Qing He
Kirk McDonald
Princeton University
May 6, 2009

Muon Rate

Abstract

This note describes a calculation of the muon rate at sea-level. The muon rate for MicroBooNE TPC is $9662\,\mathrm{s}^{-1}$ with $E_\mu > 0.2$ GeV.

1   Muon Flux at Sea Level

Muons are the most numerous charged particles at sea level. The muon flux at ground-level has been measured many times in the past 50 years [1, 2, 3, 4, 5]. If muon decay is negligible ($E_\mu > 100/\cos\theta$ GeV, where θ is the polar angle of the imcoming muon) and the curvature of the Earth can be neglected ($\theta < 70°$), the flux can be well described by the Gaisser's parameterization:

$$\frac{dI}{dEd\Omega} = \frac{0.14E^{-2.7}}{\mathrm{cm}^2\,\mathrm{s\,sr\,GeV}} \left(\frac{1}{1 + \frac{1.1E\cos\theta}{115\,\mathrm{GeV}}} + \frac{0.054}{1 + \frac{1.1E\cos\theta}{850\,\mathrm{GeV}}} \right) \tag{1}$$

In order to describe the full range of zenith angles, $0° \sim 90°$, a parameterization of the $\cos\theta \to \cos\theta^*$ is introduced by Dmitry [6].

$$\cos\theta^* = \sqrt{\frac{(\cos\theta)^2 + P_1^2 + P_2(\cos\theta)^{P_3} + P_4(\cos\theta)^{P_5}}{1 + P_1^2 + P_2 + P_4}}, \tag{2}$$

The best fitted $P_1, \ldots, P_5$ are shown in Table 1. IHEP made further modifications to the

Table 1: Best fitted parameters

Parameter	Value
P_1	0.102573
P_2	-0.068287
P_3	0.958633
P_4	0.0407253
P_5	0.817285

Gaisser's formula to make it describe the low engergy area better [7]. In IHEP's parameterization, an additonal term is added to Eq. (1):

$$\frac{dI}{dEd\Omega} = \frac{0.14}{\mathrm{cm}^2\,\mathrm{s\,sr\,GeV}} \left[E \left(1 + \frac{3.64\,\mathrm{GeV}}{E(\cos\theta^*)^{1.29}} \right) \right]^{-2.7} \left(\frac{1}{1 + \frac{1.1E\cos\theta}{115\,\mathrm{GeV}}} + \frac{0.054}{1 + \frac{1.1E\cos\theta}{850\,\mathrm{GeV}}} \right) \tag{3}$$

At high energies, the additional term is negligible. The parameters, 3.64 in the numerator and 1.29 in the power of $\cos\theta^*$, are obtained by fitting experiment data [1, 2, 3, 4, 5].
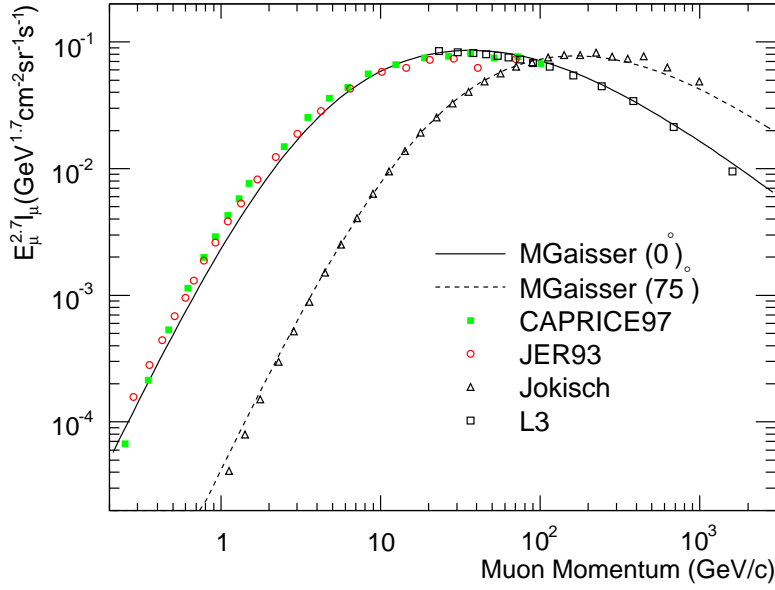
1

Figure 1: $I(E)E^{2.7}$ comparion between best fit (lines) and experiment data (points). The solid line shows the differential flux times $E^{2.7}$ at $\theta = 0°$, the dashed line shows the differential flux times $E^{2.7}$ at $\theta = 75°$.

The comparison of the parameterization (Eq. (3)) and real data is shown in Fig. 1 and Fig. 2.

Muon rate is obtained by integrating the differential flux. Different energy threshold corresponds different rate. The muon rate vs. energy threshold is shown in Fig. 3 and some selected points are shown in Table 2. The results agree with the well known form of $I \approx 1\,\mathrm{cm}^{-2}\mathrm{min}^{-1}$.

Table 2: Muon rates for different energy threshold.

Threshold	0.2 GeV	0.3 GeV	0.4 GeV	0.6 GeV	0.8 GeV	1 GeV
Rate (m^{-2}s^{-1})	172.2	166.7	161.5	151.8	143.1	135.2

2   Muon Rate for MicroBooNE TPC

To convert the rate of muons crossing a horitontal surface (R_H) to the rate of muons crossing a vertical surface (R_V), one has to times a factor, $\tan\theta \sin\phi$ [8], to the flux density.

The integrated muon rates for a unit area of verital surface are shown in Table 3. Note that R_H/R_V is very close to π.

For MicroBooNE TPC, with an active volume of $2.6 \times 2.6 \times 12\,\mathrm{m}$, the total muon rate is $2.6 \times 12 \times R_H + 2 \times (2.6 \times 2.6 + 2.6 \times 12) \times R_V$. The results are shown in Table 4.
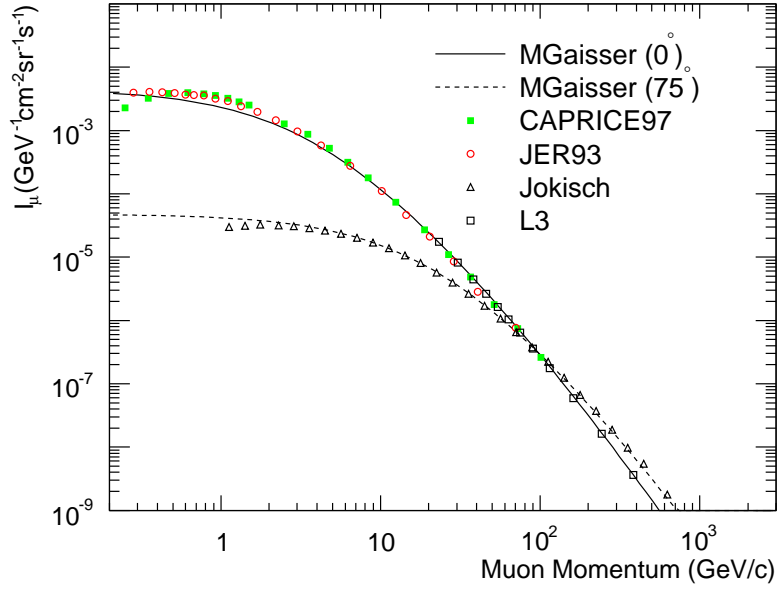
Figure 2: $I(E)$ comparion between best fit (lines) and experiment data (points). The solid line shows the differential flux at $\theta = 0°$, the dashed line shows the differential flux at $\theta = 75°$.

Table 3: Muon rates for a unit area of vertical surface.

Threshold	0.2 GeV	0.3 GeV	0.4 GeV	0.6 GeV	0.8 GeV	1 GeV
Rate $(\mathrm{m}^{-2}\mathrm{s}^{-1})$	56.5	55.2	54.0	51.6	49.4	47.4

3 Summary

The muon rate at sea level is $172.2\,\mathrm{m}^{-2}\mathrm{s}^{-1}$ with $E_\mu > 0.2\,\mathrm{GeV}$. The muon rate for MicroBooNE TPC is $9662\,\mathrm{s}^{-1}$ with $E_\mu > 0.2\,\mathrm{GeV}$.
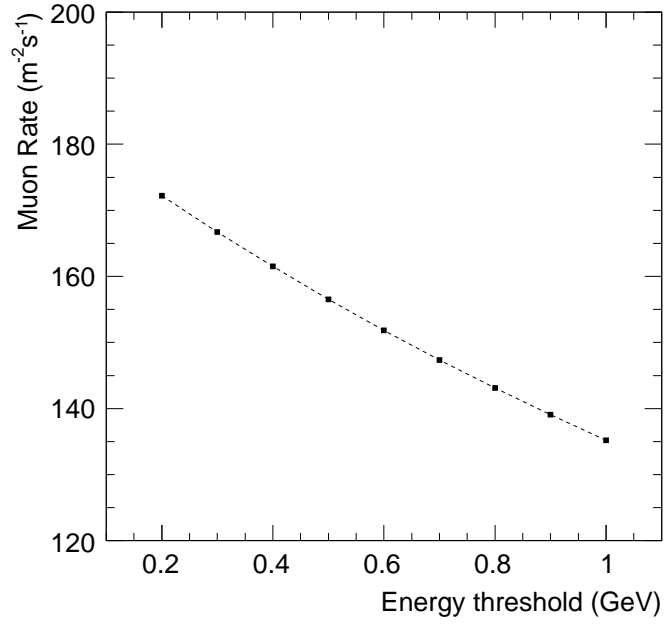
3

Figure 3: Muon rate vs. energy threshold.

Table 4: Muon rate for MicroBooNE TPC.

Threshold	0.2 GeV	0.3 GeV	0.4 GeV	0.6 GeV	0.8 GeV	1 GeV
Rate (s^{-1})	9662	9392	9138	8654	8215	7817

References

[1] H. Jokisch, K. Carstensen *et al.*, Phys. Rev. D **19**, 1368 (1979)

[2] J. Kremer *et al.*, Phys. Rev. Lett. **83**, 4241 (1999)

[3] P. Achardv *et al.* (L3 Collaboration), Phys. Lett. B **598**, 15 (2004)

[4] B. C. Rastin, J. Phys. G **10**, 1609 (1984)

[5] C. A. Ayre, J. M. Baxendale *et al.*, J. Phys. G **1**, 584 (1975)

[6] D. Chirkin, arXiv:hep-ph/0407078v1 (2004)

[7] M. Guan *et al.*, Daya Bay experiment internal note 318

[8] H. Jostlein, K. T. McDonald, MicroBooNE DocDB 198