Radar for Salt Ultra-High-Energy Neutrino Detector and Contribution of W-Gluon Fusion Process to Collision of Neutrinos against Quarks

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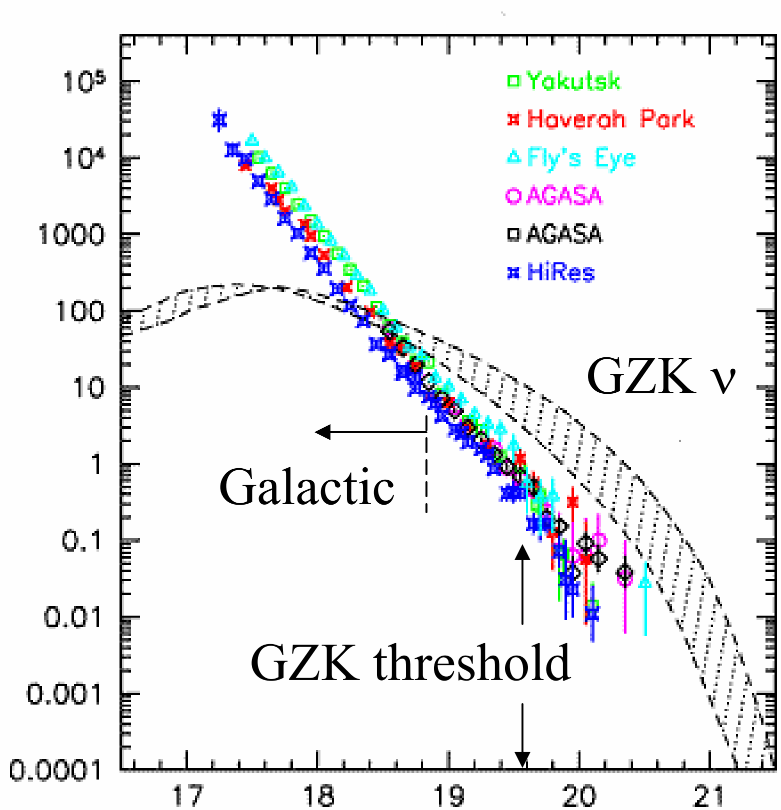
UHE Neutrinos Originate in UHE Cosmic Rays & CMB

Cosmic ray energy spectrum
Log E(dN/dE) [km^{-2} yr^{-1} $(2\pi\ sr)^{-1}$]



Log E [eV^{-1}]

●Hireso group observed Greisen-Zatsepin-Kuzmin(GZK) cutoff. Abbasi et al., PRL **100**, 101101(2008)

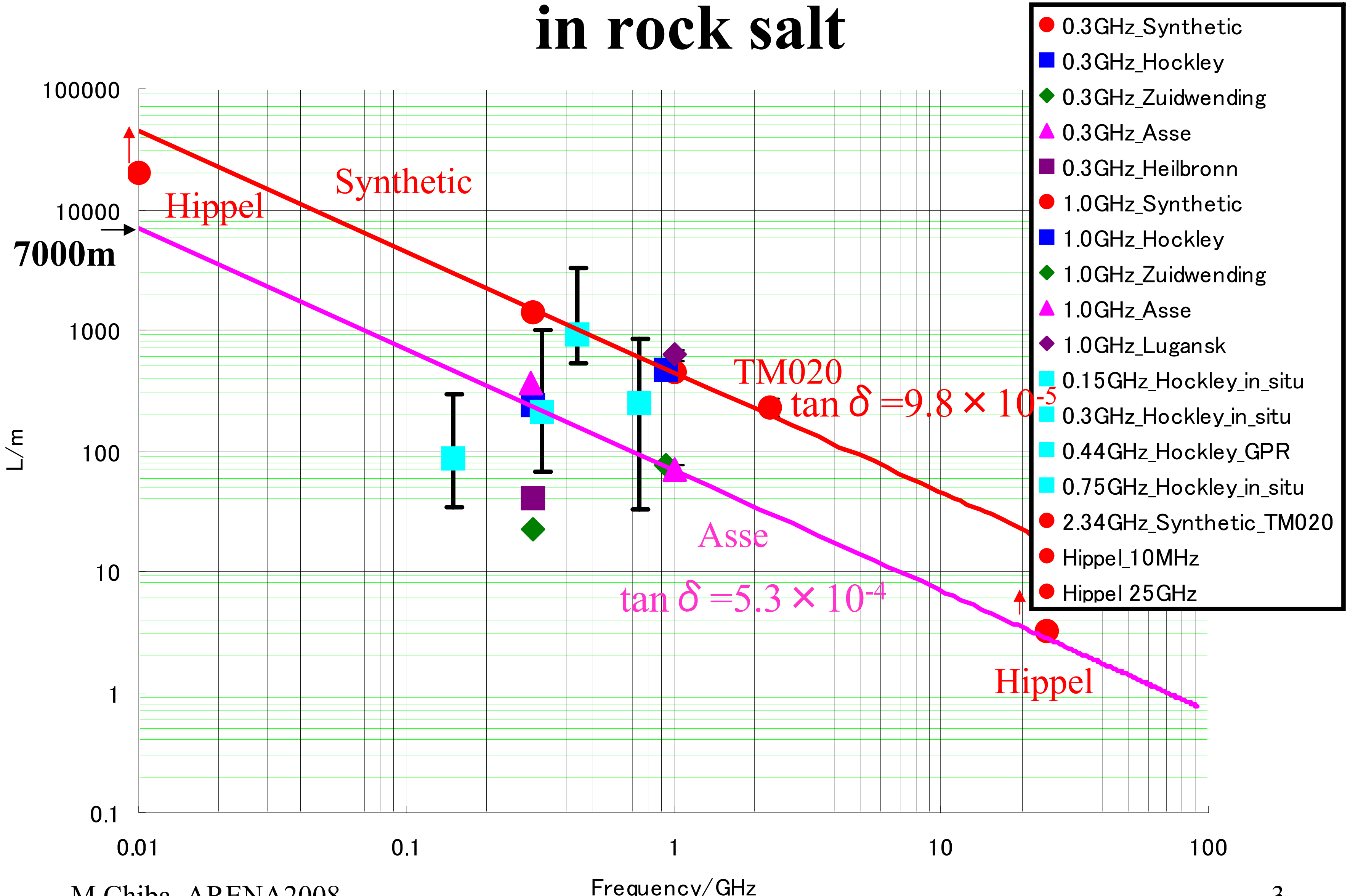
- The energy exceeds Δ production threshold.

$$p + \gamma_{2.7\,K} \rightarrow \Delta \rightarrow n + \pi^+$$
(CMB) ·
$$\pi^+ \rightarrow \mu^+ \nu_\mu$$
$$\mu^+ \rightarrow e^+ \nu_\mu \nu_e$$

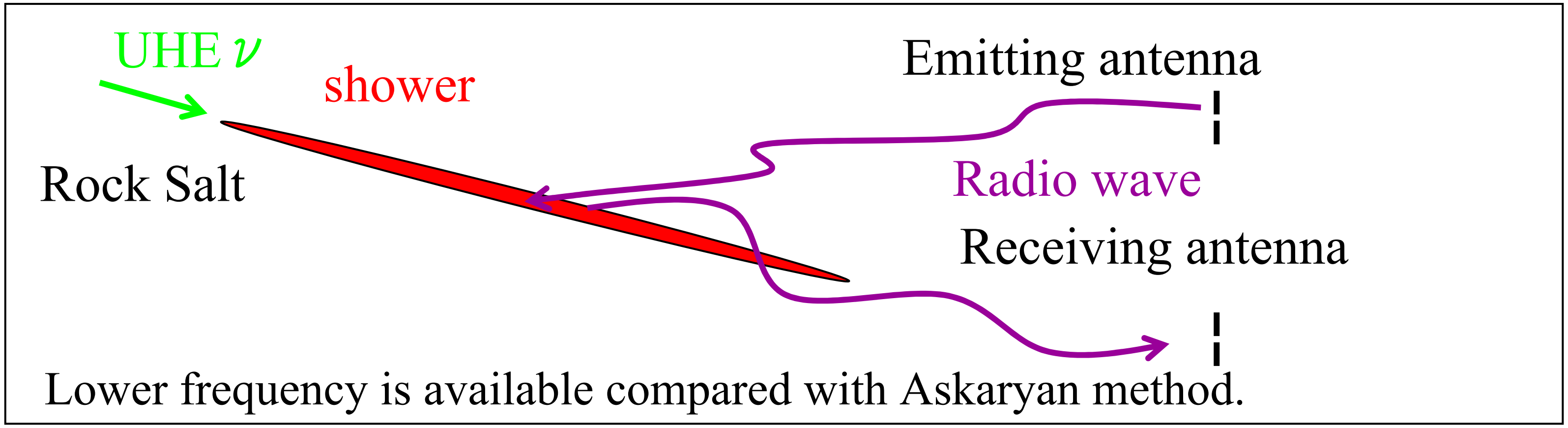
- GZK neutrino flux is as low as 1[/km^2/day] .

→Need a huge mass of detection medium

Attenuation length of radio wave for electric field in rock salt



Radar method: microwave reflection experiment



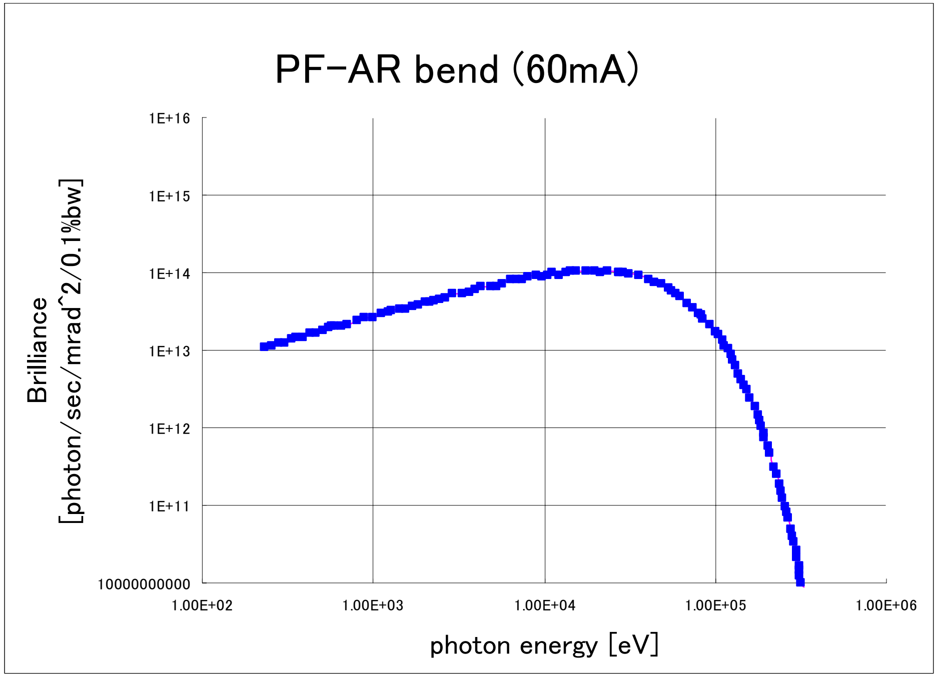
Electromagnetic ionization in rock salt generated by X ray irradiation

- X ray Spectrum: white
- Energy: 8-100 keV
- Repetition: 800 kHz
- Pulse width: 30ps

Synchrotron radiation from KEK AR electron accumulation ring

- Electron energy: 6.5GeV
- Current: 60mA
- Lifetime 10 hours

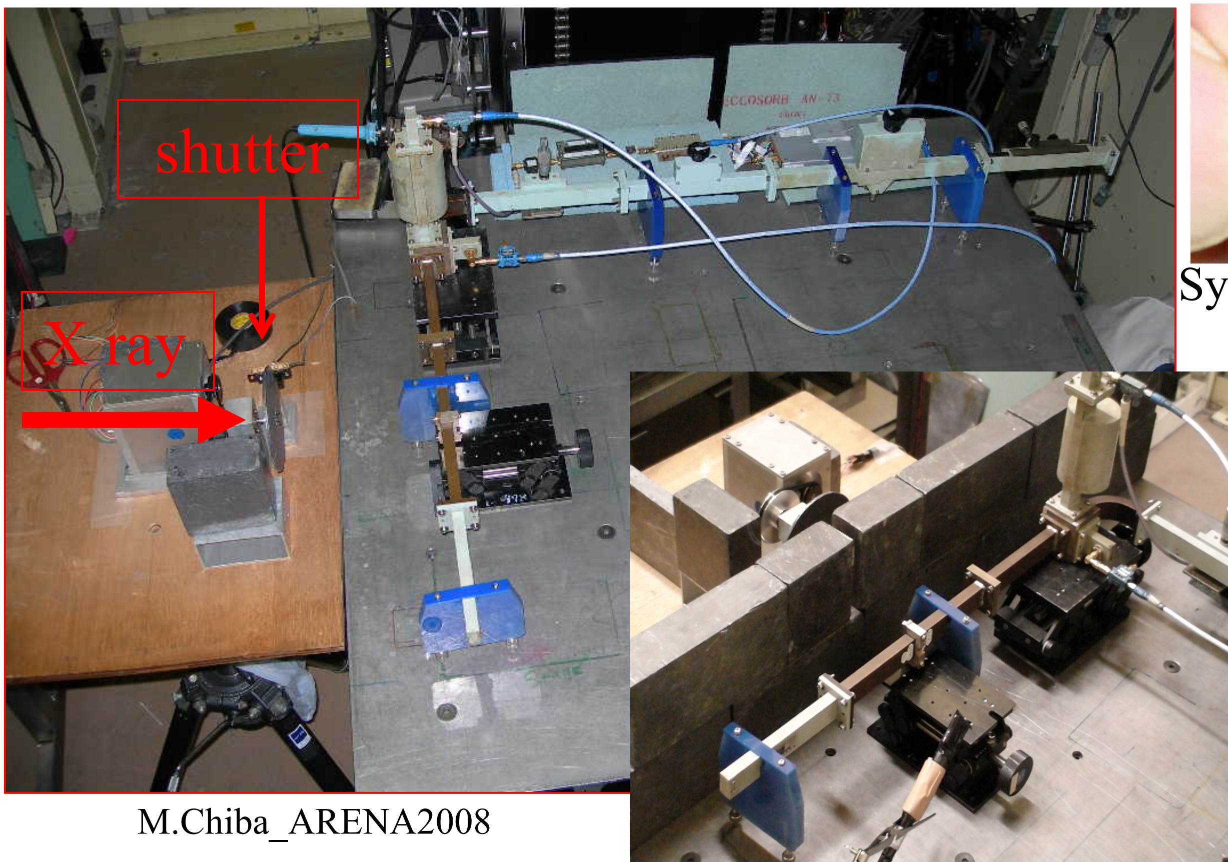
Brilliance of X ray source

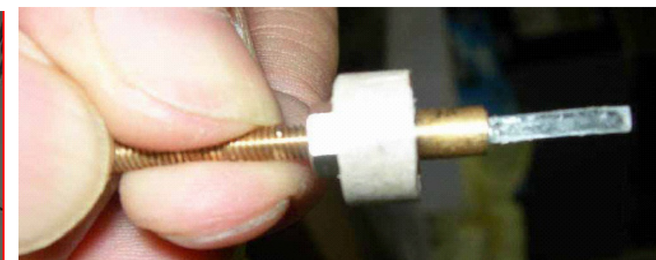


Experimental setup with X ray disc shutter

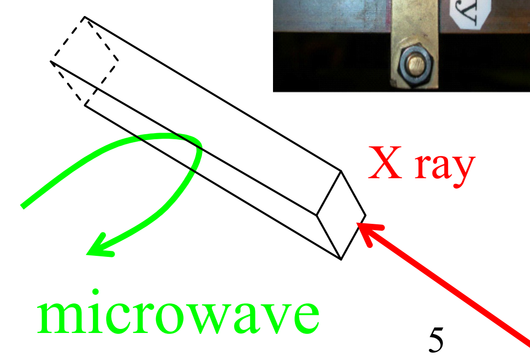
- X ray and microwave (9.4 GHz, 10^{-4} W) are irradiated to a rock salt sample, simultaneously.
- Null detection method is employed for detecting minimal signal.
- Measure microwave reflection change due to X ray irradiation.

Rotary X ray disc shutter
- Lead: 4mm^t
- Φ:100mm,
- Orifice: 4x4mm^2

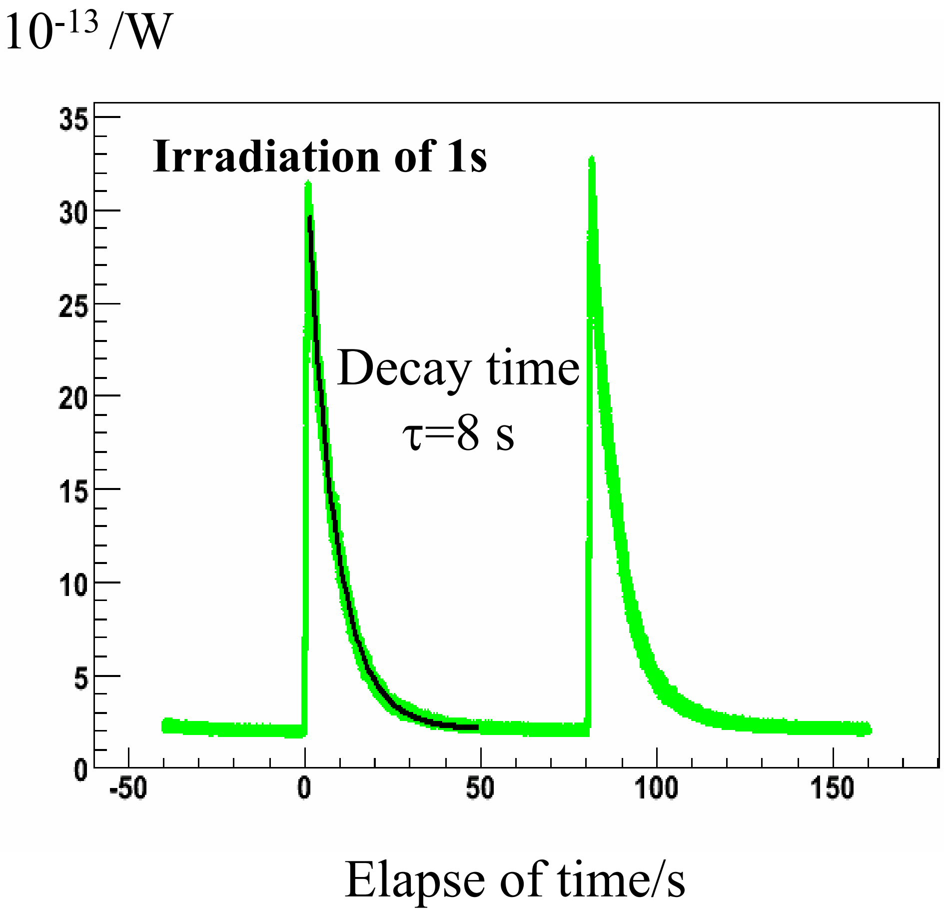


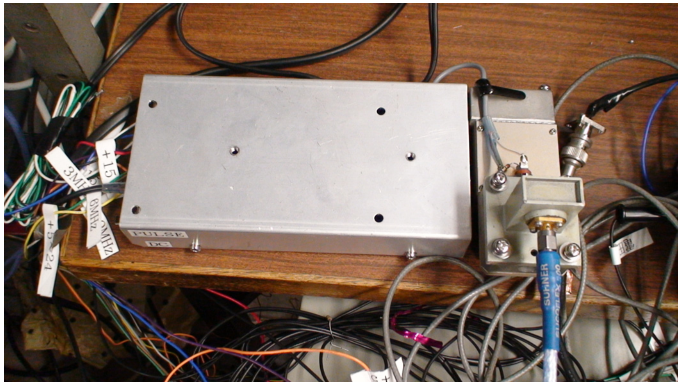


Synthesized rock salt
$2 \times 2 \times 10$ mm^3



Reflected power vs. elapse of time





Receiver:

Ueda-NEC Co. Ltd.: NRG-98

- Logarithmic amplification: 10^{12}
- Receiving power range ; 10^{-14}-10^{-4} W
- 9.4GHz, Band width: 3MHz

- Microwave reflection rate of 10^{-6} at the X ray energy deposit of 10^{19} eV/s.
- Reflection target candidates: free electrons, local thermal blobs, color centers, phonons, polarons, polaritons?

Coherency of the reflection

Reflection Power: P

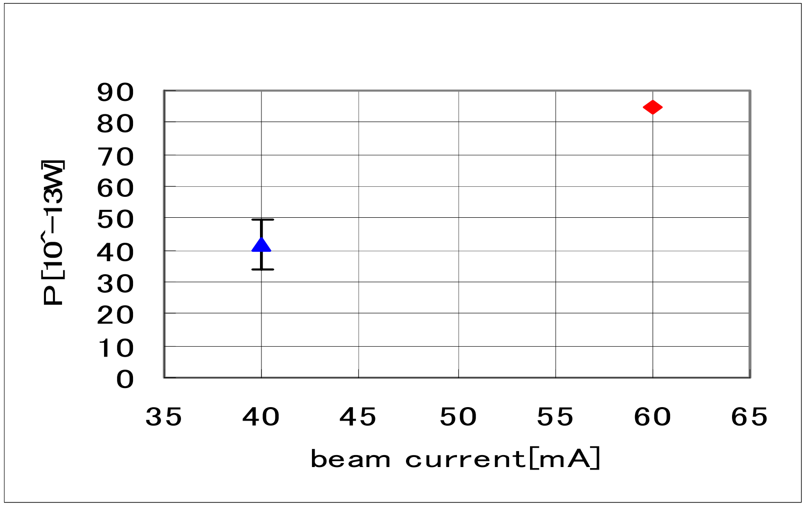
X ray intensity dependence

Complete coherence

P∝ (intensity)^2 ∝ (AR beam current)^2

P(40mA) =41.7±7.9 [10^{-13}W]

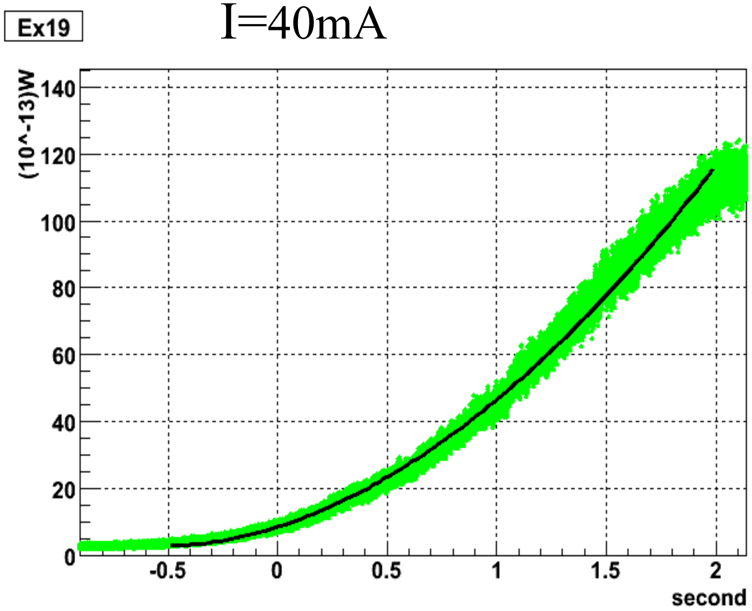
P(60mA) =84.6±0.5 [10^{-13}W]



$$\frac{P(40mA)}{P(60mA)} = 0.49 \pm 0.09 = \left[\frac{40}{60}\right]^x$$

Irradiation time dependence

I=40mA



P=At^X+B

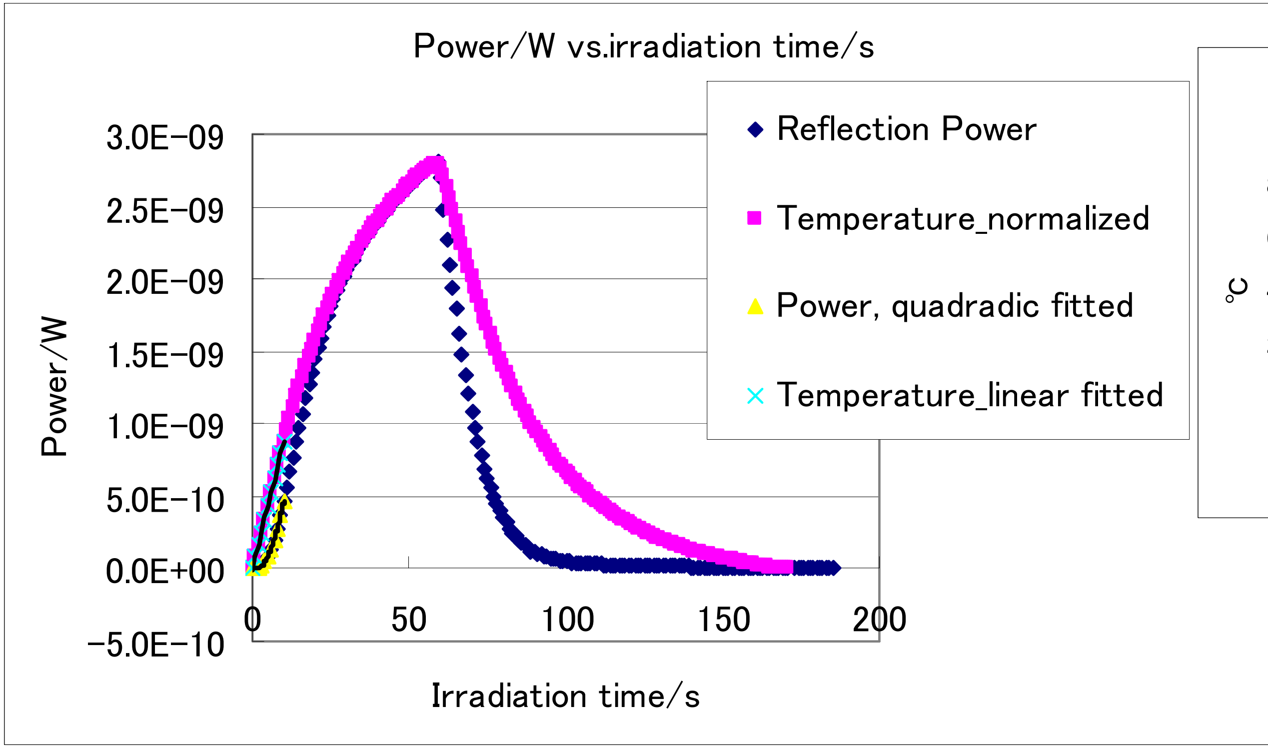
↓

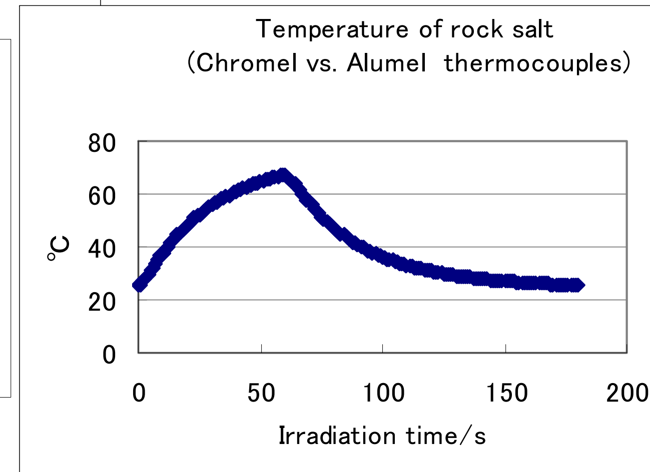
X=2.1±0.1

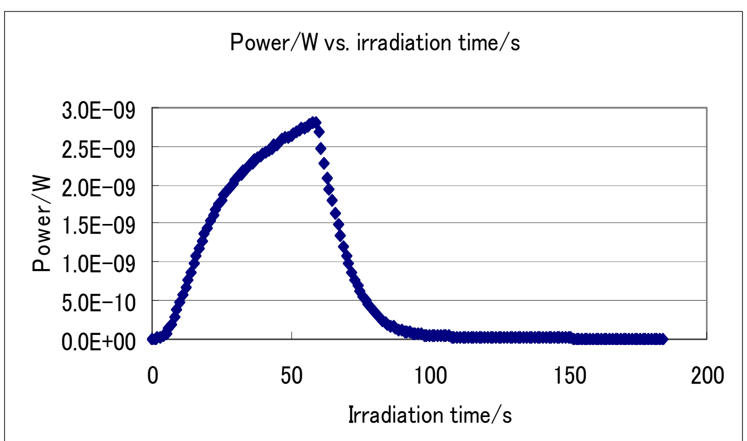
↓

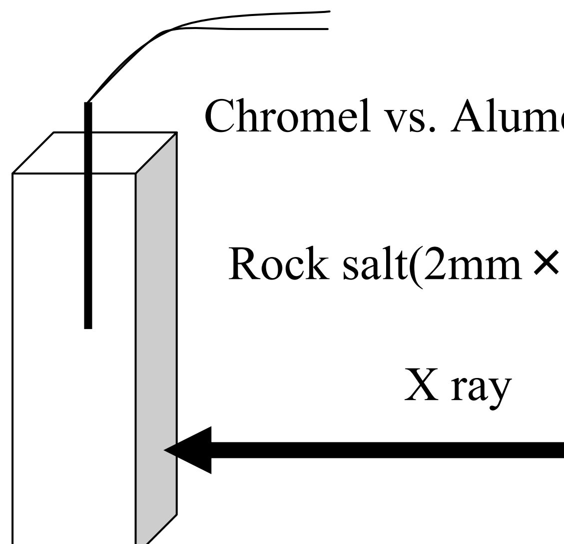
X=1.8±0.4 → P ∝ (intensity)^2 ∝ (Irradiation time)^2 → Coherent

Temperature dependence of reflected power









Temperature dependence of reflected power

J. C. Owens, Phys.Rev. 181(1969)1228

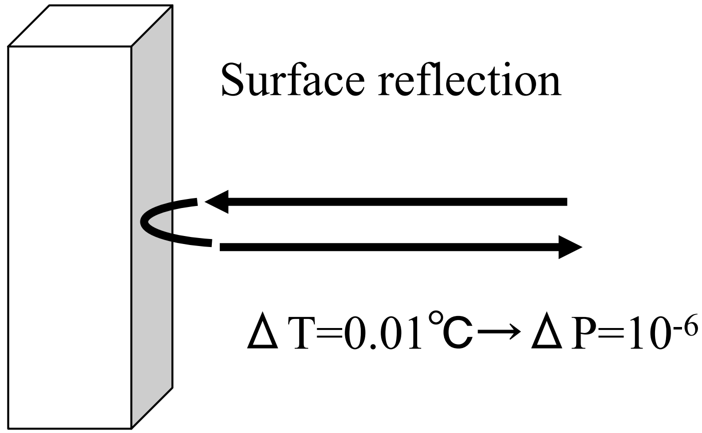
$\varepsilon' = 6860/(1980-T)+2.385$

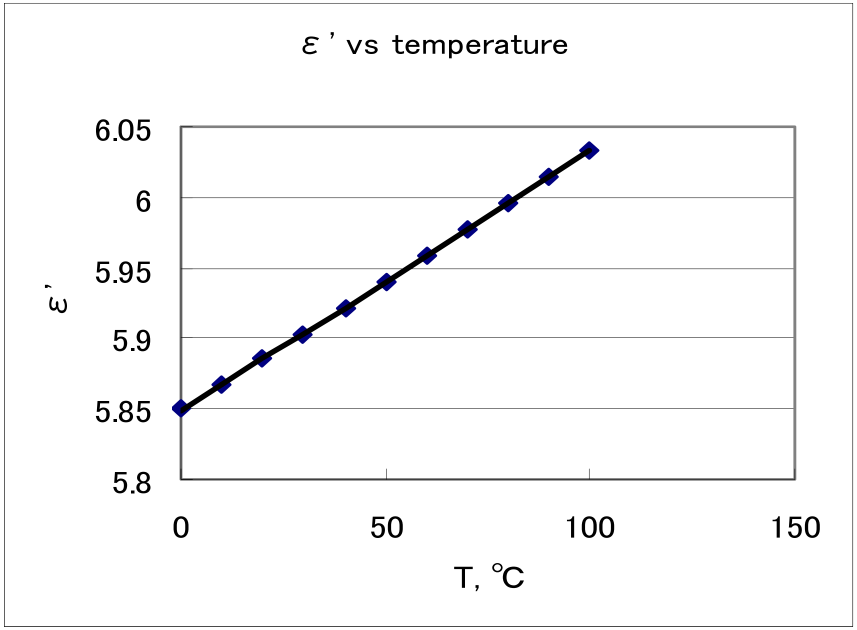
$n=\sqrt{\varepsilon'}$

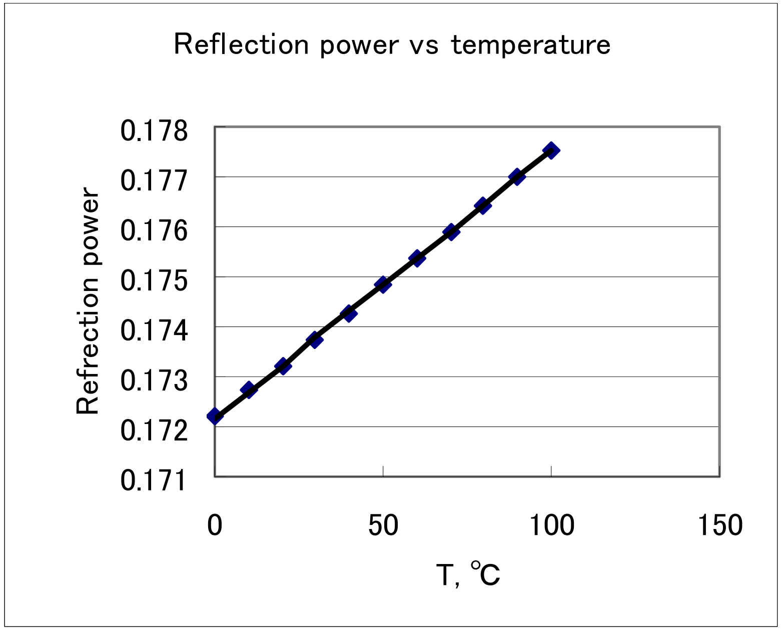
Reflected power $\propto (n-1)^2/(n+1)^2$

Temperature $\propto$ Energy deposit

$\propto$ Irradiation time

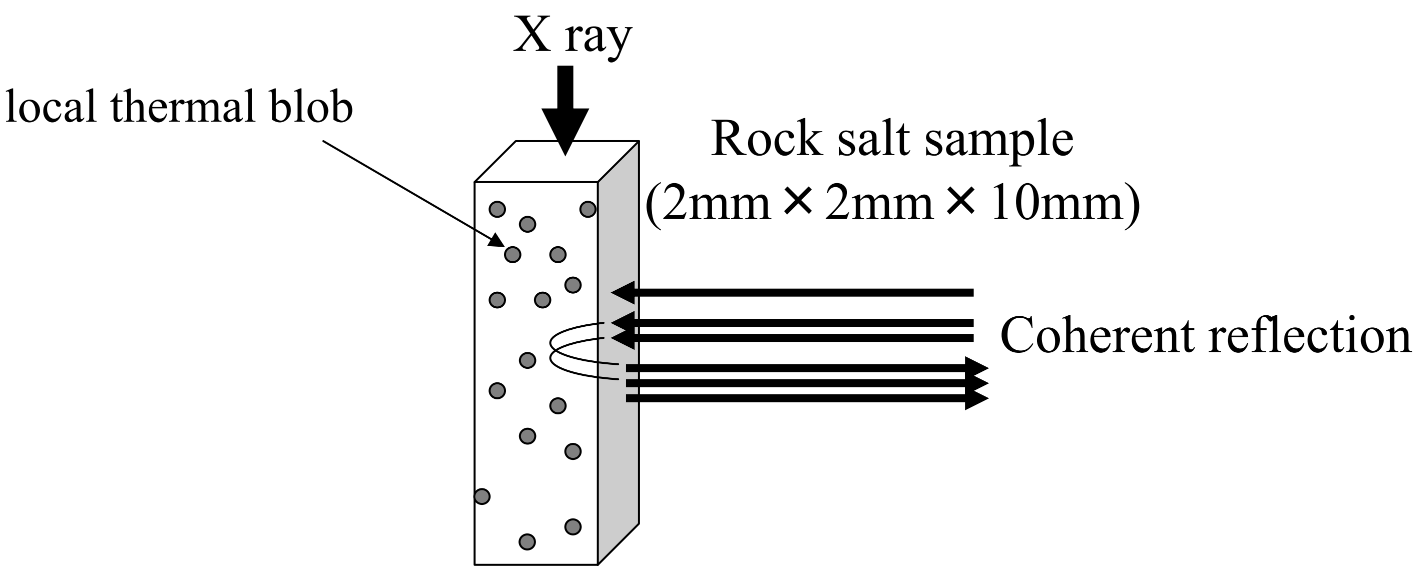






Coherent reflection of radio wave

- Increase of temperature in bulk does not explain the coherent reflection.
  - Coherency: Reflected power ∝ Square of energy deposit
  - At the beginning of irradiation, local thermal blobs are generated.



Rock salt vs. ice as reflection media

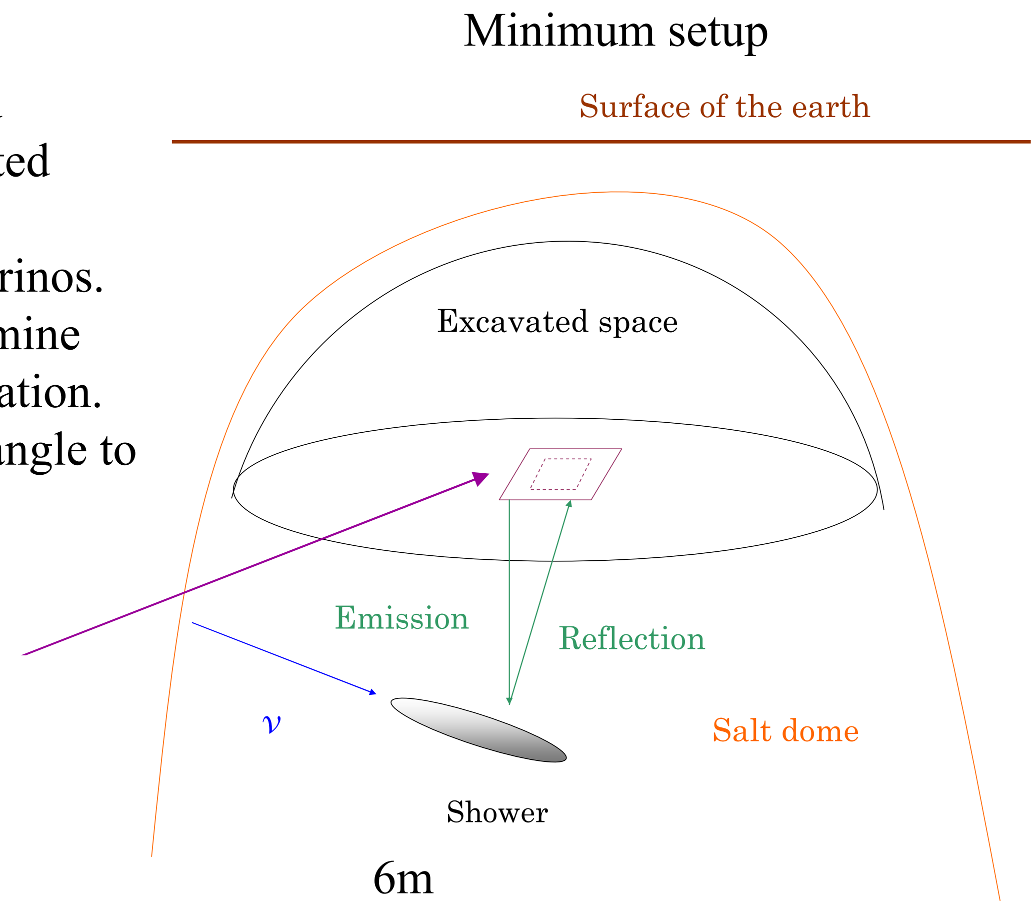
	Δ ε '/10℃	Heat capacity mJ/(mole・K)	Thermal conductivity W/(m・K)
Rock salt (20℃)	0.017	100	6
Ice (-30℃)	0.01	270	2.8

- Radio attenuation length of Antarctic ice is as long as natural rock salt.
- Ice could reflect radio wave if the reflection at rock salt is due to local thermal blobs.
- The reflection rate may be less than rock salt due to smaller permittivity change and larger heat capacity. The smaller thermal conductivity is favorable.
- Enormous Antarctic ice becomes available if the reflection is verified.

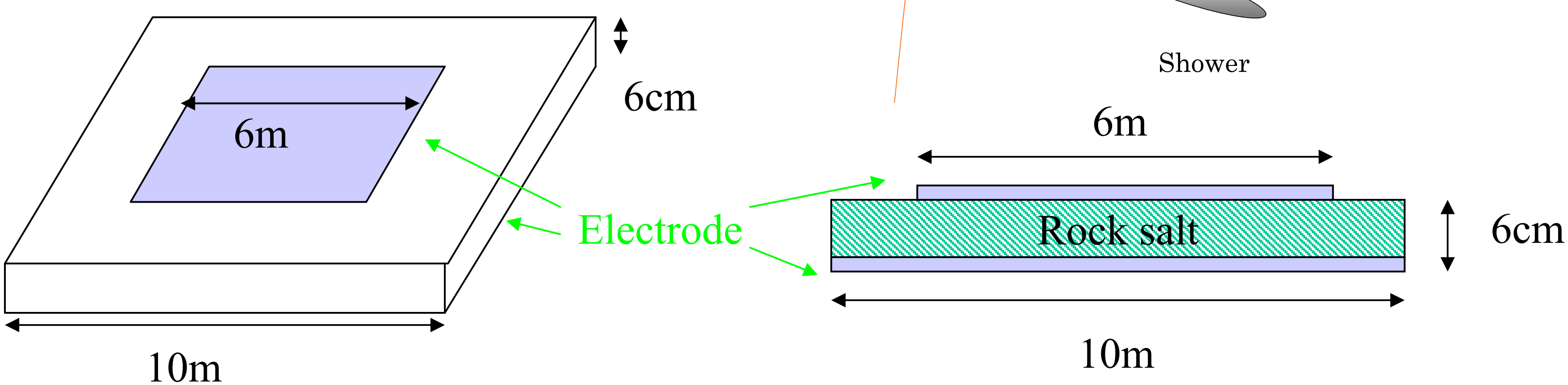
Radar method：Minimum setup

- Need no expensive boreholes.
- Utilize low frequency radio wave around 10MHz where attenuation length is expected as long as 7000m.
- Minimum setup can only count # of neutrinos.

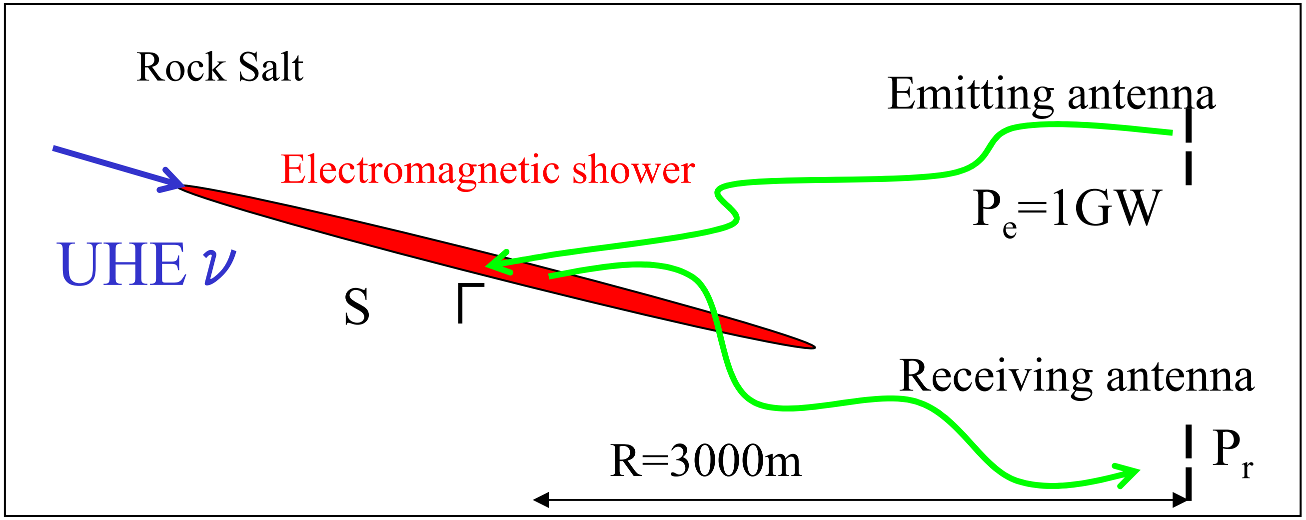
Increased receiving antennas help to determine the shower axis without directional information. Reflection efficiency is different with the angle to the antenna. Up going UHE neutrinos are absorbed by the earth.



Plane antenna on the surface（10MHz）



Receiving power vs. Range



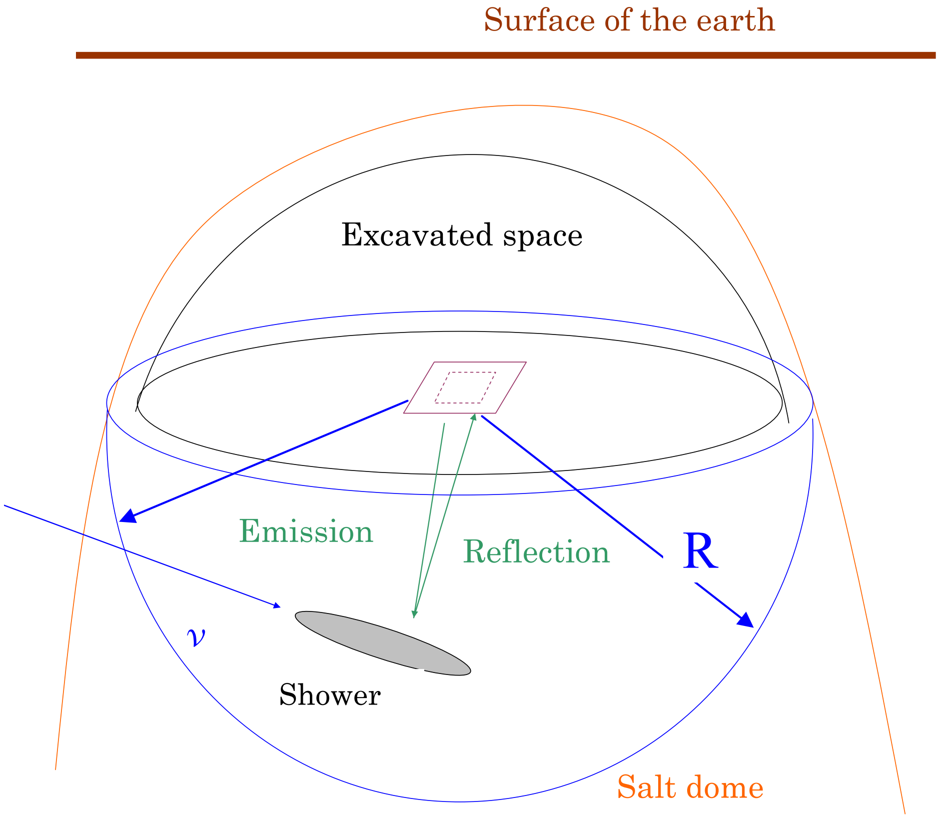
- Attenuation length in rock salt: L=7000m@ 10MHz
- Energy attenuation @R=3000m: α=(exp(-2R/L)^2=(exp(-6000/7000))^2=0.18
- Energy reflection rate: $\Gamma=10^{-6}\cdot(10^{-19}\cdot E)^2=10^{-6}$ (Shower energy: E=10^{19}eV)
- S1・S2=1 m^2: radio wave cross sections of shower and antennas
- P_e=1GW: Peak power of radar
- Receiving power: $P_r=P_e\cdot\alpha\cdot\Gamma\cdot S_1\cdot S_2\cdot(4\pi R^2)^{-2}=1.4\times10^{-14}$ W

Effective volume of rock salt for radar

E : Shower energy
Γ : Reflection efficiency
R: Rage of radar
Radar power: 1GW (Peak Power)、10MHz
Receiving power > 1×10^{-14}W

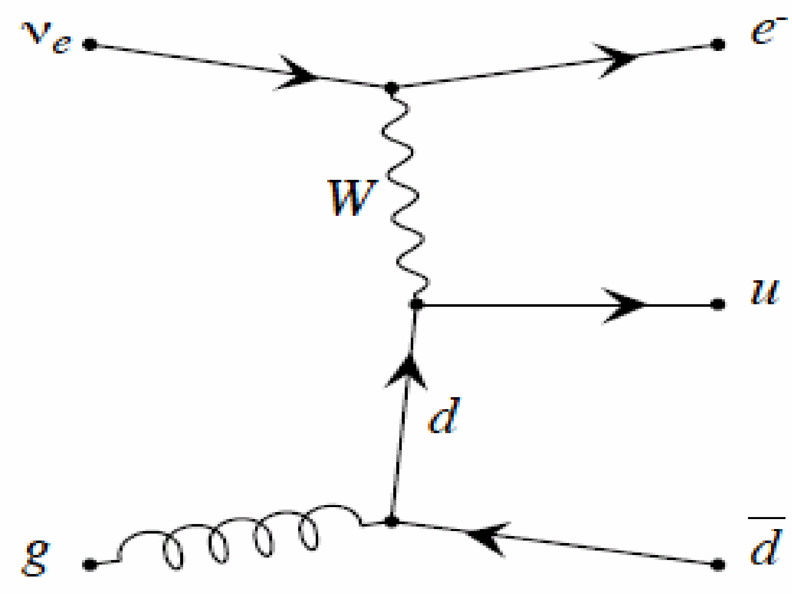
E(eV)	Γ	R/m
10^{17}	10^{-10}	469
10^{18}	10^{-8}	1310
10^{19}	10^{-6}	3180

Effective volume $\propto 2\pi R^3/3$



UHE neutrino cross section with W-gluon fusion process

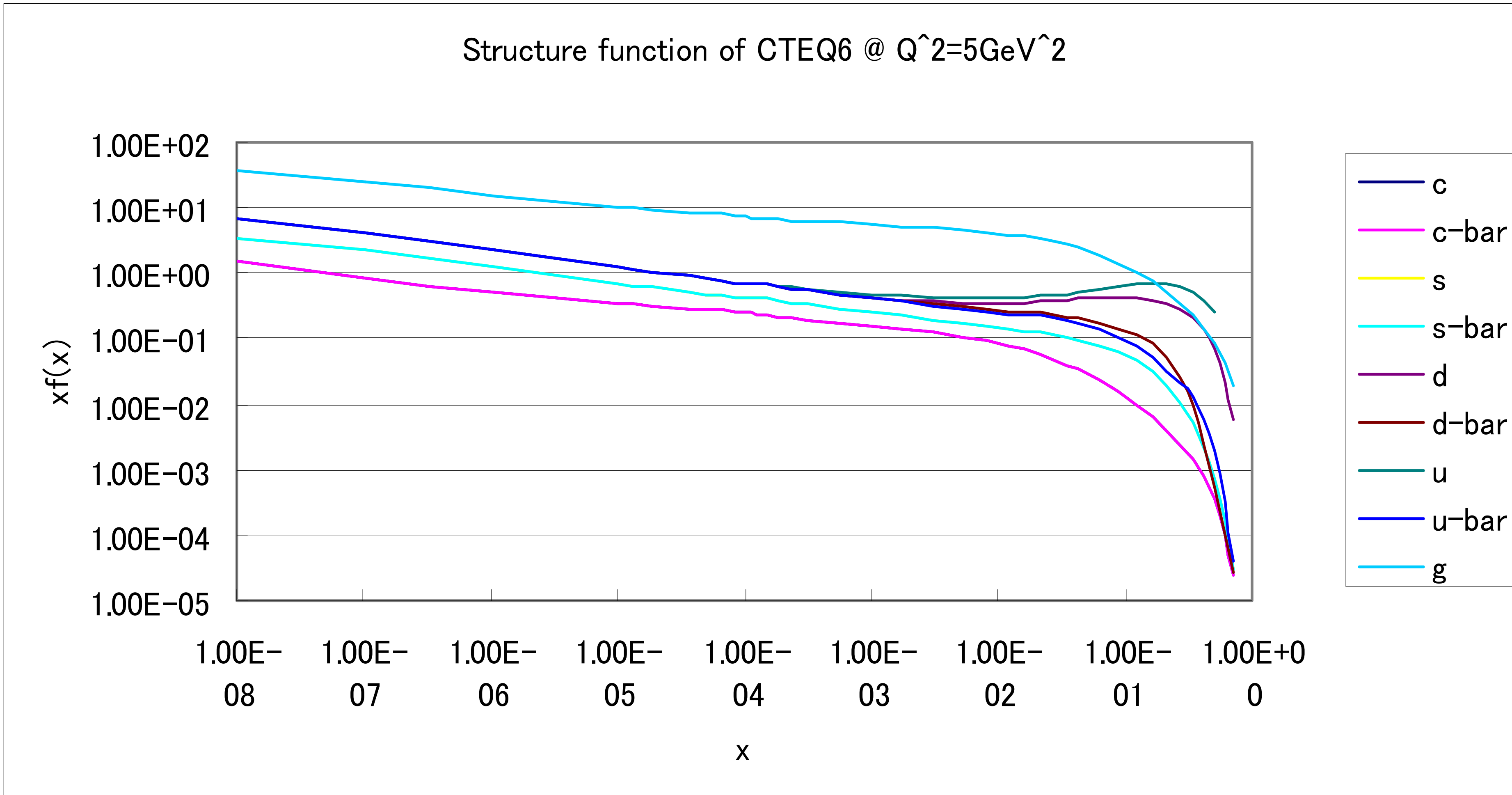
W-gluon fusion process



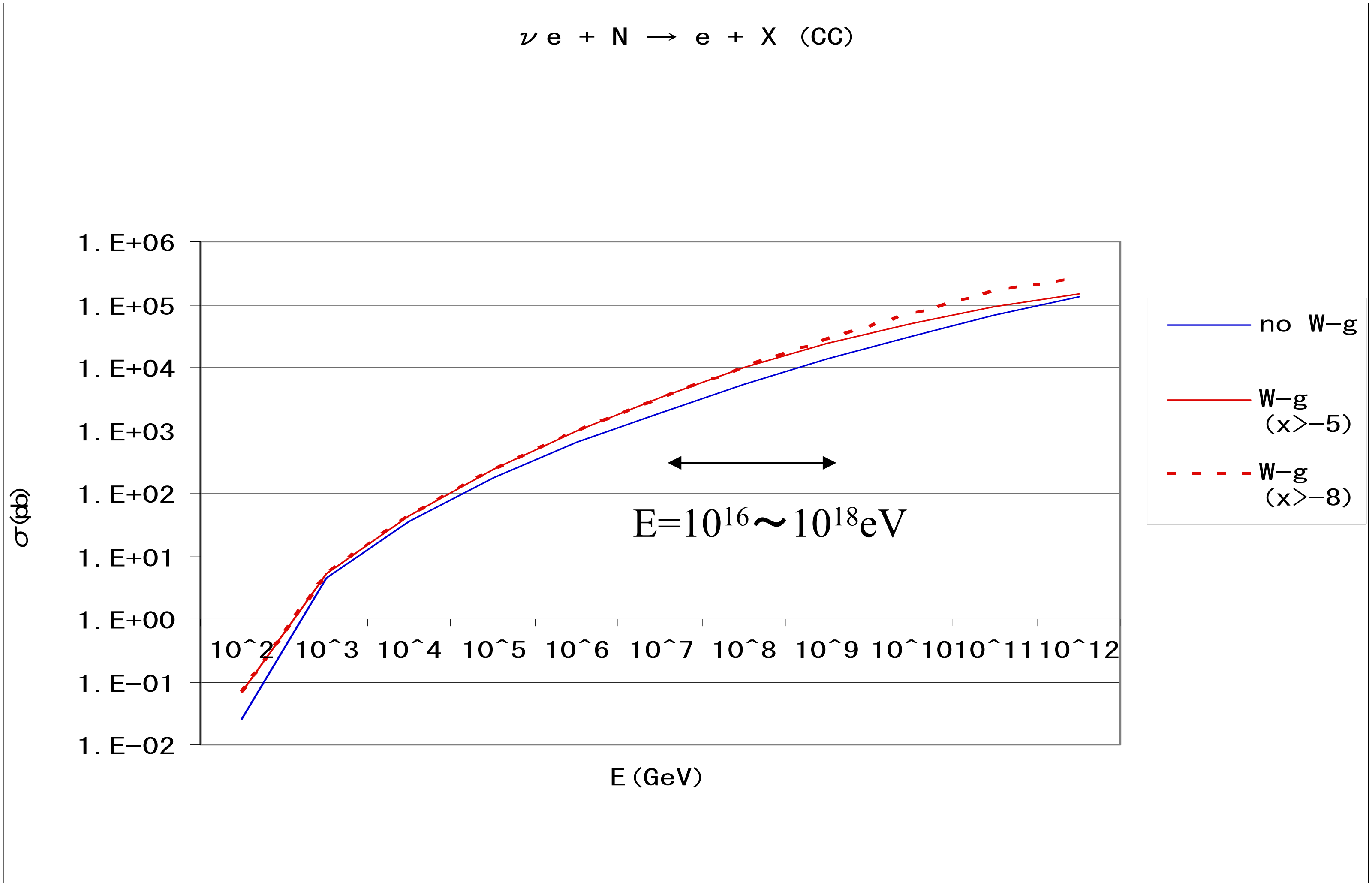
- Feynman automatic calculation program, GRACE
  Characteristics: tree & 1 loop; any # of initial and final bodies
  http://minami-home.kek.jp
- CTEQ6 proton structure function

Studied by Yuichi Chikashige, Keisuke Ibe, Tadashi Kon

Structure function of proton



Charged current cross section, $Q^2>5GeV^2$



σ (W-Gluon fusion) ≒ σ (W exchange) between E=10^{16}～10^{18}eV

σ (total) ≒ 2σ (W exchange)

Summary

- Radar method does not require expensive boreholes.
- # of GZK neutrinos/year is estimated by a simulation.

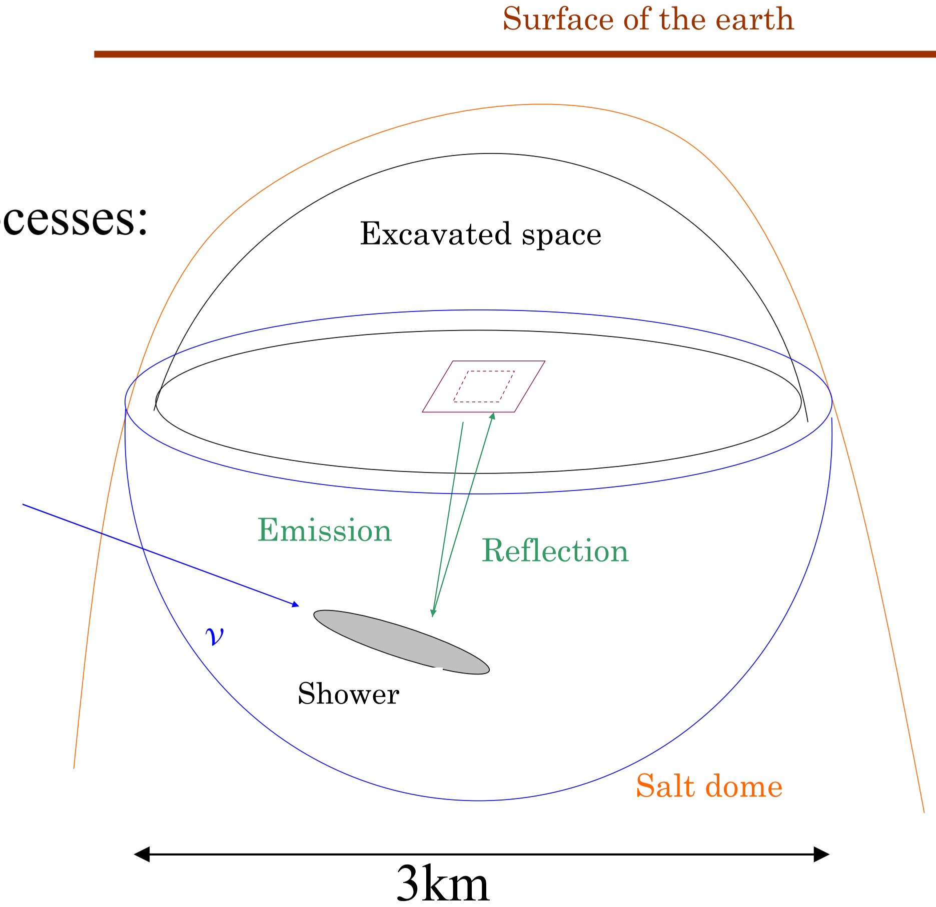
[W exchange] + [W-Gluon fusion] processes:
6～18 GZK neutrinos/year > 10^{17}eV

- Minimum setup :

# of GZK neutrinos could be counted.
High peak power radar of 1GW, otherwise array antennas of lower power are needed.

- If the reflection is due to local thermal blobs, Antarctic ice would be utilized. Acoustic wave would be reflected in a similar way .

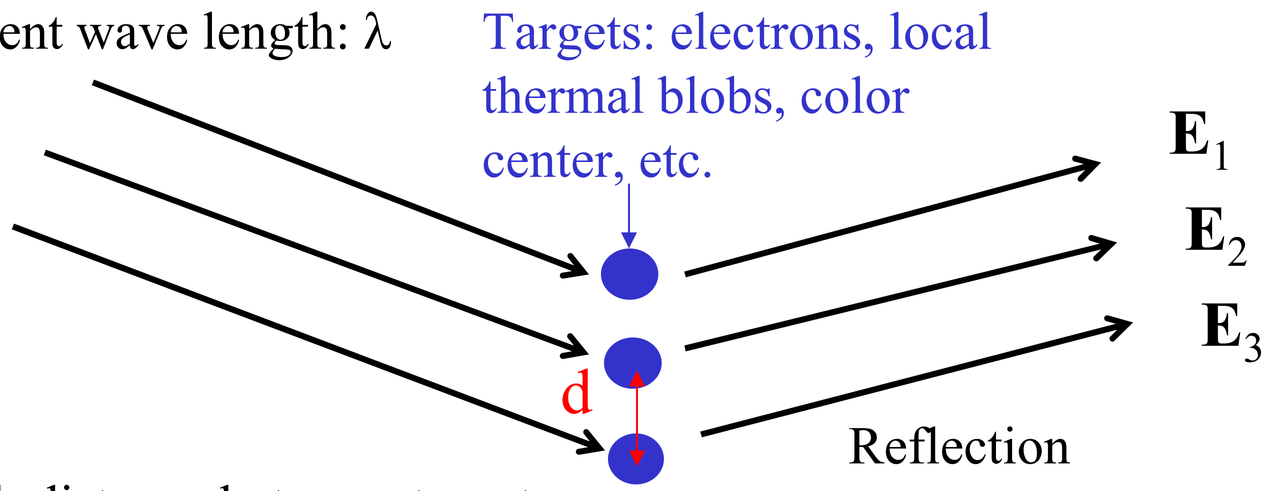
Minimum setup



Backup

Coherent scattering

Incident wave length: λ



$\lambda \gg d$: distance between targets

$$P= |\mathbf{E}_1 + \mathbf{E}_2 + \cdots + \mathbf{E}_n|^2 = |\mathbf{E}_1|^2 + |\mathbf{E}_2|^2 + \cdots + |\mathbf{E}_n|^2 + \cdots + 2\mathbf{E}_i \cdot \mathbf{E}_k + \cdots = n^x |\mathbf{E}_i|^2$$

- P: reflected power
- n: number of targets
- t: X ray integration time

If lifetime of targets is long:
$n \propto t$

$P=At^x+B$

- A, B, x: fitting parameter
- x: coherence parameter
- x=2: full coherent
- x=1: random phase

Reflected power against temperature (imaginary permittivity)

λ =0.029m (10.2GHz), ε'=5.9, L=2mm

$\tan\delta = \varepsilon''/\varepsilon'$

$L = \lambda/(\pi * \sqrt{(\varepsilon')} * \tan\delta)$

Reflection power loss: $(\exp(-0.002/L))^2$

B. Meng et al, Phys. Rev.B 53,(1996)12777

Power/2mm $\propto$ (exp(-0.002/L))^2