1. INTRODUCTION

SAD is a Cherenkov detector using silica aerogel as radiator. Silica aerogel is a porous material with structural inhomogeneities which are small compared to the wavelength of light. To look at, aerogel is rather transparent, but in the ultraviolet wavelength region the absorption is important. The refractive index of the silica aerogel used in SAD is 1.03. This gives threshold momenta for pions, kaons and protons of 0.6, 2.0 and 3.8 GeV/c respectively. SAD is consequently used for identification of rather low momentum particles in the range 0.6 - 4.5 GeV/c.

The silica aerogel detector is situated in the European Hybrid Spectrometer at the CERN Super Proton Synchrotron (SPS). It has been used in several experiments during the last few years. Section 2 describes the performance of SAD under experimental conditions. Section 3 tells the story of the detector, from the first idea to the final detector, and in Section 4 conclusions are drawn.

2. DETECTOR DESIGN AND PERFORMANCE

2.1 Detector design

SAD is part of the European Hybrid Spectrometer (EHS), which is schematically shown in Fig. 1. EHS consists of a high resolution bubble chamber (HOLEBC), which is both a target and a vertex detector, a large spectrometer composed of two magnets (M1, M2), proportional wire chambers (beam chambers, W2) and drift chambers (D1-D6), and detectors for particle identification. Charged particle identification is provided by the silica aerogel Cherenkov detector, the pictorial drift chamber (ISIS), a gas filled forward Cherenkov counter (FC) and a transition radiation detector (TRD). These detectors complement each other to a large extent and particle identification is achieved over a large momentum interval.

SAD is situated about 5 m downstream of the bubble chamber, close to the supraconducting magnet M1 (Fig. 1). It is composed of 18 identical modules.
with a total detector surface of 2.3 m$^2$. The arrangement of the 18 modules is shown in Fig. 2. The photomultipliers are surrounded by thick iron boxes to shield them from the magnetic field.

A detector module is schematically shown in Fig. 3. It has a sensitive surface of 23 x 55 cm$^2$ and an aerogel thickness between 13 and 15 cm. The volume is filled with aerogel blocks with dimensions of approximately 18x18x3 cm$^3$ and refractive index of 1.031. In general five layers of aerogel are placed on top of each other.

The Cherenkov light is collected onto two 11 cm diameter photomultipliers (PM1 and PM2, see Fig. 3) of the type RCA 8854. The photomultipliers have to be shielded from the stray field of magnet M1, which can reach 0.1 T in the region where the PM's are located. The presence of this high field seriously affects the optimisation of the PM positions and orientations. In order to make room for the rather thick and long iron cylinders around the PM's, these are placed rather far from the aerogel volume (see Fig. 3). Each group of photomultipliers is surrounded by an additional iron box (see Fig. 2).

Each group of modules was tilted somewhat towards the beam in order to optimise the geometrical acceptance and the light collection.

The reflecting surfaces of the light collection system are made from aluminized mylar 75 $\mu$m thick, attached to a frame of aluminium bars and protected by an additional layer of light tight aluminized mylar 25 $\mu$m thick. The complete detector is enclosed in a light tight box with tethlar windows. The humidity inside this volume is limited to 30 % to avoid the absorption of water by the silica aerogel.

With this construction the amount of material within the acceptance of the spectrometer is practically negligible with the exception of the aerogel itself, which represents 1.8 % of an interaction length and 5.6 % of a radiation length.
2.2 Geometrical acceptance

Fig. 4 shows the proportion of reconstructed secondary particles that go through the detector as a function of the momentum. When the particle goes very close to the edge of a module, the particle identification becomes unreliable. This also happens when several particles go through the same module. This occurs for about 35% of all particles. Removing these particles results in the useful acceptance shown as a broken line in Fig 4. For typically 40% of the reconstructed tracks with momenta below 4.5 GeV/c, SAD can contribute to the particle identification.

2.3 Light yield

The Cherenkov light yield was studied by using pions uniquely identified in ISIS. The identified pions that go through both ISIS and SAD all have momenta exceeding 2 GeV/c. The average light yield for the complete detector for $\beta=1$ particles is estimated at 7.5±0.3 photoelectrons using data from the NA22 experiment and 7.3±0.2 photoelectrons using the NA27 data (the data were accumulated during summer 1982).

In Fig. 5 and 6 the light yield is shown along the short and long sides of the modules respectively for all particles and averaged over all modules. Close to the edges of the modules the light yield is considerably lower as the particles can cross the module at an angle such that only part of the aerogel is traversed.

2.4 Particle identification

With a refractive index of 1.031 the threshold momentum is 0.6 GeV/c for pions, 2.0 GeV/c for kaons and 3.8 GeV/c for protons. The average light yield as a function of momentum is shown in Fig. 7. Also shown is the efficiency to detect a signal. SAD is useful for particle identification in the momentum region 0.6-4.5 GeV/c.
The detector has been checked using secondary particles from reconstructed photons and neutral strange particles. All particles produced a signal in the detector in accordance with expectations.

In the NA27 experiment SAD has been used to identify particles coming from charm particle decays. A relatively small fraction of these, 16% of the reconstructed tracks from charm candidates, go through SAD. Eliminating multitracks through the same module reduces the good tracks through the detector to 13%. For 57% of these tracks SAD contributes to the particle identification. A particle hypothesis is eliminated if the probability is inferior to 1%. With this criterion the wrong particle assignment is very rare, but ambiguities are frequent. These are sometimes resolved by combining the information from SAD and ISIS. In particular the number of uniquely identified kaons - an important particle in determining the identity of the charm particle - increases substantially when the information from SAD and ISIS is combined.

3. FROM IDEA TO IMPLEMENTED DETECTOR

3.1 The first discussions (1974-76)

The discussion on the construction of a general facility for physics at the CERN Super Proton Synchrotron (SPS) started around 1974 [1]. These discussions resulted a year later in a proposal to the SPS Committee [2], which was approved in the autumn 1975. The proposal described the spectrometer, the rapid cycling bubble chamber, the proportional wire chambers and the drift chambers - and the possible utilisation. To a large extent the physics was a continuation of the bubble chamber physics done at lower energies, at the CERN PS for example. Resonance production, strange particle production, diffraction and Regge physics were particular areas of interest. The study of charm particles was also mentioned, but was hardly regarded as feasible at the time. The detectors for charged particles were not described in any detail, but desired performances for a good particle identification were stated.
Particle identification in the relatively low momentum range 1-5 GeV/c has always been difficult to obtain. The detector being considered for the EHS was a high pressure gas Cherenkov detector. There were however several drawbacks with such a detector. A high pressure freon detector covering a large surface would result in a very bulky device with a lot of material for the particles to traverse.

At about the same time, solid materials with the appropriate refractive index for particle identification in this momentum interval had been developed. The most interesting material was silica aerogel [3] with which refractive indices in the interval 1.01-1.10 can be achieved. However, for low refractive indices the aerogel is very brittle and difficult to produce in any quantities.

In 1976 the construction of a silica aerogel Cherenkov detector for EHS was proposed. The detector module I originally had in mind was a neat little box with a detector surface of 15 x 15 cm² viewed by a single photomultiplier. Combining several of these modules would make it possible to cover a large surface.

Very rapidly a collaboration was formed by physicists from Brussels and Mons (Belgium) and Stockholm (Sweden) with the aim of developing and producing a silica aerogel Cherenkov detector, soon baptized SAD. Originally we considered a set of two detectors placed one after the other with refractive index 1.02 and 1.06 respectively [4]. These two detectors would complement each other very well for particle identification in the momentum interval 0.5-5.0 GeV/c. However, it was soon obvious that there were many technical problems to solve and it was not even clear that there was room in the EHS set-up for two aerogel detectors. The development work needed both for the detector itself and for the production of large quantities of aerogel made this ambitious version of the project look too large and complex for the group. We therefore concentrated on one detector only with aerogel of refractive index 1.03. This aerogel seemed relatively easy to fabricate and the threshold momenta and expected light yield looked right.
3.2 Prototype tests 1977-79

For the very small modules constructed up to now [3, 5-7], the light collection system was not at all critical. As very little was known about the optical properties of silica aerogel it was not clear how to construct the most efficient light collection system for large modules. In 1977 we therefore prepared two different light collection systems to be evaluated [8]. One had surfaces of highly diffusing material, and the other had aluminized mirrors (Fig. 8). In the diffusing box (Fig. 8a) the walls were covered with three layers of millipore filter, a white highly diffusing material. The reflectivity was typically 97% (see Appendix A1). The Cherenkov light was collected onto three 11 cm diameter photomultipliers of type RCA 8854.

In the mirror box (Fig. 8b) the light is collected by one aluminized spherical mirror in front of the two photomultipliers and by plane mirrors on the other walls. The reflectivity was measured at 80% for wavelengths exceeding 250 nm.

The aerogel volume, which had a detector surface of 18 x 52 cm², was made up of aerogel blocks of size 42 x 45 x 135 mm³ produced at Saclay.* By assembling several layers, total aerogel thicknesses of 45, 90 and 135 mm were obtained.

The two boxes were tested in a particle beam at the CERN Proton Synchrotron. Most of the data were taken with a beam momentum of 1.4 GeV/c. The boxes could be moved across the beam by remote control, and light yield spectra were collected for different aerogel thicknesses and different beam positions. The light yield for different impacts along the long side of the aerogel box is shown in Fig. 9 for the two different light collection systems. The values have been scaled to correspond to β-1 particles [8].

*Centre d'Etudes nucleaires de Saclay
With an aerogel thickness of 9 cm the number of photoelectrons for \( \beta = 1 \) particles was found to be \( 5.5 \pm 0.2 \) for the diffusing box and \( 4.6 \pm 0.2 \) for the mirror box.

The light yield for different aerogel thicknesses is shown in Fig. 10 for the diffusing box. The light yield is not a linear function of the thickness, showing the important effect of light absorption. Light yields of 5-6 photoelectrons are obtained with a good margin.

The main aim with these tests was to demonstrate that it was possible to construct efficient aerogel Cherenkov detectors with a useful area of 1000 cm\(^2\), and this was achieved with a good margin. In the process a lot had been learnt about the optical and mechanical properties of aerogel. The absorption and diffusion lengths of the aerogel had been determined as well as the reflectivity of the materials used for the different light collection systems (see Appendix A1, A2). This resulted in a very much improved confidence in the simulation programs that were now being used more systematically. These simulations showed that with relatively minor modifications of the mirror light collection system rather important gains in light yield could be obtained.

In 1978 two new prototype modules were ready to be tested. Two important modifications, common to both modules, were made. In the EHS set-up the photomultipliers would be situated in a magnetic field which could be as large as 0.1 T. To allow rather thick iron cylinders to surround the photomultipliers in order to shield them from the magnetic field (see Appendix A3), the distance between the photomultipliers had to be increased substantially. For the same reason the photomultipliers had to be moved away from the focusing light collection system [9]. These modifications made the light collection less efficient.

In order to improve the sensitivity of the photomultiplier the voltage between the cathode and the first dynode was increased to 1440 V compared to 670 V recommended by the manufacturer. This should increase the sensitivity of the photomultiplier with 25-30% [10] (see Appendix A4).
The tests of the box with the diffusing light collection system confirmed the results obtained earlier. The two modifications resulted in practically no change in the measured light yield.

For the box with the mirror light collection system, two different types of mirrors were tested. One set of mirrors was produced by evaporating aluminum onto a plexiglass support. The reflectivity was measured at around 80%. The other set of mirrors was made of 50 μm thick aluminized mylar. For wavelengths larger than 250 nm the reflectivity was measured at around 90%. The aluminized mylar showed that it was superior for several reasons:

i) the higher reflectivity resulted in a larger light yield,
ii) it represented very little material in the beam,
iii) it was very easy to handle.

The fact that the aluminized mylar was so easy to work with proved to be of great importance. A large number of slightly different mirror configurations were tried. The most important parts of our Cherenkov detector kit turned out to be a few scissors, a roll of aluminized mylar and some cardboard. The most successful mirror configuration is shown in Fig. 11, and the light yield is shown in Fig. 12. The average number of photoelectrons for β=1 particles is 6.4 ± 0.7 for 9 cm of aerogel with refractive index 1.03 [11]. These results were clearly the best obtained up to now. The fact that the mirror box only needed two photomultipliers against three for the diffusing box also spoke in its favour. We therefore proposed the construction of SAD modules with mirror light collection system for the EHS [12].

Fig. 13 demonstrates the effect of diffusion and absorption in silica aerogel. Two laser beams are sent through the aerogel from the right. The decrease in beam intensity as well as the important diffusion of the light can easily be seen. These effects are much more important for the blue light (the top beam, wavelength = 458 nm) than for the red (the bottom beam, wavelength = 633 nm) [13].
3.3 The final detector, 1980

The final module (Fig. 3) looked very much like the one last tested. However, as the majority of the particles would hit the aerogel furthest from the photomultipliers, the mirrors were slightly changed to give higher efficiency for those particles.

It took about a year and a half to produce the 18 identical modules, the support and the shielding for the magnetic field. All the iron around the photomultipliers had not only affected the light collection efficiency and the optimization of the modules but also the support for the modules. The whole construction had to become very strong and rigid.

For the rather large quantities of silica aerogel needed for this detector and for other detectors under development, the aerogel production had to become more industrialized [14]. For this detector more than 300 l of aerogel was needed*.

All 18 modules were tested in a particle beam at the CERN PS. The light yield was determined both as a function of position and angle of impact. An example of measured light yield along the long side of a module for different impact angles is shown in Fig. 14. The light yield distribution for the 18 modules (for β=1 particles) is shown in Fig. 15. The majority of the boxes have a light yield in the range 9-12 photoelectrons. The average value is 10.6 photoelectrons [15, 16]. The aerogel used for the final detector seemed more transparent than the one used earlier. This was probably the main reason for the improved light yield. The careful construction of the light collection system also contributed to the improvement.

* The aerogel was produced at the University of Lund
3.4 Use in experiments 1981-84

In the modified EHS set-up used for the so-called running-in experiment, there was no room for SAD. The installation therefore started at the end of 1980 and was finished in the beginning of 1981. Fig 16 shows a photograph of SAD in the EHS set-up taken from the back. The photograph on Fig. 17 shows the front of the lower half of the detector.

Since 1981 SAD has been used in the diffraction experiment NA23, the strange particle experiment NA22 and the two phases of the charm experiment NA27 (360 GeV/c incident π− and proton respectively) [17]. In certain momentum intervals SAD can fully identify the particles. There are often ambiguities, however, which are sometimes resolved by combining the information from SAD and ISIS. ISIS is used for identification of particles with momenta exceeding around 3 GeV/c [18].

As an example of how SAD can be used in the charm experiment [19, 20], we have chosen a neutral particle seen to decay into four charged particles in the bubble chamber. Three of the tracks go through the spectrometer. Their identification in SAD and ISIS is shown in Table 1. The -1.1 GeV/c track does not go through ISIS, and SAD identifies the particle as either an electron or a pion. For the -6.6 GeV/c track SAD does not give any useful information as the momentum is too high. ISIS does however identify the particle as a pion. The 3.0 GeV/c can be either a pion or a kaon according to SAD, and either a kaon or a proton according to ISIS. Consequently the particle is identified as a kaon.
Table 1. SAD and ISIS identification of three tracks coming from a neutral four prong decay

<table>
<thead>
<tr>
<th>$p$ (GeV/c)</th>
<th>SAD</th>
<th>ISIS</th>
<th>SAD+ISIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>-1.1</td>
<td>e/π</td>
<td>-</td>
<td>e/π</td>
</tr>
<tr>
<td>-6.6</td>
<td>e/π/K/p</td>
<td>π</td>
<td>π</td>
</tr>
<tr>
<td>3.0</td>
<td>π/K</td>
<td>K/p</td>
<td>K</td>
</tr>
</tbody>
</table>

The event was fitted as a

$$D^0 \rightarrow K^+ [π^+] π^- π^-$$

with a $D^0$ lifetimes of $2.2 \times 10^{-13}$ s.

The momentum of the $π^+$ was not measured.

### 3.5 Aerogel degradation

The light yield that we observe for SAD in EHS is clearly lower than what was observed earlier in a test beam. Fig. 18 shows the relative light yield as a function of time. It has decreased with 30% over three years. The annual decrease is now about 6%. We believe this decrease in light yield to be due to changes in the light transmission in the aerogel because of water absorption. We tried to limit this effect by maintaining the humidity of the air inside the detector at 30%.
4. **SUMMARY**

SAD was installed as planned in the EHS area. It did in fact perform better than was expected when the project started. SAD has been used in several experiments, and during this time no hardware failures have occurred.

Even though SAD is not a particularly complex detector, it still took rather long from the first idea until the detector was fully implemented. As usual the first stage was dominated by optimism. The limitations did not seem important and we wanted to go for a complete and rather complex detector system.

When we realised the complications we concentrated on a feasible but still interesting project. The move towards a realistic project fortunately started early and was very fast.

It was very soon clear that there were numerous additional investigations that had to be done in order to produce an optimized detector. The most important of these were:

- understanding the optical properties of aerogel
- understanding the effect of different reflecting materials
- optimization of the photomultiplier voltage
- shielding of the photomultipliers

In 1976 the idea to construct an aerogel detector was first presented at an EHS workshop. In 1981 the detector was installed and ready to take data. During these five years the physics interest had changed. The study of charm particles had the highest priority and EHS was modified in order to optimize it for the new situation.

It took an additional three years before physics results appeared - thus a total of eight years from detector idea to physics publications. Now the SAD people do it with charm.
ACKNOWLEDGEMENTS

The people who have worked on different aspects of the SAD project are numerous. Without their dedicated work this detector would never have seen the light of day.

APPENDIX

A1 Mirror reflectivity

The reflectivity of the light collection system is an important parameter in the optimisation of the detector. Several reflecting materials were tried and those found optimal for this detector were aluminized mylar for the mirror box and millipore for the diffusing box. Fig. A1 shows the measured reflectivity for these materials as a function of wavelength. One notices that at short wavelengths the reflectivity decreases rapidly.

A2 Light transmission

The measured diffusion and absorption lengths for the silica aerogel are shown in Table A1 for different wavelengths.

Table A1. Diffusion and absorption lengths in silica aerogel.

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>Diffusion length (mm)</th>
<th>Absorption length (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>365</td>
<td>5.5</td>
<td>210 ± 50</td>
</tr>
<tr>
<td>400</td>
<td>7.8</td>
<td>270 ± 42</td>
</tr>
<tr>
<td>500</td>
<td>18</td>
<td>625 ± 93</td>
</tr>
<tr>
<td>550</td>
<td>25</td>
<td>635 ± 100</td>
</tr>
<tr>
<td>600</td>
<td>33</td>
<td>530 ± 100</td>
</tr>
</tbody>
</table>
Both the diffusion and absorption increases rapidly with decreasing wavelength.

Taking into account the Cherenkov light production, the optical properties of both the silica aerogel and the light collection system and the response of the photomultipliers, results in a contribution to the signal for the mirror box as a function of wavelength as shown in Fig. A2. The main contribution comes from Cherenkov light of wavelength 250-450 nm.

A3 Magnetic shielding

Many of the photomultipliers would be situated in a magnetic field as high as 0.1 T. As the field should be inferior to $10^{-4}$ T for the photomultipliers to work efficiently, an efficient shielding is crucial.

Measurements on several scaled down shielding configurations have been done. The final shielding arrangement consists of three parts [9]:

i) each group of 4 or 10 photomultipliers was surrounded by a large iron box with a thickness of 10 or 20 cm,

ii) inside this box each photomultiplier was surrounded by a 54 cm long and 2 cm thick iron cylinder,

iii) nearest to the photomultiplier was a cylinder made of a high permability material, Anhyster.

With this shielding the photomultiplier efficiencies were not affected even at the highest field values, namely with an M1 peak field of 3 T and an undisturbed stray field in the region of the photomultipliers of around 0.1 T.
A4. Photomultiplier optimisation.

The photoelectron collection efficiency of the photomultiplier depends on the voltage between the cathode and the first dynode. The measured light yield as a function of this voltage is shown in Fig. A3 for the photomultiplier of type RCA 8854. The value recommended by the manufacturer is 670 V. Increasing this voltage to 1440 V resulted in a gain in light yield of 25–30%. We have not observed any negative effects of running the photomultipliers with this increased voltage.
REFERENCES

1. W. Allison et al. The advantages of a rapid cycling bubble chamber for physics at the SPS energies, CERN/SPSC 74-45.

2. CERN-Orsay-Rutgers-Stockholm Collaboration: A proposal to study multihadron events involving identified particles in high-energy interactions, CERN/SPSC/75-15.


19. M. Aguilar-Benitez et al., Proposal to measure accurately the lifetime of $D^0$, $D^\pm$, $F^\pm$, $\Lambda_c$ charm particles and to study their hadronic production and decay properties, CERN/SPSC 81-86.

FIGURE CAPTIONS

Fig. 1 The NA27 configuration of the EHS. M1 and M2 are spectrometer magnets, W2 is a proportional wire chamber, SAD is the silica aerogel Cherenkov detector, ISIS is the pictorial drift chamber and D1-D6 are drift chambers.

Fig. 2 The arrangement of the 18 identical SAD modules. The photomultipliers are surrounded by iron boxes to shield them from the magnetic field.

Fig. 3 A schematic view of a SAD Cherenkov module. The mirror light collection system is made of aluminized mylar. PM1 and PM2 are 11 cm diameter photomultipliers.

Fig. 4 The fraction of reconstructed tracks in NA27 that go through SAD as a function of the momentum. The full line represents all the tracks through SAD and the broken line those with only one track per module and which should go through the efficient part of the module.

Fig. 5 The average light yield for all boxes and all particles along the 23 cm side - the short side - of the modules.

Fig. 6 The average light yield for all boxes and all particles along the 55 cm side - the long side - of the modules. The beam position is measured from the edge of the aerogel situated furthest from the photomultipliers.

Fig. 7 Detection efficiency and number of photoelectrons as a function of momentum for pions, kaons and protons. The number of photoelectrons for $\beta = 1$ particles is 7.5.

Fig. 8a Schematic description of the diffusing box. The detector is viewed by the three photomultipliers of the type RCA 8854 (11 cm diameter).
Fig. 8b Schematic description of the mirror box. The detector is viewed by two photomultipliers of the type RCA 8854 (11 cm diameter). The spherical mirror has a radius of 80 cm.

Fig. 9 The yield $n_e$ of photoelectrons for 9 cm of aerogel as a function of beam impact along the long side of the module for $\beta = 1$ particles. The beam position is measured from the edge of the aerogel situated furthest from the photomultipliers.

a) the diffusing box
b) the mirror box
The lines indicate the expectations from Monte Carlo simulations.

Fig. 10 Variation of the photoelectron yield with the aerogel thickness for the diffusing box. The points correspond to $\beta = 1$. The curve gives the results of the simulation calculation.

Fig. 11 Cherenkov module with a mirror light collection system made of aluminized mylar. Two beam orientations are indicated.

Fig. 12 Total light yield for the module shown in Fig. 11 as a function of beam position. The full circles correspond to the beam entering at right angle, the open circles correspond to a turn of the module with $10^\circ$ (see Fig. 11).

Fig. 13 Photograph of a piece of aerogel measuring 3 x 18 cm$^3$. Two laser beams are sent through the gel from the right. One blue (top, $\lambda = 458$ nm) and one red (bottom, $\lambda = 633$ nm).

Fig. 14 Light yield as a function of beam position for different angles of incidence. The points correspond to $\beta = 1$.

Fig. 15 Average number of photoelectrons for the 18 modules scanned over the whole detector surface.

Fig. 16 Photograph of the SAD detector installed in the EHS. The detector is seen from the back.
Fig. 17 Photograph of the front of the lower half and part of the upper half of SAD.

Fig. 18 The relative light yield for SAD as a function of time. The value for May 1980 corresponds to 10.6 photoelectrons.

Fig. A1 Measured reflectivity for aluminized mylar (full line) and millipore (broken line) as a function of wavelength.

Fig. A2 Contribution to the signal in arbitrary units as a function of wavelength for the mirror box.

Fig. A3 Relative light yield as a function of the voltage across the cathode and the first dynode. The light yield is set to 1 at the voltage recommended by the manufacturer (670 V).
Fig. 2
Fig. 3
Fig. 4
TOP VIEW

SIDE VIEW

cylindrical mirror

Distances in mm.

Fig. 8a

spherical mirror cylindrical mirror

cylindrical mirror

Distances in mm

Fig. 8b
Fig. 9a

Fig. 9b
Fig. 10
Fig. 11

beam orientations

plane mirrors

cylindrical mirror

aerogel

PM1

PM2

10 cm
Fig. 12
Fig. 13
Fig. 14
Number of modules
Fig. A1
Fig. A2
Fig. A3