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Formal Report (Summary)

[PARTICLE-96-SYM#2]

Future High Energy Colliders Symposium

(October 21 - 25, 1996)

Summary Report

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BY

Zohreh Parsa

Institute for Theoretical Physics,
University of California,
Santa Barbara

&

Brookhaven National Laboratory,
Upton, NY 11973-5000

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Zohreh Parsa

Institute for Theoretical Physics,
University of California,
Santa Barbara

&

Brookhaven National Laboratory,
Upton, NY 11973-5000

"Future High Energy Colliders"

A "Future High Energy Colliders" Symposium was held October 21-25, 1996 at the Institute for Theoretical Physics (ITP) in Santa Barbara. This was one of the 3 symposia [1] hosted by the ITP and supported by its sponsor, the National Science Foundation, as part of a 5 month program on "New Ideas for Particle Accelerators." The long term program and symposia were organized and coordinated by Dr. Zohreh Parsa of Brookhaven National Laboratory /ITP.

The purpose of the symposium was to discuss the future direction of high energy physics by bringing together leaders from the theoretical, experimental and accelerator physics communities. Their talks provided personal perspectives on the physics objectives and the technology demands of future high energy colliders. Collectively, they formed a vision for where the field should be heading and how it might best reach its objectives.

As the name of this conference suggests, the primary tools for performing high energy physics research are particle beam colliders. Following the famous Einstein equation $E = mc^2$, collisions of high energy particles produce events in which much of the energy of the beams is converted into the masses of new heavy particles not normally found in nature. By studying the production and decay of these new particles, the underlying structure of the universe and the laws that govern it are unveiled.

The design and construction of particle accelerators used in high energy physics are motivated and constrained by 1) the forefront physics questions being asked, 2) the availability of technology needed to build and operate these machines as well as capabilities to detect and analyze the collisions, and 3) the cost of the machine and the availability of construction funds from home and foreign governments. High Energy Physics in the United States is now at a crossroads where its future will depend on: participation in foreign projects, upgrading and utilizing existing facilities, and new construction initiatives.

Some of the underlying physics motivations and technical issues had been addressed at earlier workshops such as Snowmass 1996. The Santa Barbara "Future High Energy Colliders" Symposium's novel aim was to begin the process of reaching a consensus on how to attain the vision.

[1] In addition to this symposium, a week long symposium was held on "New Modes of Particle Acceleration – Techniques and Sources" August 19-23, 1996. Some of the highlights of that meeting included Novel Modes of laser, plasma, wakefield accelerations, techniques and power sources. A third symposium on "Beam Stability and Nonlinear Dynamics" will be held on December 3 - 5, 1996 and will deal with some of the fundamental theoretical problems associated with accelerator physics.

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The goal of Elementary Particle Physics is to understand the nature of matter and the forces acting on it. Experiments over the last two decades have convincingly shown that the strong, electromagnetic, and weak forces are all closely related and are simply described by the "Standard Model." In particular the anticipated sixth quark, top, has been recently found at Fermilab, and the predicted properties of the Z boson, one of the carriers of the weak force, have been tested to better than 1%. There is now little doubt that the Standard Model is a very good description of the basic forces responsible for all atomic and nuclear physics. While the Standard Model is a great success, there remain many open questions in Elementary Particle Physics. Perhaps the most urgent is to understand how masses of the particles originate. To that end, new physics beyond what is currently known is required. The simplest possibility, the "Higgs Mechanism" predicts the existence of a fundamental Higgs Boson. Finding that elusive particle or whatever new physics is actually responsible for mass generation motivated the Superconducting Supercollider (SSC) and remains the primary goal of the next generation of colliders. A number of other interesting and more elaborate models have been proposed, but there is as yet no direct experimental evidence supporting any of them. Nevertheless, consistency of the Standard Model requires that the new physics responsible for mass generation occur at an energy scale of less than about 1 TeV, i.e. within the range of the next generation of accelerators. In addition to the origin of mass, there are other compelling questions. For example, the observed matter-antimatter asymmetry in the universe is not understood. Also, astrophysical observations suggest that between 90% and 99% of the matter that makes up the universe is invisible. There are a number of possible candidates for this "dark matter," but none have been proven experimentally to exist.

Currently, the operation of the Tevatron proton-antiproton collider at the Fermi National Accelerator Laboratory and the SLC electron-positron collider at the Stanford Linear Accelerator Center are at the energy frontier of the field. The use of both proton-antiproton and electron-positron collisions is important in order to provide complementary information. At the energy frontier new particles never before observed are discovered and studied, providing unique insight into the laws of nature. Recently, the LEP electron-positron collider at the CERN laboratory in Geneva began upgrading its energy, expanding the energy frontier in electron-positron collisions by about a factor of 2. Sometime near the year 2005 the LHC proton-proton collider in Geneva will operate with world record beam energy about 7 times that of the Fermilab Tevatron.

The Large Hadron Collider (LHC) at CERN is intended to address the question of the origin of mass. Because we know the energy scale associated with mass generation, we can be reasonably confident that the LHC will discover this new physics, whether it is a Higgs boson or something quite different.

Although the LHC should elucidate the origin of mass, it probably cannot answer all the outstanding questions. For that reason, a collaboration involving institutions from Germany, Japan, the United States and many other countries has been developing a design for a high energy e^+e^- collider, the Next Linear Collider (NLC). This would have a somewhat lower energy reach than the LHC, at least initially, but it would be able to make many interesting unique measurements that would complement those at the LHC. Together the LHC and the NLC should clarify the origin of mass and address many other open questions. They might also find the explanation for the dark matter in the universe and open new frontiers such as the much anticipated spectrum of heavy particles predicted by supersymmetry, an elegant extension of the underlying structure of space - time. If supersymmetry is found, it will become the focus of high energy physics. Studying its spectrum of particles and their properties will be a major experimental enterprise.

Also under discussion at Brookhaven National Laboratory, Fermilab, Lawrence Berkeley National Laboratory, and many Universities is a muon collider. The feasibility of building an accelerator in which muons collide with antimuons is currently under serious investigation. Since muons (at rest) decay in about two millionth of a second, building such a collider would be a major technological achievement. A survey of the physics that could be studied at such a machine overlaps with e^+e^- collider capabilities but also includes novelties such as the possibility for fusion of the colliding beams to produce Higgs particles. This process would permit e.g. the precise direct measurement of the mass and lifetime of the Higgs particle as well as its decay properties. However, the main enthusiasm for the muon collider stems from its potential to reach very high energies and the possibility that it could be constructed at an existing national laboratory.

An explanation of the matter-antimatter asymmetry in our universe requires first an understanding of the origin of mass. In addition, important supporting information can be obtained by studying rare interactions of a variety of known particles, including B mesons, K mesons, and muons. Such experiments are ongoing at several laboratories, and with the advent of B factories and intensity upgrades of proton synchrotrons at Brookhaven and Fermilab more will be carried out in the future.

A unique feature of the symposium was the bringing together of many physicists who will have a major impact on the future direction of the field. Especially important was the set of presentations made by the Department of Energy Director of Energy Research M. Krebs, by B. Kayser of the National Science Foundation, and by the directors of the three U.S. High Energy Physics laboratories , J. Peoples (Fermilab), B. Richter (Stanford Linear Accelerator Center) and N. Samios (Brookhaven National Laboratory). Their perspectives combined with presentations by internationally distinguished high energy and accelerator physicists provided a comprehensive picture of the issues involved in formulating appropriate goals for the future. The difficult aspects and the far reaching consequences of the decisions that must be made were further clarified during a unique panel discussion designed to initiate the process of reaching accord in the high energy community as to what the future physics and accelerator priorities should be. Although there is not unanimity of opinion in all matters, there is a consensus that an NLC should be built somewhere in the world and vigorous R & D should be pursued in promising new areas such as the muon collider concept and new modes of particle acceleration.

Given the long lead times necessary for the design of new particle accelerators, it is important for the high energy physics community to decide soon what types and energy ranges of colliders are necessary to address the additional questions which the LEP and LHC may not be able to answer.

The perspectives that were presented at the symposium on the state and future of high energy physics are vital ingredients in the continuing discussion of how the U.S. High Energy Physics community should best marshal its national scientific resources while continuing a high level of international collaboration. They should provide valuable input for ongoing discussions and in making decisions regarding the future direction of the field.

Zohreh Parsa
Chairperson for Symposium
Institute for Theoretical Physics
UCSB, Santa Barbara, California, USA/

Brookhaven National Laboratory, 901A
Upton, New York, 11973 USA
parsa@bnl.gov

INSTITUTE FOR THEORETICAL PHYSICS

UNIVERSITY OF CALIFORNIA
SANTA BARBARA, CALIFORNIA 93106-4030
http://www.itp.ucsb.edu

CONFERENCES/VISAS: (805) 893-3178
OFFICE FAX: (805) 893-2431
CREDIT CARD FAX: (805) 893-3486

ITP Conference on
Future High Energy Colliders
October 21-25, 1996
Coordinator: Z. Parsa
Advisory Committee: D. Cline, G. Jackson, W. Marciano, and P. Wilson

SCHEDULE

Monday, October 21, 1996

Time:	Speaker:	Title:
8:00 am	Registration	ITP Lobby
Convener:	**Z. Parsa, BNL**	
8:40	J. Hartle, ITP Director	Welcome
	Z. Parsa, BNL	Welcome & Introduction
Defining Perspective Presentations:		
9:00	D. Gross, Princeton Univ.	Perspectives on Future High Energy Physics
9:55	Refreshment Break	ITP Front Patio
Convener:	**G. Jackson, FNAL**	
10:25	J. Peoples, FNAL Director	Perspectives on Future High Energy Physics
11:20	B. Richter, SLAC Director	Perspectives on Future High Energy Physics
12:15 pm	Lunch	ITP Front Patio
Convener:	**R. Peccei, UCLA**	
1:45	N. Samios, BNL Director	Perspectives on Future High Energy Physics
View From Washington:		
2:40	M. Krebs, DOE	Perspectives on Future High Energy Physics,
3:35	Refreshment Break	ITP Front Patio
4:05	B. Kayser, NSF	Perspectives on Future High Energy Physics,
5:00	**Session Ends**	
5:15	Wine & Cheese	ITP Front Patio
5:45	Buffet Dinner	ITP Front Patio

Tuesday, October 22, 1996:

Time:	Speaker:	Title:
Convener:	**V. Barger, U. Wisconsin**	
9:00 am	W. J. Marciano, BNL	Physics of the Standard Model and Beyond
9:45	S. Willenbrock, UIL	Higgs Physics
10:30	Refreshment Break	ITP Front Patio
11:00	J. Gunion, UCD	Supersymmetry
11:45	T. Appelquist, Yale	Strongly Interacting New Physics
12:30 pm	Lunch	ITP Front Patio
Convener:	**M. Harrison, BNL**	
2:00	L. Rolandi, CERN	LEP Status Report
2:55	D. Amidei, U Michigan	Collider Physics at FNAL & TeV2000, Physics Issues
3:45	Refreshment Break	ITP Front Patio
4:15	G. Jackson, FNAL	TeV2000, Accelerator Issues
5:30	**Session ends**	

Wednesday, October 23, 1996:

Time:	Speaker:	Title:
Convener:	**N. Lockyer, U. Pennsylvania**	
9:00 am	E. Keil, CERN	Status of LEPII and LHC
9:45	I. Hinchliffe, LBL	Large Hadron Collider (LHC) Physics
10:30	Refreshment Break	ITP Front Patio
11:00	M. Harrison, BNL	Big Hadron Collider
11:45	H. Murayama, LBL	e^+e^- Physics
12:30 pm	Lunch	ITP Front Patio
Convener:	**D. Silverman, UC Irvine**	
1:45	F. Paige, BNL	Complementarity of Lepton and Hadron Colliders
2:25	D. Burke, SLAC	Overview & Outlook for Linear Colliders and Next Linear Collider SLAC ZDR Design
3:30	Refreshment Break	ITP Front Patio
Convener:	**L. Rolandi, CERN**	
4:05	N. Toge, KEK	Japan's Status on Next Linear Collider
4:45	R. Brinkman, DESY	Superconducting Collider (TESLA)
5:25	**Session ends**	

Thursday, October 24, 1996

Time:	Speaker:	Title:
Convener:	**A. Tollestrap, FNAL**	
8:30 am	P. Wilson, SLAC	Scaling Linear Collider to 5 TeV and above
9:10	Refreshment Break	ITP Front Patio
9:45	R. Palmer, BNL	Overview of Muon Collider Design Simulations & Detector
10:40	D. Cline, UCLA	Concepts for $mu^+ mu^-$ Cooling and Polarized Sources
11:20	V. Barger, UWI	$mu^+ mu^-$ Collider Physics Capabilities
12:05	Lunch	ITP Front Patio
Convener:	**R. Sawyer, UCSB**	
1:30	C. Heusch, UCSC	$e^- e^-$ Collider
1:50	V. Telnov, INP	Photon-Photon Collider
2:30	S. Ritz, Columbia Univ	Lepton - Hadron Collider
3:05	Refreshment Break	ITP Front Patio
Convener:	**C. Pellegrini, UCLA**	
3:35	R. Siemann, SLAC	Snowmass 96 - Summary
4:15	Z. Parsa, R. Palmer, M. Harrison (BNL) G. Jackson, A Tollestrup, (FNAL) R. Ruth, J. Irwin,, P. Wilson (SLAC) C. Pellegrini , (UCLA) and other speakers	New Reports* & Round Table Discussion on Basic Issues in the Accelerator. Physics & Technology of: Linear, Accelerators, Muon, Big Hadron. Collider, etc.. (*= To be announced)
5:30	Light Buffet Dinner	ITP Front Patio

Friday, October 25, 1996

Time:	Speaker:	Title:
Convener:	**M. Mugge, LBL**	
9:00 am	J. Irwin, SLAC	Fundamental Limitations of Particle Accelerators
9:40	Refreshment Break	ITP Front Patio
Futuristic Technology		
10:15	T. Katsouleas, USC	Highlights of "New Modes of Particle Acceleration Techniques and Sources" Symposium, ITP (96)
10:55	S. Chattopadhyay, LBL	A Report on the Advanced Accelerator Concepts Workshop (96)
11:35	Z. Parsa, BNL	Summary and Closing Talk
12:20 pm	Lunch	ITP Front Patio

BNL	Brookhaven National Laboratory
FNAL	Fermi National Accelerator Laboratory
ITP	Institute for Theoretical Physics
LBL	Lawrence Berkeley National Laboratory
LANL	Los Alamos National Laboratory
SLAC	Stanford Linear Accelerator Center
*	Space for late contributions

Dante Amidei
Randall Laboratory of Physics
University of Michigan
Ann Arbor MI 48109-1120

off. ph.: (313) 764-3266
FAX number: (313) 936-1817
amidei@umich.edu

Thomas Appelquist
Department of Physics
Sloane Physics Laboratory
Yale University
P.O. Box 208120
New Haven CT 06511-8167

off. ph.: 203-432-6969
FAX number: 203-432-6175
twa@genesis3.physics.yale.edu

Katsushi Arisaka
Department of Physics
University of California
405 Hilgard Avenue
Los Angeles CA 90024-1547

off. ph.: (310) 825-4925
FAX number: (310) 206-1091
arisaka@physics.ucla.edu

Tofigh Azemoon
European Lab for Particle Physics
CERN
CH-1211 Genéve 23
SWITZERLAND

off. ph.: +4122 767 4062
FAX number: +4122 782 8923
azemoon@hpl3.cern.ch

Mark Bachman
Physics Department
Univ. of California
Irvine CA 92717

off. ph.: (714) 824-3817
FAX number: (714) 824-7478
mbachman@uci.edu

Vernon Barger
Department of Physics
University of Wisconsin
1150 University Ave.
Madison WI 53706

off. ph.: (608) 262-8908, 4906 msg
FAX number: (608) 262-8628
barger@phenxi.physics.wisc.edu

Frederick Bernthal
Univ. Research Association, Inc.
1111 19th Street, N.W.
Suite 400
Washington DC 20036

off. ph.: (202) 293-1382
FAX number: (202) 293-5012
fbernthal@ura.nw.dc.us

Reinhard Brinkmann
DESY
Notkestrasse 85
D-2000 Hamburg 52
GERMANY

off. ph.: 49-40-89983197
brinkmann@desy.de

Carl Bromberg
Physics PA Building
Michigan State University
East Lansing MI 48824

off. ph.: (517) 353-1809
FAX number: (517) 355-6661
bromberg@msupa.pa.msu.edu

David Burke
SLAC
Stanford University
P.O. Box 4349
Stanford CA 94309

Swapan Chattopadhyay
Accelerator & Fusion Res. Div.
Lawrence Berkeley Laboratory
University of California
Berkeley CA 94720

David Cline
Department of Physics
University of California
405 Hilgard Avenue
Los Angeles CA 90024-1547

off. ph.: (310) 825-1673, 3440 msg
FAX number: (310) 206-1061
dcline@physics.ucla.edu

Andrej Czarnecki
Inst. für Theor. Teilchenphysik
Universität Karlsruhe
Postfach 6980
D-76128 Karlsruhe
GERMANY

off. ph.: (49)721 608-3373
FAX number: (49)721 370-726
ac@ttpux8.physik.uni-karlsruhe.de

Robert Diebold
Division of High Energy Physics
Office of Energy Research
U.S. Department of Energy
19901 Germantown Road
Germantown MD 20874

off. ph.: (301) 903-5490
FAX number: (301) 353-5079
robert.diebold@oer.doe.gov

Alex Dragt
Dept. of Physics & Astronomy
University of Maryland
College Park MD 20742-4111

off. ph.: (301) 405-6053, 6028 msg
FAX number: (301) 314-9525
dragt@quark.umd.edu

Anton Eppich
Department of Physics
University of California
Santa Barbara CA 93106-9530

off. ph.: (805) 893-3340
eppich@phsycis.ucsb.edu

Sergio Ferrara
Theory Division
CERN
CH-1211 Genéve 23
SWITZERLAND

off. ph.: (41)22 767-2831, 2422
FAX number: (41)22 767-3850
ferrara@crnvma.cern.ch

Jorge Fontana
4375 Via Glorieta
Santa Barbara CA 93110

off. ph.: (805) 682-3387
FAX number: (805) 893-3262

Steve Giddings
Department of Physics
University of California
Santa Barbara CA 93106-9530

off. ph.: (805) 893-4750, 3888
FAX number: (805) 893-8597
giddings@denali.physics.ucsb.edu

Henry Glass
Theory Group
Fermilab, MS-316
P.O. Box 500
Batavia IL 60510

off. ph.: (630) 840-8105
FAX number: (630) 840-2383
glass@fnal.gov

Vladimir Gorev
Plasma Processes Laboratory
Russian Research Center
Kurchatov Institute
Kurchatov Sq. 1
123182 Moscow
RUSSIA

off. ph.: (7)095 196-7658
FAX number: (7)095 943-0023
(none)

Aaron Grant
Department of Physics
University of California
405 Hilgard Avenue
Los Angeles CA 90024-1547

off. ph.: (310) 825-4814
FAX number: (310) 825-3109
grant@physics.ucla.edu

David Gross
Department of Physics
Princeton University
Princeton NJ 08544

off. ph.: 609-258-5851,5650s,4400m
FAX number: 609-258-1549
gross@puhep1.princeton.edu

John (Jack) Gunion
Department of Physics
University of California
Davis CA 95616

off. ph.: (916) 752-1134
FAX number: (916) 752-4717
JFGUCD@ucdhep.ucdavis.edu

Michael Harrison
Department of Physics
Brookhaven National Laboratory
Bldg. 1005S, P.O. Box 5000
Upton NY 11973-5000

off. ph.: (516) 344-7173
FAX number: (516) 344-5729
harrison@bnl.gov

James Hartle
Institute for Theoretical Physics
University of California
Santa Barbara CA 93106-4030

off. ph.: (805) 893-2280
FAX number: (805) 893-2431
hartle@itp.ucsb.edu

Clem Heusch
Insti. Particle Physics
University of California
Santa Cruz CA 95064

off. ph.: (415) 926-2540
FAX number: (408) 459-2635
heusch@slac.stanford.edu

John Irwin
SLAC, MS 26
Stanford University
P.O. Box 4349
Stanford CA 94309

off. ph.: (415) 926-2740
FAX number: (415) 926-4999
irwin@slac.stanford.edu

Gerald Jackson
Mail Stop 306
Fermilab
P.O. Box 500
Batavia IL 60510

off. ph.: (708) 840-2317
FAX number: (708) 840-4552
gpj@fnal.gov

Basim Kamal
Department of Physics
Brookhaven National Laboratory
Box 5000
Upton NY 11973

off. ph.: (516) 344-2365
FAX number: (516) 344-5568
kamal@wind.phy.bnl.gov

JooSang Kang
Physics :Department
Korea University
Seoul 136-701
KOREA

off. ph.: 82-2-920-1461
FAX number: 82-2-922-8749
jskang@hep.korea.ac.kr

Tom Katsouleas
Electrical Engineering
USC
Los Angeles CA 90089-0484

off. ph.: (213) 740-0194
FAX number: (213) 740-7581
katsoule@usc.edu

Boris Kayser
National Science Foundation
4201 Wilson Blvd.
Room 1015
Arlington VA 22230

off. ph.: (703) 306-1890
FAX number: (703) 306-0566
bk@einstein.mps.NSF.gov

Eberhard Keil
Theory Division
CERN
CH-1211 Genéve 23
SWITZERLAND

off. ph.: (41)22 767-3426
FAX number: (41)22 783-0552
Eberhard.Keil@cern.ch

Robert Koppensteiner
Johannes Kepler University
A-4040 Linz-Auhof
UPPER AUSTRIA

off. ph.: 43-732-2468
FAX number: 43-732-2468-9696
see comments

Martha Krebs
Division of High Energy Physics
U.S. Department of Energy
1000 Independence Ave
SW/ER-1, 17B-058
Washington DC 20585

off. ph.: (202) 586-5430
FAX number: (202) 586-4120
Martha.Krebs@er.doe.gov

Yoshitaka Kuno
Physics Dept.
KEK
Oho 1-1 Tsukuba
Ibaraki 305
JAPAN

off. ph.: (81)298 64-5419
FAX number: (81)298 64-7831
kuno@kekvax.kek.jp

James (Jim) Langer
Physics Department
University of California
Santa Barbara CA 93106-9530

off. ph.: (805) 893-7597
FAX number: (805) 893-2902
langer@physics.ucsb.edu

David Lange
Department of Physics
University of California
Santa Barbara CA 93106-9530

off. ph.: (805) 893-7218
FAX number: (805) 893-8597
lange@charm.physics.ucsb.edu

Roy Lee
Physics Department
Univ. of California
Irvine CA 92717

off. ph.: (714) 824-2630
FAX number: (714) 824-7478
rlee@pent.ps.uci.edu

Nigel Lockyer
Department of Physics
University of Pennsylvania
Philadelphia PA 19104

off. ph.: (215) 898-5806
FAX number: (215) 898-8512
lockyer@lockyer.hep.upenn.edu

William (Bill) Marciano
Particle Theory Group
Brookhaven National Laboratory
20 Pennsylvania Avenue
Upton NY 11973

off. ph.: (516) 282-3151
FAX number: (516) 282-5568
marciano@bnLajc.bnL.gov

Scott Metzler
Theory Group
Fermilab
P.O. Box 500
Batavia IL 60510

off. ph.: (708) 840-5009
FAX number: (708) 840-4343
metzler@penn01.fnal.gov

William Molzon
Dept. of Physics
University of California
Irvine CA 92717

off. ph.: (970) 544-9394
FAX number: (970) 544-9758
wmolzon@uci.edu

Andrew Morgan
Department of Physics
University of California
405 Hilgard Avenue
Los Angeles CA 90024-1547

off. ph.: (310) 825-4814
FAX number: (310) 825-3109
morgan@physics.ucla.edu

Rollin Morrison
Department of Physics
University of California
Santa Barbara CA 93106-9530

off. ph.: (805) 893-2666, 3888 msg
FAX number: (805) 893-8422
morrison@sbhep.physics.ucsb.edu

Marshall Mugge
Lawrence Livermore National Lab
P.O. Box 808
MS/L028
Livermore CA 94550

off. ph.: (510) 423-1765
FAX number: (510) 423-3371
mugge@llnl.gov

Hitoshi Murayama
Lawrence Berkeley Laboratory
50A-3115
University of California
Berkeley CA 94720

off. ph.: (415) 486-????, 4000 msg
murayama@theorm.lbl.gov

Tim Nelson
Department of Physics.
University of California
Santa Barbara CA 93106-9530

off. ph.: (805) 893-7218
nelson@charm.physics.ucsb.edu

Frank Paige
Department of Physics
Brookhaven National Laboratory
40 Brookhaven Ave., Bldg. 510A
Upton NY 11973

off. ph.: (516) 282-3836
FAX number: (516) 282-5568
paige@bnL.gov

Robert Palmer
Bldg 901A
Brookhaven National Laboratory
P.O. Box 5000
Upton NY 11973-5000

off. ph.: (516) 344-2842
FAX number: (516) 344-3248
palmer@ax61.bnl.gov

Zohreh Parsa
Department of Physics
Brookhaven National Laboratory
P.O. Box 5000
Upton NY 11973-5000

off. ph.: (516) 344-2085
FAX number: (516) 344-3248
parsa@bnl.gov

Roberto Peccei
Department of Physics
University of California
405 Hilgard Avenue
Los Angeles CA 90024-1547

off. ph.: (310) 825-1042
FAX number: (310) 206-0864
robertop@college.ucla.edu

Claudio Pellegrini
Department of Physics
University of California
405 Hilgard Avenue
Los Angeles CA 90024-1547

off. ph.: (310) 206-1677
FAX number: (310) 206-1091
pellegrini@physics.ucla.edu

John Peoples
Director
Fermilab
P.O. Box 500
Batavia IL 60510

off. ph.: (630) 840-3211
FAX number: (630) 840-2939
peop@fnal.gov

Changqing Qiao
Department of Physics
University of California
Santa Barbara CA 93106-9530

qiao@charm.physics.ucsb.edu

Burton Richter
SLAC- Director
Stanford University
P.O. Box 4349
Stanford CA 94309

FAX number: (415) 926-4500
brichter@slac.stanford.edu

Steven Ritz
Nevis Laboratory
P.O. Box 137
Irvington NY 10533

off. ph.: (212) 854-8364
FAX number: (914) 591-8120
ritz@nevis1.nevis.columbia.edu

Luigi Rolandi
European Lab for Particle Physics
CERN
CH-1211 Genéve 23
SWITZERLAND

off. ph.: +41-22-7674242
FAX number: +41-22-7830672
Luigi.Rolandi@CERN.CH

Joel Rozowsky
Department of Physics
University of California
405 Hilgard Avenue
Los Angeles CA 90024-1547

off. ph.: (310) 825-6469
FAX number: (310) 825-3109
rozowsky@physics.ucla.edu

Francesco Ruggiero
SI Division
CERN
CH-1211 Genéve 23
SWITZERLAND

off. ph.: +41 (22) 767 3726
FAX number: +41 (22) 783 0552
Francesco.Ruggiero@cern.ch

Nicholas Samios
Director
Brookhaven National Laboratory
40 Brookhaven Ave., Bldg. 460
Upton NY 11973-5000

off. ph.: (516) 344-2772
FAX number: (516) 344-5803
samios1@bnl.gov

Raymond (Ray) Sawyer
Inst. for Theoretical Physics
University of California
Kohn Hall
Santa Barbara CA 93106-4030

off. ph.: (805) 893-3488, 4111 msg
FAX number: (805) 893-2431
sawyer@sarek.ucsb.edu

Steve Schnetzer
Department of Physics
Rutgers University
P.O. Box 849
Piscataway NJ 08855

off. ph.: (908) 445-5035
FAX number: (908) 445-4343
steves@ruthep.rutgers.edu

Bertram Schwarzschild
Editorial Office
Physics Today
American Center for Physics
One Physics Ellipse
College Park MD 20740-3843

off. ph.: (301) 209-3040

Robert Siemann
SLAC, MS-26
Stanford University
P.O. Box 4349
Stanford CA 94309

off. ph.: (415) 926-3892
FAX number: (415) 926-4999
siemann@slac.stanford.edu

Dennis Silverman
Dept. of Physics & Astronomy
U.C. Irvine
4129 Physical Sciences 2
Irvine, CA 92797-4575

off. ph.: (714) 824-5149
FAX number: (714) 824-2174
djsilver@uci.edu

Sunil Somalwar
Department of Physics
Rutgers University
P.O. Box 849
Piscataway NJ 08855

off. ph.: (908) 445-0745
FAX number: (908) 445-4343
sunil@ruthep.rutgers.edu

Ray Stefanski
Theory Group, MS 200
Fermilab
P.O. Box 500
Batavia IL 60510

off. ph.: (630) 840-3872
FAX number: (630) 840-8752
stefanski@fnal.gov

Andrew (Andy) Strominger
Department of Physics
University of California
Santa Barbara CA 93106

off. ph.: (805) 893-8245, 2420 msg
FAX number: (805) 893-2902
andy@denali.physics.ucsb.edu

Robert (Bob) Sugar
Department of Physics
University of California
Santa Barbara CA 93106

off. ph.: (805) 893-4888, 3469 msg
FAX number: (805) 893-8838
sugar@sarek.physics.ucsb.edu

Valery Telnov
Institute of Nuclear Physics
630090 Novosibirsk
RUSSIA

off. ph.: (7)3832 359-533
FAX number: (7)3832 352-163
telnov@inp.nsk.su

Nobukazu Toge
KEK
National Lab. for High Energy Physics
1-1 Oho, Tsukuba
Ibaraki 305
JAPAN

off. ph.: +81(298)64-5224
toge@accad1.kek.jp

Alvin Tollestrup
Fermilab
Mail Stop 318
P.O. Box 500
Batavia IL 60510

off. ph.: (630) 840-4331
FAX number: (630) 840-2968
alvin@fnal.gov

Anthony Veletto
Department of Physics
University of California
405 Hilgard Avenue
Los Angeles CA 90024-1547

off. ph.: (310) 777-3725, 3440 msg
FAX number: (310) 825-4057
veletto@physics.ucla.edu

Scott Willenbrock
Department of Physics
University of Illinois
1110 West Green Street
Urbana IL 61801

off. ph.: (217) 333-4392, 3761 msg
FAX number: (217) 333-4990
willen@uihepa.hep.uiuc.edu

Perry Wilson
SLAC, MS-26
Stanford University
P.O. Box 4349
Stanford CA 94309

off. ph.: (415) 926-3163
FAX number: (415) 926-4999
PWILSON@SLAC.STANFORD.EDU

José Wudka
Department of Physics
University of California
Riverside CA 92521

off. ph.: (909) 787-4296
FAX number: (909) 787-4529
jose.wudka@ucr.edu

Herng Yao
Physics Department
Univ. of California
Irvine CA 92717

off. ph.: (714) 824-2174
FAX number: (714) 824-2174
yao@hepxvt.ps.uci.edu

Pavel Zenkevitch
Institute for Theoretical & Experimental Physics
B Cheremushkinskaya Ulitsa 25
RU-117 259 Moscow
RUSSIA

off. ph.: (7)095 123-0292
FAX number: (7)095 123-6584
zenkevich@vitep3.itep.ru