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A magnetic electron repeller to improve the ATHENA/WFI background level

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ABSTRACT

The WFI is a DEPFET-based device developed at MPE as one of the two focal plane instruments for the next large ESA mission for high energy astrophysics ATHENA. The expected level of instrumental background induced by the radiation environment in space is one of the parameters driving the camera design and it is required to be below $5 \cdot 10^{-3}$ cts/cm^2/sec/keV to enhance some of the unique observing capabilities of this detector. Background reduction can be obtained in a passive way by optimizing the detector shielding specifications (e.g. materials, thicknesses) and discarding frame regions affected by X-ray-like counts. In principle, a higher rejection efficiency could be achieved with an active anticoincidence system surrounding the detector, in practice this cannot be done as it would make the camera readout very complicated and introduce dead-time. In this proceeding we discuss how a passive shielding against soft electrons with efficiency comparable to that of an active anticoincidence and no dead-time issue could be obtained by means of permanent magnets. We present the concept and a very preliminary feasibility study conducted in the framework of AHEAD and demonstrate theoretically the effectiveness of this solution. Nevertheless, an actual implementation would have as drawbacks an increased mass of the camera due to the presence of magnets and a potentially disturbing residual magnetic field in the detector environment.

Keywords: particle background, secondary electrons, magnetic field, ATHENA,WFI

1. INTRODUCTION

The Wide Field Imager (WFI) [1] developed at MPE for ATHENA [2] is a DEPFET-based detector that will provide sensitive wide field imaging in the range 0.1-15 keV, with moderate spectral resolution (<150 eV @ 6 keV), high time resolution (~8 μsec window mode, ~5 msec full frame) and high count-rate capacity (~1 Crab). It consists of a large chip 512x512 pixel with 130 μm size covering a 40'x40' FOV mounted in the focus of the telescope plus a smaller fast 64x64 pixel chip, defocused by 35 mm, for the observation of bright sources. The detector will be enclosed in a metal shield in order to protect it from damaging environmental protons, that would cause atomic displacement in the Si crystal via non ionizing energy loss. Figure 1 is a drawing of the basic shielding structure, consisting of a 4 cm thick Al box. Simulations using as an input the radiation fluxes expected for an orbit around the L-2 lagrangian point show that an instrumental continuum background arises from secondary electrons and γ-rays generated by the interaction of environmental radiation with the shield [3]. Background electrons include the very soft ones emitted with an energy in the detector band (i.e. up to 15 keV) and the more energetic ones that may undergo backscattering at the detector surface, depositing only a small fraction of their energy, that in some cases could also be in the energy band of the detector (Figure 2). The illuminated side of the detector will be coated with 90 nm Al as an optical/UV filter. This coating does not have much effect on the background, being able to stop only electrons up to ~1 keV. To obtain some significant background reduction the application of a passivation layer on the non-illuminated side of the detector is envisaged. This latter works primarily by cutting the softer electrons emitted from the lower part of the shield, that contribute a larger amount of background. To prevent soft electrons from reaching the sensitive volume, a few micron thick layer should be used, the actual thickness

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being dependend on the material. An effective and technically feasible passivation may consists of 3-5 μm benzocyclobutene. This would help to reduce to some extent the background from backscattering as well, since electrons backscattered at the detector surface after penetrating just few microns would deposit energy in the passivation. The Compton background caused by primary and secondary γ-rays able to leak out through the shield and reach the detector should be minimized by adding a high-Z layer. Soft protons possibly funneled to the focal plane through the mirror system would be deflected by an external magnetic diverter mounted above the WFI camera [4]. Then, in a configuration sufficiently protected against γ-rays and focused soft protons, a major contribution to the instrumental background would come from secondary electrons ejected from the inner walls of the proton shield, which are the largest surfaces directly seen by the detector, excited by primary protons passing through. These electrons are directly absorbed or backscattered at the detector surface and cannot be discriminated from signal X-ray counts by pattern recognition as their range is much smaller than the pixel size, i.e. in most cases they are single-pixel events. The application of an inner low-Z layer to suppress Al fluorescence in principle could help to lower to some extent the continuum as well, though so far simulations with a thin Be layer have shown that the expected improvement actually would be small. To efficiently reject soft electrons an active anticoincidence system all around the detector would be needed, although this would imply a more complex camera read-out and introduce undesired dead-time.

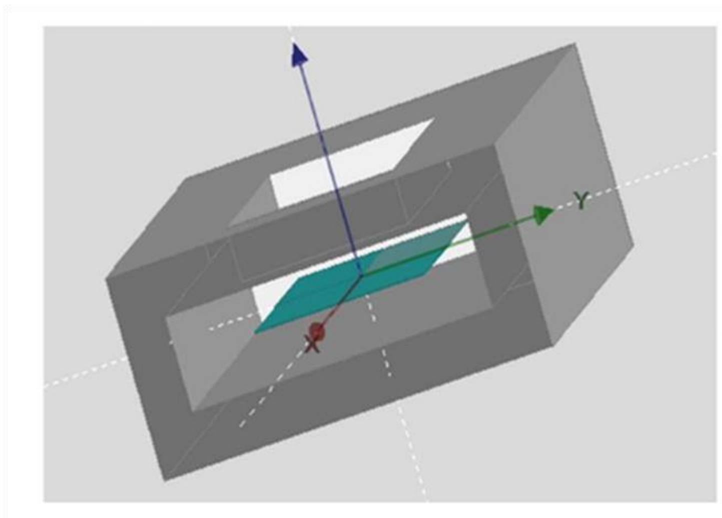

Figure 1. The 4 cm thick Al box enclosing the DEPFET detector to shield it from environmental low and medium energy protons. (image courtesy of MPE)

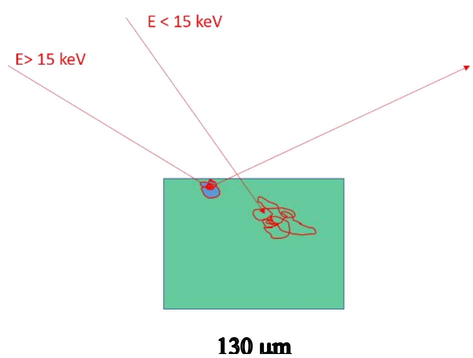

Figure 2. Soft secondary electrons impinging onto the illuminated side of a pixel with an energy in the detector band are fully absorbed in the depletion volume, their range is much smaller than the pixel size (130 μm), so in most cases they produce single-pixel events; secondary electrons with higher energies can be backscattered at the detector surface after penetrating just a few microns, the small energy loss along such a short path can result in the generation of an event in band, these also are single-pixel events.

2. THE MAGNETIC FIELD

In the framework of AHEAD (integrated Activities in the High Energy Astrophysics Domain), we investigated a technical solution to repell secondary soft electrons by means of a locally applied magnetic field enabling a change of their trajectories, such that they would be prevented from reaching the detector. We adopted and applied to our case study the approach used to get rid of secondary electron escape in Faraday cups [4]. The ad-hoc magnetic field could be provided by permanent magnets inserted within the bulk shield just a few millimeters behind its walls, inducing a magnetization of the wall surface (Figure 3). Secondary electrons excited by primary protons emerging from the walls are forced to spiralize along the magnetic lines, whilst possible fluorescence emission from the magnets would be re-absorbed in the bulk.

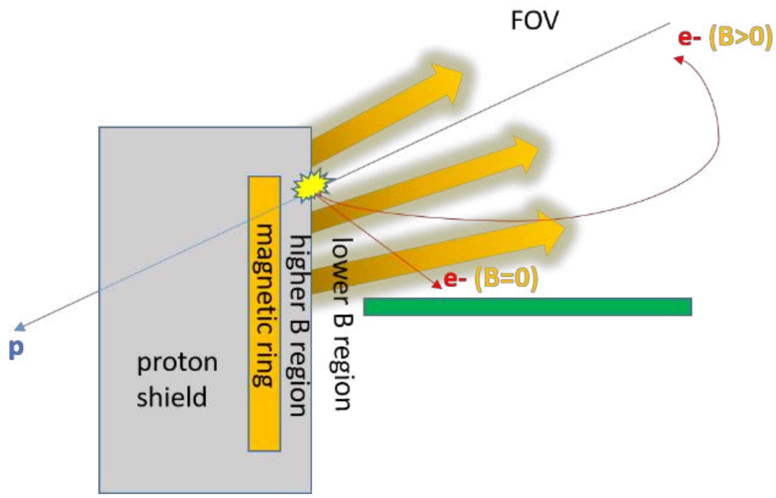

Figure 3. A permanent magnet inserted behind each shielding wall seen by the detector produces a magnetization of the wall surface. In a four-pole field soft electrons ejected by the wall surface are forced to follow trajectories that prevent them from reaching the detector surface.

We consider the case of a single metal ring (e.g. AlNiCo) magnetized along its axis producing a four-pole field, extending the analysis to the case of four walls and four rings is straightforward. The four-pole field can be approximated by the field of four magnetic monopoles:

$$H_x=W*[(x-d)*(R_1^{-3}-R_3^{-3})-(x+d)*(R_2^{-3}-R_4^{-3})]$$

$$H_y= W*y*[(R_1^{-3}+R_2^{-3})-(R_3^{-3}+R_4^{-3})]$$

$$H_z= W*[(z-d)*(R_1^{-3}+R_2^{-3})-(z+d)*(R_3^{-3}+R_4^{-3})]$$

with:

$$R_1^2=y^2+(x-d)^2+(z-d)^2$$

$$R_2^2=y^2+(x+d)^2+(z-d)^2$$

$$R_3^2=y^2+(x-d)^2+(z+d)^2$$

$$R_4^2=y^2+(x+d)^2+(z+d)^2$$

$$W=H_c*d^2/\sqrt{2}$$

In the expressions above H_c is the field strength at the center of the magnet and d the distance between the poles.

3. SIMULATED TRAJECTORIES

As a case study, we assumed a wall surface 7 x 16 cm (in the plane x,z) centered in x=3.5 cm, y=0.5 cm, z=0 cm and a detector 15 x 15 cm (in the plane y,z) centered in x=5 cm, y=9.5 cm, z=0. The assumed distance between the magnetic poles is d=8 cm. We wrote a code in IDL to solve numerically the equations of motion of electrons in the magnetic field reported in Section 2. For each electron, the initial conditions (i.e. kinetic energy, spatial coordinates x_0,y_0,z_0 at the wall surface and direction of motion) have been randomly generated. In all cases, the coordinate x_0 has been chosen in the range 5-7 cm, as we considered only repulsion of electrons impinging onto the illuminated side of the detector, the non-illuminated side being already shielded against soft electrons by the passivation. The efficiency of the magnetic field is defined as:

$$\varepsilon = (n_0 - n_H)/n_0$$

where n_0 and n_H are the number of electrons hitting the detector in the cases H_c=0 and H_c > 0, respectively. Assuming that some spacing is left between the wall surface and the edge of the detector, for electrons with kinetic energies up to 15 keV high repelling efficiencies (~90%) can be achieved with relatively weak fields (H_c ~100 G), thanks to the leverage effect. As an example, Figure 4 shows simulated trajectories of four electrons having different initial conditions, for a configuration with H_c = 75 G and a spacing s=1.5 cm between the wall surface and the edge of the detector. The motion evolves in loops that bring the electrons away from the detector before they can reach its surface, in some cases deflected electrons escape the geometry so that they would be likely absorbed somewhere else (e.g. on the filter wheel or on the baffle which would be mounted above the detector), whereas for lower energy electrons the trajectories could become so much curved that they could be re-absorbed even by the shield itself. The higher the value of H_c the higher the maximum kinetic energy that could be deflected.

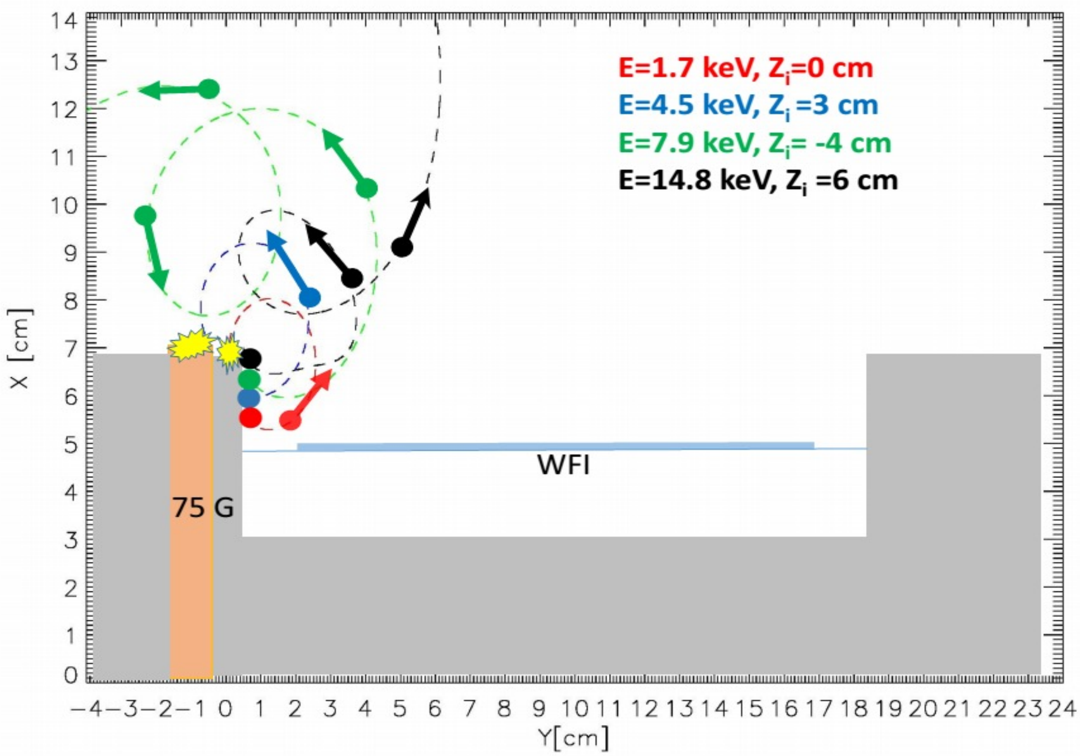

Figure 4. Simulated trajectories (projected in the Y-X plane) of four electrons with different initial conditions within the magnetic field of Section 2 assuming a strength H_c=75 G at the center of the magnet. Most electrons with initial energy lower than 15 keV are deflected from the detector.

4. RESIDUAL FIELD

A possible issue using permanent magnets close to the detector is that some residual field would remain in the surrounding environment and on the detector itself. Figure 5 shows the intensity distribution of the residual field over the detector, for the case study described in Section 3 (assuming that four magnets are applied). The residual field is higher on the pixels that face the magnetic poles and decreases from the edges to the center of the detector. How such a residual field could affect the detector functionality is a question mark, answering this question is beyond the scope of this work and would require some dedicated investigation and specific laboratory tests. In principle, a residual field could alter the motion of signal electrons in the depleted volume, however as they drift under an intense electric field, we guess that a magnetic field of the order of a few tens of Gauss would not disturb the electron motion leading to signal generation. However, some interference with the read-out electronics cannot be a priori excluded.

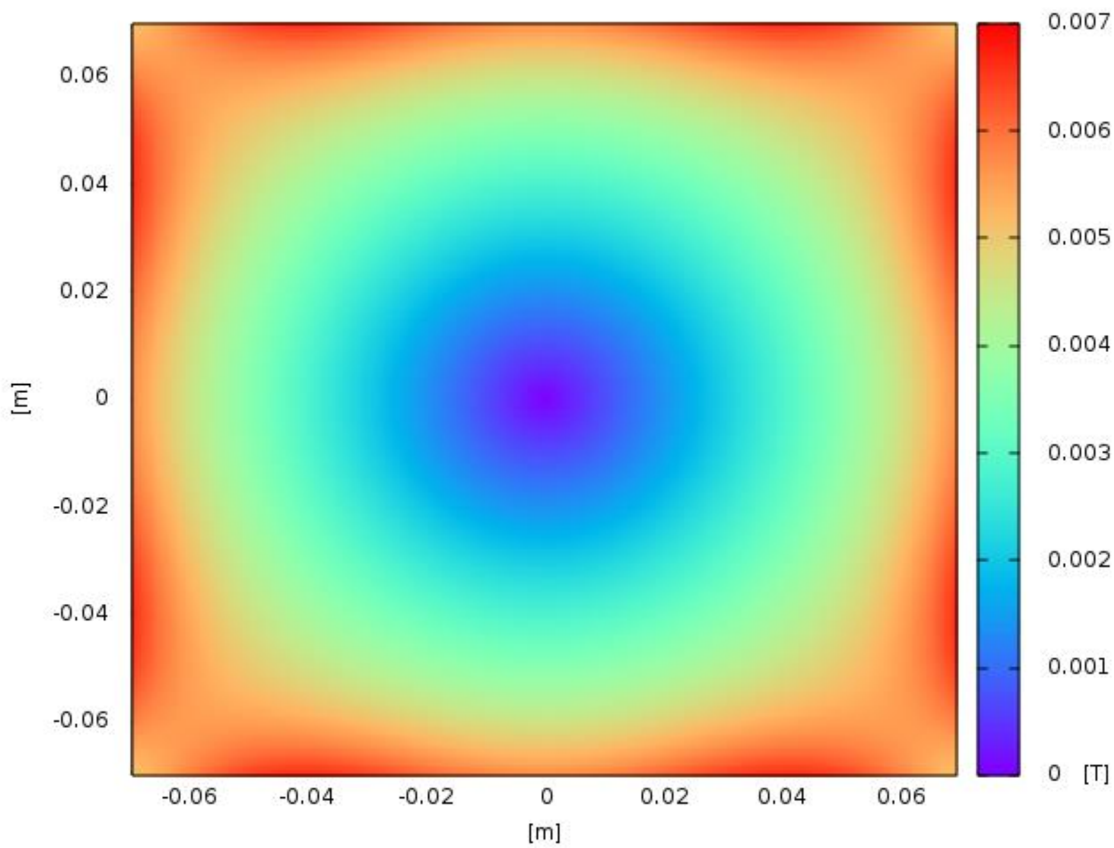

Figure 5. Intensity distribution of the residual field over the detector for a configuration with four four-pole magnets having H_c=75 G and d=8 cm.

5. SUMMARY

In the context of AHEAD, a project funded by the Horizon 2020 Framework Programme of the European Union aimed at supporting efforts for the development of technologies and investigating new and unconventional solutions to enhance the performance of instrumentation for future applications in the high energy astrophysics domain, in particular for ESA's next large X-ray mission ATHENA, we explored the possibility to use a locally applied magnetic field to repell and get rid of most soft electrons in the environment of the WFI detector, which according to our Geant4 simulations would contribute a significant fraction of the residual instrumental background. The feasibility study presented in this manuscript is very preliminary and only aims to assess theoretically the effectiveness of the approach, technical aspects of a possible practical implementation are neglected at this stage. On this basis, our simulations demonstrate that a locally applied four-pole magnetic field could be effective against secondary soft electrons and would allow to achieve very high repelling efficiencies with moderate field strengths. Nevertheless, the presence of a residual field around and over the detector, which may alter its functionality and/or the functionality of the associated read-out electronics, is a potential issue that would require a dedicated investigation and specific laboratory tests. Finally, a drawback of this solution would be an increased mass of the camera due to the presence of permanent magnets.

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