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Effective Inelasticity Coefficient for Production of Electromagnetic Component by Hadron in Carbon Emulsion Chamber

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Abstract. Hadrons in the atmosphere at mountain altitude, e.g. 600 g/cm^2 are registered with emulsion chambers, in the Pamir experiment among others with carbon chambers. High energy hadron (of tens or hundreds TeV) penetrating a chamber initiates nuclear electromagnetic cascade (NEC). Registration of hadron is made indirectly by registration of electromagnetic component of NEC.

Simulation of NEC development in C-chamber has been made using Superposition of Independent Collisions model for h-A interactions and F00 model for h-Nucleon interactions.

In the calculations effective inelasticity coefficient $K^{eff}_{chamber}$ (ratio of sum of E_γ produced in chamber to E_h above chamber) has been estimated using various inelasticity coefficient distributions of mentioned models for h-N and h-A interactions.

For extreme assumptions for inelasticity coefficient in each h-A interaction close $K^{eff}_{chamber}$ values have been received. It can be concluded that carbon emulsion chamber behaves like pseudocalorimeter.

1 Introduction

X-ray film is the detector of particles in emulsion chambers. They register the cascades of charged particles (electrons). A cascade of electrons is initiated by gamma quanta created in hadron-C or Pb nucleus interactions. There is a track seen as black spot in the place of cascade's crossing the film. Optical density of track measured in the experiment is connected with hadron energy (Malinowski, 1999).

That is why it is important what part of hadron energy is transferred into electromagnetic component during nuclear electromagnetic cascade development in the chamber. This value is described by effective inelasticity coefficient $K^{eff}_{chamber}$ used in this paper.

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2 Calculations

2.1 Assumptions of used h-A interaction model

Calculations simulating nuclear electromagnetic cascade development initiated by a hadron in the carbon emulsion chamber have been made. Carbon emulsion chamber construction used in the calculations is typical for the Pamir experiment, matter layers from top to bottom: lead - 6 cm, carbon ($\rho = 1.5 g/cm^3$) - 60 cm and lower layer of lead - 4 cm.

Hadrons initiating nuclear electromagnetic cascade in the chamber, nucleons, π and K had zenith angles sampled from $f(\theta) \sim cos^7\theta$ distribution.

Hadron energies were sampled from exponential spectrum with exponent $\beta = 2.0$.

Hadron - nucleus (h-A) interaction modelling has been made using 'sequence of independent collisions of nucleons' algorithm (in this paper it is called 'Superposition of Independent Collisions' - SIC model). The results of experiments that study h-A and A-A interactions justify such algorithm (Barlier et al., 1987).

Place of h-A interaction was estimated using cross section described by the formula:

$$\sigma^{inel}_{hA}(E) = \sigma^{inel}_{hA}(E = 0.2TeV)\left(1 + \alpha_{hA} lg^2_{10}\left(\frac{E}{0.2TeV}\right)\right) \quad (1)$$

Cross sections $\sigma^{inel}_{hA}(E = 0.2TeV)$ have been shown in Table 1, parameters α_{hA} in Table 2.

Table 1. Cross sections $\sigma^{inel}_{hA}(E = 0.2TeV)$ in [mb]

h: / A	Nucleon	π	K
C	225	171	166
Pb	1752	1447	1340

Table 2. Parameters α_{hA} in formula (1)

A: / h	C	Pb
Nucleon, π, K	0.0322	0.01776

According to SIC model h-A interaction was replaced with a m-time h-Nucleon (h-N) interaction, where average m parameter value

$$< m >= A \left(\frac{\sigma_{hA}}{\sigma_{hN}} \right) \xi \qquad (2)$$

$< m >$ values with $E_h = 0.2TeV$ have been presented in Table 3. Parameter ξ was estimated in accordance with suggestions from paper (Elias, 1978). In SIC model each interaction of h-N was made using F00 model. The F00 model was made and described by (Wrotniak, 1985).

Table 3. $< m >$ values with $E_h = 0.2TeV$

h: / A	Nucleon	π	K
C	1.43	1.26	1.08
Pb	3.17	2.57	2.32

2.2 K_{hA}^{inel} sampling

The way of sampling inelastic coefficient in h-N interaction K_{hN}^{inel} has been changed in various calculation series what enabled the analysis of $K_{chamber}^{eff}$ changes for different K_{hN}^{inel}. The following assumptions have been made.

A1:

In h-A interaction on average m h-N interactions (SIC model) were made. K_{NN}^{inel} was sampled from uniform distribution with mean 0.5 and $K_{\pi N}^{inel}$ and K_{KN}^{inel} from uniform distribution with mean 0.667 in each of m h-N interactions.

A2:

Similar to A1 SIC model has been used. The way of K_{hA}^{inel} sampling has been modified in accordance with Hufner and Klar suggestions (Hufner and Klar, 1984). Inelasticity coefficient K_{hN}^{inel} has been sampled from uniform distributions.
For nucleon - nucleon interaction K_{NN}^{inel} - mean 0.5 in the first of m interactions and with mean 0.2 in every next interaction.
For meson (π or K) - nucleon interactions $K_{\pi N}^{inel}$ and K_{KN}^{inel} with mean 0.667 in the first of m interactions and with mean 0.2 in every next interaction.

A3:

Every h-A interaction has been sampled as exactly one h-N interaction with K_{NN}^{inel} with mean 0.5 and $K_{\pi N}^{inel}$ and K_{KN}^{inel} with mean 0.667. K_{hN}^{inel} has been sampled from uniform distributions.

A4:

Assumptions similar to A3 but the shape of K_{hN}^{inel} distributions was parabolic with minimum at mean value.

Assumption A1 gives the highest accepted K_{hA}^{inel} values whereas assumption A3 minimal inelasticity coefficient values. Assumption A2 is the most realistic.

3 Results

In single h-A interaction K_{hA}^{inel} becomes symmetric with A1 and A2 assumptions and with growing m it is closing in shape to Gaussian distribution.

Mean K_{hA}^{inel} values received in the simulations for these assumptions have been shown in Table 4. The ratio of energy transferred into electromagnetic component to energy of interacting hadron is an important hadron detection in carbon emulsion chamber. This variable has been signed as K_γ and its mean values have been presented in Table 4.

Table 4. Mean K_{hA}^{inel} and K_γ values received in the simulations (for $E_h = 20TeV$)

h-A	assumptions	K_{hA}^{inel}	K_γ
Nucleon - C	A1	0.625	0.212
Nucleon - Pb	A1	0.901	0.307
π - C	A1	0.737	0.255
π - Pb	A1	0.944	0.322
Nucleon - C	A2	0.547	0.188
Nucleon - Pb	A2	0.704	0.240
π - C	A2	0.678	0.237
π - Pb	A2	0.774	0.265

The final results of calculations, mean values of $K_{chamber}^{eff}$ for various K_{hA}^{inel} assumptions have been presented in Table 5. Mean $K_{chamber}^{eff}$ values presented in column 2 are only for hadrons whose energy transferred into electromagnetic component is $E_{em} > 20TeV$, which is close to experiment. Column 3 has mean $K_{chamber}^{eff}$ values for all hadrons which interacted in the chamber, without threshold for E_{em} (>0 TeV). Column 4 - results of mean $K_{chamber}^{eff}$ for all hadrons (including noninteracting ones).

Table 5. Mean values of $K_{chamber}^{eff}$ for various K_{hA}^{inel} assumptions

	$K_{chamber}^{eff}$		
assump.	$E_{em} > 20TeV$	$E_{em} > 0TeV$	for all hadrons
A1	0.436±0.003	0.335±0.001	0.270±0.002
A2	0.413±0.004	0.303±0.001	0.248±0.002
A3	0.404±0.004		0.225±0.002
A4	0.420±0.004		0.223±0.002

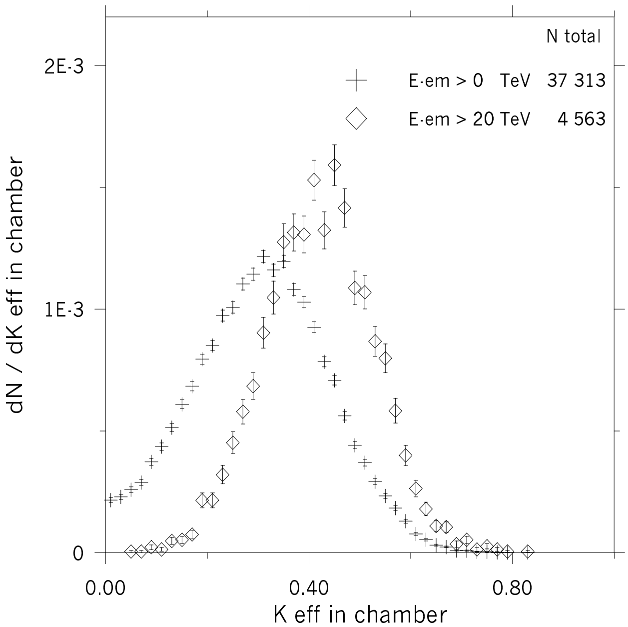

Fig. 1. $K_{chamber}^{eff}$ values distributions with A2 assumptions for energy transferred into electromagnetic component $E_{em} > 20TeV$ and $E_{em} > 0TeV$.

Differences in results in particular columns in Table 5 are closely related with the way of defining efficiency of hadron registration in carbon emulsion chamber. It is important by recalculation of E_{em} energy into hadron energy E_h above the chamber.

$K_{chamber}^{eff}$ values distributions with assumptions $E_{em} > 20TeV$ and $E_{em} > 0TeV$ have been presented in Figure 1. The distributions in the figure are normalized to 1.0.

4 Summary

Mean $K_{chamber}^{eff}$ values for extremely different assumptions for inelasticity coefficient in h-A interaction differ from one another less than 0.03 for $E_{em} > 20TeV$ and less than 0.05 for $E_{em} > 0TeV$.

It means that carbon emulsion chamber behaves by hadron registration like pseudocalorimeter.

It can be concluded from received $K_{chamber}^{eff}$ values that secondary interactions of hadrons in nuclear electromagnetic cascade contribute substantially to tracks observed in carbon emulsion chamber.

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