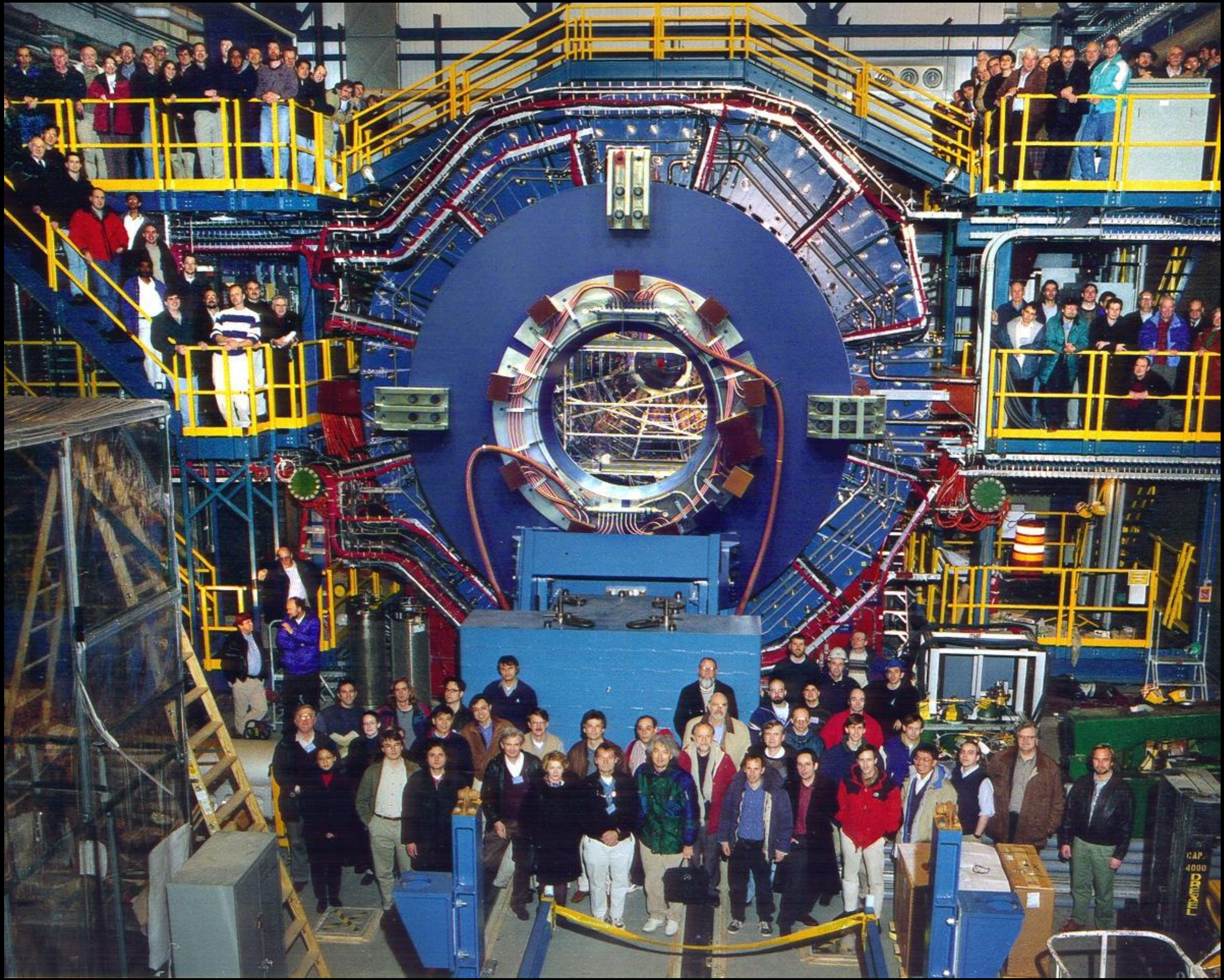
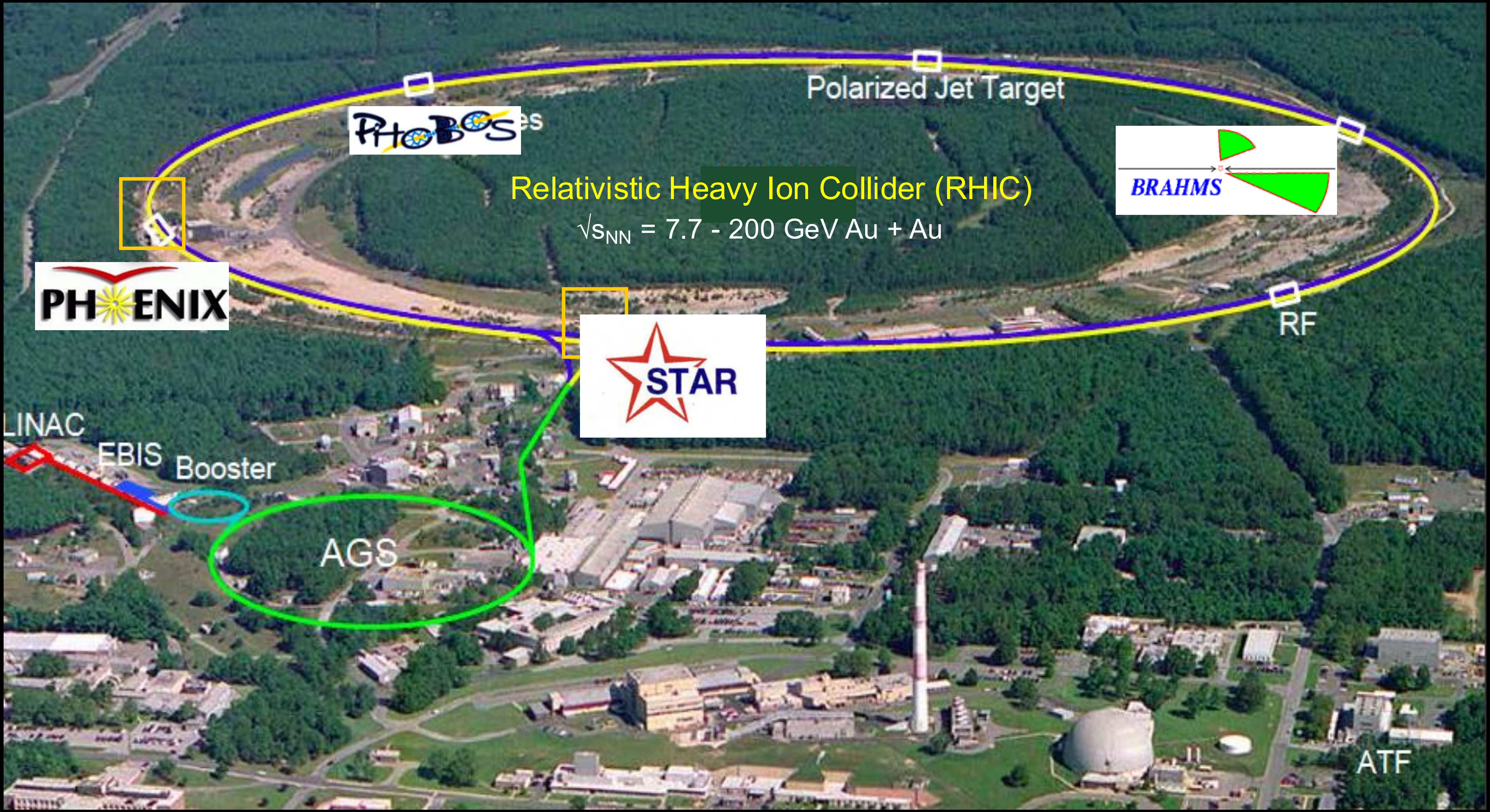
A STAR is Born!



Early RHIC



Polarized Jet Target
PHOBOS
BRAHMS
Relativistic Heavy Ion Collider (RHIC)
$\sqrt{s_{NN}}$ = 7.7 - 200 GeV Au + Au
PHENIX
STAR
RF
LINAC
EBIS
Booster
AGS
ATF

1989 – Designing & Developing an Experiment for RHIC

Applied for LBL Director's Funds (1989)
- for new initiative to design an experiment for RHIC
- Requested funds for an engineer and a postdoc
- Plus, funds to invite speakers to discuss physics and detector aspects of a new RHIC experiment
- Received $200K

Hired Bill Edwards and Bill Christie
- Edwards (mechanical design) and Christie (GEANT experiment design)

Invited Theorists and Experimentalists for physics and detector discussions
- RHIC Planning Meetings at LBL (Oct '89 – July '90) described in next slides

*Apologies - many slides that follow were digitized from transparencies!

Planning at LBL for an Experiment for RHIC

NSD/RNC Group

RHIC PLANNING CHRONOLOGY

5 Oct 89	NSD Retreat developed RNC plan
18 Oct 89	1st RHIC Planning Meeting (RPM)
30 May 90	23rd RPM
11-15 Jun 90	RHIC Experiment Workshop, LBL
2-7 Jul 90	4th Workshop on Experiments & Detectors for RHIC, BNL

Planning at LBL for an Experiment for RHIC

RHIC PLANNING MEETINGS
October 18, 1989 - May 30, 1990

VOLUME I

1. Wednesday, October 18, 1989	Miklos Gyulassy, LBL "Physics Objectives at RHIC"
2. Wednesday, October 25, 1989	Doug Greiner, LBL "4π Tracking TPC"
3. Wednesday, October 25, 1989	James Symons, LBL "Large Pt Jets at RHIC"
4. Tuesday, October 31, 1989	John Harris, LBL "Tracking and Particle Identification at Midrapidity"
5. Tuesday, October 31, 1989	Chuck Naudet, LBL "Jets in pA FermiLab"
6 Wednesday, November 8, 1989	Hans-Georg Ritter. LBL "4π Calorimetry"
7. Wednesday, November 15, 1989	Jim Carroll, UCLA/LBL "Electron Pairs"
8. Thursday, November 30, 1989	Glenn Young, ORNL "Muon Pairs"
9. Wednesday, December 13, 1989 (not included)	Discussion on Future Plans

Planning at LBL for an Experiment for RHIC

VOLUME II

10. Wednesday, January 10, 1990	Lee Schroeder, LBL "RHIC the Machine"
11. Tuesday, January 16, 1990	Tom Ludlam, BNL "Getting Started with RHIC Experiments"
12. Wednesday, January 31, 1990	Chuck Gruhn, LBL "RHIC Tracking Detectors, Compromises and Physics"
13. Wednesday, February 7, 1990	Walter Geist, LBL "High pt Jets"
14. Wednesday, February 14, 1990	Grazyna Odyniec, LBL "Strangeness Production at RHIC"
15. Wednesday, March 7, 1990	Richard Kadel, LBL "The CDF Tracking Chamber"
16. Wednesday, March 14, 1990	RHIC Discussion on Jets Matt Bloomer, LBL Jim Carroll, UCLA/LBL
17. Wednesday, March 28, 1990	Xin-Nian Wang, LBL "The Role of Multiple Mini-Jets in High Energy Hadronic Interactions"
18. Tuesday, April 3, 1990	Shoji Nagamiya Columbia University "Thoughts on a RHIC Experiment"
19. Wednesday, April 11, 1990	Bill Carithers, LBL "The CDF Calorimeters"

VOLUME III

20. Tuesday, April 17, 1990	Barbara Jacak, LANL "RHIC R&D Efforts on Calorimetry at Los Alamos"
21. Wednesday, April 25, 1990 (not included)	Leon van Hove, CERN "Recent Developments in Soft Multiparticle Production"
22. Wednesday, May 23, 1990	Doug Shy and Bill Christie, LBL Reports of Tracking and Jet/Calorimetry Subgroups
23. Wednesday, May 30, 1990	Bill Christie, Matt Bloomer, Chuck Naudet, LBL Reports of Tracking and Jet/Calorimetry Subgroups

RHIC – A New Era of Experiments in Nuclear Physics

Technological and Detector Developments

New Detector Techniques
- TPC
- RICH
- Photon Detectors
- CCD's
- Smart Calorimeters
- Scintillating Fibers
- ...

Data Acquisition
- Large Event Sizes
- Fast High Density Electronics
- Rapid Online Data Reduction
- Large Scale Data Storage
- ...

multiple

Integration of Complex Detector Systems into Experiments

Technological Developments
- Data Storage Devices and Media
- Integrated Electronics
- ...

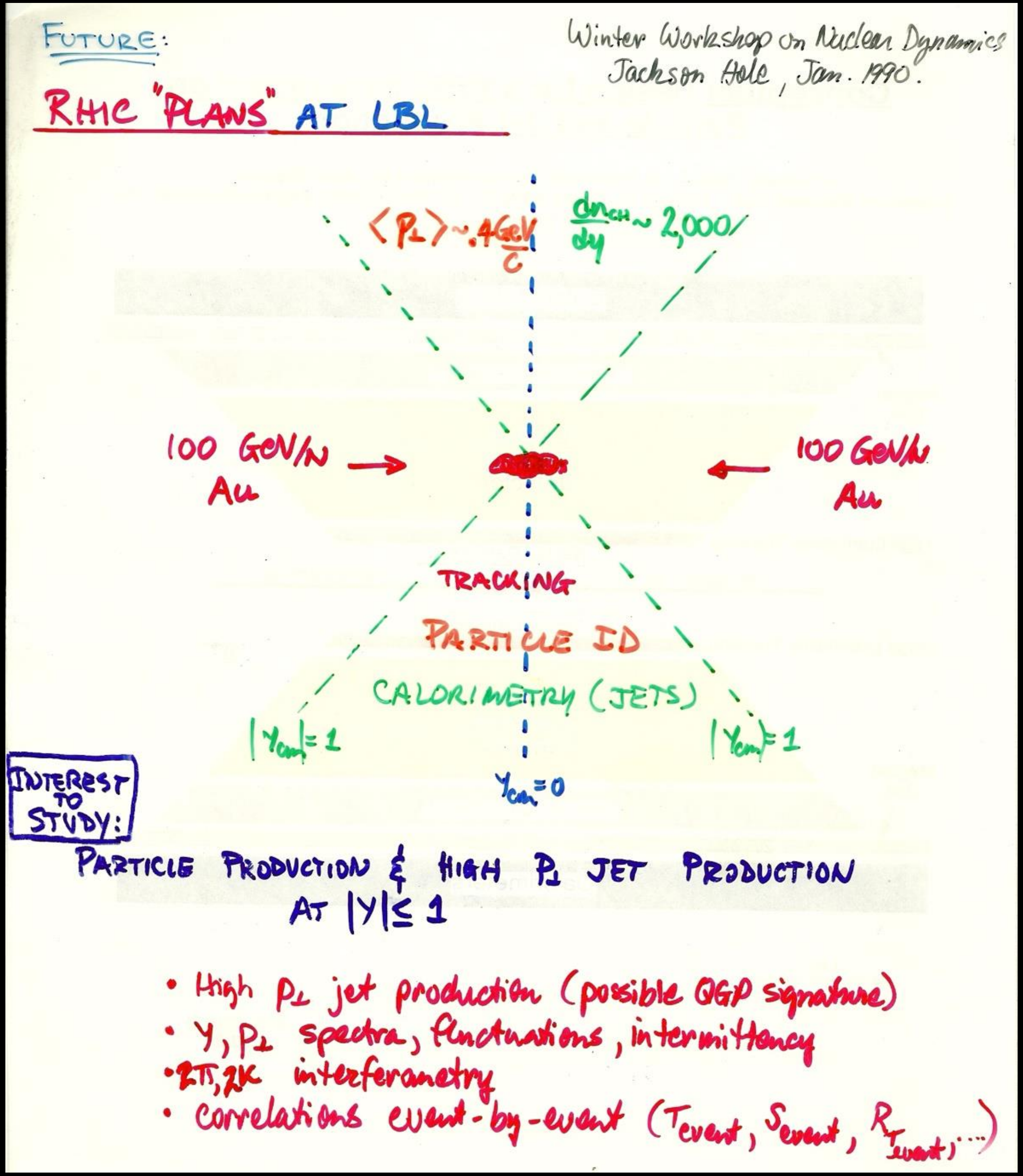
Operational and Sociological Experience

Large Collaborations
- Operation and Communication
- Planning and Organization

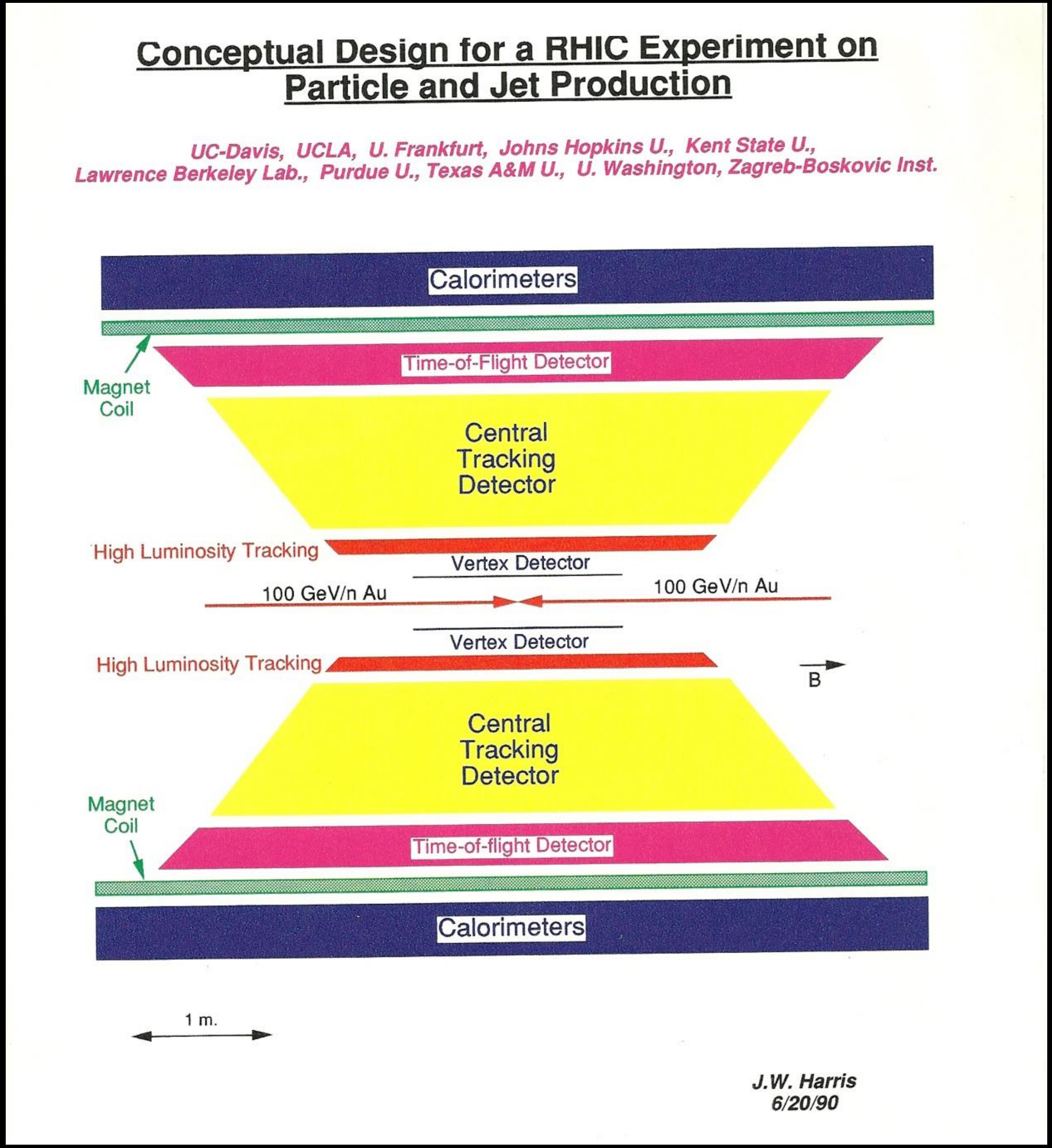
Infra-structure
- Lessons from High Energy Community
- Hiring Practices

General Remarks
- Must Combine Resources
- We Are Prepared - Is Nuclear Physics in General?

1990 Concept of a New Experiment for RHIC



Art!

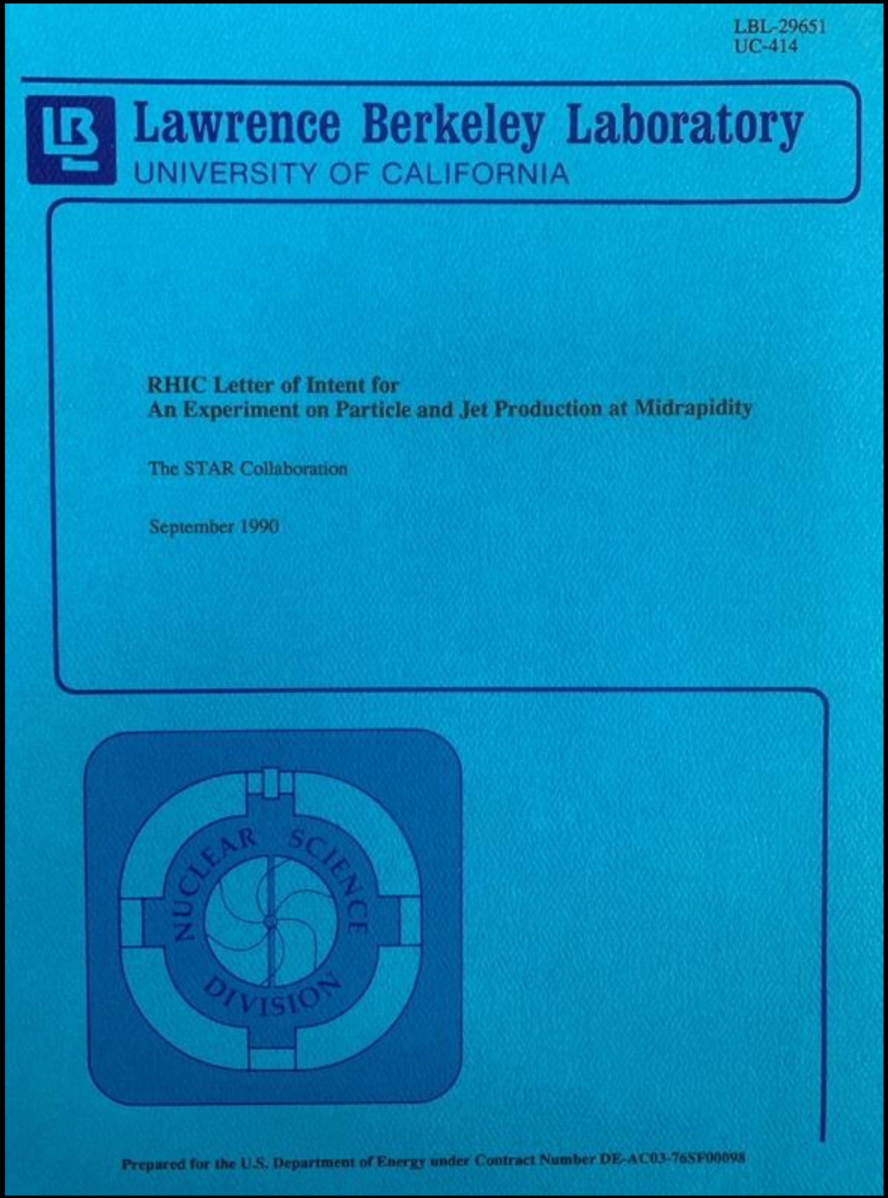


Two Proposals for TPC Experiments Submitted at RHIC

- The experiment (soon to become known as STAR) was a solenoidal design
- A TPC of dipole design was proposed by a BNL-Rice Collaboration

Newly appointed BNL Lab Associate Director (Nobel Laureate) Prof. Mel Schwartz

STAR RHIC Letter of Intent – September 1990



LBL-29651
UC-414

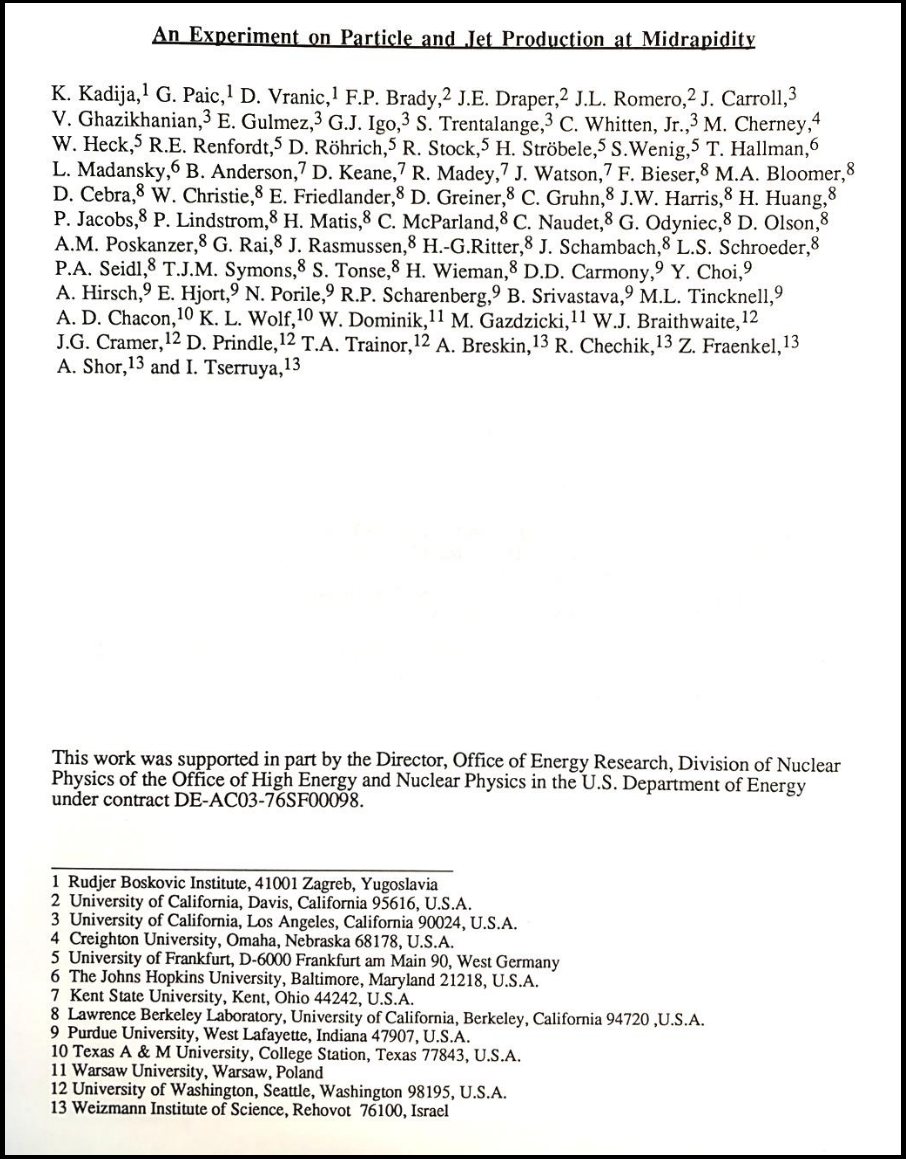
Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

RHIC Letter of Intent for
An Experiment on Particle and Jet Production at Midrapidity

The STAR Collaboration

September 1990

Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098



An Experiment on Particle and Jet Production at Midrapidity

K. Kadija,[1] G. Paic,[1] D. Vranic,[1] F.P. Brady,[2] J.E. Draper,[2] J.L. Romero,[2] J. Carroll,[3] V. Ghazikhanian,[3] E. Gulmez,[3] G.J. Igo,[3] S. Trentalange,[3] C. Whitten, Jr.,[3] M. Cherney,[4] W. Heck,[5] R.E. Renfordt,[5] D. Röhrich,[5] R. Stock,[5] H. Ströbele,[5] S.Wenig,[5] T. Hallman,[6] L. Madansky,[6] B. Anderson,[7] D. Keane,[7] R. Madey,[7] J. Watson,[7] F. Bieser,[8] M.A. Bloomer,[8] D. Cebra,[8] W. Christie,[8] E. Friedlander,[8] D. Greiner,[8] C. Gruhn,[8] J.W. Harris,[8] H. Huang,[8] P. Jacobs,[8] P. Lindstrom,[8] H. Matis,[8] C. McParland,[8] C. Naudet,[8] G. Odyniec,[8] D. Olson,[8] A.M. Poskanzer,[8] G. Rai,[8] J. Rasmussen,[8] H.-G.Ritter,[8] J. Schambach,[8] L.S. Schroeder,[8] P.A. Seidl,[8] T.J.M. Symons,[8] S. Tonse,[8] H. Wieman,[8] D.D. Carmony,[9] Y. Choi,[9] A. Hirsch,[9] E. Hjort,[9] N. Porile,[9] R.P. Scharenberg,[9] B. Srivastava,[9] M.L. Tincknell,[9] A. D. Chacon,[10] K. L. Wolf,[10] W. Dominik,[11] M. Gazdzicki,[11] W.J. Braithwaite,[12] J.G. Cramer,[12] D. Prindle,[12] T.A. Trainor,[12] A. Breskin,[13] R. Chechik,[13] Z. Fraenkel,[13] A. Shor,[13] and I. Tserruya,[13]

This work was supported in part by the Director, Office of Energy Research, Division of Nuclear Physics of the Office of High Energy and Nuclear Physics in the U.S. Department of Energy under contract DE-AC03-76SF00098.

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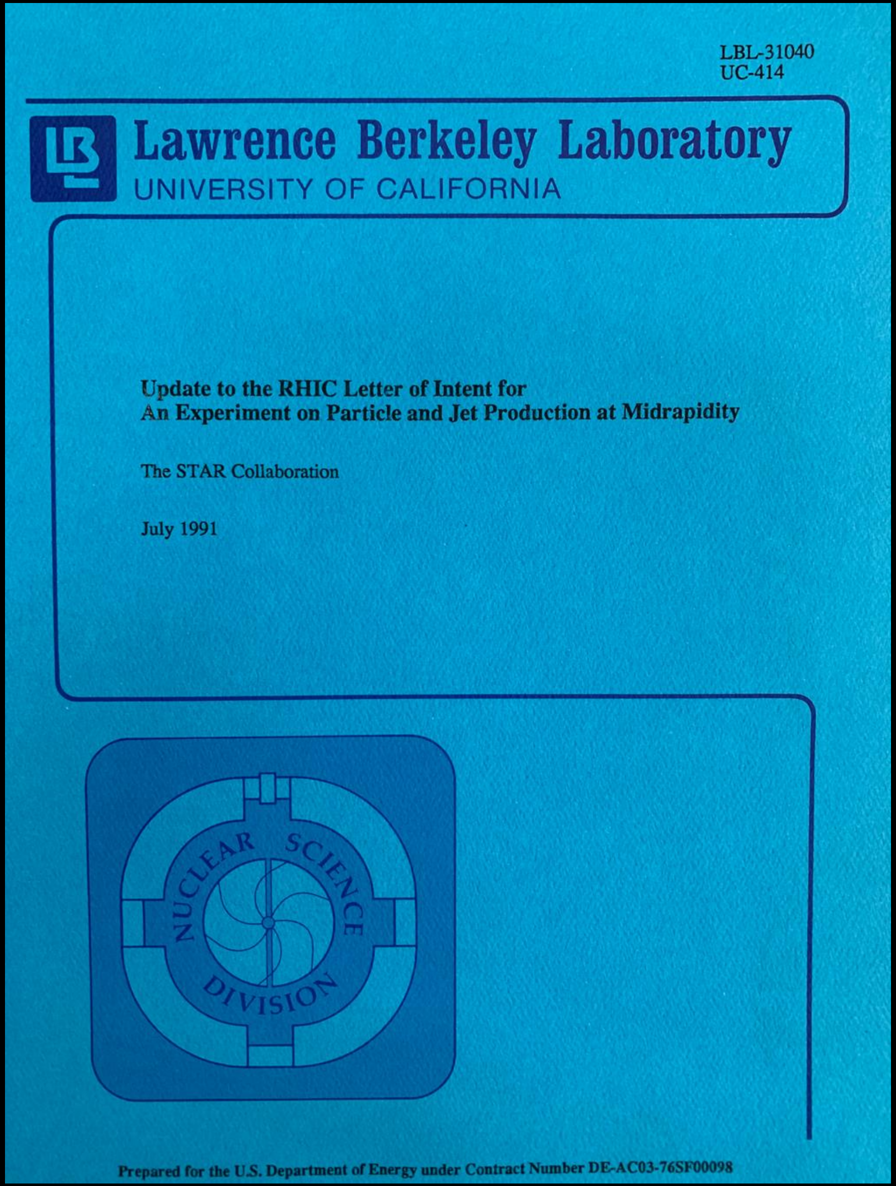
8 Lawrence Berkeley Laboratory, University of California, Berkeley, California 94720 ,U.S.A.
9 Purdue University, West Lafayette, Indiana 47907, U.S.A.
10 Texas A & M University, College Station, Texas 77843, U.S.A.
11 Warsaw University, Warsaw, Poland
12 University of Washington, Seattle, Washington 98195, U.S.A.
13 Weizmann Institute of Science, Rehovot 76100, Israel

STAR Update to RHIC Letter of Intent – July 1991



LBL-31040
UC-414

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

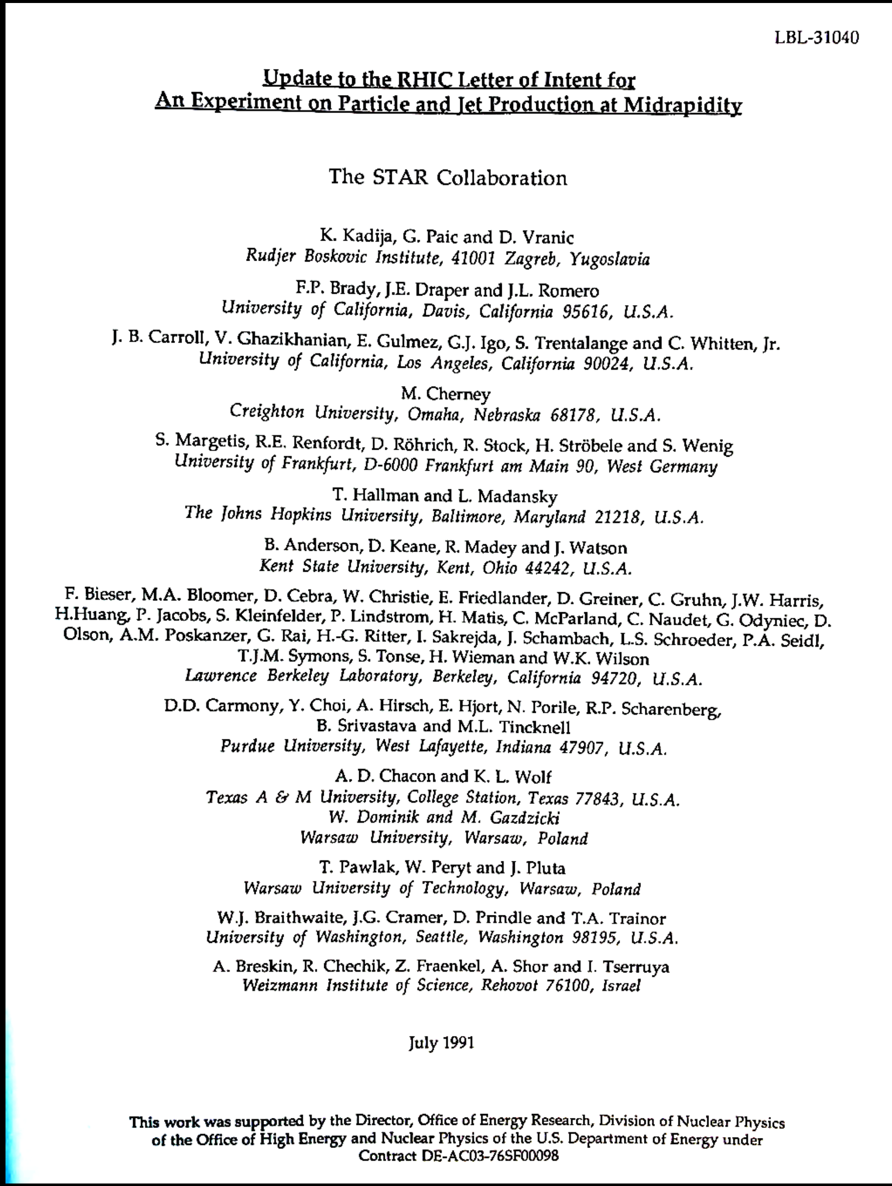
Update to the RHIC Letter of Intent for
An Experiment on Particle and Jet Production at Midrapidity

The STAR Collaboration

July 1991

NUCLEAR SCIENCE DIVISION

Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098



LBL-31040

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The STAR Collaboration

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July 1991

This work was supported by the Director, Office of Energy Research, Division of Nuclear Physics of the Office of High Energy and Nuclear Physics of the U.S. Department of Energy under Contract DE-AC03-76SF00098

Dipole TPC RHIC Letter of Intent – July 1991

Letter of Intent

Search for a Quark Gluon Plasma and Other New Phenomena with a 4π Tracking TPC Magnetic Spectrometer at RHIC *

Experimental Collaboration:

G. Danby, S.E. Eiseman, A. Etkin, K.J. Foley, R.W. Hackenburg, M. LeVine, R.S. Longacre, W.A. Love, T.W. Morris, E.D. Platner, A.C. Saulys and J.H. Van Dijk
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S.J. Lindenbaum
Brookhaven National Laboratory and City College of New York

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M. Kalplan, K. Karol and E. Vardaci
Carnegie-Mellon University

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University of Notre Dame, Notre Dame, Indiana 46556

D.L. Adams, S. Ahmad, B.E. Bonner, J.A. Buchanan, C.N. Chiou, J.M. Clement, M.D. Corcoran, T. Empl, H.E. Miettinen, G.S. Mutchler, J.B. Roberts and J. Skeens
Rice University, Houston, Texas 77251

Spokesman: B.E. Bonner

Management and Policy Board

B.E. Bonner, K.J. Foley, V.P. Kenney and S.J. Lindenbaum

Two Proposals for TPC Experiments Submitted at RHIC

Newly appointed BNL Lab Associate Director (Nobel Laureate) Prof. Mel Schwartz

Instructed the two TPC collaborations to discuss a merger

[A few comments on the process and a side comment!]

Merger forming the STAR Collaboration – 31 July 1991

31 July 1991

Update to the RHIC Letter of Intent for
An Experiment on Particle and Jet Production at Midrapidity

The STAR Collaboration

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Spokesperson: J.W. Harris
Deputy Spokespersons: E.D. Platner, A.M. Poskanzer

Slices from Merger Collaboration Meeting. Thanks Liz!

Updated Letters of Intent at RHIC

BNL PAC Meeting (August 1991), PAC gave advice to Prof. Schwartz!
Schwarz decisions on experiments:

One TPC experiment (became STAR) approved with solenoidal magnet design

PHENIX experiment to be formed from merger of four proposals

formerly TALES, SPARC, OASIS, and DIMUON

Small experiment for quick results approved PHOBOS

BRAHMS (proposed and approved later)

A Time Projection Chamber?

Why a TPC for central tracking detector?

- Is it fast enough?
- Can it handle the charged particle multiplicity?
- What about two-track and momentum resolutions (B-field strength and design)
- What about space-charge distortions?
- .
- .

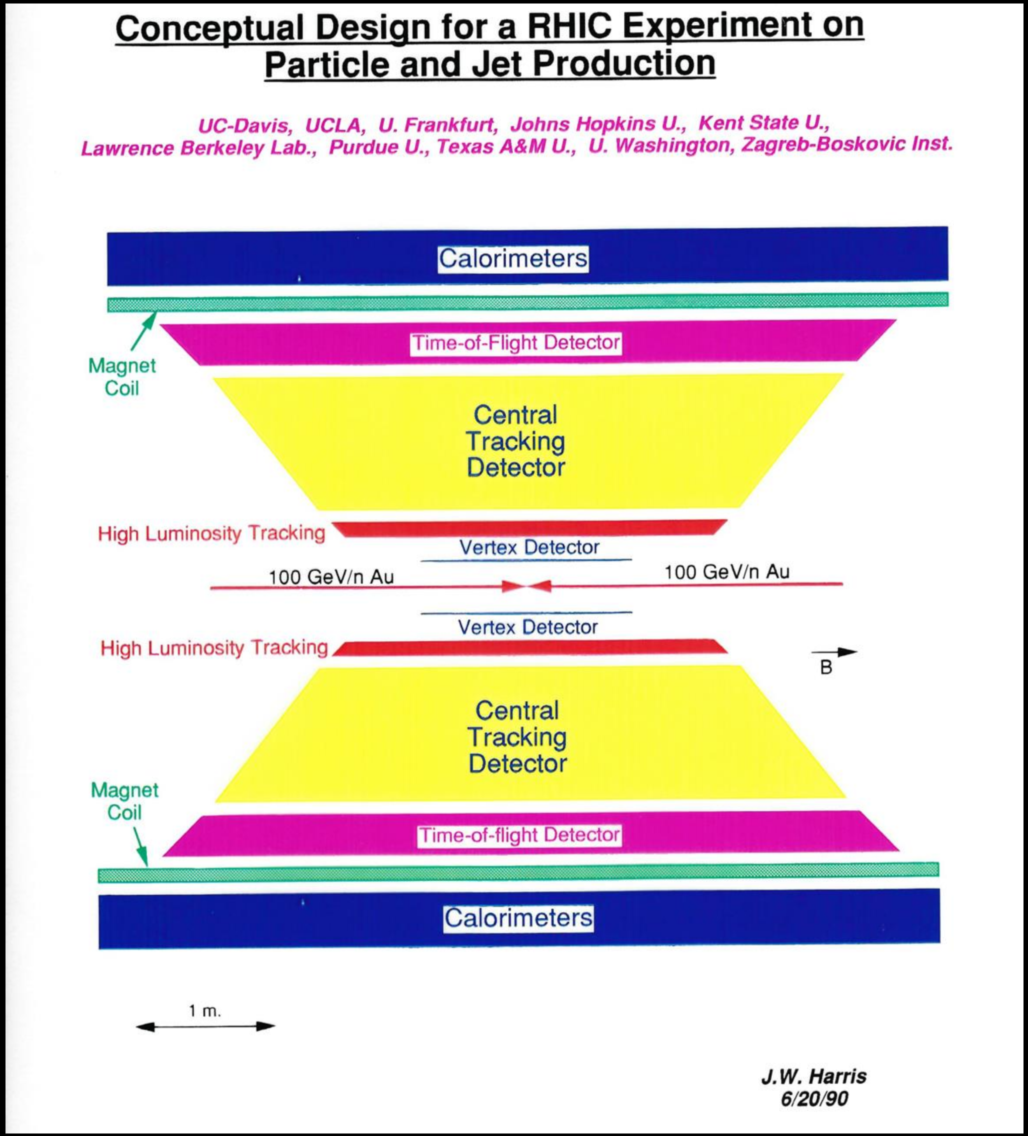
Howard Wieman became the TPC Project Director!!

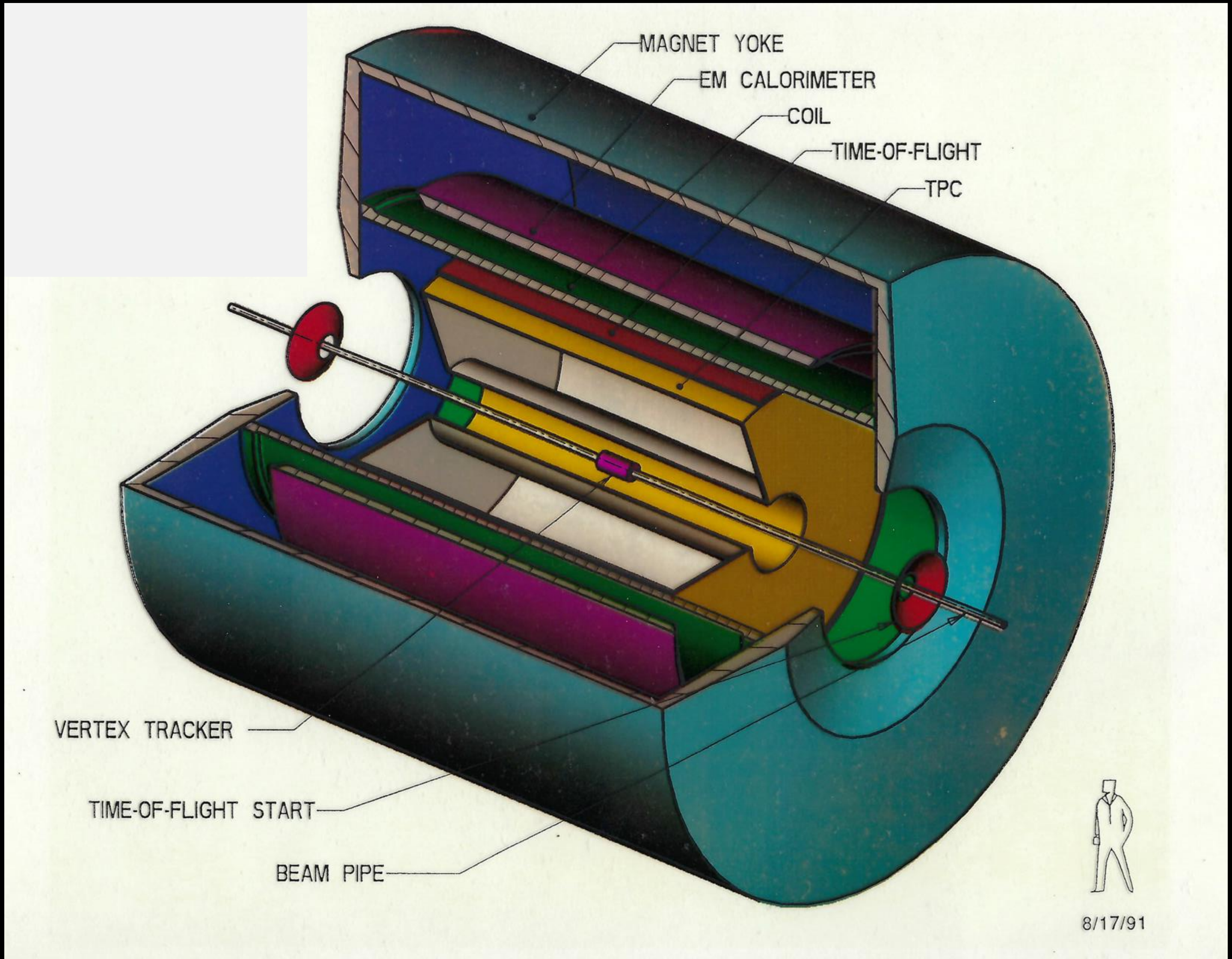
- Designed and oversaw TPC and electronics design …… whew!

Designed for 2000 charged particles per unit rapidity (from theoretical predictions)

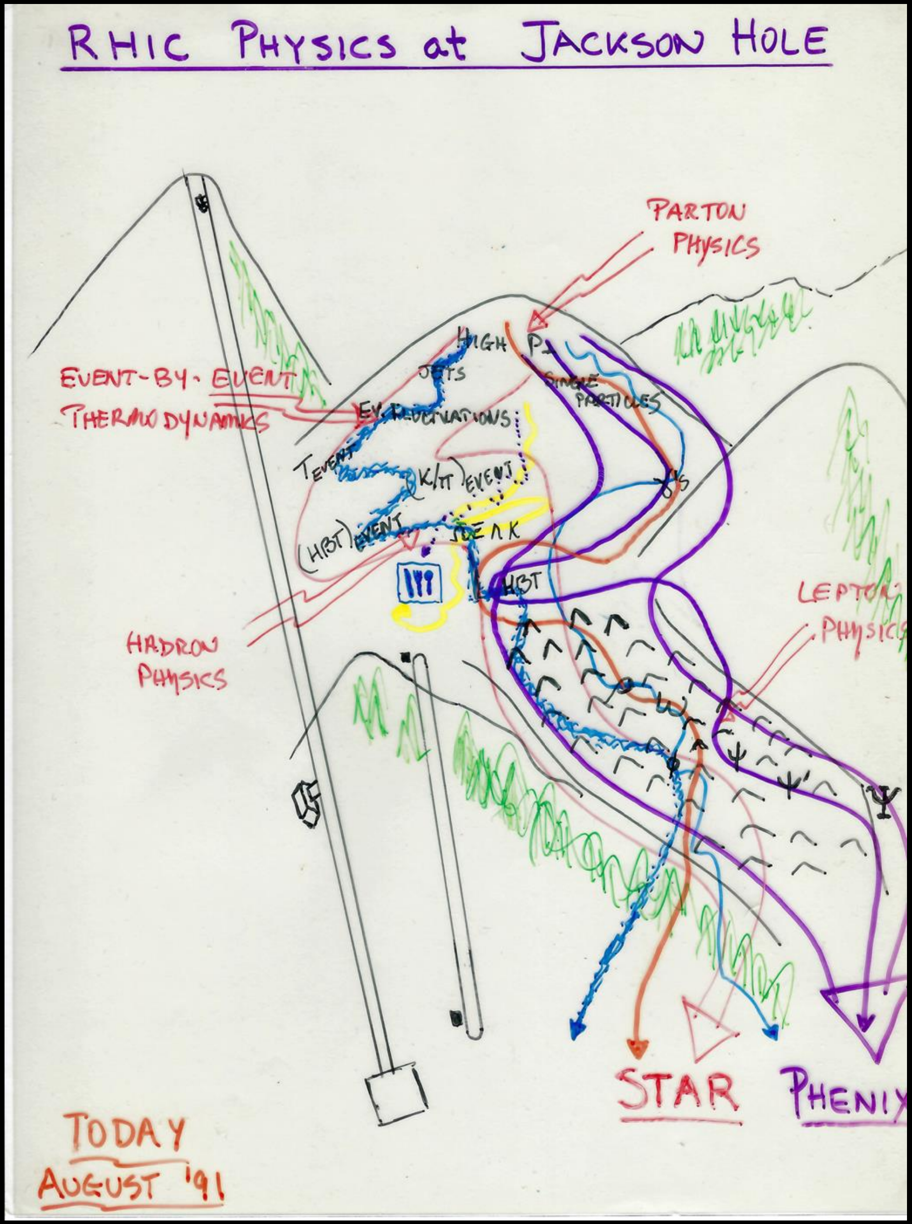
- Later measured the multiplicity at RHIC to be ~800 per unit rapidity ….. whew!
- TPC met all requirements for a successful tracking and PID detector….. whew!

Evolution of the Design for (STAR) Experiment at RHIC



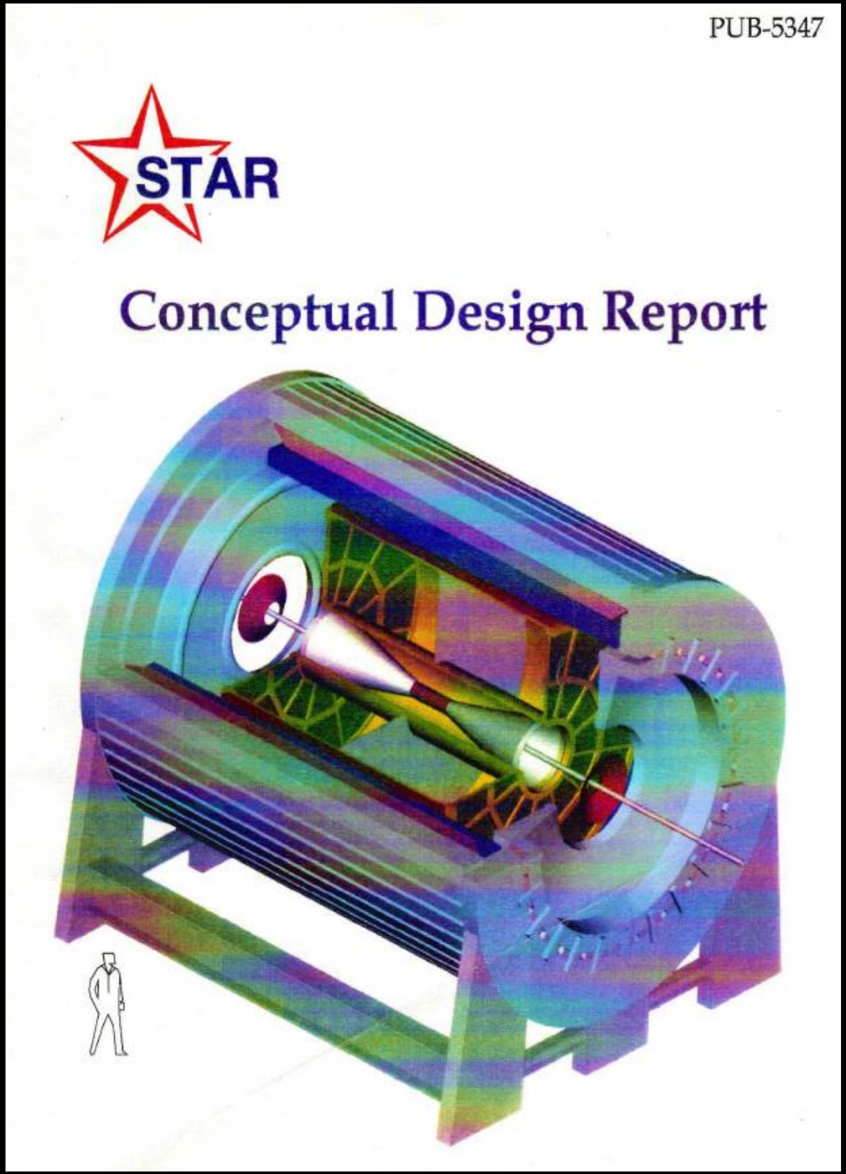


Evolution of Physics at RHIC Foreseen from 1990 - 1992

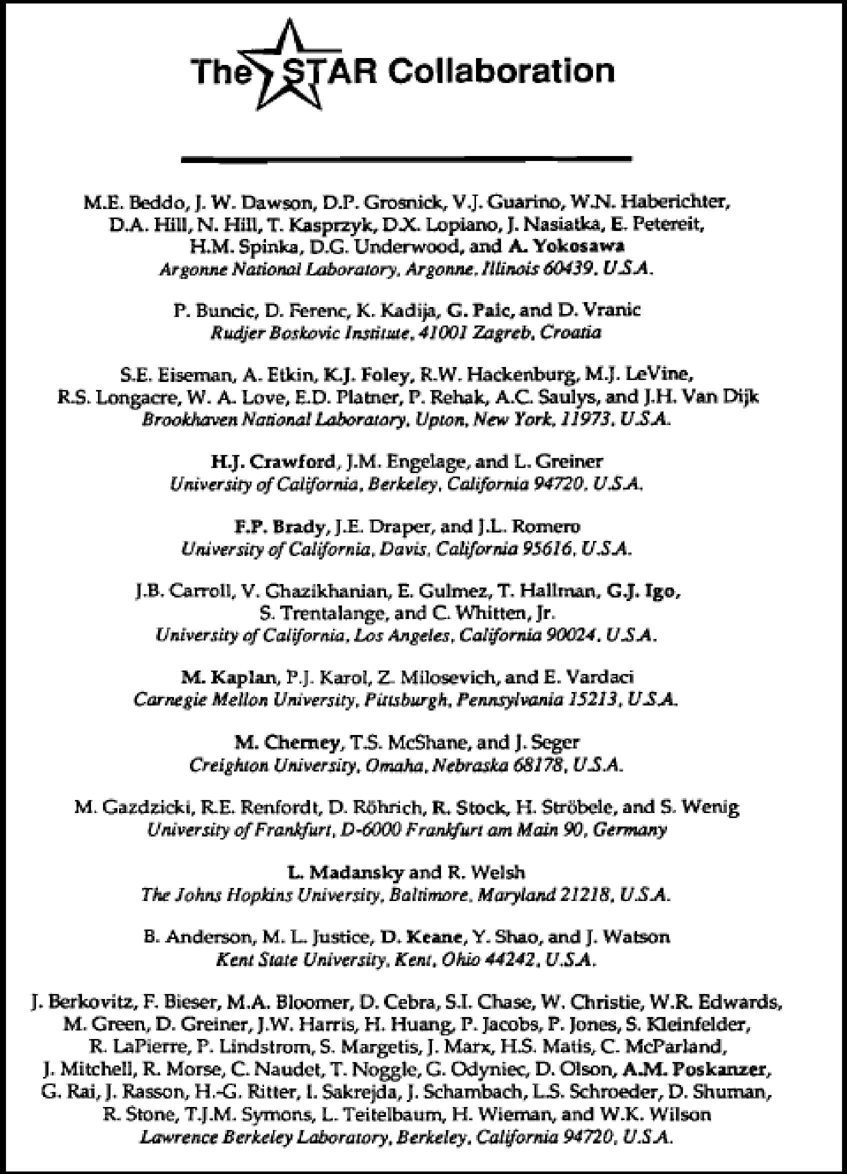


Updated LOI Physics (1991)
as presented at
WWND Jackson Hole (1992)

STAR Conceptual Design Report 1994



Jay Marx
Project Director!



The STAR Collaboration

M.E. Beddo, J. W. Dawson, D.P. Grosnick, V.J. Guarino, W.N. Haberichter, D.A. Hill, N. Hill, T. Kasprzyk, D.X. Lopiano, J. Nasiatka, **E.** Petereit, H.M. Spinka, D.G. Underwood, and **A. Yokosawa**
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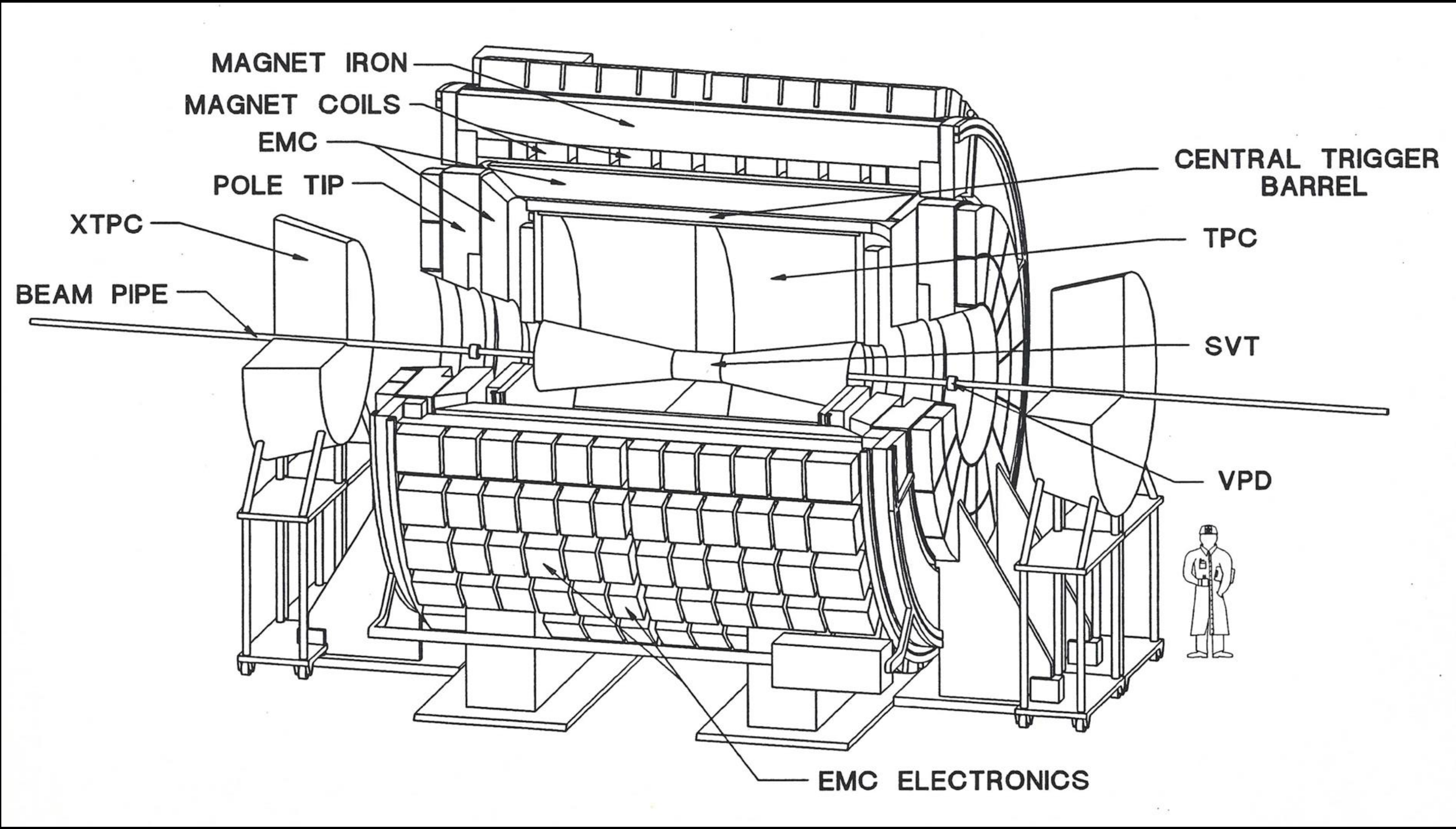
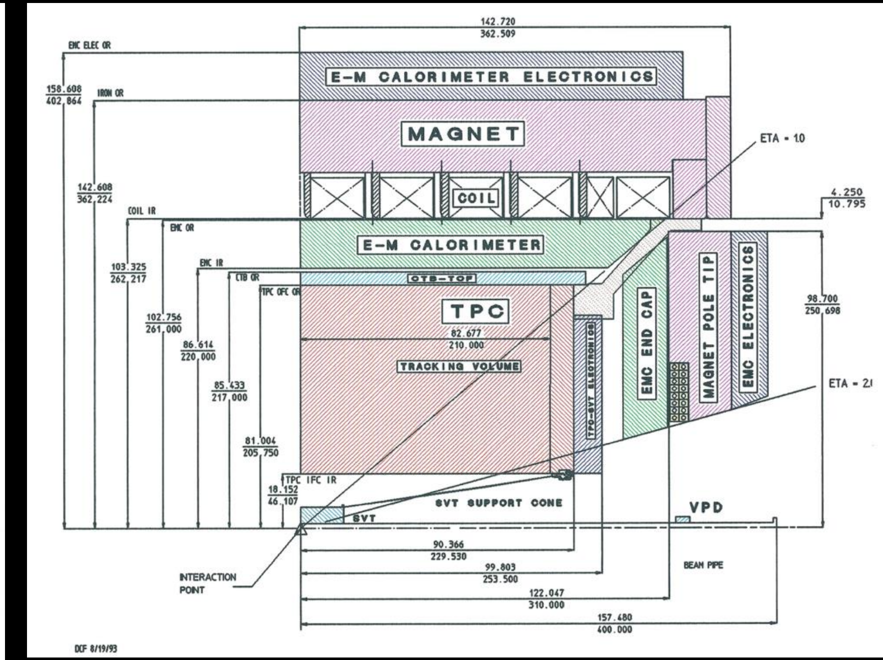
Lawrence Berkeley Laboratory, Berkeley, California 94720, U.S.A.

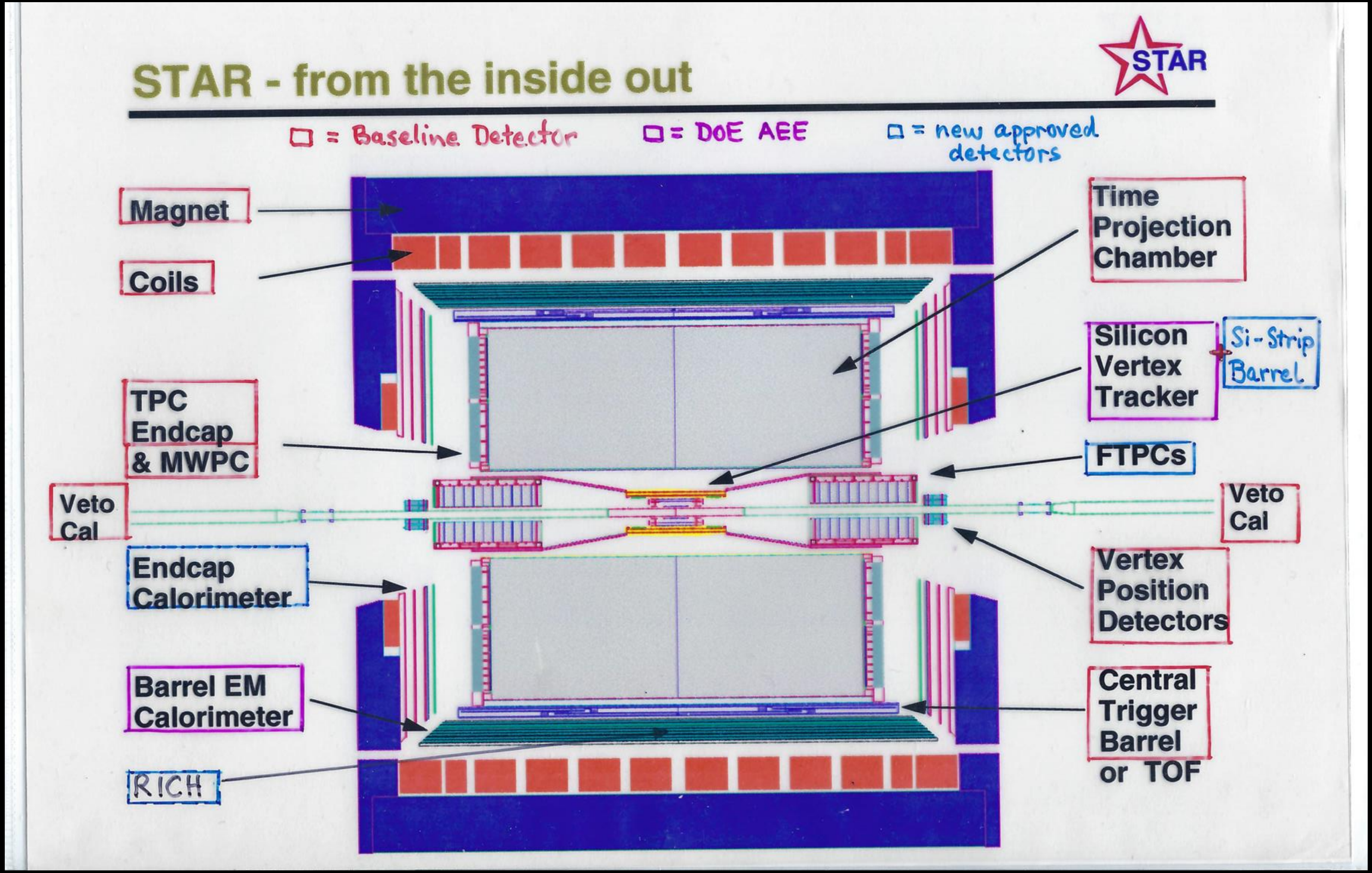
A Few of the Characters in 1994

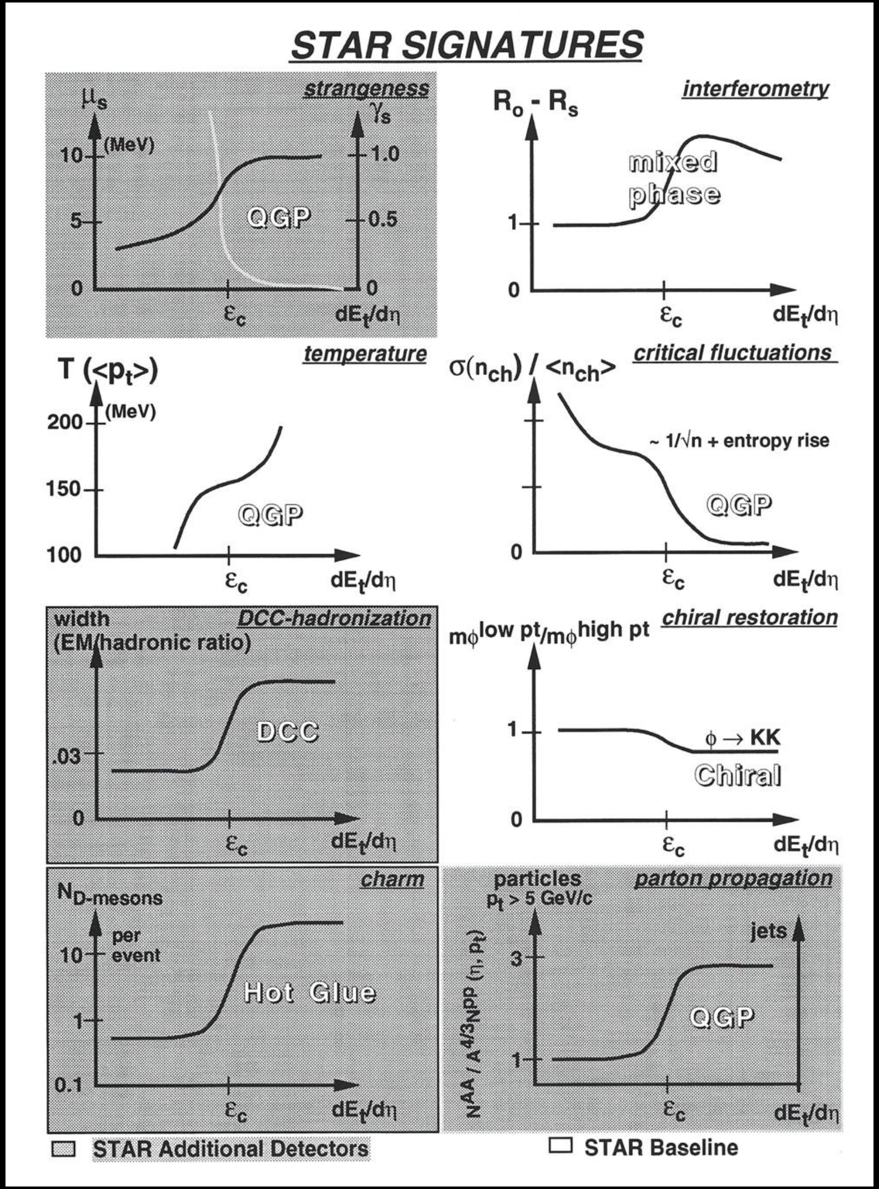
STAR Conceptual Design Report 1994



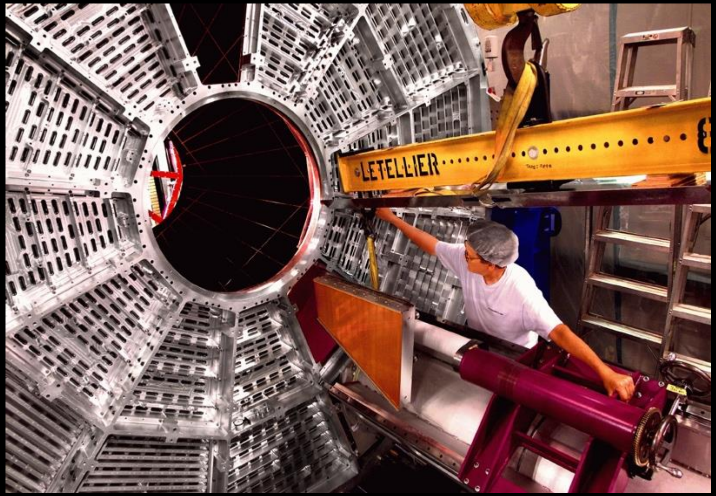


STAR Baseline Detector & Additional Equipment



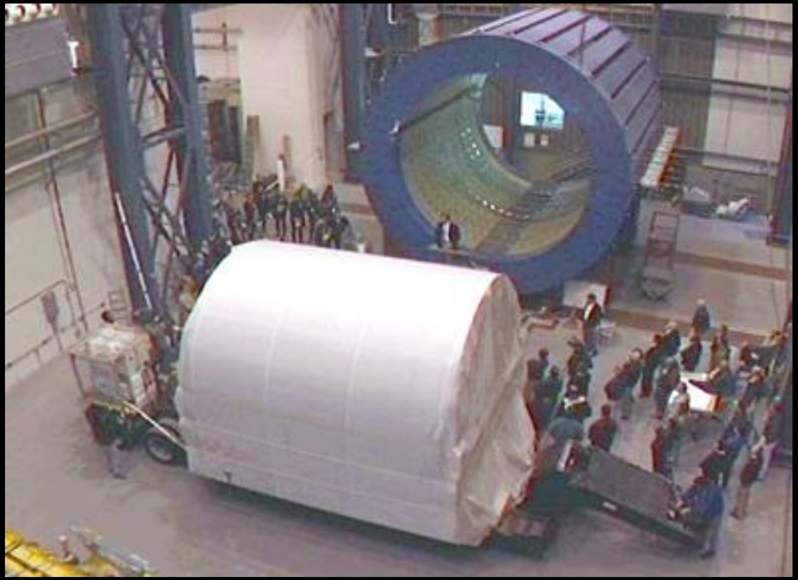


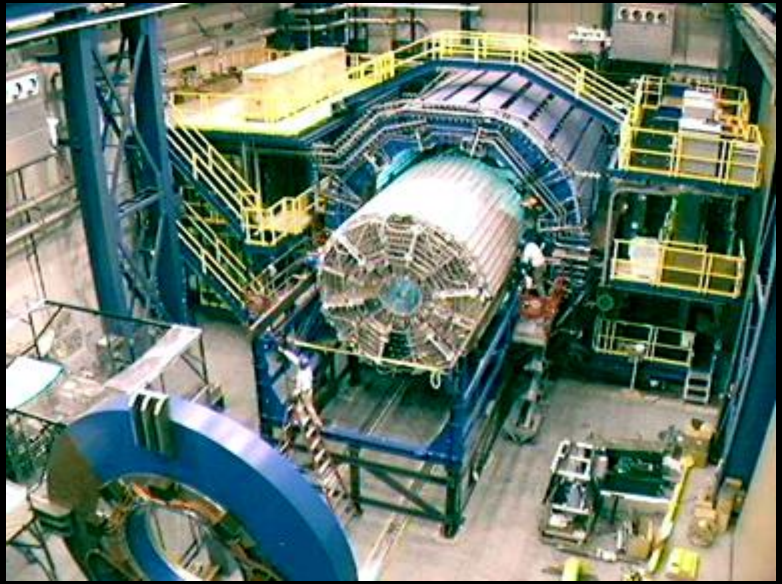
STAR TPC from LBL to BNL

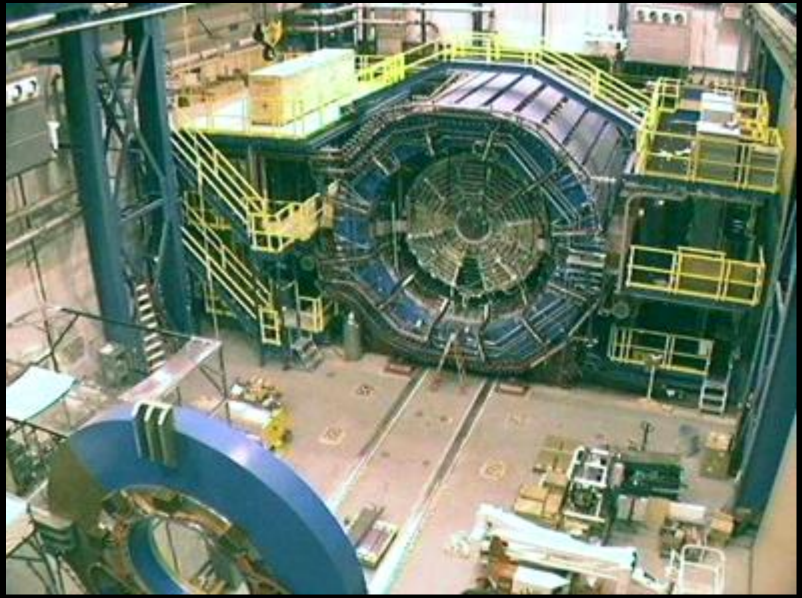


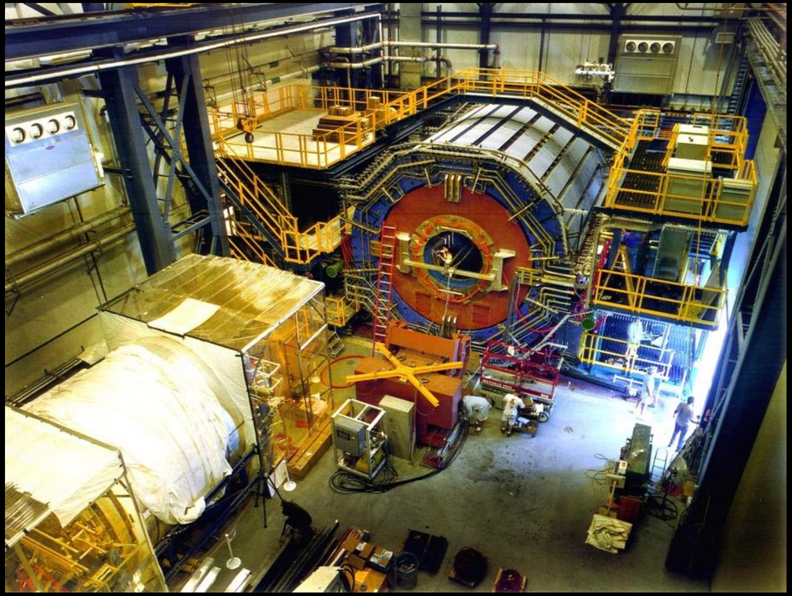
STAR TPC from LBL to BNL

STAR

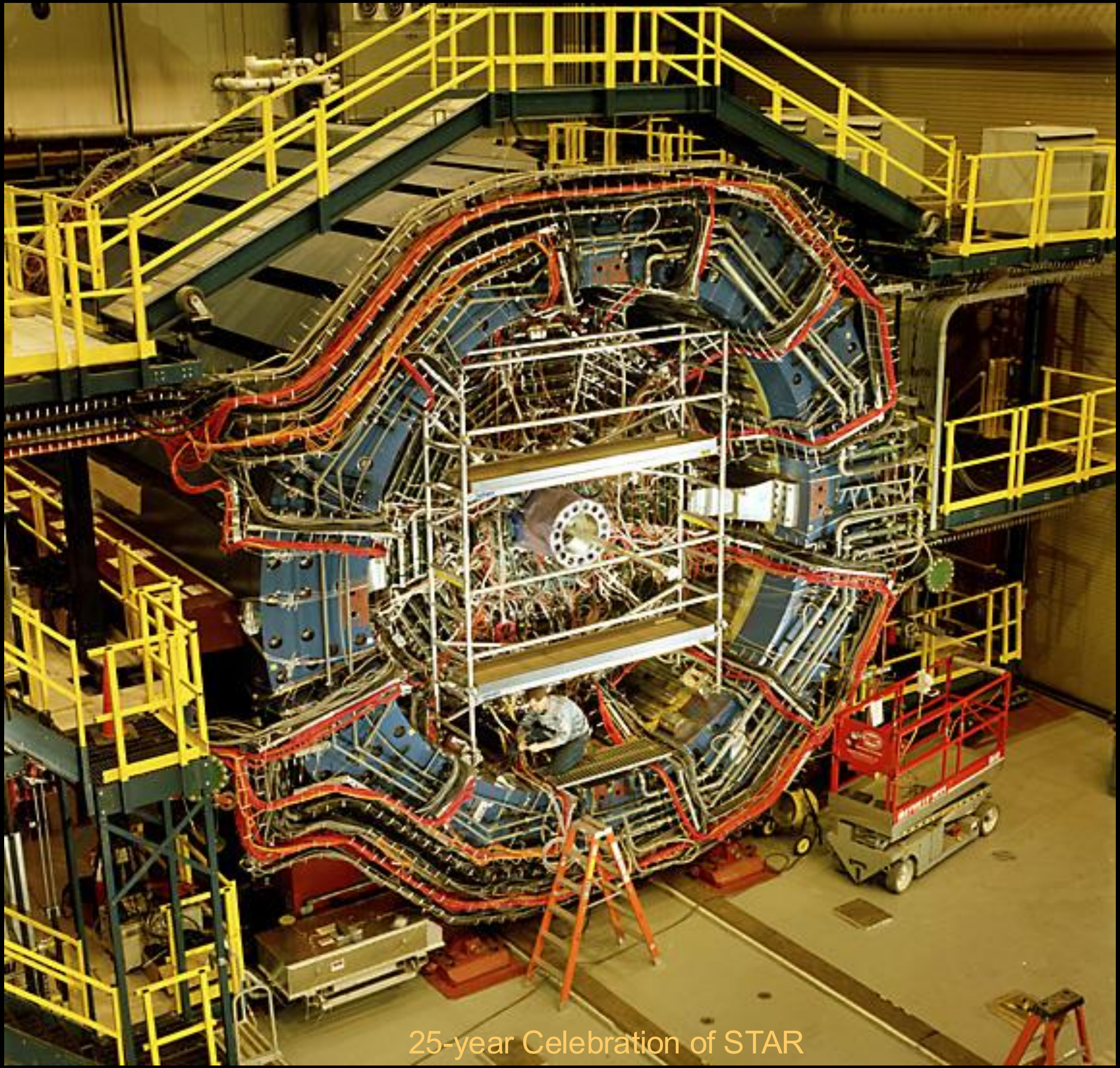








STAR Detector Ready to Roll!



Collaboration Ready to Roll!

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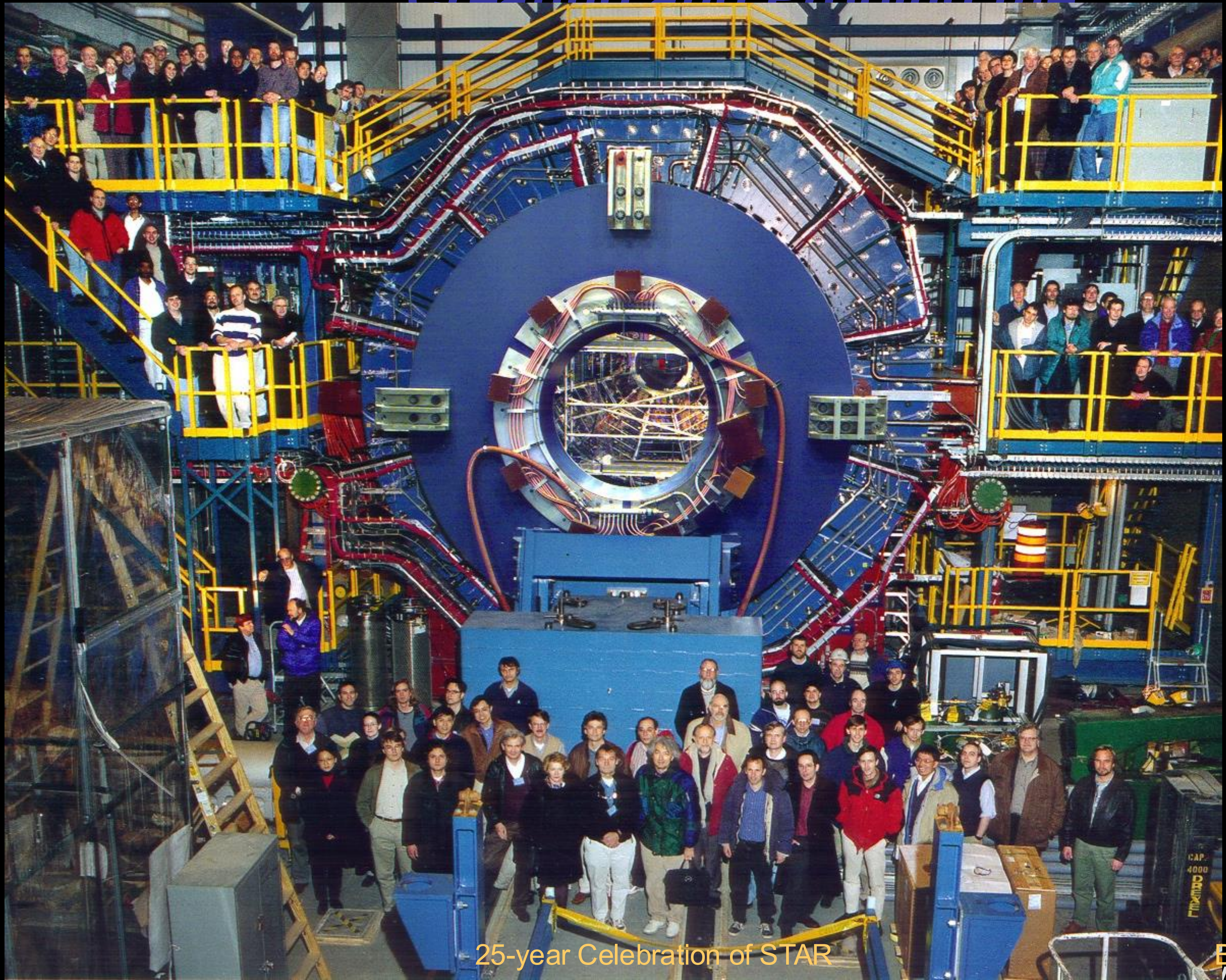
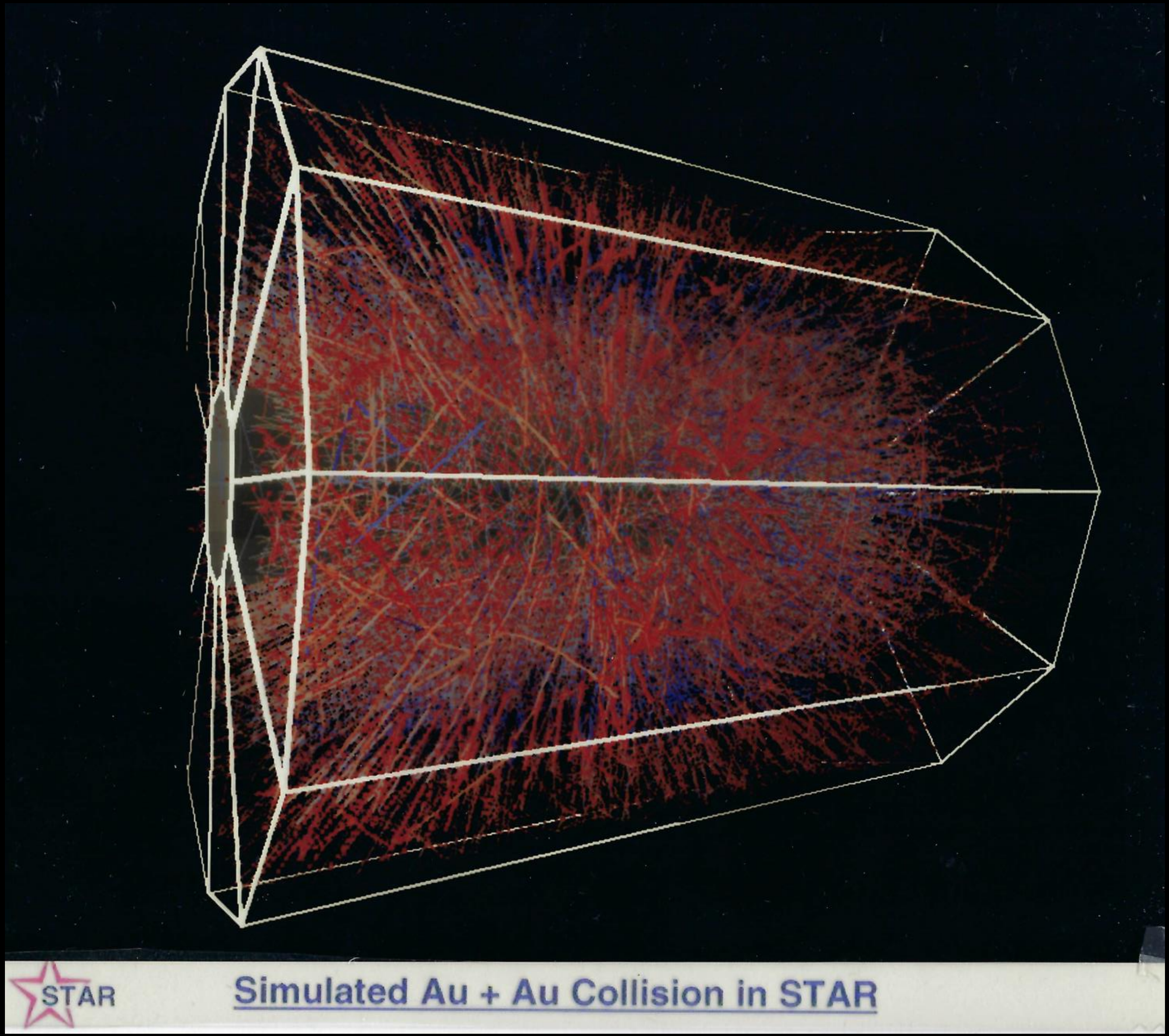
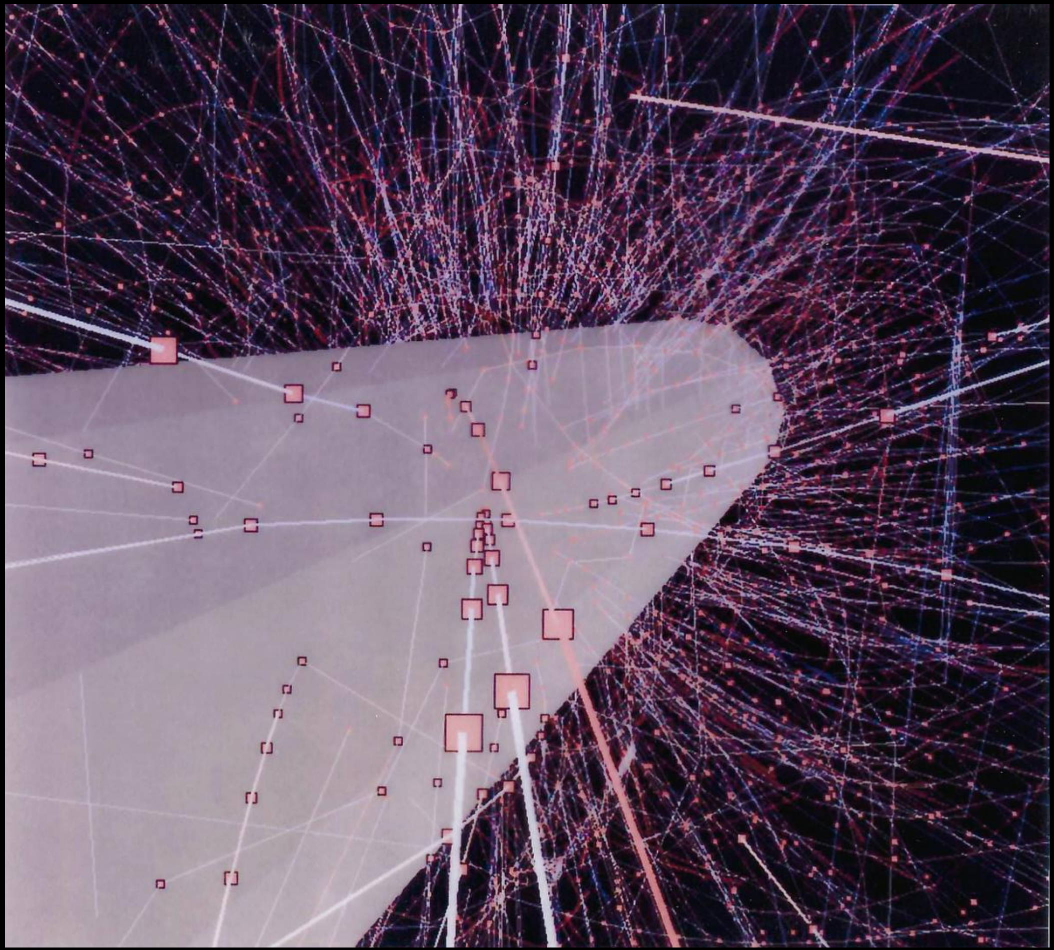


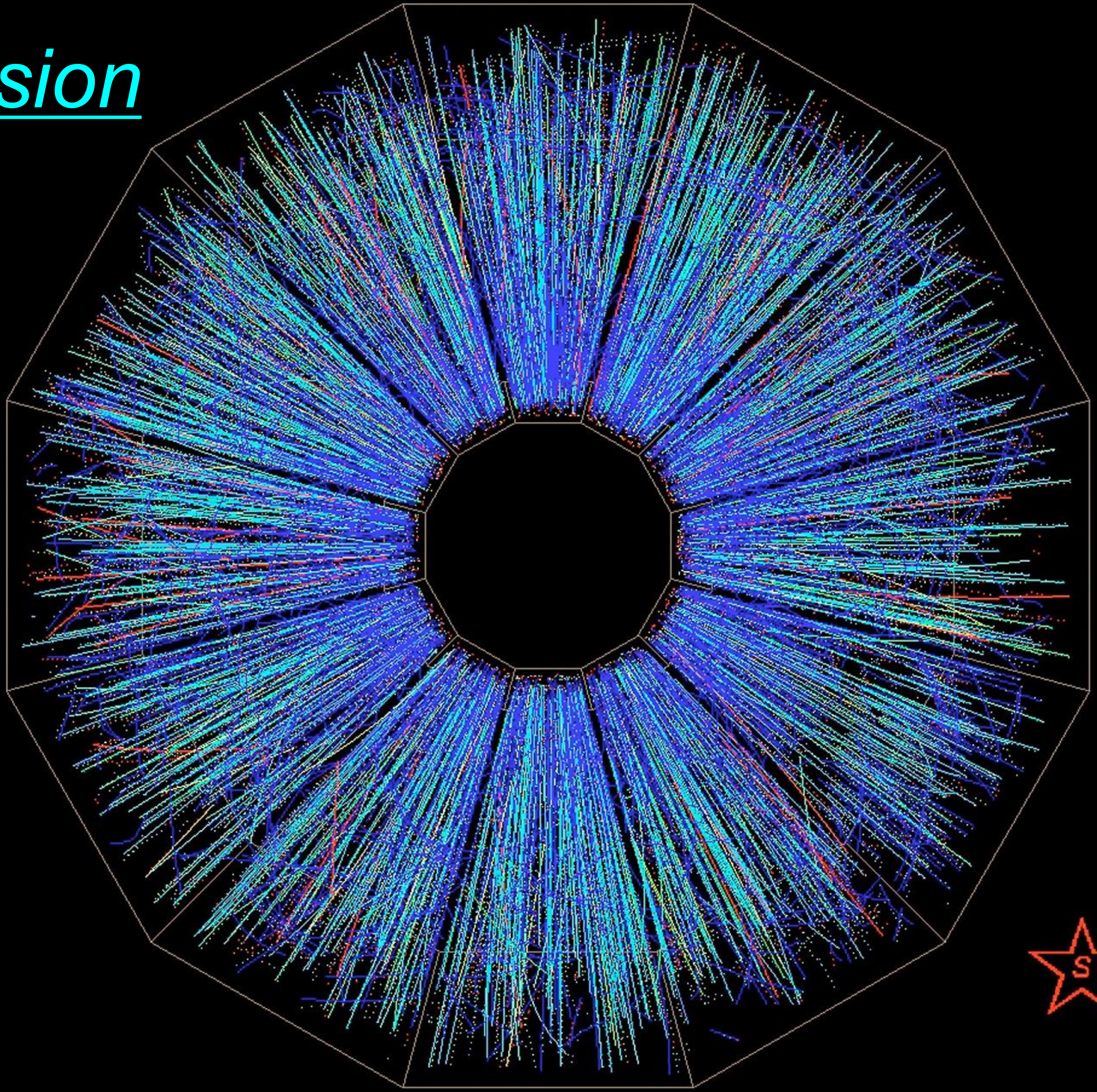
TPC Tracking Ready to Roll!





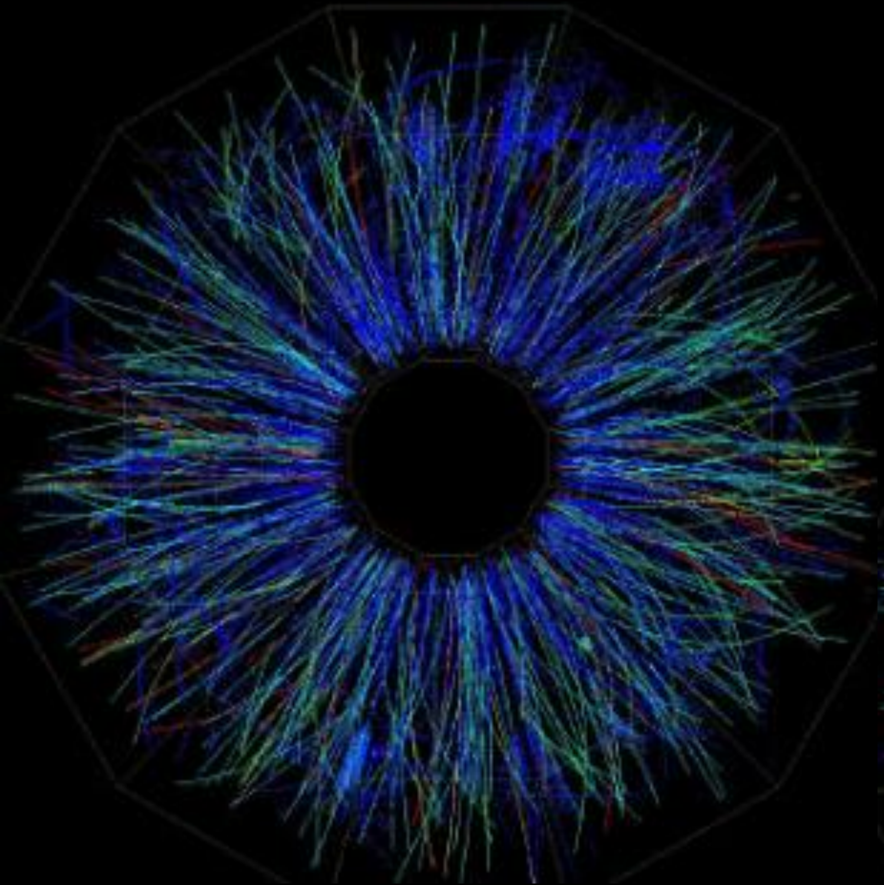
STAR Control Room - First Collisions!

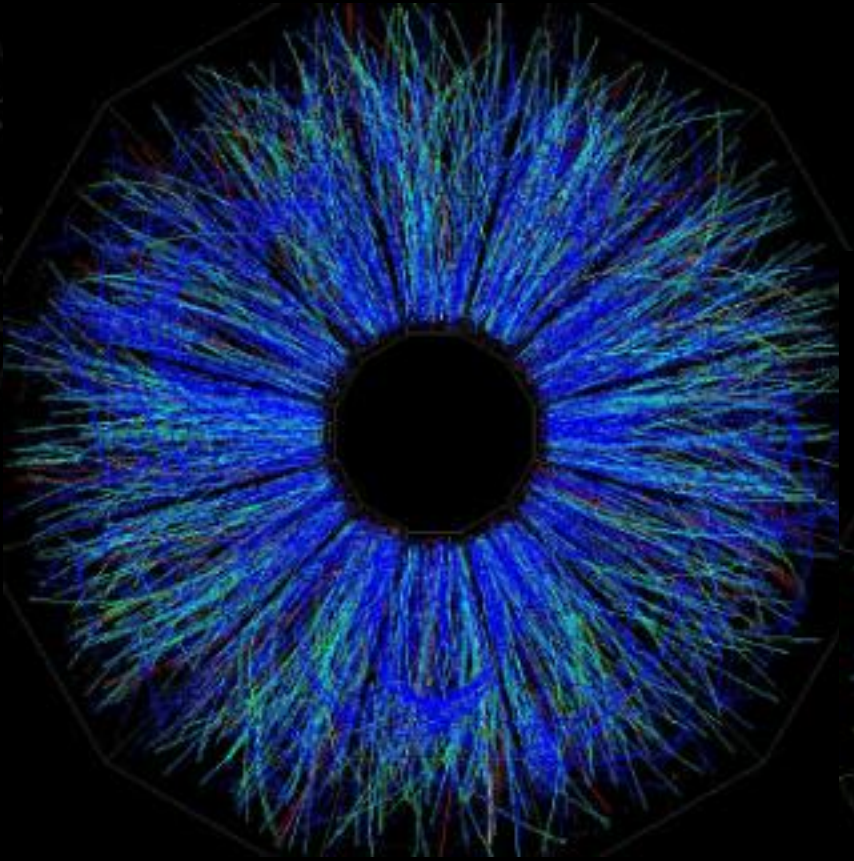
Head-on Collision

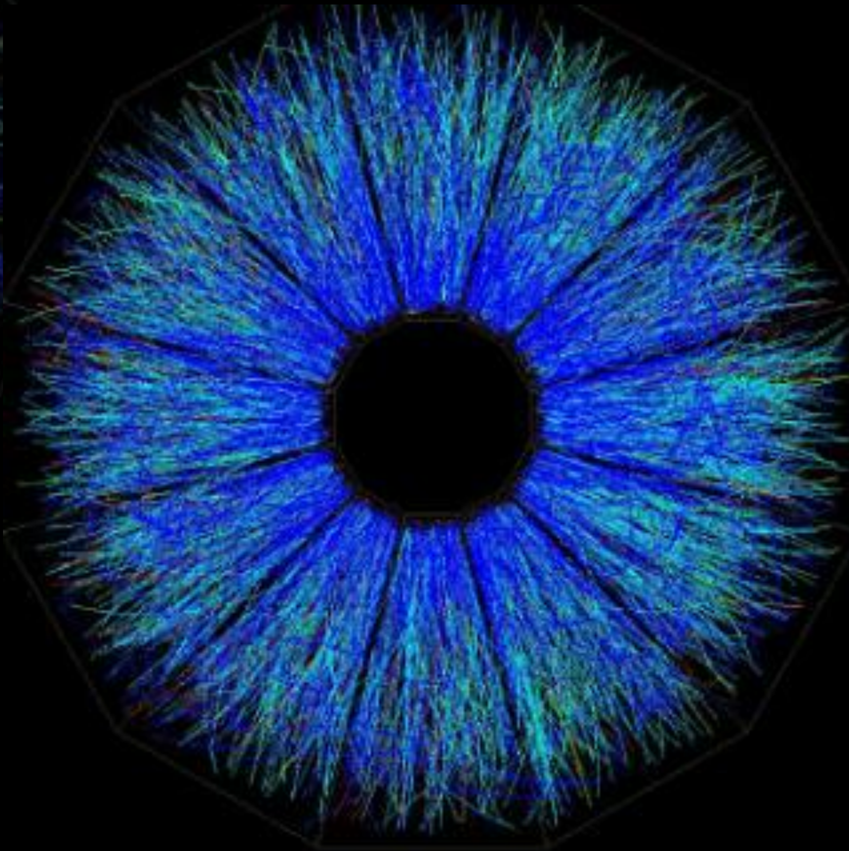


A STAR is Born!

STAR







2000

A STAR IS BORN!

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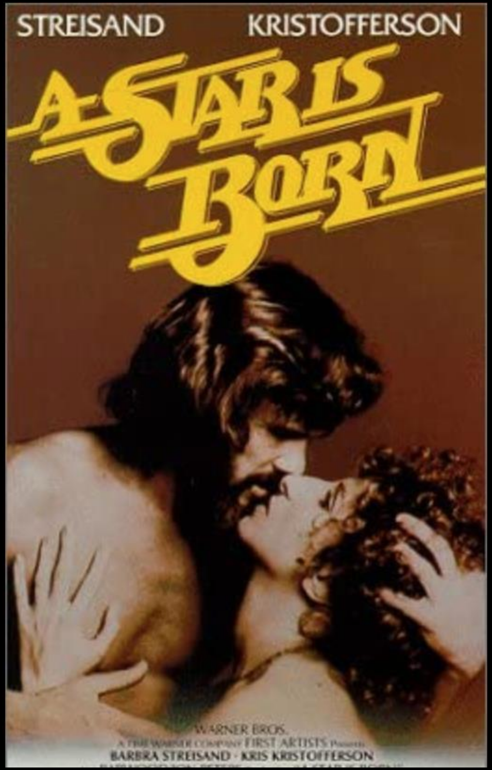

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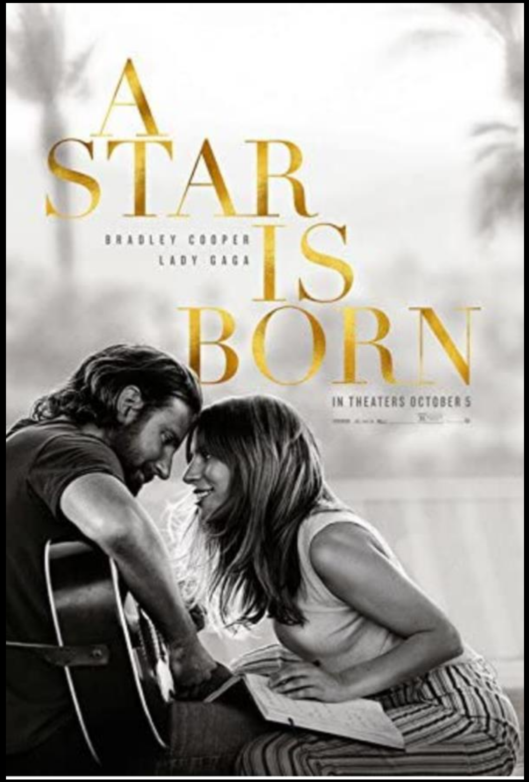
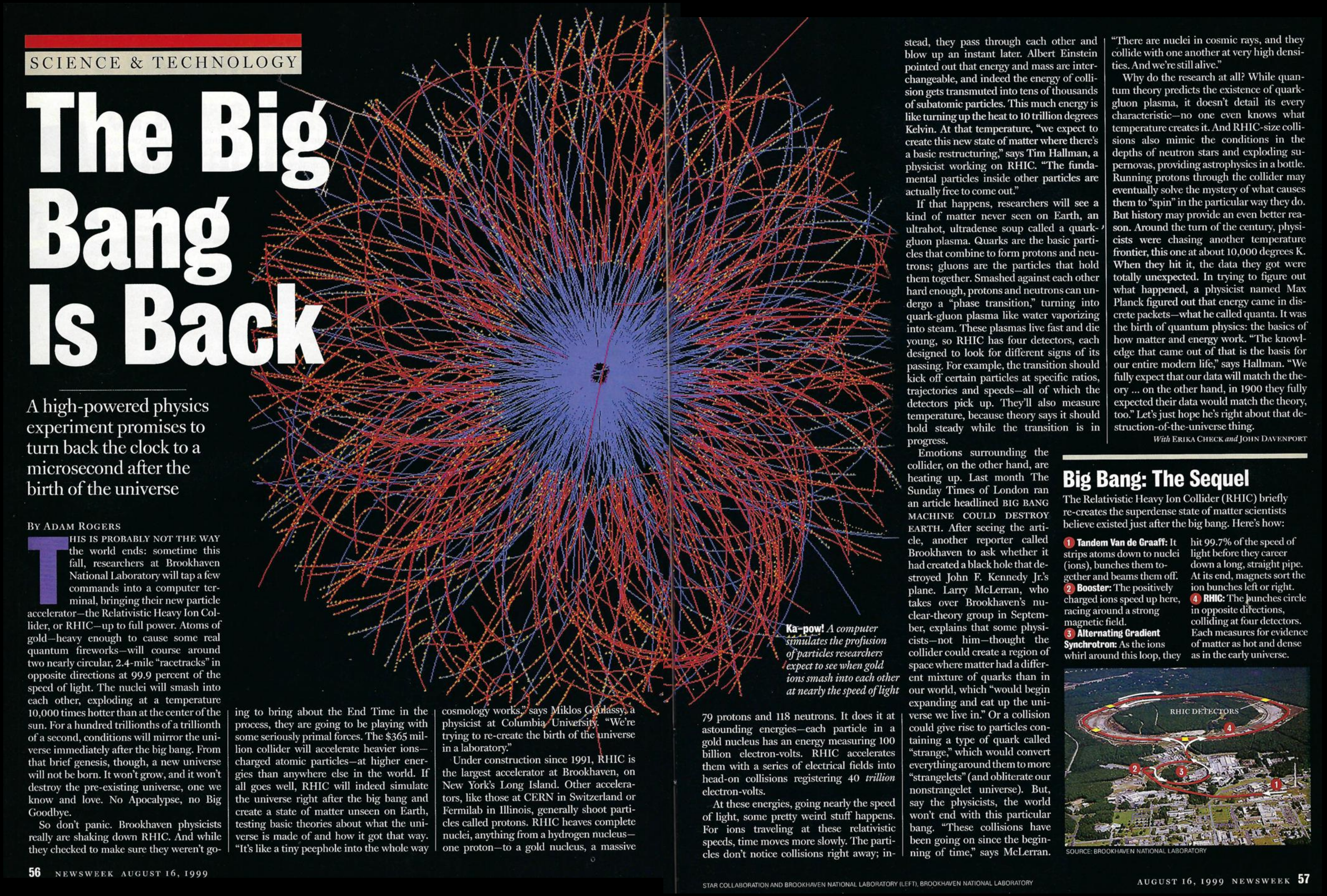


2018

A STAR is Born!

Newsweek – August 16, 1999



SCIENCE & TECHNOLOGY

The Big Bang Is Back

A high-powered physics experiment promises to turn back the clock to a microsecond after the birth of the universe

BY ADAM ROGERS

THIS IS PROBABLY NOT THE WAY the world ends: sometime this fall, researchers at Brookhaven National Laboratory will tap a few commands into a computer terminal, bringing their new particle accelerator—the Relativistic Heavy Ion Collider, or RHIC—up to full power. Atoms of gold—heavy enough to cause some real quantum fireworks—will course around two nearly circular, 2.4-mile "racetracks" in opposite directions at 99.9 percent of the speed of light. The nuclei will smash into each other, exploding at a temperature 10,000 times hotter than at the center of the sun. For a hundred trillionths of a trillionth of a second, conditions will mirror the universe immediately after the big bang. From that brief genesis, though, a new universe will not be born. It won't grow, and it won't destroy the pre-existing universe, one we know and love. No Apocalypse, no Big Goodbye.

So don't panic. Brookhaven physicists really are shaking down RHIC. And while they checked to make sure they weren't going to bring about the End Time in the process, they are going to be playing with some seriously primal forces. The $365 million collider will accelerate heavier ions—charged atomic particles—at higher energies than anywhere else in the world. If all goes well, RHIC will indeed simulate the universe right after the big bang and create a state of matter unseen on Earth, testing basic theories about what the universe is made of and how it got that way. "It's like a tiny peephole into the whole way cosmology works," says Miklos Gyulassy, a physicist at Columbia University. "We're trying to re-create the birth of the universe in a laboratory."

Under construction since 1991, RHIC is the largest accelerator at Brookhaven, on New York's Long Island. Other accelerators, like those at CERN in Switzerland or Fermilab in Illinois, generally shoot particles called protons. RHIC heaves complete nuclei, anything from a hydrogen nucleus—one proton—to a gold nucleus, a massive 79 protons and 118 neutrons. It does it at astounding energies—each particle in a gold nucleus has an energy measuring 100 billion electron-volts. RHIC accelerates them with a series of electrical fields into head-on collisions registering 40 *trillion* electron-volts.

At these energies, going nearly the speed of light, some pretty weird stuff happens. For ions traveling at these relativistic speeds, time moves more slowly. The particles don't notice collisions right away; instead, they pass through each other and blow up an instant later. Albert Einstein pointed out that energy and mass are interchangeable, and indeed the energy of collision gets transmuted into tens of thousands of subatomic particles. This much energy is like turning up the heat to 10 trillion degrees Kelvin. At that temperature, "we expect to create this new state of matter where there's a basic restructuring," says Tim Hallman, a physicist working on RHIC. "The fundamental particles inside other particles are actually free to come out."

If that happens, researchers will see a kind of matter never seen on Earth, an ultrahot, ultradense soup called a quark-gluon plasma. Quarks are the basic particles that combine to form protons and neutrons; gluons are the particles that hold them together. Smashed against each other hard enough, protons and neutrons can undergo a "phase transition," turning into quark-gluon plasma like water vaporizing into steam. These plasmas live fast and die young, so RHIC has four detectors, each designed to look for different signs of its passing. For example, the transition should kick off certain particles at specific ratios, trajectories and speeds—all of which the detectors pick up. They'll also measure temperature, because theory says it should hold steady while the transition is in progress.

Emotions surrounding the collider, on the other hand, are heating up. Last month The Sunday Times of London ran an article headlined BIG BANG MACHINE COULD DESTROY EARTH. After seeing the article, another reporter called Brookhaven to ask whether it had created a black hole that destroyed John F. Kennedy Jr.'s plane. Larry McLerran, who takes over Brookhaven's nuclear-theory group in September, explains that some physicists—not him—thought the collider could create a region of space where matter had a different mixture of quarks than in our world, which "would begin expanding and eat up the universe we live in." Or a collision could give rise to particles containing a type of quark called "strange," which would convert everything around them to more "strangelets" (and obliterate our nonstrangelet universe). But, say the physicists, the world won't end with this particular bang. "These collisions have been going on since the beginning of time," says McLerran. "There are nuclei in cosmic rays, and they collide with one another at very high densities. And we're still alive."

Why do the research at all? While quantum theory predicts the existence of quark-gluon plasma, it doesn't detail its every characteristic—no one even knows what temperature creates it. And RHIC-size collisions also mimic the conditions in the depths of neutron stars and exploding supernovas, providing astrophysics in a bottle. Running protons through the collider may eventually solve the mystery of what causes them to "spin" in the particular way they do. But history may provide an even better reason. Around the turn of the century, physicists were chasing another temperature frontier, this one at about 10,000 degrees K. When they hit it, the data they got were totally unexpected. In trying to figure out what happened, a physicist named Max Planck figured out that energy came in discrete packets—what he called quanta. It was the birth of quantum physics: the basics of how matter and energy work. "The knowledge that came out of that is the basis for our entire modern life," says Hallman. "We fully expect that our data will match the theory ... on the other hand, in 1900 they fully expected their data would match the theory, too." Let's just hope he's right about that destruction-of-the-universe thing.

With ERIKA CHECK *and* JOHN DAVENPORT

Ka-pow! *A computer simulates the profusion of particles researchers expect to see when gold ions smash into each other at nearly the speed of light*

Big Bang: The Sequel

The Relativistic Heavy Ion Collider (RHIC) briefly re-creates the superdense state of matter scientists believe existed just after the big bang. Here's how:

1 **Tandem Van de Graaff:** It strips atoms down to nuclei (ions), bunches them together and beams them off.
2 **Booster:** The positively charged ions speed up here, racing around a strong magnetic field.
3 **Alternating Gradient Synchrotron:** As the ions whirl around this loop, they hit 99.7% of the speed of light before they career down a long, straight pipe. At its end, magnets sort the ion bunches left or right.
4 **RHIC:** The bunches circle in opposite directions, colliding at four detectors. Each measures for evidence of matter as hot and dense as in the early universe.

RHIC DETECTORS

SOURCE: BROOKHAVEN NATIONAL LABORATORY

STAR COLLABORATION AND BROOKHAVEN NATIONAL LABORATORY (LEFT), BROOKHAVEN NATIONAL LABORATORY

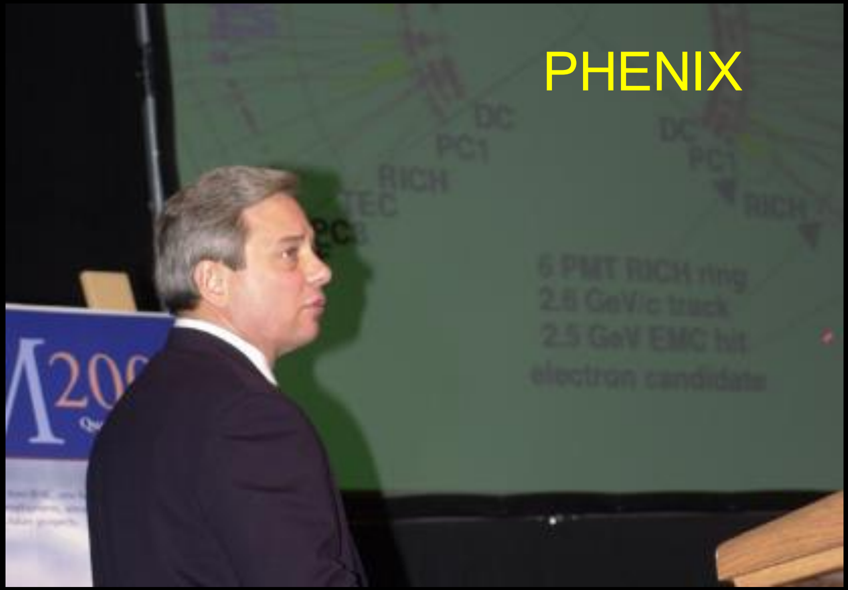
56 NEWSWEEK AUGUST 16, 1999

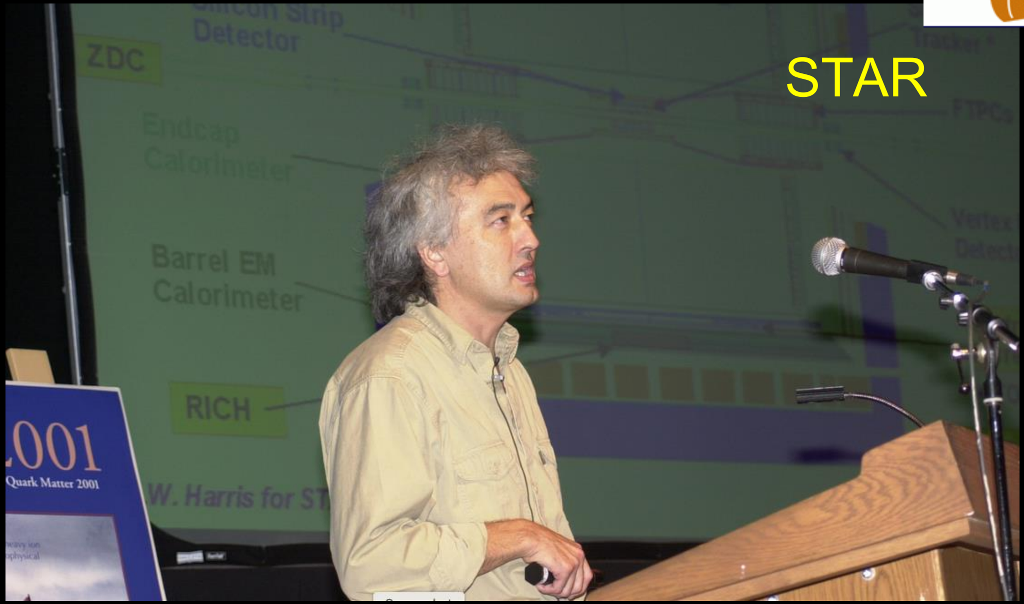
AUGUST 16, 1999 NEWSWEEK 57

The Dawn of RHIC Physics (2001)

(a real scramble)

The Dawn of RHIC Physics





PHOBOS

The Dawn of RHIC Physics (2001)

Welcome to the Quark Matter 2001 Home Page

QM2001 In The News

- Quark Matter 2001 Features First RHIC Results - *Brookhaven Bulletin, Feb. 2, 2001 (PDF Format)*
- New Collider Sees Hints of Quark-Gluon Plasma - *Science. Jan. 2001*
- On the Verge of Re-Creating Creation. Then What? - *New York Times Week In Review, Jan. 28, 2001*
- Lab Heralds a New Era - *New York Newsday Discovery Section, Jan. 30, 2001*
- Trying to Cook a Soup of Free-Range Quarks - *New York Times Science Section, Jan. 23, 2001*
- Big Bang Scientists Get Dense - *Wired News, Jan. 23, 2001*
- A Coming-Out Party for a Particle Collider - *New York Times Long Island Section, Jan. 21, 2001*
- Experiments on Dense Matter Evoke Big Bang - *New York Times, Jan. 16, 2001*
- Optimism About Ion Collider - *New York Newsday, Jan. 16, 2001*
- Highest Density of Matter Created - *Yahoo! News (AP), Jan. 16, 2001*

Flow at RHIC!

VOLUME 86, NUMBER 3 PHYSICAL REVIEW LETTERS 15 JANUARY 2001

Elliptic Flow in Au + Au Collisions at $\sqrt{s_{NN}} = 130$ GeV

K. H. Ackermann,[19] N. Adams,[28] C. Adler,[12] Z. Ahammed,[27] S. Ahmad,[28] C. Allgower,[13] J. Amsbaugh,[34] M. Anderson,[6] E. Anderssen,[17] H. Arnesen,[3] L. Arnold,[14] G. S. Averichev,[10] A. Baldwin,[16] J. Balewski,[13] O. Barannikova,[10,27] L. S. Barnby,[16] J. Baudot,[14] M. Beddo,[1] S. Bekele,[24] V. V. Belaga,[10] R. Bellwied,[35] S. Bennett,[35] J. Bercovitz,[17] J. Berger,[12] W. Betts,[24] H. Bichsel,[34] F. Bieser,[17] L. C. Bland,[13] M. Bloomer,[17] C. O. Blyth,[4] J. Boehm,[17] B. E. Bonner,[28] D. Bonnet,[14] R. Bossingham,[17] M. Botlo,[3] A. Boucham,[30] N. Bouillo,[30] S. Bouvier,[30] K. Bradley,[17] F. P. Brady,[6] E. S. Braithwaite,[2] W. Braithwaite,[2] A. Brandin,[21] R. L. Brown,[3] G. Brugalette,[34] C. Byrd,[2] H. Caines,[24] M. Calderón de la Barca Sánchez,[36] A. Cardenas,[27] L. Carr,[34] J. Carroll,[17] J. Castillo,[30] B. Caylor,[17] D. Cebra,[6] S. Chatopadhyay,[35] M. L. Chen,[3] W. Chen,[3] Y. Chen,[7] S. P. Chernenko,[10] M. Cherney,[9] A. 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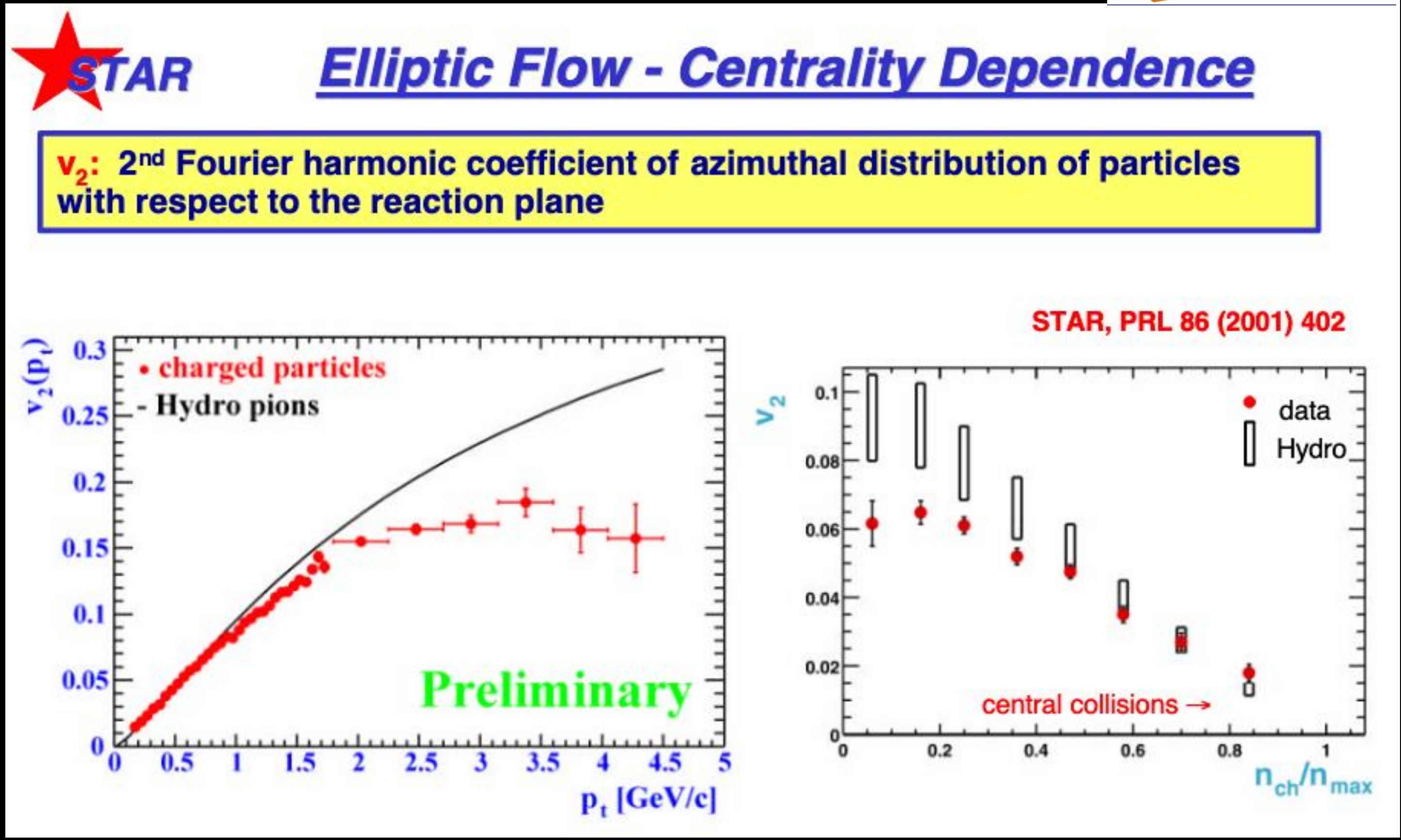


It Flows so Well – It's a Nearly Perfect Liquid!

Early Universe Went With the Flow

Posted April 18, 2005 5:57PM

Between 2000 and 2003 the lab's Relativistic Heavy Ion Collider repeatedly smashed the nuclei of gold atoms together with such force that their energy briefly generated trillion-degree temperatures. Physicists think of the collider as a time machine, because those extreme temperature conditions last prevailed in the universe less than 100 millionths of a second after the big bang.

New State of Matter Is 'Nearly Perfect' Liquid

Physicists working at Brookhaven National Laboratory announced today that they have created what appears to be a new state of matter out of the building blocks of atomic nuclei, quarks and gluons. The researchers unveiled their findings--which could provide new insight into the composition of the universe just moments after the big bang--today in Florida at a meeting of the American Physical Society.

SCIENTIFIC AMERICAN

Image: BNL

There are four collaborations, dubbed BRAHMS, PHENIX, PHOBOS and STAR, working at Brookhaven's Relativistic Heavy Ion Collider (RHIC). All of them study what happens when two interacting beams of gold ions smash into one another at great velocities, resulting in thousands of subatomic collisions every second. When the researchers analyzed the patterns of the atoms' trajectories after these collisions, they found that the particles produced in the collisions tended to move collectively, much like a school of fish does. Brookhaven's associate laboratory director for high energy and nuclear physics, Sam Aronson, remarks that "the degree of collective interaction, rapid thermalization and extremely low viscosity of the matter being formed at RHIC make this the most nearly perfect liquid ever observed."

The News of the QGP Hit the Streets

Universe May Have Begun as Liquid, Not Gas

Associated Press
Tuesday, April 19, 2005; Page A05

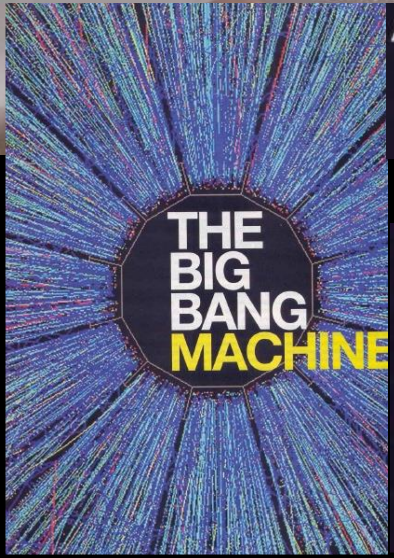
The Washington Post

New results from a particle collider suggest that the universe behaved like a liquid in its earliest moments, not the fiery gas that was thought to have pervaded the first microseconds of existence.

DISCOVER

Science, Technology, and The Future

THE BIG BANG MACHINE
A Long Island Particle Smasher Re-creates The Moment Of Creation



An atom smasher on Long Island re-creates the particle soup that gave rise to the universe

"Here is where the action takes place. This is where we effectively try to turn the clock back 14 billion years. Right above your head, about 13½ feet in the air."

Looking up, I try to imagine the events Tim Hallman is describing—atoms of gold colliding at 99.99 percent the speed of light; temperatures instantly soaring to 1 trillion degrees, 150,000 times hotter than the core of the sun. Then I try to picture a minuscule five-dimensional black hole, which, depending on your point of view, may or may not have formed at that same spot over my head. It's all a little much for an imagination that sometimes struggles with the plot of *Battlestar Galactica*.

Early Universe was a liquid

Quark-gluon blob surprises particle physicists.

nature

by Mark Peplow
news@nature.com

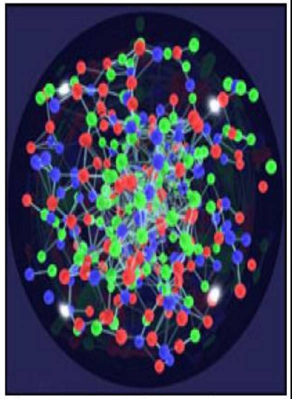
The Universe consisted of a perfect liquid in its first moments, according to results from an atom-smashing experiment.

Scientists at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory on Long Island, New York, have spent five years searching for the quark-gluon plasma that is thought to have filled our Universe in the first microseconds of its existence. Most of them are now convinced they have found it. But, strangely, it seems to be a liquid rather than the expected hot gas.

Early Universe was 'liquid-like'

Physicists say they have created a new state of hot, dense matter by crashing together the nuclei of gold atoms.

BBC NEWS

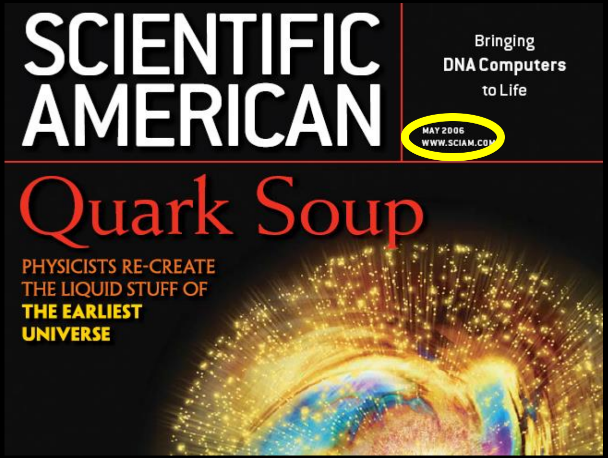


The impression is of matter that is more strongly interacting than predicted

The high-energy collisions prised open the nuclei to reveal their most basic particles, known as quarks and gluons.

The researchers, at the US Brookhaven National Laboratory, say these particles were seen to behave as an almost perfect "liquid".

The work is expected to help scientists explain the conditions that existed just milliseconds after the Big Bang.



…. and the "Nerd" Haunts!

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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*.

SCIENTIFIC AMERICAN

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THE SCIENCES

New State of Matter Is 'Nearly Perfect' Liquid

By Sarah Graham on April 18, 2005

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NEWS

RHIC groups serve up 'perfect' liquid

5 May 2005

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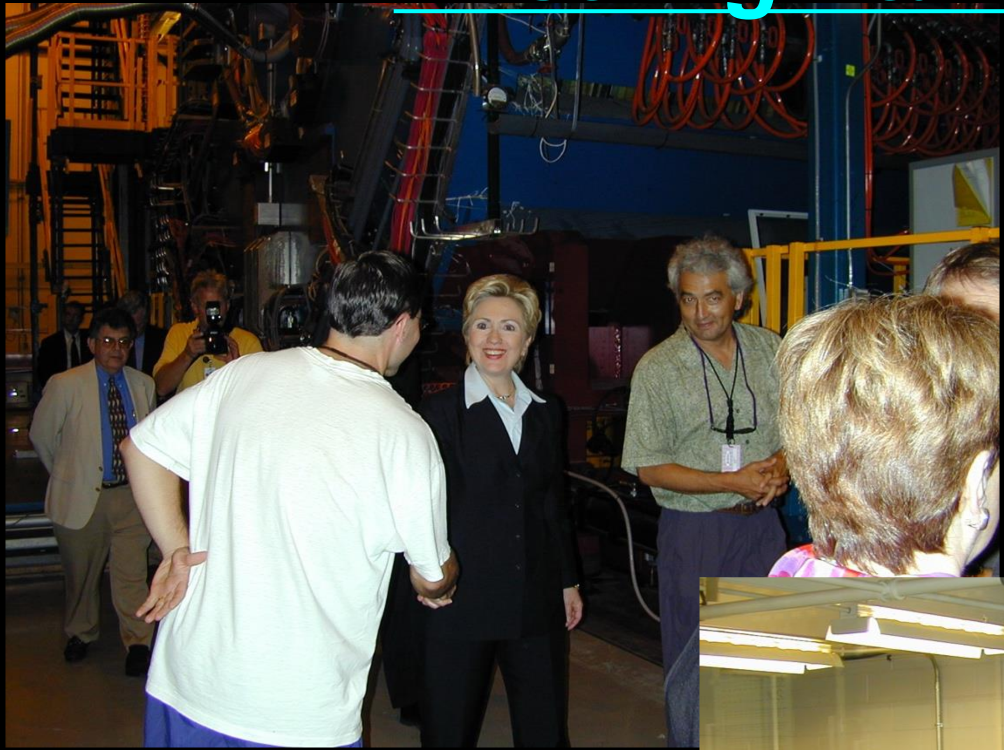
APS NEWS

June 2005 (Volume 14, Number 6)

RHIC Detects Liquid State of Quark-Gluon Matter

By Ernie Tretkoff

First Dignitaries Visit STAR and RHIC



Jet Quenching in STAR at RHIC!

Key Early STAR Jet-Quenching Papers (2000–2005)

Canonical references for first jet-quenching results:

STAR Collaboration, *Suppression of charged hadron yields at large transverse momentum in central Au+Au collisions at* $\sqrt{s_{NN}}$ *= 130 GeV*, **Phys. Rev. Lett. 89, 202301 (2002)**.

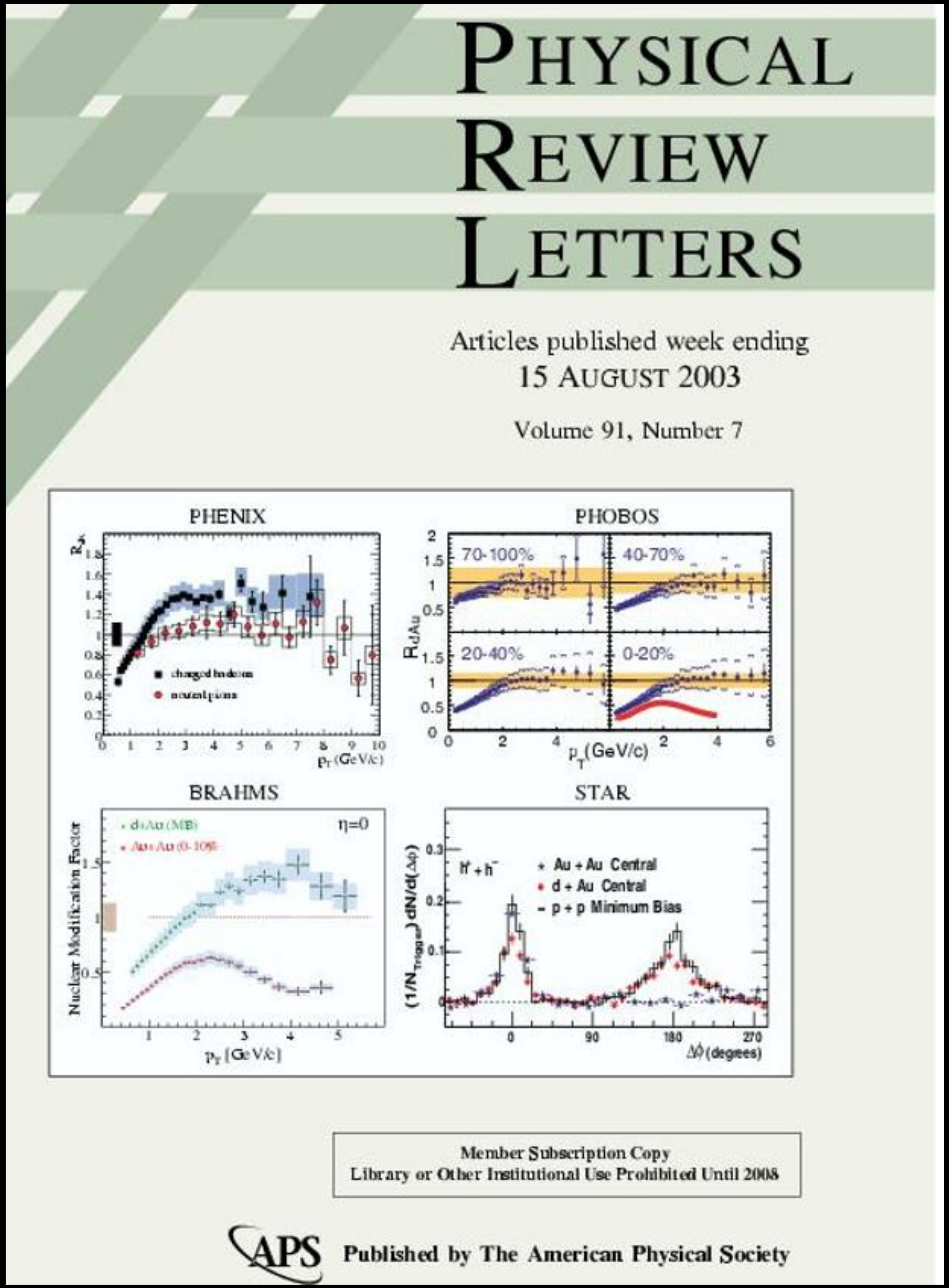
STAR Collaboration, *Azimuthal anisotropy and correlations at high transverse momentum in Au+Au collisions*, **Phys. Rev. Lett. 90, 082302 (2003)**.

STAR Collaboration, *Disappearance of back-to-back high-*p_t *hadron correlations in central Au+Au collisions*, **Phys. Rev. Lett. 90, 082302 (2003)**.

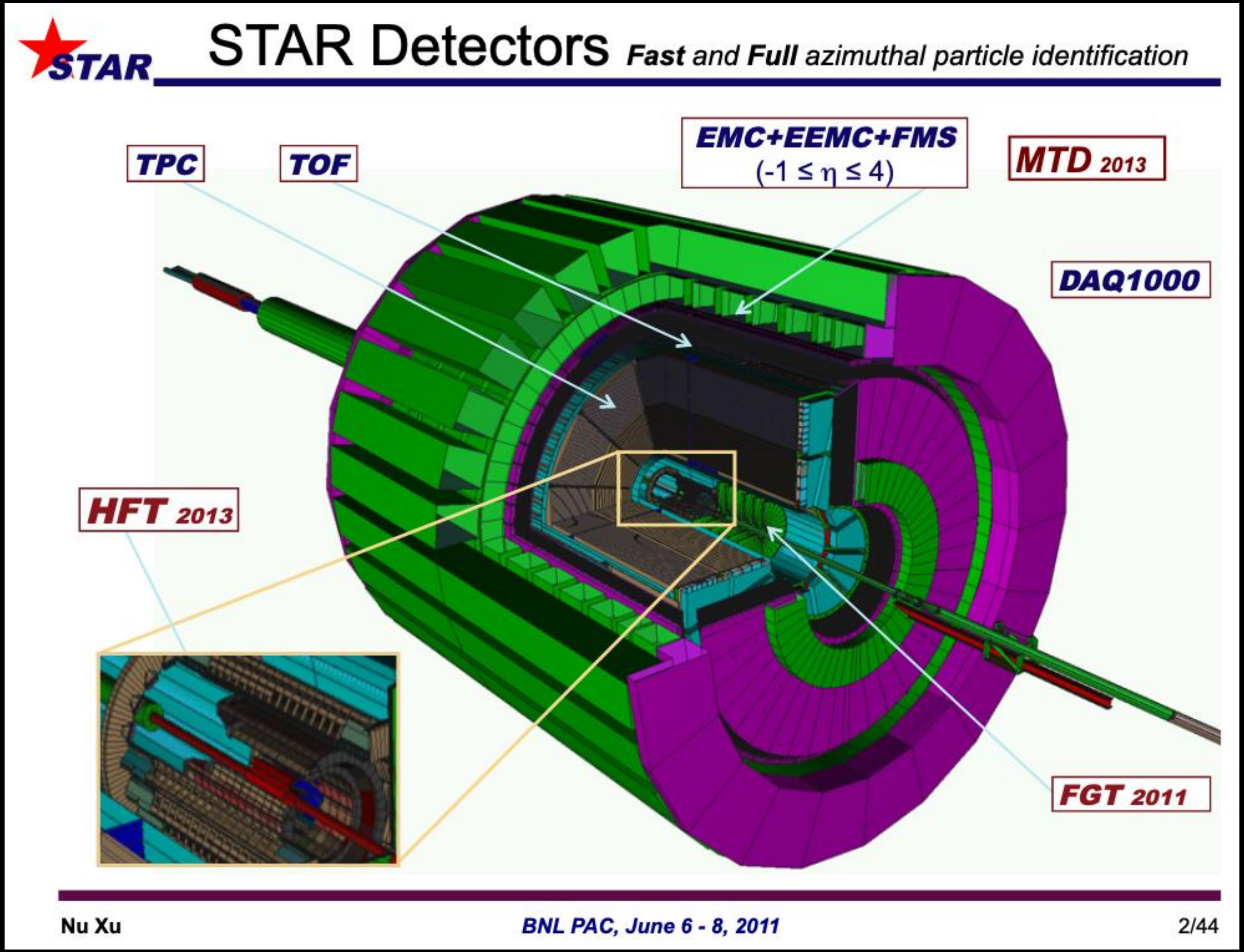
STAR Collaboration, *High-*p_t *hadron suppression in d+Au collisions*, **Phys. Rev. Lett. 91, 072304 (2003)** (control experiment showing *no suppression*).

STAR Collaboration, *Long-range rapidity correlations and jet quenching*, **Phys. Rev. C 70, 054907 (2004)**.

from ChatGPT 5.2



STAR – Growing Up!



STAR Mid-term Upgrades

Time of Flight

Forward Meson Spectrometer

DAQ1000

Heavy Flavor Tracker

Intermediate Stage Tracker

Forward Tracking

The Most Vortical Fluid Ever Observed

LETTER

doi:10.1038/nature23004

Global Λ hyperon polarization in nuclear collisions

The STAR Collaboration*

The extreme energy densities generated by ultra-relativistic collisions between heavy atomic nuclei produce a state of matter that behaves surprisingly like a fluid, with exceptionally high temperature and low viscosity[1]. Non-central collisions have angular momenta of the order of 1,000$\hbar$, and the resulting fluid may have a strong vortical structure[2–4] that must be understood to describe the fluid properly. The vortical structure is also of particular interest because the restoration of fundamental symmetries of quantum chromodynamics is expected to produce novel physical effects in the presence of strong vorticity[5]. However, no experimental indications of fluid vorticity in heavy ion collisions have yet been found. Since vorticity represents a local rotational structure of the fluid, spin–orbit coupling can lead to preferential orientation of particle spins along the direction of rotation. Here we present measurements of an alignment between the global angular momentum of a non-central collision and the spin of emitted particles (in this case the collision occurs between gold nuclei and produces Λ baryons), revealing that the fluid produced in heavy ion collisions is the most vortical system so far observed. (At high energies, this fluid is a quark–gluon plasma.) We find that Λ and $\overline{\Lambda}$ hyperons show a positive polarization of the order of a few per cent, consistent with some hydrodynamic predictions[6]. (A hyperon is a particle composed of three quarks, at least one of which is a strange quark; the remainder are up and down quarks, found in protons and neutrons.) A previous measurement[7] that reported a null result, that is, zero polarization, at higher collision energies is seen to be consistent with the trend of our observations, though with larger statistical uncertainties. These data provide experimental access to the vortical structure of the nearly ideal liquid[8] created in a heavy ion collision and should prove valuable in the development of hydrodynamic models that quantitatively connect observations to the theory of the strong force.

The primary objective of the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory is to produce a large (relative to the size of a proton) system of matter at temperatures of $T \approx 200\,\text{MeV}/k_B \approx 2.3 \times 10^{12}\,\text{K}$ by colliding gold nuclei travelling at 96.3% to 99.995% of the speed of light. Such temperatures, more than 100,000 times that at the Sun's core, characterized the Universe only a few microseconds after the Big Bang[9]. Under these extreme conditions, the protons and neutrons that comprise our everyday world melt into a state of deconfined quarks and gluons called the quark–gluon plasma[1,10]. Before RHIC was turned on in 1999, the expectation was that this plasma would be weakly coupled and highly viscous. However, the discovery of strong collective behaviour led to the surprising conclusion that the system generated in these collisions was in fact a liquid with the lowest ratio of viscosity to entropy density ever observed[8].

Since then, a large programme of experimental investigation combined with increasingly sophisticated hydrodynamic theory have succeeded in reproducing observed properties of the fluid[11]. A complete understanding of this fluid may provide deep insights into the strongest and most poorly understood of the fundamental forces in nature. Quantum chromodynamics is the theory of the strong interactions between quarks and gluons, but experimental input from RHIC is essential to understand quark confinement and the origin of hadron mass.

A collaboration of physicists from 13 countries operates the STAR detector system[12], which has recorded billions of collisions at RHIC. A rendering of the STAR experiment is shown in Fig. 1. Opposing beams of gold nuclei collide in the centre of the time projection chamber (TPC), generating a spray of charged particles. The TPC signal from a single event is shown in Fig. 2. Forward- and backward-travelling particles and fragments that experience only a small deflection are measured in the beam–beam counters.

Most collisions at RHIC are not head-on, and so involve substantial angular momentum, of the order of 1,000$\hbar$ (where $\hbar$ is the reduced Planck constant) for a typical collision. A slight sideward deflection of the forward- and backward-travelling fragments[13] from a given collision allows experimental determination of the direction of the overall angular momentum $\hat{J}_{sys}$, as shown schematically in Fig. 3.

Recently, Takahashi *et al.*[14] reported the first observation of a coupling between the vorticity of a fluid and the internal quantum spin of the electron, opening the door to a new field of fluid spintronics. In their study, the vorticity $\boldsymbol{\omega}$—a measure of the 'swirl' of the velocity flow field around any point (non-relativistically, $\boldsymbol{\omega} = \frac{1}{2}\nabla \times \boldsymbol{v}$)—is generated through shear viscous effects as liquid mercury flows next to a rigid wall.

In a heavy ion collision, shear forces generated by the interpenetrating nuclei may present an analogous situation, introducing vorticity to the fluid. Indeed, hydrodynamic calculations[15] with initial conditions tuned to reproduce measured momentum anisotropies predict tremendous vorticity in the fluid at RHIC. So far, no experimental evidence of vorticity at RHIC has been reported, and its role in the evolution of the fluid has not been explored extensively at the theoretical level.

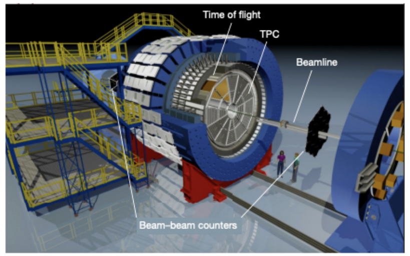


Figure 1 | The STAR detector system. Gold nuclei travelling at nearly the speed of light travel along the beamline and collide in the centre of the detector system. Charged particles emitted at mid-rapidity (that is, having a relatively small component of velocity along the beam direction) are measured in the TPC (see also Fig. 2) and the time-of-flight detectors. Forward- and backward-going beam fragments are detected in the beam–beam counters.

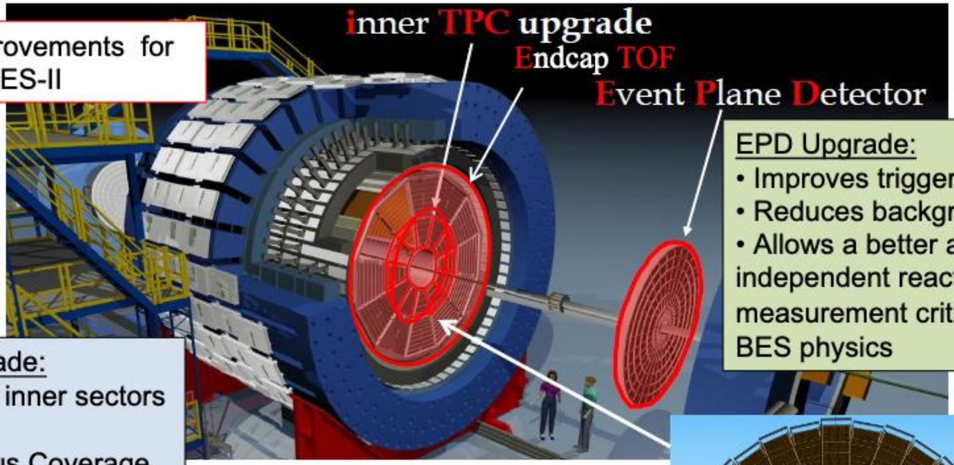
*A list of participants and their affiliations appears at the end of the paper.

Completion of STAR – Growing Up!

STAR

STAR detector at BESII

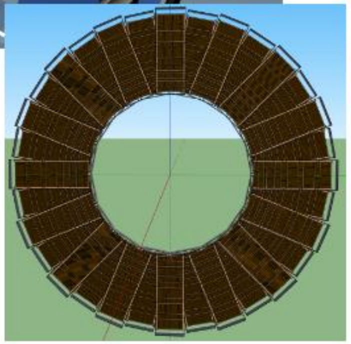
Major improvements for BES-II



EPD Upgrade:
- Improves trigger
- Reduces background
- Allows a better and independent reaction plane measurement critical to BES physics

iTPC Upgrade:
- Replaced inner sectors of the TPC
- Continuous Coverage
- Improves dE/dx
- Extends η coverage from 1.0 to 1.5
- Lowers p_T cut from 125 MeV/c to 60 MeV/c

EndCap TOF Upgrade:
- Rapidity coverage is critical
- PID at η = 1 to 1.5
- Improves the fixed target program
- Provided by CBM-FAIR



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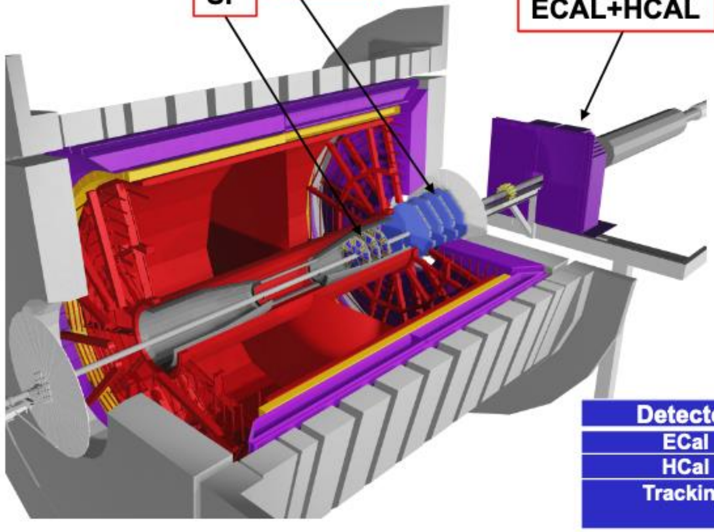
STAR forward upgrades

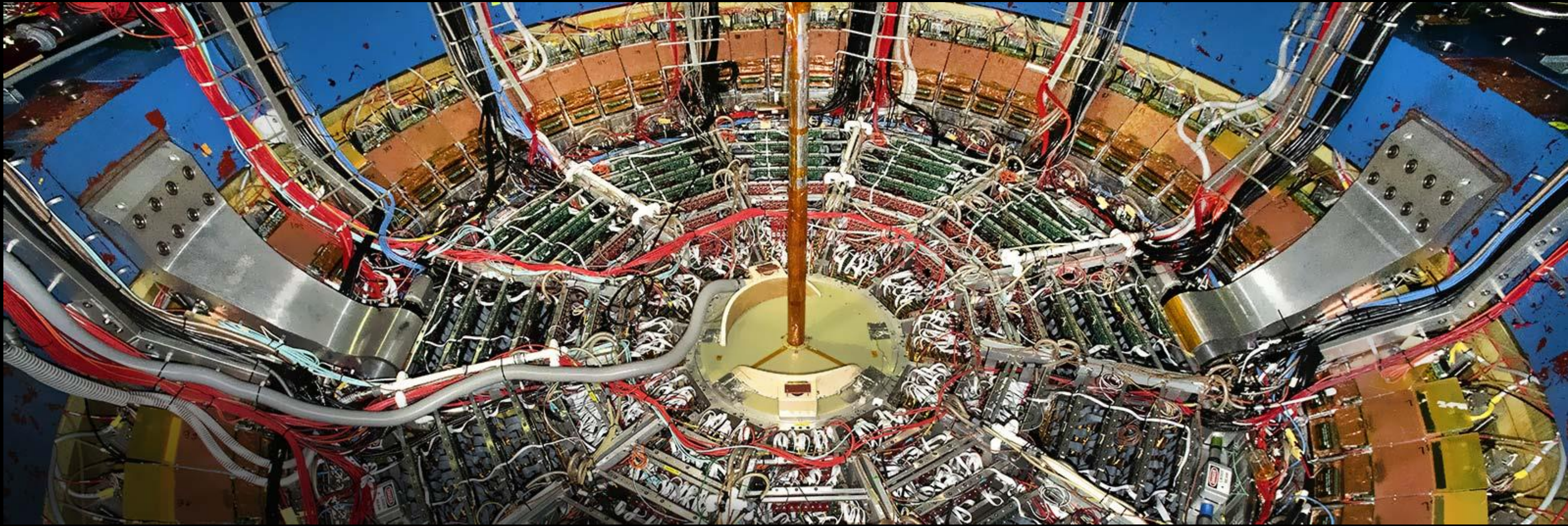


At 2.5<η<4
- Jets
- PID (π^0, γ, e, Λ)
- charged particle momentum resolution 20-30% at $0.2<p_T<2$ GeV/c
- event-plane reconstruction and trigger capability

Detector	pp and pA	AA
ECal	~10%/√E	~20%/√E
HCal	~50%/√E+10%	---
Tracking	charge separation photon suppression	$0.2<p_T<2$ GeV/c with 20-30% $1/p_T$

Lijuan Ruan, BNL 41

STAR – All Grown Up!



To date: 391 theses → 347 (PhD), 34 (Masters) and 10 (Diploma)
347 publications → 107 PRLs, 130 PRC, 50 PLB, 34 PRD, 11 Science/Nature, 15 others

26 publications in this year!

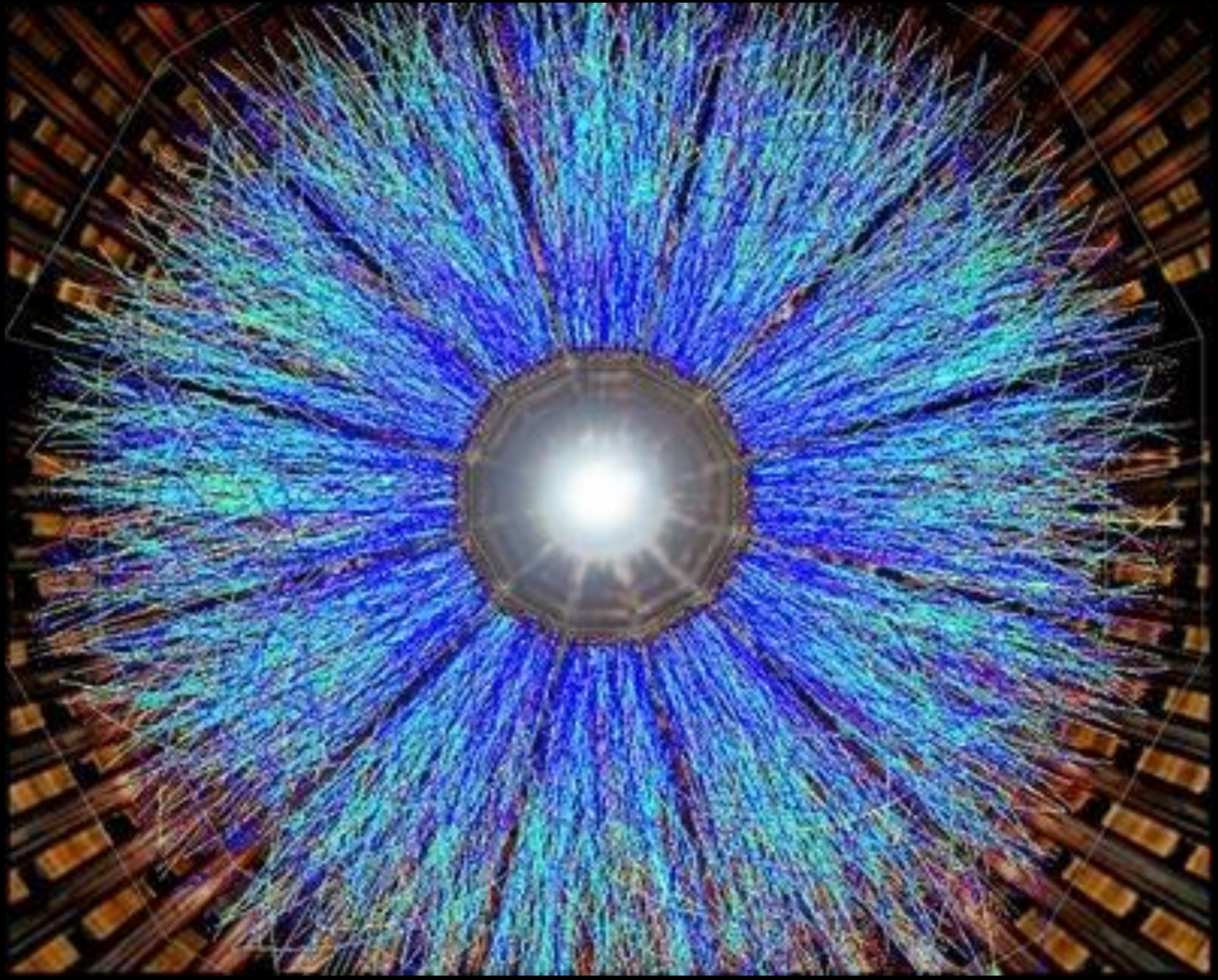
STAR has produced

the hottest,

least viscous, and

most vortical fluid ever

in the laboratory!



"Photo" credit BNL

Congratulations!

and Special Thanks

to all my STAR Collaborators!

Thanks to the Organizers of this Celebration!