Measurement of the water-Cherenkov detector response to inclined muons using an RPC hodoscope

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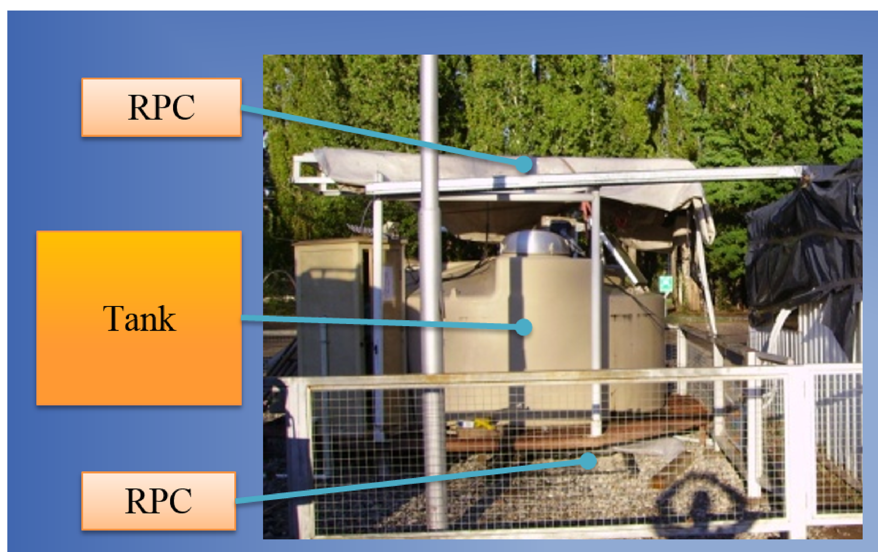
The water-Cherenkov detector (WCD) is the main building block of the Surface Detector (SD) of the Pierre Auger Observatory. The WCD samples the shower charged particles that arrive at the ground. A deep understanding of the detectors is of paramount importance.
In this work, which extends the measurements performed in Orsay with a test WCD equipped with scintillators, we aim to improve the understanding of the parameters governing the light propagation inside the WCD, namely the light reflection and absorption. For that, a hodoscope was mounted, enabling the selection of particular particle trajectories inside the WCD.

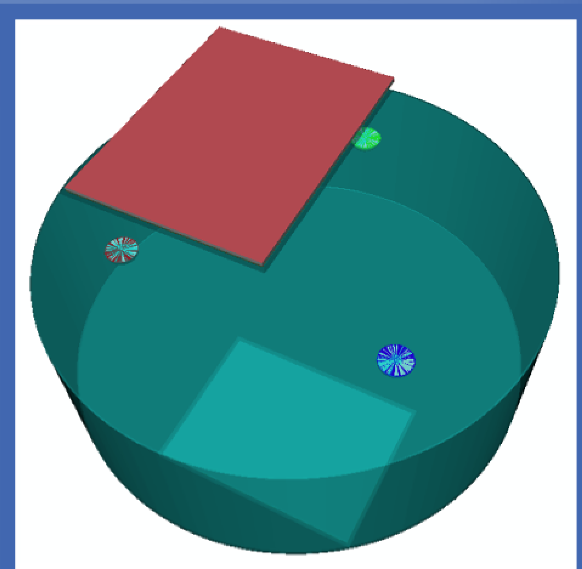
Experimental Apparatus



The hodoscope is formed by two stand alone low gas flux RPC detectors with the testing Water Cherenkov Detector placed in between.
The readout of the RPCs is segmented into small pads, which allows for an accurate reconstruction of the individual muon trajectories.
The hodoscope is used to trigger and select single trajectory events in different geometries. Both RPCs are installed in moveable structures allowing for different configurations and hence probing different regions of angles of incidence.

Dedicated Simulation

This simulation reproduces the conditions at Malargüe, accounting for geometrical and detector efficiencies.
CORSIKA simulations of the atmospheric particles were run for Malargue and then injected into a simulation of the WCD+RPC setup using Geant4 in which the RPCs setup was implemented.

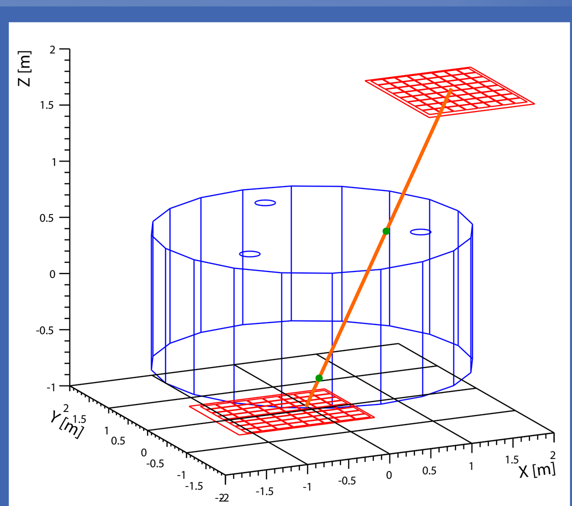


Visualisation of simulated setup

The WCD simulation is performed exactly in the same way as in the standard simulation.
The tracking in the RPCs enables the recording of the incoming particle position, direction and the time, as well as the ionizing energy deposited in the gas, which is then used to generate charge pulses. The electronic signals are then effectively simulated by a parameterisation.

Reconstruction

The RPC data were analyzed to determine the trajectory of single muons passing through the hodoscope. Events with single pads activated were chosen and their trajectory and track-length in the tank reconstructed.



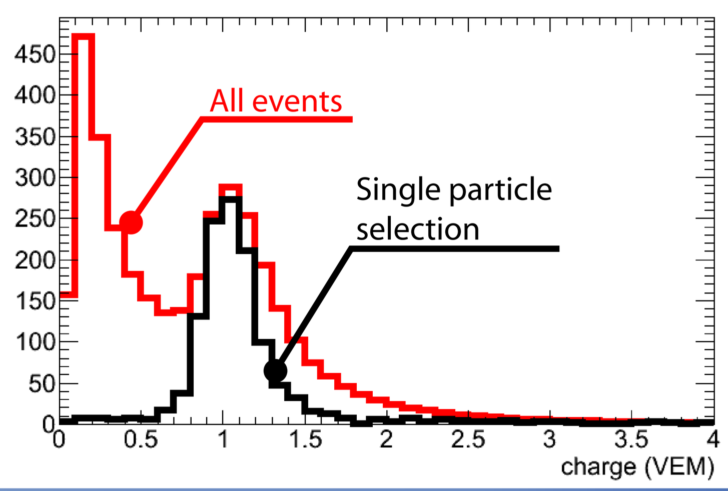
Reconstruction of a track

The baseline, peak time-bin, current and charge for high gain traces of individual PMTs and for the total trace were estimated using standard analysis methods of the Pierre Auger Collaboration.
These quantities were studied as a function of the muon trajectory.

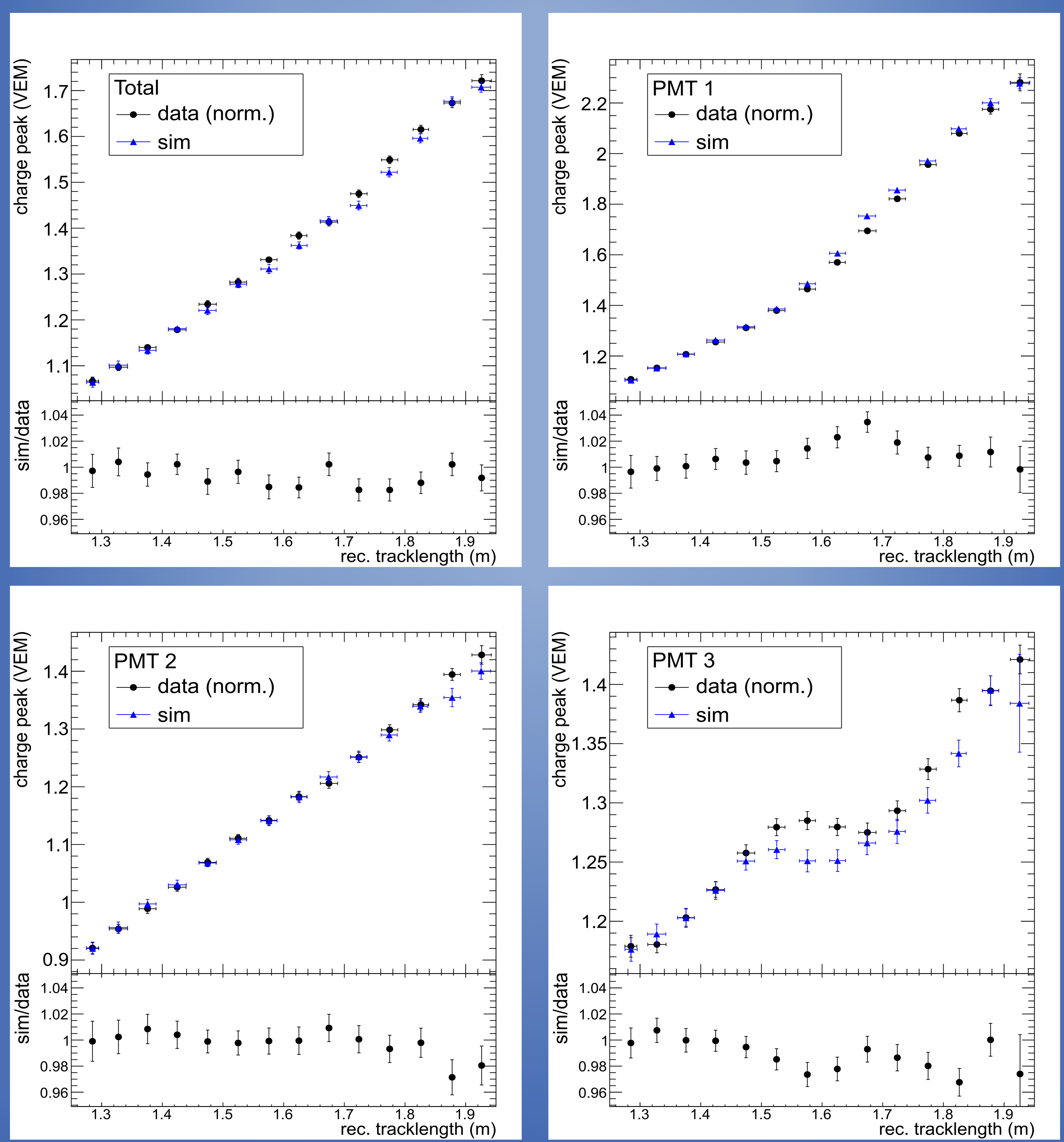
Results

When no selection is applied the WCD charge spectrum (in red) is comprised of two main components: The electromagnetic component seen as a peak in the low charge region and the muonic component seen as the second peak in the spectrum.

When the hodoscope is used to select single particles crossing both RPCs (in black) then the electromagnetic component, which is shielded from the bottom RPC by the water tank, is drastically reduced.
The single peak in the spectrum is evidence that single muons are being selected.



The position of the charge peak was studied as a function of the tracklength.
The simulation follows closely the data to the few percent level.
Structures due to geometric effects are nicely reproduced by the simulation.



The detailed measurement of individual muons crossing the WCD shows that the signal evolution with the tracklength behaves as expected when compared to the simulation. A **maximum deviation of ~2%** was found, showing that the simulation correctly describes the tank response.

In the future we foresee upgrading the setup to stabilize and enhance its acquisition capabilities. A change in the mechanical setup will allow to rotate the RPCs and increase the maximum zenith angle up to almost 90º. These measurements can be used to fine-tune the simulation of the detector and contribute to a reduction of the present systematic uncertainties deriving from the optical properties of the WCD.

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