TeVPA 2015, Kashiwa, Japan

TeV Gamma rays with ICAL-INO

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TeV-PeV Gamma-Ray Sources

- High energy gamma-rays can be produced,

1. Hadron: Pion decay
2. Lepton: Inverse compton scattering of accelerated electrons.

- TeVCat is the catalog of 165 sources that are detected with gamma-rays > 50 GeV, Pulsars, different types of AGNs (HBLs, Blazars) ,unknown sources too.
- TeV gamma rays are detected by ground based cherenkov detectors.

HESS – High Energy Strioscopic System, detect gamma rays 0.03 to 100 TeV, and is operational since 2012.

VERITAS – Very Energetic radiation Imaging Telescope Array System, with energy range 50 GeV to 50 TeV.

MAGIC – Major Atmospheric Gamma Imaging Cherenkov Telescope, with energy range 50 GeV to 30 TeV.

CTA – Cherenkov Telescope Aray Improves sensitivity of a factor of 5-10 in the current expt. about energy 100 GeV to 10 TeV, and will be able to explore in energy range 100 GeV to 100 TeV.

Muons from Gamma-ray induced showes.

Production of Muons from Gamma-rays interacting with atm., (Stanav, Vankov & Halzen 1985)

1. Photoproduction, decay of pion or kaon to muons.

$$\gamma + N \to \pi + X \quad \pi^{\pm} \to \mu^{\pm} + \nu_{\mu}(\overline{\nu}_{\mu}),$$

$$K^{\pm} \to \mu^{\pm} + \nu_{\mu}(\overline{\nu}_{\mu})$$

$$e^{+}e^{-} \to \mu^{+} + \mu^{-}.$$

important in GeV energy.

2. Muon-pair production

$$\gamma + Z \to Z + \mu^{+} + \mu^{-},$$

Z, is nucleus of the atmosphere. This channel increases at higher energy.

Muon flux from Pion-Decay.

Drees, Halzen & Hikasa (1989), Tri L. Astraatmadja , Thesis 2013

Gamma-ray with power law flux, $\gamma(\epsilon) \propto \epsilon^{-(b+1)}$, b =0, <1 or >1.

Muon flux from pion decay in case of b=1,

$$\frac{dN_\mu}{d\epsilon_\mu} = \gamma(\epsilon_\mu, t=0)\frac{\Lambda_\pi}{\lambda_{\gamma A}} z_{\gamma\pi} \frac{L_\gamma}{1+(L_\gamma/H_\gamma)\epsilon_\mu\epsilon_\pi \cos\theta},$$

Effective pion interaction length

$$\Lambda_\pi = 173 \text{ g cm}^{-2} = 4.66 \text{ radiation lengths} \qquad z_{\gamma\pi} = \frac{\sigma_{\pi\pi}}{\sigma_{\gamma N}} = \frac{2}{3}$$

Effective length of photons in atmospheric nuclei,

$$\lambda_{\gamma A} = 446.14 \text{ radiation lengths}$$

$$L_\gamma = \frac{1-r^2}{2(1-r)}\frac{t_{\max}}{\Lambda_\pi}, \quad H_\gamma = \frac{1-r^3}{3(1-r)}\left[1+\ln\frac{t_{\max}}{\Lambda_\pi}\right].$$

$$t_{\max} = \lambda_{e^+e^-} \ln\left[\frac{\epsilon_{\max}\langle x\rangle_{\gamma\to\mu}}{\epsilon}\right] \qquad \lambda_{e^+e^-} = 9/7 \quad \langle x\rangle_{\gamma\to\mu} = 0.25$$

Muon flux, direct muon-pair production.

(Bethe & Heitler, 1934) , Tri L. Astraatmadja , Thesis 2013

,

$$\frac{dN_\mu}{d\epsilon_\mu} = 2\lambda_{\rm rad}\frac{N_A}{A}\gamma_0\left(\epsilon_\mu\right)\int_0^1 dx x^b \frac{d\sigma}{dx}\left(x, \frac{\epsilon_\mu}{x}\right)\int_0^{t_{\rm max}} dt\gamma_2(t,b)$$

A is the atomic number of the nuclei involved

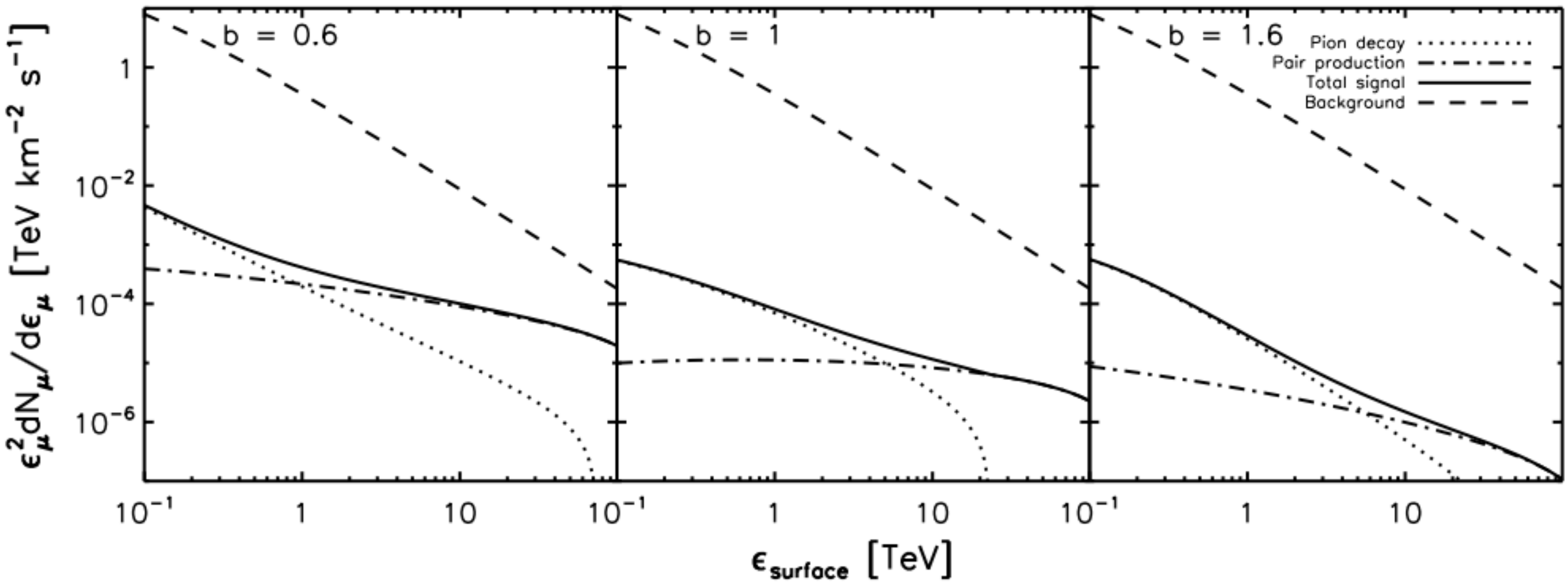
$$\epsilon_{\rm th} = \frac{2m_\mu}{m_e}\left(m_\mu + m_e\right) \simeq 43.9\,{\rm GeV}$$

$$\frac{d\sigma}{dx}(x,\epsilon_\gamma) = 4\alpha Z^2\left(r_0\frac{m_e}{m_\mu}\right)^2\left[1-\frac{4}{3}x(1-x)\right]\left[\Phi_{\rm el}(\delta)+\frac{1}{Z}\Phi_{\rm in}(\delta)\right]$$

$$\frac{dN_\mu}{d\epsilon_\mu} \approx 0.14\epsilon_\mu^{-2.7}\left[\frac{1}{1+\frac{1.1\epsilon_\mu\cos\theta}{115{\rm GeV}}} + \frac{0.054}{1+\frac{1.1\epsilon_\mu\cos\theta}{850{\rm GeV}}}\right]{\rm GeV}^{-1}\,{\rm cm}^{-2}\,{\rm s}^{-1}\,{\rm sr}^{-1}.$$

Muon background at sea level, Gaisser 1990

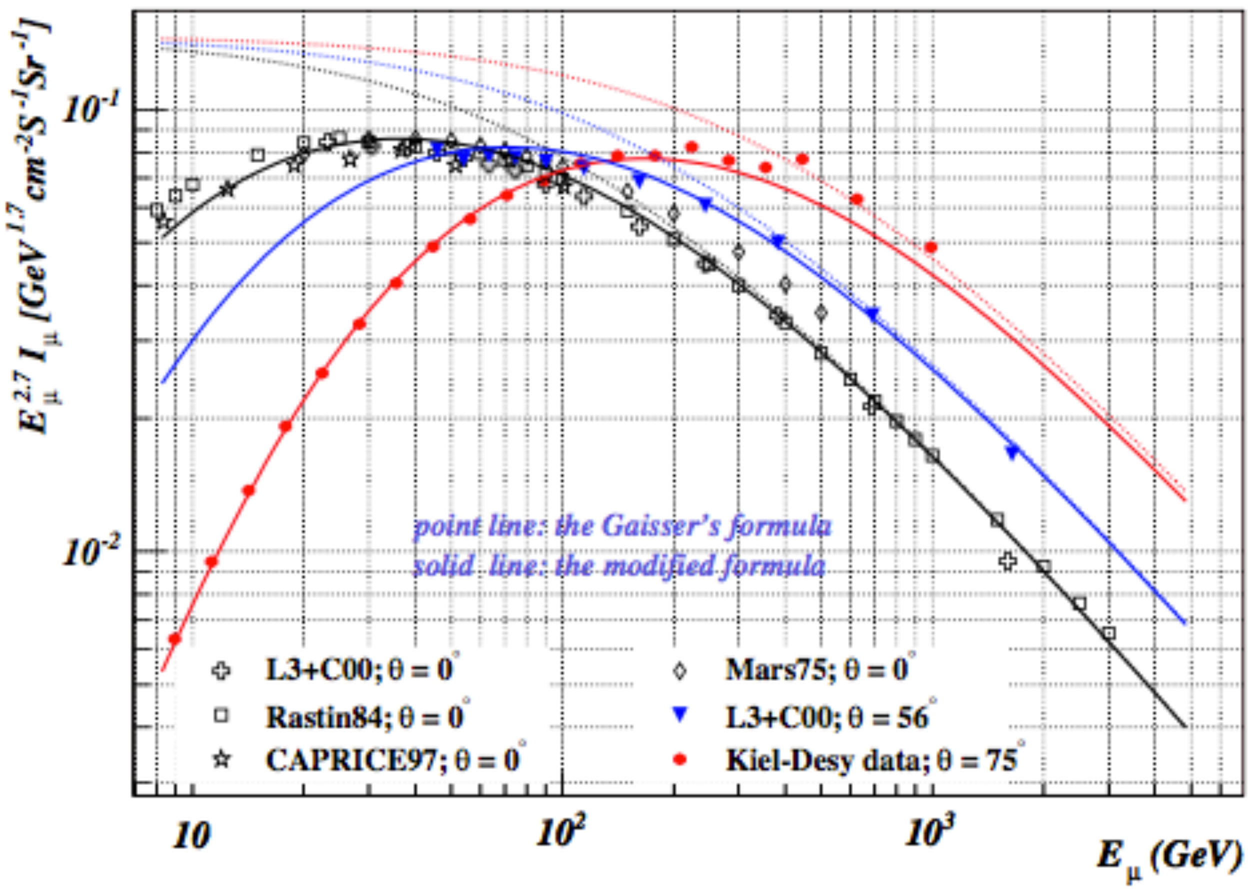
Tri L. Astraatmadja , Thesis 2013

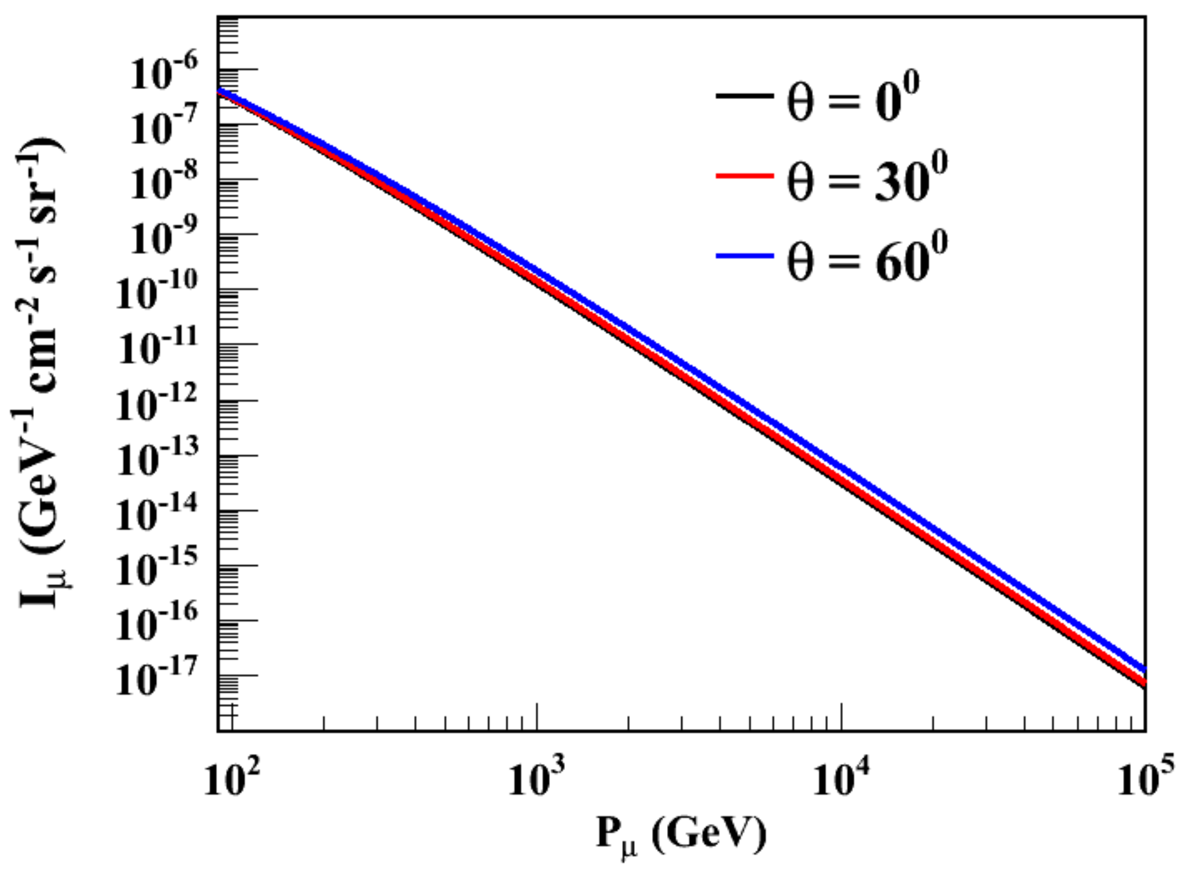


The spectrum of a fictive, unattenuated test source with fluence *fγ* = 10^{-1} TeV−1 km−2 s−1 at 1 TeV, for photon spectral indices *b* = (0.6,1,1.6), photon energy cutoff *ε*max = 300 TeV, and zenith distance *θ* = 30◦.

Modified background at sea level as in,

Daya Bay collaboration, G. Mengyun et.al.,

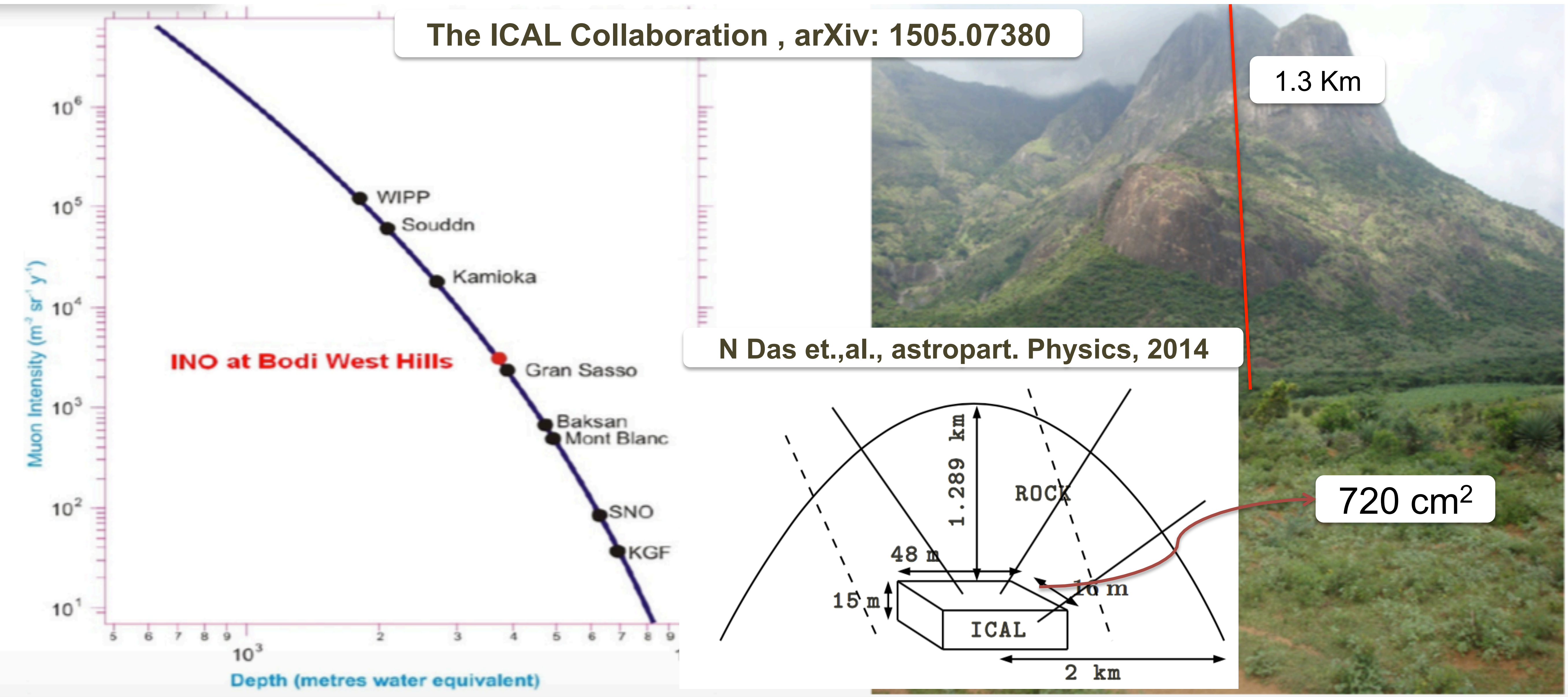




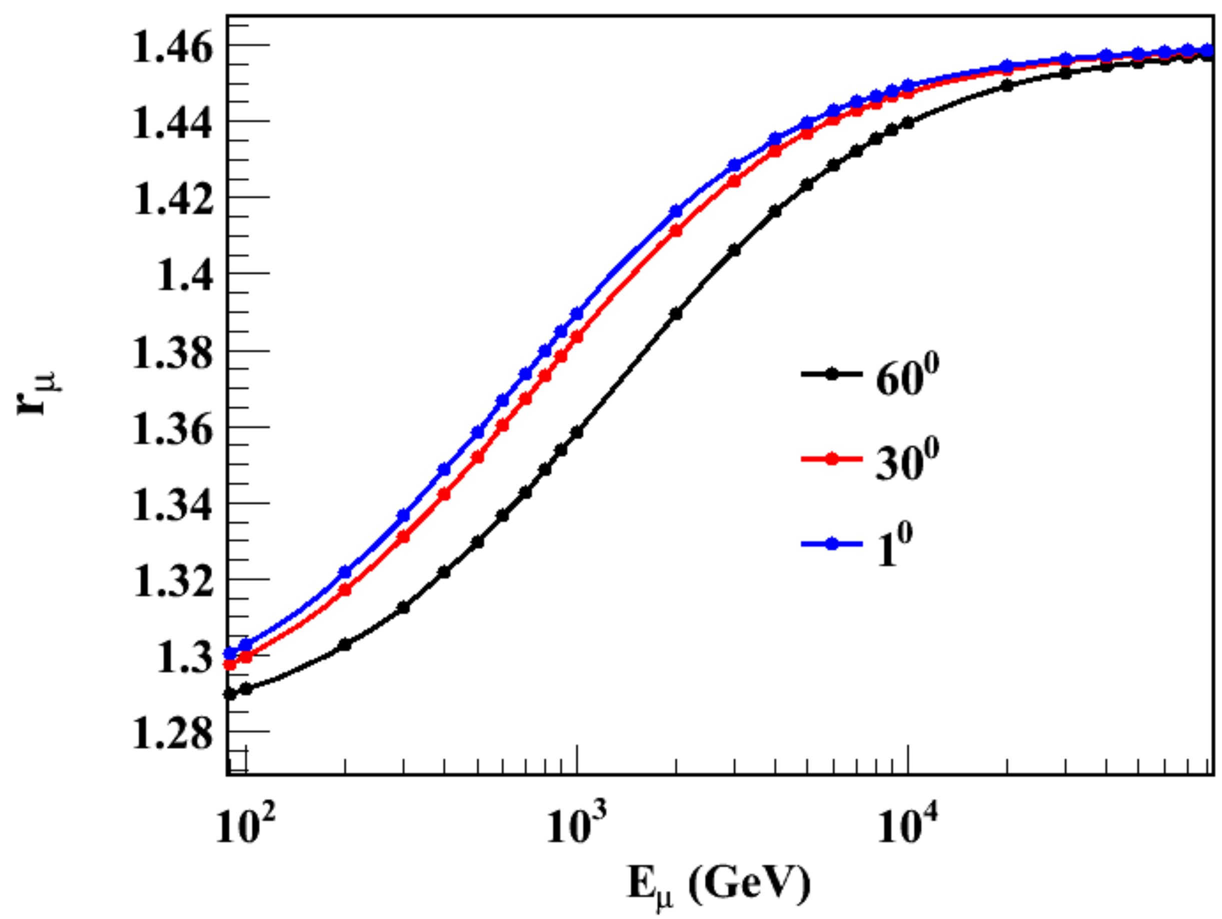
INO-ICAL

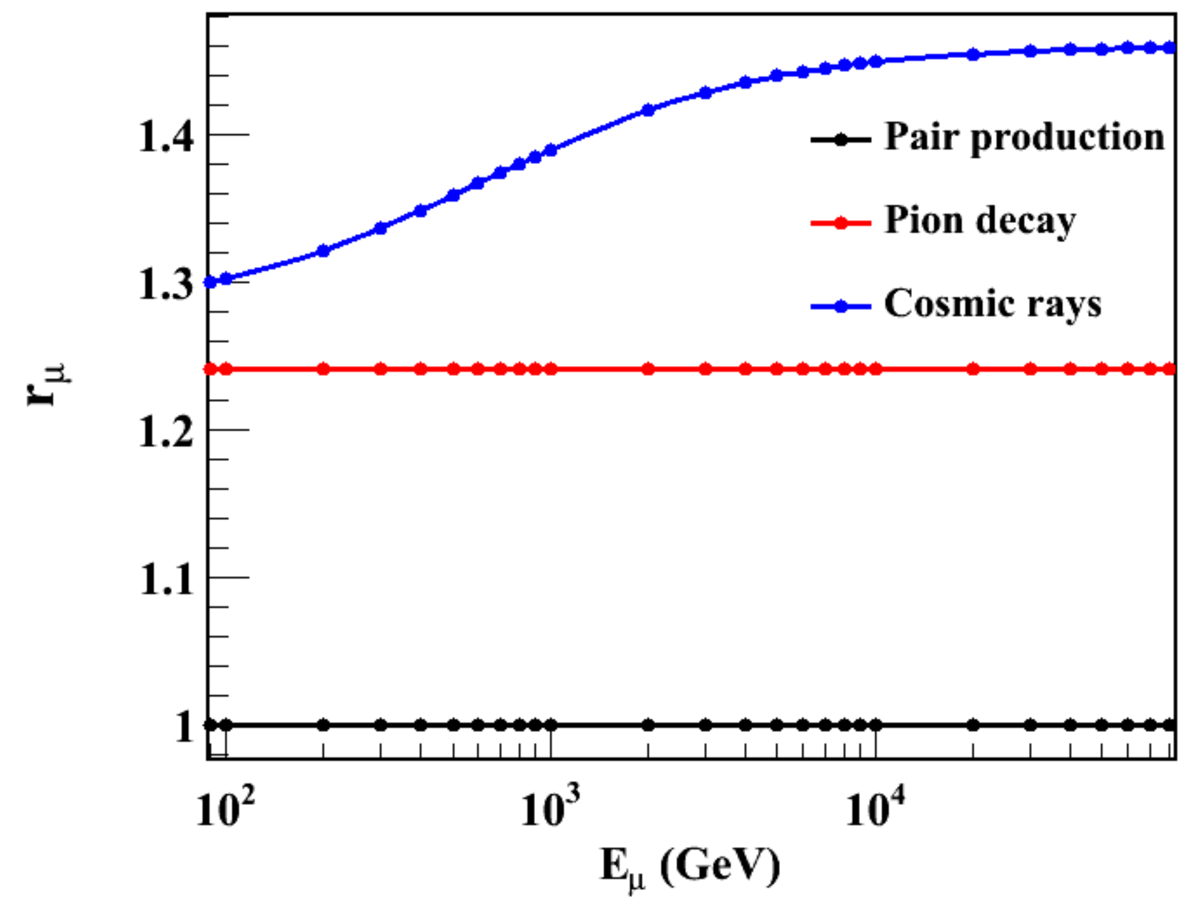
India-based Neutrino Observatory – Iron CALorimeter

- 50 kt mass with 1.5 T magnetized ICAL-INO is designed to study the Earth matter effects of atmospheric neutrinos in multi-GeV energy.
- To see the earth effect it is proposed to built in Bodi West Hills, Tamilnadu India.



Muon ratio





The figure shows muon flux ratio $r_\mu = \mu^+/\mu^-$ from photon shower with any index and any fluence , in case of both pion decay muons and muon pair production. The figure also shows the background muon ratio (P.A. Schreiner et. al., 2009) production by cosmic rays.

Summary

- Till now the High energy gamma ray study has been carried by Cherenkov telescopes.
- Detection of TeV-PeV gamma-ray induced muons by large neutrino detectors are also proposed.
- But the atmospheric muon background is too high to find out the signal.
- INO-ICAL is a proposed magnetised neutrino detector going to be built under a hill of height nearly 1 km, blocking some of the atmospheric muons.
- It has also ability to find the charge ratio of the muons produced by both atmospheric muon and gamma ray signal.