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An explanation of the beam dump experiment

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Abstract. The production of prompt neutrinos in the beam dump experiment is explained in a cluster model, by postulating the emission of strange clusters in hadron collisions, besides the usual non-strange clusters. The low mass strange clusters can decay only by the weak interaction. The leptonic and semi-leptonic decay modes of these clusters give rise to prompt neutrinos. A prediction of the model is that the ratios $\langle \nu_e \rangle / \pi^+$ at PS energies would be the same as SPS energies.

Keywords. Beam dump experiment; prompt neutrinos; strange clusters; weak decays.

In a beam dump experiment (Alibran *et al* 1978, Hansl *et al* 1978 and Bosetti *et al* 1978) at CERN SPS, prompt neutrinos have been observed in proton-nucleus collisions. The results indicate equal fluxes of ν_μ, $\bar{\nu}_\mu$, ν_e and $\bar{\nu}_e$. Several sources of the observed prompt neutrinos like charmed mesons, charmed baryons, heavy leptons and axions have been considered and found inadequate (Alibran *et al* 1978; and Bosetti *et al* 1978) to explain the observed signal. According to Bossetti *et al* (1978), short-lived light particles, yet unknown, cannot however be excluded as a source of the prompt neutrinos. If the light particle is a hadron, it must have a new quantum number to prevent its decay by strong or electromagnetic interactions. A new quantum number would imply a whole family of hadrons and possibly also a low mass quark with a new flavour. On the other hand, if the new particle is a lepton, it would be difficult to reconcile its low mass with a life-time short enough to have escaped detection so far. So it appears rather hard to explain the origin of prompt neutrinos using our conventional knowledge of particles and fields, as it is understood today.

We want to point out that, in addition to the beam dump experiment, there are two other phenomena in hadron collisions for which there are no proper explanations, namely the production of a continuum of low mass dimuons (Bunnel *et al* 1978; Anderson *et al* 1976) and a sharp rise in the spectrum of prompt electrons (Baum *et al* 1976; Barone *et al* 1978 and Bier *et al* 1976) as the transverse momentum goes to zero. The continuum of low mass dimuons cannot be accounted for by the Dalitz decays of η and ω. It cannot be explained either by the Drell-Yan model (Drell and Yan 1970, 1971) which underestimates (Branson *et al* 1976) the flux by one or two orders of magnitude or by the Bremstrahlung model (Farrar and Frautschi 1976) which also predicts a large flux of real photons and a ratio $e/\mu=3$, which are in disagreement with experiment (Bier *et al* 1976; Busset *et al* 1974; Bjorken and Weissberg (1976) and Gurtu *et al* 1976). The problem of the copious production of prompt electrons with small transverse momenta is similar to the problem of the dimuons since both seem to be electromagnetic in origin and their fluxes are also equal.

Gurtu *et al* (1976) have explained the copious production of prompt electrons in a cluster model, by assuming the production of low mass clusters with small centre-of-mass momenta. These clusters, which we denote by the symbol ρ_c, have the quantum numbers of the ρ meson. They decay into a pair of pions or a pair of leptons. Gurtu *et al* obtain simultaneous fits to the inclusive pion distribution and the ratio e/π as a function of the transverse momentum.

The purpose of this paper is to show that the beam dump experiment can also be explained in a cluster model by postulating that there also exist strange clusters with the quantum numbers of the K^* (890) meson, which we denote by the symbol K_c. The decay modes of a strange cluster K_c depends upon its mass m_{K^0}. If $m_{K_0} > m_K$ (Kaon mass), it decays by strong and electromagnetic interactions. But if $m_{K_0} < m_K$, it can decay only by the weak interaction. We propose that the neutrinos emitted in the leptonic or semi-leptonic decays of the low mass strange clusters are the source of the prompt neutrinos in the beam dump experiment. In particular, the semi-leptonic decay mode $K_c \rightarrow \pi \, l \, \nu_l$ would be the relevant one as the neutrino in a three body decay would have small momentum in the rest system of the cluster and this helps in the collimation of the neutrinos in the laboratory system.

Several authors (Gunion 1975; Dennis Sivers 1976; Green *et al* 1973) have considered the production of vector mesons like ρ, ψ, etc. in a model similar to the Drell-Yan model for lepton pair production. Their approach can be formally extended for the production of clusters as well. We may regard the generalised Drell-Yan model, shown in figure 1, as providing a common logical foundation for the production of resonances and clusters, both strange and non-strange. The cross-section for the process $A+B \rightarrow C+X$, where C is a resonance or a cluster, can be written as:

$$\frac{d\sigma_c}{d^3Q\, dQ^2} = \sum_i \int \left[f_i^A(x_1)\, f_{\bar{i}}^B(x_2) + f_i^A(x_2)\, f_{\bar{i}}^B(x_1)\right] dx_1\, dx_2$$

$$\sigma_{i\bar{i} \rightarrow c}\,(Q^2)\, \delta^3\,(\mathbf{Q}-\mathbf{P}_1-\mathbf{P}_2)\, \delta\,(Q^2 - x_1\, x_2\, S), \qquad (1)$$

where $f_i^A(x)$ $[f_{\bar{i}}^A(x)]$ are the structure functions which give the probabilities of finding a quark (antiquark) of type i, carrying a momentum fraction x of the hadron A. $\sigma_{i\bar{i} \rightarrow c}\,(Q^2)$ is the cross-section for the quark i and the anti-quark $\bar{i}$ to annihilate

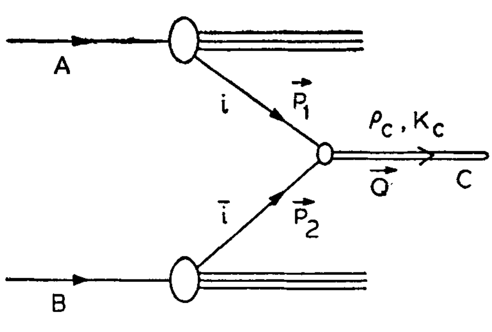

Figure 1. Drell-Yan model for the production of resonances and clusters.

to form a resonance or a cluster c at a centre-of-mass energy $(\sqrt{Q^2})$. If c is a resonance, we take the Breit-Wigner form for $\sigma_{i\bar{i}\to c}(Q^2)$, given by

$$\sigma_{i\bar{i}\to c}\,(Q^2) = 4\pi\, g^2_{ci\bar{i}}\, \frac{m_c\Gamma_c}{(Q^2 - m_c^2)^2 + m_c^2\,\Gamma_c^2}, \tag{2}$$

where Γ_c is the total width of the resonance c, m_c its mass and $g_{ci\bar{i}}$ is the coupling strength of the resonance to the quark-antiquark pair $i\bar{i}$. For the case of clusters, $\sigma_{i\bar{i}\to c}(Q^2)$ has to be parametrised suitably as a function of Q^2. This may be done so as to reproduce the dimuon continuum. In the present work, we do not pursue any further discussion of (1), which is considered as providing a conceptual basis for our cluster approach.

Our next step in the explanation of the beam dump experiment is to make an estimate of the strange clusters. One way of doing it is to consider the content of strange quarks in the sea of quark-antiquark pairs. But a more direct way is to look for experimental information on the relative cross-sections for the production of ρ and K^* (890) resonances. Considering that the dimuon signals in the continuum region and the ρ meson region as being due to the decay of clusters and resonances respectively, we write,

$$\frac{\sigma_{\rho_c^0}\left(m_{\rho_c^0} < 650 \text{ MeV}\right)}{\sigma_{\rho^0}} = \frac{\sigma_{\mu\mu}\,(m_{\mu\mu} < 650 \text{ MeV})}{\sigma_{\mu\mu}\,(m_{\mu\mu} \simeq m_{\rho^0})}, \tag{3}$$

where $\sigma_{\mu\mu}$ is the dimuon cross-section, σ_{ρ^0} is the cross-section for ρ^0 production and $\sigma_{\rho_c^0}$ is the cross-section for ρ_c^0 clusters. From the data of Anderson *et al* (1976) we find that the ratio on the r.h.s. of (3) is $\simeq 8$.

There is experimental information (Blobel *et al* 1974) on the cross-section for the production of $K^{*\pm}$ (890) at 24 GeV/c pp collisions. It is found that K^{*-} is produced mainly in the central region with a cross-section $\sigma_{K^{*-}}=0{\cdot}14\pm0{\cdot}02$ mb, while K^{*+} is produced both in the central and fragmentation regions with a cross-section $\sigma_{K^{*+}}=0{\cdot}64\pm0{\cdot}06$ mb. Since cluster production is essentially a central phenomenon, we are interested in the cross-sections for the central production. We assume that $\sigma_{K^{*-}} = \sigma_{K^{*+}} = \sigma_{K^{*0}} = \sigma_{\bar{K}^{*0}}$ for the central production and each cross-section has a value 0·14 mb at 24 GeV/c. We estimate cross-section for K^* production at 400 GeV/c by an extrapolation, assuming a power law dependence $\sim S^{\alpha}$ of the cross-section on energy. Taking a value $\alpha=0{\cdot}4$ (Blobel *et al* 1974; Jancso *et al* 1977†), the cross-section for K^* production in the central region at 400 GeV/c comes out to be 0·4 mb for each charge state. We now make the assumption that cross-section for the production of strange clusters K_c to the non-strange clusters ρ_c is in the ratio of the cross-sections for the production of K^* and ρ resonances, i.e.

$$\frac{\sigma_{K_c}}{\sigma_{\rho_c}} = \frac{\sigma_{K^{*0}}}{\sigma_{\rho^0}} \tag{4}$$

†A comparison of the data of Blobel *et al* (1974) with the data of Jancso *et al* (1977) would give a value of $\alpha \approx 0{\cdot}5$

Using (3) and the cross-section estimate $\sigma_{K^{*0}} \simeq 0{\cdot}4$ mb, we find $\sigma_{K_c} = 3{\cdot}2$ mb for each charge state of the clusters K_c at 400 GeV/c.

As only the low mass strange clusters emit the prompt neutrinos, we have to estimate the cross-section for such clusters which can generate the observed signal. Bossetti *et al* (1978) have stated that a cross-section much smaller than the case of D could explain the signal if its mass is less than the kaon mass. The cross-sections can be calculated by the method described by Gurtu *et al* (1976). Here we make approximate estimates of them to obtain the ratios $\langle \nu_e \rangle/\pi^+$, by parametrising the inclusive distributions of pions and strange clusters and integrating the inclusive distributions in appropriate energy bins and ranges of the transverse momenta determined by the geometrical acceptance. Our calculations involve two other factors, one representing the branching ratio for the decay $K_c \rightarrow \pi\mu(e)\nu_\mu(\nu_e)$ and the other representing the fraction of the solid angle, in the rest system of the cluster, into which the neutrino has to be emitted for geometrical acceptance. Our calculations approximately reproduce the cross-sections for the case of D. Assuming an average mass of 450 MeV for the low mass strange clusters and a branching ratio of 0·1 for the decay $K_c \rightarrow \pi\mu(e)\nu_\mu(\nu_e)$, we estimate that a cross-section of 30 μb for the low mass strange clusters is adequate to get $\langle \nu_e \rangle/\pi^+$ ratios agreeing with experiment. Recalling our estimate 3·2 mb for the production of strange clusters in each charge state, we infer that the observed prompt neutrino signal can be generated if one in a hundred of the strange clusters has a mass less than the kaon mass.

Without attaching a quantitative significance to our numbers, it is clear that if the strange clusters exist at a level around our estimate and a small fraction of them have masses less than the kaon mass, we have a plausible explanation for the source of prompt neutrinos. A prediction of our model is that at all energies where there is evidence for cluster formation, the ratios $\langle \nu_e \rangle/\pi^+$ would be independent of the incident energy. In particular the ratios at PS energies would be the same as at SPS energies. It would be quite interesting to repeat the beam dump experiment at PS energies to see if there is a threshold in the $\langle \nu_e \rangle/\pi^+$ ratios. If there is no threshold, it would lend strong support to our model. In any case it would rule out several possibilities based on charmed mesons and hadrons and other heavier particles.

Our explanation of the beam dump experiment is incomplete without a discussion on two questions related to it. One is about the life-time for the weak decays of the strange clusters. To emit prompt neutrinos, the life-time should be $< 10^{-11}$ sec. The clusters are possibly weakly bound systems, for which life-times shorter than what one expects, for particles of similar mass and similar quantum numbers, need not be improbable. In any case, one is not in a position to predict theoretically the absolute life-times for the semi-leptonic decays of hadrons. The other issue is about possible conceptual difficulties associated with the assumption of clusters in general and low mass strange clusters in particular. The clusters are strongly interacting objects. They are produced by strong interaction in hadron collisions and they decay by strong interaction except when forbidden by quantum numbers. Can the clusters be produced in the decay of unstable particles? If this can happen, then the kaon can decay by strong interaction into a low mass strange cluster and other particles including the photon. We know that this does not happen. We surmise that the clusters can be produced only in collision processes at high energies but not in decay processes. A possible reason for this is that the production of clusters is essentially an incoherent process like the deep inelastic scattering. It involves instantaneous and localised interactions in which a quark from one hadron annihilates an antiquark from another hadron to form a cluster. The present author (Narayan 1971) had proposed a model of particle production in hadron collisions in which the interaction between the colliding hadrons gets localised and different parts get shattered independently into fragments. A model similar in spirit but in the language of the quarks and gluons have been proposed by Pokorsky and Van Hove (1974). On the other hand, decay is a coherent process, involving the hadron as a whole. It would not be meaningful to talk of a localised interaction or a Drell-Yan mechanism, for decays of unstable particles.

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Note:

After this work was completed, we received a preprint by Asratyan *et al* (1978) about a beam dump experiment at Serpukhov. They also find a prompt neutrino signal at 70 GeV in pN-collisions and they obtain

$$(\nu_e + \bar{\nu}_e)/(\pi^+ + \pi^-) = (2{\cdot}7 \pm 2{\cdot}2)10^{-5}$$

The median value of the above ratio is in agreement with the value obtained by Bossetti *et al* (1978). While the errors are large, the result of the Serpukhov experiment is consistent with the prediction of our model that the ratio $\langle \nu \rangle_{\text{prompt}}/\langle \pi \rangle$ would have no energy dependence above a few tens of GeV.

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