# *Physics via Lepton Channels at RHIC / PHENIX*


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at

Conference on the Intersections of Particle and Nuclear Physics

in

Quebec City, Quebec, Canada

on

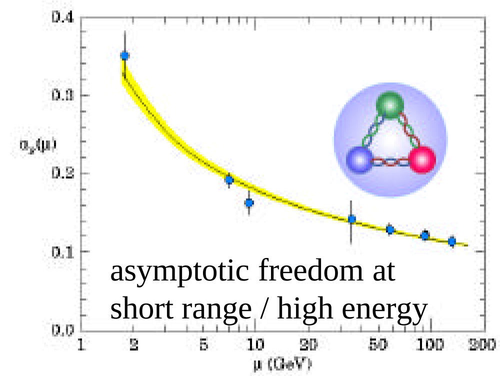
May 24, 2000

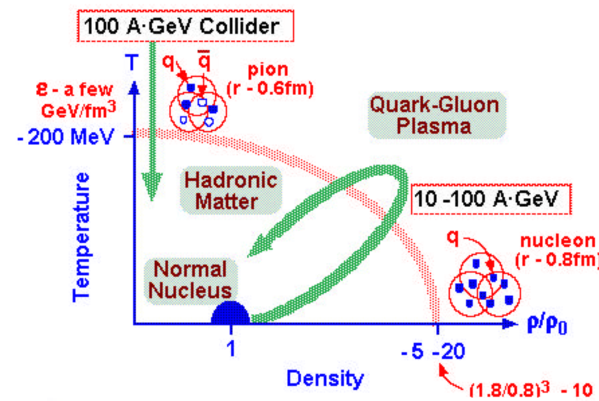
# Presentation Outline

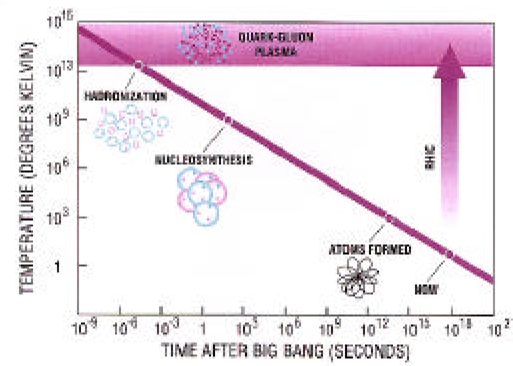
- Physics via Lepton Channels at RHIC
  - Physics Goals of RHIC
  - Relativistic Heavy Ion Physics at SPS and RHIC
- RHIC Accelerator and Experiments
- Physics via Lepton Channels in PHENIX Experiment
  - Physics Strategies and Detector System
  - Lepton Measurement Capabilities
  - Upcoming Physics
    - Systematic Studies of Quarkonium
    - Open Heavy Flavor
    - Light Vector Meson and Thermal Di-Lepton
- Summary and Conclusions

# Physics Goals of RHIC

- QCD in extreme conditions and scales
  - high energy density frontier (relativistic heavy ion physics)
    - search for and characterize deconfined quark-gluon plasma phase
  - high $Q^2$ frontier with spin degree of freedom (high energy spin physics)
    - elucidate spin structure of nucleon
- from Bevalac/SIS/AGS/SPS to RHIC
  - from high density regime to high energy density (“*temperature*”) regime
  - reproduction of conditions of universe a few μsec after big bang



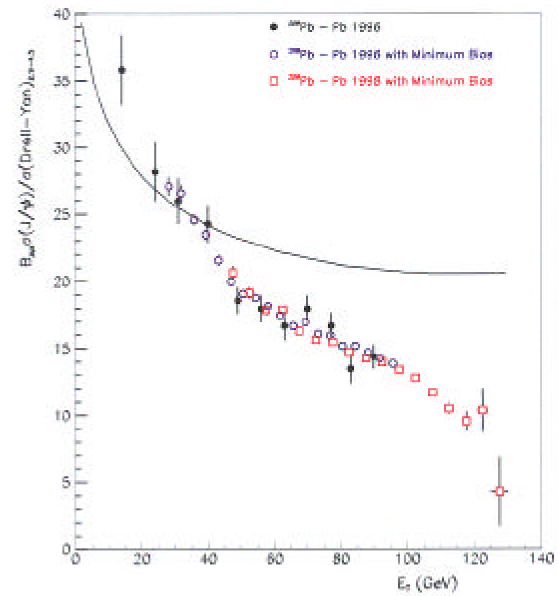



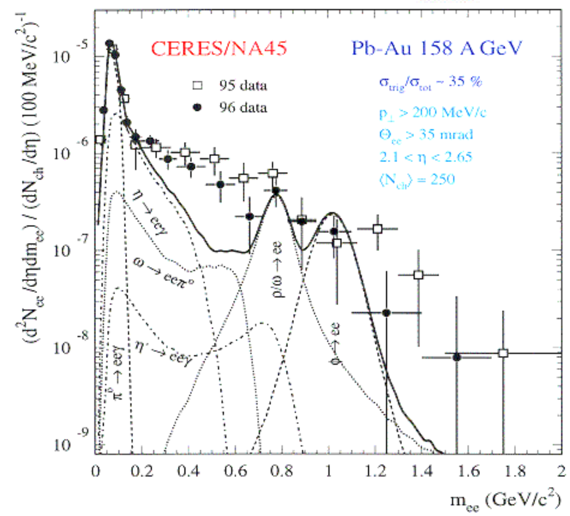
# RHI Physics at SPS and RHIC

- new state of matter claimed at CERN in February, 2000
  - SPS at 158 A GeV, *i.e.* $\sqrt{s}$ = 17 A GeV
  - quark-gluon plasma factory at RHIC with $\sqrt{s}$ = 200 A GeV ?
- combination of signatures to understand whole picture
  - hadrons to probe boundary conditions of collision dynamics
  - photons to trace evolution of system
  - leptons to probe early hot stage of collision
- CERN announcement based on 7 independent experiments
  - endorsed particular importance of lepton channels
  - RHIC experiments have comprehensive (and complementary) programs
  - especially PHENIX covers most of proposed physics probes

# Recent Lepton Channel Topics from SPS

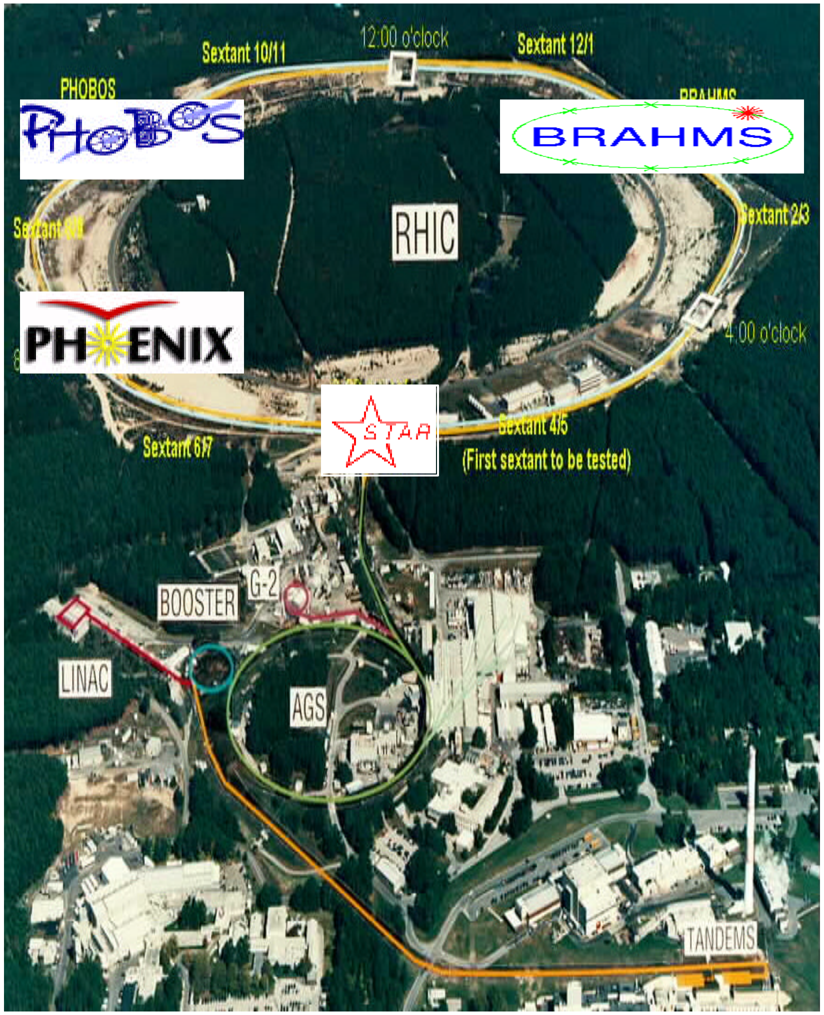
- J/Ψ “anomalous” suppression
  - NA50; Pb+Pb
  - predicted by T.Matsui and H.Satz in 1986
  - color Debye screening ?
- intermediate-mass dimuon enhancement
  - NA50; S+U, Pb+Pb
  - charm enhancement ?
- low-mass dielectron enhancement
  - NA45 (CERES); S+Au, Pb+Au
  - ρ enhancement/melting ?



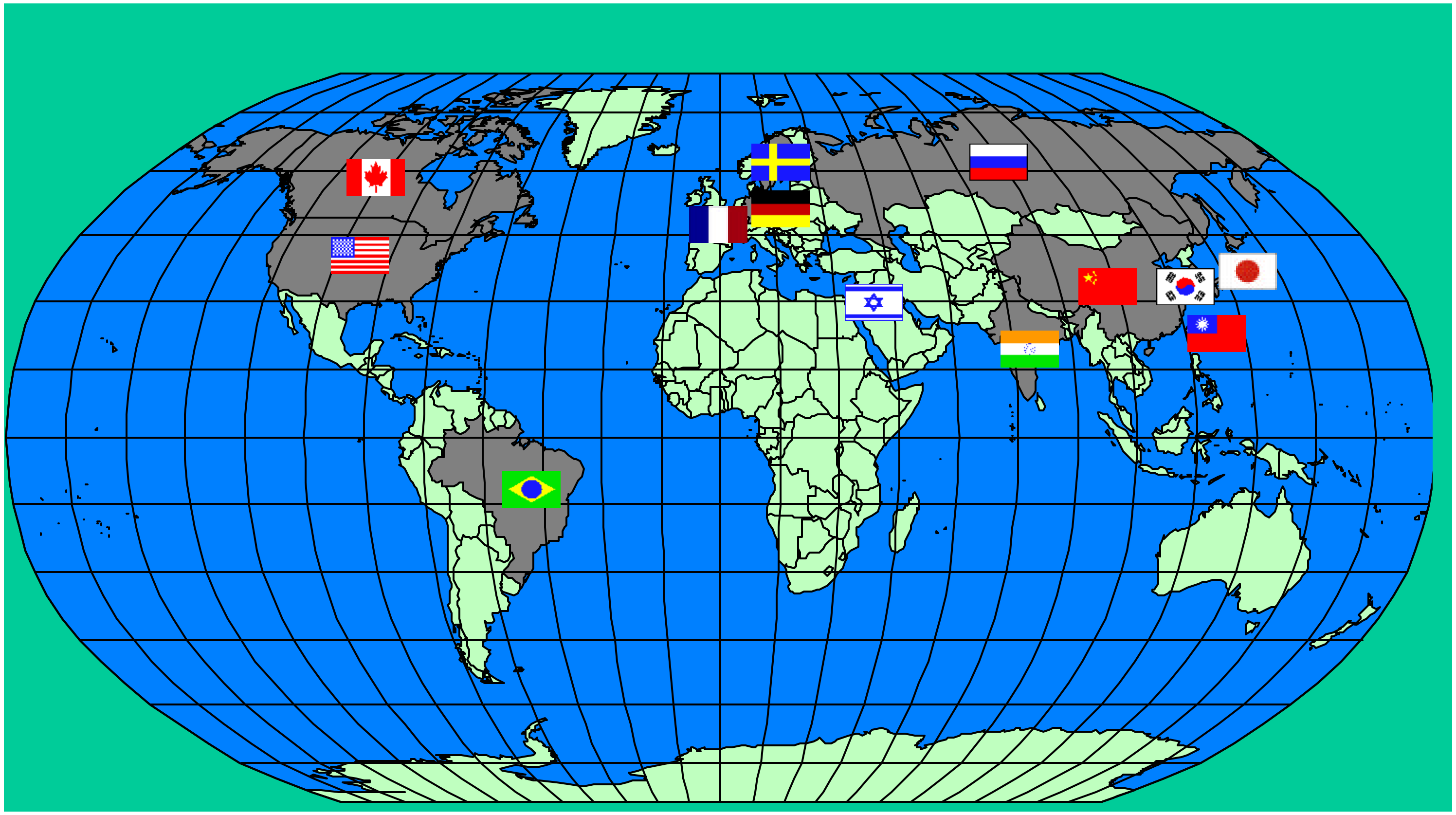
# Relativistic Heavy Ion Collider

- ultimate tool with:
  - 2 superconducting rings
  - 3.8 km circumference
  - 6 intersecting locations
  - AGS complex as injector
- versatile heavy ion collider
  - up to Au+Au at $\sqrt{s}$ = 200 GeV per nucleon
  - capable of p+p, p+A, A+B
- polarized proton collider
  - up to $\sqrt{s}$ = 500 GeV
- construction phase finished; physics run starting in weeks
- complimentary set of experiments



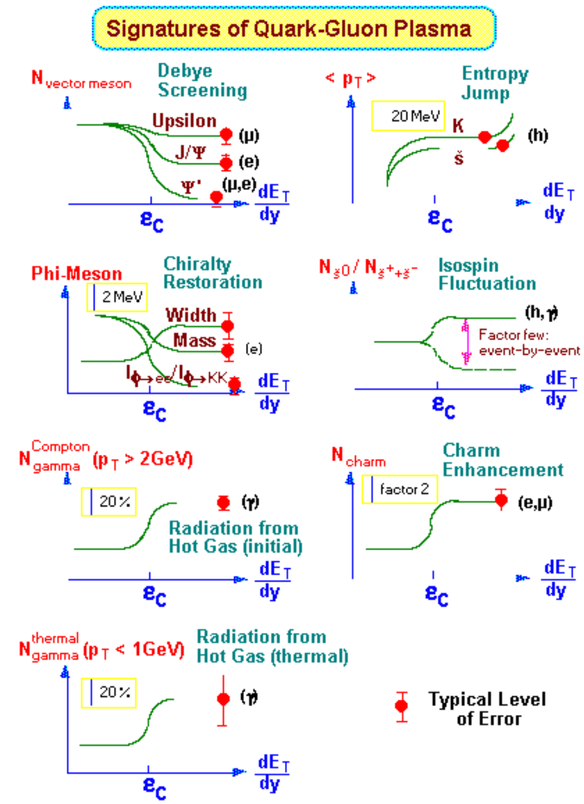
# Pioneering High Energy Nucl. Ion Exp.

- > 400 collaborators, 45 institutions, 13 countries
  - wide collaboration for wide physics



# Physics Strategies of PHENIX

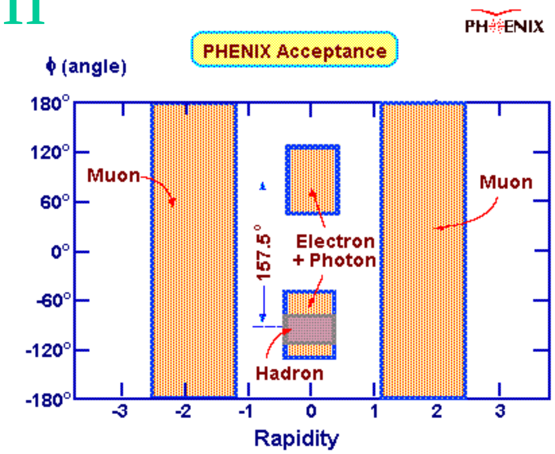
- wide variety of probes with single detector and trigger
  - sensitivity to many signatures and essentially all time scales
    - strangeness and heavy flavor (charm, bottom) production
    - jet quenching
    - color Debye screening
    - chiral symmetry restoration
      - vector meson properties
      - disoriented chiral condensation
    - thermal radiation of hot gas

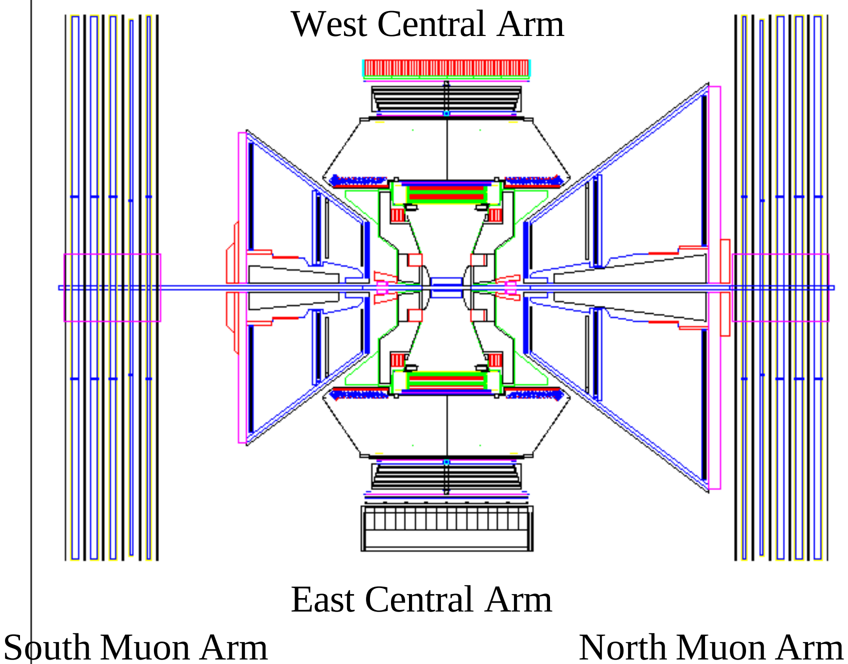



- emphasis on penetrating probes ($\gamma$, $\gamma^*$, $l$, $l^+l^-$)
  - good PID capability, high resolution, wide kinematical coverage
  - high rate capability, selective multi-level triggering

# PHENIX Detector System

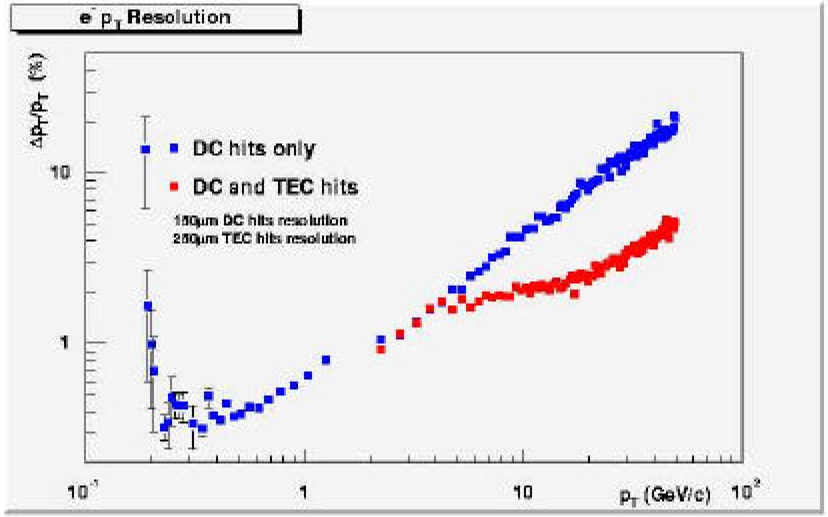
- 2 central arms for photon, electron, hadron
  - tracking chambers
  - RICH, EMCal, ToF
- 2 forward arms for muon
  - tracking chambers
  - muon identifier
- global detectors for event characterization
  - beam/beam counter
  - zero-degree calorimeter
  - multiplicity/vertex detector

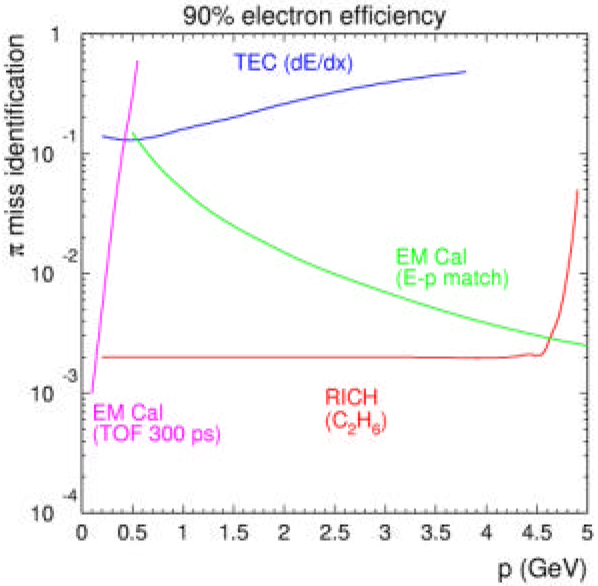


# Electron Measurement in PHENIX

- $-0.35 < \eta < 0.35$, $d\phi = \pi/2 \times 2$
- charged particle tracking
  - DC / PC / TEC (/ RICH / EMCal / ToF)
- hadron rejection at $10^4$ level in Au+Au central collisions
  - RICH / EMCal / TEC
- high momentum & mass resolution

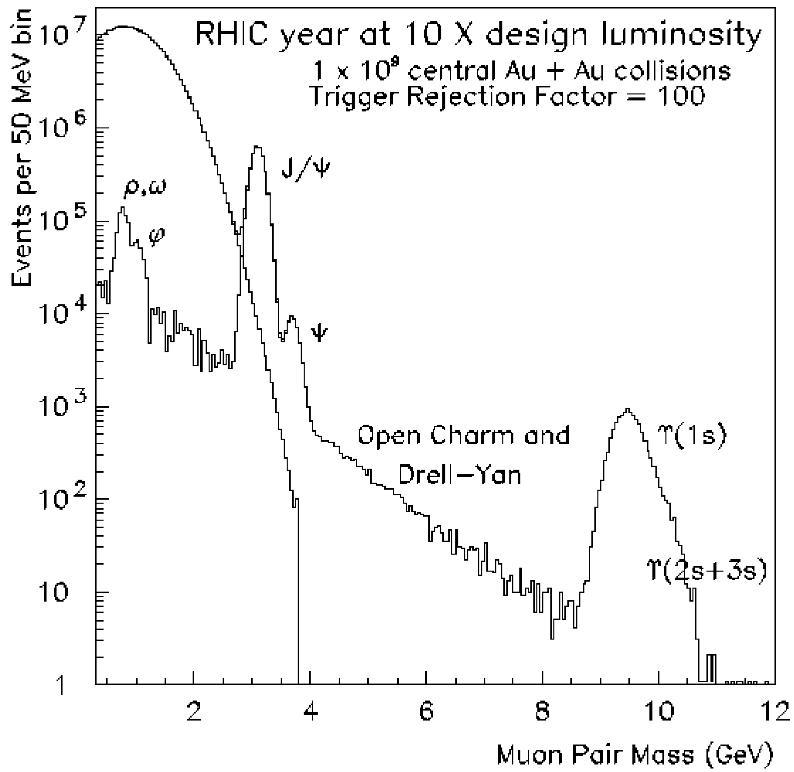


# Muon Measurement in PHENIX

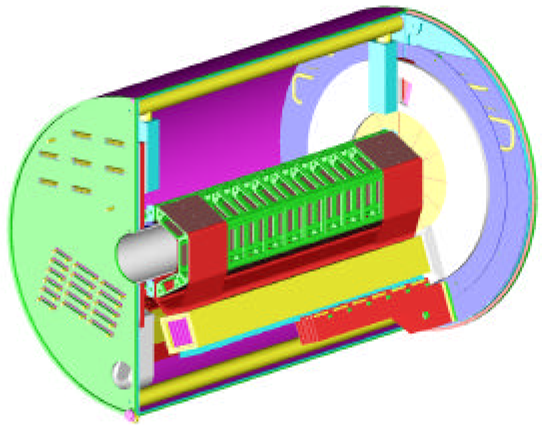
- $1.2 < \eta < 2.4$ (north), $1.2 < \eta < 2.2$ (south), full $\phi$ coverage
- tracking with 3 stations of chambers in magnetic field
- muon ID with 5 layers of steel absorber and Iarocci tubes
  - low energy cutoff at 2 GeV

PHENIX with 2 forward arms



# Event Characterization in PHENIX

- charged particle multiplicity ($dN_{ch}/d\eta$)
  - silicon strip/pad multiplicity and vertex detector
  - $-2.5 < \eta < 2.5$, full $\phi$ coverage
  - resolution $\sigma(N_{ch})/N_{ch} < 10$ % per 0.2 unit $\eta$ bin
- electro-magnetic transverse energy ($dE_t^{em}/d\eta$)
  - lead-scintillator and lead-glass calorimeter
  - $-0.35 < \eta < 0.35$, $d\phi = \pi/2 \times 2$

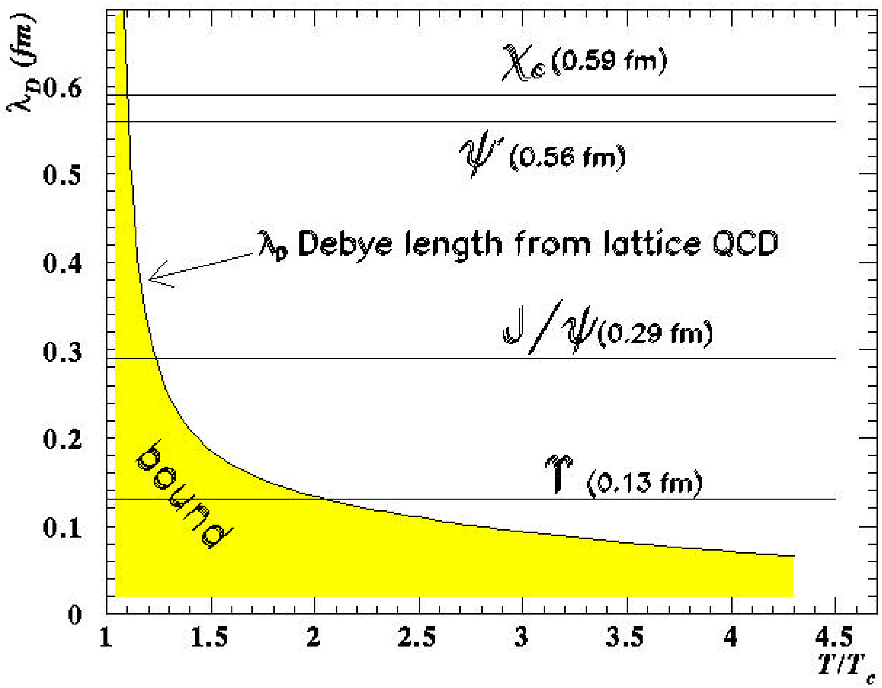


multiplicity/vertex detector

electro-magnetic calorimeter on East arm

# Quarkonium Physics at RHIC / PHENIX

- a promising probe of quark-gluon plasma phase
- SPS NA50 observations
  - $\Psi(2S)$ strongly suppressed
  - step behavior of $J/\Psi$ possibly due to $\chi_c$ and $J/\Psi$ dissolution
- expectation at RHIC, if scaled to energy density
  - $J/\Psi$ dissolution from semi-peripheral collisions
- uncertainty factors
  - elementary production cross section
  - initial state suppression (gluon shadowing)
  - ordinary nuclear absorption
  - systematic studies required



# Quarkonium Measurement in PHENIX

| | central (electron) arms | forward (muon) arms |
|---|---|---|
| rapidity coverage | $-0.35 < y < 0.35$ | $1.2 < y < 2.4$ (north)<br>$1.2 < y < 2.2$ (south) |
| $J/\Psi$ acceptance | 0.8 % of $B_{ee}\sigma$<br>(4 % of $B_{ee}\sigma$ in $\lvert y \rvert < 0.5$) | 4.3 % of $B_{\mu\mu}\sigma$ (per arm) |
| $\Upsilon$ acceptance | 1.7 % of $B_{ee}\sigma$<br>(5 % of $B_{ee}\sigma$ in $\lvert y \rvert < 0.5$) | 3.0 % of $B_{\mu\mu}\sigma$ (per arm) |
| $J/\Psi$ mass resolution | 20 MeV | 105 MeV |
| $\Upsilon$ mass resolution | 160 MeV | 180 MeV |

- central arms also measure photons with fine granularity
  - $1.9\ \% \oplus 8.2\ \% / \sqrt{E}$ [GeV] for PbSc (75 % of coverage)
  - $1.0\ \% \oplus 5.8\ \% / \sqrt{E}$ [GeV] for PbGl (25 % of coverage)

# Quarkonium Statistics in PHENIX

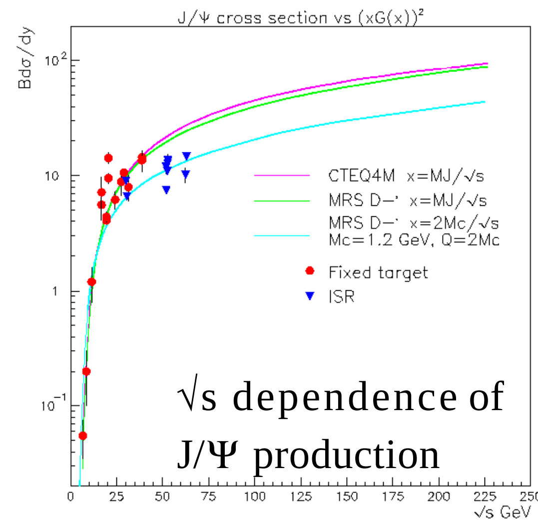
- assumptions
  - 1.6 $nb^{-1}$ integrated luminosity per year
    - RHIC nominal Au+Au luminosity of 2 $\times 10^{26}$ $cm^{-2}s^{-1}$
    - 27 weeks running with 50 % duty factor
  - $B_{ll}\sigma_{NN}(J/\Psi)$ = 400 nb

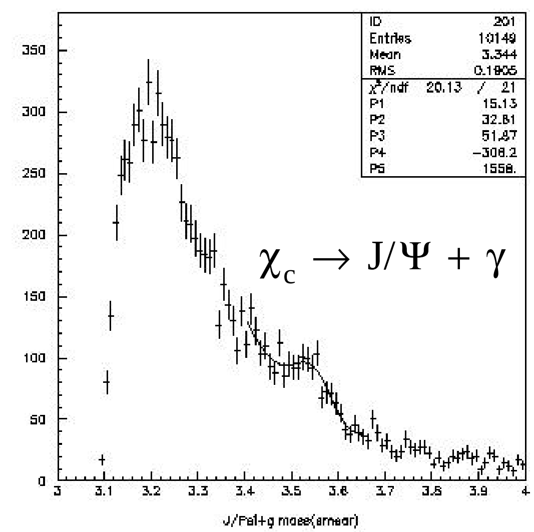
| | central arms | | forward arm (per arm) | |
|---|---|---|---|---|
| | 10 % central | min.bias | 10 % central | min.bias |
| $J/\Psi$ * | ~ 70,000 | ~ 200,000 | ~ 350,000 | ~ 1,000,000 |
| $\Psi(2S)$ * | ~ 1,400 | ~ 4,000 | ~ 7,000 | ~ 20,000 |
| $\Upsilon$ * | ~ 80 | ~ 250 | ~ 160 | ~ 500 |
| DY (> 4 GeV) | ~ 250 | ~ 700 | ~ 1,500 | ~ 4,000 |

- * absorption and suppression factors not included
  - *cf.* NA50 values for Pb+Pb at 158 A GeV ($\sqrt{s}$ = 17 A GeV)
    - 0.31 ($J/\Psi$, min.bias), 0.27 ($J/\Psi$, central), 0.06 ($\Psi(2S)$)

# Systematic Studies of Q'm in PHENIX

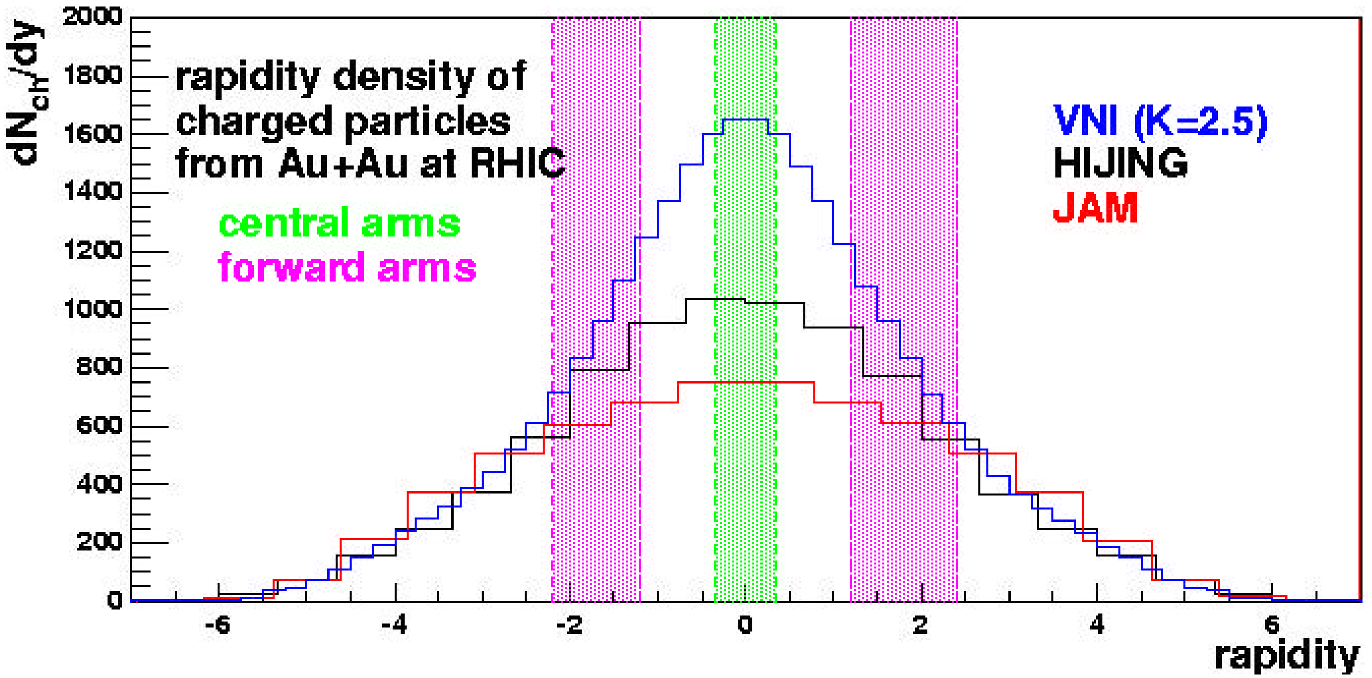
- baseline p+p / p+A measurement
- √s dependence
- rapidity / $p_t$ dependence
  - central and forward arms
  - $p_t$ from 0 to > 5 GeV/c
- J/Ψ and ϒ families
  - J/Ψ, Ψ(2S), ϒ(1S), ϒ(2S+3S)
- reference channels
  - continuum (charm, Drell Yan)
  - single lepton (charm)
  - single γ
- high statistics analysis
  - detailed centrality dependence
  - $p+p \rightarrow \chi_c \rightarrow J/\Psi + \gamma$



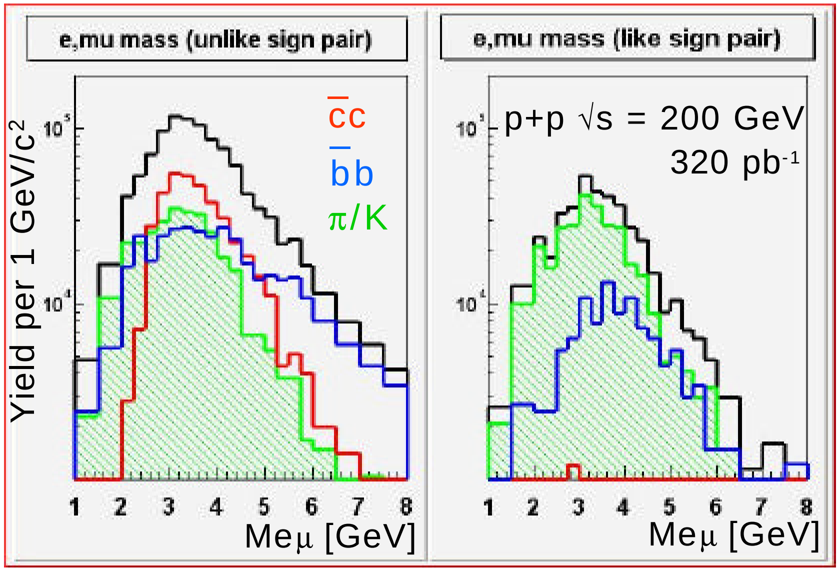
# Quarkonium in Central & Forward Arms

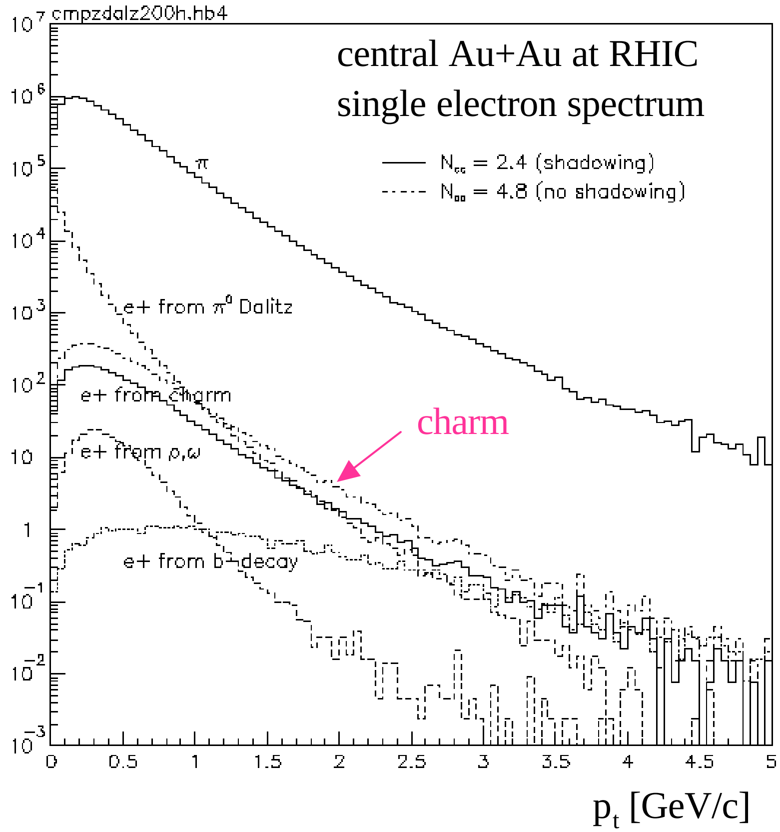
- simultaneous access to regions with different energy densities (or same energy density from different collision centralities)
  - rapidity density of produced particles as a measure
  - good test if suppression is a function of local energy density



# Open Heavy Flavor in PHENIX

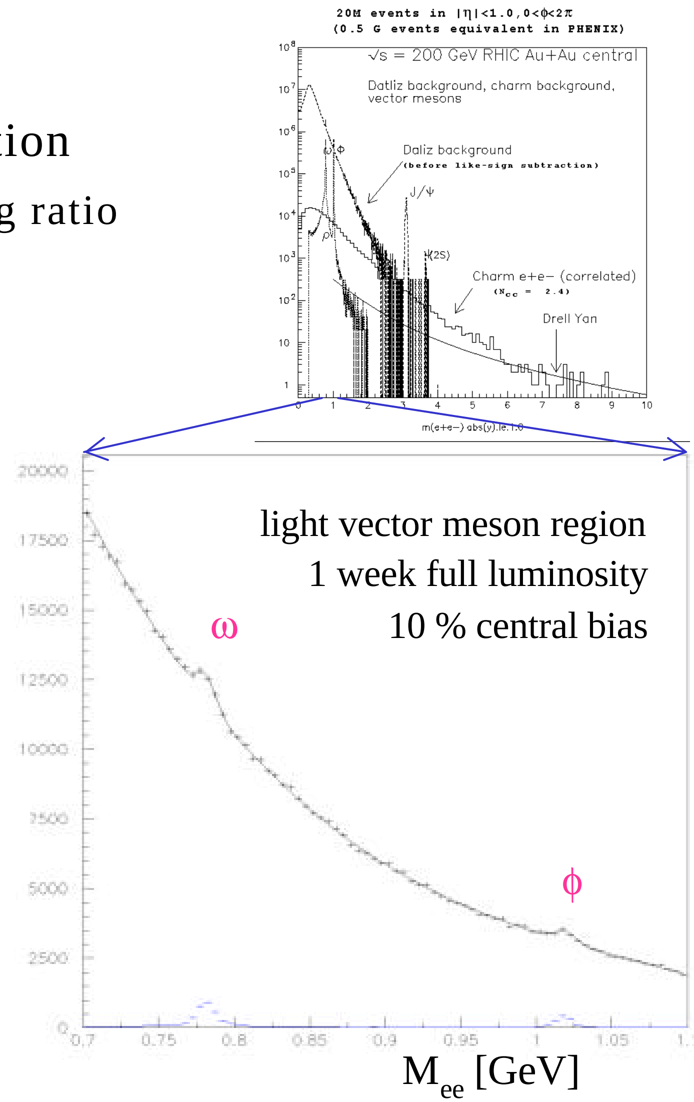
- heavy flavor (charm, bottom) production
  - probe of initial state (gluon shadowing)
  - good reference to J/Ψ production
- high $p_t$ single lepton
- high mass di-lepton
- e-μ coincidence



# LVM and Thermal $l^+l^-$ in PHENIX

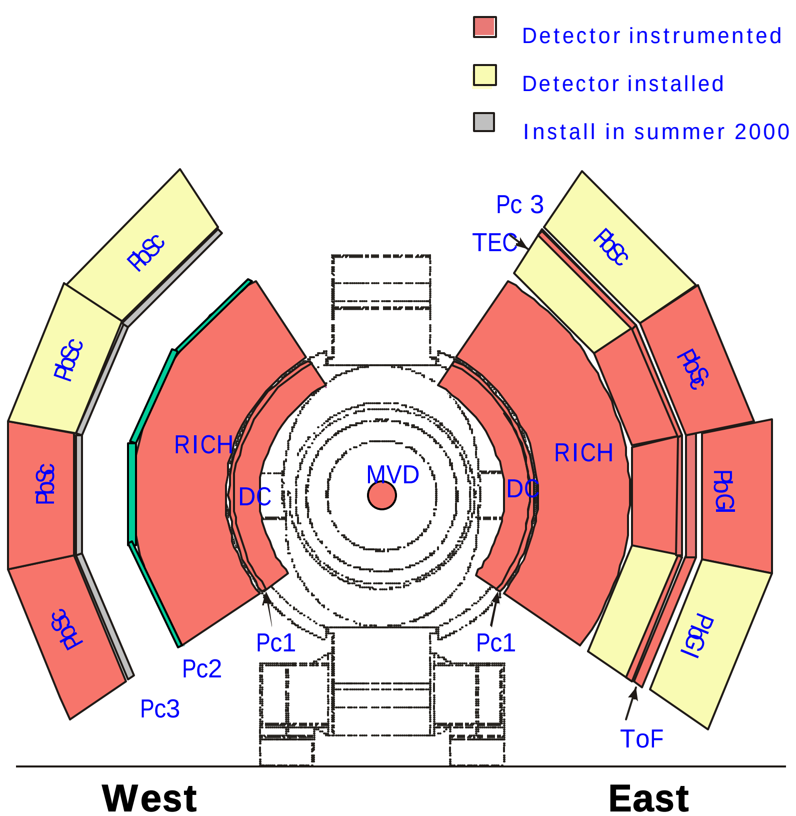
- light vector meson ($\phi$, $\omega$, $\rho$)
  - probe of chiral symmetry restoration
    - change in mass, width, branching ratio
  - separate $\phi$ and $\omega$
    - mass resolution < 5 MeV
    - S/N ~ 1/10 ($\phi$), 1/15 ($\omega$)
  - enhancement/melting of $\rho$
    - *cf.* NA45 observation
- thermal di-lepton
  - possible mass window at 1~2 GeV
  - *cf.* direct photon



# Chronological Strategies of PHENIX

- priorities in run 2000
  - a few μb$^{-1}$ of Au+Au at $\sqrt{s}$ = 140 A GeV
  - first physics from γ, *e*, *h* measurement
  - (spin commissioning)
  - (p+p to characterize baseline)
- run 2001
  - Au+Au at $\sqrt{s}$ = 200 A GeV
  - additional μ measurement
  - full coverage of MVD
  - greater sensitivity to rare probes in Au+Au
  - first results on spin physics
- run 2002 and later
  - continuing program of heavy ion and spin discoveries

PHENIX run 2000 configuration



# Upcoming Physics from PHENIX

- physics and time scales accessible in run 2000
  - initial hard process
    - jet, hard photon, high $p_t$ hadron
  - deconfinement
    - high-mass vector meson $J/\Psi$, $\Psi'$
  - chiral restoration
    - low-mass vector meson $\rho$, $\omega$, $\phi$
  - thermalization
    - soft photon, non-resonant dielectron
    - open charm via single electron
    - high $p_t$ photon from $\pi^0$, $\eta$, $\eta'$
  - hadronization
    - hadron spectra, strangeness, HBT interferometry
  - hydro-dynamics
    - transverse energy, dN/dy

# Summary and Conclusions

- RHIC is a unique facility to study QCD in extreme conditions and scales
  - construction phase has finished; first physics run starting in weeks
- SPS programs endorsed importance of lepton channels
- RHIC will address them in a systematic way
  - A+B capability from p+p to Au+Au
  - especially by the PHENIX experiment
- PHENIX is suited for physics via rare lepton probes
  - good PID; high resolution; wide kinematical coverage
  - high rate/statistics with selective multi-level triggering
  - wide variety of probes; many signatures; essentially all time scales
- first physics results from electron channels in 2000, as well as photon and hadron channels
- more systematic data (including muon channels) in 2001