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OPTICAL STUDY OF IR PRESSMAGO COLLECTOR

Lisa Gambicorti[1], Francesca Simonetti[1] Augusto Marcelli[2],
Daniele Di Gioacchino[2], Emanuele Pace[3], Antonio De Sio[3]

[1)] *INFN-Sezione di Firenze, Istituto Nazionale di Ottica Applicata-CNR, I-50125 Firenze, Italy*
[2)] *INFN-Laboratori Nazionali di Frascati Via E. Fermi 40, I-00044 Frascati, Italy*
[3)] *INFN-Sezione di Firenze, Dip. Astronomia e Scienza dello Spazio,*
Università di Firenze, I-50125 Firenze, Italy

Abstract

A feasibility study of an optical system to concentrate and to focalize the synchrotron beam for the PRESS_MAG_O experiment of the Vth Committee of the INFN has been proposed. This report describes the study of a collector with two different configurations, to match the optical and mechanical requirements, obtaining performances that are in agree with the opto-mechanical constrains. During the study the requirements has been analyzed and the performances of collectors are described in collimated and non collimated beam. At the end a comparison between the performances of the solutions and conclusions are reported.

1 INTRODUCTION

PRESS-MAG-O is an original device designed to investigate materials under extreme conditions, i.e., as a function of both pressure and DC magnetic field and in a wide temperature range [1]. The apparatus has been completely developed at the INFN as the result of a project funded by the INFN [2]. Materials like ferroelectrics or superconducting systems, magnetic transitions and new condensed matter phases can be investigated with this device that permits concurrent magnetic and optical experiments. A FTIR spectroscopic analysis in a wide IR domain represents a new strategic approach combining information of the phonon behavior with linear and non-linear electron dynamic transport processes. The apparatus is the result of a significant R&D in different areas. Several technical advancements guaranteed the construction of the cryostat and its internal components thanks also to the availability of new materials and a high level technological processes. The PRESS-MAG-O instrument has been designed to perform optical experiments such as FTIR spectroscopy in transmission or reflection modes and Raman spectroscopy. SINBAD (Synchrotron Infrared Beamline At DAΦNE), the first Italian IR beamline that exploited the great advantages of the synchrotron radiation sources in the IR domain, is operational at the INFN, National Laboratories of Frascati, since 2001 [4]. A brilliant IR SR source is ideal to perform high-pressure investigations on small samples inside a DAC and this is particularly true at DAΦNE (Double Annular Φ-factory for Nice Experiments), the Frascati electron-positron collider working in topping up mode at an energy of 0.51 GeV per beam with a maximum beam current > 2 A.
SINBAD has been designed to work at IR wavelengths from about 10 up to 10000 cm-1 and operates with a customized BRUKER Equinox 55 interferometer working in vacuum coupled to a BRUKER Hyperion 3000 microscope. Different experiments have been performed using DACs, in particular those on La1-xCaxMnO3-x manganite samples at pressures up to 10 GPa using the IR synchrotron radiation emission [5].
In more detail, the collimated beam coming out from the interferometer and entering the PRESS-MAG-O setup will be focused inside the DAC on the loaded sample by using one of the four lateral ports equipped by optical transmitting windows. Different windows can be installed: a CVD wedged diamond window is an option to cover the widest IR range down to the far-IR domain [3].
A Cassegrain concentrator has been designed to fit inside the dimension of the apparatus in order to focus the synchrotron radiation in a small-size spot (the diameter of the Airy disk is ~200 μm at the shortest wavelength) inside the diamond anvil cell.
Aim of this work is to describe the optical design to reach the requirements of this experiment.

2 OPTICAL AND MECHANICAL REQUIREMENTS

The concentrator will have the maximum possible numerical aperture, fulfilling constrains imposed by the physical dimensions of the tube in which will be placed. The wavelength range of the collector is the InfraRed and Far-InfraRed wavelength range, between 2-20 microns,

with the possibility to work down to 50 micron.
The entrance beam diameter is Φ ~ 30 mm and the optical system has to be placed inside a tube of steel, with the optical axis coincident with the axis of the tube.
At the end of the tube an optical window is present. It has 16 mm of diameter with a clear aperture of ~15 cm and the distance between the window and the axis of the magnet (where the focus of the optical system is fixed). The required spot dimension is 300 micron ± 100 micron.

2.1 Mechanical structure

The steel tube is divided in two sections. First is 225 mm of length and second is 325 mm, considering to place along the tube a ceramic break, as showed in Fig. 1 with the white color.

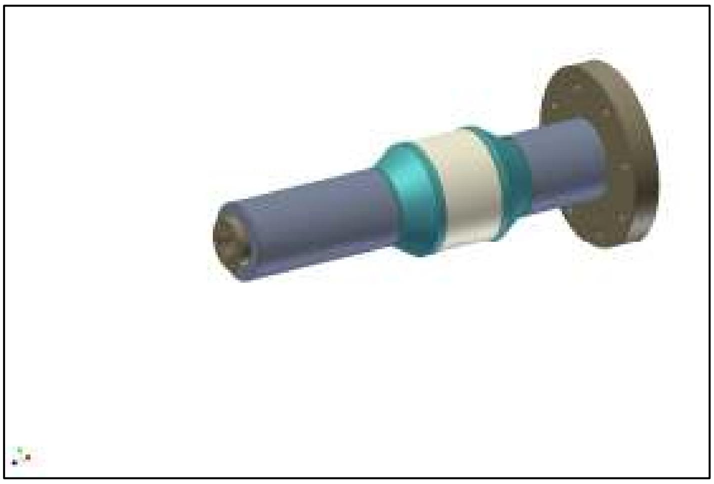


FIG 1 3D-view of the steel tube and the ceramic break.

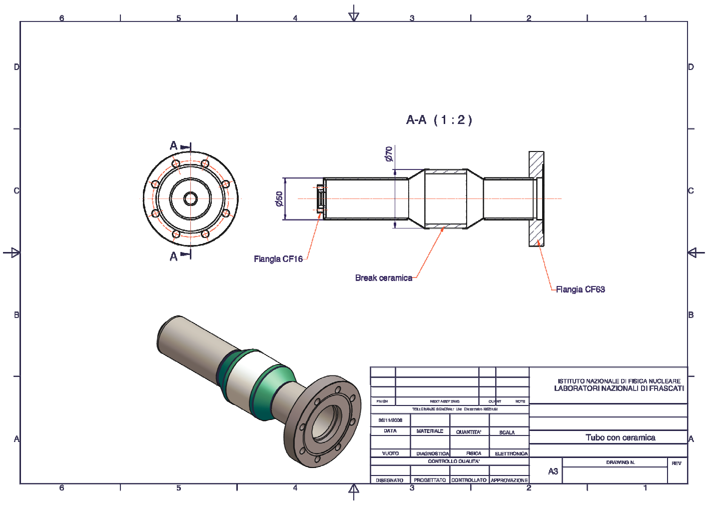


FIG. 2 Mechanical view of the external tube of PRESSMAGO optics.

TAB 1: Main system parameters

Wavelength range (micron)	2.5-50
Source collimated max diameter (mm)	40
System length available (mm)	225/325
Window thickness (micron)	500
Window clear aperture diameter (mm)	15
Distance window-target (mm)	39
Optical Tube dimension (mm)	225/325

Hypothesis:

- The solution has to be a reflecting system because the wavelength range of interest (2.5-50 micron) is quite large.
- Minimize the number of mirrors

This feasibility study shows the solutions with obscuration on axis, e.g., with a concentrator cassegrain configuration. In this system it is not efficient consider an off axis mirrors to concentrate the light to the target, although it reduces the illuminated area of mirrors.

1. Concentrator cassegrain in a 225 mm long tube

The first optical configuration is a Cassegrain, developed to be set inside an optical tube that will be inserted in an external steel tube. The mechanical axis of the system has to coincide with the optical axis and its opto-mechanical dimensions are reported in Tab. 2. Fig. 3 shows the ray tracing with a collimated source.

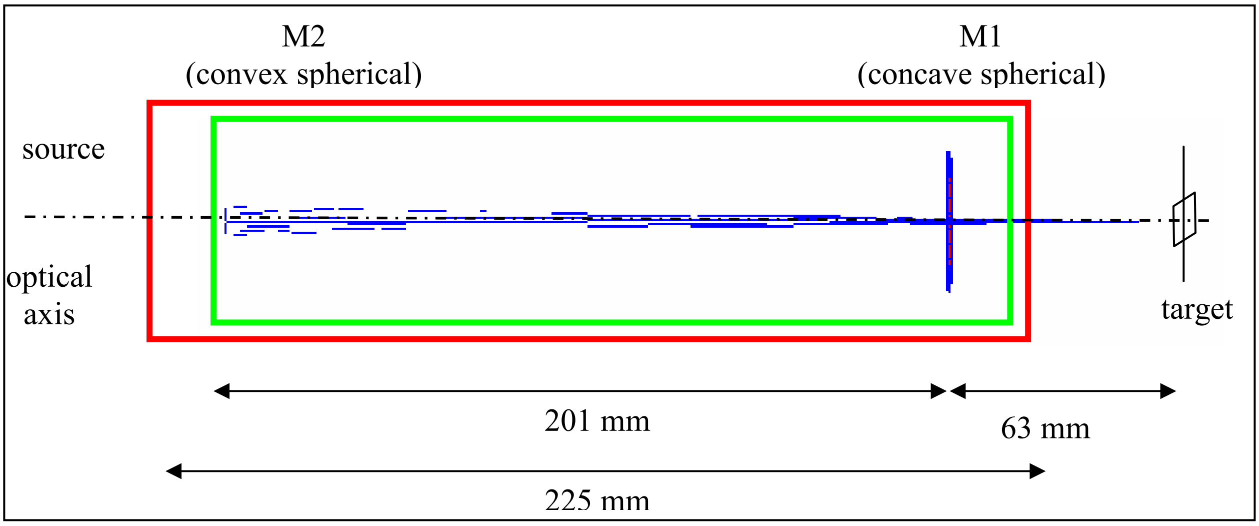


FIG 3 Layout y, z of the cassegrain solution with a 3.8% of central obstruction

TAB 2: Optical parameter to match the system requirements

f /#	33.7
Diameter Mirror M1 (mm)	40
Thickness Mirror M1 (mm)	6.7
Curvature radius concave M1(mm)	500
Diameter Mirror M2 (mm)	7.8
Thickness Mirror M2 (mm)	1.3
Curvature radius convex M2(mm)	119.94
Distance Window-M2 (mm)	5
Distance Center M1-M2 (mm)	201
Distance Center M2-target (mm)	264.8
Obstruction factor (R_2^2/ R_1^2) %	3.8
Diameter Mirror M1 (mm)	40
Global efficiency (collector) %	86.5

The efficiency of this solution is determined by its performances, the mirrors reflectivity (R=0.95) and by the obstruction coefficient that reduces the source area only by 3.8%.

Obs= 0.038

Eff= (100-3.8)*0.95*0.95=0.865

Fig. 4 and Fig. 5 show the spot diagram at the wavelength of 2.5 and 20 micron.

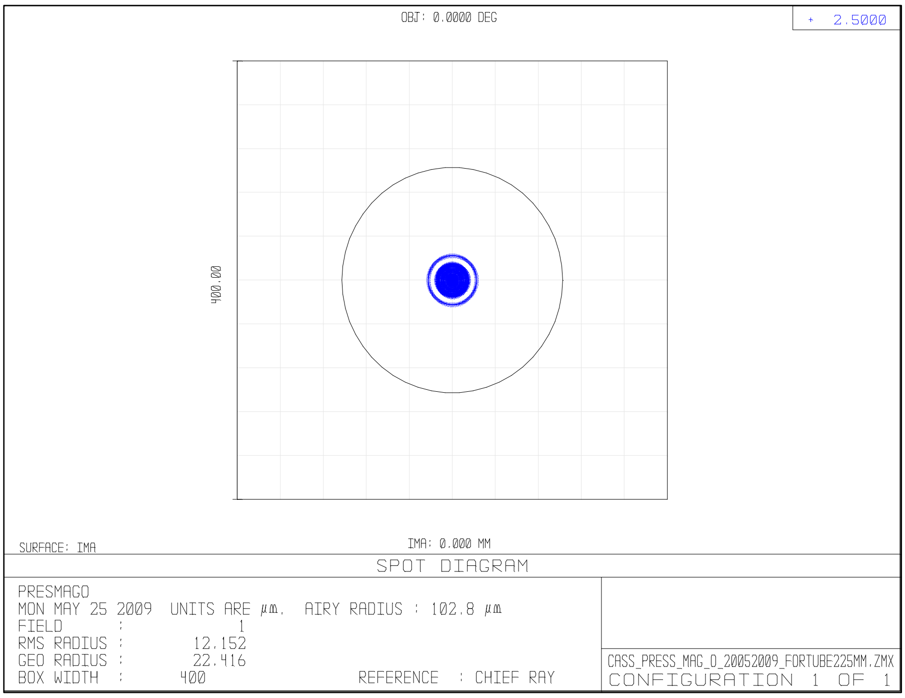


FIG-4 Spot diagram inside the Airy disk for central field of the cassegrain solution with 102.8 micron of the Airy disk at the wavelength of 2.5 micron.

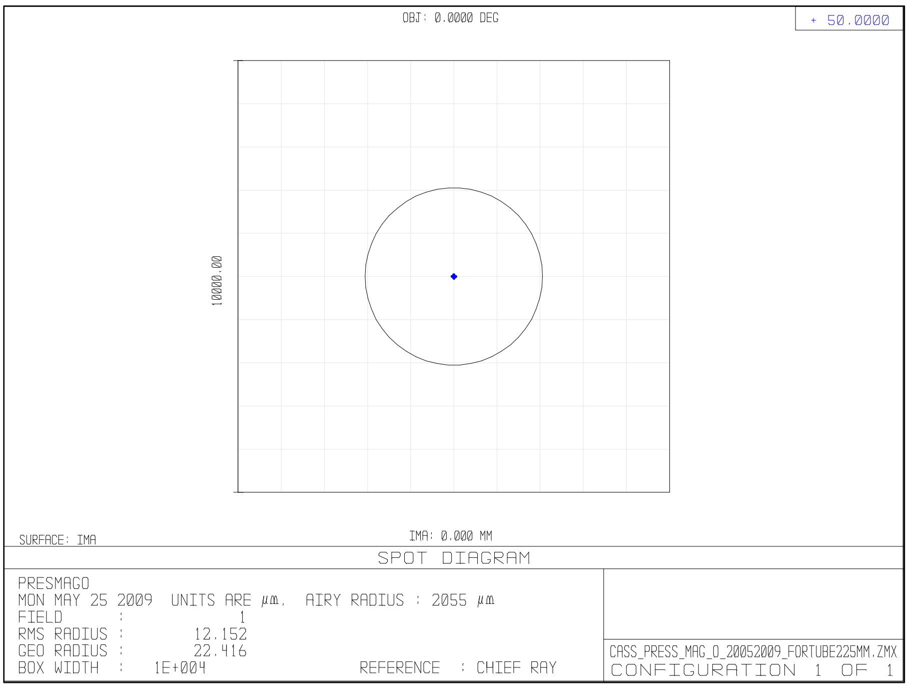


FIG 5 Spot diagram for a collimated source with a cassegrain solution with 2055 micron of the Airy disk at the wavelength of 50 micron.

The system is diffraction limited and optically perfect as the spot diagram focus inside the Airy Disk. (It represents the minimum dimension of the image that can be reached with such optical system).

2. Optical parameters for mirrors of the PRESSMAGO collector

Tab. 3 shows the mechanical tolerances of optical elements and Tab. 4 the mechanical distances. In Fig. 6 are showed the mirrors sections.

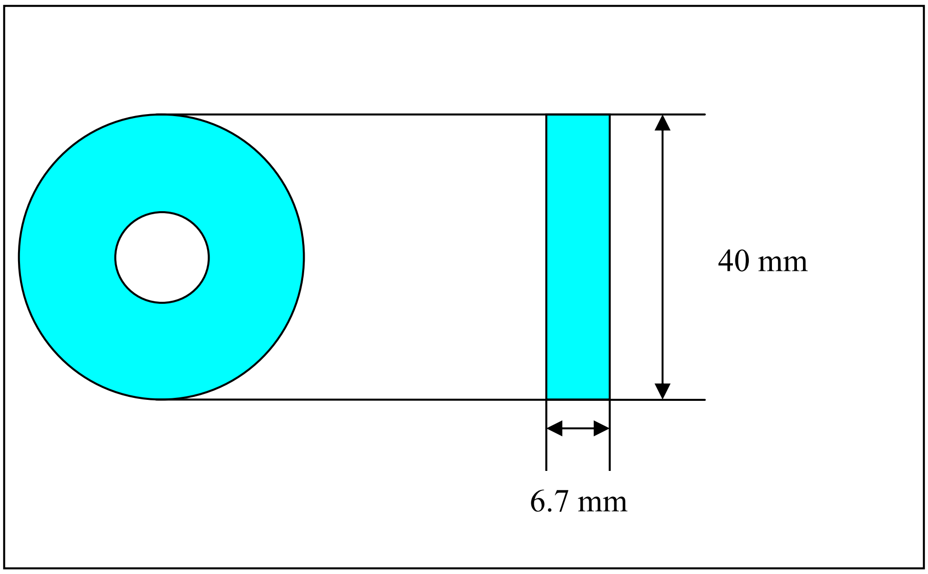
TAB 3: Optical parameters of the collector mirrors

Diameter Mirror M1 (mm)	40.0 ± 0.2
Thickness Mirror M1 (mm)	6.7 ± 0.2
Curvature radius M1(mm) concave	500
Diameter Mirror M2 (mm)	7.8 ± 0.2
Thickness Mirror M2 (mm)	1.3 ± 0.2
Curvature radius M2(mm) convex	119.94

TAB 4: Mechanical parameters of the collector mirrors

Distance sample-diamond window (mm)	39
Thickness -diamond window (micron)	500
Distance diamond window-external tube(mm)	2
Distance diamond external tube-internal tube(mm)	5
Length external tube (mm)	225
Internal Diameter of external tube (mm)	48
External diameter of internal tube	46
Internal diameter of internal tube	44
Length internal tube (mm)	220
Distance Center M1-M2 (mm)	201
Distance Center M2-target (mm)	264.8
Obstruction factor (R_2^2/ R_1^2) %	3.8
Global efficiency (collector) %	86.5

Concave mirror M1 (R=500 **mm)**



Convex mirror M2 (R=119.94 **mm)**

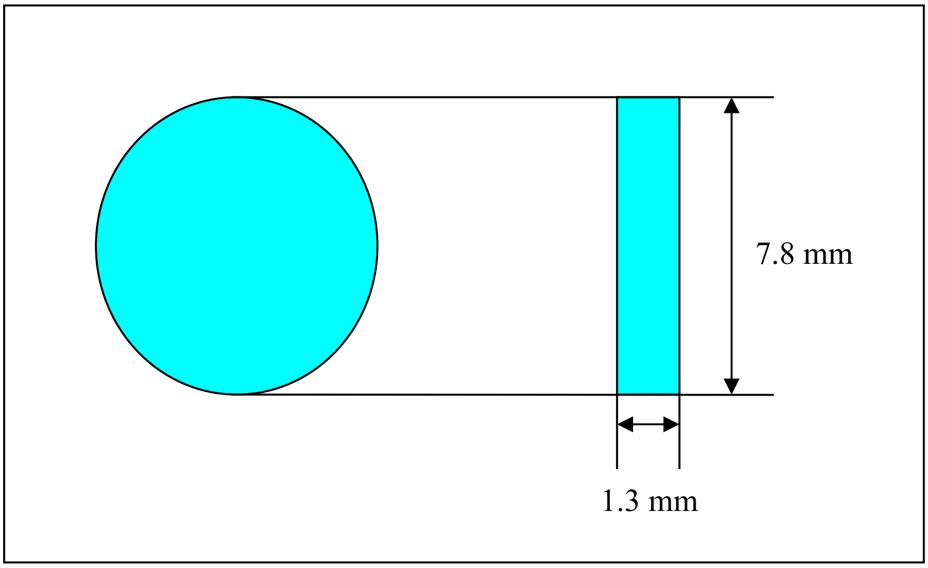


FIG 6 Mechanical layouts of primary and secondary mirrors.

3. Sensitivity analysis

The sensitivity analysis is a procedure that allows evaluating the mechanical tolerances on inter-distances and tilts maintaining focus and optical axis. The analysis allows establishing among all the more sensitive optical element, e.g., curvature radius or distances, changing the different optical parameters of defined quantities still fulfilling the diffraction limit constrains. Tab. 5 shows mechanical tolerances required to remain diffraction limited while Fig. 7 shows the image of the spot diagram obtained changing the inter-distance between primary and secondary mirror.

TAB 5: Mechanical tolerances (to remain diffraction limited)

Sensitivity Budget for baseline						
Surface	**Radius (mm) TOL**		**Thickness (mm) TOL**		**Decenter (mm) shift center spot ± 200 micron**	**Tilts_xy shift center spot ± 200 micron**
Primary concave mirror	-500	-0.6 +0.35	-201	-0.18 +0.25	±0.037	-0.010°
Secondary Convex mirror	-119.9	-0.5 +0.9	264.8	-5 +8	±0.045	±0.035°

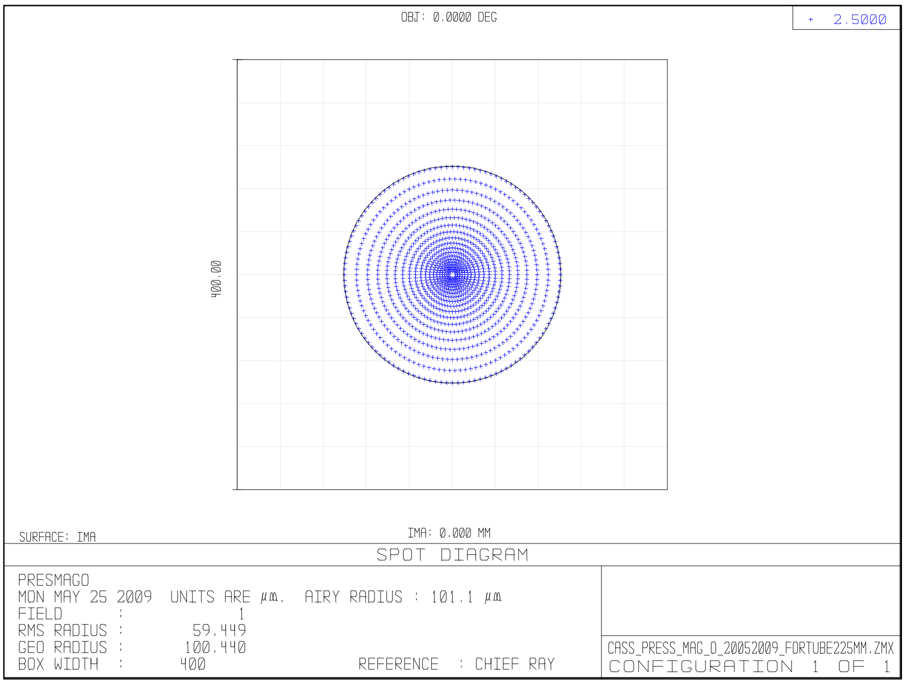


FIG 7 Spot diagram diameter of a collimated source obtained translating the secondary mirror by <u>180 micron</u> respect to the primary mirror.

Data obtained with our sensitivity analysis showed that the most sensitive elements are:

- M1 for both curvature radius and tilt (0.010° ,1.75 mrad)
- Distance M1-M2 (-0.18, +0.25 mm)
- Defocusing (± 5 mm)

To evaluate tolerances with non collimated rays the source divergence simulation has been modified and the distance of the focus has been calculated.

- 0.1 mrad (to be diffraction limited) defocusing 1 cm (to refocus)
- 1 mrad (no diffraction limited) defocusing 19 cm (to refocus)

4. Concentrator cassegrain in a 325 mm of tube

The second cassegrain configuration is also developed to be set inside an optical tube that will be inserted in an external steel tube. Fig. 8 shows the ray tracing obtained with a collimated source. The mechanical axis has to coincide with the optical axis and its opto-mechanical dimensions are reported in Tab. 6. The opto-mechanical dimensions are reported in Tab. 6.

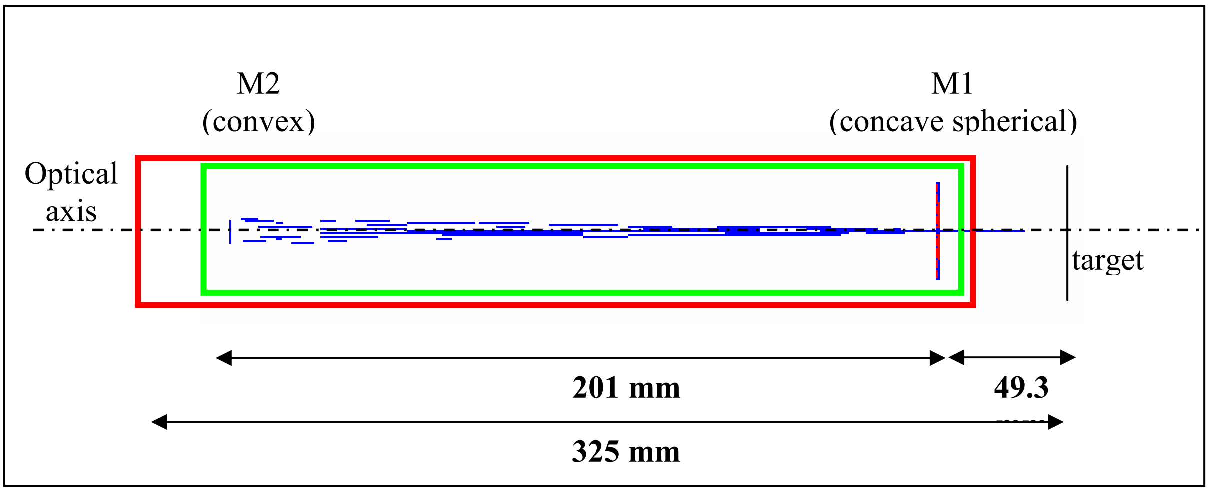


FIG 8 Layout y, z of a cassegrain solution with a 4% of central obstruction.

TAB 6: Optical parameters to match system requirements

f /#	35
Diameter Mirror M1 (mm)	40
Thickness Mirror M1 (mm)	6.7
Curvature radius concave M1(mm)	800
Diameter Mirror M2 (mm)	5.0
Thickness Mirror M2 (mm)	0.83
Curvature radius convex M2(mm)	280
Distance Window-M2 (mm)	5
Distance Center M1-M2 (mm)	300
Distance Center M2-target (mm)	349.3
Obstruction factor (R_2^2/ R_1^2) %	4%
Global efficiency (collector) %	86.6

The efficiency of this solution in determined by performances and mirrors reflectivity (R=0.95) and by the obstruction coefficient that reduce the source area by 4%.

Obs= 0.04

Eff= (100-4)*0.95*0.95=0.866

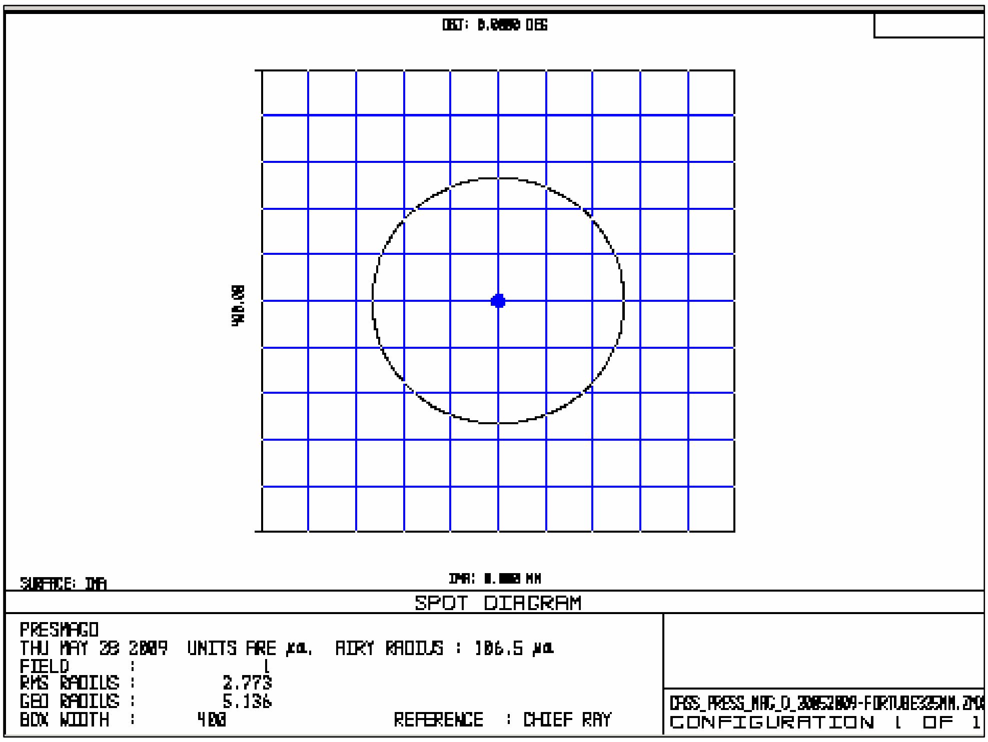


FIG 9 Spot diagram inside the Airy disk for the central field of a cassegrain solution with 106.5 micron of Airy disk at the wavelength of 2.5 micron.

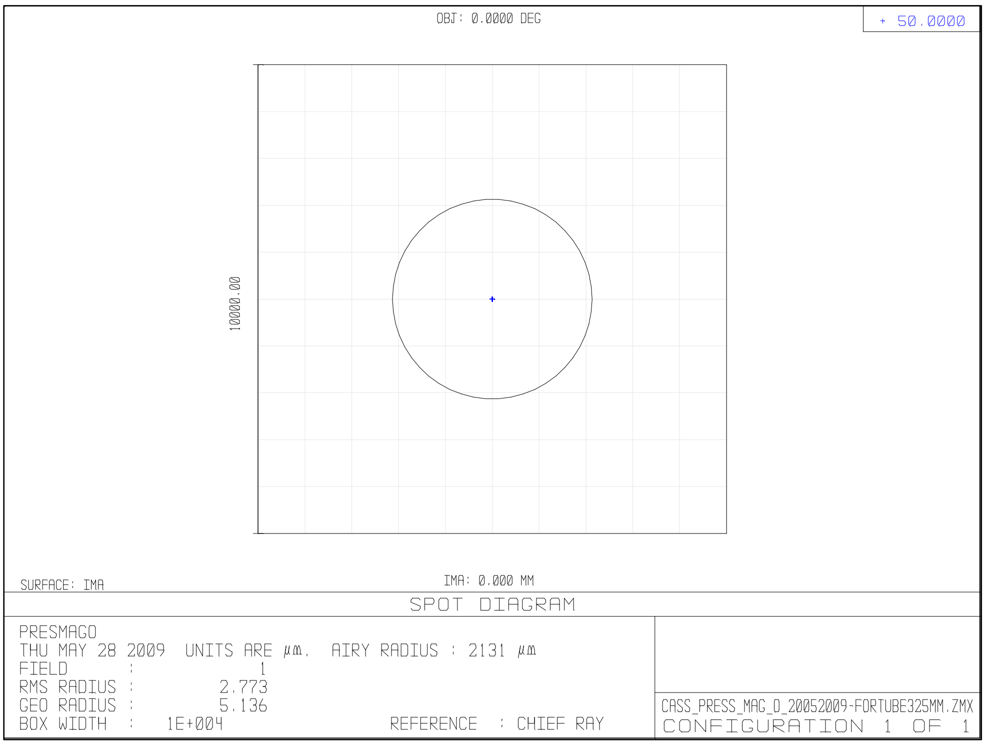


FIG 10 Spot diagram for a collimated source and a cassegrain solution with 2131 micron of Airy disk at 50 micron of wavelength.

Also in this configuration the system results diffraction limited and optically perfect as the spot diagram inside the Airy Disk shows. (It represents the minimum dimension of the image that can be reached with the optical system).

5. Optical parameters for the mirrors PRESSMAGO collector

Table 7 shows the mechanical tolerances of optical elements and Table 8 the mechanical value of distances and Fig. 6 the section of mirrors.

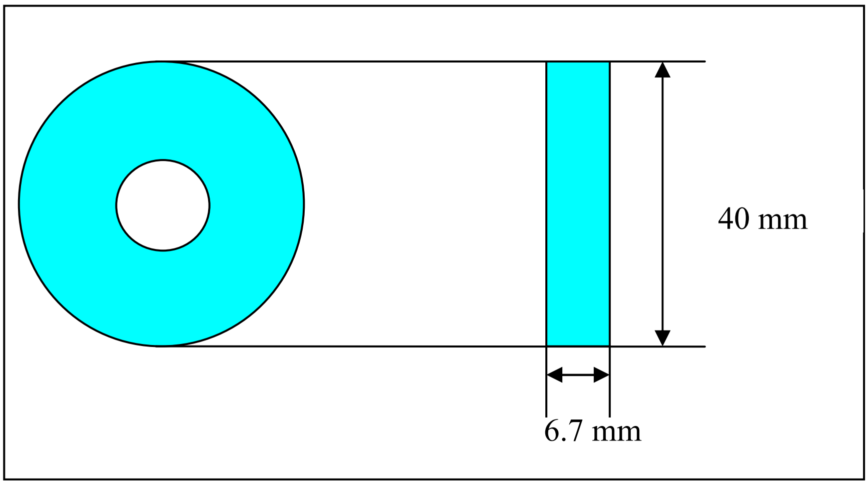
TAB 7: Optical parameters of collector mirrors

Diameter Mirror M1 (mm)	40.0 ± 0.2
Thickness Mirror M1 (mm)	6.7 ± 0.2
Curvature radius M1(mm) concave	800
Diameter Mirror M2 (mm)	5.0 ± 0.2
Thickness Mirror M2 (mm)	0.8 ± 0.2
Curvature radius M2(mm) convex	240

TAB 8: Mechanical parameters of collector mirrors

Distance sample-diamond window (mm)	39
Thickness -diamond window (micron)	500
Distance diamond window-external tube(mm)	2
Distance diamond external tube-internal tube(mm)	5
Length external tube (mm)	325
Internal Diameter of external tube (mm)	48
External diameter of internal tube	46
Internal diameter of internal tube	44
Length internal tube (mm)	320
Distance Center M1-M2 (mm)	300
Distance Center M2-target (mm)	349.3
Obstruction factor (R_2^2/ R_1^2) %	4
Global efficiency (collector) %	86.4

Concave mirror M1 (R=800 **mm)**



Convex mirror M2 (R=240 **mm)**

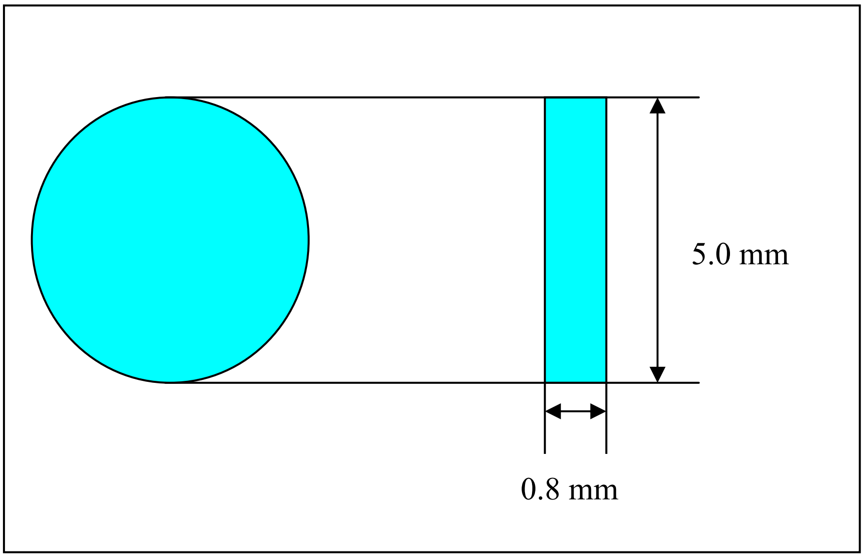


FIG 11 Mechanical layouts of primary and secondary mirrors.

6. Sensitivity analysis

The sensitivity analysis is a procedure that allows evaluating the mechanical tolerances on inter-distances and tilts maintaining focus and optical axis. The analysis allows establishing among all the more sensitive optical element, e.g., curvature radius or distances, changing the different optical parameters of defined quantities still fulfilling the diffraction limit constrains.

TAB 9: Mechanical tolerances (to remain diffraction limited)

Sensitivity Budget for baseline						
Surface	**Radius (mm) TOL**		**Thickness (mm) TOL**		**Decenter (mm)** **shift center spot ± 200 micron**	**Tilts_xy** **shift center spot ± 200 micron**
Primary concave mirror	-800	-1.3 +1.1	-300	-0.55 +0.65	±0.058	±0.0065°
Secondary Convex mirror	-280	-2.0 +2.4	-349.3	-7 +7.5	±0.080	±0.030°

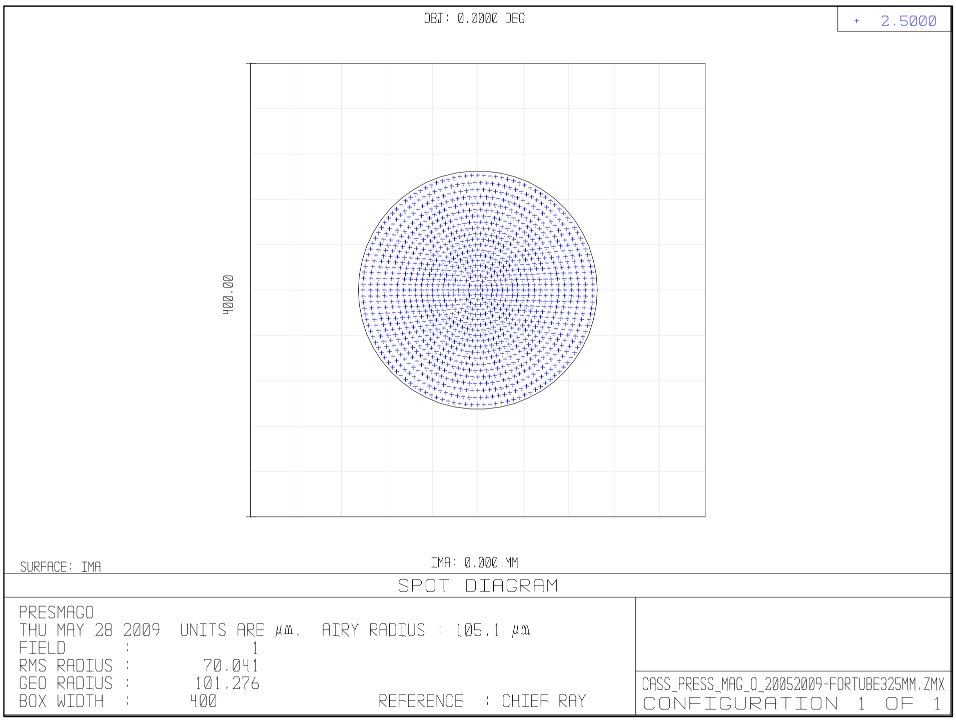


FIG 12 Spot diagram of a diameter collimated source obtained translating the second mirror by 550 micron respect to the fixed first mirror.

Data obtained with the sensitivity analysis show that the most sensitive elements are:

- M1 for both curvature radius and tilt (0.11 mrad=0.0065°)
- Distance M1-M2 (-0.55, +0.65 mm)
- Defocusing (± 7 mm)

Tolerances in non collimated rays:

- 0.16 mrad (to be diffraction limited) defocusing 1.5 cm (to refocus)
- 1 mrad (no diff limit) defocusing 17 cm (to refocus)

7. Comparison

The two optical systems are optically equivalents, both are diffraction limited and reach the main optical design requirements: the radiation is focused on ~100 micron of the Airy Disk and it is contained in ~300 microns as required.
In Tab. 10 tolerances comparisons are summarized.

TAB 10: Sensitivity and tolerances data of optical systems analyzed

Sensitivity		
	System 225 mm	**System 325 mm**
Tolerance in a collimated rays		
Mirror M1 tilt (deg)	0.010° (1.75 mrad)	0.0065° (0.11 mrad)
Distance M1-M2 (mm)	-0.18, +0.25	-0.55, +0.65
Refocusing (mm)	± 5	± 7
Tolerances with non collimated rays		
Source divergence limit with a diffraction limited system (mrad)	0.1	0.16
Refocusing (mm)	10	15
Source divergence limit with not diffraction limited system (mrad)	1	1
Refocusing (mm)	190	170

8. Conclusions

The feasibility study of an optical system to concentrate and to focalize the synchrotron beam for PRESS_MAG_O has been studied. This report describes the study of a collector with two different configurations, to merge the optical and mechanical requirements, obtaining performances that are in agree with the opto-mechanical constrains.
The study shows that the two systems are compliant with the optical requirements. The final solution has to be chosen in base on mechanical constrains, as for example to facilitate the alignment procedures and the accommodation on experiment tube. In particular in the second configuration are simpler positioning and alignment procedure because of mechanical constrains.

9. Acknowledgements

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10. References

(1) V.V. Strunzhin, R.J. Hemley and H. Mao, J. Phys: Cond. Mat. **16** (2004) S1071-S1086.
(2) D. Di Gioacchino, P. Tripodi, A. Marcelli, M. Cestelli Guidi, M. Piccinini, P. Postorino, D. Di Castro, E. Arcangeletti, J. Phys. Chem. Solid **69** (2008) 2213-2216.
(3) P. Dore, A. Nucara, D. Cannavo', G. De Marzi, P. Calvani, A. Marcelli, R.S. Sussmann, A.J. Whitehead, C.N. Dodge, A.J. Krehan and H.J. Peters, Appl. Opt. **37**, (1998) 5731.
(4) M. Cestelli Guidi, M. Piccinini, A. Marcelli, A. Nucara, P. Calvani and E. Burattini, J. Opt. Soc. Amer. A **22** (2005) 2810.
(5) A. Sacchetti, M. Cestelli Guidi, E. Arcangeletti, A. Nucara, P. Calvani, M. Piccinini, A. Marcelli and P. Postorino, Phys. Rev. Lett. **96** (2006) 035503.