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ON THE DETERMINATION OF INELASTISITY OF NUCLEUS-NUCLEUS COLLISIONS IN THE CMS EXPERIMENT

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With the aid of the HIJING generator there have been explored various options of event inelastisity characterization of nucleus-nucleus collisions in the CMS experiment at a 5·A TeV collision energy. The inelasticity estimation by the γ-quantum fraction of the total transverse energy in the very forward direction appears to be the most optimal one. Therefore, it is proposed to supplement the CMS very forward directions with electromagnetic calorimeters intended for heavy ion studies.

The investigation has been performed at the Laboratory of High Energies, JINR.

Об определении неупругости ядро-ядерных столкновений в эксперименте CMS

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С помощью генератора HIJING исследовались различные возможности для оценки неупругости ядро-ядерных столкновений при энергии столкновения 5·A ТэВ. Оценка неупругости по компоненте гамма-квантов в направлениях малых углов представляется наиболее оптимальной. Поэтому предлагается дополнить эти направления в эксперименте CMS электромагнитными калориметрами, предназначенными для исследований с тяжелыми ионами.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

The analysis of an optimal application of the CMS experiment for high luminosity nuclear physics studies at the LHC has led to a suggestion of using beams of moderate charge nuclei ($Z < 40$) [1]. This means that an adequate luminosity level is provided to make feasible hard QCD studies in nuclear matter with observation of intermediate vector bosons, direct photons and jets [2,3,4].

In order to explore new dynamic effects in nucleus-nucleus collisions, the basic QCD process measurements in the CMS detector should be supplemented with simultaneous measurements of reaction inelasticity [5]. Therefore, it is necessary to identify appropriate CMS observables allowing to solve this problem in a practical way.

A distinctive feature of the CMS spectrometry is an optimization for observation of hard processes in proton-proton collisions. Such an approach has led to a choice of a strong magnetic field in the solenoid suppressing soft charged hadron component. As a consequence, this creates a problem for inelastisity characterization in nucleus-nucleus collision due to an effective reduction of the charged hadron contribution in the event total

Table 1. The PYTHIA cross-section (mb) of basic subprocesses of proton-proton interactions at 5 TeV. ($f, f', \tilde{f}$ — fermions, g — gluons)

Subprocess	Cross-section (mb)
TOTAL	86.0
$f+f' \to f+f'$ (QCD)	19
$f+\tilde{f} \to g+g$	0.1
$f+g \to f+g$	15.6
$g+g \to f+\tilde{f}$	0.5
$g+g \to g+g$	28.2
Elastic scattering	18.1
Single diffraction (XB)	6.7
Single diffraction (AX)	6.7
Double diffraction	8.3

Table 2a. The multiplicity distribution (%). HIJING, central Ca—Ca, 5·A TeV, 4T

	B	F	VF	UF
γ's	0.9	5.6	41.5	19.2
Hadrons	0.0	0.1	6.8	25.9

Table 2b. Energy distribution (%). HIJING, central Ca—Ca, 5·A TeV, 4T

	B	F	VF	UF
γ's	0.0	0.3	6.1	27.7
Hadrons	0.0	0.0	3.9	61.9

Table 2c. Transverse energy distribution (%). HIJING, central Ca—Ca, 5·A TeV, 4Y

	B	F	VF	UF
γ's	3.0	7.7	32.1	12.2
Hadrons	0.0	0.5	14.5	30.1

transverse energy measured with the aid of calorimetry. Apriori, an inelasticity estimate based on γ's flux measurements seems to be more preferable.

To choose an optimal solution we have applied the widely used generator HIJING [6] for simulation of nucleus-nucleus collisions at a total energy of 5·A TeV. In the case of hard processes all resolved parton-parton scattering processes were included together with the initial and final state parton emission [7,8]. The following effects were included: multiple minijet production, nuclear shadowing of parton distribution functions and jet quenching [9] relating assumed parton energy losses with the colour screening length. The Glauber formalism was used for multiple production calculations. The nucleon density distribution was accepted in correspondance with the Woods-Saxon potential. To illustrate the importance of various subprocesses in the total proton-proton cross-section their contributions are given in Table 1.

Simulation was peformed for central collisions (zero impact parameter) of C—C (50 events), Ca—Ca (10 events), Nb—Nb (5 events) and Pb—Pb (2 events). The main single particle parameters for various generated pairs of nuclei were found to be similar. To illustrate the data we used here mainly Ca—Ca results as typical ones.

Thus, a practical way of the event characterization in the CMS consists in the measurement of the total transverse energy per event, E_T which is an electromagnetic and hadron calorimetry based parameter. Our simulation has shown that an influence of the solenoid magnetic field (4T) on charged hadrons leads up to a 30% drop in E_T.

The CMS detector is divided by pseudorapidity on three major parts: barrel ($|\eta| < 1.6$), forward ($1.6 < |\eta| < 3$), and very forward ($3 < |\eta| < 5$), and an uncovered region — ultra forward ($5 < |\eta|$). In our analysis we have applied γ's energy cut equal to 2 GeV and hadron one equal to 20 GeV, i.e., below lower limits of the CMS resolution curves for single particles. The gamma cut was chosen well beyond minimal ionizing particle signal. Both cuts do not seriously affect our conclusions. Tables 2*a*, *b*, and *c* show relative fractions of multiplicity, energy and transverse energy accepted by these parts. They enable us to make a conclusion about a crucial role of a very forward calorimetry for inelasticity measurements.

Figure 1 shows γ and hadron pseudorapidiry distributions. The pseudorapidity value corresponding to the distribution maximum for γ-quantum is equal to 4.3 ($\sigma = 1.3$), i.e., most part of this distribution can be covered within the very forward calorimeter acceptance. For hadron components this value is equal to 5.6 ($\sigma = 1.1$).

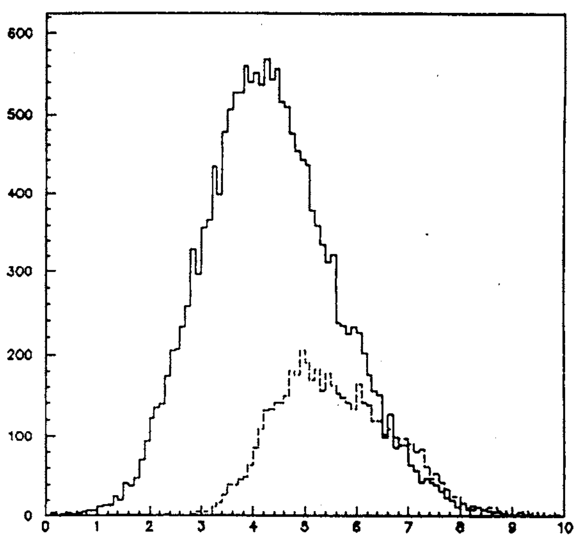

Fig.1. The effective pseudorapidity distribution of γ-guanta (upper histogram) and hadrons (lower histogram) produced in two central Pb—Pb collisions at 5·A TeV. The influence of the 4T magnetic field on charged hadrons is included. Energy cuts are mentioned in the text

The single gamma energy distribution for VF is shown in Fig.2. The mean energy and the mean transverse energy values with r.m.s. are presented in Table 3 for three major pseudorapidity regions. It can be noted that a moderate value of the VF gamma mean energy is significantly below of an operation region of presently proposed very forward calorimeter. Thus, in order to provide reliable inelasticity measurements of nucleus-nucleus collisions it appears to be necessary to include in the CMS facility a very forward electromagnetic calorimeter with suitable resolution starting from few GeV.

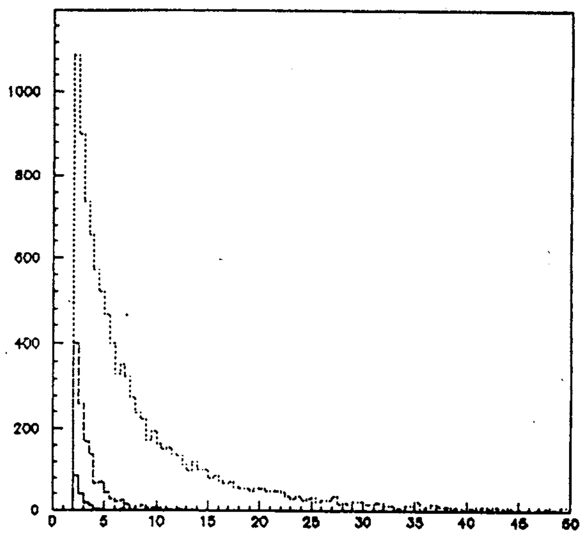

Fig.2. The γ-quantum energy distribution (GeV) in two central Pb—Pb collisions at 5·A TeV: VF — upper, F — middle, B — lower histogram, respectively. The energy cut is mentioned in the text

The multiplicity mean value for various pairs of colliding nuclei (Table 4) grows approximately linearly. Taking into account that the value of transverse energy per γ-quantum is practically the same in all

Table 3. Energy and transverse energy distribution parameters (GEV) for γ's HIJING, central Ca—Ca, 5·A TeV, 4T

	⟨E⟩	σ	⟨E_T⟩	σ
B	3.1	2.0	1.5	1.0
F	3.8	2.5	0.6	0.4
VF	8.5	8.0	0.3	0.3
UF	17.8	13.0	0.2	0.4

Table 4. Energy and transverse energy distribution parameters (GEV) for γ's HIJING, central Ca—Ca, 5·A TeV, 4T

	p—p		*Ca—Ca*		*Pb—Pb*	
	⟨N⟩	σ_N	⟨N⟩	σ_N	⟨N⟩	σ_N
B	0.2	0.77	24.9	5.8	87	—
F	1.5	1.6	154.9	26.9	657	14
VF	17.0	8.0	1139.4	148.9	5261	434
UF	14.0	6.1	528.3	37.2	2646	51

the cases we are led to a linear dependence of the total E_T in VF on the number of colliding nucleons.

It is imporant to mention that it is not possible to isolate single gammas from central collision on a 300 dm^2 area of the VF calorimeter (a shower covers of the order 1 dm^2). As a future step it is necessary to justify an opportunity to measure a total transverse energy by a simple summation of calorimeter cells with reasonable segmentation.

To summarize, we have carried out a simulation study aimed at a practical definition of inelasticity of nucleus-nucleus collisions in the CMS experiment case. Our major conclusion is the following: *in order to have the best estimate of an event total transverse energy the CMS very forward directions should be supplemented with an electromagnetic calorimetry intended for heavy ion studies.*

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