Instituto de Física
Universidade de São Paulo

Relative Calibration Methods for the Auger Fluorescence Detector

Reis, H.C. and Sato, R.

Departamento de Raios Cósmicos e Cronologia,
Universidade Estadual de Campinas - UNICAMP
Caixa Postal 6165, 13083-970, Campinas - SP, Brazil

Publicação IF - 1547/2002

UNIVERSIDADE DE SÃO PAULO
Instituto de Física
Cidade Universitária
Caixa Postal 66.318
05315-970 - São Paulo - Brasil

2 Relative Calibration Methods

We simulated four methods of relative calibration for the Auger FD. These schemes are showed at the figure 1: the Domus calibration, suggested by Paul Sommers [2] (A); a screen located in front of the aperture system with an optical fiber at the principal axis of the telescope (B); a set of two optical fibers with diffusers, installed around of the PMT's array and turned to the mirror (C). We study another scheme that it is to put one optical fiber in the middle of the mirror, illuminating the camera body (D).

Our first procedure was to simulate the optical fibers with diffusers. We generated a set of vectors obeying a constant distribution inside to a solid angle. This subroutine was used on all relative calibration methods simulated by us. The next step depends on these calibration methods. The first method simulated by us was the Domus calibration. It consists of a semi-sphere that has a diffuse surface located in front of the aperture of the optical system. In this way, rays of light are emitted by the optical fiber, installed at the curvature center, and propagated until the domus surface. This diffuse surface was simulated using a Monte Carlo subroutine in order to spreads the rays in such way that it doesn't have a preferential direction and goes back to the telescope, passing through the diaphragm and reaching the mirror and the array of PMT's respectively.The advantage of this method, comparing it with the other schemes, is that it is capable to test all the optical elements (corrector ring, diaphragm, mirror and array of PMT's). Because of this, this scheme is named *end to end calibration*. In the second scheme, the set of rays, generated by the subroutine of the diffusers, are propagated until the mirror, being reflected and reaching the array of PMT's. The third method has a diffuse screen, like as the domus but with a plane surface in front of the aperture of the FD, to spread the set of rays that are coming from the diffuser, located at the principal axis of the telescope. Our code allow us to move the diffuser along the this axis, in order to find its best position to try to produce a flux of light approximately constant. We simulated the diffuser at two distances from the center of the aperture: $1.55m$ and $0.40m$. However, this method can not really generate a constant flux because it depends on the distance from the light source until the screen, which is different for different points of the screen. With this argument, the results for the domus probably will be better than for the screen scheme. The advantage of this system is that it is more simple and may be cheaper than the domus. The fourth scheme is very simple: the set of rays reaches the array of PMT's, coming directly from the diffuser installed at the middle of the mirror.

3 Results of the Simulations and Discussions

In our analysis, each method was simulated 40 times in order to try to distinguish Monte Carlo method's fluctuations from calibration system's effects. In addition, we calculated the average and the root mean square (RMS) of each one of these set of data. In the figures 2 and 3 we have the simulation results for the domus calibration with and without the corrector lens. As we can see, the flux of light over the PMT's is approximately

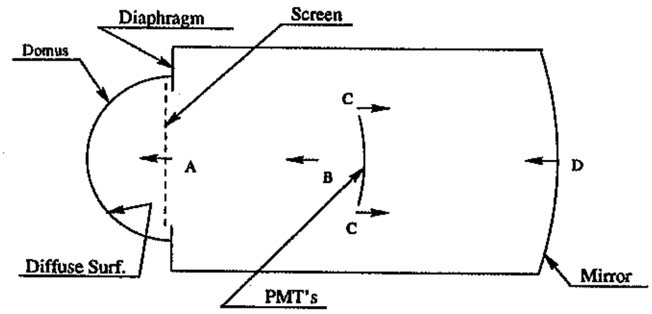

Figure 1: Schematic figure of the Auger FD. The italic letters indicate the positions of the diffusers used to simulate the calibration of PMT's and optical system

constant which makes easier the analysis of possible deviations in the signals coming from the photomultipliers.

The figure 4 shows the results obtained for simulations of the screen calibration method. We can observe that the quantity of light in each photomultiplier is approximately constant, but there is, apparently, a feature that differs from the calibration system using the domus: the screen system seems to have more photons on the edge of the camera body while the domus seems to concentrate the photons on the central region of the camera. This difference should be probably an effect of the $1/r^2$ factor of the light intensity.

In our simulations we did not consider reflections, that it will occur in consequence of the presence of the corrector ring. If we consider this effect, probably it will modify the results obtained for the domus and the screen. However, if it changes the results just slightly or does not change them, both methods, the domus and the screen, can be used to calibrate the whole optical system.

Diffusers around the array of PMT's (C in the fig. 1) can be used to determine the efficiency of the photomultipliers and the mirror reflectance too. The fig.5 shows the results for this simulation.

Another way to calibrate just the array of PMT's is to put a diffuser over the mirror (letter D in the fig.1). This method is very simple and it can be interesting to determine the efficiency of the photomultipliers. The simulation results for one diffuser located at the center of mirror illuminating directly the array of PMT's are shown at the fig.6.

As we expected, the intensity of light at the edge of the PMT's array is smaller than at the central region of the camera body in consequence of the $1/r^2$ effect and the inclination of the photomultipliers mainly at the edge of the array. An analysis of possible problems with a particular photomultiplier can be very complex which would be difficult to verify if this particular PMT is working as it desired or not.

In the last case we can calculate easily the expected signal analytically. If we consider the source of light (diffuser) as isotropic, the signal must be proportional to the solid angle

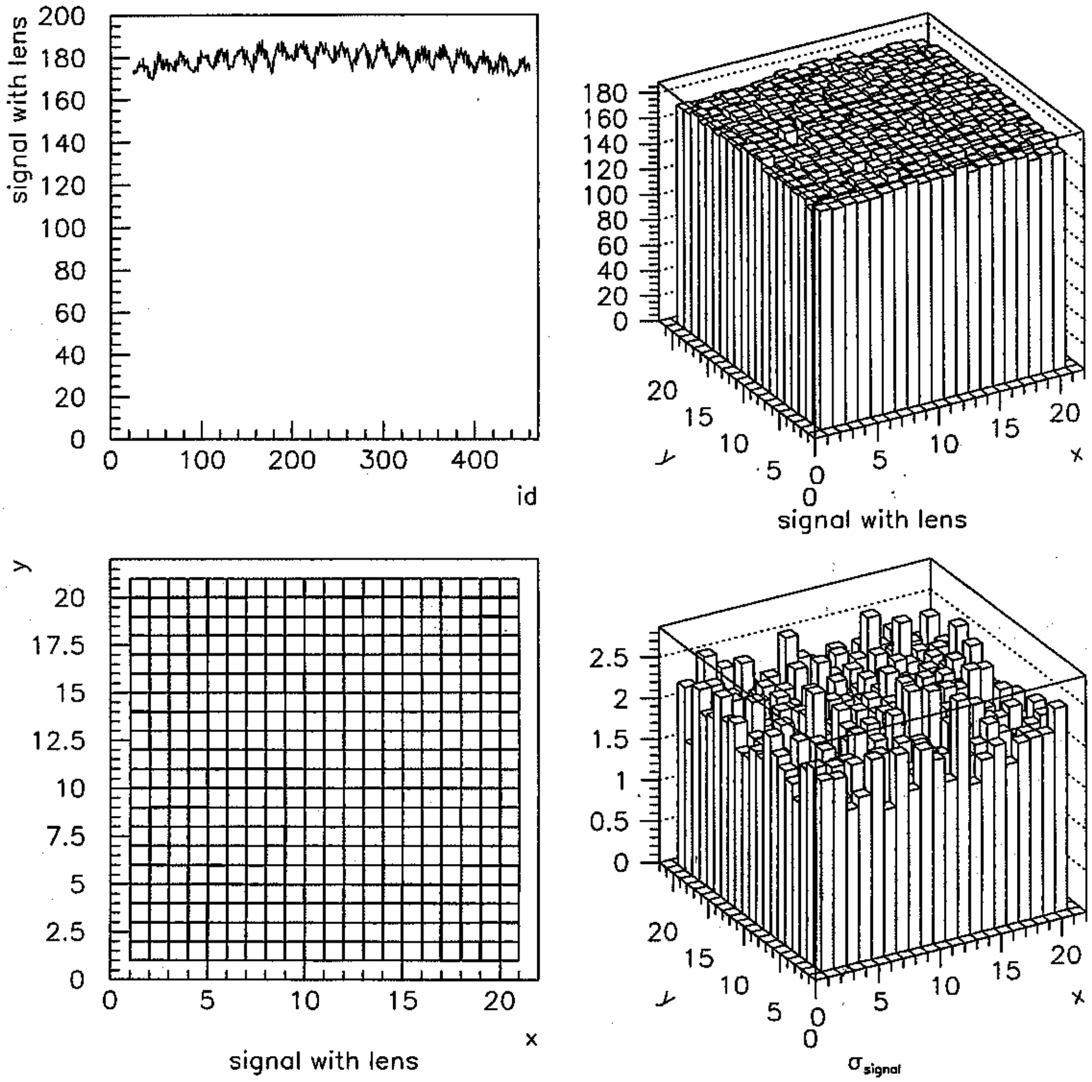

Figure 2: Results from the simulations for the domus system with corrector lens.The left upper plot is an average of 40 simulations, where *id* is a simple identification of the PMT's. The right upper and left bottom plots are average of 40 simulations but preserving the position of each photomultiplier (The arrangement of PMT's are in triangular grade. Therefore, the odd lines are slightly dislocated from the even lines). The right bottom plot shows the RMS of the 40 simulations for each one of the PMT's.

$\Delta\Omega$ defined by the photomultiplier sensible area A. When the size of sensible region is much smaller than the distance of the diffuser r the solid angle is $\Delta\Omega \approx A/r^2 \cos\theta$, where θ is the angle between the normal vector of the sensible region and direction PMT-diffuser.

The signal may have others dependences, as an example, the response of PMT for different incidence angle θ, but we don't simulate this effects, we only simulate the array of

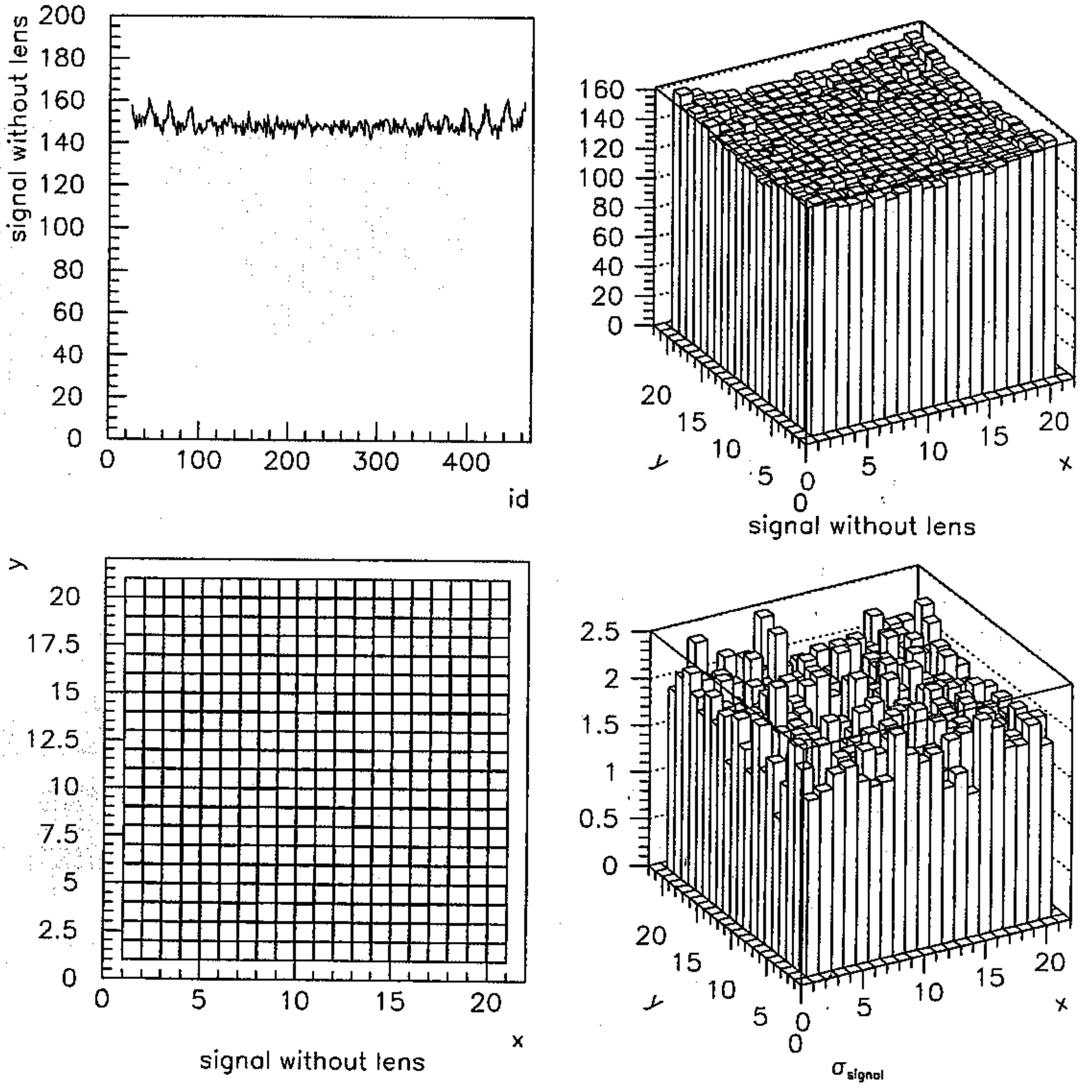

Figure 3: Results from the simulations for the domus system without corrector lens.

PMT's as a spherical surface and a simulated ray of light that touch this surface at a point $\vec{p}$ was counted to the PMT whose the center was the closest to this point. Considering these effects are much smaller than the factor $\cos\theta/r^2$ and multiplying the results by $r^2/\cos\theta$, as John A. J. Matthews *et al* [3] have done, we can see a constant distribution to all PMT's (fig. 7).

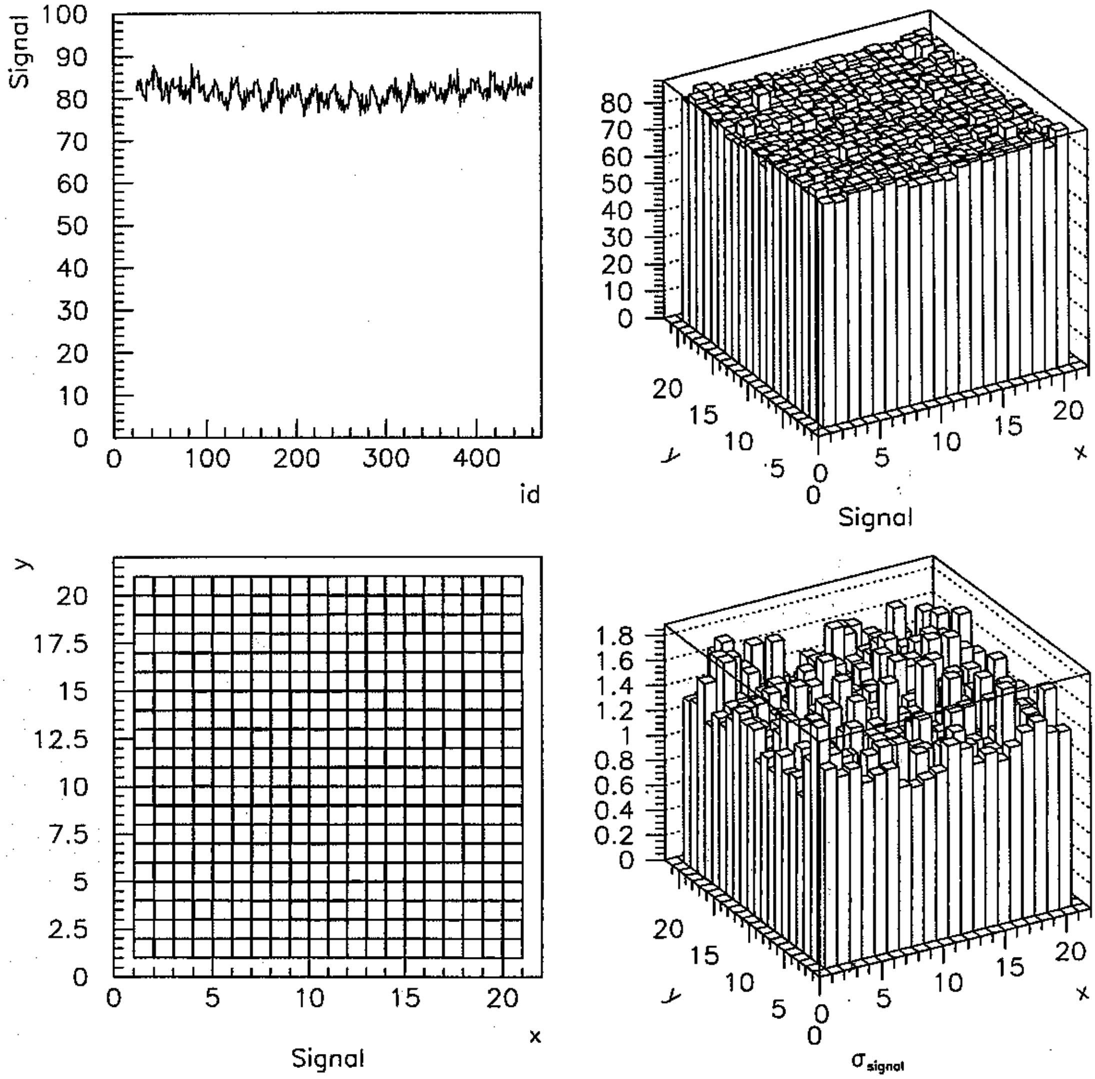

Figure 4: Results from the simulations for the screen calibration system. The source of light (diffuser) is located over principal axis of the fluorescence telescope.

4 Conclusions

We simulated some relative calibration methods for the Auger fluorescence detector using a ray-tracing program developed by us. We showed which kind of response (signal) we will have with these methods. Some of them (domus and screen calibration) are capable to test all the optical elements (diaphragm, corrector ring, filters, etc.) but they are more complicated systems than the others (light source at edge of the PMT's array or at the middle of the mirror). However, the signal of these other methods needs to be corrected in consequence of the $1/r^2$ effect and the geometrical effect of the curved surface of the

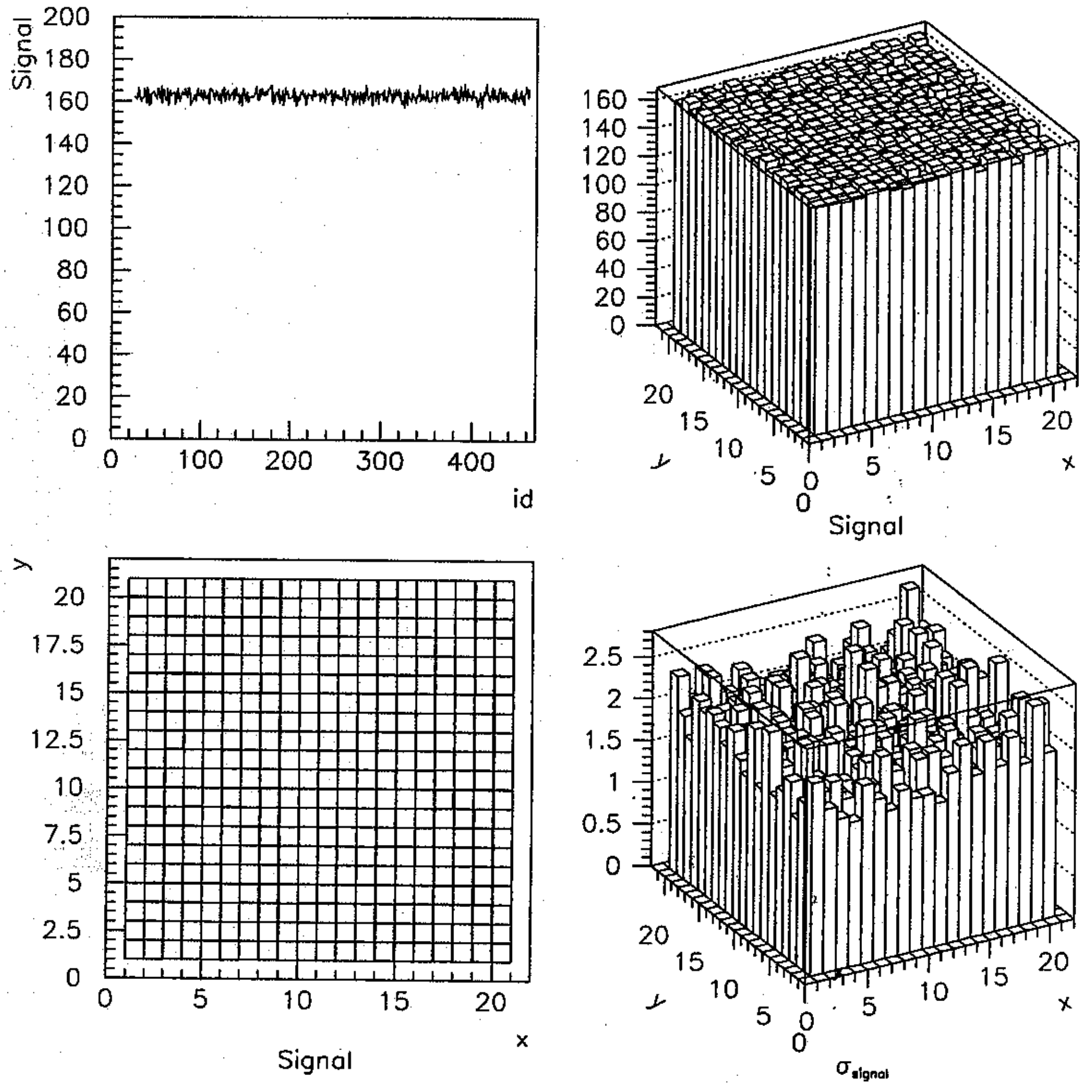

Figure 5: Results from the simulations for two diffusers located at the vertical edge of the camera body, illuminating the mirror (letter **C** in the fig.1).

camera. We have made the corrections for the system with the light source at the middle of the mirror and we have compared our results with the experimental results [3] that present a good concordance.

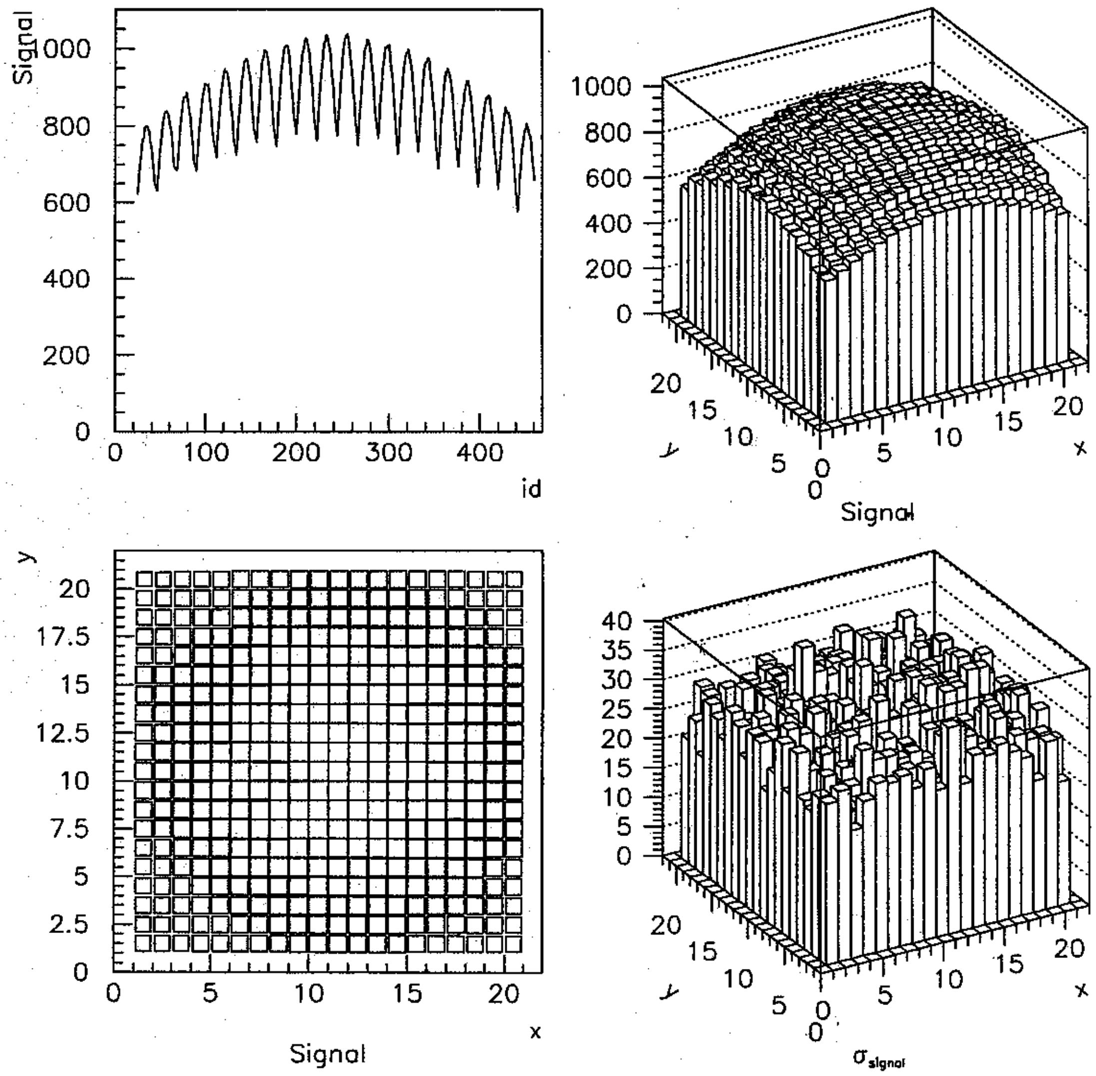

Figure 6: Results from the simulations for one diffuser located at the center of the mirror, illuminating the camera body (letter **D** in the fig.1).

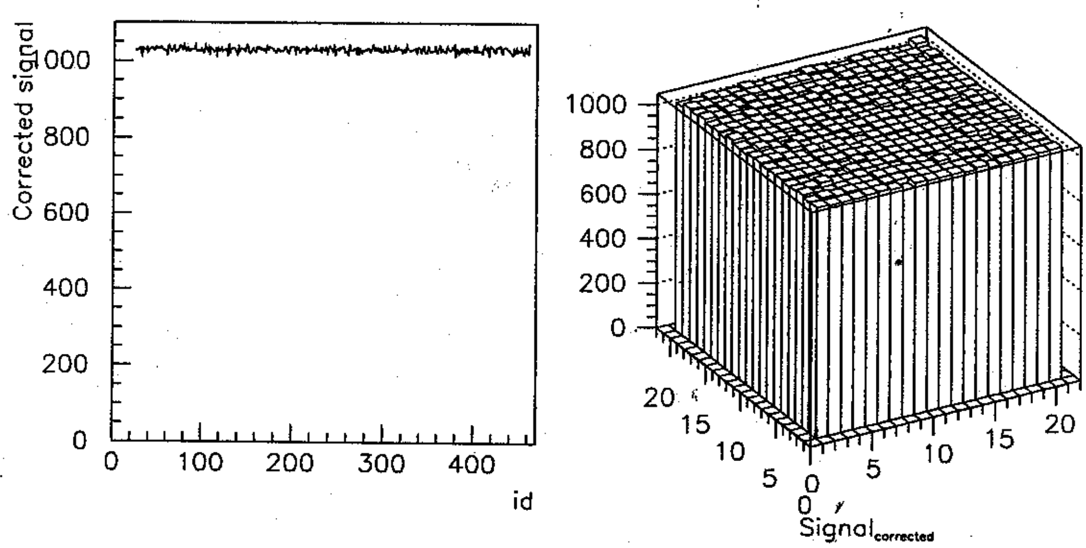

Figure 7: Results from the simulations for the same calibration system of the fig.6, considering geometrical corrections (angle and distance).

Acknowledgments

We would like to thank Carlos Ourivio Escobar for his ideas and suggestions. One of us (H.C.R.) is grateful for the hospitality of Nuclear Physics Department, University of São Paulo, where part of this work was done. This work was supported by Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) and Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Brazil.

References

[1] R. Sato *et al*, *Auger Technical Note*, GAP-99-014.

[2] P. Sommers *et al*, *Auger Technical Note*, GAP-99-012.

[3] John A. J. Matthews *et al*, *Auger Technical Note*, GAP-2000-054.