Atmospheric muons and neutrinos: spectra calculations and comparison with experiment

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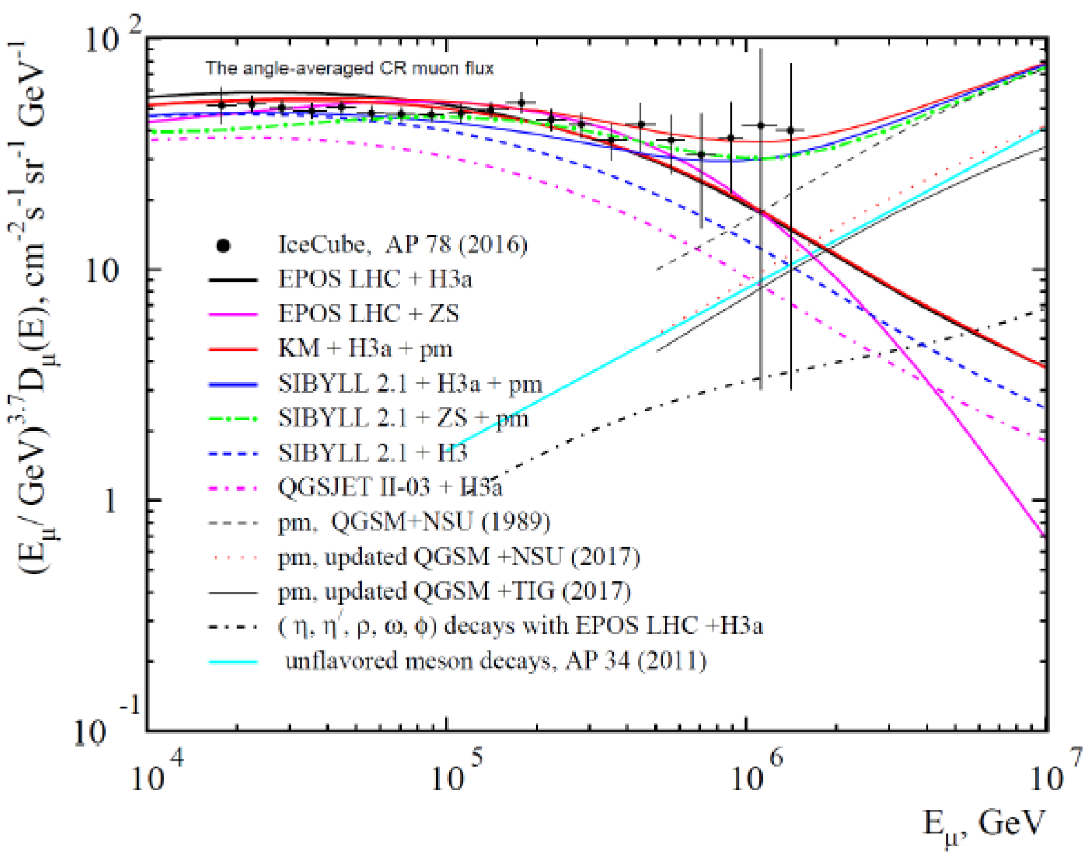
Astrophysical neutrinos and the problem of the background of atmospheric neutrinos and muons

- The main event in neutrino astrophysics of the last seven years is the detection of events from high-energy astrophysical neutrinos in the IceCube experiment
- Atmospheric neutrinos and muons are the background to such events, and it is necessary to know
- The most uncertainty in the calculation of the background of atmospheric neutrinos at energies above 200 TeV is due to the contribution of the processes of the birth and decay of strange particles $K^{\pm}, K^0, \bar{K}^0$ and enchanted particles.

Atmospheric muons

The all-sky muon flux: IceCube data and calculations



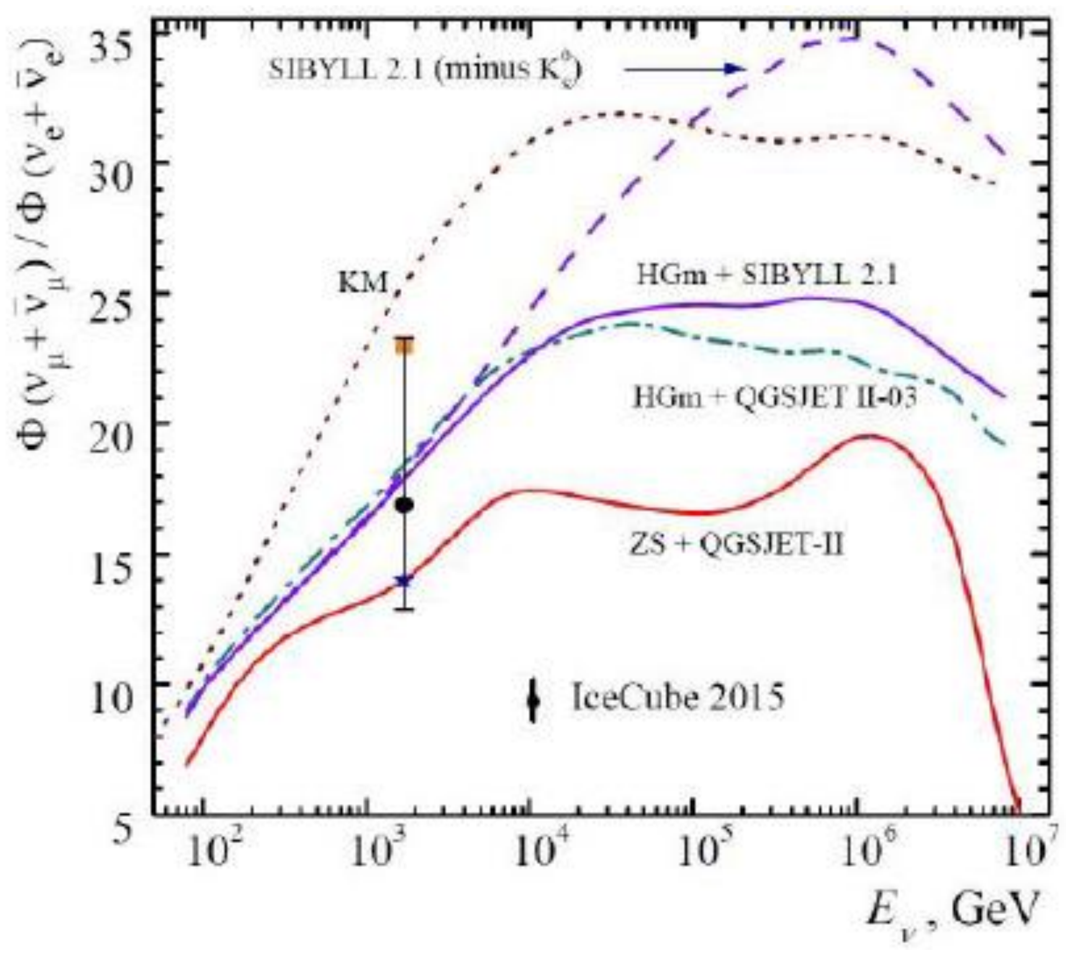
The main sources of atmospheric muons and neutrinos

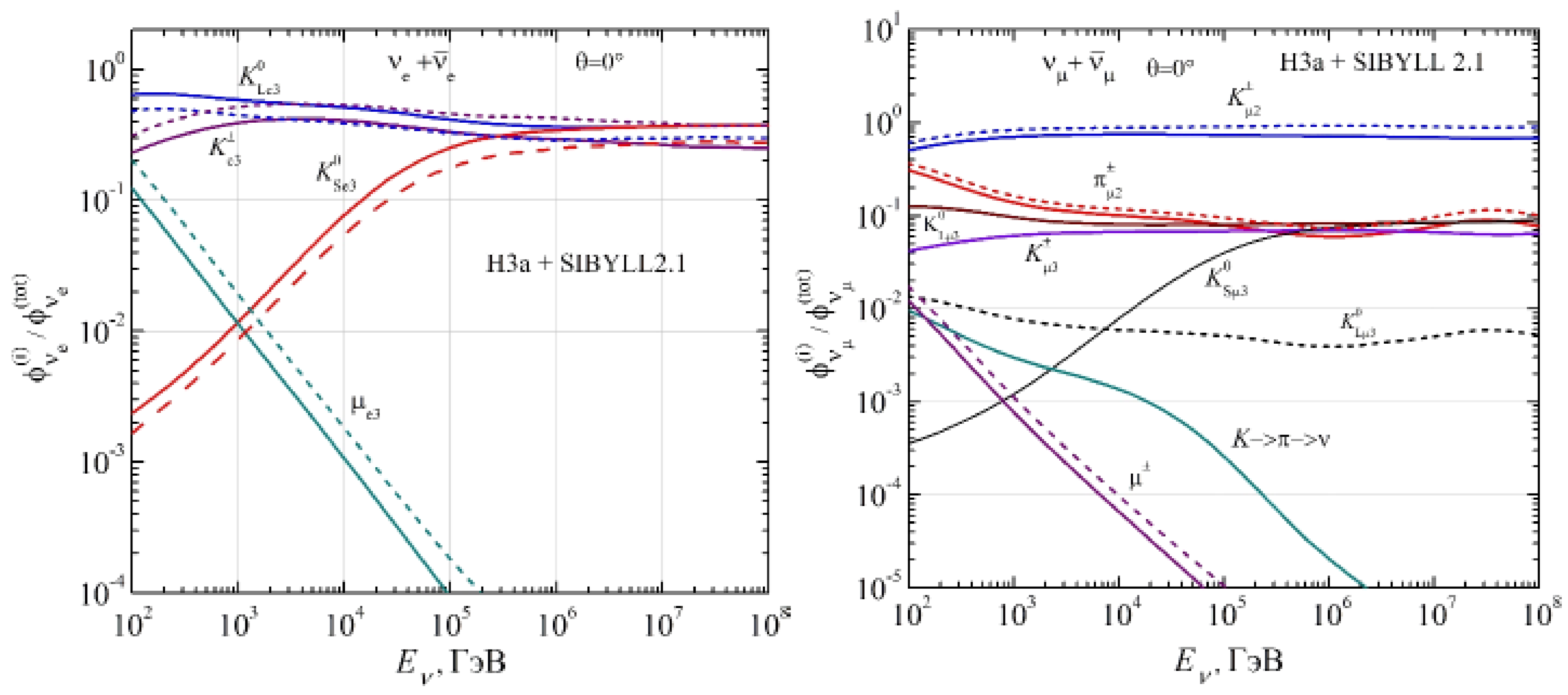
Частица (f)	Мода распада	Относительная ширина распада	Критическая энергия $E_f^{cr}(0°)$, ГэВ
$\pi^{\pm}$	$\pi_{\mu 2}:\ \mu^{\pm}+\nu_{\mu}(\bar{\nu}_{\mu})$	$\simeq 100\%$	115
$K^{\pm}$	$K_{\mu 2}:\ \mu^{\pm}+\nu_{\mu}(\bar{\nu}_{\mu})$ $\pi^{\pm}+\pi^{0}$ $K^{\pm}_{e3}:\ \pi^{0}+e^{\pm}+\nu_{e}(\bar{\nu}_{e})$ $K^{\pm}_{\mu 3}:\ \pi^{0}+\mu^{\pm}+\nu_{\mu}(\bar{\nu}_{\mu})$	$(63.55\pm0.11)\%$ $(20.67\pm0.08)\%$ $(5.07\pm0.04)\%$ $(3.35\pm0.03)\%$	857
K^0_L	$K^0_{Le3}:\ \pi^{\pm}+e^{\mp}+\bar{\nu}_e(\nu_e)$ $K^0_{L\mu 3}:\ \pi^{\pm}+\mu^{\mp}+\bar{\nu}_{\mu}(\nu_{\mu})$	$(40.55\pm0.11)\%$ $(27.04\pm0.07)\%$	206
K^0_S	$\pi^{+}+\pi^{-}$ $K^0_{Se3}:\ \pi^{\pm}+e^{\mp}+\bar{\nu}_e(\nu_e)$ $K^0_{S\mu 3}:\ \pi^{\pm}+\mu^{\mp}+\bar{\nu}_{\mu}(\nu_{\mu})$	$(69.20\pm0.05)\%$ $(7.04\pm0.08)\times10^{-2}$ $(4.69\pm0.05)\times10^{-2}$	1.12×10^{5}
$\mu^{\pm}$	$\mu_{e3}:\ e^{\pm}+\nu_e(\bar{\nu}_e)+\bar{\nu}_{\mu}(\nu_{\mu})$	$\simeq 100\%$	1.03
$D^{\pm}$	$e^{\pm}+\nu_e(\bar{\nu}_e)+$адроны $\mu^{\pm}+\nu_{\mu}(\bar{\nu}_{\mu})+$адроны	$(16.07\pm0.30)\%$ $(17.6\pm3.2)\%$	3.80×10^{7}
D^{0}	$e^{+}+\nu_e+$адроны $\mu^{+}+\nu_{\mu}+$адроны	$(6.75\pm0.29)\%$ $(6.6\pm0.8)\%$	9.65×10^{7}
$D^{\pm}_{s}$	$\mu^{+}+\nu_{\mu}$ $e^{\pm}+\nu_e(\bar{\nu}_e)+$адроны $\ell^{+}+\nu_{\ell}+$адроны	$(6.1\pm1.9)\times10^{-3}$ $(8^{+6}_{-5})\%$ $(10.8\pm0.6)\%$	9.05×10^{7}
Λ^{+}_{c}	$e^{+}+\nu_e+$адроны $\mu^{+}+\nu_{\mu}+$адроны	$(4.1\pm0.5)\%$ $(2.0\pm0.7)\%$	2.38×10^{8}

Atmospheric neutrinos

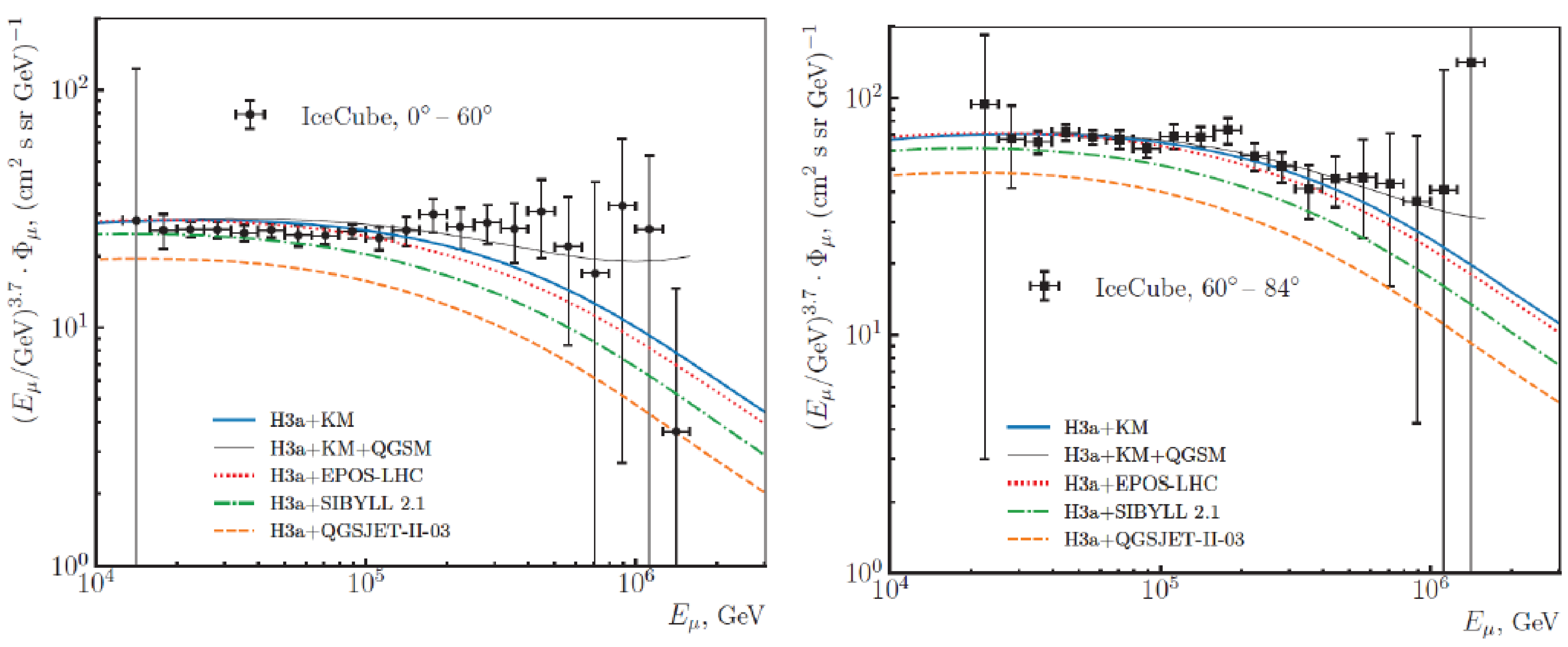
The flavor ratio of atmospheric neutrinos averaged by the zenith angle

- Honda ★ -Bartol calculations



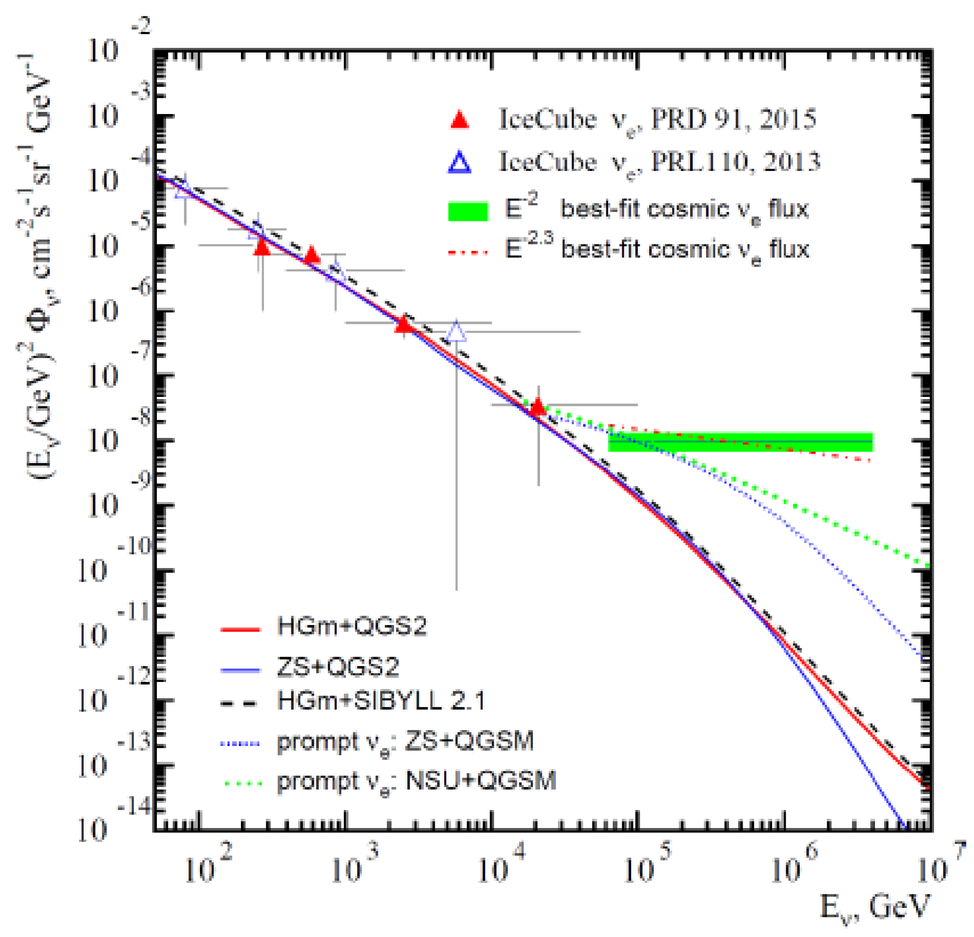


Partial contributions to vertical fluxes of the atmospheric neutrinos for the H3a + SYBILL2.1 model. Solid lines - Z-factor method, dashed lines - MCEq



Comparison of IceCube measurement data for the range of angles 0°-60°, 60°-84° and calculations of muon fluxes performed for the QGSJET II-03, SIBYLL 2.1, EPOS-LHC and KM hadron models with the H3a cosmic ray spectrum (lines).

Spectra of atmospheric electron neutrinos



IceCube ν_e: Phys. Rev. Lett. 110 (2013) 151105;

(ZS) V.I.Zatsepin, N.V.Sokolskaya, A & A. 458 (2006) 1.

(BK) D.Bindig, C.Bleve, K.-H.Kampert, 32 ICRC, Beijing, 2011, vol.1, p. 161;

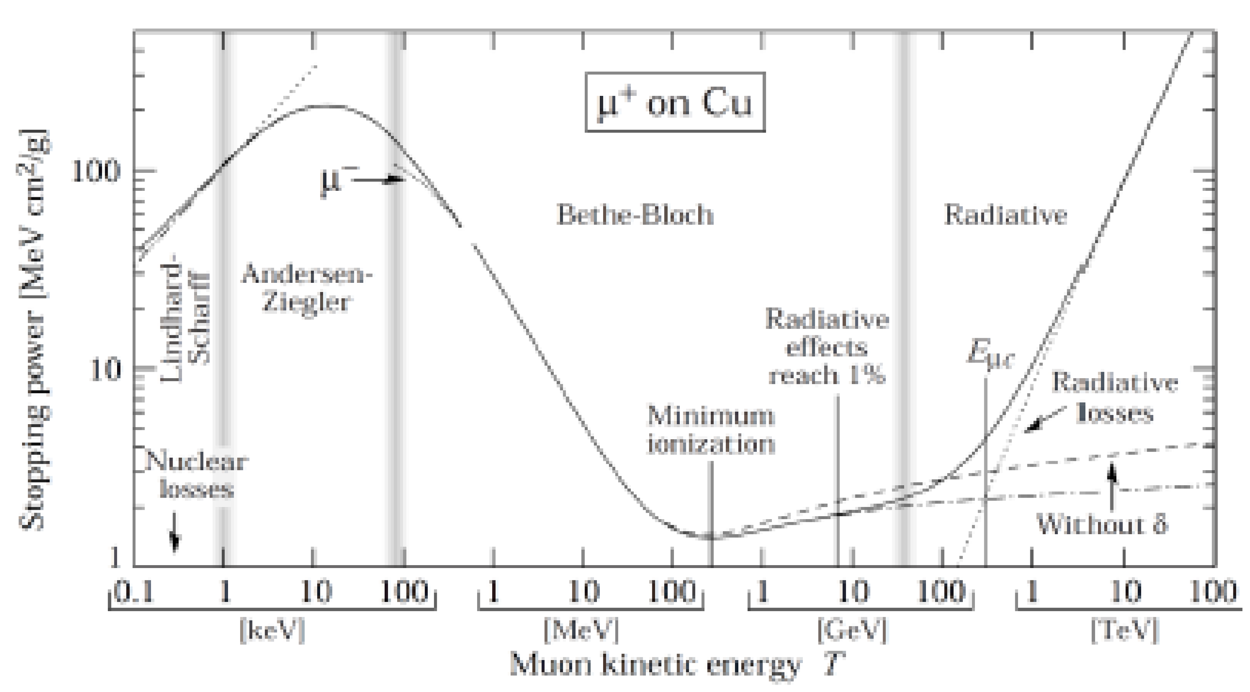
(HGm) T.Gaisser, Astropart. Phys. 24 (2012) 801, arXiv:1303.1431.

Our calculations

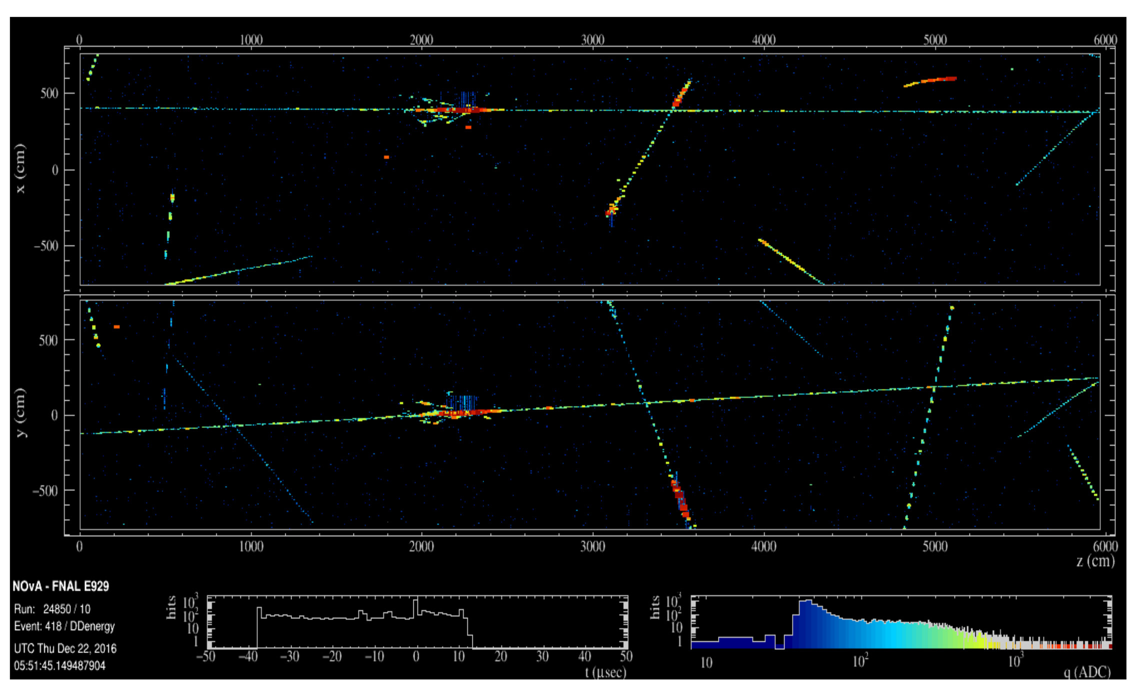
T.S. Sinegovskaya et al. Phys. Rev. D 91, 063011 (2015).

Atmospheric muons in the Far Detector of the NOvA experiment

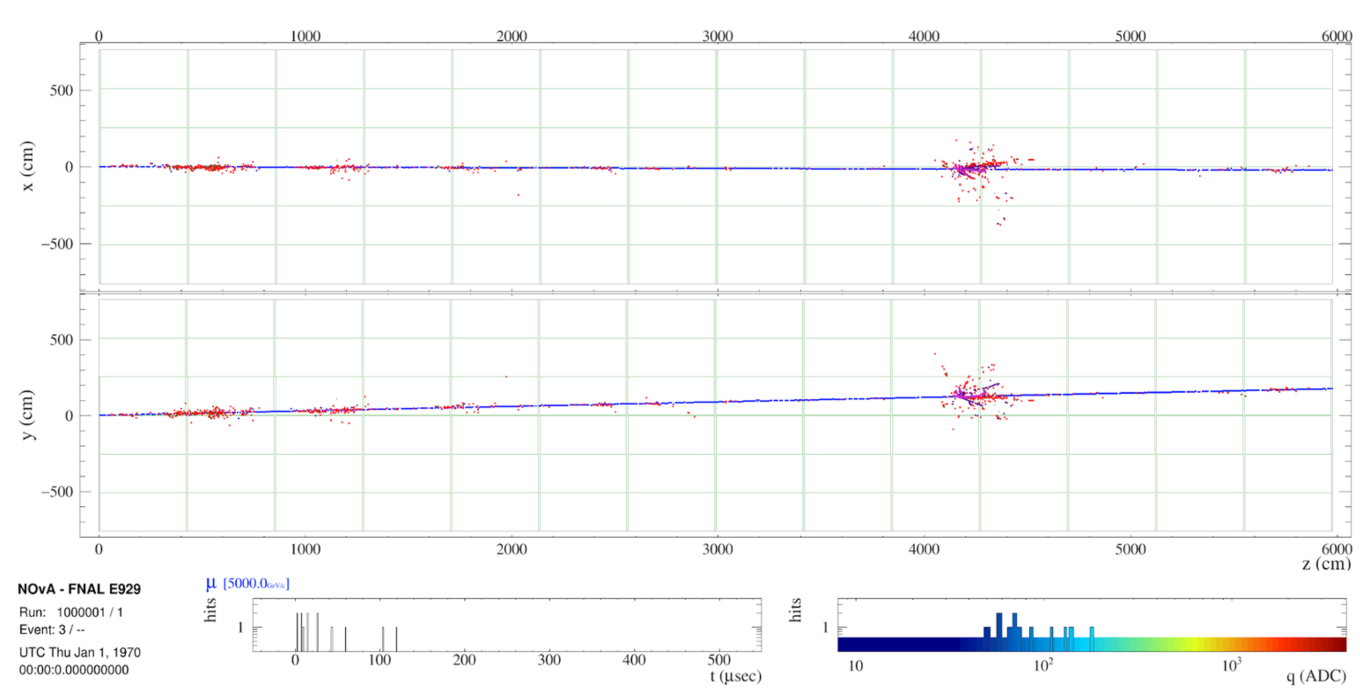
Muon processes at the matter



- Ionization
- $e^{+}e^{-}$ pair production
- Bremsstrahlung
- Photonuclear interaction



Real data (High Energy trigger)



Muon simulation at the E= 5 TeV

General deposit energy profile (Emu=5000 in Event 1)