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Estimation of Mean Normalized Multiplicity (RA) for Heavy Nuclei Collisions up to 8 TeV

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Abstract

Past studies based on energy dependence parameters such as mean normalized multiplicity compare with different proposed theoretical models to discriminate models of multi-particle production in hadron–hadron and hadron–nucleus interactions. In the recent studies based on a theoretical framework, attempts have been made by various researchers to analyze recorded data on mean normalized multiplicities at centre of mass-energy (√s) in GeV of hadron-hadron interactions for the case of proton-proton and proton–nucleus interactions and an addition to this attempt has been made to modifies the earlier parameterizations using modified values of parameters under the study. These parameters are selected on the basis of some unambiguous phenomenon. In the present research study, the mean normalized multiplicity has been calculated at different energies range (up to 8 TeV) for proton–proton and proton–nucleus interactions with different energy ranges in GeV for hadron–hadron interactions and the result is found to be good agreement with the recent experiment data available.

Keywords: *- Mean Normalized multiplicity, Proton-Proton, Proton–Nucleus Hadron-Hadron, Multi-particle production.*

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INTRODUCTION

The Quark-Gluon Plasma (QGP), a de-confined state of partonic matter predicted by Quantum Chromodynamics (QCD), is expected to be formed in ultra-relativistic heavy-ion collisions, where nuclear matter reaches high temperatures and pressures. Heavy quarks are expected to be produced in the primary partonic scatterings and there-fore to experience the whole QGP evolution. As a consequence, quarkonium, bound states of heavy quark QQ pairs, thanks to its small size (< 1 fm) and large binding energy (several hundred of MeV) are ideal probes of the strongly interacting QGP. It was predicted that in the presence of a QGP, the color-screening would lead to a sequential suppression of the quarkonium production [1].

Early work along this direction was limited to the studies of the interactions of the cosmic rays in nuclear emulsion [2-5] because cosmic rays were the only source for high energy particles. But these studies were not conclusive because the nature and energy of the incident particles were not accurately known. Due to the lack of complete knowledge of the incident particles, one could not get basic information about the mechanism of interaction. With the development of accelerators, interest in these studies was revived because the accelerators could provide beams of known particles having controlled energies and fluxes. With the help of high energy accelerators, it has become possible to probe deeper into the structure of nucleons.

Last two or three decades, the main concern of High Energy Physics is the study of elementary particles. After developing the main knowledge of the properties of elementary particles and the laws governing their interactions, physicists can apply these to a more complex system of elementary particles [6-10].On the basis of the last few decades, one physicist finds that there has been an increasing realization that nuclear targets can give the conclusions of the space-time development of every story interaction process. Hence, it was thought that interactions of hadrons with nuclei might provide some information regarding fundamental particles and their collisions, which can never be known using a simple carbon, Nitrogen and Oxygen (CNO) target.

EARLIER PARAMETERIZATION

An important aspect that distinguishes different models of multiparticle production in hadronic collisions is the dependence of the parameter mean

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normalized multiplicity (R_A) on the energy of the incident particle (E) and the mass number of the target nucleus (A_T). The parameter R_A called mean normalized multiplicity is defined as the ratio of the number of particles produced in hadron-nucleus collisions to the average number of such particles produced in hadron-hadron collisions at the same energy, i.e.

$$R_A = \frac{\text{No. of particles produced in hA Collisions}}{\text{No. of particles produced in hh Collisions}}$$

$$R_A = \frac{\langle n_s \rangle_{hA}}{\langle n_{ch} \rangle_{hh}}$$

where $\langle n_s \rangle_{hA}$ is mean multiplicity of the charged shower particles in hadron-nucleus collisions and $\langle n_{ch} \rangle_{hh}$ is the charged particle multiplicity for hadron-hadron collisions at the same primary energy. Mean normalized multiplicity (R_A) may be regarded as one of the most important parameter for testing the validity of various models to explain the dynamics of hadron-nucleus collisions at high energies. It has been suggested that for obtaining a better compatibility between the experimental results and theoretical predictions, the mean normalized multiplicity should be defined either in terms of the created charged particles or by considering the total number of final state particles, both charged and neutral. The mean normalized multiplicity, used by different authors is not in accord with its definition used to predict its behavior using different models.

Otterlund et al., [11] have indicated that this form of mean normalized multiplicity (R_A) is not a good parameter for comparison with the predictions of various models because the mean multiplicity $\langle n_s \rangle_{hA}$ contains interactions of hadrons with protons and neutrons of the target nucleus, whereas $\langle n_{ch} \rangle_{hh}$ is the average charged multiplicity for proton - proton collisions. Therefore, Otterlund et al., have suggested that the ratio R_1,

$$R_1 = \frac{\langle n_s \rangle_{hA}}{\langle n_{ch} \rangle_{hh} - 0.5}$$

Babecki et al., [12, 13] has introduced that ratio R_2 involving created particle multiplicity in proton - nucleus interactions to the created particle multiplicity in proton -proton interactions. Subtracting 2 from total charged particles $\langle n_{ch} \rangle_{hh}$ should, therefore, give the average number of "created charged particles" in proton - proton collisions, i.e. $\langle n_{ch} \rangle_{cr} = \langle n_{ch} \rangle_{hh} - 2$. In the case of proton - nucleus collisions the target appears as grey, while the incident proton

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goes as shower. Therefore, if we subtract -1, the initial channel proton, from observed shower multiplicity $< n_s >_{hA}$ we get only the "created charged particles" in p-nucleus collisions, i.e. $< n_s >_{cr} = < n_s >_{hA} - 1$ and we can write, Babecki et al., has introduced that ratio $R_{2\,as,}$

$$R_2 = \frac{< n_s >_{cr}}{< n_{ch} >_{cr}} = \frac{< n_s >_{hA} - 1}{< n_{ch} >_{hh} - 2}$$

Aziz et al. [14, 15] have pointed out the ratio R_3, while estimating the number of created charged particles; the charge exchange effect should also be taken into account. They have estimated the number of created charged particles in p-p and p-nucleus collisions. Aziz et al. have pointed out the ratio R_3

$$R_3 = \frac{< n_s >_{pA}}{< n_{ch} >_{pp}} = \frac{< n_s >_{hA} - 0.67}{< n_{ch} >_{hh} - 1.33}$$

H. Khushnood et al., [16] suggested the dependence of the mean normalized multiplicity of created charged particles, R_4, with the predictions of the simple independent particle model. He suggested the dependence of the mean normalized multiplicity of created charged particles, R_4 as

$$R_4 = \frac{< n_s >_{hA} - \alpha_A}{< n_{ch} >_{hh} - \alpha_H}$$

V. Kumar et al., [17] have suggested that the two leading particle multiplicities, α_A and α_H have values 0.7 and 0.9 respectively and therefore the above equation becomes,

$$R_5 = \frac{< n_s >_{hA} - 0.7}{< n_{ch} >_{hh} - 0.9}$$

Different physicists gave the different value of mean normalized multiplicity (R_A) by different formula such as R_1, R_2, R_3, R_4 and R_5.

PRESENT PARAMETERIZATION

In the recent study, an attempt has been made to compile the data regarding the multiplicities in hadron-hadron [18-20] and hadron- nucleus interactions in the energy of different range in GeV and with the help of these results it has been tried to establish the energy, mass number and number of nucleons dependence of multiplicities. An important parameter in this respect is the mean normalized multiplicity R_A, which has been thought to be a good measure of development of mutiparticle production. The present parameterization may be defined as

$$R_A = \frac{<n_s>_{hA}}{<n_{ch}>_{hh}} + 0.25$$

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Where $\langle n_s \rangle_{hA}$ the average number of particles is created in the collisions of hadron with the nucleus of mass number A at different range of centre of mass energy in GeV and $\langle n_{ch} \rangle_{hh}$ is the mean charged multiplicity in the case of hadron-hadron collisions. In particular, an energy independent value of mean normalized multiplicity (R_A) may be taken as ruling out the possibilities of instantaneous production and to favour the particle production through intermediate stages. However, completely unambiguous separation is not possible with these facts in mind we proceed estimate the mean normalized multiplicity (R_A). Leading particle effect i.e. the incident Hadron retains on an average half of its initial energy.

Table 1 Mean Normalized Multiplicity for hadron-nucleus collisions (Light Nuclei)

S. No	√s (GeV)	$\langle n_{ch} \rangle_{hh}$	$\langle n_s \rangle_{hA}$	R_A Cal.	R_A (Exp)
1	2	2.59	1.95	0.98	--
2	4.95	3.62	3.23	1.12	0.99 ± 0.12
3	10.25	4.81	5.03	1.24	1.15 ± 0.19
4	25	6.28	6.57	1.29	1.18 ± 0.25
5	50	7.58	7.79	1.24	1.24 ± 0.14
6	100	9.05	9.77	1.32	1.27 ± 0.34
7	150	10.29	10.72	1.31	1.22 ± 0.38
8	500	13.09	14.19	1.33	1.24 ± 1.2
9	1000	12.99	16.98	1.50	--
10	1500	13.59	17.86	1.65	1.31 ± 1.4
11	2760	14.92	20.48	1.62	--
12	7000	17.26	23.82	1.63	--
13	8000	17.70	24.23	1.62	--

Table 2 Mean Normalized Multiplicity for hadron-nucleus collisions (Intermediate Nuclei)

S. No	√s (GeV)	$\langle n_{ch} \rangle_{hh}$	$\langle n_s \rangle_{hA}$	R_A Cal.	R_A (Exp)
1	2	2.59	1.95	1.08	--
2	4.95	3.62	3.23	1.28	1.15 ± 0.17
3	10.25	4.81	5.03	1.53	1.46 ± 0.15

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4	25	6.28	6.57	1.59	1.71 ± 0.32
5	50	7.58	7.79	1.57	1.72 ± 0.11
6	100	9.05	9.77	1.63	1.99 ± 0.39
7	150	10.29	10.72	1.72	1.90 ± 0.31
8	500	13.09	14.19	1.89	2.18 ± 2.1
9	1000	12.99	16.98	1.99	--
10	1500	13.59	17.86	2.02	2.13 ± 1.4
11	2760	14.92	25.40	1.95	--
12	7000	17.26	29.285	1.95	--
13	8000	17.70	29.50	1.92	--

Table 3 Mean Normalized Multiplicity for hadron-nucleus collisions (Heavy Nuclei)

S. No	√s (GeV)	$\nwarrow n_{ch} \nearrow_{hh}$	$\nwarrow n_s \nearrow_{hA}$	R_A Cal.	R_A (Exp)
1	2	2.59	1.95	1.37	--
2	4.95	3.62	3.23	1.57	--
3	10.25	4.81	5.03	1.68	
4	25	6.28	6.57	1.91	2.15 ± 0.39
5	50	7.58	7.79	1.94	2.30 ± 0.22
6	100	9.05	9.77	2.12	2.41 ± 0.29
7	150	10.29	10.72	2.07	2.10 ± 0.83
8	500	13.09	14.19	2.17	--
9	1000	12.99	16.98	2.37	--
10	1500	13.59	17.86	2.43	--
11	2760	14.92	30.91	2.32	--
12	7000	17.26	35.40	2.30	--
13	8000	17.70	35.665	2.26	--

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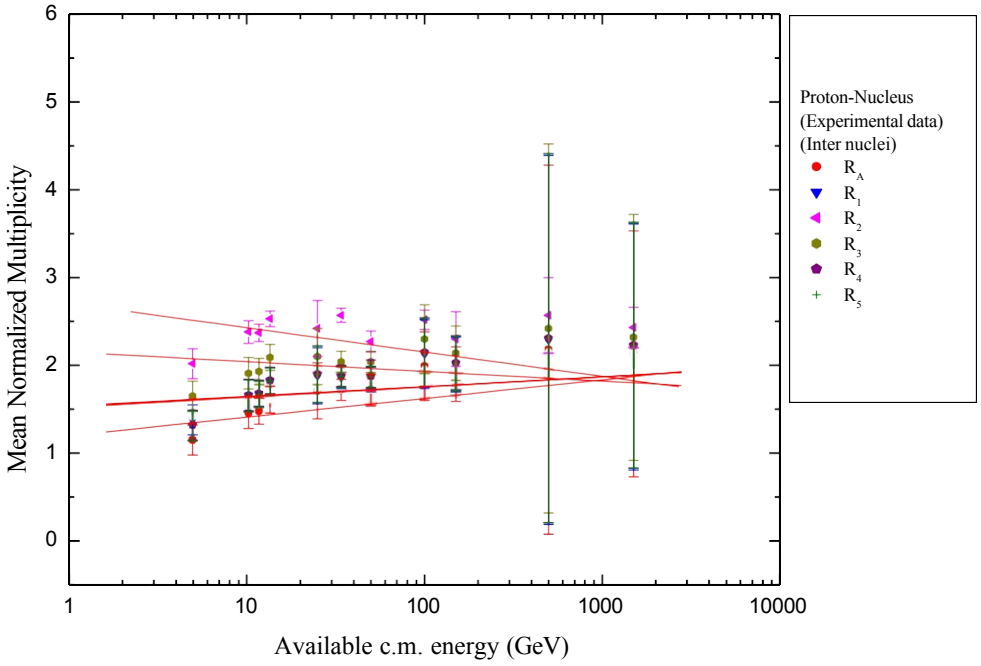

Fig 1 Variation of Mean Normalized Multiplicity for hadron-nucleus collisions (Light Nuclei)

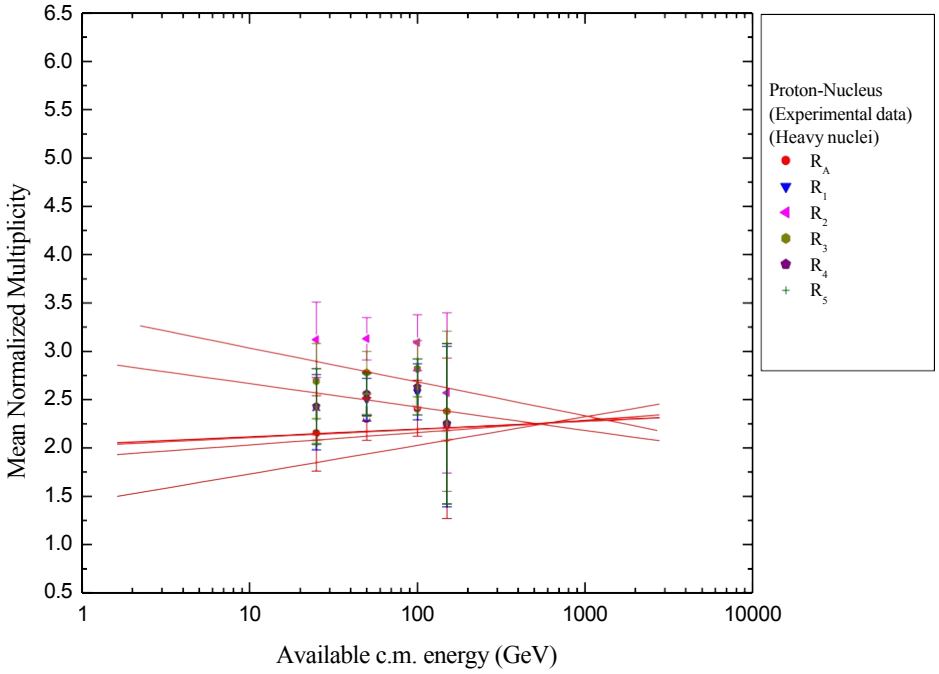

Fig 2 Variation of Mean Normalized Multiplicity for hadron-nucleus collisions (Inter. Nuclei)

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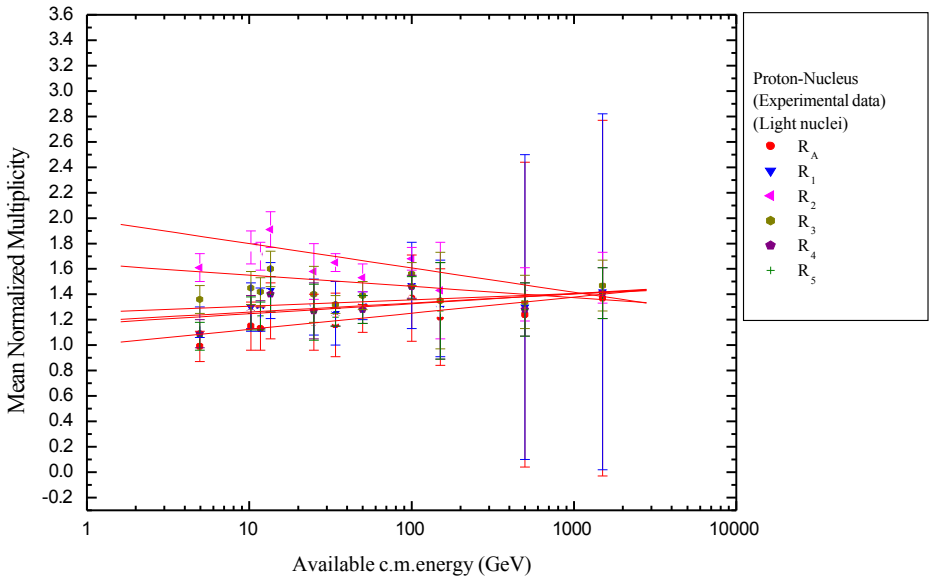

Fig.3 Variation of Mean Normalized Multiplicity for hadron-nucleus collisions (Heavy Nuclei)

RESULT

The results of the present parameterization are presented in the following Table.1, 2 & 3 and Figs. (1-3) and found to be unambiguous and applicable for the entire energy range. In the present work we conclude that the present parameterization of the mean normalized multiplicity with complex nuclei; minimize the limitations of earlier parameterization. Our approach can be applied to all the nuclei including light, intermediate and heavy nuclei over the entire energy range.

CONCLUSIONS

On the basis of our analysis and calculations in the present paper, we conclude that:

a) The different models, proposed by different physicists, have their own identities, and are found to be capable of explaining the hadronic collisions.

b) An attempt is made to modify the parameterization of mean normalized multiplicity in hadron – hadron interactions. The modified form of our parameterization provides batter agreement with experimental data as compared to the earlier parameterizations.

c) The calculated values of mean normalized multiplicity at different energies ranges in GeV, are in good agreement with corresponding

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experimental results and is found to be slightly energy dependent, but not completely independent of energy.

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