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► **To cite this version:**

H. Terazawa. SUPERHIGH ENERGY PHYSICS. Journal de Physique Colloques, 1982, 43 (C3), pp.C3-191-C3-202. 10.1051/jphyscol:1982341 . jpa-00221894

**HAL Id: jpa-00221894**

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Submitted on 4 Feb 2008

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## SUPERHIGH ENERGY PHYSICS

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## I. INTRODUCTION

I have been asked by Professor Yamaguchi, the organizer of this session on accelerator and cosmic ray physics to be a mini-rapporteur on cosmic ray side in case that Professor Chudakov who had been asked originally may not be able to come to this Conference. It is very unfortunate that Professor Chudakov, the world expert in this field, could not come so that I must do some really hard work to review not only the numerous cosmic ray data but the comparisons of them with the accelerator data as well as the various theoretical interpretations of them [1]. I will try to do my best in the following.

Let me first remind you of what we had as standards of reference in seventies by repeating my talk presented at the XVI International Cosmic Ray Conference in 1979 [2], which started as follows:

What interest us most in cosmic ray physics are the reported anomalous phenomena such as the unusually high multiplicity of charged particles seen in the Niu's charm event [3] and similar ones [4, 5] and in the Centauro events [6] with very few  $\gamma$ 's and the anomalously slow absorption seen in the Bristol event [7] and in the Tien-Shan hadronic cascade events [8]. It seems quite certain that something unusual happened not only in these events but also in the high  $p_T$  multiple core events [9], all at energies of 10-1000TeV. What is happening at around 100 TeV? The purpose of the following sections is to make my conjectures on this very intriguing question.

## 1. Why 100TeV?

It is obvious! It has been well known for a long time since the era of Heisenberg that something drastic must happen in the weak interaction at c.m. energy ( $\sqrt{s}$ ) of about 300GeV where the dimensionless parameter  $G_F s$  (where  $G_F$  is the Fermi weak coupling constant) becomes of the order of unity. More fashionably, the weak vector bosons  $W^\pm$  and  $Z$  are expected to have masses of the order of 100GeV in the Glashow-Salam-Weinberg gauge theory of electroweak interactions [10] so that they may be copiously produced or start playing important roles at lab. energies of around 100TeV. It is not only these mass scales but the mass scales of heavy leptons and heavy quarks that may indicate 100TeV as a critical lab. energy for their copious productions. In fact, in our unified model of all elementary-particle forces including gravity [11] there must exist a dozen leptons (6 neutrinos and 6 charged leptons) and a dozen flavors and three colors of quarks (18 up quarks and 18 down quarks) whose masses ( $m$ 's) should satisfy the following three sum rules:

$$\sqrt{(\sum m^4)/(\sum m^2)} = m_H/2,$$

$$\sqrt{\langle m^2 \rangle} = m_{W^\pm}/\sqrt{3} = \sqrt{\pi\alpha/\sqrt{2}G_F \sin^2 \theta_W}/\sqrt{3} \cong 35.2\text{GeV} \quad \text{and}$$

$$m_H Q^2 / \Sigma Q^2 = \sqrt{\frac{4\pi}{\kappa_0 N_0 G_F}} \exp\left(-\frac{3\pi}{2\alpha \Sigma Q^2}\right) \cong 33.5 \text{ GeV},$$

where  $m_H$  is the mass of the physical Higgs scalar  $H$ ,  $\kappa_0 = 1/3$ ,  $Q$ 's and  $N_0$  are the charges and the total number of leptons and quarks, respectively, and  $G_N$  is the Newtonian gravitational constant. Notice that the latter two sum rules indicate that the arithmetic and geometric average masses of leptons and quarks are remarkably close to each other although they are derived independently. I, therefore, strongly suggest that there exist much heavier leptons and quarks whose masses are of the order of 100GeV, which would make the 100TeV physics more colorful.

Furthermore, I wish to declare that the time has come to convince ourselves of the existence of subquarks [12], the more fundamental particles which are building blocks of these so many leptons and quarks. Also, it seems reasonable that the gauge bosons ( $\gamma$ ,  $W^\pm$ ,  $Z$ ,  $G^a$  for  $a=1-8$ , etc.) as well as the Higgs scalar ( $H$ , etc.) are all bound states of subquark-antisubquark pairs. In any case, the existence of these subquarks would make the 100TeV physics more exciting provided that the mass scale of subquarks is as low as 100-1000GeV. In fact, in our subquark model, the average effective mass of the subquarks ( $w$ ) must satisfy the following relation:

$$m_H/2 = \sqrt{\langle m_w^2 \rangle} = m_{W^\pm}/\sqrt{3} \cong 35.2 \text{ GeV}.$$

I, therefore, emphasize that the threshold energy of subquark-antisubquark pair creation may be as low as 70GeV.

## 2. What would happen at 10-1000TeV?

The strong interaction of quarks seems to be best described by quantum chromodynamics (QCD) [13], the Yang-Mills gauge theory [14] of color SU(3) [15]. It is well known that the pure QCD is asymptotically free if the total number of quark flavors is less than 16 [16]. Recently, however, we have shown that the possible freedom of QCD can not be asymptotic but only be temporary due to the mutual interference between the strong and electroweak interactions of quarks [17]. We have further suggested a possibility of "asymptotic catastrophe" where all the interactions become strong as energies go beyond the "temporary freedom" region. The turning point for the asymptotic catastrophe strongly depends on the total number of quark flavors. It should, however, be emphasized that the critical energy can be as low as 100GeV if there exist more than 18 flavors of quarks. If this is the case, not only the electroweak interactions of leptons and quarks but also the strong interaction of quarks becomes again abnormally strong so that any anomalous phenomena may well occur in 100TeV regions. Also, we have recently demonstrated that even if quarks were confined temporarily inside hadrons in QCD, they could be liberated by other interactions (e.g., the electroweak interactions) than the strong one [18]. To estimate the energy necessary for such liberation is hard at this stage. However, suppose that the origin of quark liberation is electroweak, then the threshold energy or the mass of a physical quark can be as small as 100GeV, the typical mass scale in the electroweak interactions. Therefore, it does not seem extremely radical to suggest that free quarks also may be produced at lab. energies larger than 100TeV.

As emphasized in Section 1, the one thing which is certain is the drastic change of the behavior of electroweak interactions at lab. energies of the order of 100TeV. The weak vector bosons (and the Higgs scalars, if any) can be copiously produced electroweakly. There seems to exist enough experimental evidence for the SU(2) $\times$ U(1) gauge symmetry of Glashow, Salam and Weinberg. There does not, however,

exist any evidence for the local gauge symmetry at present. It means that although the weak vector bosons  $W^\pm$  and  $Z$  in the Glashow-Salam-Weinberg model are to be found with masses of the order of 100GeV, they may not behave as elementary as expected in the model. It would be likely that they may appear just as continuum states of the "weak bosonic matter" which consists of all lepton-antilepton and quark-antiquark pairs. Not only they but also the physical Higgs scalar may appear as bound states of subquark-antisubquark pairs as expected in our subquark model. If so, they may even decay into a subquark-antisubquark pair which would produce an eminent pair of jets.

Let us now remind you of the old works of Appelquist and Bjorken [19] and of myself [20], in which the possibility of composite weak vector bosons is discussed in detail. An essential point in these works is that all the known weak interaction processes at low energies, where momentum transfers involved are small compared to the masses of weak vector bosons, can be reproduced if the spectral functions of weak vector bosons  $\rho_{1,2}(m^2)$  satisfy the conditions of

$$G_F/\sqrt{2} = g_w^2 \int dm^2 \rho_1(m^2)/m^2 \gg g_w^2 M^2 \int dm^2 \rho_2(m^2)/m^2,$$

where  $g_w (= g/\sqrt{8})$  in the Glashow-Salam-Weinberg model (where  $g$  is the SU(2) gauge coupling constant) is the semi-weak coupling constant and  $M$  is a typical order of the mass of leptons and quarks involved. These conditions together with the normalization conditions of

$$\int dm^2 \rho_1(m^2) = 1 \quad \text{and} \quad \int dm^2 \rho_2(m^2) = m_{W^\pm}^{-2}$$

can be transformed into the following two sum rules for the charged current processes, for example:

$$\int ds \sigma(\bar{\nu} l \rightarrow "W")/s = 4\pi G_F/\sqrt{2} \quad \text{and}$$

$$\int ds \sigma(\bar{\nu} l \rightarrow "W") = 4\pi g_w^2 = 2\pi^2 \alpha/\sin^2 \theta_w,$$

where "W" denotes the "charged weak bosonic matter". Also, since the neutral current processes at low energies seem to be well described by the Glashow-Salam-Weinberg model, the similar conditions can be transformed into the following two similar sum rules for the neutral current processes, for example:

$$\int ds \sigma(e^+ e^- \rightarrow "Z")/s = \pi G_F [(1-4\sin^2 \theta_w)^2 + 1]/2\sqrt{2} \quad \text{and}$$

$$\int ds \sigma(e^+ e^- \rightarrow "Z") = \pi^2 \alpha [(1-4\sin^2 \theta_w)^2 + 1]/4\sin^2 \theta_w \cos^2 \theta_w,$$

where "Z" denotes the "neutral weak bosonic matter". As far as sum rules of these types are satisfied, the "shape" of the weak vector boson does not need to be a single peak but can be anything. If the weak vector bosons appear with a few peaks followed by many bumps as illustrated in Fig. 1, it would most clearly indicate that they are not elementary but composite as expected in our subquark model. I, therefore, strongly urge experimentalists to be still alert for seeing the possible sub-structure and even for producing the possible subquark-antisubquark pairs even after the anticipated exciting discovery of the weak vector bosons in eighties.

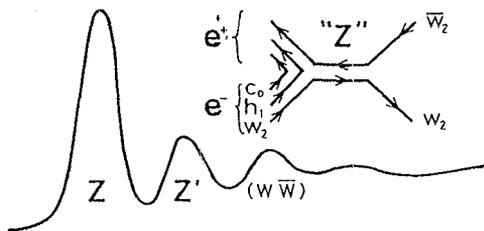


Fig. 1:  $e^+ e^- \rightarrow "Z"$

3. How can we explain the anomalous phenomena?

In concluding the first part of this talk, I shall make some conjectures on the anomalous phenomena observed in the cosmic ray events at energies of 10-1000 TeV, based on the above mentioned possible behavior of the strong and electroweak interactions of leptons and quarks at superhigh energies. The anomalously high multiplicities and possible "fire-balls" observed in the Niu's charm event and similar ones can be explained by either one of the following possibilities: 1) the production of weak vector bosons (or "weak bosonic matters") followed by their fast decays into a bunch of leptons and hadrons [21], 2) the production of very heavy leptons and/or quarks followed by their fast cascade decays into lighter leptons and/or quarks, e.g.,  $u_6 \rightarrow d_6 \rightarrow u_5 \rightarrow d_5 \rightarrow u_4 \rightarrow d_4 \rightarrow t \rightarrow b \rightarrow c \rightarrow s \rightarrow u$  [21], 3) the production of subquark-antiquark pairs followed by their fast "photonization", "weak-bosonization", "gluonization", "leptonization" and "quarkization" followed by hadronization into jets [11] and 4) the production of anomalous nuclei such as superheavy hypernuclei followed by their decays into leptons and hadrons [22]. It seems, however, hard to explain the production of a large number of nuclear active particles without noticeable emission of neutral pions and  $\eta$ 's observed in the Centauro events in either one of these pictures. It is really beyond our imagination. Also hard to explain is the anomalously slow absorption observed in the Bristol and Tien-Shan events. The slower absorption means the weaker interaction with the matter. As mentioned in Section 2, however, all the interactions of leptons and quarks might become strong at this superhigh energy on the contrary! It might be that these really unusual events be explained by the possibility 4) in which the breakdown of isospin invariance is most enhanced. In any case, these mysterious events may also indicate a revolutionary change of our notion. I should, however, mention that I have just received the papers contributed to this Conference by the UA5 and UA1 Collaborations [23] for a search for Centauro events at the CERN SPS  $p\bar{p}$  Collider which have reported no candidates. I shall review these papers in more detail later.

II. OBSERVED SUPERHIGH-ENERGY PHENOMENA

Now I am ready to review all the superhigh-energy phenomena observed so far in both accelerator and cosmic ray experiments, to make comparisons of them and to give some theoretical interpretations of them. To do that, I shall make an emphasis on the following eminent features commonly seen in all the experimental data on hadron-hadron inelastic collisions at lab. energies of the order of 10-1000 TeV or c.m. energies of the order of 100-1000GeV.

1. Rapidly increasing  $\langle n \rangle$

Fig. 2 shows all the available data [24-28] on  $\langle n_{ch} \rangle$  the average multiplicity of charged particles ( $\langle n_{ch} \rangle$ ) produced in p-p and p-p (or nucleon-nucleon) inelastic collisions at c.m. energies ( $\sqrt{s}$ ) ranging from about 10GeV to 540GeV. It clearly indicates that the average charged multiplicity increases rapidly as energy increases from the Fermilab PS energy to the CERN SPS p-p Collider energy and that the old cosmic ray balloon data point for  $\sqrt{s} \cong 180$  GeV is located remarkably well on the interpolating line between the CERN ISR p-p and p-p data points and the CERN SPS p-p data point. A reasonable fit to these data seems to be given by the formula of Thomé et al. type [25],

$$\langle n_{ch} \rangle = A \ln^2(\sqrt{s}/2m) + B \ln(\sqrt{s}/2m) + C$$

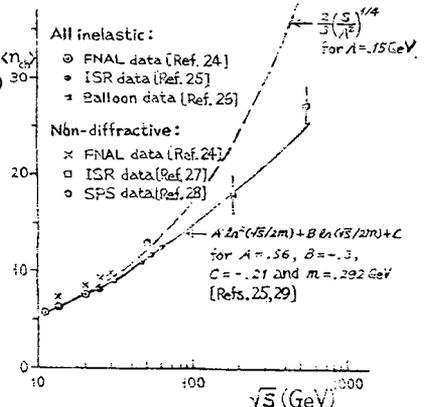


Fig. 2:  $\langle n_{ch} \rangle$  vs  $\sqrt{s}$

where the constants, A, B, C and m, are best fit by Gavai and Satz [29] as

$$A = .56, \quad B = -.3, \quad C = -.21 \quad \text{and} \quad m = .292 \text{ GeV.}$$

Although I have no time to discuss the various theoretical predictions on the increasing multiplicities, which can be found in Ref. 29 and in the contributed paper by Muraki [30], I must emphasize, as the UA5 Collaboration did, that the old and classic prediction by Fermi and Landau [31] in their statistical and hydrodynamical models of  $\langle n \rangle \propto s^{1/4}$  fails in fitting the cosmic ray balloon data and SPS p-p Collider data.

2. Gradually increasing  $\langle p_T \rangle$

Fig. 3(a) shows the three data [26-28] on the average transverse momentum of produced charged particles ( $\langle p_T \rangle$ ) as a function of the c.m. energy. It indicates that the average transverse momentum gradually increases as the energy increases from the ISR energy to the SPS energy and that the old balloon data point is again located remarkably well on the interpolating line between the ISR and SPS data points. I would not present any fit to these data at this stage with the small number of data points with the large error bars. Nor would I compare these data with any theoretical predictions. However, I would like to point out the following remarkable observation: Fermi and Landau can still survive! Suppose that

$$\langle n_{ch} \rangle \propto (\sqrt{s}/\mu)^{1/2}$$

where  $\mu$  is not a constant but an "order parameter", which can weakly depend on the energy,  $\sqrt{s}$ . This order parameter which describes the hadronic matters produced in hadron-hadron collisions may simply be proportional to the temperature (T) or more sophisticatedly be given by the vacuum expectation value of the condensating field ( $\langle \phi \rangle$ ). In any case, it seems natural to assume that also

$$\langle p_T \rangle \propto \mu.$$

Then, these two assumptions lead to the simple relation of

$$\langle n_{ch} \rangle^2 \langle p_T \rangle / \sqrt{s} = \text{constant} (= .70 \pm .05).$$

Fig. 3(b) shows that this relation is satisfied by the experimental data remarkably well.

3. Anomalously increasing  $\sigma^{-1} d\sigma/d\eta$

Fig. 4 shows the data on the normalized differential cross section ( $\sigma^{-1} d\sigma/d\eta$ ) with respect to the pseudo-rapidity ( $\eta = -\ln \tan(\theta_{c.m.}/2)$ ) from the UA5 Collaboration at the ISR and SPS p-p Colliders. Although the data from the UA1 Collaboration [32] at the SPS p-p Collider are also available, they have not been included here since their data points are systematically a little higher than the corresponding points from the UA5 and since the data at the ISR energies are not available from the UA1. This figure clearly indicates that as the energy increases from the ISR energy to the SPS one, the pseudo-rapidity distribution of produced particles changes in such a way that not only the width of the plateau gradually increases but also the height of it does. This tendency of the pseudo-rapidity distribution also

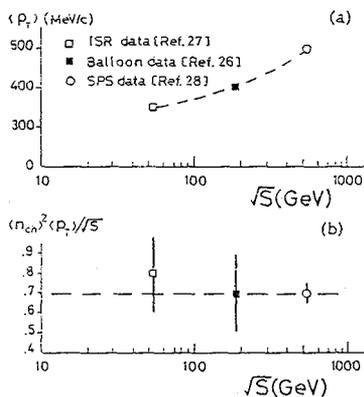


Fig. 3:  $\langle p_T \rangle$  vs  $\sqrt{s}$

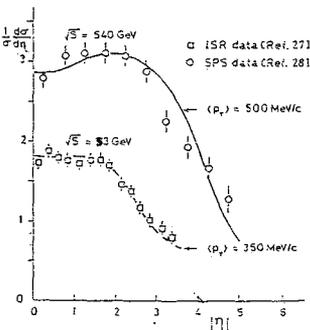


Fig. 4:  $\frac{1}{\sigma} \frac{d\sigma}{d\eta}$  vs  $|\eta|$

seems to have been well known by cosmic ray physicists for a long time but, of course, with the much less accuracies [33].

It should also be noticed that the shape of the plateau in the pseudo-rapidity distributions changes drastically. At the ISR energy, the central plateau is flat and the shape as a whole looks like that of a noble volcano such as Mt. Fuji. As the energy increases from the ISR energy to the SPS one, the shape of the mountain is deformed into that of another type of volcano either with two peaks or with a large caldera such as Mt. Aso (which has the world-largest caldera). This existence of two peaks may be misleading. It looks as if it would indicate two eminent jets or two "fire-balls" running away from each other and decaying into many hadrons. Does this mean that they have already found the evidence for subquark-antisubquark pair creations? In fact, in the contributed paper by Gao and Ho [34], they have claimed that the anomalously high multiplicities and the anomalously large transverse momenta seen in the unusual cosmic ray events can be well explained by the possible production of "subquark fire-balls". If this were the case, it would be the most exciting topic in this Conference without any question! As far as the observed pseudo-rapidity distributions are concerned, it seems premature to claim an evidence for the production of subquark-antisubquark pairs or any pairs of new heavy particles since the data for both energies of  $\sqrt{s} = 53\text{GeV}$  and  $540\text{GeV}$  can be perfectly well fit by the Monte-Carlo calculation of the UA5 Collaboration based on the conventional model with limited transverse momenta of  $\langle p_T \rangle = 350\text{MeV}/c$  and  $500\text{MeV}/c$  as is clearly seen in Fig. 4. A more detailed investigation of the azimuthal-angle distributions and the angular correlations of produced particles will be definitely needed before finding whether there exists any evidence for two eminent jets or not.

#### 4. Fire-balls? True or false?

It has been one of the most intriguing question or just a mystery for a long time in cosmic ray physics whether the so-called "fire-balls" exist or what they are if they do [6, 33]. Now that accelerator energies have increased high enough to compete with the cosmic ray energies where they claimed to find the fire-balls, accelerator physics is expected to give a definite answer to the question. In fact, the contributed papers by the UA5 and UAL Collaborations [23] for a search for Centauro events at the SPS pp Collider enable us to be much closer to the final answer, which will be discussed in the following:

Historically, the Brasil-Japan Emulsion Chamber Collaboration [6] has found several unusual cosmic ray events at superhigh energies larger than  $1000\text{TeV}$  with extremely high multiplicities of produced hadrons ( $n_h = 100 \pm 20$ ) and with unusually high average transverse momenta ( $\langle p_T^{\gamma} \rangle = .35 \pm .10\text{GeV}/c$ ) but without any  $\gamma$ 's observed and also several similar events but with much less hadron multiplicities ( $n_h = 15 \pm 2$ ) and called them "Centauro" and "Mini-Centauro" events, respectively. They have also found another type of unusual events with moderate hadron ( $\gamma$ ) multiplicities ( $n_h = 22 \pm 4$ ) but with extremely high transverse momenta ( $\langle p_T^{\gamma} \rangle = 2.0 \pm .5\text{GeV}/c$ ) and yet another type of similar events but with only two charged particles observed. They have called these types of events "Chiron" and

"Geminion" events, respectively. Table 1 summarizes these unusual events. On the other hand, very lately, the UA5 and UAL Collaborations have tried to find candidates for the Centauro type of events by the SPS pp Collider at c.m. energy of  $540\text{GeV}$ . Fig. 5 shows some of their reported results, which indicate no candidates for the Centauro events. There are only two possibilities left: 1) no Centauro events can occur in p-p

Table 1: Centauro type events [6]

event number	total visible energy (TeV)	observed hadron number	C- and Pb-jets	A-jets	interaction height (m)	average $p_T^{\gamma}$ (GeV/c)
Centauro I	230.6	49	1	-	$50 \pm 15$	0.35
Centauro IV	284.8	31	-	-	$500 \pm 206$ $113$	0.30
185-181-12	356.5	13	-	-	$160 \pm 30$	0.27
1395-1051-19	110.4	3	5	-	$300 \pm 100$	0.33
521-17	19	2	0	-	$3.0 \pm 0.2$	2.56
705-583-19	160	2	2	-	$50 \pm 15$	2.16
1985-1541-19	368.7	10	5	-	$330 \pm 30$	1.77
2125-1541-19	69.4	14	1	-	$4.2 \pm 2.2$ $-1.1$	3.28

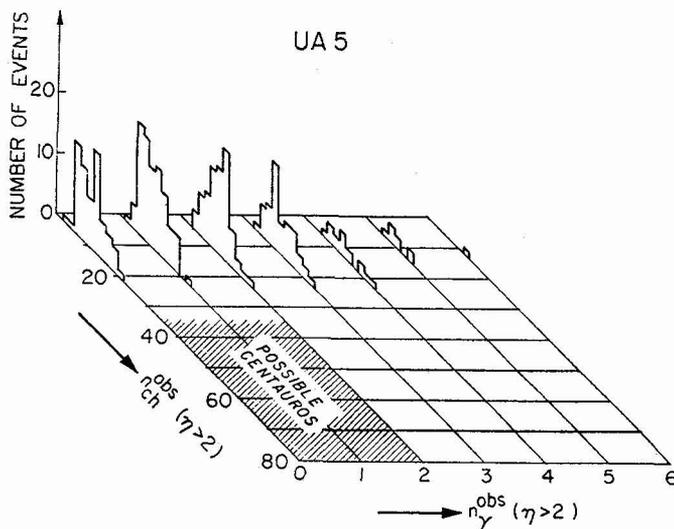


Fig. 5 : No Centauros seen [23].

collisions and 2) if they can, the threshold energy for the events to occur lies in the region between 540 GeV in the c.m. system and over 1000 TeV in the lab. system (or about 1 TeV in the c.m. system for nucleon-nucleon collisions). The former possibility would be likely if the events could be produced only by heavy nuclei as incident particles. If the latter is the case, it would be even more exciting since it would mean that there might exist a new particle or something alike with the mass of the order of 1 TeV (or 500 GeV if pair-produced). Increasing the energy of the SPS  $p\bar{p}$  Collider up to 1 TeV or building the Fermilab 2 TeV Collider would be most desired to find (or eliminate) the latter possibility.

### III. UNOBSERVED-PARTICLE TABLE

There are so many new particles predicted and yet unobserved. It seems just impossible to remember all of them. For future accelerator and cosmic ray experiments, I have revised the UNOBSERVED-PARTICLE TABLE made by Bjorken in 1977 [1] and presented it in Table 2. Obviously, I have no time to explain what these particles are, who have predicted them, who have tried to find them and what the present status of their experimental searches is, one by one. Please find these details in literatures. I, however, would like to discuss a couple of the contributed papers and the one recent paper handed to me, all of which are related to this Table.

In the contributed paper by Yock [35], he has reported the recent results from the first 2000 hours of operation of the new improved range telescope, which has been built at the University of Auckland to study heavy particles in the cosmic ray radiation and to attempt to determine conclusively if an anomalously heavy component is present. He has found two particles which appear to be anomalously heavy and has concluded that it is likely that there is a flux, near the zenith at sea level, of a few  $\times 10^{-9} \text{cm}^{-2} \text{sec}^{-1} \text{sr}^{-1}$  of low energy ( $\beta = .624$  and  $.536$ ), singly charged ( $Q = \pm 1.00$  and  $\pm .98$ ) particles with mass larger than  $4.5 m_p$ . He does not claim what they are. They can, however, be the fourth heavy charged leptons.

In the contributed paper by Muraki [36], he has claimed that the very narrow muon bundles induced by very high energy cosmic ray interactions can be explained by the production of beauty mesons (B) followed by their decays into multi-muons, as discussed in Section 3 of Chapter I. If his Monte Carlo calculation is right, it certainly indicates that what he has claimed is reasonable. He has also concluded that the production cross section of beauty mesons is as large as 200  $\mu\text{b}$  at lab. energies of 2000 TeV.

Table 2:  
UNOBSERVED-PARTICLE TABLE

1) <u>Claimed or to be observed</u>	
Quarks (q) $(\begin{smallmatrix} u, c, t, a, w, y \\ d, s, b, v, z, x \end{smallmatrix})$	$14 \text{ GeV} < m_q < .02 \text{ mg} ?$
Monopoles (m)	$m_m \sim 10^{17} \text{ GeV (theor.)}$
Tachyons (Tachy)	$m_{\text{Tachy}} \sim \text{imaginary (theor.)}$
Weak bosons ( $W^\pm$ and Z)	$m_{W^\pm}, m_Z \sim 80\text{--}100 \text{ GeV (theor.)}$
Dyons (Dy)	
Gluons (G)	
Gravitons (g)	$m_g = 0 \text{ (theor.)}$
2) <u>Well-established</u>	
New leptons (2)	
New charged leptons ( $L^-, \dots$ )	$m_L > 16 \text{ GeV}$
New neutral leptons ( $E^0, M^0, T^0, \dots$ )	$m_{E^0} > 17 \text{ GeV}, 14 \text{ keV} < m_{\nu_e} < 46 \text{ keV} ?$
(Massive neutrinos or Majorons)	$m_{\nu_\mu} < .57 \text{ MeV}, m_{\nu_\tau} < 250 \text{ keV}$
New Flavored hadrons (T, ...)	$m_T > 17 \text{ GeV}$
New onia ( $O, \dots$ )	$m_O > 34 \text{ GeV}$
Heavier gauge bosons ( $W'^\pm, Z', \dots$ )	$m_{W', Z'} > 80 \text{ GeV (theor.)}$
Higgs bosons and alike (H, ...)	$m_H > 70 \text{ GeV (theor.)}$
Scalons (Scal)	
Pseudo-Nambu-Goldstone bosons ( $P_{N-G}$ )	
Axions (a)	$170 \text{ keV} < m_a (=250 \pm 25 \text{ keV}) < 210 \text{ keV} ?$
Glueballs (Gb)	$m_g = 1440 \pm 15 \text{ MeV}, m_{\text{G}} = 1640 \pm 50 \text{ MeV}$
Super-high-spin hadrons (e.g., $\rho^{J=137}$ )	$m_J \sim \sqrt{J} \text{ GeV (theor.)}$
3) <u>Familiar</u>	
Superpartners (Sup)	
Gravitinos ( $\tilde{g}$ )	
Photinos ( $\tilde{\gamma}$ )	
Gluinos ( $\tilde{g}$ )	$m_{\tilde{g}} > 3.5\text{--}6 \text{ GeV}$
Other gauge bosinos ( $\tilde{W}, \tilde{Z}, \dots$ )	
Scalar leptons ( $S_2$ )	
Scalar neutrinos (Neutrinos) ( $S_{\nu_e}, S_{\nu_\mu}, S_{\nu_\tau}, \dots$ )	$\left. \begin{array}{l} m_{S_e} > 16.6 \text{ GeV} \\ m_{S_e} < 3 \text{ GeV} \\ m_{S_\mu} > 15 \text{ GeV} \end{array} \right\}$
Scalar charged leptons (leptinos) ( $S_e, S_\mu, S_\tau, \dots$ )	
Scalar quarks ( $S_q$ )	
Scalar up quarks (Up-Quarkinos) ( $S_u, S_c, S_t, \dots$ )	
Scalar down-quarks (Down-quarkinos) ( $S_d, S_s, S_b, \dots$ )	
Leptoquarks (X, Y, ...)	$m_X \geq 10^{15} \text{ GeV (theor.)}$
Colored bosons and fermions	
Diotons (Di)	
Subquarks (S)	
Wakems ( $w_i, i = 1, 2$ )	$m_w \sim 35 \text{ GeV (theor.)}$
Hakams ( $h_j, j = 1, \dots, N; N = 1, 2, 3, \dots, 6?$ )	
Chroms ( $C_k, k = 0, 1, 2, 3$ )	
4) <u>Others</u>	
Fire-balls (H, SH, UH quanta) ( $m_{Hq} \sim 2 \text{ GeV}, m_{SHq} \sim 20 \text{ GeV}, m_{UHq} \sim 200 \text{ GeV}$ )	
Centauro fire-balls (Cent)	$m_{\text{Cent}} \sim 200\text{--}300 \text{ GeV}$
Mini-Centauro fire-balls (Mini)	$m_{\text{Mini}} \sim 20\text{--}30 \text{ GeV}$
Chirons (Chir)	$m_{\text{Chir}} \sim 200\text{--}300 \text{ GeV}$
Geminions (Gemi)	$m_{\text{Gemi}} \sim 20\text{--}30 \text{ GeV}$
Anomalons (Anom)	$m_{\text{Anom}} \sim m_{\text{nucleus}}$
Sub-Subquarks (Ss)	
Subkomas (Sk)	

Very recently, the new JACEE (balloon-borne emulsion chamber) Collaboration [37] has reported some new unusual phenomena in nucleus-nucleus interactions at energies greater than 1 TeV/nucleon, including one event with the extremely high charged multiplicity ( $n_{ch} \geq 1050$ ) and several events with apparent high transverse momentum ( $\langle p_T(\gamma) \rangle \approx 540$  MeV/c) particle productions. Fig. 6 shows some of their results. They have concluded rather modestly that nucleus-nucleus interactions may not be presented by simple superpositions of nucleon-nucleon interactions at this high energy. May it be due to the creation of or the phase transition to abnormal nuclear matters, abnormal quark matters (or quark-gluon plasma) or what? Together with the possible existence of "anomalons" recently claimed by the Berkeley heavy-ion experimental group [38], these new unusual events observed by the JACEE Collaboration indicate that nuclear physics at very high energies would also be exciting.

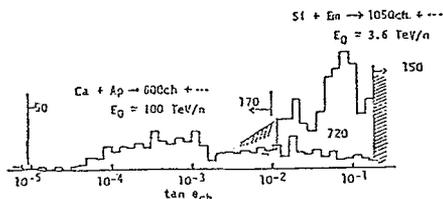


Fig. 6: JACEE events [37]

#### IV. CONCLUSIONS AND FUTURE PROSPECTS: AN ENERGY-SCALE TABLE, A FINAL THEORY AND THE END OF PHYSICS

In concluding this talk, I would like to summarize what I have discussed by the following two sentences:

- 1) The old cosmic ray data and the new accelerator data are consistent with each other at very high energies of 10-100 TeV in all the characteristic phenomena including rapidly increasing average multiplicities, gradually increasing average transverse momenta and anomalously increasing  $\sigma^{-1} d\sigma/d\eta$  except for the unusual phenomena seen in the cosmic ray data including the Centauro type of events.
- 2) In order to see whether the Centauro type of events can occur in hadron-hadron collisions, increasing the energy of the SPS  $p\bar{p}$  Collider up to, say, 1 TeV or building the Fermilab 2 TeV Collider is highly desirable.

For future prospects in superhigh energy physics, let me show an ENERGY-SCALE TABLE in Table 3. It seems to me that physics has changed already three times and will change again dramatically as energy increases by a factor of about  $3 \times 10^5$ , as can be seen in this Table. This quantization of the energy or mass scale may be related to the famous Large Number Hypothesis by Dirac [39]. It also seems to me that it has taken and will take about a quarter century to go through one generation of physics: atomic physics in 1900-1925, nuclear physics in 1925-1950, hadron physics in 1950-1975, lepton-quark physics in 1975-2000, subquark physics 2000-2025 and so on. If this continues to be the case, the end of physics will come around in 2050.

It is then natural to ask what the final theory in physics looks like. It should describe and explain not only everything in our Universe but even the origin of our Universe. I have recently tried to construct such a final theory in subquark physics [40] and in pregeometry [41], and made a candidate, "subquark pregeometry" which is based on the two principles (relativity and quantum) and the two hypotheses (fundamental length and compositeness). It effectively reproduces not only gauge theories for the strong and electroweak forces of the fermions (leptons and quarks) but general relativity of Einstein for gravity at low energies. At extremely high energies, it predicts an infinite series of nonlinear interactions of the fermions, the gauge bosons and the space-time metric. This supergrand unified theory also predicts many simple relations between the fundamental coupling constants and the particle masses and gives a simple explanation of the Big Bang of our Universe [42]. Please find the details of this new theory in my paper which will be published elsewhere [43].

The time seems to be up. Certainly, physics will end when the time ends. However, pregeometry would survive beyond the end of the time [44]!

Table 3:

ENERGY-SCALE-TABLE

	ENERGY	LENGTH	YEAR PHYSICS or PRERGEOMETRY
Extremely high Energy (EHE)	$10^{28}$ eV ( $10^{19}$ GeV) $G_N^{-1/2} = 1.221 \times 10^{19}$ GeV	$10^{-33}$ cm	2050- Subquark Pregeometry, Sub-Subquark Pregeometry or Sub-Sub-Subquark Pregeometry ? No Physics
Super-High-Energy (SHE)	$3 \times 10^{22}$ eV ( $3 \times 10^{13}$ GeV)	$3 \times 10^{-28}$ cm	2025-2050 Subquark Pregeometry or Sub-Subquark Physics ? (Subquark Pregeometry, Sub-Subquark Pregeometry or Sub-Sub-Subquark Model ?)
Ultra-High-Energy (UHE)	$10^{17}$ eV ( $10^8$ GeV)	$10^{-22}$ cm	2000-2025 Subquark Physics (Subquark Pregeometry or Sub-Subquark Model ?)
Very High Energy (VHE)	$3 \times 10^{11}$ eV ( $3 \times 10^2$ GeV) $G_F^{-1/2} = 292.9$ GeV	$3 \times 10^{-17}$ cm	1975-2000 Lepton-Quark Physics (Subquark Model)
High Energy (HE)	$10^6$ eV (1 MeV) $m_d - m_p - m_n = 2.2247(107)$ MeV	$10^{-11}$ cm (100f)	1950-1975 Hadron Physics (Gell-Mann-Zweig Quark Model of Hadrons)
Medium Energy (ME)	3 eV $R_\infty (= \alpha^2 m_e / 2) = 13.605804(36)$ eV	$3 \times 10^{-8}$ cm (3 Å)	1925-1950 Nuclear Physics (Heisenberg Model of Nuclei)
Low Energy (LE)			1900-1925 Atomic Physics (Nagaoka Model of Atoms)

Acknowledgements

I wish to thank many accelerator and cosmic ray physicists including Profs. and Drs. Y. Fujimoto, Ho Tso-Hsiu, M. Koshiha, H. Kumano, Y. Muraki, J. Rushbrooke, T. Saito, Yong-Shi Wu and Y. Yamaguchi for their useful comments and communications. I also wish to thank Professor H.P. Dürr at Max-Planck-Institut für Physik und Astrophysik, Professor A. Salam at International Centre for Theoretical Physics and Drs. D. Amati, J. Prentki and G. Veneziano for their warm hospitalities and financial supports extended to me during my stay at these Institutes where this talk has been prepared and this proceeding has been written.

References

1. For an earlier review on the similar subjects, see for example BJORKEN J.D., in *Proc. 1977 International Symposium on Lepton and Photon Interactions at High Energies*, edited by F. Gutbrod (DESY, Hamburg, 1977), p. 960.
2. TERAZAWA H., in *Proc. XVI International Cosmic Ray Conference*, Kyoto (ICRR, Univ. of Tokyo, 1979), vol. 7, p. 395.
3. NIU K., MIKUMO E., MAEDA Y., *Prog. Theor. Phys.* 46 (1971) 1644.
4. KURAMATA S. et al., in *Proc. XIII International Cosmic Ray Conference*, Denver (1973) Vol. 3, p.2239.

5. FUCHI H., et al., in *Proc. XV International Cosmic Ray Conference*, Plovdiv (1977) vol. 7, p.382.
6. BRASIL-JAPAN EMULSION CHAMBER COLLABORATION, in *Proc. XV International Cosmic Ray Conference*, Plovdiv (1977) vol. 7, p.208 and the contributed papers to this Conference, #0192 and #0193. For a review, see LATTES C.M.G., FUJIMOTO Y. and HASEGAWA S. *Phys. Rep.* C65 (1980) 151.
7. FOWLER P., in *Proc. International Conference on Theoretical Aspect of Very High Energy Phenomena*, CERN 61-22 (1961) p.125.
8. YAKOVLEV V.I., NIKOLSKY Y.I. and PAVLUCHENKO V.P., in *Proc. XV International Cosmic Ray Conference*, Plovdiv (1977) p.115.
9. See for example, GAISSER T.K., in *Proc. XV International Cosmic Ray Conference*, Plovdiv, (1977), p.24.
10. GLASHOW S.L., *Nucl. Phys.* 22 (1961) 579 ; SALAM A., in *Elementary Particle Physics*, edited by N. Svartholm (Almqvist and Wiksell, Stockholm, 1968), p.367; WEINBERG S., *Phys. Rev. Lett.* 19 (1967) 1264.
11. TERAZAWA H., CHIKASHIGE Y. and AKAMA K., *Phys. Rev.* D15 (1977) 480.  
TERAZAWA H., CHIKASHIGE Y., AKAMA K. and MATSUKI Y., *ibid.* 15 (1977) 1181;  
TERAZAWA H., *ibid.* 16 (1977) 2373, 22 (1980) 1037 and 2921;  
TERAZAWA H. and AKAMA K., *Phys. Lett.* 96B (1980) 276 and 97B (1980) 81. For a review, see TERAZAWA H., in *Proc. XIX International Conference on High Energy Physics*, edited by S. Homma et al. (Phys. Soc. of Japan, Tokyo, 1979) p.617.
12. TERAZAWA H., CHIKASHIGE Y. and AKAMA K., in ref. 11 ;  
TERAZAWA H., *Phys. Rev.* D22 (1980) 184. For recent reviews, see TERAZAWA H., in *Proc. 1981 INS Symposium on Quark Lepton Physics*, Tokyo, edited by Fujikawa K., et al. (INS, Univ. of Tokyo, Tokyo, 1981), p.296; PESKIN M.E.; in *Proc. 1981 International Symposium on Lepton and Photon Interactions at High Energies*, Bonn, edited by W. Pfeil (Univ. Bonn, Bonn, 1981). p.880. For observable effects of the sub-structure of leptons and quarks, see TERAZAWA H. and AKAMA K., *Phys. Lett.* 101B (1981) 190 and TERAZAWA H., YASUE M., AKAMA K. and HAYASHI M., *ibid.* 112B (1982) 387.
13. NAMBU, Y., in *Preludes in Theoretical Physics*, edited by A. de Shalit (North-Holland, Amsterdam, 1966) ; FRITZSCH H. and GELL-MANN M., in *Proc. XVI International Conference on High Energy Physics*, edited by A. Roberts (NAL, Batavia, 1973) vol. 2, p.135.
14. YANG C.N. and MILLS R.L., *Phys. Rev.* 96 (1954) 191.
15. HAN M.Y. and NAMBU Y., *Phys. Rev.* 139 (1965) B1006 ; MIYAMOTO Y., *Prog. Theor. Phys.*, Suppl. Extra Number (1965) 187. See also GREENBERG O.W., *Phys. Rev. Lett.* 13 (1964) 598.
16. GROSS D.J. and WILCZEK F., *Phys. Rev. Lett.* 30 (1973) 1343 ; POLITZER H.D., *ibid.* 30 (1973) 1346.
17. TERAZAWA H., CHIKASHIGE Y. and AKAMA K., *Prog. Theor. Phys.* 61 (1979) 1515.
18. TERAZAWA H., AKAMA K. and CHIKASHIGE Y., *Prog. Theor. Phys.* 60 (1978) 1521.
19. APPELQUIST T. and BJORKEN J.D., *Phys. Rev.* D4 (1971) 3726.
20. TERAZAWA H., *Phys. Rev.* D7 (1973) 3663 and *ibid.* 8 (1973) 1817. For more recent works, see BJORKEN J.D., *Phys. Rev.* D19 (1979) 335 and HUNG P.Q. and SAKURAI J.J., *Nucl. Phys.* B143 (1978) 81 and B148 (1979) 539.
21. TERAZAWA H., *Prog. Theor. Phys.* 63 (1980) 1779.
22. TERAZAWA H., INS-Report-336, May 1979, published in *Genshikakukenkhyu* (INS, Univ. of Tokyo, Tokyo) vol.25, N°6 (1981) 51 ; CHIN S.A. and KERMAN A.K., *Phys. Rev. Lett.* 43 (1979) 1292. The possibility of similar (but not the same) anomalous nuclear matters have been discussed in BJORKEN J.D. and McLERRAN L.D., *Phys. Rev.* D20 (1979) 2353.
23. UA5 COLLABORATION, The contributed paper to this Conference, #0467 and RUSHBROOKE J., in these proceedings ; UA1 COLLABORATION, the contributed paper to this Conference, #0671 and SPIRO M., in these proceedings.
24. 100 GeV/c pp, BROMBERG C. et al. *Phys. Rev.* D9 (1974) 1864;  
MORSE W.M. et al. *ibid.* 15 (1977) 66;  
100 GeV/c pp WARD C.P. et al., *Nucl. Phys.* B153 (1979) 299;  
205 GeV/c pp WHITMORE J. et al. *Phys. Rev.* D10 (1974) 273;  
303 GeV/c pp FIRESTONE A. et al. *ibid.* 10 (1974) 2080;  
405 GeV/c pp BROMBERG C. et al. *Phys. Rev. Lett.* 31 (1973) 1563.

25. THOME W. et al., Nucl. Phys. B129 (1977) 365.
26. SATO Y. et al., J. Phys. Soc. Japan 41 (1976) 1821; TAsAKA S. et al. in *Proc. XVII International Cosmic Ray Conference*, Paris (CEA, Saclay, 1981) Vol.5, p.126.
27. UA5 COLLABORATION, Phys. Lett. 112B (1982) 183.
28. UA5 COLLABORATION, Phys. Lett. 107B (1981) 310, 315 and RUSHBROOKE J., in these Proceedings ; UA1 COLLABORATION, the contributed papers to this Conference, #0672, #0673, #0674, #0675, #0676 and SPIRO M. in these Proceedings.
29. GAVAI R.V. and SATZ, Phys. Lett. 112B (1982) 413.
30. MURAKI Y., the contributed paper to this Conference, #0222.
31. FERMI E., Prog. Theor. Phys. 1 (1950) 570 ; LANDAU L.D., Izv. Akad. Nauk. SSSR, Ser. Fiz. 17 (1953) 51.
32. UA1 COLLABORATION, Phys. Lett. 107B (1981) 320 and in Ref. 28.
33. For a review, see for example LATTES C.M.G. et al., in Ref. 6.
34. GAO CHONG-SHOU and Ho TSO-HSIU, the contributed papers to this Conference, #0024, #0249, #0250, #0251, #0252.
35. YOCK P.C.M., the contributed paper to this Conference, #0214.
36. MURAKI Y., the contributed paper to this Conference, #0223.
37. The JACEE COLLABORATION, the paper presented by T. SAITO at the Second Topical Conference on Forward Collider Physics, Wisconsin, Dec. 1981, to be published in *AIP Conference Proceedings "pp Collider Physics"*.
38. FRIEDLANDER E.M. et al. Phys. Rev. Lett. 45, (1980) 1084.
39. DIRAC P.A.M., Nature 139 (1937) 323. For a recent discussion, see TERAZAWA H., Phys. Lett. 101B, (1981) 43 and reference therein.
40. For recent reviews, see TERAZAWA H. and PESKIN M.E., in Ref. 12.
41. SAKHAROV A.D., Doklady Akad. Nauk SSSR (1967) 70 [Sov. Phys. JETP 12 (1968) 1040] ; AKAMA K., CHIKASHIGE Y., MATSUKI Y. and TERAZAWA H., Prog. Theor. Phys. 60 (1978) 868. For a recent review see TERAZAWA H., in *Proc. Second Seminar "Quantum Gravity"*. Academy of Sciences of the USSR, Moscow, Oct. 1981, to be published.
42. AKAMA K. and TERAZAWA H., IC/81/118 (ICTP, Trieste, 1981) to be published in *Gen. Relativ. Gravit.*
43. TERAZAWA H., to be published.
44. MISNER C.W., THORNE K.S. and WHEELER J.A., *Gravitation* (Freeman, San Francisco, 1973).