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Neutrinos from a channelled blast wave in jets of AGN

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Abstract.

Based on a recently published model for γ-ray production by a collimated, relativistic blast wave cf. Pohl and Schlickeiser (2000), we have calculated the neutrino production resulting from the proton-proton collisions in the highly relativistic plasma in jets of AGN.

It is shown that neutrino emission is correlated with the emission of TeV γ-rays. The search for neutrino emissions from point sources like jets of AGN may be faciliated by means of TeV γ-ray light curves to drastically reduce the temporal and spatial parameter space. Given the observed TeV photon fluxes from nearby BL Lacs the neutrino flux can exceed the atmospheric background and therefore be detectable with future neutrino observatories. The bulk of the neutrino emission is expected in the energy range between 100 GeV and a few TeV.

1 Introduction

AGN, active galactic nuclei, are luminous objects at cosmological distances which have been reported as sources of high energy γ-rays. The emission is probably nonthermal radiation from relativistic jets belonging to the AGN. Earlier investigations of these processes have suggested that neutrinos are among the radiation products of the jets of AGN Here we calculate the high energetic neutrino emission from the jets of AGN, based on a recently published model for γ-ray production by a collimated, relativistic blast wave, Pohl and Schlickeiser (2000).

In this scenario a strong electron-proton beam, the jet of the AGN, is assumed to move with bulk Lorenz factor Γ and to collide with ambient matter. In that process the beam sweeps up interstellar matter which leads to a deceleration of the beam because of momentum conservation. It is important to note that the swept-up interstellar particles retain their relative velocities with respect to the jet plasma, but get isotropised in the jet rest frame by self-exited Alfénic turbulence. The spectral evolution of the energetic particles is determined by the interplay between the injection rate, i.e. the density of the interstellar medium, the energy losses from electromagnetic radiation, and diffusive escape. The neutrino production resulting from the proton-proton collisions in the highly relativistic plasma of the jet is calculated via pion and muon decay.

2 Calculation of neutrino emission

Here we calculate the neutrino emission resulting from the decay of charged pions[1] $\pi^{\pm} \rightarrow \mu^{\pm} + \nu_{\mu}(\overline{\nu}_{\mu})$ and the emission arising through the subsequent decay of charged muons $\mu^{\pm} \rightarrow e^{\pm} + \overline{\nu}_{\mu}(\nu_{\mu}) + \nu_{e}(\overline{\nu}_{e})$. We also take into account the neutrino emission resulting from the neutron β-decay $n \rightarrow p + e + \overline{\nu}_{e}$ of secondary neutrons produced in the proton-proton collisions in the blast wave. The resulting emission rates for neutrino production are calculated by:

$$Q(E_{\nu},t) = \int_{1}^{\infty} N(\gamma_{p},t)\, q(E_{\nu},\gamma_{p})\, d\gamma_{p} \tag{1}$$

where $N(\gamma_p,t)$ is the proton spectrum as determined by the model of Pohl and Schlickeiser Pohl and Schlickeiser (2000) and $q(E_{\nu},\gamma_p)$ are the source functions, which describe the respective decays analogous to Marscher et al. Marscher et al. (1980).

The temporal evolution of the proton spectra $N(\gamma,t)$ can be described by the continuity equation

$$\frac{\partial N(\gamma,t)}{\partial t} + \frac{\partial(\dot{\gamma}\, N(\gamma,t))}{\partial \gamma} + \frac{N(\gamma,t)}{T_E} + \frac{N(\gamma,t)}{T_N} = N^{*}(\gamma,t) \tag{2}$$

which includes the injection rate $N^{*}(\gamma,t)$, the energy losses from electromagnetic radiation $\dot{\gamma}$ and particle losses arising from diffusive escape and $p \rightarrow n$ reactions, described by the

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[1] The quantities in parenthesis refer to the negatively charged particles

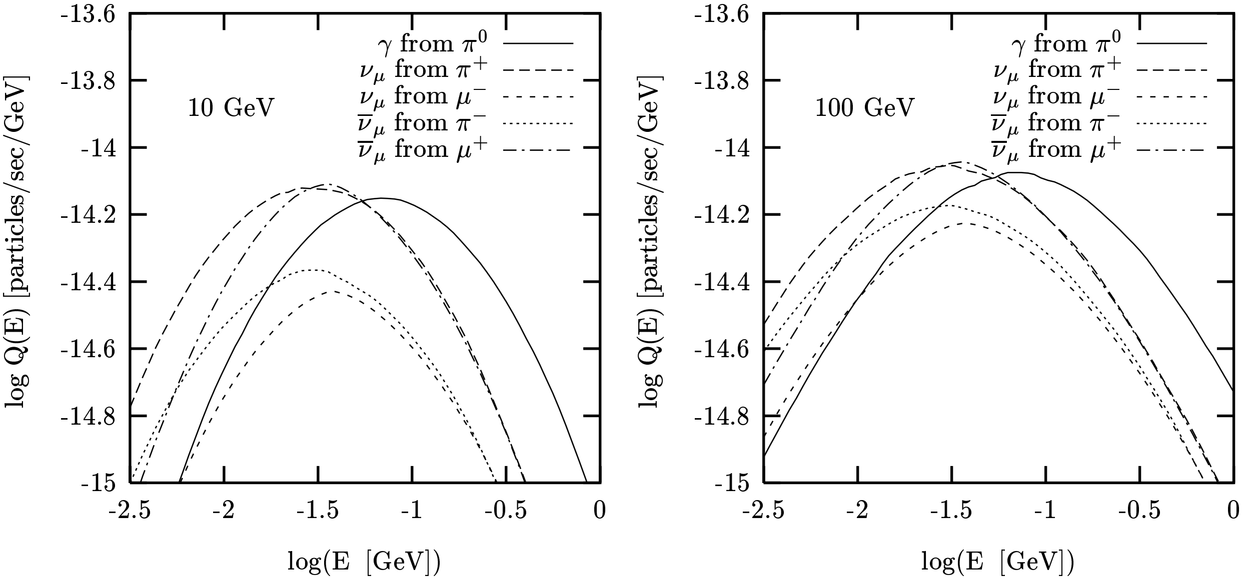

Fig. 1. The production rate of muon neutrinos resulting from the various decay modes calculated **for one proton** of kinetic energy 10 GeV and 100 GeV, respectively. Additionally we show the emission of γ-rays resulting from the decay $\pi^0 \rightarrow 2\gamma$ displayed by the solid line. The emission from the positively charged pions and muons is slightly higher than the emission from the negative ones, for the respective pion production cross section is larger.

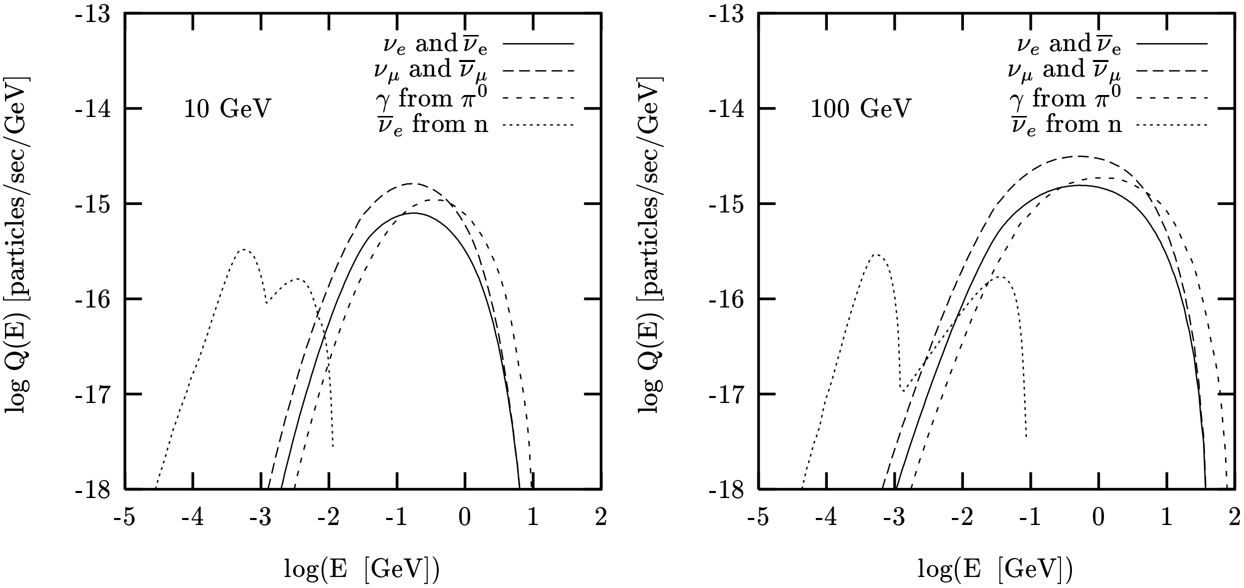

Fig. 2. Here we show the resulting production rates multiplied with E for muon- and electron neutrinos for a single proton with the same kinetic energy as in Fig. 1. The production of $\overline{\nu}_e$ and ν_e resulting from the muon decay is displayed by the solid line. The energy of anti-electron neutrinos produced by β-decay is about 2 orders of magnitude smaller, as shown by the dotted line. For the description of the neutron source function $q_n(\gamma_n, t)$ we sum the intensities of two monoenergetic neutrons, one for the thermal proton and one for the relativistic proton. The complete rates oyf muon neutrinos and γ-rays are also depicted for reference.

timescales for losses T_E and T_N, respectively. The injection rate is $N^*(\gamma, t) = N_0\ \delta(\gamma - \Gamma)$ in the case of particle isotropisation by pure electromagnetic turbulence Pohl and Schlickeiser (2000). We focus our analysis on the high energy muon neutrino emission resulting from the decay mode of pions $\pi^\pm \rightarrow \mu^\pm + \nu_\mu(\overline{\nu}_\mu)$ and subsequently $\mu^\pm \rightarrow e^\pm + \overline{\nu}_\mu(\nu_\mu) + \nu_e(\overline{\nu}_e)$. Fig. 1 and 2 show the resulting production rates of neutrinos resulting from the various decay modes calculated for one proton of kinetic energy 10 GeV and 100 GeV, respectively. Here we see, that the emission rates do not change in the energy regime of a proton up to a range of 100 GeV. The rates γ-rays resulting from the π^0-decay are also depicted. In Fig. 3 and Fig. 4 we show two examples of the spectral evolution of the total muon neutrino

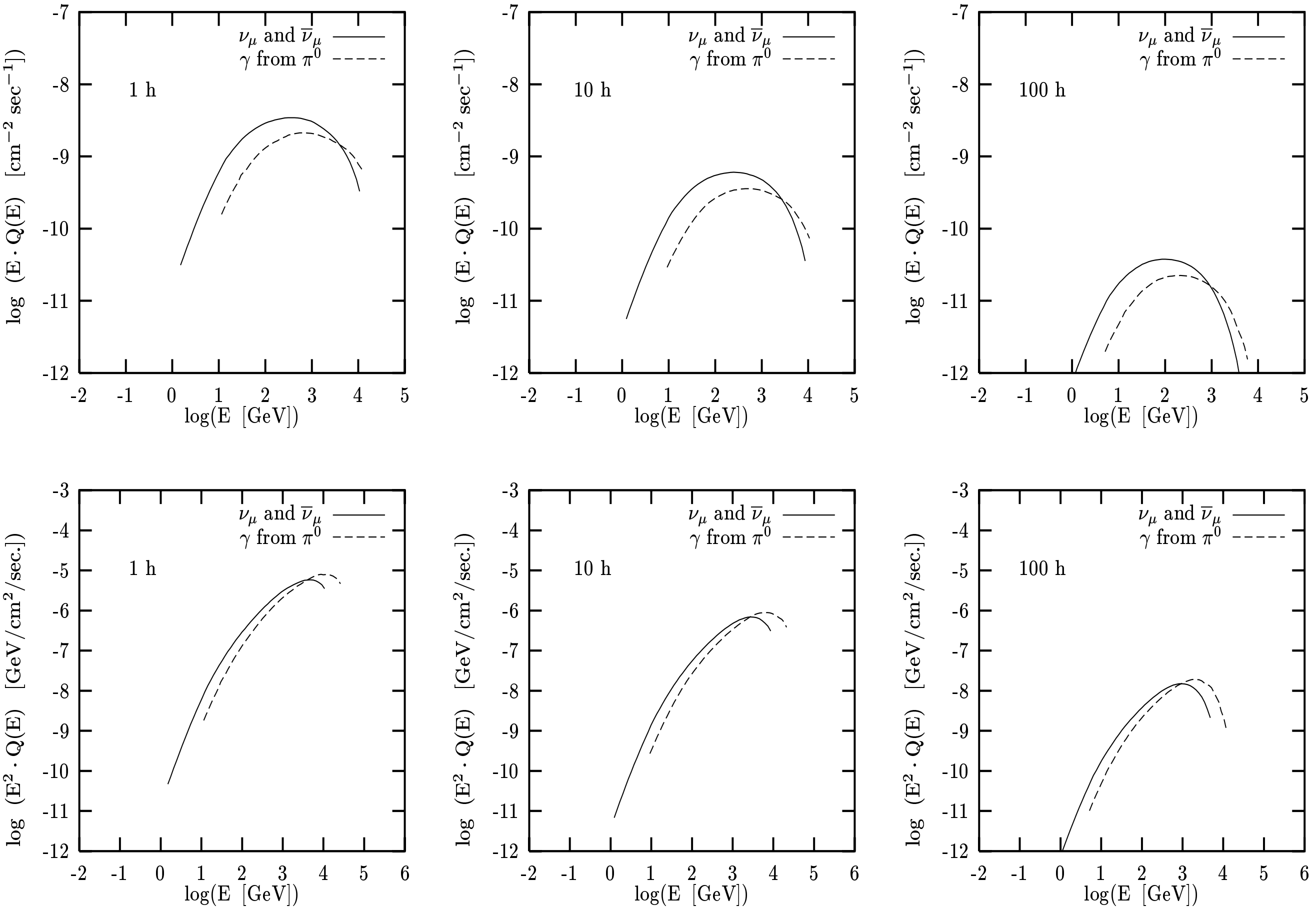

Fig. 3. The evolution of the muon neutrino emission resulting from the protons in the blast wave in comparison with the γ-ray spectra. In this example the following parameters have been used: The radius of the plasma disk is $R = 10^{14}\,\mathrm{cm}$, the thickness of the disk is $d = 3 \cdot 10^{13}\,\mathrm{cm}$, and the initial Lorentz factor $\Gamma_0 = 300$. The constant densities inside and outside the jet are $n_b = 5 \cdot 10^{8}\,\mathrm{cm}^{-3}$ and $n_i^* = 0.2\,\mathrm{cm}^{-3}$, respectively. Note that the mentioned time refers to the observer frame and therefore depends on the viewing angle θ, which we choose to be 0.1° in this example. The emission is calculated for a redshift of the AGN of $z = 0.5$. In the top row we depict the F_ν spectra and in the bottom row the $\nu\, F_\nu$ spectra. Obviously the spectral evolution of the neutrino spectra follows strictly the γ-ray production.

emission calculated with the blast wave model for the proton spectra. We assume a constant density of the background plasma. The production rate of γ-rays resulting from the decay $\pi^0 \rightarrow 2\gamma$ is depicted as well for reference. The bulk of muon neutrino emission occurs in the range between 100 GeV and 1 TeV and strictly follows the evolution of γ-ray production. The strong correlation between neutrino production and γ-ray production allows us to specifically search for neutrino emission from γ-ray bright AGN.

3 Discussion

We have calculated the neutrino emission resulting from jets of AGN, based on the assumption of the channeled blast wave model Pohl and Schlickeiser (2000), for which we have investigated the decay modes of pion and subsequent muon decay. Neutrino emission resulting from the decay of secondary neutrons has been studied as well, but may be neglectable in most cases. We have shown that neutrinos resulting from β-decay of neutrons possess an energy about two orders of magnitude lower than that of the other decay channels. The bulk of the neutrino emission is expected in the energy range between 100 GeV and 1 TeV for TeV γ-ray sources. The emission rate resulting from protons in the energy regime between 1 GeV and 100 GeV does not vary much. Therefore the time dependence of the emission spectra is completely determined by the changing spectra of incoming protons. We additionally discuss some spectra resulting from the channeled blast wave model of Pohl and Schlickeiser Pohl and Schlickeiser (2000) and observe that their shape is determined by the ratio between the cooling rate of the particles in the blast wave and the deceleration rate of the blast wave itself. Neutrino emission should be correlated with the emission of γ-rays. This allows us to distinctly look for neutrino emission from the jets of AGN by using the TeV γ-ray light curves to drastically reduce the temporal and spatial parameter space in the search for neutrino outbursts. Given the observed TeV photon fluxes from nearby BL Lacs the neutrino flux can exceed the atmospheric

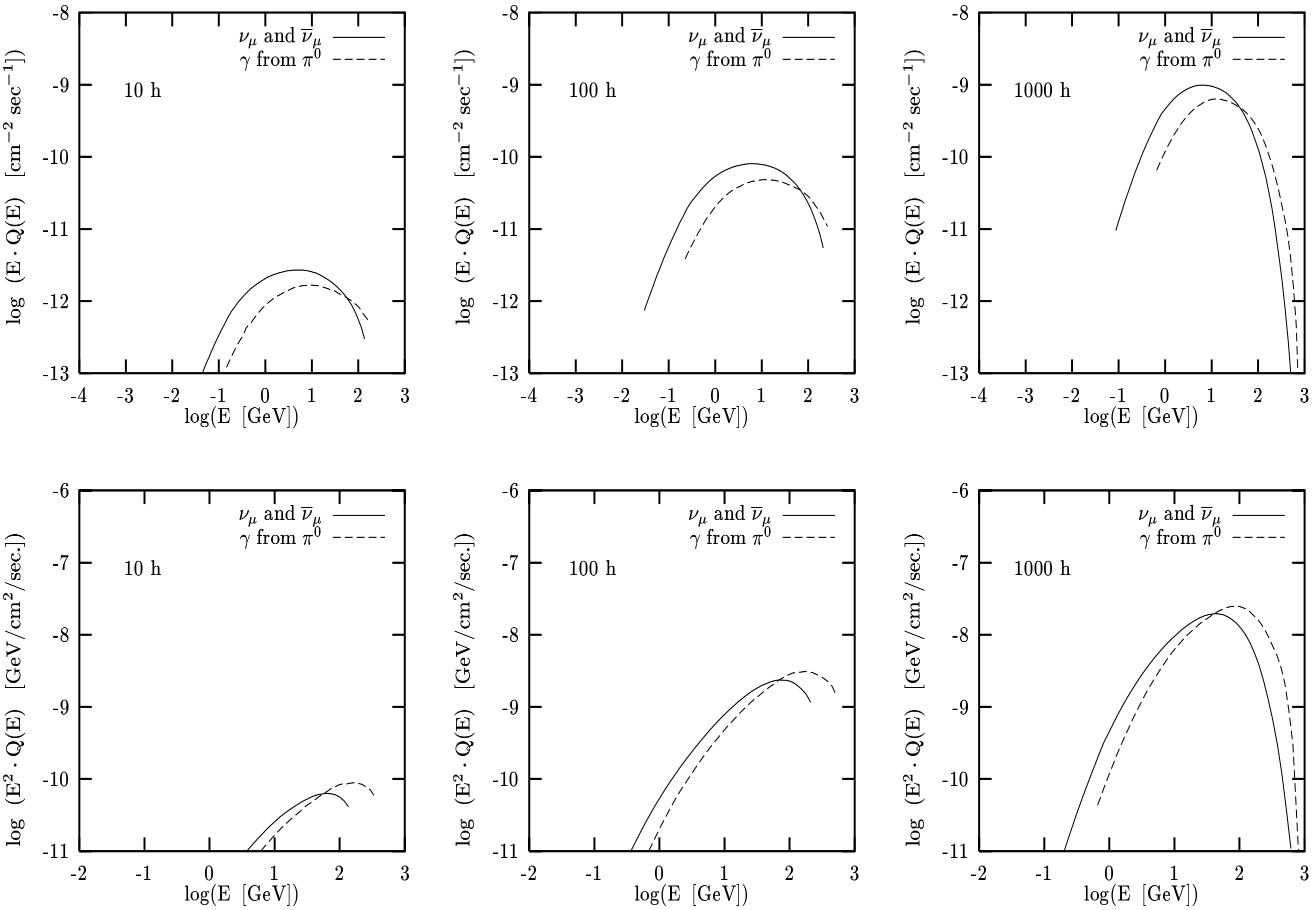

Fig. 4. The emission spectra calculated with another set of parameters,the most important of which is the viewing angle $\theta = 2^\circ$. In this case we use for the radius of the plasma disk $R = 2 \cdot 10^{15}\ \mathrm{cm}$ and $d = 10^{14}\,\mathrm{cm}$ for the thickness of the disk. The density in the jet have changed to $n_b = 10^8\,\mathrm{cm}^{-3}$ and for the density outside the blast wave $n_i^* = 1.5\,\mathrm{cm}^{-3}$ is assumed. Again we depict the F_ν spectra in the top row and the $\nu\, F_\nu$ spectra in the bottom row. The strong dependence of the observed emission on the angle θ is due to the high Lorentz factors in our model. This is responsible for the strong rise after 1000 h.

background flux and therefore be detectable with future neutrino observatories. We have estimated the neutrino detector event rate for a typical TeV γ-ray source to be about one per month Schuster et al. (2001) for the planned ICECUBE experiment, which is the same as the event rate of atmospheric neutrinos per angular resolution element.

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