Experimental Relativistic Heavy Ion Physics at BNL-RHIC

with a focus on PHENIX Experiment

Kenta Shigaki (KEK)

at

JPS Symposium “QCD Physics at RBRC”

in

Matsue, Shimane, Japan

on

September 23, 1999

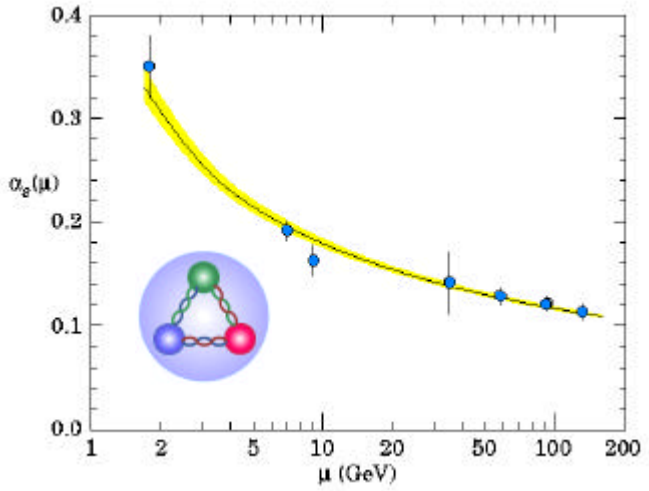
Presentation Outline

- Relativistic Heavy Ion Physics at RHIC
- RHIC Accelerator
- RHIC Experiments
- Physics Strategies of PHENIX Experiment
- Upcoming Physics from PHENIX
- Electron Measurement in PHENIX
- Summary

Physics at RHIC

- QCD in extreme conditions and scales
  - high energy density limit (relativistic heavy ion physics)
  - high Q^2 limit (high energy spin physics)

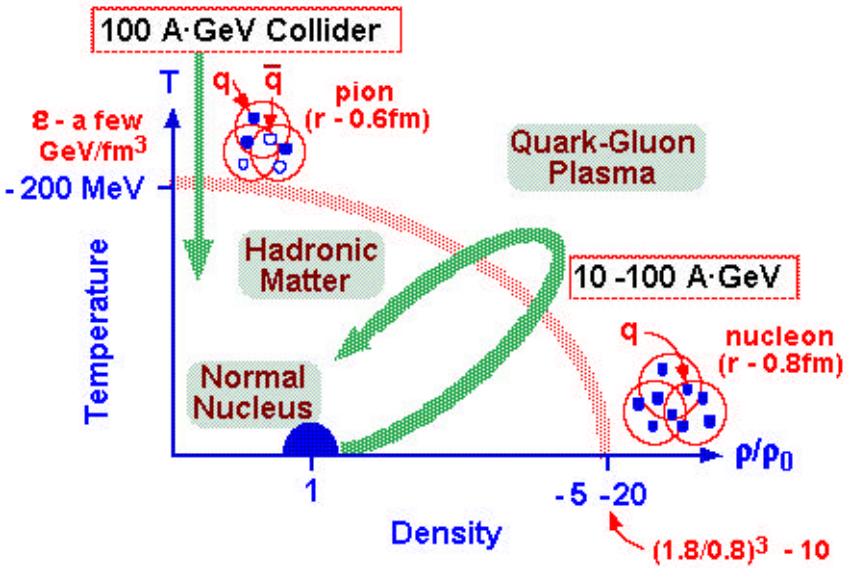
- relativistic heavy ion physics
  - search for and characterize deconfined quark gluon plasma phase
- high energy spin physics
  - elucidate spin structure of nucleon
  - talk by M.Grosse-Perdekamp

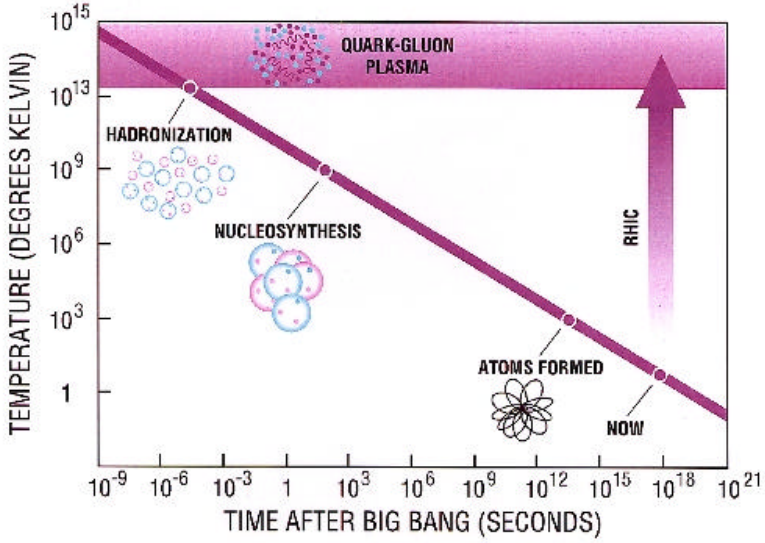


asymptotic freedom at short range / high energy

Relativistic Heavy Ion Physics at RHIC

- Bevalac/SIS/AGS/SPS
  - from high density regime to high energy density (*temperature*) regime
- RHIC
  - reproduction of universe a few μsec after big-bang



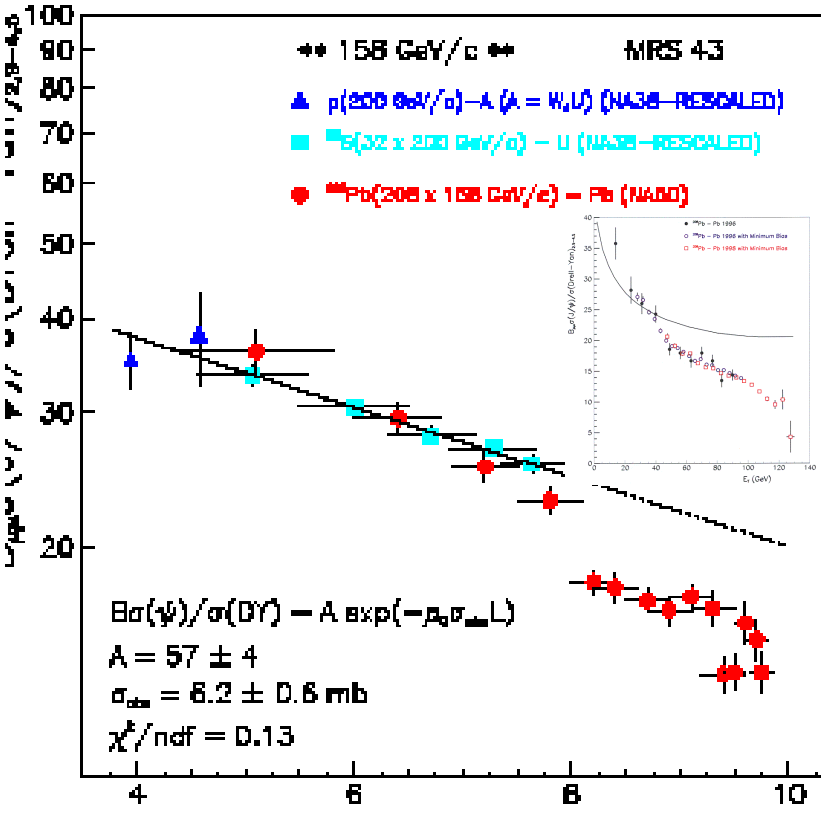


Recent Hot Topics from SPS and AGS

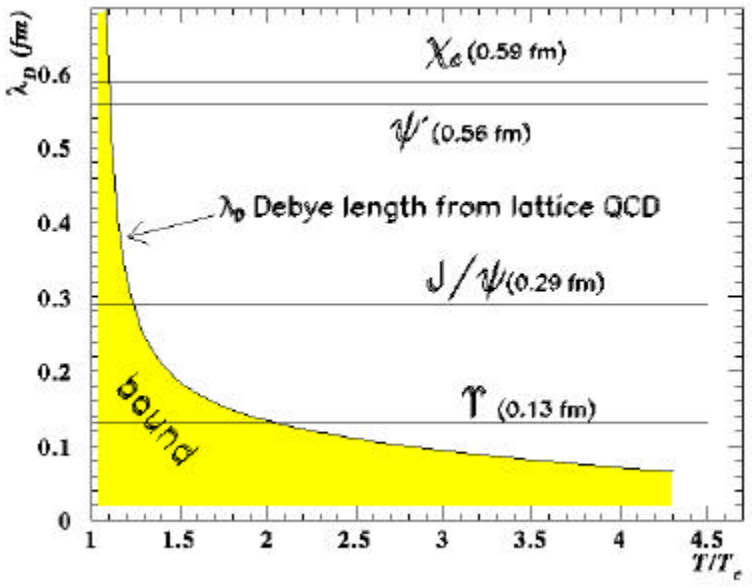
- J/Ψ “anomalous” suppression
  - SPS NA50
- low-mass dielectron enhancement
  - SPS NA45 (CERES)
- flavor equilibrium
  - AGS E866, E877
  - SPS NA49, WA97
- collective radial/directed/elliptic flow
  - AGS E866, E877, E895, E917
  - SPS NA45, NA49, NA52, WA98
- onsets of QCD phase transition ?

J/Ψ "Anomalous" Suppression

- observed in central Pb+Pb collisions by SPS NA50
  - predicted by T.Matsui and H.Satz

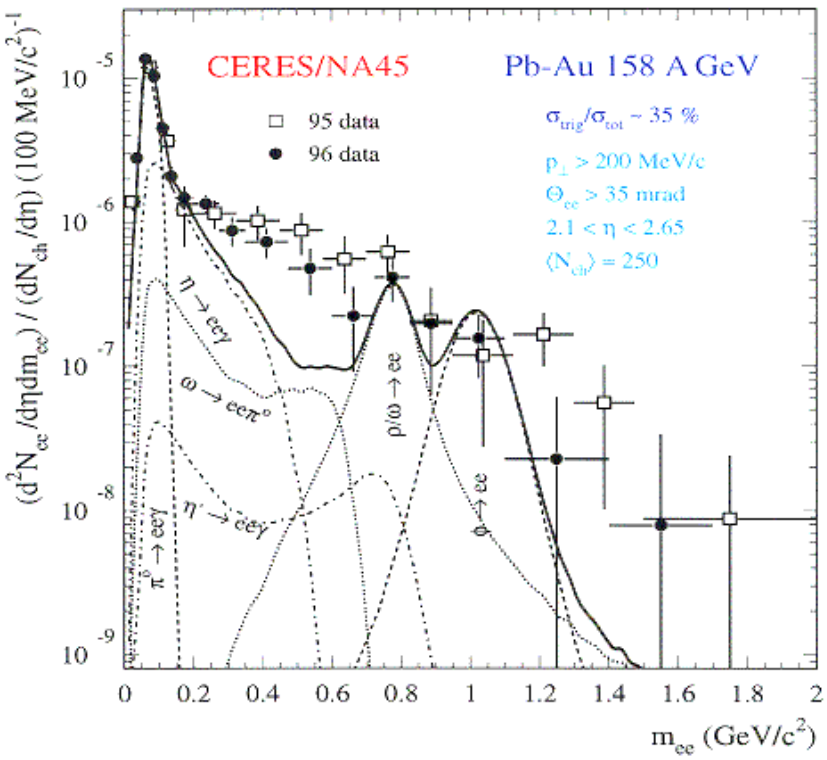


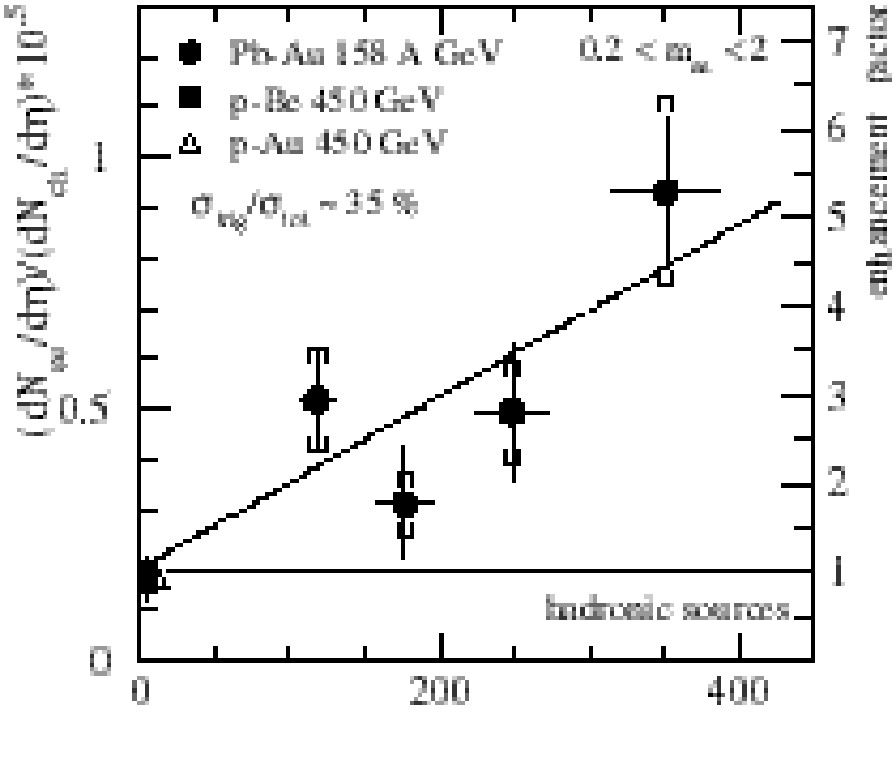
Debye screening ?



Low-Mass Dielectron Enhancement

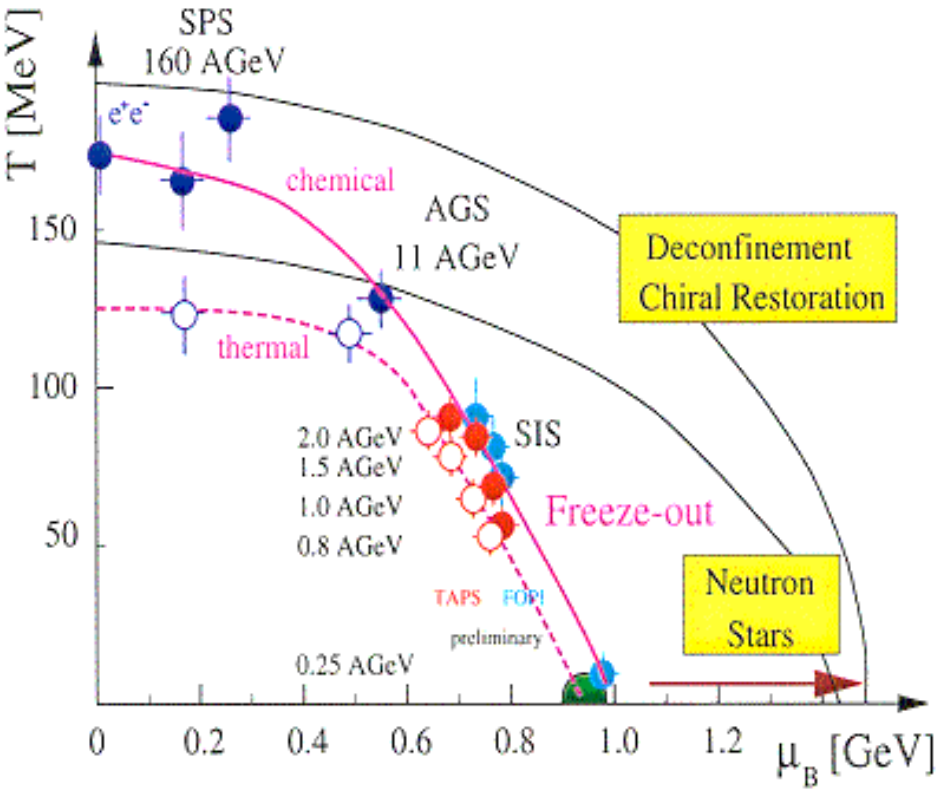
- excess over known hadronic sources observed in S+Au and Pb+Au collisions by SPS NA45
- theoretical approaches *e.g.* ρ enhancement/melting





Flavor Equilibrium

- phase diagram of hadronic matter based on hadro-chemical analysis
  - P.Braun-Munzinger, J.Stachel *et al.*

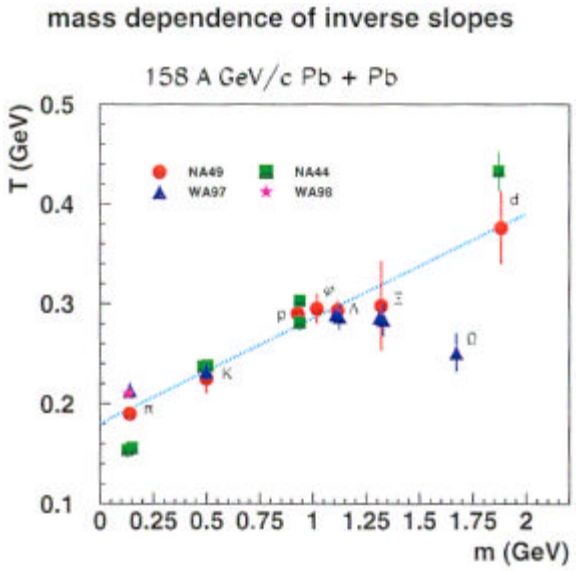


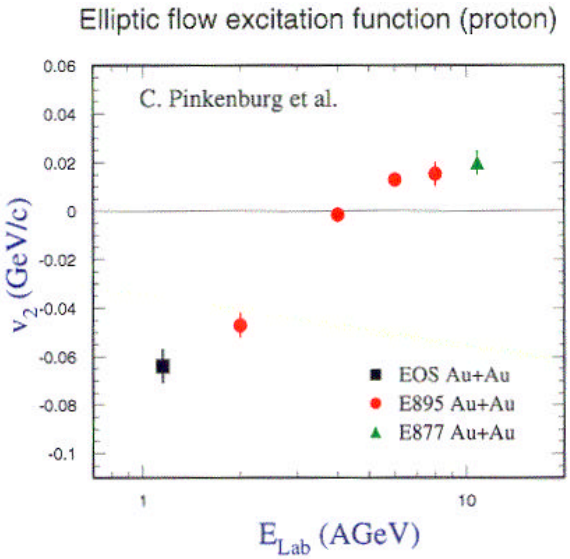
– hadro-chemical freeze-out points approach phase boundary at AGS and SPS

– RHIC and LHC expected to show clearer signal of QCD phase transition

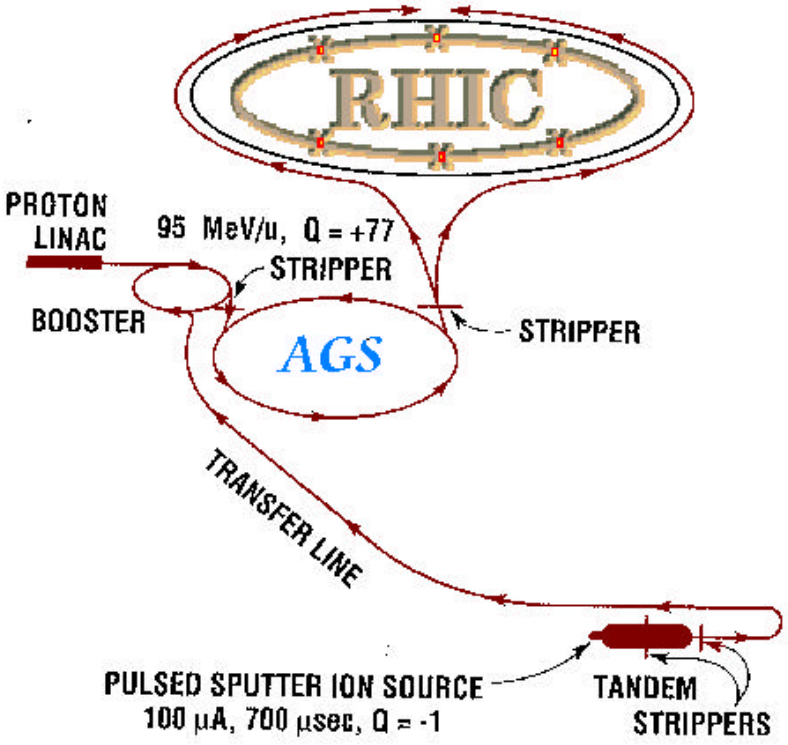
Collective Radial/Directed/Elliptic Flow

- radially flowing thermal source explains mass dependence of *temperature* parameters
  - theory by U.Heinz *et al.* ; phenomenology by N.Xu *et al.*
- directed/elliptic flow as an excitation function
  - information on shadowing, equation of state





RHIC (Relativistic Heavy Ion Collider) Accelerator

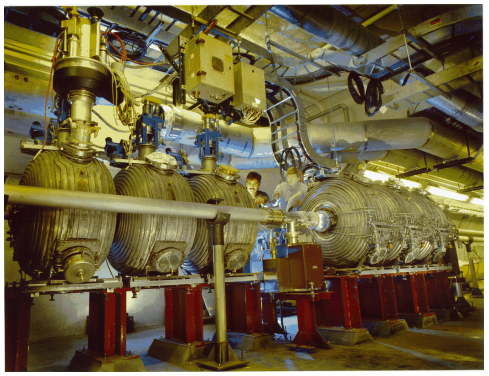


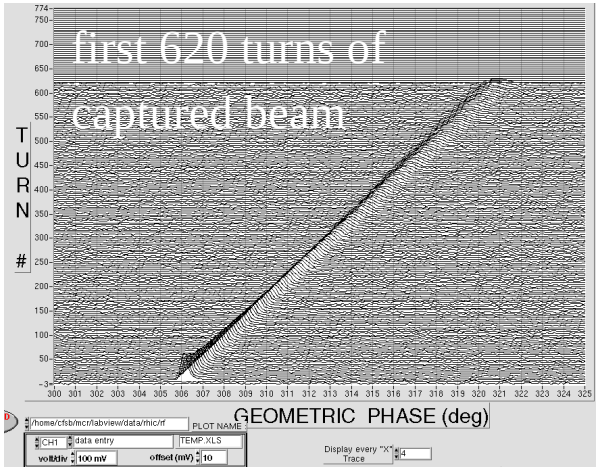
Configuration	Two Concentric Superconducting Magnet Rings	
Circumference	3.8 km	
Interaction Point	6	
Number of Bunch	60; 120 in enhanced mode	
Ion Species	ranges from p to Gold, p+A is possible	
	pp	Au+Au
Injection	Linac →Booster → AGS	Van de Graaf →Booster → AGS
E_{cm} (Maximum)	500 GeV	200A GeV
Luminosity	2×10^{32} cm^{-2}sec^{-1}	2×10^{26} cm^{-2}sec^{-1}
Polarization	70%	—
Completion	Expected in June 1999	

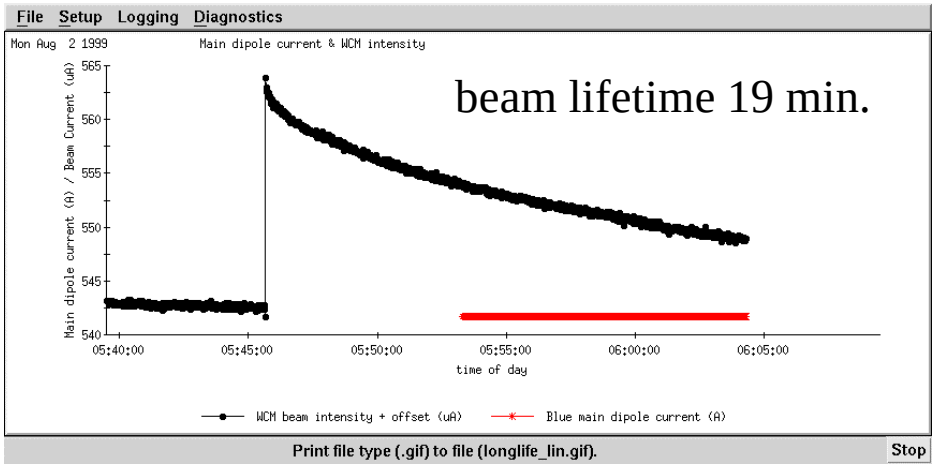
- ultimate tool with:
  - 2 superconducting rings
  - 3.8 km circumference
  - 6 intersecting locations
  - AGS complex as injector
- heavy ion collider
  - up to Au+Au at 200 A GeV
    - current max.: 18 A GeV (SPS)
  - capable of p+p, p+A, A+B
- polarized proton collider
  - up to 500 GeV
    - current max.: 20 GeV (FNAL)
    - RIKEN - BNL collaboration

Status of RHIC Accelerator

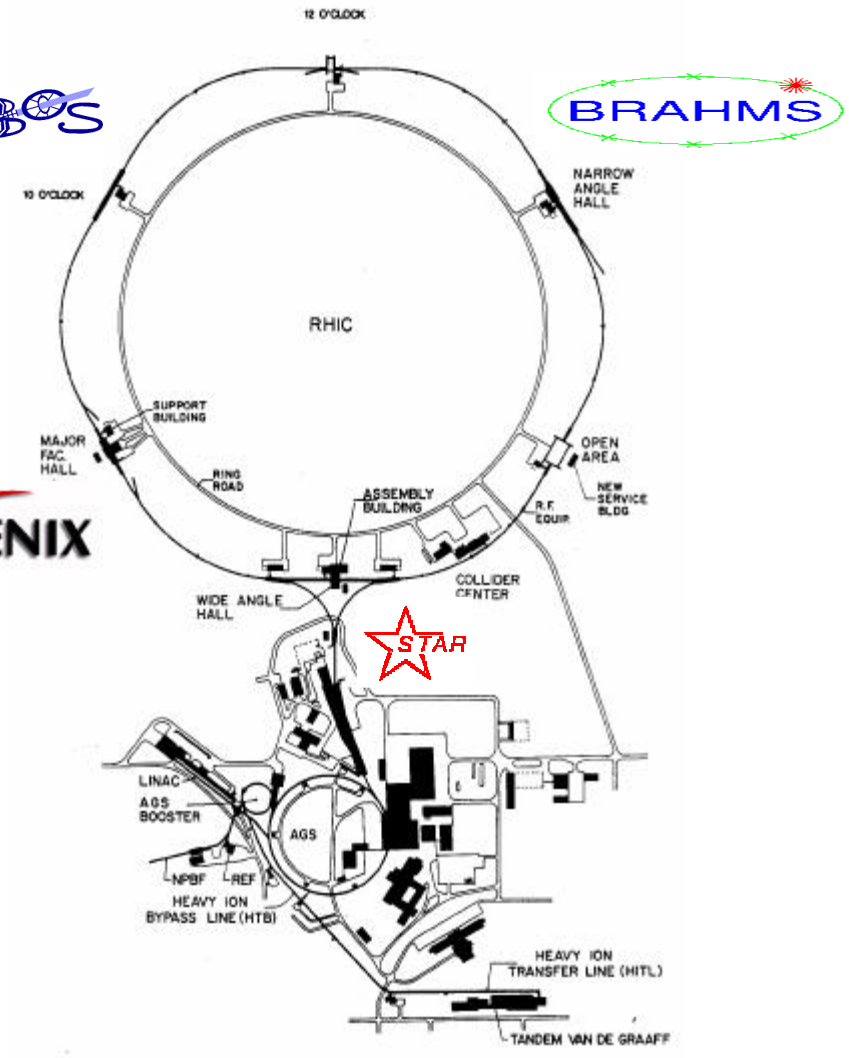
- construction phase finished in August, 1999
- physics run starting in January, 2000







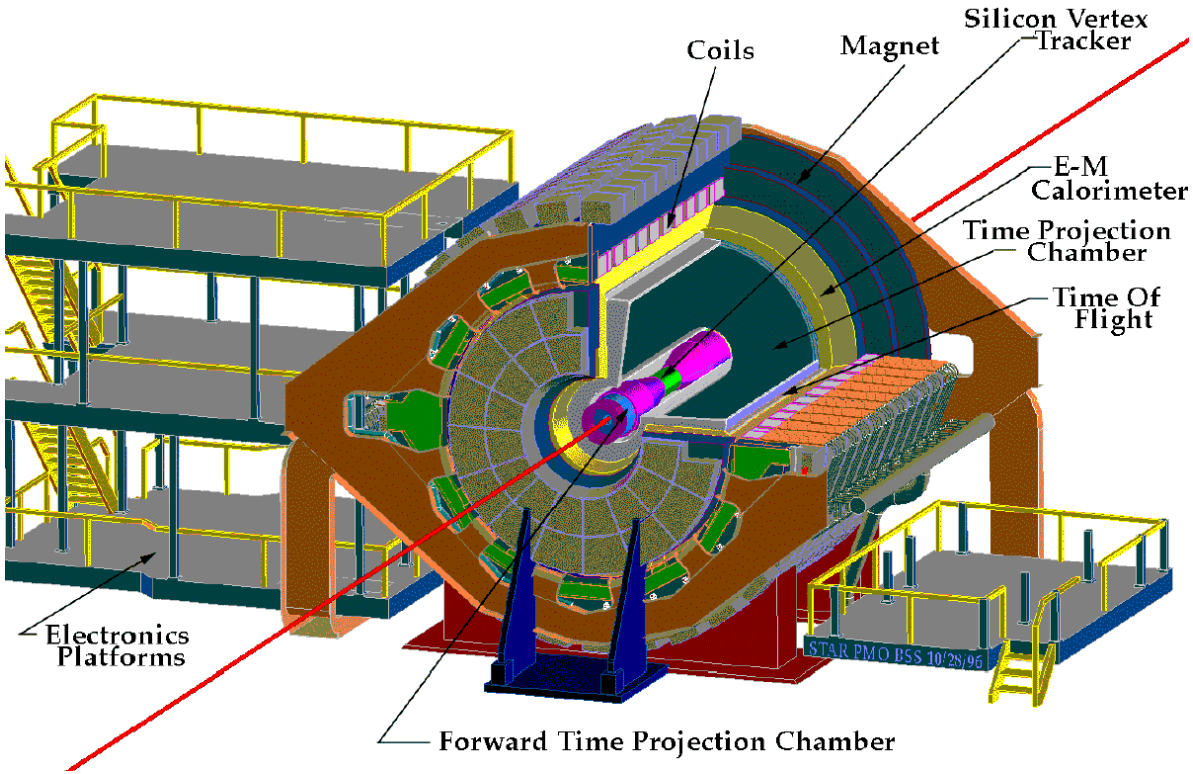
RHIC Experiments



- complimentary set of experiments
- 2 large experiments
  - STAR at 6 o'clock
  - PHENIX at 8 o'clock
- 2 small experiments
  - BRAHMS at 2 o'clock
  - PHOBOS at 10 o'clock
- 2 open collision points for future experiments

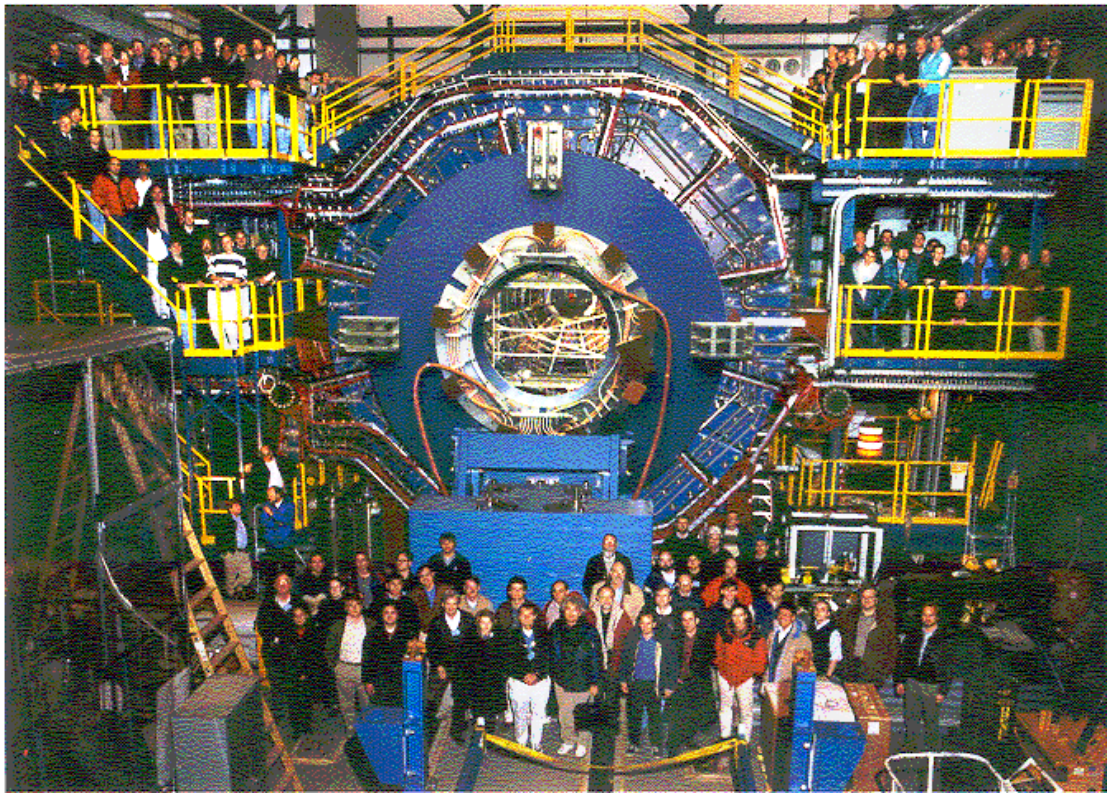
STAR (Solenoidal Tracker at RHIC) Experiment

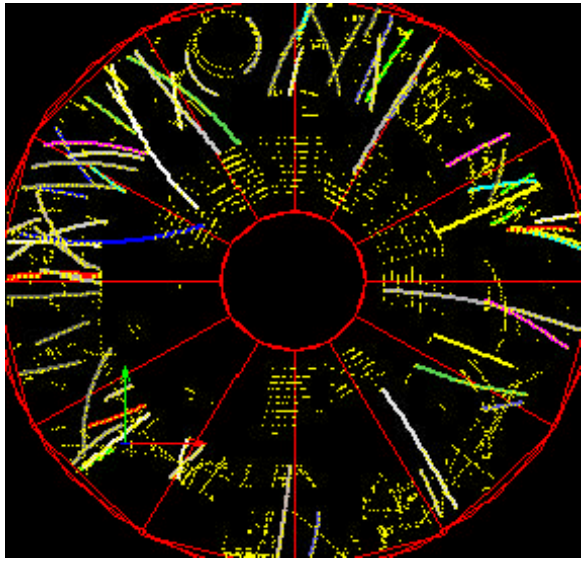
- ~ 440 collaborators, 36 institutions, 7 countries
- large TPC-based detector system
  - event-by-event recording of hadrons and jets



Status of STAR Experiment

- baseline construction completed in June, 1999

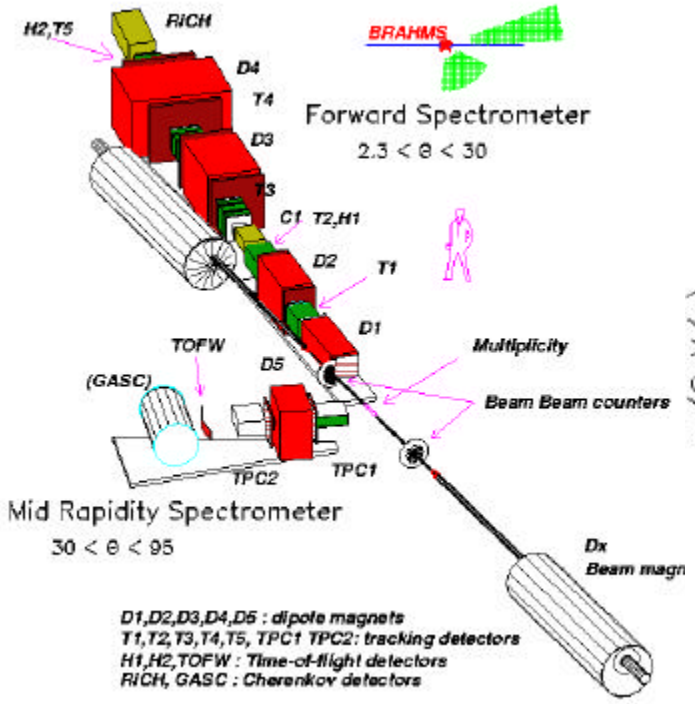


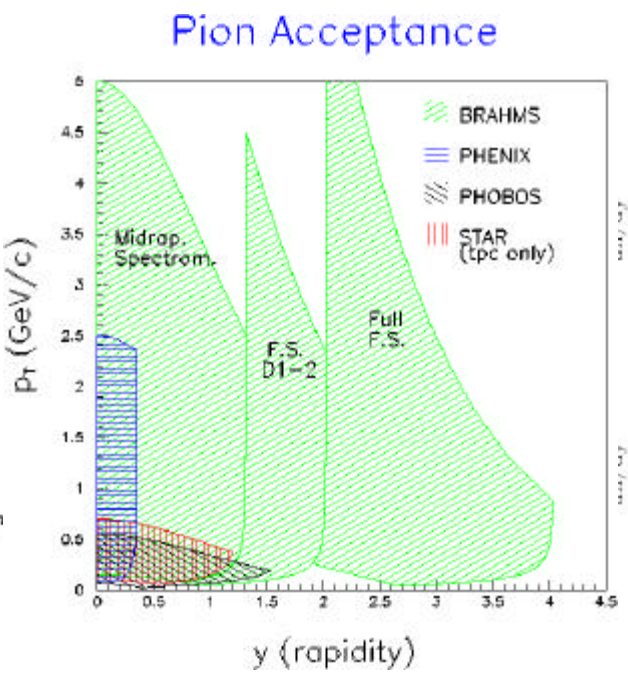


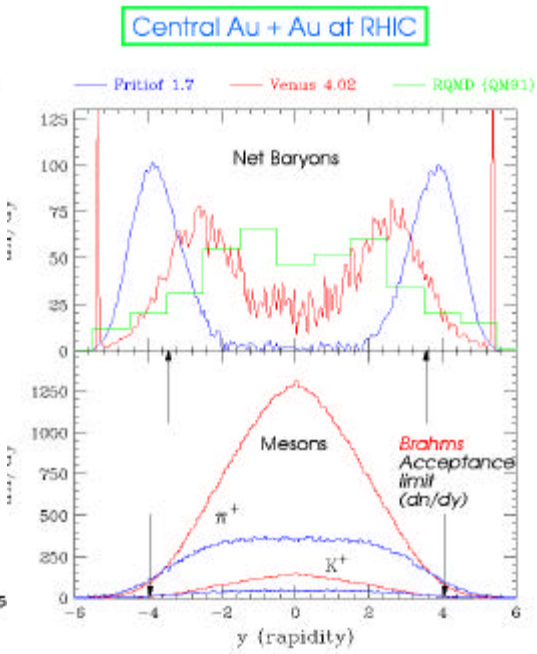
beam-gas interaction event

BRAHMS (Broad Range Hadron Mag. Spec.) Exp.

- ~ 50 collaborators, 12 institutions, 6 countries
- identified charged hadrons over wide kinematics
  - focus on reaction dynamics

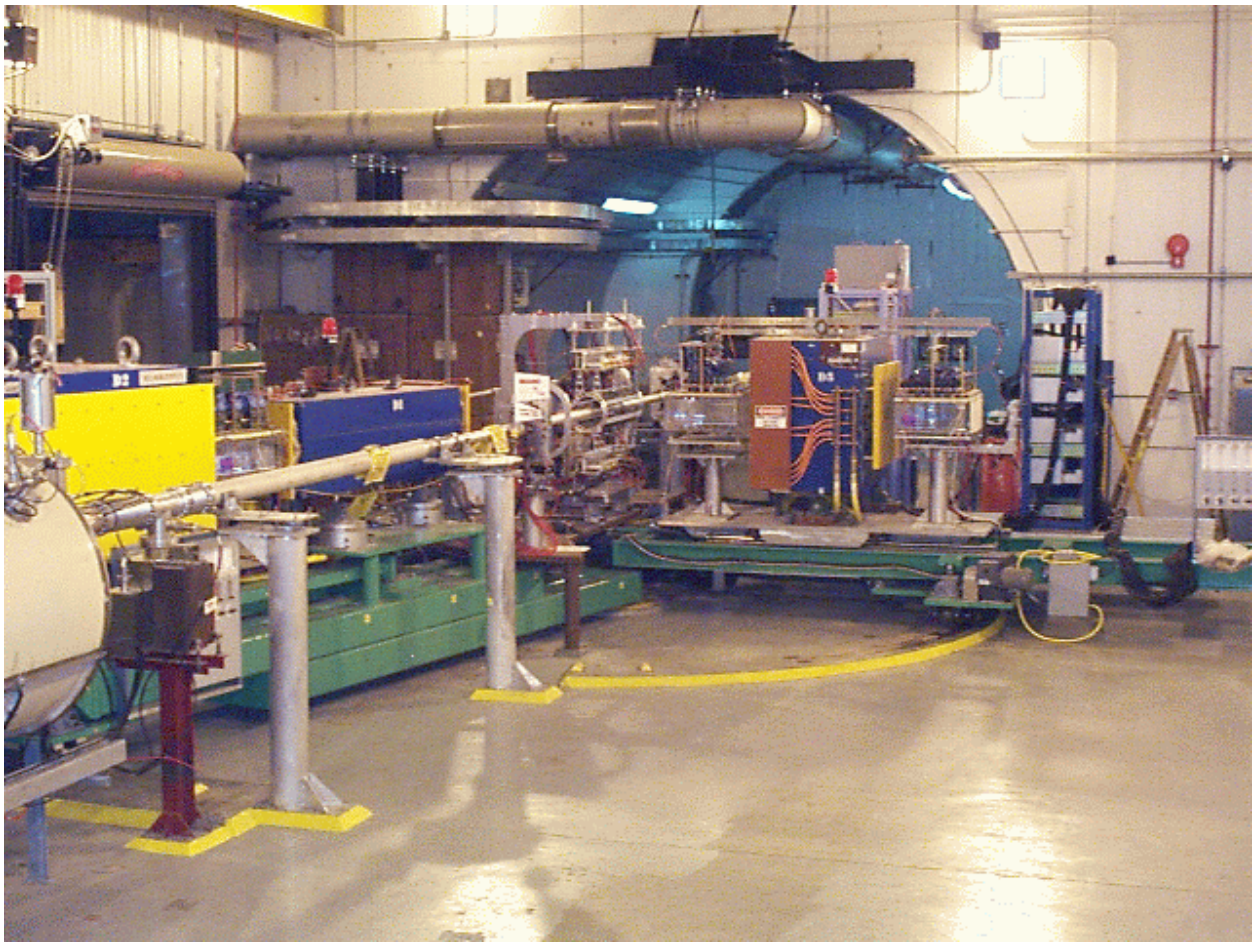






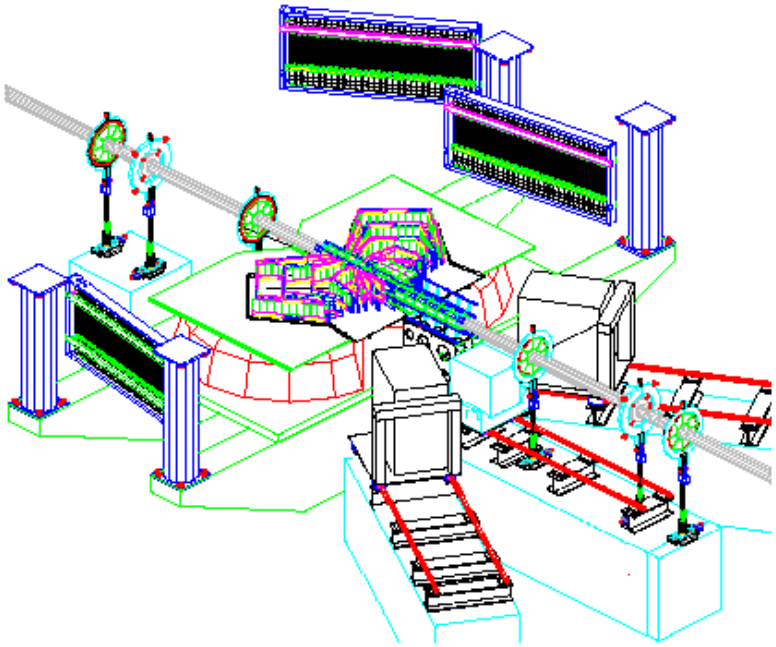
Status of BRAHMS Experiment

- baseline components ready on both arms



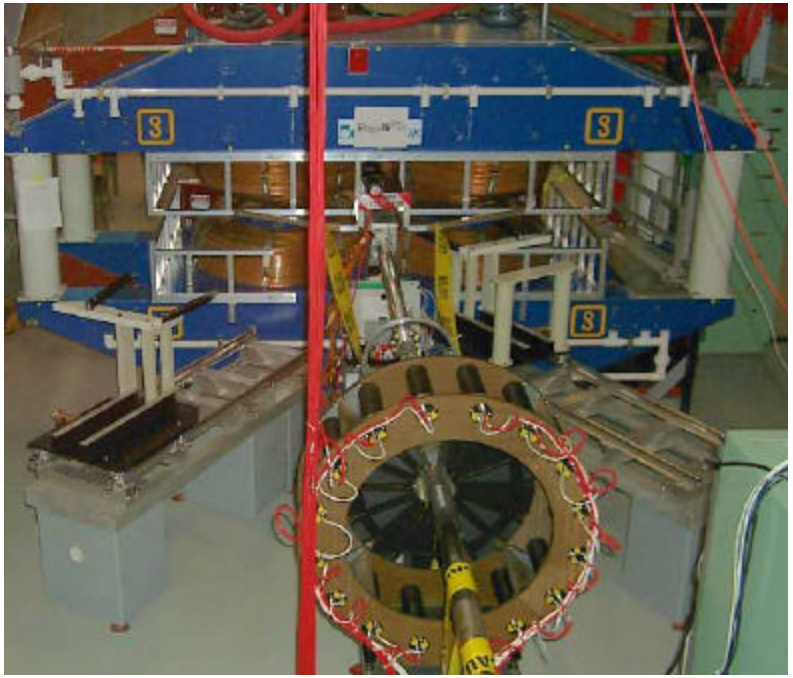
PHOBOS Experiment

- ~ 80 collaborators, 9 institutions, 3 countries
- 10K element 4π detector for $d^2N/d\eta d\phi$
- two-arm small silicon pad spectrometer
- high rate capability, minimum bias events to tape



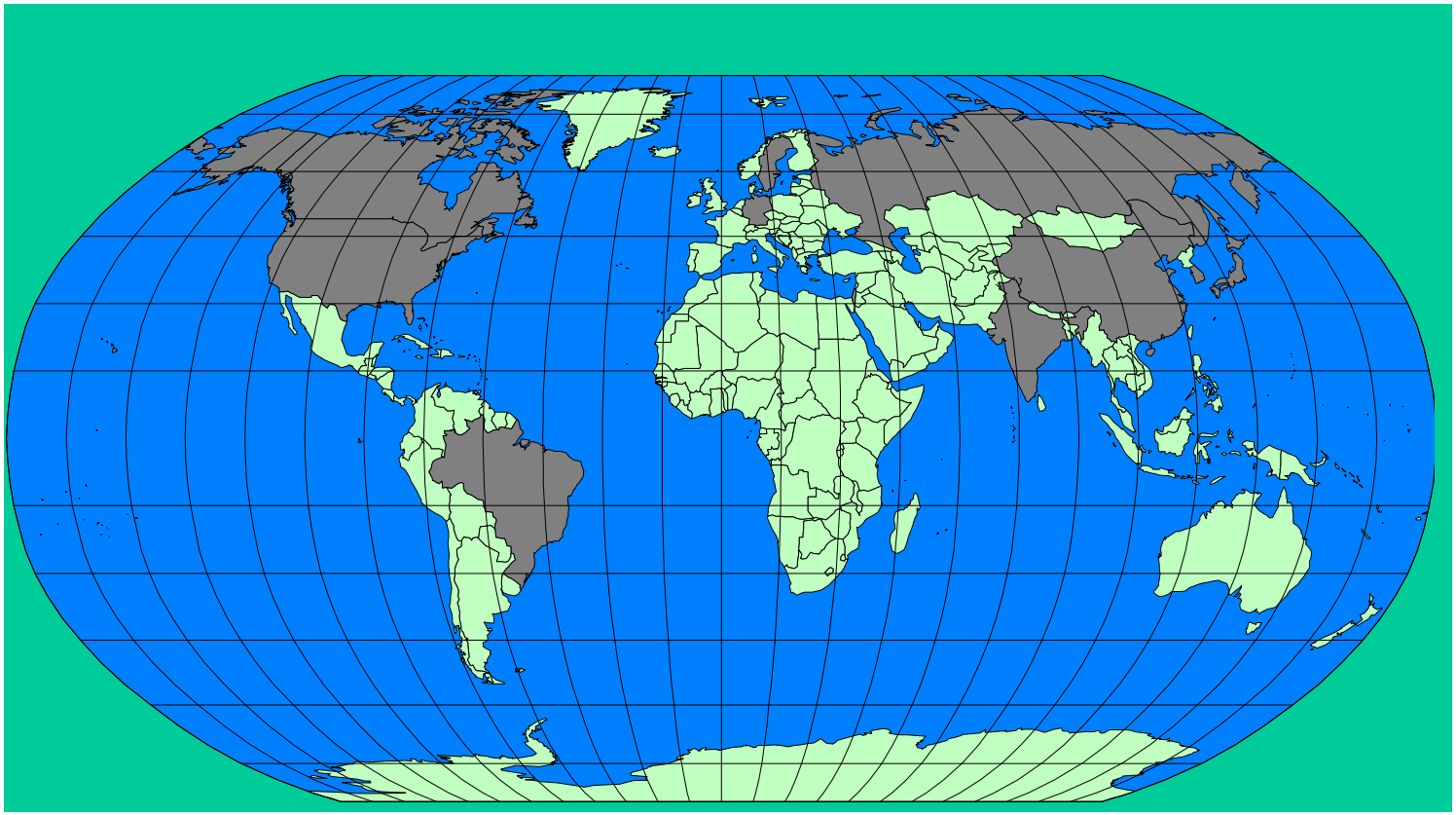
Status of PHOBOS Experiment

- all silicon detectors assembled and tested
  - multiplicity and vertex detectors
  - one spectrometer arm



PHENIX (Pioneering High Energy Nucl. Ion Exp.) Exp.

- ~ 430 collaborators, 42 institutions, 11 countries
  - wide collaboration for wide physics

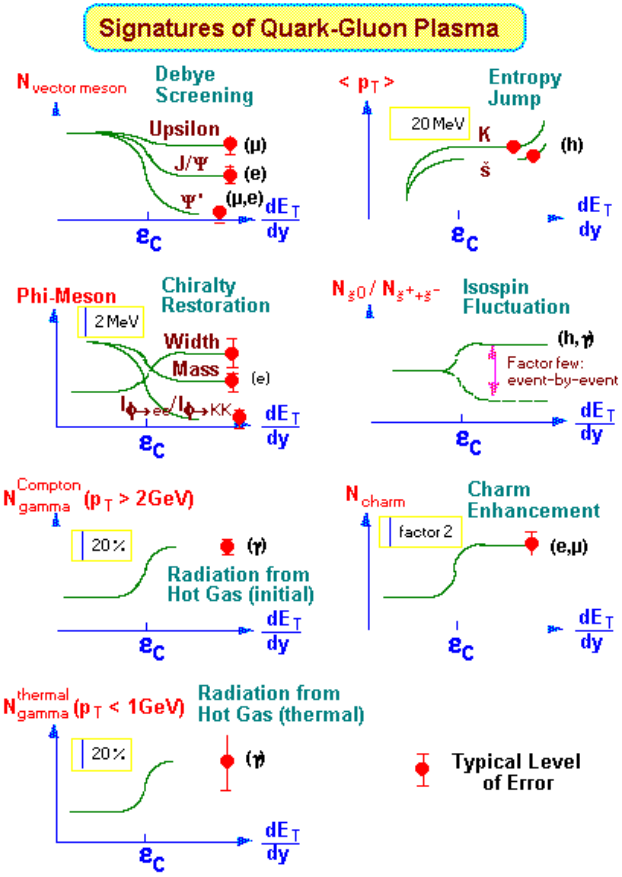


Physics Strategies of PHENIX

- wide variety of probes with same systematics

  sensitivity to many signatures and essentially all time-scales

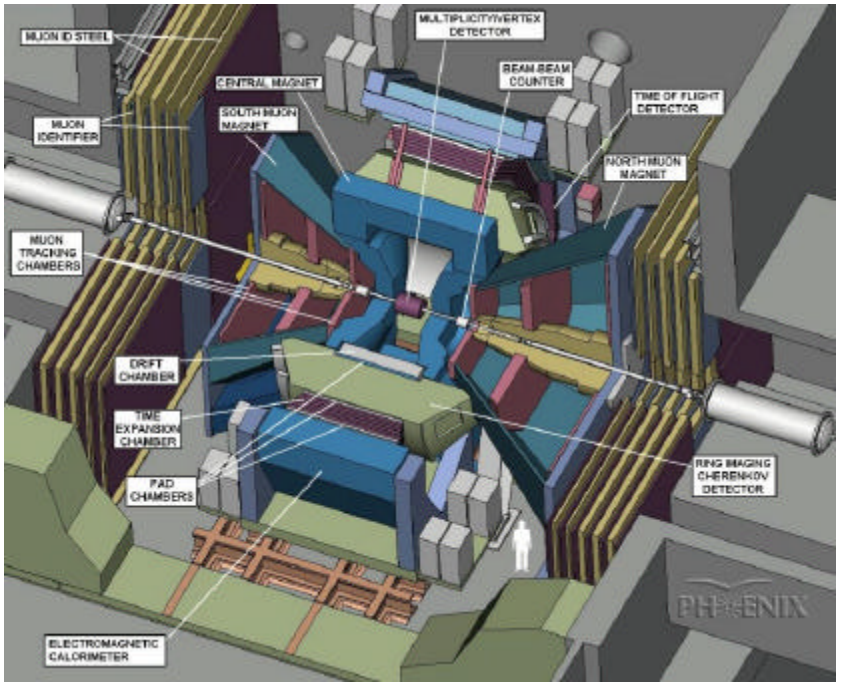
  - color Debye screening
  - chiral symmetry restoration
    - change of vector meson properties
    - disoriented chiral condensation
  - thermal radiation of hot gas
  - heavy quark (s, c) production
  - jet quenching



- emphasis on transparent probes
  - photon and vector meson via γ, γ^*, l^+l^-

PHENIX Detector System

- 2 central arms for photon, electron, hadron
  - tracking chambers
  - RICH, ToF, EMCal
- 2 forward arms for muon
  - tracking chambers
  - muon identifier
- global detectors for event characterization
  - beam/beam counter
  - multiplicity/vertex detector



Japanese Contributions to PHENIX (1)

- beam/beam counter
  - Hiroshima U.
- ring imaging Cherenkov detector
  - CNS, U.Tokyo, KEK, Waseda U., Nagasaki IAS
  - talks by K.Oyama, T.Sakaguchi (25, a.m., SB)
  - symposium talk by Y.Akiba (25, p.m., SA)
- time of flight counter
  - U.Tsukuba
- south muon spectrometer
  - RIKEN, Kyoto U., TIT
  - talk by H.D.Sato (25, p.m., SC)

Japanese Contributions to PHENIX (2)

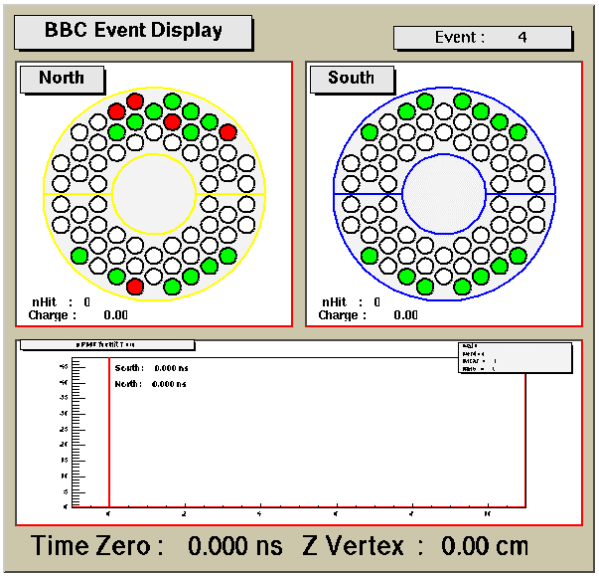
- central magnet coil, drift chamber readout chip
  - KEK
- regional computing center in Japan
  - RBRC, RIKEN, CNS, Kyoto U., KEK, etc.
  - talks by N.Hayashi, S.Sawada (25, p.m., SC)

- other hardware/software activities
  - talk by H.Torii (25, a.m., SB) on EMCal beam test
- RHIC (not only PHENIX) polarimeter
  - RBRC, RIKEN, Kyoto U.
  - talk by J.Tojo (25, p.m., SC)

PHENIX J Members at BNL

Status of PHENIX Experiment (1)

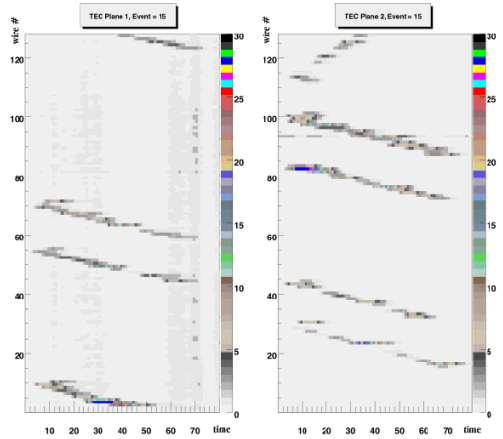
- west central arm
  - loaded with DC, PC, RICH, EMCal
  - tested with beam in June-August, 1999



beam/gas interaction event
in beam/beam counter

Status of PHENIX Experiment (2)

- east central arm
  - being assembled for installation in March, 2000
  - will have DC, PC, RICH, TEC, ToF, EMCal
- south/north muon arms
  - identifiers installed
  - trackers in year 2/3



beam/gas interaction event
in two planes of TEC

Chronological Strategies of PHENIX

- priorities in year 1 (2000) in descending order
  - first physics from Au+Au at 200 A GeV
    - > 120 M unbiased events (> 20 μb^{-1} integrated luminosity)
  - polarized proton commissioning in one ring
    - ~ 4 weeks
  - p+p running to characterize baseline physics
- year 2

  greater sensitivity to rare probes in Au+Au

  first results on spin physics

  year 3 and later

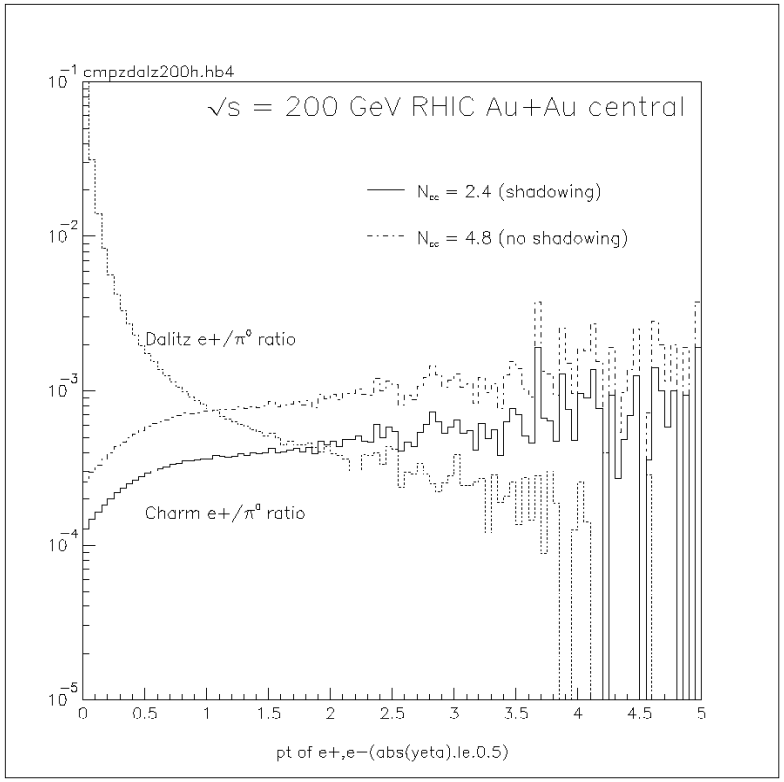
  continuing program of heavy ion and spin discoveries

Upcoming Physics from PHENIX

- physics and time scales accessible in year 1
  - initial hard process
    - jet, hard photon
  - deconfinement
    - high-mass vector meson J/Ψ, Ψ'
    - high p_t photon from π^0, η, η'
  - chiral restoration
    - low-mass vector meson ρ, ω, ϕ
  - thermalization
    - soft photon, non-resonant dielectron
    - open charm via single electron
  - hadronization
    - hadron spectra, strangeness, HBT interferometry
  - hydro-dynamics
    - transverse energy, dN/dy

Electron Measurement in PHENIX

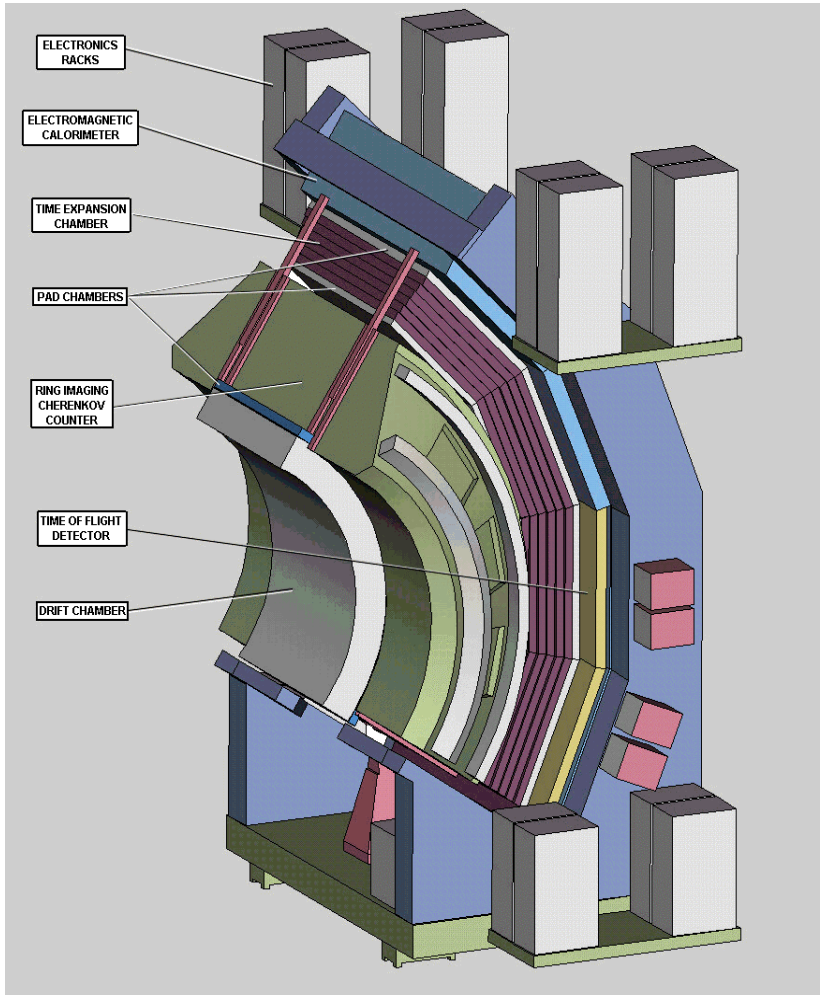
- probes of particular importance
  - dielectron spectra
  - single electron spectra
- *background* sources
  - Dalitz decay
  - heavy quarks
  - photon conversion
  - hadron mis-identification
- requirements for eID
  - roughly $10^2 \sim 10^4$
    - physics goal dependent
    - p_t dependent



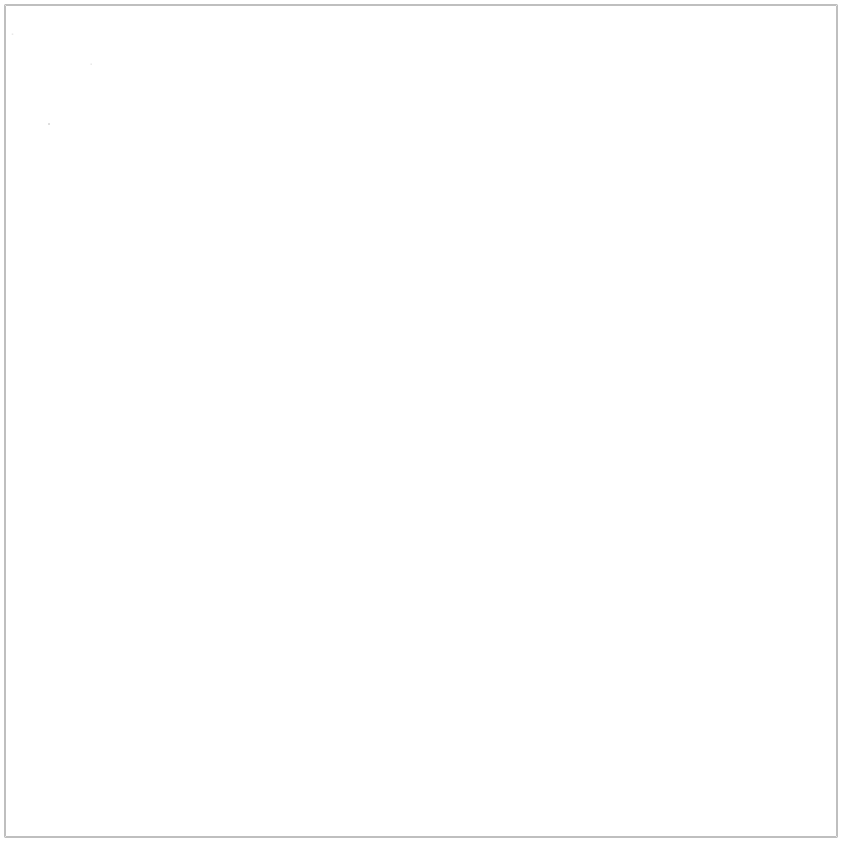
expected e/π ratio

Electron ID in PHENIX Central Arms

- charged particle tracking
  - DC, PC, TEC
  - (RICH, ToF, EMCal)
- electron identification
  - RICH
    - ring finding
  - EMCal
    - energy / momentum matching
    - time of flight
    - shower shape
  - TEC
    - energy deposit



PHENIX RICH Detector



schematics of PHENIX RICH

- primary electron identification device
- full coverage of central arm acceptance
- threshold gas Cherenkov
  - C_2H_6 (γ_{th} ~ 25)
  - CO_2 (γ_{th} ~ 35) for year 1
  - eID p_t range : 0.2 ~ 4 GeV/c
- PMT array readout
  - 5,120 channels in 2 arms
  - ~ 1 degree x 1 degree pixels

PHENIX RICH Group

- CNS, U.Tokyo — H.Hamagaki, S.Nishimura, K.Oyama, T.Sakaguchi
- Florida State U. — R.Chappell, D.Crook, A.D.Frawley
- KEK — Y.Akiba, K.Shigaki
- Nagasaki IAS — K.Ebisu, H.Hara, Y.Tanaka, T.Ushiroda
- ORNL — M.S.Emery, S.Frank, J.P.Jones, C.Moscone, J.W.Walker, A.L.Wintenberg, G.R.Young
- SUNY at SB — R.Begay, J.Burward-Hoy, J.Ferriera, T.K.Hemmick, R.Hutter, S.Salomone
- U.Tokyo — R.S.Hayano
- Waseda U. — M.Hibino, S.Kametani, J.Kikuchi, T.Matsumoto, M.Tamai

Status of PHENIX RICH Detector

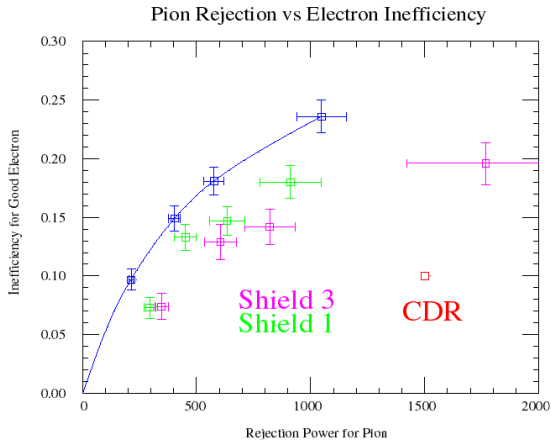
- both arms of RICH completed
- first arm installed on PHENIX west arm

PMT array in RICH gas vessel

PMT arrays reflected on mirrors;
before installation of front window

Electron Capability of PHENIX

- hadron rejection power of RICH
  - 10^4 level for single track
  - 200 ~ 1,500 in central Au+Au
- hadron contamination in electron measurement
  - ~ 20 % for single electron
  - ~ 50 % for dielectron
- signal to background ratio for vector mesons
  - ~ 1/10 for ϕ
  - ~ 1/15 for ω
  - < 1/100 for ρ



simulated dielectron spectrum

"identified" electrons

real electrons only

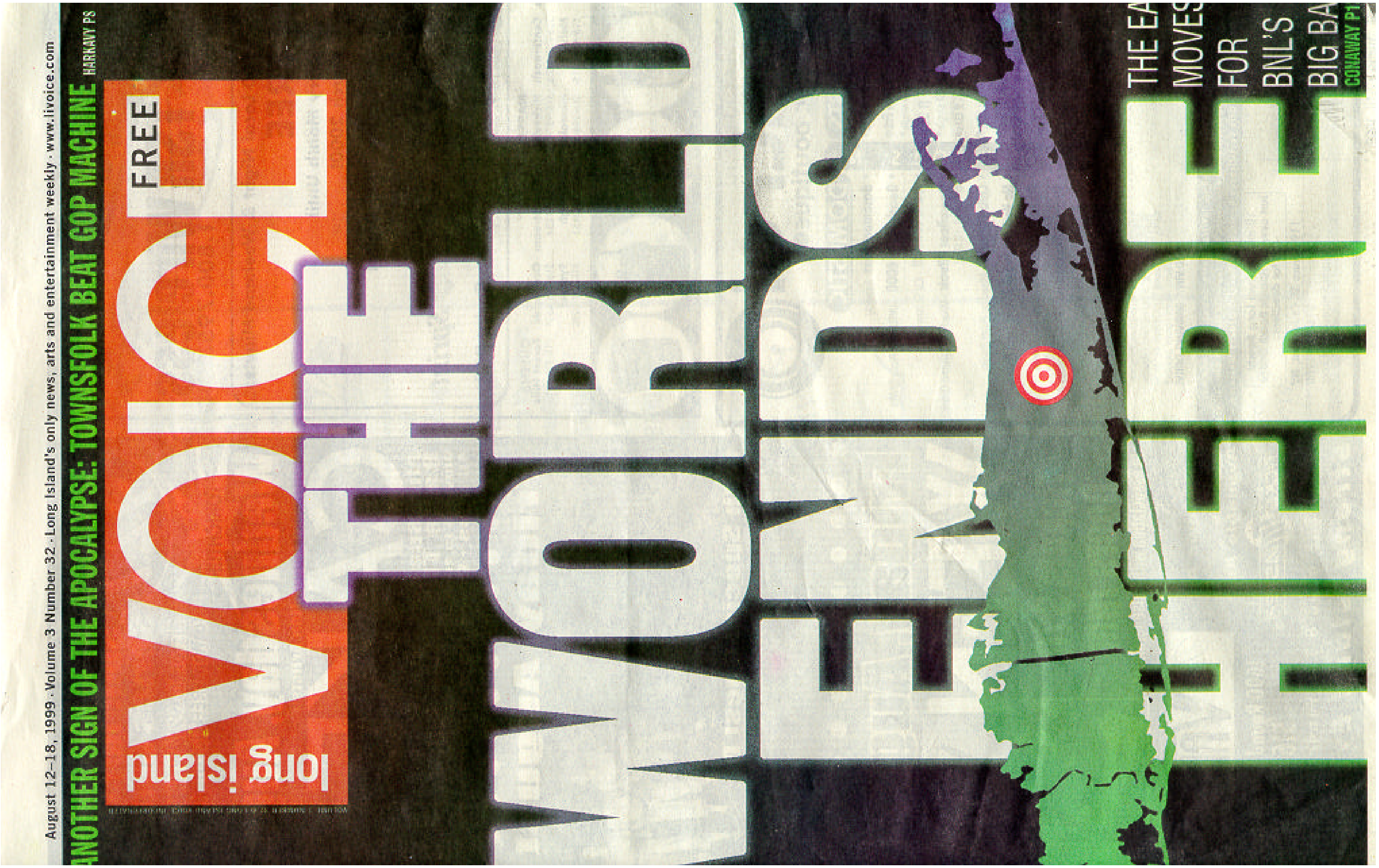
no γ conversion

ω

ρ ϕ J/Ψ

Summary

- RHIC is a unique facility to study QCD in extreme conditions and scales through two-fold approaches
  - relativistic heavy ion physics
  - high energy spin physics (*ref.* talk by MGP)
- construction phase of RHIC has finished; operation started in 1999
- first physics run starts in January, 2000
- experiments are ready to look at Au+Au collisions
  - aiming at discovery of quark gluon plasma phase
- be prepared…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ANOTHER SIGN OF THE APOCALYPSE: TOWNSFOLK BEAT GOP MACHINE
HARKAVY P5
long island VOICE
FREE
THE WORLD ENDS HERE
FOR
BNL'S
CONAWAY P1