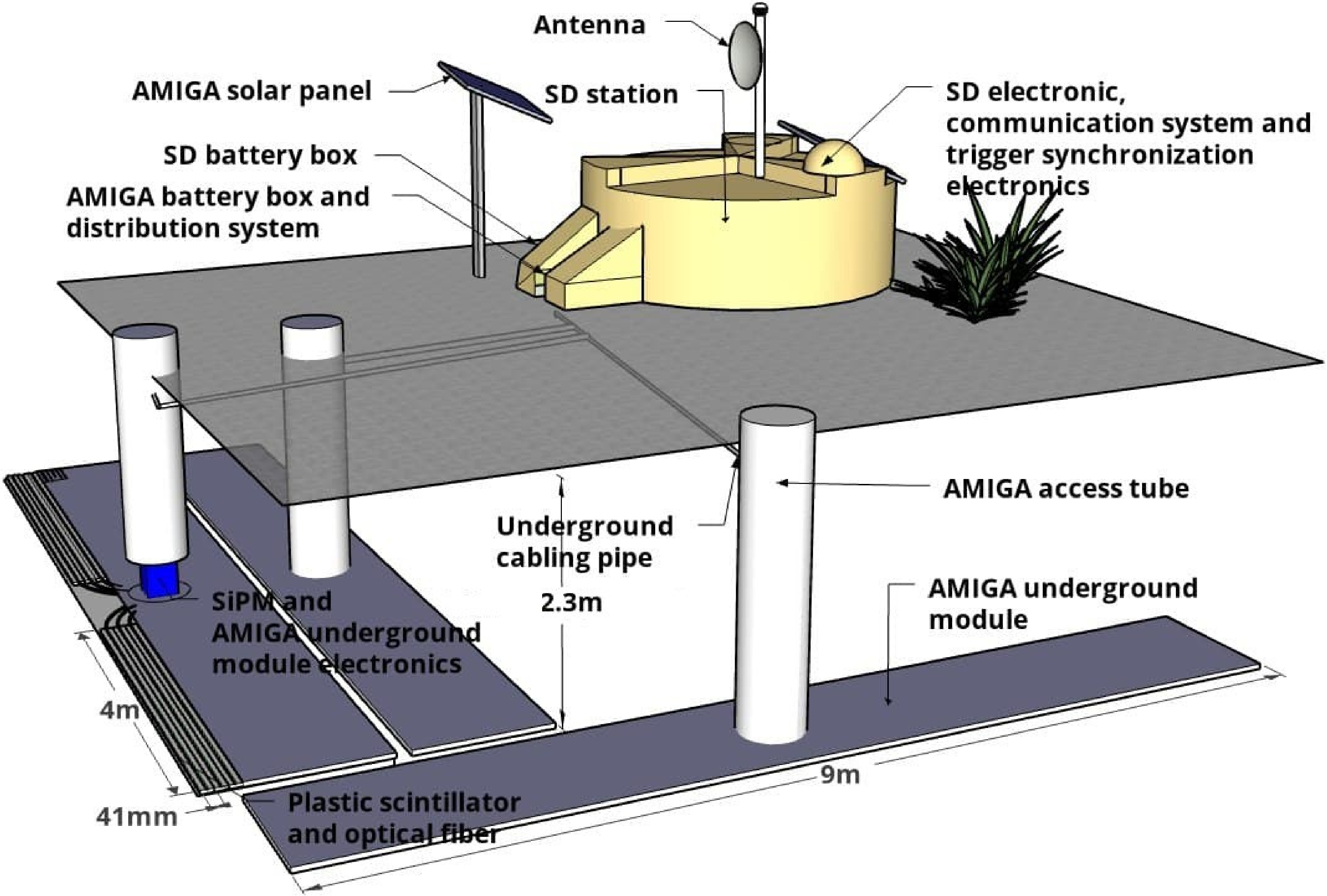
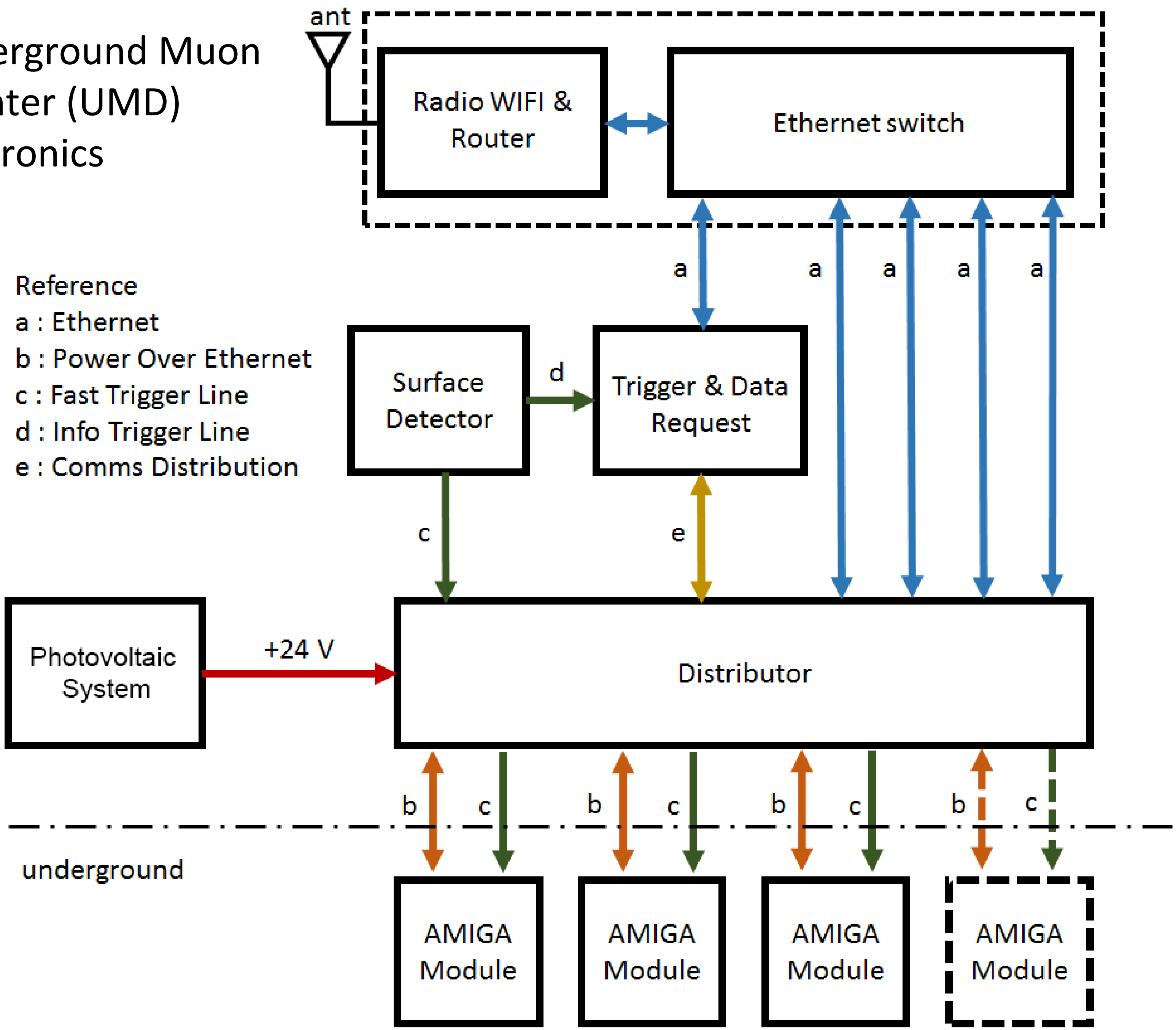
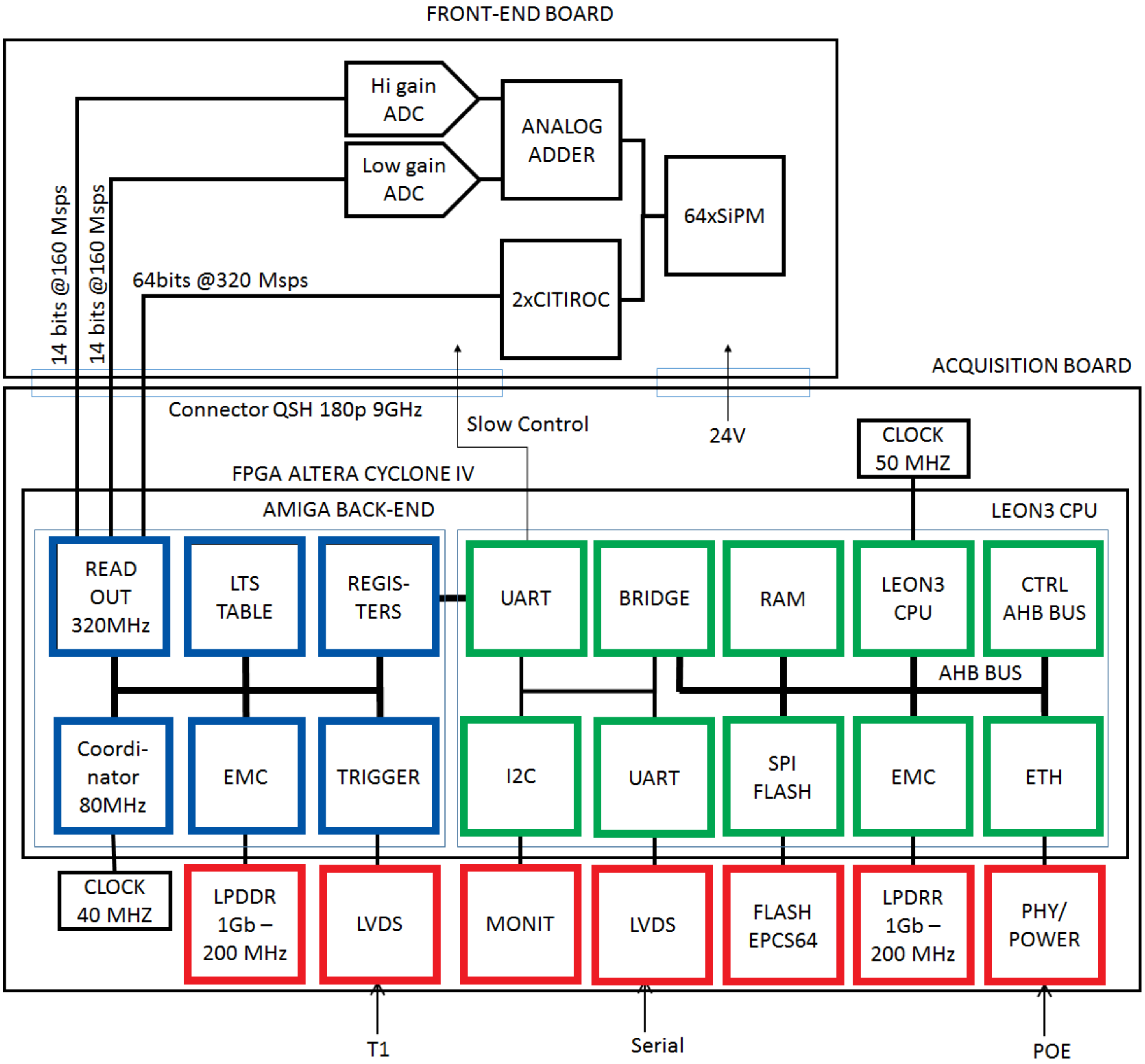
Pierre Auger Surface detector (SD) and Underground Muon Counter (UMD)



Underground Muon Counter (UMD) electronics



Reference
a : Ethernet
b : Power Over Ethernet
c : Fast Trigger Line
d : Info Trigger Line
e : Comms Distribution



FRONT-END BOARD

Hi gain ADC

Low gain ADC

ANALOG ADDER

64xSiPM

2xCITIROC

14 bits @160 Msps

14 bits @160 Msps

64bits @320 Msps

Connector QSH 180p 9GHz

Slow Control

24V

ACQUISITION BOARD

CLOCK 50 MHZ

FPGA ALTERA CYCLONE IV

AMIGA BACK-END

LEON3 CPU

READ OUT 320MHz

LTS TABLE

REGIS-TERS

UART

BRIDGE

RAM

LEON3 CPU

CTRL AHB BUS

AHB BUS

Coordi-nator 80MHz

EMC

TRIGGER

I2C

UART

SPI FLASH

EMC

ETH

CLOCK 40 MHZ

LPDDR 1Gb – 200 MHz

LVDS

MONIT

LVDS

FLASH EPCS64

LPDRR 1Gb – 200 MHz

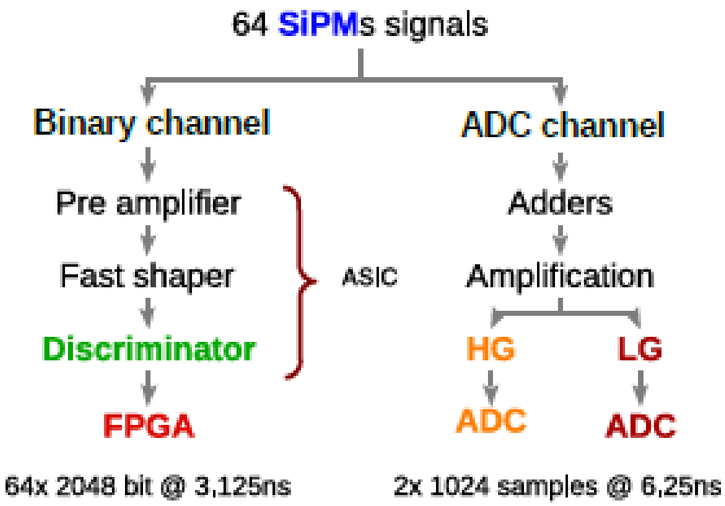
PHY/ POWER

T1

Serial

POE

UMD raw data



64 SiPMs signals

Binary channel

Pre amplifier

Fast shaper

Discriminator

FPGA

ASIC

ADC channel

Adders

Amplification

HG

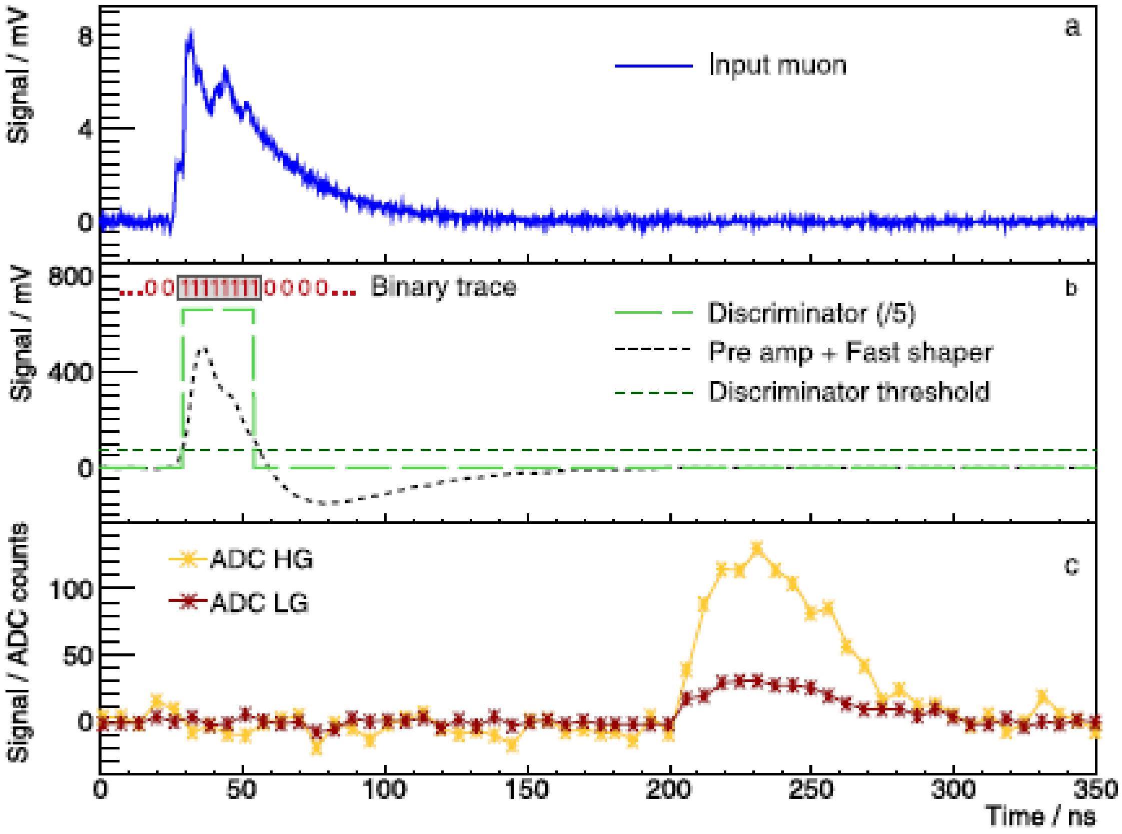
ADC

LG

ADC

64x 2048 bit @ 3,125ns

2x 1024 samples @ 6,25ns



Lab setup and Muon telescope

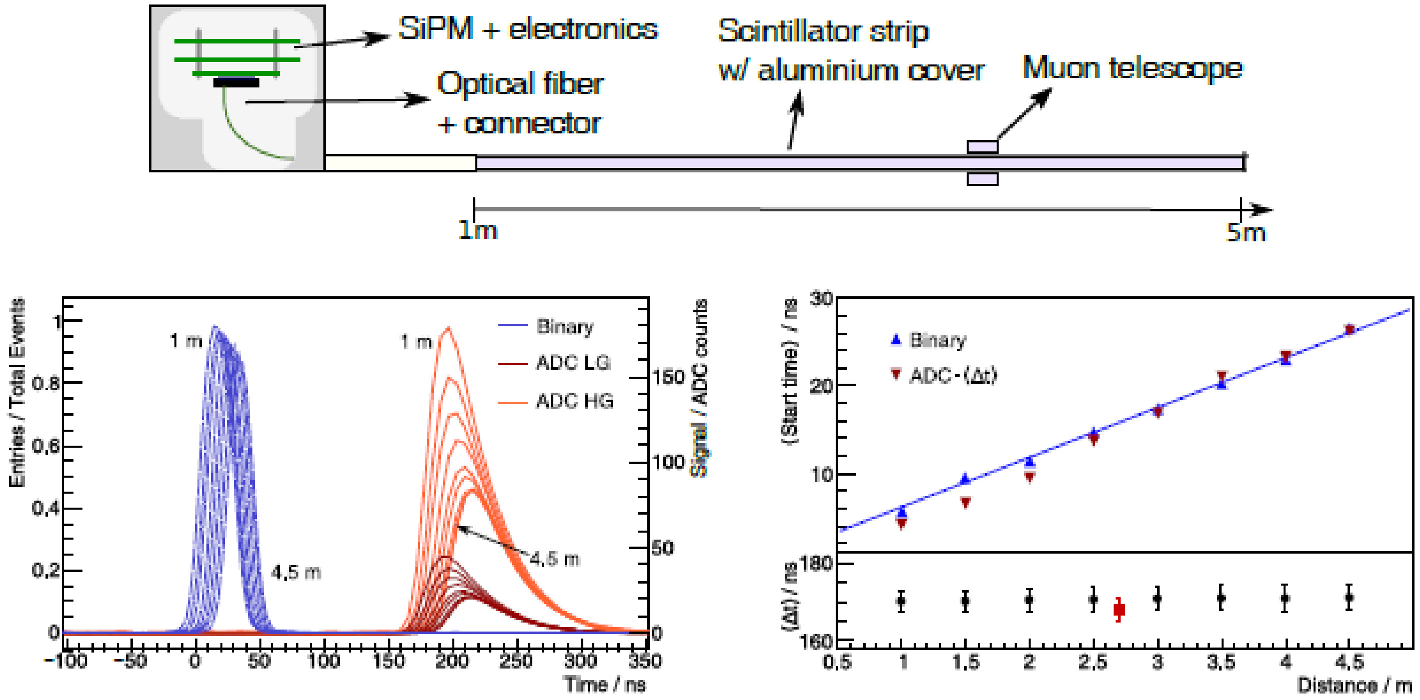


Figure 2: (Top) Schematics of the laboratory setup used to characterize the UMD traces. (Bottom-left) Average trace for the binary (dashed-blue curves) and ADC (solid-red curves) channels measured at different optical-fiber lengths (1 to 4.5 m). (Bottom-right) Signal start time as a function of the optical-fiber length, for the binary (blue triangles) and ADC (red triangles) channels. The difference between the channel start times (Δt) measured in the laboratory (blue circles) and the field (red square) is shown in the lower part.

Time structure of the current SiPM signal in AMIGA

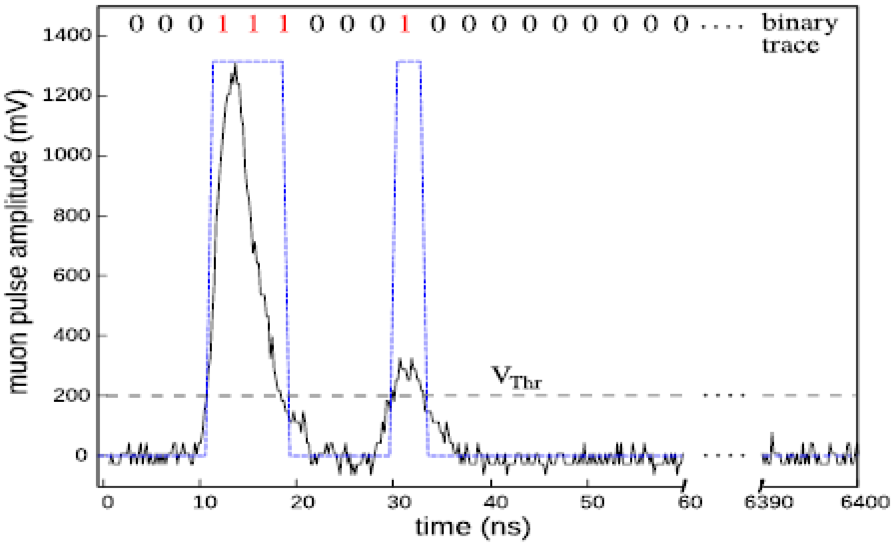


Fig. 3 The counting procedure: a muon pulse (black) is discriminated, and the discriminator signal (dashed blue) is then digitally sampled by an FPGA every 3.125 ns up to 6.4 µs. As a result, the binary trace on the top of the figure is obtained

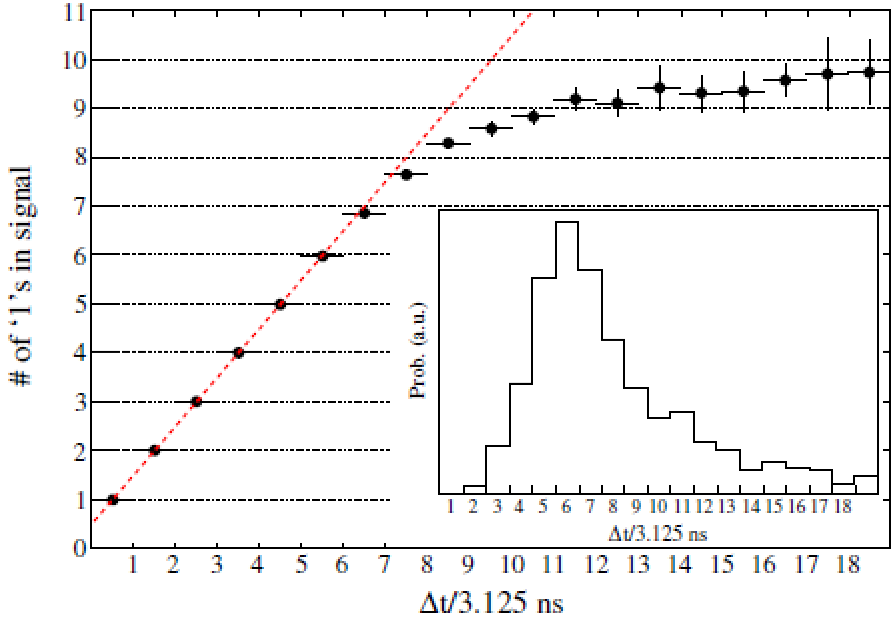
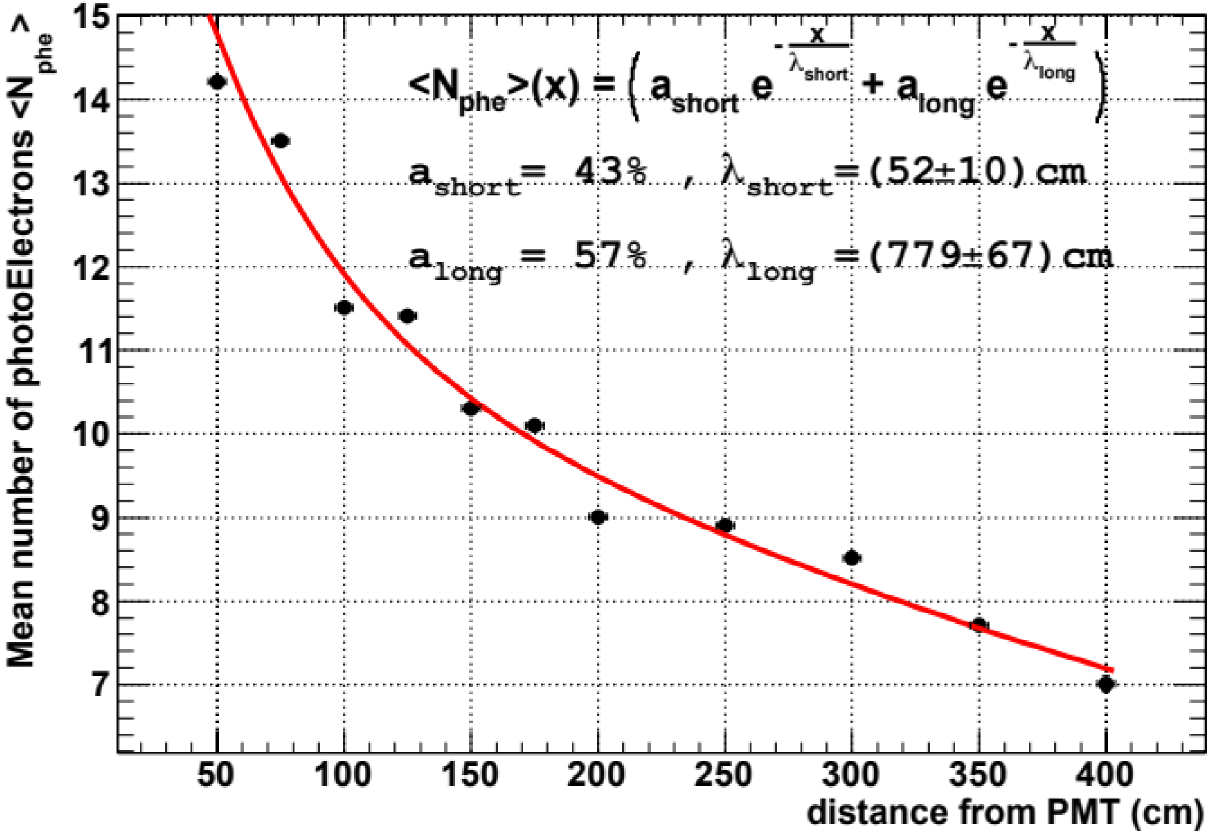


Fig. 4 Relation between the number of '1's and the length of the digital trace, Δt. The red dashed line represents the identity function. The inset shows the distribution of Δt

Measured attenuation curve



SiPMs time response

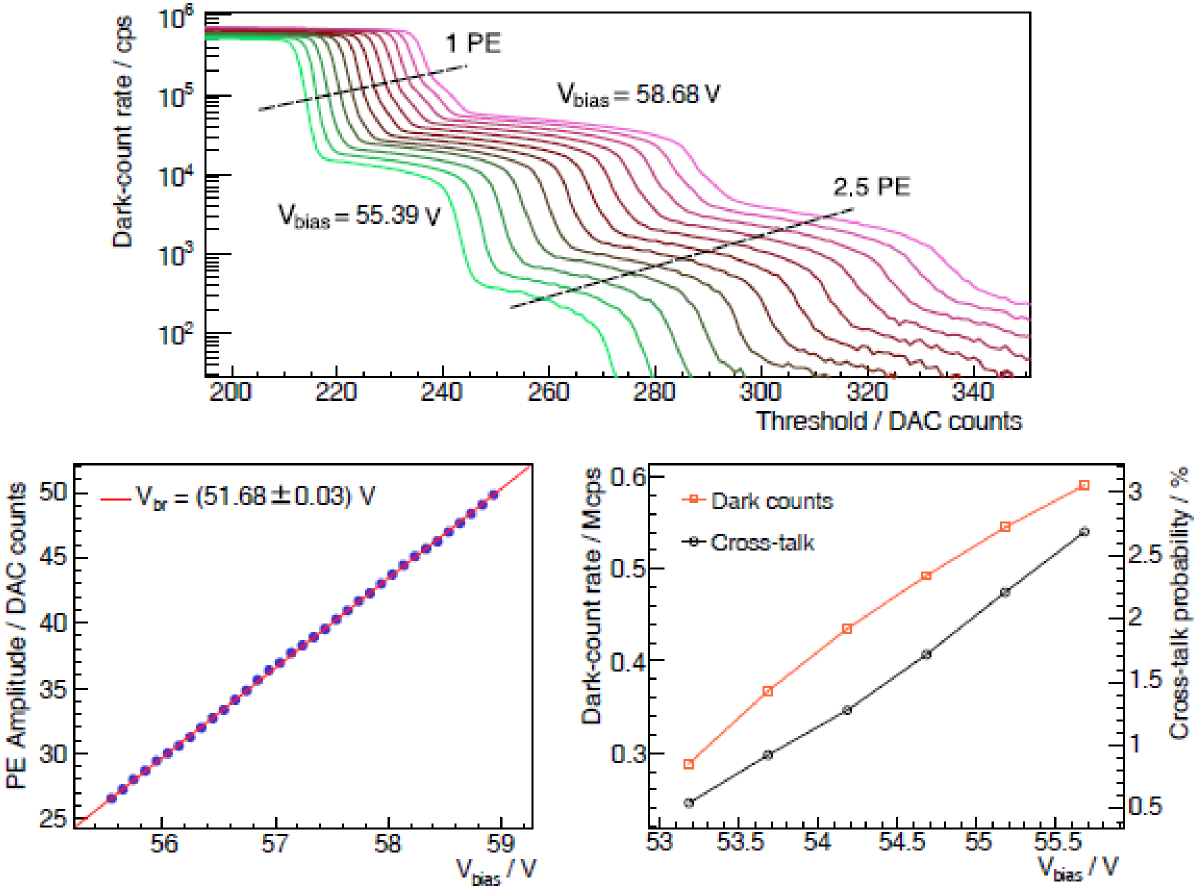


Figure 3: (Top) Dark-counts per second (cps) as a function of the discriminator threshold at different V_{bias}. The dark-count rates and PE amplitudes shift towards higher values when rising the V_{bias}. (Bottom-left) V_{br} determination for an individual SiPM. The linear extrapolation to 0 amplitude yields the value of V_{br}. (Bottom-right) Dark-count rate (red squares) and cross-talk (black dots) as a function of the V_{bias}.

SiPMs
time distribution

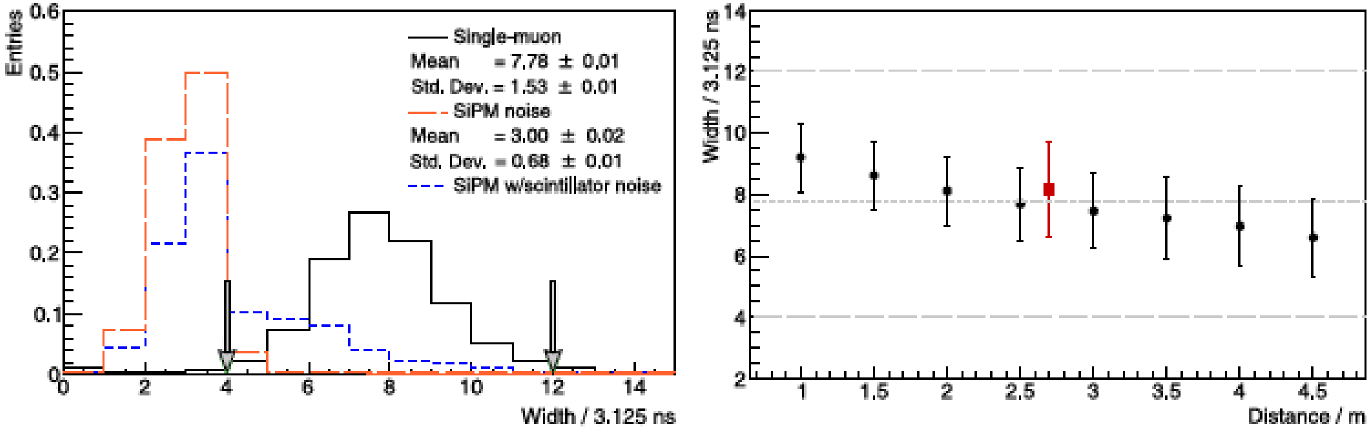


Figure 8: Binary channel. (Left) histograms of signal widths due to single muons (black), SiPM noise (long-dashed red), and SiPM plus optical fiber-scintillator noise (short-dashed blue). (Right) mean width of single-muon signals as a function of the optical-fiber length. The one standard deviation from the mean is displayed as error bars. The red square corresponds to the result obtained with field data. The widths are indicated in number of samples (3.125 ns).

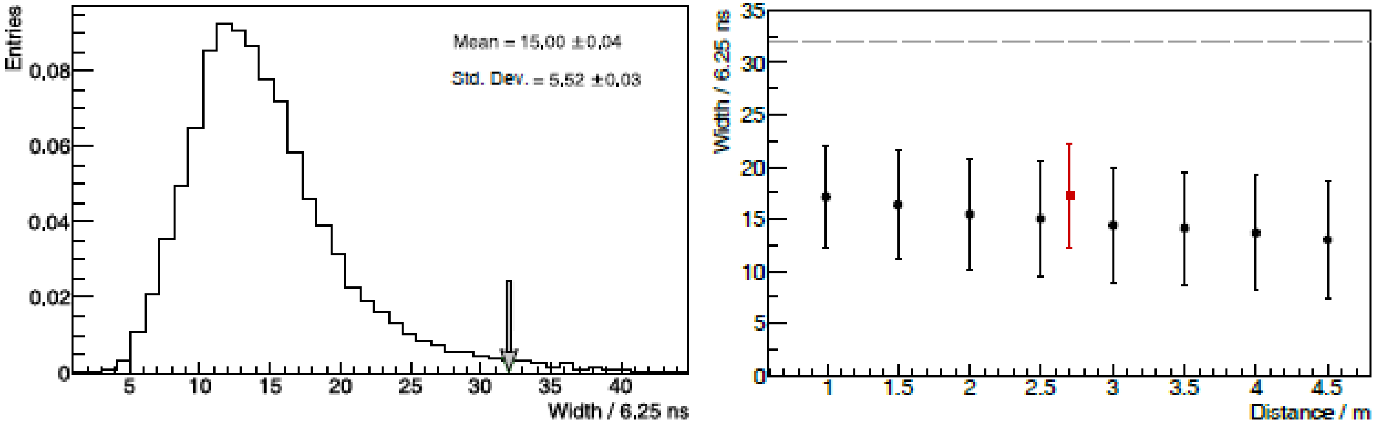


Figure 9: ADC channel. (Left) histogram of the single-muon signal width measured with the ADC in the laboratory. (Right) Mean width of the single-muon signal as a function of the position of the impinging muon. Results from the laboratory (black circles) and field (red squares) with one standard deviation as error bars are presented. The widths are indicated in number of samples (6.25 ns).

SiPMs noise

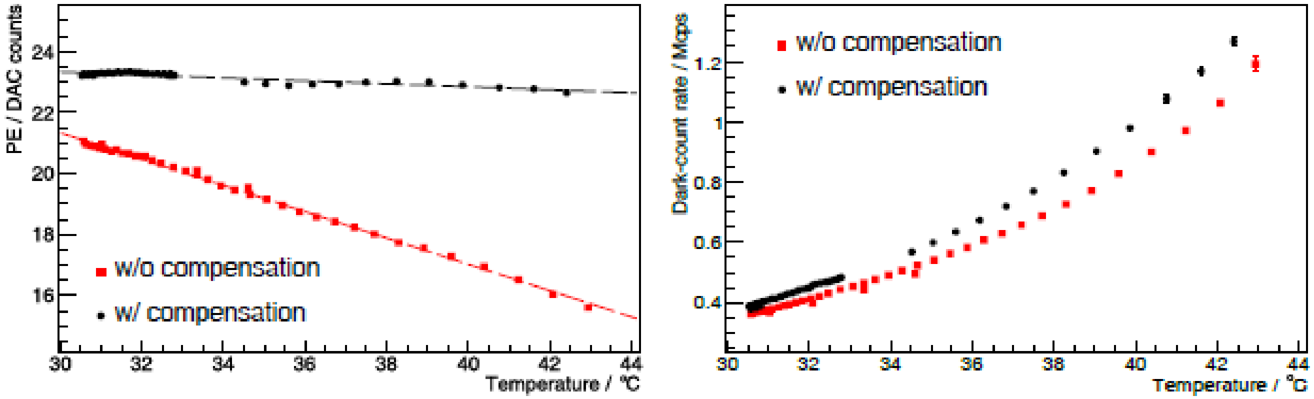


Figure 6: 1 PE amplitude (left) and dark-count rate (right) as a function of the temperature of the high-voltage source measured in the laboratory. We display the results for measurements with and without the compensation mechanism on. The fitted slopes for the PE amplitude data are (-0.049 ± 0.003) PE / °C and (-0.431 ± 0.002) PE / °C, respectively.

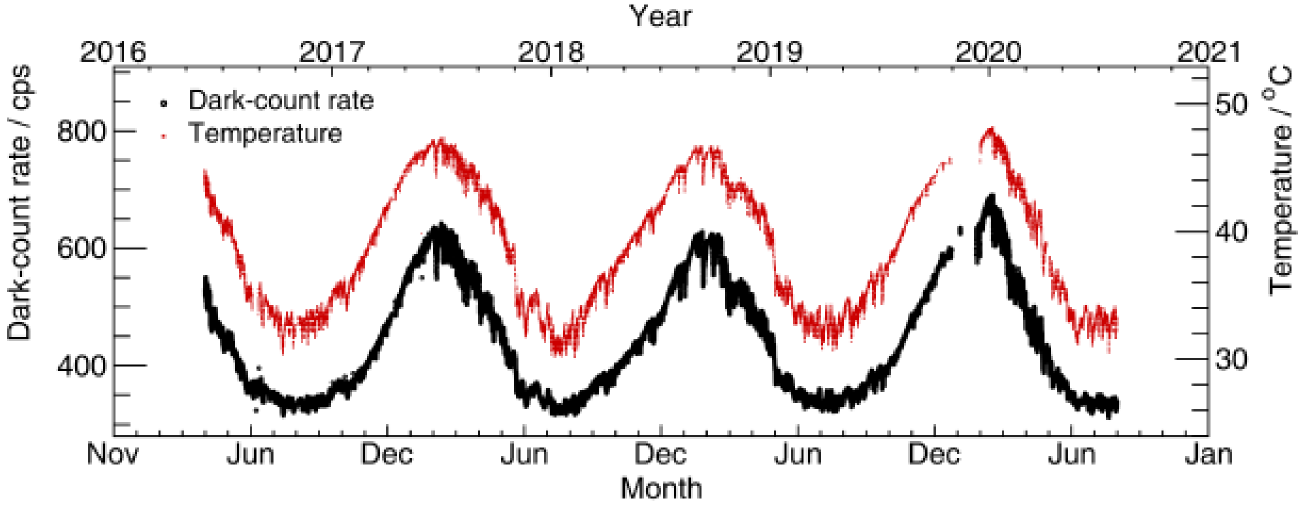
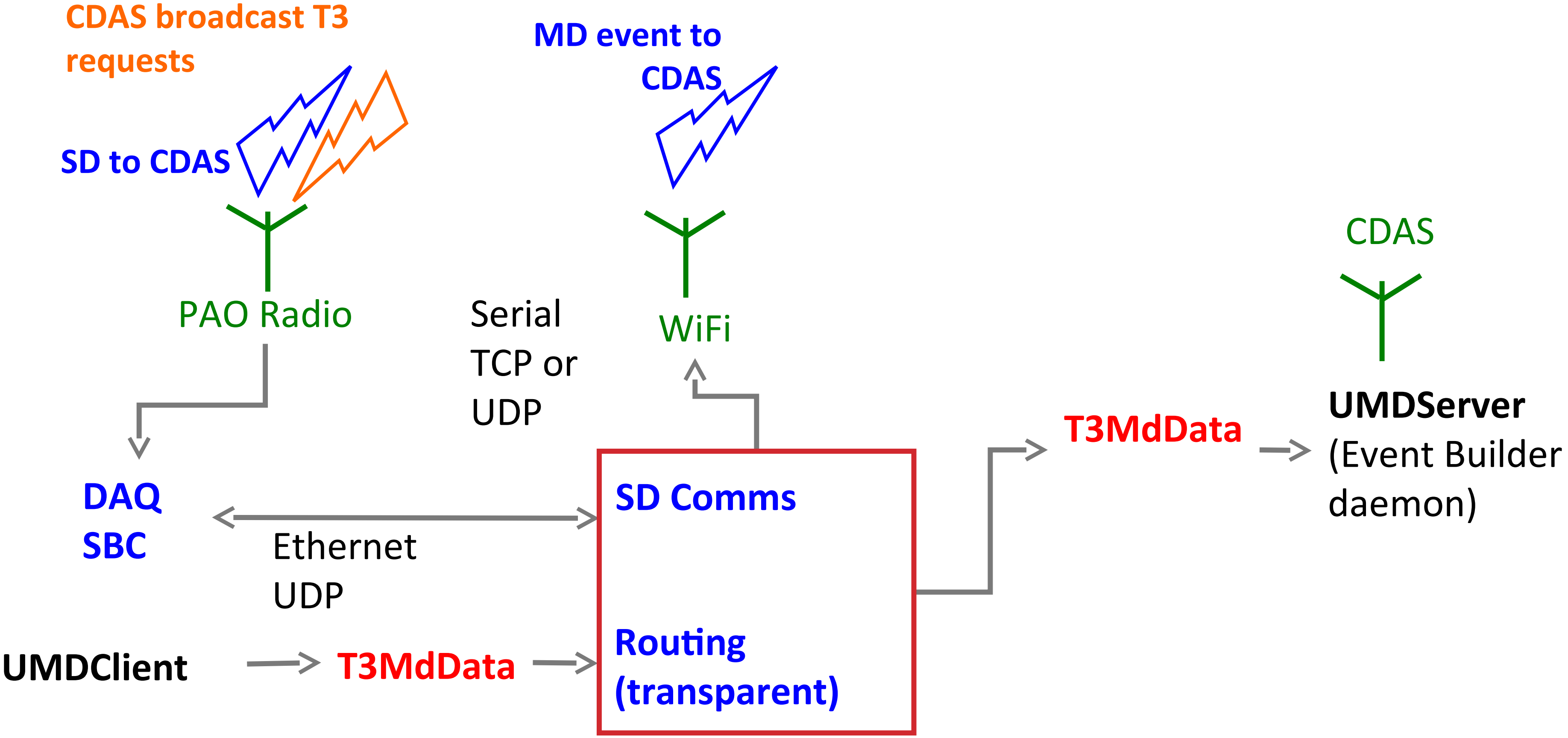


Figure 7: Mean rate per SiPM (left y-axis) and mean electronics temperature (right y-axis) averaged every hour in an example scintillation module in operation in the field. The gap between mid-December and January of 2020 corresponds to a period in which the corresponding position was not in acquisition.



CDAS broadcast T3 requests

SD to CDAS

MD event to CDAS

CDAS

PAO Radio

Serial TCP or UDP

WiFi

UMDServer (Event Builder daemon)

T3MdData

DAQ SBC

Ethernet UDP

SD Comms

Routing (transparent)

UMDClient → **T3MdData** →

What does T3MdData contain?

Msg. Header → **a) 20 bytes** (identifiers to gather n-folded counter data in 1 event in CDAS)

Msg. Data → **b) 0 to 6144 bytes** of compressed muon data

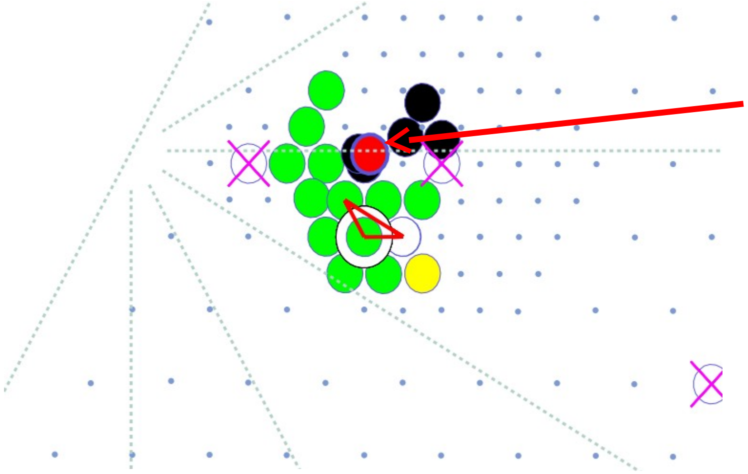
The trigger system of Pierre Auger is hierarchical:

1) The first level of trigger (T1) is generated independently by each station based on local analysis of the signals produced by its photon detector. At calibrated SD stations the threshold is set for an average T1 trigger rate of about 100 events/sec. These events are stored in a circular buffer with a capacity of 3000 events. Events are identified by a 64-bit timestamp (GTS) obtained from the GPS receiver with a latency of about 200 μs after T1 as measured in the laboratory.

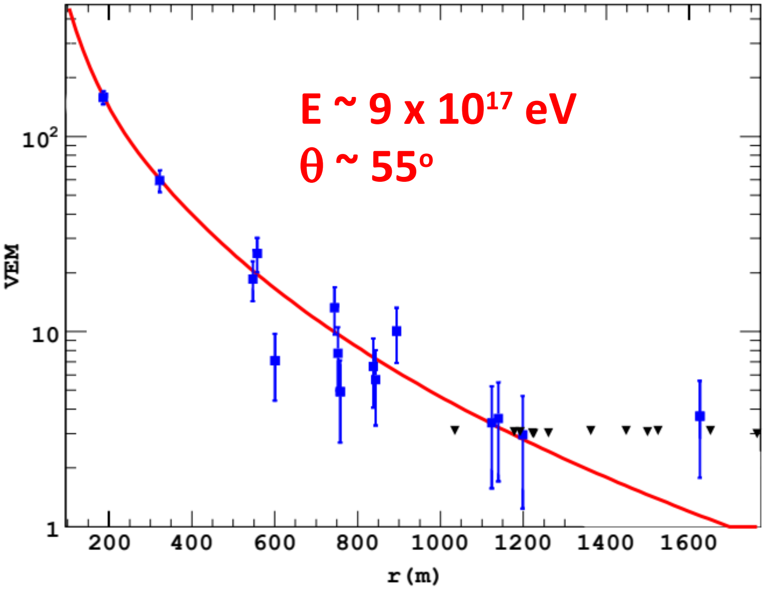
2) The station then applies predefined quality cuts to generate a second level trigger T2 with an average rate of 20 Hz. A list of T2 time-stamps is sent to CDAS (Central Data Acquisition System) once every second. CDAS searches through the list of T2 triggers for a coincidence in vicinity and time.

3) When a coincidence is found, an array trigger (T3) is sent back to participating stations and its neighbors. Upon receiving a T3 trigger request, the station replies to the CDAS with the event data, if it is present in the circular buffer.

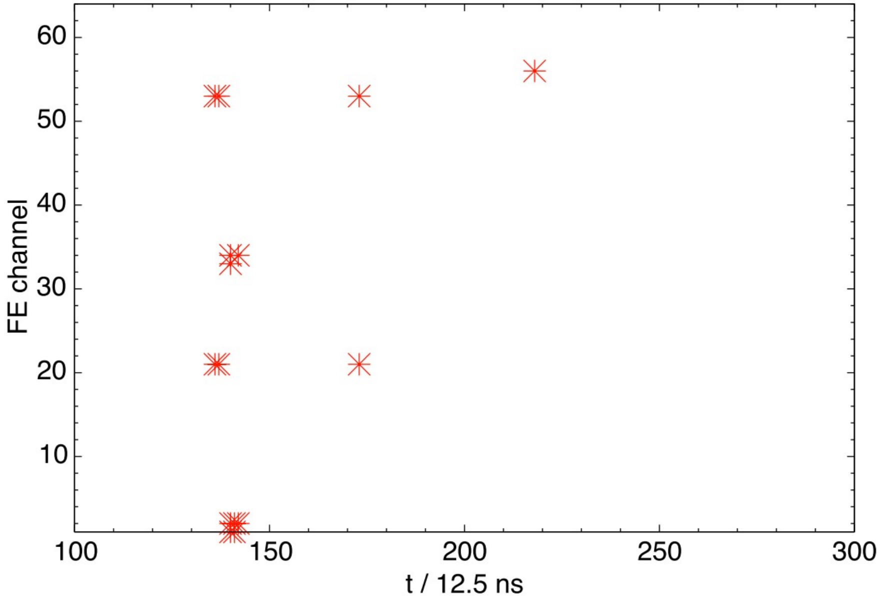
THE VERY FIRST T3: Friday 2012/02/10 @ 21:49:55 hs



Corrientes: SD+MD



E ~ 9 x 10^{17} eV
θ ~ 55°



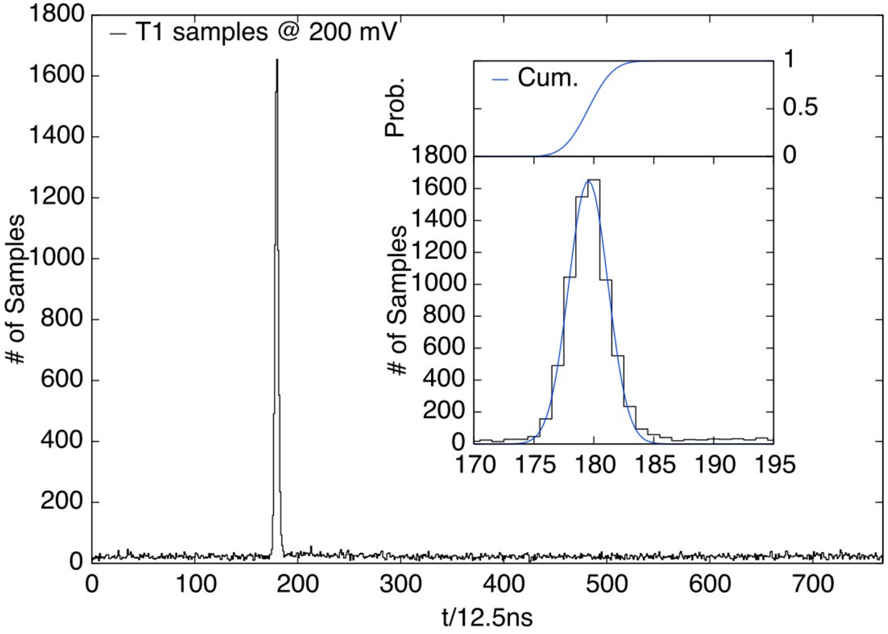
SD + MD

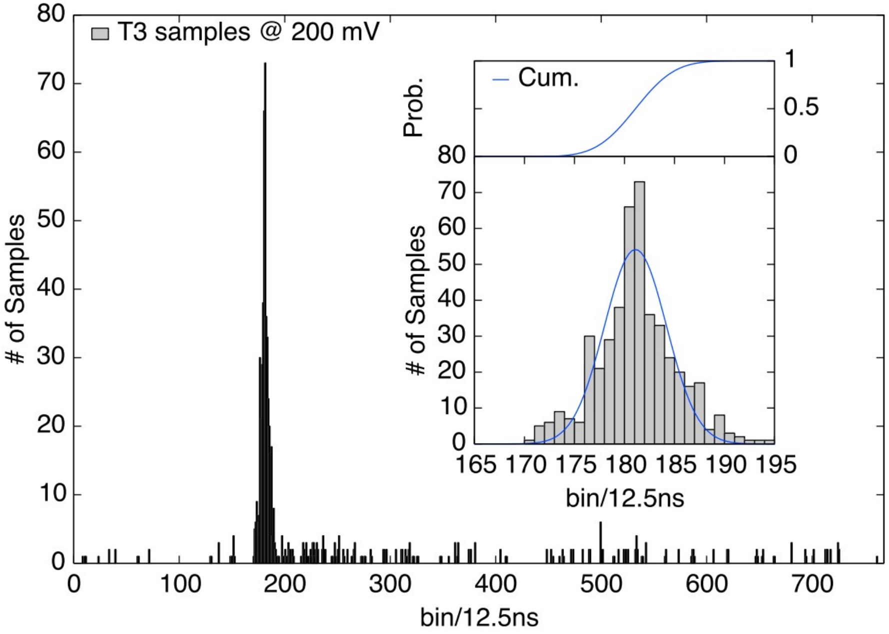
Start of a new hybrid era...

First DATA: T1 vs T3 EventS width

ICRC2011 **T1** events
(some of them were T3 but we could not know!)

T3 events
(1 week of acq)





T1 event time distribution:
width **≈60 ns**

T3 event time distribution:
width **≈200 ns**