平成３０年度
共同利用提案計画実施報告

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LPM Showerのエネルギー決定問題
「10^{21}eV以上の超高エネルギー電子ニュートリノ天文学」
の基礎研究

特徴
日本の宇宙線研究が始まって以来、初めての、日本の宇宙線研究者が、世界の宇宙線研究者に先駆けて「新しい研究領域」の開拓
CRC結成以来、「初めてのこと」

何故、現在、[10^{21} eV] なのか？

　空気シャワー(ハドロン物理学)における「最高エネルギールギー」（～10^{21} eV）は、１９９３年AGASA（**Teshima**）によって「発見」、ならば、、ニュートリノ天文学（レプトン物理学）でこれを狙う

このための「第一基礎作業」は、１９９０年、３０年弱以前に、完成、

Misaki,:
Study of Electromagnetic Cascade Showers with the LPM effect in Water for the Detection of Extremely High Energy Neutrinos (Fortschritte der Physik, 38(1990)6,413-446

Aya Ishihara の{Pev 現象}　の“発見”が、A.Misaki の「10^{21} eV」構想促進に **「火をつけた」**
現在、新学術領域「ニュートリノで開く素粒子と宇宙」の科研費研究に応募　**Aya Ishihara 、懸命にこの実現を妨害**

Nishimura-Kamata function (N-K function)

NKG function

LPM effect

1990年 IceCube AMANDA 存在しない!!

↗ Fortshritte der Physik (East Germany)

Fortschr. Phys. 38 (1990) 6, 413–446

1990年

A Study of Electromagnetic Cascade Showers with the LPM Effect in Water for the Detection of Extremely High Energy Neutrinos

超高エネルギーニュートリノの検出

An application of the matrix method to LPM showers

AKEO MISAKI

→ 岬 暁夫

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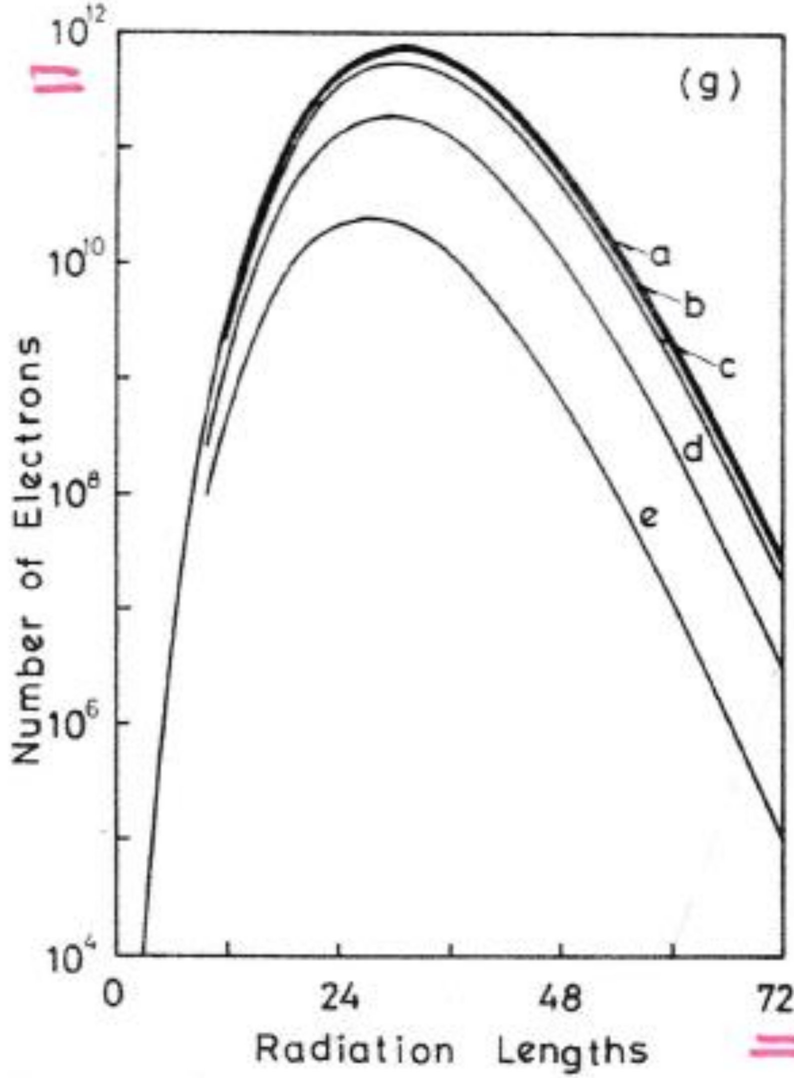
Summary

The matrix method given by Fujimaki and Misaki is proved to be a powerful means for the calculations of electromagnetic cascade showers at extremely high energies. The method is essentially simple and has wide applications for the calculation of cascade showers. This method is used for the calculation of the cascade showers with the LPM effect in water, for the detection of extremely high energy neutrinos. The characteristics of LPM showers in water are extracted referring to cascade showers in the absence of the LPM effect.



平均的描像

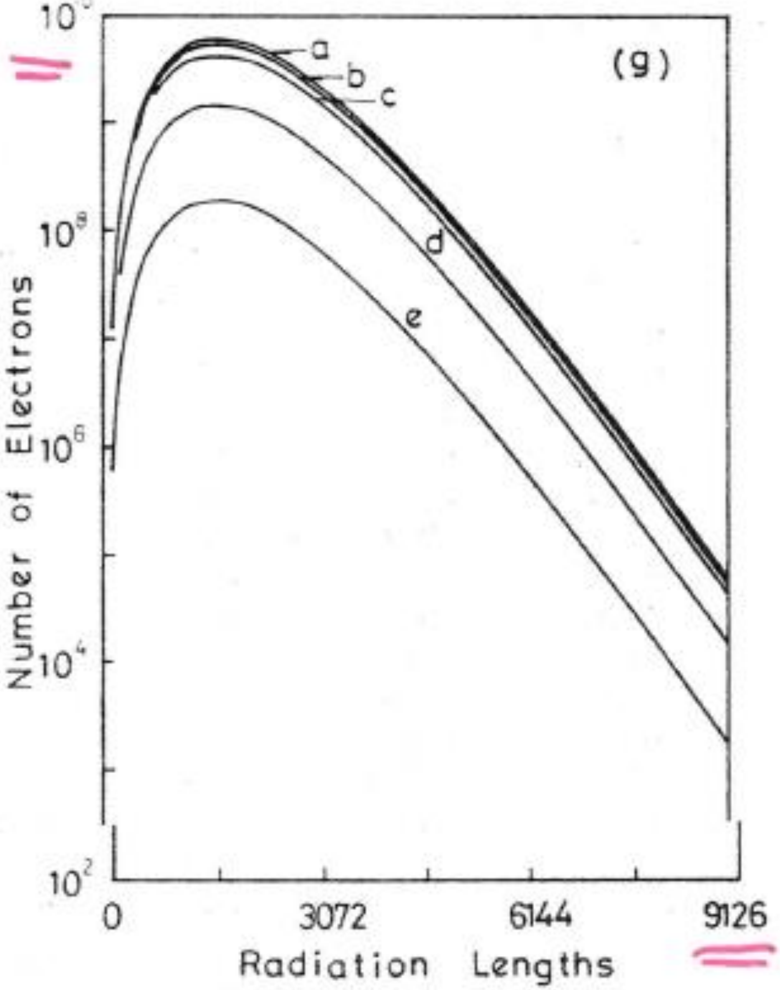
BH Shower

10^{21} eV

under Appro. B

1990年

Fig. 2g: Transition curves of electron numbers in water under Approximation B initiated by a photon of 10^{21} eV for various threshold energies. The letter attached to each curve denotes the threshold energies: $a = 10^3$ eV, $b = 10^6$ eV, $c = 10^7$ eV, $d = 10^8$ eV, $e = 10^9$ eV



LPM shower

10^{21} eV

1990年

Fig. 3g: Transition curves of electron number in water in the presence of the LPM effect including ionization loss. The primary energy is 10^{21} eV and the letter attached to each curve denotes the threshold energy: $a = 10^{5}$ eV, $b = 10^{6}$ eV, $c = 10^{7}$ eV, $d = 10^{8}$ eV, $e = 10^{9}$ eV

平均的描像

From the law of energy conservation, we obtain

$$F_{\mathrm{LPM(BH)}}(E_0/\varepsilon, t = \infty) = 1. \qquad (12)$$

シャワーカーブにおける物理量のLPMとBHの相違

(カッコ内はBH)

Table 5

Numerical values for electron number at shower maximum, N_{max}, depth of shower maximum, T_{max} and full width half maximum, FWHM, in both BH and LPM showers including ionization loss in water. Numerical values without parenthese are due to a LPM shower, while the corresponding ones in parentheses are due to a BH shower

E_0/eV	10^{15}	10^{16}	10^{17}	10^{18}	10^{19}	10^{20}	10^{21}
N_{max}	$1.04 \cdot 10^6$ ($1.07 \cdot 10^6$)	$8.31 \cdot 10^6$ ($1.00 \cdot 10^7$)	$4.58 \cdot 10^7$ ($9.48 \cdot 10^7$)	$1.73 \cdot 10^8$ ($9.04 \cdot 10^8$)	$5.82 \cdot 10^8$ ($8.63 \cdot 10^9$)	$1.91 \cdot 10^9$ ($8.26 \cdot 10^{10}$)	$6.16 \cdot 10^9$ ($7.97 \cdot 10^{11}$)
T_{Nmax}	18 (r.l.) (17 (r.l.))	24 (r.l.) (19 (r.l.))	38 (r.l.) (22 (r.l.))	78 (r.l.) (24 (r.l.))	200 (r.l.) (26 (r.l.))	569 (r.l.) (29 (r.l.))	1 696 (r.l.) (31 (r.l.))
FWHM	13 (r.l.) (12 (r.l.))	16 (r.l.) (13 (r.l.))	28 (r.l.) (14 (r.l.))	75 (r.l.) (15 (r.l.))	223 (r.l.) (15 (r.l.))	676 (r.l.) (16 (r.l.))	2 049 (r.l.) (17 (r.l.))

Nmax

Tmax

FWHM

In Table 6, the fractional dissipated energies are given for primary energies from 10^{15} eV to 10^{21} eV in a LPM shower and a BH shower, respectively. Comparing LPM showers with BH showers, it reveals that we need much more material for the design of a calorimeter in which the LPM showers are absorbed than assumed usually at higher energy. At a primary energy of 10^{21} eV, we need one hundred times as much material for the absorption of the cascade shower in the presence of the LPM effect than in the absence of the effect!!

シャワーカーブにおける物理量のLPMとBHの相違（カッコ内はBH）

Table 5. Numerical values for electron number at shower maximum, N_{max}, depth of shower maximum, T_{max}, and full width half maximum, FMHM, in both BH and LPM showers including ionization loss in water. In each row, numerical values on upper row are due to a LPM shower, while the corresponding ones on lower row are due to a BH shower.

E_0/eV	10^{15}	10^{16}	10^{17}	10^{18}	10^{19}	10^{20}	10^{21}
N_{max}	1.04×10^6	8.31×10^6	4.58×10^7	1.73×10^8	5.82×10^8	1.91×10^9	6.16×10^9
	1.07×10^6	1.00×10^7	9.48×10^7	9.04×10^8	8.63×10^9	8.26×10^{10}	7.97×10^{11}
T_{max}	18 (r.l.)	24 (r.l.)	38 (r.l.)	78 (r.l.)	200 (r.l.)	569 (r.l.)	1696 (r.l.)
	17 (r.l.)	19 (r.l.)	22 (r.l.)	24 (r.l.)	26 (r.l.)	29 (r.l.)	31 (r.l.)
$FWHM$	13 (r.l.)	16 (r.l.)	28 (r.l.)	75 (r.l.)	223 (r.l.)	676 (r.l.)	2049 (r.l.)
	12 (r.l.)	13 (r.l.)	14 (r.l.)	15 (r.l.)	15 (r.l.)	16 (r.l.)	17 (r.l.)

Reproduced from: A.Misaki, Fortschr. Phys. 38 (1990) 413-446.

Table 6

Fractional dissipated energies of electrons in water in both LPM and BH showers, for primary energies from 10^{15} eV to 10^{21} eV

F_{Water}	10^{15} eV	10^{16}	10^{17}	10^{18}	10^{19}	10^{20}	10^{21}
0.1	12.6 (11.6) (r.l.)	17.0 (13.6)	27.0 (15.4)	51.5 (17.4)	124 (19.3)	339 (21.3)	1001 (23.6)
0.2	14.5 (13.6)	19.5 (15.6)	31.1 (17.7)	62.3 (19.7)	154 (21.9)	441 (23.9)	1289 (25.9)
0.3	16.1 (15.0)	21.5 (17.3)	34.4 (19.2)	70.8 (21.5)	180 (23.7)	510 (25.8)	1529 (28.0)
0.4	17.3 (16.4)	23.2 (18.7)	37.6 (20.8)	78.9 (23.1)	203 (25.4)	582 (27.5)	1753 (29.8)
0.5	18.8 (17.7)	24.8 (19.9)	40.6 (22.3)	86.9 (24.6)	227 (26.9)	655 (29.2)	1982 (31.5)
0.6	20.1 (19.0)	26.5 (21.4)	43.8 (23.8)	95.4 (26.2)	253 (28.6)	734 (30.9)	2224 (33.3)
0.7	21.5 (20.4)	28.4 (22.9)	47.3 (25.5)	105 (27.9)	281 (30.4)	823 (32.8)	2488 (35.2)
0.8	23.3 (22.1)	30.6 (24.8)	51.9 (27.3)	117 (29.9)	318 (32.5)	935 (35.0)	2866 (37.5)
0.85	24.4 (23.3)	32.1 (25.9)	54.1 (28.6)	125 (31.2)	341 (33.8)	1007 (36.4)	3106 (38.9)
0.9	25.9 (24.7)	33.9 (27.4)	58.8 (30.1)	134 (32.9)	371 (35.3)	1102 (38.0)	3435 (40.7)
0.95	27.9 (26.8)	36.3 (29.4)	62.8 (32.1)	149 (34.9)	415 (37.7)	1246 (40.3)	3985 (43.0)
0.98	29.9 (28.5)	38.6 (31.5)	68.6 (34.7)	163 (36.9)	461 (40.5)	1404 (42.6)	4848 (45.6)

10²¹!

エネルギー損失の比

9割8分エネルギーを失なうに必要な深さ

平均的描像

LPMは4848 r.l
BHは45.6 r.l
の深さを必要とする

F_{water}	10^{15}	10^{16}	10^{17}	10^{18}	10^{19}	10^{20}	10^{21}
0.1	12.6 (11.6)	17.0 (13.6)	27.0 (15.4)	51.5 (17.4)	124 (19.3)	339 (21.3)	1001 (23.6)
0.2	14.5 (13.6)	19.5 (15.6)	31.1 (17.7)	62.3 (19.7)	154 (21.9)	441 (23.9)	1289 (25.9)
0.3	16.1 (15.0)	21.5 (17.3)	34.4 (19.2)	70.8 (21.5)	180 (23.7)	510 (25.8)	1529 (28.0)
0.4	17.3 (16.4)	23.2 (18.7)	37.6 (20.8)	78.9 (23.1)	203 (25.4)	582 (27.5)	1753 (29.8)
0.5	18.8 (17.7)	24.8 (19.9)	40.6 (22.3)	86.9 (24.6)	227 (26.9)	655 (29.2)	1982 (31.5)
0.6	20.1 (19.0)	26.5 (21.4)	43.8 (23.8)	95.4 (26.2)	253 (28.6)	734 (30.9)	2224 (33.3)
0.7	21.5 (20.4)	28.4 (22.9)	47.3 (25.5)	105 (27.9)	281 (30.4)	823 (32.8)	2488 (35.2)
0.8	23.3 (22.1)	30.6 (24.8)	51.9 (27.3)	117 (29.9)	318 (32.5)	935 (35.0)	2866 (37.5)
0.85	24.4 (23.3)	32.1 (25.9)	54.1 (28.6)	125 (31.2)	341 (33.8)	1007 (36.4)	3106 (38.9)
0.9	25.9 (24.7)	33.9 (27.4)	58.8 (30.1)	134 (32.9)	371 (35.3)	1102 (38.0)	3435 (40.7)
0.95	27.9 (26.8)	36.3 (29.4)	62.8 (32.1)	149 (34.9)	415 (37.7)	1246 (40.3)	3985 (43.0)
0.98	29.9 (28.5)	38.6 (31.5)	68.6 (34.7)	163 (36.9)	461 (40.5)	1404 (42.6)	4848 (45.6)

Table 6. Fractional dissipated energies of electrons in water in both LPM and BH showers, for primary energies from 10^{15} eV to 10^{21} eV.

エネルギー損失の比

LPMは4848 r.l.
BHは45.6 r.l.
の深さを必要とする

9割8分エネルギーを
失うのに必要な深さ

平均的描像

Reproduced from: A.Misaki, Fortschr. Phys. 38 (1990) 413-446.

J. Phys. G: Nucl. Part. Phys. **17** (1991) 719–732. Printed in the UK

1991年!!

LPM showerにおける「平均値概念」の無意味さを指摘した世界最初の論文

On the characteristics of individual cascade showers with the LPM effect at extremely high energies

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§ Faculty of General Eduction, Hirosaki University, Hirosaki, 036 Japan
|| Department of Physics, Saitama University, Japan

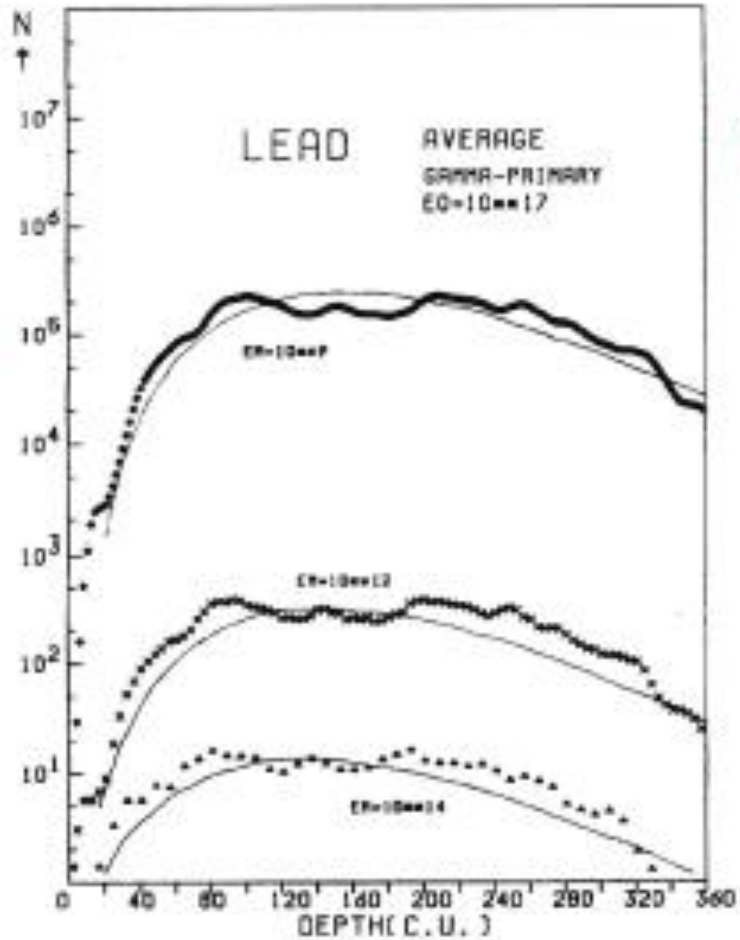
Received 23 July 1990, in final form 26 November 1990

Abstract. Characteristics of individual electromagnetic cascade showers in lead have been studied taking into consideration the Landau–Pomeranchuk–Migdal effect (LPM effect) through Monte Carlo simulation techniques. A total of 20 LPM showers have been simulated assumed to be initiated by photons or electrons of energy 10^{17} eV. We find that each of the twenty simulated showers shows multi-peak structure during its longitudinal development, unlike the smooth cascade curve obtained for showers simulated using Bethe–Heitler cross sections. It is shown that thin detectors with a depth of only few tens of radiation lengths, though good for observing showers without the LPM effect, do not provide reliable information on the real development of the LPM shower in extremely high energy regions.

4. Results and discussion

A total of 20 LPM showers have been simulated for a fixed value of 10^{17} eV for E_0 and 10^9 eV for minimum cut-off energy E_{min}, of these showers ten were initiated by photons and the other ten by electrons. The details of the simulation procedure are

$E_0=10^{17}$ eV
(全部)
20例の平均値



同じシャワーで
Ethreshold
を変えて
みてみる
平均値!!

Figure 3. The average number N of electrons in photon-initiated showers of primary energy $E_0=10^{17}$ eV in lead as a function of depth in the absorber. The three curves refer to three different values of cutoff energy E_R: 10^9, 10^{12} and 10^{14} eV. The full smooth curves give the corresponding results obtained from the numerical method.

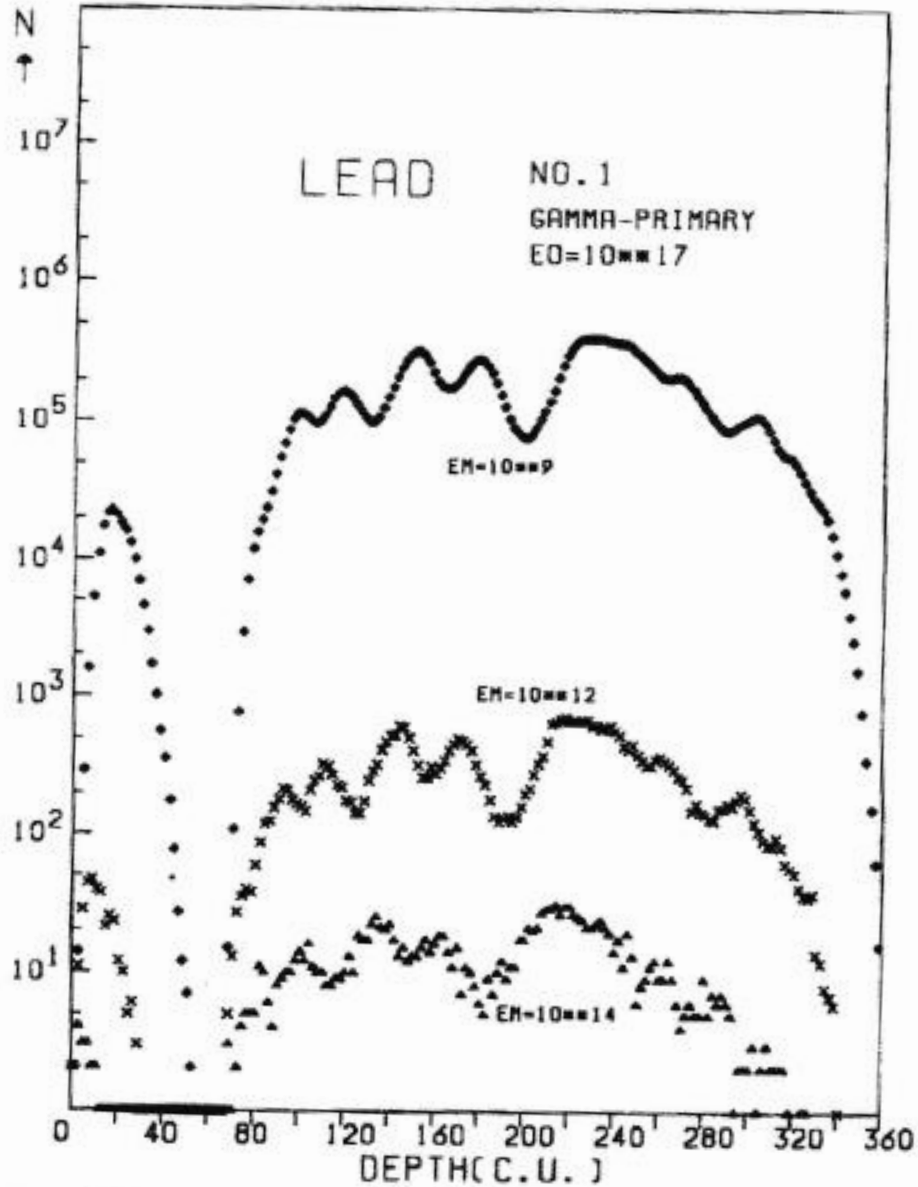


Figure 7. Number N of electrons in a photon-initiated shower (no. 1) of primary energy $E_0 = 10^{17}$ eV in lead as a function of depth in the absorber. The three curves refer to three different values of cutoff energy E_m, 10^9, 10^{12} and 10^{14} eV.

実際の1例

Ethreshold
を変化させて
シャワーカーブ
を眺める

実際のシャワー

平均値と比較せよ!!

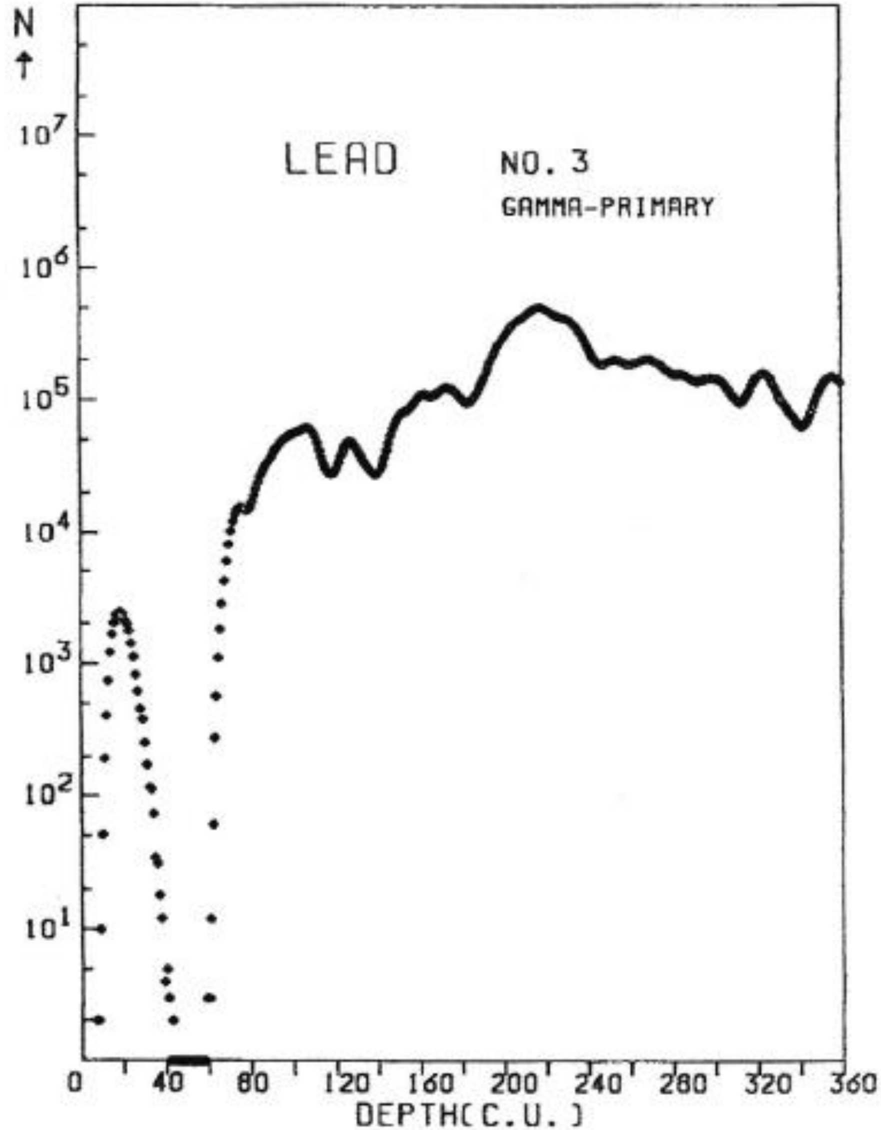


Figure 8. Number N of electrons in a photon-initiated shower (no. 3) in lead with $E_0 = 10^{17}$ eV and $E_m = 10^9$ eV.

本講演の最終目的

若い研究者に提案：前人未踏の新しい研究分野：「10^{21} eV以上の電子ニュートリノ天文学の基礎研究」をロシアの若い世代　——中国の若い世代も視野に容れて　——の共同研究を国際的に行おうではないか。　提案者の岬　暁夫は、現在８３歳、遠からず、あの世に行く。　あとは、諸君の時代がくる。
(連絡先：amisaki@sand.ocn.ne.jp、あるいは、akeobarn@gmail.com)

岬　暁夫の「独断と偏見」によれば、現在のCRCの研究に夢に満ちた実験計画は一つもない。　反論があれば、大歓迎。日本製のアイディアで、世界をのし上がっていく研究など皆無。

CRC 実行委を牛耳る“実力者”で世界を睥睨できる研究者は皆無。　かれらの本質は、“役人”研究者。　これに従っていけば、若い研究者の末路は明らかである。

研究成果は以下で発表

26th Extended European Cosmic Ray Symposium
35th Russian Cosmic Ray Conference
Altai State University / Barnaul Belokurikha Russia / July 6-10, 2018

A historical Introduction to the LPM shower

A. Misaki

Proc.(.Supple).Proc. [26^{th} E+CRC 35^{th} RCRC]
(In press, July 5-to10 , Barnaul, Russia)

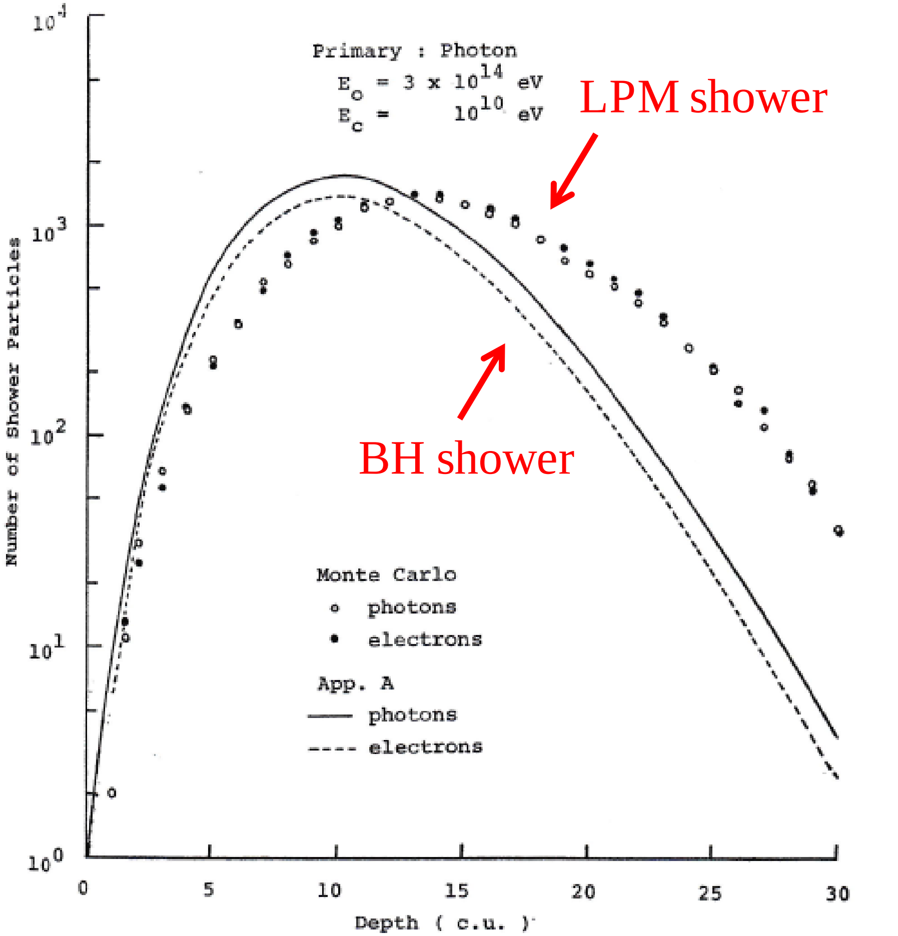


Figure 2. Transition curves for a photon-initiated shower with energy $E_0 = 3 \times 10^{14}$ eV in lead. Reproduced from Proc.Inter. Cosmic Ray Symp. on High.Ener.Phys. 148(1974),Tokyo

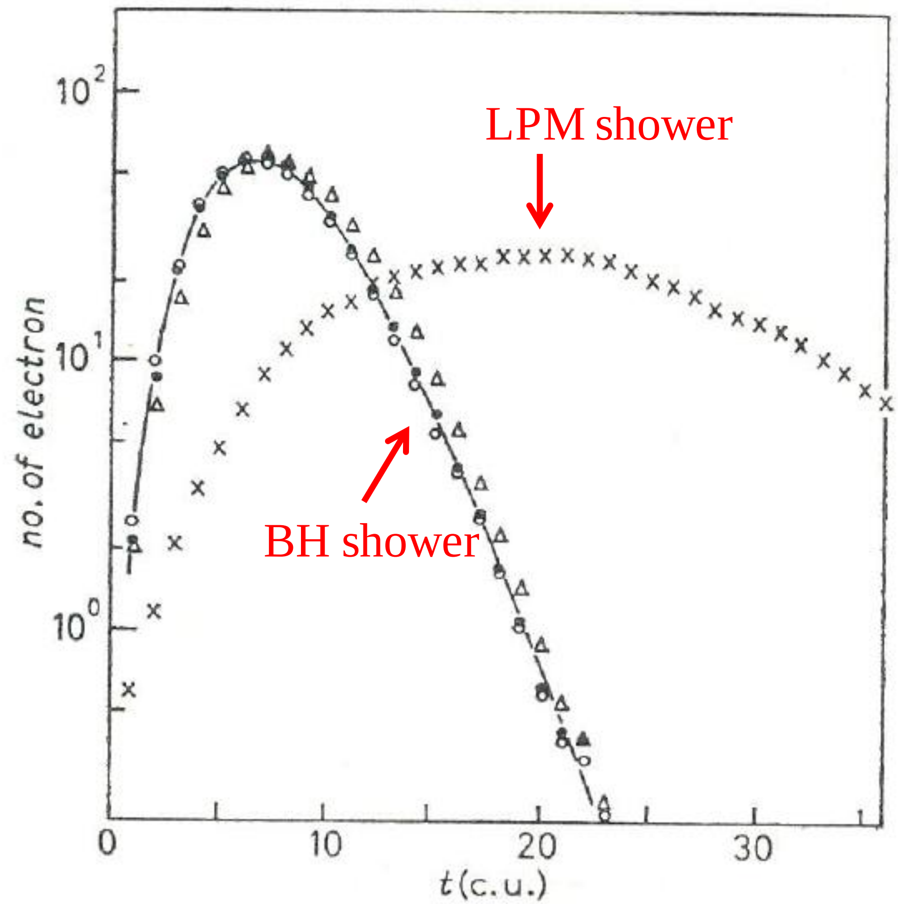
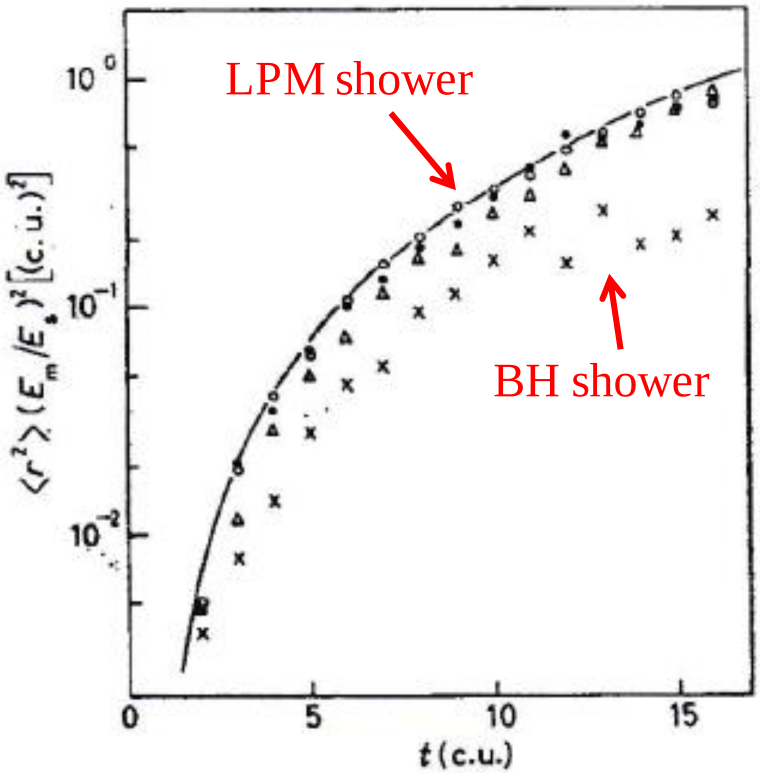


Figure 3. Transition curves of mean number of electrons in lead. Open circles show the results with Bethe-Heitler cross-sections ($E_0/E_{min}=10^3$) and closed circles, triangles and crosses show the results including the LPM effect initiated by photons with energies $E_0=10^{11}$, 10^{13}, 10^{15} eV and $E_m=10^8$, 10^{10}, 10^{12} eV, respectively.



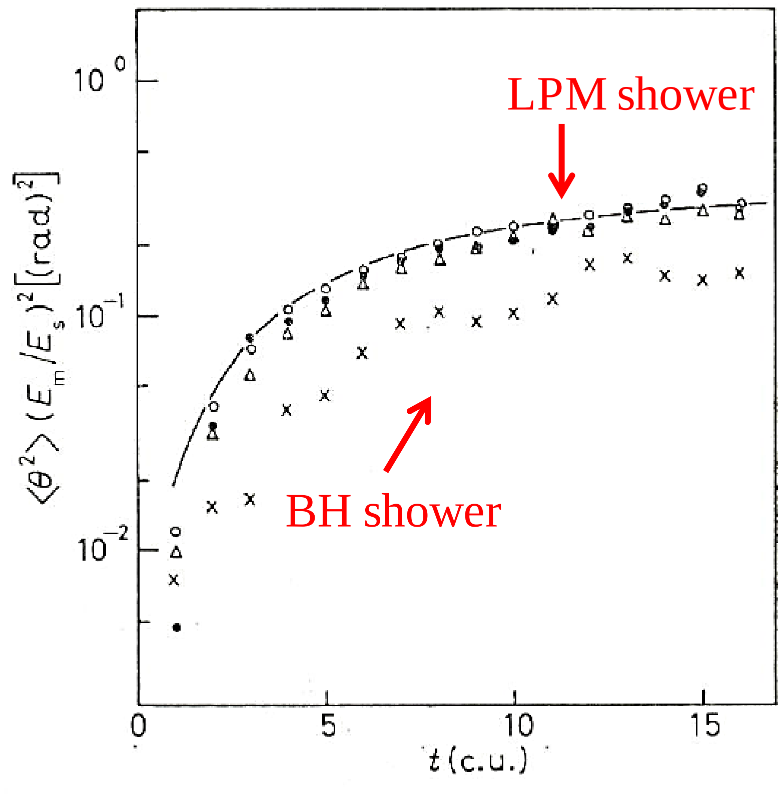


Figure 4. Mean square lateral spread of electrons in lead. Marks are the same as figure 3. $< r^2 >$ is normalized by multiplying by the factor $(E_m/E_s)^2$, where E_m is the minimum energy of observation and E_s is the scattering energy E_s=21.2 MeV. The solid curve shows analytical results under approximation A.

Figure 5. Mean square angular spread of electrons in lead. Marks are the same as figure 3. $< \theta^2 >$ is normalized by multiplying by the factor $(E_m/E_s)^2$, where E_m is the minimum energy of observation and E_s is the scattering energy E_s=21.2 MeV. The solid curve shows analytical results under approximation A.

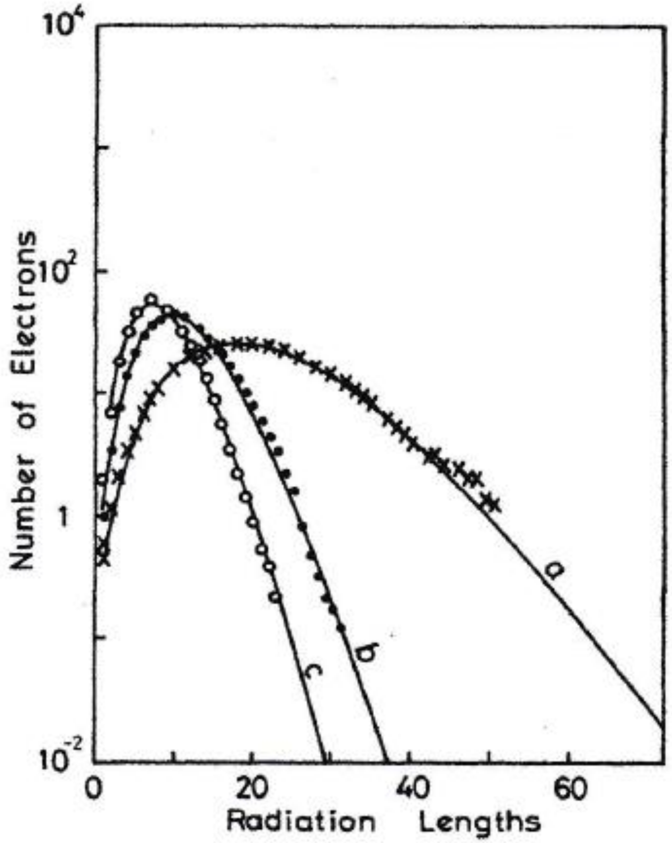


Figure 6. Comparison between the present results and the results obtained by Konishi et al. [4]. The comparison is made for LPM showers without ionization loss in lead, keeping E_0/E_{th} fixed and values of $E_0=10^{11}$, 10^{13}, 10^{15} eV. The crosses, closed circles and open circles denote $E_0=10^{15}$, 10^{13}, 10^{11} eV respectively. From A.Misaki, Phys.Rev,D,40, (1989)3086-3096

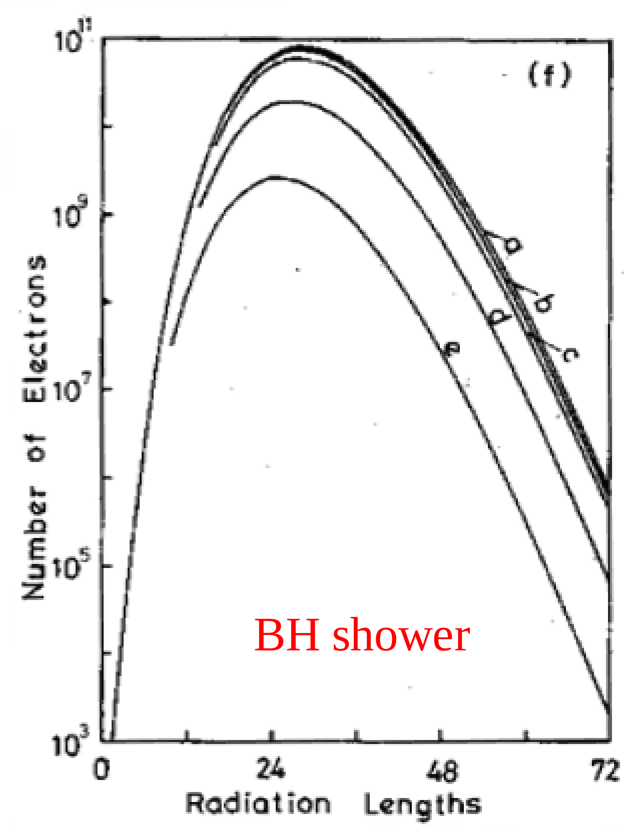


Figure 7. Transition curves of electron numbers in water under Approximation B initiated by a photon of 10^{20} eV for various threshold energies. The letter attached to each curve denotes the threshold energies: a=10^3 eV, b=10^6 eV, c=10^7 eV, d=10^8 eV, e=10^9 eV. From: A.Misaki, Fortschr. Phys. 38 (1990) 413-446

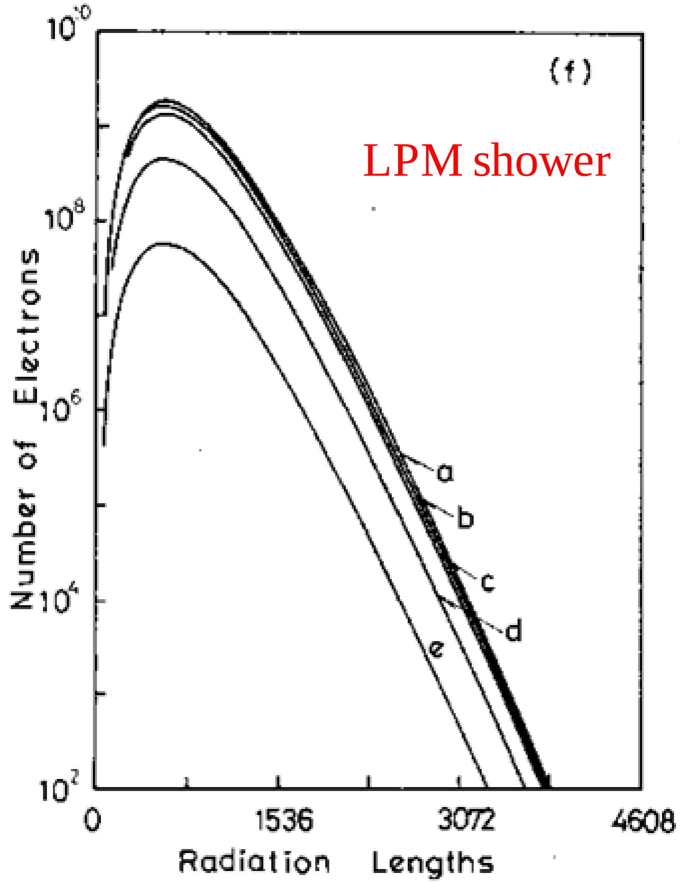


Figure 8. Transition curves of electron numbers in water in the presence of the LPM effect including ionization loss. The primary energy is 10^{20} eV and the threshold energies, *a* to *e* are the same as in figure 7. From: A.Misaki, Fortschr. Phys. **88** (1990) 413-446

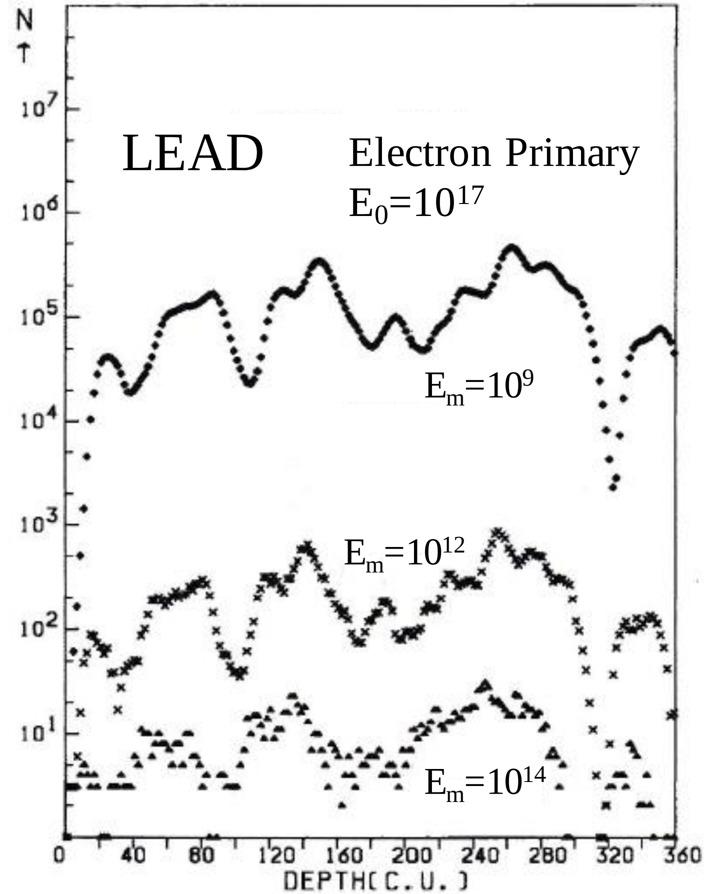


Figure 9. Number N of electrons in an electron-initiated shower of primary energy $E_0=10^{17}$ eV in lead as a function of depth in the absorber. The three curves refer to three different values of cut off energy $E_m=10^9$, 10^{12}, 10^{14} eV. From: Konishi et al, Phys.G: Nucl.Part.Phys. **17**(1991)719-732

A Fundamental of the LPM showers in water up to 10^{21} eV

K.Kato, T.Tanemori, N.Takahashi, A.Misaki

Proc.(.Supple).Proc. [26^{th} E+CRC 35^{th} RCRC]
(In press, July 5-to10 , Barnaul, Russia)

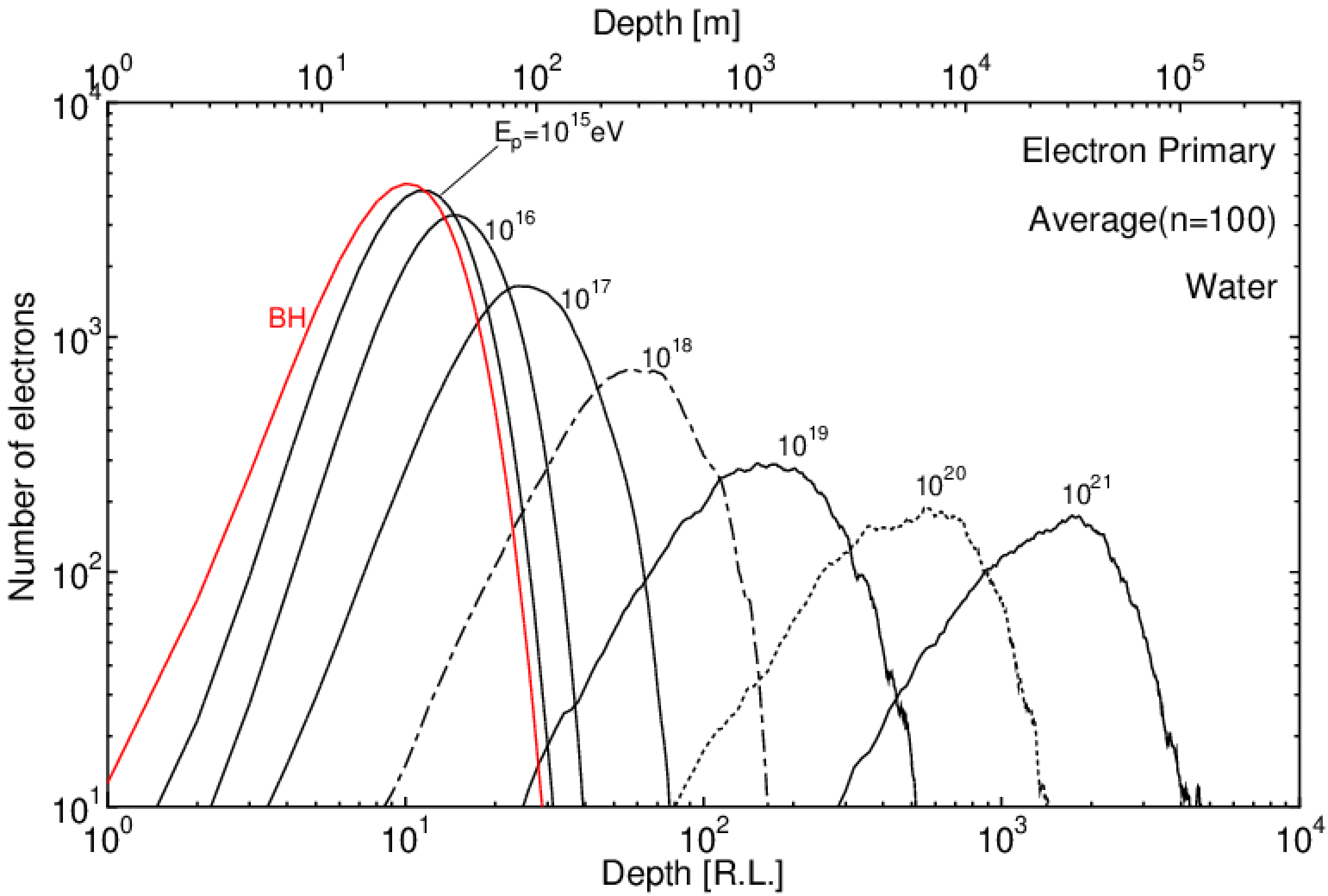


Figure 1. Cascade curves for electrons by the averaged LPM showers with different primary energies from 10^{15} eV to 10^{23} eV for keeping of $E_{prim}/E_{min}=10^5$. The average BH shower with 10^{15} eV is attached for readers' reference.

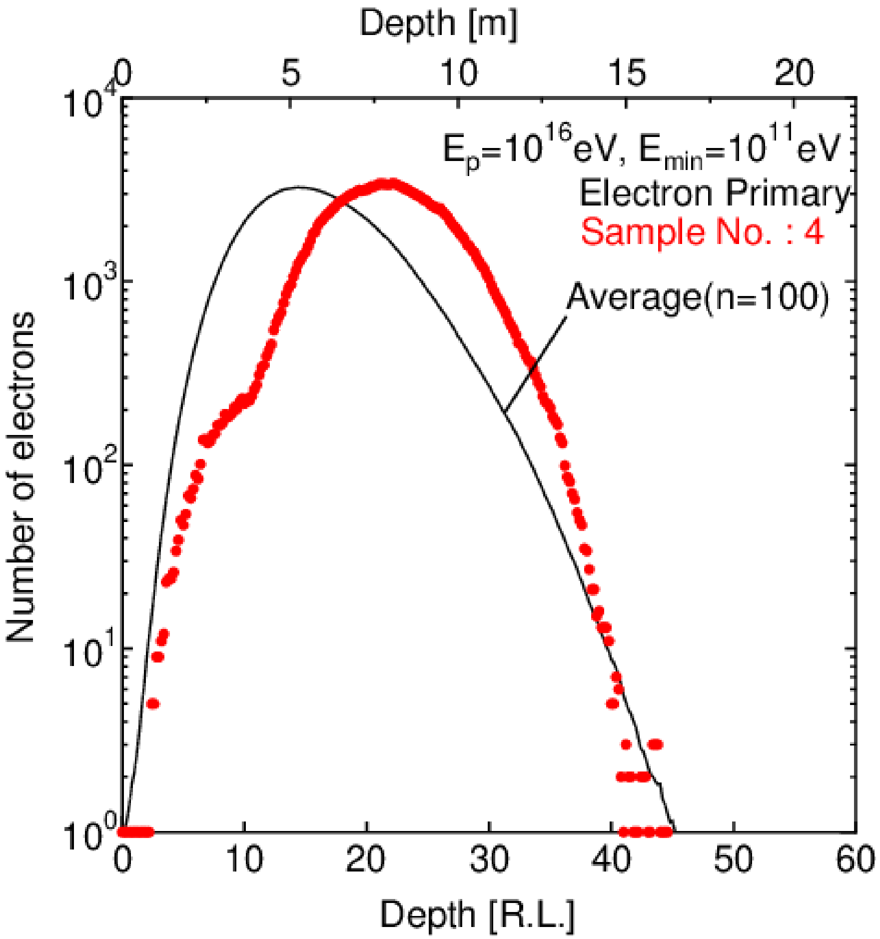


Figure 2. In two reasons, LPM effect appear clear, (1) average picture is clearly different from that of the BH shower(see, Figure 1,also), (2) the real one shows clear fluctuation compared with the average picture.

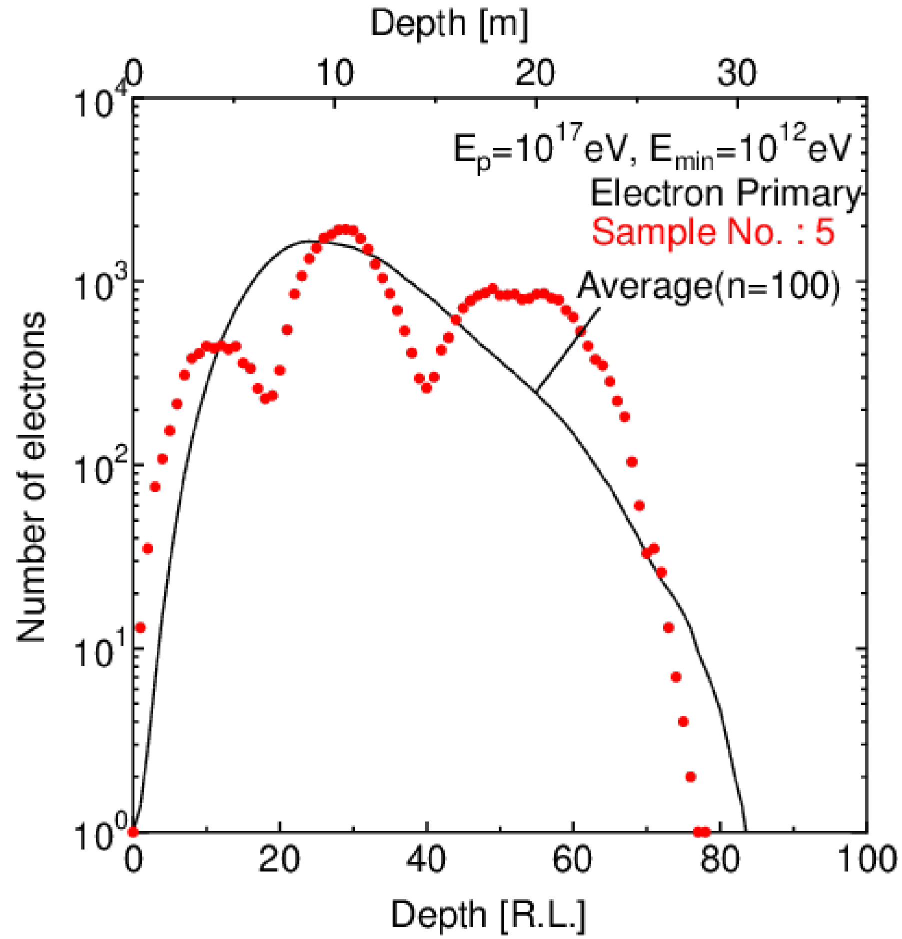


Figure 3. The multiple peak structure of the LPM shower in water clearly appears ~10^{17} eV.

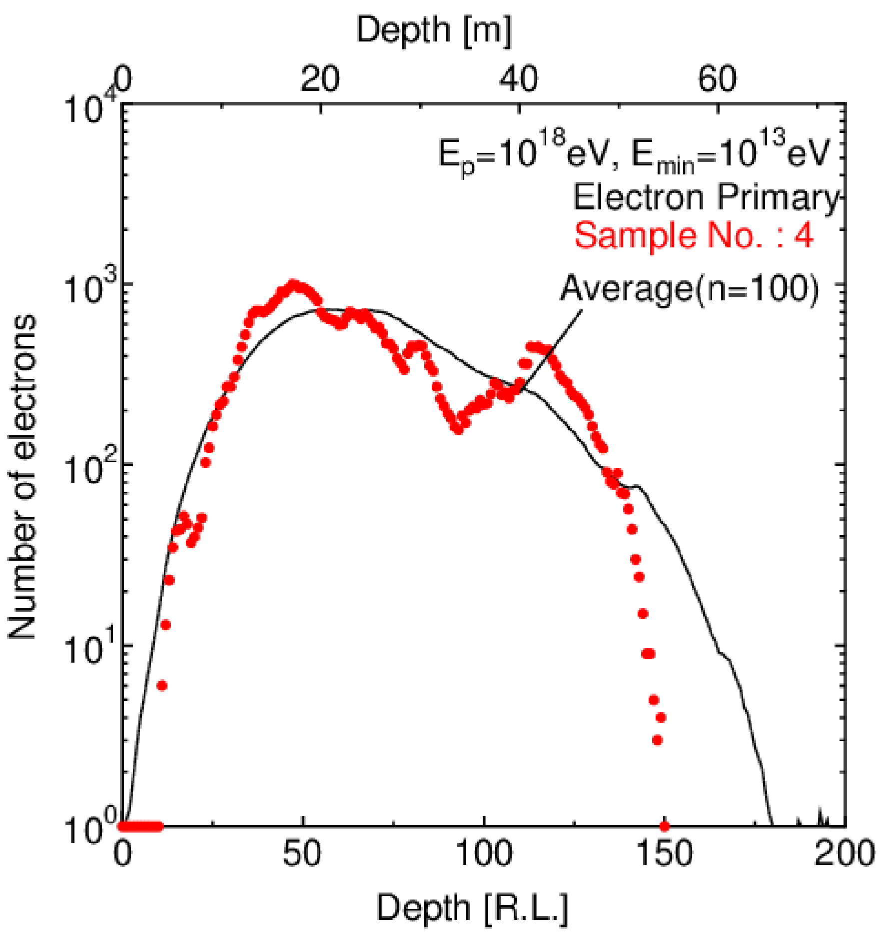


Figure 4. The LPM shower with 10^{18} eV. The typical structure of the multi-peak structure.

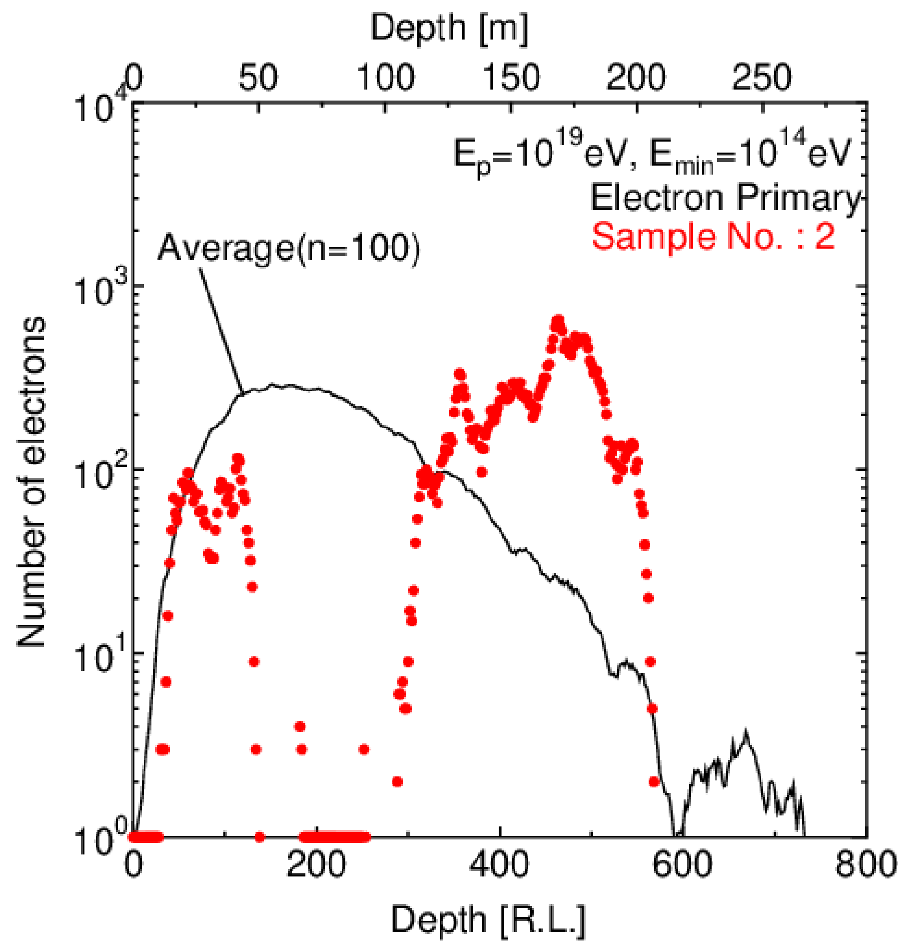


Figure 5. The separated sub-showers appear in ~10^{19}eV. A deformed kind of multi-peak structure.

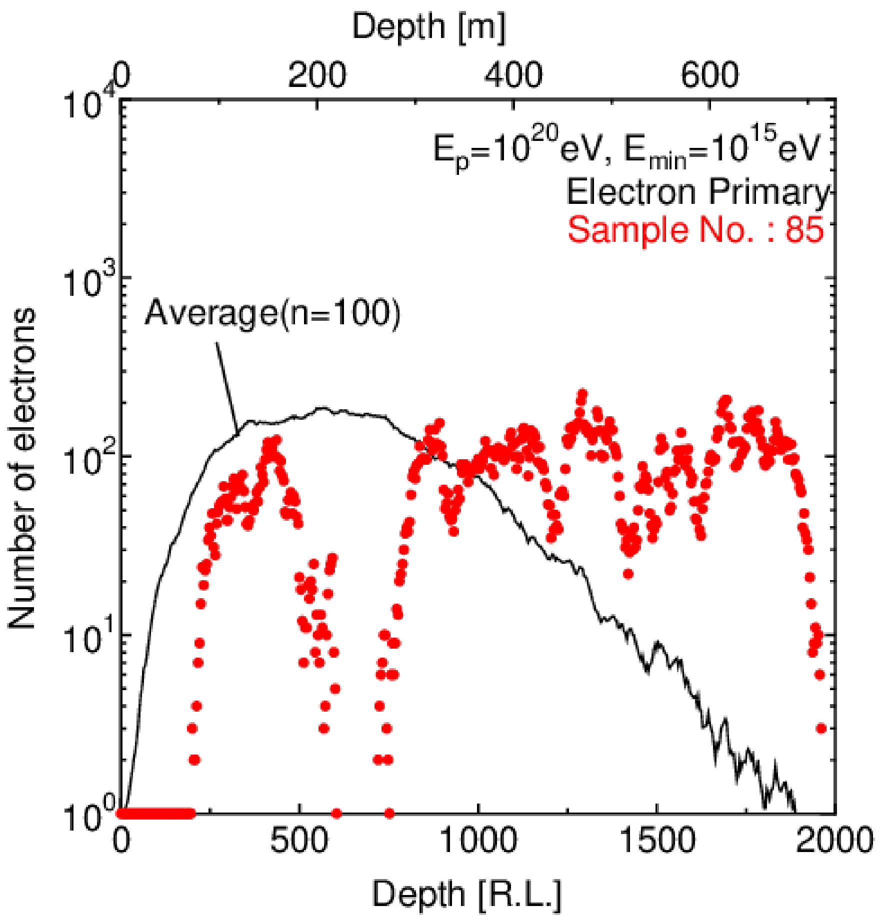


Figure 6. An example of two separated sub-showers with 10^{20} eV.

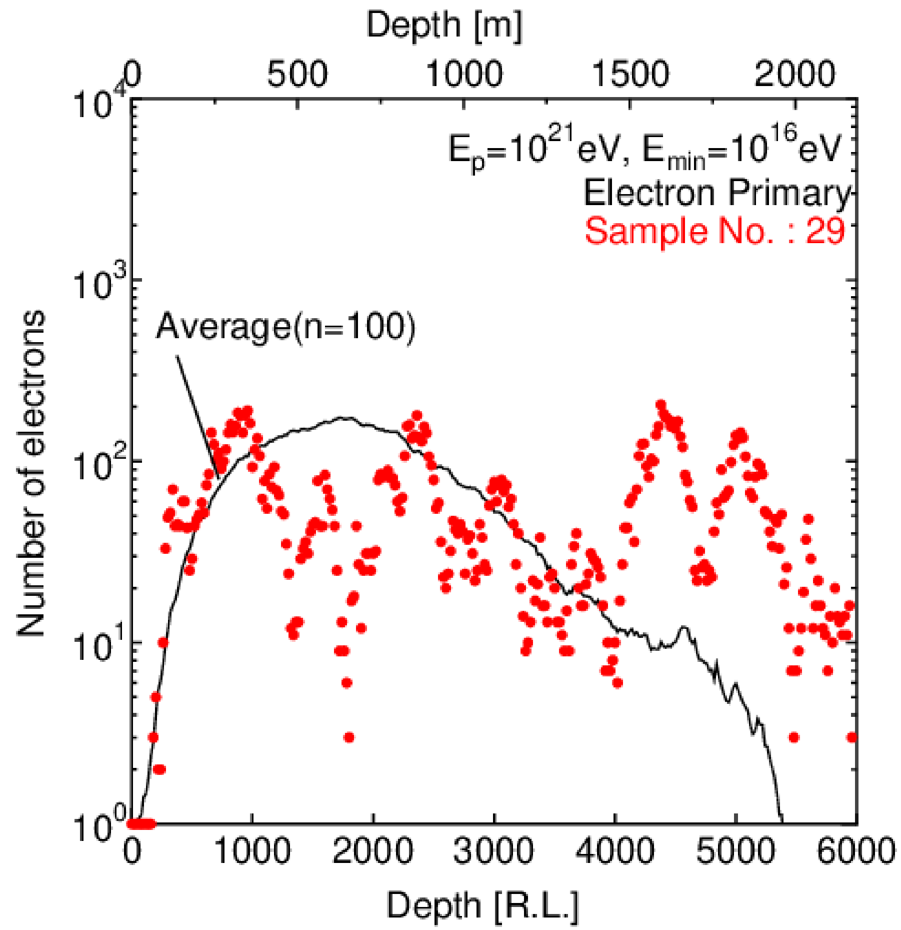


Figure 7. The LPM shower with 10^{21} eV traverses with many multi-peak without producing sub-shower. Notice that shower traverse 6000 c.u. (~ 2100 meter!!).

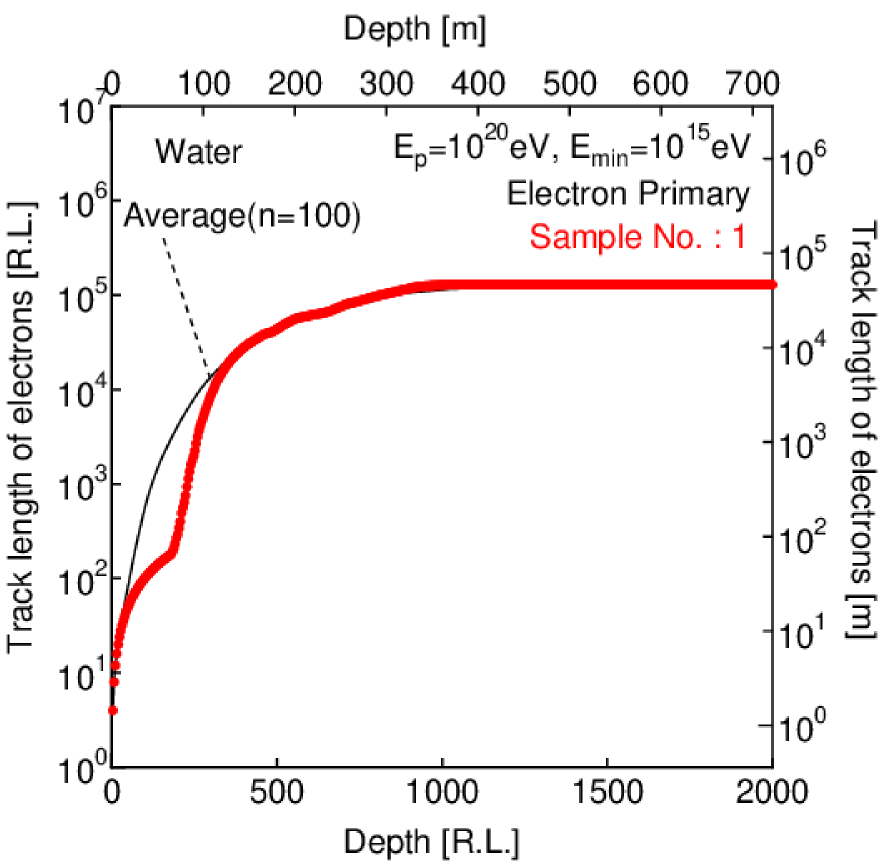


Figure 8. Track length of a LPM shower with primary energy $E_p=10^{20}$ eV.

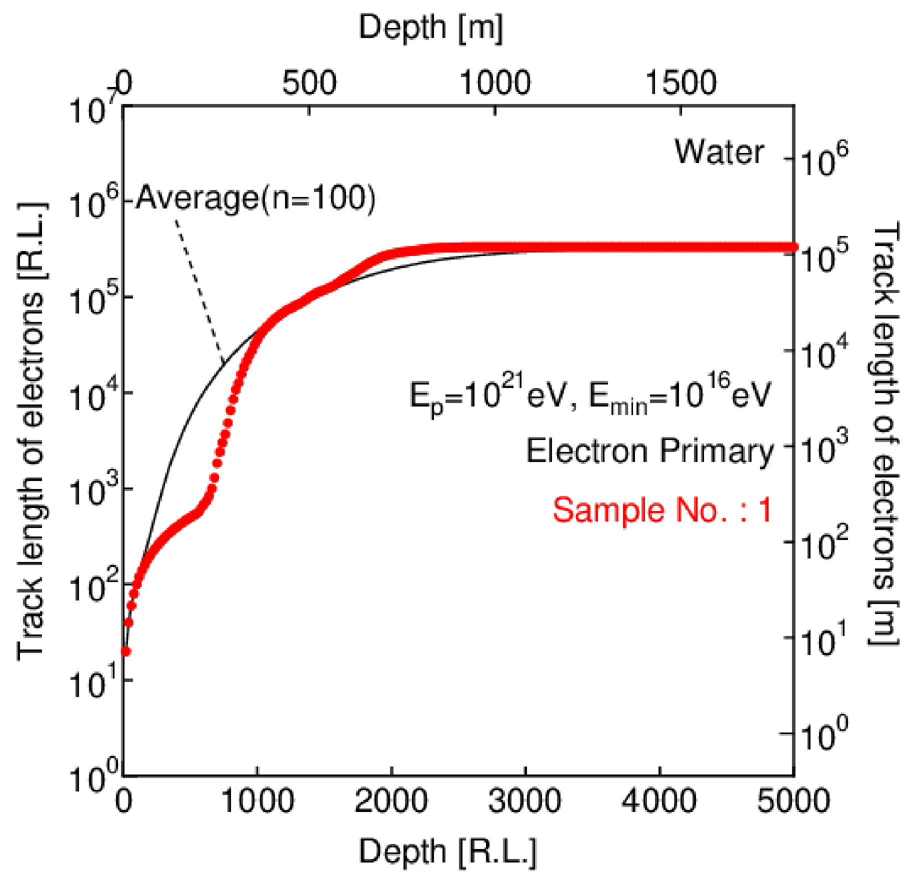


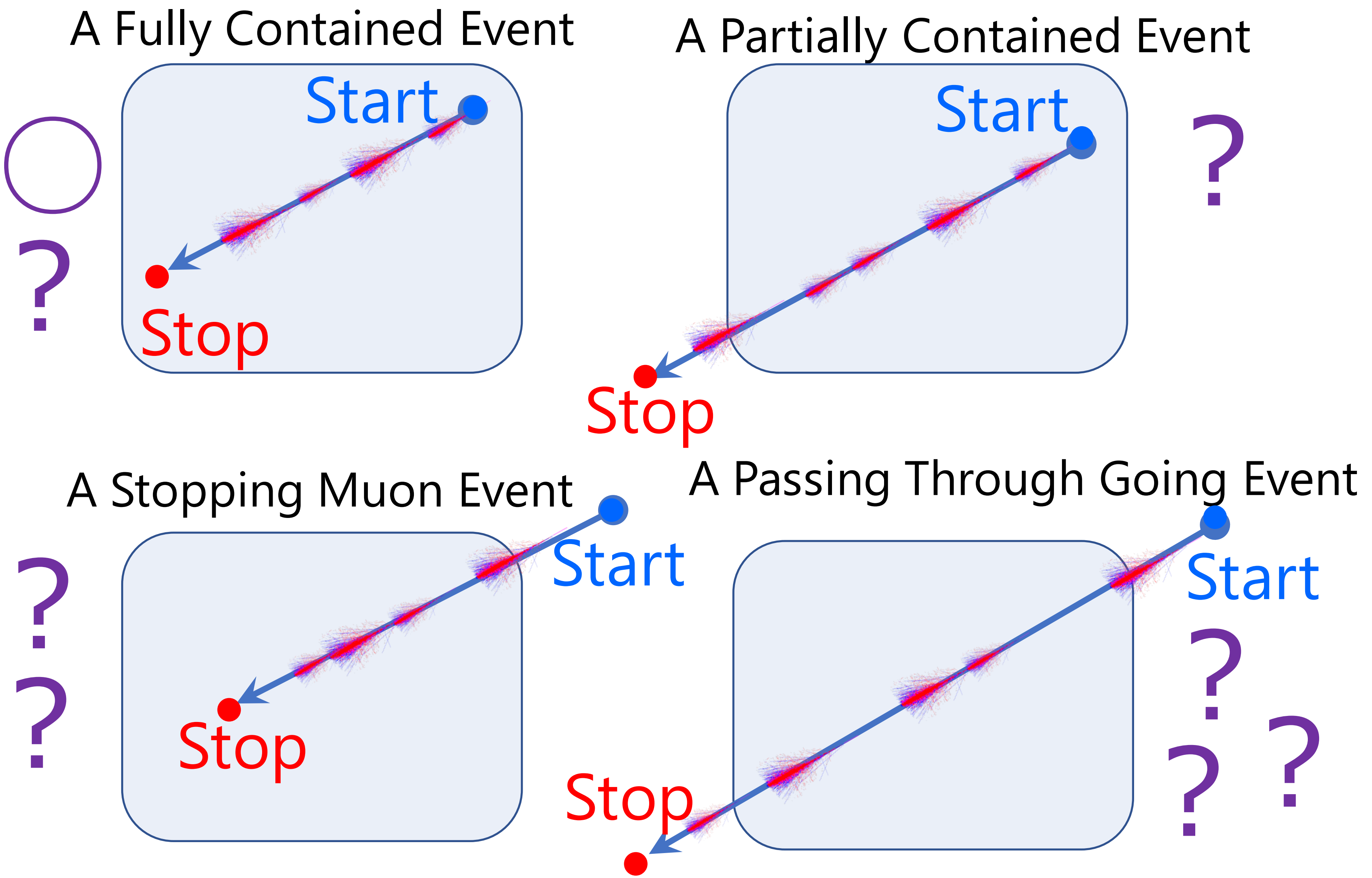
Figure 9. Track length of a LPM shower with primary energy $E_p=10^{21}$ eV.

On energy estimation of high energy muon events in KM3 detector based on a more exact range fluctuations of high energy muons

N.Takahashi, Y.Okumura, T.Tanemori, A.Misaki

Proc.(.Supple).Proc. [26th E+CRC 35th RCRC]
(In press, July 5-to10 , Barnaul, Russia)

Topology of Muon Events



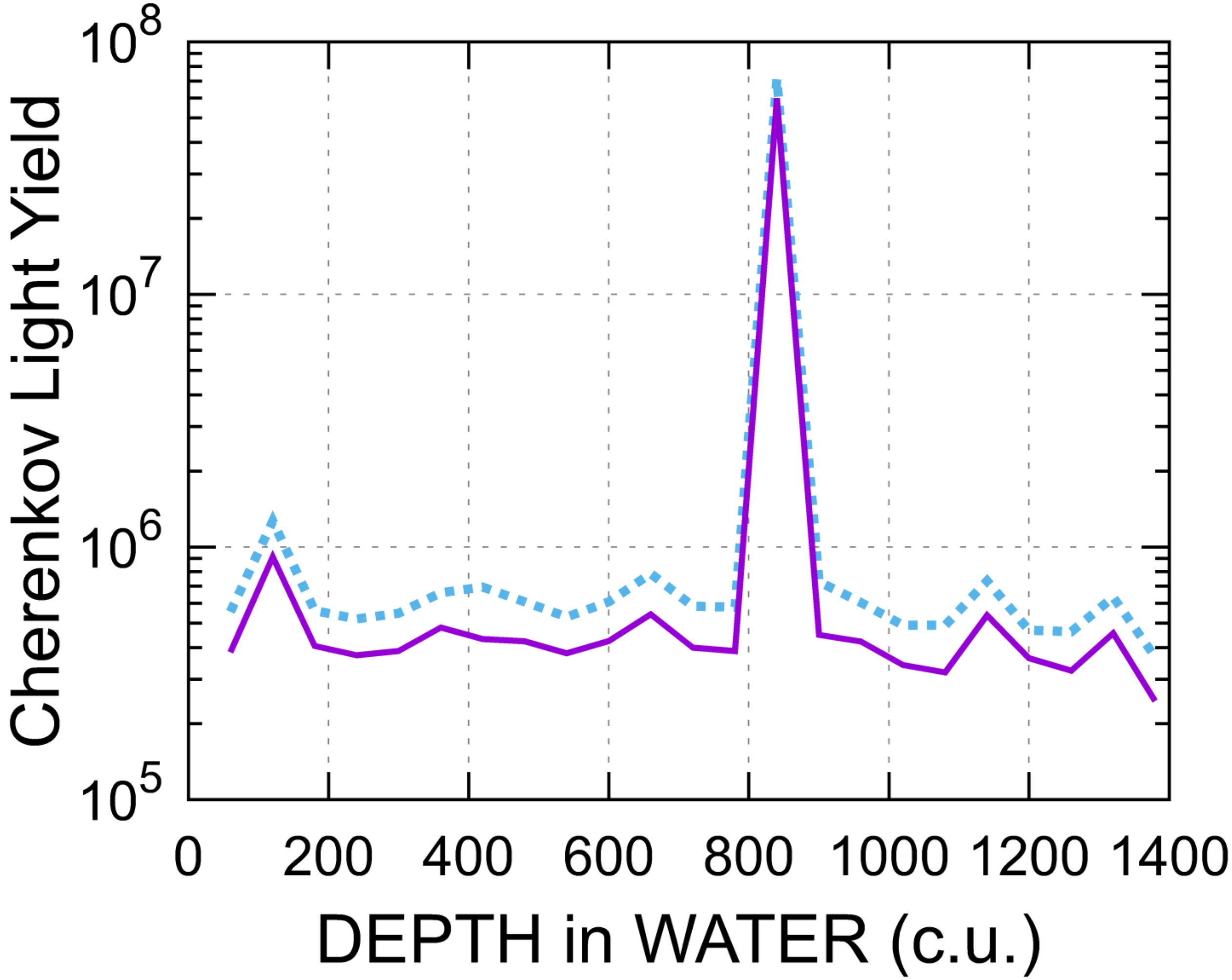


Figure 2. Transition curves for Cherenkov light in the cases of both generated Cherenkov lights and observed ones (λ = 40 m).

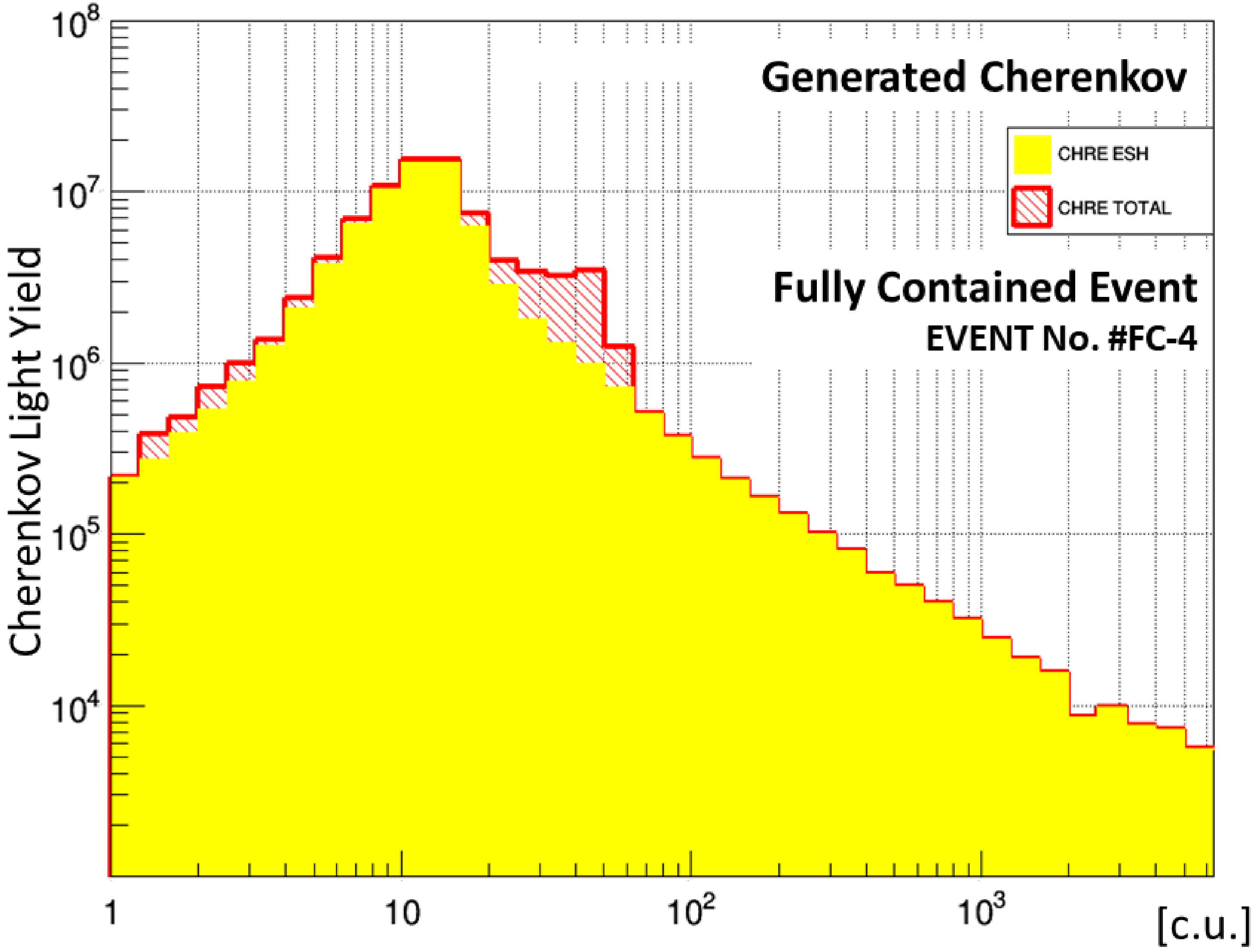


Figure 3. The lateral distribution for generated Cherenkov Lights integrated by depth.

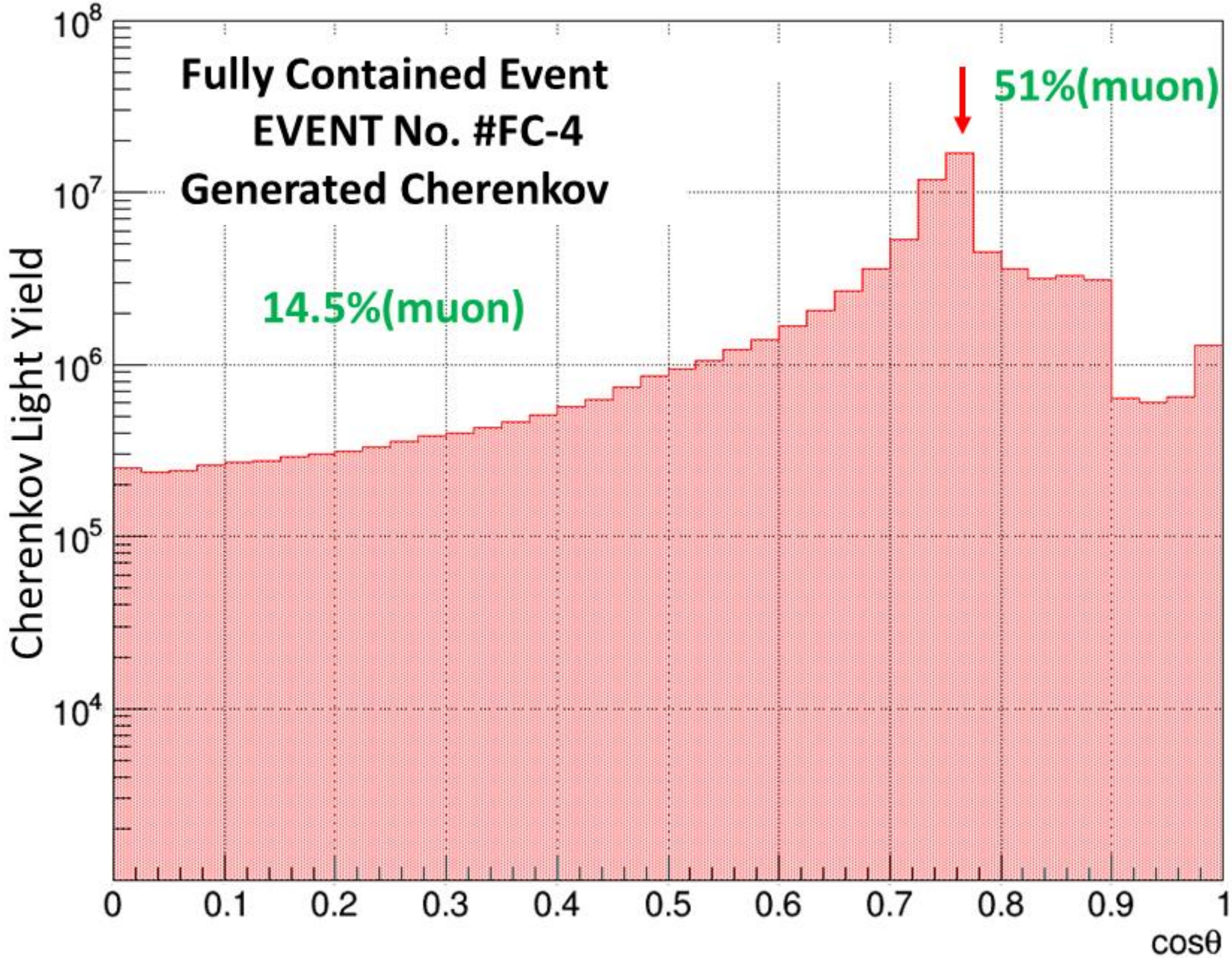


Figure 4. cosθ distribution of the generated Cherenkov lights for the parent muon and cascade shower electrons integrated by depth.

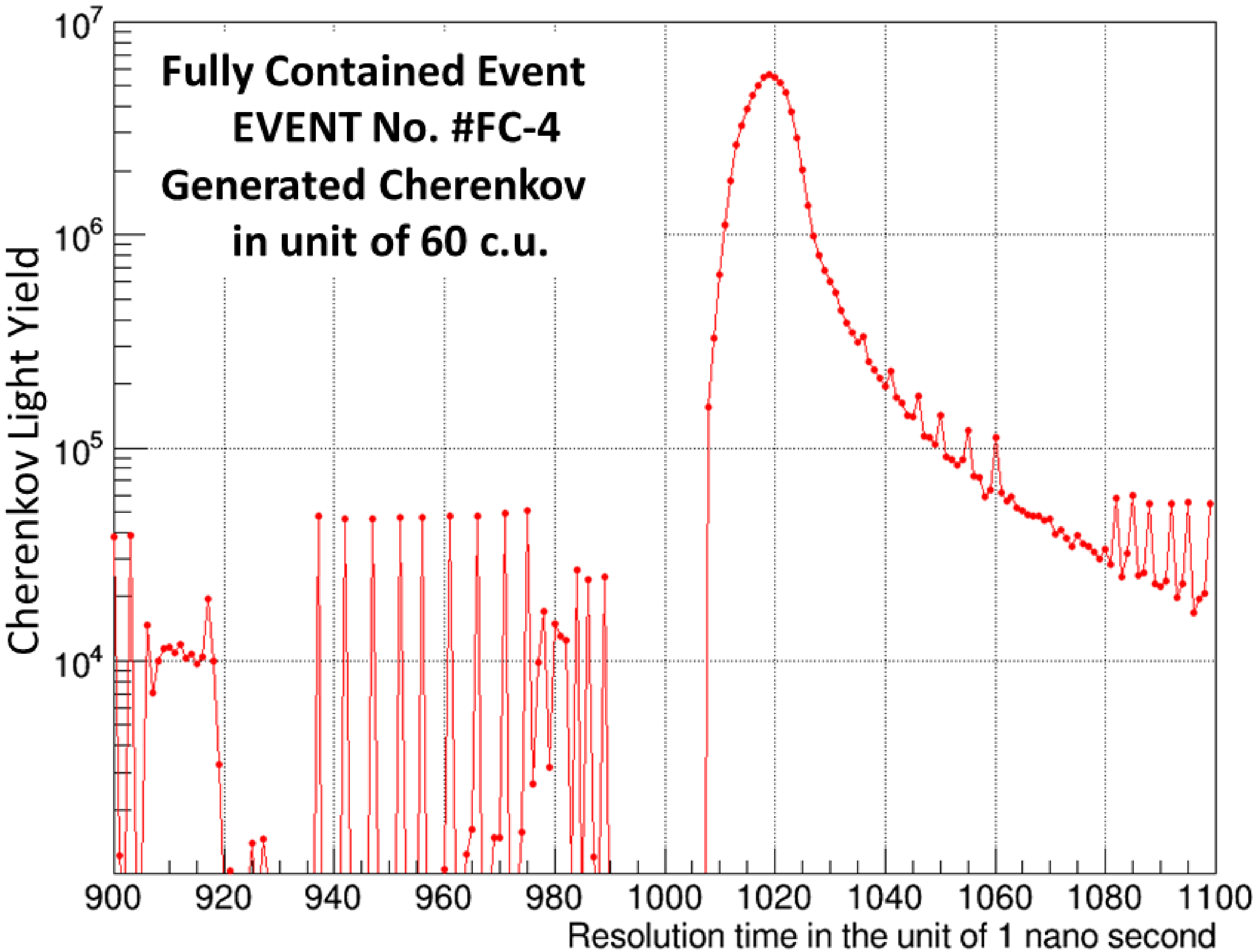


Figure 5. A part of the arrival time distribution of the generated Cherenkov light. The Cherenkov light yields due to bremsstrahlung are clearly registered. The time is measured from the generation points for the parent muon. The time resolution is one nanosecond.

Table 1. The generated Cherenkov lights for three *Fully Contained Events*. B, N, D, B+N+D denote the kinds of interactions, namely, bremsstrahlung, nuclear interaction, direct production, and the total number of interactions, respectively. M (muon), E (shower), M+E denote generated Cherenkov lights due muon, electron shower, muon + electron shower (generated total Cherenkov lights), respectively.

	Traversed depth	*Number of Interactions*				*Generated Cherenkov*		
	(m)	B	N	D	$B+N+D$	M: $muon$	E: $shower$	$M+E$
$\#FC-4$	491.8	1	0	46	47	1.23×10^{7}	7.27×10^{7}	8.50×10^{7}
$\#FC-390$	603.8	1	3	34	38	1.51×10^{7}	6.63×10^{7}	8.14×10^{7}
$\#FC-401$	975.6	3	1	64	68	2.44×10^{7}	6.10×10^{7}	8.53×10^{7}

Observed Yield	*Total*	$\sum E_{Shower}$	$\Sigma\mu$
$60\ c.u.$	6.92×10^{7}	6.05×10^{7}	8.69×10^{6}
Ratio	8.15×10^{-1}	8.33×10^{-1}	7.07×10^{-1}
$120\ c.u.$	6.68×10^{7}	6.03×10^{7}	6.44×10^{6}
Ratio	7.86×10^{-1}	8.30×10^{-1}	5.24×10^{-1}
$240\ c.u.$	1.74×10^{7}	1.35×10^{7}	3.85×10^{6}
Ratio	2.04×10^{-1}	1.48×10^{-1}	3.13×10^{-1}
$480\ c.u.$	1.51×10^{7}	1.33×10^{7}	1.83×10^{6}
Ratio	1.78×10^{-1}	1.83×10^{-1}	1.49×10^{-1}

Table 2. The dependence of the ratios of observed Cherenkov lights to generated ones in the unit length for their measurement given for one example of Fully Contained Events (#FC-4).

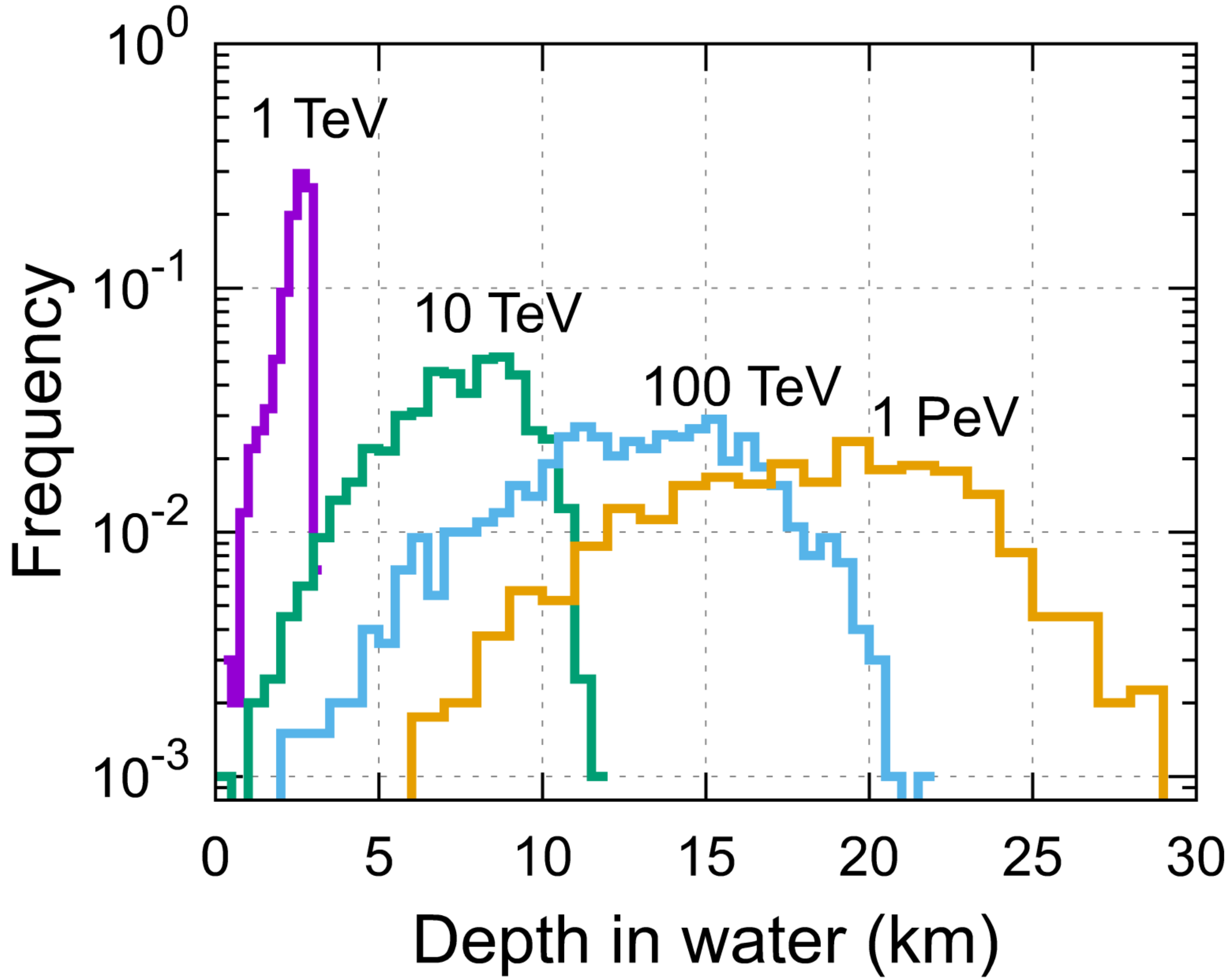
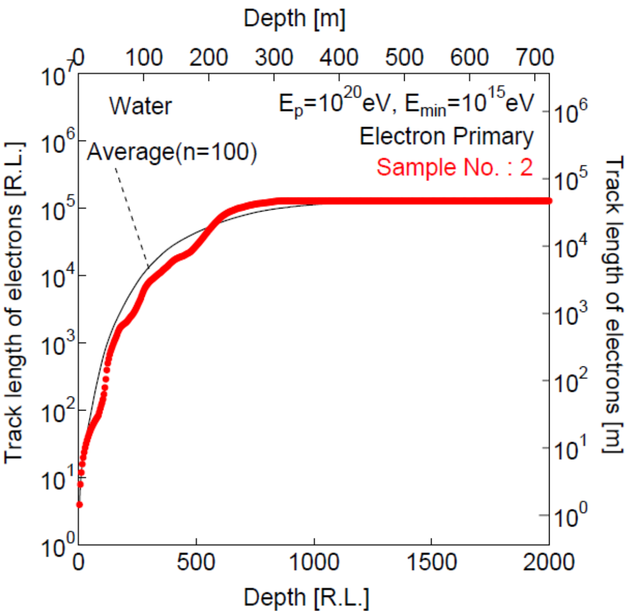


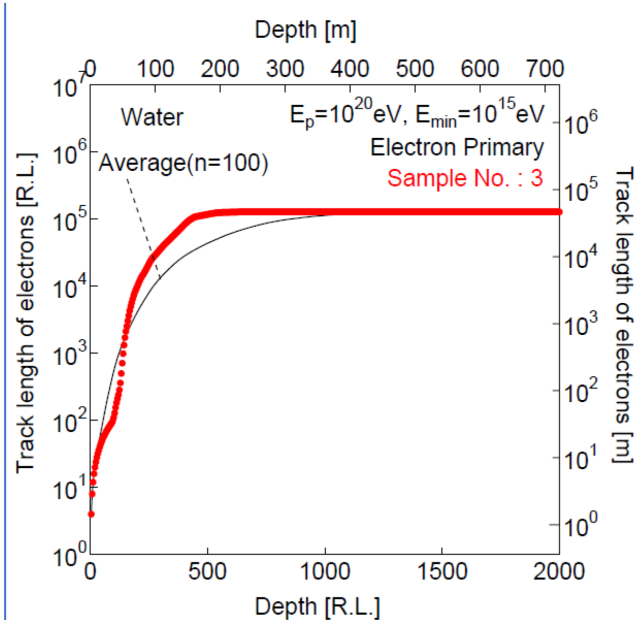
Figure 6. Range distributions for the incident muons with incident energies 10^{12} eV to 10^{15} eV. The minimum observation energies are taken as 10^{9} eV. Each sampling number is 1000.

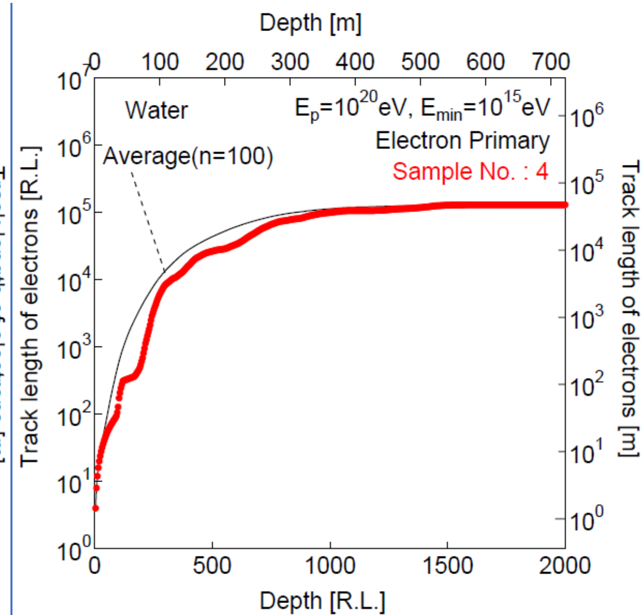
「揺動」問題

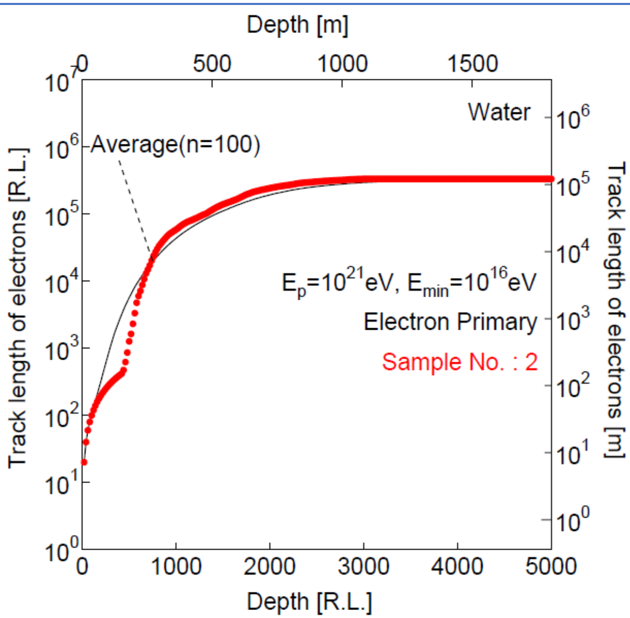
「信頼できるエネルギー決定」とは、理論的に言えば、「どれだけ、シャワー粒子のトラックレングスが測定できるか」ということである。

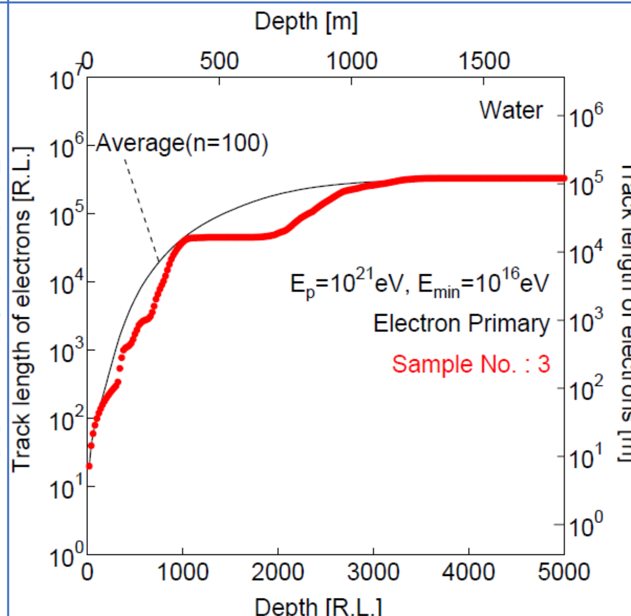
エネルギーが、シャワー粒子の直接観測、チェレンコフ輻射、電波、音響輻射、のいずれを「経由する」としても、その本質は、「シャワー粒子のトラックレングス問題」に帰着する

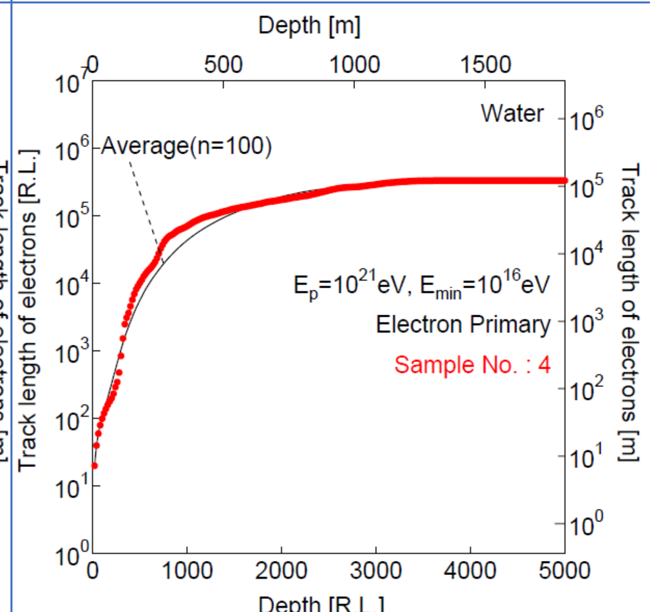

Depth [m]
Water
$E_p=10^{20}$eV, $E_{min}=10^{15}$eV
Electron Primary
Sample No. : 2
Average(n=100)
Track length of electrons [R.L.]
Track length of electrons [m]
Depth [R.L.]

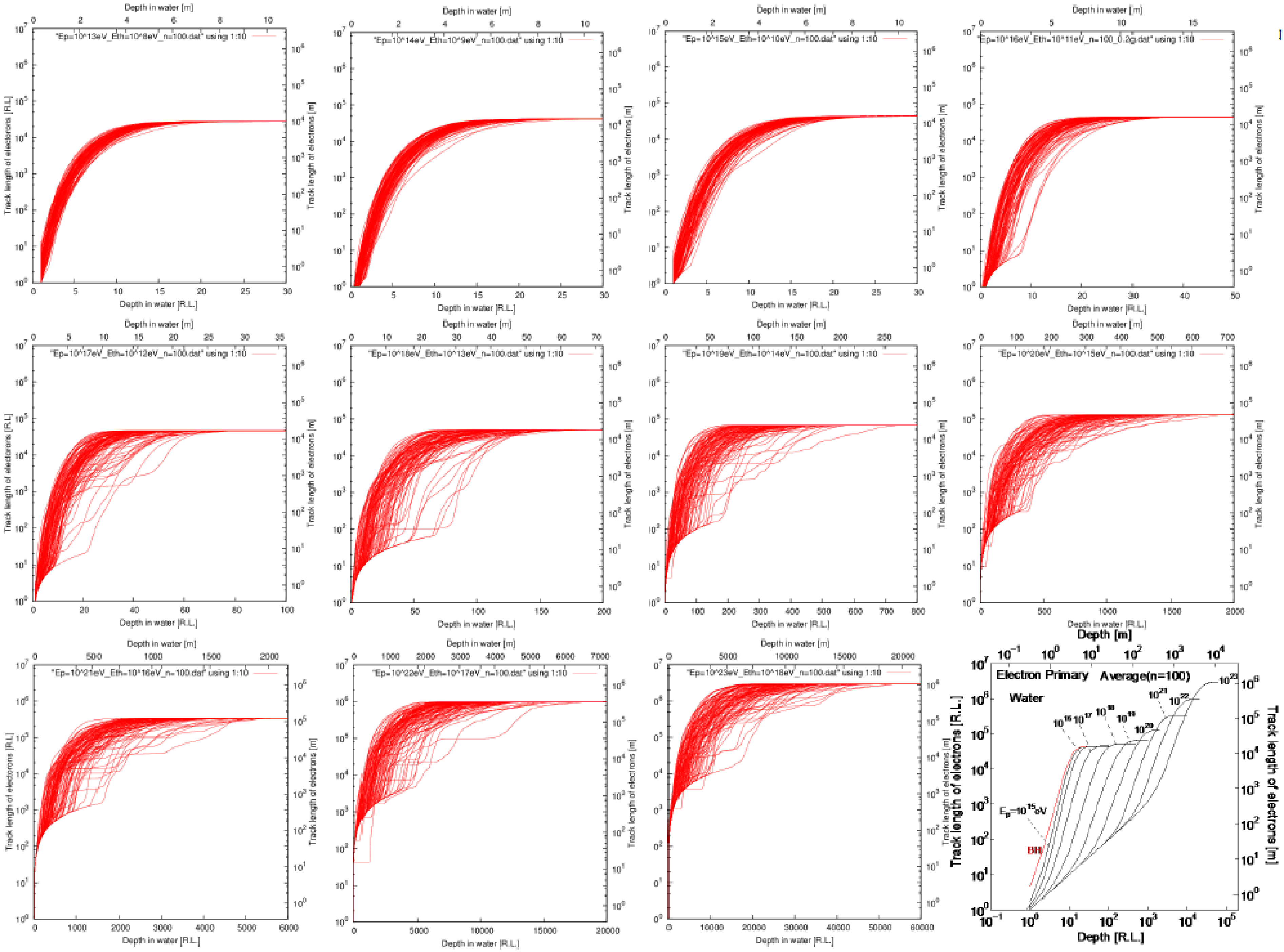

Depth [m]
Water
$E_p=10^{20}$eV, $E_{min}=10^{15}$eV
Electron Primary
Sample No. : 3
Average(n=100)
Track length of electrons [R.L.]
Track length of electrons [m]
Depth [R.L.]


Depth [m]
Water
$E_p=10^{20}$eV, $E_{min}=10^{15}$eV
Electron Primary
Sample No. : 4
Average(n=100)
Track length of electrons [R.L.]
Track length of electrons [m]
Depth [R.L.]


Depth [m]
Water
Average(n=100)
$E_p=10^{21}$eV, $E_{min}=10^{16}$eV
Electron Primary
Sample No. : 2
Track length of electrons [R.L.]
Track length of electrons [m]
Depth [R.L.]


Depth [m]
Water
Average(n=100)
$E_p=10^{21}$eV, $E_{min}=10^{16}$eV
Electron Primary
Sample No. : 3
Track length of electrons [R.L.]
Track length of electrons [m]
Depth [R.L.]

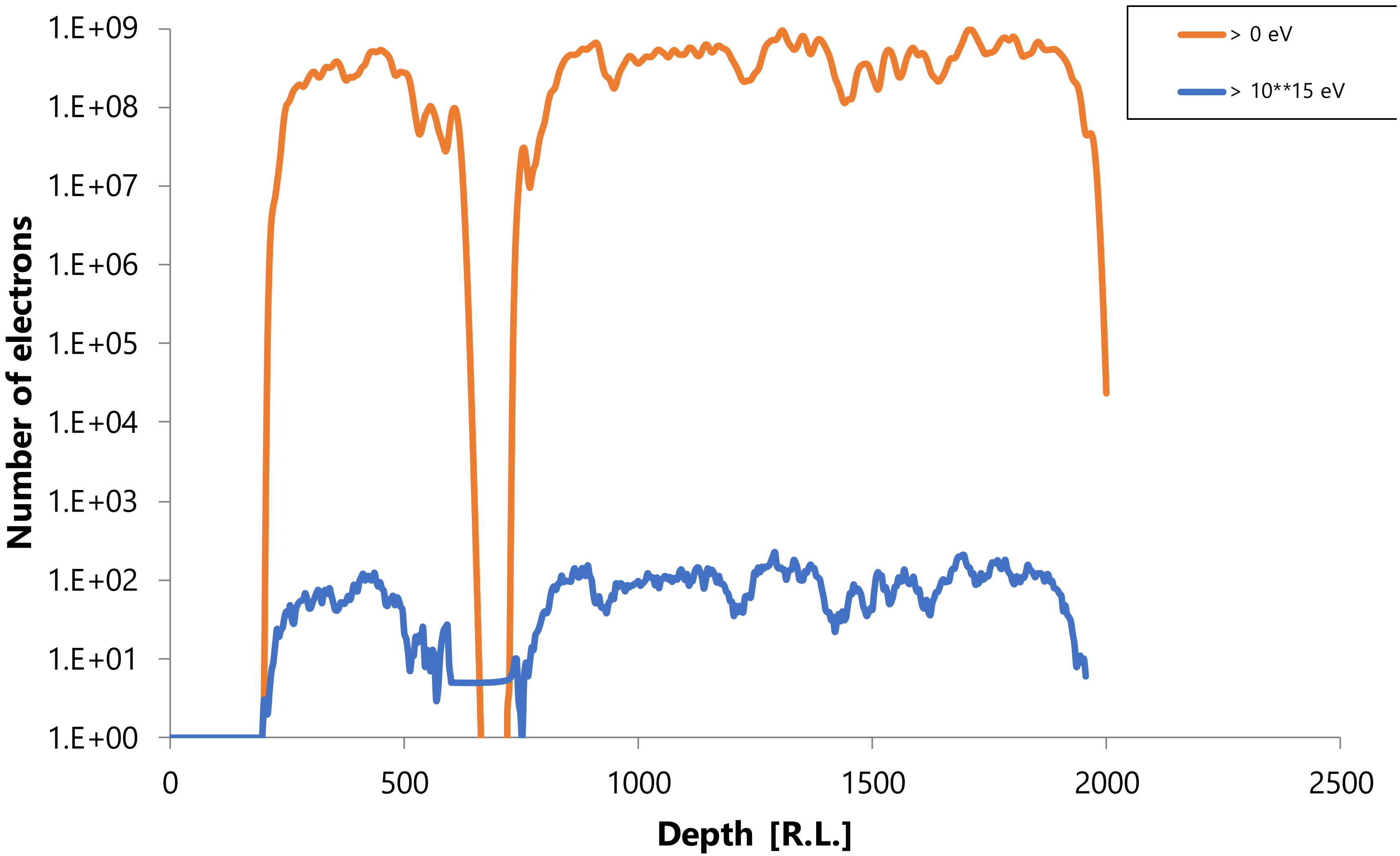

Depth [m]
Water
Average(n=100)
$E_p=10^{21}$eV, $E_{min}=10^{16}$eV
Electron Primary
Sample No. : 4
Track length of electrons [R.L.]
Track length of electrons [m]
Depth [R.L.]



Depth in water [m]
Depth in water [R.L.]
Track length of electrons [R.L.]
Track length of electrons [m]
"Ep=10^13eV_Eth=10^8eV_n=100.dat" using 1:10
"Ep=10^14eV_Eth=10^9eV_n=100.dat" using 1:10
"Ep=10^15eV_Eth=10^10eV_n=100.dat" using 1:10
"Ep=10^16eV_Eth=10^11eV_n=100_0.2g.dat" using 1:10
"Ep=10^17eV_Eth=10^12eV_n=100.dat" using 1:10
"Ep=10^18eV_Eth=10^13eV_n=100.dat" using 1:10
"Ep=10^19eV_Eth=10^14eV_n=100.dat" using 1:10
"Ep=10^20eV_Eth=10^15eV_n=100.dat" using 1:10
"Ep=10^21eV_Eth=10^16eV_n=100.dat" using 1:10
"Ep=10^22eV_Eth=10^17eV_n=100.dat" using 1:10
"Ep=10^23eV_Eth=10^18eV_n=100.dat" using 1:10
Depth [m]
Electron Primary
Average(n=100)
Water
$E_p=10^{15}eV$
BH
Track length of electrons [R.L.]
Track length of electrons [m]
Depth [R.L.]

Hybrid calculation of LPM shower

From $E_0 = 10^{20}$ eV to 10^{15}eV : Exact Monte Carlo
Below 10^{15}eV : NKG function



本研究の目的（結論）

最終的：「10^{21} eV 以上の超高エネルギー電子ニュートリノ天文学の実験的研究」

途中段階

テストプラントの建設

大規模な計算機数値実験

LPM shower の諸特性および関連研究

LPM shower の揺動の研究

BH shower に関する「基準点的」研究

ミューオンニュートリノ事象の形態学的研究

（これは、Icecube, Antares,Baikal-GVD の解析と直結）