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Neutrino fluxes and resonance physics with neutrino telescopes

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Expected atmospheric $\bar{\nu}_e$ fluxes will result in a significant number of resonantly produced low mass hadronic vector states, as the ρ, in large volume neutrino telescopes. The existence of sources of higher energy neutrinos will result in the production of higher mass states, as the D_s^* and the $(\bar{t}b)_{J=1}$. We calculate the rates of production of these states and discuss their signals. Independent of theoretical flux determinations, the detection of these states will be a tool for experimentally determining these fluxes.

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Large volume high energy neutrino telescopes with potential effective areas of the order of 10^9 cm^2 and volumes greater than 2×10^{13} cm^3 [1–3] are being planned. In this note we point out a method of determining or setting bounds on $\bar{\nu}_e$ fluxes at various energies corresponding to the production of the standard vector quark-antiquark resonances, namely, ρ, D_s^* and possibly $(\bar{t}b)$; rates for the production of other states are significantly lower because of Cabibbo or helicity suppression. This complements the Glashow [4] mechanism for resonant W^- production.

A guaranteed source, with energies below 10^4 GeV, is atmospheric neutrinos [5]. Neutrinos in this energy range will be capable of producing the ρ meson and the D_s^*. The extrapolated, to higher energies, atmospheric neutrino fluxes give totally negligible rates for the production of higher mass resonances. However, interesting sources of neutrinos with energies higher than 10^4 GeV have been postulated; active galactic nuclei (AGN) [6] are the most promising source in that TeV γ rays have been detected from Markarian 421 [7] and there is a consensus that fluxes of all neutrino flavors of comparable intensity exist [8]; as a large number of AGN's are known to exist one can estimate the expected diffuse neutrino flux [9]. Unexpected sources might be early Universe relic neutrinos [10].

Some time back Glashow [4] pointed out that the W boson can be produced in a resonant way in neutrino-electron scattering. We study the resonance production of hadronic states: ρ's, D_s^*'s with a mass of 2.1 GeV and of the $J = 1$ state of the $(\bar{t}b)$ system. For completeness we also present results for the helicity suppressed π production and the Cabibbo suppressed K^* production. For a vector meson R the rate in a volume V is

$$\text{Rate} = \frac{48\pi^3\Gamma(R\to e\nu)}{M_R m_e}\Phi\left(\frac{M_R^2}{2m_e}\right)N_eV\,, \tag{1}$$

where N_e is the electron density (in water $N_e = 3.4\times10^{23}/\text{cm}^3$) and $\Phi(E)$ is the flux, averaged over azimuthal angles, at $\bar{\nu}_e$ energy E. In the above we assume that the flux does not change rapidly over the width of the resonance. Resonance production in $\bar{\nu}_e e^-$ scattering has been previously discussed by Mikaelian and Zheleznykh [12].

The partial width $\Gamma\left[(Q\bar{q})_{J=1}\to e\nu\right]$, for a vector resonance made out of Q and $\bar{q}$ quarks, is obtained from the related electromagnetic of the $Q\bar{Q}$ system. For the latter we use the empirical relation [11]

$$\Gamma\left[(Q\bar{Q})_{J=1}\to e^-e^+\right] = 12e_Q^2\ \text{keV}\,, \tag{2}$$

where e_Q is the charge of the Q quark. In terms of the nonrelativistic quark model this implies that the wave function at the origin is proportional to the reduced mass. Using these facts, we find

$$\Gamma\left[(Q\bar{q})_{J=1}\to e\nu\right] = 192M_Q^2M_q^2\left(\frac{G_F}{4\pi\alpha}\right)^2\ \text{keV}\,. \tag{3}$$

For the ρ meson conservation of isospin gives a firmer result, consistent with the one above:

$$\Gamma(\rho\to e\nu) = 12M_\rho^4\left(\frac{G_F}{4\pi\alpha}\right)^2\ \text{keV}\,. \tag{4}$$

Combining Eqs. (1) and (3) we find, for a volume of 2×10^{13} cm^3 (the smallest of the proposed neutrino telescope volumes),

$$\text{Rate} = 8\times10^{11}\frac{M_Q^2M_q^2}{M_R}\Phi\left(\frac{M_R^2}{2m_e}\right)\Big/\text{yr}\,, \tag{5}$$

where Φ is in units of $(\text{cm}^2\ \text{s}\,\text{sr}\,\text{GeV})^{-1}$ and all masses are in GeV. For the ρ meson the corresponding result is

$$\text{Rate} = 1.7\times10^{10}\ \Phi(580\ \text{GeV})/\text{yr}\,. \tag{6}$$

Results for production of the ρ meson agree with those of Ref. [12]. For resonance made out of quarks of unequal

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TABLE I. Event rate for unsuppressed vector meson production in 2×10^{13} cm^3.

State	Energy (GeV)	ATM flux	AGN flux	Events/yr
ρ	5.8×10^2	6×10^{-11}		2.4
D_s^*	4.4×10^3	10^{-13}		0.05
$(\bar{t}b)_{J=1}$	3.2×10^7		5×10^{-21}	3.5×10^{-5}

TABLE II. Event rate for suppressed meson production in 2×10^{13} cm^3.

State	Energy (GeV)	ATM flux	Events/yr
π	19.4	10^{-5}	0.05
K^*	7.8×10^2	6×10^{-11}	0.15

masses we differ, as instead of Eq. (3), $\Gamma(R \to e\nu) = 12M_R^4\,(G_F/4\pi\alpha)^2$ keV was used; this overestimates the rates for the production of the higher mass states. The results, with calculated atmospheric (ATM) neutrino fluxes [5] and theoretically estimated active galactic neutrino (AGN) fluxes [9,13], are given in Table I. For convenience we present the flux needed to obtain 10 events/year. (For the calculations we use a t quark mass of 175 GeV.)

We also present, in Table II, results for the production of two low mass states that are either helicity suppressed π or Cabibbo suppressed K^*. We note that at $E = 6.4 \times 10^6$ GeV, the W^- production rate is 32/year.

The atmospheric neutrino flux calculations [5] are conservative and we certainly expect that the neutrino telescopes will see several ρ events per year. The ν_μ fluxes are calculated to be an order magnitude larger. Should there be any significant neutrino mixing [14] enhancing the ν_e flux, the rates due to atmospheric neutrinos would go up significantly. As mentioned earlier the rates presented in this work are for the smallest volume telescope planned. Although the rate for production of $(\bar{t}b)_{J=1}$ due to the calculated AGN neutrino flux is well below the feasibility of any telescope, there might be totally unexpected sources. The detection of hadronic resonances will provide an experimental determination or limit on $\bar{\nu}_e$ fluxes. We have presented rates for events totally contained in the neutrino telescope volume. These events will be characterized by having no visible particle entering the volume and 600 GeV or more of hadronic energy deposited locally in the detector in thin hadronic and/or electromagnetic shower of length 6–10 m [15]. The energy of a contained hadronic shower can be determined with much greater precission than that of a muon; the latter can only be determined to a logarithmic accuracy.

Under consideration is a "kilometer-cube" detector [16]. Rates for such a detector will be 50 times those presented in the tables; the rates for D_s, π and K^* will be measurable providing a good determination of the atmospheric $\bar{\nu}_e$ flux over a broad energy range.

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