Excited Quarkonia and Nuclear Matter: pA and AA (SPS,Fermilab,RHIC,LHC)

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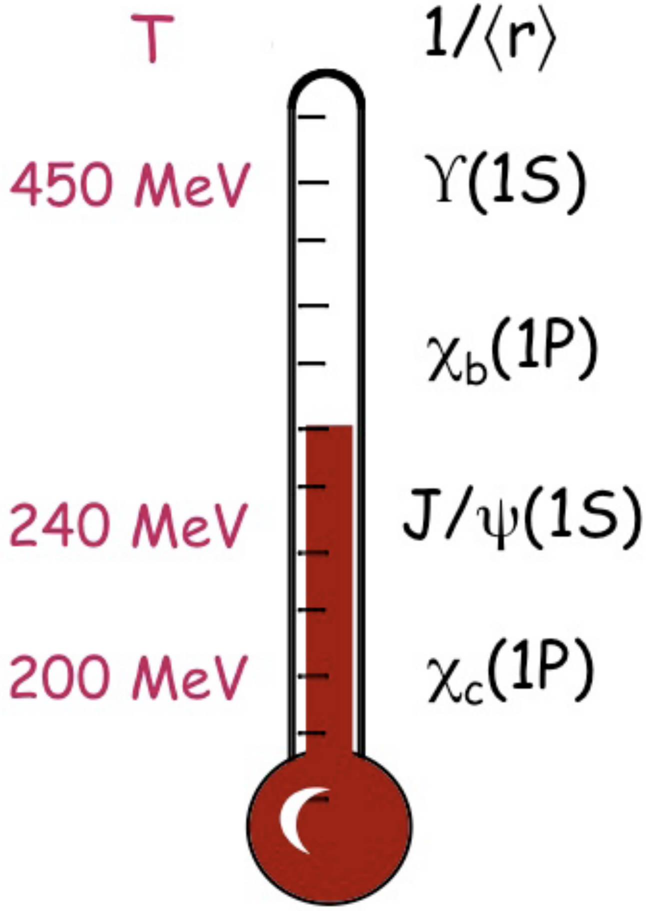
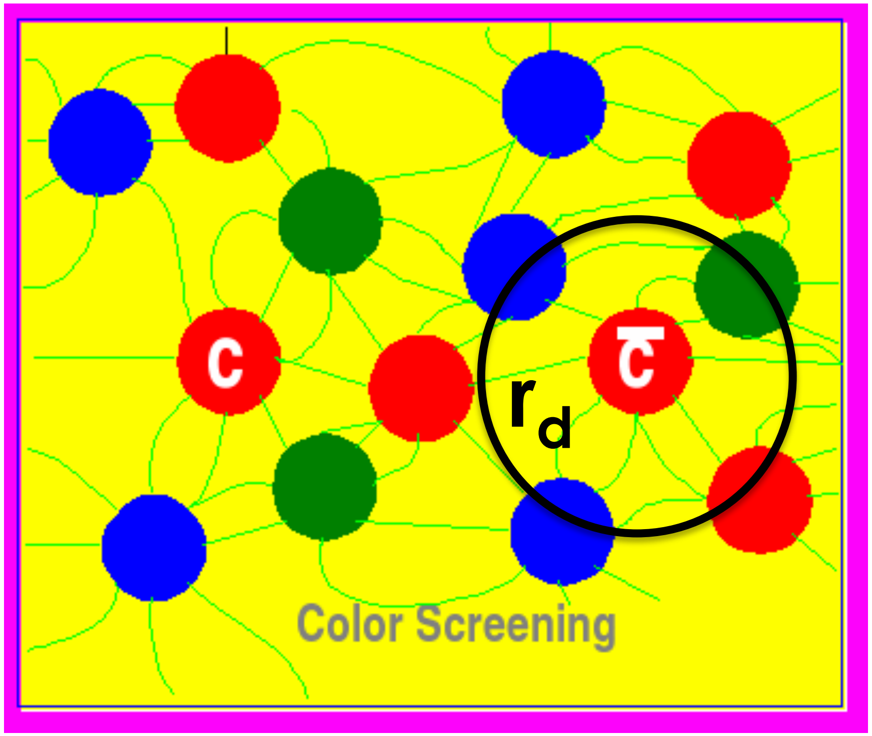
Los Alamos National Lab

ECT-Quarkonium 2016

Quarkonia as a QGP thermometer





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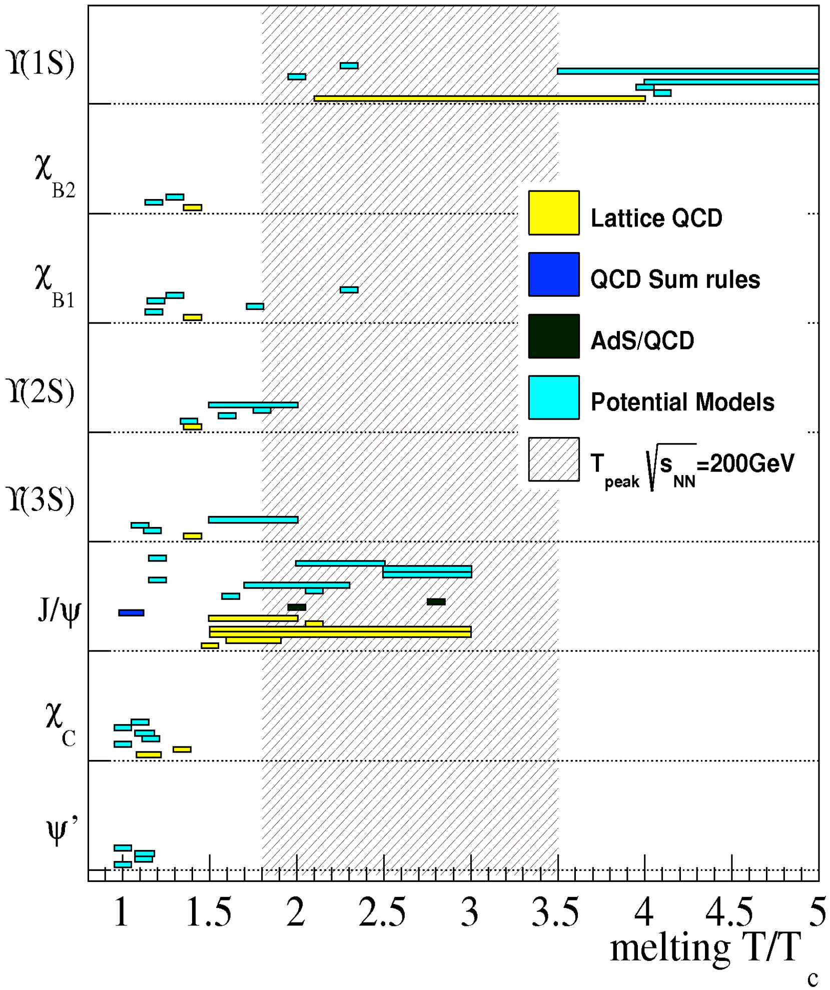
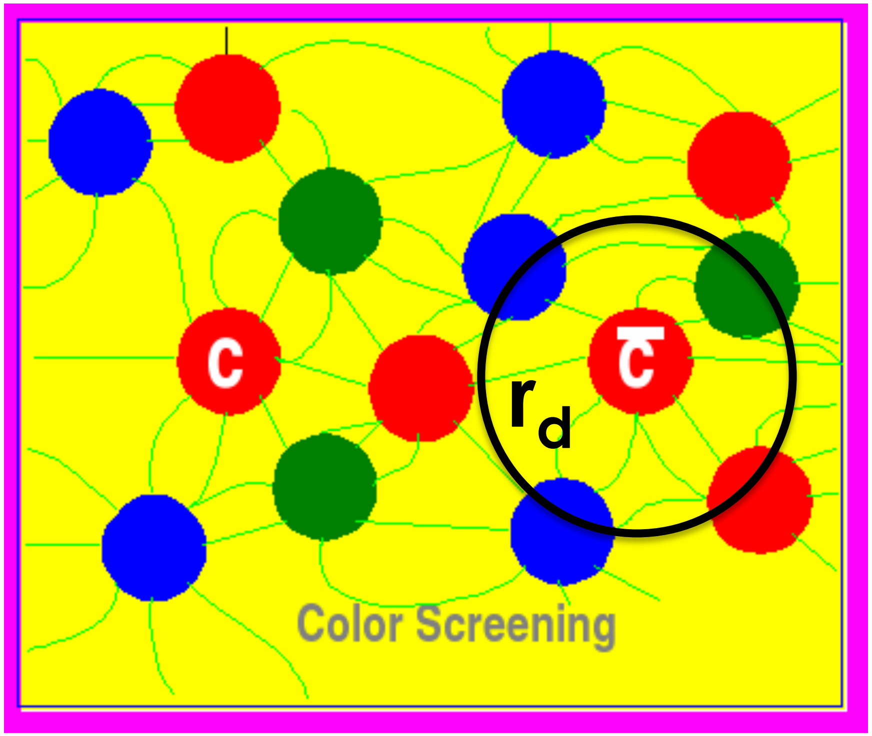
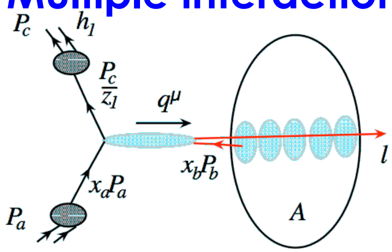




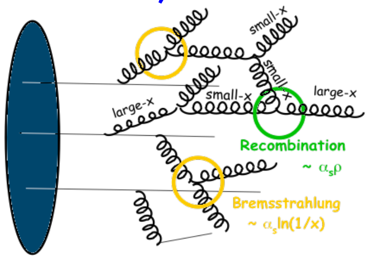
Quarkonia as a QGP thermometer

Los Alamos NATIONAL LABORATORY EST. 1943

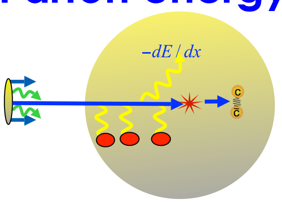
Multiple interactions



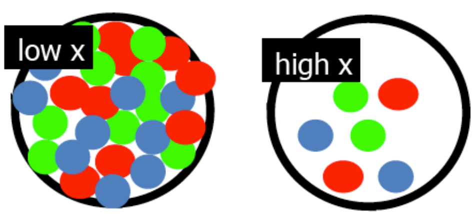
Radiation, recombinations

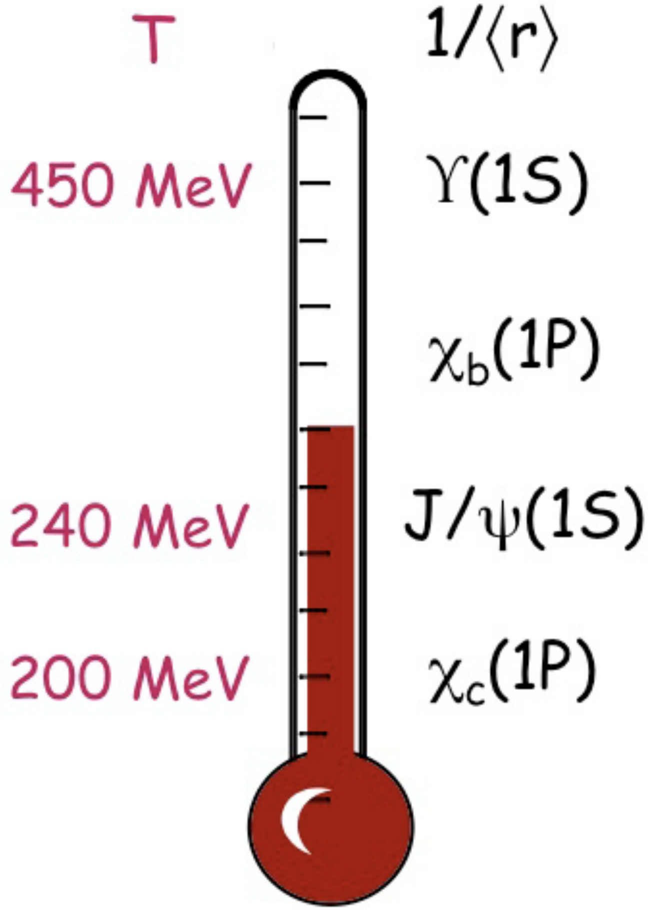


Parton energy loss

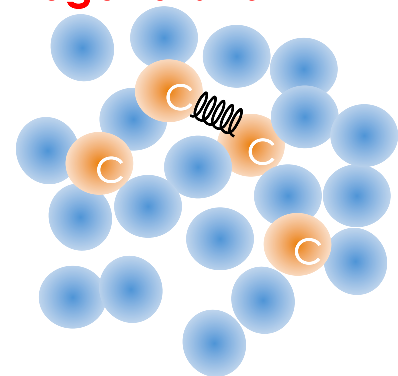


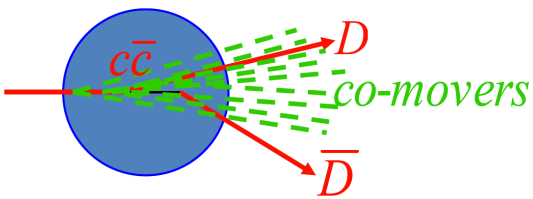
Gluon saturation



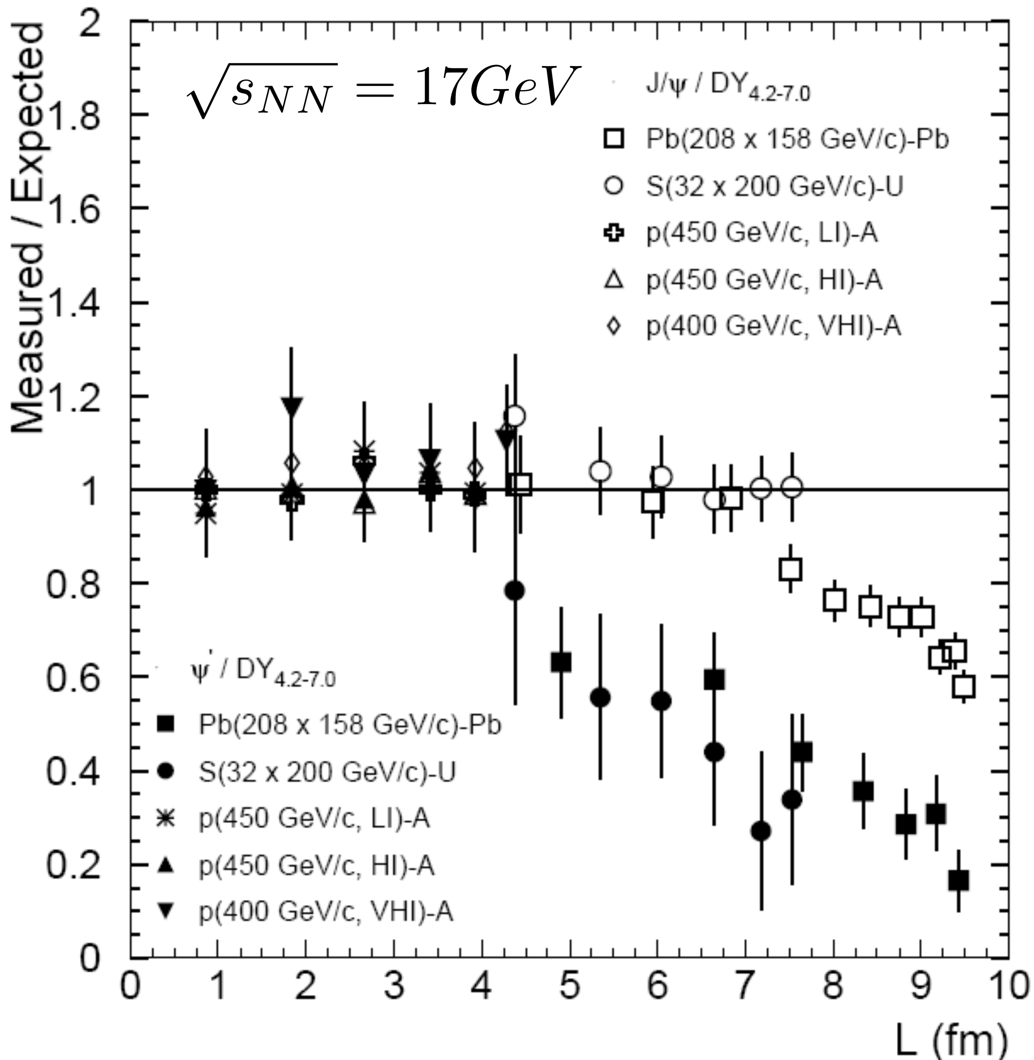


Coalescence, Regeneration





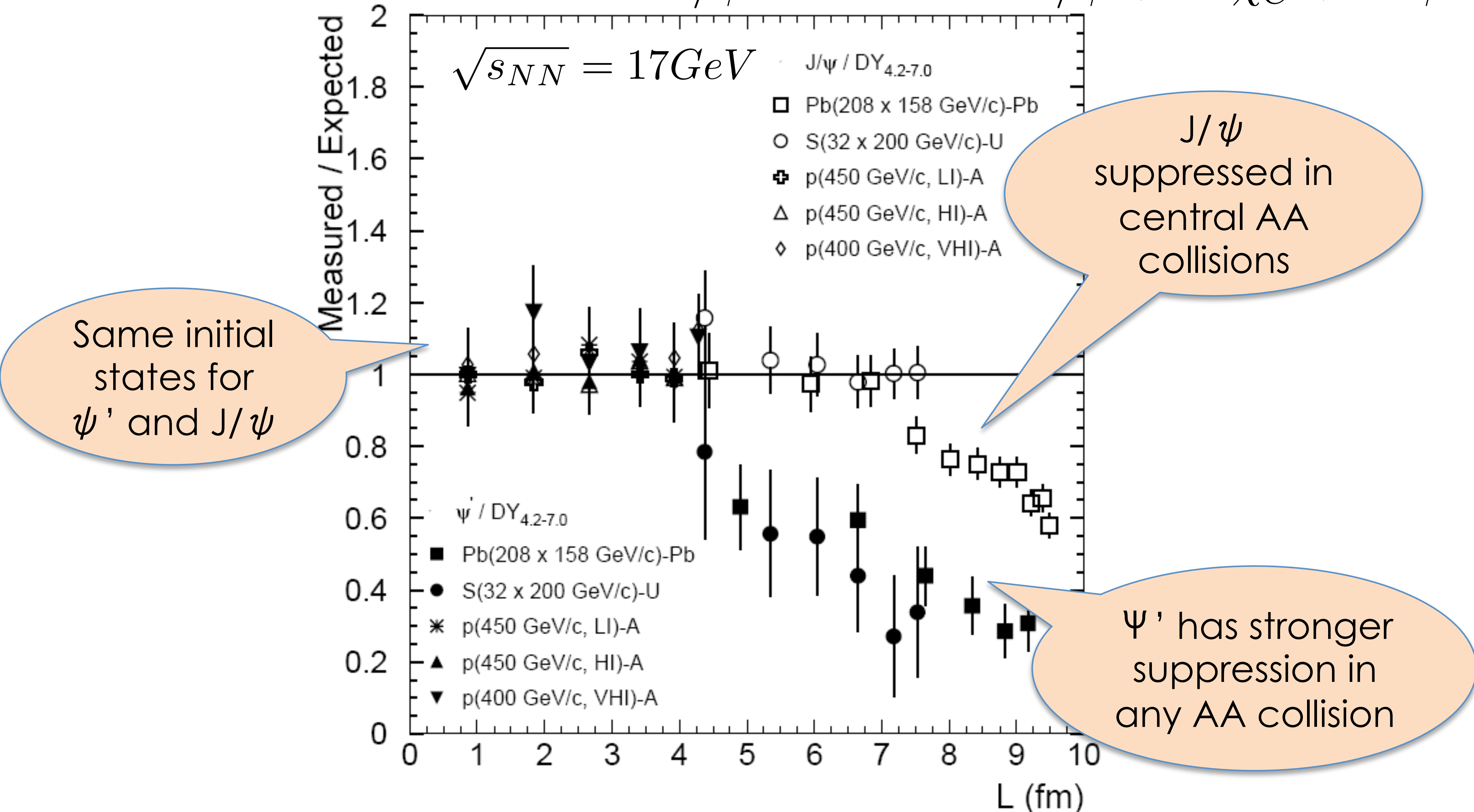
QGP Discovery in SPS ?



L = path length inside nucleus

QGP Discovery in SPS ?

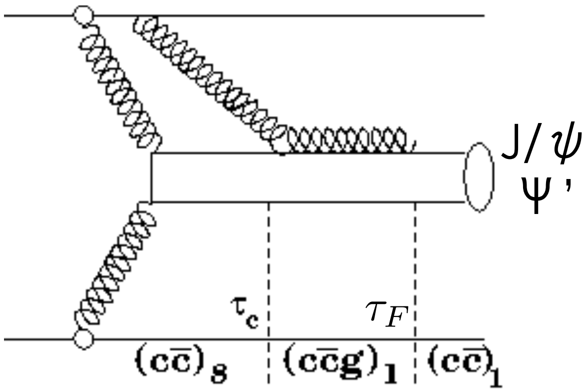
$$\text{inclusive } J/\psi = 0.6 \text{ direct } J/\psi + 0.3\chi_C + 0.1\psi'$$



L = path length inside nucleus

Cold final state effects

Time spent in the nucleus

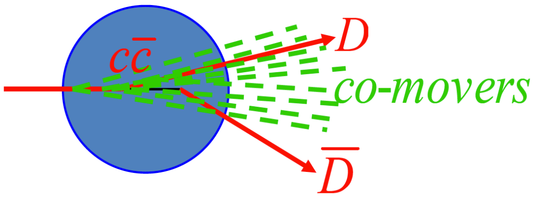


Charmonium is supposed to cross nuclear medium as a pre-resonant state before hadronization.

Does QGP color screening affects final state quarkonia or this colored cc-bar object ?

Should all states be produced as a colored state ?

Co-movers

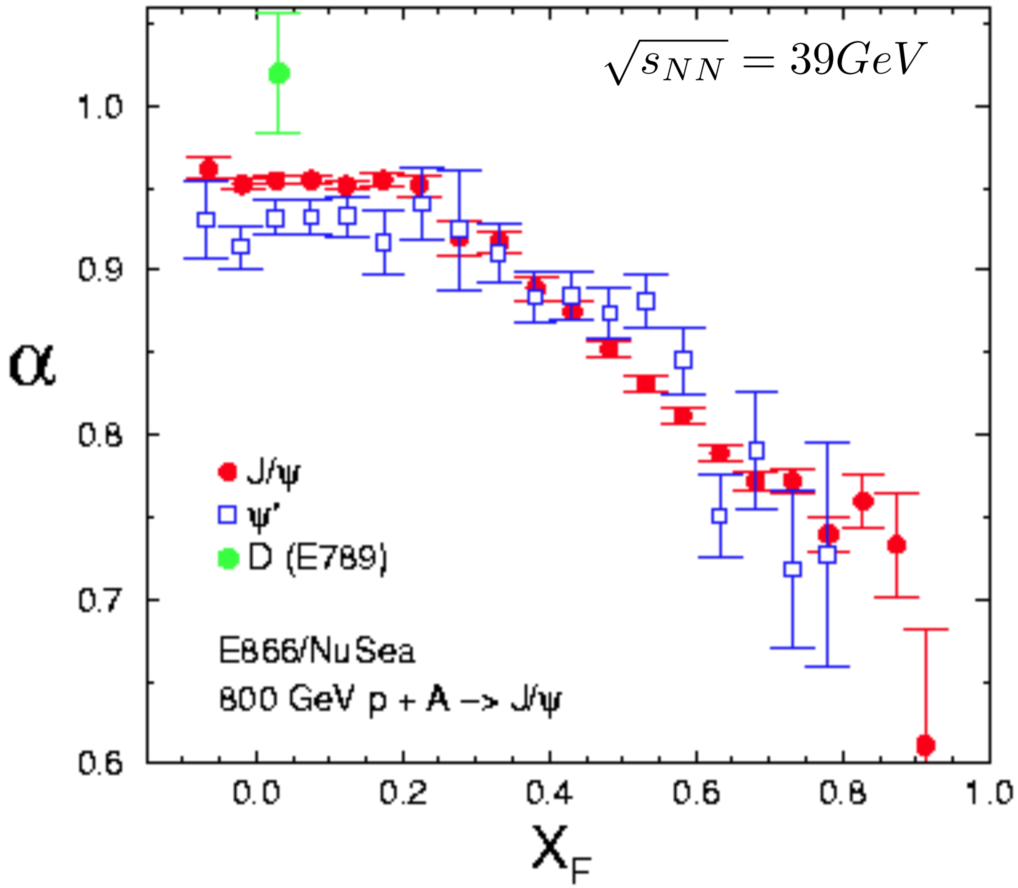


Charmonium can break in the presence of co-moving particle.

What is the J/ψ +hadron -> D+X cross section ?

ψ' in Fermilab

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

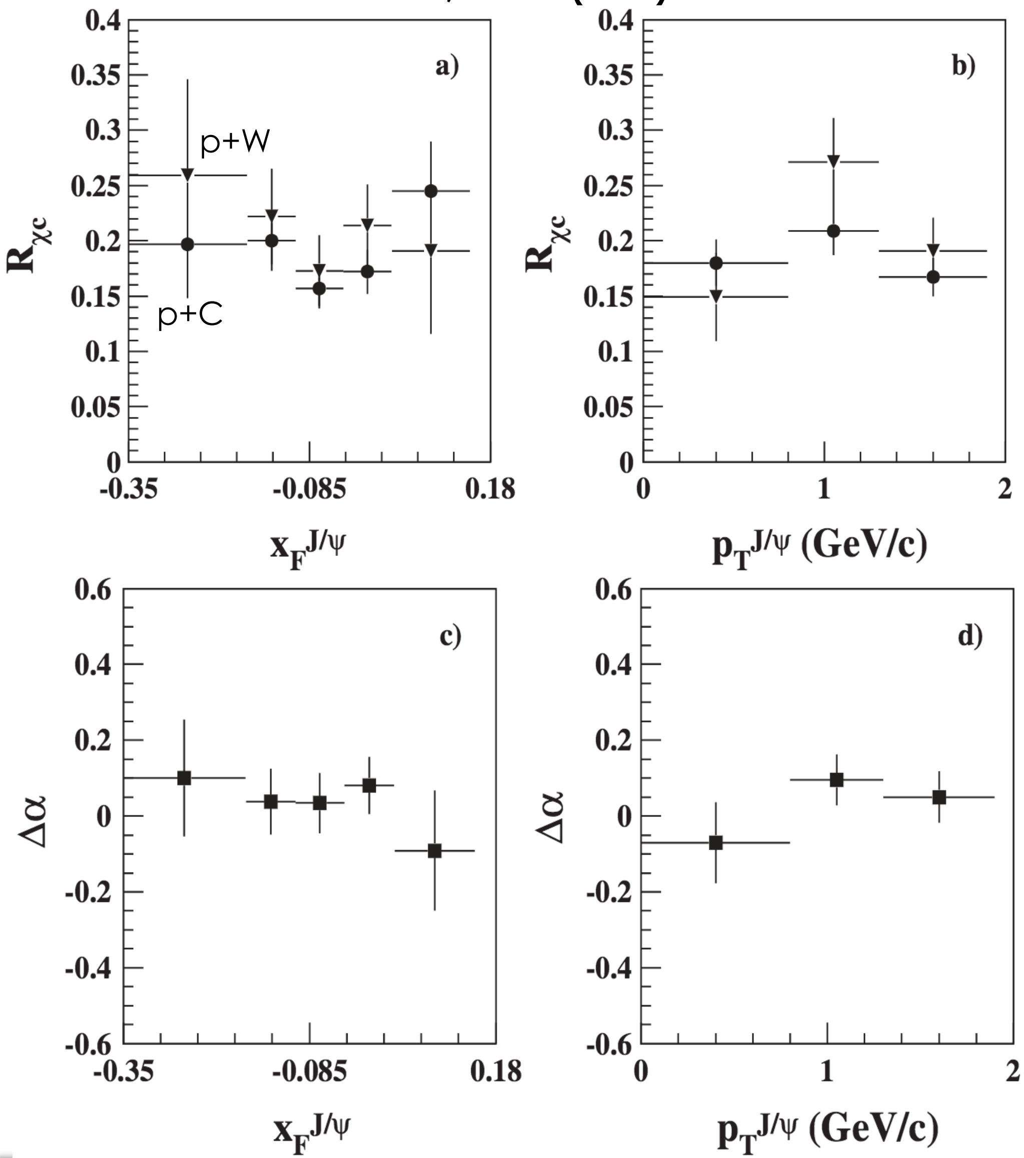


$$X_F = 2p_Z/\sqrt{s_{NN}} = x_1 - x_2$$

Just a small difference in the nuclear suppression at small x_F.

Nuclear Modification of χ_C in HERA-B

PRD79,012001 (2009)



$$\sqrt{s_{NN}} = 41.6 GeV$$

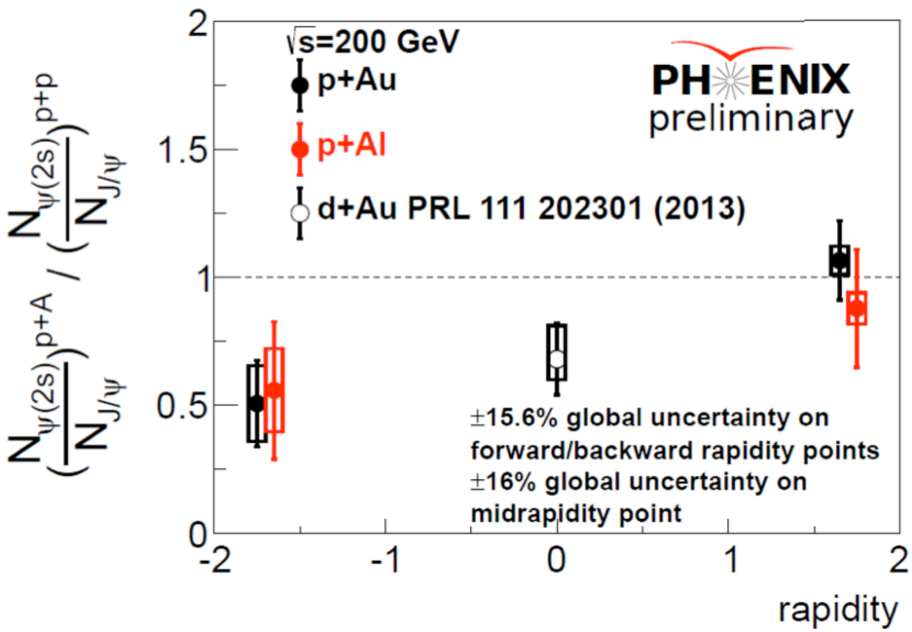
$$\Delta\alpha = \alpha_{\chi_c} - \alpha_{J/\psi} = \frac{1.}{\log\frac{A_W}{A_C}} \cdot \log\frac{R^W_{\chi_c}}{R^C_{\chi_c}}$$

χ_C suppression relative to J/ψ is small, consistent with zero.

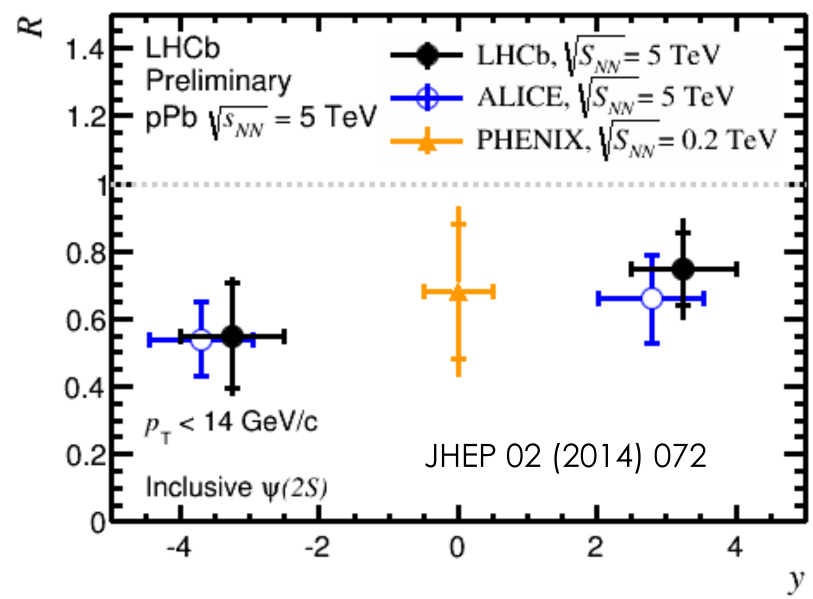
Back in early 2000 everything agreed with a hot final state suppression in SPS and RHIC charmonium data.

Many years later …

RHIC



LHC

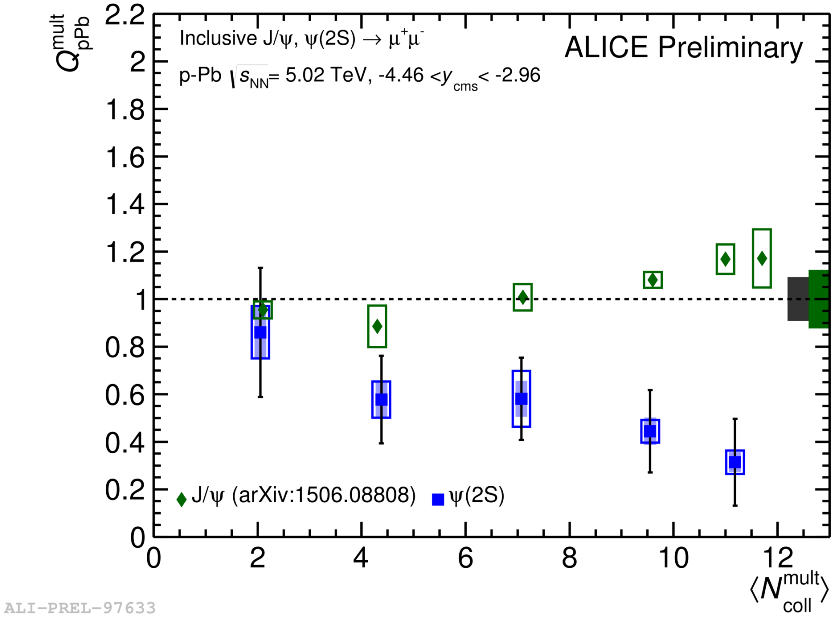


Higher multiplicities, specially towards backward rapidity and at LHC.

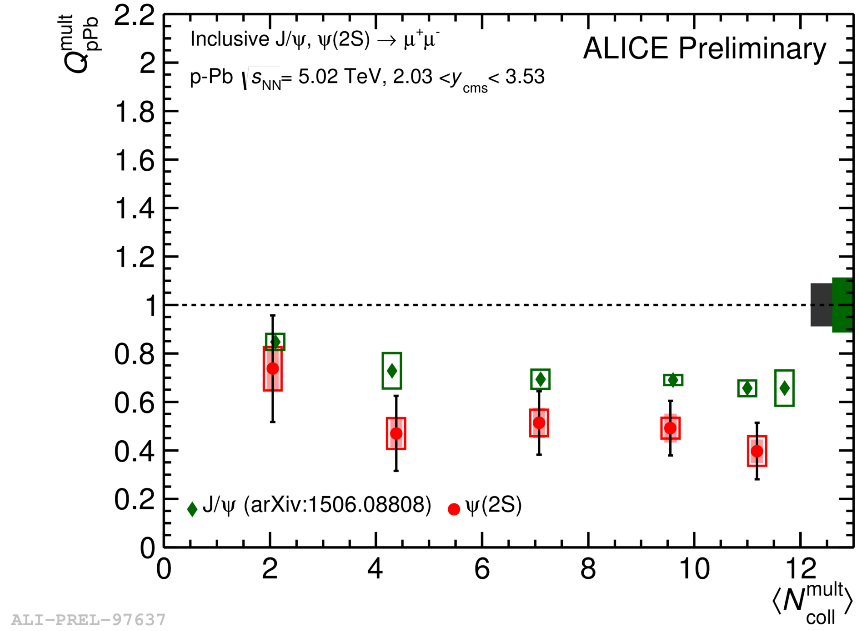
Shorter time spent inside the nucleus, specially at forward rapidity.

ψ' in ALICE

BACKWARD RAPIDITY



FORWARD RAPIDITY



Large-x region
Larger particle multiplicity
Larger time spent in nucleus

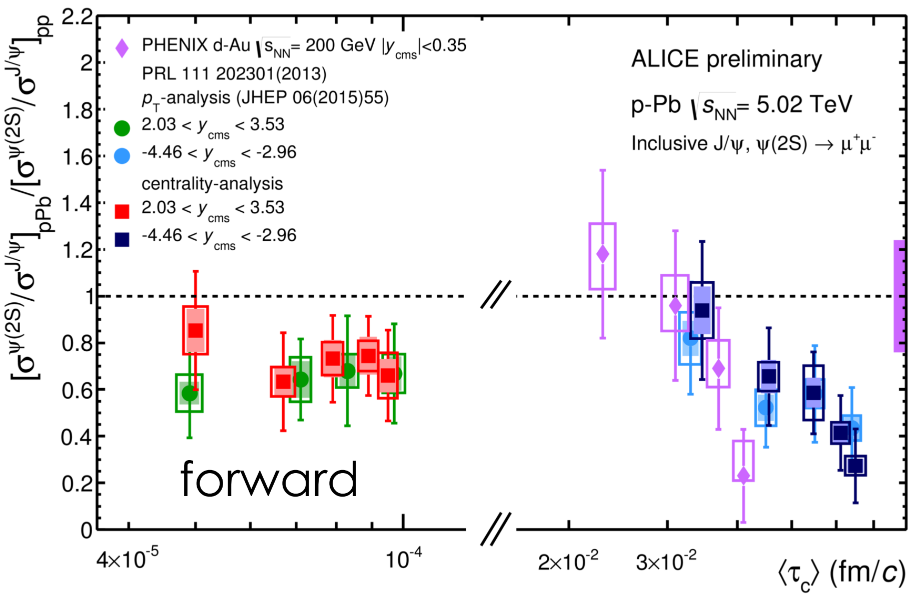
Small-x region
Smaller particle multiplicity
Shorter time spent in nucleus

Time spent in the nucleus

$$\tau = \frac{\langle L \rangle}{\beta_Z \gamma}$$

$\langle L \rangle$ = from Glauber calculation

β_Z = velocity at nucleus rest frame, calculated from p_T



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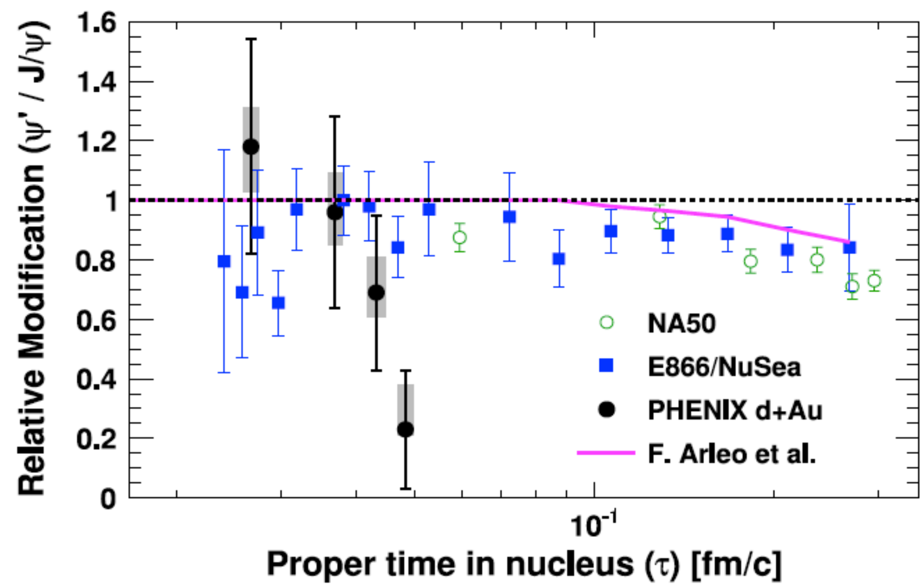
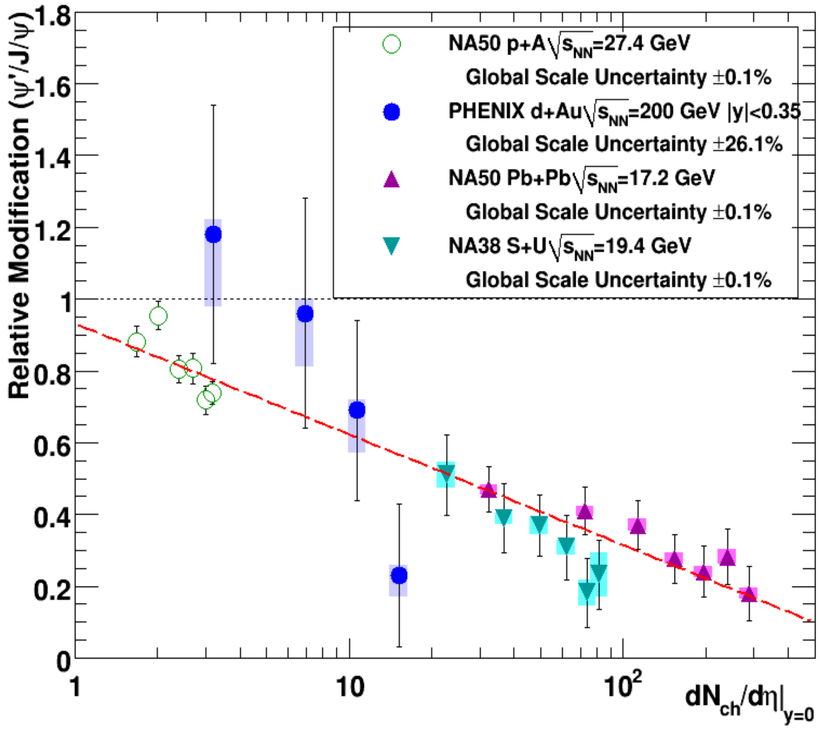
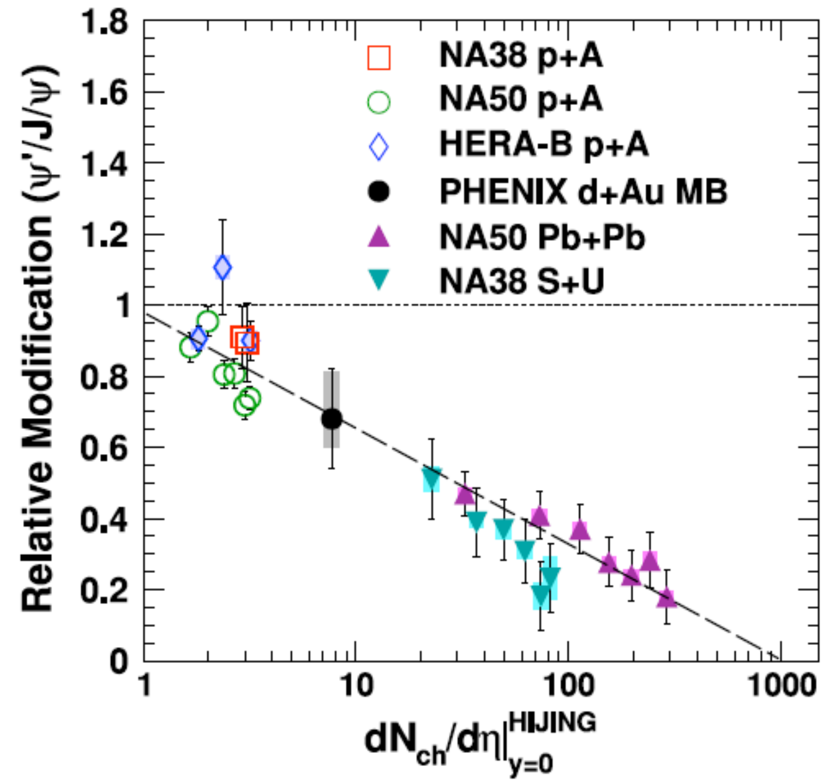


Clear difference between high energy data (higher particle densities) and low energy data.

Dependency with particle density

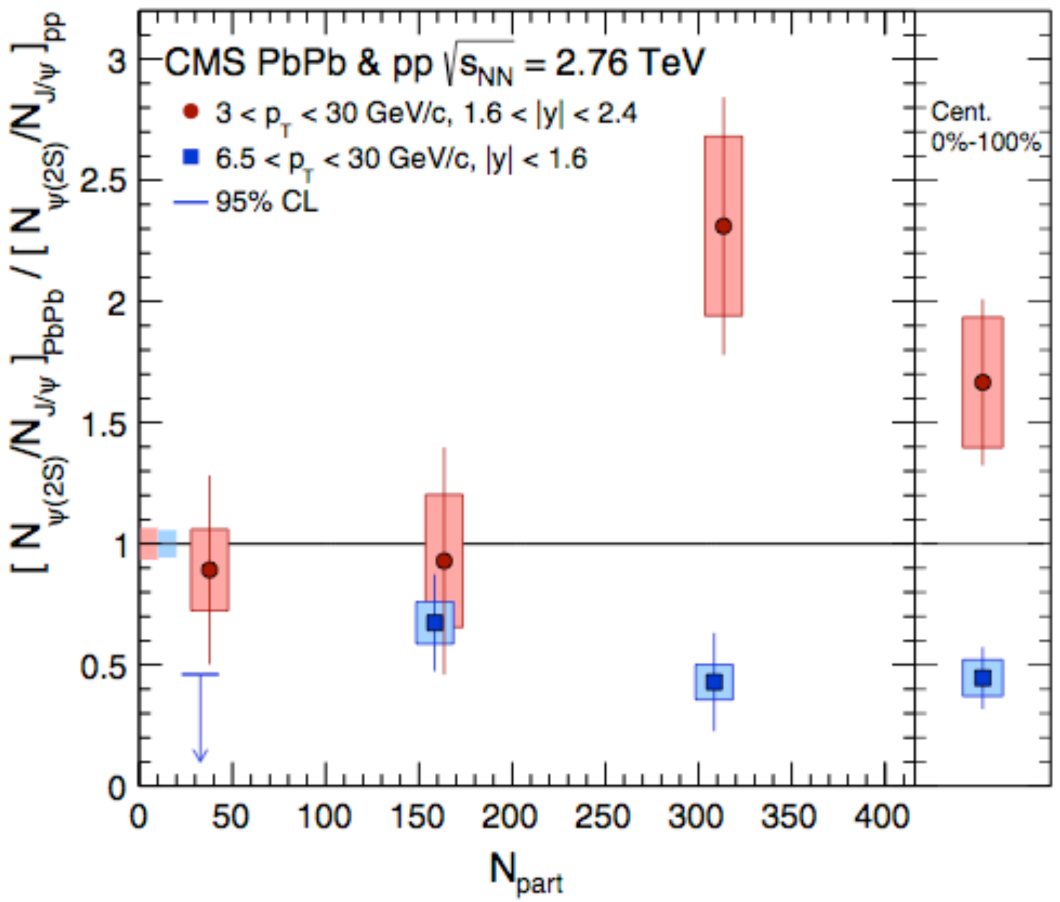




Can relative modification in SPS be just from comovers ?

Another surprise with ψ'

PRL 113, 262301 (2014)

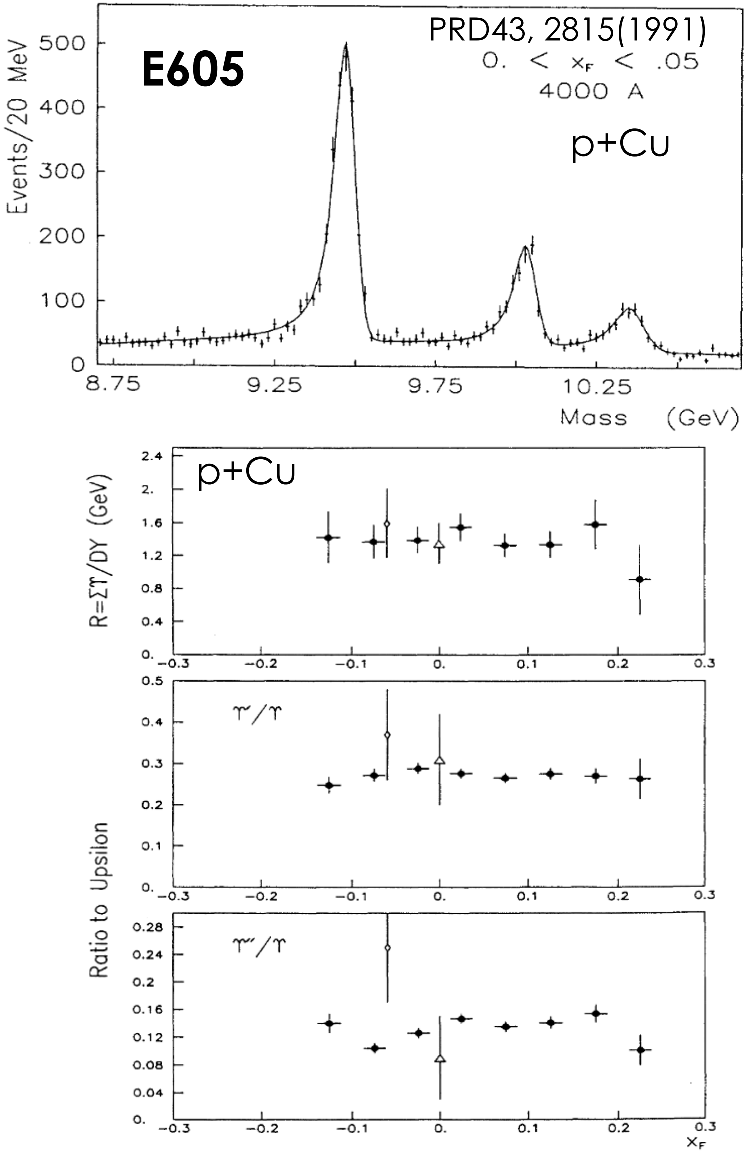


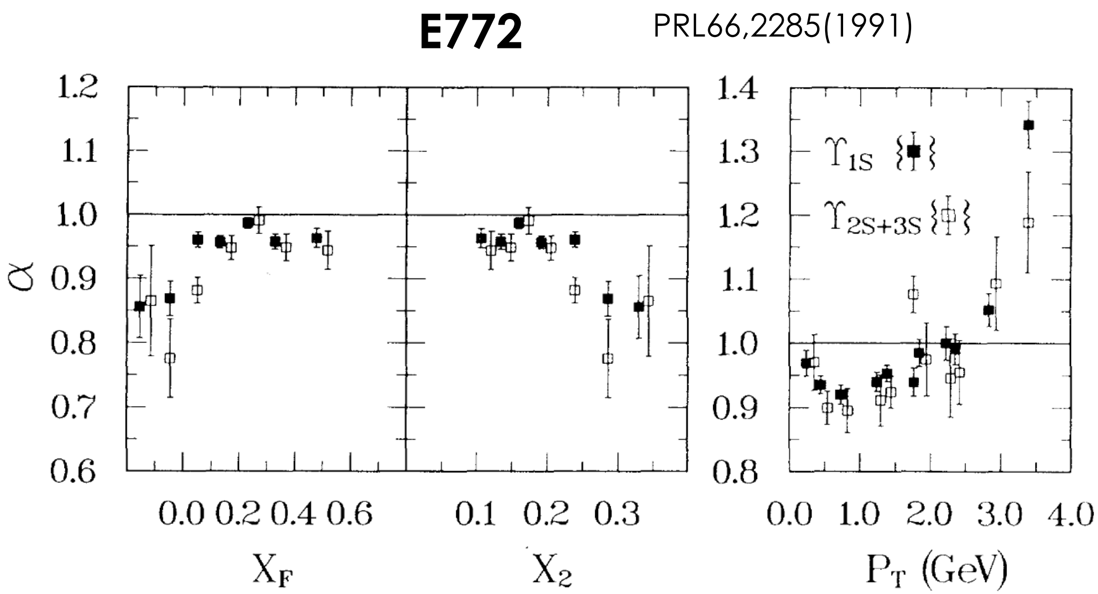
Forward rapidity.
???

Mid-rapidity.
Consistent to SPS

Excited states bottomonium

Υ nuclear modification in Fermilab

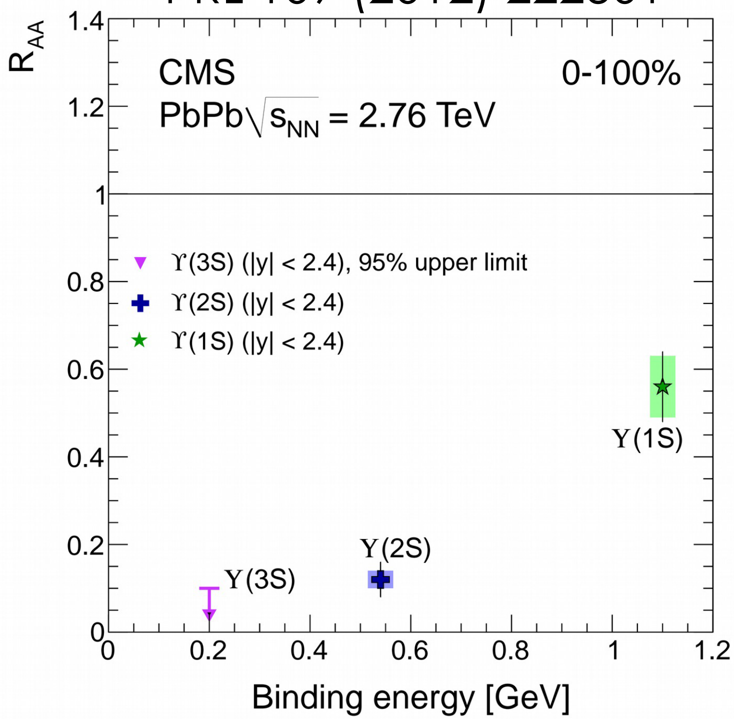




Consistent nuclear modification between 2S+3S and 1S.

Υ(2S,3S) relative suppression at LHC

PRL 109 (2012) 222301



JHEP 04 (2014) 103

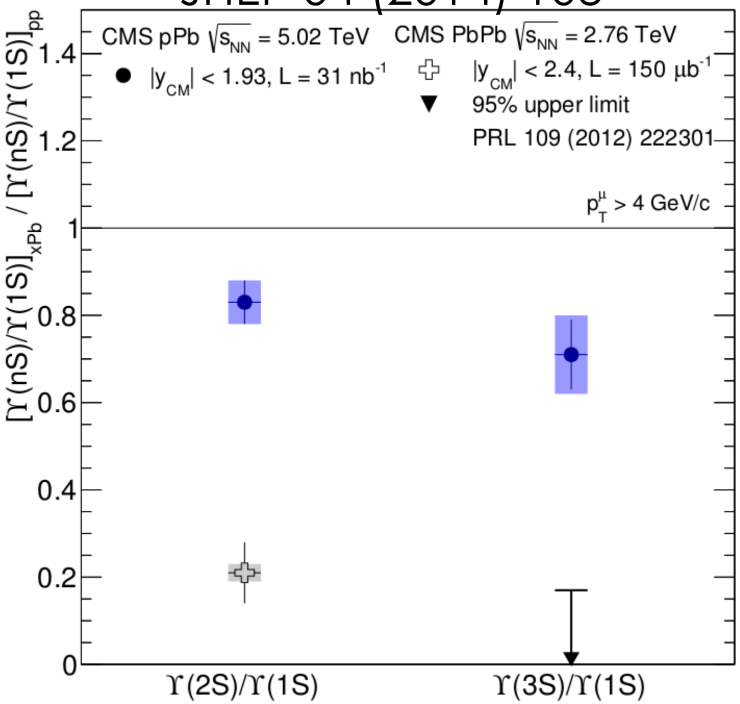
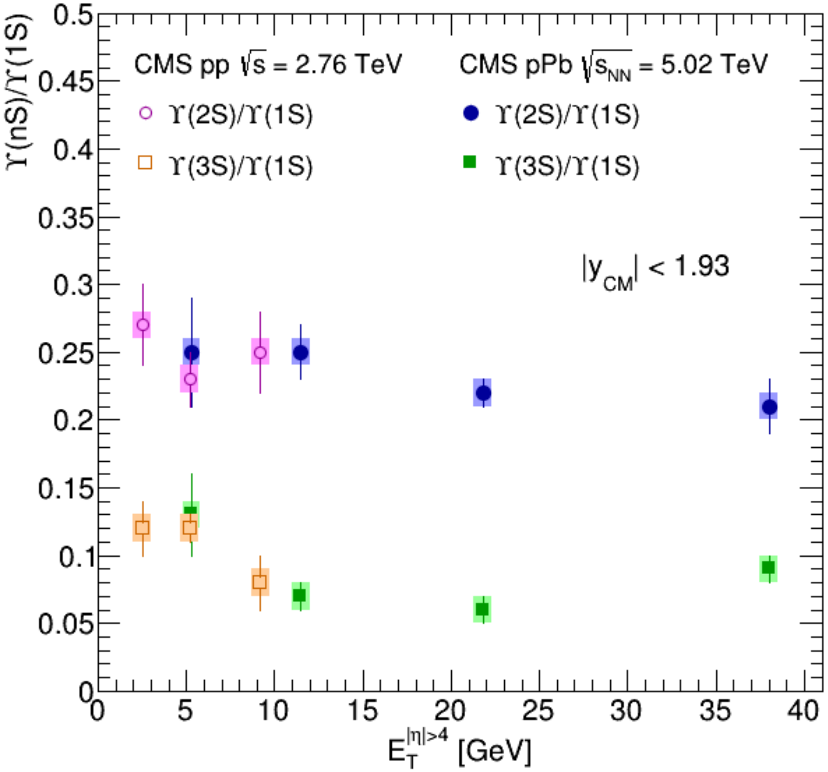


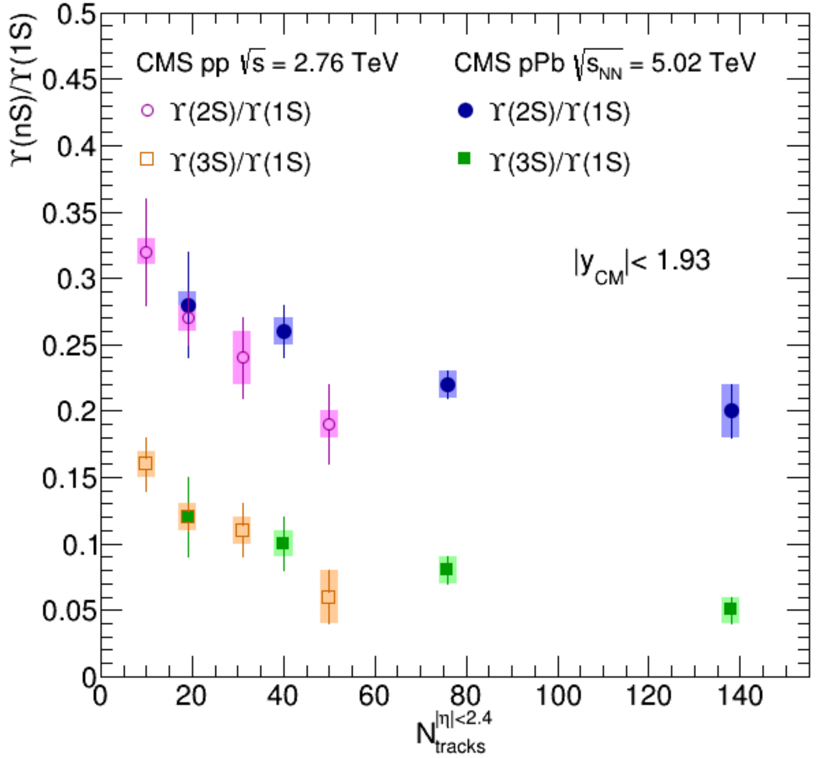
TABLE II. Feed-down fractions of the $\Upsilon(1S)$ state in $p+p$ collisions as measured by CDF for $p_T > 8$ GeV/c [50].

Source	fraction ± stat ± syst
Direct $\Upsilon(1S)$	0.509 ± 0.082 ± 0.090
$\Upsilon(2S)$	0.107 ± 0.077 ± 0.048
$\Upsilon(3S)$	0.008 ± 0.006 ± 0.004
χ_{B1}	0.271 ± 0.069 ± 0.044
χ_{B2}	0.105 ± 0.044 ± 0.014

Needs χ_B measurement to verify if direct 1S state is also suppressed.

Comovers ?





Weak dependency with forward energy.

Strong dependency with nearby particle multiplicity.

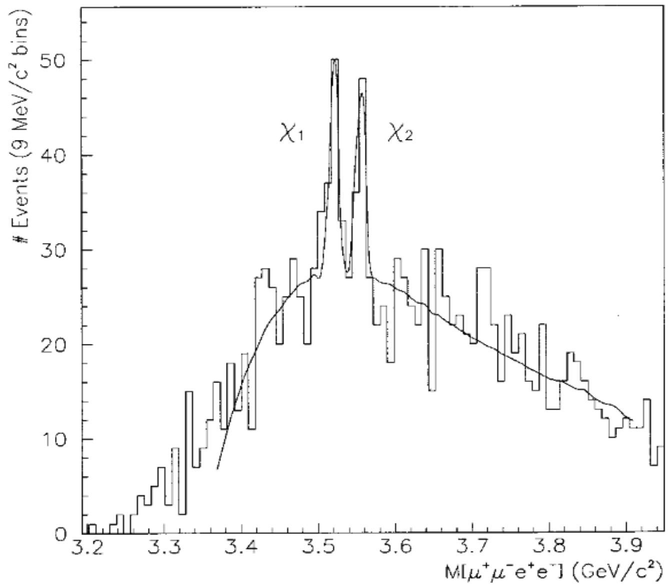
What's Next ?

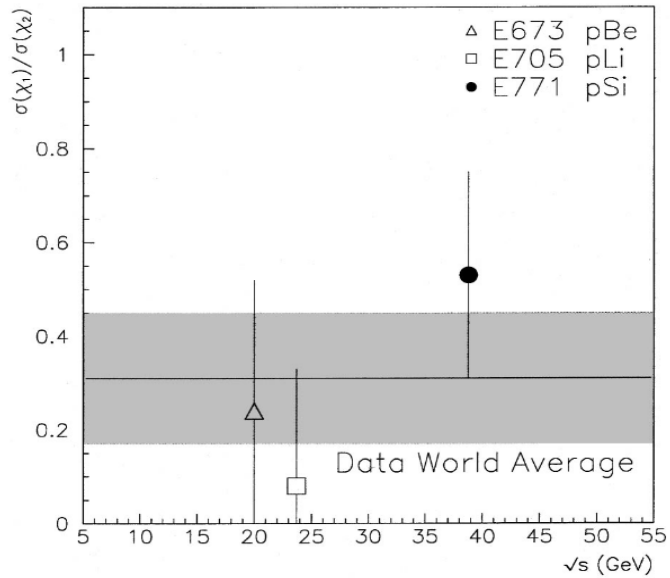
- 30 year after Matsui, Satz famous publication we still don't have a unambiguous signature of color screening
- Needs measurement of QQ-bar + hadron -> D(B) + X cross-section using nearby track mutiplicity dependences in p+p and p+A collisions
- Precise measurements at backward rapidity in p+A collisions can help understand the formation time of final quarkonia states
- The QGP thermometer requires χ_C and χ_B measurements to verify if direct ground states are suppressed and complete the picture
- Any more thoughts ?

BACKUP SLIDES

Any nuclear modification in $\sigma(\chi_{C1})/\sigma(\chi_{C2})$?

Fermilab PRD62 (2000) 032006

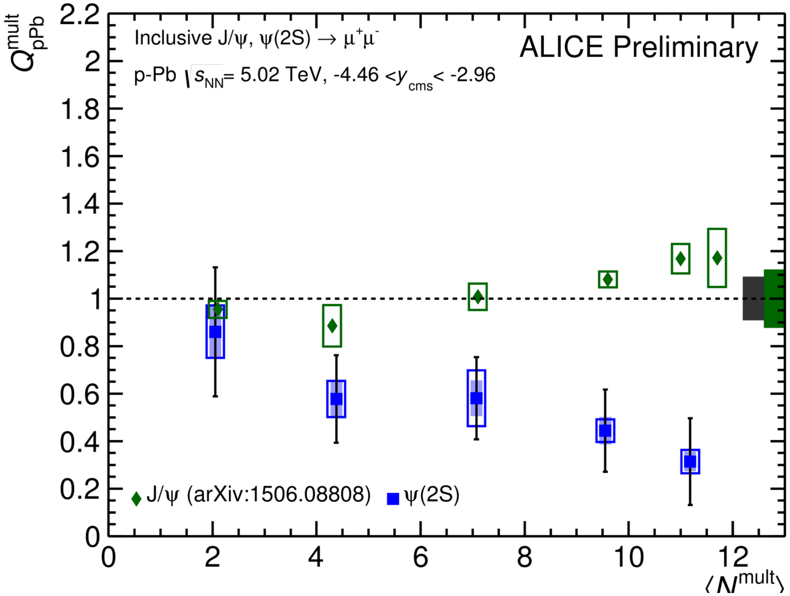




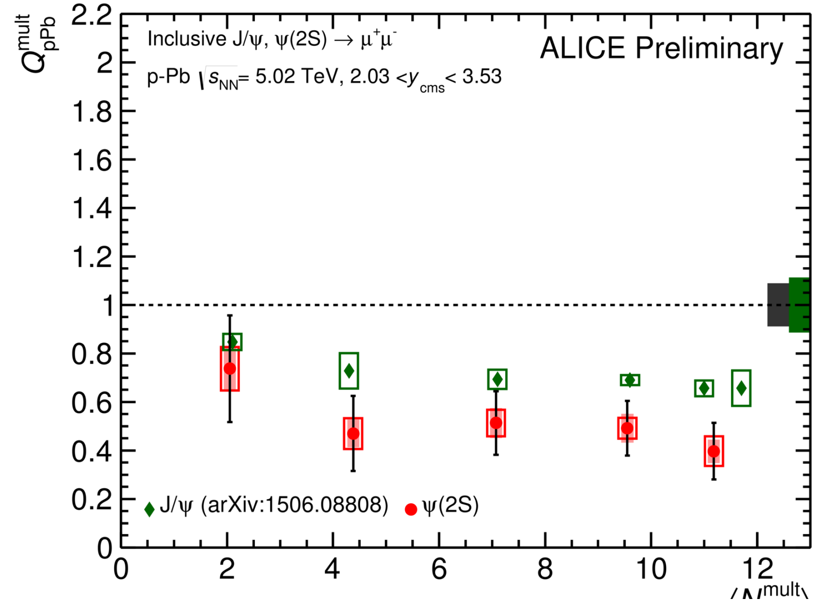
HERA-B $\sqrt{s} = 41.6$ GeV

$\frac{\sigma(\chi_{c1})}{\sigma(\chi_{c2})}$	
C	$0.60 \pm 0.12_{st} \pm 0.21_{sys}$
Ti	$0.38 \pm 0.38_{st} \pm 0.13_{sys}$
W	$0.56 \pm 0.21_{st} \pm 0.20_{sys}$
Tot	$0.57 \pm 0.10_{st} \pm 0.20_{sys}$

ALICE



Inclusive J/ψ, ψ(2S) → μ⁺μ⁻
ALICE Preliminary
p-Pb √sNN= 5.02 TeV, -4.46 <ycms< -2.96
J/ψ (arXiv:1506.08808)
ψ(2S)
Q pPb mult
⟨N mult⟩



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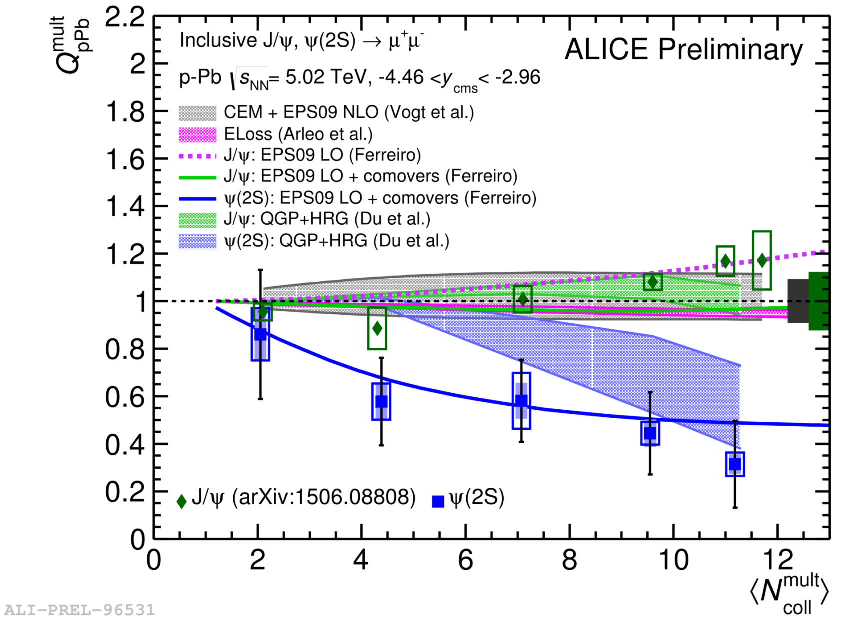

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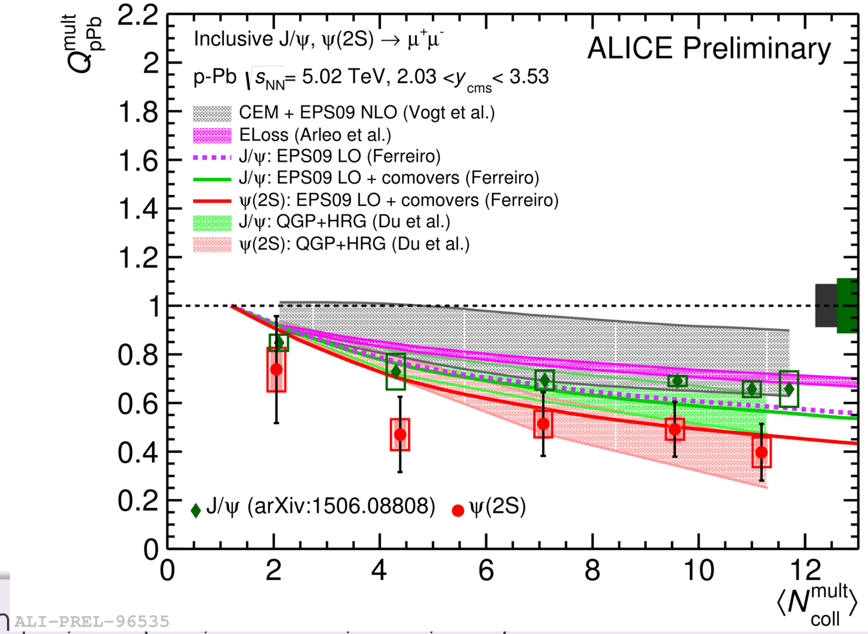
ψ(2S): EPS09 LO + comovers (Ferreiro)
J/ψ: QGP+HRG (Du et al.)
ψ(2S): QGP+HRG (Du et al.)
J/ψ (arXiv:1506.08808)
ψ(2S)
Q pPb mult
⟨N coll mult⟩
ALI-PREL-96531



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ψ(2S): QGP+HRG (Du et al.)
J/ψ (arXiv:1506.08808)
ψ(2S)
Q pPb mult
⟨N coll mult⟩
ALI-PREL-96535