Quarkonium production: open and new questions to be answered in hadronic collisions for nucleus-nucleus studies in 2030

J.P. Lansberg

IJCLab Orsay – Paris Saclay U. – CNRS

Prospectives en QCD au delà de 2030

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Impact on quarkonia as QGP tools: likely but non trivial to derive

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- What's next ?

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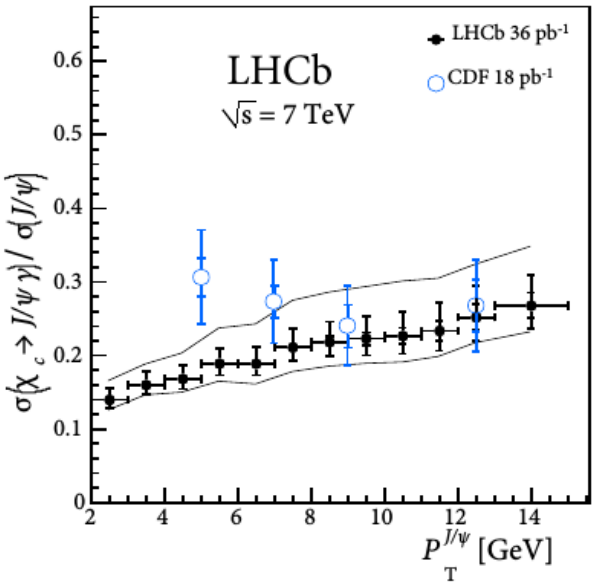
Feed downs from the excited states

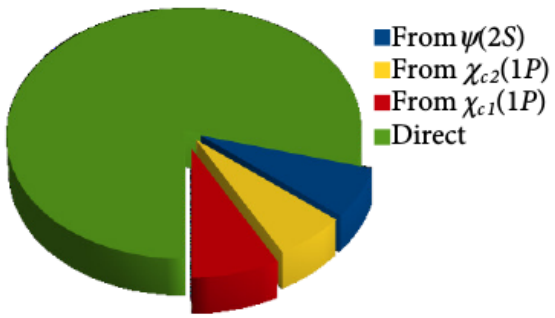
Non trivial kinematical effects

Hadroproduction

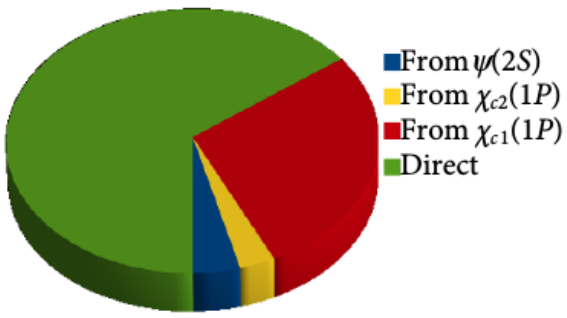
JPL. arXiv:1903.09185 [hep-ph] (Phys.Rept. 889 (2020) 1)



(a)



(b) Low P_T J/ψ



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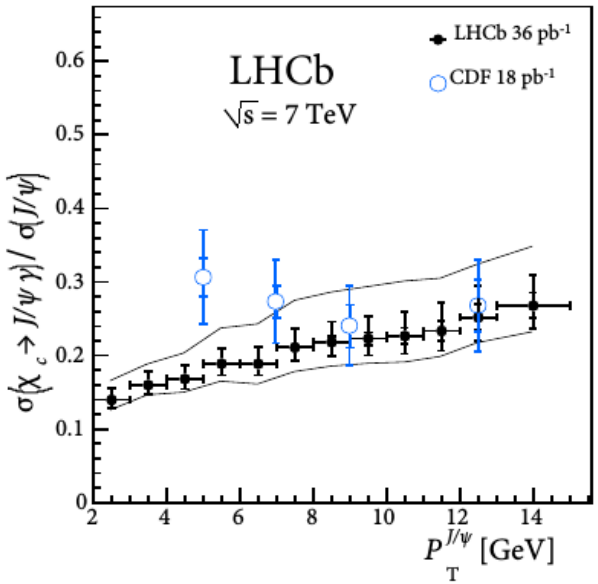

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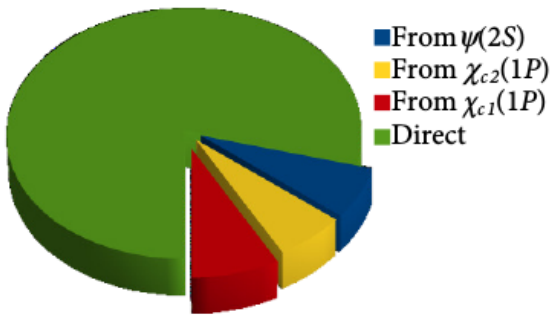

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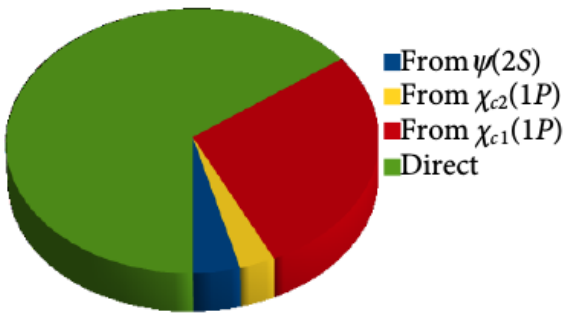

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Photoproduction:

- the b feed down is barely known.
- χ_c feed down expected to be small but never measured.

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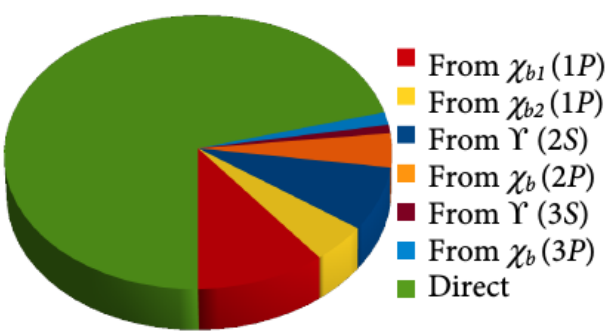

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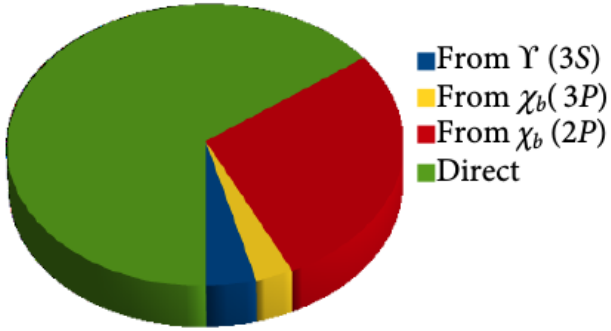
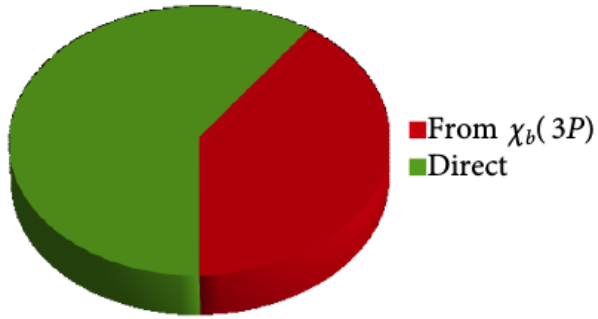


(b) Low P_T $\Upsilon(2S)$



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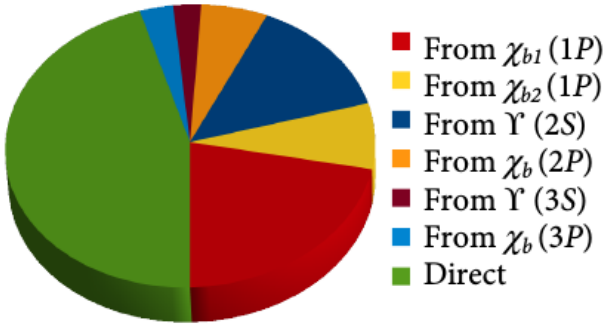
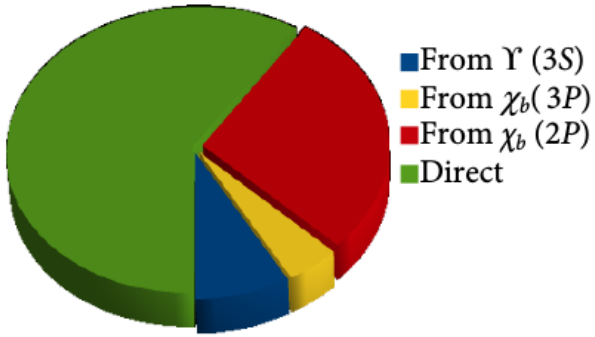


(d) High P_T $\Upsilon(1S)$



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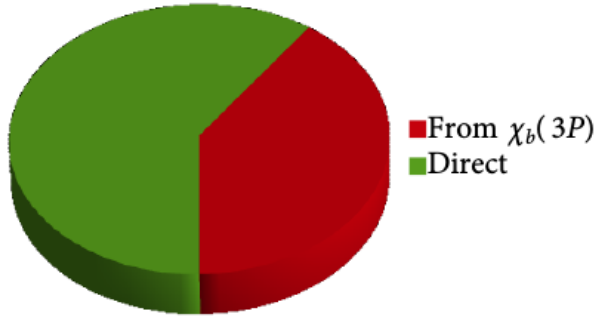

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- High Energy factorisation at NLO

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New Observables (in inclusive quarkonium hadroproduction)

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Observables	Experiments	CSM	CEM	NRQCD	Interest
J/ψ+J/ψ	LHCb, CMS, ATLAS, D0 (+NA3)	NLO, NNLO*	NLO	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	NLO	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	NLO	NLO (?)	Prod. Mechanism (CO dominant) + DPS
J/ψ vs mult.	ALICE,CMS (+UA1)	--	--	--	Initial vs Final state effects ?
J/ψ in jet.	LHCb, CMS	LO	--	LO	Prod. Mechanism (?)
J/ψ(ϒ) + jet	--	--	--		Prod. Mechanism (QCD corrections)
Isolated J/ψ(ϒ)	--	--	--	--	Prod. Mechanism (CS dominant ?)
J/ψ+b	--	--	--	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	--	--	--	
ϒ+Z	--	NLO	LO ?	LO	Prod. Mechanism + DPS
ϒ+ϒ	CMS	NLO ?	NLO	LO ?	Prod. Mechanism (CS dominant ?) + DPS + gluon TMD

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JPL, H.S. Shao PRL 111, 122001 (2013)

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- $J/\psi + J/\psi$: JPL, C. Pisano, F. Scarpa, M. Schlegel, PLB 784(2018)217
  - $d\sigma/dP_T^{\psi\psi}$ in different bins of $M_{\psi\psi}$ to study the gluon TMD f_1^g
  - Measure the azimuthal modulations to extract $h_1^{\perp g}$ [the distribution of linearly polarised gluons]
  - Feed-down pattern to confirm SPS/DPS dominance J.P.L., H.S. Shao PLB 751 (2015) 479

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- $\Upsilon + b$ via for instance Υ + nonprompt J/ψ

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- Advance to NLO for the measured observables
- Global NRQCD NLO fits with all the measured observables

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- Eloss + nPDF studies (+ CIM for excited states)

Some quarkonium projections for heavy-ion collisions with AFTER@LHC/FT-LHC

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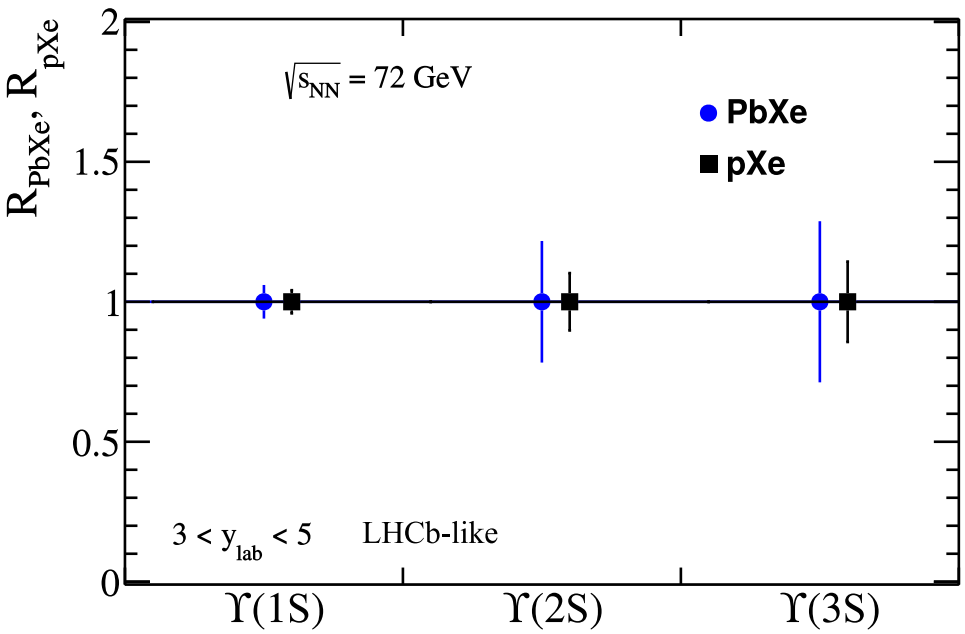

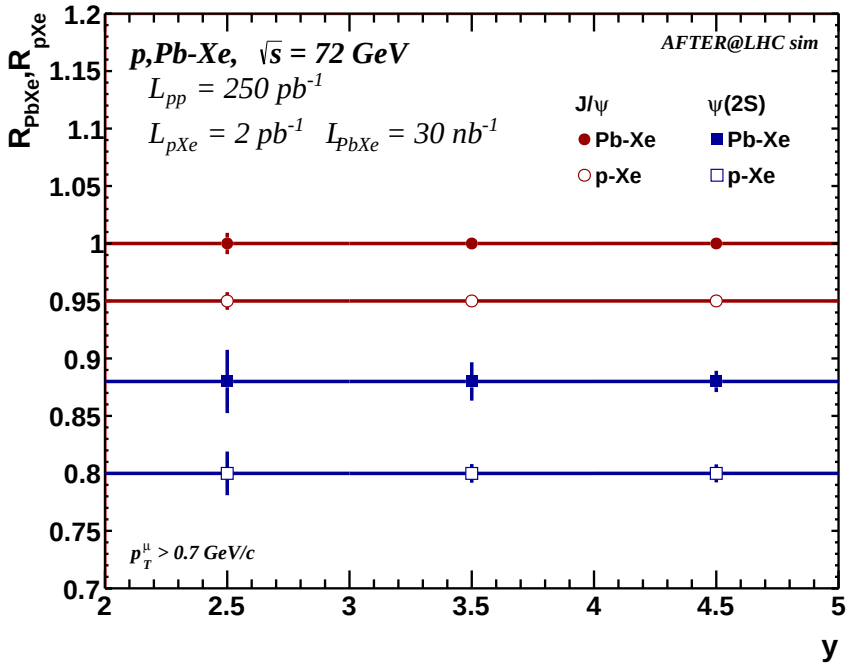

[No nuclear modifications assumed, $\mathcal{L}_{\mathrm{PbXe}} = 30\ \mathrm{nb}^{-1}$]