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TOPICS IN
GAUGE THEORIES AND THE UNIFICATION
OF ELEMENTARY PARTICLE INTERACTIONS

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Progress Report
for period March 1, 1990 - December 31, 1990

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Progress Report on Grant DE-FG02-85ER40233

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Abstract

We report on work done by the principal investigators (Y. N. Srivastava and M. T. Vaughn) and their collaborators on

- (1) phenomenology of low and medium p_t physics,
- (2) standard model results for macroscopic systems,
- (3) same sign dilepton signals from massive Majorana neutrinos,
- (4) Casimir effects for charged particles,
- (5) further macroscopic effects in quantum electrodynamics, and
- (6) n -particle amplitudes for large n beyond the tree approximation,
- (7) renormalization group analysis of unified gauge theories.

I. RESEARCH COMPLETED AND IN PROGRESS

1. Phenomenology of Low and Medium p_t -Physics (Y. Srivastava)

For the past several years I have been involved in establishing a connection between large cross-section phenomena (e.g. hadronic production, multiplicity distribution and the like) and high transverse momentum jet events well understood in QCD. Applications of mini-jets in QCD were made in the minimum bias physics to give a unified explanation of several low p_t anomalies observed in the inelastic cross-section at the CERN collider and at the Tevatron [1]. Our earlier work on large transverse momentum production of vector bosons [2] utilised a hard scattering trigger for new particle searches. We have extended this technique to study minimum bias events obtained in conjunction with the trigger for a hard scattering. For example, the E_t distribution of produced particles has been computed as a function of p_t of the vector bosons [3].

In collaboration with Halzen and Fletcher from Wisconsin, we have made a critique of the various resummation methods for soft-gluons in hard trigger processes such as W-production at LHC and SSC [4]. In W-production, the transverse momentum distribution is calculable in perturbative QCD even when the W's have small p_t . The reason is that W's with small p_t are balanced by multiple hard gluons whose p_t cancels. We have calculated the transverse energy associated with these gluons and found that it matches the hadronic energy observed in W events. This is somewhat puzzling as one would have expected additional transverse energy associated with the underlying event structure. One possible explanation for this puzzle is that identifying the underlying event with the minimum bias event overestimates the E_t in hard collisions. We now suspect that minimum bias events contain a significant number of 'mini-jet' events. UA1 has reported being able to positively identify jet-structure in about 20% of the minimum bias events [5]. These jets should significantly increase the average E_t . Thus 'minimum bias' no longer means 'soft'. Hard contributions make a significant part of the average structure of the events. The E_t of a minimum bias event has therefore no relation to the underlying event when a W is produced. A low p_t W is accompanied by many soft gluons which by definition are in a state over which there has been a colour averaging. Then, the underlying event may be similar to a minimum bias event in the sense that it has the same colour structure. However, a high p_t W will be accompanied by a hard gluon which can therefore be counted as a jet and carries an 'observable' colour. The underlying event in this case is not colourless anymore and can have a hadronic structure quite different from that in a minimum bias event. For example, the ratio of charged to neutrals may change from 2/3 to approximately 1/2. These and similar results should be tested.

Recent limits on the top mass obtained by CDF have changed radically the phenomenological studies of Higgs boson searches. These latest limits indicate that the top is heavier than the W with the consequence that the W may be produced with a rate typical of strong interactions. To identify the Higgs then, one ought to look for its channels of decay without the W. This necessitates examination of rare channels with tiny branching ratios as well as the backgrounds from 'standard' QCD sources. In ref. [6] we have computed the contribution of quark-antiquark into virtual Z pairs. Some other backgrounds such as gluon-gluon into Z plus photon are presently being computed.

References for Part 1.

1. G. Pancheri and Y. Srivastava, Proceedings of the Perugia Workshop on Multi- Particle Dynamics, June 1988. Published by World Scientific, Pancheri/Srivastava/ Hwa Editors, (1989).
2. S. Geer, G. Pancheri and Y. Srivastava, Phys. Lett. B192, 223 (1987).
3. A. Grau, G. Pancheri and Y. Srivastava, Phys. Rev. D41, 3360 (1990).
4. F. Halzen, R. Fletcher, A. Grau, G. Pancheri and Y. Srivastava, Phys. Lett. B237, 113 (1990).
5. UA1 Collaboration, Nucl. Phys. B309, 405 (1988).
6. A. Grau, G. Pancheri and Y. Srivastava, Phys. Lett. B247, 611 (1990).

2. Standard Model Results for Macroscopic Systems (Y.Srivastava)

Vacuum polarization induced effects for macroscopic systems in various numbers of spatial dimensions have been studied by us in QED and in the standard model. Some of these include

- (i) two-dimensional systems (integral and fractional quantum Hall effect) [1,2,3],
- (ii) magneto-electric effects and time-reversal violations in macroscopic systems [4],
- (iii) one-dimensional systems relevant for experiments on ballistic FET's by M. Pepper's group at Cambridge University [5] and our predictions about the quantized resistance from the chiral anomaly [6],
- (iv) electro-weak effects on circuits [7],
- (v) probing the QED vacuum via the Mossbauer effect [8].

These results are extremely precise non-perturbative predictions from field theory and as such offer a somewhat different perspective since they concern realistic albeit difficult experiments. Wherever data are available complete agreement has been obtained. Two recent theoretical results of much interest concern the longitudinal modes of the photon in the presence of matter fields. This longitudinal mode develops a compact phase[9], a result intractable in the usual perturbative treatment. Also, a complete correspondence between quantum electrodynamics and quantum fluid dynamics has been established[10].

I was invited in August 1990 to a Workshop on macroscopic quantum dynamics at Sussex in England to deliver a lecture on applications of QED in 1 to 4 dimensions as well as to be the Rapporteur for the entire workshop. In a late August issue of Nature there is a very positive report about the workshop as well as about our research. In September 1990, I was invited to deliver a similar talk at a conference on the interface between condensed matter and high-energy physics organized by Professor S. Fubini in Sardinia, Italy.

Presently an application of similar ideas is being explored for macroscopic quantum gravity. Preliminary results appear quite encouraging.

References for Part 2.

1. Y. Srivastava and A. Widom, Physics Reports **148**, 1 (1987).
2. Y. Srivastava and E. Sassaroli, A review in *Il Saggiatore* **6**, 44 (1990).
3. Y. Srivastava, Invited Talk at the Sardinia Conference on Interface between Condensed Matter and High-Energy Physics, September 1990.
4. Y. Srivastava, Two invited lectures, "Neutrino-Photon Interactions" and "Are Pulsars Magnetoelectric", delivered at the VI Capri Symposium on Interactions of Elementary Particles, May 1988. (To appear in the Proceedings).
5. D. A. Wharam *et al.*, J. Phys. C **21**, L887 (1988); 209 (1988); B. J. Van Wees *et al.*, Phys. Rev. Lett. **60**, 848 (1988).
6. Y. Srivastava and A. Widom, Proceedings of the Workshop on Macroscopic Quantum Systems, Sussex, UK, August 1990. (To be published by World Scientific).
7. Y. Srivastava and A. Widom, Phys. Lett. B **176**, 199 (1986).
8. G. Auriemma, M. DeVincenzi, Y. Srivastava, and A. Widom, Nuovo Cimento A **100**, 213 (1988).
9. Y. Srivastava and A. Widom, "The Compact Phase in QED", Northeastern University preprint (1990), submitted for publication.
10. A. Widom and Y. Srivastava, Modern Physics Letters B **4**, 1 (1990).
3. Same Sign Dilepton Signals from Massive Majorana Neutrinos (O. Panella and Y. Srivastava):

The Dirac-Majorana controversy about the nature of the neutrino has been investigated through the process $W^-W^- \rightarrow e^-e^-$, mediated by a massive Majorana exchange [1]. Such a lepton number-violating process would not occur if neutrinos were Dirac particles or if they were massless. The high energy behavior of the above process is in marked contrast to the standard model allowed process $W^+W^- \rightarrow e^+e^-$. For same-sign dileptons the cross-section goes to a constant whereas the allowed channel cross-section goes down linearly with s [2]. This has motivated an investigation of the possibility of detecting this exotic process at future hadronic colliders such as SSC or LHC. For very light neutrinos the expected number of events is exceedingly small but our calculation can be of use to search for very massive neutrinos from possible higher generations.

We are also using the same process to investigate the production of excited Majorana neutrino in the formalism developed in ref. [3]. Work is currently in progress to estimate the production rate which involves the effective W approximation [4] to evaluate the W luminosity at hadronic colliders.

References for Part 3.

1. O. Panella, Y. Srivastava and A. Widom, Talk presented at the First International Symposium on Particles, Strings and Cosmology (PASCOS 90), Northeastern University March 1990. (Proceedings to be published by World Scientific).
2. H. Primakoff and S. P. Rosen, *Ann. Rev. Nuc. Part. Sci.* **31**, 145 (1981)
3. N. Cabibbo, L. Maiani and Y. Srivastava, *Phys. Lett.* **B139**, 459 (1984).
4. S. Dawson, *Nucl. Phys.* **B249**, 42 (1985).
4. Casimir Effects For Charged Particles (O. Panella and Y. Srivastava)

The theory of forces arising from electrodynamic field fluctuations are routinely applied to polarizable media to obtain the behavior of long range van der Waals forces from a fundamental viewpoint [1,2,3]. Less well studied are the Casimir forces on particles with a net charge. We have studied some such examples [4]:

(i) case of perfect conductors

The lowest order QED correction to the usual electrostatic image force problem for a perfect conductor is calculated.

(ii) case of polarizable atoms

Here the lowest order correction to the static attraction force is found to be divergent. The source of this infinity is due to the infra-red catastrophe and a regularization has been performed through an IR cut-off factor of the power-law type. The ensuing result which is interesting is that the Casimir correction (due to two-photons) is repulsive after the soft-photon renormalization.

References for Part 4.

1. I. E. Dzyaloshinski, E. M. Lifshitz and L. P. Pitayevski, *Adv. in Phys.* **10**, 165 (1961).
2. L. S. Brown and G. J. Maclay, *Phys. Rev.* **184**, 1272 (1969).
3. Donohue *et al.*, *Annals of Phys.* **164**, 233 (1985).
4. O. Panella, A. Widom and Y. Srivastava, *Phys. Rev.* **B42**, 9790 (1990).
5. Macroscopic Effects in Quantum Electrodynamics (E. Sassaroli and Y. Srivastava)

(i) We have been studying the integral and fractional quantum Hall effect using the earlier developed formalism [1] based on the (2+1)-dimensional remnant of the (3+1)-dimensional chiral anomaly present in QED. An invited review has been presented in the official journal of INFN (Italian National Institute for Nuclear Physics) "Il Saggiatore", in Italian [2]. Some of this research has also been reported in a Workshop on the interface between high-energy and condensed matter physics in Sardinia, Italy in September 1990. The more general problem of macroscopic realization of QED in 1 to 4 dimensions for practical condensed matter systems will be part of Sassaroli's doctoral thesis.

(ii) The original suggestion by Schwinger [3] that a constant external electric field would give rise to the production of electron-positron pairs through vacuum polarization has been extended to time-dependent EM fields. This extension entails a particular formulation of the WKB method which is suitable here. A feasibility study has also been made [4] and further work is in progress.

References for Part 5.

1. Y. Srivastava and A. Widom, *Phys. Rep.* **148**, 1 (1987).
2. Y. Srivastava and E. Sassaroli, *Il Saggiatore* **6**, 44 (1990).
3. J. Schwinger, *Phys. Rev.* **82**, 664 (1951).
4. E. Sassaroli, Laurea thesis, University of Perugia, 1988.
6. Multiparticle Amplitudes for large n beyond the Tree Approximation (M. Vaughn)

Several recent calculations have dealt the behavior of n -point amplitudes in field theories with bosons when n is large. In a Euclidean-based calculation for the production of n Higgses (or W 's) in the presence of the (constrained) instanton, Ringwald [1] and later Espinosa [2] showed that this amplitude grows like $n!$, so that unitarity is naively violated at a finite energy. In two subsequent studies of ordinary ϕ^4 theory in four dimensions by Cornwall [3] and Goldberg [4], such anomalies were found at tree level, without reference to instantons. A subsequent study in the context of a Schrodinger approach to ϕ^4 [5] at tree level (*i.e.*, the WKB approximation) gave the same result. In [4] the tree graphs for $q\bar{q} \rightarrow nH$ were analyzed, with the

result that the amplitude (for $n \sim E/m_H$) was found to grow like $(\sqrt{\lambda}/m_H)^n n!$, implying a cross section in apparent violation of s -wave unitarity when $n \sim 4\pi/\lambda$. It was also noted that there is no obvious connection between these tree level results and the standard asymptotic nature of perturbation expansions [6,7] in field theory. The latter are concerned with the behavior of the expansion coefficients at *high order in perturbation theory* of a Green's function with a *fixed number* of legs. The concern here is the pathological behavior at *tree level* of an amplitude with *many* external legs.

In order to understand if this problem could be remedied by going beyond the tree approximation, Goldberg and I have studied [8] the behavior of the n -point function in a zero-dimensional scalar theory ($\mathcal{L} = -\frac{1}{2}m^2\phi^2 - \frac{1}{4}\lambda\phi^4 + J\phi$) in the presence of an external source J . We find that the $n! (\sqrt{\lambda})^n$ behavior is again obtained in saddle-point (tree) approximation; here, however, we can also show that a similar behavior $n! [f(\lambda)]^n$ persists in the full theory, where $f \sim \sqrt{\lambda}$ for $\lambda \rightarrow 0$, $f \sim \lambda^{-1/4}$ for $\lambda \gg 1$. The difficulty in the full theory can be traced to the existence of zeros in the complex J -plane of the generating functional $Z[J]$. The criterion for the existence of these zeros is shown to be established by the asymptotic behavior in J of $Z[J]$ calculated in the saddle-point approximation, although the actual locations of the zeros must be determined numerically (they not well-determined in the saddle-point approximation). None of these calculations involve perturbative expansions in λ .

We are continuing to study the large n behavior of n -point functions in more realistic theories to understand if this behavior persists. In particular, is the bad behavior of n -point functions in scalar field theories simply a reflection of the triviality of such theories? Can the same circumstances which permit asymptotic freedom in gauge theories provide the cancellations necessary to give a softer large n behavior for the n -point functions?

References for Part 6.

1. A. Ringwald, Nucl.Phys. 330, 1 (1989).
2. O. Espinosa, Nucl.Phys. 343, 310 (1990).
3. J. M. Cornwall, Phys. Lett. 243, 271 (1990).
4. H. Goldberg, Phys. Lett. 246, 445 (1990).
5. M. B. Voloshin, TPI preprint TPI-MINN-90/54-T (1990).
6. L. N. Lipatov, Sov. Phys. JETP 45 (2), 216 (1977).
7. E. Brezin, J.C. Le Guillou, and J. Zinn-Justin, Phys. Rev. D15, 1544 (1977).
8. H. Goldberg and M. T. Vaughn, "Tree and non-tree Multiparticle Amplitudes", Northeastern University preprint NUB-3008 (1990), submitted to Phys. Rev. Lett.
7. Renormalization Group Analysis of Unified Gauge Theories (M. Vaughn)

The two-loop renormalization group β -functions were computed some time ago [1-3], but the effects of scheme dependence of these equations has not been carefully studied (in particular, the two-loop β -functions for the Yukawa and scalar quartic couplings are different in a renormalization scheme which respects supersymmetry from those in the $\overline{MS}$ scheme, which does not). Also, the effects of thresholds have not been consistently taken into account - using two-loop RG equations requires for consistency the use of one-loop corrected boundary conditions in the manner outlined by Weinberg [4] and Hall [5] (among many others). I have started to work on these problems in a systematic way, but work had been slowed by the algebraic complexity until recently. There is now an algebraic manipulation program FORM (from J. Vermaseren in Amsterdam), similar to the older program SCHOONSHIP but much extended, which is available both on VAX systems and on the Macintosh. I have recently installed and tested this program, and am now making rapid progress toward creating a general scheme for dealing with the one-loop boundary conditions which must be included in continuing the two-loop RG equations from one effective theory to another.

References for Part 7.

1. M. T. Vaughn and M. E. Machacek, Nucl. Phys. B222, 83 (1983); B236, 221 (1984); B249, 83 (1985).
2. M. Fischler and J. Oliensis, Phys. Lett. 119B, 385 (1982); Phys. Rev. D28, 2027 (1983); R. van Damme, Nucl. Phys. B227, 317 (1983); B244, 105 (1984).
3. I. Jack, J. Phys. A16, 1083 (1983); I. Jack and H. Osborn, J. Phys. A16, 1101 (1983); Nucl. Phys. B249, 472 (1985).
4. S. Weinberg, Phys. Lett. 91B, 51 (1984).
5. L. Hall, Nucl. Phys. B78, 75 (1981).

II. PUBLICATIONS SUPPORTED BY THIS GRANT

1. A. Grau, G. Pancheri and Y. Srivastava, "Bloch-Nordsieck Transverse Momentum Distributions in QCD", Phys. Rev. D **41**, 3360 (1990).
2. F. Halzen, R. Fletcher, A. Grau, G. Pancheri and Y. Srivastava, "Do we understand Soft-gluon Resummation?", Phys. Lett. B **237**, 113 (1990).
3. A. Grau, G. Pancheri and Y. Srivastava, "Contribution of quark-antiquark annihilation to the production of virtual Z pairs in Hadron Colliders", Phys. Lett. B **247**, 611 (1990).
4. Y. Srivastava and E. Sassaroli, "L'effetto Hall Quantistico e l'elettrodinamica Quantistica", Il Saggiatore **6**, 44 (1990).
5. Y. Srivastava, "Macroscopic QED in 1 to 4 Dimensions", Invited Talk at the Sardinia Conference on Interface between Condensed Matter and High-Energy Physics, September 1990.
6. Y. Srivastava and A. Widom, "Quantized Resistance and the Chiral Anomaly in (1+1)- Dimensions", Proceedings of the Workshop on Macroscopic Quantum Systems, Sussex, UK, August 1990 (To be published by World Scientific).
7. Y. Srivastava and A. Widom, "The Compact Phase in QED", Northeastern University preprint (1990), submitted for publication.
8. O. Panella, Y. Srivastava and A. Widom, Talk presented at the First International Symposium on Particles, Strings and Cosmology (PASCOS 90), Northeastern University March 1990 (Proceedings to be published by World Scientific).
9. O. Panella, A. Widom and Y. Srivastava, Phys. Rev. B **42**, 9790 (1990).
10. H. Goldberg and M. T. Vaughn, "Tree and non-tree Multiparticle Amplitudes", Northeastern University preprint NUB-3008 (1990), submitted to Phys. Rev. Lett.

III. PERSONNEL SUPPORTED BY THIS GRANT

1. Y. N. Srivastava (Co-Principal Investigator)
2. M. T. Vaughn (Co-Principal Investigator)
3. Orlando Panella (Graduate Research Assistant, Fall 1988-present)
4. Elisabetta Sassaroli (Graduate Research Assistant, Summer 1989)

Particle Physics A – PHY 3651, W91

The primary text for the course is F. Halzen and A. Martin, *Quarks and Leptons*, John Wiley and Sons. Some other texts which are recommended for adjunct reading are:

1. G. Kane, *Modern Elementary Particle Physics*, Addison-Wesley.
2. D. H. Perkins, *Introduction to High Energy Physics*, 3rd Ed., Addison-Wesley.
3. D. Griffiths, *Introduction to Elementary Particles*, Harper and Row.

These first three are at the introductory level. Texts at the level of Halzen and Martin are:

4. C. Quigg, *Gauge Theories of the Strong, Weak, and Electromagnetic Interactions*, Addison-Wesley.
 5. I. J. R. Aitchison and A. J. G. Hey, *Gauge Theories in Particle Physics*, Adam Hilger.
 6. Howard Georgi, *Weak Interactions and Modern Particle Theory*, Benjamin/Cummings.
- and for your relativistic QM

7. J. D. Bjorken and S. D. Drell, *Relativistic Quantum Mechanics*, McGraw-Hill.

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