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EUSO: Extreme Universe Space Observatory - Neutrino induced showers identification

S. Bottai, F. Becattini, L. Haroyan, M. Tognetti (EUSO Team)

University of Florence and INFN Florence

Abstract. The EUSO Space Observatory will offer a unique opportunity to detect EHE neutrinos with energy exceeding 10^{19} eV. The results of a simulation of neutrino induced showers in the atmosphere are presented and the EUSO capability of detecting such an events is discussed.

1 Introduction

The EUSO project (L. Scarsi, 2000; ESA and EUSO team, 2000) aims to detect from the space the fluorescence and the ground-reflected cherenkov light emitted by extreme high energy air showers. The experiment will be accommodated on the International Space Station (ISS) and having a field of view of 60^o will be able to monitor from the space an atmospheric mass $M \approx 1.5 \cdot 10^{18}$ g with an energy threshold close to 10^{19} eV. Such enormous amount of target mass will offer the unique opportunity to detect cosmic neutrino events at extreme high energy ($E \geq 3 \cdot 10^{19}$ eV), where the predicted neutrino fluxes are generally too small to detect with under-water/ice and ground based neutrino telescopes. From cosmological point of view the existence of neutrinos with energies exceeding 10^{20} eV will deeply impact the models of particle acceleration and propagation at extreme high energy, giving probably a strong support to the *top-down* solution of the GZK cut-off problem. A complete detector and physics description of EUSO project are presented in other contributions to this conference. In this paper we briefly describe the expected response of the detector respect to showers induced by downward going neutrinos. The results of neutrino induced EAS simulations together with the evaluations of the detector efficiencies and effective acceptances are described in the following sections.

Correspondence to: S. Bottai (bottai@fi.infn.it)

2 EAS and detector simulation

Electron and muon neutrinos interact through deep inelastic scattering with the nucleons of the atmosphere, generating an electromagnetic plus a hadronic detectable shower in case of ν_e charged current (CC) interaction and only a hadronic detectable shower in all the other cases (the possibility to detect muon bursts is under evaluation and the case of ν_μ oscillation to ν_τ is not treated here). The produced showers will be detected and reconstructed using signals coming from both the fluorescence light emitted isotropically along the shower and the cherenkov light diffusely reflected from the ground. The cherenkov light information will be used to correctly reconstruct the depth of the shower. The simulation of shower formation and development, fluorescence and cherenkov light generation and transmission and detector response has been performed using UNISIM simulation package.

UNISIM (Tognetti, 2000; Bottai, 2001) is a package derived from a precursor program (Bellotti et al., 1998) based on the UNICAS alghoritm (Gaisser, 1990), where the use of both full montecarlo and shower parametrization allows a fast unidimensional simulation of shower development taking into account the fluctuations induced by the first interactions. The results of simulations have been compared with the results obtained by CORSIKA6003 code (Knapp and Heck, 2001). An almost perfect agreement has been found concerning to the shape of longitudinal profiles and to the amount of fluctuations, while a difference less than 10% has been found concerning to the slant depth of shower maximum and to the number of charged particles at shower maximum. The UNISIM package includes the LPM effect (Migdal, 1956) for electromagnetic interactions and it is able to simulate neutrino interactions inside the target mass seen by the detector. CC and NC differential cross sections used in the simulation for neutrino interactions have been calculated (Becattini and Bottai, 2001) in the framework of QCD improved parton model. We have used the parton distribution set CTEQ3-DIS (Lai et al., 1995) with NLO-DGLAP formalism for QCD evolution and assuming for partons distribution $q(x)$ at very

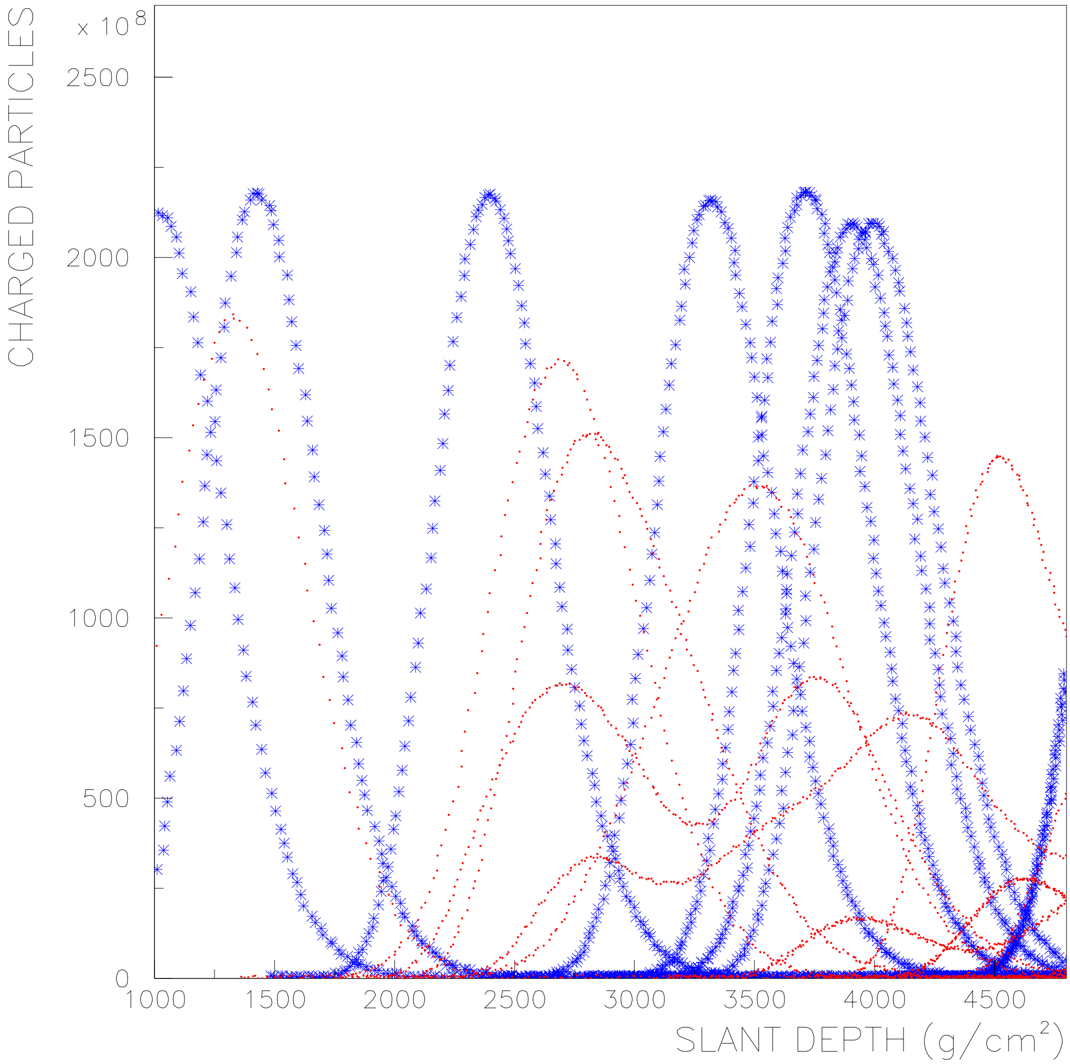

Fig. 1. A sample of shower longitudinal profiles for ν_e CC interactions. The zenith angle is fixed to $\theta_{zen} = 80^o$ and the energy of the neutrinos is $E_\nu = 3 \cdot 10^{20}$ eV. The blue big stars belong to the events simulated without LPM effect while the red small stars belong to simulations with LPM effect.

low x ($x = \mathcal{O}(10^{-8})$) the same functional form measured at $x = \mathcal{O}(10^{-5})$. Even if more sophisticated approaches for low x extrapolation have been developed using dynamical QCD (Gluck at al., 1999), the results for cross section calculations do not differ more than 10% from the approach taken here with CTEQ3-DIS plus "brute force" extrapolation(Gandhi et al., 1996; Gluck at al., 1999).

In fig.1 a sample of shower profiles is shown in case of neutrino induced showers for CC ν_e interactions (for which we expect to be more efficient) with and without LPM effect. Looking at the figure we can outline three main characteristics: the slant depth of the shower maximum (*Xmax*) is much higher than the typical value for proton showers (≈ 900 g/cm^2); due to LPM effect the number of particles at shower maximum decreases, the shower depth and the fluctuations increase; the LPM effect leads to several very irregular shape of longitudinal profiles (sometimes two clear peaks are observed in the profiles). The first characteristic, i.e. the high values of slant depth, is a consequence of the weakness of neutrino total cross section. It will be used in EUSO to distinguish between the neutrinos and other kind of less penetrating particles like proton. A demonstration of such discriminating power using $Xmax$ has been reported several times elsewhere (L. Scarsi et al., 2000) even taking into account the effect of a very preliminary and rough reconstruction alghoritm (Tognetti, 2000). In fig. 2 we show the distributions of *Xmax* for one year of protons events (10% duty cycle) and for an arbitrary number of neutrino events. In both cases the events have been selected to be triggered by fluorescence light and also accompanied by a detectable cherenkov signal. The *Xmax* value for the selection needed for the neutrino identification has to be optimized (in this work we will use *Xmax* ≥ 1100 g/cm^2).

Concerning to the second characteristic we emphasize that the contribution of LPM effect gains with increasing energy and atmospheric density, where most of neutrinos are ex-

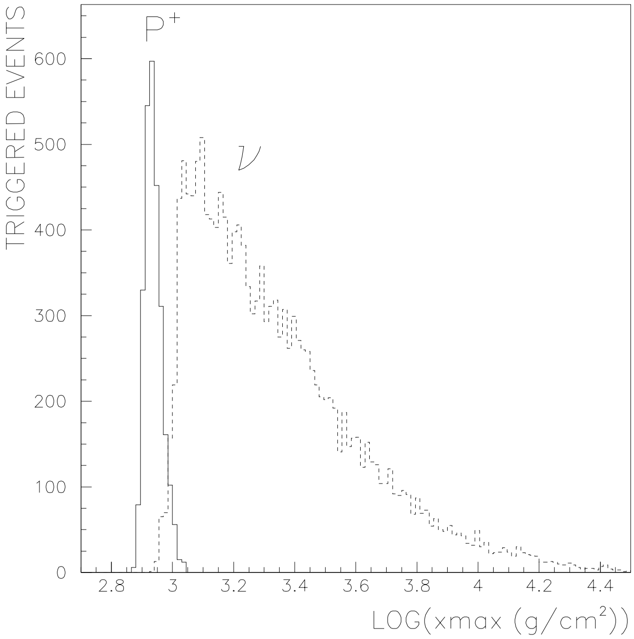

Fig. 2. *Xmax* distributions for protons and neutrinos. The proton events are simulated for one year of EUSO operation using an extrapolated P^+ flux without GZK cutoff and 10% duty cycle for live time. An arbitrary number of neutrino events are simulated in the 10^{19}eV - 10^{22}eV energy range with an isotropic flux. Only events triggered by fluorescence light and showing a detectable cherenkov signal are accepted.

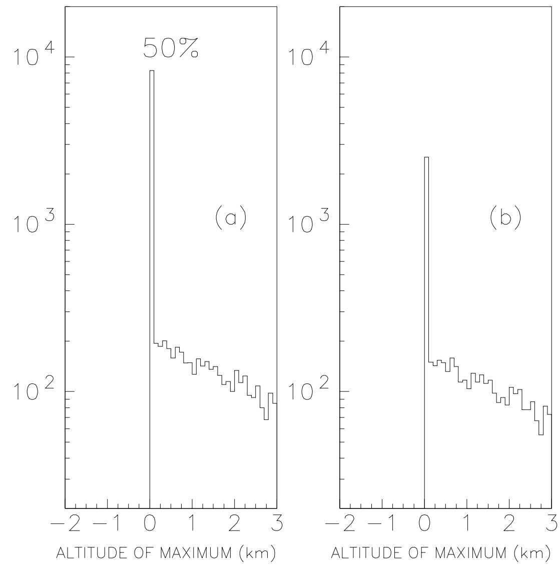

Fig. 3. Altitude of shower maximum for a sample of ν_e induced showers from an isotropic flux with energy in the range 10^{21}-10^{22} eV. If the showers develop the maximum below the ground the altitude is set to 0. In the first plot (a) the events are selected just to have $Xmax \geq 1100$g/cm^2. In this case around 50% of the events have the shower maximum below the ground. In the second plot (b) the same sample of events are also selected in order to be able to trigger the apparatus.

pected to interact. It decreases the number of particles at the maximum and enlarges the fluctuations, resulting hence in a decrease of the detector efficiency respect to what is expected without LPM effect. Finally the characteristic of irregular profile shapes is due to the well known feature of the LPM effect: it strongly affects the electromagnetic showers profile while it does not significantly change the development of hadronic showers. Since the CC ν_e induced showers are a superposition of an electromagnetic shower and of a hadronic shower, the irregular shapes can be easily understood. This feature could be used for better discriminating neutrinos from protons.

One important aspect of neutrino showers created inside the field of view of the detector is the unpleasant possibility that a part of the shower develops in the ground and not in the atmosphere. This effect is due to the high slant depth of the first interactions and it is the main factor affecting the efficiency at energies well above the threshold. It is enhanced for CC ν_e interactions by the shower elongation because of the LPM effect, which intensity increase with the energy of the produced charged lepton. In fig. 3 we show the altitude of the shower maximum for a sample of CC and NC ν_e interactions arising from an isotropic flux with energy range 10^{21}-10^{22} eV and E^{-1} spectrum. If only the slant depth selection criterion $Xmax \geq \mathit{1100}$ g/cm^2 is adopted we notice that around 50% of the events shows a maximum below the ground level (fig. 3.a). If we require to detect both the fluorescence and cherenkov light together with the selection on the depth, most of the showers with maximum below the ground are lost, while a fraction of them develops enough particles to be detected as well (fig. 3.b).

3 Effective acceptance for neutrino detection in atmosphere

The target mass monitored by EUSO will achieve $1.5 \cdot 10^{18}$g leading to an acceptance of $A^\nu \approx 10^{19}$ g·sr for an isotropic neutrino flux.

In order to take into account the effect of detector performance, overall detection efficiencies and selection criteria, we have simulated CC and NC ν_e interactions inside the EUSO atmospheric target mass using the UNISIM package described above. The EUSO entrance pupil diameter used in the simulation is $D_{pupil} = 2$m (ESA and EUSO team, 2000).

For the event selection we required the apparatus to be triggered by the fluorescence light (Catalano, 1999). In order to select a sample of events usable for precise reconstruction of slant depth we also add the request to be able to measure the cherenkov light reflected from the ground (which will be detected in only one pixel because of its limited spread in space and time at ground level). As additional selection criteria we requested also the detected showers to have a slant depth of maximum larger than 1100 g/cm^2.

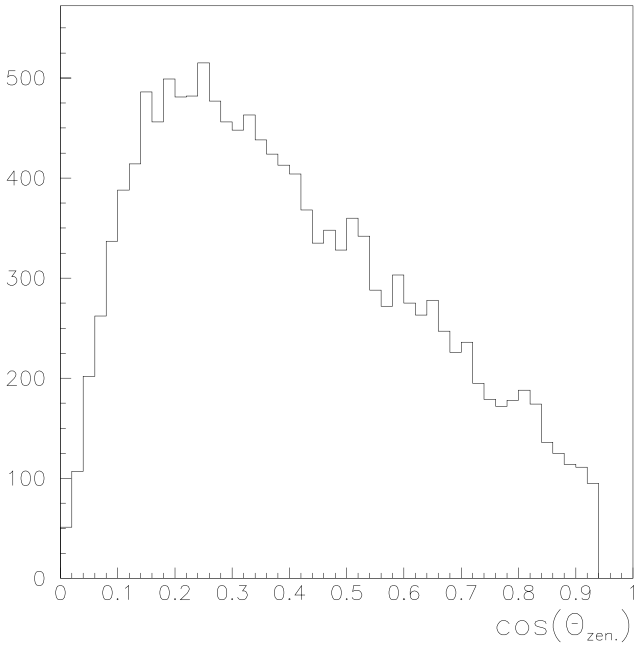

Fig. 4. Zenith angular distribution of detected neutrino events after selections.

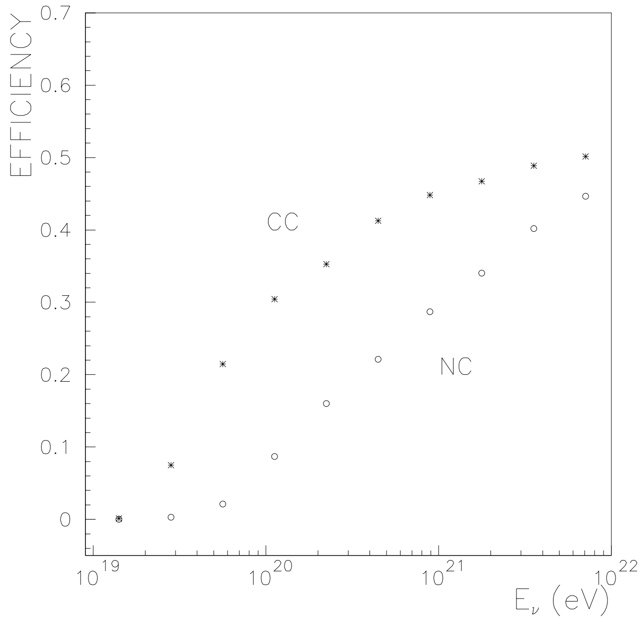

Fig. 5. Detection efficiency for CC and NC neutrino interactions. The neutrino events have been generated inside $1.5 \cdot 10^{18}$ g of atmosphere.

The angular distribution of neutrinos has been chosen isotropic and the CC interactions have been analyzed separately respect to the NC interactions. Once the trigger conditions and selection criteria are applied the angular distribution differs from its original isotropic shape. The selection by *Xmax* limits the neutrinos incoming angle at $\Theta \geq 20^0$. The request to be triggered by the fluorescence light favours the horizontal showers since their elongation in space is larger and their energy threshold is lower. Also for vertical events the probability to have a shower maximum below the ground level is higher than for horizontal one. On the other hand the request for the reflected cherenkov light detection favours vertical events (due to the reduced cherenkov light path from shower to detector) and rejects some almost horizontal events where the cherenkov light goes outside the field of view or does not hit the ground at all. In fig. 4 the angular distribution resulting from the trigger conditions and selection criteria is shown. In fig. 5 the values of efficiency $\epsilon = \frac{selected\ \ events}{generated\ \ events}$ versus the neutrinos energy are shown for CC ν_e interactions and NC ν_e interactions. For interactions induced by muon neutrinos, when the muon exiting the interaction is neglected (see first section), the efficiencies for both CC and NC interactions are expected to be very close to the case of NC ν_e interactions. The inefficiencies still exist at the high energies mainly because of some showers have their maxima below the ground level. The mean values of the efficiencies for $3 \cdot 10^{19}$eV$\leq E_\nu \leq 10^{22}$eV, E^{-1} spectrum and ν_e are $\epsilon \approx 0.4$ for CC and $\epsilon \approx 0.25$ for NC and respectively the mean values of effective acceptances are $A^\nu_{eff} = A^\nu \cdot \epsilon \approx 4 \cdot 10^{18}$g·sr and $A^\nu_{eff} = A^\nu \cdot \epsilon \approx 2.5 \cdot 10^{18}$g·sr .

In order to correctly estimate the EUSO performance we remind that the fluorescence detection needs a dark atmosphere and a conservative value of the duty cycle, not considered in the efficiency above, is around 10%.

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