Simulating the signal of the AMIGA underground detectors of the Pierre Auger Observatory

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Abstract: We present a detailed description of the simulation development and validation for the underground muon detector signal of the Auger Muons and Infill for the Ground Array (AMIGA) system, a lowerenergy enhancement at the Pierre Auger Observatory. To this aim, the detection system was thoroughly characterized in the laboratory. It consists of plastic-scintillator strips with optical fibers that conduct light towards silicon photomultipliers whose output is then processed with two complementary read-out channels. These measurements allowed us to design a fast and reliable simulation chain that fully reproduces the signal of single muons impinging on the scintillators.

1. Simulation of the underground muon detector (UMD)

73 × 3 buried modules

Two readout channels:
· Binary (low muon density)
· ADC (high muon density)

1 module:
· 10 m² scintillator detector
· 64 strips + optical fibers
· 64 silicon photomultipliers (SiPM)

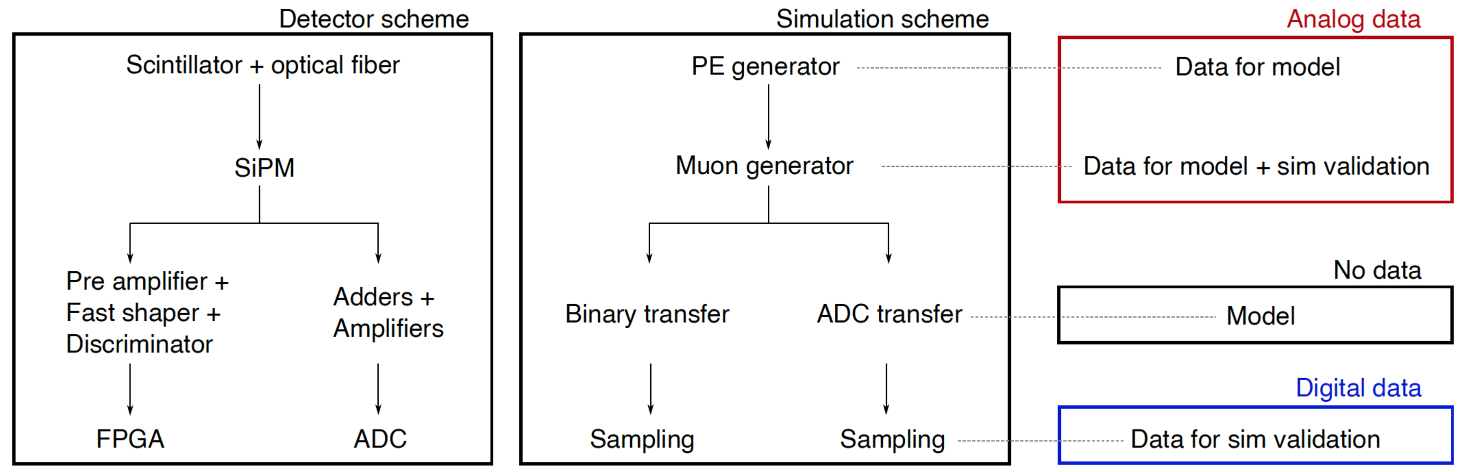

Figure 1: (schematics of the UMD detector components (left), of the simulation steps (middle) and summary of the data used to develop and validate the simulation (right).

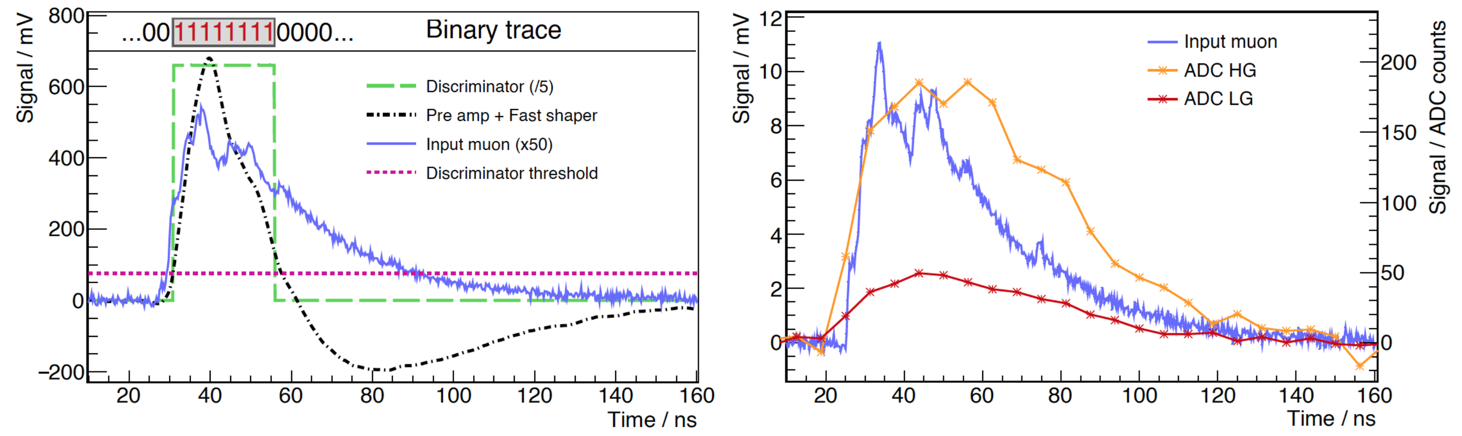

Figure 2: example of simulated binary (left) and ADC (right) traces at 2 m on the scintillator strip.

2. PE generator

Photo-equivalent (PE) generator:
· 7-parameter model
· fit to analog dark counts

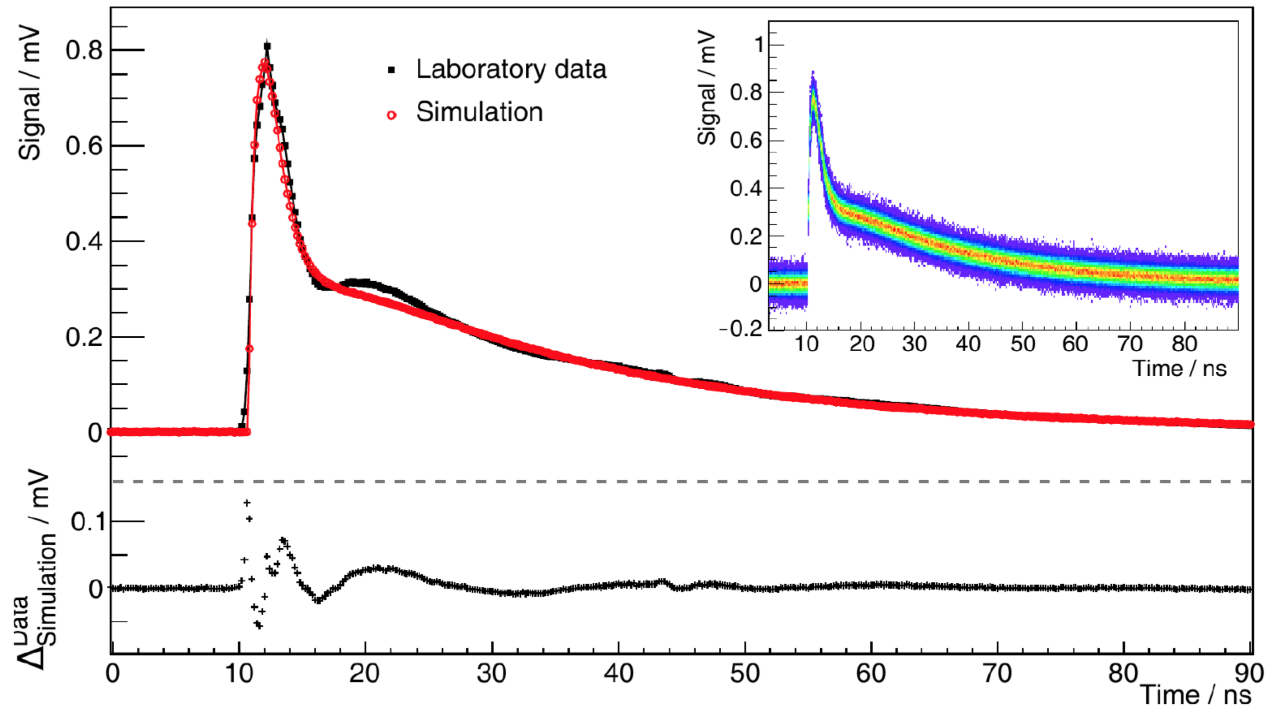

Figure 3: Mean single-PE signal. (Inset) 2000 simulated single-PE pulses. (Bottom) total difference between simulation and data.

3. Muon generator

Number of PE with double exponential decay law

Convolution of scintillator and fiber start times to determine timing

Validations performed as a function of fiber length (distance) between muon and SiPM

Main features for detector performance:
· Amplitude (binary)
· Charge (ADC)
· Full width at half maximum

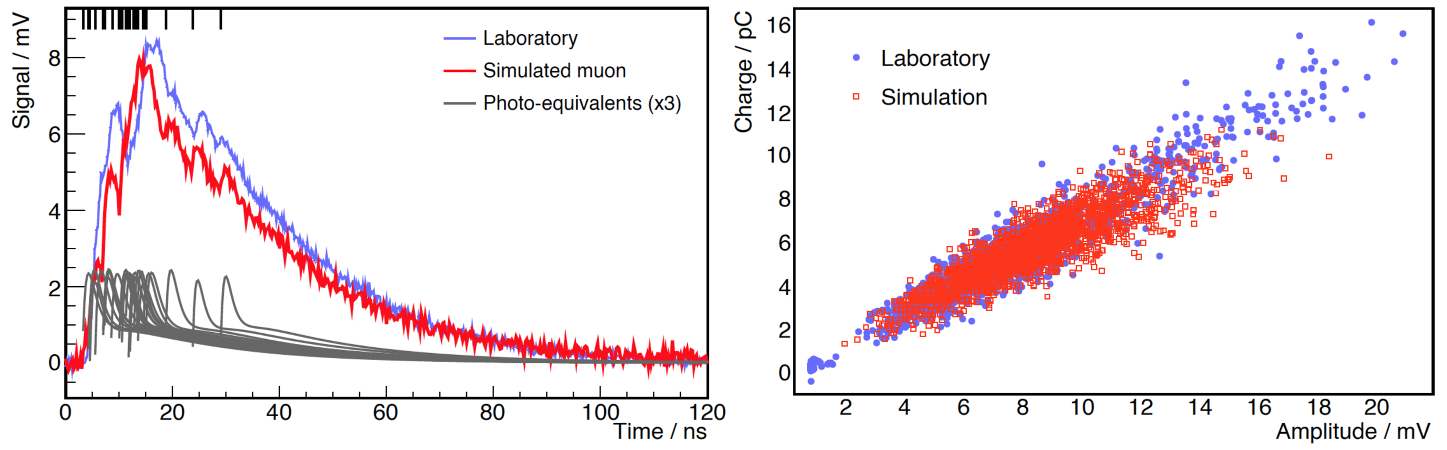

Figure 4: (Left) example muon signal at 2 m on the scintillator strip. (Right) muon signal charge as a function of the signal amplitude.

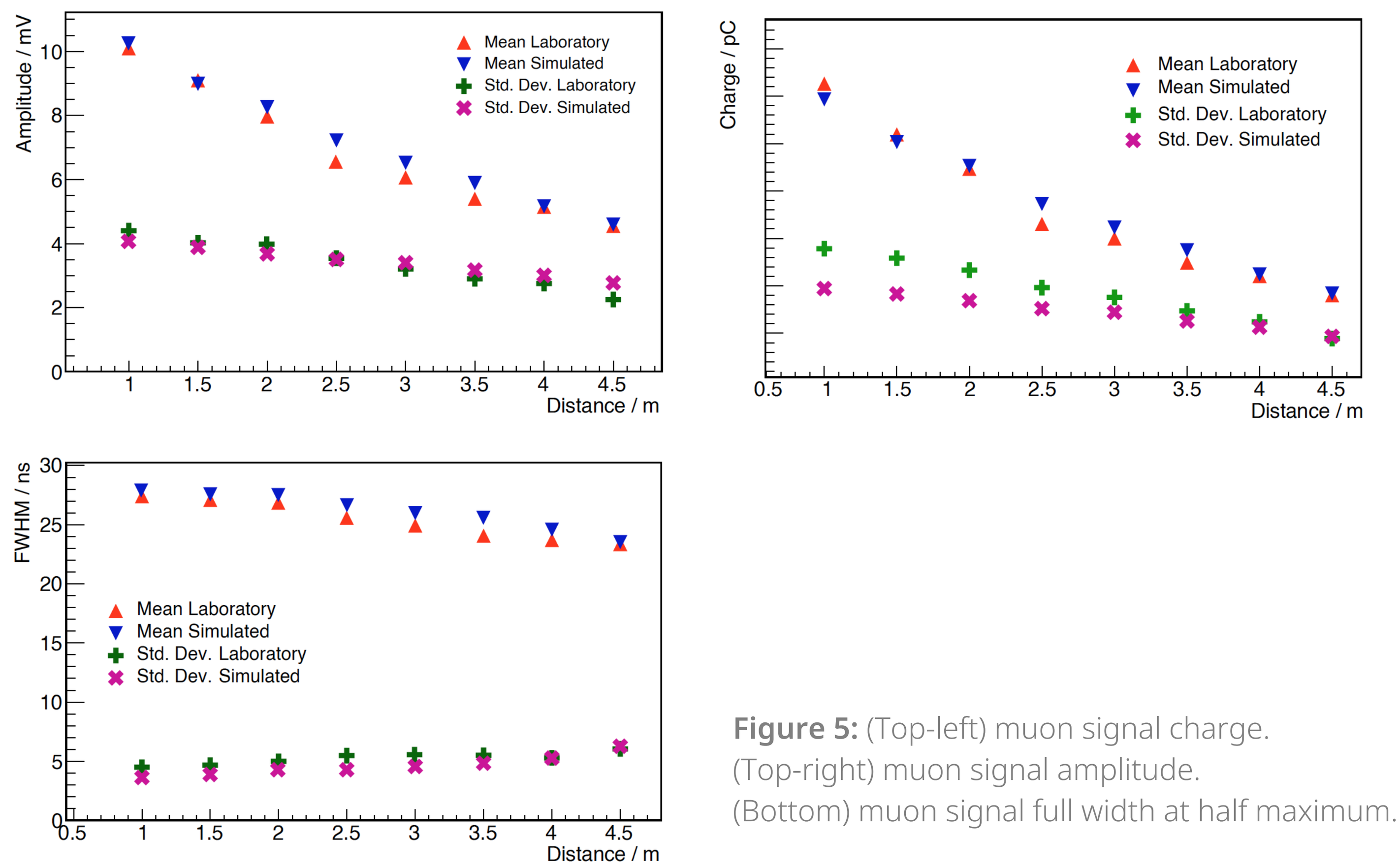

Figure 5: (Top-left) muon signal charge. (Top-right) muon signal amplitude. (Bottom) muon signal full width at half maximum.

4. Binary acquisition mode

Two amplitude thresholds tested

Reconstruction strategy depends on signal width

98.5% efficiency with 2.5 PE

Efficiency loss as expected from amplitude threshold

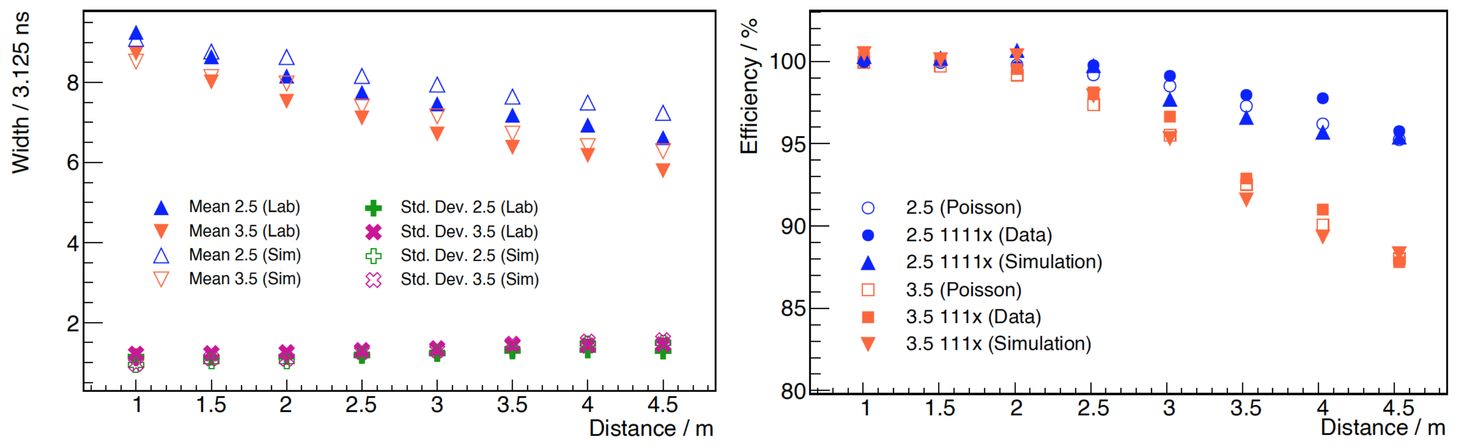

Figure 6: muon signal width (left) and muon detection efficiency (right).

5. ADC acquisition mode

Two amplification channels tested (low- and high-gain)

Reconstruction strategy depends on signal charge

Up to ~350 simultanous muons with LG

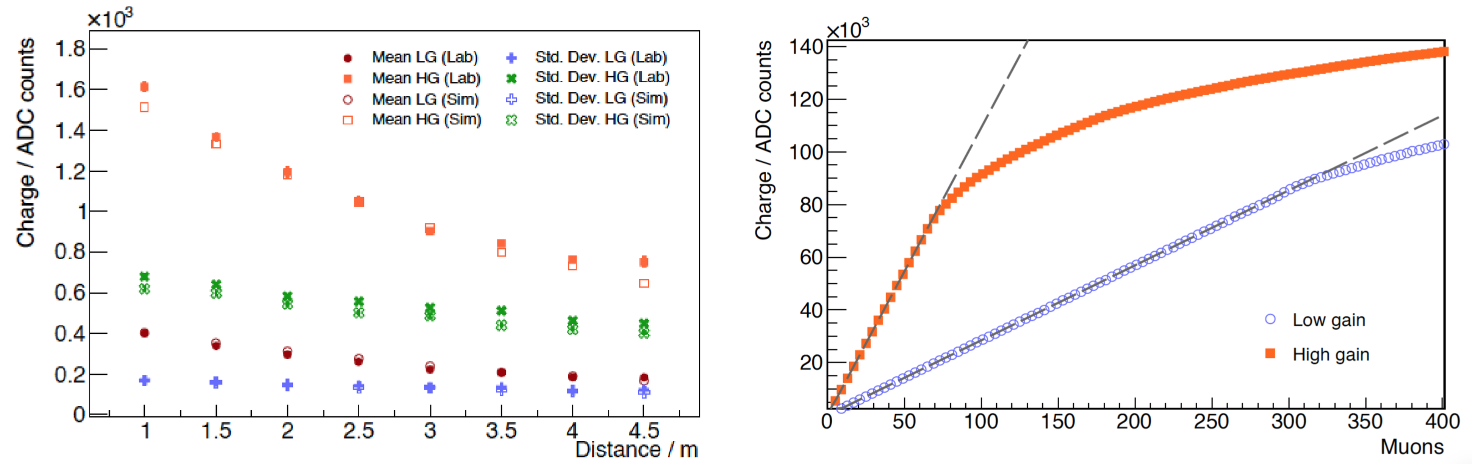

Figure 7: expectations for sub-GeV dark-matter detection with skipper-CCDs compared with current limits (gray and cyan shadows) for light (left) and heavy (right) mediators. Adapted from OSCURA at SNOWMASS

SUMMARY

- ✓ Simulation of UMD signal completed
- ✓ Good agreement between simulation and data for binary and ADC main features
- ✓ 98.5% efficiency for single-muon signals
- ✓ Saturation at ~350 simultanous muons per 10 m² module

More information and references here