January 7, 2002

Background Information on **PHYSICISTS SEE ONCE-IN-A-TRILLION EVENT - AGAIN!**

1 The basic constituents of matter.

The innermost secrets of matter and energy are being probed ever more deeply by high energy physics experiments. These particles under study compose all matter, and the laws they obey apparently apply at all times and places in the universe. The goal of particle physics is to map out this world and discover the rules that govern its behavior. This knowledge has far reaching consequences for our understanding of what the universe is and how it came to be.

Physics, astronomy and mathematics have had phenomenal success in discovering simple laws and symmetry principles which govern matter and mathematical structures at their most fundamental levels. These triumphs have unraveled the behavior of matter at the smallest scales, have had immense consequences in unravelling the history of the universe, and have led to the development of the basic mathematical models needed for such understanding.

Thanks to new experimental findings made accessible by particle accelerators worldwide, the last decades have brought a radically new and simple picture of nature on the most fundamental level. Matter in every form is assembled from a few basic building blocks called quarks and leptons. Quarks are the sub-constituents of the proton and neutron (three quarks in each), and leptons include electrons and neutrinos. The synthesis of knowledge is called the Standard Model of Particle Physics.

The Standard Model describes the remarkable discoveries made in particle physics and is consistent with all laboratory observations.[1] It not only provides a framework for describing and understanding the world around us but provides insights into the first instants of creation of the universe - the Big Bang. The Standard Model provides a unification of the strong, weak, and electromagnetic forces and hints at the possibility of incorporating the fouth known force, gravity, into quantum theory.

The Brookhaven National Laboratory experiment known as E787 is one among a group international collaborative projects, conceived to explore the interactions of elementary particles at mass, energy and sensitivity scales not previously achieved. Other experiments, now under construction, will likely discover the Higgs particle which is believed to be responsible for generating the masses of fundamental particles, and they may reveal the origin of the symmetry violation responsible for the dominance of matter over anti-matter in the known universe. In addition, this research may be capable of shedding light on the "dark matter" in the universe which constitutes 90% or more of its mass yet produces no measurable radiation.

[1] Some recent discoveries pertaining to neutrino mass may require a slight modification to the Standard Model.

1.1 Symmetry Violation and rare Kaon decay Experiments

In 1967, Andrei Sakharov showed that a matter-dominated universe (rather than one with equal parts of matter and anti-matter) could occur if a set of simple principles which involve symmetry violation were obeyed. [2] The symmetries here involve charge and space (e.g. charge conjugation C, which replaces particles with anti-particles, and left-right exchange or parity P), and time (time-reversal symmetry T). Since 1964, in experiments involving the decays of neutral K mesons, charge-parity (CP) and T symmetry violation have been observed lending support to the consistency of Sakharov's hypothesis. However, in the context of the Standard Model, these effects fail to explain the matter dominance effect by eight orders of magnitude, leading physicists to search for entirely new effects which could have profound implications for our understanding of the universe.

The phenomenon of CP violation is related to the interrelationship of the quarks - there are now known to be three distinct pair of quarks, distinguished by their masses and other properties. However, the quarks which decay are apparently mixed states of several of the known quark varieties. CP violation and quark mixing are among the most important outstanding issues in the study of elementary particle physics with profound implications on the nature of elementary particles and forces, and possibly also on the origin of matter in the universe. This is one of the main areas of worldwide activity in particle physics. While CP symmetry violation had until recently only been observed in K meson decays, great international efforts involving several thousand researchers and new accelerators and detectors have begun to study these effects using the heavier B meson.

Nevertheless, it has become clear that the most incisive measurements in the study of CP symmetry violation and quark mixing can be carried out by observing very rare branching ratios (or rates of decay) of K mesons (K), which are unstable elementary particles composed of quark-anti-quark pairs, decaying to pi mesons (π^0) and neutrino anti-neutrino pairs ($\nu\overline{\nu}$), represented by the reaction $K_L^0 \to \pi^0\nu\bar{\nu}$. Discovery and study of these reactions is the main focus of experiment E787 and a follow-on project called KOPIO. These decay modes are special because theoretical uncertainties are extremely small, and measurements of the branching ratios will provide the standard against which other measures of quark mixing and CP violation will be compared.

Even small deviations of the experimental findings for these rare K meson decays from the expectations derived from SM predictions or from other measurements, *e.g.* in the B sector, will unambiguously signal the presence of new, unheralded physics phenomena. These could take the form of new forces of nature, new fundamental particles, or perhaps, dark matter. Using current estimates of SM parameters, B($K^+ \to \pi^+\nu\bar{\nu}$) and B($K_L^0 \to \pi^0\nu\bar{\nu}$) are expected to lie in the ranges $(7.5 \pm 2.9) \times 10^{-11}$ and $(3.1 \pm 1.3) \times 10^{-11}$, respectively i.e. only a few out of every 100 billion reactions.

The importance of these measurements is related to the extreme precision with which the Standard Model can predict the branching ratios in the context of current knowledge. Although the reaction are extremely rare, the E787 experiment has obtained unprecedented sensitivity partly due to the use of the Alternating Gradient Synchrotron (AGS) accelerator of Brookhaven National Laboratory (New York) [3] which is the highest intensity proton synchrotron in the world. Using ad-

[2] A familiar symmetry of nature can be demonstrated by the rotation of a sphere - regardless of the angle of rotation, it remains a sphere and thus provides an example of constancy or "rotational" symmetry.

[3] The AGS, the highest intensity multi-GeV accelerator in the world, is a crucial facility in one of US's most important high energy physics laboratories. Planned increased intensity will allow the AGS to approach the capacity of the new Japanese Hadron Facility which is just entering a 6-year construction phase with a $3B budget and which

vanced technologies and new techniques, the E787 collaboration built the detection system shown schematically in fig. 1. The apparatus incorporated the latest techniques in particle detectors and electronics including fibers of scintillating plastic, novel tracking chambers, transient recorders operating at 500 MHz based on Gallium Arsenide charged coupled devices (CCDs) and flash analog to digital converters, and pure crystals of Cesium Iodide. The result is a tour-de-force demonstration of the power of experimental particle physics technique to uncover and study minute effects previously thought to be unobtainable. In doing so, E787 achieved an improvement in sensitivity of a factor of more than 1,000 over previous instruments opening a window of discovery that could transform our picture of nature.

While the E787 observation of two events is presently consistent with the SM, the central experimental result is twice as high, leaving open the door to a possibly momentuous discovery. If the extension of E787, now in operation, confirms a discrepancy with the SM prediction, a major new area of research will have been unearthed. Such a result could imply entirely unanticipated phenomena like the existence of a mirror universe of particles predicted in theories like Supersymmetry. E787, KOPIO and other modern particle physics experiments making use of cutting edge technologies and techniques are opening new doors in the exploration of the basic constituents of matter. In the history of science, transformative developments have often followed the introduction of new instruments and techniques, like the telescope employed by Galileo to reveal details of the planets and the inner workings of the solar system.

will not be able to begin to mount an experiment like E787 or KOPIO before the end of the decade.

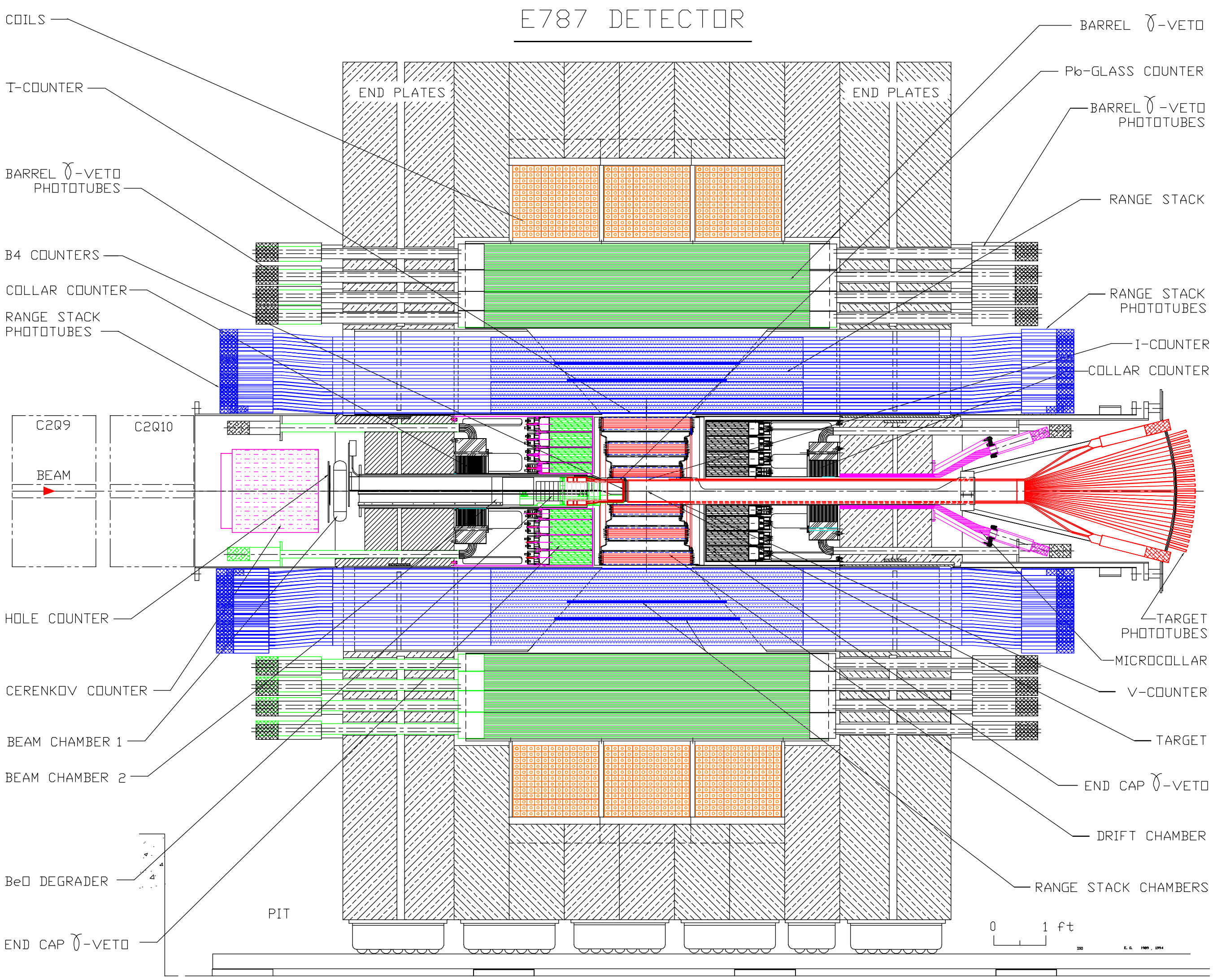

Figure 1: The E787 detector which observed the rare decays $K^+ \to \pi^+ \nu \bar{\nu}$. The K meson beam enters the solenoidal magnet from the left along the axis. K mesons lose energy in absorber material and stop in a target made of scintillating fiber detectors. A charged particle decay product π meson which emerges from the stopping target enters the detector's central drift chamber which tracks it to determine its momentum. (The trajectories of charged particles bend in magnetic fields. Neutrinos (ν) which have no charge are not observed directly.) The π meson penetrates a range stack array of scintillators and chambers, loses energy until it stops and subsequently decays to other particles which are also detected. The entire ensemble of detectors is surrounded by a γ-veto calorimeter designed to observe photons or other interacting particles very efficiently.