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## Improving the universality reconstruction using independent measurements of water-Cherenkov detectors and additional muon counters

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Shower universality has demonstrated to be a sturdy tool to describe particle showers produced by primary cosmic rays. The secondary particles at the observation level can be described by a four component model: the well known electromagnetic and muonic components, the contribution due to the electromagnetic halo of the muons, and the electromagnetic particles originating from pion decays close to ground following closely the development of the muonic component. Due to the high amount of particles produced, those distributions can be described within three parameters: The total energy  $E$ , the depth of shower maximum  $X_{\max}$ , and the muon content  $N_{\mu}$ . The energy and  $X_{\max}$  are governed by the pure electromagnetic component, while the muon scale ( $N_{\mu}$ ) gives cause to differences between hadronic interaction models and primary particles, affecting the three remaining components. Though predictions on these macroscopic parameters are already viable with a single detector type (e.g. an array of water-Cherenkov detectors), large correlations between the quantities are apparent and need to be taken into account when interpreting the data. To overcome the degeneracy, additional muon counters allow for an independent measurement of the muon number at ground and at the same time reduce systematic uncertainties due to the hadronic interaction model used. The procedure is exemplified for the case of the Pierre Auger Observatory by parameterizing the signal response of particles in the water-Cherenkov array operating with underground muon detectors. The universal parameterizations allow us to estimate independently the  $E$  and  $N_{\mu}$  on an event-by-event basis. The incorporation of muon detectors evidences e.g. the possibility of an unbiased energy estimation based only on the universality description of the shower.

### Collaboration

– not specified –

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