An easy-to-build desktop muon detector

FREE

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The design of a simple, inexpensive cosmic-ray-muon detector has led to an international outreach program.

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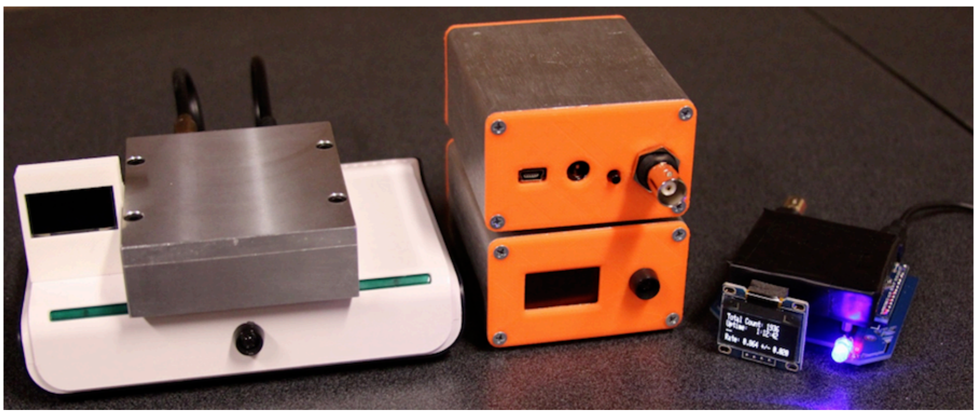


Our desktop muon detectors have steadily improved. The original model is at left. The two orange detectors are our newest design; the inner electronics for that design are at right.

On airplanes I am often asked about the blinking metallic device connected to my laptop's USB port. To assuage any suspicions, I explain that I'm a third-year physics graduate student at MIT and that the little device is actually a cosmic-ray-muon detector.

Over the past few years that detector has evolved from an instrument for a multimillion-dollar experiment to a device that high school and college physics students can construct themselves. The goal of a new program called CosmicWatch is to encourage students to build the detectors, which weigh in at less than 100 g and cost less than $100, and explore the effects of the particles that are constantly raining down on Earth's surface.

My foray into muon-detector construction began when my supervisor, Janet Conrad, and I were tasked with assisting in an upgrade of the IceCube Neutrino Observatory, a cubic-kilometer particle detector built deep in the Antarctic glacier near the South Pole. IceCube has the ability to detect the occasional astrophysical neutrino from phenomena such as gamma-ray bursts, supernovae, and black holes (see *Physics Today*, June 2014, page 30). On a far more regular basis, the observatory sees a drizzle of cosmic-ray muons. The charged particles are a decay product of the particles that form when high-energy cosmic rays collide with molecules in Earth's atmosphere. Muons are extremely penetrating, which enables a small fraction of them to travel the more than 1.5 km through the Antarctic ice to the IceCube detector.

As part of IceCube's low-energy upgrade, called PINGU, Conrad and I planned to build optically isolated scintillator targets and place them throughout the detector. If a charged particle passed through the plastic scintillator, it would emit light that we could collect using a silicon photomultiplier. Whenever the photomultiplier registered enough light at the same time as a triggered event in IceCube, we would know that the particle that triggered IceCube also passed through our target; we could use that information to help determine the particle's location and trajectory. Conrad and I called the targets muon-tagging optical modules.

The first detector prototype was very simple. I filled a small PVC pipe with liquid scintillator and inserted some circuitry and a silicon photomultiplier. Two wires penetrated the PVC cap: one for biasing the photomultiplier and one for outputting data to an oscilloscope. It was not a great design. The scintillator leaked around the cap threads, and the device looked more like a homemade bomb from a cheap movie than a particle detector. But hey, it worked. We could immediately see the signals produced from cosmic-ray muons passing through the scintillator.

The next iteration of the detector did away with the liquid scintillator and PVC piping. We found some centimeter-thick plastic scintillator panels from an old cosmic-ray experiment and built a proper light-tight enclosure from some scrap aluminum found in the machine shop. I also came across an Arduino and high-speed operational amplifiers in the MIT electronics recycling pile. Those parts, along with some pulse-shaping circuitry, resulted in a simple data acquisition system. We were able to record data directly to a computer as well as on the oscilloscope. The cost of the whole device was less than $100, with the photomultiplier accounting for the bulk of the expense.

In a June 2016 paper, we described exactly how we built the detector and provided a website link that contained all the information about our circuit boards, computer-aided design drawings, and Arduino software. Within a few days after submission to the arXiv, emails began pouring in. I was stunned to see that many of them came not from particle astrophysicists but from high school students with their own ideas for measurements or improvements. An MIT student, Mgcini Keith Phuthi, read the paper and modified our design so that his detector would communicate with his laptop through Bluetooth.

Phuthi and several other undergraduate students joined our little group to set up a small production facility. Once we started working with the new students, it was obvious that building the detector touched on several important skills. The students learned about shop practices, working with printed circuit boards, and programming microcontrollers.

We set out to see if our device would be suitable for MIT’s Junior Lab course, a class on physics lab work for undergrads. In the process, we stumbled on another use for the detector. We approached a cabinet in the corner of one lab, and as soon as we were within a meter of it, the count rate exploded; there was obviously something radioactive in there. We had a pretty good idea that it must be coming from some active gamma-ray source. One by one we took each radioactive isotope out of the cabinet and brought it close to the detector. We each had our own guess (I was thinking it would be a new cobalt-60 source), but it turned out the culprit was a large jar partially filled with dark gray powder: uranium salts. Not something I thought you could store in an undergraduate lab.

We also found something interesting in Conrad's office. On the wall, next to negatives from a bubble chamber and a lead-glass calorimeter, was a bright orange ceramic plate. It turns out that decades ago, Fiesta dinnerware was glazed with a depleted uranium–based coating. Uranium has a very long half-life, and many of the decay daughters emit radiation in the form of gamma rays. I was surprised to see so much radiation coming from dinnerware!

Over the next few weeks, we received many emails from students who wanted to build detectors for high-altitude balloon missions. The appeal of our detector stemmed from the fact that it was small and could be battery (or USB) powered, with data stored locally in a Raspberry Pi. To help with such projects, we decided to redesign the detector one more time to make it lighter and easier to build.

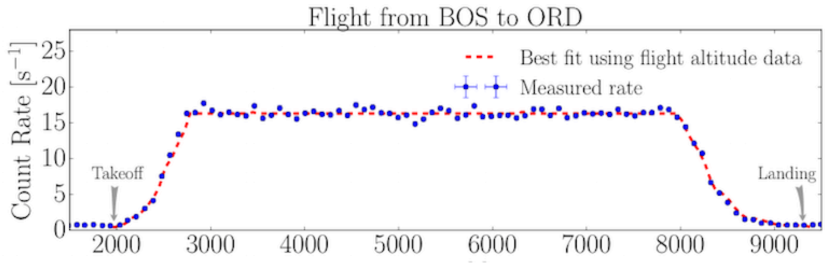
Our latest detector weighs 68 g (the model in our 2016 paper was about 10 times as heavy), draws less than a watt of power, and has an improved low-signal response. The design is so simple that it should take students just a few hours to build a full detector from scratch.

The detector is starting to gain international interest. Recently I started working with Katarzyna Frankiewicz, a PhD student from the National Center for Nuclear Research (NCBJ) in Poland. She and a colleague, Paweł Przewłocki, are working on improving the software side of the detector; they created a website for project information and data acquisition. And in collaboration with NCBJ's education and training division, Frankiewicz and Przewłocki are about to start a new educational program for high school students using 20 detectors that NCBJ and MIT built together.

Now that we have a unique detector, an international group of enthusiastic scientists, and lots of experience helping students build desktop muon detectors, we are ready to launch the CosmicWatch program. This summer our goal is to produce the first set of 100 kits, which we will use to teach a class on particle detection and astrophysics for incoming students at the Wisconsin IceCube Particle Astrophysics Center and NCBJ. Some of those detectors will be sent to local high schools for teachers to use in demonstrations. Instructors could measure the angular dependence of the cosmic-ray-muon flux, demonstrate relativistic effects with a high-altitude measurement, and conduct muon tomography. Over the winter we will move to the next generation of detectors, which will have single-photon detection and hardware-coincidence capabilities, an SD card reader, and environmental sensors.

We are not alone in the community of cosmic-ray-muon programs. Upon developing the detector, we discovered that several other groups are working toward a similar goal. We are hoping to collaborate with them to expand on what we've designed. As the project grows, we hope to be able to use the detectors for useful physics measurements. One idea is to install the detectors on planes and ships to map out cosmic-ray fluxes throughout the world. Of course, that would require further R&D and therefore more funding.

The airplane conversations regarding my strange little USB device typically end here. But I'm able to capture my questioners' attention at least one last time when I show them the measurement of the cosmic-ray-muon rate, shown in the graph below. The beauty of a good muon detector—even a small, cheap one—is that it transforms a fundamental but invisible aspect of nature into something we can see.



I used one of the detectors to measure the absolute rate of muons on a flight from Boston to Chicago. (The x-axis shows seconds.) As the airplane climbed to a cruising altitude of 9144 m, the drizzle of muons turned into a downpour.

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Vitalii Khodnevych
7 years ago

here is my detector builded few years ago
http://tqfp.org/kvital/regi...

0 0

Sascha Becher
7 years ago

But I don't get images from your detector like with the one recently used to examine a void in the Great Pyramid? Can I look through a mountain with the device and learn from it structure?

http://www.pbs.org/wgbh/nov...

0 0

Only Some Stardust ➦ Sascha Becher
7 years ago

This is a very cheap device that isn't used to look at things, or at least that's what it sounds like from the the article mentioning muons hitting in an airplane (which would be mainly coming from the sky, not the sides or out the window which is where most people would 'point' a viewer). It passively collects muons that hit it, I believe, which are going to come from all directions.

If you went inside the mountain, it would tell you how many muons were getting through. If you modified the device to take in muons from only one direction, or to give you directional/vector data, it might do what you want it to do. One way to do that might be to try shielding it except for one side? I have not tried this myself.

0 0

P

Peter Hunt

7 years ago

So any I information about how one can make one of these?

0 0

Aaron Tollman

7 years ago

Now, if you could network them with a gps location, then you would have a very large muon telescope. What an amazing picture that would make!

1 0

Marc Dion

7 years ago edited

How can we know that these are actually muons being detected. If it can detect gamma radiation from an old plate then maybe it also detects other high energy EM radiation from the sun which could explain the higher test results in the airplane, less x-rays being filtered out by the atmosphere.

0 0

T

Terry Goldman

7 years ago

'To assuage any suspicions' -- yes, but doesn't the explanation generate anxiety about being pierced by "cosmic rays"? Yow! Looks like radiation exposure is 16 or 17 times that at sea level/Chicago. Puzzling time(?) units (unlabelled axis, tsk, tsk!)-- about 1.8 hours flight time vs. Google's ~2.2?

0 0

P

Philip Gaudet

7 years ago

I'd love to get a kit with the detector. With PCB files everything else could be be home built.

0 0

C

CW Robertson

7 years ago