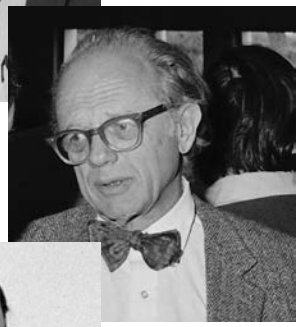
From AGS to EIC:

How Nuclear Physics Met Particle Physics and RHIC Was Born



T. Ludlam

RHIC & AGS Users Meeting

June 22, 2017

Celebrating 70 Years of Discovery at BNL

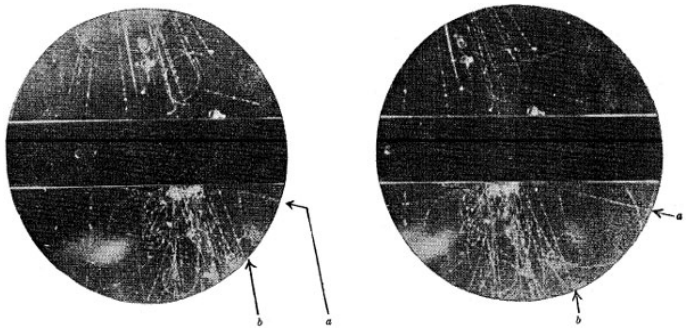
BNL's Post-War Origin

Nuclear Physics Dominant

"Atoms for Peace"

Graphite Research Reactor is First Big Facility at BNL

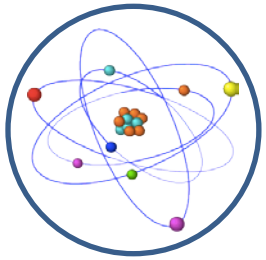
Funding by U.S. Atomic Energy Commission



Rochester & Butler discover K meson, 1947

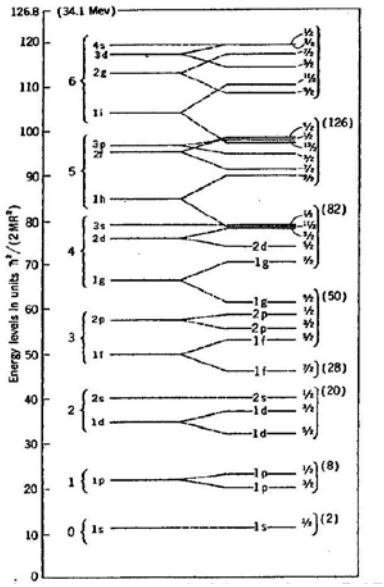
High Energy Physics via cosmic rays

Mid- Twentieth Century Building Blocks of Matter

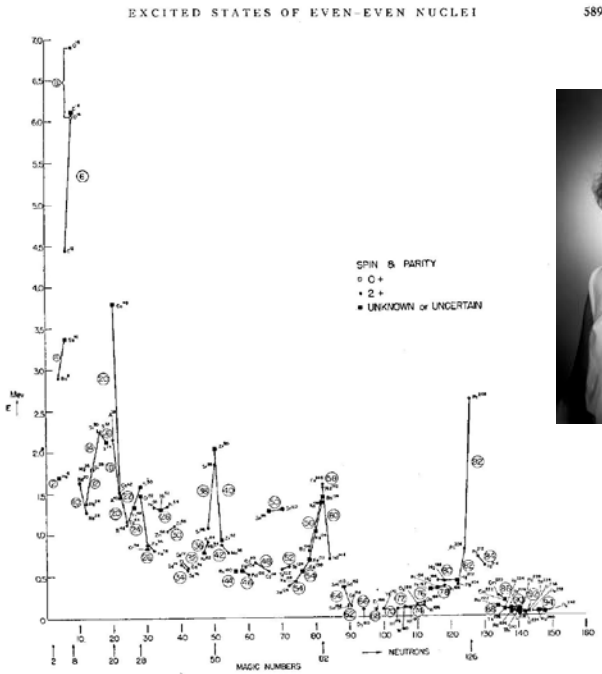


Theory and Experiment organized around models for binding of protons and neutrons in nuclear medium.

Spectroscopy of excitations across the periodic table.



Single particle shell model: spin-orbit coupling → Magic Numbers



1953 Compilation by Gertrude Scharff-Goldhaber

1960's… High Energy Physics Ascendant

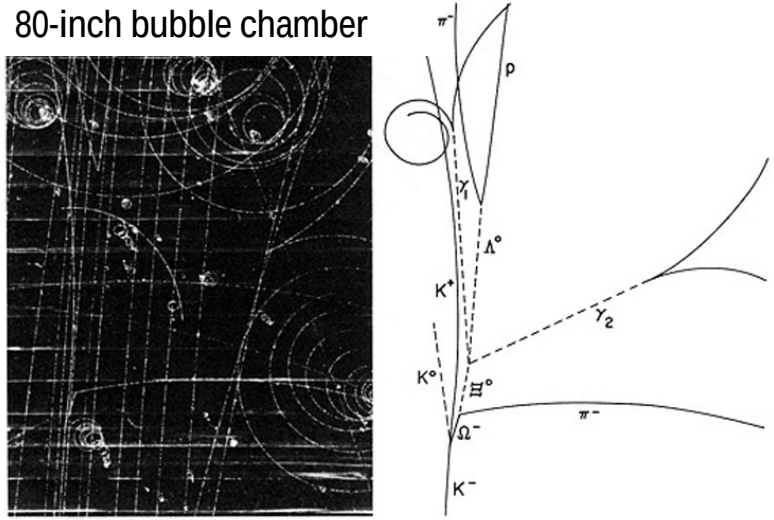
Era of big accelerators begins: Cyclotron, Bevatron, Cosmotron…

Strong Focusing synchrotron:
AGS hits a sweet spot… c.m. energy in few GeV range

Courant, Livingston, Snyder, Blewett

The Particle Data Table Explodes

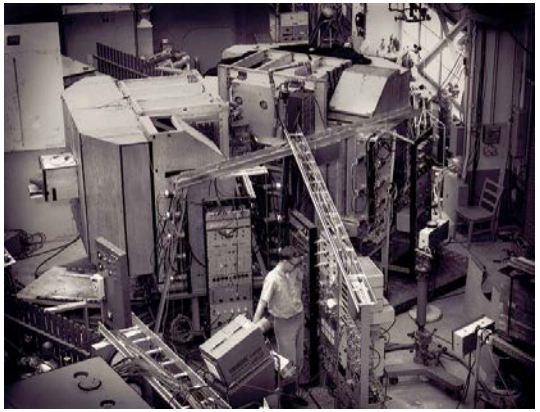
80-inch bubble chamber



Golden Era for Bubble Chambers

Setting the stage for the 8-fold way:
Quarks enter the literature

AGS: Many spigots… many experiments in an energy range rich with short-lived particle states.



Fitch-Cronin exp. Discovers CP-violating K decay, wins Nobel Prize

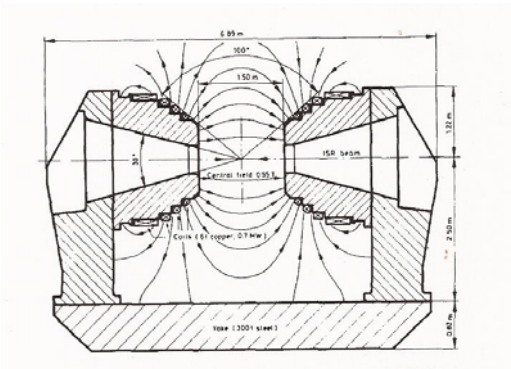
Emergence of electronic detectors and large-scale data processing

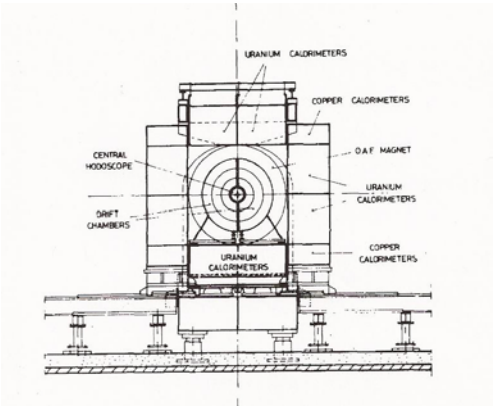
HEP and NP diverge into separate disciplines

HEP: university groups working in collaboration at big labs

BNL, CERN, ANL, SLAC….

NP: Many small university-based accelerator facilities





Axial Field Spectrometer at CERN ISR:
Brookhaven, CERN, Niels Bohr Inst., Univ. Lund, Rutherford Lab, Tel Aviv Univ.

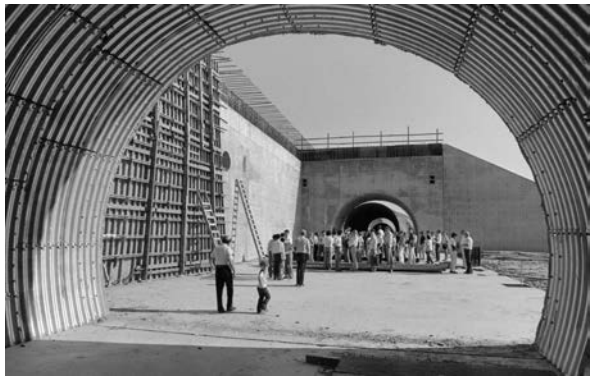
Wright Nuclear Structure Lab
Yale University

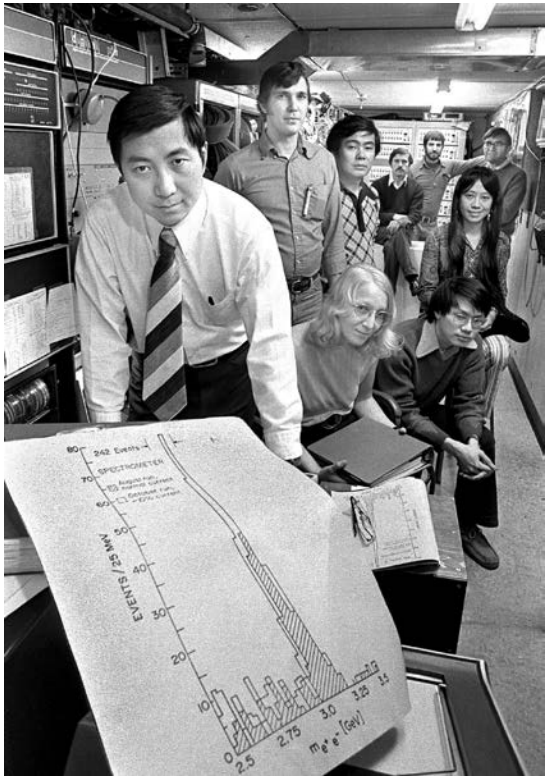
U.S. Department of Energy established in 1977:
Separate offices and advisory panels for HEP, NP

1970's: Quarks and QCD Emerge

New Energy Frontiers ISR, SPS, SLAC, Fermilab....

ISABELLE construction begun 1978:
400+400 GeV colliding beams





J/Ψ, Hard Scattering discovered.
Quest for Jets, W & Z Bosons.

AGS Still At the Forefront

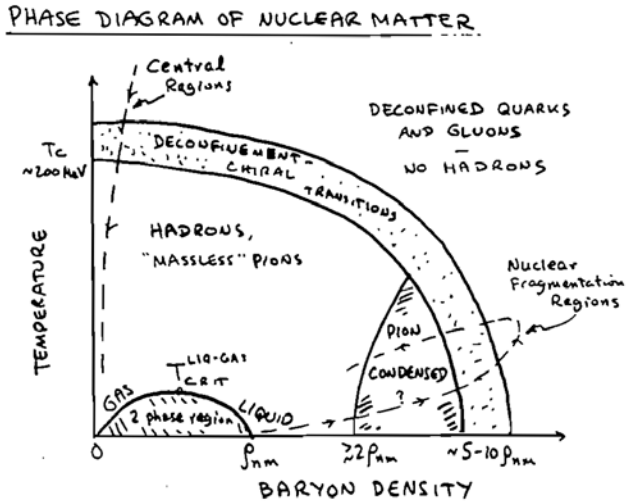
1980's: Nucleus as a medium of Quarks and Gluons

The Quark Gluon Plasma and the QCD Vacuum

"In high energy physics experiments we distribute a higher and higher amount of energy into a region with smaller and smaller dimensions.

In order to study the question of 'vacuum', we must turn to a different direction… distributing high energy over a relatively large volume."

T.D. Lee Rev. Mod. Phys. 47(1975)



Gordon Baym sketch as it appears in 1983 Long Range Plan for Nuclear Physics

The Summer of 1983

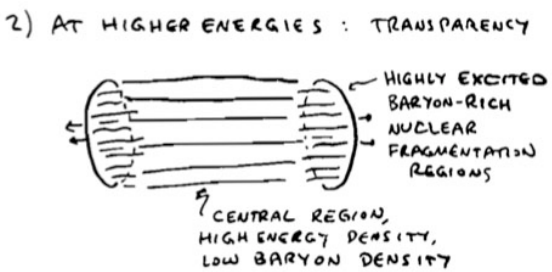
Two near-simultaneous events in July 1983 that sparked the birth of RHIC

Washington D.C. **DOE's High Energy Physics Advisory Panel (HEPAP) officially recommended the termination of the ISABELLE project.**

Cayuga Lake, Wells College **DOE's Nuclear Science Advisory Panel (NSAC) drafted a Long Range Plan for U.S. Nuclear Science stating…**
"we identify a relativistic heavy ion collider as the highest priority for the next major facility to be constructed, with the potential of addressing a new scientific frontier of fundamental importance."

- With its new Long Range Plan, Nuclear Physics embraced an endeavor for which the accelerator technology and experimental techniques resided almost entirely in the realm of High Energy Physics.

Quark Matter ’83… Where RHIC Got Started



The first “Quark Matter” Conference

Data from p-A collisions at Fermilab on nuclear stopping power showed that collision energies of 100GeV/nucleon or higher needed.

A panel chaired by D. Alan Bromley and anchored by J.D. Bjorken strongly endorsed the BNL design for RHIC, utilizing the ISABELLE infrastructure.

Bromley: **success will require *“Breaking down artificial barriers which have for a very long time separated nuclear and particle physicists”*– Including a change in the manner in which agencies fund such programs.**

Bjorken: ***“They may be your nuclei, but they are our quarks.”***

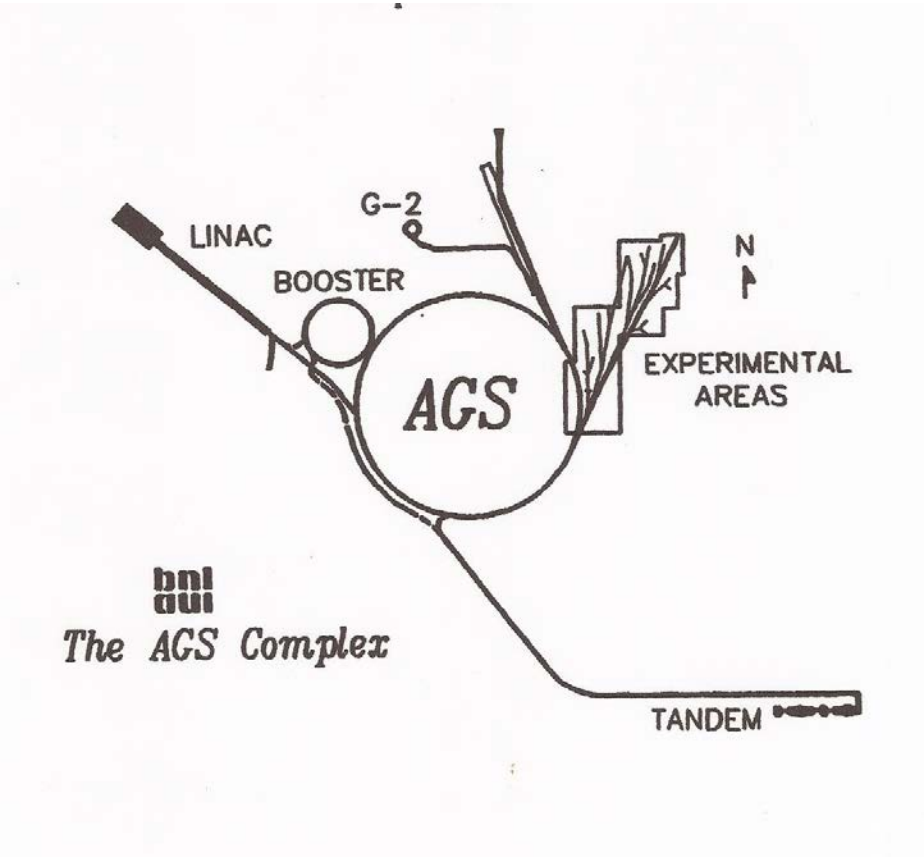
The ~20 Year Gap Between QM '83 and RHIC Physics: AGS as the Vital Bridge

HI Transfer line and Booster quickly funded.

Polarized proton capability developed.

Many beam lines and extensive fixed target infrastructure:

- Test Beams
- Fixed target HI program
- Continued HEP program:
  - Rare K-decay Exps
  - g-2



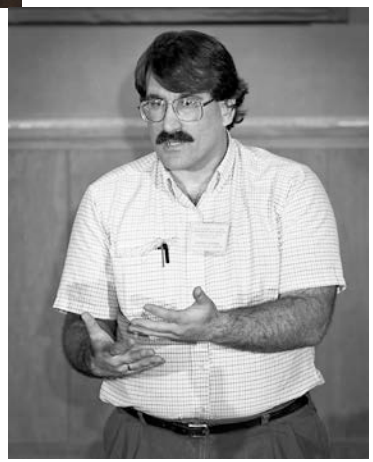
Joint effort of HEP and NP funding offices in DOE

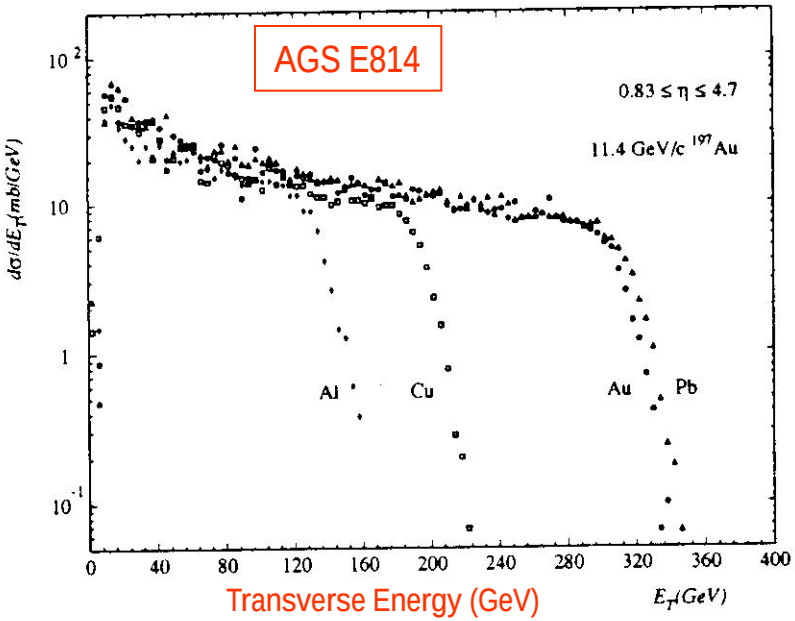
The Key Role of the AGS Heavy Ion Program

- First look at high energy HI collisions in lab experiments:
Essential input for design of RHIC experiments

- First experience for NP community with HEP instrumentation and large collaborations

- Critical training ground for a generation of RHIC experimenters.





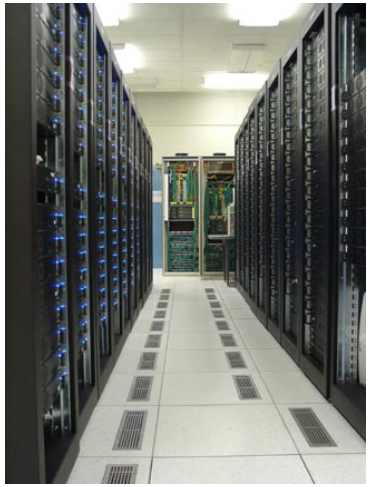
1990's… RHIC Construction

International Participation

RIKEN and RHIC Spin

- Riken-BNL Research Center established at Brookhaven to support RHIC Spin program
- RIKEN provided funds for Siberian Snakes in RHIC and second PHENIX Muon Arm
- Funds for PHENIX detector systems provided through U.S.-Japan HEP agreement.

Data Analysis Challenge

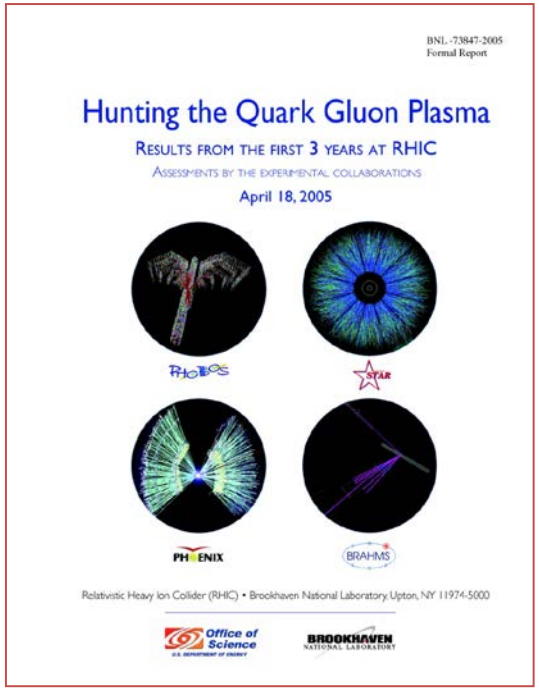


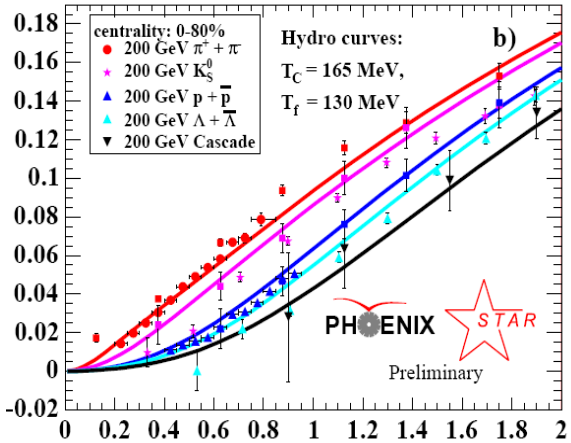
RHIC Computing Facility: Scalable architecture with commodity OTS purchases becomes a model for large scale data processing in NP and HEP

2000's… RHIC Delivers

The White Papers

Nuclear Physics A, August, 2005

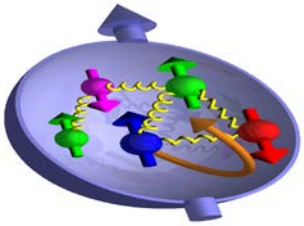




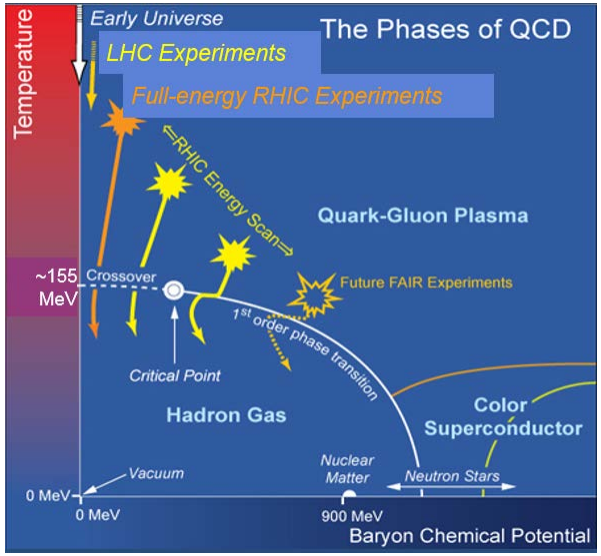
A new view of high-temperature matter:
"Ideal" Hydrodynamics

- Near-zero viscosity
- Very quick thermalization

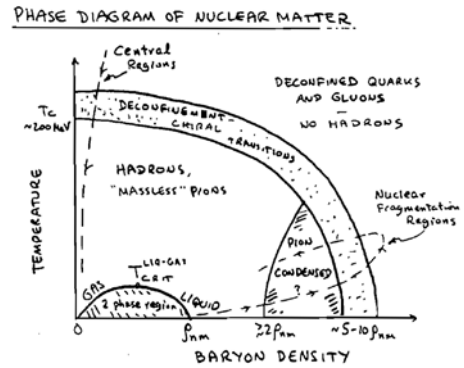
"Perfect Liquid"



RHIC Spin:
The Gluons come forward



RHIC now leads a global effort of accelerator facilities exploring the QCD phase diagram that was a cartoon in 1983.



Pushing the limits of accelerator performance and detector technology:
A uniquely NP facility developed on the shoulders of HEP

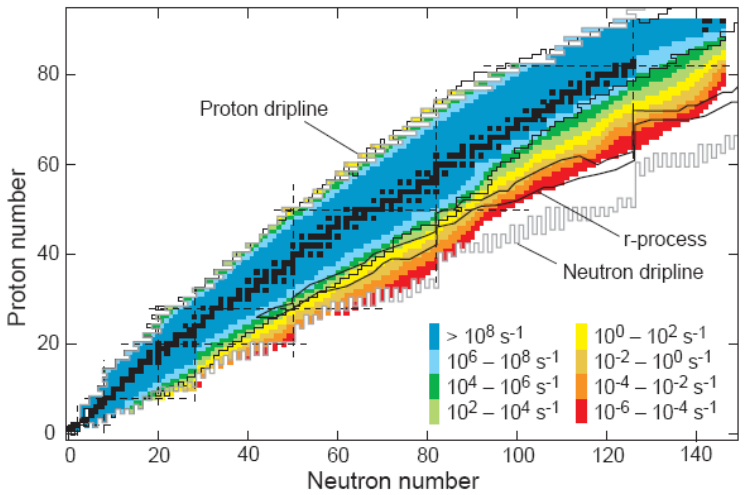
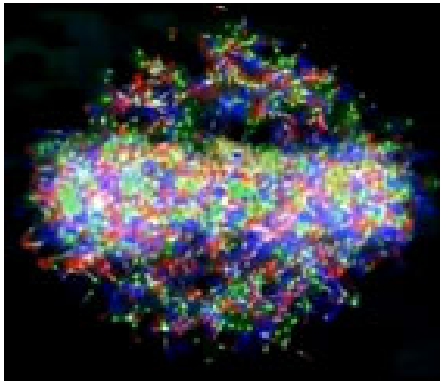
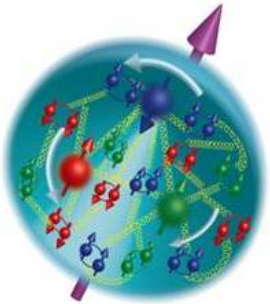
Discovering emergent QCD phenomena of broad interest for the general scientific community

Setting the stage for precision measurements of spin-dependent partonic structure in nucleons and saturated gluon matter in nuclei:

Electron Ion Collider

Two Views of Nuclear Matter for Future NP Facilities

FRIB: Nuclear Structure at the extremes of the periodic table



RHIC-EIC: "Condensed Matter with a Force of a Different Color"