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ENERGY DETERMINATION FOR RUNJOB EXPERIMENT

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Abstract

We summarize various methods of energy determination applicable for RUNJOB experiments and discuss the internal relation of each method with use of a trial model, fire-ball emission decaying isotropically into γ's ($\pi^0 \to 2\gamma$). Since the energy determination is closely related to the chamber sturcture, we also touch briefly the characteristics of chamber structure used in RUNJOB-program, slightly different from current emulsion chamber available for cosmic ray observation at both mountain and stratosphere levels.

Introduction:
RUNJOB experiment started in summer of 1995. We have launched seven balloons until now, each one loading two chambers ($2 \times$ 40cm x 50cm), and succeeded in the recovery of 6 flights. Since the volume of balloon we have used is as large as 180,000 m^3, the payload of our chamber is strictly limited within 250kg in each flight so that the balloon level keeps above $\sim$ 10 g/cm^2. This condition inevitably restricts us to use thin-type emulsion chamber, meaning that we can not apply straightforwardly the well-established photometric method for the energy determination of cascade shower, particularly for high energy event.

In order to overcome such a difficulty, we set a wide spacer between target module (lucite or stainless plate) and the calorimeter module, which enables us to measure the opening angle of secondary γ's ($\pi^0 \to 2\gamma$) produced by nuclear interaction at the target. The spacer thickness is typically 15 - 20 cm in vertical, wide enough to measure the opening angle for individual high energy γ's with $E_\gamma = 20 \sim 50$ TeV, taking the inclination effect into account. So we can estimate the total shower energy with ΣE_γ ~100TeV or more, where it is hard to catch the shower maximum in so called the transition curve in the case of thin calorimeter, though it depends on the inclination of the shower. In the next section, we summarize the energy determination method for RUNJOB chamber.

ENERGY DETERMINATION

Photometric method

Apart from the ambiguity of inelasticity fluctuation, we can estimate the shower energy released into γ-ray component with use of the cascade shower theory, which is well-established through the accelerator experiment [Hota et al., 1980]. Electron shower produced by the cascade process is detected quickly on X-ray film by naked-eye, while it is visible on nuclear emulsion plate only with help of the microscope unless otherwise the shower energy is so high, say $\gtrsim$ a few ten's TeV.

In addition to the validity of the naked-eye scanning on X-ray film, the darkness of the shower spot recorded on X-ray film gives us an information for the energy. The maximum darkness, D_{max}, is approximately proportional to the shower energy, ΣE_γ, irrespective of primary particle. The spot darkness is easily measured with use of photo-densitometer, and we get immediately the maximum darkness, the details of which are summarized in Okamoto et al., 1987 and Fujinaga et al., 1989.

As mentioned in the previous section, however, the thickness of RUNJOB chamber is as thin as $4 \sim 5$ radiation length in vertical. So, we meet often such event that the shower transition doesn't reach to the maximum point, particularly in the case of very high energy event with small azimuthal angle. In the next sub-section, we present other methods to determine the shower energy, and discuss the internal relation among them.

Opening-angle method

In RUNJOB chamber, we can measure simultaneously the opening angles of $\pi^\pm$, γ produced by nuclear interaction, and also fragment products such as proton, α, ..., in the case of heavy primary. We don't touch here the method of energy determination with use of the opening angle of fragments, which is summarized in detail in Ichimura et al., 1993.

Up to now, we have proposed several methods [Apanasenko et al., 1997, Oshev, 1998, Sveshnikova et al., 1998, Nanjo, 1998] for the energy determination in RUNJOB chamber, using the opening angles of $\pi^\pm$, γ. There are two ways of thinking in these methods. The first one is the energy sum released into secondary particles, $\pi^\pm$ and/or ($\pi^0 \rightarrow$)γ-ray, assuming p_t-constant

$$\Sigma E_a \;=\; \sum_{i=1}^{n} \frac{p_{ti,a}}{\theta_i} \;\simeq\; \langle p_{ta} \rangle \sum_{i=1}^{n} \frac{1}{\theta_i}, \tag{1}$$

where "a" denotes $\pi^\pm$ or γ, and n is the number of γ-rays or $\pi^\pm$, and $\langle p_{ta} \rangle \simeq 180$ MeV/c for γ-rays and $\simeq 350$ MeV/c for $\pi^\pm$'s. Practically, however, the average transverse momentum, $\langle p_t \rangle$, depending on emission angle in the forward region, we assume a following empirical function

$$\langle p_t \rangle(\theta) \;=\; p_0\,(1 \;-\; \mathrm{e}^{-u}), \quad \text{with } \; u = \theta \Sigma E_\gamma / M_0, \tag{2}$$

where $p_0 \sim 180$ MeV/c and $M_0 \sim 800$ MeV/c^2 for γ-rays. Now, eq. (1) is modified as, using eq. (2),

$$\Sigma E_\gamma \;=\; \sum_{i=1}^{n} \frac{p_{ti}}{\theta_i} \;\simeq\; \sum_{i=1}^{n} \frac{\langle p_t \rangle(\theta_i)}{\theta_i}, \tag{3}$$

We can solve eq. (3) with respect to ΣE_γ, and can convert it into the primary energy E_0, though the ambiguity of conversion factor still remains. We call this method $\langle p_t \rangle_\theta$-summation method.

The second method is to estimate the Lorentz factor, Γ, or equivalently the pseudo-rapidity, $\eta_c = \ln 2\Gamma$ of the fastest moving-cluster (fireball), carrying most of the total energy flow released into secondary particles. Here, we should be careful of the detection-loss bias for γ's ($\pi^{\pm}$) with large opening angle. So, in order to eliminate such effect, we select only γ's ($\pi^{\pm}$) satisfying a condition

$$\eta_{max2} - 3 < \eta < \eta_{max2},$$

where η is a familar variable, pseudo-rapidity, defined by $-\ln\tan\theta/2$, and η_{max2} is the second highest pseudo-rapidity. It is well-known that the experimental data on the pseudo-rapidity distribution in the forward cone is consistent with an isotropic emission of γ's ($\pi^{\pm}$) from moving-cluster.

Since the Lorentz factor, Γ, of the cluster is expected to be proportional to the primary energy E_0, we can determine the energy after obtaining the correlation of Γ - E_0 (or η_c - E_0) through some simulational calculation. We call this method η_c-E_0-correlation method.

Relation between $\langle p_t\rangle_\theta$-summation method and η_c-E_0-correlation method

In order to investigate the relation between $\langle p_t\rangle_\theta$-summation method and η_c-E_0-correlation method, we assume a trial model, fireball emission decaying isotropically into pions (γ's) in the multiple meson production. Let us assume a following distribution function for the energy and angle of ($\pi^0 \rightarrow$)γ's in the fireball rest system,

$$\phi(p^*,\theta^*)dp^*d(\cos\theta^*) \;=\; N_\gamma e^{-p^*/p_0}\frac{p^*dp^*}{2p_0^2}d(\cos\theta^*), \tag{4}$$

where N_γ is multiplicity of γ-rays produced by the decay of fireball and p_0 corresponds to average momentum of those in the fireball rest system.

Applying the Lorentz transformation for eq. (4), we get the energy and angular distribution in the laboratory system[Konishi et al., 1976]

$$\phi(E_\gamma,\theta)dE_\gamma d\theta^2 \;=\; N_\gamma\exp[-x(1+y^2)]dxdy^2, \tag{5a}$$

$$\text{with}\;\; x \;=\; N_\gamma E_\gamma/\Sigma E_\gamma \;\;\text{and}\;\; y \;=\; \Gamma\theta. \tag{5b}$$

Integrations with respect to x and y in eq. (5a) give

$$N_\gamma\frac{dy^2}{(1+y^2)^2} \quad : \quad \text{isotropical angular distribution,} \tag{6a}$$

$$N_\gamma e^{-x}dx \quad : \quad \text{exponential energy distribution,} \tag{6b}$$

respctively. We also get a following relation between $\langle p_t\rangle$ and θ (or η)

$$\langle p_t\rangle(\theta) \;=\; p_0\frac{2y}{1+y^2} \;=\; \frac{p_0}{\cosh(\eta\;-\;\eta_c)} \tag{7}$$

Let us substitute eq. (7) into eq. (3), then we get

$$\Sigma E_\gamma \;=\; 2p_0\Gamma\sum_{i=1}^{n}\frac{1}{1+y_i^2}.$$

Remembering the relation $\Sigma E_\gamma = M_0\Gamma = np_0\Gamma$, we obtain

$$\sum_{i=1}^{n}\frac{1-y_i^2}{1+y_i^2} \;=\; 0. \tag{8}$$

Then we obtain a following result, using a familiar relation $y = \Gamma\theta = \tan\theta^*/2$,

$$\sum_{i=1}^{n} \cos\theta_i^* \quad = \quad 0 \tag{9}$$

Eq. (9) is nothing but the relation of isotropical decay of fireball, that is, $\langle p_t \rangle_\theta$-summation method is equivalent to η_c-E_0-correlation method.

DISCUSSION

We find $\langle p_t \rangle_\theta$-summation method is equivalent to η_c-E_0-correlation method, while one may think the latter is independent of p_t. One must remember, however, that in order to estimate the opening angle θ_i, we have to determine the center of axis, satisfying

$$\sum_{i=1}^{n} p_{tx,i} \ = \ \sum_{i=1}^{n} p_{ty,i} \ = \ 0$$

Then the latter method is closely related to eq. (2) through the determination of cnter of axis. Practical application of the present consideration will be reported in the conference.

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