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PROGRESS REPORT AND RENEWAL OF GRANT DE-FG02-85ER40213

"Theory and Phenomenology of Strong and Weak Interaction High Energy Physics"

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by the

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PROJECT DESCRIPTION

This proposal requests continuing support for the theoretical high energy physics group at the University of Arizona, under Grant DE–FG02–85ER40213. The group consists of Professors Robert L. Thews, Michael D. Scadron, Adrian Patrascioiu, and Peter Carruthers, Associate Professors Doug Toussaint and Anna Hasenfratz, Assistant Professor Ina Sarcevic, postdocs Aleksandar Kocic and Raj Gandhi, and graduate students Erwin Sucipto, Bill Ryan, J. K. Kim, Robert Karlsen, and Nitesh Shah.

Plans for expansion in High Energy Physics have reached a temporary plateau, while we attempt to bring our external funding up to a level commensurate with our activities. We have just completed our first academic year with the full complement of seven faculty and two postdocs in residence. Our recent departmental recruiting activities have allowed us to bring many short– and long–term visitors to Tucson at little or no expense to the grant. During the past year our visitors included J. Stern (CERN), G. Clement (Paris), Yu. Petrov (Leningrad), E. Seiler (Munich), S. Gottlieb (Indiana), H. Satz (CERN), H. Elze (Frankfurt), and G. Karl (Guelph). The supply of high–quality students has increased dramatically since a few years ago, due in no small measure to our grant from the Department of Education for fellowships to support entering students. One of these students, Mr. Nitesh Shah, has joined our research group to work in lattice gauge theory. We benefit from the fellowship program in this case, since only summer support needs to be provided from the grant. Our group is also benefiting by interactions with other university–supported activities, including research in condensed matter theory and applied mathematics through the Center for the Study of Complex Systems, which was initiated two years ago under the guidance of Prof. Carruthers.

Our highest priority for the upcoming year is to reach a level of external funding which will allow continuing support for our existing faculty, postdocs, and students. We have been operating at a higher level of activity than our current support would normally allow, because of special circumstances in administrative and faculty startup funds available to us on a temporary basis. For example, this grant only provided nine person–months of faculty summer salary for our seven faculty members last year. All of the continuing graduate students had one–half of their support derived from departmental teaching assistantships. Our budget request reflects the actual cost of the research group activities for a one–year period, and we must approach this level of support before any additions can be considered.

PROGRESS REPORT AND PROPOSED RESEARCH

Prof. M. D. Scadron: So far in 1990 Scadron has published six papers. With A. Bramon he showed that if SU(3) breaking is taken into account in the low energy sector via the strange to nonstrange constituent quark mass ratio approximately 1.5, then the $\eta - \eta'$ pseudoscalar (P) mixing angle is -14 ± 2 degrees. This is based on all available data for tensor (T) decays $T \rightarrow PP$, vector (V) decays $V \rightarrow P\gamma$, and even pseudoscalar decays $P \rightarrow \gamma\gamma$. The second paper, published with V. Miransky, concerns dynamical symmetry breaking and the scalar sigma (σ) mass. Miransky's ultraviolet fixed–point ideas were extended down to the high end of the nonperturbative region where m_σ is about twice the quark mass. The latter σ mass also follows from Nambu–Jona–Lasinio (NJL). Scadron and his student T. Hakioglu showed how the linear σ model in one–loop order also leads to the NJL result as well as recovering the Nambu–Goldstone pion in the chiral limit. Scadron lectured on the latter topic at the Protvino meeting in the USSR (July 9–13) and at the International High Energy Conference at Singapore (Aug 2–8).

Along with S. A. Coon, Scadron's last strong interaction paper reviewed the πNN form factors and the Goldberger–Treiman (GT) discrepancy in and away from the CL. Away from the CL they recovered the presently measured 5% GT discrepancy. But in the CL this discrepancy vanishes as it should.

Scadron's remaining activity so far in 1990 is on nonleptonic weak decays. His fifth published paper in 1990 is on the kaon $\Delta I = 1/2$ rule (with V. Elias and R. Mendel) and the effect of the quark condensate. In his sixth paper (with Elias and McKeon), operator regularization is used to renormalize the s–d transition so that the latter is not rotated away and still explains the kaon $\Delta I = 1/2$ rule. With his student, R. Karlsen, Scadron is also mapping out nonleptonic meson decays $K \rightarrow \pi\pi$, $D \rightarrow \overline{K}\pi$, $D \rightarrow \overline{K}K$, $\pi\pi$ and D_s and B decays. Also Scadron and Karlsen are working on the baryon decays $B \to B'\pi$, decouplet D $\to B\pi$ decays, radiative $B \to B'\pi$, $B \to B'\gamma$ decays and on charmed baryon decays.

Prof. R. L. Thews: This research program is concerned with various areas of phenomenological studies, covering aspects of quark–gluon models for hadronic interactions, decays, and structure. Much of the recent work has focused on applications to novel effects in relativistic heavy–ion collisions, driven by new experimental results from the CERN program and prospects for the RHIC collider. Work with graduate student Erwin Sucipto on radiative decays $V \to P\gamma$ has led to the realization of new constraints on mixing angles between quark flavors imposed by factorization in gluon annihilation channels (16). At present we are reexamining the implications of new experimental data, both for the original reactions considered and also for the baryon magnetic moments which place constraints on anomalous components of quark moments. Our overall conclusions are converging toward the viewpoint that some component of the radiative decay mechanism must be sensitive to nonperturbative effects which modify in an essential way the simple picture of single–quark transition amplitudes. The long–range collaborative program with Prof. J. Cleymans of Capetown is continuing. Our initial description of nucleon structure functions as a gas of quarks and gluons has attracted some interest in circles concerned with structure function of nuclei. An application to nuclei and the EMC effect, initially presented at the Kyoto PANIC conference, awaits further development as a possible student dissertation topic. Mr. Sucipto is making progress on possible effects of background gluon distribution in hadrons on structure function evolution equations which depend on gluon radiation processes. This work may have substantial impact on predictions for cross sections in the SSC energy range. The most recent work is on understanding of the observed J/ψ suppression for events with large transverse energy in the CERN heavy ion collision experiments (NA38). We have noted that a correct quantum–mechanical description of the quark–antiquark evolution in time involves calculation of the overlap of wave functions with large relativistic components. This modifies in an essential way the kinematic dependence of the observed suppression. Present work is concerned with combining this effect with the finite spatial plasma boundary to get an overall picture of the crucial parameters. Graduate student William Ryan is preparing a numerical calculational scheme which can be used to simulate the charmonium case with realistic potentials and geometry. It is anticipated that this will lead to a dissertation topic in the area of QCD–based calculations in a background of dense nuclear matter. This may also have some impact on alternative explanations based on absorption in dense hadron matter which have been proposed recently. Prof. Thews presented the latest results of this work at the Quark Matter meeting in Menton in May, and the QCD90 meeting in Montpellier in July. He also presented a series of lectures in Capetown in January at a meeting on the phase structure of strongly interacting matter. Continuing studies of spin structure of dilepton formation in collider experiments is being driven by new experimental data from CERN and Fermilab. A possible application will be the extraction of the polarized gluon content of the proton, predicted to be large by some models which try to explain the anomalous EMC data on polarized structure functions.

Prof. Adrian Patrascioiu: A multi–year program is continuing which studies certain properties of some of the most fundamental models employed by condensed matter and high energy physicists. The models range from Heisenberg ferromagnets, to Coulomb gases and Yang–Mills gauge theories. The questions asked pertain to the true role of perturbation theory in such models, to their phase diagrams and to the possible continuum limits which could be constructed. In particular in a series of papers, Patrascioiu pointed out that there are good reasons to suspect that the use of perturbation theory in such models can lead to false conclusions, such as the existence of the celebrated asymptotic freedom in QCD4. With regard to the phase structure of such models, Patrascioiu argued that probably there is no difference between the abelian and the nonabelian models, contrary to common beliefs based on the so called topological order, which exists in the abelian models at small coupling but not in the nonabelian ones. His heuristic ideas were based on energy–entropy estimates of the type Peierls used to prove the existence of long range order in the Ising model at low temperatures. These ideas were further developed in collaboration with Drs.E.Seiler and I.O.Stamatescu and investigated numerically in a variety of models. In every instance, numerical evidence was found indicative of the existence of a phase transition precisely in the region suggested by the energy–entropy balance. In particular it was concluded that contrary to everybody else's claims, there is a deconfining transition in QCD_4 at zero temperature.

During the last year, this research program has progressed in three major ways:

1) Improved Monte Carlo updating: A major limitation of numerical studies was due to the occurrence of critical slowing down in locally updating algorithms. This limited the numerics to correlation length no larger than 20 lattice units. Two years ago Patrascioiu proposed a new type of updating which employs the Fortuin–Kasteleyn representation of the Ising model as a percolation process (a similar procedure was developed by U. Wolff). With this nonlocal updating critical slowing down is restricted and correlation lengths of 100 lattice units become easily accessible to the numerics. This idea was applied with great success to investigate a variety of models such as the O(2),O(3),Z(N) and dodecahedron spin models in two dimensions. The data strengthened the evidence that, contrary to common beliefs, the O(3) (nonabelian) model does possess a massless phase at weak coupling and is not asymptotically free. A major challenge for those calculating numerical studies is to extend this type of nonlocal updating to gauge theories. Several attempts have been pursued but so far a successful solution has not been found.

2) Proof for the existence of a massless phase in the dodecahedron spin model: It has been

quite common to assume that one can replace the the O(N) spin model by one of its discrete subgroups and if the latter is sufficiently large, it should exhibit the same phase structure at sufficiently large beta. For O(3), the largest discrete subgroup is the icosahedral Y with 60 elements. It is the invariance group of the dodecahedron, the largest regular polyhedron embedded in S2. In collaboration with Drs.J.–L.Richard and E.Seiler, Patrascioiu derived a rigorous inequality relating the dodecahedron spin model to the Z(10) one. As the latter is known to possess an intermediate massless phase, the inequality suggested a similar property for the dodecahedron. This fact was established numerically, employing the new type of Monte Carlo updating described above. It shows that a nonabelian spin model in two dimensions can exhibit algebraic decay of its correlations.

3) Proof of the existence of a massless phase in O(N) models in 2D: The Fortuin–Kasteleyn transformation used for implementing nonlocal Monte Carlo updating can also be used for analytic work. In collaboration with Dr.E.Seiler, Patrascioiu has completed the backbone of a rigorous proof for the existence of a massless phase in all O(N) models at weak coupling. The main tool used is a mapping of the original spin model into a percolation model about which much more is known. This novel approach to this 20–year old problem was described in a paper written in collaboration with Dr. E. Seiler, submitted for publication in the Physical Review Letters. Many of the details necessary to complete a rigorous proof have been worked out. A numerical verification of some of the steps has been performed and reported.

Future plans: Patrascioiu will attempt to complete a rigorous proof that all O(N) nonlinear σ–models in 2D possess a massless phase at sufficiently weak coupling. Discussions with many physicists during the summer have convinced him that the more important issue concerns the implications of this result for gauge theories. It appears almost certain now that the string tension in quarkless QCD_4 is zero, while instead of being asymptotically free, the theory has a vanishing Callen–Symanzik β–function. The phenomenological implications of this unexpected conclusion will be analyzed.

Prof. Peter Carruthers: Multiplicity Moments and the Intermittency Phenomenon:

In the past few years there has been great interest in the behavior of multiplicity moments as the resolution of phase space binning is changed. Typically one investigates the dependence of the bin averaged factorial moments as a function of the rapidity bin size Δy. Our recent work has sharpened and clarified our discovery last year that the existing data can be quantitatively explained by systematic removal of background correlations and a suggestive ansatz, the linked pair approximation (LPA) whereby the higher cumulant moments are expressed in terms of the two particle correlation function. That is, given the two particle correlation function, the moment data are explained by this simple framework without the need for new physical concepts. It is of interest that the only adjustable constants in this analysis turn out to agree with global negative binomial multiplicity distributions. The usual bin averaged factorial moments are given by integrals over suitable domains in rapidity space of the density correlation functions. These correlations include many background contributions, which can be exposed by expanding in terms of cumulant correlations. By using "vertical averaging" i.e. normalizing each bin to the average bin multiplicity we derived a set of exact moment formulas which allow a very simple analysis of data without any assumption about translation invariance of the correlation functions. Given the experimental second moment F2, we can evaluate the third cumulant moment K3, and test the LPA. Then the experimental moment F3 allows the evaluation of the fourth cumulant K4, etc. This technique has been applied with great success to NA22, UA1, UA5, NA9 and other data. At energies such as NA22 and NA9 the moments are totally dominated by "trivial" contributions of the second moment, taken from experiment. The higher cumulant correlations only comprise a few per cent of the total. However at collider energy F2 is larger, allowing one to test the LPA more precisely.

Some key conclusions are:

1. The higher cumulant moments are well described by the LPA.

2. The fitted constants of the LPA are close to those giving negative binomials, although in some cases the fifth moment experimental coefficient is smaller than NBD

3. All moments and correlation functions saturate rather than scale. It is very difficult to get good fits to power law behavior except over very small intervals.

4. If the moments were to scale, the LPA implies a homogeneous fractal for the rapidity distribution.

Several other results of these investigations are being written up at present. These include:

1. Charge dependent effects in the moment analysis. We have been working closely with the NA22 and NA9 groups on these issues.

2. Power Spectrum of the Rapidity Histograms. This tool has promise for another approach to correlations.

3. Generalized Information Correlations.

4. Rapidity gap and spike analysis, including the prediction of their correlations.

5. Bin–bin correlations involving separated rapidity bins.

6. The close analogy to galaxy and galaxy cluster distributions is quite remarkable, which fact suggests a new research direction.

7. We have shown how to decompose the cumulants in terms of "short range" correlation cumulants of fixed multiplicity and fluctuations of the single particle density from the average background. For large multiplicity we show that this correlation is dominated by cumulant moments of the single particle density fluctuation. From this point of view the moment behavior becomes still more trivial.

The basic conclusion is that the claims made for the existence of new physical phenomena in hadronic multiparticle production do not bear up under close examination. In addition a simple structure for the higher correlations has been shown to be plausible.

Prof. Doug Toussaint: My largest research project in the past ten months has been participation in one of the DOE's "grand challenge" computing projects, devoted to extending Monte Carlo studies of QCD including the effects of dynamical quarks. In this simulation we have carried out the largest simulation of full QCD to date, one which would be state of the art even for quenched calculations. We studied 12^3 times N_t lattices with two flavors of Kogut–Susskind dynamical quarks will masses of $0.025a^{-1}$ and $0.01a^{-1}$, with $N_t = 12$ and 24. We tested for systematic effects from doubling the lattice and from the accuracy of the iterative method used to compute the quark Green functions. We also studied at 16^4 lattice to explore the effects of the finite lattice size. The high statistics allowed us to observe effects of the lattice size, especially on the nucleon mass, and unexpected structure in the pion propagator which is a possible artifact of the standard technique of replicating lattices before making propagator measurements. The results of this study have been submitted to Physical Review Letters and Physical Review D.

This project continues with simulations of a 16^3 times 32 lattice on the connection machine at SCRI. In this case doubling the lattice for propagator measurements will be unnecessary. These simulations of full QCD are now reaching the point where it becomes interesting to study more complex quantities than just the masses, such as weak interaction matrix elements or hadronic coupling constants. We also intend to study QCD with dynamical Wilson quarks. This is somewhat more difficult than QCD with Kogut–Susskind quarks, partly because more computer time and memory are required and partly because there is no exact chiral symmetry so the bare quark mass must be fine tuned to reach the chiral limit. However, agreement of results with the two regularizations of lattice fermions is an important test of the lattice results.

Together with Claude Bernard, Tom DeGrand, Carleton Detar, Steve Gottlieb, Julius Kuti and Bob Sugar, I am involved in a project to carry out numerical studies of field theories such as QCD on large parallel processing machines to be installed at the San Diego Supercomputer Center. The first such machines will be a 32 processor Intel machine and a 64 processor NCube machine. We estimate that this Intel machine will achieve a sustained performance of better than 600 Megaflops on our problems. Plans call for a 256 node NCube machine to be installed later this year, and eventual upgrades of the Intel machine to as many as 2048 processors. Programming these machines requires significant effort, and code development is underway. A first version of a QCD simulation code is already running on a simulator and on a development machine at the Intel office in Oregon. Program development for these machines raises several challenging issues in itself. For example, it is by no means obvious how to divide up the computation among multiple processors, and quite likely that the methods that work for lattice gauge theory will be useful in other computational problems.

Together with Anna Hasenfratz I am continuing studies of QCD at finite density. This is a much harder problem than the conventional QCD simulations since at finite density the quark factor in the integrand of the partition function becomes complex and can no longer be used as a probability weight for generating configurations. Our current project uses a probability weight which can be thought of as the fermionic determinant for four flavors of staggered quark, except that this weight is averaged over the three possible Z3 orientations of the quarks. We then reconstruct the behavior at finite density from the eigenvalues of the fermion "propagator matrix" on these configurations. It seems possible that this method may produce convincing results on a 4^4 lattice, which represents real progress on this difficult problem.

Prof. Ina Sarcevic:

1. The Hadronic Structure of the Photon: Recent cosmic–ray data [M. Samonski and W. Stamm, Ap. J. L17, 268 (1983); B. L. Dingus, et. al. Phys. Rev. Lett. **61**, 1906 (1988); Sinha et al., Tata Institute preprint, OG 4.6–23; T. C. Weekes, Phys. Rev. Lett. 61, 275 (1989), and reference therein] showing muon excesses in air showers generated by neutral, stable particles from point sources (e.g. Cyg X–3, Her X–1, Crab Nebula) hint at new physics at high energies, presently inaccessible with existing colliders. The only candidate for such particle in the Standard Model are photons. However, conventionally, a photon–initiated shower is electromagnetic and, therefore muon–poor. The number of muons produced in an electromagnetic cascade is more than an order–of–magnitude smaller than in a hadronic shower. Only if there is a threshold effect for photoproduction at very high energies, the conventional expectations for the muon yield in photon–initiated shower would be altered. (The number of produced muons is proportional to the ratio of the photonuclear cross section and the pair–production cross section, which is 500 mb in the air.) Since at high energies the photon can interact hadronically by producing virtual quark–antiquark pairs and bremsstrahlung gluons which can interact with atmospheric nuclei, we have calculated these unconventional photon–air cross sections using the leading–order perturbative calculation and the eikonal methods to include the non–perturbative part as well as to preserve unitarity. We find that the cross sections are of the order of magnitude large than the ones previously used in the shower calculations for the observed muons [R. Gandhi, I. Sarcevic, A. Burrows, R. Durand and Q. Pi, Phys. Rev. **D42**, 263 (1990); I. Sarcevic, University of Arizona preprint AZPH–TH/90–15, talk presented at the Annual Meeting of the Division of Particles and Fields of the American Physical Society (DPF '90), Houston, Texas, January 3–6, 1990.]. We have studied the implications of the intrinsic theoretical uncertainties (such as parton structure functions at low x and p_T^{min} to the number of muons produced. By analyzing available low–energy data we have minimized the uncertainty in p_T^{min}. However, we find that the

photonuclear cross section is very sensitive to the choice of the photon structure function at low x. For example, at ultra–high energies, the cross section obtained using Duke and Owens photon structure function is 600 mb, while using Drees and Grassie structure function it is 90 mb. The later one is probably too conservative, since the procedure employed to obtain these photon structure functions, if used to obtain the gluon structure function of the proton, considerably underestimates it. Even with this theoretical uncertainty we emphasize that the hadronic structure of the photon dramatically changes the conventional picture of photon–air interactions in the UHE regime. The standard γ–air cross section is $\approx$ 1.5 mb, and is expected to be roughly constant (or logarithmically rising) with energy. The cross sections we obtained increase much more with energy and are much larger than the old standard calculation. For instance, our most conservative estimates lead to a value $\approx$ 20 mb at lab energies of 10^6 GeV. To obtain a better idea of the difference this makes to cosmic–ray experiments, we have applied them to the case of a UHE photon impinging on the atmosphere. The probability that the photon's first interaction in air is a strong, QCD interaction and, hence, that the photon acts hadronically from the start is given by the ratio, $\sigma_T/(\sigma_T + \sigma_p)$. Our γ–air cross sections imply that at the highest energies of this study ($E_{lab} \approx 10^8$ GeV), the photon can be quite hadronic ($\approx$ 50%). In order to get quantitative results for the number of muons produced in the air–shower, we plan to do full Monte Carlo analysis.

We are also presently studying the direct photon production in pbar–p collision at Tevatron energies in the context of the anomalous hadronic character of the photon. The most recent results from the CDF Collaboration indicate discrepancy between the data on inclusive photon cross section and the QCD results in the low p_T region. This could be due to the hadronic character of the photon, which gives significant contribution to the inclusive cross section in this region. We also plan to investigate the photoproduction at HERA, since in this energy range the photon structure function can be determined at low values of x, which would substantially reduce our theoretical uncertainty in the ultra–high energy photonuclear cross section, of relevance to on–going cosmic–ray experiments.

2. Multiplicities and Minijets at the Tevatron:

Recent UA5 and UA1 results on hadronic multiplicities and minijet production in pbar–p collisions at CERN Collider energies have revived the interest in strong interaction physics. We have considered the origin of the observed KNO scaling violation of the multiplicity distribution in the parton branching model. We have shown that the widening of the distribution is due to the increase of the gluon contribution to the hadronic multiplicities. We have given theoretical predictions for the multiplicities and moments at the Tevatron energies [I. Sarcevic, Nucl. Phys. **B12** (1990) 345c]. We have also shown that QCD minijet cross section with p_T^{min} of order 3 GeV and K factor of order 2 gives very good description of the minijet data. We have extrapolated our theoretical predictions to Tevatron energies indicating that measurements of the minijet production at these energies will have some resolving power to distinguish between different sets of structure functions.

We have recently extended the analysis of the inclusive differential jet cross section to the Tevatron energies. The CDF Collaboration has measured the differential jet cross section up to E_T=400 GeV, which has allowed us to compare our theoretical predictions over several orders of magnitude. We have found that the data excludes some choices of the structure function and requires K factor to be E_T dependent [P. Aurenche et. al., Ina Sarcevic, Proceedings of the Workshop on Physics at Fermilab in the 1990's, eds. D. Green and H. Lubatti (World Scientific, Singapore, 1990), pg. 212–224]. With increased statistics at higher E_T (higher luminosity) and better understanding of the CDF and D0 detector response these important QCD tests will become more and more quantitative. Any search of the exotic physics (such as top, Higgs or supersymmetric particles) will depend strongly on this QCD background, especially at SSC energies.

3. Intermittency Phenomenon in High Energy Hadronic and Nuclear Collisions

In the last few years several experimental groups have observed unusually large number of hadrons produced in a very small rapidity region in hadronic, leptonic and nuclear collisions. The measured multiplicity moments $F_i(\delta y)$, defined as $F_i = 1/M \sum_1^M \langle n_m(n_m-1)\ldots(n_m-i+1)\rangle/\langle n_m\rangle^i$, where M is the number of rapidity bins ($\delta y = Y/M$), seem to exhibit intermittent behavior, i.e. the power–law behavior as a function of the size of the rapidity bin δy ($F_i \approx (\delta y)^{-\nu}$). This behavior was found to be incompatible with the predictions of many classical hadronization models embedded in the existing Monte Carlo models (such as LUND, HERWIG, JETSET etc.). We have shown that the increase of these moments with decreasing δy is due to the hadronic short–range correlations [P. Carruthers and I. Sarcevic, Phys. Rev. Lett. **63**, 1508 (1989); I. Sarcevic, University of Arizona preprint AZPH–TH/90–21, talk presented at the 25th Rencontres de Moriond, High Energy Hadronic Interactions, Les Arcs, France, March 11–17, 1990, to be published in the Proceedings; I. Sarcevic, talk presented at International Workshop on Intermittency in High Energy Collisions}, March 18–21, Santa Fe, New Mexico, to be published in the Proceedings]. With experimental knowledge of two–particle correlations and the linked–pair ansatz for the higher–order correlations, we find excellent agreement with NA22 and UA5 data on moments $F_i(\delta y)$. [I. Sarcevic, University of Arizona preprint AZPH–TH/90–42, talk presented at Quark Matter '90 Conference, Menton, France, May 7–11, 1990, to be published in the Proceedings]. Recently, we have done detailed analysis of the intermittency effect in nuclear collisions. We have found that the saturation of the multiplicity moments in the small δy region is compatible with the measured two–particle correlation and the linked–pair structure for the higher order correlations [P. Carruthers, H. Eggers, Q. Gao and I. Sarcevic, University of Arizona preprint AZPH–TH/90–9, to appear in Int. Journal of Mod. Phys. A]. Furthermore, we have studied the possibility to have signal for intermittency or self–similar structure for large δy, which is outside the usual resonance formation region ($\delta y \geq 1$–2). Clearly, at very high energies the phase space available for particle production becomes large enough so the self–similar cascade with many branches develop as a new pattern of multiparticle production. We have constructed a simple 1–dim self–similar cascade model in which collision takes place in several steps. First, heavy mass "particle" is created, which then decays into smaller particles and so on until it reached the mass of the resonance ($M_{\pi\pi} \approx 0.5$ GeV, $\delta y_0 \approx 1$–2). This leads to a universal powe –law behavior for the multiplicity moments as a function of relative rapidity $Y/\delta y$ [I. Sarcevic and H. Satz, Phys. Lett. **B233** (1989) 251, I. Sarcevic, University of Arizona preprint AZPH–TH/90–45, invited talk presented at International Workshop on Correlations and Multiparticle Production (CAMP), Marburg, Germany, May 14–16, 1990, to be published in the Proceedings.]. The deviation from the power–law (flattening of the moments) begins at $\delta y_0 \approx 1$–2, when the resonances are formed. We find that all UA5 data for $\sqrt{s}$ = 200, 546 and 900 GeV agree very well with the predicted universal behavior. We predict that at Tevatron energies the multiplicity moments will follow the same universal power–law behavior as the UA5 data. However, since the available phase space will become larger, the self–similar cascade will have more branches (it will be "longer") and the Tevatron data will flatten out at somewhat larger value of ln ($Y/\delta y$) than the UA5 data. We are presently working on developing more realistic three–dimensional QCD type cascade which will give us predictions for the three–dimensional multiplicity moments as a function of the momentum. This will give us better understanding of the dynamical mechanism for the multiparticle production as well as the effect of the hadronization process on the shape of the multiplicity distributions.

Prof. Anna Hasenfratz: In the last few months I continued my research on the non–perturbative understanding of the Weinberg Salam model,the study of first order phase transitions and started a new project on finite density QCD studies.

In the study of the scalar sector of the standard model and the upper bound of the Higgs particle, we completed a calculation, where using the theory of chiral perturbation theory we extrapolated the value of the vacuum condensate obtained on finite lattices to infinite volume in a theoretically well controlled way.

Within the fermionic sector one of the most important problems is the understanding of chiral fermions on the lattice. Using the non–perturbative properties of the strongly coupled Yukawa systems there is a newly developed formulation to overcome the lattice fermion doubling problem. Using Wilson fermions in the strongly coupled ferromagnetic phase, the fermion masses increase as the scalars approach the continuum limit, the fermions decouple. If one can arrange that only the unwanted doublers decouple while one species remains light, one obtains a dynamical way of fermion decoupling. Previous attempts in this direction found that although the doublers probably decouple, in the resulting low energy model the light fermion behaves differently than predicted by the perturbative Weinberg–Salam model. I suggest using two different scalar fields to overcome this problem. Preliminary simulations in a U(1) symmetric model show the desired structure for the fermions, though full dynamical simulation is needed to verify that all the unwanted fields decouple without influencing the renormalized theory.

The "Top quark standard model" developed by Nambu, Miranski and Bardeen at al is a promising explanation for the chiral structure of the standard model. Additionally it predicts the top and Higgs masses as well. The present calculations however use perturbative formulae in the strongly coupled region therefore they validity is questionable. To obtain a reliable physical picture and predictions for the masses it is possible to do a lattice simulation. An SU(2) gauge–Higgs–fermion model should be sufficient to study what type of non–perturbative behavior remains in the full model, and this system can be investigated with present day resources.

A different topic I am working on is the understanding of first order phase transitions.

Recent MCRG works suggest scaling with critical exponent $\nu=1/d$ at different first order transitions. There are two "pseudo"–critical points, one in each metastable phases associated with this critical behavior. In a collaboration with a former student we are finishing a numerical study of temperature driven first order phase transition where, by studying the spectral density in fully thermalized MC simulations, we try to understand this phenomena independently of the renormalization group approach. In a collaboration with D. Toussaint and D. Stein we are working on the theoretical aspects of the problem. Finite density QCD calculations are very important for heavy ion experiments. However, the addition of chemical potential to the standard lattice action QCD results in a complex fermionic action making numerical simulations much more difficult. With D. Toussaint we worked out an alternative way to simulate the systems. Our preliminary calculations on small, 4^4 lattices are encouraging, but more work is needed to clarify the merit of the method and obtain physically meaningful results.

Dr. Raj. Gandhi: Recently I have worked on the problem of the observed excess muon content of cosmic ray showers from point sources (with A. Burrows, L. Durand, P. Hong and I. Sarcevic PR **D42**, 263, 1990). Although the experimental evidence for a 'hadron–like' muon content of what could only be (within the context of known physics) photon showers is not yet absolutely compelling, it has grown more convincing with the recent simultaneous observation of a muon rich high energy burst from the Crab at both Baksan and KGF. Before one concludes the onset of new physics, it is important to re–examine the assumptions that go into the production and development of air showers. Halzen and collaborators have pointed out the possibility of photons mimicking hadron–like behavior at high energies due to quark pair production and subsequent gluon bremsstrahlung. We have completed a detailed analysis of the consequences of this suggestion. Several sources of uncertainty were inherent to the problem, and their importance to the final answer was determined. The photon structure function (and to a lesser extent the hadron structure function) is highly uncertain at the low values of x (the parton fractional momentum) relevant to the problem, i.e., $x \approx 10^{-4}$. Moreover it is not known if the 'soft' or non–perturbative part of the total cross–section grows with energy in a way that would appreciably affect the final muon content. Closely related to this is the P_t^{min} cut used to calculate the jet cross–section, to which the result is highly sensitive. Although the muon problem needs to be explained at relatively low center of mass energies, ≈ 1 TeV, the jet cross–section rises very rapidly above this range and unitarity constraints need to be incorporated to examine the effects of higher energy primary photons. We did that using eikonal methods, which give good results in the proton–nucleon and proton–nucleus case. Finally, we are working on putting together a shower Monte Carlo to simulate the muon content and determine its sensitivity to the various photon and proton structure functions, the primary energy, the P_t^{min} cut and the 'soft' part of the cross–section and assumptions about its rise with energy. Many of these questions are relevant not only to cosmic ray physics but also to e–p physics at HERA.

Also recently, in collaboration with Adam Burrows, I have completed calculations which incorporate the effect of massive Dirac neutrinos in numerical models for the cooling of the neutron star associated with SN1987A (Phys. Lett B, in press). In the Weinberg–Salam standard model, minimally extended to include Dirac neutrino masses, the production of sterile (positive helicity) neutrinos via neutral–current neutrino–nucleon scattering proceeds at a rate that significantly affects the energetics of cooling. We determined the expected number of events, total energy in neutrinos and the burst duration for both Kamiokande II and Irvine–Michigan–Brookhaven detectors. Due to an increase in the cooling rate caused by sterile neutrinos, we found that for $m_{\nu_{\mu,\tau}} = \sqrt{(m^2_{\nu_\mu} + m^2_{\nu_\tau})} \geq 14$ keV, the expected neutrino burst is shortened to a duration that is incorporated the feedback effects of the cooling due to sterile neutrinos in a self–consistent manner and the mass limit obtained was found to be largely insensitive to the equation of state used.

Currently, I am working on a detailed study of expected neutrino signals at various detectors in the event of a galactic supernova burst. In collaboration with Adam Burrows, I am in the process of calculating expected number of events, duration of burst, possible detection of mu and tau type neutrinos and mass limits obtainable in Kamioka, IMB, Bonex, SNO and ICARUS detectors. In addition, with I. Sarcevic, I am actively investigating possible accelerator signals of the QCD structure of the photon at the Tevatron collider. This work is a natural extension of our investigations (described above) on the high–energy photo–nuclear cross sections.

Dr. Aleksandar Kocic: 1. Chiral symmetry breaking and \$QCD\$ vacuum: In (10) I studied the properties of the QCD vacuum and discussed the constraint chiral symmetry places on physical quantities. By studying several chiral models, I found that the restoration temperature in all cases are given by $T_c = 2f_\pi$. My arguments were based on counting rules for the light modes at finite temperature. Their presence was governed by the particular realization of the chiral symmetry and they give the major contribution to the thermodynamic averages. The pion mass was shown to obey the PCAC relation because of the particular geometry of the chiral symmetry breaking vacuum. I argued that it measures the response of the strongly interacting ground state to and electroweak perturbation.

2. Catalyzed symmetry breaking (with E. Dagotto and J. Kogut): In QED at strong couplings composite operators acquire large anomalous dimensions and enter the renormalized theory through the operator mixing. Our arguments that advocated nontriviality of QED beyond the quenched approximation were based on this fact. From the renormalization group point of view, we interpreted this effect as the nondecoupling of

the heavy modes – a maximal violation of the Appelquist – Carrazone theorem. Beyond perturbation theory, the suppression factors for the heavy mode contributions were found. At strong coupling the suppression factors are absent and the heavy modes give O(1) contribution at low energies. This, we pointed out, presents a field theoretical realization of the monopole catalyzed proton decay and is a consequence of the 1/r singularity of the collapsed wavefunction. The consequence of this result is that quantum electrodynamics acts as a microscope of unlimited resolving power for short–distance interactions, and can amplify short–range symmetry breaking effects. We illustrated this point by showing that, at strong couplings, perturbative nonrenormalizable parity–violating interaction survives the continuum limit giving rise to parity–violating mass. We suggested that this effect might have an application in grand unified theories (walking technicolor theories in particular), and could account for a variety of symmetry breaking effects in a natural way.

3. Finite size analysis and zero mass extrapolations in four–dimensional QED (with E. Dagotto and J. Kogut): We pursued the finite size analysis and zero mass extrapolations of the unquenched QED in more detail by studying the theory on larger lattices and for several values of the bare mass to test for the sensitivity to the extrapolation procedure. We found that on larger lattices the scaling window was smaller than before and that the value of the order parameter in the chiral limit was sensitive to the extrapolation procedure. However, our results show substantial deviations from the mean–field behavior supporting our previous (exploratory) studies based on simulations on the smaller lattices. Low–N systematics, we found, was quite similar to that of the quenched theory and qualitatively different from that in the large–N limit. The fits to essential singularity near the critical point were quite compelling, but we think that much more powerful computer simulations would be required in order to make this point precise. This we believe, is of the same degree of difficulty as extracting the asymptotic freedom from lattice QCD. We illustrated our claim by comparing the data for QED near the critical point with those of the SU(2) gauge theory in four dimensions.

4. QED in three dimensions with N flavors (with E. Dagotto and J. Kogut): We studied massless QED_3 with N flavors using computer simulations and Schwinger – Dyson equation. We found that there exists a critical N ($N_c \simeq 3.5$) beyond which the theory is massless; for low–N chiral symmetry is spontaneously broken. We presented physical arguments for the existence of critical N by understanding the scales of chiral symmetry breaking. In quenched theory we found that chiral symmetry breaking is triggered by the fermion's self–energy which is negative and infrared singular – a mechanism known to occur in two–dimensional QCD. Dynamical fermions cause partial screening of the long range force (from ln r to 1/r) and the 1/r attraction between electrons and positrons drives their condensation. In this way we mapped the theory onto four dimensional QED with coupling proportional to 1/N. From this analogy the critical N emerges clearly. Using the Schwinger – Dyson equations for the fermion and photon propagators we argued that the apparent agreement of simulations with the large–N results was accidental and that the real reason for this lies in the particular momentum scale at which chiral symmetry breaking occurs.

5. Spontaneous parity volitional in QED_3 (with E. Dagotto and J. Kogut): In four component theory there are two types of mass that violate either chiral symmetry or parity. It is believed that the existence of parity violating mass is of some relevance to high temperature superconductivity. Our preliminary calculations using Schwinger – Dyson equation in the quenched theory suggest that parity violating mass can be generated dynamically if the normal mass can. A more difficult problem is to include the effects of the fermion loops because the parity violating mass gives rise to an induced Chern – Simons term in the photon propagator that serves as an additional source of parity violation. (Its strength can be controlled by the number of flavors.) We want to determine how the two effects combine and under what circumstances parity can be broken spontaneously beyond the quenched approximation.

6. Collapse and spin – continuum limit of scalar theories (with E. Dagotto and J. Kogut):

although the phase transition in QED was discovered by studying chiral symmetry breaking, our understanding of the nontriviality of the theory was not based directly on this property, but rather on the large anomalous dimensions of the composite operators — a feature intimately related with the non–asymptotically free nature of the vector couplings. In (58) we argued that the similar scenario takes place in quenched scalar theories with vector couplings. For sufficiently large coupling we found that φ^6 and φ^8 become renormalizable and enter the renormalized theory through the operator mixing. The relevance of these operators alters the three important features of scalar theories: triviality of the scalar sector, symmetry breaking due to radiative corrections (Coleman – Weinberg effect) and fine tuning. We suggested that at strong couplings all three issues are resolved in an entirely different manner than in perturbation theory. It is our intention to pursue further these points by analytical techniques and computer simulations of scalar QED. In particular, it is of considerable interest to look for the critical surface in the extended parameter space (including the higher dimensional couplings) and determine the phase diagram and the nature of the continuum limit there.

6. Flavor symmetry breaking (with J. Kogut): We intend to apply the property of amplification of the short–distance symmetry–breaking effects in nonasymptotically free theories to the problem of flavor symmetry breaking. It has been known for some time that, unlike gauge theories, four–fermion models in four dimensions can exhibit spontaneous breaking of vector symmetries if the coupling is chosen appropriately. This choice of coupling favors generation of the isovector and disfavors the isoscalar (chiral symmetry breaking) mass. Because these theories are not renormalizable, their effect at low energies disappears. If a gauge theory like QED is supplemented with such a four–fermi interaction, by tuning the gauge coupling appropriately, it would be possible to amplify whatever is happening in the four–fermi sector and make it apparent at low energies. We want to study how this can happen. In particular, the two couplings should compete with each other since they favor different masses, and it is not clear whether sufficiently large

gauge coupling (necessary for amplification to occur), would tolerate any flavor breaking. Since the flavor symmetry breaking is spontaneous, it will be accompanied by the corresponding Goldstone bosons. Of special interest is their fate within a larger gauge group as used for example in walking technicolor theories. For this purpose, it is also necessary to verify that nonabelian gauge theories with many flavors behave in a similar way as QED.

RECENT PREPRINTS AND PUBLICATIONS

1. P. Carruthers, "Fractal Structures and Correlations in Hadronic Multiparticle Production," International Journal of Modern Physics **A4**, 5587 (1989).

2. P. Carruthers, "Scale Transformations, the Energy–Momentum Tensor and the Equation of State, in **The Nuclear Equation of State**, Part A, Ed. W. Greiner and H. Stocker, Plenum Press.

3. On the Power Dependence of Rapidity Bin Factorial Moments,", in the proceedings of the **24th Rencontres de Moriond**, 273 (Les Arcs, France, March 1989).

4. P. Carruthers, "Intermittency, Correlations, and Fractals", AZPH–TH/90–9, to be published in the proceedings of the International Workshop on **Intermittency in High Energy Collisions**, Santa Fe, March 1990.

6. P. Carruthers, "How To Build Hadronic Multiplicity Moments from Two–Particle Correlations, AZPH–TH/90–10, to be published in the proceedings of the **International Workshop on Correlations and Multiparticle Production**, Marburg, May 1990.

7. "Pseudoscalar $\eta - \eta'$ Mixing and SU(3) Breaking," A. Bramon and M. D. Scadron, Phys. Lett. **B234**, 346 (1990).

8. V. A. Miransky and M. D. Scadron, "Scalar Symmetry Breaking and Composite Scalar Bosons in Gauge Theories", Europhysics Lett. **11**, 307 (1990).

9. T. Hakioglu and M. D. Scadron, "Field Theory Calculations of the Pion Mass in One–Loop Order", Phys. Rev. **D42**, (1990).

10. S. A. Coon and M. D. Scadron, "πNN Coupling Form Factor and the Goldberger–Treiman Discrepancy", Phys. Rev. **C**, in press.

11. V. Elias, R. Mendel, and M. D. Scadron, "On–Shell Renormalization of the q–qbar Contribution to the $\Delta I = 1/2$ Self–Energy Transition", Phys. Rev. **D42**, in press (1990).

12. V. Elias, D.G.C. McKeon, and M. D. Scadron, "Operator Regularization and the $\Delta I = 1/2$ Rule for Kaon Weak Decays", Can. Jour. Phys., in press (1990).

13. "Particle mixing and Gluon Annihilation Constraints in Radiative Transitions", Erwin Sucipto and R. L. Thews, Arizona preprint (in preparation).

14. "Comments on J/ψ suppression and quantum mechanics", R. L. Thews, published in Proceedings of the 24th Rencontres de Moriond; New Results in Hadronic Interactions, 473, March 1989.

15. "Formation Time and the Suppression of J/ψ's in Relativistic Ion Collisions", J. Cleymans and R. L. Thews, Z. Phys. **C45**, 391 (1990).

16. "Bound State Dissociation in a Quark–Gluon Plasma", R. L. Thews, in proceedings of Quark Matter '90, Menton, France, May 1990, to be published in Nuclear Physics.

17. "Quantum Effects in Charmonium Formation and Signatures of a Quark–Gluon Plasma", R. L. Thews, in proceedings of QCD90, Montpellier, France, July 1990, to be published in Nuclear Physics.

18. "Introduction to Perturbative QCD", R. L. Thews, lectures presented at the Summer School in Theoretical Physics, "Phase Structure of Strongly Interaction Matter", January 1990.

19. A Patrascioiu, "Employing the Ising representation to implement nonlocal Monte Carlo updating", Nuovo Cimento **105B**, 91 (1990).

20. A.Patrascioiu,J.–L.Richard and E.Seiler, "Some inequalities for discrete spin models", Phys. Lett. **241**. 229 (1990).

21. A.Patrascioiu,J.–L.Richard and E.Seiler, "Existence of a massless phase in a 2D nonabelian ferromagnet", sbmt. Phys.Rev.Lett.

22. A. Patrascioiu and E. Seiler, "Failure of Perturbation Theory in Non–Abelian Models", sbmt. Phys. Rev. Lett.

23. A. Patrascioiu and E. Seiler, "Critical Behavior in a Model of Correlated Percolation", sbmt. to Jour. Stat. Phys.

24. I Sarcevic, "Multiplicities and Minijets at the Tevatron", Nucl. Phys. **B12**, 345 (1990).

25. I. Sarcevic, "QCD Tests at the Tevatron", (with R. Blair, J. Pumplin, R. Fletcher, S. Linn, M. Demarteau, A. Zieminski, V. Kohze, H. Weerts, N. Amos, M. Mangano, S. Kuhlmann, T. Han), Proceedings of the Workshop on Physics at Fermilab in the 1990's, eds. D. Green and H. Lubatti (World Scientific, Singapore), pg. 212–224.

26. I. Sarcevic, "Ultrahigh–energy Photonuclear Cross Sections", (with R. Gandhi, A. Burrows, L. Durand and H. Pi), Phys. Rev. **D42**, 263 (1990).

27. I. Sarcevic, "The Hadronic Structure of the Photon", University of Arizona preprint AZPH–TH/90–15, talk presented at Annual Meeting of the Division of Particles and Fields of the American Physical Society (DPF90), Houston, Texas, January 3–6, 1990 (to be published in the Proceedings).

28. I. Sarcevic, "Intermittency Phenomenon in Hadronic Collisions", University of Arizona preprint AZPH–TH/90–21, invited talk presented at the 25th Rencontres de Moriond, High Energy Interactions, Les Arcs, France, March 11–17, 1990 (to be published in the Proceedings).

29. I. Sarcevic, "Correlations and Intermittency in High Energy Multihadron Distribution", (with P. Carruthers, Q. Gao and H. Eggers), to appear in Int. J. Mod. Phys. **A** (1990).

30. I. Sarcevic, "The Origin of Intermittency in Hadronic Collisions", University of Arizona preprint AZPH–TH/90–43, talk presented at International Workshop on Intermittency in High Energy Collisions}, March 18–21, 1990, Santa Fe, New Mexico, to be published in the Proceedings.

31. I. Sarcevic, "The Self–Similar Cascade Pattern at High Energies", University of Arizona preprint AZPH–TH/90–45, talk presented at International Workshop on Correlations and Multiparticle Production (CAMP), Marburg, Federal Republic of Germany, May 14–16, 1990, to be published in the Proceedings.

32. I. Sarcevic, "Intermittency in Hadronic Collisions", University of Arizona preprint AZPH–TH/90–42, talk presented at Quark Matter '90 Conference, Menton, France, May 7–11, 1990, to be published in Nucl. Phys. **A** (Proc. Suppl.).

33. I. Sarcevic, "The Analysis of Multiplicity Moments for Hadronic Intermittency Data", (with P. Carruthers and H. Eggers), University of Arizona preprint AZPH–TH/90–46.

34. Ina Sarcevic, "Self–Similar Multihadron Production at High Energies" (with H. Satz), University of Arizona preprint AZPH–TH–89/58, to be published in Phys. Lett. **B**.

35. A. Hasenfratz, K. Jansen, J. Jersak, C. B. Lang, H. Leutwyler, T.Neuhaus, "Finite Size Effects and Spontaneously Broken Symmetries: The Case of the O(4) Model", Zeitschrift fur Physik **C46**, 257 (1990).

36. A. Hasenfratz, W. Liu, T. Neuhaus, "Phase structure and critical points in a scalar–fermion model", Phys. Lett. **B236** 339 (1990).

37. A. Hasenfratz, K. Jansen, J. Jersak, C. B. Lang, H. Leutwyler, T. Neuhaus, "The chiral symmetric O(4) model", Preprint Juelich 1990.

38. R. Gandhi, "Mass Limits on μ and τ Neutrinos from SN1987A", Proceedings of the Storrs Meeting of the Division of Particles and Fields of the American Physical Society, published by World Scientific, Nov. 1989.

39. R. Gandhi and A. Perez, "Pair production of helicity–flipped neutrinos in Supernovae", Phys. Rev. **D41**, April 1990.

40. A. Burrows and R. Gandhi, "Massive Dirac Neutrinos and the SN1987A Signal", Phys. Lett. **B** (in press).

41. R. Gandhi, "The Effect of Neutrino Mass on IMB and K II Supernova Signals", Talk at International Conference on High Energy Physics, Aug. 1990, Singapore, to appear in the proceedings.

42. "SU(3) Thermodynamics with Eight Time Slices," S. Gottlieb, W. Liu, D. Toussaint, R.L. Renken and R.L. Sugar, Phys. Rev. **D41**, 622 (1990)

43. "Binding of Holes in the Hubbard Model," E. Dagotto, A. Moreo, R.L. Sugar and D. Toussaint, Phys. Rev. Lett., submitted.

44. "Quantum Chromodynamics at $6/g^2 = 5.60$", D. Toussaint, et.al., preprint FSU–SCRI–90–104, July 1990.

45. "Hadron Spectrum in QCD at $6/g^2 = 5.6$", D. Toussaint, et. al., preprint ANL–HEP–PR–90–48, June 1990.

46. A. Kocic, "Finite Size, Fermion Mass and N_f Systematics in Computer Simulations of Quantum Electrodynamics," (with E. Dagotto and J. Kogut), Nucl Phys. **B331**, 500 (1990).

47. A. Kocic, "On the Triviality of QED with a Large Number of Flavors," (with E. Dagotto and J. Kogut), Phys. Lett. **B232**, 235 (1989).

48. A. Kocic, "Chiral Symmetry Breaking in Three Dimensional QED with N_f Flavors," (with E. Dagotto and J. Kogut), Nucl. Phys. **B334**, 279 (1990).

49. A. Kocic, "Continuum Limit of QED," Regensburg preprint, to appear in Nucl. Phys. Proceedings Supplement.

50. A. Kocic, "Collapse of the Wave Function, Anomalous Dimensions and Continuum Limit in Model Scalar Field Theories," (with E. Dagotto and J. Kogut), Phys. Lett. **B237**, 268 (1990).

51. A. Kocic, "The Equation of State and Critical Exponents in Quenched Strongly Coupled QED", (with S. Hands, J, Kogut, and E. Dagotto), preprint NSF–ITP–90–62, May 1990.

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