

From Detector Signals to Cosmic Muons

How do we turn an electrical detector signal into a particle event we can trust?

CW_TOP and CW_BOTTOM

Hands-on Day I / 14 September 2026

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Detector components



CMU reference unit

Component	Role
Scintillator	Converts deposited energy into light
SiPM and bias supply	Convert detected light into an electrical signal
Amplifier and ADC	Prepare and digitize the pulse
Nano ESP32	Applies trigger logic and builds event records
GPS / BME280 / storage	Record timing, location, conditions and data

The one-hour workflow

Time	What you will do
00–05 min	Identify the detector components and measurement chain
05–15 min	Inspect a real waveform and watch live event records
15–30 min	Open a .log file and calculate counts, duration and rates
30–45 min	Plot the ADC distribution, then compare C and N
45–55 min	Interpret the selected populations and discuss coincidence
55–60 min	Connect the data chain to IceCube/HUNT and answer the main question

6–8 groups of about 5 students. One laptop per group with the starter script ready.

Each group produces a rate summary, two ADC plots and one evidence-based conclusion.

A real waveform in the viewer

Open the waveform viewer

The instructor selects a recorded event from CW_TOP or CW_BOTTOM and shows its trace.

Read the signal together

Locate the baseline, pulse maximum and decay tail. Read the time and ADC axes. Look for clipping.

ADC = analog-to-digital converter. 12-bit codes range from 0 to 4095.

$$\Delta t = \frac{1}{f_s} = \frac{1}{10^6 \text{ s}^{-1}} = 1 \text{ } \mu\text{s}$$

At 1 MSPS, adjacent samples are 1 microsecond apart.

Live events in the local interface

Watch CW_TOP and CW_BOTTOM

The instructor opens the local web interface. Identify the displayed stream and event count.

Follow an event into the record

Find its event number, timestamp and ADC value. Notice the C/N flag; we will use it later.

Count over a common interval

Record the start and end counts and elapsed time for one stream. Compare event times with screen updates.

Activity A: open the event log

Each group receives the same .log file for the first analysis.

Field	First inspection
Event number / uptime	Check sequence, resets and gaps
Timestamp	Check the start, end and time basis
ADC	Find the recorded signal-size column
C/N flag	Keep both categories initially
Mode and file identity	Confirm one detector, one run and stable settings



Activity A: counts and rates

Use the full accepted run and record the following:

Result	Your value
Total recorded events	
Start and end time / uptime	
Elapsed duration in seconds	
All-event rate and Poisson uncertainty	

$$R = \frac{N_{\text{all}}}{T}, \quad R_C = \frac{N_C}{T}$$

$$\sigma_R \simeq \frac{\sqrt{N_{\text{all}}}}{T}, \quad \sigma_{R_C} \simeq \frac{\sqrt{N_C}}{T}$$

For now, calculate the all-event result. Keep the coincidence formulas for Activity B.

A count is a number of events. A rate is the number of events per second over the same exposure.



Activity A: compare your results

Agreement between groups

Compare total count, duration and rate with another group using the same file.

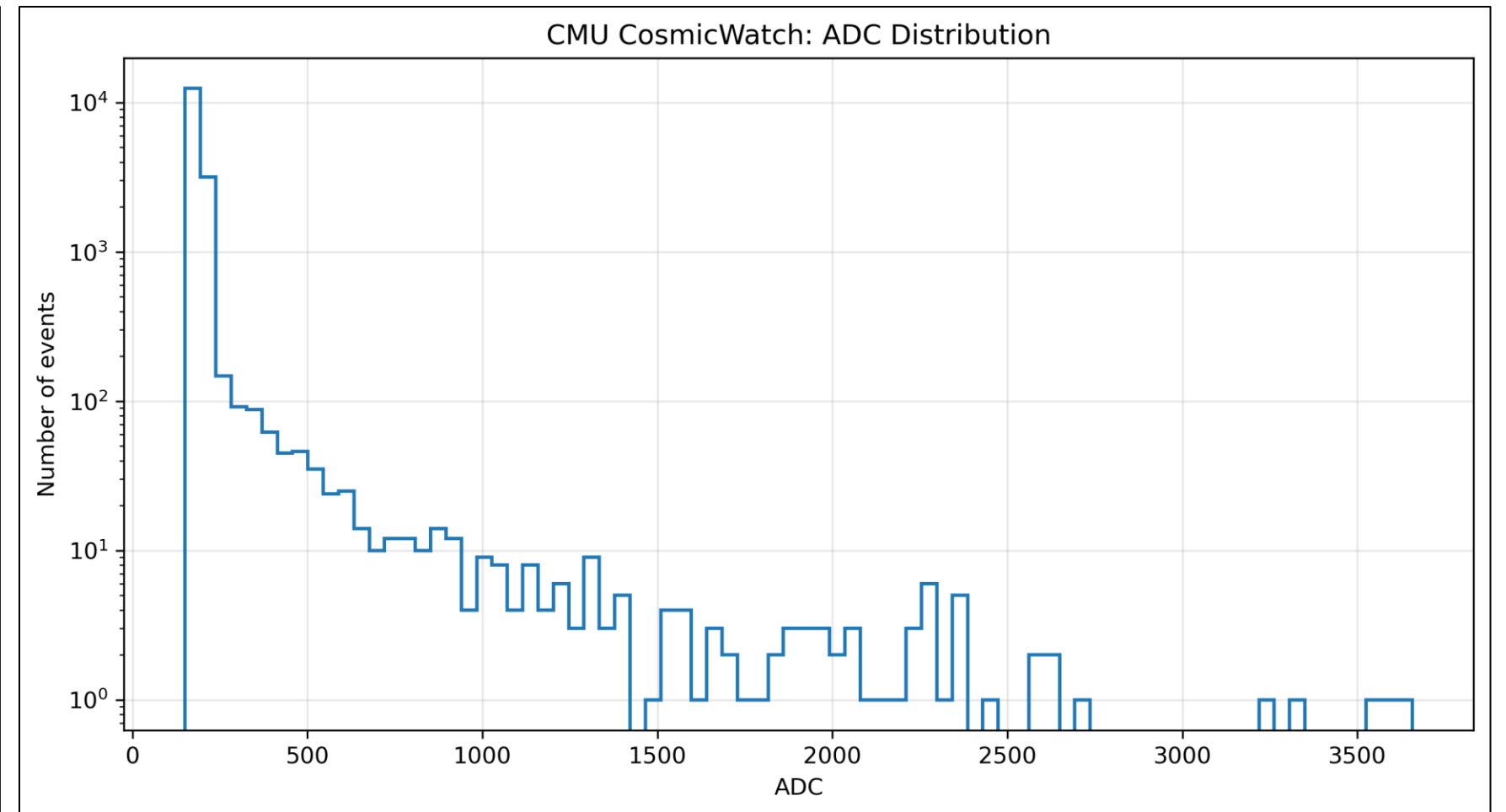
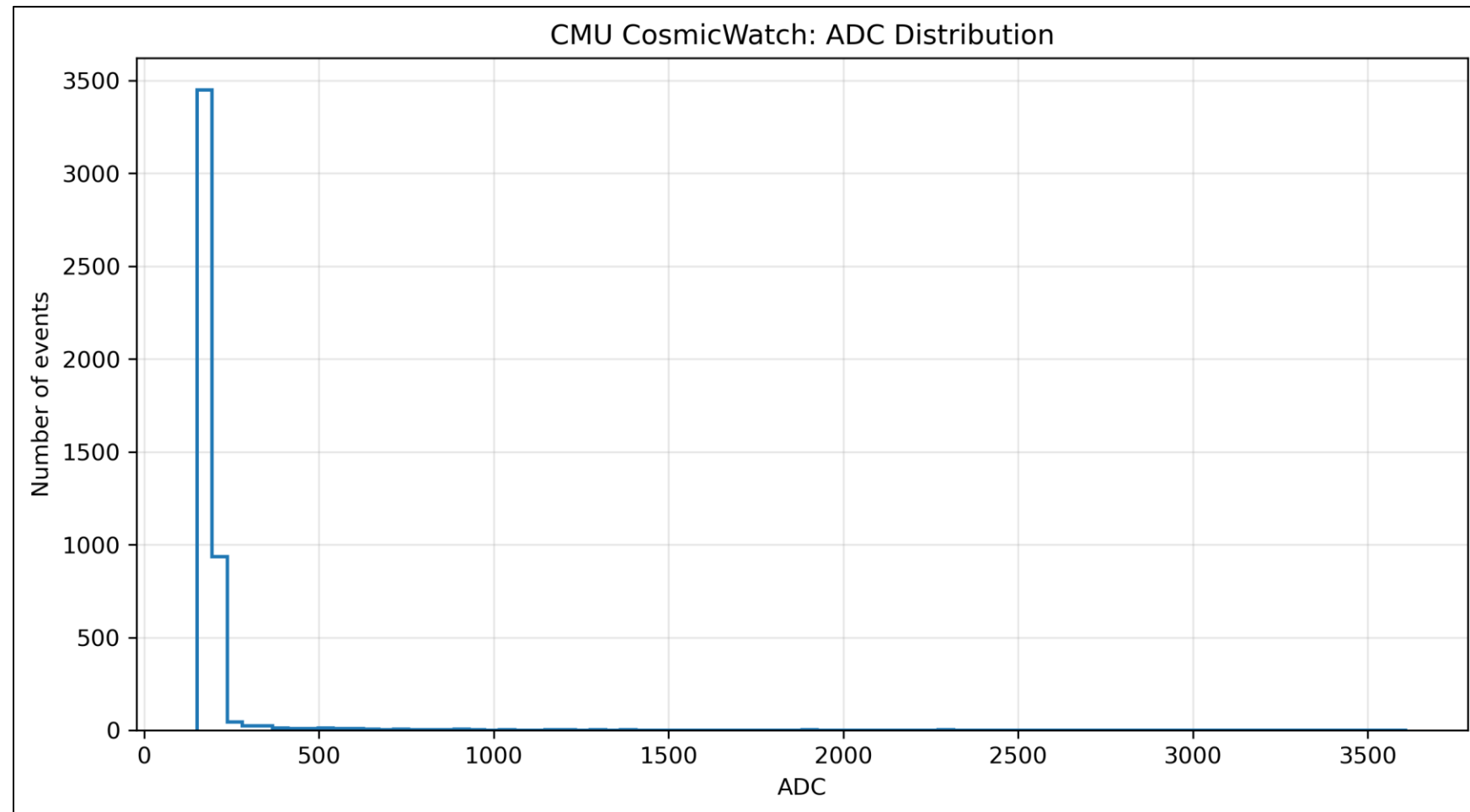
If the numbers differ

Check skipped lines, headers, duplicate records, units and the selected detector stream.

Interpret the uncertainty

The square-root rule gives a Poisson counting benchmark. It does not include every DAQ or time-dependent effect.

Activity B: the ADC distribution



The C and N populations

Label in the log	Meaning	Analysis selection
C	Coincidence-tagged event	Keep records whose final flag is C
N	Non-coincidence event	Keep records whose final flag is N
All events	Both recorded populations	Include C and N

A C tag records a timing relation between the linked detectors.

The literal N flag means non-coincidence. The total count includes both C-tagged and N-tagged records.



Activity B: compare C with N

Open 02_ADC_C_vs_N.png

Compare the distributions using identical bin edges. Each population is normalized by its own event count.

Add the coincidence result

Record the C and N counts, their ADC medians, the C-tagged rate and the C-tagged fraction.

$$f_C = \frac{N_C}{N_{\text{all}}}$$

Discuss: How do the shapes differ?
Does selection change the typical ADC value?

Compare normalized shapes as well as counts. A smaller population would otherwise look small everywhere.

Activity B: what can we conclude?

Evidence in your plots	What you can say
Different medians or shapes	Coincidence selects a different recorded ADC population
Fewer C-tagged events	The timing selection retains only part of the sample
Overlap of the distributions	ADC alone does not perfectly separate the populations
A possible edge or tail	Its origin needs checks of trigger, electronics and calibration

Write one sentence describing your measured result and one limitation.

Do not infer a muon purity, energy spectrum or detector efficiency from these plots alone.



Why coincidence is useful

Two linked detectors

A particle crossing both detectors can produce compatible signals in CW_TOP and CW_BOTTOM.

Suppression of isolated signals

The timing requirement rejects many events seen in only one detector. It can enrich a penetrating-particle sample.

Remaining ambiguity

Chance coincidences and correlated backgrounds can remain. Geometry and efficiency also affect the selected fraction.

The measured C fraction is a property of this setup and selection. It is not automatically the muon fraction.

Group result and discussion

Keep your rate summary and both plots.

Your measured result

State the rate with uncertainty, C-tagged fraction and one feature of the ADC comparison.

Your interpretation

Explain why coincidence helps. Separate your observation from your proposed explanation.

Your next check

Choose one: inter-event times, gaps, deadtime, timestamp consistency or ADC calibration.

Two or three groups give a 20-second report. All groups keep their written result.

The measurement chain in IceCube/HUNT

Measurement step	CMU CosmicWatch	IceCube / HUNT
Light production	Scintillation in plastic	Cherenkov light in ice / water
Optical sensor	SiPM	Photomultiplier tubes
Readout	Electrical pulse, ADC and event record	Digitized optical signals and timing
Analysis	Coincidence and data-quality selection	Event building, selection and reconstruction

The shared lesson is how recorded signals become a selected event sample.

We compare the measurement and data chain. CosmicWatch does not detect neutrinos in this activity.



An event we can trust

How do we turn an electrical signal into a particle event we can trust?

Inspect the real waveform and recorded event fields.

Count events over a defined exposure.

Compare ADC populations before and after selection.

Use coincidence and test remaining backgrounds or DAQ effects.

Your evidence: a rate summary, two plots and a qualified interpretation.

Day II uses these same analysis habits to examine cosmic-ray data under different observing conditions.