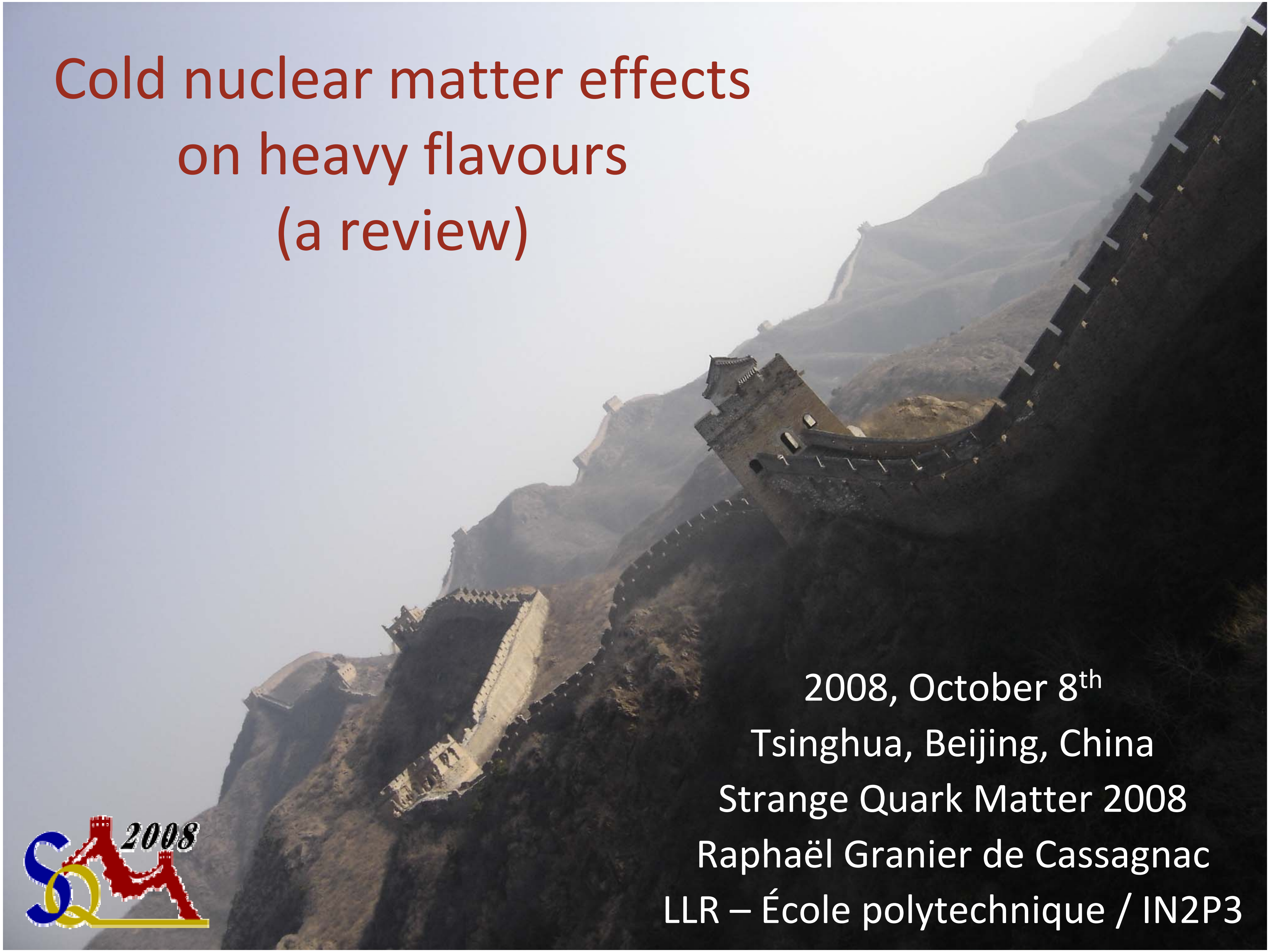
Cold nuclear matter effects on heavy flavours (a review)



2008, October 8th

Tsinghua, Beijing, China

Strange Quark Matter 2008

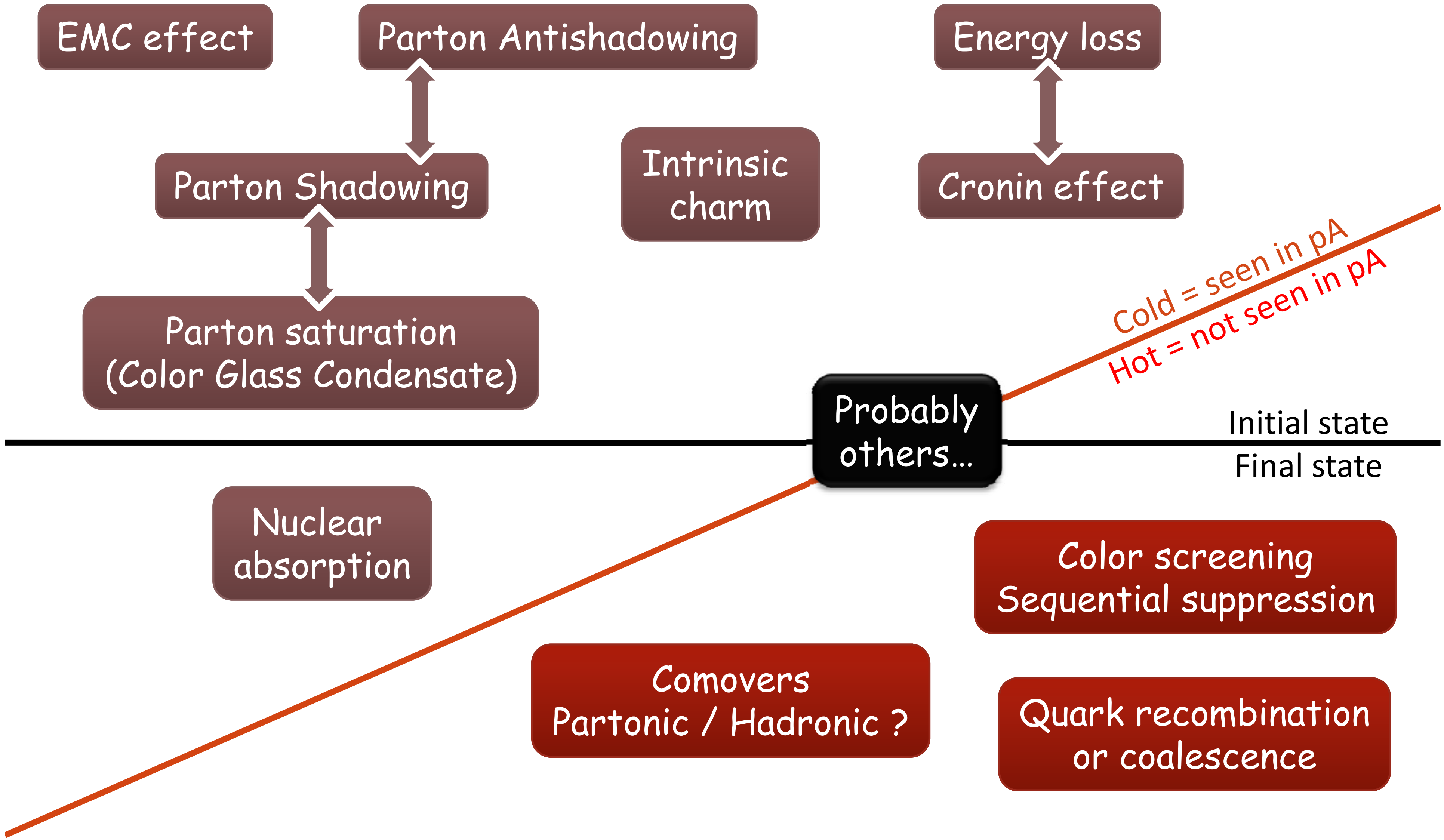
Raphaël Granier de Cassagnac

LLR – École polytechnique / IN2P3

Disclaimer

- *Before to claim for anomalous suppression, one has to check for normal suppression*
- *Cold nuclear effects on heavy flavours are so important to understand J/ψ in AA collisions…*
- *…that most of my talk was covered by Alex, Taku and others yesterday!*
- *Thus, you could have slept half an hour more…*
- *But let me try to wake you up…*

Some semantics: my definition of *cold*



Outline: go through experimental programs and observed cold effects

@SPS (20 GeV): many pA ! High statistics ! But small kinematics ($-0.1 < x_F < +0.1$) → Nuclear absorption

@FNAL, HERA (30 GeV): less pA... High statistics ! Large rapidity (x_F) coverage... → Many cold nuclear effects needed! But no AA...

@RHIC (200 GeV): only dAu, low statistics (for now), but

1. Rapidity (–2.2 to +2.4) → Absorption + (anti)shadowing
2. Centrality dependence → Data driven method
3. Open charm, with large uncertainties

Bonus: a word about Cronin effect

@LHC (5.5 TeV): likely to be as RHIC, only dPb to start with, large rapidity coverage (three experiments)... → Uncharted territory

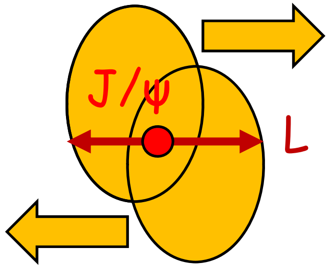
SPS charmonia & nuclear length L

Introducing nuclear absorption σ_{abs}

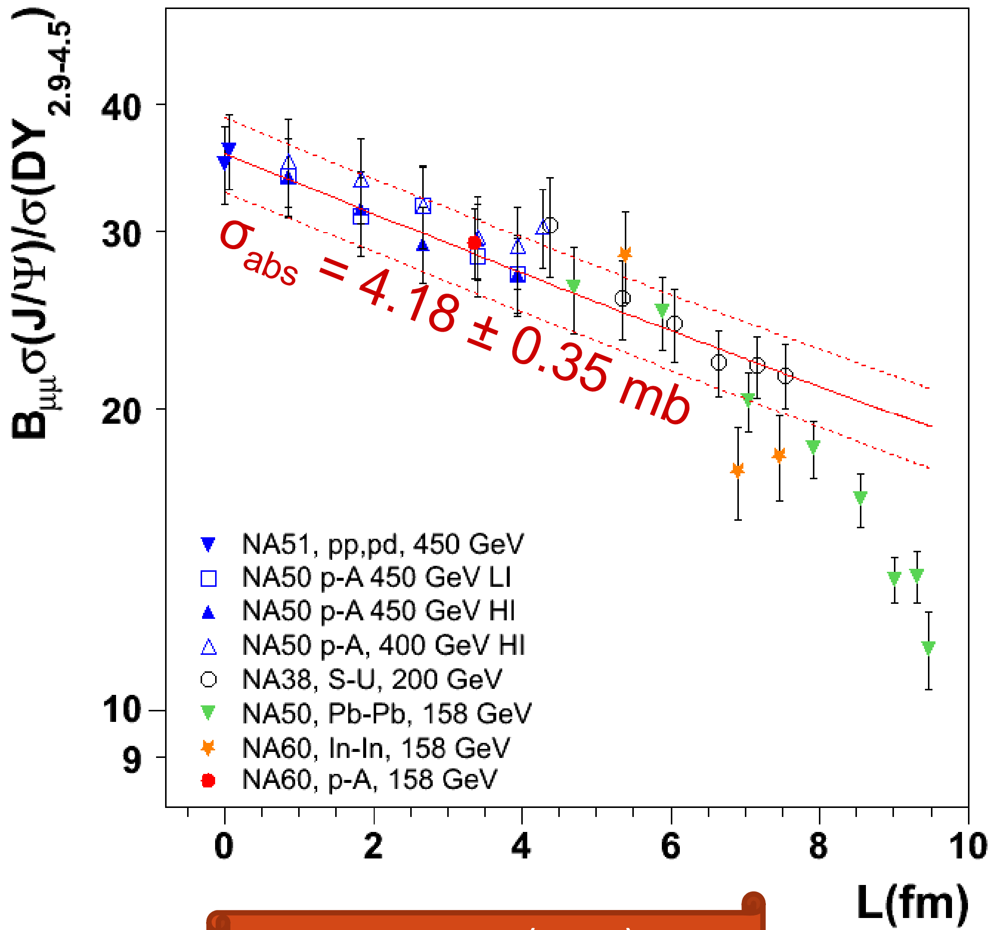
“One parameter to fit them all

And out of nuclei to unbind them”

J/ψ / Drell-Yan versus L



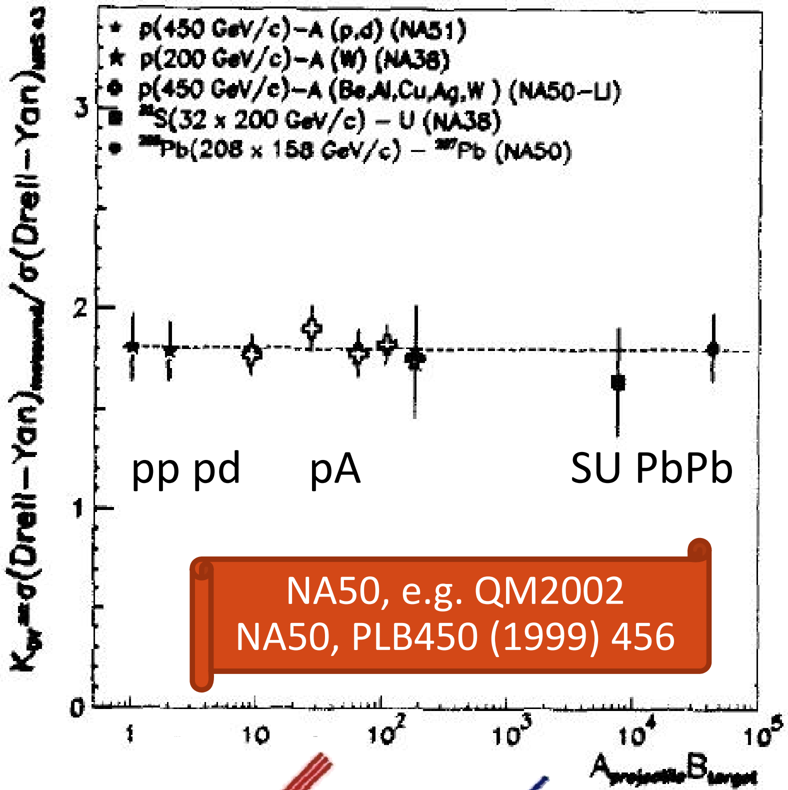
- <u>Normal nuclear absorption alone</u> does a splendid job describing pA, SU and peripheral InIn and PbPb:
  - exp ($-\sigma_{abs}\ \rho°\ L$)
    - (or more sophisticated Glauber approach)
  - L = nuclear thickness
    - Collisions subsequent to J/ψ formation
  - σ_{abs} = 4.18 ± 0.35 mb



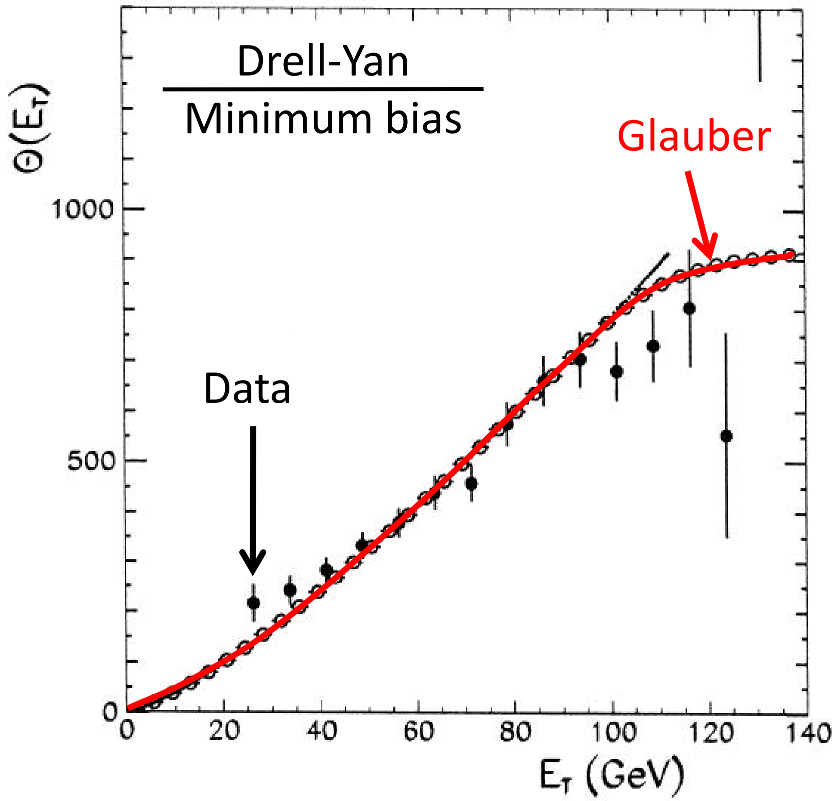
NA50, EPJ C39 (2005) 335
NA60, PRL99 (2007) 132302

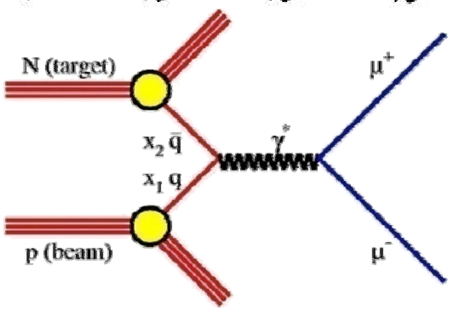
BTW, cold effects on Drell-Yan @ SPS?

AxB scaling in various systems



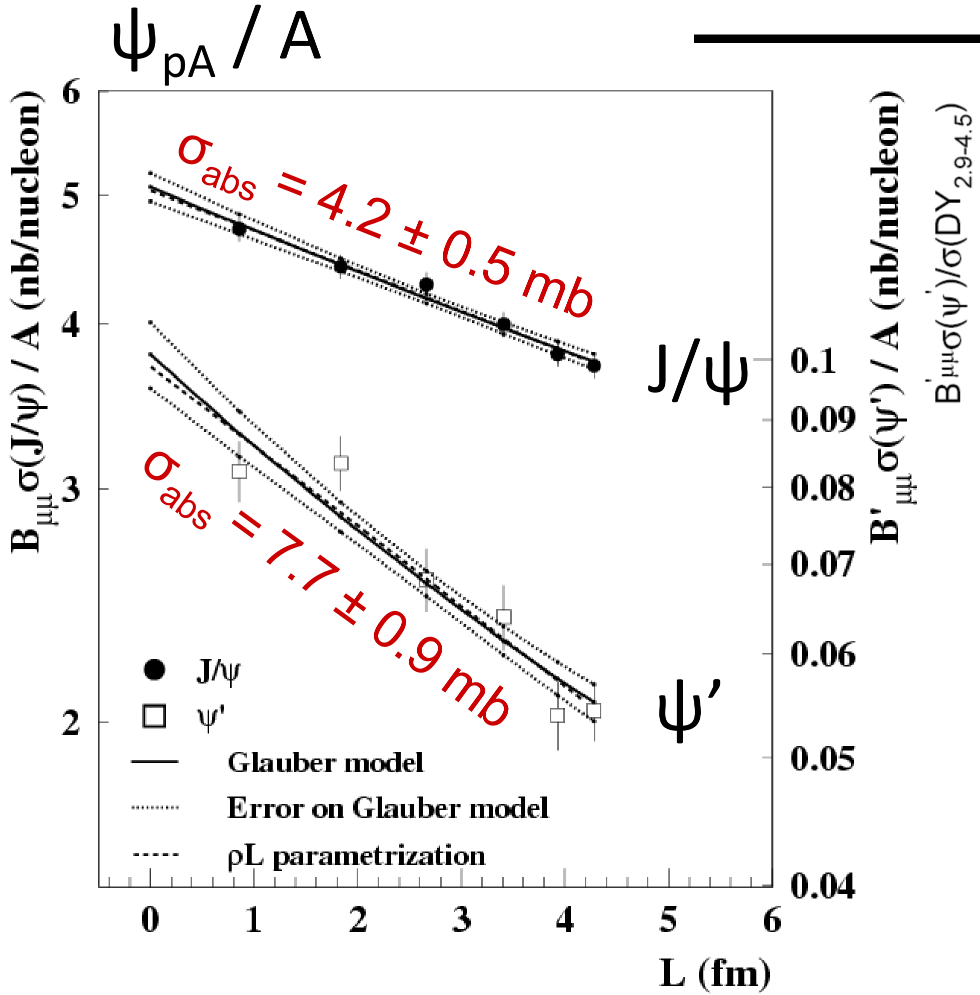
Pb+Pb Ncoll scaling

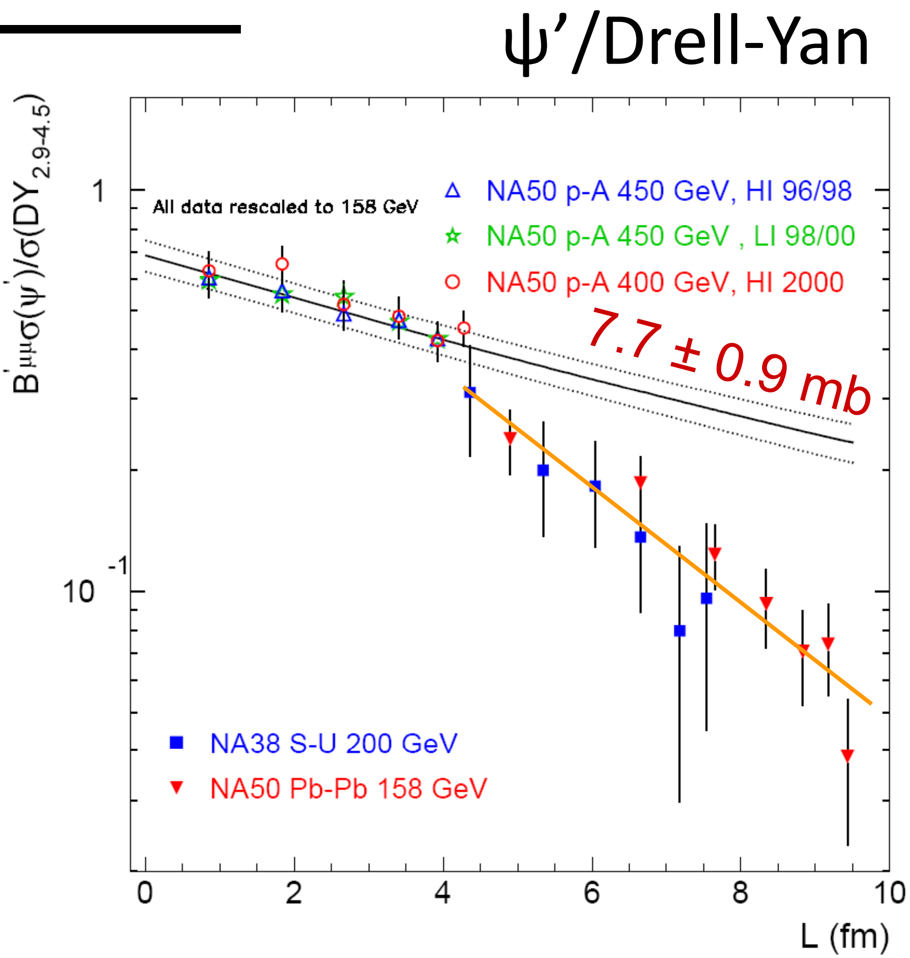




Neither cold nor hot modifications
Quark (anti)shadowing must be small
It is a good reference for charmonia

What about the ψ' ?





- ψ' are more absorbed than J/ψ

NA50, EPJC48 (2006) 329
NA50, EPJC49 (2007) 559

E866 and x_F

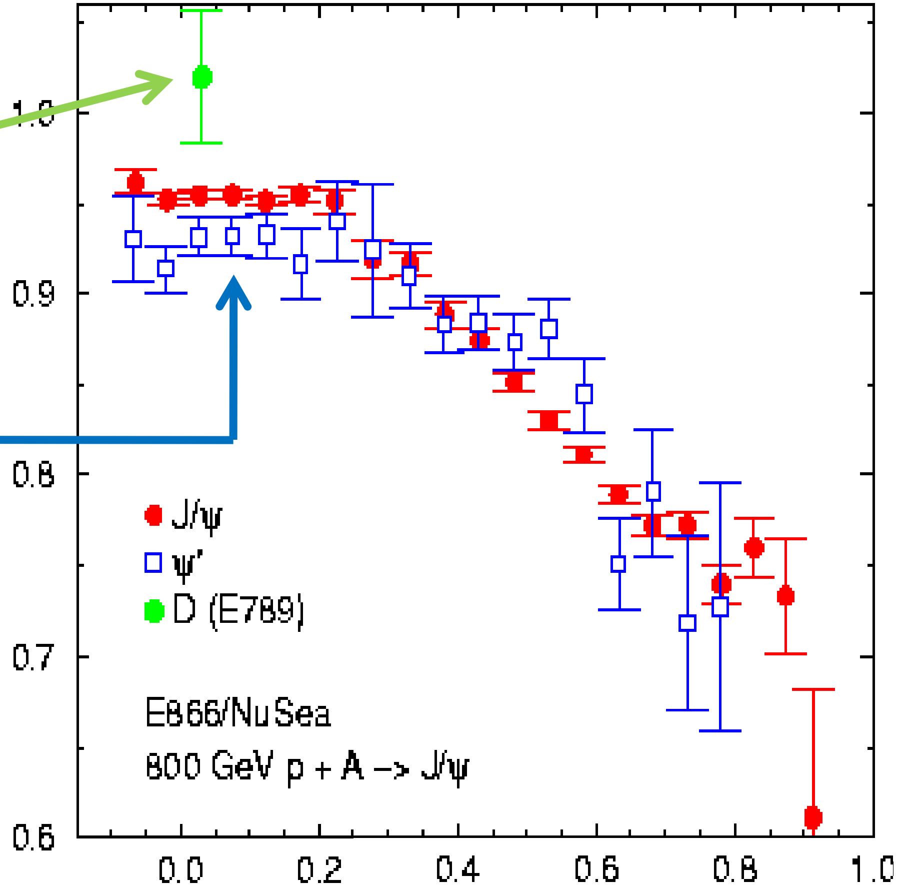
Broadening your interest gets you into trouble

J/ψ, ψ', D mesons

$\sigma_{pA} = \sigma_{pp} \times A^{\alpha}$

- At midrapidity (x_F=0):
  - D meson unmodified (within 10% accuracy)
  - → Little (gluon) shadowing
  - Again ψ' more absorbed
- Larger coverage reveals new effects…

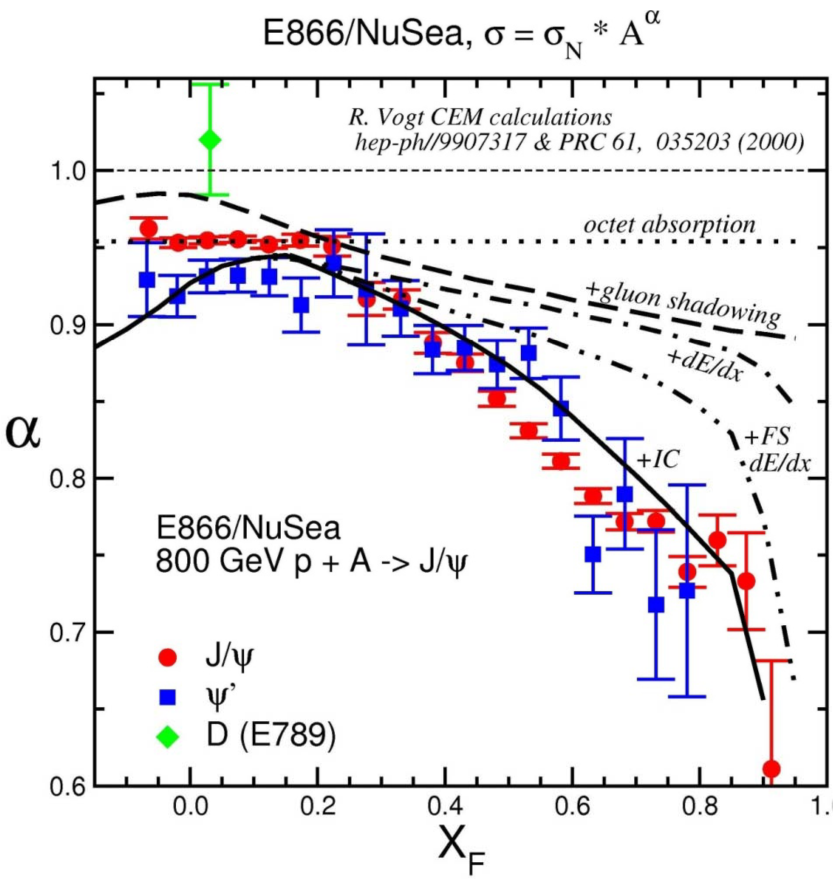
α

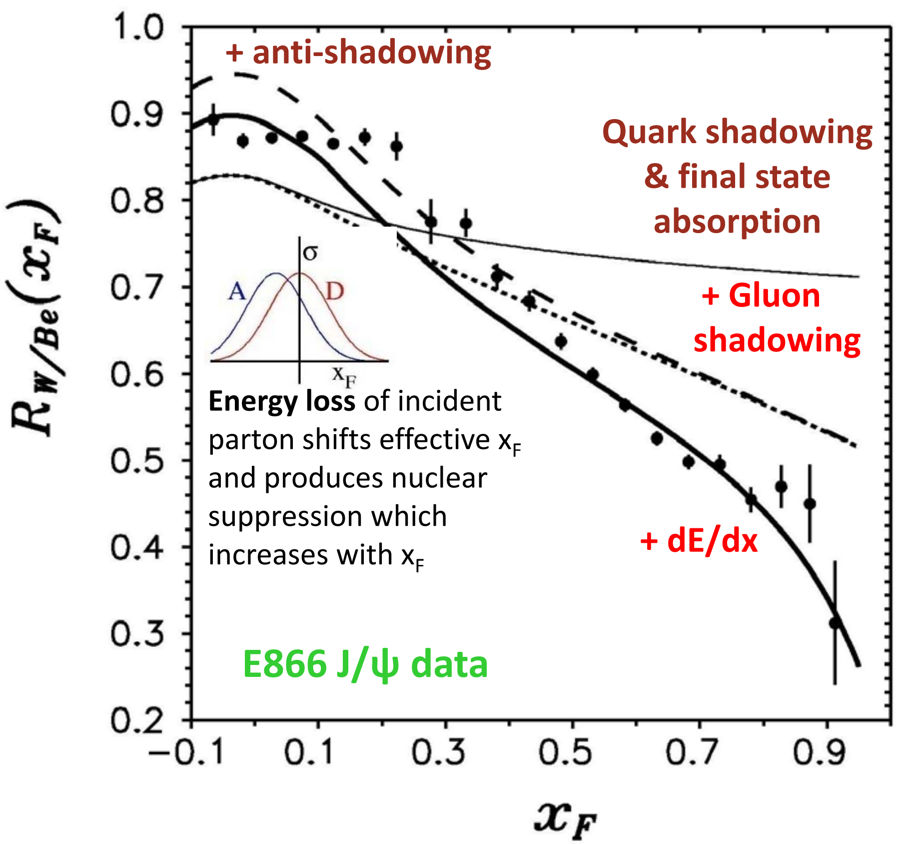


$x_F = x_p - x_A$

E789, PRL72 (1994) 2542
E866/NuSea, PRL84 (2000) 3256

Examples of how to fit the whole x_F range





Vogt, PRC61 (2000) 035203
Kopeliovitch et al, NPA696 (2001) 669
Courtesy to Mike Leitch

→Many effects, complicated story
Not very relevant for AA studies…

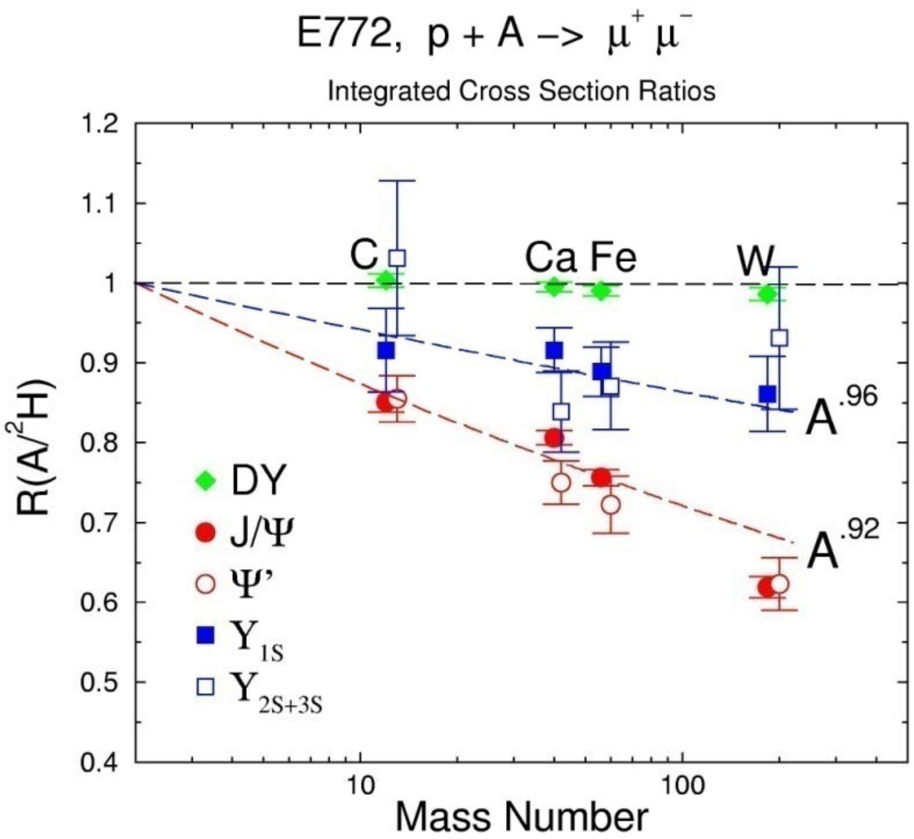
Other experiments and quarkonia

E772: Upsilon less suppressed

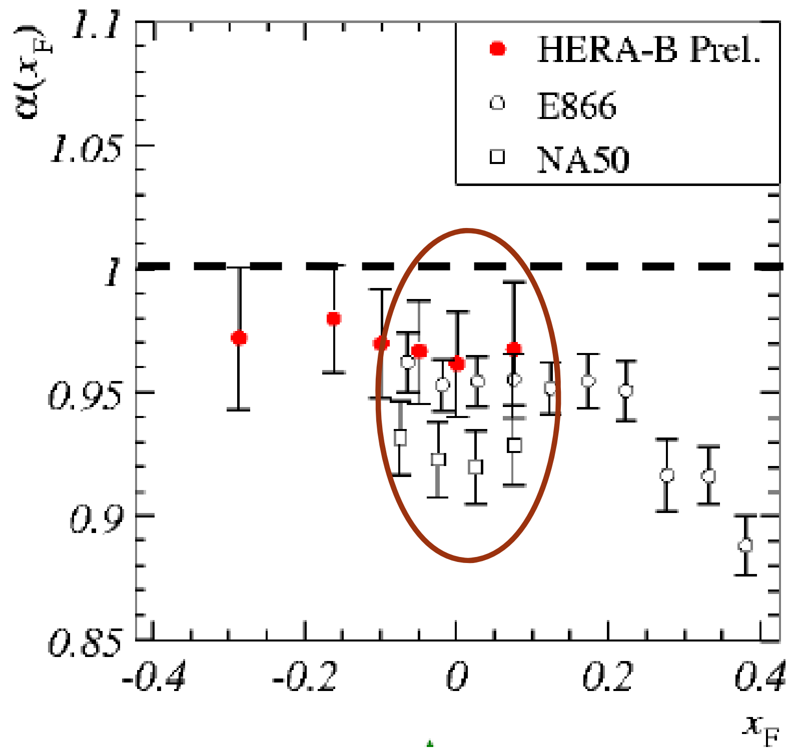
Less shadowing & absorption?

HERA B = wealth of J/ψ, ψ' and χ_c to negative x_F

J/ψ from χ_c : 18.8 ± 1.3 ± 2.4 %

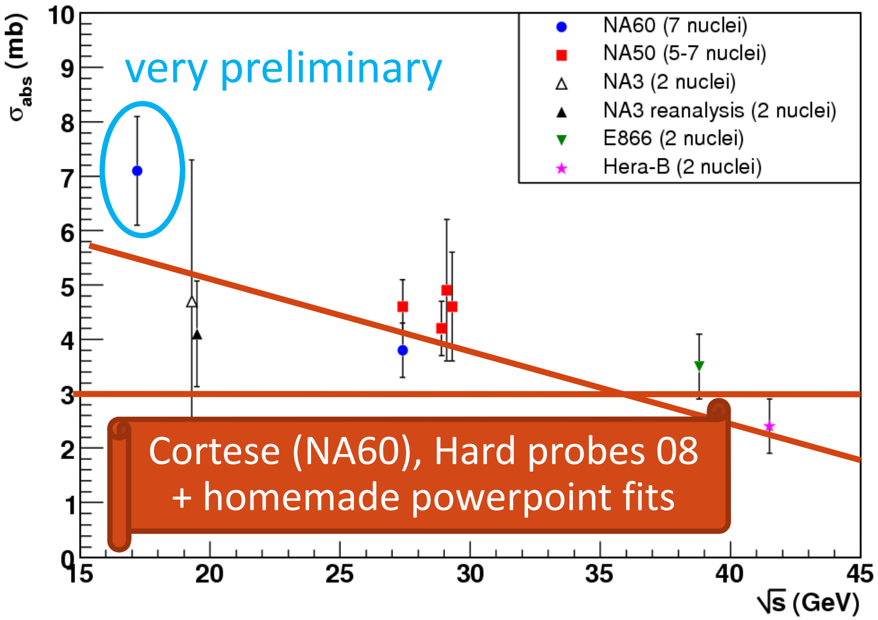


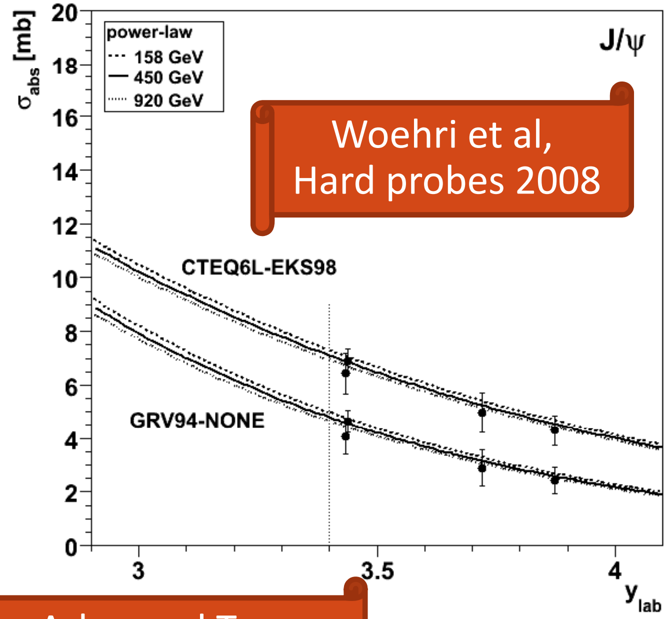
HERA B, arXiv:0807.2167



Is σ_{abs} varying with $\sqrt{s_{NN}}$?

- Theoretical arguments that it should decrease with $\sqrt{s}$ (P. Braun-Munzinger)
  - σ_{abs}= 0 @ RHIC, LHC because $t_{form} >> t_{cross}$
- When comparing experiment, please beware of effects interplay
  - Same x_F or same shadowing scheme!
- No firm conclusion…





See also, Arleo and Tram, EPJC55 (2008) 449, slide XX

RHIC & rapidity dependence

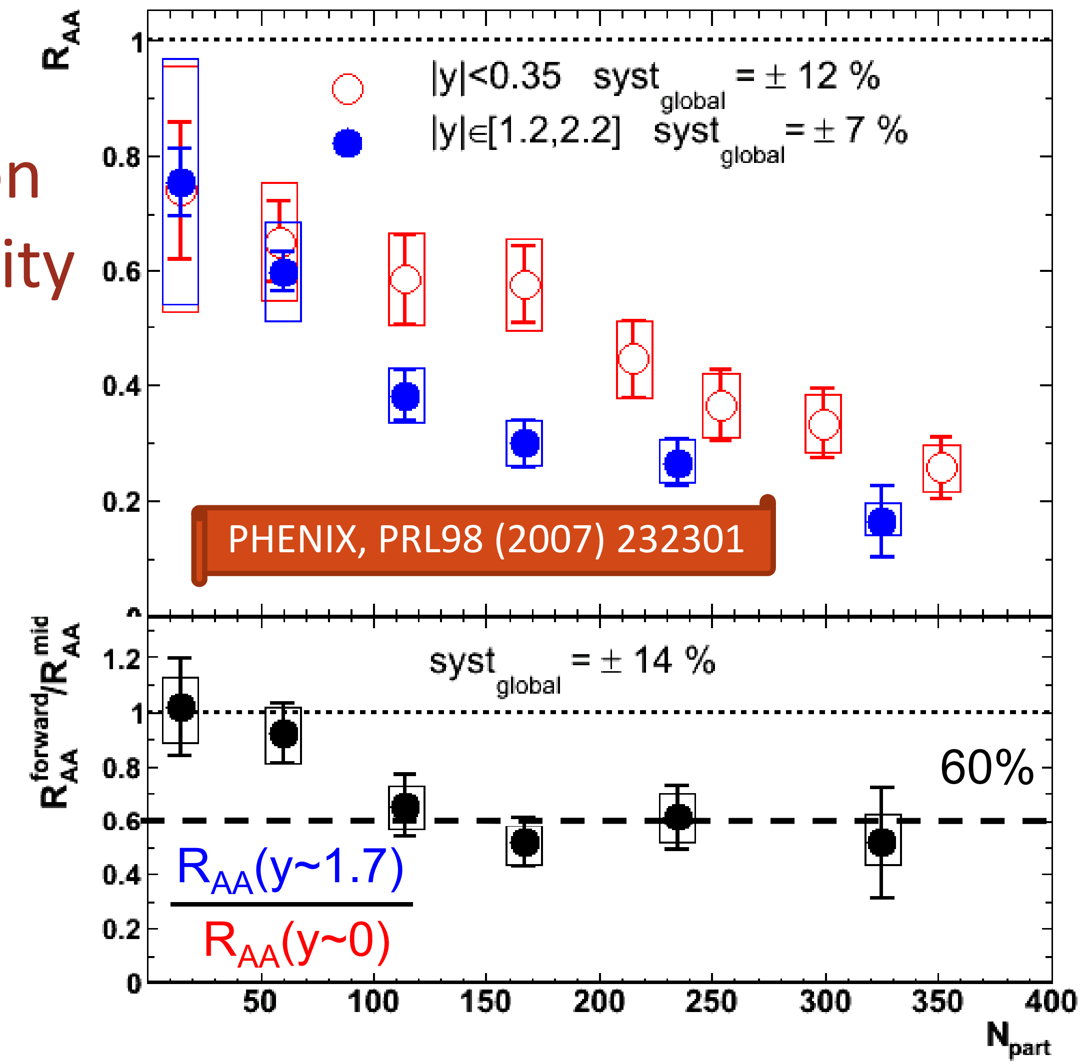
Linking rapidity and shadowing…

The hot (burning) question…

A. Linden-Levy
T. Gunji

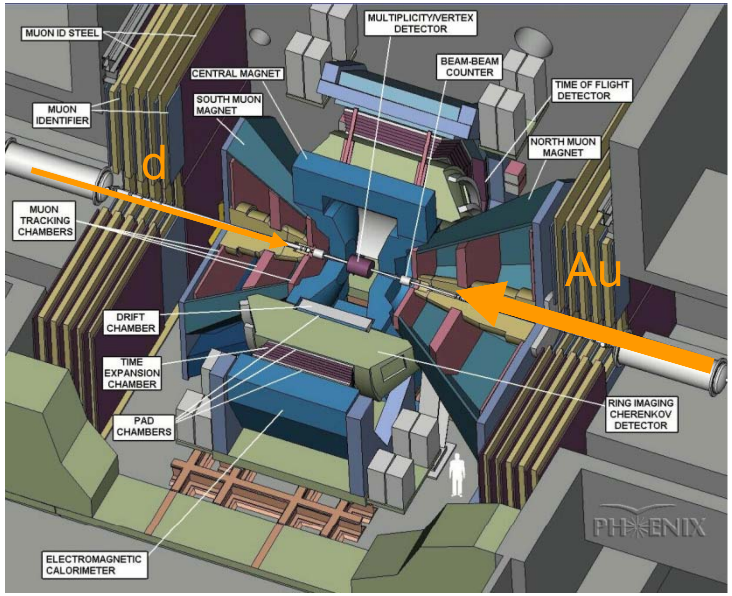
- In AA collisions, is the higher J/ψ suppression seen at forward rapidity due to cold effects?
  - Otherwise, the hot candidate is quark recombination

- The relevant plot →
  - Need a 40% effect…

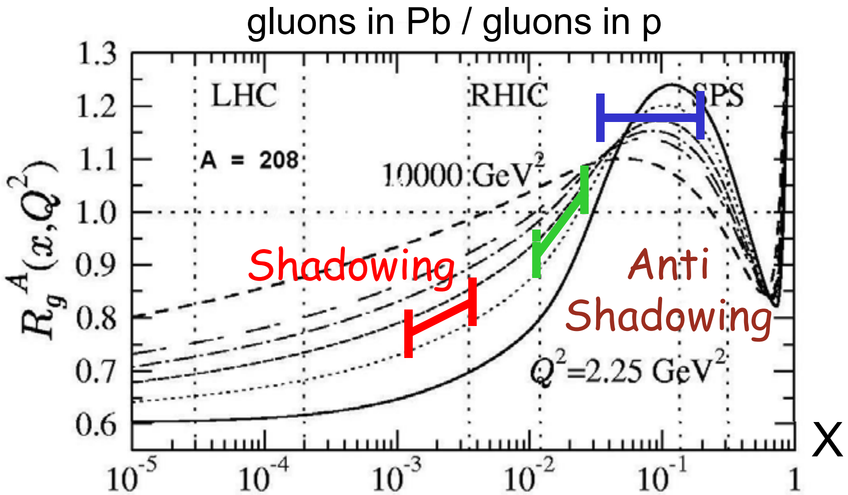


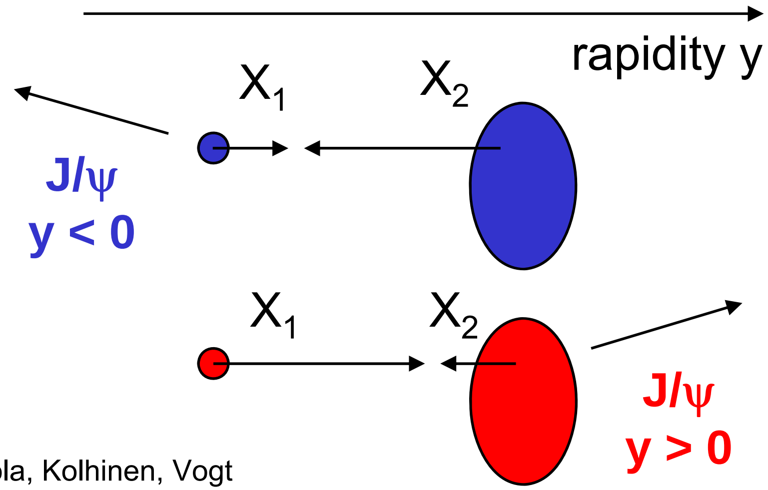
Linking rapidity & shadowing

- At RHIC, J/ψ mostly produced by gluon fusion, and thus sensitive to gluon pdf
- For example, in Phenix, rapidity probes different momentum fraction of Au gluons
  - South ($y < -1.2$) : large X_2 (in gold) ~ 0.090
  - Central ($y \sim 0$) : intermediate X_2 ~ 0.020
  - North ($y > 1.2$) : small X_2 (in gold) ~ 0.003



Example of predicted gluon shadowing in Pb



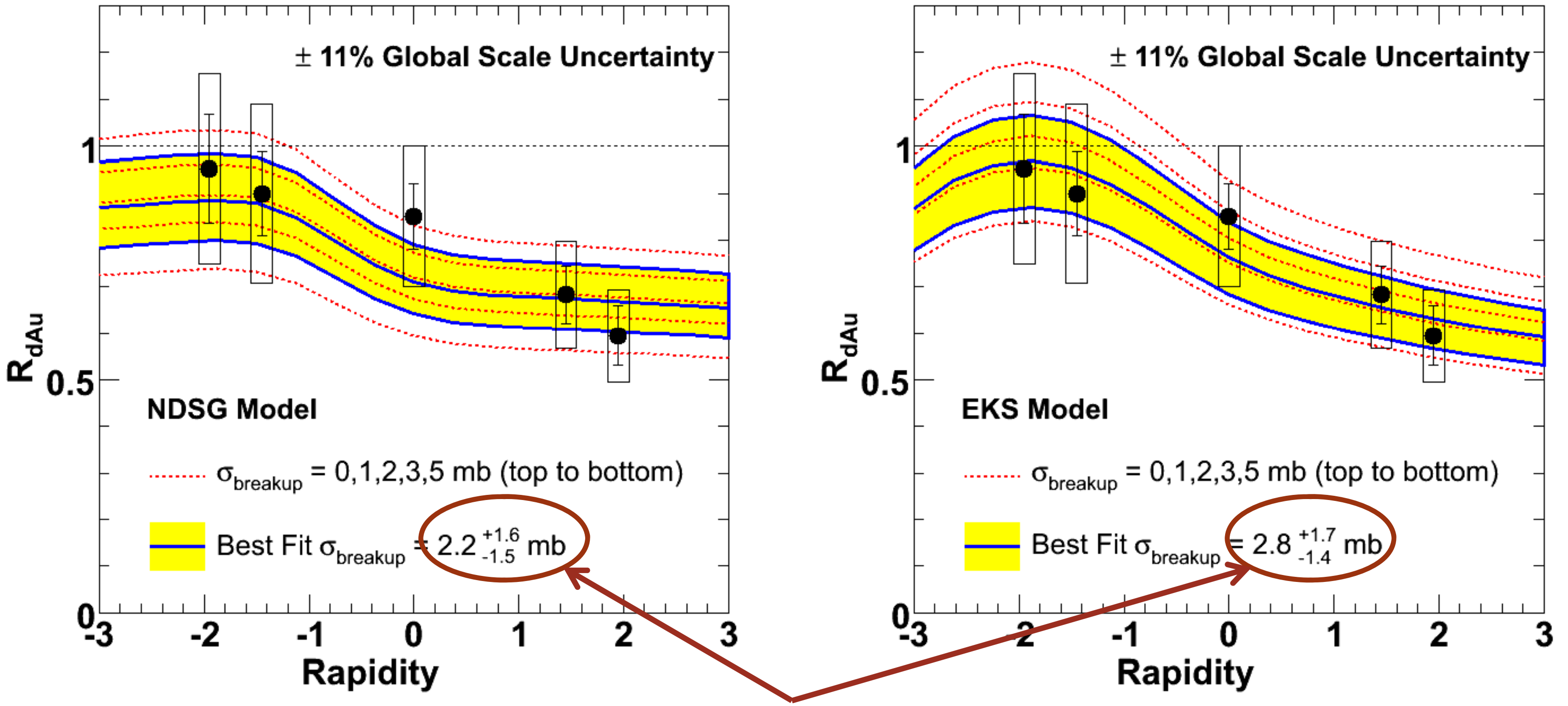


From Eskola, Kolhinen, Vogt
Nucl. Phys. A696 (2001) 729-746.

R_{dAu} vs rapidity

A. Linden-Levy

NDSG Shadowing scheme **EKS Shadowing scheme**



PHENIX, PRC 77 (2008) 024912

<u>Underestimated error bars</u> to be revisited

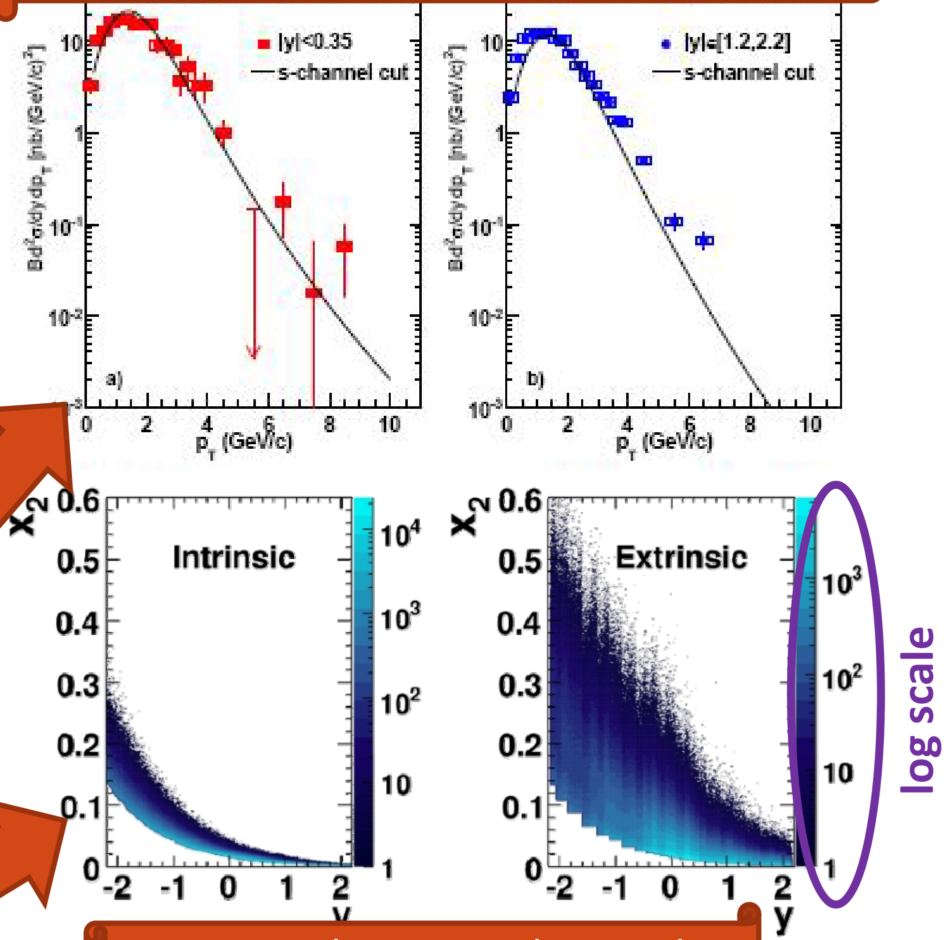
σ_{abs} not better known than a couple of mb!

No strong constraint on shadowing models

A complication : production mechanisms

- Cold effects depend on production mechanisms
- For instance :
  - g + g→ J/ψ (+ soft) giving *intrinsic* p_T (from initial gluons k_T)
  - g + g→ J/ψ + g giving *extrinsic* p_T (balanced by gluon p_T) and <u>working well for pp</u>
- Sample different $x_{Bjorken}$

Possible solution of the J/ψ production puzzle, Haberzetl & Lansberg, PRL100 (2008) 032006

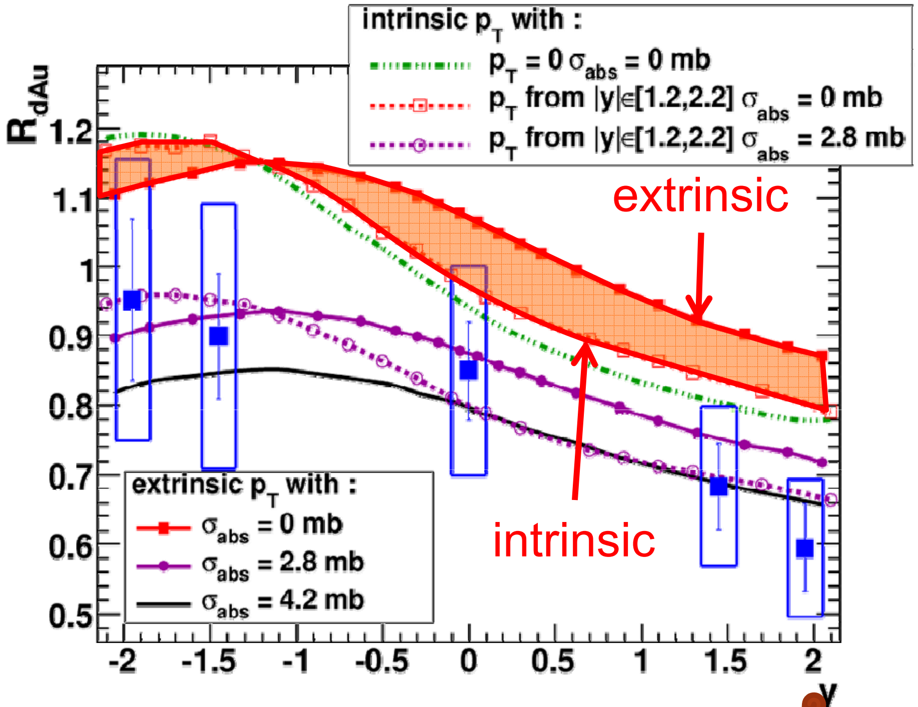


Fereiro, Fleuret, Lansberg and Rakotozafindrabe arXiv:0809.4684

Extrinsic/intrisic effect on dAu and AuAu

Effect on dAu ≈ 10%

(on top of shadowing)

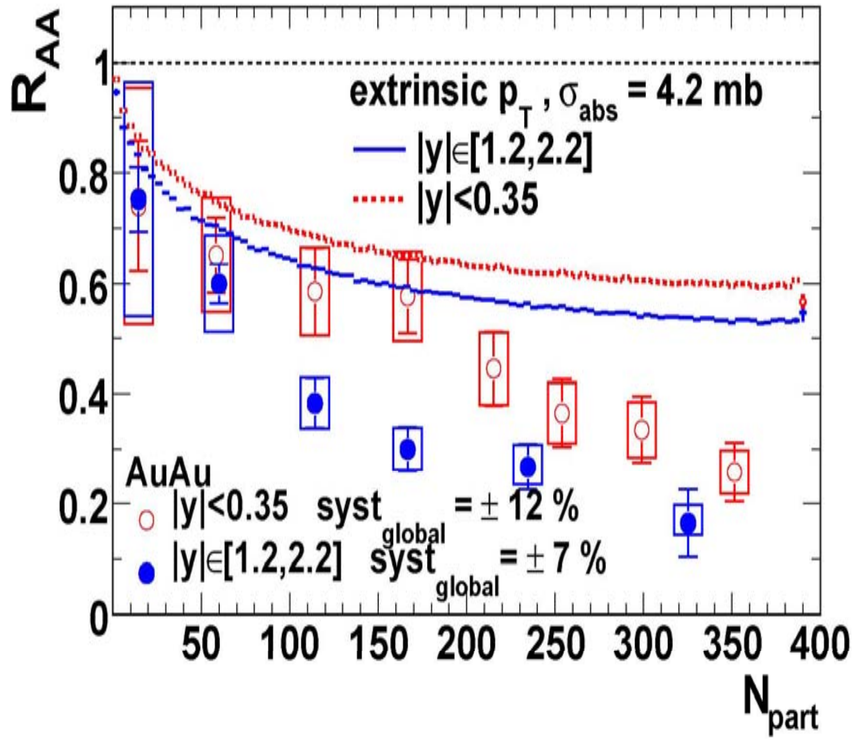


Fereiro, Fleuret, Lansberg and Rakotozafindrabe arXiv:0809.4684

Effect on AuAu

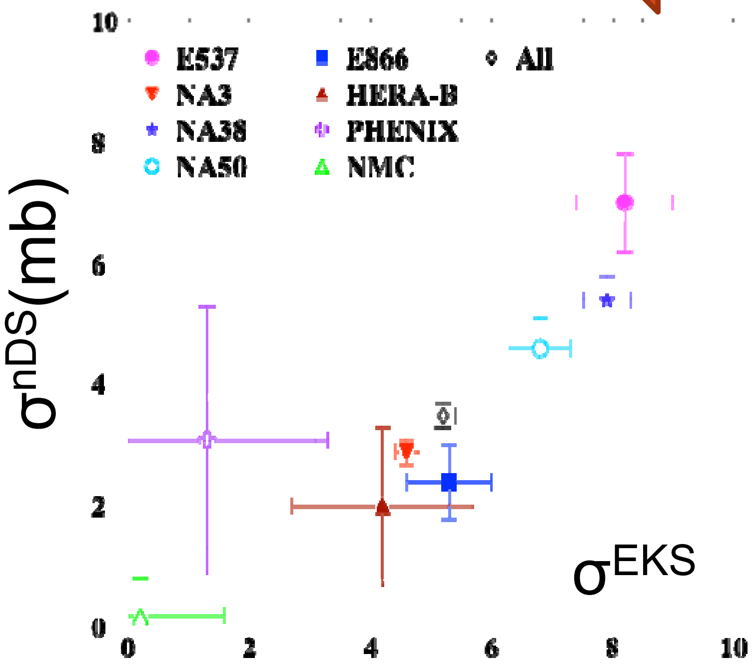
Intrinsic R_{AA}(y=1.7) = R_{AA} (y=0)

Extrinsic ≈ 10% (right direction)

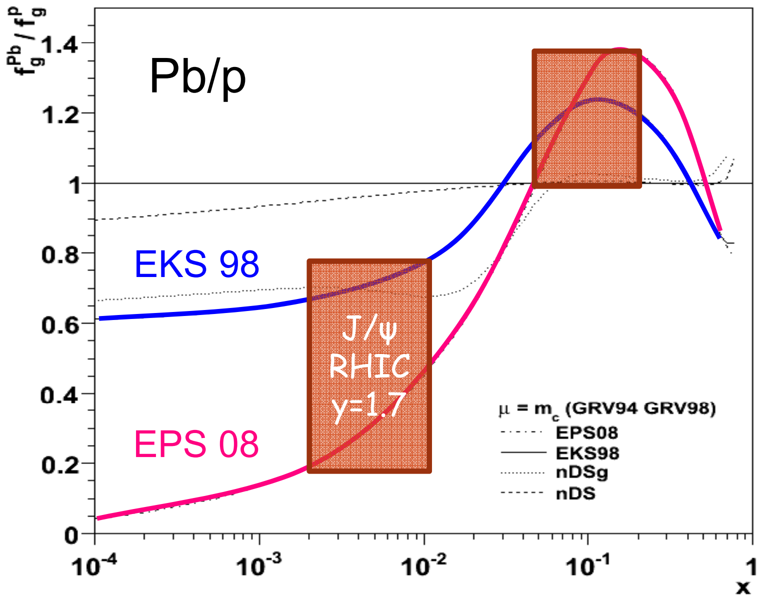


To illustrate that we don't know much…

nuclear absorption ⟷ INTERPLAY ⟷ **pdf modifications**



"Use EKS98 & EPS08 in parallel to map out most of such uncertainty"



- a global (uneasy) fit of σ_{abs} to all data
- shadowing scheme dependence of σ_{abs}
- σ_{abs} = 3.5 ± 0.2 ± 1.7 mb

Arleo & Tram, EPJC55 (2008) 449-461

Eskola, Paukkunen, Salgado, JHEP 0807 (2008) 102
Eskola & Paukkunen, Hard probes 2008

What should we do now ?

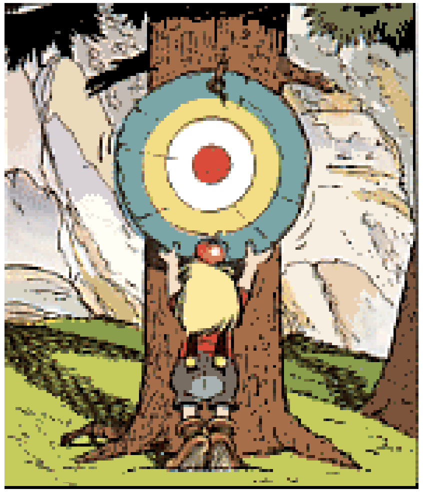
1. Try not to rely on shadowing and σ_{abs} ?

(centrality dependence and data driven method)

2. Try to disentangle them ?

(open charm)

RHIC J/ψ centrality dependence



First place where we compute centrality in pA like collisions !

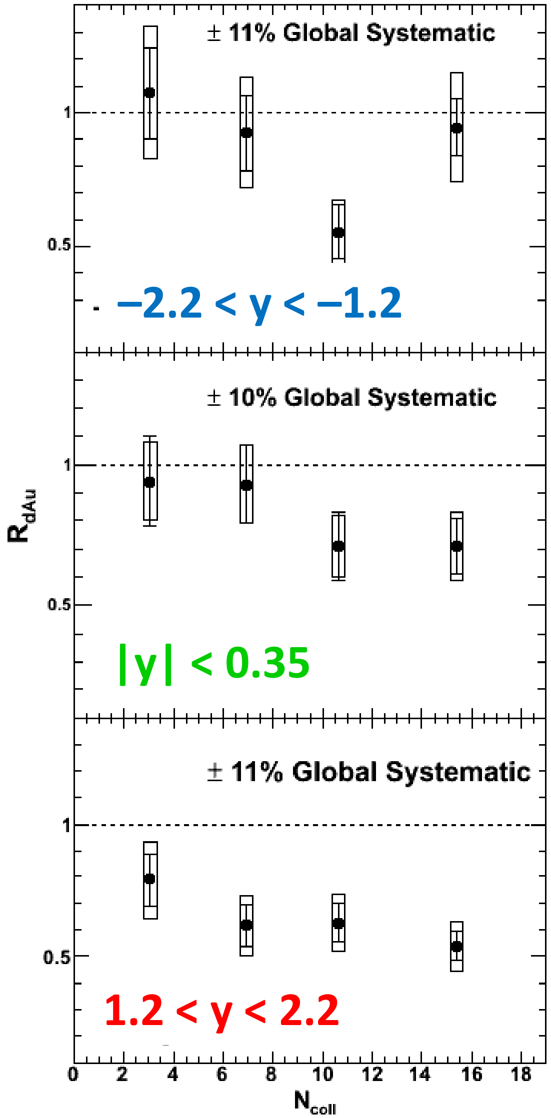
Can this replace varying A ?

A data driven method in which you don’t rely on 1/ shadowing scheme 2/ σ_{abs} 3/ production mechanism 4/ feed down ratio, but on A/ a (usually assumed) factorization and B/ the Glauber model.

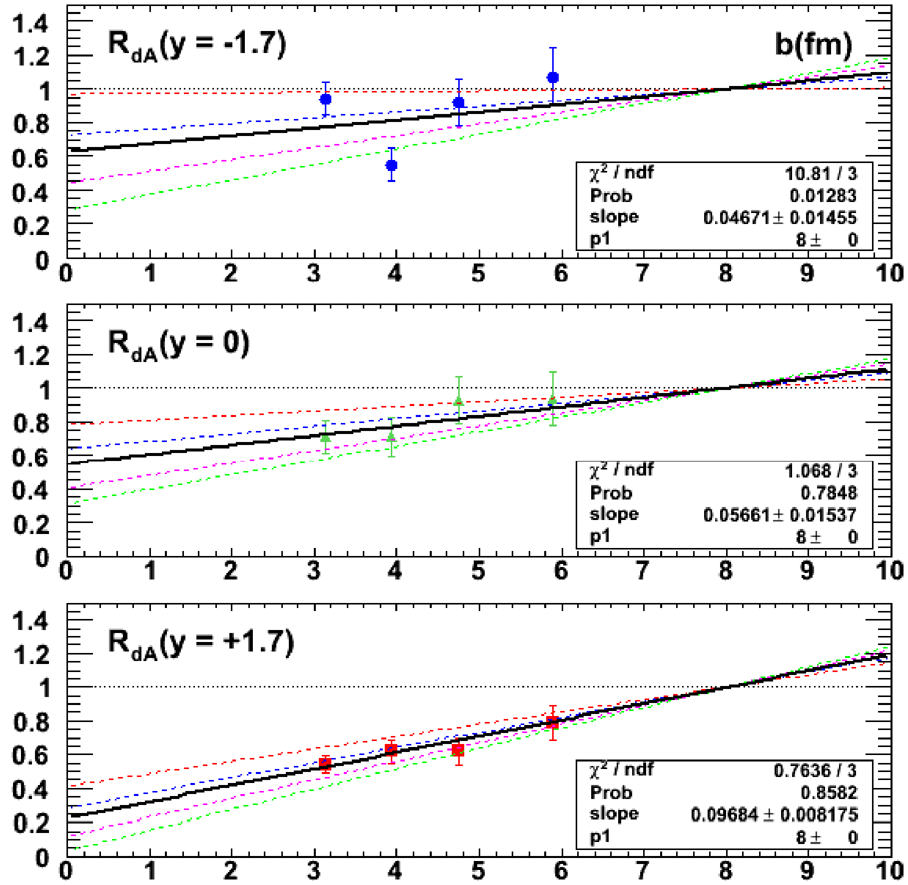
RGdC, QM06, JPG35 (2008) 104023
PHENIX, PRC 77, 024912 (2008)

PHENIX, PRC 77 (2008) 024912

R_{dA} versus centrality

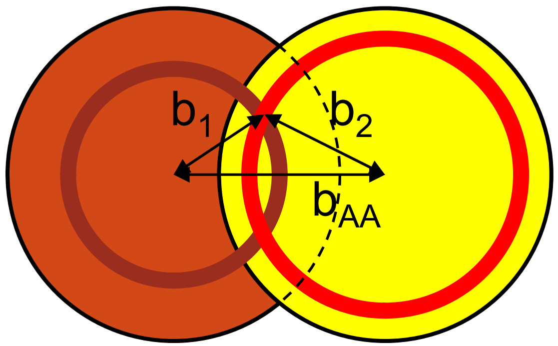


- Convert to local impact parameter and fit… Ex:



b(fm)

Plug it in a Glauber model

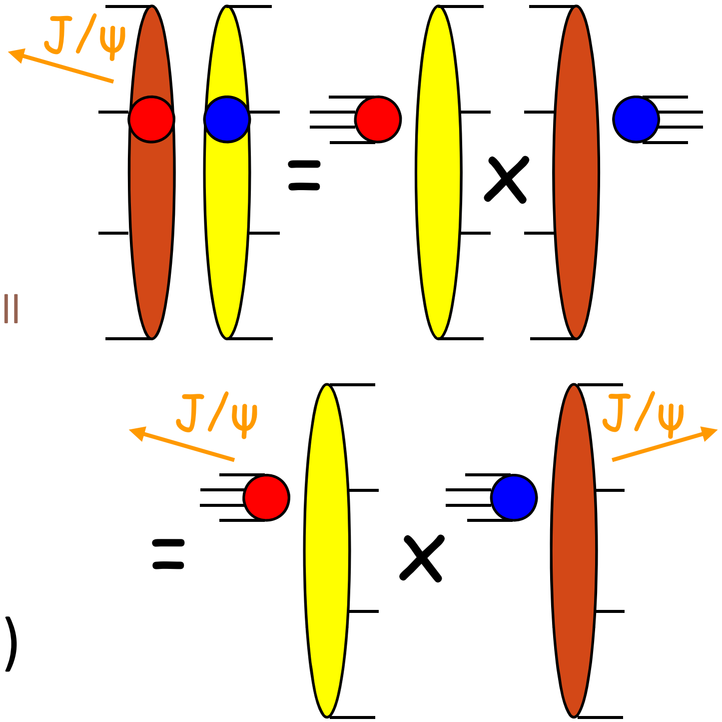


- Glauber provides, for a given A+A collision at b_{AA}, a set of N+N collisions occurring at b^i_1 and b^i_2.
- One minimal assumption is rapidity factorization: $R_{AA}(|y|, b_{AA}) =$

$$\Sigma_{collisions} [R_{dA}(-y, b^i_1) \times R_{dA}(+y, b^i_2)] / N_{coll}$$

- Correct (at least) in the case of absorption & shadowing since production :

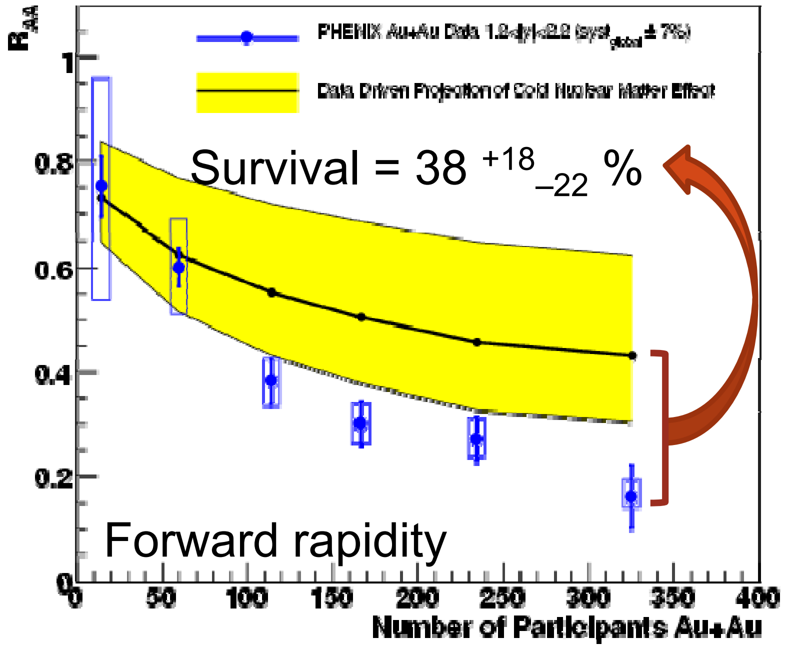
$$\sim pdf1 \times pdf2 \times \exp -\rho\sigma(L_1+L_2)$$

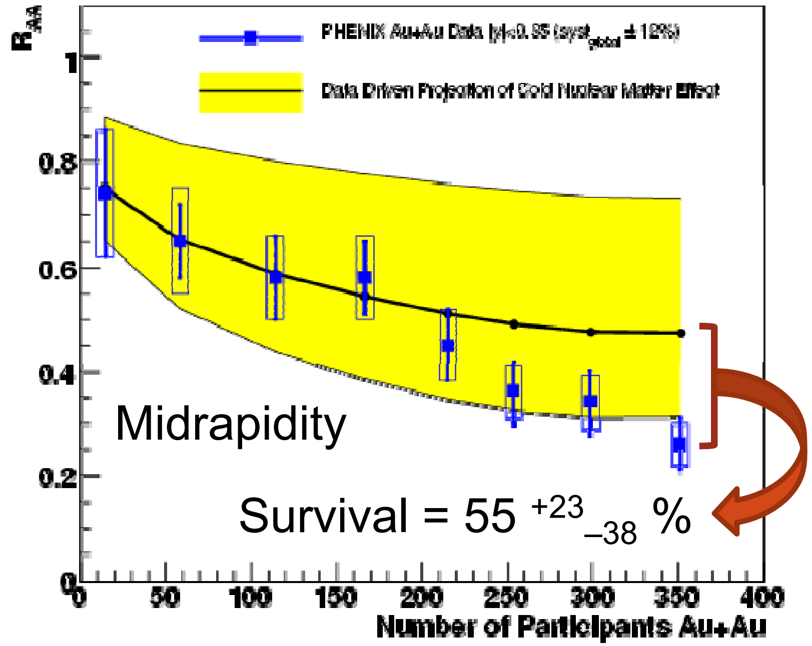


Extrapolate to AuAu

PHENIX, PRC 77 (2008) 024912

- Full error propagation of dAu uncertainties
  - [dramatic for midrapidity since R(−y) = R(+y)]

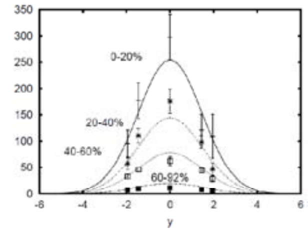




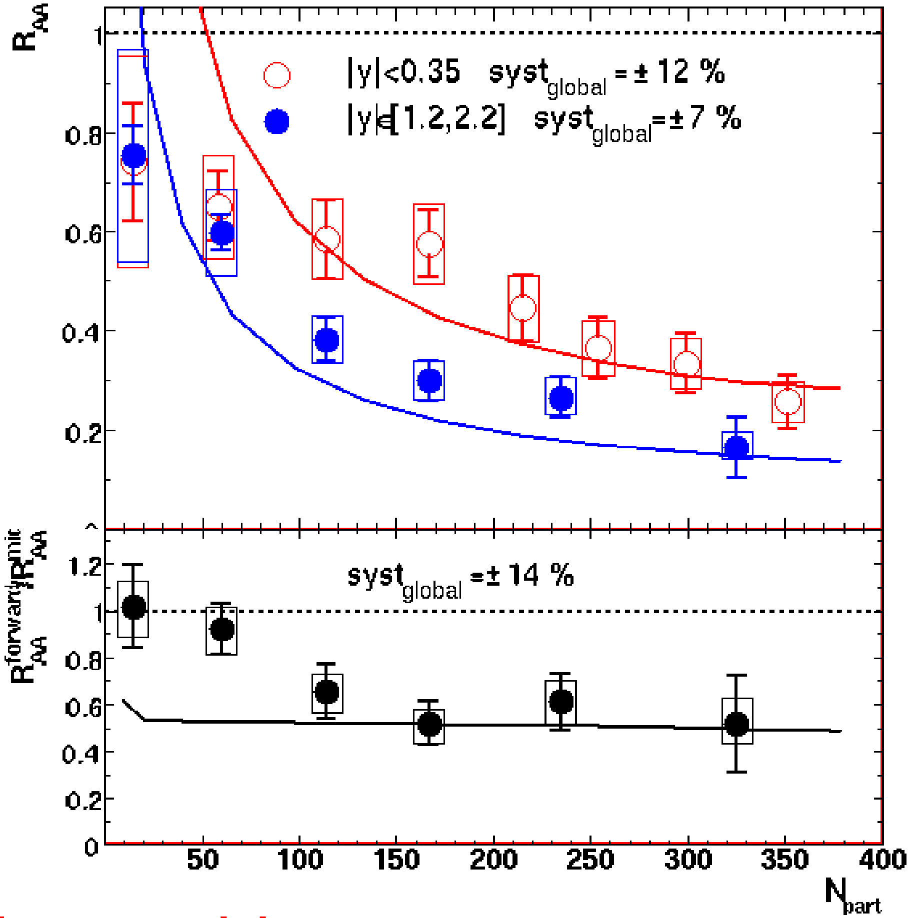
→ J/ψ anomalous suppression could be the same at mid and forward rapidity!

Recent news from CGC

Kharzeev, Levin, Nardi, Tuchin
arXiv: 0808.2954 & 0809.2933



- Gluon saturation could further suppress forward J/ψ in AuAu
  - First numerical estimate
  - Absolute amount of suppression is fitted to the AuAu data!
  - Waiting forward to new dAu data to fit them first
  - However, rapidity dependence should be ok
  - But it fails to reproduce peripheral data →
  - Anyway…



→ J/ψ anomalous suppression could be the same at mid and forward rapidity!

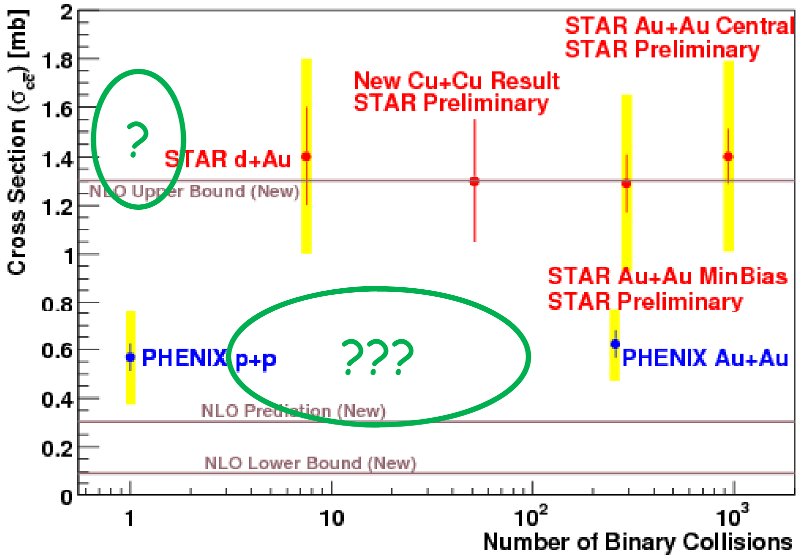
Open charm

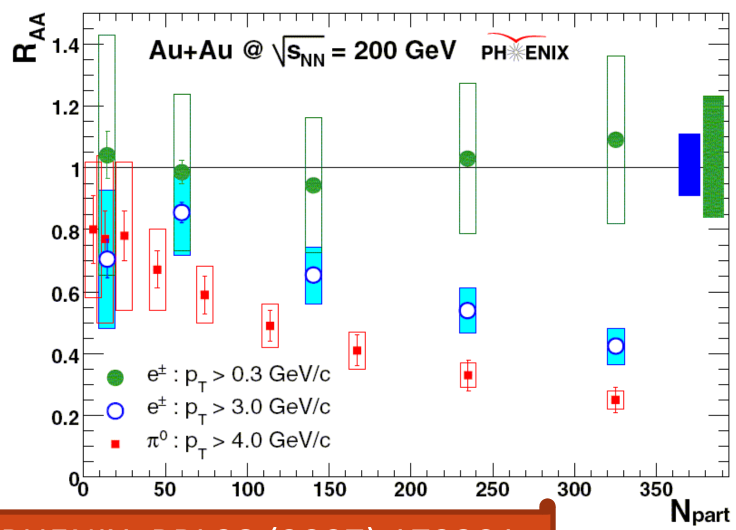
Peter
Helmut

"We want open charm!"

Should help understanding shadowing
(common with closed charm)

Heavy flavour (bulk)





PHENIX, PRL98 (2007) 172301

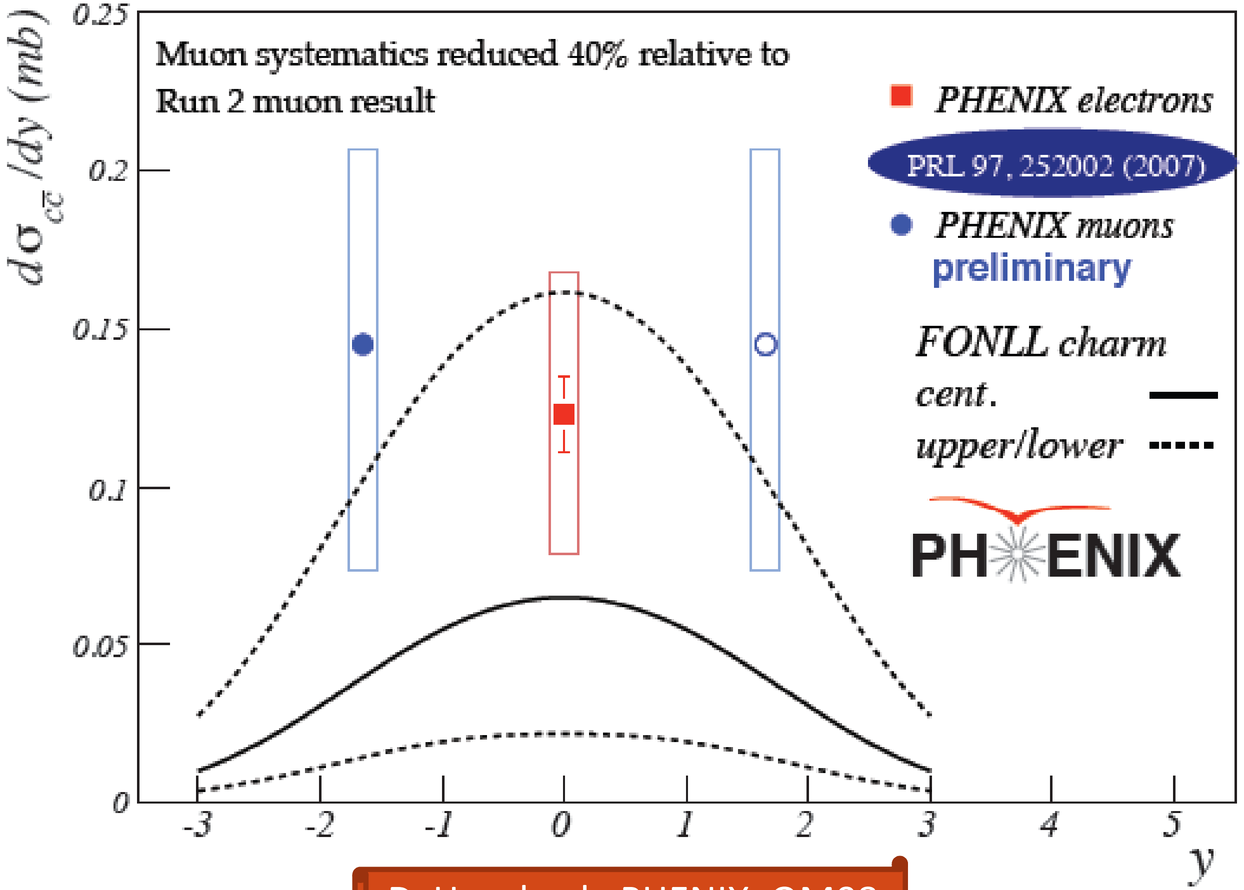
- A factor of 2 difference between experiments

  Zhangbu Xu

  – "detector material is not the issue"
- Open charm is suffering from a ≈25% systematic error
  – Too large to constrain any shadowing…
- Binary scaling (within these uncertainties…)

Heavy flavour rapidity dependence?

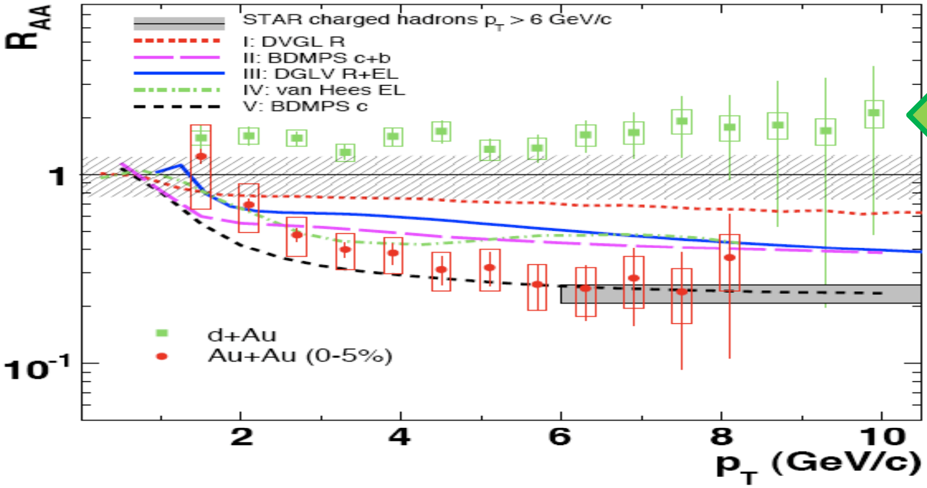
- Only pp measurement, very poorly known



D. Hornback, PHENIX, QM08

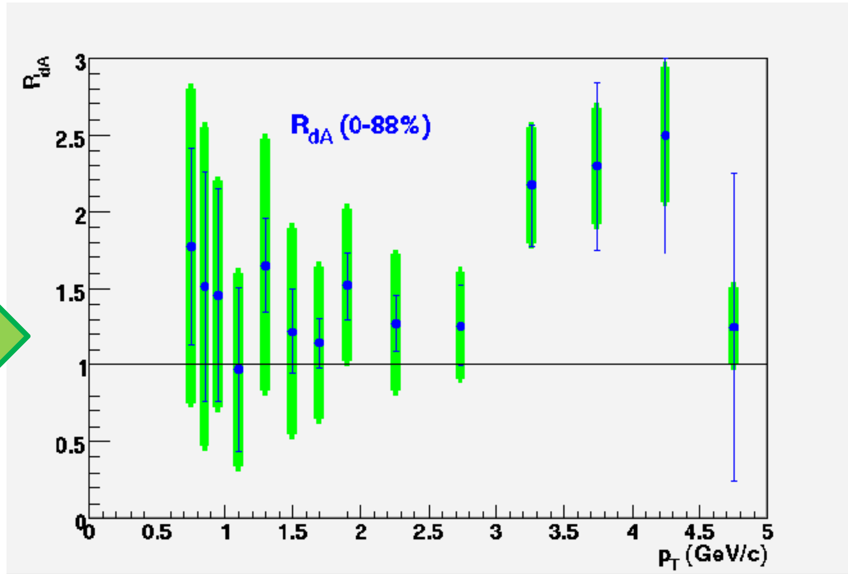
Heavy flavour (p_T dependence)

STAR, PRL (2007) 192301



- Interesting d-Au excess? Needs confirmation with run8!

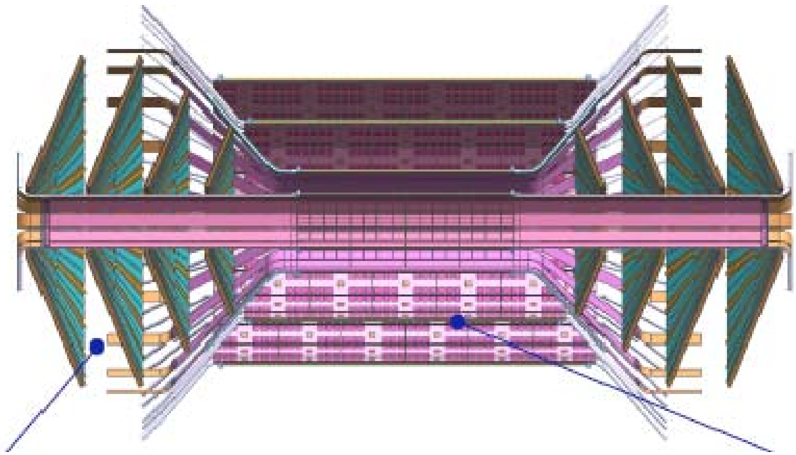
- Homemade R_{dA} from PHENIX preliminary dAu (run3) and PHENIX published pp



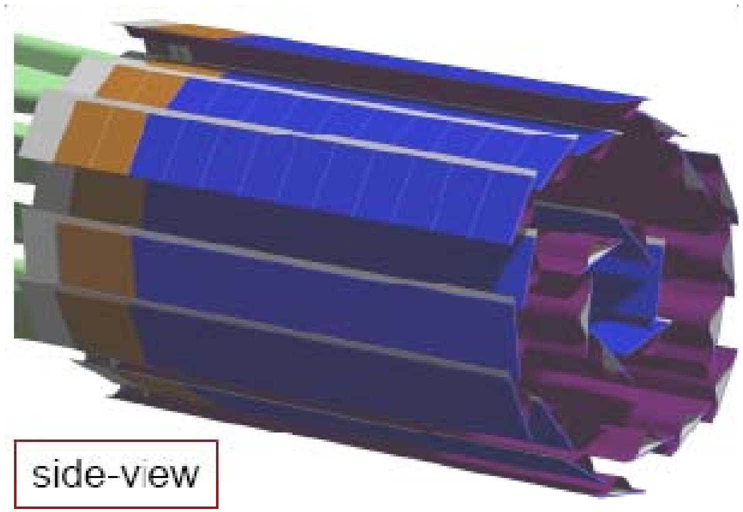
→ Wait for serious run8 analysis

Even better will be the silicon era…

- PHENIX



- STAR

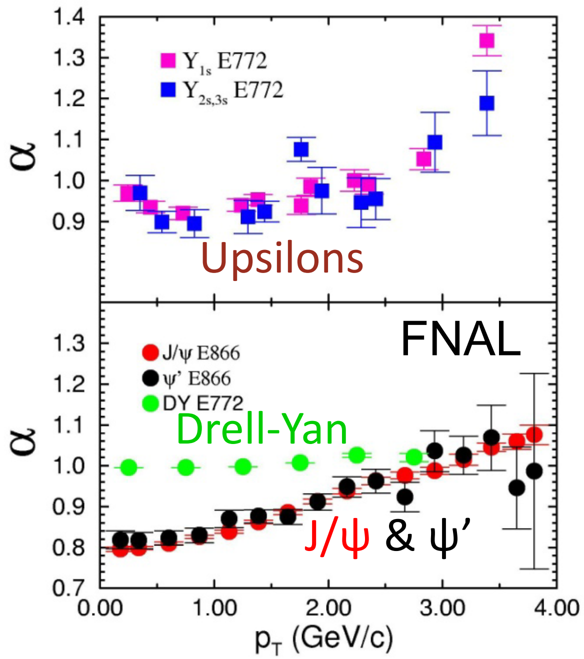


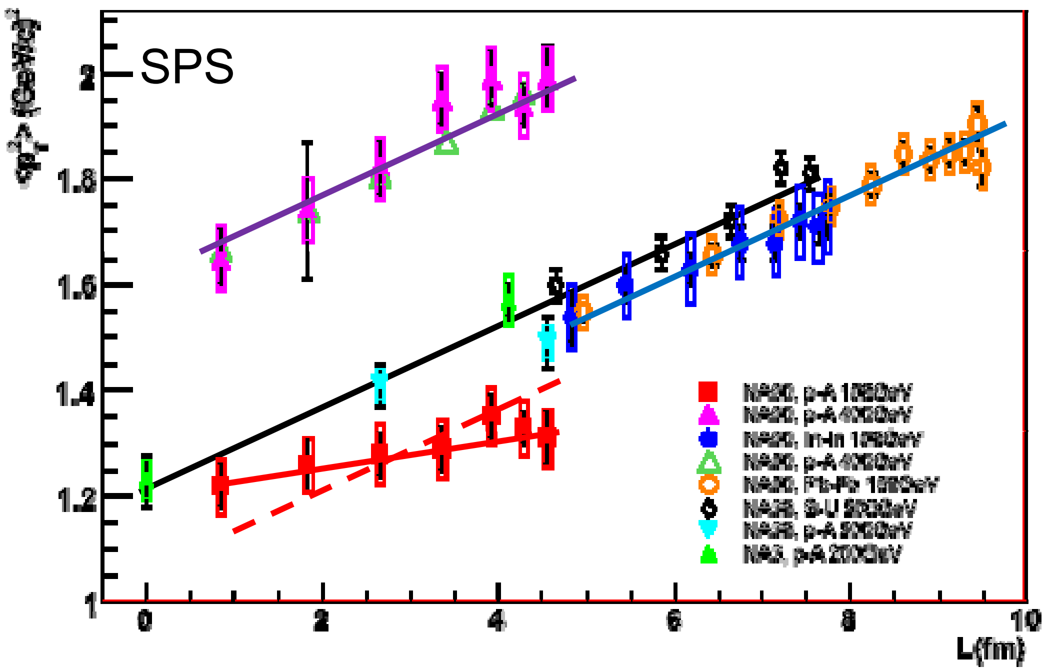
Bonus : Cronin effect and J/ψ p_T broadening

(doesn't change the total yield)

Cronin effect…

- Multiple scattering of the incoming partons raise the outgoing quarkonia p_T
  - $\langle p_T^2 \rangle_{AB} = \langle p_T^2 \rangle_{pp} + \delta \times L$ (random walk)

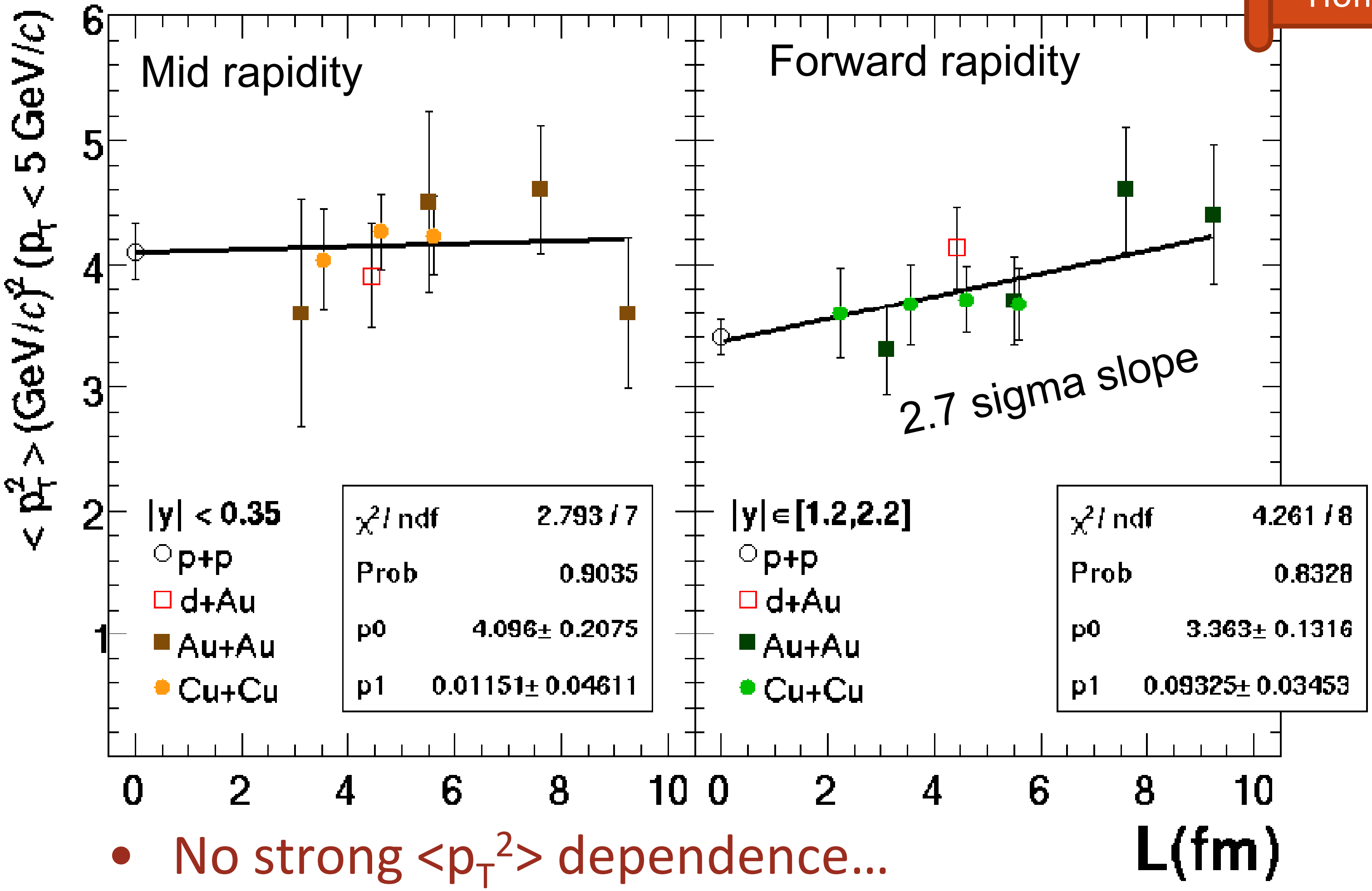




Cortese (NA60), Hard probes 08 + homemade powerpoint fits

Cronin effect at RHIC?

$<p_T^2>$ from PHENIX, PRL101 (2008) 122301
Homemade L values

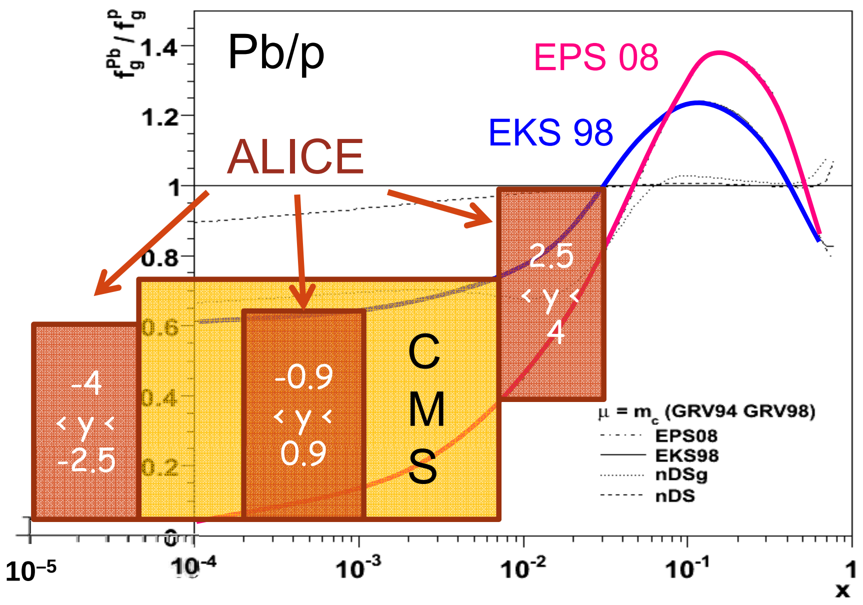


- No strong $<p_T^2>$ dependence…
- Modest rise at forward rapidity
- Could be broadening

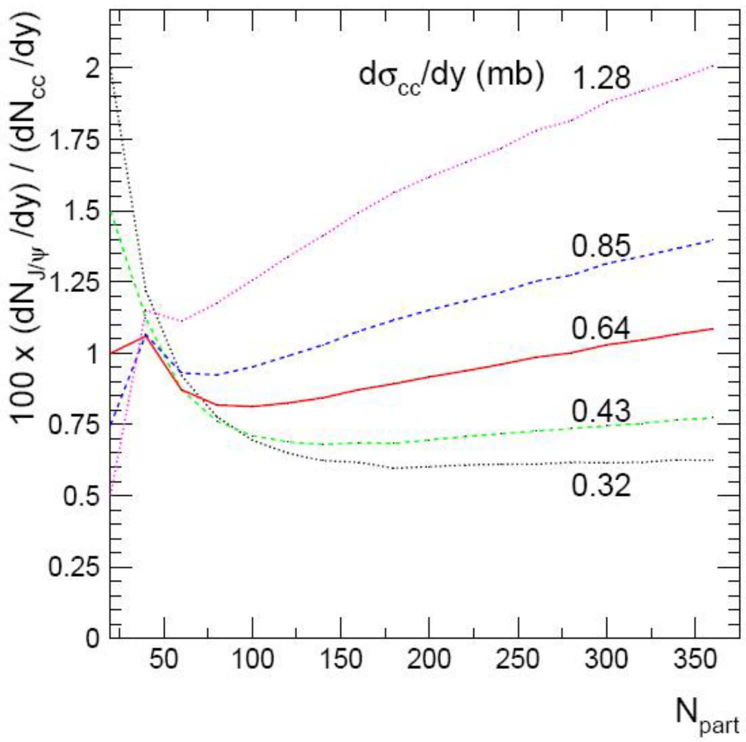
LHC = uncharted territory

LHC : another cold vs hot fight ?

- EKS vs EPS extrapolation vary by factors of 10 at LHC x's ! And you need two gluons…
- Would be fun if regeneration takes over…



(emited gluons and p_T neglected)



Conclusions

- Heavy flavour suffer from cold effects, which are quite unconstrained…
- Easier when they go in the opposite direction as the hot effects
  - e.g. for the jet quenching
- Let's hope it will be the case for the J/ψ at LHC
- But RHIC can still play:
  - RHIC run8 : J/ψ, open charm, ψ'…
  - Silicon upgrades for open charm
  - I think a dCu run could be interesting too (ala SPS)

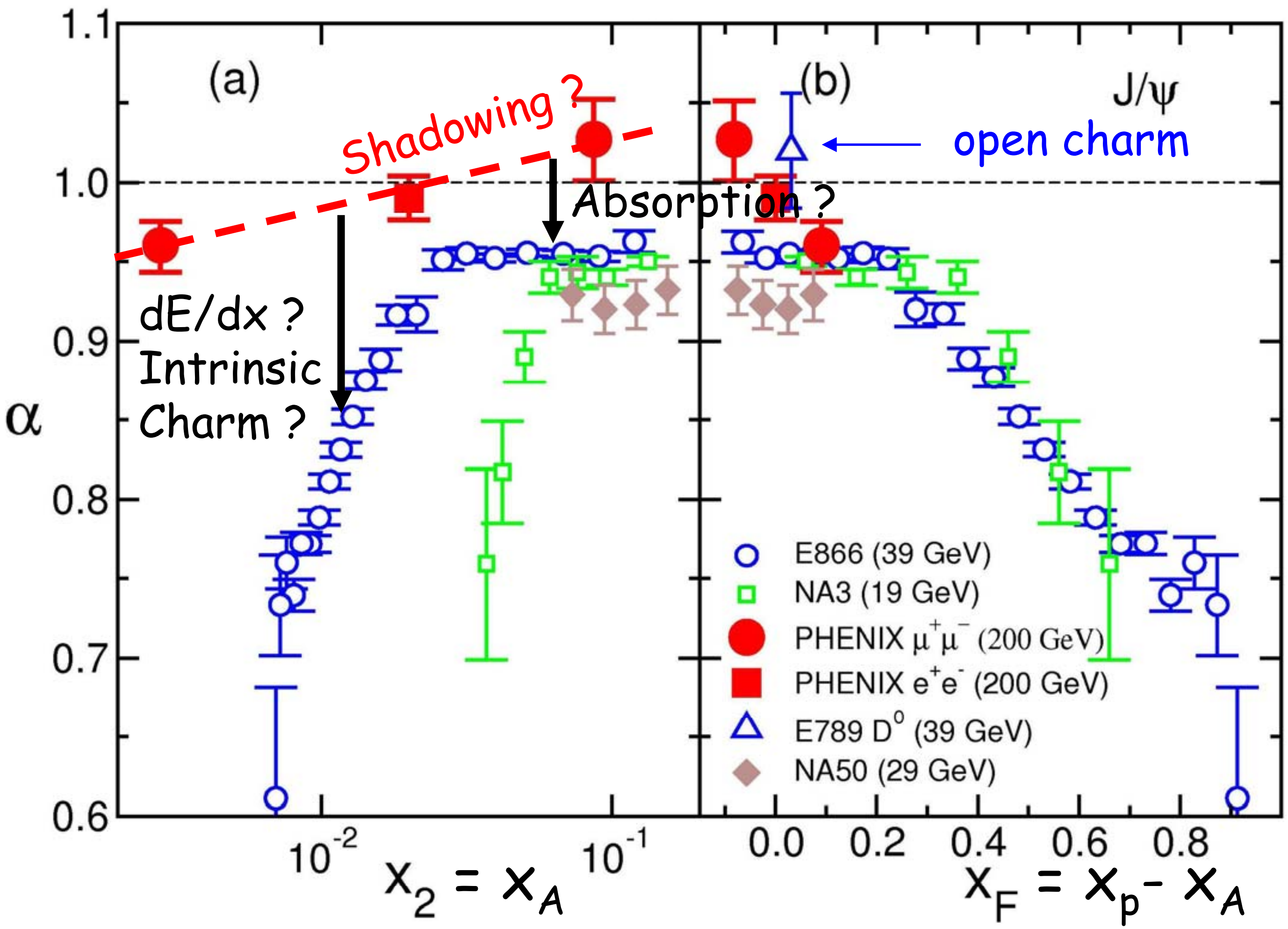
BTW, Nambu, Maskawa and Kobayashi got the Nobel Prize yesterday ☺

En 1964, quatre physiciens observent la violation légère du produit de ces deux opérations $\mathcal{CP}$. L'enjeu de cette découverte est considérable à bien des égards. En cosmologie d'une part, Sakharov remarque en 1967 que son existence est indispensable pour expliquer l'asymétrie matière-antimatière que l'on observe dans l'univers. En physique des particules d'autre part, Kobayashi et Maskawa proposent, dans le cadre du modèle standard alors balbutiant, une explication *naturelle* de la violation de $\mathcal{CP}$, valable dès l'instant que la nature dispose d'au moins trois familles de particules. Depuis 1977, nous savons qu'il en est ainsi.

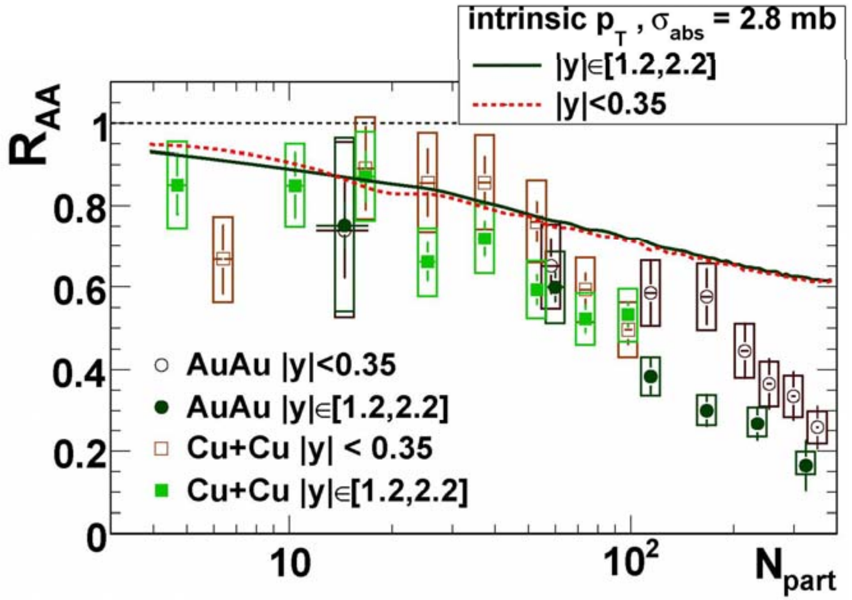
(RGdC, PhD thesis)

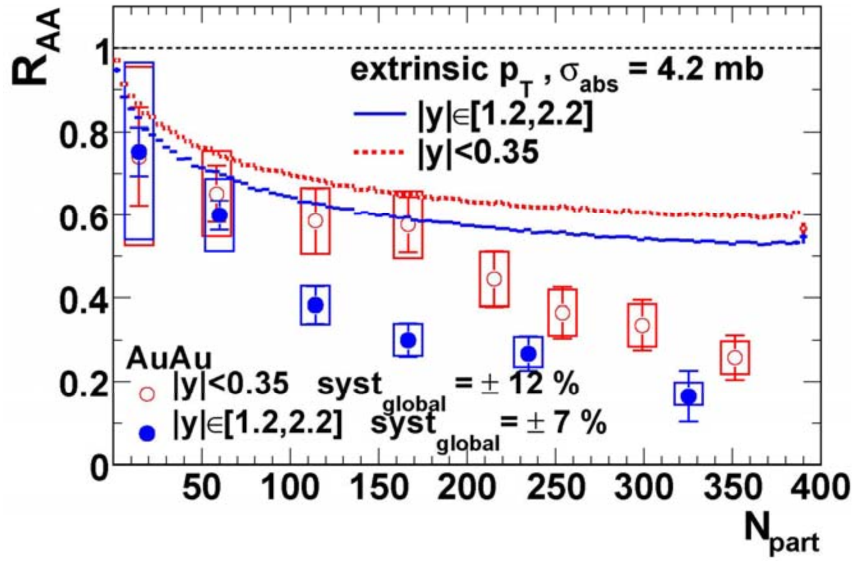
That’s all folk…

J/ψ different energy



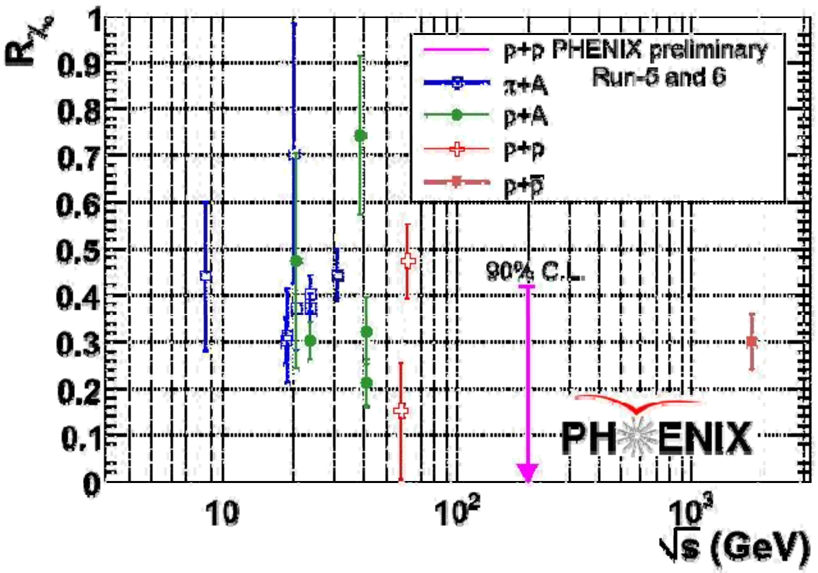
Intrisic / extrinsic on AuAu





Complication : feed-down

χ_c large dispersion



ψ' = 8.6 pm 2.5 % at RHJIC