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On Multiparticle Pseudorapidity Correlations In Central 4.5A GeV/c C–Cu Collisions

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Abstract

Multiparticle correlations of charged hadrons in the pseudorapidity space of central C–Cu interactions at 4.5A GeV/c are investigated within the intermittency approach. The transformed variables and high order scaled factorial moments modified to remove the bias of infinite statistics in the normalization, are used. Two different intermittent-like rises are obtained, one indicating a possible non-thermal phase transition, and another one for which no critical behavior is seen. This may be considered as an existence of two different regimes of particle production during cascading. Multiparticle correlations are revealed withing the method of factorial cumulant moments as well as in the comparison with the predictions of some conventional model approximations.

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In this note we present the results of a study of charged particle fluctuations/correlations in the pseudorapidity space of central nuclear collisions. The method of normalized scaled factorial moments (SFM) is used, indicating the dynamical fluctuations by a power-law rise,

$$F_q \propto M^{\varphi_q}, \qquad 0 < \varphi_q \leq q-1 \qquad (q \geq 2), \tag{1}$$

of the SFM over number of the pseudorapidity bins $\delta\eta$ [1,2,3].

The intermittency indices φ_q characterize (multi)fractal structure of the distribution [3]. In its turn fractality is argued to be a reflection of a phase transition, e.g. into a quark-gluon plasma in nuclear collisions (monofractal patterns with d_q = const.(q)) [1], or self-similar cascading (multifractals, $d_q > d_p$ at $q > p$) [2]. Intermittency had been found in different kinds of high-energy reactions, but not yet explained qualitatively by the existed particle codes [3]. Meantime, this phenomenon seems to be sensitive to the hadronization process [1,2], and important features of the intermittency systematics behavior had been also found at relativistic energies [4].

The data analyzed here come from interactions of the JINR Synchrophasotron (Dubna) 4.5 A GeV/c ^{12}C beam with a copper target inside the 2m Streamer Chamber SKM-200 [5]. The central collision trigger was used: absence of charged particles with momenta larger than 3 GeV/c in a forward cone of 2.4° was required. The scanning and handling of the film data were carried out on special scanning tables of the Lebedev Physical Institute (Moscow) [6]. A total of 305 events with the average multiplicity of 27.2 $\pm$ 0.8 in the pseudorapidity window $\Delta\eta = 0.2 - 3.0$ are considered. The accuracy of the pseudorapidity measurment in the $\Delta\eta$ does not exceed 0.1 in the η-units. Let us note that (pseudo)rapidity is shown to be the most "natural" variable to study the density correlations [7].

To circumvent the problem of the non-flat shape of the pseudorapidity one-particle spectra $\rho(\eta)$ we use a "cumulative" variable,

$$\tilde{\eta} = \int_{\eta_{min}}^{\eta} \rho(\eta')d\eta' \,/ \int_{\eta_{min}}^{\eta_{max}} \rho(\eta')d\eta' \,, \tag{2}$$

so that it leads to the uniform distribution in the [0, 1] interval [8,9]. This allows to observe higher-order moments. Further, we apply the modified SFM proposed [10] to remove the biased estimator of the SFM normalization that sensitively influences the scaling rise (1) for small bins. The bias-free SFM are defined as

$$F_q = \frac{\mathcal{N}^q}{M} \sum_{m=1}^{M} \frac{\langle n_m^{[q]} \rangle}{N_m^{[q]}} \,, \tag{3}$$

where N_m is the number of particles in the mth bin in all $\mathcal{N}$ events, and and n_m is the same for an each event. $\langle \cdots \rangle$ denote averaging over the events, and $n^{[q]} = n(n-1)\cdots(n-q+1)$.

Figs. 1 and 2 illustrates the log-log dependence of modified SFM (3) on M, depicted for $q = 3$ and 4 (see also Table 1). It is well seen the different slopes, smaller at $M \leq 22$, and greater at $M \geq 23$. Such a different behavior lends support to the existence of different regimes of particle creation at different bin averaging scales. Application of the transformed variable (2) allowed to find the M-intervals, for which rise of the $\ln F_q$ with increase of M sharply differed, up to eighth q-order [4]. Let us note that the noted change of the increasing was observed also in hadronic [11,12] and e^+e^- [3] interactions, but being opposite. Such a decrease of φ_q is explained by QCD coupling constant running for small bins [7]. On the other hand, if one uses the correlation integrals the change dissapeares [3,11,12], but it should be stressed that this method can not be treated in statistical mechanical terms [2], and moreover the results can not be directly compared to the SFM [7,13].

In Fig. 3 we present the functions

$$\lambda_q = \frac{\varphi_q + 1}{q},$$

minimum of which indicates the "critical" value, q_c, of the phase transition, [1,2]. From Fig. 3 one can conclude that two regimes of particle production exists: one, that leads to the phase transition with $q_c = 4$, and another one for which no critical behavior is seen. Taking into account very multifractal structure of the distributions considered [4], the former indicates the "non-thermal" phase transition [2].

In Fig. 3 we show also the λ_q predicted by the gaussian approximation [2] and Ochs-Wosiek approach [9]. That and the analysis of the fractal dimensions [4] show that these models meet difficulties, espesially when q_c exists; the same is found for the negative binomial [4]. Since the approximations are based on the second order SFM, the difference indicates multiparticle character of a possible phase transition.

To obtain the genuine q-particle correlations the method of normalized scaled factorial cumulants [3] is applied. The cumulants are related to the SFM, namely,

$$F_2 = K_2 + 1, \qquad F_3 = K_3 + 3K_2 + 1,$$

$$F_4 = K_4 + 4K_3 + \frac{3}{M}\sum_{m=1}^{M}(K_2^{(m)})^2 + 6K_2 + 1, \qquad \text{etc.},$$

so that assuming e.g. $K_q = 0$, $q \geq 3$, one considers the contributions to the SFM up to two-particle correlations, $F_3^{(2)}$, $F_4^{(2)}$, etc. In Figs. 1 and 2 we present $F_3^{(2)}$, $F_4^{(2)}$ and $F_4^{(3)}$. Despite the errors of the SFM and cumulants (see Table 1) the contributions of high-order correlations are visible, espessially at large M. This contradicts the results from ultra-relativistic nuclei collisions: $K_q = 0$, $q > 2$ [3], while is in agreement with that in hadronic interactions [11], reflecting sensitivity of intermittency to hadronization.

Another hint that the dynamical correlations originate mainly from soft processes, is the $p_\perp$-range, being of 0.35-0.45 GeV/c at q_c-order, closed to the range obtained in the maximum fluctuations study [4] and observed like "low-$p_\perp$ intermittency" effect [11,12].

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TABLE 1

M	F_3	$F_3^{(2)}$
2	1.149 ± 0.054	1.161 ± 0.175
3	1.171 ± 0.058	1.175 ± 0.207
4	1.185 ± 0.058	1.191 ± 0.234
5	1.189 ± 0.059	1.194 ± 0.257
6	1.195 ± 0.063	1.195 ± 0.279
7	1.185 ± 0.060	1.190 ± 0.296
8	1.183 ± 0.062	1.187 ± 0.315
9	1.191 ± 0.066	1.200 ± 0.336
10	1.209 ± 0.066	1.209 ± 0.355
11	1.263 ± 0.076	1.241 ± 0.382
12	1.190 ± 0.071	1.193 ± 0.384
13	1.245 ± 0.074	1.234 ± 0.410
14	1.217 ± 0.075	1.210 ± 0.419
15	1.236 ± 0.082	1.216 ± 0.440
16	1.243 ± 0.078	1.224 ± 0.456
17	1.223 ± 0.094	1.224 ± 0.456
18	1.232 ± 0.079	1.222 ± 0.484
19	1.221 ± 0.083	1.188 ± 0.497
20	1.241 ± 0.083	1.210 ± 0.509
25	1.301 ± 0.093	1.268 ± 0.590
30	1.312 ± 0.099	1.266 ± 0.650
35	1.368 ± 0.106	1.252 ± 0.721
40	1.413 ± 0.107	1.365 ± 0.786
45	1.385 ± 0.120	1.386 ± 0.852

M	F_4	$F_4^{(2)}$	$F_4^{(3)}$
2	1.28 ± 0.08	1.33 ± 0.37	1.28 ± 1.16
3	1.34 ± 0.10	1.36 ± 0.44	1.33 ± 1.3
4	1.37 ± 0.10	1.39 ± 0.50	1.36 ± 1.58
5	1.37 ± 0.10	1.40 ± 0.55	1.36 ± 1.73
6	1.39 ± 0.11	1.40 ± 0.59	1.39 ± 1.89
7	1.35 ± 0.10	1.39 ± 0.63	1.35 ± 2.00
8	1.36 ± 0.11	1.39 ± 0.67	1.36 ± 2.14
9	1.38 ± 0.13	1.41 ± 0.72	1.38 ± 2.30
10	1.41 ± 0.12	1.43 ± 0.76	1.41 ± 2.44
11	1.59 ± 0.16	1.50 ± 0.83	1.55 ± 2.67
12	1.38 ± 0.15	1.40 ± 0.82	1.36 ± 2.65
13	1.51 ± 0.16	1.49 ± 0.88	1.51 ± 2.86
14	1.47 ± 0.19	1.43 ± 0.90	1.41 ± 2.92
15	1.57 ± 0.22	1.45 ± 0.94	1.49 ± 3.12
16	1.54 ± 0.18	1.47 ± 0.98	1.52 ± 3.21
17	1.62 ± 0.31	1.42 ± 1.00	1.41 ± 3.34
18	1.51 ± 0.20	1.46 ± 1.04	1.50 ± 3.44
19	1.57 ± 0.23	1.39 ± 1.06	1.52 ± 3.54
20	1.57 ± 0.22	1.44 ± 1.09	1.49 ± 3.61
25	1.72 ± 0.25	1.56 ± 1.29	1.70 ± 4.32
30	1.69 ± 0.25	1.56 ± 1.42	1.61 ± 4.75
35	1.89 ± 0.29	1.52 ± 1.56	1.86 ± 5.36
40	1.72 ± 0.25	1.77 ± 1.76	1.82 ± 5.88
45	1.79 ± 0.37	1.71 ± 1.91	1.84 ± 6.59

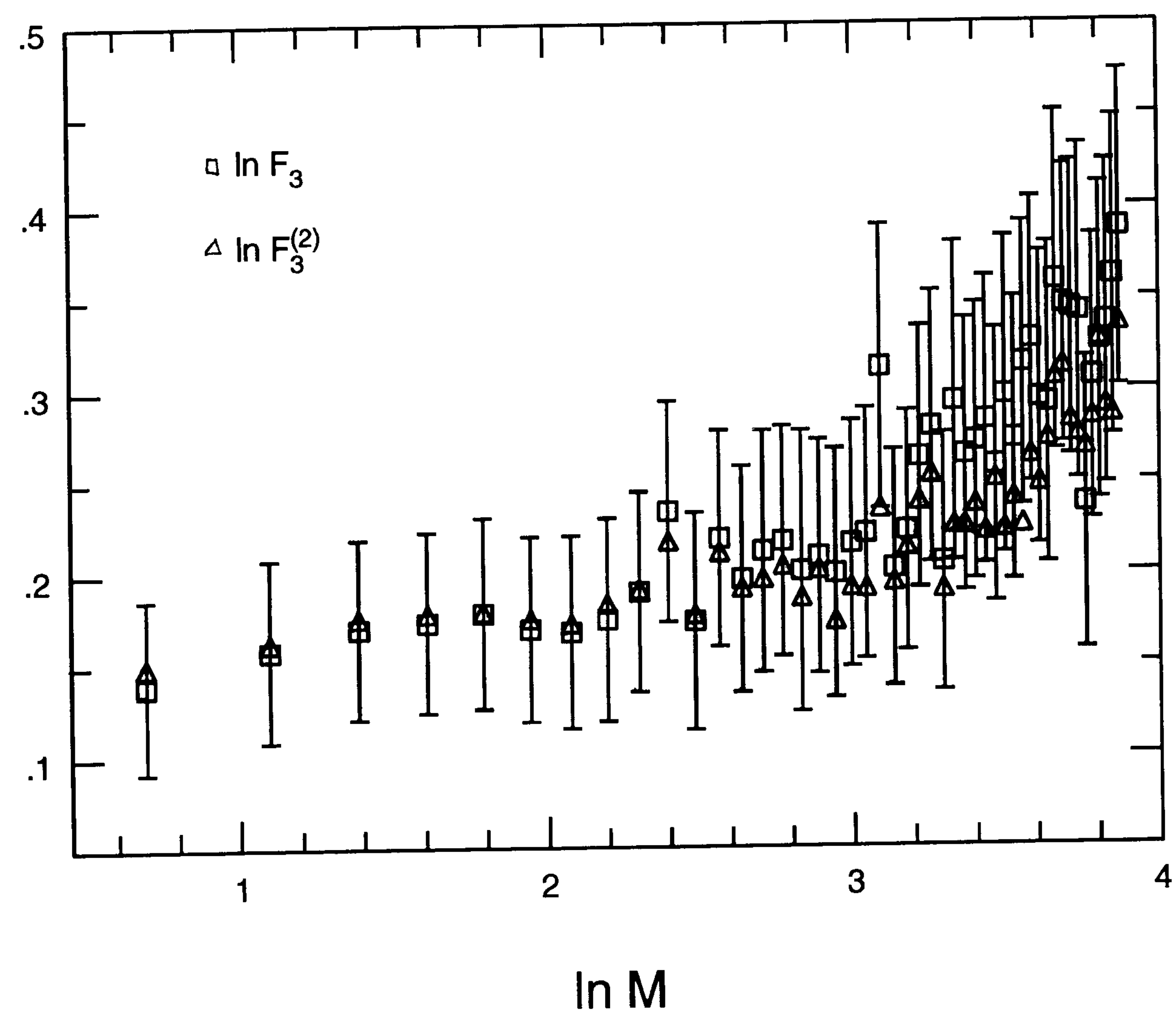


Figure 1

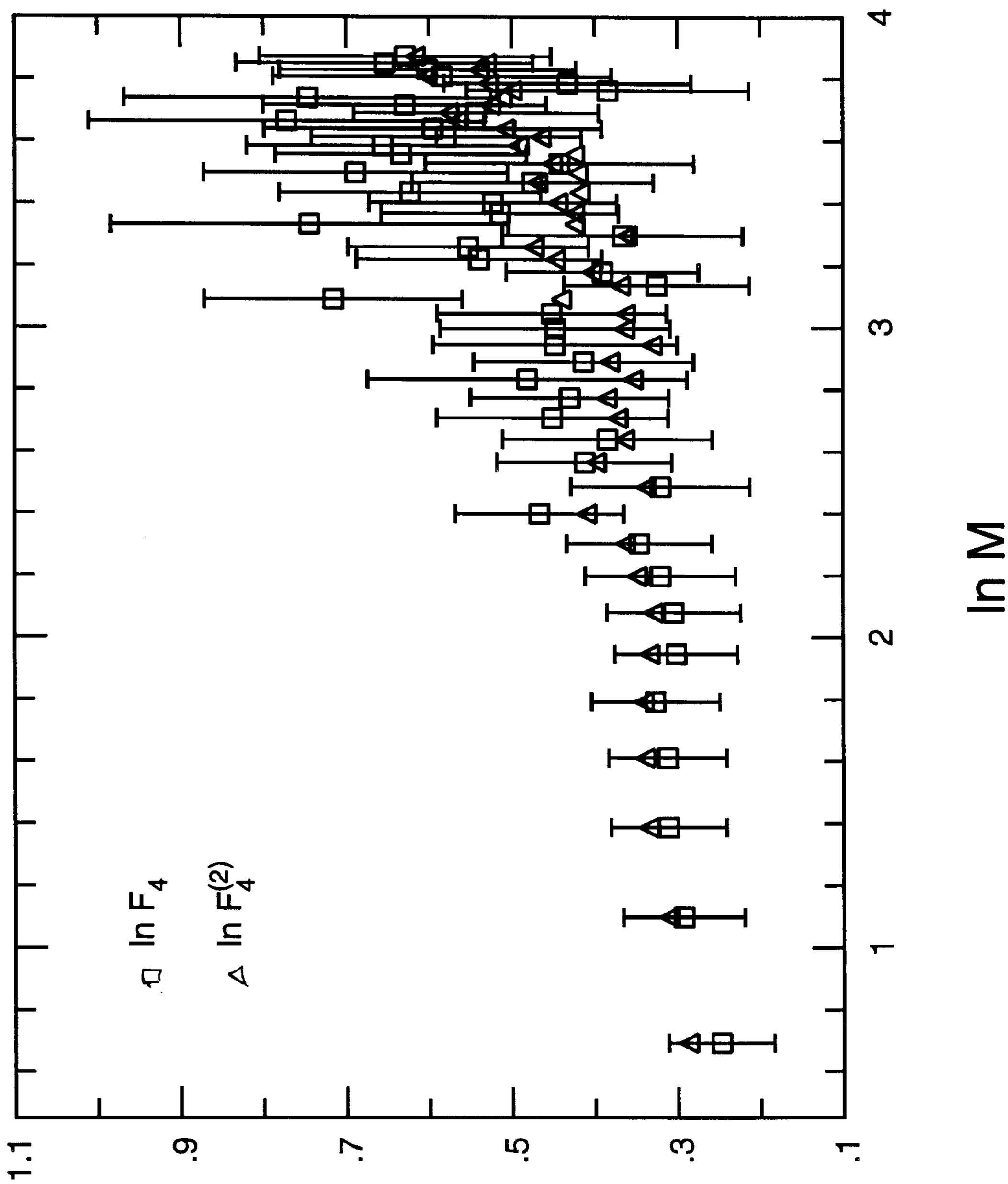


Figure 2a

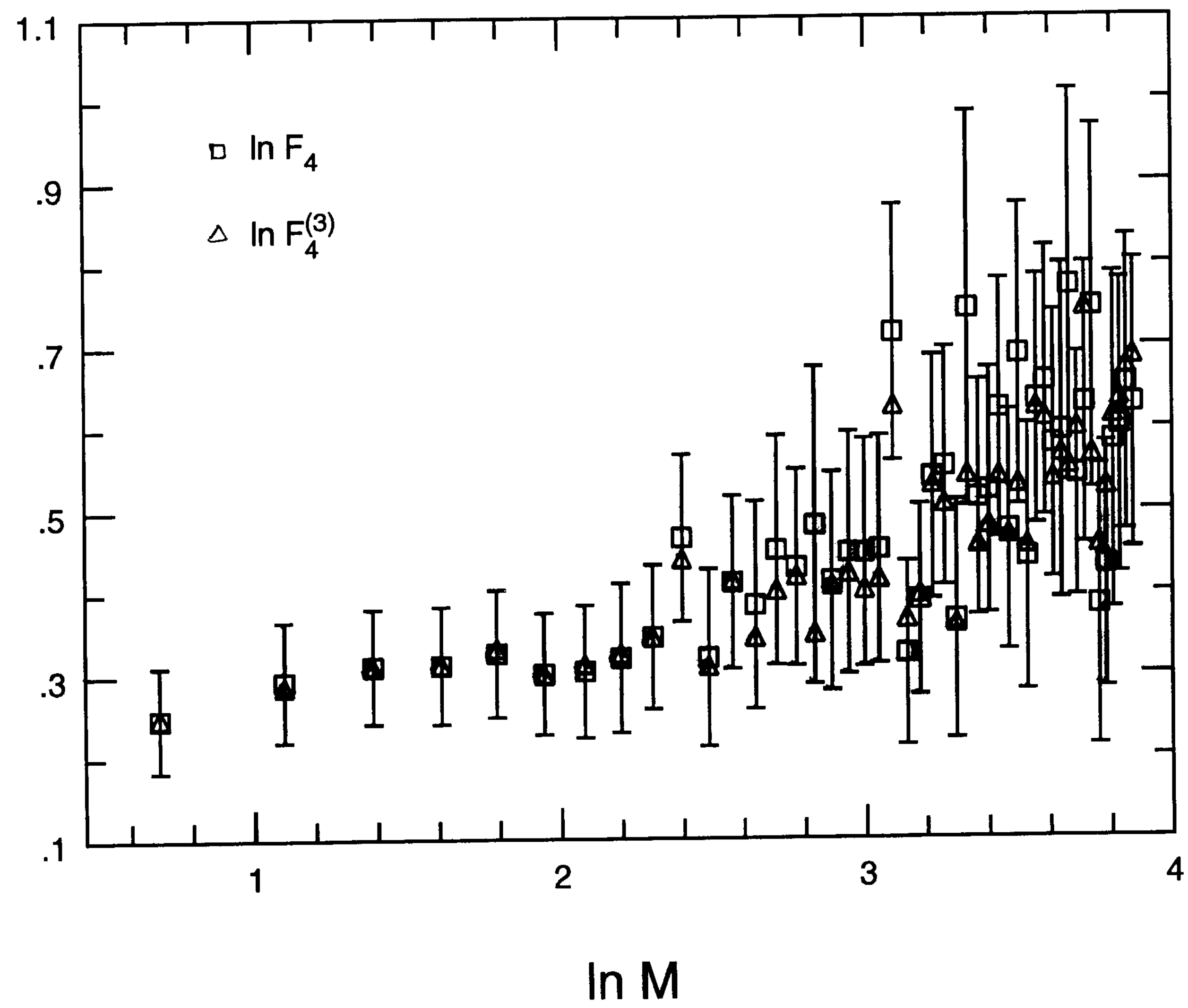
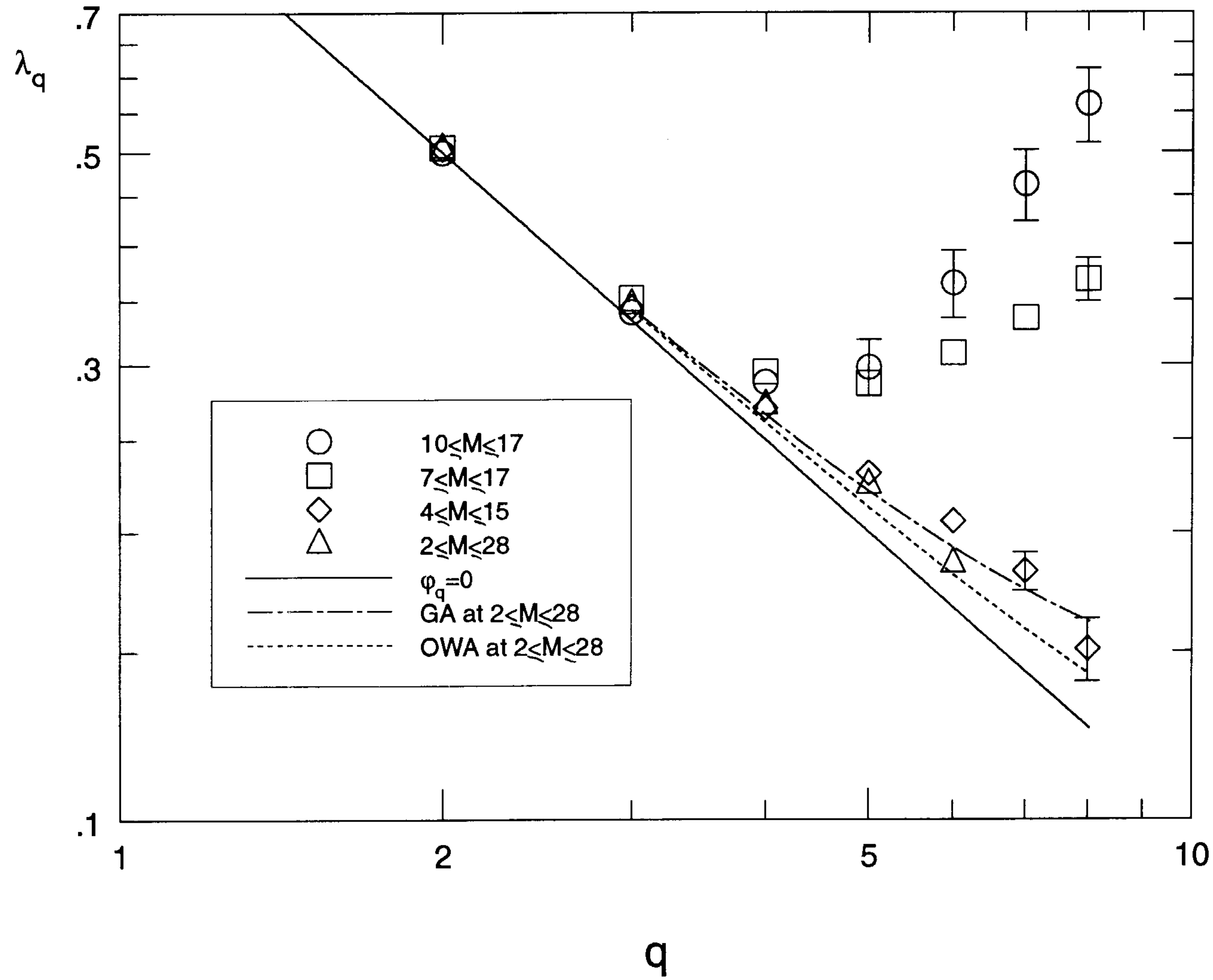


Figure 2b



λ_q
.7
.5
.3
.1
1
2
5
10
q
10≤M≤17
7≤M≤17
4≤M≤15
2≤M≤28
φ_q=0
GA at 2≤M≤28
OWA at 2≤M≤28

Figure 3