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THE FIRST CENTURY OF COSMIC RAYS, AN HISTORICAL OVERVIEW

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Abstract. The 1912 balloon flights of Victor Hess and related activities in those years are reviewed. Subsequent research during the early 20th Century is noted, including the discovery of the positron, mesons, and air showers. The cosmic ray–accelerator interrelations are noted, including cosmic ray studies at Echo Lake and Mt. Evans, Colorado (USA). The more recent evolution of cosmic ray research programs to astrophysical and cosmological studies, and the major programs such as Auger and AMS conclude this discussion of the century of cosmic ray research.

1. The Hess Discovery

In the early 20th Century, radiation had been discovered, radium (and other radioactive elements) identified, and the ionization of air (and other gasses) by radiation, detected by the electroscope, studied. The fact that some level of ionization of the air was observed everywhere was interpreted as due to residual traces of radioactive elements in the Earth's crust (soil, rocks, etc.). In 1912, Victor Hess, an Austrian physicist, took an electroscope in a hydrogen-filled balloon up to an altitude of almost 6000 meters (over Germany), and found that the atmospheric ionization increased with altitude by about a factor of three above that at ground level, leading him to conclude that there was a source of ionization incident on the Earth's atmosphere from above. From balloon flights during a solar eclipse, he also deduced that the source of this radiation was not the sun. Hess' observations were confirmed by Werner Kohlhörster, from other balloon flights in 1913 and 1914, up to about 8000 m, showing an increase (from ground level) of about a factor of 8. Robert Millikan, a very well-known and respected physicist at that time, at first did not believe the Hess and Kohlhörster results, but later made measurements himself which convinced him of their validity, and he coined the term “Cosmic Rays”.

2. Early Discoveries

In 1927, Jacob Clay, using an ionization chamber, sailed between Java and the Netherlands, and observed a significant latitude effect (due to variations in the Earth's magnetic field). In that year Dmitri Skobeltsyn first photographed cosmic ray tracks in a cloud chamber. Kohlhorster and Walter Bothe (1929) and Bruno Rossi (1930), using Geiger–Muller counters and coincidence circuits, found that a fraction of cosmic rays traversed as much as 25 cm of lead. In 1933, Rossi, Arthur Compton, and Luis Alvarez observed an East–West asymmetry of primary cosmic rays, demonstrating that the primaries were positive particles (e.g. protons). It may be noted that this was Alvarez' Ph.D. thesis topic. Marcel Schein, from balloon flights in 1940, showed that the primaries were mostly protons. In 1933, Rossi and (later) Pierre Auger observed the coincidence of cosmic ray particle signals between horizontally-separated counters, hence the discovery of air showers. Balloon experiments, up to altitudes of 30 km, verified that primary cosmic rays included He plus a small fraction of heavier nuclei, in addition to protons (the primary, dominant component).

Before the evolution of particle accelerators, fundamental particle physics discoveries were made in cosmic ray studies. In 1932 Carl Anderson discovered the positron in a cloud chamger photograph of cosmic rays. Later (1936–1937), a group consisting of Dr. Anderson, Neddermeyer, Street, and Stevenson discovered the μ-meson (now known as the “muon”, but then called the “mesotron”); a particle with a mass between that of a proton (or neutron) and an electron (or positron). They first identified it as the Yukawa particle; the Japanese physicist H. Yukawa had postulated that the strong interaction was mediated by a quantum particle with a rest mass lighter than that of the proton (analogous to the role of the photon in electromagnetism). Ten years later, the pion (π-meson) was discovered by Lattes, Occhialini, and Powell, and found to be a strongly-interacting meson which decayed into the muon with a very short half-life. In those years (1947–1953) the K-meson (or kaon) was discovered by Powell, Butler, and Rochester. And, in the early '50s (1951–1953), the lightest hyperons were discovered in cloud chamber studies at the French Pic du Midi research station (at an elevation of about 2850 m in the Pyrenees); the Λ, Σ, and Ξ particles. An excellent summary of these early milestones is contained in a Physics Today article [1].

3. The accelerator–cosmic ray interaction

The first accelerator to achieve an energy of over 1 GeV was named the "Cosmotron" – the 3 GeV proton synchrotron at the Brookhaven National Laboratory (near New York). This name recognized the high-energy discoveries in elementary particle physics in cosmic ray studies, and the probability that this higher energy accelerator would continue in that path; which indeed it did. The "Bevatron", at the Lawrence Berkeley National Laboratory (California) accelerated protons to an energy of 6 GeV (or 6 billion electron volts) in 1955. Soon after, the anti-proton was first discovered there. With the invention of strong (or alternating gradient) focusing, the Brookhaven and CERN (in Geneva, Switzerland) laboratories both built proton synchrotrons of about 30 GeV, completed around 1960. Also, in the mid-sixties, at the Dubna Laboratory (north of Moscow) the 10 GeV Synchro-Phasetron, and at the Argonne Laboratory (near Chicago) the 12 GeV ZGS (zero-gradient synchrotron) were completed. Of course, there were also electron accelerators completed and operating then. Hence, most of the physicists' studies of elementary particle physics moved away from cosmic rays and over to accelerators during these years (the 1950s and 1960s).

In the early 1960s, with the success of the Brookhaven AGS and the CERN PS, there were extensive discussions among the active physicists about the construction of the next generation of accelerator facilities and laboratories; accelerators with an energy above 100 GeV. There were arguments and confusion in both Europe and America concerning where and by whom such facilities would be built, how they would be financed, and how they would be managed. Such a machine would be too large to fit on the existing sites of CERN or Brookhaven, for example, and there were intense discussions over the organizational structure required to build and manage such a facility.

4. The Echo Lake and Mount Evans research program

During this period of uncertainty and frustration in the early 1960s, at an international high-energy physics meeting in Dubna, a group of us were discussing this situation, and Guiseppe Cocconi noted that the flux of cosmic ray protons above 100 GeV, at mountain elevations, would be sufficient to make serious studies of nuclear interactions at these energies. This stimulated a group of us; myself and other Midwestern particle physics colleagues, to consider an experimental facility in the Colorado mountains. We proceeded to get a National Science Foundation grant, and, in 1965, equipped a semi-trailer with a large spark chamber, proportional chambers, plus a hadron calorimeter, and took it to the summit of Mt. Evans, Colorado (elevation 4300 m). This site, and another lower elevation site near Echo Lake (elevation 3260 m) were managed by Denver University, and had earlier hosted many outstanding cosmic ray physicists, including Bruno Rossi, Giuseppi Cocconi, John Wheeler, Marcel Schein, Ken Greisen, Wayne Hazen, Arthur Compton, and others.

The following summer, we built a larger detector in a wooden building, leaving the adjacent semi-trailer available for the electronics and the operators. The detector was designed to search for free quarks, possible cosmic ray particles with a charge (hence ionization) 1/3 or 2/3 that of known particles, e.g. of relativistic cosmic ray muons. The detector included two 3-layer multi-wire gas proportional counters, each of about 2 square meters area; below these were a 2-section wide gap spark chamber and beneath that a 7-layer iron and scintillation counter hadron calorimeter. Of course, the quark search was primarily carried out by the 6 independent ionization measurements, while the other detectors were early feasibility models of components we would possibly use in a much larger detector. This detector was initially located on the Mt. Evans summit, however the road to the summit was only open during the three summer months, so, to maintain operations year-round, we moved the building and semi-trailer to the Echo Lake site, which included lodgings, and was accessible year-round. Indeed, about that time, C.B.A. McCusker in Australia reported a positive result in a quark search; a cloud chamber track with 1/3 the ionization of a relativistic muon. However we were able to continue our quark search for over a year, and found no quark candidates, and hence published a convincingly negative result [2]. Subsequent searches, with cosmic rays, at particle accelerators, and in stable matter, have all confirmed the absence of free quarks.

At the 1967 International Cosmic Ray Conference in Alberta, Canada, Grigorov and his Russian colleagues reported results from the "Proton" Russian satellites; in particular, the p–p inelastic cross section (deduced from interactions in a graphite and a polyethylene target) was reported to be about 22 % greater at about 500 GeV than at 20 GeV [3]. This stimulated our group to pursue the direct study of p–p interactions at Echo Lake, where we had begun to build a larger detector. Bruce Cork (from Berkeley) arranged for a 2000 liter liquid hydrogen target to be built for incorporation into our detector, which was built in a new, larger wooden building. The detector complex was about 4.5 m tall, and consisted of a top scintillation counter, a spark chamber 2×2 meters, consisting of two 20 cm gaps, the liquid hydrogen target, and another 2 gap 2×2 meter spark chamber. Below this was a set of three multigap thin plate spark chambers (10 gaps total) separated by iron plates and scintillators (for observing EM showers and nuclear interactions), and below this a large total absorption calorimeter, with 10 layers of counters between iron plates, which together totaled 1130 g/cm^2. An array of scintillation counters around the mid-plane of the hydrogen target served as a veto to restrict triggered events to unaccompanied incident cosmic ray particles (virtually all protons). The resulting data, 90° stereo-photographs and digital data of the recorded events, were analyzed at our home institutions just as spark chamber and bubble chamber data from accelerators were being analyzed.

From our data, we confirmed that the p–p inelastic cross section was essentially constant between 20 GeV (as measured at the Brookhaven and CERN accelerators) and $\sim$ 500 GeV, proving the Russians wrong [4]. We continued with other data collection; secondary particle multiplicity and angular distributions, p–nuclear cross sections with targets of carbon, iron, and lead, and other studies. Gaurang Yodh later found that the Russian result was the result of back scattering of reaction products in their calorimeter below their target. Of course, we now know, from the TOTEM LHC data, that the p–p cross section rises to about 100 mb at 7 TeV c.m. (about 25 PeV equivalent cosmic ray energy); although our Echo Lake measurements (below a TeV) were confirmed by accelerator data.

Of course, in the late 1960s, the Fermi National Accelerator Laboratory, managed by the newly-formed Universities Research Association (representing major universities from all across the U.S.) was established near Chicago, where it began construction of the 300 GeV synchrotron. And in Europe, CERN expanded its site and undertook to build the SPS (Super Proton Synchrotron). In 1972 the Fermilab synchrotron commenced operation, and we closed the cosmic ray program and moved our activities to accelerators.

5. Recent cosmic ray research

For the past 40 years, the major emphasis of cosmic ray research has been directed towards questions in astrophysics and cosmology; for example, studies of the primary spectrum and composition with balloon and satellite-borne detectors for studies up to TeV energies, and surface air shower arrays, especially the Auger and the Telescope Array. Also, studies of X-rays, gamma rays, gamma ray bursts, etc. Neutrino astronomy is a current lively topic, with detector arrays on the kilometer scale, and the strange taxonomy of neutrons; three "flavors" (corresponding to the electron, muon, and tau), and three different mass eigen states. There are extensive presentations of these topics at this Workshop, so they will not be discussed here. Many other recent and current cosmic ray research activities are also addressed here, including the most recent results from the PAMELA and other satellite detectors. We look forward to future reports of results from the AMS-02 magnetic spectrometer, aboard the International Space Station.

An area of particle physics/cosmic ray research which is still active is the use of emulsion chambers. These are stacks of nuclear emulsions and/or X-ray film, separated by sheets of metal (or, sometimes, graphite) in which the tracks of particles from cosmic ray interactions may be observed and studied. Most of this activity is currently carried out by Russian, Japanese, and Brazilian physicists, with emulsion chamber arrays on mountains in Kazakhstan, Bolivia, and Tibet. A recent interesting Workshop, where the latest results were reported, was held in 2010 at Plock, Poland. Unusual particle physics phenomena which were discussed included the "Centauro" phenomena (high energy interactions with a dirth of neutral pions, hence gammas, as reaction products). Other phenomena discussed were the azimuthal anisotropy of the final states of very high energy interactions, and the "long flying component", an apparently strongly-interacting reaction product particle which travels well beyond a conventional interaction length before interacting [5]. Although I personally do not believe that any of these three phenomena represent new physics, they merit discussion and study, and I certainly support the research activities and goals of these groups.

This is a very abbreviated history, with an emphasis on the earlier events and discoveries, in view of the more recent research discussed at this Workshop. However it was indeed interesting reviewing those earlier years. We look forward to future discoveries and to the solutions to our many remaining cosmic ray problems.

References

[1] Carlson, P.: 2012, Physics Today 65. No. 2, 30

[2] Jones, L.W.: 1973, Bulletin of the American Physical Society II, 18, 33

[3] Grigorov, N.L., et al.: 1967, Proceedings of the Tenth International Cosmic Ray Conference Part A, 512

[4] Jones, L.W., et al.: 1972, Nuclear Physics B43, 477

[5] Kempa, J., et al.: Emulsion Chamber Observations of Centauros, Aligned Events and the Long-Flying Component, Central European Journal of Physics (to be published)

Discussion

Francesco Ronga — It is interesting to remember the underwater measurements made by D. Pacini in 1907–1911; see arXiv 1103–4392 (A. de Angelis).

Lawrence Jones — This was indeed a relevant set of measurements, which also hinted at an extra-terrestrial source of cosmic rays.