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# Minimax: Multiparticle Physics at the TeVatron Collider[★]

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## ABSTRACT

The history and status of test/experiment T864 (search for disoriented chiral condensate) at the Fermilab collider is described.

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## 1. Prehistory: The FAD Initiative at the SSC

At present I and about two dozen others, listed at the end of this document, are engaged in a small test/experiment[1] in the Fermilab Tevatron collider. It is called Minimax (T864), and its purpose is to explore large-cross-section physics in the forward direction, especially in the region where anomalies are persistently reported by the cosmic-ray community.

This initiative evolved from another one[2], the FAD (full-acceptance detector) initiative for the SSC. The basic FAD philosophy was to provide a survey instrument for that collider, able to search for complex patterns in individual events as a signature for new physics. By maximizing the information per event the idea was to maximize the discovery potential for the unexpected. An important feature of FAD was to cover regions of phase space not seen by generic barrel detectors, in particular pseudorapidities up to ± 11 or so.

The FAD initiative began in early 1991, with submission[3] of an expression of interest (EoI-19) to the SSC laboratory. After receiving initial encouragement from the SSC, a working group was formed, and a first meeting held in December 1991. By now the signatories in the working group number more than one hundred. Several meetings have followed the first one, most notably a week-long workshop in Boulder, Colorado, in July 1992, which greatly advanced the theory ideas, the conceptual design of the detector, and the understanding of problems of backgrounds, etc.

Since that time, there have been fewer meetings. But there have been a number of spinoff activities. On the theory side, there now exists rather widespread interest and activity[4] in the originally rather unfamiliar topics of hard diffraction (rapidity gaps and jets in the same event), of the use of this signature for Higgs-boson searches[5], and of disoriented chiral condensate[6]. On the experimental side, the major collider detector groups at Fermilab are actively looking for evidence for (or against) hard diffraction[7]. There is interest at RHIC and LHC in FAD physics. Some R&D has been carried out on large aperture quadrupole analyzing magnets[8], a design which is largely untried but which appears to be especially attractive for forward-direction, and perhaps even central, collider magnetic spectrometers. And a fruitful linkage of FAD physics with B-physics has been initiated.

Given the demise of the SSC, the FAD working group is now dormant. There is some interest in linking with an LHC and/or RHIC group, but no specific action has been taken.

## 2. From FAD to MAX to Minimax:

In the fall of 1992, a new spinoff activity was initiated. It became clear that experimentation at Fermilab could do much to advance the FAD physics and test the viability of FAD detector conceptual design. Led by Michael Longo, with myself as co-spokesman, a proposal (E864:MAX) was submitted[9] to Fermilab for a small collider experiment in the C0 collision region. The emphasis was on the search for hard diffraction and disoriented chiral condensate. After considerable deliberation, the laboratory rejected the proposal on the advice of its program advisory committee. At that point Cyrus Taylor and I decided to try again. Together with most of the original MAX group we submitted in April 1993 a new, scaled down proposal[1] for a test program (T864: Minimax) small enough to not require the time-consuming reviews by the program committee. The physics goals were limited to the search for disoriented chiral condensate, and the acceptance of the apparatus, far from being full, now borders on being near-empty.

In late May the proposal was given conditional approval by the director, John Peoples, and by July we had a signed memorandum of understanding with the laboratory, allowing us to go full speed ahead. During the summer the experimental area was cleaned up and made ready for use. Apparatus was built/acquired, and by September it was being installed. Initial commissioning using circulating Main Ring beam began in November and by now (January 1994) the shakedown of the apparatus, using the circulating Tevatron beam, is well along. However, we have not seen and will not in all probability see many proton-antiproton collisions for some time. In normal operation electrostatic separators separate proton and antiproton beams at C0 in order to optimize luminosity at CDF and D0. We do anticipate scheduled running time in collider mode before the end of the current run, now scheduled to be about December 1994. Test runs and extensive beam-gas runs should occur this spring. A long summer shutdown will allow us to upgrade the apparatus and optimize what we now have. We expect the Minimax experiment *per se* to end with the present run, with future plans not yet formulated.

## 3. The Minimax Detector:

The first purpose of the Minimax program is to test whether physics measurements in the forward direction very near the beam pipe are viable. We deal with production angles of 10-80 milliradians. The apparatus is adjacent to the beam pipe about 5 meters downstream of the collision point. Much of the readout electronics is in a rather hostile radiation environment.

If the apparatus does survive, the primary physics goal is the search for dis-

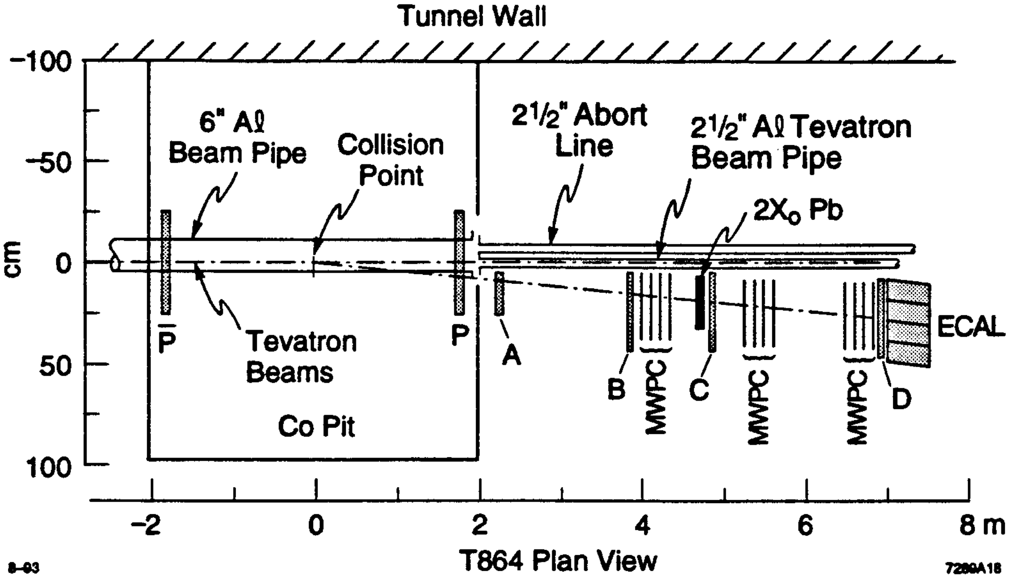

Figure 1: Plan view of the Minimax apparatus.

oriented chiral condensate. The details of this search is the main subject of the next section. In brief we strive to measure event-by event the number of photons and number of charged particles traversing the acceptance of the apparatus. The acceptance will be a small circle in the lego plot of radius no more than 0.8 or so, centered at a pseudorapidity of about 4. A by-product of this work should be some contributions to the study of intermittency phenomena via measurements of charged/neutral particle multiplicity distributions as a function of lego-plot area. Such measurements should be accessible both in beam-gas and beam-beam collisions.

The apparatus is located in the C0 experimental area, most recently used by the E735 experiment of Gutay et al. (search for quark-gluon plasma). It is shown in plan view in Fig. 1; detector components are shown in Fig. 2. The C0 area is semi-developed; there is a shallow pit 18″ deep in the neighborhood of the collision point. Upstream and downstream the Tevatron beam is a scant 10.5″ off the floor. Just above looms the Main Ring and its abort channel. There is a Tevatron abort channel going by our apparatus as well. Although it is not used in collider mode, the string of Lambertson magnets immediately upstream, of very limited vertical aperture, supply a robust beam of background through our apparatus. There are evidently no special low-beta focussing magnets at C0, so the luminosity when collisions do occur is 200 times less than at CDF/D0.

The heart of the apparatus is a small tracking telescope of 12 multiwire proportional chambers of size 30 cm × 30 cm, 128 wires per chamber, constructed last summer at Case Western Reserve University[10]. We intend to put about 2 radiation lengths of converter within this telescope to convert photons and count the shower cores. Scintillator, provided by Duke University and Virginia Polytechnic

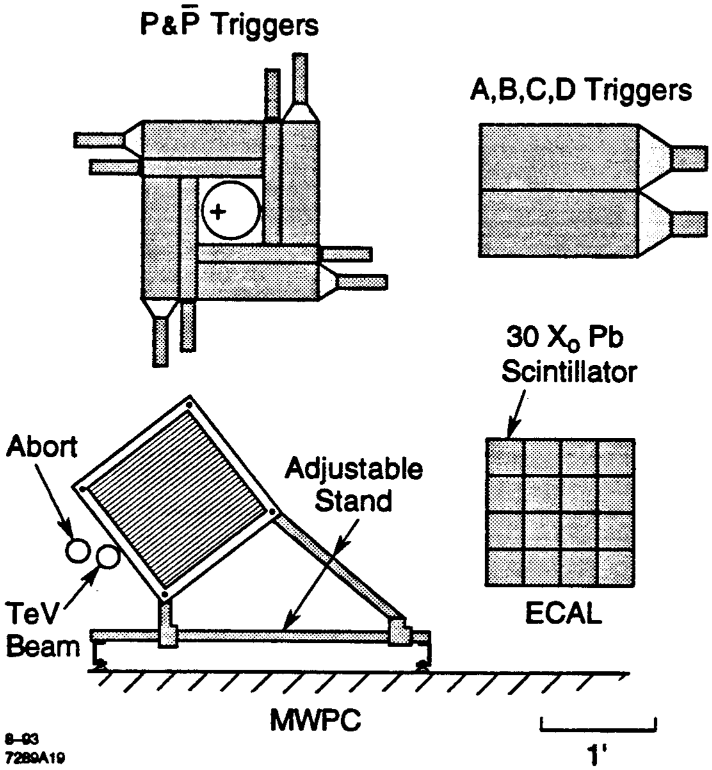

Figure 2: Minimax detector components.

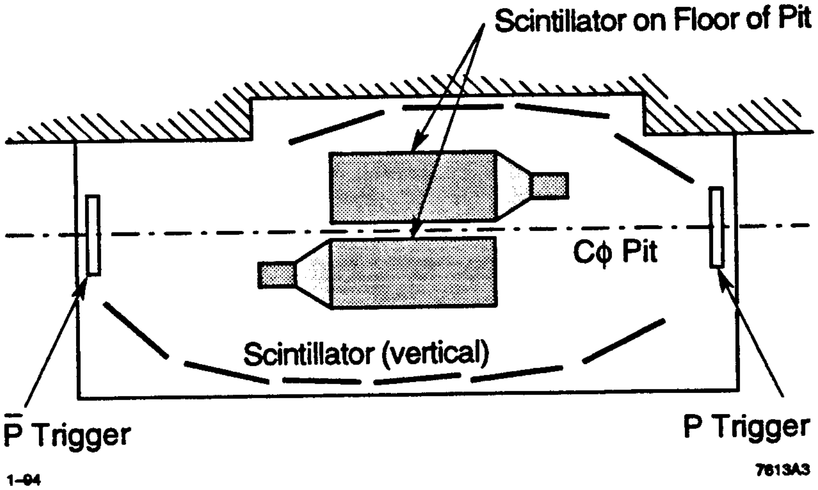

Figure 3: Layout of "Stonehenge" scintillators in the C0 pit.

Institute, is strategically placed to provide a trigger. The basic trigger (see Fig. 1) is a coincidence between those labeled ABCD, augmented by beam-beam triggers labeled $p$ and $\bar{p}$. Twelve large scintillation counters, provided by VPI and nicknamed Stonehenge, are installed in the C0 pit (Fig. 3). They each have a lego acceptance of about one unit of $\delta\eta \times \delta\phi$ and may provide additional discrimination between beam-beam and beam-gas triggers. They may also provide a coarse measure of associated multiplicity.

Downstream of the tracking telescope is a simple electromagnetic calorimeter contributed by the University of Michigan. It is composed of sixteen $4'' \times 4''$ blocks of lead-scintillator sandwich (30 radiation lengths),each read out by a single phototube, and should be helpful for diagnostics.

Readout electronics for the rear eight chambers has been provided by the Michigan group. Pulse height information for every wire is recorded. The four front chambers are read out by a Nanometrics system last used in the direct-photon experiment E706; only latch information is recorded. The data acquisition system utilizes a VaX 3100 supplied by Fermilab.

The success of the Minimax program clearly depends on the ability to contain the heavy backgrounds expected to be present so near to the beam in a less-than-ideal environment. A major help in this respect has been the replacement of the original stainless steel beam pipe alongside the tracking telescope with a thin wall aluminum pipe. This was accomplished by the Fermilab accelerator division in spite of severe time and fiscal constraints. While the original pipe presented at least 10 radiation lengths to photons from the collision point, the new pipe reduces this to less than one. Our Monte Carlo simulations support simple common sense that this improvement will make an enormous difference.

## 4. Physics

### 4.1. *Disoriented Chiral Condensate*

The primary goal of the T864 program is the search for events containing the residue of disoriented chiral condensate (dcc) produced in the primary collision. The theoretical ideas[6] are very speculative. But if they are right, they could provide an interpretation of the Centauro/anti-Centauro anomalies claimed to have been seen in cosmic-ray events.

The basic notion is that in the interior of the expanding shell of debris produced in a $p\bar{p}$ collision there is created not the usual vacuum of the strong interactions, but one of its near-degenerate alternatives, characterized by a different order parameter. Nowadays this parameter-the chiral orientation-is, ironically, most easily explained by comparing it with the famous vacuum orientation associated with the Higgs sector. There, as for the strong interactions, the order parameter is a vector in a four-dimensional internal space. The orientation of the true vacuum lies in the Higgs direction, and the other three directions have the quantum numbers of the Goldstone modes swallowed up by the gauge bosons. In the strong interactions, the vacuum direction is that of the $0^{++}$ sigma meson (the Higgs boson of the strong interactions) and the other three are in the pion (Goldstone) directions. So if in the fireball interior the vacuum orientation is tilted toward one of the pion directions, then when the fireball shell hadronizes, the interior vacuum will relax to the true vacuum by emission of a coherent semiclassical pulse of pions with the same (cartesian) isospin as had the vacuum disorientation. That is, if the order parameter is knocked toward the $\pi^0$ direction, then all the emitted dcc pions will be $\pi^0$'s. This leads to anomalously large fluctuations in the charged-to-neutral ratios and the motivation for the experiment.

It is not trivial to search for the purported disoriented chiral condensate. The coherent pions of interest have to be found in the presence of the debris from the hot shell. So existing data from accelerators, especially in the forward direction where the cosmic ray data exists, are not decisive. The strongest constraint is probably the NA5 data[11] from the SPS collider, which does not see evidence for Centauro behavior at the level expected from the Chacaltaya observations. But the limit is still fairly loose. In any case it may be that there is less debris background in the forward direction. While this is only speculation, we choose it as the best region in which to look. It is after all where the cosmic-ray evidence exists.

A principal piece of inspiration for us comes from an event found by the JACEE collaboration[12]. It originates within a balloon-borne emulsion calorimeter. The proton primary and the primary vertex are seen, and the gamma-ray shower cores found below are tracked back to their point of conversion and determined to point to the primary vertex. As one sees in Fig. 4, there is a large excess of gamma rays at the largest rapidities. The primary energy as measured by the summed energies of the gamma rays is in excess of 15 TeV. The cms energy is less than 2 TeV. To get to the Fermilab rapidity distribution, one needs only to subtract off about 3 units. This puts the anomalous region right in the Minimax acceptance

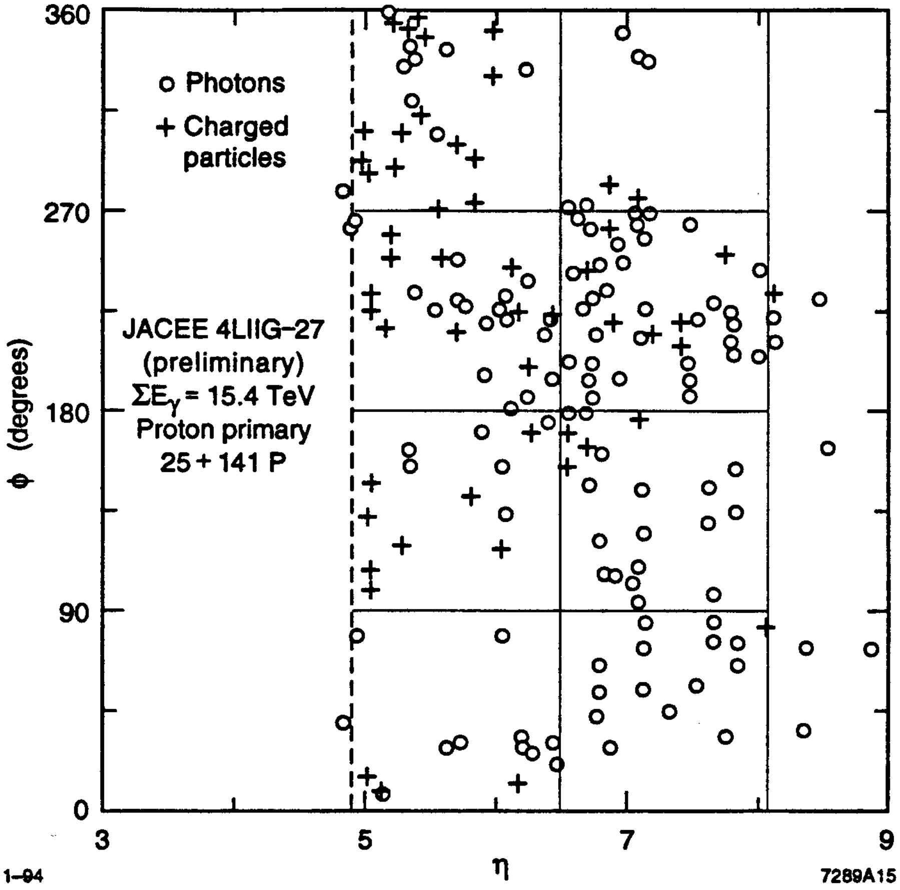

Figure 4: Lego plot of an unusual event from the JACEE collaboration[12], divided into sectors each of which approximates the Minimax design acceptance.

domain.

The probability of seeing such a JACEE distribution, according to Pythia gospel, is very small. We subdivide the event into sectors as shown in Fig. 4; each sector is about the same size as the Minimax acceptance. We find that in 5 out of 8 of the sectors the odds of finding such charged/neutral multiplicities is less than a part per million if the Pythia simulation is realistic.

Our strategy for the dcc experimental search is as follows. For a given observed total "pion multiplicity"

$$N = N_{ch} + \frac{1}{2}\, N_\gamma$$

we determine the distribution of the "neutral fraction"

$$f = \frac{N_\gamma}{2N}\ .$$

Common sense (and even Pythia) predicts a binomial-distribution for $f$, peaked at 1/3, with width narrowing as multiplicity increases. However, because the dcc pulse is semiclassical and highly correlated, what is expected from dcc is a limiting

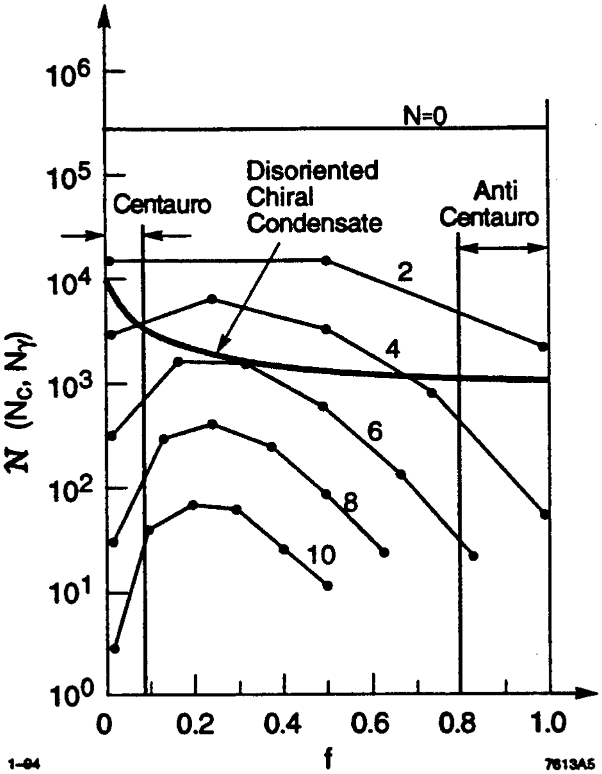

Figure 5: Expected distribution for the neutral fraction f for various total pion multiplicities according to 5 × $10^5$ Pythia Monte Carlo events. Also shown is the dcc inverse square root distribution, which is essentially independent of pion multiplicity.

distribution which is inverse square-root:

$$\frac{dN}{df} = f^{-1/2} \ .$$

This is depicted in Fig. 5. The integrable singularity near $f = 0$ is the Centauro region (no $\pi^0$), and the region near $f = 1$ the antiCentauro (all $\pi^0$). We intend to proceed by cutting, for example, on f large (or small) and then plotting the frequency of finding f beyond some cut as function of total pion multiplicity. Again common sense provides an exponential fall with increasing multiplicity, while a dcc component should, as shown in Fig. 6, lead to a flattening (saturation).

### *4.2. Intermittency*

A by-product of this program may be some modest contribution to the study of intermittency[13]. We should be able, for our acceptance, to measure, within a circle of radius $R$ in the lego plot, the joint multiplicity distribution in $N_{ch}$ and $N_\gamma$. We can study this as a function of the chosen radius $R$ from a minimum of perhaps 0.1 to a maximum of about 0.8, and in the region of rapidities of 3 to 5. We may be able to make rough cuts on associated multiplicity and study the dependence on that as well.

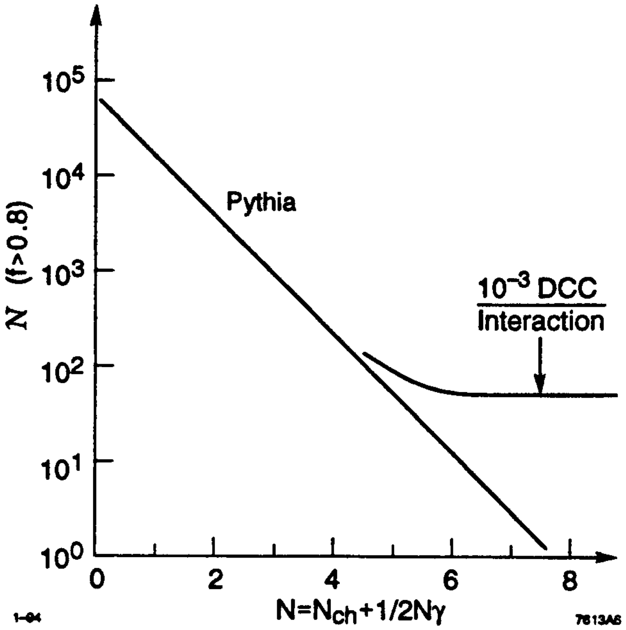

Figure 6: Probability for finding $f > 0.8$ as function of total pion multiplicity N. The input is the same as for Fig. 5.

Since we are newcomers to this area of research, we very much welcome advice and suggestions on how best to make use of the data we hope to soon acquire.

## 5. Acknowledgments

We have had a great deal of assistance from a large number of Fermilab staff members, too many to list here. To all, our heartfelt thanks for helping us to get going in an unusually short period of time. We do wish to especially thank C. Hojvat and J. Streets for their essential help. Important parts of the apparatus have been obtained from the earlier Fermilab experiments E665 and E706, and we thank those collaborations for their cooperation. We also thank C. Wang of Duke University for his generous assistance.

## 6. List of Collaborators

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