Proceedings of ICRC 2001: 319 © Copernicus Gesellschaft 2001

ICRC 2001

Negative excess in the electromagnetic component of GAS and the radio emission

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Abstract. Simulations of shower development using CORSIKA code for primary proton and iron nuclei from 10^5 GeV up to 10^{11} GeV have been performed. About 25% negative charge excess in the electromagnetic component of shower had been found, confirming earlier theoretical predictions. The net negative charge (occuring mainly as a result of positron annihilation) might produce coherent Cherenkov radio emission.
The calculation of the fluorescence emission at the highest energies has also been performed by a fast method of simulation and the consequences of the diquark breaking mechanism in first interaction are investigated.

1 Introduction

The primary energy estimation from a small number of signals scattered at large distances is a crucial and complex problem for surface arrays of detectors, dedicated for the electromagnetic or penetrating components. We give here attention to complementary approaches more correlated with the entire longitudinal development in the atmosphere,

- the radio emission,
- the Cherenkov light emission,
- the fluorescence emission.

In all circumstances, we investigate, among the different changes expectable in the multiple production, the diquark breaking mechanism consequences in the conversion of observable and traditional estimators to primary energy.

2 Negative excess from CORSIKA/EGS simulations

In a recent paper based on radioemission detected with antennas for a bunch of 0.2 up to $1{\cdot}10^{10}$ electrons of 28.5 GeV produced in SLAC and cascading in a target of sand, corresponding to the energy of a giant air shower (Saltzberg et al., 2000), the Askaryan effect (Askaryan, 1961) has been observed; this effect predicted as a strong coherent radio and microwave Cherenkov emission for cascades propagating within a dielectric, results from the negative charge excess close to 30%, mainly generated by the annihilation of positrons in the atmosphere. Taking the opportunity of the CORSIKA/EGS code with simulation outputs separating easily positive and negative particles, we have calculated the negative excess in the atmosphere for primary energies under 10^8 GeV for energy thresholds for both electrons and positrons of 1 MeV (Corsika Version 5.624). A regular negative excess of about 30% is observed for the different showers, near shower maximum (fig. 1) for primary energy of 10^7 GeV.

At larger energies (above 10^8 GeV), the same calculations have been performed with a thinning factor 10^{-4} and a threshold of 15 MeV for both electrons and positrons. A regular negative excess by 20% is ascertained around the maximum depth in the longitudinal developments averaged for groups of 100 showers, shown here respectively for proton and iron primary of 10^9 GeV (fig. 2) and for proton and photon primary of 10^{11} GeV (fig. 3). The photon is supposed to be generated under 50 gcm^{-2} to avoid magnetic bremsstrahlung.

It is interesting to note on fig. 3d that the electron excess remains in the same proportion and is not smeared out by the LPM effect. We observe also that the radio emission will not be very different to distinguish the different primaries. Taking into account the different threshold taken in our calculations under and above 10^8 GeV, we can also conclude to the perfect continuity of the radio emission with energy and the validity of the calculation under thinning technique. The options used in CORSIKA (QGSJET for interaction model...) are similar to those described in a previous work (Capdevielle et al., 2000).

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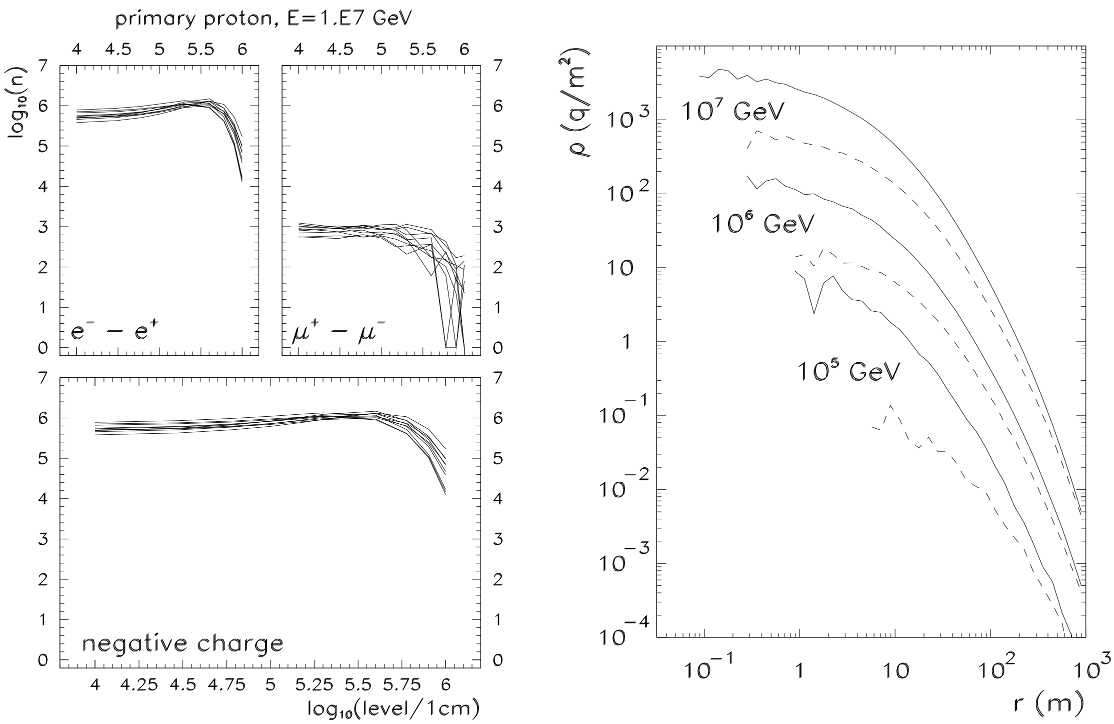

Fig. 1. Left: Excess of negative charge for primary proton 10^7 GeV versus observation level. Right: Lateral distribution of negative charge excess at 600 m a.s.l. for proton (solid lines) and iron (broken lines) initiated showers.

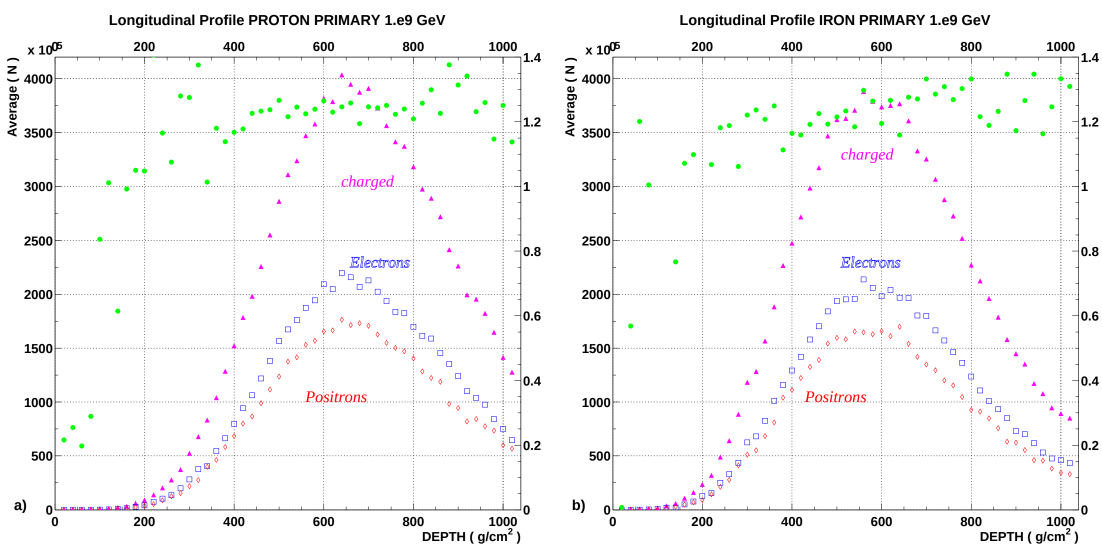

Fig. 2. Energy = 10^9 GeV; primary particle: a) proton and b) iron. The scale on the right side of each figure is for the quotient of the number of electrons / number of positrons: $\frac{N_{e-}}{N_{e+}} \simeq 1.2$.

3 Diquark breaking mechanism and reversed knee

In a previous work (Capdevielle et al., 1997), we had involved in the simulation the quark flow chart diagram representing the diquark breaking mechanism (fig. 4) as proposed by Capella (Capella, 1998).

The diquark breaking mechanism disturbs strongly the leading particle effect present in the different models used in cosmic rays. In the classical form of the dual parton model, the three valence quarks of the proton projectile are separated in a fast diquark and an other valence quark slowed

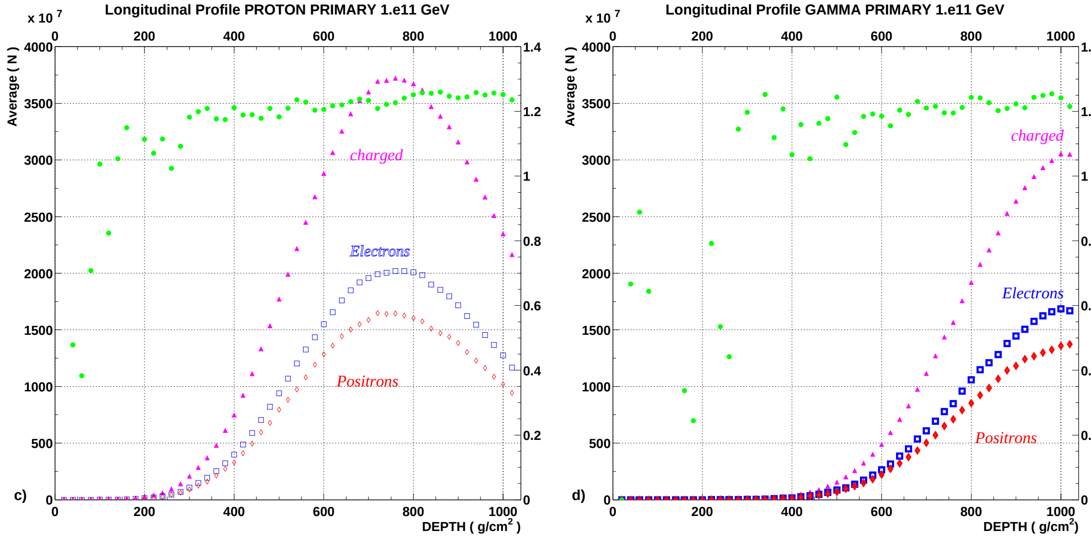

Fig. 3. Energy = 10^{11} GeV; primary particle: c) proton and d) photon.

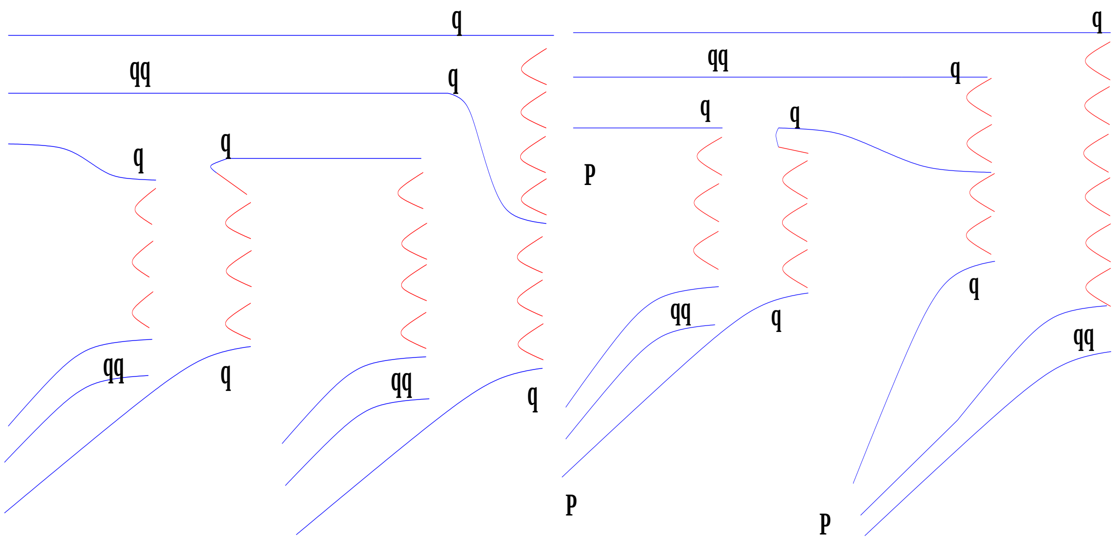

Fig. 4. Feynmann diagram of diquark breaking.

down. The diquark is recombined with one quark of the sea to produce, the most commonly, an outgoing leader baryon propagating the energy deeper in the cascade. According to the diagram of fig. 4, the three valence quark separated will be recombinated in various meson structures in pairs $|u\bar{d}>$, $|d\bar{u}>$,...or neutral mesons as $1/\sqrt{2}(d\bar{d} - u\bar{u})$. The configuration with the simultaneous final state for the valence quark of $3\pi^0$'s could be especially interesting with a probability of emergence that we can evaluate from the quark content and the quark additive model as $1/27$. Such configuration (with intermediate final states of higher probabilities, one pair of charged pions and one neutral, one pair of neutral and one charged...) will transfer a large part of energy to the electromagnetic component and this energy will be definitely missing for both hadronic and penetrating components. Remembering that for the same primary energy, the cascade theory shows that one primary photon produces at maximum, approximately, two times more electrons, we can expect a large electron excess for some cascades initiated with diquark breaking. The longitudinal development calculated for protons of the same energy of $3 \cdot 10^8$ GeV is compared to a classical development, here the model HDPM2 with D–option (Capdevielle, 2001), on fig. 5. The electron size at maximum is twice in the assumption of diquark breaking and relatively rare recombination simultaneously in 3 neutral pions. If we consider the steepness of the differential size spectrum, such behaviour is no more rare when comparing showers of the same size at maximum. We give here some properties calculated with our Ω code based on the structural stability of the subshowers to fasten the Monte Carlo calculations (Capdevielle et al., 1997), first for Diquark breaking and for HDPM. We have respectively at sea level $4.44 \cdot 10^{13}$ Cherenkov photons cumulated against $4.16 \cdot 10^{12}$ and we receive at 20 km from shower axis 117 photons/cm^{-2} from

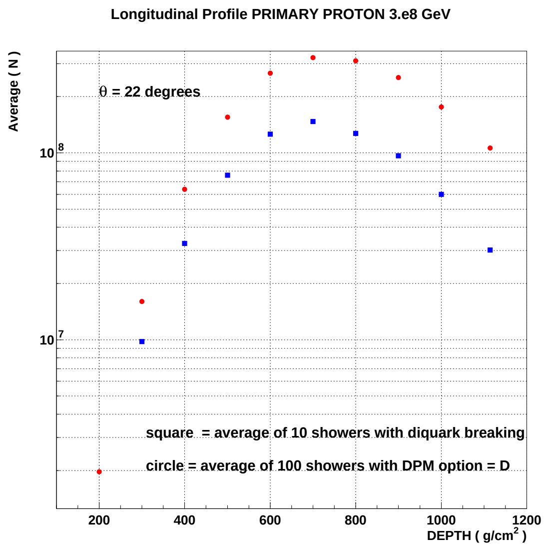

Fig. 5. Simulation with DPM model with option D (100 showers), and diquark breaking (10 showers).

fluorescence instead of 70. In both cases, the depth of maximum is 730 gcm^{-2} and 700 gcm^{-2}. This electron excess as observing that this altitude is close to the level of Tien Shan experiment could explain the reversed knee observed (Nikolsky and Romakhin, 2000).

4 Discussion

The net negative charge excess of about 25% had been found in the electromagnetic component of simulated showers. Registration of Cherenkov radio emission produced by this charge (if possible) might help to estimate the energy of the shower and to distinguish the type of primary particle. Results of our simulations strongly support experimental attempts to detect high energy cosmic ray showers by coherent radio Cherenkov emission.

We have also shown that a large electron excess can be expected for some cascades initiated with diquark breaking, giving rise to enhanced Cherenkov and fluorescent emission. At $5 \cdot 10^{19}$ eV, such showers are at maximum near 900 gcm^{-2} and they could appear as showers exceeding 10^{20} eV with smaller than expected muon content.

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