ESTIMATION OF THE TOTAL INELASTICITY COEFFICIENT IN INTERACTION OF ⩾20 TeV HADRONS WITH LEAD

Kanevsky B.L., Mikhailova I.A., Rakobolskaya I.V., Sveshnikova L.G.

Institute of Nuclear Physics, Moscow State University, Moscow 119899, USSR

Experimental data on the interaction mean free path of hadrons with energy $E_0 \geqslant 20$ TeV in lead obtained with multilayer X-ray emulsion chambers(XEC) are compared with results of simulation of nuclear-electromagnetic cascades in lead chamber. It is shown that, to explain experimental data, the value of the total inelasticity coefficient, $\langle K \rangle \sim .8$ should be assumed.

Multilayer XEC allow determination of gamma-ray and electron energy, E_γ, the energy $E_\lambda^{(\gamma)}$ released into the electron-photon cascade(EPC) in hadron-lead nuclear interaction, and the origin depth Δt of an electron-photon cascade induced in a chamber by gamma-rays, electrons, and hadrons. The experimental procedure and chamber design have been described in detail in /1/.

In paper /2/ of the "Pamir" Collaboration, the results have been presented of measurement of the hadron interaction mean free path, λ_{meas}, in lead chambers obtained by analysing the hadron flux(about 700 events) over an area of 140 m^2. After efficiency of hadron registration in chambers of different thickness has been allowed for more accurately, the authors of /2/ obtained the following results:

$\lambda_{meas}=185\pm40$ g/cm^2 for energy $E_h^{(\gamma)}=5-10$ TeV,
$\lambda_{meas}=213\pm24$ g/cm^2 for energy $E_h^{(\gamma)} \geqslant 10$ TeV,
$\lambda_{meas}=197\pm29$ g/cm^2 for energy $E_h^{(\gamma)} \geqslant 20$ TeV.

The measured value of λ_{meas} can be seen to be independent of $E_h^{(\gamma)}$ within errors and $\lambda_{meas}=207\pm17$ g/cm^2.

The measured value of λ_{meas} concerns the summary flux of nucleons and charged pions with energies $E_0 \geqslant 20$ TeV. The pion fraction in this flux can be estimated based on calculations in terms of quasiscaling models, e.g., from /3/. This magnitude is almost independent of a model and, on average, pions present ~30% and nucleons ~ 70% in the total hadron flux at the given depth(596 g/cm^2).

The value of λ_{meas} may differ from the proper interaction mean free path for hadrons in lead, λ_{prop}, due to the following causes:

A. The influence of an admixture of electron-photon component

When determining λ meas, cascades with $\Delta t \geq 8$ c.u. were taken into account. The number of EPC induced by gamma-rays and electrons at depth 8-10 c.u. from the chamber boundary was less than 2% of the hadron-induced cascades.

B. The influence of the boundary effects.

Using the angular distributions of $\cos\theta^{5.3}$ for hadrons and $\cos\theta^{5.8}$ for gamma-rays and the power law energy spectrum with the differential power index 3 ,obtained in /4/, the procedure of hadron and gamma-ray registration in a 2mx5m chamber (a standard size of lead chambers in the "Pamir" Collaboration) was Monte-Carlo simulated. The cascades interacting in a chamber and leaving its volume and additional cascades arriving from air, when taken into account, change the value of λ meas by less than 3%.

C. Allowance for secondary interactions.

The impossibility to follow entirely the hadron cascades in a chamber due to a high registration threshold leads to appearing the hadron-induced cascades for which we measure Δt of the second and subsequent interactions instead of the first one. So, there exist cascades in which in first interaction the energy $E_h^{(1)}$ lower than threshold was released while the energy released in one of subsequent interactions exceeds the threshold. There are also the cascades with energy released in the first and second interactions being higher than the threshold and the second interaction occures at a point of 15-20 c.u. far from the first one. So, the second interaction was mistaken as the first one of another hadron.

The existence of these cascades leads to overestimation of λ meas compared with λ prop, Monte-Carlo simulations were performed to eliminate the distortions of λ meas. The scheme of simulations used is presented in /5/. Energy E_0 of the primary protons inducing in a chamber nuclear-electromagnetic cascades was simulated with respect to the spectrum with the differential power index 3 . The point of the first interaction in a chamber was computed with λ prop= 190 g/cm2. Random stars imitating nuclear interaction were simulated according to /6/.

In the first version of simulations, the difference in inelastic interaction of incident hadron with protons and nuclei was neglected, leading particles being simulated in the x-presentation with respect to the inclusive spectrum from /7/, and the mean value $\langle K \rangle$ being equal to .5. In the second version of simulations, use was made of the data on the inclusive spectrum of leading particles obtained in terms of an additive quark model regarding the atomic number of the target-nucleus in /8/, the mean value being $\langle K \rangle = .8$. The electromagnetic cascades resulting from the decay of π^0-meson for particles with energy $E_\gamma > E_{thr}^{em}$ ($E_{thr}^{em} = .5 \cdot 10^{12}$ eV) were also Monte-Carlo simulated allowing for the processes of pair production, bremsstrahlung radiation, and Rutherford scattering. To obtain the electron number and the optical density of X-ray film within a circle of given radius(R=140 um) caused at an observation level by the initial gamma-rays and electrons(with energies $E_\gamma < E^{em}_{thr}$) use was made of the averaged cascade curves calculated to the core approximation. Optical densities in X-ray film produced by simulated cascades at various depths in lead were processed by the same program as experimental ones /1/.

For each version of calculations, ~1000 events with $E_h^{(\gamma)} \geq 4$ TeV and 8 c.u. $\leq \Delta t \leq$ 64 c.u. were simulated. The λ meas-values obtained for the two versions of calculations are listed in Table 1 together with the corresponding values of λ_{prop} deduced from the experimental values of λ_{meas} and from ratios of λ_{prop} and λ_{meas} obtained in different versions of calculations.

Table 1. Ratios of λ_{prop} and λ_{meas} obtained when analysing simulated cascades

	calculation		experiment	
	λ_{prop} g/cm^2	λ_{meas} g/cm^2	λ_{meas} g/cm^2	λ_{prop} g/cm^2
<K> =0.5	190	340±30	207±17	115^{+22}_{-17}
<K> =0.8		230±20		173^{+30}_{-29}

The contribution of the pion component allowed for do not practically change the obtained ratios of λ_{meas} and λ_{prop}. In the energy region ~ 200 GeV an inelastic cross section σ_{inel} in the π-Pb-interaction is by a factor of 1.1-1.3 less than in the pPb-interaction that may lead to an increase in λ_{prop} for the total hadron flux by less than 5%. σ_{inel} of the pion and nucleon interactions on lead are expected to come closer with increasing energy/9/. <K> in the πPb-interaction is larger than in the pPb-interaction, leading to a less diversity of λ_{meas} from λ_{prop} in the πPb-interaction.

Experimental data obtained at accelerators and in cosmic rays for the hPb-interaction shows that up to energies of several TeV, an increase in σ_{inel}^{hPb} within errors is absent and $\sigma_{inel}^{hPb} \approx 1800$ mb/10/. For higher interaction energies, in /9/, using the Glauber model, the following values have been obtained: $\sigma_{inel}^{pPb} \approx 1900$ mb that corresponds to $\lambda_{prop}^{pPb} = 180$ g/cm^2 and $\sigma_{inel}^{\pi Pb} = 1734$ mb that corresponds to $\lambda_{prop}^{\pi Pb} \approx 199$ g/cm^2 for E_o=20-100 TeV.

Thus, the experimental value λ_{meas}=207±17 g/cm^2 for the summary hadron flux is consistent with the expected value λ_{prop}^{hPb}=180 g/cm^2 for $E_o \geq 20$ TeV for the total inelasticity coefficient <K>~.8 only.

References

1. Bayburina S.G. et al. Trudy FIAN, 1984, v.154.
2. Borisov A.S. et al. Proc. of Intern. Symp. on Cosmic Rays and Particle Physics, Tokyo, 1984, 426-430.
3. Erlikin A.D., Kuzuna N.P., Preprint N 95 FIAN, 1980.

4. Bayburina S.A. et al. Proc. 18th ICRC, 1983, 7, 420-423.
5. Belyaev A.A. et al. EPC in cosmic rays at superhigh energies, Moscow, "Nauka", 1981.
6. Astafiev V.A. et al. Proc. 14th ICRC, 1975, 7, 2593.
7. Eilten et al., Nucl. Phys., B44, 333, 1972.
8. Anisovich V.V., Braun Yu.M., Shabelsky Yu.M., Yadernaya Fizika, 1984, 39, vyp.4, 934-946.
9. Jofa M.Z., Pukhov A.E., Yadernaya Fizika, 1985, 40, vyp. 7.
10. Garyaka A.P. et al. Izv. AN Arm. SSR, 78, vyp.1, 1983, 66-78.