Significance of Inverse μ^+/μ^- Charge Ratio correlated with neutrino-antineutrino abundance

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Abstract

The well known charge positive excess of muons in cosmic rays has been reproduced at various altitudes, using the CORSIKA simulation program with a classical primary spectrum dominated by protons. In the case of simulations with primary neutrons, the excess of negative charged muons appears as a consequence of isospin conservation, charge conservation and charge exchange mechanisms; as it could be expected from the first arguments explaining the positive excess, this charge asymetry concerns mainly the muons with energies not too far from the leading cluster in the cascade(0.5% up to 10% of the primary energy).One very interesting result is the prediction of an inverse muon charge ratio effect during the solar flares. We have explored this effect for solar neutrons emitted during solar flares in the energy range 1-100 GeV and report the signatures of negative muon charge ratio on muons from 50 MeV up to 10 GeV. The circumstances of more energetic muons (0.1 to 10 TeV), connected with neutrons coming from more distant sources, as well as the possible enhancement of electronic anti-neutrinos in the neutrino component generated when neutron interacts with astrophysics targets have been also investigated.

1 Interaction of high energy solar flares particles in atmosphere

Our simulation was performed using version 5.20 of the programme CORSIKA (Capdevielle et al.92). We have adapted this code (Capdevielle and Muraki,99) to the various interactions and specific processes concerning the particle propagation through the atmosphere by dividing the dynamical range for the computation into two parts of energy ranges:
(a) the lower part of the high energy domain ,

for p-A collisions ,i.e., at laboratory energies in the range $50GeV < E_{lab} < 1000GeV$. The most energetic particles seen today from solar flares penetrating the atmosphere have been reported at energies above 500 GeV by the Baksan group (Karpov et al.97) using the underground scintillation telescope /BUST/.
(b) the intermediate energy region and the nuclear physics domain, at energies less than $\sqrt{s} \sim 10GeV$ ($E_{lab} < 80GeV$).

At energies less than 80 GeV (in Laboratory system), all the hadron multi-production is provided by the program GHEISHA (Fesefeldt, 85)), which is included in the CORSIKA package. This program plays an important role in the present work. We underline here how the very detailed processes implemented in GHEISHA have been critical in determining solar flare consequences (diffractive dissociation, Fermi motion,treatment of $K^{\pm}$, K^0, η,, production of Λ , Σ, Ω and their antiparticles,...)
As for many Monte Carlo codes at the lowest energies, there are however some limits in the employment of GHEISHA (inaccurate energy and momentum conservation for instance) and a better treatment of muons below 1 GeV would require special codes for intermediate energy physics (Ferrari and Sala 93).
The treatment of the electromagnetic cascade has been carried out using the programm EGS4 (Nelson et al.,85)), adapted to the atmosphere simultaneously with the hadron and lepton propagation. Muons are propagated down to mountain levels. In this calculation, we have taken into account the different energy losses, the deviations in the direction of propagation caused by the multiple Coulomb scattering and the earth magnetic field.

Our Monte-Carlo generator of solar flare events (lower thresholds of 50MeV for hadrons and 10 MeV for e.m. component) has been adapted from CORSIKA, linked with GHEISHA and EGS4, using the HDPM option when necessary. Target diagrams at each of the experimental altitudes such as Norikura and Chacaltaya (2800m and 5200m a.s.l. respectively) and in some cases sea level, Mauna Kea (4200m) and Tibet (4300m a.s.l.) or Akeno (900m a.s.l.) are generated for each event. The target diagram contains the momenta and coordinates of each particle: neutron, proton, positive and negative muon, gamma, electron and positron. One data bank of half a million events induced in atmosphere by solar neutrons or protons with kinetic energies between 1 and 100GeV has been obtained. Some sets have been sampled, also, following the primary cosmic ray energy spectrum, considered above 10GeV, as represented by a unique power law (with $\gamma = -2.7$) according to recent compilations (Simpson 83,Papini 96) involving minimal and maximal solar activity under 10GeV.

2 The negative muon excess in neutrons induced events

2.1 The positive excess for proton induced events The excess of positive muon over negative muons is one of the most well known properties of cosmic rays. The charge ratio $r = \mu^+/\mu^-$ observed at sea level is 1.25 (Frazer 72) ; such value is exactly reproduced by CORSIKA for the most common muon energy of 2GeV.

The altitude dependance of this positive muon excess has been recently measured by the experiments HEAT(Tarle et al 97) and CAPRICE(Barbiellini et al.97).) The results of our first approach by simulation (these experiments deal with muons in the kinetic energy range 200MeV - 3GeV) are in good agreement with the experimental data of HEAT. The value measured by Caprice at $3.45 g/cm^2$ (near 40km altitude in the residual atmosphere) shows an important enhancement of the positive muon excess $r = 1.64 \pm 0.08$. This appears out of the field of our simulation and disagrees with the measurements of MASS (Brunetti 96) and earlier magnetic spectrometer measurements(Bogdonov et al. 79, Krizmanic 95).

CORSIKA reproduces quite well the positive excess, owing to the isospin symmetries for isoscalar targets involved in GHEISHA. The air target is well known to reduce the positive excess as 1.22, when a value of 1.46 can be expected from a single nucleon target . For muons of very high energy , r increases with E_μ in reason of the more important production of muons via charged kaons (which are not in the same isospin multiplets) and the K's produced in association with leading Λ or Σ.

2.2 The negative excess for neutron induced cascades As it could be expected by converting the arguments derived from the treatment of diffusion equations, turning the proton excess in input at the top of the atmosphere to a neutron excess, the positive excess of the muons turns systematically to a negative muon excess when neutron induced showers are simulated with CORSIKA.

We have ascertained this property directly on the charged pions and kaons produced in the earliest interactions. The negative pion excess was also obtained with the program NUCRIN in CERN for neutron projectiles.

The natural isospin spectroscopy of the atmosphere (nis) is shown on fig. 1(left) at Chacaltaya level for samples of 20000 to 1000 events with energies increasing from 5 up to 100 GeV. Positive excess for protons and negative excess for neutrons have quite symmetric behaviour when plotted versus muon kinetic energy, especially for muon energies more close to the leading cluster. An energy threshold for muons 20 to 10 times lower than the primary energy appears to give the best chances to observe a non negligible number of muons with a maximal contrast.

This effect, present at all the altitudes, combined with the collimation properties can be used as a new signature of neutrons emitted in solar flares.

2.3 The antineutrino-electron excess for neutron induced events Another astrophysical effect appears in the case of neutron primaries , correlated with the increase of neutrino-electron abundance (the decrease of r suggests also an increase of the global ratio of electronic to muonic neutrinos).

The actual conditions of ν production and propagation in CORSIKA, including exact kinematics of two and

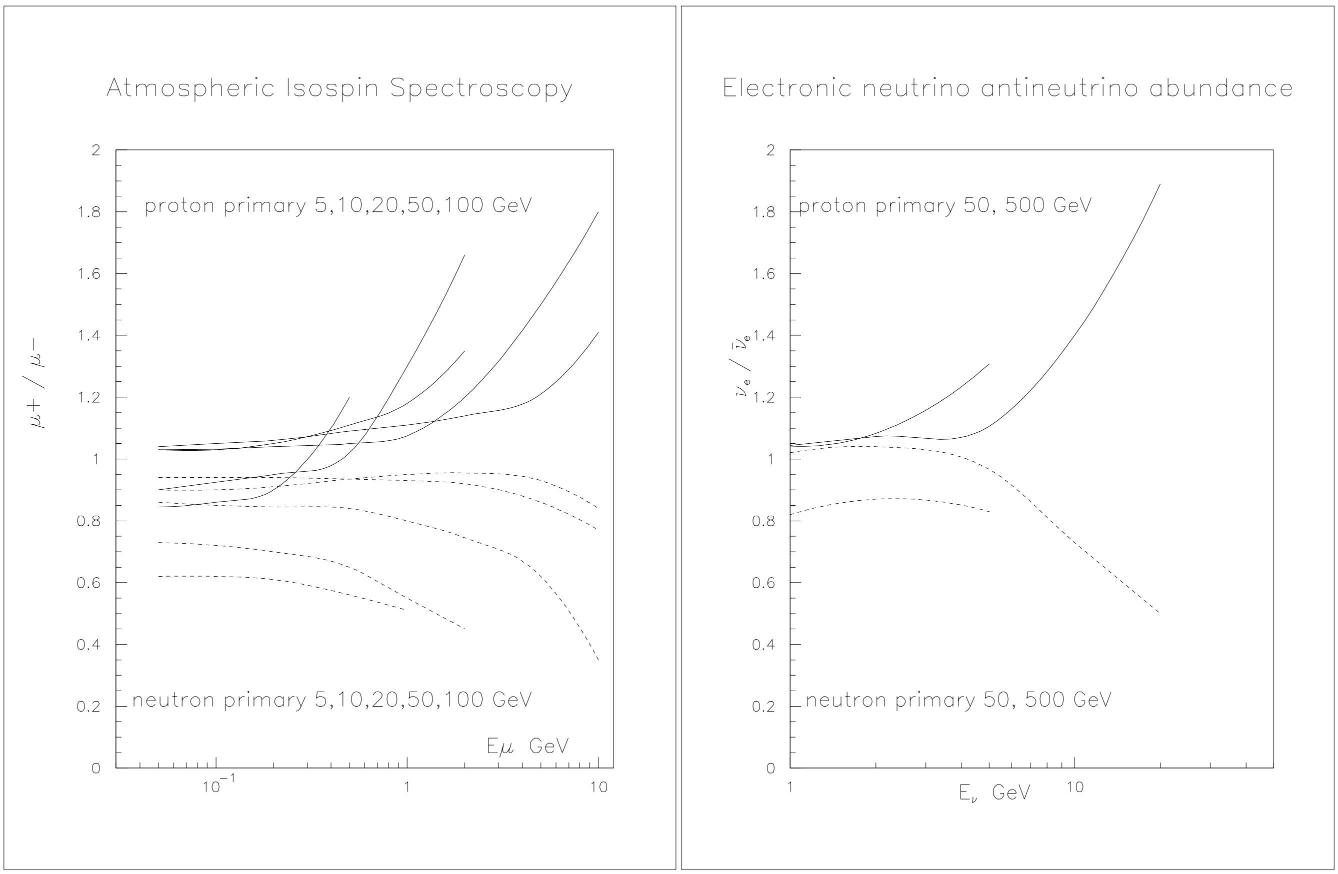

Figure 1: Natural isospin spectroscopy.

three body decays, taking into account the polarization of the muons allows more accurate estimations. The excess of electronic antineutrinos is well confirmed by our Monte Carlo simulation in an energy window extended from about 1% up to 10% of the primary neutron energy. A symmetric situation (excess of electronic neutrinos is observed in the case of proton-induced showers for $E_p = E_n = 500 GeV$. (situation presented on fig.1 right).

The proportion of muonic neutrinos to muonic antineutrinos remains comparable (for protons and neutrons) and consequently the total ratio of neutrinos to antineutrinos is not very much affected by the contrast neutron/proton primaries.

In the case of astrophysics target where neutral Hydrogen and Helium are the most common constituents, the factor $r = \mu^+/\mu^-$ for proton primaries rises up to 1.5, as asymmetries in isospin conservation, charge conservation and exchange become more important. Then, the excess of electronic antineutrinos generated by neutrons in such media can be expected to be more consequent. Furthermore the relative excess of antineutrino-electrons due to primary neutrons of high energy from solar flares or from the diffuse primary component would have to be taken into account in the simulations used to approach the neutrino oscillation.

3 CONCLUSION

The inverse muon charge ratio offers new possibilities for the investigation of solar flares from ground level . The space time distribution of muon charge ratio is also interesting and the possible anisotropies (for muons above several TeV) could be correlated with the emission of neutrons from nearby sources, such as Loop1 or Geminga.

Simultaneously, the analysis of electronic antineutrino excess correlated with solar flares but also with neutron cascading in astrophysics targets like AGN's, point sources or in direction of galactic center, galactic planes and spiral arms (and its general distribution in space and time with possible anisotropies) can provide new and fundamental observations.

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