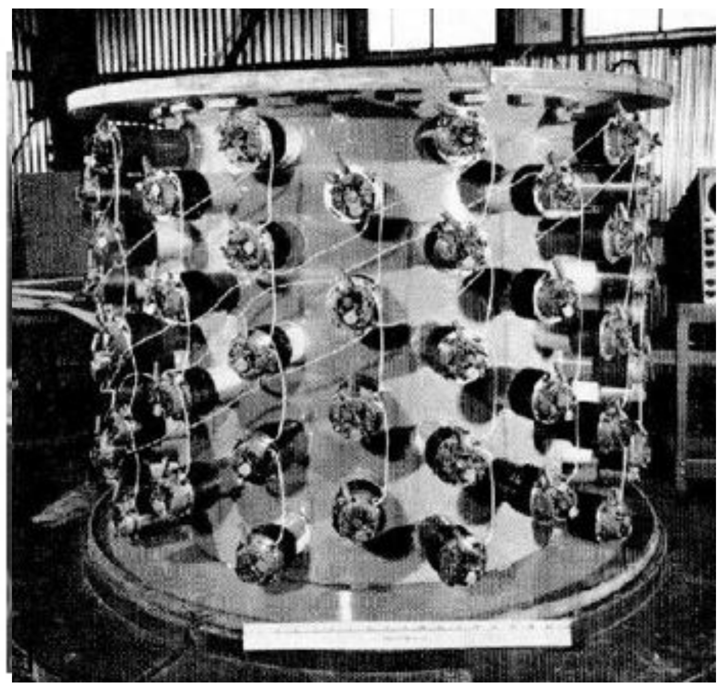
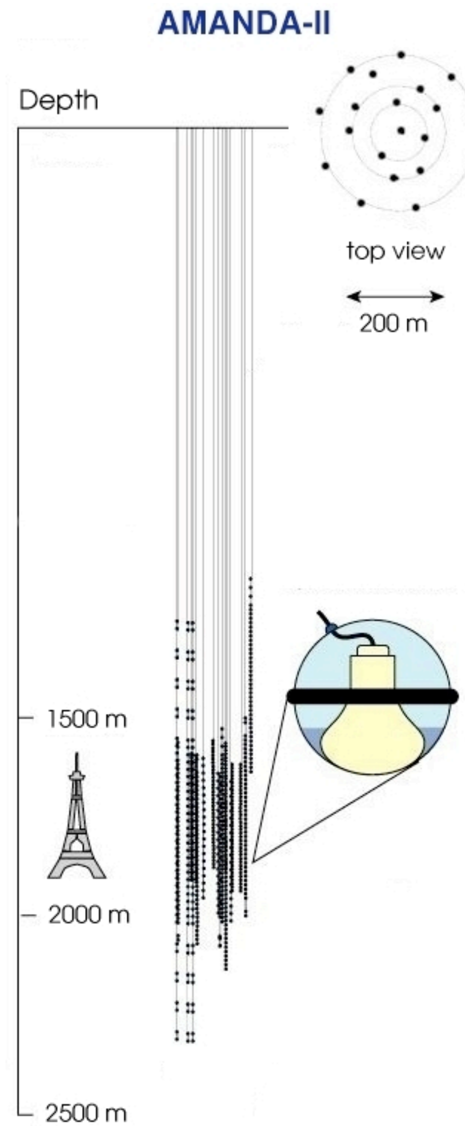
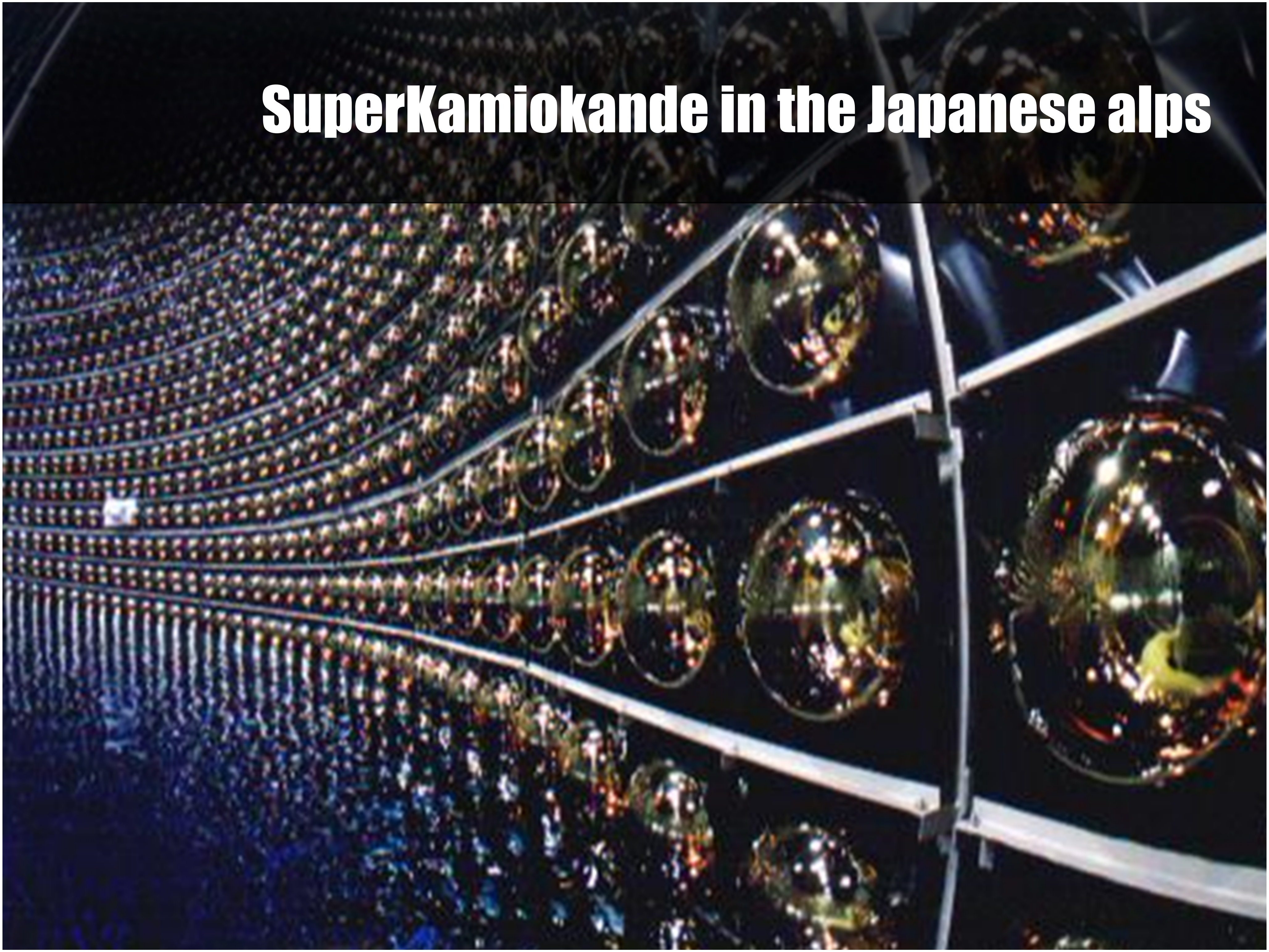
a one billion ton neutrino detector ?

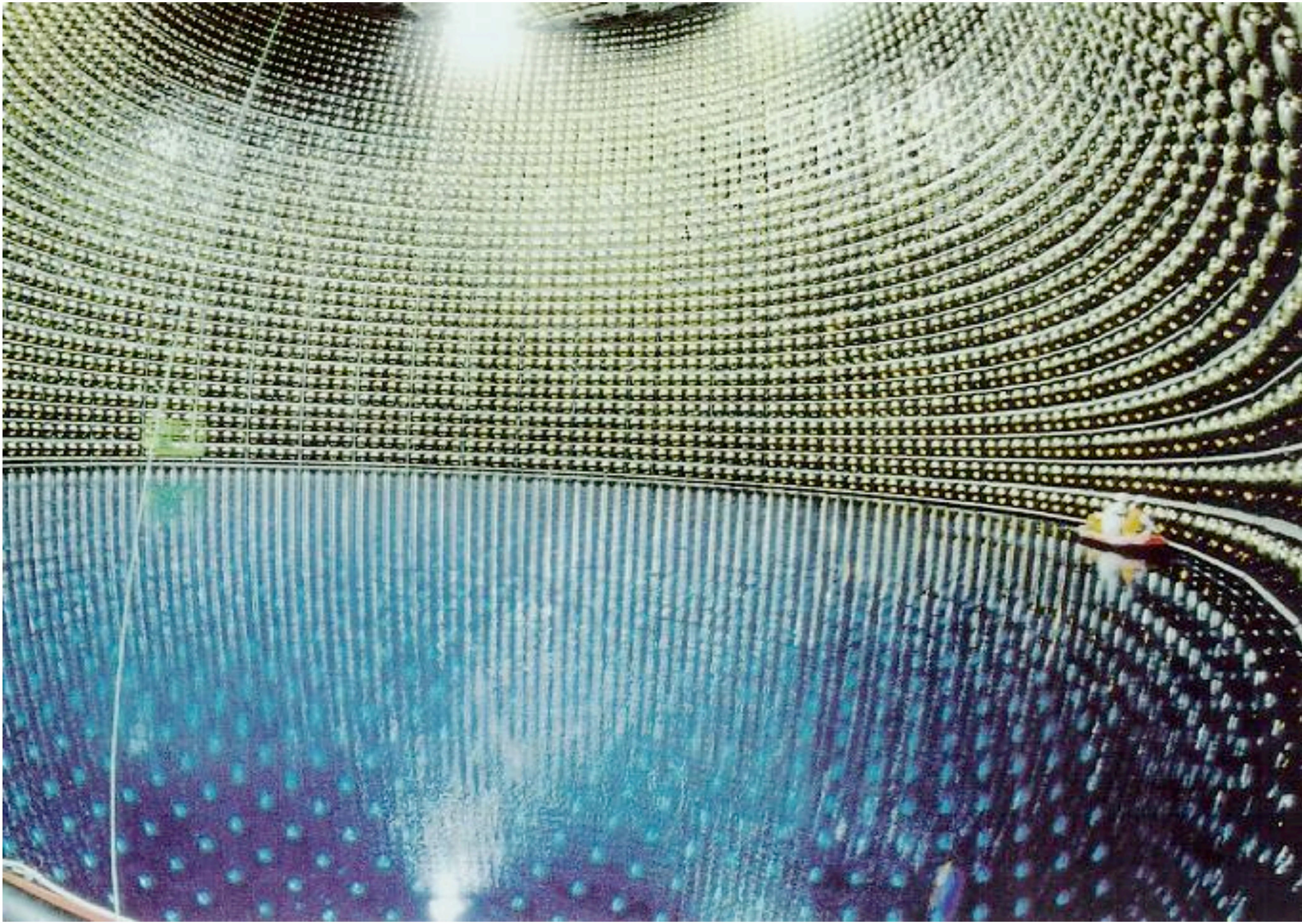
requires kilometer-scale neutrino detectors

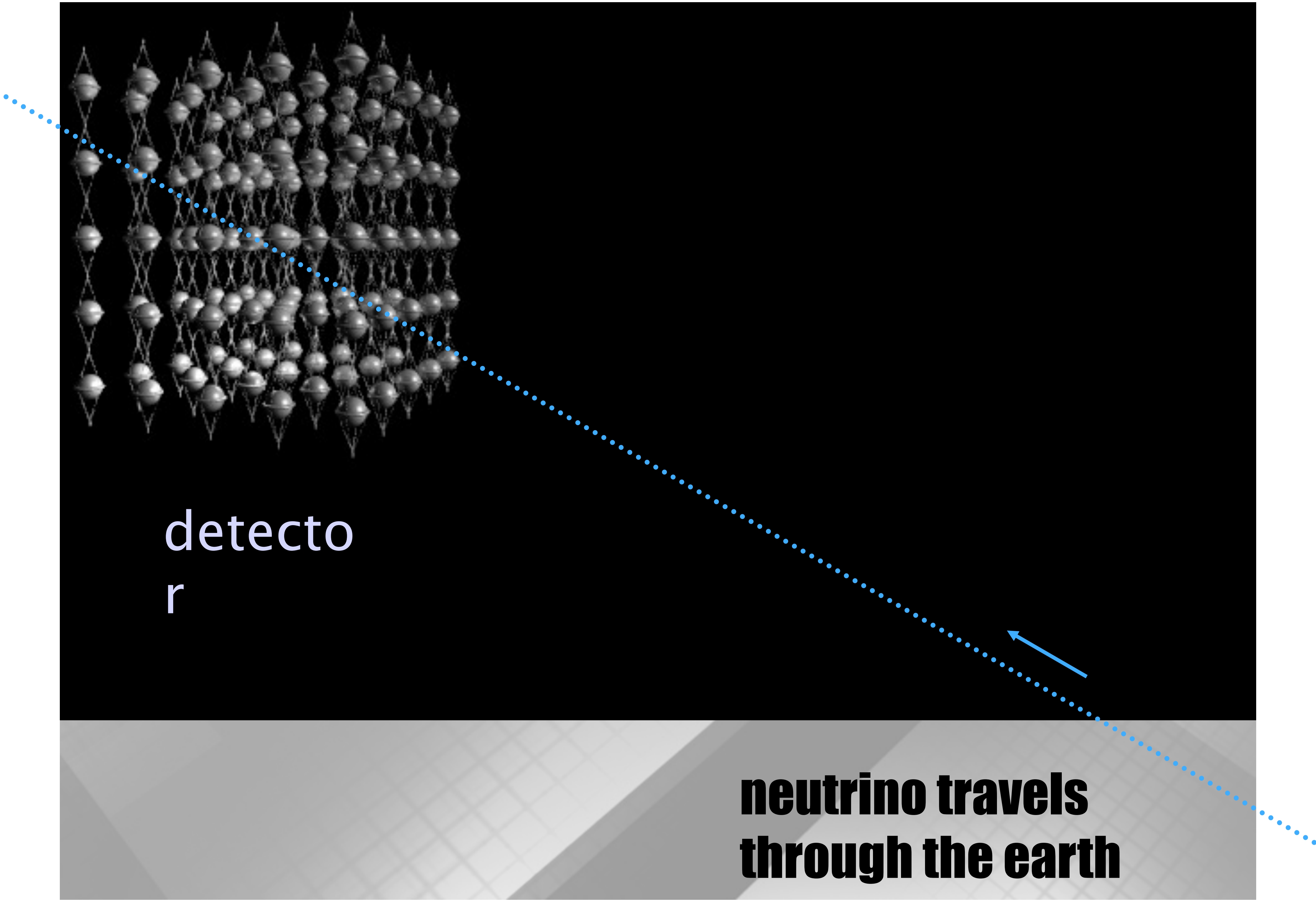




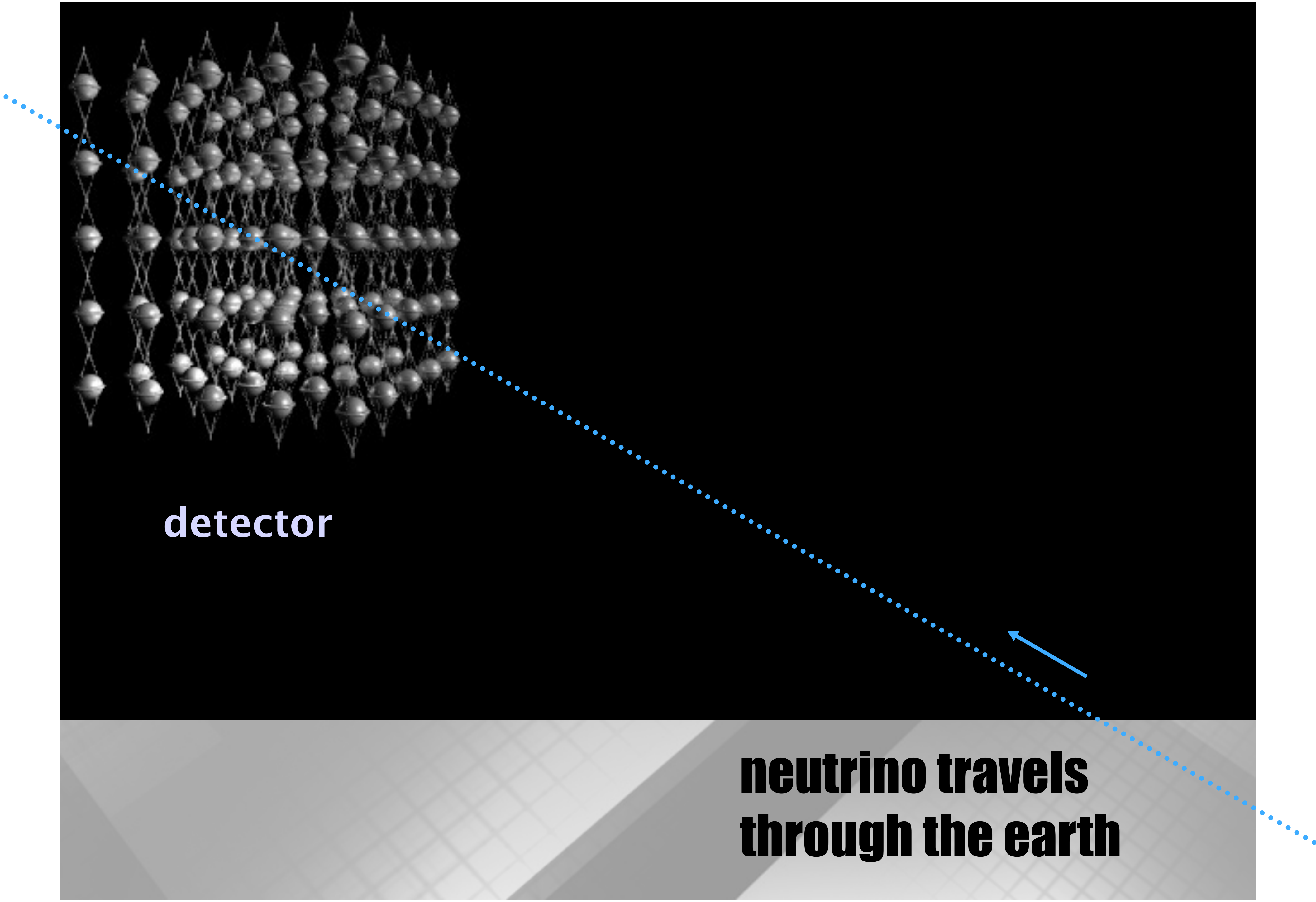
SuperKamiokande in the Japanese alps



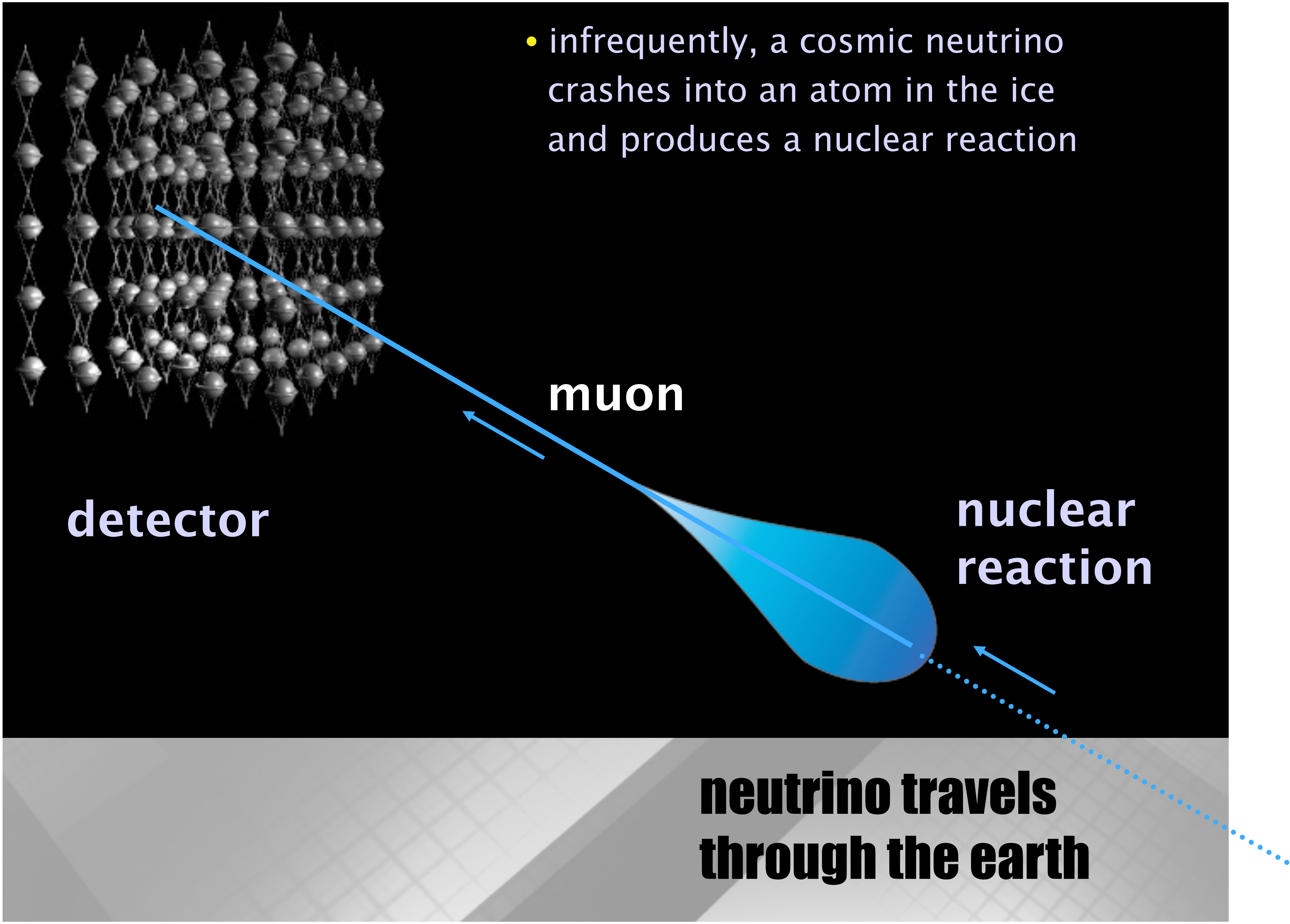


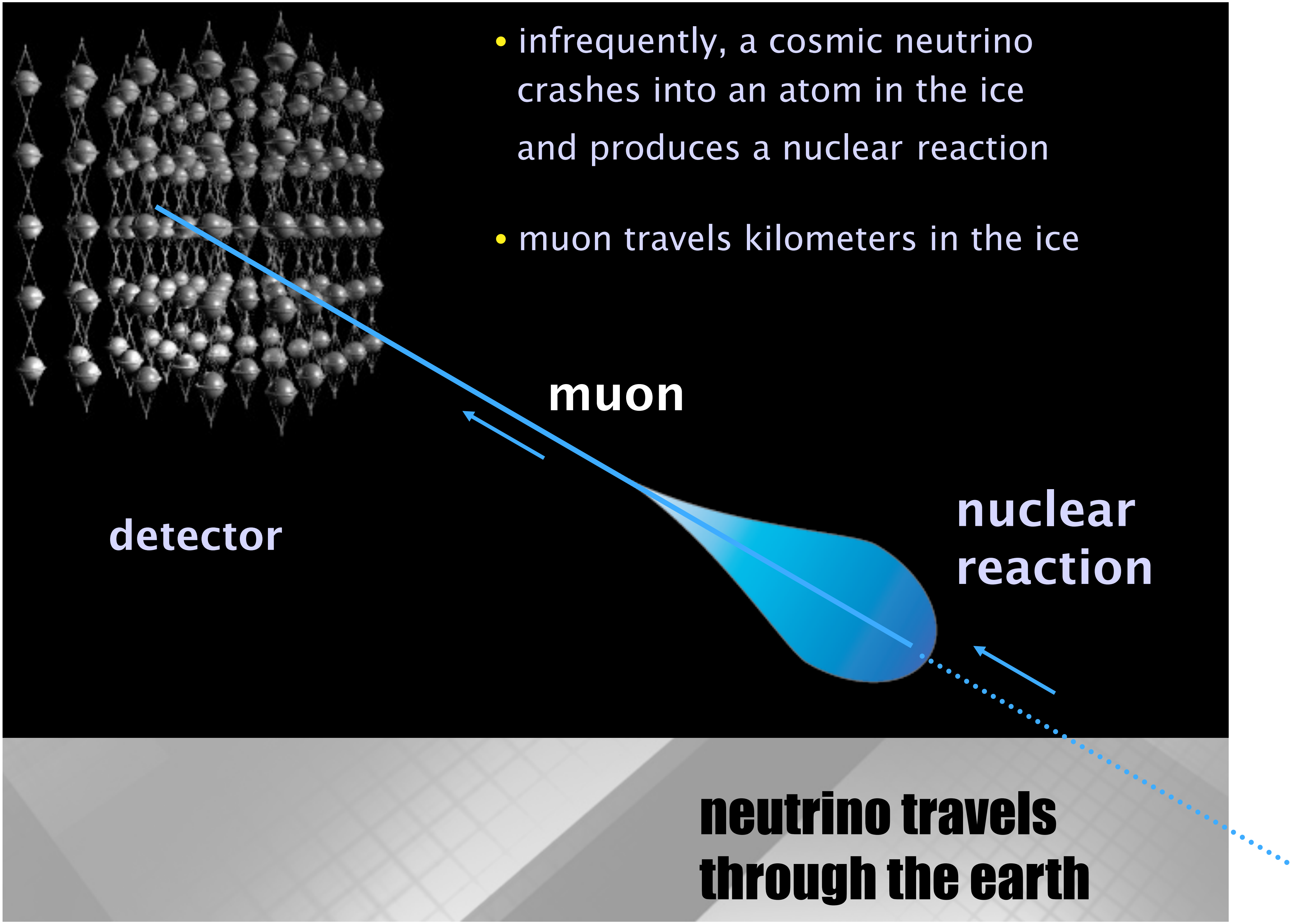

detecto
r
neutrino travels
through the earth

Photomultiplier Tube

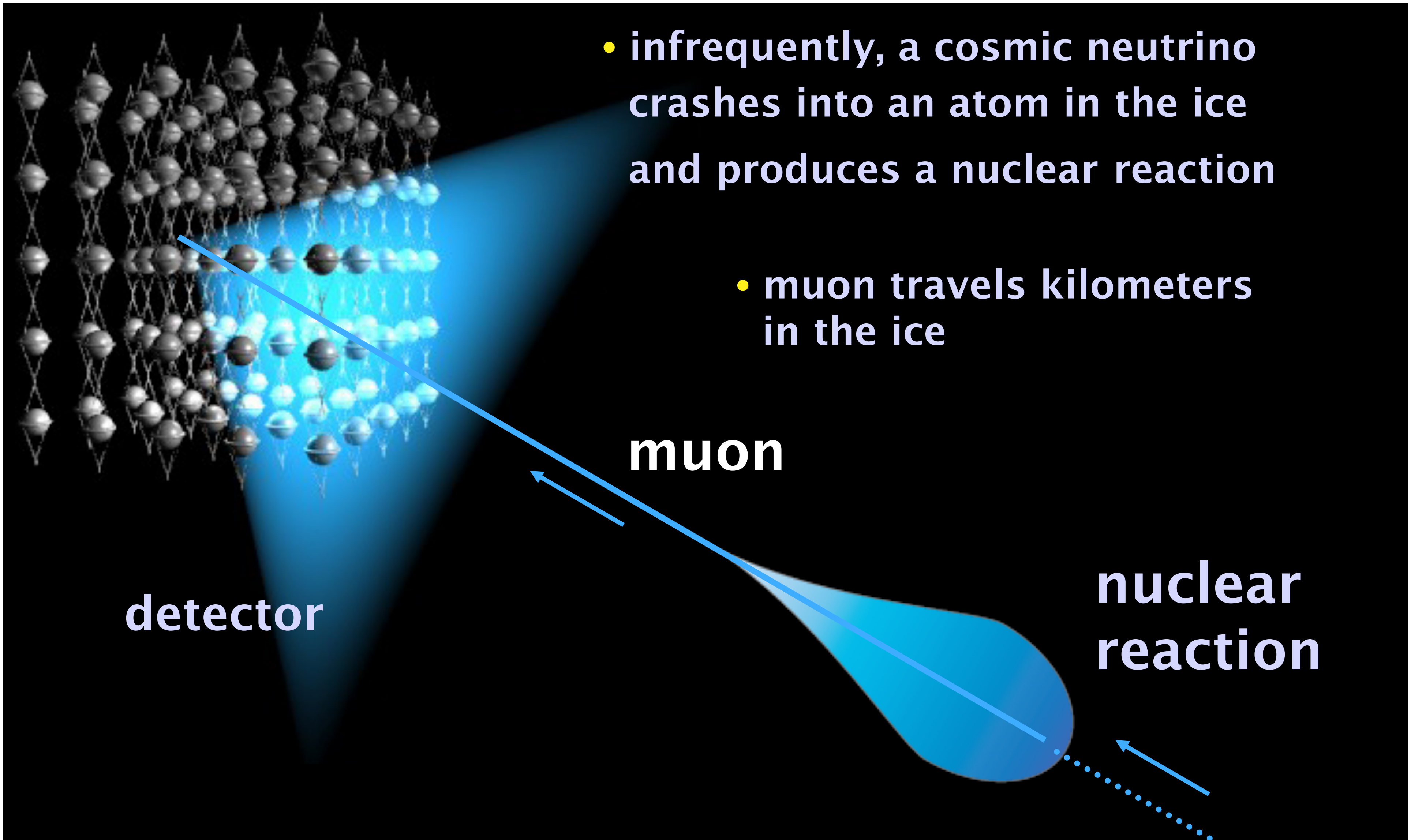

detector
neutrino travels
through the earth

- infrequently, a cosmic neutrino crashes into an atom in the ice and produces a nuclear reaction

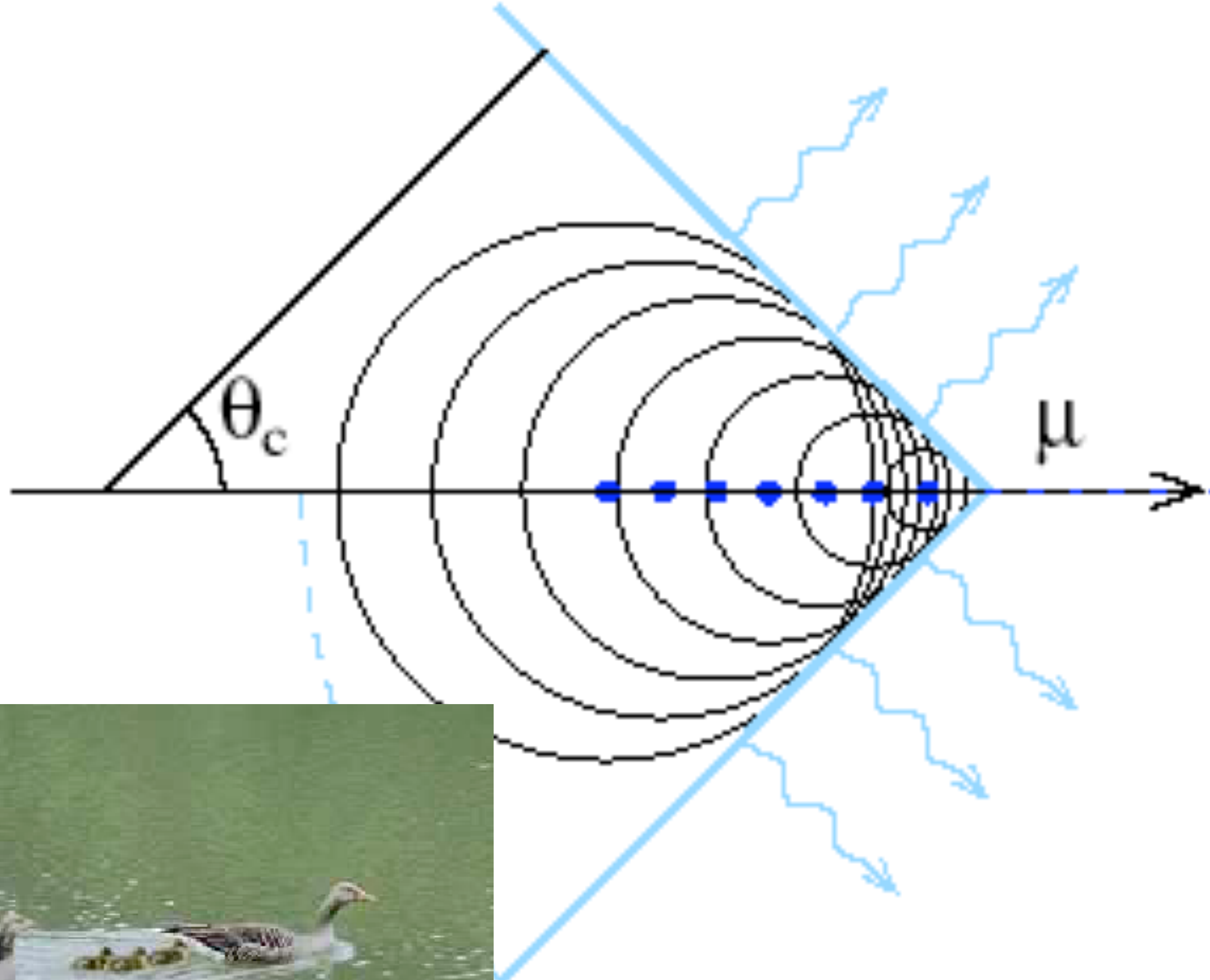



• infrequently, a cosmic neutrino crashes into an atom in the ice and produces a nuclear reaction
• muon travels kilometers in the ice
muon
detector
nuclear reaction
neutrino travels through the earth

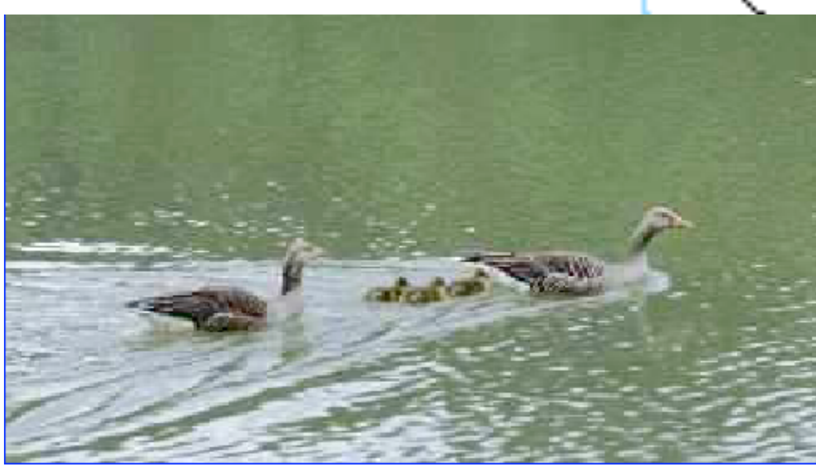
- infrequently, a cosmic neutrino crashes into an atom in the ice and produces a nuclear reaction
- muon travels kilometers in the ice



- blue light produced in nuclear reaction
- optical sensors capture (and map) the light



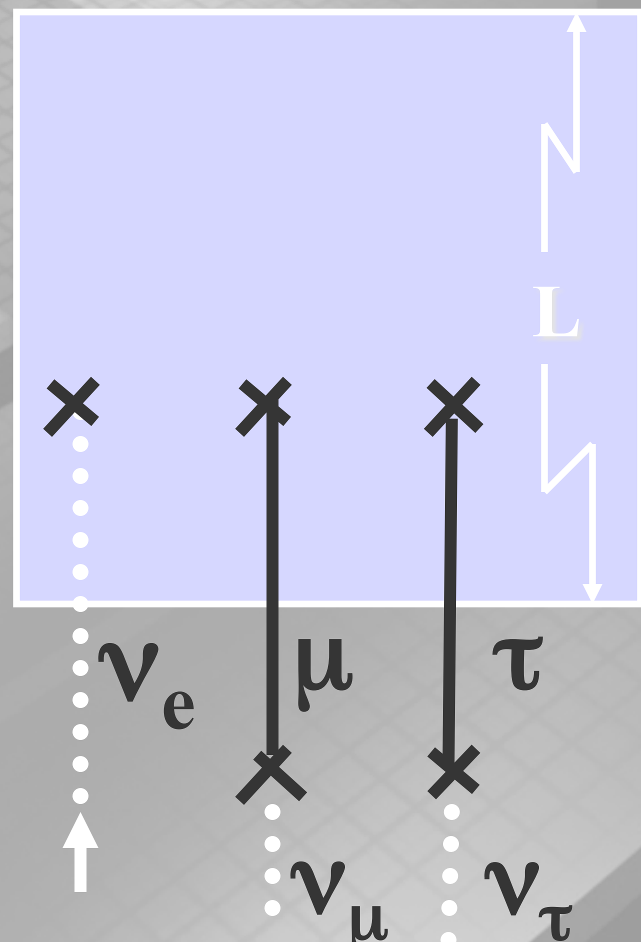
θ_c
μ



Neutrino Detection Probability

neutrino survives

$$e^{-\frac{L}{\lambda_\nu}}$$



neutrino detected

$$1 - e^{-\frac{L}{\lambda_\nu}}$$

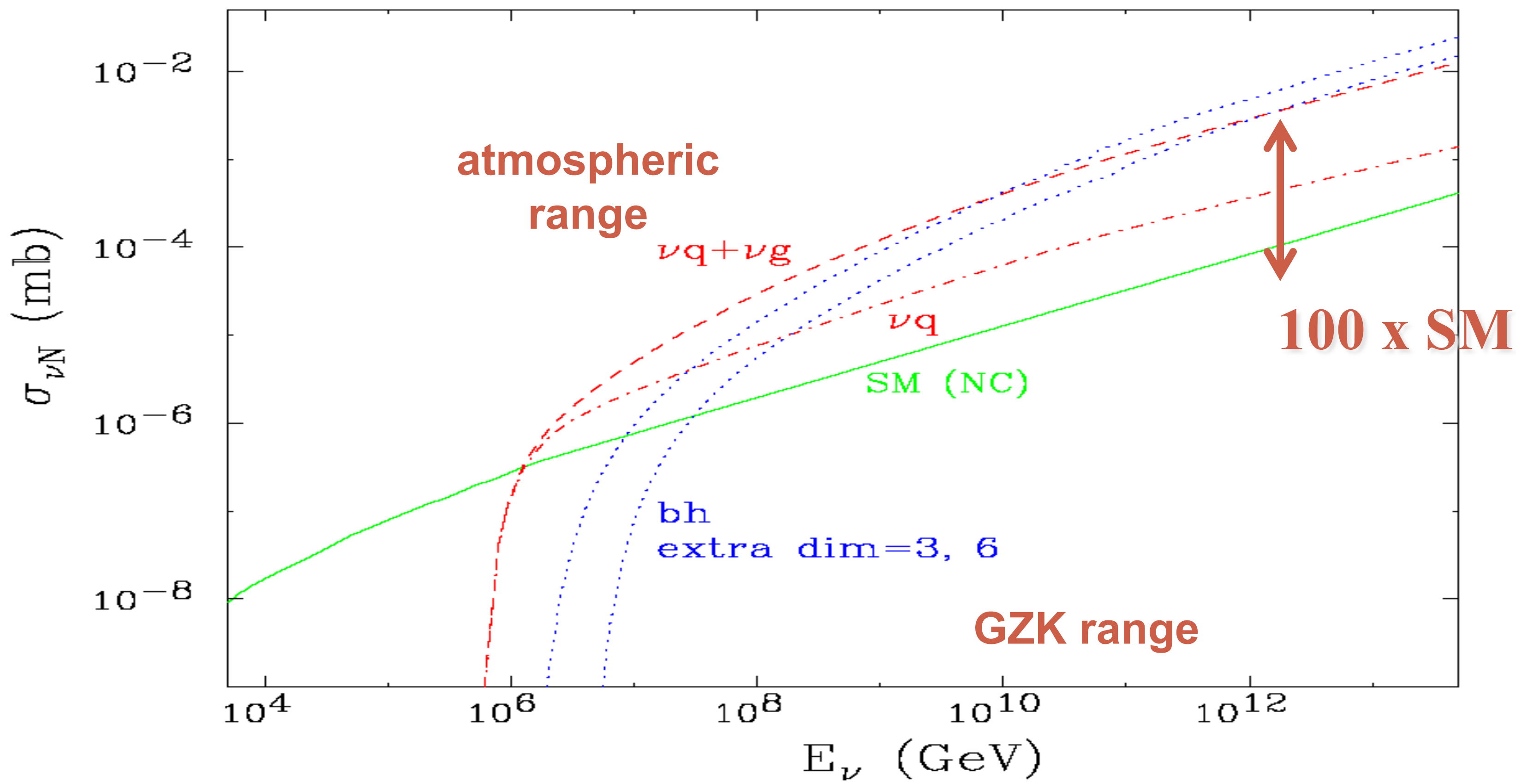
$$\simeq \frac{L}{\lambda_\nu}$$

$$P_{det} = nL\,\sigma_\nu$$

for ν_μ : $L \longrightarrow R_\mu\ [E_\mu = (1 - y)\, E_\nu]$

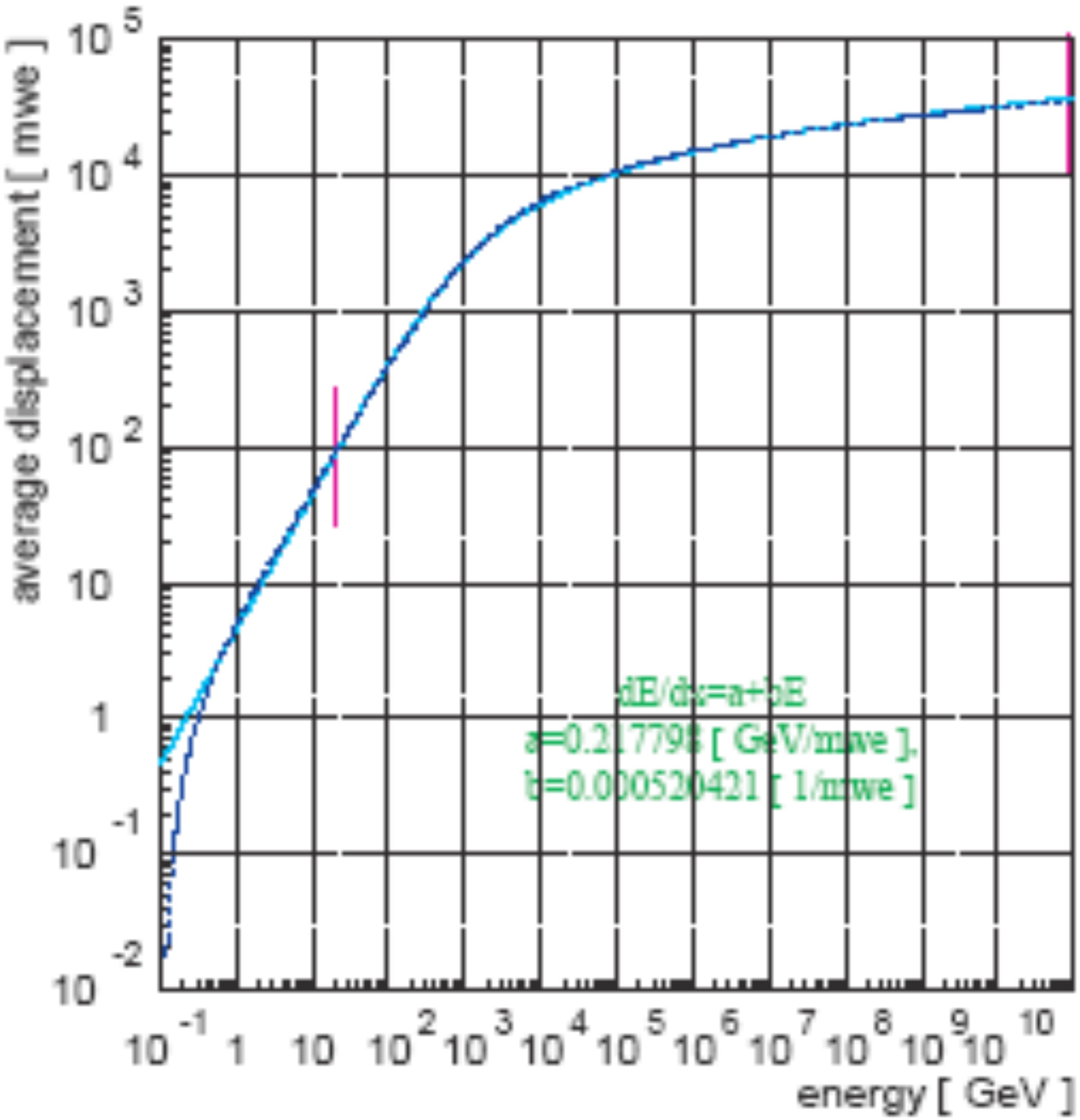
for ν_τ : $L \longrightarrow \frac{E_\tau}{m_\tau}\, c\, \tau_\tau$

Neutrino Astronomy Explores Higher Dimensions

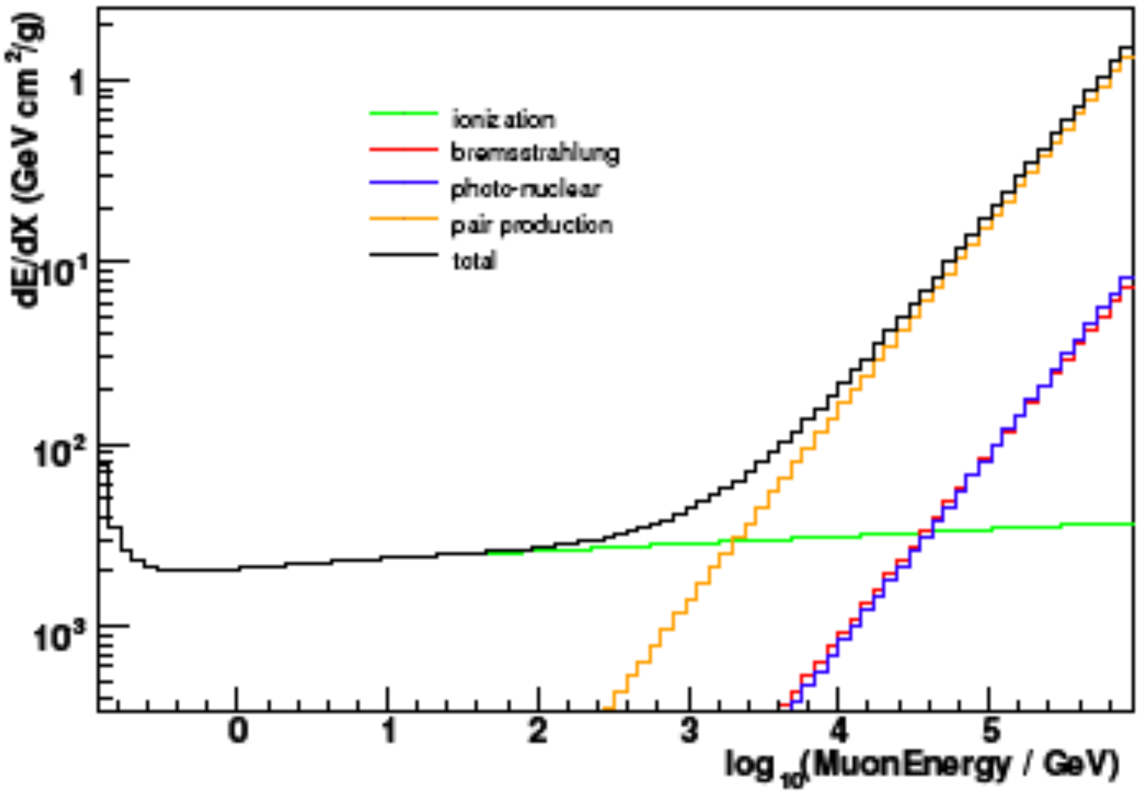


TeV-scale gravity increases PeV ν-cross section

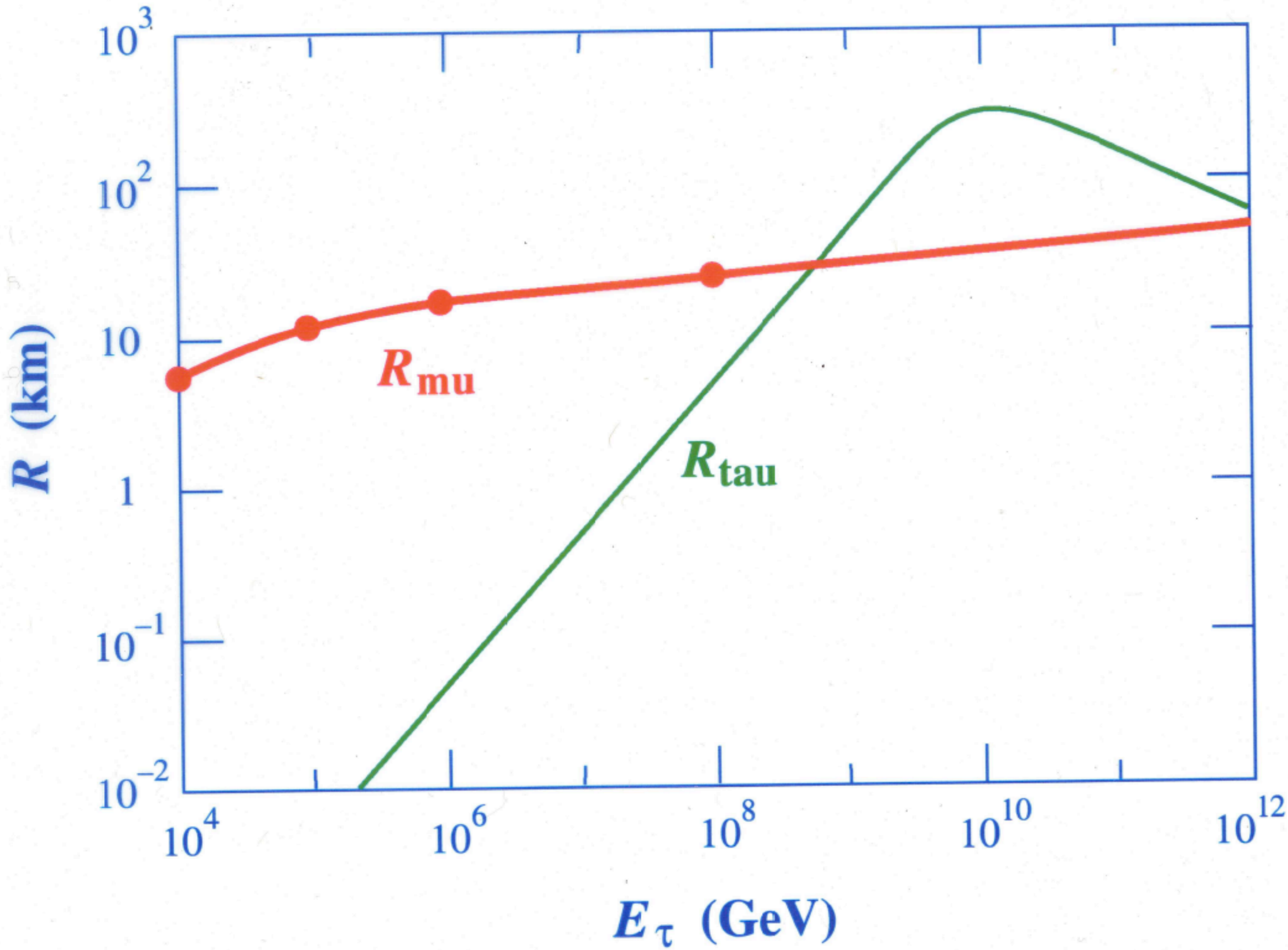
muon range



average displacement [mwe]
dE/dx=a+bE
a=0.217798 [GeV/mwe],
b=0.000520421 [1/mwe]
energy [GeV]

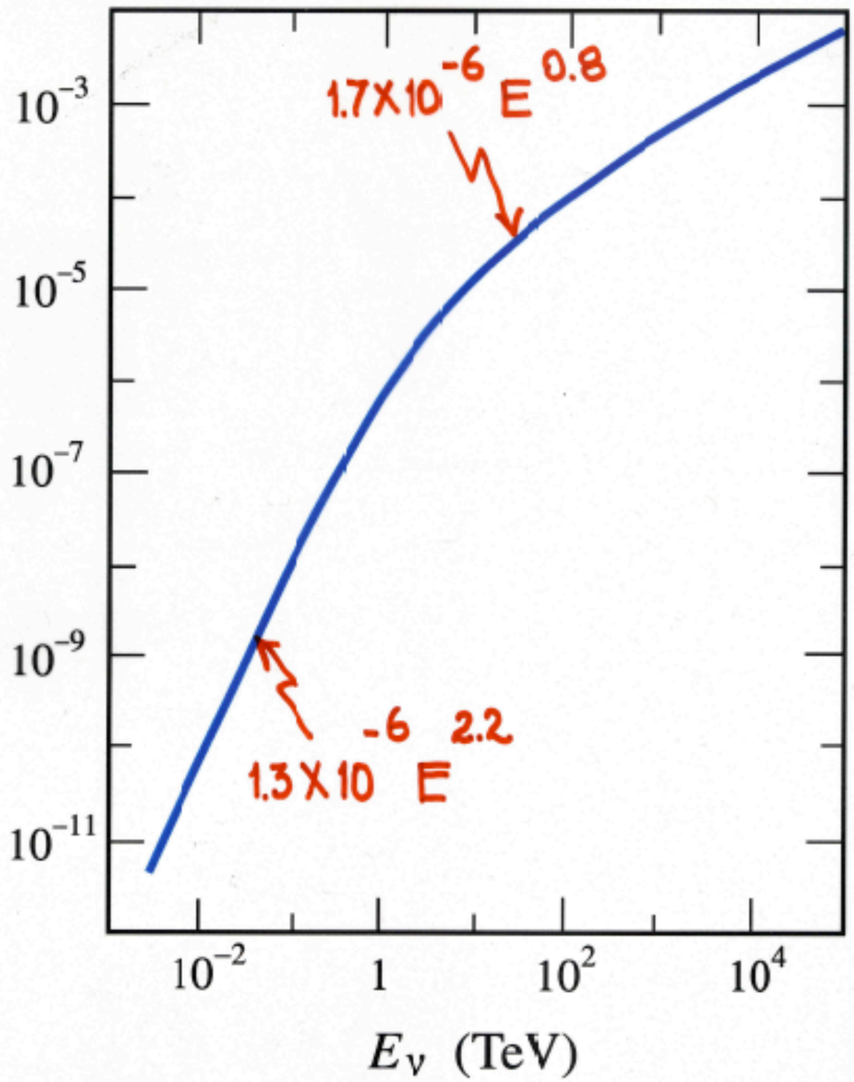


dE/dX (GeV cm^2/g)
1
10^{1}
10^{2}
10^{3}
0
1
2
3
4
5
log$_{10}$(MuonEnergy / GeV)
ionization
bremsstrahlung
photo-nuclear
pair production
total



10^3
10^2
10
1
10^{-1}
10^{-2}
R (km)
R_{mu}
R_{tau}
10^4
10^6
10^8
10^{10}
10^{12}
E_τ (GeV)

- $P_{\nu \to \mu} = \text{density} \cdot \sigma_\nu(E) \cdot R_\mu(E)$



- $N_{events} = \text{AREA} \int \frac{dN_\mu}{dE} P_{\nu \to \mu} \, dE$

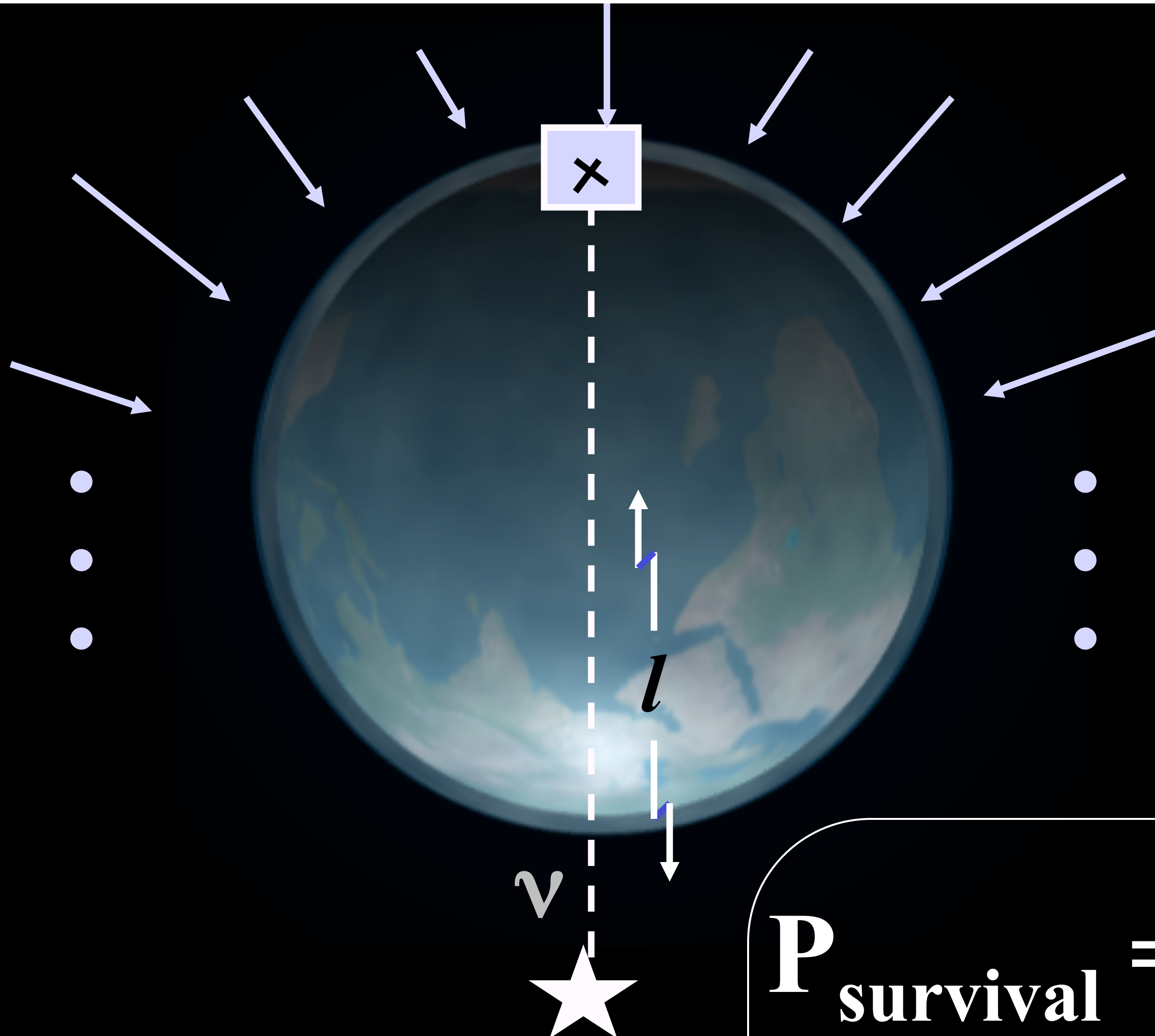
neutrino and muon area

$$events = A_\nu \times \Phi_\nu$$

$$= A_\mu \times P_{\nu \to \mu} \times \Phi_\nu$$

$$P_{\nu \to \mu} = \lambda_\mu / \lambda_\nu = R_\mu n \sigma_\nu \cong 10^{-6} E_{TeV}$$

$$A_\nu = P_{\nu◊\mu} A_\mu$$



the earth as a cosmic ray muon filter

$$P_{survival} = \exp -(l / \lambda_\nu)$$

$$\lambda_\nu^{-1} = n\, \sigma_\nu\, (E_\nu)$$

$$n = \rho\, N_A$$

a neutrino of 70 TeV has an interaction length equal to the diameter of the earth

flux of extra-galactic cosmic rays

ankle → one 10^{19} eV particle per km squared per year per sr

$$E^2 \frac{dN}{dE} = \frac{10^{19}\, eV}{(10^{10}\, cm^2)(3 \times 10^7\ sec)\, sr}$$

$$= 3 \times 10^{-8}\ GeV\ cm^{-2}\ sec^{-1}\ sr^{-1}$$

Waxman-Bahcall Flux

oscillations

$$\Phi_\nu = \frac{1}{2} \times \frac{1}{2} \times \Phi_{CR} \times \frac{d_H}{d_{CMB}} \cong \Phi_{CR}$$

$$\frac{\nu_\mu + \overline{\nu_\mu}}{\nu_e + e}$$ in π^+ decay

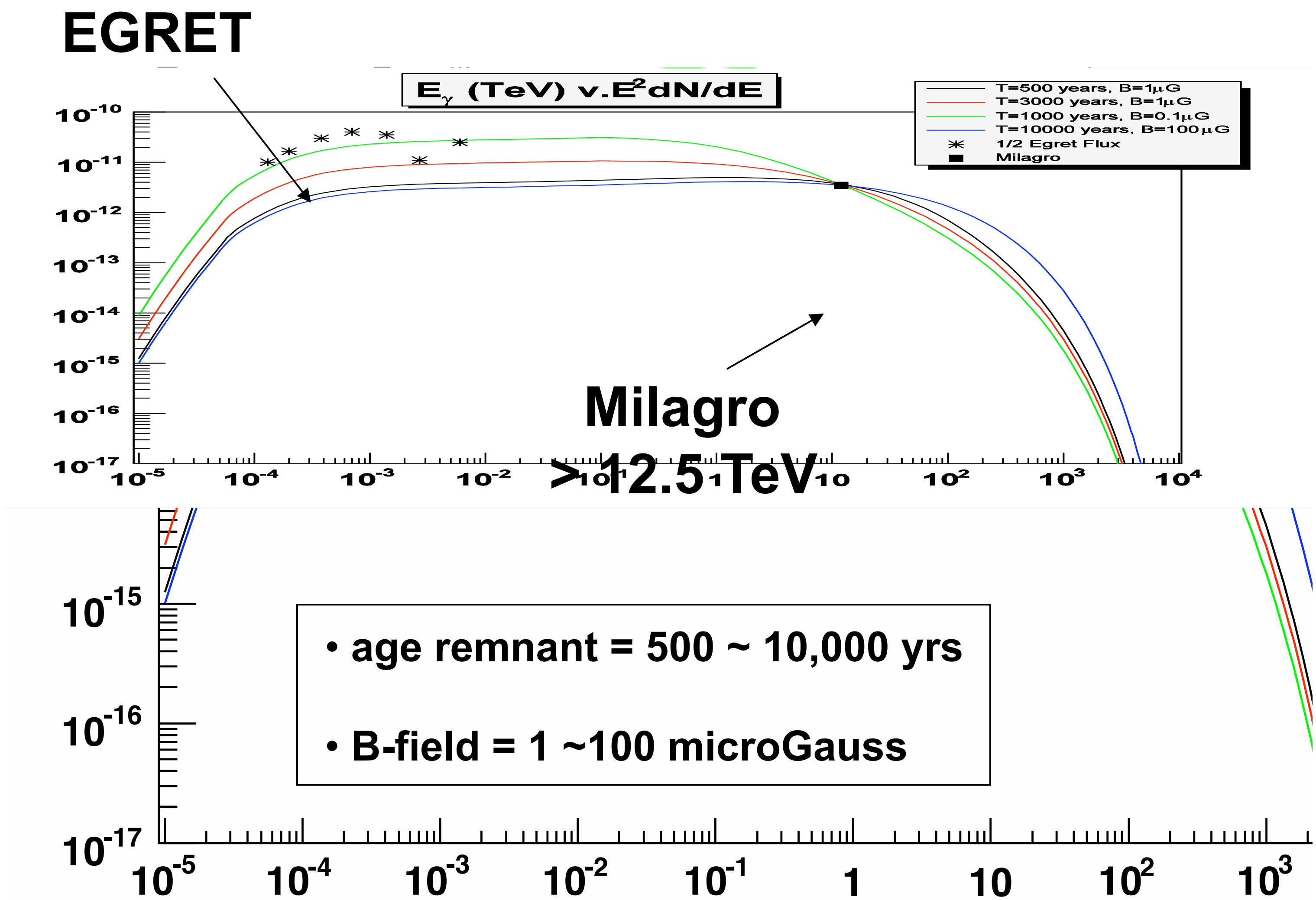
• events per km2 year:

$$N = 2\pi \times area \times time \times \int \frac{dN}{dE} P_{\nu \rightarrow \mu}\, dE$$

[redacted]

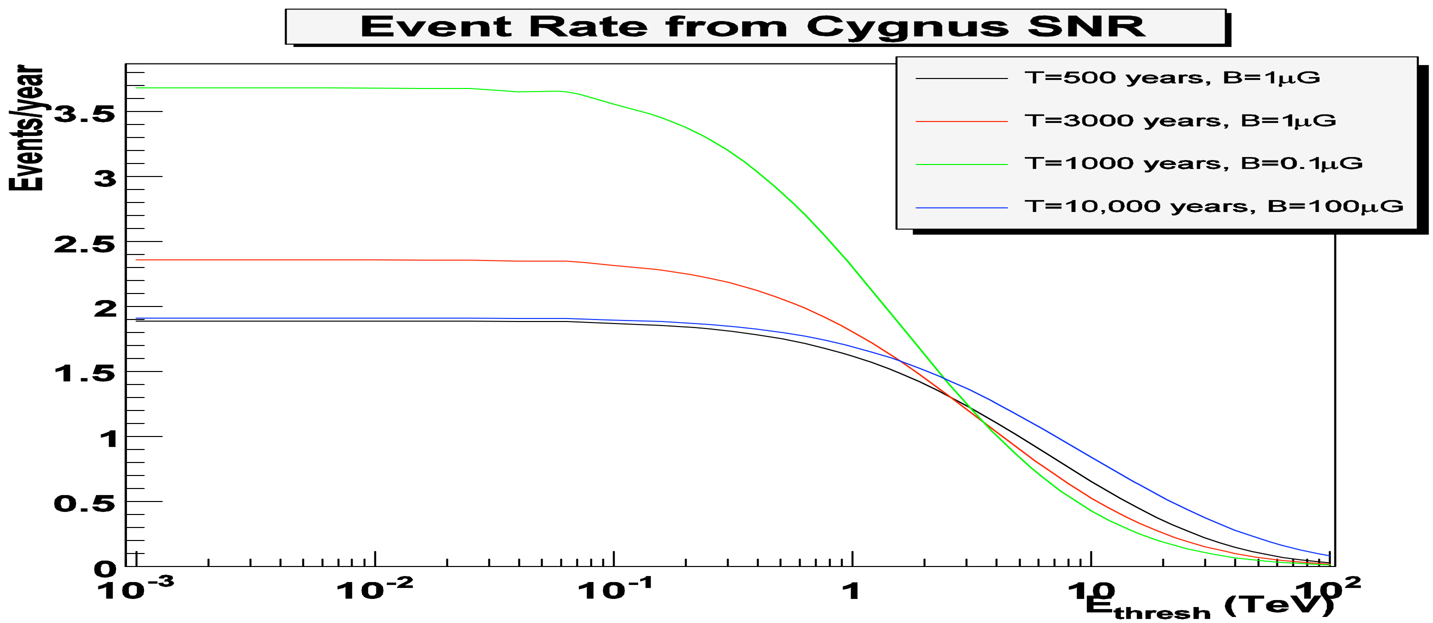
[redacted]

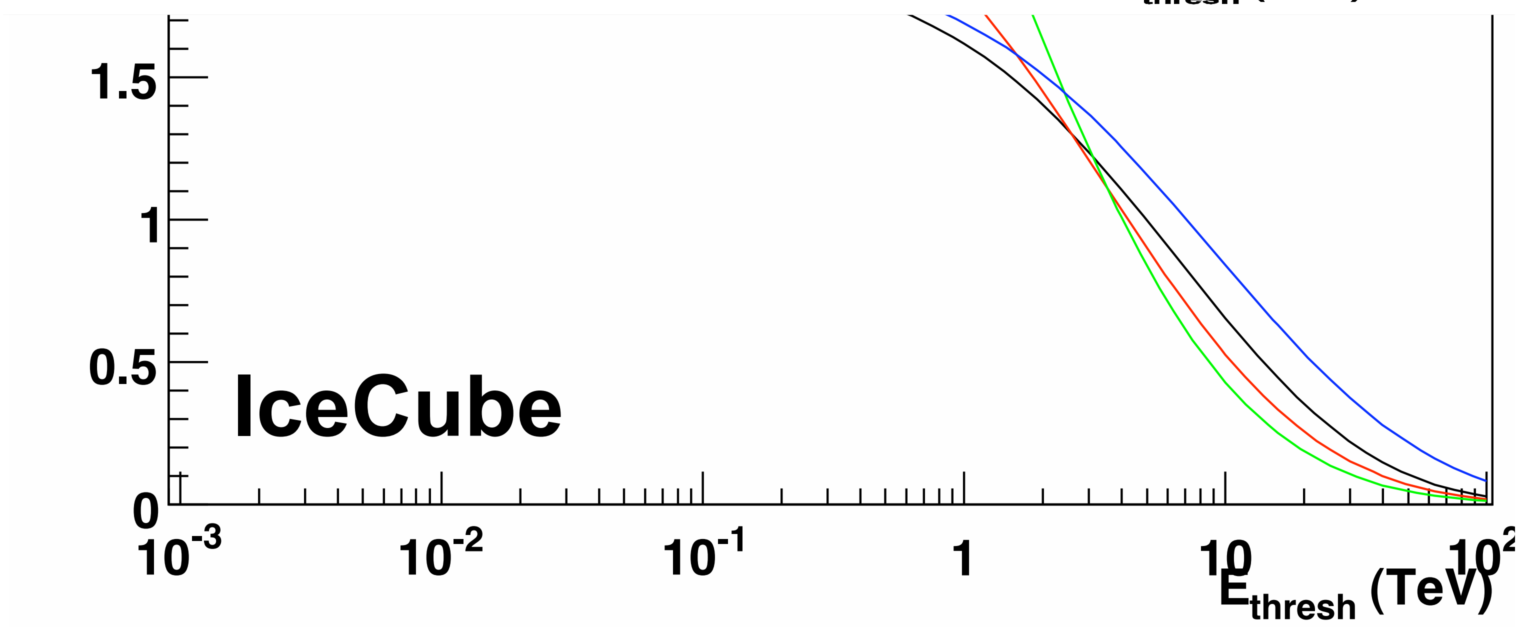
$$N \cong 80 \times \log \frac{E_{\nu\, max}}{E_{\nu\, min}} \cong 500\, events$$



EGRET
E_γ (TeV) v.E^2dN/dE
T=500 years, B=1μG
T=3000 years, B=1μG
T=1000 years, B=0.1μG
T=10000 years, B=100μG
1/2 Egret Flux
Milagro
Milagro
>12.5 TeV
• age remnant = 500 ~ 10,000 yrs
• B-field = 1 ~100 microGauss

(0.5 Crab only !)


Event Rate from Cygnus SNR
Events/year
T=500 years, B=1μG
T=3000 years, B=1μG
T=1000 years, B=0.1μG
T=10,000 years, B=100μG
3.5
3
2.5
2
1.5
1
0.5
0
10^-3
10^-2
10^-1
1
10
10^2
E_thresh (TeV)

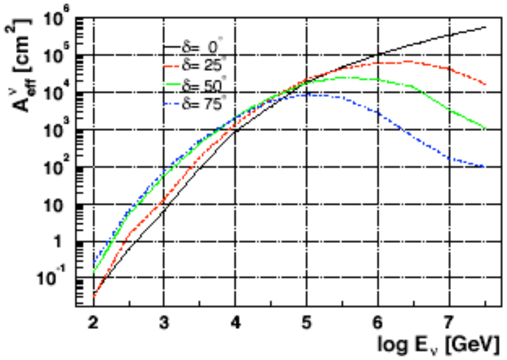

1.5
1
0.5
0
IceCube
10^-3
10^-2
10^-1
1
10
10^2
E_thresh (TeV)

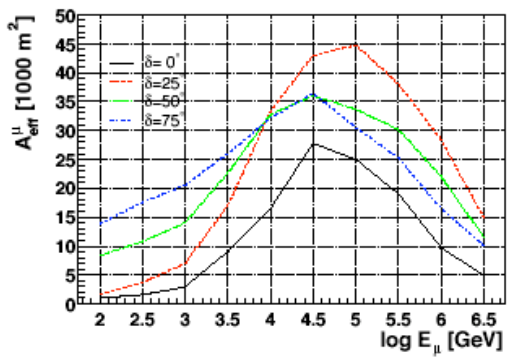
at TeV energy

Neutrino area: 10~100 cm^2

Muon area: ~ 10,000 m^2

(geometric area 0.03—0.1 km^2)





the AMANDA Detector