Tuning parametric models of the atmospheric muon flux in MUPAGE to data from the KM3NeT detector

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1. KM3NeT

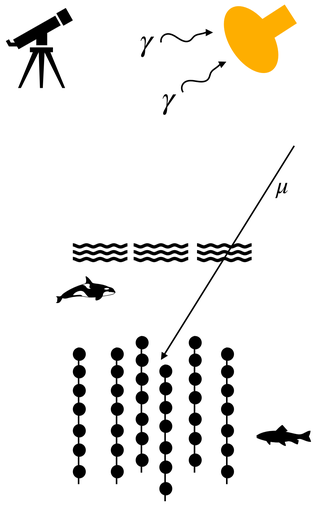
KM3NeT is a neutrino research infrastructure of 2 detectors being built in the Mediterranean Sea.

Photomultiplier tubes (PMTs) record the Cherenkov light from
- particles produced in neutrino interactions
- atmospheric muons
- Potassium-40 decay.

These PMTs are enclosed in optical modules.
18 optical modules form a detection unit.

The KM3NeT/ORCA detector currently operates with 6 detection units (ORCA-6).

KM3NeT can distinguish individual atmospheric muons, measure transverse momentum
→contribute to cosmic ray physics!

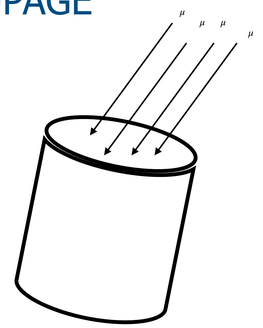


2. MUPAGE

Generates muons on a virtual can surface according to parametric formulae.

These formulae describe the flux, lateral spread, and energy spectrum of the muons.

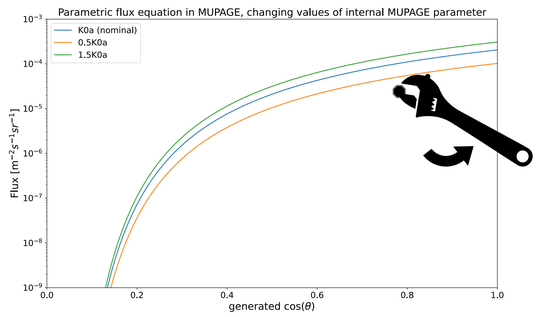
For high-precision measurements in KM3NeT, this simulation should describe the data to a high-degree of accuracy.



3. Tuning

Internal parameters in MUPAGE can be varied, changing the generated distributions.

Tune reconstructed observables from KM3NeT simulation to agree with data.



4. Simulation Chain

muon generation

Cherenkov light propagation

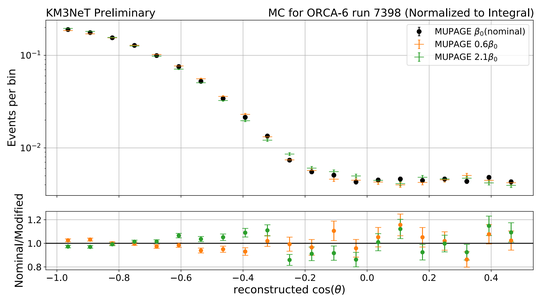
trigger & detector simulation

Reconstruction chain

5. Which Parameters?

A data run from ORCA-6 is simulated, and the parameters in MUPAGE are varied by the same amount, one at a time.

→ Gives the 6 parameters with the greatest impact on the distributions:
$\beta, \nu_{1b}, K_{1a}, d_{0b}, b_{1b}, \rho_{0b}$.



An example is shown here, with β affecting the reconstructed atmospheric muon direction. We see the effect on the shape only.

6. Quantify the Agreement Between Simulation & Data

The significance S gives a value of 0 when the *shape* of two distributions are exactly the same.

Simulate observables in the KM3NeT detector for different MUPAGE parameters, and use the significance to compare them to data.

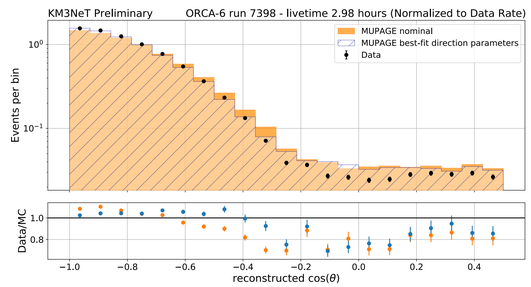
→ something to minimise.

$$S = \frac{1}{N}\sum_{i=0}^{N}\frac{|a_i - K\cdot b_i|}{\sigma^2(a_i + K^2\cdot\sigma^2(b_i))}$$

7. Data-MC Comparisons - Preliminary Scan of Parameters

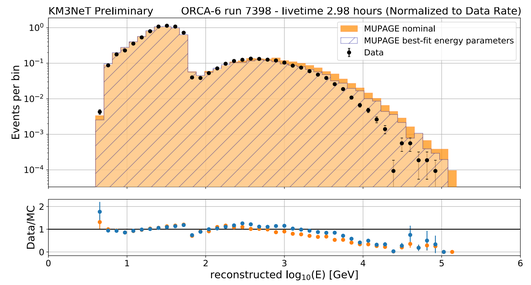
The 6 MUPAGE parameters are varied independently, and the observables are compared between simulation and data.

Preliminary result for the best agreement parameters in the reconstructed direction.



Different parameters give the best agreement for the energy distribution.

⟹ these simulated distributions can be tuned, can agree better than nominal case.



Cuts: $\cos\theta < 0.5, E > 5$ GeV. Focusing on the agreement in *shape*.

TL;DR A study of tunable parametric simulations is achieved with MUPAGE parameters, and through the significance test, the agreement between Monte Carlo and data can be quantified & improved for a preliminary scan of MUPAGE parameters.
This contribution highlights the effort to achieve high precision measurements in KM3NeT.

S. Adrian-Martinez *et al.*, *"Letter of intent for KM3NeT 2.0"*, J. Phys. G **43** (2016) no.8, 084001

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