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A Study of the Corrector Plates for the Auger Fluorescence Detector

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Abstract

In this work we study the possibility to increase the diaphragm's radius of the fluorescence detector of the Auger project in order to increase the effetive light collection area, keeping the spot size at the photocatode within acceptable limits. We simulated the optical system of the fluorescence detector in a possible real situation: we consider imperfections on the mirror and on the corrector plate.

1 Introduction

One of the last questions to be answered about the design of the Auger project's fluorescence detector [1] (FD), is if it must be installed with corrector plates in order to reduce the size of the spot of light reflected at the photocathodes. In a previous work [4] we developed a ray-tracing program to simulate the behavior of the FD's optics in the presence of two kind of lenses [2]. The calculations made in that study confirmed the results obtained by Matthiae and Privitera [3], where it was shown that a sensible reduction on

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the spot size (almost one order of magnitude!) is obtained. In principle, this results would be sufficiently convincing to implement the corrector plates on the aperture diaphragm of the FD. However, it is convenient to note that we considered, as well as the authors of ref. [3], the mirrors and lenses ideally defined, i.e., the surfaces of these two optical elements did not have any kind of imperfections from the fabrication process.

In this work we focused our attention over two points: first of all, we want to know if the use of the corrector plate on the FD allow us to increase the aperture of the diaphragm without deteriotating the optical system's resolution. The advantage gained from this modification is the possibility to increase the effective light collection area and, consequently, to increase the signal to noise (S/N) ratio. As a second aim, we consider imperfections on the optical elements (mirror and lenses) in order to approximate the Schmidt camera to a more real situation. We use the same ray-tracing program of ref. [4] just adding a new subroutine that simulates the flutuations (imperfections) on the surfaces of the mirror and lenses.

In our simulations of the Schmidt camera we used the following parameters: Radius of curvature of the mirror $R_{mirror} = 3.4m$; Field of view of $30^o \times 30^o$; Diaphragm's radius $R_{dia} = 0.85m$.

The structure of this note is as follow. In section II, we make a brief description of the subroutine that introduces the imperfections on the mirrors and on the corrector plate. Section III includes the simulations of the Schmidt camera with and without corrector plate in the presence of imperfections. Section IV contains our study of a possible increase on the diaphragm's aperture. In section V we show our results. Concluding remarks constitute section VI.

2 Schmidt Camera with Imperfections on the Optical Elements

The uncertainties on the surface of the mirror and lenses I and II [2] were introduced in the following way: We consider $\hat{n}_i$ the surface's ideal normal unit vector of some kind of optical element (mirror or lenses) (fig.1). We can define two unit vectors, $\hat{\delta}_o$ and $\hat{\delta}_\perp$,

$$\hat{\delta}_o \cdot \hat{n}_i = 0; \tag{1}$$

$$\hat{\delta}_\perp = \hat{\delta}_o \times \hat{n}_i \ . \tag{2}$$

We construct a vector $\vec{\delta}$ from the unit vectors (1) and (2) which represents the displacement suffered by the ideal normal unit vector of optical element considered,

$$\vec{\delta} = \delta sin\theta' \hat{\delta}_o + \delta cos\theta' \hat{\delta}_\perp \ , \tag{3}$$

where δ obeys a Gaussian distribution and θ' an uniform angular distribution between 0 and π. The new normal (real normal) unit vector, $\hat{n}_r$, is given by the following relation:

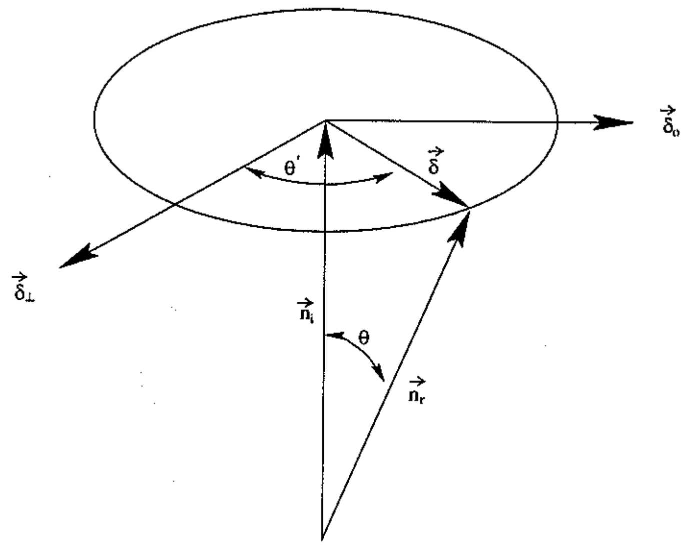

Figure 1: Fluctuations' geometry around $\hat{n}_i$.

$$\hat{n}_r = \hat{n}_i + \vec{\delta} \ . \tag{4}$$

We must point out that we are considering small displacements from $\hat{n}_i$ and therefore, we can make use of the following approximation to small angles:

$$\delta \simeq \theta * |\hat{n}_i| \quad \rightarrow \quad \delta \simeq \theta \ . \tag{5}$$

3 Simulations

We supposed that the manufacturing of mirrors and lenses can achieve a precision of 1 *mrad* and 4 *mrad* to the displacement angle θ, respectively. We have also considered a wider range of fabrication uncertainties (see figs. 6–8).

The criterion here adopted by us to define the spot radius was to consider the radius that contains 90% of the photons that reaches the cluster of PMT's.

Following we will show the figures spot size diagrams with its respectively radial distribution for incidence angles of 0^o and 20^o degrees. We consider the Schmidt camera with and without corrector plate.

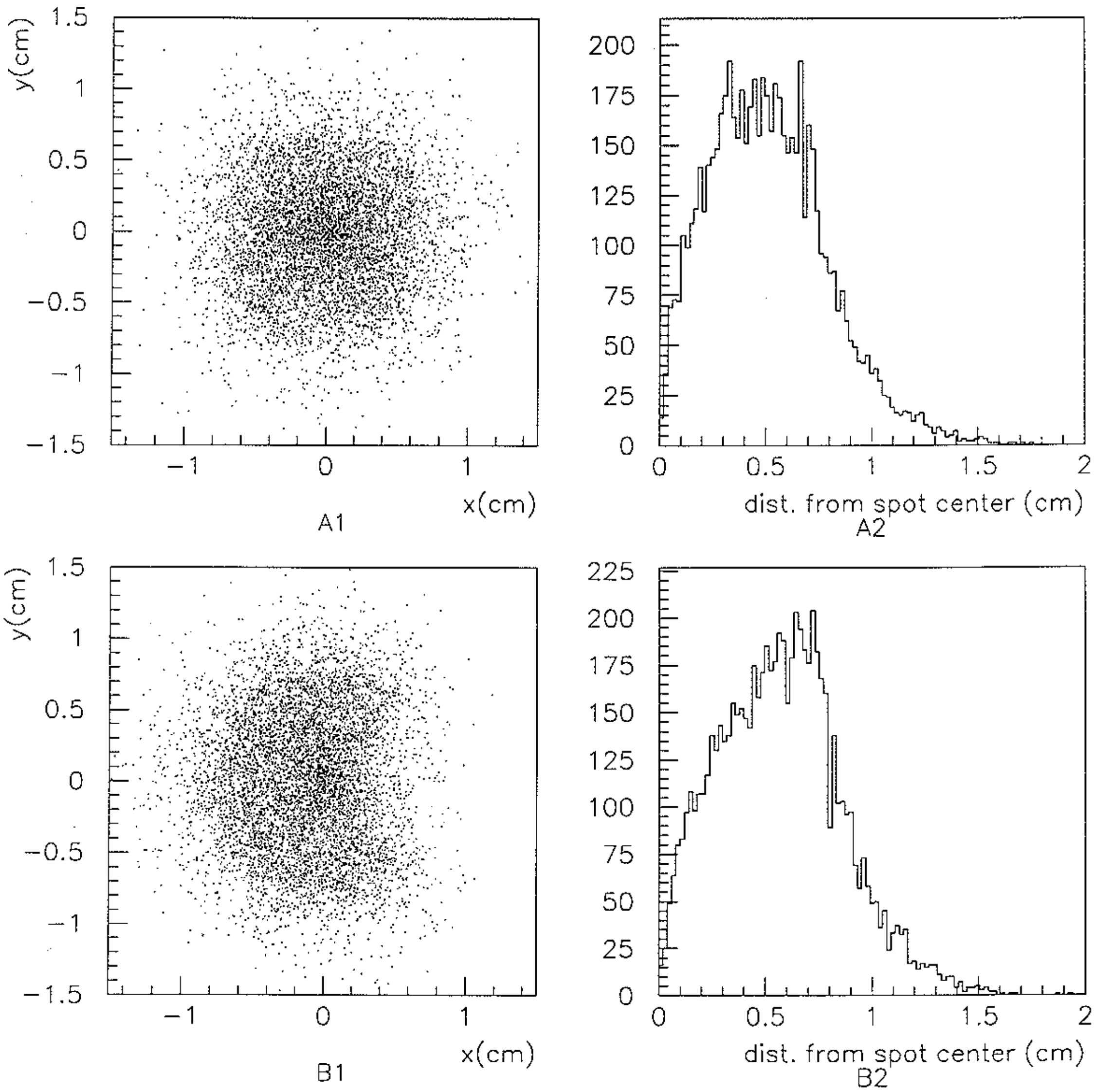

Figure 2: Projection of the spot on the spherical cluster of PMT's at the focal plane for a Schmidt camera without corrector plate, with incidence angles of 0^o (fig.A1) and 20^o (fig.B1). Figures A2 and B2 are the corresponding radial distribution of the spot size.

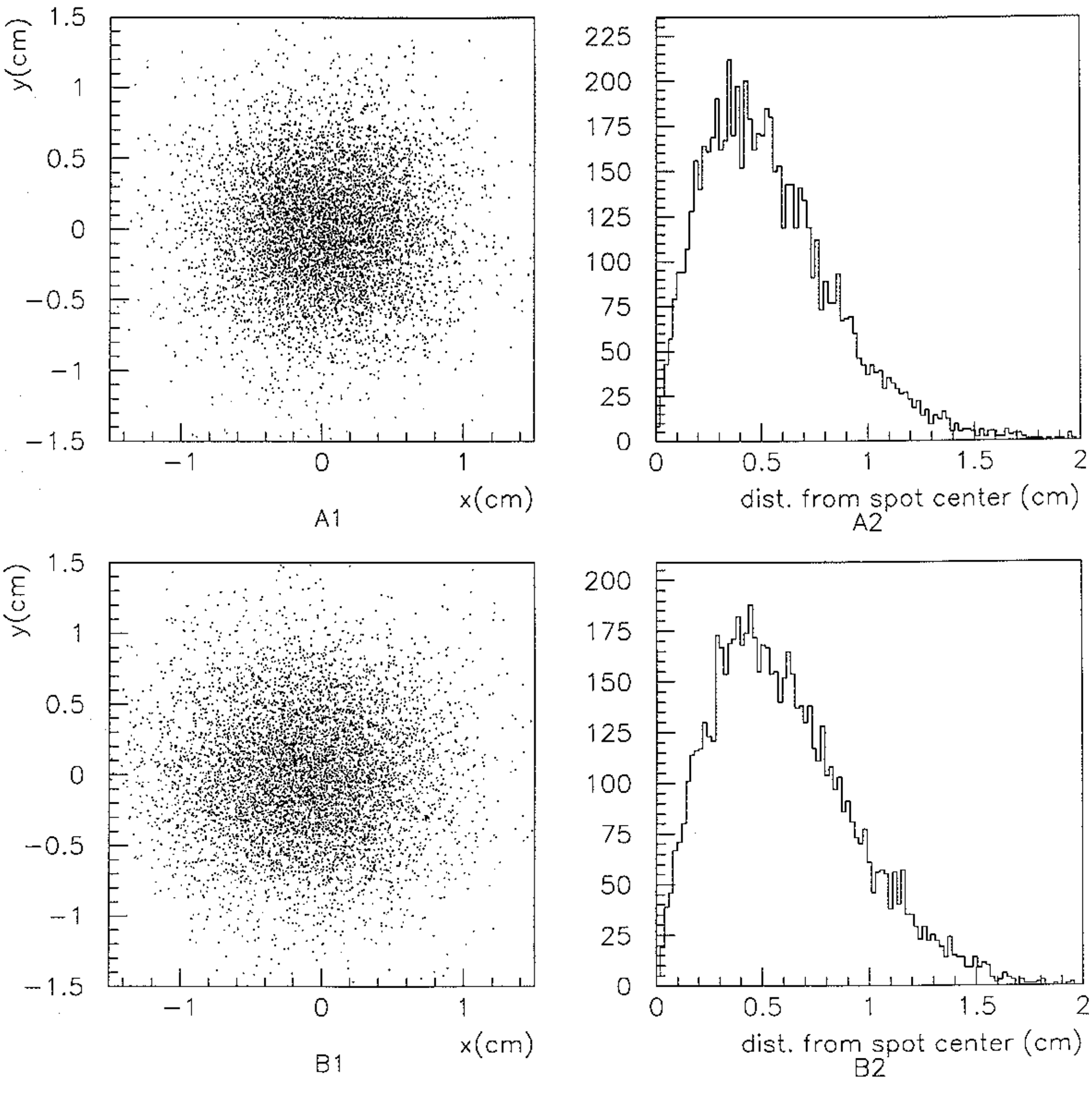

Figure 3: Projection of the spot on the spherical cluster of PMT's at the focal plane for a Schmidt camera with corrector plate type I, with incidence angles of 0^o (fig.A1) and 20^o (fig.B1). Figures A2 and B2 are the corresponding radial distribution of the spot size.

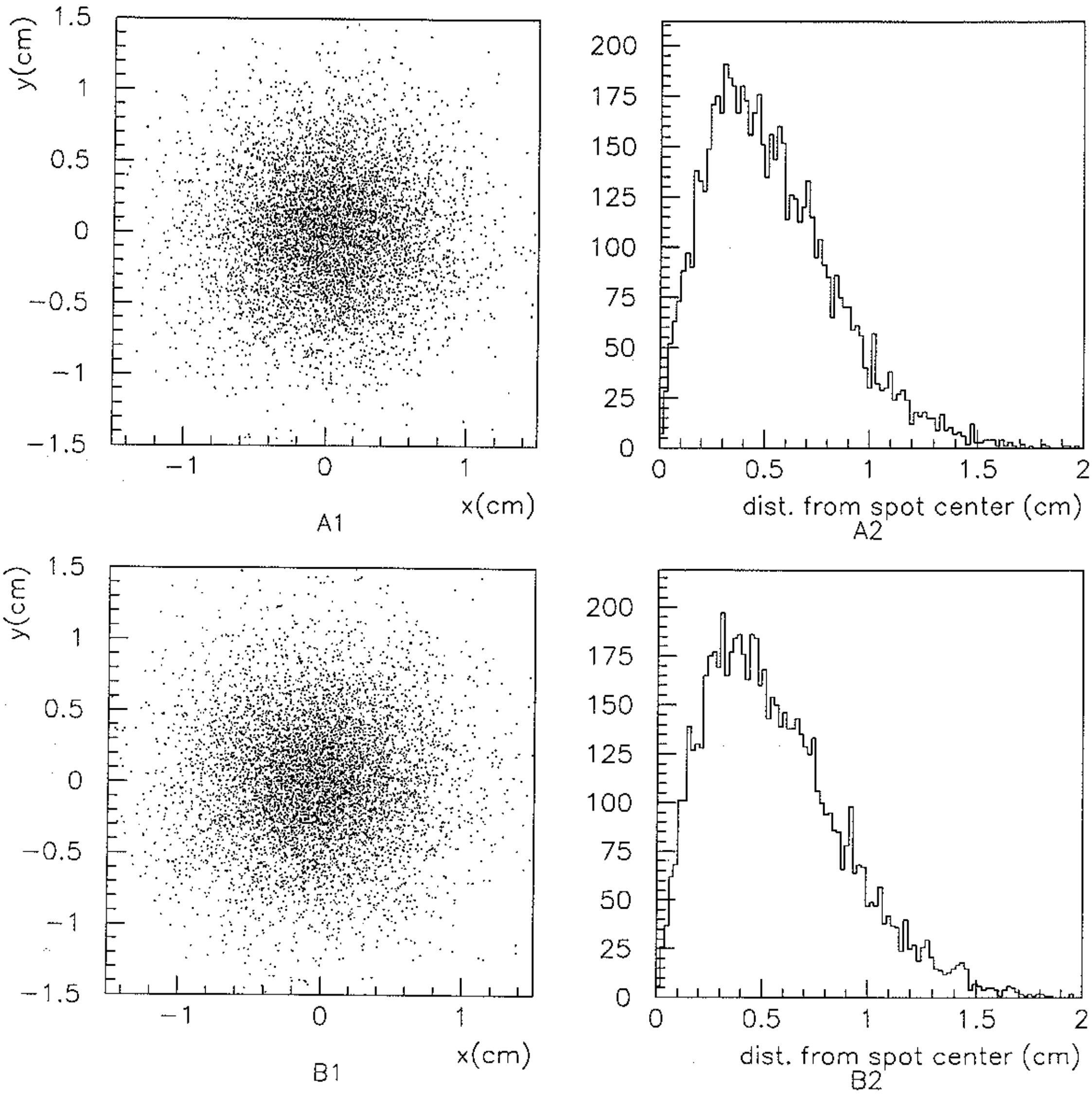

Figure 4: Projection of the spot on the spherical cluster of PMT's at the focal plane for a Schmidt camera with corrector plate type II, with incidence angles of 0^o (fig.A1) and 20^o (fig.B1). Figures A2 and B2 are the corresponding radial distribution of the spot size.

	$R_{foc} = 1.743m$	
	spot size	
angle	Radius	Radius
(degree)	*(mm)*	*(degree)*
0	8.77	0.29
5	9.06	0.30
10	9.24	0.30
15	9.46	0.31
20	9.36	0.31

Table 1: Spot size values of the simulations without corrector plate with uncertainty of 1 *mrad* for different angles of incidence.

	corrector plate I				corrector plate II			
	$R_{foc} = 1.706m$				$R_{foc} = 1.743m$			
	4 *mrad*		1 *mrad*		4 *mrad*		1 *mrad*	
angle	Radius	Radius	Radius	Radius	Radius	Radius	Radius	Radius
(degree)	*(mm)*	*(degree)*	*(mm)*	*(degree)*	*(mm)*	*(degree)*	*(mm)*	*(degree)*
0	9.51	0.32	9.48	0.32	6.51	0.21	6.21	0.20
5	9.60	0.32	9.51	0.32	6.48	0.21	6.21	0.20
10	9.81	0.33	9.71	0.33	6.61	0.22	6.36	0.21
15	10.19	0.34	9.77	0.33	6.85	0.23	6.23	0.20
20	10.59	0.36	10.12	0.34	7.54	0.25	6.27	0.21

Table 2: Spot size values of the simulation with corrector plate for different angles of incidence with uncertainties of 1 *mrad* on the mirror and 1 *mrad* and 4 *mrad* on the corrector plate.

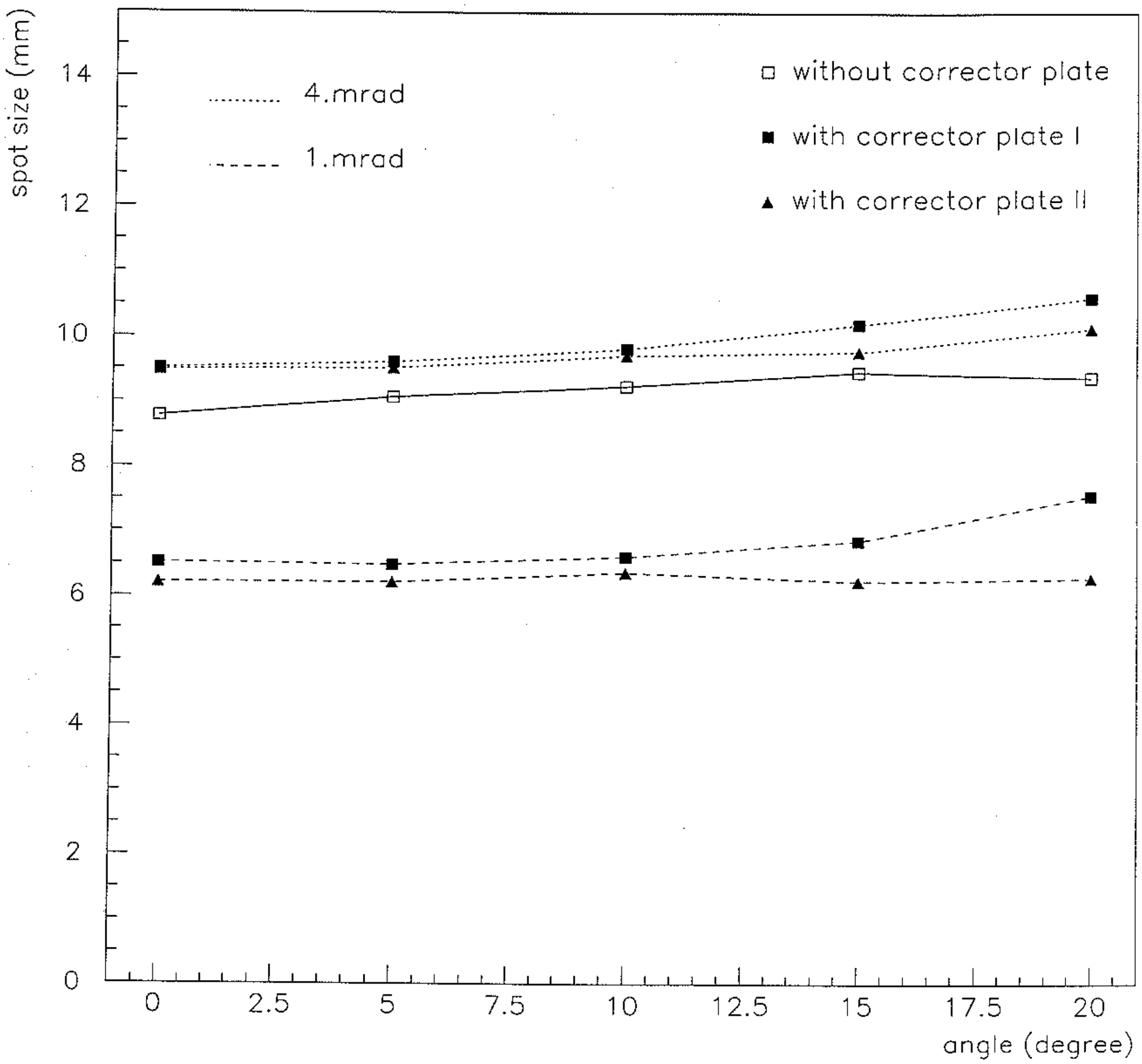

Figure 5: Spot size as a function of the incidence angle for the Schmidt system with and without corrector plate, considering uncertainty on the mirror and on the corrector plate ($\sigma_{mirror} = 1\ mrad$ and $\sigma_{lens} = 1\ mrad$ and $\sigma_{lens} = 4\ mrad$).

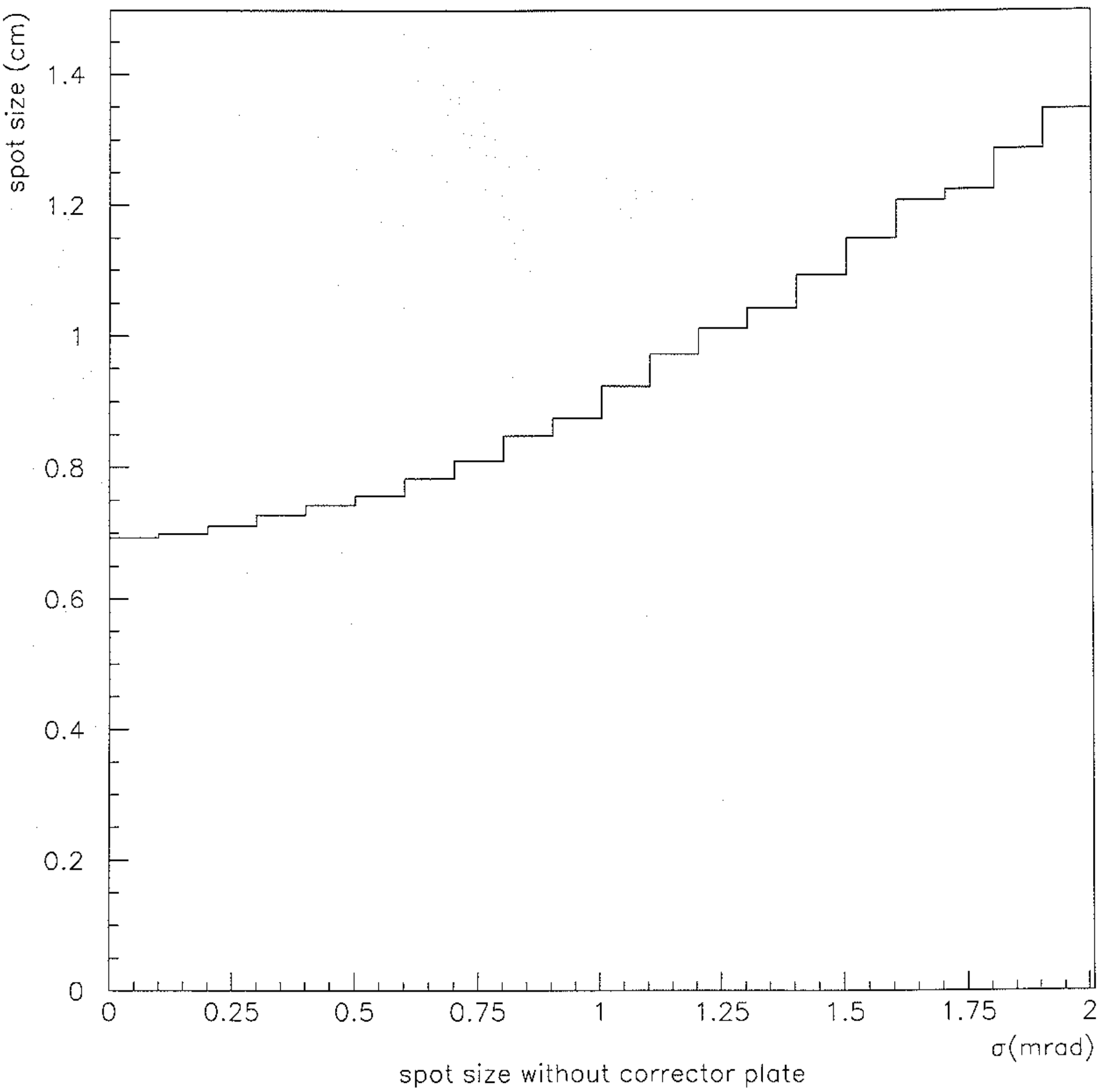

Figure 6: Spot size as a function of the uncertainty on the mirror (σ_{mirror}). Incidence angle 0^o.

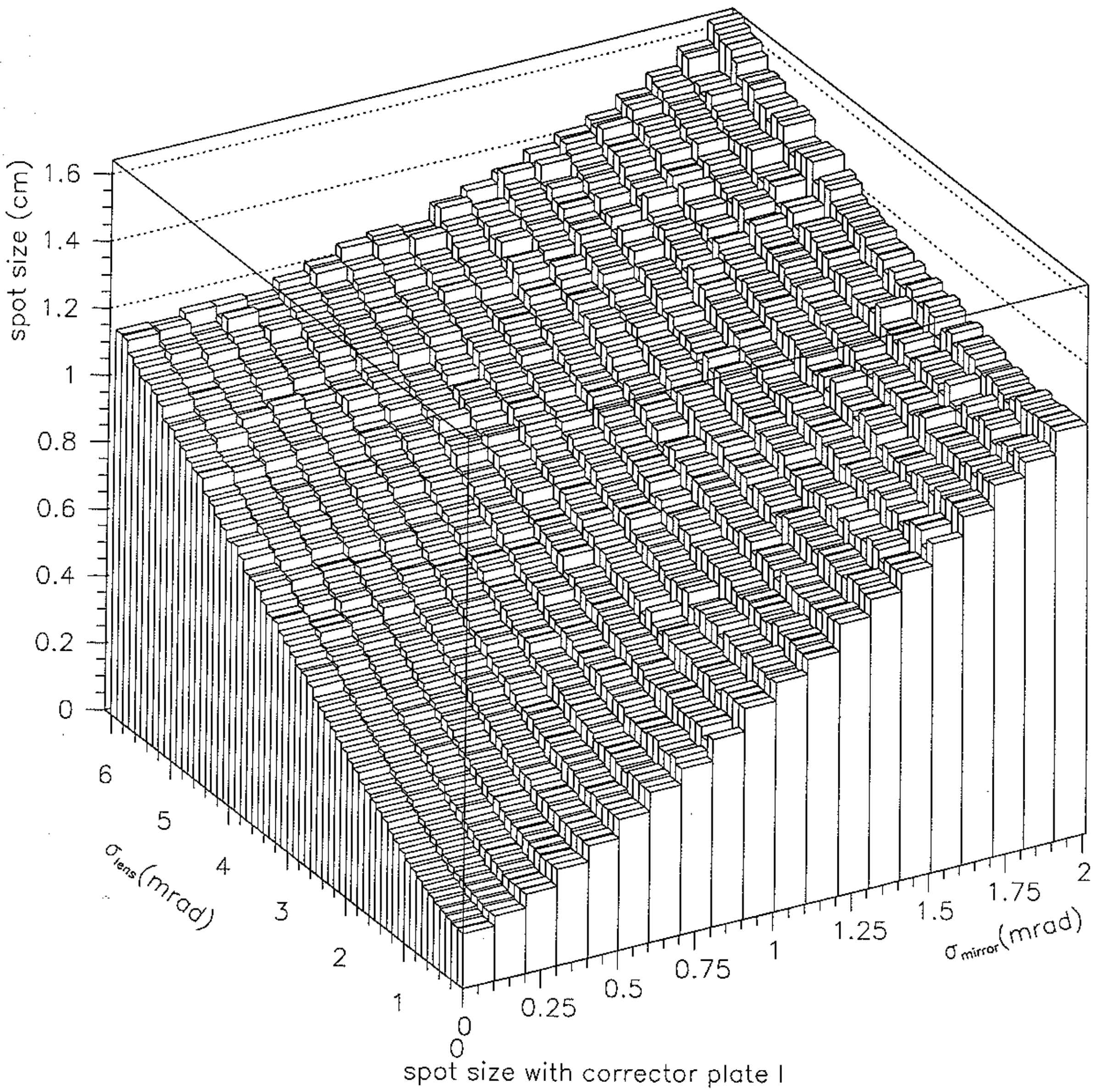

Figure 7: Spot size as a function of the uncertainty on the mirror (σ_{mirror}) and on the corrector plate type I (σ_{lens}). Incidence angle 0^o.

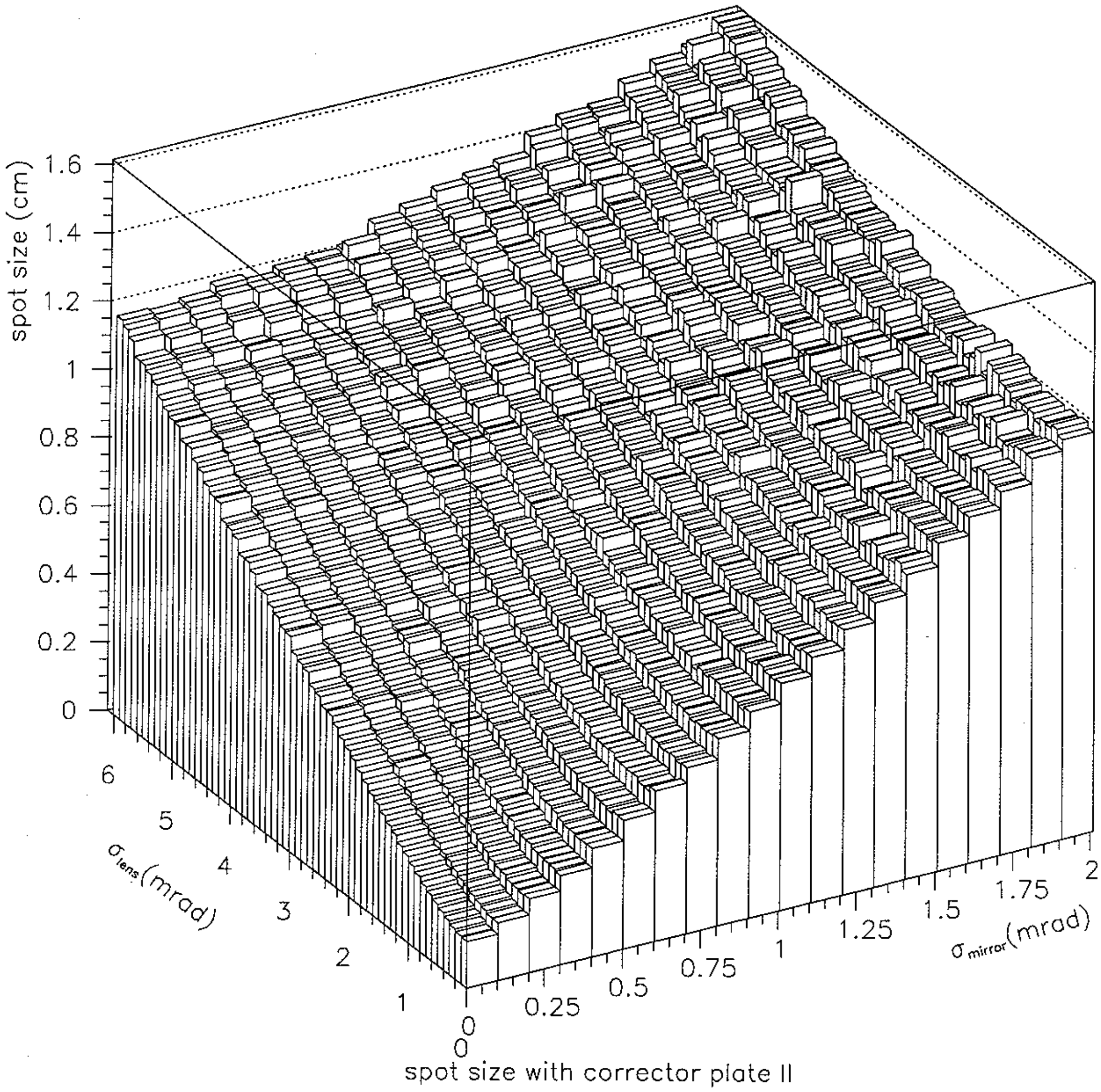

Figure 8: Spot size as a function of the uncertainty on the mirror (σ_{mirror}) and on the corrector plate type II (σ_{lens}). Incidence angle 0^o.

4 Increasing the diaphragm's radius

It is clear from this and previous studies [3, 4] that a good quality corrector plate increases the resolution of the optical system, as expected. However, the crucial question is how to increase the signal to noise ratio, S/N, in the FD, as this is the figure of merit that controls the quality of our detector (shower reconstruction, X_{max} resolution, etc). To improve S/N we increase the effective light collection area by increasing the diaphragm radius covering it with a corrector plate. This is what we now investigate.

We performed the simulations with the intent of finding the maximum diaphragm's radius keeping the spot size under control [$R_{spot} = 1cm$ $(0.6^o \times 0.6^o)$ and $R_{spot} = 1.7cm$ $(1^o \times 1^o)$].

spot size(cm)	1.7			1.0		
	$R_d(m)$	$R_{focal}(m)$	A	$R_d(m)$	$R_{focal}(m)$	A
without corrector plate	1.07	1.772	1.0	0.895	1.748	1.0
with corrector plate I	1.28	1.735	1.6	1.132	1.720	1.9
with corrector plate II	1.35	1.745	1.8	1.191	1.789	2.1

Table 3: This table shows the necessary diaphragm's radius to keep the same spot size when we use the Schmidt camera without corrector plate and with each type of corrector plate.A is the ratio between effective area with corrector plate and without corrector plate. Incidence angle 0^o. Both mirror and corrector plate have $\sigma_{mirror} = sigma_{lens} = 1\ mrad$

5 Results

It becomes clear from the analysis of the figures and histograms that the effect of imperfections on the two principal optical elements of the Schmidt camera (mirror and lenses) turns the surface of these two elements into diffuse surfaces, as we can see comparing the results of the previous section with the simulations results of references [3] and [4]. In addition, we have three new results:

- Considering the mirror and the corrector plate with $\sigma_{lens} = \sigma_{mirror} = 1\ mrad$, there is a significant difference between the spot's radius with and without lenses. For example, if we consider a incidence angle of zero degree, $R_{spot} \approx 8.77mm$ without corrector plate and $R_{spot} \approx 6.21mm$ with corrector plate type II. This corresponds to a reduction of 30% in the spot's radius. A reminder in order at this point, our optical system follows the reference design not the one studied in ref. [3] which is FD prototype design.

- If we consider instead $\sigma_{lens} = 4\ mrad, \sigma_{mirror} = 1\ mrad$, we observed that the spot's radius in the case of Schmidt camera with corrector plate type II ($R_{spot} \approx 9.48mm$)

is greater than the case without corrector plate ($R_{spot} \approx 8.77mm$) (incidence angle of zero degree). In addition, we can see from figures (6-8) that the spot size is less sensible to the corrector plate uncertainty in comparison with mirror uncertainty and if the uncertainties are not small ($\sigma_{mirror} > 1\ mrad$ and $\sigma_{lens} < 3\ mrad$) the implementation of corrector plate does not cause a significant reduction of spot size. Considering these results, we would not recommend a FD with corrector plate, of course.

- On the othe hand, there is another important result which favors a FD with corrector plate. We see from the table 3 the possibility of increasing the diaphragm's radius keeping the spot size to an acceptable value. For example, if we consider a fixed value for the FD resolution, $1^o \times 1^o$, we have $R_{dia} \approx 1.07m$ without corrector plate and $R_{dia} \approx 1.35m$ with the corrector plate type II. If we want to be more discerning with the radius of spot, we can consider the FD with a resolution of $0.6^o \times 0.6^o$. In this case, we have $R_{dia} \approx 0.895m$ without corrector plate and $R_{dia} \approx 1.191m$ with corrector plate type II. This difference corresponds to a increase of 100% in the light collected area.

6 Conclusions

Our conclusions are the following: We need to know if the manufacture can reach the necessary high precision in order to reduce the spot size and how much it will cost. If we can have this good quality on the mirrors and corrector plate and if it is not expensive, we will have a good difference between the spot radius' results with and without lenses. Otherwise, the spot size with corrector plate is worst than without it.

However, we have shown that there is another good reason to install the corrector plate on the FD: we can increase the aperture of the diaphragm in order to have a larger light collection area and, in this way, improve the S/N ratio.

In addition, we can see that mirrors are more sentitive to manufacturing imprecisions than corrector plates. If we improve the precision of the mirrors, the spot size reduces rapidly as we can see in figures (7-8).

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