ON THE EXPERIMENTAL PROGRAMS FOR A SUPER-HIGH-ENERGY (1000-Bev) ACCELERATOR, AND FOR A HIGH-INTENSITY (30-Bev) ACCELERATOR

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I. Super-High-Energy Accelerators

It is not surprising that we find it difficult to make any reasonable extrapolation from experiments at 30 Bev to an experimental program at 1000 Bev. Even at 30 Bev, very little is yet known about the basic collision processes. At present, it appears that the cosmic-ray studies of proton interactions in the range 1000 to 10,000 Bev provide the most reasonable means for estimating what some of the outstanding possibilities may be at 1000 Bev. As we shall remark below, however, the scope of the cosmic-ray data is very limited (or nonexistent) in important directions, both now and in the foreseeable future.

We discuss some of the possibilities under a number of headings:

1. New particles? In the present period, our list of particle states is being extended rapidly. Can we expect this situation to persist at higher energies? The known quantum numbers do not lead to selection rules which could forbid rapid decay for states of high excitation energy. It is reasonable to expect that the present AGS accelerator is adequate to map out the full extent of the discrete levels which we are now beginning to explore.

On the other hand, we emphasize that there may well be further quantum numbers for the strong interactions, still to be discovered. For example, some years ago M. Goldhaber suggested the possibility of a high-lying baryonic series related to the known baryons as the muon is related to the electron. This particular possibility would be equivalent to the existence of a new quantum number (the muonic number, let us say) for the baryons. We recall that there was no hint of the strangeness quantum number in the heyday of low-energy nuclear physics.

Many of us expect the existence of both charged and neutral intermediate bosons associated with the weak interactions, with couplings whose strength is (logarithmically) intermediate between those for the nuclear and the beta-decay interactions. We note that there is no evidence that these neutral bosons would have neutrino couplings (absence of neutral lepton currents!), so that their formation would require the interaction of nuclear particles, e.g. $\pi^- + p \rightarrow n + W^o$. All of these bosons may well be extremely massive, requiring correspondingly high energies for their production.

There is also the possibility of heavy leptons L, continuing the sequence e, μ, ... These heavier leptons would not be seen as decay products, for their parent particles would be so heavy that their weak-decay processes would have negligible branching ratios relative to their strong-decay processes. These leptons could be produced directly in neutrino processes, if their coupling happens to be with ν_μ or ν_e. They could certainly be produced by electromagnetic pair-production processes, thus $\gamma + Z^A \rightarrow L^+ + L^- + Z^A$, for sufficiently high γ energies.

2. <u>High-energy collision processes.</u> At least two categories of information are of interest:

(a) Particle structure at small distances, corresponding to impact parameters $\lesssim 10^{-15}$ cm. Information on this question may be regarded as the most significant single purpose for the construction of super-high-energy accelerators. To obtain it involves the study of collisions involving high momentum transfer, say $\gtrsim 10$ Bev/c ; with such small impact parameters, $b = \hbar/\Delta \lesssim 2 \times 10^{-15}$ cm, the cross section for all such processes is necessarily small, of order $\pi b^2 \approx 10^{-29}$ cm^2. The branching ratio for all such processes in p-p collisions is therefore low, of order 10^{-4}, so that there is little likelihood of obtaining such information from cosmic-ray studies.

We emphasize that, for such collisions, our interest lies in a complete picture of individual events, and in the study of correlations between different aspects of the phenomena, rather than in statistical studies of the final particles from many such collisions. Information of this kind is not yet available even for p-p collisions at 30 Bev. For the p-p system, storage rings appear likely to be the most convenient technique, providing the intensity of background events can be sufficiently reduced. On the other hand, we are interested in the same kind of information for $\pi^{\pm}$-p, $K^{\pm}$-p and $\bar{p}$-p collisions, so that it appears that the technical problems of the detailed observation and measurement of such events in the laboratory system will have to be faced sooner or later. Typically, these small-impact-parameter collisions may be expected to lead to one or more final baryons with large transverse momentum, and to a large inelasticity factor, with a relatively high rate for meson production, especially for mesons with a large transverse momentum. It is quite possible that none of the collisions yet observed in cosmic rays correspond to such small impact parameters.

The simplest of such collisions, as regards both experimental technique and interpretation, are the large-angle elastic collisions. However, their cross section falls rapidly with increasing momentum transfer Δ, perhaps like Δ^{-6} if the trend noted recently by R. Serber continues, whereas the total cross section for large-momentum-transfer collisions falls only like Δ^{-2}, as we have just pointed out above. To be specific, we may illustrate the kind of question of interest by asking what happens, as the p-p energy rises, to the hard-core repulsion known in the p-p interaction at low energies. Does the outer region of the hard core become primarily absorptive, leaving a strong elastic repulsion pushed to ever smaller distances with increasing E? Or is the hard core finite in strength, and simply unimportant even at 30 Bev? The answer to this question does not seem to be known even for the energy range 10-30 Bev.

(b) Collisions of large impact parameter. Here we have first diffraction scattering which reflects primarily the properties of the inelastic processes. Ultimately, at sufficiently high energies, we expect some Regge-pole behavior to set in, but this may well require incident energies very far in excess of those we are discussing here.

In the long run, the observation of the inelastic processes themselves may prove to be more illuminating. For the energy range 1000-10,000 Bev, the cosmic-ray work of Levi Setti, Koshiba, et al. at Chicago has given us some picture of the inelastic processes for large-impact-parameter collisions. The essential features are (1) that the baryons suffer relatively small energy loss (typically 20% inelasticity),

(2) that the majority of the pions are emitted from a blob of mesonic matter left behind by the nucleons (as shown by the relatively low center-of-mass momenta observed for the pions, the median momentum being about 400 Mev/c, and by the relative isotropy of these low momentum pions) and (3) the emission of some very fast pions closely collimated with the forward (or backward) direction, at a rate of about 1 per p-p collision.

The study of the properties of this blob of mesonic matter, left behind in these p-p collisions, is of particular interest. What is its shape and structure, and what are the fluctuations in its properties? Here again, it is the study of individual complete events which will be most informative. The comparison with annihilations of $\bar{p}$-p collisions at comparable blob energy would also be instructive. For 20% inelasticity at 1000-Bev laboratory energy, the blob center-of-mass energy is about 10 Bev, comparable with the mesonic energy resulting from a $\bar{p}$-p annihilation collision for $\bar{p}$ with about 50-Bev laboratory energy.

At present it is believed that the fast pions result from the decay of nucleonic resonance states formed in these large-impact-parameter collisions. This hypothesis needs to be checked empirically, and the relative frequency for the various nucleonic excitations determined. These pions would naturally have γ values comparable with those for the final nucleons, so that the intensity of fast pions (energies 50-400 Bev) will be quite high (of order 0.5 per incident nucleon, in this momentum range).

(c) <u>Secondary beams.</u> From the remark just made, it appears reasonable to expect that strong pion beams, well collimated (angles typically 10^{-3} radian), will be available at very high energies (say up to 400 Bev/c) with a rather satisfactory intensity (at least 0.1 per nucleon incident on the target, in the momentum range 50-400 Bev/c). The cross-section and interaction studies possible with these beams constitute one of the major purposes of the construction of such an accelerator.

However, these pion beams will also give rise to (1) a correspondingly high flux of high-energy muons, up to 200 Bev/c and beyond, which will be available for μ-proton scattering experiments, important for their clues to the structure of both the muon and the proton. Similarly, (2) there will be correspondingly high fluxes of neutrinos (ν_μ) and antineutrinos ($\bar{\nu}_\mu$) at correspondingly high energies, with which weak-interaction studies will be possible with rather respectable cross sections, possibilities about which I need say little at this stage. Finally, (3) the corresponding π^o production and decay will lead to a high gamma-ray flux, with strong intensity (at least 0.1 photon per incident nucleon) over the energy range 25-200 Bev, allowing some possibility for the study of very-high-energy electromagnetic processes.

We have little idea about the K, $\bar{p}$ and hyperon production rates to be expected, nor about their laboratory-energy distributions. However, it is reasonable to expect $K^{\pm}$ beams of appreciable intensity, at least for moderate laboratory energies, although perhaps not at such high energies as appear likely for the strong tail of the pion spectrum. For all of these secondary beams, experimental questions of the same type as those discussed above for p-p collisions will be those of interest. Again, complete pictures of events involving high momentum transfer will be of special interest.

It is reasonable to expect that the fast outgoing nucleons may frequently be replaced by outgoing hyperons or hyperon isobars, perhaps at a rate of order $(m_\pi/m_K)^2 \approx 10\%$ per p-p collision. If this proves correct, even short-lived particles like $\Sigma^\pm$ and Ξ^- (and Ω^-?) may frequently have appreciable path lengths (of order 1-10 meters) before decay. If it proves technically feasible to separate these particles within this distance, this will open up the possibility of studying hyperon-nucleon interactions directly at energies 10-100 Bev and perhaps higher.

II. High-Intensity AGS (30-Bev) Accelerator

There can be little argument against the value of higher intensities (say 10^{13} protons per pulse) for proton accelerators, although it is reasonable to query their necessity for the strong-interaction experiments of major interest. The importance of such high intensities is quite clear for experiments with secondary particles whose only interactions are weak or electromagnetic. For neutrino experiments, such an increase in intensity will be quite crucial; the observation of neutrino-induced events in hydrogen is a possibility of outstanding importance, especially for neutrino energies high enough for production of intermediate bosons. Higher intensities would also be valuable for other weak-interaction experiments with strongly-interacting particles, e.g., for the direct production of the neutral intermediate boson through processes such as

$$\pi^+ + p \rightarrow W^o + N^*_{3/2}$$

$$\pi^- + p \rightarrow W^o + n$$

These higher intensities would also lead to accurate muon-proton scattering data at present AGS energies, another really important possibility.

For strong-interaction experiments, higher intensities will allow greater refinement in the definition of the beams (concerning both purity and momentum) required for accurate experiments. In many such experiments, however, what seems to be needed is greater time-integrated intensity, rather than greater instantaneous intensity; i.e., longer running time at intensities well within what is available at present. Possibly, with higher-intensity accelerators, there will develop beam-sharing procedures of much greater sophistication than at present, with perhaps a hundred experiments set up for long runs around the periphery of the accelerator.

There is a great variety of experiments which would become possible in this way. Let us give several examples. Hyperon-nucleon scattering studies, including polarization-correlation effects, can lead to significant conclusions on many important points, e.g., (1) the π-hyperon couplings for Λ, Σ and Ξ (and even Ω) may be determined from these data, just as the π-nucleon coupling constant has been deduced from nucleon-nucleon scattering data, and (2) information can be obtained on the hard core, and on the spin-orbit force, appropriate to each of these systems, ΛN, ΣN, ΞN and ΩN, from which we may hope to clarify our understanding of their origin in the baryon-baryon interaction. The investigations of Ω and higher Ω^* states (if these really exist) through the study of high-energy $\bar{p}$-p interactions appears a promising procedure, but the cross sections are certainly very small, so that higher $\bar{p}$ intensities are desirable. Tests of higher symmetries are required for situations involving large energy and momentum transfer, in situations such that the large symmetry-breaking mass differences which exist between the low-lying mesons (π, K, η) no longer give rise to significant deviations of the cross sections from the relationships which would exist if the higher symmetry were exact; again, such situations usually involve processes with small cross sections.

Higher intensities would also be of benefit for more detailed studies of the rarer decay modes for the low-lying particle states. Typical examples are illustrated by the study of the K_e^+/K_μ^+ ratio, the character and mechanism for $K_{e\nu\gamma}$ decay, the detailed properties of K_{e4} decay, and electromagnetic decay processes such as $\Sigma, \Lambda \rightarrow N\gamma$, $\Xi \rightarrow \Sigma\gamma$, $K_{\pi\pi\gamma}$, and $K_2^o \rightarrow \gamma\gamma$ and e^+e^-, as well as the non-mesic decay interaction $\Lambda N \rightarrow NN$. Another important series of projects would be the study of the polarization properties of Λ, Σ and Ξ beta decay, as well as the study of all such properties for the Ω-decay processes. Not all of these weak interactions can be explored in the high-energy neutrino experiments.

The development of a high-intensity AGS facility at 30 Bev would allow a great extension in the breadth and depth of the experimental studies of all the strongly-interacting particle states, both "elementary particles" and "resonance states" (unless the super-high-energy accelerators find further series of strongly-interacting particles associated with new quantum numbers). The systematic exploration of the parameters of these states, their quantitative family relationships, and the systematics of their production mechanisms may be expected to hold the attention of a large fraction of particle physicists for more than another decade, and increasing the intensity of the AGS accelerator could well speed up these studies in a very significant way, leading on to an understanding of the symmetries and the other properties of the basic forces responsible for these particle states. At the same time, over a relatively short time scale, such a facility would allow a range of quantitative neutrino experiments of fundamental importance for our understanding of the weak interactions, involving directly the ν-p and $\bar{\nu}$-p interactions processes (as well as the ν-n and $\bar{\nu}$-n processes), and of the nature of the leptons.