

Evaluation of expected solar flare neutrino events in the IceCube observatory

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I. Solar Flares and Neutrinos

Since the end of the eighties and in response to an increase in the total neutrino flux in the Homestake experiment in a possible coincidence with large solar flares, solar neutrino detectors have searched for solar flare signals.

Neutrinos from the decay of mesons, which are themselves produced in collisions of accelerated protons with the solar atmosphere, would provide a novel window on the underlying physics of the acceleration process.

Flares emit radiation across the entire electromagnetic spectrum. The most energetic γ -rays – produced by the decay of pions – will play an important role in solar flare neutrino (SFv) search.

II. Evaluation of SFv @ Earth

A Geant4 simulation of proton-nucleus interactions has been designed to evaluate the flux of SFv at 1 AU. The "Model of chromospheric flare regions"^a has been used to define the interaction region. The influence of the following parameters has been studied:

- the proton spectral index: $\gamma = -3.1^b$ and -2 (1)
- the high-energy cutoff: 1, 2, 3 and 5 GeV (2)
- the direction of the accelerated flux
- the angular distribution (3)



III. SFv in IceCube

IceCube - the neutrino observatory located at the South Pole - has been originally designed to study TeV neutrinos. The current detector is made of 86 strings; each one containing 60 optical modules connected to it. These 5160 modules are located between 1450 and 2450 meters below the South Pole surface.

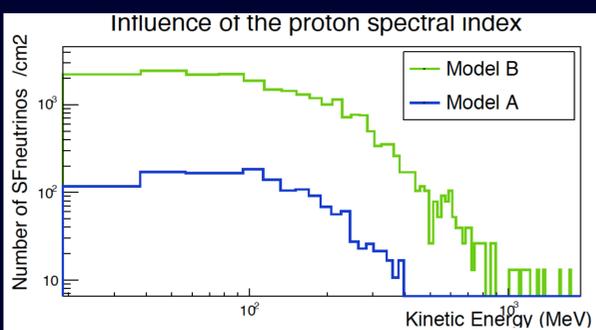
DeepCore (DC): In order to be sensitive to neutrinos with a lower energy, IceCube contains a denser part - DeepCore. This subdetector is characterized by a higher density of optical modules. This allows IceCube to detect neutrinos from 100 MeV and above.

Supernova data acquisition system^c (Sndaq): Searching for increase in the noise level in the detector, the supernova system is able to detect large amounts of neutrinos with an energy as low as 10 MeV.

Summary of the neutrino spectrum and the number of events in IceCube produced by one solar flare

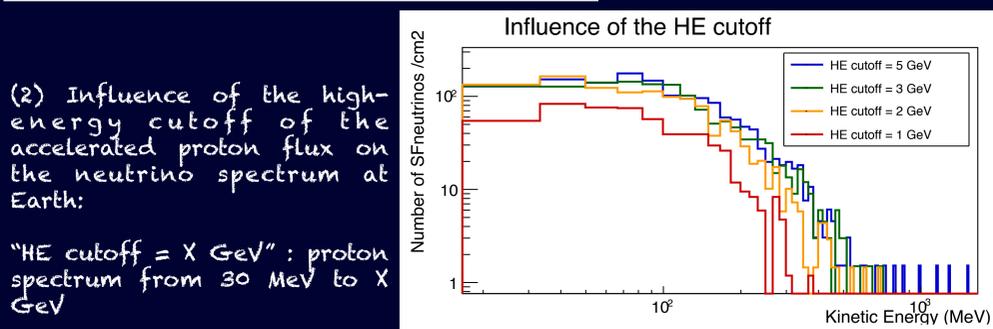
1 SF	Detector	Model A // HE cutoff = 5 GeV	Spectrum	Expected # Events	Required for 3 σ detection
10-100 MeV	I3/SNDAQ	770 # SFv/cm ²	E^0	193	~ 50 000
100-1000 MeV	DC	783 # SFv/cm ²	$E^{-2.3}$	89	~ 100

We can eliminate most of the atmospheric and radioactive background by looking for neutrinos in a short time-window defined by gamma-ray observations



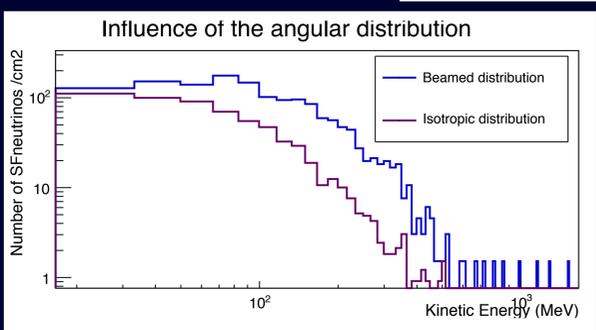
(1) Influence of the spectral index of the accelerated proton flux on the neutrino spectrum at Earth:

- Model A (from b): $E^{-3.1} - 2.2 \cdot 10^{33} p$
- Model B: $E^{-2} - 2.97 \cdot 10^{31} p$



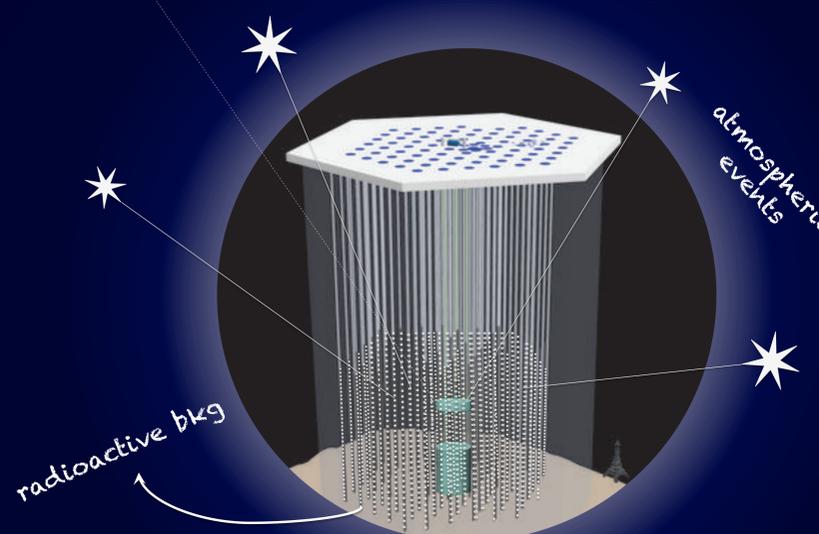
(2) Influence of the high-energy cutoff of the accelerated proton flux on the neutrino spectrum at Earth:

"HE cutoff = X GeV": proton spectrum from 30 MeV to X GeV



(3) Influence of the angular distribution of the accelerated proton flux on the neutrino spectrum at Earth:

- beamed (tangent): \oplus
- isotropic: \oplus



IV. Novel idea for a stacking analysis

As seen in the table, there is a realistic chance to see solar flare neutrinos above 100 MeV with DeepCore. Although a flare-by-flare analysis might not be promising, a stacking analysis will be carried out. In order to maximize the chance of a detection, we will restrict the sample to solar flares for which γ -rays from pion-decay have been tagged. The FWHM of these emissions in the impulsive phase does not exceed 4 minutes^d. Using satellite data as a reference, a time-profile analysis of a few solar flares would lead to a detection in the DC assuming the current model. FERMI observations^e suggest that the number of flares with pion-decay gamma-ray emission is higher than hitherto expected (20 events detected between 6/2010 and 7/2012).