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DETECTION OF MASSIVE UNSTABLE PARTICLES IN INCLUSIVE TRANSVERSE MOMENTUM SPECTRA

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Detection of Massive Unstable Particles in Inclusive Transverse Momentum Spectra

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ABSTRACT

It is shown that two-body decays of unstable particles produced in very high-energy hadronic collisions must show up as peaks in the single-particle momentum spectra of their decay products observed near $y_{CMS} \cong 0$.

New massive objects can be detected whenever these peaks distort the steeply falling p_T-continuum. Preliminary evidence for such distortions (one of which may be due to the charmed D-meson) is obtained from pion spectra measured at the CERN ISR.

For the last two decades, the distribution of the transverse momentum component p_T of secondaries from high energy hadronic collisions (abbreviated hereafter as p_T-spectra) have provided valuable information about the mechanism of multiple particle production, especially after the discovery of a specific "large-p_T behavior" at the CERN ISR.

In the innumerable investigations of this subject, p_T-spectra have always been treated as essentially smooth curves and all model predictions tested against experiment[1,2] have been equally smooth. Actually, one wonders why p_T-spectra should have been thought of as smooth in the first place. Indeed we know that a large fraction of the pions or kaons observed in the final state arise from the decay of short-lived intermediate states, many of which have two-body decay channels with non-negligible partial widths.

The aim of this work is to draw attention to the fact that in measurements at 90° CMS, especially of the kind carried out at the CERN ISR,[4,5] decay products from short-lived massive objects (abbreviated hereafter as SMO) will produce structures in the p_T-spectra which can be used to detect the parent particle. Indeed some evidence of such effects is already at hand.

If the SMO is created at rest it is obvious that its decay will produce tertiaries (say, pions) with a δ-type p_T-spectrum, say $\delta(p_T - p^*)dp_T$. At first sight it might seem that the angular and momentum distribution of the parent SMO will wash out this sharp line. This, however, is not so. Indeed, all particle production spectra are steeply falling. Furthermore, decay kinematics allow observation of tertiaries at 90° CMS only for a very restricted range of (low) rapidities of the SMO. As a result, it can be shown that the spectrum of tertiaries at 90° is always peaked at a momentum close to p^*.

We illustrate this by a simple example. Let the parent particle be emitted with a flat rapidity distribution and vanishing transverse momentum. If p^* is the decay momentum in the SMO's rest frame (determined, for the case of two-body decay only by the three relevant masses), the spectrum of momenta p of any decay product of mass m observed at 90° CMS is

$$f(p)dp \sim pdp(m^2 + p^2)^{-1}(p^{*2} - p^2)^{-\frac{1}{2}}. \qquad (1)$$

This expression has a flat maximum at a value of p close to m and diverges at $p = p^*$. Experimental resolution and/ or resonance width will change the divergence to a sharp peak close to p^*.

If the SMO mass M^* is relatively low (as is e.g. the case of ρ or ϕ mesons) the peak in the 90° pion or kaon spectrum will be located in a region where it is drowned in the continuum. However, for really massive particles like, e.g. the charmed D-meson, the decay momentum p^* is so high that, even with an unfavorable phase-space and/or branching ratio to two-body decay, the D-decay can become competitive to the point when it is able to distort the slope of the (steeply falling) continuum.

Fig. 1a shows the 90° p_T-spectrum of pions from $D \rightarrow \kappa + \pi$ decay obtained by Monte Carlo. D-mesons were produced in a $\sqrt{s} = 53$ GeV p-p collision with a flat rapidity distribution and a "reasonable" transverse momentum distribution. It is obvious that a sharp peak in the pion spectrum is present close to p^*. A change to isotropic D-production in the pp CMS only enhances the sharpness of the peak.

Fig. 1b shows the distortion produced by this decay spectrum when it is superimposed on an exponential pion background 5000 times richer in particles.

Obviously, the heavier the hypothetical SMO, the better a chance it stands to pierce the background.

As to existing experimental evidence Fig. 2 shows a summary of pion spectra observed at the ISR for $\sqrt{s}$ going from 21 to 63 GeV. The logarithmic slope

$$B \equiv \frac{-d}{dp_T} \quad \ell n\left(E\frac{d^3\sigma}{dp^3}\right)_{y=0} \tag{2}$$

is plotted against p_T. The measurements cover the range 0.2-5 GeV, over which the continuum intensity (indicated by decimal logarithms of the differential cross section above the arrows) drops by 7 orders of magnitude. The points are weighted averages from a) 5 $\sqrt{s}$-values below 2 GeV (charged pions[3]); b) 4 $\sqrt{s}$-values (neutral pions) above 2 GeV.[4] A significant "wiggle" is seen in the charged pion spectrum at the value predicted for the decay of the D-meson ($\sim$ 0.85 GeV/c)[5]. The numbers on top of Fig. 2 show the frequency of positive and negative deviations from an exponential fit in the independent runs with different values of $\sqrt{s}$. The obvious non-random behavior of these numbers at the "wiggle" is independent proof for statistical significance of the latter.

The absence of a similar "wiggle" in the proton spectra ($\chi^2/n = 14/10$) measured with the same experimental setup proves that B is not distorted by errors in the momentum calibration.

The π^0-spectrum shows evidence for at least two "wiggles" which, if taken at face value and assigned to two-body decays of new, hypothetical SMO's would place these in the mass range of $M^* \cong 7\text{-}9$ GeV.

This raises the urgent need for a new generation of high-accuracy p_T-experiments.

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REFERENCES AND FOOTNOTES

1. A recent review of large p_T phenomena can be found in S. D. Ellis and R. Stroynowski, Rev. Mod. Phys. 49, 753 (1977).

2. E. M. Friedlander and R. M. Weiner, Lawrence Berkeley Laboratory Report LBL-7724; submitted to Phys. Rev. Lett.

3. B. Alper et al., Nuc. Phys. B100, 237 (1975).

4. F. Busser et al., Phys. Lett. 46B, 471 (1973).

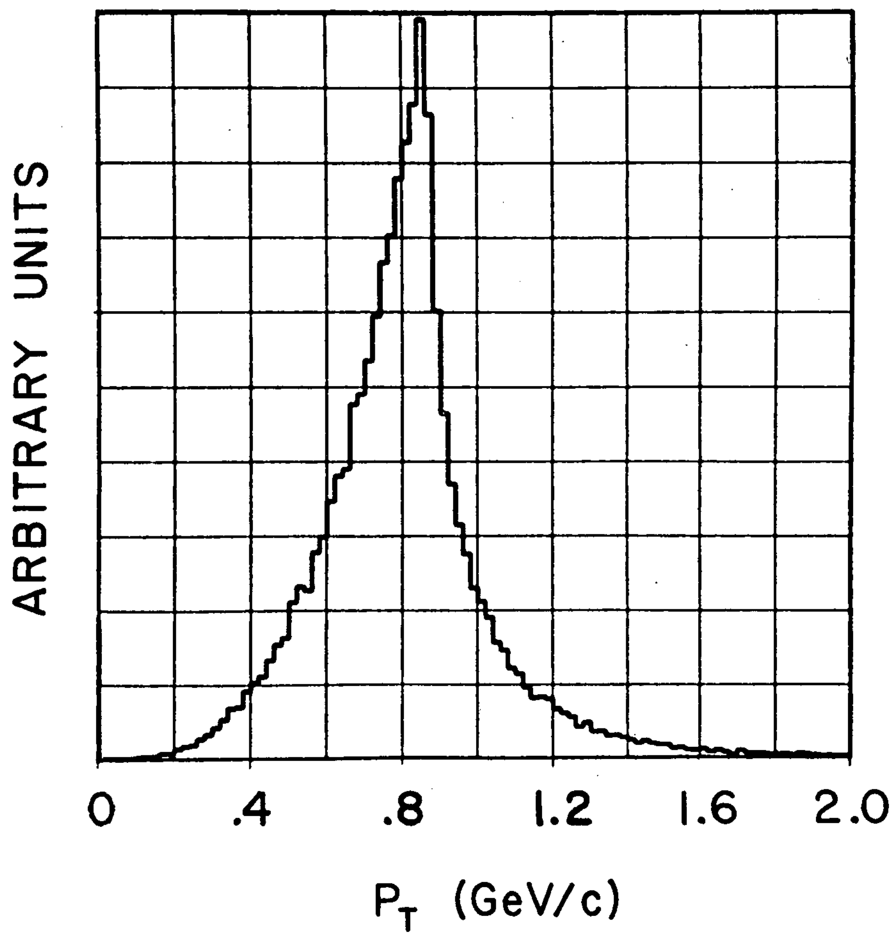
5. The only other candidate for this distortion is the $\pi^+\pi^-$ decay of the g(1680) resonance ($p^* \cong 0.83$ GeV/c). Most of the well-established resonances have p*-values too low to compete with the continuum.

FIGURE CAPTIONS

Fig. 1a Pion spectrum at 90° CMS expected from $D \to k + \pi$ decay (arbitrary units).

Fig. 1b Logarithmic slope of a pion spectrum resulting from superposition of 0.02% $D \to k + \pi$ decays (Fig. 1a) and of a pion continuum falling like exp $(-6\ p_T)$.

Fig. 2 Deviations from an exponential fit of the logarithmic slopes of pion spectra measured at the CERN ISR; circles = $\pi^\pm$, weighted mean of runs at $\sqrt{s}$ = 23, 31, 45, 53, and 63 GeV; triangles = π^0, weighted mean of runs at 23, 31, 45, and 53 GeV; numbers on top of each experimental point show how often positive (+) and negative (-) deviations occurred in the different runs.



XBL 787-9646

Fig. 1a

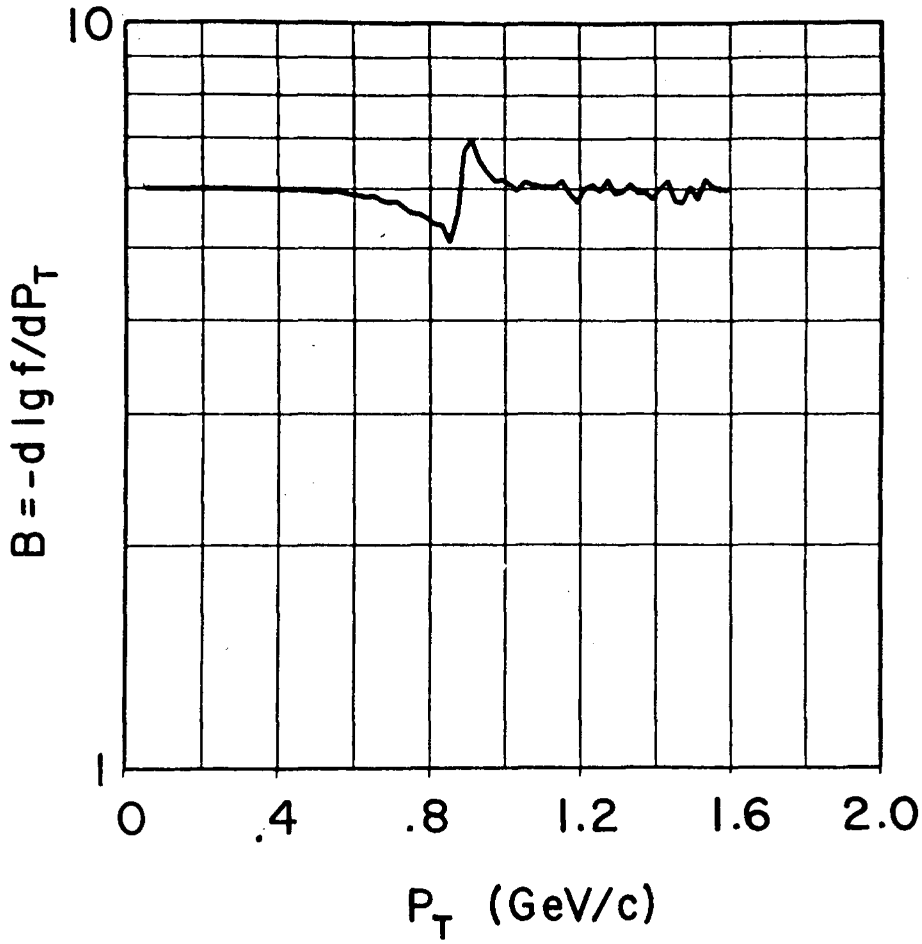


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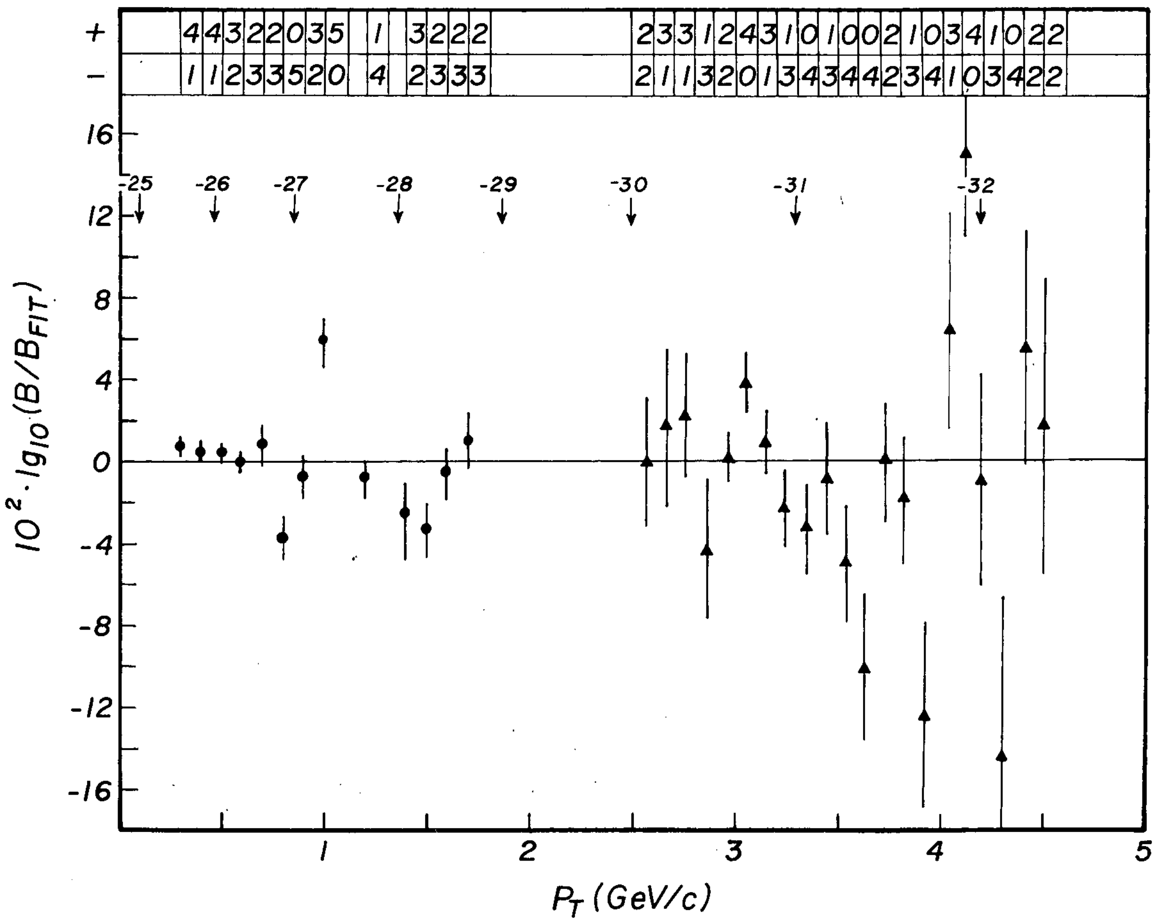
Fig. 1b



XBL 787-9648

Fig. 2

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