CHERENKOV DETECTION OF COSMIC RAYS IN HANOI: RESPONSE TO ELECTRONS AND TO MUONS

Nguyễn Thị Thảo

Bukit Tinggi, 11/2012

Outline

1. Motivation and method
2. Response to feed-through muons: VEM calibration
3. Muon decays: simulation
4. Autocorrelation measurements: time distributions
5. Auto correlation measurements: charge distributions
6. Conclusions

1. Motivation and method

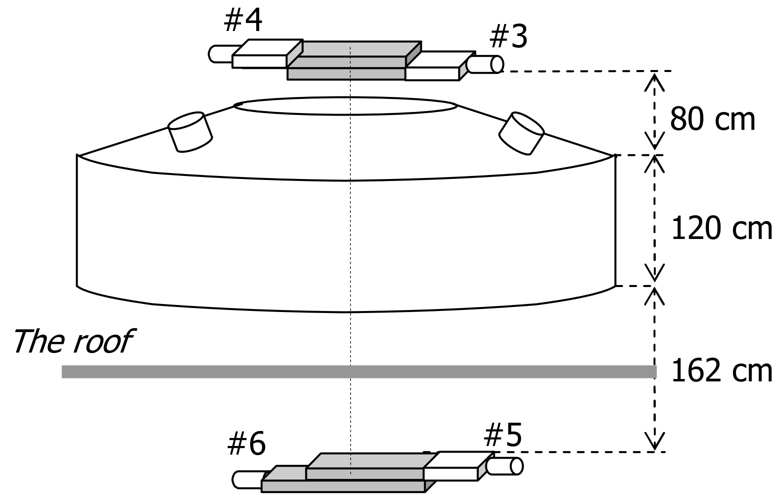
Motivation

1. To study the response of the Cherenkov detector to low charges.
2. To measure the contribution of multimuons from the same shower, and compare it with the lateral distribution function evaluated using the satellite tanks.

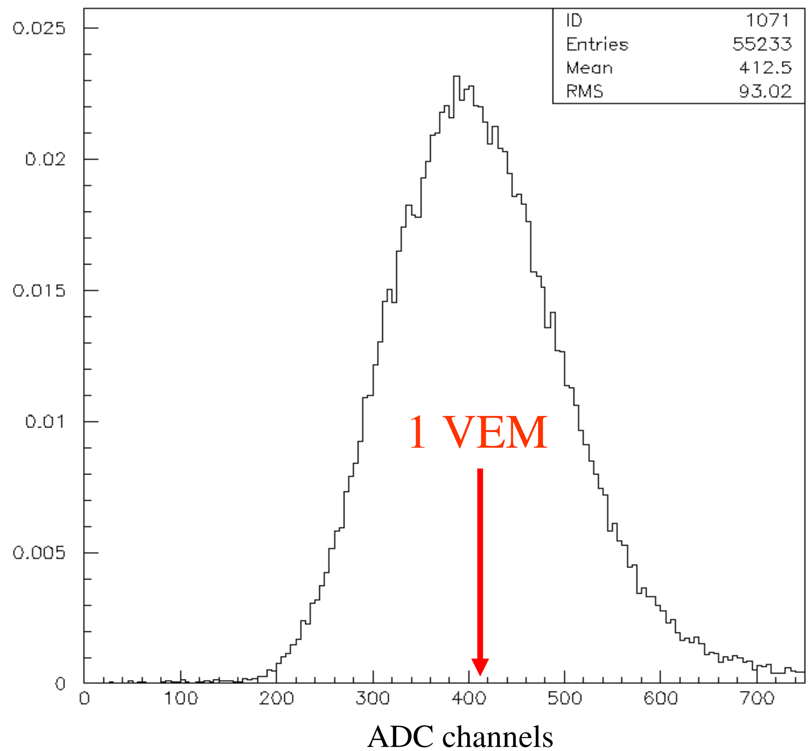
Method

Detect stopping muon decays (the electron signal is weak) and pairs of correlated muons by measuring auto-correlation spectra for several detection thresholds.

2. Response to feed-through muons: VEM calibration



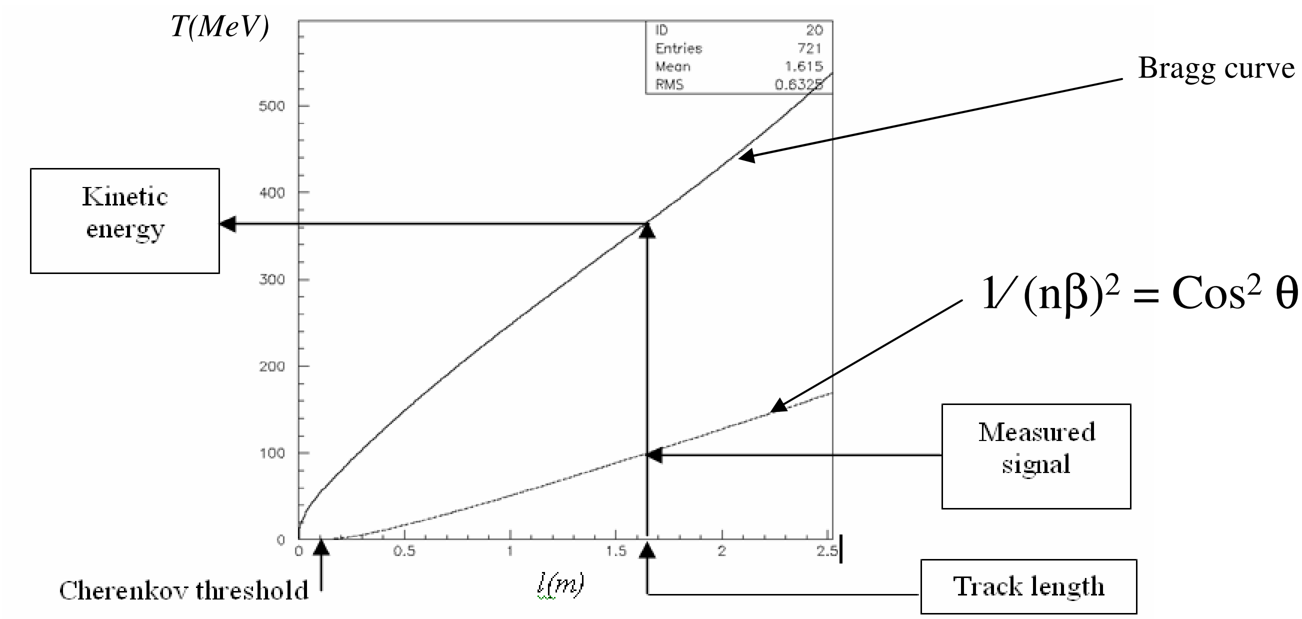
The Cherenkov detector is a 12'000 litres water tank equipped with three 9" PMTs used to detect Cherenkov photons emitted when a charged particle passes through water at a speed greater than the velocity of light in water. A scintillator hodoscope bracketing above and below the centre part of the Cherenkov counter provides the trigger on the particles feeding through the Cherenkov counter. The associated Cherenkov signals (above Cherenkov threshold) are proportional to the track length. As most muons are relativistic, vertical feed through muons give a reference signal used as unit of charge (VEM).

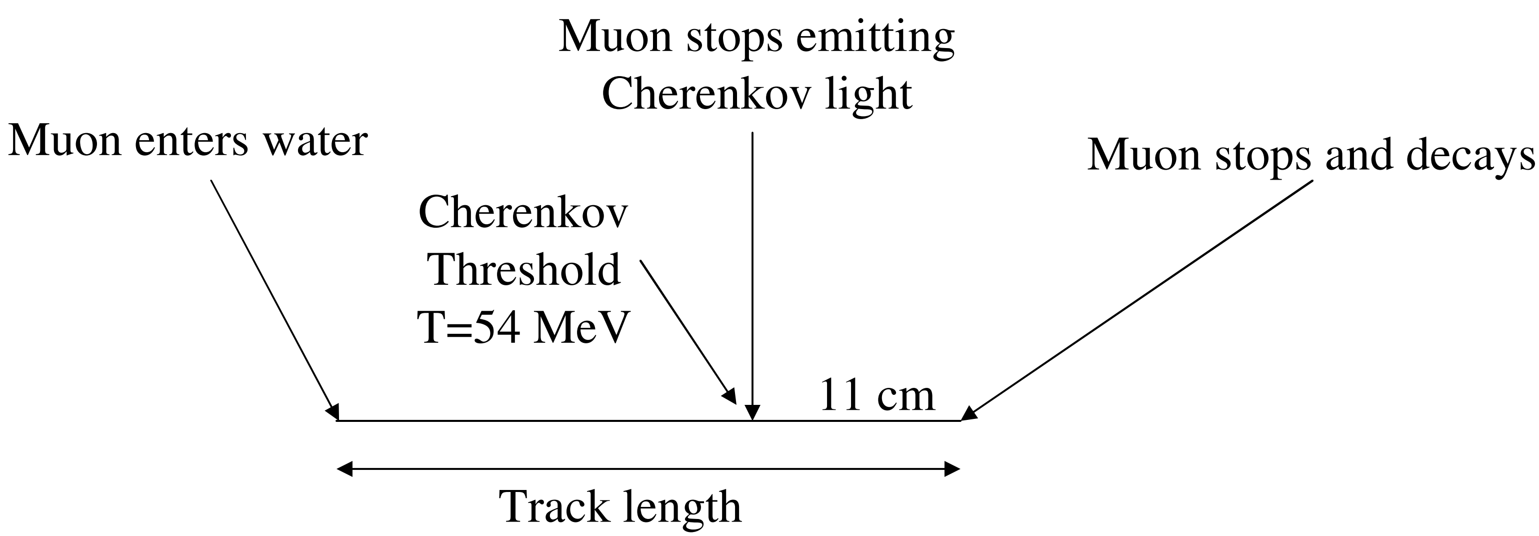


Vertical feed through muons give a charge distribution having a relative rms value of 22.5%. We obtain a calibration of the charge measurement with a precision of 2.4 %.

3. Muon decays: simulation

In preparation for the measurements, we have made a simulation to evaluate what can be expected in terms of rate and of signal.
Muons are slowed down in the Cherenkov detector due to ionization energy losses.
Vertical muons start feeding through the detector as soon as their kinetic energy (T) exceeds 280 MeV. The longest track length in water for inclined muons corresponds to a kinetic energy of 385 MeV. The detector only detects charged particles having kinetic energy above Cherenkov threshold (54 MeV for muons, 0.26 MeV for electrons). We evaluate that about 6% to 7% of muons crossing the detector will be stopped.


T(MeV)
ID 20
Entries 721
Mean 1.615
RMS 0.6325
500
400
300
200
100
0
0 0.5 1 1.5 2 2.5
l(m)
Bragg curve
Kinetic energy
$1/(n\beta)^2 = \cos^2\theta$
Measured signal
Track length
Cherenkov threshold


Muon stops emitting Cherenkov light
Muon enters water
Muon stops and decays
Cherenkov Threshold T=54 MeV
11 cm
Track length

4. Autocorrelation measurements: time distributions

We use a time to amplitude converter (TAC) followed by a multi channel analyser (MCA) to record the distribution of the time separating two successive signals, a signal being the coincidence between two PMTs of the Cherenkov detector. The electronics is such that only pair of signals separated by less than 10 μs can activate the TAC. Spectra are recorded for different values of the threshold applied on the signals and of a minimal delay D_1 of the second signal with respect to the first.

Auto-correlation spectra are fit to a form

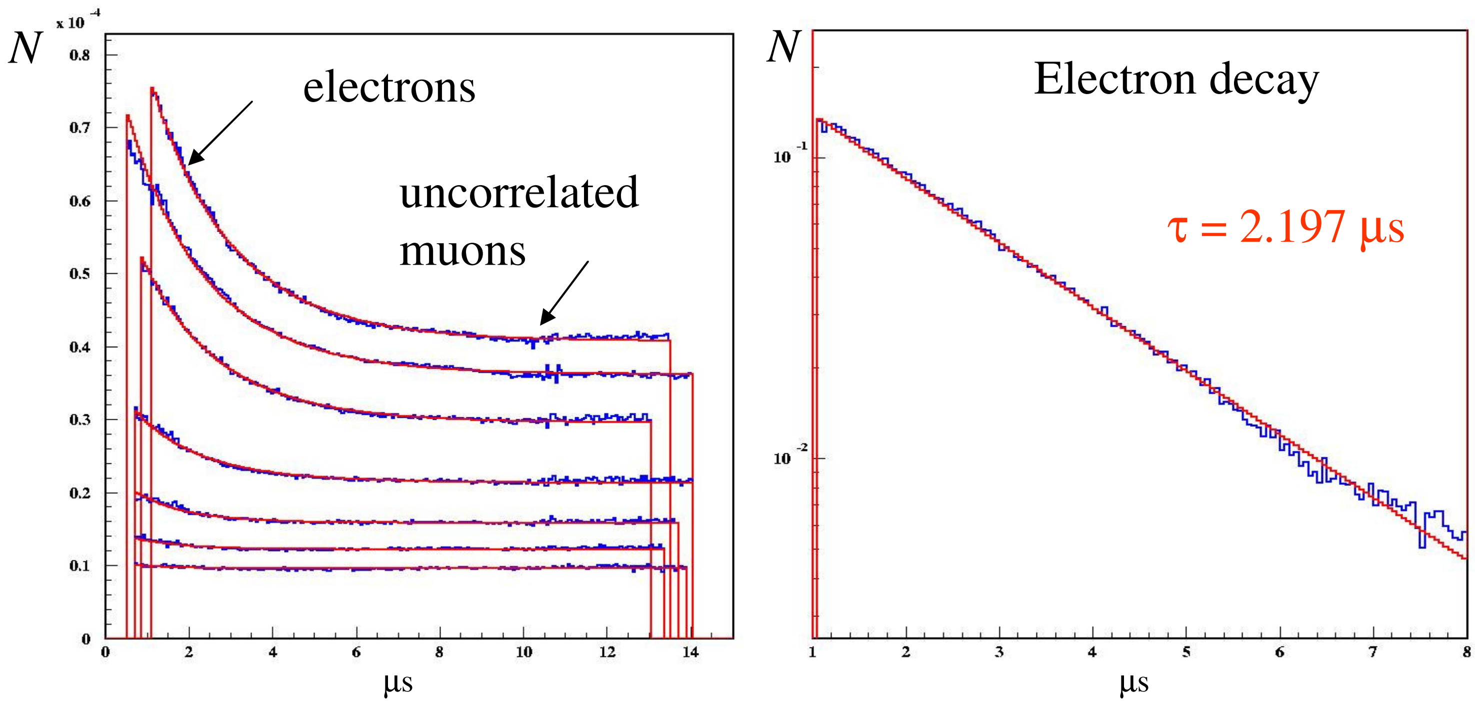
$$f = R\,exp(-Rt) + g_0 R_{sh} exp(-R_{sh}t) + \varphi R^+(\rho^+ exp(-R^+t) + \rho^- exp(-R^-t))$$

R ~ 40 Hz accounts for a pair of uncorrelated muons.

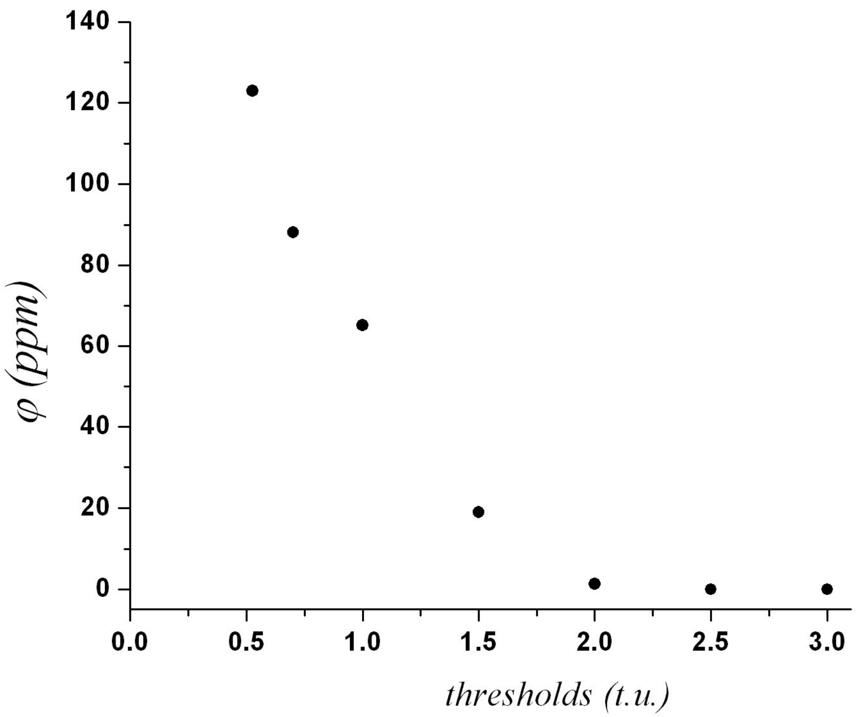
g_0 measures the probability of detecting a muon pair from a same shower with a time distribution described by a time $1/R_{sh}$.

R^+ is the muon decay rate in vacuum and R^- is the disappearance rate of negative muons, including both decays and capture in water. $\rho\pm$ are the fractions of positive and negative muons. They are fixed to their known values.

φ is proportional to both the detection efficiency for decay electrons and the probability for a muon to stop in the detector. They are the fitted parameters and depend on the threshold, which takes 7 different values (0.525, 0.7, 1.0, 1.5, 2.0, 2.5, 3.0 threshold unit (t.u)).



The best fit to a sum of four exponentials gives a χ^2 value of 1.020 per degree of freedom (of which there are 118’185), providing evidence for the quality of the fit and for negligible systematic errors. The ratio between measurements and model has a Gaussian distribution having a σ of 5.3 %.



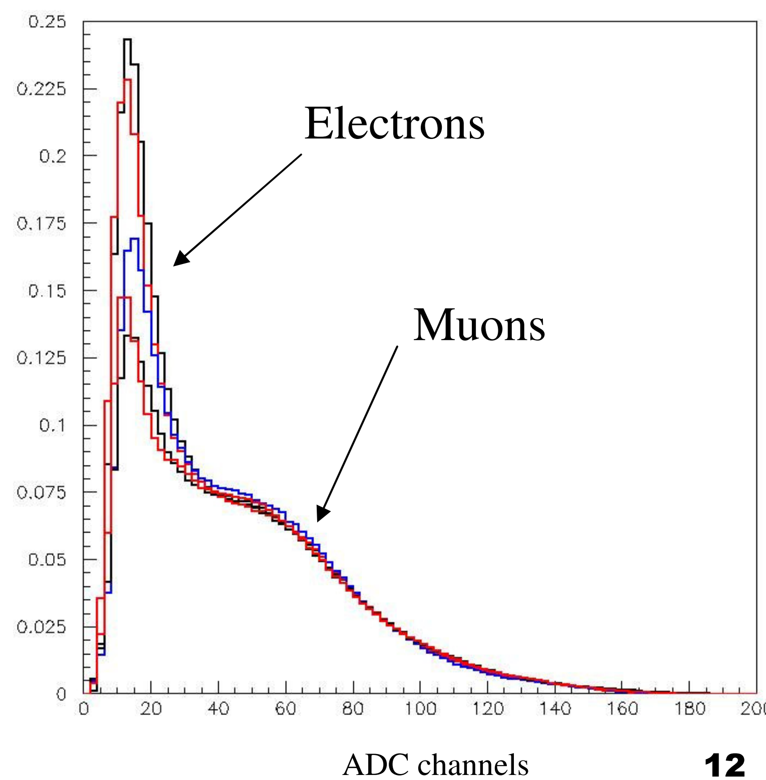
The best fit value of parameter g_0 is $(0.79\pm0.05)\times10^{-5}$ for a decline time $1/R_{sh}$ of 1.13±0.04 μs; in most cases, it can be neglected.

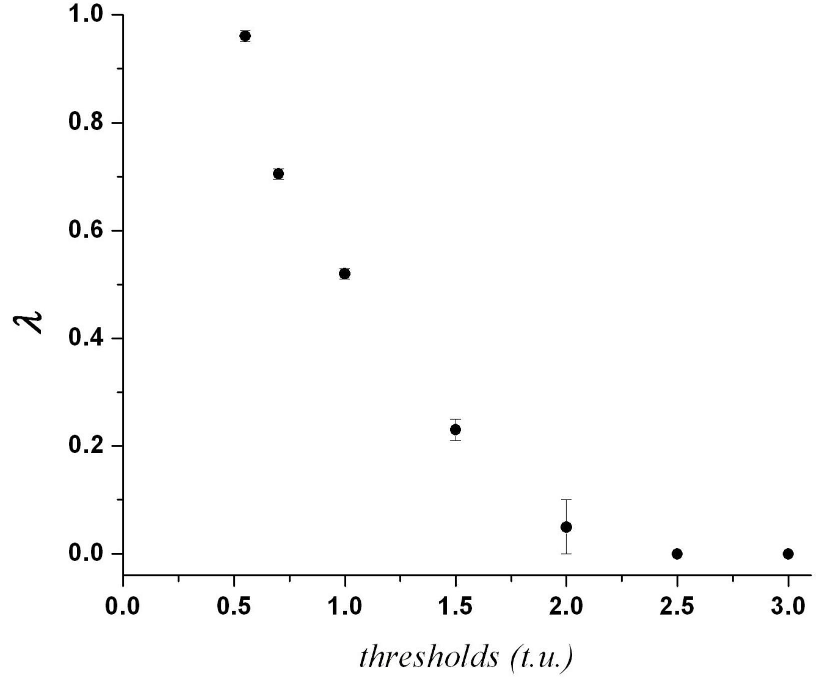
The dependence of φ on threshold shows that the sensitivity to electron detection drops to zero when the threshold reaches its higher values.

5. Autocorrelation measurements: charge distributions

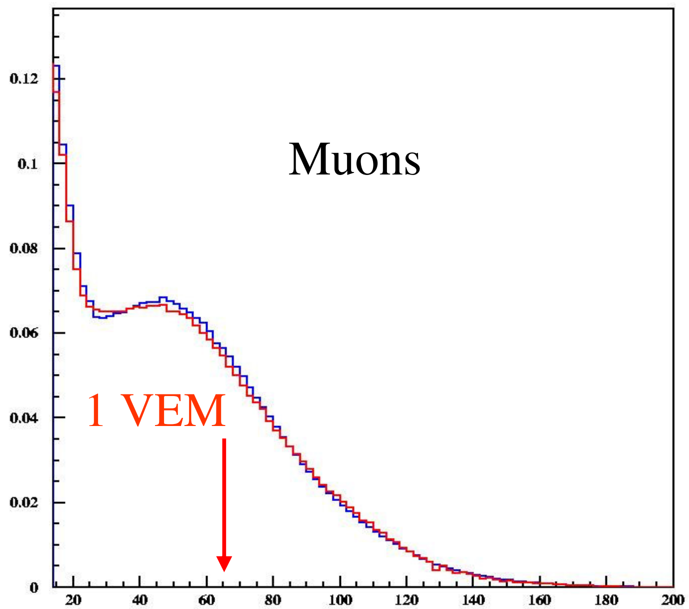
Charge distributions of the second signal are fit to a form
$S_{i,j,k}=N_{i,j}C_i\{F^{\mu}_{k}+\lambda_i exp(-(D_j/\tau)F^{el}_{k}\}$ (i labels the spectrum, j the threshold)
F^{el} and F^{μ} are the distributions associated with decay electrons and muons;

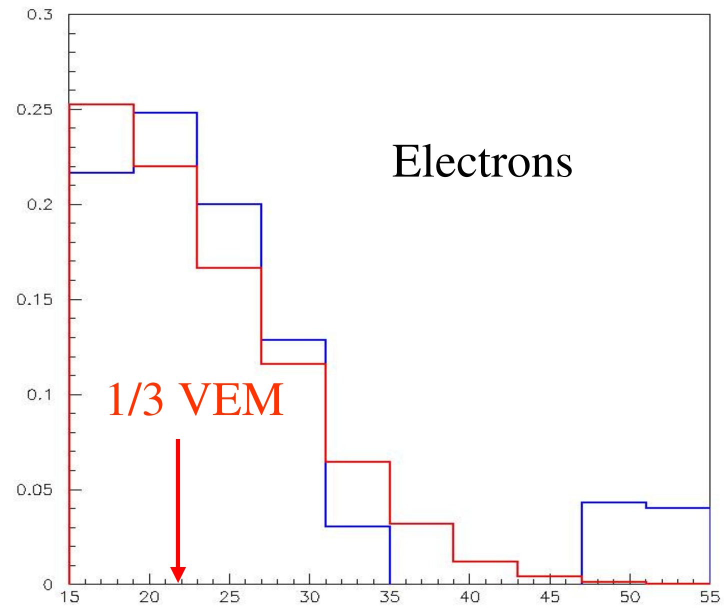
λ_i accounts for the fact that when the threshold increases, so does the fraction of stopping muons and therefore of detectable decay electrons;
The exponential term accounts for the exponential decrease of the electron contribution as a function of delay $D_1=D_j$ to account for its different values and τ is taken equal to 2 μs in order to account for capture;
C_i describes the cut-off due to the threshold applied to the signals.





Above a threshold of 2 threshold units, electrons do no longer contribute. The sharp decrease of the λ parameters as a function of threshold illustrates the difficulty of the measurement: the measurement of the electron distribution rests fully on the low threshold data; the higher threshold data are only good at fixing the muon distribution.





The best fit muon charge distribution fits with what is expected for inclusive muons.

The electron charge distribution gives a mean electron energy of 0.29±0.04 VEM

6. Conclusions

We have presented measurements of the response of the VATLY Cherenkov detector to electrons and muons. Relativistic feed-through muons have been used to calibrate the charge scale. Autocorrelation time and charge measurements have allowed for disentangling important information related to the performance of the detector:

– Excellent agreement has been found with the known decay and capture parameters of muons in water;

– The contribution of muon pairs from a same shower has been measured and found negligible in most cases;

– The dependence on threshold of the electron detection efficiency has been measured with good precision;

– The electron and muon charge distributions have been separately measured.

These results provide a useful contribution to the understanding of the PAO detectors, in particular in the domain of low charges.

Financial support from VATLY, INST, Worldlab and Nafosted is gratefully acknowledged.

Thank you for your attention

TAC logic and timing diagram