J/Ψ and open charm measurements at RHIC/PHENIX

CIPANP 2003
NYC, May 19-24

David Silvermyr, LANL

Outline

Physics with Open Charm and Charmonium

- for p-p, d-Au and Au-Au at RHIC

Open Charm Measurements

- via single electron spectra: at 130 and 200 GeV.

J/Ψ Production Measurements

- J/Ψ->$\mu^+\mu^-$, e^+e^- for p-p, Au-Au (and d-Au) at 200 GeV

PHENIX

Charm Physics

p-p

- Comparison with pQCD calculation
- Measurement of gluon density G(x)
- Base line for charm physics in pA and AA

p(d)-A

- Gluon shadowing
- Energy loss of gluons in cold nuclear matter
- Base line (normal nuclear effect) for charm physics in AA

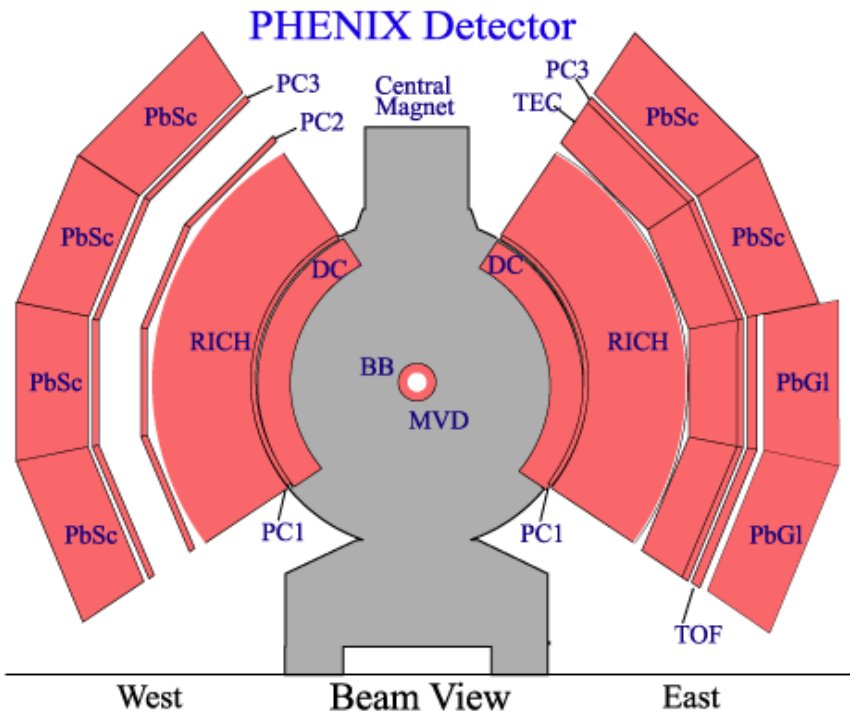
A-A

- Gluon shadowing
- Energy loss of charm in high density matter
- Thermal production of charm in high temperature QGP

Single lepton spectra at high p_T is a useful way to study charm/heavy-quark production.

PHENIX

PHENIX Central Arms & Electron Measurements



- High resolution tracking and momentum measurement from Drift Chamber. Matching with Pad Chambers.
- Good electron identification from Ring Imaging Cherenkov detector and Electromagnetic Calorimeter.
- High performance Level-1/Level-2 trigger.

Centrality selection with Beam -Beam Counters and Zero-Degree Calorimeters.

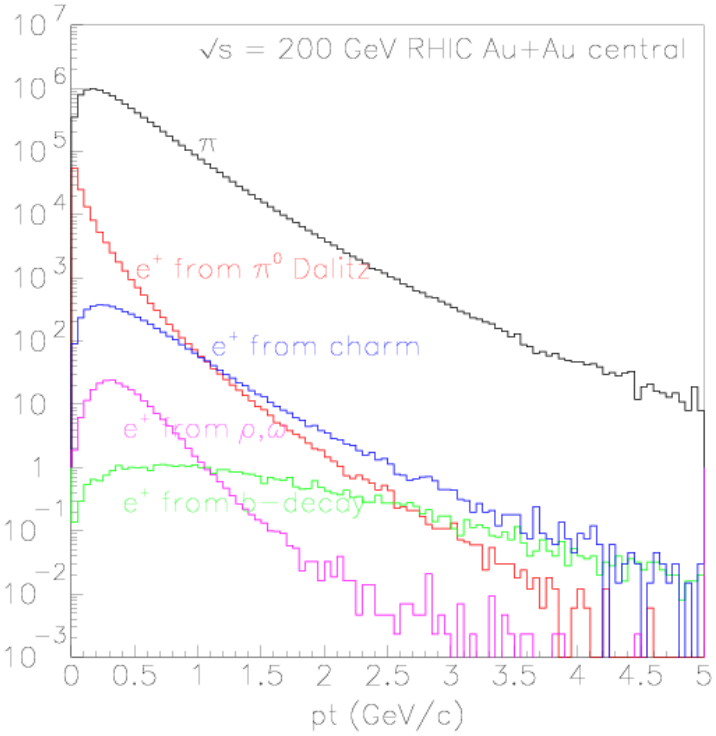
Measure electron between

$|\eta| <= 0.35$ and $p >= 0.2$GeV

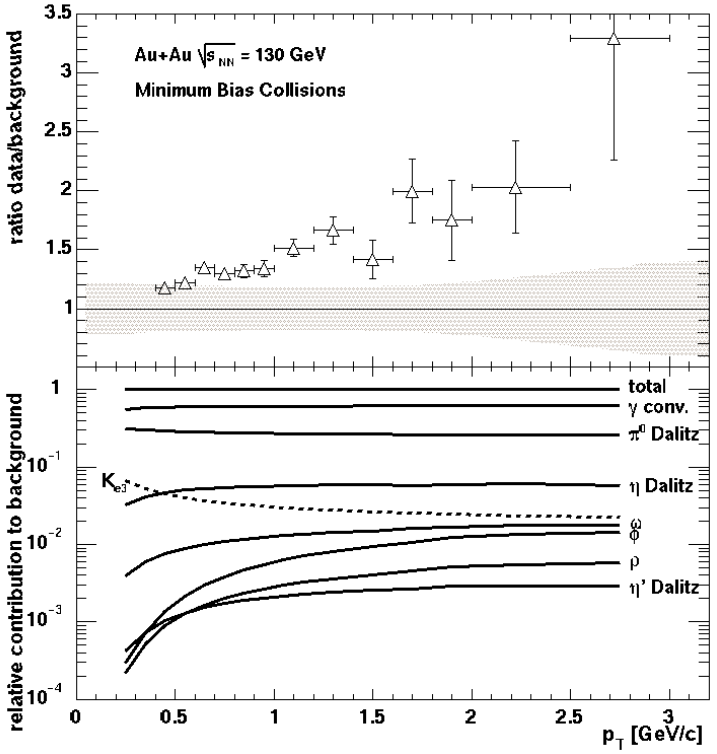
PHENIX

Charm and Single Electrons at RHIC

Simulation before RHIC



PHENIX data (PRL88)



Expected at RHIC that charm decay can be the dominant component of single electron in p_T > 1.5 GeV/c

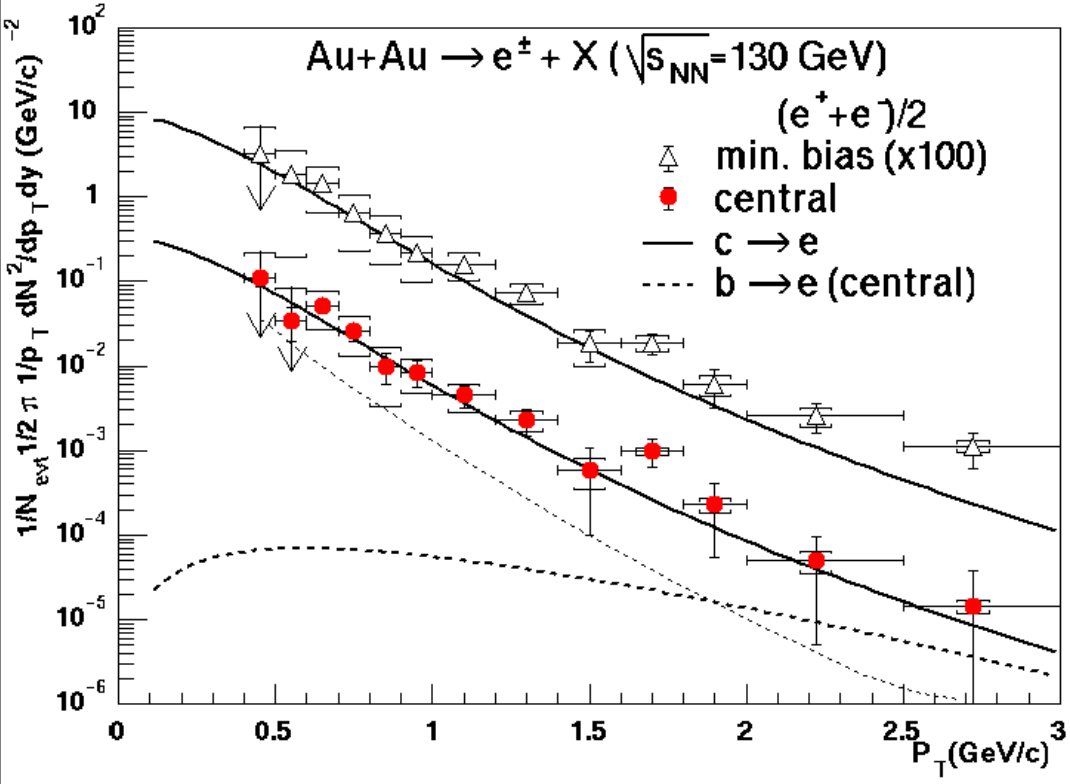
Large production cross section of charm (300-600 μb)

- Production of high pt pions strongly suppressed relative to binary collision scaling
- Production of charm quark roughly scale with binary collisions.

PHENIX observed excess in single electron yield over expectation from light meson decays and photon conversions => charm signal at RHIC

PHENIX

Open Charm in PHENIX: Run-1 AuAu Single Electron data



Compared single electron signal with the expected charm contribution

$EdN_e/dp^3 = T_{AA} Ed\sigma/dp^3$

T_{AA}: nuclear overlap integral

$Ed\sigma/dp^3$: electron spectrum from charm decay calculated using PYTHIA

=> Reasonable agreement

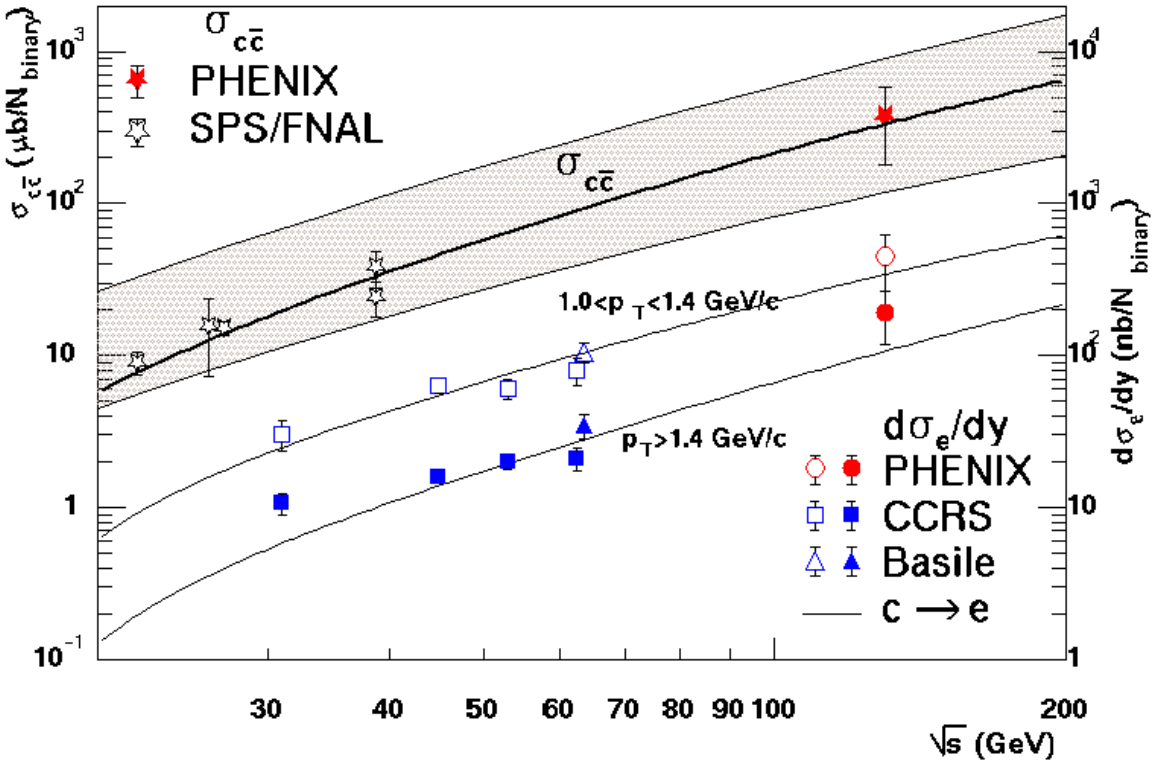
Assuming that all single electron signal is from charm decay and with binary collision scaling, charm cross section at 130 GeV is obtained as:

$\sigma_{cc}^{0\text{-}10\%} = 380 \pm 60\ (stat) \pm 200\ (sys)\ \mu b,$

$\sigma_{cc}^{0\text{-}92\%} = 420 \pm 33\ (stat) \pm 250\ (sys)\ \mu b$

PHENIX

Comparison with other Experiments



Single electron cross sections and charm cross sections are compared with

Solid curves: PYTHIA

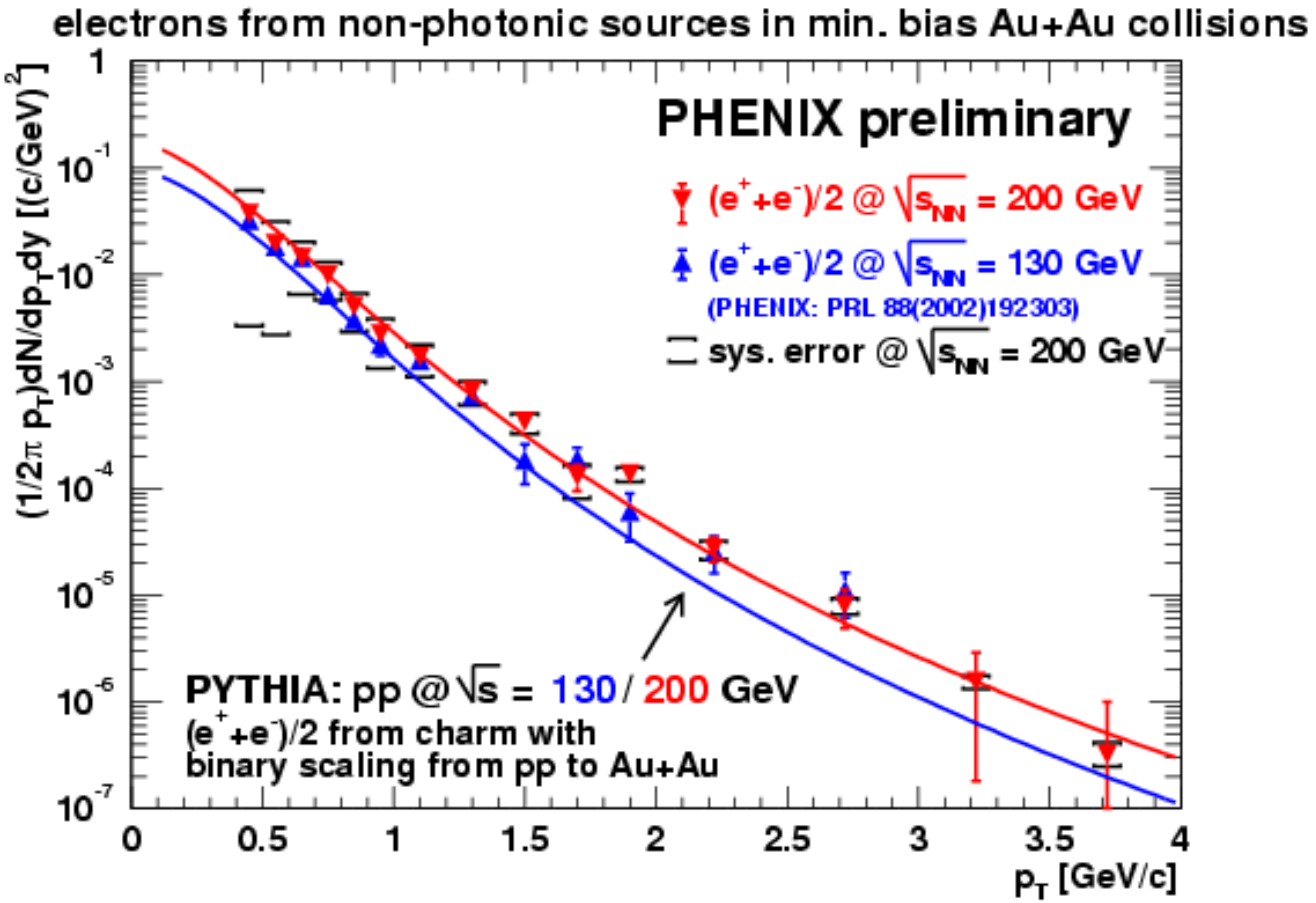
Shaded band: NLO QCD

Assuming binary collision scaling, PHENIX data are consistent with √s systematics (within large uncertainties)!

PHENIX

Run-2 AuAu Single Electron Result

Run-2: extra handle on systematics;
Comparing runs with and without installed extra photon converter

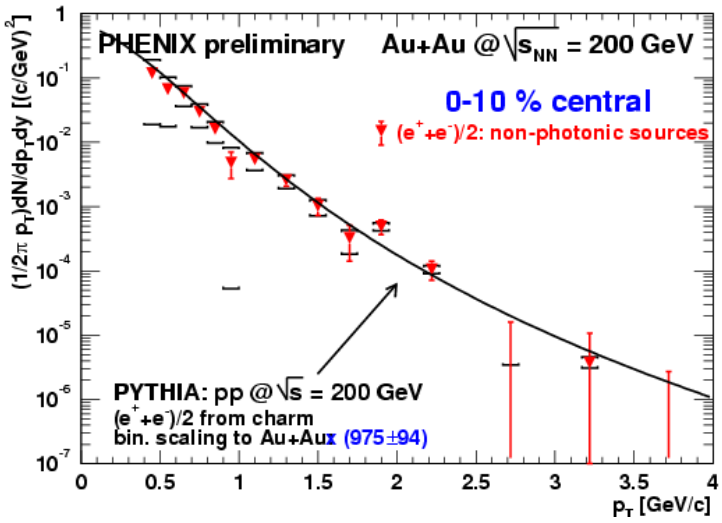


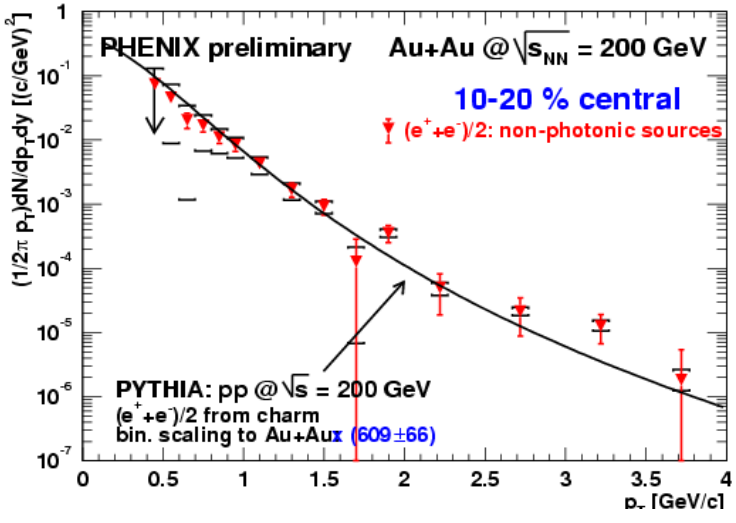
The yield of non-photonic electron at 200 GeV is higher than 130 GeV
The increase is consistent with PYTHIA charm calculation
(σ_{cc} (130 GeV) = 330 μb, σ_{cc} (200 GeV) = 650 μb)

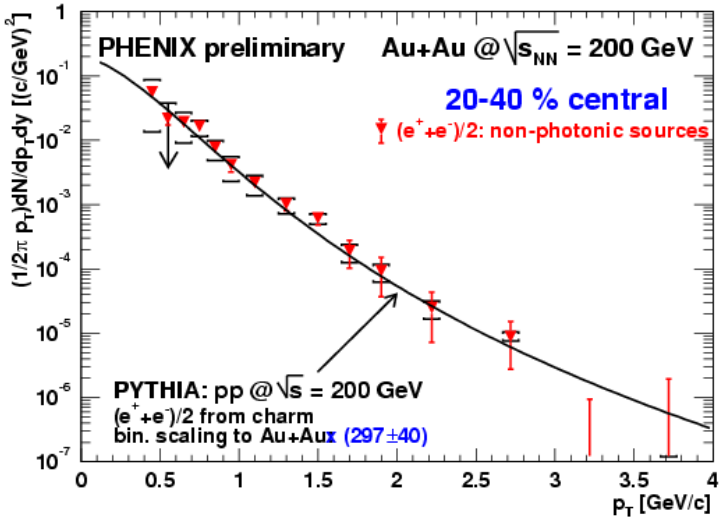
Large systematic uncertainty due to material thickness without converter.
The error will be reduced in the final result.

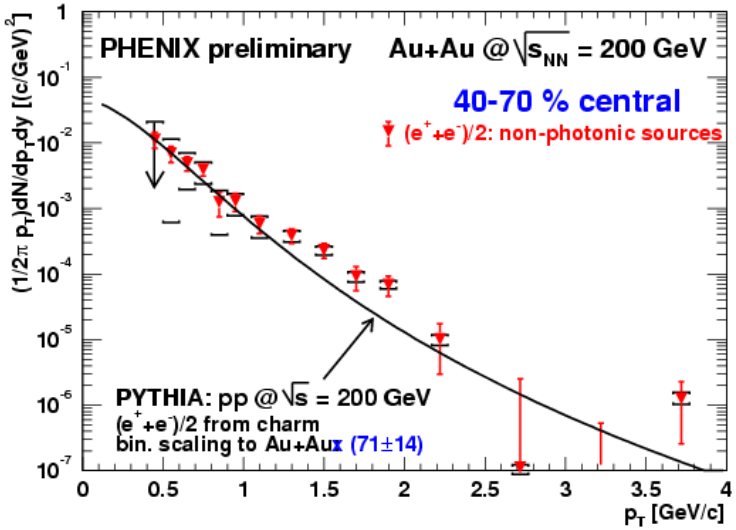
PHENIX

Centrality Dependence









PHENIX data consistent with the PYTHIA charm spectrum scaled by number of binary collisions in all centrality bins!

PHENIX

J/Ψ Production

p-p : study of production mechanism and cross sections

- Color evaporation model, Color singlet model, Color octet model
- Polarization, Rapidity dependence (electron and muon channels)
- Production of J/Ψ, Ψ',.. states
- Base line for pA and AA

p(d)-A : study of "normal nuclear effect": shadowing and energy loss

- Nuclear dependence of $\sigma(J/\Psi)$: A^{α} or σ_{abs} (nuclear absorption)
- Base line for AA

A-A : study of "medium effect" in high density matter

- J/Ψ suppression : signature of QGP (Matsui/Satz)
- J/Ψ formation by c quark coalescence at RHIC/LHC ?

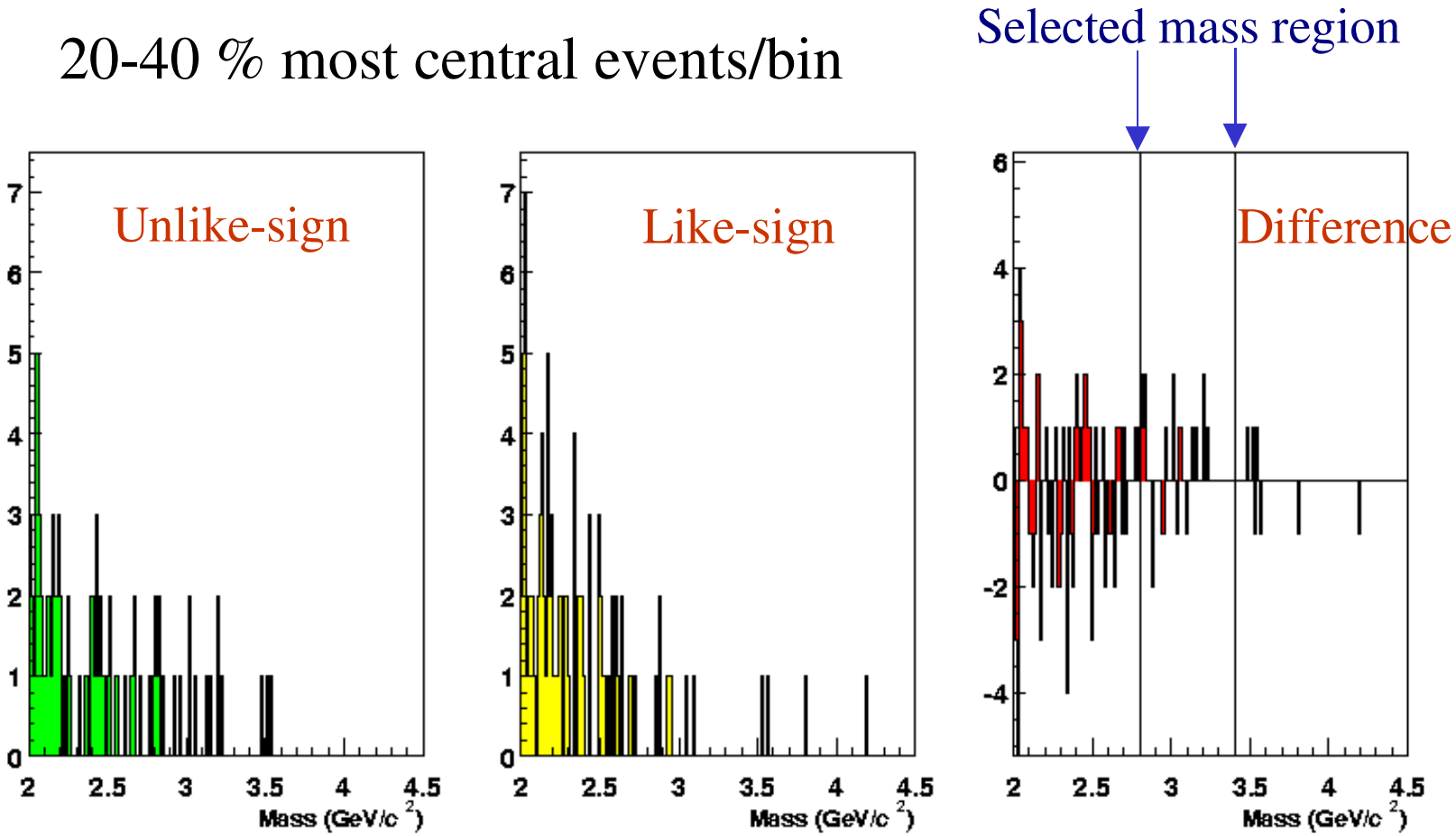
Comparisons between various collision species are very important.

Studies done via both dielectron and dimuon channels in PHENIX.

PHENIX

Run-2 AuAu Dielectrons

20-40 % most central events/bin



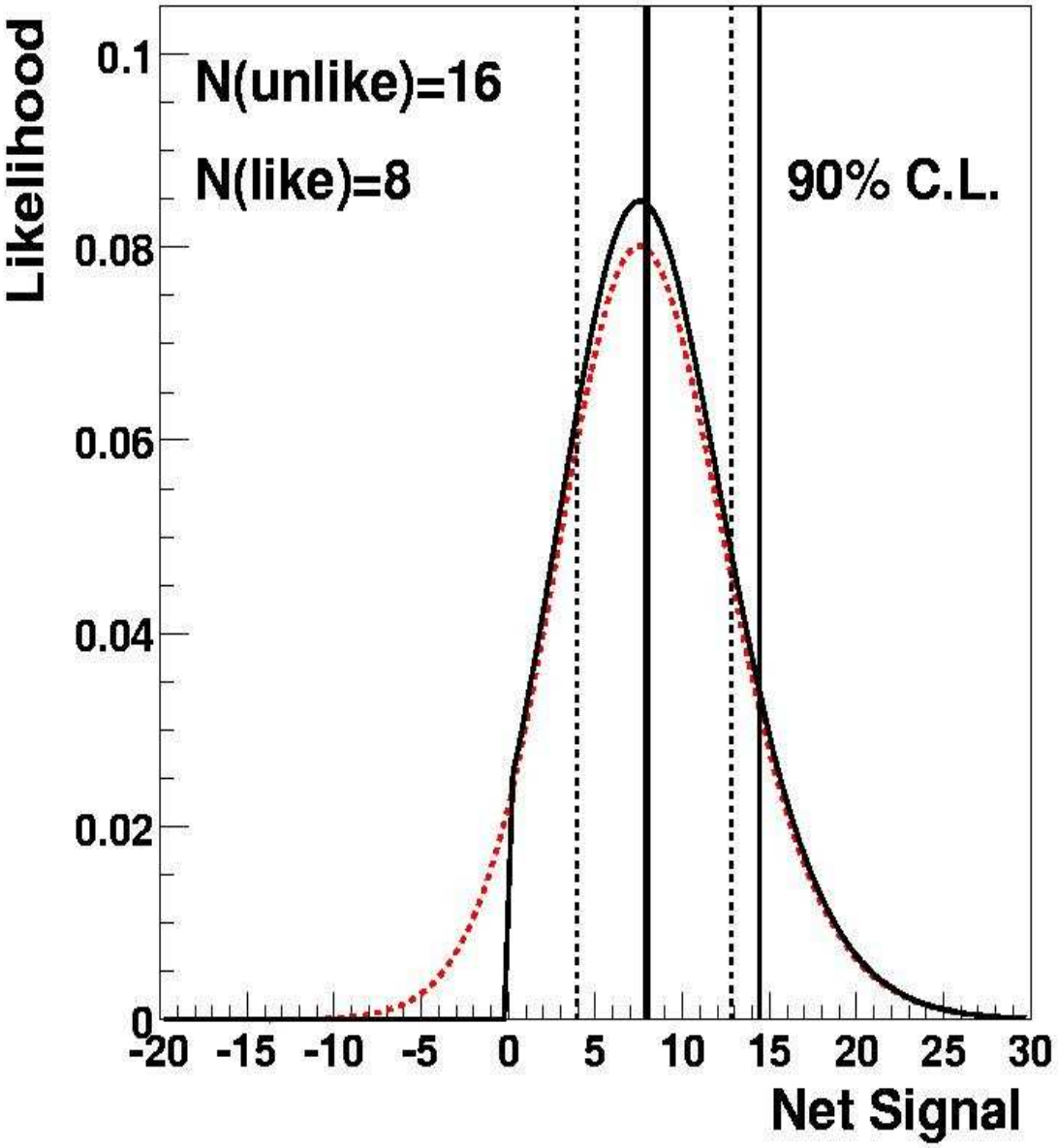
Analysis limited by statistics. 3 centrality bins are used: 0-20%, 20-40%, 40-90%.

PHENIX

Statistics

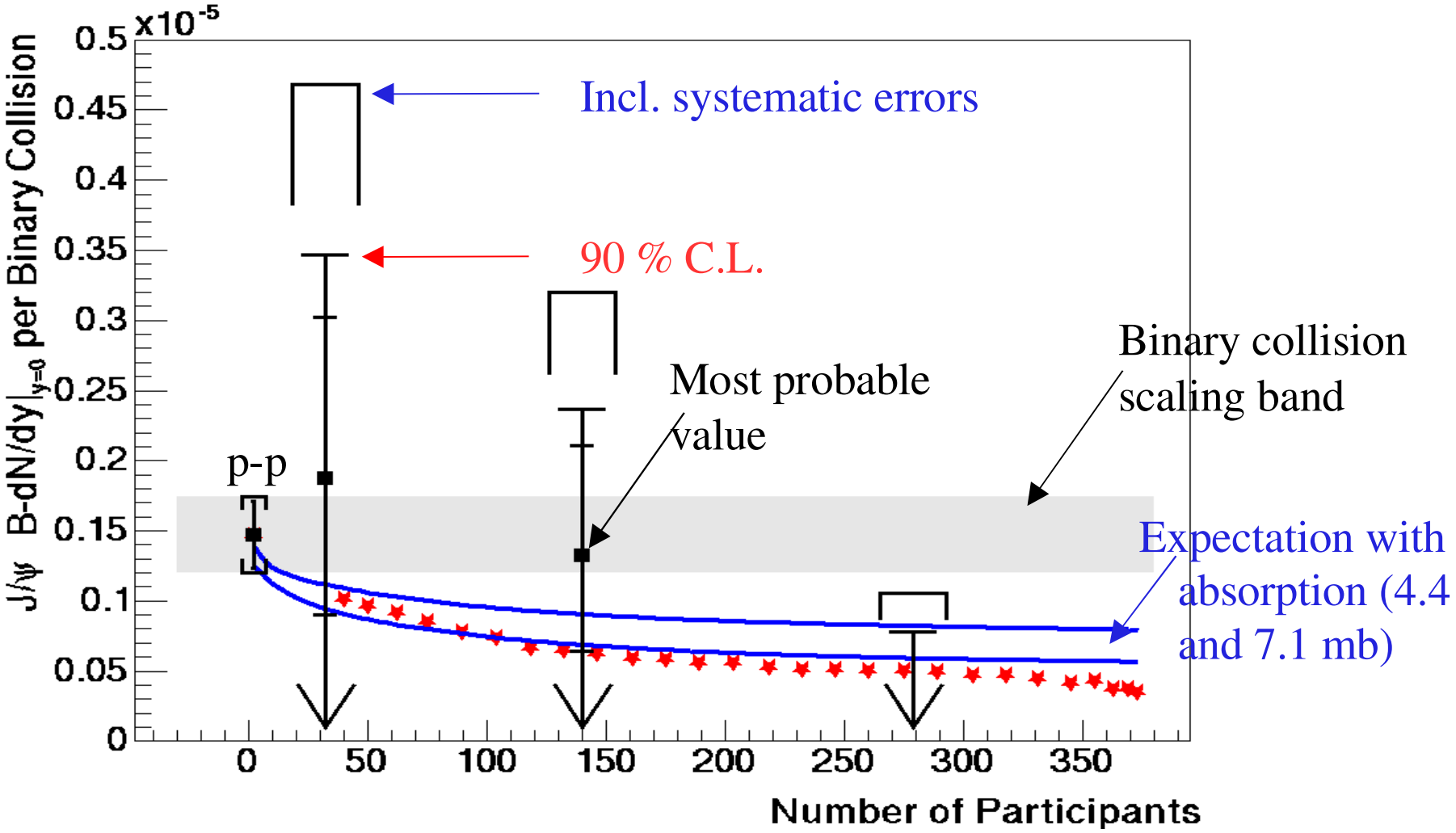
20-40 % most central bin

Based on unlike and like-sign counts, the most probable signal and the associated 90 % confidence limits are calculated.



PHENIX

Centrality dependence

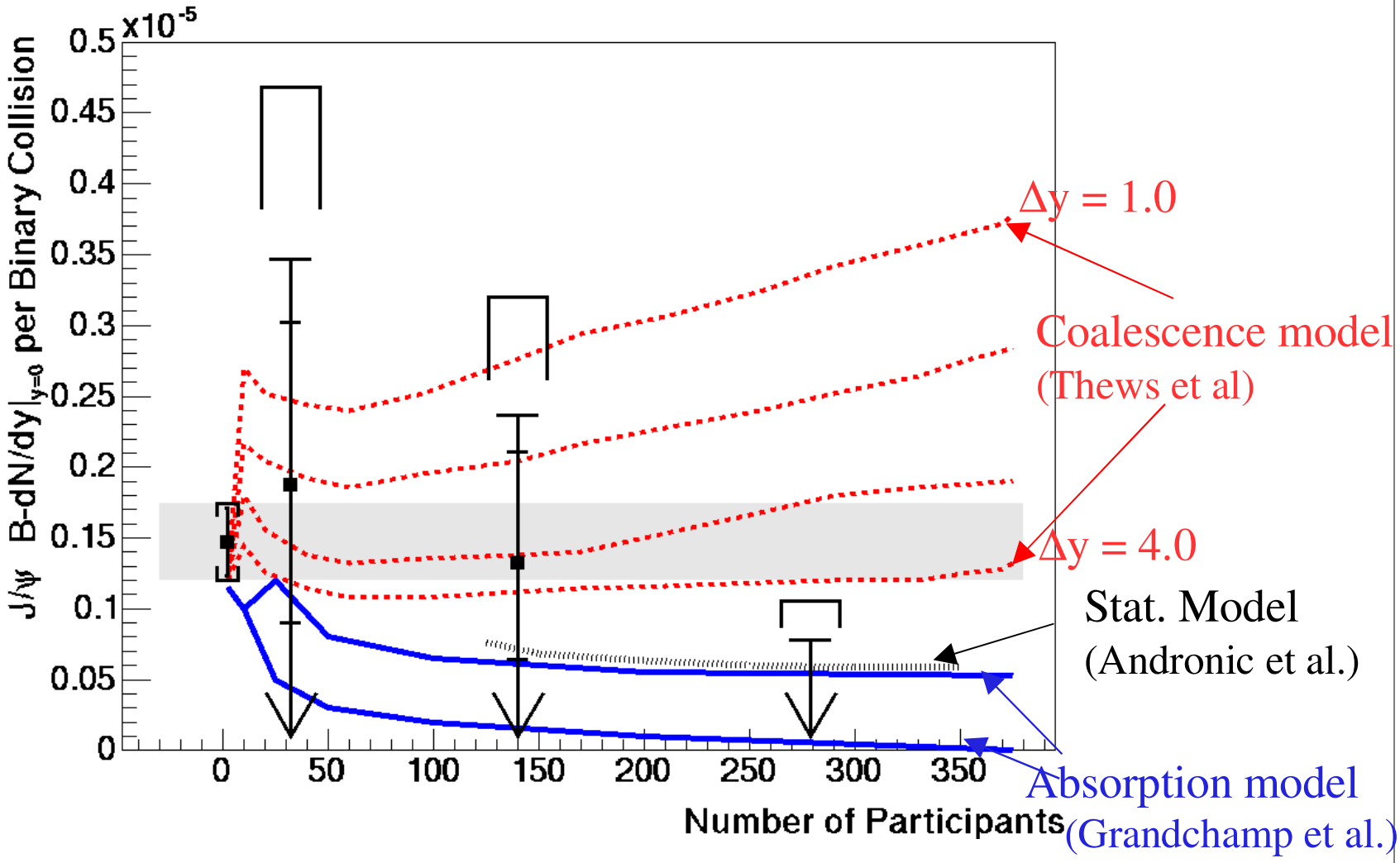


NA50 points normalized to pp point (described shortly..)

- for shape comparisons only.

PHENIX

Model Comparisons



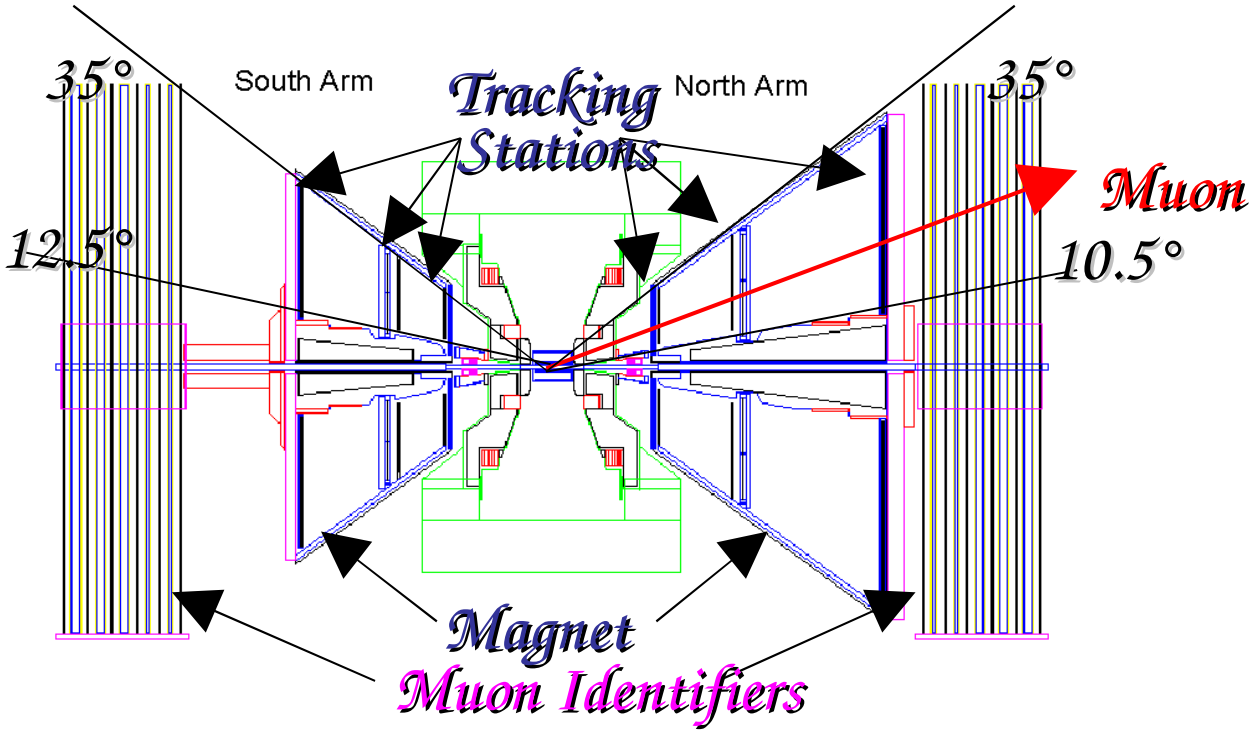
Disfavor models with enhancement relative to binary collision scaling. Cannot discriminate between models that lead to suppression relative to binary collision scaling.

PHENIX

PHENIX Muon Arms

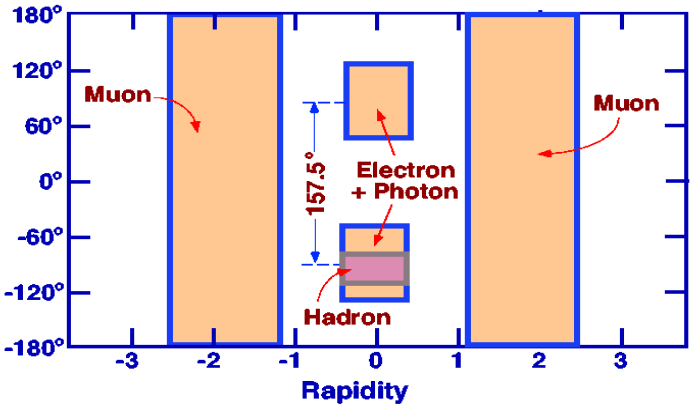
(Run-2 p-p and onwards: Electrons are still detected in the central arms..)

2 Muon Trackers =
2x3 stations
2 Muon Identifiers
= 2x5 planes



South Arm:
Began operations
in 2001: Run-2.

North Arm:
Installed in 2002.

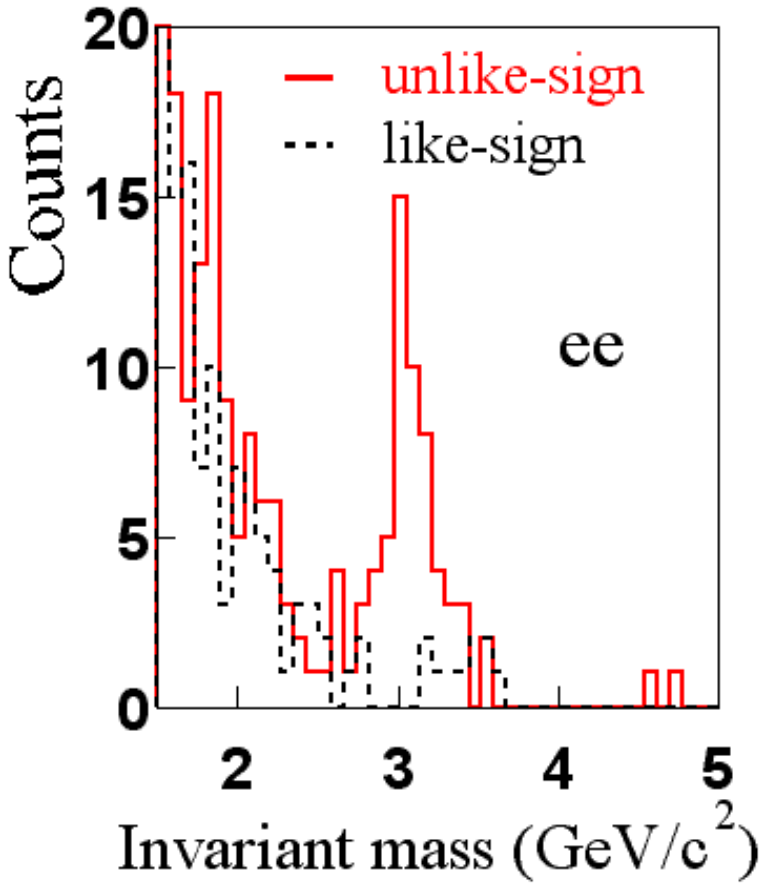


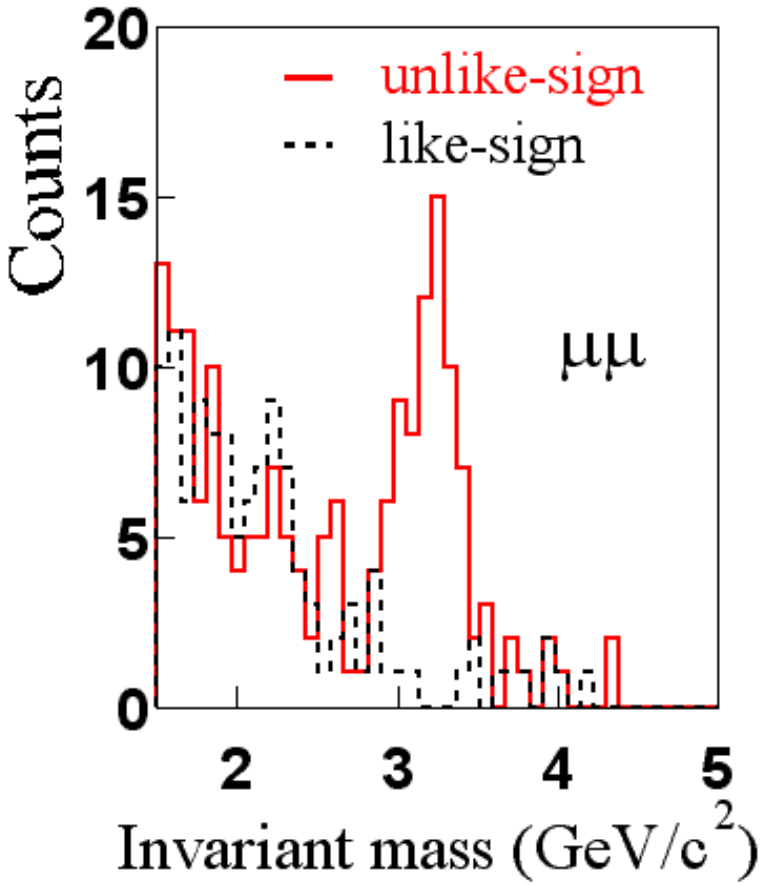
Acceptance : $1.2 < |\eta| < 2.4$

$\Delta\Phi = 2\pi$

Muon minimum momentum ~ 2 GeV/c

Run-2 pp Results

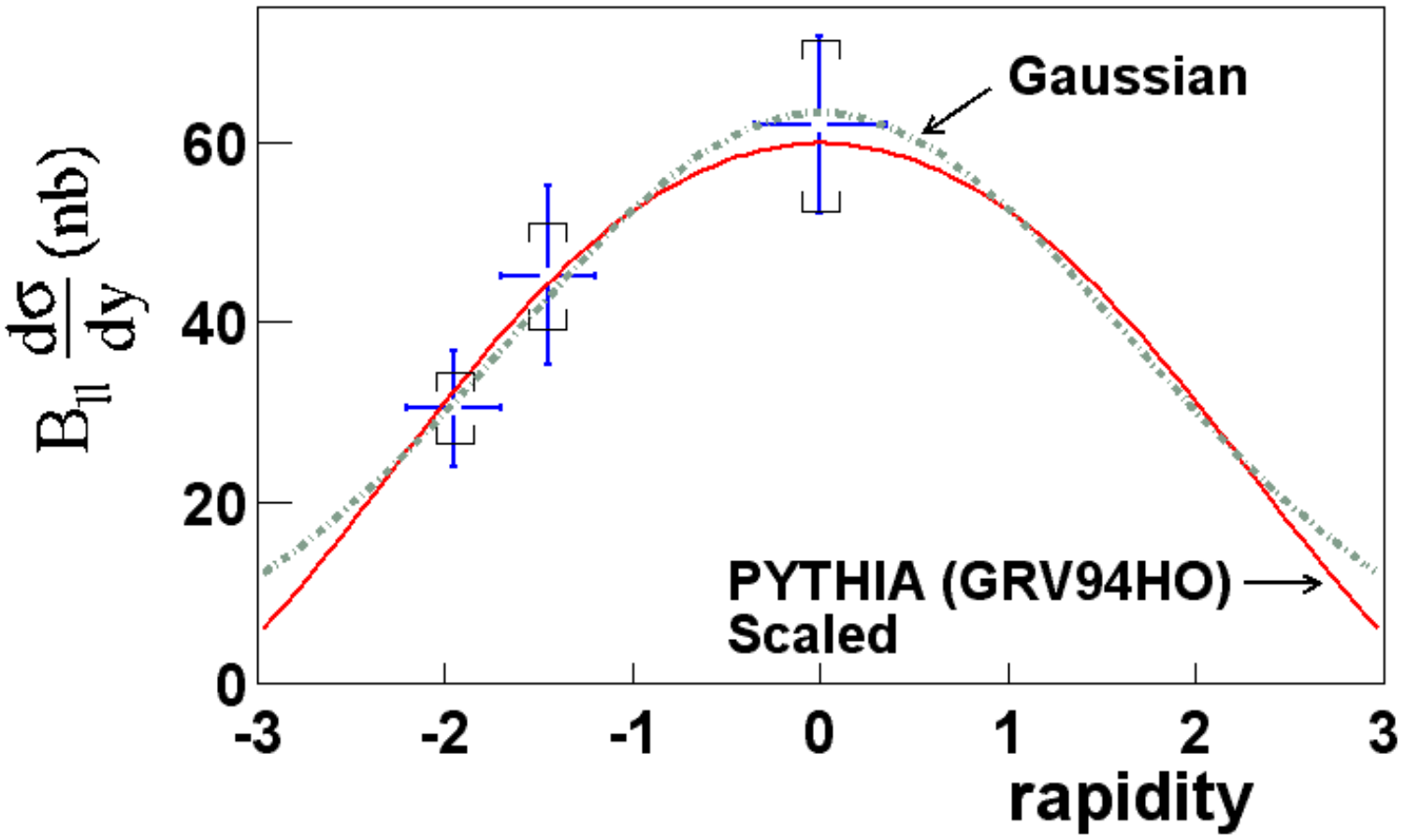




Clear J/Ψ signals seen in both central and muon arms.
Resolutions in agreement with expectations.

PHENIX

Rapidity Distribution

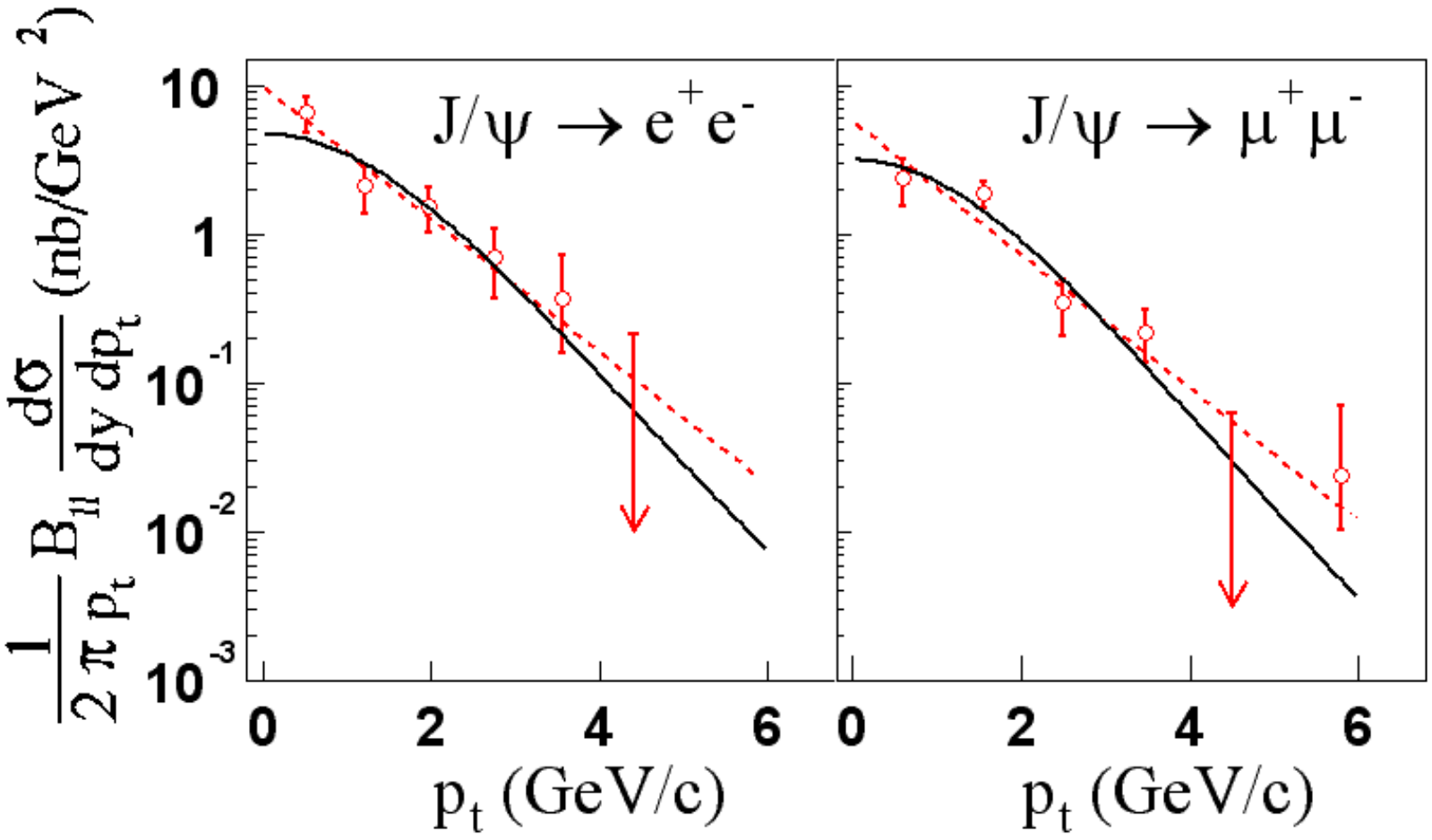


Integrated cross-section : 3.98 ± 0.62 (stat) ± 0.56 (sys) ± 0.41(abs) μb

Estimated B decay feed down contribution : < 4% (@ 200 GeV)

PHENIX

p-p : J/Ψ p_T distribution

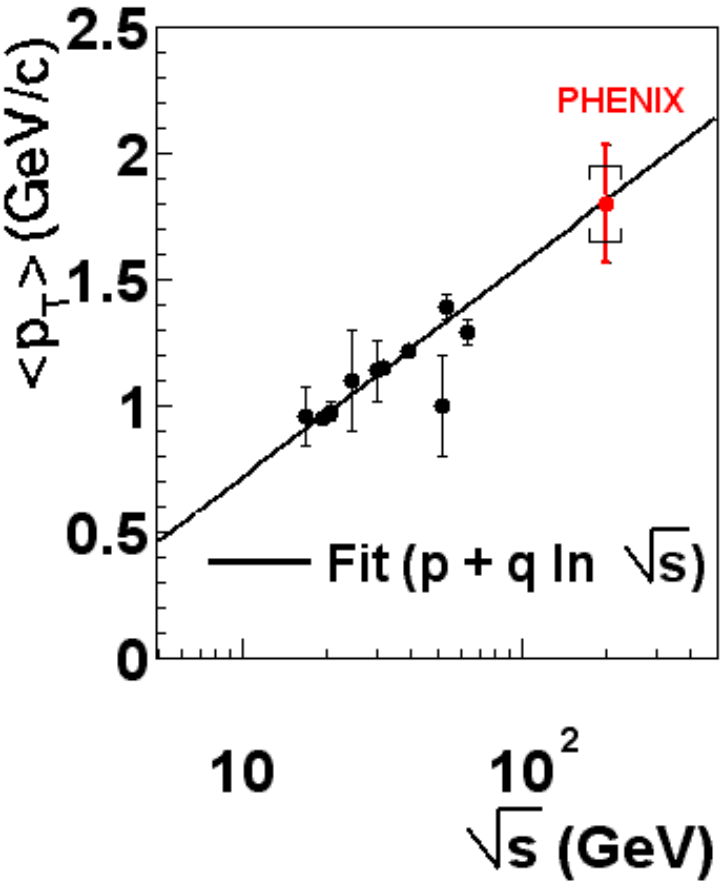


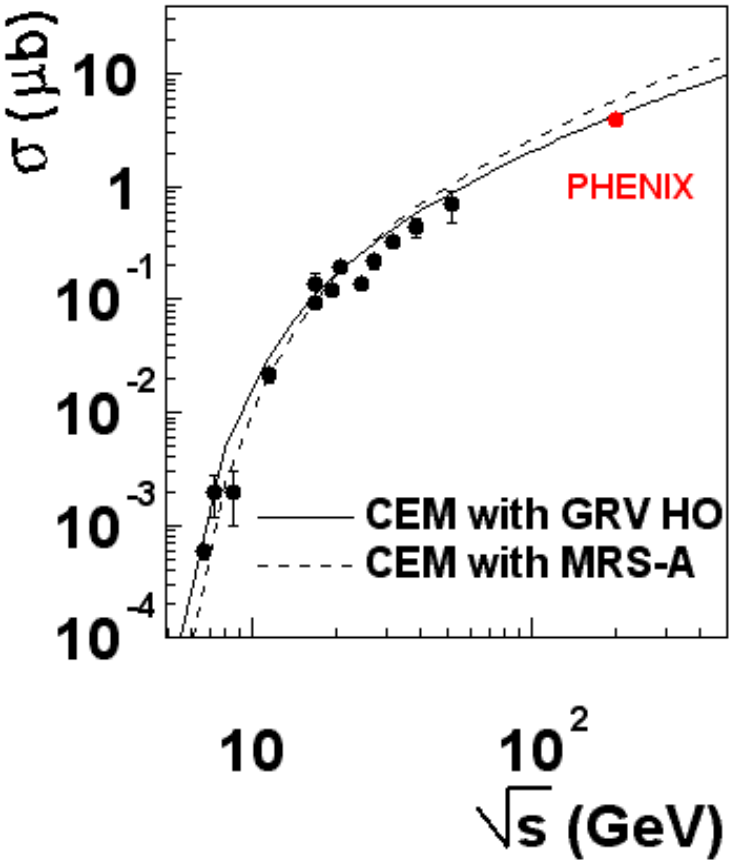
Combination of electron and muon results and phenomenological and exponential fits gives:

$\langle p_T \rangle$ = 1.80 ± 0.23 (stat) ± 0.16 (sys) GeV/c

PHENIX

Comparisons with other Experiments



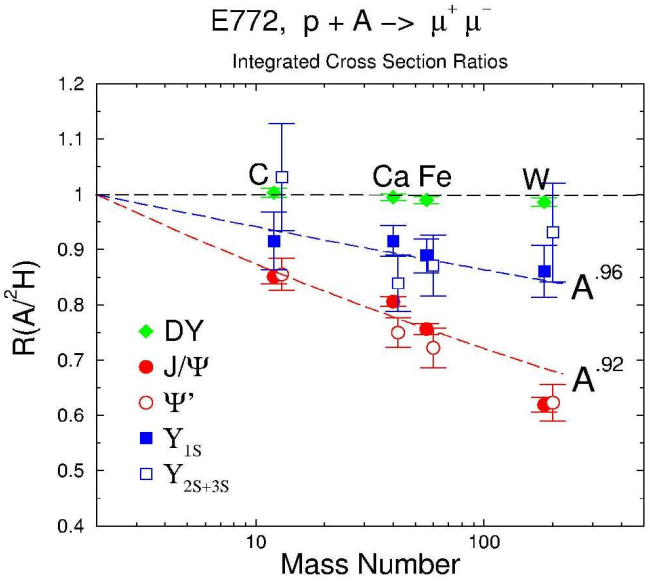


Phenomenological fit for average p_T; p = 0.531, q= 0.188

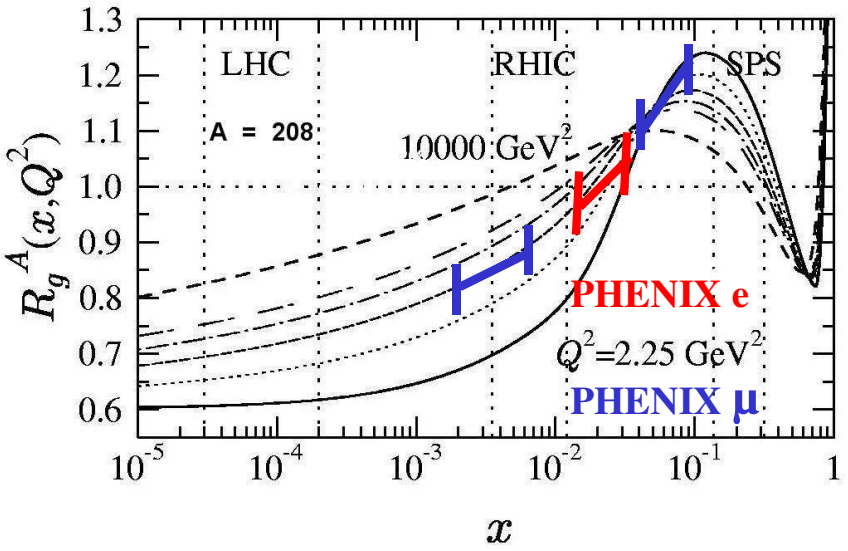
Cross-section well described by Color Evaporation Model.

PHENIX

J/Ψ Suppression / Gluon Shadowing



Eskola, Kolhinen, Vogt hep-ph/0104124



J/Ψ suppression : an effective signature of Quark-Gluon Plasma (QGP) formation?

Color screening in a QGP would destroy $c\bar{c}$ pairs before they can hadronize into charmonium

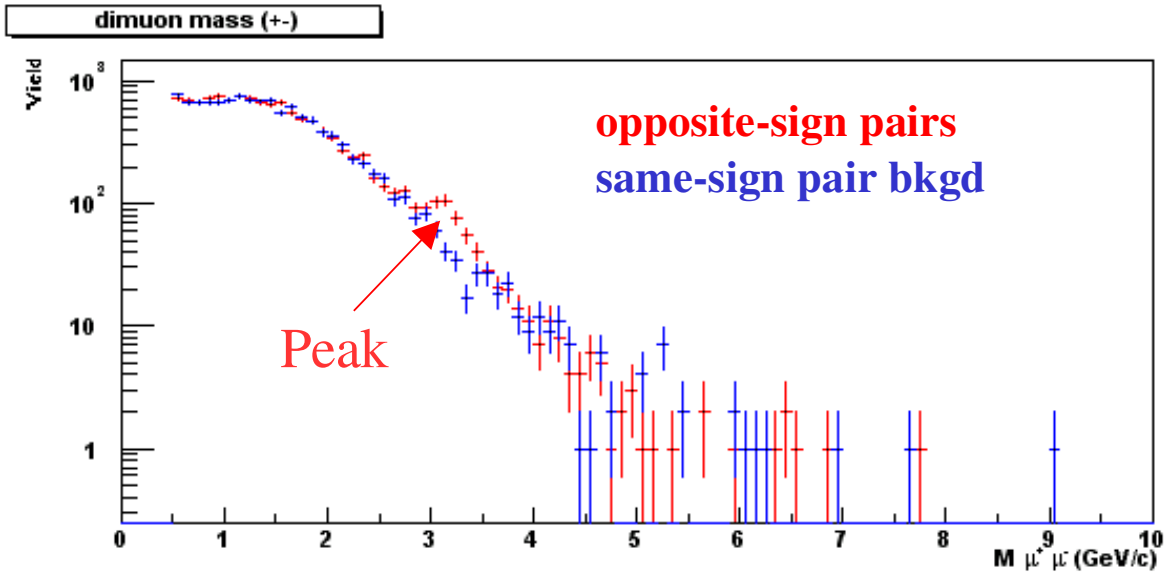
Ordinary nuclear effects, like gluon shadowing, can also affect J/Ψ's. These can be studied in e.g. d-Au collisions.

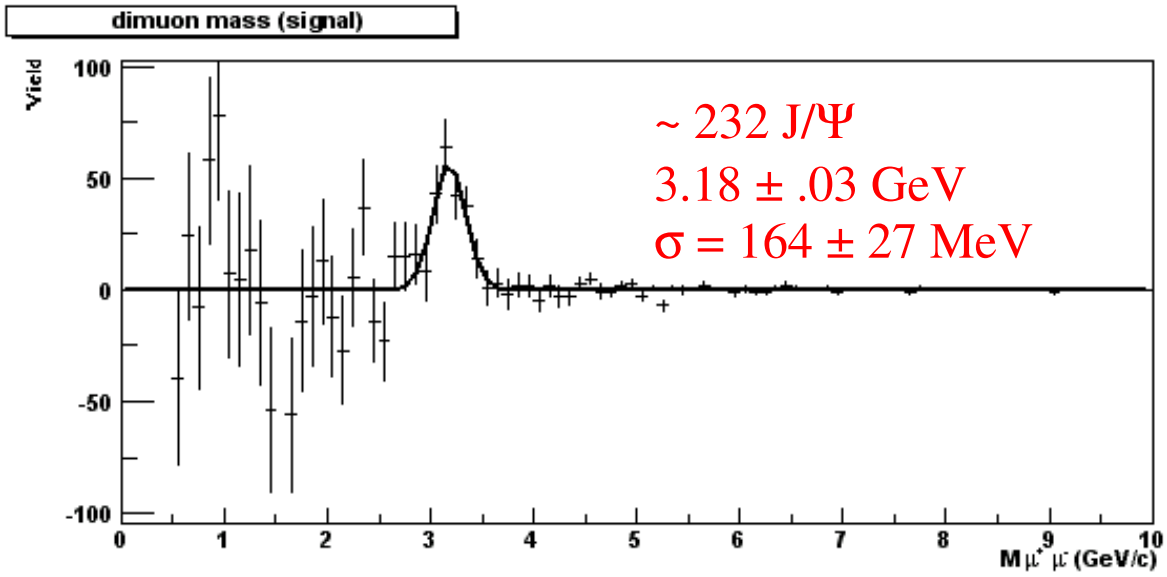
Gluon shadowing effects for nuclei, for the relevant x and Q^2 regions for PHENIX, have large uncertainties (e.g. Eskola vs Kopeliovich)

Run-3 dAu : South muon arm

Analyzed a subset of the data.

Expect of the order of a factor of four improvement of the statistics when the whole d-Au run is included.





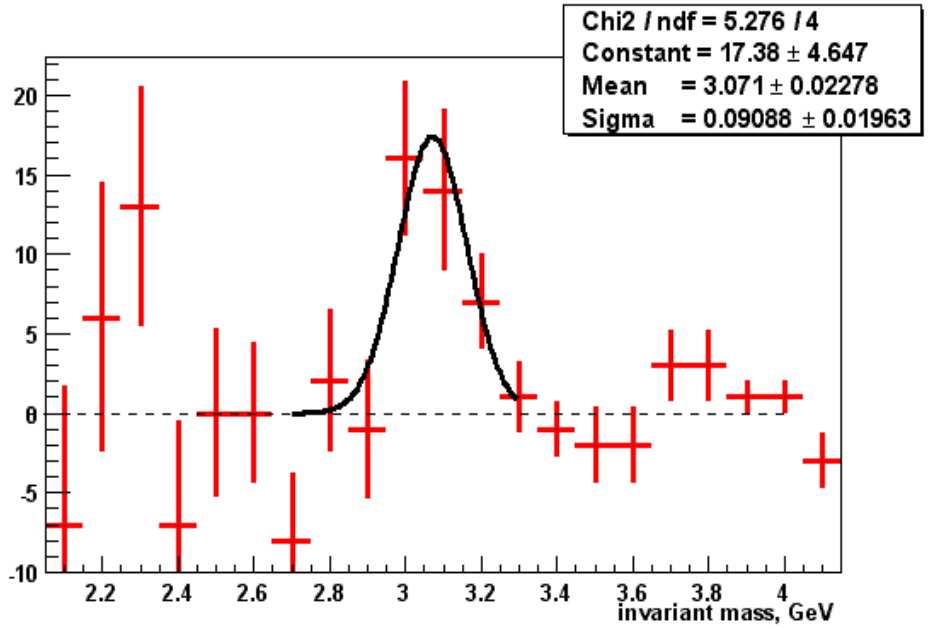
PHENIX

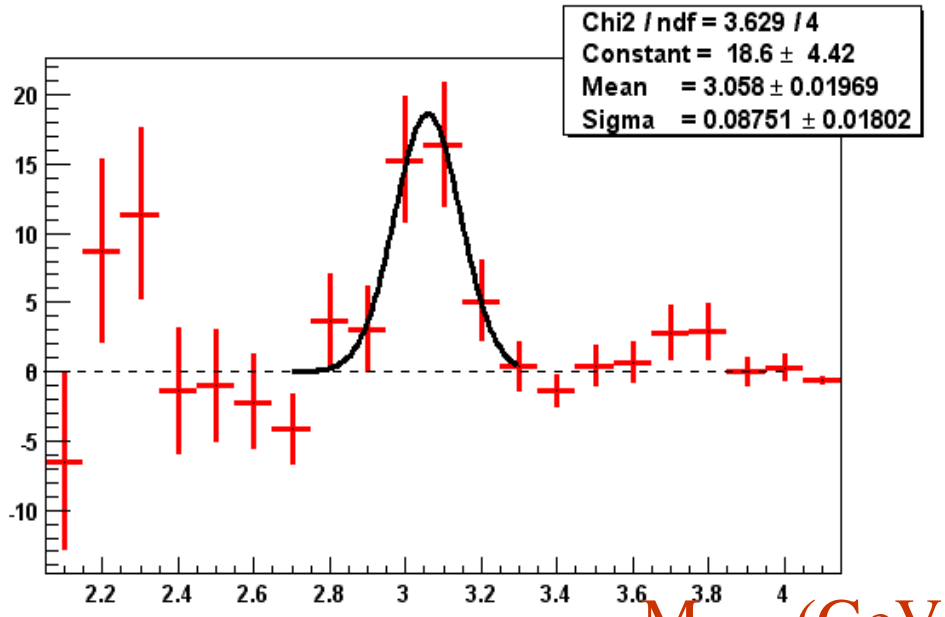
$M_{\mu+\mu-}$ (GeV/c^2)

Run-3 dAu : Central arms

(Analyzed another subset of the data)

Top plot shows subtracted difference using like-sign as background estimate, bottom is with using mixed events.





M_{e+e-} (GeV/c^2)

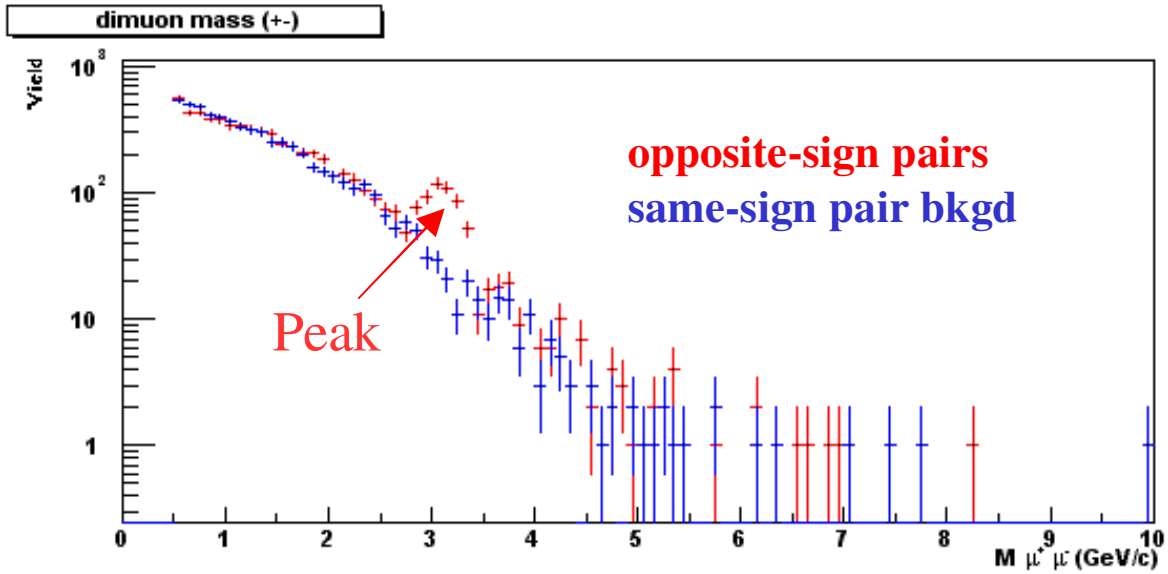
PHENIX

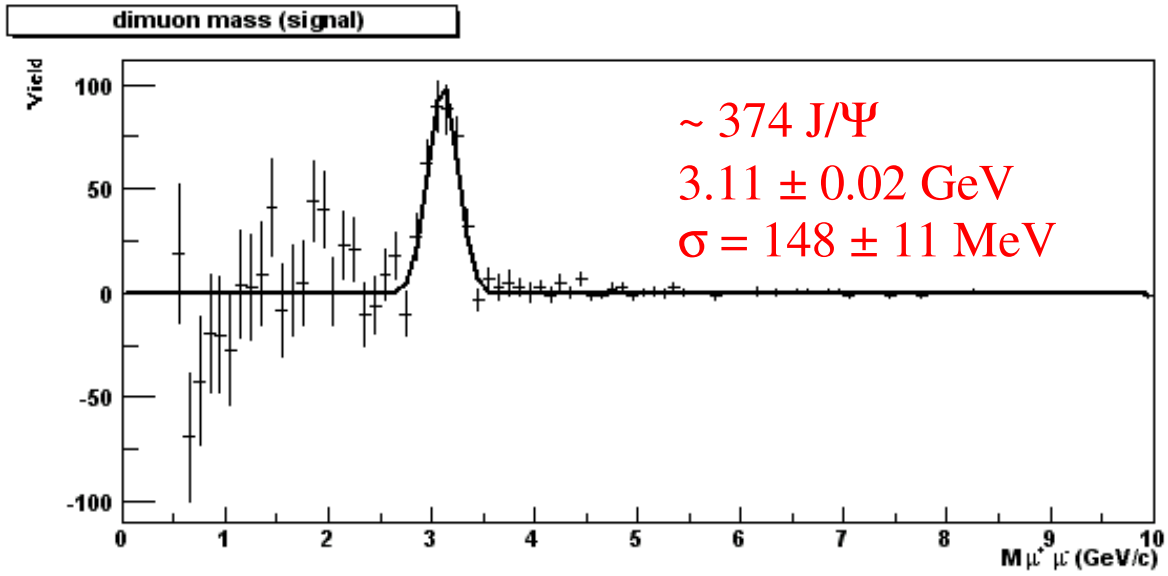
Run-3 dAu : North muon arm

Note: yet another different data sample, no corrections for detector & trigger eff. or acceptance.

Direct comparisons between the yield in the arms are thus meaningless for now.

But hopefully not for too long..



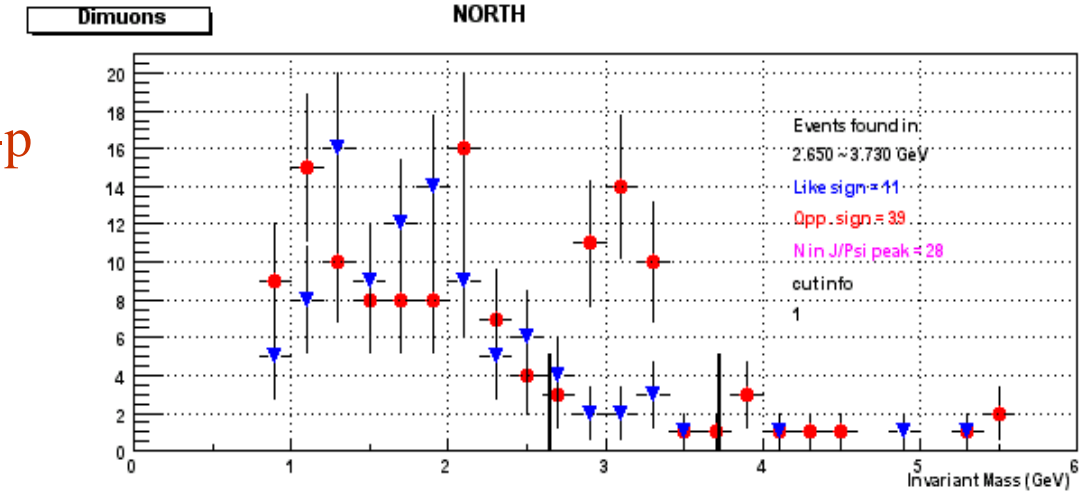


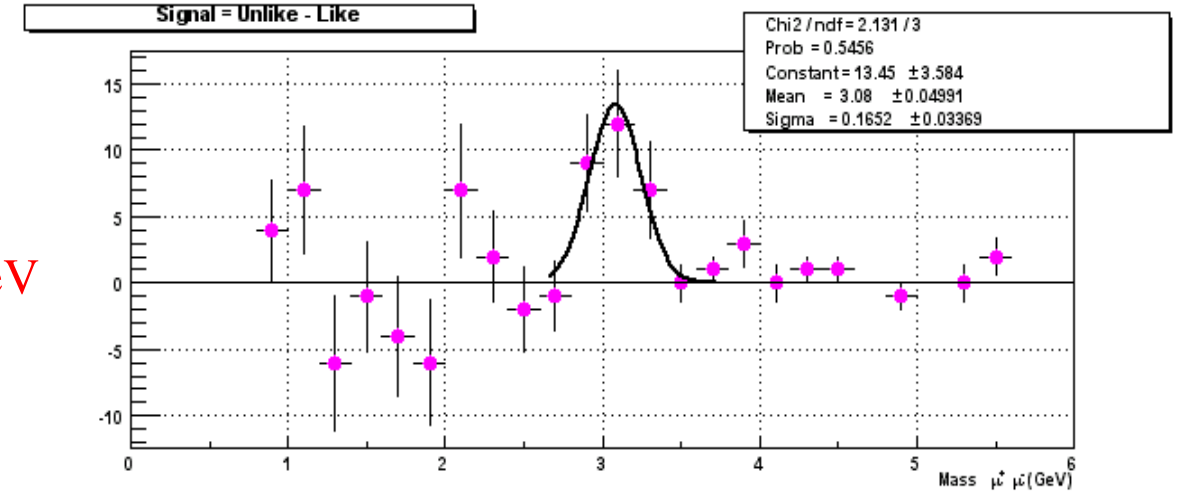
$M_{\mu+\mu-}$ (GeV/c^2)

PHENIX

Run-3 p-p : North muon arm

A first look at a Run-3 p-p data subset





~ 28 J/Ψ's

3.08 ± 0.06 GeV

σ = 165 ± 34 MeV

PHENIX

$M_{\mu+\mu-}$ (GeV/c^2)

Summary

Charm production measured by single electron spectra

- consistent with binary collision scaling

The first J/Ψ's in p-p and Au-Au interactions at RHIC have been obtained

- p-p cross section in agreement with color evaporation model
- Au-Au centrality dependence disfavors enhancement models

First d-Au run recently completed. More substantial yields were obtained.

- Should give us more understanding about e.g. gluon shadowing
- Baseline for comparisons with the upcoming high statistics Au-Au run

PHENIX

Outlook

There are quite a few results and work-in-progress, that were not covered here, e.g.:

- Single muon (high pT) spectra
- Au-Au J/Ψ dimuon analysis
- e-μ coincidences (alt. charm measurement)

The p-p part of Run-3 is ongoing and should result in a significantly improved p-p data sample.

In the near future, a high luminosity Au-Au run is expected.

For the longer term, a Si-Vertex upgrade is being worked on.

- would enable direct measurements of open charm via secondary vertices.

PHENIX

A lot more to look forward to!

PHENIX

12 Countries; 57 Institutions; 460 Participants*

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
	University of Tokyo, Bunkyo-ku, Tokyo
	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
	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

*as of July 2002

Luminosity summary

Run	Year	Species	$s^{1/2}$ [GeV]	$\int Ldt$	N_{tot}
01	2000	Au-Au	130	1 μb^{-1}	10M
02	2001/2002	Au-Au	200	24 μb^{-1}	170M
		p-p	200	0.15 pb^{-1}	3.7G
03	2002/2003	d-Au	200	2.74 nb^{-1}	5.5G
		p-p	200	ongoing	

PHENIX

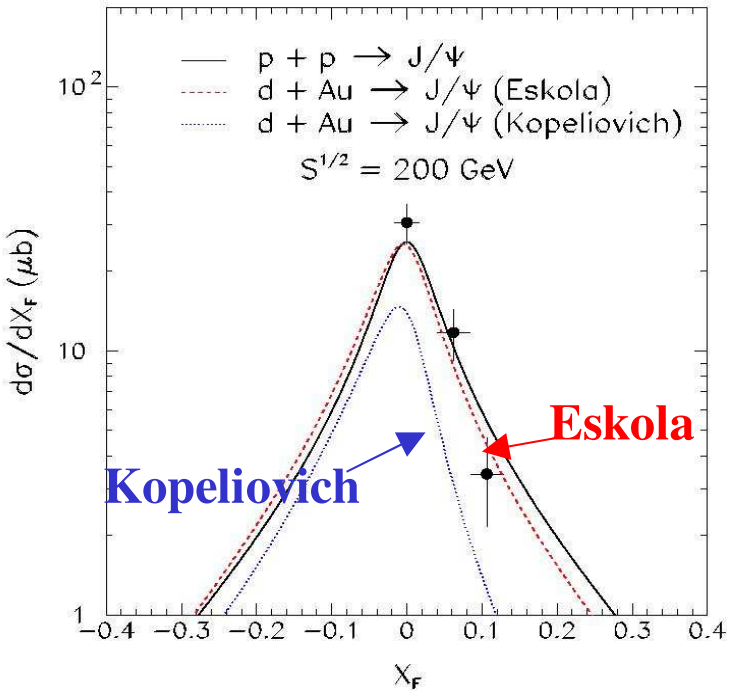
Kinematics

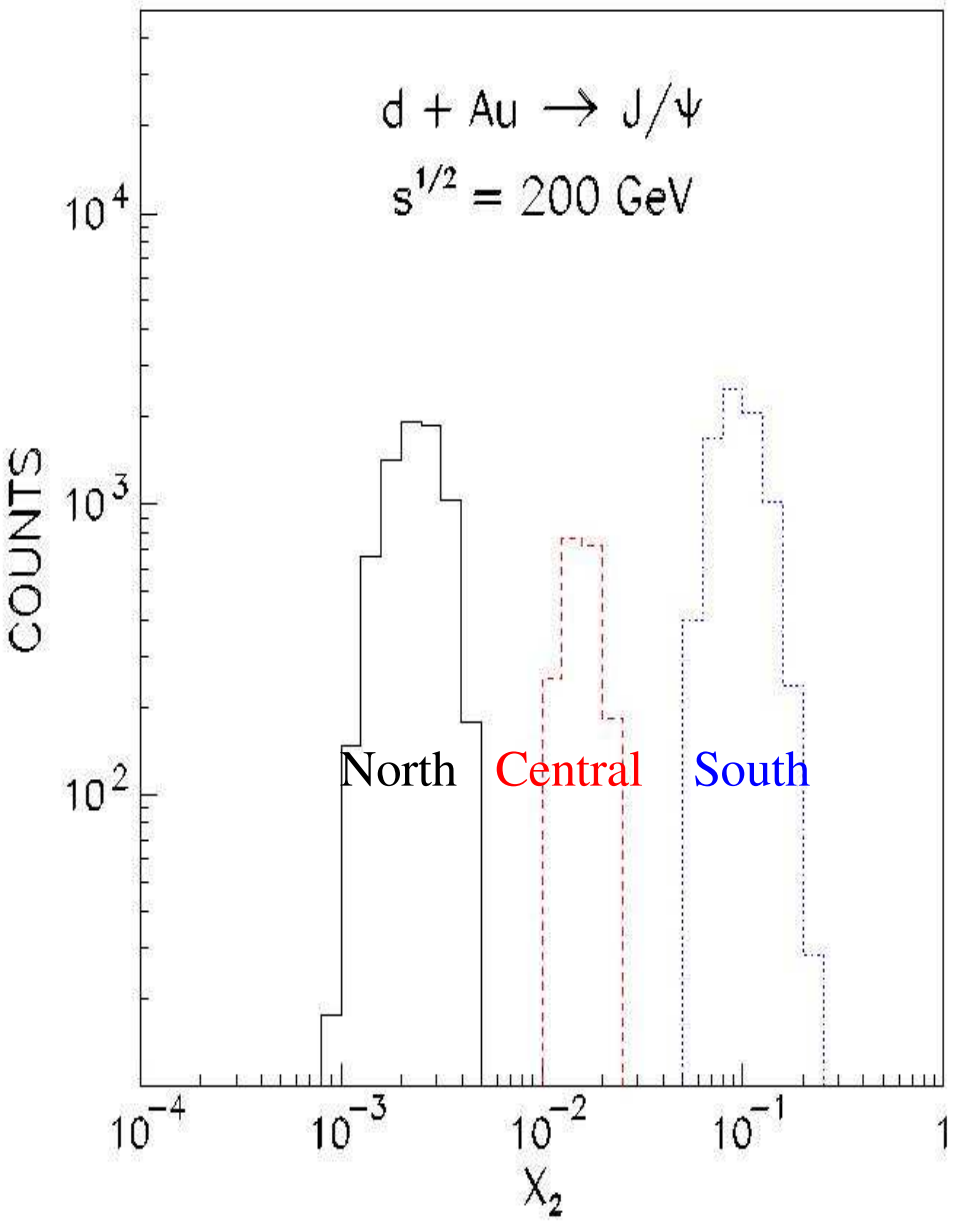
$x_F = 2*p_z/\mathrm{sqrt}(s)$.

$\tau = m^2/s$,

$x_1 = 1/2*(x_F+\mathrm{sqrt}(x_F^2+4*\tau))$;

$x_2 = x_1 - x_F$





PHENIX