Some notes about pp and more…

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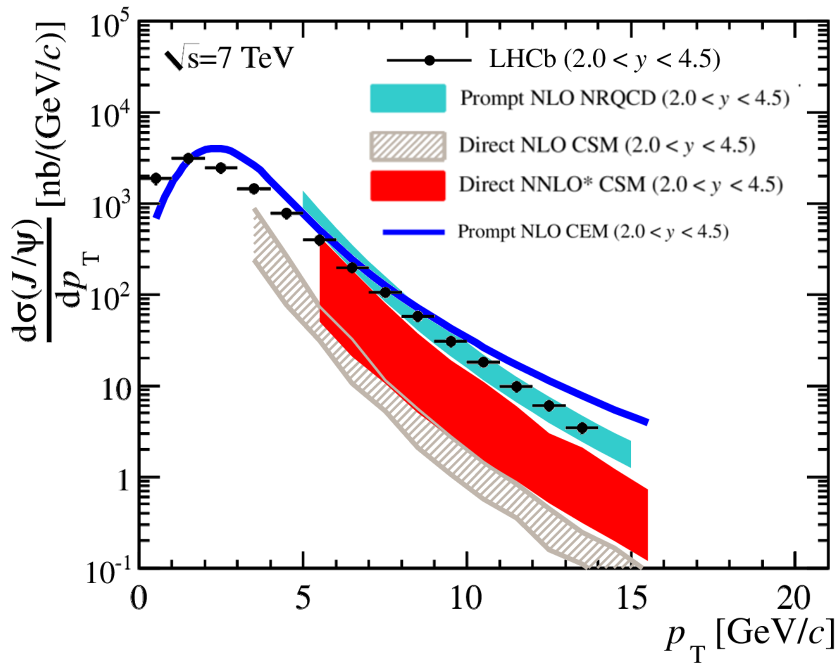
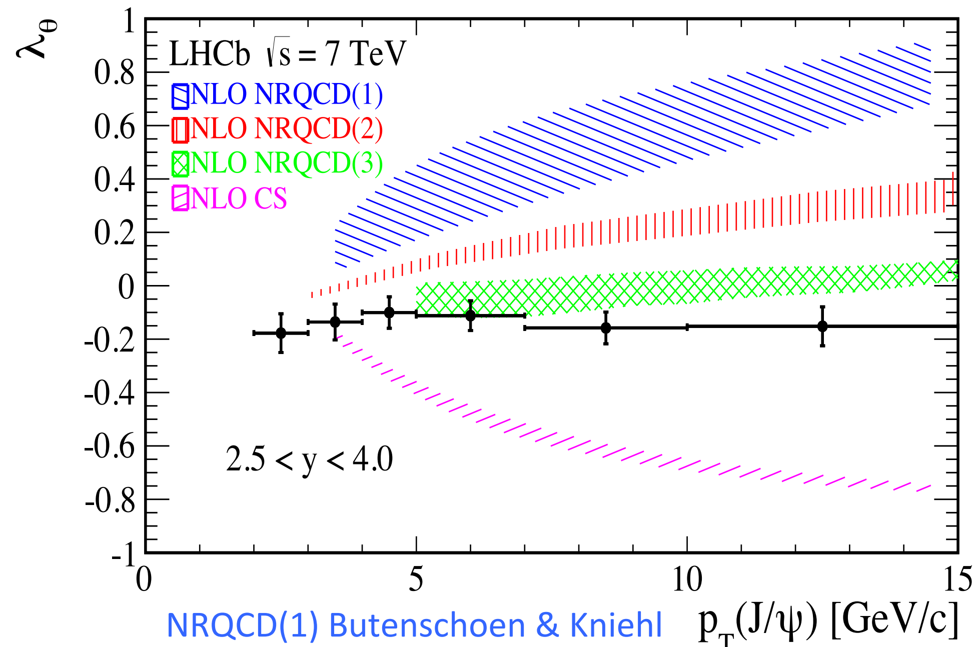
State of the art for the J/Ψ



Sapore Gravis Review arXiv:1506.03981



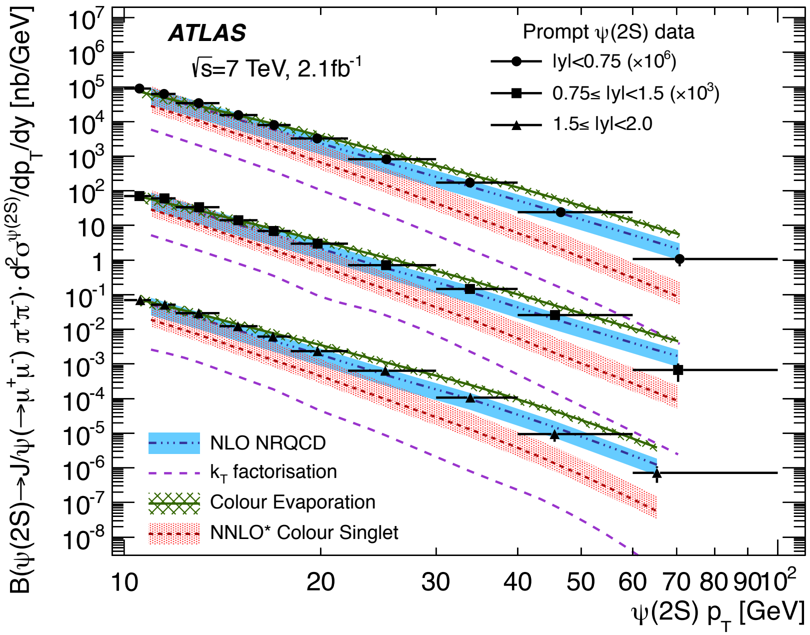
NRQCD(1) Butenschoen & Kniehl

NRQCD(2) Gong et al.

NRQCD(3) Chao et al.

At low and mid p_T –which is the region where quarkonium heavy-ion studies are mainly carried out– none of the models can simply be ruled out owing to their theoretical uncertainties (heavy-quark mass, scales, non-perturbative parameters, unknown QCD and relativistic corrections, ...).

State of the art for the Ψ(2S)



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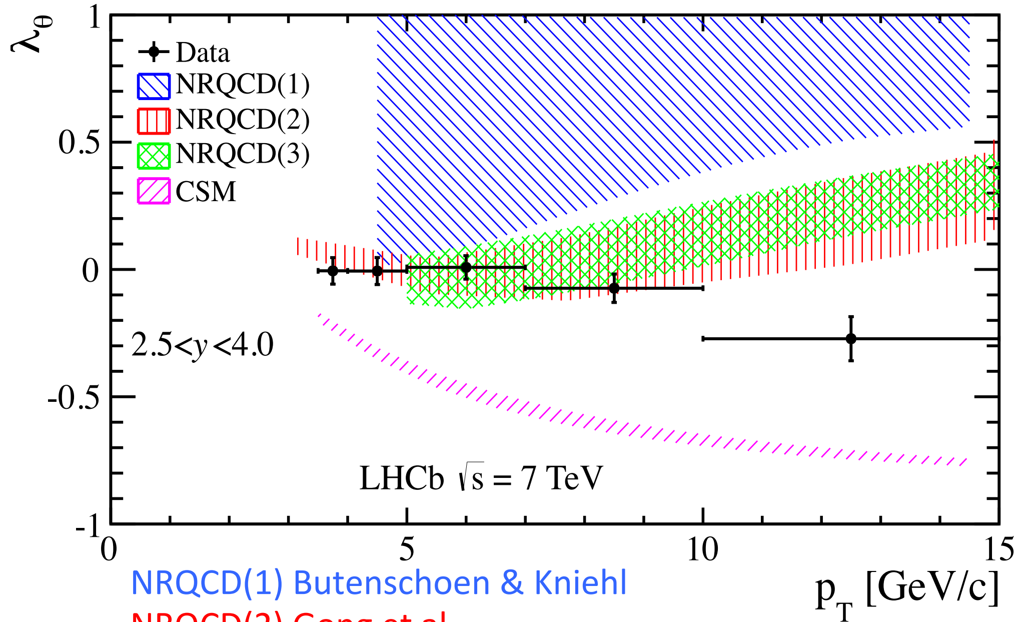

NRQCD(1) Butenschoen & Kniehl
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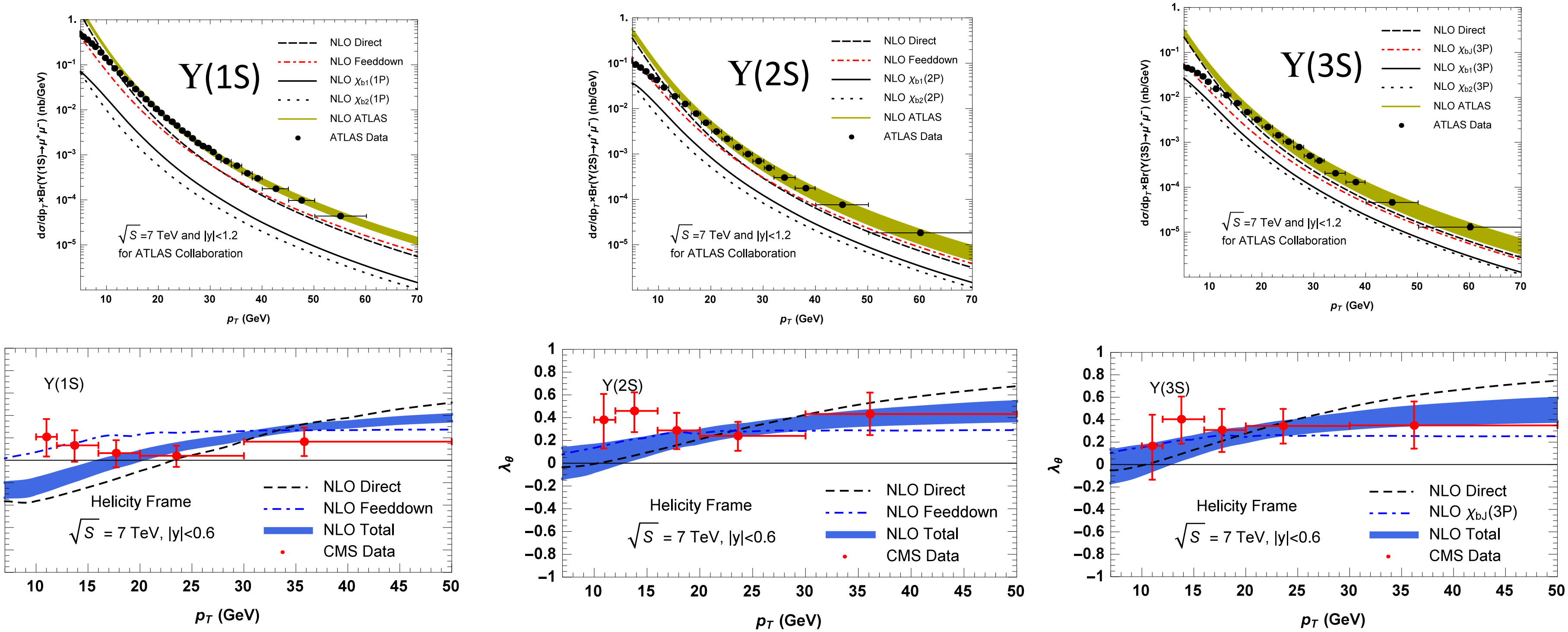
At low and mid p_T –which is the region where quarkonium heavy-ion studies are mainly carried out– none of the models can simply be ruled out owing to their theoretical uncertainties (heavy-quark mass, scales, non-perturbative parameters, unknown QCD and relativistic corrections, ...).

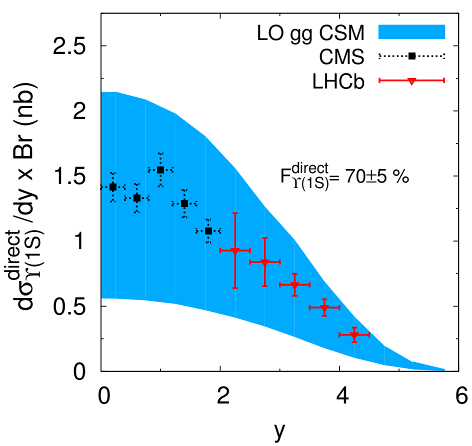
State of the art for the Υ

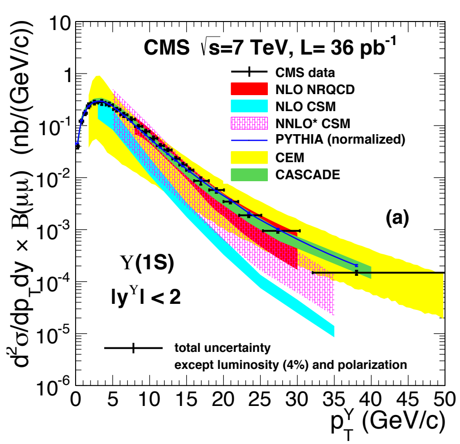
- Larger mass, higher scale and slower velocity could make Υ a better candidate for NRQCD

Hang et al.



Lansberg





- None of the models can simply be ruled out due to their theoretical uncertainties
- Rapidity dependence of the Υ(1S) in line with the CS expectations -no evidence of CO contributions nor excluded-
- In general, LHC data are much more precise than theory

New developments on production

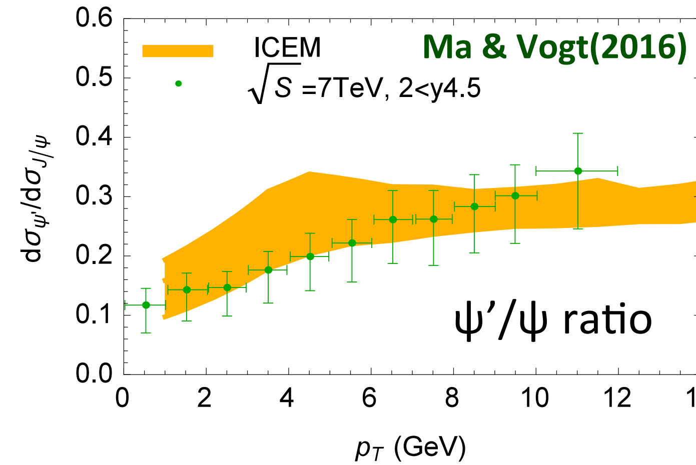
- Color Evaporation Model (CEM) Improved

$$\sigma_Q^{(N)LO} = F_Q \int_{2m_Q}^{2m_H} \frac{d\sigma_{Q\bar{Q}}^{(N)LO}}{dm_{Q\bar{Q}}} dm_{Q\bar{Q}}$$

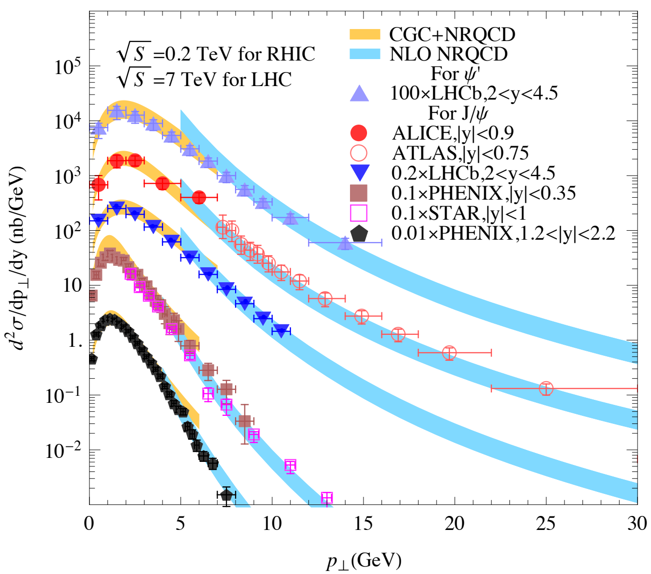
changes to M_ψ

- Explicit charmonium mass dependence
  => ψ'/ψ ratio no longer p_T independent
- Relates $\langle p_\psi \rangle$ to the $c\bar{c}$ pair momentum
  => explain the high p_T data better
- LO calculation of quarkonium polarization in the CEM, longitudinal polarized @ LHC

Cheung & Vogt(2017)



- Saturation meets NRQCD



- Uses Color Glass Condensate saturation model of gluon distributions in the proton with NLO NRQCD matrix elements
- Saturation physics at low p_T, normal collinear factorization at high p_T, matching at intermediate p_T

Ma, Venugopalan & Zhang (2015)

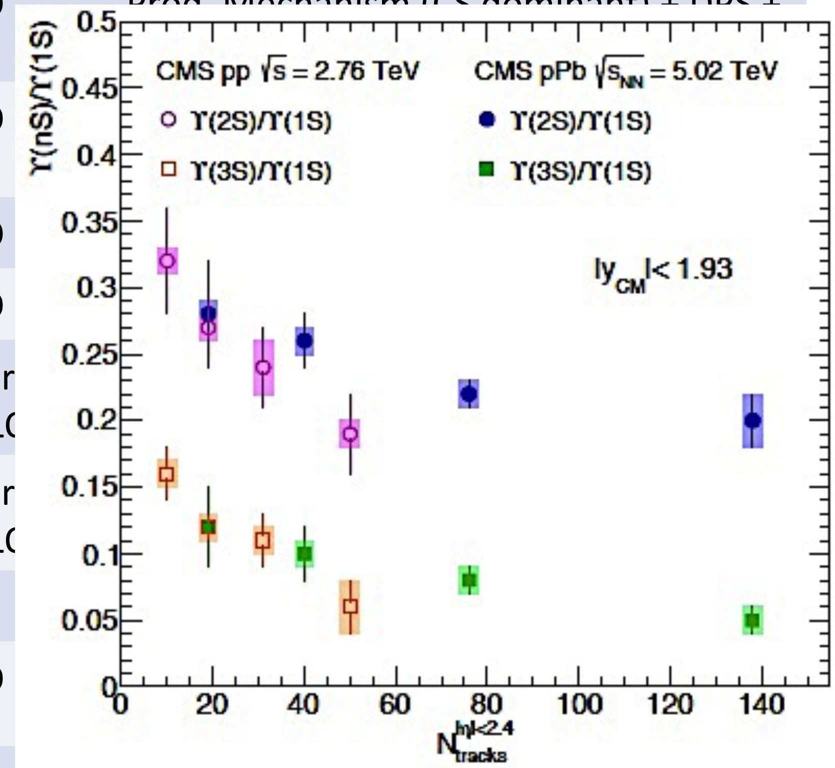
New observables

Observables	Experiments	CSM	CEM	NRQCD	Interest
J/ψ+J/ψ	LHCb, CMS, ATLAS, D0 (+NA3)	NLO, NNLO*	LO ?	LO	Prod. Mechanism (CS dominant) + DPS + gluon TMD
J/ψ+D	LHCb	LO	LO ?	LO	Prod. Mechanism (c to J/psi fragmentation) + DPS
J/ψ+ϒ	D0	(N)LO	LO ?	LO	Prod. Mechanism (CO dominant) + DPS
J/ψ+hadron	STAR	LO	--	LO	B feed-down; Singlet vs Octet radiation
J/ψ+Z	ATLAS	NLO	NLO	Partial NLO	Prod. Mechanism + DPS
J/ψ+W	ATLAS	LO	LO ?	Partial NLO	Prod. Mechanism (CO dominant) + DPS
J/ψ vs mult.	ALICE,CMS (+UA1)	--	--	--	Density effects (Saturation/Hydro)
J/ψ+b	-- (LHCb, D0, CMS ?)	--	--	LO	Prod. Mechanism (CO dominant) + DPS
ϒ+D	LHCb	LO	LO ?	LO	DPS
ϒ+γ	--	NLO, NNLO*	LO ?	LO	Prod. Mechanism (CO LDME mix) + gluon TMD/PDF
ϒ vs mult.	CMS	--	--	--	Density effects (Saturation/Hydro)
ϒ+Z	--	NLO	LO ?	LO	Prod. Mechanism + DPS
ϒ+ϒ	CMS	NLO?	LO?	LO?	Prod. Mechanism + DPS + gluon TMD

Lansberg (2018)

New observables

Observables	Experiments	CSM	CEM	NRQCD	Interest
J/ψ+J/ψ	LHCb, CMS, ATLAS, D0 (+NA3)	NLO, NNLO*	LO ?	LO	Prod. Mechanism (CS dominant) + DPS +
J/ψ+D	LHCb	LO	LO ?	LO	
J/ψ+ϒ	D0	(N)LO	LO ?	LO	
J/ψ+hadron	STAR	LO	--	LO	
J/ψ+Z	ATLAS	NLO	NLO	Par NL	
J/ψ+W	ATLAS	LO	LO ?	Par NL	
J/ψ vs mult.	ALICE,CMS (+UA1)	--	--	--	
J/ψ+b	-- (LHCb, D0, CMS ?)	--	--	LO	
ϒ+D	LHCb	LO	LO ?	LO	DPS
ϒ+γ	--	NLO, NNLO*	LO ?	LO	Prod. Mechanism (CO LDME mix) + gluon TMD/PDF
ϒ vs mult.	CMS	--	--	--	Density effects (Saturation/Hydro)
ϒ+Z	--	NLO	LO ?	LO	Prod. Mechanism + DPS
ϒ+ϒ	CMS	NLO?	LO?	LO?	Prod. Mechanism + DPS + gluon TMD

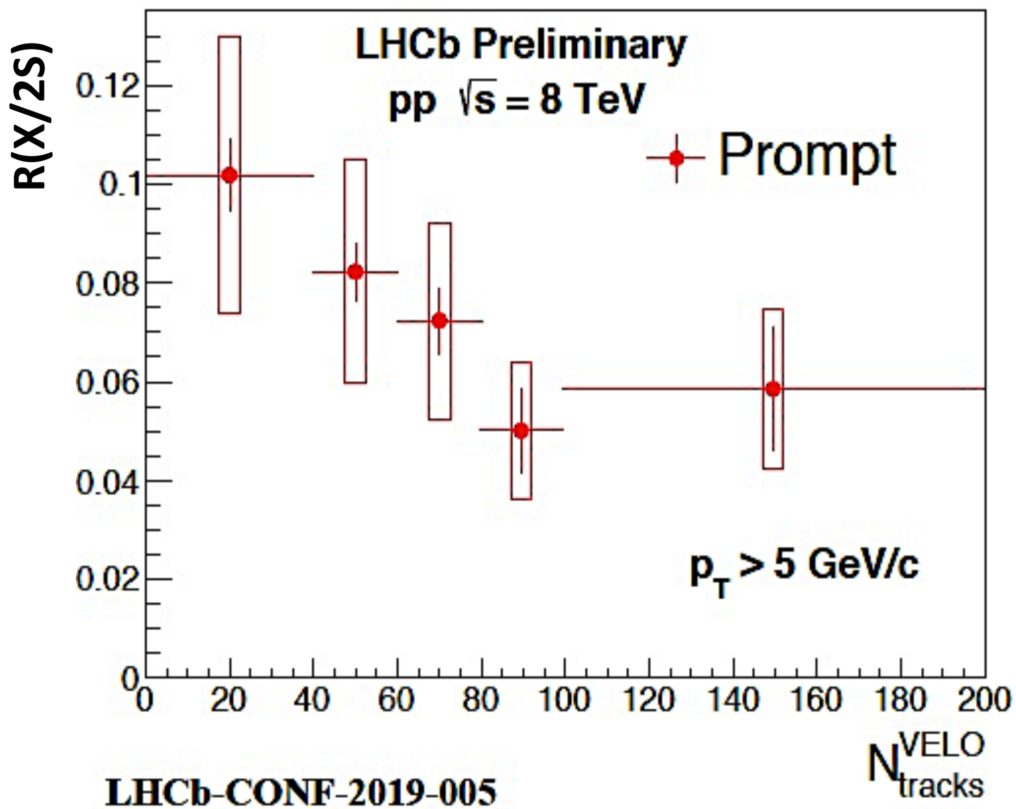


Lansberg (2018)

The nature of the X(3872)

In collaboration with L. Maiani, A. Polosa and C. Salgado

- Motivation: recent LHCb results on X(3872) versus multiplicity



LHCb-CONF-2019-005

The nature of the X(3872): interaction cross sections

- Considering the following binding energies and sizes:

	$E^{Q}_{\rm thr}$	r_Q	$\sigma^{Q}_{\rm geo}$
$\psi(2S)$	50 MeV	0.45 fm	6.36 mb
X(3872) tetraquark	21 MeV	0.65 fm	13.27 mb
X(3872) molecular	0.01 MeV	3.5 fm	384.84 mb

For the 2S: Satz 0512217
For the X tetraquark: Esposito,Polosa 1807.06040
Maiani et al. 0412098
For X molecular: Beveren & Rupp

- Applying the formulae for interaction with the medium:

E. G. F., J.P. Lansberg, arXiv:1804.04474

$$\sigma^{co-\mathcal{Q}_{b\bar{b}}} = \sigma_{\rm geom}\left(1 - \frac{E_{\rm Binding}}{E_{co}}\right)^n$$

$\sigma_{\rm geom} \equiv \pi r^2_{\mathcal{Q}_{b\bar{b}}}$

$E_{\rm Binding} \equiv 2M_B - M_{\mathcal{Q}_{b\bar{b}}}$, *i.e.* the threshold energy

$E^{co} = \sqrt{p^2 + m^2_{co}}$ the average energy of the comovers

- Average over Bose-Einstein distribution of the medium:

$$\langle\sigma^{co-Q}\rangle(T_{\rm eff}, n) = \frac{\int_{E^Q_{\rm thr}}^{\infty} dE^{co}\, \mathcal{P}(E^{co}; T_{\rm eff})\, \sigma^{co-Q}(E^{co})}{\int_{E^Q_{\rm thr}}^{\infty} dE^{co}\, \mathcal{P}(E^{co}; T_{\rm eff})}$$

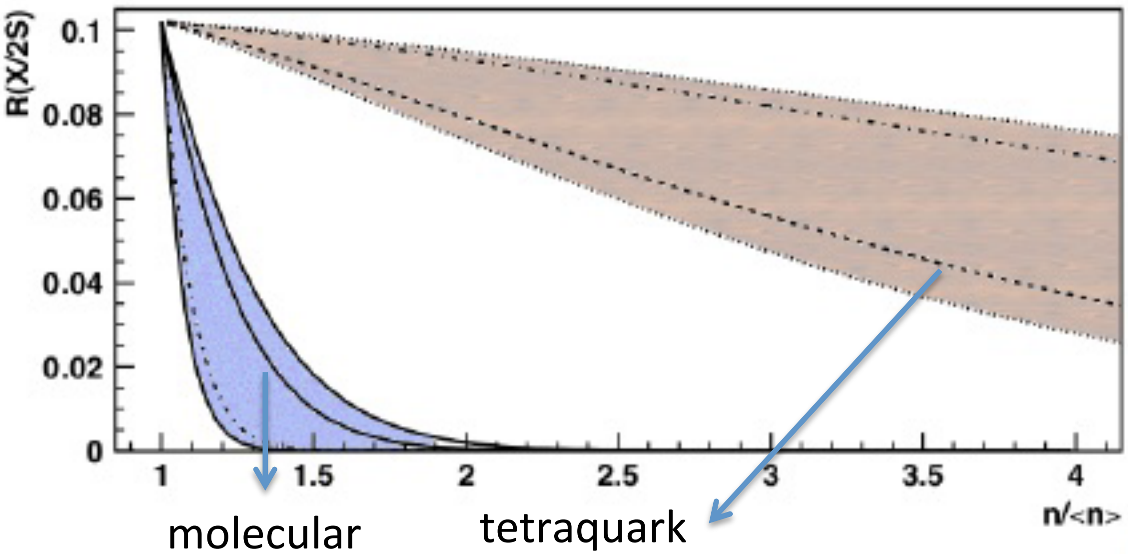
$$\mathcal{P}(E^{co}; T_{\rm eff}) \propto 1/(e^{E^{co}/T_{eff}} - 1)$$

With the above values, our results for the averaged comover cross sections are: 5.15 ± 0.84, 11.10 ± 1.56 and 329.43 ± 55.39 mb for the $\psi(2S)$, X(3872) tetraquark and the X(3872) molecular state, respectively. The uncertainty corresponds to the one of the temperature and the nature of the medium, of gluonic or hadronic nature.

Cross sections very close to their geometrical value due to small binding energies

The nature of the X(3872): pp collisions WORK IN PROGRESS

- In order to measure the effects of the comovers with increasing multiplicity, we calculate the rate X(3872)/ψ(2S) vs n/<n> being <n> the mean pp multiplicity



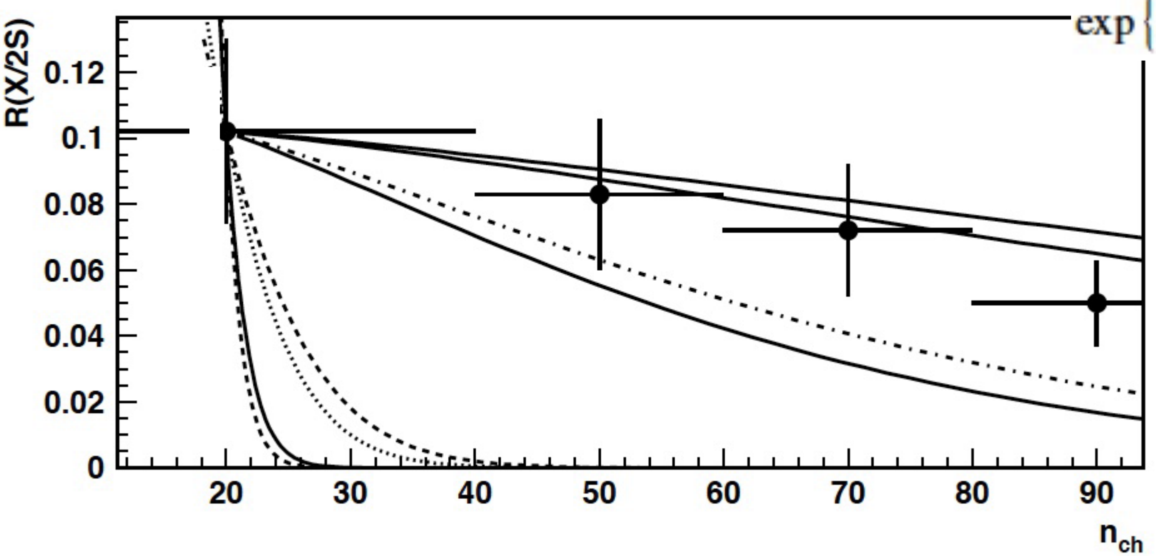
Our results are normalized to the experimental value obtained for the first bin, i.e. 0.1

(no interaction for n=<n>)

$$\tau \frac{d\rho^{\mathcal{Q}}}{d\tau}(b,s,y) = -\sigma^{co-\mathcal{Q}}\,\rho^{co}(b,s,y)\,\rho^{\mathcal{Q}}(b,s,y)$$

$$\exp\left\{-\sigma^{co-Q}\,\rho^{co}(b,s,y)\,\ln\left(\rho^{co}(b,s,y)/\rho_{pp}(y)\right)\right\}$$

n   n/<n>

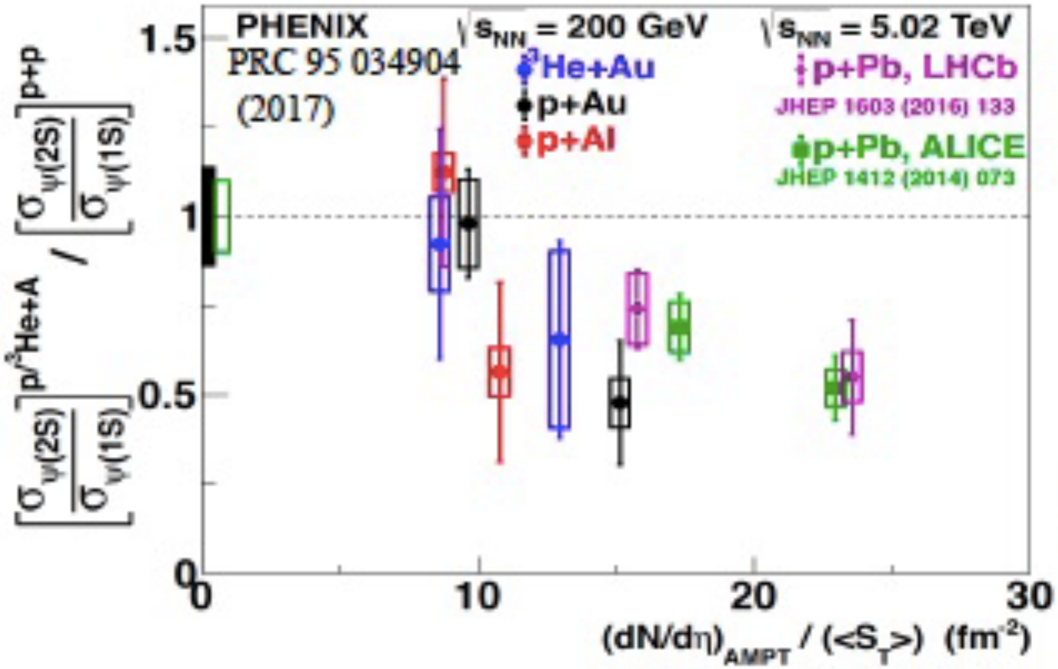


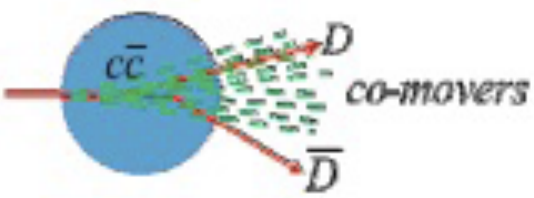
pp collisions at 8 TeV and forward rapidity

LHCb data QM2019

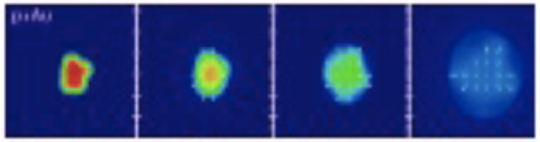
The nature of the X(3872): proton+proton collisions

- Suppression of weakly-bound quarkonia states has bee studied for decades in pA collisions
  - Ratios of $\psi(2S)/_{J/\psi}$ and $\Upsilon(2S,3S)/_{\Upsilon(1S)}$
- In general, final state effects are required to explain difference in suppression between states
-





cf. PLB 749 98 (2015)

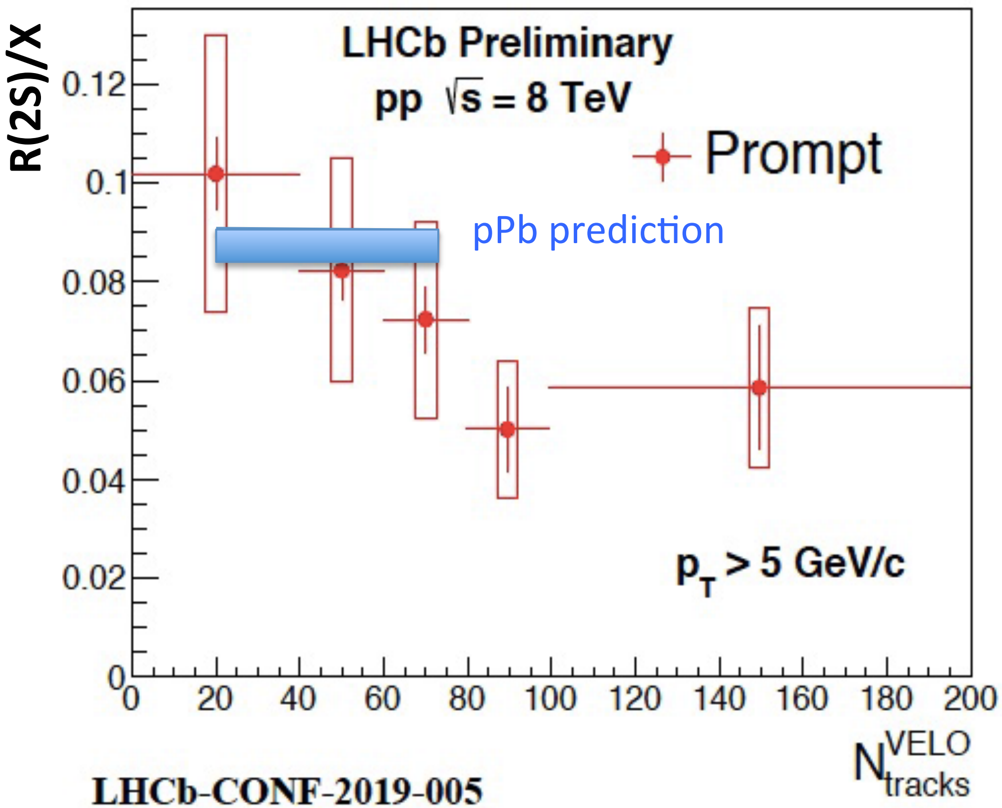


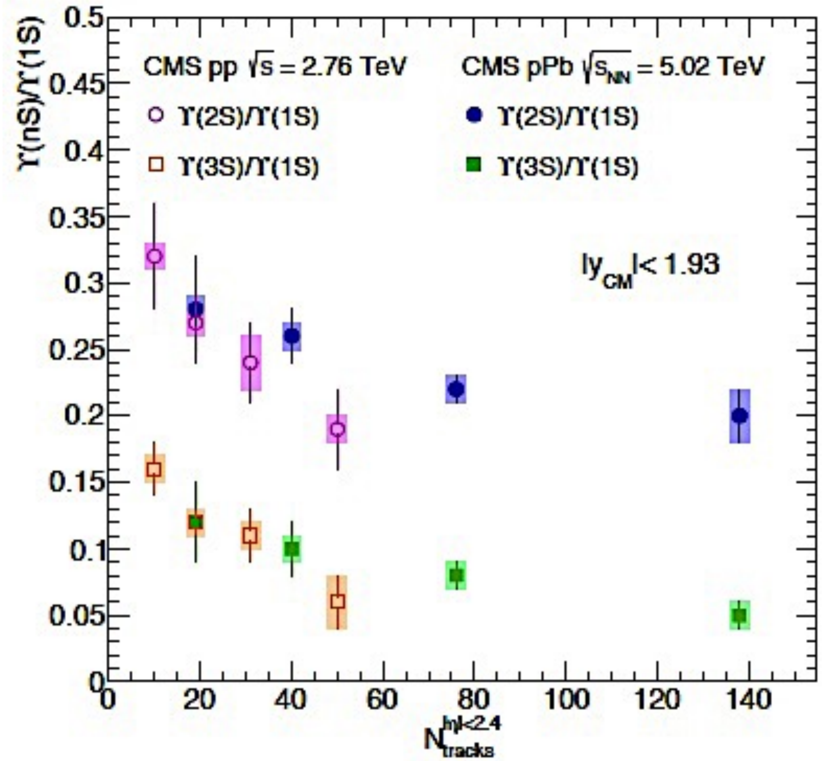
PHENIX, Nature Physics 15 214 (2019)

Durham QM2019

The nature of the X(3872): pp & pPb collisions WORK IN PROG

- In fact, the effect found by LHCb is similar to the one previously found by CMS





Preliminar results from the comover interaction model seem to favorize the tetraquark interpretation

The nature of the X(3872): PbPb collisions

- In case of PbPb collisions, it is neccessary to include recombination

$$\tau \frac{\mathrm{d}\rho^{\mathcal{Q}}}{\mathrm{d}\tau}(b,s,y) = -\sigma^{co-\mathcal{Q}}\, \rho^{co}(b,s,y)\, \rho^{\mathcal{Q}}(b,s,y)$$

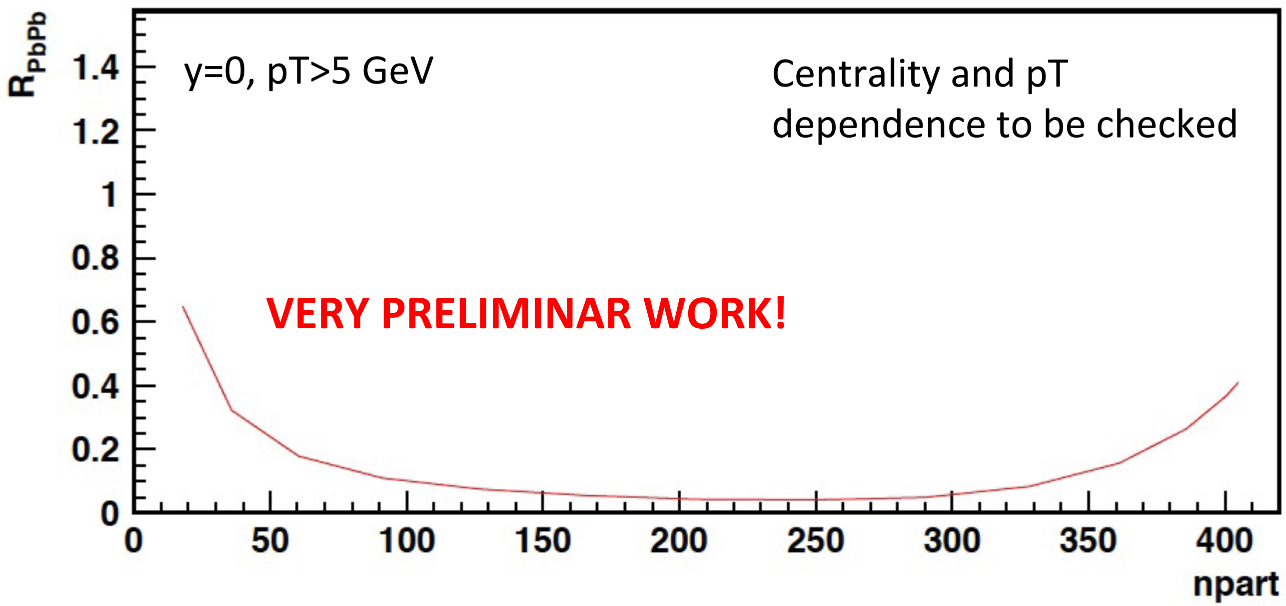
arXiv:0712.4331
arXiv:1210.3209

$\mathrm{d}\sigma_{pp}^{c\bar{c}}/\mathrm{d}y$

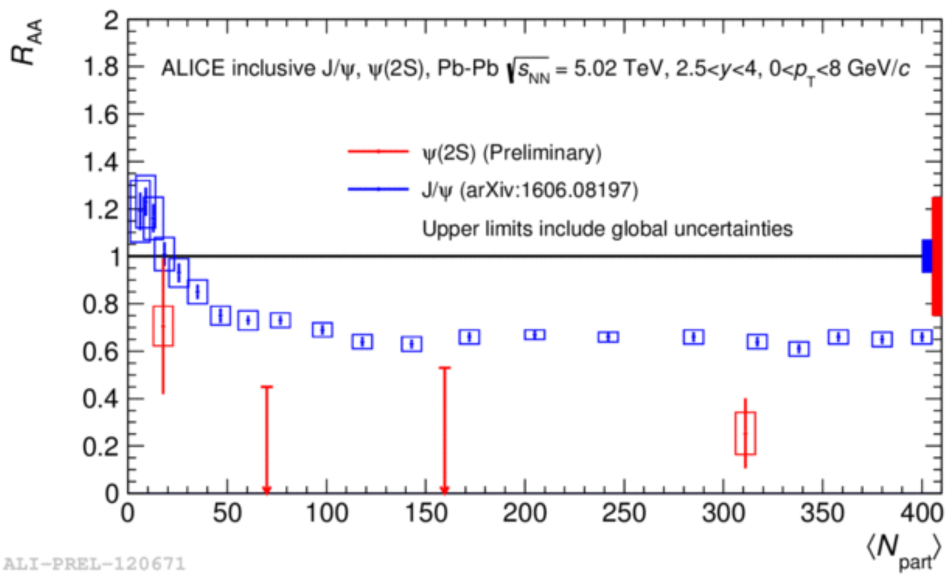
$$\tau \frac{\mathrm{d}\rho^{\mathcal{Q}}}{\mathrm{d}\tau}(b,s,y) = -\sigma^{co-\mathcal{Q}}[\rho^{co}(b,s,y)\, \rho^{\mathcal{Q}}(b,s,y) - \rho_c(b,s,y)\rho_c(b,s,y)]$$

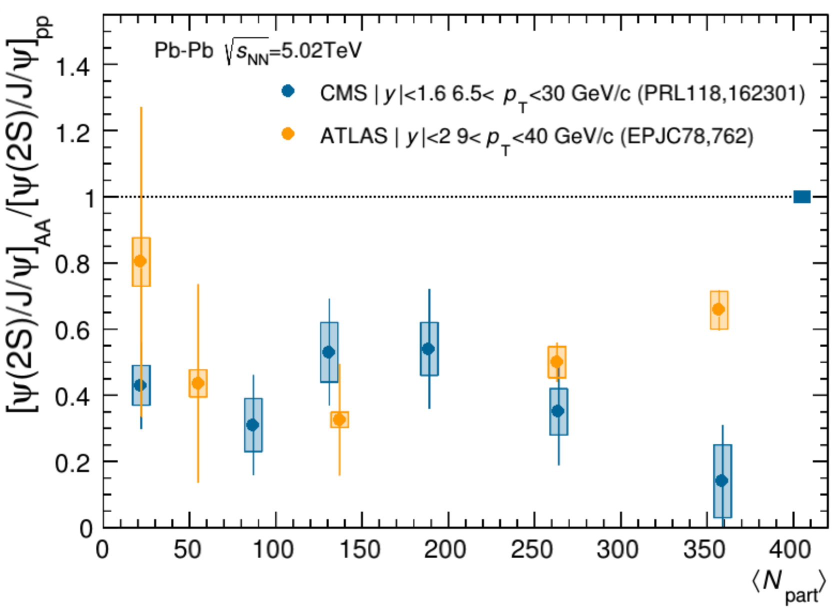
- It is driven by the number of c cbar pairs

PbPb collisions at 5 TeV: result for Ψ(2S)

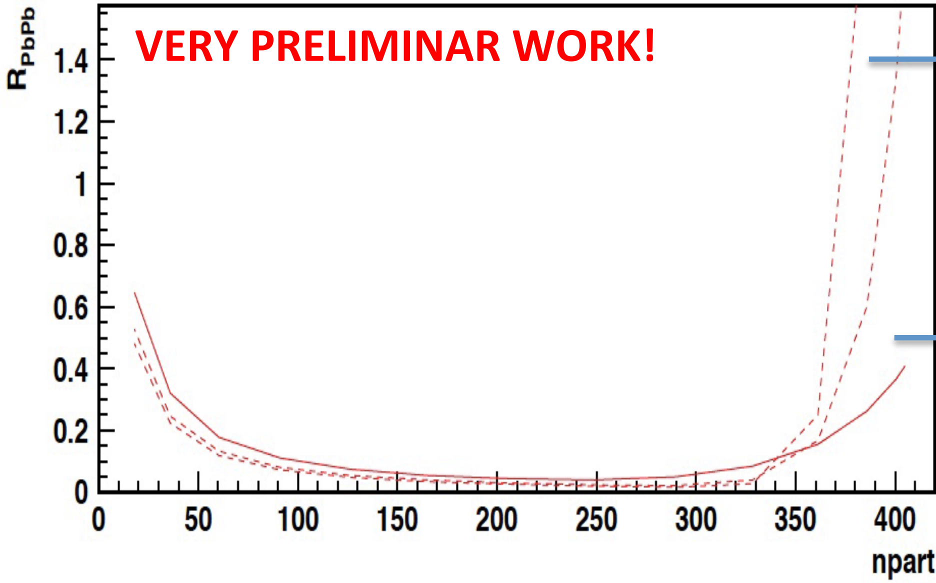


Integrated value:
$R_{PbPb}\psi(2S)$=0.147
to be compared with experimental values
$R_{PbPb}\psi(2S)$=
0.14 +/-0.06 +/-0.02
(15<pT<20 GeV/c)
$R_{PbPb}\psi(2S)$=
0.2187+/-0.1123+/-0.0963
0<pT, forward rapidity





PbPb collisions at 5 TeV: result for $\Psi(2S)$ & X(3872)



Tetraquark from 1 to 1.7 fm

Integrated value:
$R_{PbPb}\psi(2S)$=0.147,
R_{PbPb}(X(3872)=1.239 (for 1.7 fm) to
0.59 (for 1 fm)

2S