Structure function of excess charge in Rock Salt

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Introduction

SND group is aiming at detecting GZK ν

Standard GZK ν Flux :

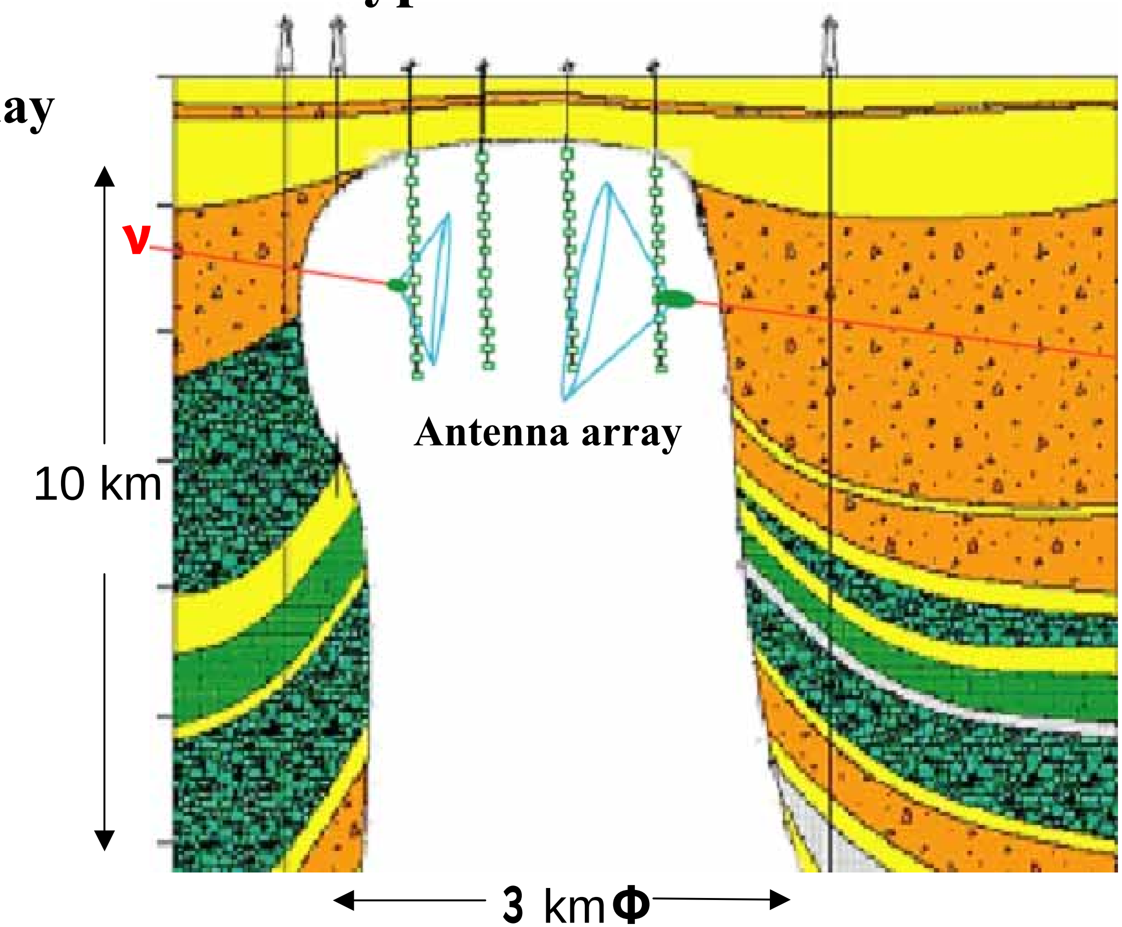
～ 1 per km^2 per day

We need a large detector !!

SND

- **Detector medium:**
  Salt dome
- **Detect Cherenkov radio emission**

Typical Salt dome

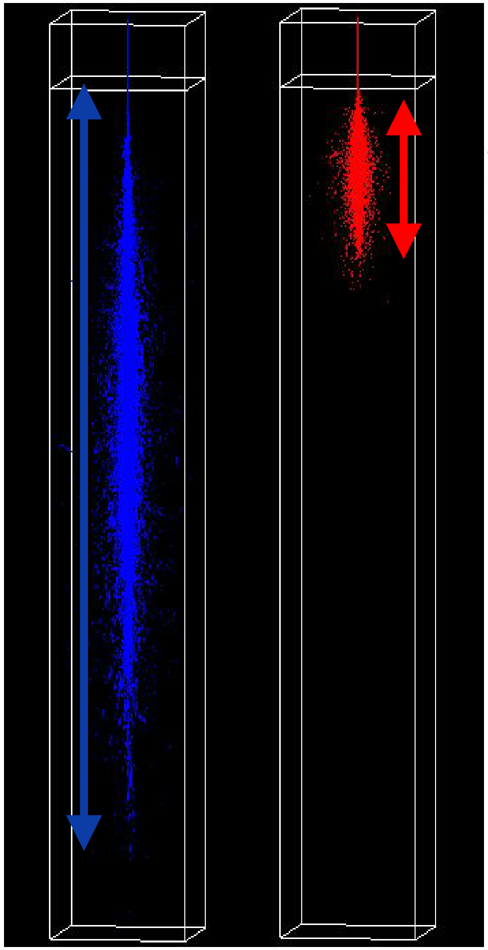


Comparison of Rock salt & Ice with high energy EM shower

	Ice	Rock salt
Refractive index *n*	1.78	2.43
Cherenkov threshold energy for electron E_{th}(KeV)	107	50
Density ρ (g/cm^3)	0.92	2.22
Radiation length t_R (cm)	36	10

- EM shower size of rock salt is small
  → Coherence is strong
- Rock salt is appropriated than ice with radio emission

1 PeV EM shower



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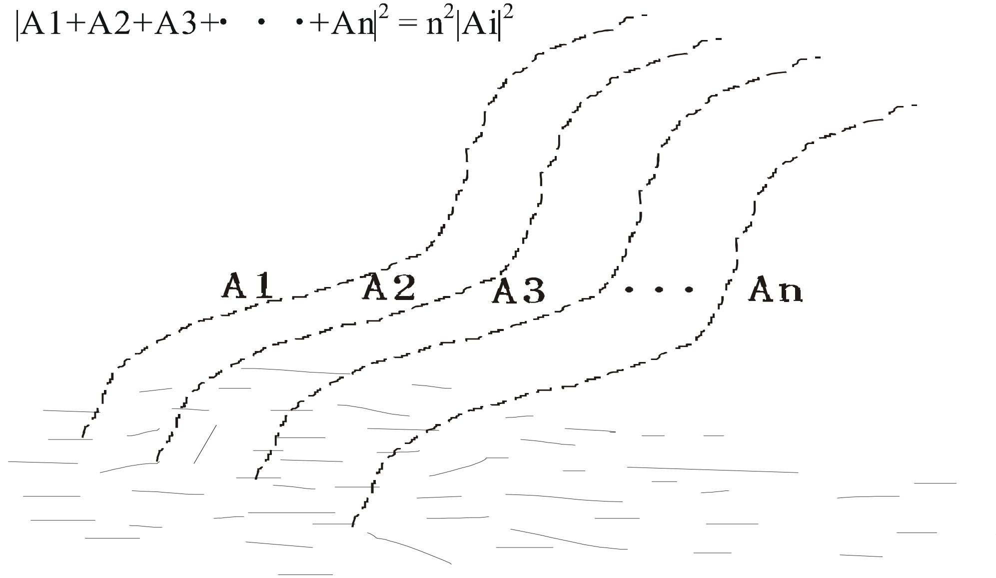
Askaryan effect
(= Coherent Cherenkov Process)

- EM cascades produced in neutrino interactions
- Number of electrons is larger than positrons in EM cascades
  : excess electrons
- Excess electrons radiate radio wave coherently
  (Distance between excess electrons << Radio wavelength)
  → Power of radio wave $\propto E^2$ (E: EM cascade energy)
  → It has been confirmed by the SLAC experiment.
  D. Saltzberg, P.Gorham et al., Phys. Rev. Lett. 86(2001)2802-2805

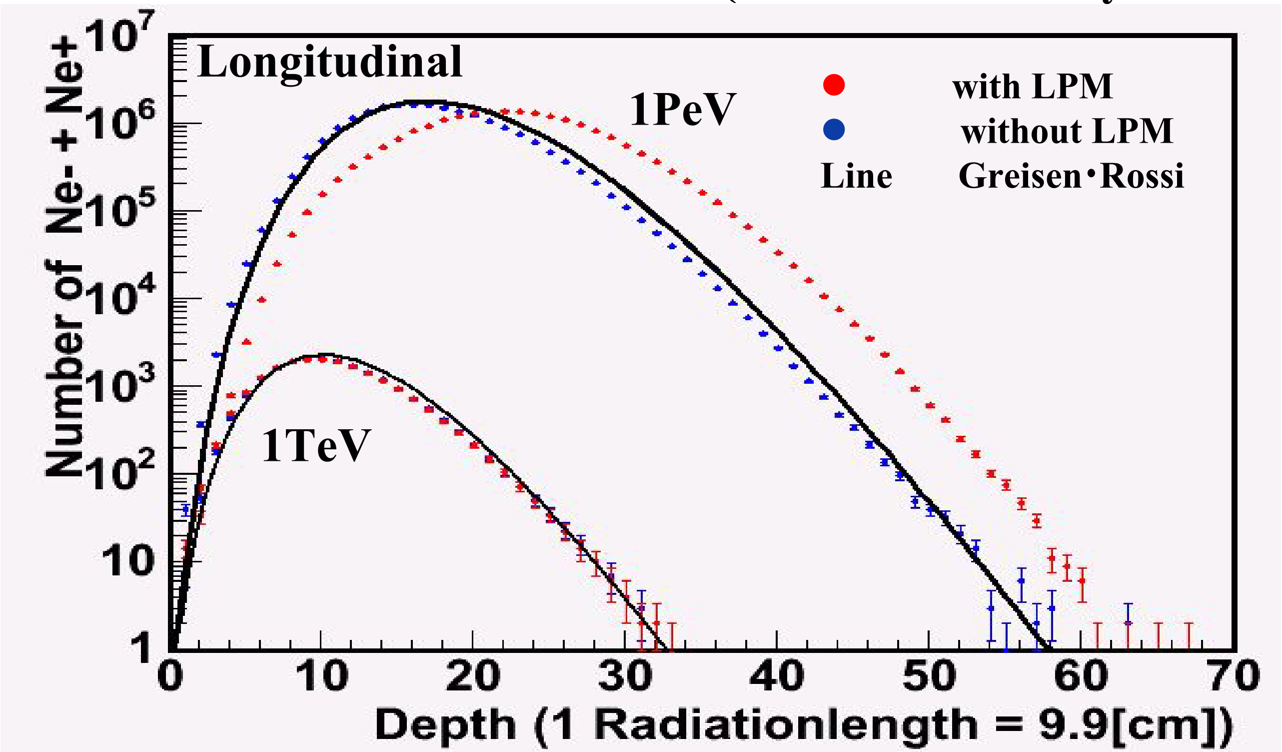
$$|A1+A2+A3+\cdots+An|^2 = n^2|Ai|^2$$

Electron or photon beam →



EM Cascade Simulation with Geant4.5.2

- Incidence electron energy : 1TeV～10PeV,   Threshold energy: 1MeV
- Without LPM: Brems.   σ(E >100TeV) = σ(E =100TeV)
  γ Conversion   σ(E >100GeV) = σ(E =100GeV)
- LPM is included in electron and positron Brems., not yet in γ Conversion
- The result was compared with other calculations
  Longitudinal : Approximation B, Greisen, Rossi
  (Review of modern physics , volume 13,1941, P240)
  Lateral : NKG function (Handbuch der PhysikXLVI/2,1967,1)



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Structure function (Longitudinal)

Greisen, Rossi

$$N(t) = \frac{0.31}{\sqrt{\ln(\frac{E_0}{\varepsilon_0})}} \exp[t(1 - \frac{3}{2}\ln\left(\frac{3t}{t+2\ln\left(\frac{E_0}{\varepsilon_0}\right)}\right))]$$

t ·· Radiation length
E_0 ·· Primary energy
ε_0 ·· Critical energy

I

$$N(t) = \frac{\alpha_L}{\sqrt{\ln\left(\frac{E_0}{\varepsilon_0}\right)}} \exp[t(1 - \beta_L \ln\left(\frac{\gamma_L t}{t+\chi_L \ln\left(\frac{E_0}{\varepsilon_0}\right)}\right))]$$

I LPM Correction

Coefficient replacement

$0.31 \rightarrow \alpha_L$ $\frac{3}{2} \rightarrow \beta_L$

$3 \rightarrow \gamma_L$ $2 \rightarrow \chi_L$

II

$$N(t) = \frac{\alpha_L \cdot 0.22}{\sqrt{\ln\left(\frac{E_0}{\varepsilon_0}\right)}} \exp[t(1 - \beta_L \ln\left(\frac{\gamma_L t}{t+\chi_L \ln\left(\frac{E_0}{\varepsilon_0}\right)}\right))]$$

II Excess electrons

→Excess track rate: $\eta_T = 0.22$ at 1PeV

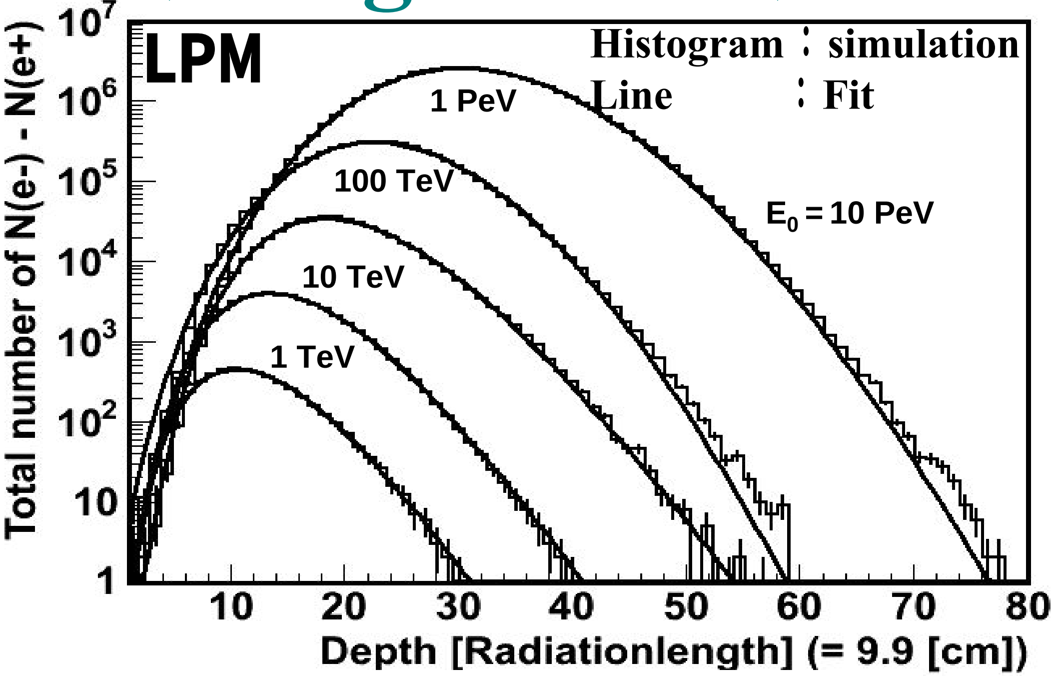
$$\eta_T = \frac{(\text{Excess track length})}{(\text{Total track length})}$$

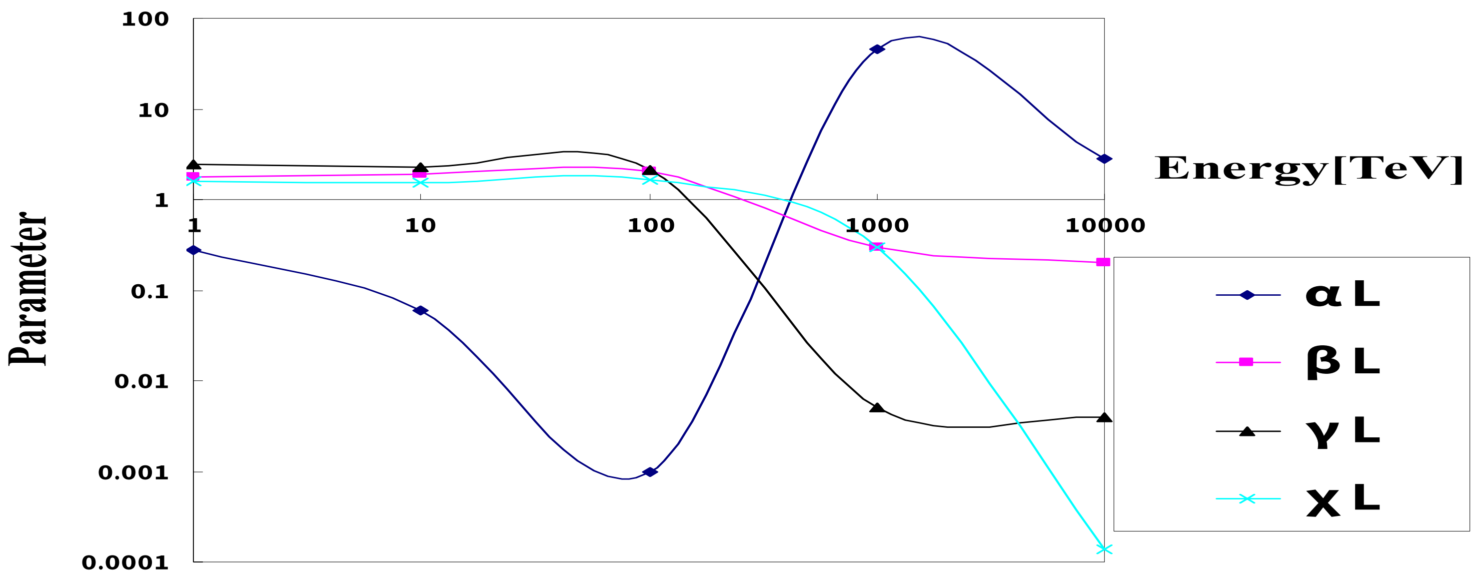
Structure function (Longitudinal)

$$N(t) = \frac{\alpha_L \cdot 0.22}{\sqrt{\ln\left(\frac{E_0}{\varepsilon_0}\right)}} \exp\left[t\left(1-\beta_L \ln\left(\frac{\gamma_L t}{t+\chi_L \ln\left(\frac{E_0}{\varepsilon_0}\right)}\right)\right)\right]$$

- $E_0 < 100\,\mathrm{TeV}$

  $\beta_L \sim 2.0,\ \gamma_L \sim 2.2,\ \chi_L \sim 1.6$





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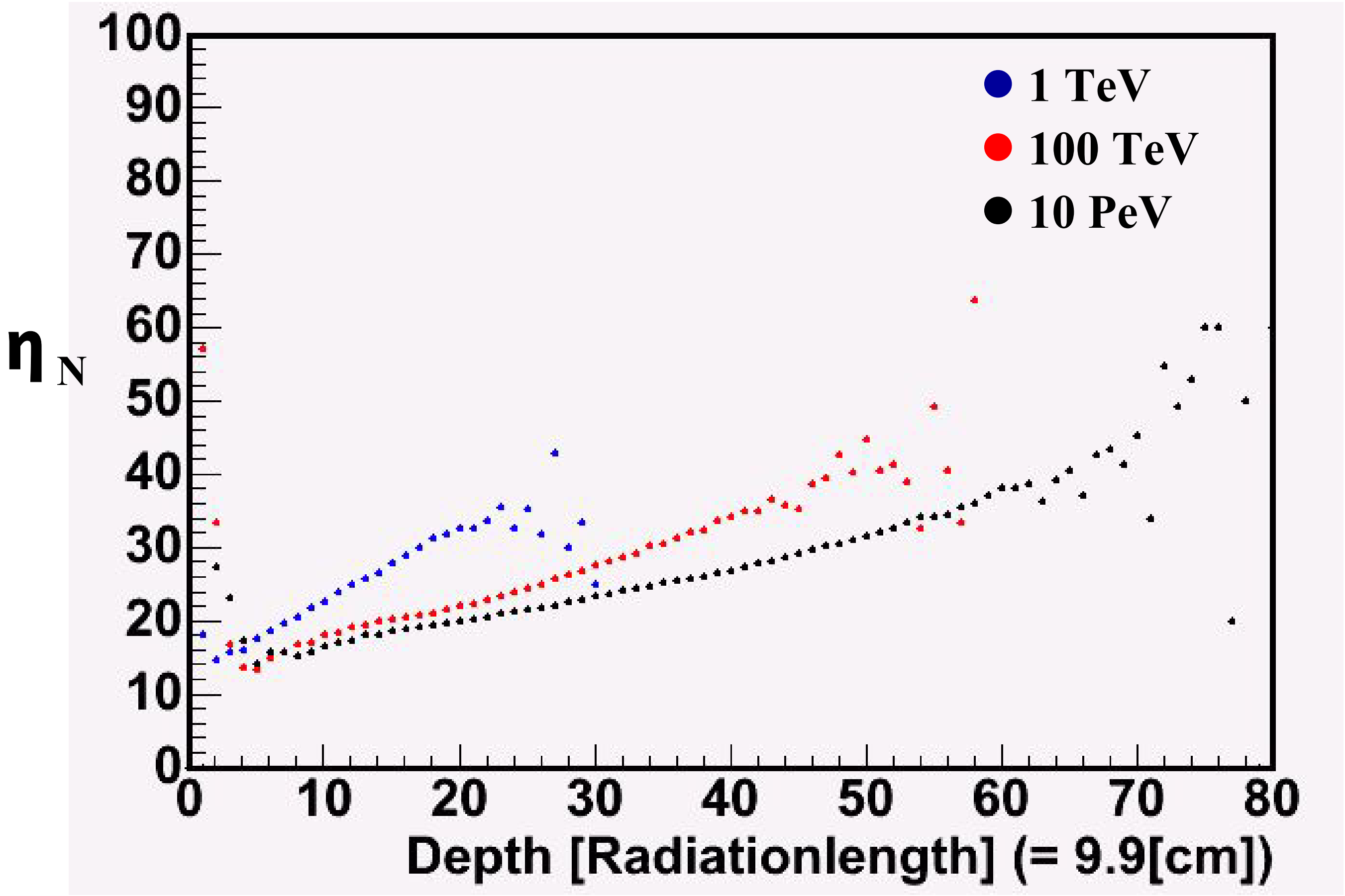
Excess number rate

- Excess number rate: $\eta_N = (Ne^- - Ne^+) / (Ne^- + Ne^+)$
- η_N increases with depth

  : γ Conversion decreases at large depth → Number of positrons decreases



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Structure function (Lateral)

NKG

$$N_{Lat}(t,t_R) = \frac{N(t_R)}{t_M^2} t^{s-1}(1+t)^{s-4.5}$$

I

$$N_{Lat}(t,t_R) = \frac{N(t_R)}{t_M^2} t^{s-\beta_T}(1+t)^{s-\gamma_T}$$

II

$$N_{Lat}(t,t_R) = \alpha_T \frac{N_L(t_R)}{t_M^2} t^{s-\beta_T}(1+t)^{s-\gamma_T}$$

I Age parameter correction

Replacement

$1 \rightarrow \beta_T$ $4.5 \rightarrow \gamma_T$

II LPM correction

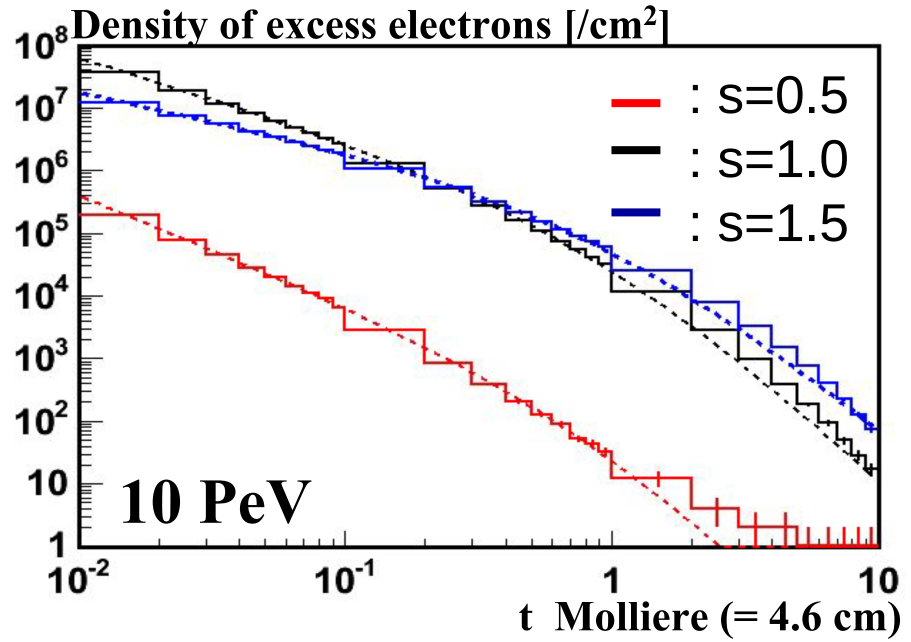
$N(t_R) \rightarrow \alpha_T N_L(t_R)$

- t ‥ Molliere length $t_M = 4.6$[cm] (Molliere length of Rock salt)
- t_R ‥ Radiation length
- $N_{Lat}(t,t_R)$ ‥ Area density [/cm²]
- $N(t_R)$ ‥ Number of total electrons in $t_R \sim t_R + 1$
- $N_L(t_R)$ ‥ Number of excess electrons in $t_R \sim t_R + 1$
- s ‥ age parameter (Shower maximum: $s = 1$)

$$s = \frac{3t_R}{t_R + 2\left(\frac{E_0}{\varepsilon_0}\right)}$$

Structure function (Lateral)

$$N_{Lat}(t,t_R) = \alpha_T \frac{N_L(t_R)}{t_M^2} t^{s-\beta_T} (1+t)^{s-\gamma_T}$$

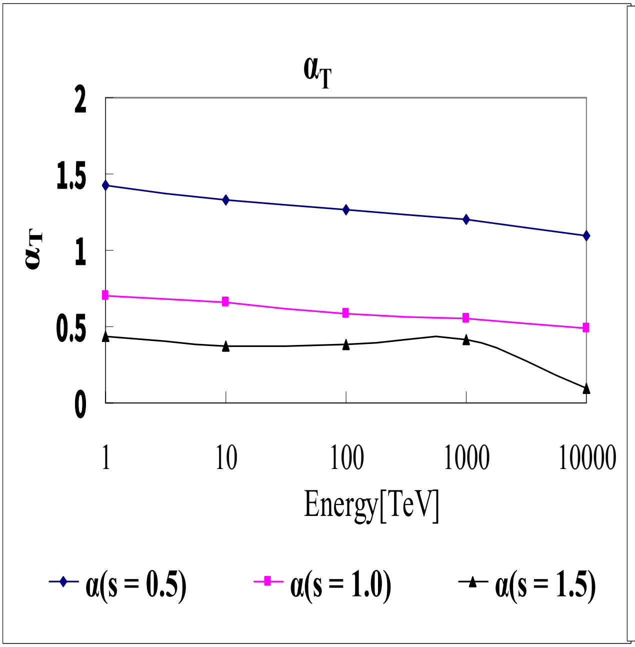


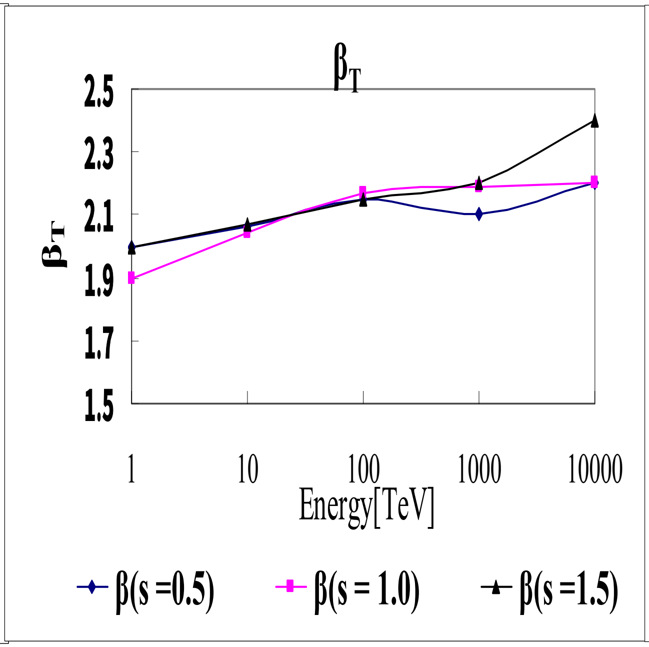
Parameter value

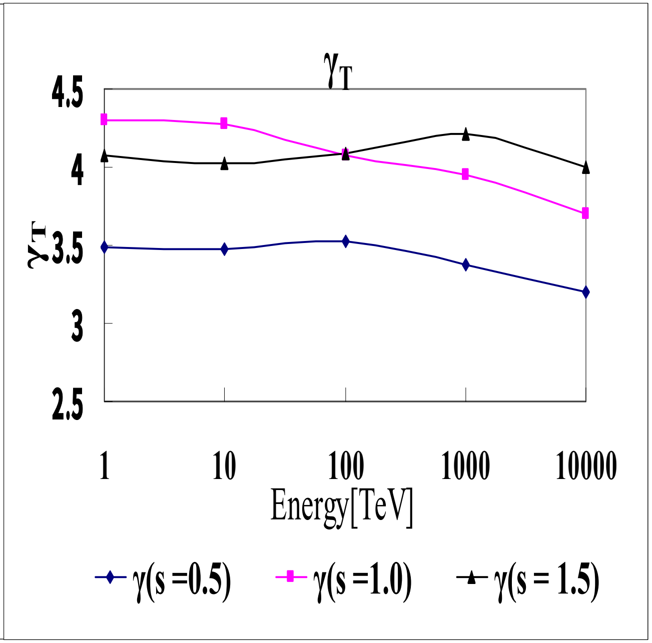
α_T = 0.3 ～ 1.5

β_T = 1.9 ～ 2.4

γ_T = 3.7 ～ 4.5 ($0.8 < s < 1.6$) 3.2 ～ 3.5 ($s < 0.8$)







Summary

- **A ultra-high energy (UHE) EM shower was simulated with Geant4.**

- **A structure function of an excess electrons was obtained with LPM effect**
- **LPM effect is important (E ≧ 1PeV)**

- **Age parameter (0.8 < s < 1.6) has been extended to 0 < s <1.6 region for lateral distribution.**

Future plan

- **Coding the program of the radio wave radiation from an UHE EM shower using our structure function**

END OF TALK