Significance of the contrasted topology of high energy μ^+/μ^-

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Abstract

We investigate the relation of the muon charge excess with the nature of the primary, according to isospin conservation and charge exchange mechanism in the earliest interactions. The opportunity to associate a negative charge excess to neutron primaries above 100TeV could be used in Astrophysics for close sources, like the Loops or Geminga. The selection of events with zenithal and azimutal incidences favouring the maximal deflection by the geomagnetic field suggests some new criteria to discriminate proton and heavy nuclei in the "knee" region. We discuss also the chance to observe in muon target diagram the properties of alignement of UHE events seen in emulsion chambers near 10^7 GeV.

1 Inclusive data and HDPM (Hybrid Dual Parton Model)

1.1 p_t distribution In the collision generator HDPM (Capdevielle 89), the hadrons coming from the fragmentations of the chains stretched between valence quarks and diquarks of projectile and target are represented mainly by one pair of normal distributions (symetric around CMS for p-p collisions) in rapidity(slide 3) . The sum restores the traditional plateau with gaussian wings. The center and width of those gaussian functions are first adjusted to the pseudo-rapidity distributions of NSD inclusive data as follows ; couples (p_{t_i}, y_i) are generated for each secondary. The p_t distribution is the QCD functional form taking into account the new correlation between central rapidity density and $\langle p_t \rangle$ observed in UA1-Mimi (minimum bias experiment (Bocquet96)).

A dichotomic Monte Carlo generator of transverse momenta was developed to reproduce this new situation and we observed a consequent rise of the total inelasticity of about 10% at $\sqrt{s} = 630 GeV$(Capdevielle et al.,97)

1.2 New pseudo-rapidity distributions at $\sqrt{s} = 630GeV$ The guidelines of the rapidity generation mechanism in HDPM were adjusted in order to reproduce the inclusive and also semi-inclusive measurements of UA5 experiment(Alner et al.,87) on charged pseudo-rapidity distributions. Recently, at the occasion of tests for hadronic B-physics experiment, new and precise measurements with micro-strips silicon detectors have been performed allowing pseudo-rapidity estimation for $1 \leq \eta \leq 6$. The results obtained by Harr et al.(1997) are plotted (open circles) together with the previous results of UA5 (diamonds) on slides 2,4 . The important discrepancy in the distribution profile for $\eta \geq 3.6$ can be observed. We have superimposed the histograms derived from the simulation of 2000 collisions generated with HDPM modified (it was inserted in CORSIKA from the adjustment to UA5 data for NSD component) after tuning the rapidity generator to reproduce the most recent observation. In this last case, the center of gravity of the partonic strings have been shifted to $\eta = 1.88$ and the width of the chains after fragmentation have been enlarged to 1.17.

1.3 Enhanced inelasticity One simple kinematic treatment by summing up the energies carried by the different secondaries gives (from the average on one sample of 2000 collisions) the inelasticities in Laboratory system related to the total incoming energy.The inelastic enhancement resulting from slide 2 comes from the increase of the transverse mass of each secondary and even more from y_i
$E_i = m_{t_i} \cosh(y_i + y_0)$, with $m_{t_i}^2 = m_i^2 + p_{t_i}^2$,
(y_0 is the rapidity of the incoming particle). The total inelasticity rises from 0.54 (our previous agreement with UA5 data to 0.73 (0.47 for charged). The constrainct of the new trajectory (one rapidity or pseudo-rapidity of 6 corresponds to one value Feymann's x of 0.3) is more efficient. Unfortunately at $\sqrt{s} = 1800GeV$ (slide 5), we have no constrainct to indicate the tendancy near fragmentation region ; there are no values of pseudo-rapidity density measured for $\eta \geq 3.0$. We note that if we conserve the same generation procedure

than at $\sqrt{s} = 630GeV$, we obtain herealso a total inelasticity of 0.7. Such values are very close of one previous estimation of total inelasticity in p-Air collisions derived from the interpretation of Gamma ray families measurement with X-ray film emulsion chambers (Capdevielle et al.1994) in the energy range 1000-10000 TeV using the Quark Gluon String Jet model, giving comparable results to the modified Hybrid Dual Parton Model (HDPM).

1.4 Scaling violation in fragmentation region It has been in fashion to plot in the mirror system , all the distributions of pseudo-rapidity density (slide 7) to support the validity of Feymann's scaling in fragmentation region. One violation by less than10% was tolerated in Dual Parton Model (Capella et al.1994). This tendancy looks artificially plausible as far as we don't consider the points of Harr et al.. This new data plotted again on slide 7 , where we have isolated with the same scale the measurements at collider energy, exhibits, as our inelasticity balance, one significant tendancy to scaling violation in fragmentation region. It could be very interesting to know, as it was done for UA5, the behaviour of the semi-inclusive data corresponding to the recent inclusive measurements of Harr et al.. Several questions happen about the extrapolations at energies above LHC ; the summation of the transverse energy gives for some collisions at 100 EeV, energy densities exceeding 100 GeV/Fm^3.

2 The negative muon excess in neutrons induced events

2.1 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. 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/.

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 for low enrgy muons. 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).

2.2 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.

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.

2.3 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 slide 8 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.

2.4 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 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 $E_p = E_n = 500 GeV$ and 50 GeV (situation presented on slide 10).

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 Coplanar events

Using the combination of some rare fluctuations (diffractive component, KNO fluctuations to high multiplicity for small diffractive mass, fluctuations of n_{ch} versus n_γ such that the γ's have individual energies under the threshold of the emulsion chamber, we have simulated events similar to the Centauro (Wlodarczyk,93). The inelasticity increase is not expected to produce some geometrical alignement of secondary particles as clear as the Concorde event (diap.10,11,12) registrated near $10^7 GeV$ (Capdevielle,97); however we have started some simulations with CORSIKA (Capdevielle et al.92, Heck et al.98) to explore the consequences of some special circumstances implied by the semi-inclusive data. At least, we obtained the evidence that the energy distribution of the 211 γ's can be easily reproduced with a small cascading in the atmosphere ; for instance, the superposition of 3 proton collisions, a quite banal configuration for an atmospheric depth of 105 $g - cm^{-2}$ and a proton mean free path of about 60 $g - cm^{-2}$ reproduces quite well the multiplicity and the energy distribution observed. Simulations are in progress to understand further geometric consequences of the semi-inclusive data in the stratospheric environment. Obviously, similar linear structures for charged pions (as suggested by Pamir data) to the gamma's of diap.12 will be smeared out by the atmospheric propagation and has poor chances to appear in the muon target diagram.

4 Muon component and geomagnetic field

One advantage of CORSIKA is that particles and antiparticles are followed individually : such is the case of positive and negative muons that we can distinguish during the propagation in the atmosphere, as well as at the arrival of the penetrating component at ground level. The deflection of the muons during their propagation involves the multiple Coulomb scattering and the curvature of the trajectories, as for all the charged particles of the simulation, in the Earth's magnetic field.

In order to point out some typical signature of the primary particle in the contrast of the properties of positive and negative muons, we have calculated in each shower the separations of positive and negative muons barycenters, $\delta_{\mu\mu}$, and the orientation, $\phi_{\mu\mu}$ of this dipole in azimutal angle. This separation, more clear in the case of nuclei, appears also connected with the statistical reduction of the fluctuations of showers initiated by nuclei.
To understand the benefit of this geomagnetic effect, a sample of several hundred showers , for muons with energies exceeding 300 MeV, has been simulated and some systematic features have emerged. For near vertical showers , at $10^6 GeV$, the orientation to East-West direction of the dipole and the net barycenter separation by 100m in favour of iron initiated showers is clear, whatever may be the azimutal incidence.(diap.15,16,17) One tremendous barycenter separation by 500m is obtained in the case of very inclined showers ($\Theta = 55°$).

The discrimination between heavy and light nuclei at UHE can be carried on both directions:

- ratio of μ^+,μ^- at convenient distances
- ellipticity of the muon component

In the absence of detectors for muon charge identification, we introduce the ellipticity factor $\epsilon(r) = \rho_{\mu//}(r)/\rho_{\mu\perp}(r)$, ratio of total muon densities at the same distance from the shower axis , on one axis oriented along the muonic dipole and on the axis perpendicular in the core center. At present, we have confirmed this synopsis inspired by the analytical approach by our Monte Carlo data, for muons with energies above 50 GeV (i.e.independanly from GHEISHA , after comparing the positive (or negative) muon charge excess in 4 sectors delimited by the diagonals in the frame determined by the muonic dipole and the axis perpendicular in shower axis (diap.14,22). The evolution from barycenters of 300 MeV (black) up to 100 GeV(violet) is shown on diap.18 at fixed zenith and azimut angles ; the barycenters for muons of 300 MeV versus azimutal angle for proton and iron are presented on diap.19, 20 , 21.

5 Conclusion

Those new elements support a significant increase of the total inelasticity in the Knee energy region/around 0.65 - 0.7 if we take into account single diffraction and nucleon-Air effects/. This implies a more important absorption of the electromagnetic component of Extensive Air Shower and a relative more important muon-electron abundance, as well as one maximum depth at higher altitude. The average mass required in the primary component in current interpretations of EAS data could then have been overestimated in calculations made with inelasticies values around 0.5. From the point of view of microscopic physics, this can be connected with the modified distribution at high x (Huston 1998) for the valence d quark or with di-quark breaking circumstance. The explanation of geometrical alignements of secondaries is not yet elucidated : however, multiplicities and momenta distributions of those special events can be reproduced with normal Ln(s) Physics and expected cascading in the atmosphere.
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.

Another interesting observation is that the geomagnetic field can help the discrimination between heavy nuclei and proton by the lateral muon distribution ellipticity and the charge excess in muon densities. This requests observations in two pairs of sectors (both centered on shower axis),the former oriented along the dipole defined by the barycenters of positive and negative muons, the latter perpendicular ; such topologic discrimination will become more efficient by selecting the proportion of showers with incoming direction close to the vertical plane perpendicular to the Earth magnetic field .

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