EARLY RESULTS FROM MINIMAX, A DISORIENTED CHIRAL CONDENSATE SEARCH AT THE TEVATRON

C. C. TAYLOR
Department of Physics
Case Western Reserve University
Cleveland, Ohio 44106-7079, USA

Representing the MiniMax Collaboration[1]

We present early results from an experimental search (T-864, MiniMax) for Disoriented Chiral Condensate (DCC) at the Fermilab Tevatron Collider at $\sqrt{s} = 1.8\ TeV$. In order to analyze the data on joint charged-particle/photon distributions, we have identified robust observables with many desirable properties. These observables are insensitive to many efficiency corrections and the details of the modeling of the primary pion production mechanisms while maintaining sensitivity to the production of DCC, as opposed to the generic, binomial-distribution, partition of pions into neutral and charged species. The formalism is applied to the MiniMax data.

1 Disoriented Chiral Condensates

There has recently been renewed interest in semiclassical mechanisms of pion production in high-energy collisons of hadrons and of heavy ions.[2] One hypothesis in particular is that pieces of strong-interaction vacuum with an unconventional orientation of the chiral order parameter may be produced in high energy collisions. This disoriented chiral condensate (DCC) is then supposed to decay into a coherent semiclassical pion field having the same chiral orientation.

The primary signature of this mechanism is the presence of large, event-by-event fluctuations in the fraction, f, of produced pions that are neutral. Conventional mechanisms of particle production, including those used in standard Monte Carlo simulations, predict that the partition of pions into charged and neutral species is governed by a binomial distribution which, in the limit of large multiplicity, leads to a sharp value of $f \approx 1/3$. We refer to this as *generic* pion production. On the other hand, for the decay of a pure DCC state the distribution of neutral fraction is very different, $p(f)df = 1/(2\sqrt{f})df$, in the limit of large multiplicity. Some other production scenarios involving the common feature of coherent final states lead to identical f distributions.

Theoretical considerations, together with the interpretation of some reported cosmic ray phenomena[3] in terms of DCC, suggest that the one should look in the forward direction in high energy collisions at Tevatron energies. In addition, DCC pions are expected to be of comparatively low p_t.

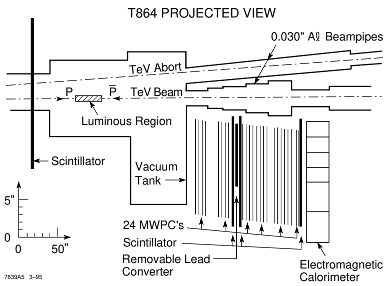

Figure 1: The MiniMax Detector

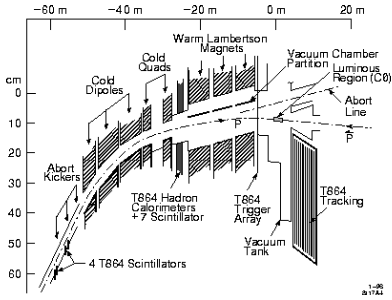

Figure 2: Upstream Instrumentation

2 The MiniMax Detector

With the above considerations in mind, the MiniMax collaboration (Fermilab T-864) has carried out an exploratory search for DCC at the C0 collision area of the Tevatron collider. Proposed in April 1993, the experiment completed running in January 1996.

Figure 1 shows the layout of the detector in the vicinity of the collision region.

Charged particles are identified by reconstructing tracks through a telescope of 24 MWPCs which have an acceptance of radius $r \approx 0.65$ in (η, ϕ) space, centered on $\eta = 4.1$. Gamma rays are identified by reconstructing tracks originating from conversions in a 1 X_0 lead converter which can be remotely inserted after the eighth chamber of the tracking telescope. In addition, an electromagnetic calorimeter is located behind the last chamber. The wire chambers are mounted behind a thin (0.25 in) window in the large vacuum tank. Scintillator is placed on the far side of the vacuum tank, behind the lead converter, and immediately in front of the electromagnetic calorimeter. Coincidences between the arrays, in time with the beam passage, provide the trigger. Because of substantial interactions of forward secondaries with the beampipe beneath the detector, the floor, etc., occupancies in the chamber are quite high. While this poses substantial challenges in track reconstruction, a corollary is that the trigger is extremely efficient, recording some $35 - 40$ mb of the inelastic cross section.

MiniMax also has instrumentation in the upstream proton direction (see Figure 2). Of particular interest are the scintillators located about 50-60 m from the collision point. These counters are sensitive to final state p-bars with Feynman-$x \sim 0.85 - 0.95$, and thus constitute a tag for diffractive events.

3 Analysis Challenges and Robust Observables

Even from this It should be clear, even from this very brief description of the experiment, that we face many challenges in trying to infer either the presence or absence, within limits, of DCC signals from the data. The MiniMax acceptance is small, so that it is improbable that both γ's from a π^0 enter the detector acceptance. The conversion efficiency per γ is about 50%. Not all γ's come from π^0's. Not all charged tracks come from $\pi^{\pm}$'s. The multiplicities are rather low, because of the small acceptance, so that statistical fluctuations are very important. Detection efficiencies for charged tracks and γ's are momentum-dependent and are not the same. Efficiency functions may be dependent upon the observed multiplicity or other parameters. The efficiency for triggering when no charged track or converted γ is produced within our acceptance is relatively low and different from that for events in which at least one charged particle or converted γ is detected.

Nevertheless, we find that there do exist observables which are robust in the sense that, even in the presence of large (uncorrelated) efficiency corrections and convolutions from produced π^0's to observed γ's, the observables take very different values for pure DCC and for generic particle production. Each such observable is a ratio, collectively referred to as R, of certain bivariate normalized factorial moments, that has many desirable properties. The R's do not depend upon the form of the parent pion multiplicity distribution. The R's possess definite and very different values for pure generic and pure DCC pion production. The R's are independent of the detection efficiencies for finding charged tracks, provided these efficiencies are not correlated with each other or with other variables such as total multiplicity or background level. The R's are independent of the magnitude of the null trigger efficiency. Some of the R's are also independent of the γ efficiencies in the same sense as above. In the remaining cases, the R's depend only upon one parameter, ξ, which reflects the relative probability of both photons from a π^0 being detected in the same event.

4 Generating Functions and Robust Observables

Generating function techniques have been extremely useful in studies of multiparticle production. Most practical studies, however, have considered the properties of a single species (usually charged particles) at a time. In the case of DCC, however, formal tools for the study of the joint distribution of charged particles and photons are required; the MiniMax collaboration has devoted substantial effort to developing such tools.[4]

The starting point is the generating function for factorial moments of the number of observed charged particles and gamma rays,

$$G(z_{ch}, z_\gamma) = \sum_{n_{ch}, n_\gamma = 0}^{\infty} p(n_{ch}, n_\gamma) z_{ch}^{n_{ch}} z_\gamma^{n_\gamma}. \tag{1}$$

where $p(n_{ch}, n_\gamma)$ denotes the probability distribution for the observation of n_{ch} charged particles and n_γ gamma rays in a multiparticle event within a given phase-space region. The partial derivatives of $G(z_{ch}, z_\gamma)$ evaluated at $z_{ch} = z_\gamma = 1$ generate the factorial moments:

$$f_{i,j} \equiv \left(\frac{\partial^{i,j} G(z_{ch}, z_\gamma)}{\partial {z_{ch}}^i \partial {z_\gamma}^j} \right)_{z_{ch}=z_\gamma=1}. \tag{2}$$

For example, we have, $f_{1,0} = \langle n_{ch} \rangle, f_{0,1} = \langle n_\gamma \rangle$, etc.

Under assumptions implicit in properties of the robust observables outlined above, it can be shown that

$$G_(z_{ch}, z_\gamma) = \int_0^1 df p(f) \sum_N P(N)[f(\epsilon_0 + \epsilon_1 z_\gamma + \epsilon_2 z_\gamma^2) + (1-f)(1-\epsilon_{ch}) + \epsilon_{ch} z_{ch})]^N, \tag{3}$$

where ϵ_{ch} is the probability of observing a charged pion, ϵ_i are the probabilities of observing i gamma rays from the decay of a π^0, and $p(f) = \delta(f - \hat{f})$ if the partition of parent pions into charged and neutral species is binomial with neutral fraction $\hat{f}$, and $p(f) = 1/(2\sqrt{f})$ for a DCC.

Defining normalized bivariate factorial moments $F_{i,j} = f_{i,j}/(f_{1,0}^i f_{0,1}^j)$, one can show that the quantities $r_{i,1} = F_{i,1}/F_{i+1,0}$ are robust in the sense introduced above, and take the values $r_{i,1}(generic) = 1$ for generic (binomial) distribution of neutral and charged pions, and $r_{i,1}(DCC) = 1/(i+1)$ for a DCC. In addition, the $r_{i,j} = F_{i,j}/F_{i+j,0}, j > 1$ depend on only the single (detector dependent) parameter ξ related to ϵ_2.

5 Early Results

Table 1 shows the measured values of lower-order ratios of the factorial moments. The results were found to be independent of the run conditions, independent of the converter thickness or composition, and the same in events with or without a diffractive tag. The data are consistent with the generic production mechanisms. Comparison between the different trigger samples, and between the calculated and Monte Carlo [5] corrected values suggest the errors

Table 1: Values of $r_{i,j}$ from the data and Monte Carlo; errors are statistical only

$r_{i,j}$	PYTHIA and GEANT	pure DCC	DCC and GEANT	Data
$r_{1,1}$	$1.01 \pm .02$	0.500	$0.56 \pm .01$	$0.98 \pm .01$
$r_{2,1}$	$1.02 \pm .05$	0.333	$0.40 \pm .03$	$0.99 \pm .02$
$r_{3,1}$	$1.09 \pm .14$	0.250	$0.34 \pm .05$	$1.03 \pm .04$

due to systematic effects are in the 5% range. We believe we are sensitive to admixtures of DCC mechanisms to the $10 - 20\%$ level. More work is needed, however, to place a limit on the quantity of DCC we may observe. These values are dependent on the model used to mix DCC into the generic fragmentation.

Acknowledgments

This work has been supported in part by the U.S. Department of Energy, the National Science Foundation, the Gugenheim Foundation, the Timken Foundation, the Ohio Supercomputer Center, and the Case Western Reserve University Provost's Fund.

References

1. See the MiniMax webpages, *http://fnmine.fnal.gov* for public information about the MiniMax experiment, including a collaboration list and links to papers which have been released.
2. For a review, K.Rajagopal, in Quark-Gluon Plasma 2, ed. R.Hwa, World Scientific, 1995, HUTP-95-A013.
3. C.M.G.Lattes, Y.Fujimoto and S.Hasegawa, *Phys. Rep.* **65** 151 (1980).
4. T.Brooks *et al*, Analysis of Charged-Particle/Photon Correlations in Hadronic Multiparticle Production. Submitted to *Phys. Rev.* **D**.
5. GEANT Detector and Simulation Tool, CERN, PM0062 (1993).
   T. Sjostrand *CERN-TH.6488/92 (PYTHIA 5.6 Manual)*