

Status of RHIC and Its Detectors

Presentation at
1999 ICFA Seminar

Fermi National Accelerator Laboratory
October 5, 1999

Satoshi Ozaki
Brookhaven National Laboratory

Brookhaven Science Associates
U.S. Department of Energy

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RHIC Project Mission

DOE's Flagship Research Facility for Nuclear Physics Research
High Energy Heavy Ion Collider to Study the Transition to QGP Phase of Matter

CDR: May 1986
KD1: January 1991
KD2: January 1991
KD3: January 1992
Rings Completed 1/99
Commission'g Began 5/99
CD4 August 12, 1999

TEC=\$ 486.9M,
TPC=\$ 616.5M

Uses Existed Tunnel, Exp. Halls,
and He Refrigerator

AGS Complex as Injector,
Spin Physics Capability: RIKEN-BNL Collaboration
The Value of Completed RHIC Facility > \$1B



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Performance Specifications

Ion Species: A~200 (Au) to A=1 (Proton),
Includes Collisions of Unequal Ion Species

	For Au-Au	For p-p
Beam Energy	100-30 GeV/u	250-30 GeV
Luminosity	$2 \times 10^{26} \text{ cm}^{-2}\text{sec}^{-1}$	$1.4 \times 10^{31} \text{ cm}^{-2}\text{sec}^{-1}$
Number of Bunches/Ring	60 ($\rightarrow$ 120)	60 ($\rightarrow$ 120)
Luminosity Lifetime	~ 10 Hrs	>10 Hrs
β^* at Collision Points	10 m $\rightarrow$ 2 m (1m?)	10 m $\rightarrow$ 2 m (1m?)

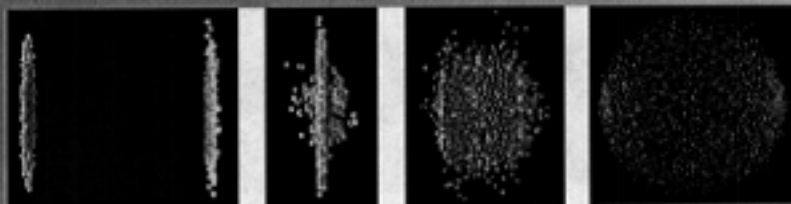
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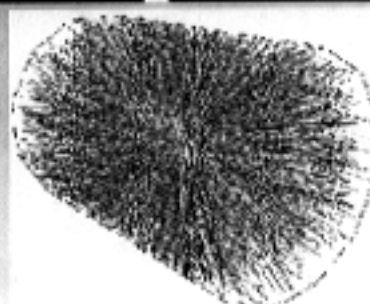
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Collision of Relativistic Heavy Ions



Highly Charged Vacuum State
Temperatures $>10^{12}$ K
 $\sim 10,000 \times$ Sun's Temperature



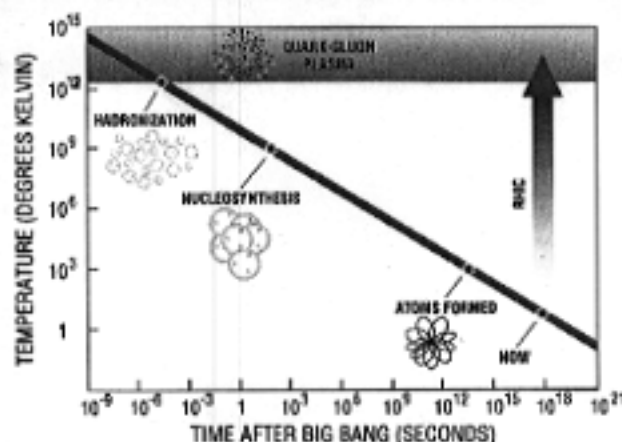
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Evolution of the Universe through Phase Transitions



Temperature vs. Time after the Big Bang

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Physics Objectives

Collisions of Heavy Ions at RHIC $\Rightarrow$

Highly Charged States of Vacuum: High Temp. and High Density

Transition into Quark-gluon Plasma Phase of Matter

Conditions of the Universe at a Few μ sec After the Big Bang

Discovery of the Phase Transition

Formation and Study of Quark-gluon Plasma

Interaction of Deconfined Quarks in Plasma

Recreation of the Cool Down $\rightarrow$ Physics of the Early Universe

Collisions of Polarized Protons (RIKEN Collaboration) $\Rightarrow$

Hard QCD/spin Physics

Spin Structure of Nucleons

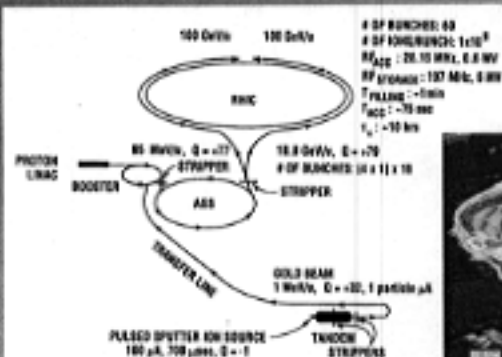
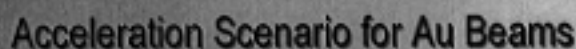
Spin Dependence in W/Z Production

High Energy p-p Elastic Scattering and Total Cross Section

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Dipoles, 8 cm ϕ (360),
CQS Assemblies, 8 cm ϕ (420),
Dummy (100)



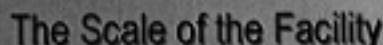
Final Focus Quadrupoles, 13 cm ϕ (96)
IR Dipoles, 10 cm ϕ (24)
IR Dipoles, 18 cm ϕ (12)

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Two Concentric Superconducting Magnet Rings (3.8 km circumference)
Intersecting at Six Locations for Relativistic Heavy Ion Collisions
Total Length of the accelerator rings: 7.5 km

400 m Long AGS-to-RHIC Beam Transfer Line

24kW He Refrigerator and Cryogen Distribution System

Two RF systems Acceleration (28 MHz) & Storage (200MHz)

Three Experimental Halls, One Enlarged IR Tunnel, One Open Area (Block House), and One Area with Foundation for Future Detector

Four Complementary Detectors for the First Round of Physics

Dedicated Computing Facility for Data Store, Reconstruction & Mining

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The Collider: Recent Achievements

- The First Sextant Test (February 1997):
 - Met the Milestone Schedule
 - Gold Beams Transported through One Sixth of the Ring
- Completed Magnet Production (September 1998):
 - Within a Week of Milestone
 - 1740 units of Superconducting Magnets
 - Dipoles/CQS/Dummy for Arcs and Insertions 880 units
 - Large Bore Magnets for Interaction Region 132 units
 - Good and Uniform Field Quality
 - Good Quench Performance for All Cryo-Tested Magnets
- Assembly of the RHIC Rings Completed in January 1999:
 - Within a Month of Milestone

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The Arc Section

The End of
Completed
RHIC Sector



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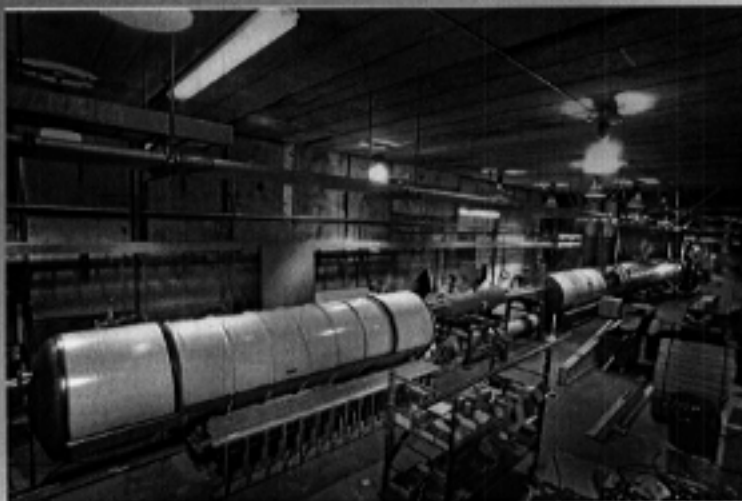
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Interaction Region

IR Magnet
Assembly



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Acceleration and Storage RF Cavities

28 MHz RF for Injection
Capture and Acceleration at
up to 600KV per Ring
Bunch Rotation & Transfer to
the 197 MHz System



197 MHz RF for Short Bunches
for Collisions
3/Ring (3MV) + 4 Common (4MV)
Total 7 MV/Beam

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The Collider: Commissioning Status

Cryogenic System:

Blue Ring Cooled to Operating Temperature (4.6 K) on May 26

Yellow Ring Cool-down to 4.6 K on July 14

Beam Commissioning:

Permission to Commission with Low Intensity Beam on June 24

Established Closed Orbit in Blue Ring

Captured, Stored, and Accelerated Beams in Blue Ring

Stored Beam Life ~ 45 min.

Establish Closed Orbit and Captured Beams in Yellow Ring

Runs Ended on August 16th

DOE Critical Decision (CD) [Begin Operating]:

Approved on August 12

The First Year Operation:

To Begin in December 1999: Nominally 32 Weeks

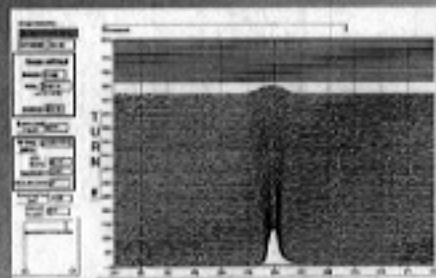
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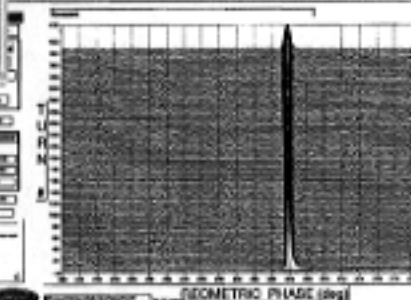
Beam Circulation and Capture (Blue Ring) July 16, 1999



Circulating Beam in Blue Ring
Confirmed 1600 turns

Beam Bunch Captured in RF
Bucket

↓ Beam Lasting Several msec



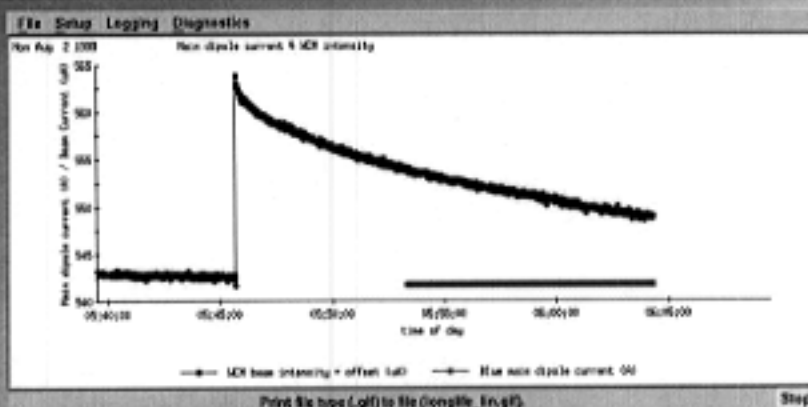
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Beam Life Time in Blue Ring



Beam Mean Life = ~19 min.

The Mean Life of ~45 min Has Been Achieved

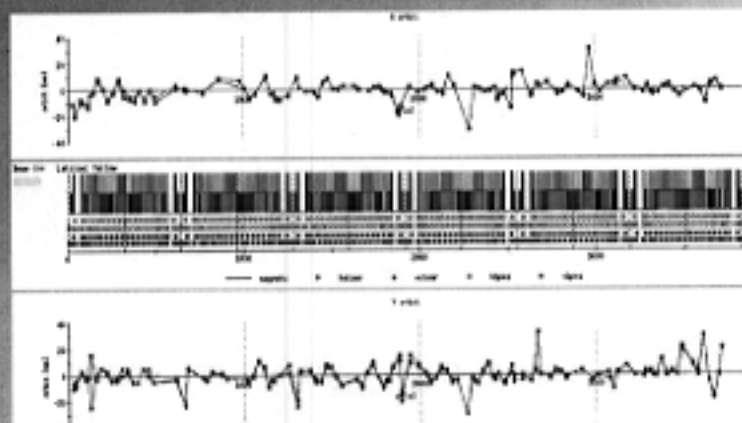
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Beam Orbit in the Yellow Ring



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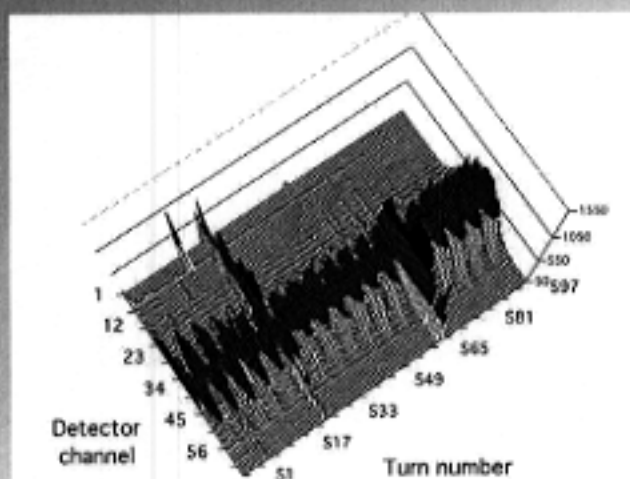
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Turn-by-Turn Beam Profile

Measured
by
Ionization
Profile
Monitor



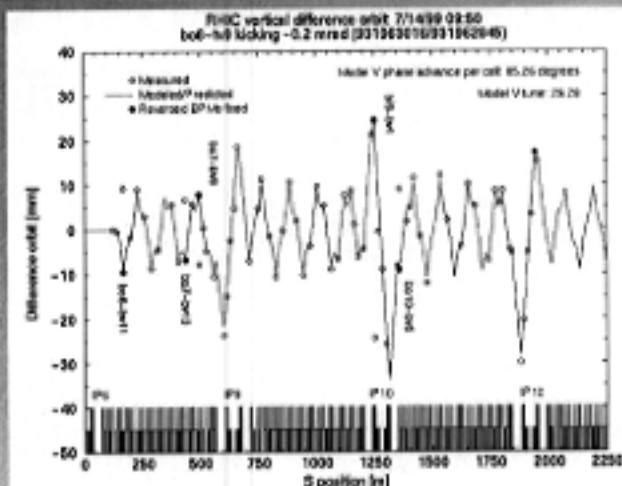
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The Tune: Prediction vs Measurements



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SPIN PHYSICS PROGRAM

RIKEN-BNL Collaboration

Collisions of Polarized Protons
 $\sqrt{s} \leq 500 \text{ GeV}$

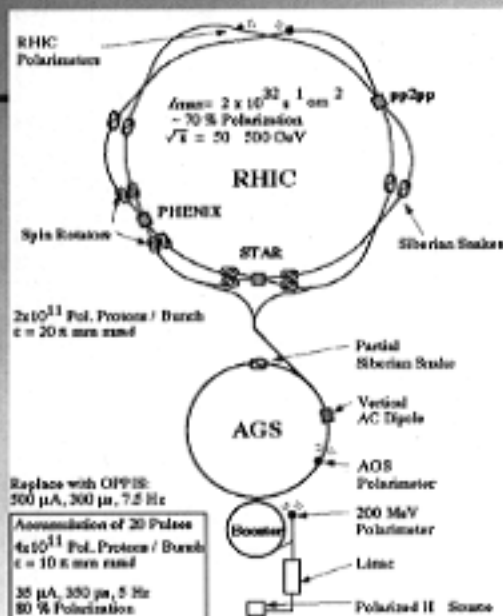
Frontier Studies of

- Spin Structure of Nucleon
- Gluon Structure Function
- Spin Dependent $W^\pm$ Production

AGS:
 Accelerates Polarized Protons

RHIC:
 Siberian Snakes and Spin Rotators

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The First Complete
 Siberian Snake

Four Helical dipoles:
 4T, 2 m long,
 & 360° Twist

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The Detector Status

\$ 115M of Trust Fund for Initial Complement of Detectors

Programmatic Policy Decision by BNL HE/NP PAC

Two Large Scale Detectors: STAR and PHENIX

Two Small Scale Detectors: PHOBOS and BRAHMS

The Trust Fund was Leveraged Well:

- Supported Construction of Basic Detector Systems
- Significant Foreign Contributions: Cash, In-kind, and Intellectual
- DOE Funding for Additional Experimental Equipment (AEE)

Detectors Were at Respective Collision Points for Commissioning:

- Degree of Completeness Varied from Detector to Detector
- Observed Beam-Gas Events in the Commissioning Runs
- Further Instrumentation to be Added for the First Year Physics

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Signature of QGP Change in Observable at Given E_T/dy

Global Variables

E_T , n_c , dn_c/dy

Hadrons

$d\sigma/dp_T$ of identified π , K, p, p-bar, etc.

strangeness production: K^+ , K^- , ψ , etc.

HBT Interferometry: $\pi\pi$ and KK

open charm

Charm Enhancement

Dileptons

soft continuum

non-resonant continuum: 1 – 3 GeV

ρ , ω , ϕ mass, width & cross Section

J/ψ , ψ' , Υ suppression:

Chirality Restoration

Debye Screening

Photons

π , η^0 , η'

continuum direct photons: very soft

Radiation from Hot Gas

Hard Scattering

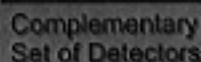
jet + jet

hard photon + jet

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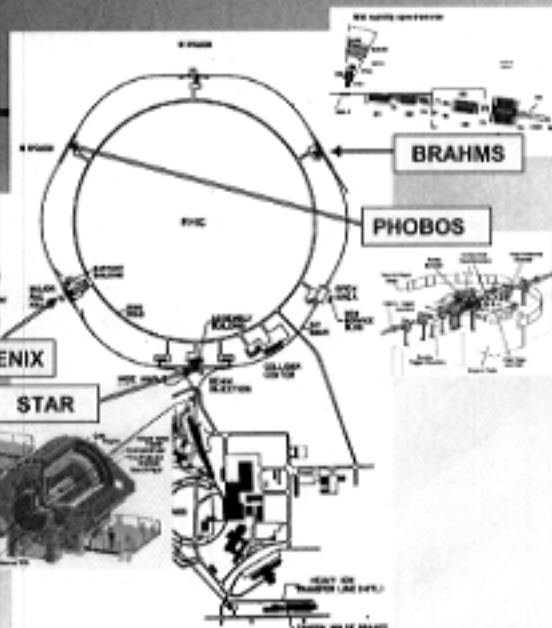
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STAR
PHENIX
PHOBOS
BRAHMS

~900 Participants,
~90 Institutions of
19 Countries Worldwide

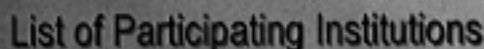
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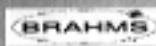
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Country	Company
Canada	Black & Veatch Inc., Toronto
	Laurier-Lussier Inc., Lussier, Quebec
	McLennan Engineering Inc., Toronto
Chile	Chilean National Corporation
Colombia	Colombian National Corporation
Costa Rica	Costa Rican National Corporation
Cuba	Cuba National Corporation
Czech Republic	Czech National Corporation
Dominican Republic	Dominican National Corporation
Ecuador	Ecuador National Corporation
El Salvador	El Salvador National Corporation
France	France National Corporation
Germany	Germany National Corporation
Ghana	Ghana National Corporation
Greece	Greece National Corporation
Haiti	Haiti National Corporation
Honduras	Honduras National Corporation
Hungary	Hungary National Corporation
India	India National Corporation
Indonesia	Indonesia National Corporation
Italy	Italy National Corporation
Jamaica	Jamaica National Corporation
Japan	Japan National Corporation
Korea	Korea National Corporation
Laos	Laos National Corporation
Lebanon	Lebanon National Corporation
Libya	Libya National Corporation
Luxembourg	Luxembourg National Corporation
Mexico	Mexico National Corporation
Morocco	Morocco National Corporation
Netherlands	Netherlands National Corporation
Nicaragua	Nicaragua National Corporation
Norway	Norway National Corporation
Peru	Peru National Corporation
Philippines	Philippines National Corporation
Poland	Poland National Corporation
Portugal	Portugal National Corporation
Romania	Romania National Corporation
Russia	Russia National Corporation
Saudi Arabia	Saudi Arabia National Corporation
Spain	Spain National Corporation
Sweden	Sweden National Corporation
Switzerland	Switzerland National Corporation
Taiwan	Taiwan National Corporation
Tanzania	Tanzania National Corporation
Togo	Togo National Corporation
Turkey	Turkey National Corporation
Uganda	Uganda National Corporation
Ukraine	Ukraine National Corporation
United Kingdom	United Kingdom National Corporation
United States	United States National Corporation
Uruguay	Uruguay National Corporation
Venezuela	Venezuela National Corporation
Zambia	Zambia National Corporation
Zimbabwe	Zimbabwe National Corporation



Source of Data	Study Area
1. U.S. Laboratories	Aluminum, Lead, Mercury Cadmium, Copper, Nickel, Silver Lithium, Sodium, Zinc, Cobalt, Selenium
2. Airborne	Aluminum, Arsenic Barium, Bismuth, Cadmium Chromium, Cobalt, Copper, Lead, Nickel, Silver, Zinc
3. Geological	Aluminum, Barium, Bismuth, Cadmium, Chromium, Cobalt, Copper, Lead, Nickel, Silver, Zinc
4. Soil	Aluminum, Barium, Bismuth, Cadmium, Chromium, Cobalt, Copper, Lead, Nickel, Silver, Zinc
5. Water	Aluminum, Barium, Bismuth, Cadmium, Chromium, Cobalt, Copper, Lead, Nickel, Silver, Zinc
6. Food	Aluminum, Barium, Bismuth, Cadmium, Chromium, Cobalt, Copper, Lead, Nickel, Silver, Zinc
7. Plants	Aluminum, Barium, Bismuth, Cadmium, Chromium, Cobalt, Copper, Lead, Nickel, Silver, Zinc
8. Animals	Aluminum, Barium, Bismuth, Cadmium, Chromium, Cobalt, Copper, Lead, Nickel, Silver, Zinc
9. Humans	Aluminum, Barium, Bismuth, Cadmium, Chromium, Cobalt, Copper, Lead, Nickel, Silver, Zinc
10. Other	Aluminum, Barium, Bismuth, Cadmium, Chromium, Cobalt, Copper, Lead, Nickel, Silver, Zinc



State/Region	Institution
Alabama	Alabama State University
Alaska	University of Alaska
Arizona	Arizona State University
Arkansas	Arkansas State University
California	University of California
Colorado	University of Colorado
Connecticut	University of Connecticut
Delaware	University of Delaware
District of Columbia	Georgetown University
Florida	University of Florida
Georgia	Georgia Institute of Technology
Hawaii	University of Hawaii
Idaho	University of Idaho
Illinois	University of Illinois
Indiana	University of Indiana
Iowa	University of Iowa
Kansas	University of Kansas
Kentucky	University of Kentucky
Louisiana	University of Louisiana
Maine	University of Maine
Maryland	University of Maryland
Massachusetts	University of Massachusetts
Michigan	University of Michigan
Minnesota	University of Minnesota
Mississippi	University of Mississippi
Missouri	University of Missouri
Montana	University of Montana
Nebraska	University of Nebraska
Nevada	University of Nevada
New Hampshire	University of New Hampshire
New Jersey	University of New Jersey
New Mexico	University of New Mexico
New York	University of New York
North Carolina	University of North Carolina
North Dakota	University of North Dakota
Ohio	University of Ohio
Oklahoma	University of Oklahoma
Oregon	University of Oregon
Pennsylvania	University of Pennsylvania
Rhode Island	University of Rhode Island
South Carolina	University of South Carolina
South Dakota	University of South Dakota
Tennessee	University of Tennessee
Texas	University of Texas
Utah	University of Utah
Vermont	University of Vermont
Virginia	University of Virginia
Washington	University of Washington
West Virginia	University of West Virginia
Wisconsin	University of Wisconsin
Wyoming	University of Wyoming

PHSEOS

State/Location	Institutions
Alabama	Alabama State University
Alaska	University of Alaska, Fairbanks
Arizona	Arizona State University
Arkansas	Arkansas State University
California	California State University, Long Beach
Colorado	University of Colorado, Boulder
Connecticut	University of Connecticut
Delaware	University of Delaware
District of Columbia	Georgetown University
Florida	University of Florida
Georgia	Georgia Institute of Technology
Hawaii	University of Hawaii
Idaho	University of Idaho
Illinois	University of Illinois, Urbana-Champaign
Indiana	Indiana University, Bloomington
Iowa	University of Iowa
Kansas	University of Kansas
Kentucky	University of Kentucky
Louisiana	Louisiana State University
Maine	University of Maine
Maryland	University of Maryland, College Park
Massachusetts	University of Massachusetts, Amherst
Michigan	University of Michigan, Ann Arbor
Minnesota	University of Minnesota, Minneapolis
Mississippi	University of Mississippi
Missouri	University of Missouri, Columbia
Montana	University of Montana
Nebraska	University of Nebraska, Lincoln
Nevada	University of Nevada, Reno
New Hampshire	University of New Hampshire
New Jersey	Rutgers University, Newark
New Mexico	University of New Mexico, Albuquerque
New York	Columbia University, New York City
North Carolina	University of North Carolina, Chapel Hill
North Dakota	University of North Dakota
Ohio	University of Ohio, Columbus
Oklahoma	University of Oklahoma
Oregon	University of Oregon
Pennsylvania	University of Pennsylvania
Rhode Island	University of Rhode Island
South Carolina	University of South Carolina, Columbia
South Dakota	University of South Dakota
Tennessee	University of Tennessee, Knoxville
Texas	University of Texas, Austin
Vermont	University of Vermont
Virginia	University of Virginia, Charlottesville
Washington	University of Washington, Seattle
West Virginia	University of West Virginia
Wisconsin	University of Wisconsin, Madison
Wyoming	University of Wyoming

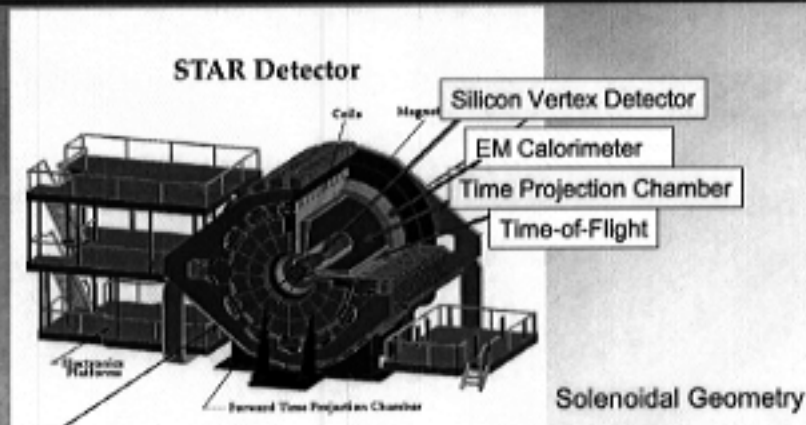
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STAR Detector



Large Solid Angle Tracking with Cylindrical TPC
 Particle Identification by dE/dX Sampling
 Event-by-event Recording of Hadrons and Jets

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STAR Detector in the Assembly Hall

Solenoid
 Magnet

TPC
 Being Readied
 for Installation



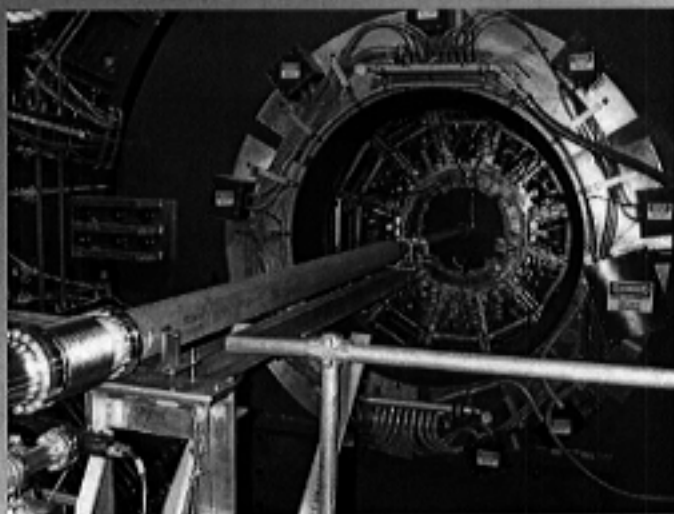
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STAR Detector at the Collision Point



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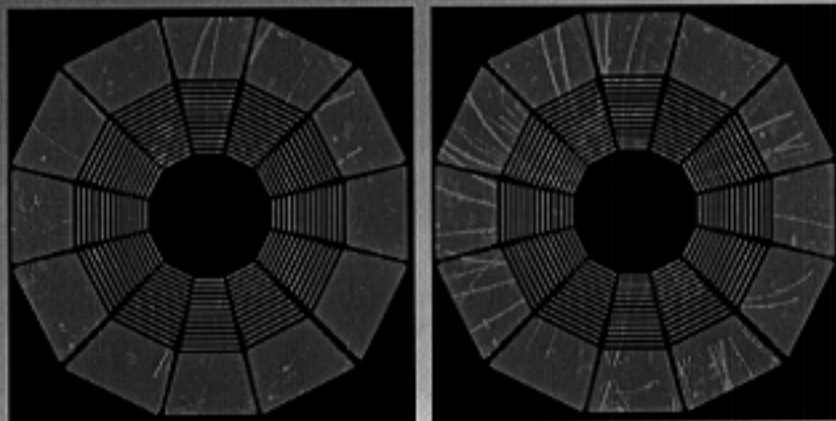
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STAR Beam - Gas Events (?)

July 27, 1999



B field = 0.25 Tesla

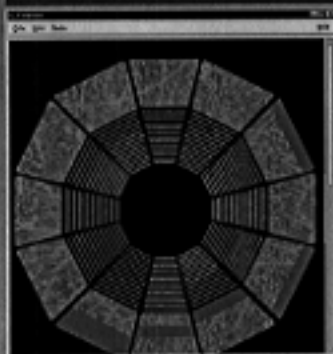
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STAR Beam - Gas Event (?)



Clusters, Space-points, and tracks reconstructed with offline Software

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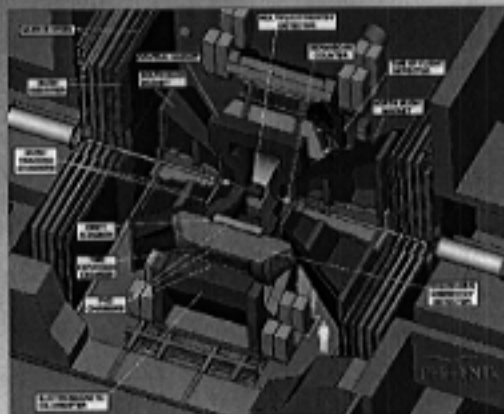
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PHENIX Layout

- Axial Field Geometry
- High Rate Capability
- Two Central Arms
Layers of Various Detectors for Tracking and Particle ID
- Leptons/Photons/Hadrons in Selected Solid Angles
 $|Y| \leq 1, 2 \times (\Delta\phi = 90^\circ)$
(Lepton Pairs)
- North and South Muon Arms
- Signatures of Phase Transition in Many Different Observables



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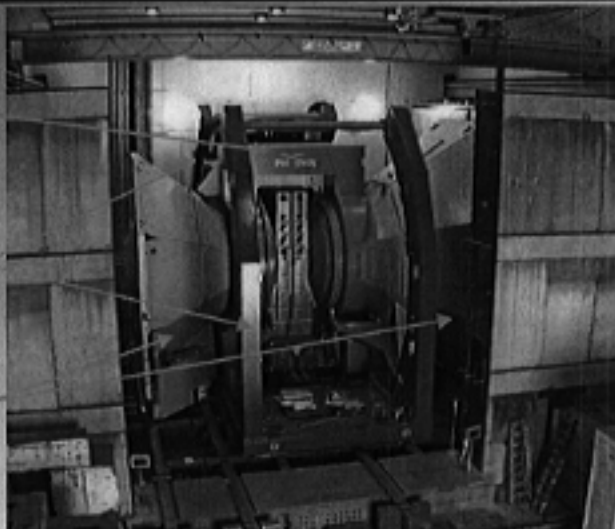


PHENIX Detector at the Collision Point

Central Spectrometer
Magnet

East and West
Detector Carriage

North and South
Muon Spectrometer



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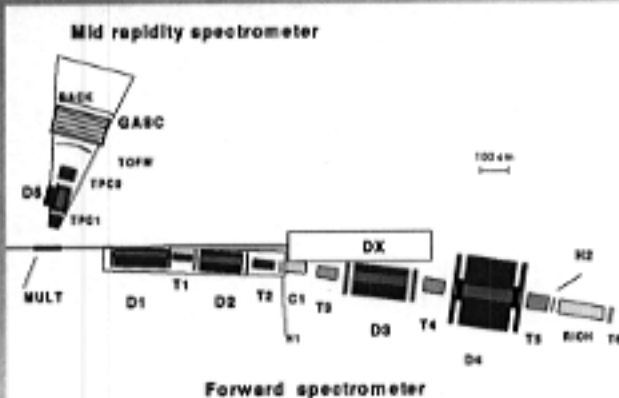
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BRAHMS Detector

Two-Arm, Small
Acceptance
Spectrometer with
Variable Setting and
Good Particle ID

Inclusive Particle
Production over Full
Rapidity Ranges



Significant Participation of Niels Bohr Institute and Other European
Groups

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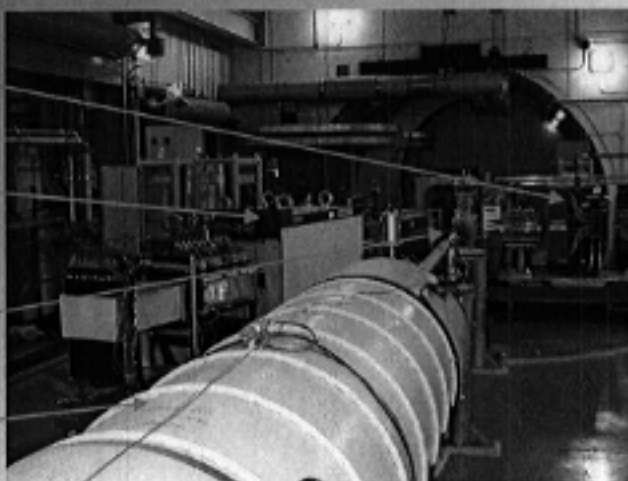
BRAHMS Detector at 2 O'Clock Hall

Mid-Rapidity
Spectrometer

Forward
Spectrometer

Multiplicity Array

DX Magnet



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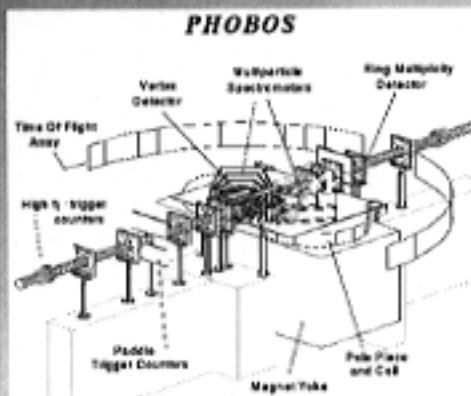
PHOBOS Detector

Two-arm Spectrometer

Exclusive Use of High
Resolution Silicon Detector

→ "Table Top"

Charged Hadrons and
Leptons in Selected Solid
Angle with Very High Event
Rate



Significant Participation of Groups from Poland

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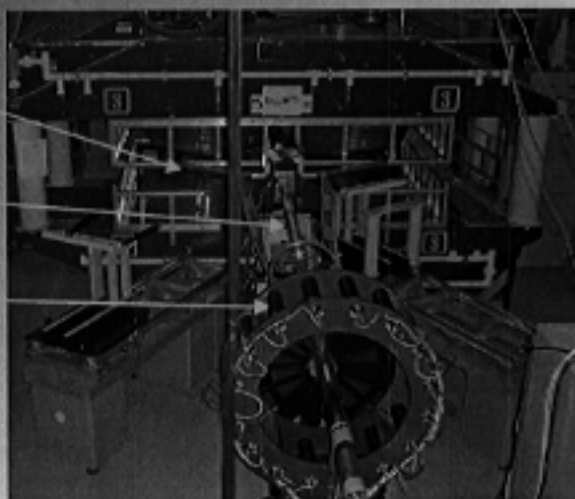


PHOBOS Detector at the Collision Point

Twin Pole D-Magnet
for Si μ -strip
Spectrometer

Beam Pipe

Si Multiplicity Detector



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RHIC Computing Facility

	CPU	Storage
July 1999	8,800 SPECint95	11.5 TBytes
FY2000 Goal	18,000 SPECint95	40.0 Tbytes
	1 SPECint95 ~ 13.3 MFLOPS	

Robotic Tape System (Silo)
(300 Tbytes: 180 Mbytes/sec)



RCF Intel Linux Processor Farm
7000 SPECint95: 440 Intel CPU

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Summary and Conclusions

- RHIC is Now in Commissioning Phase
- The "Beam Test" Indicates that the Collider is Fundamentally Sound in its Design and Construction
- STAR, PHENIX, PHOBOS and BRAHMS made good progress in the Detector Construction, and Participated in the "Beam Test" Using Part of Their Detectors.
- The RHIC Enjoys Strong and Very Significant International Collaborations in its Program
- The First Year of Physics Program is to Start Soon with Au-Au Collision Program
- Collisions of Polarized Protons is planned for FY2001, with Accelerator Study beginning in FY2000

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