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# Algorithms based on isotropic azimuthal angle distribution of interaction secondaries

**C. R. A. Augusto[1], S. L. C. Barroso[2], P. C. Beggio[3], A. O. Carvalho[2], M. J. Menon[2], C. E. Navia[1], R. Oliveira[2], and E. H. Shibuya (Brazil-Japan Collaboration of Chacaltaya Emulsion Chamber Experiment)[2]**

[1]Instituto de Física, Universidade Federal Fluminense, 24210-130 Niterói, RJ, Brazil
[2]Instituto de Física 'Gleb Wataghin', Universidade Estadual de Campinas, 13083-970 Campinas, SP, Brazil
[3]Laboratório de Ciências Matemáticas, Universidade Estadual do Norte Fluminense, Campos dos Goytacazes, RJ, Brazil

**Abstract.** An azimuthal angle distribution of events measured by Brazil-Japan Chacaltaya Emulsion Chamber Experiment (B-J Collaboration) shows that the secondaries produced by cosmic ray interaction particle are isotropic. Algorithms based on these observations were analytically calculated and their application to near 372 interaction events will be presented. One of these algorithms is equivalent to Duller-Walker plot High-Energy Meson Production. Duller and Walker (1954) and therefore it is possible to anlyse the events as having structure of jet emission, through tests of their 'sphericity'. From the distribution of this ad-hoc defined sphericity it is possible to infer about the jet structure. Another apropriate combination of the calculated moments is used to get insights of superposition of interactions and/or production of more than one jet simultaneously.

## 1 Introduction

A series of detectors called emulsion chambers (for instance in Fire-Balls in Pion Multiple Production. B-J Collaboration (1983)) have been exposed to Cosmic Rays incident on the Observatory of Mount Chacaltaya (5220 m above sea level and 20 km far from La Paz City, Bolivia) by B-J Collaboration, since 1962. The geographic coordinates of this Observatory are: $16^0 20^{'} 45^{''}$ South and $68^0 07^{'} 31^{''}$ West, which corresponds to geomagnetic coordinates $4^0 50^{'} 40^{''}$ South and $0^0 50^{'} 20^{''}$ East, respectively. These exposures observe secondaries of hadronic interactions as black spots in X-ray films and clusters of electron tracks in emulsion plates, both photosensitive material composing the detector. Lead plates are inserted between the envelopes containing photosensitive material, working either as a eletromagnetic particles converter or as a target for hadronic interaction particles. Then, the sensitive material of the detector always registers groups of electromagnetic tracks.

*Correspondence to:* E. H. Shibuya
(shibuya@ifi.unicamp.br)

## 2 Description of experiment and method

A typical emulsion chamber is constituted by an upper chamber over blocks of compacted plastic sheets or asphalt pitch, both located on a iron frame platform and below those, an lower detector spaced by an air gap. The analysis was done in a sample of 372 events, where 87 events are observed only in the lower detetor, then these events are called C-jets. Other 285 events, called A-jets, were observed since the upper detector. Included in these A-jets sample there are 5 unusual events, Centauro events, analysed in two other contributions for the conference.

Beyond a traditional analysis done in some occasions, here we suggest a method based on an azimuthal isotropic decay of secondaries observed in figure 1. The superposed experimental distributions for A-jets and C-jets were compared with a uniform distribution and resulted in reduced $\chi^2$ values between 1.1 and 1.8.

Based on this observed isotropic azimuthal angle distribution, the secondary particles distribution composed by energy

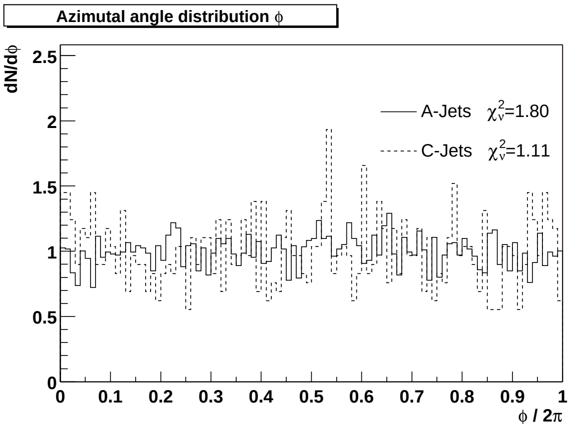


**Fig. 1.** Azimuthal angle distribution

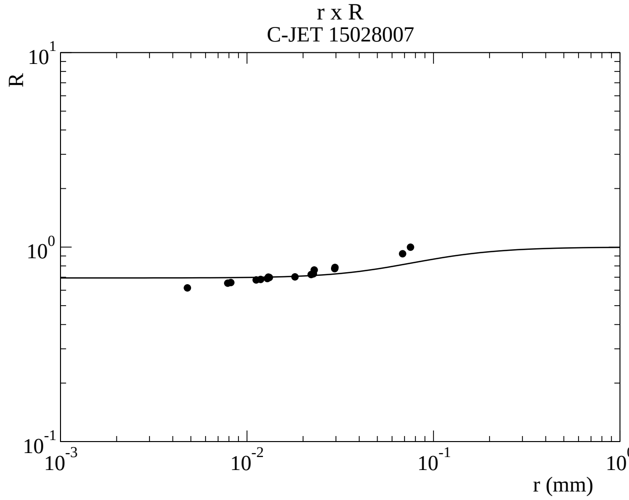


**Fig. 2.** Example of algorithm R for C-jet

$E^*$ and solid angle $\Omega^*$, expressed in a center of mass system,

$$dN = g(E^*, \Omega^*) dE^* d\Omega^*) \tag{1}$$

transforms in a general expression for the moments below, where $E_i$ and $\theta$ are the energy and zenital angle of $i^{th}$ particle, n is the order of moment, $\Gamma$ and M are the Lorentz factor and Invariant Mass of the group of particles, respectively.

$$\Sigma E_i(\Gamma\theta_i)^n \simeq M\Gamma \int_{\frac{1-\Gamma^2\theta^2}{1+\Gamma^2\theta^2}}^{1} \frac{(1-x^2)^{\frac{n}{2}}}{2(1+x)^{n-1}} dx \tag{2}$$

All the moments are functions of $\Gamma\theta$ and so, functions of r/$\bar{r}$, where $\bar{r}$ is related to Lorentz factor and H(interaction height) through $\Gamma = \bar{r}/H$. Therefore, the algorithms are useable even for events without height determined.

Taking the $0^{th}$, $1^{st}$, $2^{nd}$ and $3^{rd}$, a proper combination of them, each one normalized, it were constructed algorithms called R and mDW. The first one, R, is defined as a ratio as follows:

$$R = \frac{[\Sigma E_i][\Sigma E_i(\Gamma\theta_i)^2]}{[\frac{4}{\pi}\Sigma E_i(\Gamma\theta_i)]^2} \tag{3}$$

where both, the numerator and denominator, are functions of $\Gamma\theta$ and of squared Invariant Mass as could be seen in the appendix. So, the events that fits this analytical curve are events coming from one jet produced at one single interaction point. Examples of application of algorithm R are presented in figures 2 and 3 for C-jet and A-jet, respectively. This algorithm was firstly used in Indication of $\eta$-meson production in gamma-ray families. Shibuya (1983) to present production of mesons heavier than $\pi^0$ mesons.
The second algorithm was called mDW due to its similarity to the Duller-Walker plot (High-Energy Meson Production. Duller and Walker (1954)), used to show the sphericity of a jet. It differs from that in the fact that it uses also the energy of each member of a jet and does not necessary to know the total multiplicity, a priori. The events that fits this curve are interpretable as spherical because the slope is 2, same kind of reasoning for the isotropic characteristic coming from DW-plot. It it defined as,

$$mDW = \frac{1}{4M\Gamma}[\Sigma E_i + \frac{4}{\pi}\Sigma E_i(\Gamma\theta_i) + \Sigma E_i(\Gamma\theta_i)^2 + \frac{4}{3\pi}\Sigma E_i(\Gamma\theta_i)^3] \tag{4}$$

In figure 4 this algorithm was applied for various A-jets, C-jets and also for Centauro events with the height determined through kinematics of $\pi^0 \rightarrow \gamma + \gamma$ and triangulation method. In fact, with the general expression above, it is also possible to calculate moments of order higher than $3^{rd}$. In principle, addition of these greater order moments to the algorithm mDW could smooth this curve. The difficult comes from the normalization factor of these moments, for instance the $4^{th}$ moment has a $\log(1+\Gamma^2\theta^2)$ factor that does not converge at $\Gamma\theta \rightarrow \infty$.

## 3 Results and discussions

As 87 analysed events comes from a localized target of Carbon we have the vertex of the interaction point with the precision of the geometric distance of the gap, i.e. around 14% because the height is H=(170 $\pm$ 23)cm. This is not the case of A-jets. Then, for the events with difficult height determination, mainly A-jets, we used the algoritms in function of r/$\bar{r}$.

Defining 'sphericity' as the slope of best fitted mDW algorithm we got the histogram of this quantity in figure 5. Expected value of 2 for a isotropic decay of secondaries is not observed. Mean value of ad-hoc defined 'sphericity' is between 1.3 and 1.6, as got from the histogram, that means most of events are jet-like with A-jets more isotropical in zenital angle distribution. Improvement for these 'sphericity'values could be done, fitting the analytical curve in the experimental data.

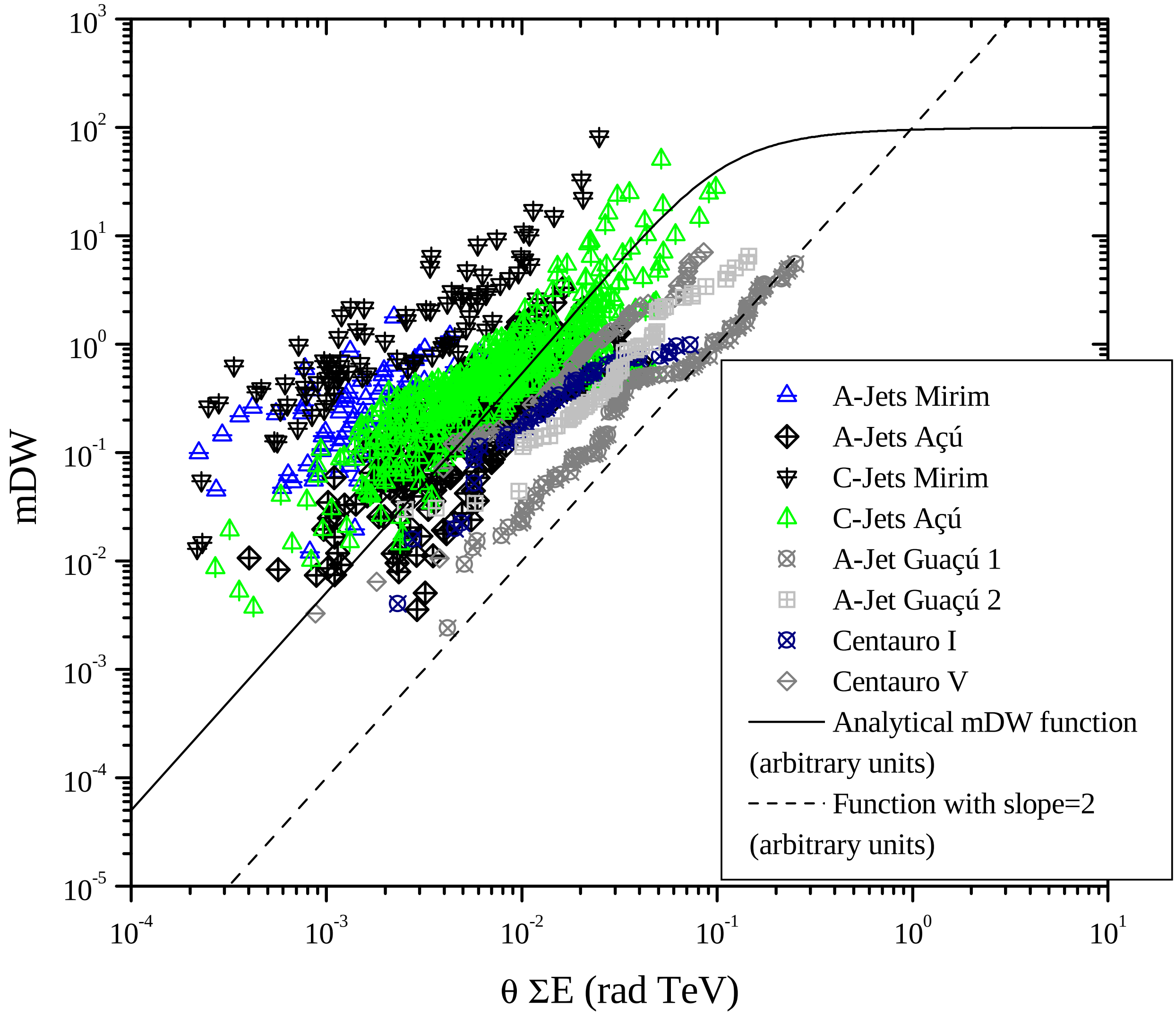


**Fig. 4.** Algorithm mdW for some events with measured interaction point

Also an application to 9,360 simulated events using CORSIKA/QGSJET procedure (Part of the results gotten, under this procedure and a simulation of emulsion chamber done by M.Tamada, were used in the reference, Tamada & Ohsawa (2000)) was done and used in a paper submitted to this conference (Search of centauro like events. C.R.A.Augusto et al. (2001)). The procedure is based on the CORSIKA5.20 code (Knapp et al. (1997)) where it is incoporated the QGSJET model (Kalmykov et al. (1994)).

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**Appendix A**

Below, we list 6 moments obtained from a general expression in the text. For the purpose of this paper we used the first 4 moments, because the $5^{th}$ moment does not converge, in spite of the $6^{th}$ has a limit for $\Gamma\theta \to \infty$.

$$\Sigma E_i(\Gamma\theta_i)^0 \simeq M\Gamma[1 - \frac{1}{(1+\Gamma^2\theta^2)^2}] \tag{A1}$$

$$\Sigma E_i(\Gamma\theta_i)^1 \simeq M\Gamma[\frac{\arctan\Gamma\theta}{2} - \frac{(\Gamma\theta - \Gamma^3\theta^3)}{2(1+\Gamma^2\theta^2)^2}] \tag{A2}$$

$$\Sigma E_i(\Gamma\theta_i)^2 \simeq M\Gamma[\frac{\Gamma^2\theta^2}{1+\Gamma^2\theta^2}]^2 \tag{A3}$$

$$\Sigma E_i(\Gamma\theta_i)^3 \simeq M\Gamma[\frac{3\arctan\Gamma\theta}{2} - \frac{3\Gamma\theta + 5\Gamma^3\theta^3}{2(1+\Gamma^2\theta^2)^2}] \tag{A4}$$

$$\Sigma E_i(\Gamma\theta_i)^4 \simeq M\Gamma[2\log(1+\Gamma^2\theta^2)^2 - \frac{3\Gamma^4\theta^4 + 2\Gamma^2\theta^2}{(1+\Gamma^2\theta^2)^2}] \tag{A5}$$

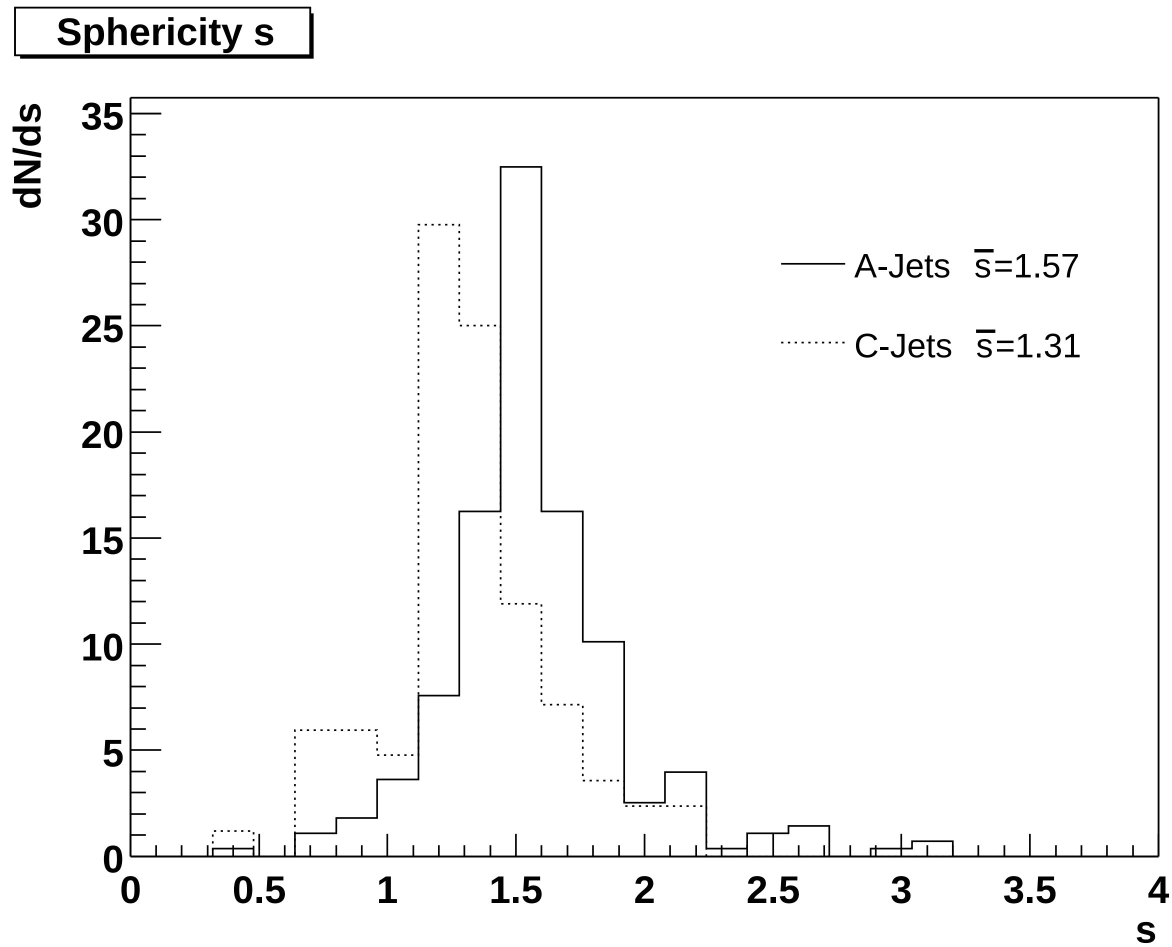


**Fig. 5.** Distribution of ’sphericity

$$\Sigma E_i(\Gamma\theta_i)^5 \simeq M\Gamma[\frac{3\Gamma^4\theta^4 - 4\Gamma^3\theta^3 + 18\Gamma^2\theta^2 + 4\Gamma\Theta + 3}{(1+\Gamma^2\theta^2)^2}] \times [\frac{\Gamma\Theta}{2} - \arctan\Gamma\theta] \quad (A6)$$

## References


N.M.Duller and W.D.Walker, Phys.Rev.93,No.1,(1954),215.

Brasil-Japan Collaboration of Chacaltaya Emulsion Chamber Experiment, Prog.Theo.Phys.,Supp.76,(1983),1.

Shibuya,E.H., Proc. $XVIII^{th}$ ICRC,vol.11,(1983),97.

M.Tamada & A.Ohsawa, Nucl.Phys.B581,(2000),73.

C.R.A.Augusto et.al., accepted to be presented to this conference.

J.Knapp, D.Heck and G.Shatz, Nucl.Phys.B(Proc.Suppl.)52B (1997),136 & 139; D.Heck, J.Knapp, J.N.Capdevielle, G.Schatz & T.Thouw, Forschungszentrum Karlsruhe FZKA 6019(1998). Kernforschungszentrum

N.N.Kalmykov, S.S.Ostapchenko & A.I.Pavlov: Bull.Russ. Acad.Sci., Phys.Ser.58 (1994) 21; N.N.Kalmykov, S.S.Ostapchenko, Phys.At.Nucl. 56 (3), (1993), 346.


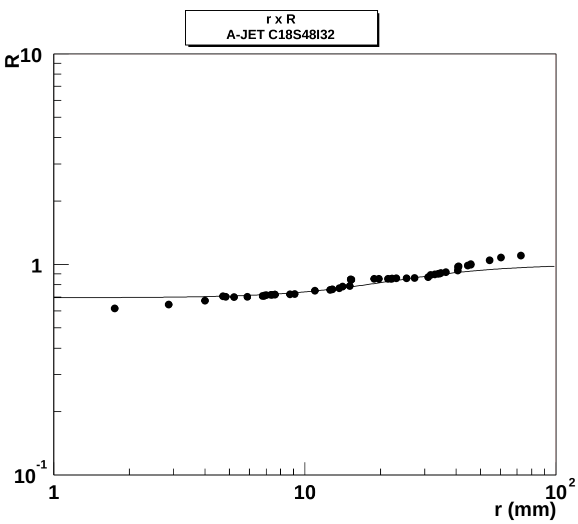


**Fig. 3.** Example of algorithm R for A-jet