NAL PROPOSAL No. 13

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IONIZATION SPECTROMETER DEVELOPMENT AND CALIBRATION

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Abstract

An ionization spectrometer measures particle energy by developing a nuclear-electromagnetic cascade so that most of the incident energy is transferred to low energy charged particles, which then deliver their energy to the detector by ionization energy loss. The design optimization and calibration of these detectors at high energies is essential to several NASA satellite programs to measure high energy cosmic ray composition and spectra, and they may also be important to experiments at NAL. The beam requirements for this program would be best satisfied by a variable energy (10 - 500 Gev) diffraction scattered proton beam of very low intensity (a few protons/pulse) whose operation would not interfere with the main accelerator schedule.

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Physics Justification

The group represented in this proposal have been engaged for a number of years in several separate programs to measure the composition and spectra of high energy galactic cosmic rays above the atmosphere in the 10^{10} - 10^{14} eV region.[1] We have carried out a number of balloon flight experiments to develop the instrumentation and obtain preliminary results, and more are planned. However, even though much work has been done by ourselves and others, including a series of Russian satellite experiments,[2] on this energy region, the data is very incomplete and many contradictions have arisen. Well designed satellite experiments offer the main hope for real progress toward the goal of firm information on high energy galactic cosmic ray spectra. We believe that this information may be vital to the continued progress of astrophysicists and astronomers in understanding the structure of our galaxy, not only because high energy cosmic rays provide a new probe of distant regions, but also because it is becoming increasingly clear that cosmic radiation plays an important role in galactic dynamics.[3]

We have recently collaborated on a detailed proposal[4] to carry out a high energy cosmic ray spectra experiment on one of the High Energy Astronomical Observatory series of 4 unmanned, heavy payload launches (scheduled each year, beginning in 1974). Flight opportunities will be very limited (but finite since programs such as the Manned Orbiting Laboratory are being planned) since the overall cost of each launch will be comparable to the cost of NAL, so we wish to plan very thorough optimization and calibration studies at the highest available energies. Judging by our experiences at other accelerators, it is not likely that suitable opportunities will exist at the required times unless considerable advanced preparations are made to meet the beam requirements for such work.

Ionization spectrometers[5] (various versions are also known as total absorption spectrometers and total absorption nuclear cascade (TANC) counters) seem to offer unique capabilities in many situations in the 10^{10} - 10^{15} eV energy region to measure total particle or event energies with a detector of modest dimensions ($\ell \approx \frac{1}{2}$m.) and weight ($m \approx 2 \times 10^3$ kg). The ionization spectrometer utilizes the fact that a hadron entering any dense material generates nuclear and electromagnetic cascade showers. If the dense material has a thickness of 6 to 8 nuclear mean free paths, a large fraction of the energy will be dissipated by ionization energy loss within the ionization spectrometer. A signal proportional to the amount of ionization is obtained either by sampling scintillator or ionization chamber layers throughout the absorber or by using a dense material which itself scintillates or emits Cerenkov radiation. The relationship between initial particle energy and the output signal is subject to nonlinearities and fluctuations depending upon such factors as the fraction of energy contained within the ionization spectrometer, the fraction of energy lost to breaking nuclear bonds, the location and orientation of the incoming particle path relative to the ionization spectrometer, the statistical fluctuations in the cascade shower development, and the dynamic range of the ionization detectors and output electronics.

While the performance of an ionization spectrometer can be simulated by a Monte Carlo calculation, detailed comparisons between calculations and experiment are needed in the 30 - 500 Gev region to determine the best values of the many parameters which go into such calculations. Even after the development of trustworthy Monte Carlo programs, each prototype and final flight model ionization spectrometer for a satellite experiment should be thoroughly checked and calibrated with laboratory protons in the 10 - 500 Gev range.

It seems quite likely that work on ionization spectrometer development will contribute significantly to their finding important applications in NAL experiments. This may depend greatly upon how far it is possible to go in achieving good energy resolution, low cost, and ability to distinguish $e^{\pm}$, γ, $\mu^{\pm}$ and hadrons.

Experimental Arrangement

A typical arrangement of a satellite (or balloon) experiment utilizing an ionization spectrometer is shown in Fig. 1. The ionization spectrometer is 46cm x 46cm in area on the entrance face and 86cm thick. For a satellite experiment, particles entering the two opposite ends would both be used in order to double the effective counting rates. When in operation above the atmosphere, the number of particles striking the ionization spectrometer from all sides would be of the order of 1/ millisecond, which fixes the order of magnitude of the "singles" counting rates which the photomultiplier tubes and gating electronics will be designed to handle. Since we would like to test the performance of the ionization spectrometer along with its satellite (or balloon) electronics, this sets an upper limit of ~ 1/millisecond to the peak rate of calibration beam protons which could enter the ionization spectrometer. A typical event readout time is 50 milliseconds, so, with any beam spill length less than 50 ms, only one event can be read out per accelerator pulse.

A calibration beam characteristic which would be very important is that the proton energy be readily adjustable from 10 Gev to the maximum possible accelerator energy (~500 Gev). An energy resolution of 1-2% would be adequate, since present calculations indicate ionization spectrometer energy resolutions ~15-30% FWHM. The beam could be either well focussed, or spread out over a 20" x 20" area, since the satellite and balloon experimental apparatus will have digital spark chambers or proportional chambers to measure the trajectory of each incoming proton. Desired beam characteristics are summarized in Table I.

About 1000 events would be needed for each entrance location, direction, and energy studied. A typical calibration run might involve data collection for 10 entrance locations times 3 entrance angles times 5 energies, or 150,000 events. Assuming one event per pulse and an average of 4 sec/pulse, 167 hours would be required per calibration, plus the time needed to initially tune the beam and retune it to four other energies. Setup and tune-up time for the ionization spectrometers, themselves should be very short by usual accelerator standards, perhaps 3 days, at most, since the equipment is designed to be self-contained and to operate without operator attention for long periods.

During the first year of accelerator operation our group can forsee a need for at least two, and preferably five or six calibration runs at ~200 hours each. Since other cosmic ray and high energy groups are working with similar ionization spectrometers which would have similar calibration proton beam requirements,we forsee a demand which can be met only if facilities exist such that runs can be readily arranged on a "parasitic" scheduling basis.

Apparatus

The special requirement for this proposal is a proton beam with characteristics close to those summarized in Table I. A possible approach might be to diffraction scatter a small fraction of the protons from the main ring at a time in the acceleration cycle which can be adjusted to obtain a few protons of any desired energy. If some such solution appears technically feasable to NAL staff members and if a rough estimate of the cost could be obtained, we would propose to seek NASA funding for such a facility.

Table I

Characteristics of Proposed Calibration Proton Beam

Energy	10 - 500 Gev (Adjustable
Energy resolution	~ 1% (FWHM)
Particle flux	3 - 10 protons/pulse
Beam spill	1 - 3 ms
Peak particle intensity	1 - 3 protons/ms
Beam spot size	20" x 20" or less

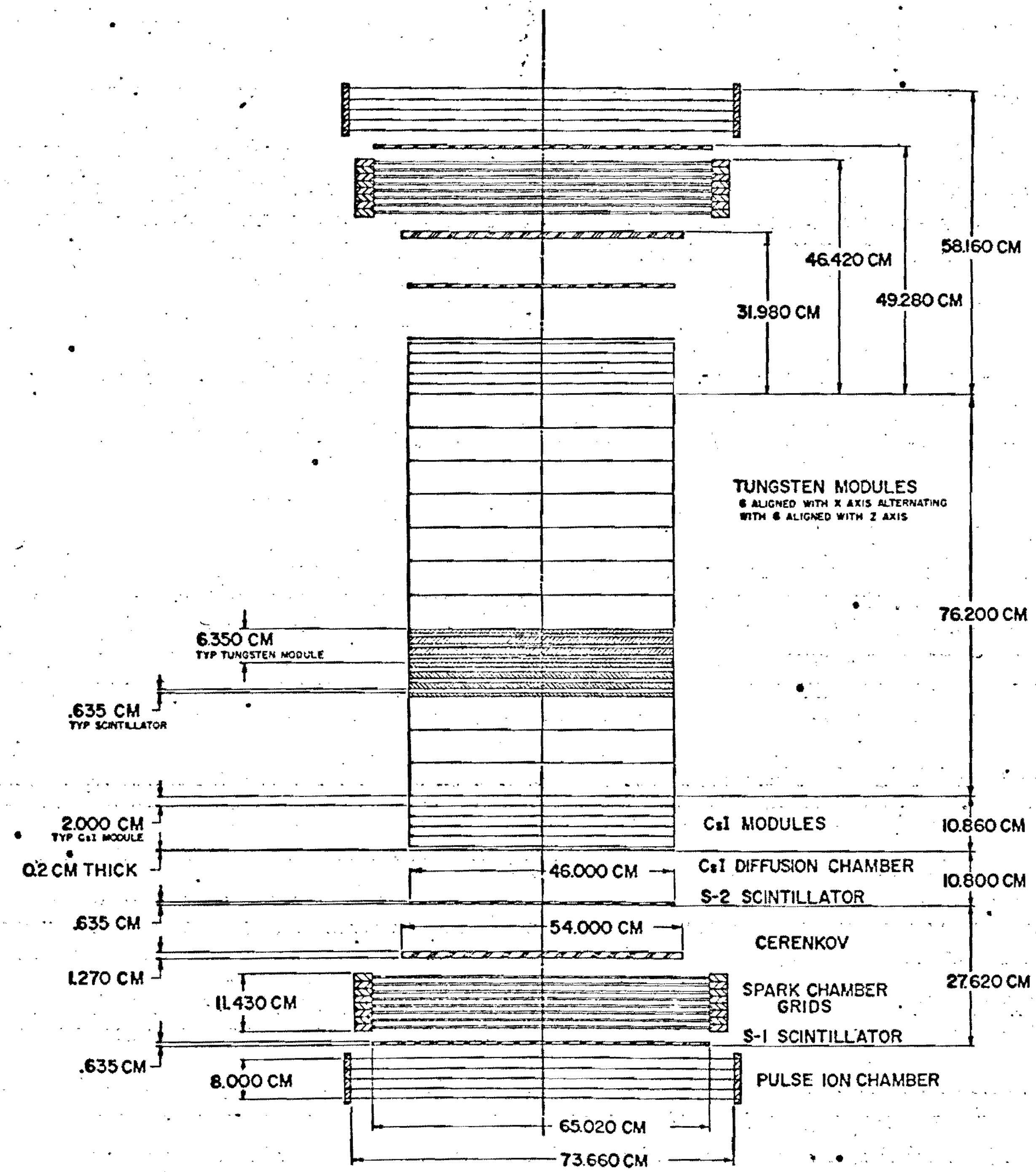

Figure 1. Schematic diagram of experiment showing dimensions.

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