Abstract: The EPHIN instrument (Electron Proton Helium INstrument) forms part of the COSTEP experiment (COm-prehensive SupraThermal and Energetic Particle Analyser) within the CEPAC collaboration on board of the SOHO spacecraft (SOlar and Heliospheric Observatory). The EPHIN sensor is a multi-element array of six solid-state detectors A to F with anti-coincidence to measure energy spectra of electrons in the range 250 keV to > 8.7 MeV, and hydrogen and helium isotopes in the range 4 MeV/n to > 53 MeV/n. The single count rates for detector E in the beginning of 1996 began to gradually increase due to detector noise and became so high that the detector had to be excluded from the coincidence logic at the end of the same year. In order to recover the lost energy ranges for protons and helium, we apply a method based on the approach of Goulding (1979). The same method has been applied in addition to improve the isotope determination of helium and an extension of the helium energy range up to more than 100 MeV/nucleon. With this new data set the modulation during the last solar minimum will be investigated.

Keywords: SOHO, EPHIN, Particle Detectors, particle identification

1 Instrumentation

The SOlar and Heliospheric Observatory (SOHO) spacecraft was successfully launched on 2 December 1995 and put into an halo orbit around the inner Lagrangean point L1 [Domingo et al.(1995)]. The EPHIN sensor is displayed in Figure 1 and is a multi-element array of solid-state detectors with anti-coincidence to measure energy spectra of electrons in the range 250 keV to > 8.7 MeV, and hydrogen and helium isotopes in the range 4 MeV/n to > 53 MeV/n [Müller-Mellin et al.(1995)]. The sensor head consists of a stack of six silicon detectors, surrounded by an anti-coincidence shield of plastic scintillator. Two passivated ion-implanted detectors (A and B) define the 83° full width conical field of view with a geometric factor of 5.1 cm² sr. Detectors A and B are divided into six segments. This coarse position sensing permits sufficient correction for path length variations needed to resolve isotopes of hydrogen and helium. Another important advantage of segmentation is the capability to implement a commandable or self-adaptive geometric factor. On detection of high count rates in the centre segment A₀, the logic will disable all but the inner circular segments of both detectors A and B, reducing the effective geometric factor by a factor of 24 to permit measurements of fluxes as high as 10⁶ counts/(cm² s sr) without significant dead time losses. The lithium-drifted detectors C, D, and E stop electrons up to 10 MeV and hydrogen and helium nuclei up to 53 MeV/n. The ion-implanted detector F allows particles stopping in the telescope to be distinguished from penetrating particles. The fast plastic scintillation detector G is used in anti-coincidence in order to reduce the background.

2 dE/dx - E method, stopping particles

The differential energy loss per path length of a charged particle with energy E, charge z, and velocity v passing through matter with electron density ne, and excitation potential I is described by the equation by the Bethe formula (relativistic form)

\[
\frac{dE}{dx} = \frac{4\pi}{m_e c^2} \frac{n_e}{\beta^2} \left( \frac{e^2}{4\pi\epsilon_0} \right)^2 \left( \ln \left( \frac{2m_e c^2 \beta^2}{I(1-\beta^2)} \right) - \beta^2 \right)
\]

In order to identify incident particles in a multi-element telescope, the dE/dx – E-method can be used. Measure-
Figure 2: \( \Delta E_A \) vs. \( E_{tot} \) for different particle species as measured by EPHIN. \( \Delta E_A \) and \( E_{tot} \) correspond to the energy loss in detector A and the total registered energy respectively (see Fig. 1).

The slight deviation at its low energy end results from the breakdown of the assumption that \( \Delta E_A \) in detector A can serve as a good approximation for \( dE/dx \), as these particles already lose a large fraction of their energy in the first detector.

3 Optimized particle identification

By plotting \( \Delta E_A \cdot E_{tot} \) over \( E_{tot}/\Delta E_A \) the distribution in Fig. 2 is rotated counter-clockwise by 45° and thus, the different particle populations arrange themselves as horizontal curves. Therefore, \( \Delta E_A \cdot E_{tot} \) (hereafter called particle identification number (PIN)) is a proxy for the particle type. Besides some instrumental effects, the resolution of the PIN and therefore the capability to differentiate between different particle types is effected by a dependence on \( E_{tot}/\Delta E_A \).

To calculate a correction for this effect, in a first step the particle populations arrange themselves as horizontal curves.

The combined distribution shown in Fig. 3 can than be used to calculate the average dependence of the PIN on \( E_{tot}/\Delta E_A \) for the considered particle types. Therefore, the fitted third order polynomial shown in Fig. 3 can be used as correction for these particles. For comparison, a histogram of PINs is shown in Fig. 4 for both, the original and the corrected data. As one can see, the correction explained above decreases the peak-widths of all three considered particle populations. This is of particular interest to distinguish between \(^3\text{He}\) and \(^4\text{He}\), as both populations superpose each other due to instrumental effects. Therefore, the decreased peak width of each particle population at unchanged distance between the peaks does improve the instruments capability to distinguish between particles.

4 \( dE/dx - dE/dx \) method

In addition to the \( dE/dx - E \) method for stopping particles, it is also possible to identify particles penetrating a whole detector stack. This identification can be done by using the \( dE/dx - dE/dx \) method. For example a particle with the unknown total energy \( E_{tot} \) coming from above penetrating all solid state detectors of EPHIN loses energy in detector A (\( dE/dx_{detA} \)). It then loses energy in detector B, but due to the energy loss in detector A, the kinetic energy of the particle has decreased, and thus the \( dE/dx \) measured in detector B is higher than \( dE/dx_{detA} \). For particles entering the telescope from behind, the same is true, only that the \( dE/dx \) increases from bottom to top. EPHIN provides four \( dE/dx \) measurements (\( E_{tot}, E_{tot} - dE/dx_{detA}, E_{tot} - dE/dx_{detB}, E_{tot} - dE/dx_{detB} - dE/dx_{detA} \)). By using these four measurements it is possible to identify the particle species up to a certain energy, as shown on Fig. 5. For particles with higher energies the identification method no longer works. Due to the behaviour of energy losses in matter \( dE/dx \) particles approaching the energy of minimal ionisation will have decreasing energy loss. This means that the total energy \( E_{tot} \) and the energy loss in the first detector, \( E_{tot} - dE/dx_{detA} \), show only a small difference, and so the \( dE/dx \) in the different detectors also show only a small difference. This means for minimal ionizing particles the \( dE/dx \) is nearly the same in every detector, and so its not possible to get information about the distance to the source (above or behind) or the exact energy of the particle.
Figure 5: Energy loss in detectors A to D vs. energy loss in detector E, using data taken during solar quiet times in January 1996.

5 Correction of noise in detector E

Detector E was designed to cover the upper energy range of EPHIN, covering electrons from 5.3 to 8.7 MeV, and protons and heavier nuclei from 42 to 53 MeV/nuc. Early in 1996 it was discovered that detector E began to get noisy, which resulted in incorrect energy loss measurements in detector E, and thus to wrong total energy measurements. Since detector E cannot provide the total energy of stopping particles anymore, we use an approach based on the methods by [Goulding et al.(1979)] to approximate the energy of particles passing detector D but not reaching the anticoincidence detector F (i.e. stopping in detector E). We choose a time interval during solar quiet times dominated by galactic-cosmic-rays (GCR) in January 2009 (see Fig. 6), to demonstrate the effect of the correction without having to take into account instrumental effects like dead-times or priority handling of species.

Figure 6: Energy loss in detectors A to D vs. energy loss in detector E, using data taken during solar quiet times in January 2009.

According to [Goulding et al.(1979)], the relation of the range R of an ion with energy E passing through matter can take the form of a simple powerlaw,

\[ R = \alpha E^\beta, \]

where \( \beta \) is a parameter which depends on the target material (\( \beta \approx 1.7 \) for Silicon), and \( \alpha \) is an independent parameter, which is proportional to \( mz^2 \) of the impinging particle. Based on this equation we can find a formula to calculate the total energy \( E_{\text{tot}} \) of an incoming particle according to

\[ E_{\text{tot}}^{i+1} = \left[ \frac{\Delta x}{\alpha} + \left( E_{\text{tot}}^i - \Delta E \right)^\beta \right]^{\frac{1}{\beta}}. \]

(3)

If the total energy \( E_{\text{tot}}^i \) of a particle is known or can be approximated, the particle type and isotope are known (i.e. \( \alpha \) is known), and the energy loss in at least one detector is known, eq. (3) can be used to iteratively determine the total energy \( E_{\text{tot}}^{i+1} \) of the particle. This means that for particles stopping in detector E, we can recalculate the total energy based on the energy loss in the previous detectors, which allows us to correct the energy loss in detector E. Since particle identification based on the faulty total energy can be erroneous as well, in each step of the iteration we additionally recalculate \( \alpha \) of the particle, based on the recalculated total energy.

Fig. 7 shows the result of the energy recalculation. The proton and Helium tracks are clearly separated again, while additionally a small fraction of particles loses more energy in detector E than before. This can be explained by the correction method overestimating the energy loss in detector E. These particles can be easily excluded from further analysis by simple cuts in the energy loss in detector E, so they don’t contribute to the creation of spectra.

Figure 7: Energy loss in detectors A to D vs. energy loss in detector E, using data taken during solar quiet times in January 2009, after the recalculation of the total energy.

6 Penetrating Helium

For particles which penetrate completely through the stack of solid state detectors separate \( dE/dx \) measurements are made. Charge resolution for penetrating particles is possible up to about 100 MeV/nucleon. Figure 8 shows the energy loss in the detector C versus the energy loss in detector D for penetrating particles. It can be clearly seen that different particle species build characteristic tracks in this diagram. Also the incident direction (from above or behind) can be identified. We used the \( dE/dx - dE/dx \) described in section 5 to identify Helium from above and from behind. As it is seen in figure 8, the separation works up
to a certain energy. For Helium coming from above this method works up to 75 MeV/nuc. For higher energies some backward particles are counted as particles from above. By using a correction method, based on a double gaussian fit perpendicular to the bisecting line in figure 8, it is possible to enhance the identification energy range of the EPHIN to 100 MeV/nuc for Helium. This multiparameter analysis reduces the background level of spurious events to a negligible level. Figure 9 shows a time profile of Helium fluxes in the energy range of 56.3 to 73.4 MeV/nuc. The flux is scaled to Carbon fluxes in the same energy per nucleon range measured by ACE/CRIS. Due to the same charge to mass ratio of Helium and Carbon, the flux modulation during the solar cycle is the same. The modulation of the Helium flux is in very good agreement with the Carbon flux. In the first area of the figure you can see an enhanced Helium flux, with respect to Carbon. This is due to Anomalous Cosmic Ray component during solar minimum.

7 Conclusion

A simple but valuable correction method for the PIN \((\Delta E_A \cdot E)\) to correct for a dependence on \(E/\Delta E_A\) was presented here. Comparison between uncorrected and corrected data has shown the improved capability to distinguish between particle species, especially between \(^3\)He and \(^4\)He, after the correction was applied.

We have also shown that using an iterative method based on Goulding et al.(1979) to recalculate the total energy of an incoming particle, we were able to correct for noise in detector E. The same approach can be adapted to particles penetrating the instrument, to distinguish the incident direction of particles and increase the energy range for Helium up to 100 MeV/nuc.

References

