Giving new life to old equipment

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Experimental Particle Physics in the classroom? No way, you might think. But with help from three physics laboratories and second-hand equipment from old CERN experiments, we have assembled a cosmic ray detector.

Introduction

Particle physics, the study of the most basic components of the Universe and its interactions is for all its importance a subject seldom taught at school. One of the obstacles might be the difficulty of perceiving particles as real, physical entities. And yet, it is possible for us physics teachers to detect (in more than one way) and study particles from cosmic rays –a natural and readily available source.

Cosmic Rays

Cosmic rays (figure 1) are high-energy particles –mostly protons– coming from outer space.

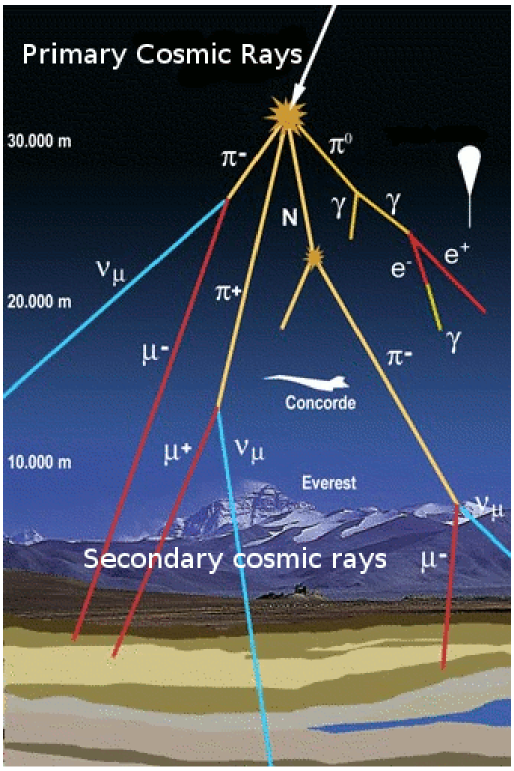

Figure 1: Production of Secondary Cosmic Rays in the Atmosphere

When these particles hits the nuclei of atoms in the Earth's atmosphere, further particles, known as secondary cosmic rays, are produced. These, in turn, can undergo more collisions or decay into other particles. The result is that large numbers of particles, mainly neutrinos and muons, reach the surface of the earth. Neutrinos are uncharged particles very hard to catch, as they interact very slightly with matter. However, muons, which are very similar to electrons but much heavier, can be easily detected[1] with relatively simple equipment such as scintillation detectors.

The detector: design and purpose

Scintillation detectors for cosmic rays are well known[2] and have been frequently used as educational instruments, suitable for teaching particle physics in high schools[3,4]. Indeed, there are several programmes devoted to its design, construction and use of detectors in schools, such as those sponsored by Fermilab or SLAC (in the QuarkNet scheme) and LBNL[5], and even detector arrays for the study of ultra – high energy cosmic rays[6].

Although the detector described here follows quite closely the Berkeley Lab design[7], (particularly using their data acquisition, or *DAQ*, circuit for counting particles), it is special in that many of its parts come from old CERN experiments or are related to the European Laboratory for Particle Physics in other ways.

Let's review quickly the device (figure 2).

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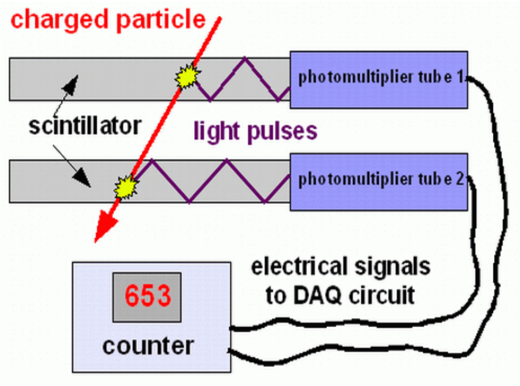

Figure 2: A coincidence scintillation detector

When a charged particle traverses a plastic scintillator this material emits a pulse of light, which is later reflected in its walls (covered in aluminium foil or Teflon) and ends up in a light guide (a plastic cylinder) that takes it to a photomultiplier tube (PMT). There it is transformed into an amplified electrical current ready to be "seen" in an oscilloscope or fed into an electronic circuit which, in our case, transforms the analogue signals from the PMTs into digital signals and counts them.

Being interested mainly in detecting secondary cosmic rays, two such detectors have been assembled in coincidence, which means that the DAQ circuit counts only particles detected simultaneously (in fact within a very short time interval) in both in order to discard signals due to electronic noise, light leaks, radioactivity, etc. Besides, the geometric arrangement of the paddles, which are parallel to each other, implies that we only count particles coming from a cone around the perpendicular to the paddles

This detector was built by three High – School teachers[8] with extensive guidance from experimental High – Energy physicist Luciano Romero (from CIEMAT, Madrid). We worked together in our spare time from December 2004 to April 2005 to develop a project for the 2005 "Madrid for Science" Fair where the detector was presented to the general public. The project, called *Jump on Einstein's wagon!*, was about relativity and it occurred to us that a cosmic ray detector would help in showing that special relativity is a physical theory and as such related to experimental facts and with measurable consequences, like the so-called "time dilation".

Most of the particles detected with our kit should be muons produced at an average height of 15 km[9]. Muons are unstable particles with a mean lifetime τ of about 2.2 μs, so they will travel typical distances of less than $c\tau$, about 660 m, before decaying (c is the maximum possible speed, that of light in vacuum).

The number of surviving muons decreases exponentially with time (or travelled distance, which is proportional to the time of flight) so that after (15000/660) ≈ 23 times $c\tau$, we expect very few particles, as $e^{-23} \approx 10^{-10}$, but surprisingly we can detect roughly half the initial flux on Earth's surface. This can be explained[10] by noting that τ is the mean life measured in the particle's rest frame, but secondary cosmic ray muons are created and arrive at the detector with speeds close to that of light. According to special relativity their "internal clocks" run more slowly in the frame (our rest frame) in which they are moving. This is "relativistic time dilation" for muons, whose mean life is "stretched" to the order of ten times its value at rest. To tell the truth, you have to be very careful when comparing fluxes at different heights, because there are more factors involved than just relativistic effects[11].

CERN, other big laboratories, and our detector

If the only way to assemble a detector like ours were to buy the parts ready-made or, even worse, order them to fit our needs, it wouldn't have been possible for ordinary high-school Physics teachers to do it, but we've had the help of several high-energy physics laboratories which have provided materials especially designed for educational purposes, as the Berkeley Lab data acquisition board, or which had been used in past experiments and were no longer needed.

The plastic scintillator in the "paddles" (fig. 3) was ordered by the Instituto de Física Corpuscular (*IFIC*), a particle physics institute in Valencia, Spain, for their time-of-flight subdetector in the Delphi experiment – one of the four experiments at the Large Electron – Positron Collider (LEP) at CERN.

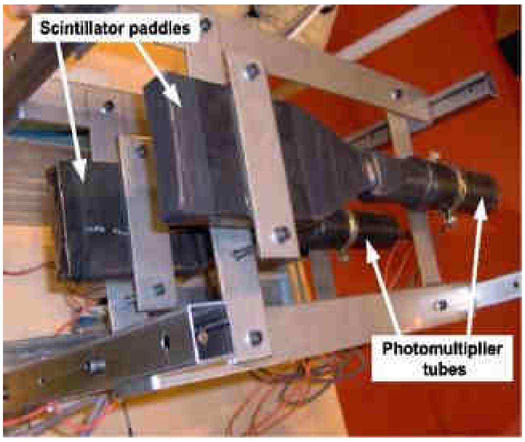

Figure 3: The scintillator paddles and photomutiplier tubes

When Delphi was dismantled in 2001 following LEP's closedown, IFIC took back the photomultiplier tubes and light guides, two of which ended up in our detector. These PMTs are fed from an old high–voltage power source (figure 4) which we got from CIEMAT –a national laboratory with one of its branches in Madrid devoted to high-energy Physics– but which had also been used at CERN in the 1980s.

After the initial work in our High Schools (finding materials and people to help us, designing the detector, preparing the parts and assembling the DAQ circuit), the final assembly and testing took place in March 2005 at CIEMAT's hall 75, in which part of the muon drift tube chambers for CMS's[12] central muon detector were being set up at the time (figure 4).

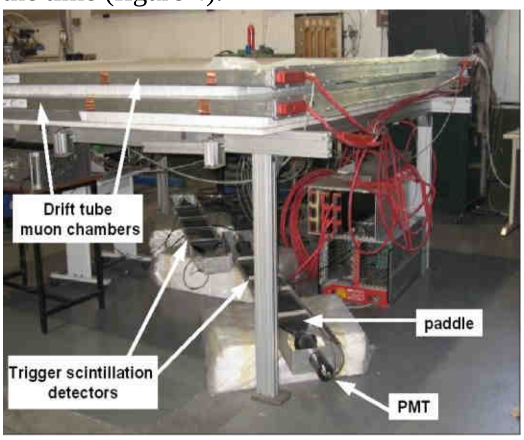

Figure 4: Drift tube muon chambers for CMS being tested with cosmic rays at CIEMAT. On the lower part you can see two scintillation detectors used as part of the trigger system.

In figure 4 you can also see two scintillation detectors, very similar to ours, used for testing the chambers with cosmic-ray muons. Signals from particles detected in the simple, very well known and reliable scintillation detectors trigger the muon chambers to be tested.

It is also worth noting (see figure 5) that the DAQ circuit board is mounted on a spare piece of aluminum plate of those used to build the CMS drift chambers.

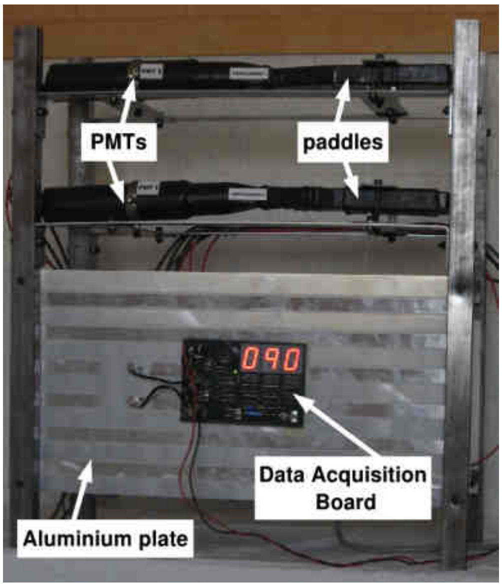

Figure 5: Frontal view of the detector

Conclusion

Now that the detector is ready for making measurements, students involved in its operation will learn not only about particle physics, electronics, statistics, etc., but they will take an active part in a number of significant scientific experiments. These could clued, besides the one described above, measuring the distribution of muon counts per unit time or the variation of coincidences as the paddles are placed at different separations, studying the variation of coincidence rate with angle from the vertical, investigating the relationship between coincidence rate and variations in atmospheric pressure...

If you are interested, go to your local nuclear or particle-physics lab and ask. There are many physicists who would be happy to help!

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.

Antonio Ferrer, Miguel Ángel Sanchis and José Ramón Ros (IFIC, Valencia), not only provided the PMTs and the scintillator plastic, but ordered the paddles to be cut and polished for us.

Howard Matis (LBNL, Berkeley) provided the circuit board and kindly helped us to find some of the parts for it.

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NOTES AND REFERENCES

[1]Their traces can actually be *seen* with a very simple home-made instrument, the cloud chamber, described for example by Andrew Foland in http://w4.lns.cornell.edu/~adf4/cloud.html (accessed April 2006)

[2]Leo, WR. 1994 *Techniques for Nuclear and Particle Physics Experiments 2nd ed.*, chapter 9. Springer – Verlag

[3]Mühry, Henry and Patrick Ritter 2002 Muons in the Classroom, *The Physics Teacher* **40** 294 – 300

[4]Dunne P, Costich D and O'Sullivan S 1998 Measurement of the mean lifetime of cosmic ray muons in the A-level Laboratory. *Physics Education* **33** 296–302

[5]http://quarknet.fnal.gov/toolkits/ati/crdetectors.htm (accessed April 2006) and http://www.slac.stanford.edu/quarknet/ (accessed April 2006). For the QuarkNet scheme, see http://quarknet.fnal.gov (accessed April 2006).

[6]such as the *NALTA* consortium in North America (http://csr.phys.ualberta.ca/nalta/, accessed April 2006) or the *Projecto Ciência Viva* in Portugal (http://www.lip.pt/experiments/trc/, accessed April 2006)

[7]The *Assembly Manual for the Berkeley Lab Cosmic Ray Detector* can be accessed at http://www.lbl.gov/abc/cosmic/documentation/CosmicDetector2-0.pdf

[8]Pedro Valera, from "Matemático Puig Adam" High School in Getafe (Madrid, Spain), Carlos Herrero, from "Juan de Herrera" H. S. in San Lorenzo de El Escorial (Madrid, Spain) and the present author (then at "Juan de Herrera" H. S.)

[9]See, for instance, the Cosmic Ray section (and particularly subsection 24.3) of the *2006 Review of Particle* Physics: W.-M. Yao *et al.*, Journal of Physics G **33**, 1 (2006), available at http://pdg.lbl.gov/2006/reviews/cosmicrayrpp.pdf.

[10]See for instance Mermin, ND 2005 *It's About Time*. chapter 6. Princeton UP, or http://www2.slac.stanford.edu/vvc/theory/relativity.html

[11]See Easwar N and MacIntire DA 1991 Study of the effect of relativistic time dilation on cosmic ray muon flux—An undergraduate modern physics experiment. *Am. J. Phys.* **59**, 589. or Frisch DH and Smith JH 1963 Measurement of the Relativistic Time Dilation Using μ-Mesons *Am. J. Phys.* **31**, 342. TE Coan and J Ye's notes on muon physics, available at http://diablo.phys.northwestern.edu/~mvelasco/Physics_359-3/muon.pdf, are also useful.

[12]CMS, the Compact Muon Solenoid, is one of the four huge detectors of CERN's new accelerator, the Large Hadron Collider or LHC. For more information, see http://www.interactions.org/LHC/ (accessed June 2006)

