Quarkonium production

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Jornadas LIP
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The promise of heavy quarkonium

How does hadron formation happen?

Simplest QCD system to be studied: quark + antiquark
How do they combine into a bound state?

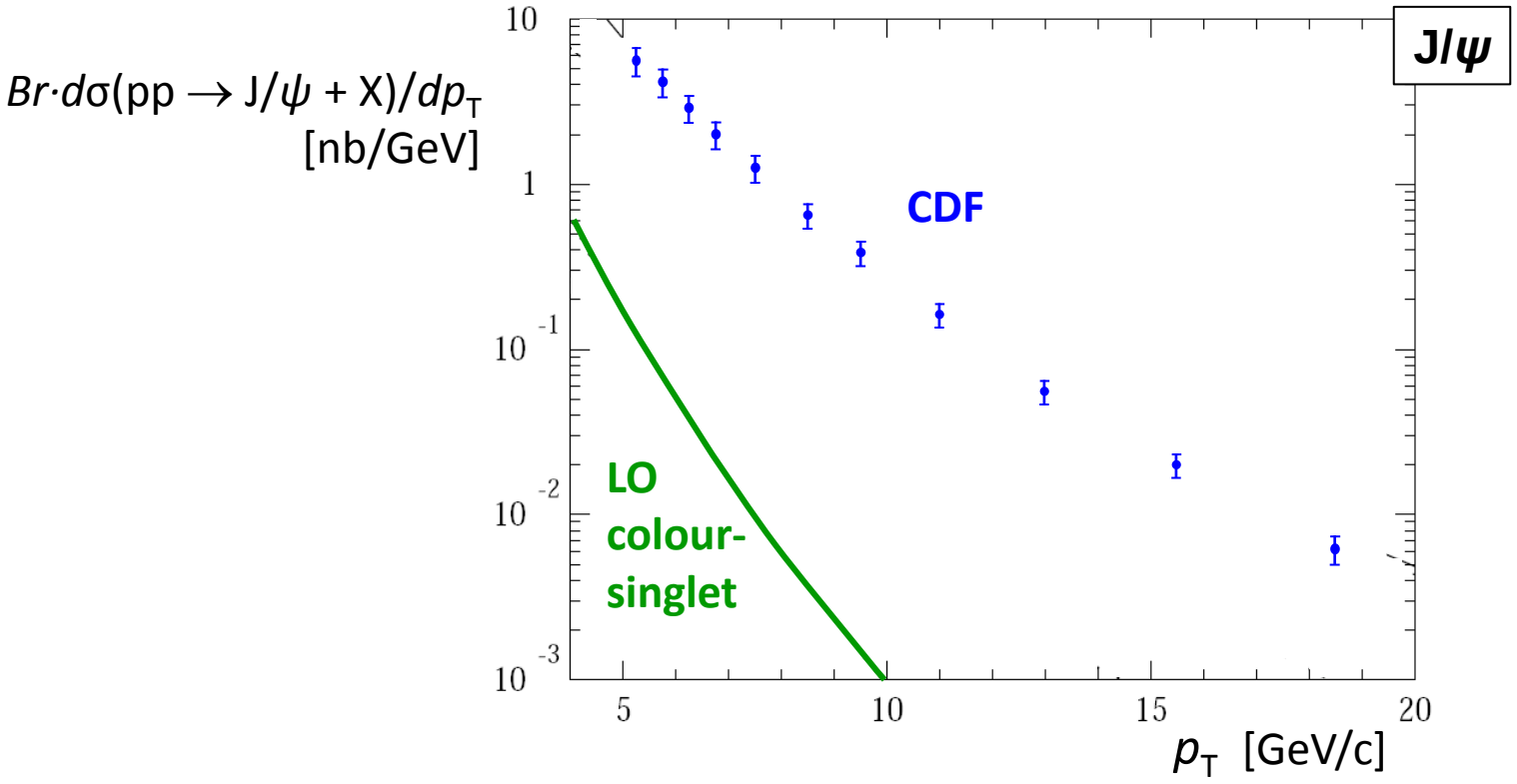
We must use heavy quark pairs (QQbar)
In the QQbar c.o.m. frame the two quarks are nonrelativistic: velocity "v" << 1
Only in this condition the bound-state formation phase ($\tau \sim 1/vm_Q$) is well distinct from the perturbative hard-scattering phase ($\tau \sim 1/m_Q$)

We would never "have time to see" the formation of a pion, since it is almost simultaneous to the parton-scattering process

Heavy quarkonium production studies can offer an unique insight into the dynamics of the strong interaction

But for years they have been diverted by theoretical and experimental puzzles...

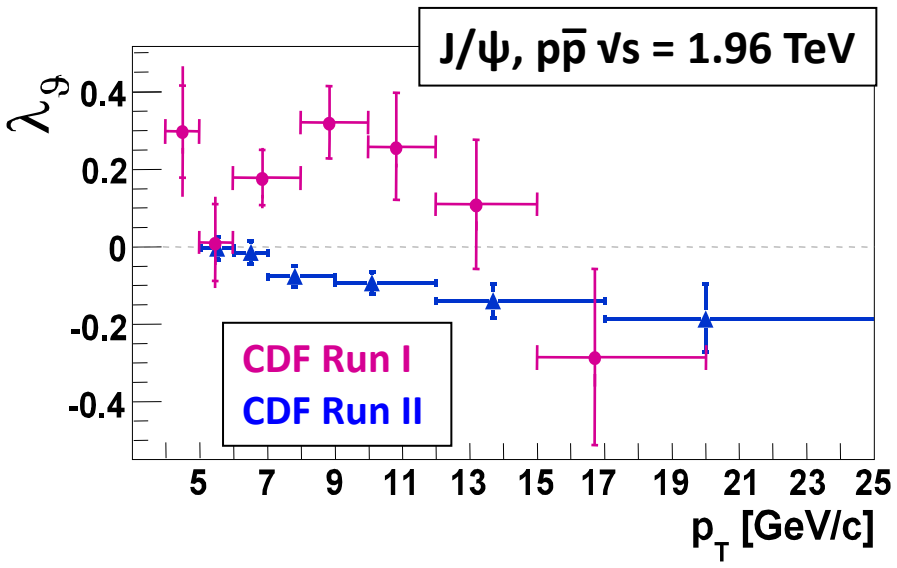
The real story: a quest through “anomalies”...

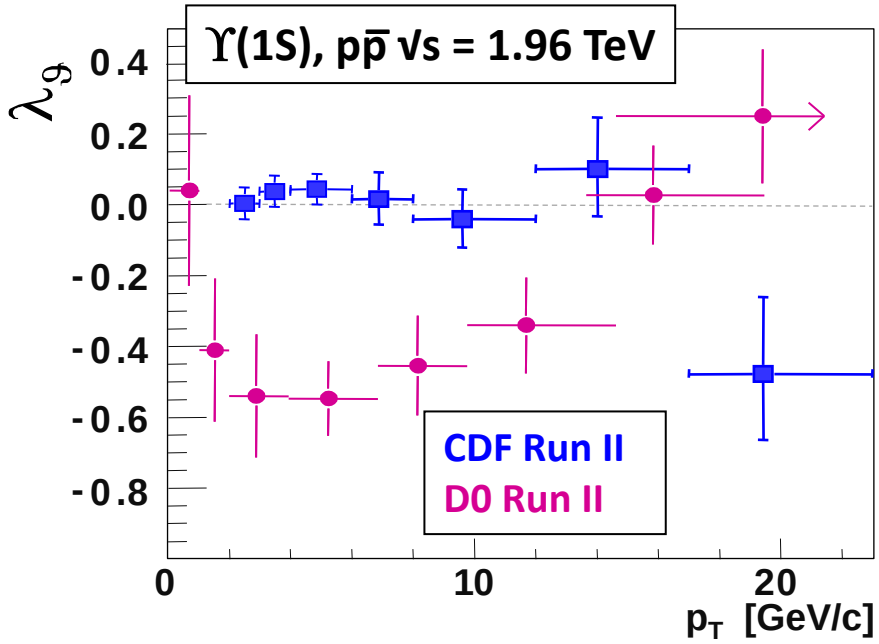


In 1995, **CDF** observed J/ψ and ψ(2S) prompt production cross sections ~50 times larger than the existing prediction.
Only assumption: the QQbar is produced already colour-neutral at hard-scattering level

→ colour-octet processes must, instead, be the dominant ones!
→ birth of the nonrelativistic QCD (NRQCD) factorization framework

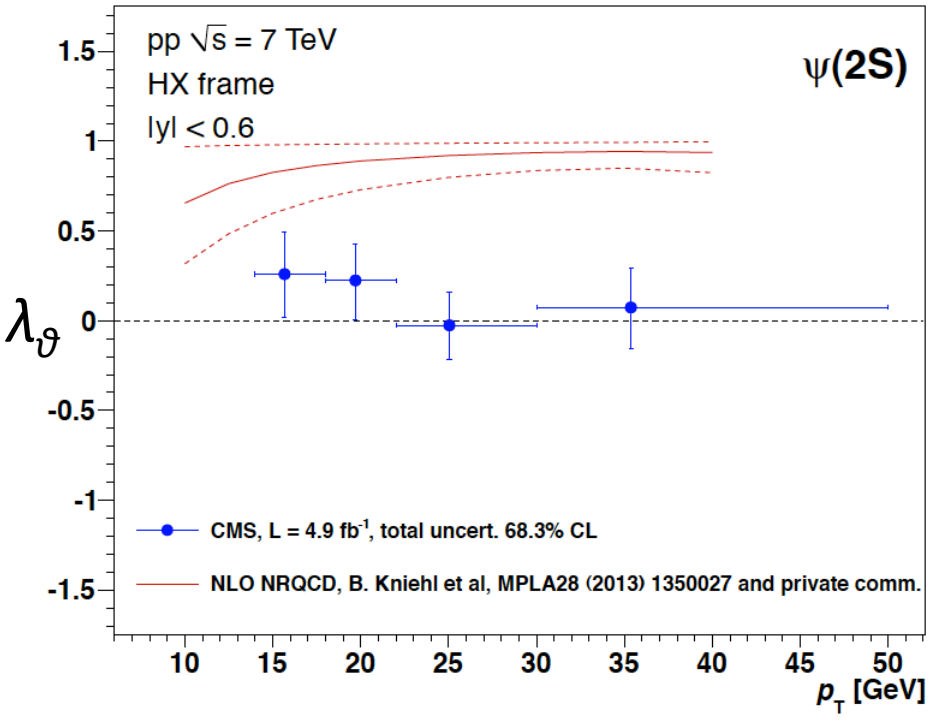
...mistakes...


J/ψ, pp̄ √s = 1.96 TeV
λ_ϑ
0.4
0.2
0
-0.2
-0.4
CDF Run I
CDF Run II
5 7 9 11 13 15 17 19 21 23 25
p_T [GeV/c]


Υ(1S), pp̄ √s = 1.96 TeV
λ_ϑ
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
CDF Run II
D0 Run II
0
10
20
p_T [GeV/c]

...and "puzzles"

A landmark prediction of NRQCD is that directly produced ψ(2S)'s are transversely polarized (feed-down effects blur the J/ψ picture)



CMS made the first precise measurement of ψ(2S) polarization, in striking disagreement with NRQCD!

CERN Courier July/August 2013

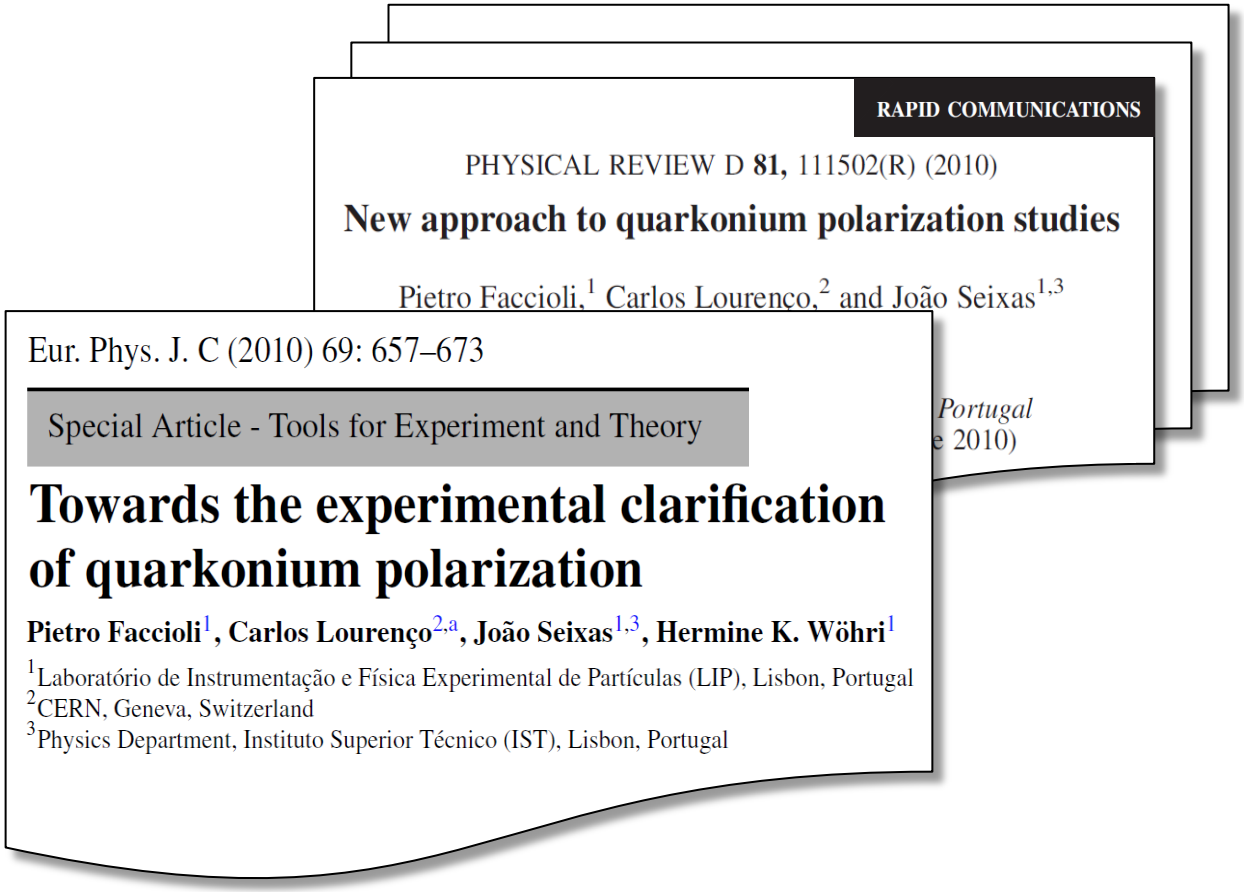
The return of quarkonia

Pietro Faccioli, LIP-Lisbon.

The physics of heavy quark–antiquark bound states is a long-standing puzzle, made more intriguing by results from the LHC.

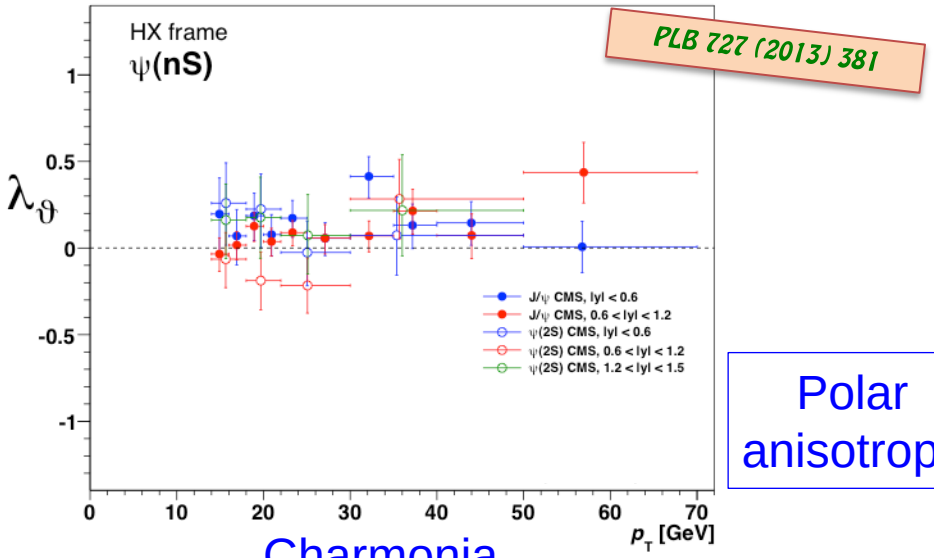
The progressing clarification and the LIP role

The situation is improving significantly thanks to the LHC data !
LIP has been giving crucial contributions to this progress,
by leading the CMS quarkonium polarization measurements and
by proposing improved techniques for polarization measurements



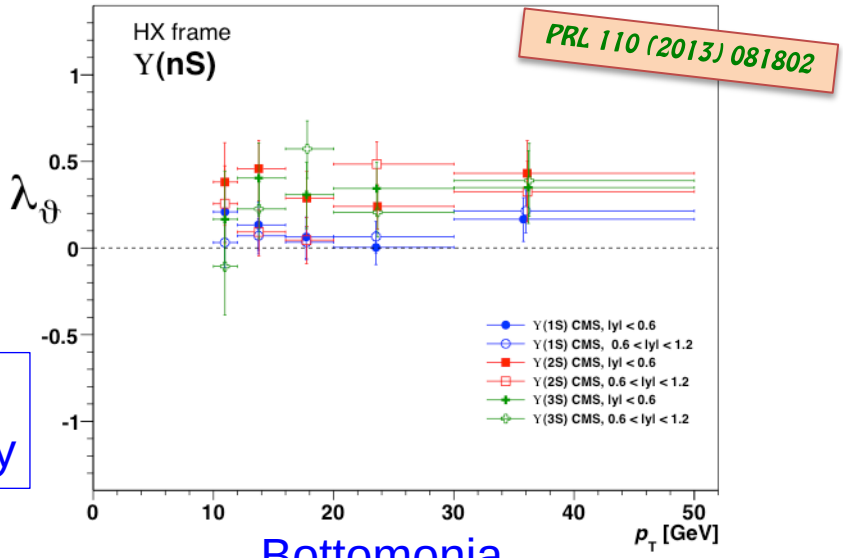
The progressing clarification and the LIP role

The CMS bottomonium and charmonium polarization measurements excluded strong anisotropies

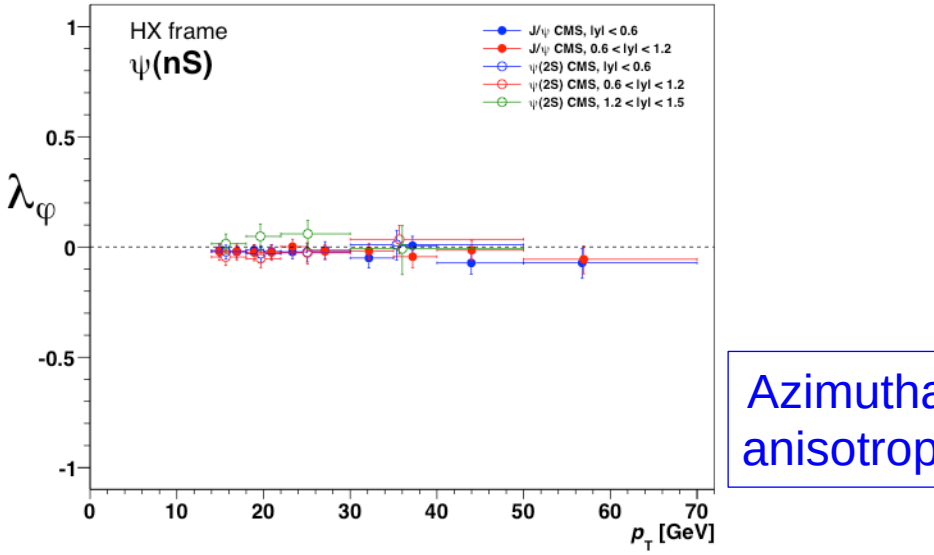


Charmonia

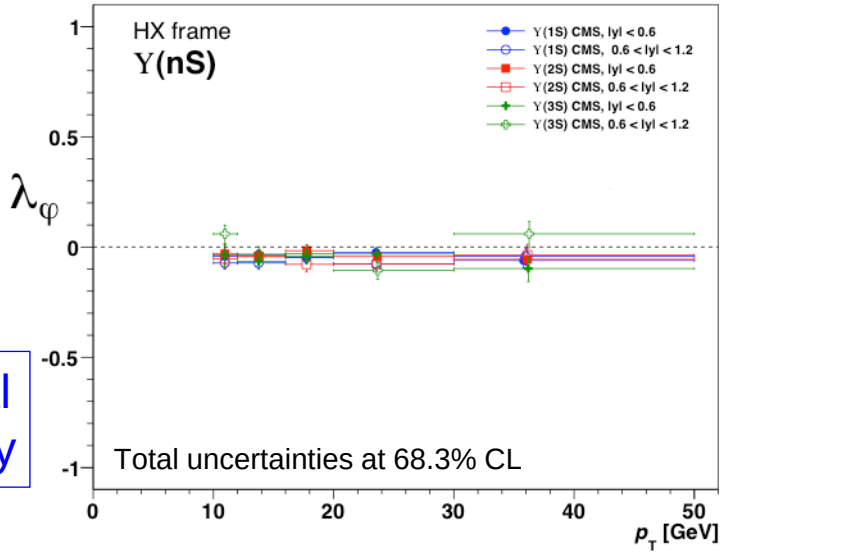
Polar anisotropy



Bottomonia



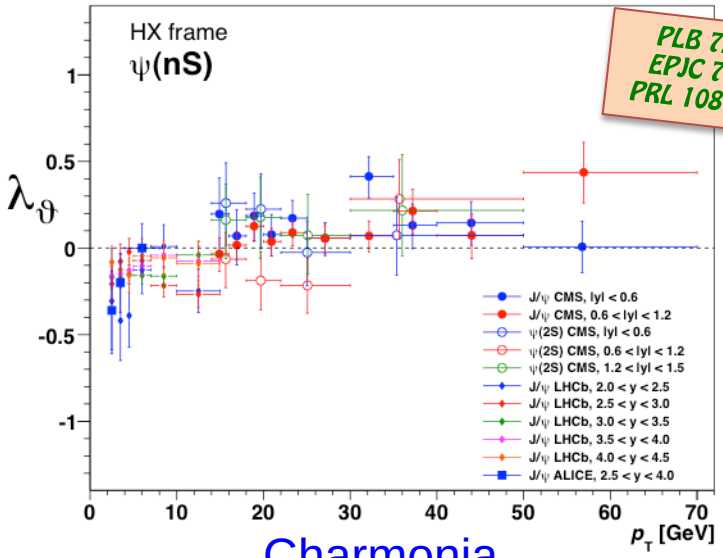
Azimuthal anisotropy



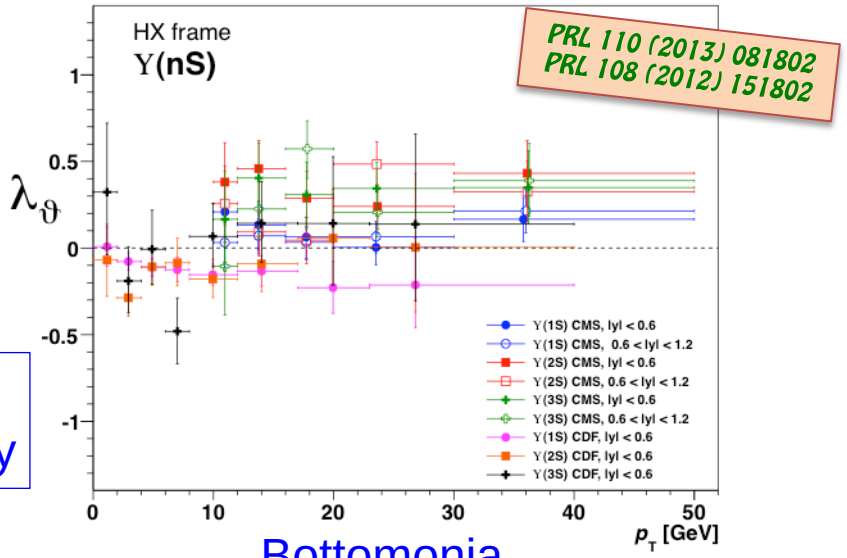
The progressing clarification and the LIP role

Also LHCb, ALICE and CDF used similar techniques.

Now we have a consistent experimental scenario!



PLB 727 (2013) 381
EPJC 73 (2013) 2631
PRL 108 (2012) 082001

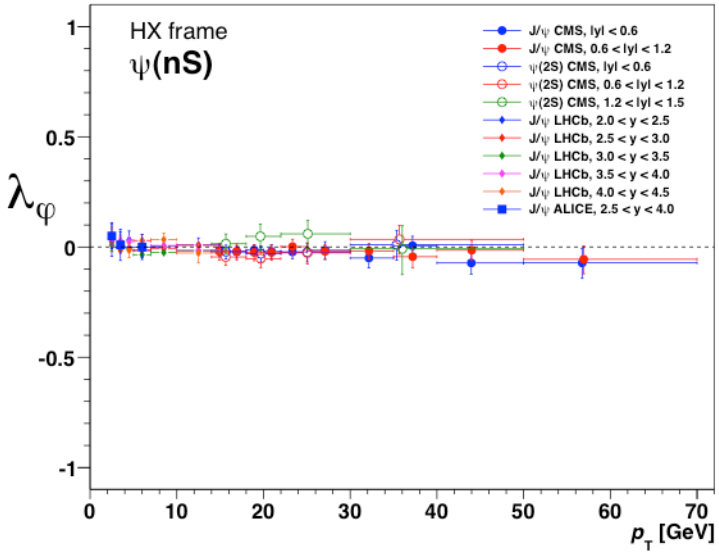


PRL 110 (2013) 081802
PRL 108 (2012) 151802

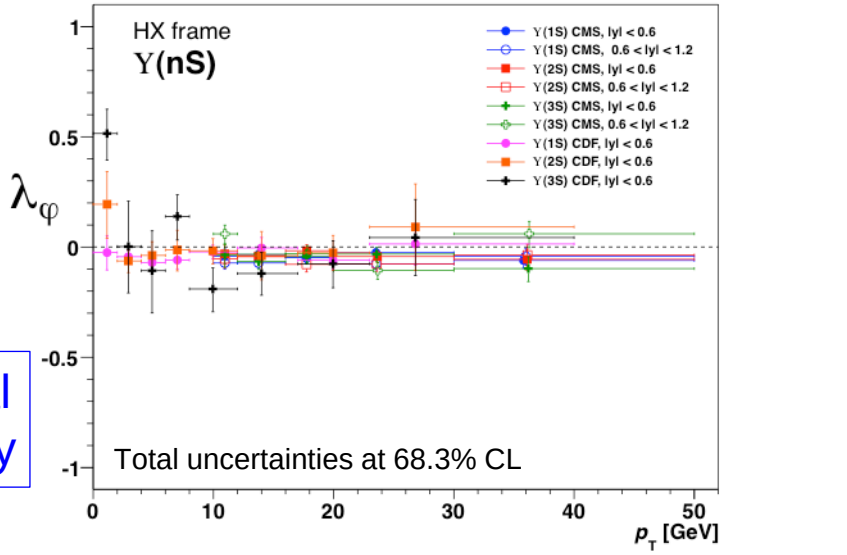
Polar anisotropy

Charmonia

Bottomonia



Azimuthal anisotropy



The progressing clarification and the LIP role

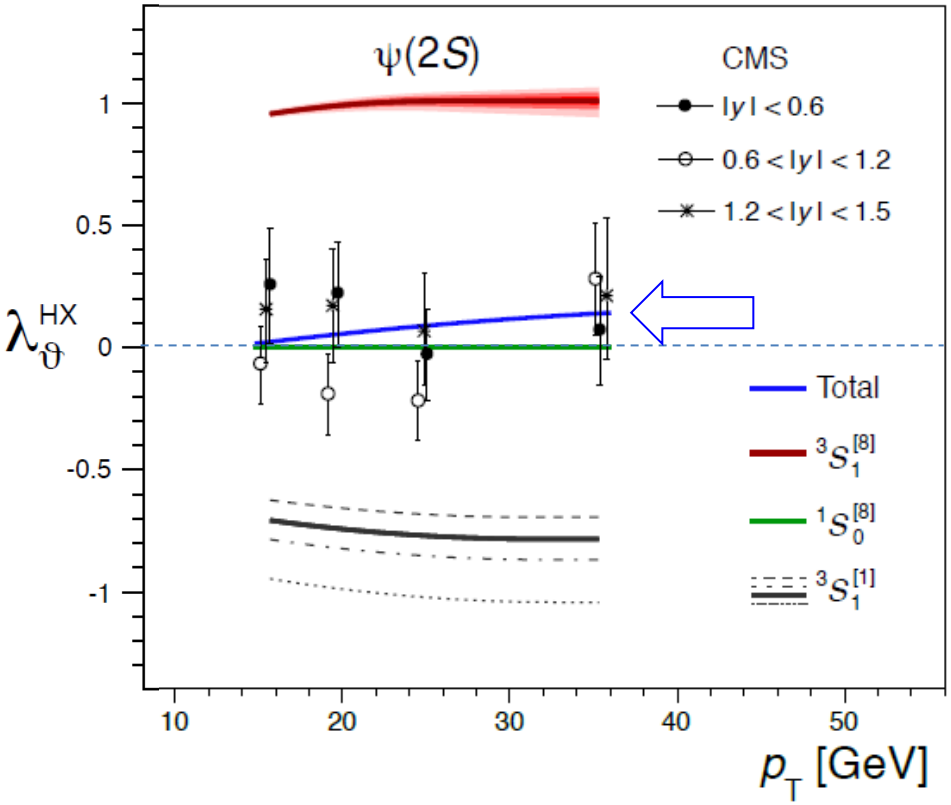
We have recently proposed a new approach to data-theory comparison

(shown at LIP-Lisbon seminar 20/12/2013)

arXiv:1403.3970v1 [hep-ph] 16 Mar 2014

Quarkonium production in the LHC era: a polarized perspective

Pietro Faccioli[1,2], Valentin Knünz[3], Carlos Lourenço[4], João Seixas[1,2] and Hermine K. Wöhri[4]



With a proper consideration of known theory limitations and of uncertainty correlations, the "quarkonium polarization puzzle" disappears!

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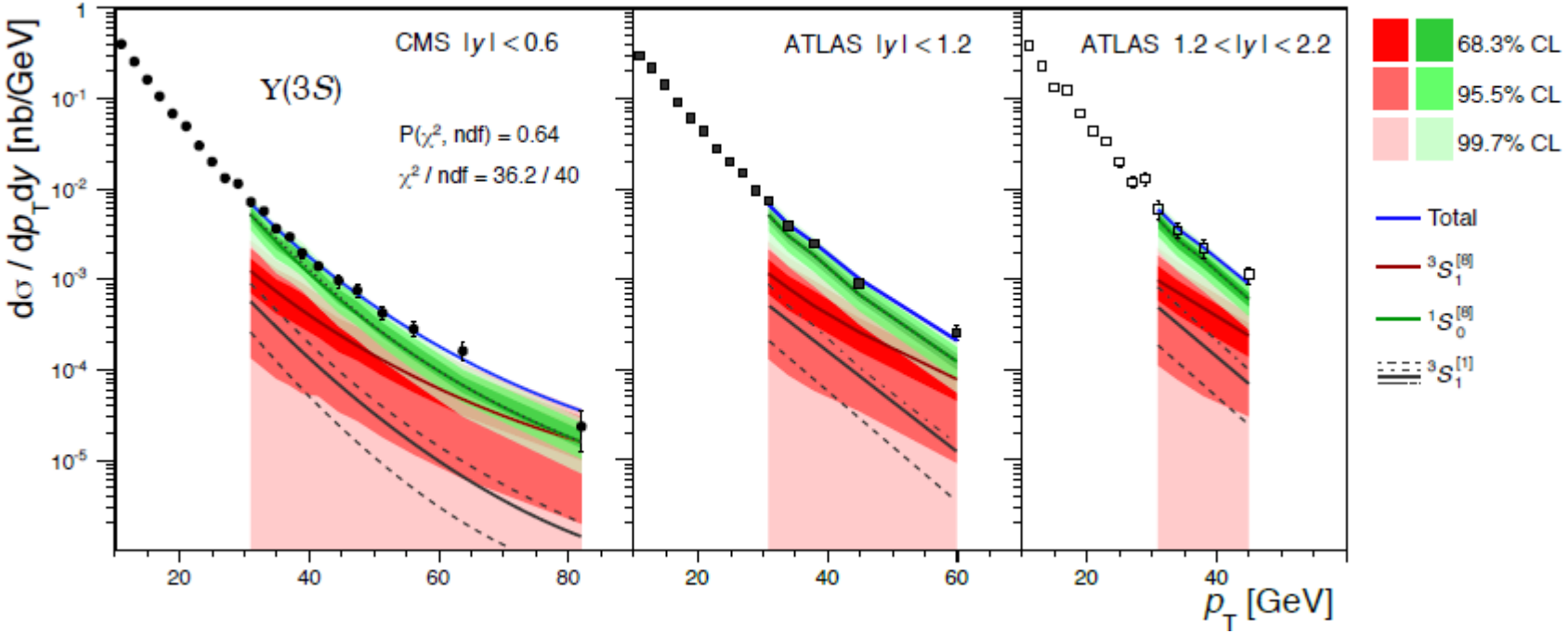
Our global fit of ψ(2S) + ϒ(3S) data from CMS and ATLAS shows very good agreement with NRQCD at sufficiently high p_T, where the "factorization" ansatz should work



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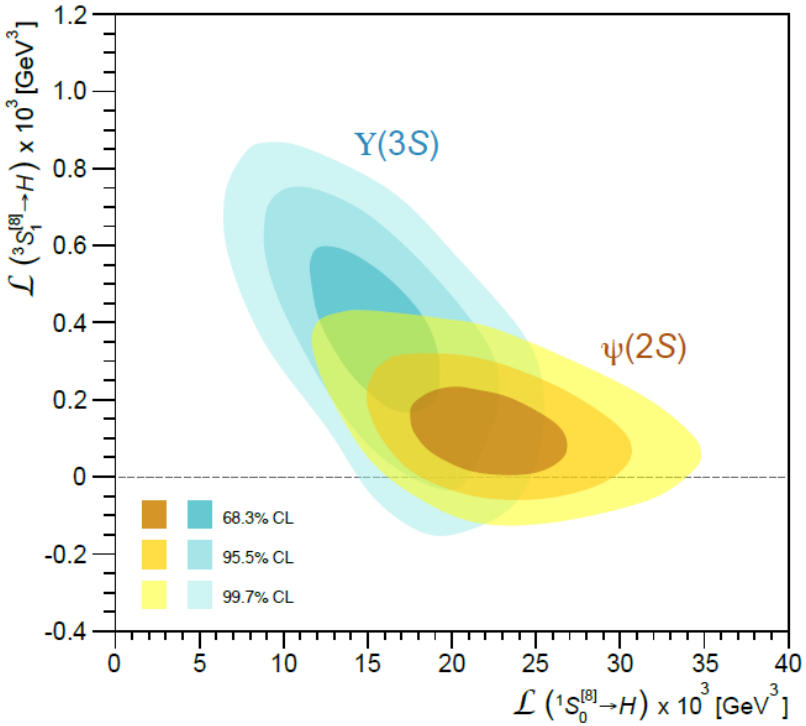
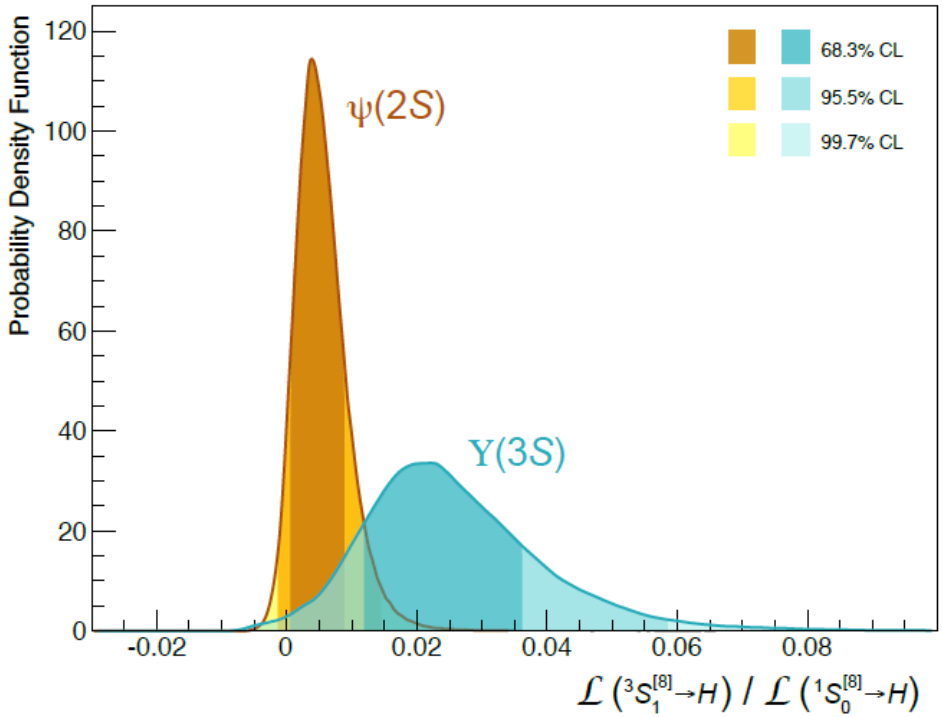
... and non-trivial analogies/hierarchies already start showing up in the bound-state-formation probabilities (LDMEs; the free parameters of NRQCD)





Finally back to the interesting question!

We can finally **use** NRQCD to
measure *the properties of the pre-resonance-to-resonance transitions*

Quarkonium production analyses have the potential to become precision studies of QCD bound-state formation!

New paths will be opened also towards the interpretation of quarkonium suppression in nuclear collisions

CMS measurements with LIP participation will continue to populate and constrain the picture

- χ_c cross sections and polarizations
- improved ψ and Υ measurements towards high pT
- measurements vs particle multiplicity in the event:
  test universality of the factorization and/or discover new-physics effects
- χ_b cross sections
- χ_b polarizations (after 2015)
- exclusive production channels and different collison systems:
  test LDME universality (after 2015)