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Nucleus-Nucleus Interaction above Several Hundred GeV/n

The JACEE Collaboration

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1. Introduction

At an extreme condition of high pressure, constituents of hadron, quark and qluon, are expected to be deconfined and then transit into a plasma phase(Quark-Gluon-Plasma). Such an extreme condition can be realized through high density hadronic matter and at present, we have no means other than to observe signals from such state through high energy heavy ion collision[7].

The Japanese-American Cooperative Emulsion Experiment(JACEE) have been investigating high energy nuclear interactions of cosmic ray nuclei by mean of balloon-borne emulsion chamber. Current exposure parameters are listed on Table 1. Analysis of last two experiments(JACEE4 and JACEE5) are still in progress. The quasi-inclusive characteristics of nucleus-nucleus collisions above TeV/n region obtained by first three experiments and some anomalous phenomena observed in our experiment had been already reported[1,2]. We present here, a result of semi-inclusive* analysis of sample set of central collision events, concerning to multiplicity, rapidity fluctuation for extremely high multiplicity events and correlation between transverse momentum and estimated energy density.

Flight	Altitude (g/cm^2)	Time (hrs)	Area (m^2)
JACEE0	8.0	29.0	0.20
JACEE1	3.7	26.5	0.80
JACEE2	4.0	29.6	0.80
(JACEE3	5.0	39.0	0.25)
JACEE4	4.5	56.0	0.80
JACEE5	5.0	15.0	0.80

Table 1. Exposure Parameter

2. Method

The emulsion chamber have primary, target, space and calorimeter

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sections. The primary section contains emulsion layers of high and low sensitivity(Fugi ET7B and ET-6B), coated 0.150-0.200 mm thick on both side of 0.800 mm acrylic base, and CR-39, where primary charge is measured by grain counting, delta ray counting on emulsion and etched pitch rate in CR-39, errors contained in charge measurement being 0.2e, 0.5e and 1e, respectively. The target section contains sandwich of 2.0 mm thick acryl plate and thin (0.050 - 0.075 mm) doubly coated emulsion plates to follow secondary tracks from nuclear collision, thick emulsion plates are also placed in this section for measurement of heavy fragment charge, the spacer of honeycomb is located at the downstream thereof to separate secondary particle. The calorimeter contains 1.0 - 2.5 mm thick lead plates, X-ray films and thin emulsion plates, where gamma ray, most of all from π^0, makes electron cascade shower which is visible on X-ray films for high energy event. The shower energy is measured by electron counting method for the most of events which shower cores are separated enough for electron counting, error in energy measurement for shower core being 22%. Emission angle of charged particle is measured by track position on emulsion plates. Relative error in angle measurement is less than 0.1 in unit of pseudo-rapidity. Transverse momentum of shower core is obtained from the energy and an angle measured from energy weighted center of shower cores. The average transverse momentum of an event is estimated by fitting of the distribution assuming exponential function. The above procedure with energy measurement overestimates average Pt by 3-7% in average depending on observed gamma ray multiplicity. In addition to this, one should note that, in exclusive analysis, event to event fluctuation may be larger than the above error. As an estimation of Pt of π^0 from observed gamma ray $Pt\gamma$, $\langle 2Pt\gamma \rangle$ is used for conventionally, which procedure, from kinematic reason, overestimates 43%, 5% and 0.9 % for π^0 Pt 100, 300 and 700 MeV/c, respectively, and average Pt of pion in the concerning energy region is known to be over 340 MeV/c[4]. For the case that shower cores overlap with each other in the most forward region depending on vertex location in the calorimeter, the transverse momentum of secondary π^0 is estimated from shower transition in forward restricted angular region, since profile of such superposed shower is determined by both angular and energy/Pt distribution of the secondary. Some events in calorimeter permit measurement with each core separated at large angular region probably due to their very high transverse momenta. In such case, Pt of shower core should be regarded as that of π^0. For the primary energy estimation, the mean Castagnoli method as well as total radiated cascade energy $\Sigma E\gamma$ are used.

3. Results

Tables 2-a and 2-b shows seven high multiplicity events of Ns greater than 400 and of two events of light nucleus with Carbon target events. Three events in Table 2-a were already reported, where observed multiplicity can be interpreted within calculation of Multi-Chain-Model(MCM)[3]. And also, all

Event Type	E_0 (TeV/n)	Nch	$2Pt\gamma$ (GeV/c)	$Pt\pi^0$(cone) (GeV/c)	$dn/d\eta\|_{\eta c}$	#
Ca + Pb	1.5	1050^{+300}_{-50}	0.95±0.31	0.55±0.05	258±12	A88
Si + Ag/Br	4.1	1010±30		0.55±0.05	183±10	G03
Ca + C	100.	760±30	0.525±0.04		81±10	G00
Si + Pb	4.	780	not yet		not yet	B02
Ca + Pb	0.5	670±40	not yet		142±8.4	H60
Ca + Pb	1.8	457	2.1±0.1		100±16	D27
Ar + Pb	1.0	416	1.2±0.2		134±8	C27

Table 2-a. High multiplicity events(Nch > 400) in JACEE

observed multiplicity in Table 2-a are still within prediction at impact parameter b=0 fm,(maximum predictable multiplicity is not necessary realized at b=0 fm for heavy nuclei, A > 16, depending on nuclear density distribution), however events in Table 2-b are out of MCM calculation.

Event Type	E_0	Nch	2Ptγ	dn/dη|nc	Nch(MCM)	D
Li + C	15.	217	0.76±0.08	37.5±4.3	154	37
He + C	20.	156	0.62±0.08	26.5±3.6	122	30

Table 2-b. Unit same as Table 2-a. 6 and 7-th column are model calculation by MCM at b=0 fm.

The averaged transverse momentum of listed events, which are considered to be central collision, exhibit extremely high Pt values comparing to interpolation value from CERN ISR and SPS collider experiments[4].

We now estimate energy density of event, for which we use that was proposed by Bjorken[5], as in the following.

$$\epsilon \equiv \sqrt{\langle Pt\rangle^2 + m\pi^2} \cdot dn/d\eta|\eta_c \cdot 1.5/V,$$

where $dn/d\eta|\eta_c$ is a pseudo-rapidity density of charged particle at CMS system, V being an interaction volume for which we choose $V = C\ Amin^{2/3}$, $C=2\pi$. Amin is the minimum of Aproj and Atarget. In the case of heavy fragment(s) existing in the secondary, mass number reduction is applied for Aproj. Fig. 1 shows scatter diagram between estimated energy density and Pt for which we used 2<Ptγ> for the most case, which procedure does not significant influence on the result as previously mentioned, for the events apparently giving π^0 Pt, measured values are used as themselves.

At present, pseudo-rapidity fluctuation analysis had been performed for two high multiplicity events(G0 and G3), wherein multiplicity and its dispersion in windows of width δ on pseudo-rapidity are estimated from Independent Emission Model(IEM) of pure statistical assumption and from MCM, respectively. Results is that both of event are favor for IEM but for MCM, due to the observed fluctuation is not so large comparing to MCM, events G0 and G3 deviating 3σ from MCM and within 1σ and 1.4σ from IEM, respectively.

Azimuthal angle distribution of four events from high multiplicity events(A88, G0, G3 and H66) are also analyzed by Fourier transformation method. Similar analysis had been already proposed by F.Takagi on pseudo-rapidity distribution[6]. According to this analysis, three events (A88, G3 and H60) exhibit dipole structure, which probability is expected to be one event among several ten to several hundred events assuming independent

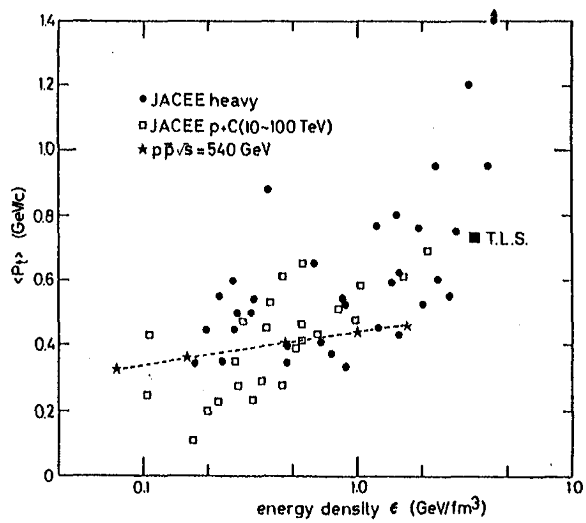

Fig.1 Correlation between energy density and Pt.

emission of secondary, while event G3 is almost isotropic in azimuth.

4. Discussions and summary

As shown in Fig.1, the average transverse momentum seems to grow rapidly over the energy density around 2 GeV/fm . Multiple scattering effect for possible interpretation for this correlation does not describe qualitatively. If the observed correlation is attributed to phase transition of QGP, the observed characteristic energy density is consistent with the predicted critical value for deconfinement of quark and qluon at temperature around 200 MeV[7]. Though there still exists ambiguity in quantitative estimation for energy density such as volume estimation, the observed correlation characteristics might not change substantially.

From the view point of multiplicity, MCM gives fairly good estimation for high multiplicity events, however there still exist the events above maximum prediction of MCM. In the lower energy region of 20-60 GeV/n, there also observed extremely high multiplicity events from minimum bias sample of Fe group primary[8]. Because of a freedom of impact parameter, event to event analysis for multiplicity in nucleus-nucleus collision can not result in fruitful conclusion. However, this kind of analysis not only is a test for assumed conventional picture but also gives a key to reveal a mechanism which determines a final state of nuclear collision.

The present fluctuation analysis requires more statistics to get constructive conclusion. The current result indicates that angular distribution on pseudo-rapidity as well as on azimuth can not be interpreted by simple superposition of nucleus-nucleus collisions for some high multiplicity events.

While the present fluctuation analysis is related to many particles correlation in final state, few particles correlation analysis of charged particle is also possible from our data sample. Detail analysis and discussions on this regard from a short range pair correlation is presented in this conference[9].

Although there exists still theoretical ambiguity in final state estimation from QGP, it seems that we might come close to QGP signal.

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