A NORMALIZATION PROCEDURE FOR CREME96 SPECTRA

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Creme96 model is largely used to get a smooth flux of cosmic rays inside the heliosphere. We compare the results of Creme96 model with measurements of AMS-01, BESS98, and IMP-8 experiments. A normalization procedure for the period of June 1998 is also presented.

1. The CREME96 model

CREME96 (Cosmic Ray Effects on Micro-Electronics) is a code for creating numerical models of the ionizing radiation environment in near Earth orbits [1]. This model is widely used in aerospace industry for evaluating how radiation affects spacecraft electronics. Package includes models of galactic cosmic rays (GCR), anomalous cosmic rays and solar energetic particles. Model of GCR in CREME96 is based on the semi-empirical model of Nymmik et. al. [2], which rates the solar-cycle variations to the observed time-history of the Wolf (sunspot) number. Model is available across web page interface (see the web page https://creme96.nrl.navy.mil/). Creme96 can be used as quick reference also for scientific study. For this reason we are interested to evaluate uncertainty of CREME96 model for proton spectra in near Earth environment. Authors quote a mean discrepancy of the GCR model with experimental data of ~ 25% [1]. We want to test, and possibly to improve, this accuracy comparing the model with the more recent measurements.

2. Comparison with experimental data

Since few years ago GCR measurements at the Earth vicinity presented a poor accuracy. Finally in June 1998 AMS-01 [3] performed a precise measurement of GCR spectrum at an altitude of 380 *km*, with an accuracy ranging from ~ 4.5%, in the low part of the spectrum, to ~ 5.2%, at high energy. One month later

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BESS, a balloon borne experiment [4], has confirmed the spectrum of primary protons. The accuracy quoted by BESS collaboration is ~ 2.8% in the low energy part while rises to ~ 5.0% at high energy. In Figure 1 the ratio AMS-01/BESS98 proton spectrum is shown. The agreement is mostly inside 2% and is dominated by the data scatter. This agreement is still better than the combined AMS-BESS uncertainty (~ 2.4% at low energy up to ~ 3.6% at high energy), and it is a confirmation of the correct calibration of the two experiments.

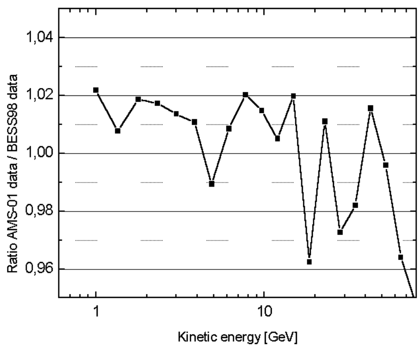

Figure 1. Ratio of AMS-01 proton spectrum / BESS98 proton spectrum.

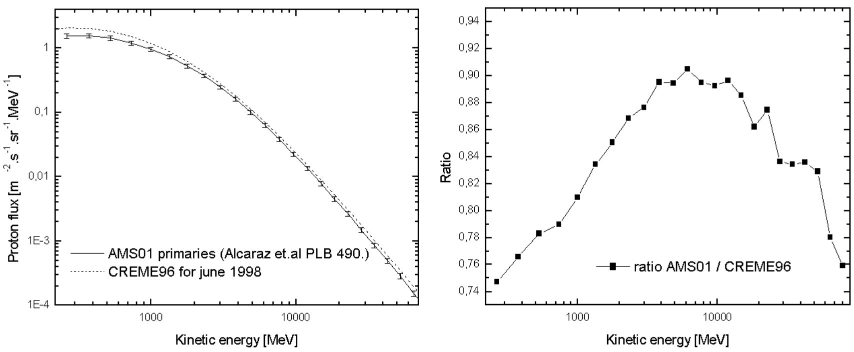

Figure 2. Left panel: Comparison of AMS-01 primary proton spectrum [1] with CREME96 spectrum for June 1998 (AMS-01 flight date). Right panel: Ratio AMS-01 / CREME96 proton flux.

Therefore we decided to use AMS measurement to estimate how precise is the proton spectrum produced by CREME96 model. Figure 2 presents a comparison between AMS-01 data CREME96 proton flux evaluated for June 1998. Data from Creme96 have been re-binned in the AMS-01 energy intervals [1] and the *ratio* has been evaluated:

$$Ratio = AMS\text{-}01\ flux\ /\ Creme96\ flux \quad (1)$$

This *Ratio* is shown in the right panel of Figure 2. The discrepancy is minimum at ~ 6 *GeV* (~ 10%) and increases towards both low and high energy up to ~ 25%, confirming the expected uncertainty. The shape of this discrepancy is regular and then a "*normalisation*" of the CREME96 spectrum can be operated, taking advantage of the accuracy of AMS-01 data.

3. The normalisation procedure

From the Figure 2 (right panel) we can identify two regions: in the low energy range (200 *MeV* – 6.155 *GeV*) the *Ratio* is increasing; while in the high energy interval (6.155 *Gev* – 80 *GeV*) the *Ratio* is decreasing. We operated a fitting procedure separately for these two energy regions. The low energy part has been fitted by the following function *F1*:

$$F1 = A \cdot (1 + E)^{B} \quad (2)$$

E is the kinetic energy in *MeV*. Best fit parameters are summarized in Table 1.

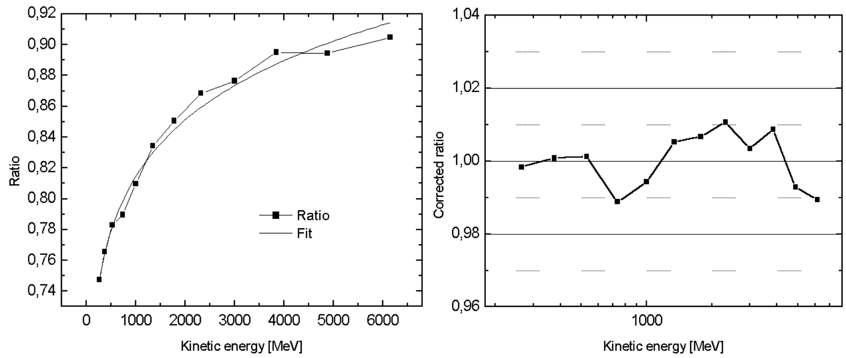

Figure 3. Left panel: Fit of the *Ratio* AMS-01/CREME96 for the energy interval < 6.155 *GeV*. Right panel: Residuals of the fit function.

Results of the fit are shown in Figure 3. In the right panel the residuals of the normalisation are shown. The discrepancy is lower than 1%.

For the high energy part of the spectrum ($E > 6.155$ *GeV*) we get a normalisation fit using two different approaches. First we use a simple linear function to fit the *Ratio*, as suggested by Figure 4. The fitting function *F2* is:

$$F2 = A + B \cdot E \quad (3)$$

E is still in *MeV*. Best fit parameters are still summarized in Table 1.

Table 1. Best fit parameters of the normalisation functions *F1, F2, F3*.

Function	Parameter A	Parameter B
F1	$(525 \pm 9) \times 10^{-3}$	$(64 \pm 2) \times 10^{-3}$
F2	$(910 \pm 5) \times 10^{-3}$	$(-19 \pm 1) \times 10^{-7}$
F3	$(652 \pm 248) \times 10^{-3}$	$(58 \pm 27) \times 10^{-3}$

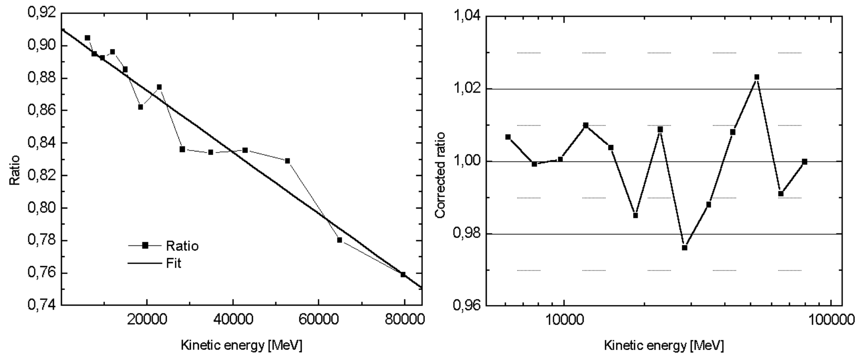

Figure 4. Left panel: Linear fit of the *Ratio* AMS-01/CREME96 for the energy interval > 6.155 *GeV*. Right panel: Residuals of the linear fit function.

Results of the linear fit are shown in Figure 4. In the right panel we can see as the discrepancy in the energy band 6.155 *GeV* - 80 *GeV* is lower than 2%.

The second method to correct the high energy CREME96 spectrum is based on the shape of un-modulated GCR spectrum, described by a power law function. Both AMS-01 and CREME96 spectrum for energies in the range 6.155 *GeV* – 80 *GeV* have been fitted by a power law function $\Phi = \Phi_0 \cdot E^{-\gamma}$.
The normalisation function *F3*, obtained comparing the power law fits is:

$$F3 = A \cdot E^{B} \quad (4)$$

Now the kinetic energy E is in *GeV*, and the best fit parameters are also shown in Table 1. Comparison of normalised CREME obtained by the function *F3* with AMS-01 is shown in Figure 5. The residuals of the power law normalisation are still inside a 2%, except for the very high energy bins.

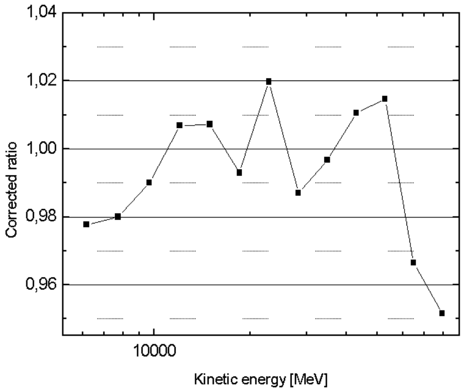

Fig. 5. Residuals of the power law fit of the *Ratio* AMS-01/CREME96 for the energy > 6.155 *GeV*.

Therefore we obtained a normalisation of the CREME96 spectrum to the AMS-01 data with a discrepancy of 2%, which correspond to the rough accuracy of experimental data, in the full range of energy of AMS, if combined with BESS98. This is particularly important at high energy, because here the results should be unaffected by the variability due to the solar modulation.

4. Comparison with time data set

Our normalisation procedure is limited to only one period, because precise experimental measurements like AMS-01 or BESS98 are available only for June/July 1998. But it is interesting also to follow the time evolution of the CREME96 spectrum comparing it with available data. The main source of data are the several IMP-8 experiments. We used the Chicago Cosmic Ray Nuclear Composition (CRNC) experiment (see the web page http://ulysses.sr.unh.edu/WWW/Simpson/imp8.htm) and Goddard Medium Energy (GME) experiment (see the web page http://spdf.gsfc.nasa.gov/imp8_GME/GME_home.htm). The comparison is shown in Figure 6, where we can see as CREME96 model fits CRNC data up to year 1998, probably the deadline of the model fine tuning. After this period there is a large over-estimation of the flux. Comparison with GME data shows an under-estimation of the flux (in both the energy bands chosen for comparison) up to 1998. Later conversely there is again an over-estimation of the flux. We must consider as the accuracy of these measurements is not comparable with AMS-01, and that at these energies short time solar events can be present. Anyway this comparison is useful to understand as the normalisation procedure we have presented in this paper can not apply for low energy bands like that measured by IMP-8 experiments, for time periods different from 1998. This limitation is even more severe for the years following 1998.

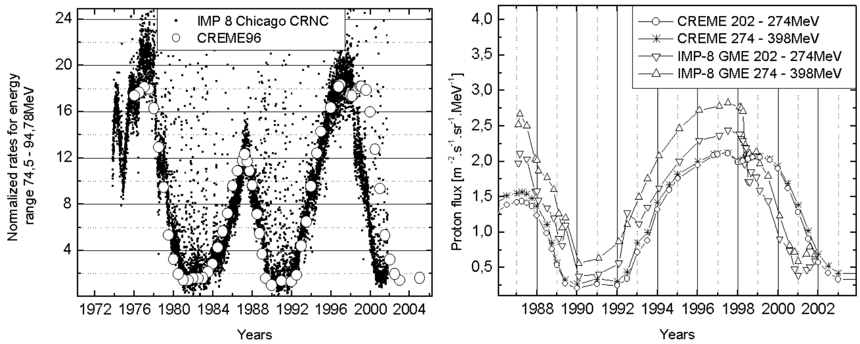

Figure 6. Left panel: CREME96 compared with IMP-8 CRNC for energy band 74.5 – 94.78 *MeV*. Right panel: Comparison with IMP-8 GME in the energy intervals 202 – 274 *MeV* and 274 – 398 *MeV*.

5. Conclusions

We present an evaluation of CREME96 proton flux accuracy based on AMS-01 data taken in June 1998. The accuracy of experimental data (few %) allows a normalisation procedure for the CREME96 model. This results remain effective also for different periods at high energy. But below few *GeV* the solar modulation is strong and accurate measurements are requested for the different solar activity periods.

References

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