HIDDEN AND OPEN HEAVY FLAVOUR PRODUCTION WITH HEAVY IONS AT RHIC ENERGIES

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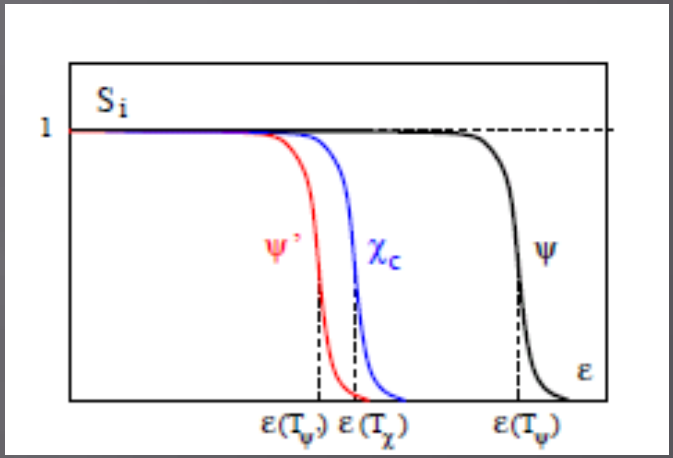
10-100 GeV d or p or A -A collisions

- RHIC and also 10-100 GeV experiments
- Heavy quarkonia production
- Open heavy flavours
- A bit of Heavy ion collisions,
- Mostly pA collisions

Heavy flavors: a probe of the medium

- In particular the interest of the quarkonias , sensitive to screening in QGP

But also to collisions with nucleons,
Or other cold nuclear matter effects



H.Satz hep-ph 0609197 2006

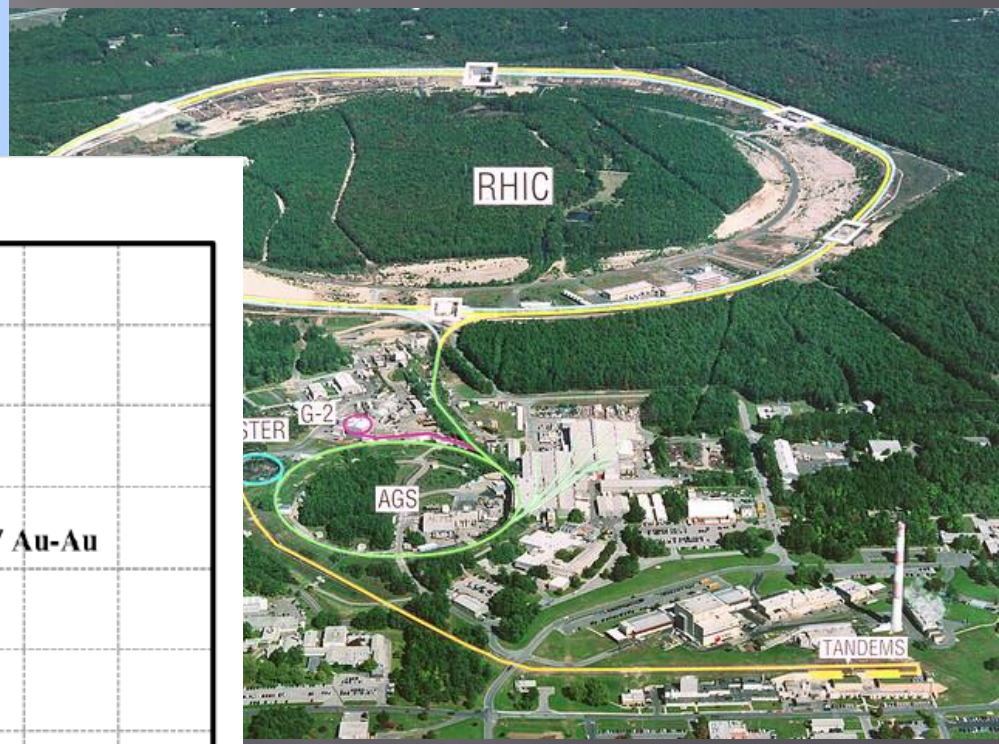
- Two main classes ?
- - associated with Nuclei (shadowing, CGC…
- - associated with collision (Eloss, $\sigma_{absorption}$, breakup, comovers

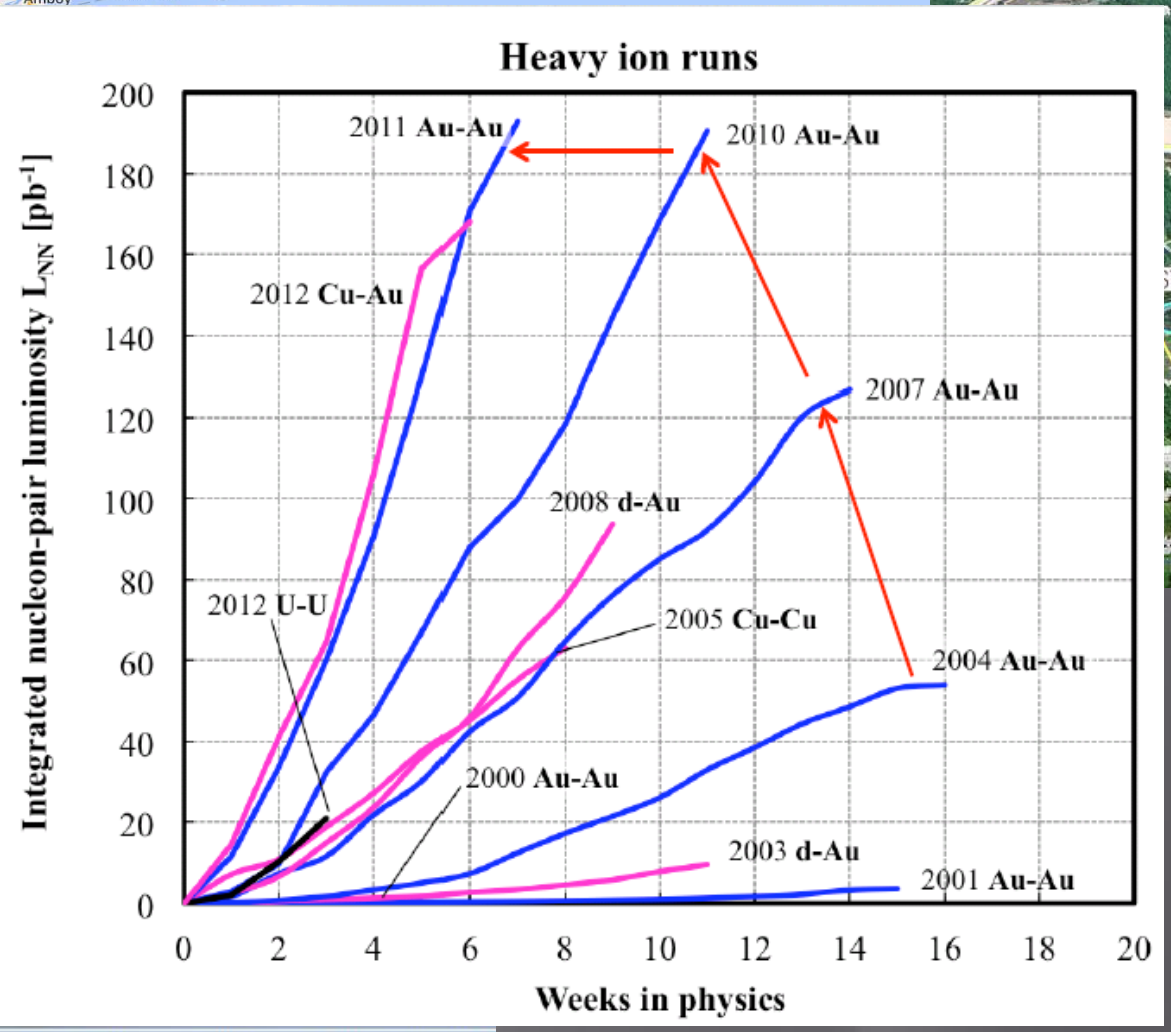
(together in « higher twist » ?)

forewords

- Centered on RHIC results, d Au
- Very rich domain, a lot of progress has been made in the last 10-20 years, especially for quarkonia.
- Will not cover everything.
- Critical behaviors not probable but
- Are there peculiar trends, beyond the « average one », possibly signature of one of the expected cold nuclear (p-A) effects ?
- Hopes to separate competing effects ?

RHIC
at Brookhaven National laboratory

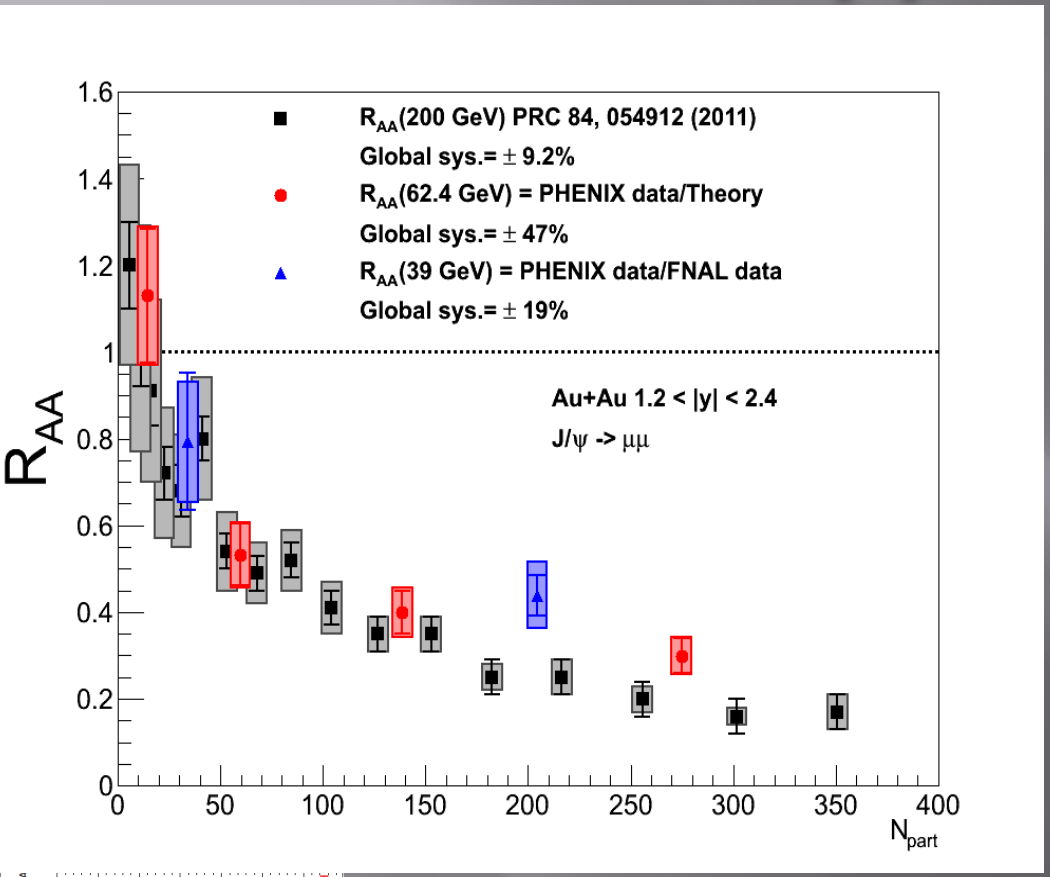


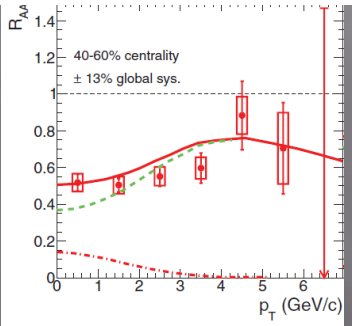


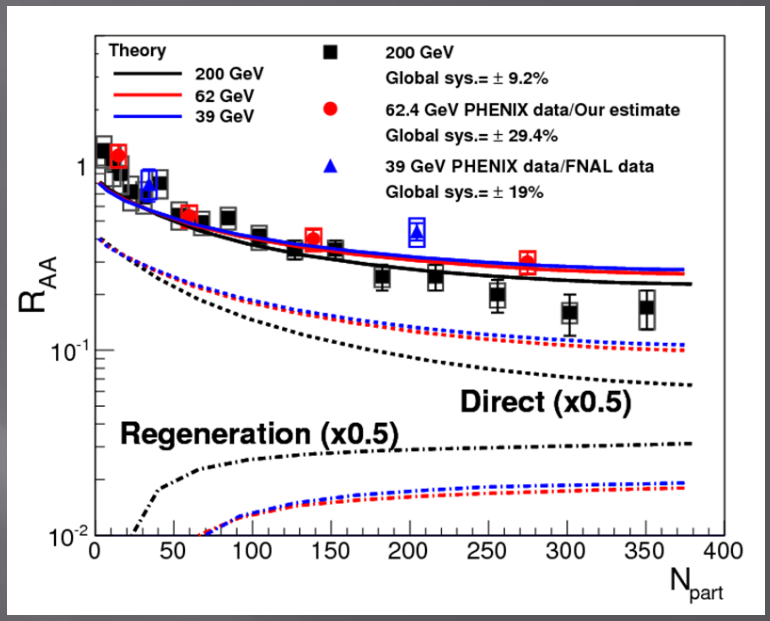
Impressive increase of luminosity during the last decade

Some Heavy ion results

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





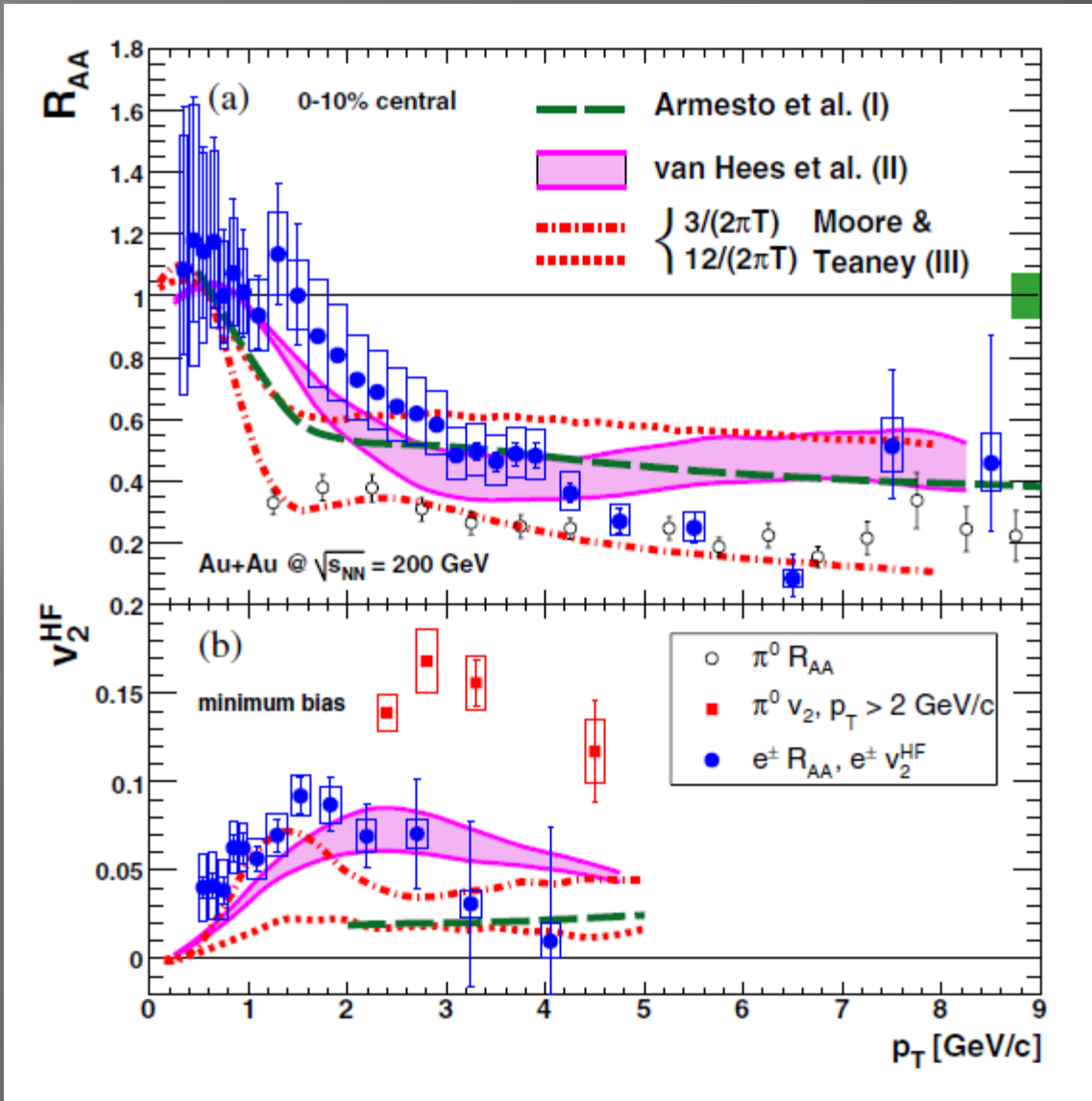


Suppression and régénérations compensate ?

(Zhao & Rapp PRC 82 064905 2010)

Open flavor

- 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)



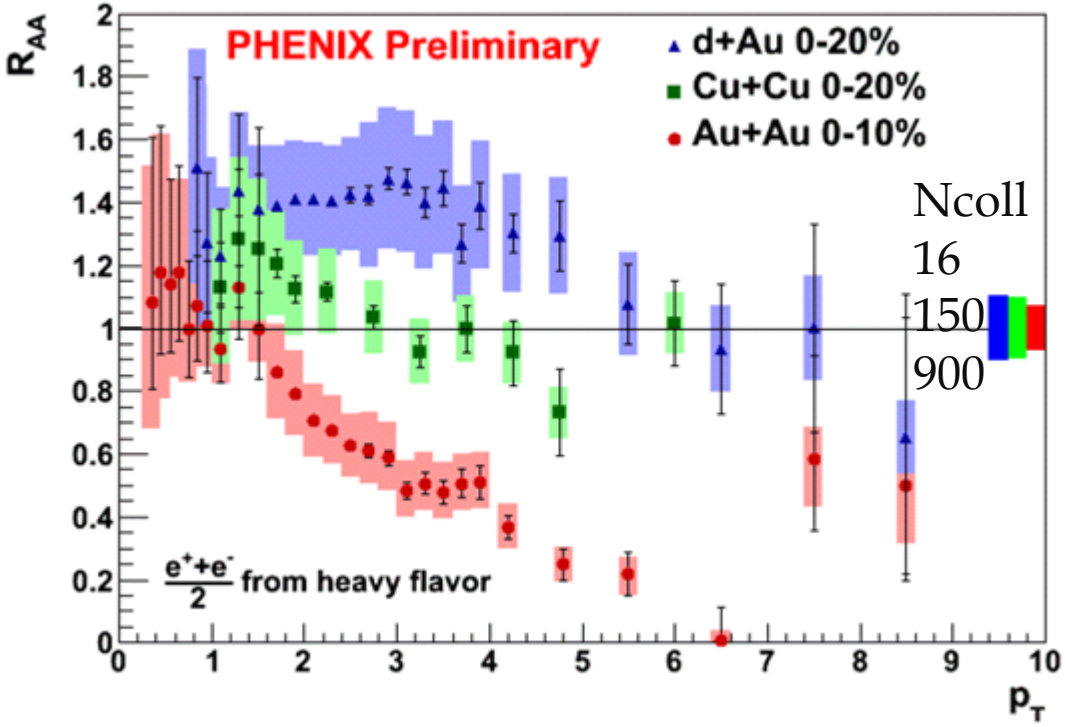
Open flavor

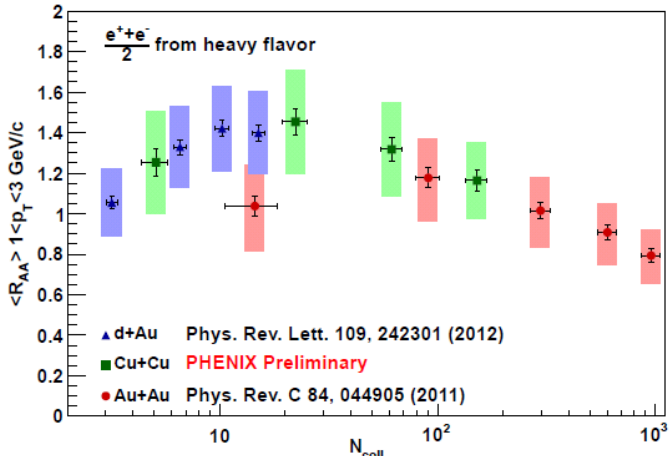
Single electrons from heavy flavor in the central region
d-Au and Au-Au : PRL 109 242301 2012

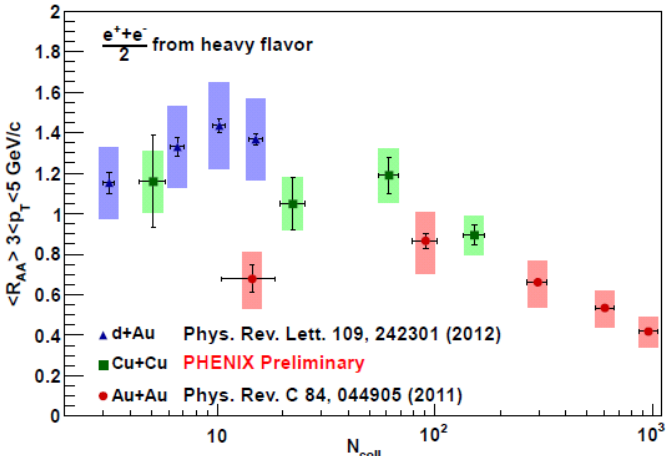
Integrated: Scales with Ncoll in AuAu
Decreases with Pt

Strong change with ions:

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







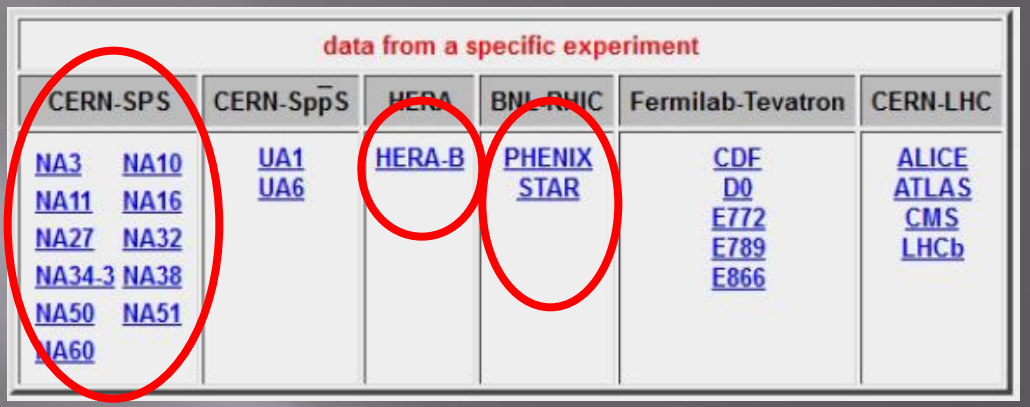
Versus Ncoll in p_T domains (%3 Gev/c)

The need to understand the production process and cold matter effects

→ p, d, h -A collisions

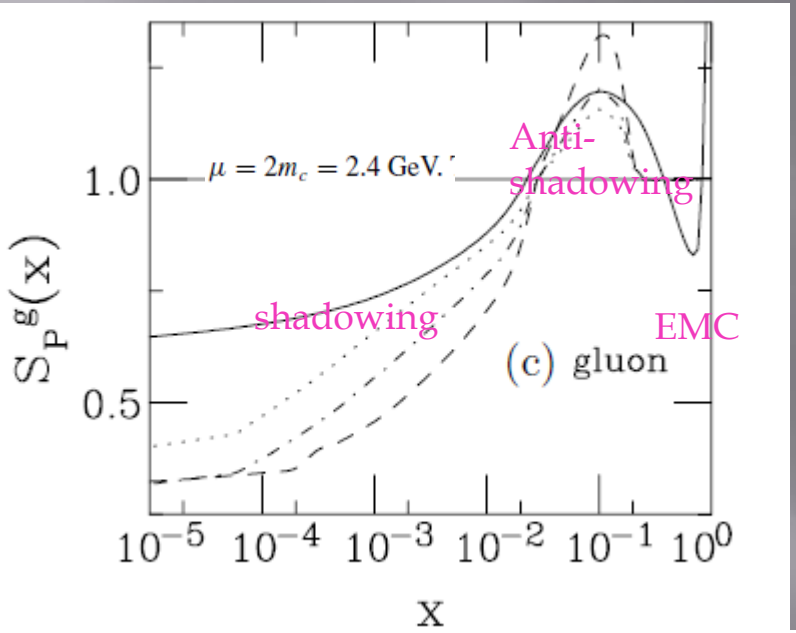
p-A heavy flavour measurements at the 10-200 GeV (√s)

Sapore gravis produced a beautiful database ! In HEP DATA



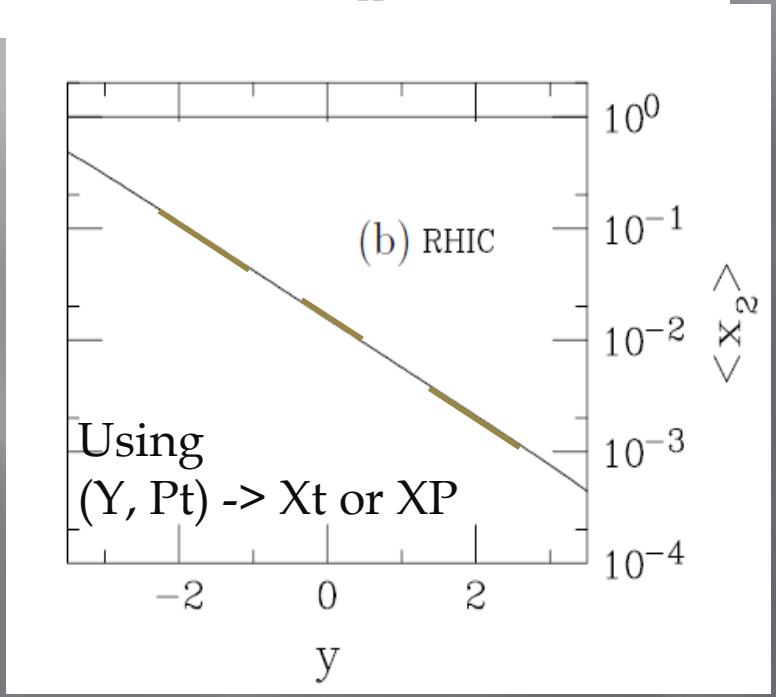
Exp.	√S	Ycm	p-A	measured	$Y_{cm}^{(n-n)}$ domain
Star	200	5.36	d-Au	D, ee	|η|<1
Phenix	200	5.36	d-Au	e, μ, ee ; μμ	|η|<0.35 & 1.2-2.1
Hera-B	41.6		C, Ti, W	D° D^+Ds..	-0.15<XF<-0.05
E866	38.8	3.7	Be Fe W	μμ	0<XF<1
E789	38.8	3.7	Be Au	D°, Ď°	0<XF<0.08
NA50	29.1	3.44	Be Al Cu Ag W Pb	μμ	0<Y<1
NA60	17.5	2.9	Be Al Cu In W Pb U	μμ	0.3<Y<0.8
NA3	19.4	3.	H^2, Pt	μμ	0<XF<0.8

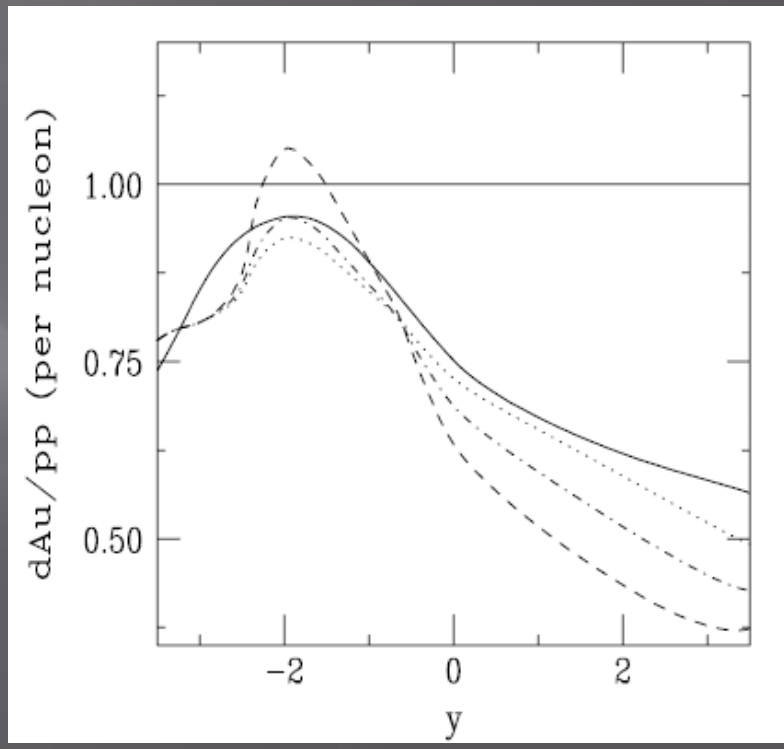
parton distribution in Nuclei



Starting from shadowing-antishadowing EMC , for gluons

From R.Vogt PRC 71, 054902 (2005)





One finally transforms the effect as a function of rapidity

(for J/ψ)

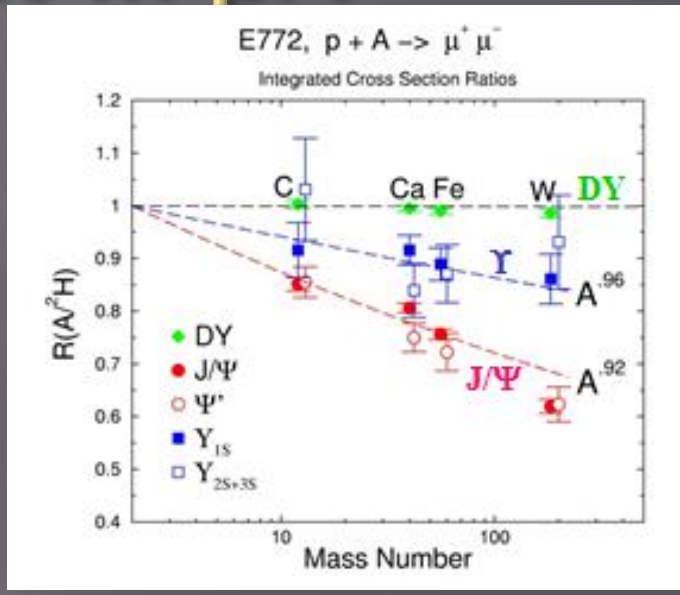
Several ways of quantifying the suppression effect in pA

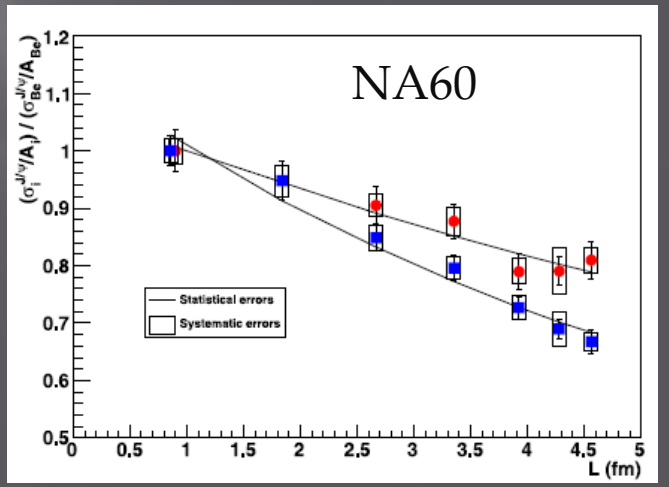
- pA cross sections : alpha parameter

$$\sigma_{pA} = k\, A^{\alpha}$$

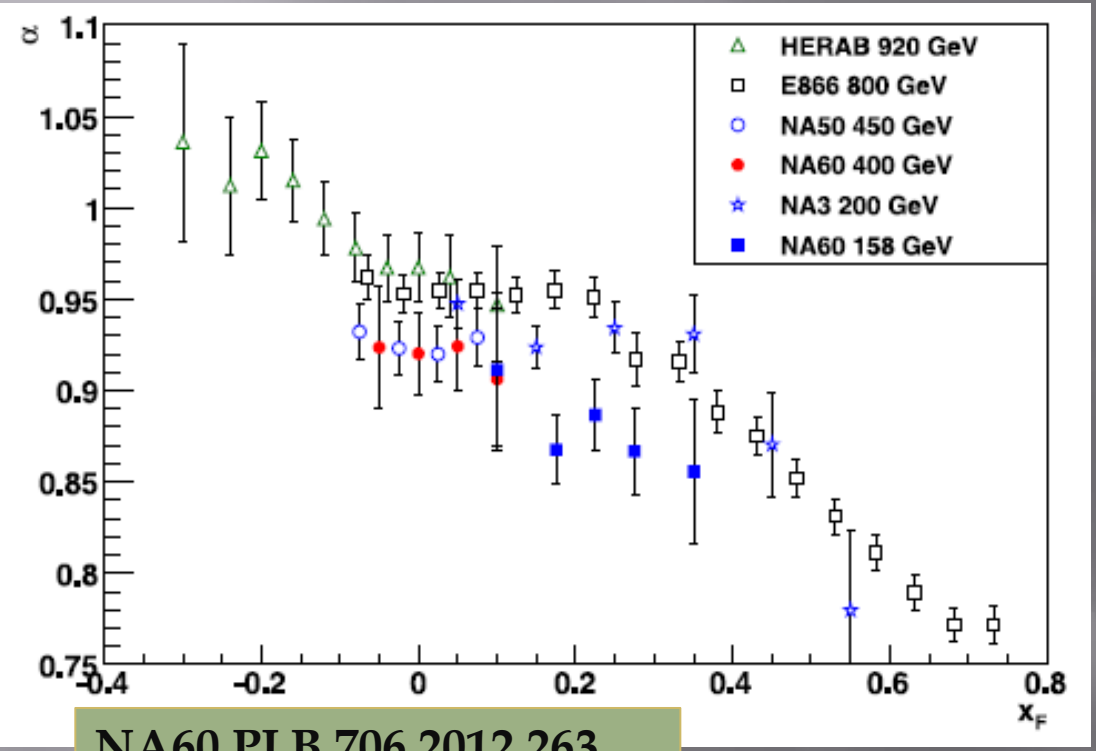
- RpA: production ratio between pA and pp*Ncoll [well suited for centrality domain, for instance Rcp central/peripheral, and one system]

Also, a traduction of RpA or α can be performed, for instance to get an equivalent absorption cross section (exponential alternative to A^{α}





$\sigma_{pA} \propto A^{\alpha}$

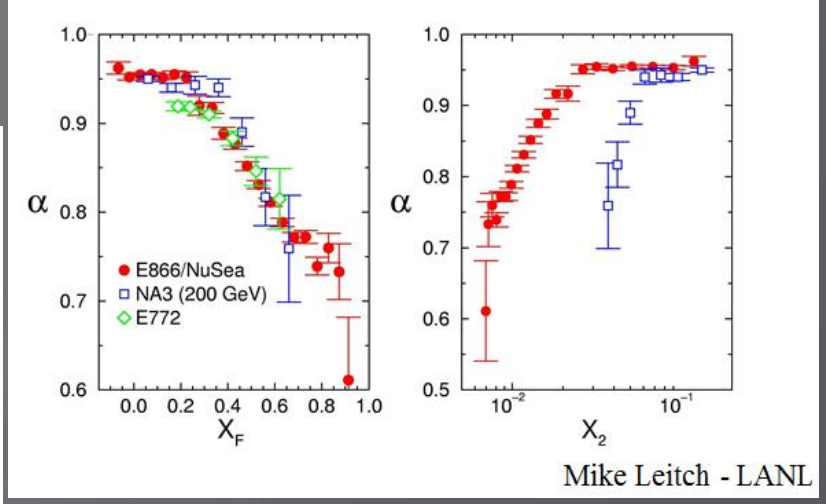


NA60 PLB 706 2012 263

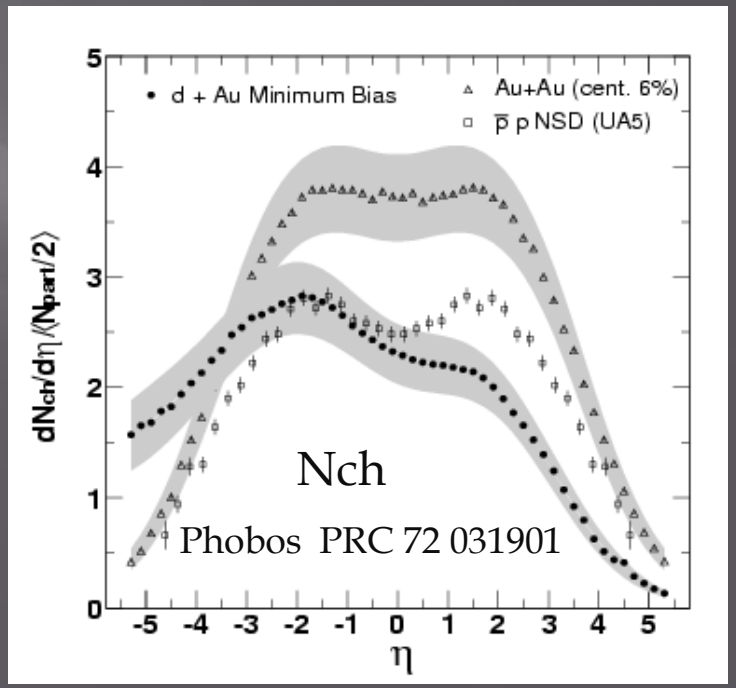
General increase of the effect with XF
Effect decreasing with increasing energy

A suppression as a function of the longitudinal variable, which is also a general trend in soft productions: the assymetry of the Y distribution associated to the assymetry of the p-A collision

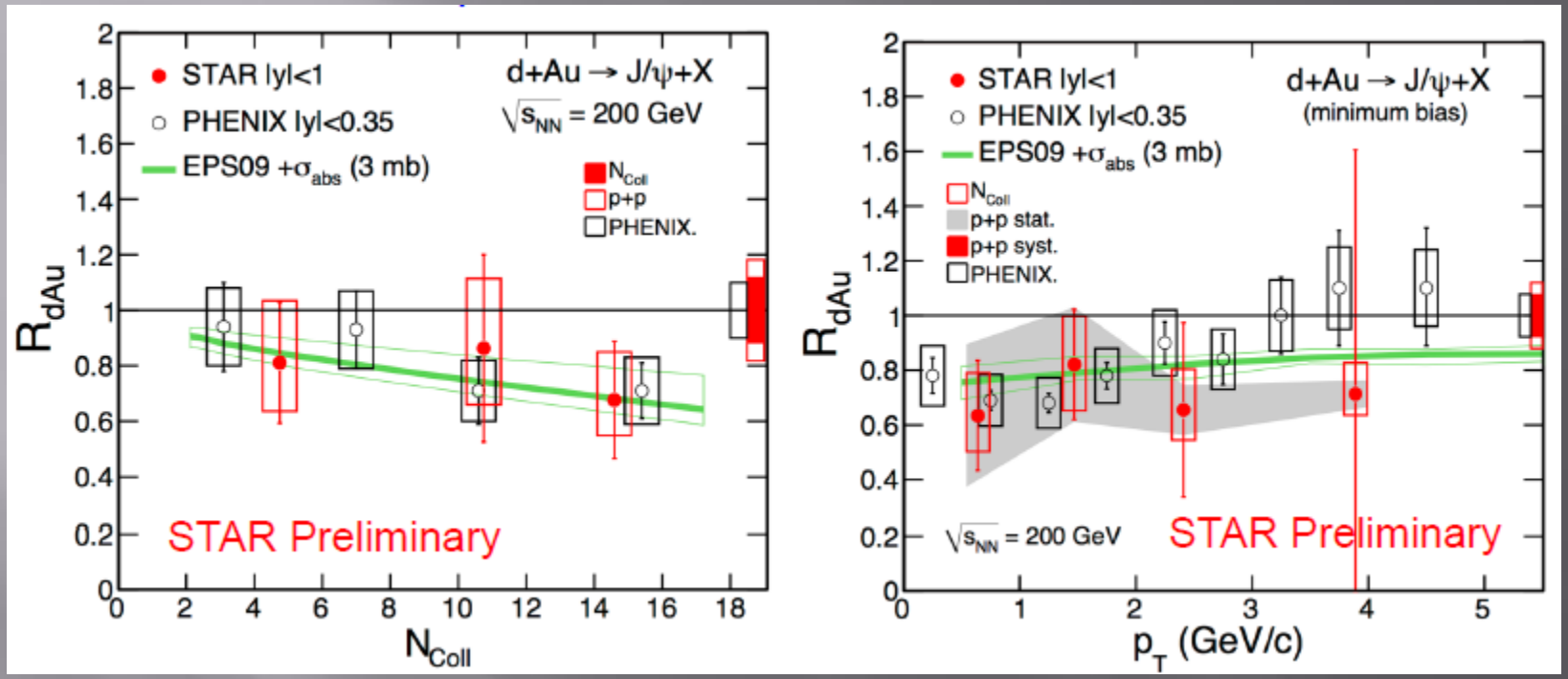
(→ If σabs, it increases with Y)
Lourenco et al. : no universal σ



Should scale with parton X2 ?



J/ψ CNM suppression at RHIC : RdAu



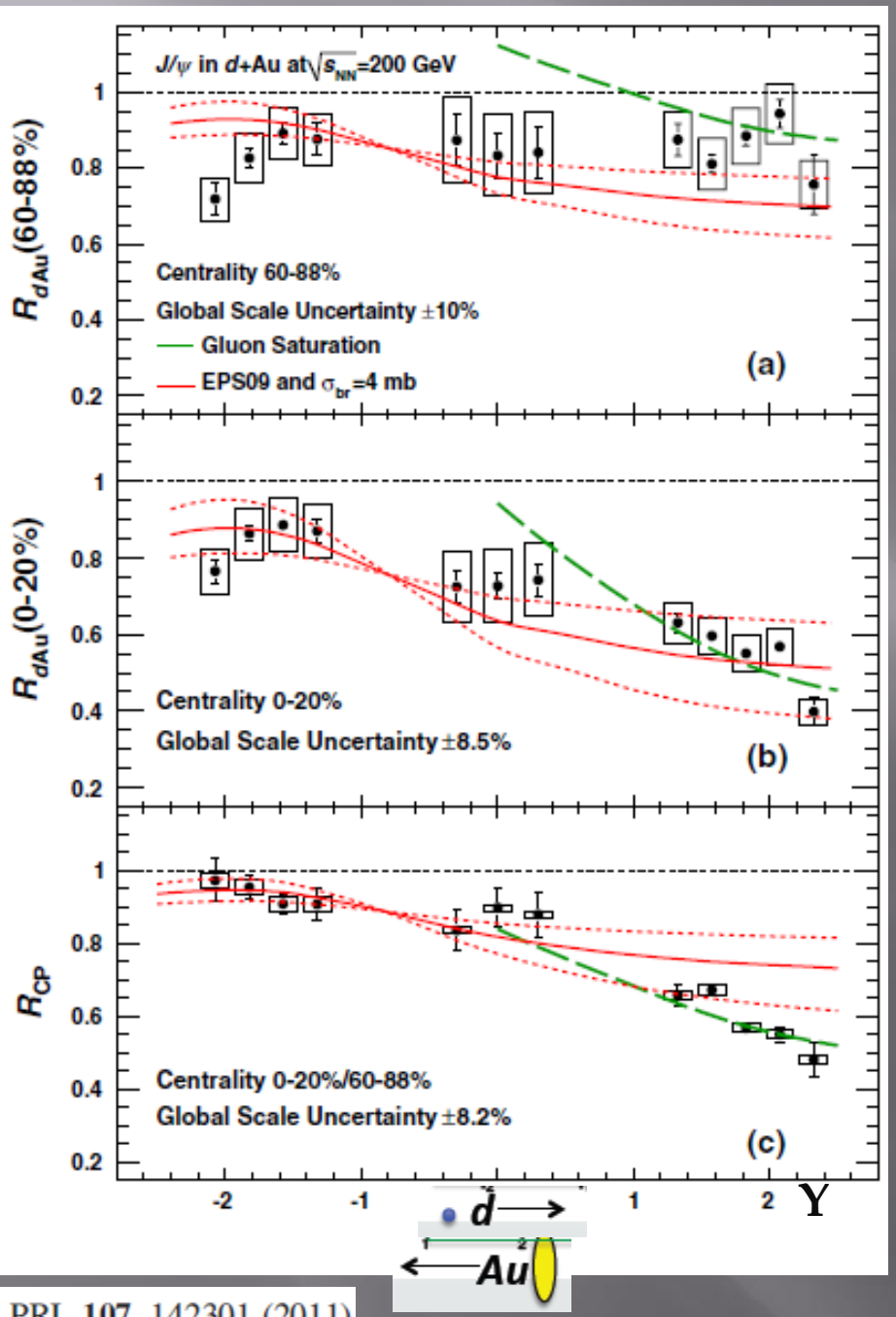
STAR, Jaroslav Bielcik, Hard Probes 2013

Phenix and Star Results in agreement
Suppression of J/ψ , consistent with effect of shadowing and nuclear absorption

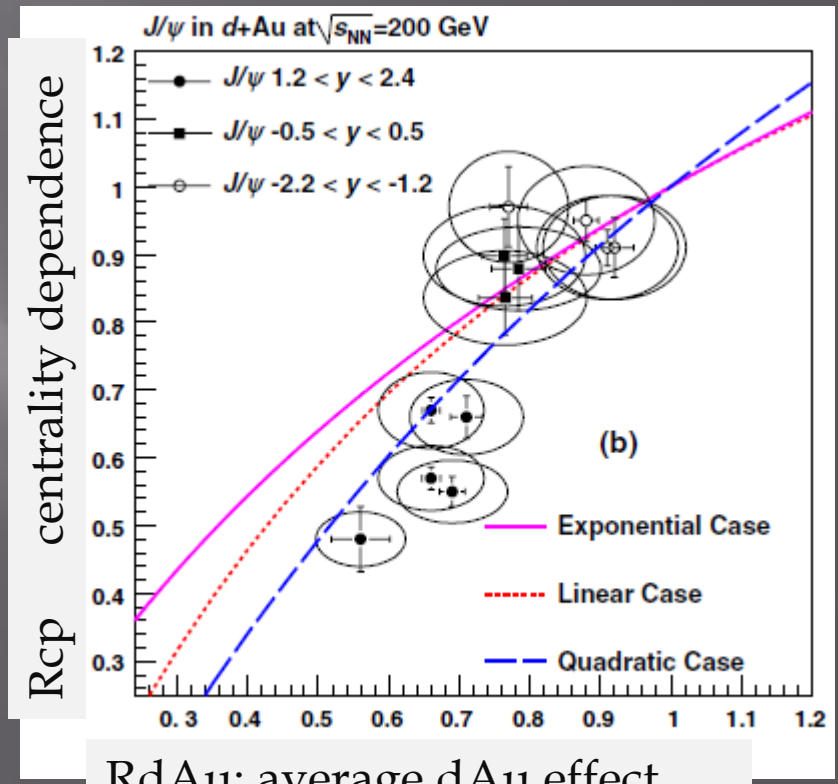
Also: PHENIX and STAR observe the **decrease is at low PT**

J/ψ PHENIX

Suppression, increasing with rapidity and with centrality . Can be quite reproduced with structure function+shadowing, and nuclear absorption

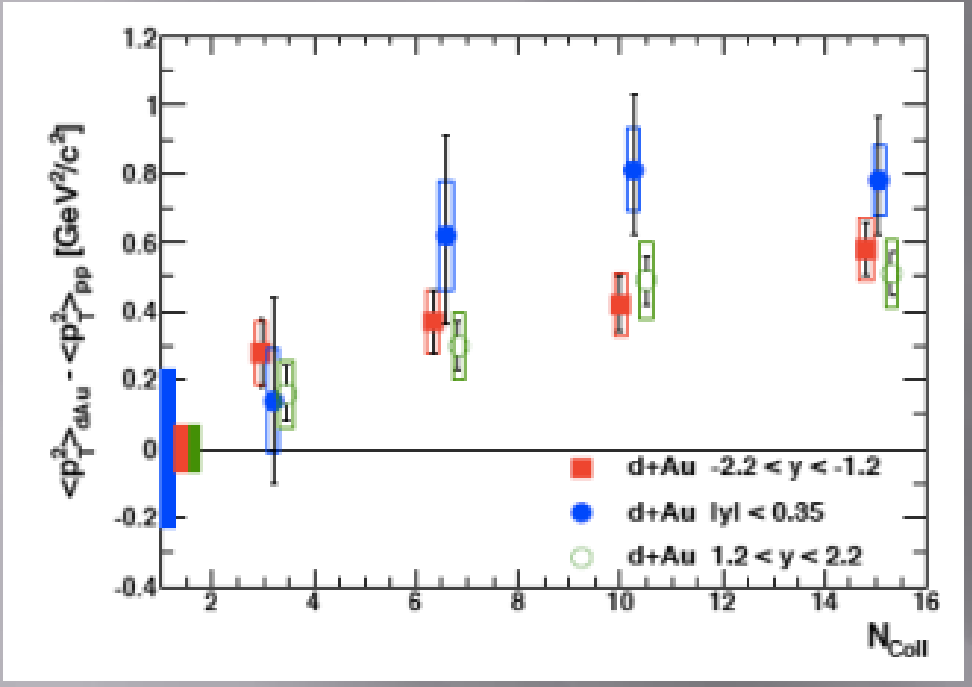


PRL 107, 142301 (2011)

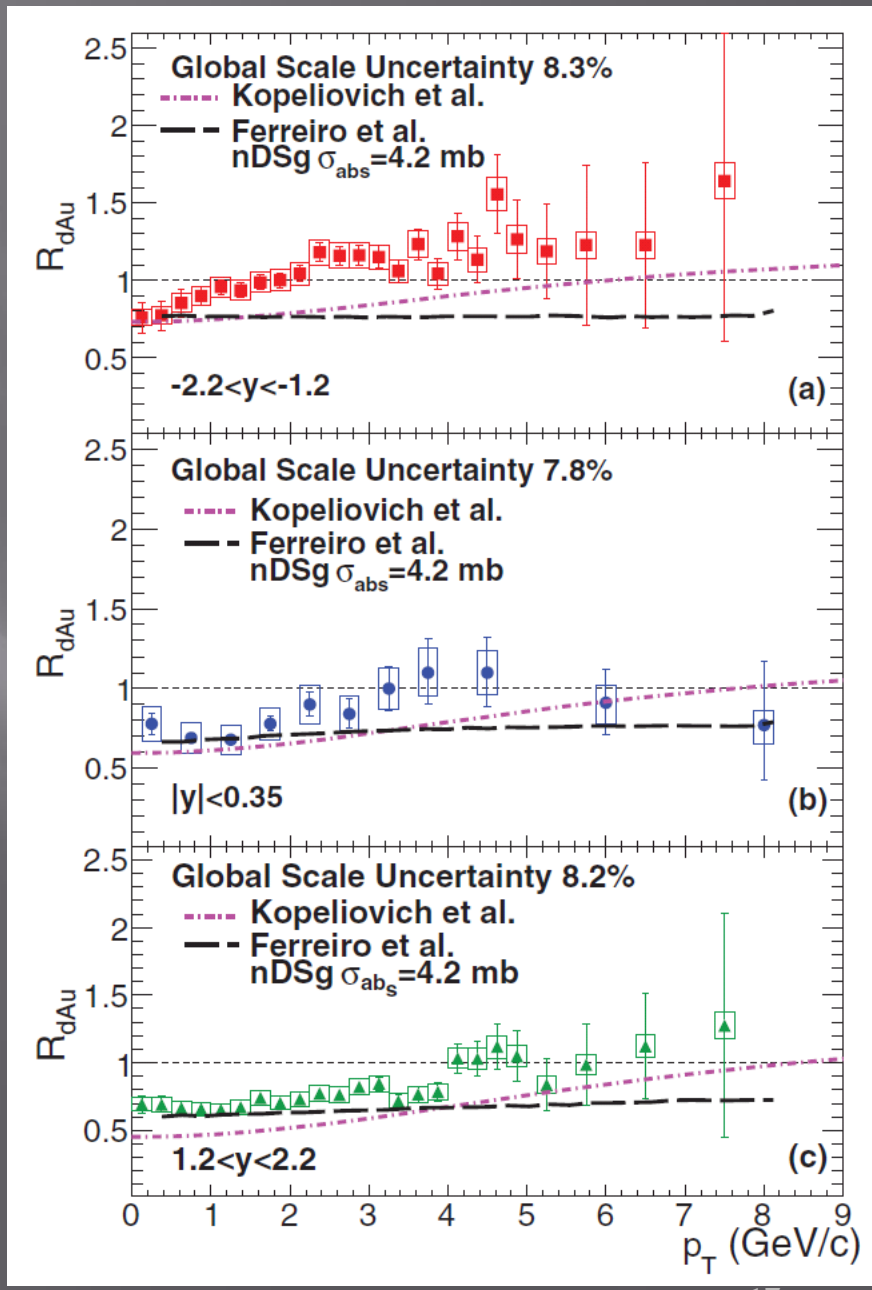


RdAu: average dAu effect

Slope is sensitive to the thickness dependence of the suppression in the nucleus



more Increase in backward Y (Au going)



$\langle P_T^2 \rangle$ Increases with Pt.

Cronin multiple scattering effect

gluon distributions are not very well known, but even assuming shadowing antishadowing similar to quarks,

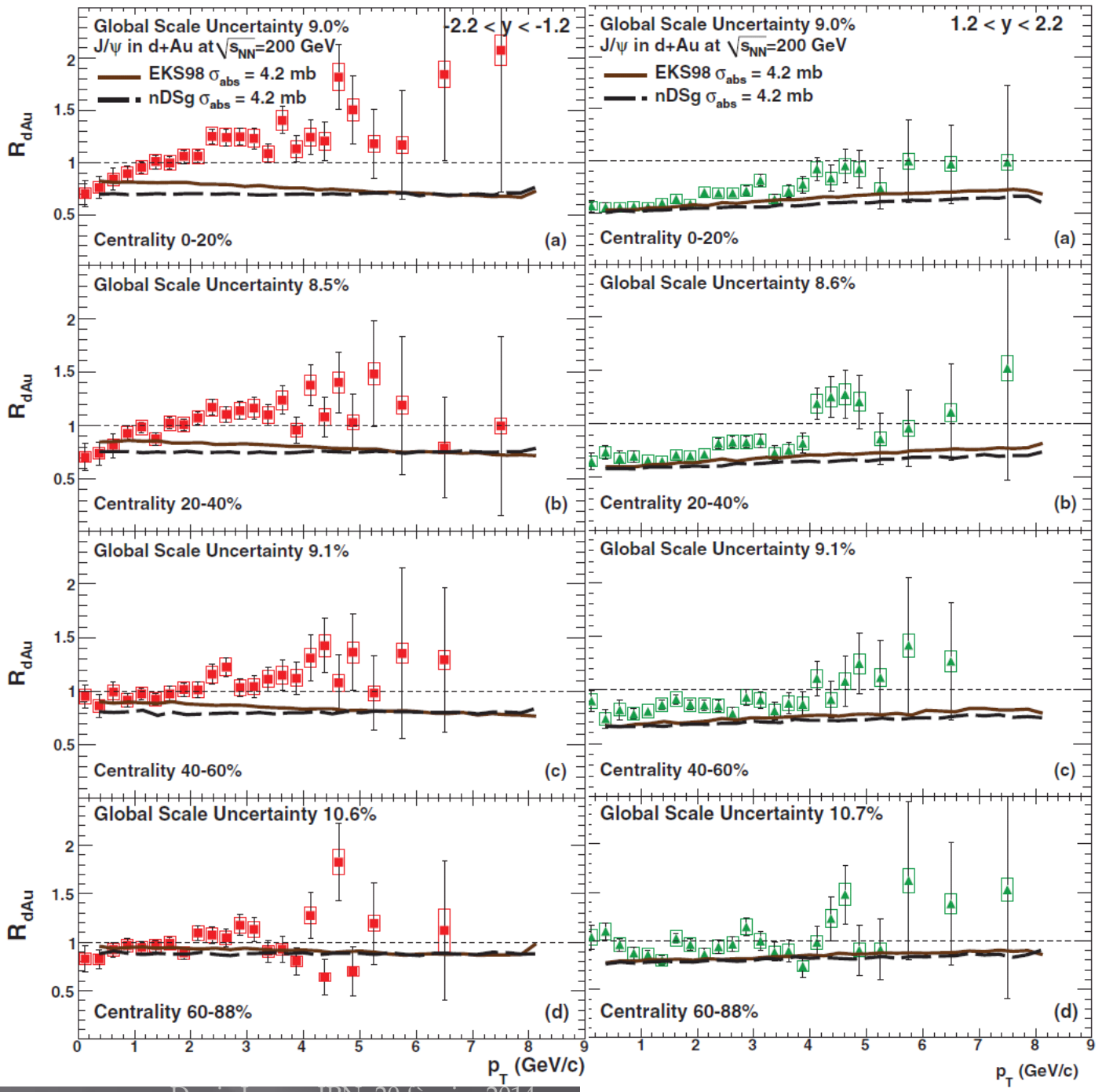
the assymetry backward/forward and Pt distribution are not simultaneously reproduced

PHENIX PRC87, 034904 (2013)

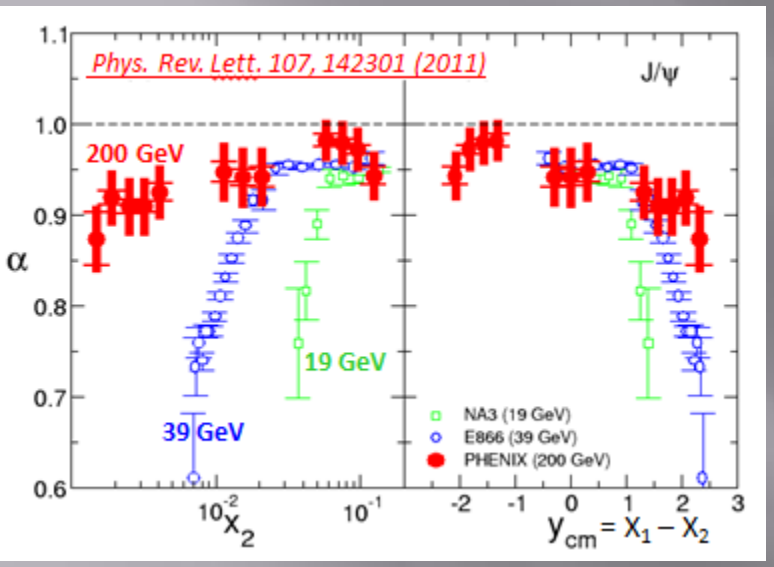
Whereas they compare in peripheral reactions,

backward and forward RdAu have different evolution

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



~Phenix PRL96 012304



The proof of the shadowing is in the…

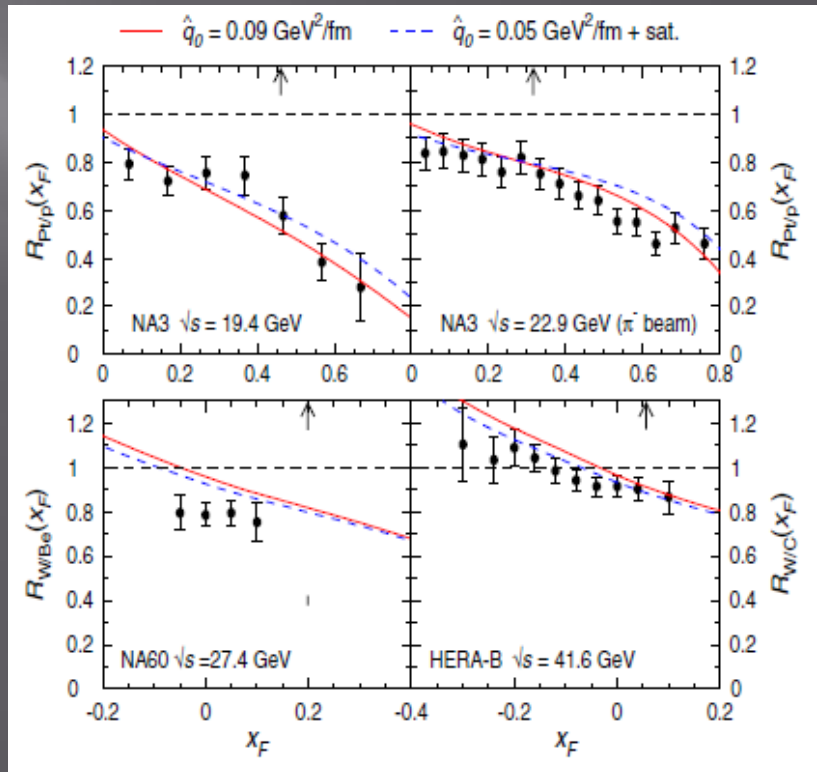
Mike Leitch, BNL 01/2013

Long standing puzzle with X2….
QCD factorization violated by higher twist mechanisms
D.Kharzeev Nuc Phys 1770 2006 40, citing Brodsky 1991

This shows that the « shadowing » is not the main effect (S.Peigné QWG2013)

Another explanation: the « soft » interactions (Eloss), in the travel across the medium, could reproduce both Y and Pt distribution, for all energies and quarkonia, with only *one parameter*

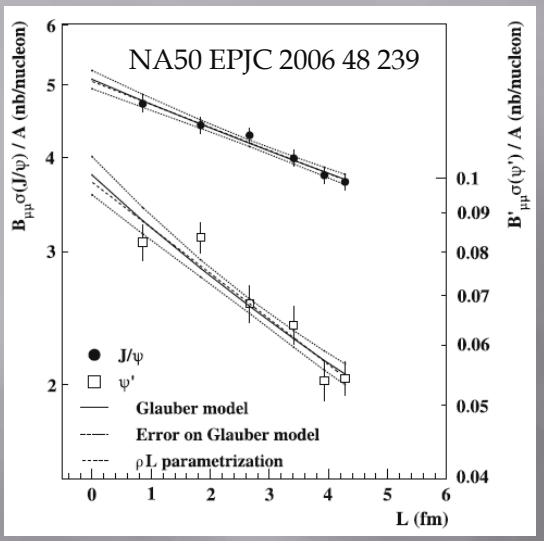
Arleo, Peigné, 1212.0434



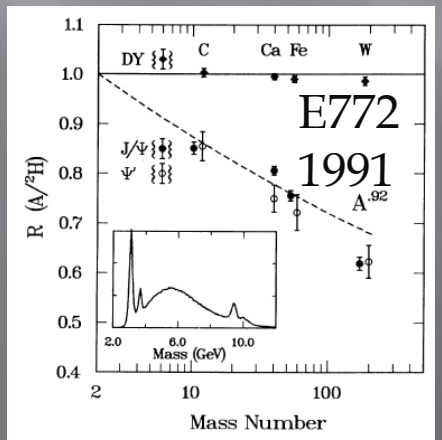
CNM (and or seen as absorpsion)

End of XXth century: Collision of cc pair with nucleon

-> α , σ_{abs}



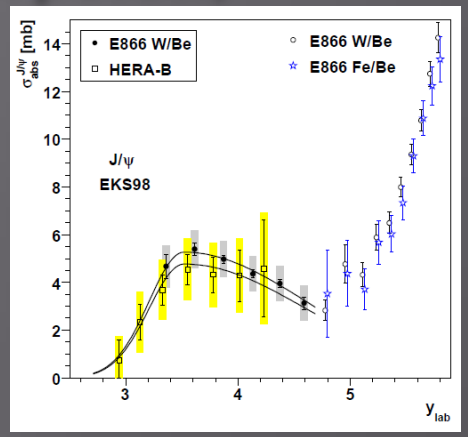
$$\sigma_{\text{p-A}} = \sigma_0^{\rho L}\, A\, \exp(-\sigma_{\text{abs}}^{\rho L} \cdot \langle \rho L \rangle)$$



Beginning XXIth century: introduction of **time dilation** (F.Arleo et al. PRC 61 054906 2000), affecting breakup cross section

$$\sigma_{(c\bar{c})_1 N}(\tau) = \sigma_1 \left(\frac{\sqrt{s}}{10\ \text{GeV}} \right)^{0.4} \left(\frac{r_{c\bar{c}}(\tau)}{r_\psi} \right)^2$$

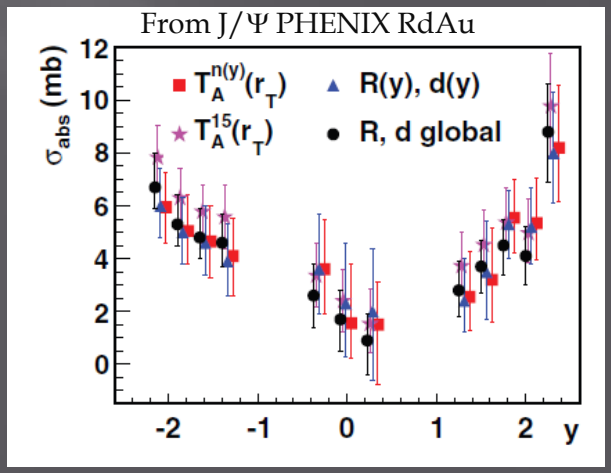
because of the expansion time of the quarkonia (about 0.3 fm/c)



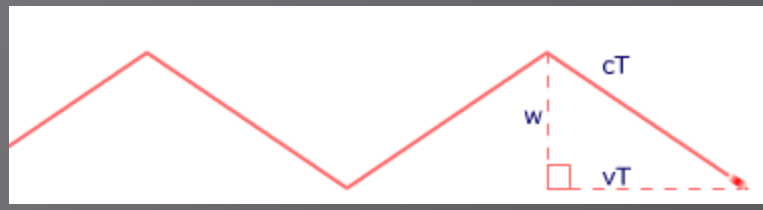
2009 Lourenco Vogt Wohri JHEP 02 014
Nuc Pdf, -> σ_{abs} **depends** on rapidity, energy

Nuc PdF *and* absorption(Y)

2013 McGlinchey Frawley Vogt PRC87 054910: pdf nuc RT dependence (**centrality in dAu**)
also : time dilation



Time dilation



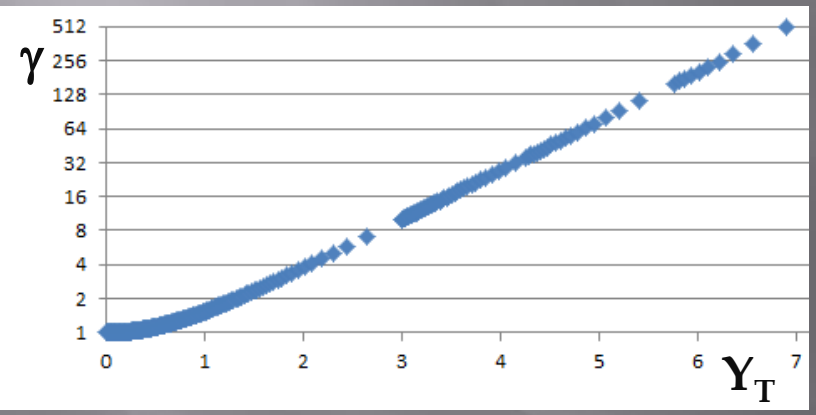
Looks Simple, but slippery subject (see web)

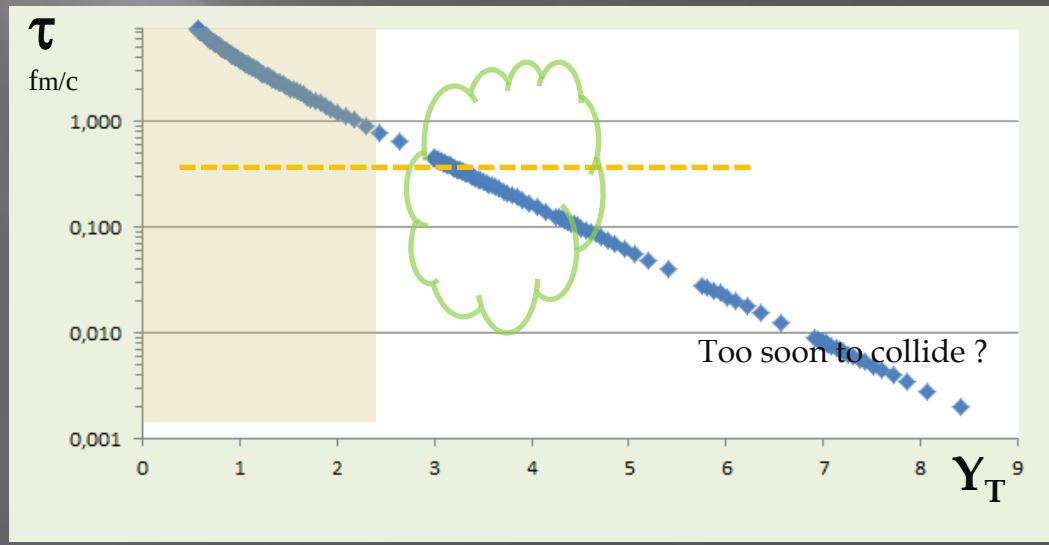
A light packet traveling (w) between two mirrors is studied by an observer moving perpandicularly with speed v. Light is moving at speed c for all observers. $(cT')^2+(vT)^2=(cT)^2$ leads to the usual γ factor for T/T' (increase of « life » time)
[it works but: is it ok ? No instant transmission ?]

$$\tau = L / (\beta \gamma)$$

Time for crossing 4.5 fm (matter at rest), as a function of the rapidity of the particle, in the proper time of the moving particle.

γ evolves as exp(Y)



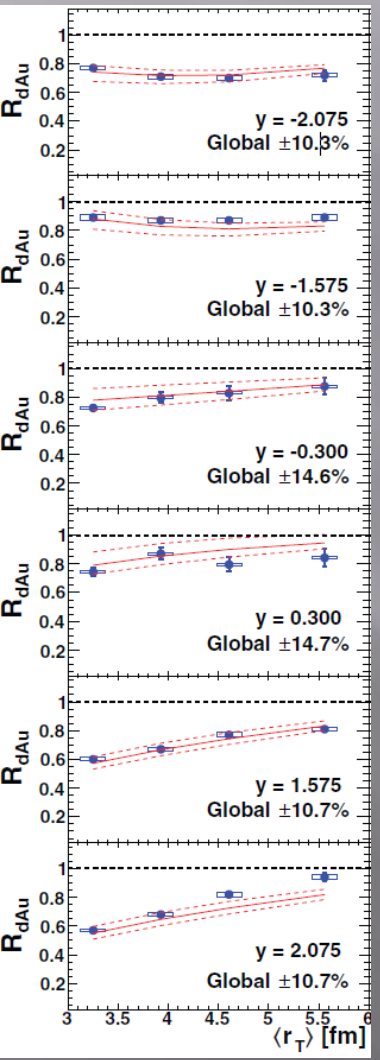


Y_T rapidity of the particle , in the Heavy target frame

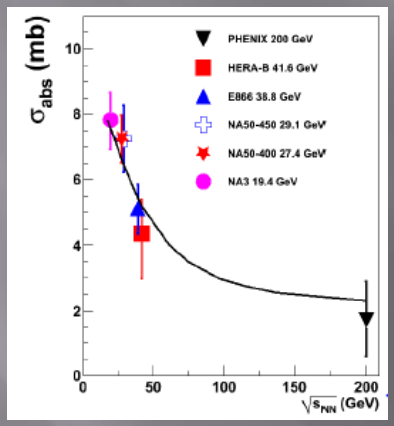
For rapidities around ~~3-4, a quarkonia will be in the middle of its expansion

Rapidity, energy, and proper time dependences of the absorption

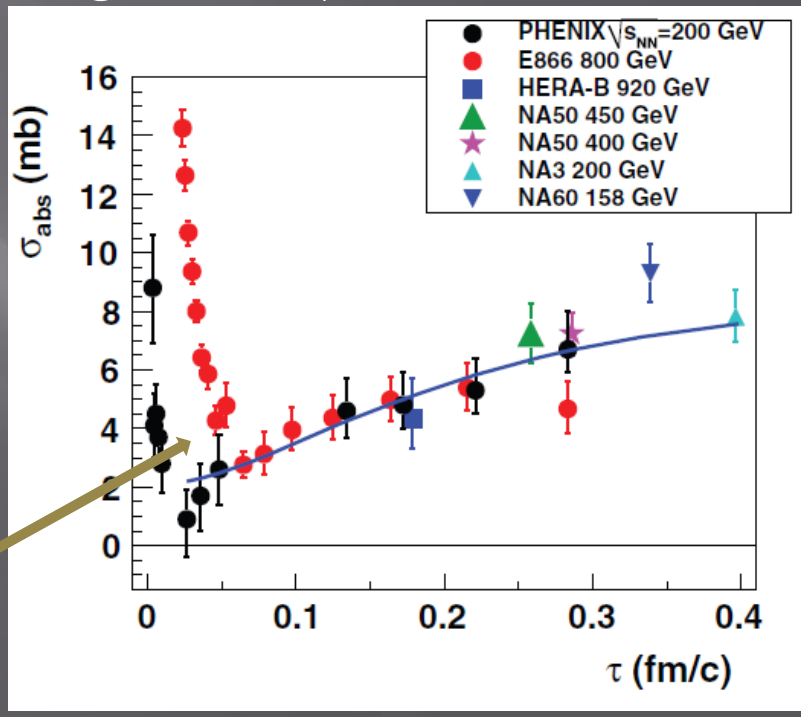
Mc Glinchey, Frawley Vogt PRC 87 054910



Separate absorption (EPS09 NLO) from shadowing , by fitting rapidity distributions as functions of centrality



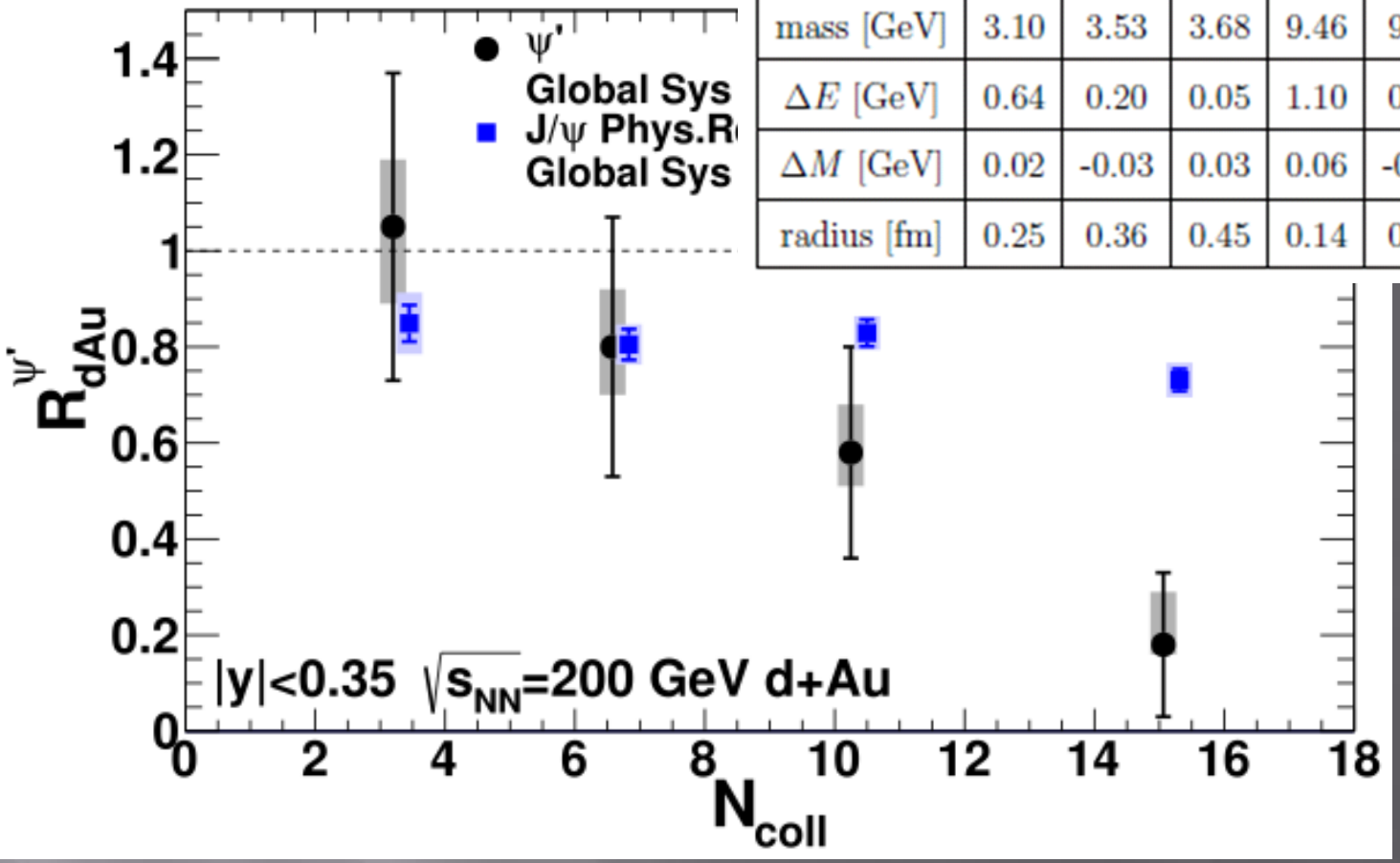
At mid and backward (heavy one) rapidity the absorption depends on the time spent by the particle in the target (α L/γ)



Other mechanism needed for high rapidities

Quarkonia:
not only thermometers, but also chronometers

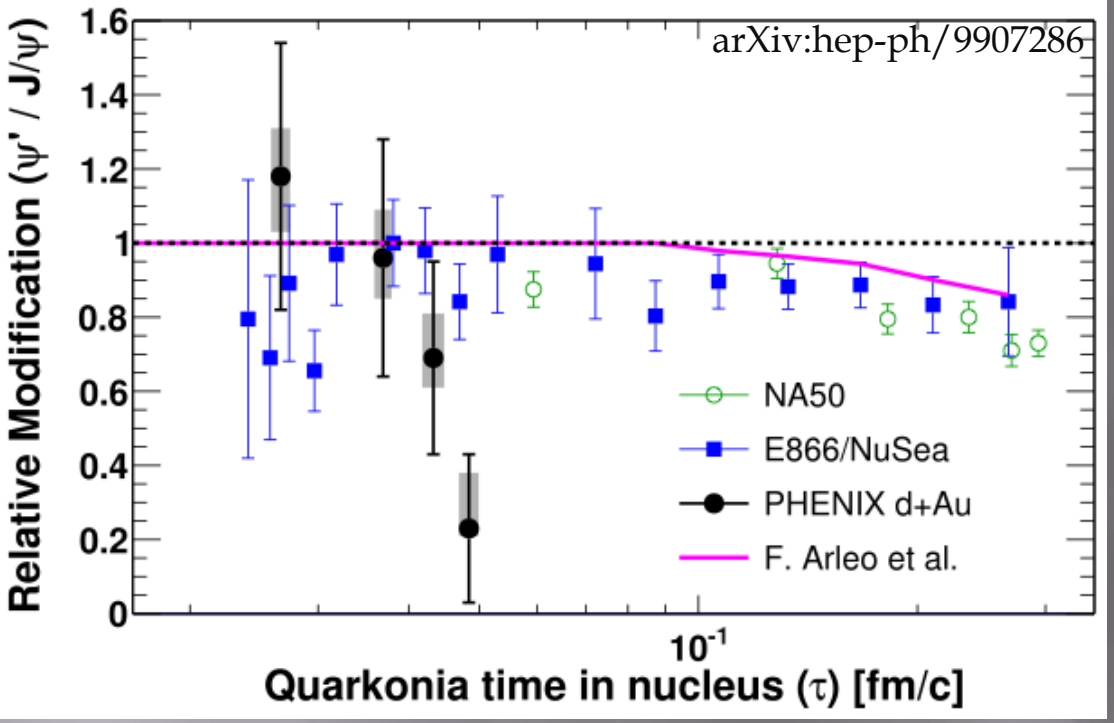
PHENIX arXiv:1305.551

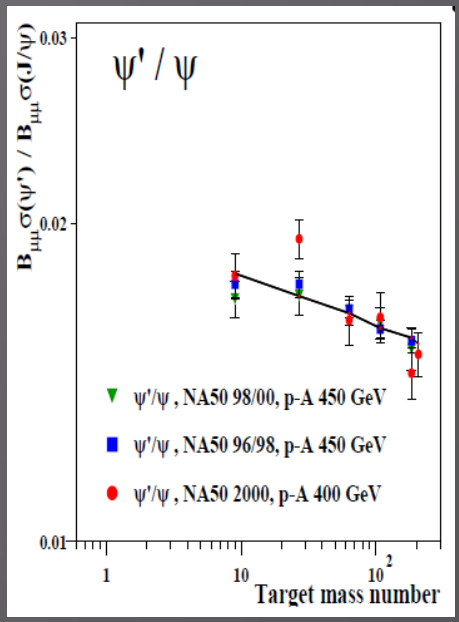


state	J/ψ	χ_c	ψ'	Υ	χ_b	Υ'	χ_b'	Υ''
mass [GeV]	3.10	3.53	3.68	9.46	9.99	10.02	10.26	10.36
ΔE [GeV]	0.64	0.20	0.05	1.10	0.67	0.54	0.31	0.20
ΔM [GeV]	0.02	-0.03	0.03	0.06	-0.06	-0.06	-0.08	-0.07
radius [fm]	0.25	0.36	0.45	0.14	0.22	0.28	0.34	0.39

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

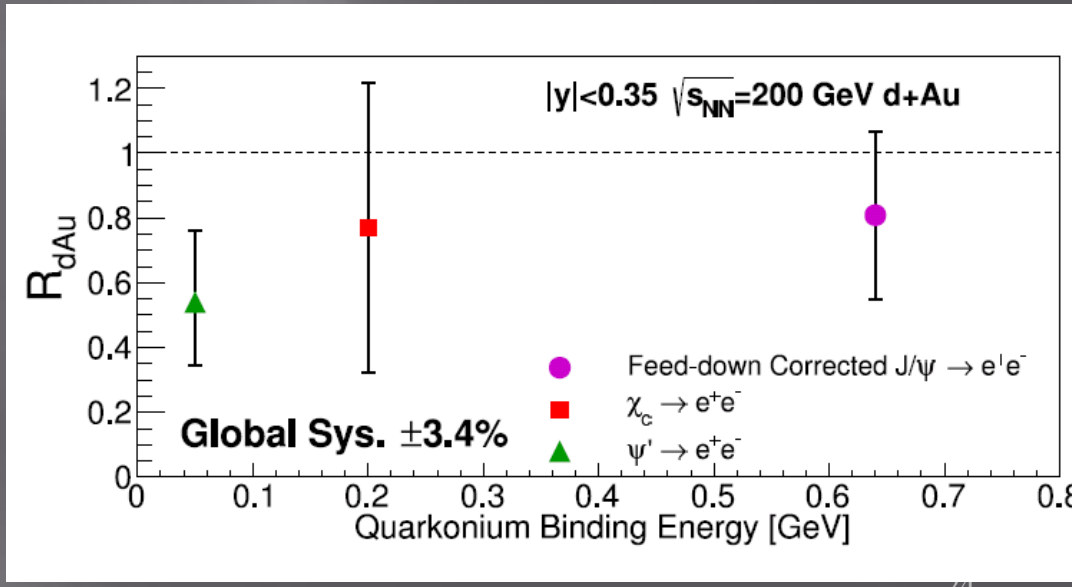




Unexpected difference between Ψ' and Ψ suppression at the beginning of the formation process.

more quarkonia species become available

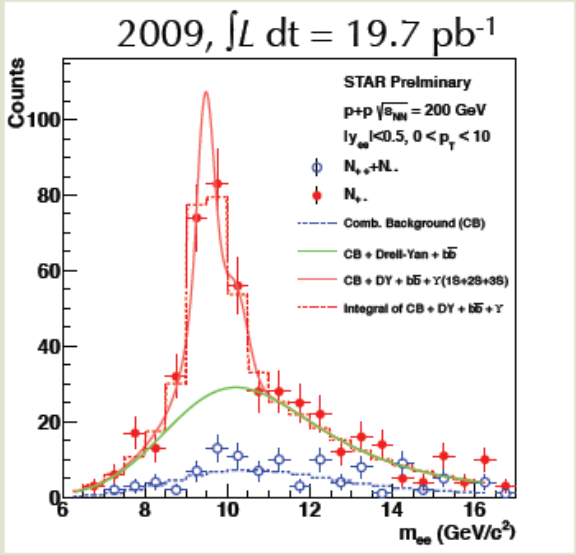
prospects for the study of the quarkonia suppression with respect to their binding energy



Υ in STAR

2009 pp

(Borrowed from Manuel Calderon de la Barca, WWND 2013)

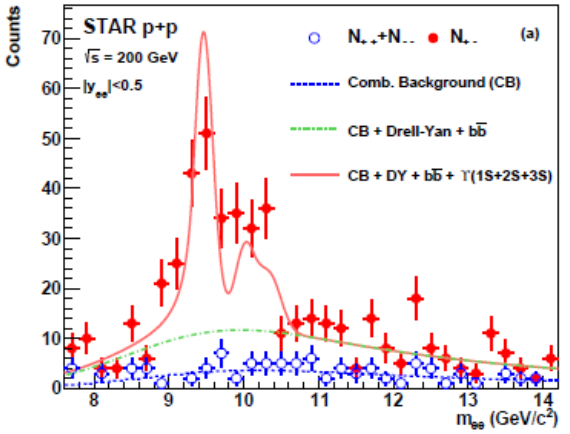


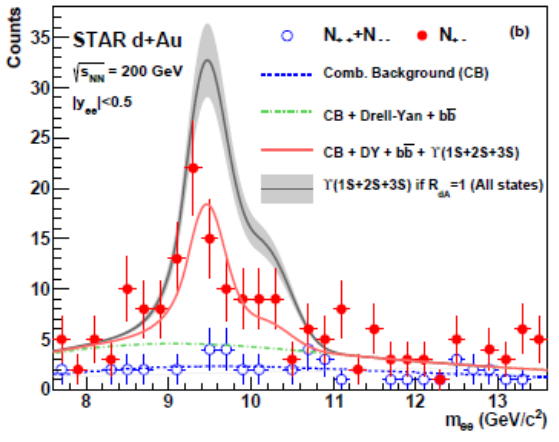
N_Υ(total)= 145±26(stat.)

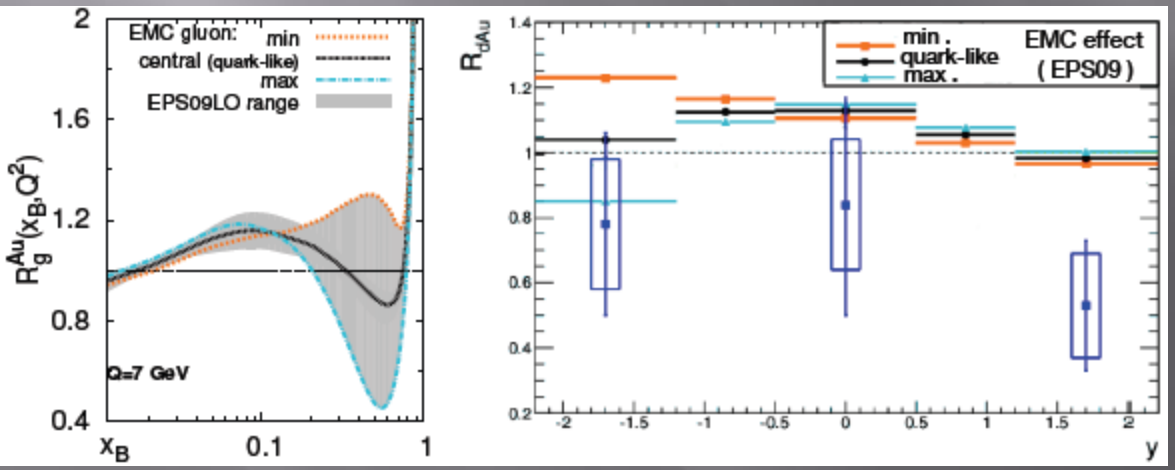
$$\sum_{n=1}^{3} \mathcal{B}(nS) \times \sigma(nS) = 91.8 \pm 16.6 \pm 19 \text{ pb}$$

STAR Preliminary

February 5, 2013 WWND 2013







RdAu = 0:67 ± 0:12(stat:) ± 0:04(sys:) ± 0:08(p+p sys:) (Archiv 1312.3675)

→ **Additional cold matter suppression**

« consistent with previous measurements from p+A fixed-target experiments"

Rakotozafindrabe al 2012 1207.3193

Probing **gluon** EMC

Υ in PHENIX

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

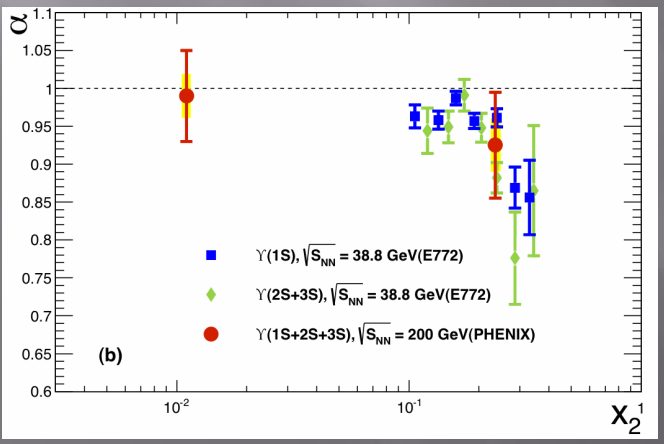
Suggests a backward suppression,

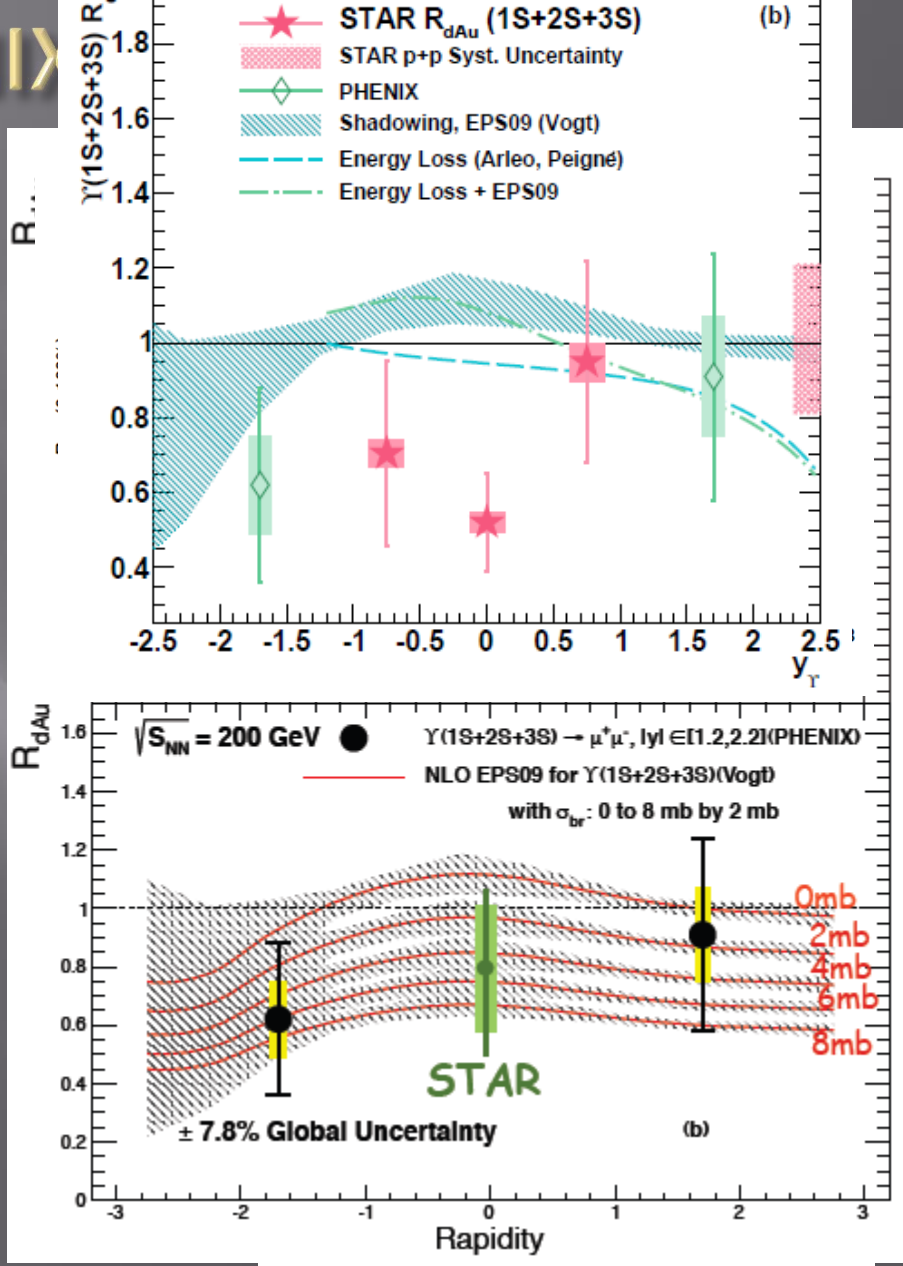
could be induced by the parton distributions (EMC effect)

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

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

Or nuclear break up ?





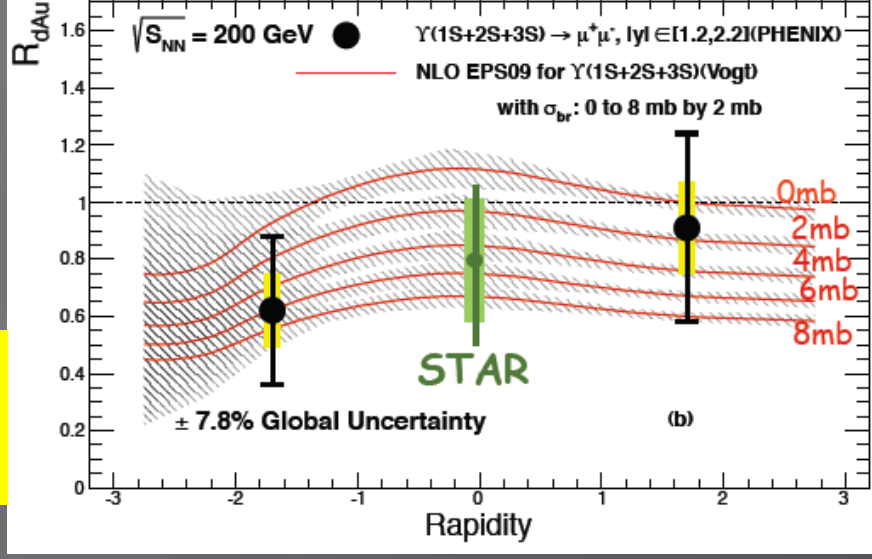
PHYSICAL REVIEW C **87**, 044909 (2013)

Υ: sensitive measurement ?

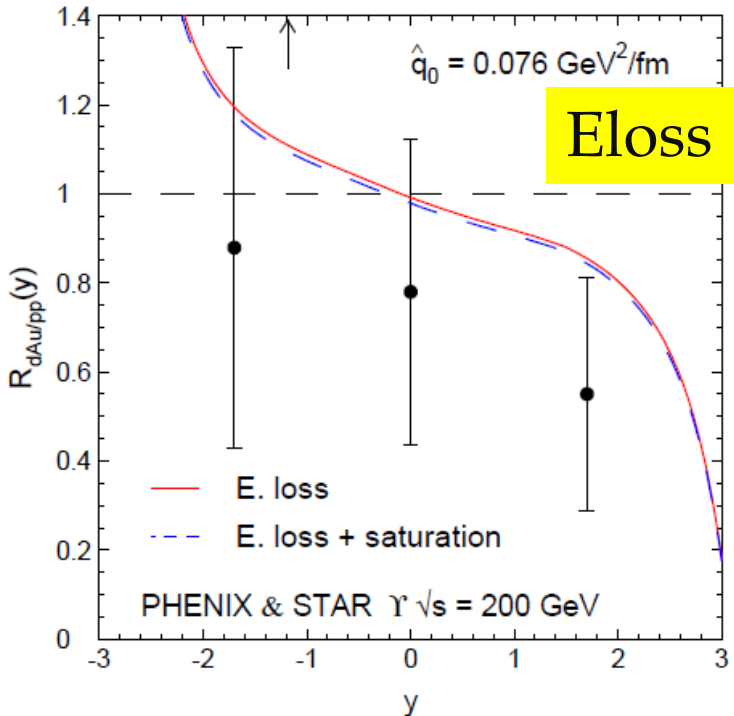
(If confirmed with more precision)

« EMC » effect ? (for gluons)

Or

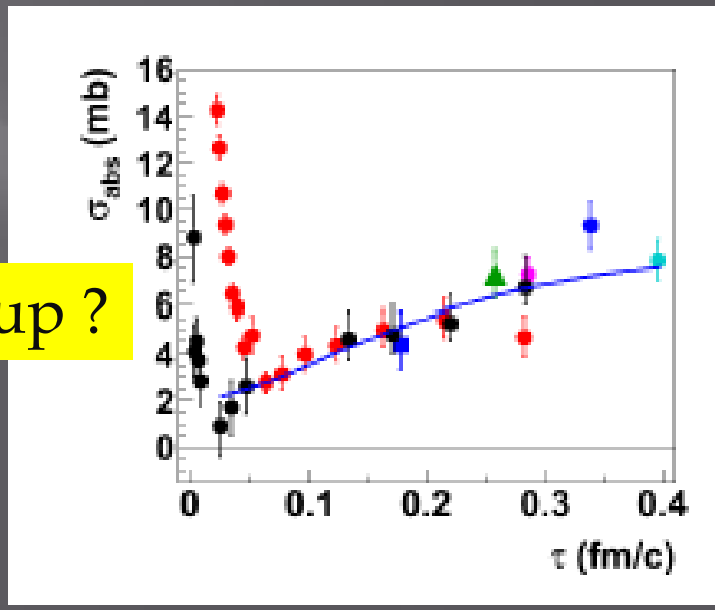


Eloss



+ breakup ?

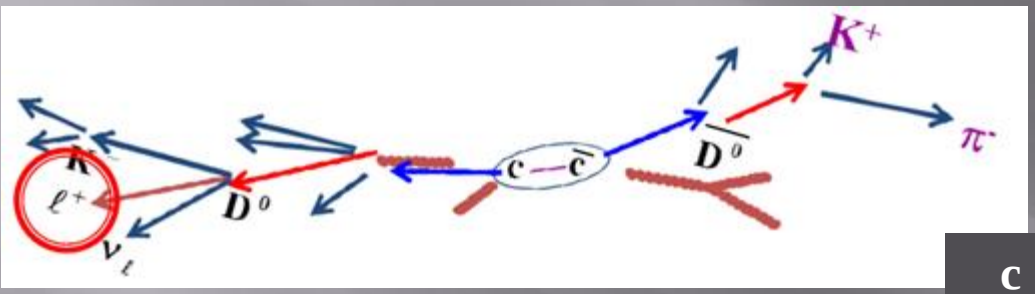
(Υ<0)



Open Heavy Flavor

Open flavor originates from the same production mechanism as quarkonia

H.Satz this morning: we have to consider the ratio hidden/open HF



(Nelson, Vogt, Frawley arxiv:1210.4610 : aim at calculating quarkonia from model tuned on open flavor production in pp)

c -> D (*, ¯, 0, +,s ….)

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

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

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

One way: single leptons:

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

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

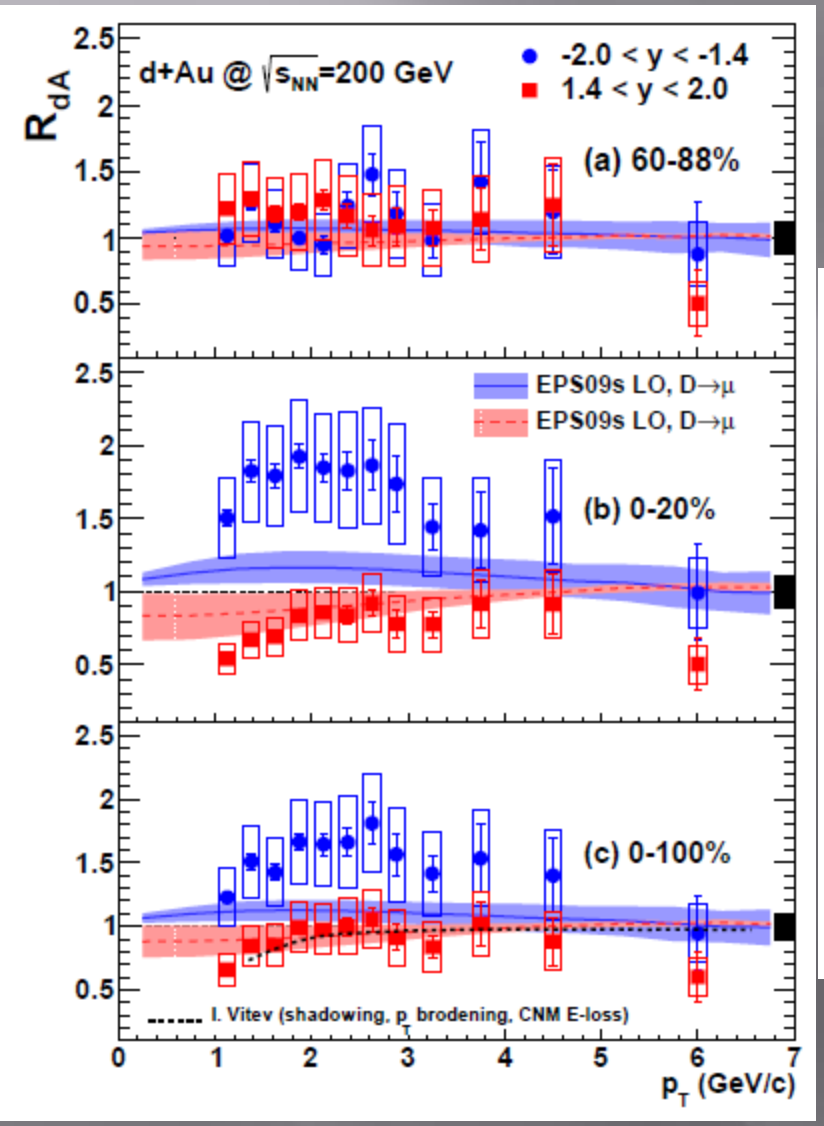
Single leptons in PHENIX

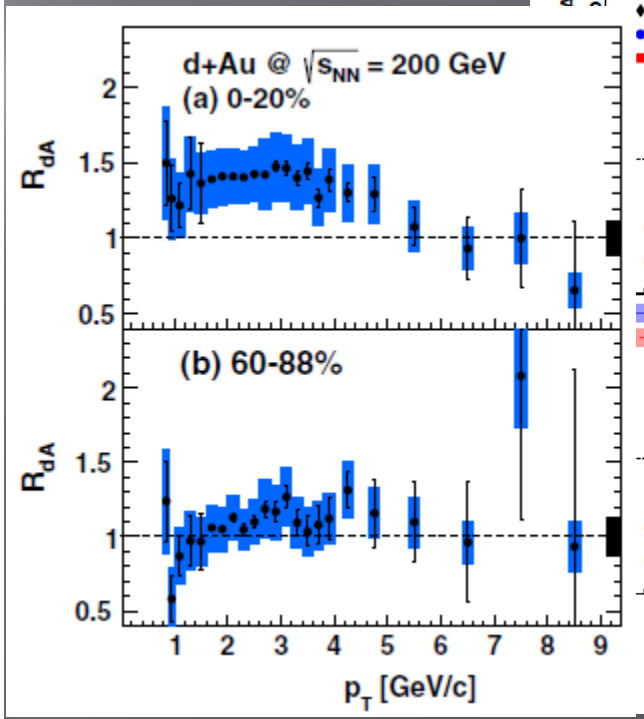
- Peripheral collisions: RdAu~1
- With centrality

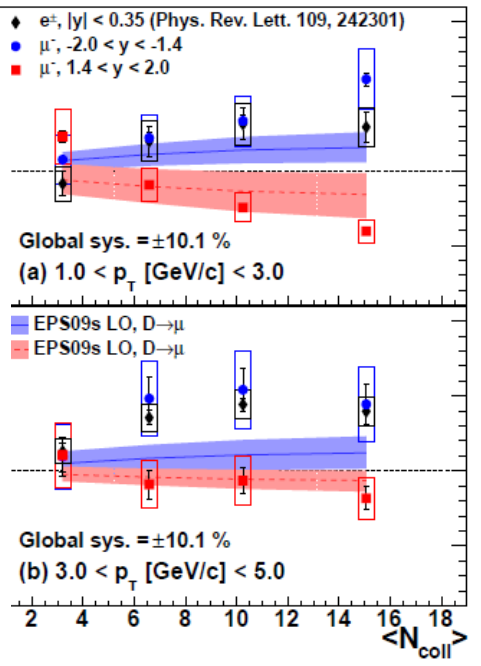
Low Pt:

Increase in backward (Au) domain

Decrease in forward (d) domain

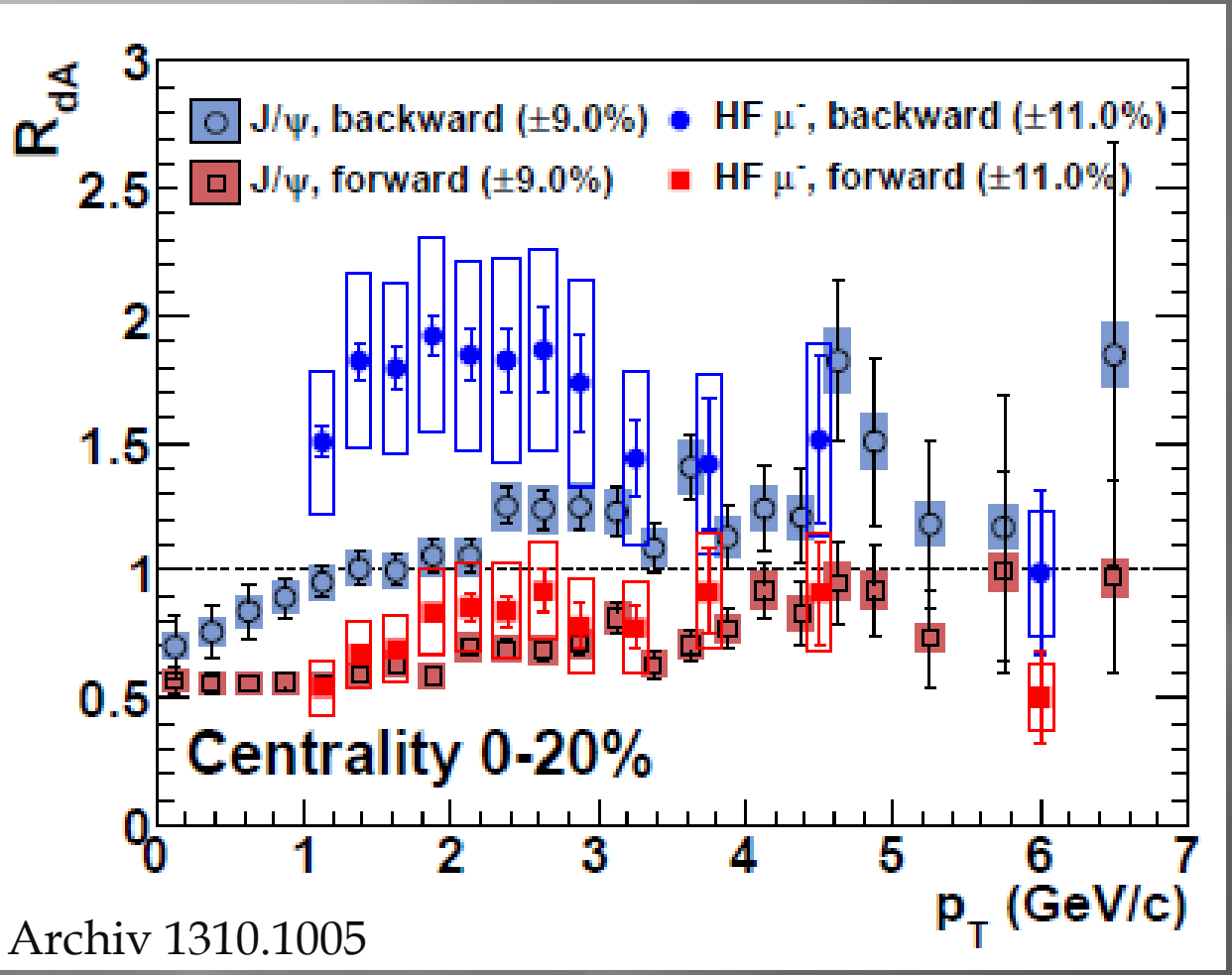






Central rapidity domain: compares with backward one

Open vs hidden



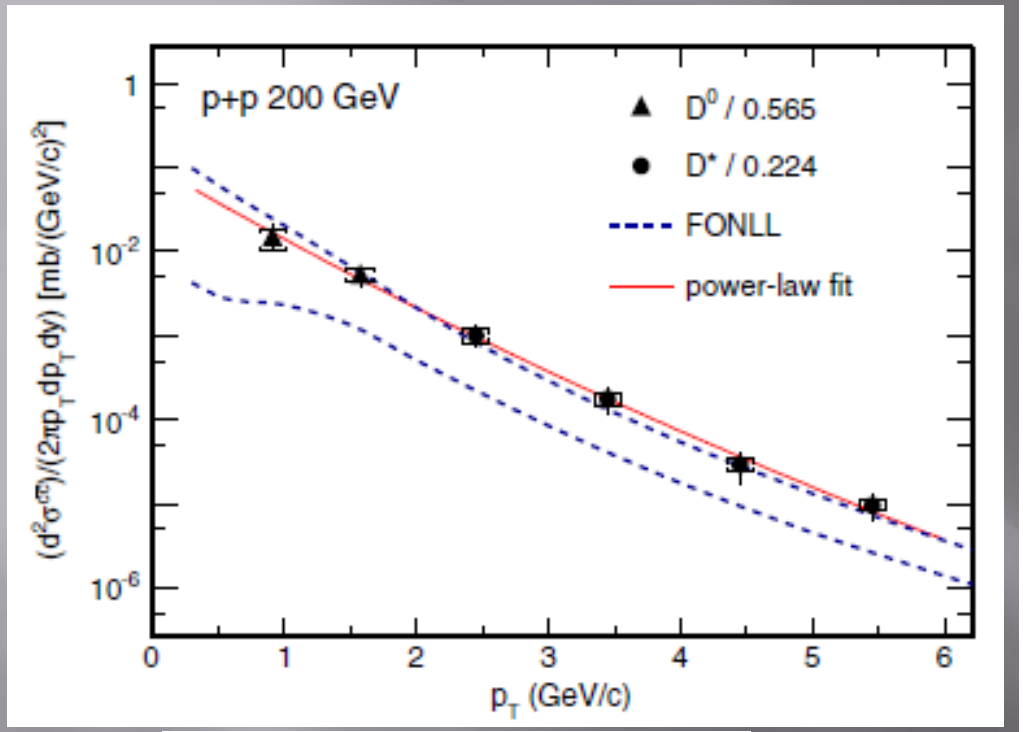
Archiv 1310.1005

With centrality

* d rapidity hemisphere: Similar suppression for hidden and open

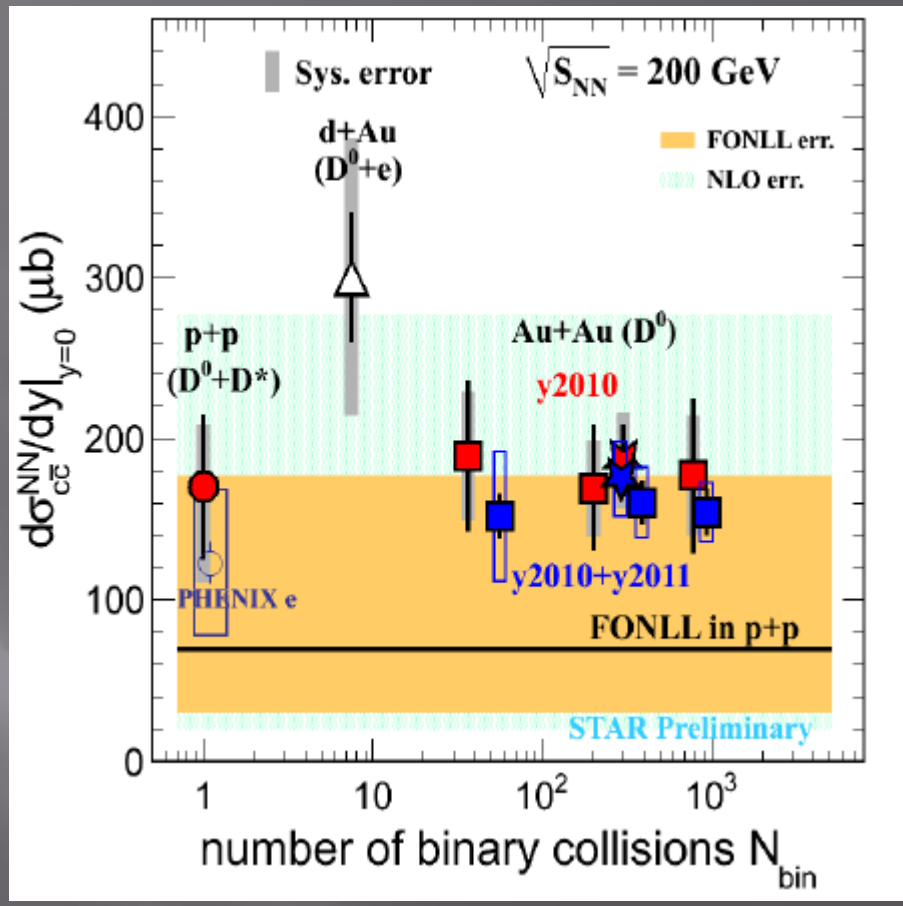
* Au hemisphere: Quarkonia suppression (smaller)
Reverse behaviour for openHF :
increase of Open HF

STAR open HF: D



$$\left.\frac{d\sigma}{dy}\right|_{y=0}^{c\bar{c}} = 170 \pm 45(\text{stat})^{+38}_{-59}(\text{sys})\ \mu\text{b}.$$

2009 measurement, PRD 86 072013



(From C.Kikola , DIS 2013)

RdAu displays a clear increase
Also for D production.

RHIC results contrasts with HERA B and E789 results (α~1) ? (Y~0)

d-Au:

	$dN(D^0)/dy\|_{y=0}$ (10^{-2})	$d\sigma_{c\bar{c}}^{NN}/dy\|_{y=0}$ (mb)
D^0	2.8±0.4±0.8	0.29±0.04±0.08
$D^0+e^{\pm}$	2.9±0.4±0.8	0.30±0.04±0.09

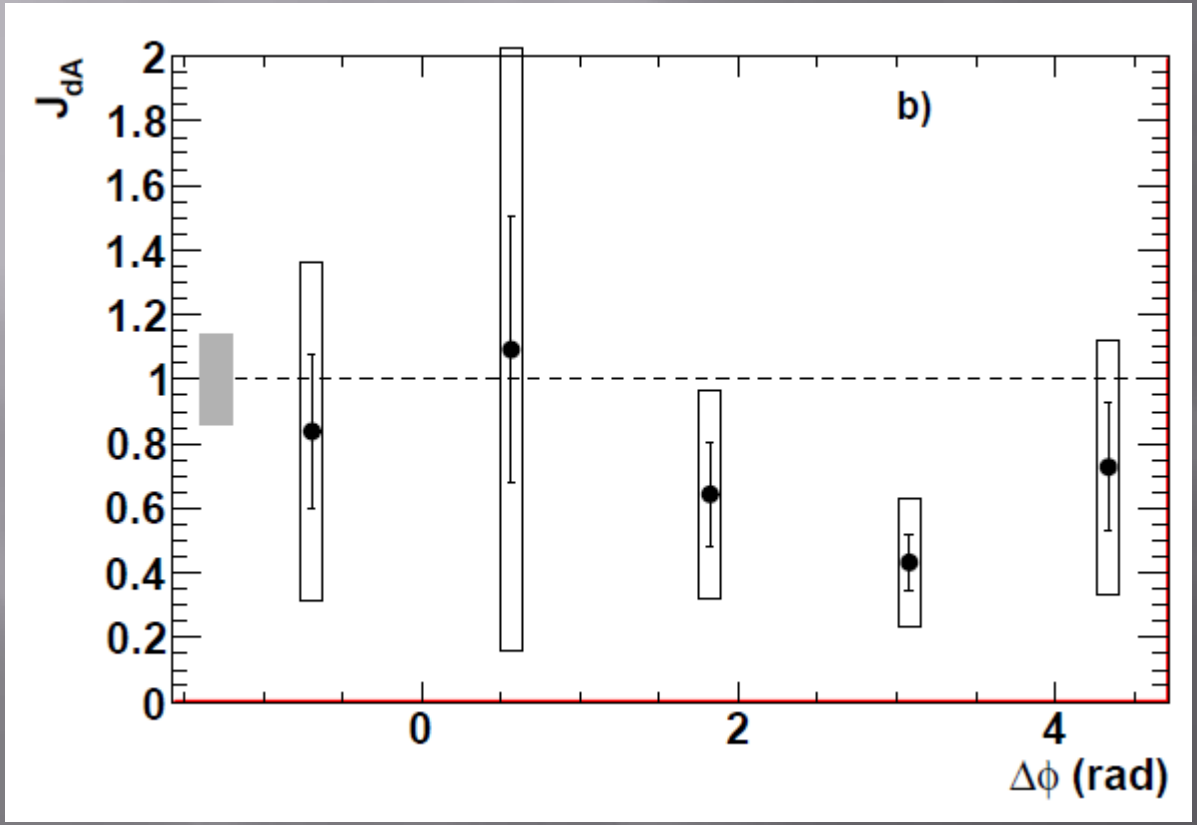
PRL 94 (2005) 62301

e-μ
PHENIX pp dAu

Archiv 1311.1427

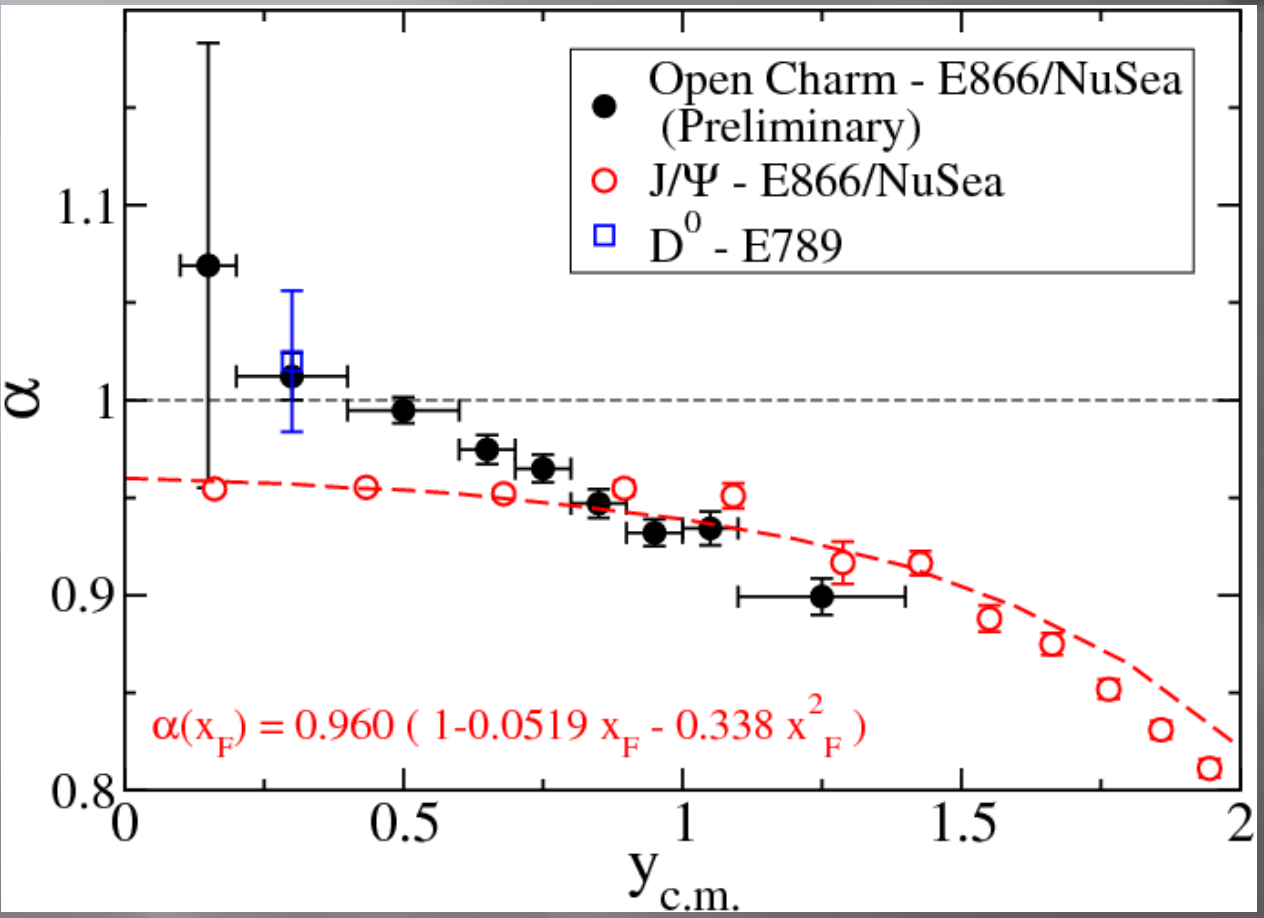
- Correlated production, decorrelated decay (only)

(no resonance dilepton decay, drell yan, … no « correlated background »)



J_{dA} ← R_{dA} (ϕ)

Lower energy



D meson:
Rather strong dependence of pA evolution with rapidity

Mike Leitch BNL pA workshop
07/01/2013

10-200 GeV (d)p-A CNM HF

- Benefits from measurement on a wide rapidity domain, effects are strongly depending on « rapidity » (PT too)
- Still to weight the different processes. Needed for AA. Questions the basic knowledges of collisions.
- dramatic effects appears when going from pp to pA (dAu):

- Psiprime suppression and additional suppression
- Upsilon backward eventual suppression (increasignly suggested at RHIC, seen at FNAL) ?
- Backward and central rapidity: increase of the open HF

- → Strong Open/hidden backward difference

- PDF or Eloss and/or breakup ? (PDF: second order effect (not scaling with X2) ?
- Time dilation and various qq probes improve sensitivity ?
- Quarkonia: QGP thermometer in AA , CNM chronometer in pA?
- Let's continue toward the motion picture of the collisions !