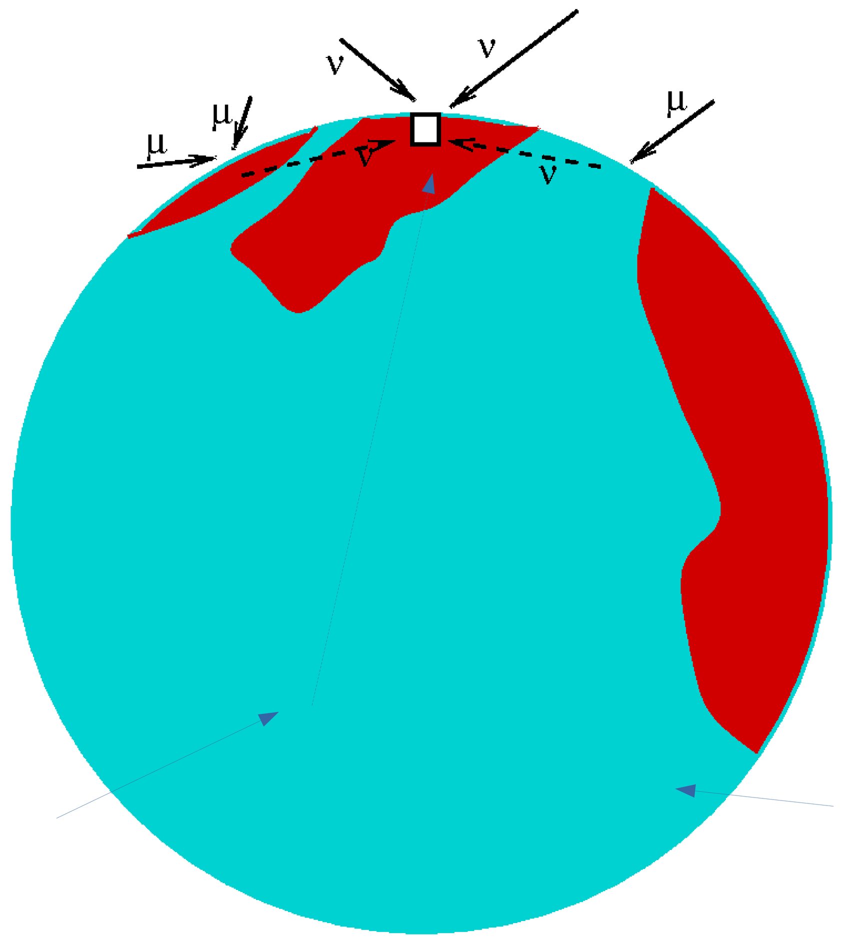

Atmospheric Neutrino Flux Below 100 MeV.

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Abstract

The difficulty of the calculation of atmospheric neutrino flux below 100MeV is in the treatment of muon decay in the earth. Especially the muon the neutrino coming produced by the muon capture by a nucleus is relatively unknown process as the source of the atmospheric neutrino. In this paper, we study generally the muon decay in the material at the surface of the Earth following the work of Wan-Lei Guo [1], including the muon capture by a nucleus, and carry out the calculation of the atmospheric neutrino flux using our Monte Carlo Code, atmnc3 [2] and present a preliminary result.

The muon capture by atomic nuclei is considered as the most unknown part of the muon decay in the matter. Guo treated the neutrino from the muon capture by the assumption that the energy spectrum of γ from a π^-–absorbed nuclei is fairly similar to that of ν from nucleus captured μ^- as suggested in Ref. 3, and compiled the probabilities of atomic capture and nucleus capture as in Table 1. Then he studied the neutrino from the muon capture by O nuclei with the $^{16}O(\pi^-,\gamma)^{16}N^*$ data from Ref. 4.

Elements	Mass (%)	Number (%)	$P(Z)$	Atomic capture (%)	τ_{μ^-} (ns)	Huff factor	D_{μ^-} (%)
O	47.51	62.13	1.00	60.26	1795.4	0.998	81.56
Si	31.13	23.89	0.84	19.46	756	0.992	34.14
Al	8.15	3.91	0.76	2.88	864	0.993	39.05
Fe	3.92	2.27	3.28	7.21	206	0.975	9.14
Ca	2.57	2.07	1.90	3.81	332.7	0.985	14.92
Na	2.43	2.27	1.00	2.21	1204	0.996	54.58
K	2.32	1.28	1.54	1.91	435	0.987	19.54
Mg	1.50	1.99	0.93	1.79	1067.2	0.995	48.33
Ti	0.38	0.17	2.66	0.45	329.3	0.981	14.70
P	0.07	0.02	1.04	0.02	611.2	0.991	27.57

Table 1. The probability of absorption by a atom and atmic nuclei for the dominant materials at the surface of the Earth.

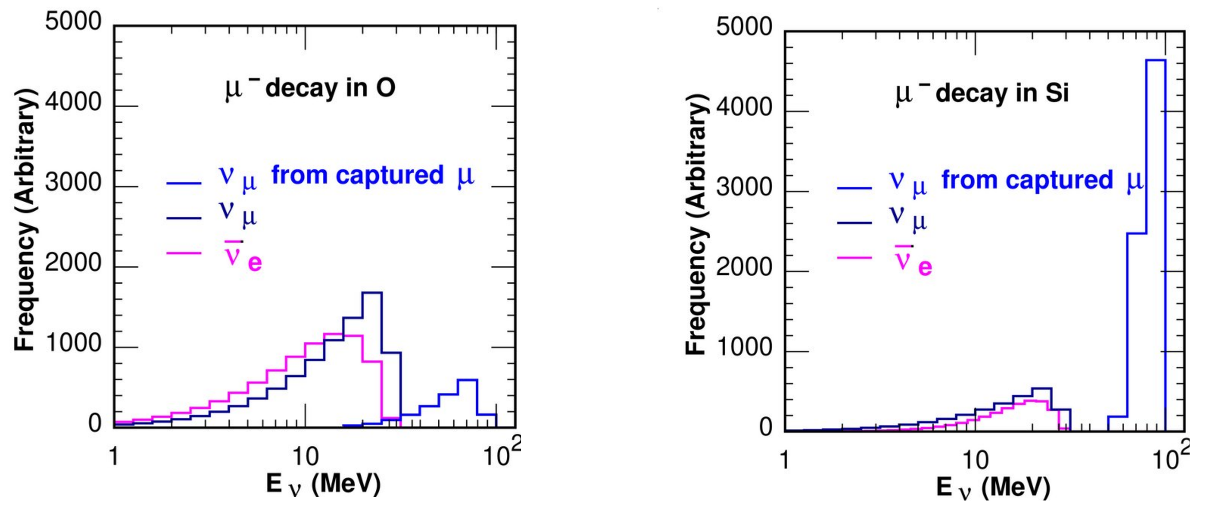

Fig.4, Enegy spectra of neutrino absorbed in O atom (left panel) and Si atom (right panel)

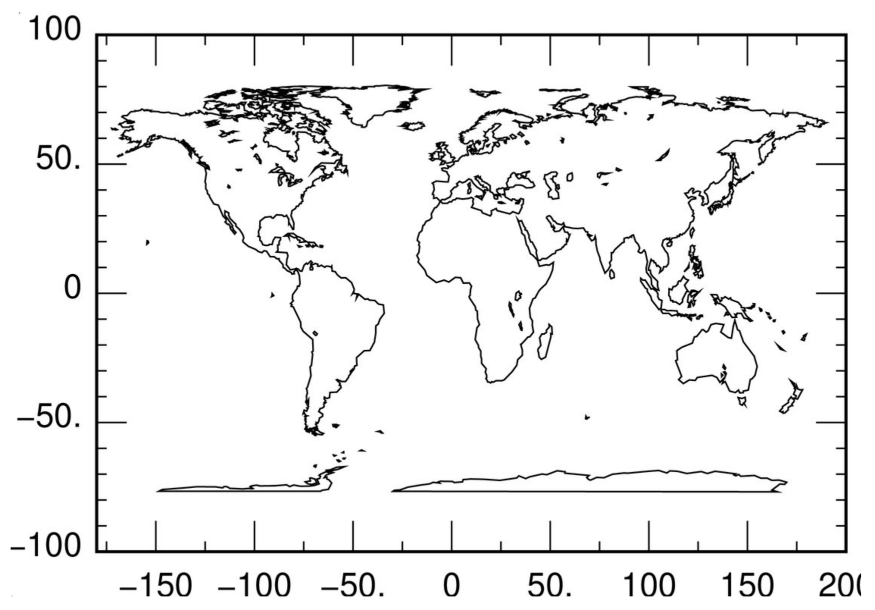

Fig. 5, World map for the muon hit point on the Earth

Following Guo's work, we look for the γ-spectrum data from π^-–absorbed nuclei and find $^{28}Si(\pi^-,\gamma)^{28}Al$ data in Ref. 3, but could no more. The experimental data of γ-spectra from heavier nuclei seems not so rich above Si. Therefore, we just use the resuls for Si for heavier nuclei than Si. However, considering the difference of γ-spectra in π^- absorption of O and Si, the difference of them between heavier nuclei and Si may be large. The study must be repeated when proper data are available to us.

The actual calculation of the muon decay in matter follows the flowchart shown in Fig. 3 in atmnc3. We note we do not treat the muon nucleus interaction in this code, but just assume all the muon enter the Earth loose it's energy by the electromagnetic energy loss in rock or water and stop in the Earth material. Then captured by a atom and the nucleus following the probability in Table 1. In this assumption μ^+ decays freely.

In the left panel of Fig. 4, we depicted the neutrino spectra when μ^- is captured by O atom, and in the right panel, when μ^- is captured by Si atom. We find that the there is a large difference in the ν_μ spectrum between them. This is mainly due to the difference of the probability of nucleus absorption between them.

In the Global simulation with atmnc3, we used the world map shown in Fig. 5 to identify if the muon enters in water or in rock. However for the Latitude > 70° and < 70°, we assumed the surface is covered by the ice. When μ^- enters in water or ice, we consider it stop there and produce the neutrinos following the energy spectra shown in the left panel of Fig.4. When it hits the land area, we consider it produce the neutrino following the energy spectra shown in right panel of Fig.4.

Thus calculated atmospheric neutrino flux below 100 MeV is averaged for all over the directions and depicted in Fig. 6 for SK and JUNO with muon decay in the Earth and without it. We see the difference between with and without muon decay in the Earth. This is due to the free decay of stopped muon in the Earth. We expect the neutrino from muon capture by a nucleus at around 70~80 MeV. However, we do not see a clear difference between with and without muon decay in the Earth at this energy.

In Fig 7 we show the angular variation of the flux ratio of with/without muon decay in the Earth at 31.6 MeV (left panel) and at 79.4 MeV (right panel). We can find the flux enhancement due to the muon capture by a nucleus in the right panel of Fig.7. However, it is difficult to estimate the flux value correctly in this preliminary study, since our virtual detector is set to be the same as the calculation for higher energy atmospheric neutrino (r_{det} ~1000km). It depends on much local structure near the neutrino detector. We expect ~20% enhancement for horizontal direction.

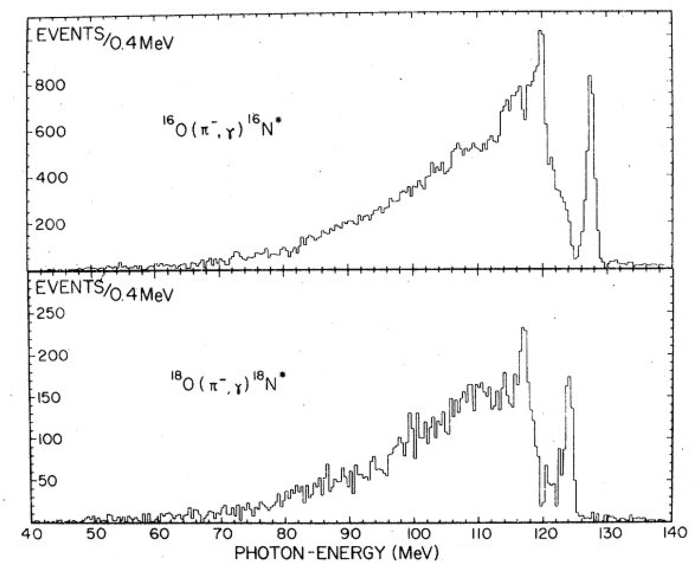

Fig. 1, γ-spectra for $^{16}(\pi-,\gamma)^{16}N^*$ and $^{18}O(\pi-,\gamma)^{18}N^*$ reactions.

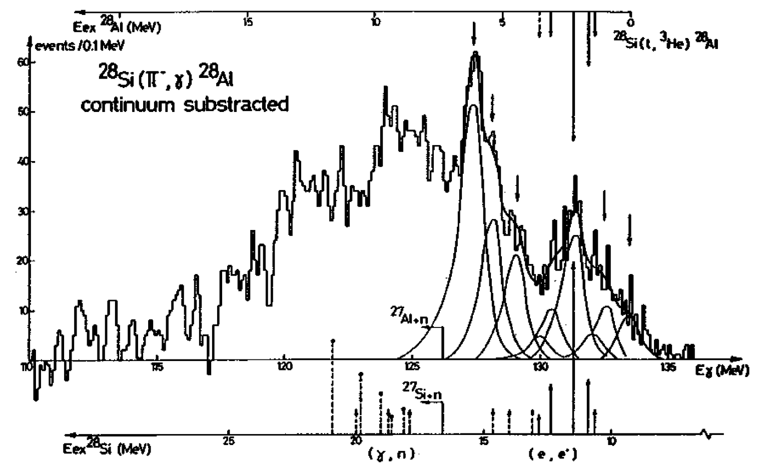

Fig. 2, γ-spectra for $^{28}Si(\pi^-,\gamma)^{28}Al$ and $^{28}Si(t\,^3He)^{28}Al$ reactions.

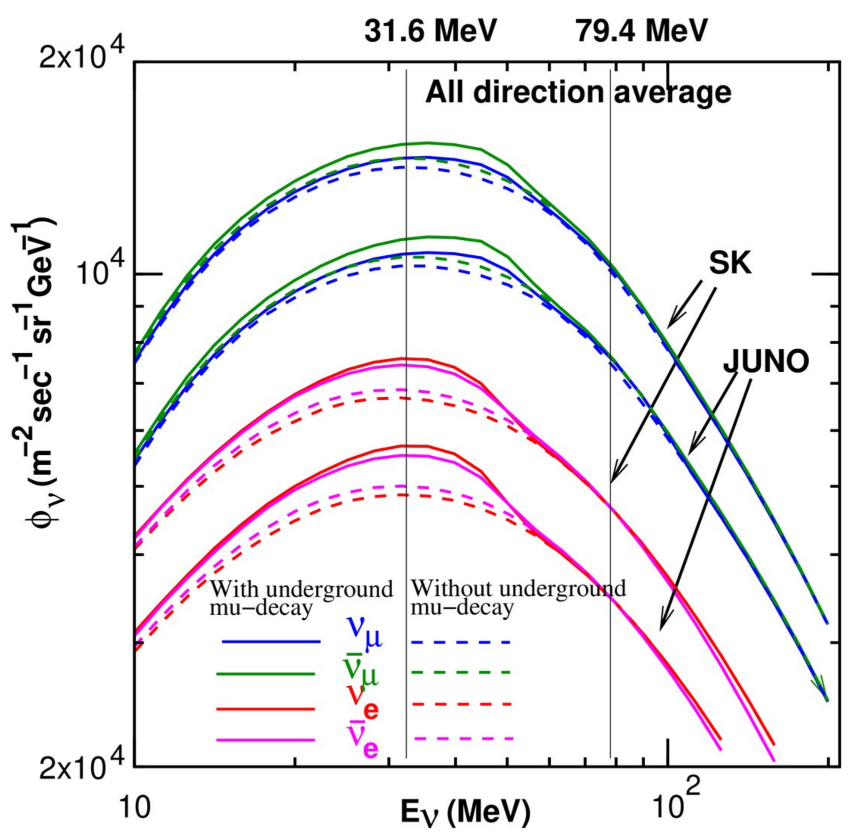

Fig. 6 All direction averaged atmospheric neutrino flux at SK and JUNO

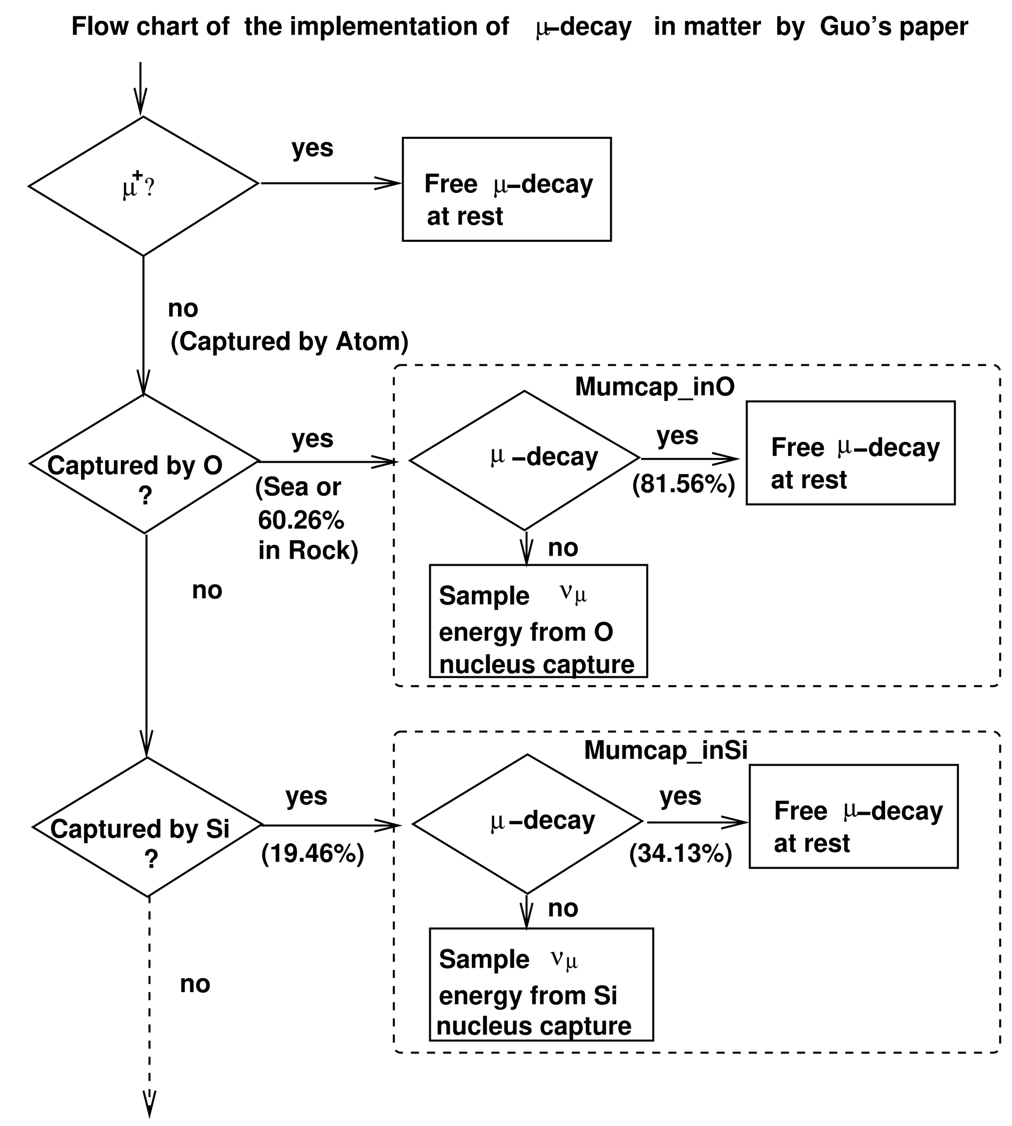

Fig. 3 Flowchart for muon decay in the Earth for atmnc3.

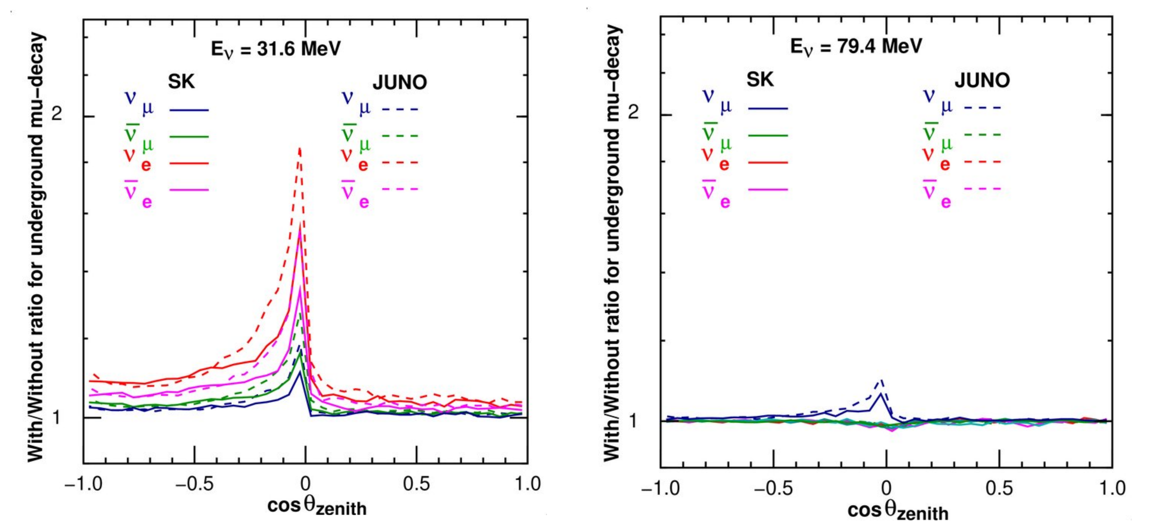

Fig. 7, The angular variation of the with/without muon decay in the Earth at 31.6 MeV in left panel and 79.4 MeV in right panel. Only ν_μ shows a little enhacement near horizontal direction.

References

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