Optimization of electromagnetic and hadronic extensive air showers identification using muon detectors of TAIGA experiment

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Introduction

The TAIGA experiment is searching for new intergalactic and extragalactic information from high energy astroparticles which carrying energy in the range from tens of TeV to several PeV. The experiment includes HiSCORE wide-angle optical detectors, Imaging Atmospheric Cherenkov Telescope, Tunka-Rex (Tunka Radio Extension), Tunka-Grande (scintillation detectors) which are spread on the area around 1 km^2 at Tunka valley, Baikal[1]. There are 19 Tunka-Grande stations are working since 2014. New Taiga-Muon stations will extend the existing muon detectors system to a new level. Taiga-Muon experiment is looking forward to improve identification of primary gamma-quanta events in the range greater than 100 TeV.

1 Simulation

1.1 Selection of particles

The extensive air showers of both gamma quanta, protons, and iron are created by Corsika package using QGSJET-II-04 with FLUKA library[2]. In this simulation 1000 primary particle shower events are created with 100 TeV, 300 TeV, 1 PeV, and 3 PeV energies and zenith angles 0^0, 30^0, and 45^0. Only for cross verification EAS of iron is used. In addition to that low energy(1-50 TeV) gamma and proton showers are created. The COAST library package is used to select the secondary particle on ground level based on the detector position[3], which later used as input data of Geant4 simulation. To consider effects of multiple scattering and width of electromagnetic shower the area of interest is extended by increasing 25 cm extra length from the edges of counters[4]. The extensive air shower core is randomized : 1000 primary events are spread in the 50 m circumference according to locational origin in Geant4 model. There is an additional energy cut of 10 MeV for electron, positron, and gamma while selecting the particles in the area of interest.

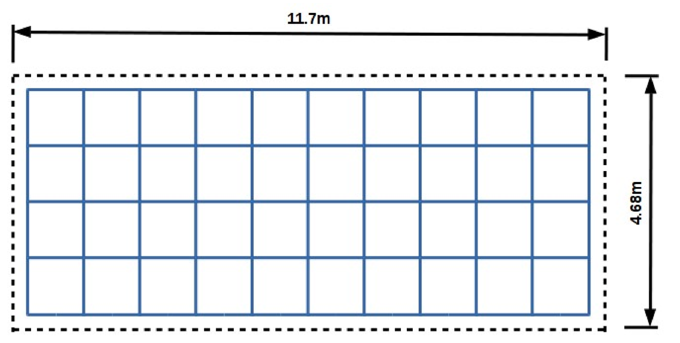

Figure 1: Selection of secondary particles in Taiga-Muon station. There are 48 counters in one station(40-underground,8-surface)

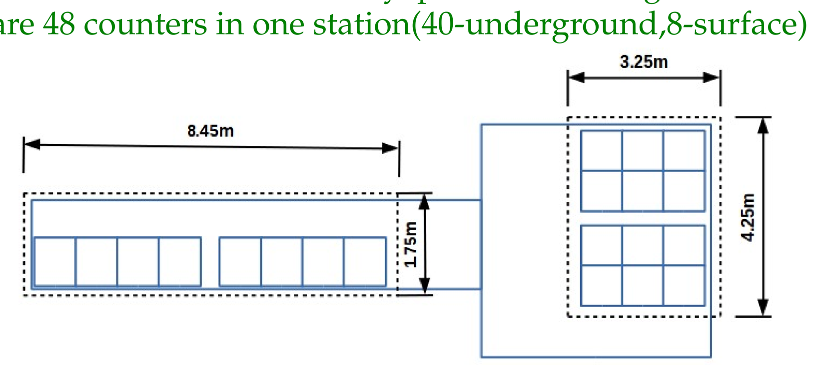

Figure 2: Selection of secondary particles in Tunka-Grande station.There are 20 counters in one station(8-underground,12-surface)

1.2 Geant4 simulation

- The dimension of a Tunka-Grande scintillation plate is 80x80x4 cm. Polyvinyl toluene (NE102A) is used as the scintillator material. The counter frame is made from duraluminum[5].
- Taiga-Muon scintillation plate dimension is 100x100 cm. Part of this plate has thickness of 2 cm, other - 1 cm. Each counter contains one PMT and 4 wavelength shifters. Polystyrene based plastic is used as scintillator. The frame of the counter is made from stainless steel.
- In Taiga-Muon counter scintillation plates are surrounded with polystyrene foam of density 0.25 g/cm^3. The counter is divided to 26 parts. The number of photoelectrons created in each parts are calculated.
- The soil is used as absorber for secondary gammas and electrons (positrons). The geology data on soil type in the place of TAIGA experiment is used to describe the chemical composition of the absorber(Oxygen-57.2%, Silicon-35.5%, Aluminum-5.4%, Hydrogen-1.9%)[6][7][8].

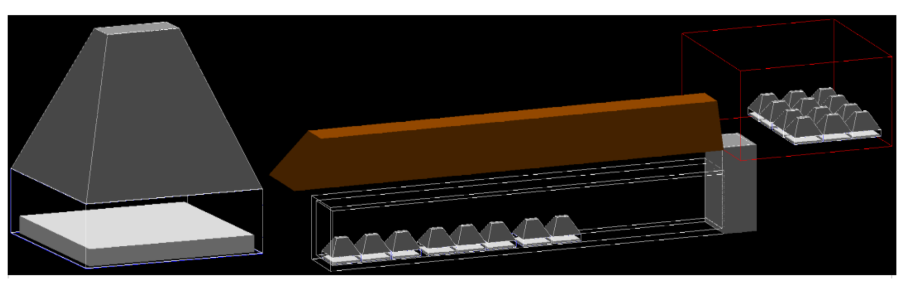

Figure 3: Geant4 model of Tunka-Grande counter and station.

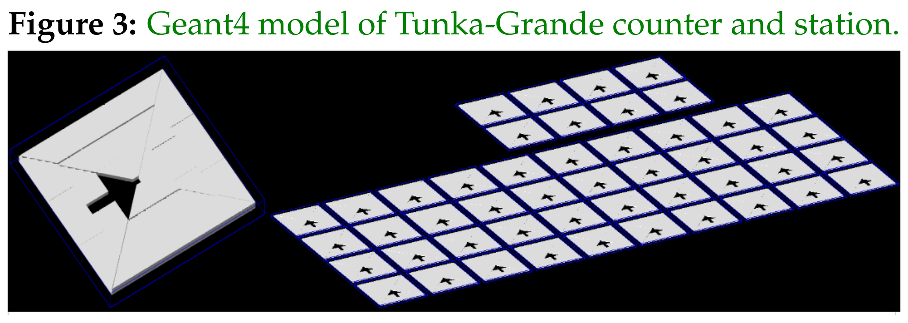

Figure 4: Geant4 model of Taiga-Muon counter and station.

2 Data analysis methods

The signal amplitude is calculated as total number of photoelectrons and normalised it to detection area. Only triggered events are taken into account. The suppression factor of electromagnetic showers from hadronic showers is studied. There are two methods to find out suppression factor.

Threshold method : The sum of signal amplitude in underground detectors is calculated. Then number of events below or above on this parameter is calculated for gamma and proton extensive air shower.

Ratio method : The ratio of sum of signal amplitude in underground counters over surface counters is calculated. Then number of events below and above on this parameter is calculated for gamma and proton extensive air shower.

$$Efficiency\,of\,gamma = \frac{Number\,of\,events\,below\,threshold}{Total\,trigger\,events}$$

$$Efficiency\,of\,proton = \frac{Number\,of\,events\,above\,threshold}{Total\,trigger\,events}$$

$$Fake\,factor\,of\,proton = 1 - Efficiency\,of\,proton$$

$$Suppression\,factor = \frac{Efficiency\,of\,gamma}{Fake\,factor\,of\,proton}$$

3 Results

3.1 Trigger efficiency

Presence of at least 2 photoelectrons in a counter is considered as a signal. The trigger efficiency is calculated based on presence of signal, in at least two surface counters of one station.

Zenith angle	Energy	Gamma	proton	Iron
0 degree	100 TeV	63.7	60.1	18.5
	300 TeV	95.3	93.9	76.8
	1 PeV	100	100	99.8
	3 PeV	100	100	100
30 degree	100 TeV	22.6	32.5	5.4
	300 TeV	65.9	71.8	42.2
	1 PeV	98.8	98.6	93.5
	3 PeV	100	100	100
45 degree	100 TeV	0.8	6.1	0.4
	300 TeV	6.9	24.5	5.0
	1 PeV	37.5	67.0	42.0
	3 PeV	87.1	95.4	90.8

Table 1: Trigger efficiency of Taiga-Muon

3.2 Absorber thickness optimization

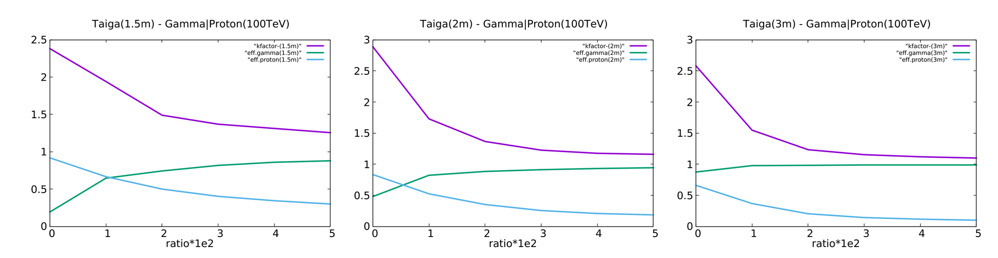

Figure 5: suppression factor, efficiency of proton and gamma of three different thickness

Comparatively better suppression factor with absorber thickness 2 m. Proton efficiency is dropping for 3 m, but more or less same for 1.5 m and 2 m. So that, 2 m could be the effective thickness of absorber.

3.3 Tunka-Grande and Taiga-Muon

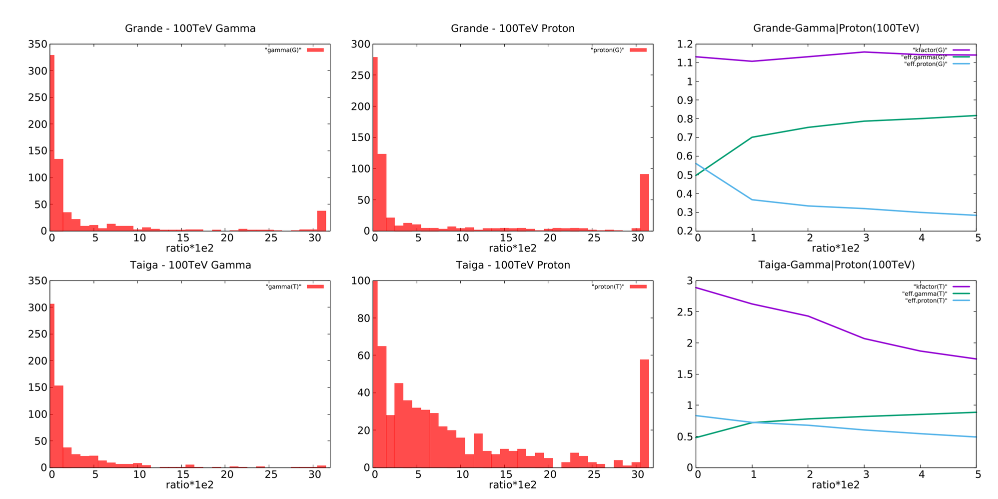

Figure 6: Comparison between Tunka-Grande and Taiga-Muon with energy 100 TeV, zenith angle 0^0 of Gamma and Proton.

The suppression factor is comparatively better for Taiga-Muon. It is mainly because of large detection area.

3.4 Station distance optimization

	Distance	Gamma	Proton
atleast 1 stn	50 m	96.5	93.2
atleast 2 stn		77.7	77.1
atleast 3 stn		52.8	55.7
atleast 1 stn	75 m	79.9	78.0
atleast 2 stn		33.7	42.6
atleast 3 stn		12.2	19.0
atleast 1 stn	100 m	55.0	56.9
atleast 2 stn		13.5	17.8
atleast 3 stn		2.7	3.9

Table 2: Trigger efficiency of stations(Note: stn - station)

Several surface counters of Taiga-Muon is simulated by separating them each other with distance 50 m, 75 m, and 100 m. The trigger efficiency of station is analyzed.

3.5 Comparison of data analysis methods

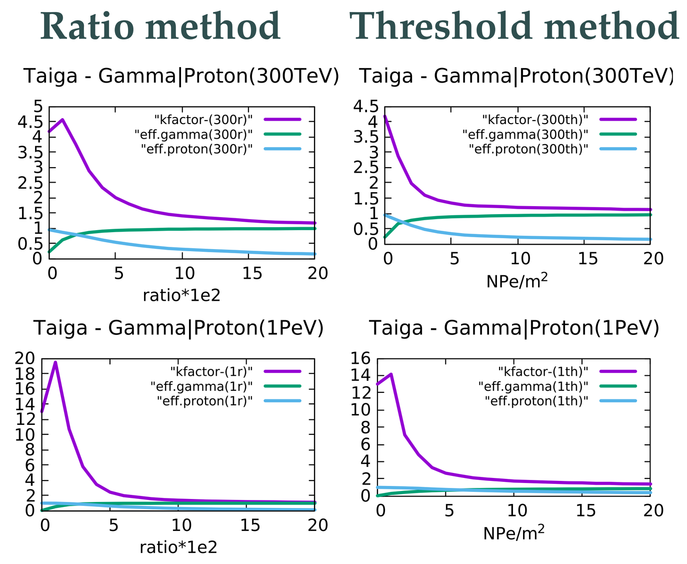

Figure 7: Comparison between data analysis methods.

Comparatively ratio method shows better suppression factor. So that, throughout the study ratio method is used for result analysis.

3.6 Finding lowest energy range

Energy	Gamma	Proton
50 TeV	33.7	33.9
40 TeV	25.9	26.7
30 TeV	17.1	19.4
20 TeV	9.6 m	11.4
10 TeV	2.7	4.0
1 TeV	1.0	2.0

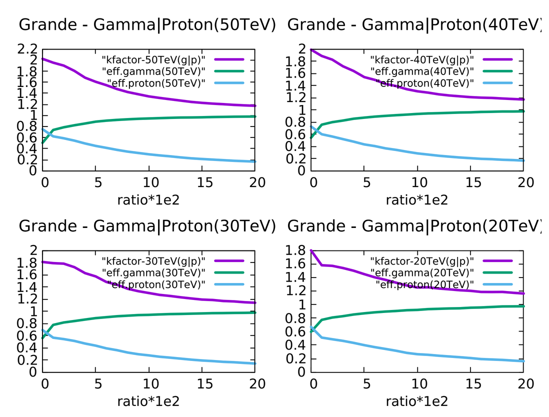

Figure 8: Result analysis of low energy primaries gives trigger efficiency(left) and suppression factor(right) for Taiga-Muon station.

The trigger efficiency is less for lower energy primary particle. Even-though, it is showing acceptable suppression factor. To eliminate the statistical error the results are verified with 10000 primary events.

3.7 PID performance

The Taiga-Muon station simulated with energy range 100 TeV - 3 PeV and zenith angle 0^0. In all cases it shows good suppression factor.

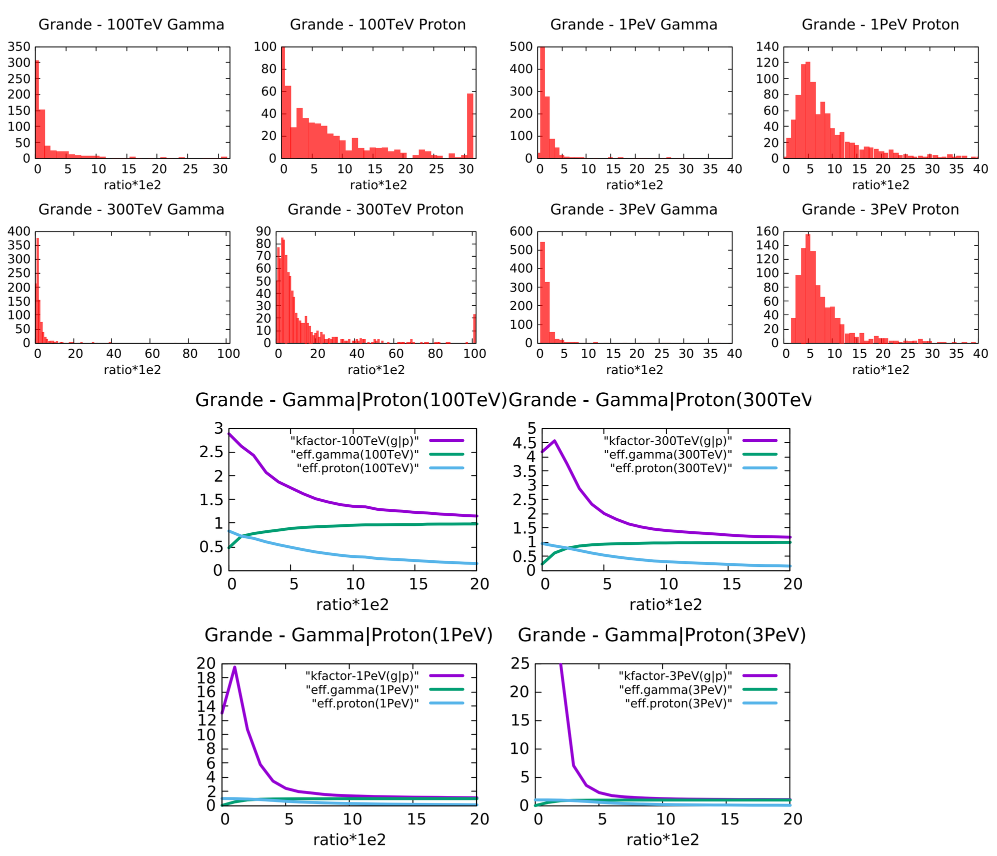

Figure 9: Result analysis of Gamma and Proton with energy 100 TeV,300 TeV,1 PeV,3 PeV and zenith angle 0^0.

4 Conclusions

- Corsika and GEANT4 realistic model of Taiga-Muon station is created and it is working well.
- Effective thickness of soil absorber should be 2 m.
- The effective distace between stations should be 50 m.
- Ratio method can be used for EAS identification.
- $\sim$ 50 TeV is the lowest energy range that can be identified by Taiga-Muon station.

Reference

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