Measurement of Attenuation Length for Radio Wave in Natural Rock Salt and Performance of Detecting Ultra High-Energy Neutrinos

M.Chiba, M.Fujii, T.Kamijo, Y.Shibasaki, Y.Takayama, F.Yabuki, O.Yasusda, A.Amano*, Y.Chikashige*, T.Kon*, S.Mori*, S.Ninomiya*, Y.Shimizu*, Y.Takeoka*, M.Utsumi**, Y.Watanabe***

Tokyo Metropolitan University,
Seikei University*, Tokai University, NAO*****

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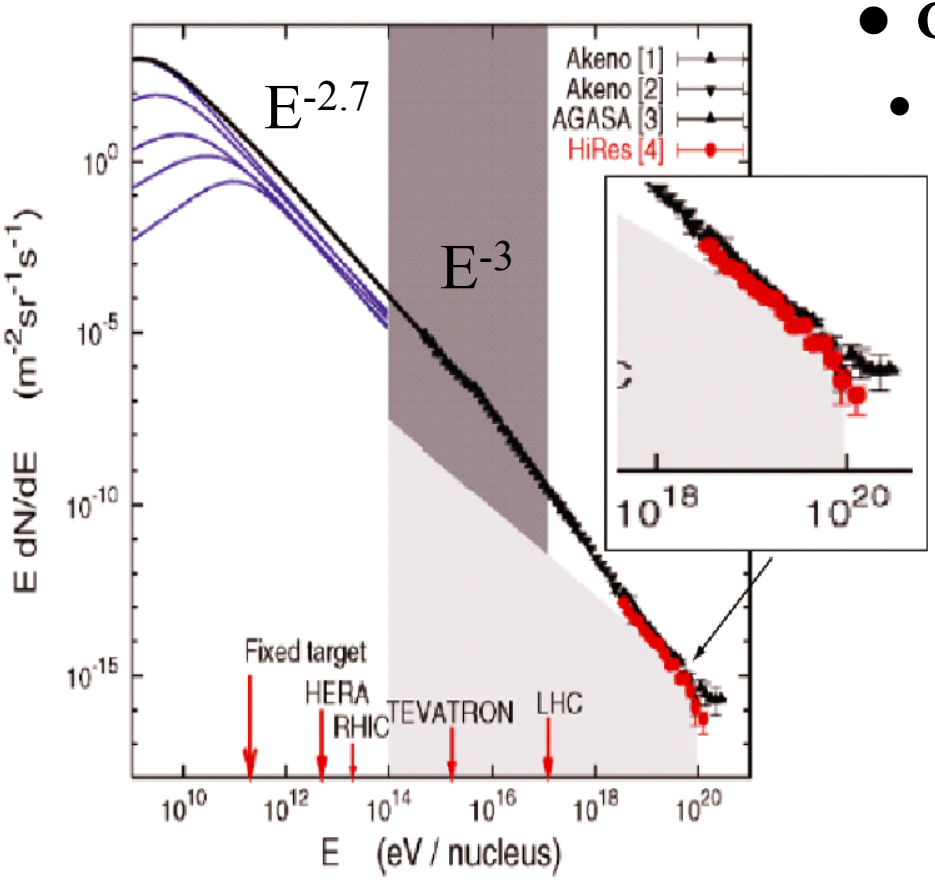
UHE Neutrinos Originate in UHE Cosmic Rays & CMB

Cosmic ray energy spectrum



- **Observed highest energy exceeds 10^{20}eV**
- **Cosmic microwave background exists.**
  - **Greisen-Zatsepin-Kuzmin(GZK) effect.**

- **The energy exceeds Δ production threshold.**

$$p + \gamma_{2.7\,k} \rightarrow \Delta \rightarrow n + \pi^+$$

(CMB)

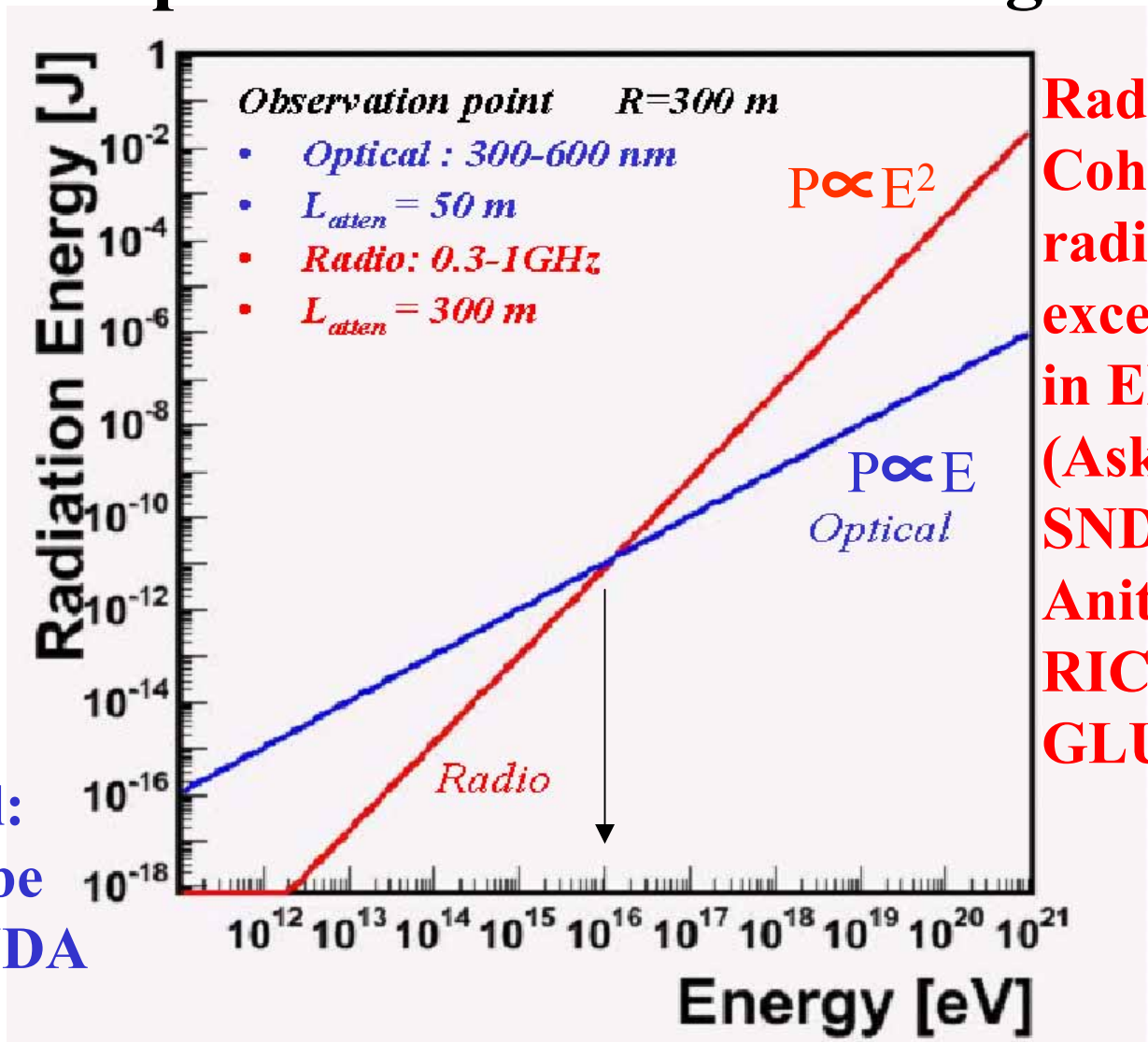
$\pi^+ \rightarrow \mu^+ \nu_\mu$

$\mu^+ \rightarrow e^+ \nu_\mu \nu_e$

- **GZK neutrinos (10^{19}eV) flux is as low as 1 [/km^2/day] .**

→Need a huge mass of detection medium

Chrenkov Radiation Energy
Optical vs. Radio Wave Region



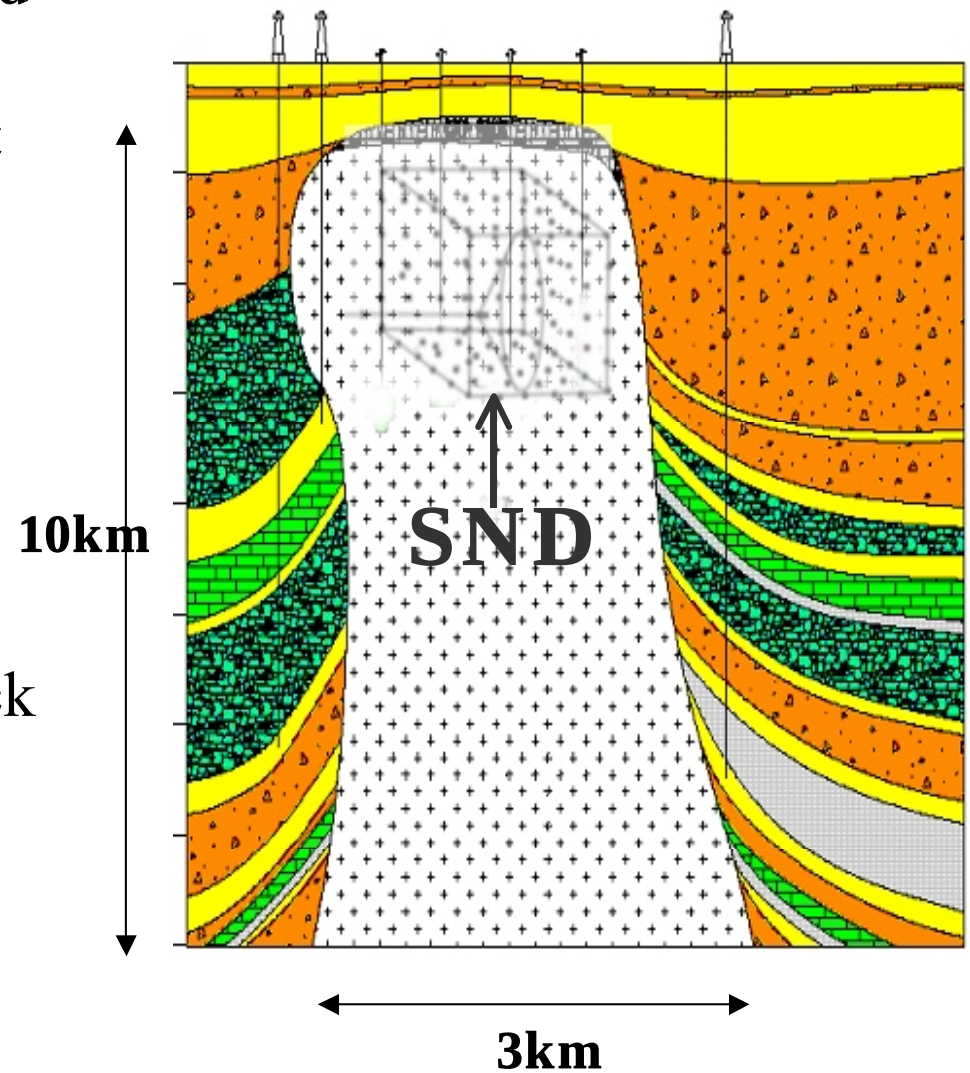
Radio wave:
Coherent radiation from excess electrons in EM shower: (Askaryan effect):
SND/SalSA
Anita
RICE
GLUE

Optical:
Ice Cube
AMANDA

Salt Neutrino Detector Installed in a Salt Dome

1. Rock salt is free from liquid and gas permeation：petroleum or natural gas are likely to deposit around a salt dome.
2. Free from water permeation leads good radio wave transparency in a salt dome.
3. Covered soil prevents surface radio wave to penetrate.
4. Conceivable background is black body radiation in salt dome.

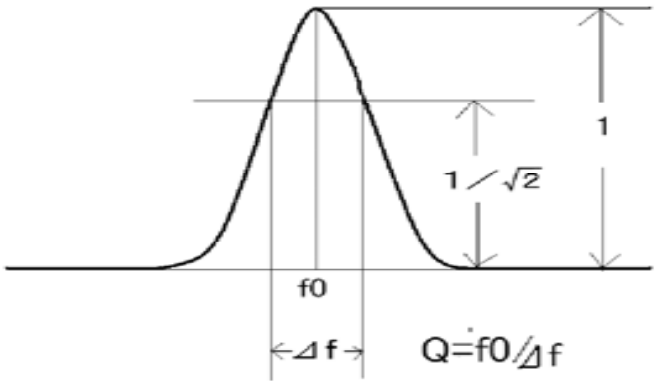
Dow Earth Sciences, Geol: J.Hertzing



M.Chiba

Attenuation Length: Cavity Perturbation Method

Resonance curve

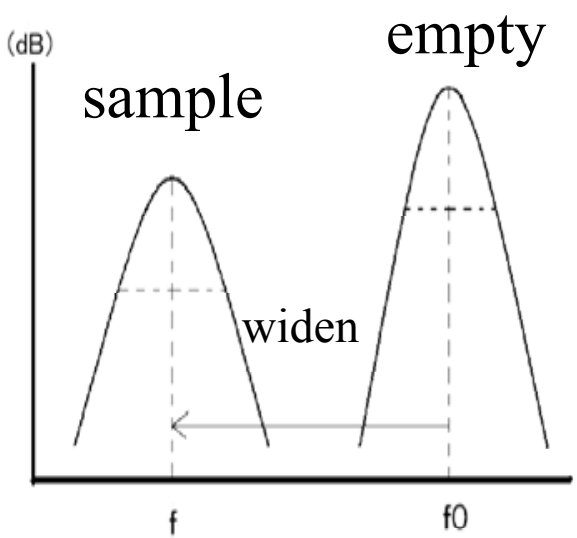


Complex permittivity

$$\varepsilon' = 1 - \frac{1}{\alpha_\varepsilon}\frac{f - f_0}{f}\frac{V}{\Delta V} = n^2$$

$$\varepsilon'' = \frac{1}{2\alpha_\varepsilon}\left(\frac{1}{Q} - \frac{1}{Q_0}\right)\frac{V}{\Delta V}$$

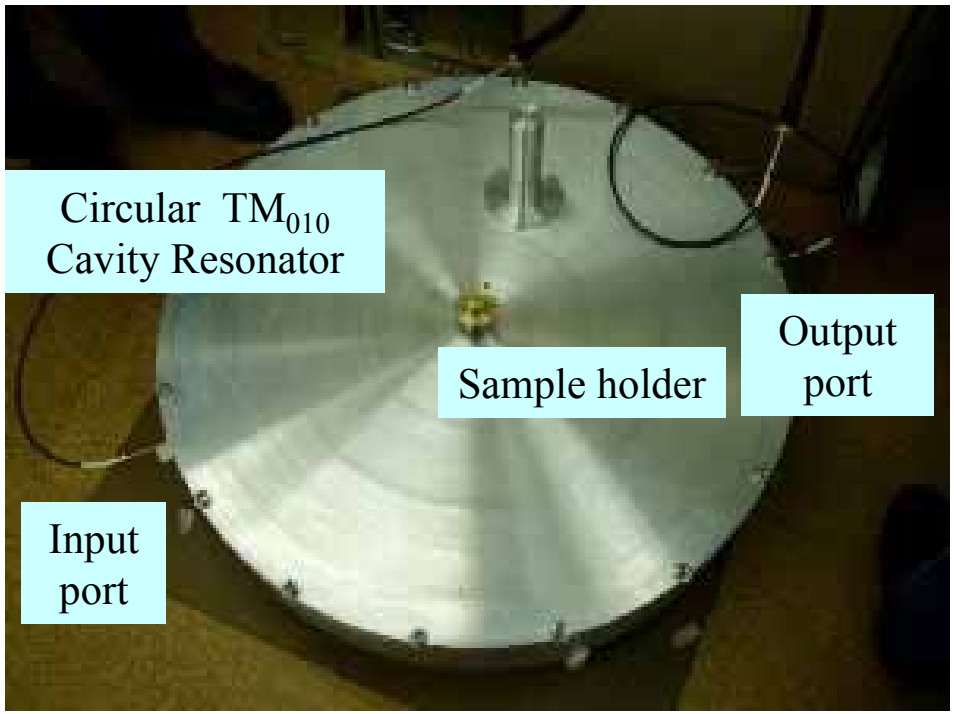
$$\tan\delta = \frac{\varepsilon''}{\varepsilon'} \qquad \varepsilon = \varepsilon' - j\varepsilon'' = \varepsilon'(1 - j\tan\delta)$$



f_0: center frequency in empty
f : center frequency with sample
Q_0: empty
Q: with sample
ΔV: volume of sample<<V
V : volume of cavity
α_ε=1.855 (TM010)
n: refractive index

Attenuation length: $L_\alpha = \frac{\lambda}{\pi\sqrt{\varepsilon'}\tan\delta}$

0.3GHz Cavity with Closed Insertion Hole



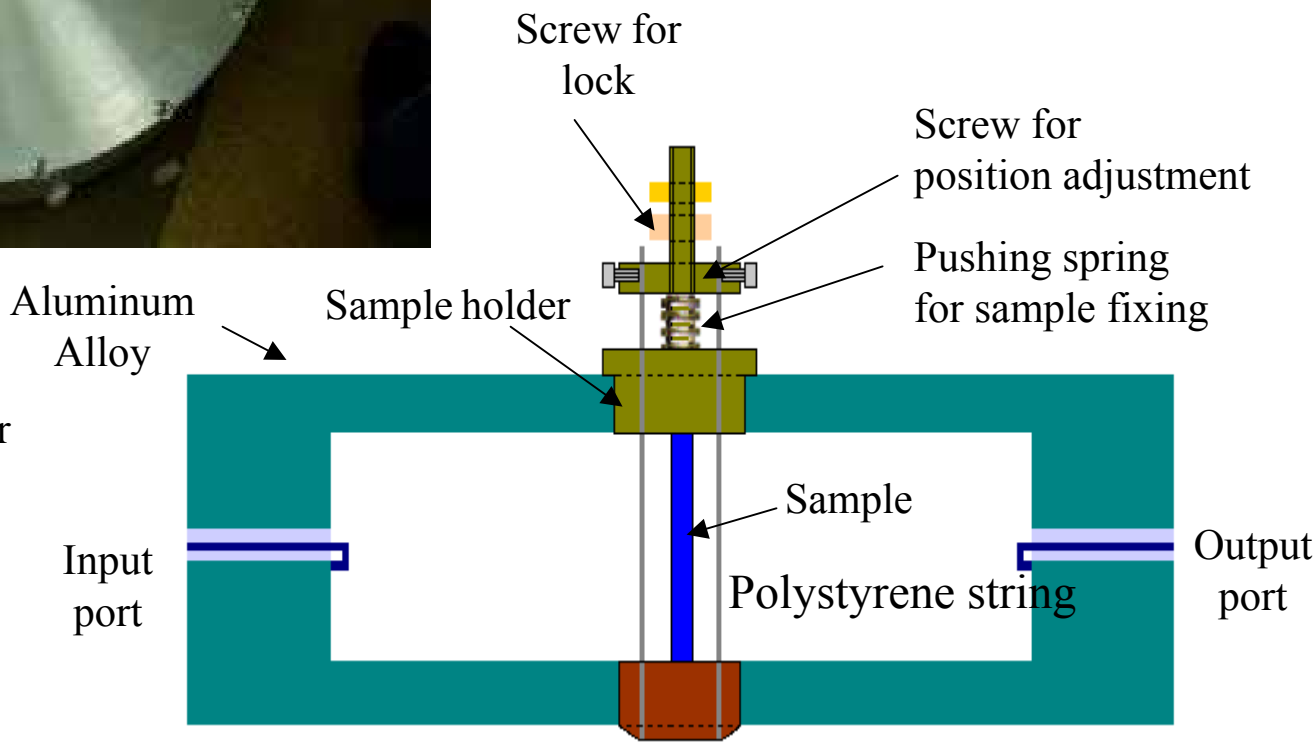
Mode: TM_{010}

f=0.3GHz Q=10,000

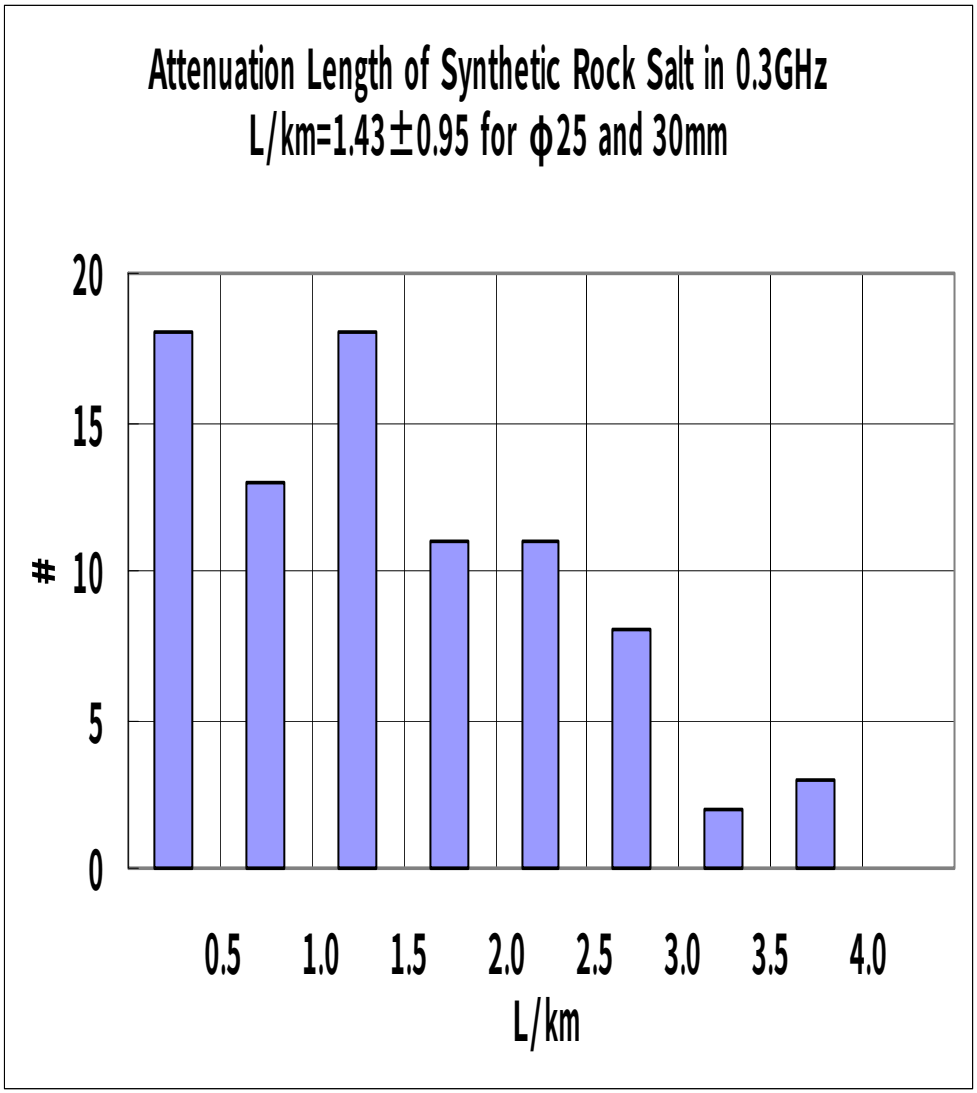
Inner Size:749mmϕ x 100mm

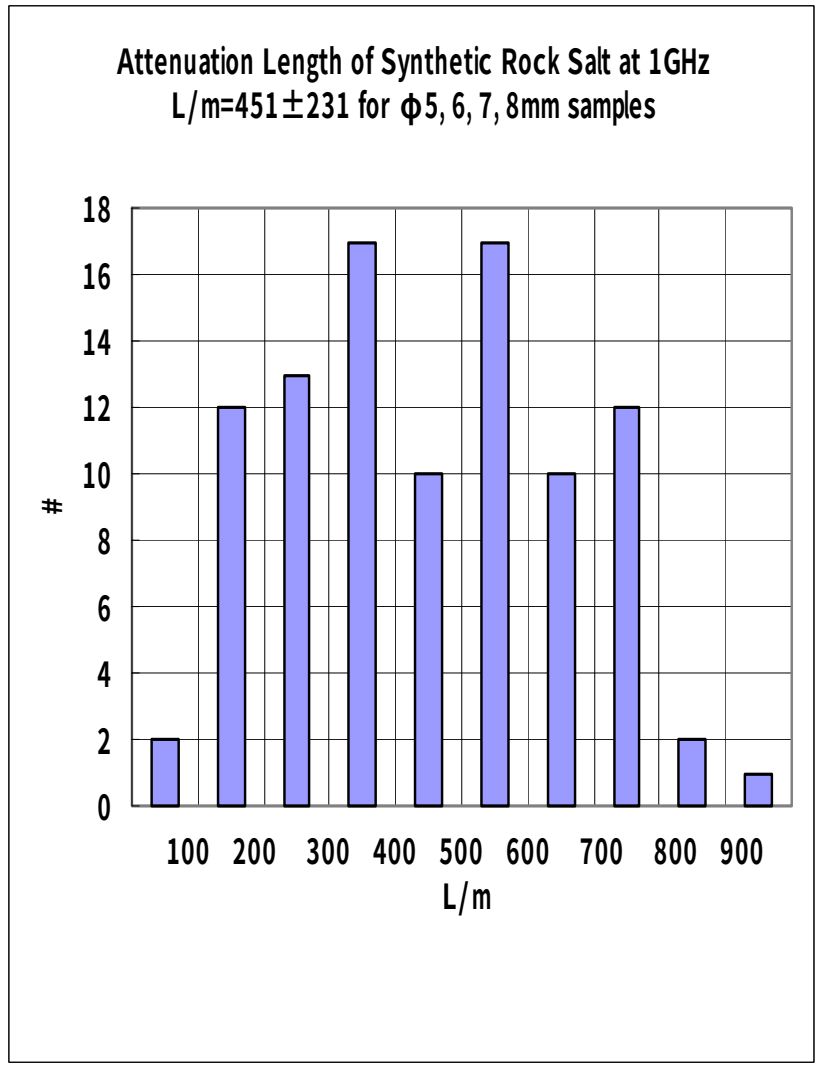
Sample diameter: <30mmϕ

Sample holder
with stand

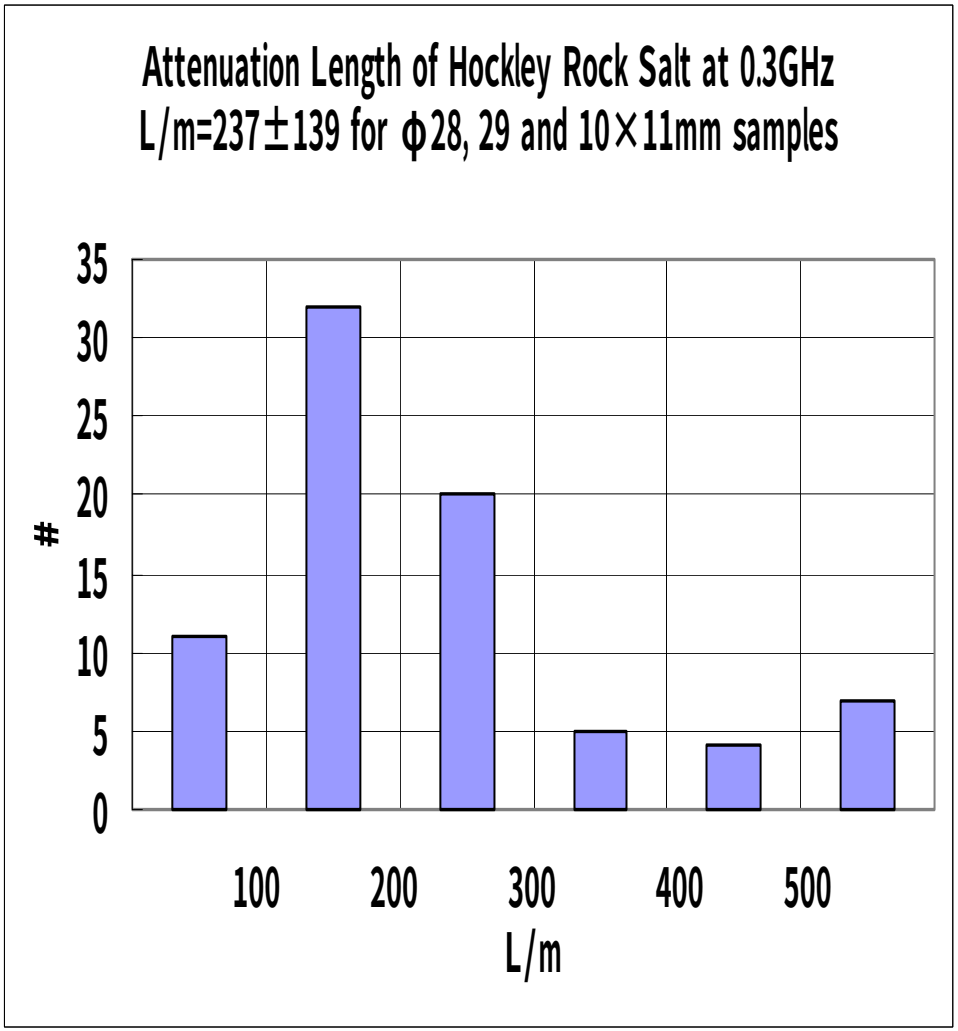


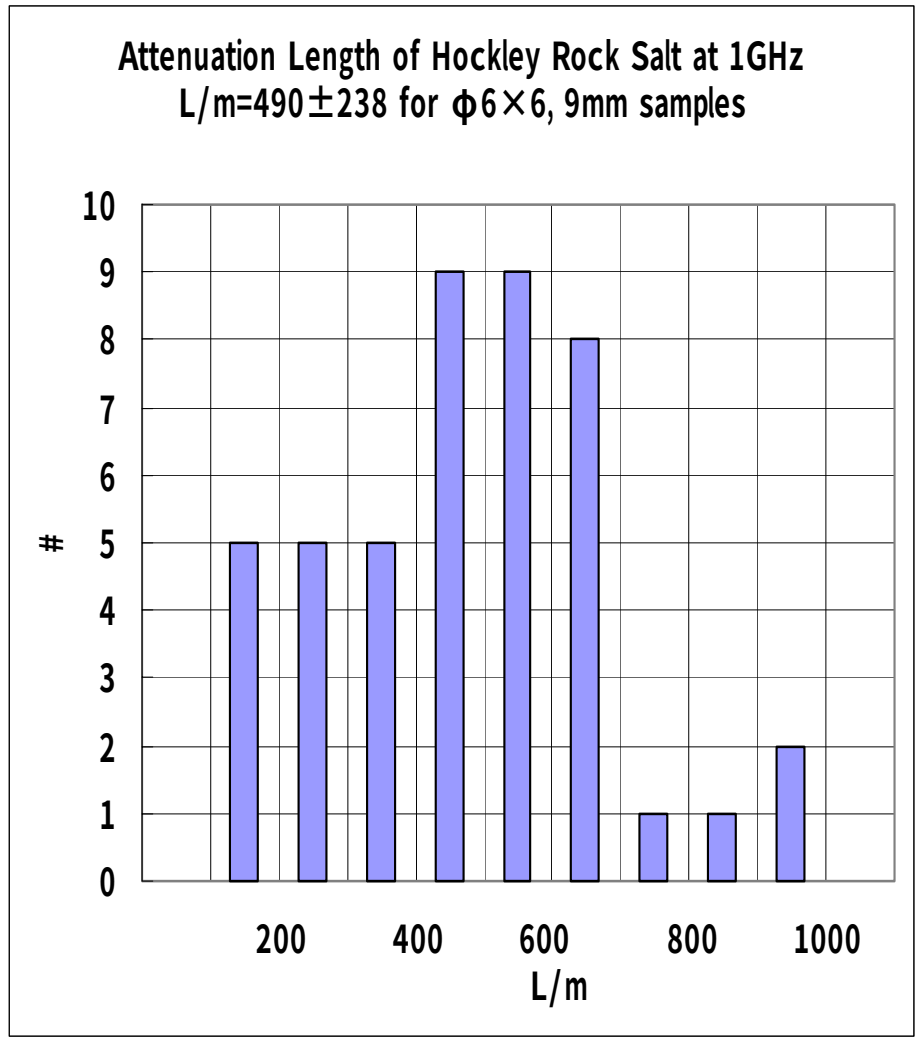
Synthetic Rock Salt :Preliminary



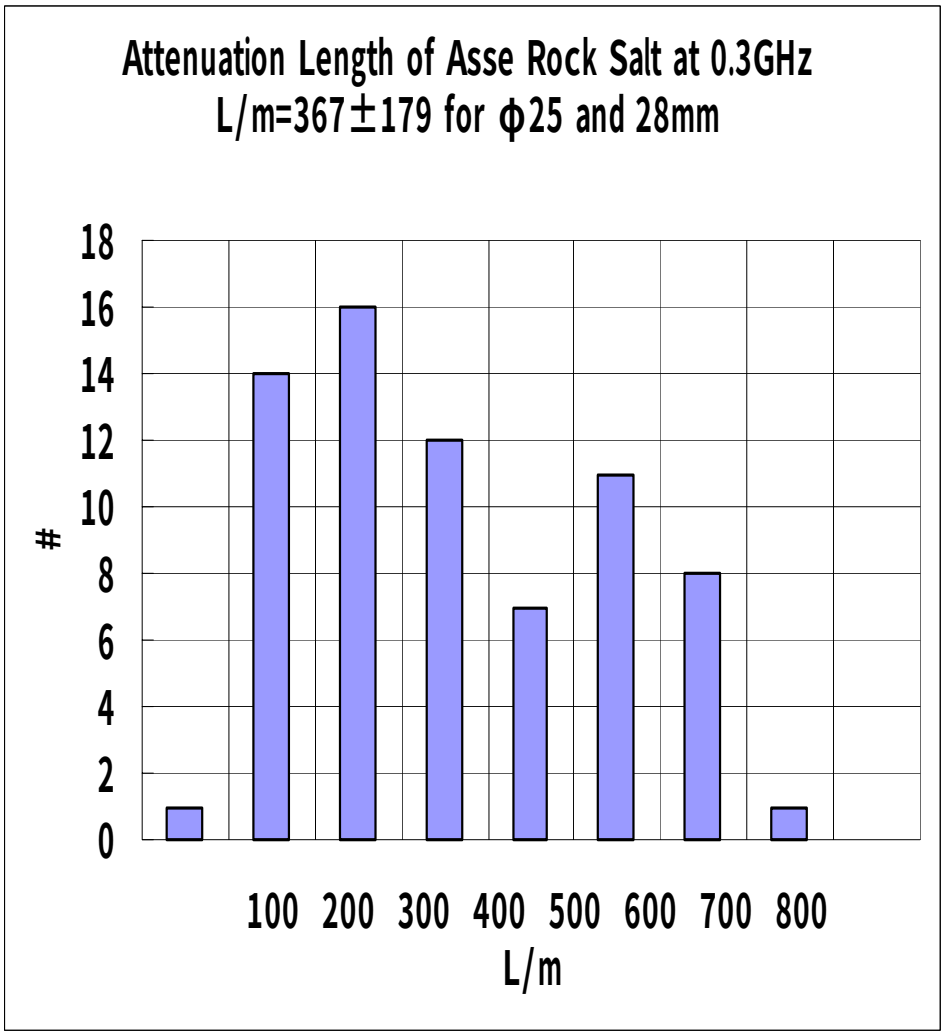


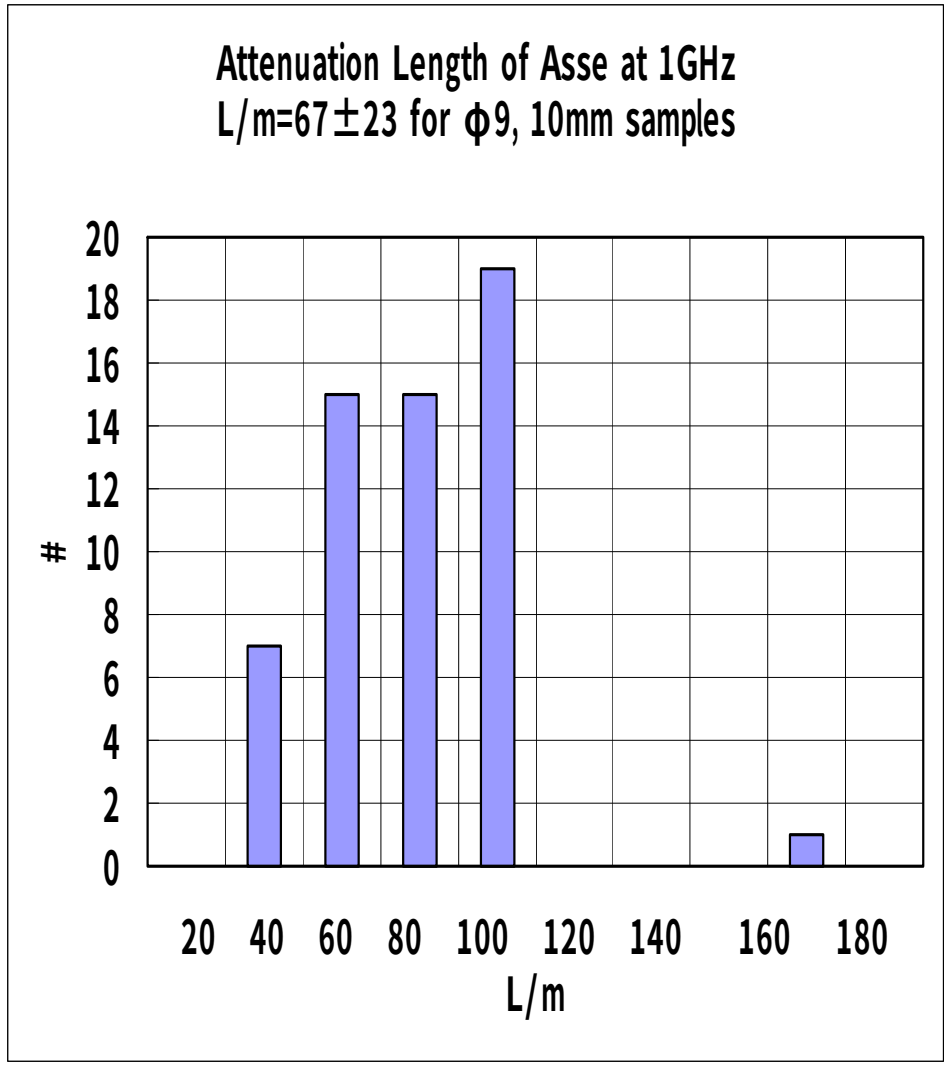
Hockley Rock Salt (Texas): Preliminary



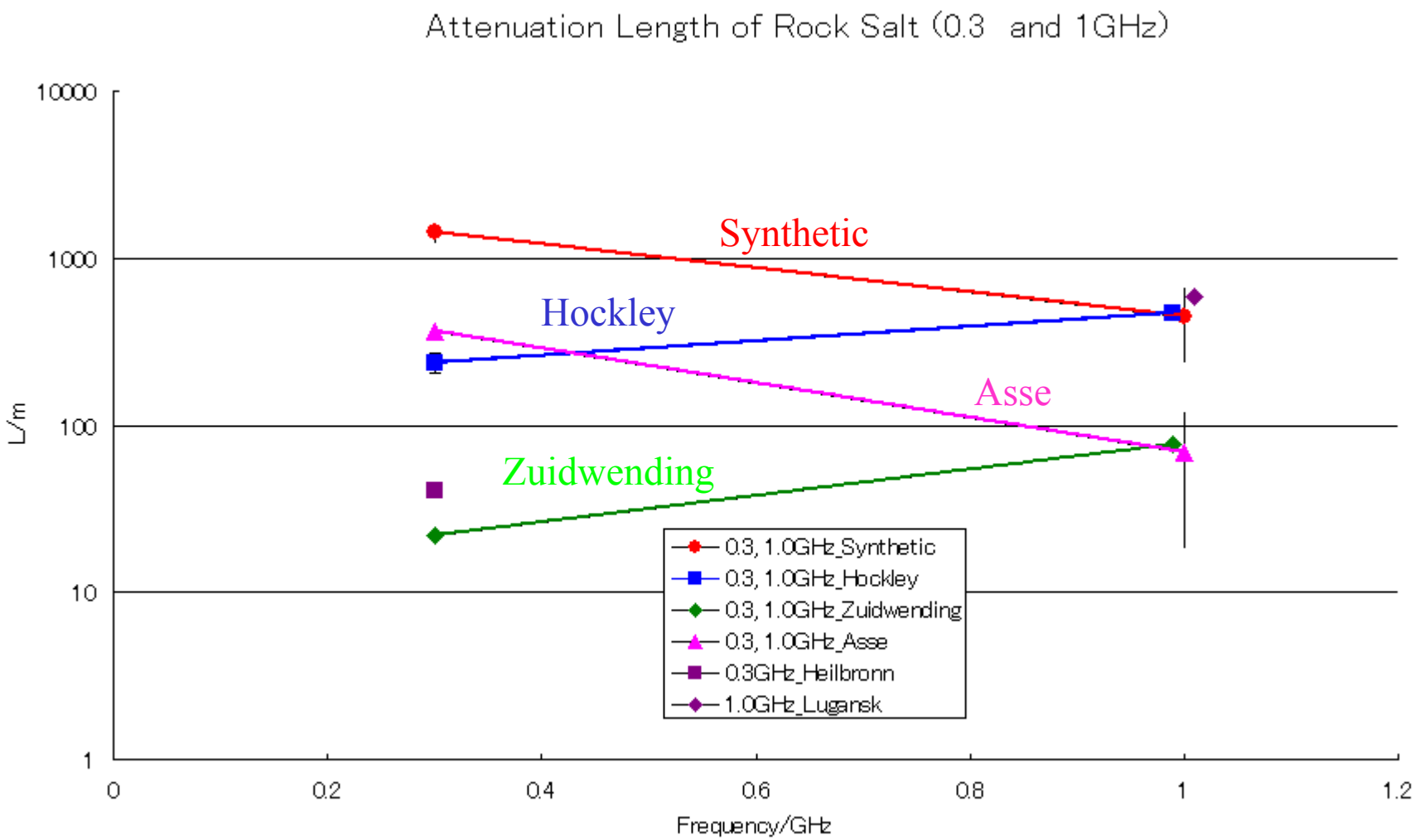


Asse Rock Salt (Germany): Preliminary

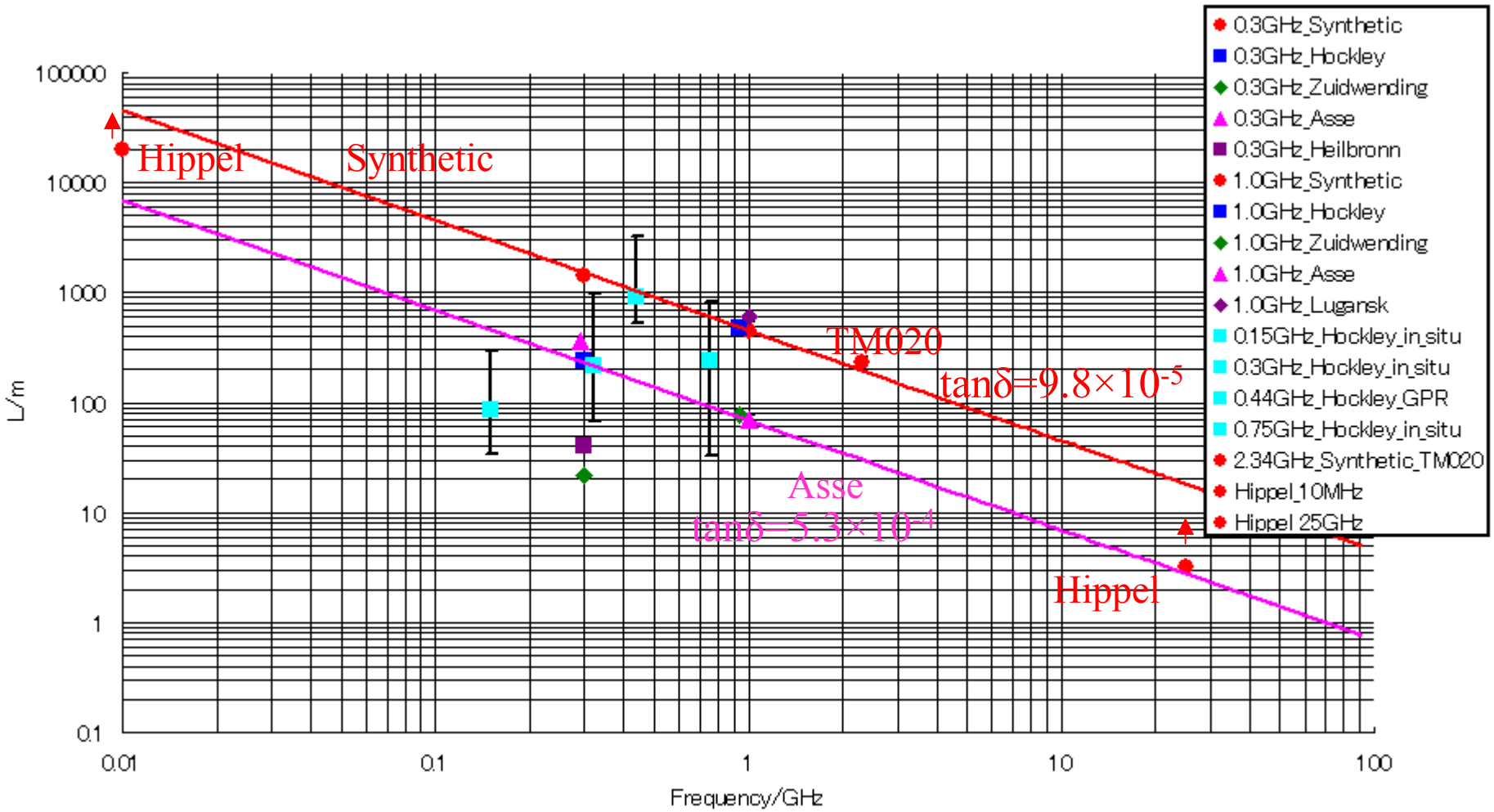




Two types of Frequency Dependence (Preliminary)



Attenuation Length of Rock Salt (Preliminary)



SND Simulation: EM Shower Simulation in 1D

- **EM shower is simulated as a charge distribution in 1D: Q(r)**
- **Structure function of excess electrons:**

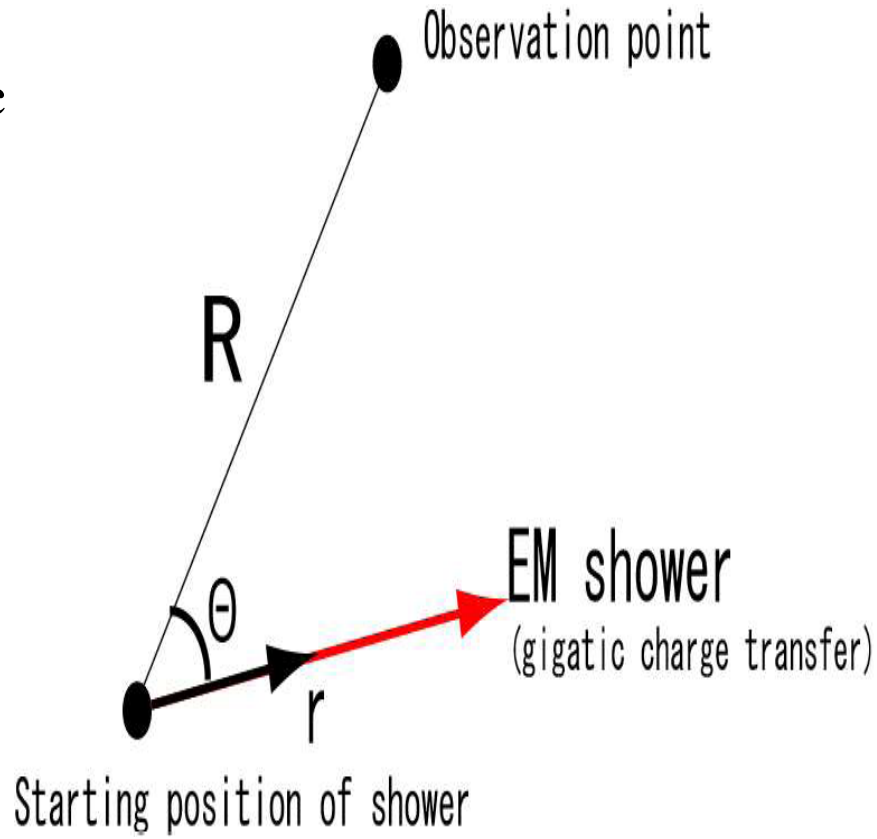
1Dimension, Velocity of the particles =c

→Fast calculation of electric field

(J. Alvaretz-Muniz et al., Phys. Rev.D, 62, 2000, 063001)

$$E = -\frac{i\omega n^2}{\sqrt{2\pi c^2 R}} e^{ikR} \sin\theta \int Q(r) e^{ipr} dr$$

$$p = (1 - n\cos\theta)\omega / c$$



R: Distance from origin of a shower to observer

r: position of charge, ω: frequency of radiation

n: refractive index, θ: angle between shower and observer

1D structure function of excess electrons

- **Geant4.5.2. is used for space distribution of excess electrons (E_{shower} =10^{15} -10^{16} eV).**
- **Modified Greisen parameterization is used to fit Geant4 shown as the solid line.**
- **α, β, γ are determined from 10^{15}-10^{16} eV Geant4.**
- **Geant4 includes LPM effect in bremsstrahlung at E>10^{15} eV.**

$$N = \frac{0.31 \times 0.26}{\sqrt{\alpha}} \exp\left[\beta t\left(1 - \gamma \times \ln\left\{\frac{3 \times \beta t}{\beta t + 2\alpha}\right\}\right)\right]$$

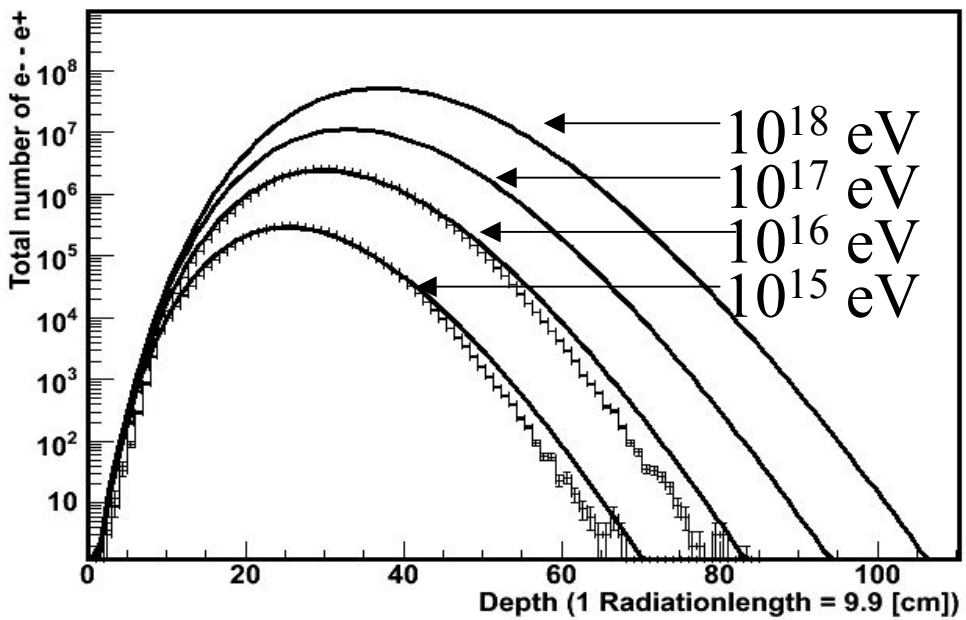
$$\alpha = \ln\left[\frac{\text{Energy}}{\left(44.686 \times (E+1)^{E} - 34.9092\right) \times 10^{4} \times \varepsilon}\right]$$

$$E = \log_{10}\left(\frac{\text{Energy}}{10^{15}\,\text{eV}}\right)$$

$$\beta = 0.15 - 0.021 \times \ln(\text{Energy})$$

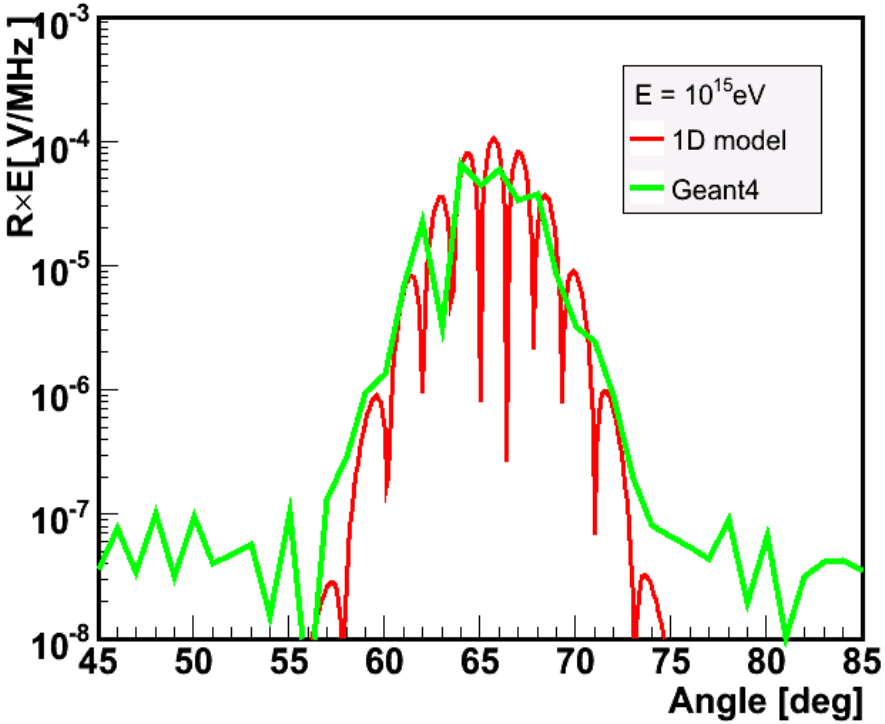
$$\gamma = 5.1 - 0.11 \times \ln(\text{Energy})$$

ε: Critical Energy

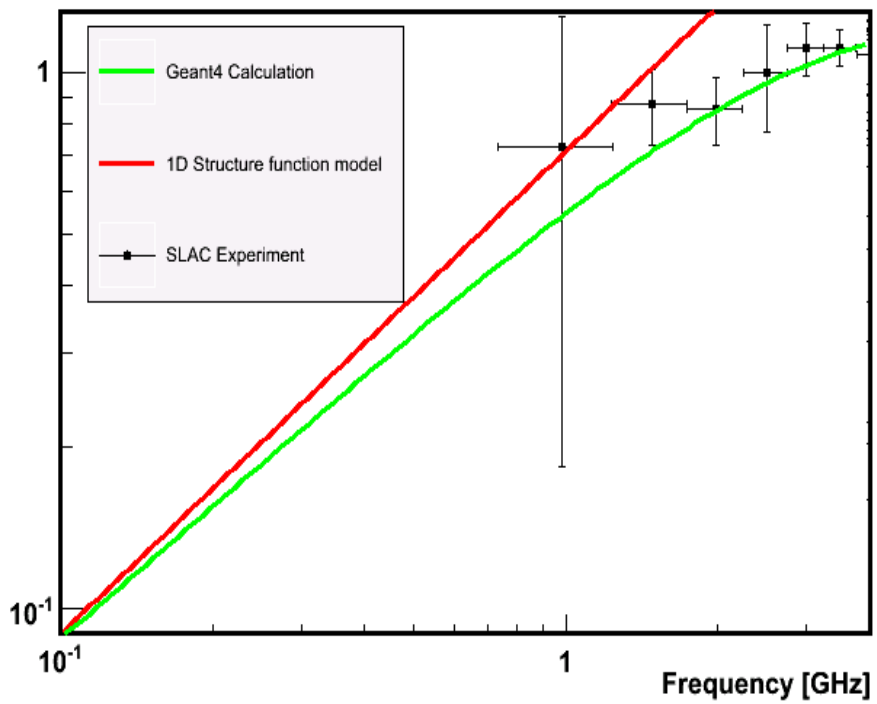


Angular and Frequency Distribution of Electric Field 1Dimensional structure function vs. Geant4

Angular distribution



Frequency distribution

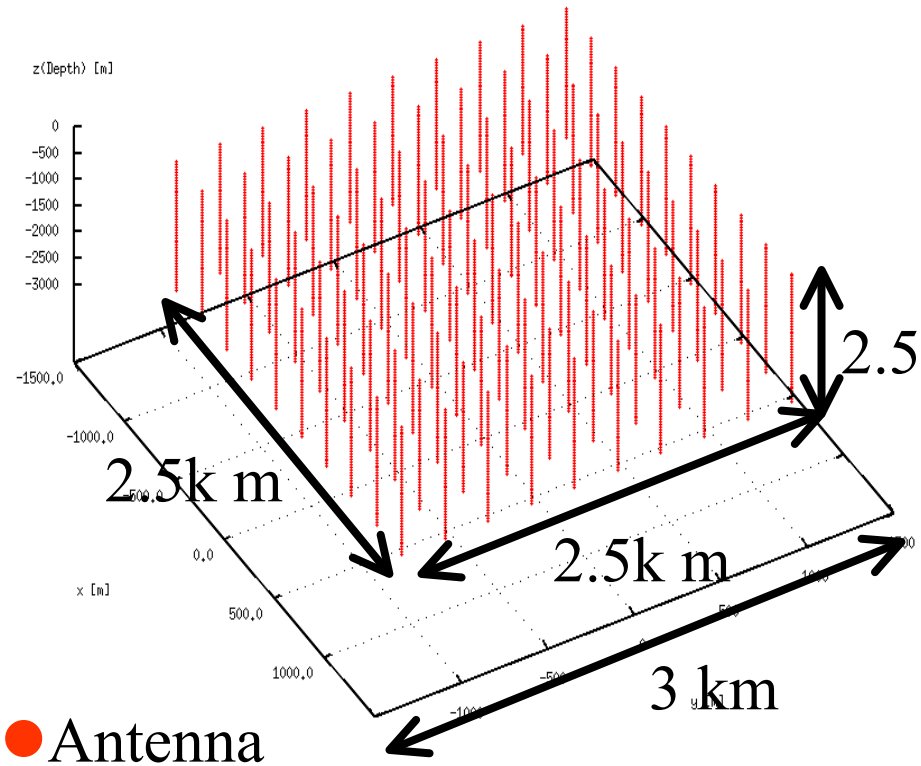


- **1D Angular distribution shows clear interference pattern due to high statistics. 1D envelope in angular distribution is consistent with Geant4.**
- **Frequency distribution: Geant4 is normalized to SLAC experiment at 2GHz. 1D model becomes close to Geant4 under 1GHz to be used.**

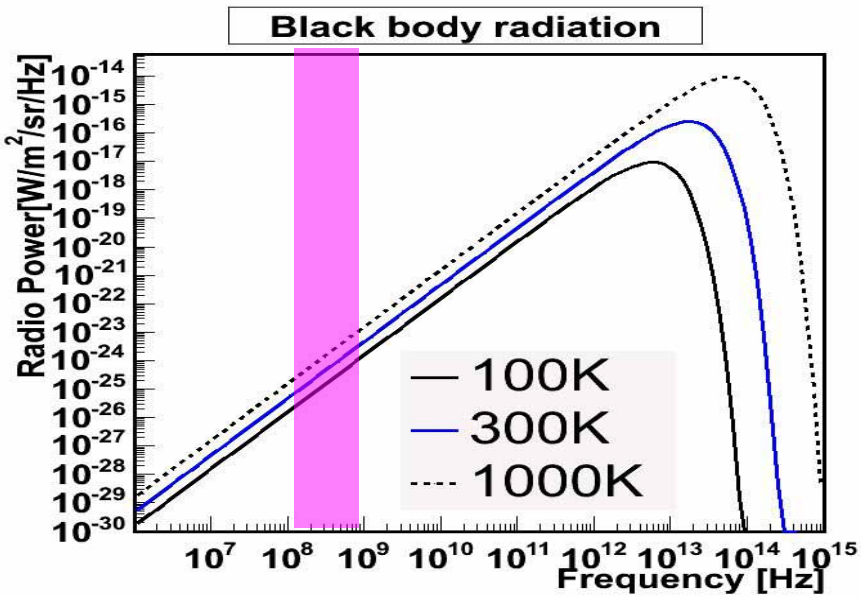
Conditions of SND Simulation

- **Effective volume: 3×3×3[km³]**
- **Att. Length: Asse with freq. dep.**
- **Antennas: 10×10×50**

Spacing: 250m horizontal, 50m depth



- Antenna



- **Band width: 100[MHz] – 500 [MHz]**

300K radiation: 6.9×10^{-6} V/m

- **Attenuation length of rock salt**

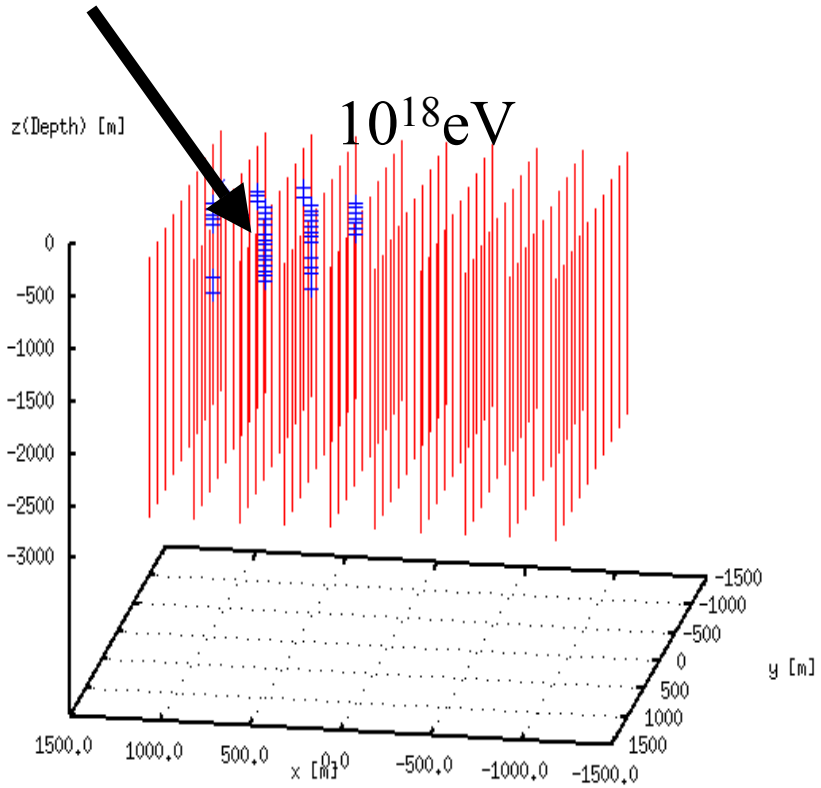
$$L = \frac{\lambda}{\pi \sqrt{\varepsilon'} \tan \delta}$$

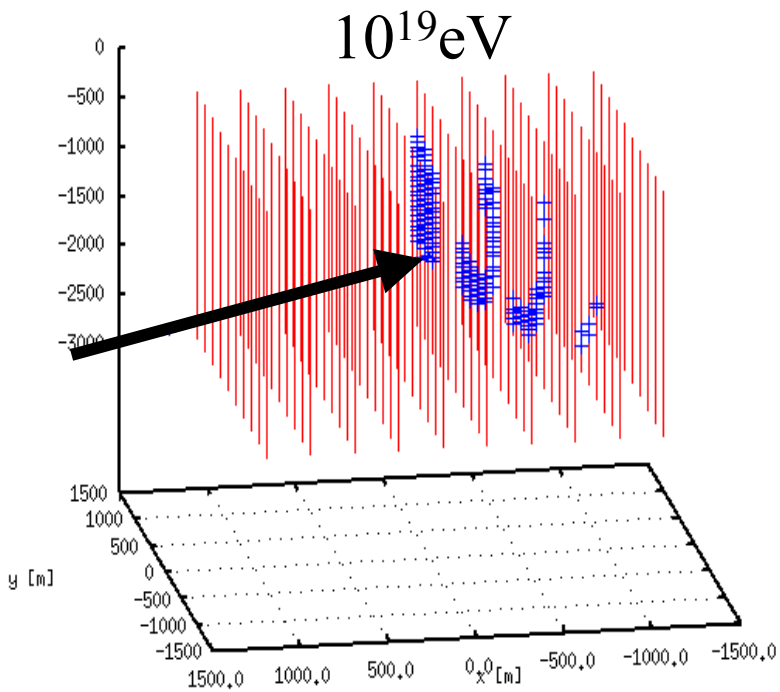
$$\varepsilon' = 5.97$$ Asse(Germany)

$$\tan \delta = 5.28 \times 10^{-4}$$

Hit Antennas

E field at antenna ＞ 6.9×10^{-6}[V/m] (Black body radiation)



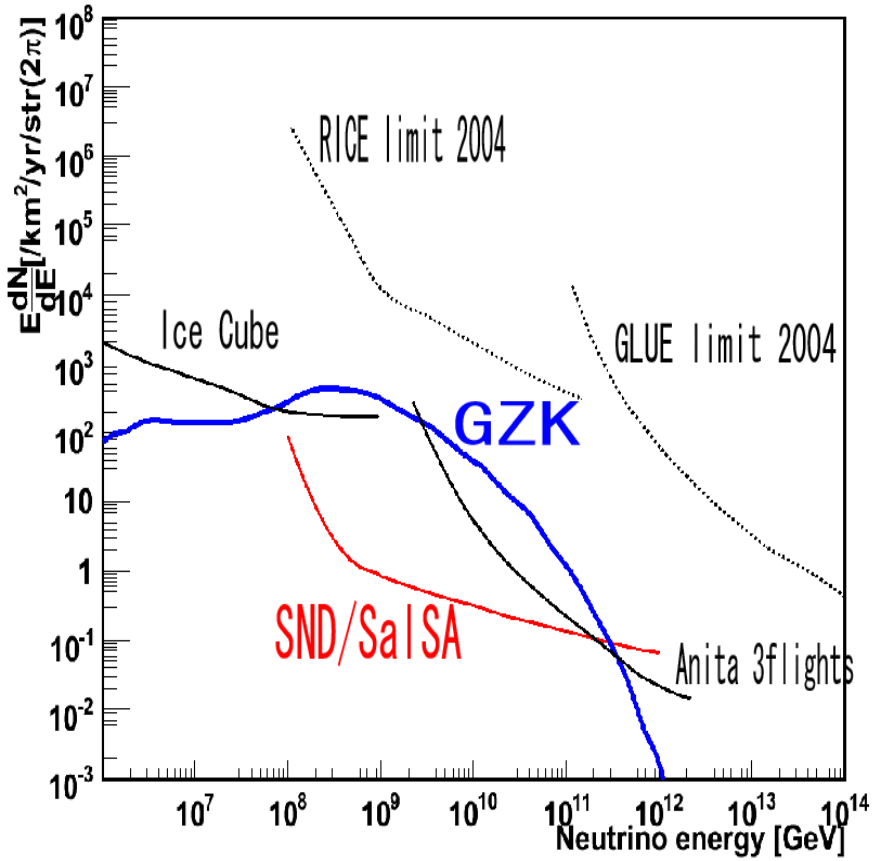


45 **number of hit antennas** **158**

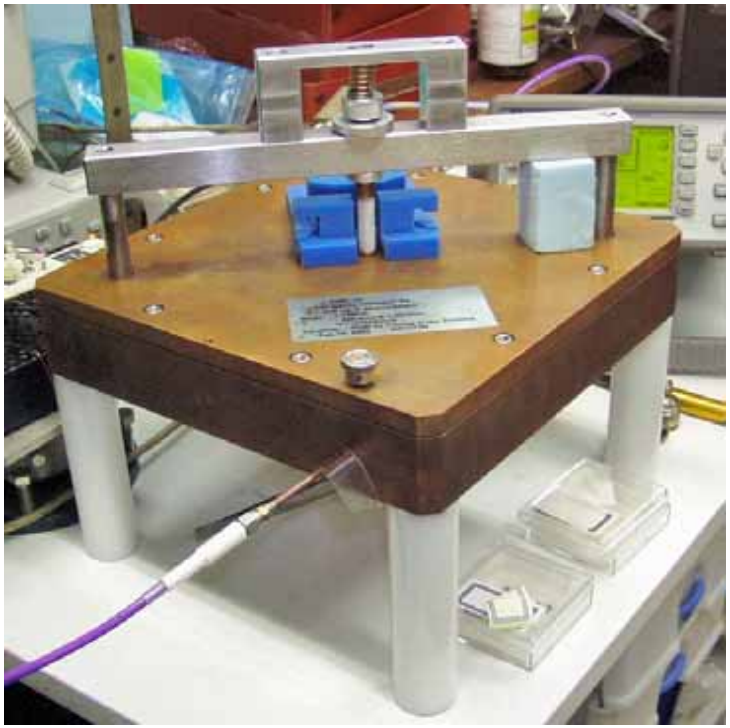
Solid line: Shower direction
Red: Antennas
Blue: Hit antennas

Summary

- Long attenuation length is found at Asse and Hockley rock salt. There are two types of frequency dependences of the attenuation length. One is consistent with a hypothesis as tanδ being constant with frequency and the other is not.
- Structure function of 1D excess electron in a EM shower afford to get EM field@E >10^{18} eV.
- Simulation is done taking into realistic attenuation length of natural rock salt, black body radiation, receiver band width.
- Computer times are 1D (5 min) and Geant4 (10 days)@10^{16}eV.
- GZK neutrinos will be detected 8〜62 event/year.



1GHz Cavity Resonator with Closed Insertion Hole

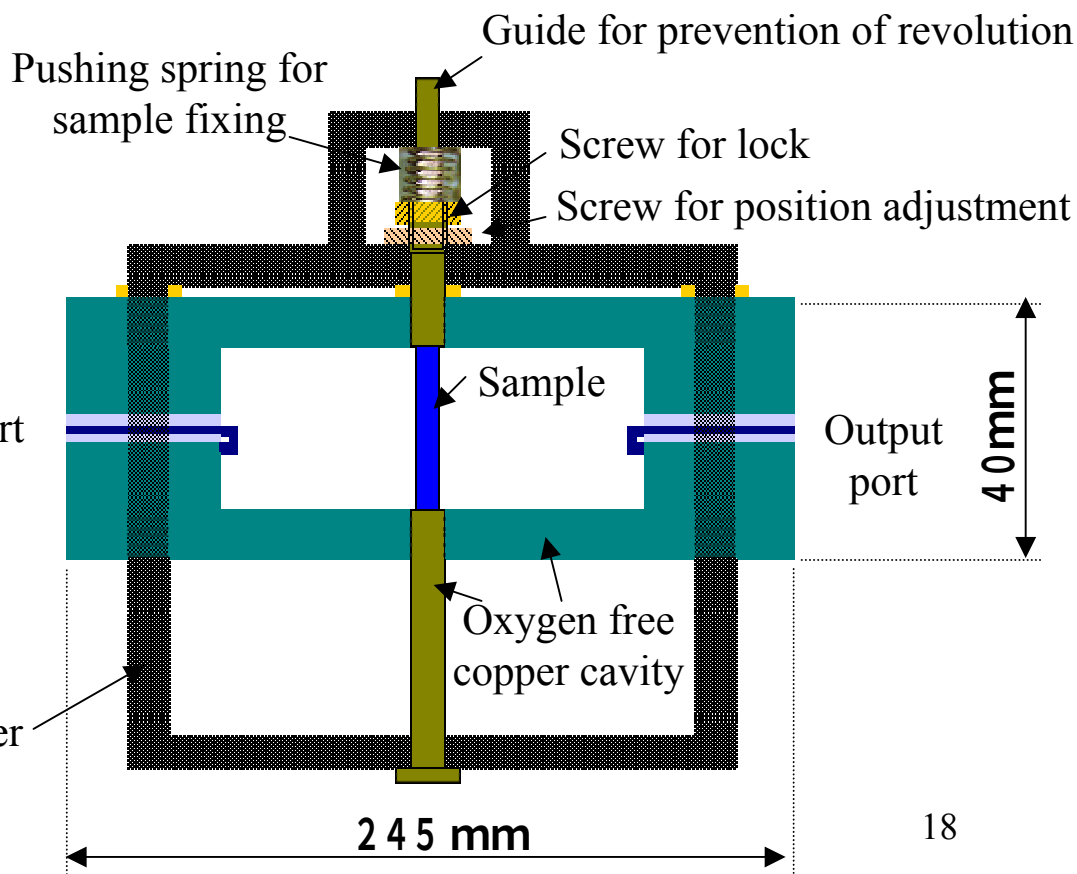


Mode: TM_{010}

f=1.0GHz Q=10,000

Inner Size: 225mmϕ x 30mm

Sample diameter: <10mmϕ



The most difficult task is to make a good shape of rock salt samples. Shorter sample is easy to shape.

0.2GHz cavity under construction

φ1124×100 mm, Aluminum, Q will be 8,000.

Attenuation Length for Air (Preliminary)