MULTIPARTICLE DYNAMICS 1998: SUMMARY TALK

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Many new experimental results and theoretical ideas about multiparticle production processes appeared during the last year. Some of them have been reported at this Symposium, and I try to describe the presented state of affairs in brief, referring for more complete presentation to the original talks and references therein. The Figures demonstrating the statements of this review are not shown here since they can be found in the original talks. In each section, experiment goes first followed by theory.

Compared with previous years, I notice the steady tendency of increasing interest in correlation studies and interactions of nuclei considered as a strongly interacting medium, i.e. in collective effects in particle physics. The non-perturbative aspects of multiparticle dynamics attract more attention even though the perturbative QCD demonstrates further success in its region of applicability.

1 Pomeron physics

One of the main problems we wanted to understand for a long time is whether we are at asymptopia or have not reached it yet. In 1956, when 10 GeV Dubna accelerator started its operation, I came as an undergraduate student to I. Pomeranchuk and remember him answering this question: "Yes, because $10 \gg 1$!" Actual c.m.s. energy was about 4 GeV only, compared to nowadays 1800 GeV at Tevatron and awaited 14000 GeV at LHC. On the contrary, in 1998 we are sure that the asymptopia is far away and we hardly have a chance to come there. Our belief is based on strong increase of total cross sections with energy, small-$x$ behavior of structure functions and other experimental
facts, as well as on slow (logarithmic) approach to asymptotical regime and large higher order corrections in the perturbative QCD.

The data of ZEUS and H1 collaborations on deep inelastic scattering (Derrick, Marage) imply the Pomeron effective intercept somewhere in the region between 1.08 and 1.2 in accordance with earlier results and expectations. The same conclusion follows from strong increase of the structure function at small $x$ and fixed $Q^2$. The scaling violation is well fitted by QCD with next-to-leading corrections. The various distributions of dijets in DIS favor hard $q$–hard $g$ picture.

The exclusive processes of vector meson production from $\rho$ to $\Upsilon$ have been studied at HERA in detail. The slope of the differential cross section $b$ decreases with increase of the parton virtuality $Q^2$ as expected. Since $b = R^2$, where $R$ is an effective distance in $q\bar{q}$-pair created by $\gamma^*$, it indicates the stronger color transparency effect of mutual screening of color charge of components of the pair at small $R$ (analogous to Chudakov effect in electrodynamics). The total cross section of $\rho$-production behaves as $\sigma(\gamma^*\rho) \propto (Q^2 + m^2_{\rho})^{-n}$ with $n = 2.24 \pm 0.09$ at large $Q^2$ that is quite close to awaited $Q^{-6}$ behavior. At smaller $Q^2$ the decrease is slower. However the overall normalization of the cross section can be estimated theoretically (by Pomeron- exchange models) with large uncertainty (up to the order of magnitude). With $Q^2$ increasing, the shares of heavier mesons increase compared to the $\rho$-share.

The results on helicity amplitude behavior show that the ratio of the longitudinal to transverse cross sections increases with $Q^2$ but not as fast as theory predictions what poses a new problem to theorists. The shape analysis of diffractive processes reveals that the central particle density at $y = 0$ in DIS is higher than in $e^+e^-$. Also, the forward-backward correlations are stronger in DIS.

The data of HERA have been compared with the data on inelastic diffraction in $pp$-processes at Tevatron (Goulianos) where single, double and two-Pomeron diffractive processes as well as $W$ and heavy flavor production are analyzed. These processes should tell us about the evolution of hadronic systems on a large time scale, but the space-time picture is not clear yet. The CDF data on dijets and $W$ indicate the gluon content of Pomeron of about 60-70% (with 40-30% of quarks, correspondingly). To consolidate the data about the energy behavior of the single diffraction cross section (with a "knee" at $\sqrt{s} = 22$ GeV), the $M^2$-dependence of its differential cross section and $W$-production, it has been proposed to use the renormalized flux of Pomerons corresponding to the scaling of the gap probability. The theoretical implications of such a procedure should be thought over. The pretentious claim to explain at the next conference "What is Pomeron?" has been put forward, and
we will remember it!

The study of two-Pomeron diffraction processes at 85, 300 and 450 GeV (Kirk) has revealed an interesting effect of the azimuthal correlation of two recoiled protons. It can be used to learn more about the Pomeron-Pomeron interaction.

Concerning the theoretical approach to Pomeron problem, we used to think in terms of the so called soft and hard Pomerons. Soft Pomerons are ascribed to solutions of DGLAP equations with $x$-distribution in DIS of the type

$$W(x, Q^2) \propto \exp \sqrt{c \ln \frac{1}{x} \ln \frac{Q^2}{\Lambda^2}}.$$  

Hard Pomeron is related to BFKL equation and gives rise to the behavior $W(x, Q^2) \propto \left(\frac{x}{x_0}\right)^{-\Delta}$ where in Born approximation one estimates $\Delta_B = \frac{\alpha_s}{2\pi} 12 \ln 2 \approx 0.4 - 0.5$ at $Z^0$. Surely, the phenomenological pole-like fits with $\alpha_P(0) > 1$ should be considered as preasymptotical ones because they would violate the Froissart bound in asymptotics. In QCD, $\alpha_s \to 0$ asymptotically, and therefore there is no direct contradiction with the Froissart bound. Nevertheless, the high intercept of the hard Pomeron always looked especially suspiscious, and new results (Lipatov) show that corrections to it are so high indeed ($\Delta_{NL} = \Delta_B(1 - a\Delta_B)$ with $a = 2.3$) that the position of the intercept moves closer to 1 and becomes completely undeterminate until next corrections are calculated. Thus the clear separation between soft and hard Pomerons has been lost in what concerns the energy behavior. Are they mixed? Moreover, the problems with unbounded (from below) spectrum and with oscillations (!) of total cross sections in $\overline{\text{MS}}$-scheme (absent in BLM-scheme ?) should be solved.

On the phenomenological side we saw impressive fits (Block) of the total, elastic, differential cross sections as well as ratios of real to imaginary parts of the forward scattering amplitude in the framework of the "QCD inspired" eikonal model. It provides $\sigma_{\text{tot}} \propto c \ln^2 s$ with small value of the factor $c (\sim 10^{-3}$ of Froissart bound) and, in particular, predicts all above characteristics to be measured at LHC. It states that zero curvature of the slope of $d\sigma/dt$ at Tevatron indicates that we are at preasymptotic region yet, and its curvature should become negative at LHC. Let us see whether it works there, and what the chosen form of the eikonal phase means.

The soft+hard Pomeron picture (called heterotic Pomeron) has been still in use (Tan) to account for minijet production at high energies. It attempts to incorporate diffusion in the impact parameter (soft Pomeron and large color dipoles) and in $p_T$ or virtuality (hard Pomeron and small dipoles). The factorization seems to be broken as it happens for multiple BFKL poles as well. It would be desirable to get the correspondingly modified DPM to confront such an idea to multiparticle production data.
To study Pomeron properties, the method of factorial moments was applied to final states of $P\gamma^*$-collisions in DIS (Zhang). It is shown that the second factorial moment (i.e. the dispersion of multiplicities) is sensitive to Pomeron structure and insensitive to its flux. The relationship with above experimental data should be clarified.

2 Multiplicities

The study of multiplicity distributions (MD) is fruitful because they contain in the integrated form all the correlations of the interacting system. The intensive search for scaling laws and QCD predictions for MD (they are infrared-safe!) give impact for the theoretical activity.

New precise experimental data on MD in $pp$-processes in the energy range from 300 GeV to 1800 GeV of Tevatron has been reported (Walker). If compared with earlier UA5 data at the same energy 546 GeV, it shows wider MD, is more precise at high multiplicities and less at low. Let us note that just these two wings of MD correspond to unusual events with extremely developed and underdeveloped cascades, respectively. Therefore they are especially interesting and must be accurately measured. Both the density and the average number of particles increase with energy. The MD maximum is located at $n_{max} \approx 0.8 \langle n \rangle$ and the shoulder is visible that provokes to fit it by a sum of two NBD (four free parameters!) with an energy threshold for the second NBD and about 30% of $\sigma$ at 1.8 TeV in there. It reminds of old conjecture of DPM (or QGSM) that the rescattering produces MD with several shoulders. The similar shoulder has been seen in $e^+e^-$ processes.

With some assumptions about the energy dependence of NBD parameters, one can get (Ugoccioni) predictions for MD at LHC energies from UA5 data but Tevatron data implies that initial fits should be reconsidered. Also, for the fit to be more consistent, the triple rescattering must be taken into account.

The general question about foundations of NBD is usually answered in the phenomenological way. That is why its generalizations have been used. The only one with some QCD background is the generalized NBD (Hegyi) which stems from the Poissonian transform of MD obtained in some approximation of QCD and known as the generalized gamma-distribution. Nevertheless, even though quite effective in phenomenological fits, NBD does not appear in QCD which predicts different asymptotical behavior of MD moments compared with NBD. Namely, at asymptotic energies the ratio of cumulant to factorial moments behaves in QCD as $q^{-2}$ while in NBD with $k = 2$ (this choice is closest to QCD in $q$-asymptotics) it is represented by the different formula $2/q(q+1)$ i.e. with twice larger ratio in asymptotics. Other scaling laws beside KNO
have been looked for (Ploszajczak) in the form
\[ \langle n \rangle^\delta P_\delta(n) = f((n - \langle n \rangle)/\langle n \rangle^\delta) \]
with \( \delta \neq 1 \) in search for a possible signature of phase transitions.

QCD predicts quite distinct oscillating preasymptotic behavior of cumulant moments of MD (and, consequently, of their ratio to factorial moments) with first minimum at their rank about \( q_{\text{min}} \approx 5 \). Experiment in \( e^+e^- \) at \( Z^0 \) peak supports this prediction (Metzger) for the full phase space as was known earlier from other data. Sometimes it is interpreted as a combined result of hadronization and MCs showers described by NLO, not NNLO. I’d like to stress that NNLO terms in analytical QCD appear as a byproduct of higher order derivatives taking into account conservation laws fully inserted in MCs which therefore include beside NLO some contributions of higher order approximations of QCD as well. That is why their agreement with data is puzzling only in the sense that the hadronization does not destroy it even at very high ranks.

Special attention has been paid to multiplicities in gluon and quark jets (Gary, Langefeld). Their ratio \( r \) slightly exceeds 1 and increases with energy. According to QCD, it should approach asymptotically the ratio \( C_A/C_F = 2.25 \). Experimentally at \( Z^0 \) peak \( r = 1.51 \pm 0.02 \pm 0.05 \) for the full phase space and \( r = 1.82 \pm 0.04 \pm 0.06 \) for soft particles (\( y \leq 2 \)). In NLO, it is equal to 2.05 and disagrees with experiment. If higher order corrections, the energy conservation in the triple vertices and the overall conservation law are taken into account in formalism of QCD equations for generating functions, agreement can be restored. However, there is yet an unsettled problem with higher order analytical calculations in the renormalization group approach which claim smaller corrections.

Even more puzzling is a reported rather large difference between the ratio of energy slopes of average multiplicities and \( r \) itself which changes from 0.95 at lower energies to 0.7 at \( Z^0 \). It should be much smaller according to theoretical estimates because it is proportional to the slope of the running coupling constant which is small in pQCD. It demonstrates the running property of the QCD coupling being zero for fixed coupling. Do we see here the non-perturbative effect at work as it has been claimed by DELPHI collaboration? If so, it would be very important. Before answering this question one should understand the role of higher order QCD terms which becomes even more essential in the slopes than in the ratio \( r \). Still it is hard to reconcile this fact with the well known small slope of the running coupling constant. Besides, the asymptotical series expansion of pQCD does not account for the exponentially (in \( \sqrt{\ln s} \)) damped terms which are important for fits starting at comparatively low energies. Theoretically, it is easy to estimate that for the second derivatives the corresponding difference is approximately twice larger but it
seems difficult to measure it in experiment with high enough precision. These differences are sensitive to higher order QCD corrections since each derivative enlarges the role of higher orders. Also, the energy evolution of dispersions of MD in quark and gluon jets would be of interest. With high statistics at $Z^0$ and elaborated methods of jets separation it can be studied and compared with theory which predicts the difference in asymptotic values of dispersions and in their slopes. The progress in this field is really impressive.

Multiplicities in heavy quark jets (de Angelis) also have some special features. The accompanying gluon radiation of heavy quarks should be suppressed due to their high mass compared with that of light quarks. The difference in multiplicities of $b\bar{b}$- and light quark events is predicted in QCD to stay constant with energy while in the "conservative" model taking into account just energies it should decrease with energy. Earlier data up to LEP1-energies did not allow to decide which approach is correct due to both experimental and theoretical uncertainties. Experiments at LEP2 strongly support the QCD conclusion. I would like to note that the angular distribution of the accompanying radiation in $b\bar{b}$-events should be of a "ring-like" or "dead-cone" type i.e. suppressed at forward angles as determined by propagators of $b$-quarks. It has not been studied yet in experiment.

An elaborated procedure of restoration of $\pi^0$-MD (Krasznovszky) from the secondary photons in $\pi p$-processes at 40 and 250 GeV has supported the common belief that KNO-scaling is valid in this energy region for neutral pions as well as for charged pions.

Finally, one should stress that the knowledge of MDs is important not only by itself but also for practical purposes of predicting the neutrino beams to be sent from CERN to Gran Sasso, for example (Bonesini).

3 Single-particle distributions

Single-particle distributions have been intensively investigated in many reactions and, especially, in high-energy nucleus-nucleus collisions during last years (Seyboth, Humanic, Sandor, Wang, Tserruya, Masera). The universal feature seen in PbPb-events at 158 GeV for secondaries $\pi^\pm, p^\pm, K^\pm, \Lambda^\pm, \Xi^\pm$ is their exponential decrease with the transverse mass $m_T = \sqrt{m_0^2 + p_T^2}$: $dN/dm_T \propto m_T \exp[-m_T/T]$, where $T$ is parameterized as $T = T_0 + \beta_T m_0$, $T_0 = 140\text{MeV}$, $\beta_T \approx 0.4$, $m_0$ is the mass of the particle, $p_T$ its transverse momentum. Let us stress that up to now the explanation of such universality is obtained in the framework of the thermodynamical approach only. For multi-strange hyperons the inverse slopes $T$ deviate from the linear increase with the particle mass.

The parameter $T$ increases for a bigger system, namely $T_{\text{PbPb}} > T_{\text{SS}} >$
It is interesting to note that in $pp$-collisions there is no substantial dependence of $T$ on $m_0$. Sometimes this nuclear effect of increase of the inverse slope with particle masses is ascribed to the transverse radial flow of particles or to the final-state rescattering. As seen from these universal distributions, the integrated yields are also larger for a bigger system i.e. $Y_{PbPb} > Y_{SS} > Y_{pp}$. For particles of the same species but with different electric charges the integrated yields are different. For example, the ratio of $K^+$ to $K^-$ integrated yields in PbPb at 158 GeV is about 1.84 (larger than in SS or $pp$) and increases for lower energies. It is of interest in connection with a possible signature of the quark-gluon plasma in event-by-event analysis.

The proton rapidity distributions from central PbPb-collisions show the phenomenon of baryon stopping i.e. of comparatively large fraction of protons in the central rapidity region. Fritiof model predicts smaller baryon stopping, while RQMD overestimates it. Multiple collisions could qualitatively explain baryon stopping. At the same time, the pion rapidity distribution in the whole rapidity range ($0 < y < 6$) is insensitive to baryon stopping. It scales from SS to PbPb and peaks at midrapidity.

The strangeness enhancement has been observed in nucleus-nucleus collisions and shown to increase with the strangeness content of a particle. It is often considered as a signature of possible phase transition to quark-gluon plasma.

Very intriguing observations have been reported (Stassinaki, Perepelitsa, Tserruya, Masera) about the production of photons and dileptons in $(\pi, K, p)p$, SS, PbPb collisions at energy of hundreds GeV. In the region of $\rho, \omega$-resonances the strong excess (over all traditional calculations) of photons with low transverse momenta $p_T^{(\gamma)} < 40$ MeV has been seen as well as the low $p_T$ excess for $e^+e^-$ pairs with masses in the range $0.25 < m_{e^+e^-} < 0.68$ GeV. The excess factor ranges from 3 to 7 compared with QED and decay estimates in different reports. It depends on the rapidity range studied, is stronger in the central region and increases with particle density at midrapidity. Attempts to explain it include hypothesis about $\pi\pi$-annihilation, shift of masses and widths of $\rho, \omega$ with the temperature as well as more exotic ones like appearance of special domains in the QCD vacuum. However, no reliable conclusion has been reached. Something happens at large distances, and we have no explanation. Are we partons in charge of this effect? If yes, it would be a signature of a non-perturbative mechanism. Can Bose-Einstein effects reveal its origin? Still, there is no signal consistent with the large excess of low-mass electron-positron pairs in SAu photon measurements and in pBe at 450 GeV by HELIOS collaboration.

In the region of high-mass dilepton pairs, one observes the well known
anomalous $J/\psi$ suppression in PbPb so that the $E_T$ integrated cross section is reduced by the factor $0.74 \pm 0.06$ with respect to the absorption model prediction. The ratio of dimuon decays of $J/\psi$ to Drell-Yan pairs shows strong decline for PbPb from usual exponential fit valid for lighter colliding nuclei and hadrons. There is some enhancement in the mass region between $\rho, \omega$ and $J/\psi$ which could be ascribed to enlarged charm production. An additional $\psi'$ suppression is observed both in SU and PbPb data.

The detailed impressive review of efforts of 4 collaborations preparing for future experiments at RHIC has been presented (Jacak). Our general hope is that the experimental results on interaction of objects with high complexity beside revealing their geometrical structure will give us insight into the properties of the QCD vacuum, in the equations of state of the hadronic matter, in specifics of field theories at the finite temperature. They will help us understand the properties of the heavy neutron stars and of the matter at early stages of the Universe.

The distributions in DIS and $e^+e^-$ processes have been compared and discussed in connection with QCD predictions (Milstead, Chliapnikov, Böhrer, Sarkisyan). The status of the hump-backed plateau in $\xi = \ln 1/x$-variable is confirmed with the position of the peak and its width well fitted by MCs both in DIS and $e^+e^-$. The reported approximate scaling of $\xi_{max}/\langle n \rangle^{1/2}$ is somewhat of surprise since in QCD $\xi_{max} \propto \ln s + O(\ln^{1/2} s)$, while $\langle n \rangle^{1/2} \propto \exp[c \ln^{1/2} s]$ so that it can approximately hold just in some energy interval only. It must be sensitive to the angular ordering (contrary to Chliapnikov’s statements) because otherwise $\langle n \rangle$ drastically differs for ordered and non-ordered cascades (the factor $c$ is different). The scaling violations in $ep$ are well described by pQCD but the event shape spectra need power corrections. The particle content in $ep$ and 3-jet $e^+e^-$ events with different species studied poses some problems because MCs are sometimes unable to describe it.

The high mass and high $p_T(E_T)$ physics at Tevatron with further plans of the accelerator reconstruction have been described (Giokaris). The relative yields, cross sections and masses of heavy mass states with limits on Higgs masses (about $< 250$ GeV) are presented. The controversial issue of the excess at very high $E_T$ claimed by CDF has been discussed in connection with the quark compositeness problem.

4 Correlations and fluctuations

This topic is naturally the most widely discussed in multiparticle dynamics. It can be separated in three parts dealing, correspondingly, with correlations of identical particles (HBT-effect), general correlations and fluctuations stud-
ied mostly by moments behavior, and special collective effects and cascade modifications. There were many talks devoted to it. The integrated form of correlations appears already in the overall multiplicity distributions as has been separately discussed. The recent conference "Correlations and Fluctuations" in Hungary was specially devoted to this subject, and more detailed presentations can be found in its proceedings.

The main aim of studies of correlations between identical particles (HBT-effect) which arise due to (anti)symmetrization of the wave function is to understand the space-time parameters of the interaction (Smirnova, de Jong, Humanic, Wang). Such a symmetrization results in excess over 1 of the normalized correlation function for two identical bosons in the region of small relative momenta with a width inverse proportional to the radius of the interaction region. For identical fermions (usually, two protons) the antisymmetrization gives rise to the negative correlation function at very small momenta, changing sign and possessing a positive maximum which indicates their interaction range. Both curves measured in nucleus-nucleus collisions for $\pi\pi$ and $pp$ agree with our intuitive ideas about nuclei sizes. However somehow they show that while the production of particles in nucleon collisions is effective at distances $r \leq 1.5$ fm, it becomes crucial at much larger distances $r > 5$ fm in nucleus-nucleus collisions. It would imply some retardation effect within the future light cone for the collision process. It depends on the transverse masses and atomic number decreasing for larger $m_T$ as $m_T^{-1/2}$ and increasing for heavier nuclei. The attempts to explain $m_T$-dependence by rescattering or flow are questionable because the similar effect has been observed in $e^+e^-$. Is the dynamics of this long-distance effect related somehow to large time scales essential for diffraction processes? It is interesting to note that the peak height in $pp$-correlations (equal about 1.14 ± 0.04) does not depend on energy in the wide energy range from 100 MeV to 200 GeV where physics of the process must change drastically.

In AA, there is no dramatic difference between the longitudinal and transverse sizes for various species and at high transverse momenta (with somewhat larger values of $R_{long}$ for low $k_T$ pions only). Therefore it is hard to explain the abovementioned $J/\psi$ suppression by the drastic change of the space-time picture. Such a difference has been noticed in $e^+e^-$ and hadron-hadron collisions. In $e^+e^-$, the shape of the region is elongated so that $R_{long} \approx 2R_{out} \approx 2R_{side}$. With overall fit of the form $C_2 = N(1 + \lambda_2 \exp[-R^2Q^2])$ it has been found that $R \approx 0.5$ fm, $\lambda_2$ increases and $R$ decreases with $m_T$ increasing (compare to AA, where $\lambda_2$ does not increase while $R$ decreases as well). With increase of the multiplicity, the radius $R$ increases also. One should remind, however, that the variable $Q^2$ is not very well suited for such fits, and, in practice, the
points at small $Q^2$ are usually omitted when fits are done.

The three-particle correlations in $e^+e^-, \pi p, pp$ differ from AA (Bialas, Smirnova, Sarkisyan). The 3-particle cumulant moments revealing "genuine" correlations differ from zero in $e^+e^-$ (with $R_3 \approx 0.6$ fm) and within experimental errors are consistent with zero in AA. Let us note, however, that the amplitude of oscillations of $H_q$-moments increases for targets with more complex structure. It shows that higher rank cumulants may become larger just in AA.

Interesting conjectures have been made about the role of HBT-correlations in processes of $W$-production in $e^+e^-$-collisions. Various theoretical schemes predicted that the difference between the charged multiplicities in processes with both produced $W$’s decaying in hadrons and the doubled multiplicity of those processes when only one of the two created $W$’s decays hadronically $\Delta(n_{ch}) = n_{\pi}(WW) - 2n_{\pi}(W)$ should be non-zero and range between $-3$ and $2.1$ (Fialkowski) due to HBT-correlations. The latest experimental data (de Jong) at $\sqrt{s}=183$ GeV (LEP2) show $\Delta_{exp} = 0.2 \pm 0.5$ and no difference in $x$-distribution of the two processes. However, the preliminary DELPHI data at 172 GeV gives $\Delta = 3.9 \pm 1.6$. The influence of HBT-correlations on the mass shift of $W$ was earlier estimated sometimes as exceeding 50 or even 100 MeV but recent (model dependent) results show that it ranges between 0 and $50 \pm 20$ MeV. Therefore one is tempted to conclude that no clear signal of influence of HBT-correlations on $W$ masses has been seen until now. The importance of the color reconnection in $W$-mass shifts can be clarified by studying the "inclusive" 3-jet events (Gary).

The problem of implementation of HBT-correlations in MC-schemes is non-trivial due to the quantum-mechanics origin of this effect. It has been addressed by three groups. Two of them (Todorova-Nova, Lund) deal with matrix elements. The third group (Fialkowski) deals with the density matrix and iterative rescaling procedure with Gaussian BE-functions in JETSET. First results claim that $R_{long} \neq R_T$, $K_3 \neq 0$ and $\Delta M_W \sim 10 \pm 10$ MeV that agrees with discussion above. Some cross-checks should be still done (e.g. on the positivity of the Wigner function in the last approach).

The study of general correlations and fluctuations in smaller phase space regions is usually related (Bialas) to notions of intermittency and fractality. Started for hadronic processes, it has been extended to all initial particles and nuclei. Actually it shows the evolution of MD for ever smaller phase space regions in 1, 2 or 3 dimensions. According to QCD predictions in DLA (sometimes, with some NLO corrections taken into account as well) the factorial moments should first increase linearly on the double-logarithmic scale for smaller intervals with subsequent "knee" and curvature at ever smaller inter-
vals. Qualitatively, these trends are seen in experimental data (Mandl). The approximation used for analytic calculations is too crude to be quantitatively true. In the computer solution of equations for generating functions with conservation laws properly taken into account, the agreement is very good both for moments in small bins and in the whole phase space region (oscillations of $H_q$-moments discussed above) as was shown (Lupia) at recent "Correlations and Fluctuations'98" conference. I would comment that the overall energy conservation leads to power corrections, and they can contribute several per cents at comparatively low energies. However no power-like dynamical terms have been taken into account. Probably, more important fact is that in computer calculations no Taylor expansion is used, and therefore all high order terms are included. MC models are also able to fit the experimental data reasonably well. Thus I do not see any important disagreement here but would prefer to rely on the qualitative features and on limitations of the method than insist on quantitative description now. The only but crucial problem is that, with one-to-one correspondence between partons of pQCD and hadrons, it looks as if the boundary between short-distance and large-distance phenomena has been shifted so far that no space for large distances is left. Is it so? How does it correspond to new conclusions from multiplicities of quark and gluon jets?

Further multidimensional extension of this method uses the difference between the scales in different directions of the phase space and, therefore, the self-affine transformations (Liu). The values of respective Hurst exponents show the degree of the anisotropy in different directions. It has been also proposed (Blazek) to exploit other characteristics such as frequency moments and dispersion moments. These proposals must be applied to a wide range of experimental data to prove their fruitfulness.

In DIS, the correlations between the current and target regions in the Breit frame have been studied (Chekanov) by measuring the function $\rho = \langle n_c n_t \rangle - \langle n_c \rangle \langle n_t \rangle$ which is predicted to be negative in QCD. It is sensitive to the gluonic structure function and to gluon density, however, the hadronization influences it. The forward-backward correlations have been also measured and the anticorrelation was observed with $\rho_{FB} = \langle n_F n_B \rangle - \langle n_F \rangle \langle n_B \rangle \approx -2.5$ in the range $10 < Q^2 < 10^3$ GeV$^2$. For identical colliding particles, it must be negative in a sample of events with a fixed multiplicity. Thus its sign is not a surprise, and it would be desirable to know how much of its value is due to dynamics and mixture of different multiplicities, respectively.

Many important theoretical questions concerning correlations have been raised at the Symposium: Are there collective effects where particles and nuclei act as a medium? Are there specific correlations modifying the parton cascade? How can we observe phase transitions if any? etc. For example, if the nucleus
still "remembers" during the initial stage of collision that it is quite a solid object, then "sling effects" could be noticed. Not discussed here was the widely disputed problem of the suppression of gluon radiation in a hadronic medium (analogous to the so called Landau-Pomeranchuk-Migdal effect in QED).

The influence of the hadronic medium on final correlations can be observed in predicted peculiar correlations of pions with the opposite sign charges slowly moving in opposite directions with equal (in modulus) momenta (Andreev). The origin of this effect is the fact that fields in a medium are not free and undergo Bogoliubov transformation to become free at the end. Therefore the particle and antiparticle operators are mixed and the "shadow" of HBT-correlations appears in that form.

The predicted a year ago and only recently published (Andersson) effect of screwiness at the end of the parton cascade has been already confronted to experiment (de Angelis). The correlation length in $p_T$ and helicity conservation in a 3-gluon vertex define a special angular distance so that the dipoles can not be very short, and the gluonic classical field acquires a helix structure as if screwed on the phase-space cylinder. It would produce a special pattern of events in the $(\theta, \phi)$- plane with some periodicity or, in other words, display a peak at the "resonant" value of frequency $\omega$ in an expression $|\sum_j \exp(i(\omega y_j - \phi_j))|^2$ with sum over rapidities $y_j$ and azimuthal angles $\phi_j$ of all particles in an event sample. No such peak (periodicity) has been found both in DELPHI data and in the traditional JETSET73-based simulation. It does not exclude the chance that the period is either shorter or longer than those which could be resolved. Other possibilities are that the resonance decays smear it or the multiplicity is still too low to get a clear effect in event-by-event analysis and the effect is washed out in a sample of events. Further studies are needed.

Such a long discussed collective effect specific for hadron-nucleus collisions as the cumulative effect has been described in the framework of the "QCD inspired" model (Braun). It consists in recoil of impinging protons in the region kinematically inaccessible for proton-proton collisions. It has been shown that the nuclear structure function is steeply decreasing in this region as $\exp[-16x]$, and particle production with $|x| > 1$ is damped as well: $\exp[-6x]$. The number of particles increases as $n \propto A^{1+\xi}$, and the ratio of different species is $n_p : n_\pi : n_K = 100 : 10 : 1$.

When discussing nucleus-nucleus collisions, I omitted several comments in different talks on a very important problem of existence of the phase transition from the hadronic phase to the quark-gluon plasma. Here I'd like to mention the thermodynamical approach (Diakonos) which deals with this problem by considering the chiral field $(\sigma, \vec{\pi})$ in 3 dimensions. It predicts clusters of pions with intermittent behavior in the momentum space which give rise to
low-multiplicity critical events with minijet-like structure in \((y, \phi)\)-plane. The second order phase transition is advocated. The whole approach is similar to considering the O(4) Heisenberg magnet in 3 dimensions.

Some collective effects deserved, in my opinion, more attention than just the private discussions. Among them are the energy flows, the peculiarities in pseudorapidity distributions of dense and narrow groups of particles, the abovementioned LPM and sling effects.

The methods of experimental study of correlations evolve nowadays to studying the patterns in high-energy and high-multiplicity individual events. The progress in this direction would be noticeable, in particular, if one is able to measure the impact parameter in each event. It has been claimed (Treleani) that the large number of minijets in heavy ion collisions at LHC energies and a very narrow distribution at \(p_T^{\text{min}} \to 0\) will allow to fix the impact parameter in a subsample. The geometrical picture with multiparton distributions has been used. In my opinion, the difference in virtualities of colliding partons can widen the distribution. Therefore, the stability of conclusions concerning the impact parameter with respect to varying virtualities of partons creating minijets should be proved and various \(x\)-regions considered.

If this method is just a proposal for future studies, the method of the wavelet analysis finds already real applications. Earlier, discrete wavelets were used for analysis of some theoretical cascade models. I proposed to use the continuous wavelets for pattern recognition in individual high-multiplicity events, and EMU-15 data were used. At this Symposium, the discrete wavelets have been used for that same purpose (Petridis) with analysis of NA49 data on PbPb interactions at 158 GeV as well as of some theoretical and MC models. It helps reveal the substructures on the event-by-event basis at various scales and is more powerful than the traditional Fourier analysis. One hopes to provide the classification scheme when using this method and to find out events with special patterns (jets, minijets, DCC, ring-like events, azimuthal flows, screwiness, sling effects etc). It is especially important in search for limitations of theory and of simulation tools.

5 Special final states and interaction mechanisms

The spectroscopy of the final state particles was among the main topics a decade ago. Nowadays the PDG tables are filled so densely that main interests shifted to mechanisms of particle production. There were several experimental (Shephard, Kirk, Walker, Sandor, Tsereruya, Masera, Chliapnikov, Bohrer, Giokaris) and theoretical (Calucci, Draggiotis, Wong, Musulmanbekov, Treleani, Diakonos, Xie Qu-bing) talks where these problems were touched (some-
times in combination with topics discussed above). Without describing them in more detail, I will briefly mention these problems just to show their variety and refer to original talks for more details. Spectroscopy interests move now to exotic mesons, glueball searches, Higgs, sparticles or to the partial wave analysis e.g. looking for exotic quantum numbers $J^{PC} = 1^{--}$ signals in such final states as $\eta \pi^0$, $\eta \pi^-$, $\rho \pi^-$, $\varphi \pi^-$ etc (Shephard). In nucleus-nucleus interactions, the most hot discussions are about the existence of the quark-gluon plasma. In this direction, the search for strangeness enhancement, strangelets, $J/\psi$ suppression, dileptons, DCC, color rearrangement, jets propagation in nuclei, rescattering, direct photons and many other effects is going on. Production rates of $d$ and $\bar{d}$ are essential also for comparison with their ratio in our Galaxy (Walker). In $e^+ e^-$-collisions, there were reported at this Symposium results on inclusive production at $Z^0$, on high masses and high-$p_T$ events with special emphasis on jet properties, on some exotic channels with extremely low cross sections like $e^+ e^- \rightarrow Z^0 Z^0 \rightarrow b \bar{b} c \bar{c}$ etc. Some new models of the hadron structure with relationship between constituent and current quarks, of hadroproduction with an ambitious program of computation of multiparticle amplitudes in the framework of the effective action approach and the generating function technique, and of a Hamiltonian model for such processes have been reported as well but they are at the very initial stage and can attract the attention only after their internal problems are solved and the successful application to experiment done what has not been attempted until now.

6 Cosmic rays and forward detectors

The review talks on cosmic ray physics (Schmitz, Stanev, Jones, Lindner, Fonseca, Lorenz) were of interest especially in connection with new physics results and RHIC and LHC coming to operation. Surely, the recent discovery at SuperKamiokande of neutrino oscillations and neutrino masses attracted much attention.

Concerning the multiparticle dynamics, it has been stressed again that the energy region covered by cosmic ray studies ranges from $10^{11}$ to $10^{20}$ eV in the lab. system, and accelerators actively enter this field with Tevatron at $2 \cdot 10^{15}$eV and LHC at $10^{17}$eV. The cosmic ray fluxes at these energies are very low already. However, there is the substantial difference in the regions of the phase space studied in CR and at accelerators. The fragmentation region with main energy flux and relatively small number of secondary particles is investigated in CR installations while LHC detectors will see mostly the pionization region with many comparatively slow particles (90% of the energy flux will be outside the ATLAS detector!). Leading particle properties carry parton information
and could provide better discriminants than structure functions. Probably, BFKL effects are enhanced there.

New facilities for future CR experiments have been described. They include huge installations covering several thousands of squared kilometers!

Many facts from CR observations which have not been seen at accelerators attract the attention of particle physicists:

1. A knee of the CR spectrum at energies about $10^{15} - 10^{16}$ eV can be of interest if it is due to big changes in the nature of generic particle interactions at that energy as it is speculated sometimes. It is more trivial if it happens due to the change of the CR flux composition.

2. Centauros are exotic events with many charged hadrons created and no (or small number) gammas from neutral pion decays. Respectively, antiCentauros contain many gamma-rays and no (or small number) charged particles. Recent idea of the disoriented chiral condensate with the anomalous distribution of $\pi^0$ compared with $\pi^\pm$ of the type $P(f) \propto f^{-1/2}$, $f = n_0/n_{tot}$ favors Centauros. However, more simple explanations with isospin conservation in coherent or squeezed states would do the same job. Recent results of CR Brazilian group again show that 20-30% of DCC is needed. However, CDF results show that $\sigma_{\text{Cent}} \leq 10 \mu b$ (within $1.3 < |\eta| \leq 4.1$), and T864 (MiniMax) experiment claims that there is no Centauro signal at few per-cent level albeit in the central pseudorapidity region as well.

3. MiniCentauros - no signature in accelerator experiments yet.

4. Chirons are miniclusters with very small relative $p_T$. Are these fluctuations in core distributions of the dynamical origin?

5. Heavy flavors. JACEE collaboration has studied in detail 15 events from the low-multiplicity part of MD with less than 50 secondaries at the primary energy higher than 1 TeV per nucleon. 64 secondary vertices consistent with $b$ or $c$ decays have been found. Can one explain this peculiarity of the low-multiplicity events? Is it due to the energy increase of the heavy flavor production cross section?

6. Long-flying cascades (Tien-Shan experiment) at $E > 10^{14}$ eV penetrate deeply in the installation. They could be explained if the cross section of charm hadroproduction increases with energy and becomes about 1.5 mb at $10^{14}$ eV. I reported about it 12 years ago at the similar Symposium. Also, strangelets have been considered as a possible explanation.

7. Aligned events (Pamir experiment) are characterized by the non-uniform distribution of the high-energy secondaries and cores in the emulsion chamber so that they tend to be placed along straight lines. There were 6 multicore events observed. The attempts to explain them by a string decay result in estimates which are twice below their production rate.
8. **Inelasticity** i.e. the share of energy going to secondary non-leading particles $K = \langle 1 - \frac{E'}{E_0} \rangle$ decreases with energy increasing as favored by CR data but disfavored by most models.

9. **Violation of Feynman scaling** in the fragmentation region is claimed according to analysis of CR data. The common problem for CR calculations is the uncertainties with recalculation of $pp$ to $pA$ and $AA$ processes and with mass composition of primary CR radiation.

Thus we have many CR facts in the fragmentation region of multiparticle production which apart Pomeron diffractive processes urgently ask for doing the forward physics at accelerators. Some forward detectors are built at RHIC. Unfortunately, most operating and almost all planned detectors are not aimed at these problems. Nevertheless there are some proposals of detectors which cover the forward region (only the last one in this list was described here but I mention also some others and the physicists dealing with these proposals):

1. FELIX detector (Bjorken et al) has not been approved yet.
2. CDF proposal for forward detector (Goulianos) also has not been approved until now.
3. Emulsion chambers with any target (Kotelnikov) can be easily installed and operated as fixed target (lower energies!) experiments in an extracted beam (Tevatron, HERA, LHC?). Usual problem with low statistics can be soon overcome with the help of automatic tables for emulsion processing installed.
4. CASTOR detector (as a forward detector of ALICE at LHC) has been described (Bartke) at this Symposium. Operating at LHC with the pseudo-rapidity coverage $5.6 \leq \eta \leq 7.2$ it would check the CR results on Centauros, long-flying component and strangelets, in particular.

However, this detector has been only partly approved and it will start operating at LHC not earlier than in 2005 while some above proposals can be put forward quite soon, in principle, albeit at lower energies. We hope that physics community will get financial resources for these proposals to be at work in the nearest future and we will learn many more interesting facts about multiparticle dynamics at next meetings.

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