ON PHYSICS WITH A HIGH-INTENSITY PROTON ACCELERATOR BELOW 30 GeV

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Summary

The types of physics that would be pursued at a high-intensity, moderate-energy proton accelerator are discussed. The discussion is drawn from the deliberations of the 30-GeV subgroup of the Fixed-Target Group at this workshop.

Prologue

What follows is a picture, deliberately drawn with broad-brush strokes, of the discussions of the 30-GeV subgroup of the Fixed-Target Group.[1] The general conclusions are discussed by Lee Pondrom in his Working Group Summary.[2] Many specific processes that could be addressed by a high-intensity, moderate-energy machine are discussed in detail in individual contributions to these proceedings. It is the purpose of this note to give a brief overview of the kinds of physics that could be studied by such a machine.

Three high-intensity machines with energies in the vicinity of 30 GeV have been discussed. First, there is the possibility of increasing the intensity of the Brookhaven Alternating Gradient Synchrotron (AGS) by as much as a factor of 10, using a storage-accelerating ring fed by the linac. This could yield up to 5×10^{13} p/s at 28 GeV. Second, there is work in progress[3] designing a 100-μA (6×10^{14} p/s), 100% duty factor, 16-GeV synchrotron fed by LAMPF at Los Alamos. Finally, a design effort is under way for a machine with similar parameters at TRIUMF[4] in Canada.

Perspective

The electroweak theory of Weinberg and Salam has provided a very accurate description of weak and electromagnetic interactions. Quantum chromodynamics (QCD) appears to be a promising candidate theory of the strong interactions. There have even been partially successful attempts to unify all of these forces (Grand Unified Theories). The central issues in particle physics are whether these theories are indeed correct and if extensions to these models are required. In general, these issues can be investigated in several ways. At very high energies, searches can be made for the production of the various heavy particles predicted by these theories (and for those predicted by extensions to these theories). Searches can also be made for new phenomena that are either predicted by specific models or are totally unexpected.

At lower energies, precision experiments can be performed to measure very rare processes or search for small deviations from expected results. In this way, one is using the experimental precision to probe the small effects caused by unseen heavy particles. At some higher energy, these effects would be expected to grow with energy. However, this energy scale may be well beyond reach. For example, the particle conjectured to mediate proton decay has a mass of $\approx 10^{15}$ GeV.

Historically, many fundamental discoveries and most of the stringent limits on unexpected phenomena have come from fixed-target accelerators, which were not the highest energy machines available at the time. Included in the first category are the discovery of weak neutral currents[5] at the CERN PS and the discovery of the J/Ψ[6] (or at least the J part) at the AGS. The list of examples of the second category is long and includes constraints on the form of the weak-charged current[7] (from muon decay), limits on lepton-number conservation,[8] limits on strangeness-changing weak-neutral currents,[9] and essentially all of our knowledge of the parameters of CP violation.[10] In addition, much of our information on fundamental-particle properties and spectroscopy comes from these machines.

Exempla

One area that can obviously benefit from increased intensity is the study of neutrino interactions. Present experiments studying neutrino-electron-elastic scattering expect to measure the total cross sections. This information serves as an important check of the Weinberg-Salam model. More detailed tests of the model including investigations of the space-time structure of the current and the nature of the neutrino (Dirac vs Majorana) require measurements of the angular distribution (or $d\sigma/dy$). These measurements cannot be performed at present facilities. A narrow-band neutrino beam with 10 to 100 times the AGS flux is needed.

Studies of the low-q^2 behavior of neutrino-proton and neutrino-deuteron scattering would provide extremely valuable information on the weak-neutral-current interaction with quarks. Higher neutrino fluxes would permit the smaller, more heavily instrumented detectors that are required. A high-intensity proton accelerator might also be an excellent source of ν_e and $\bar{\nu}_e$ using either K_L^0[11] decays or a muon-storage device (a "racetrack"[12] or a Lobashev[13] bottle).

The study of many rare-decay modes would be facilitated by the high-intensity, high-quality (and high-purity) kaon beams that would be available. Examples of such decays are the strangeness-changing muon-number-violating decays $K^0 \to \mu^\pm e^\mp$ and $K^+ \to \pi^+\mu^\pm e^\mp$; the generic class of decays $K^+ \to \pi^+ +$ "nothing" (where "nothing" could be $\nu\bar{\nu}$, $\tilde{\gamma}\tilde{\gamma}$, or axion, for example); the CP-violating decay $K_L^0 \to \pi^0 e^+ e^-$; and the search for muon polarization in $K_L^0 \to \mu^+\mu^-$. The decay $K^+ \to \pi^+\pi^0$ provides a convenient source of tagged π^0's to study $\pi^0 \to e^+e^-$, $\pi^0 \to \nu\bar{\nu}$, and $\pi^0 \to \tilde{\gamma}\tilde{\gamma}$. One should also be able to significantly improve the mass limit for the muon neutrino.

The phenomenon of CP violation was discovered nearly twenty years ago. Since that time, considerable time and effort have been spent to study and elucidate the effects. At present there is no satisfactory theoretical understanding of CP violation. The data are consistent with the superweak model (which postulates the existence of a new $\Delta S = 2$ interaction), with CP violation generated in the Higgs sector, with CP violation emanating from a phase in the weak-mixing (Kobayashi-Maskawa) matrix, and with other possible milliweak mechanisms. The only way to distinguish between these models is to improve the accuracy of the measurements of the CP-violation parameters. The clean neutron-free K^0 beams, which could be constructed at a high-intensity proton accelerator, would greatly facilitate these measurements. As two examples, $|\eta_{00}/\eta_{+-}|^2$ could be measured to a precision of ≈0.2% in a few months of running.[14] The component of muon-polarization transverse to the decay plane in $K^+ \rightarrow \pi^0\mu^+\nu_\mu$ (Ref. 15) could be measured with a precision of one part in 10^3. Such a measurement is an excellent probe of Higgs interactions.

A high-intensity proton accelerator would be an excellent source of muons. Muon-number-violating processes (such as $\mu^+ \rightarrow e^+\gamma$, $\mu^+ \rightarrow e^+e^+e^-$, and $\mu^-Z \rightarrow e^-Z$) ultimately may be best measured at such a machine. The muon-anomalous magnetic moment, $g_\mu - 2$, could be measured with an order-of-magnitude improvement in accuracy.[16] Such a measurement would result in the most sensitive test of QED as well as tests of the strong- and weak-interaction contributions to $g_\mu - 2$.

Other areas for study include[3] hypernuclei, nuclear-physics studies with pions and kaons, exotic atoms, QCD tests, particle spectroscopy (including searches for glueballs), studies of $\bar{p}$ interactions, hyperon interactions and decays, and nucleon-nucleon interactions. The range of physics available for study would test existing models and search for a broad spectrum of new phenomena.

Marginalia

An aspect of accelerators that should not be neglected is related to the subject of the sociology of particle physics. This topic was the subject of many discussions at this workshop, both formal and informal. It was a matter of widespread concern that in the future at higher energy machines, especially colliders, there will be fewer experiments, each with many more collaborators. The experience at LEP certainly is in line with this observation. The problems stemming from this situation are the personal satisfaction a physicist might feel as a result of his efforts, the difficulties in incorporating new and innovative ideas into experiments, and the need to provide an appropriate situation to train graduate students. In all of these areas, a high-intensity medium-energy proton accelerator will be superb. There will be a large number of experiments, each with only a moderate number of participants. The program should be flexible enough to allow some risky innovative experiments. The experiments will be of modest size so that graduate students will be able to grasp all aspects of an experiment and make substantial contributions.

These issues should not be taken lightly. In a real sense, the future of the field depends upon solving these problems. The physics at a moderate-energy high-intensity proton accelerator is at the cutting edge of the field. The fact that it will substantially help solve these problems is an extremely important side benefit.

References

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