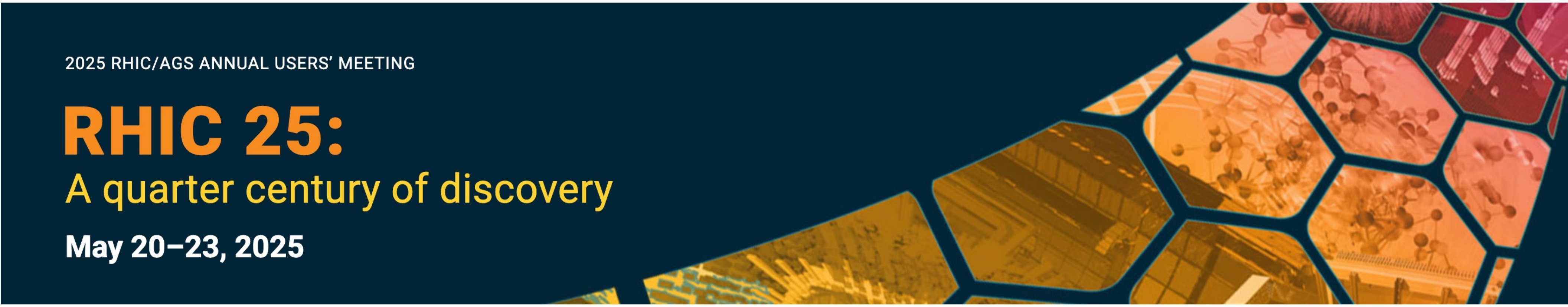


The Birth of RHIC and Its First Discoveries

presented at the

2025 RHIC/AGS Annual Users' Meeting
Brookhaven National Laboratory

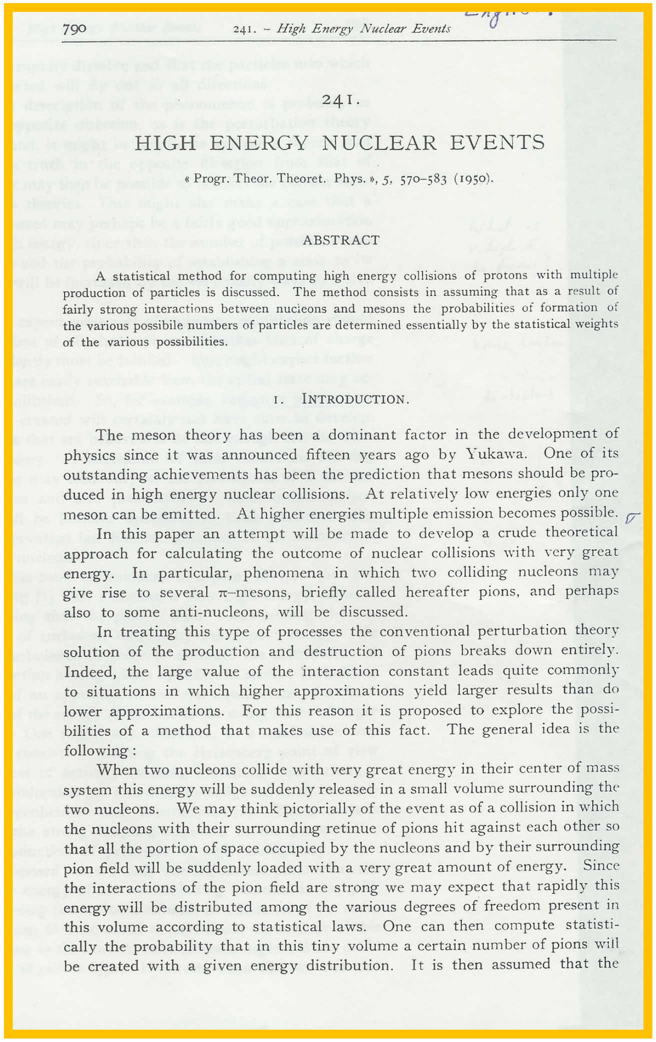
May 22nd, 2025

W.A. Zajc
Columbia University

Profound thanks to Wit Busza, Larry McLerran,
Rob Pisarski and Ann Therrien

This work was supported by the United States Department of Energy Grant DOE-FG02-86ER-40281

Fermi (1950)



241.

HIGH ENERGY NUCLEAR EVENTS

« Progr. Theor. Theoret. Phys. », 5, 570–583 (1950).

ABSTRACT

A statistical method for computing high energy collisions of protons with multiple production of particles is discussed. The method consists in assuming that as a result of fairly strong interactions between nucleons and mesons the probabilities of formation of the various possibile numbers of particles are determined essentially by the statistical weights of the various possibilities.

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In this paper an attempt will be made to develop a crude theoretical approach for calculating the outcome of nuclear collisions with very great energy. In particular, phenomena in which two colliding nucleons may give rise to several π–mesons, briefly called hereafter pions, and perhaps also to some anti-nucleons, will be discussed.

In treating this type of processes the conventional perturbation theory solution of the production and destruction of pions breaks down entirely. Indeed, the large value of the interaction constant leads quite commonly to situations in which higher approximations yield larger results than do lower approximations. For this reason it is proposed to explore the possibilities of a method that makes use of this fact. The general idea is the following:

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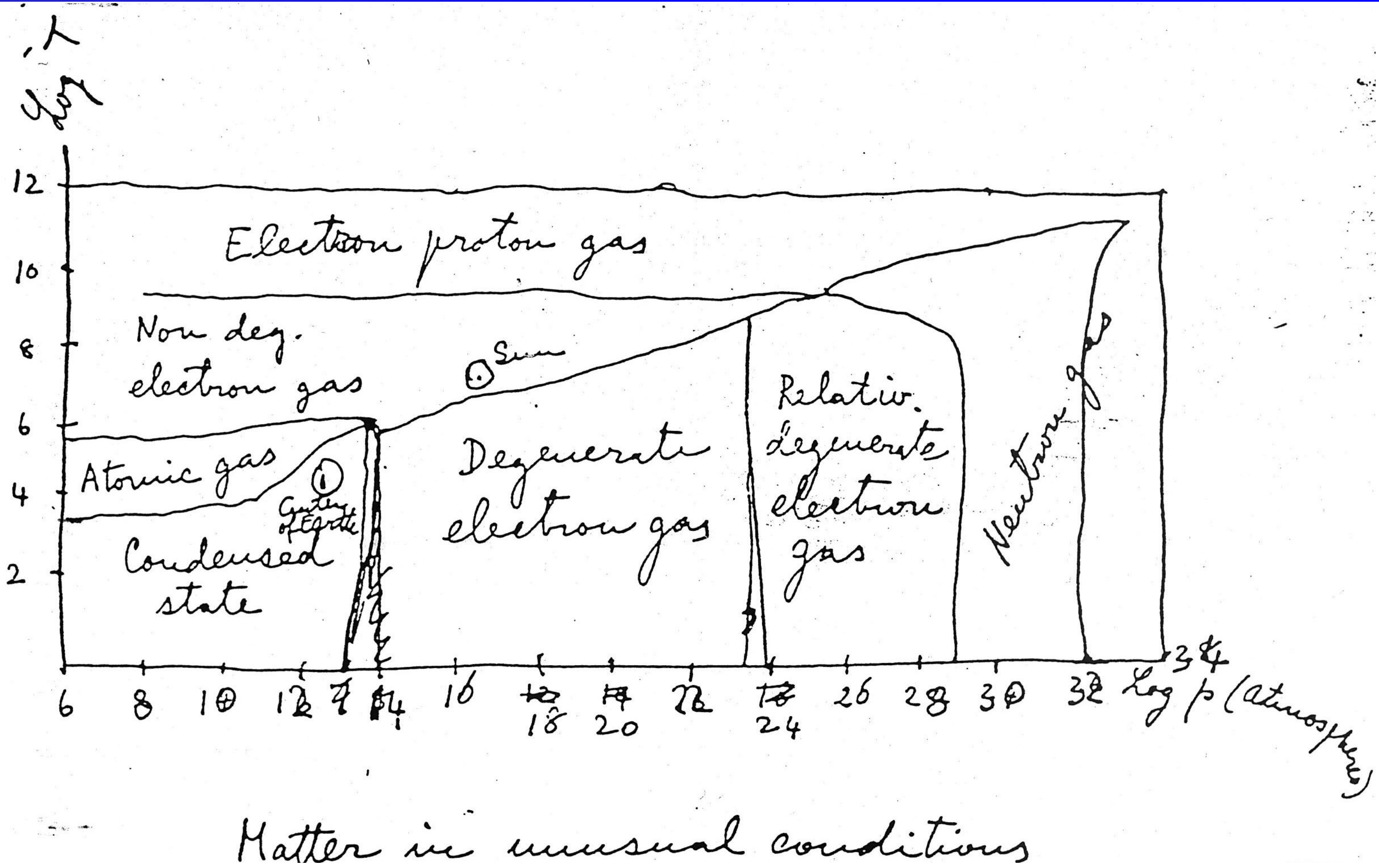
W.A. Zajc

Fermi (1952) *Notes on Thermodynamics and Statistics*



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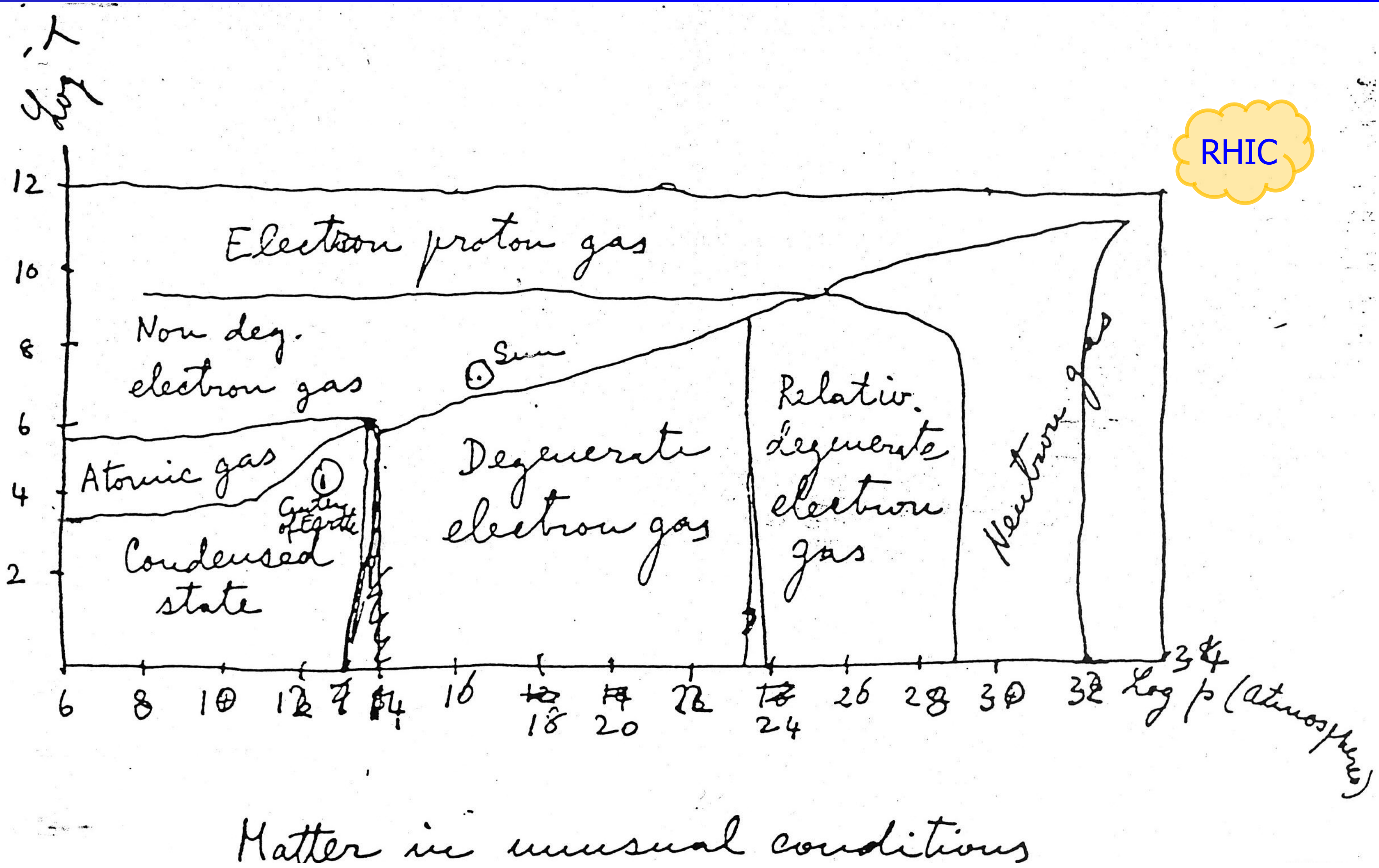

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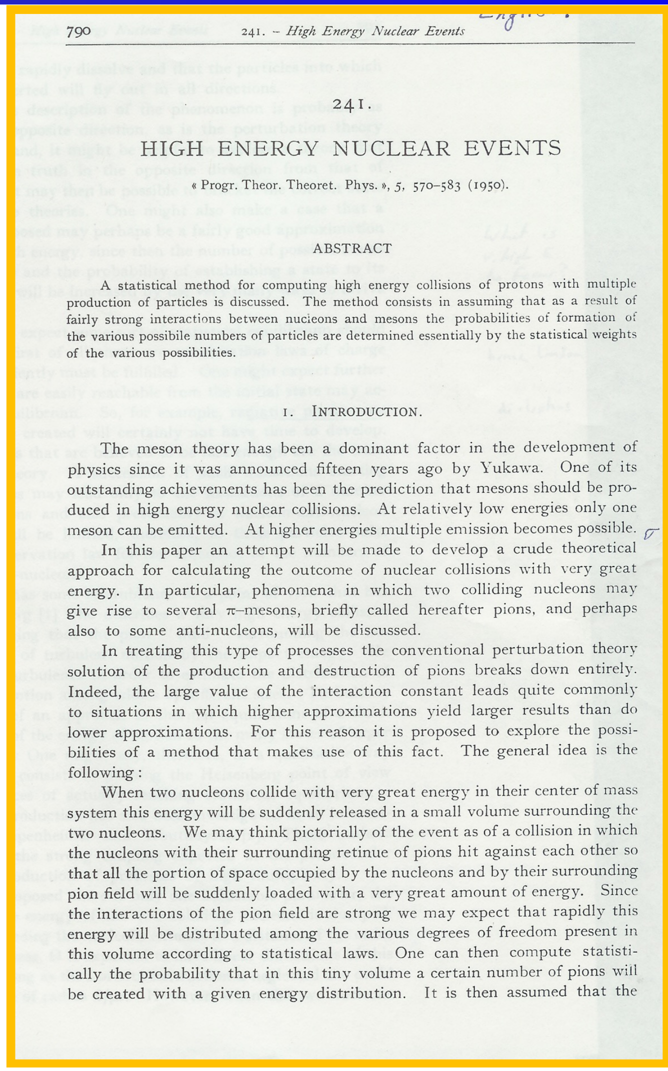

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88. A HYDRODYNAMIC THEORY OF MULTIPLE FORMATION OF PARTICLES

1. Introduction

Experiment shows that in collisions of very fast particles a large number of new particles are formed in multi-prong stars. The energy of the particles which produce such stars is of the order of 10^{12} eV or more. A characteristic feature is that such collisions occur not only between a nucleon and a nucleus but also between two nucleons. For example, the formation of two mesons in neutron–proton collisions has been observed at comparatively low energies, of the order of 10^9 eV, in cosmotron experiments[1].

Fermi[2,3] originated the ingenious idea of considering the collision process at very high energies by the use of thermodynamic methos. The main points of his theory are as follows.

(1) It is assumed that, when two nucleons of very high energy collide, energy is released in a very small volume V in their centre of mass system. Since the nuclear interaction is very strong and the volume is small, the distribution of energy will be determined by statistical laws. The collision of high-energy particles may therefore be treated without recourse to any specific theories of nuclear interaction.

(2) The volume V in which energy is released is determined by the dimensions of the meson cloud around the nucleons, whose radius is $\hbar/\mu c$, μ being the mass of the pion. But since the nucleons are moving at very high speeds, the meson cloud surrounding them will undergo a Lorentz contraction in the direction of motion. Thus the volume V will be, in order of magnitude,

$$V = \frac{4\pi}{3}\left(\frac{\hbar}{\mu c}\right)^3 \frac{2Mc^2}{E'}, \tag{1.1}$$

where M is the mass of a nucleon and E' the nucleon energy in the centre of mass system.

(3) Fermi assumes that particles are formed, in accordance with the laws of statistical equilibrium, in the volume V at the instant of collision. The particles formed do not interact further with one another, but leave the volume in a "frozen" state.

С. З. Беленький и Л. Д. Ландау, Гидродинамическая теория множественного образования частиц, *Успехи Физических Наук*, 56, 309 (1955).
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W.A. Zajc

Landau (1955) Was Inspired by Fermi . . .

. . . to make some rather harsh statements:

"The defects of Fermi's theory arise mainly because the expansion of the compound system is not correctly taken into account…(The) expansion of the system can be considered on the basis of *relativistic hydrodynamics*." (emphasis added)

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W.A. Zajc

(One of) the Origins of the Study of Relativistic Nuclear Collisions

- Seminal Event:
  The Bear Mountain Workshop,
- Nov. 29 to Dec. 1, 1974

- "This Workshop addressed itself to the intriguing question of the possible existence of a nuclear world quite different from the one we have learned to accept as familiar and stable."

- Prime Mover: *T.D. Lee*
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BNL 50445
(Physics, Nuclear – TID-4500)

Report of the Workshop on
BEV/NUCLEON COLLISIONS OF HEAVY IONS – HOW AND WHY

November 29–December 1, 1974
Bear Mountain, New York

Supported by
NATIONAL SCIENCE FOUNDATION
and
NEVIS LABORATORIES, COLUMBIA UNIVERSITY

Organizing Committee
A. KERMAN, L. LEDERMAN, T.D. LEE, M. RUDERMAN, J. WENESER

Scientific Reporters
LAWRENCE E. PRICE, JAMES P. VARY

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CONTENTS

T.D. and the Origin of Relativistic Heavy Ion Collisions

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A Possible New Form of Matter at High Density*

T.D. Lee
Columbia University, New York, New York 10027

I. INTRODUCTION

In this talk, I would like to discuss some of my recent theoretical speculations, made in collaboration with Gian-Carlo Wick. Over the past year, we have tried to investigate the structure of the vacuum. It is through this investigation that the possibilities of vacuum excitation states and abnormal nuclear states have been suggested. Before coming to the main topic, whether or not there may be the possibility of a new form of matter at high density, perhaps I should first digress on questions related to the vacuum.

In physics, one defines the vacuum as the lowest energy state of the system. By definition, it has zero 4-momentum. In most quantum field-theoretic treatments, quite often the vacuum state is used only to enable us to perform the mathematical construct of a Hilbert space. From the vacuum state, we build the one-particle state, then the two-particle state, . . . ; hopefully, the resulting Hilbert space will eventually resemble our universe. From this approach, different vacuum state means different Hilbert space, and therefore different universe.

Nevertheless, one may ask: What is this vacuum state? Does it have complicated structure? If so, can a part of this structure be changed? Ever since the formulation of relativity, after the downfall of the classical aether concept, one learns that the vacuum is Lorentz invariant. At least, one knows that just running around and changing the reference system won't alter the vacuum. However, Lorentz invariance alone does not insure that the vacuum is necessarily simple. For example, the vacuum can be as complicated as the product or sum of any scalar field or other scalar object at the zero 4-momentum limit:

$$\text{vacuum} \sim \phi^n \quad \text{or} \quad (\bar{\psi}\psi)^m \quad \text{at} \quad k_\mu = 0\,. \tag{1}$$

From Dirac's hole theory, one knows that the vacuum, though Lorentz-invariant, can be rather complicated. That this complicated structure of the vacuum may in part be changeable is suggested by the large variety of broken symmetries, found especially over the past two decades.

If we consider symmetry quantum numbers such as the isospin **I**, the strangeness S, the parity P, . . . , we find

$$\frac{d}{dt}\begin{Bmatrix} \mathbf{I} \\ S \\ P \\ C \\ CP \\ \vdots \end{Bmatrix}_{\text{matter}} \neq 0\,. \tag{2}$$

*This research was supported in part by the U.S. Atomic Energy Commission.

small because of Lorentz contraction, and the barrier B becomes $\sim \frac{1}{2}|\mathbf{p}|^{-1}m_p^2$, which may also be too low to hold the nucleons together. The best value may perhaps be $\approx$100 to several hundred MeV/nucleon in the center-of-mass system.

VI. REMARKS

The question whether we live in a "medium" or in a "vacuum" dates back to the beginning of physics. From relativity, we know that the "vacuum" must be Lorentz-invariant. As remarked before, Lorentz invariance by itself does not mean that the "vacuum" is simple. From Dirac's hole theory, one has learned that the vacuum, though Lorentz-invariant, can be rather complicated. However, so long as all of its properties cannot be changed, so long as, e.g., the value of vacuum polarization cannot be modified, then it is purely a question of semantics whether the vacuum should be called a medium or not.

What we try to suggest is that if we do indeed live in a medium, then there should be ways through which we may change the properties of that medium.

It may be worth while to emphasize once again how limited have been our experiences in either nuclear physics or particle physics. So far almost all our nuclear physics experiments have been restricted to nuclei at a constant density. We have never really ventured out to study nuclear physics at any densities other than the normal one. Likewise, in particle physics, we have a similar tradition in specializing along a fairly narrow direction. Take, for example, high energy physics. Hitherto, we have concentrated only on experiments in which we distribute a higher and higher amount of energy into a region with smaller and smaller dimensions. In order to study the question of "vacuum," or the possibility of the abnormal states, we must turn to a different direction; we should investigate some "bulk" phenomena by distributing high energy or high nucleon density over a relatively large volume. *The fact that such directions have never been explored should*, by itself, *serve as an incentive for doing such experiments*. As we have discussed, there are possibilities that abnormal states may be created, in which the nucleon mass may be very different from its normal value. It is conceivable that inside the volume of the abnormal state some of the symmetry properties may become changed, or even that the usual roles of strong and weak interactions may become altered. If indeed the properties of the "vacuum" can be transformed, we may eventually be led to some even more striking consequences than those that have been discussed in this lecture.

T.D. and the Origin of Relativistic Heavy Ion Collisions

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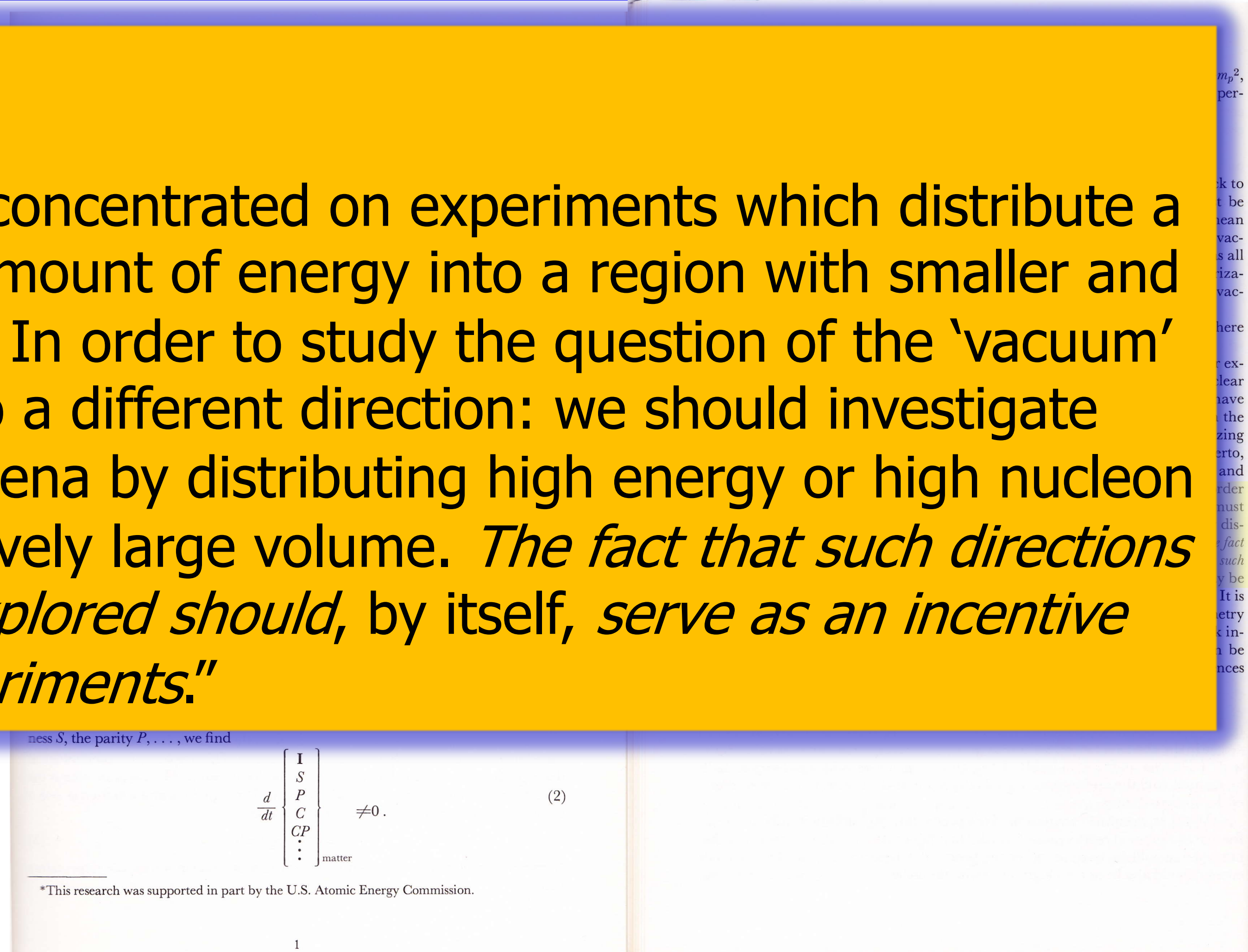

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- But note: No mention of
  - Quarks
  - Gluons
  - QGP

Parallel, Independent Developments 1973-1974

- 1973 = Birth of QCD
- Politzer, Gross and Wilczek

Volume 30, Number 26 PHYSICAL REVIEW LETTERS 25 June 1973

[14]Y. Nambu and G. Jona-Lasino, Phys. Rev. 122, 345 (1961); S. Coleman and E. Weinberg, Phys. Rev. D 7, 1888 (1973).

[15]K. Symanzik (to be published) has recently suggested that one consider a $\lambda\varphi^4$ theory with a negative λ to achieve UV stability at $\lambda = 0$. However, one can show, using the renormalization-group equations, that in such theory the ground-state energy is unbounded from below (S. Coleman, private communication).

[16]W. A. Bardeen, H. Fritzsch, and M. Gell-Mann, CERN Report No. CERN-TH-1538, 1972 (to be published).

[17]H. Georgi and S. L. Glashow, Phys. Rev. Lett. 28, 1494 (1972); S. Weinberg, Phys. Rev. D 5, 1962 (1972).

[18]For a review of this program, see S. L. Adler, in Proceedings of the Sixteenth International Conference on High Energy Physics, National Accelerator Laboratory, Batavia, Illinois, 1972 (to be published).

Reliable Perturbative Results for Strong Interactions?*

H. David Politzer
Jefferson Physical Laboratories, Harvard University, Cambridge, Massachusetts 02138
(Received 3 May 1973)

An explicit calculation shows perturbation theory to be arbitrarily good for the deep Euclidean Green's functions of any Yang-Mills theory and of many Yang-Mills theories with fermions. Under the hypothesis that spontaneous symmetry breakdown is of dynamical origin, these symmetric Green's functions are the asymptotic forms of the physically significant spontaneously broken solution, whose coupling could be strong.

Renormalization-group techniques hold great promise for studying short-distance and strong-coupling problems in field theory.[1,2] Symanzik[2] goes to zero, compensating for the fact that there are more and more of them. But the large-p^2 divergence represents a real breakdown of

PHYSICAL REVIEW D VOLUME 8, NUMBER 10 15 NOVEMBER 1973

Asymptotically Free Gauge Theories. I*

David J. Gross†
National Accelerator Laboratory, P. O. Box 500, Batavia, Illinois 60510
and Joseph Henry Laboratories, Princeton University, Princeton, New Jersey 08540

Frank Wilczek
Joseph Henry Laboratories, Princeton University, Princeton, New Jersey 08540
(Received 23 July 1973)

Asymptotically free gauge theories of the strong interactions are constructed and analyzed. The reasons for doing this are recounted, including a review of renormalization-group techniques and their application to scaling phenomena. The renormalization-group equations are derived for Yang-Mills theories. The parameters that enter into the equations are calculated to lowest order and it is shown that these theories are asymptotically free. More specifically the effective coupling constant, which determines the ultraviolet behavior of the theory, vanishes for large spacelike momenta. Fermions are incorporated and the construction of realistic models is discussed. We propose that the strong interactions be mediated by a "color" gauge group which commutes with SU(3) × SU(3). The problem of symmetry breaking is discussed. It appears likely that this would have a dynamical origin. It is suggested that the gauge symmetry might not be broken and that the severe infrared singularities prevent the occurrence of noncolor singlet physical states. The deep-inelastic structure functions, as well as the electron-positron total annihilation cross section are analyzed. Scaling obtains up to calculable logarithmic corrections, and the naive light-cone or parton-model results follow. The problems of incorporating scalar mesons and breaking the symmetry by the Higgs mechanism are explained in detail.

Parallel Paths that Nonetheless Converged

- Focus of this review article:
- 1973 to 1983, convergence of
  - Bear Mountain
    “exciting the vacuum” program
  - Understanding bulk QCD effort
- 1983 as *Fundamentum Anni*
  - “a remarkable year, marked by confluence, convergence and consequence. More specifically, that year saw confluence in a particular theoretical approach to applying hydrodynamics, convergence of experimental and theoretical efforts in understanding the expected reaction dynamics, and far-reaching consequences of funding decisions made by the U.S. government.”

arXiv > nucl-th > arXiv:2504.08720

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Nuclear Theory

[Submitted on 11 Apr 2025]

The Early History of the Quark-Gluon Plasma

W. Busza, W.A. Zajc

We present the historical antecedents to the field of relativistic heavy ion physics, beginning with early attempts to model the strong interaction and ending with the endorsement of a relativistic heavy ion collider in the 1983 U.S. Long-Range Plan for Nuclear Science. Particular attention is paid to two major themes: 1) A program to study high density states of nuclear matter emerging from the 1974 Bear Mountain conference and 2) Efforts to understand the predictions of QCD for matter at high densities and/or temperatures.

Comments: 23 pages, Contribution to "Quark Gluon Plasma at Fifty - A Commemorative Journey", Publisher: Springer Nature Switzerland AG, Editors: Tapan Nayak, Marco Van Leeuwen, Steffen Bass, Claudia Ratti, James Dunlop

Subjects: **Nuclear Theory (nucl-th)**; High Energy Physics - Phenomenology (hep-ph); Nuclear Experiment (nucl-ex)

Cite as: arXiv:2504.08720 **[nucl-th]**
(or arXiv:2504.08720v1 **[nucl-th]** for this version)
https://doi.org/10.48550/arXiv.2504.08720

Submission history

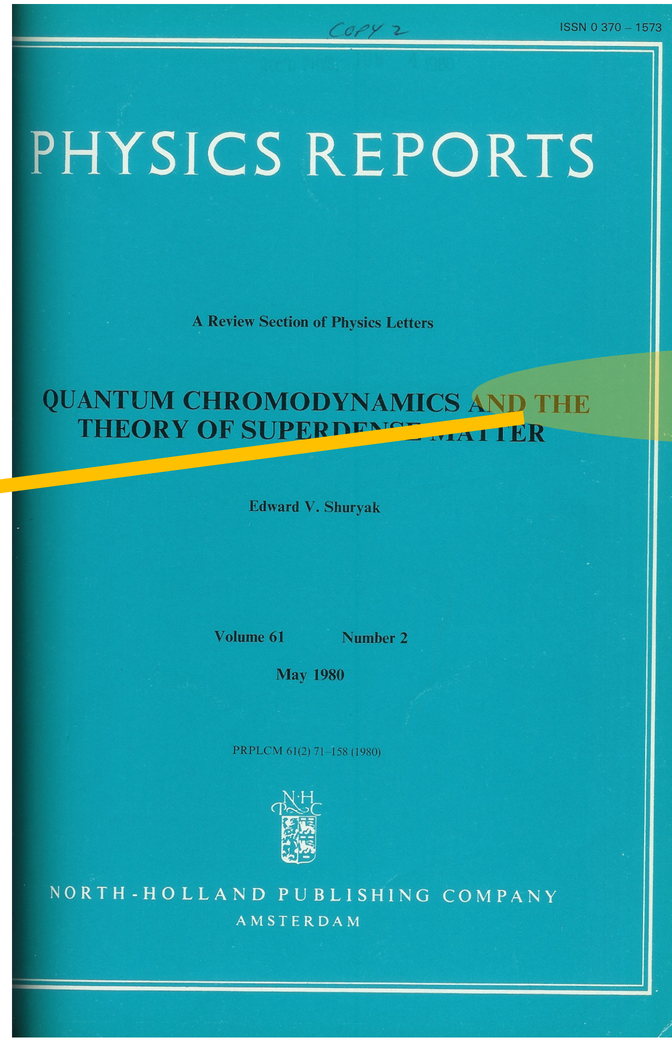
From: W.A. Zajc [view email]
[v1] Fri, 11 Apr 2025 17:34:13 UTC (83 KB)

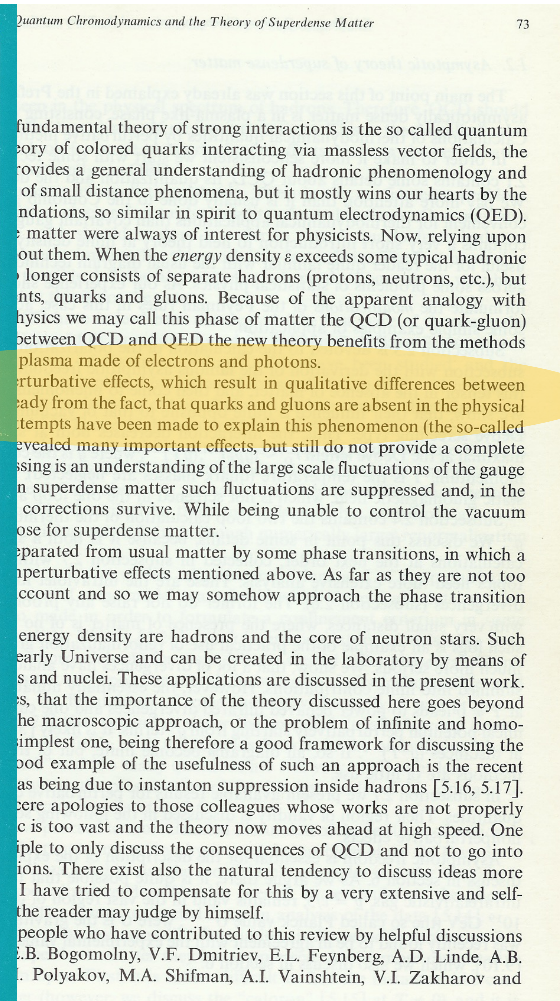
Shuryak 1980

- Shuryak publishes first "review" of thermal QCD- and coins a phrase:

  "Because of the apparent analogy with similar phenomena in atomic physics, we may call this phase of matter the QCD (or quark-gluon) plasma."

  (QGP)





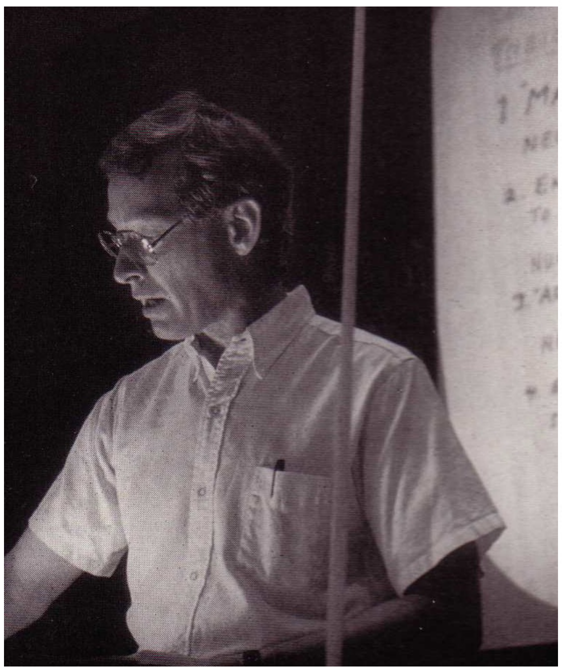
Quantum Chromodynamics and the Theory of Superdense Matter 73

fundamental theory of strong interactions is the so called quantum
ory of colored quarks interacting via massless vector fields, the
ovides a general understanding of hadronic phenomenology and
of small distance phenomena, but it mostly wins our hearts by the
ndations, so similar in spirit to quantum electrodynamics (QED).
matter were always of interest for physicists. Now, relying upon
out them. When the *energy* density ε exceeds some typical hadronic
longer consists of separate hadrons (protons, neutrons, etc.), but
nts, quarks and gluons. Because of the apparent analogy with
hysics we may call this phase of matter the QCD (or quark-gluon)
between QCD and QED the new theory benefits from the methods
plasma made of electrons and photons.
rturbative effects, which result in qualitative differences between
ady from the fact, that quarks and gluons are absent in the physical
tempts have been made to explain this phenomenon (the so-called
evealed many important effects, but still do not provide a complete
sing is an understanding of the large scale fluctuations of the gauge
n superdense matter such fluctuations are suppressed and, in the
corrections survive. While being unable to control the vacuum
ose for superdense matter.
parated from usual matter by some phase transitions, in which a
nperturbative effects mentioned above. As far as they are not too
ccount and so we may somehow approach the phase transition

energy density are hadrons and the core of neutron stars. Such
early Universe and can be created in the laboratory by means of
s and nuclei. These applications are discussed in the present work.
s, that the importance of the theory discussed here goes beyond
he macroscopic approach, or the problem of infinite and homo-
implest one, being therefore a good framework for discussing the
ood example of the usefulness of such an approach is the recent
as being due to instanton suppression inside hadrons [5.16, 5.17].
ere apologies to those colleagues whose works are not properly
c is too vast and the theory now moves ahead at high speed. One
iple to only discuss the consequences of QCD and not to go into
ions. There exist also the natural tendency to discuss ideas more
I have tried to compensate for this by a very extensive and self-
the reader may judge by himself.
people who have contributed to this review by helpful discussions
.B. Bogomolny, V.F. Dmitriev, E.L. Feynberg, A.D. Linde, A.B.
. Polyakov, M.A. Shifman, A.I. Vainshtein, V.I. Zakharov and

An Important Prophet

- *CERN Courier,* January 1982, pp. 17-20

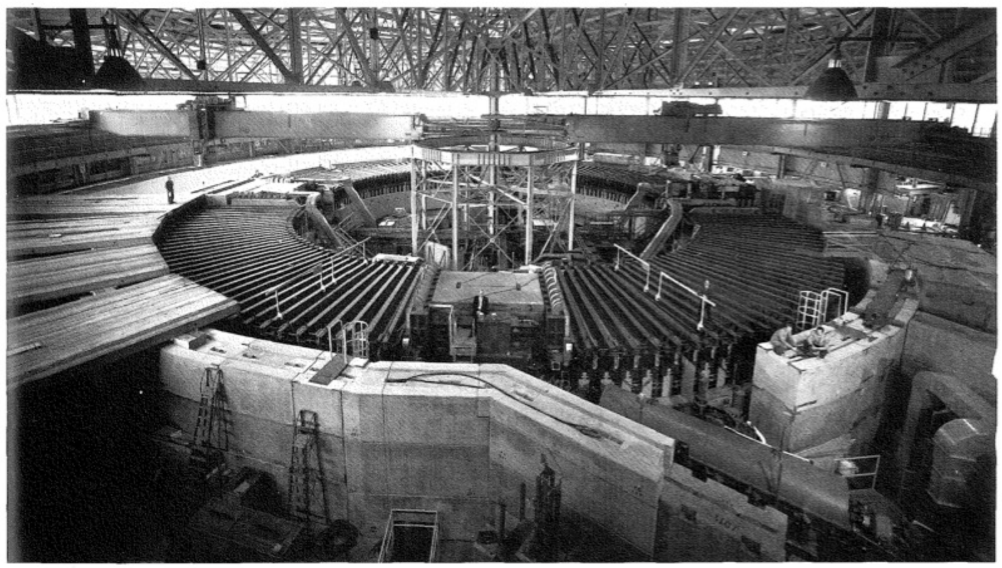


New possibilities with nucleus-nucleus collisions

by W. Willis

The Bevatron at Berkeley, now part of the Bevalac and scene of experiments with high energy heavy ion beams. However these energies of several GeV per nucleon may be insufficient to reveal important phenomena in nucleus-nucleus collisions.

(Photo LBL)



Quarks and gluons exist; they are nearly massless, but it is very hard or even impossible to knock them out of the proton. It is now widely believed that this strange state of affairs is due to the properties of the physical vacuum state as it now exists in our part of the Universe. In this view, the ground state of the vacuum

scopic volume of physical vacuum. This effect confines the quarks and gluons, which carry colour, inside the hadrons. On the scale of hadrons, quantum fluctuations make the phenomena more complex, but a simple picture postulates that the strong colour fields inside the hadron create a local volume of space which

The symmetry of the state has been broken, without any arbitrary direction entering in the laws of nature. By a quite similar mechanism, the parameters of the physical vacuum could determine the seemingly arbitrary breaking of symmetries in particle physics, though the fundamental laws remain symmetrical.

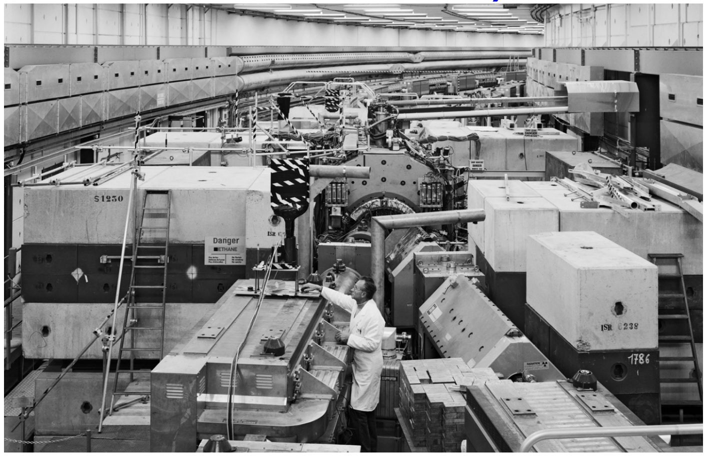
The CERN ISR

- The world's first *light* ion collider

The CERN ISR

- The world's first *light* ion collider

  (and first hadron collider detectors)



Circa 1979: VENUS ??

Aerial view of the Berkeley site with the location of the proposed relativistic heavy ion machine superimposed. The numbered buildings refer to existing facilities which could be used with the new machine.

(Photo LBL)

nucleons to produce sigmas or lambdas, emerge as pions.

One spectrometer measured the momentum of the incident kaons, while the specially-designed SPES II spectrometer built by Saclay analysed the emergent pions. The large momentum acceptance of this instrument allowed pions coming from sigma and lambda production to be measured in the same spectrum.

In addition, a scintillation counter surrounding the target was used to detect the fragmentation of hypernuclei and the decay of lambdas.

The sigma hypernuclei signals were found 77 MeV above the usual lambda hyperon levels, corresponding to the mass difference between lambdas and neutral sigmas. The production of sigma hypernuclei was a quarter that of lambda hypernuclei, as expected from the relative probabilities of the different possible strangeness-exchange reactions.

Their width was measured at less than 8 MeV, a surprisingly narrow signal in view of the instability of sigma particles in nuclear matter.

Further studies will now have to establish whether this narrow signal is a peculiarity with light nuclei, or whether it is also found with heavier nuclei.

The results with beryllium–9 also show a small peak which might correspond to hypernuclei containing negatively-charged sigmas. The position of this candidate peak suggests that the interaction between sigma particles and nuclei differs from that between lambdas and nuclei, but that the sigma-nucleus interaction appears to be the same for neutral and negatively-charged sigmas.

Further experiments with higher levels of sigma hypernucleus production could require more intense low energy kaon beams than exist at present.

BERKELEY
The VENUS project

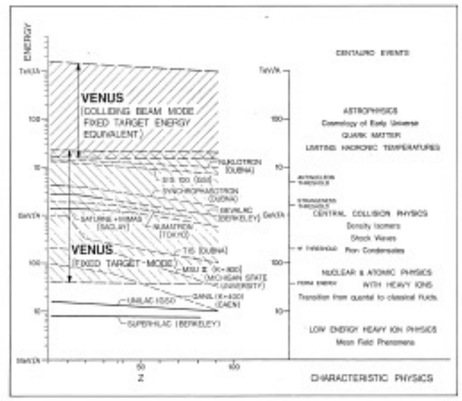
With several years of experience in operating the Bevalac complex for relativistic heavy ion physics behind them, the accelerator physicists and experimentalists at Berkeley have prepared a project which would enable them to pursue this field of research with increased vigour beyond the late 1980s. The project is known as VENUS, for Variable Energy Nuclear Synchrotron.

The aim has been to design a very versatile machine with the following major characteristics: intense ion beams from protons to uranium, low energy (40 MeV per nucleon) capability so as to 'overlap' with other machines, much higher intensities in the intermediate energy range than those currently available from the Bevalac, peak energies well above those available from the Bevalac (up to 20 GeV per nucleon for heavy ions), colliding ion beams of up to 20 GeV per nucleon in each beam.

The machine incorporates two superconducting accelerator/storage rings, about 200 m in diameter, in a tunnel on the Berkeley site. It will use the SuperHILAC as injector. Because of the slope of the site, half the tunnel would be bored into the hillside.

The operation sequence for the full energy beam would be to inject ions into one ring at about 8.5 MeV/A and accelerate to 1 GeV/A. Further stripping can then take place without loss and the ions would be transferred to the second ring for continued acceleration to 20 GeV/A. The beams could then be used for fixed target physics. However for beams of energy less than 8 GeV/A stripping is not necessary and the second ring can be used to 'stretch' the

Graph of the energies and ion species which could be covered by the VENUS project at Berkeley. Other existing and planned machines are also indicated. On the right is a list of the fields of physics which could be studied by the machine in its various operating modes.



beam for a better duty cycle. Colliding beam operation would be achieved by stacking many pulses in one ring and then transferring half of the beam back into the other ring (with its magnet field reversed) via an S-shaped reinjection line. The two rings cross in six locations and three would be available for colliding beam physics.

Many of the present facilities around the Bevalac complex could be used. The superconducting magnets are foreseen as improved versions of the ESCAR type, developed at Berkeley, to give peak fields of 4 T and a rate of change of field of about 1 T per s. Four separate r.f. systems are required to ensure all the various beam manipulations. Vacuum in the 10^{-11} torr range is needed to allow partially stripped heavy ions to be accelerated and stored.

The physics which would be accessible with VENUS spans the entire range from low energy nuclear and atomic physics (with ion beams available from energies of 40 MeV/A) through to the unexplored territory of very high energy heavy ion studies and 'quark matter' (with ion beams colliding at equivalent fixed target energies of up to 1 TeV/A).

The primary motivation is the possibility of creating dense, highly excited nuclear systems, far outside known nuclear physics. To pick just a couple of topics in particle physics where the machine may be used to investigate new phenomena – multiple quark scattering could be observed and the study could contribute to the understanding of quantum chromodynamics. The highest energy collisions could reach the region where the strong interaction appears to take on different characteristics such as have been seen in the 'Centauro events' with their dearth of neutral pions.

The estimated cost for construction of VENUS is around $ 100 million and it is believed that the machine would be in operation in 1987 if authorization comes through by 1983. A proposal to the Department of Energy will be prepared in the course of the next year and it is hoped that the necessary research and development work on the machine components could then begin in 1981.

VENUS would extend an area of physics in which Berkeley has played a pioneering role.

LOS ALAMOS
The future of medium energy physics

The usual arrangement of a Scientific Review Committee (by whatever name at a given accelerator) hearing research proposals from many separate groups, may sometimes appear formidable. In addition, coverage of the research field this way may be fragmentary. In an effort to circumvent these problems, LAMPF recently held a two-week Workshop on Program Options in Intermediate Energy Physics, involving broadly-based teams of both experimentalists and theoreticians. The Workshop was asked to raise critical questions in nuclear and particle physics and to recommend how they can best be addressed in the next few years by intermediate-energy accelerators.

The Workshop was organized by a steering committee, chaired by Earle Lomon (MIT), which outlined some topics to be discussed: fundamental interactions and symmetries, nuclear modes of motion, structure, and reaction mechanisms.

Circa 1979: VENUS ??

nucleons to produce sigmas or lambdas, emerge as pions.

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ALAMOS
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tions and symmetries, nu-
modes of motion, structure,
action mechanisms.

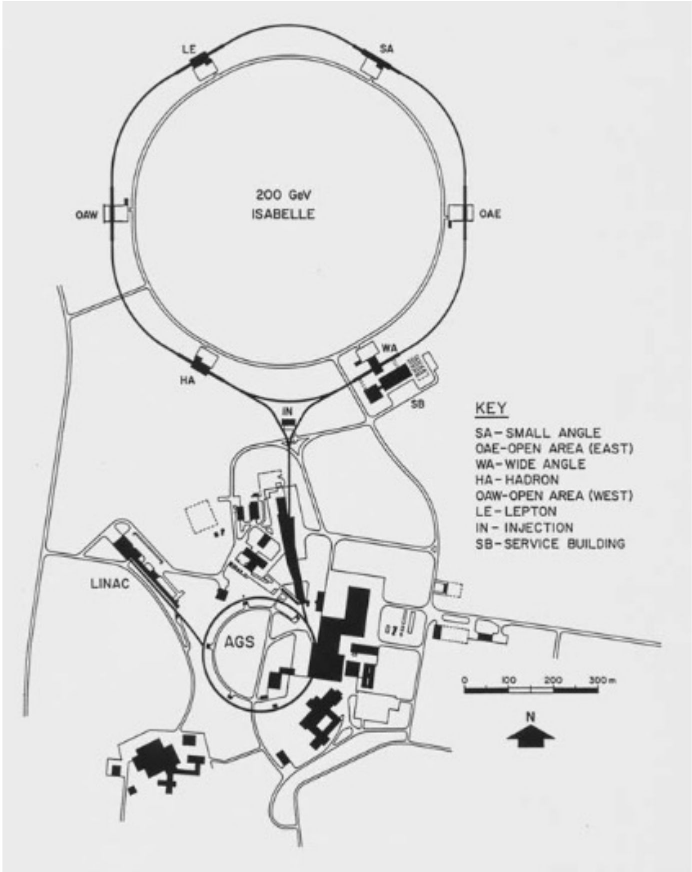
407

In the World of High Energy Physics . . .

- 1971: Fitch panel (AUI) endorses ISABELLE 200 GeV+200 GeV
- 1974: HEPAP approves ISABELLE at BNL
- 1978: Construction start
- . . . Issues with superconducting magnet design(s)
- 1982: "Desertron" rumblings appear, ISABELLE → CBA (Colliding Beams Accelerator)
- 1983: HEPAP considers path forward . . .

References:

1. *Quenched! The ISABELLE Saga, I*, R. Crease, Physics in Perspective **7**, 330-376 (2005)
2. *Quenched! The ISABELLE Saga, II*, R. Crease, Physics in Perspective **7**, 404-452 (2005)



July 14, 1983

- The effective termination of CBA

◀ SUBJECTS

BIG ACCELERATOR ON LONG ISLAND GETS A 'NO' VOTE

A panel of top physicists who advise the Federal Government recommended yesterday that an incomplete atom smasher at the Brookhaven National Laboratory on Long Island be scrapped. The move, upholding an earlier decision of a subcommittee, almost certainly marks the end of the accelerator, known as Isabelle and recently renamed the Colliding Beam Accelerator, or C.B.A. The bill for the half-built machine already runs to $200 million. The single most expensive pure-science project in the country, the finished machine would cost $650 million or more.

CONTINUE READING: Full Text

PUBLISH DATE
July 14, 1983

PAGE NUMBER
30

SUBJECTS
Atomic Energy
Physics
Research

Costs to Repair I-95 Bridge Put At $37 Million

Hartford Says Insurance Could Pay $14 Million

By RICHARD L. MADDEN

The New York Times/Joyce Dopkeen

Ester Lebreton and her children outside their home in Greenwich, Conn., as construction proceeded on a temporary ramp for I-95.

For Residents, Greenwich Has Turned Into a Turnpike

Big Accelerator On Long Island Gets a 'No' Vote

Panel Favors Scrapping of Brookhaven Project

By WILLIAM J. BROAD

A panel of top physicists who advise the Federal Government recommended yesterday that an incomplete atom smasher at the Brookhaven National Laboratory on Long Island be scrapped.

The move, upholding an earlier decision of a subcommittee, almost certainly marks the end of the accelerator, known as Isabelle and recently renamed the Colliding Beam Accelerator, or C.B.A.

The bill for the half-built machine already runs to $200 million. The single most expensive pure-science project in the country, the finished machine would cost $650 million or more.

The decision yesterday was by the High Energy Physics Advisory Panel of the Department of Energy, a group of 15 physicists headed by Dr. Jack Sandweiss of Yale University. On Monday a subcommittee of the panel also called for an end to the project. The full panel unanimously upheld that decision.

The recommendation to abandon the project was sent to the Department of Energy.

Department Expected to Concur

The President's science advisor, Dr. George A. Keyworth, has publicly called for a stop to the project, and the Department of Energy is expected to concur.

"The chances of this machine being built are very slim," a Brookhaven spokesman said.

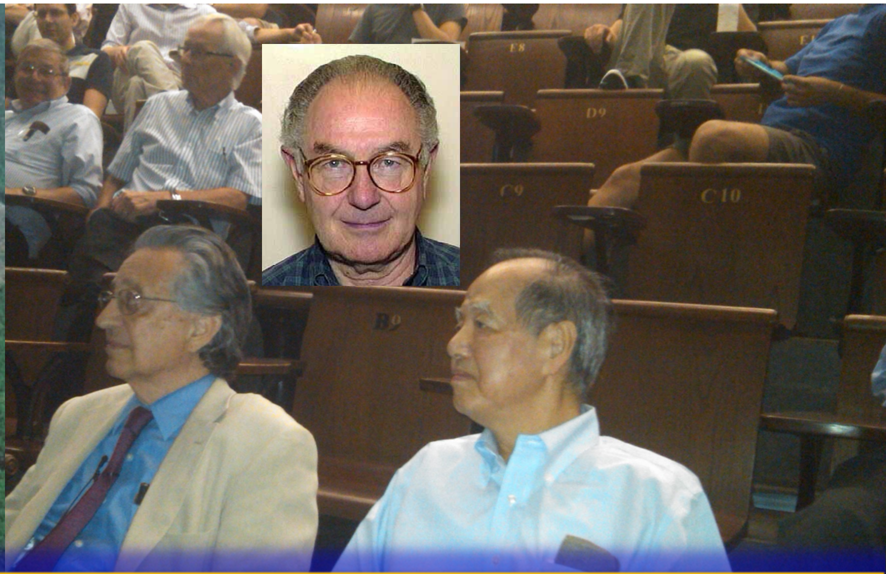
When ground was broken in 1978, the atom smasher was meant to keep the United States at the forefront of particle physics for at least a decade. The machine would push protons to blinding speeds through a 2.4-mile circular tunnel and smash them apart in a quest to find the fundamental building blocks of nature.

But problems in the construction of 1,100 superconducting magnets put the project years behind schedule. Though recently solved, these technical obstacles caused the Administration to cut construction funds. Today the tunnel, near Upton, L.I., stands empty.

Brookhaven scientists lobbied hard for completion of the atom smasher. But the consensus among American physicists is that well-financed European rivals have moved so rapidly with new accelerators that the Brookhaven project, nearly four years behind schedule, is now obsolete.

The Origin of RHIC (1983)

- Required reading: *Recombinant Science: The Birth of the Relativistic Heavy Ion Collider (RHIC),* Robert P. Crease, Historical Studies in the Natural Sciences, Vol. 38, No. 4 (Fall 2008), pp. 535-568



- Lee invited Sandweiss and Samios over to his visitor apartment. “I said, ‘Come to my place and we’ll pool our sorrows together.’ Lee pulled out a pot of curried chicken Jeannette had made for him: the three consumed it all, and put a large dent in a case of Beaujolais Nouveau as well. They did all the mourning that they were able, and then Lee promoted the idea of a heavy- ion collider, which he found Samios was greeting with increasing enthusiasm.
“With Beaujolais,” Lee remarked later, “you can look into the future more easily.”

The Origin of RHIC (1983)

- Required reading: *Recombinant Science: The Birth of the Relativistic Heavy Ion Collider (RHIC),* Robert P. Crease, Historical Studies in the Natural Sciences, Vol. 38, No. 4 (Fall 2008), pp. 535-568
- Literally contemporaneous with these events at BNL: The Long Range Plan for Nuclear Physics meeting at Wells College (upstate NY).
- Shuttle diplomacy ensued . . . (via Tom Ludlam)
- Out of that meeting:

> - It is the opinion of this Committee that the United States should proceed with the planning for the construction of this relativistic heavy ion collider facility expeditiously, and we see it as the highest priority new scientific opportunity within the purview of our science.

- Why?
  "…a spectacular transition to a new phase of matter, a quark-gluon plasma, may occur… "

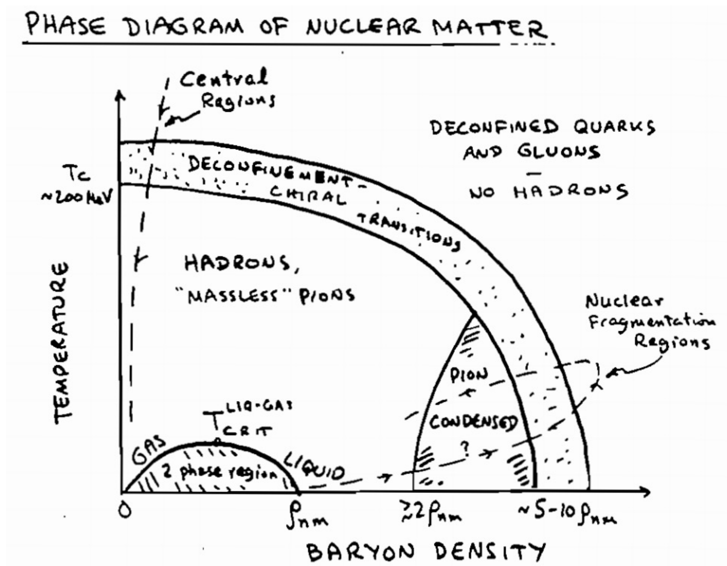


Fig. II.9-A. Expected phases of nuclear matter at various temperatures and baryon (or nucleon) densities, showing the "hadronic phase" including a gas-liquid phase transition region, and the transition region to deconfined quarks and gluons. The dashed lines illustrate trajectories in this phase diagram that can be explored in ultra-relativistic heavy ion collisions.

1983 As the *Fundamentun Anni*

- The extraordinarily adept transition CBA → RHIC
- The endorsement of a high-energy collider in the NP Long-Range Plan
- Publication of Bjorken's enormously influential "hydro" paper
  - *Highly Relativistic Nucleus-Nucleus Collisions: The Central Rapidity Region*, Phys. Rev. **D27**, 140 (1983)
- Quark Matter 1983 held at Brookhaven
  - Explicitly noted in the Preface by Tom Ludlam and Harvey Wegner: "newly analyzed data from Fermilab on the crucial question of nuclear stopping power provided the basis for improved estimates of the required collision energies. "

Nuclear Stopping Power,
W. Busza and A.S. Goldhaber,
Phys. Lett. **B139**, 235 (1983).

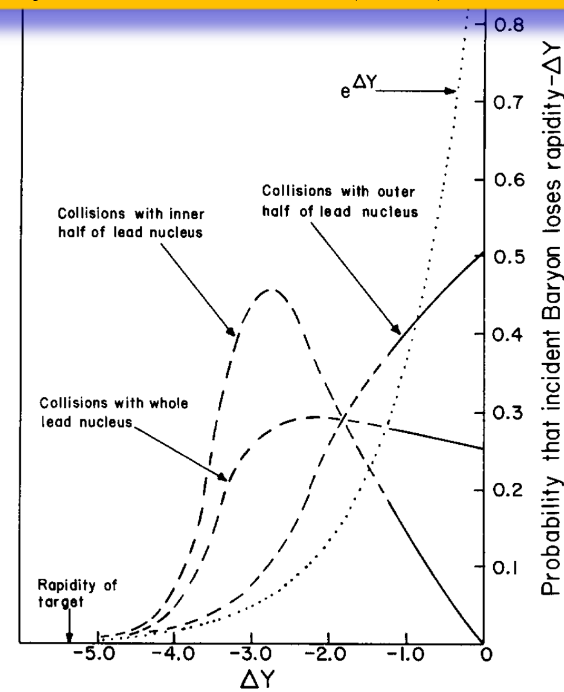
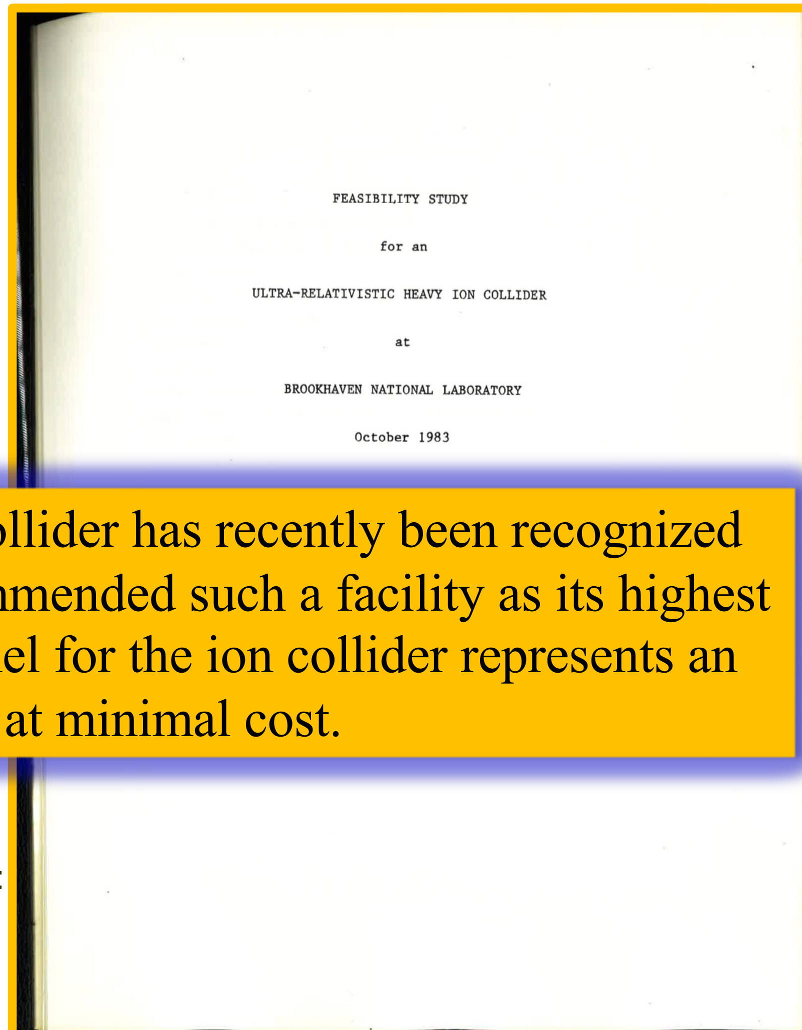


Fig. 3. Extrapolated probability distributions for rapidity loss of protons striking lead nuclei. The dashed lines are the extrapolated portions. The constraint that the normalized total, central, and peripheral inclusive cross sections should all be smooth makes the extrapolations nearly unique.

1983 As the *Fundamentun Anni*

- The extraordinarily adept transition CBA → RHIC
- The endorsement of a high-energy collider in the NP Long-Range Plan


FEASIBILITY STUDY

for an

ULTRA-RELATIVISTIC HEAVY ION COLLIDER

at

BROOKHAVEN NATIONAL LABORATORY

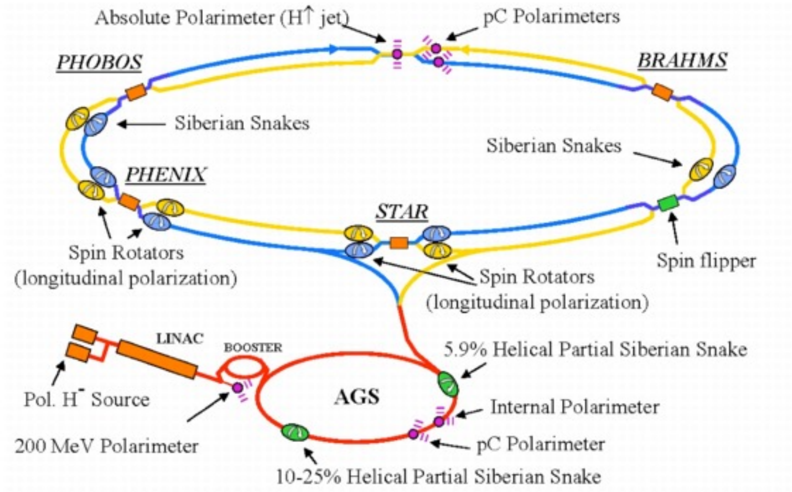
October 1983

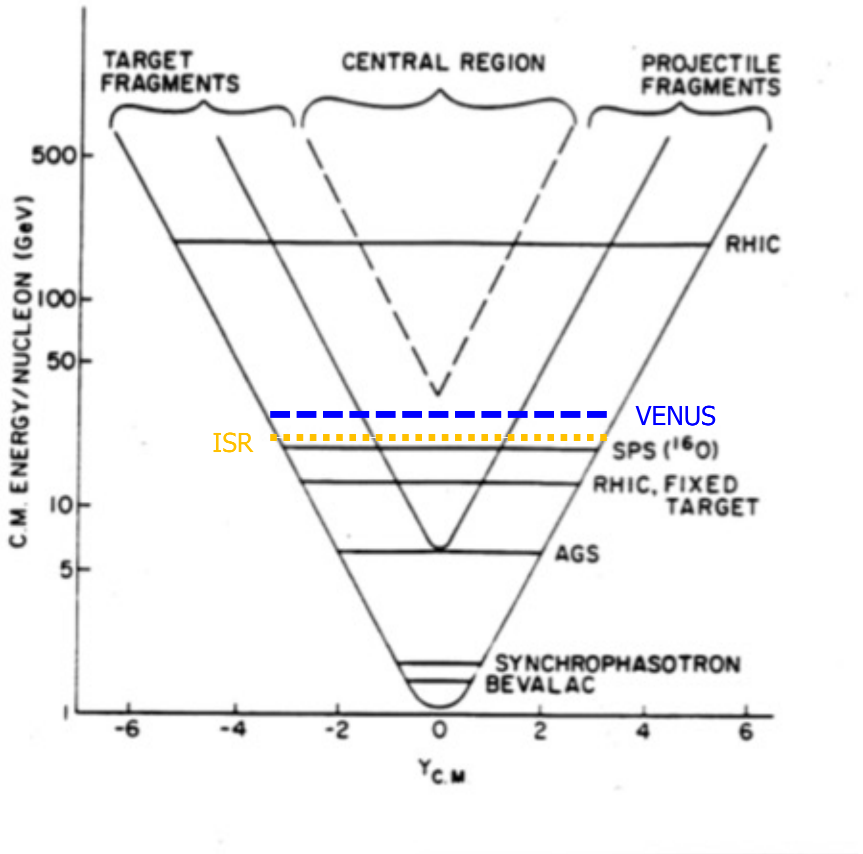
- The physics interest in an Ultra-Relativistic Heavy Ion Collider has recently been recognized by the Nuclear Science Advisory Committee which recommended such a facility as its highest priority new program. . . The availability of the CBA tunnel for the ion collider represents an unprecedented opportunity to construct the new machine at minimal cost.

- Quark Matter 1983 held at Brookhaven
  - Explicitly noted in the Preface by Tom Ludlam and Harvey Wegner: "newly analyzed data from Fermilab on the crucial question of nuclear stopping power provided the basis for improved estimates of the required collision energies. "

RHIC

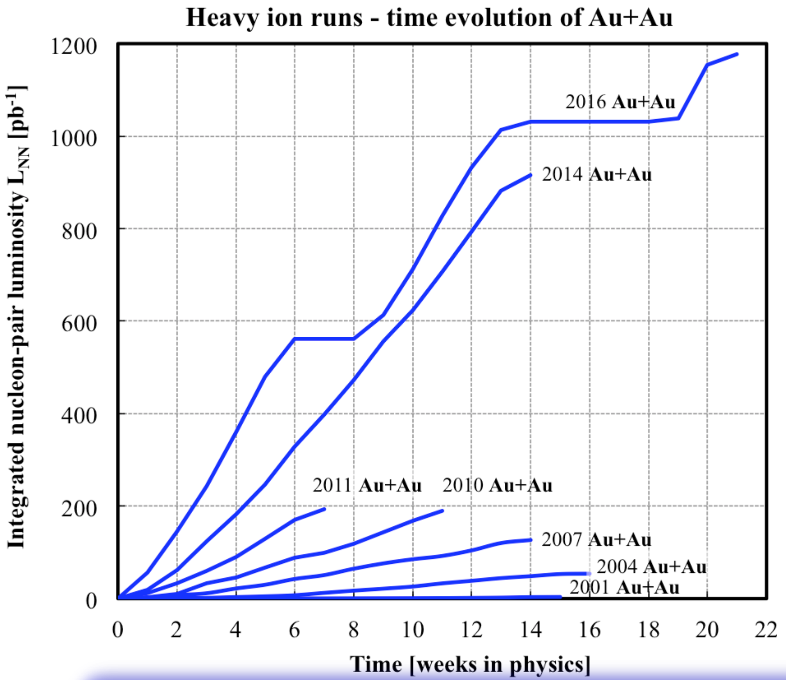
- The world's first *purpose-built heavy* ion collider

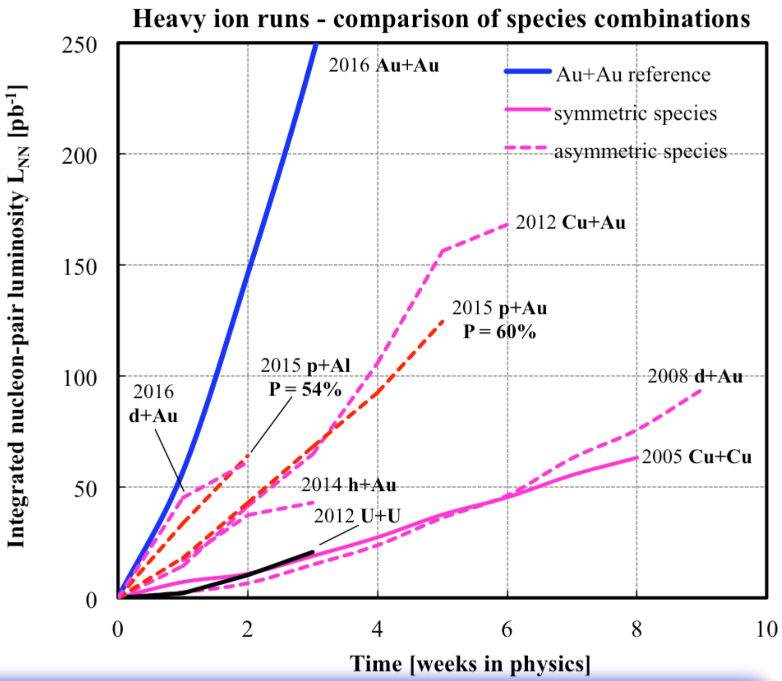




RHIC

- The world's first *purpose-built* heavy ion collider
  - Has demonstrated its enormous flexibility
  - Has enabled *25 years* of fundamental discoveries

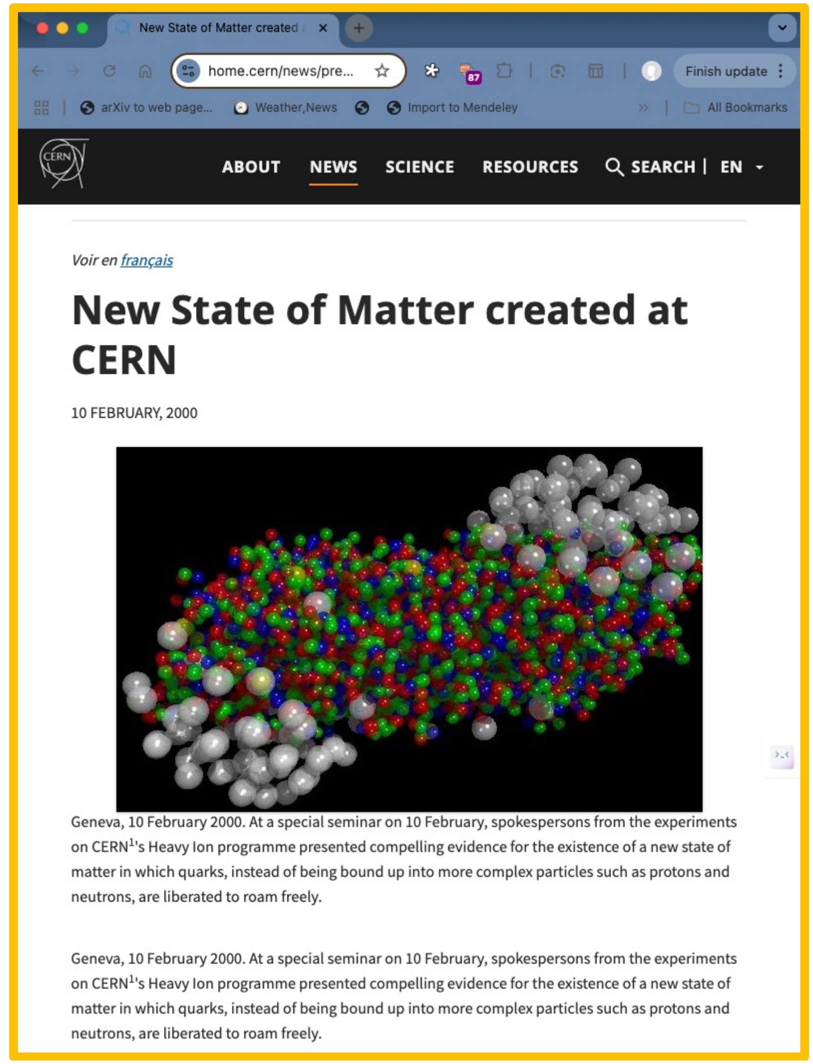




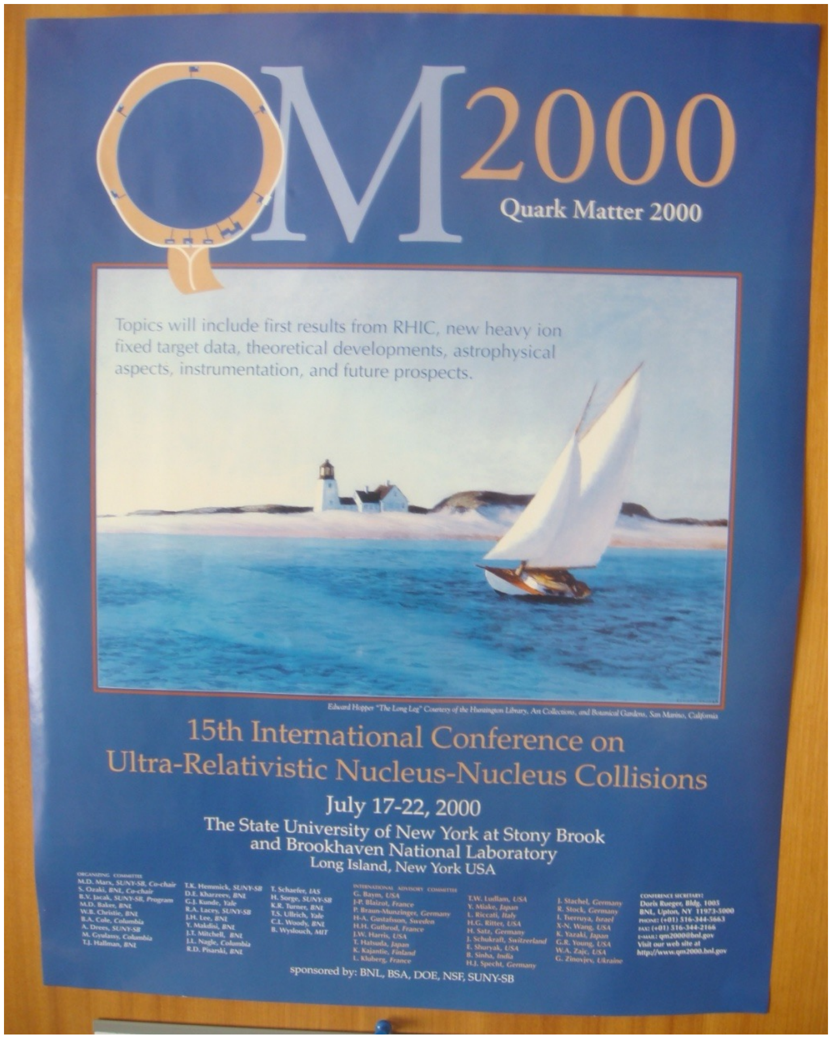
→ *RHIC is the most versatile collider ever built !*

An Unfortunate Affair - 2000 CERN Press Release

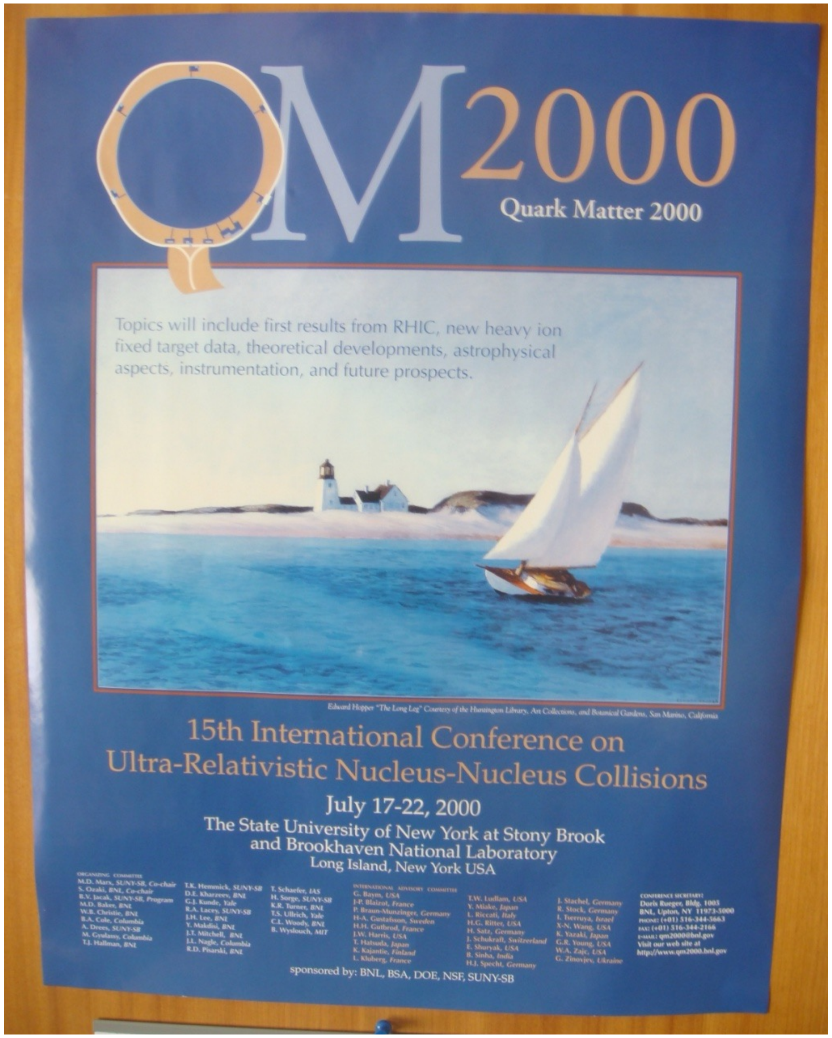
- ”Good” news (from the RHIC perspective): It did not directly claim discovery of the quark-gluon plasma.
- Bad news:
  - Was not linked to publication of peer-reviewed findings.
  - Nonetheless stated
    - “the experiments on CERN's Heavy Ion programme presented compelling evidence for the existence of a new state of matter in which quarks, instead of being bound up into more complex particles such as protons and neutrons, are liberated to roam freely.”



RHIC's First Phase Transition



RHIC's First Phase Transition



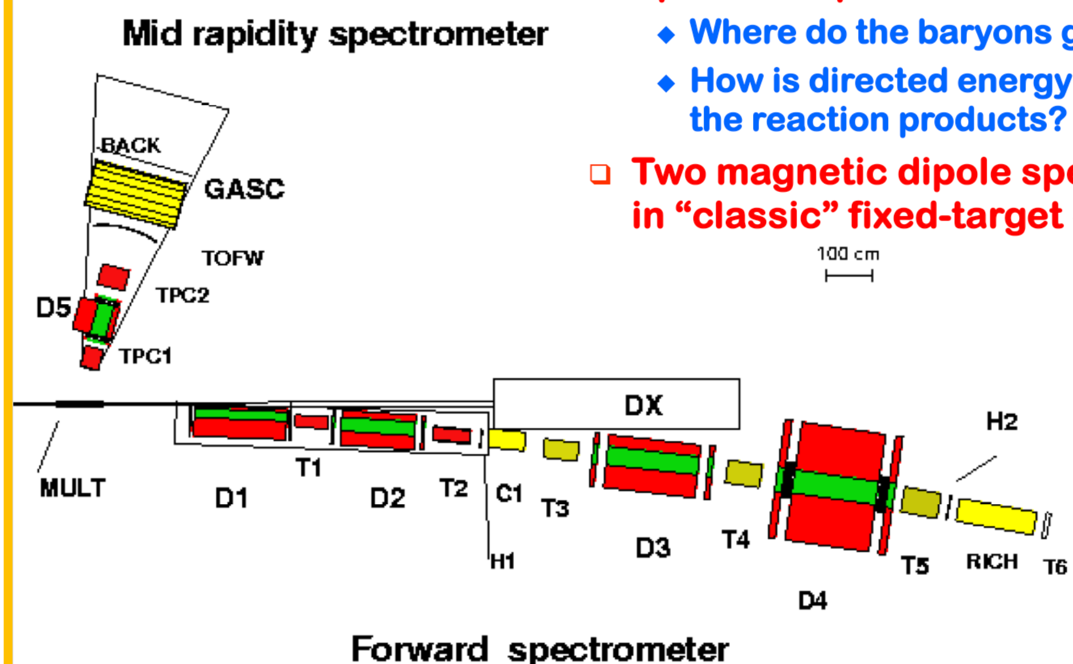
Not Described Here . . .

- The long arduous process by which 7 proposals became 4 approved experiments.
- Mel's vision
  - 2 large ($30M) experiments
    - "Facilities"
    - Permanent installations
  - 2 small (~$5M) experiments
    - Flexible
    - Replaceable

BRAHMS

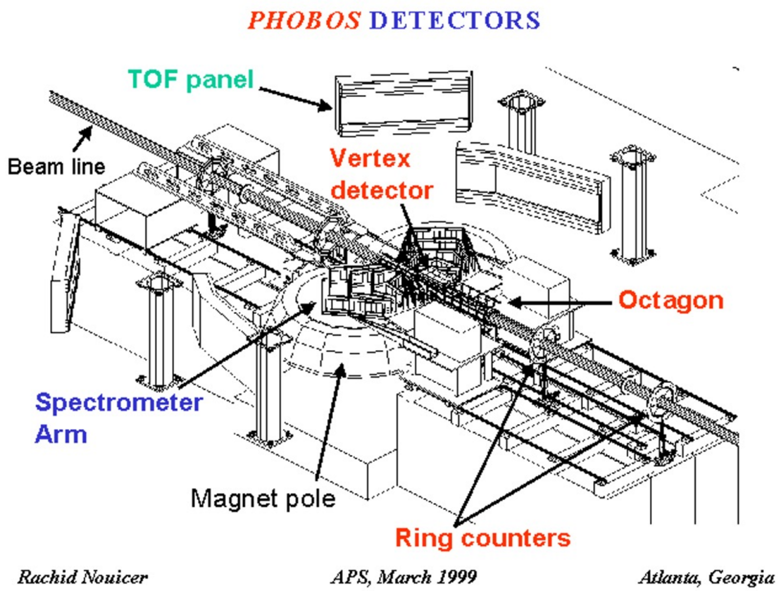
An experiment with an emphasis:

- **Quality PID spectra over a broad range of rapidity and p_T**
- **Special emphasis:**
  - **Where do the baryons go?**
  - **How is directed energy transferred to the reaction products?**
- **Two magnetic dipole spectrometers in "classic" fixed-target configuration**



W.A. Zajc

PHOBOS



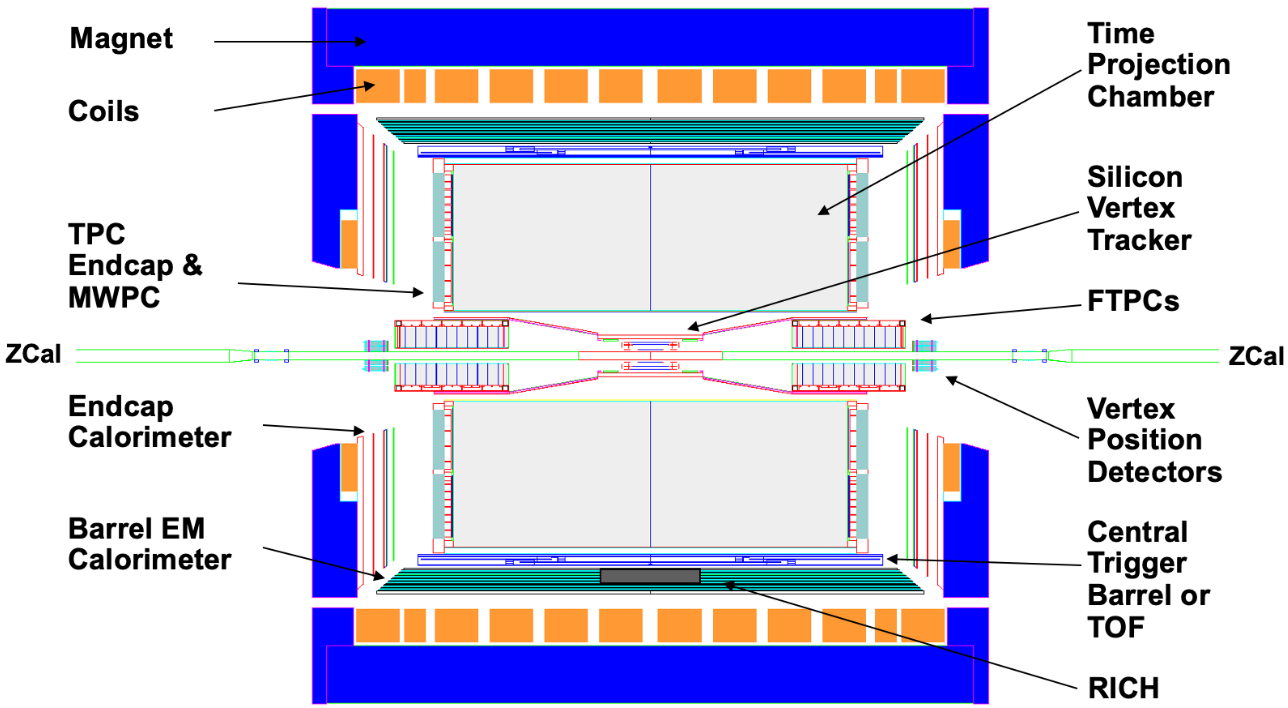
An experiment with a philosophy:

- **Global phenomena**
  - ➡ large spatial sizes
  - ➡ small momenta
- **Minimize the number of technologies:**
  - All Si-strip tracking
  - Si multiplicity detection
  - PMT-based TOF
- **Unbiased global look at very large number of collisions (~10^9)**

Quark Matter 2001

STAR

- **An experiment with a challenge:**
  - Track ~ 2000 charged particles in $|\eta| < 1$



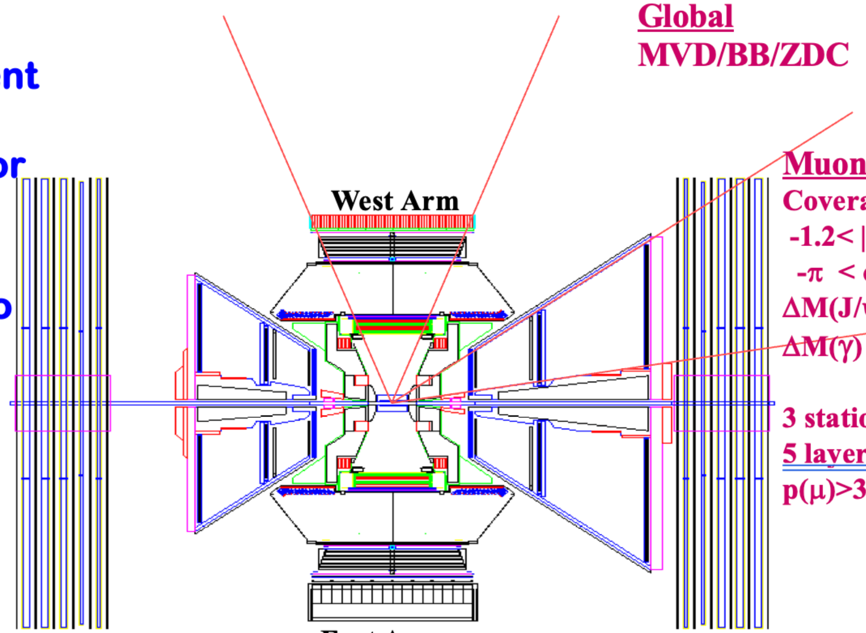
Quark Matter 2001

PHENIX

QM2001 | RHIC

- An experiment with something for everybody
- A complex apparatus to measure
  - Hadrons
  - Muons
  - Electrons
  - Photons

Executive summary:
- *High* resolution
- *High* granularity



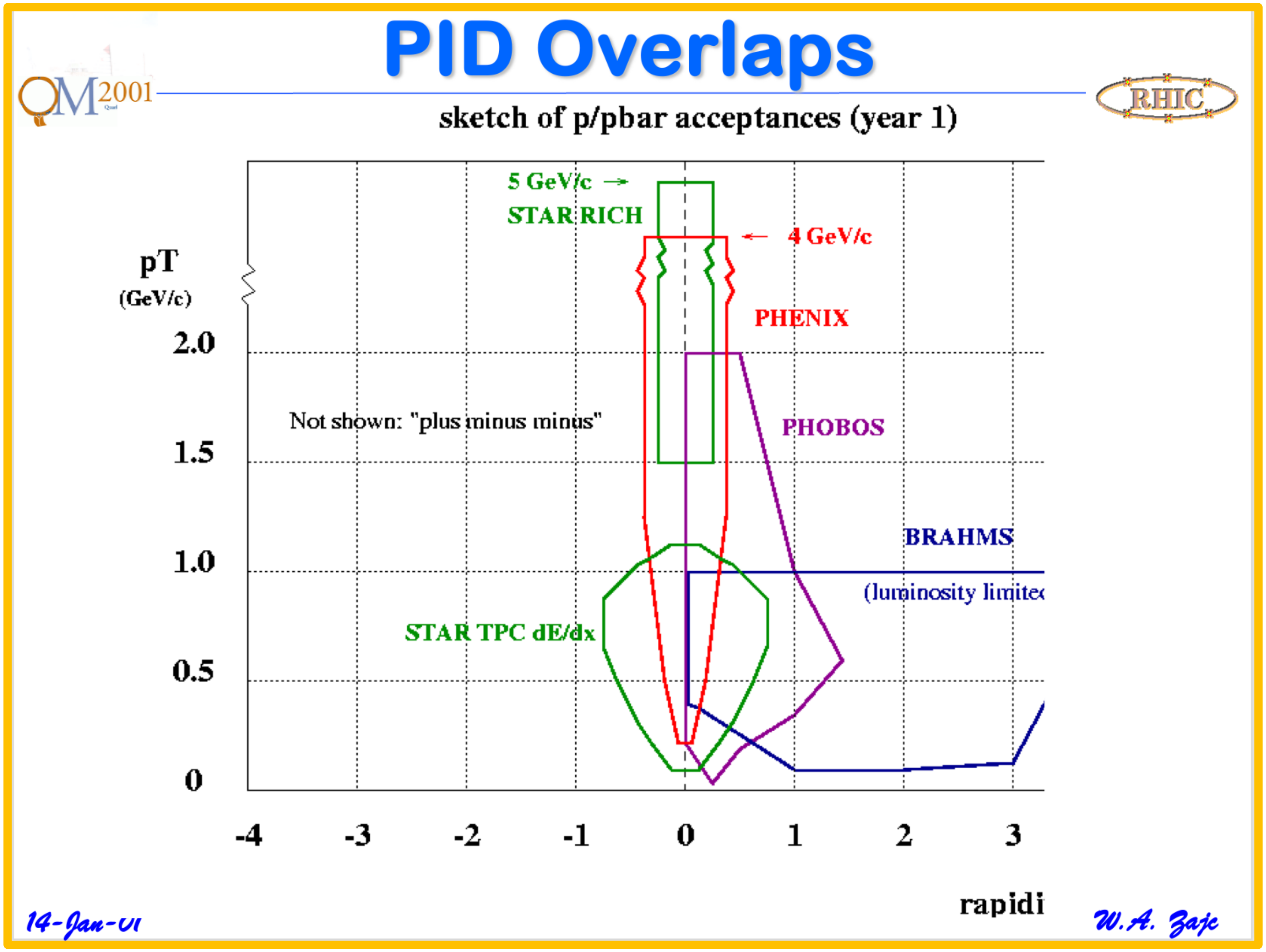
Global
MVD/BB/ZDC

Muon Arms
Coverage (N&S)
-1.2< |y| <2.3
-π < φ < π
ΔM(J/ψ)=105MeV
ΔM(γ) =180MeV

3 station CSC
5 layer MuID (10X_0)
p(μ)>3GeV/c

Central Arms
Coverage (E&W)
-0.35< y < 0.35
30º <|φ |< 120º
ΔM(J/ψ)= 20MeV
ΔM(γ) =160MeV

Quark Matter 2001

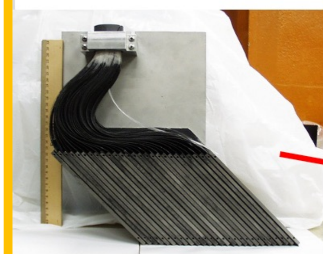


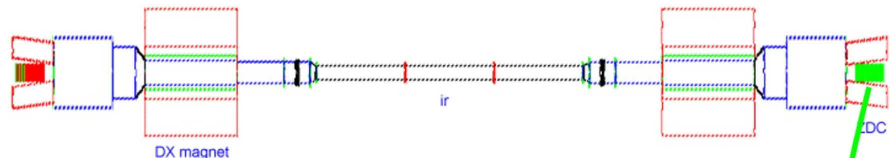
Quark Matter 2001

RHIC ZDC's

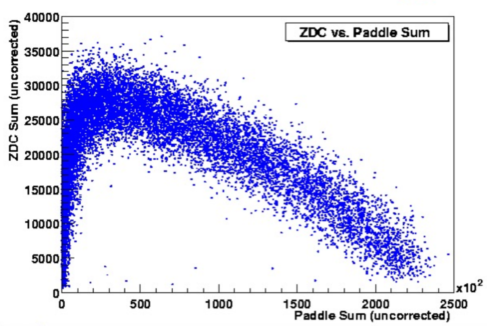
QM2001 — RHIC

- ZDC ? Zero Degree Calorimeter
- Goals:
  - Uniform luminosity monitoring at all 4 intersections
  - Uniform event characterization by all 4 experiments





- Process:
  - Correlated Forward-Backward Dissociation
  - σ_{tot} = 11.0 Barns (+/- few %)



42

Prediction January, 2001

Time to Physics

QM2001

RHIC

Again, learn from the past:

First CDF publication:

***Transverse-Momentum Distributions of Charged Particles Produced in p-pbar Interactions at 630 and 1800 GeV*, F. Abe et al., Phys. Rev. Lett. 61, 1819 (1988).**

- **~One year from data-taking.**
- **Much simpler final state!**

✖ ***We will be hard-pressed to reach this goal***

✕ ***And much harder-pressed to maintain "CDF-like" rate***

VOLUME 61, NUMBER 16 PHYSICAL REVIEW LETTERS 17 OCTOBER 1988

Transverse-Momentum Distributions of Charged Particles Produced in $\bar{p}p$ Interactions at $\sqrt{s} = 630$ and 1800 GeV

F. Abe,[16] D. Amidei,[3] G. Apollinari,[11] G. Ascoli,[7] M. Atac,[4] P. Auchincloss,[14] A. R. Baden,[6] A. Barbaro-Galtieri,[9] V. E. Barnes,[12] F. Bedeschi,[11] S. Belforte,[11] G. Bellettini,[11] J. Bellinger,[17] J. Bensinger,[2] A. Beretvas,[14] P. Berge,[4] S. Bertolucci,[5] S. Bhadra,[7] M. Binkley,[4] R. Blair,[1] C. Blocker,[2] J. Bofill,[4] A. W. Booth,[4] G. Brandenburg,[6] D. Brown,[6] A. Byon,[12] K. L. Byrum,[17] M. Campbell,[3] R. Carey,[6] W. Carithers,[9] D. Carlsmith,[17] J. T. Carroll,[4] R. Cashmore,[4] F. Cervelli,[11] K. Chadwick,[4,12] T. Chapin,[13] G. Chiarelli,[11] W. Chinowsky,[9] S. Cihangir,[15] D. Cline,[17] D. Connor,[10] M. Contreras,[2] J. Cooper,[4] M. Cordelli,[5] M. Curatolo,[5] C. Day,[4] R. DelFabbro,[11] M. Dell'Orso,[11] L. DeMortier,[2] T. Devlin,[14] D. DiBitonto,[15] R. Diebold,[1] F. Dittus,[4] A. DiVirgilio,[11] J. E. Elias,[4] R. Ely,[9] S. Errede,[7] B. Esposito,[5] A. Feldman,[6] B. Flaugher,[14] E. Focardi,[11] G. W. Foster,[4] M. Franklin,[6,7] J. Freeman,[4] H. Frisch,[3] Y. Fukui,[8] A. F. Garfinkel,[12] P. Giannetti,[11] N. Giokaris,[13] P. Giromini,[5] L. Gladney,[10] M. Gold,[9] K. Goulianos,[13] C. Grosso-Pilcher,[3] C. Haber,[9] S. R. Hahn,[10] R. Handler,[17] R. M. Harris,[9] J. Hauser,[3] T. Hessing,[15] R. Hollebeek,[10] L. Holloway,[7] P. Hu,[14] B. Hubbard,[9] P. Hurst,[7] J. Huth,[4] H. Jensen,[4] R. P. Johnson,[4] U. Joshi,[14] R. W. Kadel,[4] T. Kamon,[15] S. Kanda,[16] D. A. Kardelis,[7] I. Karliner,[7] E. Kearns,[6] R. Kephart,[4] P. Kesten,[2] H. Keutelian,[7] S. Kim,[16] L. Kirsch,[2] K. Kondo,[16] U. Kruse,[7] S. E. Kuhlmann,[12] A. T. Laasanen,[12] W. Li,[1] T. Liss,[3] N. Lockyer,[10] F. Marchetto,[15] R. Markeloff,[17] L. A. Markosky,[17] P. McIntyre,[15] A. Menzione,[11] T. Meyer,[15] S. Mikamo,[8] M. Miller,[10] T. Mimashi,[16] S. Miscetti,[5] M. Mishina,[8] S. Miyashita,[16] N. Mondal,[17] S. Mori,[16] Y. Morita,[16] A. Mukherjee,[4] C. Newman-Holmes,[4] L. Nodulman,[1] R. Paoletti,[11] A. Para,[4] J. Patrick,[4] T. J. Phillips,[6] H. Piekarz,[2] R. Plunkett,[13] L. Pondrom,[17] J. Proudfoot,[1] G. Punzi,[11] D. Quarrie,[4] K. Ragan,[10] G. Redlinger,[3] J. Rhoades,[17] F. Rimondi,[4] L. Ristori,[11] T. Rohaly,[10] A. Roodman,[3] A. Sansoni,[5] R. Sard,[7] V. Scarpine,[7] P. Schlabach,[7] E. E. Schmidt,[4] P. Schoessow,[1] M. H. Schub,[12] R. Schwitters,[6] A. Scribano,[11] S. Segler,[4] M. Sekiguchi,[16] P. Sestini,[11] M. Shapiro,[6] M. Sheaff,[17] M. Shibata,[16] M. Shochet,[3] J. Siegrist,[9] P. Sinervo,[10] J. Skarha,[17] D. A. Smith,[7] F. D. Snider,[3] R. St. Denis,[6] A. Stefanini,[11] Y. Takaiwa,[16] K. Takikawa,[16] S. Tarem,[3] D. Theriot,[4] A. Tollestrup,[4] G. Tonelli,[11] Y. Tsay,[3] F. Ukegawa,[16] D. Underwood,[1] R. Vidal,[4] R. G. Wagner,[1] R. L. Wagner,[4] J. Walsh,[10] T. Watts,[14] R. Webb,[15] T. Westhusing,[7] S. White,[13] A. Wicklund,[1] H. H. Williams[10] T. Yamanouchi,[4] A. Yamashita,[16] K. Yasuoka,[16] G. P. Yeh,[4] J. Yoh,[4] and F. Zetti,[11]

[1] *Argonne National Laboratory, Argonne, Illinois 60439*
[2] *Brandeis University, Waltham, Massachusetts 02254*
[3] *University of Chicago, Chicago, Illinois 60637*
[4] *Fermi National Accelerator Laboratory, Batavia, Illinois 60510*
[5] *Laboratori Nazionali di Frascati, Istituto Nazionale di Fisica Nucleare, Frascati, Italy*
[6] *Harvard University, Cambridge, Massachusetts 02138*
[7] *University of Illinois, Urbana, Illinois 61801*
[8] *National Laboratory for High Energy Physics (KEK), Tsukuba-gun, Ibaraki-ken 305, Japan*
[9] *Lawrence Berkeley Laboratory, Berkeley, California 94720*
[10] *University of Pennsylvania, Philadelphia, Pennsylvania 19104*
[11] *Istituto Nazionale di Fisica Nucleare, University and Scuola Normale Superiore of Pisa, Pisa, Italy*
[12] *Purdue University, West Lafayette, Indiana 47907*
[13] *Rockefeller University, New York, New York 10021*
[14] *Rutgers University, Piscataway, New Jersey 08854*
[15] *Texas A&M University, College Station, Texas 77843*
[16] *University of Tsukuba, Ibaraki 305, Japan*
[17] *University of Wisconsin, Madison, Wisconsin 53706*

(Received 8 June 1988; revised manuscript received 5 September 1988)

Measurements of inclusive transverse-momentum spectra for charged particles produced in proton-antiproton collisions at $\sqrt{s}$ of 630 and 1800 GeV are presented and compared with data taken at lower energies.

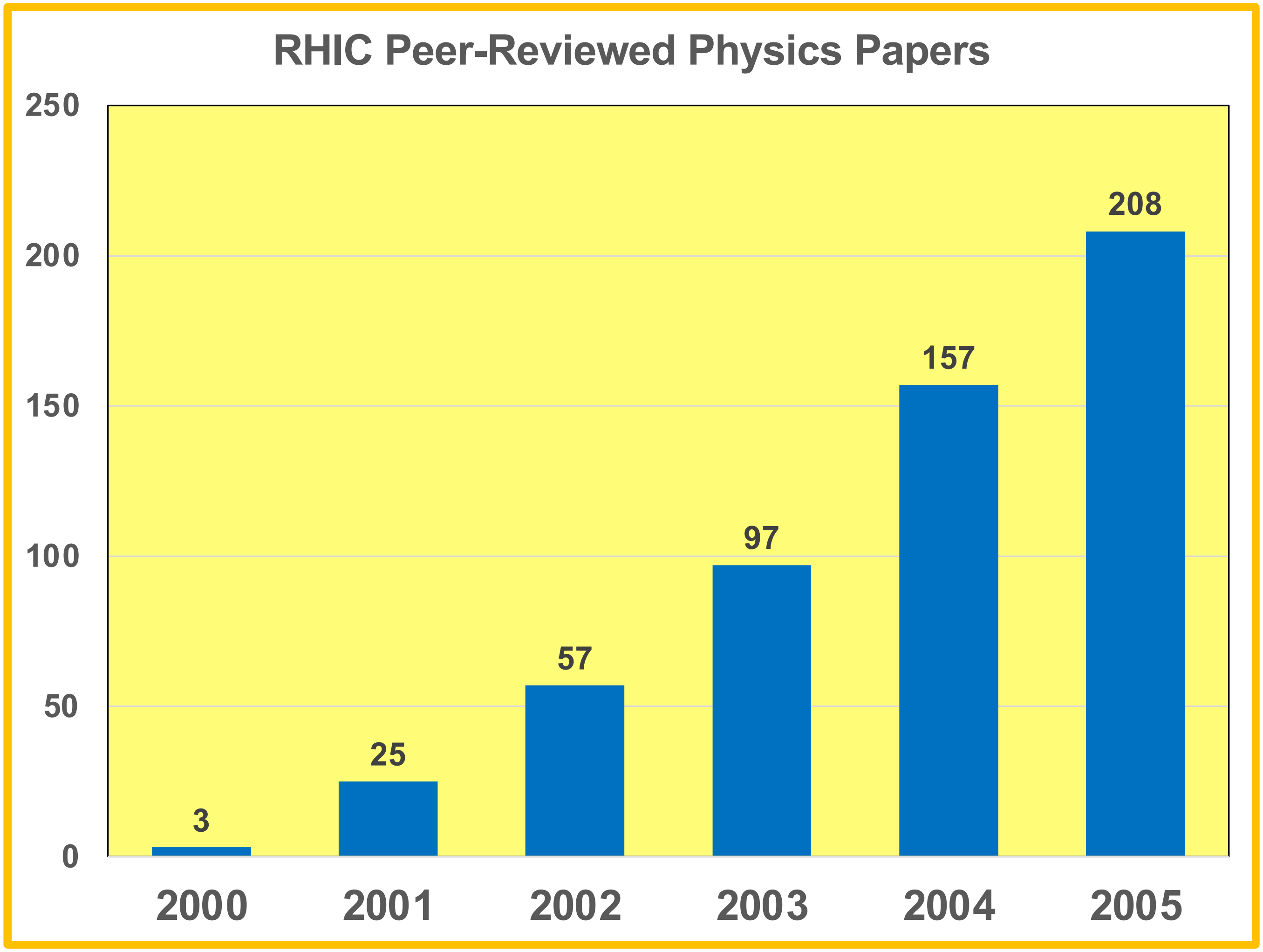
PACS numbers: 13.85.Ni

1819

14-Jan-01 45 *W.A. Zajc*

Wrong !!

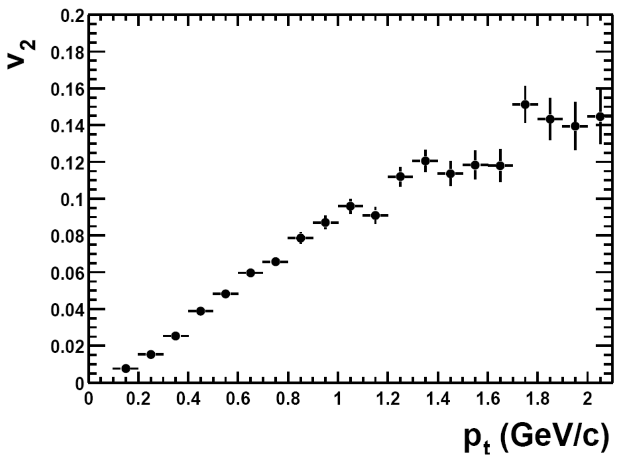
Well – we were indeed hard-pressed.



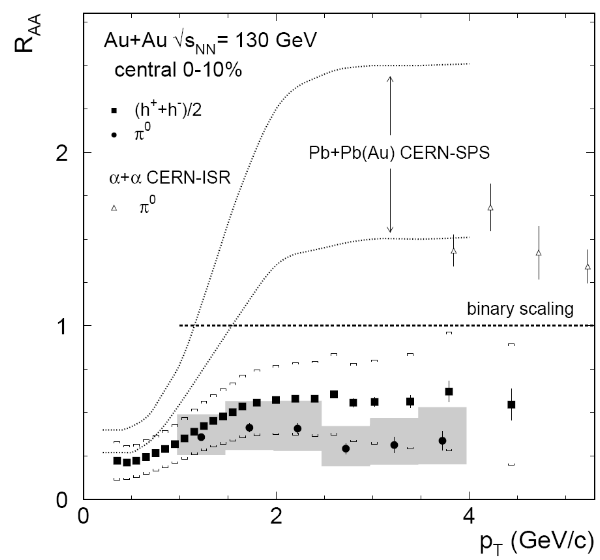
But we pressed hard!

RHIC's First Two Major Discoveries

- Discovery of strong "elliptic" flow:
  - Elliptic flow in Au+Au collisions at $\sqrt{s_{NN}}$= 130 GeV, STAR Collaboration, Phys.Rev.Lett.86:402-407,2001
  - *882 citations*

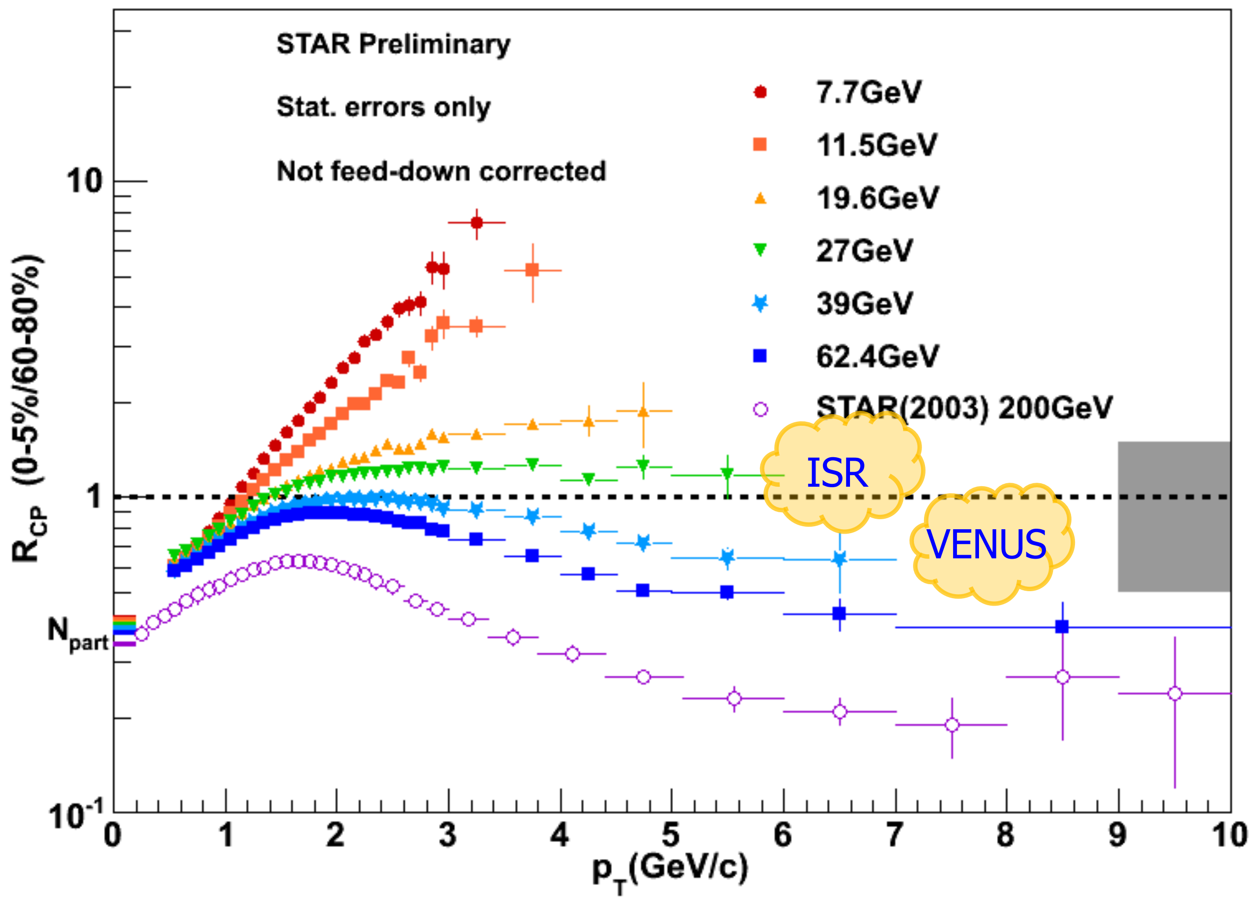


- Discovery of "jet quenching"
  - Suppression of hadrons with large transverse momentum in central Au+Au collisions at $\sqrt{s_{NN}}$ = 130 GeV, PHENIX Collaboration, Phys.Rev.Lett.88:022301,2002
  - *1265 citations*



How Fortunate !

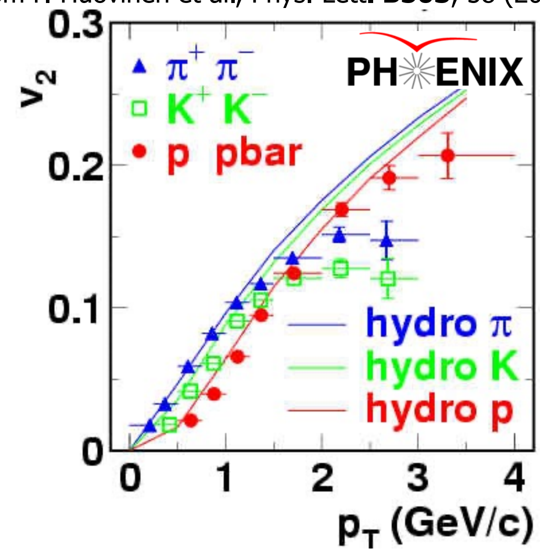
- Suppression effect not present at lower √s 's

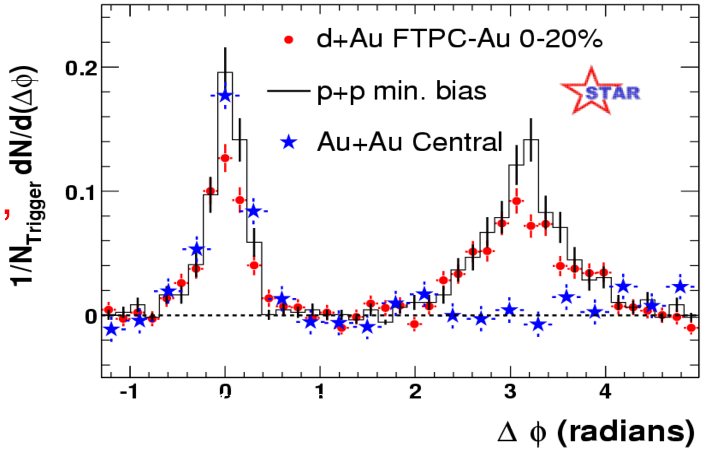


Extending Those Major Discoveries

- "Fine structure" in elliptic flow:
  - Elliptic flow of identified hadrons in Au+Au collisions at $\sqrt{s_{NN}}$= 200 GeV, PHENIX Collaboration, Phys.Rev.Lett.91:182301,2003
  - *908 citations*
- Disappearance of away-side "jet"
  - Disappearance of back-to-back high p_T correlations in central Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV, STAR Collaboration, Phys.Rev.Lett.90:082302,2003
  - *946 citations*

Hydro from P. Huovinen et al., Phys. Lett. **B503**, 58 (2001)





Critical *in situ* Control Measurement

- 2000 – first collisions
- 2001 – major results from all 4 collaborations
- 2002 – first full-energy Au+Au run
- 2003 – d+Au control run

Contacts: Karen McNulty Walsh, (631) 344-8350 or Peter Genzer, (631) 344-3174 PRINT

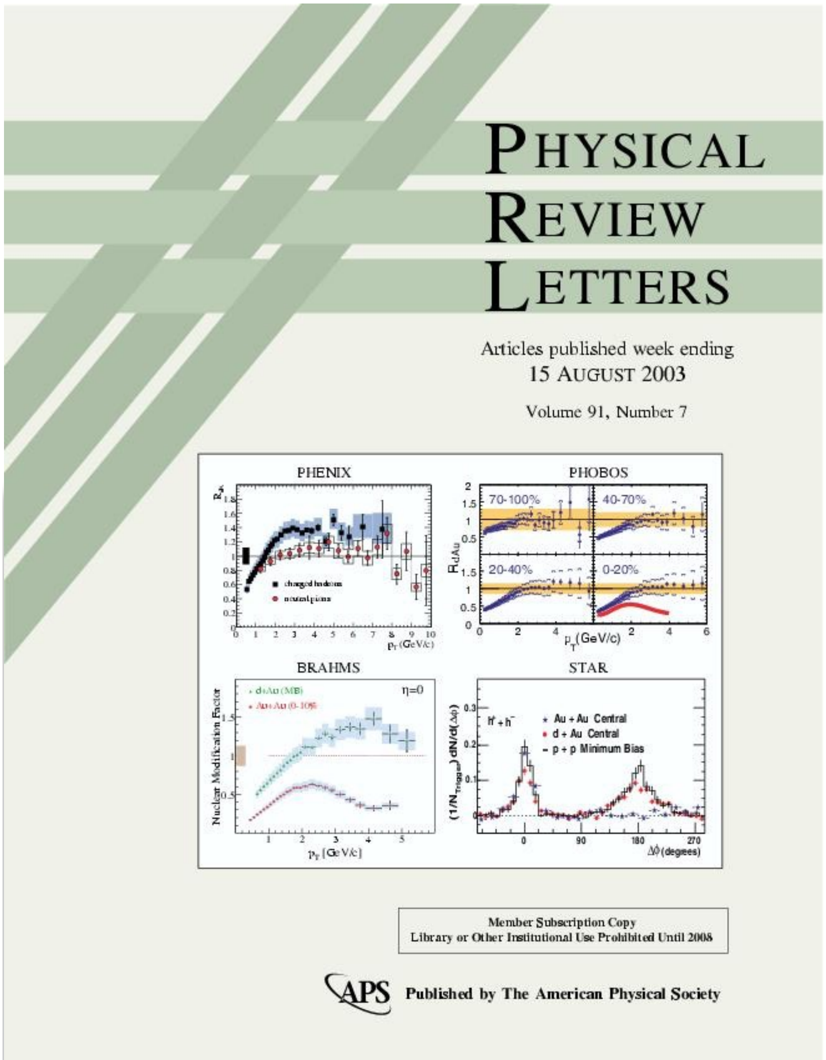
Exciting First Results from Deuteron-Gold Collisions at Brookhaven

Findings intensify search for new form of matter

June 11, 2003

UPTON, NY — The latest results from the Relativistic Heavy Ion Collider (RHIC), the world's most powerful facility for nuclear physics research, strengthen scientists' confidence that RHIC collisions of gold ions have created unusual conditions and that they are on the right path to discover a form of matter called the quark-gluon plasma, believed to have existed in the first microseconds after the birth of the universe. The results will be presented at a special colloquium at the U.S. Department of Energy's Brookhaven National Laboratory on June 18 at 11 a.m., to coincide with the submission of scientific papers on the results to Physical Review Letters by three of RHIC's international collaborations.

The scientists are not yet ready to claim the discovery of the quark-gluon plasma, however. That must await corroborating experiments, now under way at RHIC, that seek other signatures of quark-gluon plasma and explore alternative ideas for the kind of matter produced in these violent collisions.



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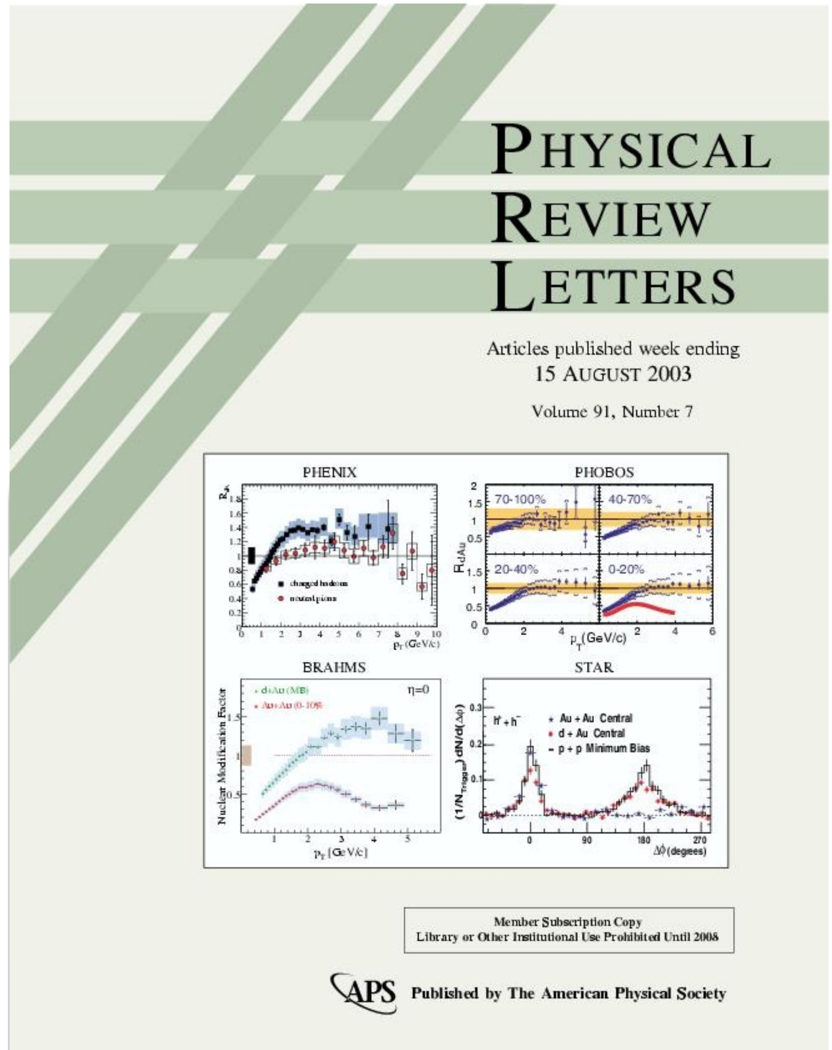
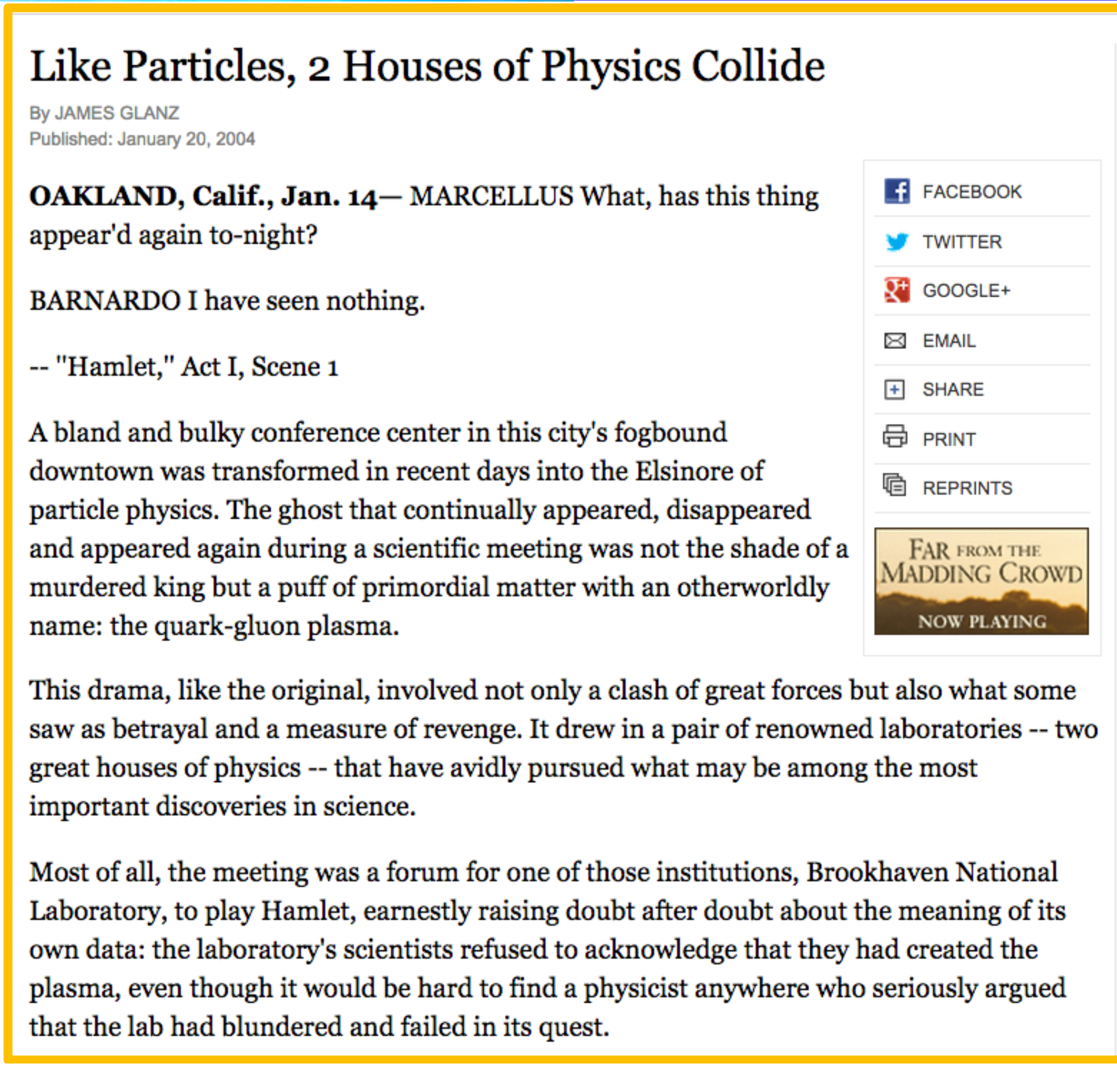


- Jan-24: 97 RHIC publications but . . .
- New York Times article by Jim Glanz emphasized “reluctance” to announce QGP discovery.
- This was enormously polarizing . . .



Like Particles, 2 Houses of Physics Collide

By JAMES GLANZ
Published: January 20, 2004

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OAKLAND, Calif., Jan. 14— MARCELLUS What, has this thing appear'd again to-night?

BARNARDO I have seen nothing.

-- "Hamlet," Act I, Scene 1

A bland and bulky conference center in this city's fogbound downtown was transformed in recent days into the Elsinore of particle physics. The ghost that continually appeared, disappeared and appeared again during a scientific meeting was not the shade of a murdered king but a puff of primordial matter with an otherworldly name: the quark-gluon plasma.

This drama, like the original, involved not only a clash of great forces but also what some saw as betrayal and a measure of revenge. It drew in a pair of renowned laboratories -- two great houses of physics -- that have avidly pursued what may be among the most important discoveries in science.

Most of all, the meeting was a forum for one of those institutions, Brookhaven National Laboratory, to play Hamlet, earnestly raising doubt after doubt about the meaning of its own data: the laboratory's scientists refused to acknowledge that they had created the plasma, even though it would be hard to find a physicist anywhere who seriously argued that the lab had blundered and failed in its quest.

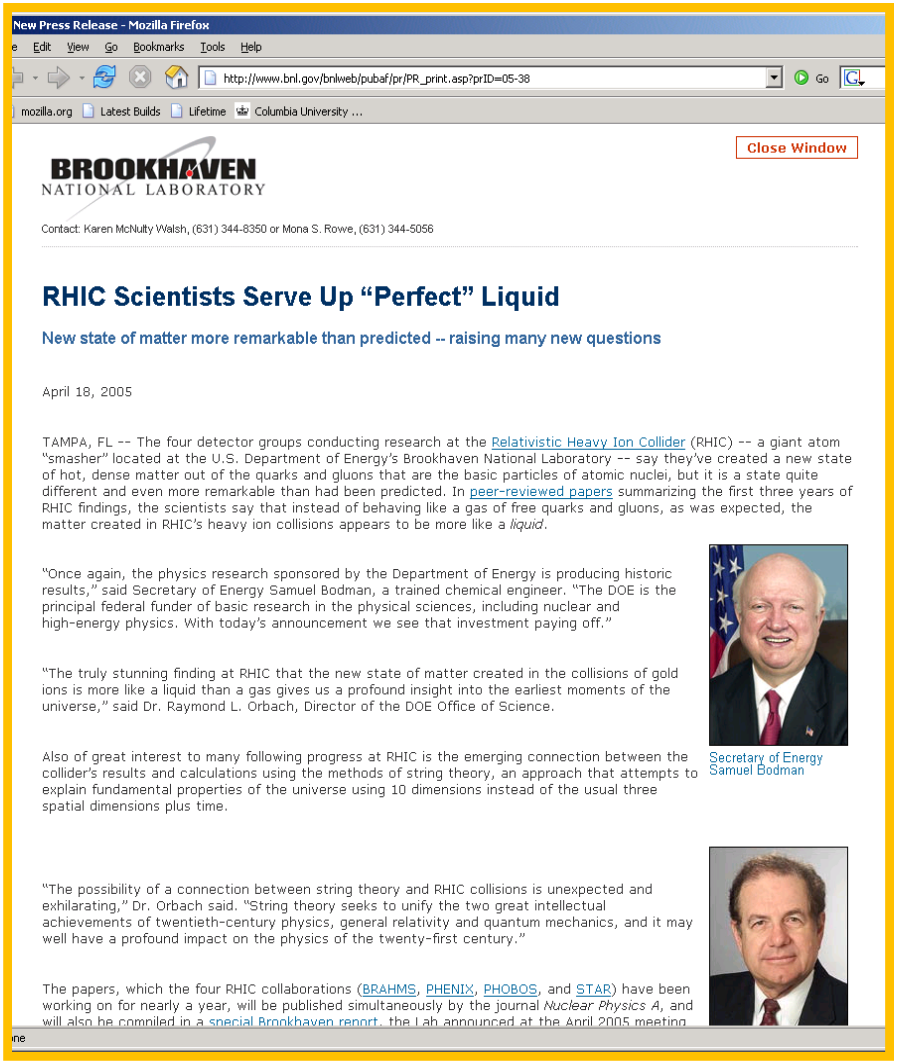
From That Article

- …the CERN announcement *''added more confusion than light to the story''* (RHIC scientist)
- Those words were like daggers . . .
- *"They (BNL) were just starting a half-billion-dollar operation and we (CERN) are saying: 'Bye-bye. We have stolen your child' "* (Senior CERN scientist)
- To announce a discovery now, Dr. Xyyyyyy said, *''the very same people who were very critical have to eat their words.''*
- *''It's no mystery to me why they haven't announced it,''* Dr. Mueller said. ''*I think the lab has been appropriately cautious.''*

Causality in the White Paper Process

- 12-Feb-04: Discussion Sam Aronson, Tim Hallman, WZ "RHIC Science Retreat"
- 20-Feb-04: Tim Hallman, WZ discuss possible "white papers"
- 25-Feb-04: Spokesperson's meeting, WZ charged to draft a process
- 27-Feb-04: Experiments invited to contribute ~15-page paper to RBRC Series
- 29-Feb-04: Draft process for White Papers's distributed to other spokespersons + Sam Aronson
- 02-Mar-04: Spokespersons discuss politely declining publication in RBRC Series
  - Unrealistic time scale (April 5)
  - Interference with existing White Paper process
  - Would replicate rather than address CERN announcement
- 04-Mar-04: Draft response circulated (7 AM); revised draft (3 PM)
-
- (Extraordinary period of work, writing, negotiations)
-
- 04-Oct-04: PHENIX WP posted to archive, other experiments to follow
-
- (Another extraordinary period consolidating understanding strong coupling ←→ η / s…)
- 18-Apr-05: Perfect liquid announcement

RHIC Success !!



New Press Release - Mozilla Firefox

http://www.bnl.gov/bnlweb/pubaf/pr/PR_print.asp?prID=05-38

Close Window

BROOKHAVEN NATIONAL LABORATORY

Contact: Karen McNulty Walsh, (631) 344-8350 or Mona S. Rowe, (631) 344-5056

RHIC Scientists Serve Up "Perfect" Liquid

New state of matter more remarkable than predicted -- raising many new questions

April 18, 2005

TAMPA, FL -- The four detector groups conducting research at the Relativistic Heavy Ion Collider (RHIC) -- a giant atom "smasher" located at the U.S. Department of Energy's Brookhaven National Laboratory -- say they've created a new state of hot, dense matter out of the quarks and gluons that are the basic particles of atomic nuclei, but it is a state quite different and even more remarkable than had been predicted. In peer-reviewed papers summarizing the first three years of RHIC findings, the scientists say that instead of behaving like a gas of free quarks and gluons, as was expected, the matter created in RHIC's heavy ion collisions appears to be more like a *liquid*.

"Once again, the physics research sponsored by the Department of Energy is producing historic results," said Secretary of Energy Samuel Bodman, a trained chemical engineer. "The DOE is the principal federal funder of basic research in the physical sciences, including nuclear and high-energy physics. With today's announcement we see that investment paying off."

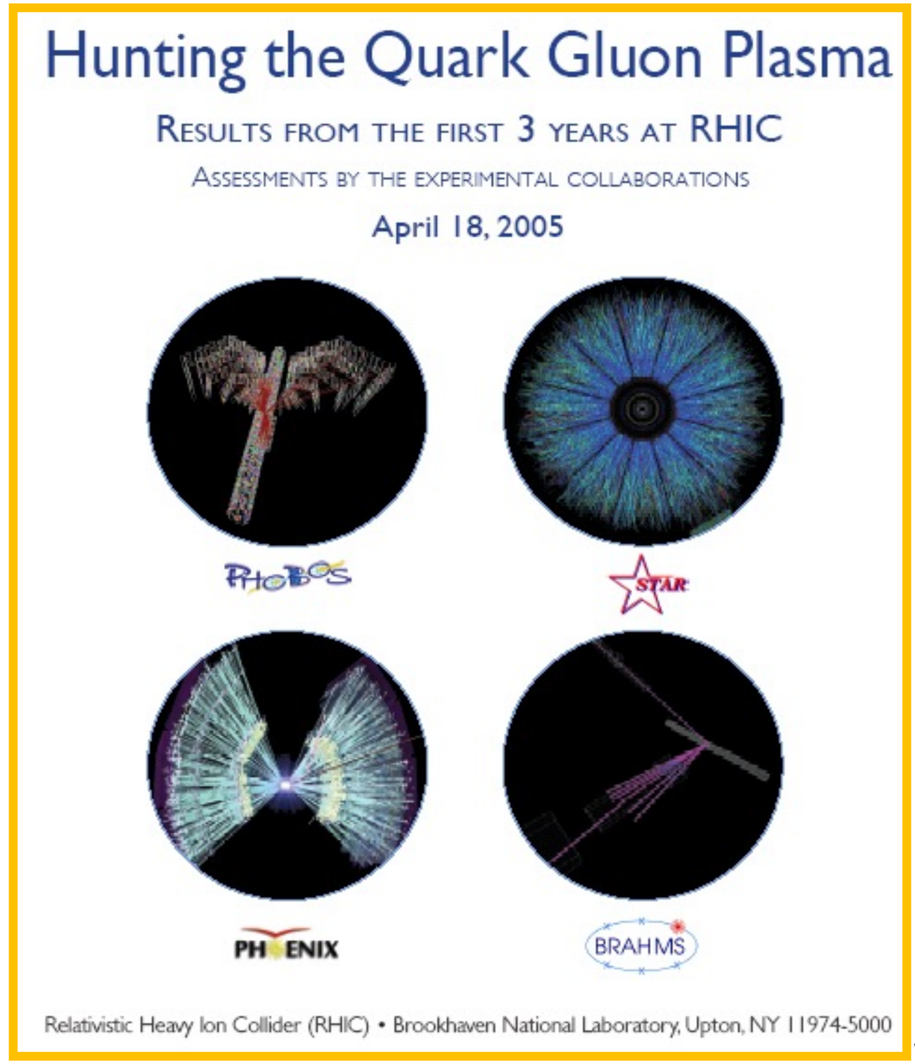
"The truly stunning finding at RHIC that the new state of matter created in the collisions of gold ions is more like a liquid than a gas gives us a profound insight into the earliest moments of the universe," said Dr. Raymond L. Orbach, Director of the DOE Office of Science.

Secretary of Energy Samuel Bodman

Also of great interest to many following progress at RHIC is the emerging connection between the collider's results and calculations using the methods of string theory, an approach that attempts to explain fundamental properties of the universe using 10 dimensions instead of the usual three spatial dimensions plus time.

"The possibility of a connection between string theory and RHIC collisions is unexpected and exhilarating," Dr. Orbach said. "String theory seeks to unify the two great intellectual achievements of twentieth-century physics, general relativity and quantum mechanics, and it may well have a profound impact on the physics of the twenty-first century."

The papers, which the four RHIC collaborations (BRAHMS, PHENIX, PHOBOS, and STAR) have been working on for nearly a year, will be published simultaneously by the journal *Nuclear Physics A*, and will also be compiled in a special Brookhaven report, the Lab announced at the April 2005 meeting



W.A. Zajc

RHIC Scientists Serve Up 'Perfect' Liquid

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Contacts: Karen McNulty Walsh, (631) 344-8350 or Peter Genzer, (631) 344-3174

RHIC Scientists Serve Up 'Perfect' Liquid

New state of matter more remarkable than predicted — raising many new questions

Monday, April 18, 2005

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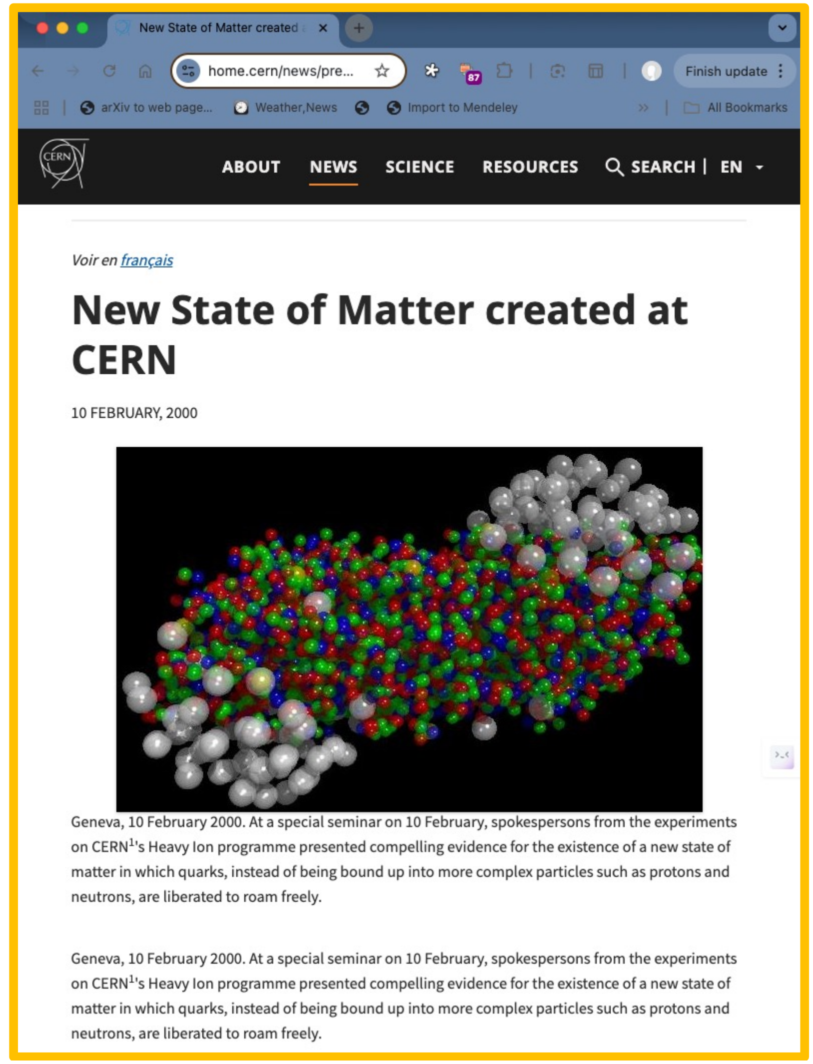
An Unfortunate Affair - 2000 CERN Press Release

- ”Good” news (from the RHIC perspective): It did not directly claim discovery of the quark-gluon plasma.
- Bad news:
  - Was not linked to publication of peer-reviewed findings.
  - Nonetheless stated
    - “the experiments on CERN's Heavy Ion programme presented compelling evidence for the existence of a new state of matter in which quarks, instead of being bound up into more complex particles such as protons and neutrons, are liberated to roam freely.”



Voir en français

New State of Matter created at CERN

10 FEBRUARY, 2000

Geneva, 10 February 2000. At a special seminar on 10 February, spokespersons from the experiments on CERN[1]'s Heavy Ion programme presented compelling evidence for the existence of a new state of matter in which quarks, instead of being bound up into more complex particles such as protons and neutrons, are liberated to roam freely.

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Current Perspective - 2000 CERN Press Release

arXiv > nucl-th > arXiv:2412.19393

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Nuclear Theory

[Submitted on 27 Dec 2024]

Hydrodynamic Description of the Quark-Gluon Plasma

Ulrich Heinz, Björn Schenke

We review the history and success of applying relativistic hydrodynamics to high-energy heavy-ion collisions. We emphasize the important role hydrodynamics has played in the discovery of the quark-gluon plasma and its quantitative exploration.

Comments: 32 pages, 6 figures, Contribution to "Quark Gluon Plasma at Fifty - A Commemorative Journey", Publisher: Springer Nature Switzerland AG, Editors: Tapan Nayak, Marco Van Leeuwen, Steffen Bass, Claudia Ratti, James Dunlop
Subjects: **Nuclear Theory (nucl-th)**; High Energy Physics - Phenomenology (hep-ph)
Cite as: arXiv:2412.19393 **[nucl-th]**
(or arXiv:2412.19393v1 **[nucl-th]** for this version)
https://doi.org/10.48550/arXiv.2412.19393

Submission history

From: Björn Schenke [view email]
[v1] Fri, 27 Dec 2024 00:50:15 UTC (451 KB)

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An assessment of the insights gained from the heavy-ion program at the CERN SPS during the 1980s and 1990s [48] concluded that compelling evidence for the creation of "a new form of matter" had been found but stopped short of claiming unambiguous discovery of the quark-gluon plasma, nor did it comment on its perfectly liquid collective dynamical properties. The latter became only obvious after theory had progressed to a quantitative understanding of the bulk of the very comprehensive and precise experimental data collected at RHIC.

New State of Matter created at CERN
home.cern/news/pre...

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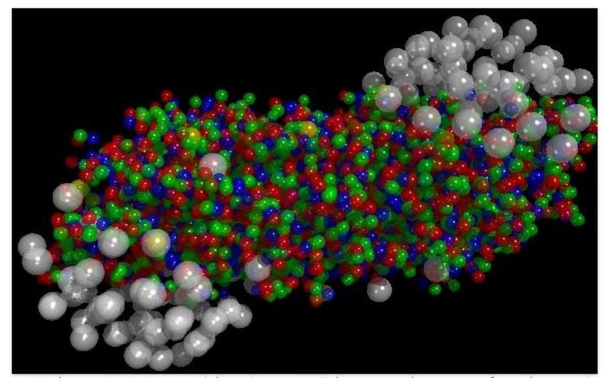
Voir en français

New State of Matter created at CERN

10 FEBRUARY, 2000



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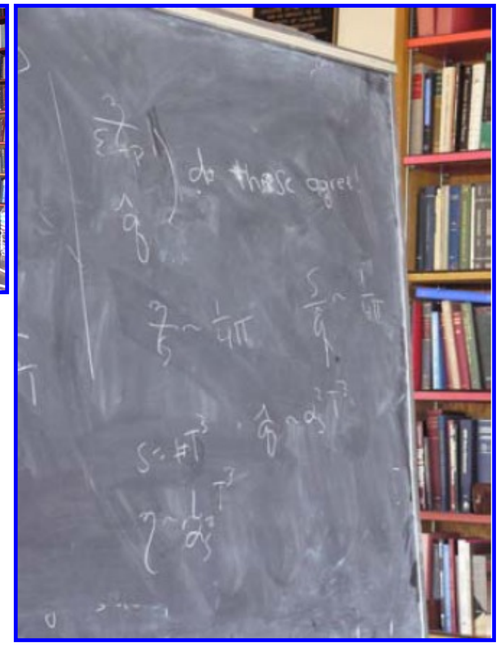
Since That Time . . .

- The RHIC “perfect liquid” paradigm has prevailed.
- The discoveries have continued to ``flow” from RHIC.
- Quantitative precision has increased enormously.
- Can now confidently attest to uniqueness of QGP.

It Is Only Appropriate . . .

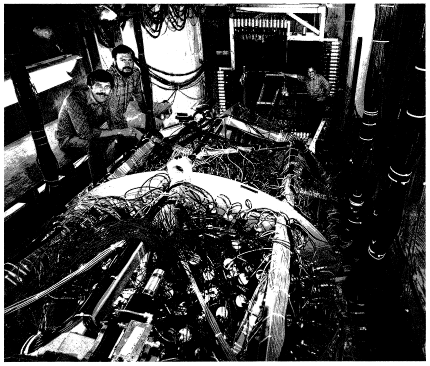
- To take a moment to offer our profound thanks to
  - The visionary leadership that made RHIC possible
  - The incredible operation of RHIC by the Collider-Accelerator Dept.
  - The superb skills of the BNL technical staff
  - The humbling efforts of our graduate students and postdocs
  - The theory community that has risen to the challenge from RHIC data
  - The organizers of this meeting.

Boulder Workshop Mar-05



VENUS ??

The Plastic Ball/Plastic Wall detector at the Berkeley Bevalac — an example of the growing interest in nuclear reactions using beams of heavy ions.



BERKELEY
VENUS rising

From 15—18 September a Workshop was held at the Lawrence Berkeley Laboratory to discuss the proposal which it is intended to present by the end of this year concerning the accelerator complex, known as VENUS, for physics with heavy ion beams. The project, as then conceived, was described in the December 1979 issue, page 406. The ultimate aim is to have multi-GeV per nucleon colliding beams but the financial resources to reach this aim are not within reach at the moment. Much could be done, however, to extend the research programme by building just the injection stages of the full VENUS project.

The interest in nuclear physics with heavy ion beams has grown in the past decade with the use of the Bevalac (the ex-Bevatron constant gradient synchrotron fed by the SuperHILAC heavy ion linear accelerator). It now supports a community of some 200 physics users and in addition has a thriving biomedical research programme (which we return to as a separate item at the end of this article). This year the abilities of the accelerator have been increased via a new ion source (ABLE) on the linac, to make good beams of ions up to uranium available, and via the installation of a new vacuum liner in the synchrotron to achieve a low enough pressure for the heavier ion beams to be transmitted during their acceleration. These improvements have worked very well and usable beams of uranium ions at 1 GeV per nucleon can now be provided to the experimenters.

Just as important, in terms of pulling out significant results, is the coming into action of more sophisticated detectors. There has been difficulty in extracting the physics from the complex heavy ion collisions (as was commented upon by the DOE nuclear science review committee, chaired by Erich Vogt, which reported on existing research facilities in June of this year). The new detectors are a heavy ion superconducting spectrometer, HISS, and the 'Plastic Ball' described in our November 1981 issue, page 393. There are projects to add the lampshade magnet and, longer term, a heavy ion Time Projection Chamber. The improved detection abilities should help to clarify the information which has come from the first survey of collisions between high energy nuclei.

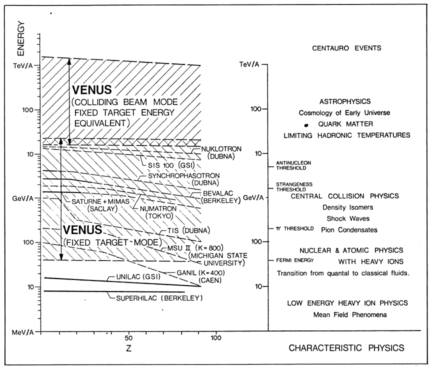
The VENUS project in its present form requires rebuilding the prestripper on the SuperHILAC to increase injected ion beam intensities by a factor of ten. Two rings would then receive the beams. A superconducting booster ring of 30 m radius would accelerate uranium ions to 7 GeV per nucleon. The second d.c. superconducting stretcher ring, probably stacked on top of the first ring (both of them being installed in the Bevatron hall), will store ions and allow 100% duty factor with the beams ejected to external targets. A variety of modes of operation with interplay between the two rings would be possible. In particular beams from this second ring could be reinjected into the first ring after stripping so as to be accelerated to higher energies (10 GeV per nucleon which is ten times the energy available from the present Bevalac). Stochastic cooling in the storage ring may also be used to produce beams with much lower energy spread, 10^{-5}, than is possible now. At a later date, two large superconducting rings each to give colliding beam energies of 20 GeV per nucleon could be built to take VENUS parameters to the very high

centre of mass energies initially projected.

High fields from the superconducting magnets are anticipated for all the storage rings — for example 6 T in the dipoles of the booster ring. This is in line with a programme of work on high field superconducting magnets at Berkeley initiated several years ago with the major aim of developing magnets suitable for the next generation of high energy proton synchrotrons (20 TeV and above). The goal of the development programme is to produce magnets capable of 10 T in a 4 cm bore. En route, the team did build an 'alternative ISABELLE magnet' and, with a four-layer coil structure, achieved 7.6 T in helium-2 at 1.8 K with little training.

Two designs are being pursued at Berkeley to achieve high current density in the superconductor with minimum copper stabilizer. One involves a four-layer coil structure like the alternative ISABELLE magnet; the other involves the use of niobium-tin conductor in rectangular cable — the so-called 'block' design — operating at 4.2 K. Niobium-titanium and niobium tin are possibilities for the superconductor. (Another approach, involving Fermilab and KEK, is to use a niobium-titanium-tantalum alloy in a four layer magnet. KEK are also trying niobium-tin and niobium-titanium.) It is hoped to have a first niobium-titanium prototype tested before the end of the year.

Graph of the energies and ion species which could be covered by the VENUS project at Berkeley. Other existing and planned machines are also indicated. On the right is a list of the fields of physics which could be studied by the machine in its various operating modes.



Plans for a 'medical accelerator'

The success of the biomedical programme on the Bevalac has led to the National Institute of Health funding a study at Berkeley to design a heavy ion accelerator appropriate for use in a hospital environment. For the treatment of cancer by bombardment with particle beams, heavy ions seem to be emerging as the strong candidate. The use of neutrons is also continuing but pion beams are now not in favour. The pion facility at LAMPF has been closed down and the PIGMI project at Los Alamos to develop a pion accelerator for hospitals is no longer active (though it did yield some superb accelerator technology). The production of secondary beams of pions is harder than using primary beams and biologically their effect is not as useful as heavy ions.

The present design for a 'medical accelerator' aims to achieve beams of silicon ions (which are preferred in order to limit spallation from the irradiated volume) at an energy of 800 MeV per nucleon using a synchrotron. Lower mass ions could also be accelerated and perhaps argon ions.

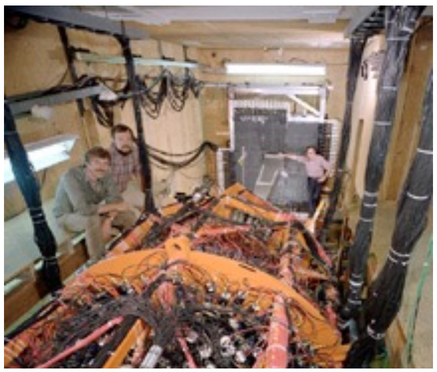
Great emphasis is put on operational simplicity and reliability since the accelerator will have to run in an environment where little accelerator expertise will be available. The design will incorporate a radio-frequency quadrupole to avoid a high voltage Cockcroft-Walton. The Berkeley team fed in the idea of rings in the RFQ structure to help in balancing the structure. In addition to the synchrotron design there is also work on the system to deliver beam to the patient so as to irradiate the required volume in the most effective way.

With this medical accelerator it is hoped that an extensive programme of heavy ion therapy can be carried out to ensure a very thorough evaluation of effectiveness and appropriateness for different types of cancer.

W.A. Zajc

VENUS ??

The Plastic Ball/Plastic Wall detector at the Berkeley Bevalac — an example of the growing interest in nuclear reactions using beams of heavy ions.



BERKELEY VENUS rising

From 15—18 September a Workshop was held at the Lawrence Berkeley Laboratory to discuss the proposal which it is intended to present by the end of this year concerning the accelerator complex, known as VENUS, for physics with heavy ion beams. The project, as then conceived, was described in the December 1979 issue, page 406. The ultimate aim is to have multi-GeV per nucleon colliding beams but the financial resources to reach this aim are not within reach at the moment. Much could be done, however, to extend the research programme by building just the injection stages of the full VENUS project.

The interest in nuclear physics with heavy ion beams has grown in the past decade with the use of the Bevalac (the ex-Bevatron constant gradient synchrotron fed by the SuperHILAC heavy ion linear accelerator). It now supports a community of some 200 physics users and in addition has a thriving biomedical research programme (which we return to as a separate item at the end of this article). This year the abilities of the accelerator have been increased via a new ion source (ABLE) on the linac, to make good beams of ions up to uranium available, and via the installation of a new vacuum liner in the synchrotron to achieve a low enough pressure for the heavier ion beams to be transmitted during their acceleration. These improvements have worked very well and usable beams of uranium ions at 1 GeV per nucleon can now be provided to the experimenters.

Just as important, in terms of pulling out significant results, is the coming into action of more sophisticated detectors. There has been difficulty in extracting the physics from the complex heavy ion collisions (as was commented upon by the DOE nuclear science review committee, chaired by Erich Vogt, which reported on this year). The new detectors are a heavy ion superconducting spectrometer, HISS, and the 'Plastic Ball' described in our November 1981 issue, page 393. There are projects to add the lampshade magnet and, longer term, a heavy ion Time Projection Chamber. The improved detection abilities should help to clarify the information which has come from the first survey of collisions between high energy nuclei.

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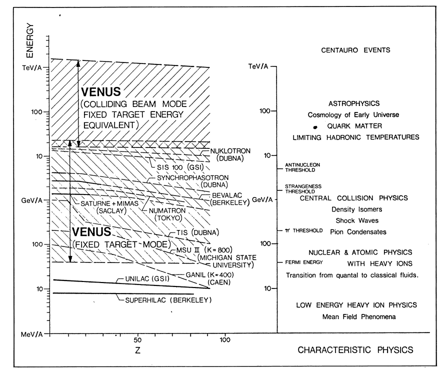

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W.A. Zajc

Addressing the nature of QGP discovery

- From the PHENIX "White Paper"
- nucl-ex/0410003
- (1958 citations)

Q: What is the most relevant *"experimentally observed property"*?

A. *Viscosity*
(suitably normalized)

so that concepts such as temperature, chemical potential and flow velocity apply and the system can be characterized by an experimentally determined equation of state. Additionally, experiments eventually should be able to determine the physical characteristics of the transition, for example the critical temperature, the order of the phase transition, and the speed of sound along with the nature of the underlying quasi-particles. While at (currently unobtainable) very high temperatures $T \gg T_c$ the quark-gluon plasma may act as a weakly interacting gas of quarks and gluons, in the transition region near T_c the fundamental degrees of freedom may be considerably more complex. It is therefore appropriate to argue that the quark-gluon plasma must be defined in terms of its unique properties *at a given temperature*. To date the definition is provided by lattice QCD calculations. Ultimately we would expect to validate this by characterizing the quark-gluon plasma in terms of its experimentally observed properties. However, the real discoveries will be of the fascinating properties of high temperature nuclear matter, and not the naming of that matter.

1.2 Experimental Program

The theoretical discussion of the nature of hadronic matter at extreme densities has been greatly stimulated by the realization that such conditions could be studied via relativistic heavy ion collisions [32]. Early investigations at the Berkeley Bevalac (c. 1975–1985), the BNL AGS (c. 1987–1995) and the CERN SPS (c. 1987–present) have reached their culmination with the commissioning of BNL's Relativistic Heavy Ion Collider (RHIC), a dedicated facility for the study of nuclear collisions at ultra-relativistic energies [33].