quarkonia et saveurs lourdes

Denis Jouan / PHENIX collaboration

and

outlines

- Introduction
- Experimental set up
- Quarkonia
- Open heavy flavor

p-p, A-A , dAu , CuAu

Heavy flavors as a probe of QGP

- As suggested by T.Matsui and H.Satz (1986)

Heavy flavors c and b quark production have special interest for testing the beginning of the collision process

- Produced in the beginning of the collision (mainly gluon fusion)
- Quarkonia sensitive to QGP screening effect

- Open charm and beauty also probe the hot matter produced (at RHIC: perfect liquid)

Heavy flavors mesons are good probes of many phenomenon

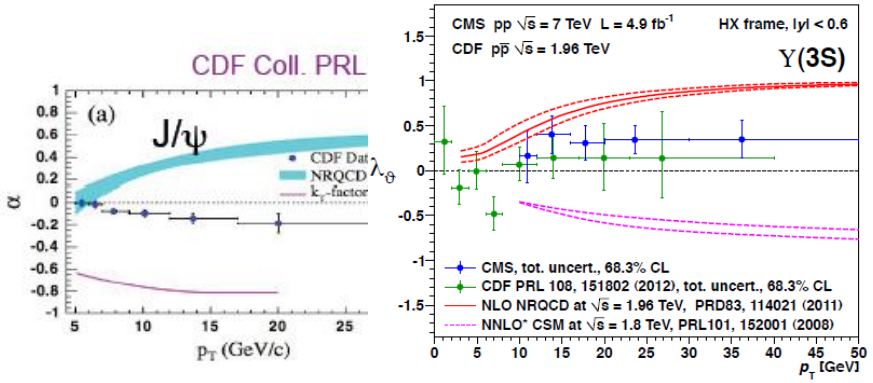
- pp the reference for the production process
- dAu nuclear effects (cold nuclear matter)
- A-A hot QCD medium

Inversely, even if discovered 40 years ago, quarkonia & heavy productions have still been subject to surprises in the last 20 years

There is still to learn on the tool itself

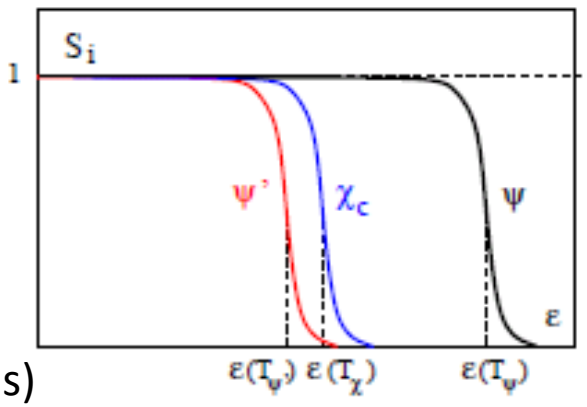
(see for instance: R.Vogt N.P.B214(2011)147)

V. Kartvelishvili EPJconf49 13008 2013



Quarkonia : thermometers of QGP

state	J/ψ	χ_c	ψ'	Υ	χ_b	Υ'	χ_b'	Υ''
mass [GeV]	3.10	3.53	3.68	9.46	9.99	10.02	10.26	10.36
ΔE [GeV]	0.64	0.20	0.05	1.10	0.67	0.54	0.31	0.20
ΔM [GeV]	0.02	-0.03	0.03	0.06	-0.06	-0.06	-0.08	-0.07
radius [fm]	0.25	0.36	0.45	0.14	0.22	0.28	0.34	0.39



Melting from color screening in QGP (radius)

H.Satz hep-ph 0609197v1 2006

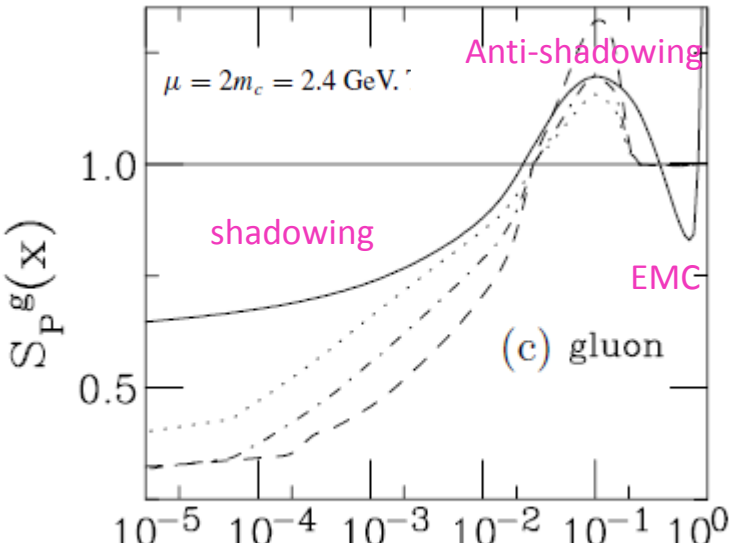
But also

- Initial stage effects
- Nuclear parton distributions
- collisions, all Cold hadronic matter effects
- Recombinations ?

- Competing effect,
-Competing viewpoints ?
(ex: shadowing vs thermal,
with/without time evolution)

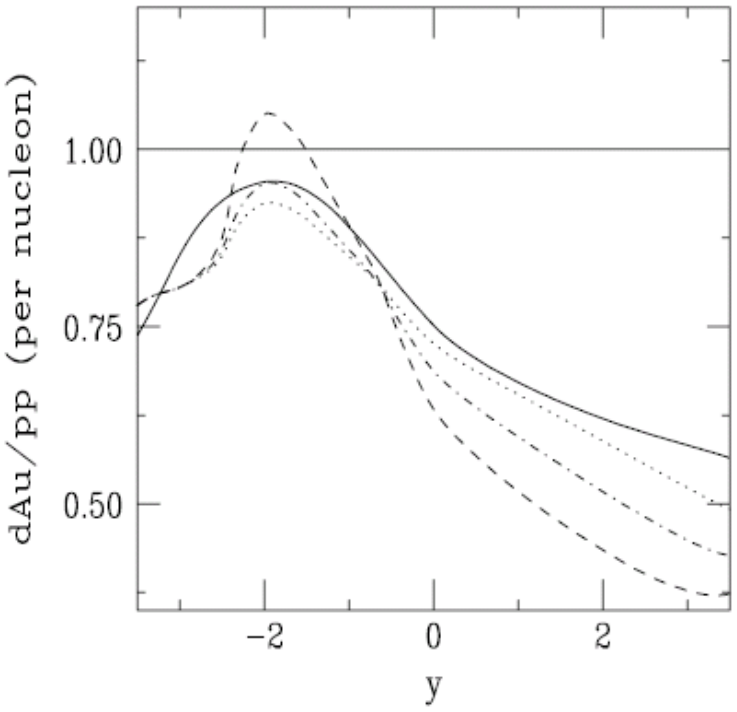
What cocktail in what proportions ?
This needs a set of equations
(=> detailed measurements)

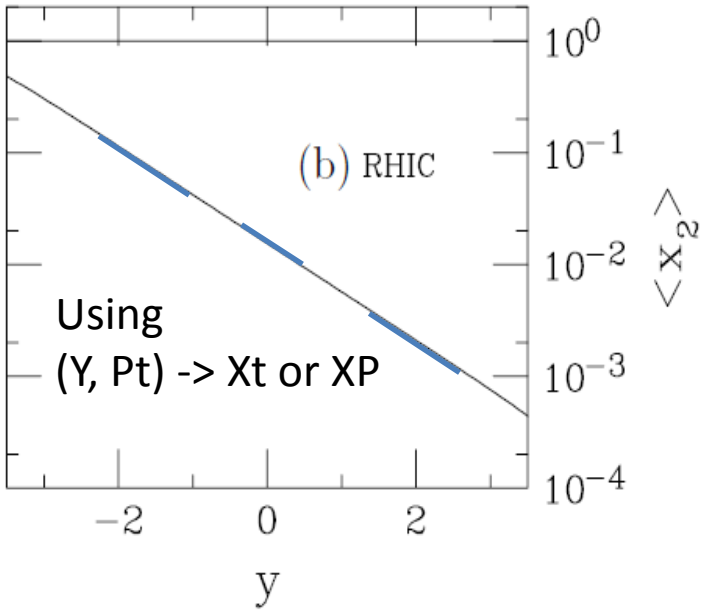
nucleus parton distribution



Starting from parametrization shadowing-antishadowing EMC , for gluons

From R.Vogt PRC 71, 054902 (2005)

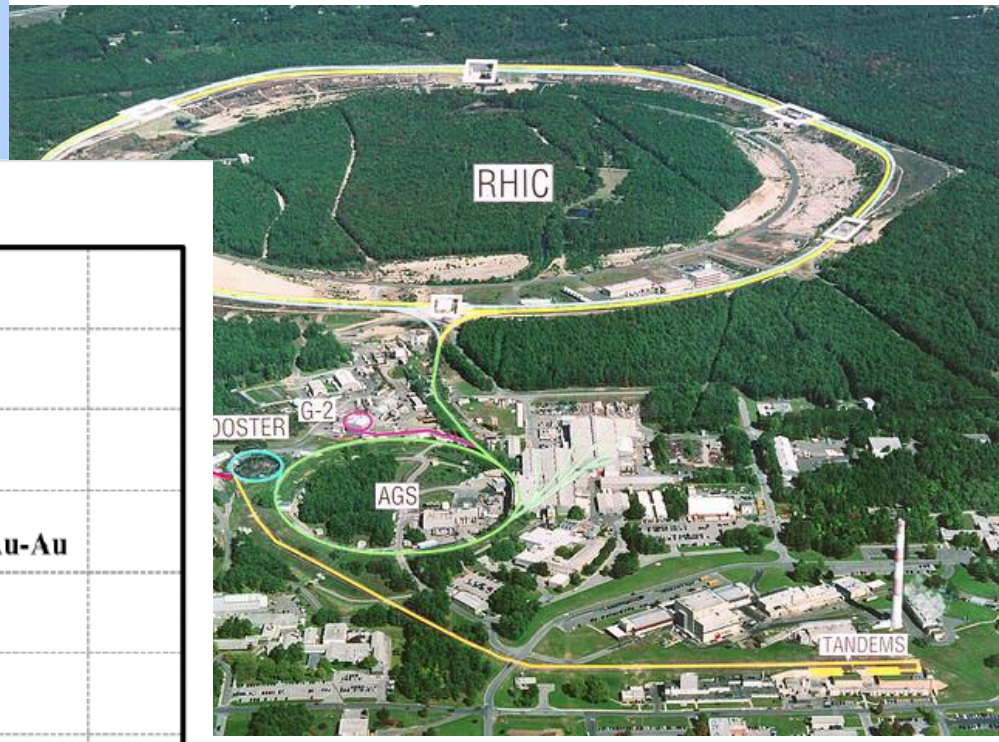


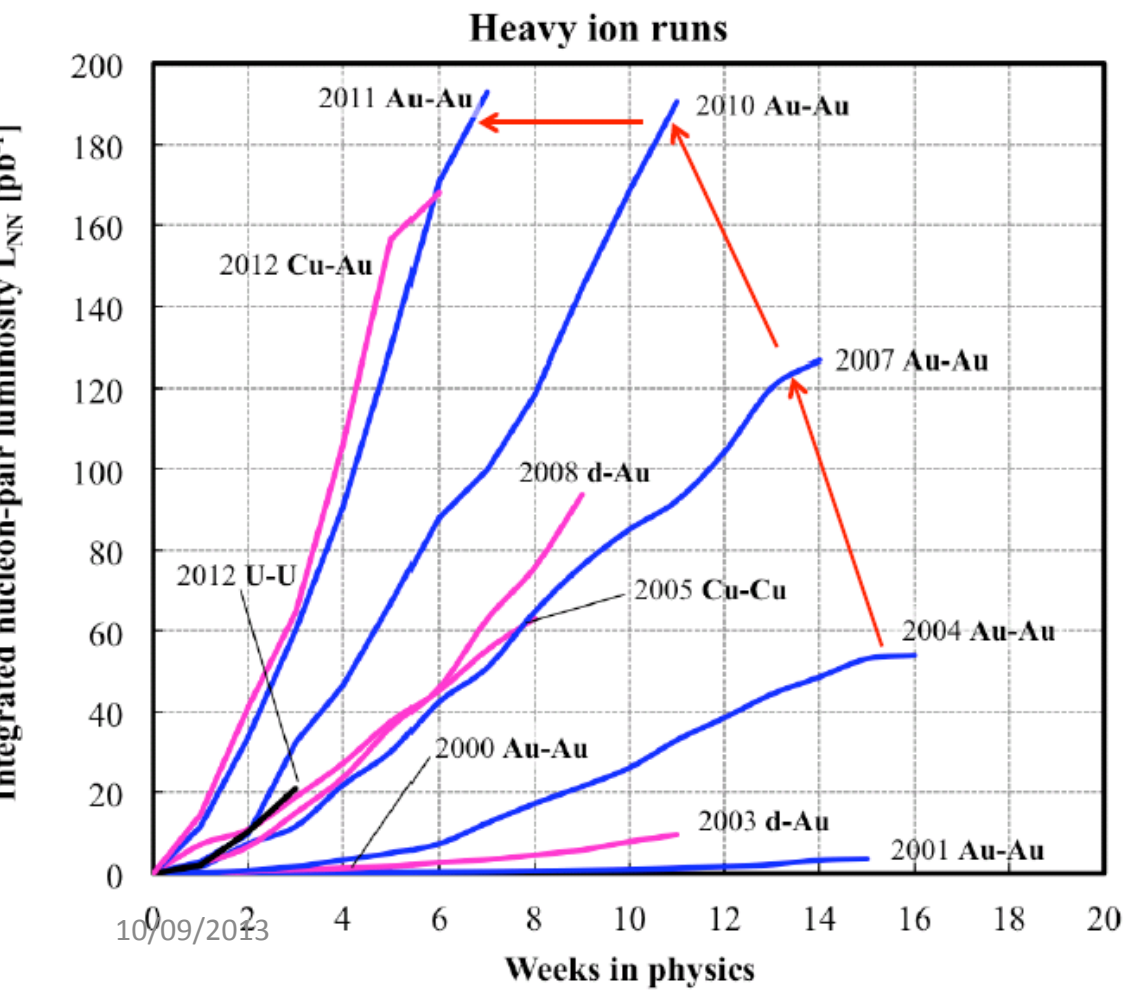


One finally transforms the effect as a function of rapidity

RHIC

at Brookhaven National laboratory





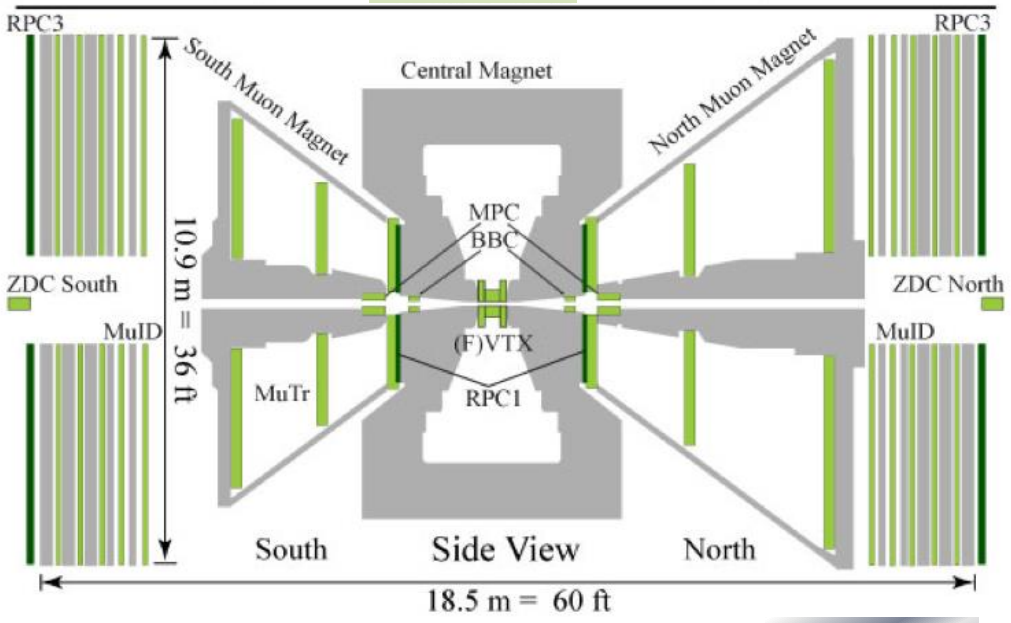
Impressive increase of luminosity during the last decade

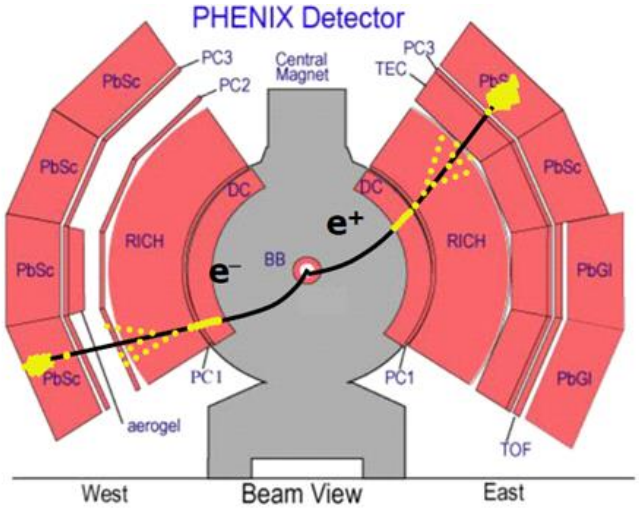
PHENIX

$\mu^+\mu^-$

$|\eta|<.35$

$1.2>\eta>2.2$

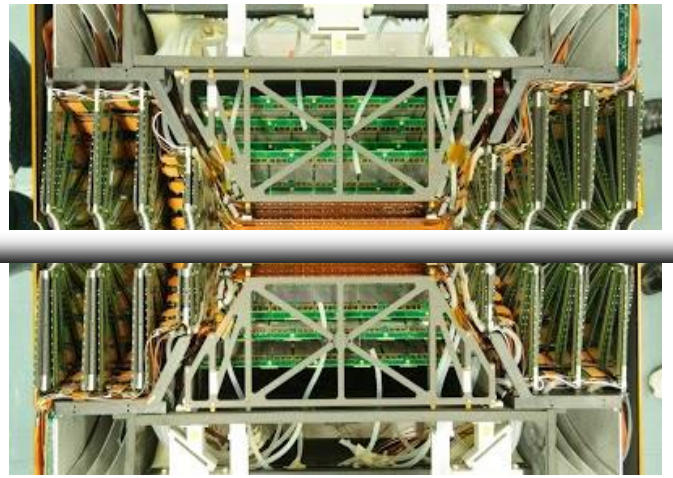




Energy in calorimeter
electron ID in RICH
Tracking in Drift chamber

←Au

d→

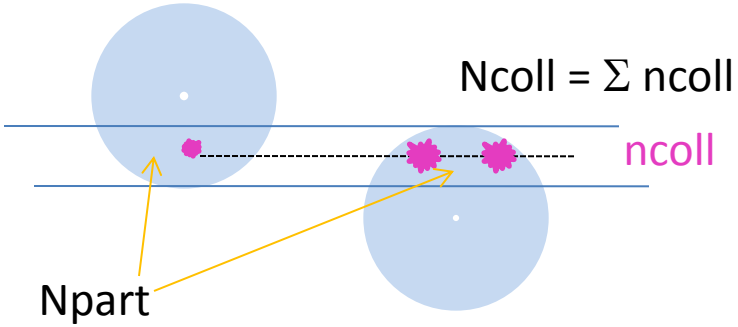


FVTX and VTX :
full forward and central vertex trackers in run 14

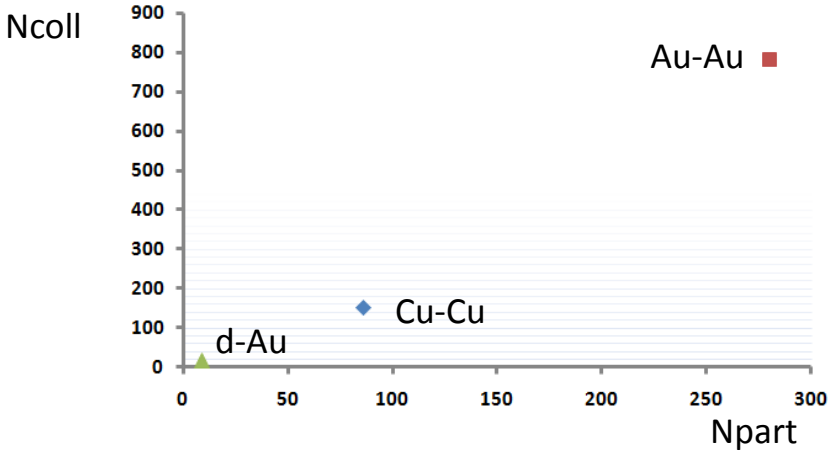
Also other upgrades:
muon piston calorimeter

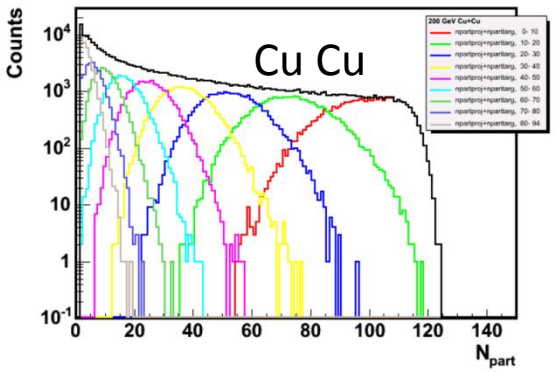
R_{AA}

$$R_{AA} = \frac{dN_{AA}^{J/\psi}/dy}{N_{coll}\, dN_{pp}^{J/\psi}/dy}$$

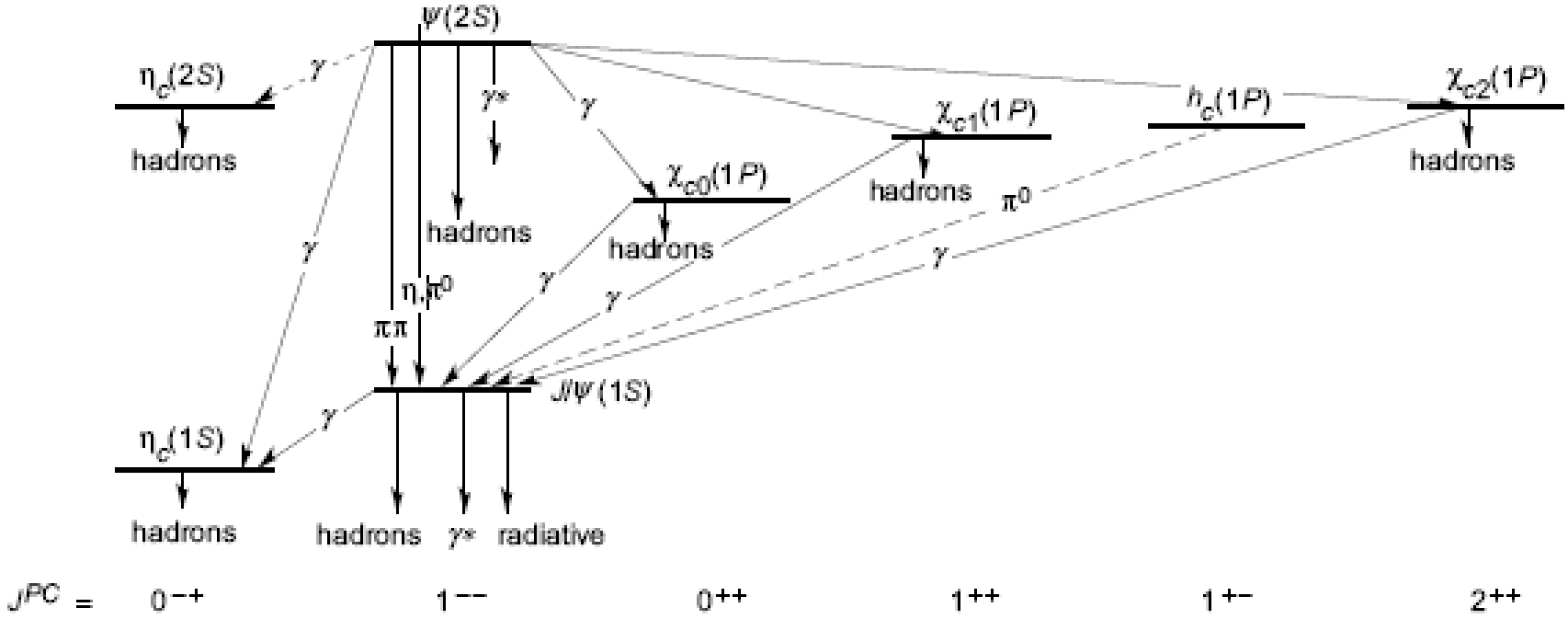


Npart reflects the total energy available (->soft) (Ncoll ~ $Npart^{4/3}$)
Ncoll an estimate of the number of parton collisions (->hard)





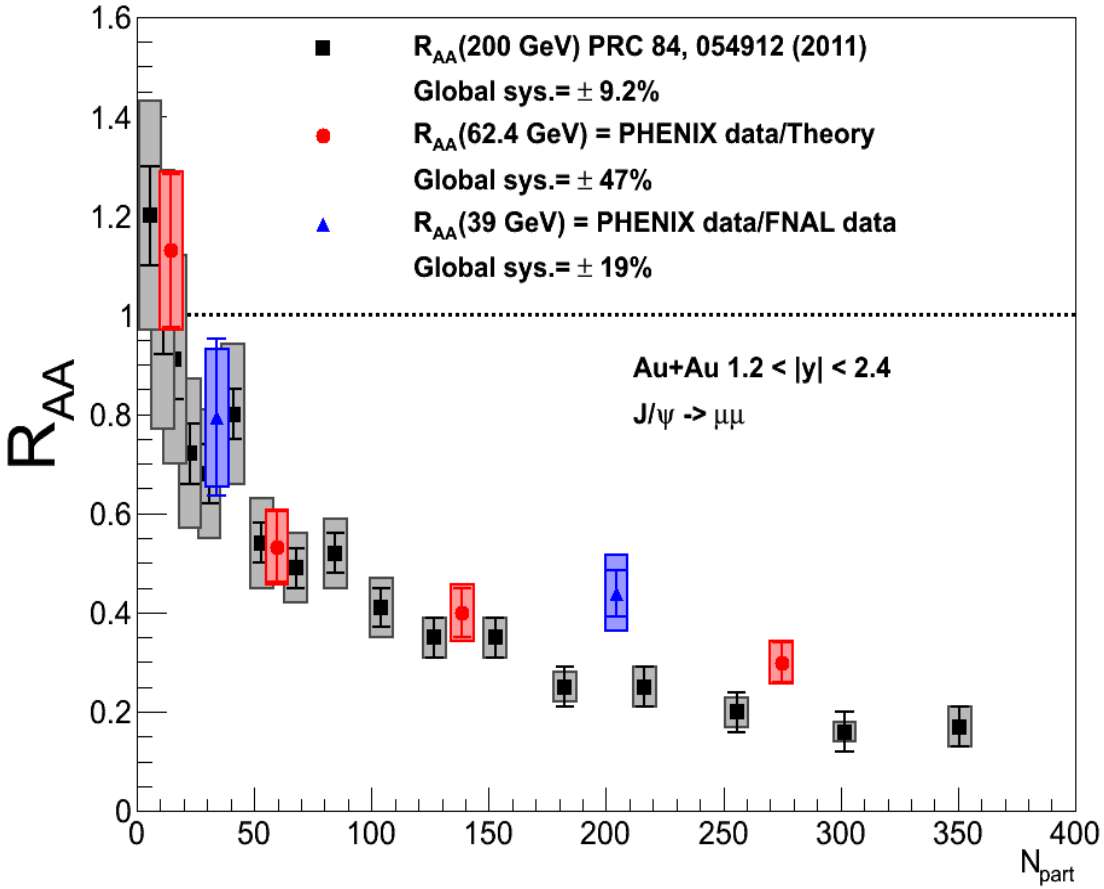
Charmonia

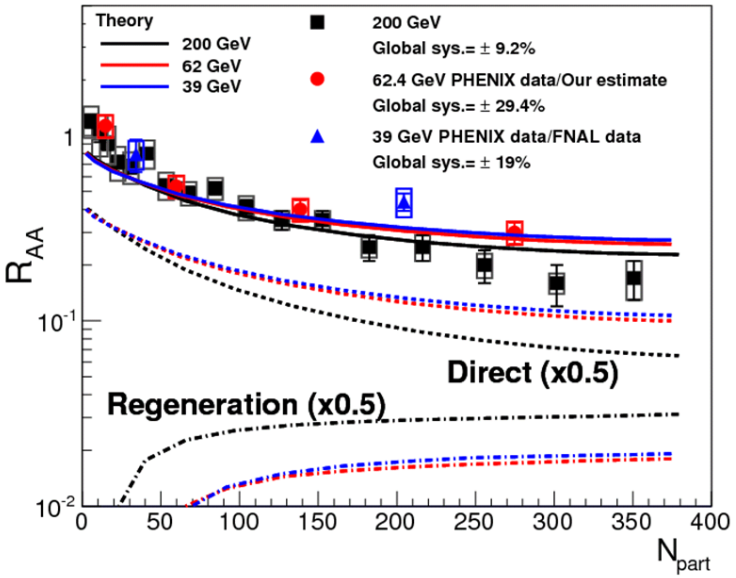


Heavy quarks pairs:
good probes: rare, weak light mesons coupling, various states and binding energies
But

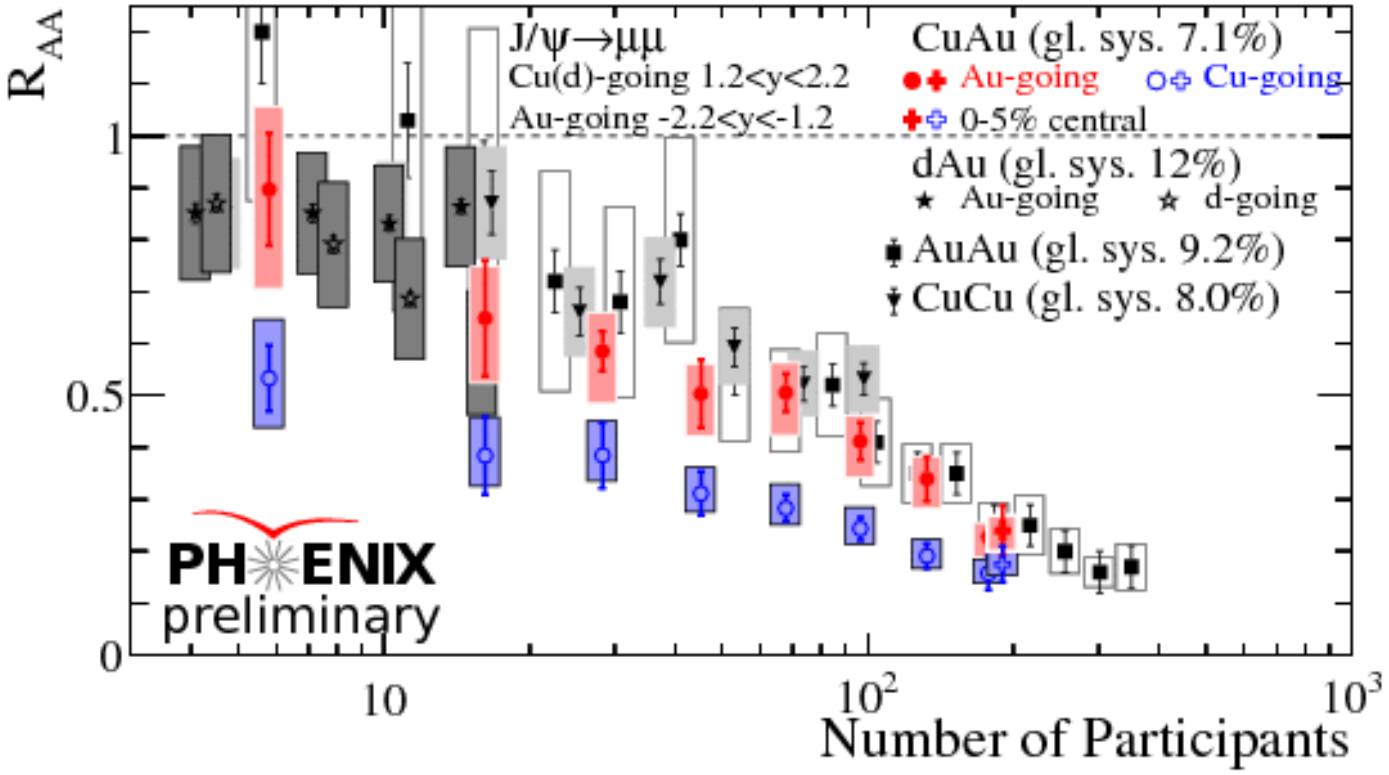
χ_c and Ψ' feeding of J/Ψ
(also from open beauty)

From SPS to RHIC, and back: the suppression is stable





Suppression and regeneration compensate (Zhao & Rapp PRC 82 064905 2010)



Assymetric ions collision

- Au going: close to Au-Au
-Cu going : stronger start, but closer for most central (whereas Cu completely absorbed: contradictory with corona effect)
- small Npart: more suppression with Cu than with d

Unexpected ?

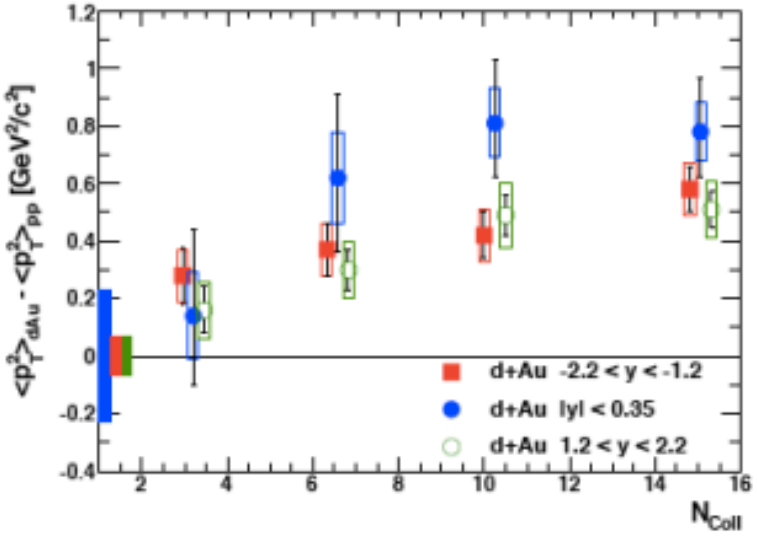
Cold nuclear matter reference: d-Au

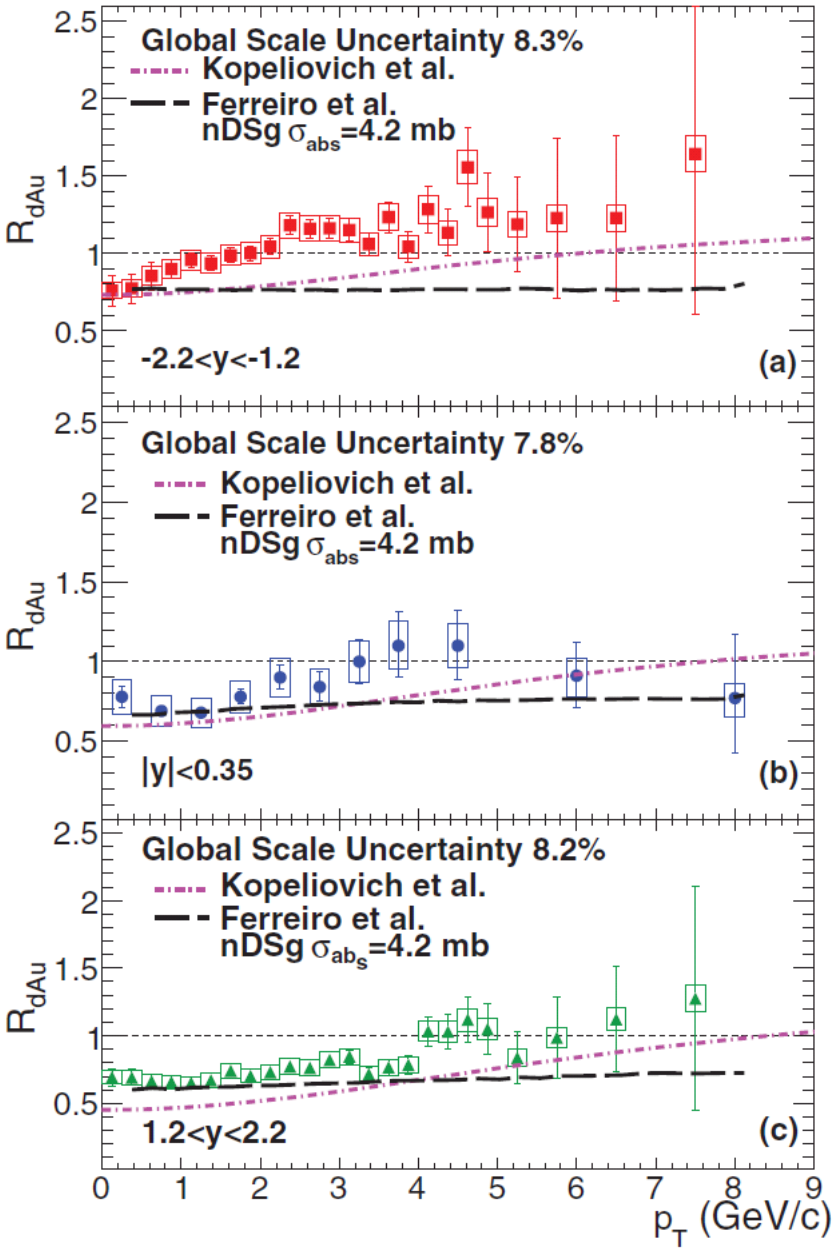
-Increase with Pt.

Cronin multiple scattering effect

- Increase in most of the Au-going Y region

PHENIX PRC87, 034904 (2013)



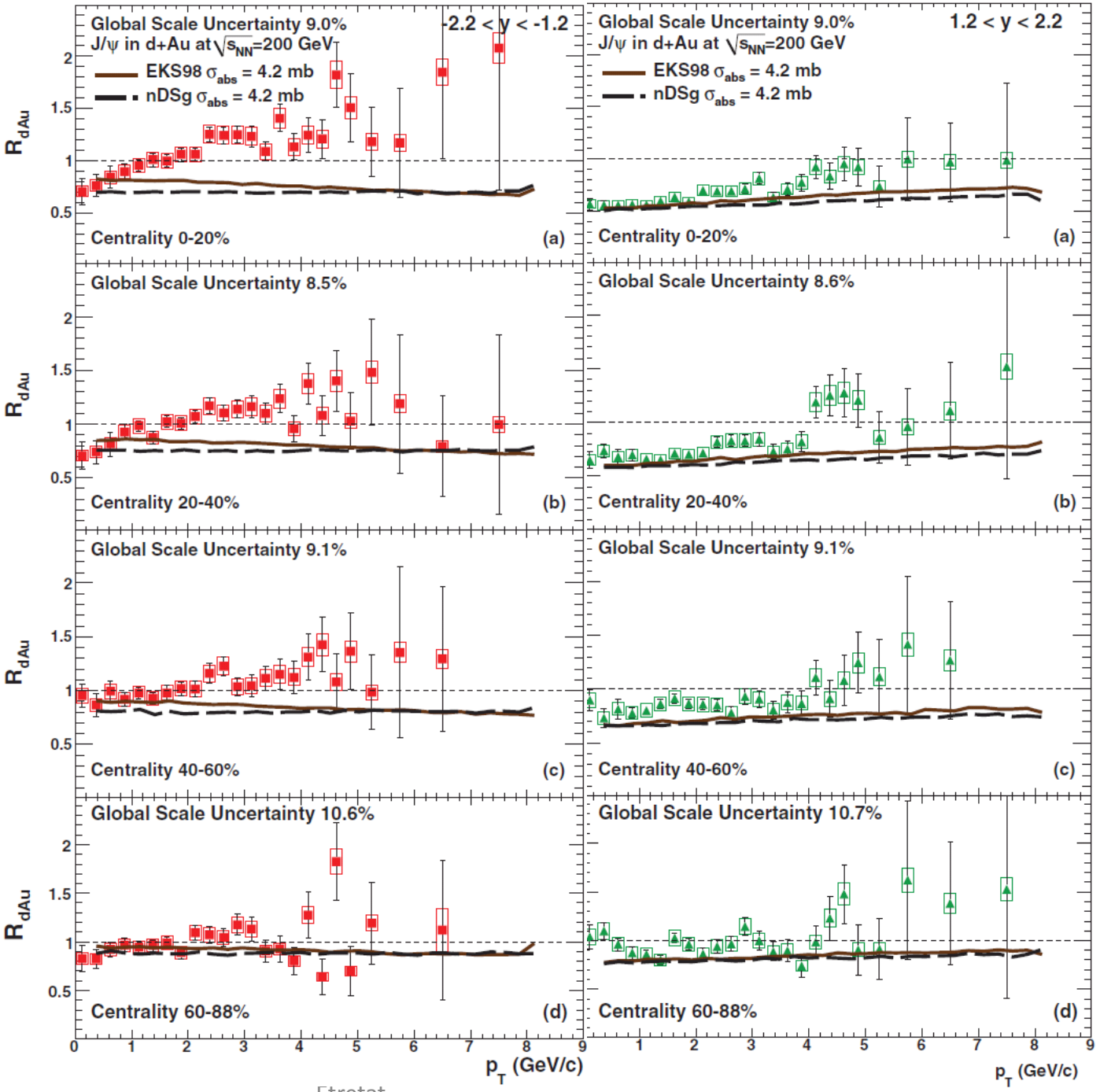


gluon distributions are not very well known, but even assuming shadowing antishadowing as for quarks, the assymetry backward/forward and Pt distribution is not simultaneously reproduced

Similar in peripheral reactions, backward and forward RdAu have different evolution

In the backward region the shadowing model leads to a decrease with Pt

(Perhaps the use of x1, x2, should be upgraded ?)



PHENIX arXiv:1305.5516

state	J/ψ	χ_c	ψ'	Υ	χ_b	Υ'	χ_b'	Υ''
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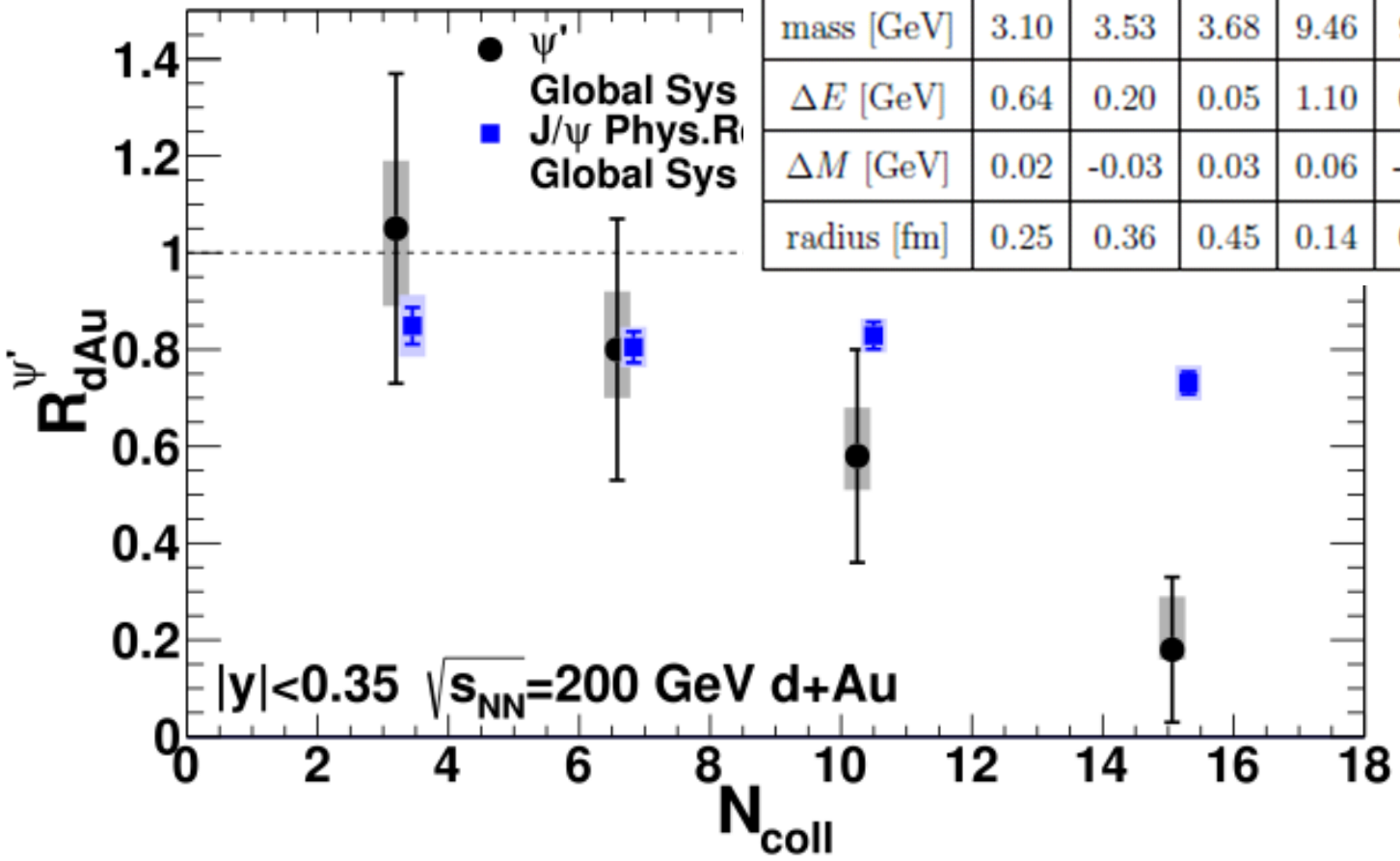
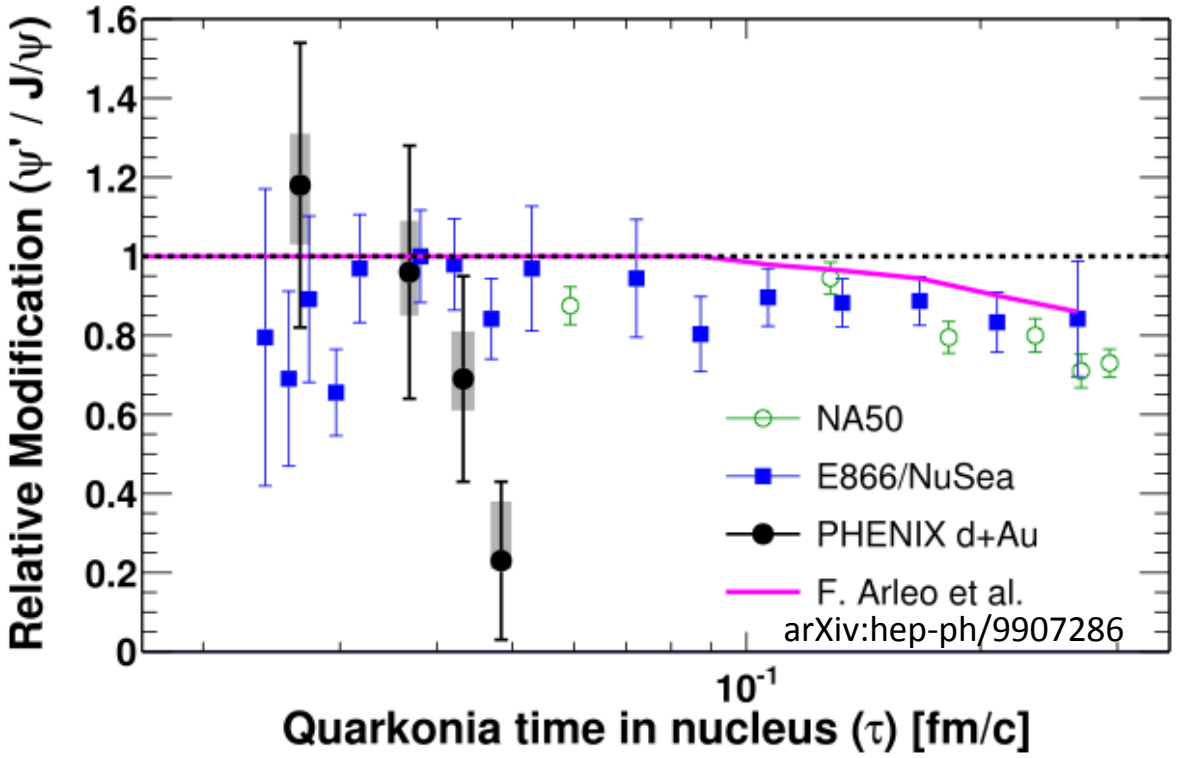


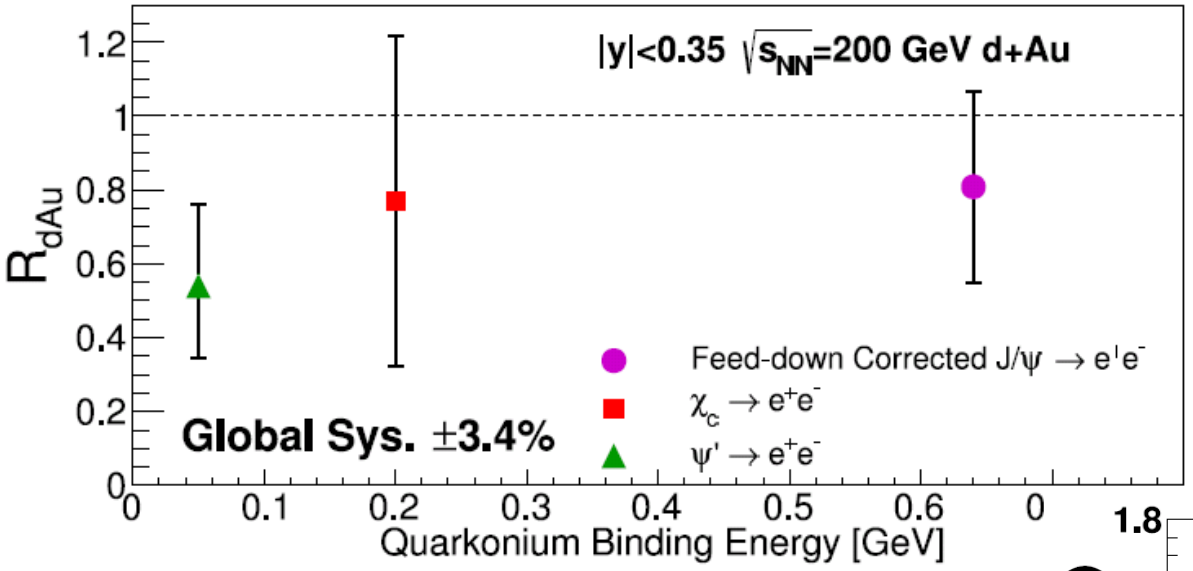
Another surprise: much more important suppression for Ψ' than for the Ψ

The Ψ' is expected to melt before the J/Ψ, due to its larger radius and smaller binding energy. It is observed in SPS H.I.collisions, but not expected in d-Au at RHIC due to the smaller available time



Unexpected difference between Ψ' and Ψ suppression at the beginning of the formation process.

PHENIX arXiv:1305.5516

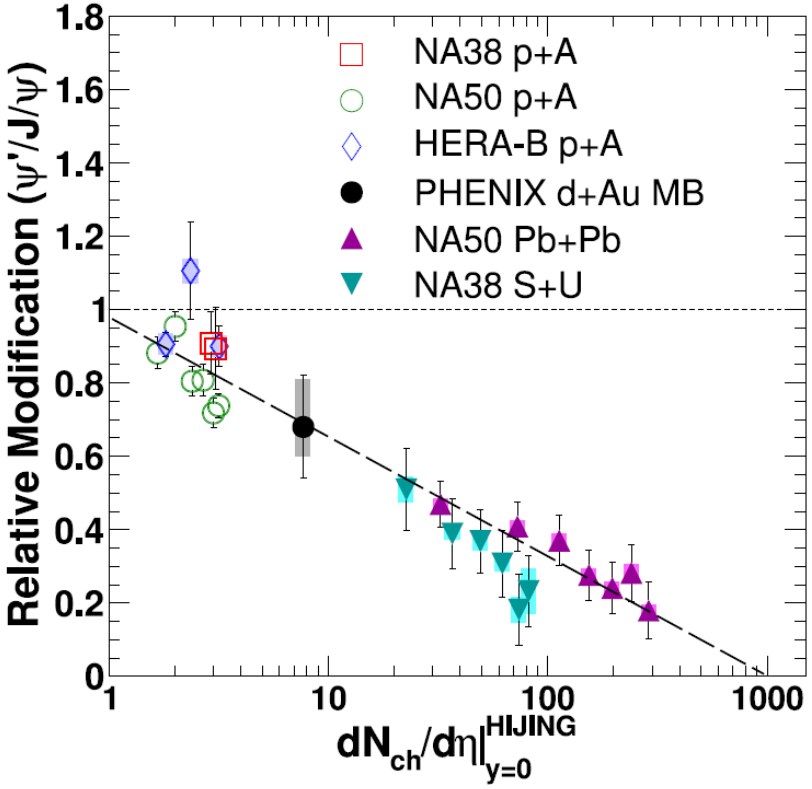


Opening of new dimensions

more quarkonia species become available

prospects for the study of the quarkonia suppression with respect to their binding energy

A consistent overall pattern of the relative suppression
Too soon to determine if there are several regimes here



Low statistics, then no significant constraint. Reasonable agreement with NLO calculations

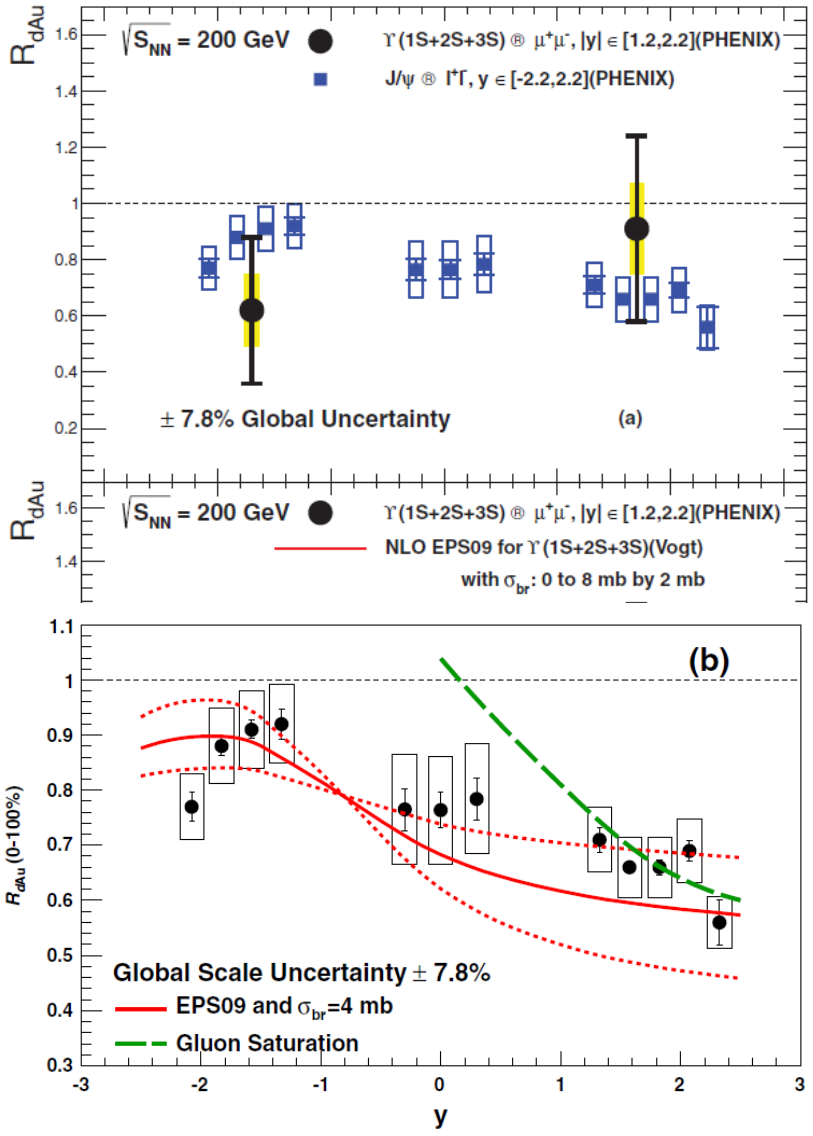
Suggests a backward suppression,

also induced by the parton distributions (EMC effect)

→A possible atypical behaviour of hard production (%soft)

a unique PDF effect ?
(+cf J/psi ?)

Or nuclear break up ?

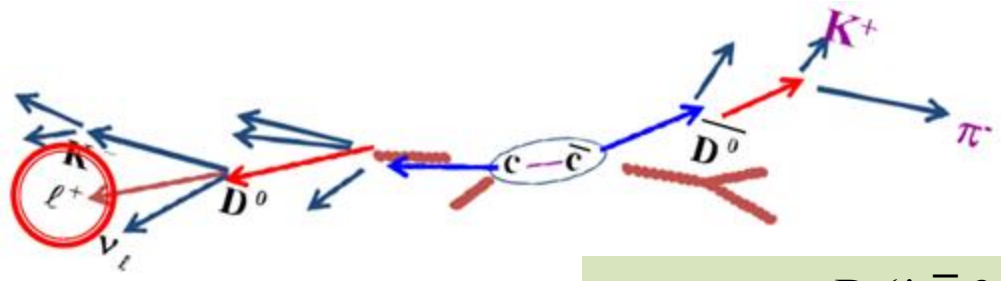


) (2013)

Open Heavy Flavor

Open flavor originates from the same production mechanism as quarkonia

(R.Nelson, R.Vogt, A.D.Frawley arxiv:1210.4610 : aim at calculating quarkonia from model tuned on open flavor production)



c -> D (*, ¯, 0, +,s ….)

-> $D^{+,-}$ or D^0 or $D_s^{+,-}$

(~16%) (~7%) (~7%) **-> lepton** + anything

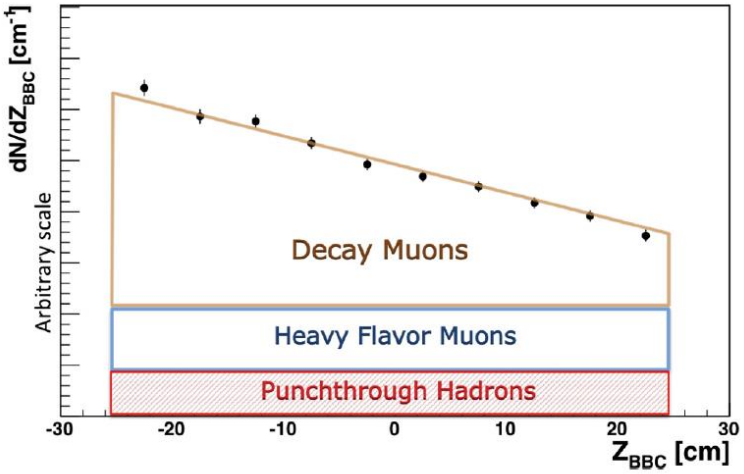
(also b-> B->D + X) [*]

[*] a correlated component of like sign dimuons has been extracted (L.Patel, DIS2013)

Harder than quarkonia to extract: must be separated from the contribution from low masses mesons

Extracting the heavy flavor component in the single lepton spectrum

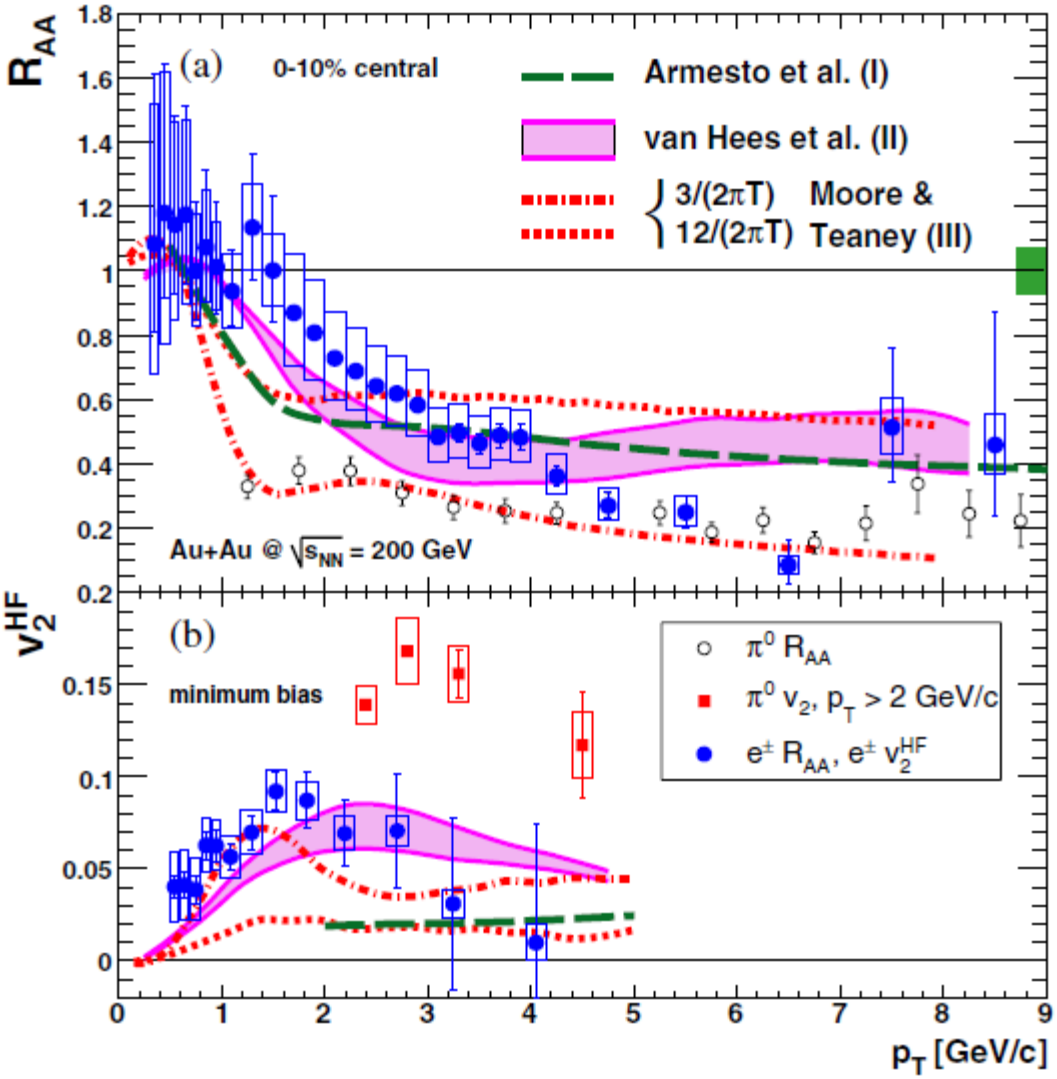
- Pions, Kaons , produce muons, but their decay length is several meters, whereas B and D particles are at the 0.1-0.5 mm level
- -> determine the corresponding fraction, related to the slope of the production rate as a function of the distance to the absorber



Another relative approach is used for electrons, with a converter , allowing to increase the photonic production of electrons

Monte Carlo cocktails of all sources are basic important tools

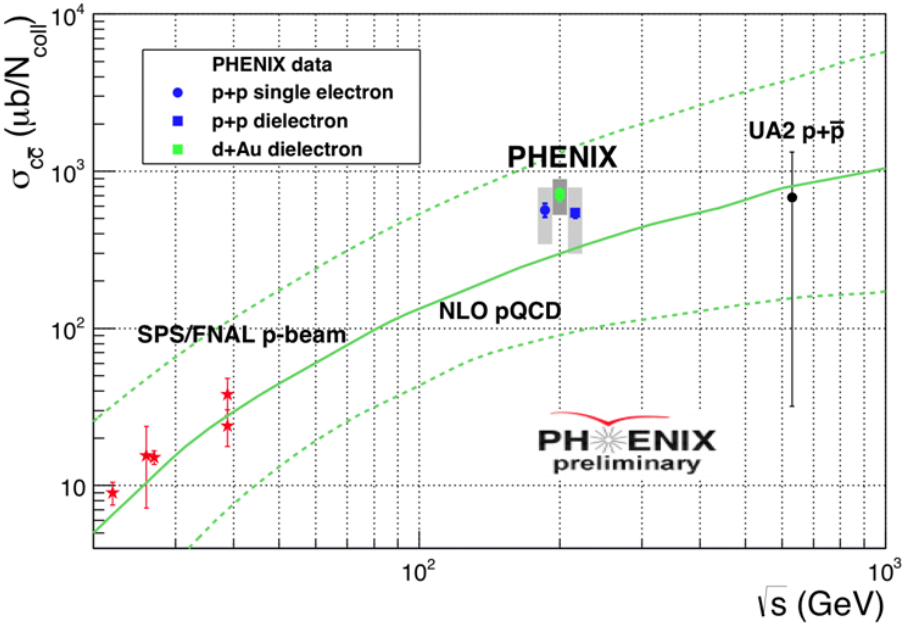
- Less interaction than light quarks expected (suppression of forward gluon radiation)
- Strong coupling observed
- models suggest small relaxation time or diffusion coefficient
- Calls for extended models: individual collisions (more important at Rhic ?), dissociation in QGP, shadowing.
- toward time evolution of medium and HF mesons ? (and separate treatment for b and c)

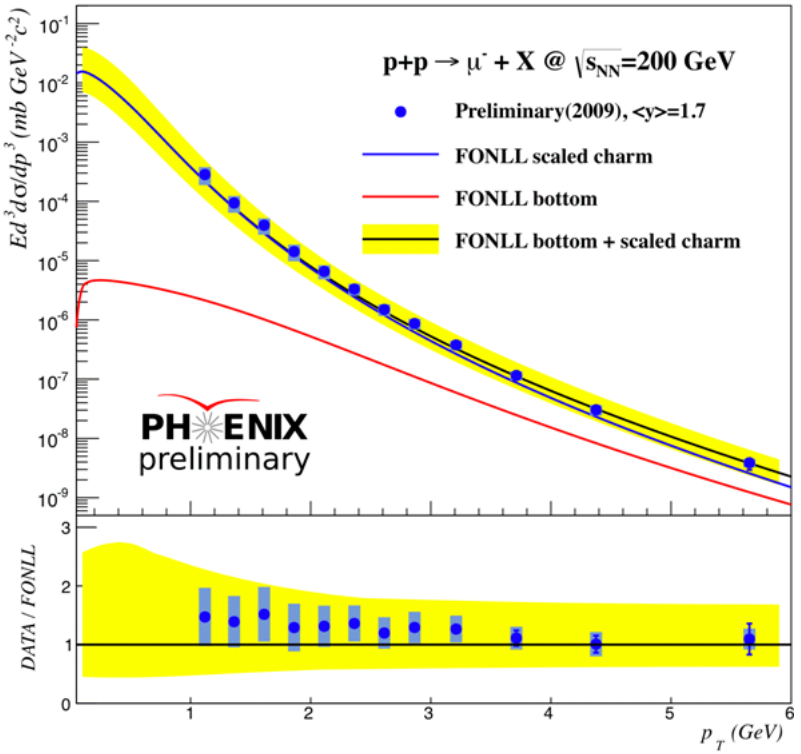


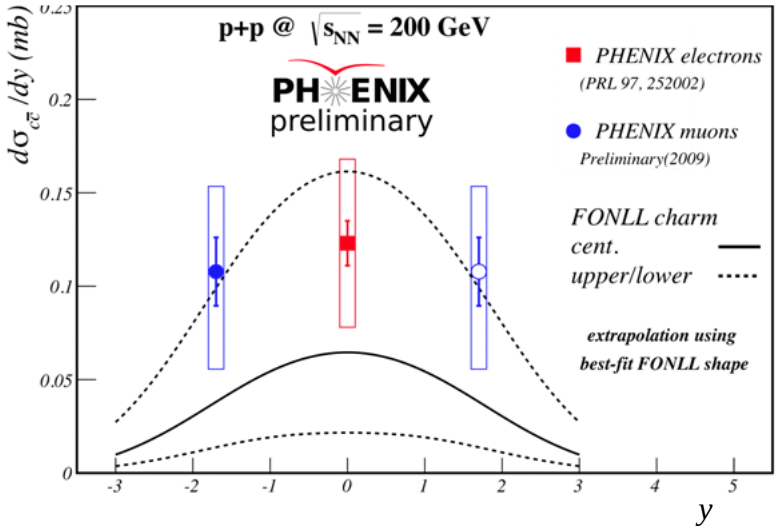
Beside this main trend, let's looks a some other finer experimental details

p-p

p-p is consistent with previous measurement and FONLL





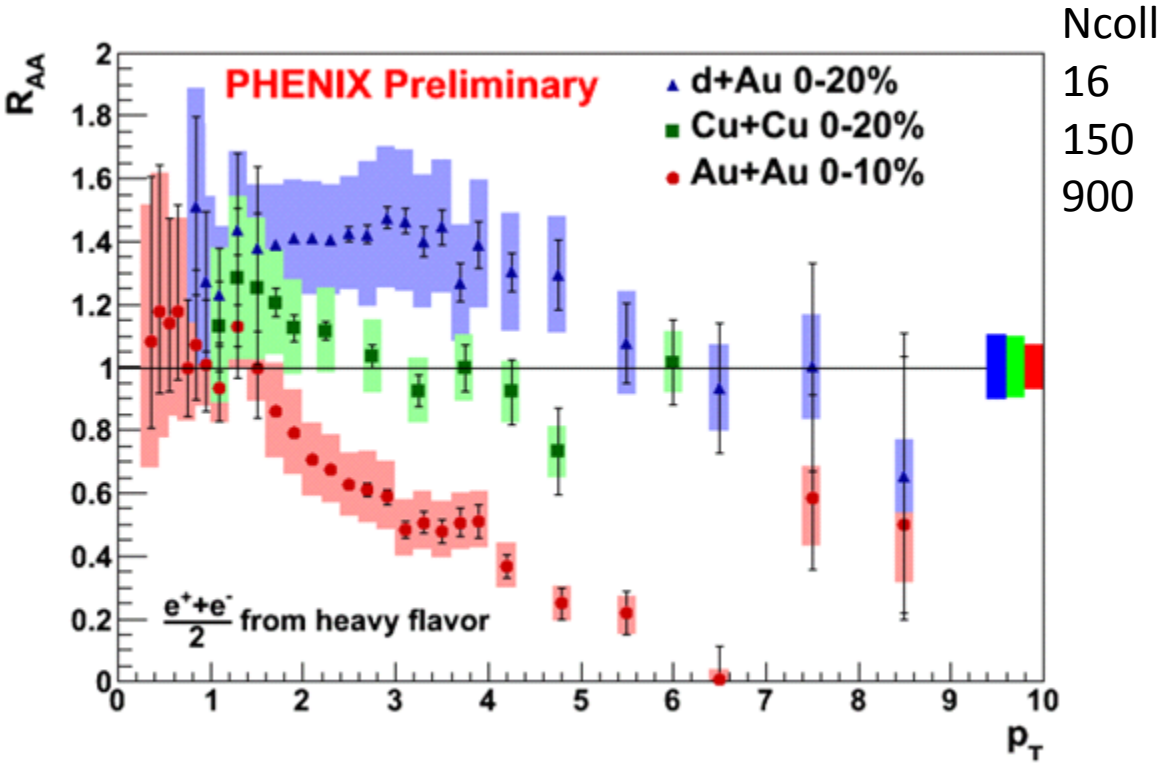


With Cu-Cu From d-Au to Au-Au

Single electrons from heavy flavor in the central region
d-Au and Au-Au : PRL 109 242301 2012

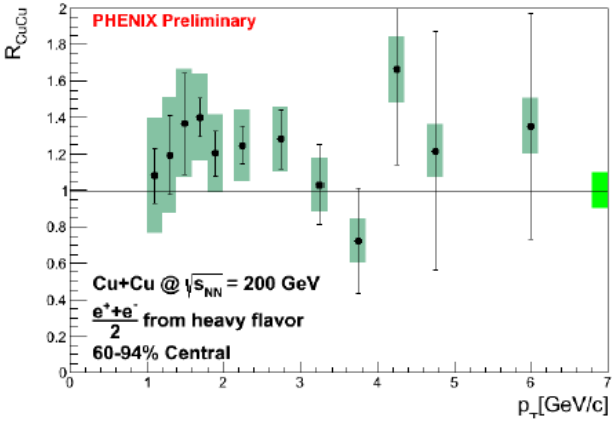
Strong change with ions

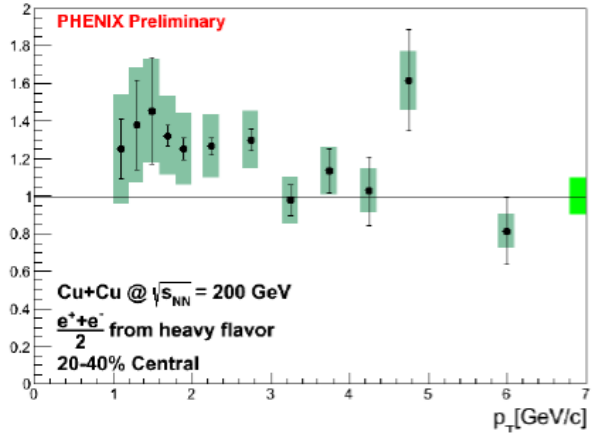
- dAu: increase, and with Pt
- Au-Au decrease
- Cu-Cu in between

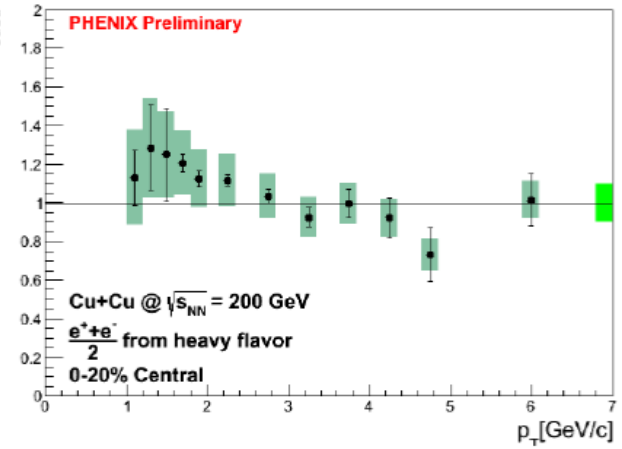


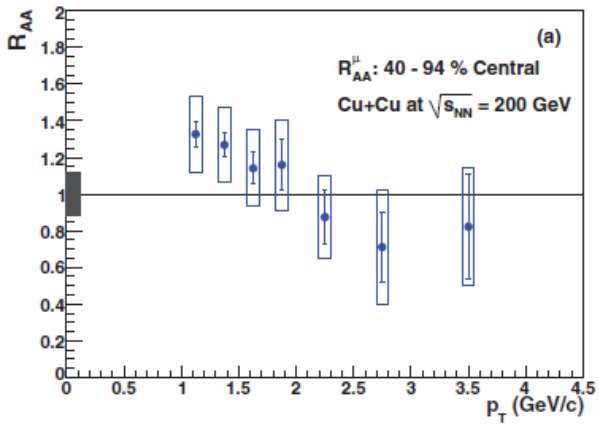
Centrality and rapidity

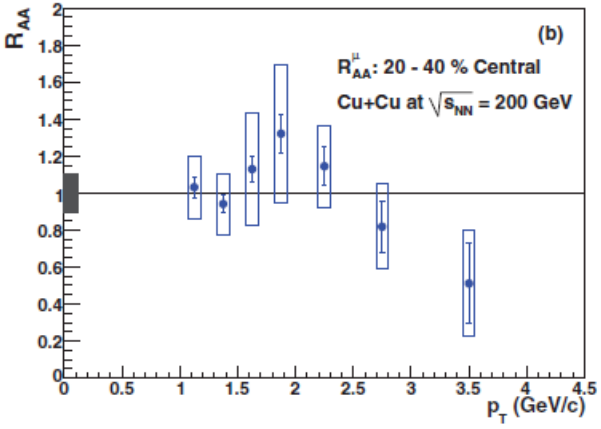
Enhancement in the central rapidity

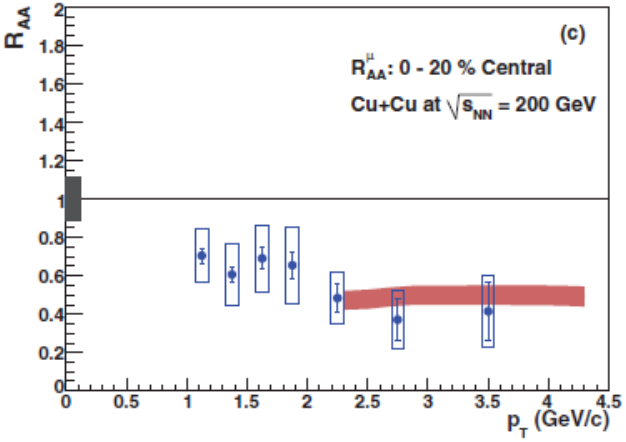






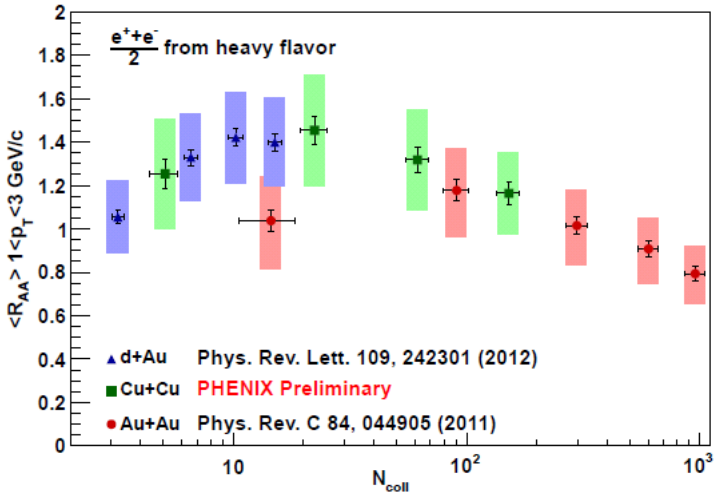


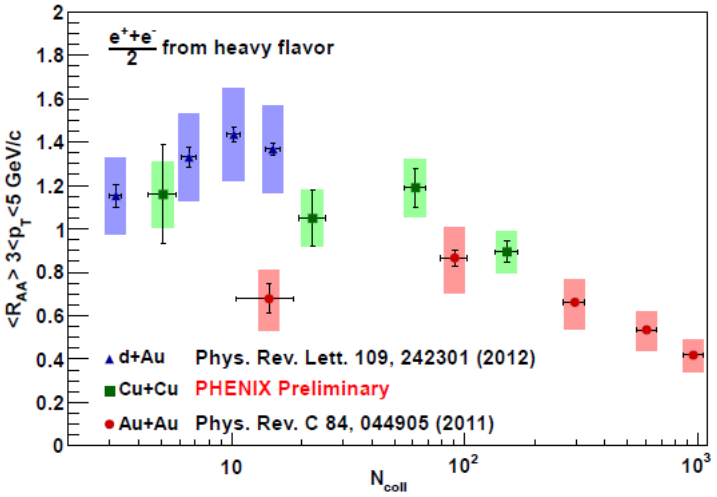


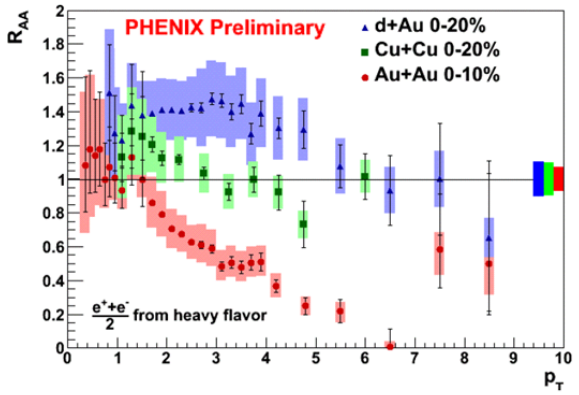


- A decrease with centrality, in the forward hemisphere

P_T

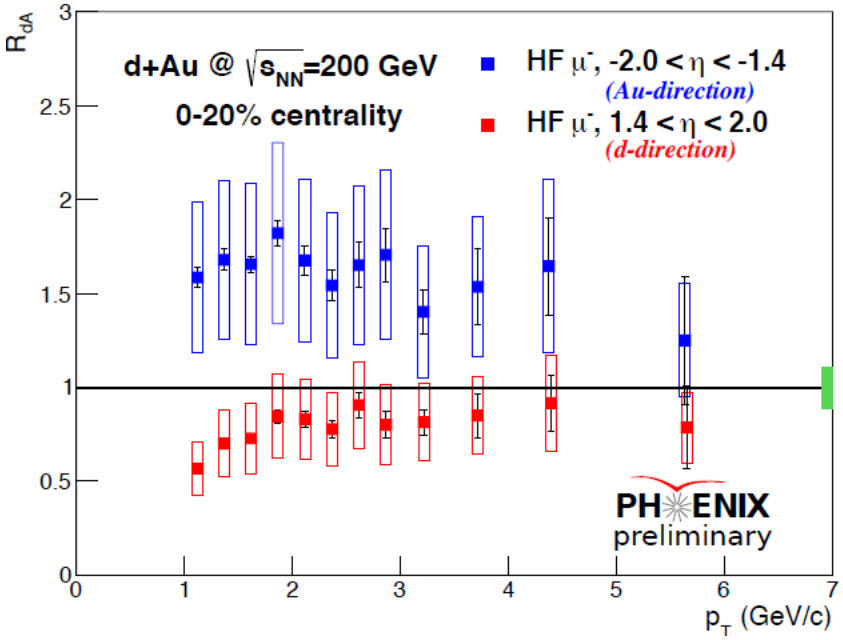






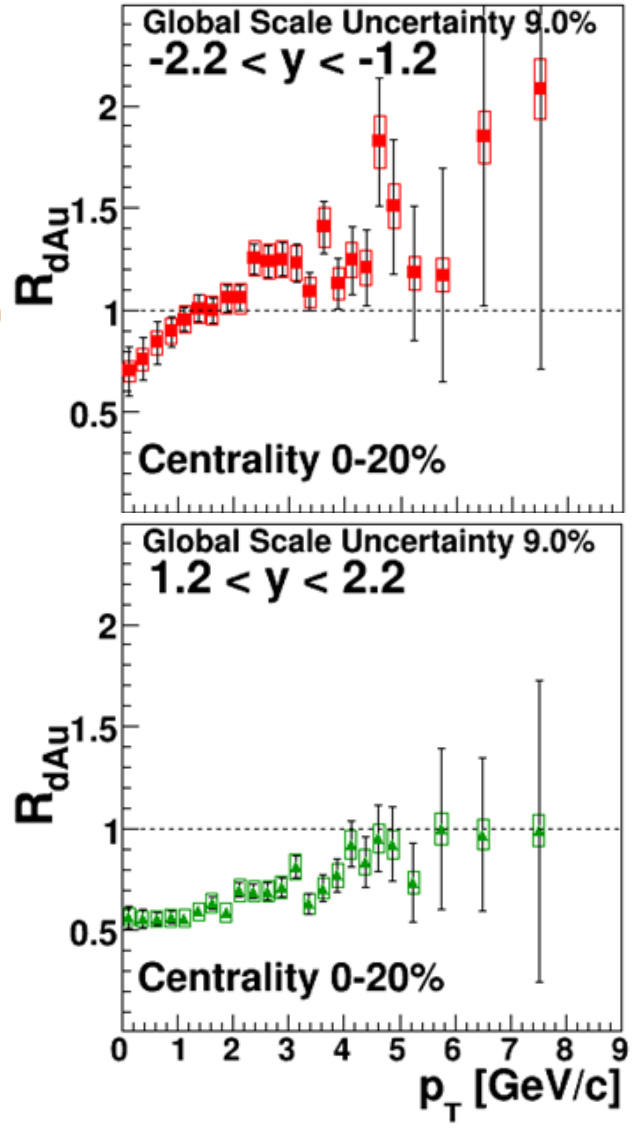
$<R_{AA}>$ Displays a global trend from d-Au to Au-Au, with respect to Ncoll,
Here in the central rapidity domain

Rise of Cronin effect then damping ?



d-Au ?

- Qualitatively compare with Cu-Cu,
- and for the forward/backward decrease with quarkonia production



But Backward RdAu for **J/psi** has a reverse behaviour (decrease)

Effect of nuclear **breakup on quarkonia** ?

Summary/ final remarks

- A set of extended measurement has been obtained, allowing more detailed description of the changes from pp to Au-Au, in rapidity and Pt, thank to **p-dAu, Cu-Au, Cu-Cu and energy scan** . This allow to follow the evolution of production processes, from pp to Au-Au and sometimes reverse behavior are observed during this evolution
- Whereas a general suppression is observed for them in central AuAu collisions, Quarkonia and heavy flavor productions show partly similar trends, a global decrease of the production in the rapidity domain of the lighter nucleus, but also definite differences in particular in **the backward (heavy nucleus) rapidity domain**, suggesting nuclear breakup of the quarkonia.

- This ongoing quest for more precise and detailed results, for which new detectors will help soon, shows perhaps already signs that the characterization of the relative weight of the various effects will become reachable. Pt-Y correlations, especially in backward domain, could bring challenge for models.
- New dimensions appears: time evolution of Ψ', more quarkonia species ..
- The multidimensional high precision set of equations is perhaps not so far

Backup

arXiv:1305.5516 [nucl-ex]

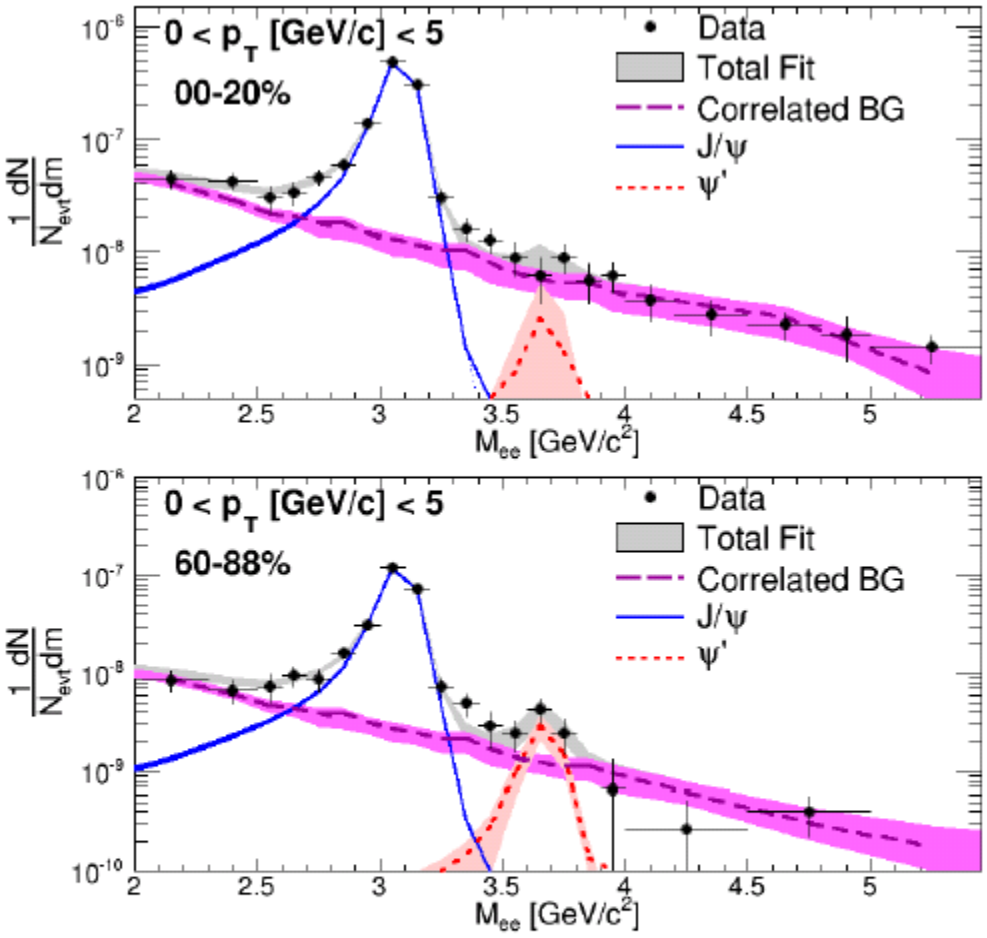
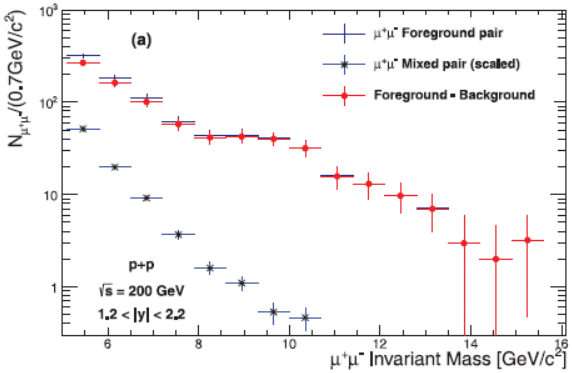
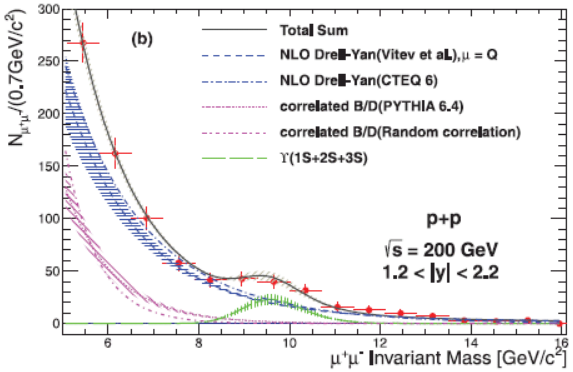
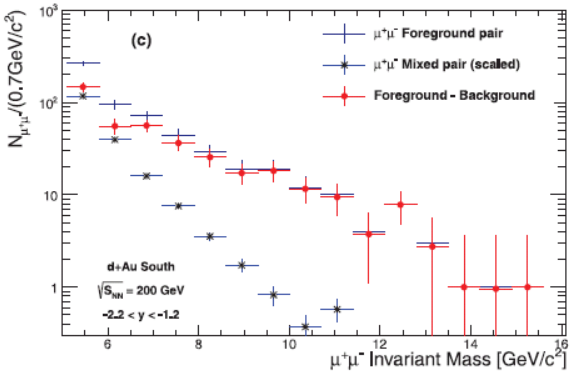
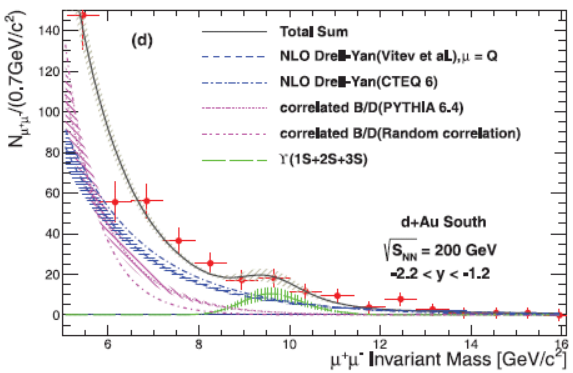


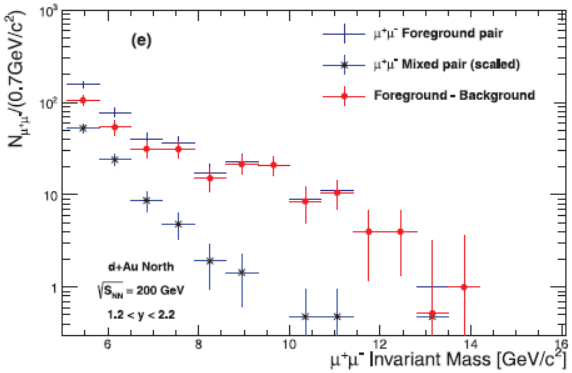
FIG. 1: (Color online) The e^+e^- mass distribution, after like-sign subtraction, for 0–20% (Top) and 60–88% (Bottom) d+Au collisions. The line shapes are those fit to the data in order to extract the ψ' yield.

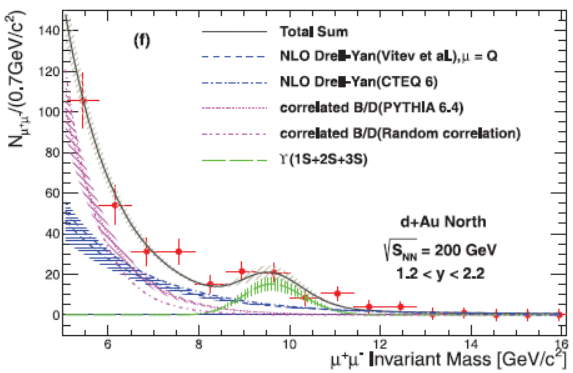

(a)
μ⁺μ⁻ Foreground pair
μ⁺μ⁻ Mixed pair (scaled)
Foreground - Background
p+p
√s = 200 GeV
1.2 < |y| < 2.2
N_μ⁺μ⁻/(0.7GeV/c²)
μ⁺μ⁻ Invariant Mass [GeV/c²]

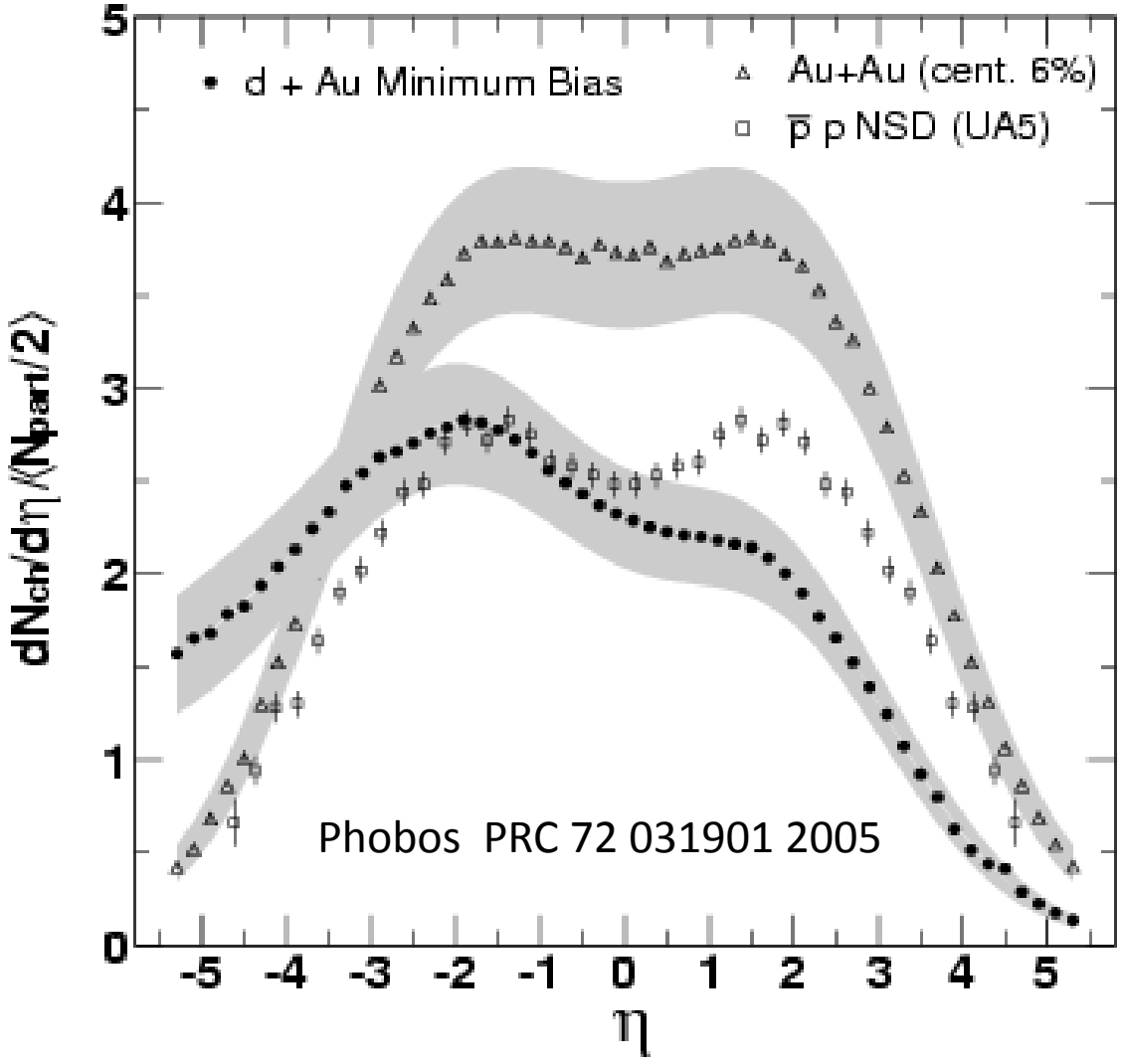

(b)
Total Sum
NLO Drell-Yan(Vitev et al),μ = Q
NLO Drell-Yan(CTEQ 6)
correlated B/D(PYTHIA 6.4)
correlated B/D(Random correlation)
ϒ(1S+2S+3S)
p+p
√s = 200 GeV
1.2 < |y| < 2.2
N_μ⁺μ⁻/(0.7GeV/c²)
μ⁺μ⁻ Invariant Mass [GeV/c²]


(c)
μ⁺μ⁻ Foreground pair
μ⁺μ⁻ Mixed pair (scaled)
Foreground - Background
d+Au South
√S_NN = 200 GeV
-2.2 < y < -1.2
N_μ⁺μ⁻/(0.7GeV/c²)
μ⁺μ⁻ Invariant Mass [GeV/c²]


(d)
Total Sum
NLO Drell-Yan(Vitev et al),μ = Q
NLO Drell-Yan(CTEQ 6)
correlated B/D(PYTHIA 6.4)
correlated B/D(Random correlation)
ϒ(1S+2S+3S)
d+Au South
√S_NN = 200 GeV
-2.2 < y < -1.2
N_μ⁺μ⁻/(0.7GeV/c²)
μ⁺μ⁻ Invariant Mass [GeV/c²]


(e)
μ⁺μ⁻ Foreground pair
μ⁺μ⁻ Mixed pair (scaled)
Foreground - Background
d+Au North
√S_NN = 200 GeV
1.2 < y < 2.2
N_μ⁺μ⁻/(0.7GeV/c²)
μ⁺μ⁻ Invariant Mass [GeV/c²]


(f)
Total Sum
NLO Drell-Yan(Vitev et al),μ = Q
NLO Drell-Yan(CTEQ 6)
correlated B/D(PYTHIA 6.4)
correlated B/D(Random correlation)
ϒ(1S+2S+3S)
d+Au North
√S_NN = 200 GeV
1.2 < y < 2.2
N_μ⁺μ⁻/(0.7GeV/c²)
μ⁺μ⁻ Invariant Mass [GeV/c²]


d + Au Minimum Bias
Au+Au (cent. 6%)
p̄ p NSD (UA5)
Phobos PRC 72 031901 2005
dN_ch/dη /⟨N_part/2⟩
η