PHENIX in 10 Minutes

presented at the

2026 RHIC/AGS Annual Users' Meeting
Brookhaven National Laboratory

May 14th, 2026

W.A. Zajc
Columbia University

Profound thanks to all my PHENIX Collaborators!

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

The Birth of "PHENIX"

BROOKHAVEN NATIONAL LABORATORY
ASSOCIATED UNIVERSITIES, INC.

Upton, Long Island, New York 11973

(516) 282-
FTS 666- 7711

Office of the Director

September 9, 1991

Prof. P. Braun-Munzinger
Department of Physics
SUNY-Stony Brook
Stony Brook, NY 11794-3800

Prof. S. Nagamiya
Department of Physics
Columbia University
538 West 120th Street
New York, NY 10027

Dr. G. Young
MS 373
Oak Ridge National Laboratory
P.O. Box X, Bldg. 6003
Oak Ridge, TN 37830

Dear Peter, Shoji and Glenn:

This is to confirm the discussion we had on Tuesday, September 3, 1991 regarding the decisions made by the Program Advisory Committee with respect to your RHIC Letters of Intent.

1. The Committee decided to reject all three of the Letters of Intent because of what were felt to be major deficiencies in each of them.

2. The Committee decided to place the emphasis on a detector designed to study electrons and photons emerging from the QGP. In this regard, it will address some of the basic physics interests of each of your groups.

3. The Laboratory has appointed Sam Aronson as Spokesman and Project Director with the charge of developing a new collaboration to design and build such a detector. We strongly urge each of you and your current respective collaborators to join in this effort. Those of you who are primarily interested in hadron physics will be welcomed by the STAR collaboration which has been empowered to build a large TPC detector.

4. The Laboratory is prepared to contribute at most $30 million to the design and construction of this detector. Hopefully, you can find resources outside of the Laboratory to augment this sum.

5. It is hoped that the new collaboration can present a conceptual design to the Technical Advisory Committee in mid December. Sam Aronson will have final authority as to the technical and scientific content of the proposal. He is in the process of forming an advisory committee composed primarily of the leadership of the three former collaborations to assist in the conceptual design.

Although I realize that each of you is very disappointed, I hope that you will find it possible to become a part of this effort. We need all of you in order to maximize our probability of success.

Sincerely,

Mel Schwartz
Associate Director
High Energy and Nuclear Physics

MS:laz
cc: HENP PAC Membership

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- RIP:
  - Dimuon
  - TALES/SPARC
  - OASIS
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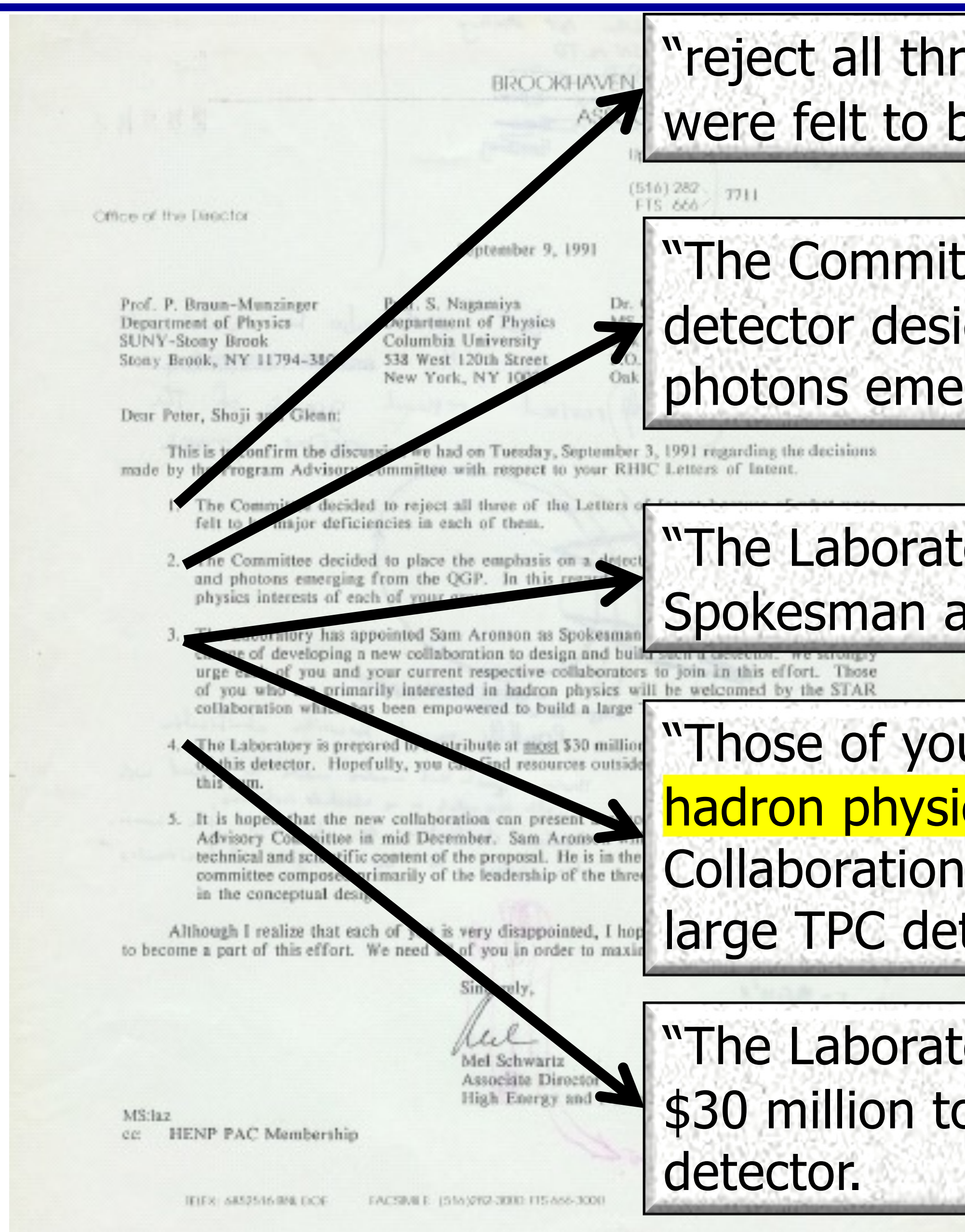
  - RE2
  - "RHIC Experiment 2"

The Birth of PHENIX


BROOKHAVEN
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(516) 282 7711
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Dr.
Oak

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"The Laboratory is prepared to contribute at <u>most</u> $30 million to the design and construction of this detector.

A Long Interregnum…

- Dominated by the struggles you can easily imagine that follow from forced marriage of three major experiments…

- Most significant event: Profoundly wise decision by Sam Aronson to separate Project Director and Spokesperson ➔ *Shoji Nagamiya*

大先生

PHENIX Is Born

BROOKHAVEN BULLETIN
Vol. 48 - No. 11 March 18, 1994
BROOKHAVEN NATIONAL LABORATORY

The PHENIX Has Risen: Second Major RHIC Experiment Approved

Following a successful two-day review of the cost and schedule proposed for the Pioneering High Energy Nuclear Interaction Experiment, the detector known for short as PHENIX was approved on March 10 as the second major experiment for BNL's Relativistic Heavy Ion Collider (RHIC).

In the search for quark-gluon plasma at RHIC, PHENIX will be competing with STAR, which is short for the Solenoidal Tracker at RHIC and which was approved in January 1993. Despite nearly a year's lead time for STAR, both detectors are expected to be ready to "do RHIC physics on the day the machine turns on in 1999," says Thomas Ludlam, RHIC Associate Head for Detectors & Experiments.

"By the nature of the physics we will be investigating, our detector is very complex, but we now understand how to build it within budget and on time," comments Shoji Nagamiya, PHENIX Spokesman and a professor of physics at Columbia University.

In giving its approval to PHENIX, "The Technical Advisory Committee [TAC] was quite satisfied that all the budget, scheduling and management questions that were raised last November have been answered," continues Ludlam, who convenes this committee. "This review has allowed us to get the most physics for our dollar, and, in the process, the physics has been strengthened."

After PHENIX's conceptual design report was approved last February by the RHIC Program Advisory Commit-

Within the 8 o'clock experimental hall in which the second major RHIC detecter will be housed, the PHENIX management surveys the plans for the Pioneering High Energy Nuclear Interaction Experiment: from left Walter Kehoe, Assistant to the Project Manager, RHIC; Shoji Nagamiya, PHENIX Spokesman, Columbia University; Glenn Young, Deputy Project Director, Oak Ridge National Laboratory; Sam Aronson, Project Director, Physics Department; and Leo Paffrath, Project Engineer, RHIC. They report to the PHENIX Detector Council, which is made up of 12 heads of the detector's major subsystems, which is chaired by Aronson and meets every month or two. In addition, the entire collaboration gathers twice a year to review its progress, with the next meeting scheduled for this August at BNL.

Photos in this issue by Roger Stoutenburgh

ule estimate to Ludlam's TAC last November. At that time, however, the committee gave the experimenters five more months to reduce the cost of their detector by $4.5 million.

"Instead of turning off any of the major subsystems, we tightened everything, especially the electronics and data-acquisition system," comments Sam Aronson, PHENIX Project Director, Physics Department. "While we won't be able to install as much of the detector as we had initially hoped, we will still be able to handle all the physics that RHIC can deliver from day one until the machine reaches its design intensity. To go beyond that, as is expected, we will have to find some additional funds to install the deferred components."

While some $36.7 million is now available from RHIC construction funds to build PHENIX, the actual cost of the detector is approximately $70 million. To cover the other half of the bill, PHENIX management enlisted collaborators from Japan, Russia, Germany and elsewhere in the U.S., who are contributing money, building components at discounted prices, and/or bringing already constructed parts from other experiments. Invitations to join PHENIX are being discussed with other Europeans and Japanese

(continued on page 2)

Coming Up

Chemist F. Sherwood Rowland, of the University of California, Irvine, will give an AUI Distinguished Lecture on Tuesday, March 29. His talk on "The Depletion of Stratospheric Ozone by Chlorofluorocarbons" will be held at 4:30 p.m. in Berkner Hall.

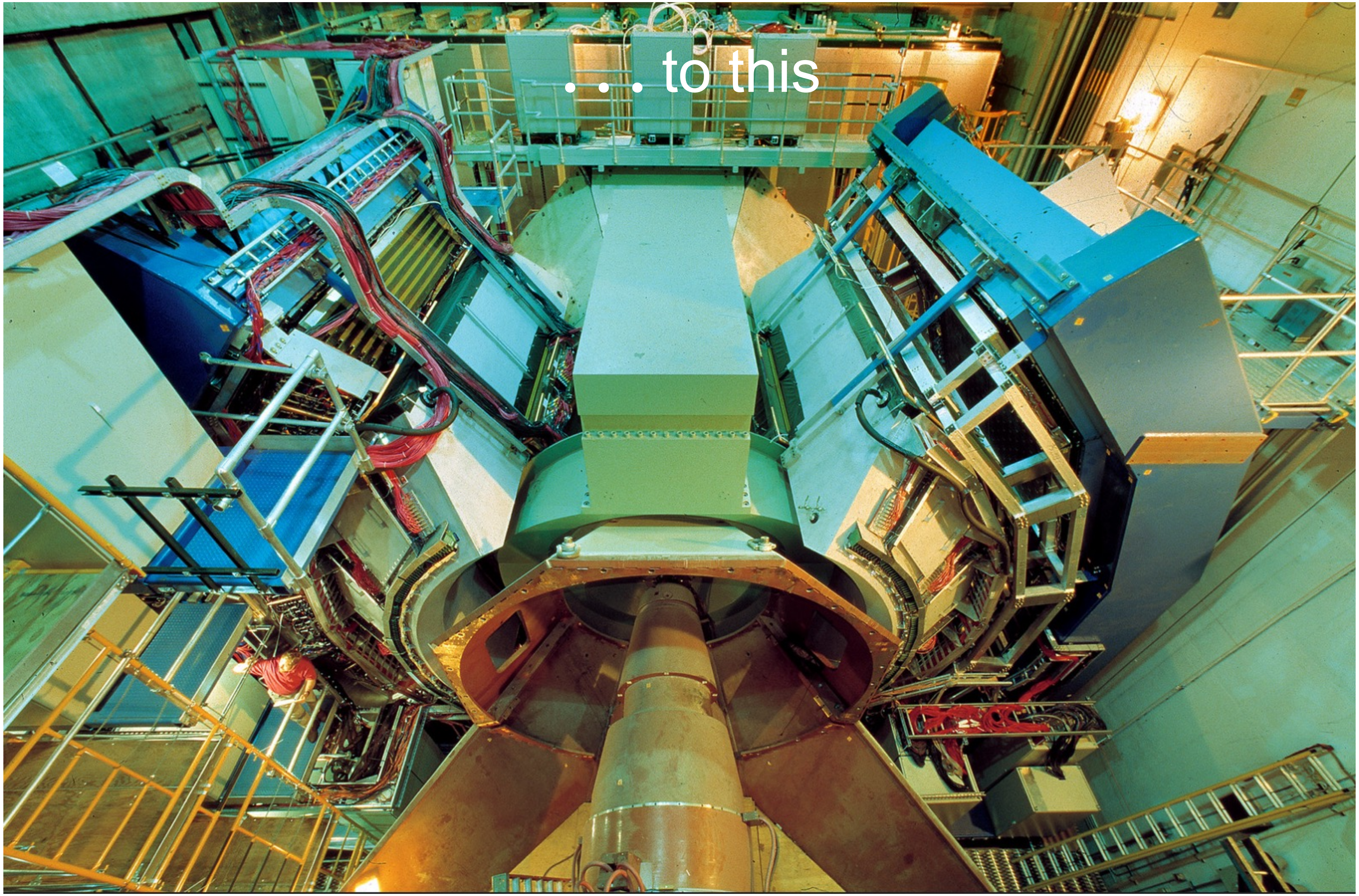
Tenure for Three Brookhaven Researchers

PHENIX: 10-Mar-94
(STAR: Jan-93)

Despite nearly (sic) a year's lead time for STAR, both detectors are expected to be ready to "do RHIC physics on the day the machine turns on in 1999".

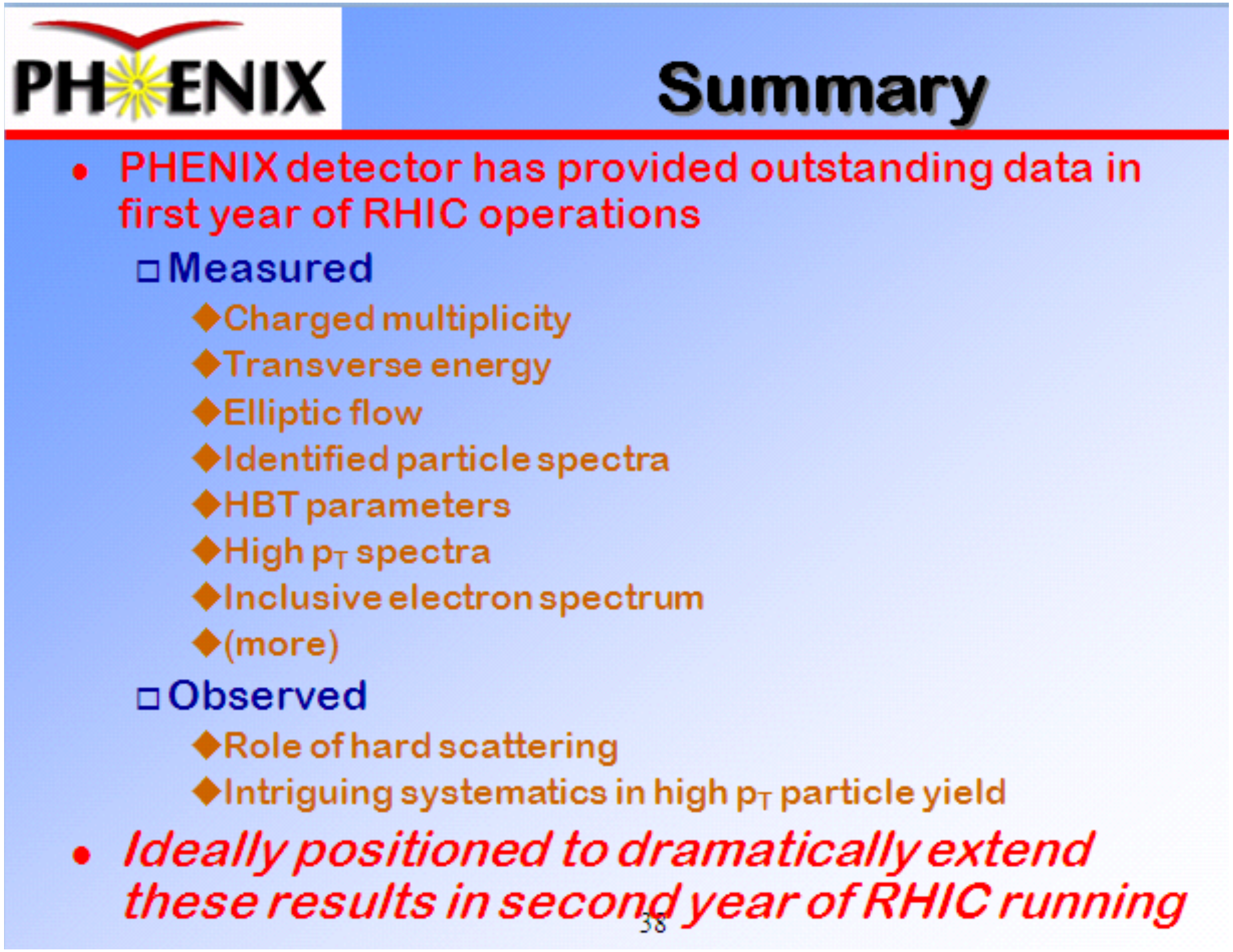
(To reduce costs) "Instead of turning off any of the major subsystems, we tightened everything, especially the electronics and data acquisition system".

A very fraught process transforming this . . .


. . . to this

First Event, June 15th, 2000 !

PHENIX Data Debut at QM01

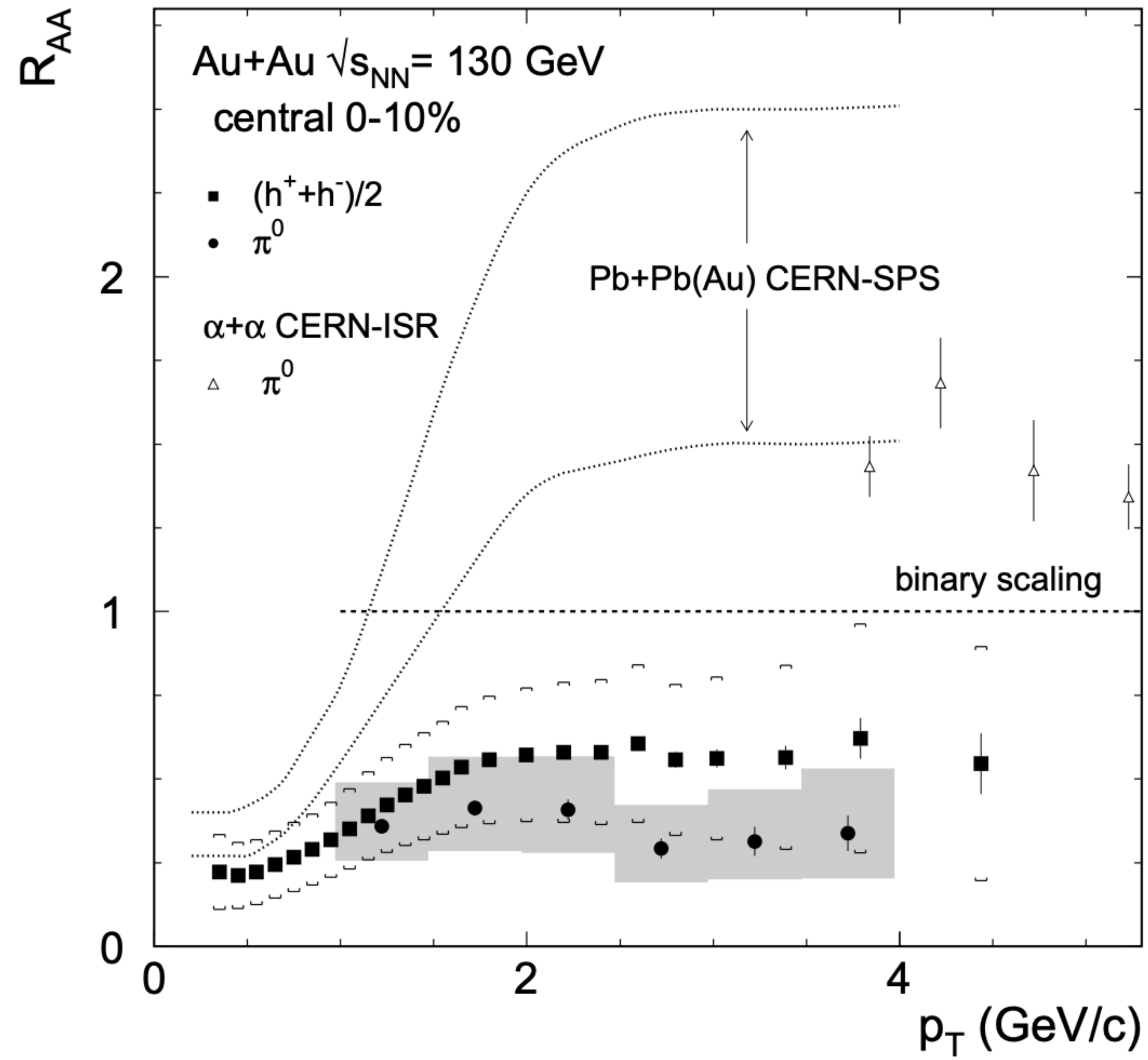


Result from Various PHENIX Generations


PHENIX
OVER ONE BILLION SERVED

2002: First Result on "Jet" Suppression

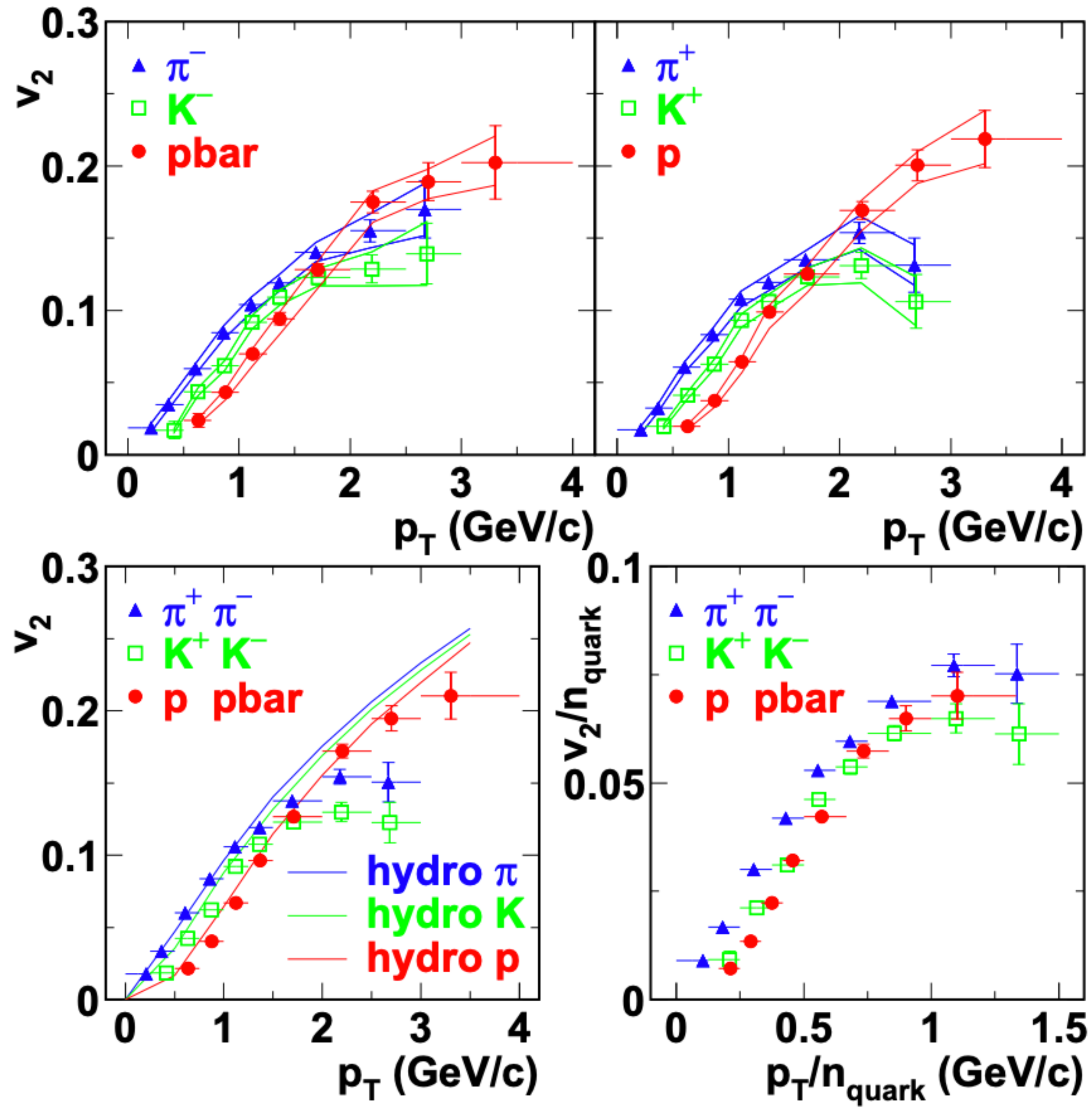
Suppression of hadrons with large transverse momentum in central Au+Au collisions at $\sqrt{s_{NN}} = 130$ *GeV*,
PHENIX Collaboration
K. Adcox *et al.*, Phys.Rev.Lett. **88** (2002) 022301
e-Print: nucl-ex/0109003 [nucl-ex]



2003: First Look at Quark Recombination Effects

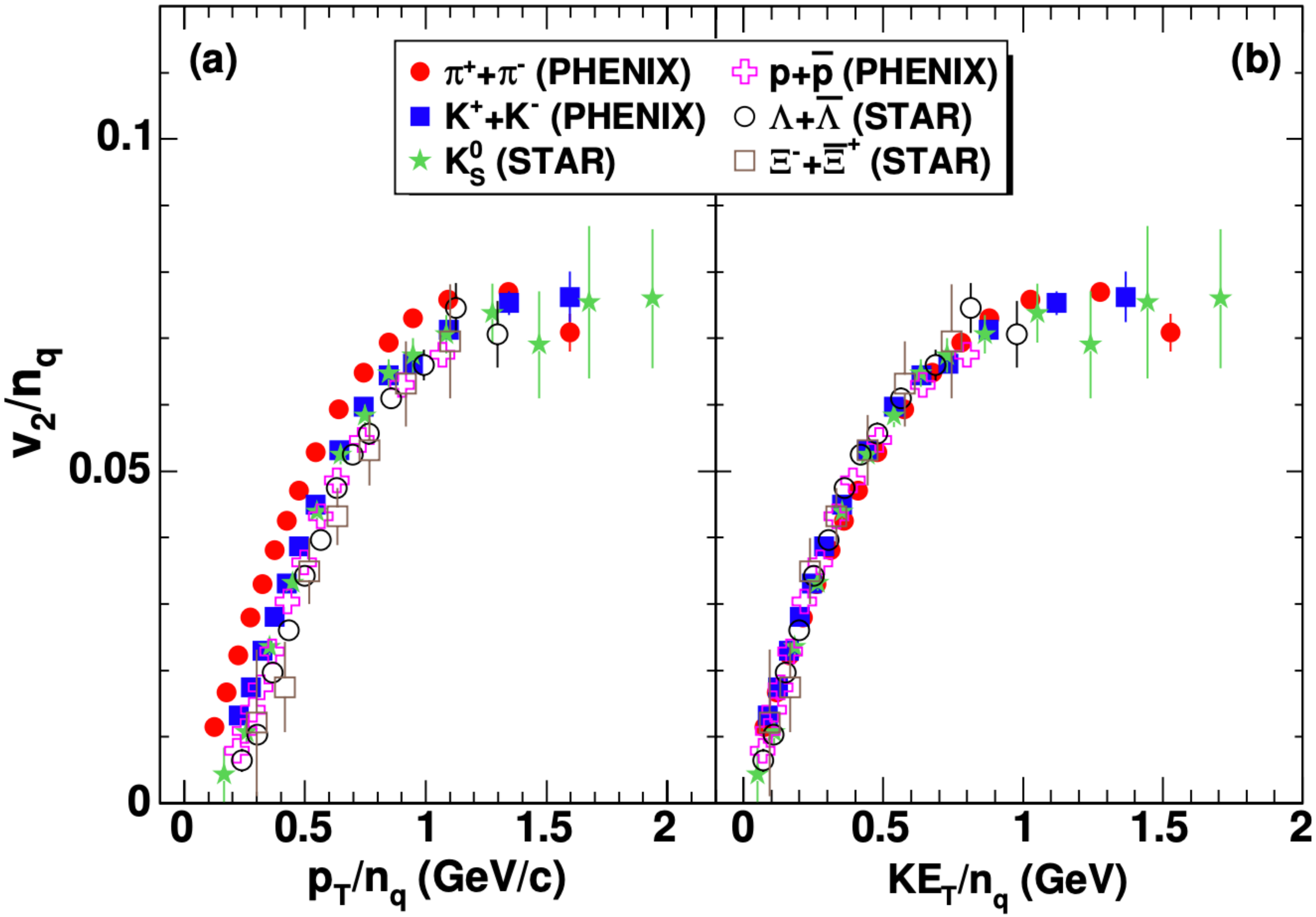
Elliptic flow of identified hadrons in Au+Au collisions at $\sqrt{s_{NN}}$ *= 200 GeV*,
PHENIX Collaboration
S.S. Adler *et al*., Phys.Rev.Lett. **81** (2003) 182301
e-Print: nucl-ex/0305013 [nucl-ex]

"Finally, our scenario requires the assumption of a thermalized partonic phase characterized by an exponential momentum spectrum. Such a phase may be appropriately called a quark-gluon plasma."
Hadronization in heavy ion collisions: Recombination and fragmentation of partons,
R. Fries *et al*., Phys.Rev.Lett. 90 (2003) 202303
e-Print: nucl-th/0301087 [nucl-th]



2007: Second Look at Quark Recombination Effects

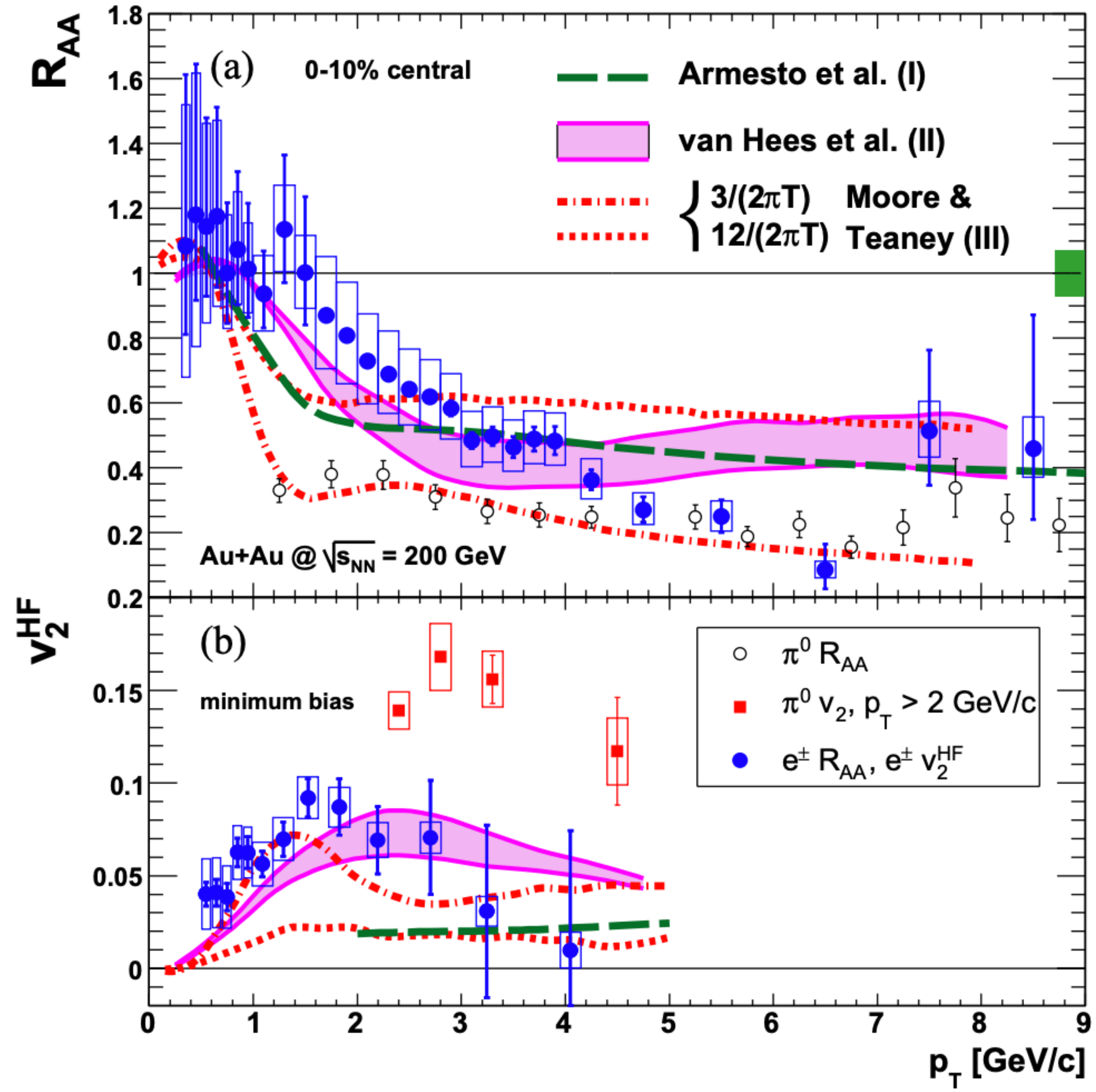
Scaling properties of azimuthal anisotropy in Au+Au and Cu+Cu collisions at $\sqrt{s_{NN}}$ = 200 GeV,
PHENIX Collaboration
S.S. Adler *et al.*,
Phys.Rev.Lett. **98** (2007) 162301
e-Print: nucl-ex/0608033 [nucl-ex]



2007: First Look at Heavy Quarks and η/s

" . . . provides an estimate for the viscosity to entropy ratio $\eta/s \approx (4/3 - 2)/4\pi$, intriguingly close to the conjectured quantum lower bound *$1/4\pi$."*

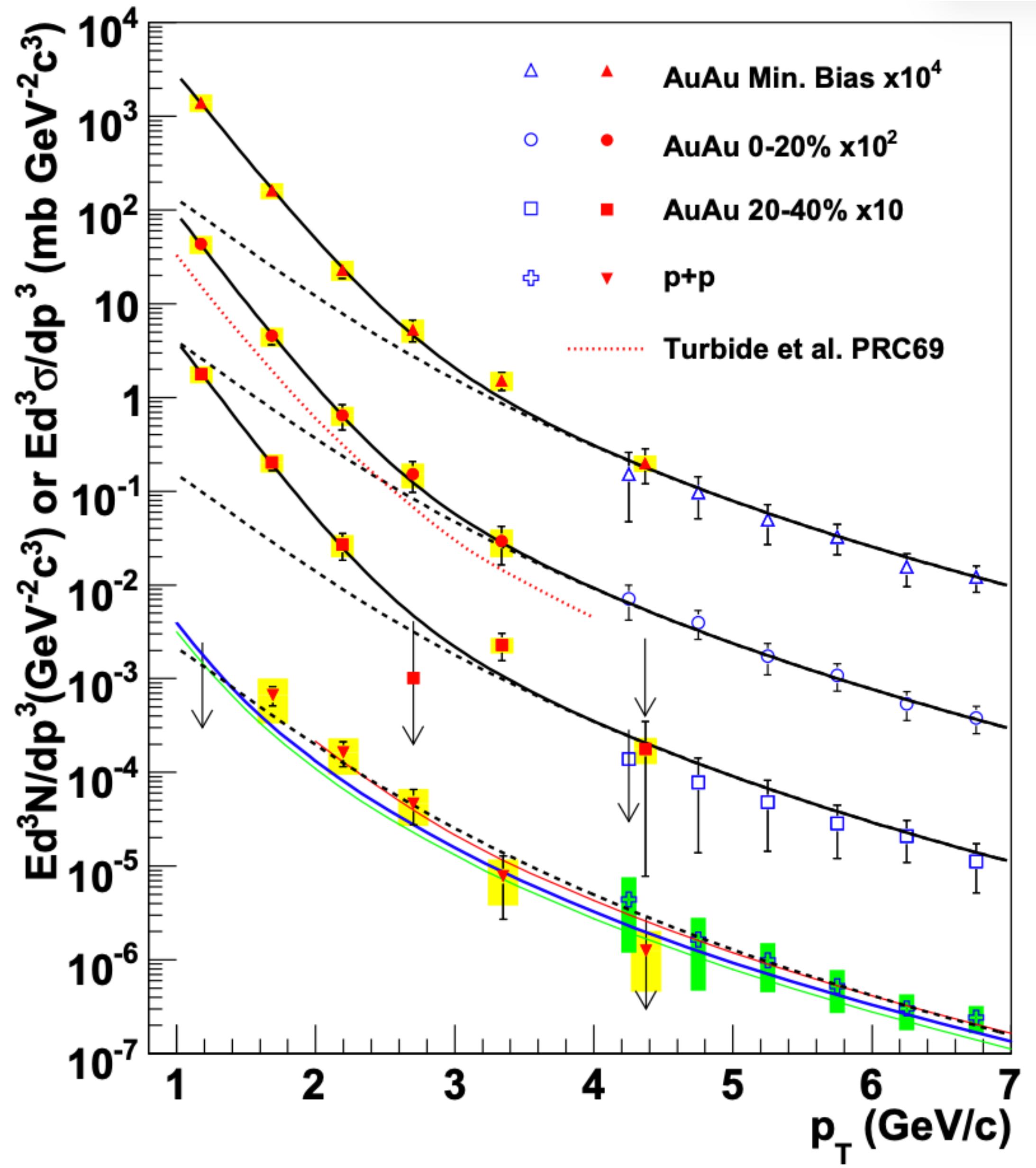
Energy Loss and Flow of Heavy Quarks in Au+Au Collisions at $\sqrt{s_{NN}} = 200$ GeV,
PHENIX Collaboration
S.S. Adler *et al.*, Phys.Rev.Lett. **98** (2007) 172301
e-Print: nucl-ex/0611018 [nucl-ex]



2010: First Measurement of QGP Temperature via Photons

"Hydrodynamical models with T_{init} *~300–600 MeV at* τ_0 *~0.6–0.15 fm/c* are in qualitative agreement with the data. Lattice QCD predicts a phase transition from hadronic phase to quark gluon plasma at *~170 MeV.*"

Enhanced production of direct photons in Au+Au collisions at $\sqrt{s_{NN}}$ *= 200 GeV, and implications for initial temperature,*
PHENIX Collaboration
S.S. Adler *et al.*, Phys.Rev.Lett. **104** (2010) 132301
e-Print: e-Print: 0804.4168 [nucl-ex]



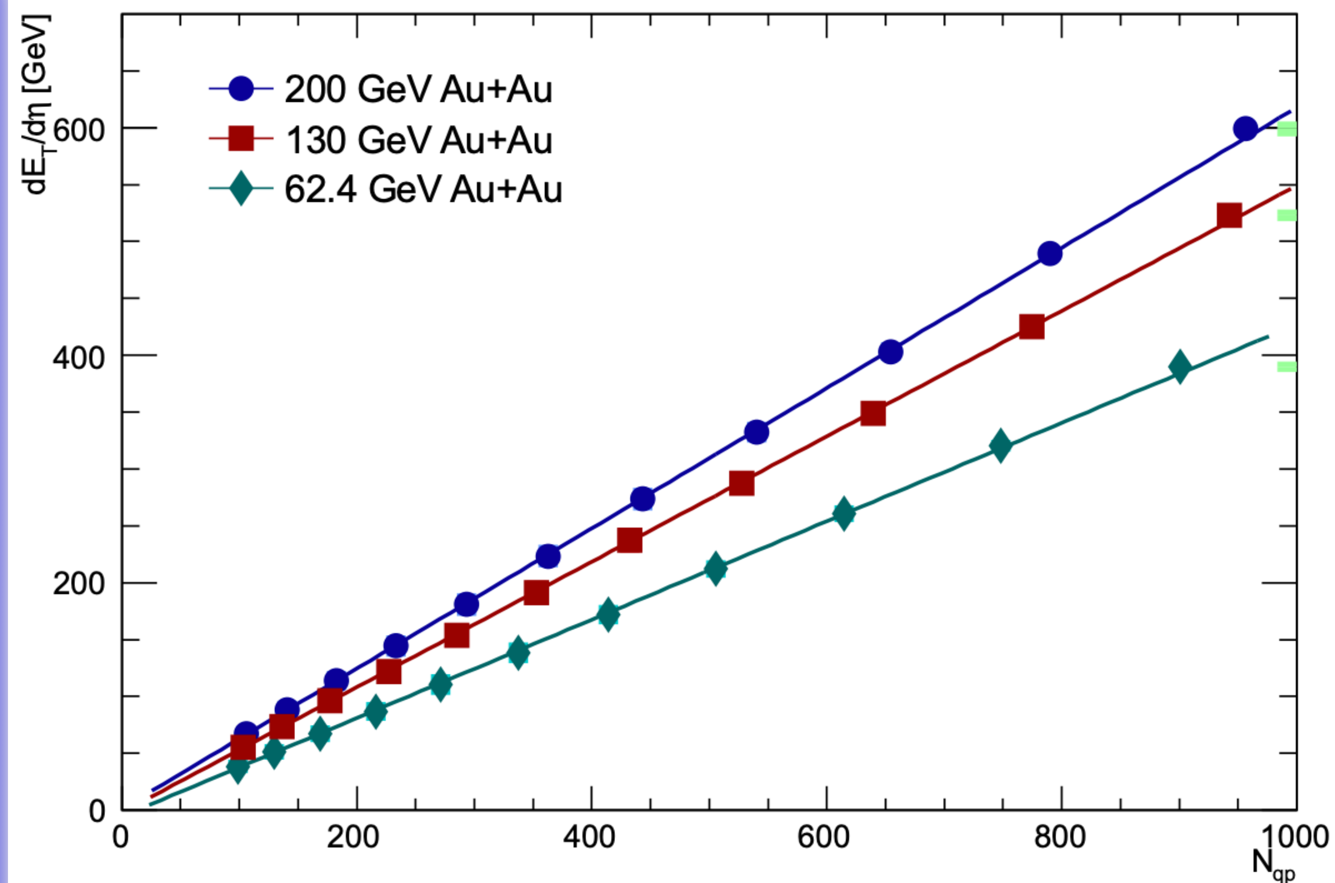
2014: A Hidden Discovery – Quark-Participant Scaling

"This result demonstrates that rather than implying a hard scattering component in N_{ch} and E_T distributions,

Eq. 6 $dE_T{}^{AA}/d\eta = (dE_T{}^{pp}/d\eta)\ [(1-x)\langle N_{part}\rangle/2 + x\langle N_{coll}\rangle]$

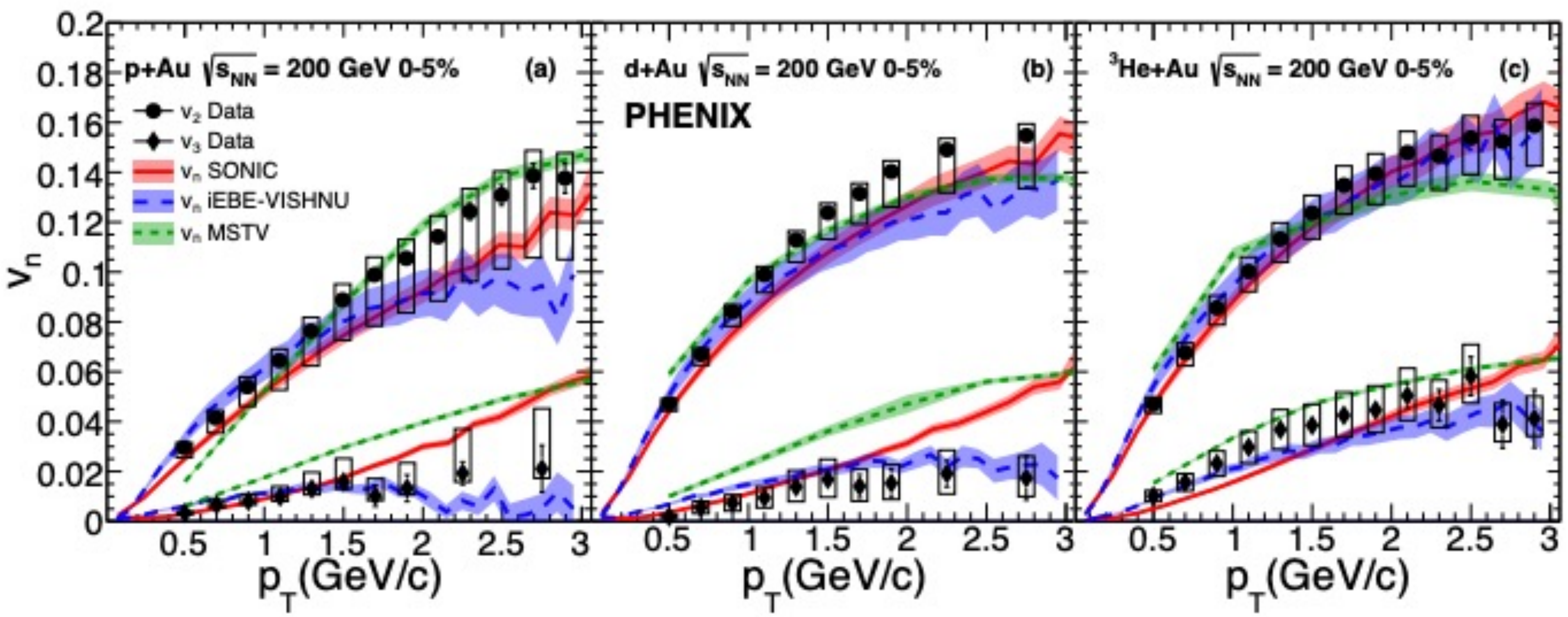
is instead a proxy for the number of constituent-quark participants Nqp as a function of centrality"

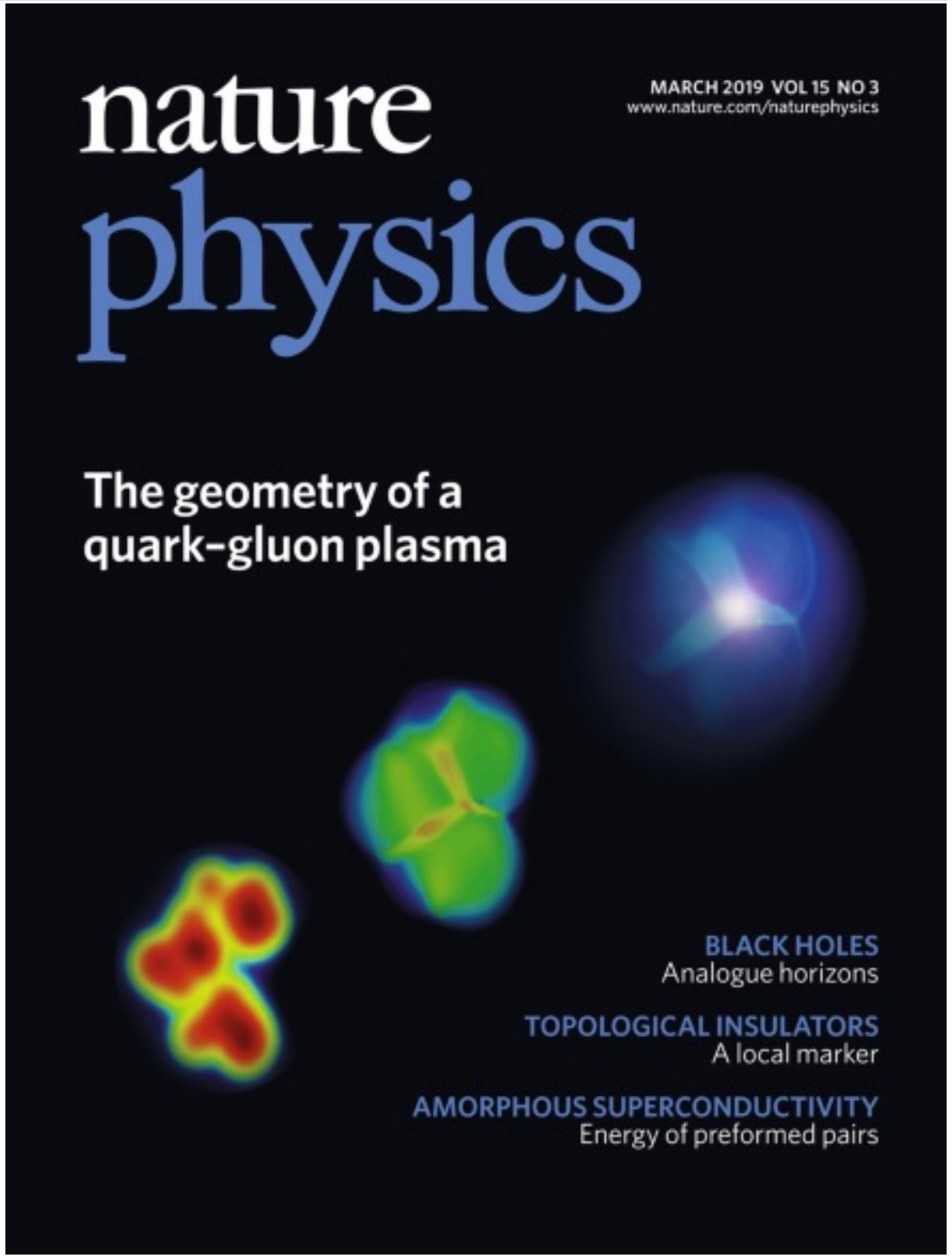
Transverse-energy distributions at midrapidity in p+p, d+Au, and Au+Au collisions at $\sqrt{s_{NN}}$ *= 62.4-200 GeV and implications for particle production models,*
PHENIX Collaboration
S.S. Adler *et al.*, Phys. Rev. **C89** (2014) 044905 e-Print: e-Print: 1312.6676 [nucl-ex]



2019: First Examination of Initial Collision Shapes

Creation of quark–gluon plasma droplets with three distinct geometries,
PHENIX Collaboration
C. Aidala *et al.*, Nature Phys. **15** (2019) 214,
e-Print: e-Print: 1805.02973 [nucl-ex]





A Unique Bit of PHENIX History

- *Every* one of PHENIX's nearly 300 publications has been handled by *one* person:
- Brant Johnson,
  PHENIX Scientific Correspondent
  to the journals

- I am *very* overdue
  in publicly acknowledging
  Brant's untiring and impeccable work
  on behalf of PHENIX.

RHIC Discoveries in Perspective

- From QCD Made Simple (F. Wilczek, August, 2000 *Physics Today*):
- . . . we invoke a procedure that is often useful in theoretical physics. . .The stratagem tells you to make clear-cut simplifying assumptions, work out their consequences, and check to see that you don't run into contradictions. In this spirit we tentatively assume that we can describe high-temperature QCD starting with *free quarks and gluons*.
- But there is a second, more rigorous level that remains a challenge for the future. Using fundamental aspects of QCD theory, similar to those I discussed in connection with jets, one can make quantitative predictions for the emission of various kinds of "hard" radiation from a quark-gluon plasma. We will not have done justice to the concept of *a weakly interacting plasma of quarks and gluons* until some of these predictions are confirmed by experiment.

RHIC Discoveries in Perspective

- RHIC's data produced a *paradigm shift* in our understanding of the quark-gluon plasma.

- Nothing could be further from the truth than the old model of QGP as a state where quarks "are liberated to roam freely".

- Rather, for thermal QCD, asymptotic freedom is relevant only asymptotically (!)

- Instead – the quark-gluon plasma is the most strongly-coupled liquid ever produced, quantified in the very low value of η/s .

- This will be (is) the textbook legacy of RHIC.

Back-up Material

W.A. Zajc
Physics Department
Columbia University, New York, NY

Thanks to all my PHENIX Collaborators and other colleagues at RHIC

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

RHIC Discoveries in Perspective

- From QCD Made Simple (F. Wilczek, August, 2000 *Physics Today*):
- . . . we invoke a procedure that is often useful in theoretical physics. I call it the Jesuit Stratagem, inspired by what I'm told is a credal tenet of the Order: "It is more blessed to ask forgiveness than permission." The stratagem tells you to make clear-cut simplifying assumptions, work out their consequences, and check to see that you don't run into contradictions. In this spirit we tentatively assume that we can describe high-temperature QCD starting with *free quarks and gluons*.
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Current Perspective

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

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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.

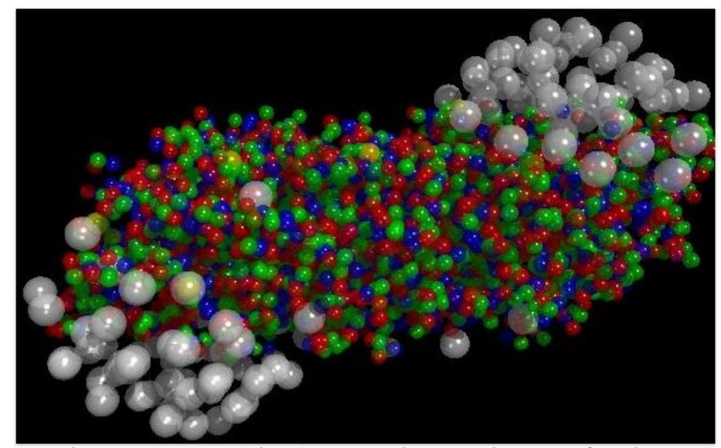
New State of Matter created at ...
home.cern/news/pre...

ABOUT NEWS SCIENCE RESOURCES SEARCH | EN

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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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

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

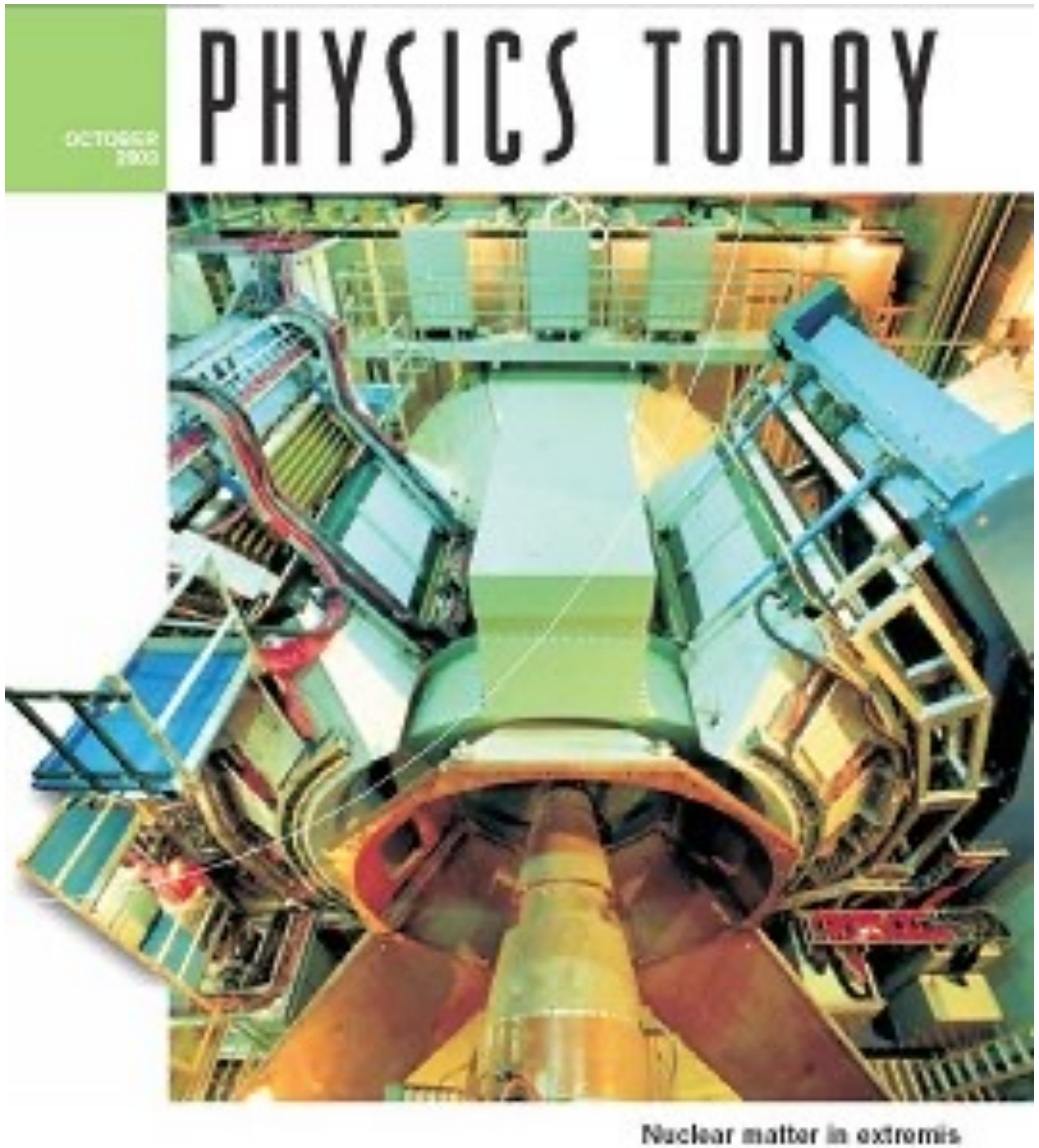
The theoretical discussion of the nature of hadronic matter at extreme densities has been greatly stimulated by the realization that such conditions could be studied via relativistic heavy ion collisions [32]. Early investigations at the Berkeley Bevalac (c. 1975–1985), the BNL AGS (c. 1987–1995) and 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].

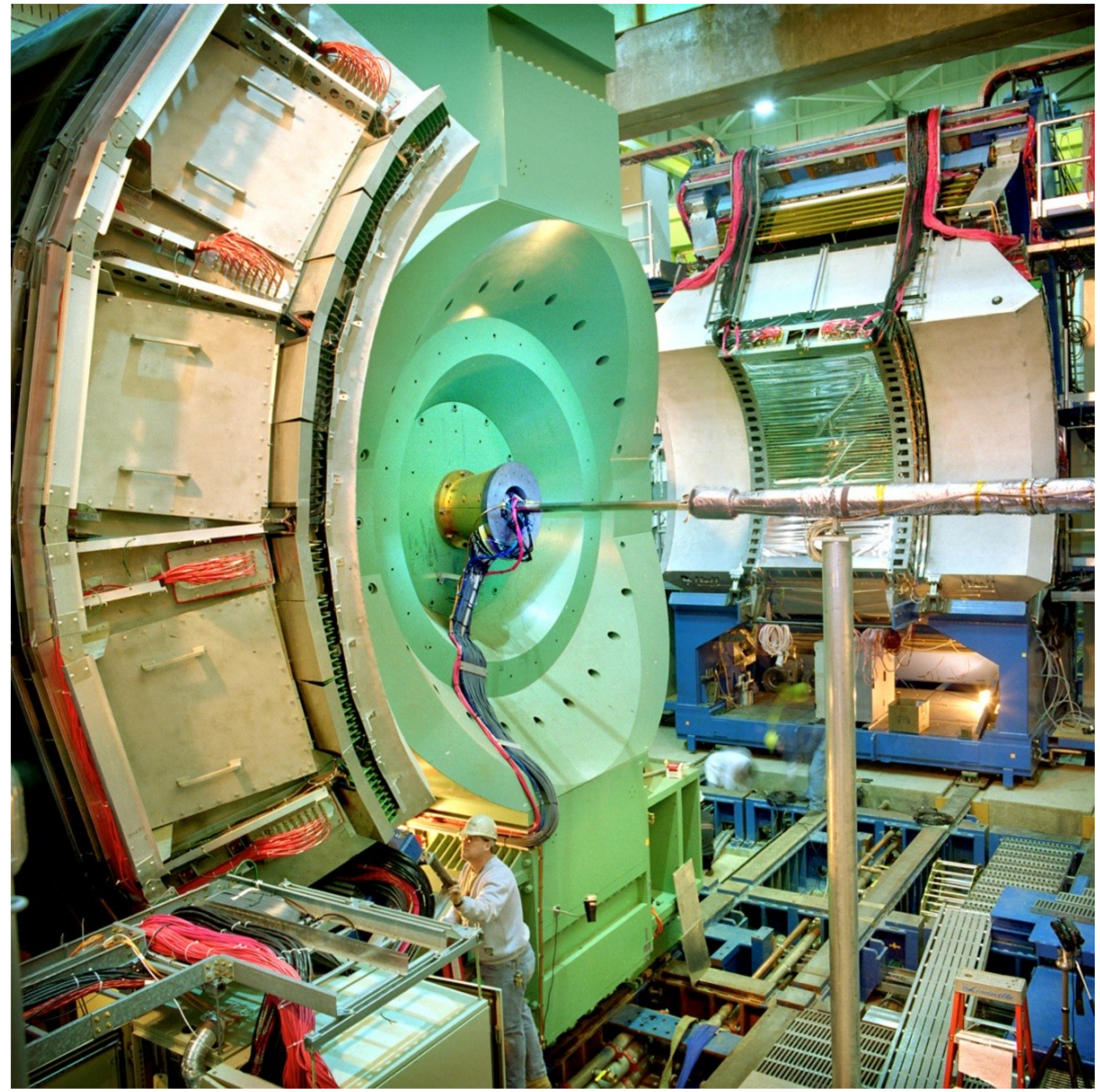
PHENIX (well, me) Bragging at QM01

PHENIX

Summary

- PHENIX detector has provided outstanding data in first year of RHIC operations
  - Measured
    - Charged multiplicity
    - Transverse energy
    - Elliptic flow
    - Identified particle spectra
    - HBT parameters
    - High p_T spectra
    - Inclusive electron spectrum
    - (more)
  - Observed
    - Role of hard scattering
    - Intriguing systematics in high p_T particle yield
- *Ideally positioned to dramatically extend these results in second year of RHIC running*


PHYSICS TODAY
OCTOBER
Nuclear matter in extremis



- 26-Jul-02: BNL Institutional Plan site visit: Undersecretary, Director of Office of Science unconvinced RHIC had done anything interesting
- RHIC Program Review by the Nuclear Physics Division of the U.S. Department of Energy
- Brookhaven National Laboratory,
  July 31 – August 2, 2002
- *Will you guarantee RHIC-I will discover QGP* ?

PHENIX (Mandated) Minimalism