HIGH p_t CROSS SECTION FROM MULTIPLE CORE RATES IN AIR SHOWERS

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ABSTRACT

The general problem is outlined. The current status of analysis of the Leeds spark chamber observations is given. Comparison is made with the results of other groups.

INTRODUCTION TO THE GENERAL PROBLEM

There have been many observations of multiple cores in air shower detectors. Those made with spark chambers[1-5] have the greatest potential for translation into the lateral structure of the incident shower itself, a problem that has received some attention[3,6,7] but that requires further analysis.

Finally, there is the basic question of testing models of high p_t production by comparison with observed rates of subcores. This has been done preliminarily with available information.[3,4,8,9] In order to make the comparison really meaningful, considerably more analysis is required. The uncertainties in determiniations of the normalizations and of the slopes need further attention.

INTRODUCTION TO THE ANALYSIS PROBLEM

Our group is not yet ready to address the question posed in the program: "Multiple cores and high p_t - can the connection be made?" It is believed that the answer is positive[1-4] and we concur in that belief. But there is still much to be done before models of high energy interactions can be confidently tested.

The expected relative cross section of a few percent[9] is just high enough for statistically significant cosmic-ray observations. But the major problem is to make other uncertainties as small as the statistical uncertainty. (1) First is the question of the effective "beam". The Tokyo groups have made estimates based (a)[2] on simulations by Tanahashi, and (b)[4] on the measured hadron component of air showers at sea level plus the measured attenuation length in air. Both methods have large uncertainties. Updated simulations are needed for improvement here. In principle, fluctuation effects can also be obtained from simulations. (2) Second is the interpretation of the role of the atmosphere as analyzer, which is coupled to the

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question of the nature of the high p_t "particle". If it is a pion, simulations have shown that a π^o is the most likely source of a subcore.[1,10] If it is a jet, a jet with a π^o as the leading pion is the most likely source. Therefore, analyses made to date[2,4] have assumed π^o sources. The analytical solutions of Nishimura and Kidd[11] for electromagnetic showers have been used. If it seems to be desirable to consider fluctuations, it is probably necessary to do simulations here also. (3) Third is the question of interpreting the detector response. We are using limited-current spark chambers, which give the best representation of the number of shower particles of any feasible detector. However, there is an observable transition effect of the electromagnetic radiation produced by roof beams above the spark chambers, seen at Leeds. (4) The final question on this list is that of efficiency of detection of (i) subcores in the main shower , and apparent subcores due (ii) to fluctuations in main shower particles and (iii) to hadron interaction in overlying materials.

In this paper, I shall outline the current status of our work, which means primarily a discussion of (3) and (4). Then there will be a brief comparison to other groups.

PARTICLE DETECTION; SUBCORE DETECTION

(a) The multiparticle detection efficiency of limited-current spark chambers similar to ours has been measured relative to scintillators.[1] However, there are uncertainties of interpretation of scintillator data due to effects such as scattered particles, local interactions, and statistical breadth. Therefore, we have determined the efficiency from studies of spark chamber photos alone. From the statistics of sparklet clusters in test photos with trigger delay, we deduce an efficiency $\simeq$ 100% in spark formation. The ultimate limit is photographability, because the spark brightness diminishes as the available energy per chamber is shared among an increasing number of sparks.

(b) We have measured our scanning efficiency for subcores from comparison of two independent scans of ~ 60,000 photos. The result is 82% efficiency for double scanned photos. However, this is primarily for rather sharply peaked subcores. We are uneasy about our efficiency for detecting broad subcores, particularly in the larger showers, a problem that the Norikura group has found to be serious.[5] We are working on this question.

(c) Correction for subcores that are missed because the array is finite and because subcores cannot be seen in the dense, inner region of showers is made either from the subcore events themselves, or from a larger sample of main showers with the observed radial frequency distribution of subcores folded in. The result is ~ 0.3 for this efficiency factor.

(d) There is a potential contamination factor due to subcores simulated by statistical fluctuations. In order to estimate this, we have first looked for evidence of residual dependence in the lateral positions of the particles resulting from common parentage. This has been done by counting sparks in bins at a given distance from a shower axis and calculating the standard deviation for each set of bins. We have found that $S^2=(0.94 \pm 0.07)\ (\langle n\rangle)^2$, averaged over the samples, with no significant dependence on shower size or distance from the axis. Therefore, we conclude that the statistics of independent events are a good approximation. Our first cut, in the scanning, was for "subcores" with $n_o \geq 30$ in a circle of 25 cm radius above background ≤ 30. The Hillas analysis[12] for the effect of moving a bin to maximize the count can be used to get an upper limit to the probable number of fluctuations to 60 or more within the 25 cm bin. This has been done, using observed background distributions in the calculation. The result is that no more than 9 (to a 90% confidence level) would have occurred. This is a drastic upper limit since (i) 30 is the minimum n_o in our sample, (ii) the central bin is surrounded by bins that are somewhat above average. Our conclusion is that the number of false subcores generated by fluctuations is negligible.

The corrections from (b) and (c) above will be made after a discussion of the transition effect.

TRANSITION EFFECTS

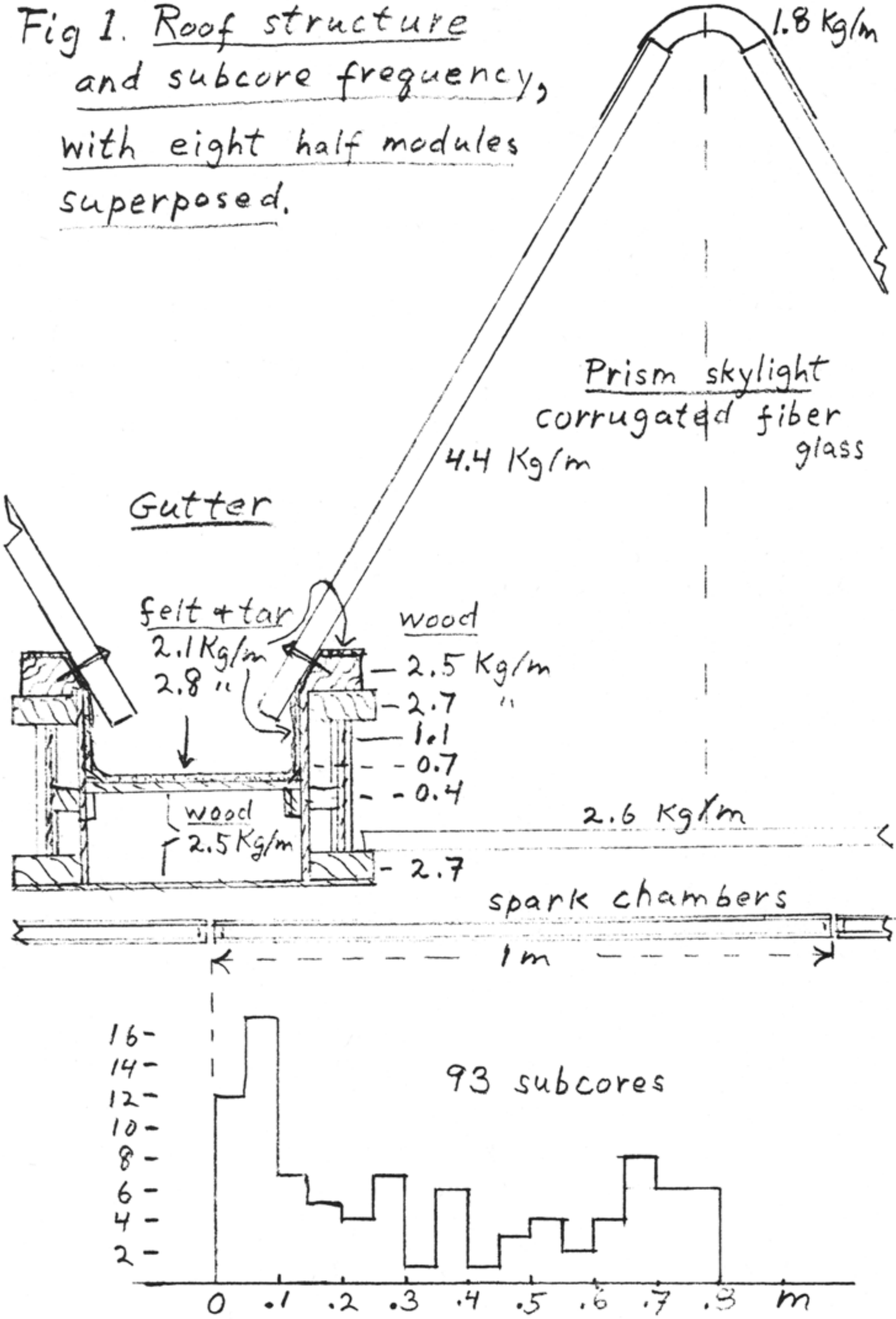
The spark chambers are mounted directly beneath the roof, which is made of wood and fibre glass (Fig. 1).

(a) The average transition effect of the EM Component is expected to be small since the roof averages only 2.6 $gm/cm^2 \simeq 0.06$ shower units. The effective Z is not much different from air. Hence the total number of particles simply decreases as if the shower had traversed another 20 m of air (we are past the shower maxima). But the lateral structure is altered, particularly by the beams (12 $gm/cm^2 \simeq 0.3$ shower unit). Observationally, we can barely detect the beam effect, and only within a meter or two of the axes of large showers, $N \geq 10^6$, where pair production dominates over particle absorption.

We conclude that there might be some distortion of subcores by the beams but not by the prisms (skylights).

(b) The hadron component is a different story; it can generate "subcores", particularly in the beams. Our roof geometry is quite like that at Kiel, where this effect was discovered.[6] We observe a qualitatively similar effect of clustering under the beams (Fig. 1).

Fig 1. Roof structure and subcore frequency, with eight half modules superposed.



CORRECTION FOR HADRON INTERACTIONS

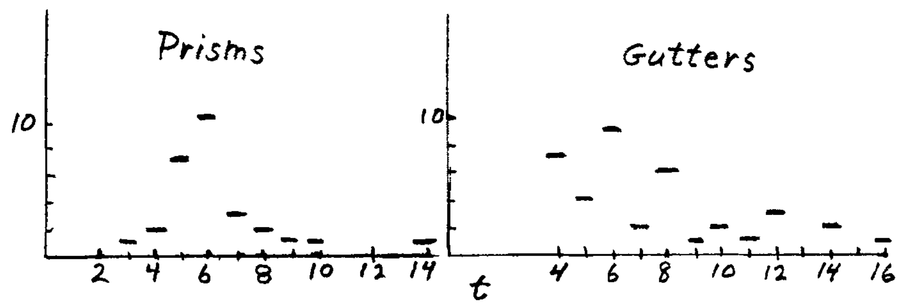
The expected number of subcores produced by hadron interactions in the roof can be estimated from hadron intensity and scaling of accelerator multiplicity distributions[7] but the input data are uncertain. Therefore, we are trying to rely primarily on our observations by using the observed overlying mass effect on the number and steepness of the subcores.

A subsample of 66 from the 93 observed subcores is ready for this analysis. These are separated into 28 subcores observed under the prisms (1 gm/cm^2) and 38 under the gutters (3.6 gm/cm^2). In each case, the subcores have an air subcore component N_A and a locally produced component N_H. The former is proportional to the area and the latter depends on the mass. Due to secondary interactions, there is a relative factor of about 3 in addition to the mass factor itself.[7] Using the above sort of modeling, we get:

	Prisms	Gutters
N_A	25	20
N_H	3	18

We then turn to the steepness distribution of the subcores (steepness measured by the production height t (s.u.) from Nishimura-Kidd[11] fits) in order to see if there is a correlation with their origins. Figure 2 shows the results. They are not clear cut. However, taken together with the Kiel observation of correlation of steepness and beam effect[6] and unpublished results from FNAL thick-target data[7], the best sorting is based on the assumption of local interactions producing steeper events.

Fig. 2. Frequency vs t, which is the depth in shower units but is also a measure of steepness.



As a sample of high likelihood shower subcores, we select the 25 prism events with t>4 and the 18 gutter events with t>6. The p_t's for these events are obtained with the usual assumption that neutral pions are the most likely source. The Nishimura-Kidd results for gamma rays are used to find E_0, assuming equal energies for the gammas. For the lateral displacement, r, of the subcore from the projected direction of the interacting particle, we follow the Tokyo choice of measuring from the symmetry axis of the main shower. This choice will be tested in the future when we start modeling and simulating. Our p_t distribution is shown in integral form in Fig 3, along with those from Tokyo[2,4].

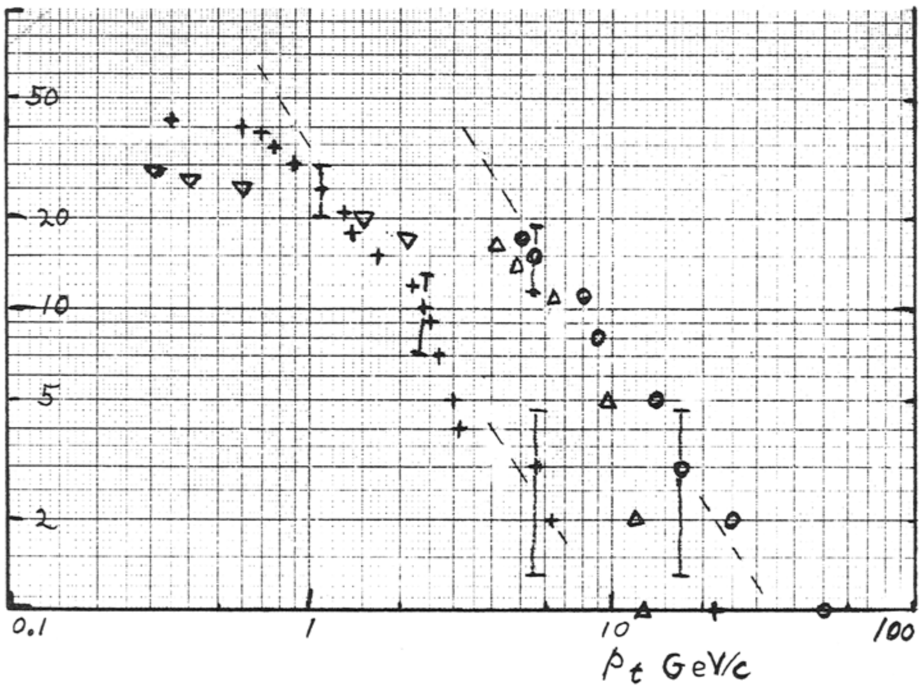


Fig. 3. Integral p_t distributions: +, this experiment; o, Tokyo[2] (shower trigger); △, subcore data, ▽, hadron data, Matano et al[4] (burst trigger). The error bars are only statistical.

The distributions in Fig 3 show only the results of direct reduction of our data with no explicit correction for biases of any kind. There appears to be a fall-off at low p_t, which is probably due to subcores that are lost in main shower background near the main shower axis.

INTERPRETATION

The slope of our distribution is essentially the same as the Tokyo[2] results. Taken at face value, this integral slope of -1.7 favors the gluon exchange model of parton-parton scattering[13] as pointed out by Gaisser[9]. Apparently, it is very unlikely that the (-6) integral slope of the interchange model[14] can describe the data, but one should not be misled into that conclusion by the error bars.

The data themselves suggest biases and uncertainties. Relative bias against observing low p_t events is suggested by the fall-off on observed slope at low p_t, which is very unlikely at production. We deliberately set our trigger requirement at a very low level (central density 5 or $10/m^2$) in order to make any trigger threshold effect negligible. We have measured our scanning efficiency and the results appear to indicate that it is high, right down to the level where small subcores are lost in statistical background from the main shower.

Another conclusion from the data is forthcoming when we turn to rates. The Tokyo array observation[2] was for $20m^2 \times 422da = 8440m^2da$. Our observation reported here is nominally for $35m^2 \times 175da = 6000m^2da$ and will probably be reduced to $\sim 5000m^2da$ when the average useful area is considered. Fig. 3. displays a factor 7 difference in number which leads to a factor $(5000/8440)7 \simeq 4$ in rate. (Matano et al[4] do not give their running time so we cannot compare to them.) What problems does the rate discrepancy indicate? The absolute rate is required (actually the rate relative to showers) in order to obtain the partial cross section. This has been done preliminarily[2,4,9]; but is it uncertain by a factor 4 as suggested above? Secondly, the disagreement in rate may be indirect evidence of problems that affect the slope significantly, in spite of apparent agreement in slope at the moment.

Trigger: the Tokyo trigger is more selective, which is in the wrong direction for explanation (our dead time is negligible, even at our high rate).

Scanning cut: our size cut is at a lower level, again in the wrong direction for explanation.

Scanning efficiency: our measured efficiency (for what we found by visual scanning) was high. Tokyo does not mention scanning efficiency. Perhaps Tokyo found some subcores by detailed counting studies, as was found necessary by the Norikura group[15]; if so, they do not mention it.

Data cuts: We kept all events above 30 net within a 25 cm circle that we believed were unlikely to be due to statistical fluctuations; Tokyo cut out events that had a production height≤6, because of large uncertainties in p_t. Again, the effect is in the wrong direction.

Event cuts: We cut to ~2/3 of the observed subcores by rempving likely local interaction events originating in the roof structure; Tokyo (private communication) may have cut out 2 or 3 events that could have come from beams. These do not explain the factor 4.

Overlying material effects: We have made the corrections indicated above. The Tokyo roof supports were minor, and the roof was only ~1gm/cm^2. Thus, there would be few roof interactions. There were large glass mirrors above the spark chambers, constituting ~2gm/cm^2. It is unlikely, but perhaps possible, that most of their subcores originated in the mirrors. Our data on roof effects are not very helpful because they are for subcores that are mostly smaller than the Tokyo subcores.

p_t sample cuts: Tokyo made a cut $p_t \geq 5$ GeV/c. We chose to make no p_t cuts, in case lower p_t data helped to determine the slope of the frequency distribution.

Summary: There is no evident potential explanation of the disagreement in rates. We are testing for the presence of "hidden subcores" that we can find only by detailed counts in regions that have only a hint of excess sparks.

RATE IN AIR

The corrections for finite detector size and masking by dense regions near shower axes were made by measuring the observable azimuths at the subcore distances. The result is about a factor 3 for conversion from number of observable subcores to number in the showers whose axes hit the array.

CONCLUSIONS

The results of our first year of operation appear to corroborate the Tokyo results of a p_t integral distribution no steeper than p_t^{-2}. But we have reservations stemming from disagreement in absolute rate. We are looking for the existence of "hidden subcores" that are very difficult to find from visual inspection alone. We are going to examine possible sources of bias that would affect the slope.

We are abstracting data from our second year of operation, taken under a new thin, light roof that minimises local interactions.

We plan to do modelling and simulations in order to sharpen the testing of interaction models by subcore observations.

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