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SEARCH FOR A DIFFERENCE BETWEEN THE STRANGE AND NONSTRANGE QUARK OF THE K^+ MESON

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ABSTRACT

A tendency for the π^- to peak at small negative rapidity in the center of mass for the reaction $K^+p \rightarrow \pi^- + X$ at 100 GeV may be related to a difference in the momentum spectra for the strange quark and the nonstrange quark in the K^+ meson, as may anomalies in the average multiplicity of charged particles and in the p_T^{max} of events as a function of π^- rapidity.

In general one might expect the strange and the nonstrange quark of the K meson to share the momentum of the parent particle differently.[1] We may attempt to understand these differences by parameterizing them in terms of quark masses.[2,3,4] However, independently of the details of effective quark masses, one can address the phenomenological questions of whether there are effects in Kp interactions which are not present in πp and pp interactions. In particular, in the light of the above ideas, one might hope to distinguish in K^+p interactions two different kinds of collisions, one involving the strange quark which on the average carries most of the K^+ momentum and one involving the nonstrange quark which carries only a small fraction of the K^+ momentum.

For its heuristic value, we use a model where the hadron-hadron collision is dominated by a single quark-quark collision, and the average momenta of the $\bar{s}$ and u quarks in the K^+ are shared in the ratios $1-\alpha \approx 1$ and $\alpha << 1$ respectively.[5] We identify two cases and their consequences:

<u>Reaction I</u>. The $\bar{s}$ quark from the K^+ collides with one of the three quarks in the proton.

a) The quark-quark center of mass energy, $\sqrt{s_{qq}}$, is relatively large.

b) The particles produced will be symmetric in the quark-quark center of mass and centered about a positive value of y, the rapidity in the K^+p center of mass.

c) Because of the large s_{qq} the average number of produced particles, as measured by the average number of charged particles, $\langle n_c \rangle$, is relatively large.

d) The range in y of the produced particles will be relatively large, because of the large s_{qq}.

e) The transverse momentum distribution of produced particles should reflect the large s_{qq} by exhibiting an increased tail at large p_T[6].

Reaction II. The u quark from the K^+ collides with one of the three quarks in the proton.

a) s_{qq} is relatively small.

b) The produced particles center about a negative value of y.

c) $\langle n_c \rangle$ will be relatively small.

d) The produced particles will have a relatively narrow range of y values.

e) There should be fewer events having particles of large p_T.

Given the relative values of the K^+p, π^+p and pp total cross sections, one expects that the cross section for Reaction I is about one-half the cross section for Reaction II. At Fermilab energies and below, there will be a background in the central region in both cases, consisting of particles from fragmentation of the beam and projectile, or in alternative language, from the reclothing of the spectator quark(s) in the incident K^+ and proton.

The K^+p data we will examine were extracted from a large sample of pp and π^+p events at 100 GeV/c obtained in the FNAL 30" HBC.[7] The solid histogram in Fig. 1 shows the inclusive rapidity spectrum for the π^- produced in the K^+p interactions. Negative pions are selected since they are relatively likely to originate directly in quark collisions, whereas positive pions are relatively more likely to originate from the fragmentation of the inci-

dent K^+ or proton. For comparison the dashed histogram shows the much more numerous data for $\pi^+p \to \pi^- + X$ in the same bubble chamber exposure. The π^+p data have been normalized to the K^+p data at $y = +0.25$ to show the difference in shape, an apparent peak at $y \approx -.25$ and a steep drop at $y \approx -1.75$. A quantitative measure of the difference in shapes can be seen in the forward ($y>0$) to backward ratios, $R(\pi^+p) = 1.27 \pm 0.034$ and $R(K^+p) = 1.07 \pm 0.091$.

The asymmetry of the $\pi^+p \to \pi^-$ spectrum favoring the pion beam direction is similar to that found in data at 18 GeV/c and 25 GeV/c.[8,9] We find that this asymmetry at 100 GeV vanishes just as it did at lower energies if one transforms to the center of momentum system for a quark-quark collision as suggested by a simple two-quark, three-quark model of the pion and proton respectively. We refer to such a reference system as the "quark frame."

The $pp \to \pi^-$ spectrum is not shown here, but we find it to be quite symmetric as it must be because of the symmetry of the initial state. We therefore feel there is no systematic bias in our data processing systems which would produce the bump at negative rapidity in the K^+p spectrum.

Since the shape of a rapidity spectrum remains the same for a boost along the beam direction, we can use Fig. 1 to estimate the mass ratio, or more precisely the average momentum division, for the two quarks in the K^+ meson. The excess of π^-'s appears to peak near $y = -0.75$. The Lorentz system in which this peak is centered is moving with velocity β in the center of mass system, where $y(\text{peak}) = 0.5\ \ln\left[(1+\beta)/(1-\beta)\right] = 0.5\ \ln(3K)$, and K is the fraction of the beam momentum carried by the colliding quark

($K = \alpha$ of footnote 5 in this case). We then compute a momentum sharing ratio $\alpha = K \approx 1/13$, appropriate for Reaction II. Reaction I should then contribute a broad distribution centered at $y \approx +0.51$ corresponding to $K = 1-\alpha \approx 12/13$, with roughly half the rate of Reaction II. The data are consistent with such a two-component picture, but by itself Fig. 1 is only suggestive with a two standard deviation difference between the shapes of the π^+p and K^+p data.

Fig. 2a is a plot of the average charged multiplicity for those events which contribute a π^- to a particular bin in Fig. 1. Finer binning in Fig. 2 is possible because of the better statistics available on $\langle n_c \rangle$. One can see in Fig. 2b that the difference between this multiplicity plot for K^+p events and the corresponding one for π^+ events has a dip greater than three standard deviations in the bin $-0.5 \leq y \leq -0.25$ and is generally low from $-0.75 \leq y \leq +0.25$. If this dip, which centers at $y \approx -.37$, is attributed to Reaction II, it implies a momentum sharing ratio $\alpha = K \approx 1/6$ and a Reaction I component at $y = +0.46$, broad, weaker, and with a net positive excess of $\langle n_c \rangle$. The positive value of the difference histrogram for $0.25 \leq y \leq 1.25$, is also consistent with the above picture.

A further feature of the data is a difference in the transverse momentum spectra for K^+p events as compared with π^+p when plotted as a function of rapidity in the same way. The average p_T^2 as a function of y shows much more marked anomalies than the average p_T, when comparing K^+p interactions with the (smooth) π^+p interactions (not shown). This suggests that the effect lies

mainly in the small number of tracks at large values of p_T. Accordingly Fig. 2c shows a plot of $\langle p_T^{max} \rangle$, the largest p_T for any track in a given event averaged over all events which contribute a π^- to a particular bin in Fig. 1. Since each event contributes only one track, statistics are poor but the trend is evident for a general excess of $\langle p_T^{max} \rangle$ for the K^+p events in the region $0 \leq y \leq +2$ and a dip in the region $-1 \leq y \leq 0$, consistent with the trends of the other figures. Ignoring for the moment this apparent structure, the K^+p data nonetheless have a weighted average (over all y) of $\langle p_T^{max} \rangle = 0.736 \pm 0.016$ GeV/c while the corresponding π^+p value is 0.607 ± 0.014 GeV/c, a six standard deviation difference. We attribute this excess to the fact that broad, high P_T, large multiplicity Reaction I will cause the largest p_T track of the typical event to be used in a relatively large number of y^- bins, while the events of Reaction II will appear in fewer bins, and hence will have lower weight in the overall average.

We have considered two additional possibilities which might give an apparent low momentum component for the reaction $K^+p \rightarrow \pi^- + X$. (a) Low momentum e^-'s produced symmetrically in the c.m.s. which were incorrectly assigned a pion mass in the lab frame. (b) Low energy π or p contamination in the K^+ beam.

Evidence for electron bremsstrahlung was searched for in one-half of the data sample by rescanning with a momentum template and examining f.r.m.s. from TVGP fits. While these methods failed to locate any electron candidates not previously eliminated from the pion sample by scanning, their sensitivity (perhaps as low as

several per cent for the higher lab momenta) is not sufficient to rule out possibility (a). If (a) is the explanation of the effect, then there is still a real difference in the physics of K^+p interactions and π^+p or pp interactions.

Pions or protons in the K^+ beam with momenta of 65 GeV/c or less would produce a peak at y = -0.2 or less. A sample of 271 tagged K^+ beam tracks was measured on an HPD with rms errors peaking below 2 microns. The average momentum of this sample was found to be 100 GeV/c with a width of ±10 GeV/c. There was no evidence of a low momentum component. No measured beam track with rms error less than 4 microns was below 70 GeV/c. Proportional wire planes in the drift space between final beam magnets and the bubble chamber made it possible to observe the direction of the beam tracks with precision. All K^+ beam tracks, both in the final data sample and in the specially measured sample of beam tracks, were consistent with the correct angle and position correlations predicted by our beam optics.

In summary, at 100 GeV the K^+p data when compared to the π^+p data appear to exhibit three anomalies which are possibly related to each other in the light of a heuristic model of unequal momentum sharing by the $\bar{s}$ and u quarks in the K^+. Additional support for quark momentum effects in hadron-hadron scattering is also seen in the peaking of the $\pi^+p \to \pi^-$ inclusive rapidity distribution at a value of $y \approx +0.25$. Better K^+p statistics are needed, preferably in an experiment which again has π^+p and pp events, to confirm the existence of the anomalies, and to permit a more quantitative study

of their agreement with the predictions of quark momentum models.

We would like to thank J. Rosner for his interest and stimulating discussions on this topic, and R. H. Capps for a most helpful conversation.

Footnotes

1. For discussion and applications of quark momentum spectra see R. P. Feynman, Photon-Hadron Interactions, p. 134, W. A. Benjamin, Inc. (1972).
2. It is commonly assumed that the strange quarks are heavier than the u and d quarks by something like 100 MeV/c^2 in order to explain observed mass differences. In discussing charm recently Gaillard, Lee and Rosner (Ref. 3) have in addition adopted the relation $m_u \approx m_d \approx 4$ MeV/c^2.
3. M. K. Gaillard, B. W. Lee and J. L. Rosner, Rev. Mod. Phys. 47, 277 (1975).
4. M. Gell-Mann, R. J. Oakes and B. Renner, Phys. Rev. 175, 2195 (1968) and S. L. Glashow and S. Weinberg, Phys. Rev. Letters 20, 244 (1968).
5. In a naive model we would write $\alpha = m_u/(m_s + m_u)$.
6. Such an increase with hadronic s_{hh} is seen in bubble chamber pp data between 10 and 200 GeV, H. Bøggild and T. Ferbel, Annual Review of Nuclear Science 24, 474 (1974), Figure 17.
7. V. E. Barnes et al., Phys. Rev. Letters 34, 415 (1975).
8. N. N. Biswas et al., Phys. Rev. Letters 26, 1589 (1971).
9. J. W. Elbert, A. R. Erwin, W. D. Walker, Phys. Rev. 3D, 2042 (1971).

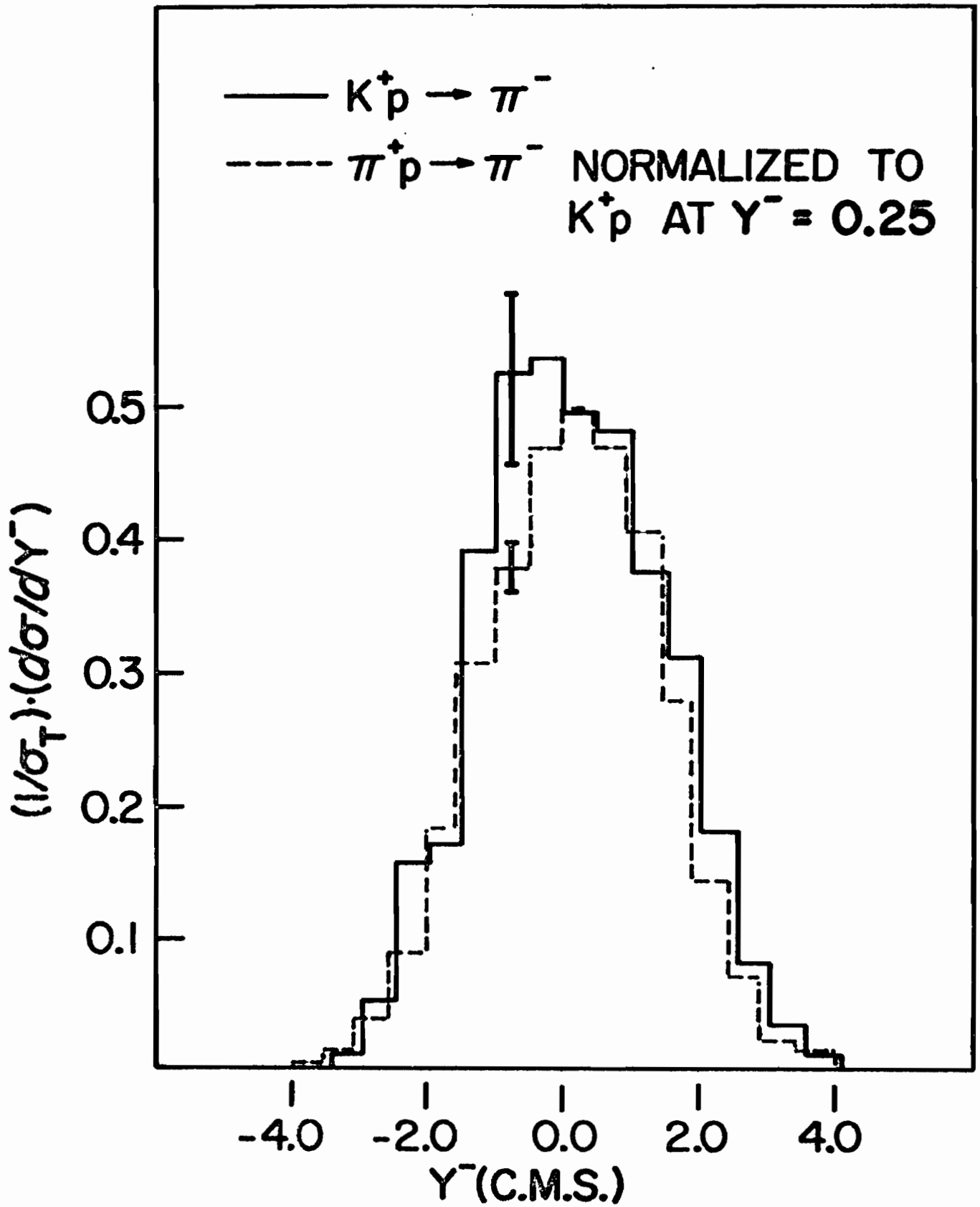
Figure Captions

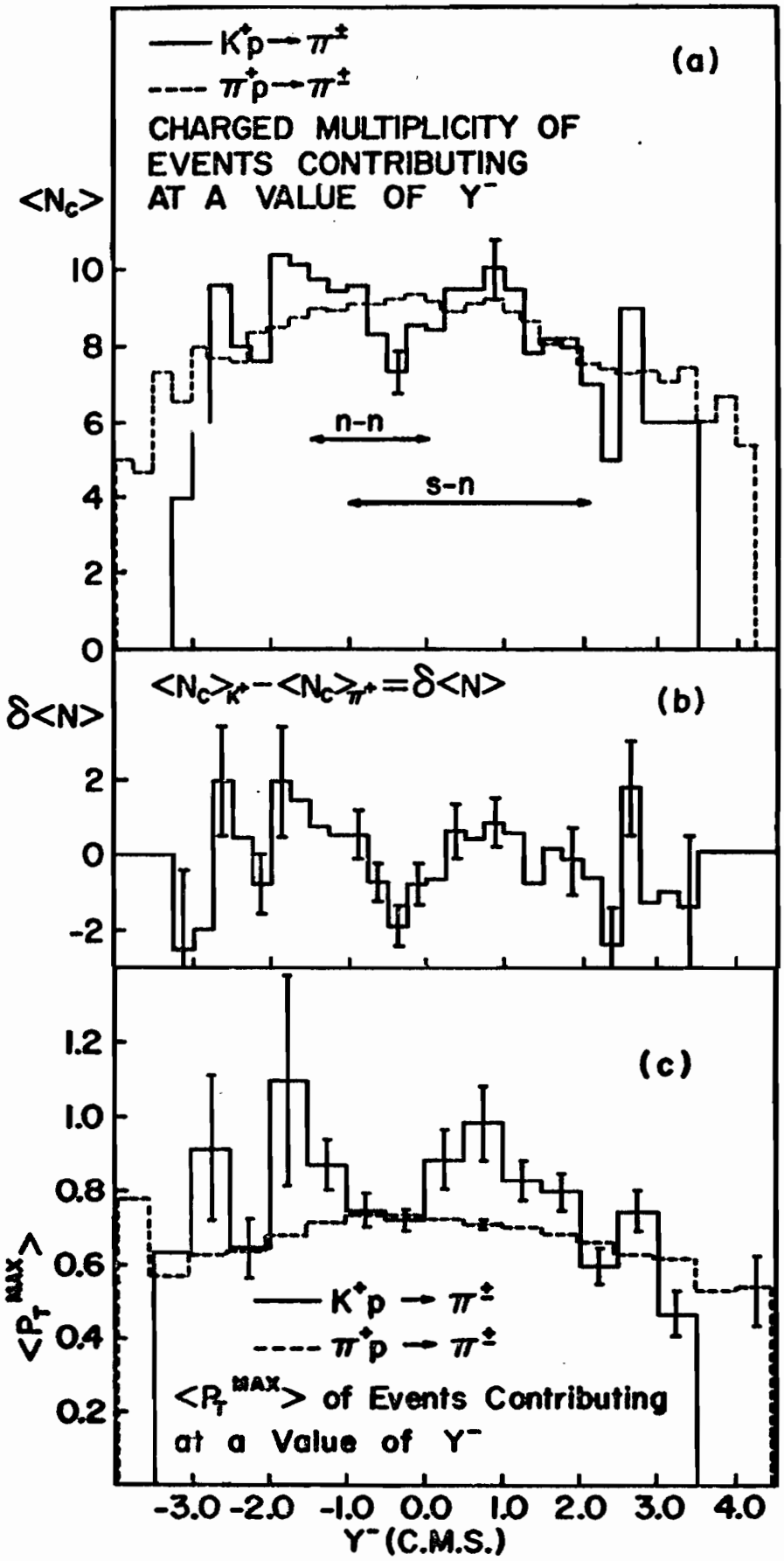
Fig. 1 Rapidity distribution of negative tracks from K^+p (solid line) and π^+p (dashed line) interactions. Rapidity $y = 0.5\ \ell n\ [(E+p_L)/(E-p_L)]$ in the C.M.S.

Fig. 2(a) Average multiplicity of the sample of events which contributes one or more negative tracks each to a given rapidity interval. The arrows indicate relative estimated rapidity widths for normal-normal and strange-normal quark collisions using the observed multiplicities and $\alpha \approx 1/13$.

(b) Difference between K^+p and π^+p multiplicity above.

(c) The average of the maximum p_T in events which contribute one or more negative tracks to a given rapidity interval in Fig. 1. ——— K^+p events. - - - π^+p events.


$K^+p \rightarrow \pi^-$
$\pi^+p \rightarrow \pi^-$ NORMALIZED TO
K^+p AT $Y^- = 0.25$
0.5
0.4
0.3
0.2
0.1
$(1/\sigma_T)\cdot(d\sigma/dY^-)$
-4.0
-2.0
0.0
2.0
4.0
Y^-(C.M.S.)


K⁺p → π±
π⁺p → π±
(a)
CHARGED MULTIPLICITY OF EVENTS CONTRIBUTING AT A VALUE OF Y⁻
<Nc>
n-n
s-n
<Nc>K⁺ − <Nc>π⁺ = δ<N>
(b)
δ<N>
(c)
<PT MAX>
K⁺p → π±
π⁺p → π±
<PT MAX> of Events Contributing at a Value of Y⁻
Y⁻ (C.M.S.)