A preliminary measurement of the all-particle cosmic-ray energy spectrum with AIROBICC (.5 PeV - 5 PeV)

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As is well known, the measure of the Cherenkov light intensity allows us to determine the primary energy of the cosmic ray E_0. In our Rome contribution ('Determination of the Depth of Maximum Development and Primary Energy of Cosmic Ray Showers with AIROBICC' by F. Arqueros and J. Cortina), we described a method which is able to achieve a fine energy resolution independently of the nature of the incident particle. Since this work was presented in the last HEGRA meeting at Munich, some progress has been made:

a) The initial parameter L_{int}, the total light inside the 'hump', has been replaced by ρ_{90}, the Cherenkov light density at 90 meter distance from the core position. ρ_{90} provides us with a better initial measure of the energy.

b) As it is shown in fig. 1, the dependence of the corrected Cherenkov light at 90 m on E_0 is very similar for all primaries and therefore the optimum correction is expected to be near independent of the primary energy. You can compare this fig. 1 with fig. 3 of the Rome contribution.

As a result an improved determination of the energy (independent of the nature of the primary particle) has been found. The error in the energy is about 17% at 100 TeV.

By applying this method, we have used real data of AIROBICC in order to study the all-particle spectrum of the cosmic rays. As a result we will show a possible evidence of a change in the slope at about 2 PeV. At lower energies the spectrum shows some unexpected features which we think are due to an experimental artifact.

Next we summarize the procedure and details of our analysis:

1/ We have made use of those runs in the interval 1800-2050 for which ρ_{90} and the light radius, 'r_L', were rather stable. These runs amount to about 50% of the old data analyzed in Munich. The remaining runs are not reliable unless an appropriate correction on both parameters is applied. We have selected showers with zenithal angles < 20 degrees and distance of the core from edge of array > 15 m.

2/ For both MC and real data, ρ_{90} has been determined from the so-called inner fit (i.e. exponential fit of $\rho(r)$ in the radial interval 10 - 90 m). The relation between $photons/cm^2$ and ADCs signal has been obtained from the comparison of the integral ρ_{90} spectrum between real data and the MC prediction (factor of about 1/2 with respect to the old calibration).

3/ The light radius has been determined for both MC and real data. In MC, r_L has been calculated from the 'inner fit', however in real data we had to used the so-called 'total fit' of the Cherenkov lateral distribution (i.e. exponential fit between 20 and 200 m). since the inner fit for real data is not available presently. It has been found that in the energy range of this work ($\log \rho_{90} > 4.5$) both determinations of r_L are very similar (discrepancies lower than 8%).

4/ In fig. 2 we show the differential spectrum of ρ_{90}. It can be seen a sort of depression in the light density range $4 \cdot 10^4$ - $6 \cdot 10^4$. We think this effect is related to the transition from using low to high gain ADCs since: a) In this density range the analysis program switch from high to low gain ADC data. b) We have found that this depression also takes place in the distribution of the Cherenkov light density at others core distances. In fig. 2 it can be seen that the ρ_r distributions for $r = 60$ and 140 m show a similar behaviour in the above mentioned light density range. This effect should be further studied in raw data. This depresion forces us to work in the range $\log E(TeV) > 2.7$ TeV.

	Spectral index
p	2.7±0.1
Fe	2.6±0.1
a=0.25	2.6±0.1
a=0.50	2.5±0.1
a=0.75	2.6±0.1
a=1.0	2.8±0.1

Table 1: *Spectral indices as determined from several calibration of the energy for runs 1867-1915*

5/ In fig. 3 we show our result of the differential all-particle spectrum in the energy range 0.5 - 5 PeV. There is a possible evidence of a change in the slope from $\gamma = 2.6 \pm 0.1$ in the energy range 0.5 - 2 PeV to $\gamma = 3.0 \pm 0.1$ in the range 2 - 6 PeV. The energy of each event has been obtained from ρ_{90} with the appropriate correction (corrective factor a = 0.75; see Rome contribution) by using the measured r_L value as above explained. We have not been able to state if this change in the slope we have found is due to a possible saturation of the low gain ADCs. Some strategies may be adopted:

a) It has been proposed to compare this result with that obtained with inclined showers since for these the saturation should take place at the same ρ_{90} value and therefore at a higher energy. Unfortunately a MC calculation has showed us that for an incident angle of 30 degrees the effect should be negligible.

b) E. Lorenz has suggested to study the saturation of the huts near the core in the raw data. We still have not been able to work on this point.

c) Let us suppose the saturation of the low gain ADC turns significant somewhere near channel 3000. This channel corresponds to a density of about $4 \cdot 10^6$ - $8 \cdot 10^6$ pht/m^2. According to our calculations ρ_{90} reaches such a value at $\sim$ 100 PeV and ρ_{10} at $\sim$ 10 PeV. As we determine ρ_{90} by making a fit in the range 10 - 90 m, we suspect the effects of saturation start to take place between these two energies.

6/ In order to check the effect of a posible error in our correction procedure we have calculated the differential spectra under the following assumptions:

a) All of the cosmic rays are protons or alpha particles. Here we have determined the energy by using the relatioship between ρ_{90} and E_0 for protons (from our MC).

b) All of them are iron nuclei.

c) Also we have determined the energy by using several values of the corrective factor ranging from 0 to 1 (the optimal value according to our MC is 0.75).

In the table it can be seen that the spectral indices in the range 0.5 - 2 PeV do not significantly change under two extreme assumptions (a and b). A simple estimate shows that according to our MC results on ρ_{90} vs E_0 for both primaries (p and Fe), the spectral index should decrease in about 0.06 units for a pure proton composition to a pure iron composition. On the other hand the espectral index is not very sensitive to the corrective factor (c).

In order to fully understand all of these points and more deeply investigate all the feature of the spectrum near the *knee*, we plan to work in the following questions:

- We shall study the saturation of the low gain channel and the high to low gain transition in the raw data.

- We intend to make use of the new MC library and possibly change the parameter ρ_{90} to ρ_{110} in the energy calibration, as we think it is more appropiate in the new Cherenkov simulation.

- We shall increase our statistics with data analyzed with the new analysis programs.

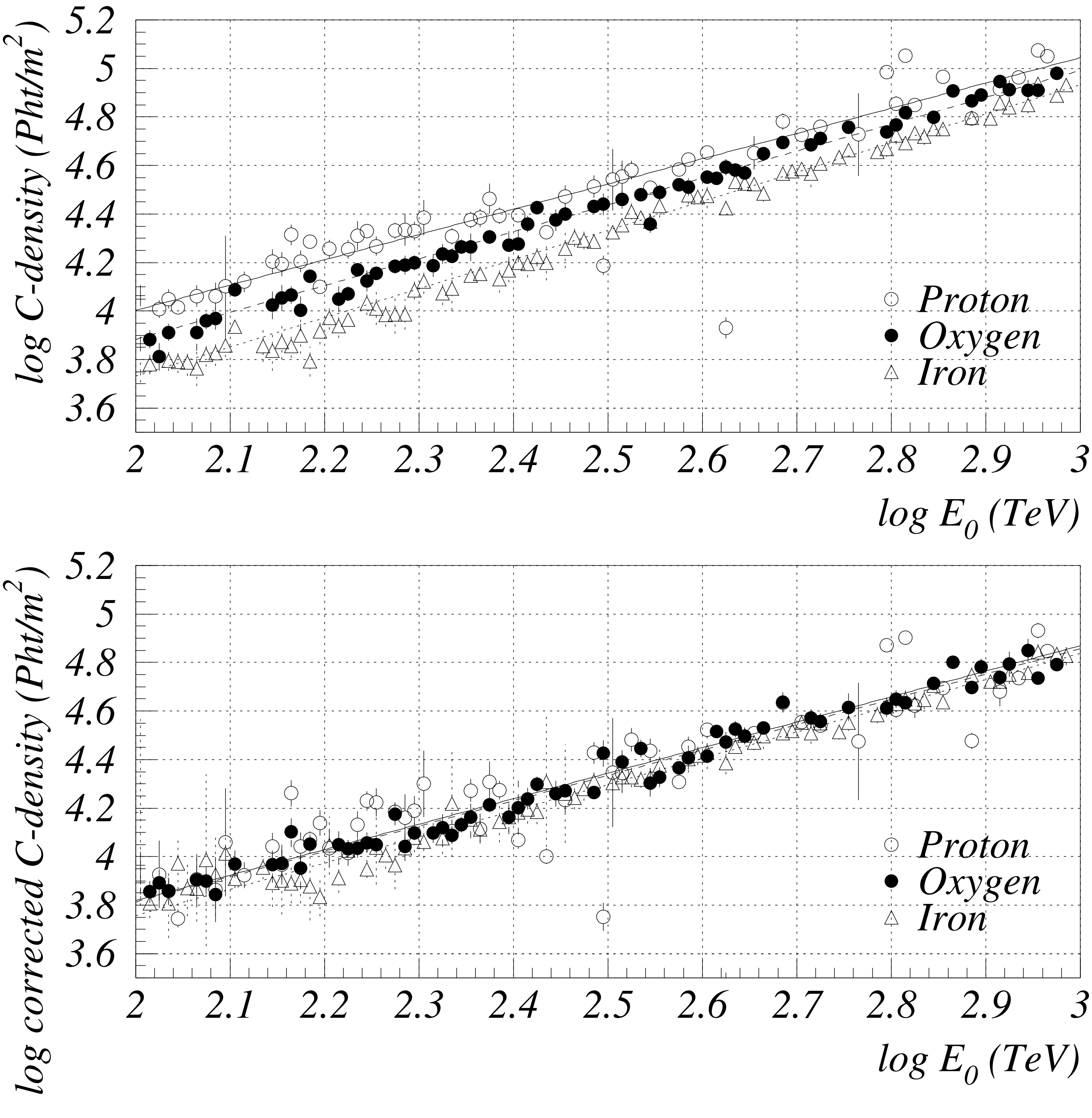

Figure 1: *Effect of the energy correction based on the position of X_{max} for showers in the energy range 0.1 - 1 PeV and 10° incident angle.*

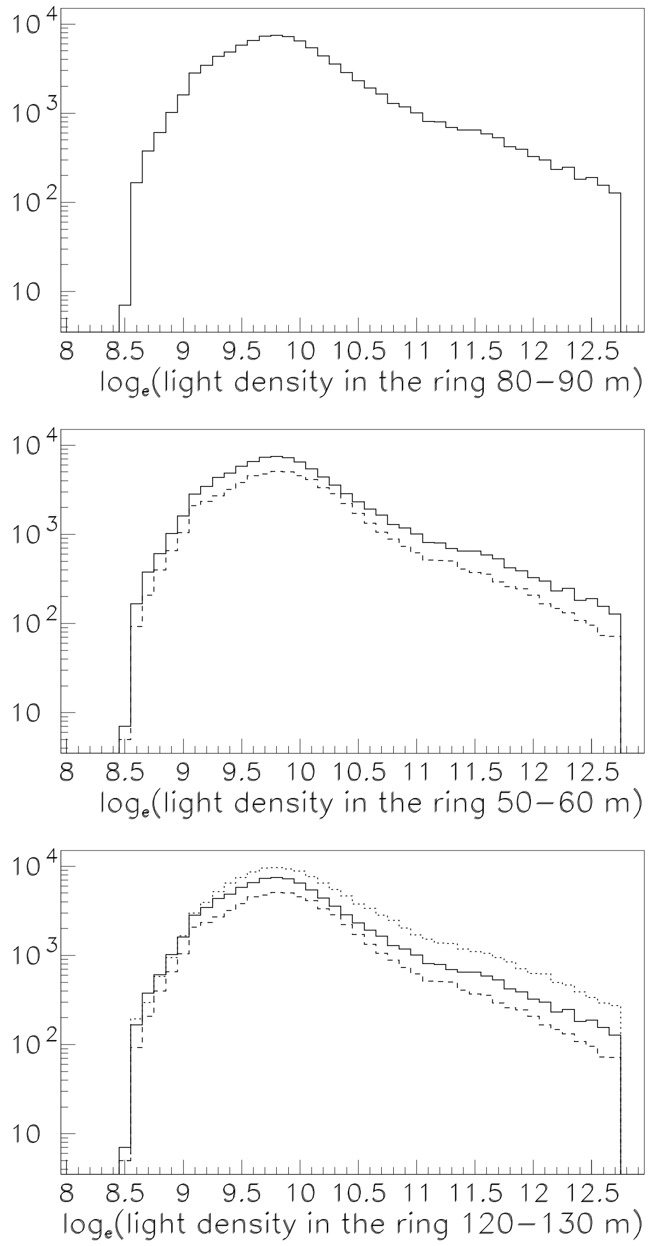

Figure 2: *Light densities distributions in three different rings. The depression is always observed in the same range of densities.*

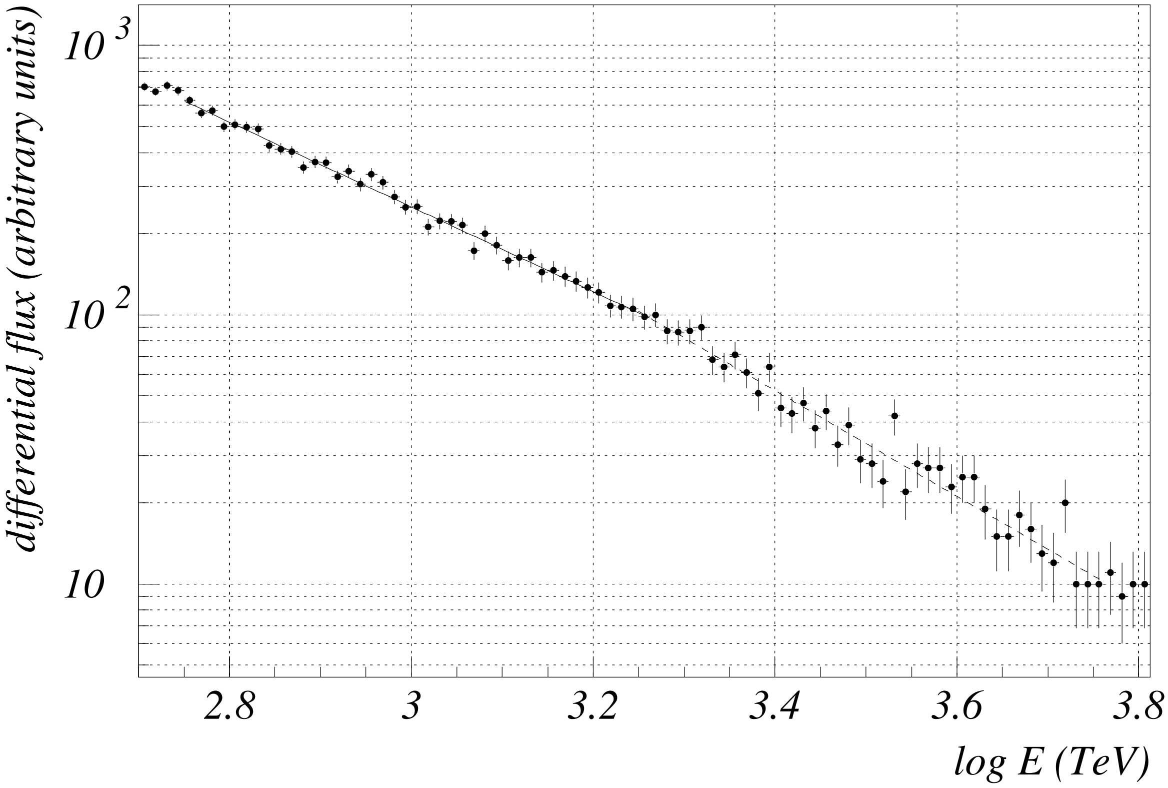

Figure 3: *Differential spectrum of the cosmic ray flux in the energy range 200 TeV - 10 PeV. The fits of the curve at the two different intervals 200 - 1000 TeV and 2 PeV - 10 PeV show a possible evidence of the so-called 'Knee'. The spectral index is found to change from a value of* $\gamma = 2.6$ *to* $\gamma = 3$.