" material fields up to 2.2 mT. When these fields for the physical protection of the PMT is advisable to use non-magnetic material. This result is important for SHiP experiment (the estimated value of the magnetic field strength of ~ 1 mT), which will provide much more light protective housing with high shielding ratio. Shields based on multilayer film structures are more effective shields than those constructed from permalloy foil and allow the use of PMTs [11, 12].

Acknowledgments

We are grateful to our colleagues from CERN for providing the original screens in the LHCb experiment.

References

- [1] Ulrich Heinz 2008 *Physica Scripta* **78**(2)
- [2] Asaka T, Blanchet S and Shaposhnikov S 2005 *Phys. Lett. B* **631** 151 (*arXiv*: hep-ph/0503065)
- [3] Asaka T and Shaposhnikov M 2005 *Phys. Lett. B* **620** 17 (*arXiv*: hep-ph/0505013)
- [4] <http://ship.web.cern.ch/ship/>
- [5] The ATLAS Collaboration 2008 *JINST* **3** S08003
- [6] The ALICE Collaboration 2008 *JINST* **3** S08002
- [7] The LHCb Collaboration 2008 *JINST* **3** S08005
- [8] Grabchikov C, Sosnovskar L and Sharpa T 2009 (in Russian) Multilayer electromagnetic shield *RB patent no 11843 from 2009.01.28* (Original Russian title: *Mnogoslojny elektromagnitny ekran Patent RB №11843 ot 2009.01.28*)
- [9] P W Nyunt *et al.* 2015 *Physics Procedia* **74** 151-7
- [10] [Muravyev-Smirnov S S *et al.* 2014 (in Russian) *XLVIII PNPI School on condensed state physics CSP-2014* 118 (original Russian title: *48-aja Shkoly PIJaF po fizike kondensirovannogo sostojanija FKS-2014. Sbornik tezisov*)
- [11] V V Dmitrenko *et al.* 2015 *Rev. Sci. Instrum.* **86** 013903
- [12] P Wai *et al.* 2016 *Journal of Physics: Conf. Series* **675** 042006