On the Psi(2S) over J/psi production yield in pp and pA collisions

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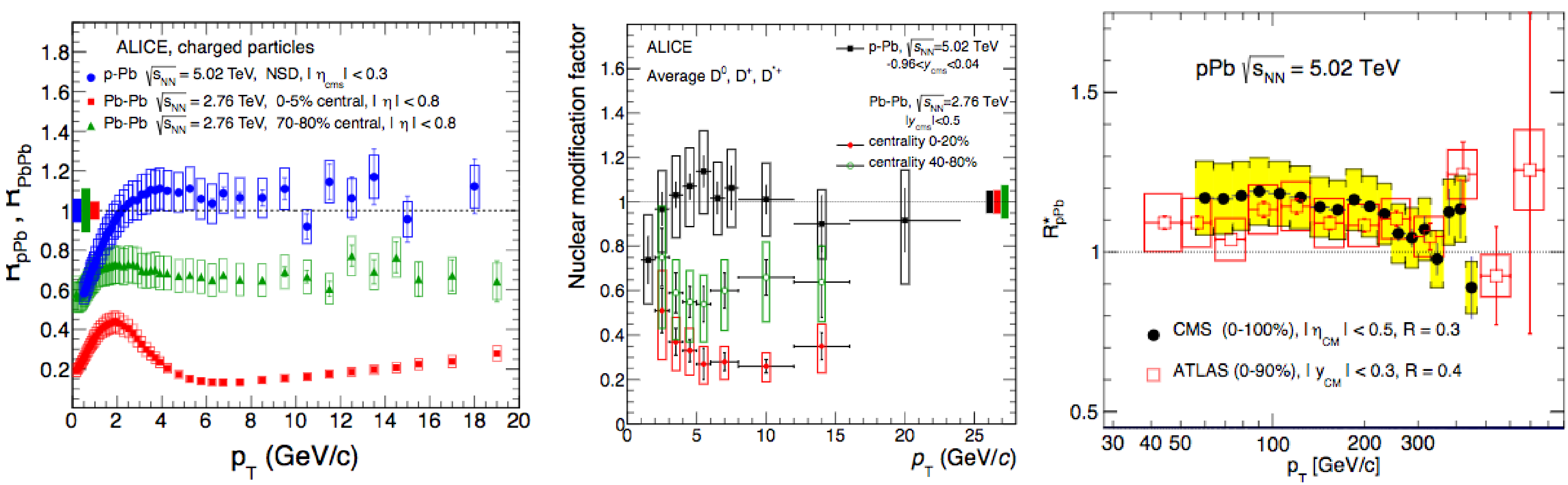
FCPPL Quarkonium Production Workshop 2017, Beijing, Chine

p-Pb at the LHC (I)

- p-A probes the physics of the initial stage
- First p-Pb collisions at 5.02 TeV by the LHC in 2012

Salgado et al, JPG39 (2012) 015010

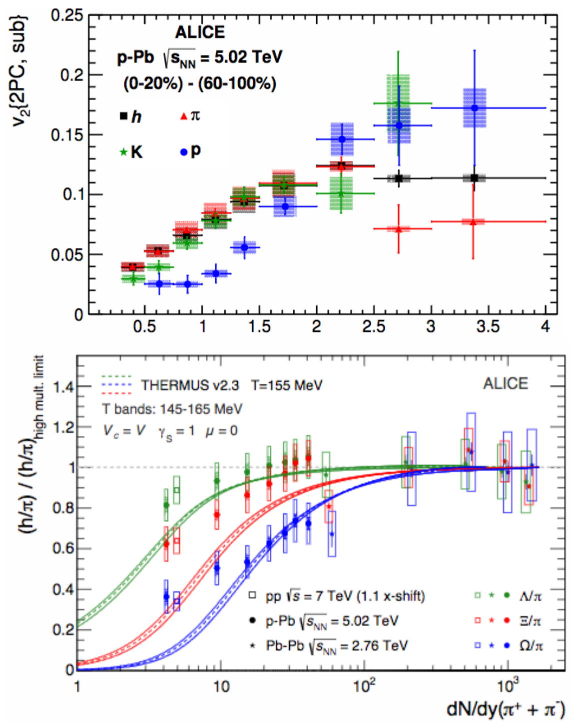


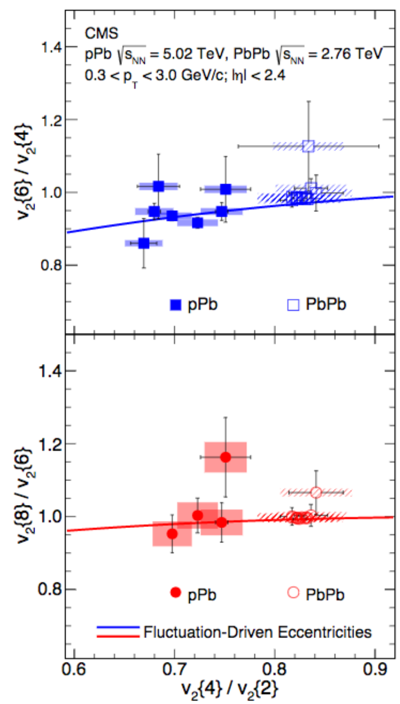
ALICE, PRL110 (2013) 082301, ALICE PRL 113 (2014) 232301, CMS EPJC76 (2016) 372
Many more measurements have been performed by LHC experiments

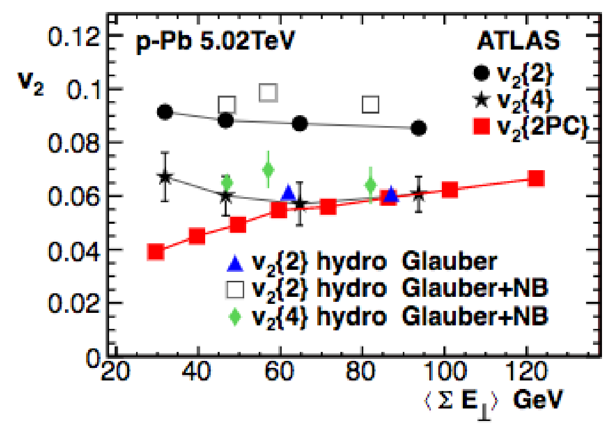
But …

p-Pb at the LHC (II)

- But green outside, red inside …
- Soft probes: qualitative similarity to measurements in A–A collisions which are rather intriguing
- *Grosso modo* Hydro + fluctuations explains the data







ALICE PLB726 (2013) 164, CMS PRL115 (2015) 012301, ALICE PLB758 (2016) 389, Bozek et al PRC88 (2013) 014903

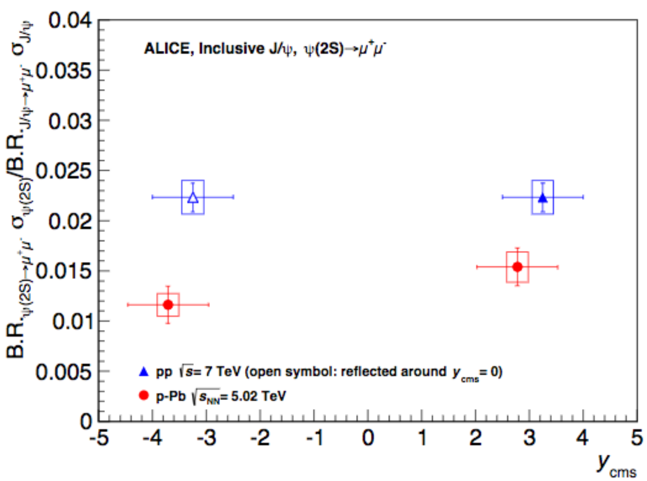
Many more measurements have been performed by LHC experiments

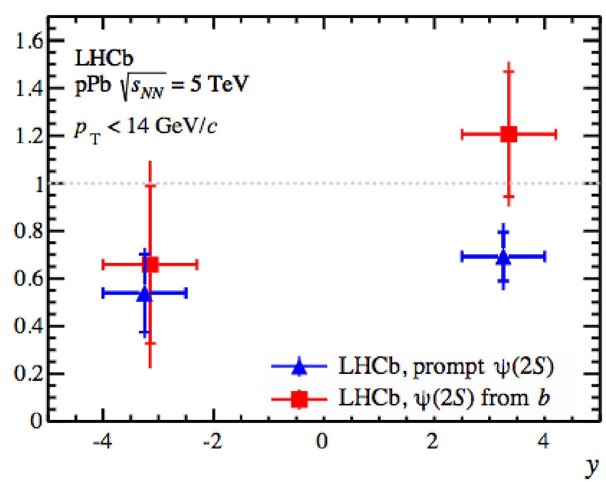
p-Pb at the LHC (III)

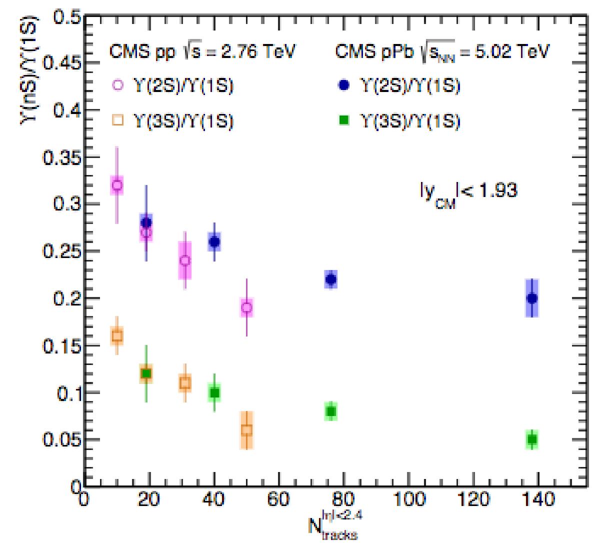
- Collectiveness in p-Pb (and also high multiplicity pp)?
- One of the most intriguing results at the LHC
- Why hard probes are blind to collectiveness like effects in p-Pb?
  - Transverse size of the initial stage smaller than in Pb-Pb collisions
  - Low pT hard probes can become interesting: Heavy Quarks

p-Pb at the LHC (IV)

- Relative suppression of higher nS quarkonium resonances : Psi(2S), Y(2S) and Y(3S)
- Can initial state effects explain these observations?







ALICE JHEP 12 (2014) 073, LHCb JHEP 03 (2016) 133,
CMS JHEP 04 (2014) 103, ALICE JHEP 06 (2016) 050

Times Scales

- pp collision time scale $1/\langle m_T \rangle$ ~ 0.1-0.2 fm/c
- Hadronisation time $1/\Lambda_{QCD}$~1 fm/c
- Heavy ccbar (bbar) production $1/2M_Q$~ 0.08 (0.02) fm/c
- Disentangling between 1S, 2S or 3S states $1/\Delta M$ ~ 0.35 (0.2-0.6) fm/c
- I will focus next in the relative Psi(2S)/Jpsi yield ratio. Upsilon case is more complex due to the richer feed down contributions from higher resonances.

Bjorken PRD27 (1983) 140, PHENIX NPA (2005) 184, SaporeGravis EPJC46 (2016) 107

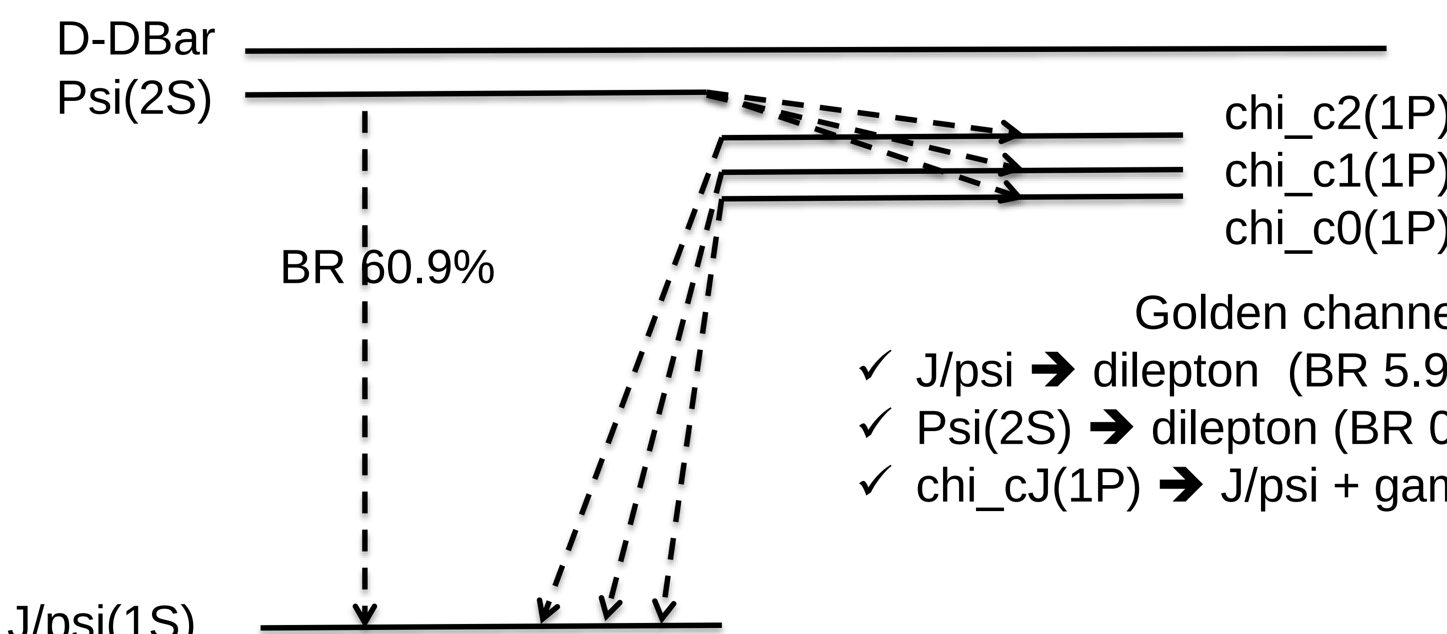
Motivation/Definitions

Relative yield ratios of quarkonium with the same quantum number are interesting sine many physics mechanism cancel. Namely initial effects like shadowing and energy lost are expected to do not change the relative ratios.

- Direct = directly production in the collisions at t~1 fm/c
- Prompt = Direct + decay from higher resonances at t˜10^2-10^3 fm/c
- Inclusive = Prompt + decay of hadrons with beauty quarks at t˜10^{10} fm/c

Direct versus Prompt

- Psi(2S) prompt = Psi(2S) direct
- J/psi(1S) direct :



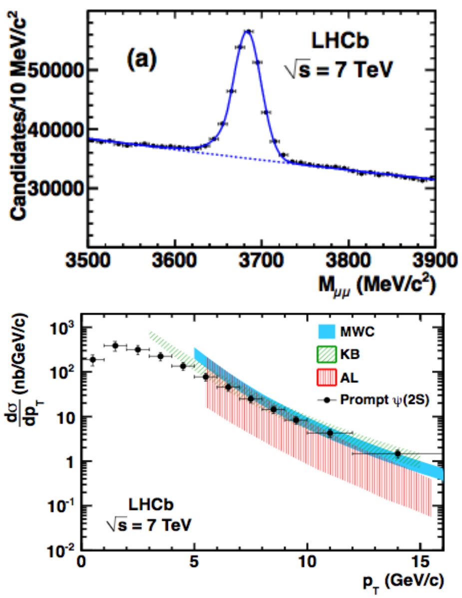
Golden channels

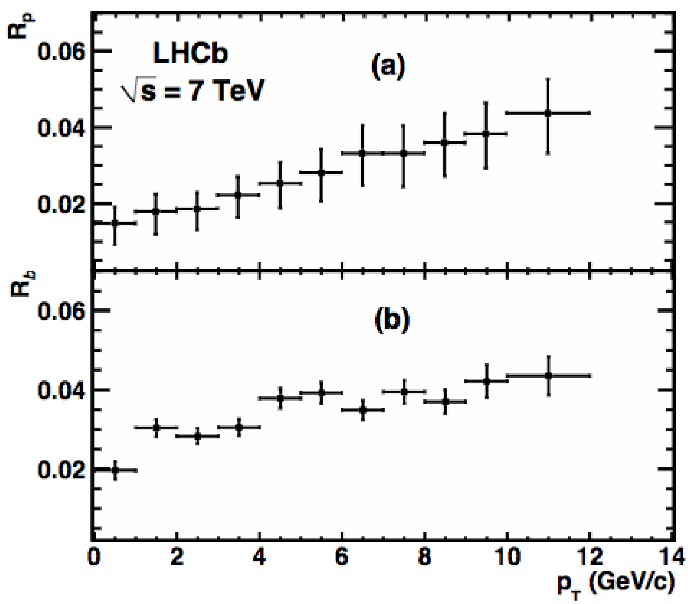
- ✓ J/psi ➔ dilepton (BR 5.961%)
- ✓ Psi(2S) ➔ dilepton (BR 0.789%)
- ✓ chi_cJ(1P) ➔ J/psi + gamma

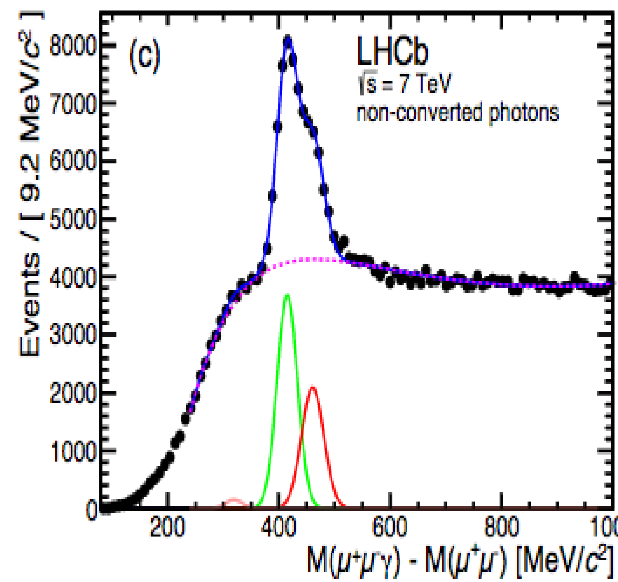
$$R^{\mathrm{D}}_{J/\psi/\Psi(2S)} = \frac{Y^{\mathrm{D}}_{J/\psi}}{Y^{\mathrm{D}}_{\Psi(2S)}} = \frac{R^{\mathrm{P}}_{J/\psi/\Psi(2S)}}{1 - R_{\chi_c \to J/\psi} - 0.609 R^{\mathrm{P}}_{J/\psi/\Psi(2S)}}$$

Psi(2S)/Jpsi in pp at the LHC

- Relative prompt ratios measured by LHCb and ALICE at foward rapidities at 7 and 8 TeV
- Feed-down from chi_c measured by LHCb for p_T>2 GeV







Prompt ratios:
LHCb pp 7 TeV : 0.137±0.021
ALICE pp 7 TeV : 0.170±0.017
ALICE pp 8 TeV : 0140±0.022

Chi_cJ feeddown
(15±2)% down to pT=0
(Aurélien BEAUFRERE L1 2016)

Direct Ratio
Psi(2S)/Jpsi
0.18±0.03

LHCb EPJC72 (2012) 2100, ALICE EPJC74 (2014) 2974, ALICE EPJC76 (2016) 184, LHCb PLB718 (2012) 431

Theory predictions

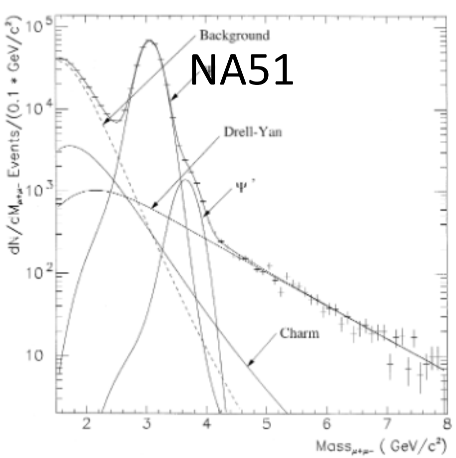
- Initial c-cbar pair distance ˜1/2M_Q ~0
- Direct Psi(2S)/Jpsi ratio only depends on the charmonium wave functions at the origin
- Charmonium wave functions at the origin are given by the widths of the dilepton decay channels
- Agreement with LHC experimental results within 2,2sigmas

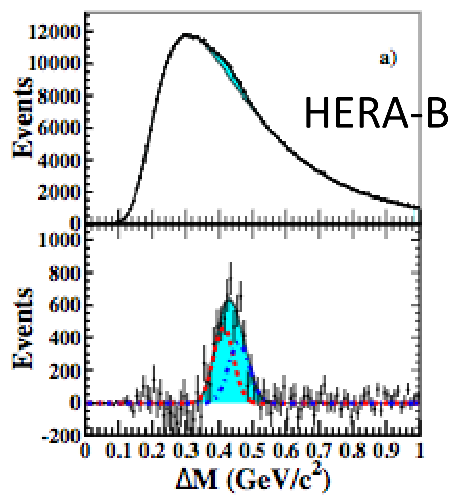
$$R^{\mathrm{D}}_{J/\psi/\Psi(2S)} = \frac{\Gamma(\Psi(2S) \to e^+e^-)}{\Gamma(J/\psi \to e^+e^-)} \frac{M^3_{J/\psi}}{M^3_{\Psi(2S)}} = 0.25 \pm 0.01$$

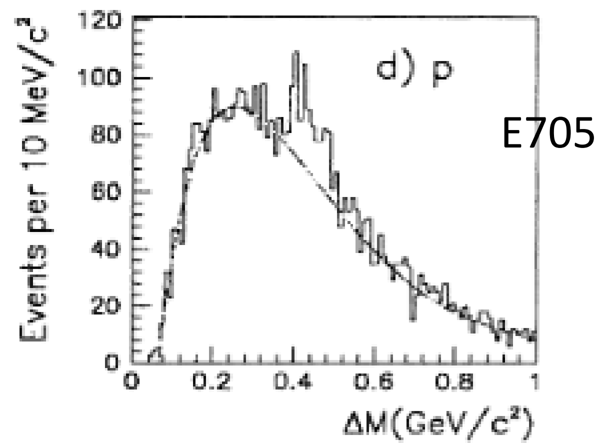
Vanttinen et al PRD51 (1995) 3332, Schuler PhD Thesis (1994)

Psi(2S)/Jpsi pp at 20-50 GeV

- pp and pd at 29 GeV by NA51
- chi_c contribution measured by E705 experiment in p-Li at 24 GeV and HERA-B in p-C, p-Ti and p-W at 41.6 GeV







Prompt ratios:
NA51 pp 29 GeV :
0.1187±0.0034
NA51 pd 29 GeV :
0.1263±0.0036

Chi_cJ feeddown
Hera-B (18.8±2.6)%
E705 (30±4)%

Direct Ratio
Psi(2S)/Jpsi
0.166±0.007
0.196±0.014

NA51 PLB438 (1998) 35, HERA-B EPJC49 (2007) 545, HERA-B PRD79 (2009) 012001, E705

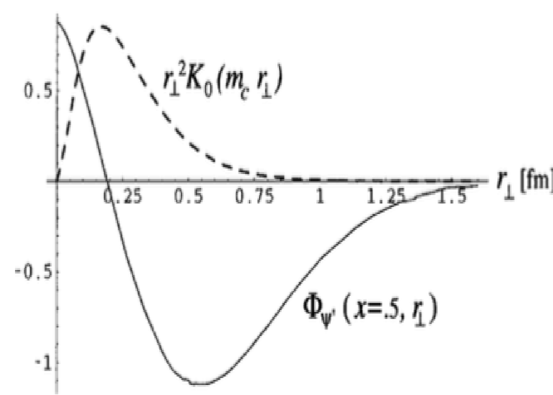
Direct Psi(2S)/Jpsi in pp

- Agreement within experimental errors at 20-50 GeV and at 7-8 TeV
- Better precision is needed in pp collisions (factor 3-6 improvement should be possible)
- Results suggest (namely at low energy) ratio below LO theoretical prediction

« NLO » Theoretical prediction

- Realistic determination of the initial wave function of the c-cbar pair
- Dependence on the number of gluons exchanged (photo versus hadroproduction)
- Dependence on the heavy quark potential model

$R_{el}^{\gamma N} = \sigma_{\psi'} / \sigma_{J/\psi}$	BT	Cornell
Eq. (8)	0.033	0.070
$\lvert \Phi_{\psi'}^{NR}(0)/\Phi_{J/\psi}^{NR}(0) \rvert^2$	0.65	0.64
$r_\perp^2 \to r_\perp$	0.19	0.23

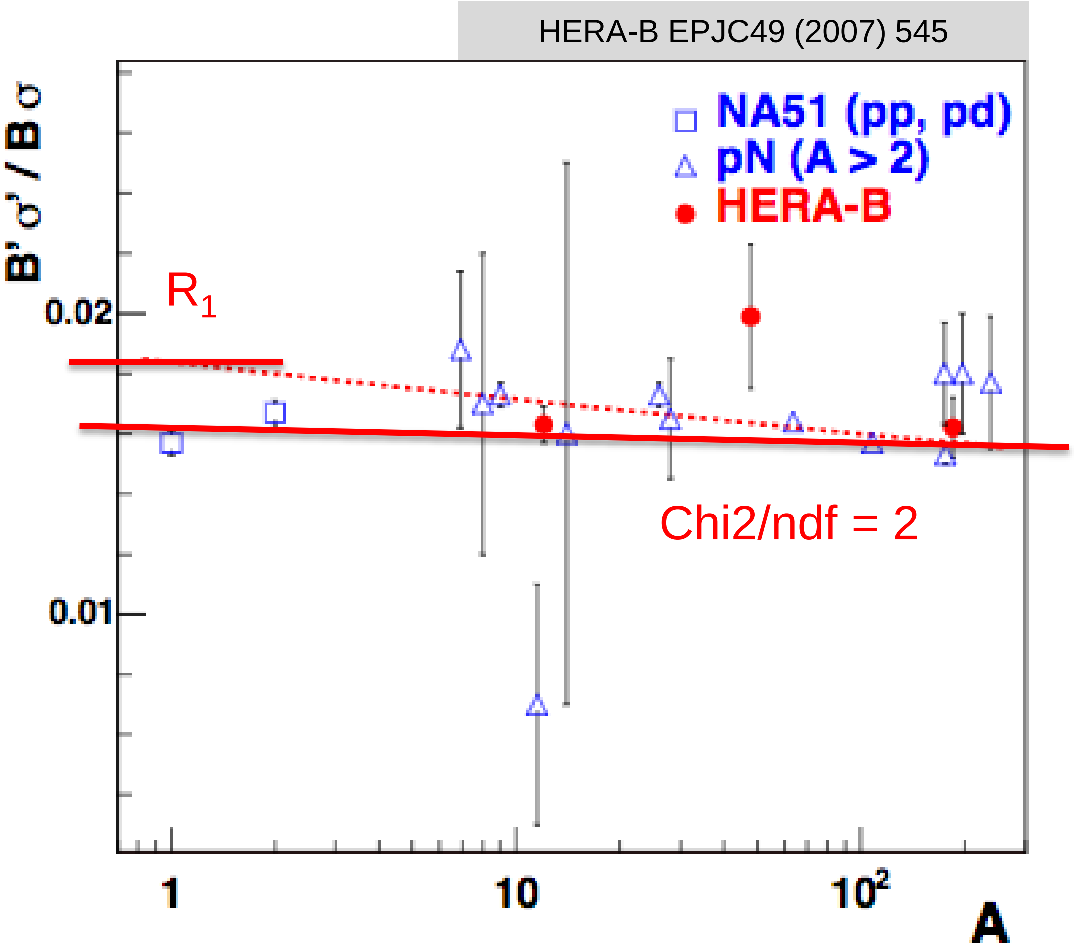


Marvelous paper of Hoyer & Peigné PRD61 (2000) 031501

Psi(2S)/Jpsi ratio in p-A collisions

1. at low Energies (20-50 GeV)
2. d-Au at RHIC energies
3. p-Pb at LHC energies

p-A at 20-50 GeV



Inter-experiment results in agreement with constant Psi(2S)/Jpsi ratio with A

But compatible with $R = R_1 \times A^{\Delta\alpha}$

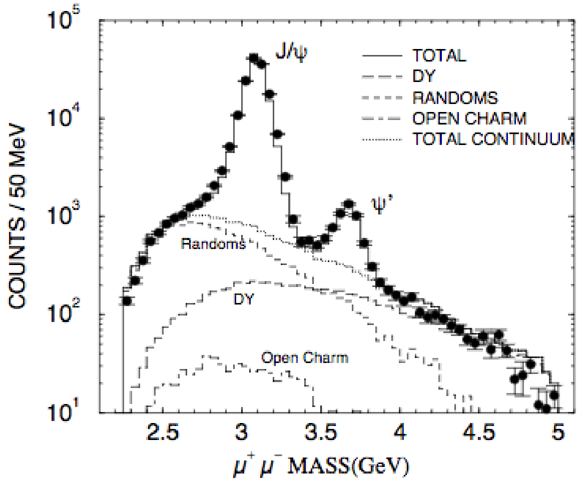
$R_1 = 0.139 \pm 0.006$

$\Delta\alpha = -0.030 \pm 0.004$

$$\frac{BR(J/\psi \rightarrow \text{dilepton})}{BR(\psi(2S) \rightarrow \text{dilepton})} = 7.56 \pm 0.15$$

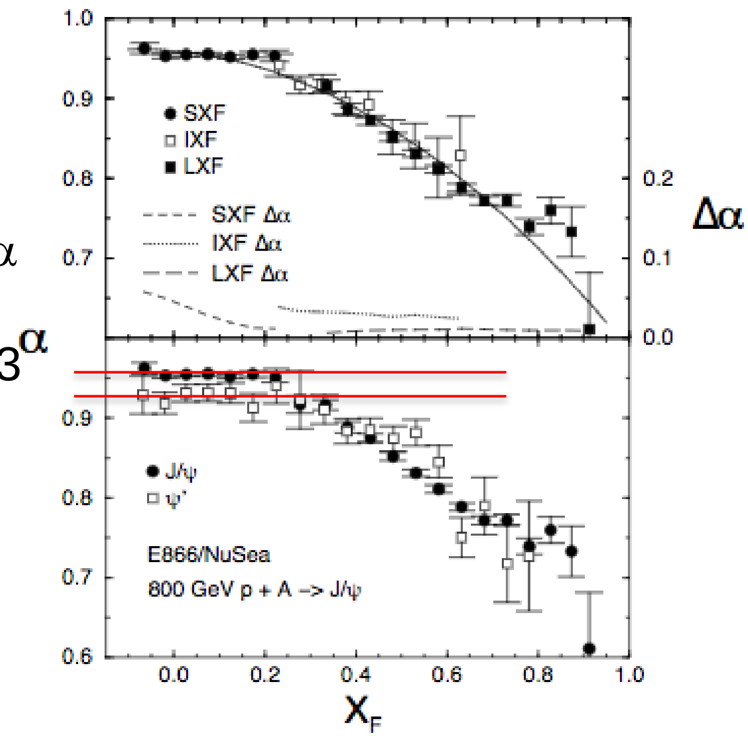
Relative Psi(2S) to Jpsi suppression at low energies

p-A sqrt(s) 39 GeV
Be, Fe, W
Relative measurement



E866 NuSea PRL84 (2000) 3256

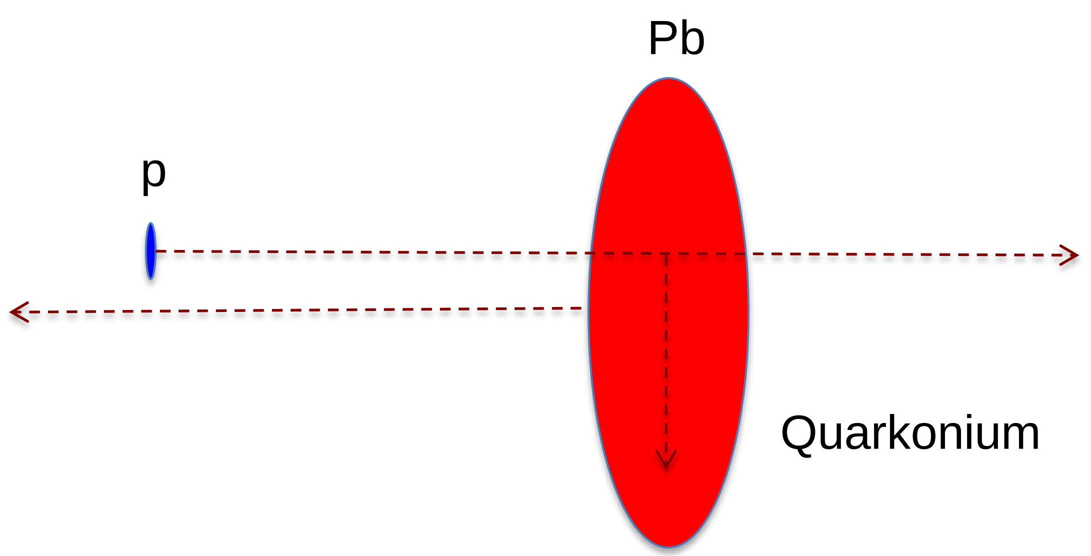
Compatible with $\Delta\alpha$ =-0.030
Relative error 0.003



Intra-experiment results (better precision) confirms the dependence $A^{\Delta\alpha}$. Less than 20% relative suppression for p-Pb

Crossing time

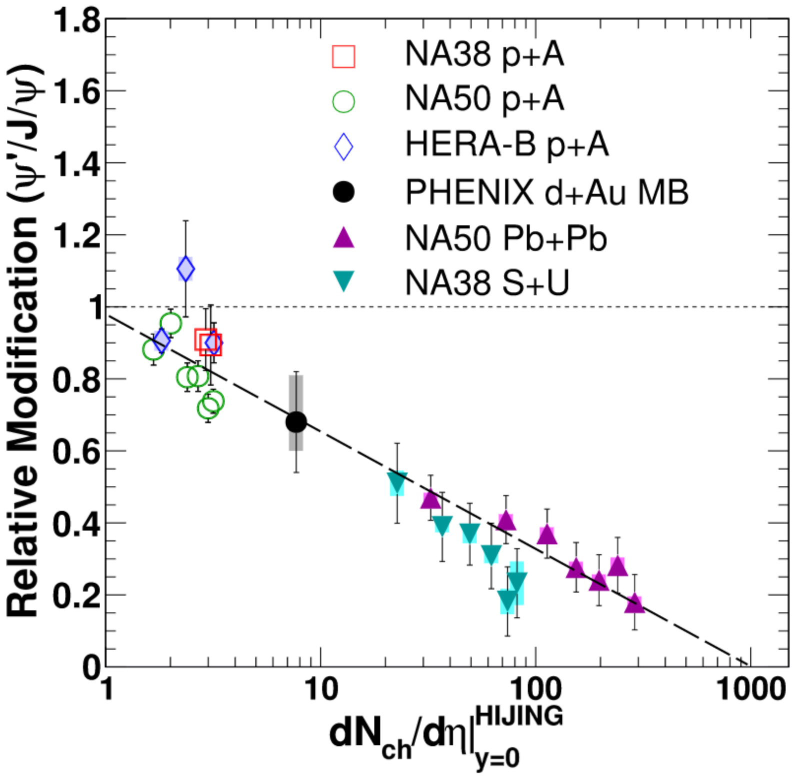
$\langle D\rangle = 4R/3$
$\gamma = \cosh(y_A - y_0)$
$yA = -\ln(\text{sqrt}(s)/m_N)$
$t_c = 2R/3\gamma$



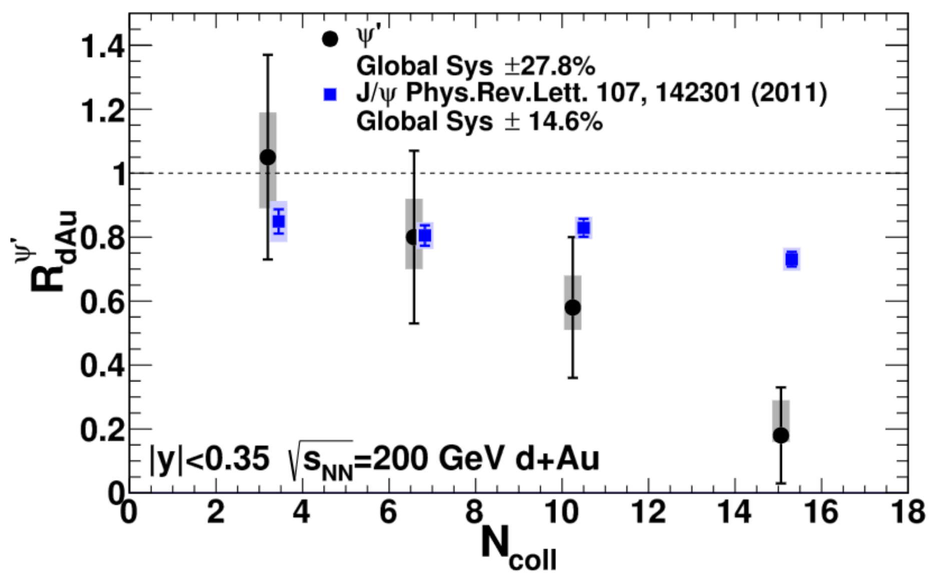
sqrt(s) (GeV)	y_A	Backward (fm/c)	Mid-rapidity (fm/c)	Forward (fm/c)
20	3.0	1.2 (y_0=-1)	0.44 (y_0=0)	0.16 (y_0=1)
200	5.4	0.30 (y_0=-2)	0.04 (y_0=0)	0.005 (y_0=2)
5000	8.6	0.09 (y_0=-4)	0.002 (y_0=0)	0.00003 (y_0=4)

Charmonium nuclear absorption is not possible at high energies since quarkonium is formed out side of the nucleus

d-Au by PHENIX at RHIC

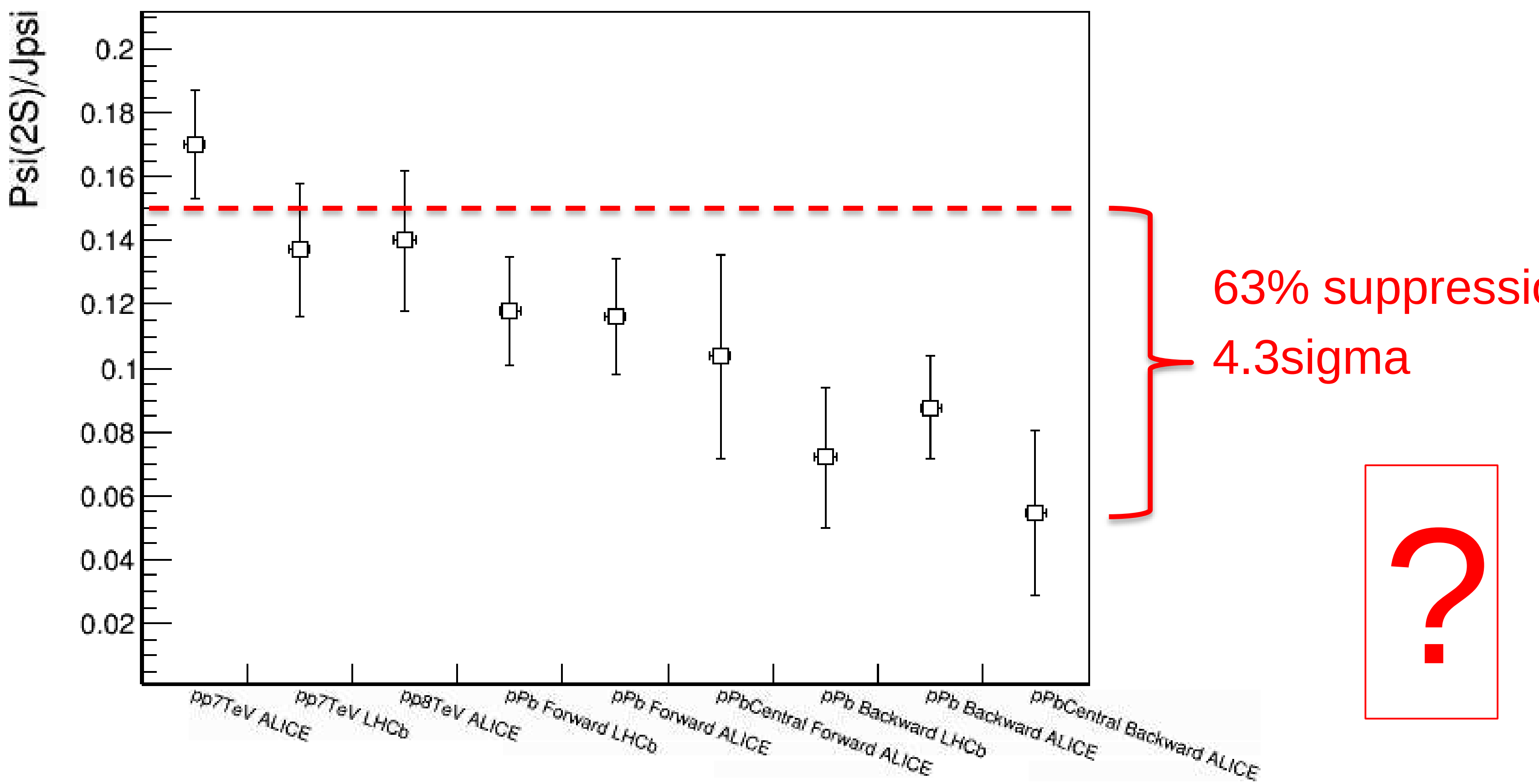


PHENIX PRL111 (2013) 20



Hint for relative suppression of the Psi(2S) yield with respect to the Jpsi

Psi(2S) to Jpsi relative suppression in p-Pb at the LHC



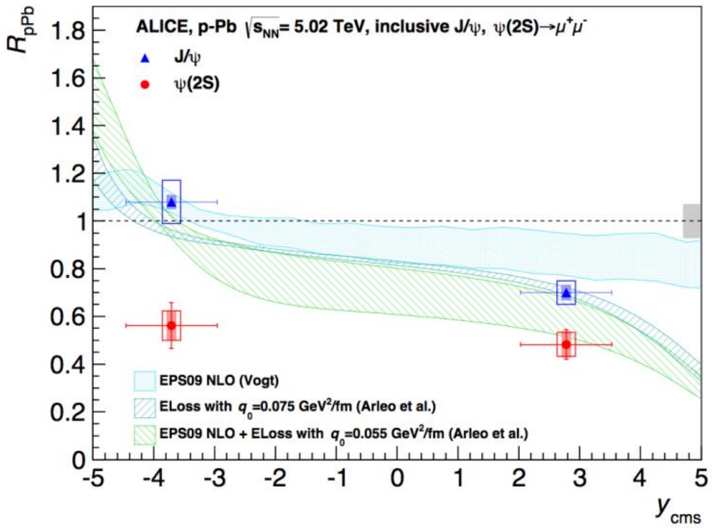
ALICE JHEP 12 (2014) 073, LHCb JHEP 03 (2016) 133, ALICE JHEP 06 (2016) 050

1. Chic contribution?

If chic contribution increases, the direct ratio could not change. But:

- Cannot explain upsilon measurements
- Increase with centrality
- Chic contribution about 67% in central collisions at backward rapidity.
- Chic R_{pPb} about 2.3 in central p-Pb at backward collisions
- Which physics is behind?

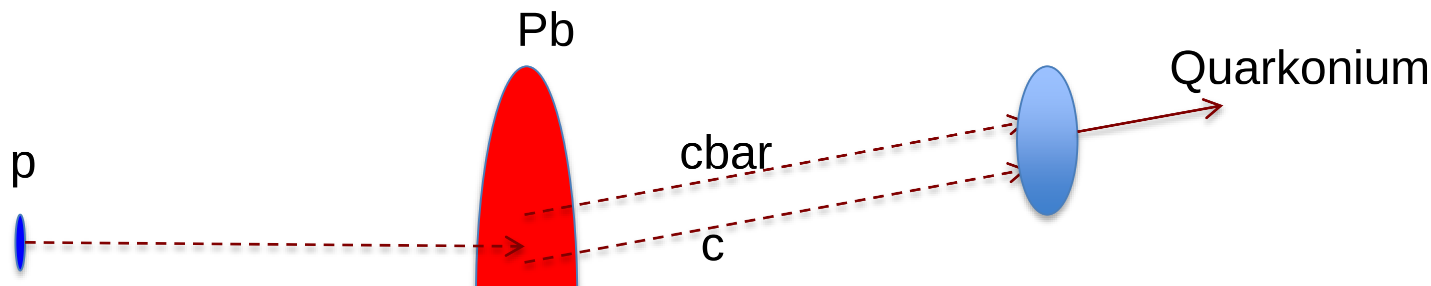
$$R^{D}_{J/\psi/\Psi(2S)} = \frac{Y^{D}_{J/\psi}}{Y^{D}_{\Psi(2S)}} = \frac{R^{P}_{J/\psi/\Psi(2S)}}{1 - R_{\chi_c \to J/\psi} - 0.609 R^{P}_{J/\psi/\Psi(2S)}}$$



Chic contribution in p-Pb has to be measured by LHCb experiment

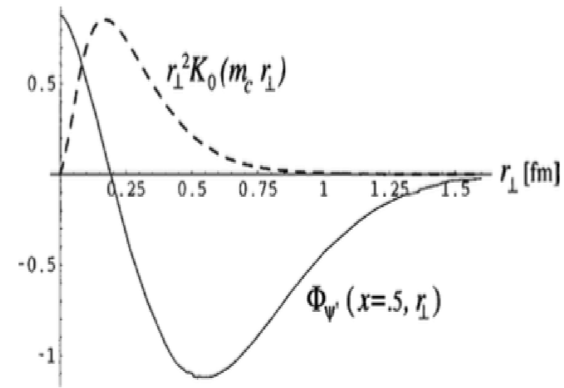
ALICE JHEP 12 (2014) 073, LHCb JHEP 03 (2016) 133, ALICE JHEP 06 (2016) 050

2. Modification of the wave function of the ccbar pair



If the initial wave function of the c-cbar is enlarged, Psi(2S)/Jpsi ratio decreases due to the Psi(2S) node effect:

- Which is the physics behind?



Hoyer & Peigné PRD61 (2000) 031501

Measurement of the Psi(2S)/Jpsi yield ratio in high multiplicity pp collisions has to be measured by ALICE and/or LHCb experiments

3. Final state effects

Which is the initial hadron density at hadronization?

$$\rho_{\mathrm{h}} \approx \frac{3}{2} \times \frac{dN_{\mathrm{ch}}}{dy} \times \frac{1}{V_{\mathrm{h}}}$$

$$V_{\mathrm{h}} \approx \pi(r_{NN} + \tau_{\mathrm{h}} c)^2 \times (\tau_c + \tau_{\mathrm{h}})c$$

$$\left.\frac{dN_{\mathrm{ch}}}{dy}\right|_{y=0} \approx \left.\frac{dN_{\mathrm{ch}}}{d\eta}\right|_{\eta=0} = \langle N_{\mathrm{part}}\rangle \times \left(\frac{\sqrt{s_{\mathrm{NN}}}}{100\ \mathrm{GeV}}\right)^{0.2}$$

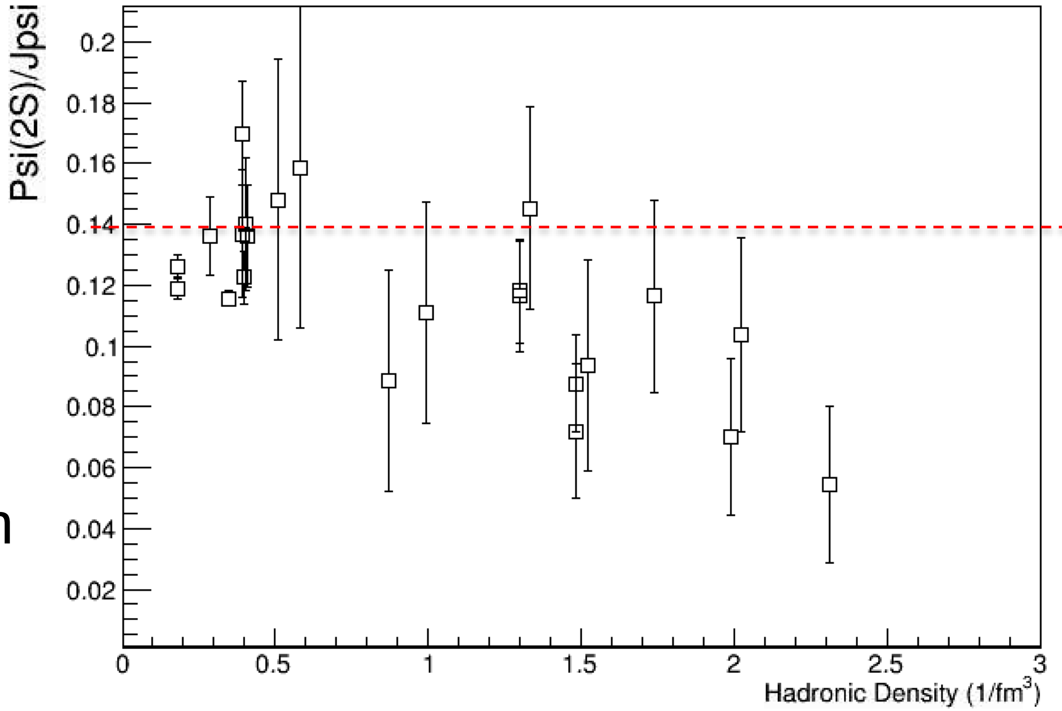
r_{NN} = 1 fm/c, t_c crossing time, t_h = 1 fm/c

From EPOS:
LHC backward dNch/dy = 0.77 x |dNch/deta|_eta=0
LHC forward dNch/dy = 0.63 x |dNch/deta|_eta=0

Bjorken PRD27 (1983) 140, PHENIX NPA (2005) 184, Bozek et al PRC88 (2013) 014903, ALICE PRL110 (2013) 032301, EPOS K. Werner Private Mitteilungen

Psi(2S)/Jpsi versus rho_H

- No suppression at low energy pA. Hadron density < 1 fm^3
- Similar hadron density in pA at low energy and pp at LHC
- Relatively good scaling with the experimental results
- Larger at LHC backward than LHC forward
- At the LHC, hadron density above 1 fm^3

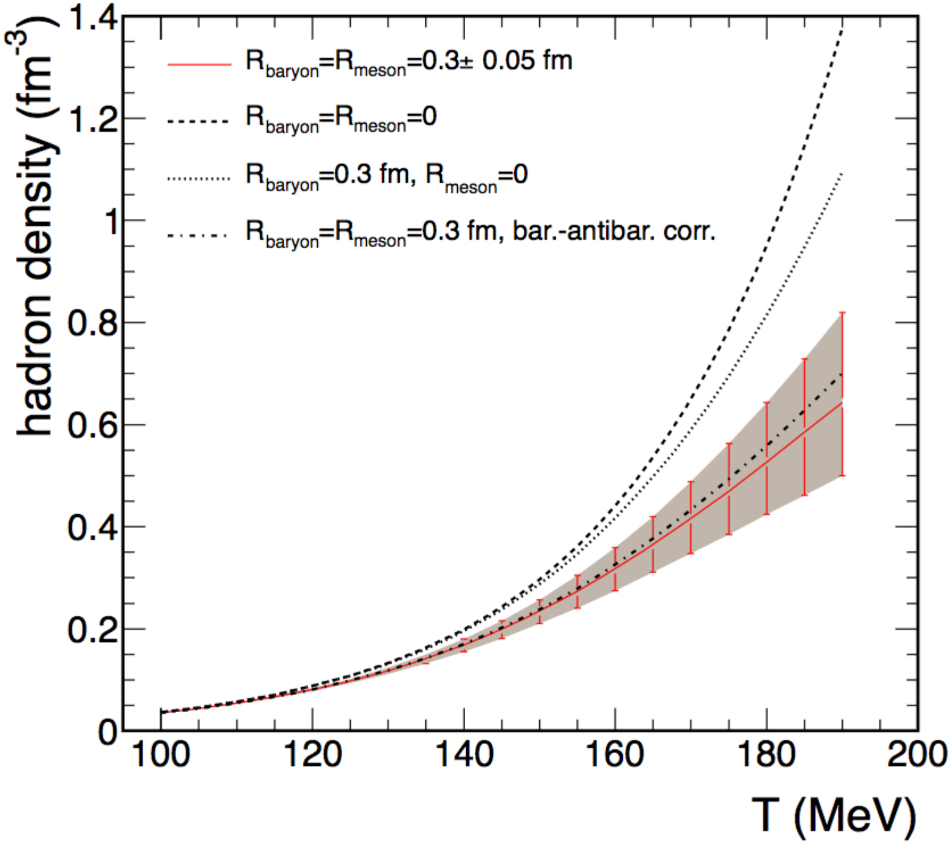


Measurement of the Psi(2S)/Jpsi yield ratio in high multiplicity pp collisions has to be measured by ALICE and/or LHCb experiments

Psi(2S)/Jpsi at mid-rapidity has to be measured by ALICE experiment

Hadron Density in equilibrium

- Hadron density above 06-1 fm^{-3} not possible
- Above it parton degrees of freedom appears
- Hadronisation in p-A at the LHC could take longer than 1/L$_{QCD}$
- Many parton interactions in the final stage cannot be neglected for hadron densities above 1 fm^{-3}



Andronic et al PLB718 (2012) 80

Dissociation Temperatures

state	χ_c	ψ'	J/ψ	Υ'	χ_b	Υ
T_{dis}	$\leq T_c$	$\leq T_c$	$1.2T_c$	$1.2T_c$	$1.3T_c$	$2T_c$

Colour screening

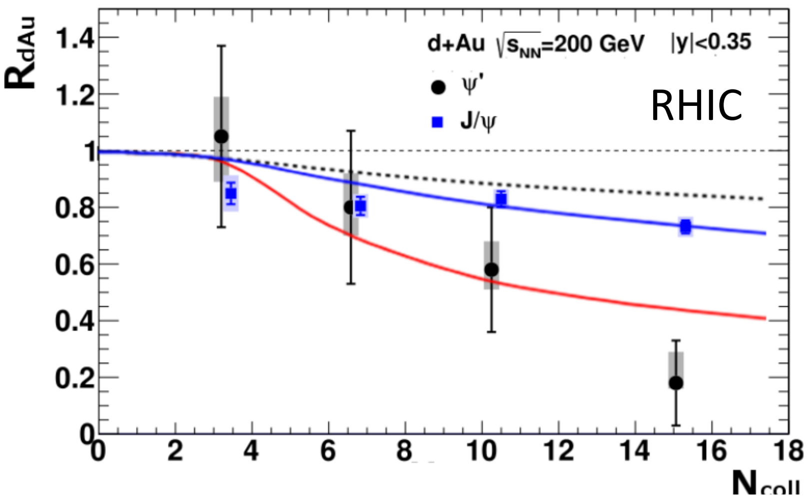
Mocsy & Petreczky PRL99 (2007) 211602

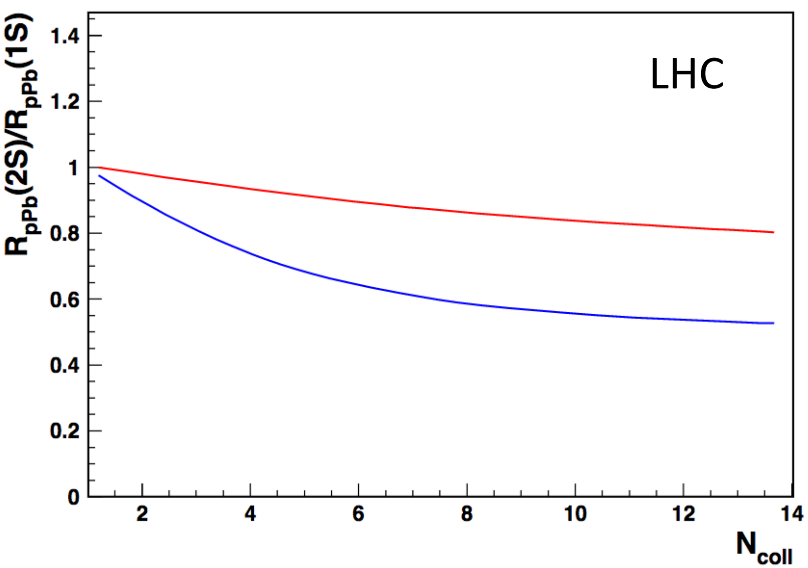
- Chic and Psi(2S) dissolves at temperatures below QGP transition temperature.
- Is this what we are observing in p-Pb collisions at LHC energies?

If chic dissolves, direct Psi(2)/Jpsi suppression could even be stronger.
Chic contribution in p-Pb has to be measured by LHCb experiment

Dissociation by comovers

Ferreiro PLB749 (2015) 98





A final state effect

Excellent description of the experimental data on Psi(2S)/Jpsi at RHIC and at the LHC

- What is a comover?
- Psi(2S) is formed and then destroyed.
- dN_{ch}/deta ≠ dN_{ch}/dy at large rapidities

Measurement azimuthal dependence of the Psi(2S)/Jpsi yield in pp and p-Pb collisions

Conclusion

- Suppression of the Psi(2S)/Jpsi in p-Pb collision at the LHC is an intriguing result
- It seems a final state effect. It could explain upsilon results in pp and p-Pb collisions
- My favourite interpretation is the colour screening of the c-cbar potential due to high colour density in p-Pb collisions at the LHC

- Other alternative physics explanations cannot be excluded: chic, c-cbar wave function modification, comovers
- Which are the experimental measurement to disentangle among the explanation (next slide)?

Propectives

- Measurement of the chic contribution in p-Pb collisions Measurement of the Psi(2S)/Jpsi ratio in high multiplicity pp collisions
- Measurement of the Psi(2S)/Jpsi ratio in p-Pb at mid-rapidity
- Measurement of azimuthal evolution of the Psi(2S)/Jpsi ratio in p-Pb collisions
- Measurement of p_T evolution of the Psi(2S)/Jpsi ratio in p-Pb collisions (improving the experimental precision)
- What transport models applied to p-Pb collisions tells us?

Au boulot!

LHCb

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A JOURNEY OF DISCOVERY