An Antimatter, Hypernuclear, Calm and “Collective” Kind of Guy

Declan Keane was honored as a fellow of the American Physical Society

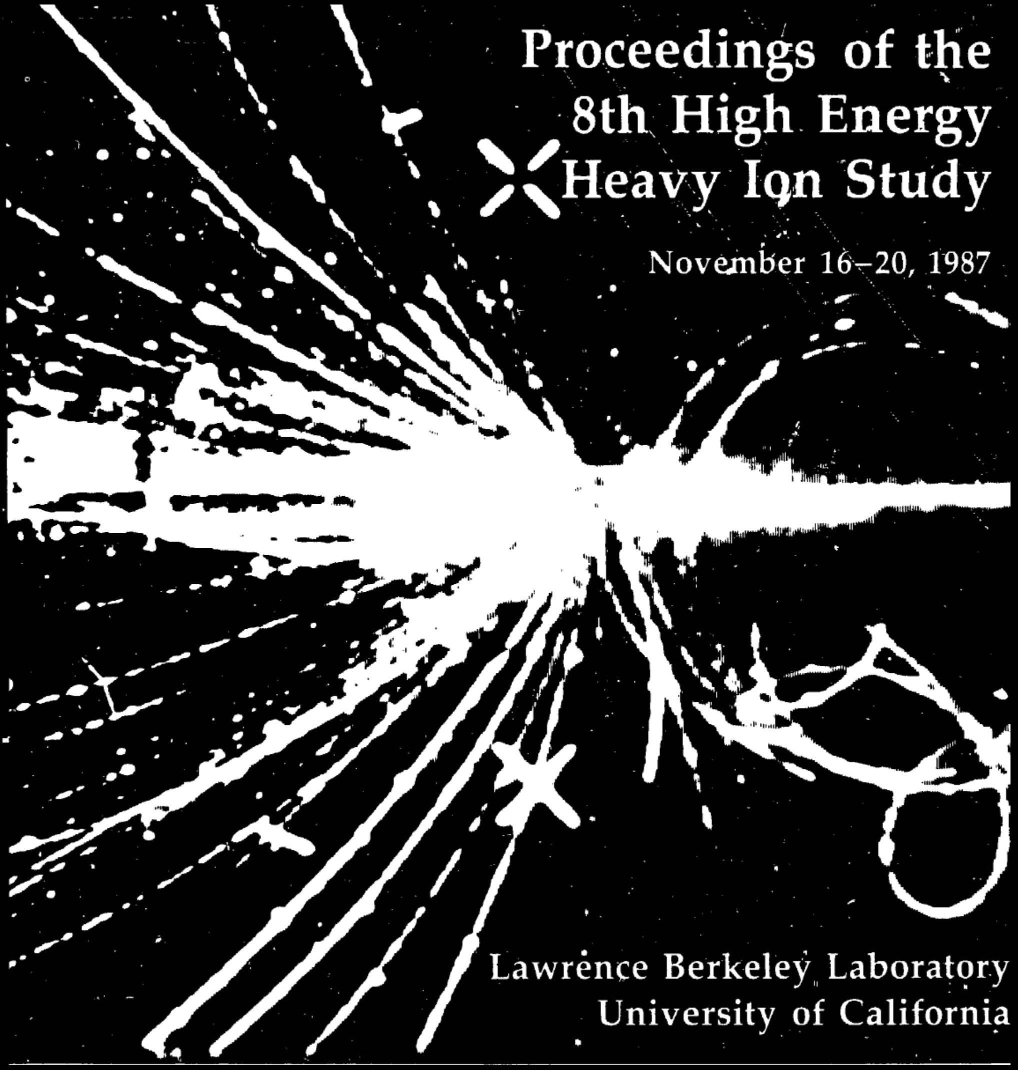
“for his leadership in the study of collective phenomena using directed flow and the discovery of antimatter hypertriton and Helium-4 in high-energy nuclear collisions at the Relativistic Heavy Ion Collider (RHIC).”

Professional Chronology

- 1981 – 1987, University of California, Riverside, Postdoctoral Fellow
- 1988 – present, Professor, Kent State University, Department of Physics
- 1990 – present, Active and Founding Member of STAR Collaboration
- c. 1998 – Spokesperson for Brookhaven AGS experiment E895

Early Days at the BEVALAC

1981 – 1987, University of California, Riverside, Postdoctoral Fellow



Early Days at the BEVALAC

1981 – 1987, University of California, Riverside, Postdoctoral Fellow

LBL-24580

Proceedings of the
8th High Energy Heavy Ion Study

Lawrence Berkeley Laboratory
November 16–20, 1987

Jointly sponsored by

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Lawrence Berkeley Laboratory
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Edited by

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This work was supported by the U.S. Department of Energy under Contract No. DE-AC03-76SF00098

Comparisons of VUU Predictions with Streamer Chamber Data
D. Keane (Presenter), S. Y. Chu, S. Y. Fung, Y. M. Liu, L. J. Qiao, G. VanDalen, M. Vient,
S. Wang, J. J. Molitoris, and H. Stöcker………page 165

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Early Days at the BEVALAC

1981 – 1987, University of California, Riverside, Postdoctoral Fellow

COMPARISONS OF VUU PREDICTIONS WITH STREAMER CHAMBER DATA

D. Keane, S.Y. Chu, S.Y. Fung, Y.M. Liu,† L.J. Qiao, G. VanDalen, M. Vient, and S. Wang†

Department of Physics, University of California, Riverside, California 92521

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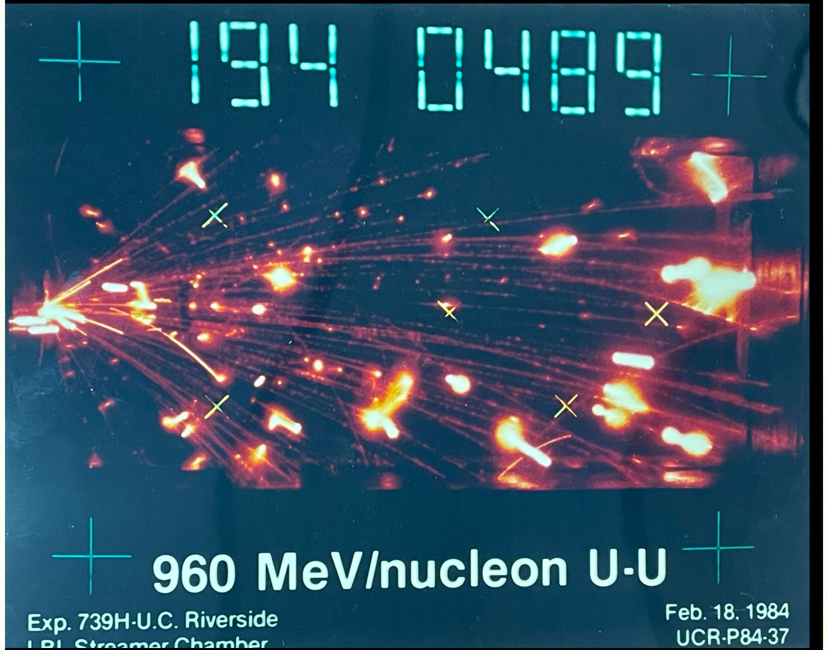
Institut für Theoretische Physik, Goethe Universität, D-6000 Frankfurt am Main, West Germany

Abstract

Experimental charged particle inclusive and exclusive parameters for several nuclear systems are compared with microscopic model predictions based on the Vlasov-Uehling-Uhlenbeck equation, for various density-dependent nuclear equations of state (EOS). Inclusive variables and multiplicity distributions are in good agreement, and are not sensitive to the EOS. Rapidity spectra show evidence of being useful in determining whether the model uses the correct cross sections for binary collisions in the nuclear medium, and whether momentum dependent interactions are correctly incorporated. Sideward flow parameters do not favor the same nuclear incompressibility at all multiplicities, and there are indications that the present model may provide only an upper limit on the true stiffness of the EOS. Findings relating to impact parameter averaging and the mass and energy dependence of transverse flow are also presented.



STATUS OF MULTI-PION CORRELATIONS AT HISS*

D. Olson[a], W. Christie[b1], T. Abbott[a], D. Beavis[c], P. Brady[b], H. Crawford[d], S. Fung[a], D. Keane[a], P. Lindstrom[e], Y. Liu[f], W. Müller[e], T. J. M. Symons[e], C. Tull[b], W. Wieman[e]

[a]University of California, Riverside, CA 92521
[b]University of California, Davis, CA 95616
[c]Brookhaven National Lab., Upton, NY
[d]University of California Space Sciences Lab., Berkeley, CA 94720
[e]Lawrence Berkeley Lab., Berkeley, CA 94720
[f]Harbin Institute, People's Republic of China

1 Introduction

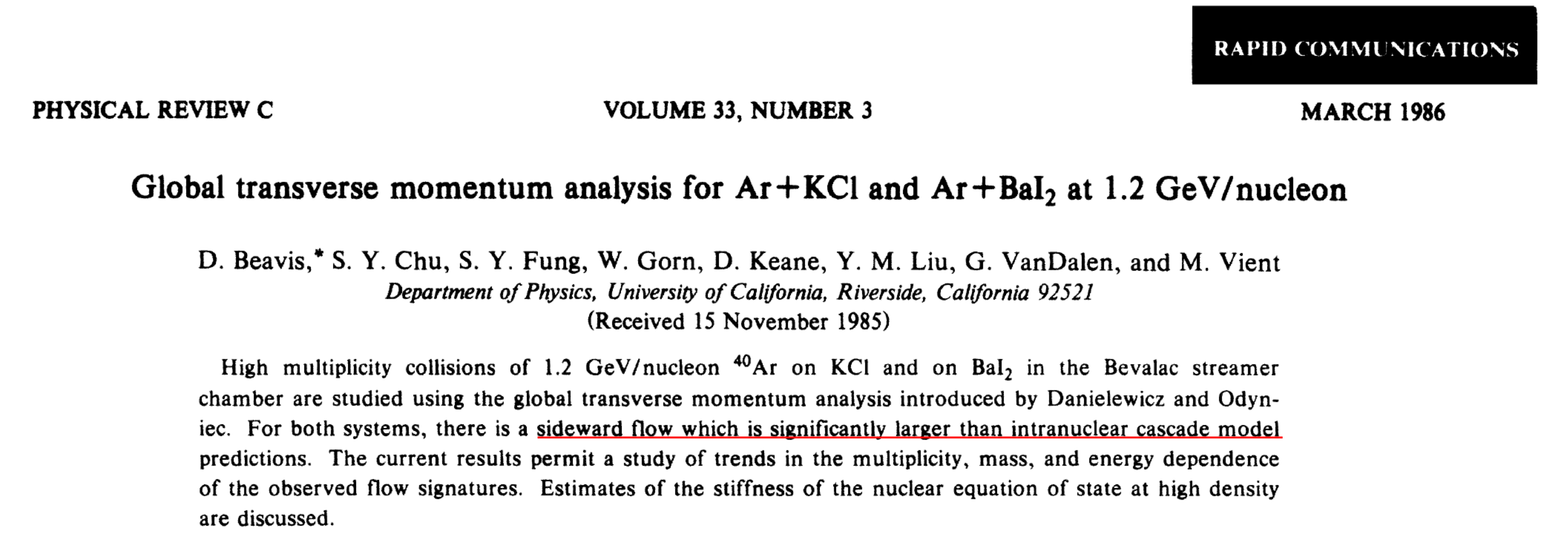
Bevalac experiment E684H is an investigation of multi-pion correlations at HISS. This is a continuation of the studies carried out at the LBL streamer chamber by the Riverside group.[1,2] While the streamer chamber experiments were studies of pion correlations over the entire range of mid-rapidity phase-space with modest statistics, the HISS experiment covers a large-but-limited range in phase-space with high statistics. During a run in April/May 1987 we obtained our primary data sample for 1.8 GeV/nucleon Ar+KCl and a secondary sample with 1.2 GeV/nucleon Xe+La.

*supported by DOE Contract DE-AS05-76ER04699, NSF Grant PHY81-21003, and NASA Grant NGR-05-003-513

[1]PhD thesis

Early Days at the BEVALAC

1981 – 1987, University of California, Riverside, Postdoctoral Fellow



RAPID COMMUNICATIONS

PHYSICAL REVIEW C VOLUME 33, NUMBER 3 MARCH 1986

Global transverse momentum analysis for Ar+KCl and Ar+BaI$_2$ at 1.2 GeV/nucleon

D. Beavis,* S. Y. Chu, S. Y. Fung, W. Gorn, D. Keane, Y. M. Liu, G. VanDalen, and M. Vient
Department of Physics, University of California, Riverside, California 92521

(Received 15 November 1985)

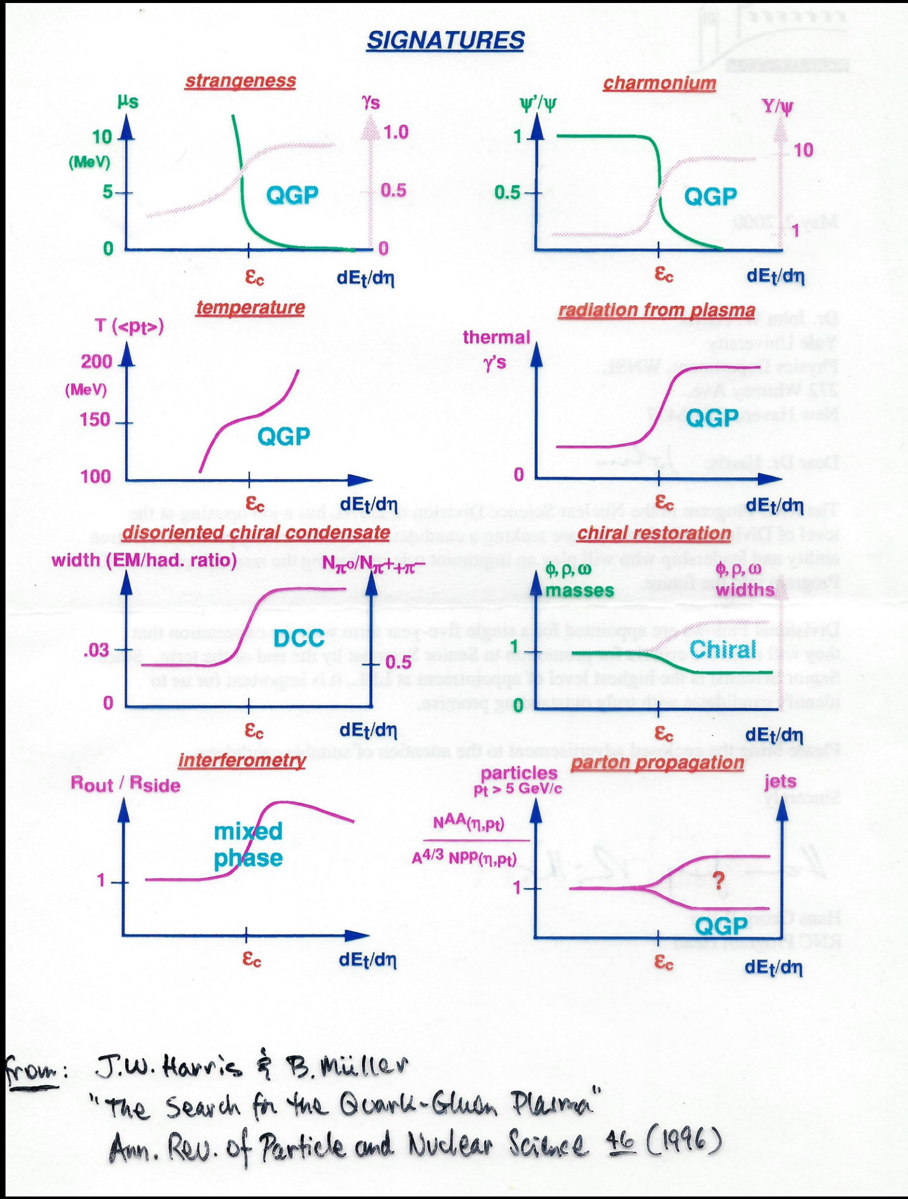
High multiplicity collisions of 1.2 GeV/nucleon ^{40}Ar on KCl and on BaI$_2$ in the Bevalac streamer chamber are studied using the global transverse momentum analysis introduced by Danielewicz and Odyniec. For both systems, there is a sideward flow which is significantly larger than intranuclear cascade model predictions. The current results permit a study of trends in the multiplicity, mass, and energy dependence of the observed flow signatures. Estimates of the stiffness of the nuclear equation of state at high density are discussed.

On to RHIC

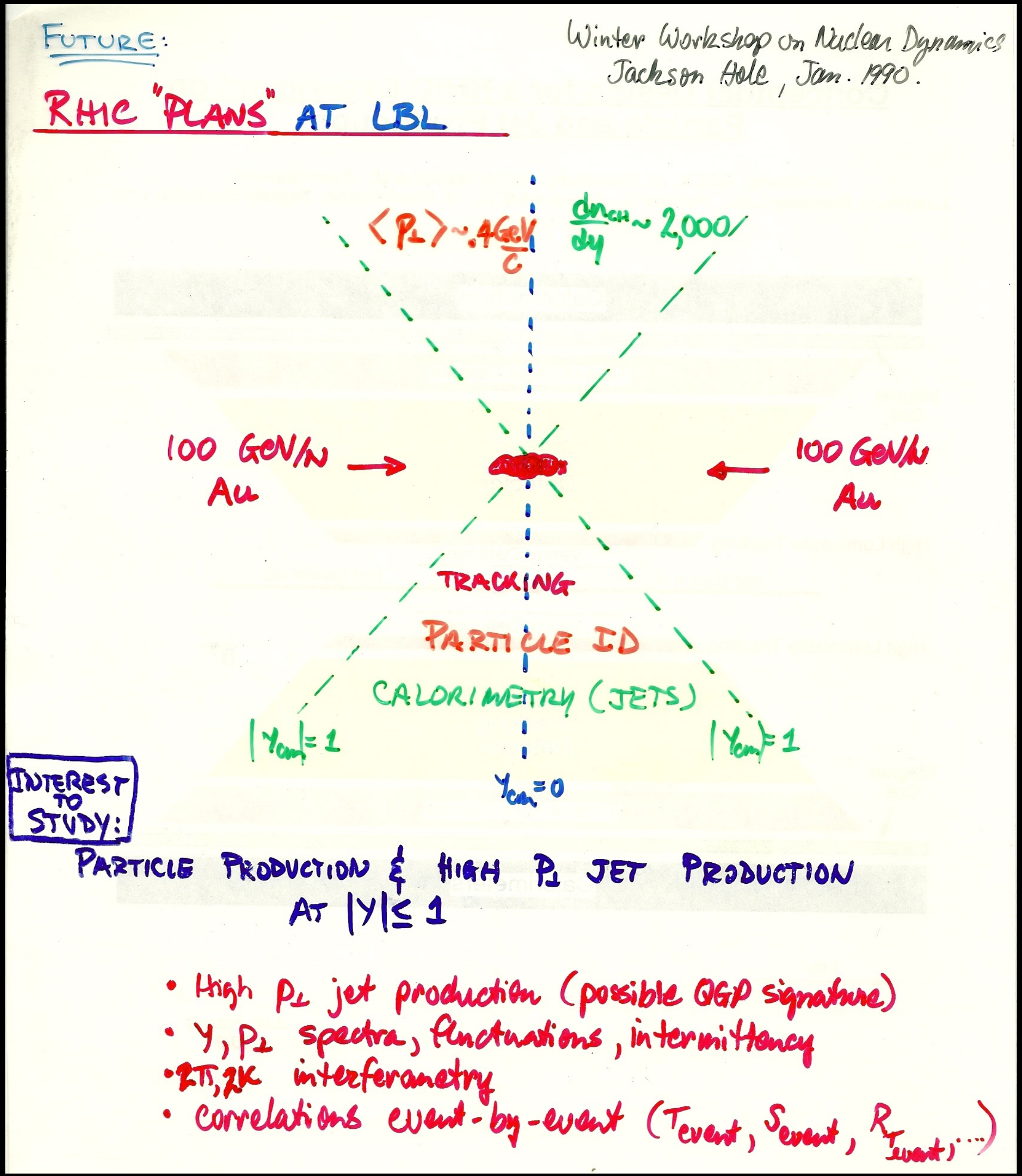
1988 – present, Kent State University, Professor Declan Keane

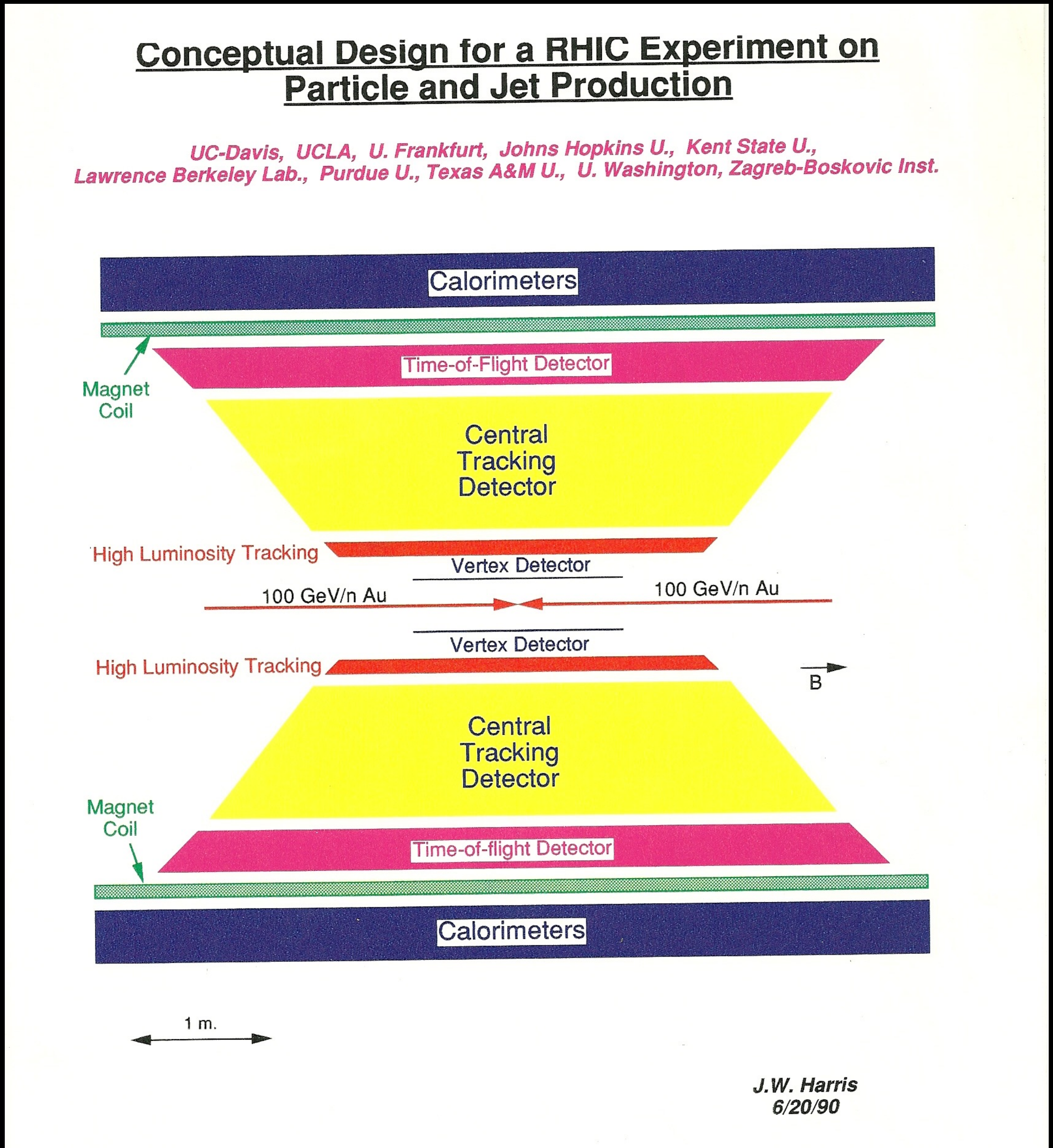
Founding Member of STAR!

Conceptual Basis for STAR Physics



Concept of a New Experiment for RHIC





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

NUCLEAR SCIENCE DIVISION

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]

Founding Members of STAR!

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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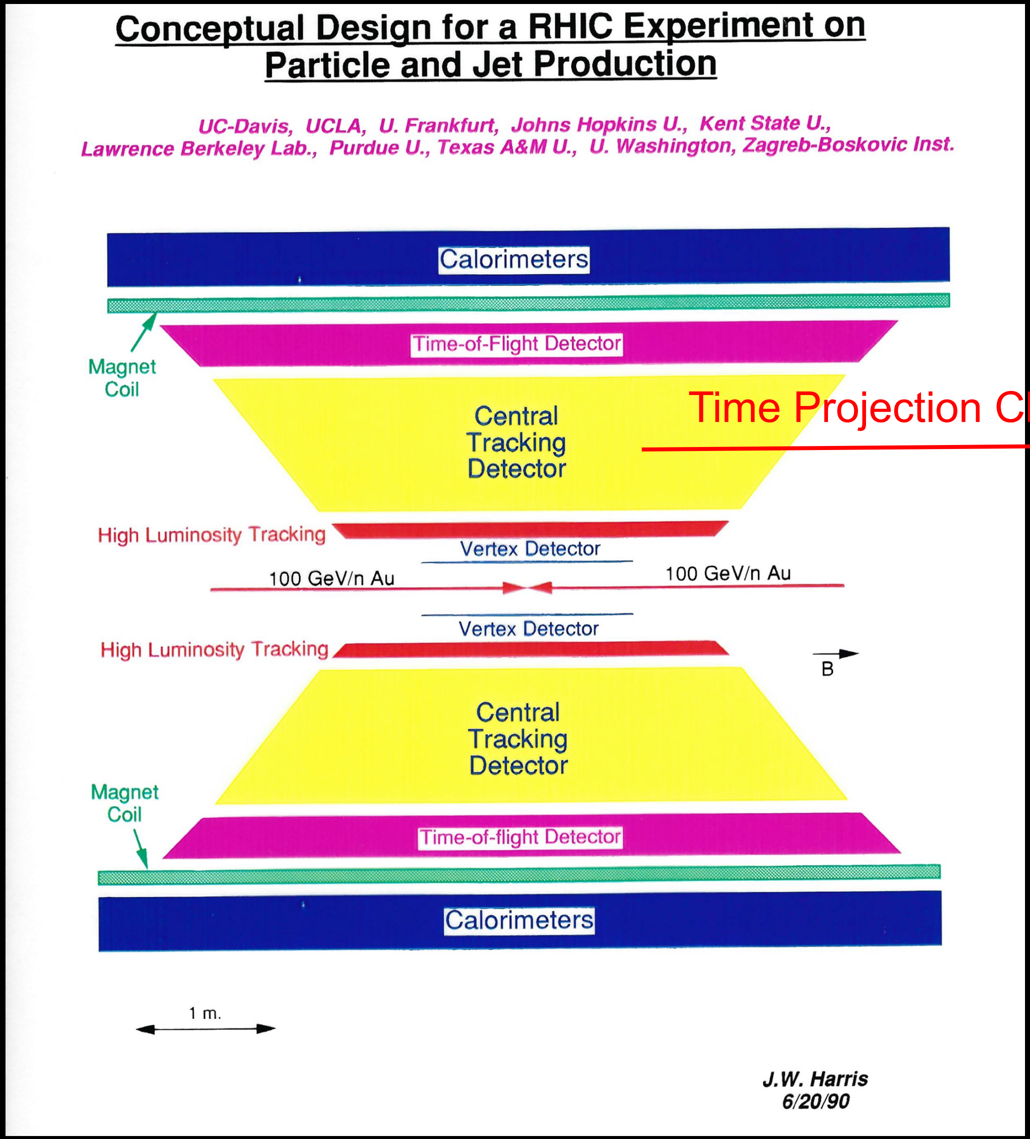
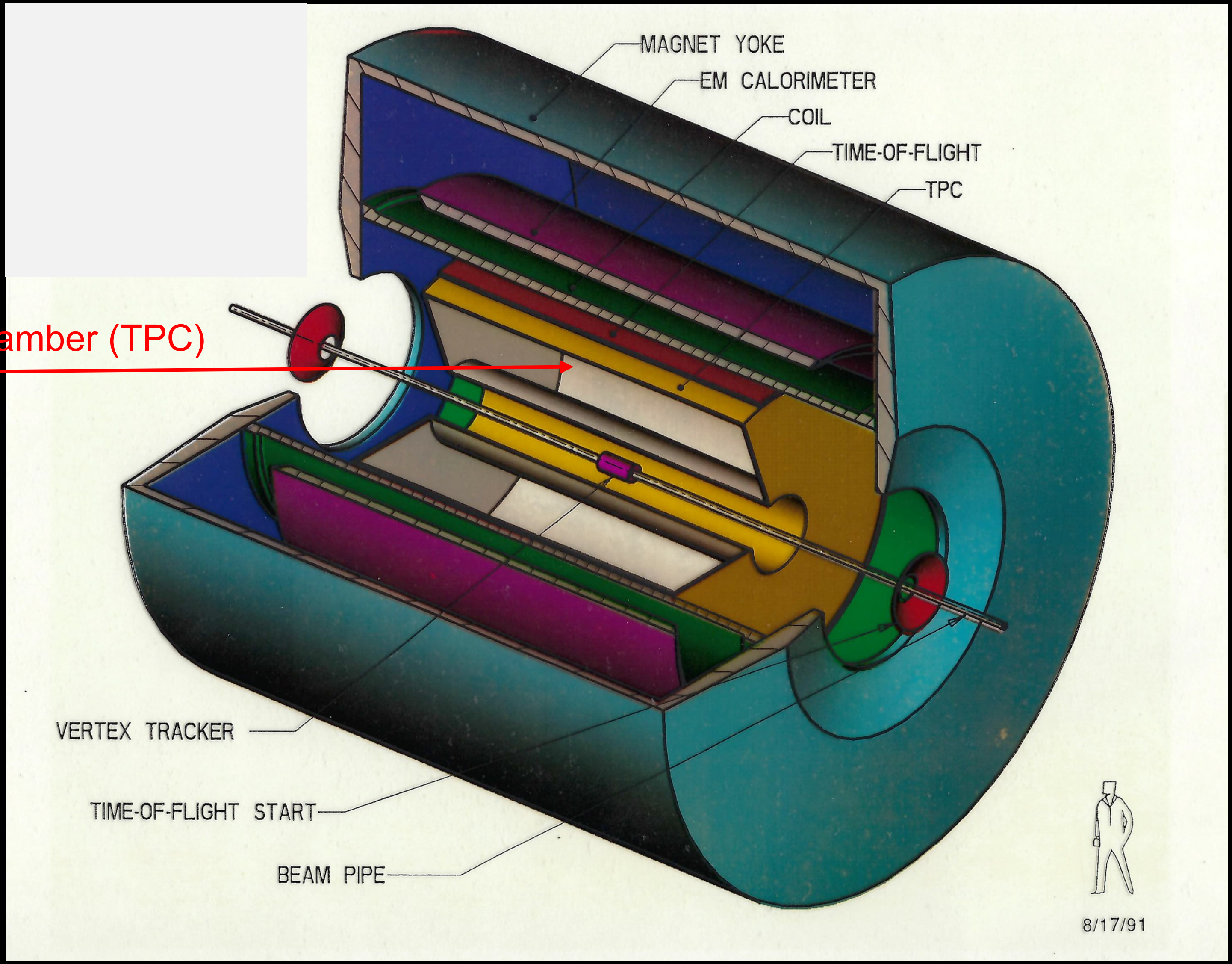
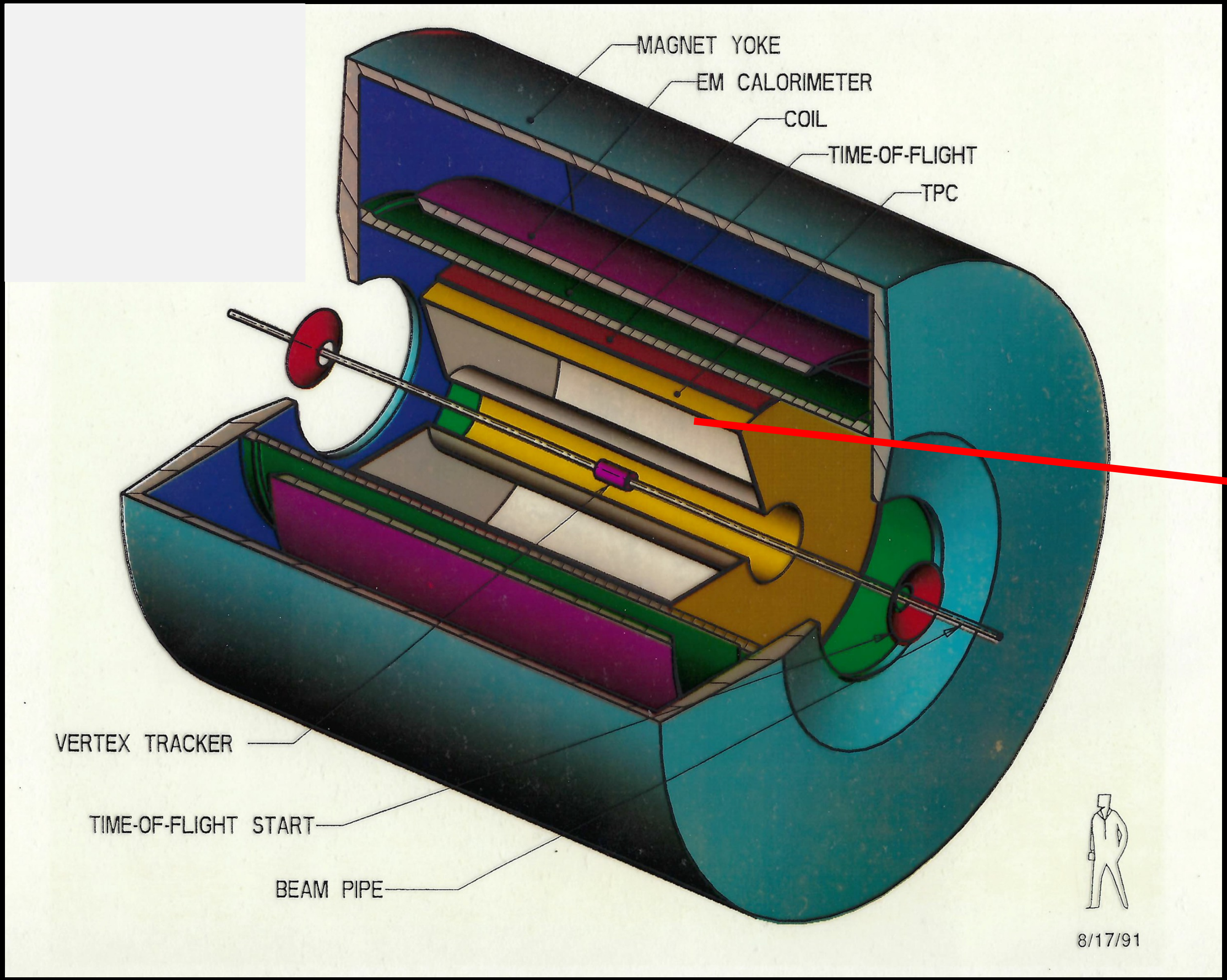
Design Evolution for Experiment at RHIC

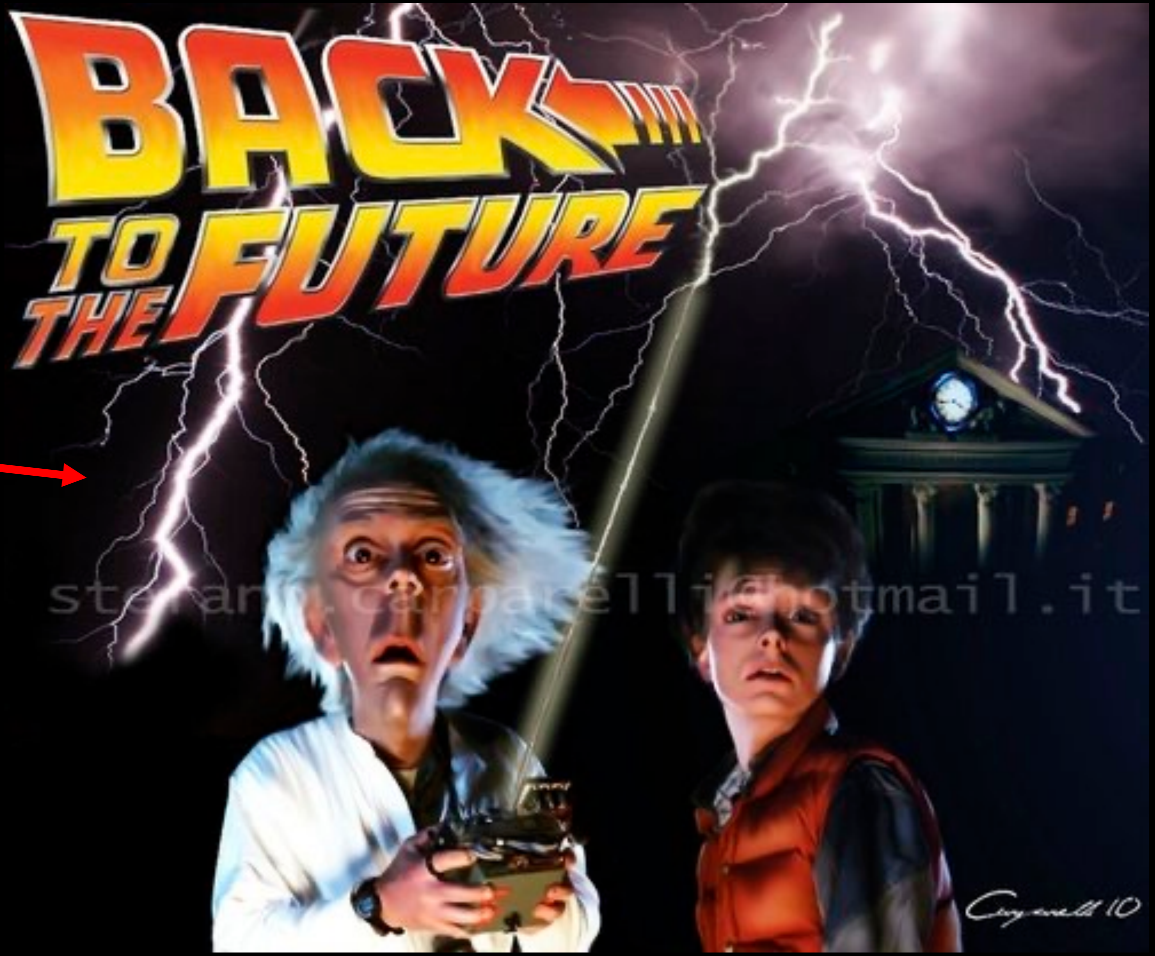




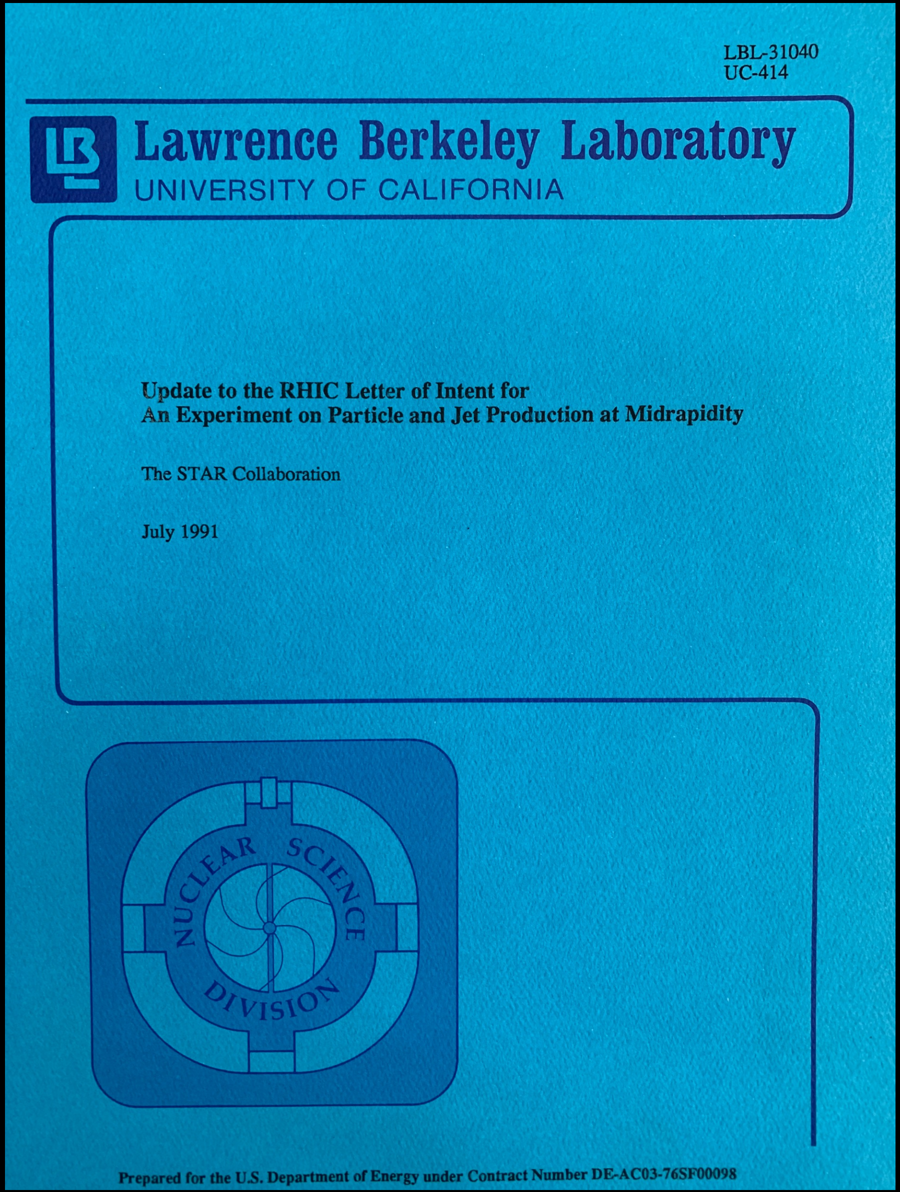
Design Evolution for Experiment at RHIC



Time Projection Chamber (TPC)



Update to RHIC Letter of Intent – July 1991


LBL-31040
UC-414

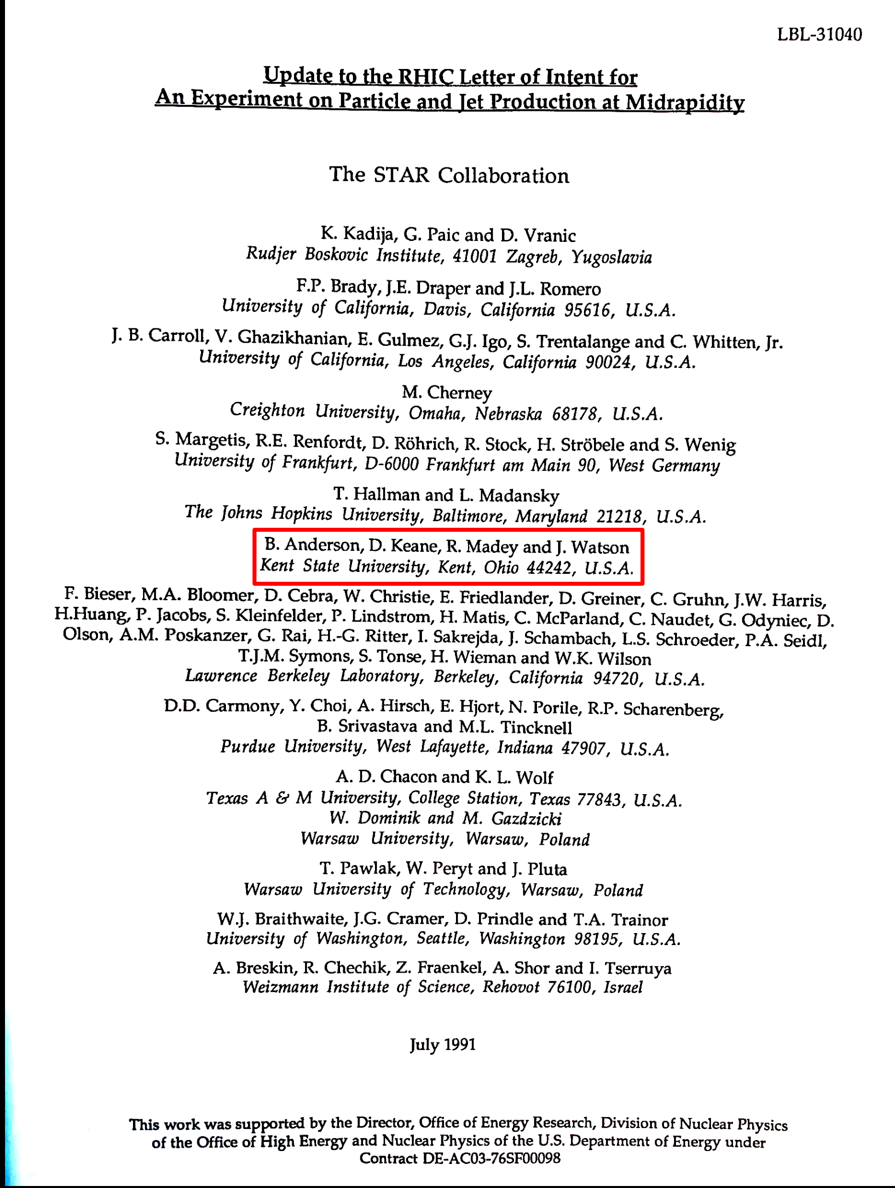
Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

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

The STAR Collaboration

July 1991

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


LBL-31040

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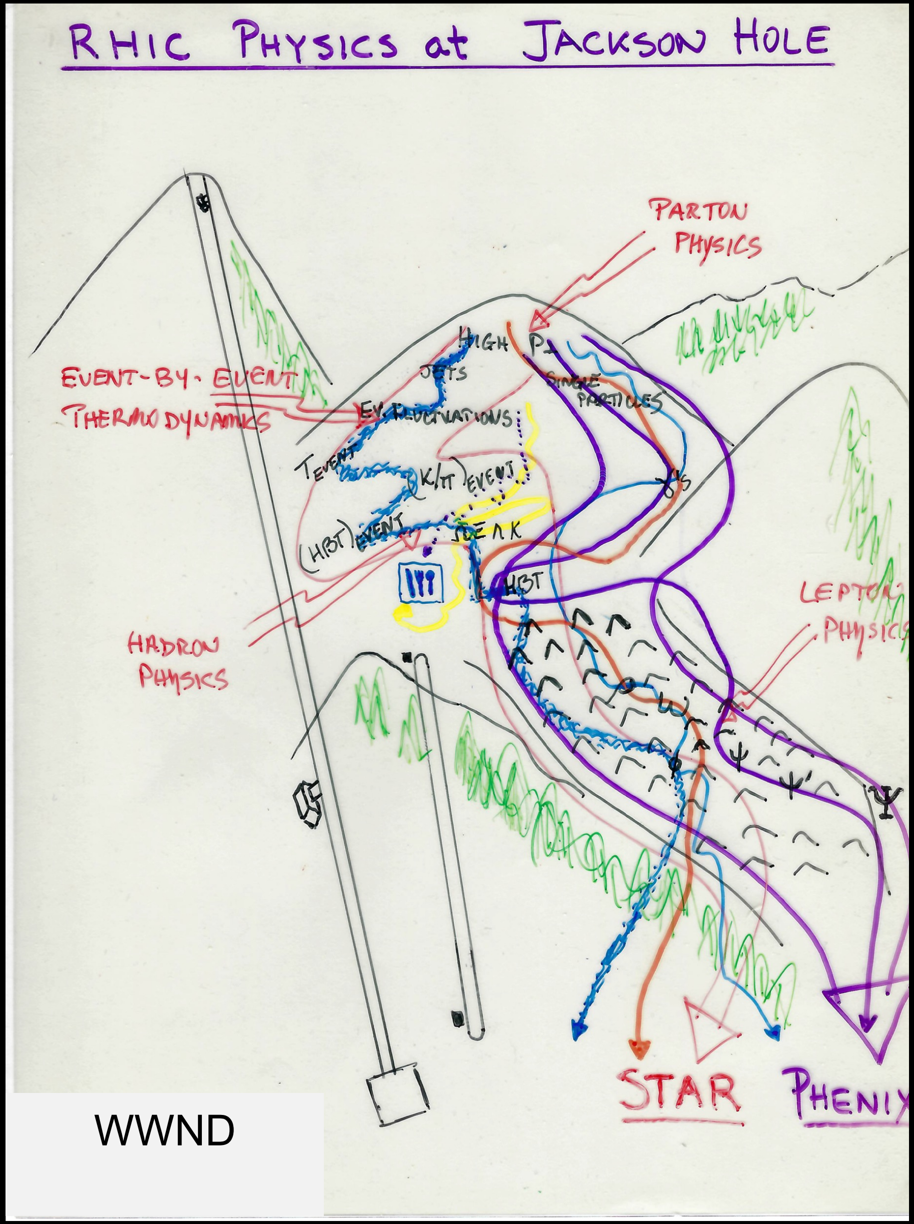
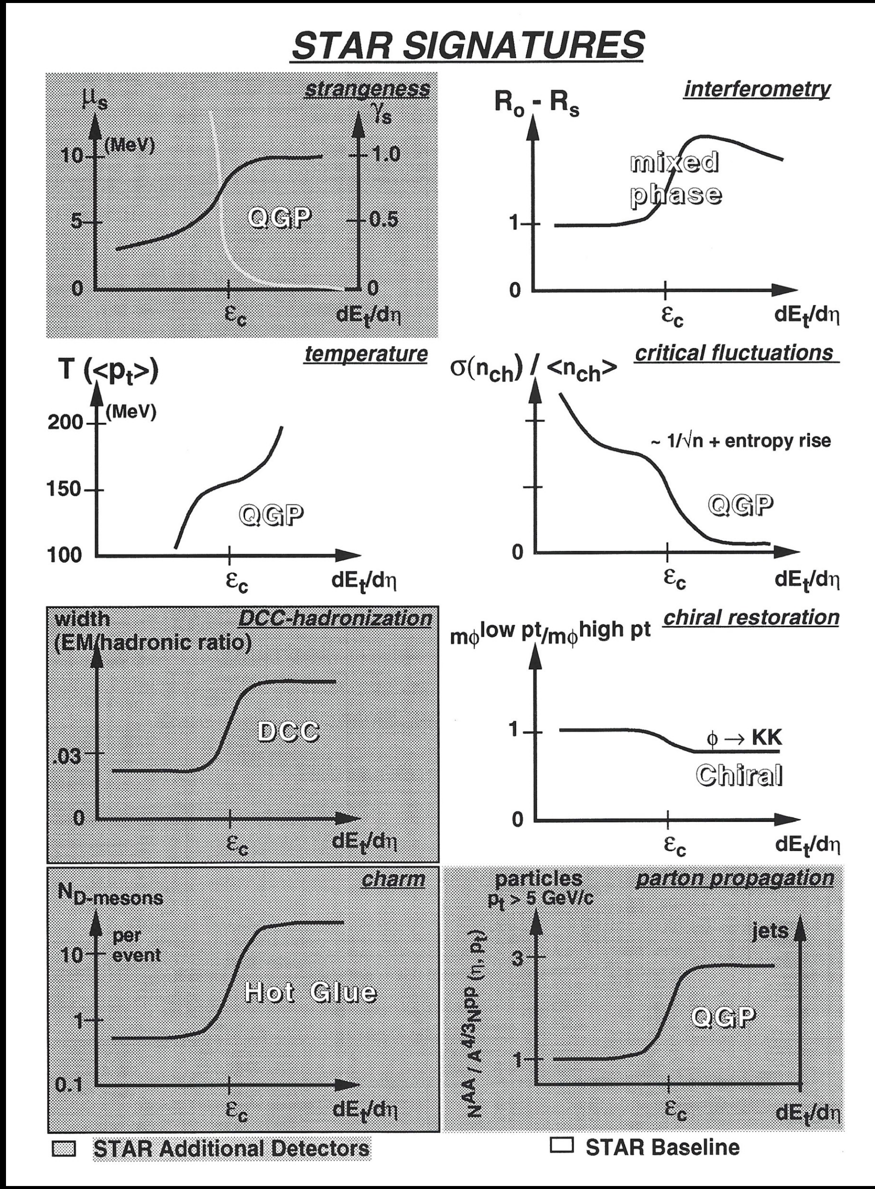
July 1991

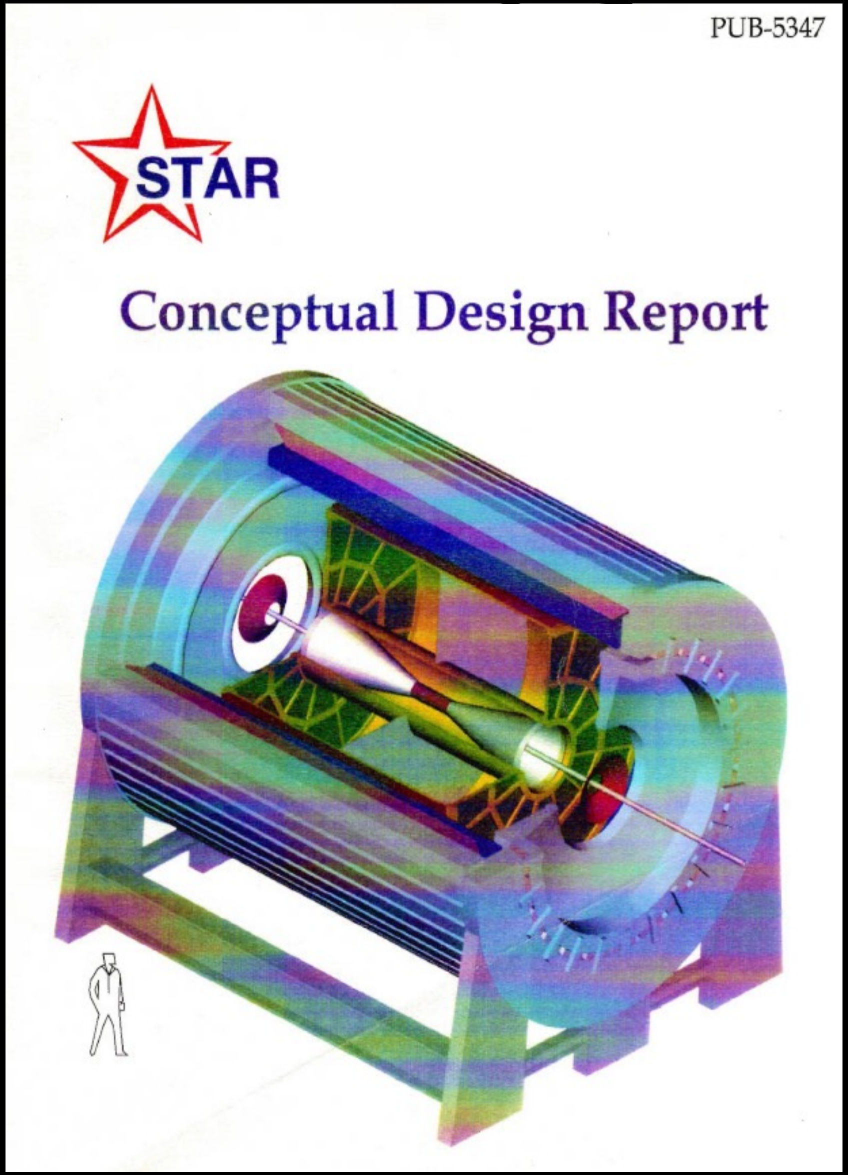
This work was supported by the Director, Office of Energy Research, Division of Nuclear Physics of the Office of High Energy and Nuclear Physics of the U.S. Department of Energy under Contract DE-AC03-76SF00098

Evolution of Physics at RHIC Foreseen from 1990 - 1992





STAR Conceptual Design Report 1994



Jay Marx
Project Director!

The STAR Collaboration

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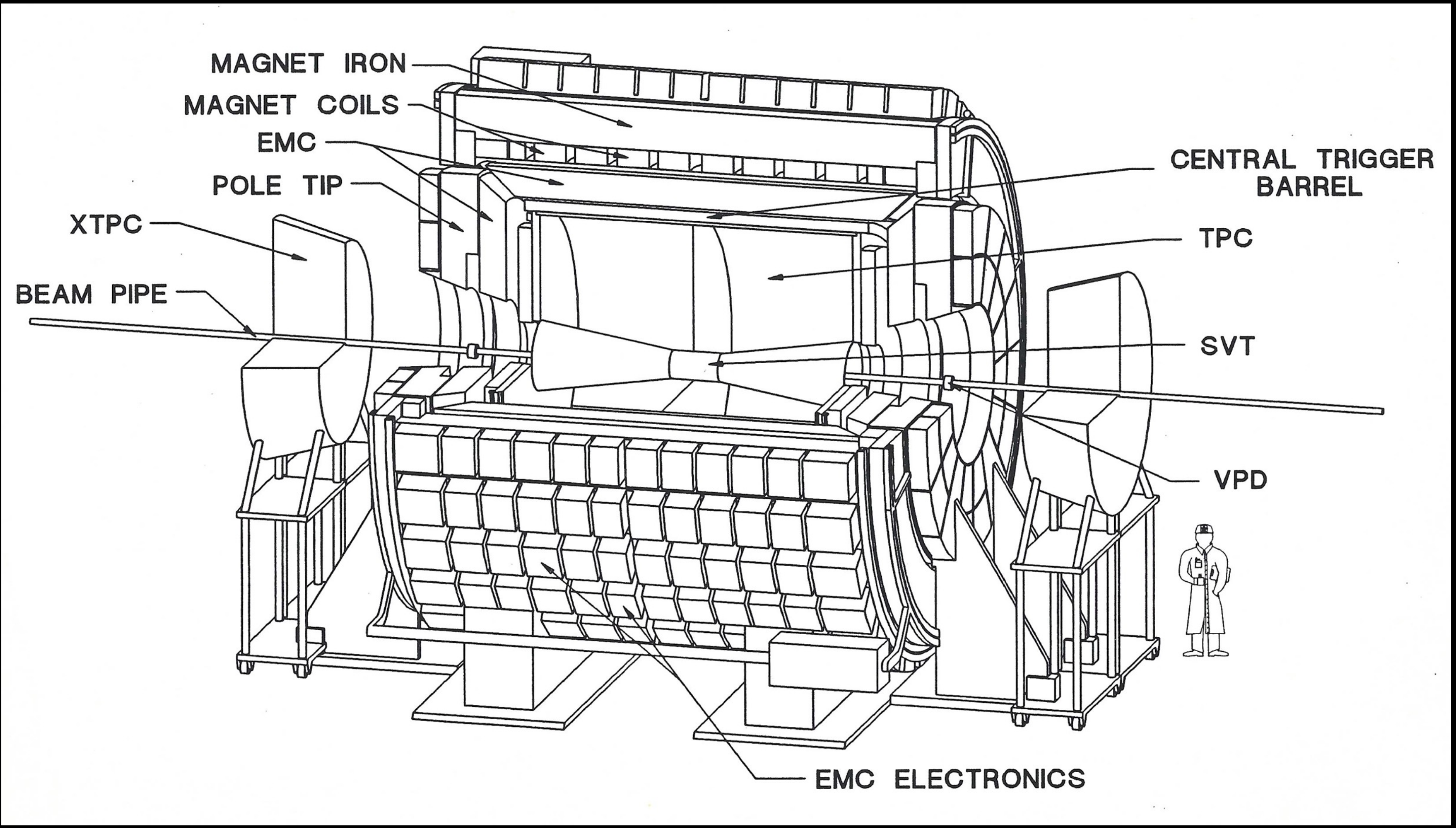
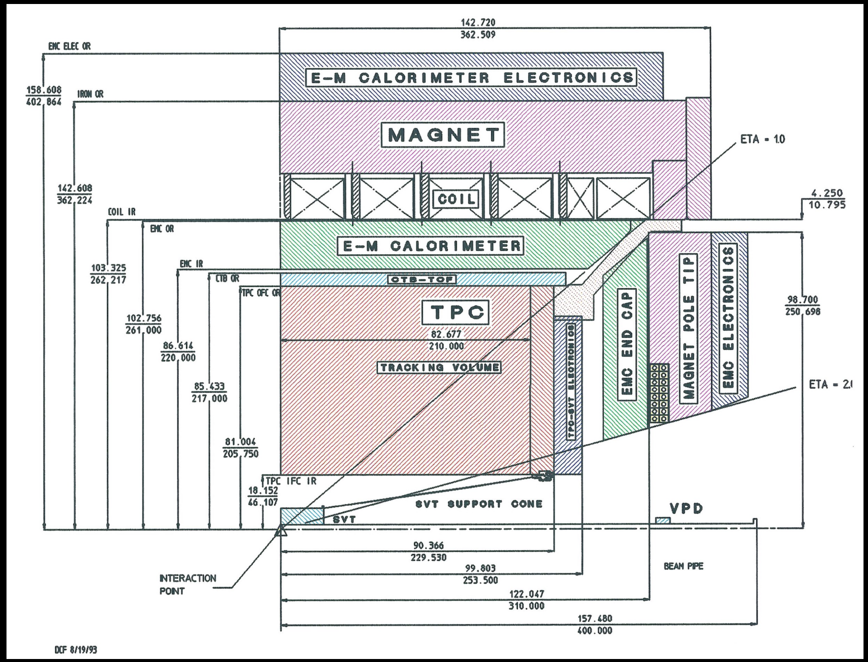
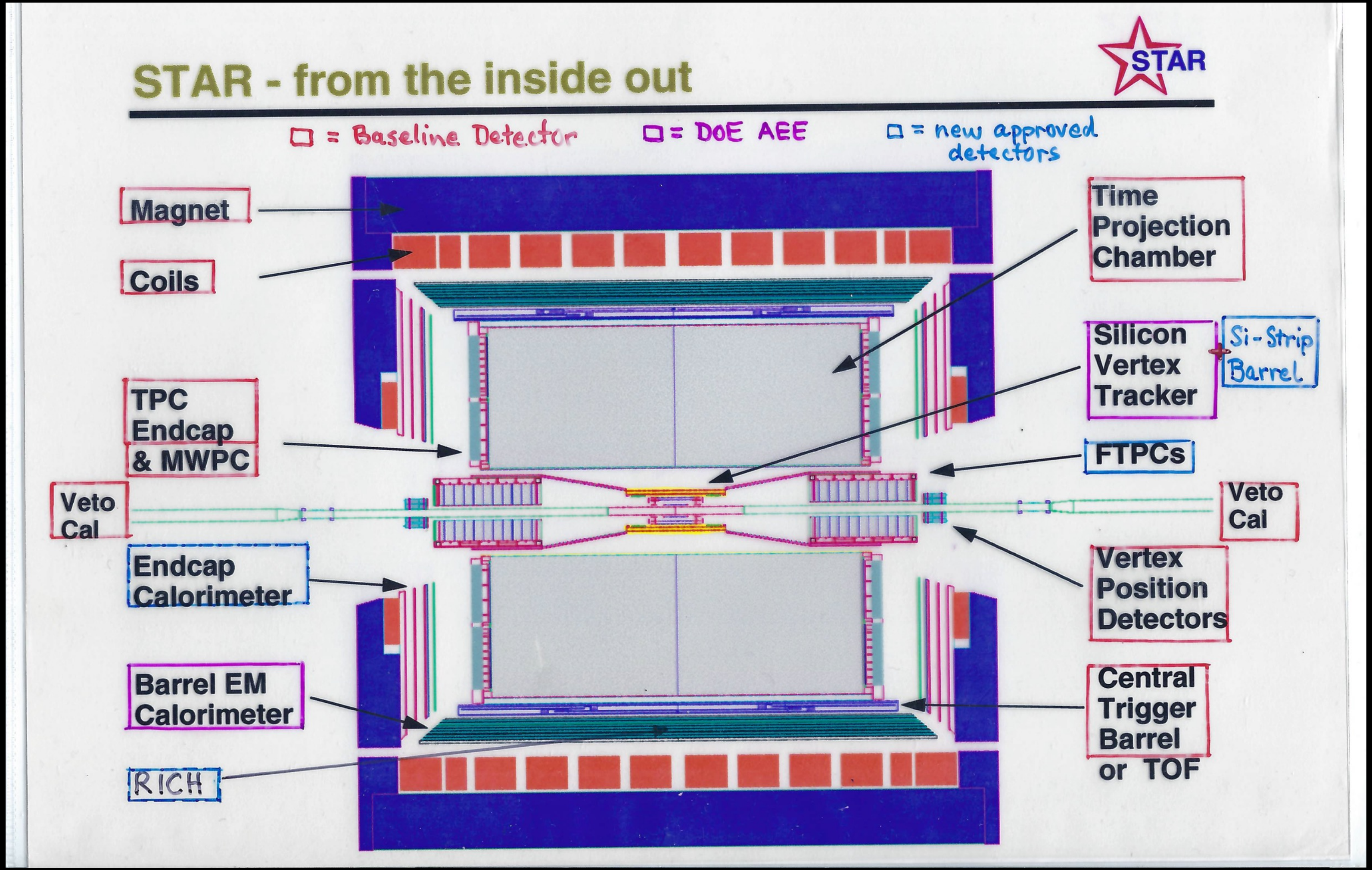
Lawrence Berkeley Laboratory, Berkeley, California 94720, U.S.A.

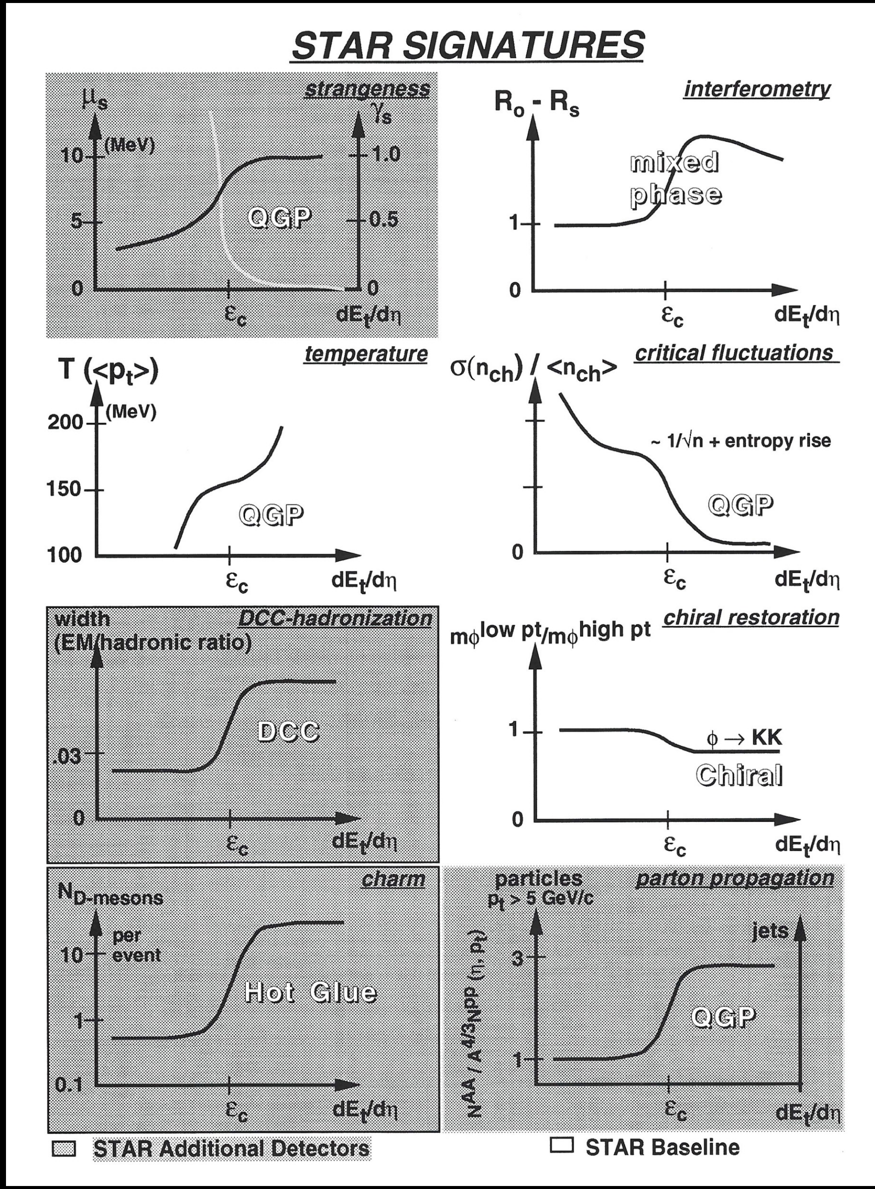
STAR Conceptual Design Report 1994





STAR Baseline Detector & Additional Equipment





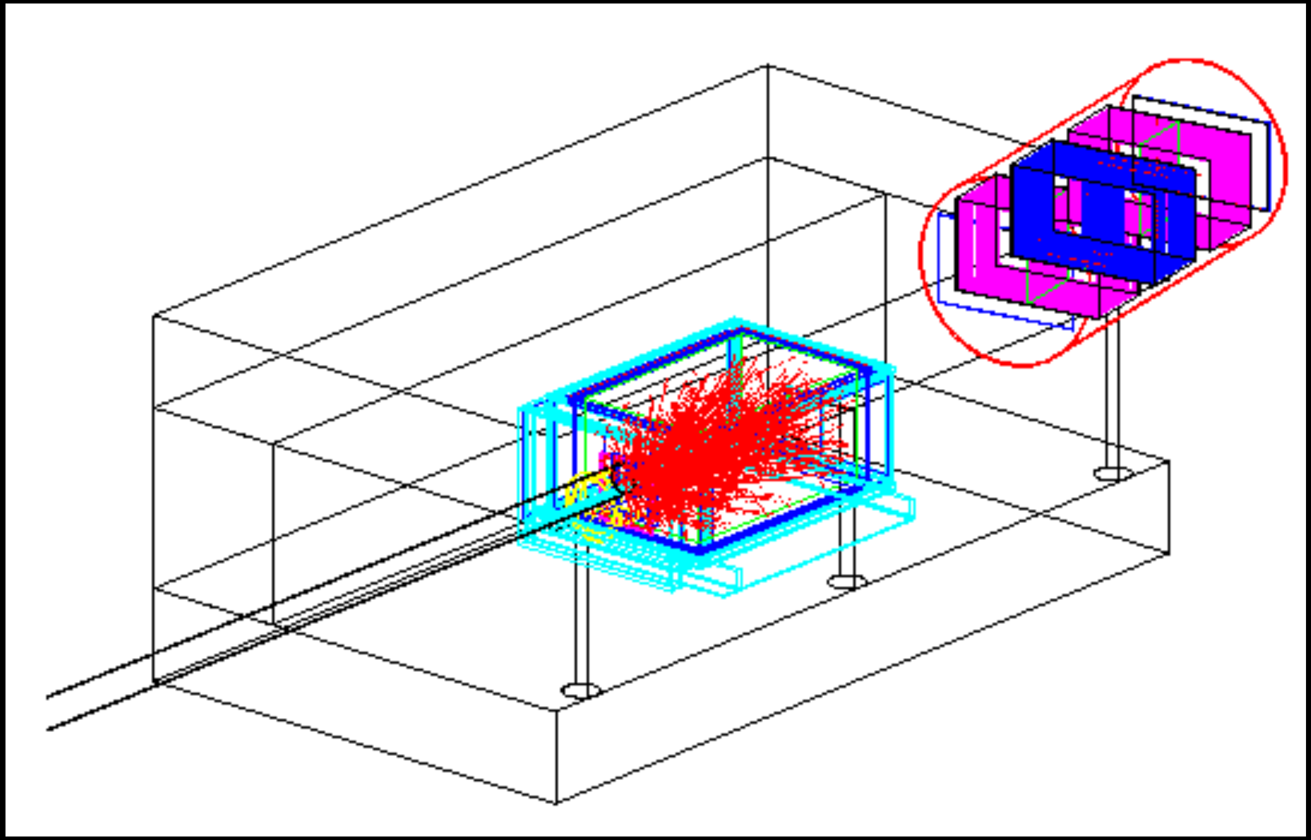
Before RHIC Data & RHIC Beam Energy Scan

Mid-to-Late 1990's

EOS Time Projection Chamber + MUSIC

Spokesperson for Brookhaven AGS experiment E895

in energy range of then future RHIC Beam Energy Scan



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Sideward Flow in Au+Au Collisions between 2 A and 8 A GeV.
Physical Review Letters, 84 (2000) 5488.

Spokesperson for Brookhaven AGS experiment E895
in energy range of then future RHIC Beam Energy Scan

VOLUME 84, NUMBER 24 PHYSICAL REVIEW LETTERS 12 JUNE 2000

Sideward Flow in Au + Au Collisions between 2*A* and 8*A* GeV

H. Liu,[7] N.N. Ajitanand,[12] J. Alexander,[12] M. Anderson,[5] D. Best,[1] F.P. Brady,[5] T. Case,[1] W. Caskey,[5] D. Cebra,[5] J. Chance,[5] B. Cole,[4] K. Crowe,[1] A. Das,[10] J. Draper,[5] M. Gilkes,[12] S. Gushue,[2] M. Heffner,[5] A. Hirsch,[11] E. Hjort,[11] L. Huo,[6] M. Justice,[7] M. Kaplan,[3] D. Keane,[7] J. Kintner,[8] J. Klay,[5] D. Krofcheck,[9] R. Lacey,[12] M.A. Lisa,[10] Y.M. Liu,[6] R. McGrath,[12] Z. Milosevich,[3] G. Odyniec,[1] D. Olson,[1] S.Y. Panitkin,[7] N. Porile,[11] G. Rai,[1] H.G. Ritter,[1] J. Romero,[5] R. Scharenberg,[11] L.S. Schroeder,[1] B. Srivastava,[11] N.T.B. Stone,[1] T.J.M. Symons,[1] S. Wang,[7] J. Whitfield,[3] T. Wienold,[1] R. Witt,[7] L. Wood,[5] X. Yang,[4] W.N. Zhang,[6] and Y. Zhang[4]

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[3]*Carnegie Mellon University, Pittsburgh, Pennsylvania 15213*
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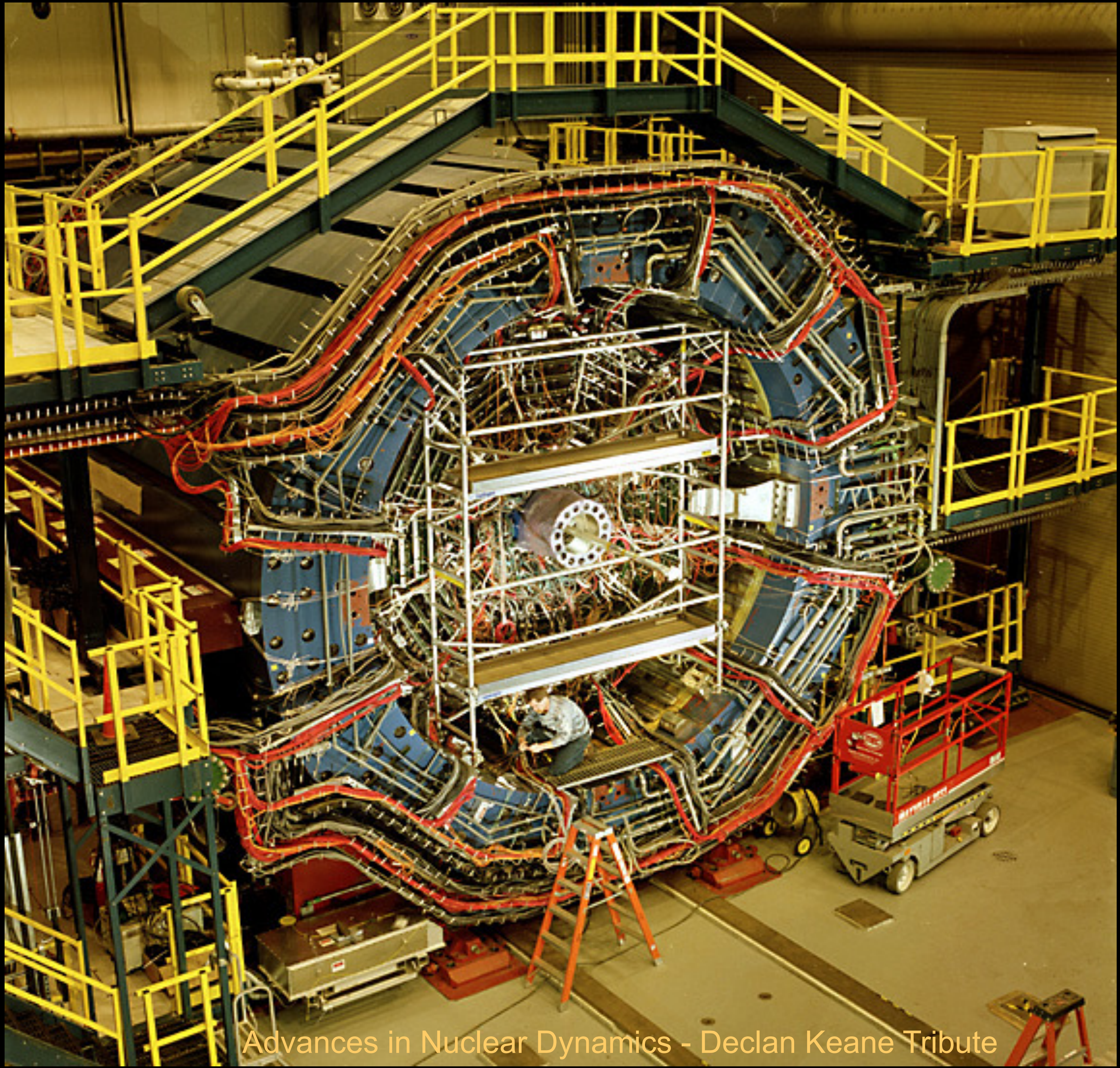
(Received 23 August 1999; revised manuscript received 5 April 2000)

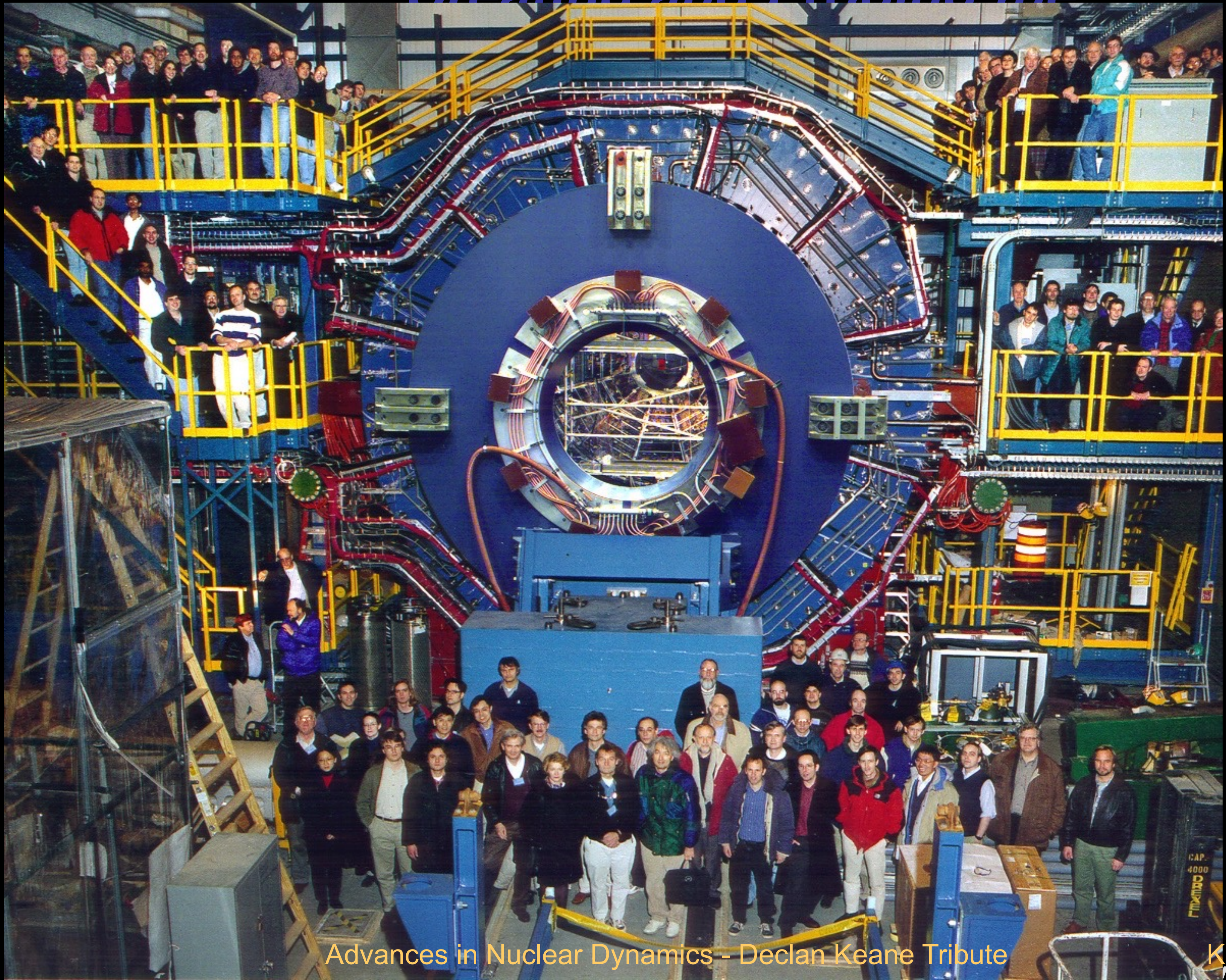
Using the large acceptance Time Projection Chamber of experiment E895 at Brookhaven, measurements of collective sideward flow in Au + Au collisions at beam energies of 2*A*, 4*A*, 6*A*, and 8*A* GeV are presented in the form of in-plane transverse momentum $\langle p_x \rangle$ and the first Fourier coefficient of azimuthal anisotropy v_1. These measurements indicate a smooth variation of sideward flow as a function of beam energy. The data are compared with four nuclear transport models which have an orientation towards this energy range. All four exhibit some qualitative trends similar to those found in the data, although none show a consistent pattern of agreement within experimental uncertainties.

PACS numbers: 25.75.Ld

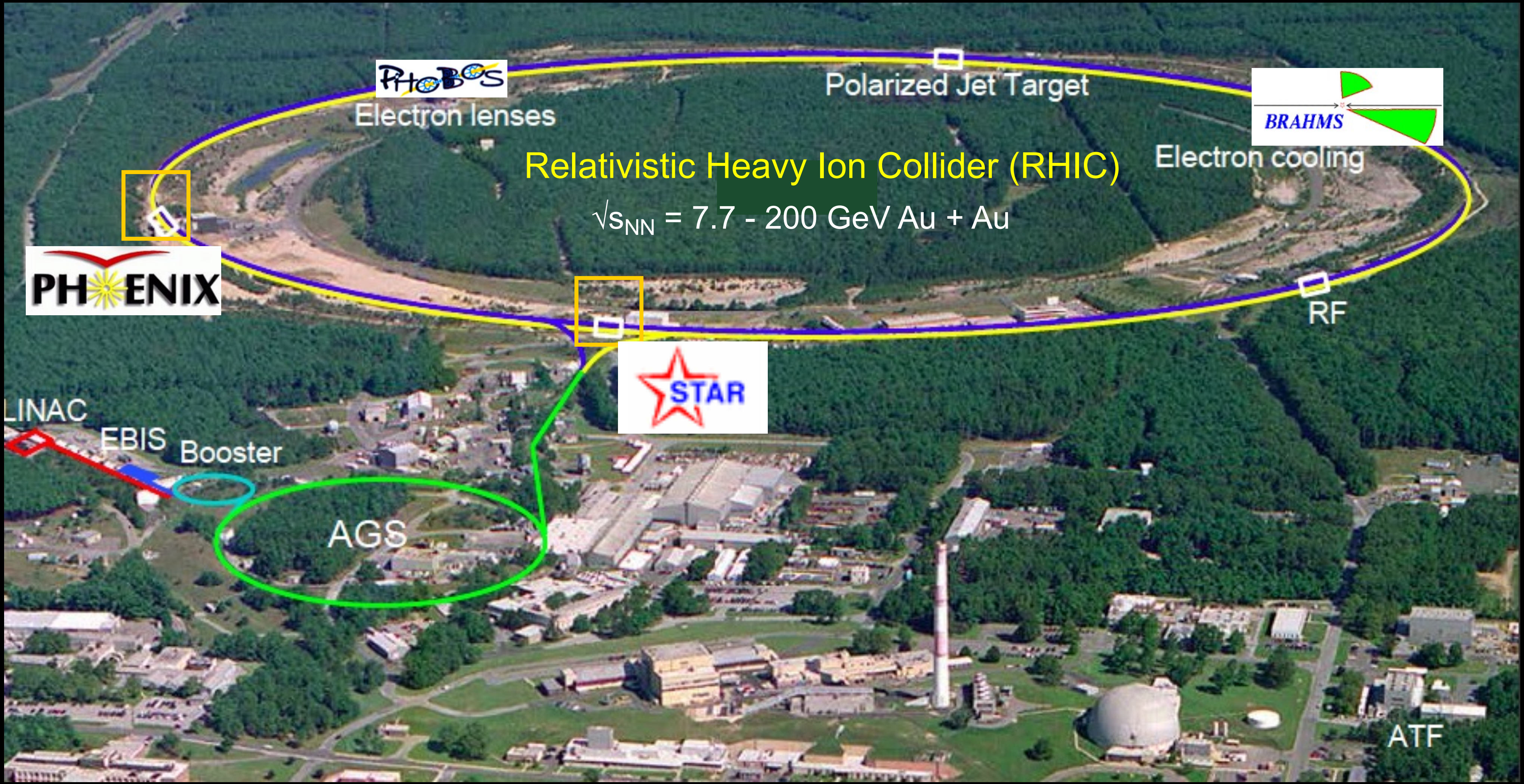
Meanwhile at RHIC – STAR Detector Ready to Roll!



STAR Collaboration Ready to Roll!



STAR



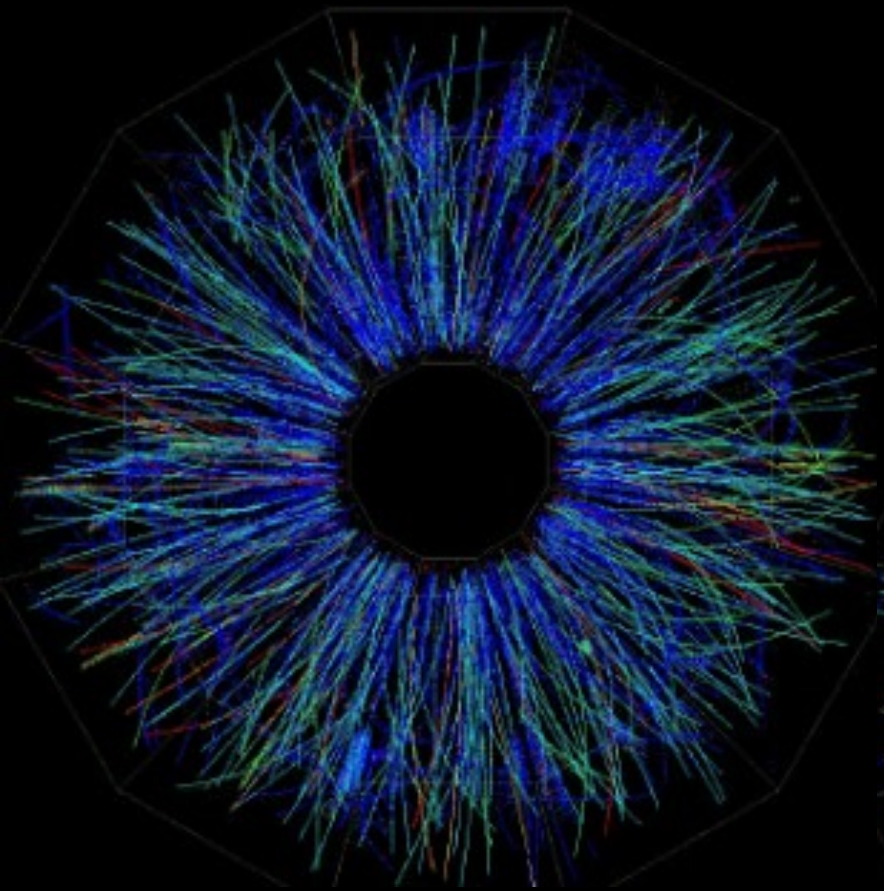
Polarized Jet Target
Electron lenses
BRAHMS
Relativistic Heavy Ion Collider (RHIC)
Electron cooling
√sNN = 7.7 - 200 GeV Au + Au
PHENIX
RF
STAR
LINAC
EBIS
Booster
AGS
ATF

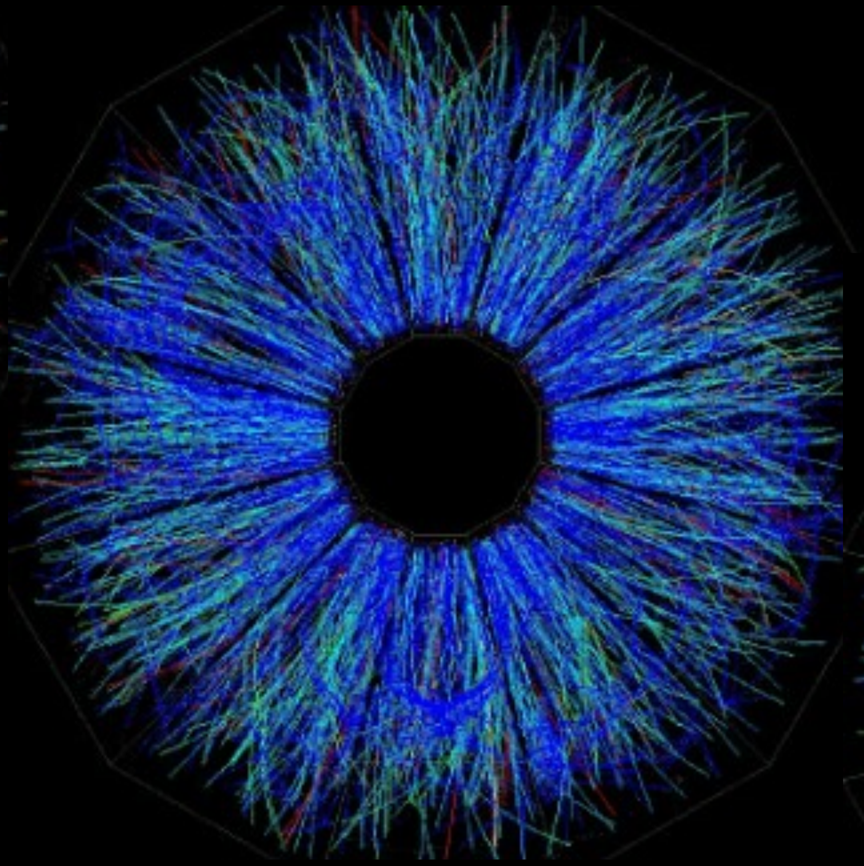
STAR Control Room - First Collisions!

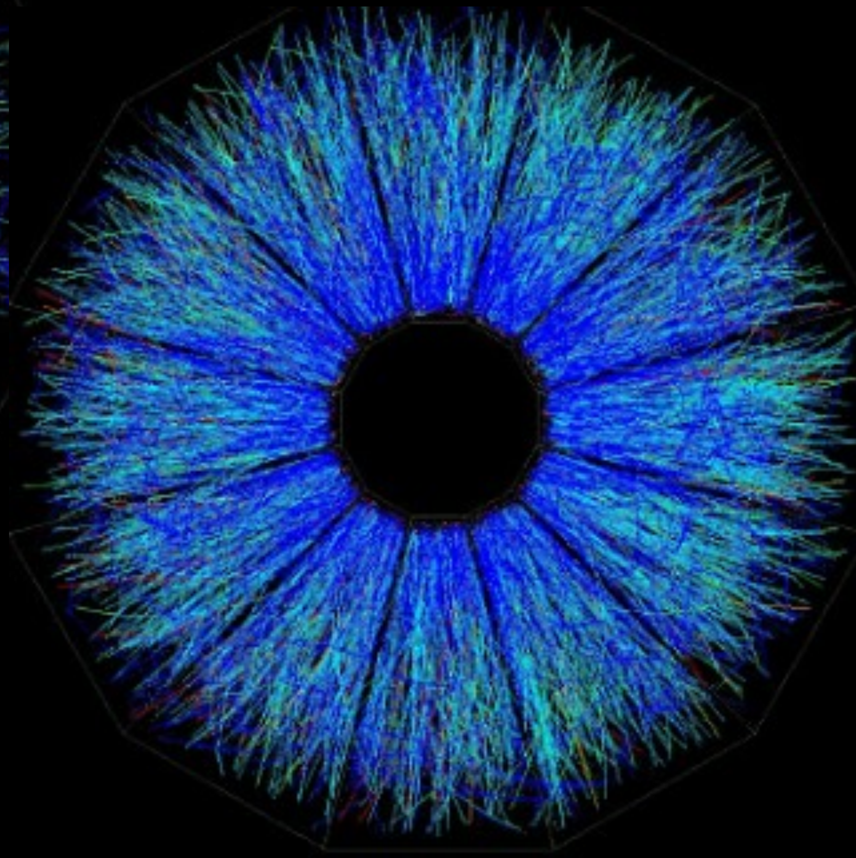
STAR

John Harris (Yale) Advances in Nuclear Dynamics - Declan Keane Tribute Kent State U. - Dec 1-2, 2023

STAR is Born!

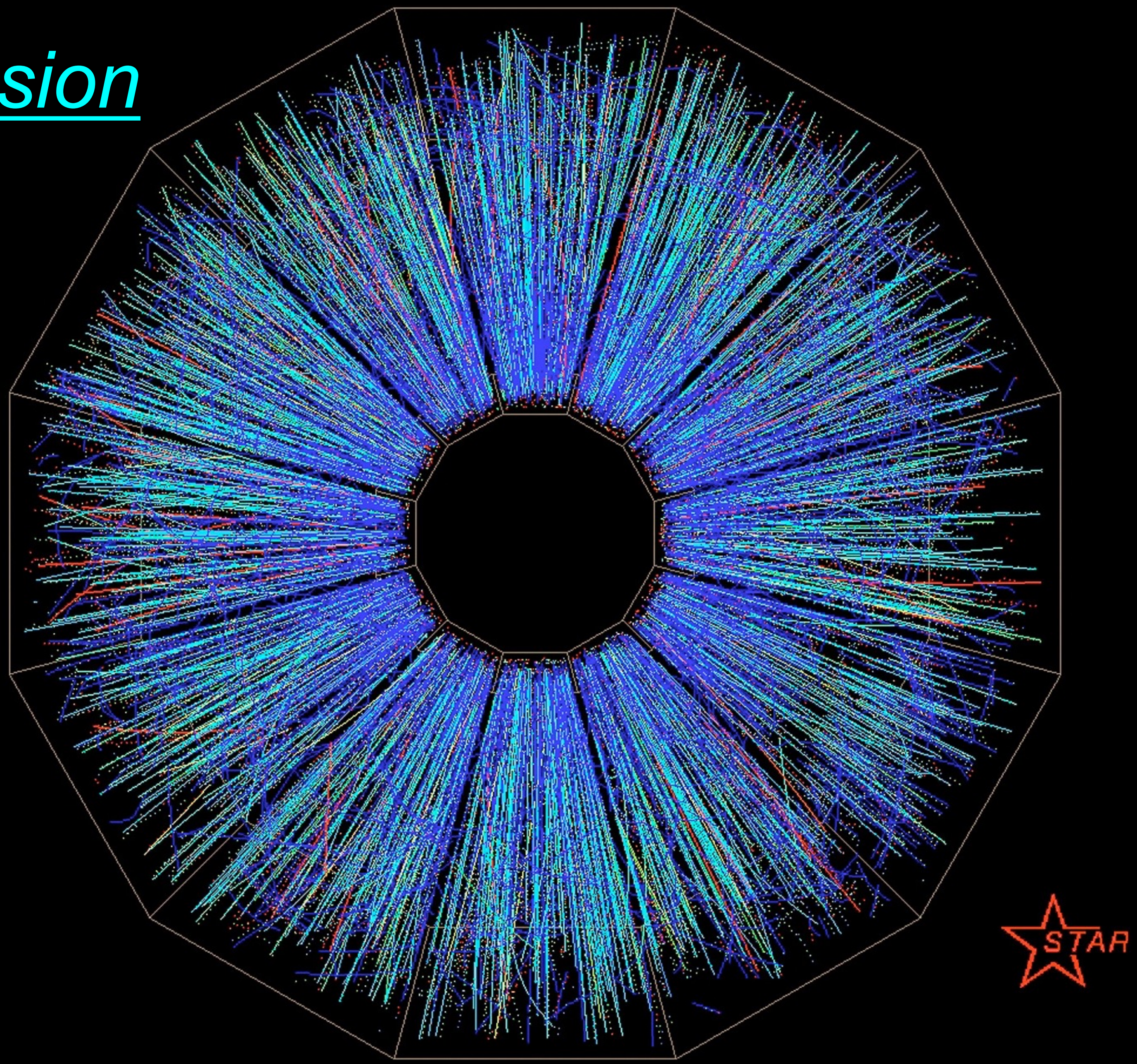






2000

Head-on Collision



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. Chikanian,[36] B. Choi,[31] J. Chrin,[9] W. Christie,[3] J. P. Coffin,[14] L. Conin,[30] C. Consiglio,[3] T. M. Cormier,[35] J. G. Cramer,[34] H. J. Crawford,[5] V. I. Danilov,[10] D. Dayton,[3] M. DeMello,[28] W. S. Deng,[16] A. A. Derevschikov,[26] M. Dialinas,[30] H. Diaz,[3] P. A. DeYoung,[8] L. Didenko,[3] D. Dimassimo,[3] J. Dioguardi,[3] W. Dominik,[32] C. Drancourt,[30] J. E. Draper,[6] V. B. Dunin,[10] J. C. Dunlop,[36] V. Eckardt,[19] W. R. Edwards,[17] L. G. Efimov,[10] T. Eggert,[19] V. Emelianov,[21] J. Engelage,[5] G. Eppley,[28] B. Erazmus,[30] A. Etkin,[3] P. Fachini,[29] C. Feliciano,[3] D. Ferenc,[6] M. I. Ferguson,[7] H. Fessler,[19] E. Finch,[36] V. Fine,[3] Y. Fisyak,[3] D. Flierl,[12] I. Flores,[5] K. J. Foley,[3] D. Fritz,[17] N. Gagunashvili,[10] J. Gans,[36] M. Gazdzicki,[12] M. Germain,[14] F. Geurts,[28] V. Ghazikhanian,[7] C. Gojak,[14] J. Grabski,[33] O. Grachov,[35] M. Grau,[3] D. Greiner,[17] L. Greiner,[5] V. Grigoriev,[21] D. Grosnick,[1] J. 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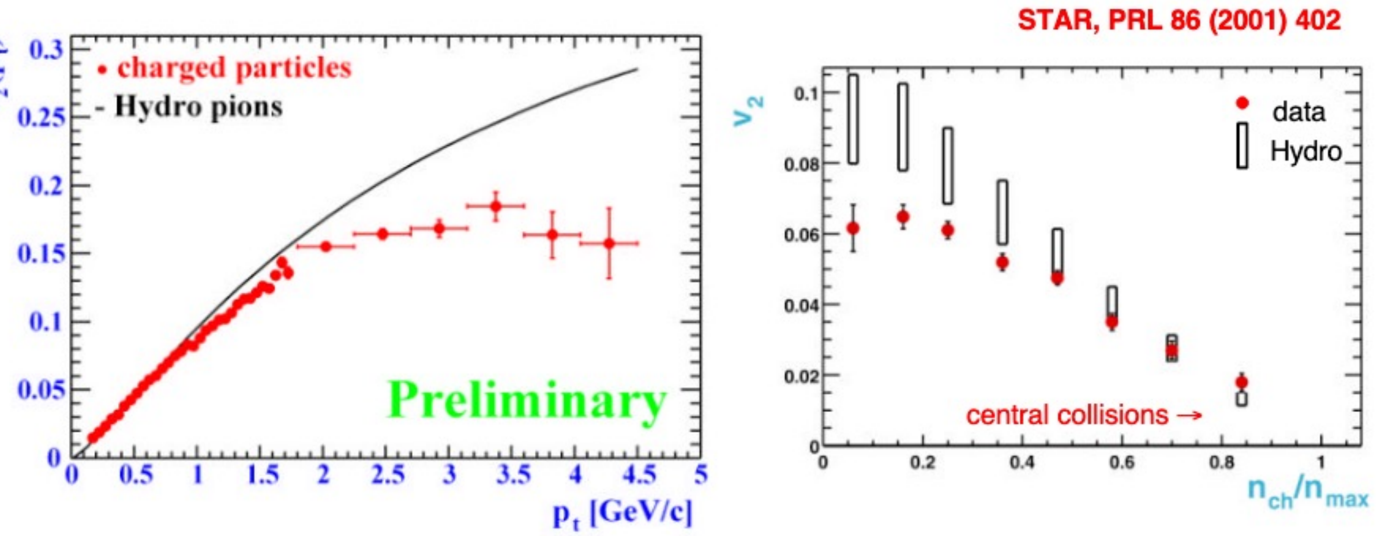
Tarchini,[14] J. Tarzian,[17] J. H. Thomas,[17] V. Tikhomirov,[21] A. Szanto de Toledo,[29] S. Tonse,[17] T. Trainor,[34] S. Trentalange,[7] M. Tokarev,[10] M. B. Tonjes,[20] V. Trofimov,[21]

QM 2001 Quark Matter 2001

STAR Elliptic Flow - Centrality Dependence

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



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.

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.

by Mark Peplow
news@nature.com

nature

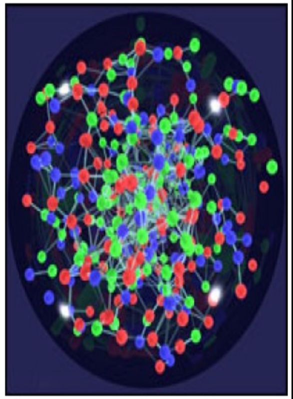
The Universe consisted of a perfect liquid in its first moments, according to results from an atom-smashing experiment.

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

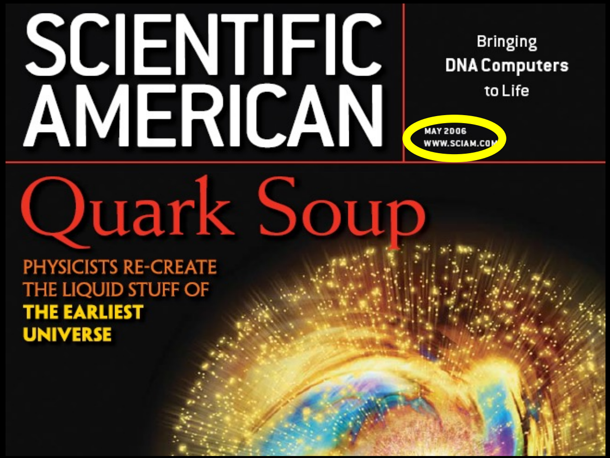


The impression is of matter that is more strongly interacting than predicted

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 — CELEBRATING 175 YEARS

THE SCIENCES

New State of Matter Is 'Nearly Perfect' Liquid

By Sarah Graham on April 18, 2005

CERNCOURIER | Reporting on international high-energy physics

Physics | Technology | Community | In focus | Magazine

NEWS

RHIC groups serve up 'perfect' liquid

5 May 2005

APS physics

Publications | Meetings & Events | Programs | Membership

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

STAR Seminal* Papers on Flow, Antimatter, Hypernuclei

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

C. Adler *et al.* (STAR Collaboration)
Phys. Rev. Lett. **87**, 182301 – Published 10 October 2001

Observation of the antimatter helium-4 nucleus

The STAR Collaboration

Nature **473**, 353–356 (2011) | Cite this article

Beam-Energy Dependence of the Directed Flow of Protons, Antiprotons, and Pions in Au+Au Collisions

L. Adamczyk *et al.* (STAR Collaboration)
Phys. Rev. Lett. **112**, 162301 – Published 23 April 2014

Beam-Energy Dependence of Directed Flow of Λ, $\bar{\Lambda}$, $K^{\pm}$, K^0_s, and ϕ in $\rm Au + Au$ Collisions

L. Adamczyk *et al.* (STAR Collaboration)
Phys. Rev. Lett. **120**, 062301 – Published 6 February 2018

Measurement of interaction between antiprotons

The STAR Collaboration

Nature **527**, 345–348 (2015) | Cite this article

Global Λ hyperon polarization in nuclear collisions

The STAR Collaboration

Nature **548**, 62–65 (2017) | Cite this article

Measurement of the mass difference and the binding energy of the hypertriton and antihypertriton

The STAR Collaboration

Nature Physics **16**, 409–412 (2020) | Cite this article

Pattern of global spin alignment of φ and K^{*0} mesons in heavy-ion collisions

STAR Collaboration

Nature **614**, 244–248 (2023) | Cite this article

** My definition!*

Comment: 7 PRLs published in 2001 by STAR (on all topics)!

Antimatter in Heavy-ion Collisions

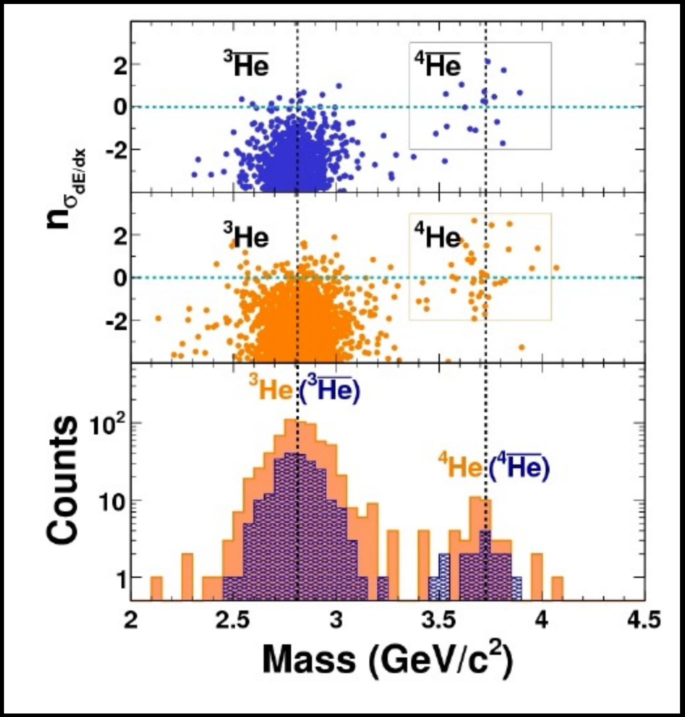
nature

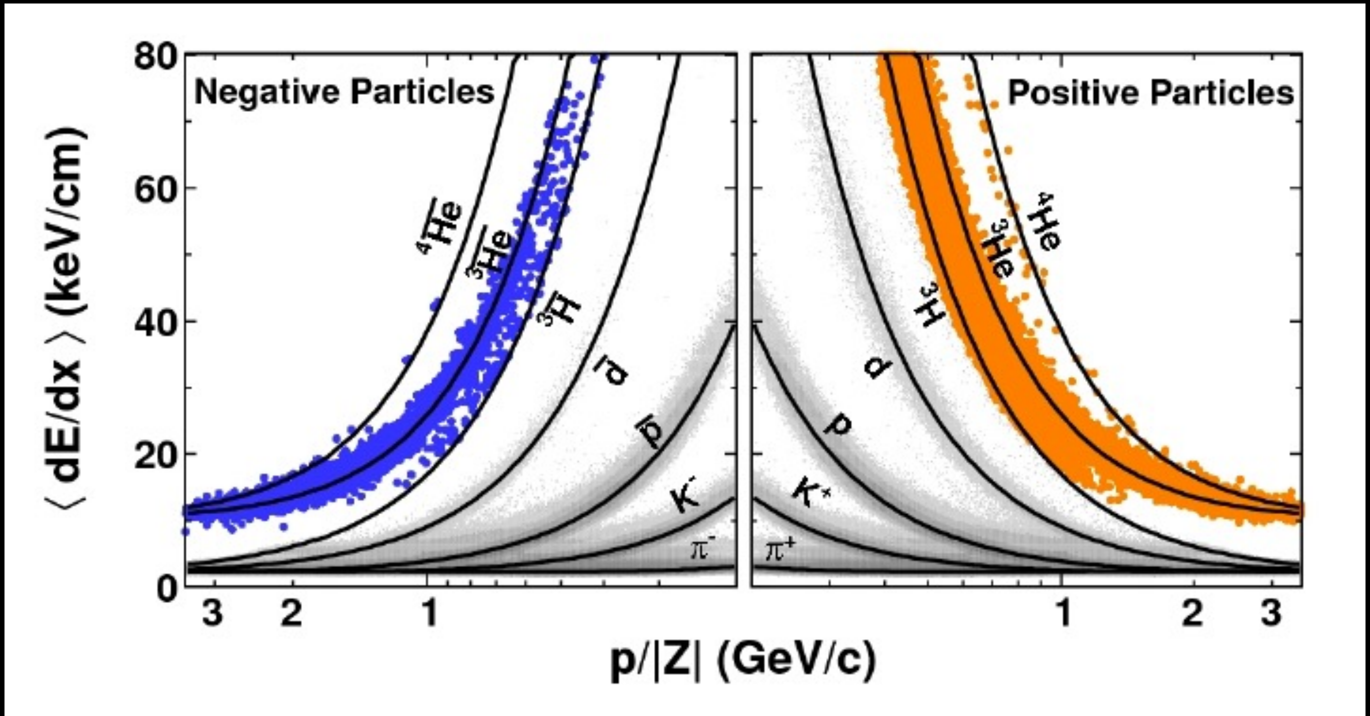
Letter | Published: 24 April 2011

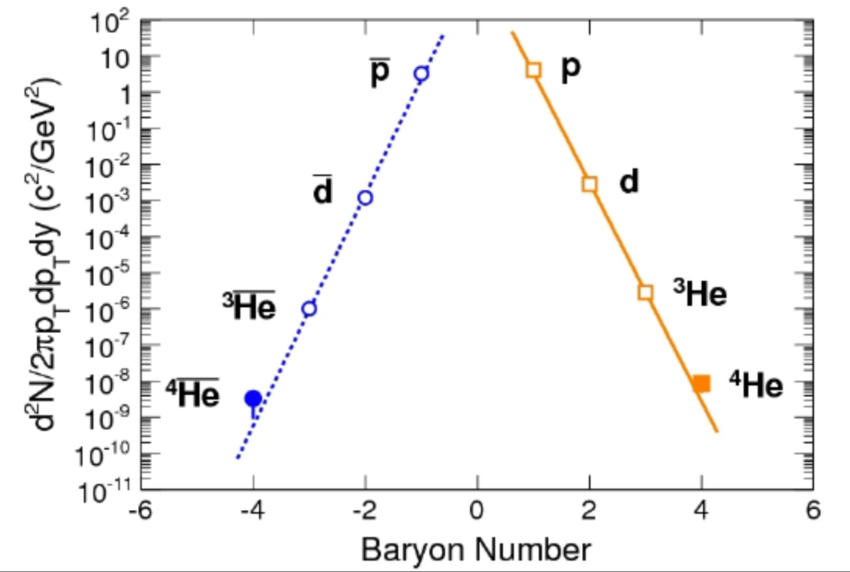
Observation of the antimatter helium-4 nucleus

The STAR Collaboration

Nature **473**, 353–356 (2011) | Cite this article







Antinuclei in Heavy-ion Collisions

ELSEVIER

Physics Reports
Volume 760, 20 October 2018, Pages 1-39

Antinuclei in heavy-ion collisions

Jinhui Chen [a b], Declan Keane [d], Yu-Gang Ma [a c], Aihong Tang [e], Zhangbu Xu [e f]

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https://doi.org/10.1016/j.physrep.2018.07.002   Get rights and content

Abstract

We review progress in the study of antinuclei, starting from Dirac's equation and the discovery of the positron in cosmic-ray events. The development of proton accelerators led to the discovery of antiprotons, followed by the first antideuterons, demonstrating that antinucleons bind into antinuclei. With the development of heavy-ion programs at the Brookhaven AGS and CERN SPS, it was demonstrated that central collisions of heavy nuclei offer a fertile ground for research and discoveries in the area of antinuclei. In this review, we emphasize recent observations at Brookhaven's Relativistic Heavy Ion Collider and at CERN's Large Hadron Collider, namely, the antihypertriton and the antihelium-4, as well as measurements of the mass difference between light nuclei and antinuclei, and the interaction between antiprotons. Physics implications of the new observations and different production mechanisms are discussed. We also consider implications for related fields, such as hypernuclear physics and space-based cosmic-ray experiments.

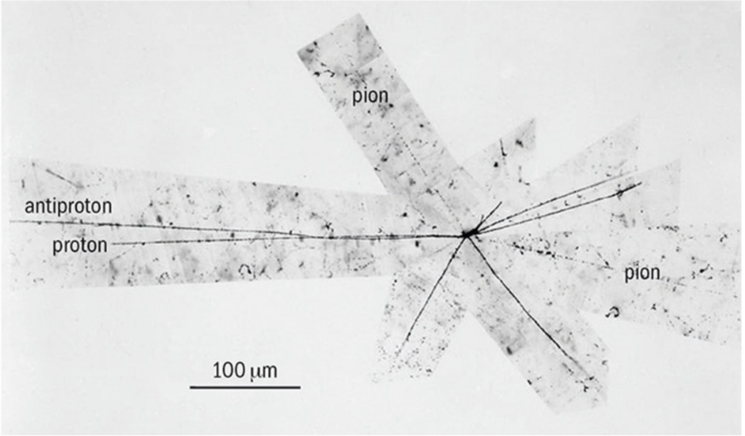

Fig. 3. An antiproton annihilation vertex in nuclear emulsion. In the microscopic image reproduced here, the emitted charged particles include two pions, a proton, and several unidentified charged particles [25].

O. Chamberlain, W.W. Chupp, G. Goldhaber, E. Segrè, C. Wiegand, E. Amaldi, G. Baroni, C. Castagnoli, C. Franzinetti, A. Manfredini,
"Antiproton star observed in emulsion," Phys. Rev. 101 (1956) 909–910.

Antimatter Hypernucleus in Heavy-ion Collisions

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RESEARCH ARTICLE

Observation of an Antimatter Hypernucleus

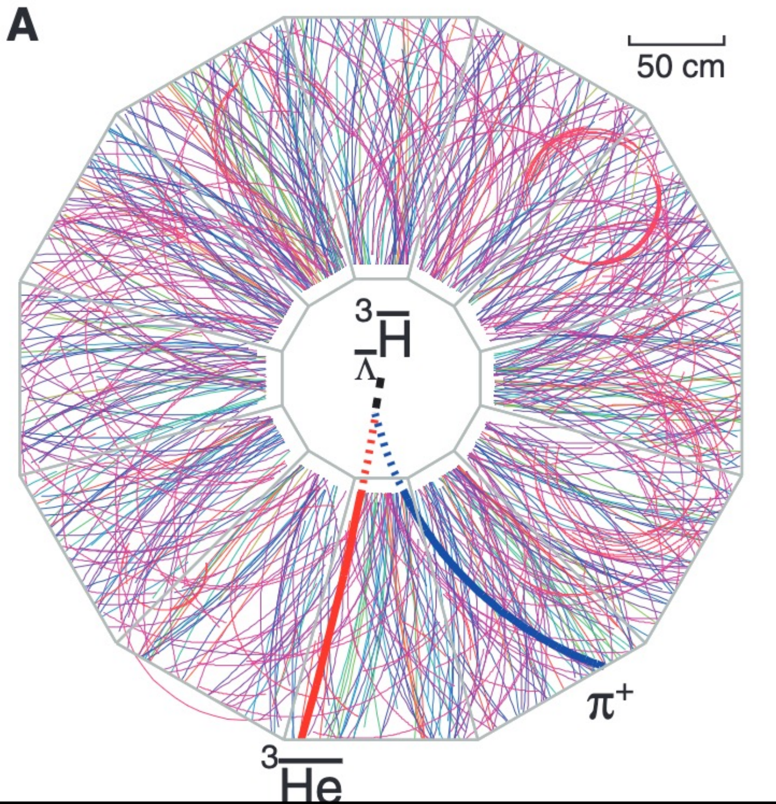
THE STAR COLLABORATION, B. I. ABELEV, M. M. AGGARWAL, Z. AHAMMED, A. V. ALAKHVERDYANTS, I. ALEKSEEV, B. D. ANDERSON, D. ARKHIPKIN, G. S. AVERICHEV, [...], AND Y. ZOULKARNEEVA +382 authors Authors Info & Affiliations

SCIENCE • 4 Mar 2010 • Vol 328, Issue 5974 • pp. 58-62 • DOI: 10.1126/science.1183980

Abstract

Nuclear collisions recreate conditions in the universe microseconds after the Big Bang. Only a very small fraction of the emitted fragments are light nuclei, but these states are of fundamental interest. We report the observation of antihypertritons—comprising an antiproton, an antineutron, and an antilambda hyperon—produced by colliding gold nuclei at high energy. Our analysis yields 70 ± 17 antihypertritons ($^{3}_{\bar{\Lambda}}\overline{\mathrm{H}}$) and 157 ± 30 hypertritons ($^{3}_{\Lambda}\mathrm{H}$). The measured yields of $^{3}_{\Lambda}\mathrm{H}$ ($^{3}_{\bar{\Lambda}}\overline{\mathrm{H}}$) and $^{3}\mathrm{He}$ ($^{3}\overline{\mathrm{He}}$) are similar, suggesting an equilibrium in coordinate and momentum space populations of up, down, and strange quarks and antiquarks, unlike the pattern observed at lower collision energies. The production and properties of antinuclei, and of nuclei containing strange quarks, have implications spanning nuclear and particle physics, astrophysics, and cosmology.

Fig. 2. A typical event in the STAR detector that includes the production and decay of a $^{3}_{\bar{\Lambda}}\overline{\mathrm{H}}$ candidate: (**A**) with the beam axis normal to the page, (**B**) with the beam axis horizontal. The dashed black line is the trajectory of the $^{3}_{\bar{\Lambda}}\overline{\mathrm{H}}$ candidate, which cannot be directly measured. The heavy red and blue lines are the trajectories of the $^{3}\overline{\mathrm{He}}$ and π^{+} decay daughters, respectively, which are directly measured.



Antimatter Hypernucleus in Heavy-ion Collisions

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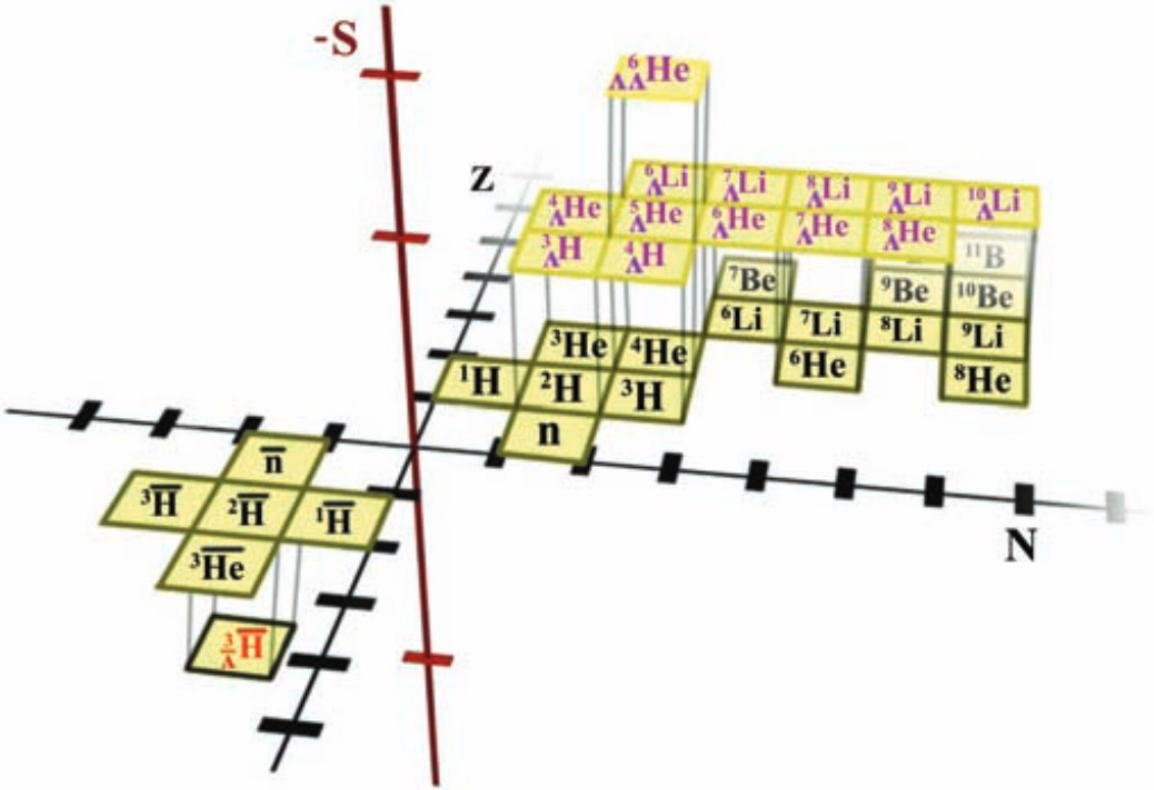
RESEARCH ARTICLE

Observation of an Antimatter Hypernucleus

THE STAR COLLABORATION , B. I. ABELEV, M. M. AGGARWAL, Z. AHAMMED, A. V. ALAKHVERDYANTS, I. ALEKSEEV, B. D. ANDERSON, D. ARKHIPKIN, G. S. AVERICHEV, [...], AND Y. ZOULKARNEEVA +382 authors Authors Info & Affiliations

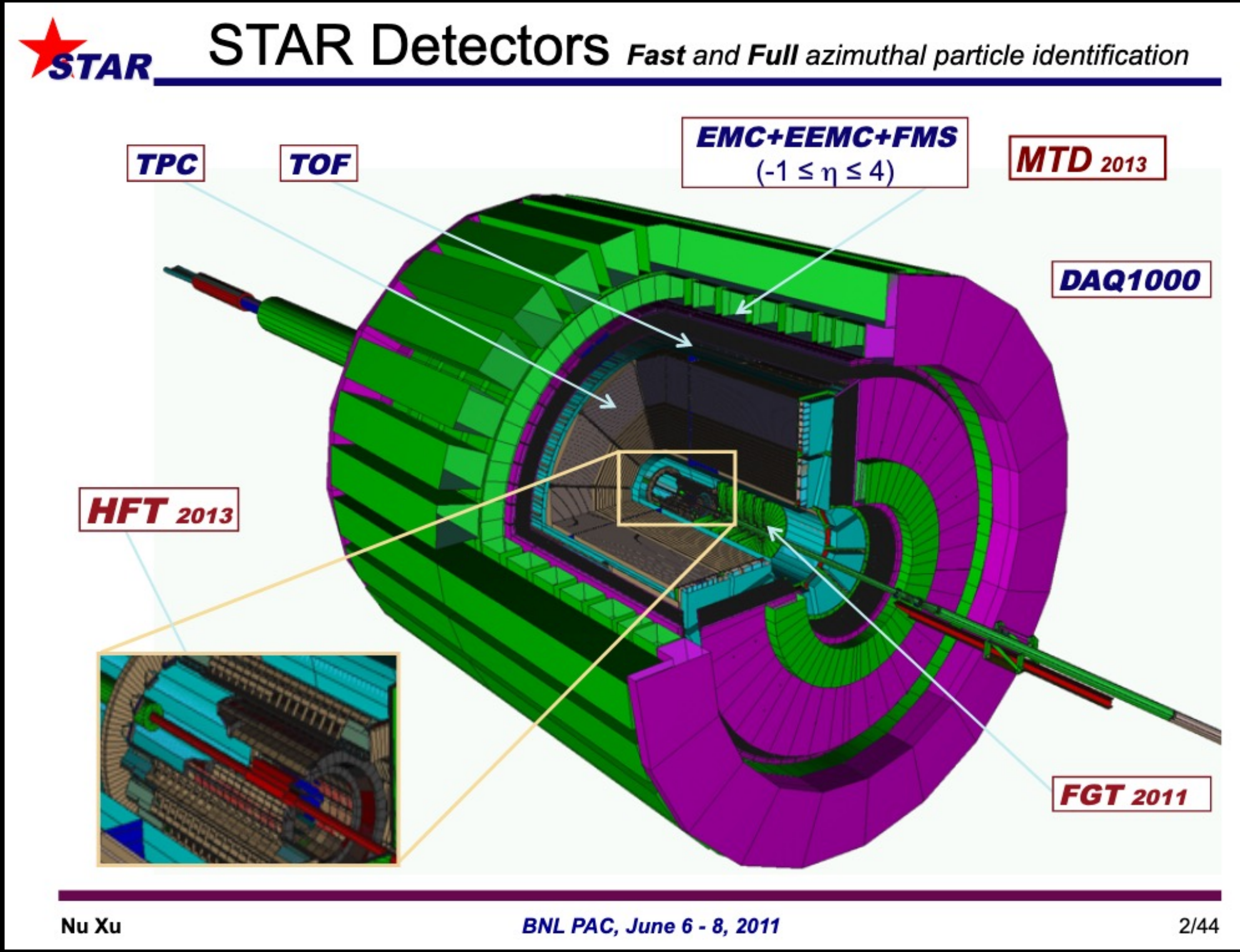
SCIENCE • 4 Mar 2010 • Vol 328, Issue 5974 • pp. 58-62 • DOI: 10.1126/science.1183980

Fig. 1. A chart of the nuclides showing the extension into the strangeness sector. Normal nuclei lie in the (*N*, *Z*) plane. Antinuclei lie in the negative sector of this plane. Normal hypernuclei lie in the positive (*N*, *Z*) quadrant above the plane. The antihypertriton $^{3}_{\Lambda}\overline{H}$ reported here extends this chart into the strangeness octant (*S*) below the antimatter region in the (*N*, *Z*) plane.



STAR – Growing Up!

STAR



STAR Mid-term Upgrades

Time of Flight

Forward Meson Spectrometer

DAQ1000

Heavy Flavor Tracker

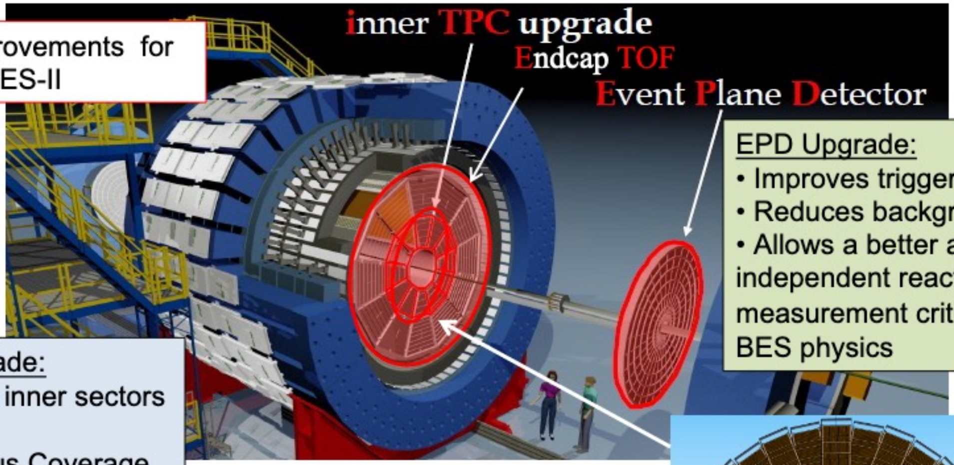
Intermediate Stage Tracker

Forward Tracking

Completion of STAR – Growing Up!

STAR detector at BESII

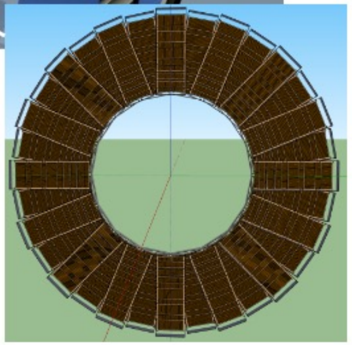
Major improvements for BES-II



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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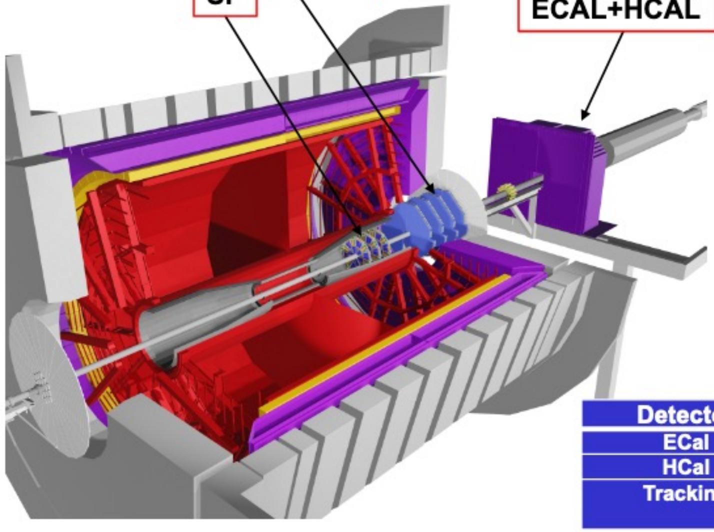
STAR forward upgrades



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% $1/p_T$

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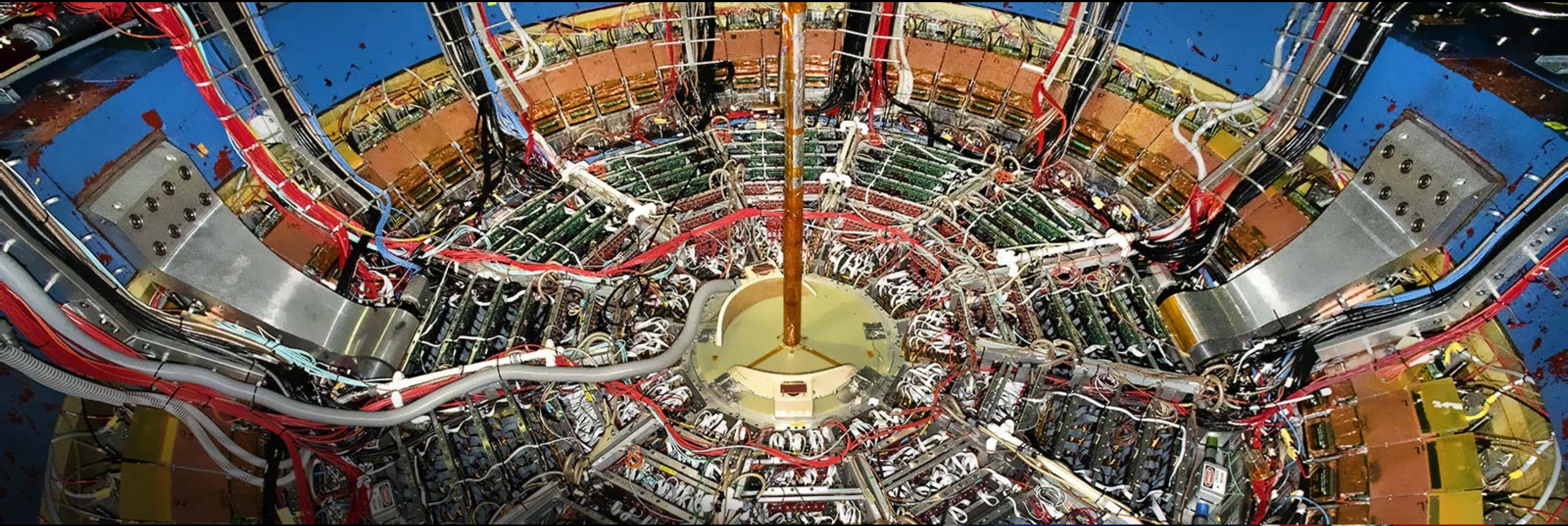
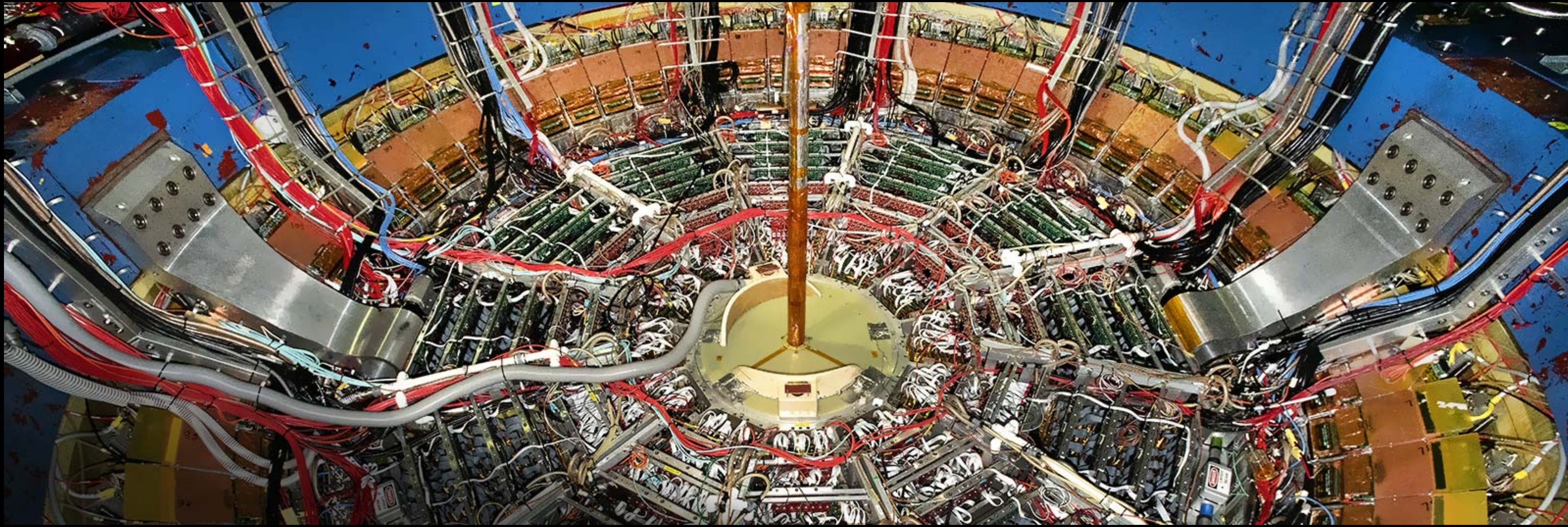
Antimatter, Hypernuclei, Collective Flow



STAR – All Grown Up!



To date: 348 theses → 307 (PhD), 33 (Masters) and 8 (diploma)

358 journal publications → 105 in PRL and 7 in Science Advances and Nature Physics

Thanks for your attention!

Special thanks to

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friends at Kent,

and the Organizers of this Symposium

Extra Slides