P-25: Subatomic Physics

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Introduction

The Subatomic Physics Group (P-25) is engaged primarily in fundamental nuclear- and particle-physics research. Our objective is to conduct diverse experiments that probe aspects of subatomic reactions, in order to provide a more thorough understanding of the basic building blocks that make up our universe. Although our main focus is basic research, we also have a strong effort in applied programs such as proton radiography. To conduct our research, we often participate in large-scale collaborations that involve physicists from universities and institutions around the world, and we participate in or lead experiments at a variety of facilities. Currently, we are conducting research and developing new programs at Los Alamos National Laboratory and other laboratories, including Brookhaven National Laboratory (Brookhaven) and Fermi National Accelerator Laboratory (Fermilab). The following sections highlight the significant experiments and activities that we are currently pursuing.

The PHENIX Program at RHIC

P-25 has been exploring the subatomic physics that defined the universe at its beginning. Big Bang cosmology pictures a time very early in the evolution of the universe when the density of quarks and gluons was so large that they existed as a plasma, not confined in the hadrons we know today (neutrons, protons, pions, and related particles) (see Figure 1). As operations are commencing at Brookhaven's Relativistic Heavy-Ion Collider (RHIC), the effort has begun to produce a small sample of this primordial quark-gluon plasma in the laboratory and to study its exotic properties. The challenge facing the international collaborators involved in the RHIC program is to identify the fleeting transition into this deconfined phase of matter.

Physics Division has a long tradition of experiments at the high energy-density frontier, and P-25 is playing a major role in defining the search for the quark-gluon plasma and the related physics program for RHIC. To meet these goals, P-25 is playing a key role in constructing two major subsystems for the PHENIX (Pioneering High-Energy Nuclear Interaction eXperiment) detector, one of two major collider detectors at the RHIC facility. The PHENIX

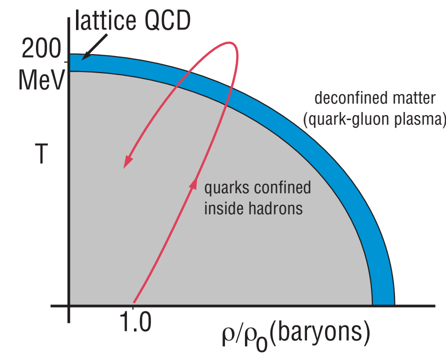

Figure 1. Lattice QCD calculations predict that at higher temperatures and densities, there will be a transition of matter from the confined state to the deconfined state, as shown by the solid band. Research with RHIC will explore this transition of matter.

collaboration currently consists of over 300 physicists and engineers from universities and laboratories in the U.S. and 14 foreign countries. Our work focuses on the multiplicity/vertex detector (MVD) and the muon subsystem. The MVD is the smallest and among the most technically complex of the PHENIX systems. It will surround the region where the two beams of 100-GeV/nucleon ions intersect. The functions of the MVD are to determine the precise location of the interaction vertex and to measure the global distribution and the total number of secondary charged particles; these properties are crucial parameters in fixing the energy density achieved in the collision fireball. A partially instrumented MVD has taken highly preliminary data during the first physics run of the PHENIX.

The muon detectors, the largest subsystem in PHENIX, consist of two sets of position-sensitive tracking chambers surrounding conical magnets at opposite ends of the detector. Muons are identified by recording their penetration into a series of large steel plates interspersed with detection planes, all of which lie behind the magnets. The muon subsystem plays a central role in P-25's physics agenda because it is optimized for examining hard-scattering observables at very high temperatures and densities, where the strong force is smaller and easier to calculate using perturbative quantum chromodynamics (QCD). The first detector, known as the South Arm, is complete and is being moved into the interaction region for data taking in 2001. The North Arm is under construction; its completion date will depend on the availability of funds and periods for installation. (More details on this experiment are available in the research highlight "The PHENIX Detector Program at RHIC" in Chapter 2.)

High-Energy Nuclear Physics

Another area of study in P-25 is parton distribution in nucleons and nuclei, and the nuclear modification of QCD processes such as production of J/ψ particles (made up of a pair of charm/anticharm quarks). We are currently publishing research on this topic from a program centered at Fermilab. This program began in 1987 with measurements of the Drell-Yan process in fixed-target proton-nucleus collisions. Those measurements showed that the antiquark sea of the nucleon is largely unchanged in a heavy nucleus. In our most recent measurements during the NuSea Experiment (E866), we demonstrated a large asymmetry between down and up antiquarks, presumably due to the nucleon's pion cloud (see Figure 3). In addition we showed that the production of heavy vector mesons such as the J/ψ is strongly suppressed in heavy nuclei. We mapped out this effect over a broad range of J/ψ energies and angles. Although the causes of this suppression are not yet fully understood, it is already clear that absorption in the final state plays an important role, as do energy-loss of the partons and shadowing of the gluon distributions. The muon arms at PHENIX are well poised to continue these studies when protons are collided with heavy ions at RHIC.

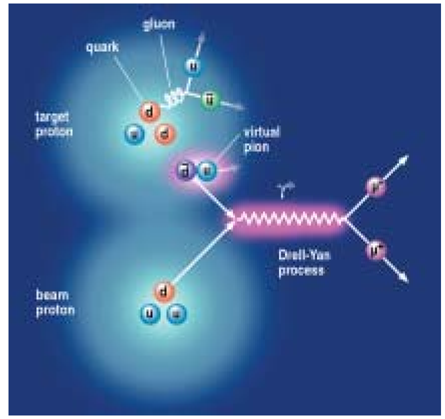

Figure 2. A proton consists of three valence quarks held together by gluons in a sea of quark-antiquark pairs. These pairs may be produced by gluon splitting, a symmetric process generating nearly equal numbers of anti-down, $\bar{d}$, and anti-up, $\bar{u}$, quarks, or from virtual-pion production, an asymmetric process that generates an excess of $\bar{d}$. We can determine $\bar{d}/\bar{u}$ by measuring the properties of the muon pairs produced in the Drell-Yan process, which occurs when a quark in a proton beam strikes a sea antiquark in a target.

Spin Physics at RHIC

The muon detectors at PHENIX are also designed to study which components of the proton carry its spin. When both beams at the RHIC collider are composed of polarized protons, the proton-proton interactions will be directly sensitive to the fraction of spin carried by the gluons (see Figure 2). Previous measurements of deep inelastic scattering have only been sensitive to the sum of the quark and antiquark contributions to the spin, but the availability of polarized protons to induce the Drell-Yan process allows the separation of these two components by measuring the antiquark piece alone. Additionally, by measuring the asymmetry of the charge states of the intermediate vector boson (W), the flavor dependence (*i.e.*, the difference between up and down quark contributions) can be extracted. Spin physics is expected to commence at RHIC after a year or two of heavy-ion experimentation.