Heavy quark measurements in the PHENIX experiment at RHIC

Strangeness in Quark Matter 2004
Cape Town, South Africa, 15-20 September, 2004

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CEA Saclay, for the PHENIX collaboration

Outline

- motivations
- the PHENIX experiment
- selected open charm results
- selected J/ψ results
- conclusion and outlook

Physics motivation

heavy quarks are produced at the early stage of the collision
via parton hard scattering

Open charm measurements

sensitive to parton distribution functions, gluon polarization (for polarized p+p)
sensitive to properties of the produced nuclear medium

- energy loss by gluon radiation?
- thermal enhancement?
- collective flow?

J/ψ measurements

p+p collisions:

- J/ψ production mechanism (CSM, COM, CEM)
- parton distribution functions
- baseline for d+Au and Au+Au

d+Au collisions: "normal" nuclear effects (shadowing, nuclear absorption)

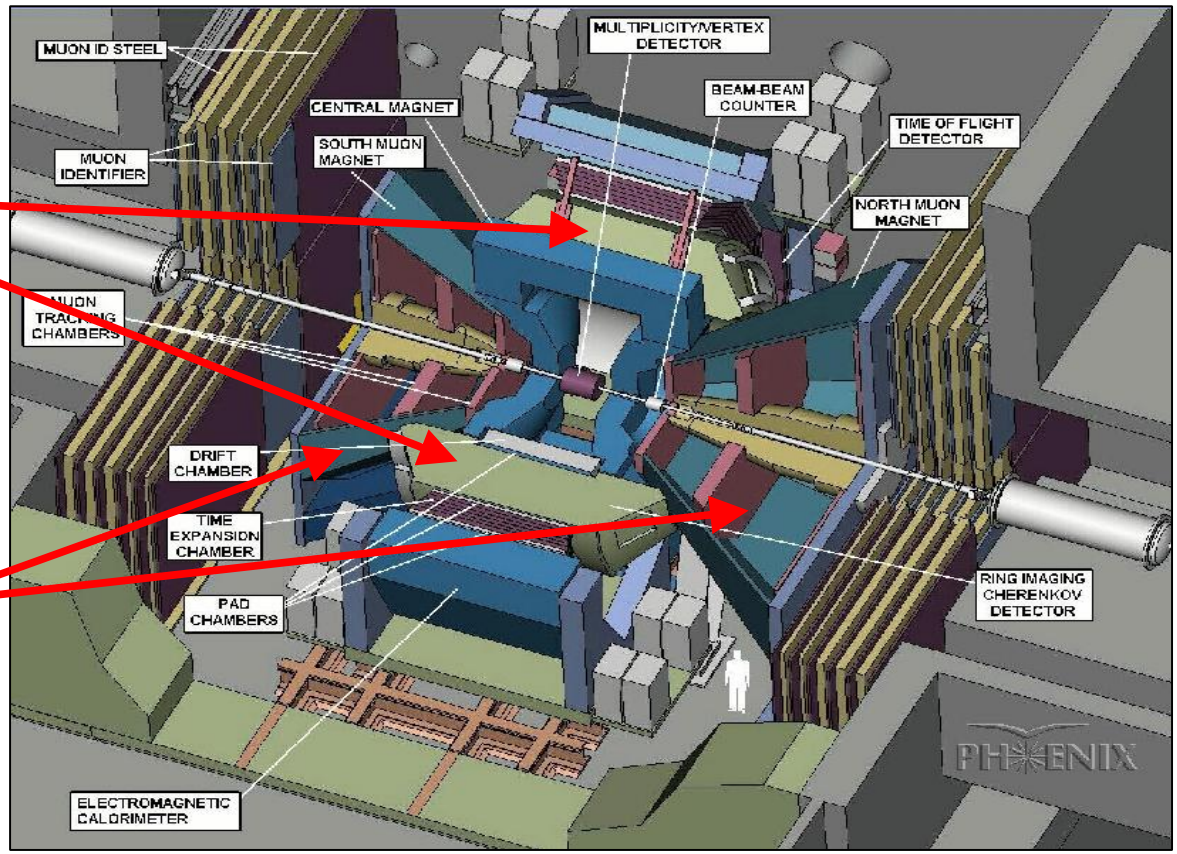
Au+Au collisions: "abnormal" nuclear effects due to hot dense medium

- suppression due to color screening?
- enhancement due to charm quark coalescence?

The PHENIX detector

Central arms:
hadrons, photons, <u>electrons</u>
$p \geq 0.2$ GeV/c
$|\eta| \leq 0.35$

Muon arms:
<u>muons</u> at forward/backward rapidity
$p \geq 2$ GeV/c
$1.2 < |\eta| < 2.4$



Open charm measurement

Indirect measurement via semi leptonic decay:
we measure single electron spectra in central arm
we estimate and subtract contributions from

- π^0 Dalitz decay: $\pi^0 \rightarrow \gamma ee$
- γ conversion
- η Dalitz decay: $\eta/\eta' \rightarrow \gamma\ ee$
- light vector mesons decay: $\rho \rightarrow ee$, $\omega \rightarrow (\pi^0)ee$, $\varphi \rightarrow (\eta)ee$

we call the remaining electrons **non-photonic electrons**
they are dominated by charm and bottom semi leptonic decays

Single electron background evaluation

Cocktail method (data driven simulations):

- π contribution based on PHENIX π^0, π^+ and π^- spectra
- γ conversion contribution from material budget in the acceptance
- light meson contributions from lower energy data and m_t scaling from π data

Convertor method (to validate the γ **conversion** yield estimate):

we compare single electron spectra with/without a thin converter added to the acceptance

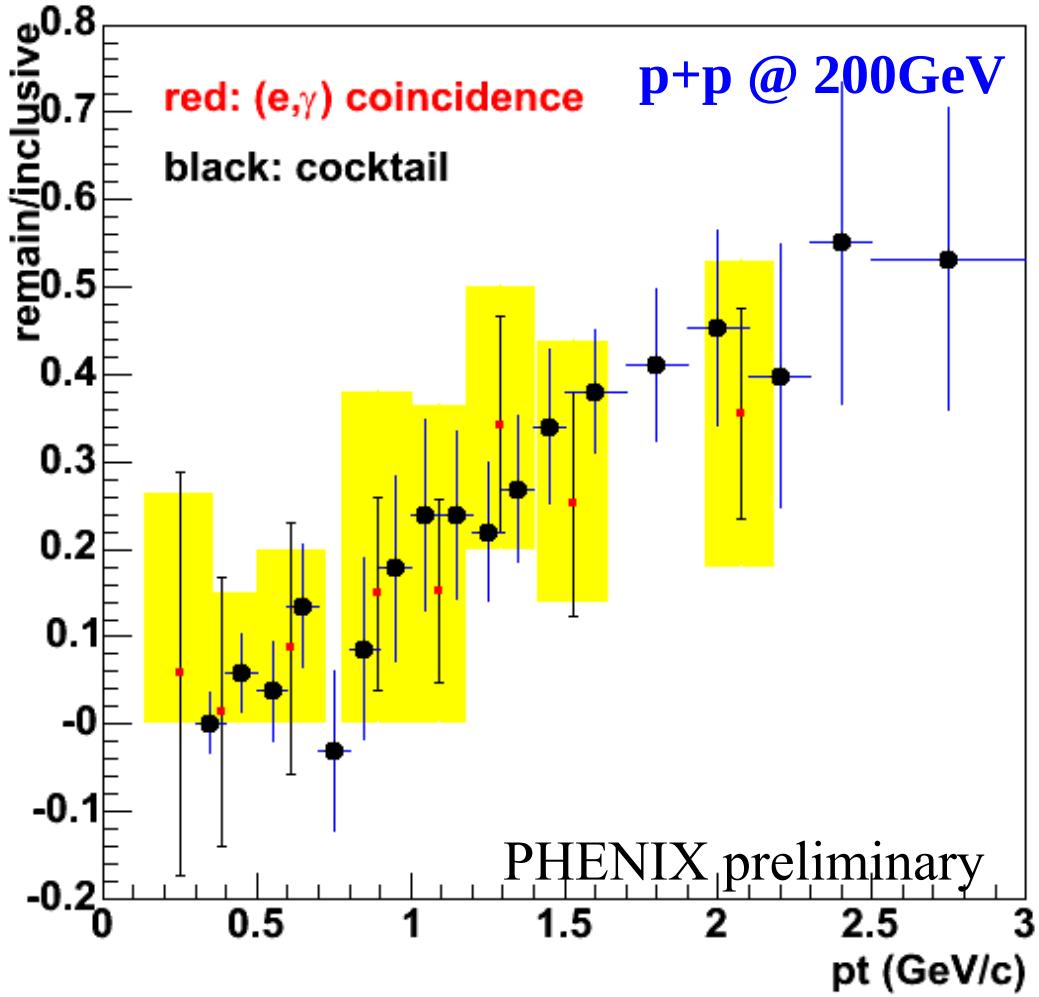
$\Rightarrow$ separation between photonic/non photonic electron sources

Direct measurement of meson decay contribution using γe coincidences:

we measure γe invariant mass around the π/η mass,

we subtract combinatoric background using event mixing

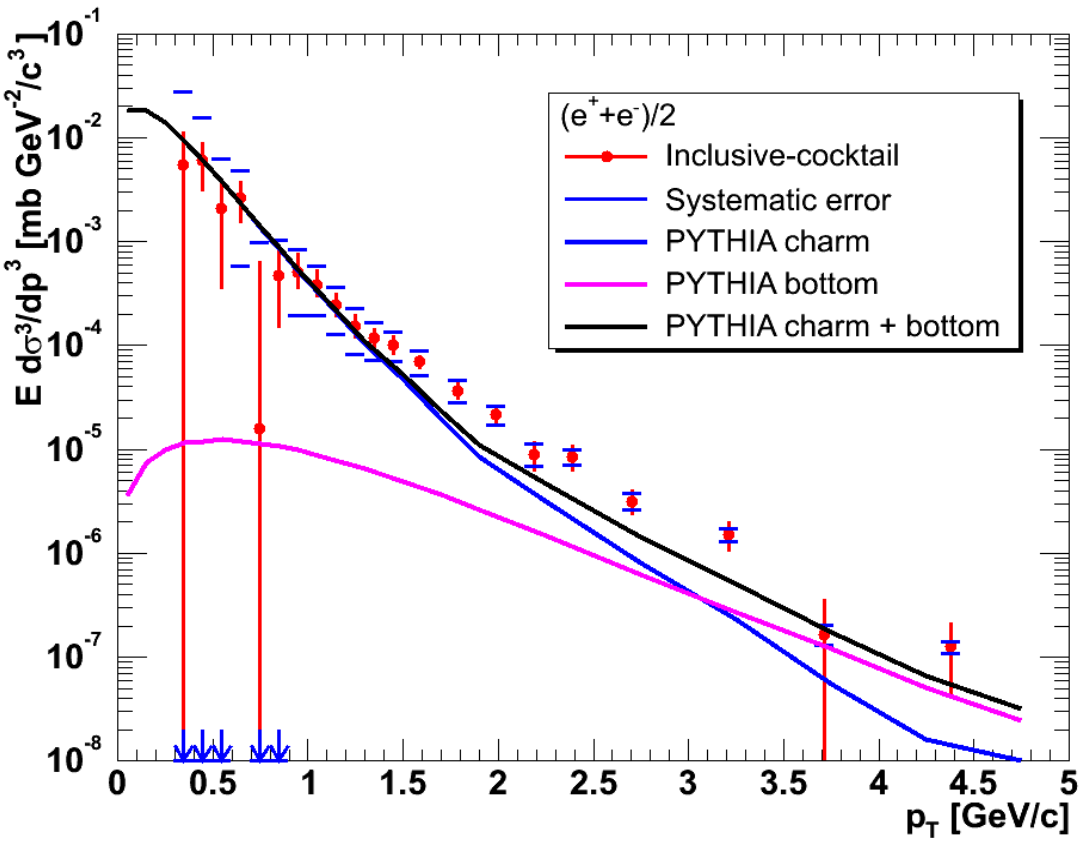
non photonic/inclusive electron spectra



- ratio of non-photonic electrons / total increases with p_t
- good agreement between direct measurement and cocktail simulation, though limited statistics. Validates both methods, since they are independent

p+p @ 200 GeV - comparison to PYTHIA

non photonic electron yield vs p_t



PHENIX preliminary

leading order PYTHIA tuned to low energy data doesn't match for $p_t > 1.5$ GeV

p+p @ 200 GeV - comparison to PYTHIA

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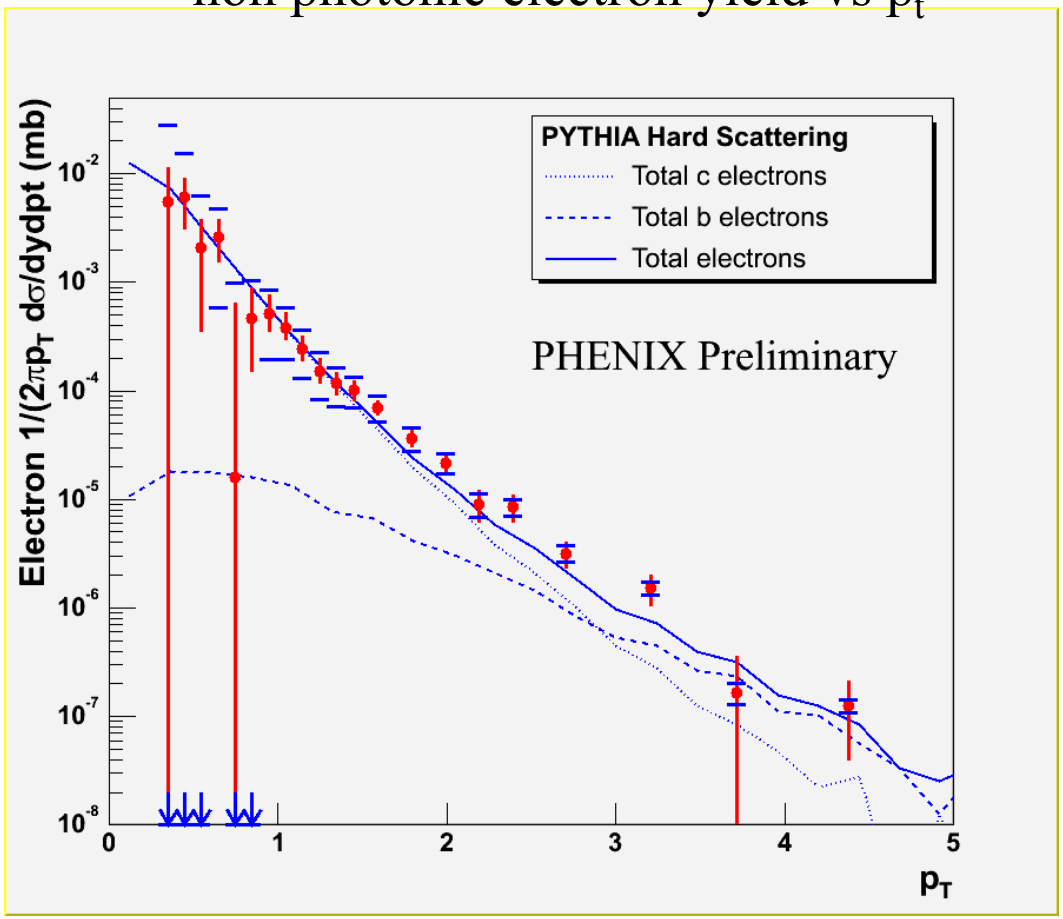
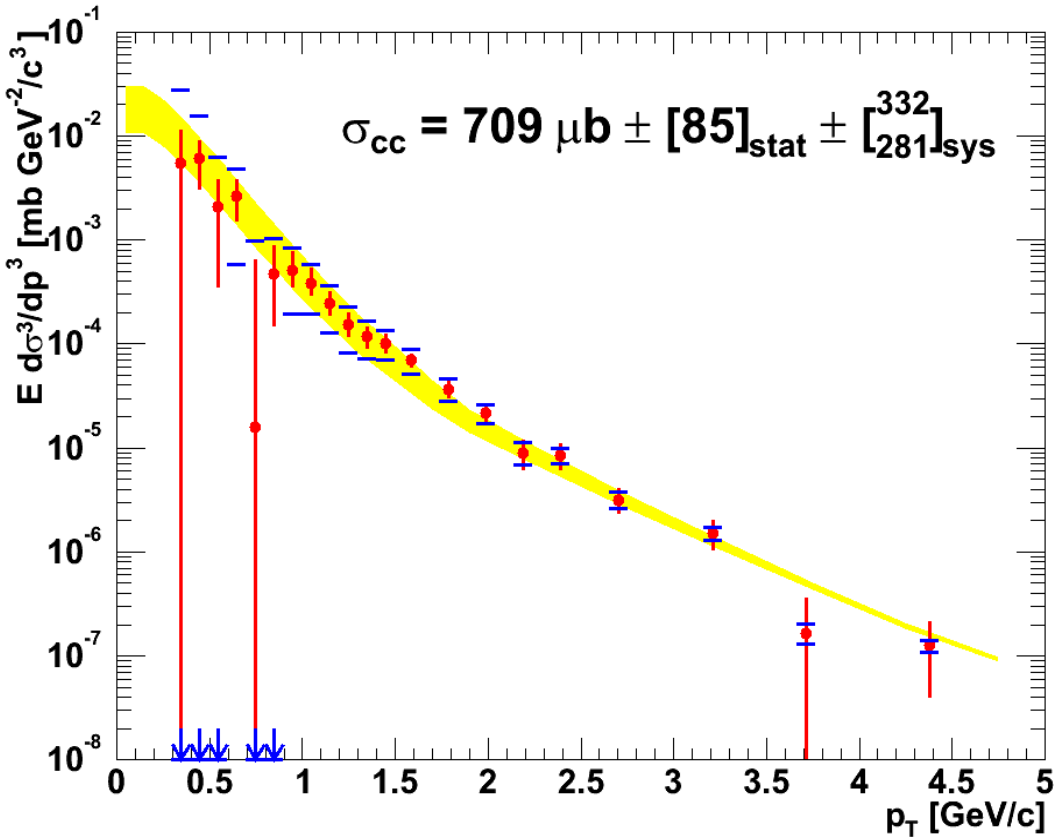


better matching achieved when taking all heavy quark production processes into account.

p+p @ 200 GeV - comparison to PYTHIA

non photonic electron yield vs p_t



PHENIX preliminary

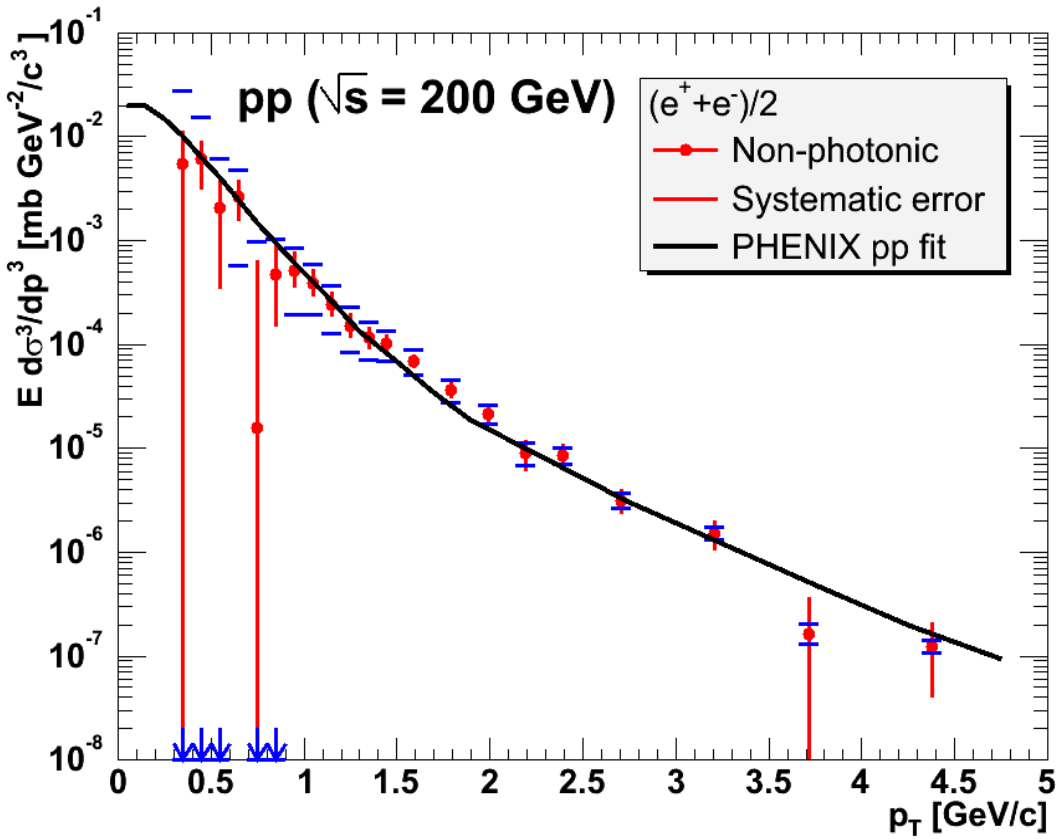
better matching also achieved when letting charm and bottom contributions scale independently.

⇒ usable for total cross-section calculation.

$\sigma_{cc} = 709 \pm 85 \pm {}^{332}/_{281}$ μb

p+p @ 200 GeV - comparison to PYTHIA

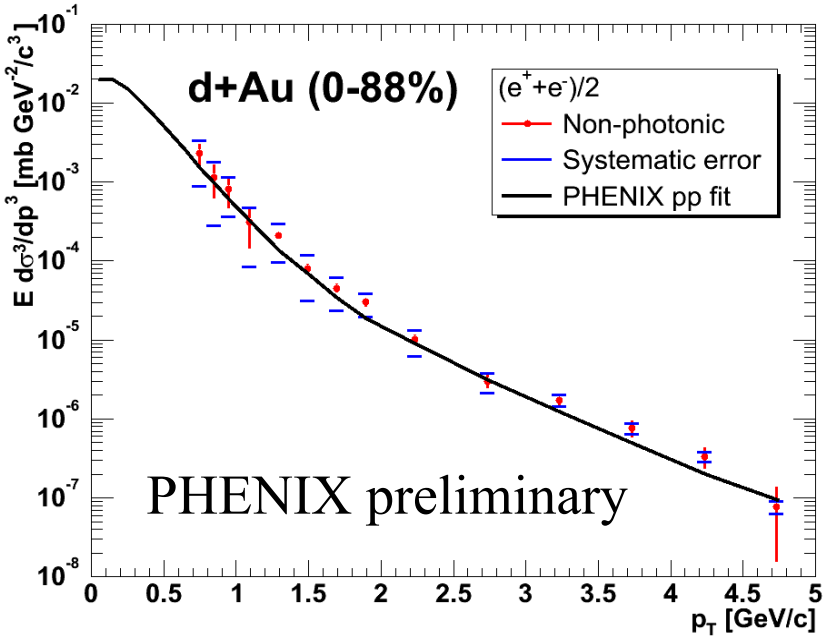
non photonic electron yield vs p_t

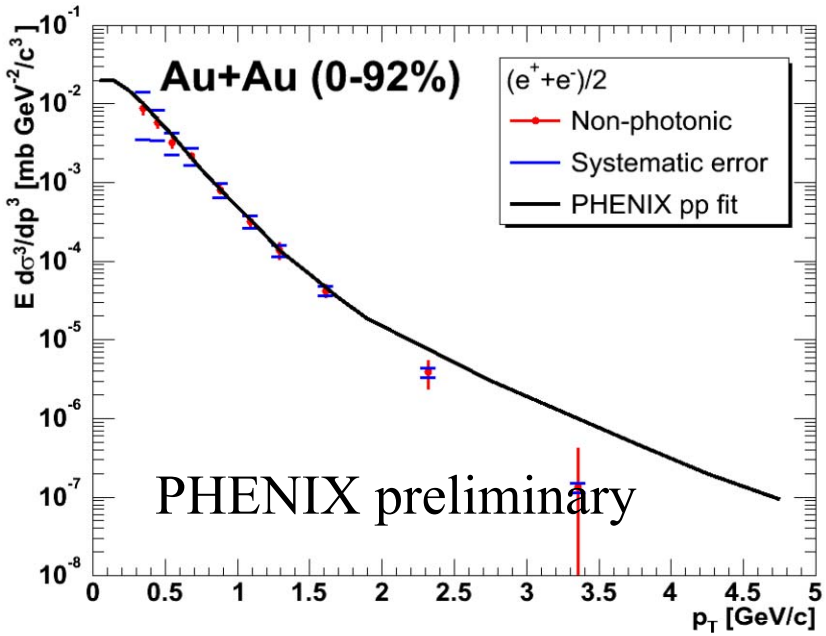


PHENIX preliminary

anyway,
we use a <u>phenomenological</u> fit to the data to compare with other species (d+Au, Au+Au)

d+Au @ 200 GeV Au+Au @ 200 GeV





d+Au and Au+Au data divided by N_{coll} and plotted against PHENIX p+p fit

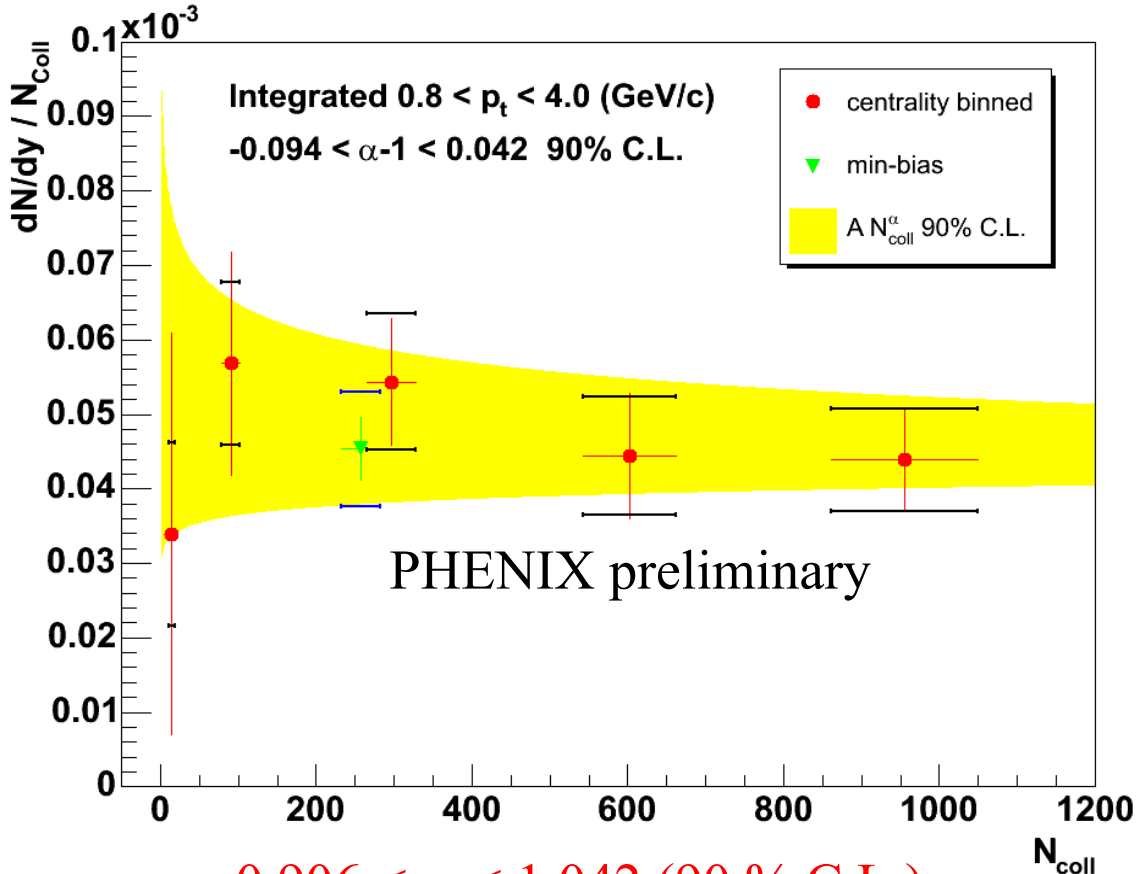
d+Au: perfect agreement within error bars

Au+Au:

- good agreement at low p_t
- deviation from p+p for $p_t > 2$ GeV/c $\Rightarrow$ energy loss ?
- but: **poor statistics**

Au+Au @ 200 GeV vs centrality

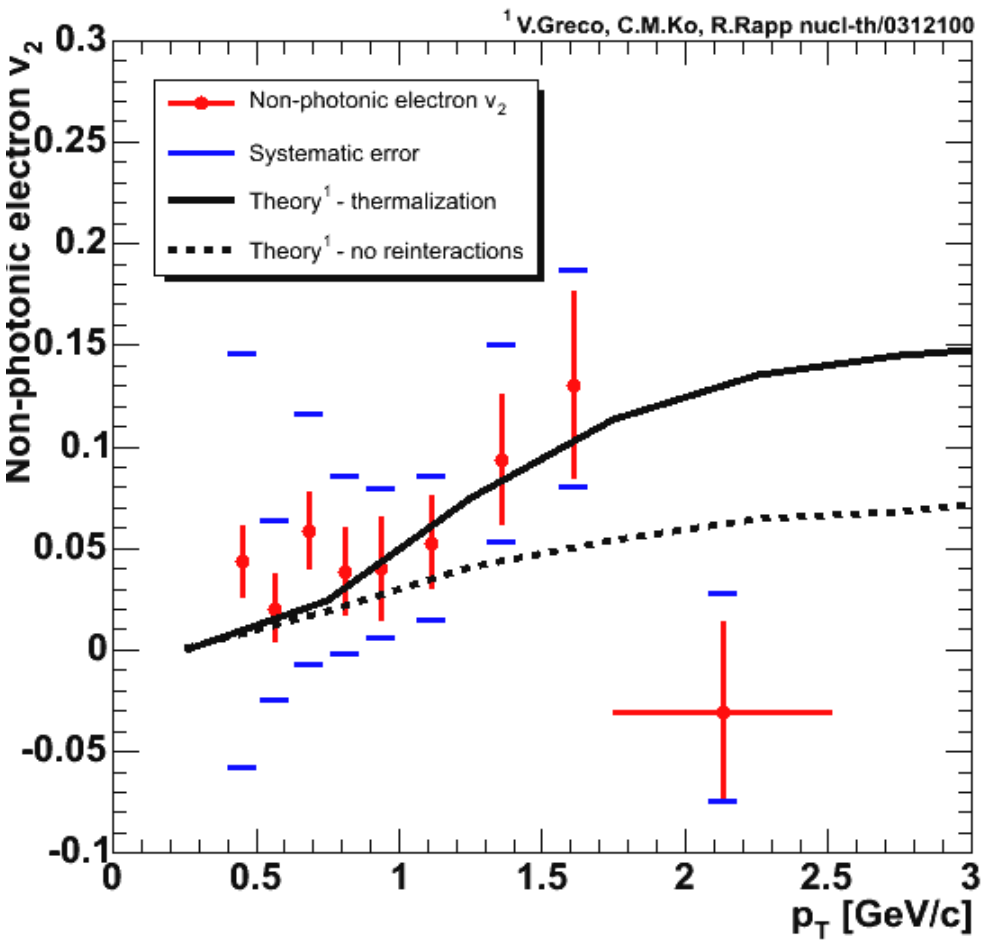
We fit non-photonic electrons vs N_{coll}: **$dN/dy = AN_{coll}^{\alpha}$**



$0.906 < \alpha < 1.042$ (90 % C.L.)

same conclusion for d+Au collisions

Au+Au @ 130 GeV flow measurement



- we measure total electron flow
- we subtract photonic electron contribution
- we plot remaining (non photonic) flow wrt p_t

not enough statistics to distinguish between the two scenarios

J/ψ measurement

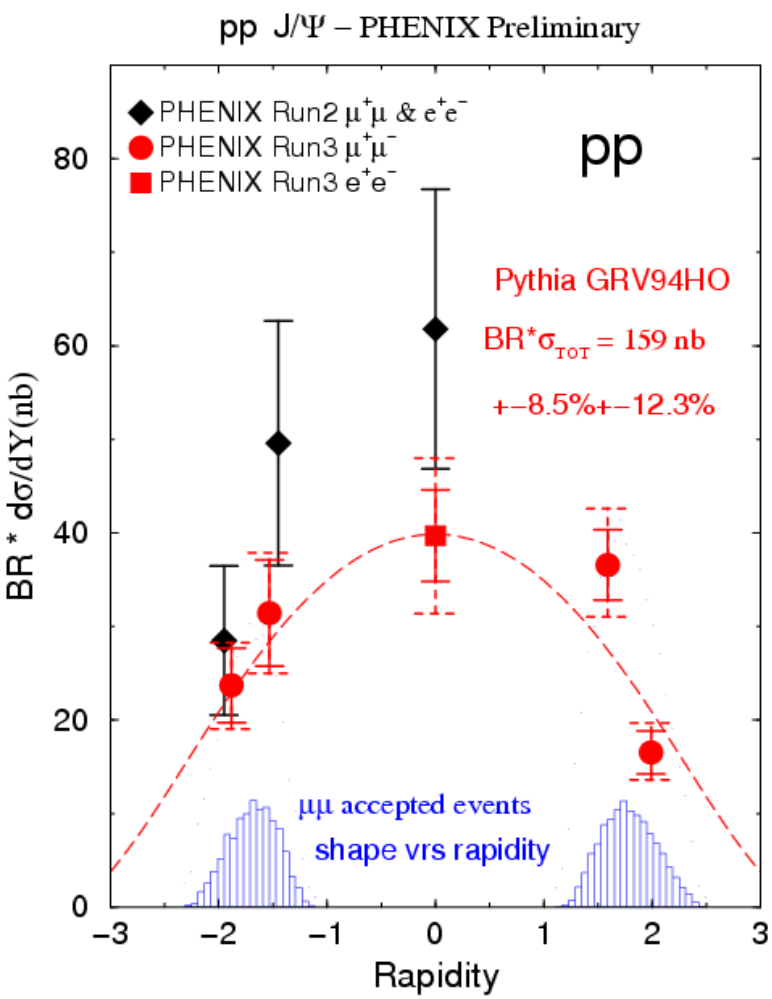
Direct measurement from invariant mass spectrum

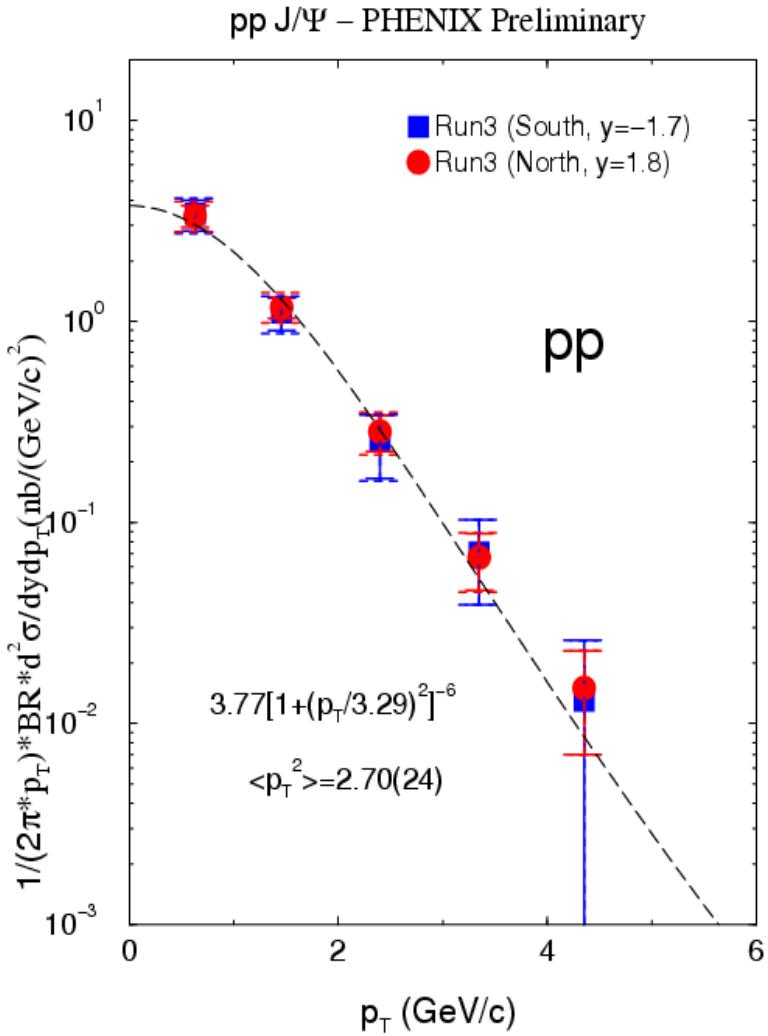
Central arms: $J/\psi \rightarrow e^+e^-$ BR (%) = 5.93 ± 0.10
using RICH and EMCal for electron identification,
drift/pad chambers for tracking

Muon arms: $J/\psi \rightarrow \mu^+\mu^-$ BR (%) = 5.88 ± 0.10
using Iarocci tubes + absorber layers for muon identification
cathode strip chambers for tracking

combinatoric background is subtracted using the like-sign pairs
physical background (open charm/Drell-Yan) is fitted using an exponential

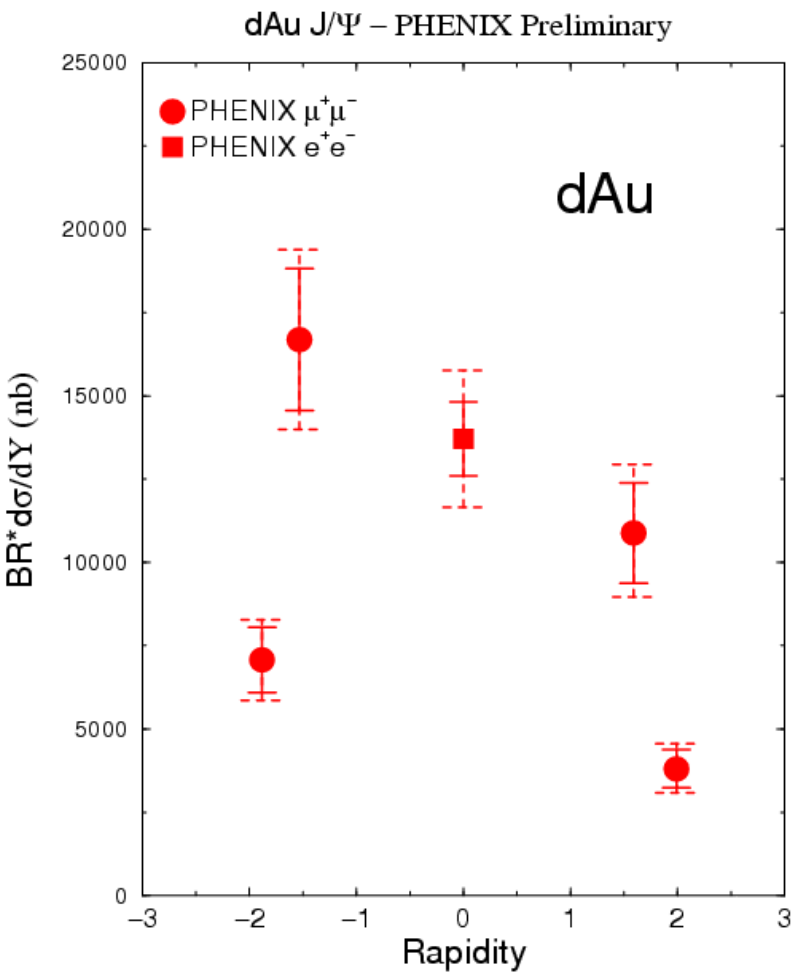
p+p @ 200 GeV (2002/2003 data)

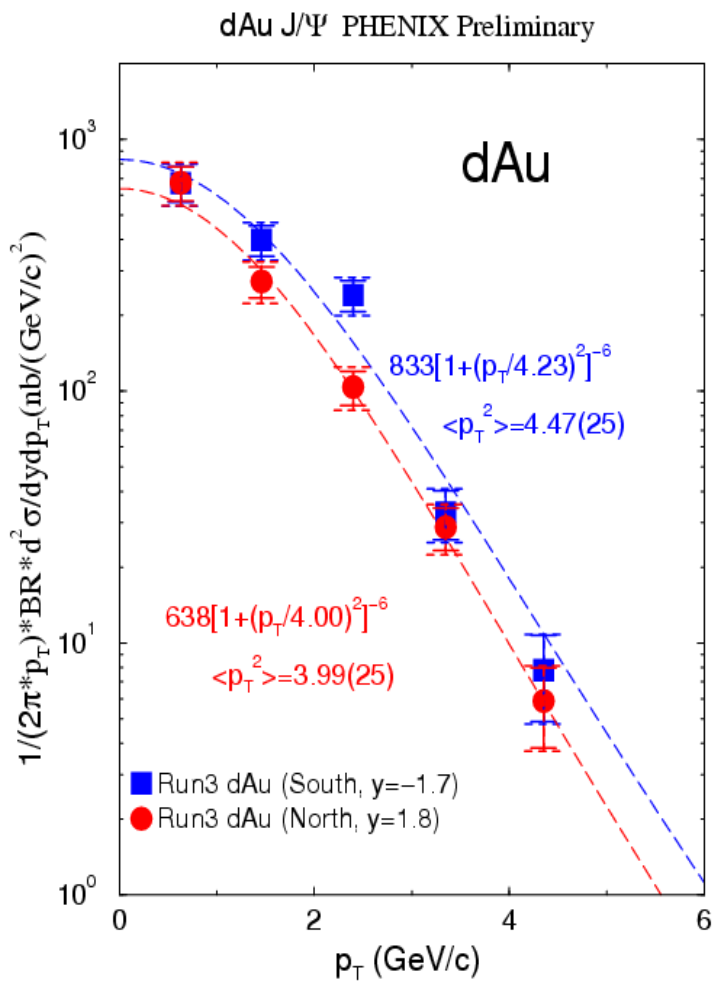




total cross section from Run3 data $BR.\sigma_{tot} = 159$ nb ± 8.5 % ± 12.3 %

d+Au @ 200 GeV (2003 data)





y<0 y>0

large x_{Au} (~0.09) small x_{Au} (~0.003)

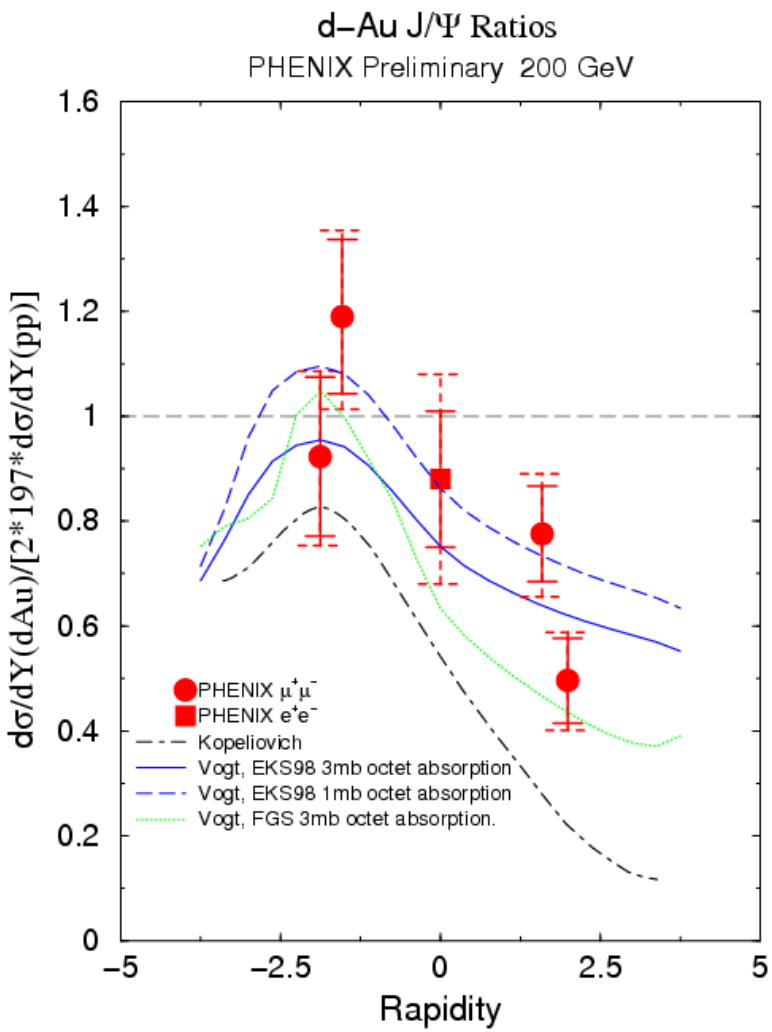
anti-shadowing region shadowing region

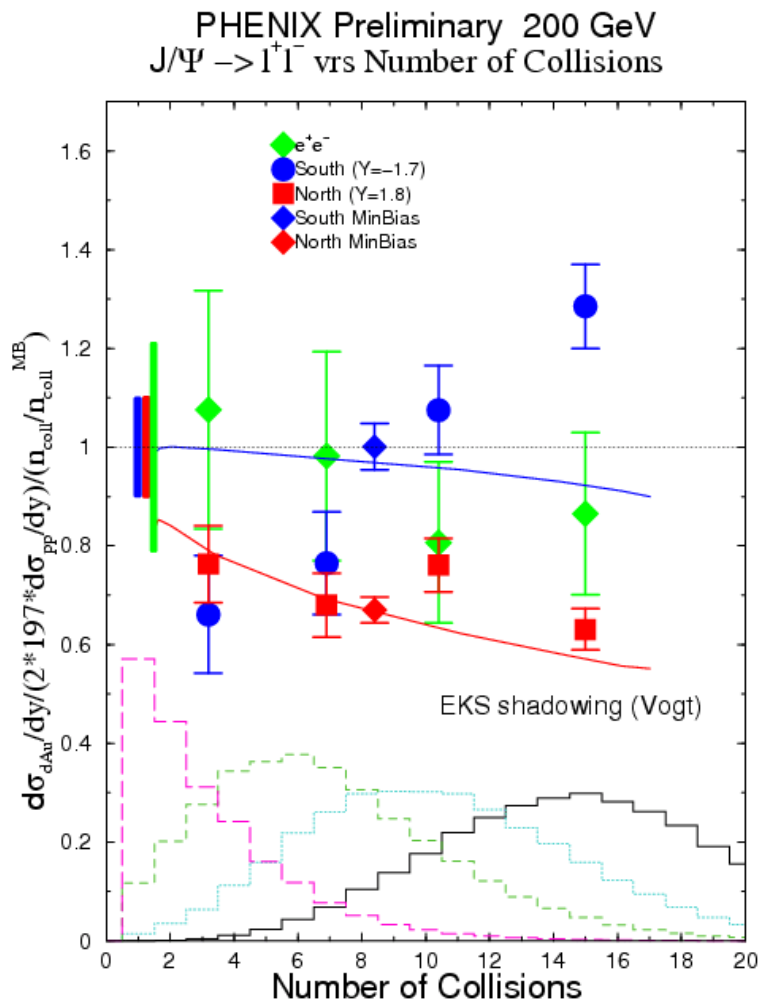
$\langle p_t^2\rangle_{dAu} - \langle p_t^2\rangle_{pp} = 1.77 \pm 0.35\ \mathrm{GeV}^2$

$\langle p_t^2\rangle_{dAu} - \langle p_t^2\rangle_{pp} = 1.29 \pm 0.35\ \mathrm{GeV}^2$

$\Rightarrow$ **p_t broadening**

d+Au vs p+p @ 200 GeV





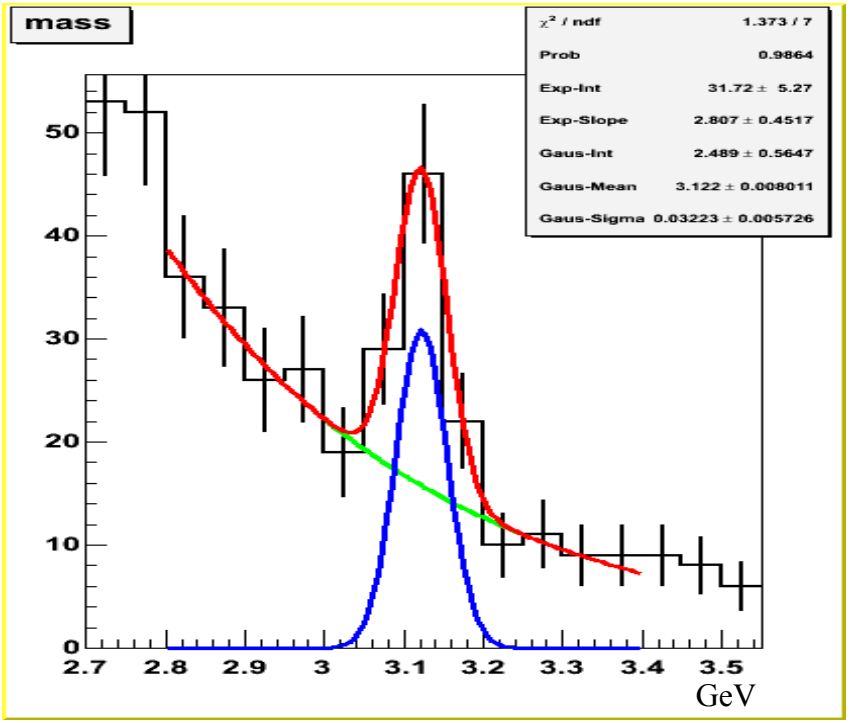
weak nuclear absorption
weak shadowing at small x_{Au} (y>0)

surprisingly steep rise vs N_{coll}
at y<0 (large x_{Au}). still under study

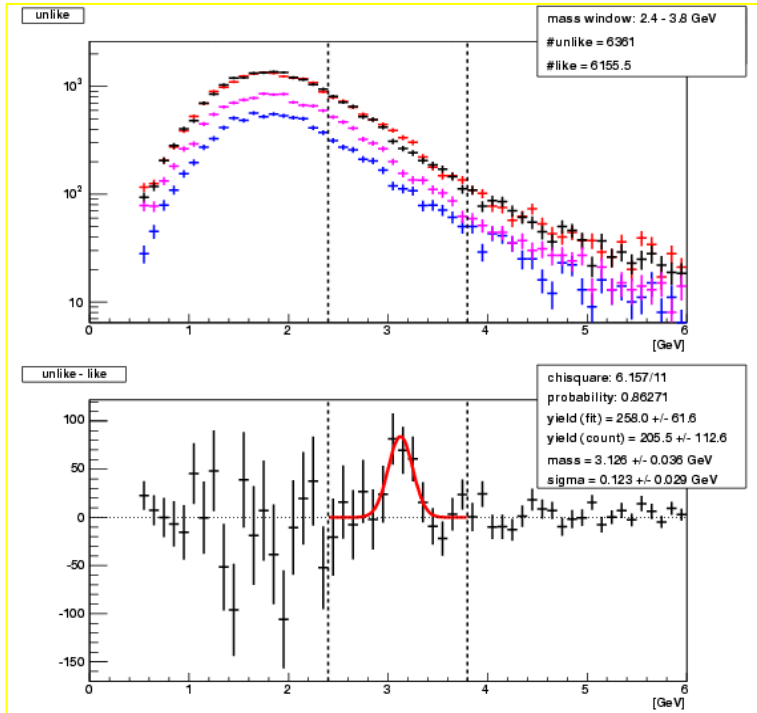
need more statistics to discriminate models

Au+Au @ 200 GeV (2004 data)

J/ψ → ee



J/ψ → μμ



Clear J/ψ signal in both central and muon arms from a small fraction of filtered data.

work in progress to:

- process all data (240 μb^{-1} minbias events, 270 TB)
- estimate efficiency and acceptance corrections

Conclusion and outlook

Open charm

- p+p non photonic electrons matches PYTHIA when taking all heavy quark production mechanisms into account
- d+Au and Au+Au non photonic electrons yields exhibit N_{coll} scaling
  no strong enhancement/suppression of charm cross section in nuclear system
- more statistics needed, especially for v_2 measurement.
  We expect a lot from run4 (2004) data analysis.

- the same study is to be done in the muon arms using single muons
- direct measurement from D meson decay ($D^0 \rightarrow K\pi$)
  using a future vertex detector for displaced vertex identification to remove background

Conclusion and outlook

<u>Charmonium</u>

p+p collisions: we measured total and differential J/ψ cross section, vs p_t and y

d+Au collisions:

- evidence for weak shadowing and weak nuclear absorption
- evidence for p_t broadening when comparing $\langle p_t^2 \rangle_{d+Au}$ vs $\langle p_t^2 \rangle_{p+p}$
- unexpected steep rise of the J/ψ yield wrt N_{coll} in the anti-shadowing region

Au+Au collisions:

- Run2 (2002) has poor detector performance and low luminosity
- Run4 (2004) has 50 times more data, being analyzed presently

the PHENIX collaboration

12 Countries; 58 Institutions; 480 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

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Eötvös Loránd University (ELTE), Budapest

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Bhabha Atomic Research Centre, Bombay

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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

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Kangnung National University, Kangnung
Korea University, Seoul
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Oak Ridge National Laboratory, Oak Ridge, TN
University of Tennessee, Knoxville, TN
Vanderbilt University, Nashville, TN

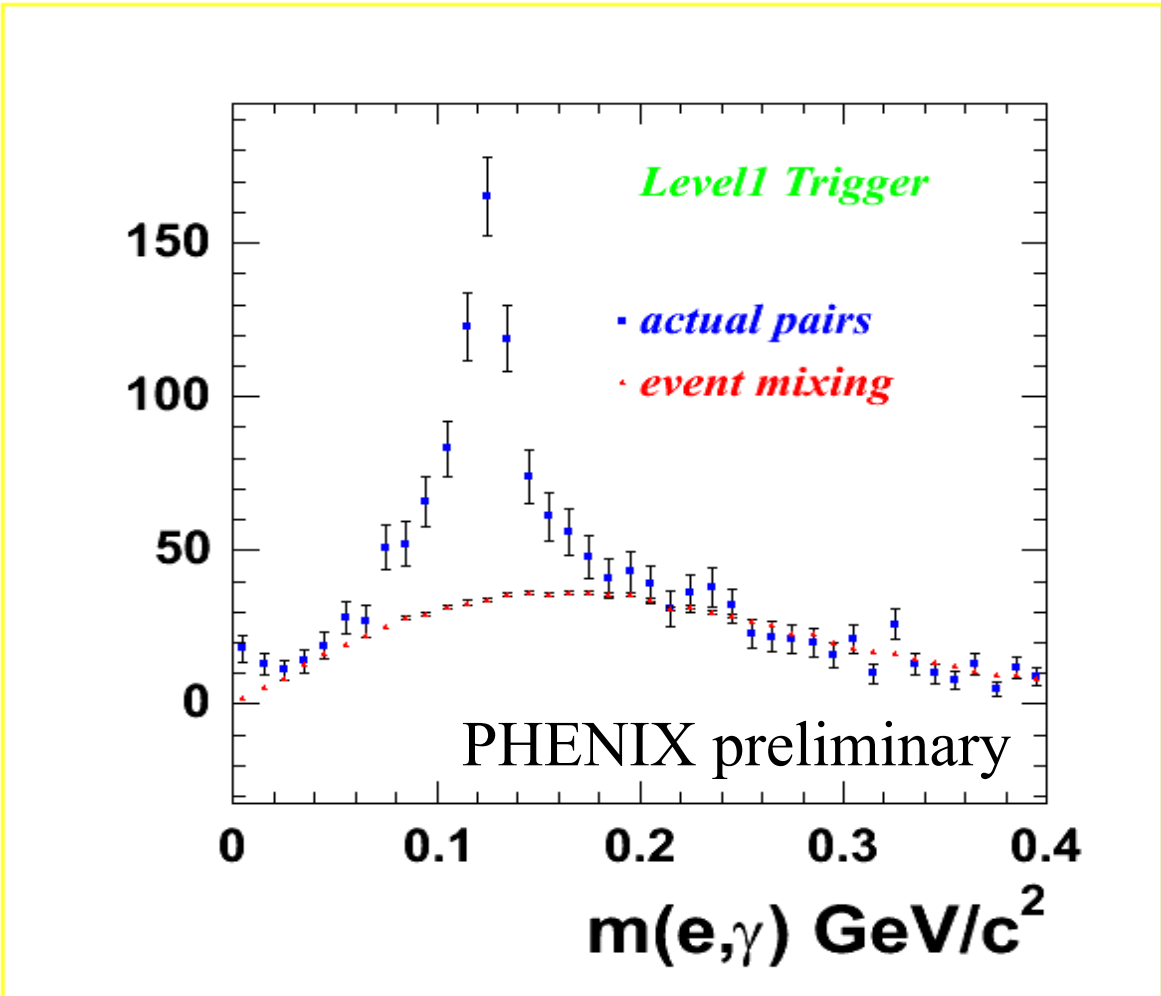
***as of January 2004**

PHENIX data taking periods

year	ions	luminosity	detectors
2000	Au+Au @ 130 GeV	1 μb^{-1}	central (electrons)
2001	Au+Au @ 200 GeV	24 μb^{-1}	central arm + 1 muon arm
2002	p+p @ 200 GeV	150 nb^{-1}	
2002	d+Au @ 200 GeV	2.74 nb^{-1}	central arm + 2 muon arms
2003	P+p @ 200 GeV	350 nb^{-1}	
2004	Au+Au @ 200 GeV	240 μb^{-1}	
	Au+Au @ 62 GeV	9 μb^{-1}	
	p+p @ 200 GeV	325 nb^{-1}	

direct measurement of the meson decay background

γ-e invariant mass



p+p @ 200 GeV - comparison to PYTHIA

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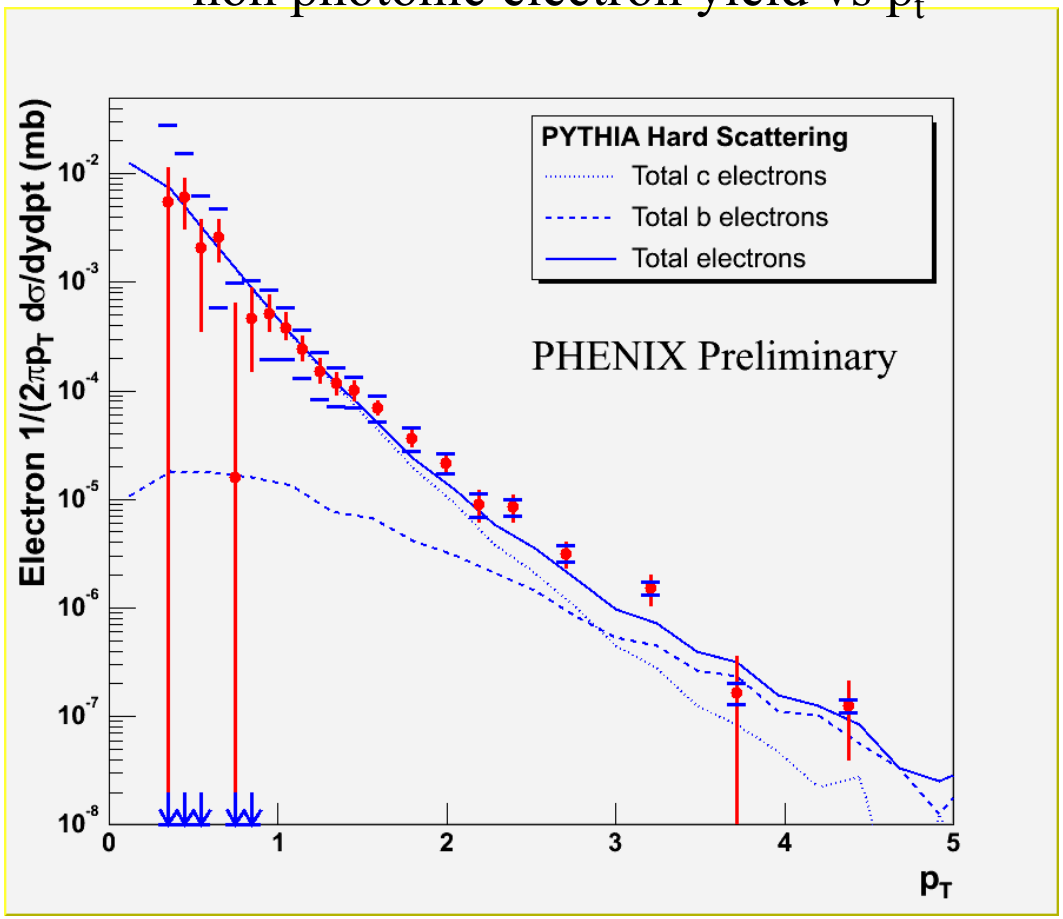


Better matching achieved when taking all heavy quark production processes into account.

* i.e. taking only gg/qq pair creation processes into account to create heavy flavor

Charm production diagrams

from E. Norrbin and T. Sjostrand, Eur. Phys. J. C17 (2000) 137.

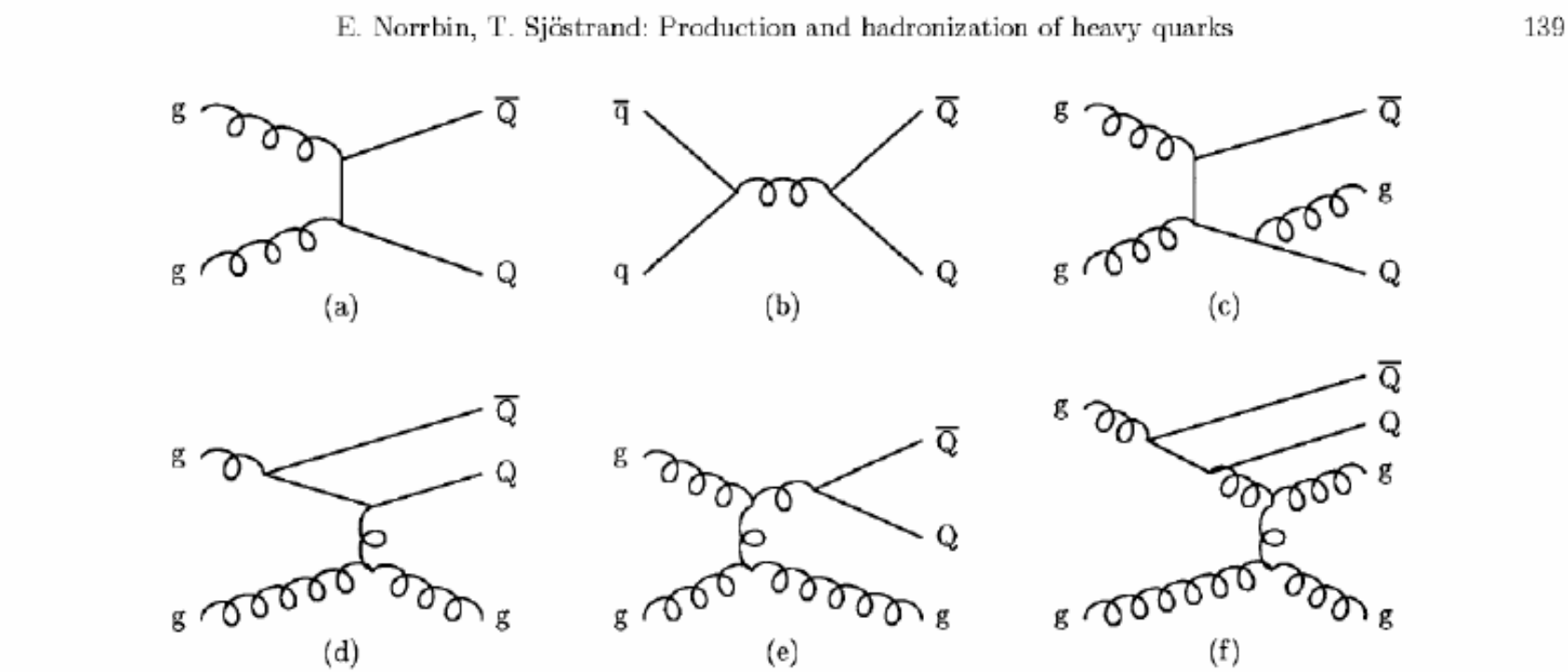
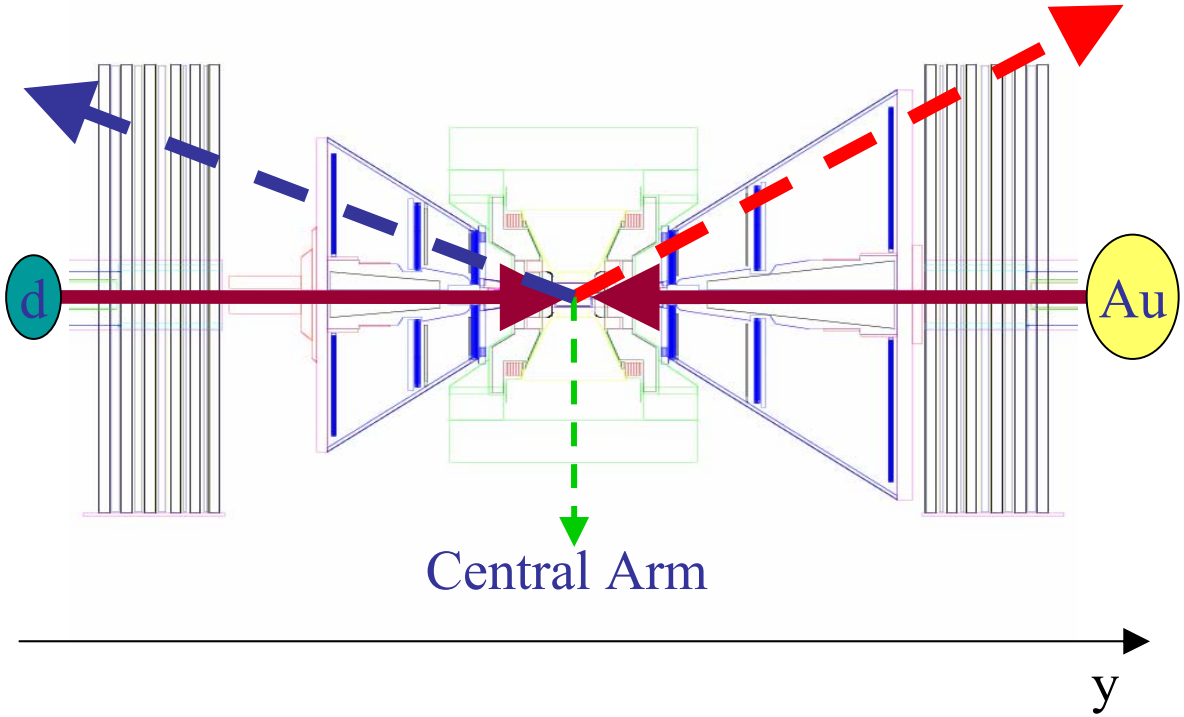


Fig. 1a–f. Examples of heavy-flavor production diagrams. **a**,**b** Leading order. **c** Pair creation (with gluon emission). **d** Flavor excitation. **e** Gluon splitting. **f** Events classified as gluon splitting but of flavor-excitation character

(a, b, c):	pair creation
(d, f):	flavor excitation
(e):	gluon splitting

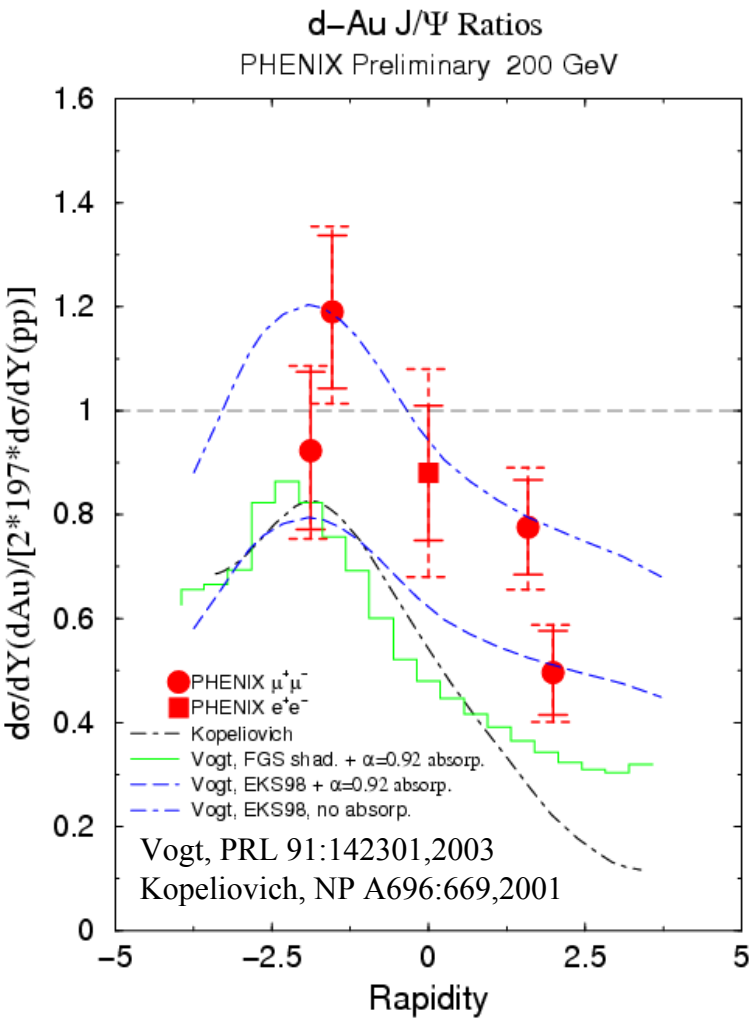
d+Au @ 200 GeV

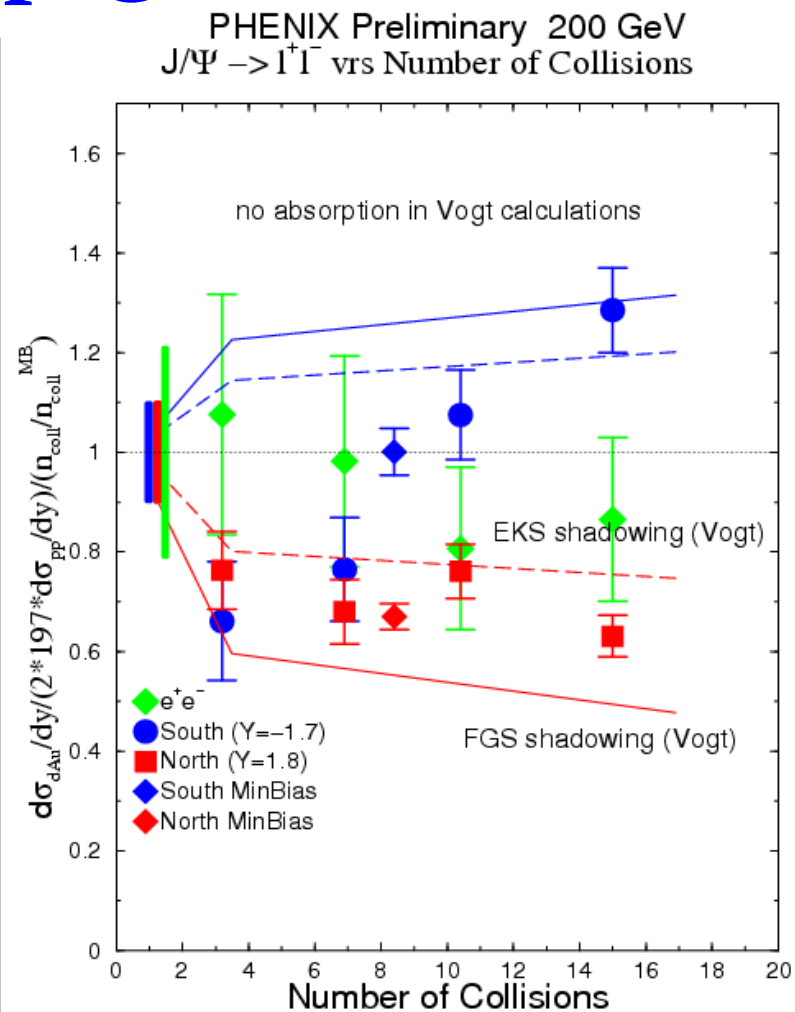


$y<0 \Rightarrow$ large x in gold nuclei

$y>0 \Rightarrow$ small x in gold nuclei

d+Au vs p+p @ 200 GeV





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