Quarkonium production from d-Au to Au-Au

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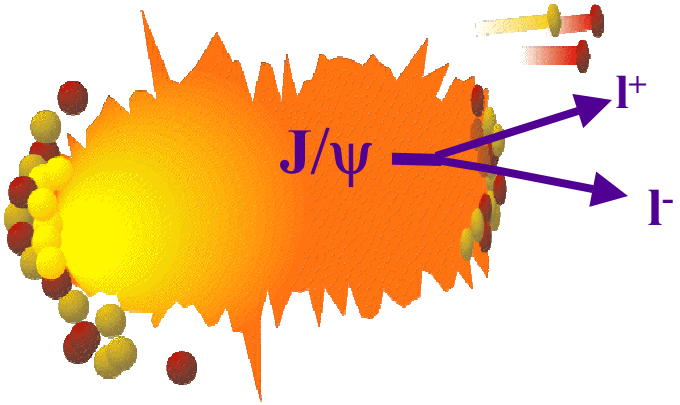


Hard Probes 2004
Ericeira, Portugal
November 5, 2004

Outline

- **Charmonium at RHIC**
- **The PHENIX Detector**
- **Charmonium Measurements in PHENIX**
  - p-p Collisions
  - d-Au Collisions
  - First Measurement in Au-Au Collisions
- **Summary, conclusions, and outlook.**

Charmonium Physics at RHIC

- **We expect a screening of the attractive potential as we approach the deconfinement transition**
- **This color screening may results in a decrease in the number of heavy quarkonia states**
- **Alternative models predict enhancement from c-cbar coalescence as the collision volume cools.**
  - ⇨ Comparisons between various collision species are very important.
  - ⇨ Studies done via both dielectron and dimuon channels in PHENIX.

PHENIX Collaboration

12 Countries; 58 Institutions; 480 Participants*

*as of January 2004

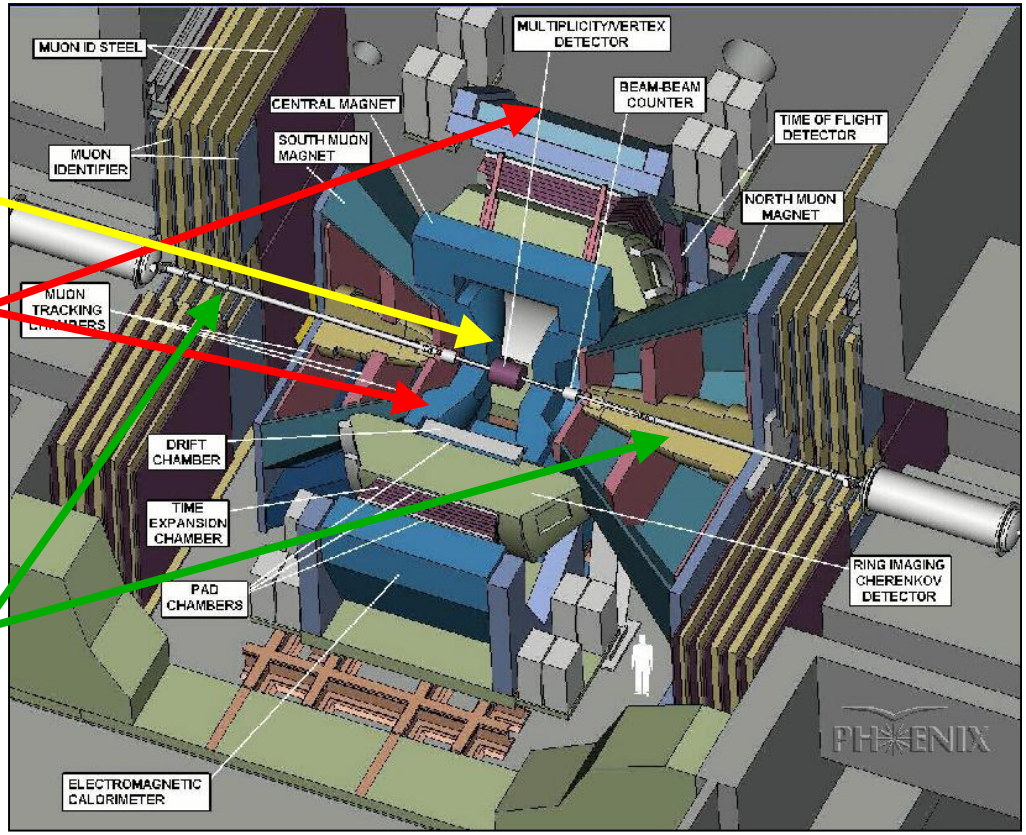
Brazil	University of São Paulo, São Paulo
China	Academia Sinica, Taipei, Taiwan
	China Institute of Atomic Energy, Beijing
	Peking University, Beijing
France	LPC, University de Clermont-Ferrand, Clermont-Ferrand
	Dapnia, CEA Saclay, Gif-sur-Yvette
	IPN-Orsay, Universite Paris Sud, CNRS-IN2P3, Orsay
	LLR, Ecòle Polytechnique, CNRS-IN2P3, Palaiseau
	SUBATECH, Ecòle des Mines at Nantes, Nantes
Germany	University of Münster, Münster
Hungary	Central Research Institute for Physics (KFKI), Budapest
	Debrecen University, Debrecen
	Eötvös Loránd University (ELTE), Budapest
India	Banaras Hindu University, Banaras
	Bhabha Atomic Research Centre, Bombay
Israel	Weizmann Institute, Rehovot
Japan	Center for Nuclear Study, University of Tokyo, Tokyo
	Hiroshima University, Higashi-Hiroshima
	KEK, Institute for High Energy Physics, Tsukuba
	Kyoto University, Kyoto
	Nagasaki Institute of Applied Science, Nagasaki
	RIKEN, Institute for Physical and Chemical Research, Wako
	RIKEN-BNL Research Center, Upton, NY
	Rikkyo University, Tokyo, Japan
	Tokyo Institute of Technology, Tokyo
	University of Tsukuba, Tsukuba
	Waseda University, Tokyo
S. Korea	Cyclotron Application Laboratory, KAERI, Seoul
	Kangnung National University, Kangnung
	Korea University, Seoul
	Myong Ji University, Yongin City
	System Electronics Laboratory, Seoul Nat. University, Seoul
	Yonsei University, Seoul
Russia	Institute of High Energy Physics, Protovino
	Joint Institute for Nuclear Research, Dubna
	Kurchatov Institute, Moscow
	PNPI, St. Petersburg Nuclear Physics Institute, St. Petersburg
	St. Petersburg State Technical University, St. Petersburg
Sweden	Lund University, Lund
USA	Abilene Christian University, Abilene, TX
	Brookhaven National Laboratory, Upton, NY
	University of California - Riverside, Riverside, CA
	University of Colorado, Boulder, CO
	Columbia University, Nevis Laboratories, Irvington, NY
	Florida State University, Tallahassee, FL
	Florida Technical University, Melbourne, FL
	Georgia State University, Atlanta, GA
	University of Illinois Urbana Champaign, Urbana-Champaign, IL
	Iowa State University and Ames Laboratory, Ames, IA
	Los Alamos National Laboratory, Los Alamos, NM
	Lawrence Livermore National Laboratory, Livermore, CA
	University of New Mexico, Albuquerque, NM
	New Mexico State University, Las Cruces, NM
	Dept. of Chemistry, Stony Brook Univ., Stony Brook, NY
	Dept. Phys. and Astronomy, Stony Brook Univ., Stony Brook, NY
	Oak Ridge National Laboratory, Oak Ridge, TN
	University of Tennessee, Knoxville, TN
	Vanderbilt University, Nashville, TN

PHENIX Detector

Event characterization detectors in middle

Two central arms for measuring hadrons, photons and electrons

Two forward arms for measuring muons



$J/\psi \rightarrow ee$ in central arms

electron measurement in range:

$|\eta| \leq 0.35$

$p_e \geq 0.2$ GeV/c

$J/\psi \rightarrow \mu\mu$ in forward arms

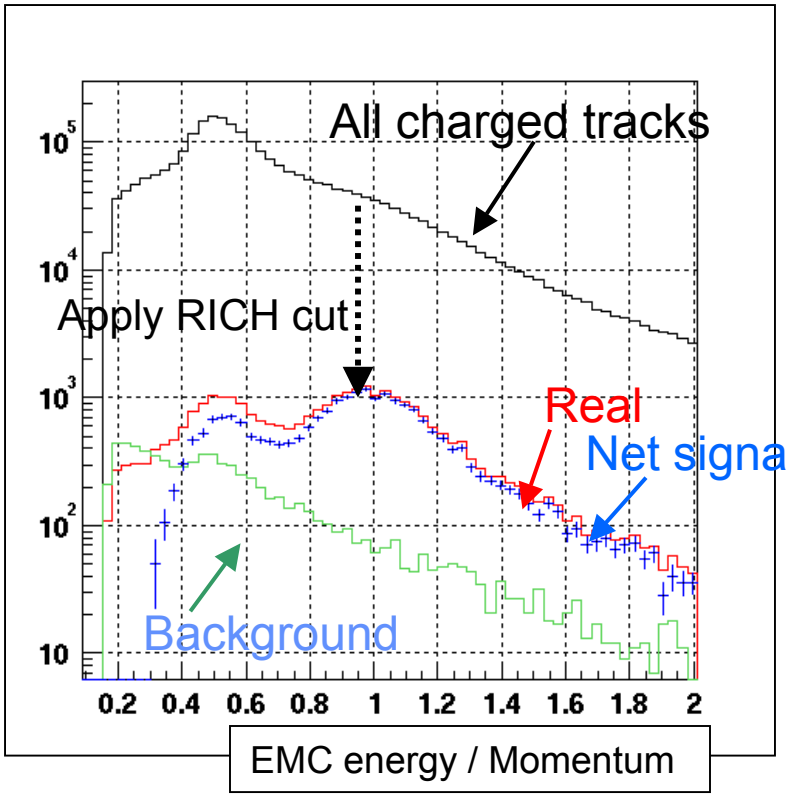
muon measurement in range:

$1.2 < |\eta| < 2.4$

$p_\mu \geq 2$ GeV/c

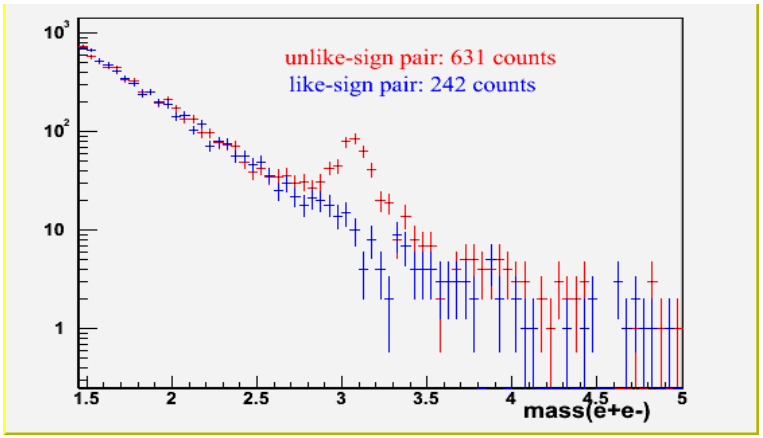
Electron Identification

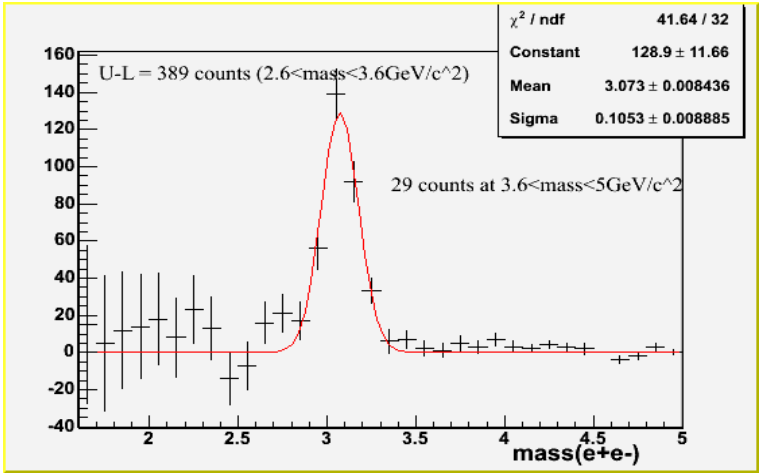
- **PHENIX has excellent electron identification capabilities.**
  - Ring Imaging Cherenkov Counter - threshold selection
  - TEC/TRD - dE/dx and TR measurement
  - Electromagnetic Calorimeter - Energy-Momentum match



Di-electron analysis

Example : dAu sample



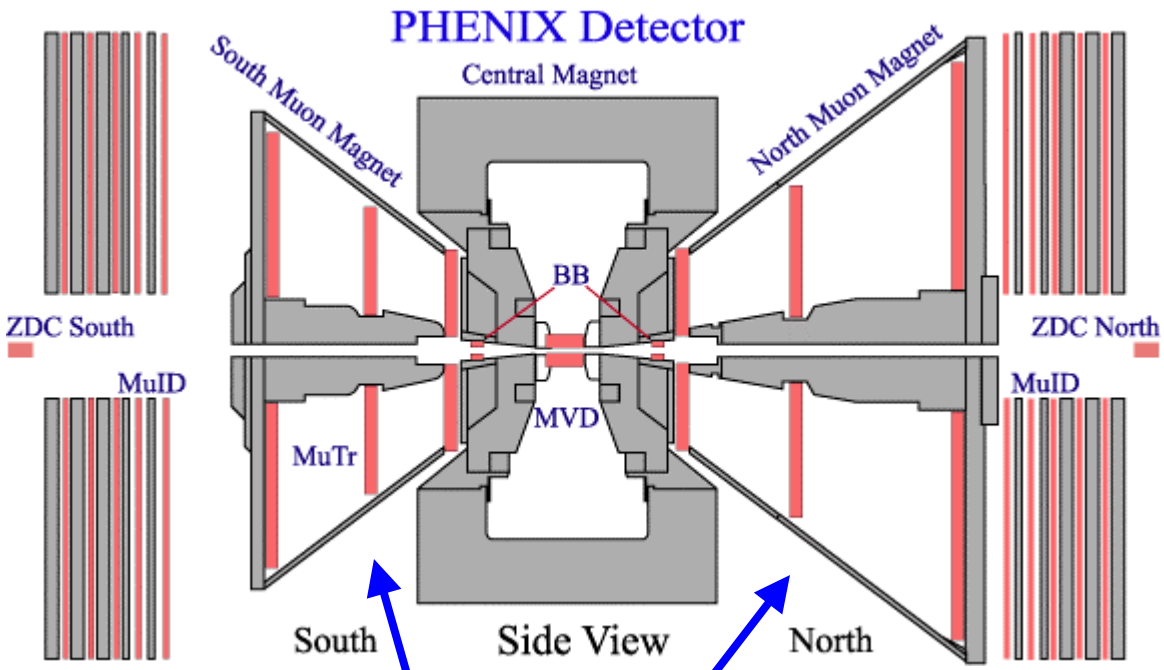


Mass Resolution ~ 100 MeV

- **Identify electron**
  - RICH ring cut
  - $0.5 < E/p < 1.5$
- **Di-electron invariant mass spectra**
- **Subtract combinatorial background**
  - **Signal = N_{+-} - (N_{++} + N_{--})**
    Count J/ψ
- **Correct for acceptance and efficiencies**

  → Cross section

Muon Measurements



Muon tracker (MuTR)

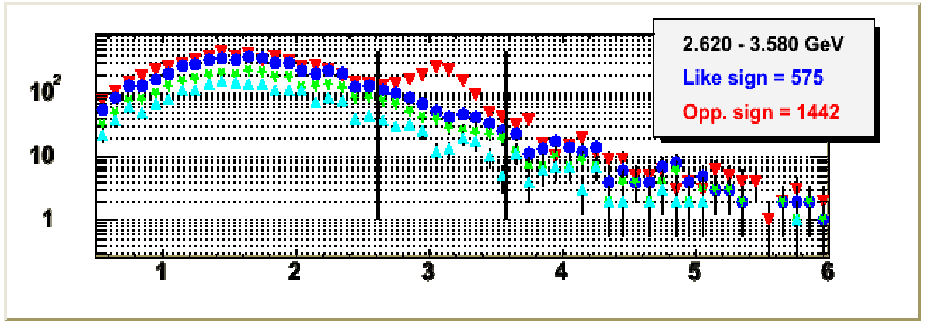
3 stations of cathode strip chambers per arm

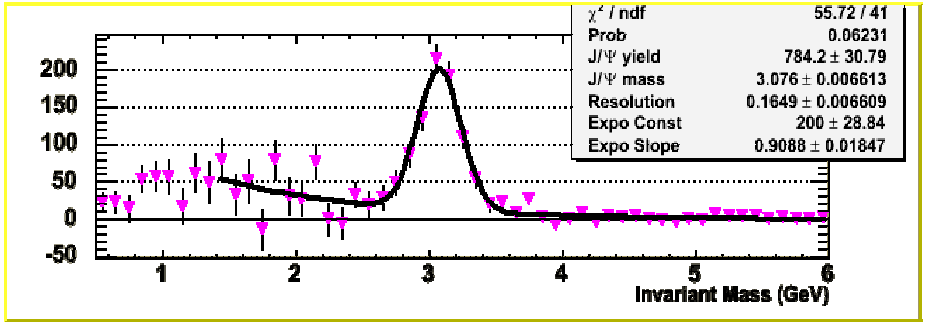
Muon identifier (MuID)

5 gaps per arm filled with planes of transversely oriented Iarocci tubes

Di-muon analysis

Example : dAu North Arm Sample





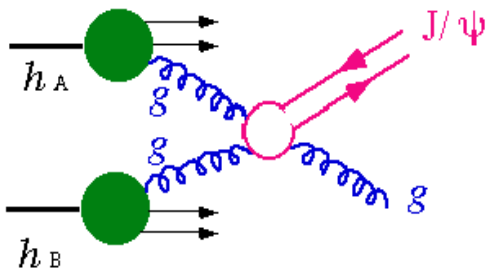
Mass Resolution ~ 150 to 200 MeV

- **Identify muons**
  - Depth in Identifier
- **Di-muon inv. mass spectra**
- **Subtract combinatorial backgrounds**
  - Signal = $N_{+-} - 2\sqrt{(N_{++})(N_{--})}$
- **Work in progress to quantify physical backgrounds :**
  - Open charm & beauty, Drell-Yan, a hint of ψ'

  For now: fit gauss J/ψ+exp bg
- **Correct for acceptance and efficiencies**

  → Cross section

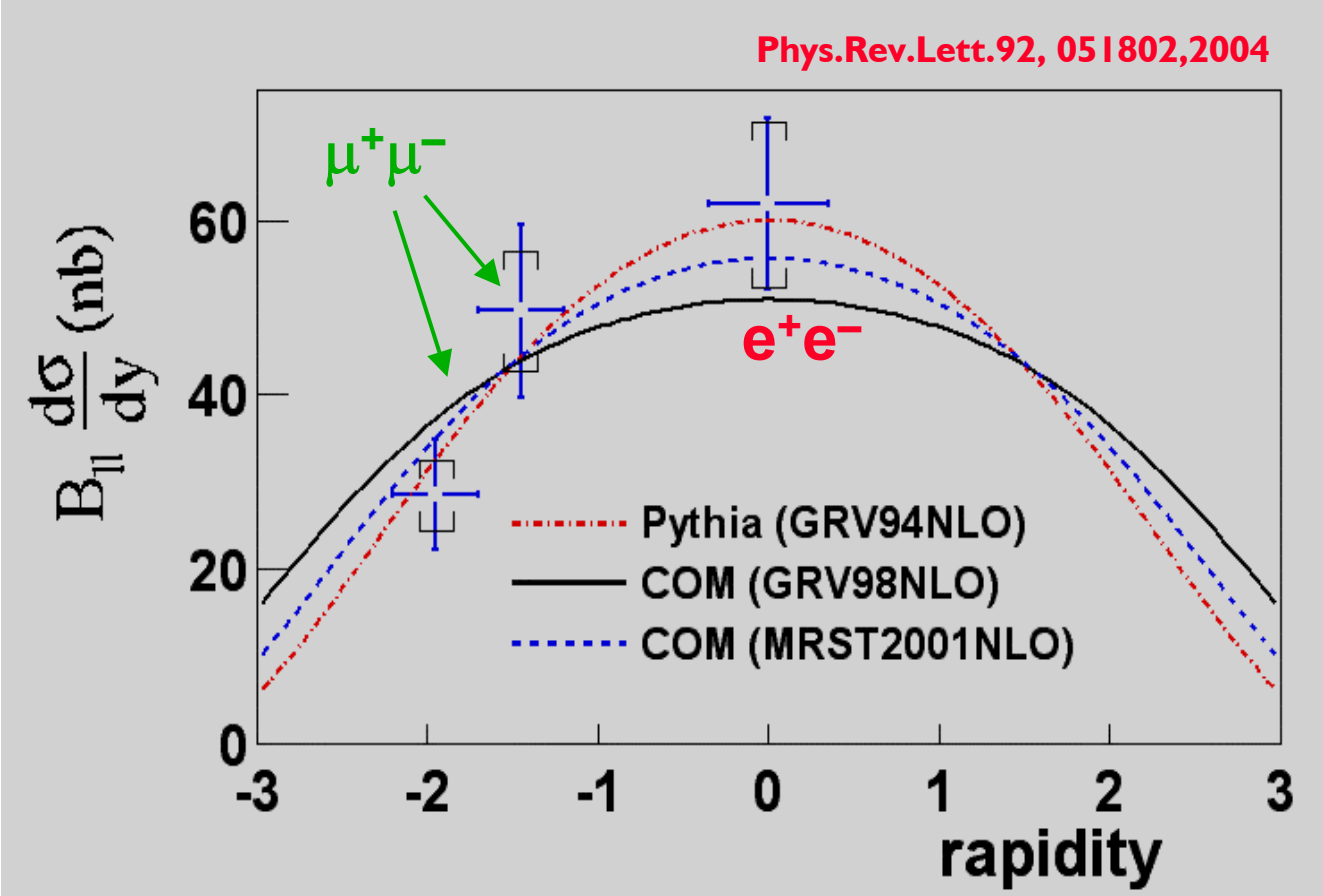
Do we understand the basic production mechanism?



- **The production mechanism of charmonium in p-p collisions is not yet well understood.**
  - Color evaporation model, Color singlet model, Color octet model
  - Polarization, Rapidity dependence (electron and muon channels)
  - Production of J/Ψ, Ψ',.. states

- **We need a good measurement of J/ψ cross section in p+p at RHIC**
  - Base line for pA and AA

J/Ψ in p+p Collisions @ 200 GeV (2002 data)



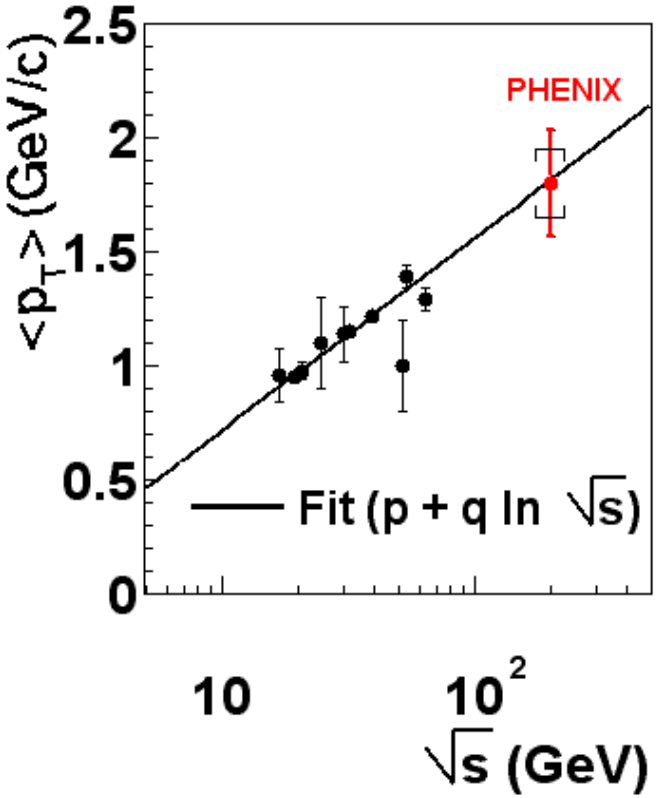
Results consistent with shapes from various models and PDF.

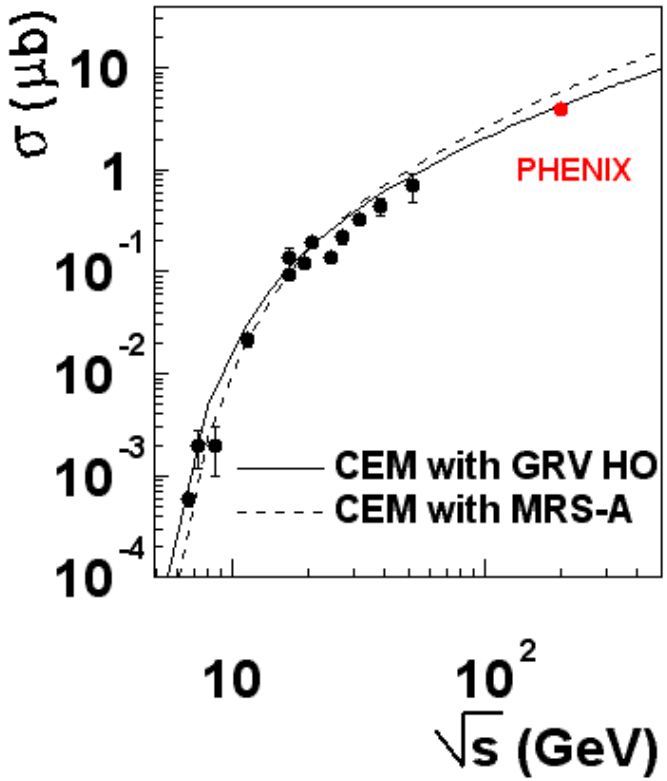
Take the PYTHIA shape to extract our cross-section

Integrated cross-section :

234 ± 36 (stat) ± 34 (sys) ± 24(abs) nb

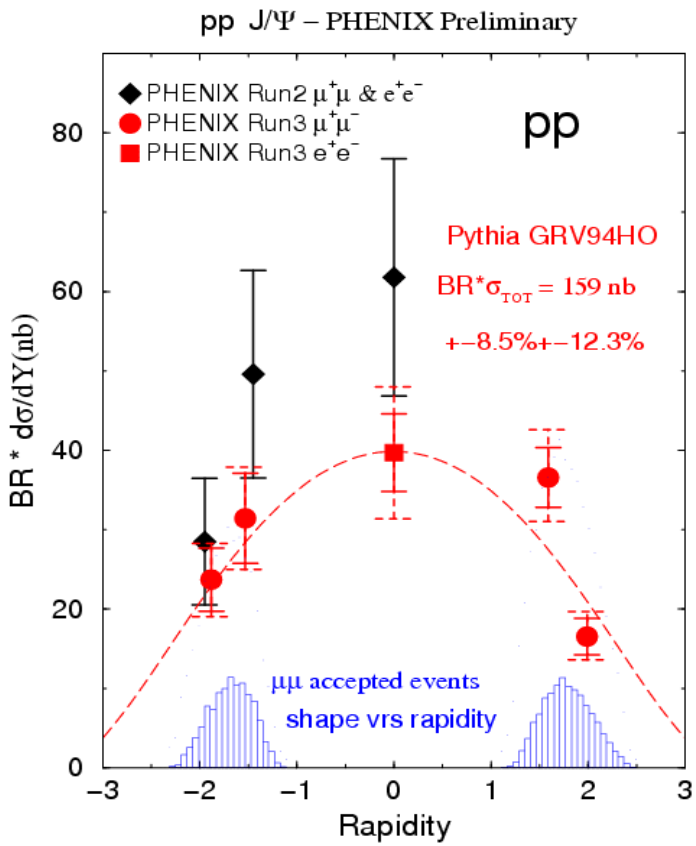
Energy Scaling

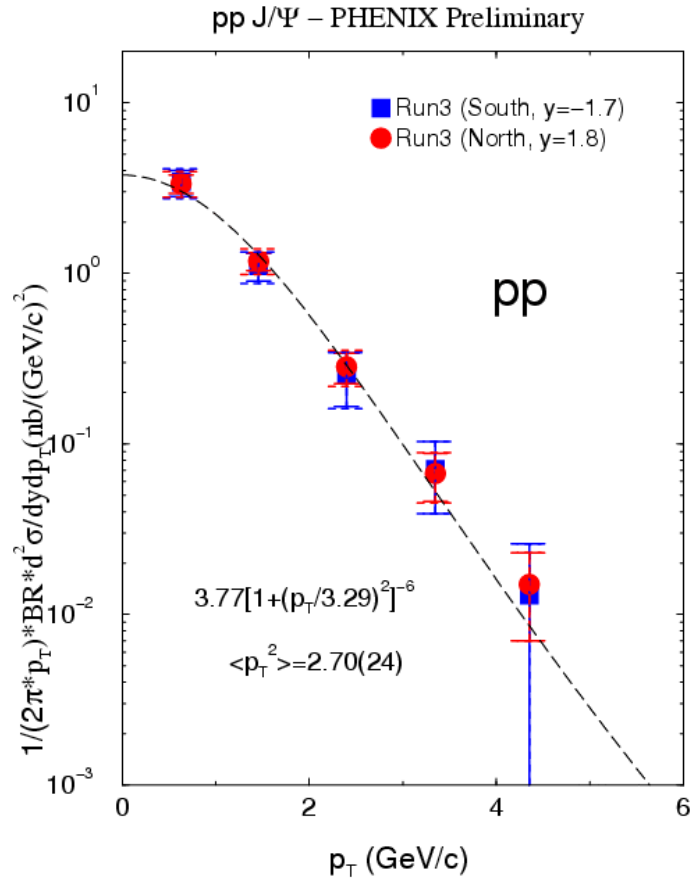




- **Phenomenological fit for average pT**
  - p = 0.531, q= 0.188
- **Cross-section well described by e.g. Color Evaporation Model.**

J/Ψ in p+p Collisions @ 200 GeV
(2003 Preliminary data)





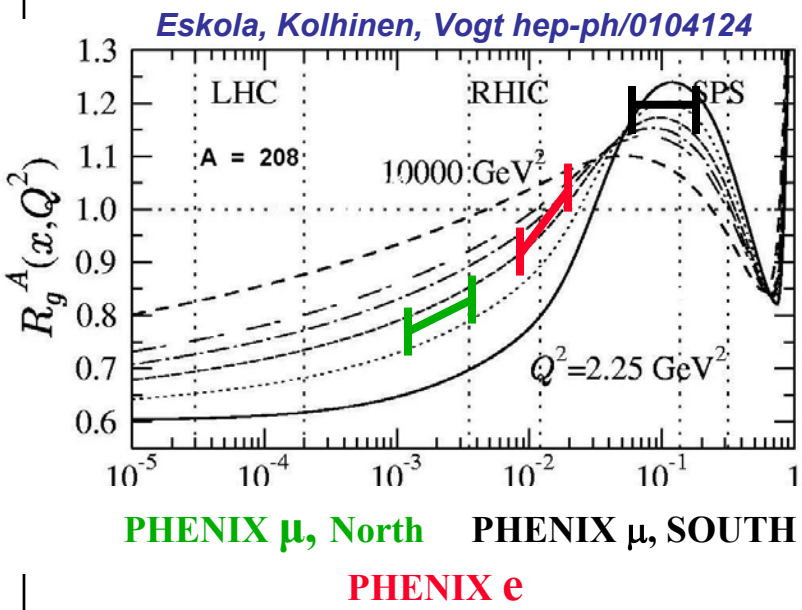
total cross section from Run2 data $BR.\sigma_{tot} = 234 \pm 36 \pm 34 \pm 24$ nb

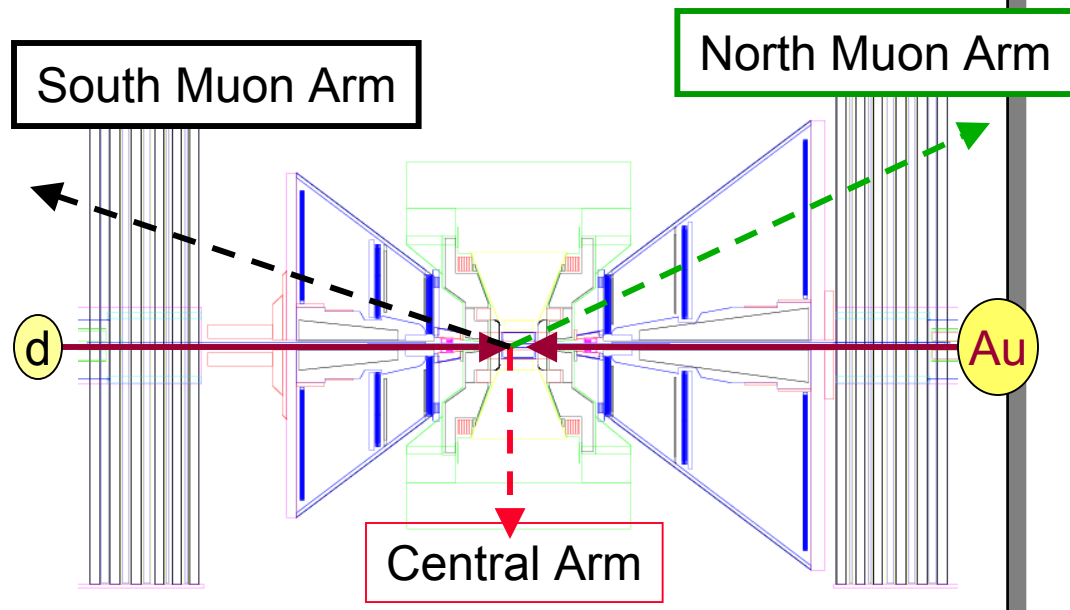
total cross section from Run3 data $BR.\sigma_{tot} = 159$ nb $\pm$ 8.5 % $\pm$ 12.3 %

Charmonium in d-Au Collisions

- **Study of "normal nuclear effects": shadowing and energy loss**
  - Nuclear dependence of $\sigma(J/\Psi)$: A^{α} or σ_{abs} (nuclear absorption)
  - dE/dx not expected to be significant effect at RHIC energies
  - Overall absorption expected
  - Base line for AA

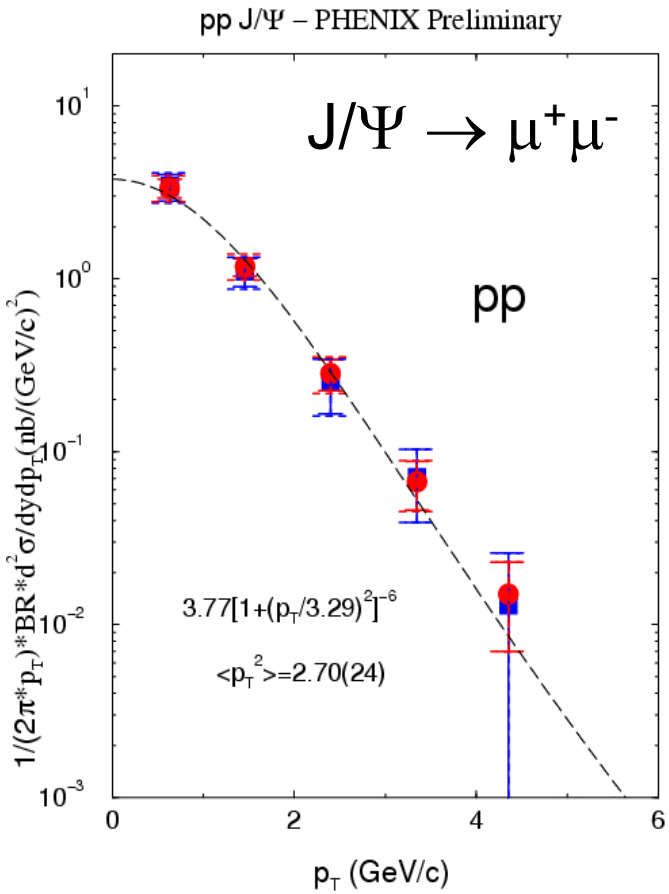
d-Au Collisions

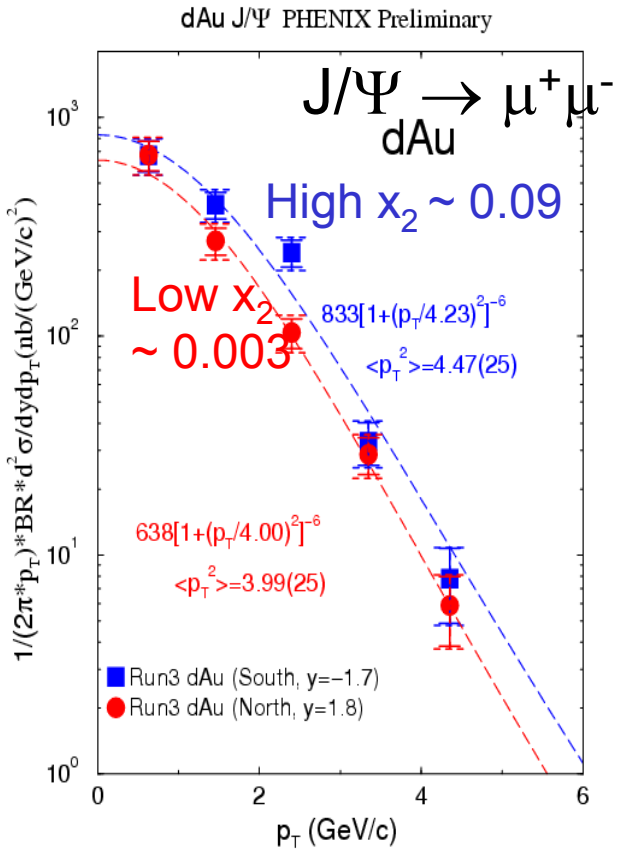




- **PHENIX measurements cover different ranges of the Au parton momentum fraction where shadowing and anti-shadowing are expected**
  - **South (y < -1.2) : large X_2 (in gold) ~ 0.09**
  - **Central (y ~ 0) : intermediate X_2 ~ 0.02**
  - **North (y > 1.2) : small X_2 (in gold) ~ 0.003**

Cross section versus p_T





$\Delta\langle p_T^2\rangle =$

$\langle p_T^2\rangle_{dAu} - \langle p_T^2\rangle_{pp}$

1.77 ± 0.35 GeV^2

1.29 ± 0.35 GeV^2

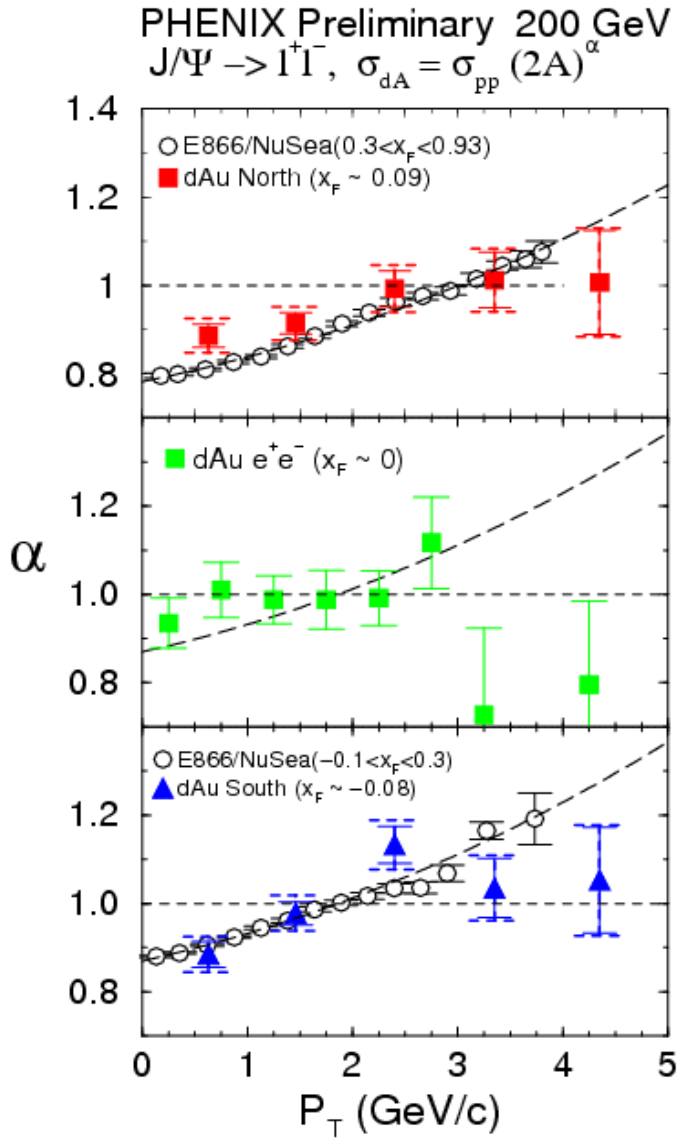
(preliminary)

p_T is broadened for dAu

dAu/pp versus p_T

p_T broadening comparable to lower energy ($\sqrt{s}$ = 39 GeV in E866)

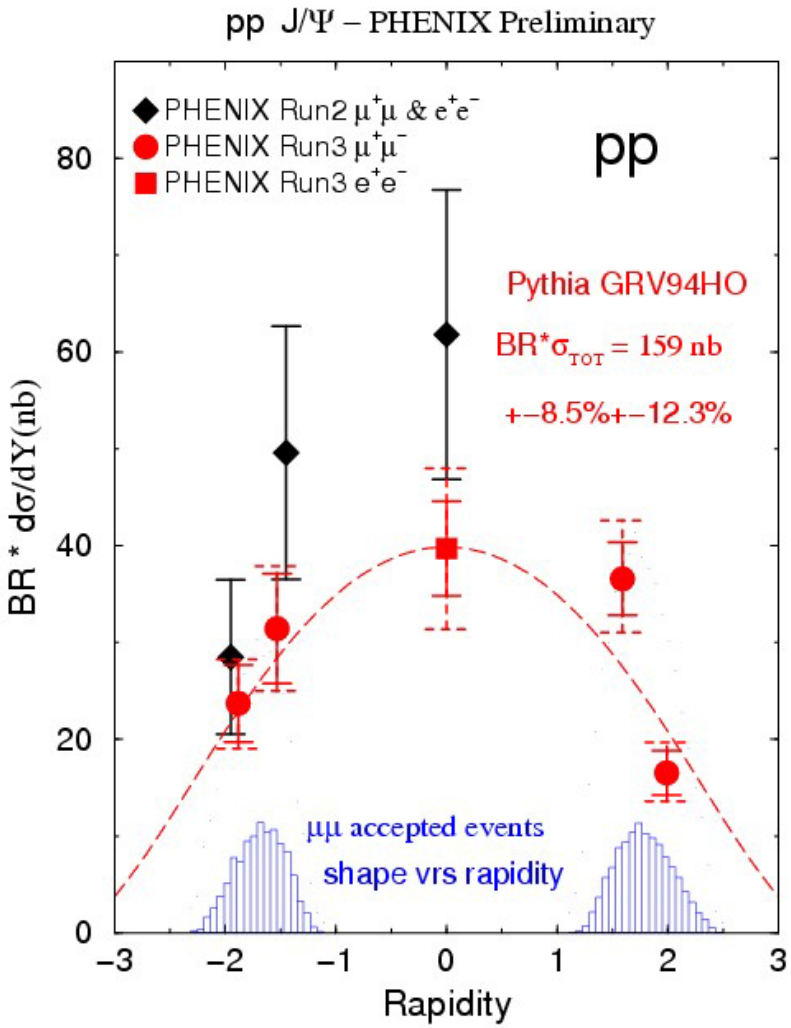
$$\sigma_{dA} = \sigma_{pp}(2\times197)^{\alpha}$$

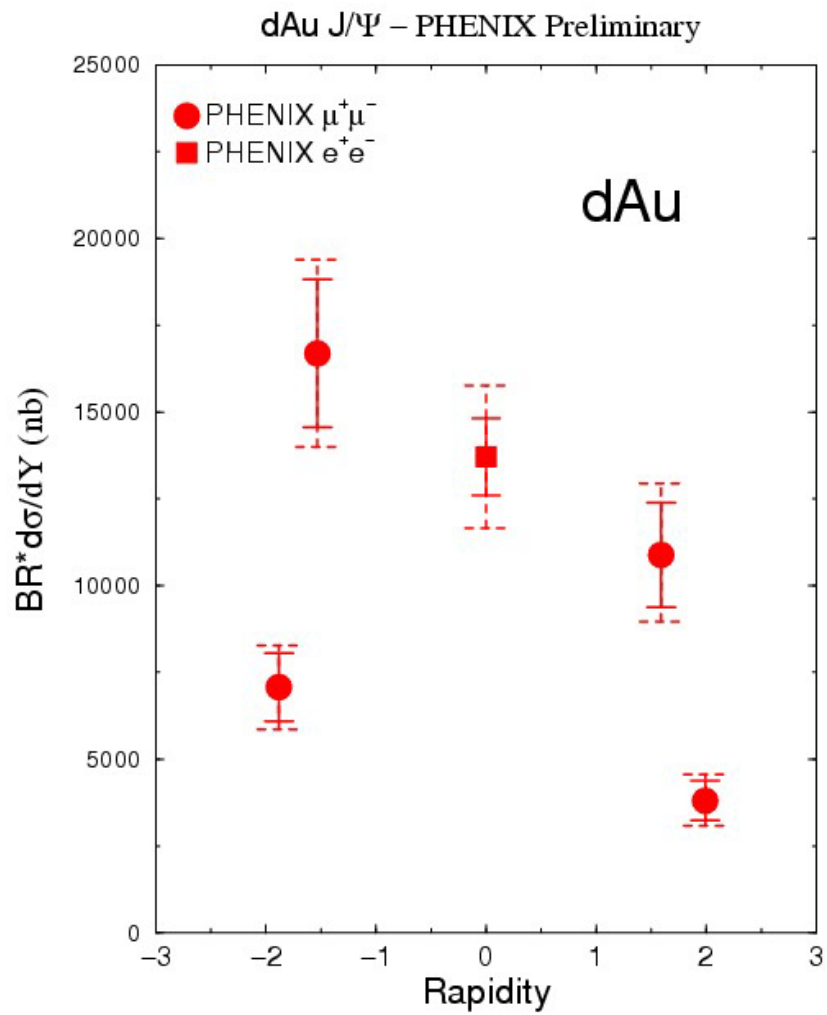


Low x_2 ~ 0.003

High x_2 ~ 0.09

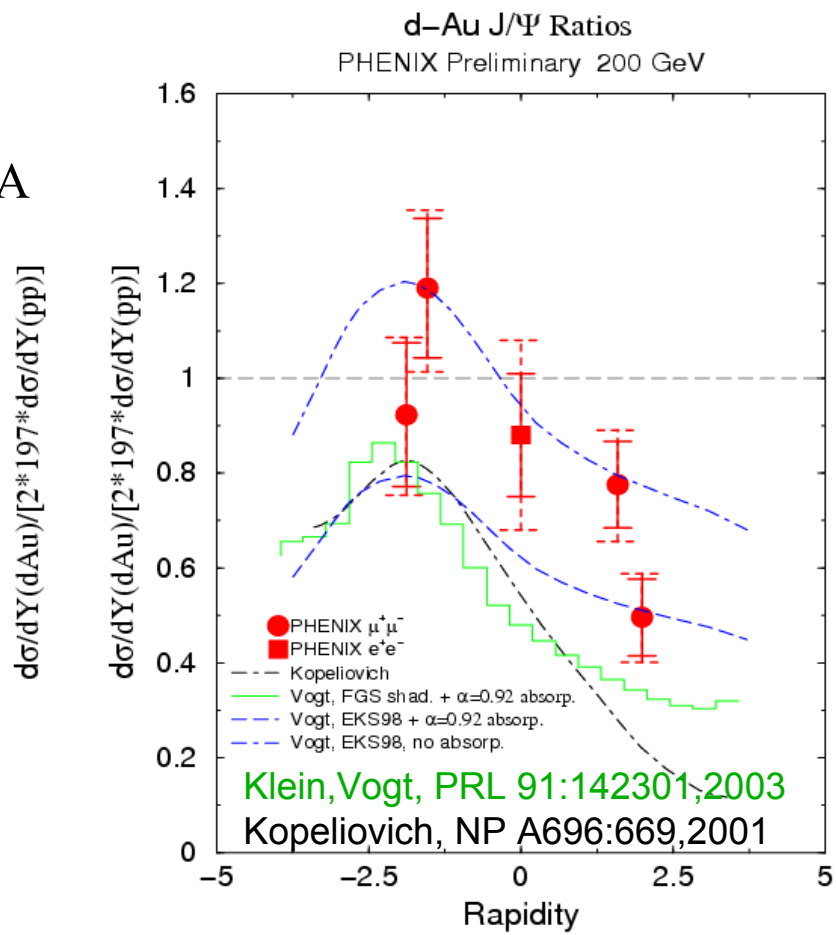
J/Ψ Rapidity Distribution in dAu and pp

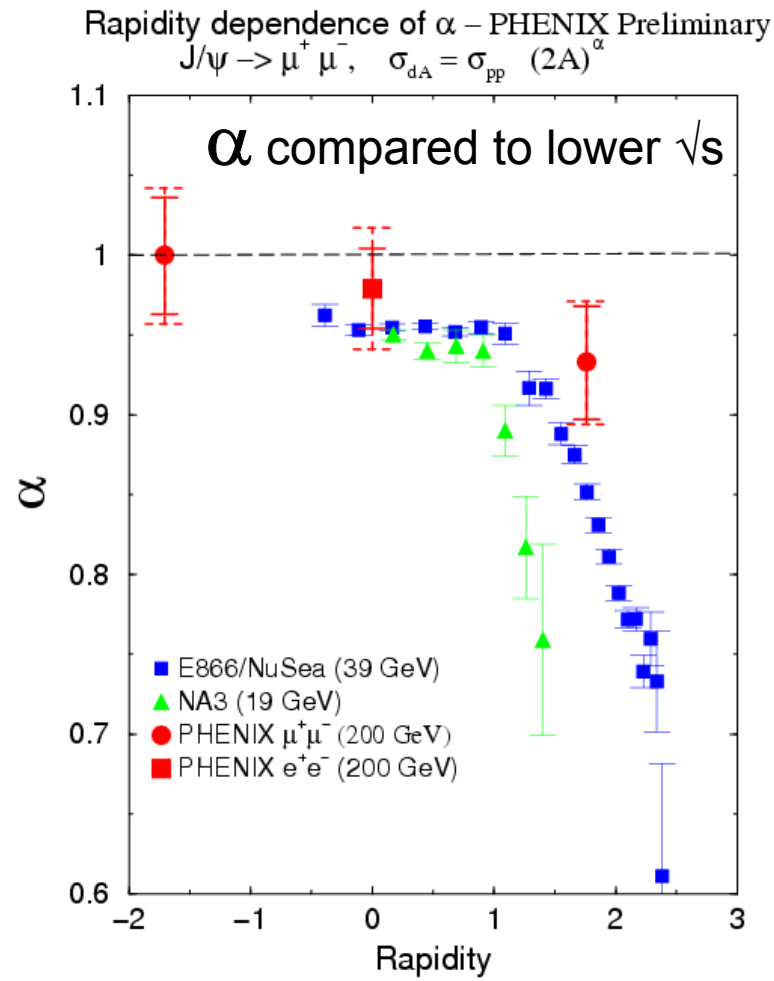




dAu/pp versus rapidity

R_{dA}





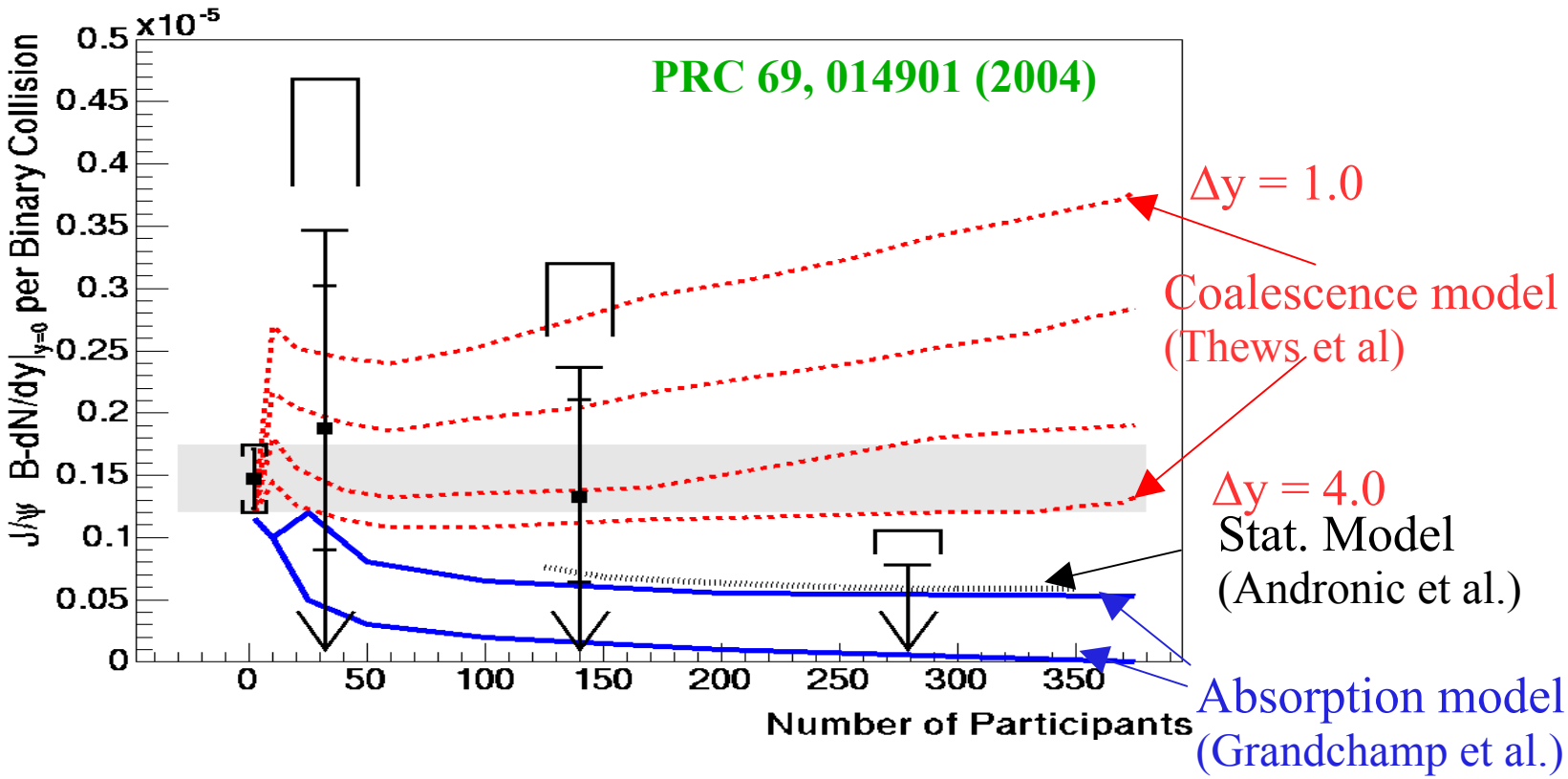
- **Data favors (weak) shadowing + (weak) absorption ($\alpha > 0.92$)**
- **With limited statistics difficult to disentangle nuclear effects.**

Charmonium in Au-Au Collisions

- **Study of "medium effect" in high density matter**
  - J/Ψ suppression : signature of QGP
  - J/Ψ formation by c quark coalescence

- **Experimental plan is to establish that the (to be observed) charmonium suppression/enhancement pattern results from QGP**
  - Study vs. p_T
  - Study vs. centrality
  - Study in lighter systems
  - Study vs. a control

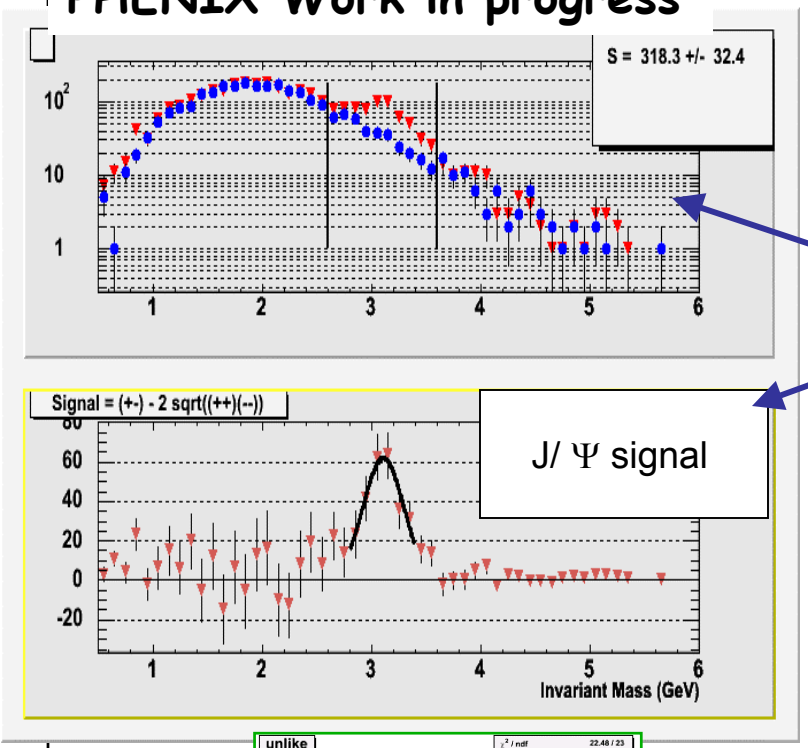
J/Ψ in Au+Au Collisions @ 200 GeV (2002 data)



- **Disfavor models with enhancement relative to binary collision scaling. Cannot discriminate between models that lead to suppression relative to binary collision scaling.**

J/Ψ in Au+Au Collisions @ 200 GeV (2004 data)

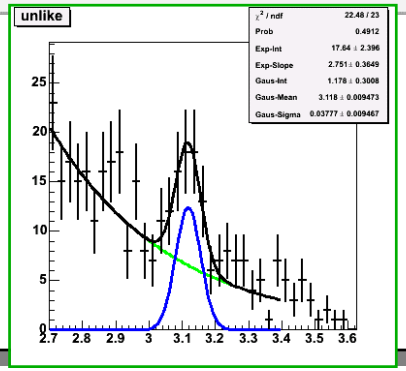
PHENIX Work in progress



Analysis underway of a data sample (240 μb^{-1} minbias events, 270 TB)

Example of Dimuon invariant mass - South arm - Peripheral AuAu Collisions (40-92%)

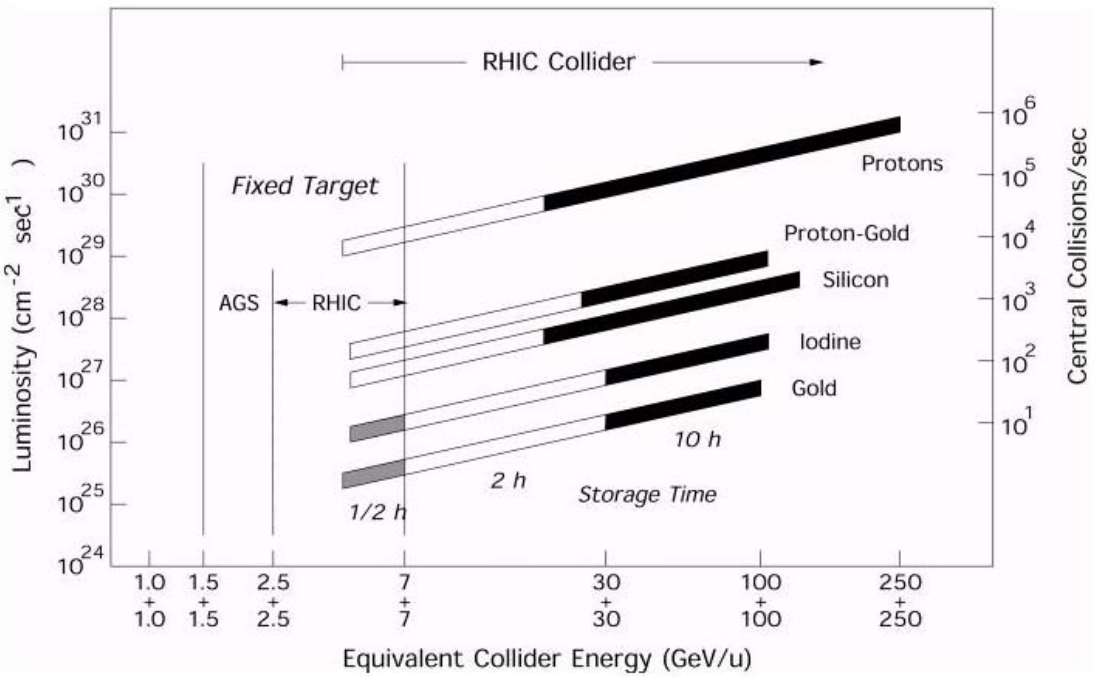
(~30% of data set)



Example of Dielectron invariant mass minium bias sample (< 10% of data set)

Near future at RHIC

- **Full exploration of J/ Ψ and Ψ' production versus "N_{binary}"**
- **Look forward to future runs with high luminosity where also studies for different collision species and with varying energy can be made**
- **Cool-down of the RHIC ring for the upcoming run will start on Nov 8**
  - CuCu collisions and long p-p run



Summary

- **p+p collisions:**
  - we measured total and differential J/ψ cross section, vs pt and y
- **d+Au collisions:**
  - evidence for weak shadowing and weak nuclear absorption
  - evidence for pt broadening when comparing

$$\langle p_t^2 \rangle_{d+Au} \text{ vs } \langle p_t^2 \rangle_{p+p}$$

- **Au+Au collisions:**
  - Run2 (2002) has low luminosity
  - Run4 (2004) has 50 times more data, presently being analyzed
  - New Cu-Cu run about to start

STAY TUNED !

More on "Heavy flavor production in PHENIX" by Olivier Drapier tomorrow