Study of parton correlations via double parton scatterings in associated quarkonium production in high energy accelerator experiments

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Motivations for associated quarkonium production studies

The study of quarkonium production has been proposed to probe perturbative and nonperturbative properties of QCD.

- J/ψ+W was proposed as a golden channel to probe the color octet contribution and thus to test NRQCD

  V. D. Barger et al., PLB **371** (1996) 111

- J/ψ+J/ψ production could be the key process to study the double parton scattering (DPS)

Motivation for BSM search:

- Υ+W could be a decay channel of a charged Higgs boson

  J. A. Grifols, J. F. Gunion, A. Mendez. Phys. Lett. B **197** (1987) 266.

- DPS becomes important in high √s collision :

  ⇒ Important background in multi-particle final states

Recent experimental progress:

- ATLAS observed J/ψ+W and J/ψ+Z

  ATLAS Coll. (J~ψ Z) Eur.Phys.J. C **75** (2015) 229; (J~ψ W) JHEP **1404** (2014) 172

- CMS & ATLAS data of di-J/Ψ in conflict with NRQCD (color singlet model)

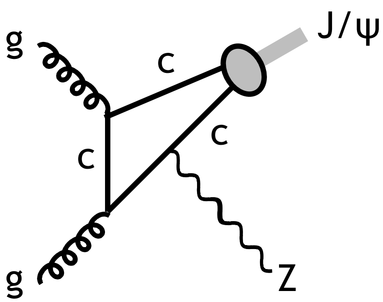
  CMS Collaboration, JHEP **1409** (2014) 094.

J/ψ+W/Z

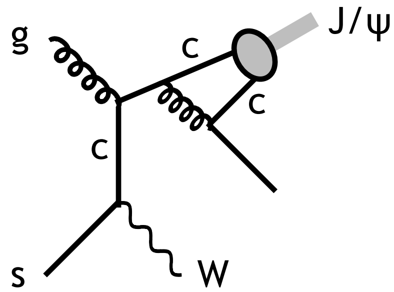
Quarkonium+vector boson production

Theoretical computations were carried out up to NLO in α_s

NLO NRQCD J/ψ+W : L. Gang et al., PRD **83** (2011) 014001;
NLO NRQCD J/ψ+Z : L. Gang et al., JHEP **02** (2011) 071 ;
NLO CSM J/ψ+Z : B. Gong, J.P. Lansberg, C. Lorce, J.X. Wang, JHEP **1303** (2013) 115;
Missing LO CSM J/ψ+W : J.P. Lansberg, C. Lorce, PLB **726** (2013) 218



LO CSM



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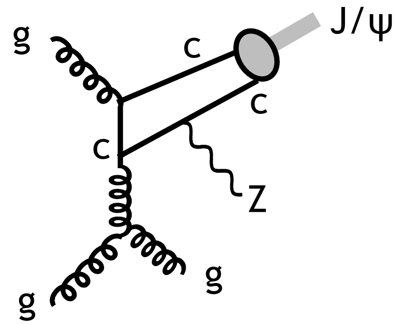
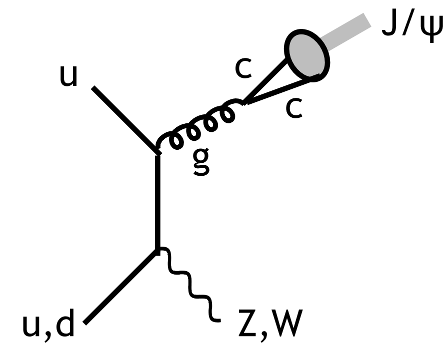


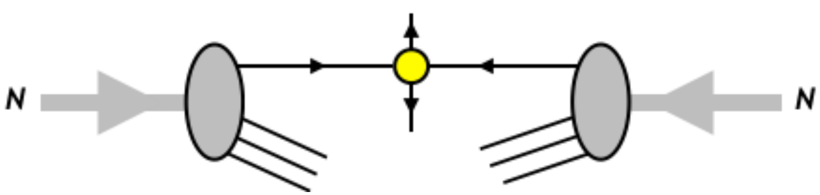
NLO CSM



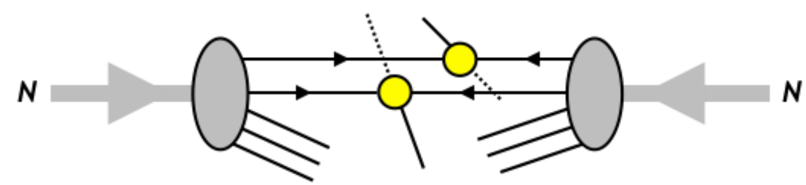
LO NRQCD

Based on these recent works, one expects the octet and singlet contributions to be on the same order of magnitude

Let us note that, in addition, double parton scattering (DPS) could also contribute to such an associated production, just as γ+jet , W+Z, W+W productions



Single Parton Scattering (SPS)



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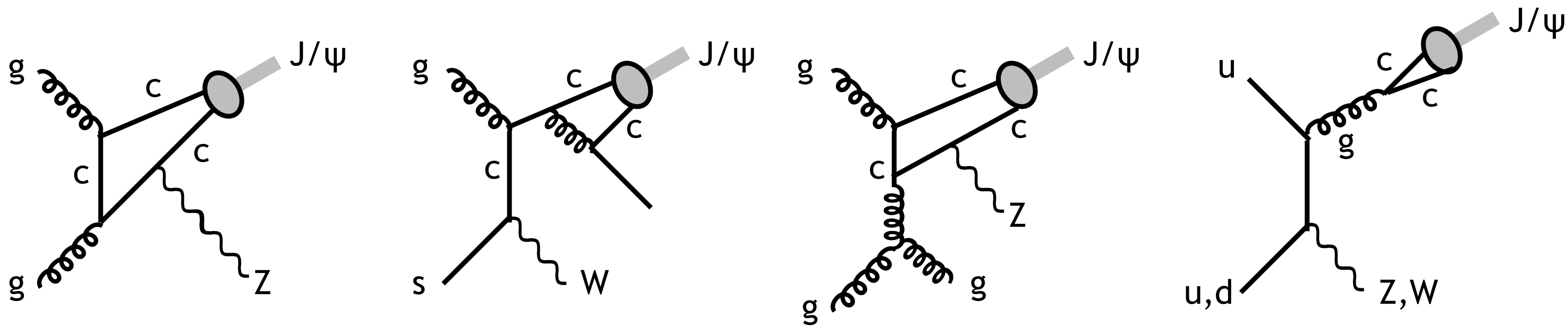

LO CSM | **LO CSM** | **NLO CSM** | **LO NRQCD**

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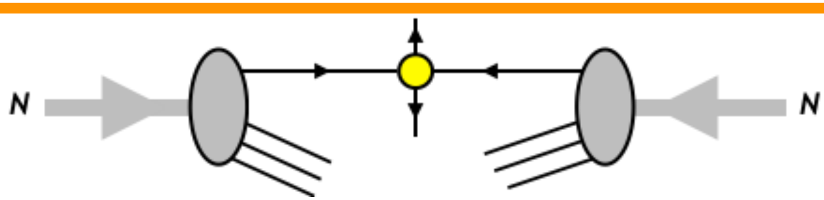

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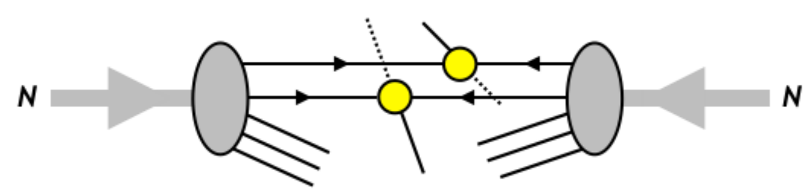


Double Parton Scattering (DPS)

ATLAS vs. "theory"

Overall, the ATLAS data-theory comparison looks as follows:

	ATLAS	*DPS (σ_{eff} = 15 mb)*	*CSM*	*COM*
Z+J/ψ	1.6±0.4 pb [1]	0.46 pb	0.025 - 0.125 pb [5]	< 0.1 pb [4]
W+J/ψ	$4.5^{+1.9}_{-1.5}$pb [2]	1.7 pb	(0.11±0.04) pb [6]	(0.16 - 0.22) pb [3]

[1] ATLAS Collaboration, Eur. Phys. J. C **75** (2015) 229
[2] ATLAS Collaboration, JHEP **1404** (2014) 172
[3] L. Gang et al., PRD **83** (2011) 014001
[4] L.Gang et al., JHEP **1102** (2011) 071
[5] B. Gong et al., JHEP **1303** (2013) 115
[6] J.P. Lansberg, C. Lorce, PLB **726** (2013) 218

ATLAS data are significantly above the SPS (CSM+COM), and the DPS can only account for a fraction of the data.

(> 3 σ for J/ψ+Z, > 2 σ for J/ψ+W)

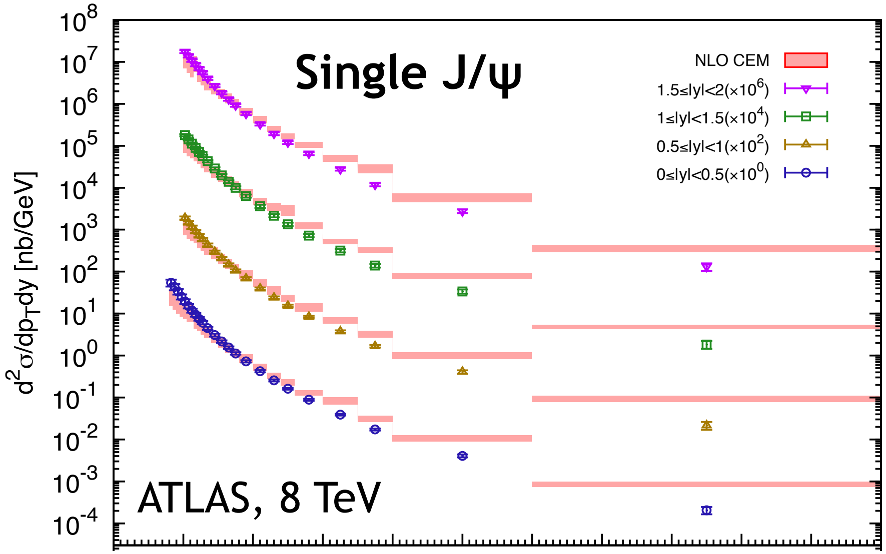
A natural question arises : Is SPS underestimated?

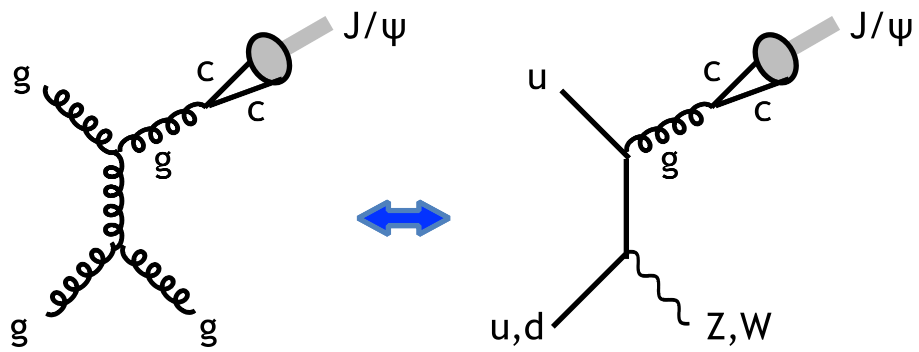
Building up an upper limit to the SPS with the color evaporation model

The CEM for single quarkonium production
overshoots the data at high p_T (see below).
This is due to the dominance of the 1-gluon fragmentation (~ $^3S_1^8$)

The same is expected to occur for J/ψ+W and J/ψ+Z.

⇒ CEM : conservative upper limit on the SPS yield





We will compute it in both cases at NLO with MadGraph5_AMC@NLO.
J. Alwall et al. , JHEP **07** (2014) 079

Digression on DPS

At high energies, multiple parton interactions can become relevant, despite of being formally of higher twist.

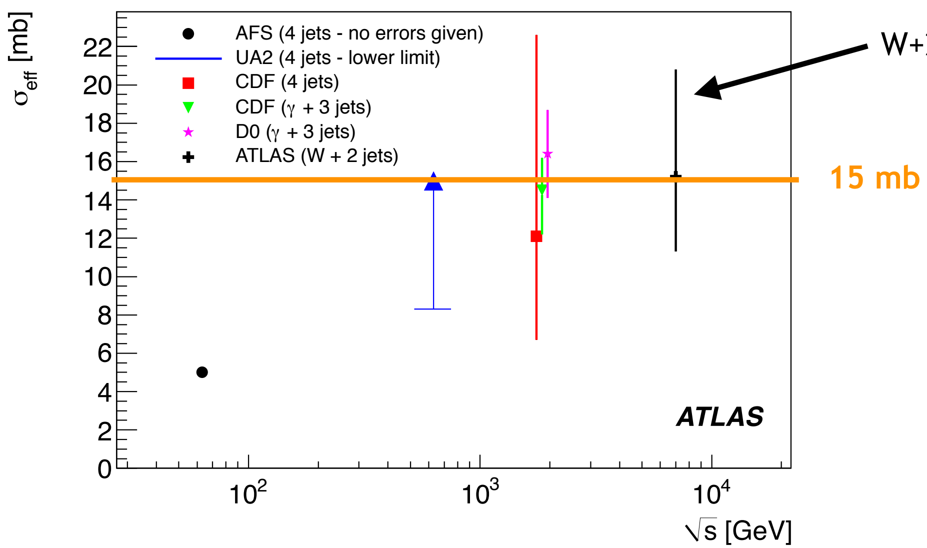
They are in fact necessary to restore the unitarity of the cross section and are related to the strong increase of the parton densities at high energy.

Similarly, this can also happen for Double hard Parton Scatterings (DPS) which then occur independently.

As such it makes sense to parametrize the DPS cross sections by the so-called pocket-formula:

$$\sigma^{\mathrm{DPS}}(A+B) = \frac{\sigma(A)\sigma(B)}{\sigma_{\mathrm{eff}}}$$

In the case of J/ψ+W and J/ψ+Z, ATLAS used their measured cross sections for σ(J/ψ), σ(W) and σ(Z), and σ_{eff} determined by their W+2jets data (see below).

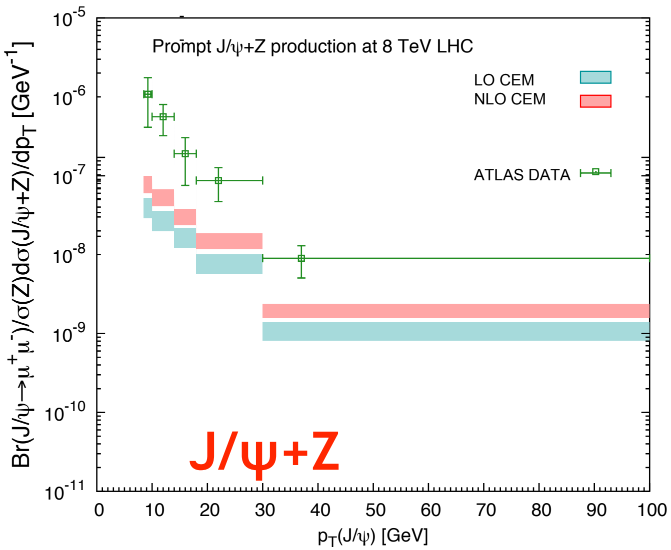


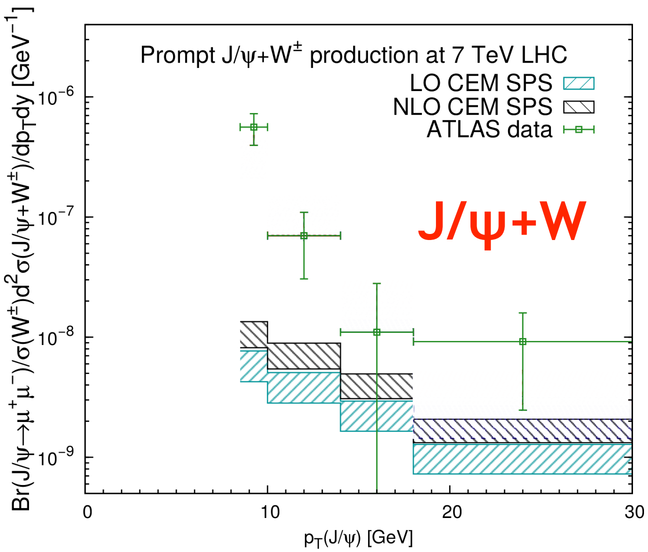
W+2jets [ATLAS, New J. Phys. **15** (2013) 033038]

Results for the Color evaporation model at NLO

	ATLAS	DPS (σ_{eff} = 15 mb)	CSM	COM	CEM (NLO)
$Z+J/\psi$	1.6±0.4 pb	0.46 pb	0.025 - 0.125 pb	< 0.1 pb	$0.19^{+0.05}_{-0.04}$ pb [1]
$W+J/\psi$	$4.5^{+1.9}_{-1.5}$pb	1.7 pb	(0.11±0.04) pb	(0.16 - 0.22) pb	0.28±0.07 pb [2]

[1] J.-P. Lansberg and H.-S. Shao, JHEP **1610** (2016) 153
[2] J.-P. Lansberg, H.-S. Shao, and NY, PLB **781** (2018) 485





⇒ **Upper limit by CEM does not solve the problem.**

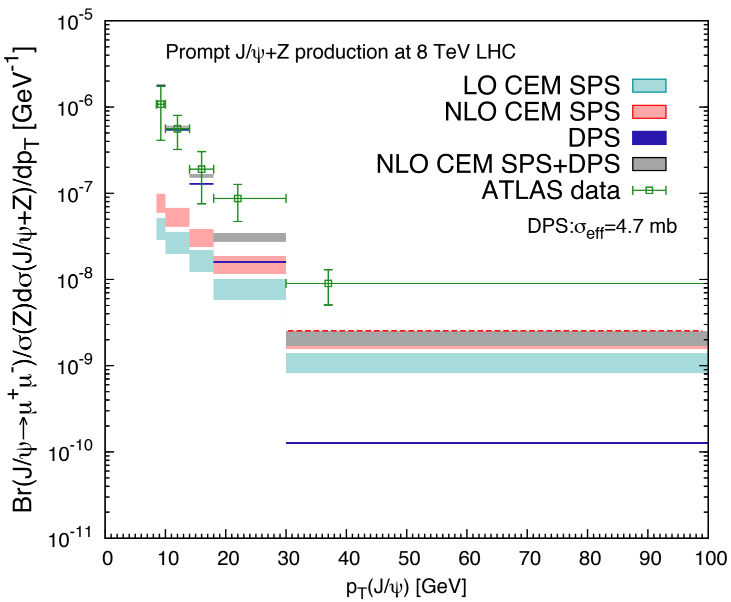
⇒ **Can it be solved by increasing the DPS?**

J/ψ + Z : tuning the DPS with ATLAS data

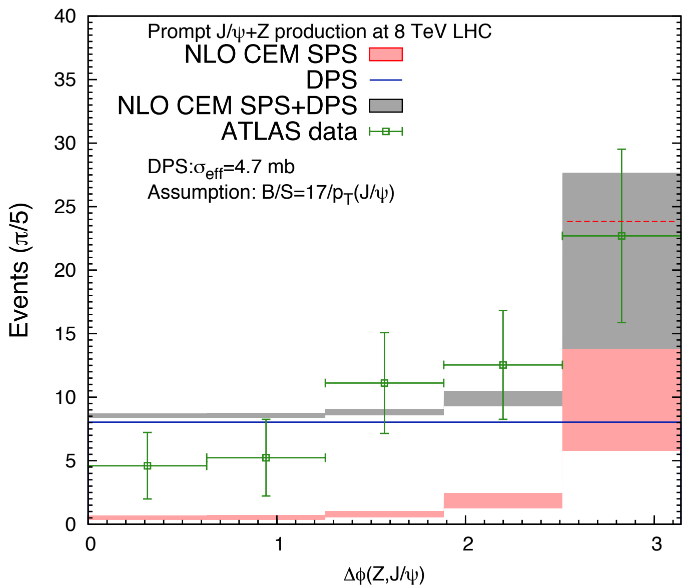
We fit σ_{eff} to the ATLAS data subtracted from the SPS

and we obtain $\sigma_{eff} = (4.7^{+2.4}_{-1.5})$ mb J.-P. Lansberg and H.-S. Shao, JHEP **1610** (2016) 153

	ATLAS	*DPS (σ_{eff} = 4.7 mb)*	*CSM*	*COM*	*CEM (NLO)*
Z+J/ψ	1.6±0.4 pb	1.47 pb	0.025 - 0.125 pb	< 0.1 pb	$0.19^{+0.05}_{-0.04}$ pb [1]



p_T distribution



azimuthal distribution

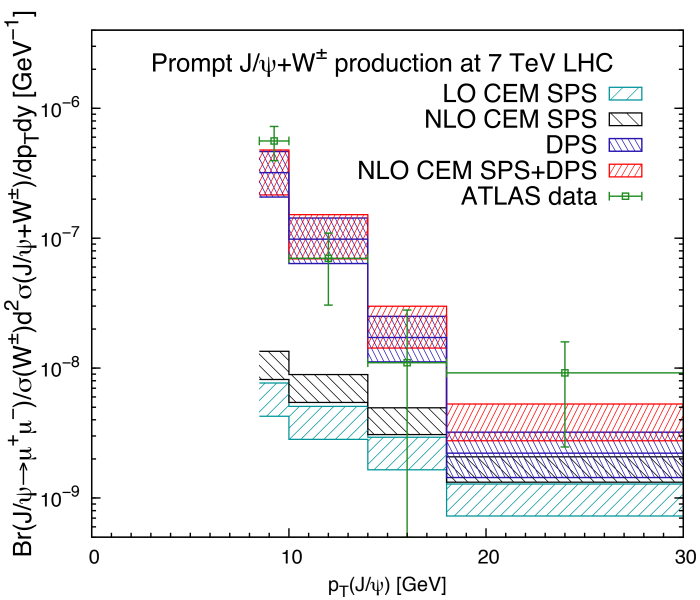
Increasing the DPS seems to solve the puzzle
(the SPS yield favored by ATLAS acceptance is visible at $\Delta\varphi=\pi$).

J/ψ + W : tuning the DPS with ATLAS data

For J/ψ+W, we obtain σ_{eff} = $(6.1^{+3.3}_{-1.9})$ mb

J.-P. Lansberg, H.-S. Shao, and NY, to appear PLB **781** (2018) 485

	ATLAS	DPS (σ_{eff} = 6.1 mb)	CSM	COM	CEM (NLO)
W+J/ψ	$4.5^{+1.9}_{-1.5}$pb	4.18 pb	(0.11±0.04) pb	(0.16 - 0.22) pb	0.28±0.07 pb



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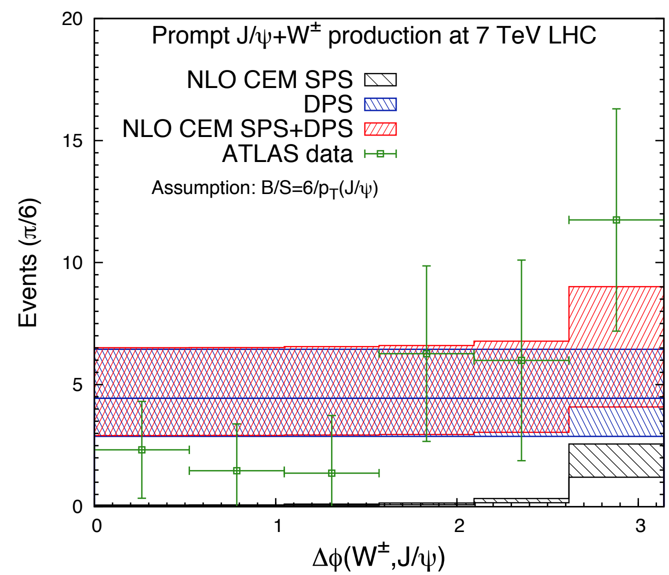


azimuthal distribution

Like for the J/ψ+Z case, increasing the DPS seems to solve the puzzle.

Quarkonium-pair

Quarkonium pairs

Di-J/Ψ production studied by LHCb, CMS, ATLAS, D0

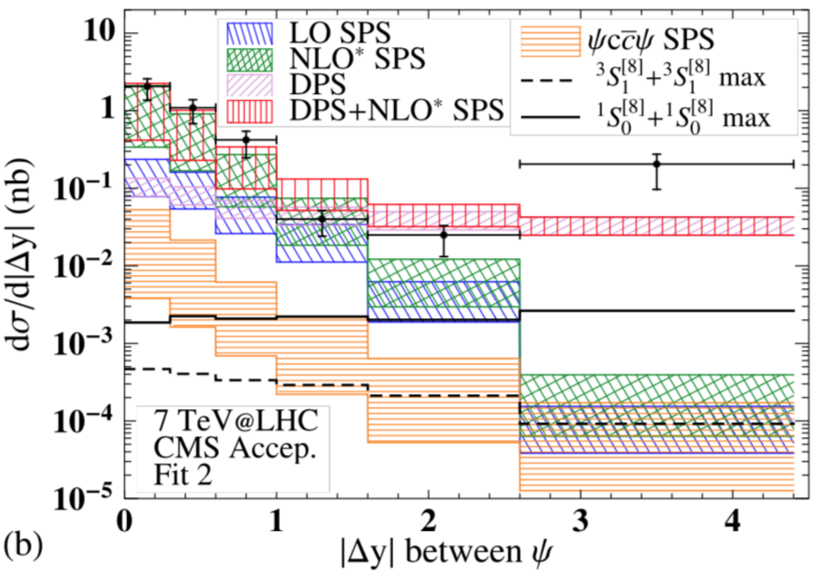
CMS Collaboration, JHEP **1409** (2014) 094
ATLAS Collaboration, EPJC **77**, 76 (2017)
LHCb Collaboration, JHEP **1706** (2017) 047
D0 Collaboration, PRD **90**, 111101(R) (2014)

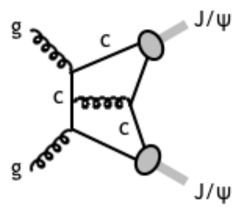
- **Only D0 and ATLAS performed DPS extraction**
  - **D0 :** $\sigma_{\text{eff}} = (4.8 \pm 0.5(\text{stat}) \pm 2.5(\text{sys}))\,\text{mb}$
  - **ATLAS :** $\sigma_{\text{eff}} = (6.3 \pm 1.6(\text{stat}) \pm 1.0(\text{sys}))\,\text{mb}$
- **SPS uncertainty too large to extract σ_{eff} from LHCb (low pT -> SPS also flat in Δφ)**
- **CMS did not try to extract σ_{eff}**
  - **DPS study by Lansberg and Shao** $\sigma_{\text{eff}} = (8.2 \pm 2.0 \pm 2.9)\,\text{mb}$

    J.-P. Lansberg and H.-S. Shao, PLB**751**, 479 (2015)

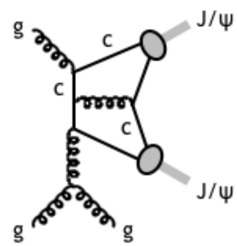
  - **However on-going discussions about the actual size of SPS**

    He and Kniehl, PRL 115, 022002 (2015)





LO CSM

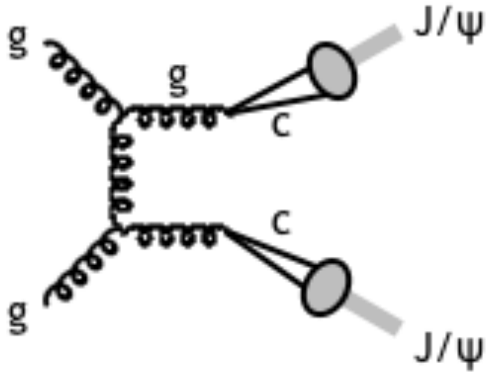


NLO CSM

The LO COM yield depends on (NRQCD LDME)^2 and is thus affected by large uncertainties such that some colleagues wonder if the data could be described without the DPS.

Di-J/Ψ production and the CEM

To get the order of magnitude of the contribution from octet transition, we use again the CEM :

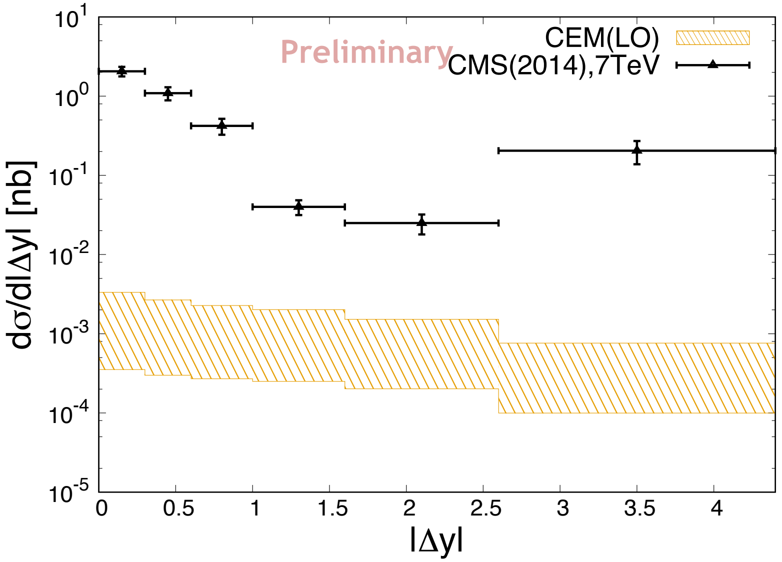


LO COM : gluon-fragmentation

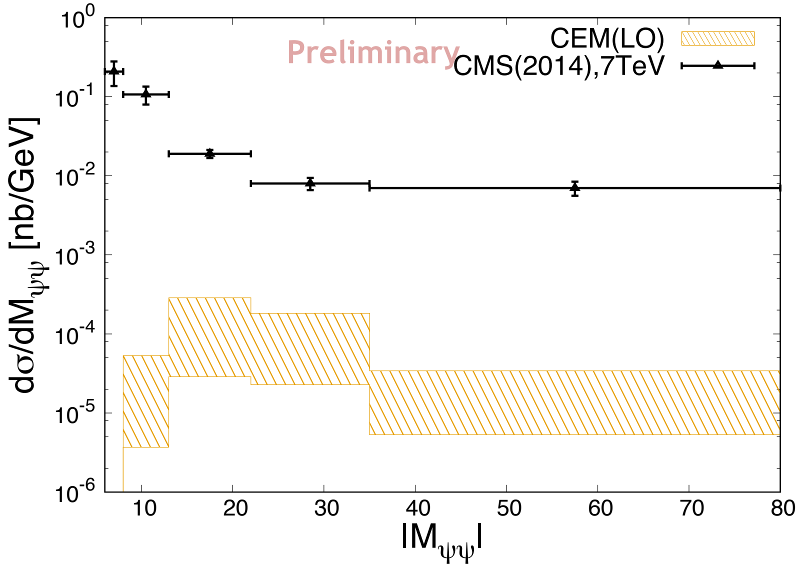
Like for J/Ψ+Z/W, CEM yield should give realistic estimation of the octet yield

CEM result with CMS setup (7TeV, inclusive)

|Δy| :



Mψψ :



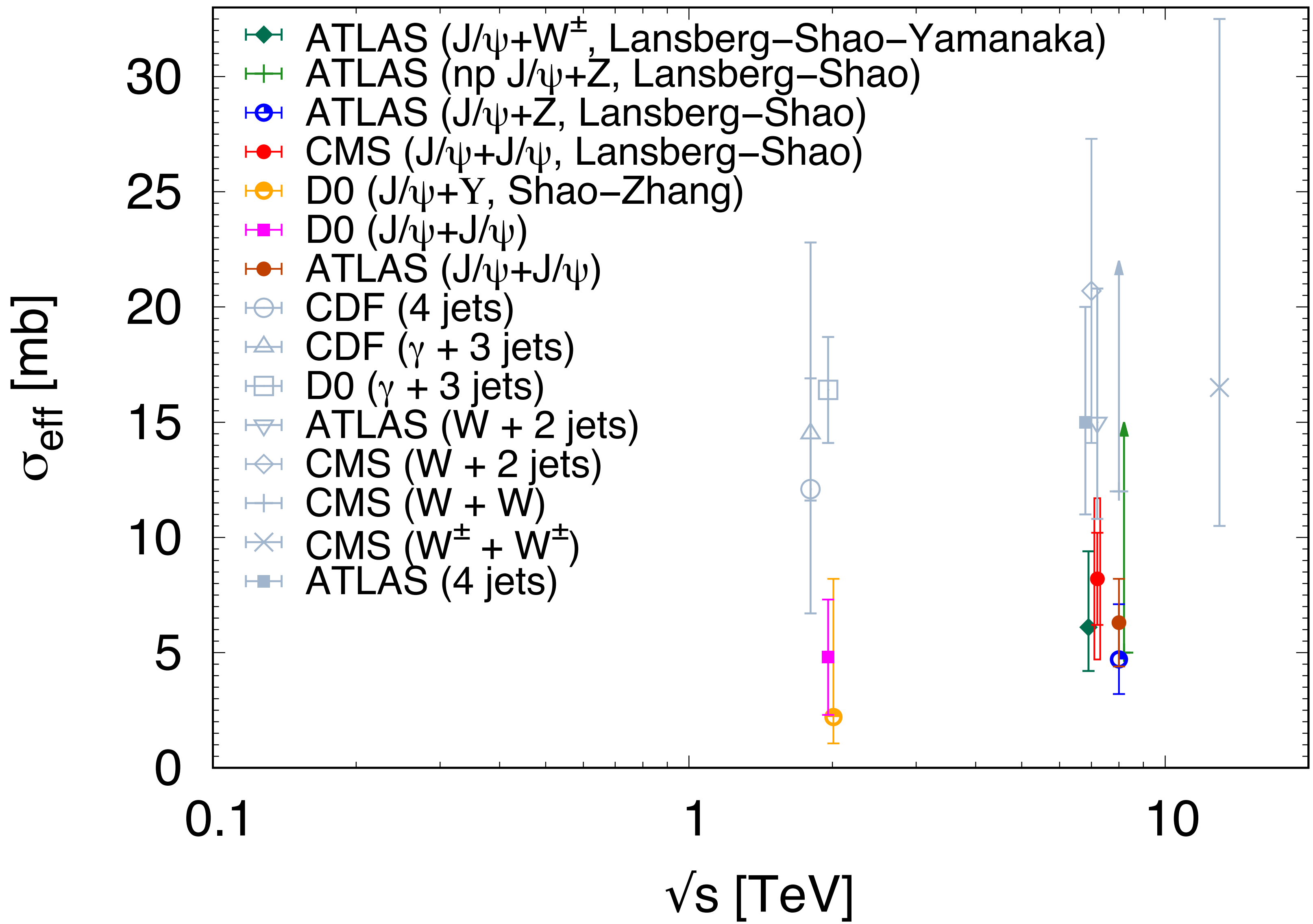
Exp. data : CMS Collaboration, JHEP 1409 (2014) 094.

Since we found out that the LO NRQCD result of He & Kniehl overshoots our CEM result, we believe that their result is too optimistic (arguable choice of the LO LDMEs?)

We take this as the confirmation of the DPS extraction of Lansberg and Shao

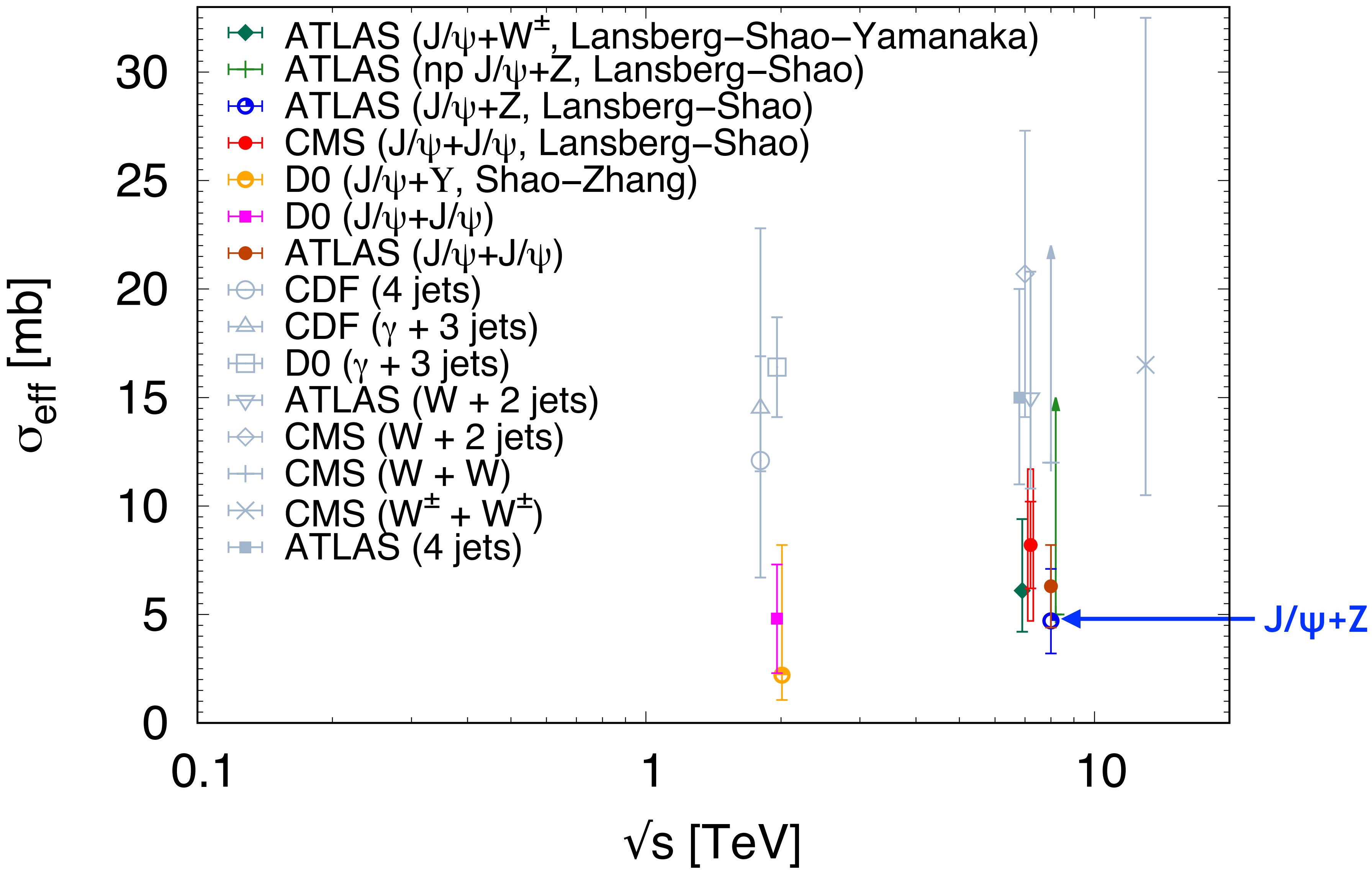
(J.-P. Lansberg and H.-S. Shao, PLB**751**, 479 (2015))

Overall



⇒ **All central rapidity quarkonium data point at a small σ_{eff}**

Overall



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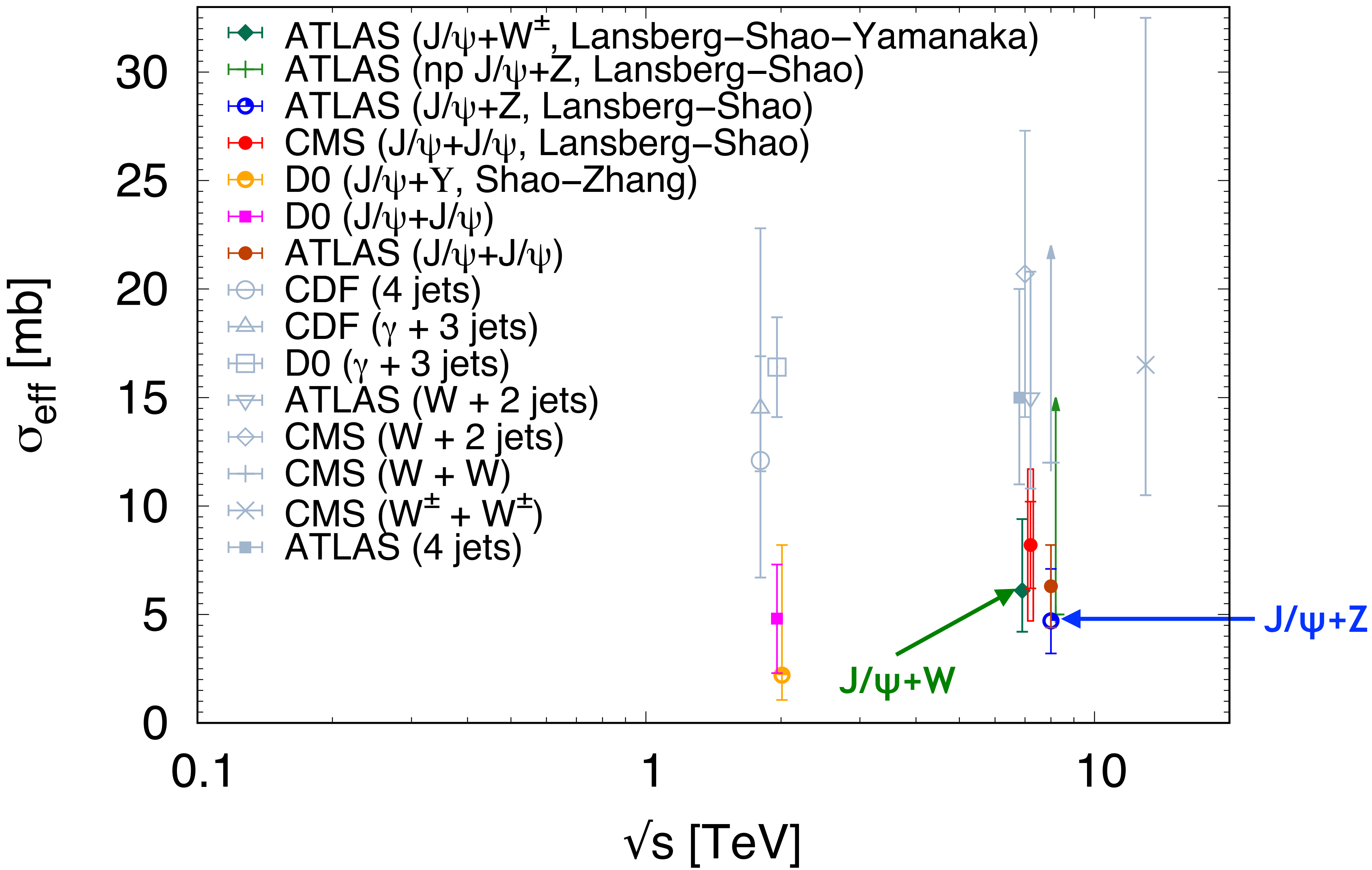

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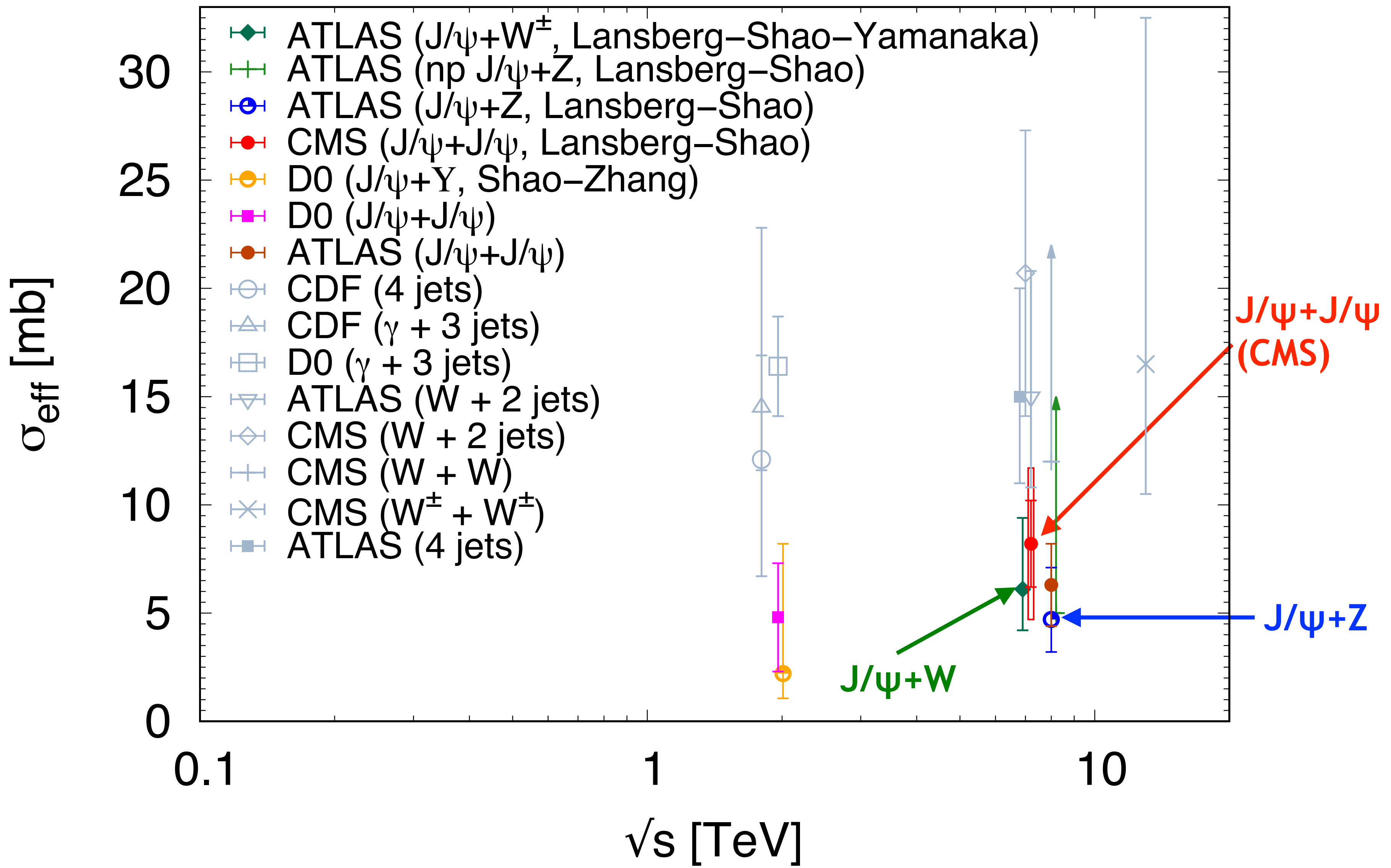

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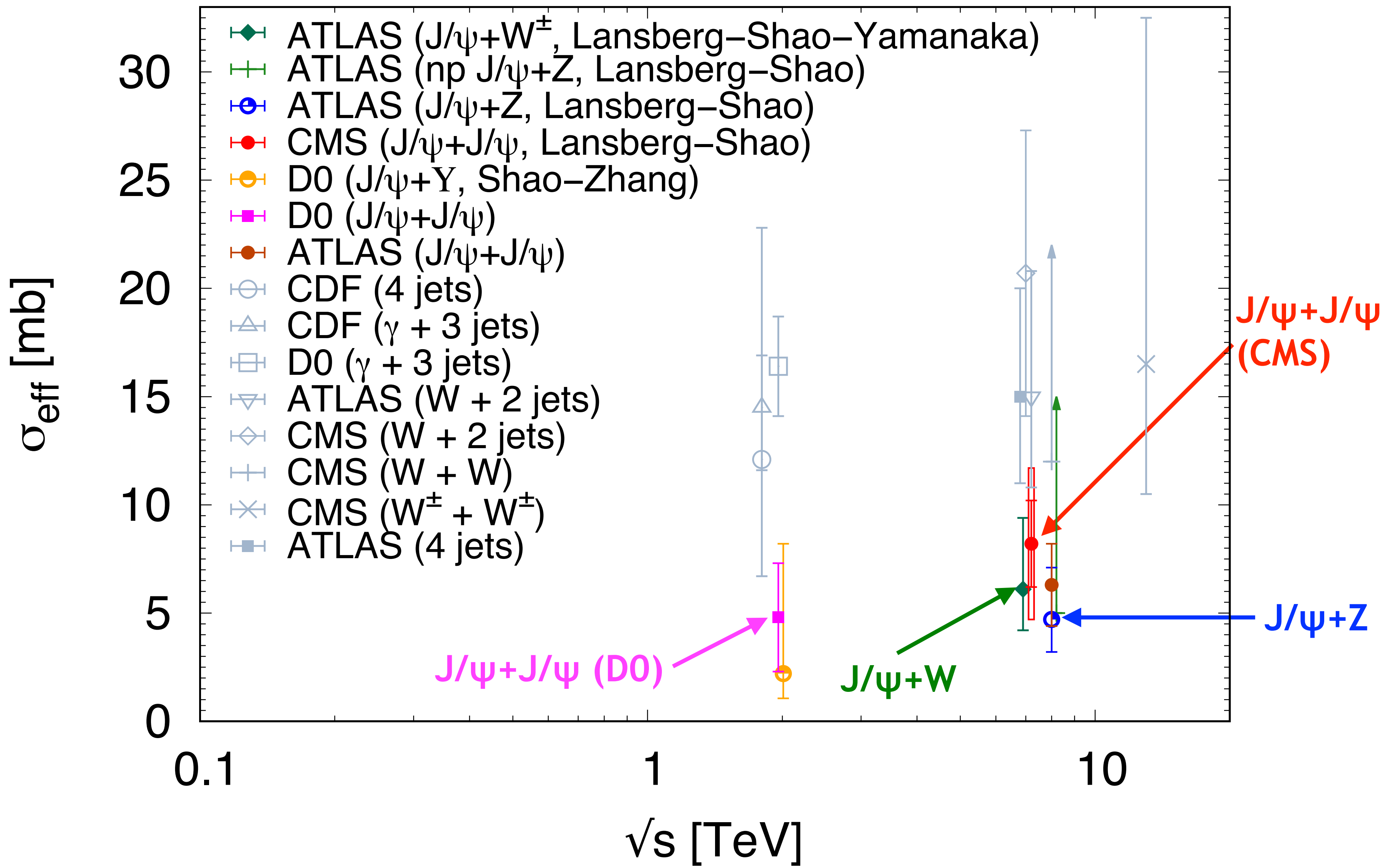

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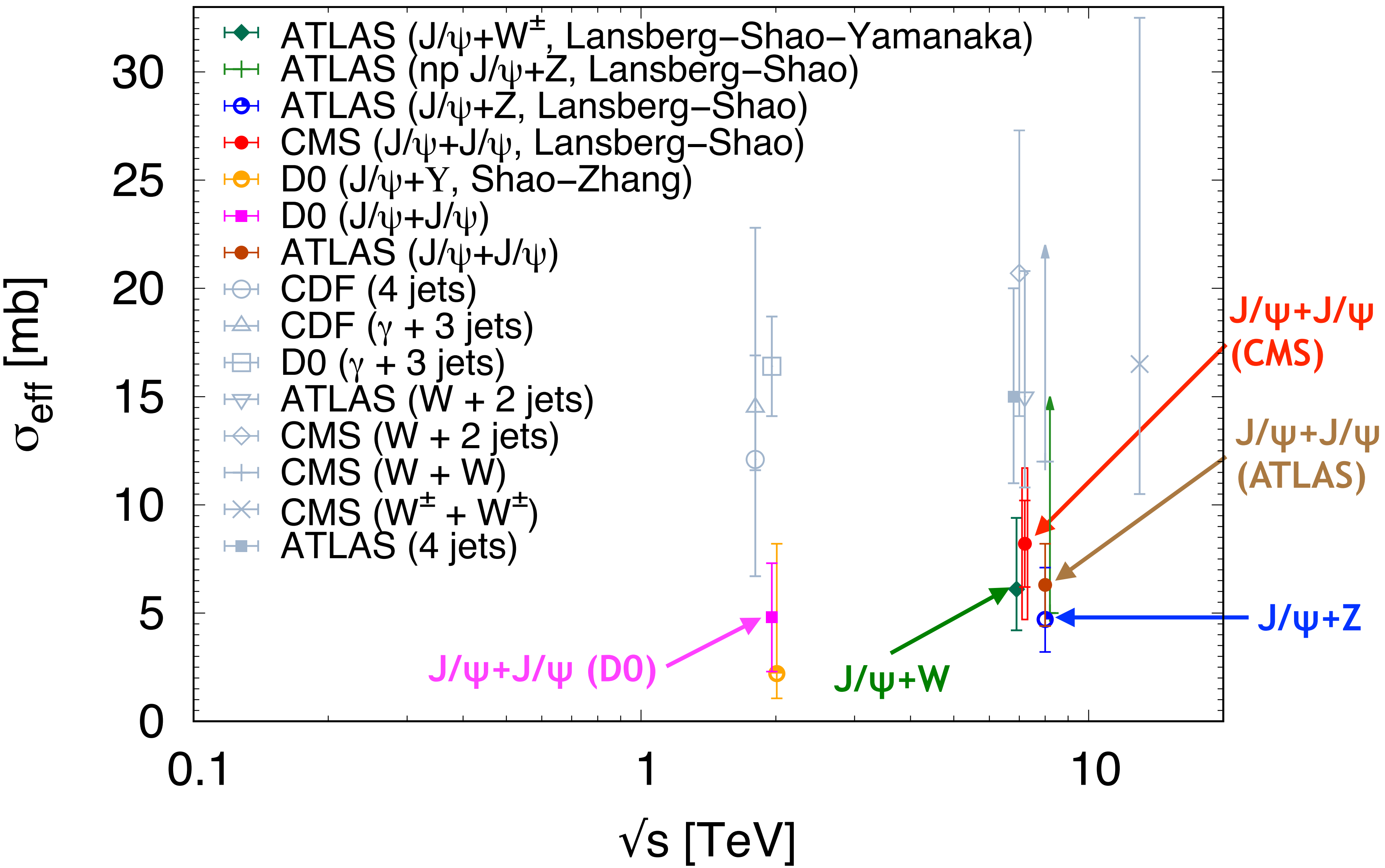

⇒ All central rapidity quarkonium data point at a small σ_{eff}

Summary:

- The associated production of J/ψ+W/Z was measured by ATLAS: discrepancies with SPS+DPS (σ_{eff}=15mb) was seen.
- In order to check whether the SPS was underestimated, we evaluated the NLO CEM yield for J/ψ+W/Z.
- The conservative upper limit set by the CEM does not solve the discrepancy with the ATLAS data.
- In fact, J/ψ+W/Z show evidence for DPS.
  J/ψ+Z : $\sigma_{eff} = (4.7^{+2.4}_{-1.5})$ mb
  J/ψ+W : $\sigma_{eff} = (6.1^{+3.3}_{-1.9})$ mb
- J/Ψ+J/Ψ production also requires DPS contributions in some part of the phase space.
- σ_{eff} seems to be smaller for quarkonia than for jets: hint for flavor dependence?

End