# $J/\Psi$ Suppression and Collision Dynamics in Heavy Ion Collisions

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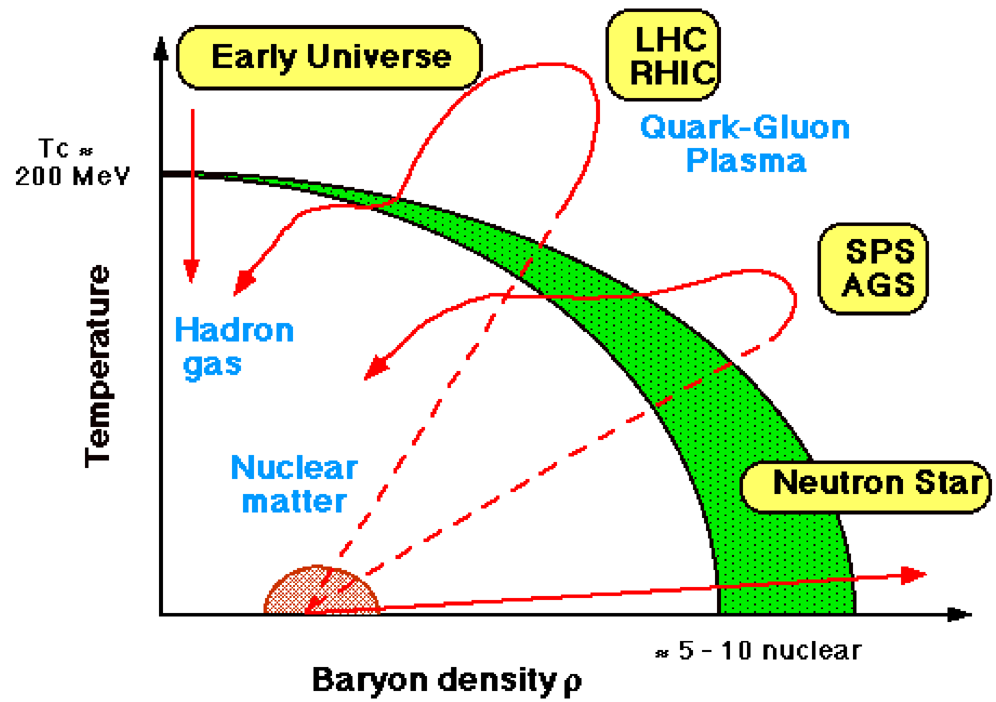
# Nuclear Matter Phase Diagram

- At high temperature and density, nuclear matter is expected to undergo a phase transition to a Quark-Gluon Plasma
- Recreates the state of matter in the universe a few microseconds after the Big Bang



# The Phase Transition(s)

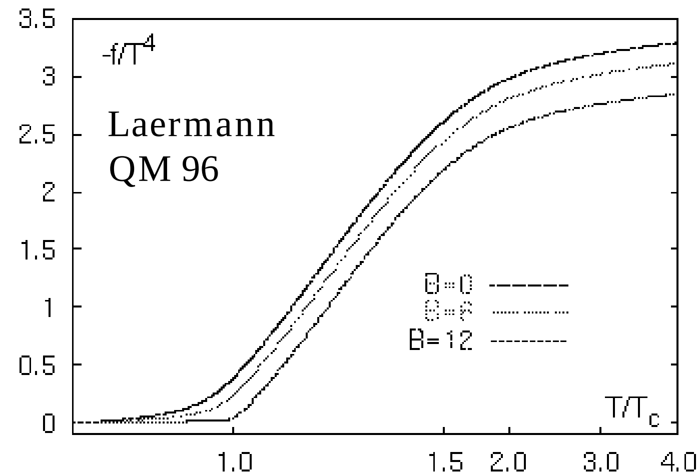
- The phase transition is actually two transitions:

  Deconfinement Transition:
  Quarks and Gluons are no longer confined to hadrons

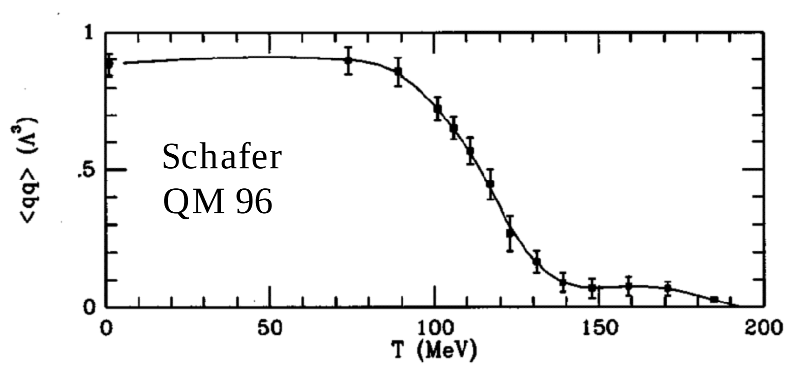
  Chiral Symmetry Restoration:
  Quark Condensate goes to ~0

- Recent Lattice Calculations suggest a transition temperature of ~150-200 MeV--should be accessible experimentally

Deconfinement Transition

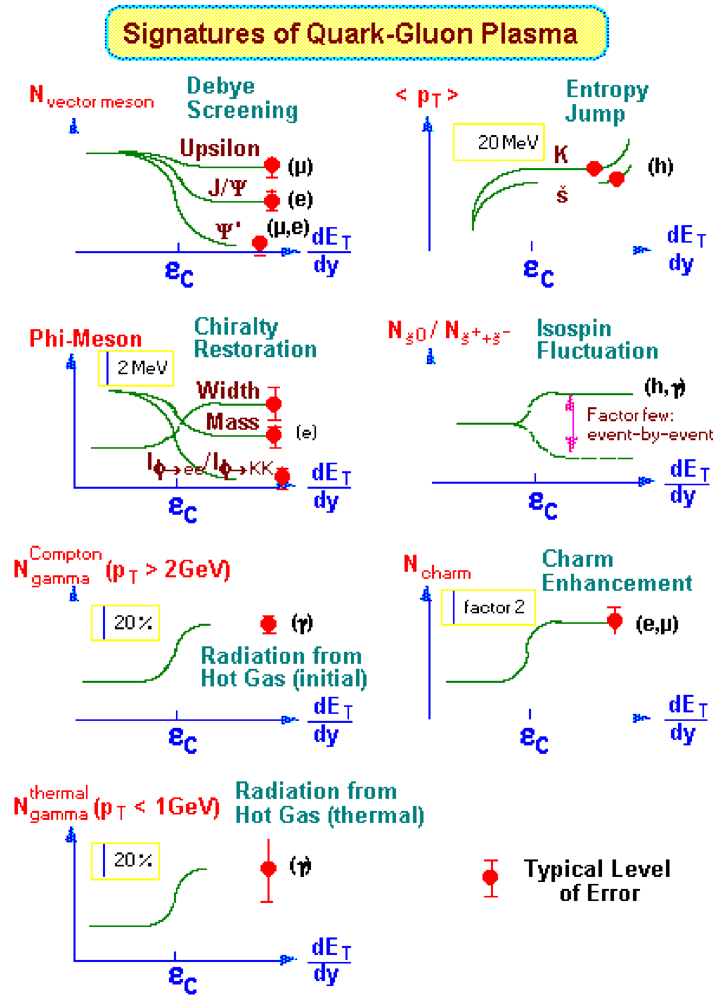



Chiral Restoration



# Signatures of the QGP

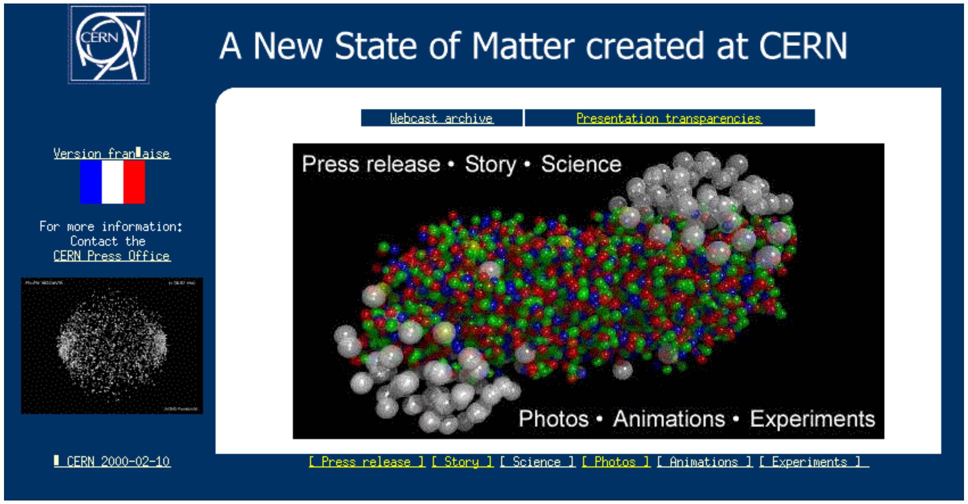
- Deconfinement Probes:
  - J/Ψ, Ψ ' Suppression
  - Increased dE/dx of partons (Jet Quenching)
  - Strangeness, antibaryon enhancement
  - Direct photons 2-5 GeV from gluon-quark Compton scattering
  - Enhanced dilepton pairs 1-3 GeV from quark-antiquark annihilation
- Chiral Symmetry Probes:
  - Change in ρ, ω, ϕ mass, width and BR
  - Disoriented Chiral Condensates




S. Nagamiya, PHENIX

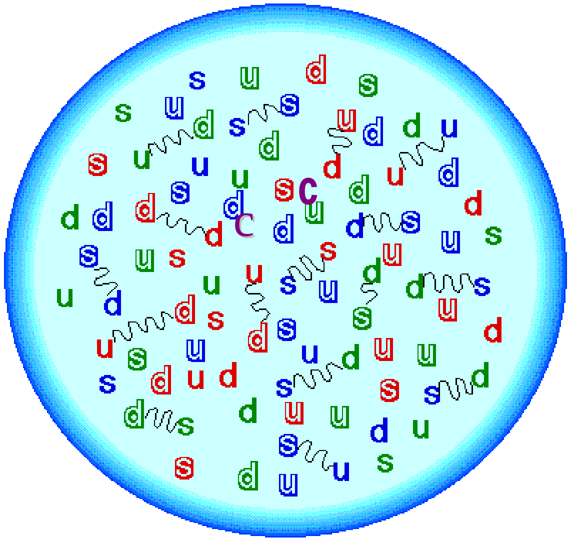
# Recent CERN Announcement

Http://www.cern.ch/CERN/Announcements/2000/NewStateMatter/

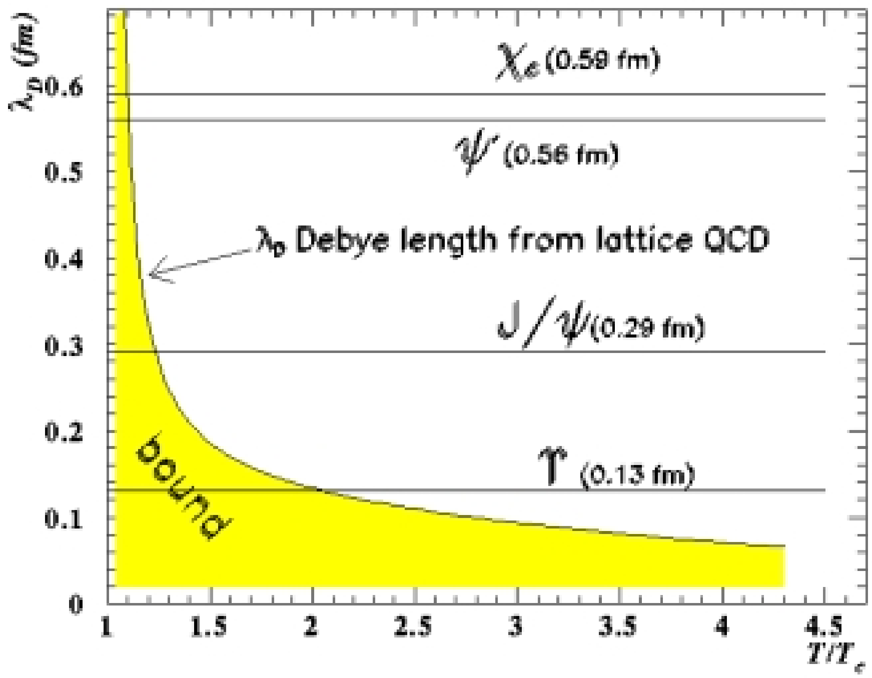



- "Circumstantial Evidence" for QGP includes:
  - » J/Ψ Suppression
  - » Enhanced Production of Strange Particles
  - » Temperature ~180 MeV from particle abundance ratios
  - » Energy density ~2-4 GeV from extrapolating back final state energy

# Debye Screening



C-Cbar screened in a QGP




- In a deconfined medium, attraction between c and cbar is screened (Matsui and Satz)
- As Debye length decreases with increasing temperature, different states are screened

# “Normal” J/Ψ Suppression

- Initial expectation was J/Ψ would not interact in normal nuclear matter
- Yield in pA data far exceeded expectations
- A dependence of pA data indicated absorption well beyond expectation
- These puzzles can be resolved by “color octet model”--explains “normal J/Ψ Suppression”

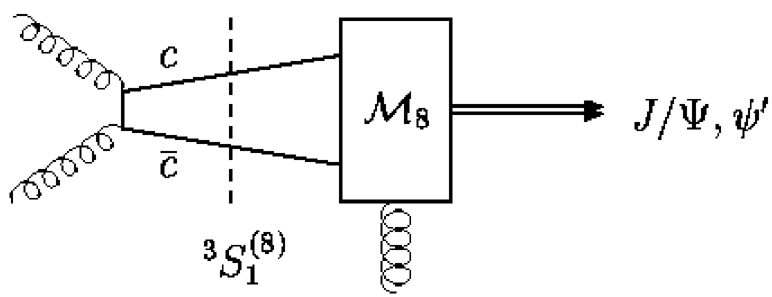
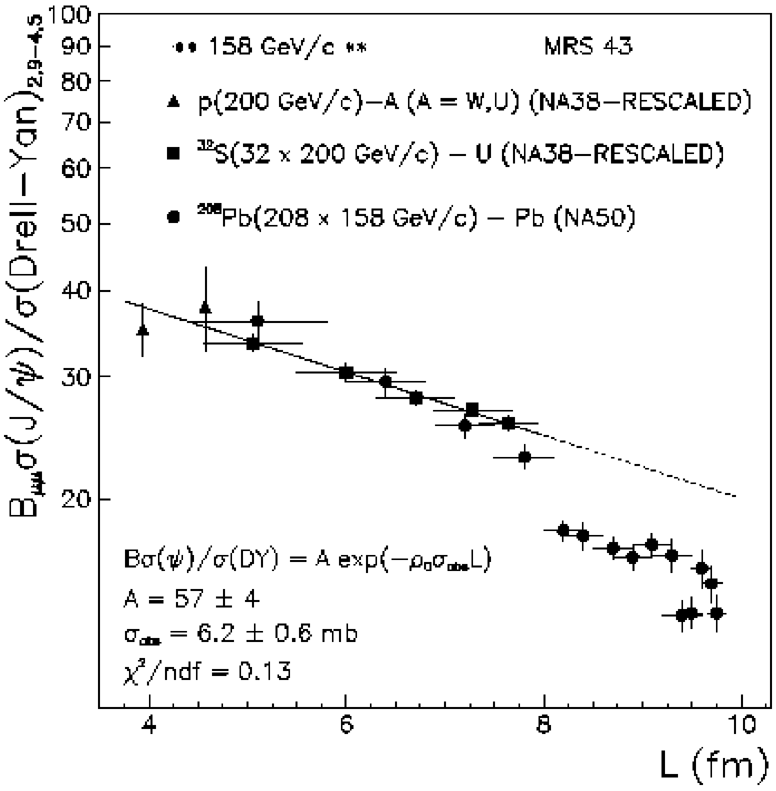



Figure from B. Muller

# “Anomalous” J/Ψ Suppression

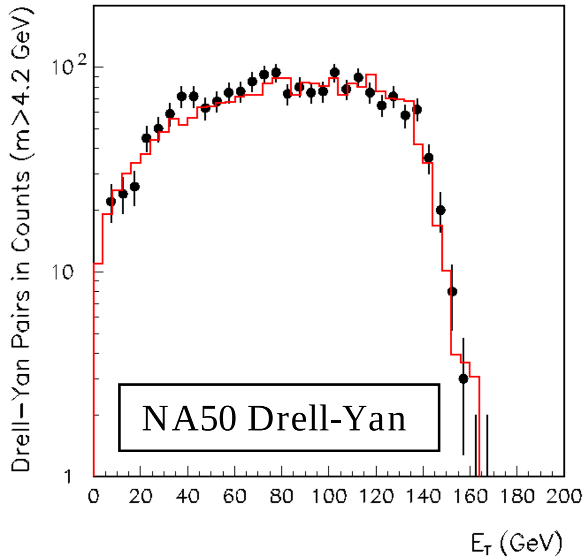
NA38, NA50 J/Ψ to DY ratio

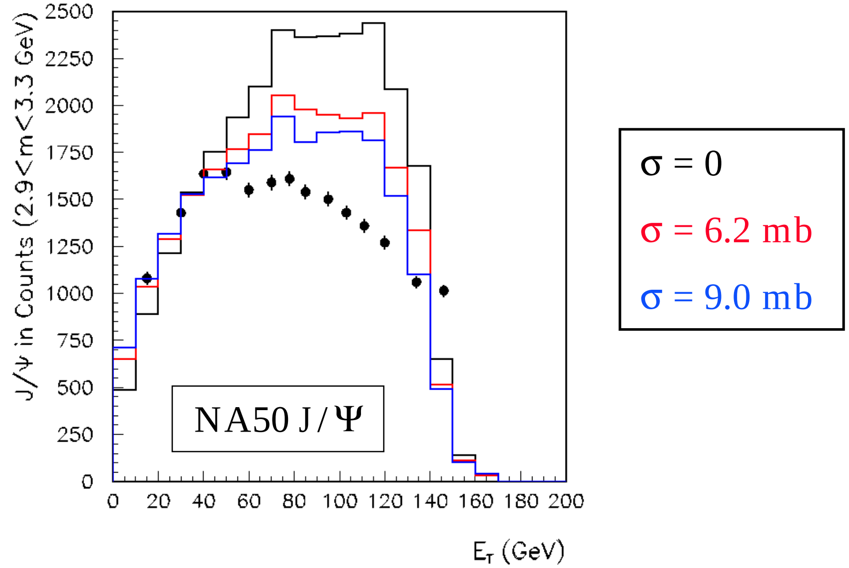



L. Ramello, Quark Matter ‘97

- Yields from p-A and A-A (through S) described by absorption cross section of 6-8 mb--consistent with predictions for c-cbar-g color octet state
- Yields from Pb-Pb collisions display absorption beyond this level, so-called “anomalous suppression”
- Plotted against “L”, the mean length through nuclear material. This is not an ideal parameter--not a measured quantity, saturation for large systems
- Need to look at J/Ψ, DY individually, as a function of centrality

# Comparison to Simple Glauber




- Simple Glauber model, with production from all N-N collisions equally likely
  MJB, J.L. Nagle, Physics Letters B465, 21 (1999)
- Collision dynamics based on observed A-A systematics:
  $E_T$ = constant * Wounded nucleons, smeared by 94% $/\sqrt{E}$ resolution
- Drell-Yan yields are fit very well
- J/Ψ yields are not fit well with absorption cross sections from 6-9 mb

# “Explaining” Anomalous Suppression

- Absorption by Hadronic Co-Movers

  Inelastic scattering by hadrons at similar momentum

- Gluon Shadowing

  Increased EMC effect in larger systems

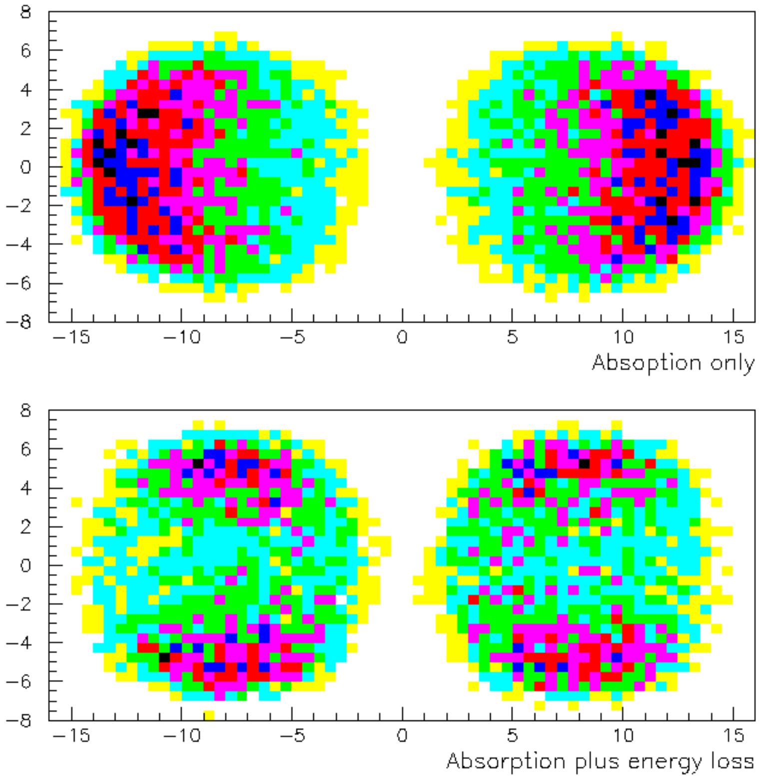
- Initial State Energy Loss

  Reduced Production in Later Collisions

- Quark-Gluon Plasma

# Geometry of Energy Loss

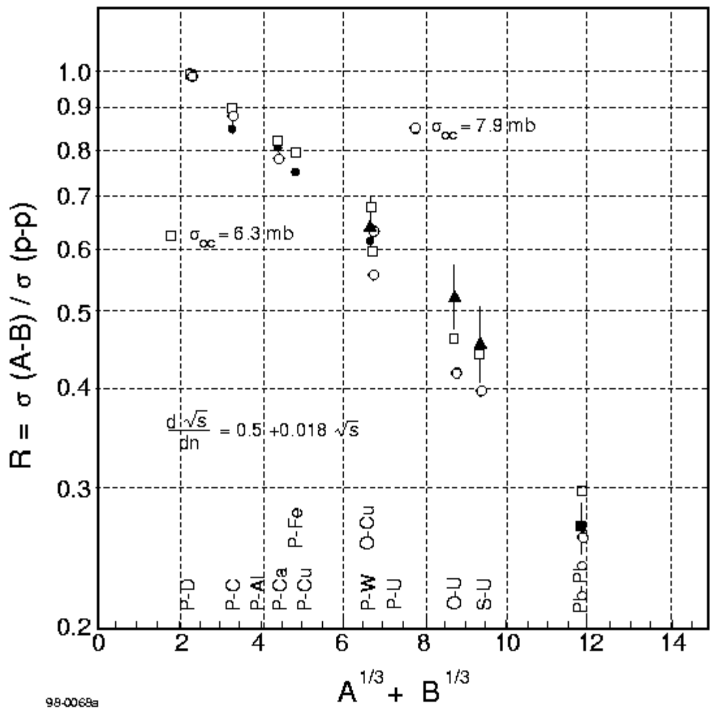
Absorption only




Absorption + Energy Loss

- Nucleons lose energy as they traverse the colliding nucleus
- Production of $J/\Psi$ and Drell-Yan have steep energy dependence
- Affects $J/\Psi$ and DY differently
- Reduces total yield
- Reduces Cronin effect, changes $p_t$ spectrum
- Mimics QGP signal

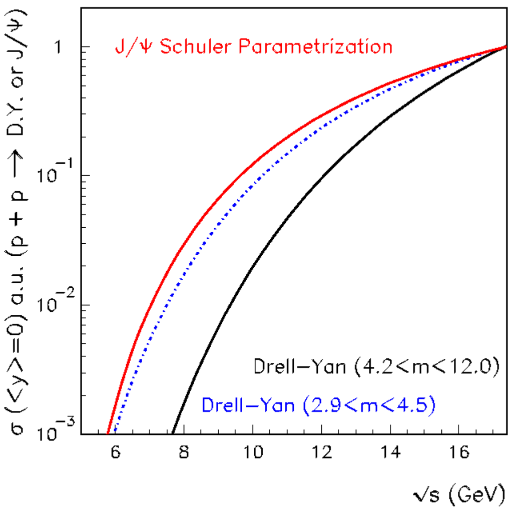
# Energy Loss in Min Bias Collisions

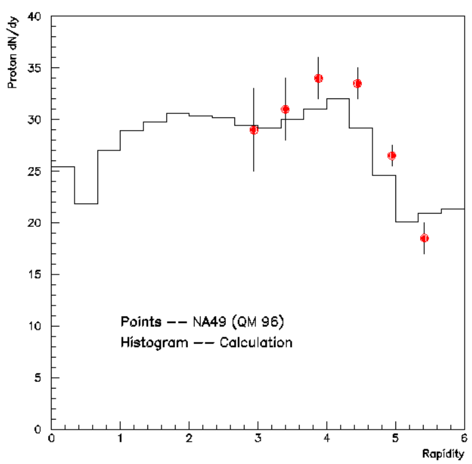



Frankel & Frati, hep-ph/9710532

- J/Ψ yield per N-N Collision, plotted against Mean Number of N-N Collisions
- Absorption only gives simple exponential
- Energy loss suppresses from simple exponential
- Want to look at detailed centrality dependence, for both J/Ψ and Drell-Yan

# The Model and Parameters

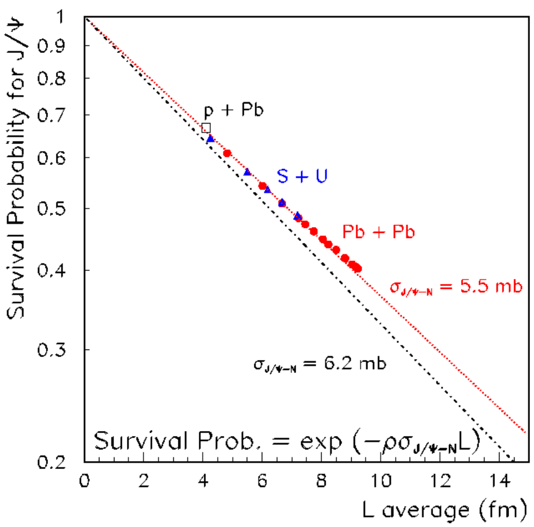



Comparison to NA49 Central Pb+Pb using 33% momentum loss per collision

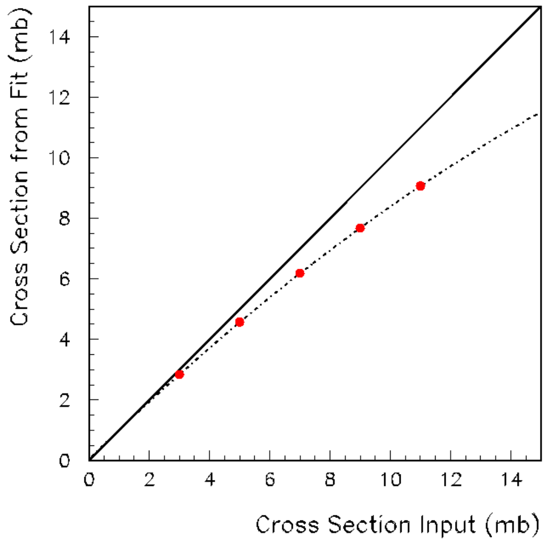
- Glauber Formalism, using 30mb N-N cross section
- Disregarding energy loss, all N-N Collisions contribute equally
- J/Ψ produced "at rest", absorption cross section 7.1 mb (MJB, J.L.Nagle, PRC59,2713)
- Production of J/Ψ and DY depends on energy of N-N Collision
- Stopping in p-A collisions suggest nucleons lose ~40% of their momentum per collision at t=∞

# The “L Parameter” and Absorption Fits




MJB & JLN

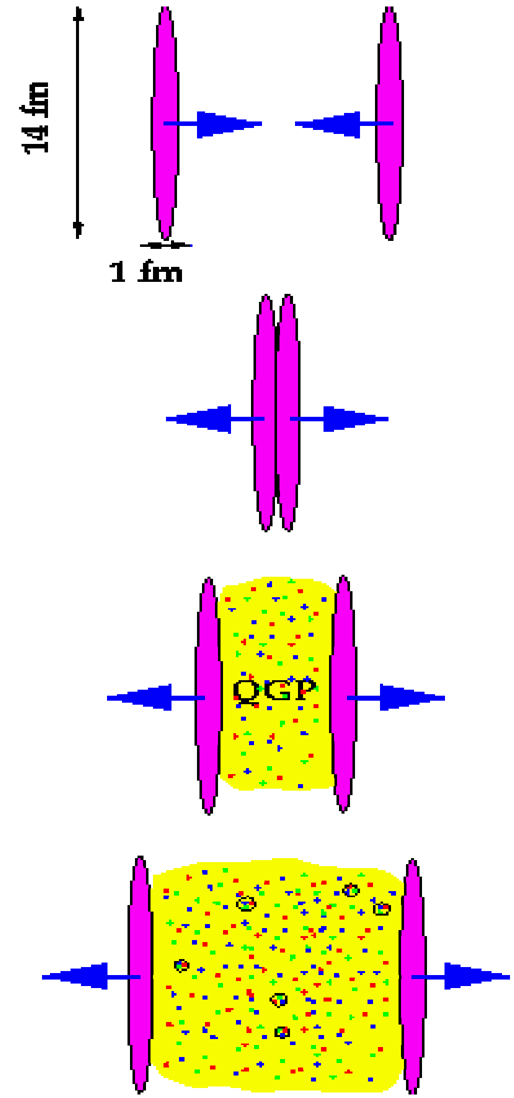
PRC, May 99



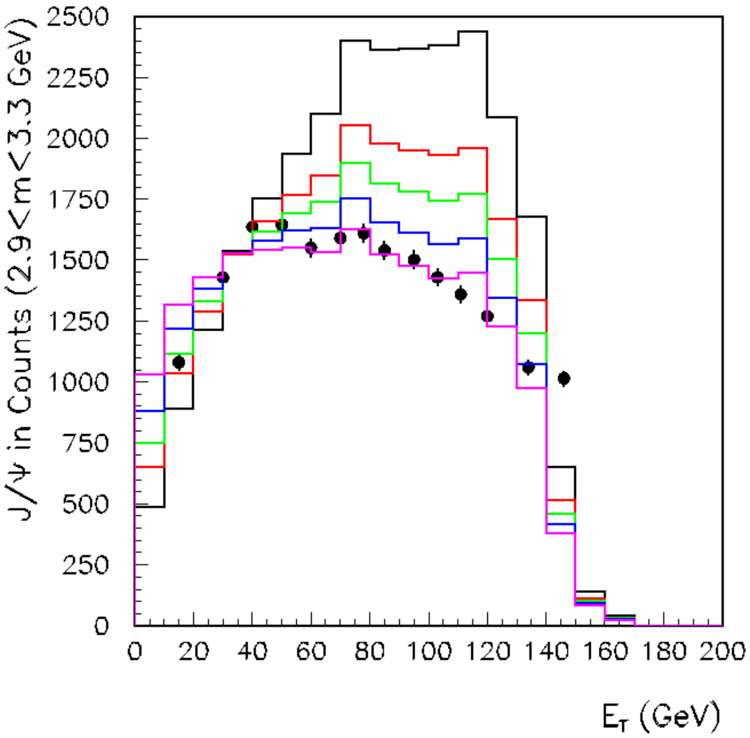

- At fixed impact parameter, J/Ψ path lengths vary widely; each centrality bin represents a variety of impact parameters
- A simple average over path lengths underestimates absorption cross section; using an iterative process, a refit gives 7.1 ± 0.6 mb
- Consistent with an fit with different methodology (7.3 ± 0.6 mb, Kharzeev et al, ZPC74, 307 (1997)

# Time Scales and Collision Dynamics

- At CERN energies, nuclei cross in ~0.1 fm/c
- Most energy loss is via soft interactions, with a time scale of a few fm/c
- Some fraction of this energy loss is at short time scale, treat as a variable parameter

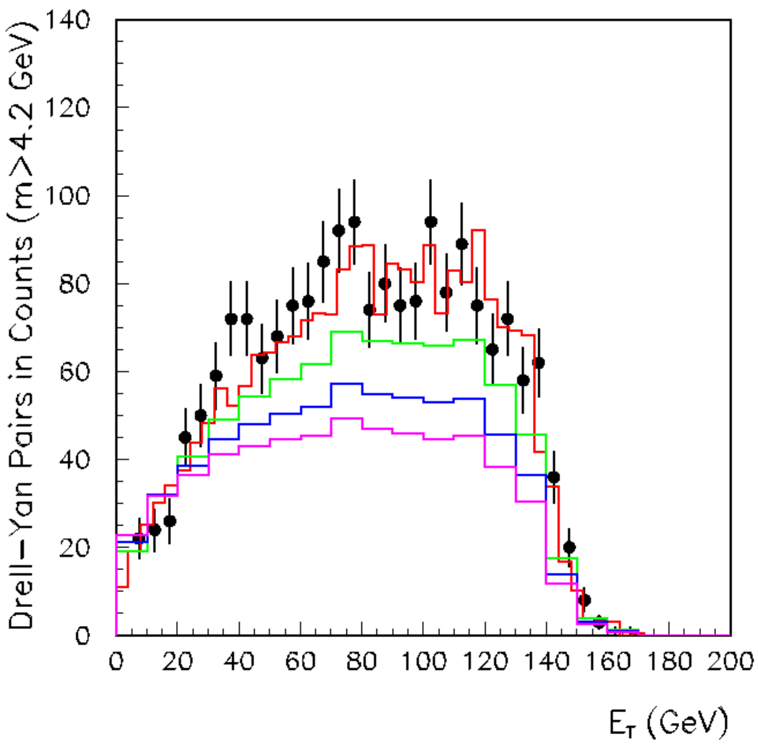


# J/Ψ Yields with Energy Loss




- Several values of Energy Loss 0%, 5%, 10% and 15% momentum per collision (0%, 15%, 30%, 50% of total t=∞ loss)
- Normalization chosen to give best fit in lowest two $E_T$ bins
- Highest Energy Loss matches spectral shape well

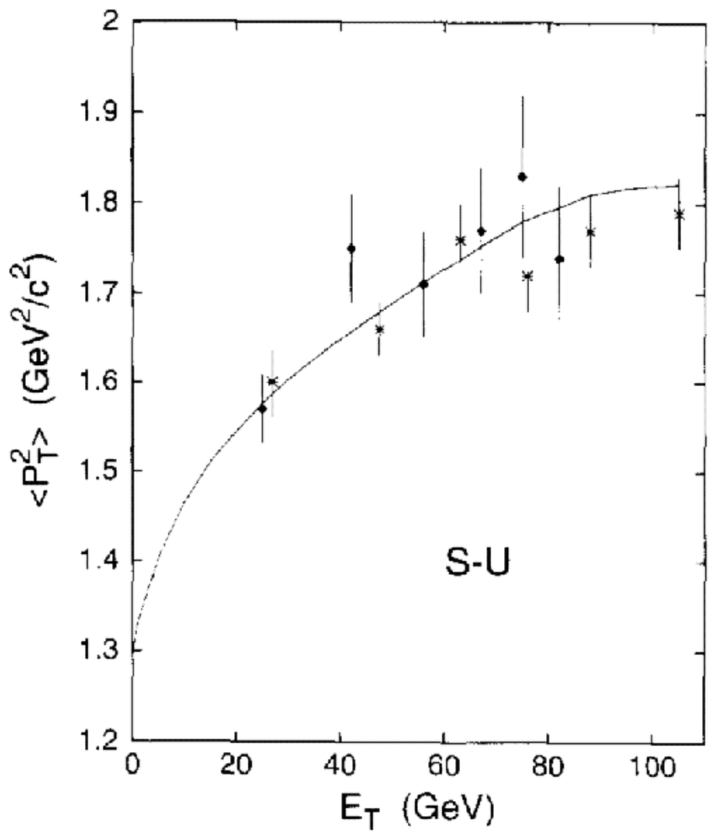
# Drell-Yan Yields with Energy Loss




- Several values of Energy Loss 0%, 5%, 10% and 15% momentum per collision
- Normalization chosen to give best fit in lowest $E_T$ bins
- Hard to reconcile any energy loss with data
- Is it reasonable to assume same energy loss is applicable for both J/Ψ and DY?

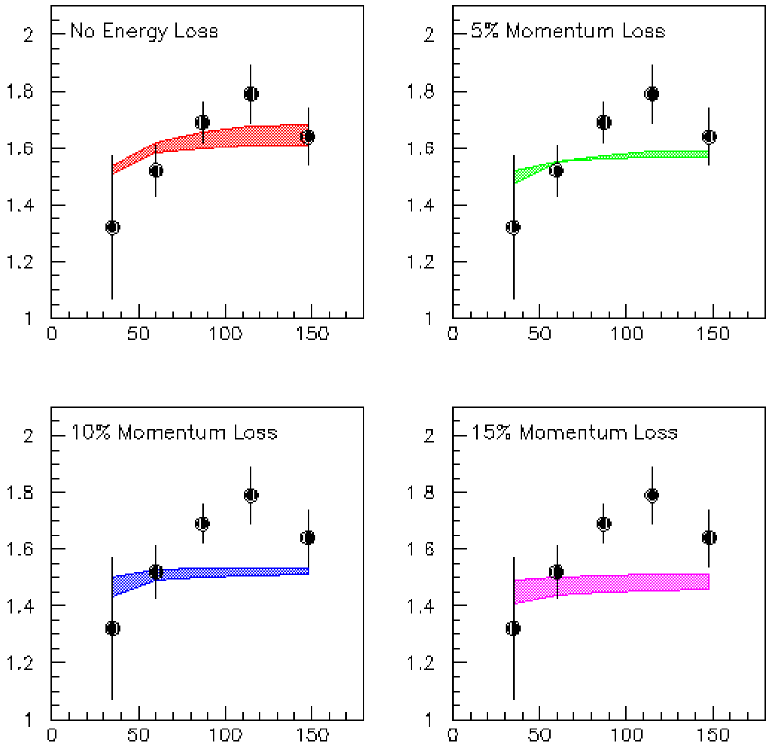
# Cronin Effect

$<p_t^2>_N = <p_t^2>_{pp} + N\ \Delta p_t^2$



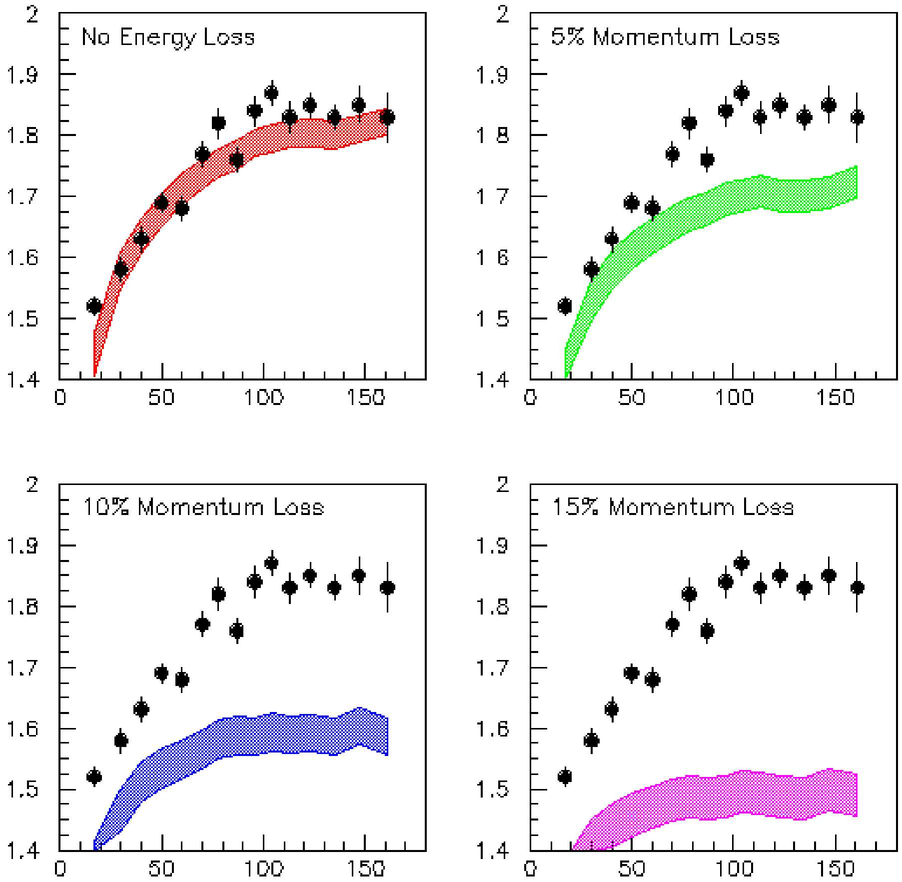

- Prior N-N Collisions broaden transverse momentum ("Cronin effect")
- J/Ψ: $<p_t^2>_{pp} = 1.23 \pm 0.05$ GeV$^2$ (NA3); $\Delta p_t^2$=0.125 GeV$^2$ (fit to pA + AA, Kharzeev et al, PLB 405, 14 (1997))
- DY: $<p_t^2>_{pp} = 1.38 \pm 0.07$ GeV$^2$ (NA3); $\Delta p_t^2$=0.056 GeV$^2$ (fit to pA + AA, Gavin and Gyulassy, PLB 214, 241 (1988))

# Drell-Yan $\langle p_t^2 \rangle$ with Energy Loss



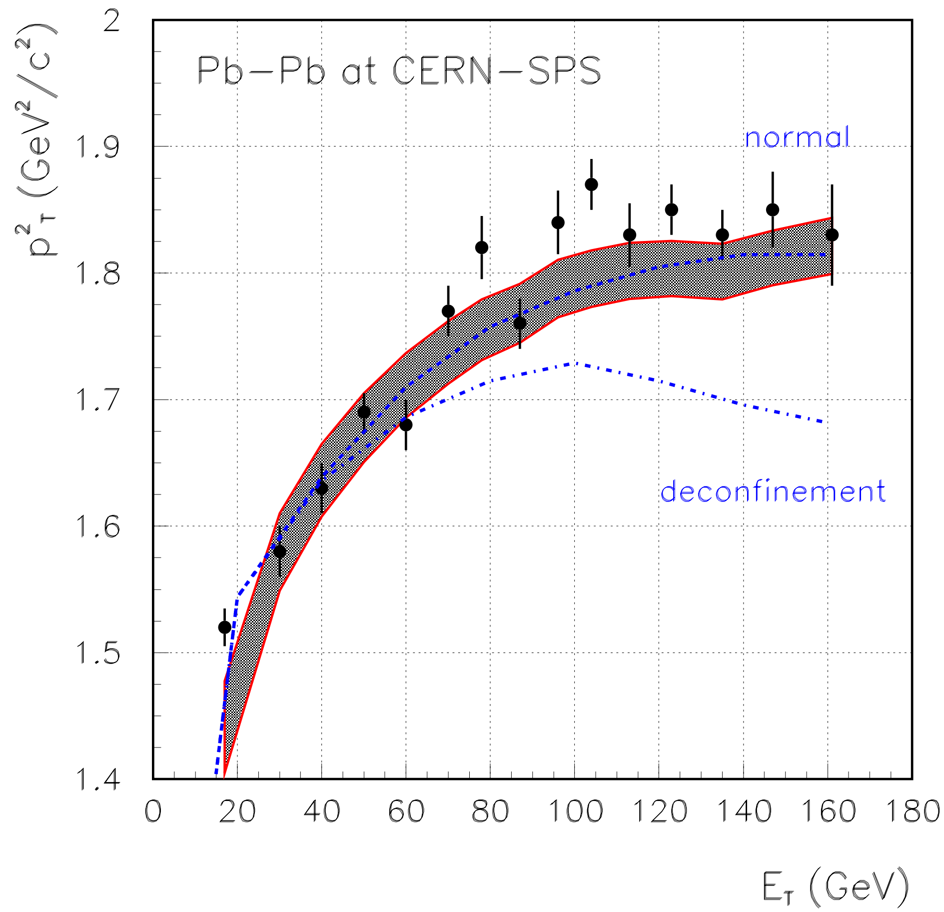

- Several values of Energy Loss 0%, 5%, 10% and 15% momentum per collision
- Spectra not very sensitive to energy loss

# J/Ψ $\langle p_t^2 \rangle$ with Energy Loss




- Several values of Energy Loss 0%, 5%, 10% and 15% momentum per collision
- Large values of Energy Loss do not fit data
- Not consistent with Energy Loss required to fit J/Ψ yields

# Is QGP necessary to fit J/Ψ $<p_t^2>$?




- Must take error in pp data into account
- pp data taken at 200 GeV; scaling to 158 GeV (linear in s) reduces pp "intercept" to 1.13 GeV$^2$--changes normalization, not shape
- J.L.Nagle, MJB, Phys. Lett. B465, 21 (1999)
- D.Kharzeev, M.Nardi, H.Satz, Phys. Lett. B405, 14 (1997). Concluded QGP necessary to fit data, but shown here rescaled for pp energy.

# Conclusions (Part 1)

- Within normalization uncertainty, J/Ψ $<p_t^2>$ spectrum is consistent with a normal hadronic scenario
- J/ Ψ Yields are not consistent with a simple Glauber calculation. Adding Energy Loss can fit the J/Ψ yield shape ...BUT
- Energy Loss cannot consistently fit both J/Ψ and Drell-Yan yields
- Energy Loss cannot consistently fit both J/Ψ yields and J/Ψ $<p_t^2>$ spectra
- Energy Loss does not appear to explain "anomalous" J/Ψ suppression

# Requirements for Analysis

- J/Ψ Measurement

  Yields and Transverse Momenta Spectra

  Both over a large range of system size, from pp, pA, several AA

- Benchmark measurement

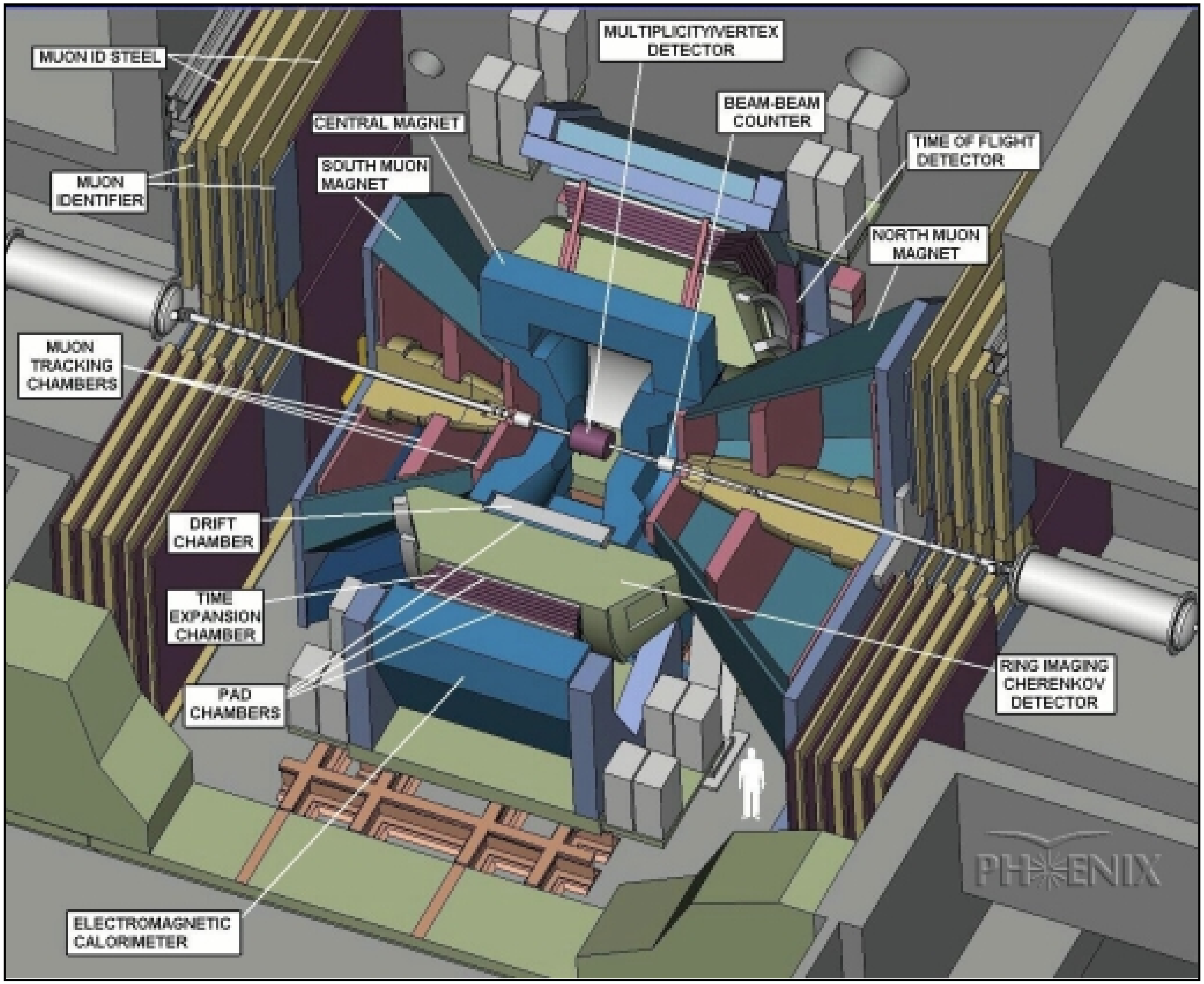
  Drell-Yan over same range of geometries

- Collision Dynamics

  Energy loss systematics from pA, AA

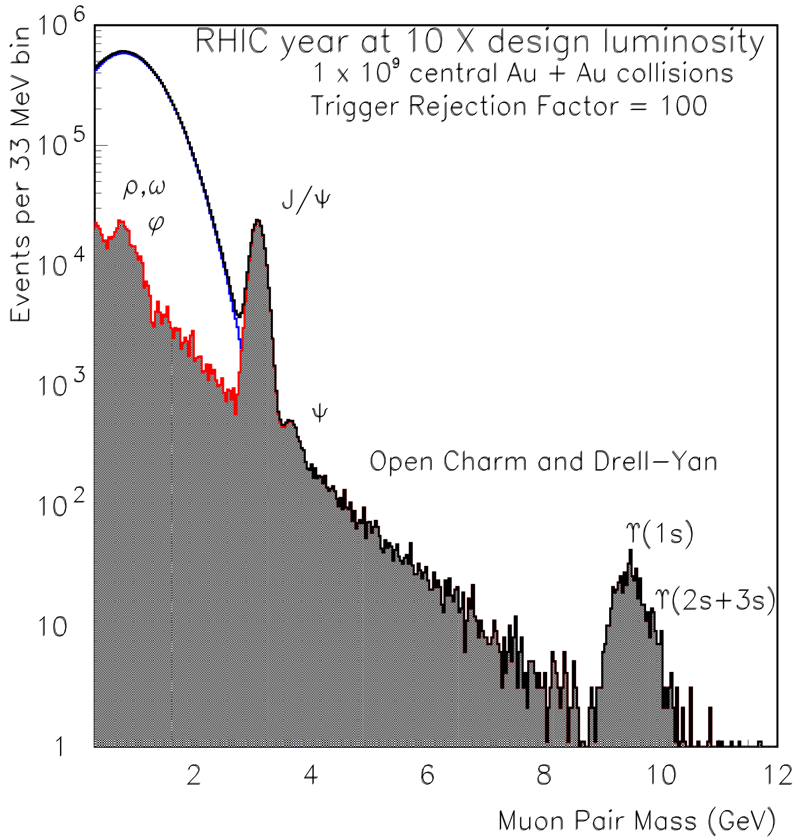
  Geometric dependence of $E_t$, secondary multiplicity

# PHENIX Experiment at RHIC

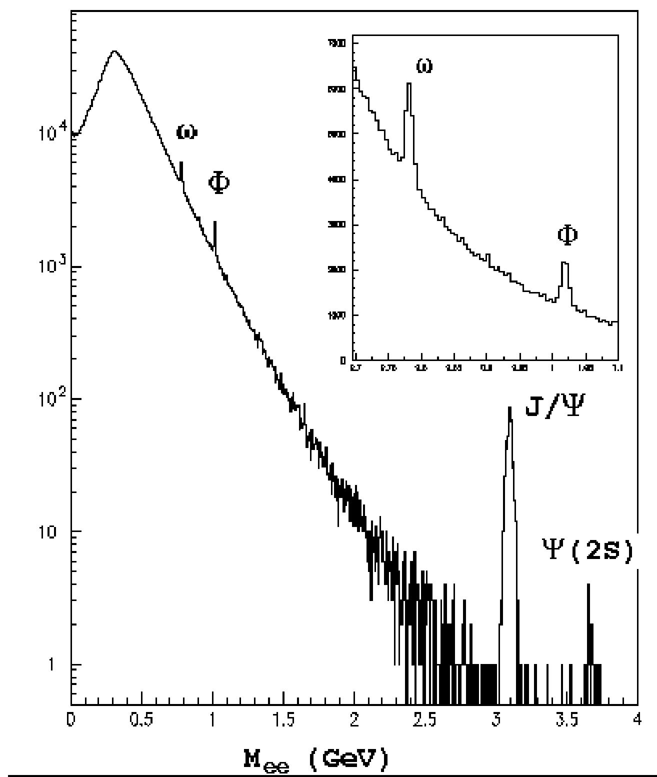


# Dileptons in PHENIX

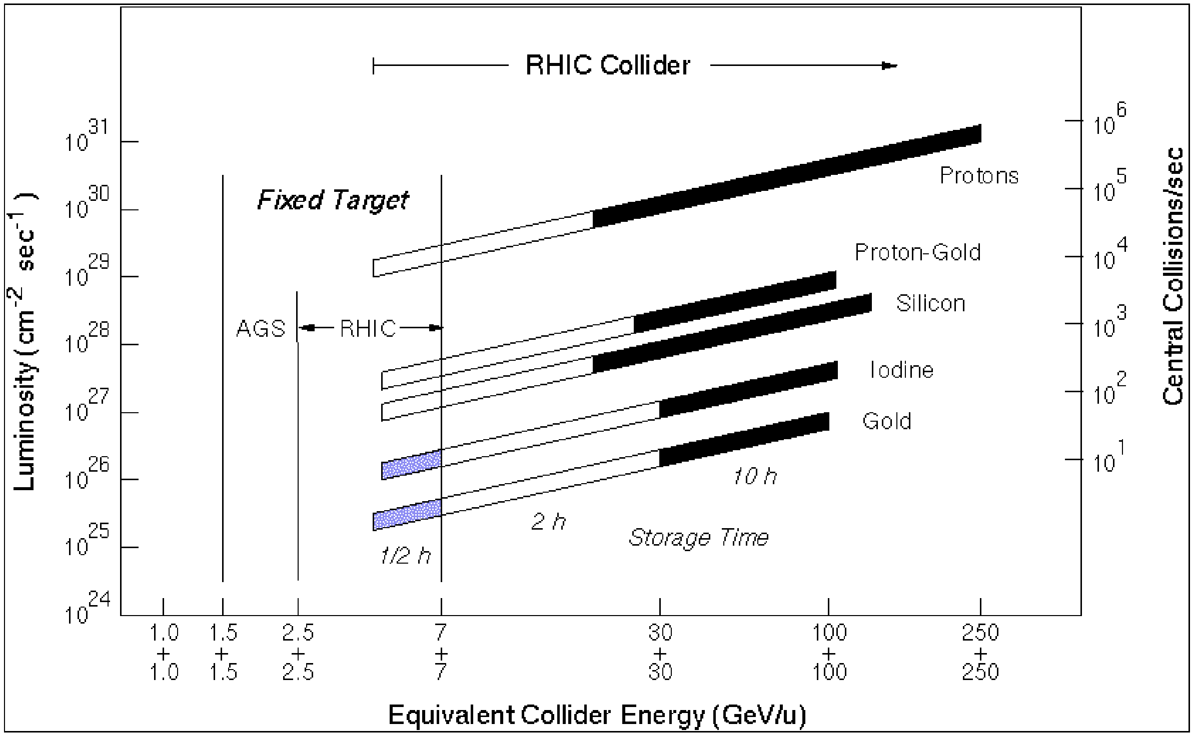
## Dimuon spectrum




## Dielectron Spectrum



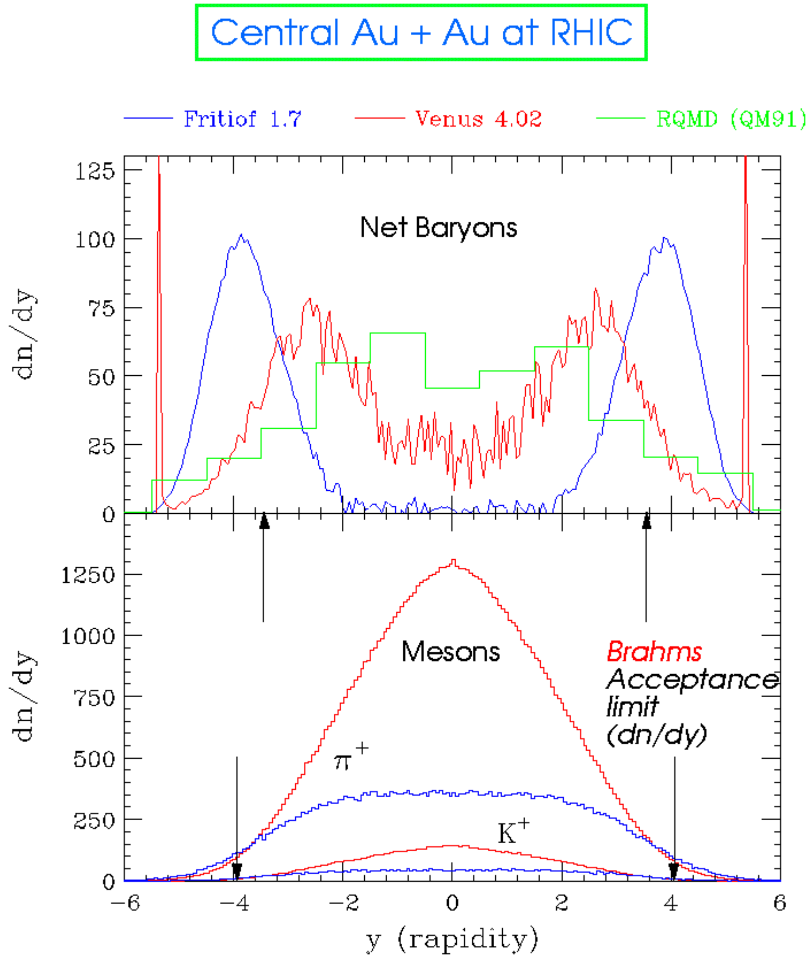
# RHIC -- A Versatile Accelerator



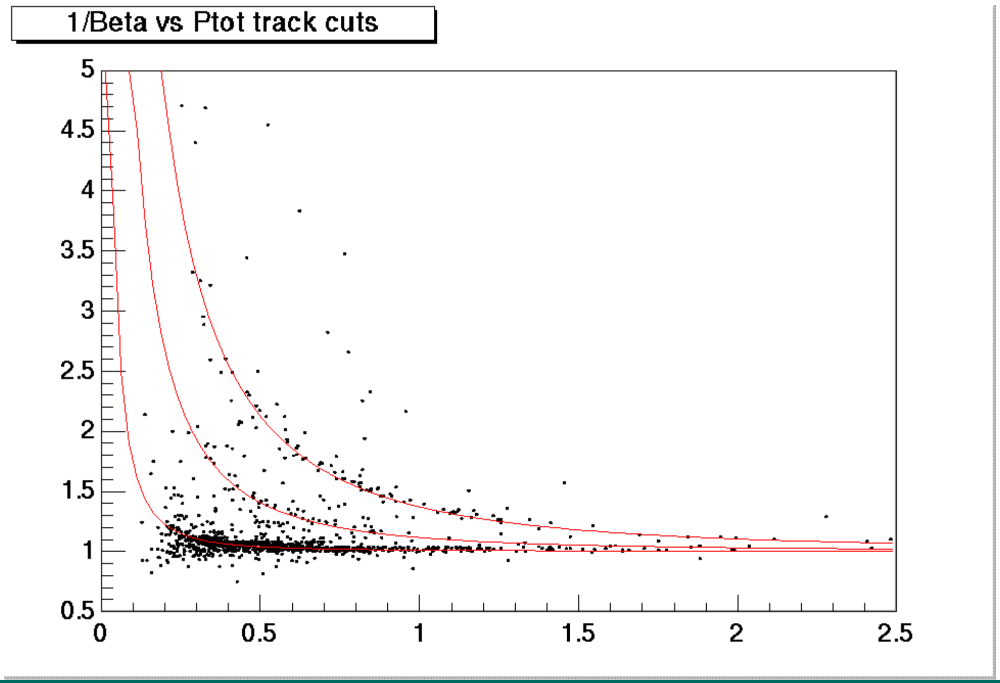

- Heavy Ion Program  Vary Species and Beam Energy
- p-A Program, Spin Program  polarized protons
- Four Experiments  Complementary Physics, Common Centrality Measurement

# Extrapolating to RHIC

- Large uncertainty in extrapolating collision dynamics from AGS/SPS to RHIC
- Proton dN/dy measured over large phase space by BRAHMS
- Charged Particle Multiplicity measured over large phase space by PHENIX MVD, PHOBOS, STAR
- These distributions are essential to understanding the environment in which the J/Ψ is produced



# Hadrons in PHENIX




- Measure transverse momentum in central arms to ~1%
- Identified hadrons in central arms

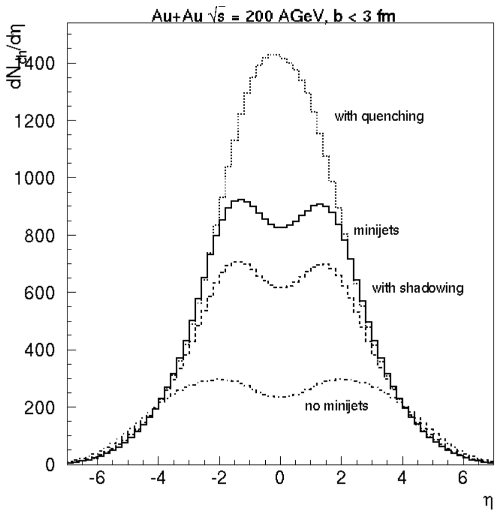
  $\pi$/K to 2.5 GeV using TOF

  K/p to 3.5 GeV using TOF
- Simulations ongoing to assess full PID capability of PHENIX

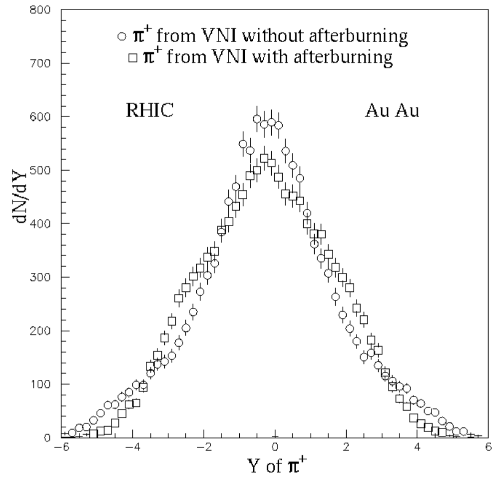
# Hard Processes and Multiplicity

- Hard Processes generate ~50% of particle multiplicity at RHIC (Gyulassy)
- Simple extrapolation from AGS/SPS not valid
- Interesting physics in measuring multiplicity
- Measurement of charged particle transvere momenta spectra constrain hadronic comover models

HIJING with various parton processes




VNI Parton Cascade with hadronic cascade



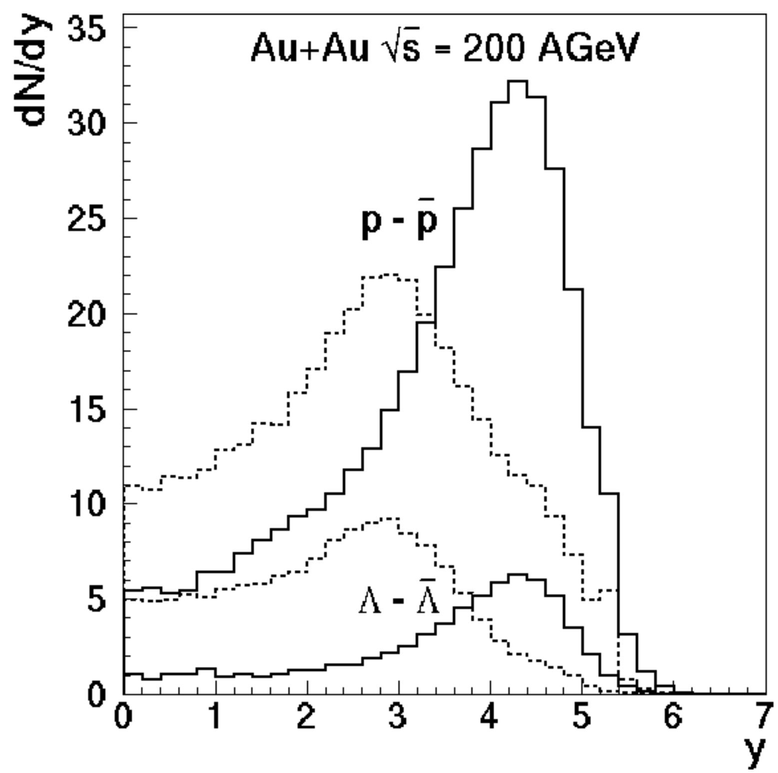
# Baryon Structure at RHIC?

- Recent revival of old idea-- baryon junction
- "ball" of soft gluons is basis of baryons, with 3 valence quarks held by color "strings"
- Not ruled out by existing data
- Observables at RHIC--

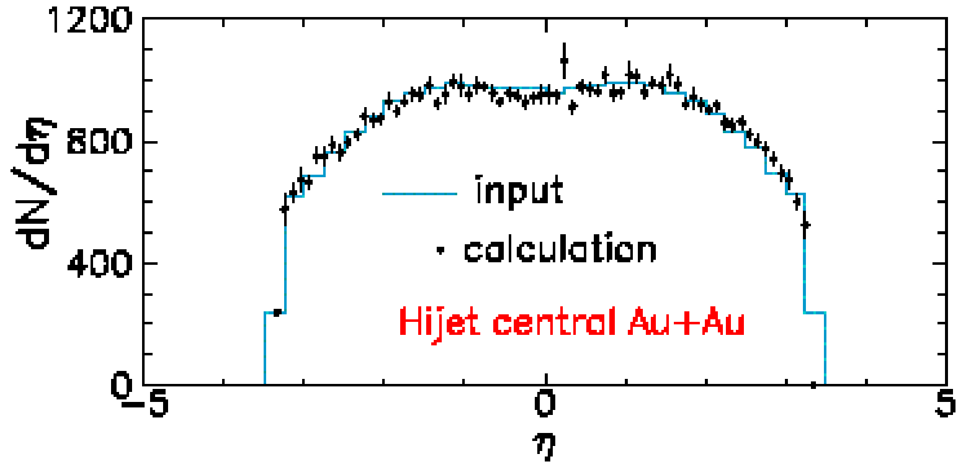
  Antibaryon / baryon ratio at
  mid-rapidity (PHENIX)

  Baryon stopping (BRAHMS)

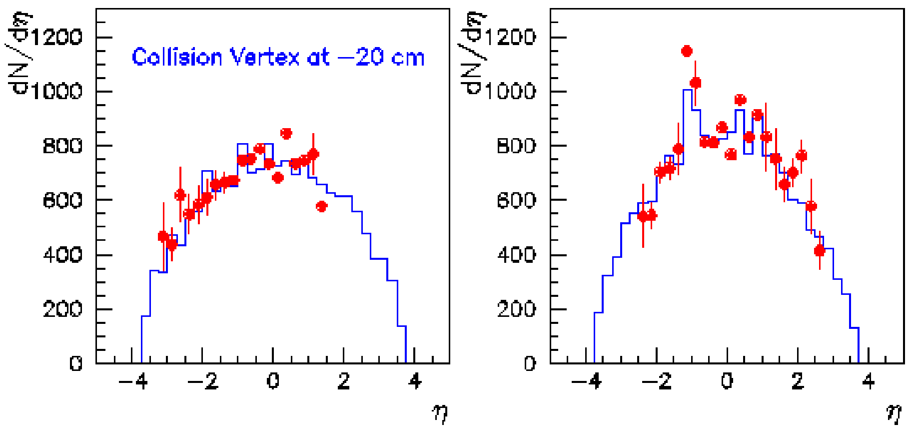
  Hard forward mesons (BRAHMS)
- Impact on J / Ψ yield is under investigation



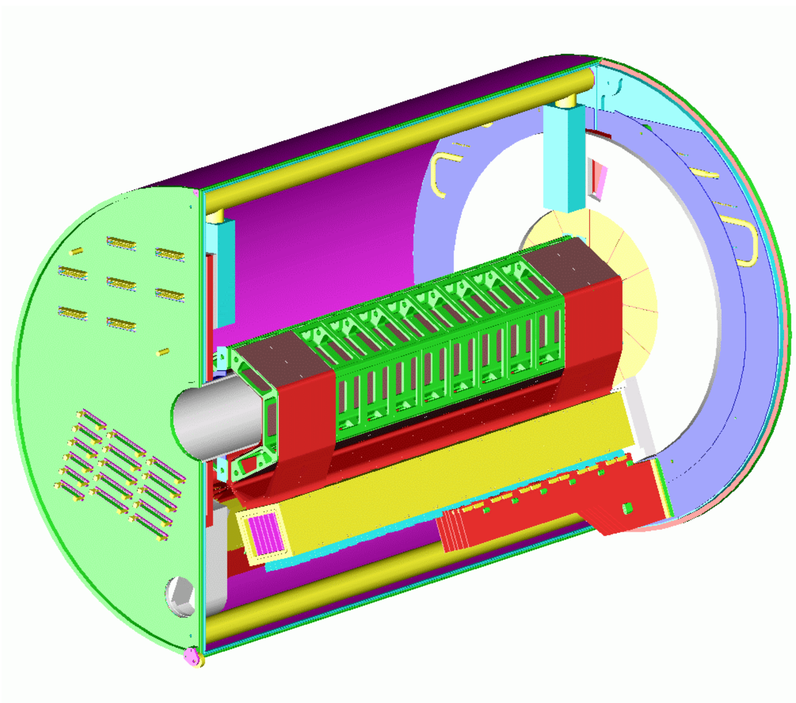
# Multiplicity in PHENIX




- Measure Charged Particle Multiplicity accurately over large pseudorapidity range
- Measure dN / dη, dN / dηdϕ
- Sensitive to localized fluctuations on an event-by-event basis

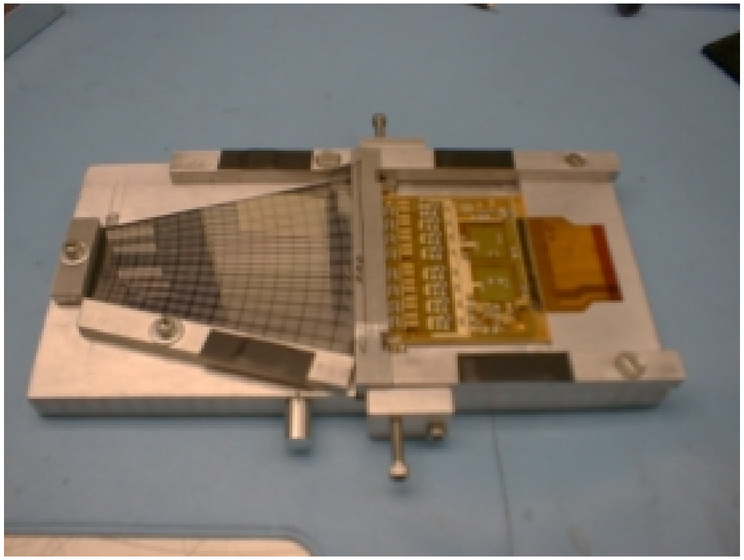


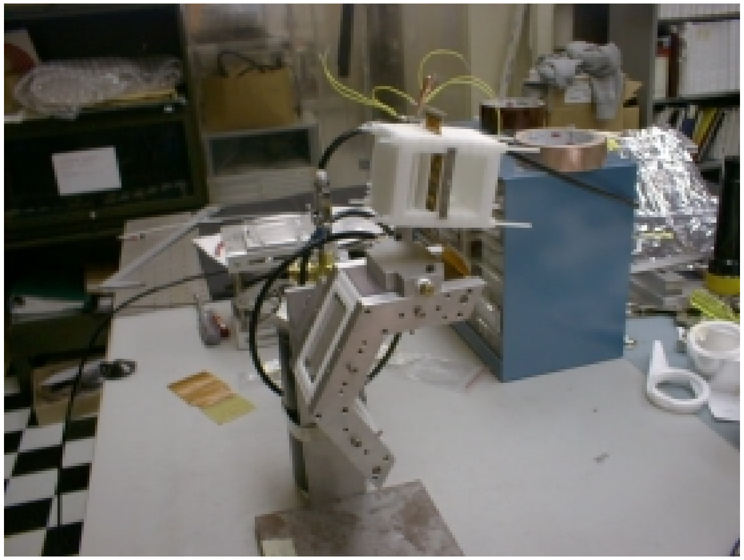
# PHENIX MVD

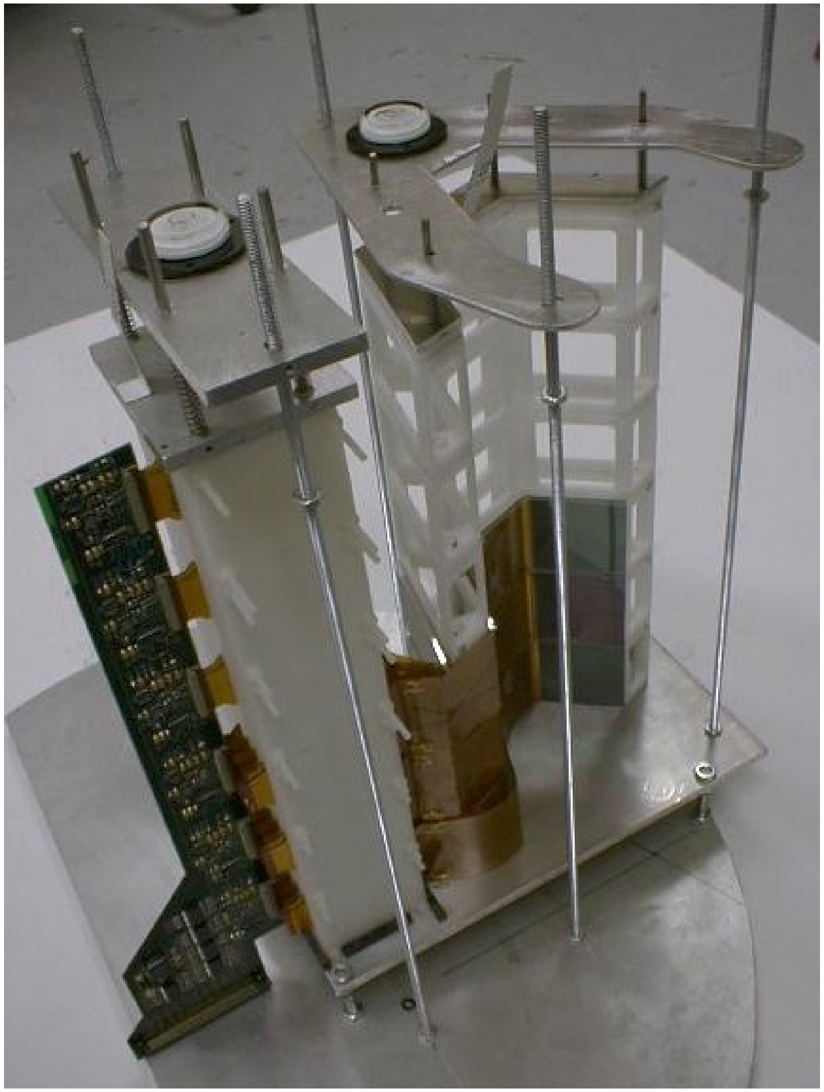


- Inner and Outer Hexagonal Barrels of 200 micron pitch Si Microstrips
- Si Pad Endcaps $2mm^2$ to $4.5mm^2$
- Multichip Module Electronics, 256 Channels in ~$4.5cm^2$
- ~35,000 Total Channels

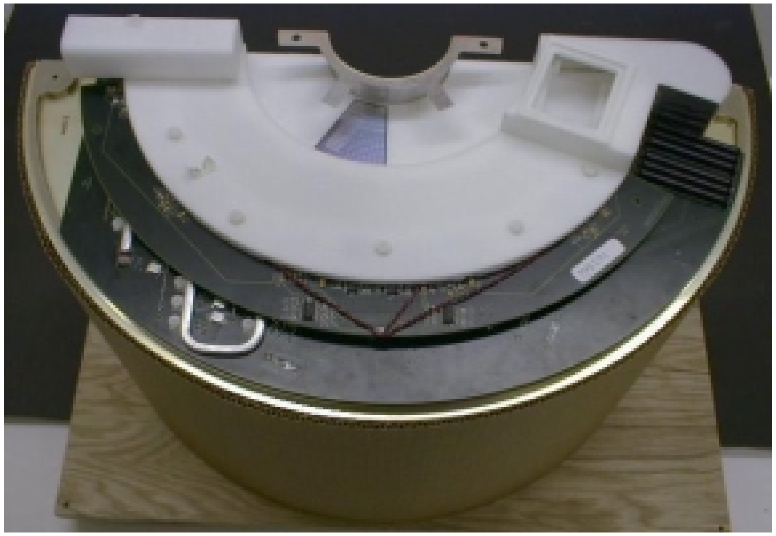
# MVD Construction

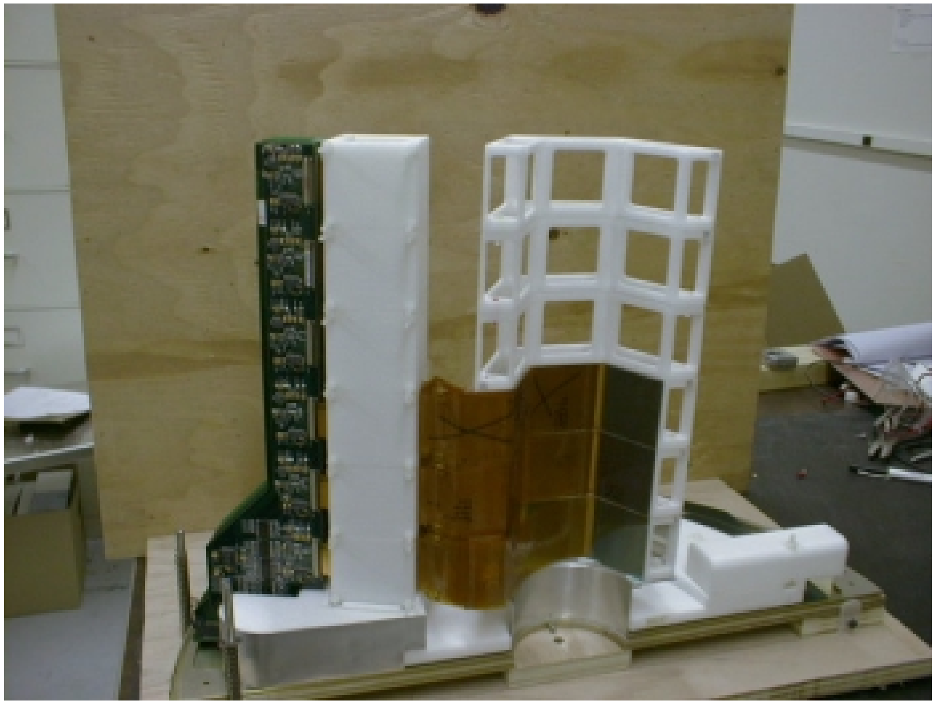






# MVD Construction (II)





# Conclusions (Part 2)

- A full understanding of J/Ψ suppression will require systematic measurement of yields over numerous geometries AND an understanding of the collision dynamics
- PHENIX is well situated to measure J/Ψ and higher mass states in both muon and electron channels
- PHENIX is well situated to investigate collision dynamics via global variables and hadron spectra
- Expect collision dynamics to be the most interesting physics early in the RHIC program
- These measurements will set the context for later physics analyses