Latest Results from MiniMax

- Introduction
- Physics of DCCs
- Description of the Apparatus
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- How we Tracked and found Vertices
- Event Monte Carlos - PYTHIA & DCC generator
- Data Analysis
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Workshop on Hadron Systems at High Density and/ or High Temperature.

7^{th} August 1997

URL=http://fnmine.fnal.gov/

Jon Streets, for the MiniMax Collaboration...

Latest Results from MiniMax

MiniMax Collaboration

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Introduction to MiniMax

Pre-History

- 1991-1992 FAD initiative at the SSC
- Sept. 1992 - March 1993 - MAX proposal at Fermilab
- April 1993 - 1996 MiniMax

Goals

- Far-Forward Collider Experimentation to look at Multiparticle Production
- Search for Cosmic-Ray Anomalies (Centauro, Anti-Centauro - JACEE)
- Search for Disoriented Chiral Condensate (DCC)

Physics - What is a DCC?

Disoriented Chiral Condensates are used to explain some high multiplicity events seen in Cosmic Ray experiments. These events have anomalous values of

$$f = \frac{N_{\pi^0}}{N_{\pi^0} + N_{\pi^{ch}}}$$

and low relative p_T (*a.k.a.* Chiron Behavior).

DCCs are produced in collisions where the debris expand a few fermi before hadronising.

The relatively cold interior of the collision region is a strong-interaction vacuum.

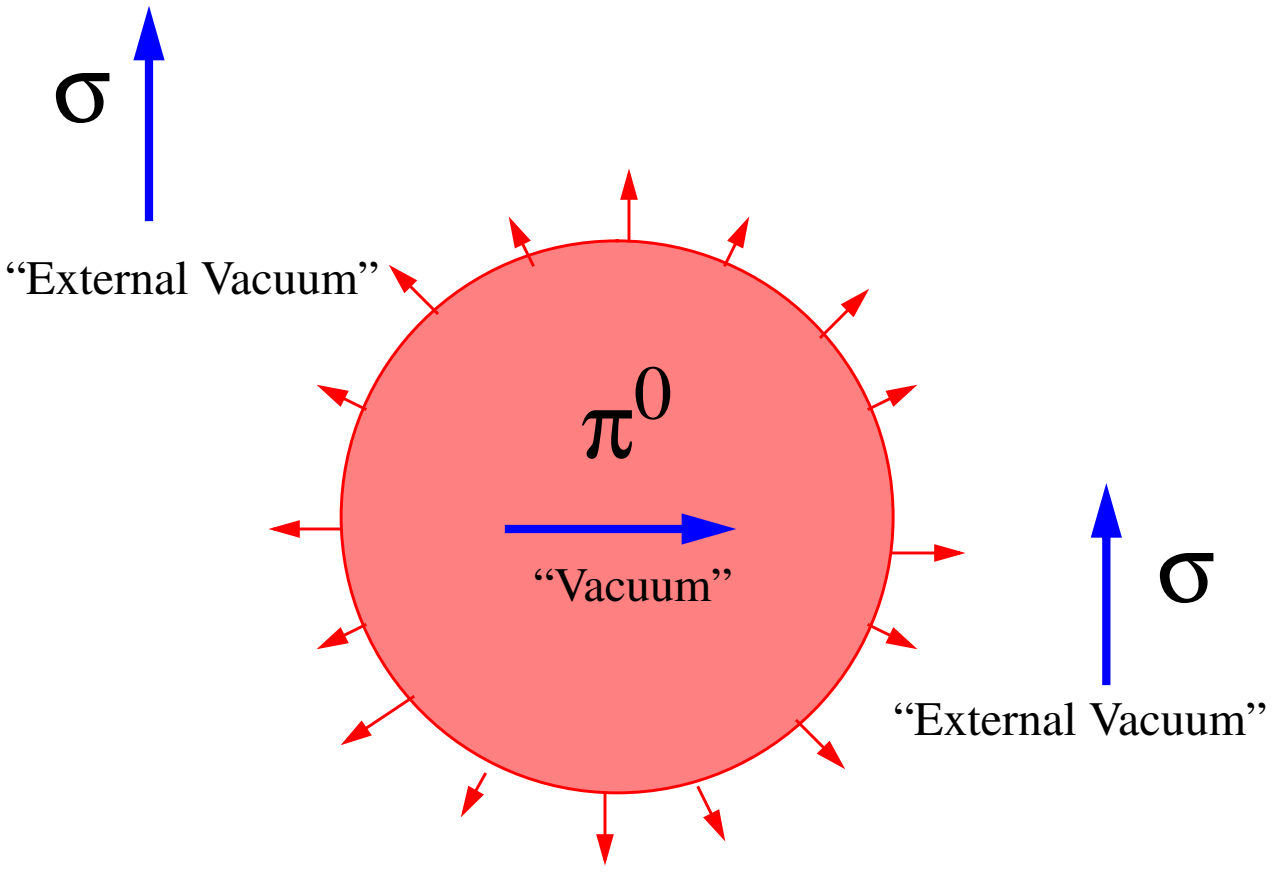
It is almost degenerate due to the approximate $SU(2)_L \times SU(2)_R$ chiral symmetry, and described by the $(\sigma,\underline{\pi})$ model, where $\underline{\pi}=(\pi^+,\pi^-,\pi^0)$.

The orientation of the σ field defines the pionic content of the condensate, and affects the coherent hadronisation of the hot exterior.

DCC from the Strong-Interaction Vacuum

45 GeV p's on 18 TeV $\bar{p}$'s

Produce...



Disoriented Chiral Condensate within an Expanding Hot Shell which Evolves into a Coherent Pulse of Pions.

Generic (Binomial) distribution

In the generic model, we assume equal probabilities for production of π^+, π^- and π^0's. This leads to a probability P[n,N] of n π^0's from N π's:

$$P[n, N] = \left(\frac{1}{3}\right)^n \left(\frac{2}{3}\right)^{(N-n)} \frac{N!}{n!(N-n)!}$$

where

$$n = N_{\pi^0}, N = N_{\pi^0} + N_{\pi^+} + N_{\pi^-}$$

and

$$\langle f \rangle = \frac{1}{3}$$

DCC distribution

The Probability distribution for n π^0's from N particles can be shown to be:

$$P[n, N] = \left(\frac{2^N N!}{2^n n!}\right)^2 \frac{(2n)!}{(2N+1)}$$

which leads to

$$P(f)df = \frac{1}{(2\sqrt{f})}df$$

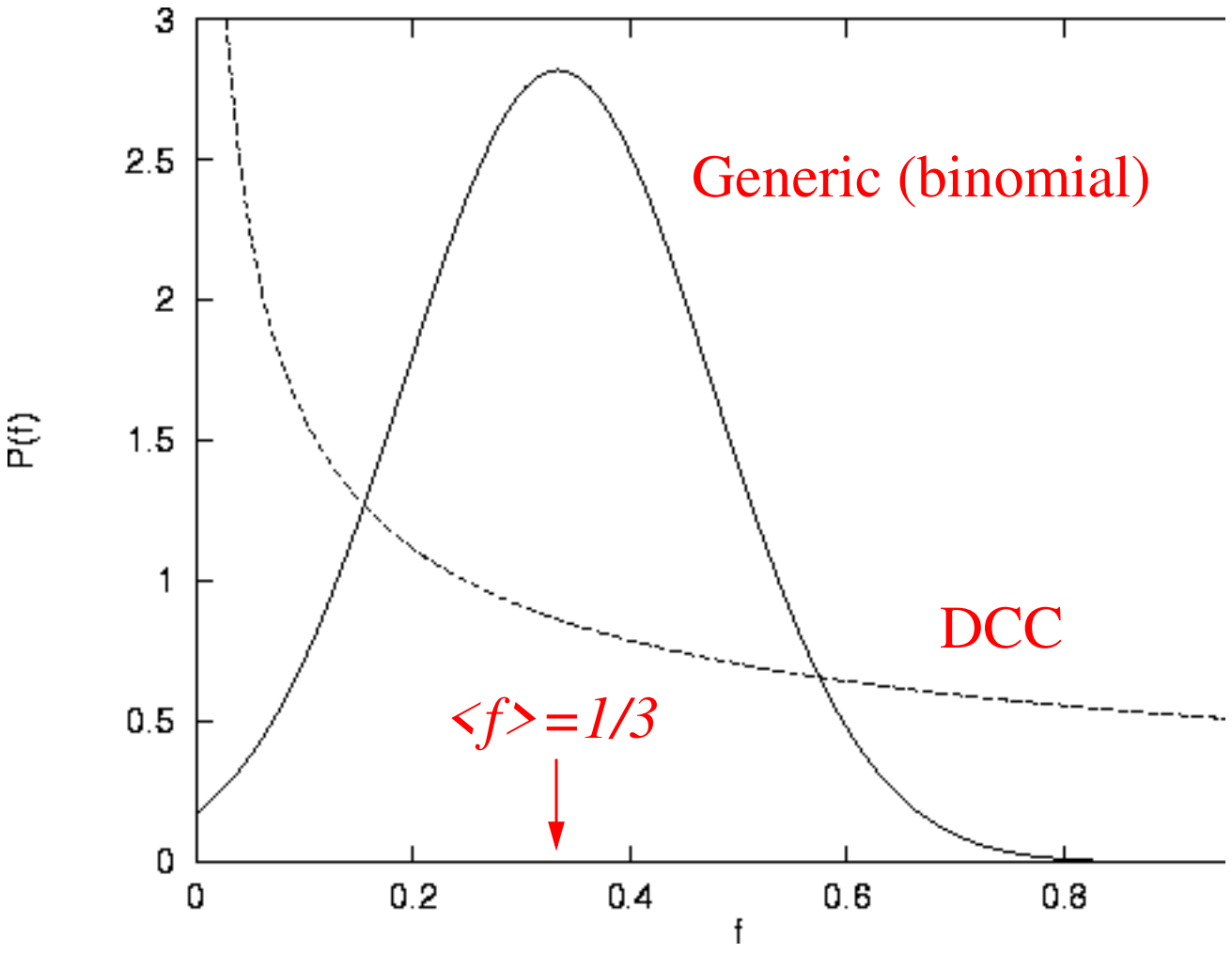
and again

$$\langle f \rangle = \frac{1}{3}$$

This probability distribution gives higher values for f=0 and f=1 than the generic case.

Comparison of the generic and DCC distributions

$$f = \frac{N_{\pi^0}}{N_{\pi^0} + N_{\pi^{ch}}}$$



Cosmic Ray Evidence

Centauro Events

- $n_{ch} \sim 100$
- $n_{\gamma} \sim 0$
- CMS Energies ~ 1 *TeV*
- Seen in forward direction ($\eta \sim 3.5$ to 4.5)
- Relative p_T of secondaries is low (Chiron Behavior)
- Possibly Diffractive

Anti-Centauro Event(s)

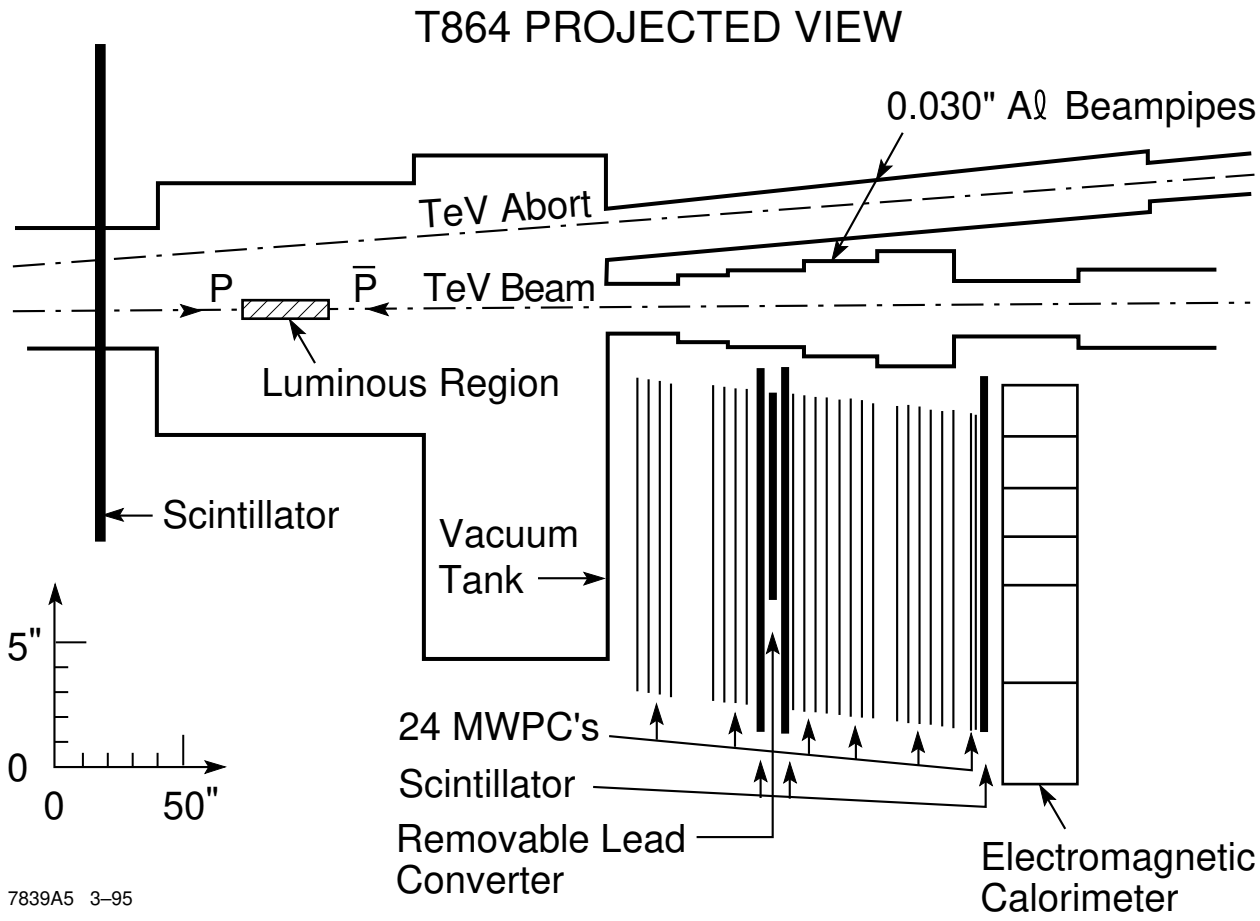
- $n_{ch} \sim 18$
- $n_{\gamma} \sim 60$
- CMS Energy > 200 *GeV*
- Chiron Behavior

Is there evidence at the Tevatron, in a rest frame with 45 *GeV* p's on 18 TeV $\bar{p}$'s?

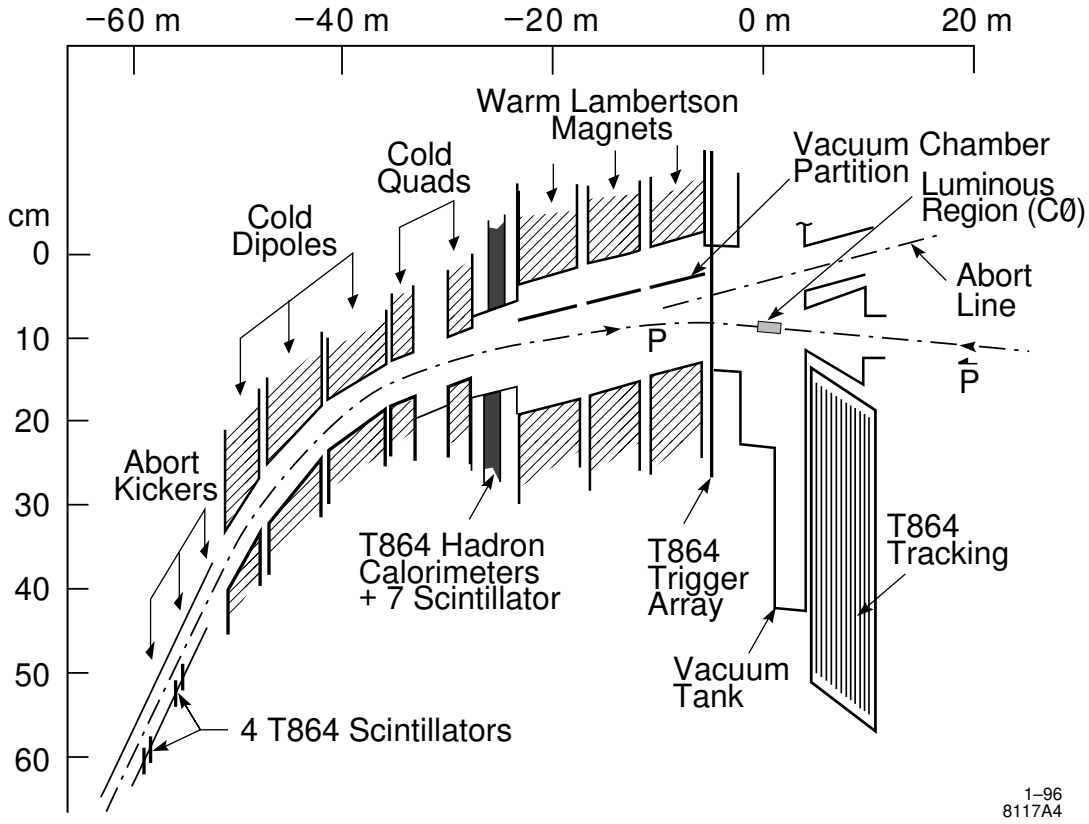
Description of the Apparatus

- Located at the C0 interaction region of the Tevatron.
- Run parasitically to E811 and $\bar{p}$ production (with beam separators switched off at C0 and E0).
- Acceptance - (η,ϕ) radius of 0.65 at η=4.1
- 24 MWPC, each have 128 wires with 0.1” spacing. 5-30% occupancy per wire, > 95% efficiency.
- Movable Lead and Iron Converters after 8th MWPC (X_0 = 0.5, 1, 2)
- Pb-Scintillator EM calorimetry behind chambers, and Pb-Scint. Fibre EM CAL 25m upstream.
- Trigger scintillators inside MWPC telescope & upstream, and far upstream.
- DAQ - CAMAC (50% Michigan ADCs, 50% Nanometric Latches) read via VAX 3200.

Apparatus Layout



Interaction Region



Backgrounds, Triggers and Rates

- Triggered on upstream $\bar{p}$ counter in coincidence with telescope counter.
- Beam gas (with separators on) give 5-20 *Hz*
- With separators off, see 300 *Hz*, at $1 \times 10^{30} cm^{-2} sec^{-1}$
- Measure 35-40 *mb* of total cross-section σ_{pp}=50 *mb*
- High trigger efficiency due to showers from beam-pipe, floor, *etc*.

Upstream tagging

- $\bar{n}$ and $\bar{p}$ calorimeters placed at 25*m* - accept $\bar{p}$'s with x_F=*0.5 +/- 0.1*. Very little change in tracking data.
- Scintillator at 55*m* - accept $\bar{p}$'s with x_F=*0.87 +/- 0.05*. See change in $\bar{p}$ trigger scintillator multiplicity distribution.

Data Analysis

Method used to detect DCC contribution in data sample.

- Measure tracks in front (charged tracks) and behind converter (charged tracks and conversions from π^0's), as a function of Pb thickness.
- Compare numbers of tracks seen with GEANT simulations of generic (PYTHIA) and DCC generators.

Problems

- Small acceptance for both γ's from π^0
- Conversion efficiency in Pb is 50% per γ
- Not all observed tracks come from π^+ and π^-'s
- Momentum & multiplicity dependence of charged and neutral detection

Tracker

Method

- Tracking performed in 4 stages:
  1. All 24 chambers (charged straight throughs)
  2. 8 chambers before converter (charged scatters)
  3. 16 chambers after converter (neutrals)
  4. 8 chambers after converter (wide angle neutrals)
- Required 2 pairs of "cross-hair" chambers to define a road in other chambers.
- Required hits in other chambers, within a cut on χ^2
- Remove duplicates
- Fit track in (u,v)

Comments

- Works for NHITS<600 (94% of the data sample)
- Possible efficiency correlations with high NHITS.
- Pipe Showers tend to cause hits in the chambers immediately after the converter.

Vertexer

Track segments are investigated to determine the probability that they meet at common points at the plane of the converter.

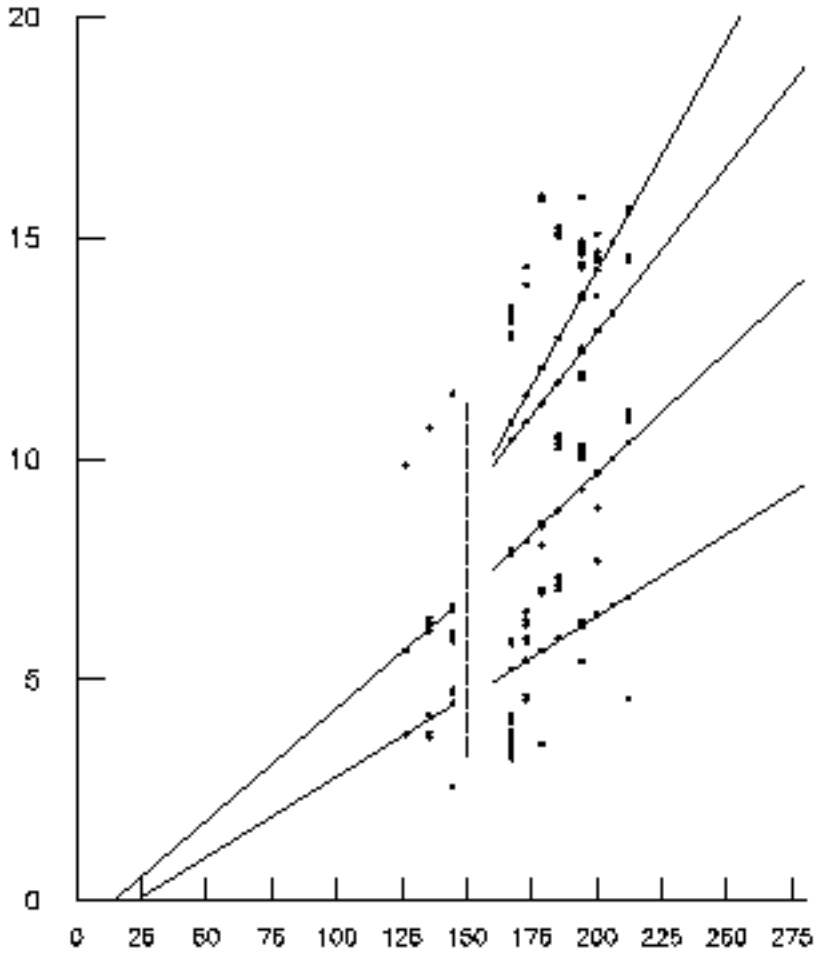
Pointing to vertex required (to remove pipe showers).

Algorithms and cuts are tuned from GEANT simulations.

Detection efficiencies:

- 85% for > 3 GeV charged pions
- 50% for > 2GeV π^0's

Typical Event



evnum= 82, nhits= 304

Event Generators

GENERIC

- PYTHIA 5.702 and JETSET 7.401 - see *http://thep.lu.se/tf2/staff/torbjorn/Welcome.html*
- Default parameters, except don't decay long lived particles ($c\tau$ >1cm) for study of K^0_S and Λ^0's (decayed in GEANT)

DCC Generator

- Pions, with neutral fraction, f:

$$P(f)df = \frac{1}{(2\sqrt{f})}df$$

- Snowball thrown with radius 0.6 units in $\eta-\phi$ space towards MiniMax.
- Pions in DCC flat in $\eta-\phi$ space
- Average 5.0 pions per DCC
- σ_p of pions in DCC is 100MeV/c
- p_T of DCC 500MeV/c

DCC generator parameters were varied to study acceptance.

Cancelling the Systematics

We measure the numbers of charged tracks, and use a vertex algorithm at the plane of the Pb converter to measure the number of γ's assumed to come from π^0's.

We find reasonable shapes of

$$\frac{dN}{d\eta} and \frac{dN}{d\phi}$$

and normalizations consistent with extrapolations from UA5 and CDF.

Just a MiniMax moment

Consider the generating function $G(z_{ch},z_0)$, which is the product of the probability that a hadron will fragment with a fraction z of the hadrons momentum:

$$G(z_{ch}, z_0) = \sum_{N_{ch}, N_0}^{\infty} z_{ch}^{N_{ch}} z_0^{N_0} P(N_{ch}, N_0)$$

It can be shown that the Factorial Moments

$$f_{mn}=(m,n)^{th}\ Derivative\ of\ G(z_{ch},z_\gamma)$$

$$\text{at } z_{ch}= z_0=1$$

are independent of the fragmentation model if the following track detection efficiencies are uncorrelated:

- ε_{ch} = Probability of observing a charged pion track
- ε_0, ε_1, ε_2 = Probability of seeing 0, 1 or 2 γ's from a decaying π^0.

More MiniMax Moments

The factorial moments are calculated to be quantities which we can extract directly from the data:

- $f_{10} = \langle N_{ch} \rangle$
- $f_{01} = \langle N_{\gamma} \rangle$
- $f_{11} = \langle N_{ch} N_{\gamma} \rangle$
- $f_{20} = \langle N_{ch}(N_{ch}-1) \rangle$
- $f_{30} = \langle N_{ch}(N_{ch}-1)(N_{ch}-2) \rangle$
- $f_{21} = \langle N_{ch}(N_{ch}-1)N_{\gamma} \rangle$

It is possible to combine ratios of these moments which result in Experimentally Robust Variables (*i.e.* independent of acceptance) which should be different for DCC and Generic generators.

See "Analysis of Charged-Particle/Photon Correlations in Hadronic Multiparticle Production"

http://fnmine.fnal.gov/papers/final.ps

Robust Observables

Ratios of the factorial moments are independent of efficiency corrections and different for Generic and DCC fragmentations. They are called Robust Observables:

$$r_{11} = \frac{f_{11} f_{10}}{f_{20} f_{01}} = 1(Generic), \frac{1}{2}(DCC)$$

$$r_{21} = \frac{f_{21} f_{10}}{f_{30} f_{01}} = 1(Generic), \frac{1}{3}(DCC)$$

and, in general:

$$r_{i1} = \frac{f_{i1} f_{10}}{f_{(i+1)0} f_{01}} = 1(Generic), \frac{1}{i}(DCC)$$

Note that r_{ij}

are independent of

- the form of the parent π multiplicity distribution
- ε_{ch} (if charged and neutral detection efficiencies are uncorrelated
- the trigger efficiency.

And r_{i1} is independent of the γ finding efficiency.

And r_{ij} possess definite and very different values for pure Generic and pure DCC pion production mechanisms.

Analysis Steps

1. Find $\langle N_{ch} \rangle$, $\langle N_{\gamma} \rangle$, $\langle N_{ch} N_{\gamma} \rangle$, $\langle N_{ch}(N_{ch}-1) \rangle$, *etc*.
2. Calculate the r_{ij}'s.

Latest Results from MiniMax

Values of r_{ij}, Statistical Errors only

r_{ij}	PYTHIA and GEANT	pure DCC	DCC and GEANT	Data
r_{11}	1.00(1)	0.50	0.58(1)	1.023(4)
r_{21}	1.00(3)	0.33	0.44(3)	1.03(1)
r_{31}	1.03(7)	0.25	0.39(5)	1.06(3)
r_{41}	1.29(18)	0.20	0.42(11)	1.12(6)
r_{51}	2.03(56)	0.17	0.51(37)	1.34(14)
r_{61}	3.6 ± 1.3	0.14	0.51(73)	2.08(40)
r_{02}	1.36(2)	1.80	1.51(5)	1.57(1)
r_{12}	1.37(5)	0.62	0.67(5)	1.56(2)
r_{22}	1.45(15)	0.31	0.43(8)	1.55(4)
r_{03}	2.35(15)	3.54	2.77(34)	3.37(7)
r_{13}	2.47(30)	0.90	1.17(27)	3.11(12)
r_{04}	4.82(86)	7.34	6.0 ± 1.8	8.97(62)

Sensitivity to fraction of DCC in event

Fraction of DCC	r_{11}	r_{21}	r_{31}
0.00	1.01(2)	1.02(5)	1.09(14)
0.02	1.00(2)	1.00(5)	1.01(15)
0.05	0.97(2)	0.93(5)	0.95(10)
0.10	0.95(2)	0.89(4)	0.89(8)
0.20	0.93(2)	0.83(4)	0.77(7)
0.50	0.84(1)	0.71(3)	0.68(6)
1.00	0.74(1)	0.60(3)	0.55(6)
DATA	**1.023(4)**	**1.032(10)**	**1.056(25)**

Fraction of events DCC **added** to Generic events

i.e. 0.10 indicates a DCC is added to 1 in 10 Generic events.

Also checked

- No significant Run to Run dependence
- No significant Dependence on Converter Thickness or composition
- Data consistent with events which triggered on large energies in the far upstream (25m) $\bar{n}$ hadron and $\bar{p}$ calorimeters, and events which triggered on hits in the very far upstream (55m) scintillators.
- No dependence on r_{i1}'s with multiplicity (as measured by the counters at 5m).

Summary

- PYTHIA is consistent with the Generic (Binomial) Production Mechanisms, the r_{i1}'s are consistent with 1 for the full GEANT simulation.
- Detector acceptance (GEANT) changes the DCC r_{i1}'s, but the results are easily distinguishable from 1.
- All r_{i1}'s are consistent with Generic (Binomial) Production Mechanisms to $<2\sigma$.
- Dependence of r_{ij} on Systematic Effects $\leq 5\%$
- Sensitivity to DCC Admixture is at 10% level (model dependent)
- Diffractive-tag r_{ij}'s are consistent with total sample, so no evidence for more DCC production in diffractive sample than in total.

Conclusions and Outlook

- Data Quality is good
- No evidence for DCC as Yet (though not ruled out at <10% level)
- Factorial-Moment Method using r_{ij} looks promising.
- data is consistent with production by only generic mechanisms for total sample and diffractive-tagged events

To Be Done

- VEE's, to measure spectra of K^0_S's and Λ^0's
- $dN_{ch}/d\eta$ and $dN_\gamma/d\eta$ - require trigger and detector efficencies, and high NHITS.

Long Range Plans

- C0 may have a future with far forward physics - see Zero Degree proposal

http://www.fnal.gov/projects/zdp

- New Initiative for LHC: FELIX (Forward ELastic and Inelastic eXperiment)

http://www.cern.ch/FELIX