BNL 66299

Proceedings of RIKEN BNL Research Center Workshop Volume 13

CONF-9810135--PROC.

PHYSICS OF THE 1 TERAFLOP RIKEN-BNL-COLUMBIA QCD PROJECT

October 16, 1998

Organizer

Robert Mawhinney

FIRST ANNIVERSARY CELEBRATION

October 16, 1998

RIKEN BNL Research Center

Building 510, Brookhaven National Laboratory, Upton, NY 11973, USA

Other RIKEN BNL Research Center Proceedings Volumes:

Volume 12 - Quarkonium Production in Relativistic Nuclear Collisions - BNL-
September 28–October 2, 1998 - Organizer: Dmitri Kharzeev

Volume 11 - Event Generator for RHIC Spin Physics - BNL-66116
September 21–23, 1998 - Organizers: Naohito Saito and Andreas Schaefer

Volume 10 - Physics of Polarimetry at RHIC - BNL-65926
August 4–7, 1998 - Organizers: Ken Imai and Doug Fields

Volume 9 - High Density Matter in AGS, SPS and RHIC Collisions - BNL-65762
July 11, 1998 - Organizers: Klaus Kinder-Geiger and Yang Pang

Volume 8 - Fermion Frontiers in Vector Lattice Gauge Theories - BNL-65634
May 6–9, 1998 - Organizers: Robert Mawhinney and Shigemi Ohta

Volume 7 - RHIC Spin Physics - BNL-65615
April 27–29, 1998 - Organizers: Gerry Bunce,
Yousef Makdisi, Naohito Saito, Mike Tannenbaum and Aki Yokosawa

Volume 6 - Quarks and Gluons in the Nucleon - BNL-65234
November 28–29, 1997, Saitama, Japan
Organizers: Tashiaki Shibata and Koichi Yazaki

Volume 5 - Color Superconductivity, Instantons and Parity (Non?)-Conservation at
High Baryon Density - BNL-65105
November 11, 1997 - Organizer - Miklos Gyulassy

Volume 4 - Inauguration Ceremony, September 22 and
Non-Equilibrium Many Body Dynamics - BNL- 64912
September 23–25, 1997 - Organizer - Miklos Gyulassy

Volume 3 - Hadron Spin-Flip at RHIC Energies - BNL-64724
July 21 - August 22, 1997 - Organizers: T.L. Trueman and Elliot Leader

Volume 2 - Perturbative QCD as a Probe of Hadron Structure - BNL-64723
July 14–25, 1997 - Organizers: Robert Jaffe and George Sterman

Volume 1 - Open Standards for Cascade Models for RHIC - BNL-64722
June 23–27, 1997 - Organizer - Miklos Gyulassy

Photographs by Joseph Rubino, Minoru Yanokura, BNL Video and the Information Technology Division

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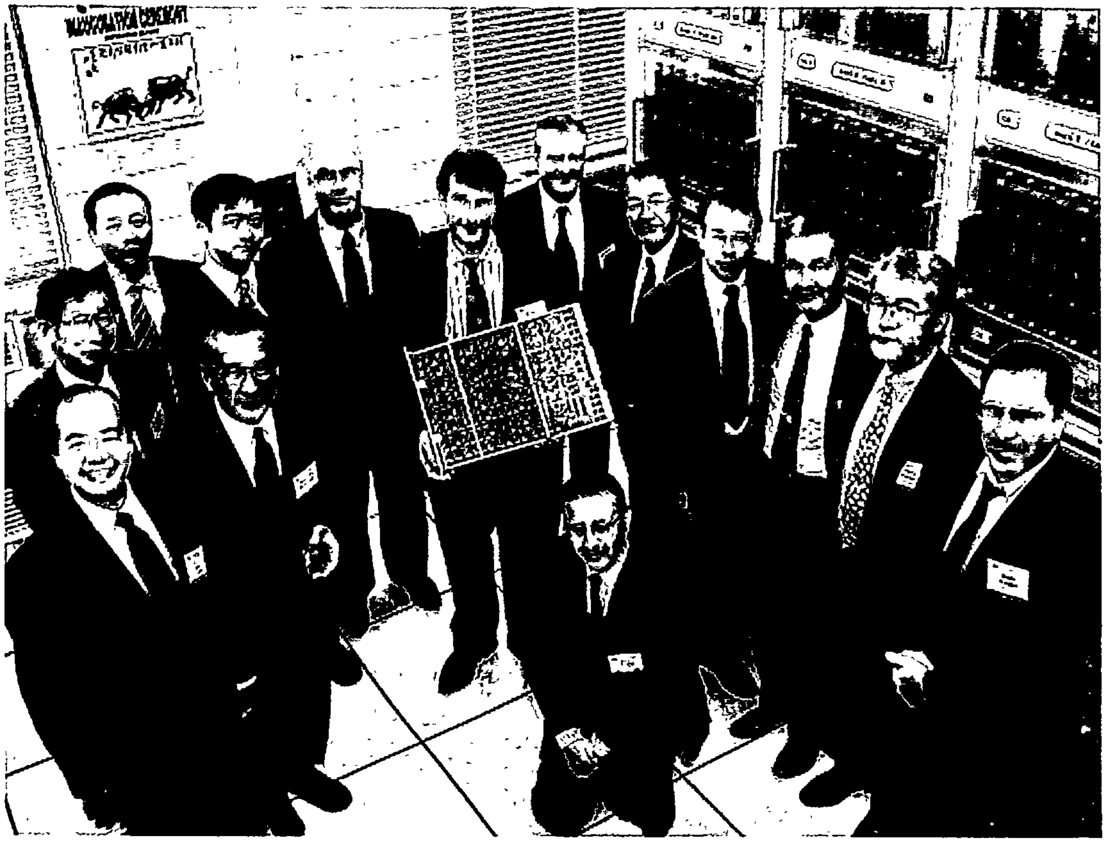
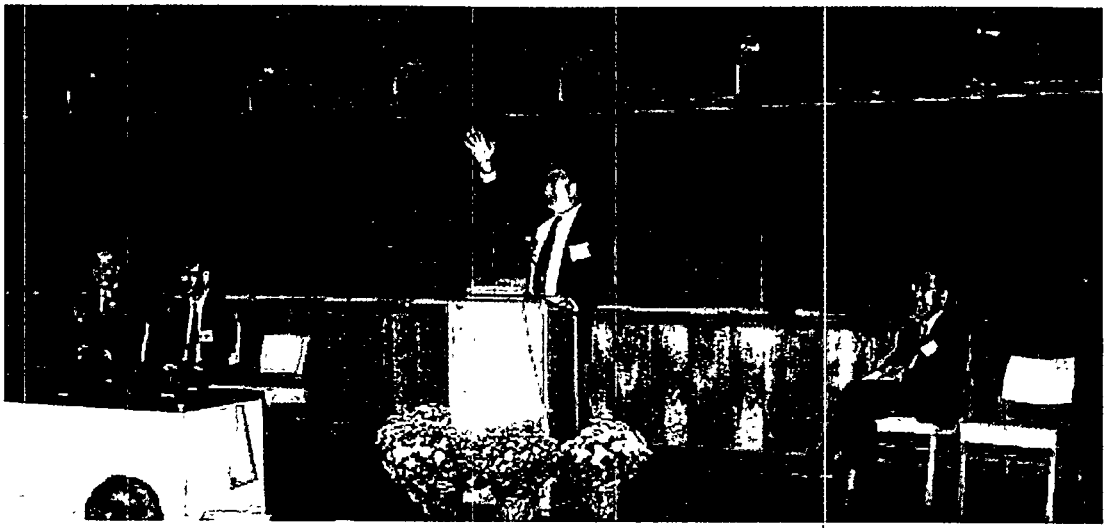
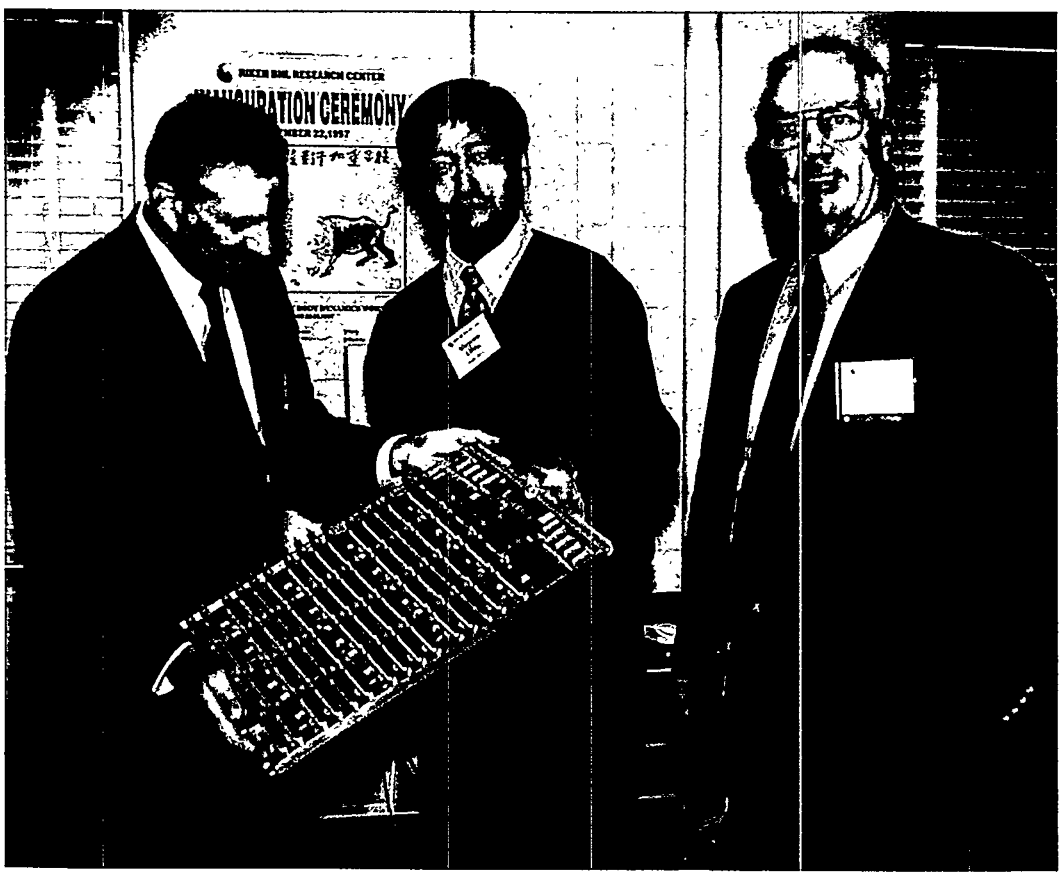


Top Photo. (Clockwise, from left)
T. D. Lee, RIKEN BNL Research Center (RBRC) Director, Columbia University (CU);
Shun-ichi Kobayashi, President of RIKEN, The Institute of Physical &Chemical Research, Japan; Kouichi Yazaki, University of Tokyo, Japan; Minoru Yanokura, RIKEN;
Shigemi Ohta, RBRC and KEK, Japan;
Edward McFadden, BNL;
Robert Mawhinney, CU;
John Marburger, BNL Director; Satoshi Ozaki, RHIC Project Director, BNL;
Norman Christ, CU;
Fujio Sakauchi, RIKEN; Akira Ukawa, University of Tsukuba, Japan;
Raph Kasper, CU; and (center)
Nicholas Samios, RBRC Deputy Director.

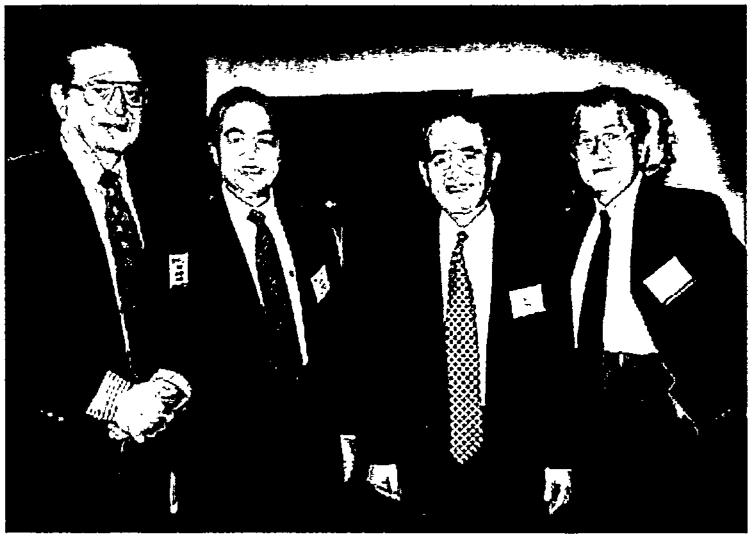
Photo Left.
Shun-ichi Kobayashi,
President of RIKEN, Japan



Dr. John H. Marburger, Director, Brookhaven National Laboratory



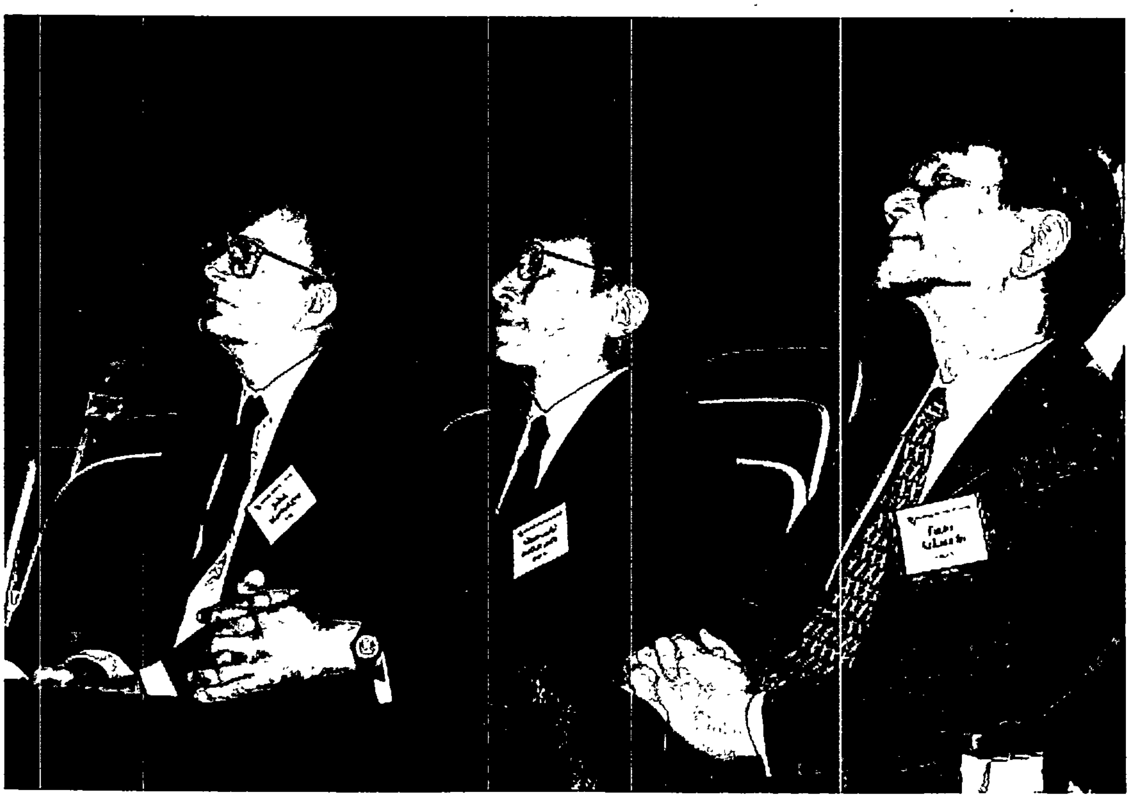
Dr. John H. Marburger (BNL), Dr. Shigemi Ohta (KEK/RBRC), and Mr. Edward McFadden (BNL)



Dr. Nicholas P. Samios, Professor T. D. Lee,
Dr. Akira Masaike, and Dr. Satoshi Ozaki

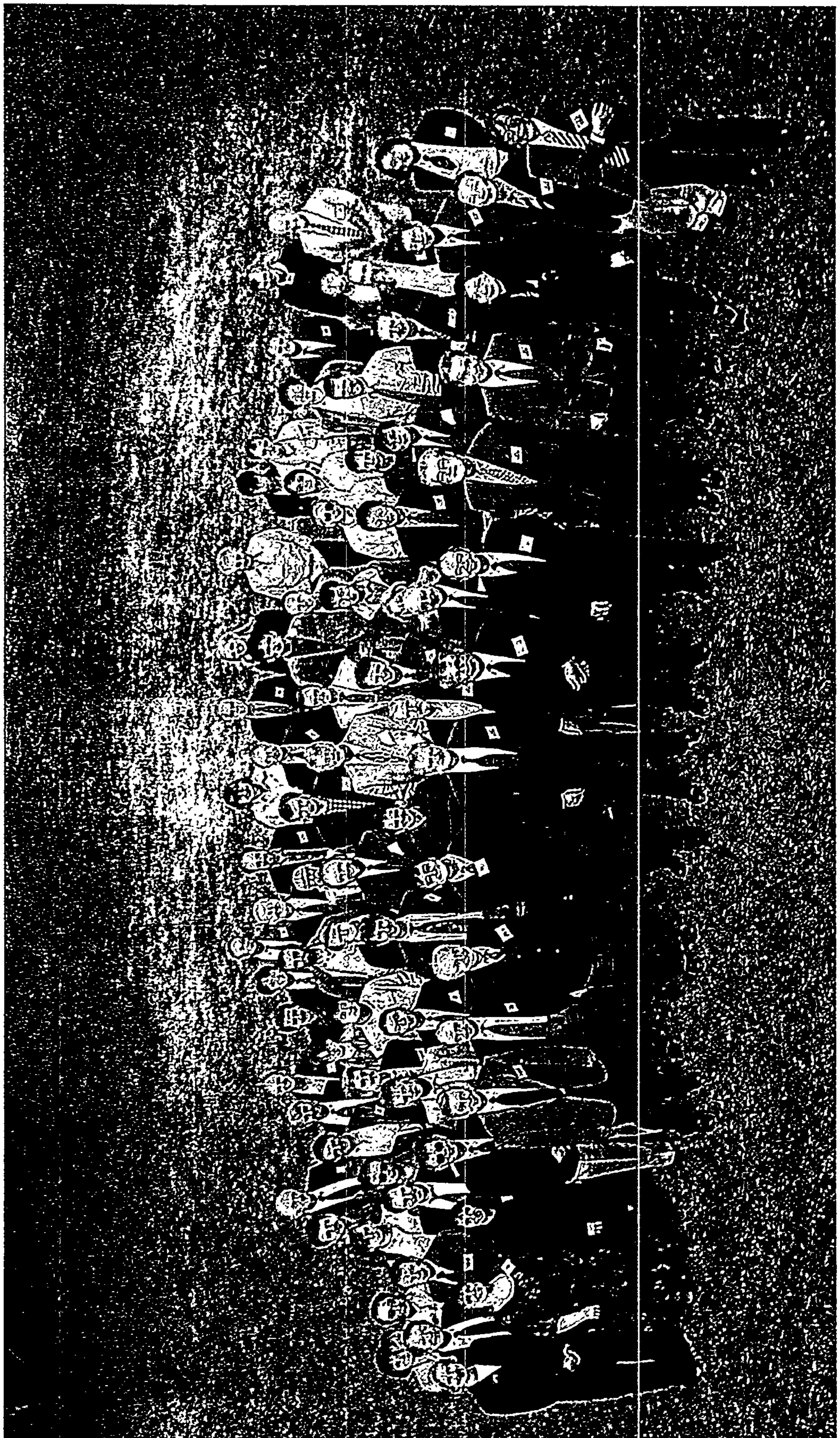
Dr. Satoshi Ozaki (BNL, RHIC Project Director)
Chairperson of the RBRC First Anniversary Symposium

Professor Tsung-Dao Lee, Director, RBRC; Columbia University
Presentation at the RBRC First Anniversary Symposium/Celebration



Akiko Arima, Michael J. Tannenbaum (BNL), George Sterman (SUNY, SB), Peter Bond, Nicholas P. Samios, Yousef Makdisi, Richard Melucci, and Satoshi Ozaki (BNL)

Shigemi Ohta, Doris Rueger, Rae Greenberg, Fern Simes, and Akiko Arima with the RIKEN-BNL Supercomputer



RIKEN BNL Research Center

Bldg. 510, Brookhaven National Laboratory, Upton, NY 11973, USA

FIRST ANNIVERSARY CELEBRATION

Friday, October 16, 1998
Brookhaven National Laboratory
Physics Department, Large Seminar Room

PROGRAM

09:00 AM	Registration Desk Opens *(Physics Department, Seminar Lounge)*
10:00 AM	*SYMPOSIUM*
	Chairperson: Doctor Satoshi Ozaki
	Addresses by: Professor Shun-ichi Kobayashi, President of RIKEN Doctor John H. Marburger, III, Director of BNL Professor T. D. Lee, Director of RIKEN BNL Research Center Professor Shigemi Ohta, RIKEN BNL Research Center & KEK
11:15 AM	Tour of 0.6 Teraflop Computer, Building 515
12:00 Noon	Luncheon *(Berkner Hall, Room B)*
02:00 PM	*Parallel Program*
	Tour of BNL Facilities: RHIC, NSLS, and IMAGING CENTER *(Meet at Berkner Hall)*
	Workshop: Physics of 1 Teraflop RIKEN-BNL-Columbia QCD Project *(Physics Department, Small Seminar Room)* Organizer: Robert Mawhinney

Remarks by RIKEN President Shun-ichi Kobayashi on the occasion of the first anniversary of the RIKEN BNL Research Center

My name is Dr. Kobayashi. I became the president of RIKEN this August after the resignation of the former president, Professor Arima. I previously did research in Low Temperature Physics for many years at the Tokyo and Osaka Universities.

Recently, Riken has expanded many projects. Last year, we established the RIKEN BNL Research Center, the Brain Science Research Center, and started the RIBF construction project in Accelerator Science, which is one of RIKEN's traditional research fields. We also celebrated the opening of the Genome Science Center last October, which is dedicated to new research in the field of Genome Science. Concerning this RIKEN BNL Research Center, we have great pleasure in the completion of the dedicated Computer, which is one of the most powerful Computers for Lattice QCD in the world. Together with the collaborative relationship with Columbia University and BNL, staff and the researchers for this development should be congratulated for their effort to finish it within one year.

As experimental studies have to be done from a scientific point of view, the experiments using the high energy Relativistic Heavy Ion Collider (RHIC) facility--which is under construction at BNL--will provide the answer. We think it is quite important for researchers at RIKEN to have a collaborative research agreement between BNL and RIKEN over the RHIC experimental project. The establishment of an experimental group at the RIKEN BNL Research Center means that the members of the Center would play an active part in both the experimental and theoretical fields.

Finally, I wish the Center a lot of success under the excellent leadership of Professor T. D. Lee with support from BNL, and a number of leading universities as well.

Shun-ichi Kobayashi

Remarks by BNL Director John Marburger on the occasion of the first anniversary of the RIKEN/BNL Research Center

I first learned about the RIKEN/BNL Research Center from its distinguished Director T.D. Lee and co-founder Nick Samios. At first I suspected them of exaggerating because it was difficult for me to understand how a Center so recently established could have accomplished so much. But the accomplishments have been tangible: workshops, publications, the formation of a small but vibrant research community, even the actual construction of a "supercomputer" optimized for quantum chromodynamics calculations, and advances in software needed to exploit it.

Before long the mystery of such rapid accomplishment became clear to me. Each partner had been inspired by the vision of Director Lee about what could be accomplished with such a center at the Brookhaven National Laboratory. The idea of an intellectual community to take advantage of the discoveries soon to be made at BNL's Relativistic Heavy Ion Collider is very compelling. The administrations at BNL and at RIKEN moved immediately to take advantage of Professor Lee's willingness to lead the Center. T.D. Lee's vision, energy, and charismatic leadership drew intellectual support from many quarters, and soon the exciting and productive group was formed whose accomplishments we are celebrating now.

Few such centers have become so productive in such a short time. Already in its first year this Center has become an indispensable part of the Brookhaven National Laboratory mission. I pledge to you my support to keep up this momentum. As the vision of RHIC becomes a reality during 1999, the vision of the RIKEN/BNL Center will grow into a position of leadership in the new world of physics RHIC will unveil. I wish to extend my deep gratitude to the leaders of RIKEN to make this marvelous asset available to us. And I look forward eagerly to anniversary number two!

John Marburger

First Anniversary Celebration*

President Kobayashi, Director Marburger, Distinguished Guests and Colleagues:

We are here to celebrate the first anniversary of the RIKEN BNL Research Center. It may be appropriate to review some of the major events that led to the founding of the Center and what had been achieved during its first year.

- May 16 - 17, 1996
  My first visit to RIKEN
  Discussion with Dr. A. Arima
  Vision of a new Center
- September 22, 1997
  Inauguration of the RIKEN BNL Research Center
- February 19, 1998
  Beginning of the 0.6 Teraflop
  Supercomputer construction
- August 28, 1998
  Completion of the Supercomputer
- October 16, 1998
  First Anniversary Celebration

On May 16th and 17th, 1996, I was invited by Dr. Akito Arima to Riken. Although that was my first visit, I had known for a long time that much of the strength of Japan's scientific achievement began at the Institute of Physical and Chemical Research. This was the center where Dr. Yoshio Nishina founded his famous school of physics. Many physicists were trained there, including Hideki Yukawa and Shinichiro Tomonaga. I knew both of them quite well. Professor Yukawa was at Columbia University from 1949 to 1953, and he received his Nobel Prize while he was a professor there. It was his return to Japan that opened up a theory position which I accepted, and it is his office at Columbia that I have occupied since 1953.

On my way from the airport to RIKEN, I was thinking of Dr. Nishina and his landmark paper on the Klein-Nishina formula, which he wrote as a young scientist at the Niels Bohr Institute. I thought of the connection of the Niels Bohr Institute to RIKEN through Nishina, and of RIKEN to Columbia through Yukawa. Each of these institutions made revolutions in physics that were of permanent value. The people involved in each place were not many. Yet, their research led to changes that affected almost everyone. The continuity between these relatively small groups of exceptional people, linked together in their common search for the basic laws of nature, extending over nearly a century from continent to continent, gives me faith in the nobility of humankind.

In my meeting with Dr. Arima, our conversation naturally turned to the subject of scientific creativity and the best way to nurture it. The Niels Bohr Institute played

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* Given by T.D. Lee during the First Anniversary celebration of the RIKEN BNL Research Center on October 16, 1998.

an essential role in the development of quantum mechanics in the 1920's. At that time, Bohr had already formulated his quantization rule and Einstein had completed his Theory of Relativity. A new generation of physicists went through the Bohr Institute, including Heisenberg, Dirac, Pauli, Nishina, and others. While Bohr and Einstein were still active at that time, they did not discover quantum mechanics. Quantum mechanics was created by this new group of young physicists, mostly in their twenties.

In the 1930's and 1940's, there were new challenges in nuclear forces and quantum electrodynamics. At that time, the heroic generation who created quantum mechanics was still active. Yet these new challenges were met and resolved by another group of younger theorists and experimentalists, Yukawa, Tomonaga at RIKEN, Schwinger, Lamb, Kusch at Columbia and Feynman, Dyson at Cornell. Again, almost all were in their twenties and thirties.

In the 1950's came the strange particles and their puzzling behavior. Once more, the new physics was made by yet another young generation of physicists: Gell-Mann, Nambu, Yang, myself and others. Then, in the late 1960's and 70's, there remained the tasks of completing the unification of the electromagnetic and the weak interactions into a single electroweak force and the formulation of the strong interaction in terms of quantum chromodynamics. These problems were solved by still another generation of young physicists, Weinberg, Glashow, Politzer, 't Hooft and others.

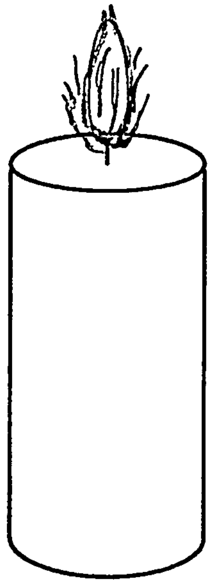
The progress of physics depends on young scientists facing new challenges. To create the new physics, there has to be the right place at the right time for these young scientists. This pattern will not change.

I mentioned to Dr. Arima that the time is now ripe for another revolution in physics, one which will connect the microscopic particle with the macroscopic state of the physical vacuum. When the Relativistic Heavy Ion Collider is turned on in 1999 at BNL, we expect a new state of matter to be created in which chiral symmetry will be restored and the confinement of quarks and gluons in normal nuclear matter will no longer hold. The actual discovery of this state is yet to be made. If realized, it will open the door to a new realm in which, for the first time, the coherent properties of the vacuum can be changed through experimental means. These changes will become an integral part of the new physics that determines the behavior of subnuclear particles. RHIC physics is at the forefront of our science. It intersects with nuclear, particle and relativistic condensed matter physics. And once again, the forging of this frontier and the search for the new laws of physics will be done by another generation of young physicists.

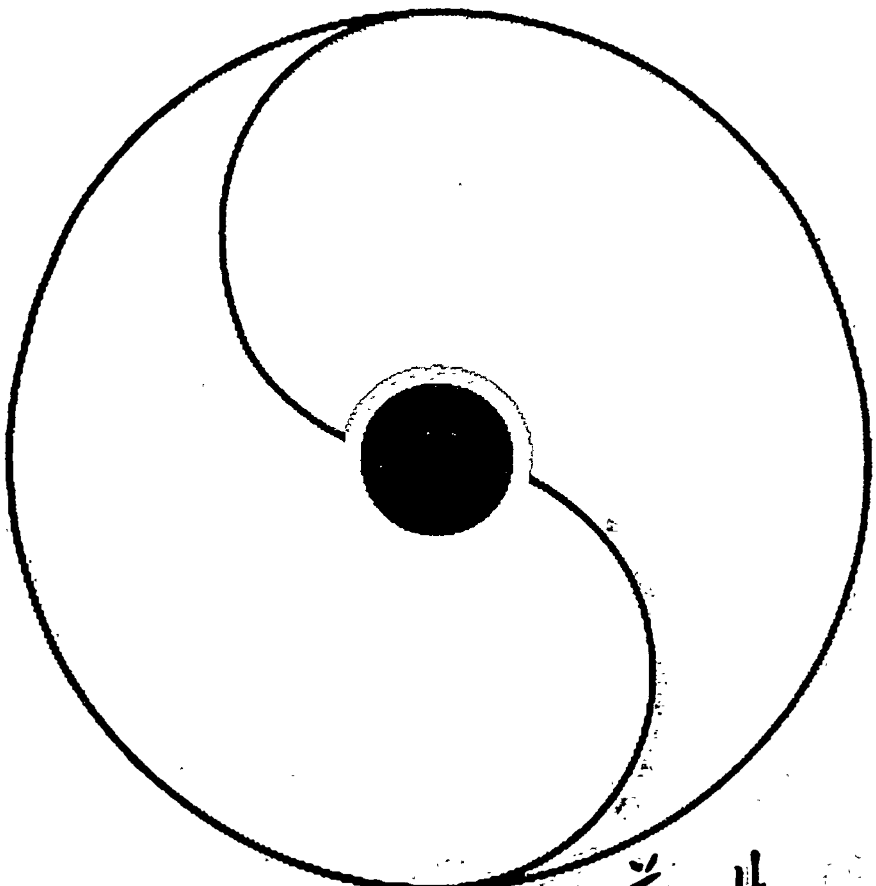
Dr. Arima and I both felt that a new center dedicated to this quest should be created, and that it would be best located near the RHIC accelerator. We also agreed that the center should have both theorists and experimentalists so that the theoretical and experimental discoveries will come hand in hand.

We then discussed how large the theoretical component should be. I mentioned that, in order for the young scientists to have close interaction with each other, the core theory group cannot be too large, about fifteen would be nearly ideal. This was the case during the most creative periods at the Niels Bohr Institute in the 1920's and at the Institute for Advanced Study in Princeton in the late 1940's and early 1950's. Dr. Arima agreed with my general idea.

This is how the RIKEN BNL Research Center came into being.
The RBRC logo, which I designed, reflects the spirit of the Center and the philosophy of Lao Tse. Science is the Unity. RIKEN and BNL form the Duality, with the Center we become the Trinity. From the Trinity all others follow.



First Anniversary



The Tao generates one
One generates two,
Two generates three,
Three generates
ten thousand things.

道生一
一生二
二生三
三生萬物

- Lao Tse (6th century BC)

The RIKEN BNL Research Center was inaugurated on September 22, 1997, and I was appointed the Director on October 1st. As mentioned before, the Center is dedicated to the research of strong interaction physics. It started with a Theory Division, and more recently also introduced an Experimental Division. The present scientific staff members are listed below:

RBRC RESEARCH SCIENTISTS

Fellows:	T. Blum	D. Khazeer	D. Rischke
	M. G. Perdekamp (E)		
Postdocs:	D. Boer	H. Fujii	S. Sasaki
	J. Schaffner-Bielich	M. Wingate	Y. Yasui

Senior Scientists (mostly volunteers) and Experimental Collaborating Scientists:

A. Baltz	G. Bunce (E)	M. Gyulassy	T. Ichihara (E)
R. Jaffe	K. Kunita (E)	T. D. Lee	R. Mawhinney
S. Ohta	N. Saito (E)	N. Samios	E. Shuryak
Y. Watanabe (E)			

The experimental group is still in its infancy. We are currently in the middle of selecting the experimental postdocs. On the theory side, there are nine fellows and postdocs at present. The original projection for fifteen full time positions will be achieved in the next two years.

I will now turn to our academic activities:

Weekly Seminars

Spin Physics	Tuesdays	Organized by R. Jaffe and G. Bunce
Nuclear and High Energy Theory	Wednesdays	Organized jointly with BNL theorists
QCD and RHIC Physics	Thursdays	Organized by D. Richke

Physics is everywhere at the Center, in the offices, at the corridors, around the coffee machine and during lunches. These weekly seminars provide the main arteries of communications in-depth discussions. They are all well attended. Besides the RBRC members, active scientists from BNL, Columbia, Stoney Brook are regular participants.

The Tuesday spin physics seminar organized by Bob Jaffe and Gerry Bunce deserves a special mention. The participants consists half of theorists and half of experimentalists. In the short span of a year, it has unified the scientific community active in this field. With the RHIC accelerator to be on-line next year, BNL will be the world center of spin physics research. The RBRC Tuesday seminars have succeeded in defining the critical spin experiment which have to be done and in focusing on the important physics information that should be extracted. This is an excellent example of the close working relationship between the theory and experimental divisions of the RIKEN BNL Research Center.

The research activities and the intellectual intensity of the Center are further enriched by the RBRC Workshops. Each Workshop centers on a specific important problem in strong interaction physics. The participants consist of the Center scientists and other leading experts from all over the world. A useful feature is to have rapid publication of the proceedings, so that the results of the workshops can be readily disseminated. Here, at the Center the proceedings are available within a few weeks after the workshops. This is another unique feature of the Center.

To date, twelve workshops have already taken place at RBRC, of theses, four are on spin physics and eight on RHIC and other QCD physics. These are listed in Table 1, together with the upcoming RBRC workshops. The first nine proceedings have already been distributed world-wide. Within this Japan Fiscal Year, five more workshops will take place. This afternoon, as part of the First Anniversary Celebration, there will be a workshop organized by Bob Mawhinney on the "Physics of one Teraflop RIKEN - BNL - Columbia QCD Project."

A test of the quality of any research institution is that of its scientific publications. The lastest count gives 31 scientific papers written by RBRC members. Table 2 gives the list of these papers.

The construction of the 0.6 Teraflop RIKEN BNL Research Center Supercomputer began on February 19th of this year and was completed on August 28th. This must be a world record for speed of construction. It has just been awarded the SC98 Golden Bell Finalist for Price Performance. I wish to thank the Brookhaven CCD scientists for their help and support.

The RBRC 0.6 Teraflop is working in tandem with the Columbia 0.4 Teraflop forming the combined RIKEN-BNL-Columbia one Teraflop QCD project. The Columbia component was funded through the U.S. Department of Energy. We are fortunate to have the leadership of Norman Christ and Bob Mawhinney for this joint project. There are already a number of new physics results that have been obtained, both within QCD and without, demonstrating the flexibility of this supercomputer.

Measured against all the World's fastest supercomputers the RBRC 0.6 Teraflop takes the twelfth place. When combined with the Columbia 0.4 Teraflop, the RIKEN BNL Columbia Teraflop QCD project ranks number eight, topped primarily by the defense driven organizations, such as National Security Agency, Sandia, ONR, · · · . Among non-defense related research projects, ours is second only to the JPL of Cal Tech.

RIKEN • BNL • Columbia

Quantum Chromodynamics (QCD) Project

Quantum Chromodynamics (QCD) Project

Total Peak Speed: 1100.8 Gflops

Given the enormous computational demands of quantum field theory and the easily parallelized nature of this problem, it is natural to design and build massively parallel machines whose design is optimized for this type of calculation.

The QCDSP *(Quantum Chromodynamics on Digital Signal Processors)* computers designed at Columbia are such machines.

RIKEN • BNL Research Center

Columbia University Center

SC98

Gordon Bell Prize "WINNER" for Price Performance

List of the world's top 12 most powerful computing sites

National Security Agency	1) 4088.76 - (18-JUN-1998) [NSA]
Sandia National Laboratories	2) 2225.28 - (03-SEP-1998) [SANDIA]
Office of Naval Research	3) 2000 - (16-JUN-1998) [ONR]
Los Alamos	4) 1585.99 - (08-SEP-1998) [LANL]
Gov't Comm Hqts	5) 1360 - (13-JUL-1998) [GCHQ]
California Institute of Technology	6) 1222.32 - (20-AUG-1998) [JPL-CALTECH]
	7) 1181.97 - (04-SEP-1998) [LLNL]
東京大學 The University of Tokyo	8) 1080 - (27-AUG-1998) [C]
BMDOLINK BALLISTIC MISSILE DEFENSE ORGANIZATION	9) 1000 - (16-JUN-1998) [BMDO]
IRVINE SENSORS CORP. Inventors of 3D Semiconductor Products for a New Generation	10) 1000 - (04-SEP-1998) [IRVINE-SENSORS]
Meteorological Office	11) 792 - (05-NOV-1997) [METO]

12) 665.6 - (11-SEP-1998) [BNL]
1) Riken/BNL QCDSP/12288 614.4
2) Riken/BNL QCDSP/1024 51.2

14-SEP-1998

National Security Agency · United States of America

1) 4088.76 - (18-JUN-1998) [NSA]

Sandia National Laboratories

2) 2225.28 - (03-SEP-1998) [SANDIA]

Office of Naval Research
ONR
800 N. Quincy St., Arlington, VA 22217-5660

3) 2000 - (16-JUN-1998) [ONR]

Los Alamos

4) 1585.99 - (08-SEP-1998) [LANL]

Gov't Comm Hqts

5) 1360 - (13-JUL-1998) [GCHQ]

California Institute of Technology 1891

6) 1222.32 - (20-AUG-1998) [JPL-CALTECH]

7) 1181.97 - (04-SEP-1998) [LLNL]

RIKEN · BNL · Columbia
Quantum Chromodynamics (QCD) Project

8) 1100.8 - (11-SEP-1998) [BNL]

RIKEN-BNL-Columbia (QCD) Project

1)	Columbia University Center	QCDSP/8192	409.6
2)	Riken/Brookhaven Natl Lab	QCDSP/12288	614.4
3)	Columbia University Center	QCDSP/1024	51.2
4)	Riken/Brookhaven Natl Lab	QCDSP/512	25.6

東京大學
The University of Tokyo

9) 1080 - (27-AUG-1998) [C]

BMDOLINK
BALLISTIC MISSILE DEFENSE ORGANIZATION

10) 1000 - (16-JUN-1998) [BMDO]

14-SEP-1998

At present we have nine of the fifteen theory slots filled. This forms a strong core group. The important task is how to utilize the remaining six full-time positions to realize the aim of the Center: the study of strong interactions through the nurturing of a new generation of young physicists. How can we attract globally the best young minds to our field, and how would we provide the best environment so that they can make the next revolution in physics? The new tenure track strong interaction theory/RHIC physics Fellow initiative may become a crucial step in realizing this objective.

At the beginning of this year, many of my colleagues told me that all theory tenure track positions in particle and high energy nuclear physics are in the string theory and cosmology. In March this year, as I made a lecture tour throughout the country, I discovered to my great surprise that this was true. It struck me as most astonishing that the entirety of the available theory tenure track positions can be narrowed to so limited a number of scientific endeavors. To explain, let me draw an analogy.

Imagine a scenario in 1917, the experiment or solar bending of light just confirmed the general theory of relativity. Einstein was at the pinnacle of his creativity, ready to move on to the ultimate unification of all theories. Suppose at that time the entire physics community were to declare that all future theoretical physics positions should only be to follow Einstein. We would have by now no quantum mechanics, no Schroedinger equation, no Dirac equation, · · · . It would be the end of modern physics.

Now by 1917, Einstein had succeeded not only in his theory of relativity, but also had developed the theories of Brownian motion, photo-electricity, solid vibrations, · · · , a body of work extending to almost all branches of physics. Now, in 1917 even Einstein could not predict the direction which physics would take in the immediate following decade from 1917 to 1927.

No single physicist, no matter how great and no single school of physicists can safely predict the future. That we now should place nearly our entire high energy theory support into string theories and cosmology is a matter of great concern. Even more so, after two decades, the string theory had zero success in predicting any physics phenomenon that can be subject to a rigorous and quantitative test.

It occurred to me that this nearly disastrous situation might provide a golden opportunity for the RIKEN BNL Research Center. On April 14, Dr. Jack Marburger and I launched a new initiative:

New Tenure Track Strong Interaction Theory
RHIC Physics Fellow Program

- Each Fellow spends half time at RBRC and half at the participating institution.
- Each participating institution must hold a tenure track position in strong interaction physics (high energy nuclear theory, RHIC phenomenology, perturbative and lattice QCD, hadronic spin physics, hadronic spectra and matrix elements).

To date seven institutions have joined this initiative; that means seven new tenure-track positions have been created. In this new program, RBRC supports each Fellow only for the time that the Fellow is at the Center. Thus, the six unfilled positions become 12 RHIC Physics Fellows. This new initiative aims at the entire physics community globally. The international character and especially the balance of the strong Japanese component of the present theory group will be maintained and strengthened.

I am confident, with this new initiative, RBRC will attract the best young talents, and be ready for the physics that will come out of the RHIC accelerator. What are the challenges in modern physics? Two of these challenges are listed below:

- Half of the elementary particles are unfree.
- Lack of precision QCD calculations.

How should we meet them. This is the Year of the Tiger, so I made two sketches.

1998 is
the year of
the tiger.

10/16/98

TDL

With intelligence

10/16/98

With the help of a dedicated supporting team:

Irene Tramm

Pam Esposito

Rae Greenberg

Fern Simes

Doris Rueger (RHIC Project)

Professor T. D. Lee presenting bouquets to Fern Simes; Rae Greenberg, Doris Rueger and Pam Esposito at the First Anniversary Celebration Symposium

Table 1

Proceedings of RIKEN BNL Research Center Workshops

Volume 7 RHIC Spin Physics (BNL 65615)
April 27-29, 1998 — Organizers: Gerry Bunce, Yousef Makdisi, Naohito Saito, Mike Tannenbaum, Larry Trueman and Aki Yokosawa

Volume 8 Fermion Frontiers in Vector Lattice Gauge Theories (BNL 65634)
May 6-9, 1998 — Organizers: Robert Mawhinney and Shigemi Ohta

Volume 9 High Density Matter in AGS, SPS and RHIC Collisions (BNL 65762)
July 11, 1998 (in conjunction with RHIC '98) — Organizers: Klaus Kinder-Geiger and Yang Pang

Volume 10 Physics of Polarimetry at RHIC (BNL 65926)
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Volume 12 Quarkonium Production in Relativistic Nuclear Collisions (in preparation)
September 28 - October 2, 1998 — Organizer: Dmitri Kharzeev

Volume 13 Physics of the 1 Teraflop RIKEN-BNL-COLUMBIA QCD Project — First Anniversary Celebration (in preparation)
October 16, 1998 — Organizer: Robert Mawhinney

Volume 14 Quantum Fields In & Out of Equlibrium (in preparation)
October 26-30, 1998 — Organizers: Dan Boyanovsky, Hector De Vega and Rob Pisarski

Volume 15 QCD Phase Transitions (in preparation)
November 4-7, 1998 — Organizers: Thomas Schaeffer and Edward Shuryak

Table 2

RIKEN BNL Research Center
Publication List

RBRC/#

1. H. Fujii and H. Shin, "Dilepton Production in Meson Condensed Matter," Prog. Theor. Phys. 98, 1139 (1997).

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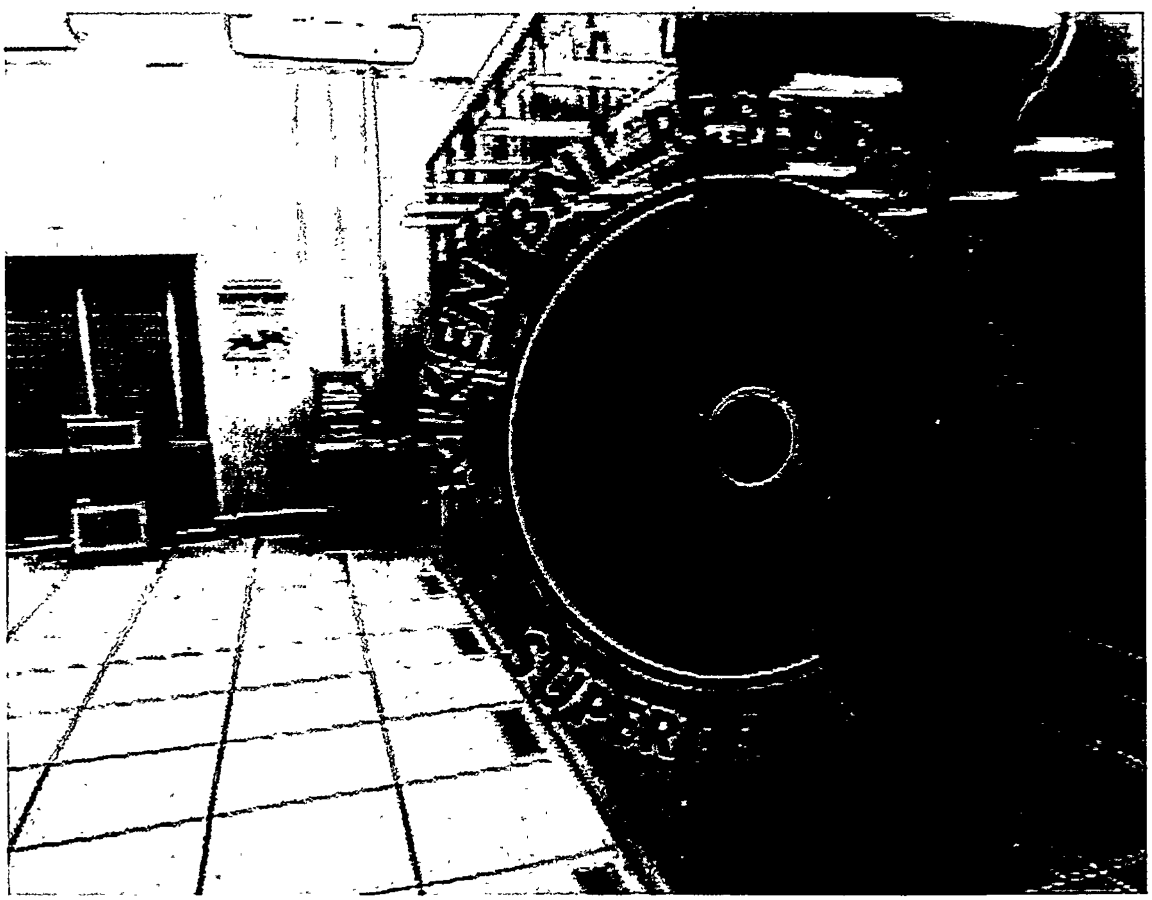
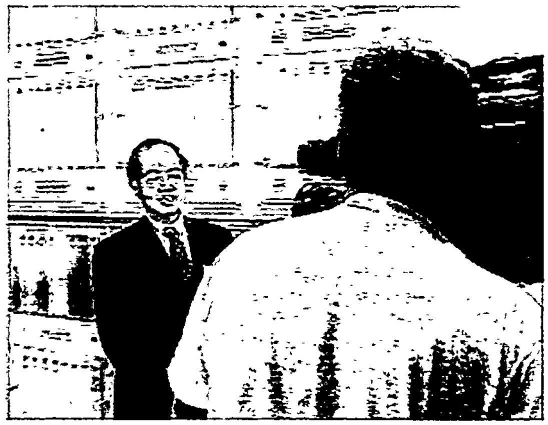
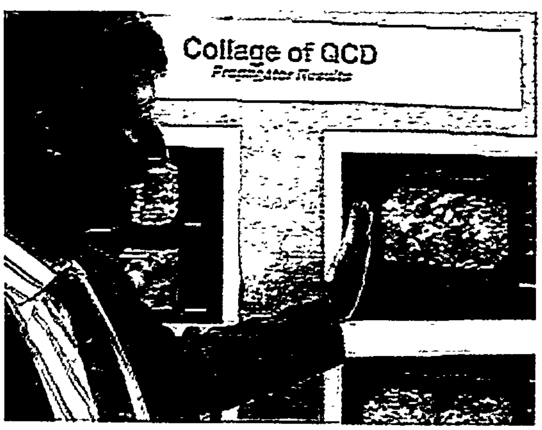
Workshop on Physics of the 1 Teraflop RIKEN-BNL-Columbia QCD Project

October 16, 1998








Collage of QCD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Preface to the Series

The RIKEN BNL Research Center (RBRC) was established in April 1997 at Brookhaven National Laboratory. It is funded by the "Rikagaku Kenkysho" (Institute of Physical and Chemical Research) of Japan. The Center is dedicated to the study of strong interactions, including hard QCD/spin physics, lattice QCD and RHIC physics through nurturing of a new generation of young physicists.

During the first year, the Center had only a Theory Group. At present, the Theory Group consists of nine Postdocs and Fellows and has an active Visiting Scientist program. In addition, the Center organizes workshops centered on specific problems in strong interactions.

Now, at the Center's first anniversary celebration, an Experimental Group has been started and construction of a 0.6 teraflop parallel processor which was begun at the Center on February 19, 1998 was completed on August 28, 1998. In addition, a new Tenure Track Strong Interaction Theory RHIC Physics Fellow Program is under way. To this date eight institutions have joined this initiative. The Center had has held twelve workshops thus far.

Each workshop speaker is encouraged to select a few of the most important transparencies from his or her presentation, accompanied by a page of explanation. This material is collected at the end of the workshop by the organizer to form a proceedings, which can therefore be available within a short time.

T. D. Lee
October 16, 1998

Introduction

A workshop was held at the RIKEN-BNL Research Center on the afternoon of October 16, 1998, as part of the first anniversary ceremony for the center. Titled "Workshop on Physics of the 1 Teraflop RIKEN-BNL-Columbia QCD Project", this meeting brought together the physicists from RIKEN-BNL, BNL and Columbia who are using the QCDSP (Quantum Chromodynamics on Digital Signal Processors) computer at the RIKEN-BNL Research Center for studies of QCD. In addition, Akira Ukawa, a leader of the CP-PACS project at the University of Tsukuba in Japan, attended and gave a talk on the Aoki phase. There were also others in attendance who were interested in more general properties of the QCDSP computer.

The QCDSP computer and lattice QCD had been presented during the morning ceremony by Shigemi Ohta of KEK and the RIKEN-BNL Research Center. This was followed by a tour of the QCDSP machine room and a formal unveiling of the computer to the attendees of the anniversary ceremony and the press. The rapid completion of construction of the QCDSP computer was made possible through many factors: 1) the existence of a complete design and working hardware at Columbia when the RIKEN-BNL center was being set up, 2) strong support for the project from RIKEN and the center and 3) aggressive involvement of members of the Computing and Communications Division at BNL. With this powerful new resource, the members of the RIKEN-BNL-Columbia QCD project are looking forward to advances in our understanding of QCD.

Many of the talks in the workshop were devoted to domain wall fermions, a discretization of the continuum description of fermions which preserves the global symmetries of the continuum, even at finite lattice spacing. This formulation has been the subject of analytic investigation for some time and has reached the stage where large-scale simulations in QCD seem very promising. Pavlos Vranas (until recently at Columbia) had investigated the 2-d Schwinger model and Tom Blum and Amarjit Soni had done a first measurement of the value for the B_K parameter for $K-\bar{K}$ mixing. Both calculations were successful and showed the formulation to be promising.

With the computational power available from the QCDSP computers, we are looking forward to an exciting time for numerical simulations of QCD. The expertise available from RIKEN-BNL, BNL and Columbia physicists should be a good match to the computational resources. Mike Creutz, in addition to taking part in the QCD related work, also talked about using QCDSP for other, non-QCD problems involving fermions.

We would like to thank Pam Esposito and Rae Greenberg for their help in organizing this workshop and the center for its continued support.

Thanks to Brookhaven National Laboratory and to the U.S. Department of Energy for providing the facilities to hold this workshop.

Robert D. Mawhinney

Organizer

RIKEN BNL Research Center

Workshop on Physics of the 1 Teraflop RIKEN-BNL-Columbia QCD Project
October 16, 1998
Physics Department - Room 2-160
Organizer: Robert Mawhinney

AGENDA

2:00 pm

	10 min	Mawhinney	*The QCDSP computer*
	30 min	Creutz:	*Grassmann integration on QCDSP*
	30 min	Soni:	*Open problems in weak matrix elements*
	20 min	C. Dawson:	*Non-perturbative Renormalization*
	20 min	Tim Klassen:	*Anisotropic lattices*
	20 min	Wingate:	*Quark masses*
4:10–4:30			Break
	30 min	Ukawa:	*Aoki Phase*
	20 min	Sasaki:	*Lattice study of correlation between instantons and monopoles*
	30 min	Christ:	*DWF zero modes in quenched theories*
	20 min	Siegert:	*$U(1)_A$ effects with domain wall fermions*
7:00 pm			Dinner

The QCDSP Computer

Robert Mawhinney
Columbia University

QCDSP

QCDSP stands for Quantum Chromodynamics on Digital Signal Processors. QCDSP was designed primarily by physicists (led by the group at Columbia) to provide low cost computational power for lattice QCD. It is a generally programmable, massively parallel computer with nodes connected in a four-dimensional nearest neighbor mesh.

Columbia University finished a 0.4 Teraflops, 8,192 node QCDSP machine in April, 1998. This machine, and its research and development costs, were paid by the U.S. Department of Energy.

The 0.6 Teraflops, 12,288 node QCDSP machine at RIKEN-BNL, was unveiled today. The first funds for this machine were spent in July 1997.

QCDSP Operating System

Two major componenets: Q-SHELL and QCDSP kernels.

1. The Q-SHELL runs on the host and is a derivative of tcsh with built-in commands to access QCDSP.

2. The QCDSP kernels are loaded when the machine boots and provide I/O from host to QCDSP as well as user support. Each node runs its own kernel, so QCDSP is fully MIMD.

During machine boot, the hardware is checked as the kernels are loaded. The four-dimensional configuration of the machine is determined as well as the topology of the boot network.

Example Q-SHELL commands

- qreset_boot: issues a hardware reset to QCDSP and boots the entire machine.
- qload myfile: loads myfile to specified node(s)
- qrun myprog: loads and runs myprog on specified node(s)
- qunload_lattice: unloads an SU(3) gauge field lattice from QCDSP to the host
- qread: show contents of QCDSP memory.

The Q-SHELL also contains a number of commands for hardware debugging, including checking for communications errors and errors local to a node.

QCDSP kernels

- No attempt to put UNIX on each node since it takes too much memory and provides unnecessary features.

- QCDSP kernels support standard C library calls. fopen(), fclose(), fprintf() access host file system from QCDSP. printf() prints to host screen.

- Kernel calls handle 4d communications

- Kernels allow arbitrary mapping of physics 4d coordinate axes to machine 4d coordinate axes.

- MPI not implemented, but could be.

Programming Environment

- Programs written and compiled on host
- Single motherboards used for debugging
- C, C++ and assembly languages available
- Only 2 Mbytes of memory per node.
- Limited memory bandwidth from DSP to DRAM. For better performance, must manage bandwidth by arranging location of data and code.
- C++ DSP programs cross-compile on host, except for communications calls.

Grassmann Integration on QCDSP

Michael Creutz
Brookhaven National Laboratory

Grassmann Integration on QCDSP

Michael Creutz

Brookhaven National Laboratory

Implement on QCDSP a direct evaluation of multiple Grassmann integrals

Why:
- A. New algorithms (chemical potential)
- B. What can QCDSP do?

Convert Grassmann integral to
Fock state manipulations

$$Z = \int (d\psi) e^{S(\psi)} = \langle 0| \ e^{S(a)} \ |F\rangle$$

- $[a_i, a_j^\dagger]_+ = \delta_{ij}$
- one a_i for each ψ_i
- $a_i|0\rangle = 0$
- $|F\rangle \equiv a_n^\dagger ... a_2^\dagger a_1^\dagger |0\rangle$

- expand e^S
- one factor of a_i for each Fermion
- same rule as for Grassmann integration

Integrate sequentially

- pick one variable a_i
- define S_i as all terms involving a_i
- $\tilde{S}_i$ everything else
- $S = S_i + \tilde{S}_i$
- assume bosonic action so S_i and $\tilde{S}_i$ commute

$$Z = \langle 0|e^{\tilde{S}_i} e^{S_i}|F\rangle$$

$\tilde{S}_i$ contains no a_i

- $\langle 0|e^{\tilde{S}_i} \ n_i = 0$
- $n_i = a_i^\dagger a_i$
- insert projection operator $1 - n_i$

$$Z = \langle 0|e^{\tilde{S}_i} \ (1 - n_i) \ e^{S_i}|F\rangle$$

$a_i^2 = 0$

- S_i is linear in a_i
- $e^{S_i} = 1 + S_i$

$$Z = \langle 0 | e^{\tilde{S}_i}\ (1 - n_i)\ (1 + S_i) | F \rangle$$

$1 - n_i$ is a projection

- $a_i\ (1 - n_i) = 0$
- $S_i\ (1 - n_i) = 0$
- $\tilde{S}_i\ (1 - n_i) = S\ (1 - n_i)$
- replace $\tilde{S}_i$ with full action S

$$Z = \langle 0 | e^{S}\ (1 - n_i)\ (1 + S_i) | F \rangle$$

Repeat for all sites

$$\boxed{Z = \langle 0 |\ \prod_i\ (1 - n_i)\ (1 + S_i)\ | F \rangle}$$

Algorithm:

- initialize with full state
- loop over sites:
- apply $1 + S_i$
- apply $1 - n_i$
- return coefficient of empty state

With a local interaction

- finished sites empty
- new sites out of range filled
- nontrivial only in transverse volume
- sparse state space ideal for hash storage

1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
X	X	X	X	X	1	1	1	1	1
0	0	0	0	Ψ	X	X	X	X	X
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

- only sites labeled "X" undetermined
- only store information on those rows

Hash Tables

- $|\psi\rangle = \sum_s \psi_s |s\rangle$
- i.e. store and retrieve $\psi(|s\rangle)$

Make a three column table:

- state $|s\rangle$; bits $\leftrightarrow$ occupations
- coefficient ψ_s
- flag for active table element

Hash function $h(|s\rangle)$

- returns "pseudo-random" trial location
- let state "seed" a random number generator

Storing $(\psi, |s\rangle)$ pair:

- i=$h(|s\rangle)$
- until stored:
-     if i empty or i holds $|s\rangle$ store $(|s\rangle, \psi)$
-     i $\leftarrow$ i+1

Fetching $\psi(|s\rangle)$:

- i=$h(|s\rangle)$
- until done:
-     if i empty return 0
-     if i holds $|s\rangle$ return ψ
-     i $\leftarrow$ i+1

Advantages

- fast lookup $O(1)$ on average, $O(n)$ worst case
- search only to next empty site
- don't store zeros
- absent states don't take up space
- symmetries automatic

Garbage collection

- for removing states
- $1 - n_i$ projection
- dynamical table growth
- translation: combine equivalent states

Sweep table

- remove and reinsert each element

- repeat to stability
- works in parallel

On QCDSP

Based on my communication routines

- #define DATASIZE element
- #include communication.C
- allocate(n) get space for n elements
- store(i,x) store element x in location i
- fetch(i) return element from location i
- worksync() resolve all stores/fetches
- http://thy.phy.bnl.gov/~creutz/qcdsp

also included

- add(i,x) like store but adds to existing x
- onnode(i) true if element on current node
- utilities (global sum, global and, ...)

Enhance with new functions

- #define hindex $|s\rangle$
- #define hvalue ψ
- #include hashcom.C
- hstore($|s\rangle$,ψ)
- hadd($|s\rangle$,ψ)
- hfetch($|s\rangle$)

Comments

On receiving a store or fetch message, processor checks his part of the table, forwards unresolved requests to next processor.

A processor does/needs not know where an element will wind up.

A processor does/needs not know where an element came from.

Processor knows what he has locally, apply $1 + S_i$ and send out for storage.

No wait before next state

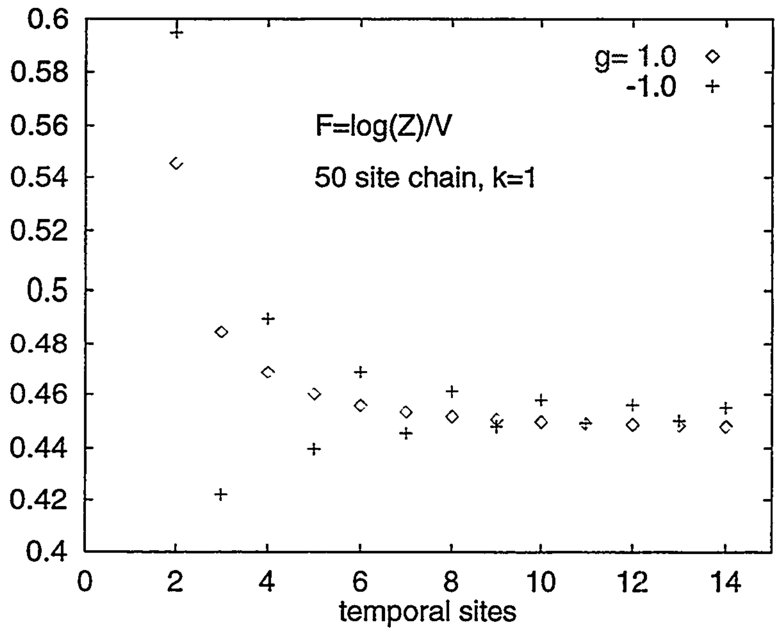
- communication in parallel
- no non-local fetches

Test on 1+1 dimensional model

- $Z = \int (d\psi d\psi^*) e^{S_t + S_h + S_I}$

- $S_t = \sum_{i,t} \psi^*_{i,t}(\psi_{i,t} - \psi_{i,t-1})$
- $S_h = k \sum_{i,t} \psi^*_{i,t}\psi_{i+1,t} + \psi^*_{i+1,t}\psi_{i,t}$
- $S_I = g \sum_{i,t} \psi^*_{i,t}\psi_{i,t}\psi^*_{i+1,t}\psi_{i+1,t}$

$\log(Z)/N_i N_t$ for $g = \pm 1$ on 50 site chain:

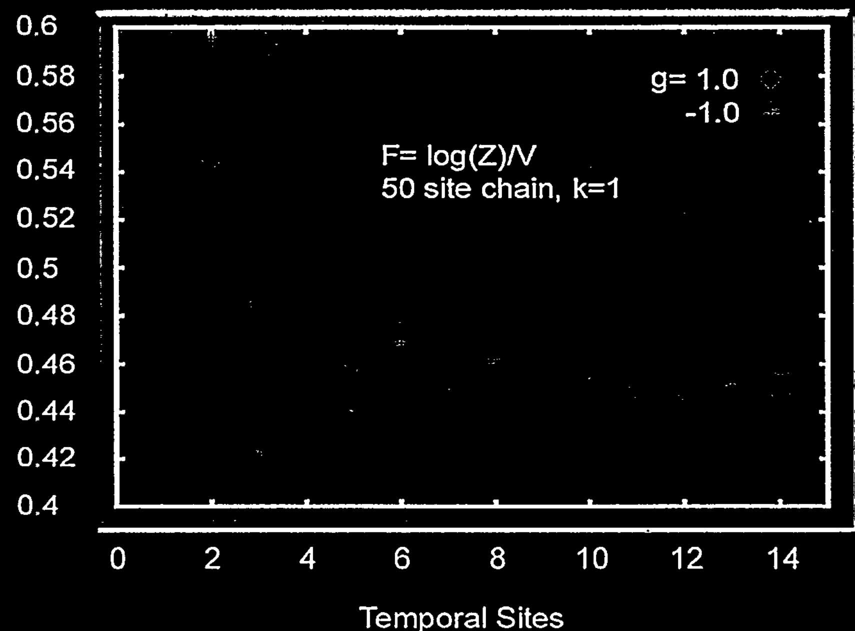


- $N_t = 14$: $5\frac{1}{4}$ hours on 2048 nodes
- 1400 Grassmann variables (14 * 50 * 2)

Scaling test on small system (12 by 10)

- 16 motherboards 7 times faster than 1
- non-local communication $\rightarrow$ longer distance
- naively expect $8 = 16 * \left(\frac{2+2+4+4}{4+4+8+8}\right)$
- 1 motherboard $\sim$ ultra-Sparc

The First Non-QCD Physics
to run on the
RIKEN-BNL SuperComputer



The "free energy" for a spinless electron hopping along a fifty site chain with two values for a nearest neighbor interaction.

"Time" is split into a number of discrete temporal slices, shown as the x axis. The points with 14 time slices were run on a 2048 processor section of the RIKEN-BNL Supercomputer, taking about 7 hours.

The partition function is

[illegible]

with

[illegible]

The figure is taken from M. Creutz, "Grassmann integrals by machine", hep-lat/9809024, to appear in proceedings of Lattice '98, Boulder (1998). The algorithm is described in M. Creutz, "Evaluating Grassmann integrals", hep-lat/9806037, Phys. Rev. Letters (in press).

Open Problems in Weak Matrix Elements

Amarjit Soni
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SUMMARY

A. SONI 10/21/98

1. H-L System: Is χS costing in accuracy?
[Are the lattice # for f's systematically below expt].

2. B_K: DO DWQ have better scaling than B_K or not?
How can we reconcile $B_K^{latt} \Leftrightarrow B_K^{\chi PT}$.
→ (1 loop) [ME to all orders]

3. Use of LWCPT for matching & renorm. is dissatisfying
How far can we go with NPR methods. ⇒ CHRIS

4. Improved χl prop. of DWQ opens up the most exciting possibility w r t $K \to 2\pi$
CAN DWQ help solve the $\Delta I = 1/2$ PUZZLE?

5 " " " cal. of M.E. for ϵ'/ϵ.
WITH 4DS VERY TIMELY
QCDSP can competitively look for effects of New Physics.

6. $B \to \pi\pi, K\pi$ 1st principles cal dont appear ~~practicable~~ tractable.
Can we still use the lattice and ~~app~~ address questions of importance to phenomenology
e.g. $\frac{B^0 \to \rho\rho}{B^0 \to \pi^+\pi^-}$
ratio such as this crucial for Asy B-factories.

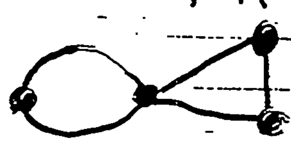
CLASSIFICATION

TYPE	Examples / Quick Survey	APPLICATIONS & IMPLICATIONS	REMARKS
1. $\langle M \vert \Theta_2 \vert VAC\rangle$	Master graph; f_{D}, f_{Ds}; f_{B}, f_{Bs}	Pure leptonic → NOOZE(V_{td})	Comp with expt.
2A $\langle M_1 \vert \Theta_2 \vert M_2\rangle$	$D \to K(K^*) \ell\nu$; $B \to \pi(\rho) \ell\nu$; $B \to K^* \gamma$	Semileptonic → form factors → NOOZE(V_{ub}); radiative → " (V_{td})	q^2 dependence
2B $\langle M \vert \Theta_4 \vert \bar{M}\rangle$	$K\bar{K}$; $B_d-\bar{B}_d$; $B_s-\bar{B}_s$	Mixing → NOOZE(V_{td})	K → LO χPT+EXP; SU(3)
3. $\langle M_1 \vert \Theta_4 \vert M_2 M_3\rangle$	$K \to 2\pi$; $B \to K\pi$, $\to \pi\pi$	$\Delta I = 1/2$; ϵ'/ϵ; CP; CP, Δ	2 Possible Approaches: I. $K \to 2\pi$ ϵ'/ϵ; II. $B \to 2\pi, K\pi$. UNCHARTERED TERRITORY

Introduce [illegible] for each

Apply $K\bar{K}$ [illegible] for each [illegible]

Then last column of Issues for each: I f_{B_s}; II B_K



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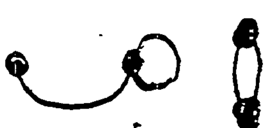

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⋮

CONFRONTING $\Delta I = 1/2$ Rule with DWQ

Since DWQ exhibit such remarkably good χl behavior (for $N_5 \gtrsim 10$) as evidenced in B_K, $\bar{\Psi}\Psi$ ---

THEY open up a new avenue of attack to the long standing puzzles of $\Delta I = 1/2$ Rule, calc. of ϵ'/ϵ ...

For Large N_5 $\quad K \to 2\pi \Rightarrow K \to \pi + K \to 0$

4pt f^n $\quad$ ↓ 3pt f^n $\quad$ 2pt f^n

$$\langle K^0 | O | \pi^+\pi^- \rangle = \frac{i(m_K^2 - m_\pi^2)}{m^2_{Mf}} \left\{ \langle K^+ | O | \pi^+ \rangle - b \langle K^0 | O | vac \rangle \right]$$

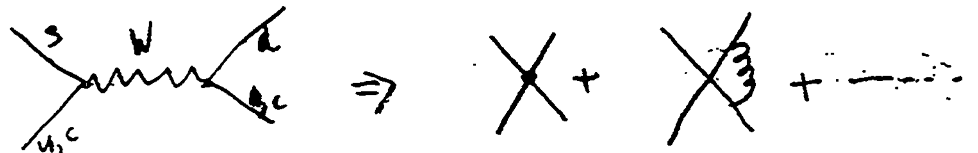
$$\frac{[K^0 \to \pi^+\pi^-]_{1/2}}{[K^0 \to \pi^+\pi^-]_{3/2}} = \frac{[K^+ \to \pi^+]_{1/2} - b\,[K^0 \to vac]}{[K^+ \to \pi^+]_{3/2}}$$

IS THE ONLY CHANCE for QCDSP to compete with LHC ... in uncovering New Physics.

[with the built in checks of the lattice you can imagine coming up with $12 \pm 2 \pm 2$ rather than 22!]

$\Delta S = 1 \Rightarrow \Delta I = 1/2$ RULE, ϵ'/ϵ . . .

$\Delta S=1$



[$\Delta I = 1/2, 3/2$ ONLY]

$$H_W^{\Delta S=1} \Rightarrow \sum_{\pm} C_\pm (M_W/\mu, g(\mu)) \; O_\pm(\mu)$$

$$O_\pm = [\bar{s}\gamma_\mu^L d \, \bar{u}\gamma_\mu^L u \pm \bar{s}\gamma_\mu^L u \, \bar{u}\gamma_\mu^L d] - (u \to c)$$

[WILSON]

$$O_\pm^{cont}(\mu) = Z_\pm O_\pm^{latt} + Z_\pm' O_\pm' + Z_3 \bar{s}d + Z_3' \bar{s}\gamma_5 d + Z_5 \bar{s}\sigma_{\mu\nu}F^{\mu\nu}d + Z_5' \bar{s}\sigma_{\mu\nu}F^{\mu\nu}\gamma_5 d$$

$\leftarrow$ lower dim ops

WRONG CHIRALITY

$$Z_\pm' O_\pm' = Z_S \, S \times S + Z_P \, P \times P + Z_T \, T \times T + Z_V \, V \times V + Z_A \, A \times A$$

[WI OPS are CPS even]

USE CPS & GIM

$Z_3' \Rightarrow [(m_s - m_d)(m_c - m_u)/a] \, c_3'$ $\qquad \bar{s}\gamma_5 d$ $\qquad$ 4 $K \to 2, 3\pi$

$Z_3 \Rightarrow [(m_c - m_u)/a^2] \, c_3$	e^{-N_S}	$\bar{s}d$	4 $K \to \pi$

$Z_5' \Rightarrow (m_s - m_d) \, c_5'$ $\qquad \bar{s}\sigma_{\mu\nu}F^{\mu\nu}\gamma_5 d$

$Z_5 \Rightarrow (m_c - m_u) \, c_5$ $\qquad \bar{s}\sigma_{\mu\nu}F^{\mu\nu}d$

PROBLEM: USE of (1-loop) LkCPT for Renorm & matching is not satisfactory.

COMMON TO all such calculations

Non-Perturbative Improvement with Wilson Fermions

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Non-Perturbative Improvement with Wilson Fermions

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The technique of non-perturbative renormalisation using momentum space propagators has been highly successful in calculating the renormalisation factors for lattice QCD calculations. An attempt to extend this technique to the non-perturbative improvement of operators in the on-shell improved theory is described. The vital role of B.R.S.T. symmetry in determining the operators that must be included in the mixing is described, and the results of a preliminary study of the flavour non-singlet fermion bilinear operators is presented. In particular the limitations of the technique, due to large of-shell $O(a)$ terms, are pointed out.

Approaches to Non-Perturbative Renormalisation.

1. Gauge Invariant Ward Identities
   - Powerfull, but limited in scope.

2. Non-gauge Invariant methods.
   - ward identities on quark states.
   - off shell momentum subtraction scheme (MOM). *

3. Fix conditions directly on hadronic states
   - must sacrifice a physical prediction.

Mom Scheme

The basic idea of the MOM scheme is;

(1) Compute greens function of operator in question between <u>off-shell quark states</u> <u>in a fixed gauge</u> and <u>at 'large' Euclidean momenta</u>.

$$G_\Gamma = \sum_{x,y}' \exp(-ip.x + ip.y) \times$$

$$\langle \psi(x) \quad \bar{\psi}\,\Gamma\,\psi(0) \quad \bar{\psi}(y) \rangle$$

"Large" momenta.

The renormalisation scale must simultaneously satisfy the requirements

$$\mu \gg \Lambda_{QCD}$$

- so the perturbative form of the correlators may be trusted.

$$\frac{1}{a} \gg \mu$$

- so lattice artifacts may be neglected.

Gauge Fixing

① Gribov Ambiguities

② BRST symmetry.

Extra operators that may mix ;

(i) Non-gauge ; but BRST invariant.

(ii) Non-gauge or BRST invariant that vanish by the equations of motion.

- problem for singlet bilinear operators + $\Delta S = 1$ effective hamiltonian.

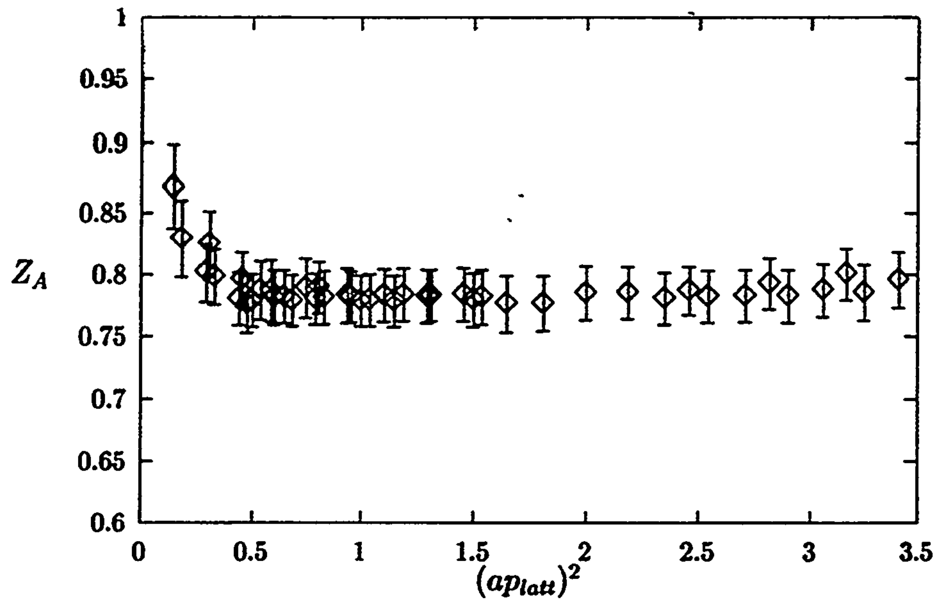

Figure 1: Z_A in the chiral limit

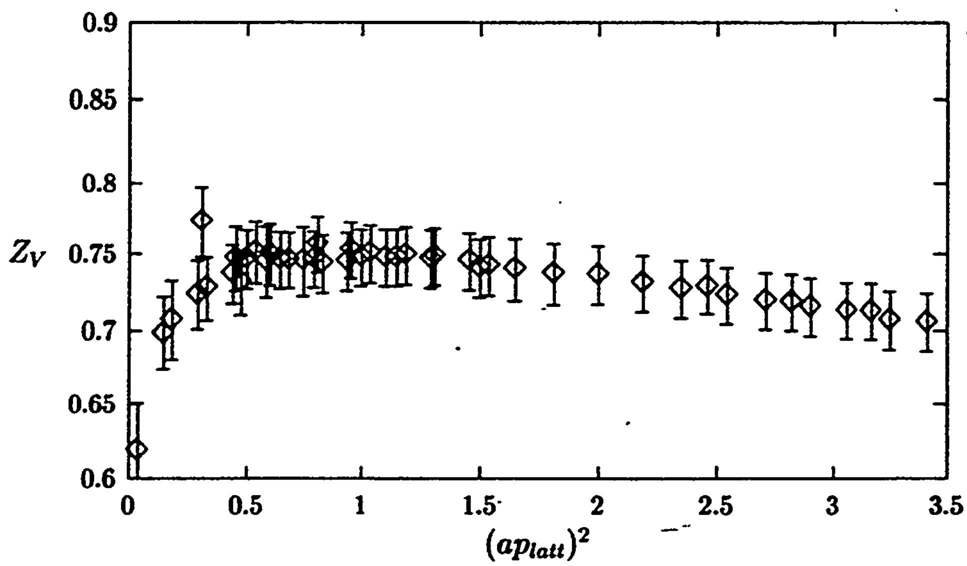

Figure 2: Z_V in the chiral limit

QCD on Anisotropic Lattices

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QCD on Anisotropic Lattices

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Anisotropic lattices, with a temporal lattice spacing smaller than the spatial one ($\xi \equiv a/a_0 > 1$), are useful, often crucial, for the study of a variety of phenomenologically important questions in lattice QCD. First, there is the simple practical advantage of having (many) more time slices to identify plateaux before the signal gets lost – exponentially fast – in the noise, which is crucial for accurate glueball studies (Morningstar and Peardon), transport coefficients of the QGP, and, perhaps to a lesser extent, P-wave mesons or other particles with bad signal-to-noise properties.

More conceptual problems related to discretization errors arise for lattice thermodynamics, and especially *heavy quarks*. We will concentrate on the latter, where the issue is simply that standard, relativistic actions break down when $am_q > 1$, and it is currently too costly to study a sequence of lattices with $am_q \ll 1$ for charm or bottom quarks, even in the quenched approximation.

At present two approaches are widely used for quarks with $am_q > 1$: (i) NRQCD and (ii) the Fermilab or heavy relativistic approach. NRQCD seems to break down for charmonium, due to large quantum and relativistic corrections to the action (Trottier). The approach we pursue is similar to the Fermilab one, in that we also use a relativistic Symanzik improvement framework and give up the manifest O(4) symmetry of the action by going to an anisotropic lattice, where the quark action has only an O(3) symmetry. The same is true for a heavy quark on an isotropic lattice; the Fermilab approach is the special case of an isotropic lattice in our approach.

The crucial question in a relativistic Symanzik approach to heavy/anisotropic quarks is the mass dependence of the coefficients. To eliminate all O(a) errors, so that observables really scale like a^2 towards the continuum, requires the coefficients in the action to be not just coupling but also *mass dependent.* There are three coefficients whose coupling and mass dependence has to be tuned for a heavy/anisotropic Wilson-type quark action: a bare velocity of light ν and two clover coefficients. The former can be tuned by demanding that the dispersion relation of the pseudo-scalar, say, be relativistic for small momenta; the latter using the Schrödinger functional background field method and the chiral Ward identity (PCAC). On isotropic lattices the coefficients have a strong mass dependence, even classically, which is currently ignored in the Fermilab approach.

In our exploratory quenched anisotropic simulations of the charmonium spectrum (see below and [1,2]) we only tuned ν exactly, and used a Landau link tadpole estimate for the clover coefficients. We ignored the mass dependence of the clover coefficients: If it were linear this would be legitimate, since it would only introduce O(a^2) errors. Classically, linearity of the coefficients holds well on anisotropic lattices; on the quantum level this issue has to be further investigated [2].

Note that in the quenched approximation the bare anisotropy in the gauge action can be determined independently of the quark action, $\xi_0 = \xi_0(\xi, \beta)$. We did so in [3].

1. T.R. Klassen, hep-lat/9809174.
2. T.R. Klassen, in preparation.
3. T.R. Klassen, Nucl. Phys. **B533** (1998) 557 [hep-lat/9803010].

Symanzik Improvement on (An)Isotropic Lattices

- In the scaling region, the lattice theory can be described by an effective continuum action of form:

$$S_{\text{eff}} \;=\; S_0 \;+\; a \sum_i c_{1i}\, S_{1i} \;+\; a^2 \sum_i c_{2i}\, S_{2i} \;+\; \ldots$$

- S_{ni} are all operators allowed by (lattice) symmetries, modulo **redundant** operators that can be eliminated by field equations.
- In **isotropic** light quark case: $S_0 = \bar{\psi}(\not{D} + m)\psi$. For suitably chosen $c_{1i} = c_{1i}(g^2)$ lattice artifacts of observables scale like a^2.
- For **heavy/anisotropic** quarks: $S_0 = \bar{\psi}(\not{D}_0 + \nu \not{\mathbf{D}} + m)\psi$.
  ν is a "bare velocity of light", to restore space-time exchange symm.
  Due to reduced manifest symmetry, $O(4) \to O(3)$, more terms S_{ni}.
- Claim (Fermilab): For suitable $(\nu, c_{1i}) = (\nu, c_{1i})(g^2, a_0 m, \xi)$ errors are $O(a^2)$, no errors in mass. Clear if $a_0 m \ll 1$. True also for $a_0 m \gg 1$?

Tim Klassen

Form of Quark Actions on Anisotropic Lattices

- Up to $\mathrm{O}(a)$ an anisotropic/heavy action can have the following terms

$$\not{D}_0\,(1+\mathrm{O}(am))\,, \quad \not{\mathbf{D}}\,(1+\mathrm{O}(am))\,,$$

$$\underbrace{aD_0^2}\,, \quad \underbrace{a\sum_k D_k^2}\,, \quad \underbrace{a[\not{\mathbf{D}},\not{D}_0]}\,, \quad a\sum_k \sigma_{0k}F_{0k}\,, \quad a\sum_{k<l}\sigma_{kl}F_{kl}\,.$$

- Considering most general field transformation one finds **three redundant** terms at $\mathrm{O}(a)$; can rescale coefft of $\not{D}_0$ to 1.
- One strategy: demand that first- and second-order derivatives combine in form of Wilson operators W_μ. Leads to cheap action:

$$S \;=\; a_0 a^3 \sum_x \bar{\psi}(x)\, Q\, \psi(x)\,,$$

$$Q \;=\; m_0 + W_0\gamma_0 + \nu\sum_k W_k\gamma_k \;-\; \frac{a}{2}\left[\omega_0\sum_k \sigma_{0k}F_{0k} + \omega\sum_{k<l}\sigma_{kl}F_{kl}\right]$$

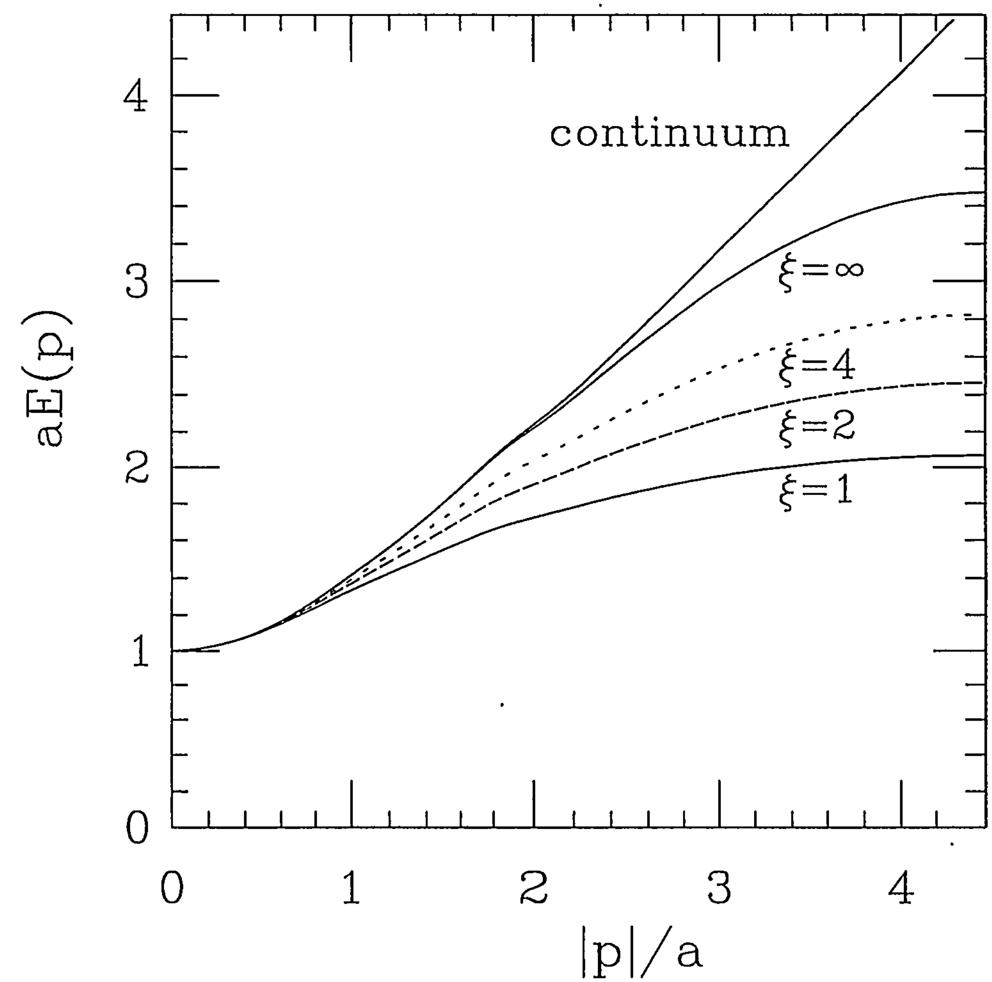


Figure 3: Classical dispersion relation for the anisotropic Wilson action improved to all orders in the quark mass with full projection property.

The Anisotropic Wilson QCD Action

In terms of dimensionless quantities, full action can be written as:

$$S = S(\beta, \xi_0, m_0, \nu, \omega, \omega_0) = S_G + S_Q$$

$$S_G = \frac{\beta}{N} \sum_{x,k>l} \frac{1}{\xi_0} \mathrm{Re\,Tr}\,(1 - P_{kl}(x)) + \xi_0 \,\mathrm{Re\,Tr}\,(1 - P_{0k}(x))$$

$$S_Q = \sum_x \hat{\bar{\psi}}(x)\; a_0 Q\; \hat{\psi}(x)\,,$$

$$a_0 Q = a_0 m_0 + \hat{W}_0 \gamma_0 + \frac{\nu}{\xi_0} \hat{W}_k \gamma_k - \frac{1}{2}\left[\omega_0\, \sigma_{0k} \hat{F}_{0k} + \frac{\omega}{\xi_0}\, \sigma_{kl} \hat{F}_{kl}\right].$$

- For given β, ξ, m_0: Tune ξ_0, ν, ω, ω_0 to give same renormalized anisotropy ξ in gauge and quark sector and no $\mathrm{O}(a^0, a)$ errors.
- Quenched: $\xi_0 = \xi_0(\xi, \beta)$ independent of quark parameters.

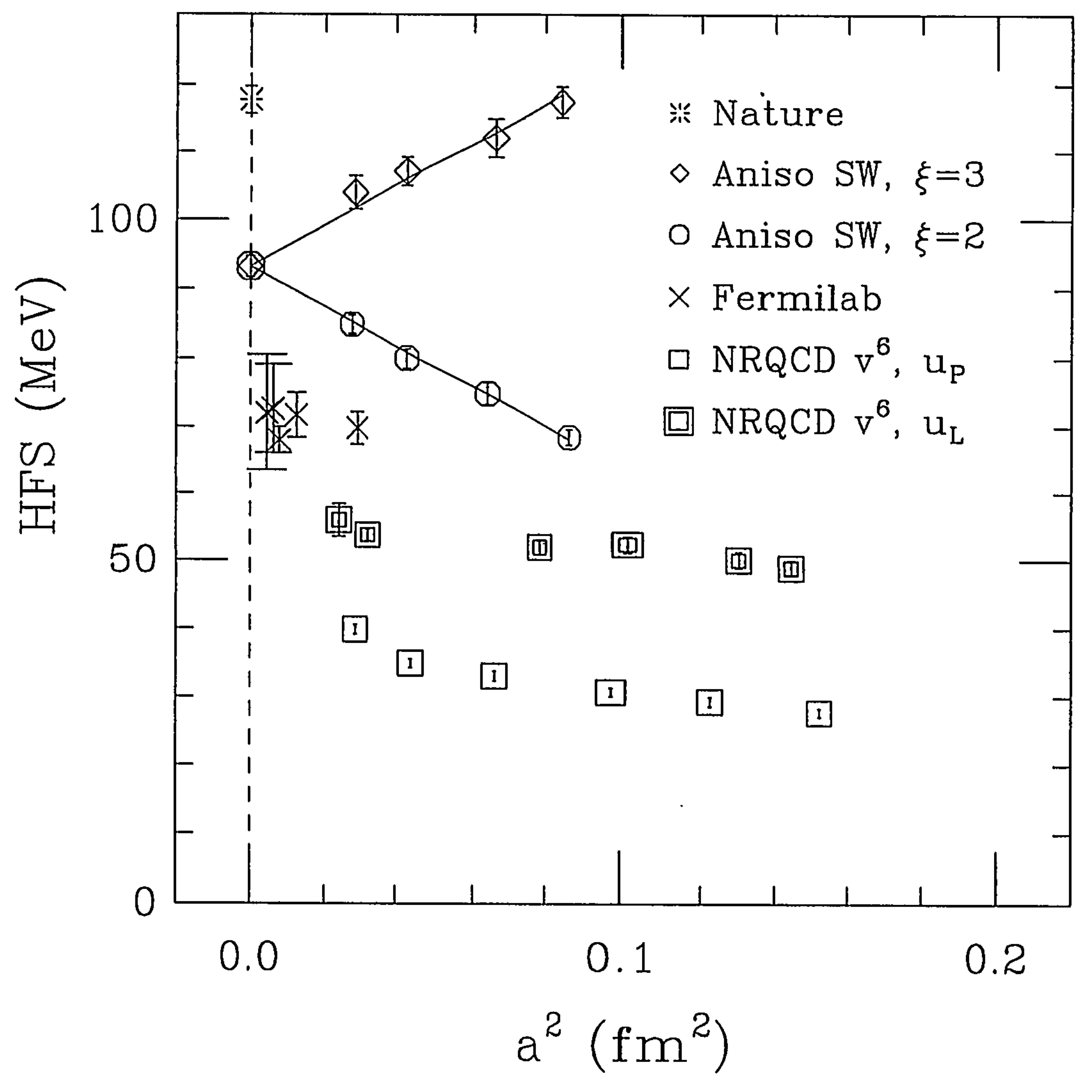


Figure 11: (Quenched) Charmonium HFS from various formalisms.

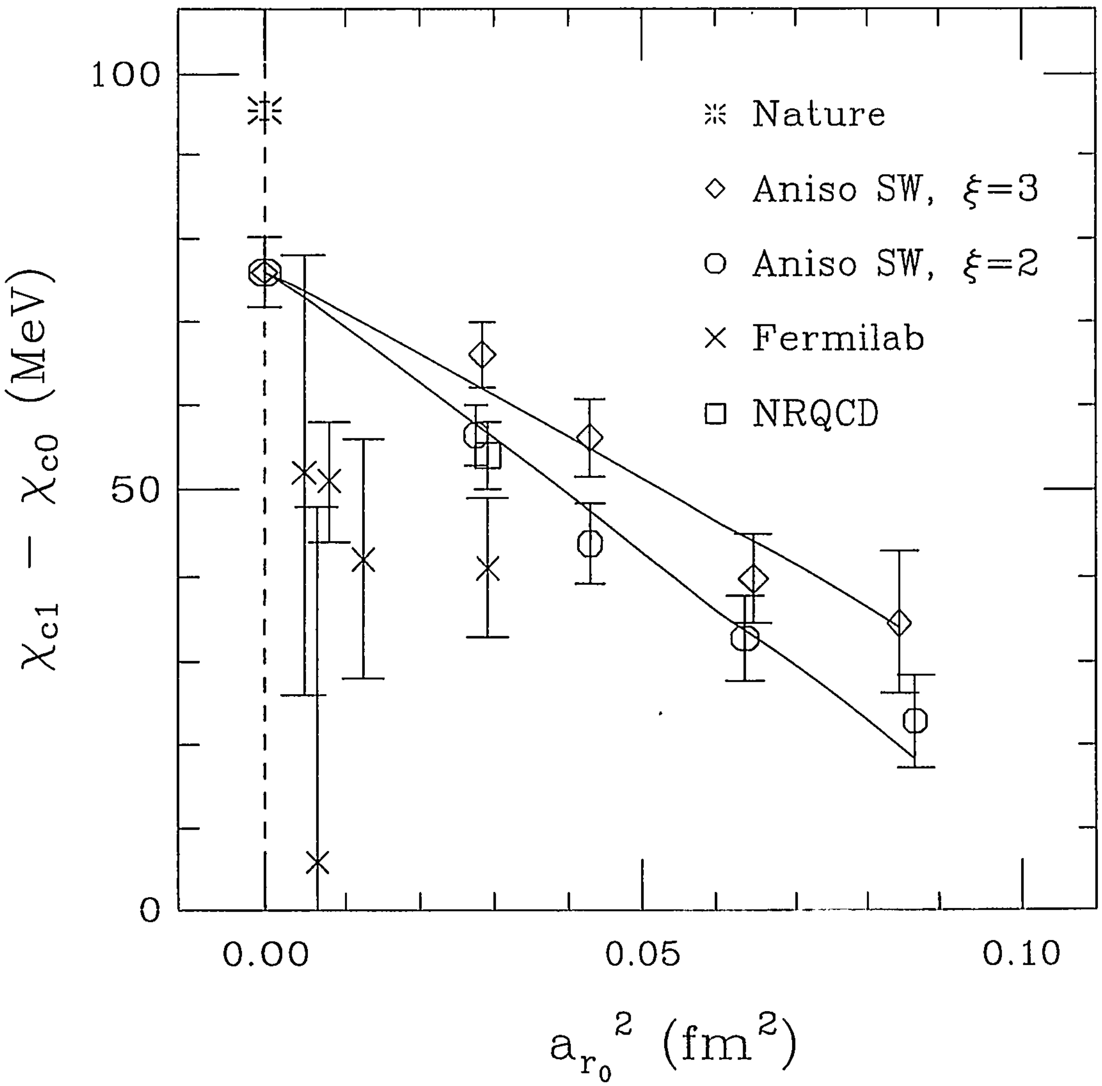


Figure 12: P-wave triplet splitting $1^3P_1 - 1^3P_0$.

Strange Quark Mass: First Results with Domain Wall Fermions

Matthew Wingate
Brookhaven National Laboratory

Strange Quark Mass: First Results with Domain Wall Fermions

Matthew Wingate, with Tom Blum and Amarjit Soni

In this talk I summarize our exploratory calculation [1, 2] of the strange quark mass using domain wall fermions. We have computed the one–loop mass renormalization and display the result in the first slide. In addition to the multiplicative renormalization of the quark mass m^{LAT}, the domain wall mass M is shifted. In the second slide, the shift M_c is estimated from the size of the tadpole graph, which is significantly larger than the half–circle graph. However, the shift M_c coincides with the additive renormalization of ordinary 4–d Wilson fermions. The third slide shows the pion mass squared for different values of M at $\beta = 6.0$ and $N_s = 14$. The dotted lines are fits to the ansatz that the renormalization of M is purely additive. Of course this is not strictly correct, but for this range of M and at the present level of precision, this assumption fits the data quite well. In slide 4 we plot the same data as a function of m to demonstrate that the pion mass squared extrapolates linearly to zero at $m = 0$ within the errors. Finally, we determine the strange quark mass by setting the kaon to its physical value and apply the one–loop renormalization factor. Slide 5 shows our results in comparison to those using other fermion discretizations. Our result for this work is $m_s(2\text{ GeV}) = 82(15)$ MeV in the $\overline{\text{MS}}$ regularization scheme.

References

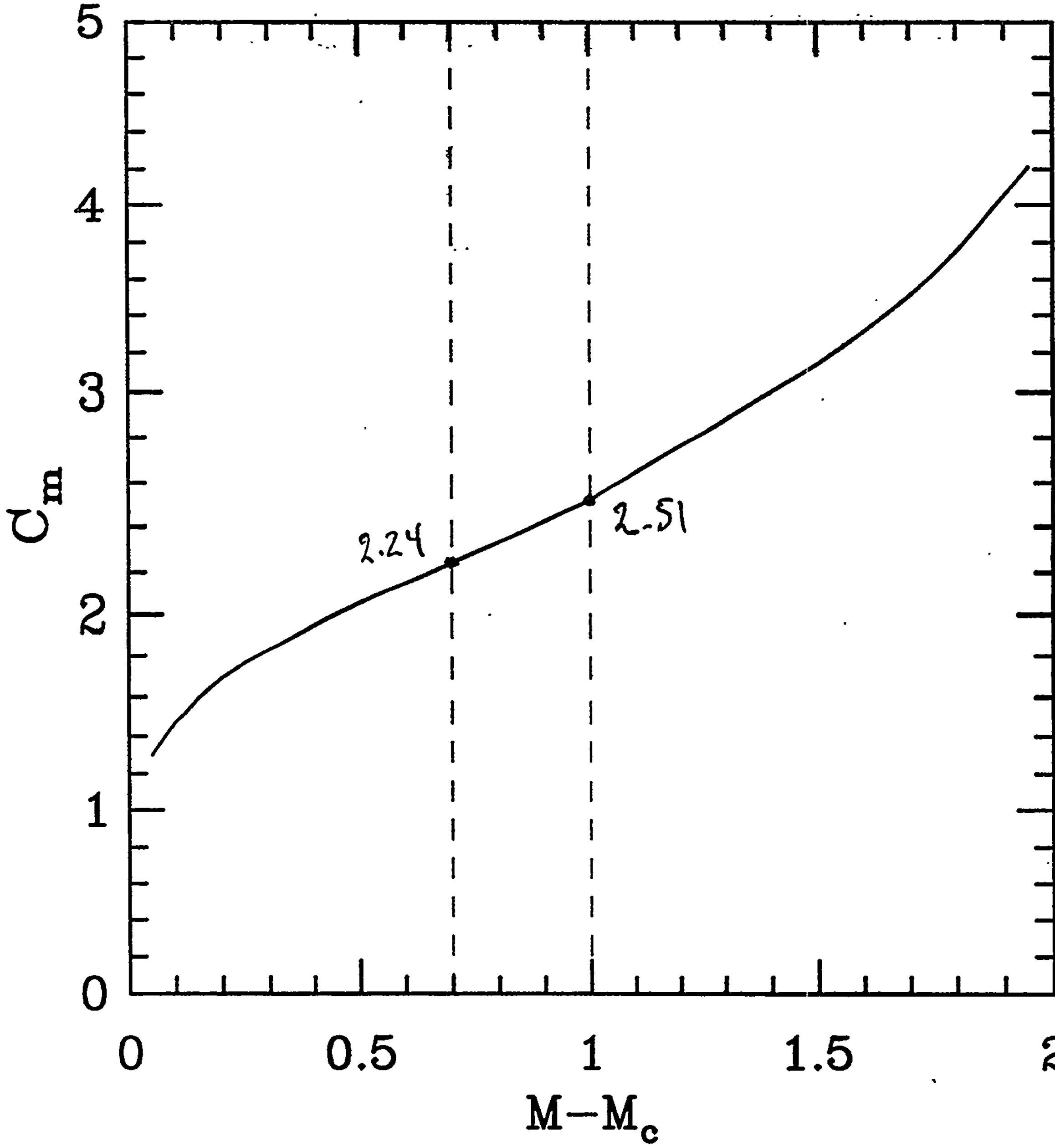
[1] T. Blum, A. Soni, and M. Wingate, parallel talk at the "International Symposium on Lattice Field Theory 1998", Boulder, CO, USA, hep-lat/9809109.

[2] T. Blum, A. Soni, and M. Wingate, manuscript in preparation.

$$m^{\overline{MS}}(\mu) = m^{LAT}\left[1 - \frac{2}{\pi}\alpha_{\overline{MS}}(\mu)\left(\ln \mu a - C_m\right)\right]$$

$$C_m = \ln \pi - \frac{1}{4} + \frac{1}{6}\left(\frac{I}{2} + \tilde{I}_p - \tilde{I}_m\right)$$

Perturbative matching constant



Compare

$C_m = $
- 2.16 Wilson
- 3.22 SW (Improved Wilson)
- 6.54 !? KS (Staggered)

- 1-loop graphs <u>additively</u> renormalize M

$$M \to M +$$  $$\Big|_{\sim \frac{1}{a}} +$$  $$\Big|_{\sim \frac{1}{a}}$$

β	$-$  *
5.85	0.79
6.0	0.74
6.3	0.67

* using $g^2\left(\frac{3.41}{a}\right)$

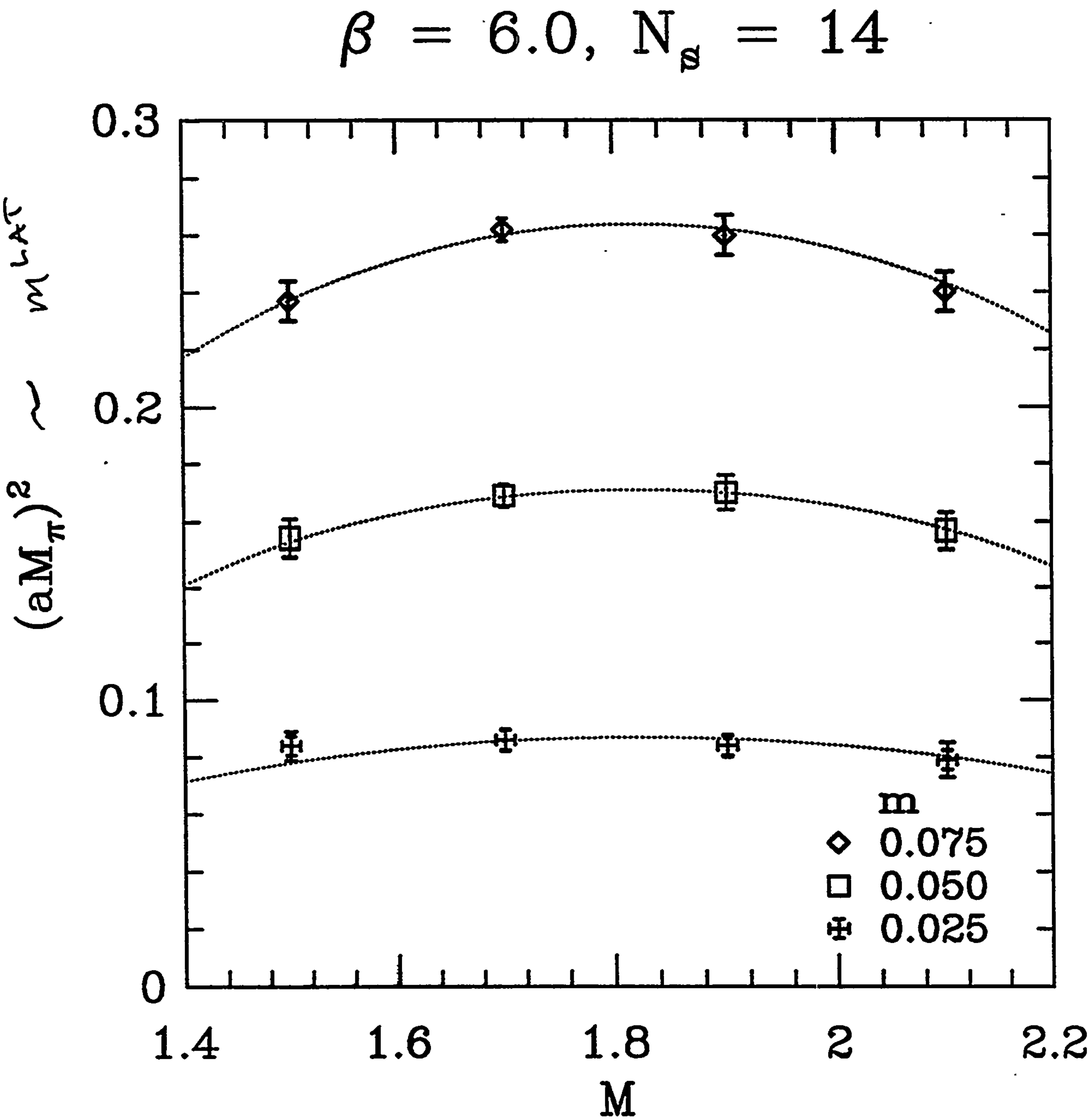
- DW 5-d mass M $\Leftrightarrow$ Wilson hopping parameter κ^W

$$M \to M - M_c^W ,$$

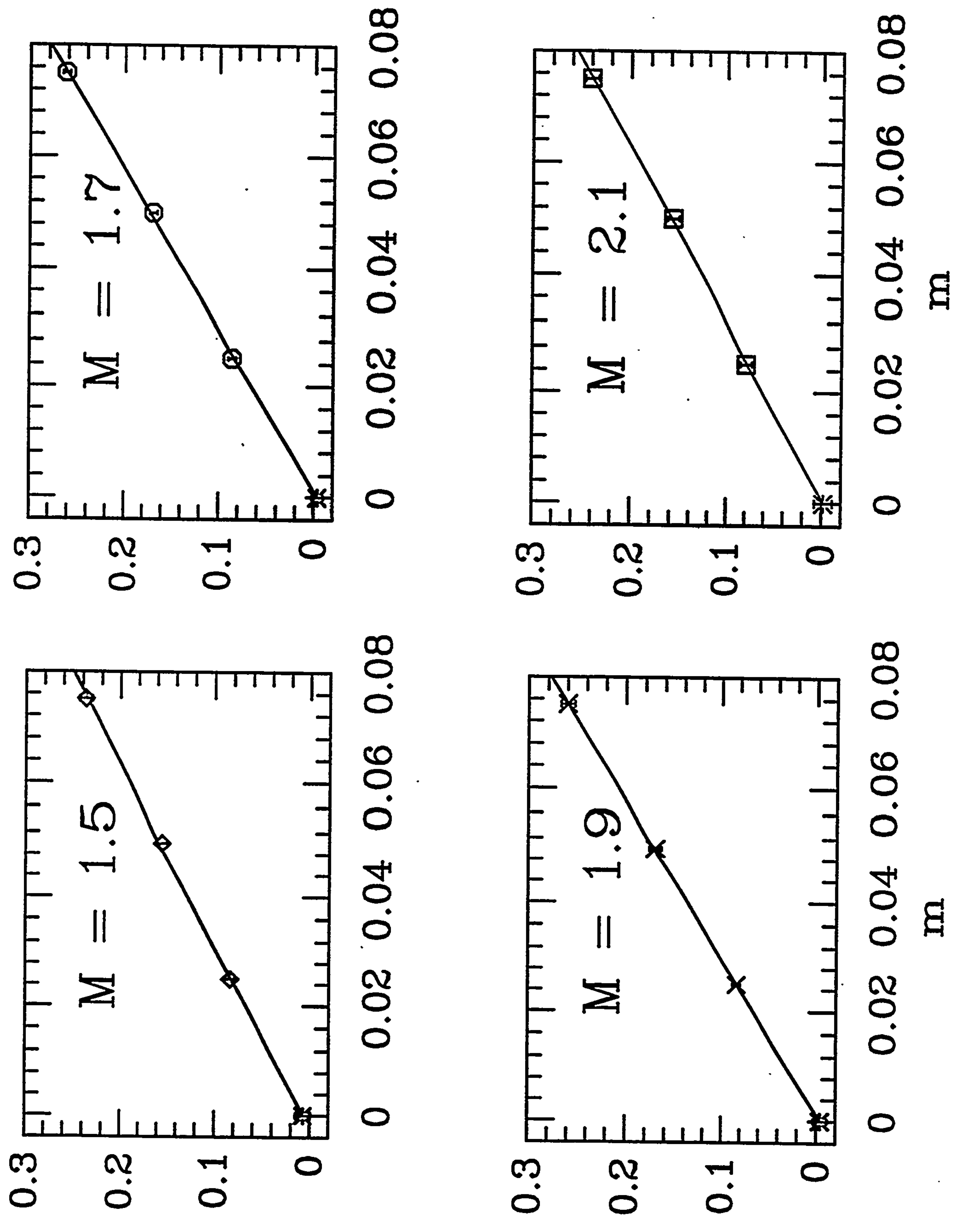
$$M_c^W = -\left(\frac{1}{2\kappa_c^W} - 4\right)$$

Narayanan, Neuberger, SCRI

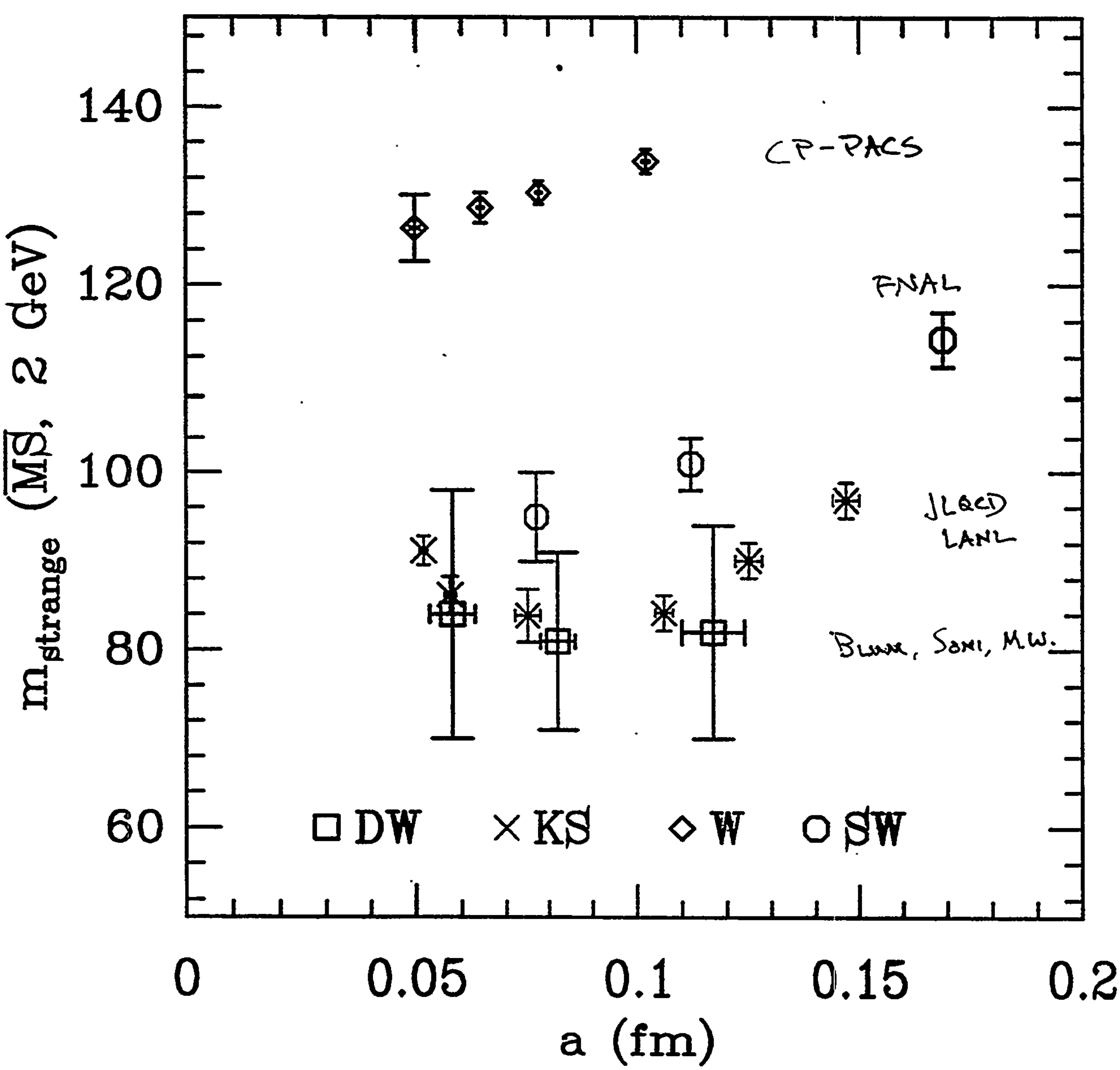
β	M_c^W
5.85	0.908
6.0	0.819
6.3	0.708



$$m^{LAT} = m\,(M - M_c^w)\left[2 - (M - M_c^w)\right]$$


M = 1.5
M = 1.7
M = 1.9
M = 2.1
$(aM_\pi)^2$
m
0
0.02
0.04
0.06
0.08
0.1
0.2
0.3

strange quark mass (in MeV)



DW Weighted avg. of 3 β's :

$m^{strange}_{\overline{MS}}(2\text{ GeV}) = 82(15)$ MeV

↳ stat. + sys.

Issues with the Aoki Phase

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98.10.16

Issues with the Aoki Phase

Akira Ukawa
Center for Computational Physics
University of Tsukuba

§ 1. A brief reminder

§ 2. Existence of the phase

- Dependence on N_t -

§ 3. Finite T phase transition

- Dependence on N_f -

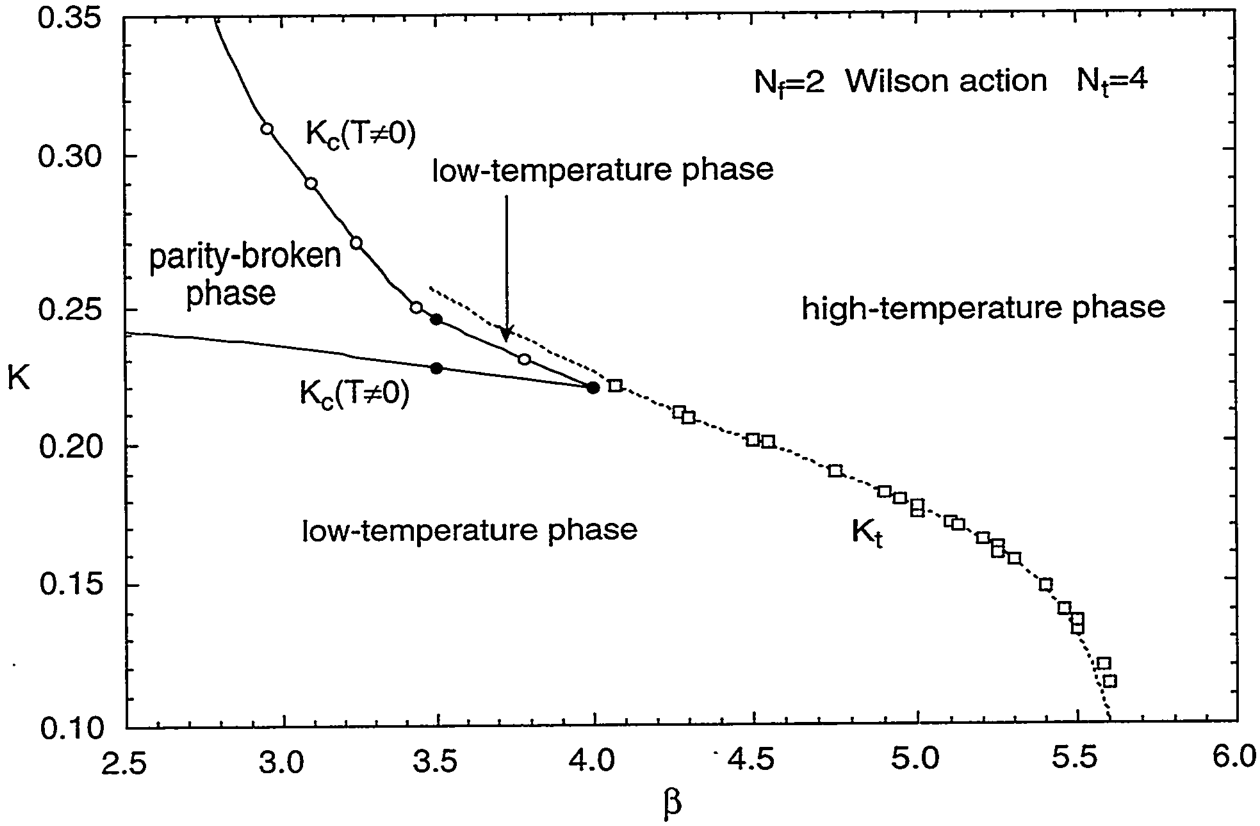
§ 4. Continuum limit

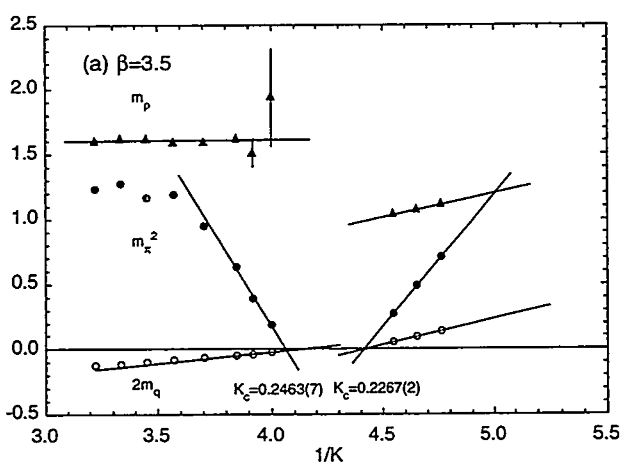
- fun with 2d Gross-Neveu model -

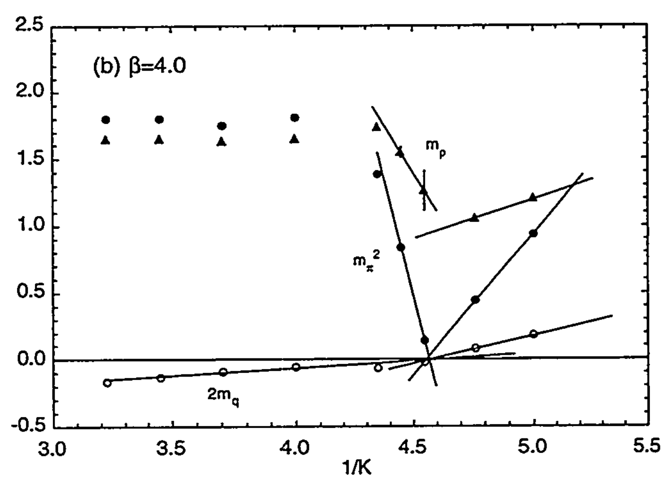
§ 5. Summary

Results for 2-flavor QCD: $8^3 \times 4$ lattice

- phase diagram from study of pion mass





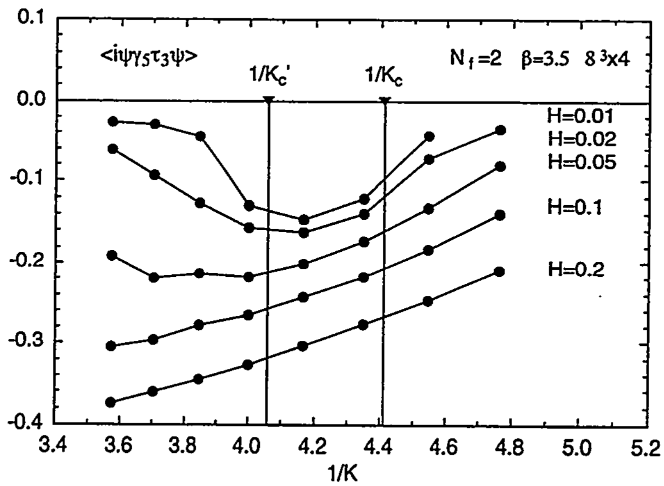


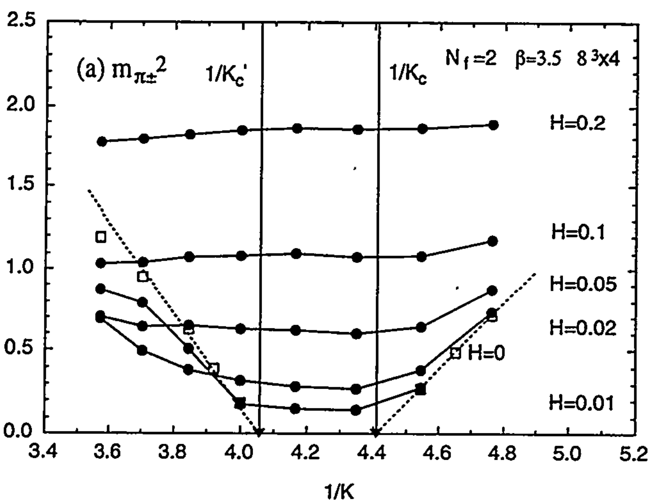
• explicit check of parity-flavor breaking inside the Aoki phase

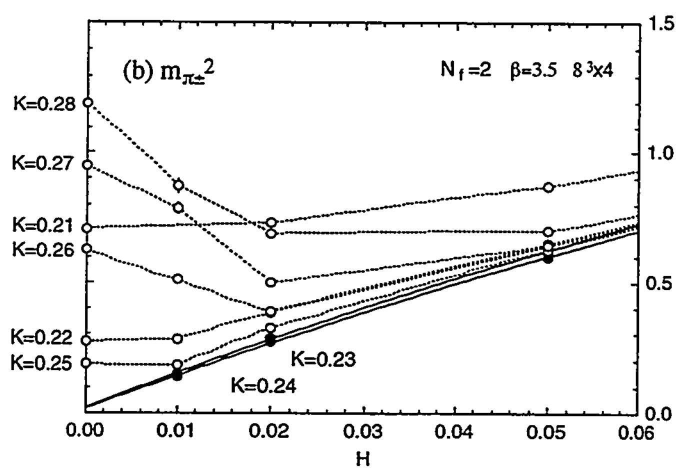
symmetry breaking field: $L_{ext} = h\bar{\psi}i\gamma_5 \frac{\tau_3}{2}\psi$

expect: $\lim_{h \to +0} \left\langle \bar{\psi}i\gamma_5 \frac{\tau_3}{2}\psi \right\rangle \neq 0$ order parameter

$\lim_{h \to +0} m_{\pi^\pm}^2 = 0$ NG boson of broken symmetry

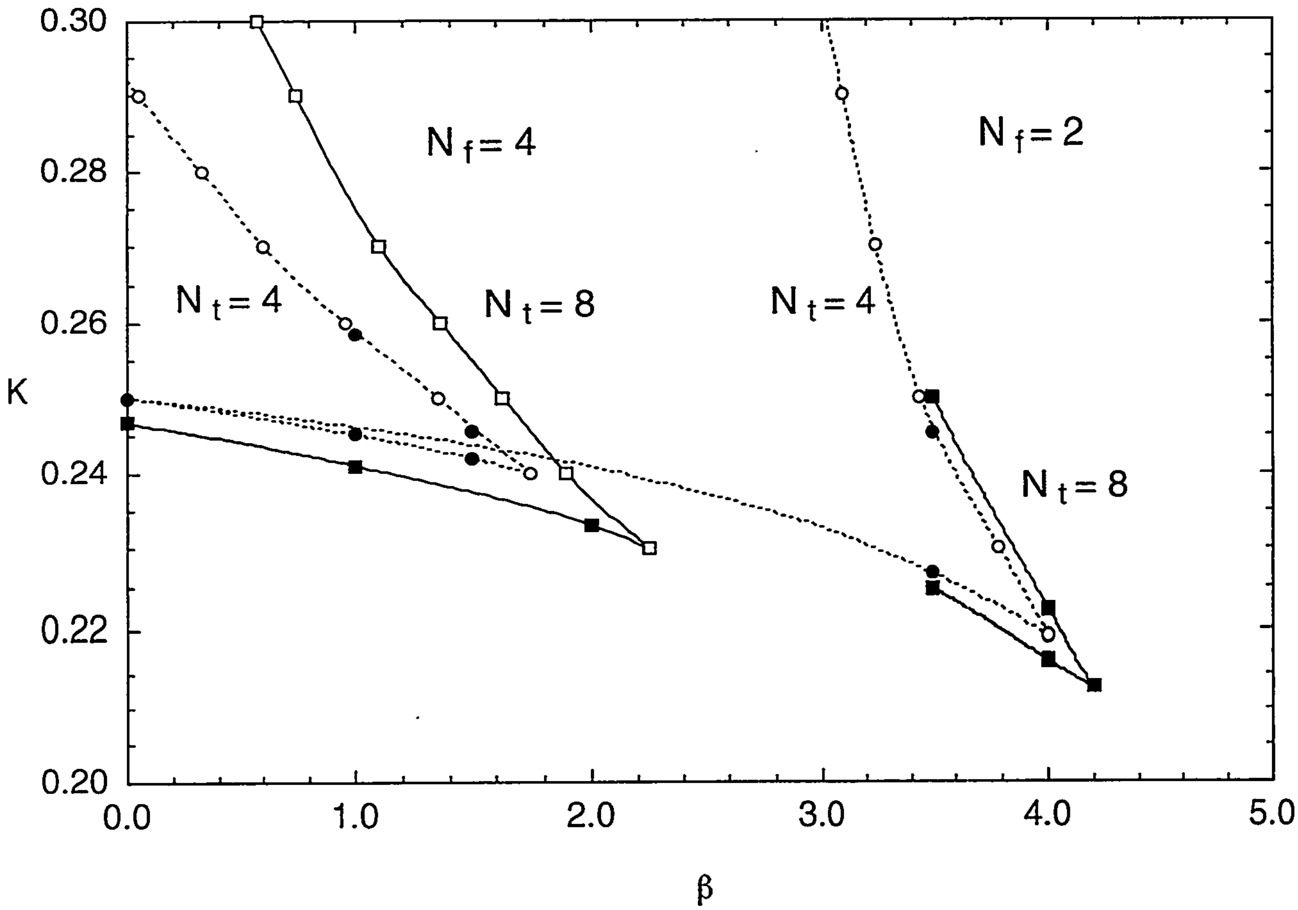






Results for N_t dependence :

$8^3 \times 4$ and $8^3 \times 8$ $\qquad N_f = 2$ and 4

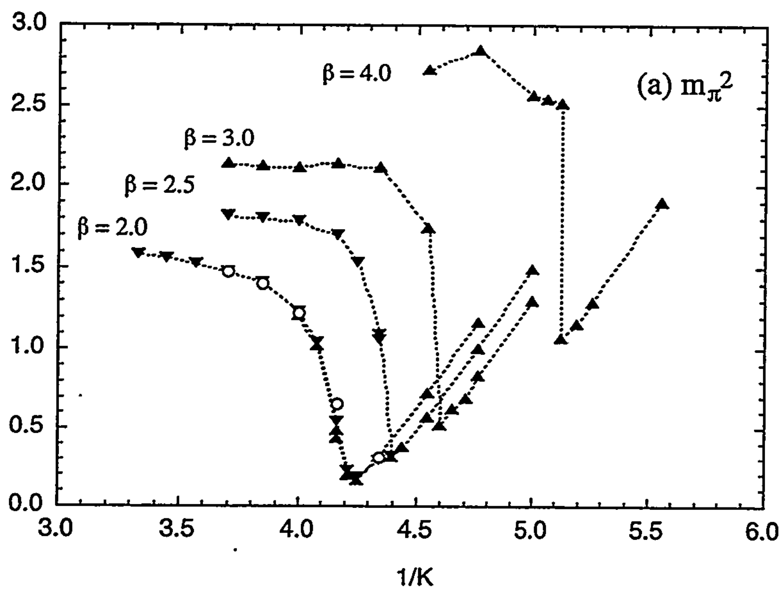


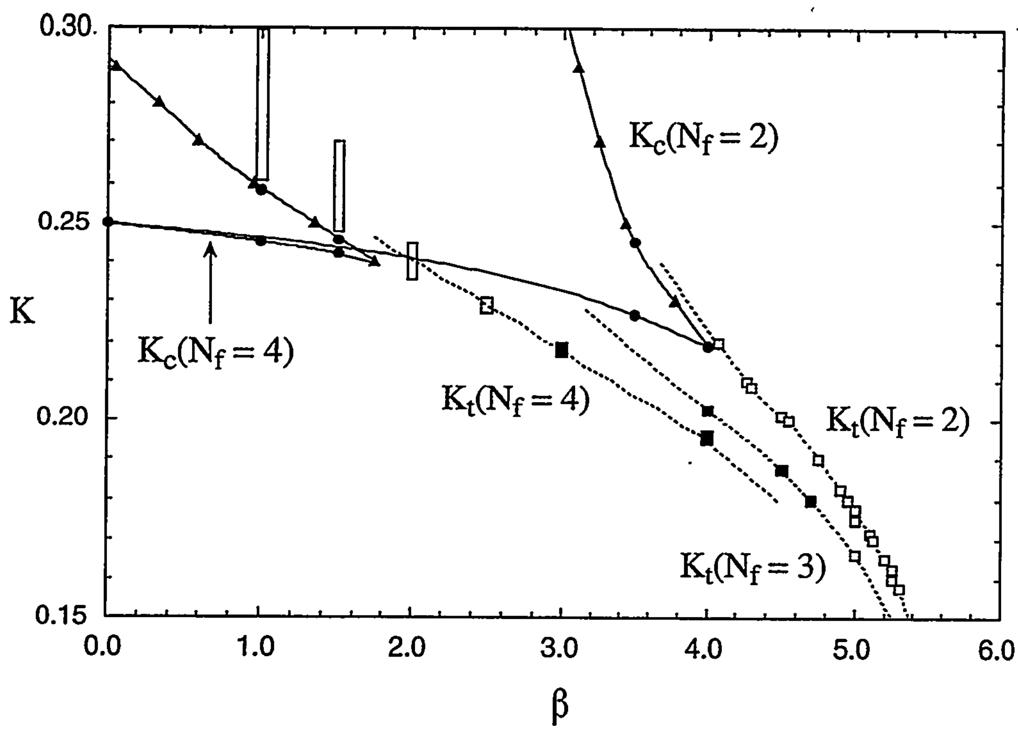
- "finger" grows *only very* slowly with N_t
- This explains the negative result of search by Bitar $\leq 10^3 \times 10$ and $\beta \geq 5.0$

hep-lat/9602027

• puzzling result for 4-flavor finite-T transtion:

1st order transition turns into a cross over close to the critical line





Conclusions

- *The Aoki phase does exist and is relevant in taking the continuum of QCD with the Wilson-type actions*

- *It is a lattice artifact, and yet we need to know how to handle it.*

- *And if we know how, the continuum theory has the chiral properties we expect to obtain.*

References:

• QCD/numerical
Aoki-Kaneda-Ukawa-Umemura
PRL 76 (96) 873; NPB(PS) 47 (96) 511;
NPB(PS) 53 (97) 438;PRD 56 (97) 1808
Bitar-Edwards-Heller-Narayanan-Singleton
NPB (PS) 63 (98) 829;PLB 418 (98) 167;
NPB 518 (98) 319;hep-lat/9802016

•QCD/effective chiral lagrangian
M. Creutz '96 BNL Workshop(hep-lat/9608024)
Sharpe-Singleton PRD 58 (98) 074501

• Gross-Neveu in 2d/analytical
Izubuchi-Noaki-Ukawa PRD (hep-lat/9805019)

Lattice Study of Correlation Between Instantons and Monopoles

Shoichi Sasaki
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Lattice Study of Correlation between Instantons and Monopoles*

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The several lattice QCD simulations have showed the existence of the non-trivial correlation between instantons and QCD-monopoles in spite of the fact that these topological objects originate from different homotopy groups. However, nobody knows whether it has some physical significance, or not, from the topological viewpoint [1].

In 1982, Ezawa and Iwazaki advocated the hypothesis of abelian dominance, which is essentially composed of two sentences [2]:

- Only the abelian component of gauge fields is relevant at a long-distance scale.
- The non-abelian effects are mostly inherited by magnetic monopoles.

Actually, lattice Monte Carlo simulation indicates that abelian dominance for some physical quantities reveals in the maximally abelian (MA) gauge [1].

Here, an unavoidable question arises relating to the non-trivial correlation between instantons and QCD-monopoles. *In the abelian dominated system, is it possible for the non-abelian topological nature to survive?* For such an essential question, Ezawa and Iwazaki have proposed a remarkable conjecture [2]: once abelian dominance is postulated, the topological feature is preserved by the presence of monopoles.

An analytical study [3] is made to find the relationship between the topological charge and QCD-monopoles in the lattice formulation base on the hypothesis of abelian dominance. The topological charge is explicitly represented in terms of the monopole current and the abelian component of gauge fields in the abelian dominated system [3]. This is consistent with the previous study, which shows that QCD-monopoles strongly correlate with the presence of fermionic zero-modes in the MA gauge [4].

[1] For a review article, see M.I. Polikarpov, Nucl. Phys. **B** (Proc. Suppl.) **53** (1997) 134.

[2] Z.F. Ezawa and A. Iwazaki, Phys. Rev. **D25** (1982) 2681; *ibid* **D26** (1982) 631.

[3] S. Sasaki and O. Miyamura, hep-lat/9811029.

[4] S. Sasaki and O. Miyamura, to be published in Phys. Lett. **B**; hep-lat/9810039.

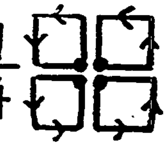
*This talk is based on some recent works (Ref.2 and Ref.3) with O. Miyamura.

Application of abelian dominance hypothesis to topological charge

Naive definition of topological density on lattice :

$$q(s) \equiv \frac{1}{2} \varepsilon_{\mu\nu\rho\sigma} \, \mathrm{tr}\{ P_{\mu\nu}(s) P_{\rho\sigma}(s) \}$$

where $P_{\mu\nu}(s)$ denotes the clover-averaged SU(2) plaquette.

$$P_{\mu\nu}(s) \equiv \frac{1}{4}$$  $$= \frac{1}{4}\{ U_{\mu\nu}(s) + U^{\dagger}_{-\mu\nu}(s) + U^{\dagger}_{\mu-\nu}(s) + U_{-\mu-\nu}(s)$$

 is the SU(2) elementary plaquette : $U_{\mu\nu}(s)$

Extract topological charge from

$$Q_L \equiv -\frac{1}{16\pi^2} \sum_s q(s) \simeq Q_{cont} + O(a^6)$$

where $Q_{cont} \equiv -\frac{1}{16\pi^2} \sum_s \mathrm{tr}\{ a^4 g^2 G_{\mu\nu}(s) {}^{*}G_{\mu\nu}(s) \}$

Here, the SU(2) link variable is expected to be U(1)-like as $U_\mu(s) \sim u_\mu(s) \equiv \exp\{ i\sigma_3 \theta_\mu(s) \}$, if the QCD vacuum is described as the abelian dominated system in a suitable abelian gauge.

$$\begin{cases} \theta_\mu(s) \equiv \tan^{-1}[U^3_\mu(s) / U^0_\mu(s)] \in [-\pi, \pi) \\ U_\mu(s) = U^0_\mu(s) + i\sigma_a U^a_\mu(s) \quad (a = 1, 2, 3 \end{cases}$$

<u>Consider</u> the abelian analog of topological density

- Replacement : $U_\mu(s) \longrightarrow u_\mu(s)$ in the definition of $q(s)$

$$q_{Abel}(s) = \frac{1}{2}\varepsilon_{\mu\nu\rho\sigma}\,\mathrm{tr}\{p_{\mu\nu}(s)\,p_{\rho\sigma}(s)\}$$

$$= -\frac{1}{16}\sum_{i,j,k,l=0}^{1}\varepsilon_{\mu\nu\rho\sigma}\sin[\theta_{\mu\nu}(s-i\hat{\mu}-j\hat{\nu})]\cdot\sin[\theta_{\rho\sigma}(s-k\hat{\rho}-l\hat{\sigma})]$$

where $p_{\mu\nu}(s) \equiv \frac{1}{4}\sum_{i,j=0}^{1} u_{\mu\nu}(s-i\hat{\mu}-j\hat{\nu})$

$$u_{\mu\nu}(s) \equiv u_\mu(s)u_\nu(s+\hat{\mu})u_\mu^\dagger(s+\hat{\nu})u_\nu^\dagger(s) = \exp(i\sigma_3\underline{\theta_{\mu\nu}(s)})$$

Now, we need only <u>the leading order term</u> in powers of the lattice spacing to determine the topological charge, so that we want to get the expression of q_{Abel} <u>in the continuum limit ; $a \to 0$</u>.

<u>Note</u> "$u_{\mu\nu}$ is a multi-valued function as $\theta_{\mu\nu} \in [-4\pi, 4\pi)$"

$$\theta_{\mu\nu}(s) = \partial_\mu\theta_\nu(s) - \partial_\nu\theta_\mu(s)$$

$\Longrightarrow$ One can devide $\theta_{\mu\nu}$ into two part :

$$\theta_{\mu\nu}(s) = \bar{\theta}_{\mu\nu}(s) + 2\pi n_{\mu\nu}(s)$$

integer-value $n_{\mu\nu} = 0, \pm 1, \pm 2$

U(1) field strength ; $\bar{\theta}_{\mu\nu} \in [-\pi, \pi)$

Taking the naive continuum limit $a \to 0$,

$$q_{Abel}(s) \approx -\varepsilon_{\mu\nu\rho\sigma}\bar{\Theta}_{\mu\nu}(s)\bar{\Theta}_{\rho\sigma}(s)$$

where $\bar{\Theta}_{\mu\nu}(s) \equiv \frac{1}{4}\sum_{i,j=0}^{1}\bar{\theta}_{\mu\nu}(s-i\hat{\mu}-j\hat{\nu})$

To see the explicit contribution of monopoles to q_{Abel}

1) Define the monopole current k_μ as

$$k_\mu(s) \equiv \frac{1}{4\pi}\varepsilon_{\mu\nu\rho\sigma}\partial_\nu\bar{\theta}_{\rho\sigma}(s+\hat{\mu})$$

$$= -\frac{1}{2}\varepsilon_{\mu\nu\rho\sigma}\partial_\nu n_{\rho\sigma}(s+\hat{\mu})$$

the Bianchi identity ; $\varepsilon_{\mu\nu\rho\sigma}\partial_\nu\theta_{\rho\sigma} = 0$

(the integer-valued magnetic current)

following DeGrand-Toussaint's definition in the compact U(1) gauge theory

2) Introduce the dual potential $B_\mu(s)$

$$(\Delta^2\delta_{\mu\nu} - \Delta_\mu\Delta_\nu)B_\mu(s) = -2\pi\mathcal{K}_\mu(s)$$

where $\mathcal{K}_\mu(s) \equiv \frac{1}{8}\sum_{i,j,k=0}^{1}k_\mu(s-i\hat{\nu}-j\hat{\rho}-k\hat{\sigma})$

Δ_μ denotes the nearest-neighbor central difference operator ; $\Delta_\mu f(s) = \frac{1}{2}\{\partial_\mu + \partial'_\mu\}f(s)$

$$= \frac{1}{2}\{f(s+\hat{\mu}) - f(s-\hat{\mu})\}$$

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Thus, we can perform the Hodge decomposition on $\bar{\Theta}_{\mu\nu}(s)$ with the dual potential $B_\mu(s)$ as

$$\bar{\Theta}_{\mu\nu}(s) = \Delta_\mu A'_\nu(s) - \Delta_\nu A'_\mu(s) + \varepsilon_{\mu\nu\rho\sigma}\Delta_\rho B_\sigma(s)$$

where A'_μ denotes the Gaussian fluctuation.

After a little algebra,

$$\varepsilon_{\mu\nu\rho\sigma}\bar{\Theta}_{\mu\nu}(s)\bar{\Theta}_{\rho\sigma}(s) = 16\pi A'_\mu(s) K_\mu(s) + \cdots\cdots$$

※ the ellipsis stands for the total divergence, which will drop in the summation over all site.

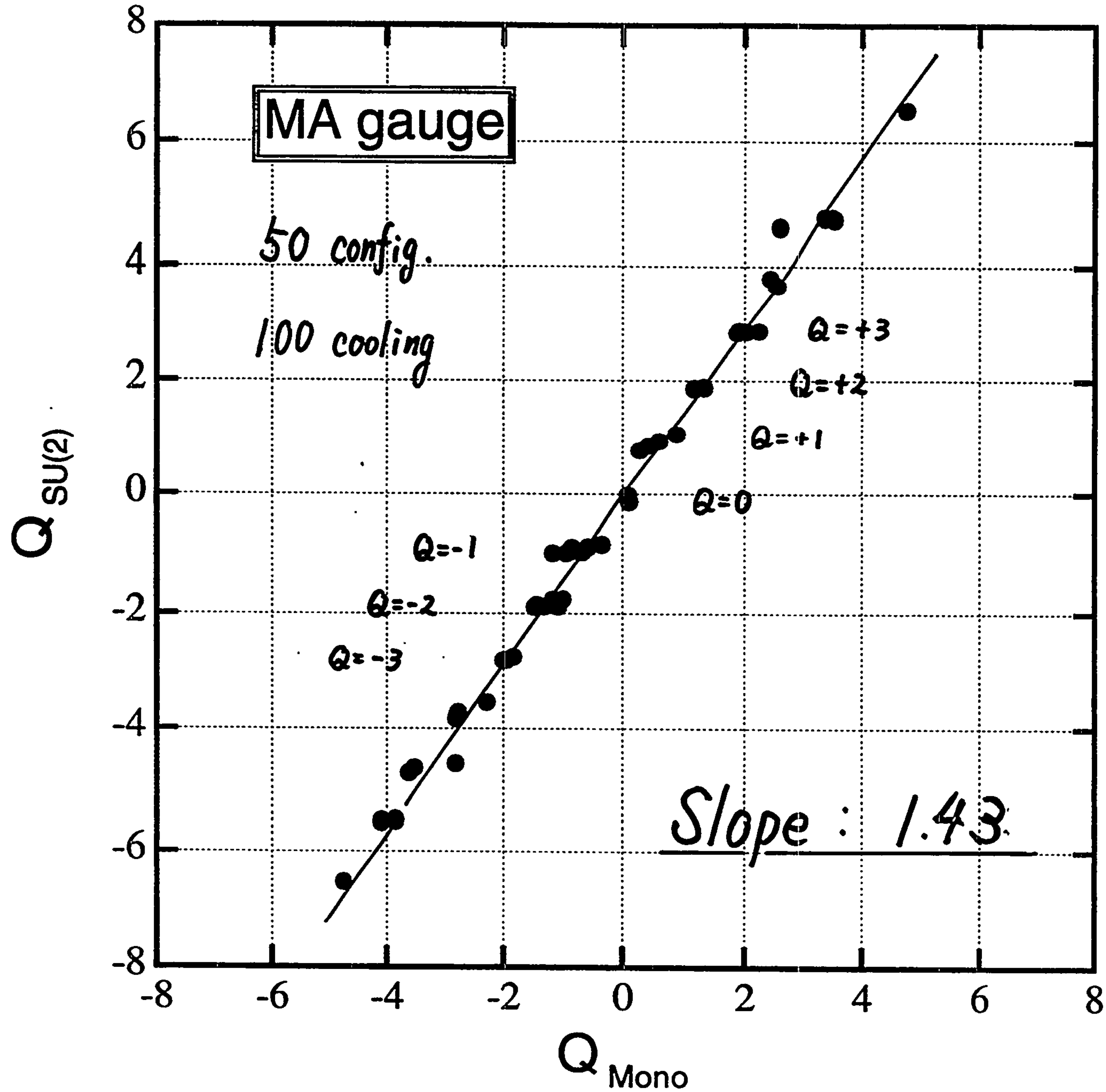
Finally

$$\boxed{Q_{cont} \simeq -\frac{1}{16\pi^2}\sum_s q_{Mono}(s)}$$

$$q_{Mono}(s) \equiv -16\pi A'_\mu(s) K_\mu(s)$$

This implies that

"<u>topological features would be inherited by monopoles in the abelian dominated system</u>",



“ $Q_{Mono} \approx 0.7 \times Q_{SU(2)}$ ”

16^4 lattice at $\beta = 2.4$

Fermion Zero-Modes in Quenched QCD

Norman H. Christ
Columbia University

Fermion Zero-Modes in Quenched QCD [1]

Norman H. Christ

October 16, 1998

As we study QCD more deeply, the properties of the eigenvalue spectrum of the Dirac operator become increasingly important. Viewing QCD from the perspective of the Feynman path integral, we have known for some time that the spectrum of small eigenvalues of the Dirac operator in the typical gauge field background appearing in the path integral has far-reaching physical consequences. The Banks-Casher formula demonstrates that the phenomena of chiral symmetry breaking can be understood as directly arising from a non-zero density of Dirac eigenvalues at the point $\lambda = 0$. In addition, the physical consequences of the axial anomaly are closely related to the zero modes of the Dirac operator in topologically non-trivial gauge field configurations.

In this talk I would like to summarize recent work of the Columbia group using our new *QCDSP* machines to study the zero-modes of the Dirac operator in quenched QCD. Here, without the usual Dirac determinant representing the effects of fermion loops, gauge configurations with small eigenvalues will be enhanced relative to simulations including dynamical quarks. Through such a study, we expect to learn something of the distribution of topologically non-trivial gauge configurations in pure QCD and their effect on the fermionic degrees of freedom.

We propose to study the zero modes of a particularly interesting lattice Dirac operator, that defined by the 5-dimensional domain wall fermion formalism. In the limit of large extent in the fifth dimension, this formulation is capable of realizing exact zero modes in contrast with staggered fermions where a "zero-mode shift" smears potential zero modes away from zero or Wilson fermions were there is no uniquely identified mass value at which physical "zero-modes" become zero eigenvectors of the Wilson Dirac operator. As an efficient tool to identify possible zero modes, we examine the quenched chiral condensate, $\langle\bar{\psi}\psi\rangle$. Dirac zero- (or near-zero-) modes will show up in $\langle\bar{\psi}\psi\rangle$ as a dramatic $1/m$ divergence as the fermion mass m approaches zero.

Let us discuss our results. First, in Figure 1, we show the behavior of $\langle\bar{\psi}\psi\rangle$ in the background of a single instanton-like configuration with superimposed gauge noise. The figure demonstrates a clear $1/m$ signal coming from the expected zero mode. Figures 2 and 3 show a similar $1/m$ behavior, now in a zero temperature simulation on $8^3 \times 32$ and $16^3 \times 32$ configurations. It is important to notice that the coefficient of this $1/m$ term decreases from $3.3(3) \times 10^{-6}$ to $0.6(1) \times 10^{-6}$ as the volume is increased by a factor of 8. This is the behavior that might be expected from zero modes arising from a dilute gas of instantons where the net topological charge per unit space-time volume decreases as $1/\sqrt{\Omega}$, for space-time volume Ω.

Finally in Figure 4, we show a similar comparison of $\langle\bar{\psi}\psi\rangle$ computed on $16^3 \times 4$ and $32^3 \times 4$ lattices at $\beta = 5.71$, just above the finite temperature, $N_t = 4$, phase transition. Here the $1/m$ coefficient remains constant as the volume increases suggesting this $1/m$ term is a feature of the thermodynamic limit for the quenched transition. This is expected on theoretical grounds as in argued in hep-lat/9807018. A somewhat more sophisticated argument is presented on the next page.

[1]This is the joint work of Ping Chen, George Fleming, Adrian Kaehler, Catalin Malureanu, Robert Mawhinney, Gabriele Siegert, ChengZhong Sui, Pavlos Vranas and Yuri Zhestkov

Quenched $1/m$ Divergence in $\langle\bar{\psi}\psi\rangle$ for $T > T_c$

Here we derive a formula relating the topological susceptibility χ_{top} and the large volume limit of a $1/m$ term in $\langle\bar{\psi}\psi\rangle$ for $T > T_c$. Begin with a formula expressing the partition function for N_f-flavor QCD as a function of the quark mass matrix M and the theta parameter, θ:

$$Z = e^{V\{E_0 + E_2\,\text{tr}M^\dagger M + F\,\text{re}(\det[M]e^{i\theta})\}}. \tag{1}$$

This expression is valid in the limit of large spatial volume V and the analyticity in M is expected for $T > T_c$. Given this expression for Z, we can compute both χ_{top} and $\langle\bar{\psi}\psi\rangle$ by performing derivatives with respect to θ and M respectively:

$$\chi_{\text{top}} = -\frac{\partial^2}{\partial\theta^2}\ln Z \tag{2}$$

$$\langle\bar{\psi}\psi\rangle = \sum_{i=1}^{N_f}\frac{\partial}{\partial M_{i,i}}\ln Z \tag{3}$$

Finally, following Bernard and Golterman, we introduce a second N_f flavors of bosonic spin-$\frac{1}{2}$ fields with mass matrix $\tilde{M}$. The graded flavor symmetry of this combined theory implies that Z in Eq. 1 becomes:

$$Z = e^{V\{E_0 + E_2\,\text{tr}[M^\dagger M - \tilde{M}^\dagger\tilde{M}] + F\,\text{re}(\det[\frac{M}{\tilde{M}}]e^{i\theta})\}}. \tag{4}$$

The quantities χ_{top} and $\langle\bar{\psi}\psi\rangle$ can now be evaluated in the quenched theory for real M and $\theta = 0$ by using Eq's. 2 and 3 and then setting $M = \tilde{M}$. One easily obtains:

$$\chi_{\text{top}} = F \tag{5}$$

$$\langle\bar{\psi}\psi\rangle = E_2\,\text{tr}M + F\,\text{tr}\frac{1}{M} \tag{6}$$

So that as $M \to 0$, $\langle\bar{\psi}\psi\rangle = \chi_{\text{top}}\,\text{tr}\frac{1}{M}$, the desired relation.

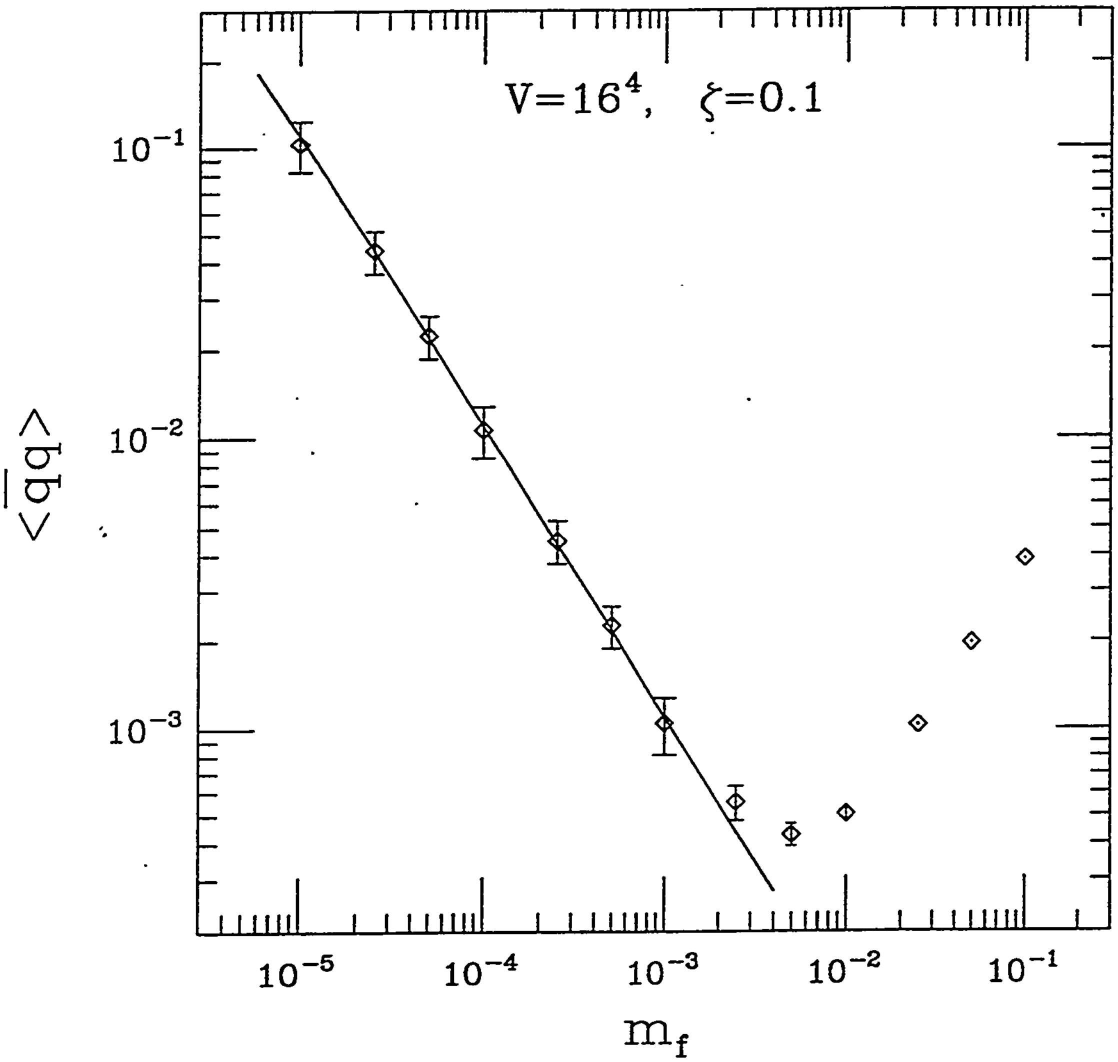
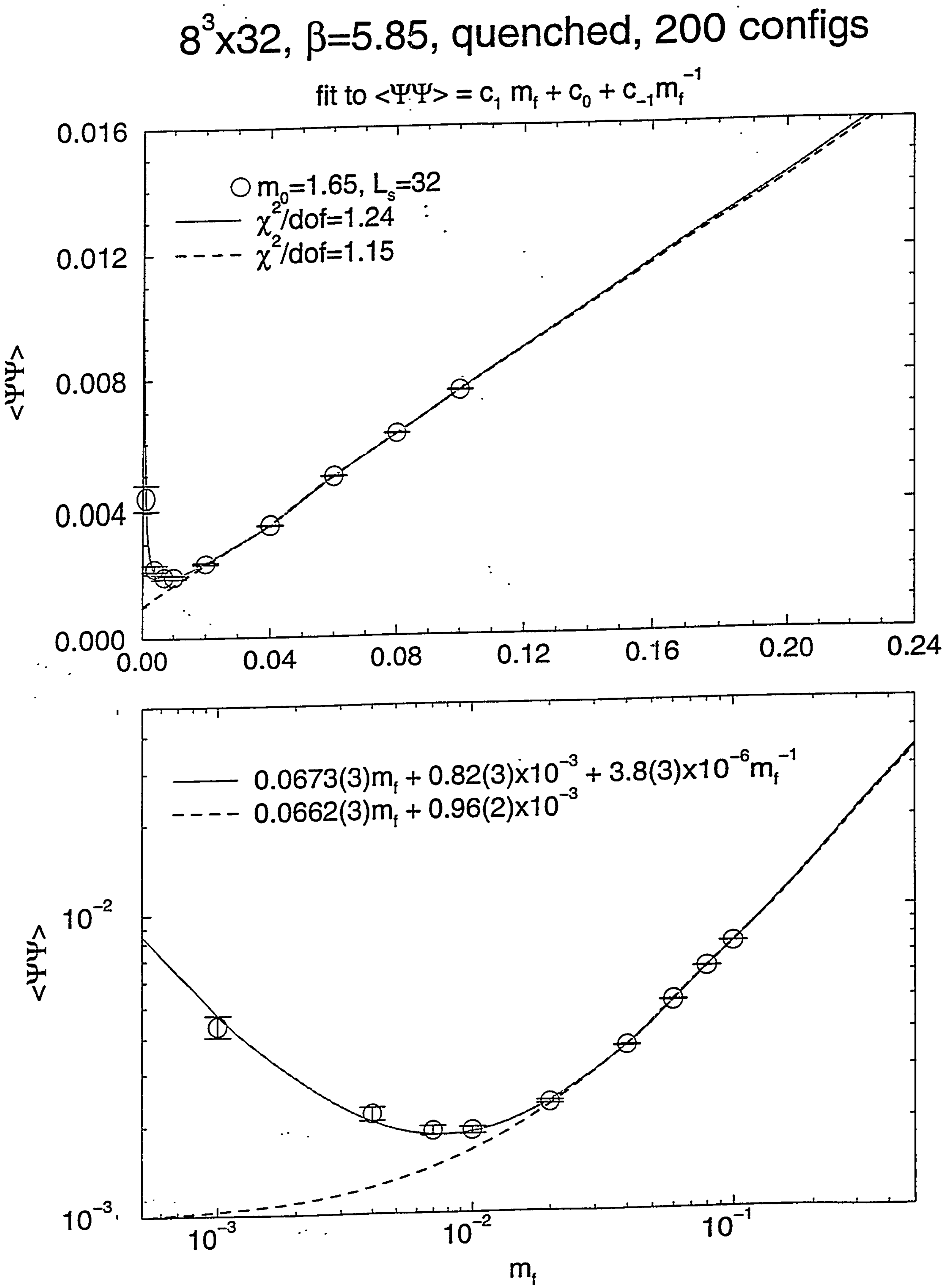
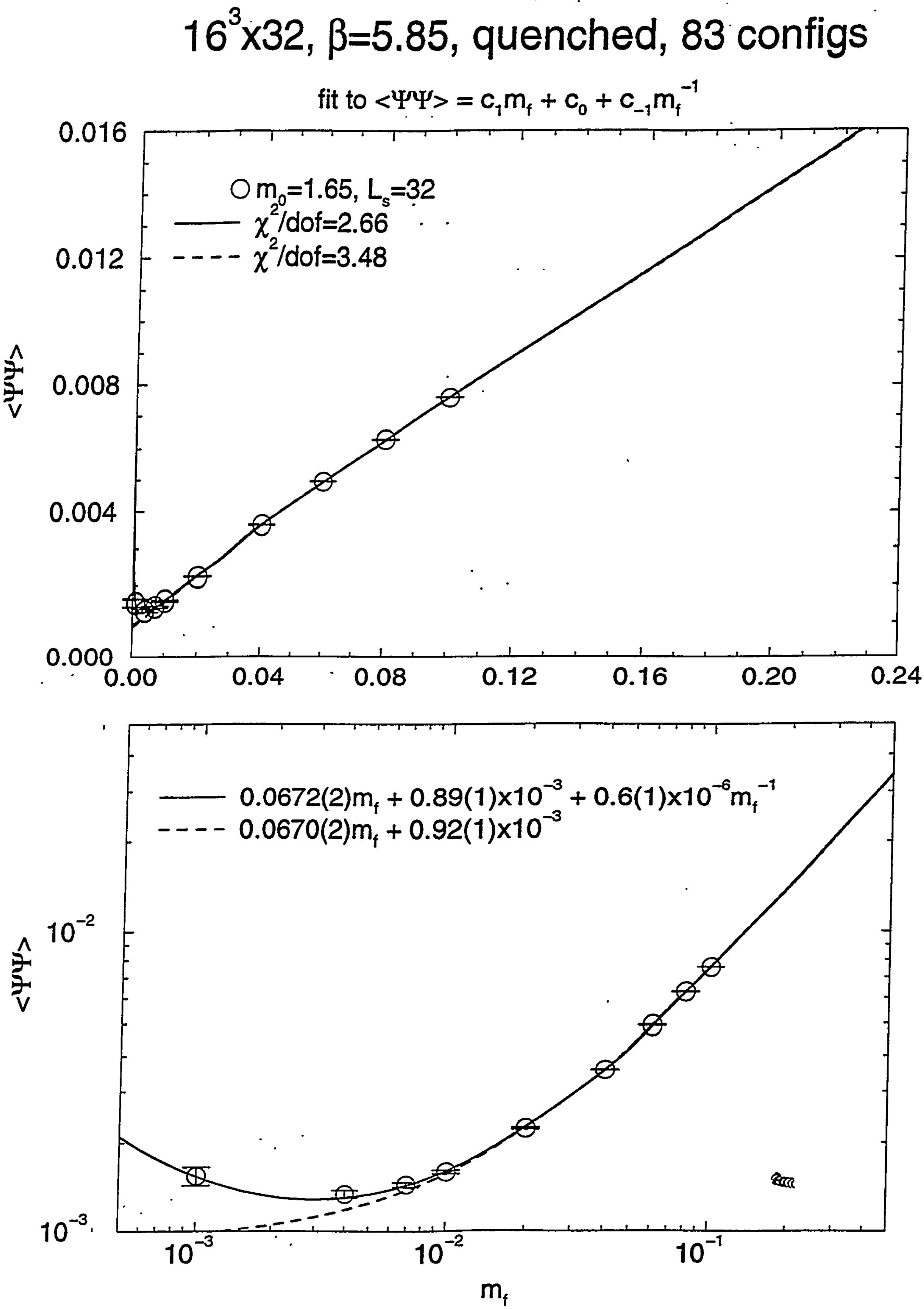

V=16^4, ζ=0.1
10^{-1}
10^{-2}
10^{-3}
$\langle \bar{q}q \rangle$
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
m_f

Figure 1



8³x32, β=5.85, quenched, 200 configs
fit to <ΨΨ> = c₁ m_f + c₀ + c₋₁m_f⁻¹
m₀=1.65, L_s=32
χ²/dof=1.24
χ²/dof=1.15
<ΨΨ>
0.000
0.004
0.008
0.012
0.016
0.00
0.04
0.08
0.12
0.16
0.20
0.24
0.0673(3)m_f + 0.82(3)x10⁻³ + 3.8(3)x10⁻⁶m_f⁻¹
0.0662(3)m_f + 0.96(2)x10⁻³
<ΨΨ>
10⁻²
10⁻³
10⁻³
10⁻²
10⁻¹
m_f

Figure 2



16³x32, β=5.85, quenched, 83 configs
fit to <ΨΨ> = c₁m_f + c₀ + c₋₁m_f⁻¹
m₀=1.65, L_s=32
χ²/dof=2.66
χ²/dof=3.48
<ΨΨ>
0.016
0.012
0.008
0.004
0.000
0.00
0.04
0.08
0.12
0.16
0.20
0.24
0.0672(2)m_f + 0.89(1)x10⁻³ + 0.6(1)x10⁻⁶m_f⁻¹
0.0670(2)m_f + 0.92(1)x10⁻³
10⁻²
10⁻³
10⁻¹
m_f

Figure 3

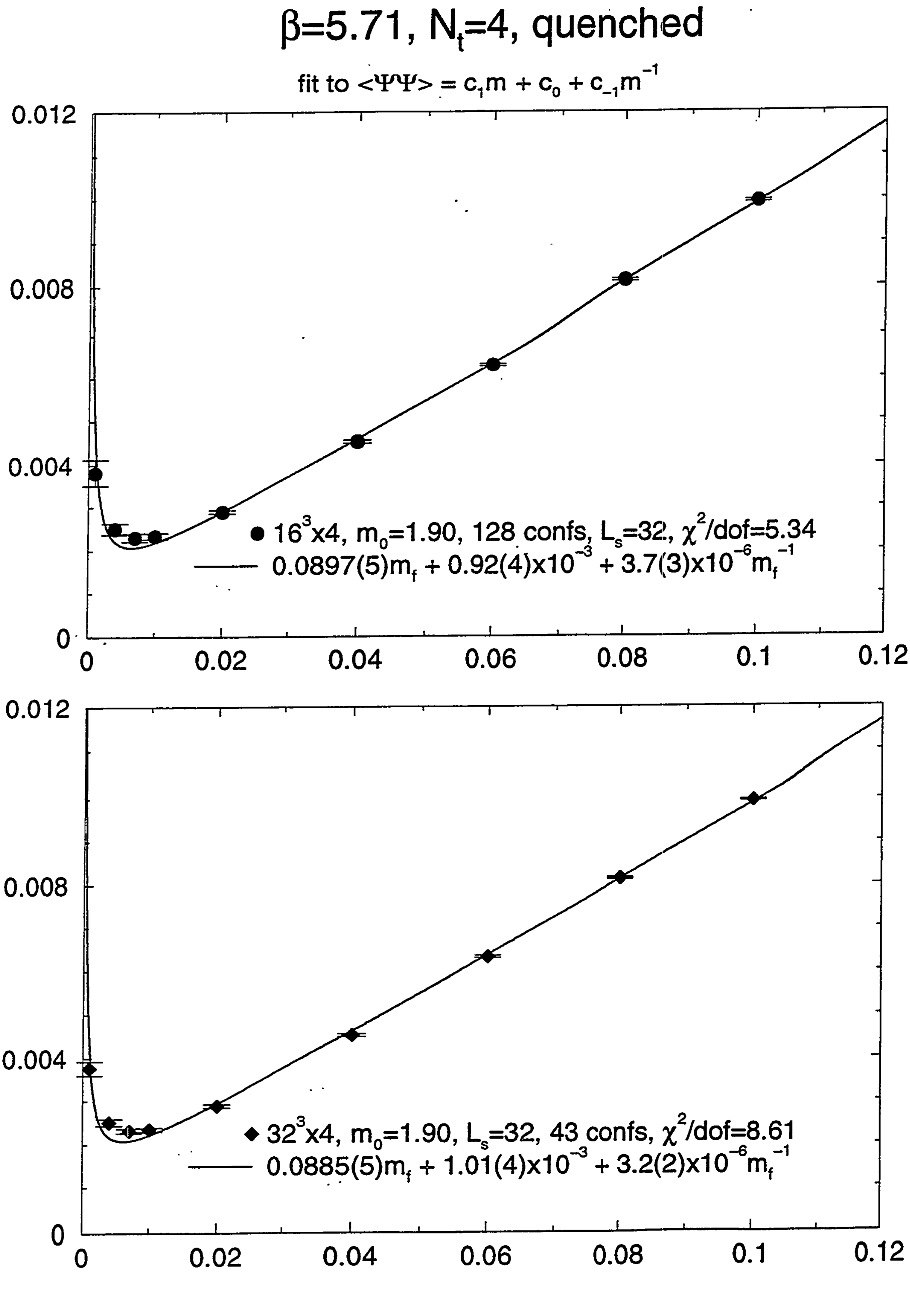

β=5.71, N_t=4, quenched
fit to <ΨΨ> = c_1m + c_0 + c_-1m^-1
16^3x4, m_0=1.90, 128 confs, L_s=32, χ^2/dof=5.34
0.0897(5)m_f + 0.92(4)x10^-3 + 3.7(3)x10^-6m_f^-1
32^3x4, m_0=1.90, L_s=32, 43 confs, χ^2/dof=8.61
0.0885(5)m_f + 1.01(4)x10^-3 + 3.2(2)x10^-6m_f^-1
0.012
0.008
0.004
0
0.02
0.04
0.06
0.08
0.1
0.12

Figure 4

$U_A(1)$ Effects with Domain Wall Fermions

Gabriele Siegert
Columbia University

$U_A(1)$ effects with domain wall fermions

G. Siegert[1][2]

Domain wall fermions (DWF) are very suited for a search for $U_A(1)$ effects since they have the full symmetry in the limit L_s infinite. In the other fermion formulations one must always disentangle the $U_A(1)$ effects from finite a effects.

The $U_A(1)$ rotates the pseudoscalar pion $\pi = \bar{\psi}\gamma^5\tau^a\psi$ into the scalar delta $\delta = i\bar{\psi}\tau^a\psi$. If we had full $U_A(1)$ symmetry, these two particles would be degenerate.

For the susceptibility of the pion one finds

$$\int d^4x d^4y \langle\bar{\psi}(x)\gamma^5\tau^a\psi(x)\bar{\psi}(y)\gamma^5\tau^b\psi(y)\rangle = -\langle Tr(\gamma^5\tau^a\frac{1}{D+m}\gamma^5\tau^b\frac{1}{D+m})\rangle \quad (1)$$

$$= -\langle Tr(\tau^a\tau^b\frac{1}{-D+m}\frac{1}{D+m})\rangle. \quad (2)$$

With $Du = i\lambda u$ and the mean spectral density $\bar{\rho}(\lambda)$ this is

$$= -\delta_{ab}N_f\Omega\int_{-\infty}^{\infty} d\lambda\bar{\rho}(\lambda)\frac{1}{\lambda^2+m^2}. \quad (3)$$

For the susceptibility of the delta one finds similarly

$$\int d^4x d^4y \langle i\bar{\psi}(x)\tau^a\psi(x)i\bar{\psi}(y)\tau^b\psi(y)\rangle = \langle Tr(\tau^a\frac{1}{D+m}\tau^b\frac{1}{D+m})\rangle \quad (4)$$

$$= \delta_{ab}N_f\Omega\int_{-\infty}^{\infty} d\lambda\bar{\rho}(\lambda)\frac{1}{(i\lambda+m)^2} \quad (5)$$

$$= \delta_{ab}N_f\Omega\int_{-\infty}^{\infty} d\lambda\bar{\rho}(\lambda)(\frac{-1}{\lambda^2+m^2}+\frac{2m^2}{(\lambda^2+m^2)^2}) \quad (6)$$

To their difference

$$\int d^4x d^4y \langle\bar{\psi}(x)\gamma^5\tau^a\psi(x)\bar{\psi}(y)\gamma^5\tau^b\psi(y)\rangle - \langle i\bar{\psi}(x)\tau^a\psi(x)i\bar{\psi}(y)\tau^b\psi(y)\rangle \quad (7)$$

$$= \delta_{ab}N_f\Omega\int_{-\infty}^{\infty} d\lambda\bar{\rho}(\lambda)\frac{-2m^2}{(\lambda^2+m^2)^2} \quad (8)$$

in the $m \to 0$ limit only zeromodes contribute. Following you find our results on the lattice.

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[1]supported by Max-Kade-Foundation

[2]done in collaboration with P. Chen, N. Christ, G. Fleming, A. Kaehler, T. Klassen, C. Malureanu, R. Mawhinney, C. Sui, P. Vranas, L. Wu, Y. Zhestkov

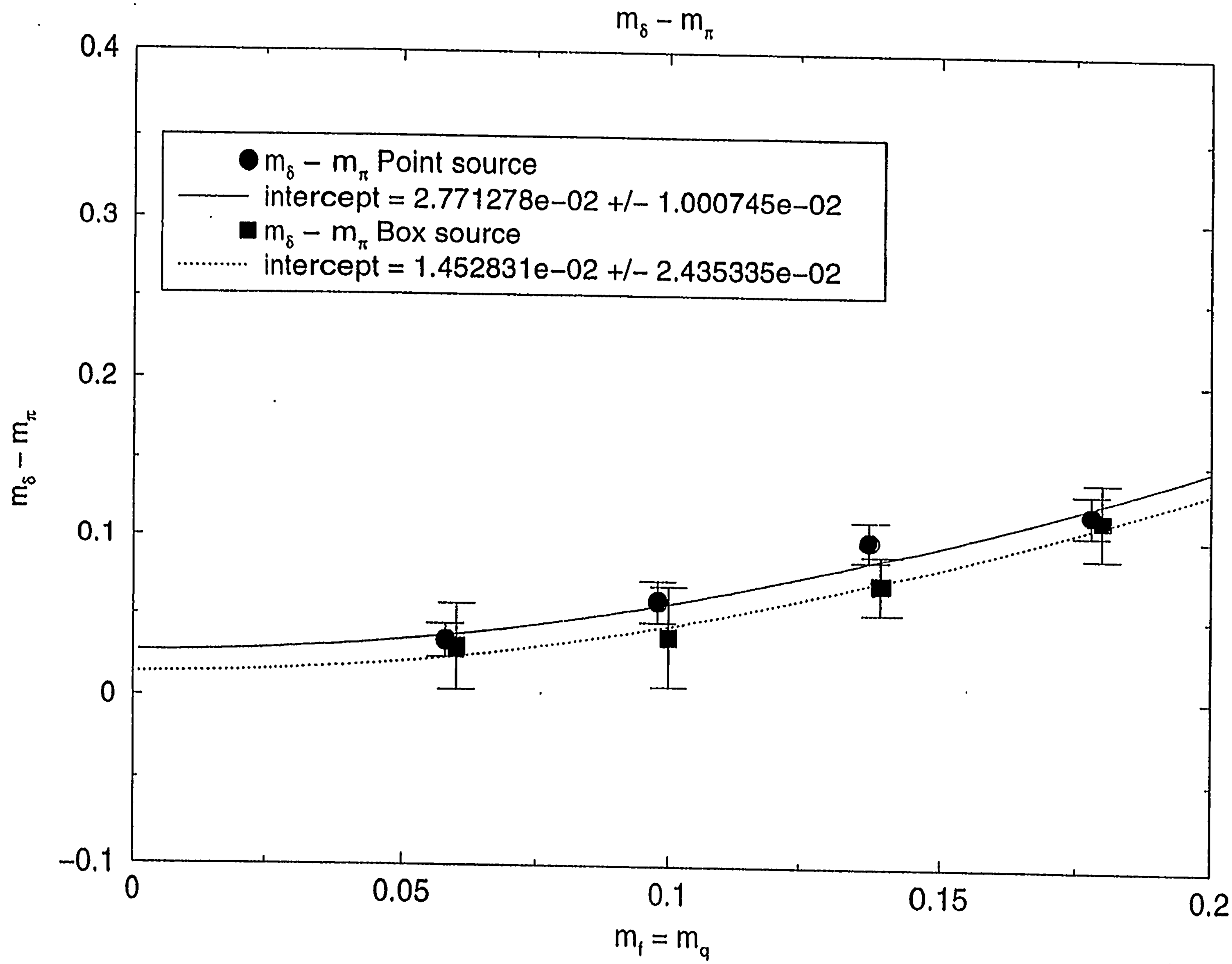
Run Parameters

Lattice: $16^3 \times 4$
$\beta = 5.45$ and 5.40
$L_s = 16$
$M_0 = 1.9$
$m_f = 0.06$ 0.10 0.14 0.18 and 0.06 0.08 0.10 (0.12) 0.14
$n_f = 2$
stepsize = 0.0078125
# steps = 64
measurement of point source spectrum every five trajectories
measurement of box source spectrum every 100 ($\beta = 5.45$) or every 10 ($\beta = 5.40$) trajectories

Statistics

β	m_f	# meas. point source	# meas. box source
5.45	0.06	272	14
	0.10	296	11
	0.14	276	14
	0.18	294	15
5.40	0.06	338	94
	0.08	220	100
	0.10	332	122
	0.14	264	104

$16^3 x4\ \beta=5.45\ M_0=1.9\ L_S=16$



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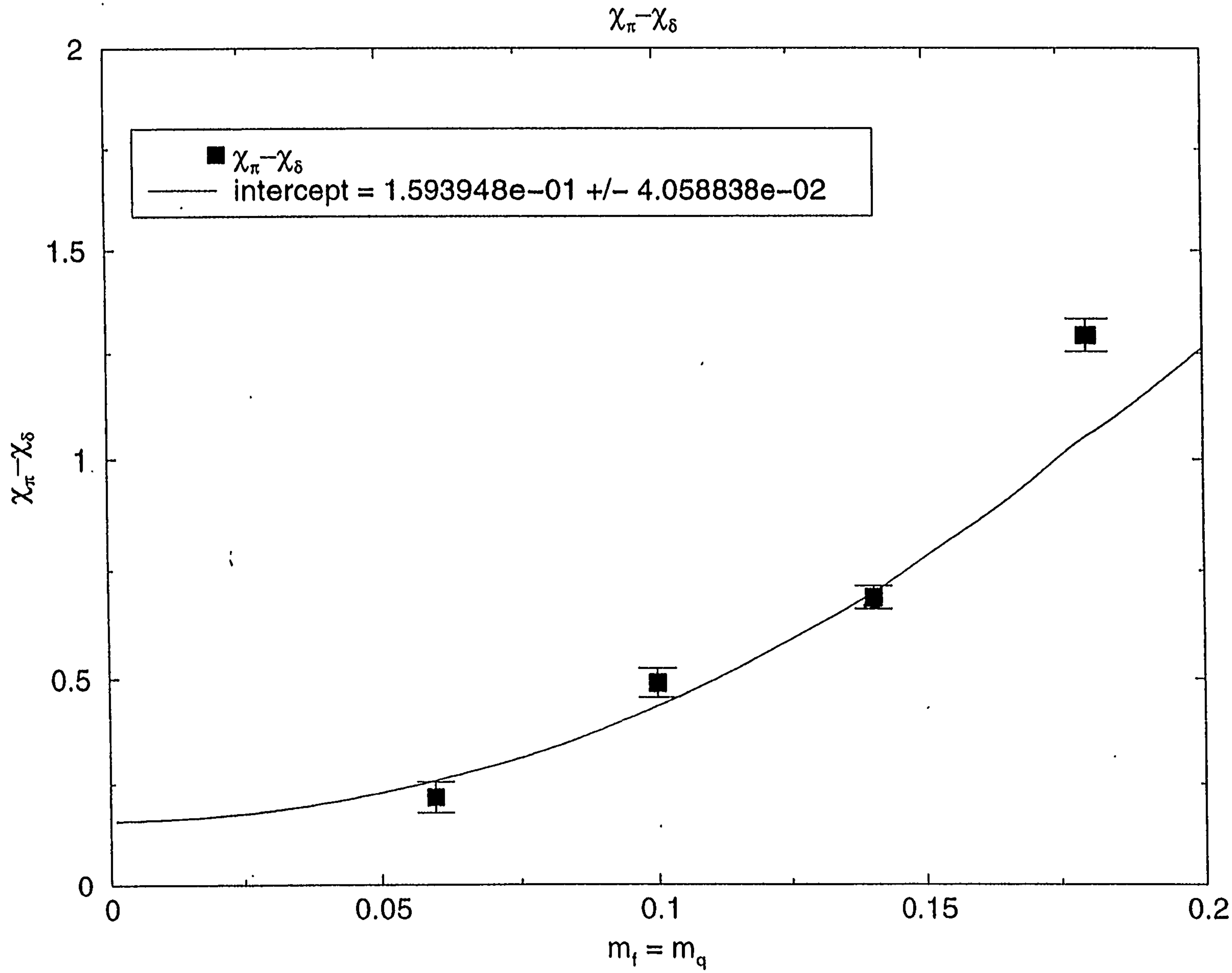
$16^3 x4\ \beta=5.45\ M_0=1.9\ L_S=16$



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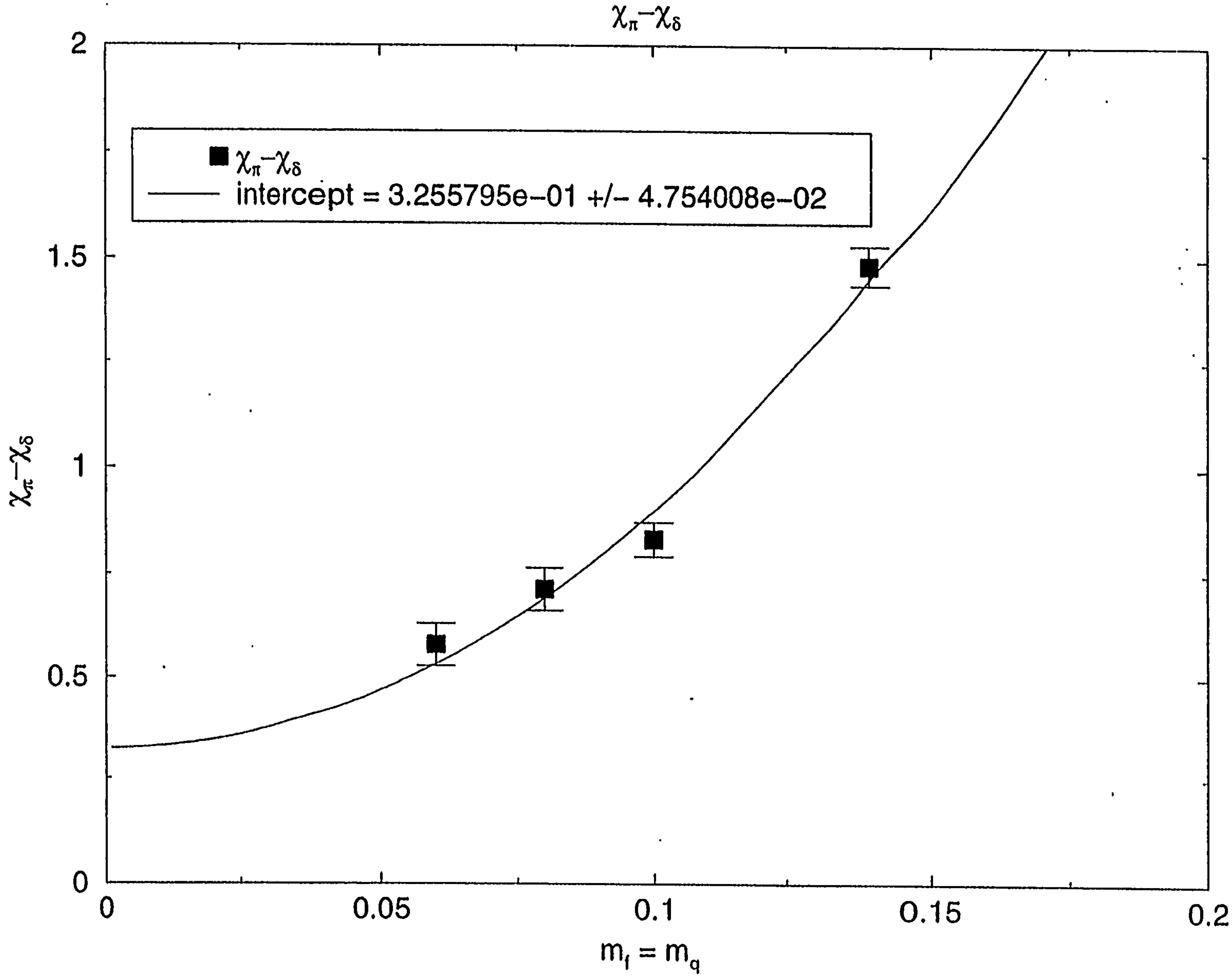
16^3x4 β=5.40 M_0=1.9 L_S=16



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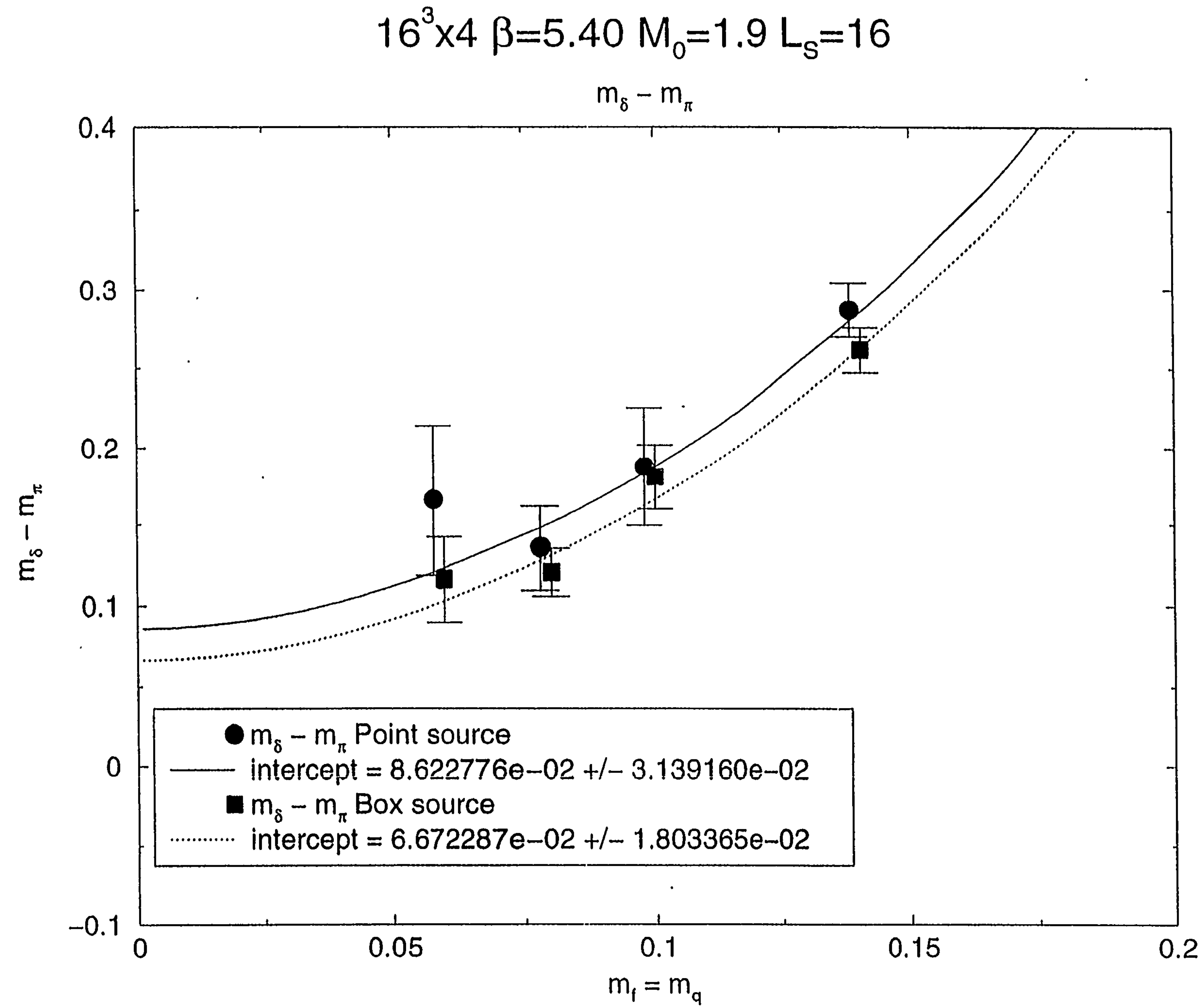

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Workshop on Physics of 1 Teraflop RIKEN-BNL-COLUMBIA QCD Project
October 16, 1998
Organizers: Robert Mawhinney

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WORKSHOP ON PHYSICS OF 1 TERAFLOP RIKEN-BNL-COLUMBIA QCD PROJECT
OCTOBER 16, 1998
ORGANIZERS: ROBERT MAWHINNEY

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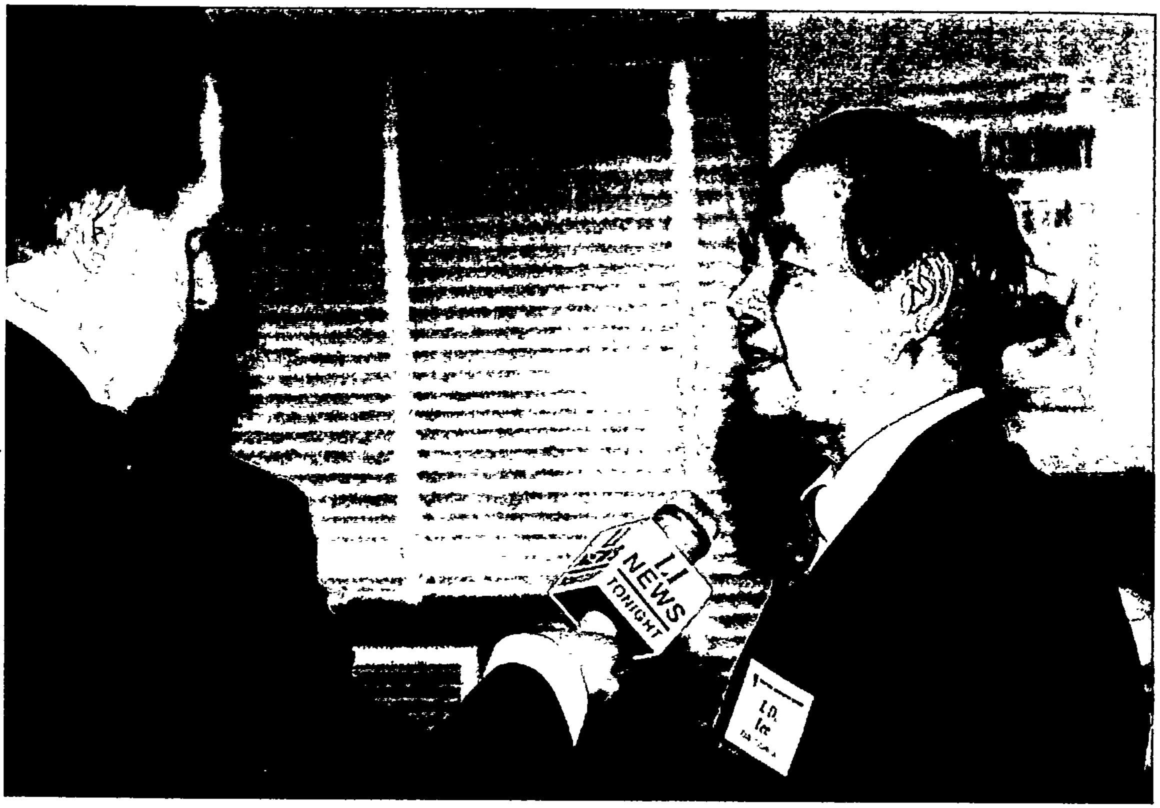

Media Coverage of the Unveiling of the RIKEN-BNL Supercomputer

Shun-ichi Kobayashi, T. D. Lee and John Marburger
Unveiling the RIKEN-BNL Supercomputer

COLUMBIA UNIVERSITY
IN THE CITY OF NEW YORK
PRESIDENT'S ROOM

October 21, 1998

Dear T. D.:

I am writing to extend my congratulations to you and your colleagues on the remarkably successful first year of operations of the RIKEN-Brookhaven Research Center. In my remarks at the inauguration of the Center a year ago, I expressed confidence that the Center would make valuable contributions to physics. But I had no idea that it would do so in so little time!

Three aspects of the Center deserve special mention. First, it provides a dramatic demonstration of the possibilities and the benefits of international collaboration in modern science. Recent failures of international projects have received considerable attention and might lead some to question the wisdom of embarking on new ventures, but you and the leaders of RIKEN have shown that cooperation can occur and that when it does everyone benefits. Second, the Center has focused on the nurture and encouragement of a new generation of young physicists; more such institutions are needed to assure that the flourishing of science will continue into the coming century. Third, the Center stands as a symbol that Brookhaven National Laboratory remains at the forefront of basic research, even as it lives through troubled times. I know that the new management of the Laboratory, and certainly Columbia's part of that management, is committed to preserving and enhancing Brookhaven's role as one of the world's preeminent scientific laboratories.

Columbia is proud of the role it has played in the early life of the Center. Your participation, together with that of others in the Columbia physics department, has been central to the rapid and productive start of the research program. The collaboration between the Center and Columbia on the construction of the supercomputer has been accomplished with speed and effectiveness that was hoped for but could not have been predicted.

The accomplishments of the Center have forced me to revise my already high expectations even higher still. I wish you and the Center good fortune as it moves into the future. And again, congratulations on an impressively successful first year!

Sincerely,

George Rupp

Professor T.D. Lee
829 Pupin
MC 5208

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FASTEST MULTI-PURPOSE NON-COMMERCIAL SUPERCOMPUTER IN WORLD UNVEILED AT BROOKHAVEN NATIONAL LABORATORY

UPTON, NY — The fastest multi-purpose non-commercial supercomputer in the world was unveiled today at the U.S. Department of Energy's Brookhaven National Laboratory.

With a top operating speed of 600 billion calculations per second, or 0.6 teraflops, the supercomputer is the 12th fastest over all in the world. At a cost of only $1.8 million, it is also one of the least expensive.

Scientists will use the machine to carry out forefront physics research, some so complicated it can only be done using the world's fastest computers.

The computer was designed and built by scientists and computer specialists from Columbia University and BNL, and funded by the Japanese RIKEN laboratory as part of its support of the RIKEN-BNL Research Center established in 1997 at BNL.

"This computer is a tribute to the creativity and resourcefulness of BNL, Columbia University and RIKEN Laboratory scientists who created it," said Secretary of Energy Bill Richardson. "This generation of machine and much larger ones soon to follow will be the new tools of discovery and innovation for science and society to solve complex problems in global climate, energy, technologies and basic research."

Called the RIKEN-BNL QCD supercomputer, the machine is optimized for advanced research into quantum chromodynamics, or QCD, the model of matter based on the "strong force" that binds quarks and gluons in the particles that make up the center of every atom in the universe.

Among other projects, the computer's speed will allow scientists to predict and analyze the behavior of subatomic particles and phenomena that will be produced at BNL's newest "atom smasher," the Relativistic Heavy Ion Collider (RHIC), now under construction.

RHIC aims to create the quark-gluon plasma, a form of matter not seen since just after the Big Bang. During that fleeting instant, quarks and gluons are thought to have existed independently of their usual bonds, before protons and neutrons "condensed" out of the super-hot plasma.

"This is what Brookhaven Lab is all about," said BNL Director John Marburger. "We have a strong collaboration, including a major regional university and an international partner, working on one of the most difficult and basic problems at the frontier of science, and at the same time we are strengthening Long Island's economy through direct investment." Over $1,000,000 in components for the supercomputer were purchased from Long Island firms.

— more —

The machine is a finalist for the Gordon Bell prize for price-performance at the upcoming SC98 High Performance Networking and Computing conference in November.

"All of us at the RIKEN-BNL Research Center are eager to put this supercomputer to the test in our attempts to solve some of the most pressing questions of modern physics," said the center's director, Nobel Prize winner T.D. Lee.

A Unique Machine for Physics

The supercomputer stands almost nine feet high and is mounted in six large racks that are water-cooled to keep the machine from overheating.

There are a total of 12,288 nodes, or processors, in the computer, providing the calculational power needed to handle the demands of tracking the movement of millions of virtual subatomic particles.

A specially designed custom computer chip called a node gate array, or NGA, handles communications between the nodes and is at the heart of the supercomputer's design. Each NGA is paired with a Texas Instruments 50-megahertz processor and two megabytes of DRAM to form a single processing unit or "node" of the machine. Each node is constructed on a small printed circuit board called a "daughterboard." Sixty-four nodes are combined and attached to a larger structure called a "motherboard." There are 192 motherboards in all.

"Essentially, this computer turns space and time into a four-dimensional lattice, which can be thought of as a three-dimensional grid at any moment of time," said Robert Mawhinney, one of the Columbia physicists who led the design team for the RIKEN-BNL machine and its 0.4-teraflop sister machine at Columbia's physics department. "The computer can be used for many grid-oriented problems and in our problem, the grid gives reference points for calculating where particles are at any given moment."

"The smaller the boxes in the grid or the lattice," Mawhinney continued, "the more precise we can be in our calculations. Of course, the smaller and more numerous the boxes, the more computing power is required. But with this machine, the calculations will be more precise than ever before."

Shopping Locally

The supercomputer may be of world-class stature, but it has local roots. Nearly one-third of the components used to build the machine were purchased from Long Island firms in a competitive bidding process.

The two largest contracts were awarded to electronic components distributors Marshall Industries of Hauppauge, for $540,000, and Nu Horizons Electronics Corp. of Melville, for $236,000. In a critical step, the assembly of all the daughterboards and motherboards was performed by AJC Electronics of Syosset under an $89,000 contract. The final process of installing and debugging the complete system was handled largely by BNL's Computing & Communications staff.

Other Long Island companies that supplied components include: Hadco Corp. of Uniondale, for more than $115,000 in printed circuit boards; Bell Microproducts of Smithtown, $7,800; Anthem Electronics of Commack, $6,000; and Dove Electronics of East Setauket, $500.

"We were glad that much of what we needed was available through local suppliers," said Lee. "To build such a large computer from scratch is a massive task, but the job was made easier by the excellent service we received from these companies."

The RIKEN laboratory, whose name is short for "Rikagaku Kenkyusho," meaning Institute of Physical and Chemical Research, is supported by the Japanese Science and Technology Agency. It is located near Tokyo.

Brookhaven National Laboratory carries out basic and applied research in the physical, biomedical and environmental sciences and in selected energy technologies. Brookhaven is operated by Brookhaven Science Associates, a nonprofit research management organization, under contract with the U.S. Department of Energy.

More information on the supercomputer is available on the Web at http://www.ccd.bnl.gov/riken_bnl/qcd_project/qcdp.html

BNL unveils supercomputer

Question: What is almost nine feet tall, has local roots, and can compute at a speed of 600 billion calculations per second?

Answer: The new supercomputer just unveiled at Brookhaven National Laboratory, the fastest, multi-purpose, non-commercial computer in the world. With an operating speed of 0.6 teraflops, the computer is the twelfth fastest of all the supercomputers in the world. At a cost of only $1.8 million, it is also one of the least expensive.

Scientists will use the machine to carry out pioneering physics research, some so complicated it can only be done by using the world's fastest computers.

The computer was designed and built by scientists and computer specialists from Columbia University and Brookhaven National Laboratory, and funded by the Japanese RIKEN laboratory as part of its support of the RIKEN-BNL Research Center established in 1997 at BNL.

"This computer is a tribute to the creativity and resourcefulness of the scientists who created it," said Secretary of Energy Bill Richardson. "This generation of machine and much larger ones soon to follow will be the new tools of discovery and innovation for science and society to solve complex problems in global climate, energy, technologies, and basic research."

Called the RIKEN-BNL QCD supercomputer, the machine is optimized for advanced research into quantum chromodynamics, the model of matter based on the "strong force" that binds quarks and gluons in the particles that make up the center of every atom in the universe.

Among other projects, the computer's speed will allow scientists to predict and analyze the behavior of subatomic particles and phenomena that will be produced at BNL's newest atom smasher, the Relativistic Heavy Ion Collider now under construction.

The Relativistic Heavy Ion Collider aims to create the quark-gluon plasma, a form of matter not seen since just after the Big Bang. During that fleeting instant, quarks and gluons are thought to have existed independently of their usual bonds, before protons and neutrons condensed out of the super-hot plasma.

"This is what Brookhaven Lab is all about," said director John Marburger. "We have a strong collaboration, including a major regional university and an international partner, working on one of the most difficult and basic problems at the frontier of science, and at the same time we are strengthening Long Island's economy through direct investment." He said that over $1 million in components for the supercomputer were purchased from Long Island firms.

"All of us at the research center are eager to put this supercomputer to the test in our attempts to solve some of the most pressing questions of modern physics," said the center's director, Nobel Prize winner T. D. Lee.

The computer is mounted in six large racks that are watercooled to keep it from overheating. There are a total of 12,288 nodes, or processors, in the computer, providing the calculational power needed to handle the demands of tracking the movement of millions of virtual subatomic particles.

A specially designed custom computer chip called a node gate array handles communications between the nodes and is at the heart of the supercomputer's design. Each chip is paired with a Texas Instruments 50-megahertz processor and two megabytes of DRAM to form a single processing unit or node of the machine. Each node is constructed on a small printed circuit board called a "daughterboard." Sixty-four nodes are combined and attached to a larger structure called a "motherboard." There are 192 motherboards in all.

"Essentially, this computer turns space and time into a four-dimensional lattice, which can be thought of as a three-dimensional grid at any moment of time," said Robert Mawhinney, one of the Columbia physicists. "The computer can be used for many grid-oriented problems, and in our problem, the grid gives reference points for calculating where particles are at any given moment."

A lot of brain power in one room: Creators of the new supercomputer pose with one of the motherboards constructed locally: T.D. Lee, Nobel Prize winner in Physics in 1958 and director of RIKEN-BNL Research Center; Shun-ichi Kobayashi, president of RIKEN lab, Japan; Koichi Yazaki, University of Tokyo, head of RIKEN theory; Shigemi Ohta, scientist, RIKEN and KEK; Minoru Yanokura, associate director, RIKEN Center; Edward McFadden of Bayport, RIKEN Supercomputer project manager; Robert Mawhinney, associate professor of physics, Columbia University; John Marburger, Director, BNL; Satoski Ozaki, head of RHIC; Norman Christ, physics department chairman, Columbia University; Sakauchi, RIKEN board; Akira Ukawa, professor, University of Tsukuba; Raphael Kasper, professor of physics, Columbia University; and Nicholas Samios, BNL deputy director for RIKEN. Not pictured, Paul Poleski of Bayport, who helped to build the supercomputer.

Nearly one-third of the components used to build the machine were purchased from Long Island firms. The two largest contracts were awarded to electronic distributors Marshall Industries of Hauppauge for $540,000, and Nu Horizons Electronics Corporation of Melville for $236,000. In a critical step, the assembly of all the daughterboards and motherboards was performed by AJC Electronics of Syosset under an $89,000 contract. Other companies that provided components include Hadco Corporation of Uniondale for more than $115,000 in printed circuit boards, Bell Microproducts of Smithtown for $7,800, Anthem Electronics of Commack for $6,000, and Dove Electronics of East Setauket for $500.

"We were glad that much of what we needed was available through local suppliers," said Lee. "To build such a large computer from scratch is a massive task, but the job was made easier by the excellent service we received from these companies."

—Chuck Anderson

Brookhaven Review - October 22, 1998

BNL Gets A Supercomputer

by Joel Reitman

The fastest multipurpose non-commercial supercomputer in the world was unveiled at Brookhaven National Laboratory (BNL). The computer was designed and built by scientists and computer specialists from Columbia University and BNL.

Called the RIKEN-BNL QCD supercomputer, the machine is optimized for advanced research into a model of matter based on quarks and gluons, the particles that make up the center of every atom in the universe.

The computer's speed will allow scientists to predict and analyze the behavior of subatomic particles that will be produced at BNL's newest atom smasher, the Relativistic Heavy Ion Collider (RHIC), now under construction.

Scientists will use the machine to carry out research in the forefront of physics, so complicated that it can only be done using the world's fastest computers.

"This generation of machine and larger ones to follow will be the new tools of discovery and innovation to solve complex problems in global climate, energy, technologies, and basic research," said Secretary of Energy Bill Richardson.

Over $1,000,000 in components for the supercomputer were purchased from Long Island firms.

"This is what BNL is all about," said BNL Director John Marburger. According to Marburger, BNL is strengthening Long Island's economy through direct investment.

The supercomputer may be of world-class stature, but it has local roots. Nearly one-third of the components were purchased from Long Island firms. The two largest contracts were awarded to Marshall Industries of Hauppauge for $540,000 and Nu Horizons Electronics Corporation of Melville for $236,000.

Other Long Island companies that supplied components include AJC Electronics of Syosset, Hadco Corporation of Uniondale, Bell Microproducts of Smithtown, Anthem Electronicsof Commack, and Dove Electronics of East Setauket.

World's Fastest Computer Debuts at Brookhaven Lab

The fastest multi-purpose non-commercial supercomputer in the world was unveiled yesterday at Brookhaven National Laboratory in North Shirley/Upton.

With a top operating speed of 600 billion calculations per second, or 0.6 teraflops, the supercomputer is the 12th fastest over all in the world. At a cost of $1.8 million, it is also one of the least expensive, according to lab officials.

Scientists will use the machine to carry out forefront physics research, some so complicated it can only be done using the such an ultra-fast computer.

The computer was designed and built by scientists and computer specialists from Columbia University and BNL, and funded by the Japanese RIKEN laboratory as part of its support of the RIKEN-BNL Research Center established in 1997 at BNL.

"This computer is a tribute to the creativity and resourcefulness of the Brookhaven National Laboratory, Columbia University and RIKEN Laboratory scientists who created it," said Secretary of Energy Bill Richardson. "This generation of machines and much larger ones soon to follow will be the new tools of discovery and innovation for science and society to solve complex problems in global climate, energy, technologies and basic research."

Called the RIKEN-BNL QCD supercomputer, the machine is optimized for advanced research into quantum chromodynamics, or QCD, the model of matter based on the "strong force" that binds quarks and gluons in the particles that make up the center of every atom in the universe.

Among other projects, the computer's speed will allow scientists to predict and analyze the behavior of subatomic particles and phenomena that will be produced at BNL's newest "atom smasher," the Relativistic Heavy Ion Collider (RHIC), now under construction.

"To have such a strong synergy between two facilities at Brookhaven, RHIC and the RIKEN BNL center, while at the same time supporting our local high-technology sector, is truly satisfying," said BNL Director John Marburger. Over $ 1,000,000 in components for the supercomputer were purchased from Long Island firms."

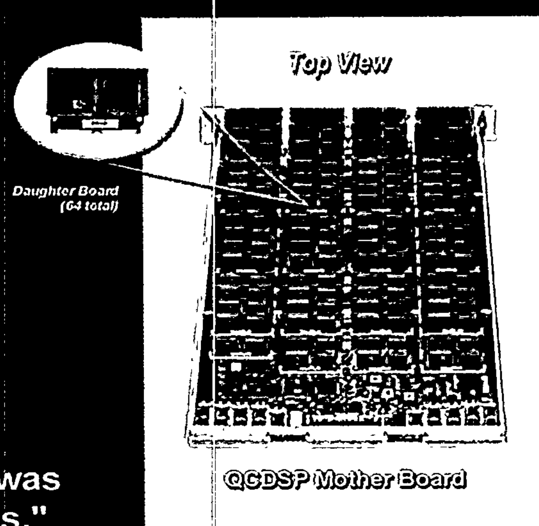
South Shore Press - October 20, 1998

Shopping Local

This *Supercomputer* may be of a "world-class" stature, but it has local roots. Nearly one-third of the components used to build this machine were PURCHASED from Long Island firms in a competitive bidding process.

The contracts were:

1.) Marshell Industries, Ronkonkoma
2.) NuHorizons Electronics, Melville
3.) AJS Electronics, Syosset
4.) Hadco Corp, Uniondale
5.) Bell Microproducts, Smithtown
6.) Anthem Electronics, Commack
7.) Dove Electronics, East Setauket
8.) Todd Products, Brentwood
9.) Local construction firms for the site preparation (A/C, Elec, etc)



"Building this machine from scratch was made easier by using local companies."

RIKEN-BNL Research Director
T.D. Lee

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TV CLIPS

DATE	October 16, 1998
TIME	5:00-6:00 PM
STATION	Rainbow News 12
LOCATION	Long Island, N.Y.
PROGRAM	News 12 Evening Edition
ACCOUNT NUMBER	67/6508
NIELSEN AUDIENCE	N/A

Scott Feldman, co-anchor:

One of the world's fastest computers is now on the Island. Engineers at Brookhaven National Lab and Columbia University built this supercomputer that can make six hundred billion calculations a second. The 1.8 million dollar computer was unveiled today.

TV CLIPS

DATE	October 16, 1998	ACCOUNT NUMBER	67/6508
TIME	6:00-6:30 PM	NIELSEN AUDIENCE	487,000
STATION	WCBS-TV (CBS) Channel Two		
LOCATION	New York		
PROGRAM	2 News at 6:00		

LISA COOLEY, co-anchor:

Well, speaking of brains, every Tuesday night Marilyn vos Savant answers some very tough questions on News 2 at 11:00. But tonight we found a computer that can do even better. Marilyn is fast, but this nine-foot-tall computer can answer 600 billion questions in just one second. The supercomputer was unveiled today at Brookhaven Laboratory on Long Island, which is run by the Energy Department. The machine's going to work on problems in the global climate, technology and basic research. It is the 12th fastest computer in the world, as a matter of fact.

TV CLIPS

DATE	October 16, 1998	ACCOUNT NUMBER	67/6508
TIME	6:00-6:30 PM	NIELSEN AUDIENCE	721,000
STATION	WNBC-TV Channel Four		
LOCATION	New York		
PROGRAM	News Channel 4		

Jane Hanson, co-anchor:

Finally, we all know it's better when it's homemade, but take a look at the world's fastest homemade computer. This supercomputer was designed and built by the scientists of Brookhaven National Lab and Columbia University (visual of the supercomputer). This baby features twelve thousand two hundred and eighty-eight chips. It's capable of six hundred billion calculations per second, took six months to build at a cost of 1.8 million dollars with local parts. It will be used to test the theories of quantum physics, such things as the Big Bang theory.


55
55

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TV CLIPS

DATE	October 19, 1998	ACCOUNT NUMBER	67/6508
TIME	11:00-11:30 PM	NIELSEN AUDIENCE	4,000
STATION	WLNY-TV (Ind.) Channel 55		
LOCATION	Riverhead, N.Y.		
PROGRAM	News 55 Live at Eleven		

Jamie Colby, anchor:

A major breakthrough in the world of science. Brookhaven National Laboratory is now home to a machine that may be able to solve questions that have perplexed physicists for centuries.

Shari Bregman reporting:

You are looking at the fastest non-commercial supercomputer in the world. The new computer, which was unveiled here Friday, will allow scientists at the Brookhaven National Laboratory to conduct physics research faster than ever before.

Edward McFadden (Advanced Computer Analyst): Nothing that we've ever had even is in the same class as what this computer is capable of providing in terms of calculations per second.

Bregman: Six hundred billion calculations per second to be exact. It took scientists and computer specialists a year and a half to put together the advanced system, and physicists are looking forward to doing analysis that wasn't possible with slower computers.

Shigemi Ohta (Physicist): We will investigate how the universe started and the big bang or how the protons spin, why the protons spin so rapidly.

Bregman: The supercomputer is worth between ten and fifteen million dollars, but it only cost about 1.8 million to build, the reason: It's homemade. Over one-half of the components were bought from local Long Island companies, which kept the costs way down.

In Upton, Shari Bregman, News 55.

Colby: Construction of the supercomputer was funded by the Japanese RIKEN Laboratories as part of its support of the Brookhaven National Lab Research Center.

24 Clips

Nielsen Audience Source: Nielsen Media Research, July 1998, Persons 2+, NSI 4-week Averages
Video cassettes are available for four weeks from our affiliate: VMS (212)736-2010

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TV CLIPS

DATE	October 16, 1998	ACCOUNT NUMBER	67/6508
TIME	5:00-6:00 PM	NIELSEN AUDIENCE	606,000
STATION	WABC-TV Channel Seven		
LOCATION	New York		
PROGRAM	Eyewitness News		

Diana Williams, co-anchor:

And another computer marvel. The world's fastest multi-purpose non-commercial supercomputer was unveiled at the Brookhaven National Lab in Upton. It's kind of like Sam's brain (referring to Sam Champion, the meteorologist). The machine has a top operating speed of six hundred billion calculations per second. Scientists will use the supercomputer to carry out cutting-edge physics research. Sam just uses his brain to calculate the weather forecast.

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RADIO CLIPS

DATE	October 16, 1998	ACCOUNT NUMBER	67/6508
TIME	1:30-2:00 PM		
STATION	KNWX 770 AM		
LOCATION	Seattle		
PROGRAM	News		

Jeannie Lockhart reporting:

Wouldn't you love to have this to do your taxes? Sam Litsinger tells us about a new super computer that's now crunching numbers at lightning speed.

Sam Litsinger reporting:

It's billed as the fastest non-commercial super computer on the planet. It's named the Riken BNLQCD, but maybe we can just call it Riki. Anyway, it's nine feet tall, needs water to keep it from overheating, and it can answer six hundred billion questions in one second. Riki's just gone to work at the Brookhaven National Laboratory on Long Island and will be used for physics research--among other things, allowing scientists to predict and analyse the behavior of sub-atomic particles. Humans can't even begin to process such complicated calculations. Riki handles them in the blink of an electron eye. Sam Litsinger, CBS News.

RADIO CLIPS

DATE October 16, 1998
TIME 5:30-6:00 PM
STATION WCBS 880 AM
LOCATION New York
PROGRAM News

ACCOUNT NUMBER 67/6508

Deborah Rodriguez, anchor:

WCBS News time 5:52. It's nine feet tall, needs lots of water to keep cool and can answer six hundred billion questions in one second. No it's not Michael Jordan at a press conference. Sam Liskinzer--Lis--Lissinger says it's a computer that does things that you can hardly imagine, and it's just made its debut on Long Island.

Sam Lissinger reporting:

It's billed as the fastest non-commercial supercomputer on the planet. It's name The RIKEN-BNL QCD, but maybe we can just call it Ricky. Anyway, it's nine feet tall, needs water to keep it from overheating, and it can answer six hundred billion questions in one second. Ricky's just gone to work at the Brookhaven National Laboratory on Long Island and will be used for physics research among other things, allowing scientists to predict and analyze the behavior of subatomic particles. Humans can't even begin to process such complicated calculations. Ricky handles them in the blink of an electronic eye.

Sam Lissinger, CBS News.

RADIO CLIPS

DATE October 16, 1998
TIME 2:00-2:19 PM
STATION WINS 1010 AM
LOCATION New York City
PROGRAM News

ACCOUNT NUMBER 67/6508

Ralph Howard reporting:

On Long Island, Brookhaven National Lab unveiled it's new super computer. The lab calls it the twelfth-fastest computer in the world and the fastest in non-commercial use. We're told the computer can answer six hundred billion questions in one second. The outfitters, the energy department, said the computer cost just 1.8 million dollars.

RIKEN · BNL · Columbia

Quantum Chromodynamics (QCD) Project

DOE NEWS

NEWS MEDIA CONTACT:
Jeff Sherwood, 202/586-5806

FOR IMMEDIATE RELEASE
November 13, 1998

Energy Department Lab Scientists Sweep Supercomputing Awards

Orlando, FL. -- Researchers from four U.S. Department of Energy (DOE) laboratories this week were honored by the high-performance scientific computing community as recipients of top awards presented at SC98, the annual high-performance networking and computing conference.

An international team of scientists including the department's Oak Ridge and Lawrence Berkeley National Laboratories won the 1998 Gordon Bell prize for best performance of a supercomputing application. The team won the award for their modeling of 1,024 atoms of a metallic magnet. Although the team won for its 657 Gigaflops performance level (657 billion calculations per second), it subsequently was able to have the application run at more than one trillion calculations per second.

Another 1998 Gordon Bell prize recognizes scientists who achieve the best price/performance level on a computer system. The winning team in this category is a collaboration of universities and DOE national laboratories led by Columbia University and involving the department's Brookhaven National Laboratory and Fermi National Accelerator Laboratory. The winning machine, costing only $1.8 million, is a multi-purpose, non-commercial supercomputer with a top operating speed of 600 billion calculations per second. It will carry out forefront physics research. The machine was built at Brookhaven and funded by the Japanese RIKEN laboratory as part of its research center at Brookhaven supporting the Relativistic Heavy Ion Collider.

The two other finalist entries for the Gordon Bell prizes also included DOE laboratories. The department's Sandia National Laboratories, the University of California at Berkeley and Intel Corp. used DOE's ASCI Red, a supercomputer with more than 4600 dual-processor Pentium Pro nodes at Sandia, to calculate electronic structures. The computer sustained a performance of 605 Gigaflops. The finalist for best price/performance was the department's Los Alamos National Laboratory's Avalon computer costing $150,000 and performing 20 billion operations per second.

Gordon Bell, who has both designed high-performance computers and administered national research programs, sponsors the annual prize.

R-98-172

Phillip Colella, a mathematician at DOE's Lawrence Berkeley National Laboratory, received the 1998 Sidney Fernbach Award at the conference, which concludes today in Orlando. Colella received the award for his "outstanding contribution in the application of high performance computers using innovative approaches." The Fernbach Award, created in memory of a computer scientist at DOE's Lawrence Livermore National Laboratory, is presented by the IEEE (Institute of Electrical and Electronics Engineers) Computer Society.

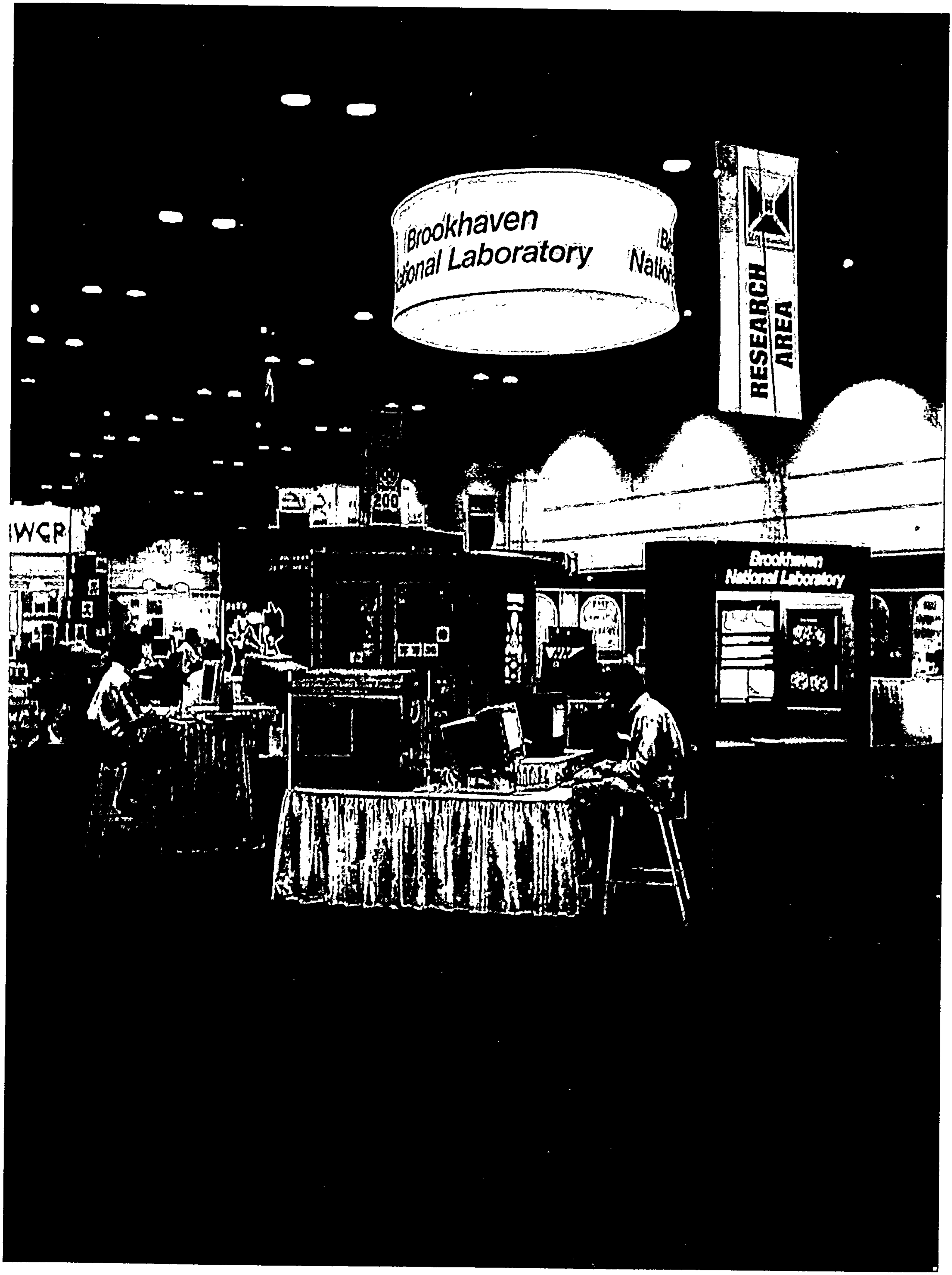
"These awards are continuing recognition of the Department of Energy's leadership in the field of scientific supercomputing," said Ernest Moniz, Under Secretary of Energy and a speaker at the conference. "For more than 40 years, scientists working in DOE's research areas have driven -- and in some cases, invented -- many of the innovations in high-performance computing and networking." Moniz noted that the nation's first supercomputers were developed to support DOE programs and that the department created the Energy Sciences Network (ESnet) to allow researchers across the country to utilize DOE's supercomputing centers.

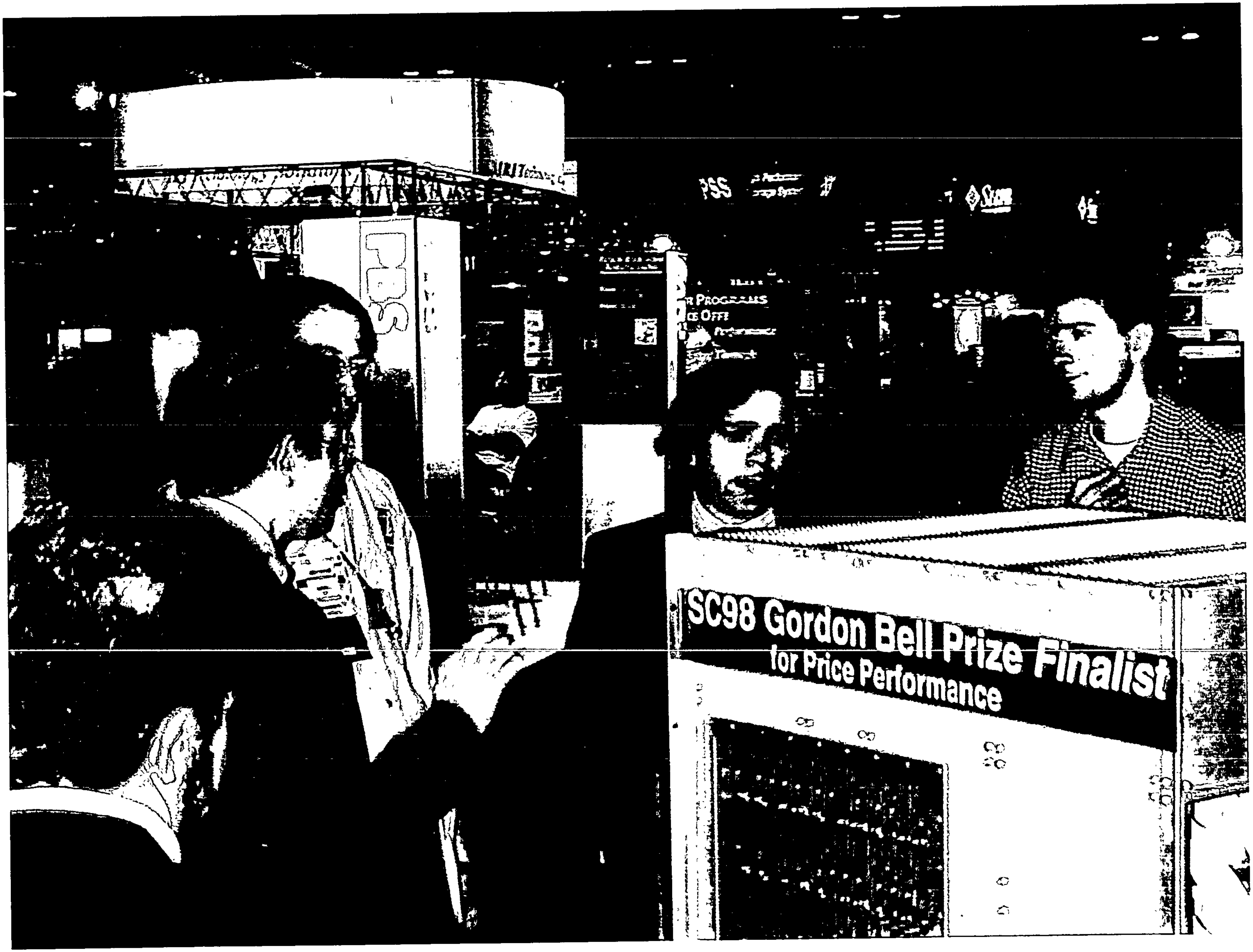
In the past few weeks, the department's supercomputers have set record-breaking computing achievements, racing past the milestone of a trillion computing operations per second. Supercomputing will play an increasingly central role in maintaining the safety and reliability of the nation's nuclear deterrent, improving the efficiency of combustion systems, improving our understanding of the atmosphere and oceans, developing advanced materials and advancing many other scientific and engineering areas central to the department's missions.

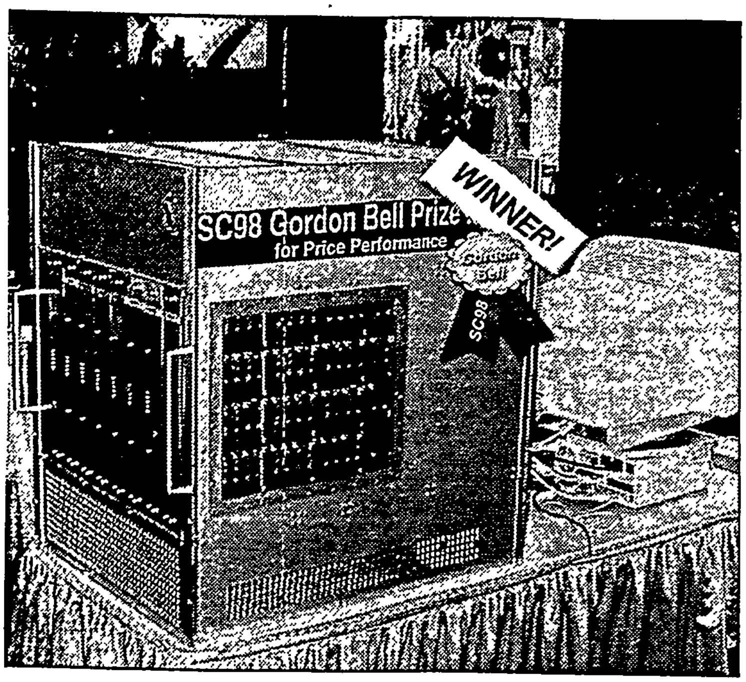
Moniz, who spoke on "Challenges for the Future" at SC98, said, "All of these achievements are part of the Department of Energy's emphasis on taking supercomputing the next big step forward. Revolutionary advances in computation and simulation promise a new era for scientific discovery and technological innovation. DOE is working with the National Science Foundation and other agencies to develop supercomputing and its applications. This will result in stronger national security, improved medical technology, the development of new efficient manufacturing processes, stronger educational programs and a stronger 21st century economy."

Additional information on the prize winners/finalists is available from the laboratories' public affairs offices and on the Internet at: **http://supercomp.org/sc98/awards/**

R-98-172 -DOE-


Brookhaven
National Laboratory
RESEARCH
AREA
Brookhaven
National Laboratory


SC98 Gordon Bell Prize Finalist
for Price Performance
PBS



BNL Supercomputer wins prize

It may be a sign of the times that we award prizes to computers instead of people, but recently the super machine built by Edward McFadden of Bayport and scientists from Brookhaven Lab took top honors at a computing conference held at Orlando, Florida, early in November.

Just weeks after unveiling the world's fastest multipurpose non-commercial supercomputer, the team that built the 0.6-teraflop physics machine showcased its unique architecture and capabilities at the SC98 High Performance Networking and Computing conference.

Da winnah! Supercomputer built by BNL and Columbia rests with its laurels.

The team from Brookhaven National Laboratory and Columbia University showed off a sample crate of motherboards from the massively parallel machine at its booth in the research exhibits hall. They also pointed out the inexpensive do-it-yourself construction that kept costs of the supermachine to around $1.8 million for the entire project. The computer has a top operating speed of 600 billion calculations per second, and is designed to carry out cutting-edge physics research. The machine was built at Brookhaven and funded by the Japanese RIKEN laboratory as part of its research center at Brookhaven supporting the Relativistic Heavy Ion Collider.

McFadden, the project manager for the construction and installation of the supercomputer, said, "This week I have completed my thirty-fifth year of service at BNL, and this has been my most exciting project and year. It's not every day you get to build the world's fastest non-commercial supercomputer for a Nobel Prize winner (Professor T. D. Lee). This project also required close collaboration with the chairman of the physics department at Columbia University and scientists from around the world."

McFadden added that Paul Poleski, also of Bayport, was one of the hardware technicians who built the machine. Poleski and four other technicians have maintained the other supercomputers used at Brookhaven for the past 20 years.

For their efforts, the scientists received the prestigious Gordon Bell prize for achieving the best price/performance level on a computer system. Gordon Bell, who has both designed high-performance computers and administered nation research programs, sponsors the annual prize.

According to the Department of Energy, supercomputers will play an increasingly central role in maintaining the safety and reliability of the nation's nuclear deterrent, improving the efficiency of combustion systems, improving our understanding of the atmosphere and the oceans, developing advanced materials, and advancing many other scientific and engineering areas central to the department's missions.

—Chuck Anderson

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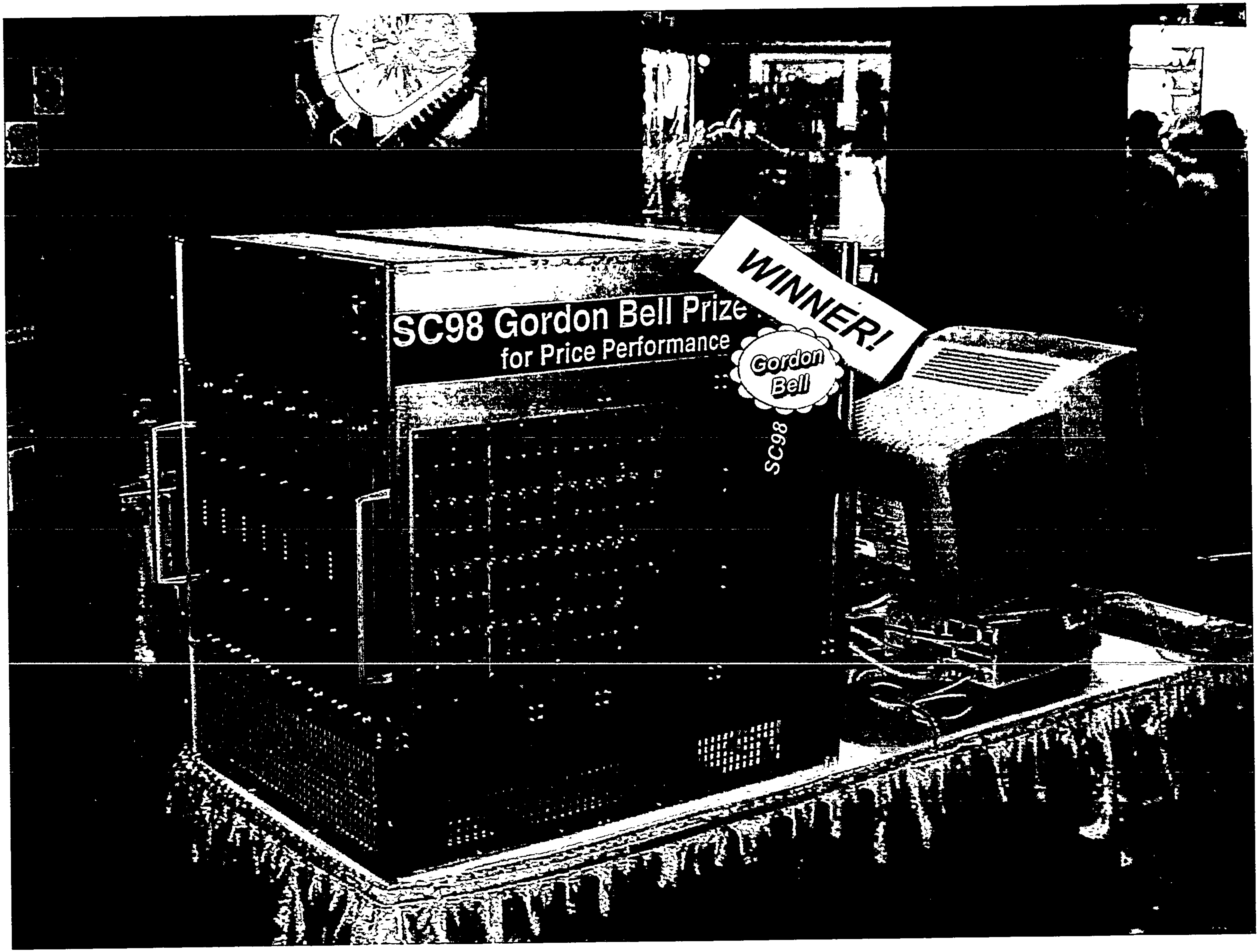
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