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Detectors For High Energy Nuclear Collisions: Problems, Progress and Promise

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1. INTRODUCTION

I present here an encapsulation of the discussions which took place in the topical session on Detectors for High Energy Nuclear Collisions. It is not a proper summary, but a perspective view of the main issues raised in the presentations of Gordon, Gruhn, DiGiacomo, Albrow and Lindenbaum and the responses we have heard from the audience and the session chairman, Chris Fabjan.

First, it is clear from the theoretical discussion at this conference and its predecessors that we do not yet know of a precisely defined means for identifying and measuring a quark-gluon plasma. Many different signals have been discussed as characteristic of the radiation from a state in which the nucleonic degrees of freedom have given way to a system of locally unbound quarks and gluons in a condition which approximates thermal equilibrium. Background radiation from the hadronic matter which accompanies the creation and space-time evolution of such a state should be readily understood in terms of a long experience with soft hadronic processes in high energy collisions of elementary particles. What is not well-understood is the relative strengths of these signals and backgrounds.

An experimental program will involve a systematic study of many reaction products, and detectors sensitive to different forms of radiation which may be used to probe the nature of matter created in the collision. Assuming that interesting events are relatively rare, the measurement strategy will be to employ selective triggers to choose events indicative of a favorable thermodynamic environment. This thermodynamic characterization must be done event-by-event with measures such as particle multiplicity, energy and momentum flow, and inclusive particle spectra sampled in various kinematic regions. Having selected such a sample one can then bring to bear specific measurements of signatures and probes, such as lepton pair spectra, particle flavor ratios, etc.

This approach implies a measurement capability similar to that which exists in spectrometers for high energy elementary particle experiments, but there

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are important differences. The most striking is the extraordinary level of particle multiplicities which experiments must deal with in high energy nucleus-nucleus collisions: Estimates for RHIC reach up to ~10,000 particles per event. In addition, most of the essential measurements involve soft particles, with transverse momenta and pair masses characteristic of the kinetic energies in a thermalized plasma. This is in contrast with the elementary particle case where the focus is largely on rare processes produced in the high P_T tails of momentum distributions. For nuclear beam experiments the signals of interest must generally be extracted from the high multiplicity component of soft particles.

Howard Gordon has shown some detector configurations designed to carry out such a program. These include experiments which are very close to realization for the first high energy beams of relatively light ions (oxygen, sulfur) which are coming on this year at CERN and BNL, and conceptual designs for the most extreme case of heavy beams colliding at the highest energies in RHIC. Each of these experiments aims for a rather global measurement of each event. And each program (AGS, SPS, RHIC) has come out looking like an ensemble of quite different experiments, where every experiment is optimized for a particular class of measurements. This seems to reflect the general belief that very large, all-purpose detector systems would require too many compromises and would be too expensive. This trend toward leaner experiments designed to optimize the measurement of specific signals and probes has the advantage of bringing many different detector technologies into the hunt for many different types of evidence for new phenomena. One would not want to over-optimize the design of experiments on the basis of current theoretical predictions, as these may be off the mark in important respects, and we do not want to be insensitive to those truly unexpected results which may well lead to the most important discoveries.

There are now eight large experiments in preparation for the coming ion beams at the AGS and SPS. These look very much like medium-to-large scale high energy physics experiments, and it does not appear that in these experiments there are any crucial measurements which are precluded by a short-fall of detector technology. The main detector issues seem to be with the more extreme experimental environments of the next round, when oxygen and sulfur beams go to gold or uranium, and the AGS/SPS fixed target configurations give way to the high energy collider environment of RHIC. I list below some of these issues as they were discussed in this session.

Lepton Pairs: Measurements of pair spectra, for either muons or electrons, are expected to play the crucial role of revealing directly the radiation of virtual photons from a hot plasma. The problem is that the main interest lies with small transverse masses (few GeV down to few hundred MeV), and the background from decays of low P_T pions is enormous. As we saw in Howard Gordon's talk, several of the CERN experiments will measure muon pairs in the classical way, taking advantage of the fixed target kinematics at SPS energies to employ thick hadron absorbers and short lengths for pion decay. At a collider, in the central region, the kinematics are not so favorable. A study at last year's RHIC workshop[1] showed what appear to fundamental limitations on the measurement of low-mass muon pairs in this situation.

For effective measurement of low-mass electron pairs the instrumentation must be capable of electron/hadron discrimination at a level ~ 10^5. Nick DiGiacomo has presented here the latest technology for achieving such sensitivity with a high degree of spatial segmentation. These technical capabilities notwithstanding, the presence of hundreds of π° decays per event means there will be many spurious electrons and, ultimately, a background level of pair combinations below which a signal cannot be detected even with "perfect" instrumentation. Such limits have been studied for some configurations[2], and need more attention.

Tracking: The question of multitrack resolution is a perennial topic of discussion, with some answers soon forthcoming as several different tracking arrays get set for the ion beams at CERN and BNL. These include a streamer chamber and a TPC covering large solid angles, and two approaches to small aperture spectrometry: The HELIOS experiment at CERN employs a slit in the calorimeter wall covering a large angle for single-particle and pair measurements, but very small solid angle so that the tracking (drift chambers with charge division) requires no special technology for high numbers of tracks. Experiment E802 at Brookhaven has a spectrometer arm, with roughly equal coverage in θ and ϕ, designed to handle up to 20 tracks in a solid angle of about 20 msr. This detector uses many planes of MWPC in traditional XYUV configuration, relying on precise reconstruction of hits in each plane and powerful pattern recognition algorithms to sort out the track reconstruction.

It is generally conceded that, with the possible exception of the TPC device, none of the tracking systems now being implemented for oxygen and sulfur beams would be satisfactory for high energy gold or uranium beams. Sam Lindenbaum showed some Monte Carlo results for the E810 TPC design which look very promising. Chuck Gruhn, however, is already looking ahead to ways of reinforcing the capability of these devices for the really high track densities and total multiplicities of future experiments.

Fluctuations; Rate Capability: Most of the fixed-target experiments are designed for relatively modest event rates. The instrumentation is not designed to push the limits of rate capability. This is not for lack of beam intensity. It reflects the fact that the focus is more on the complexity of events, assuming that the interesting phenomena will not have vanishingly small cross sections. Similarly, the event rates at RHIC, given the design luminosity will be of order 10^4-10^6; far less than the extreme represented by the planned SSC. Still, these rates are not small and they could be much larger if the physics program requires it; i.e., if it becomes desirable to examine certain striking but very rare processes. In the RHIC proposal, for example, possible upgrades are discussed which could increase the luminosity by an order of magnitude.

Working Close to the Beam: Backgrounds and other problems.

Both Gruhn and DiGiacomo have stressed the desirability of clean tracking in an environment where there is a high density of particles. Near the highly charged beams however, electromagnetic backgrounds can be expected to be severe. Workers at the Bevalac have given us many graphic examples of chamber volumes completely obscured by swarms of killer delta rays. This is of particular concern for the active targets foreseen for fixed target experiments at the AGS and SPS, and for the operation of close-in "vertex detectors" at the collider.

Calorimetry: Mike Albrow has shown how the power and flexibility of calorimeter techniques which have been developed over the past decade in high energy physics will play in central role for sensitive experiments with high energy nuclear beams. The optimization of calorimeter systems for the heavy ion experiments will be different in the heavy ion case however, generally leading to simpler and cheaper detectors. Thus, for RHIC, a 4π calorimeter need not be as deep as for a hadron or electron collider of similar energy. This is because the energy is carried by a large number of soft particles, and fluctuations in energy loss due to (small) leakage will not be great. Also, because of the enormous energies and multiplicities, energy resolution will doubtless be dominated by systematic, rather than statistical errors, and so expensive solutions such as uranium absorber may not be necessary. In the same vein, the "4π" calorimeter for RHIC need not be hermetic in the sense required for most current-generation high energy physics collider detectors; small areas where the device is insensitive are probably acceptable, and this should allow for simpler and cheaper construction.

A common thread of discussion in all of the above topics has been how to tap high energy physics expertise in the design and implementation of large detector systems for nuclear beams. For the first-round experiments at the CERN SPS and, to a lesser extent, the Brookhaven AGS, the collaborations include a mix of high energy and nuclear physicists with detector systems based on apparatus originally built for particle physics experiments. For future experiments, continued collaborations of this sort may call for some blurring of the boundaries which exist in the funding agencies between high energy and nuclear physics. The advent of large-scale detector systems at a major accelerator facility operated by nuclear physics should be accompanied by the development of a well-organized R&D infrastructure such as has been carefully and successfully nurtured by high energy physics for many years.

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