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Impulsive ^{3}He-rich solar energetic particle events detected with SOHO/EPHIN*

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Abstract. We report observation of ^{3}He-rich solar energetic particles (SEP) events detected by Electron Proton and Helium Instrument (EPHIN) aboard the Solar and Heliospheric Observatory (SOHO) spacecraft. EPHIN has been detecting Helium isotopes in the energy range 4-53 MeV/n since December 1995 using a ΔE-E sensor system with solid-state detectors. In this paper we concentrate on observations of SEP with excess in the ^{3}He abundance. The abundances ^{3}He/^{4}He and ^{4}He/^{1}H have been obtained and compared among different events. Energy spectra of protons, ^{3}He, ^{4}He have been studied.

1 Introduction

Since the discovery that some small SEP events can have enhancements of ^{3}He abundance by several orders of magnitude over solar system values (Hsieh, K. C. and Simpson, J. A. , 1970), these events have been the subject of intensive study. These events which are known as impulsive because of its impulsive time profile, are different in their characteristics and their origins from larger, gradual events. Because these events are relatively small, spectral forms are difficult to investigate. Möbius et al. (1982) reported an increase in the ^{3}He/^{4}He ratio between 0.44 and 4.1 MeV/n with the energy and Mazur et al. (1995) found that the spectra extended up to 16 MeV/n. In most of the cases the energy spectra fit power law forms.

EPHIN uses a stack of silicon solid state detectors to identify electrons, hydrogen and helium isotopes using ΔE-E technique. Instrumental details of the sensor have been reported in Müller-Mellin et al. (1995).

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2 Observations

From December 1995 to December 2000 EPHIN has been observing SEP events with ^{3}He/^{4}He ratios exceeding 0.1. These events are ^{3}He-rich event are usually soft and produce measurable ^{3}He counting rates only in the more intense events or event with very high ^{3}He abundance. Sometimes the event is in coincidence with the decay of a gradual SEP event. Because of these difficulties in the data analysis we have selected thirteen ^{3}He-rich SEP events whose characteristics have been written in Table 1. Usually ^{3}He-rich events are also electron and heavy ions enriched.

Table 1. ^{3}He-rich events detected by EPHIN on board SOHO spacecraft.

Event	^{3}He onset	^{3}He/^{4}He	^{4}He/p	γ
August 10, 1997	23:02	0.29	0.27	
November 28, 1997	17:02	0.36	0.16	3.2
March 21, 1999	18:29	0.42	0.13	~ 5
March 22, 1999	19:55	16.	0.04	
May 9, 1999	20:38	0.04	0.009	
May 12, 1999	08:10	1.87	0.011	5.6
June 18, 1999	10:34	0.38	0.03	3.5
August 7, 1999	19:26	6.5	0.004	4.2
August 14, 1999	06:00	0.23	0.10	
November 1, 1999	02:38	0.87	0.22	2.1
December 24, 1999	01:26	0.68	0.01	2.9
May 23, 2000	23:02	0.31	0.073	3.9
August 22, 2000	01:12	1.46	0.11	4.9

The August 10, 1997, March 22, 1999 and August 14, 1999 events were so weak that we can not obtain ^{3}He energy spectrum in order to determine spectral index. Events with very high ^{3}He abundances are those with an absence almost complete of ^{4}He such as in March 22, 1999 and August 7, 1999 events. In the August 10, 1997 impulsive SEP (ISEP) event ^{3}He is delayed 2 hours and 12 minutes from the ^{4}He. The November 28, 1997 ISEP has 36 % ^{3}He during low beta plasma period. ^{3}He and ^{4}He arrive together. In both events, not clear source have been found.

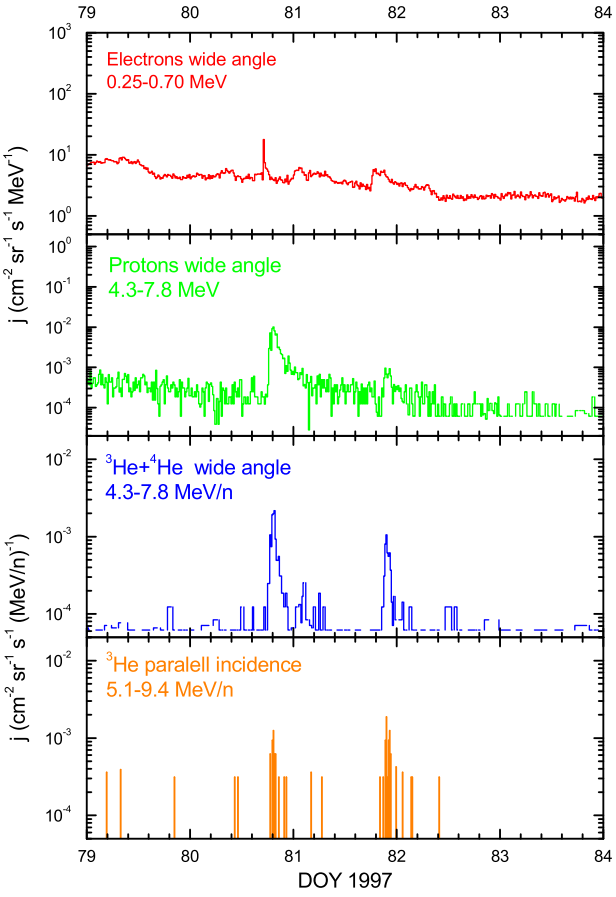

Fig. 1. Temporal profiles of electrons, protons ^{3}He and ^{4}He intensities detected with SOHO/EPHIN 5 minutes averaged of the March 21 and 22 ^{3}He-rich SEP events.

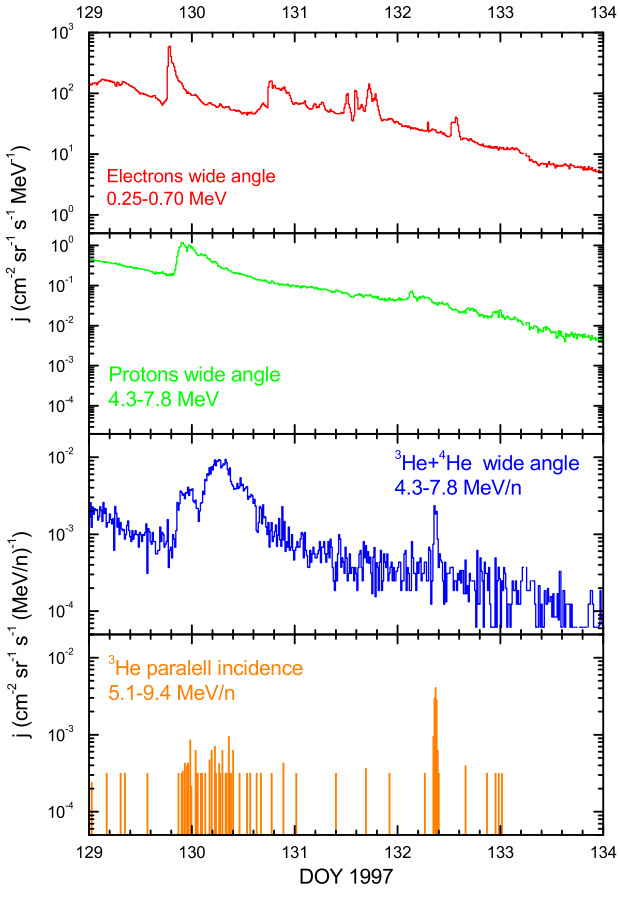

Fig. 2. Temporal profiles of electrons, protons ^{3}He and ^{4}He intensities detected with SOHO/EPHIN 5 minutes averaged of the May 9 and 12 ^{3}He-rich SEP events.

In March 1999, two ISEP events have been detected (Figure 1). Both of them were ^{3}He-rich. They were very weak and short duration (5 and 3 hours respectively). Solar Geophysical Data indicate weak type III radio bursts but no H_α nor X-ray flares have been detected. March 21 event has a 42 % ^{3}He but March 22 event has ^{3}He/^{4}He abundance ratio as high as 16 (Wiedenbeck et al., 1999). Because of the low intensity of the March 22 event we can not obtain Helium energy spectra.

In May 1999, two ISEP events account during a period of very low density in the solar wind reported by WIND spacecraft. May 9 event is in coincidence with the beginning of the density decay. The proton and Helium temporal profiles show two peaks structure. The May 12 event can not be observed in proton and electrons but is very defined in Helium with a duration of approximately 1 hour in ^{3}He and ^{4}He isotopes (Figure 2). In the May 12 event the ^{3}He/^{4}He abundance ratio is as high as 1.87 between 08:10 and 09:50 UT.

The June 18, 1999 ISEP event is observed in electron profiles as a sequence of multiple overlapping injections that are observed in the He flux as a gradual increase of the intensity. The ^{3}He energy spectra obtained is very good with high abundance ratio and low intensity of protons mainly during the firsts three electrons bursts.

The August 7 and 14, 1999 events were not observable in the protons channels. The August 7 ISEP event has very high ^{3}He/^{4}He abundance ratio with low level of electron flux. By contrast, August 14 event cause approximately 2 magnitude orders increase in the electron intensity.

November 1, 1999 ^{3}He-rich SEP event has 87 % of ^{3}He. Only weak increase in the electron intensity was correlated with this event. A hard ^{3}He energy spectrum up to 10 MeV/nucleon was obtained with spectral index higher than those of electrons and protons that were only 2.2 and 2.7 respectively.

The December 24 event accounted was associated to an heliospheric current sheet crossing with a very high peak in the density and North oriented magnetic field. This event was 2 days duration, with low intensity in all the particles detected by EPHIN. The ^{3}He energy spectrum was hard with 2.9 spectral index compared to 3.3 obtained for ^{4}He and protons and 3.6 for electrons.

During 2000 year we have selected for analysis the May 23 and the August 22 SEP events. The August 22, 2000 event seams to be really two, a first very sharp, with short duration

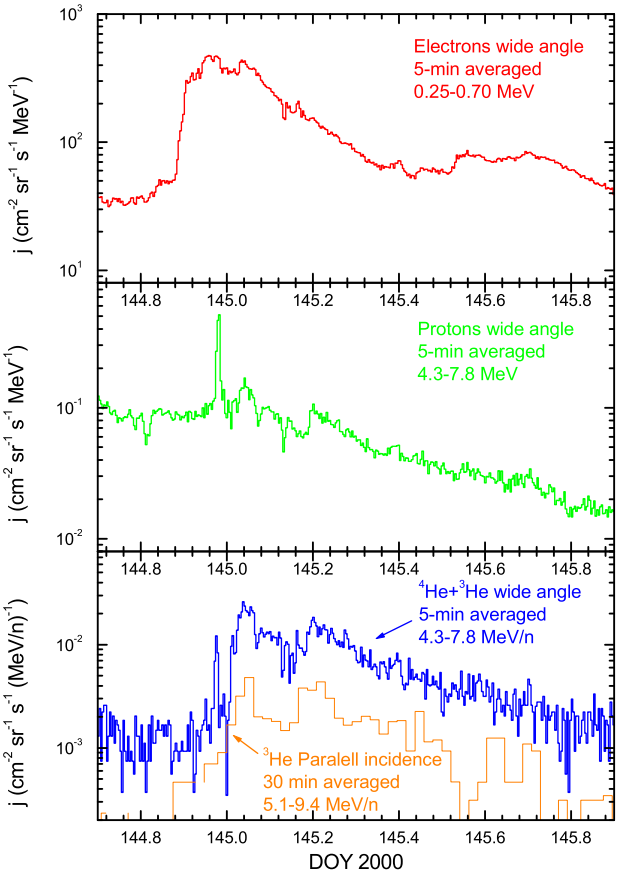

Fig. 3. Temporal profiles of electrons, protons ^{3}He and ^{4}He intensities detected with SOHO/EPHIN 5 minutes averaged of the May 23, 2000 ^{3}He-rich SEP event.

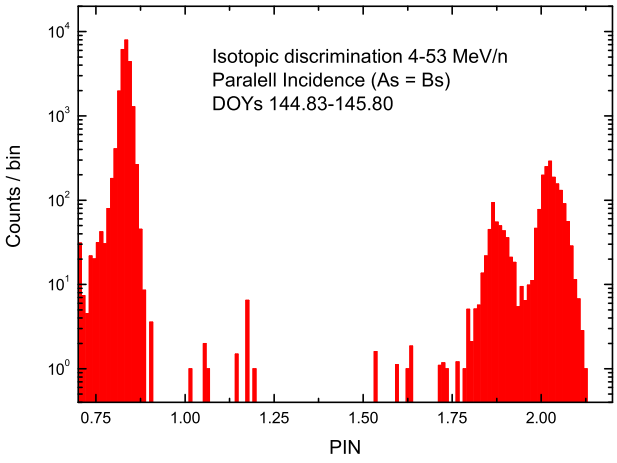

Fig. 4. Histogram showing the obtained particle identification number (PIN) of detected particles in parallel incidence during May 23, 2000 ^{3}He-rich SEP event.

in electron, proton and ^{4}He temporal profiles followed by a second one, weak in electron, proton and ^{4}He with longer duration, about 1 day, and ^{3}He rich with abundance ratio of ^{3}He/^{4}He$= 1.46$. Following we show observational features of the May 23, 2000 event.

3 The May 23, 2000 ^{3}He-rich ISEP event

Figure 3 shows electrons, protons and helium intensities 5 minutes averaged of the May 23, 2000 event. In the electron intensity the event start at 19:55 UT of the 144 day of the year 2000. The electron profiles show a double injection structure. Two hours and 38 minutes after at 22:34 UT an spike-like is observed followed by another two increases, last one was so weak in protons that it is difficult to observe. In the helium intensity spike-like increase is of lower intensity followed by two more intense and longer peaks. The event is also observed in ^{3}He but there is not spike-like increase in the ^{3}He temporal profile.

Particles detected during the May 23 SEP event, in the energy range 4-53 MeV/nucleon and parallel incidence, were identified obtaining the particle identification number (PIN) following del Peral et al. (1998). Figure 4 shows the histogram of the obtained results. The histogram contains three peaks: on the left the protons peak and on the right ^{3}He and ^{4}He peaks. The ratio of peak areas, gives the ratio of particle abundance which in this event was ^{3}He/^{4}He~ 31 %.

Figure 5 shows the energy spectra of electrons, protons, ^{3}He and ^{4}He. Fits of the energy spectra and the fits to power law with spectral index γ that were obtained very similar varying from 3.7 for electrons and protons to $\gamma = 4.0$ for alpha particles. The helium isotopes energy spectra demonstrates that abundance ratio remains constant in the energy range of detection of the EPHIN sensor.

4 Discussion

The thirteen events discussed here illustrate a variety of features of ^{3}He-rich impulsive solar energetic particle events. Some of them have multiple injection characteristics. Another are very short with only one or two hours of duration. Some event has no association to proton flux increase or electron flux increase. Most of them have not a flare that may be clearly associated as source of the event. The ions are accelerated up to a maximum energy between 10 and 30 MeV/n. The ^{3}He/^{4}He ratio varying from 0.04 to 16 and ^{3}He energy spectral index vary in a wide range between 2.1 and 5.6.

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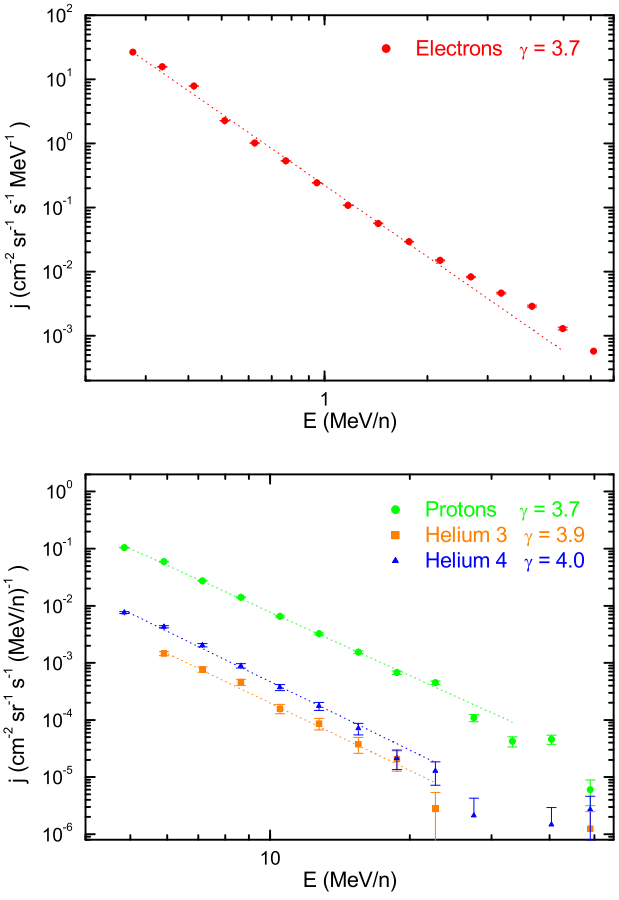

Fig. 5. Electron, proton, ^{3}He and ^{4}He energy spectra in the detection energy range of the EPHIN sensor. Dotted lines are the power law fits obtained.

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