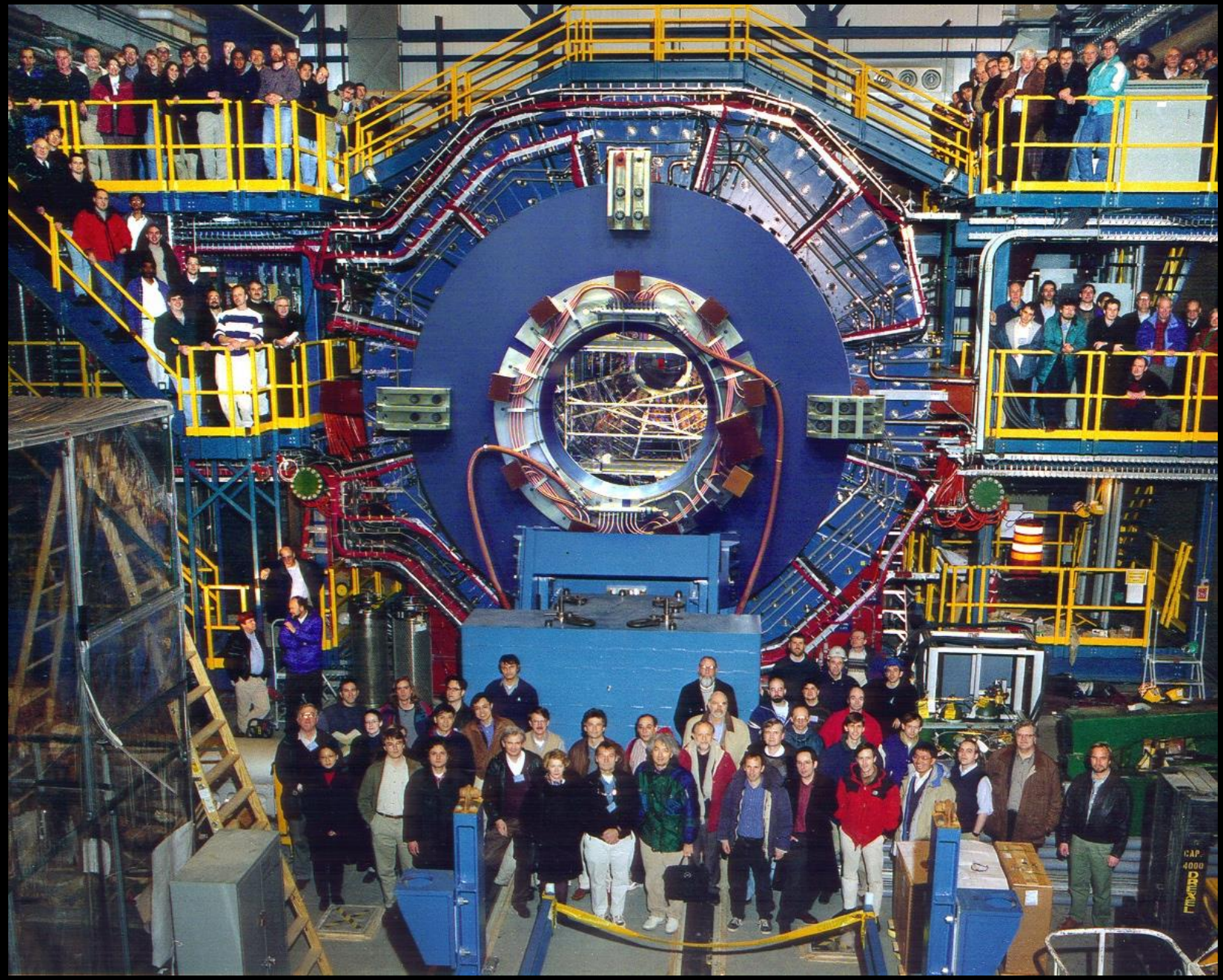
Early Days of the STAR Experiment

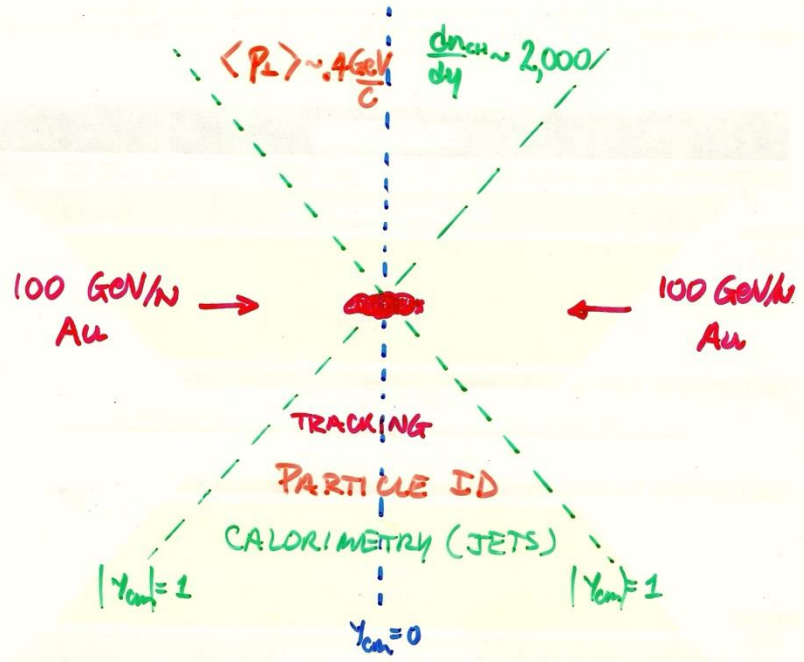


1990 Concept of a New Experiment for RHIC

FUTURE:

Winter Workshop on Nuclear Dynamics
Jackson Hole, Jan. 1990.

RHIC "PLANS" AT LBL



INTEREST TO STUDY:

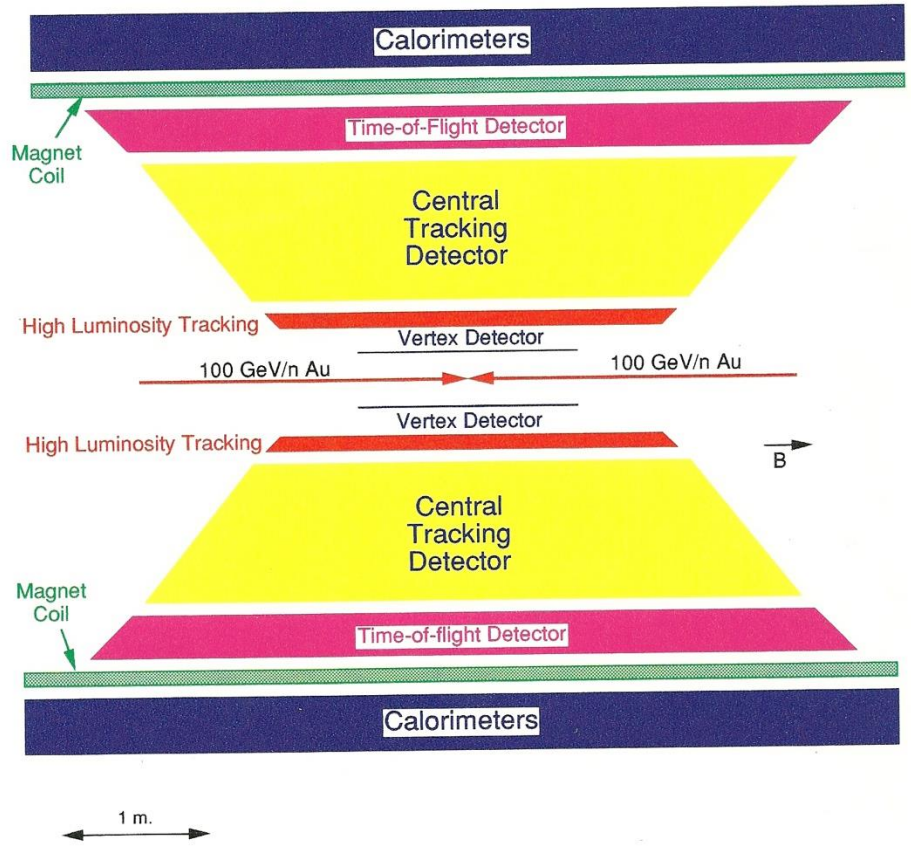
PARTICLE PRODUCTION & HIGH $p_\perp$ JET PRODUCTION AT $|y| \leq 1$

- High $p_\perp$ jet production (possible QGP signature)
- y, $p_\perp$ spectra, fluctuations, intermittency
- $\pi\pi$, KK interferometry
- correlations event-by-event (T_{event}, S_{event}, $R_{T\,event}$, ...)

McDraw!

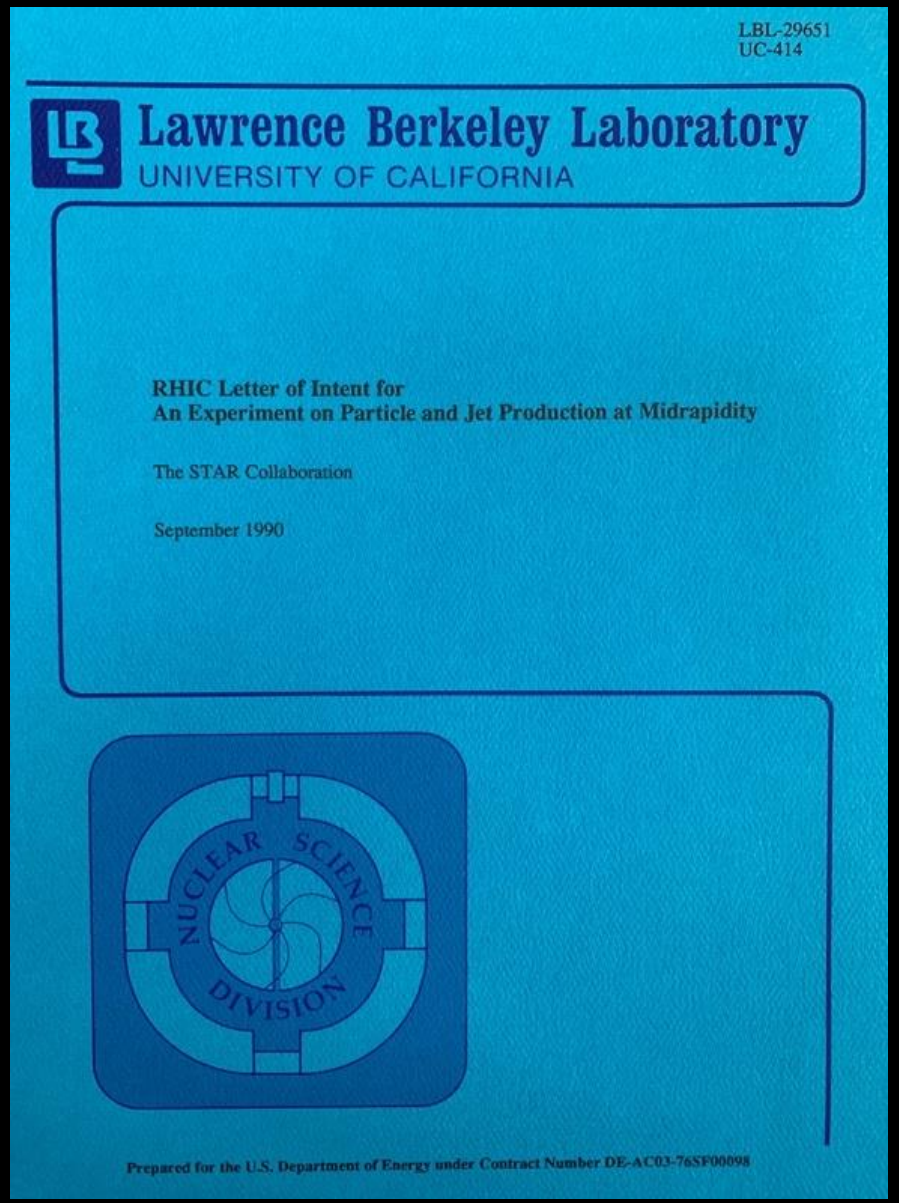
Conceptual Design for a RHIC Experiment on Particle and Jet Production

UC-Davis, UCLA, U. Frankfurt, Johns Hopkins U., Kent State U.,
Lawrence Berkeley Lab., Purdue U., Texas A&M U., U. Washington, Zagreb-Boskovic Inst.



J.W. Harris
6/20/90

RHIC Letter of Intent for New Experiment – Sept. 1990



An Experiment on Particle and Jet Production at Midrapidity

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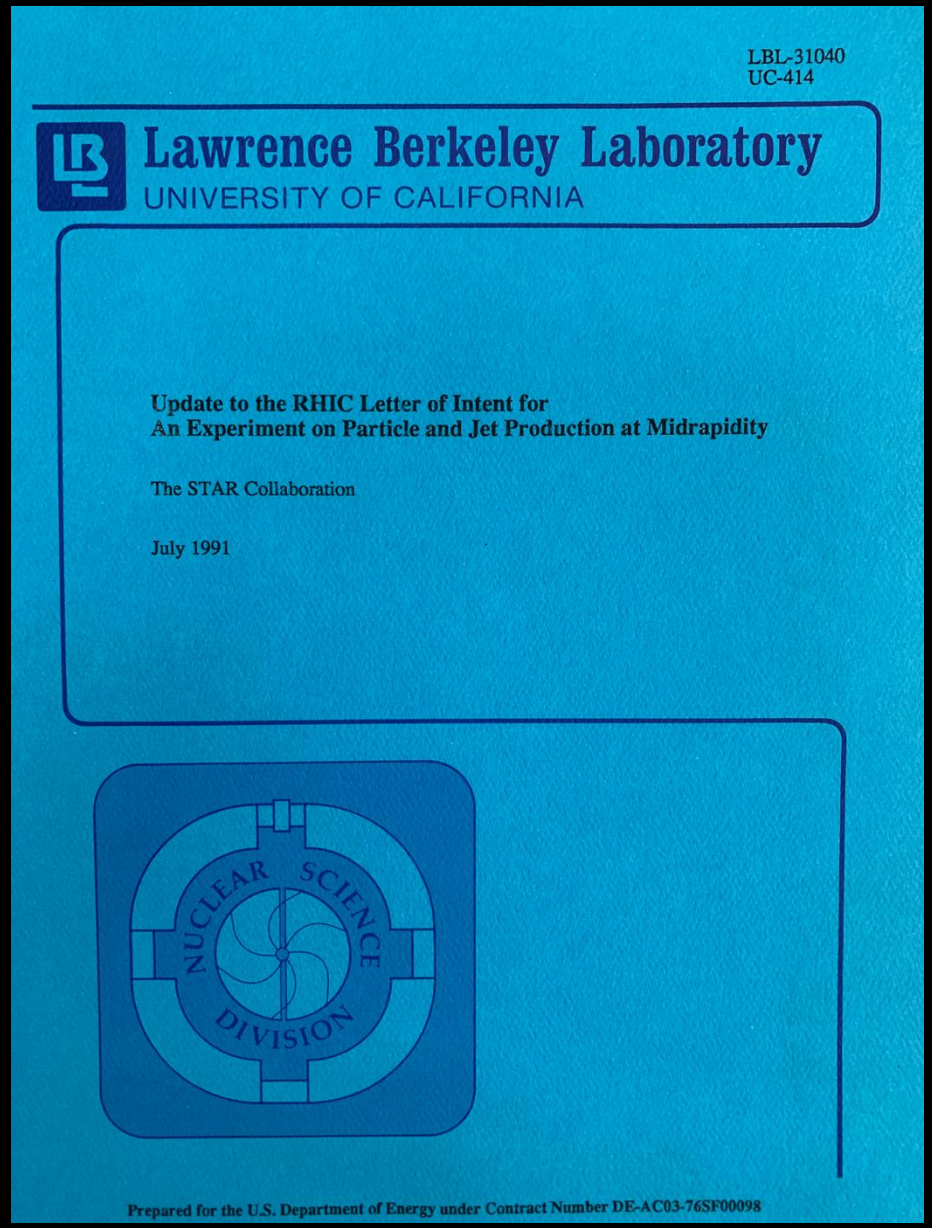
12 University of Washington, Seattle, Washington 98195, U.S.A.
13 Weizmann Institute of Science, Rehovot 76100, Israel

Update to Letter of Intent for STAR Experiment – 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

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July 1991

Merger forming the STAR Collaboration – 31 July 1991

31 July 1991

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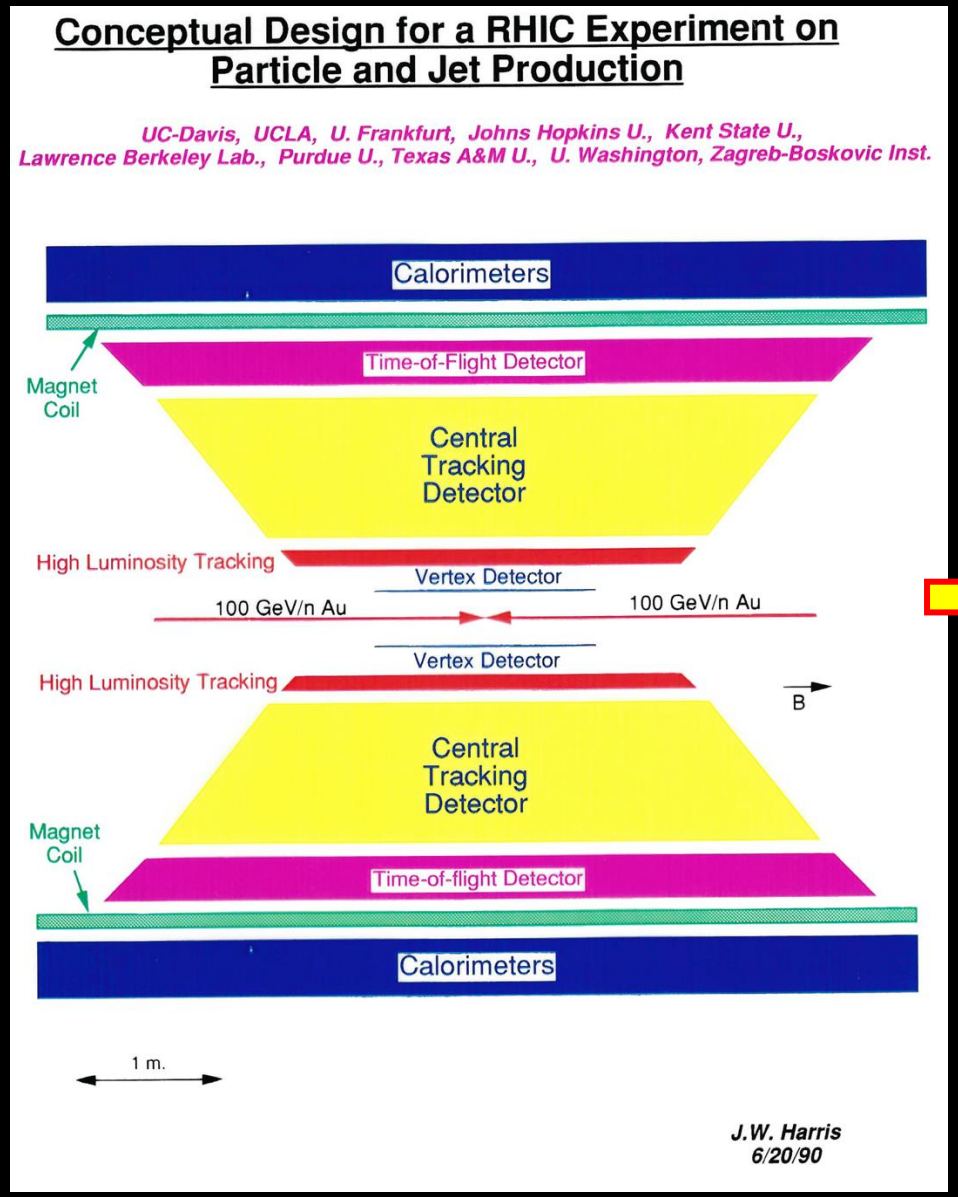
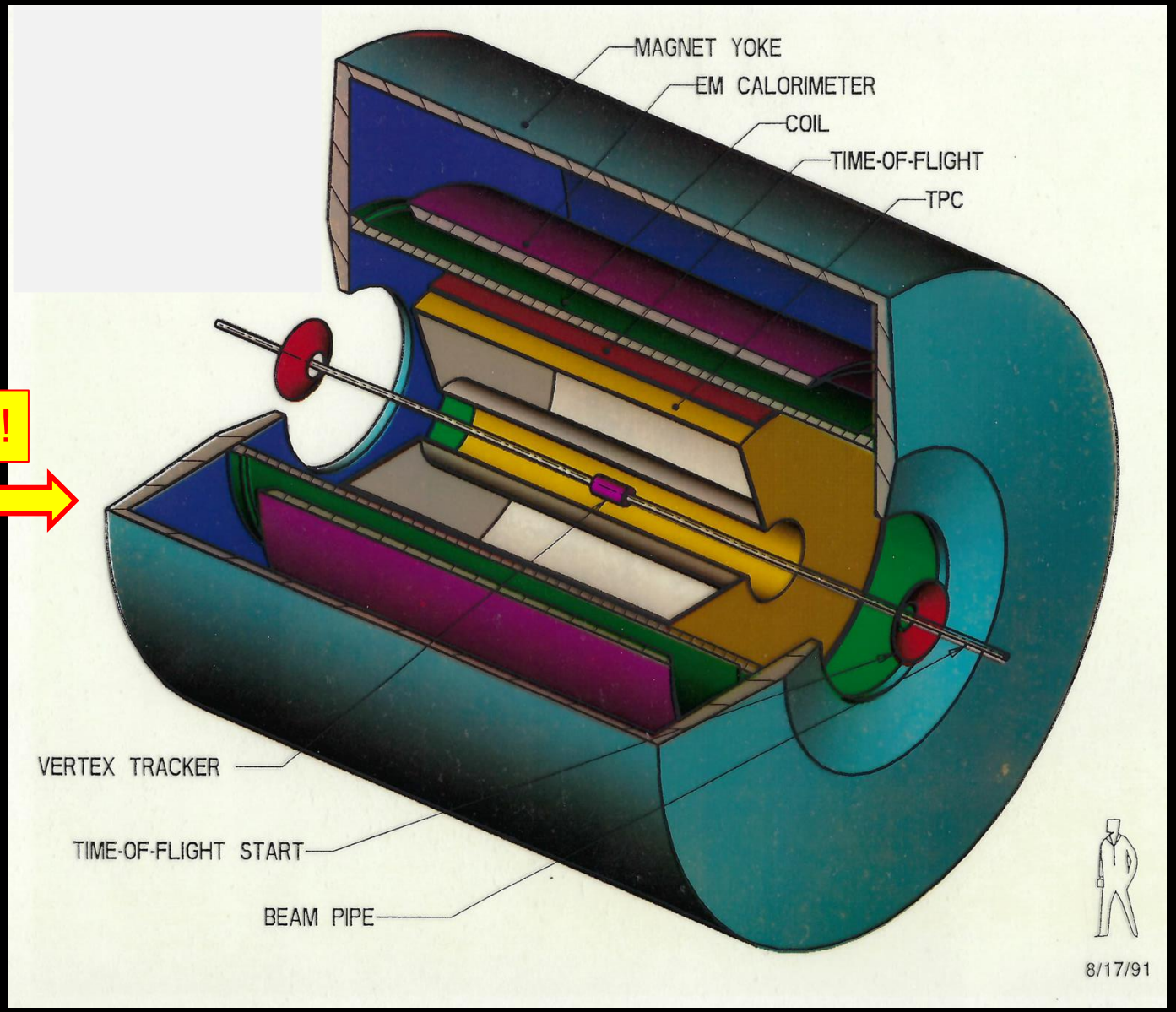
Spokesperson: **J.W. Harris**
Deputy Spokespersons: **E.D. Platner, A.M. Poskanzer**

Evolution of the Design for an Experiment (STAR) at RHIC



CAD!



Updated Letters of Intent for Future RHIC Experiments

BNL PAC Meeting (August 1991), Mel Schwarz (BNL-ALD) decision on experiments:

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

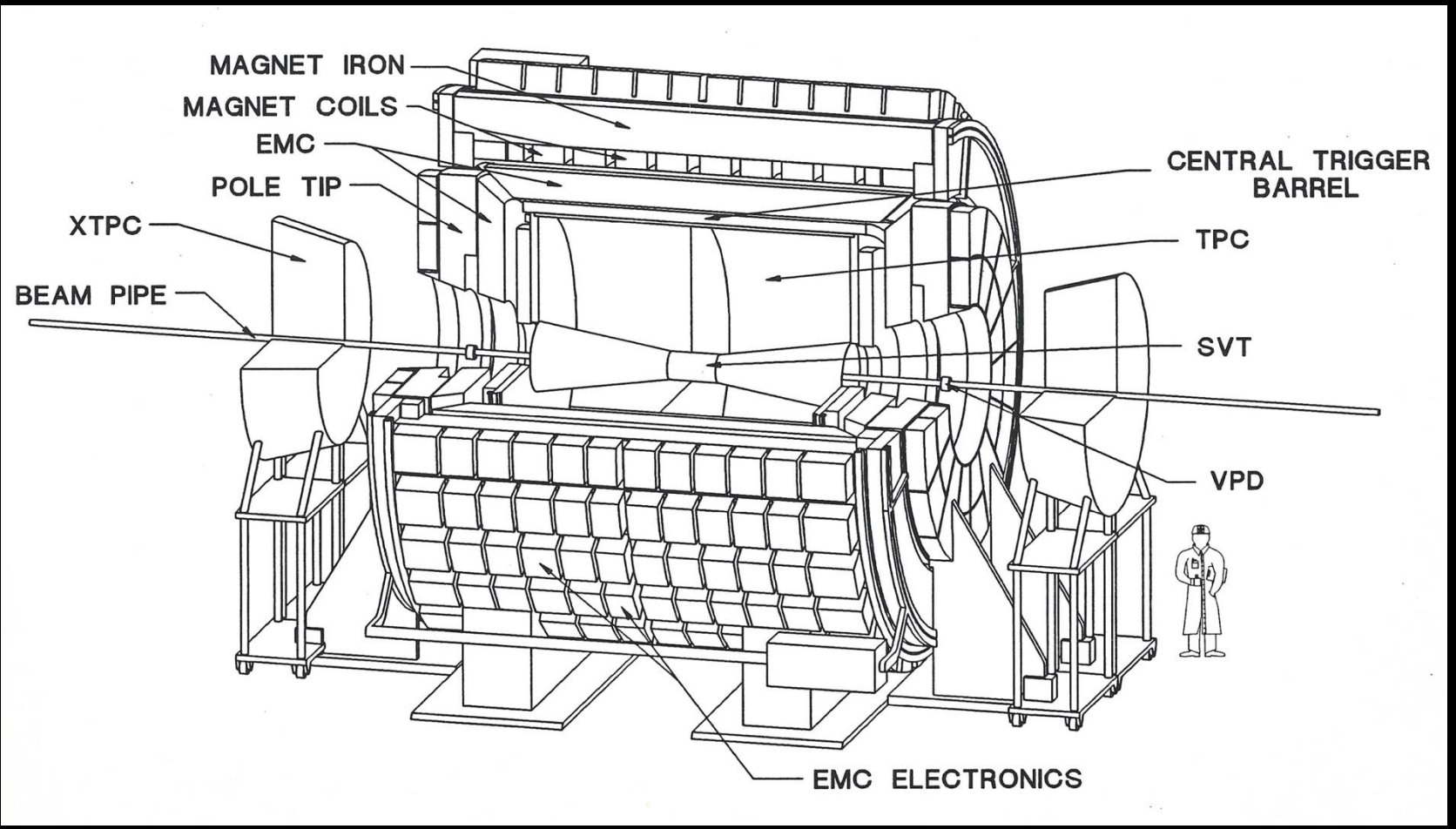
2. PHENIX experiment to be formed from merger of four proposals
   (TALES, SPARC, OASIS, and DIMUON)

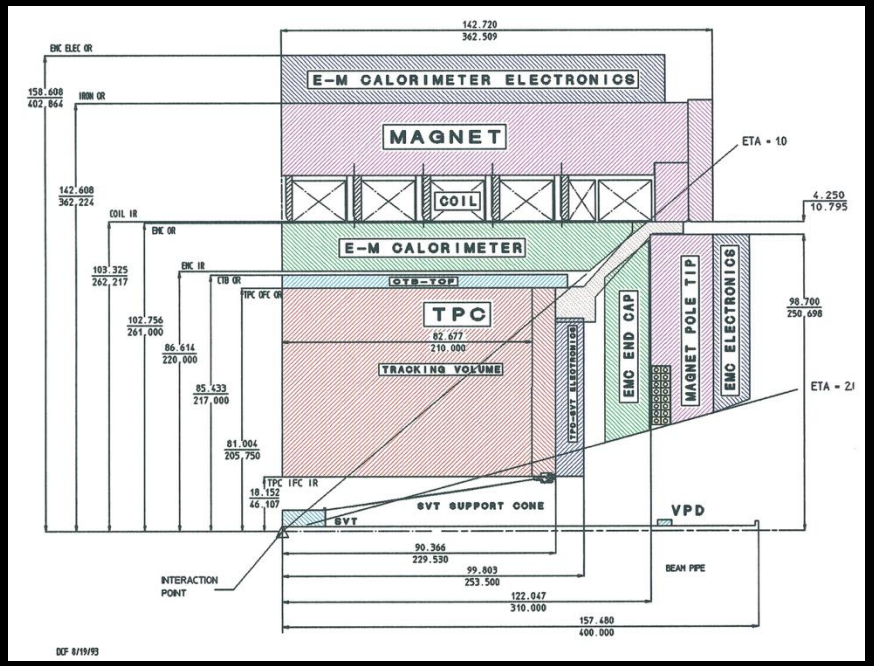
3. Small experiment for quick results approved PHOBOS

4. BRAHMS (proposed and approved later)

A Few of the Characters at Beginning of STAR

STAR Conceptual Design Report 1994





Some Questions about 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?
- .
- .

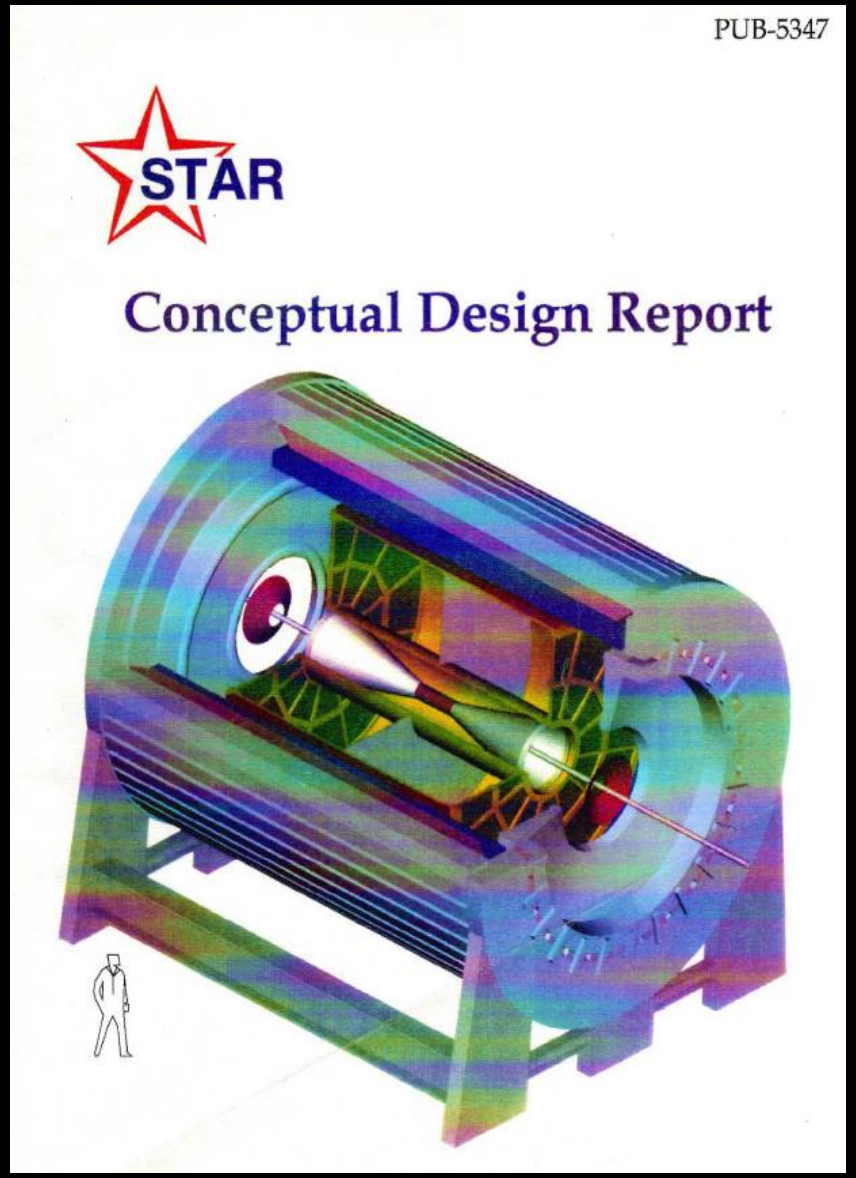
Howard Wieman became the TPC Project Director!!

- 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!

STAR Conceptual Design Report 1994



Jay Marx
Project Director!

The STAR Collaboration

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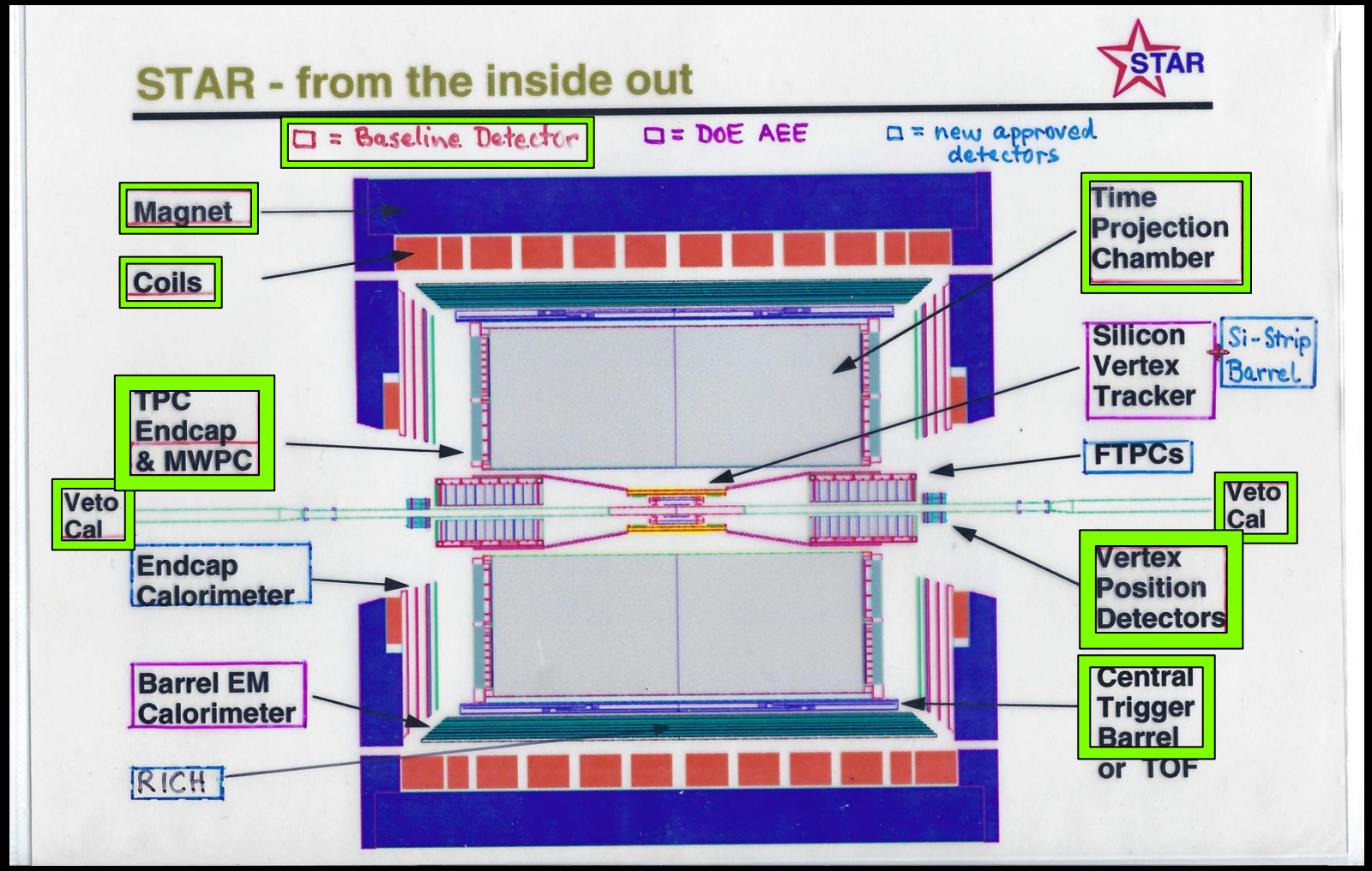
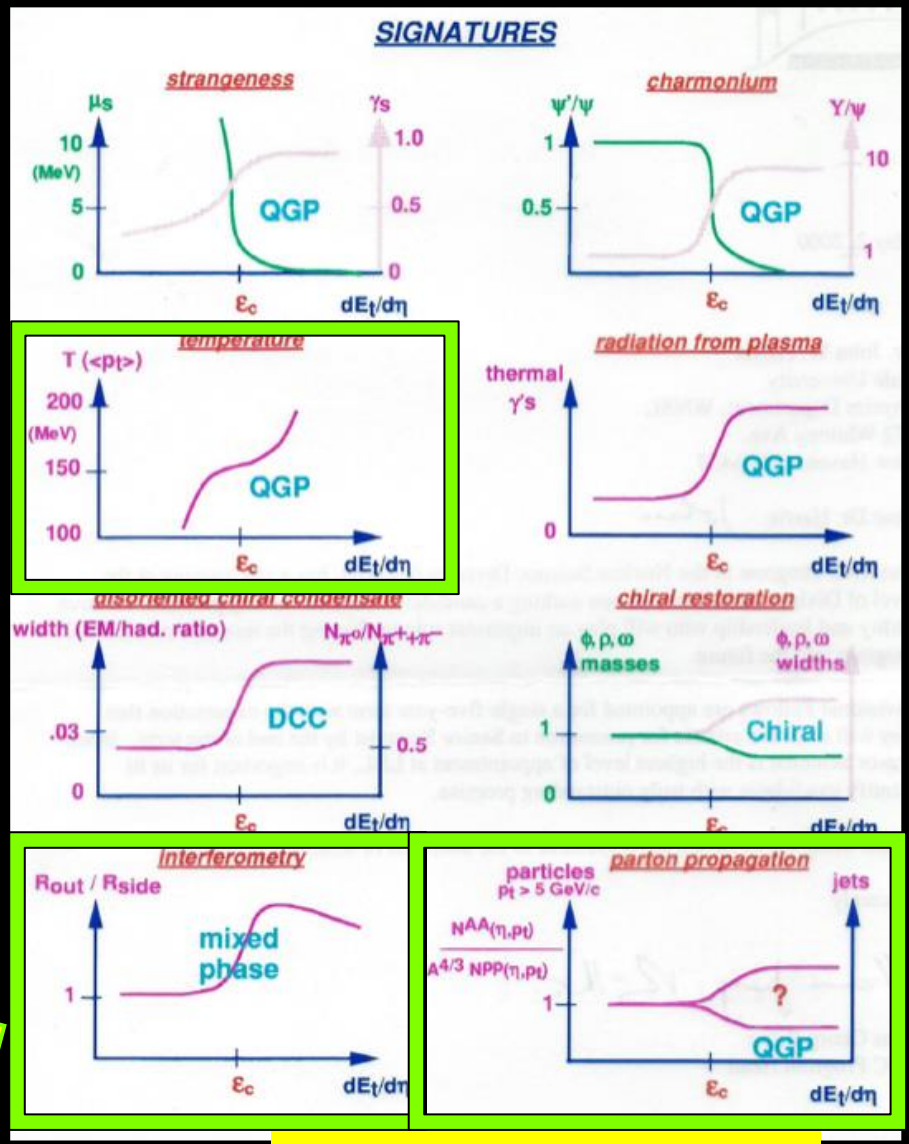
STAR Baseline Detector & Deferred Additional Equipment

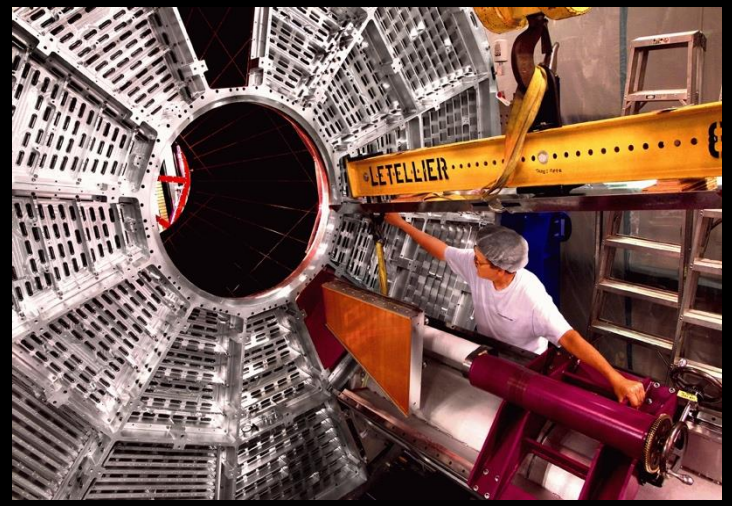




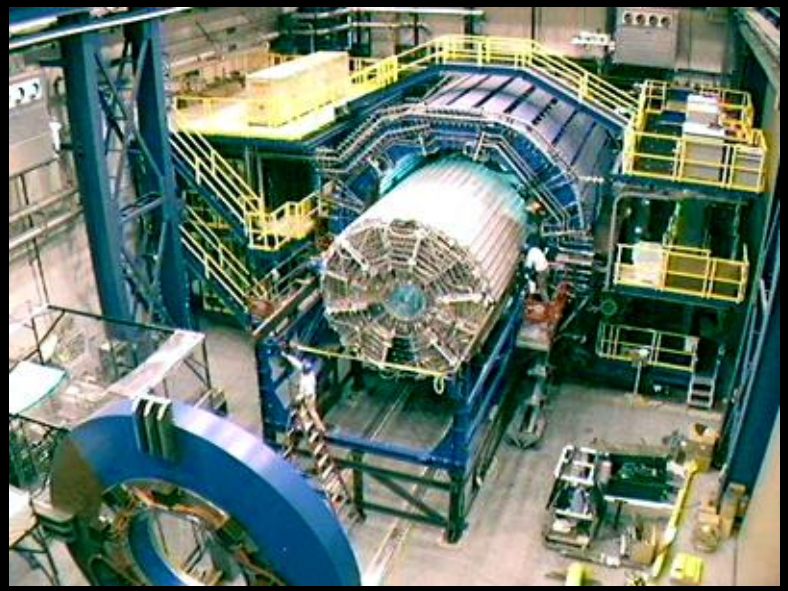
"The Search for the Quark – Gluon Plasma," J. W. Harris & B. Müller, Ann. Rev. Nucl. Part. Sci. 46, 71 (1996) [arXiv:hepph/9602235 [hep-ph]].

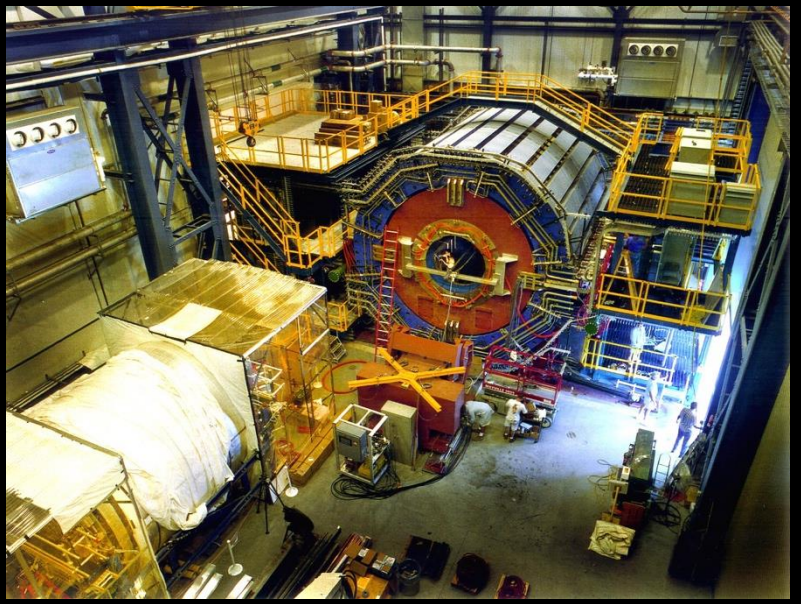
dE_t/dn ~ energy density

STAR TPC from LBL to BNL

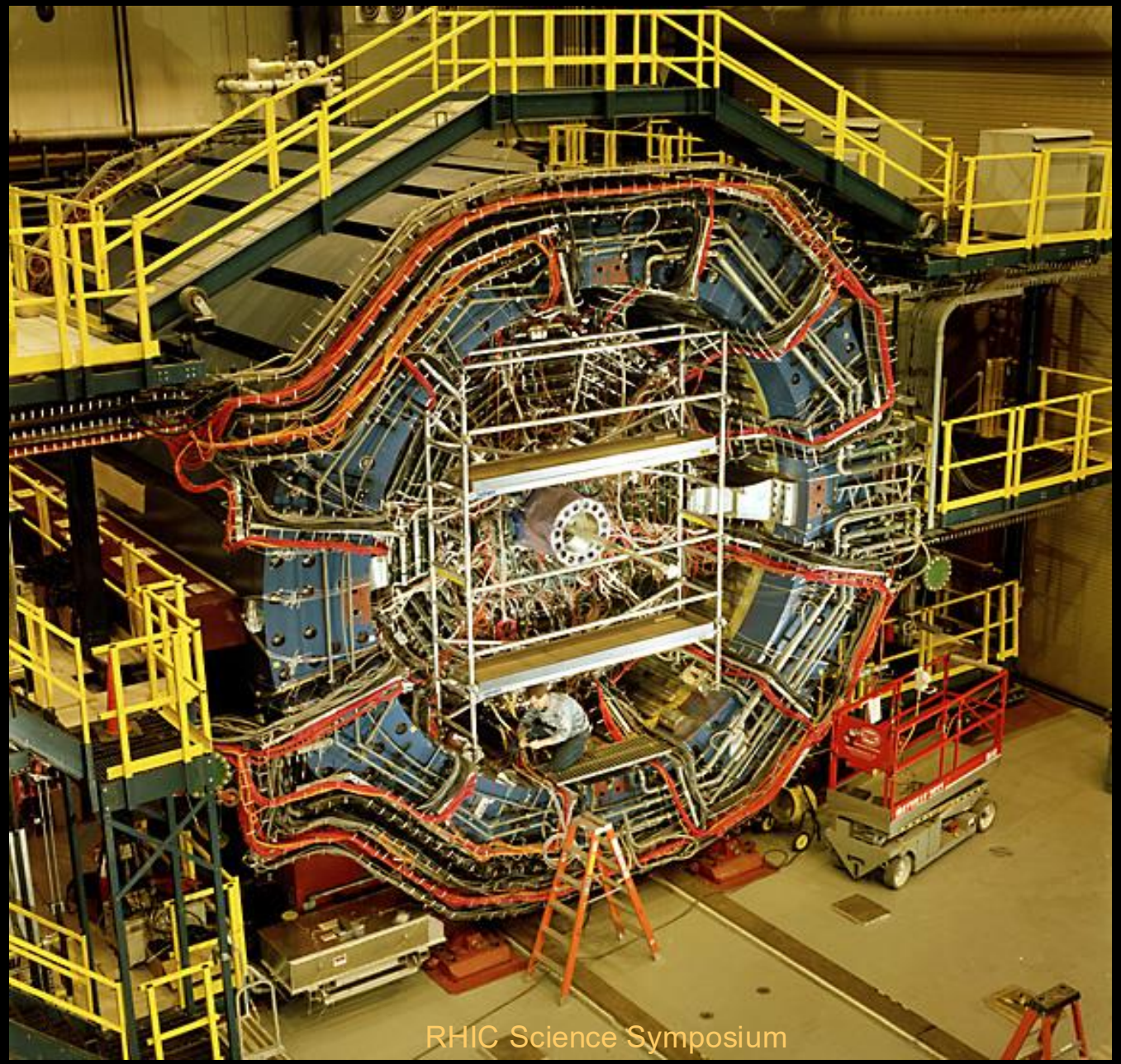


STAR TPC from LBL to BNL

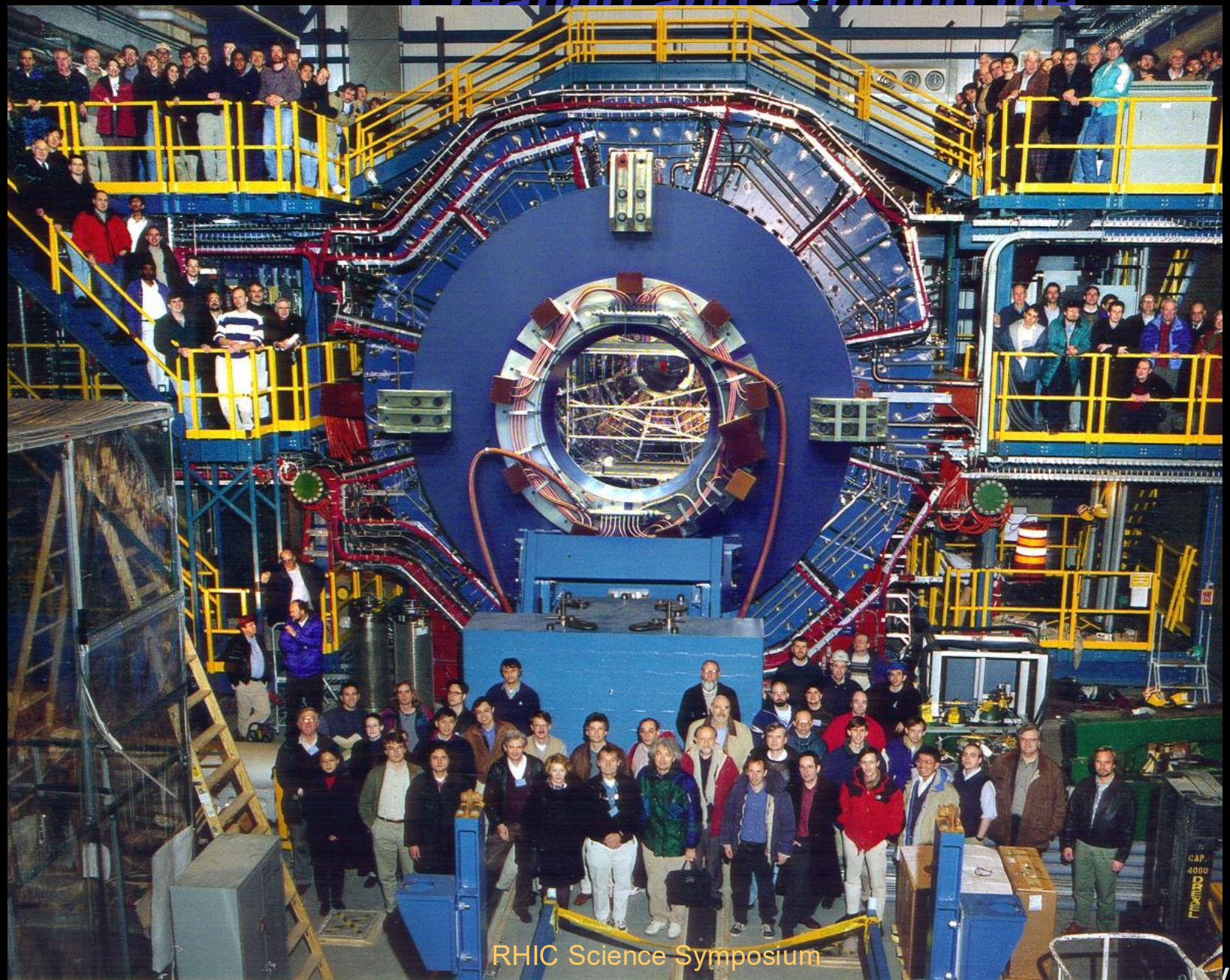




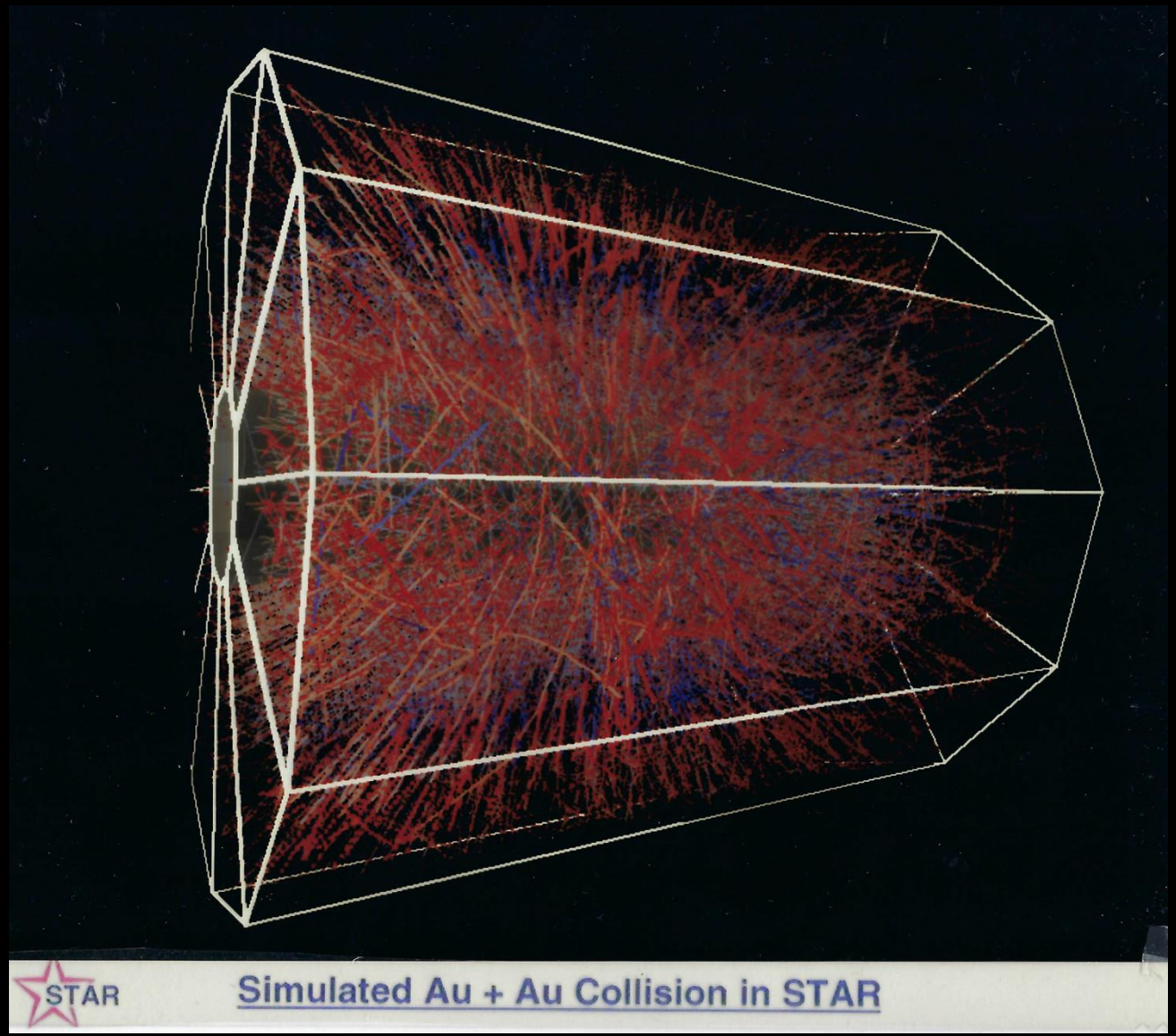
STAR Detector Ready to Roll!

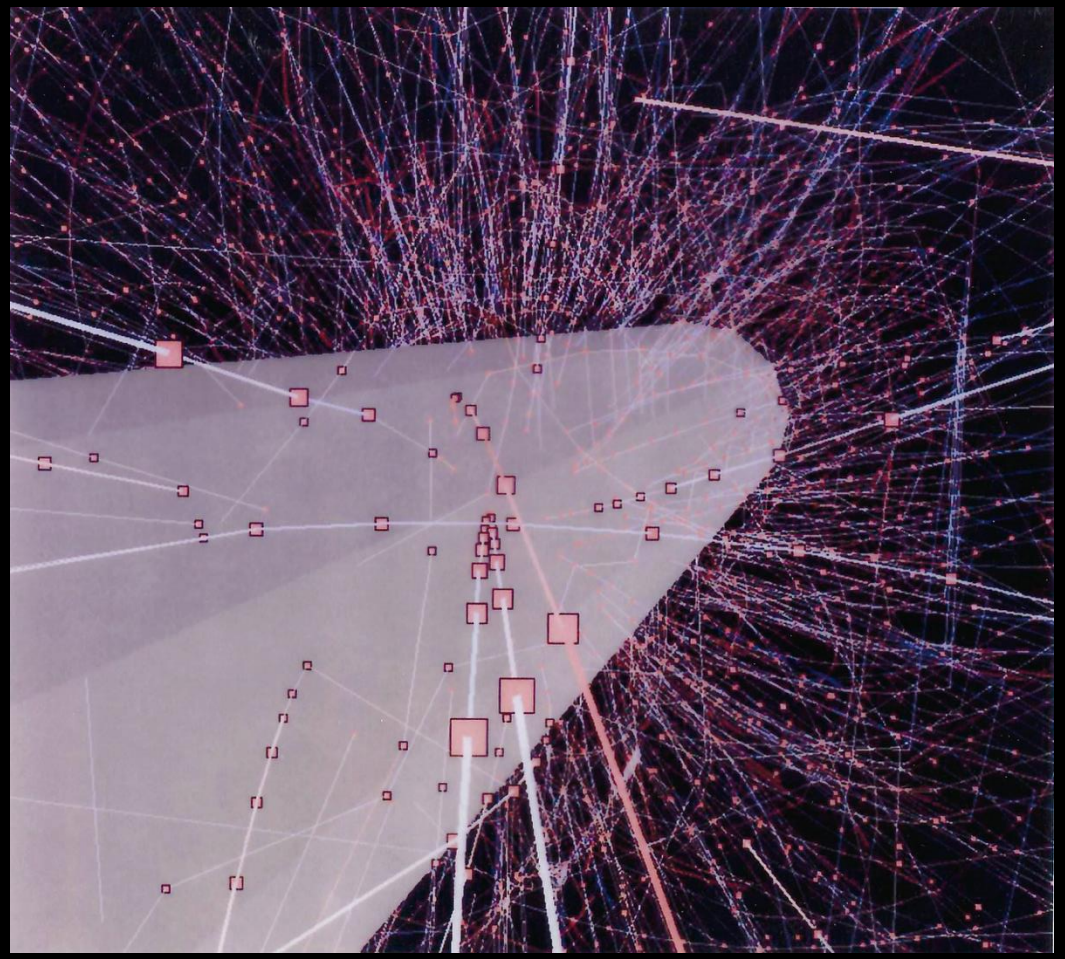


Collaboration Ready to Roll!



TPC Tracking Ready to Go!

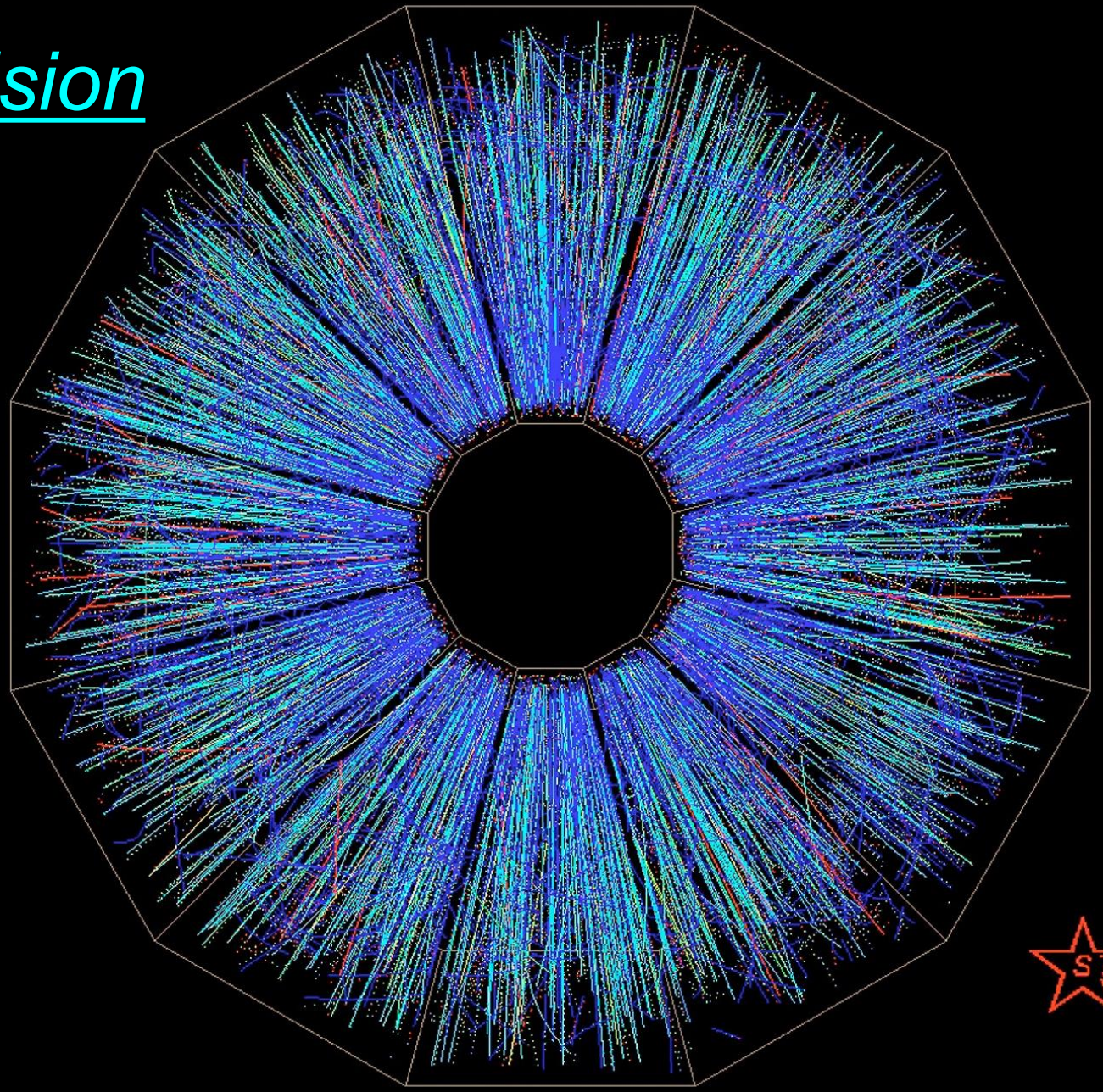




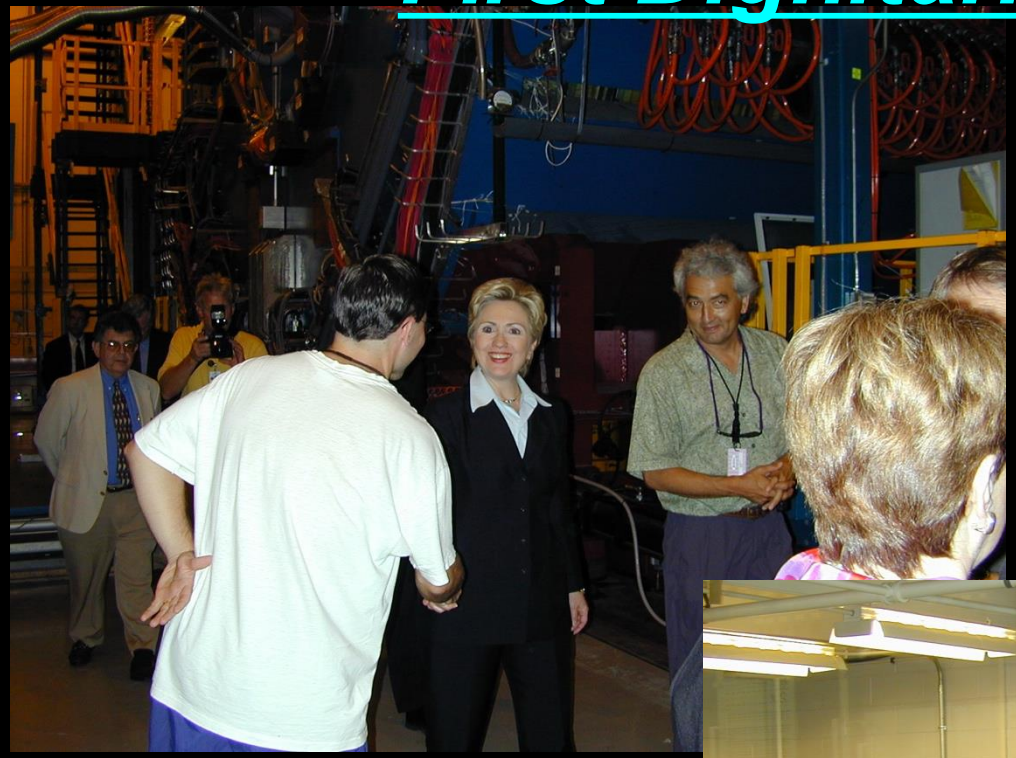
STAR Control Room and First Collisions!

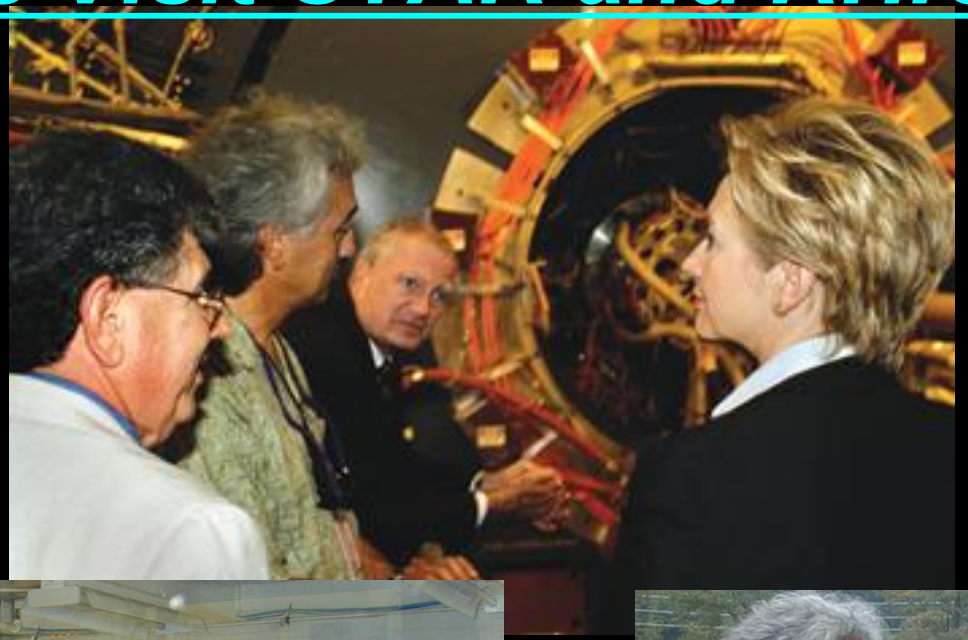
There was a Conundrum in STAR Control Room! before FIRST COLLISIONS!

Head-on Collision

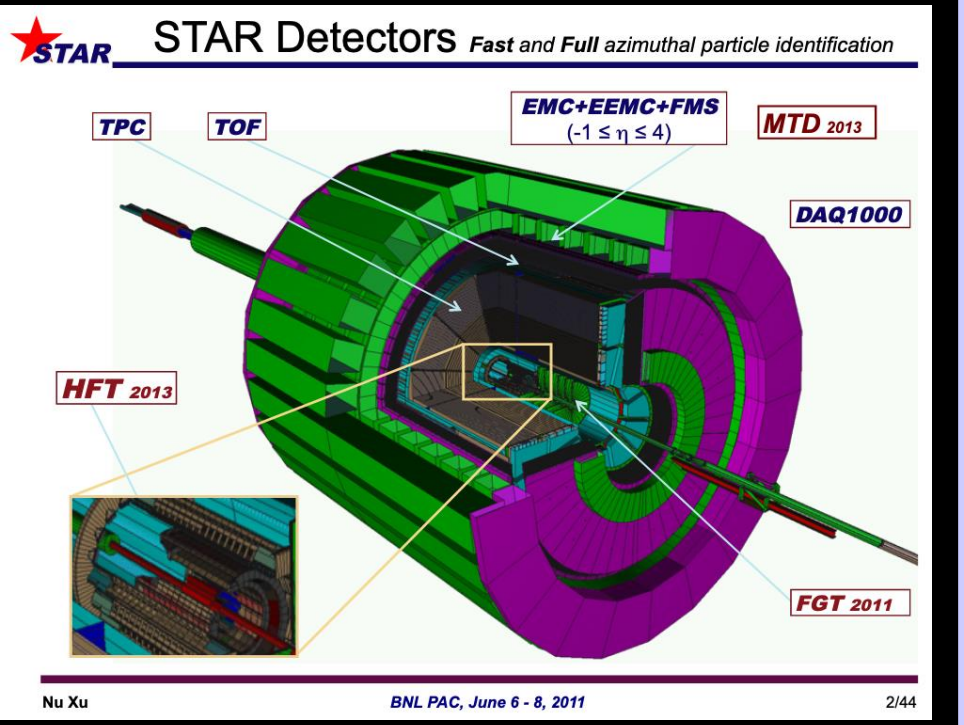


First Dignitaries Visit STAR and RHIC





STAR Growing Up (into its Teens)!



STAR Upgrades

Electro-Magnetic Calorimetry

Time of Flight

Forward Meson Spectrometer

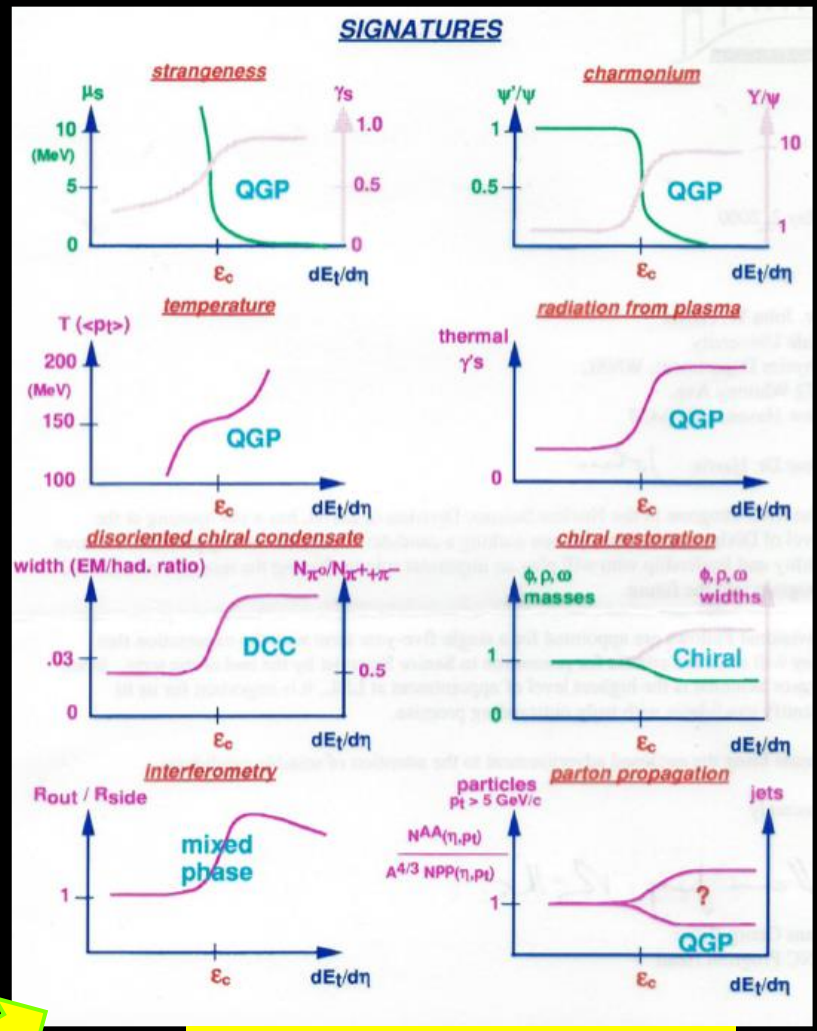
DAQ1000

Muon Tracking Detector

Heavy Flavor Tracker

Intermediate Stage Tracker

Forward Tracking



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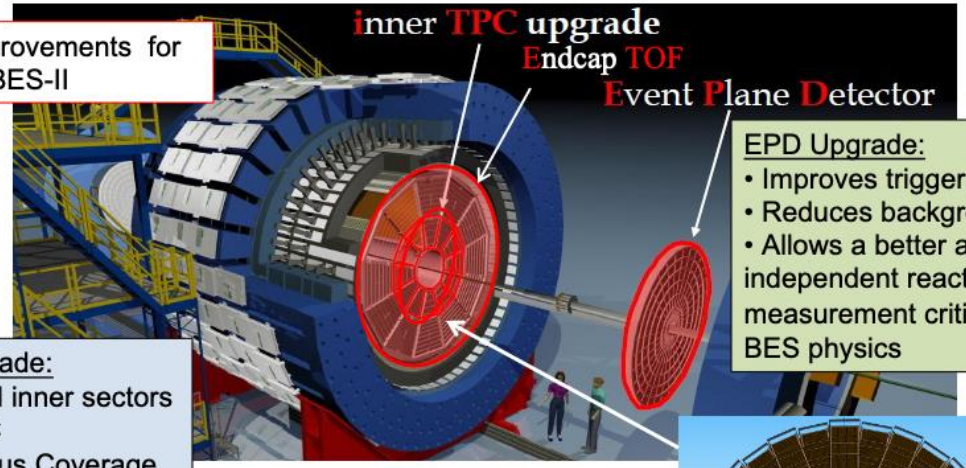
dE_t/dn ~ energy density

Completion of STAR – Grown Up (2020's)!

STAR detector at BESII

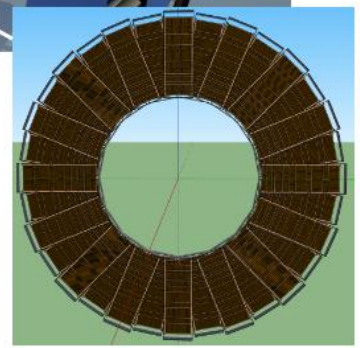
Major improvements for BES-II



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

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

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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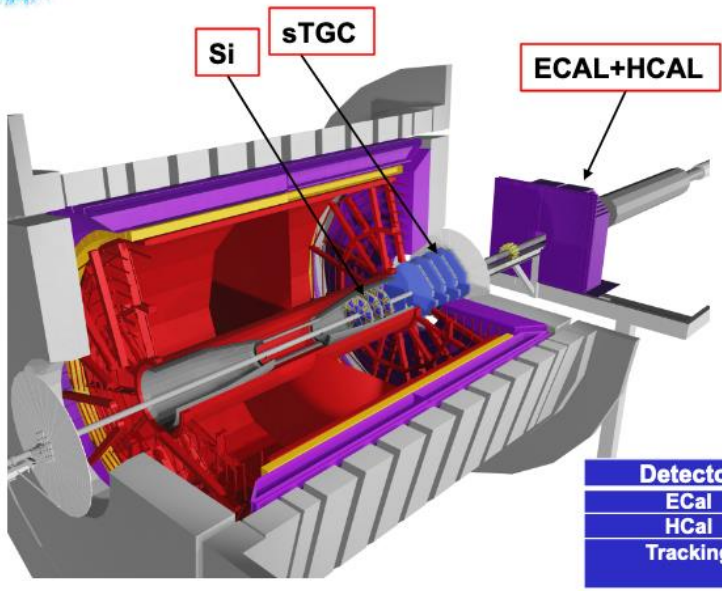
STAR forward upgrades



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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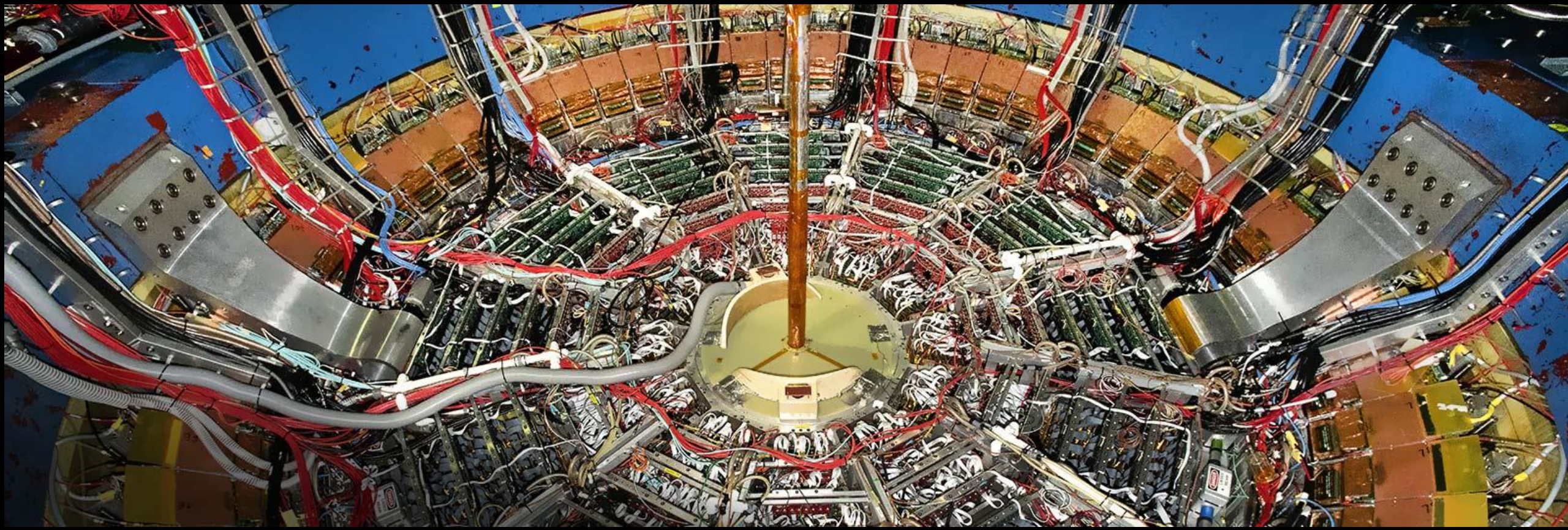
STAR – All Grown Up!

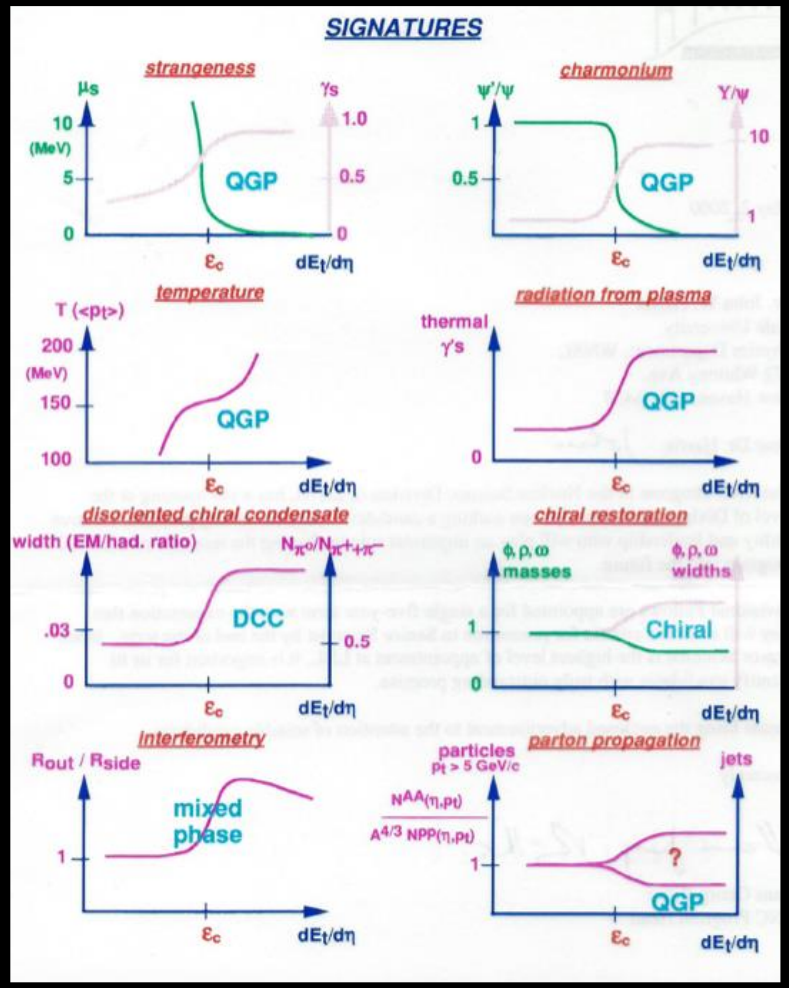


At the end of 2025: *391 theses → 347 (PhD), 34 (Masters) and 10 (Diploma)*

347 publications → 107 PRLs, 130 PRC, 50 PLB, 34 PRD, 11 Science/Nature, 15 others

26 publications in this year!

Signatures – Unanticipated & New Developments



"QGP Signatures" Revisited,
J. W. Harris & B. Müller,
Eur. Phys. J. C 84, 247 (2024),

- Collective Flow ✓
- Flow Fluctuations ✓
- Coalescence of Valence Quarks ✓
- Vortical Flow (Polarization in AA) 🔧
- Small Systems (including pp & pA) 🔧
- Equation of State at High Density 🔧
- Exotic Nuclear States 🔧
- Jet Substructure 🔧
- Energy Energy Correlations 🔧
- Dead-cone in pp (in AA 🔧)
- Baryon Junctions? 🔧
- Critical Point? 🔧
- CME 🔧

X DCCs / Anomalous Chiral Effects

- Others (TBD) 🔧 🔧 🔧

🔧 Still work to be done

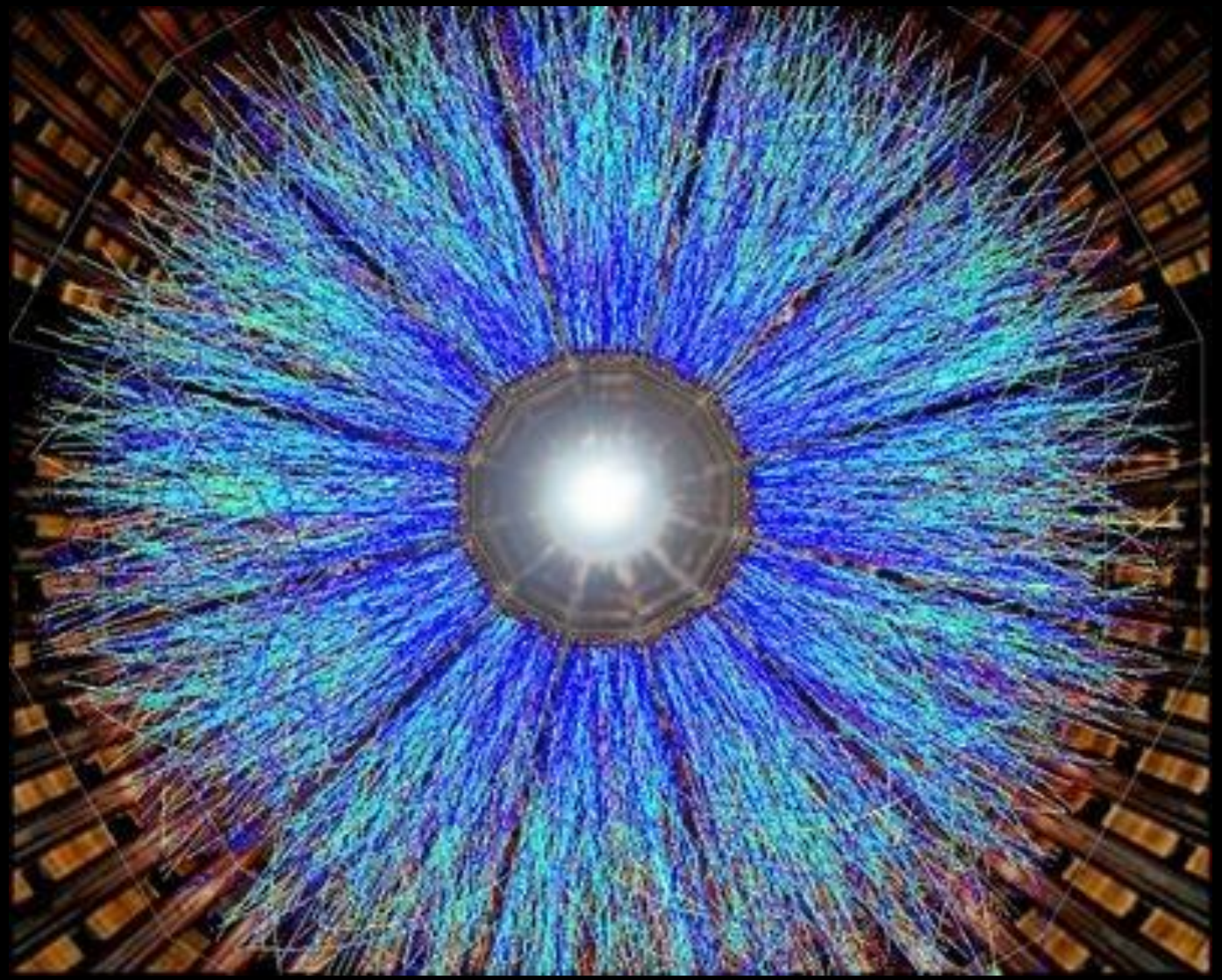
RHIC has produced the

hottest,

least viscous, and

most vortical fluid ever

in the laboratory!



"Photo" credit BNL

Thanks

to all my STAR Collaborators!

STAR Publications in Science, Nature, etc. (2010 – 2025)

Observation of an Antimatter Hypernucleus
Science 328 (2010) 58

Measuring spin correlation between quarks during QCD confinement
Nature 650 (2026) 65

Imaging Shapes of Atomic Nuclei in High-Energy Nuclear Collisions
Nature 635 (2024) 67

Observation of the Antimatter Hypernucleus Anti-H4Lambda
Nature 2024 (2024) 77

*Observation of Global Spin Alignment of phi and K*0 Vector Mesons in Nuclear Collisions*
Nature 614 (2023) 244

Global Lambda hyperon polarization in nuclear collisions: evidence for the most vortical fluid
Nature 548 (2017) 62

Measurement of interaction between antiprotons
Nature 527 (2015) 345

Observation of the antimatter helium-4 nucleus
Nature 473 (2011) 353

Precise measurement of the mass difference and the binding energy of hypertriton and antihypertriton
Nature Physics 16 (2020) 409

Tomography of Ultra-relativistic Nuclei with Polarized Photon-gluon Collisions
Science Advances 9 (2023) 3903

Temperature Measurement of Quark-Gluon Plasma at Different Stages
Nature Communications 16 (2025) 9098