An upgraded focal plane detector for the MAGNEX spectrometer

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Abstract

An upgraded and improved version of the focal plane detector (FPD) of the large-acceptance magnetic spectrometer MAGNEX is described here. The FPD consists of a tracker operating at low pressure and of a silicon detector wall. Thanks to a different geometry of the electron multiplication and induction elements, the new detector guarantees a superior signal to noise ratio, resulting in a more accurate tracking and a cleaner identification of the detected heavy ions. The new detector has been tested by using a \textsuperscript{18}O beam at an energy of 84 MeV. A description of the new FPD that pinpoints the innovation and the obtained performances is given and discussed in details.

Keywords: Magnetic spectrometer, Focal plane detector, MAGNEX

1. Introduction

Modern nuclear physics studies often require to join the advantages of the magnetic spectrometry (strong rejection factors of reaction products, zero-degree measurements, etc.) with the possibility to measure heavy ions.

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Moreover, in order to explore rare nuclear processes [1, 2, 3], modern magnetic spectrometers have grown toward large acceptance in momentum and solid angle as well as large dynamic range in mass and energy [4, 5, 6, 7]. An example of this class of devices is the MAGNEX spectrometer [8, 9, 10] installed at the INFN-LNS laboratory in Catania. Its magnetic structure, based on a vertically focusing quadrupole and a horizontally dispersing and focusing bending magnet, ensures a momentum acceptance of about 24% and a solid angle of 50 msr. The development of large-acceptance magnetic spectrometers requires more advanced Focal Plane Detectors (FPD). These have to provide not only an unambiguous particle identification, but also an accurate three-dimensional tracking of the ions trajectory downstream of the magnetic elements [11, 12, 13, 14]. The FPDs are, therefore, the heart of the modern large-acceptance magnetic spectrometers. In the present paper the upgrade of MAGNEX FPD [15] will be described. The new FPD has been developed with the aim to improve the tracking and the identification performances.

The paper is organized as follows: Section 2 describes the design of the new detector, emphasizing the new adopted solutions compared to the previous ones; Section 3 presents a detailed characterization of the new FPD response to beam generated ions; Section 4 summarizes the results and our conclusions.

2. Focal plane detector design

The MAGNEX FPD consists of two sections: a gas tracker sensitive to the energy loss of the ions and a stopping wall for the measurements of their residual energy [15]. The gas tracker is a proportional drift chamber with a total active volume of 1360×200×90 mm$^3$, divided in six sections that are six independent position-sensitive proportional counters, whereas the stopping wall, placed behind the gas tracker, is made of 57 silicon pad detectors covering an area of 1360×200 mm$^2$, see Fig. 1.

2.1. The gas tracker

The gas tracker is contained in a vacuum chamber that is isolated from the high-vacuum upstream region by a large mylar® window (220×920 mm$^2$) with typical thickness ranging from 1.5 to 6 µm, depending on the pressure filling the chamber. The active region is filled with 99.95% isobutane at pressure that ranges from few mbar up to several tenths of mbar. The use
of pure isobutane guarantees a fast drift velocity and very good operational stability, [16, 17, 18]. In order to avoid further dead layer there is no exit window, the silicon detectors of the stopping wall are therefore embedded in the gas. The FPD vacuum chamber is movable of $\pm 0.08\,\text{m}$ along the optical axis of the spectrometer to allow to translate the focal plane according to different focus conditions. In order to reduce the effect of the chromatic aberrations the FPD is tilted at an angle $\theta_{\text{tilt}}=59.2^\circ$ relative to the optical axis direction [19].

In the tracker, sketched in Fig. 1 it is possible to identify three different regions. A drift region defined by the cathode and the Frisch grid, a multiplication region which extends between the Frisch grid and the proportional wires, and an induction region which extends between the DC wires and the segmented anode.

The drift region is defined by the cathode, an aluminum plate $1200\times90\,\text{mm}^2$ large that is usually biased at voltage values ranging between -900 and -1500 V and a Frisch grid, that is made of ten gold-plated tungsten wires with a diameter of 50 $\mu\text{m}$ placed at a distance of 5 mm one from each other. In order to make as uniform as possible the electric field of the drift region

Figure 1: Sketch of the lateral view of the new MAGNEX FPD.
and to shield the inner electric field from the high voltage applied to the silicon detectors at the stopping wall [20], the active area of the tracker is surrounded by a double partition grid consisting of 41 couples of rings made of gold-plated wires.

The multiplication region is 20 mm high and is defined by the Frish grid and the plane where 10 proportional wires are located. Each of the proportional wires is 50 µm thick and is made of gold-plated tungsten. Such wires are biased to a voltage usually in the range between +500 V and +1300 V, provided by a common power supply. The ten wires are shared among the six proportional counters DC$_i$, i=1,..., 6. DC$_2$ and DC$_5$ have just a single wire while the other DCs have two proportional wires as shown in Fig. 2. An additional partition grid similar to the one used in the drift region is present with the aim to reduce the border effects of the electric field in the multiplication region.

The induction region is defined by the plane where the 10 proportional wires lay and the anode: the latter consisting of a segmented read-out plane. In Fig. 2 a bottom view of the anode is shown. The anode is divided in 6 longitudinal strips, one for each DC, being the strip corresponding to DC$_2$ and DC$_5$ 8 mm wide while the others are 16 mm wide. Each strip is further segmented in pads (221 for DC$_2$ and DC$_5$ and 223 for DC$_{1,3,4,6}$) oriented along the spectrometer optical axis, that is with an angle equal to $\theta_{tilt}$, see Fig. 2.

2.2. The silicon stopping wall

The silicon stopping wall is embedded in the gas filling the tracker to avoid further dead layers. The stopping wall is made of 57 silicon detectors arranged in 19 columns. Each detector is 50×70 mm$^2$ wide and 500 µm or 1000 µm thick depending on the range of the ions to stop. They are mounted orthogonally to the optical axis of MAGNEX in order to minimize the effective dead layer. The closest distance of the silicon detector from the active area of the tracker is 15 mm that is enough to avoid interference with the electric field of the drift region of the tracker.

2.3. The working principle

When an incident particle crosses the entrance window entering the drift region, it generates a track of ions and electrons in the gas. The presence of a uniform electric field of about 50 V/cm in the drift region makes the ions drift towards the cathode and the electrons towards the Frish grid, these last with
a velocity of about $5 \text{ cm/\mu s}$ [16]. After the Frisch grid the primary electrons enter the multiplication region, are then accelerated by the strong electric field generated by the proportional wires and the multiplication occurs. Since the gas counters work in a proportional regime, the avalanches produced close to the wires generate a signal on the wires themselves which is proportional to the energy loss of the ion in the gas. Therefore six independent measurements of the energy loss are available, one for each DC.

In addition to the signal produced on the DC wires, the electron avalanche produced close to the wires induces a charge in a given number of pads of the strip laying just above the wires. The center of gravity of the charge distribution of the pads corresponding to a given DC is extracted. The six centers of gravity are converted in horizontal position providing six independent measurements $X_i$ with $i = 1, \ldots, 6$. From them, the position of the crossing point between the ion track and the focal plane $X_f$ as well as the horizontal angle of the track $\theta_f$ is obtained. After crossing the gas tracker the ions hit the silicon detector stopping wall.

The vertical position is extracted by measuring the arrival time of the
electron avalanches in the wires taking advantage of the fact that the tracker works in a regime where the drift velocity is almost constant in the whole volume of the detector. Six vertical positions are extracted measuring the drift time of the primary electrons along in the drift region. The start signal is generated when the ion producing the track hits one of the silicon detector of the stopping wall. The six vertical positions $Y_i$ with $i = 1, \ldots 6$ are used to obtain the vertical position $Y_f$ on the focal plane detector and the angle $\phi_f$ of the ion track. The 57 silicon detectors of the stopping wall, in addition to the start signal for the drift time measurements, provide also the residual energy of the ions that is used mainly for identification purposes.

Thanks to the very small dead layer, almost entirely due to the mylar® window, the energy threshold for the detection of charged particles crossing the FPD is about 0.5 MeV/u.

3. Detector Performances

The FPD was tested with a $^{18}$O beam delivered by the tandem MP at INFN Laboratori Nazionali del Sud in Catania, Italy, at an energy of 84 MeV impinging on thin gold and carbon targets. The interaction between the beam particles and the target took place in the center of the MAGNEX scattering chamber. The angle between the optical axis of the spectrometer and the beam direction is named $\theta_{opt}$. The spectrometer worked in full-acceptance mode which means an angular range $\theta_{lab} < (\theta_{opt} - 5.2^\circ) < \theta_{lab} < (\theta_{opt} + 6.3^\circ)$ [21, 22]. Two collimators were installed upstream the target in order to limit the spot size and angular divergence of the beam at the target position to 1.78 mm $\times$ 1 mrad in the horizontal direction and 2.8 mm $\times$ 1.2 mrad in the vertical one. In some of the runs a multi-hole collimator was placed 206 mm downstream the target in order to select ejectiles with well defined trajectories. The multihole collimator has 65 circular holes with a diameter of 1 mm, arranged in five rows 11.5 mm spaced and 13 columns 3 mm spaced. The ions coming from the target which enter in the spectrometer acceptance were momentum analyzed and focused on the FPD. The FPD was filled with isobutane C$_4$H$_{10}$ at a pressure of 15 mbar. In the following section we will analyze the main characteristics of the FPD, that is the resolution of the energy lost in the gas; the angular resolution; the position resolution, and the particle identification performances.
3.1. Energy loss measurements

Even if the energy loss measurement of the new FPD is based on the same principles as the old one Ref. [15], some difference is present. In fact the old FPD was composed of five drift chambers, but, usually, only the central one, the largest, was used to measure the energy loss $\Delta E$. In the present FPD, there are six independent drift chambers with comparable active volume ($\text{DC}_1$, $\text{DC}_2$, $\text{DC}_3$, $\text{DC}_4$, $\text{DC}_5$, $\text{DC}_6$). The total active volume of the six drift chambers is larger than the volume of the single drift chamber used in the old FPD for the $\Delta E$ measurement. This fact ensures higher charge collection and therefore a better energy resolution for the new FPD, in the same ionization conditions.

Before making any further consideration on the $\Delta E$ measurements we have to underline that the FPD of a large-acceptance spectrometer should be designed to measure trajectories with very different incident angles $\theta_f$ and therefore with different effective lengths inside the FPD itself. In the case of MAGNEX the FPD is tilted of $\theta_{\text{tilt}}=59.2^\circ$ relative to the central trajectory, and $\theta_f$ (angle in the dispersive direction) ranges between a minimum value of 40° and a maximum value of 72°.

Therefore the linear length of the trajectory inside the active volume of the FPD can range from about -35% up to about +65% of the central trajectory. The contribution coming from the non-dispersive direction is almost negligible since the angle in $\phi$ ranges from -2° to +2° [12].

As a consequence the $\Delta E$ measurement is corrected for the effective thickness and normalized to the energy loss of the reference trajectory angle $\theta_{\text{tilt}}=59.2^\circ$. Therefore we introduce the quantity $\Delta E_{\text{corr}}$:

$$\Delta E_{\text{corr}} = \Delta E \frac{\cos \theta_f}{\cos \theta_{\text{tilt}}}$$  \hspace{1cm} (1)

To evaluate the effectiveness of this correction procedure the elastic scattering of $^{18}$O beam at 84 MeV on a 122 $\mu$g/cm$^2$ thick gold target was used. The FPD was working with 99.95%-pure isobutane gas at a pressure of 15 mbar. The voltage applied to the cathode and wires were -1000 V and +720 V respectively. The effect of such a correction is shown in Fig. 3. In the left panel $\Delta E$ as a function of $\theta_f$ is shown and it is evident the dependence of the measured energy loss from the horizontal incident angle $\theta_f$. In right panel, where $\Delta E_{\text{corr}}$ as a function of $\theta_f$ is shown, the dependence of the energy on the angle $\theta_f$ is removed as expected. It is, therefore, evident that a
precise measurement of the angle \( \theta_f \) is not only important for reconstruction purposes but it is also critical for identification purposes using the \( \Delta E-E \) technique.

Border effects for the charge-collection efficiency are known to be present in particular at the entrance and exit of the FPD, where the electric field could be not uniform. Such non uniformity can worsen the tracking performances and generate a dependence of the collected charge from the \( y \)-coordinate. In order to mitigate such effects the voltage of the partition grid in the electron multiplication region was varied looking for the achievable best condition. The change of the energy channel for different values of the partition grid potential, all other parameters being equal, is shown in Fig. 4 where \( y \) vs \( \Delta E_{\text{corr}} \) is plotted for DC\(_1\) (example of a border DC) and DC\(_3\) (example of a central DC). Different colors correspond to different bias applied to partition grid potential. For the case of the central DC\(_3\) there is no effect, for DC\(_1\) there is a strong effect that reduces the amplitude of the energy loss signals and virtually removes the dependence on the \( y \) coordinate.

In order to study the intrinsic resolution of the energy loss (\( \Delta E \)) measurement, the elastic scattering data collected with the multiple hole collimator were analyzed. Moreover, the events corresponding to each hole of the collimator were selected with a condition in \( \theta_f \) (\( \Delta \theta_f < 2 \) mrad) and \( y \) (\( \Delta y < 2 \) mm) in order to remove the dependence on the ion trajectory. While the FWHM of the \( \Delta E_{\text{corr}} \) distribution for each single DC\(_i\) was about 10\%, the
overall resolution obtained by summing all the energy measured by the six
DCs is about 5%. The total energy here considered is given by

$$\Delta E_{\text{tot}} = \Delta E_{\text{corr}1} + \Delta E_{\text{corr}2} + \Delta E_{\text{corr}3} + \Delta E_{\text{corr}4} + \Delta E_{\text{corr}5} + \Delta E_{\text{corr}6}$$

The result does not depends significantly on the particular value of $\theta$ and $y$.

An example of such calibrated energy spectrum is shown in Fig. 5.

3.2. Particle identification

In this section the particle identification procedure and typical results for
the new MAGNEX FPD are shown. The data were taken using a $^{18}$O beam
at 84 MeV impinging on a 238 $\mu$g/cm$^2$ thick $^{12}$C target. The spectrometer
was set at $\theta_{\text{opt}}=10^\circ$.

In Fig. 6 the energy lost in the drift chamber corrected for the incident
angle ($\Delta E_{\text{corr}}$) versus the residual energy $E_{\text{res}}$ measured by one of the silicon
detectors is shown. The different loci correspond to different values of the
atomic number $Z$.

In Fig. 7 the position on the FPD $X_f$ versus the residual energy $E_{\text{res}}$ in
one of the silicon detectors is shown. In this plot ions with the same $Z$ gather
on lines with the same slope, larger (smaller) slopes correspond to larger
(smaller) $Z$. Ions having same $Z$ but different masses can be identified as lines
with the same slope but shifted at smaller (larger) $X_f$ value for low (high)
masses. This is the result of the relationship between the kinetic energy (related to the parameter $E_{res}$) and the magnetic rigidity (related to the parameter $X_f$) of the charged particles traversing a magnetic spectrometer. This identification technique has been reported in details in Ref. [23]. These lines can be transformed in vertical lines using a rotation in the plane $X_f - E_{res}$ as shown in Fig 8. After the rotation, the loci corresponding to oxygen isotopes with charge state $8^+$ are selected, thus a cut on $X_f$ is performed and, eventually, they are projected on the x-axis (Fig. 9). From this figure the mass resolving power of the FPD can be determined; it is defined as $R = M/\Delta M$, where $M$ is the mass of the central peak and $\Delta M$ is the FWHM of such peak. For example for oxygen ions the resolving power, in this specific working conditions, is $M=1/136$, as shown in Fig. 9.

3.3. Position and angle measurements in the dispersive direction

The position along the horizontal direction is determined by means of the distribution of charge induced on the pads. The number of hit pads is usually between 5 and 25 depending mainly on the incident angle of the ion $\theta_f$ and its energy loss. A generalization of the center of gravity method [24]
Figure 6: Typical $\Delta E_{\text{tot}} - E_{\text{res}}$ plot for single silicon detector. Loci of isotopes from carbon to magnesium are well separated.

Figure 7: Typical $X_f$ vs $E_{\text{res}}$ plot for a single silicon detector.
Figure 8: $X_f$ vs a function of the residual energy and the position on the focal plane $f(E_{\text{res}}, x_f)=E_{\text{res}} - (a \times x_f^2 + b \times x_f + c)$ for oxygen ions. It is possible to identify ions with different charge states: $6^+, 7^+, 8^+$. 
is used to extract the centroid of the charge distribution as discussed in Refs. [25, 15].

The position resolution has been estimated using the multi-hole collimator. Several effects can influence the estimate of the position resolution like: the size of the collimator holes, the beam-spot size, multiple scattering in the detector itself, and straggling in the entrance window. These effects can be partially compensated by considering the difference between two coordinates as, for example, $X_i - X_3$ instead that a single coordinate $X_i$. $X_3$ was chosen as reference wire since, being a central drift chamber, it is less sensible to border effects that could affect the edge drift chambers.

In Fig. 10 the angle $\theta_f$ versus $X_3 - X_4$ is shown after a gate on the elastic scattering was applied. Each spot of the plot corresponds to a bunch of trajectories passing through the same hole having a given average angle $\theta_f$ at the focal plane As $\theta_f$ increases the $X_3 - X_4$ distribution of each spot becomes broader.

For each spot of Fig. 10 a narrow gate of 2 mrad in $\theta_f$ was applied and the position distributions of all the $X_i$ variables where obtained. Such angular
spread corresponds, for example, to a position spread of about 0.12 mm at $\theta=40^\circ$ and 0.65 mm at $\theta=72^\circ$. This geometrical contribution to the overall width of the position distribution is shown in Fig. 11 as a continuous line for all the $X_i$, while points correspond to the experimental FWHM measured at each angle. The horizontal resolution $X_i$ was estimated for all the wires. No significant difference between different $DC_i$ was found. The final resolution is estimated to be around 0.6 mm for each wire.

All the coordinates $X_i$, $i=1,\ldots,6$ are used, together with the longitudinal coordinates $Z_i$, $i=1,\ldots,6$ for the definition of the horizontal angle $\theta_f$. The use of six points guarantees a better precision compared to the previous FPD that used just four points.

The plot of measured $\theta_f$ is shown in Fig. 12. Each peak in the plot corresponds to trajectories passing through one of middle-raw hole of the multi-hole collimator. The difference in counts for each peak is due to different cross section of the elastic scattering at different angles.

The method used to estimate the angular resolution is described in detail in the following. The first step consists in selecting a group of trajectories by applying a gate on the first and the last DCs, (i.e. DC$_1$ and DC$_6$). The
Figure 11: Horizontal resolution (FWHM) as a function of the angle $\theta_f$. The lines represent the geometrical contribution to the resolution due to the selected angle.
trajectories are selected with an average \( \theta_f \) value of 1000 mrad and a FWHM of 3.2 mrad.

In the second step the trajectory of the events selected in the first step are extracted, using the \( X_i \) obtain from the other four DCs, thus excluding \( X_1 \) and \( X_6 \). The angular distribution of such events has a spread of 3.9 mrad (FWHM), taking into account the initial spread of selected trajectories it is possible to extract a value for the \( \theta_f \) resolution of the tracker of 2.2 mrad (FWHM). The resolution here extracted should be considered as an upper limit of the actual \( \theta_f \) resolution, since the resolution of the full tracker is done using six X-positions for each events instead of the previous four X-positions we were using for the \( \theta_f \) resolution estimation. The resolution here obtained is much better than the previous detector, where 5 mrad (FWHM) was obtained using a similar procedure.

### 3.3.1. The cross-talk effect

A phenomenon present in the old FPD that affected the horizontal position measurements of the ion track is the cross-talk [25]. In fact, the electron avalanche produced by a given proportional wire can induce a charge also
Figure 13: Schematic representation of the induction signal formation in the regions of DC4, DC5, and DC6 multiplication wires. The areas of the main charge induction are denoted with the filled contours, while the areas denoted with the dotted contours correspond to the cross-talk induced signal.

in pads corresponding to a neighboring wire. Therefore, the resulted charge distributions measured for a given wire may be distorted affecting the final determination of the \( X_i \) coordinate.

In order to mitigate this problem some modification in the new FPD design was required. The geometry of the wires and strips was changed making the average distance between two adjacent strips larger than the distance between each wire and the corresponding strip. The segmented strips were separated from each other by a 2 mm spacer as shown in Fig. 2.

We briefly describe the adopted procedure for estimating the cross-talk induced signal on DC5 strip for a typical event, the same procedure can be extended for the other DCs. As a first step, the measured induced charge distributions of DC4 and DC6 wires were fitted each by a Gaussian function. Since DC4 and DC6 are composed by two wires each (see Fig. 2) the charge distribution was decomposed into two internal Gaussian curves, each one describing the induced charge of each wire. Then, having determined the height \( A \), the centroid (mean value) and the standard deviation \( \sigma \) of the distributions, each one was further decomposed into two Gaussian functions.
with:

\[ A_a = A_b \approx A/2 \]  \hspace{1cm} (2)

\[ \sigma_a = \sigma_b \approx \sigma \]  \hspace{1cm} (3)

where, \( A_a, A_b \) are the heights and \( \sigma_a, \sigma_b \) are the standard deviations of the two Gaussian functions. These so called “internal” Gaussian functions are associated to the signal originating the induced charge of each of the two wires composing DC\textsubscript{4} and DC\textsubscript{6}, namely, DC\textsubscript{4a}, DC\textsubscript{4b}, DC\textsubscript{6a} and DC\textsubscript{6b}. In the last step of the analysis, the DC\textsubscript{4b} and DC\textsubscript{6a} distributions were superimposed to the measured induced signal of DC\textsubscript{5} and were renormalized such as to describe the shape of the distribution. The results of the charge distribution analysis for DC\textsubscript{5} for a single elastic scattering event with \( \theta_f \approx 62^\circ \) are presented in Fig. 14. It is evident that the distortion in the shape of the charge distribution caused by the cross-talk is small. In addition, the amplitude of cross-talk signal is well-below the level of the threshold, which was determined through an iterative procedure by means of the optimized Center Of Gravity (COG) algorithm \[25\]. Therefore, we may conclude that the cross-talk phenomena are under control.

3.4. Vertical position and angle measurements

The Y resolution has been calculated plotting \( Y_3 \) versus the difference \( Y_1 - Y_2 \) shown in Fig. 15. The five spots correspond to the particle passing through each of the five vertical rows of holes of the multi-hole collimator. The FWHM of each spot on the abscissa-projection is 0.6 mm giving a resolution of about 0.4 mm for the single CD.

The vertical angle \( \phi \) is obtained by a linear fit of the six vertical positions \( Y_1, Y_2, Y_3, Y_4, Y_5, Y_6 \) and the six coordinates \( Z_1, Z_2, Z_3, Z_4, Z_5, Z_6 \) defined by the position of the six drift chambers. That is

\[ Z_i = a_0 + a_1 Y_i \]  \hspace{1cm} (4)

where \( a_1 \) is \( \tan(\phi) \). For the estimate of the angular resolution we used the formula for the error of the parameters of a linear fit:

\[ \sigma_{a_1}^2 = \Sigma_{i=1}^{N} \left( \frac{\partial a_1}{\partial y_1} \sigma_y \right)^2 = \sigma_y^2 \frac{N}{N (\Sigma_{i=1}^{N} y_i^2) - (\Sigma_{i=1}^{N} y_i)^2} \]  \hspace{1cm} (5)
Figure 14: Charge distribution analysis for the induction pads over the DC\textsubscript{5} proportional wire. The dashed gray line corresponds to the total charge distribution collected by the induction pads over the DC\textsubscript{5} wire. The dashed green and the dashed-dotted magenta lines represent the cross-talk induced signal from DC\textsubscript{4b} and DC\textsubscript{6a} wires respectively. The solid orange line corresponds to the signal after subtracting the cross-talk contribution and the dashed black line represents the value of the threshold as it was determined using the COG algorithm [25].
where in place of $N \left( \sum_{i=1}^{N} y_i^2 \right) - \left( \sum_{i=1}^{N} y_i \right)^2$ the Y resolution have been used. The resolution $\delta \phi$ depends on the horizontal angle of the particle trajectory $\theta_f$ since this influences the actual trajectory length inside the tracker. It ranges from 0.3 to 0.7 mrad for trajectories with $\theta_f=40^\circ$ and $\theta_f=70^\circ$ respectively.

We conclude that, also in the vertical direction the position resolution as well the angular resolution are better than those of the previous detector.

4. Summary and Conclusions

The new focal plane detector of the large-acceptance MAGNEX spectrometer has been described underlining the innovative aspects relative to the previous FPD.

It keeps many characteristics of the old FPD, that is the capability to work at pressure ranging from few mbar to several tenth of mbar using a thin entrance window. This guarantees a very low detection threshold and the capability to identify particles in a broad range of ionizing condition. The main characteristics of the new MAGNEX focal plane detector and position and angular resolution obtained by using the scattering of $^{18}$O beam of 84 MeV are listed in Tab. 4.
Table 1: Main characteristics of the new FPD of MAGNEX spectrometer.

| Characteristic                        | Value  |
|---------------------------------------|--------|
| Energy loss resolution for $^{18}$O  | 5%     |
| Horizontal position resolution        | 0.6 mm |
| Horizontal angular resolution         | 2.2 mrad |
| Vertical position resolution          | 0.4 mm |
| Vertical angular resolution           | 0.5 mrad |

The new design based on the segmentation of the gas tracker in six drift chambers all of similar size guarantees better performances in terms of tracking precision. The track is now sampled in six positions to be compared to the four of the old FPD, with a consequent better position and angular resolution of the ion tracks. The energy loss the performances have been improved since a longer portion of the track in the ionizing gas is sampled compared to the previous FPD, guaranteeing an higher resolution and therefore a better identification capability. In the design of the new detector, a special care has been given to reduce the effects of the cross-talk between neighboring strips. In the new FPD the cross-talk has been minimized and its effects on the track reconstruction are now negligible.

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