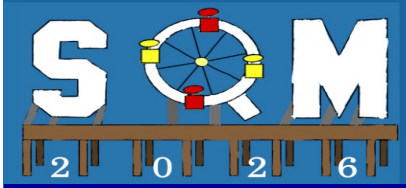


Early Days of the PHENIX Experiment and the Journey of RHIC Discoveries

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

Thanks to all my PHENIX Collaborators and other colleagues at RHIC

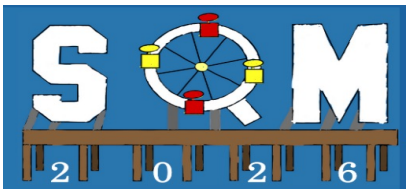
**This work was supported by the United States
Department of Energy Grant DOE-FG02-86ER-40281**



Overview

2

- The emphasis will be on truly early days
- More history than science
- Mostly pictures
- It's all about PHENIX ... 😊



In the beginning ...

3

- 1990: Workshop over July 4th holiday at BNL
- Converged (?) to 7 working groups on various detector proposals

Bulletin
Brookhaven National Laboratory
Volume I, Number 3
July 1990

Workshop on Experiments and Detectors for RHIC: Issues and Ideas Amid July 4 Fireworks

The fourth workshop on experiments and detectors for RHIC was held at Brookhaven during the first week of July. Beginning on Monday and winding up at noon on Saturday. A gathering of nearly 200 soon-to-be users of the RHIC facility assembled for an intensive week of discussions and working groups focussed on the preparation of letters of intent for experiments at RHIC. As announced in the April edition of the RHIC Bulletin, these Letters are due September 28, 1990, and are the first step in a sequence of events which will lead to the first round of experiments for the collider.

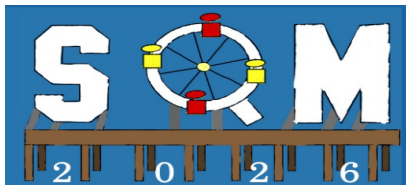
At the core of this summer's workshop was the activity of seven working groups, each developing its concept for a RHIC detector. In concert with this activity, the workshop participants also addressed a number of issues related to the implementation of an experimental program at RHIC. Among these issues, the major topics of discussion were related to the detailed configuration of the collision regions at RHIC, including the existing experimental halls and machine questions such as possible luminosity upgrades, and the plans for detector R&D.

The meeting took place amid local celebrations of the Independence Day holiday, and fireworks lit the skies in surrounding communities as the workshop participants toiled into the night. Although the week of

(Continued on page 2)

Photos by Roger Stontenburgh

Making their points at the RHIC workshop: clockwise from top . . . Bob Ledoux, MIT; Wit Busza, MIT; Satoshi Ozaki, RHIC Project Head; Shoji Nagamiya, Columbia University; John Harris, Lawrence Berkeley Laboratory.



In the beginning ...

4



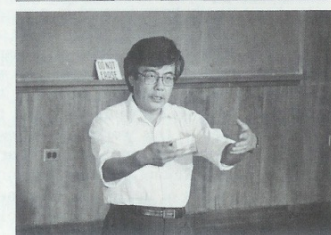
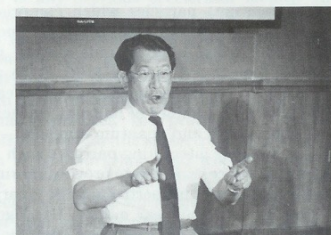
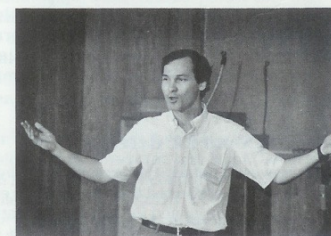
Workshop on Experiments and Detectors for RHIC: Work and Ideas July 4 Fireworks

A workshop on experiments and detectors for RHIC was held during the first week of July. Beginning on Monday and ending at noon on Saturday. A gathering of nearly 200 soon-to-be RHIC facility assembled for an intensive week of discussions. Groups focussed on the preparation of letters of intent for RHIC. As announced in the April edition of the RHIC e Letters are due September 28, 1990, and are the first in a sequence of events which will lead to the first round of construction for the collider.

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(Continued on page 2)



Photos by Roger Stoneman

Participants at the RHIC workshop: clockwise from top ... Bob Ledoux, MIT; Satoshi Ozaki, RHIC Project Head; Shoji Nagamiya, University of California; John Harris, Lawrence Berkeley Laboratory.

Proposals for Detector R&D: Timetable and Procedures

As announced at this summer's workshop, it is intended that there will be a shift in emphasis of the RHIC detector R&D program from its initial rather generic scope to an effort more closely related to specific RHIC experiments. To this end, it was decided that the major commitment of funds for the coming year (fiscal year 1991, which begins October 1, 1990) would be made after the letters of intent have been received and evaluated.

The deadline for submission of Letters of Intent to be considered at the November meeting of the Program Advisory Committee is **SEPTEMBER 28, 1990**. Proposals for detector R&D should be submitted by this date as well.

In order to ensure continuity of work in progress, decisions regarding interim funding of the on-going R&D projects were made following the July 3 meeting of the Detector Advisory Committee. In most cases these decisions involved relatively small commitments of funds, with the expectation that a new proposal would be submitted in September detailing the specific relevance of the proposed work to a particular RHIC detector concept.

The guidelines for submission of letters of intent (RHIC Bulletin, April 1990) include an Appendix of up to five pages for discussion of R&D requests. This is not meant to take the place of separately submitted R&D proposals. The discussion in the letters of intent should give an overview of the associated R&D needs. If there are several R&D proposals associated with a letter of intent, this overview discussion should indicate priorities.

Proposals for Detector R&D submitted by the September 28 deadline will be evaluated by the Detector Advisory Committee, whose recommendations will be input to the Program Advisory Committee, when it meets November 8-10, 1990 to consider letters of intent. Decisions on R&D funding will be announced shortly after the PAC meeting.

Guidelines: The detector R&D proposals should contain the following information:

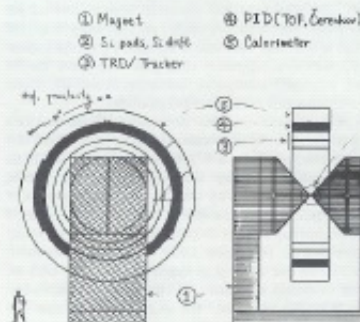
1. How is the proposed work related to RHIC?
 - What measurement problem is being addressed?
 - Suitability for the RHIC environment
 - Is it generic?
 - If not, what proposed detector does it fit into?
2. Organization of the proposed work
 - Goals
 - Milestones: timetable of expected results and key decision points
 - Outline of long-term goals (beyond 1991) if appropriate.
 - Detailed budget requests.
 - Names and time fractions of people doing the work
 - Indicate specific tasks if possible.
3. Other information
 - Test beam resources required, if any.
 - Is this work coupled with other efforts of the group (e.g. an on-going experiment, SSC R&D...)?

The detector R&D proposals should be submitted to: Thomas W. Ludlum
RHIC Office, Bldg. 1005S-4
Brookhaven National Laboratory
Upton, New York 11973

Sketches from the Workshop: 3 New Detector Concepts



Left, large acceptance detector for charged particles and jets, with a solenoidal magnet. Right, toroidal magnet spectrometer for large transverse momentum photons, charged particles and jets.



An "open focussing spectrometer", with axial field magnet.

Our Collective DNA

Proposals for Detector R&D Timetable and Procedures

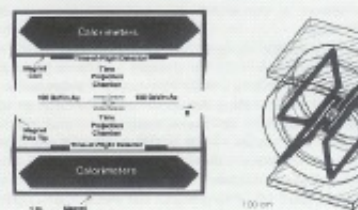
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Sketches from the Workshop: 3 New Detector Concepts

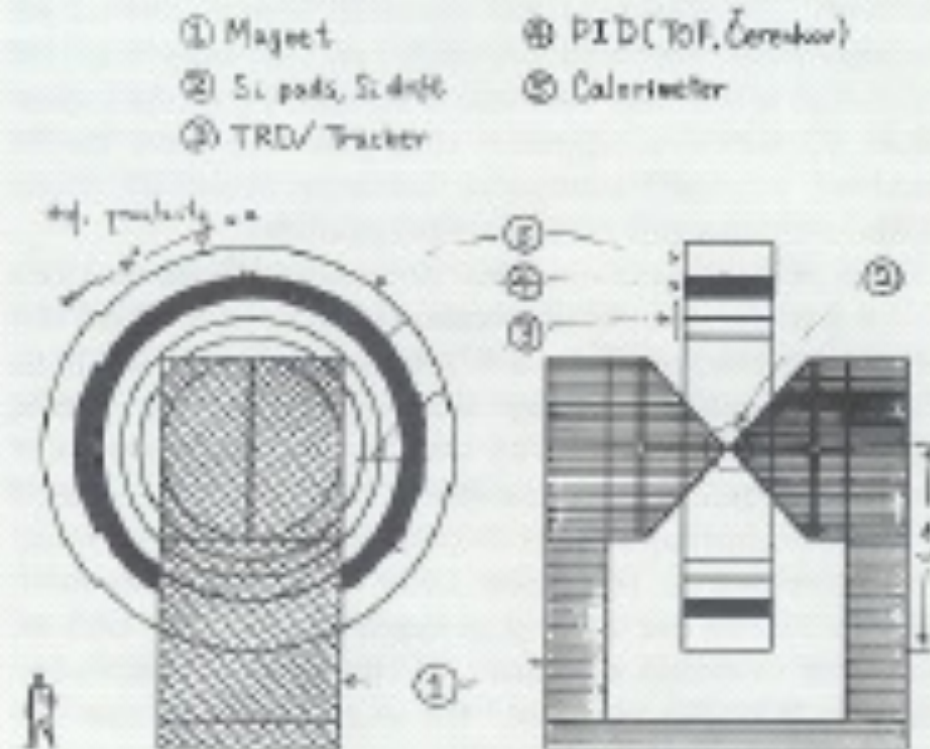


Left, large-acceptance detector for charged particles and jets, with a solenoidal magnet. Right, toroidal magnet spectrometer for large transverse momentum photons, charged particles and jets.

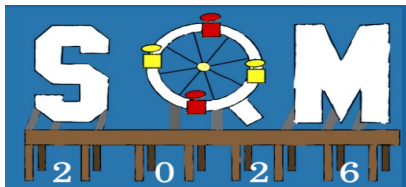
Sketches from the Workshop: 3 New Detector Concepts



Left, large-acceptance detector for charged particles and jets, with a solenoidal magnet. Right, toroidal magnet spectrometer for large transverse momentum photons, charged particles and jets.

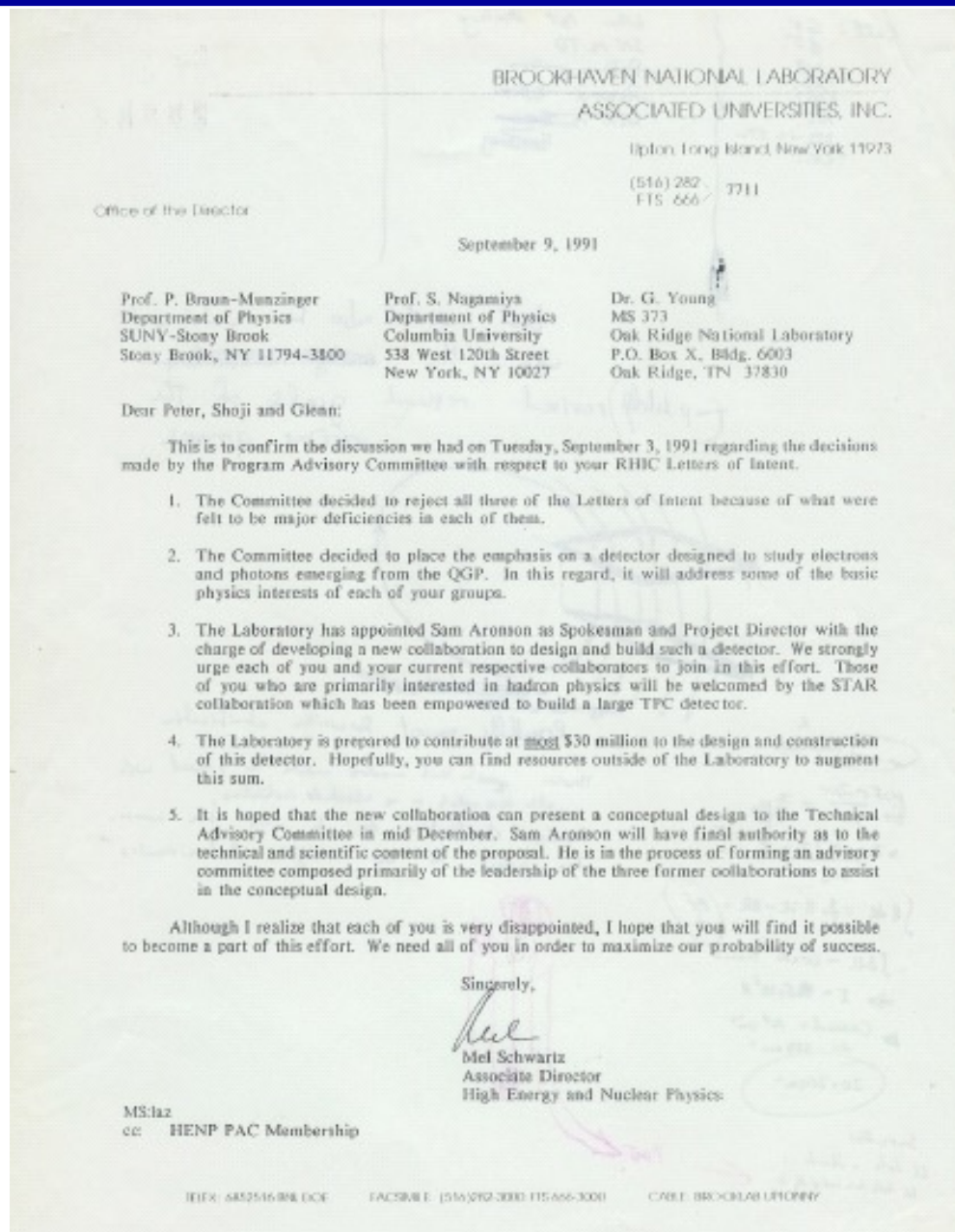


An "open focussing spectrometer", with axial field magnet.



1991 Labor Day Massacre

7

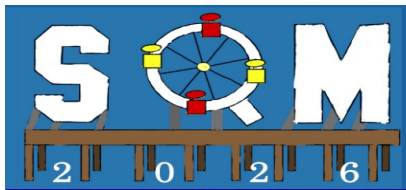


● RIP:

- ❑ Dimuon
- ❑ TALES/SPARC
- ❑ OASIS

● Née

- ❑ RE2
- ❑ “RHIC Experiment 2”



1991 Labor Day Massacre

8

BROOKHAVEN
AS
11
(516) 282-7711
FIS 666

Office of the Director
September 9, 1991

Prof. P. Braun-Munzinger
Department of Physics
SUNY-Stony Brook
Stony Brook, NY 11794-3150

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

Dr. M. S. ...
Oak

Dear Peter, Shoji and Glean:

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 they were felt to be major deficiencies in each of them.
2. The Committee decided to place the emphasis on a detector designed to measure electrons and photons emerging from the QGP. In this regard, the physics interests of each of your groups are being considered.
3. The Laboratory has appointed Sam Aronson as Spokesman and Project Director. The goal is to develop a new collaboration to design and build 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 the Laboratory.
5. It is hoped that the new collaboration can present its proposal to the Program Advisory Committee in mid December. Sam Aronson is currently reviewing the technical and scientific content of the proposal. He is in the committee composed primarily of the leadership of the three groups involved in the conceptual design.

Although I realize that each of you is very disappointed, I hope you will become a part of this effort. We need all of you in order to maximize the potential of this effort.

Sincerely,

Mel Schwartz
Associate Director
High Energy and Particle Physics

MS:laz
cc: HENP PAC Membership

TELEX: 6852516 BNL DCE FACSIMILE: (516) 972-3000; FTS 666-3000

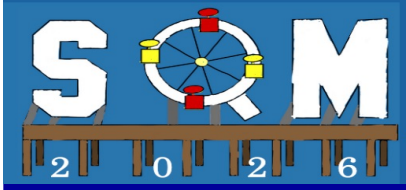
"reject all three Letters of Intent because of what were felt to be major deficiencies in each of them."

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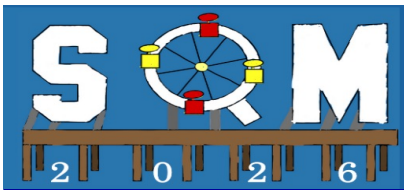
A Long Interregnum...

9

- 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

10

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 Committee,



Within the 8 o'clock experimental hall in which the second major RHIC detector 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.

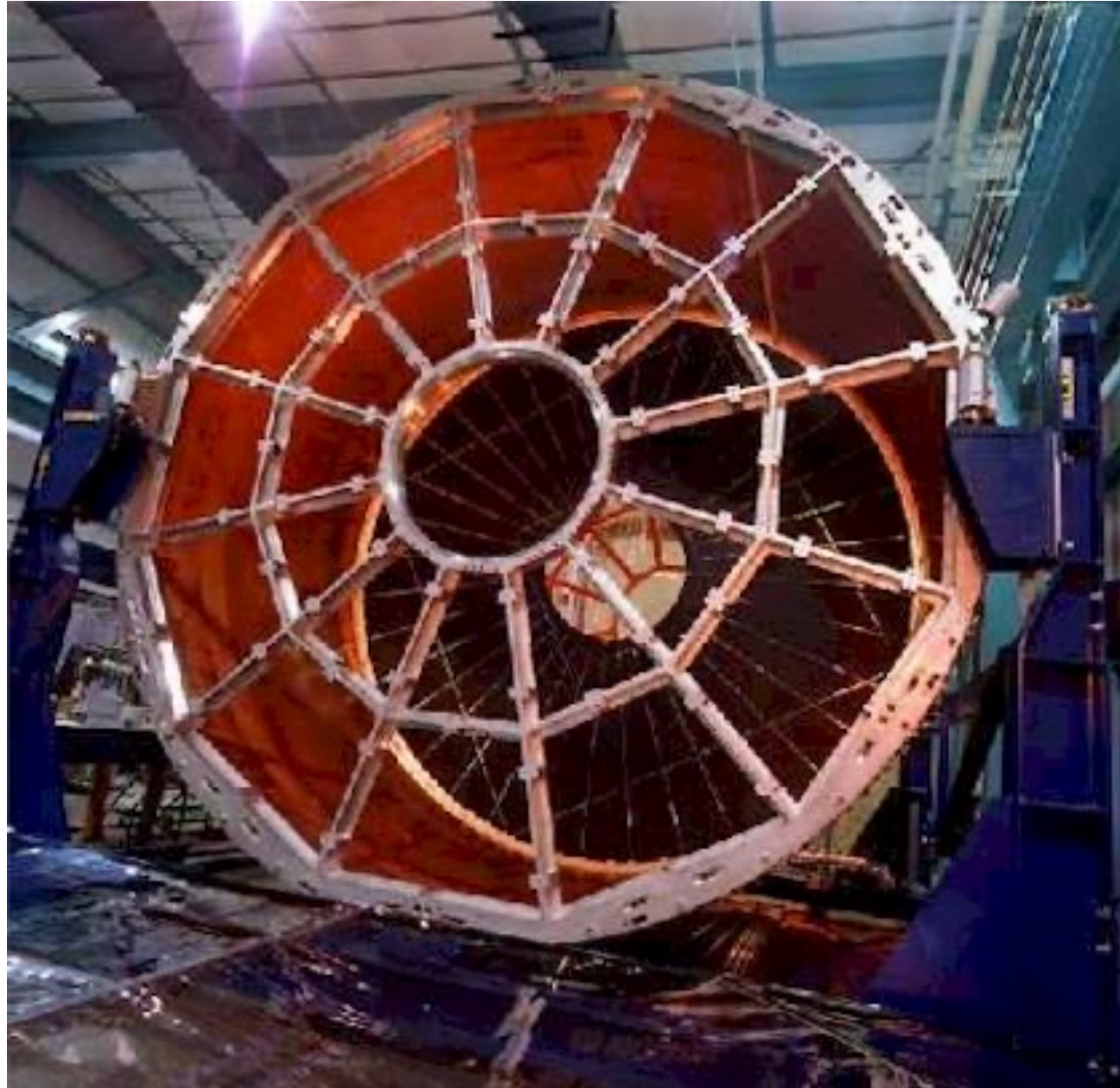
Tenure for Three Brookhaven Researchers

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

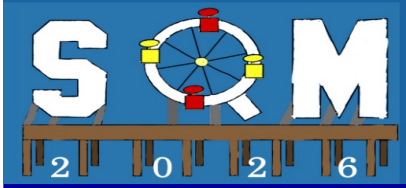
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STAR TPC circa 1997







Question

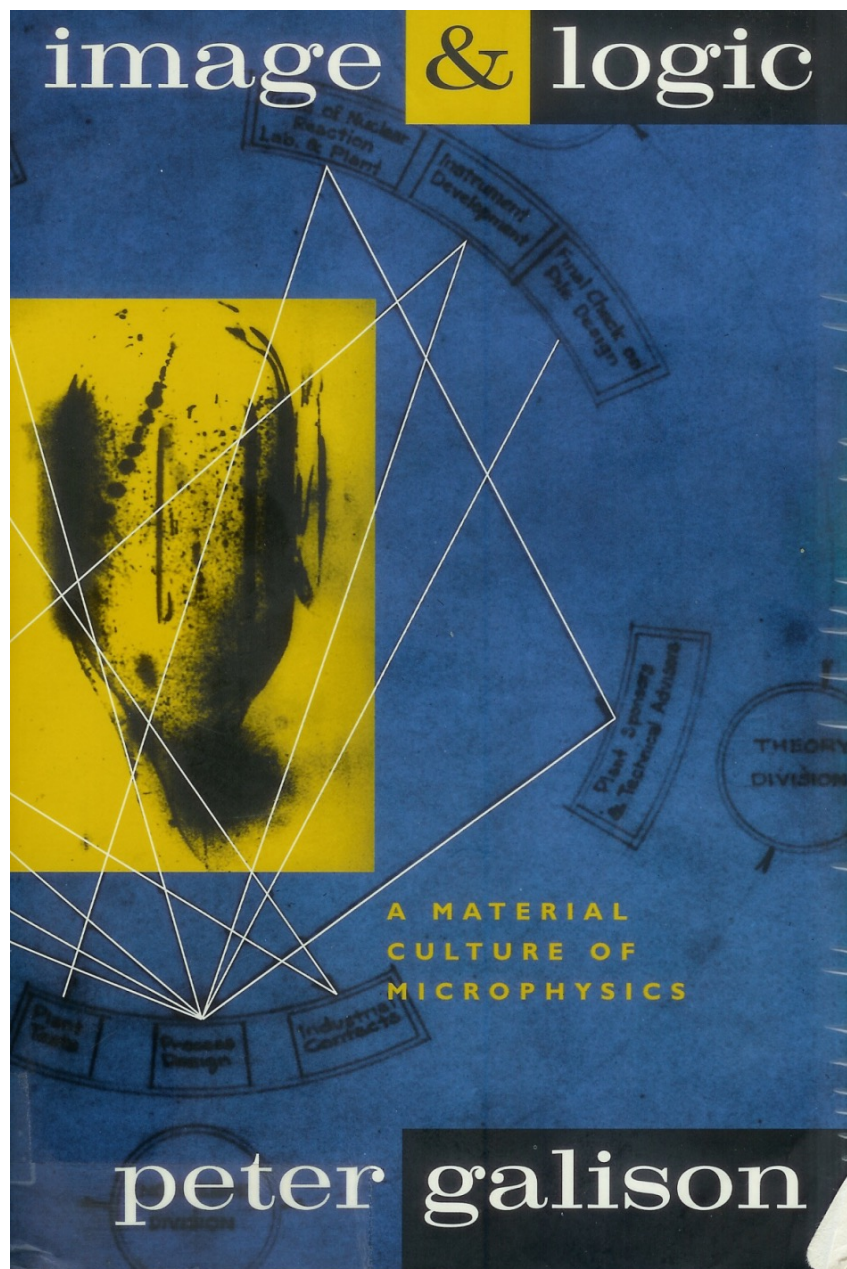
13

- How do you overcome a 1+ year head-start by a better organized and more coherent effort ??

First step:
*Know your
competition.*

1997: Insider Knowledge Published ...

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A Worked Example

608 Time Projection Chambers: An Image Falling through Space

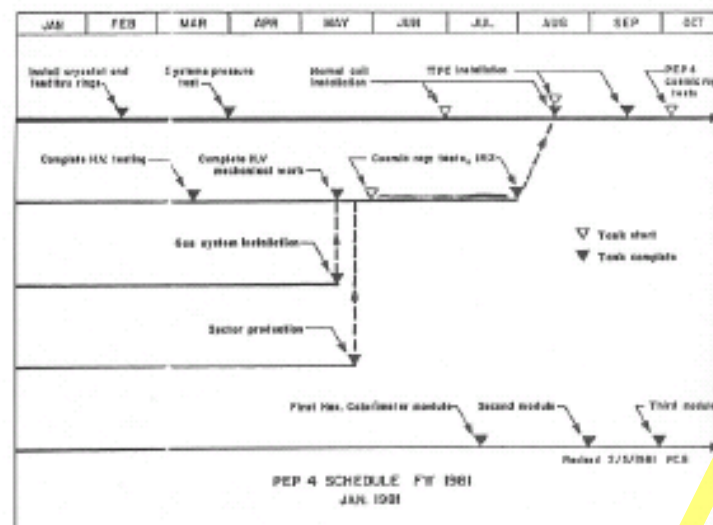


Figure 7.18 Critical path (1978). This small sample of critical path management indicates the kinds of tasks that had to be coordinated. A full critical path diagram was many times this size and vastly more complex. Source: Marx, "PEP-4 Status Report," TPC-LBL-81-23, talk given at SLAC Department of Energy review, 2 April 1981, JMP. Courtesy of Lawrence Berkeley Laboratory, University of California.

that were right in the long term but caused "unhappiness" in the short term were not being made. Lead engineers had to be strengthened; the drift chamber needed additional engineering help; one engineer desperately had to have assistance, as he was doing double duty as chief mechanical engineer and lead engineer for the support structure; the lead calorimeter team needed more engineering staff; and the high-voltage system was falling woefully behind schedule. Worst of all, the heart and soul of the project, the TPC proper, is threatened with failure due to insufficient leadership. A "TPC Czar" was needed, and absent that Marx argued that Nygren himself should take over. "We are not doing well, and the flaws remain in the system. The project needs aggressive leadership. . . . You asked that I level with you. I have done so."⁸⁹

Less than two months later, Marx himself was asked to take over as project manager of the now troubled enterprise. It was a job, Marx asserted, that he

⁸⁹ Marx to Nygren, "View of PEP-4 from Prospective of the Acting Project Manager," 14 August 1981, file "PEP-4 Project Management," box 7, JMP.

- Jay Marx was the Project Manager on the first (~1978) large TPC

"the heart and soul of the project, the TPC proper"

- Jay and John got this, allowing them to defer sub-systems while preserving TPC physics


- Key difference from PHENIX:

(To reduce costs) "Instead of turning off any of the major subsystems, we tightened everything..."

- The design of PHENIX *required* this, making Day-1 readiness *very* challenging

Doing Triage


- Mar-97, Costa Mesa workshop: Abandon all tracking, just measure neutral mesons in calorimeter??
☐ No !
- Jul-98: Ames meeting – too much experiment left at the end of the money...




Guidance

“That which does not kill us, makes us stronger.”
(Friedrich Nietzsche)

“A man's got to know his limitations.”

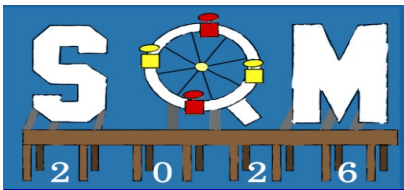


You can't always get what you want
 But if you try sometime
 Yeah, you just might find
 You get what you need
(Jagger/Richard)



Well, less is more, Lucrezia...
 Ah, but a man's reach should exceed his grasp,
 Or what's a heaven for? ...
(Robert Browning, 1855)


23-July-98
W. A. Zajc



Doing Triage

17

- Mar-97, Costa Mesa workshop: Abandon all tracking, just measure neutral mesons in calorimeter??
 - ❑ No !
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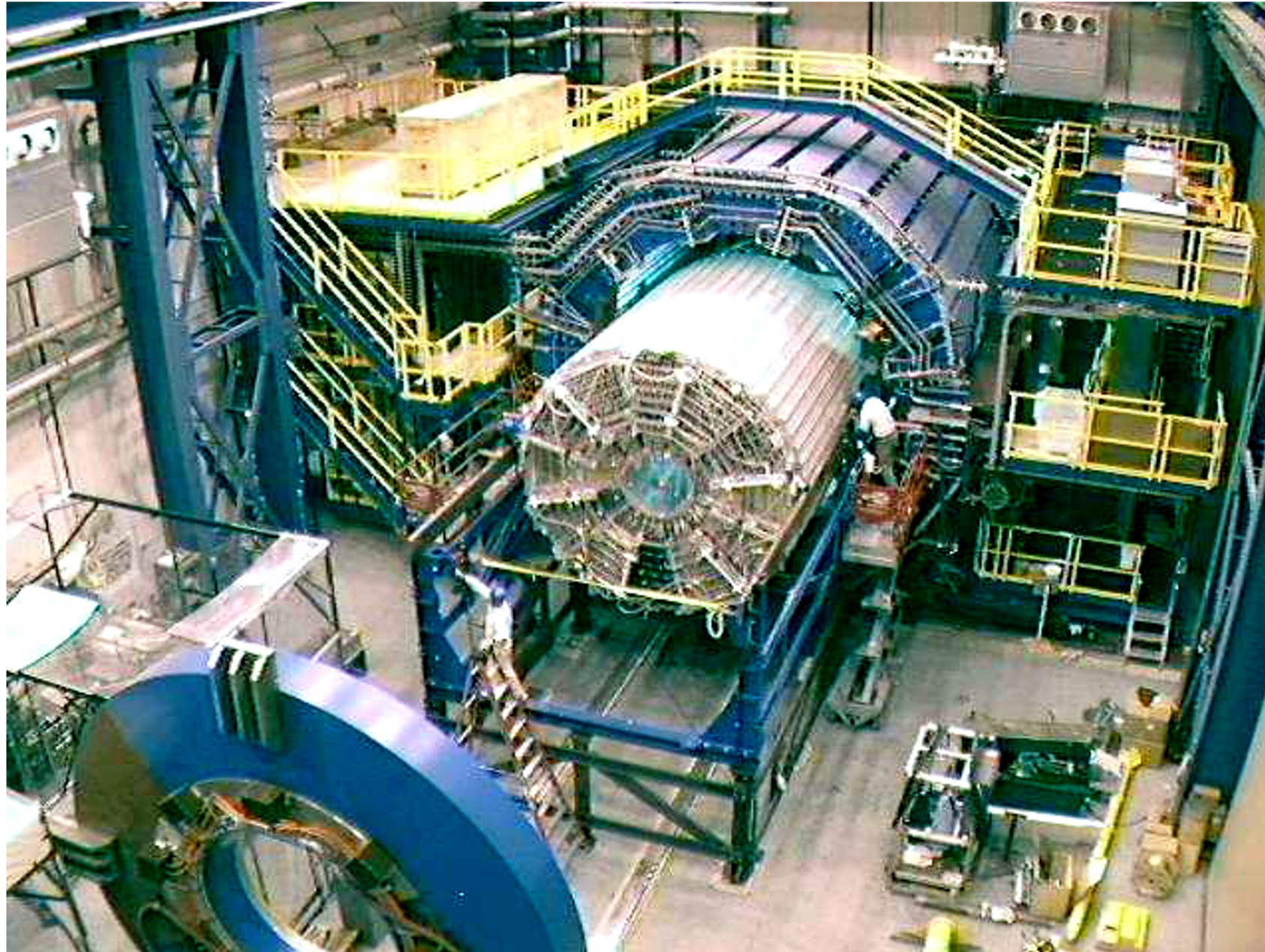


Real Guidance

- Our reach has exceeded our grasp
- We can count on funds only up to our grasp
- We must have a clear set of principles from which to prioritize:
 - ❑ We must have a Year-1 physics capability
 - ❑ That physics must be matched to (expected) machine ramp-up
 - ❑ That physics should (ideally) be
 - ◆ of maximal impact
 - ◆ unique
 - ❑ We must not make decisions now that later cripple completion of PHENIX

23-July-98 *W. A. Zajc*

STAR Circa Nov-98

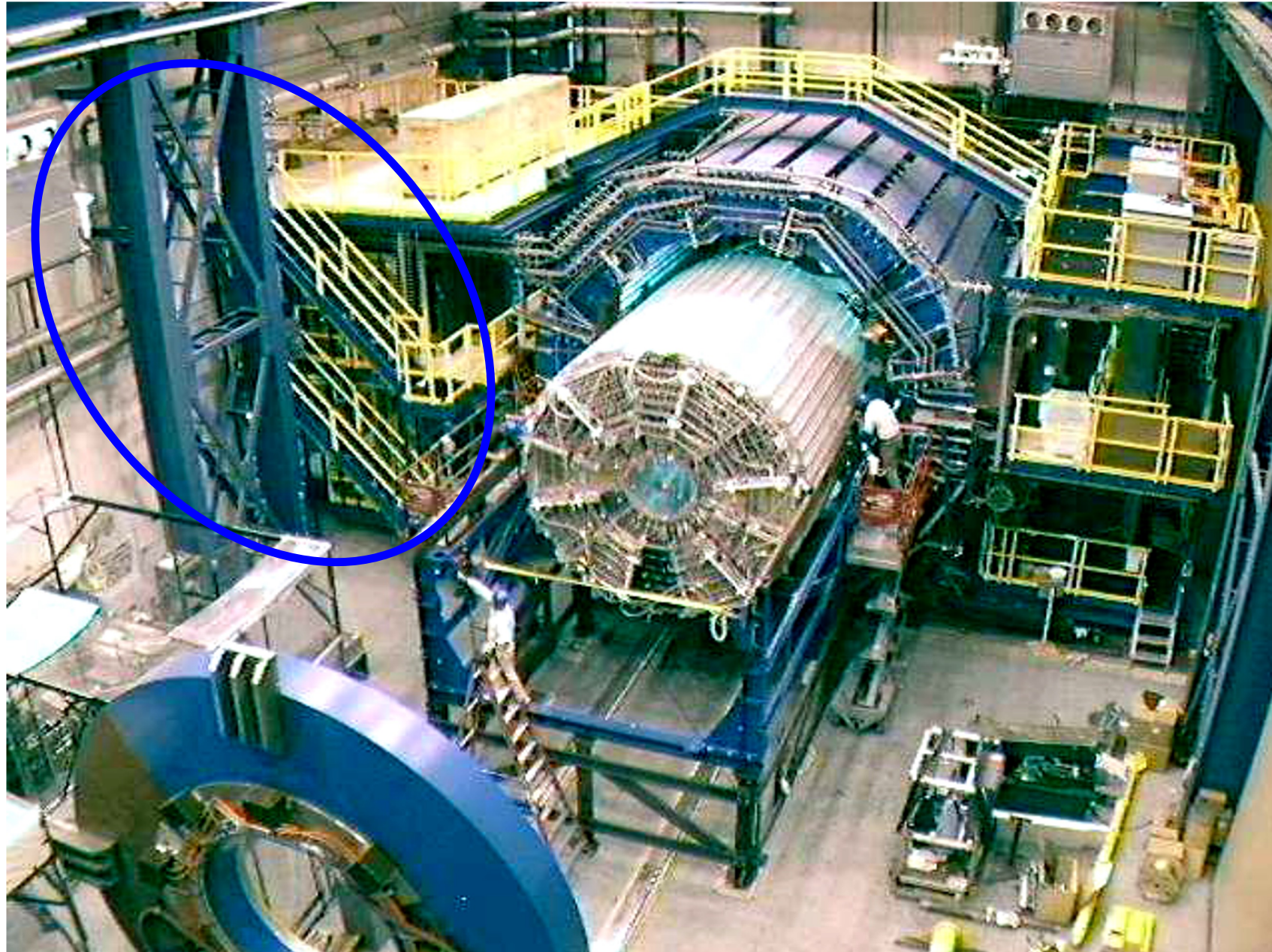


PHENIX Nov-98

- Some assembly required

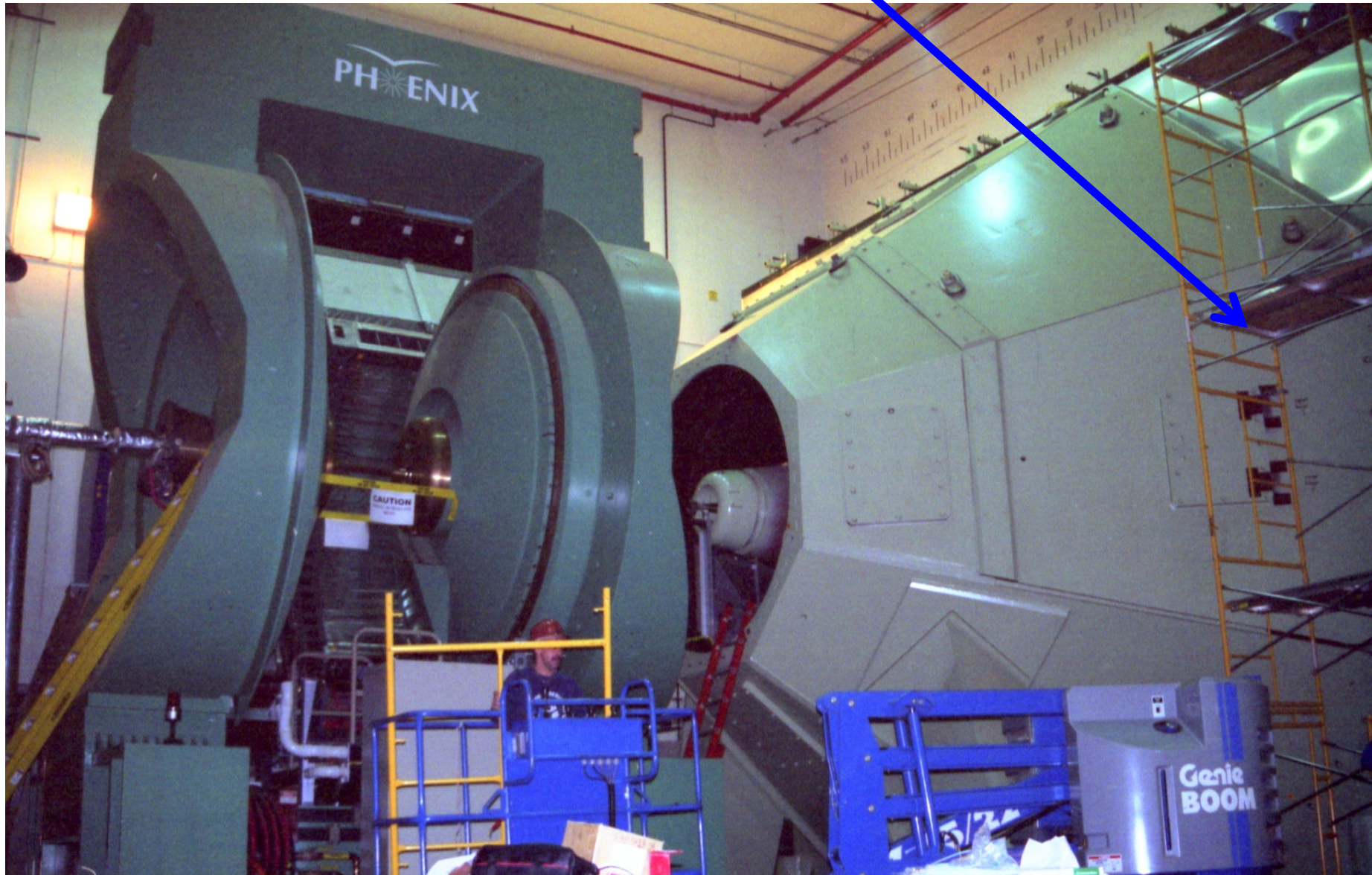


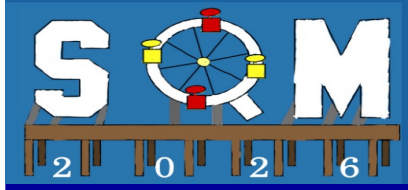
STAR Circa Nov-98



PHENIX Minimalism

The PHENIX version of stairs

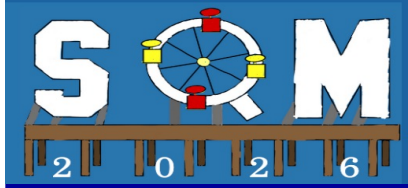




Stairs Are For Sissies

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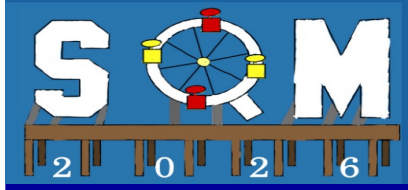




Umm, Maybe I'm a Sissy...

23



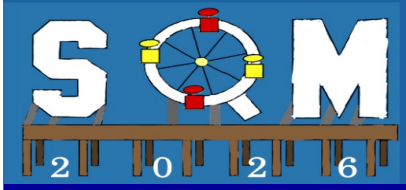


Imitation is the Sincerest Form of...

24

- Reports in from the field (1997):

“ ‘Relentless encouragement’ is a good catch phrase. It's what xxxx xxxxxx tells me is the stunning difference between STAR and PHENIX management.”



Building Morale

25

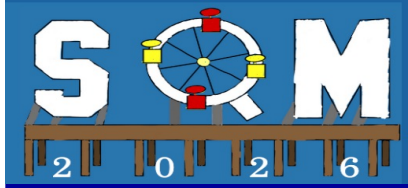
- Thursday, December 10th , 1998:
1st Annual PHENIX Holiday Party
- Held at Brookhaven Center
- Institute goofy “PHENIX-ian Awards”

Most Friendly



Most Thrifty

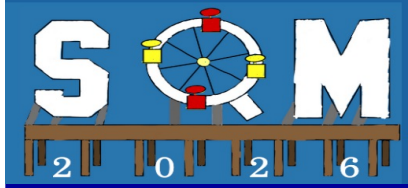




Travels Farthest to Work

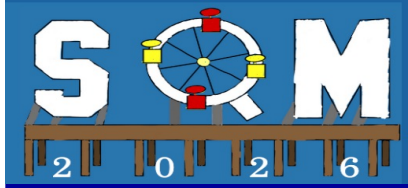
28





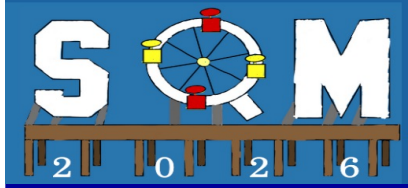
Shows Most Transparencies in a Talk²⁹





Request for Remarks from BNL Management

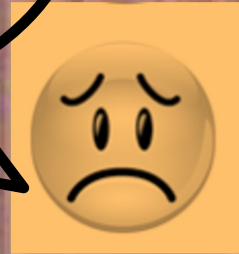


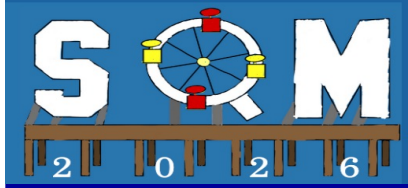


Management Morale Building

31

disparaging remarks
on PHENIX
management...

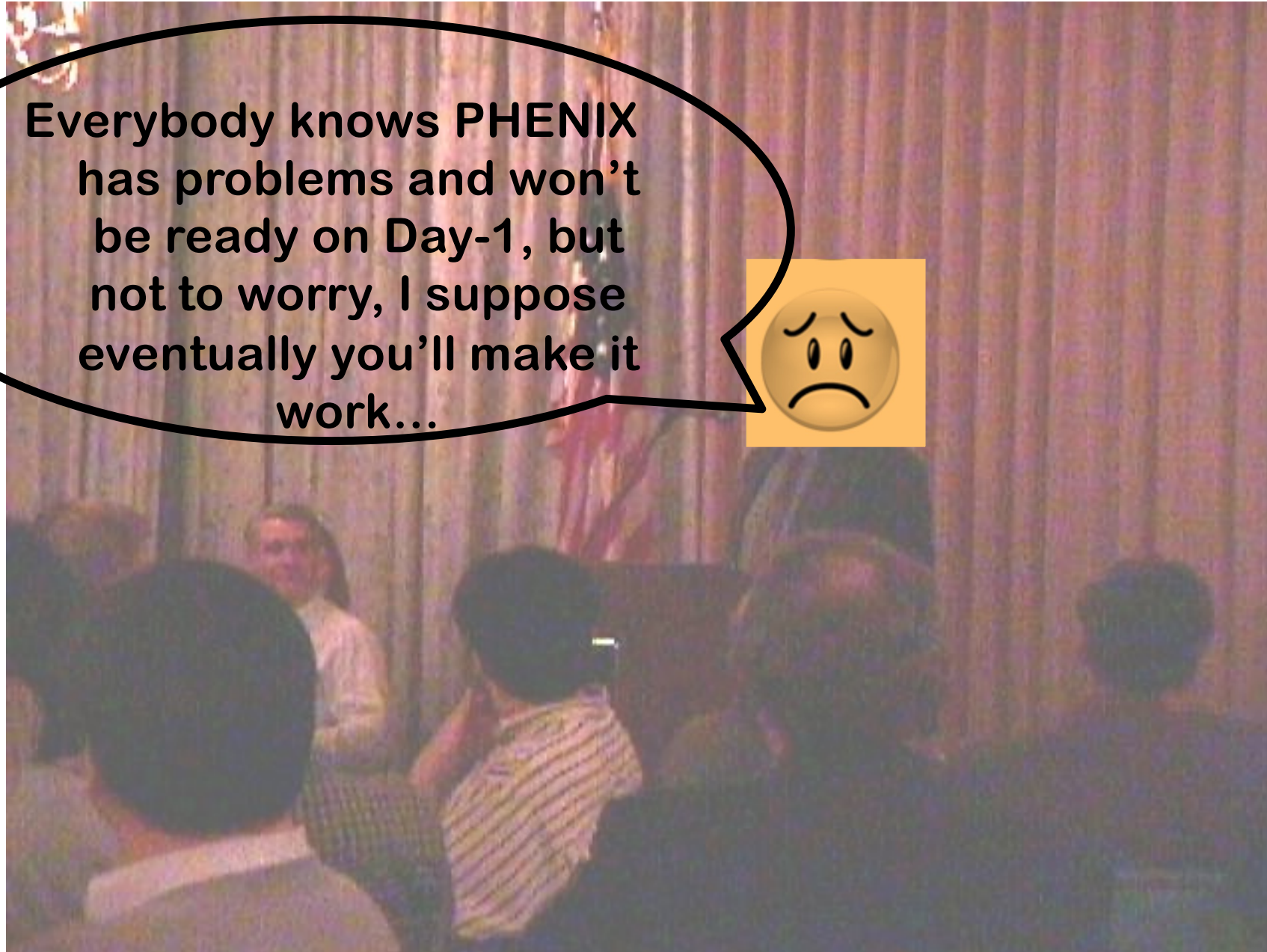
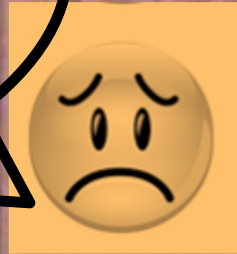


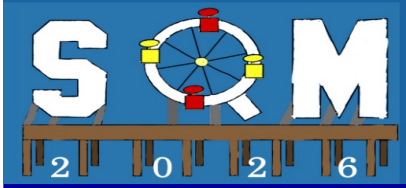


Management Morale Building

32

Everybody knows PHENIX
has problems and won't
be ready on Day-1, but
not to worry, I suppose
eventually you'll make it
work...

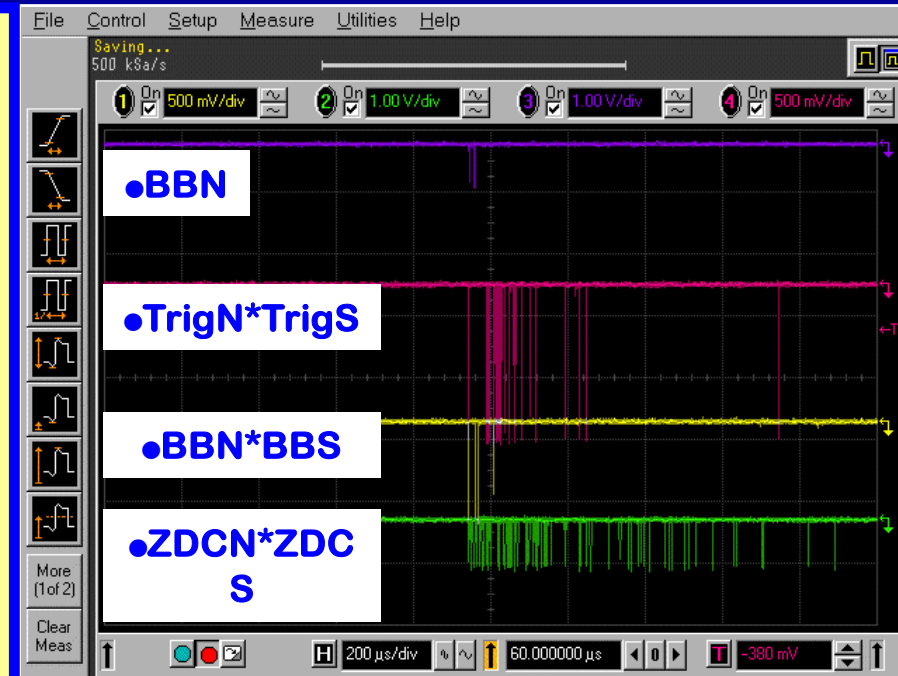




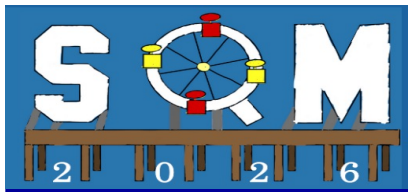
1999: RHIC Turn-On

33

- RHIC broadcast messages
 - for: Jul 3 00:10:55 1999
 - Updated 22:50 Friday July 2nd, 1999
 - BLUE RING COMMISSIONING CONTINUES
 - 2250: Beam restored to sector 10.
- PHENIX corroborated the first shot of beam with coincident events in scintillators and ZDC!

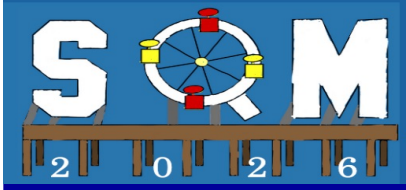


- Jul-99: Successful engineering run of RHIC Blue Ring, parts of PHENIX
- Oct-99: Suggestions of 2-4 week RHIC Schedule delays
- Nov-99: “The timing of Quark Matter 2000 was predicated on the end of the first RHIC physics run and the availability of local conference facilities. The realities of bringing on-line a new generation of machines and world-class detectors suggests that we revisit this schedule.”



1999: A Strange Morale Booster³⁴

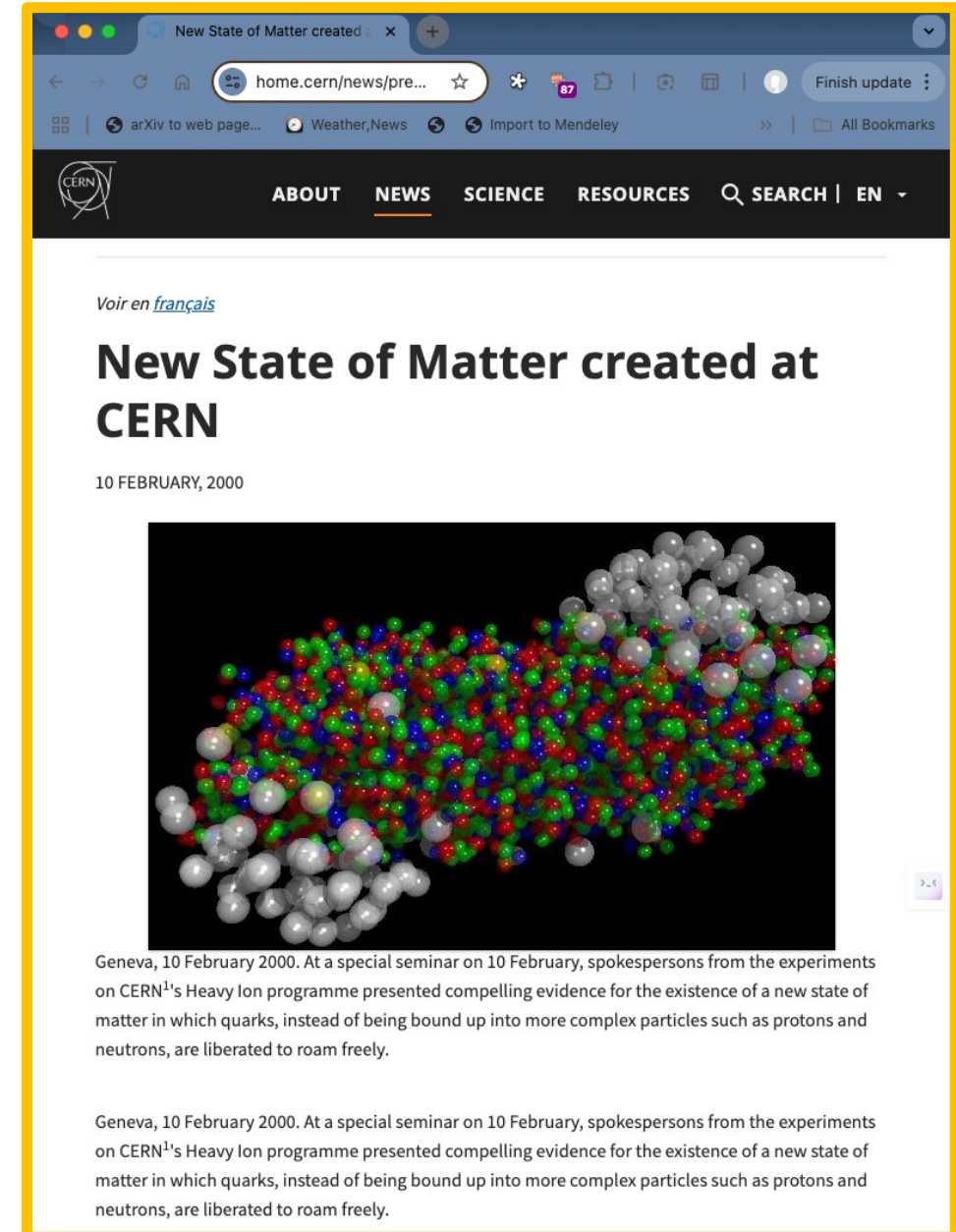
- Several month RHIC schedule delay
 - (Mechanically unstable vacuum pipe support inside cryostat for short corrector magnet...)
- 18-Oct-99: (Public) **“The recently announced delay of the RHIC schedule provides us with an opportunity to make ready a significant fraction of the Baseline detector for the very start of RHIC operations.”**
- (Private): **“should be a call to arms to come and help in this last ditch effort to even the playing field with the other experiments!”**

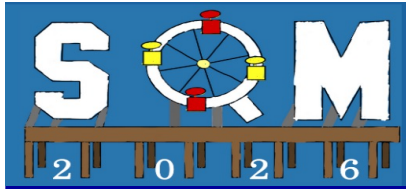


2000 CERN Press Release

35

- “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.”





First RHIC Phase Transition

36

QM2000
Quark Matter 2000

Topics will include first results from RHIC, new heavy ion fixed target data, theoretical developments, astrophysical aspects, instrumentation, and future prospects.

Edward Hopper "The Long Log" Courtesy of the Huntington Library, Art Collections, and Botanical Gardens, San Marino, California

15th International Conference on
Ultra-Relativistic Nucleus-Nucleus Collisions
July 17-22, 2000
The State University of New York at Stony Brook
and Brookhaven National Laboratory
Long Island, New York USA

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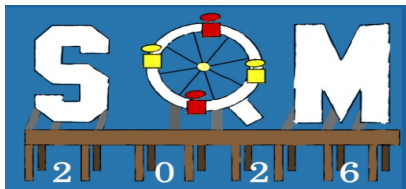
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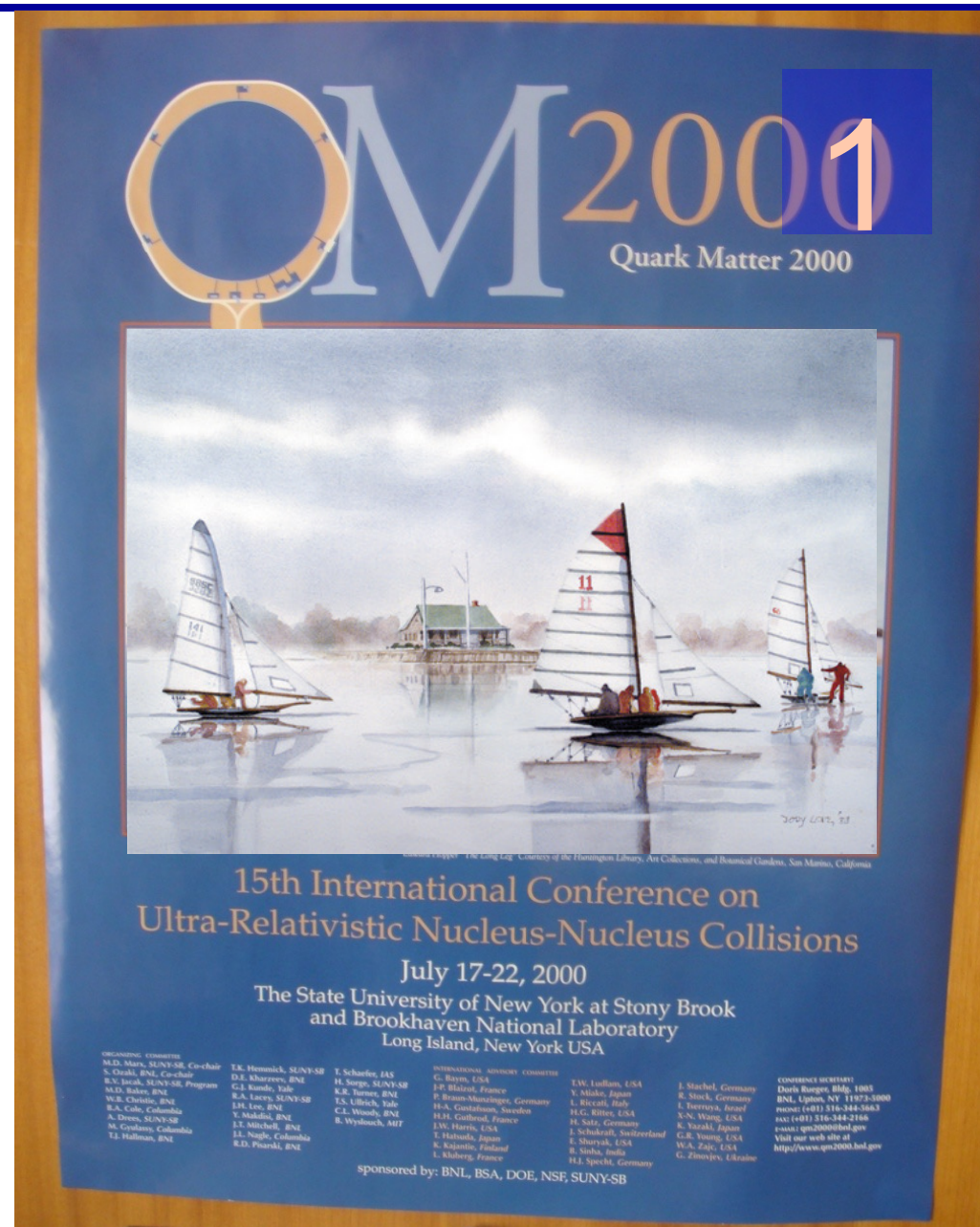
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BNL, Upton, NY 11973-5000
phone: (+01) 516-344-5663
fax: (+01) 516-344-2166
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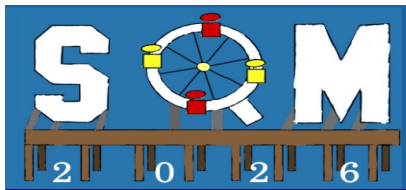


First RHIC Phase Transition

37







PHENIX Data Debut at QM01

39



PHENIX OVERVIEW

W.A. Zajc

Columbia University
for the PHENIX Collaboration



Central vs. Peripheral Yields

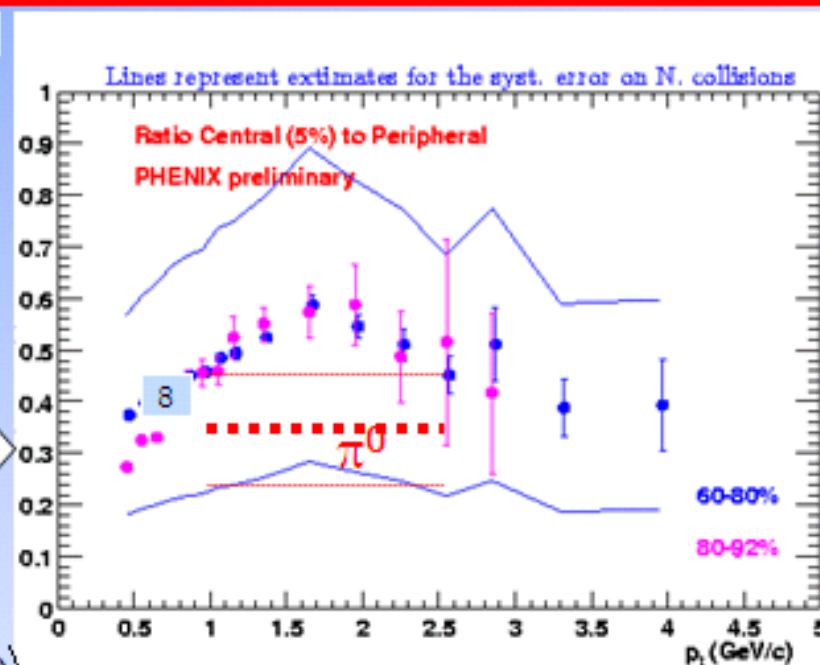
- Can study relative yields within the data set:

- Compare central to peripheral spectra vs. p_T
- Scale by the average number of collisions

$$\text{Ratio} = \frac{\text{Yield(Central)} / \langle N_{\text{COLL}}(\text{Central}) \rangle}{\text{Yield(Peripheral)} / \langle N_{\text{COLL}}(\text{Peripheral}) \rangle}$$

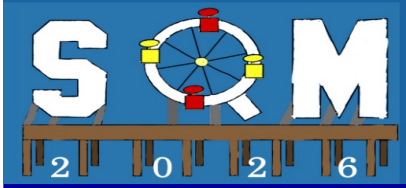
- Ratio unity if yields scale as number of collisions
- Ratio found to be less than 1, decreasing for $p_T > 2 \text{ GeV/c}$
- Same is observed in π^0 analysis (very different systematics)

4



3

2



First Jet Quenching Paper

41

- Suppression of hadrons with large transverse momentum in central Au+Au collisions at $\sqrt{s_{NN}} = 130$ -GeV.

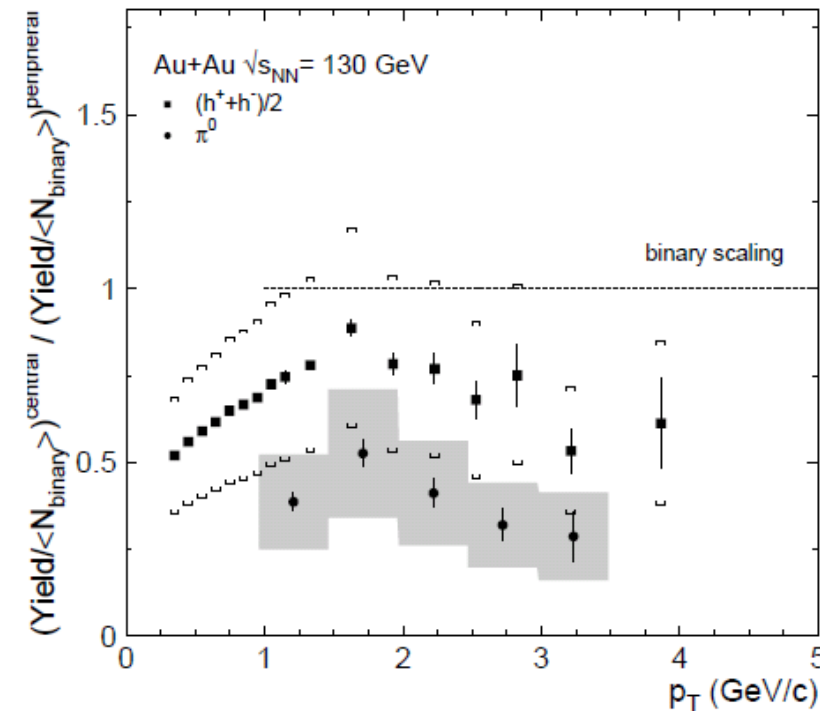
([K. Adcox et al.](#)).

Sep 2001. 6pp.

Phys.Rev.Lett.88:022301,2002

e-Print: [nucl-ex/0109003](#)

- 1282 citations



John at QM01



QM01: STAR Results on Quenching



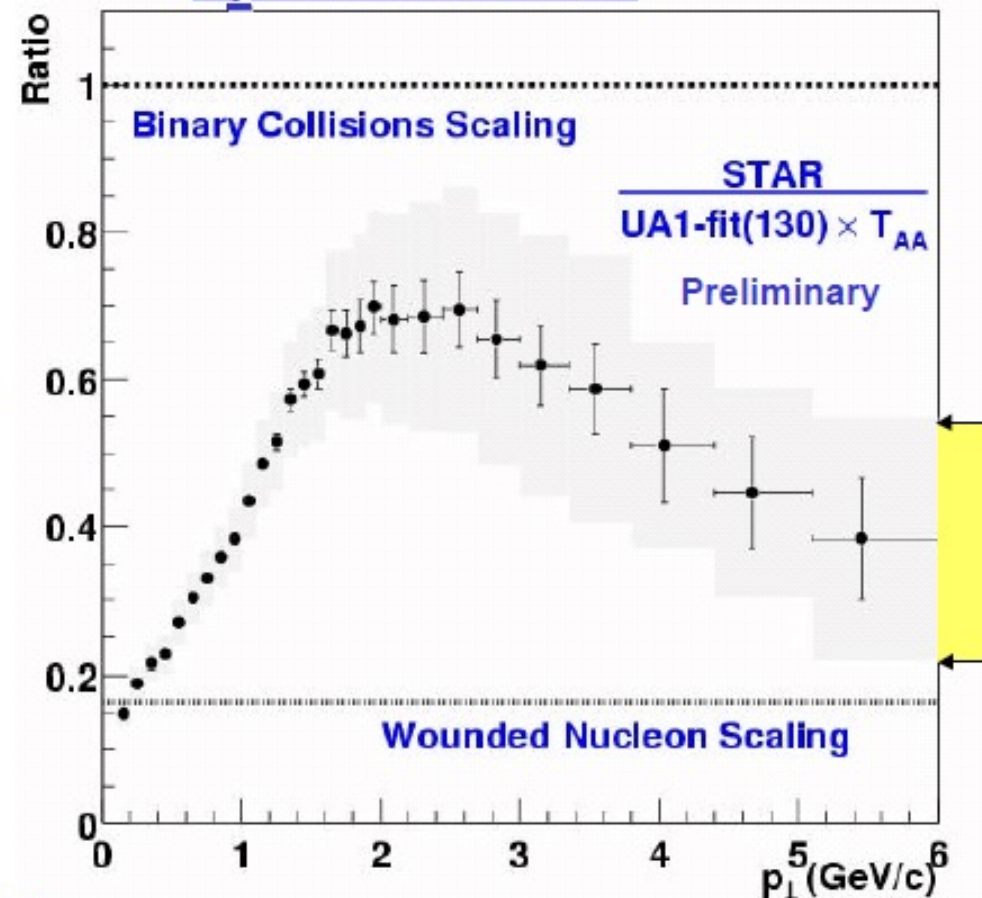
Negative Hadrons: Compare with $\bar{p}p$ p_t - distributions

UA1 $\sqrt{s} = 200$
 $\Rightarrow R (130/200)$

From power law scaling
 $R = 0.92$ at $0.2 \text{ GeV}/c$
 $R = 0.70$ at $2 \text{ GeV}/c$

"Hard" Scaling
 Nuclear Overlap Integral
 $T_{AA} = 26 \text{ mb}^{-1}$ for 5% most central
 $N_{AA} / N_{pp} = N_{\text{bin coll}} = 1050$

"Soft" Scaling
 $N_{AA} / N_{pp} = (344 / 2)$



J.W. Harris for STAR at QM2001

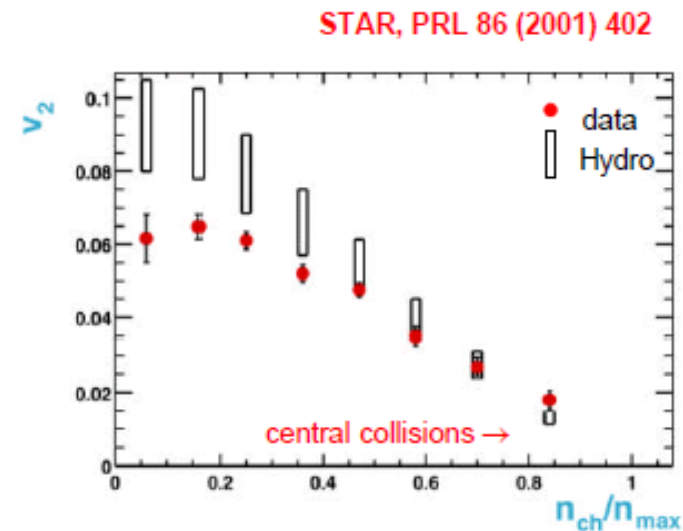
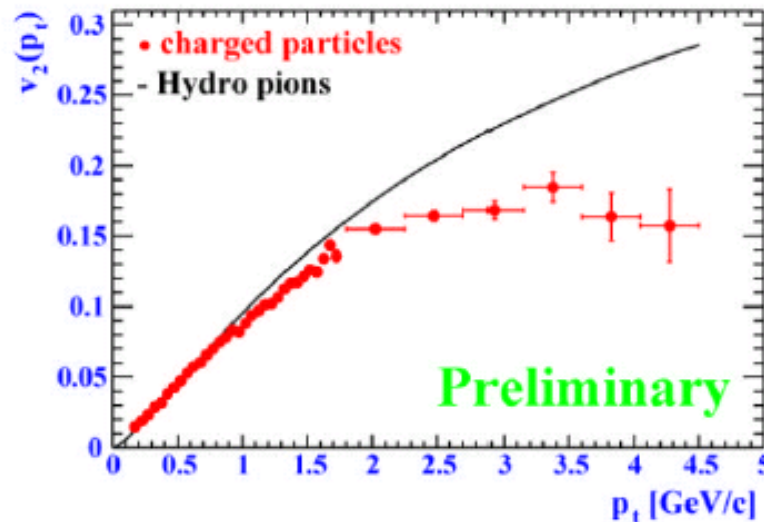
QM01: First Elliptic Flow Results

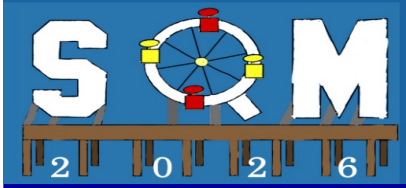


STAR

Elliptic Flow - Centrality Dependence

v_2 : 2nd Fourier harmonic coefficient of azimuthal distribution of particles with respect to the reaction plane

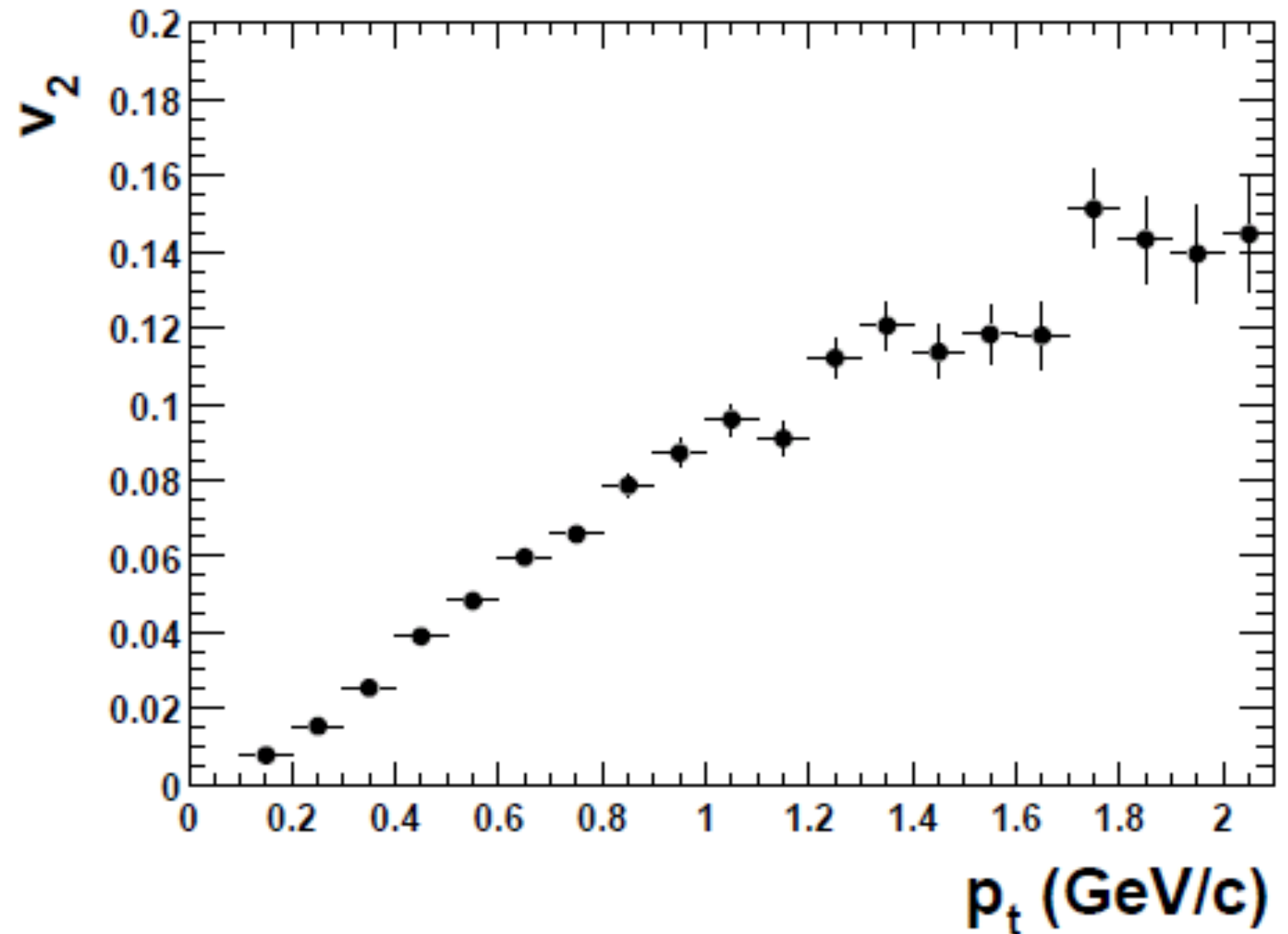




First Elliptic Flow Paper

45

- *Elliptic flow in Au + Au collisions at $(S(NN))^{1/2} = 130$ GeV.*
(K.H. Ackermann *et al.*).
Phys.Rev.Lett.86:402-407,2001.
e-Print: [nucl-ex/0009011](https://arxiv.org/abs/nuclex/0009011)
- 906 Citations



QM01: PHENIX Results on Flow

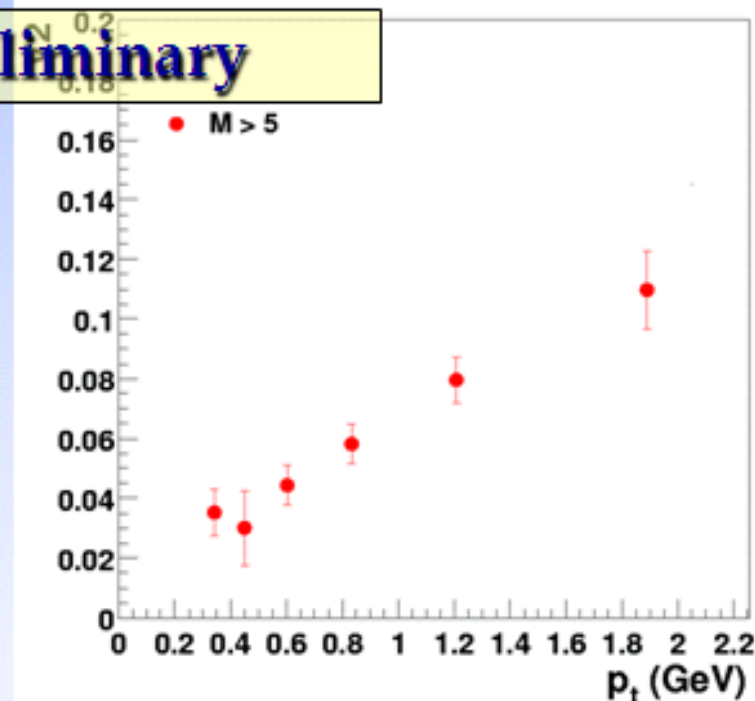
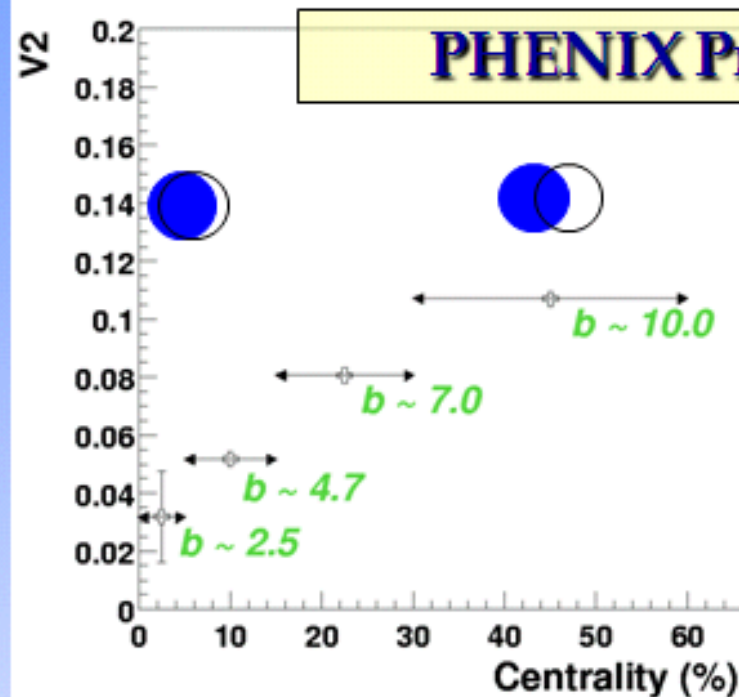


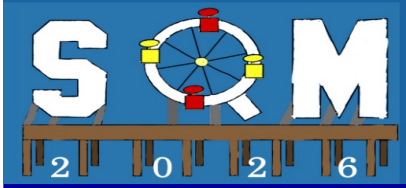
Elliptic Flow

- Extract v_2 's from $C(\Delta\phi)$
- Qualitative trends consistent with STAR results

Wednesday, Parallel Session II

R. Lacey: *Elliptic Flow Measurements with the PHENIX Detector System*





STAR Doing PHENIX Physics

47

- Disappearance of back-to-back high $p(T)$ hadron correlations in central Au+Au collisions at $\sqrt{s(NN)} = 200\text{-GeV}$.

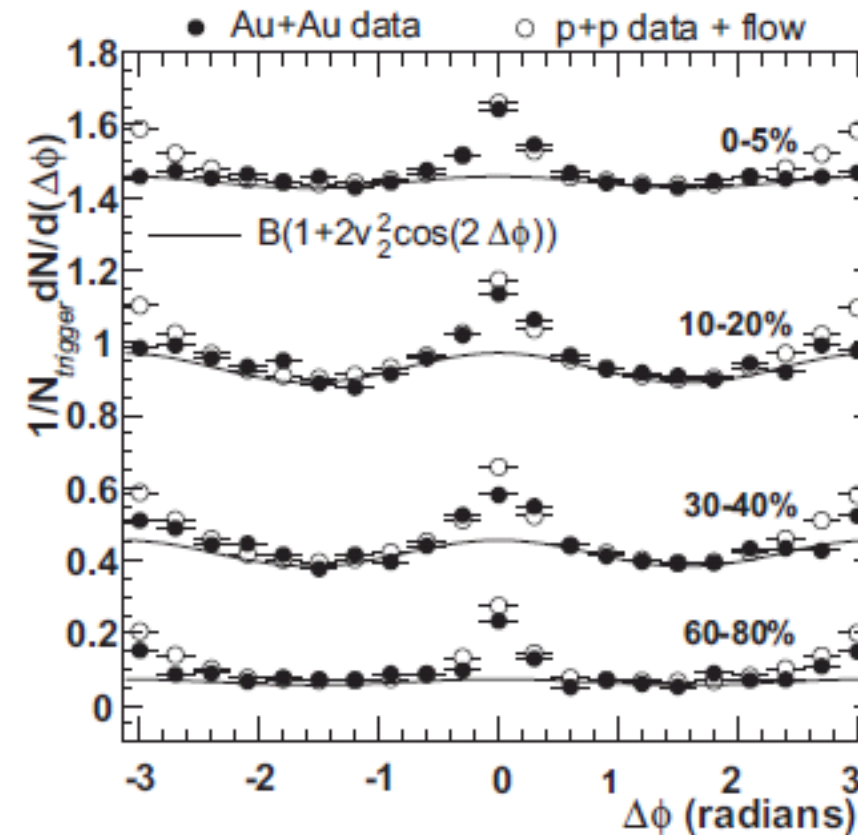
([C. Adler et al.](#)).

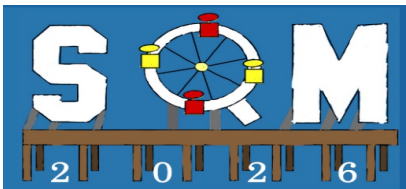
Oct 2002. 6pp.

Phys.Rev.Lett.90:082302,2003

e-Print: [nucl-ex/0210033](#)

- 959 Citations





PHENIX doing STAR Physics

48

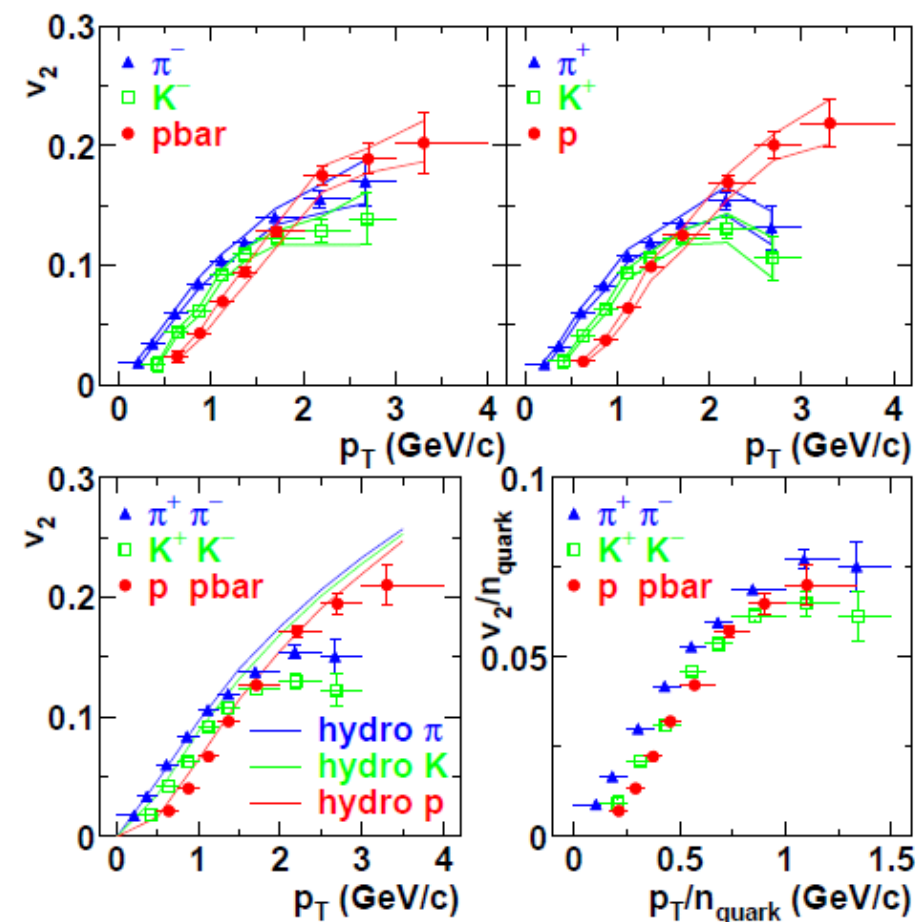
- *Elliptic flow of identified hadrons in Au+Au collisions at $s(NN)^{1/2} = 200\text{-GeV}$.*

(Stephen Scott Adler *et al.*).

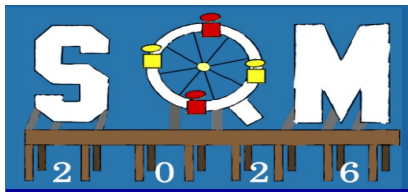
Phys.Rev.Lett.91:182301,2003.

e-Print: [nucl-ex/0305013](https://arxiv.org/abs/nuclex/0305013)

- 922 citations
- HA !



“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.”



Critical *in situ* Control Measurement 49

- 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



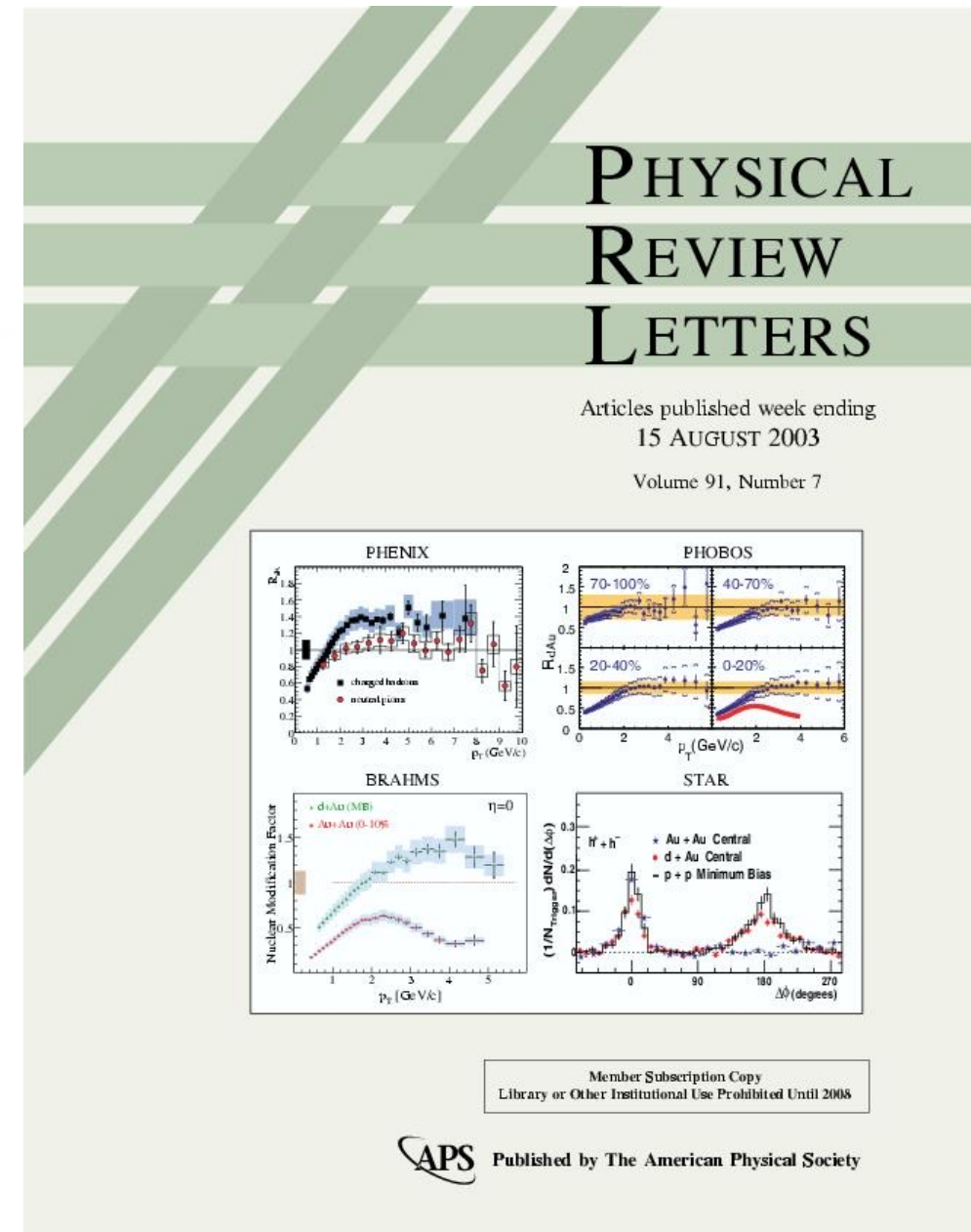
Exciting First Results from Deuteron-Gold Collisions at Brookhaven

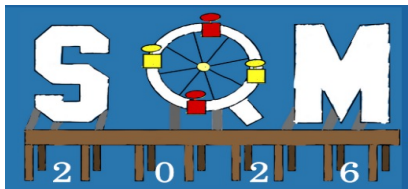
Findings intensify search for new form of matter

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.





Critical *in situ* Control Measurement

50

- 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



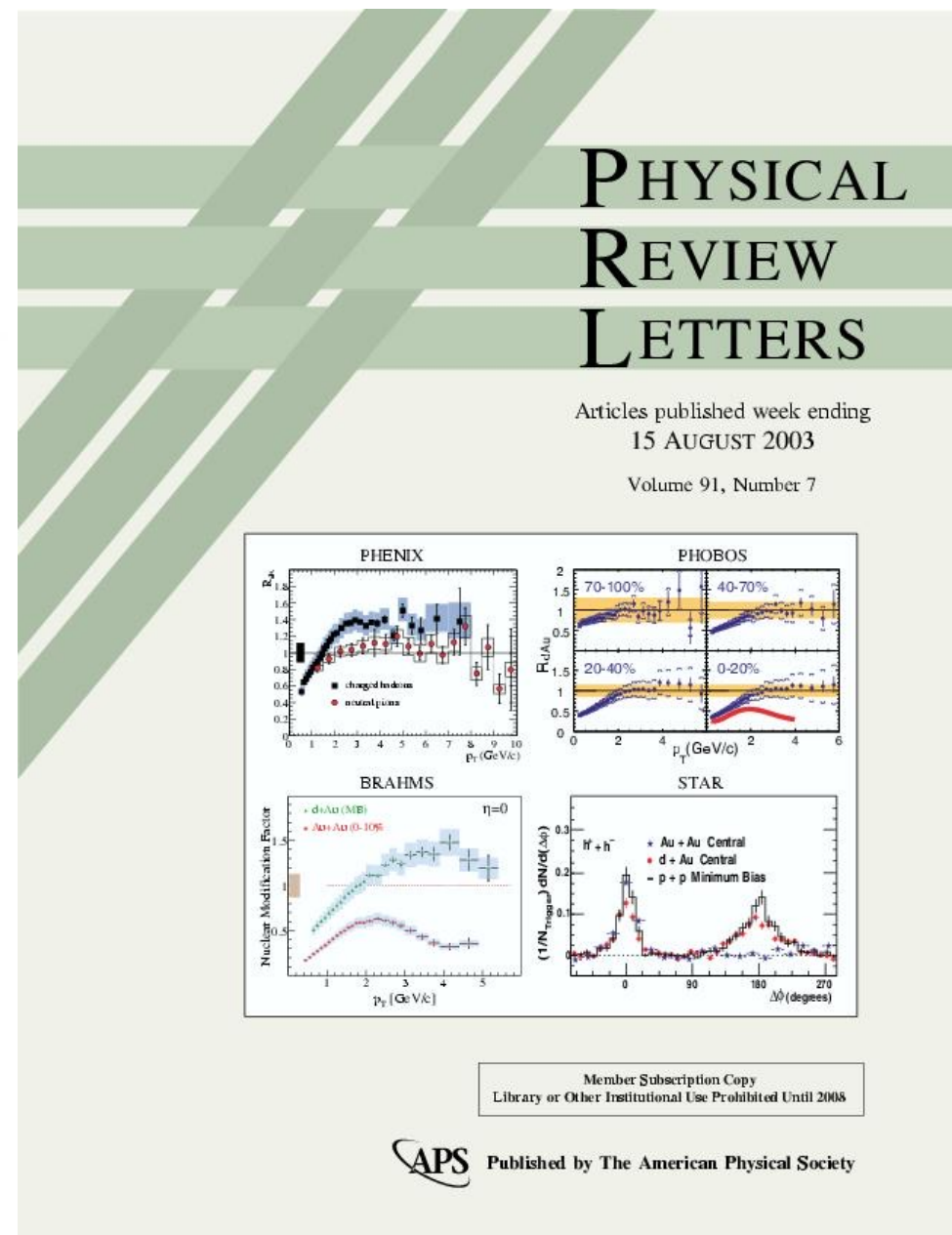
Exciting First Results from Deuteron-Gold Collisions at Brookhaven

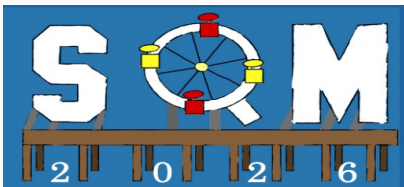
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The “Crisis”



51

- 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

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.

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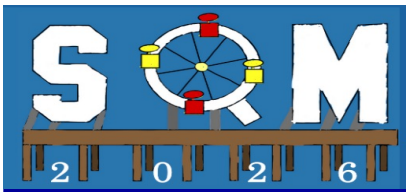
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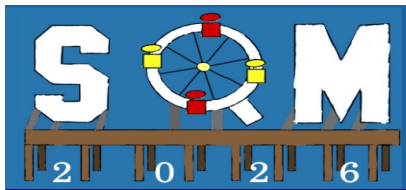




From That Article

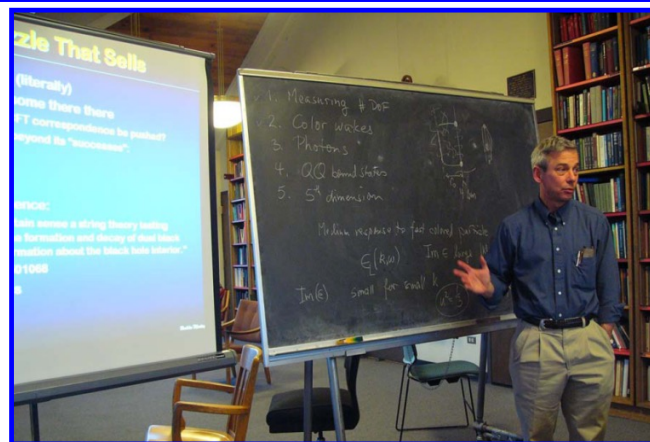
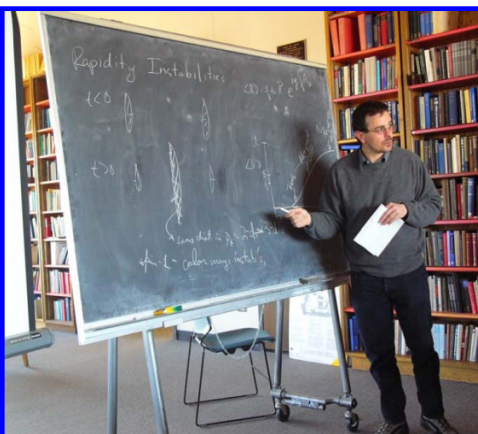
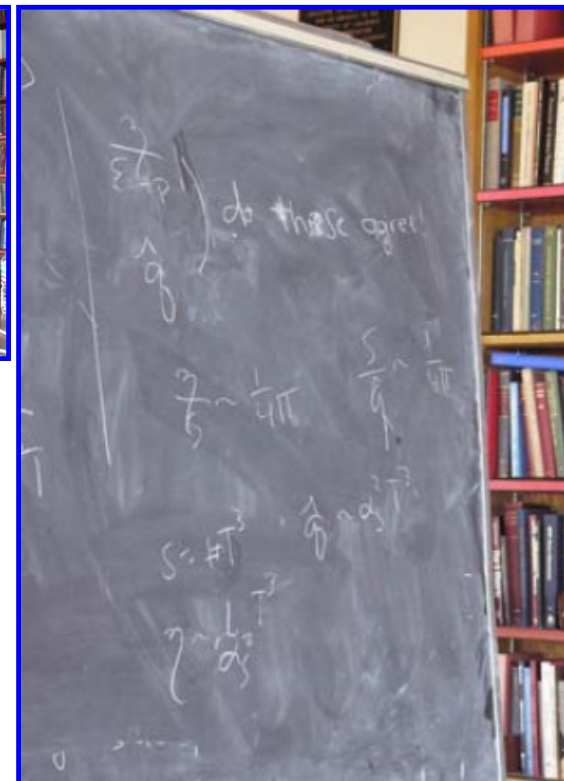
52

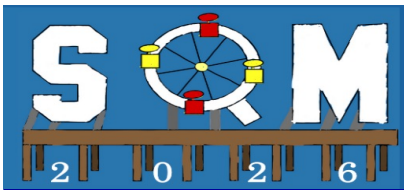
- ...the (previous) CERN announcement
"added more confusion than light to the story" (RHIC scientist)
- Those words were like daggers . . .
"They (BNL) were just starting a half-billion-dollar operation and we (CERN) are saying: 'Bye-bye. We have stolen your child' " (Senior CERN scientist)
- To announce 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."*



Boulder Workshop Mar-05

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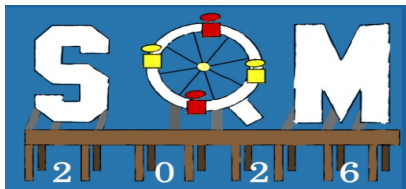
Boulder Workshop Mar-05

54



Sizzle That Sells

- New horizons in QCD (literally)
- There appears to be some there there
 - How far can the AdS/CFT correspondence be pushed?
 - Will it tell us anything beyond its “successes”:
 - ◆ $\eta / s = 1 / 4\pi$
 - ◆ $s / s_{SB} = 3 / 4$
 - ◆ What else?
- How to exploit for science:
 - “Thus RHIC is in a certain sense a string theory testing machine, analyzing the formation and decay of dual black holes, and giving information about the black hole interior.”
 - H. Nastase, [hep-th/0501068](#)
- How to exploit for \$'s



RHIC Success !!

New Press Release - Mozilla Firefox

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

mozilla.org Latest Builds Lifetime Columbia University ...

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.

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.

ne

Hunting the Quark Gluon Plasma

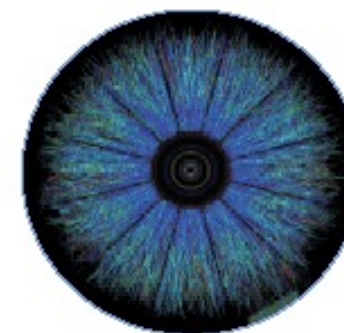
RESULTS FROM THE FIRST 3 YEARS AT RHIC

ASSESSMENTS BY THE EXPERIMENTAL COLLABORATIONS

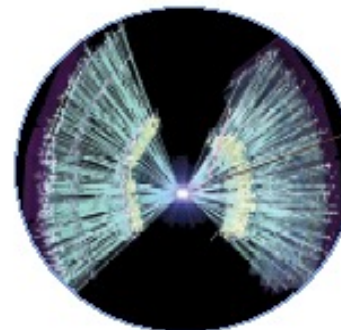
April 18, 2005



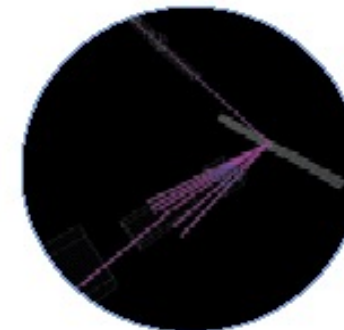
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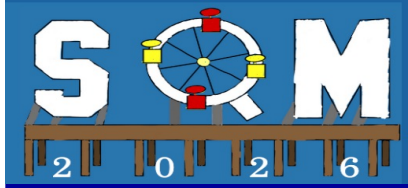


PHENIX



BRAHMS

Relativistic Heavy Ion Collider (RHIC) • Brookhaven National Laboratory, Upton, NY 11974-5000



RHIC Scientists Serve Up 'Perfect' Liquid

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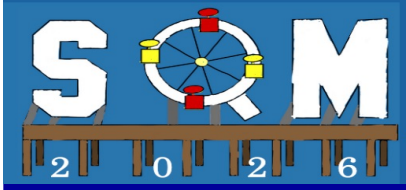
Contacts: [Karen McNulty Walsh](#), (631) 344-8350 or [Peter Genzer](#), (631) 344-3174

RHIC Scientists Serve Up 'Perfect' Liquid

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

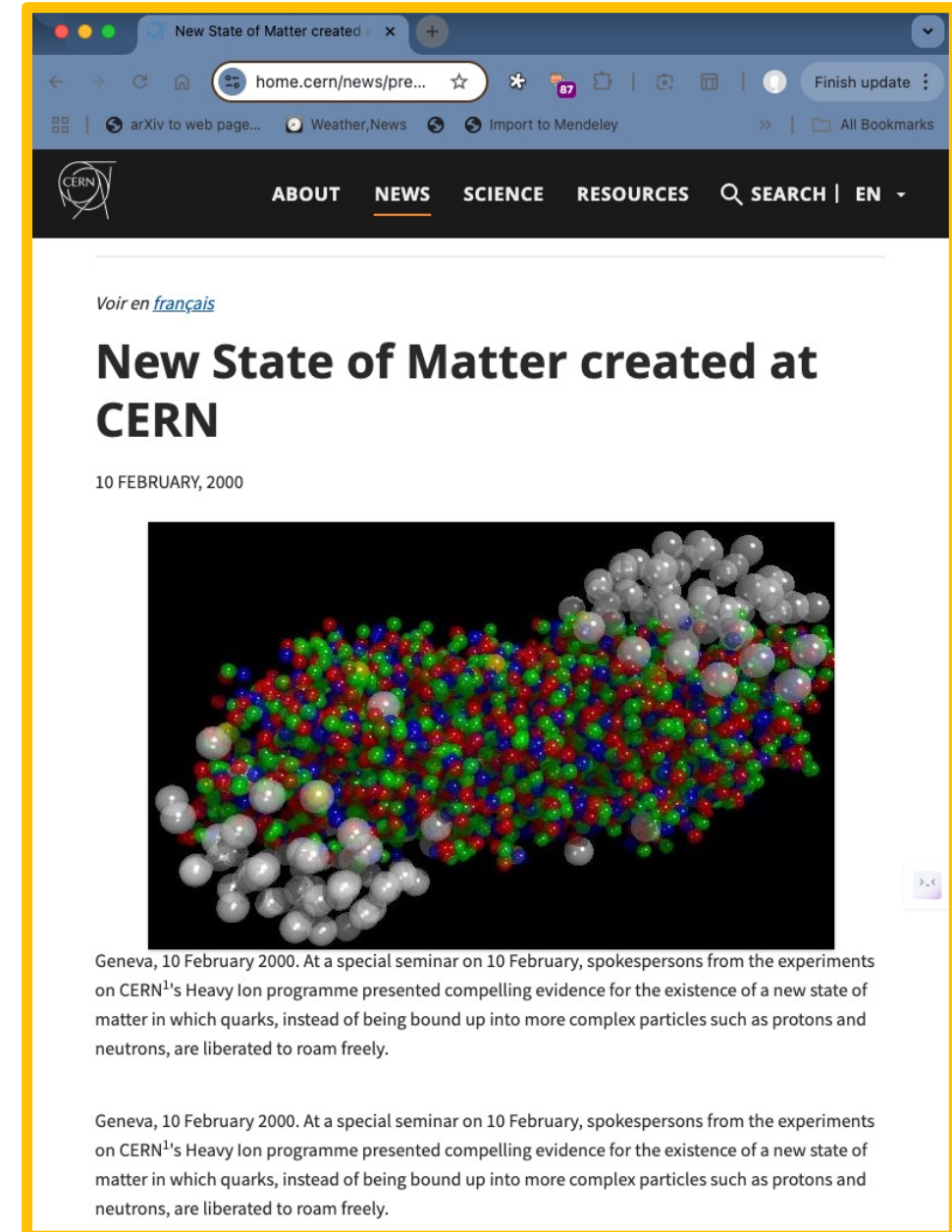
Monday, April 18, 2005

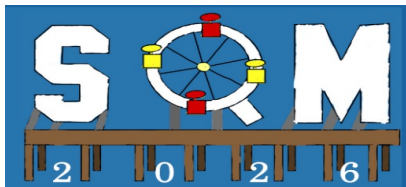
TAMPA, FL — The four detector groups conducting research at the [Relativistic Heavy Ion Collider](#) (RHIC) — a giant atom "smasher" located at the U.S. Department of Energy's Brookhaven National Laboratory — say they've created a new state of hot, dense matter out of the quarks and gluons that are the 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*.



2000 CERN Press Release⁵⁷

- “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.”





Current Perspective

58

arXiv > nucl-th > arXiv:2412.19393

Search... All fields Search

Help | Advanced Search

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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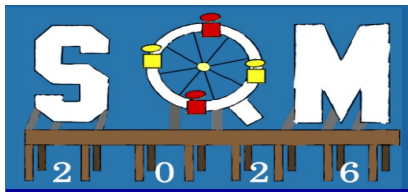
[Voir en français](#)

New State of Matter created at CERN

10 FEBRUARY, 2000

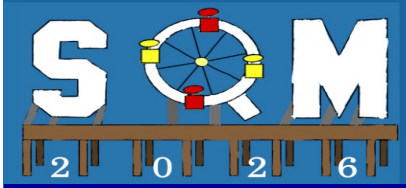
Geneva, 10 February 2000. At a special seminar on 10 February, spokespersons from the experiments on CERN's Heavy Ion programme presented compelling evidence for the existence of a new state of matter in which quarks, instead of being bound up into more complex particles such as protons and neutrons,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

Geneva, 10 February 2000. At a special seminar on 10 February, spokespersons from 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 Discoveries in Perspective⁵⁹

- 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, 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.

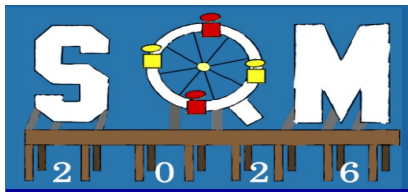


Back-up Material

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

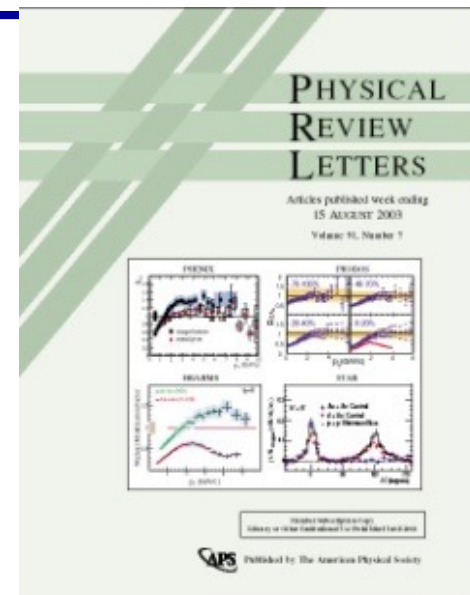
Thanks to all my PHENIX Collaborators and other colleagues at RHIC

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

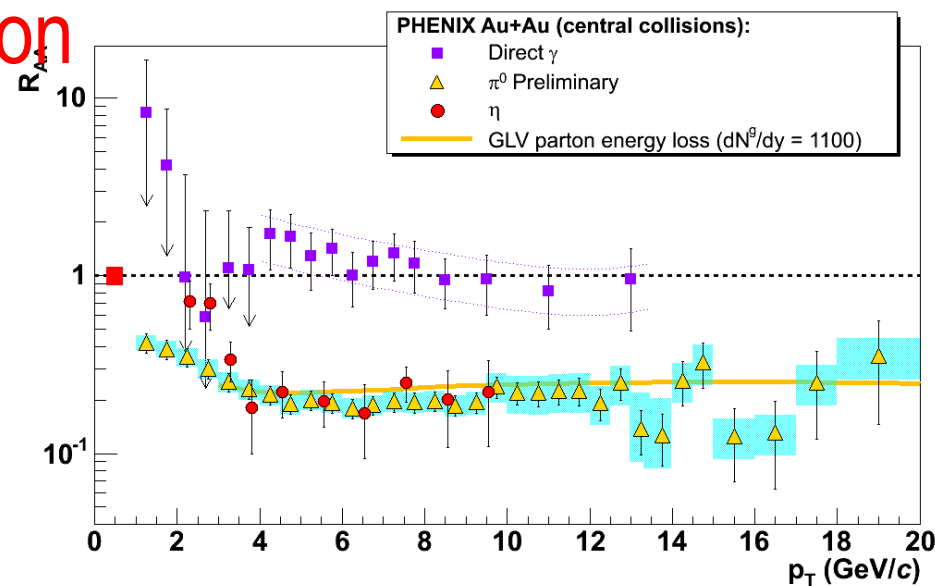


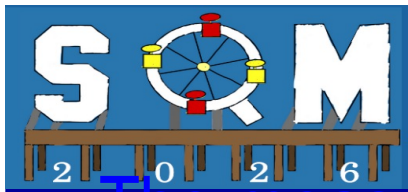
Critical *in situ* Control Measurements

- *No* suppression in d+Au collisions
- *Primordial* rate of hard scatterings as per QCD:
 - Verified in yield of open charm production
 - Verified in direct photon production



⇒ Perturbative primordial
yields in Au+Au
collisions *absorbed*
in *strongly*-coupled
dense, opaque *medium*

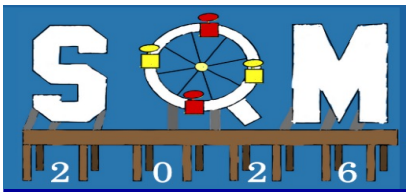




Also – an Intensified Search for Improved Theory

- The measures of hydrodynamics flow at RHIC were in qualitative agreement with *ideal* relativistic hydrodynamics.
- *Ideal* → no dissipation → *zero* viscosity
- But in 2003-4 a new bound appeared from the AdS/CFT (Anti-de Sitter Space/Conformal Field Theory) correspondence in string theory (!):
 - *A Viscosity Bound Conjecture*,
P. Kovtun, D.T. Son, A.O. Starinets, $\frac{\eta}{s} \geq \frac{\hbar}{4\pi} \sim 0.08\hbar$
hep-th/0405231

In retrospect – anticipated in a 1985 argument using the uncertainty principle: Dissipative Phenomena in Quark-Gluon Plasmas, P. Danielewicz, M. Gyulassy, Phys.Rev. D31, 53,1985.



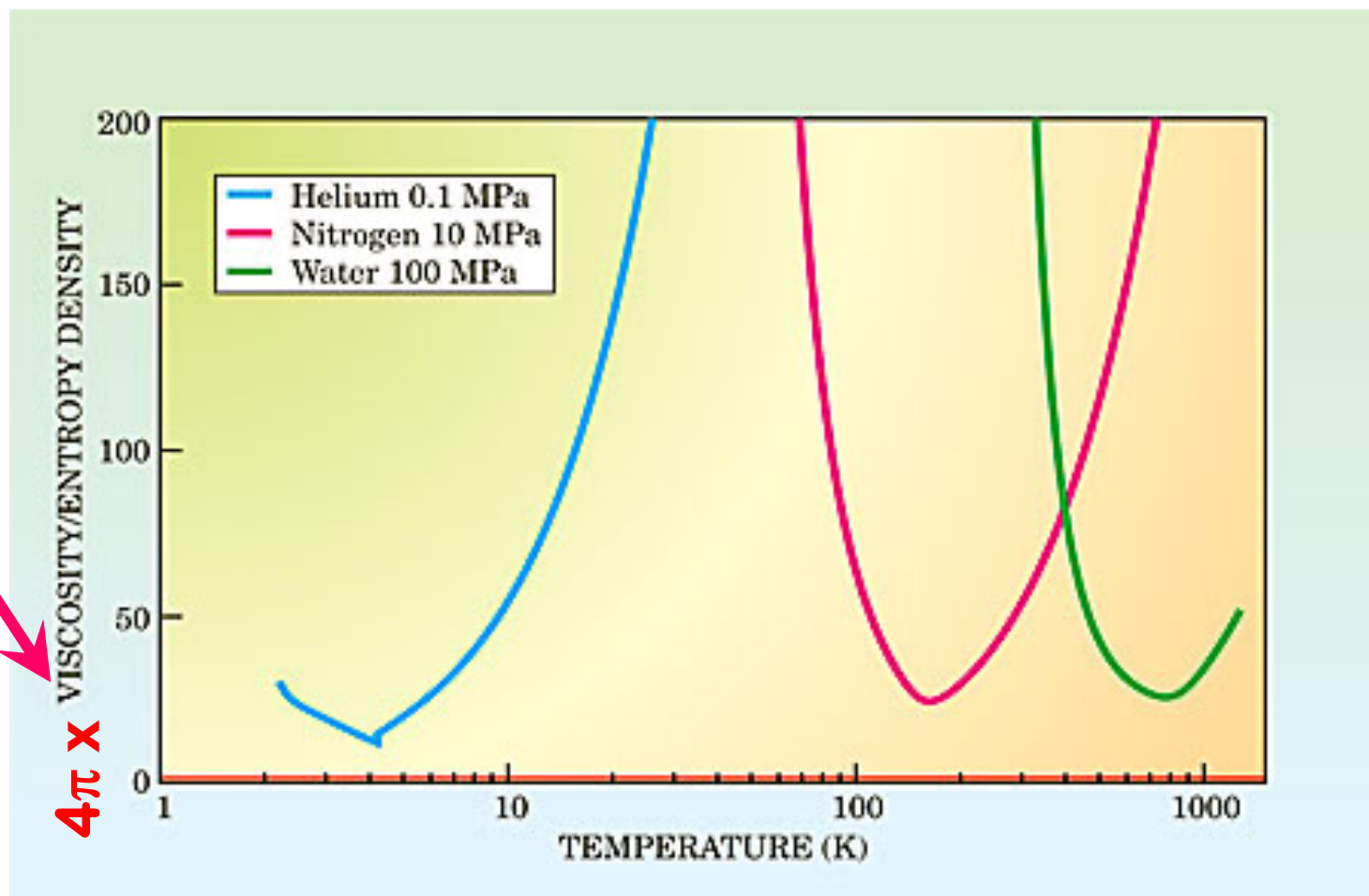
Is The Bound Respected ?

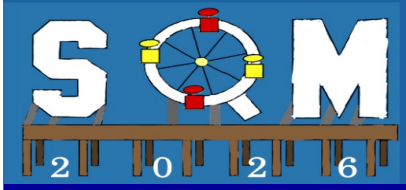
- All ordinary fluids exceed the KSS bound by factors of 10-1000.

▫ “A Viscosity Bound Conjecture”,
P. Kovtun,
D.T. Son,
A.O. Starinets, hep-th/0405231

$$\frac{\eta}{s} \geq \frac{\hbar}{4\pi}$$

- $4\pi \times$ KSS bound
is at unity on this scale.
- Various
guess-timates
strongly suggested the value
of η/s in the QGP formed at RHIC
fell below the observed minimum
for all known fluids (!)

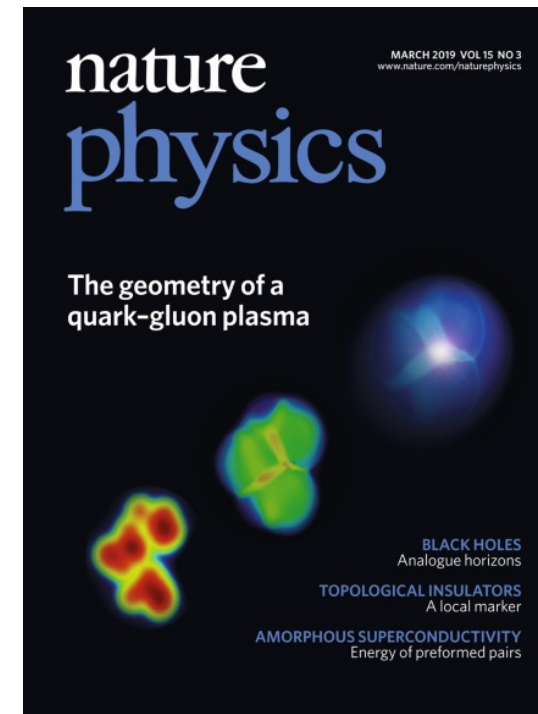


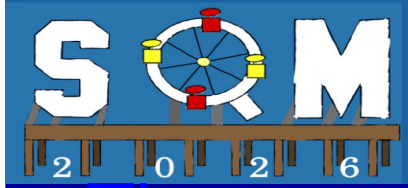


The Game Was Afoot !

64

- Theory community embarked on a decade long effort to
 - Develop truly relativistic viscous hydrodynamics
 - Control all aspects of modeling to provide reliable error estimation
- In the meantime, RHIC discoveries continued unabated:
 - Flow signatures simplified at quark level
 - Extend v_2 to v_3 , v_4 , . . .
 - Systematic exploration of flow in small systems
 - Heavy quarks (charm) participate in the “bulk” flow
 - Direct photon production consistent with QGP
 - Extraordinary vorticity of the collision state





The Game Was Afoot !

65

- Theory community embarked on a decade long effort to
 - Develop truly relativistic viscous hydrodynamics – a hard problem!

the conservation laws in the form shown in Eqs. (33), (34), and (35). The resulting equations of motion are formally given as

$$\begin{aligned}\tau_{\Pi}\dot{\Pi} + \Pi &= -\zeta\theta + \mathcal{J} + \mathcal{K} + \mathcal{R}, \\ \tau_n\dot{n}^{(\mu)} + n^\mu &= \kappa_n I^\mu + \mathcal{J}^\mu + \mathcal{K}^\mu + \mathcal{R}^\mu, \\ \tau_\pi\dot{\pi}^{(\mu\nu)} + \pi^{\mu\nu} &= 2\eta\sigma^{\mu\nu} + \mathcal{J}^{\mu\nu} + \mathcal{K}^{\mu\nu} + \mathcal{R}^{\mu\nu}.\end{aligned}\quad (63)$$

We remark that in order to derive these equations of motion, it is necessary to use Eq. (46) in the following form,

$$\sum_{j=0}^{N_\ell} \tau_{ij}^{(\ell)} \Omega_{jm}^{(\ell)} = \Omega_{im}^{(\ell)} \frac{1}{\chi_m^{(\ell)}}. \quad (64)$$

In the above equations of motion all nonlinear terms and couplings to other currents were collected in the tensors \mathcal{J} , \mathcal{K} , \mathcal{R} , \mathcal{J}^μ , \mathcal{K}^μ , \mathcal{R}^μ , $\mathcal{J}^{\mu\nu}$, $\mathcal{K}^{\mu\nu}$, and $\mathcal{R}^{\mu\nu}$. The tensors \mathcal{J} , \mathcal{J}^μ , and $\mathcal{J}^{\mu\nu}$ contain all terms of first order in Knudsen and inverse Reynolds numbers,

$$\begin{aligned}\mathcal{J} &= -\ell_{\Pi n} \nabla \cdot n - \tau_{\Pi n} n \cdot F - \delta_{\Pi\Pi} \Pi \theta - \lambda_{\Pi n} n \cdot I + \lambda_{\Pi\pi} \pi^{\mu\nu} \sigma_{\mu\nu}, \\ \mathcal{J}^\mu &= -n_\nu \omega^{\nu\mu} - \delta_{nn} n^\mu \theta - \ell_{n\Pi} \nabla^\mu \Pi + \ell_{n\pi} \Delta^{\mu\nu} \nabla_\lambda \pi_\nu^\lambda + \tau_{n\Pi} \Pi F^\mu - \tau_{n\pi} \pi^{\mu\nu} F_\nu \\ &\quad - \lambda_{nn} n_\nu \sigma^{\mu\nu} + \lambda_{n\Pi} \Pi I^\mu - \lambda_{n\pi} \pi^{\mu\nu} I_\nu, \\ \mathcal{J}^{\mu\nu} &= 2\pi_\lambda^{(\mu} \omega^{\nu)\lambda} - \delta_{\pi\pi} \pi^{\mu\nu} \theta - \tau_{\pi\pi} \pi^{\lambda(\mu} \sigma_{\lambda}^{\nu)} + \lambda_{\pi\Pi} \Pi \sigma^{\mu\nu} - \tau_{\pi n} n^{(\mu} F^{\nu)} \\ &\quad + \ell_{\pi n} \nabla^{(\mu} n^{\nu)} + \lambda_{\pi n} n^{(\mu} I^{\nu)}.\end{aligned}\quad (65)$$

where we defined $F^\mu = \nabla^\mu P_0$. In principle, one could replace this quantity by the acceleration \dot{u}^μ using Eq. (35). The tensors \mathcal{K} , \mathcal{K}^μ , and $\mathcal{K}^{\mu\nu}$ contain all terms of second order in Knudsen number,

$$\begin{aligned}\mathcal{K} &= \zeta_1 \omega_{\mu\nu} \omega^{\mu\nu} + \zeta_2 \sigma_{\mu\nu} \sigma^{\mu\nu} + \zeta_3 \theta^2 + \zeta_4 I \cdot I + \zeta_5 F \cdot F + \zeta_6 I \cdot F + \zeta_7 \nabla \cdot I + \zeta_8 \nabla \cdot F, \\ \mathcal{K}^\mu &= \kappa_1 \sigma^{\mu\nu} I_\nu + \kappa_2 \sigma^{\mu\nu} F_\nu + \kappa_3 I^\mu \theta + \kappa_4 F^\mu \theta + \kappa_5 \omega^{\mu\nu} I_\nu + \kappa_6 \Delta_\lambda^\mu \partial_\nu \sigma^{\lambda\nu} + \kappa_7 \nabla^\mu \theta, \\ \mathcal{K}^{\mu\nu} &= \eta_1 \omega_\lambda^{(\mu} \omega^{\nu)\lambda} + \eta_2 \theta \sigma^{\mu\nu} + \eta_3 \sigma^{\lambda(\mu} \sigma_{\lambda}^{\nu)} + \eta_4 \sigma_\lambda^{(\mu} \omega^{\nu)\lambda} \\ &\quad + \eta_5 I^{(\mu} I^{\nu)} + \eta_6 F^{(\mu} F^{\nu)} + \eta_7 I^{(\mu} F^{\nu)} + \eta_8 \nabla^{(\mu} I^{\nu)} + \eta_9 \nabla^{(\mu} F^{\nu)}.\end{aligned}\quad (66)$$

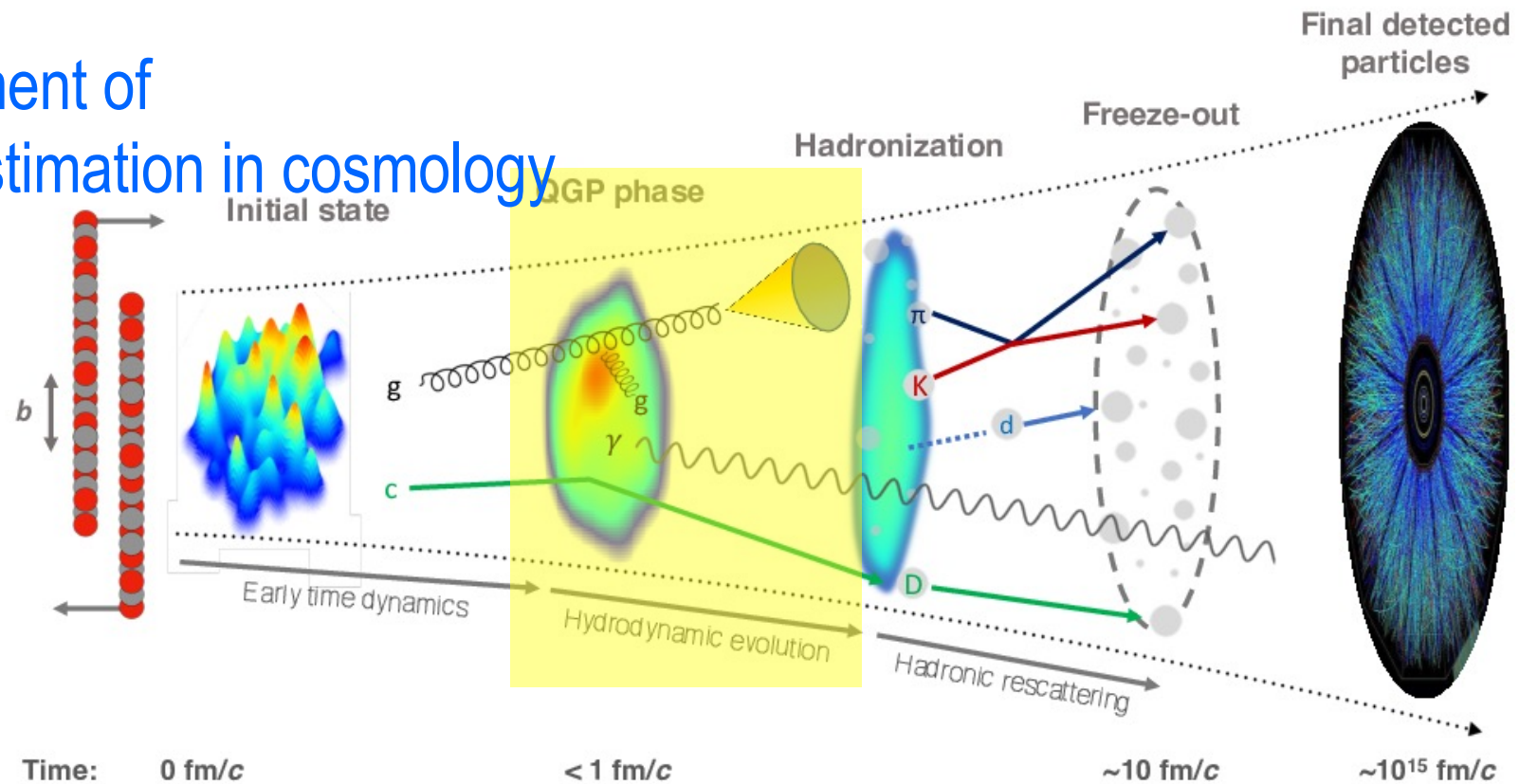
Derivation of transient relativistic fluid dynamics from the Boltzmann equation,

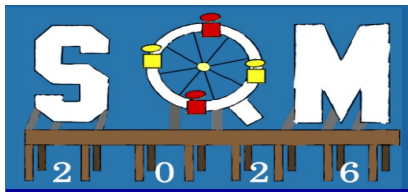
G. Denicol et al., Phys.Rev. D85 114047, (2012).

<https://inspirehep.net/literature/1089847>

The Game Was Afoot !

- Theory community embarked on a decade long effort to
 - Develop truly relativistic viscous hydrodynamics
 - Control all aspects of modeling to provide reliable error estimation
 - ◆ A multi-scale problem
 - ◆ Benefited from the development of multi-parameter Bayesian estimation in cosmology
 - ◆ Error estimates on η/s now available conditioned on ~20 parameter “marginalization”





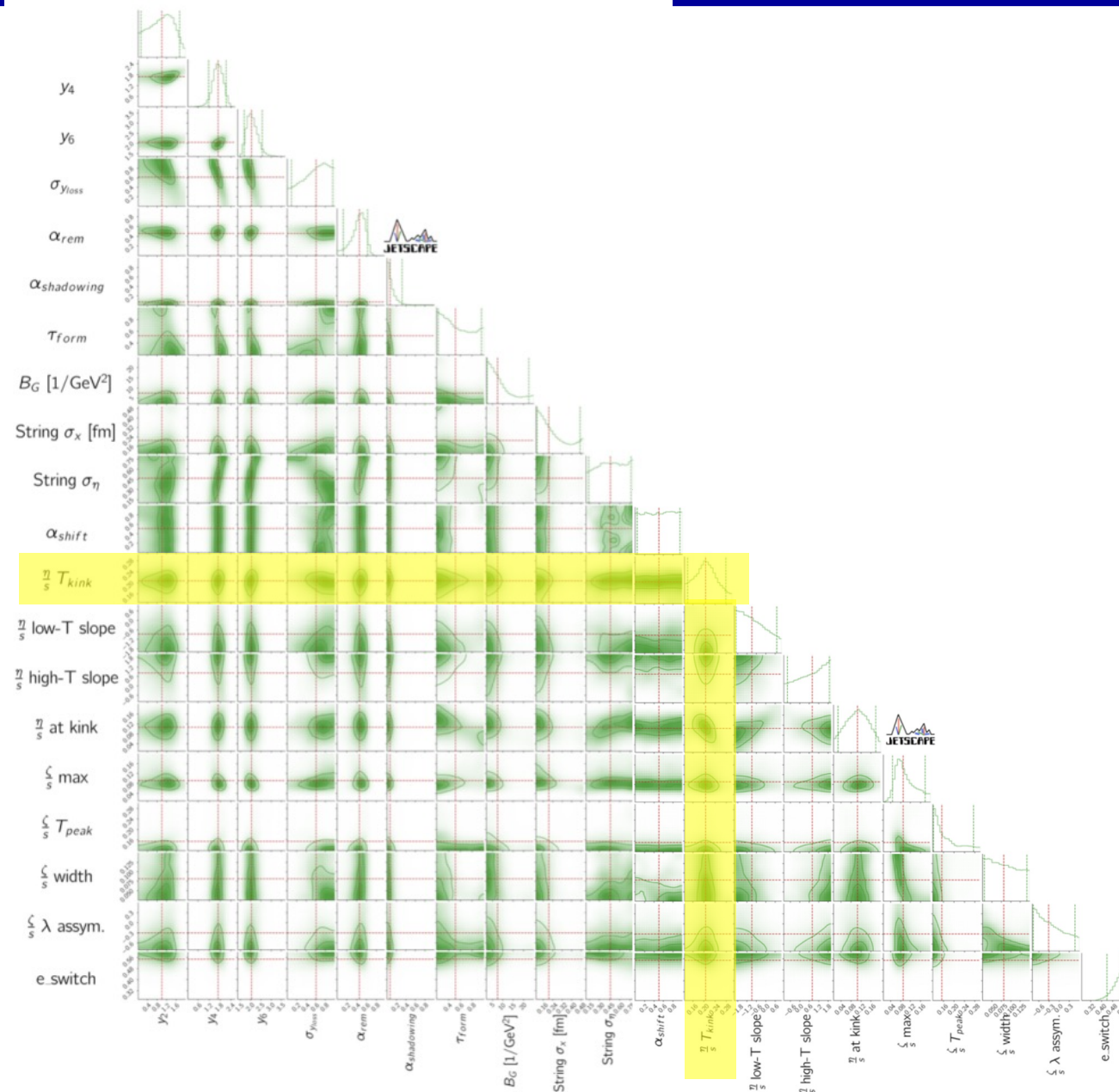
Reliable Parameter Estimation

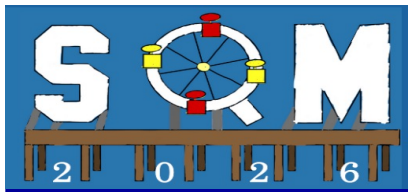
67

- Most recent results indicate

$$\frac{\eta}{s} = 0.12$$

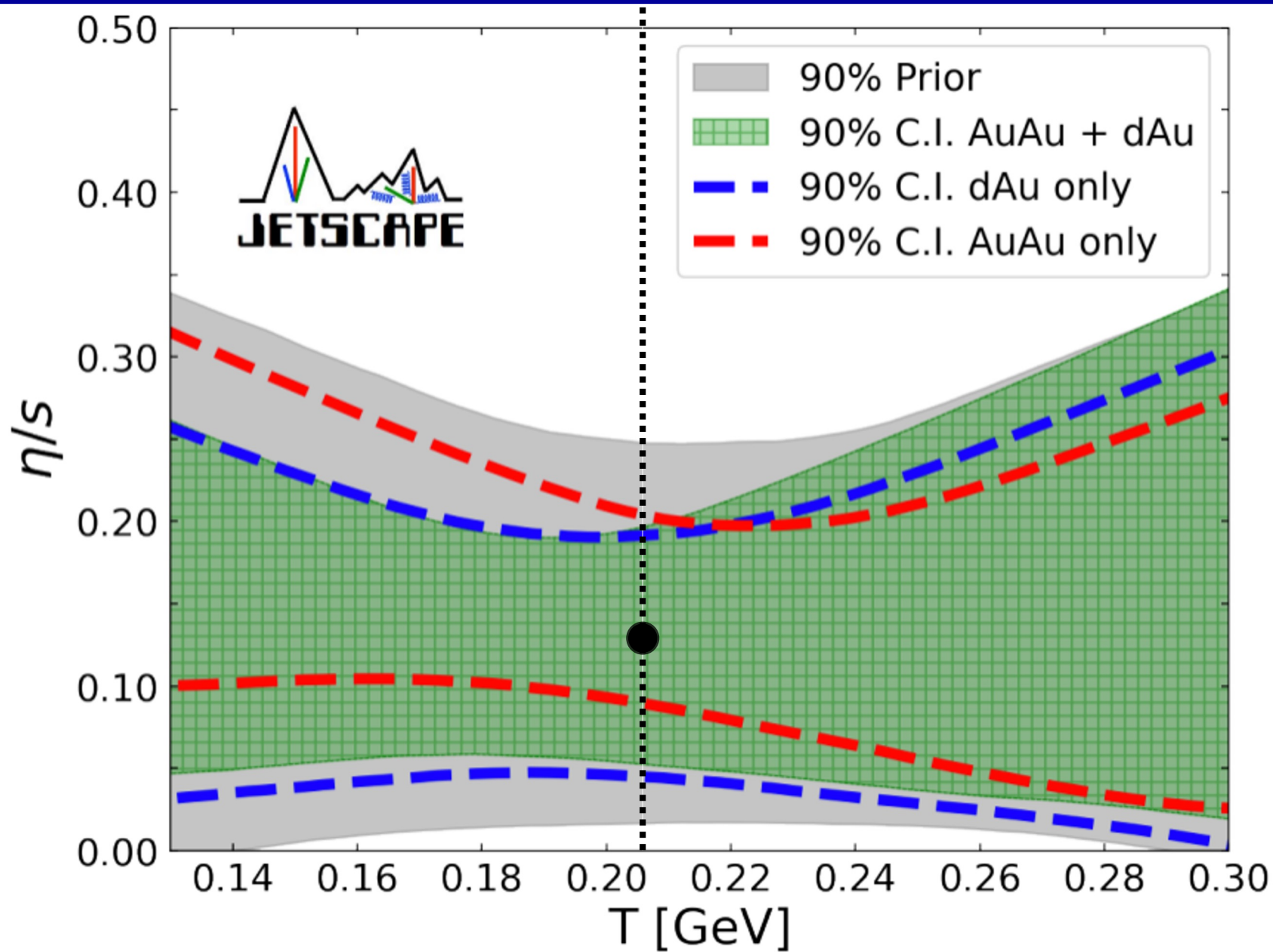
Longitudinal Dynamics of Large and Small Systems from a 3D Bayesian Calibration of RHIC Top-energy Collision Data,
JETSCAPE Collaboration, A. Mankolli et al.,
<https://arxiv.org/abs/2601.17234>





With Fully Marginalized Errors

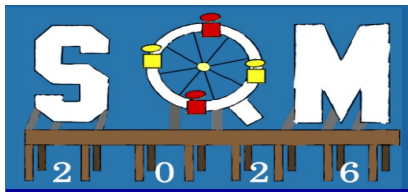
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👉 Note also that this analysis also estimates the temperature dependence of η/s .

$$\frac{\eta}{s} = 0.12 \pm 0.04$$

$$\sim 1.5 \cdot \frac{1}{4\pi}$$



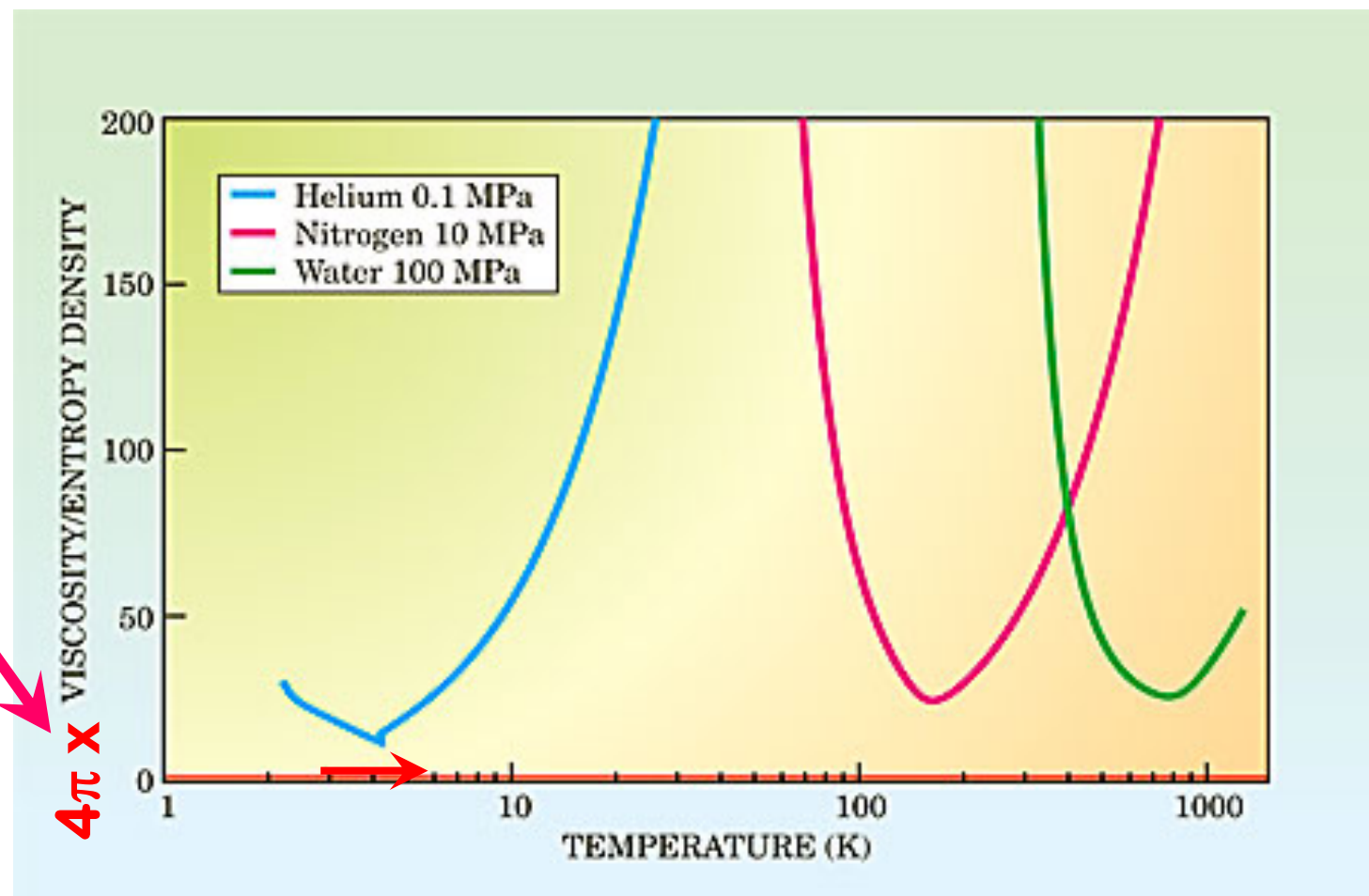
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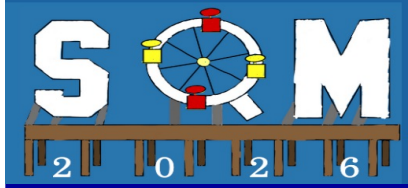
- All ordinary fluids exceed the KSS bound by factors of 10-1000

$$\frac{\eta}{s} \geq \frac{\hbar}{4\pi}$$

- ▶ “A Viscosity Bound Conjecture”,
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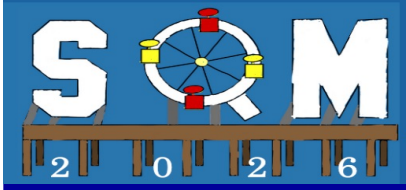
- $4\pi \times$ KSS bound
is at **unity** on this scale.
- RHIC QGP is
at $(1-2) \times$ **unity**
on this scale
- but at a temperature
 $\sim 10^{10}$ times higher !





RHIC's Final Day – 9 am, February 6th, 2026⁷⁰

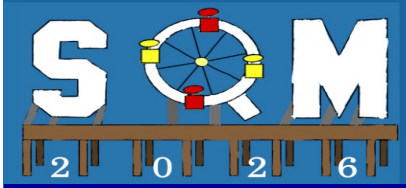




RIP RHIC

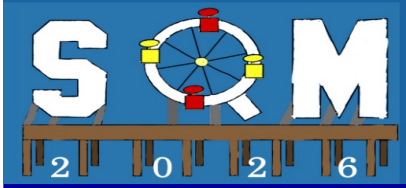
71

- RHIC has indeed fulfilled its destiny.
- The results from the world's most versatile collider have revolutionized our understanding of non-perturbative QCD and the quark-gluon plasma.
- But RHIC will not Rest In Peace, but instead . . .
- Will form the basis for the Electron-Ion Collider



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 \leftrightarrow η / s...)
- 18-Apr-05: Perfect liquid announcement



Addressing the nature of QGP discovery

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

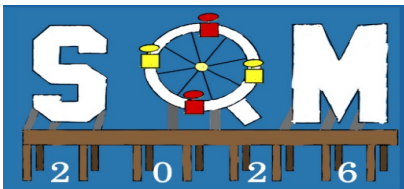
Q: What is the most relevant
“experimentally
observed property”?

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



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*

QM01: A Failed Zajc Prediction

QM2001

Time to Physics



Again, learn from the past:

First CDF publication:

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

F. Abe,⁰⁴³ D. Amidei,⁰² G. Apollinari,⁰¹² G. Ascoli,⁰⁹ M. Atac,⁰⁴⁰ P. Aschmann,⁰⁴² A. R. Baden,⁰⁴⁰ A. Barbaro-Galtieri,⁰⁴¹ V. E. Barnes,⁰¹² F. Boudet,⁰¹² S. Boffardi,⁰¹² G. Boletini,⁰¹² J. Belling,⁰¹² J. Bessiere,⁰¹² A. Bessiere,⁰¹² P. Borge,⁰⁴² S. Bertolucci,⁰¹² S. Bhadra,⁰¹² M. Blackley,⁰⁴⁰ R. Blair,⁰¹² C. Blocker,⁰¹² J. Bodil,⁰⁴² A. W. Booth,⁰⁴² G. Brandenburg,⁰⁴⁰ D. Brown,⁰⁴² A. Byon,⁰¹² K. L. Byrum,⁰¹² M. Campbell,⁰¹² R. Carey,⁰⁴² W. Cassel,⁰⁴² D. Carlsmith,⁰¹² J. T. Carroll,⁰⁴² R. Cashmore,⁰⁴⁰ F. Cervelli,⁰¹² K. Chadwick,⁰¹² T. Chape,⁰¹² G. Chiarini,⁰¹² W. Chinowsky,⁰⁴² S. Chingale,⁰¹² D. Cline,⁰¹² D. Connor,⁰⁴² M. Contreras,⁰⁴² J. Cooper,⁰⁴² M. Coudell,⁰⁴² M. Cacciari,⁰⁴² C. Day,⁰⁴² R. DeFabbis,⁰¹² M. DeFazio,⁰¹² L. DeMott,⁰¹² T. Devlin,⁰⁴² D. DiBartolomeo,⁰¹² R. Diebold,⁰¹² F. Dittus,⁰⁴² A. DiVirgilio,⁰¹² J. E. Elias,⁰⁴² R. Ely,⁰⁴² S. Enos,⁰⁴² B. Esposito,⁰⁴² A. Feldman,⁰⁴² B. Flaugher,⁰⁴² E. Focardi,⁰¹² G. W. Foster,⁰⁴² M. Franklin,⁰⁴² J. Freeman,⁰⁴² H. Frisch,⁰⁴² Y. Fukui,⁰⁴² A. F. Garfinkel,⁰⁴² P. Giannetti,⁰¹² N. Gokhale,⁰¹² P. Gionis,⁰¹² L. Gladys,⁰⁴² M. Gold,⁰⁴² K. Goulianos,⁰¹² C. Gossio-Pichler,⁰⁴² C. Haber,⁰⁴² S. R. Hahn,⁰⁴² R. Handler,⁰¹² R. M. Harris,⁰⁴² J. Hauser,⁰⁴² T. Hening,⁰¹² R. Hollebeck,⁰⁴² L. Holloway,⁰¹² P. Ho,⁰⁴² B. Hubbard,⁰⁴² P. Hume,⁰⁴² J. Huth,⁰⁴² H. Jeane,⁰⁴² R. P. Johnson,⁰⁴² U. Joshi,⁰⁴² R. W. Kadell,⁰⁴² T. Kamae,⁰¹² S. Kanda,⁰⁴² D. A. Kardalis,⁰¹² E. Karliner,⁰¹² E. Kearns,⁰⁴² R. Kephart,⁰⁴² P. Kenyon,⁰⁴² H. Kevorkian,⁰¹² S. Kim,⁰⁴² L. Kirsh,⁰⁴² K. Kondo,⁰⁴² U. Krue,⁰¹² S. E. Kuhlmann,⁰¹² A. T. Laasana,⁰¹² W. Li,⁰⁴² T. Liu,⁰¹² N. Lockyer,⁰⁴² F. Marcheno,⁰¹² R. Markeloff,⁰¹² L. A. Markonby,⁰¹² P. McIntyre,⁰¹² A. Menzione,⁰¹² T. Meyer,⁰⁴² S. Mikamo,⁰⁴² M. Miller,⁰⁴² T. Minachi,⁰⁴² S. Misotti,⁰¹² M. Mishina,⁰⁴² S. Miyashita,⁰⁴² N. Mondal,⁰¹² S. Mori,⁰⁴² Y. Morita,⁰⁴² A. Mukherjee,⁰⁴² C. Newman-Holmes,⁰⁴² L. Nodman,⁰¹² R. Paoletti,⁰¹² A. Parr,⁰⁴² J. Patrick,⁰⁴² T. J. Phillips,⁰⁴² H. Piskorski,⁰⁴² R. Plankert,⁰¹² L. Pondrom,⁰¹² J. Proulx,⁰¹² G. Puzi,⁰¹² D. Quarrie,⁰⁴² K. Ragan,⁰⁴² G. Radlinger,⁰¹² J. Rhoades,⁰¹² F. Rimondi,⁰⁴² L. Ristori,⁰¹² T. Rohaly,⁰⁴² A. Roodman,⁰⁴² A. Sansoni,⁰¹² R. Sand,⁰¹² V. Scarfone,⁰¹² P. Schlachet,⁰¹² E. E. Schmitt,⁰⁴² P. Schoenow,⁰¹² M. H. Schuch,⁰¹² R. Schwimmer,⁰⁴² A. Scribano,⁰¹² S. Segler,⁰⁴² M. Sekiguchi,⁰⁴² P. Sestini,⁰¹² M. Shapiro,⁰⁴² M. Shend,⁰¹² M. Shibata,⁰⁴² M. Shochet,⁰¹² J. Siegrist,⁰⁴² P. Sinervo,⁰⁴² J. Skarha,⁰¹² D. A. Smith,⁰¹² F. D. Soider,⁰¹² R. St. Denis,⁰⁴² A. Stefani,⁰¹² Y. Takaiwa,⁰⁴² K. Takikawa,⁰⁴² S. Tarn,⁰¹² D. Theriot,⁰⁴² A. Tollestrup,⁰⁴² G. Tonelli,⁰¹² Y. Tsai,⁰⁴² F. Udagawa,⁰⁴² D. Underwood,⁰¹² R. Vidal,⁰⁴² R. G. Wagner,⁰¹² R. L. Wagner,⁰⁴² J. Walsh,⁰⁴² T. Watts,⁰⁴² R. Webb,⁰¹² T. Westhousen,⁰¹² S. White,⁰¹² A. Wicklund,⁰¹² H. H. Williams,⁰⁴² T. Yamamoto,⁰⁴² A. Yamashita,⁰⁴² K. Yamoka,⁰⁴² G. P. Yeh,⁰⁴² J. Yeh,⁰⁴² and F. Zetti,⁰⁴²

⁰⁴³Argonne National Laboratory, Argonne, Illinois 60439

⁰⁴²Brandeis University, Waltham, Massachusetts 02154

⁰¹²University of Chicago, Chicago, Illinois 60637

⁰⁴⁰Fermi National Accelerator Laboratory, Batavia, Illinois 60510

⁰⁴¹Laboratori Nazionali di Frascati, Istituto Nazionale di Fisica Nucleare, Frascati, Italy

⁰¹²Harvard University, Cambridge, Massachusetts 02138

⁰¹²University of Illinois, Urbana, Illinois 61801

⁰⁴²National Laboratory for High Energy Physics (KEK), Tsukuba-gun, Ibaraki-ken 305, Japan

⁰⁴²Lawrence Berkeley Laboratory, Berkeley, California 94720

⁰¹²University of Pennsylvania, Philadelphia, Pennsylvania 19104

⁰¹²Istituto Nazionale di Fisica Nucleare, University and Scuola Normale Superiore di Pisa, Pisa, Italy

⁰⁴²Purdue University, West Lafayette, Indiana 47907

⁰⁴²Rockefeller University, New York, New York 10021

⁰⁴²Rutgers University, Piscataway, New Jersey 08854

⁰⁴²Texas A&M University, College Station, Texas 77843

⁰¹²University of Tsukuba, Ibaraki 305, Japan

⁰¹²University of Wisconsin, Madison, Wisconsin 53706

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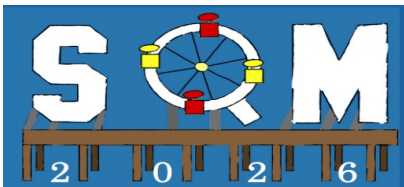
Measurements of inclusive transverse-momentum spectra for charged particles produced in proton-antiproton collisions at \sqrt{s} of 630 and 1800 GeV are presented and compared with data taken at lower energies.

PACS numbers: 13.87.N0

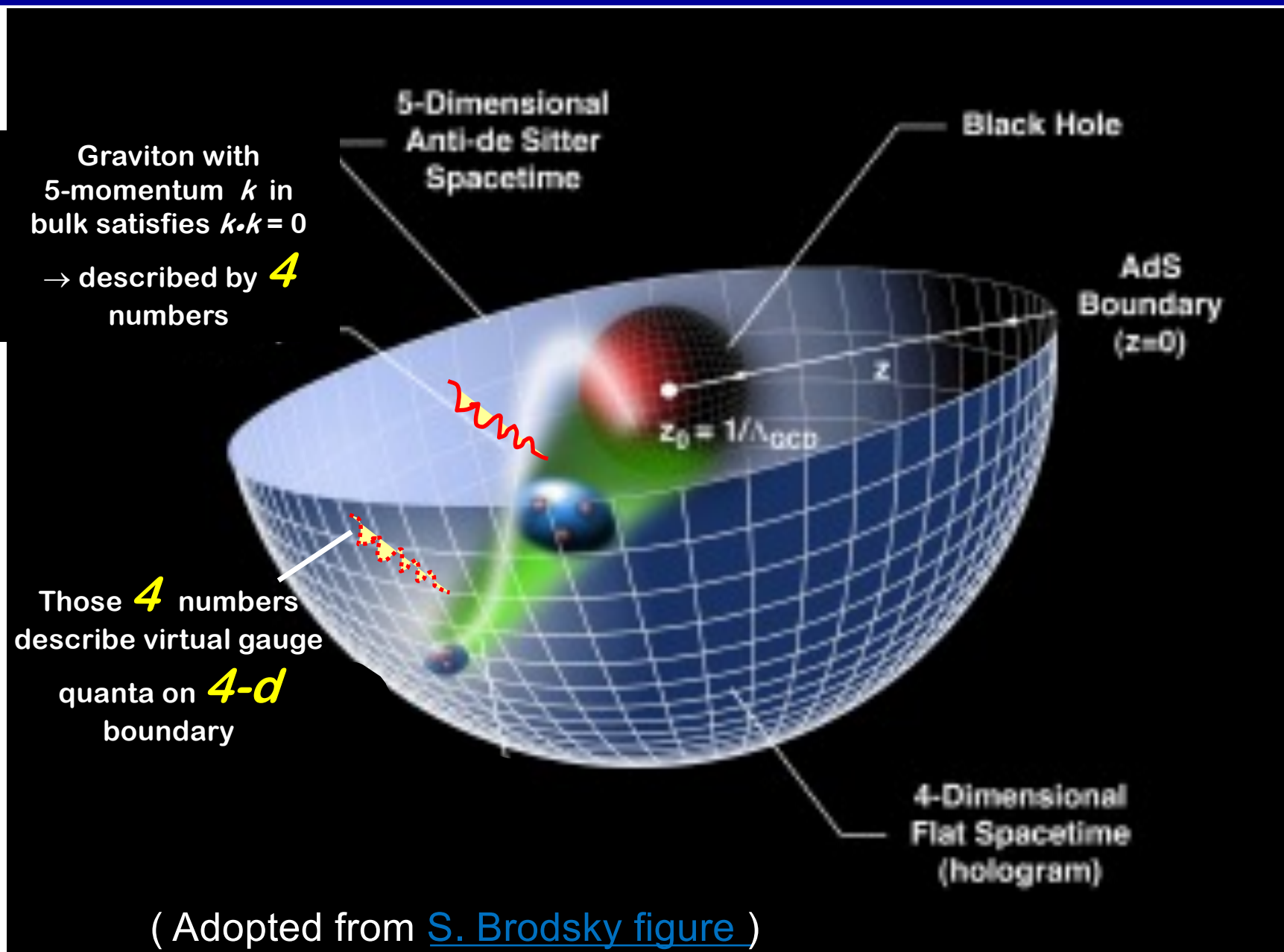
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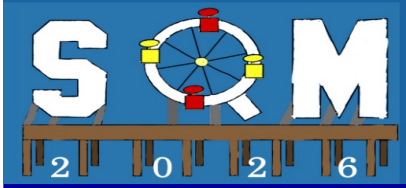
14-Jan-01

W.A. Zajc

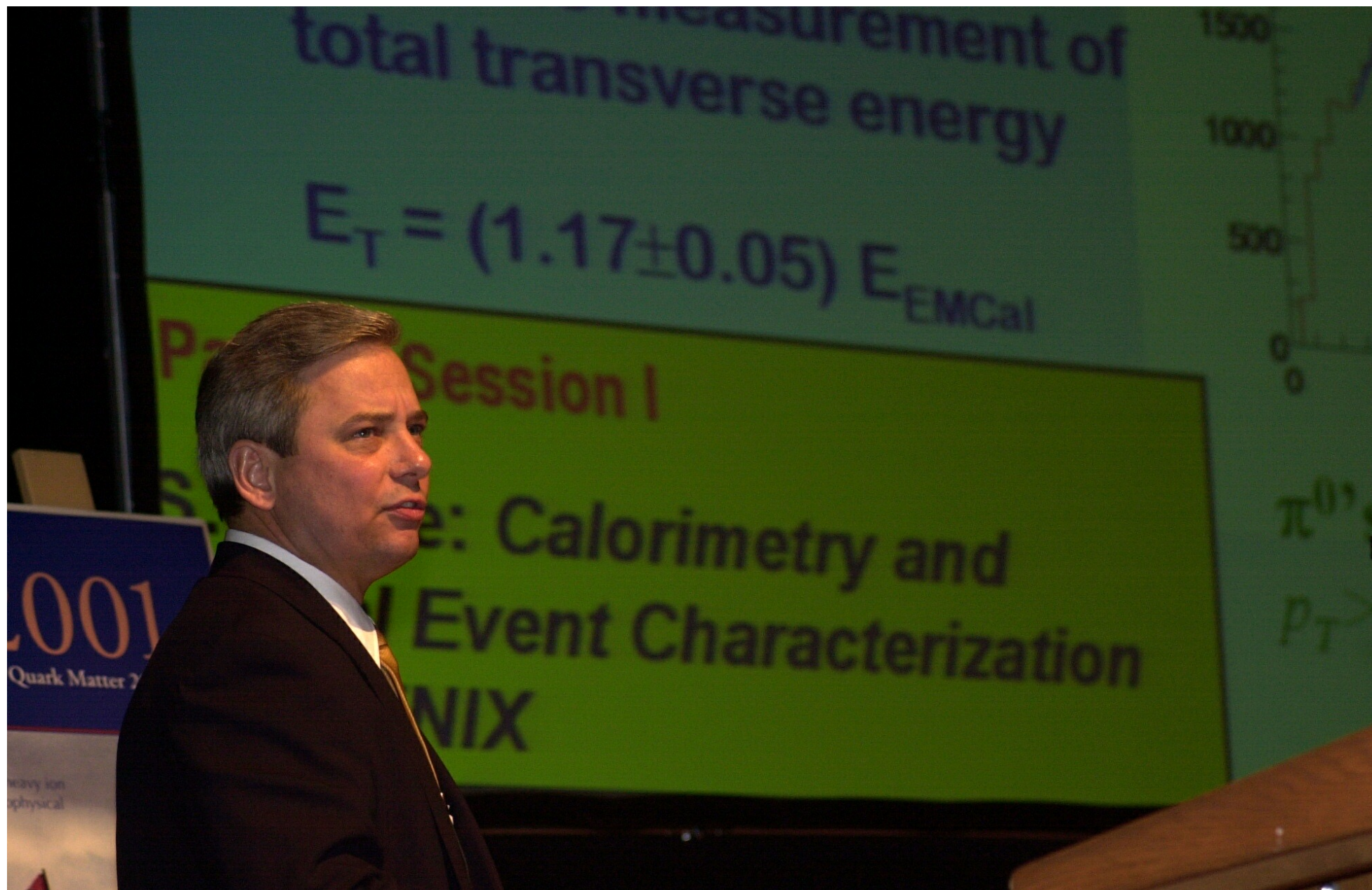


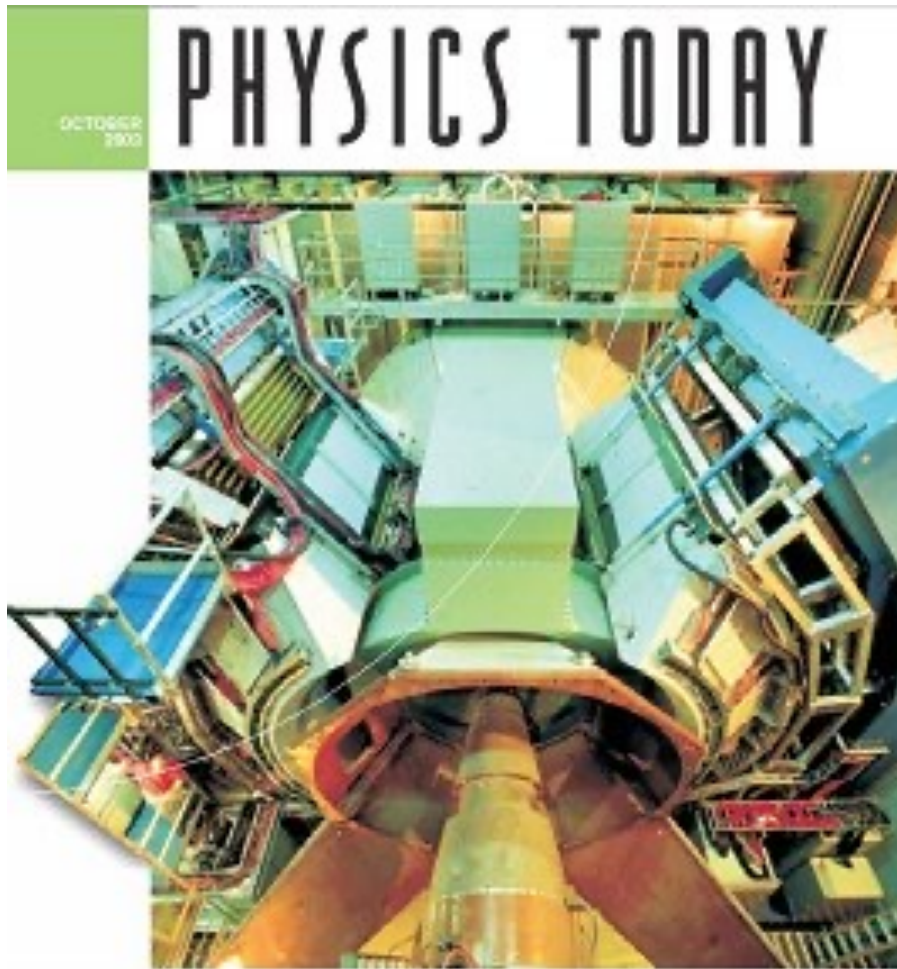
$$(\text{Minimal}) \text{ AdS / CFT} \Rightarrow \frac{\eta}{s} \geq \frac{1}{4\pi}$$



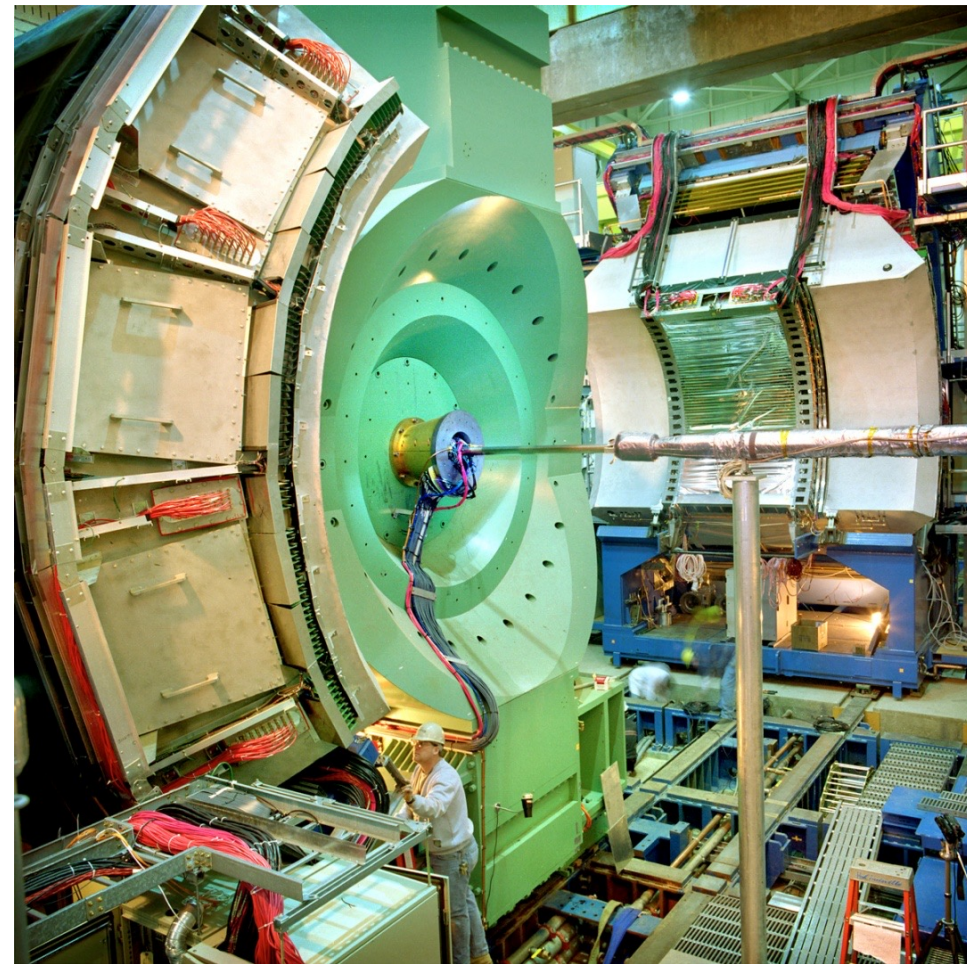


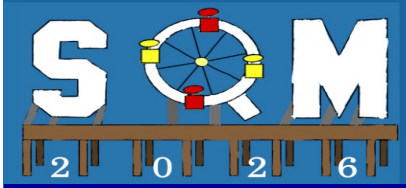
- 18-Feb-00
- QUARK MATTER POSTPONEMENT
We would like to announce that the next Quark Matter conference has been postponed from its original dates of July 17-22, 2000 to January 15-20, 2001 due to the interference of the original date with the extension of the first RHIC running period.



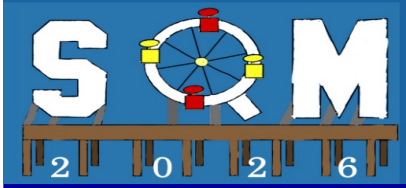


Nuclear matter in extremis





- 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 ?*



- 18-Oct-99: (Public) **“The recently announced delay of the RHIC schedule provides us with an opportunity to make ready a significant fraction of the Baseline detector for the very start of RHIC operations. This is a wonderful chance for us to begin RHIC physics with both the East and West arms, with the obvious tremendous gain in our early physics potential. Obviously, it behooves us to do all that is possible to ensure the success of this new plan... By staying on track to complete the East Arm assembly by early December, we can be in position to do physics with both central arms as soon as there are collisions in RHIC. With your continued efforts, this can and will be accomplished.”**
- (Private) “should be a call to arms to come and help in this last ditch effort to even the playing field with the other experiments!”