The primary proton spectrum in the range $0.5 \div 50$ TeV from the observation of hadrons at EAS-TOP

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Abstract. The primary cosmic ray proton spectrum in the energy range $0.5 \div 50$ TeV is obtained from the hadron energy spectrum recorded by the EAS-TOP Hadron Calorimeter (Campo Imperatore, National Gran Sasso Laboratory, 2000 m a.s.l.). The hadron flux at $820 \text{ g cm}^{-2}$ has been measured in the range $30 \text{ GeV} \div 10 \text{ TeV}$, where it is well described by a single power law $S(E_h) = (2.25 \pm 0.20 \pm 0.34^{+0.04}_{-0.02}) \times 10^{-7} (E_h/1000)^{-2.79^{+0.06}_{-0.08}} \text{ (m}^2 \text{ sr GeV})^{-1}$. The CORSIKA/QGSJET simulation is used to interpret the data; it is verified that the code describes well the hadron propagation by reproducing the ratio of hadron fluxes as measured at $820 \text{ g cm}^{-2}$ and sea level respectively by EAS-TOP and KASCADE experiments, in the considered energy range. The heavier nuclei component is subtracted in accordance to the expectations from direct measurements. The results on the primary proton spectrum are presented and the procedure of data analysis and accuracy of the measurement are discussed.

1 Introduction

The hadron spectrum is measured at the atmospheric depth of $820 \text{ g cm}^{-2}$ by means of the EAS-TOP calorimeter, in the energy range $30 \text{ GeV} \div 10 \text{ TeV}$.

Such spectrum, which includes surviving primaries and secondaries produced in the interactions in atmosphere, retains significant information about the primary energy/nucleon spectrum, thus dominated by the proton primary component, in a primary energy range in which the crossing of different experimental data is quite important.

The primary proton spectrum is derived from such data, in the energy range $0.5 \div 50 \text{ TeV}$, by means of: a) a simulation of the cosmic ray propagation in the atmosphere based on the CORSIKA code with QGSJET interaction model (Capdevielle J.N. et al., 1992; Kalmykov N.N. et al., 1993); b) the subtraction of the Helium contribution of the total flux (with maximum uncertainty $\simeq 15\%$), calculated by using its flux as derived from the direct measurements and the quoted interaction model.

The CORSIKA/QGSJET code is checked with good consistency by comparing the calculated and measured hadron fluxes at the EAS-TOP and KASCADE atmospheric depths ($820$ and $1000 \text{ g cm}^{-2}$ respectively).

The hadron flux measurement, the verification of the interaction model used for the interpretation of the data and the derived proton flux are presented and discussed, with their systematic uncertainties.

2 The detector

The EAS-TOP Extensive Air Shower array (Aglietta et al., 1993) is located at Campo Imperatore, 2005 m a.s.l., above the underground Gran Sasso Laboratories. The EAS-TOP Muon and Hadron Detector (Adinolfi R. et al., 1999) is a $140 \text{ m}^2$ calorimeter made of nine planes, each composed by a $13 \text{ cm}$ Fe absorber (except for the uppermost plane which is unshielded), two layers of streamer tubes and one layer operating in “quasi-proportional” mode, for a total depth of $818.5 \text{ g cm}^{-2}$. The tubes are $12 \text{ m}$ long, with $(3 \times 3) \text{ cm}^2$ section and operate with a $(50\% + 50\%)$ Argon and Isobutane mixture. The streamer tubes act as tracking detectors; the “quasi-proportional” ones are used to record high particle densities, i.e. for hadron calorimetry, and operate in saturated proportional mode. The signal charge is picked up by an external matrix of $840 (40 \times 38) \text{ cm}^2$ pads placed on top of the tubes; the pad signals are transferred to charge integrating ADCs with 15 bit dynamical range, saturation occurring at $1 \text{nC} (\simeq 12000 \text{ particles})$.

A set of $(80 \times 80) \text{ cm}^2$ scintillators is lodged below two absorber layers; each of them is centered on a pad and discriminated at the level of 30 particles, corresponding to an energy threshold of about $30 \text{ GeV}$; three of them are used for the present analysis. Their logical OR, which generates the read out of the whole detectors, defines the “local hadron trigger”, its frequency being $f_h \simeq 0.06 \text{ Hz}$. 

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