Quarkonium production (at LHC)

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Heavy flavour production

- **Powerful QCD tests**, instead of using QCD to estimate observables, use production measurements to qualify QCD
- New theory developments confronted to new experimental results. Impressive progress in both domains

<u>**Charmonia production puzzle:**</u>

- First attempt created « **J/ψ production puzzle** »
- Extension with « **J/ψ production AND polarization puzzle** »
- « **J/ψ production AND polarization AND η_c(1S) production puzzle** » with the η_c(1S) production measurement by LHCb
- **More precision** in conventional studies and **new sources of input**: associated production, isolation, production in pPb and PbPb collisions, …
- Comprehensive model of **HF production** still missing

Quarkonium production in NRQCD

- Two scales of production:
  hard process of **$Q\bar{Q}$ creation** and **hadronization of $Q\bar{Q}$** at softer scales
- **Factorization**:

$$d\sigma_{A+B\to H+X} = \sum_n d\sigma_{A+B\to Q\bar{Q}(n)+X} \times \langle \mathcal{O}^H(n) \rangle$$

Short distance: perturbative cross-sections + pdf for the production of a $Q\bar{Q}$ pair

Long distance matrix elements (**LDME**), non-perturbative

- **Colour-singlet model**: intermediate $Q\bar{Q}$ state is colourless and has the same J^{PC} quantum numbers as the final-state quarkonium
- **Colour-octet model** : not colourless, J^{PC} of $Q\bar{Q}$ pair and charmonium differs
  → adjusted in the long-distance part by soft gluon(s) emission
  → LDMEs extracted from experimental data
- **Universality**: *same LDME for prompt production and production in b-decays*
- Heavy-Quark **Spin-Symmetry**: links between colour-singlet and colour-octet LDME of different quarkonium states

Charmonium production processes

"Hard" processes

- e+e- production (B-factories)
- **hadroproduction (hadron colliders)**

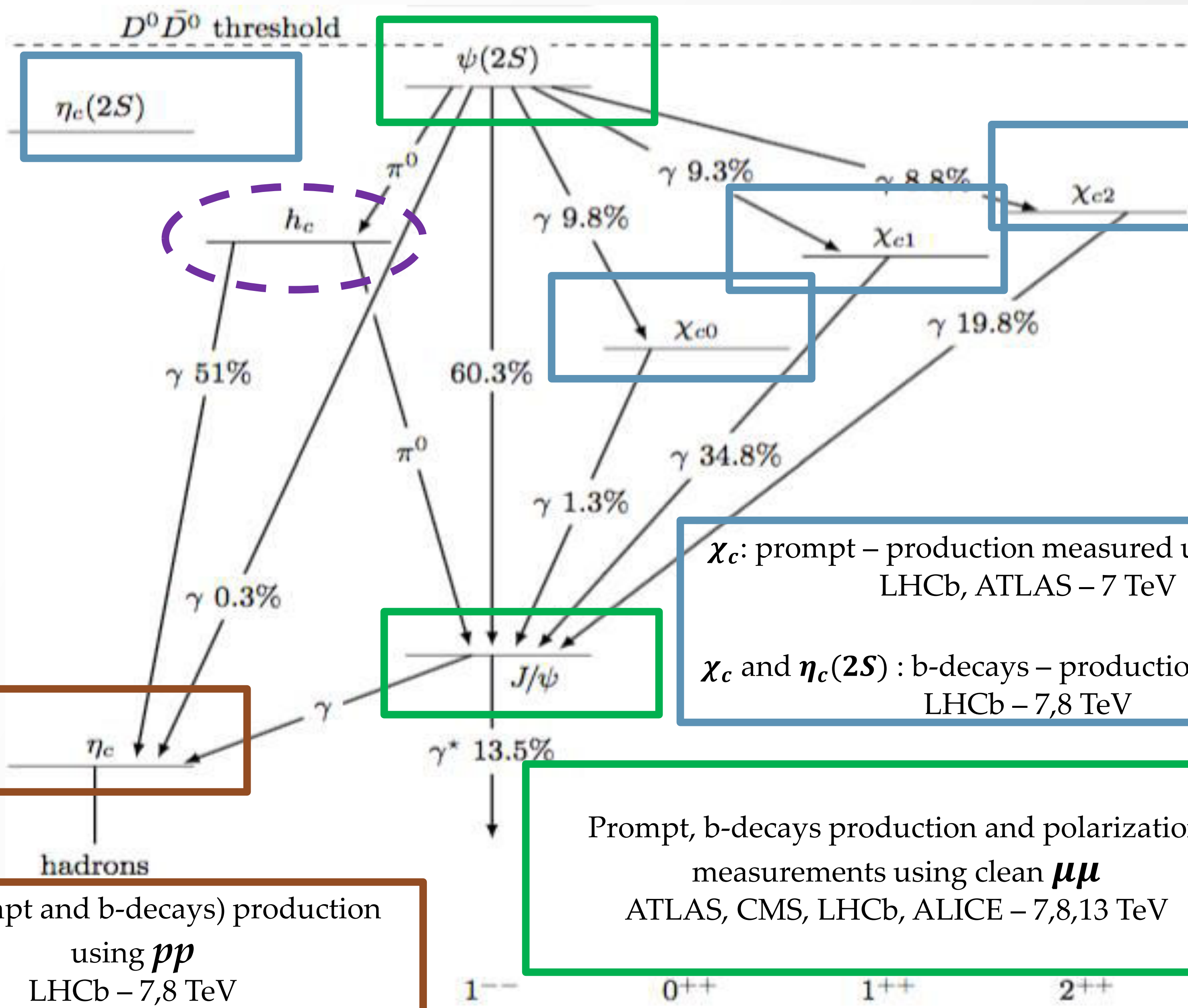
Production in decays:

- B-decays **(~5 GeV)**
  – accessible at B-factories and hadron colliders
- Bottomonium decays **(~11 GeV)**
  – accessible at B-factories and hadron colliders(?), not many decays observed so far
- Z decays **(~90 GeV)**
  – not many decays observed so far
- Higgs decays **(~120 GeV)**
  – not observed so far
- t-decays **(~170 GeV**)
  – not observed so far

Production in soft processes (for soft QCD measurements):

- Photoproduction
- Central exclusive production

Charmonia family



χ_c: prompt – production measured using $\mathbf{J/\psi\gamma}$
LHCb, ATLAS – 7 TeV

χ_c and $\eta_c(2S)$: b-decays – production using $\phi\phi$
LHCb – 7,8 TeV

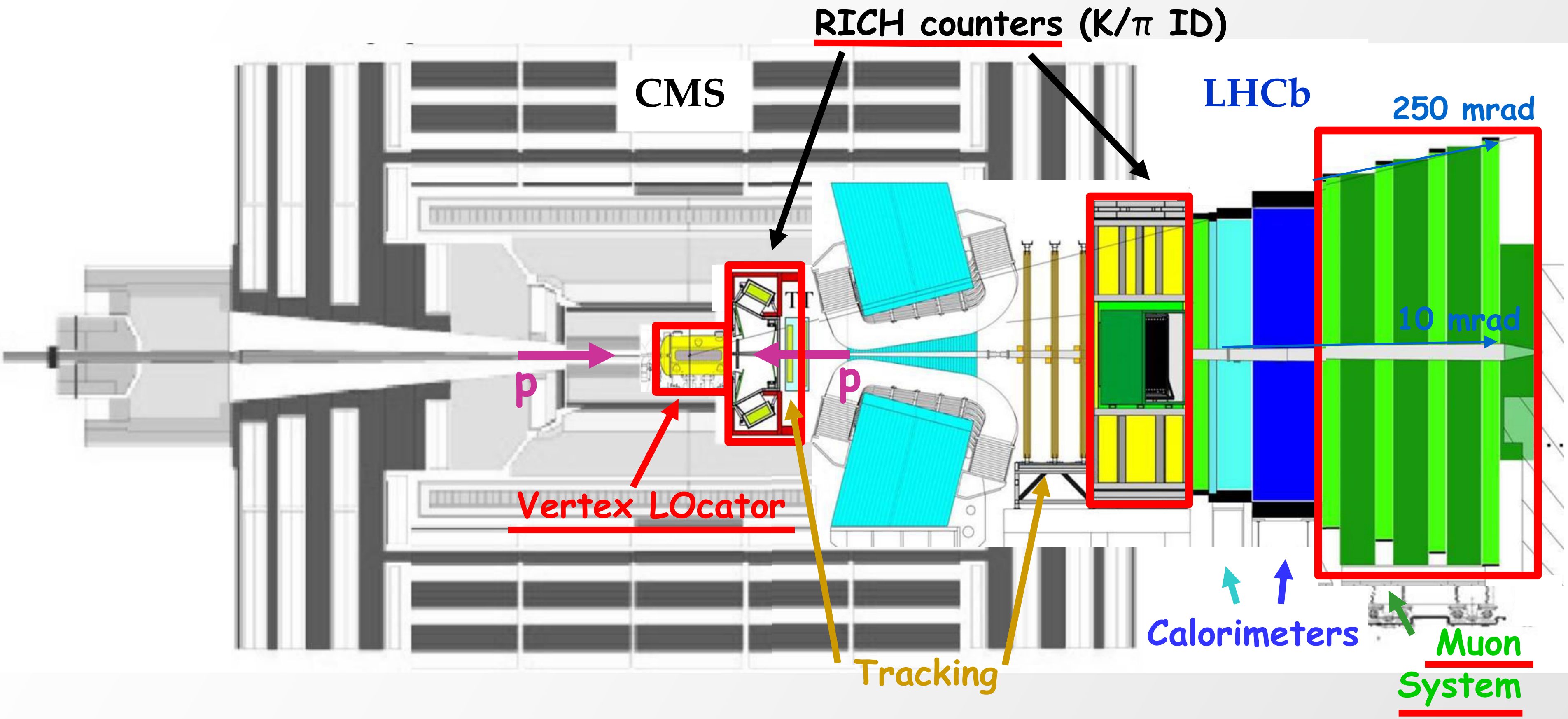
Prompt, b-decays production and polarization measurements using clean $\mu\mu$
ATLAS, CMS, LHCb, ALICE – 7,8,13 TeV

η_c (prompt and b-decays) production using pp
LHCb – 7,8 TeV
First meas at hadronic machines

LHCb detector vs central detectors (ATLAS, CMS)

JINST 8 (2013) P08002, INT.J.MOD.PHYS.A30 (2015) 1530022

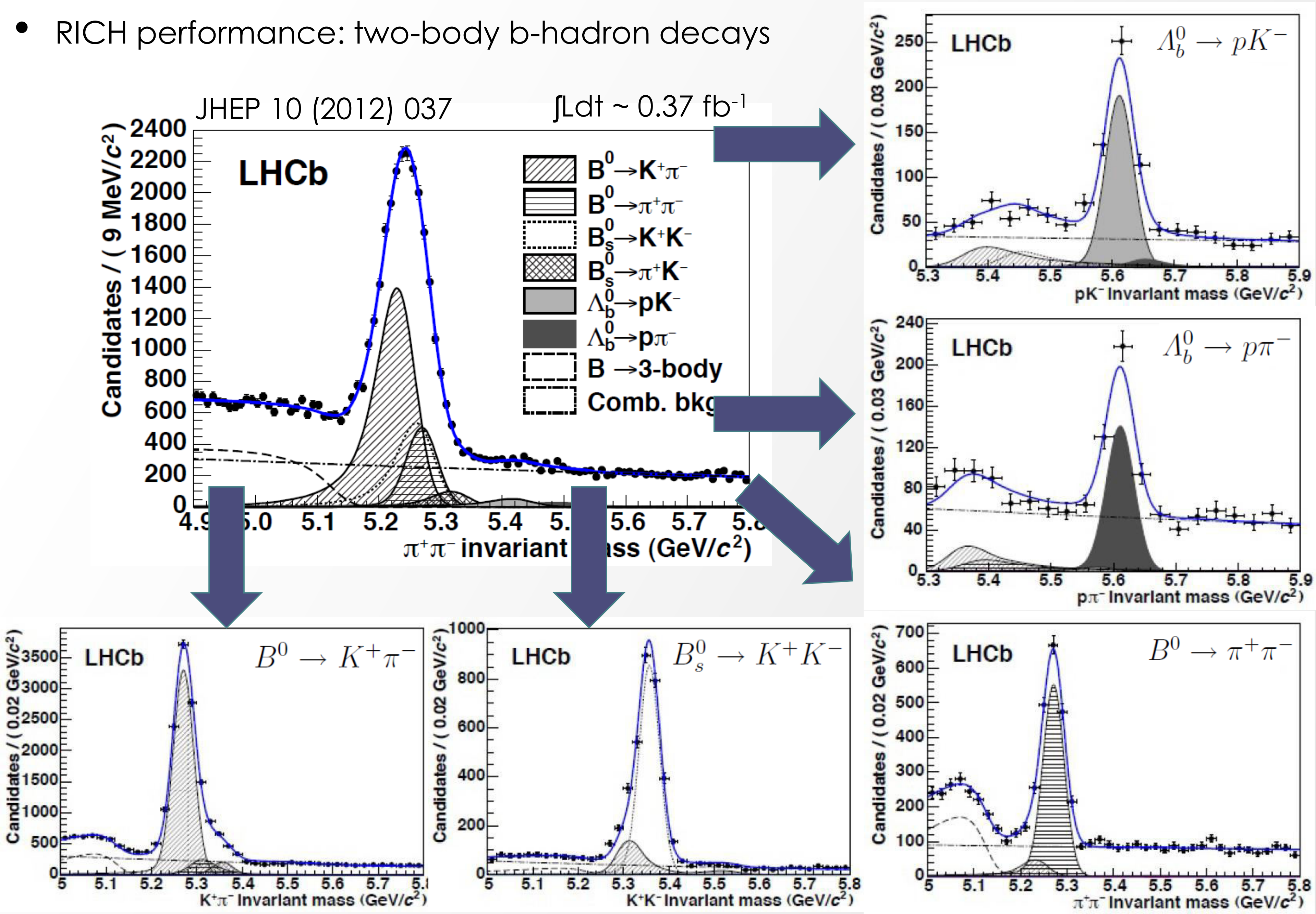
- **Forward peaked HQ production** at the LHC, second b in acceptance once the first b is in
- Forward region $1.9 < \eta < 4.9$, **~4% of solid angle**, but **~40% of HQ production x-section**



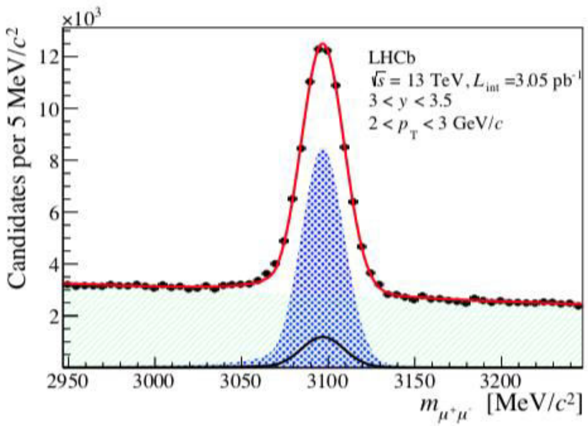
- **Complementary cross-section measurements** and overlap in terms of rapidity and p_T
- Key detector systems for production measurements: **vertex reconstruction (VELO), particle identification (Muon detector, RICHs), Trigger**
- Allows to perform study of **charmonia decays** through **hadronic final states**

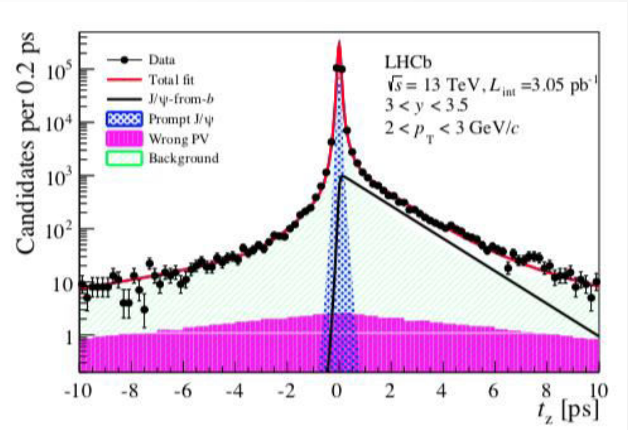
Charged hadron identification with RICH at LHCb

- RICH performance: two-body b-hadron decays

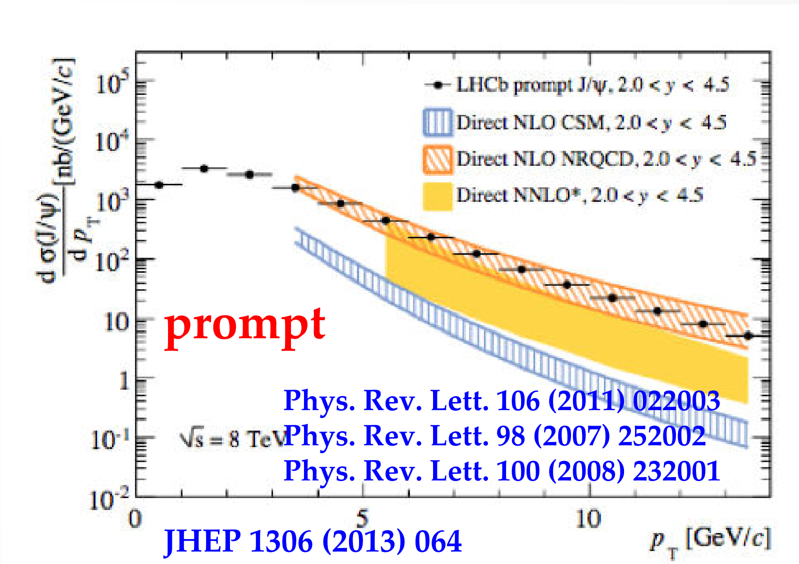


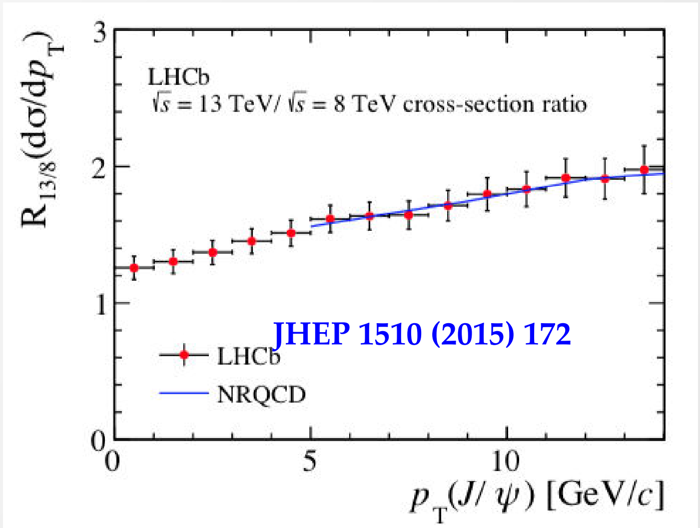
J/ψ hadroproduction at LHCb using J/ψ → $\mu\mu$





- clean signal from J/ψ → $\mu\mu$
- separate prompt production and production b-decays by fitting pseudo-proper lifetime





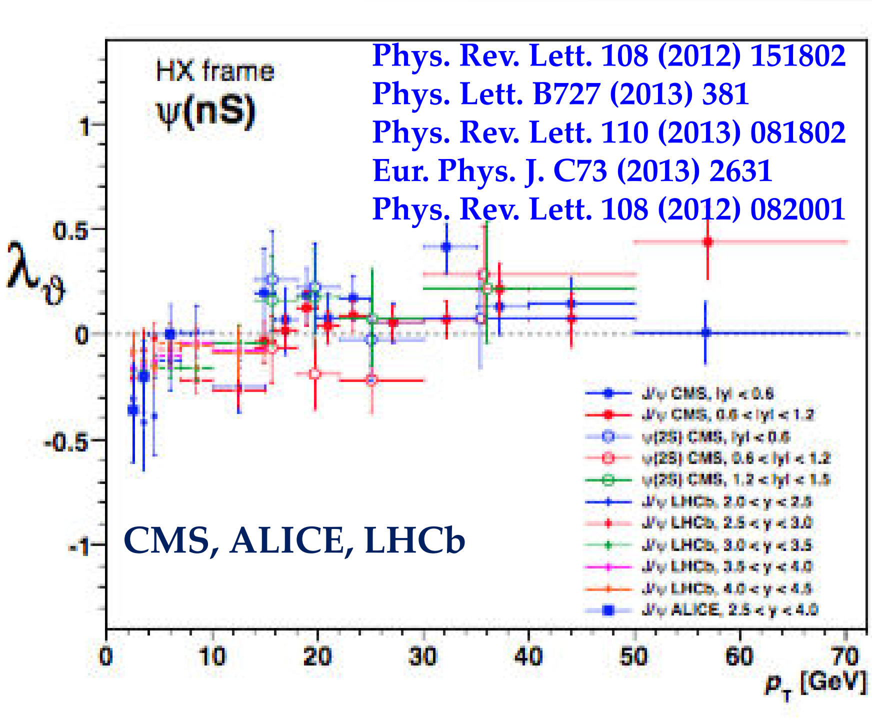
- Measurements of Tevatron and LHC (CDF, CMS, ATLAS, LHCb) experiments are in agreement
- Could not be described by CS NLO and NNLO -> motivation to investigate CO
- **Described by NRQCD NLO, dominated by CO contributions**

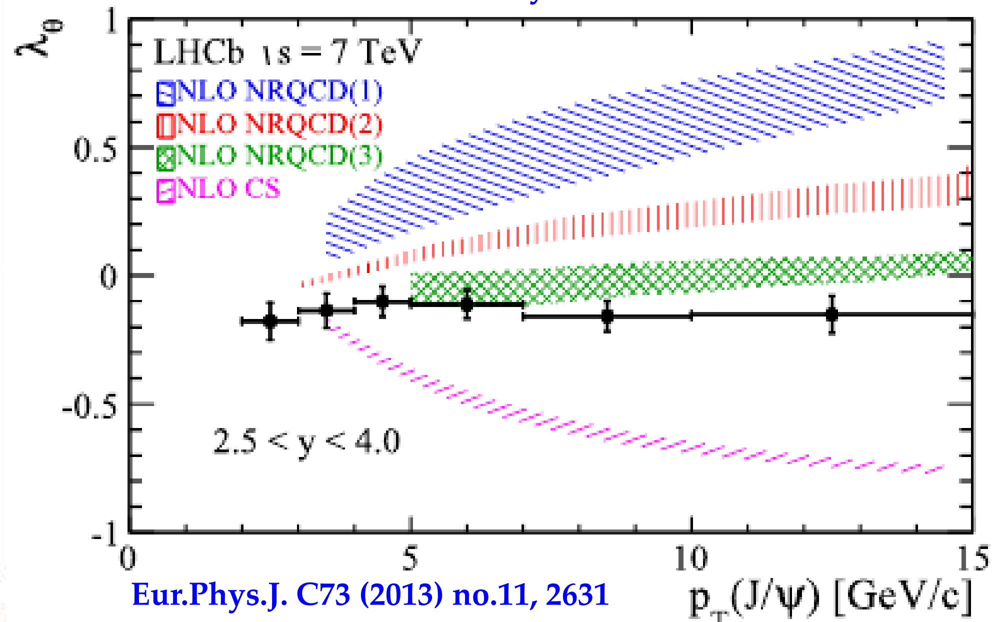
Ratio of 13 TeV/ 8 TeV production:

- **Many systematic uncertainties cancelled**
- **Ultimane theory precision**

J/ψ polarization using J/ψ → $\mu\mu$

Phys. Rev. Lett. 108 (2012) 172002
Phys. Rev. Lett. 110 (2013) 042002
Phys. Rev. Lett. 108 (2012) 242004





$$\frac{dN}{dCos\theta} \sim 1 + \lambda_\theta Cos^2\theta$$

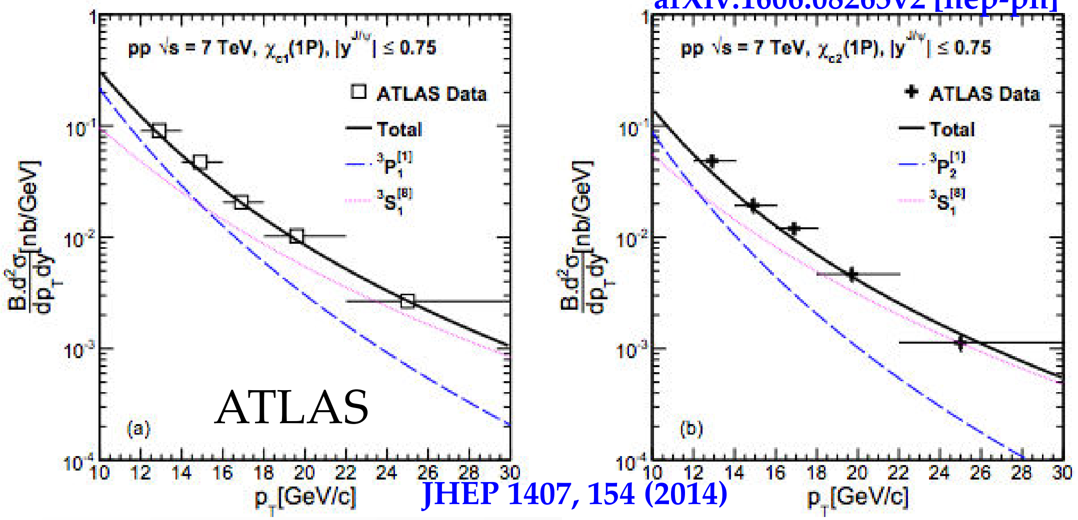
J/ψ polarization:

- Measurements of Tevatron and LHC experiment are in agreement CO predicts strong polarization
- **Large CS contribution is needed → can be explained by feed-down contribution?**

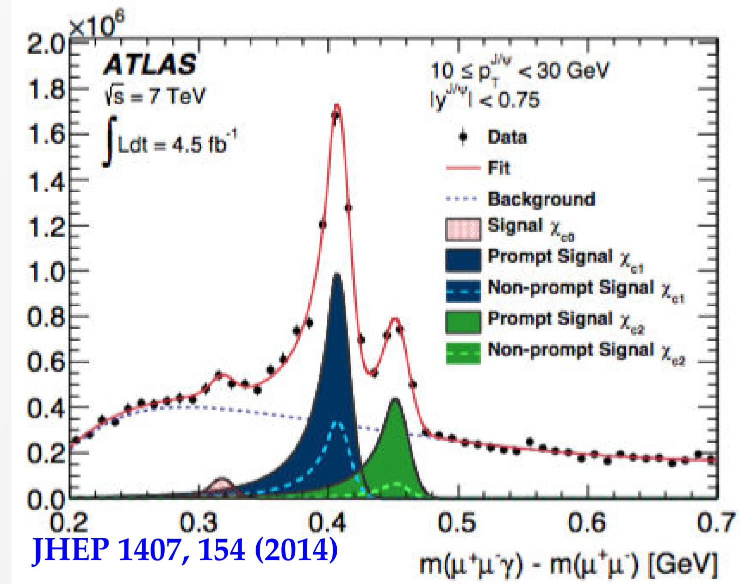
$\chi_{c1,2}$ prompt production using $\chi_{c1,2} \rightarrow J/\psi\, \gamma$

NRQCD fit for absolute production:

arXiv:1606.08265v2 [hep-ph]

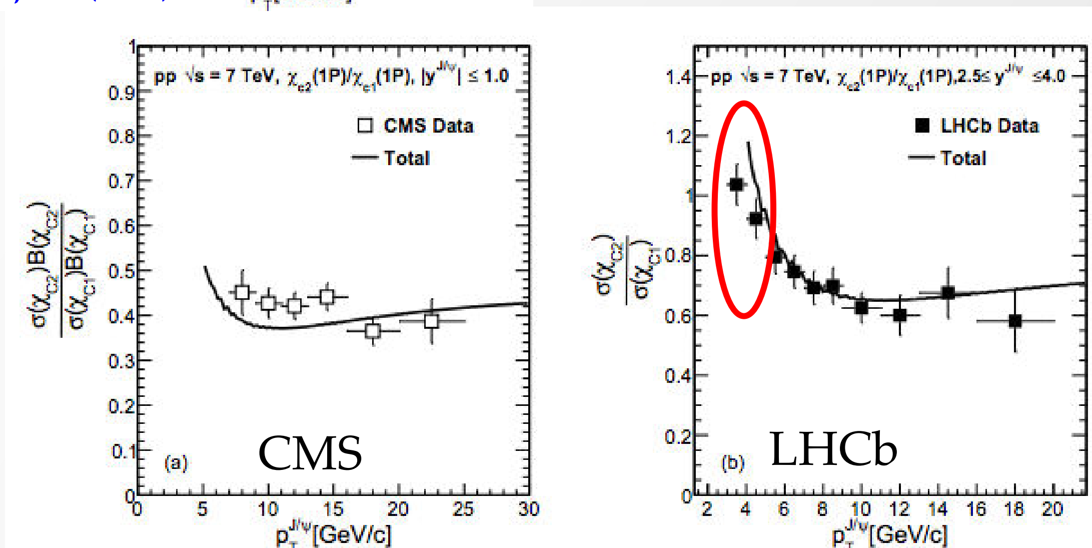


JHEP 1407, 154 (2014)



JHEP 1407, 154 (2014)

More precise when looking for ratio:



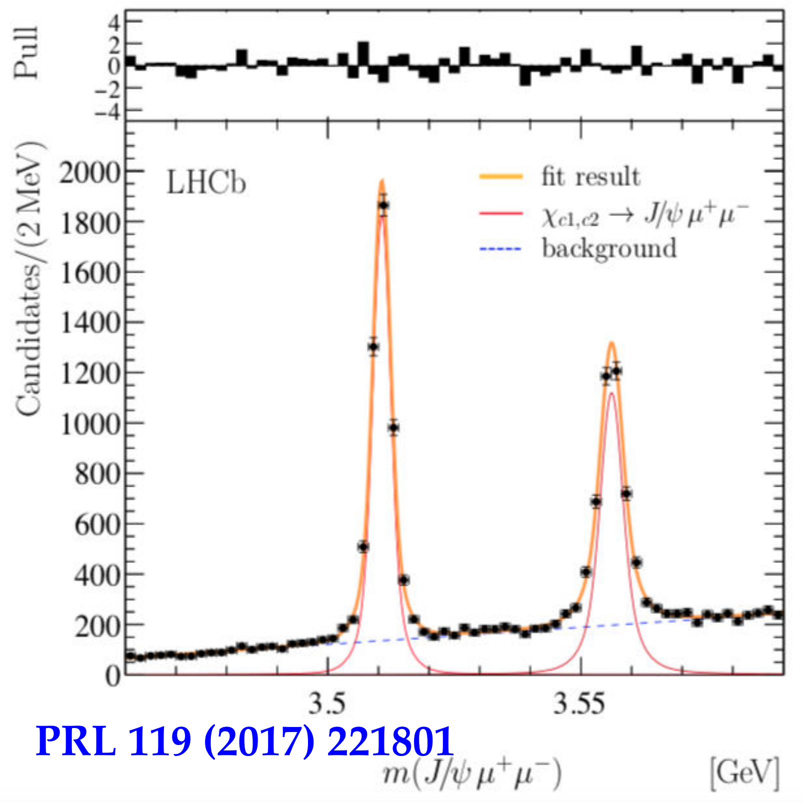
Eur. Phys. J. C 72, 2251 (2012) JHEP 1310, 115 (2013)

- **color Octet LDME extracted from fit**
- small p_T region has to be explored

Accessing $\chi_{c1,2}$ using $\chi_{c1,2} \rightarrow J/\psi\mu\mu$ at LHCb

- First observations of $\chi_{c1,2} \rightarrow J/\psi\mu\mu$ decay modes
- Extremely clean signals
- Measurements of $\chi_{c1,2}$ resonance parameters are competing with world average precision
- New channel for production measurements

Quantity [MeV]	LHCb measurement	Best previous measurement	World average
$m(\chi_{c1})$	3510.71 ± 0.10	3510.72 ± 0.05	3510.66 ± 0.07
$m(\chi_{c2})$	3556.10 ± 0.13	3556.16 ± 0.12	3556.20 ± 0.09
$\Gamma(\chi_{c2})$	2.10 ± 0.20	1.92 ± 0.19	1.93 ± 0.11



PRL 119 (2017) 221801

- **Very promising channel to measure χ_c hadroproduction at low p_T**
- **Similar studies can be done at CMS?**

Charmonium production using decays to **ppbar**

- **Prompt and b-decay production** distinguished via decay time value (t_z-cut) or t_z-fits

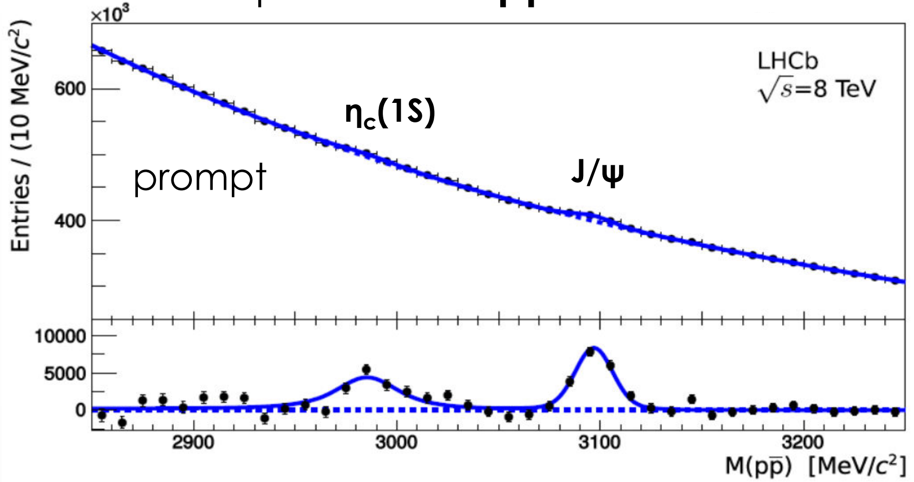
$$t_z = \frac{z_{SV} - z_{PV}}{p_z} M_{p\bar{p}}$$

- **First measurements of $\eta_c(1S)$ prompt production** at 7 and 8 TeV and b-decay production: PhD thesis (M. Teklishyn, 2014) and **Eur.Phys.J. C75 (2015) 311**,
- Measurement of **differential cross-sections (pT)**, experimental precision is worse than theoretical one
- **Strong impact on theory models**: contrary to theory expectations, $\eta_c(1S)$ prompt production entirely described by Color-Singlet contribution.

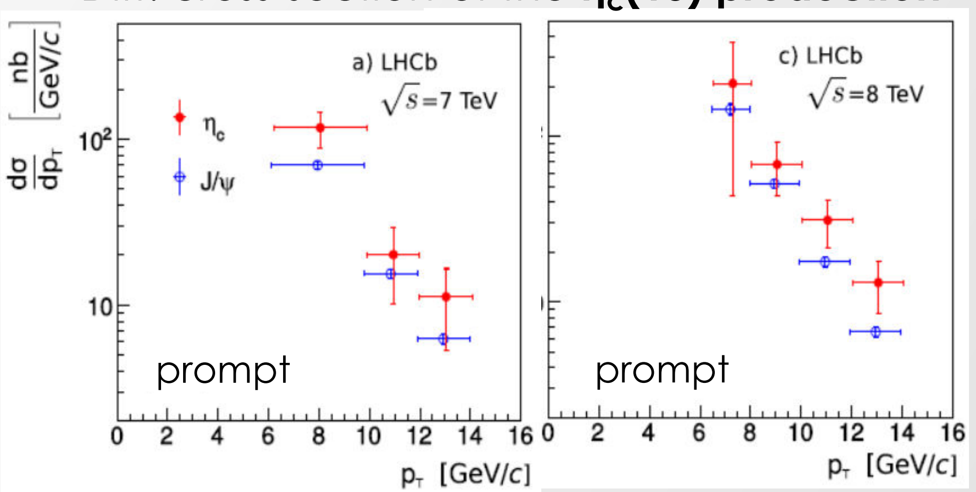
\+ *First measurement of $\eta_c(1S)$ production in inclusive b-decays*

Eur.Phys.J. C75 (2015) 311

Inv. mass spectrum of **$p\bar{p}$ from collision vertex**



Diff. cross-section of the **$\eta_c(1S)$ production**

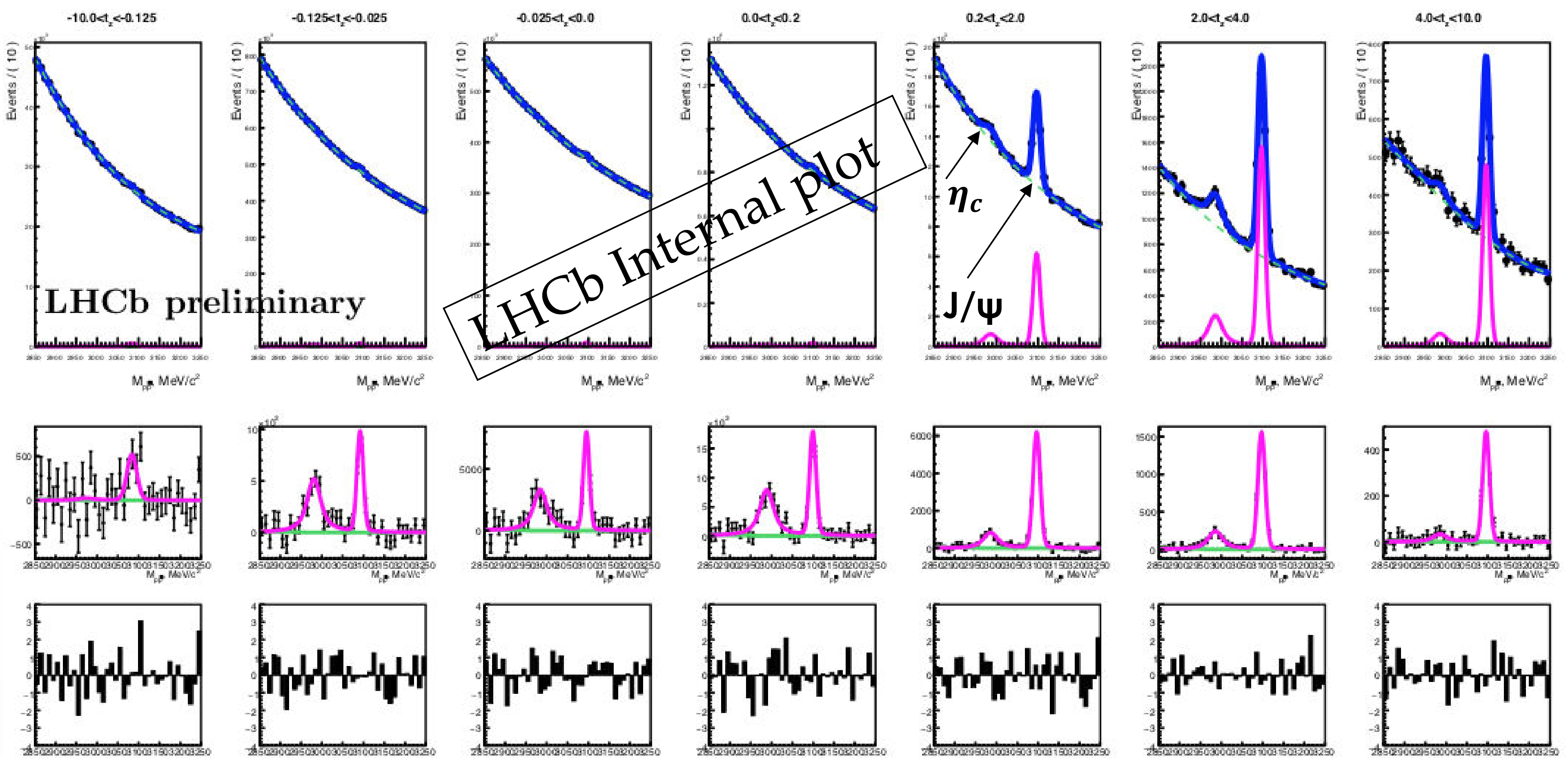


$$\sigma_{\eta_c(1S)} = 0.52 \pm 0.09 \pm 0.08 \pm 0.06\ \mu\text{b} \quad \sqrt{s} = 7\,\text{TeV}$$

$$0.59 \pm 0.11 \pm 0.09 \pm 0.08\ \mu\text{b} \quad \sqrt{s} = 8\,\text{TeV}$$

$\eta_c(1S)$ production at 13 TeV using its decay to **ppbar** (internal results)

- **Master thesis of Valeriia Zhovkovska**



Yields extraction:

1. **Simultaneous likelihood fit to $M(p\bar{p})$ in bins of [p_T, t_z]:**

   to extract charmonia yields

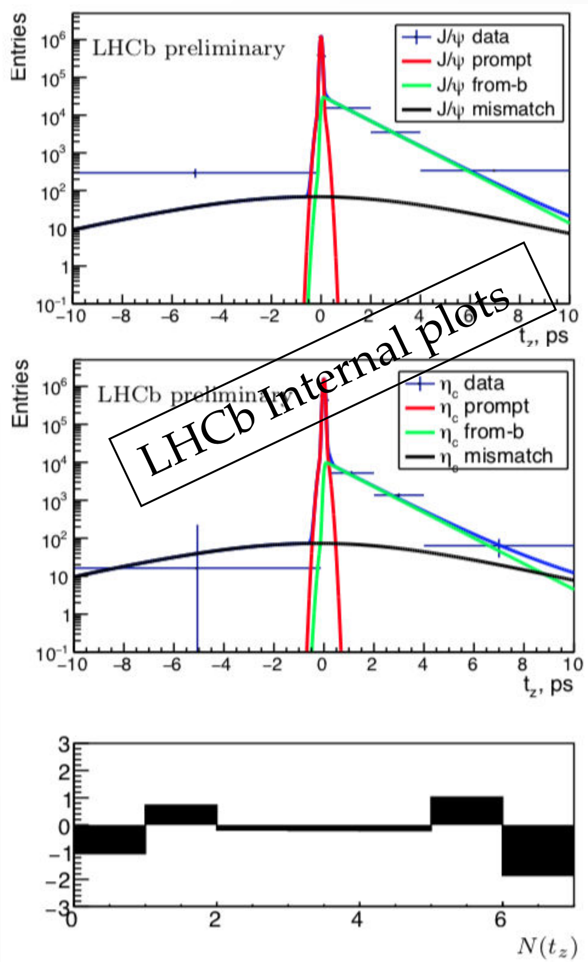
2. **Simultaneous integral χ^2 t_z fit in p_T bins**

   to separate prompt and from *b*-decays charmonia

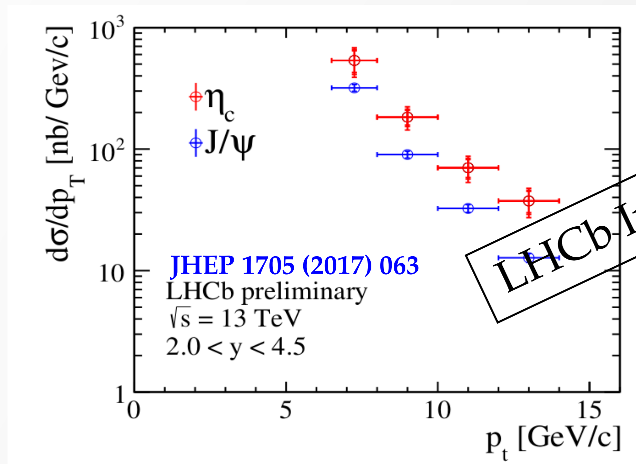
$\eta_c(1S)$ production at 13 TeV using its decay to **ppbar** (internal results)

- Measurement of **differential cross-sections (pT)**
- Analysis of **η_c(1S) production at 13 TeV** being completed

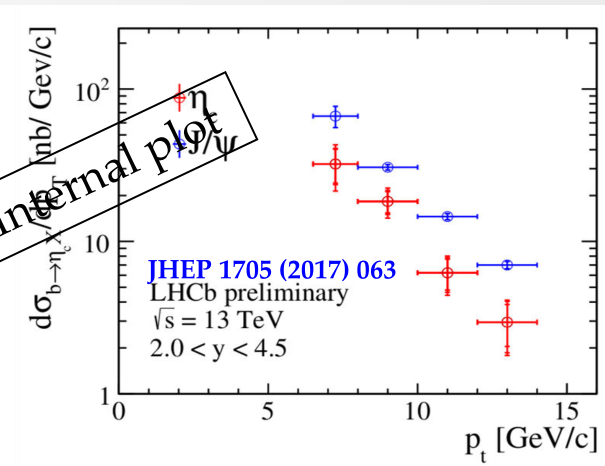
Simultaneous (J/ψ and η_c) χ^2integral t_z-fit
in bins of p_T: *projection on p_T bin [8,10] GeV/c*



Prompt production



Production from *b*-decays



Preliminary internal result:

$$\sigma_{\eta_c} = 1.39 \pm 0.12_{\text{stat}} \pm 0.10_{\text{syst}} \pm 0.16_{\text{BR}}\ \mu\text{b}$$

$$\frac{BR_{b\to\eta_c X}}{BR_{b\to J/\psi X}} = 0.444\ \pm 0.076_{stat} \pm 0.034_{stat} \pm 0.047_{BR}$$

6.5 GeV/c < PT < 14.0 GeV/c / 2.0 < y < 4.5

Better precision for prompt production compare to Run I measurement

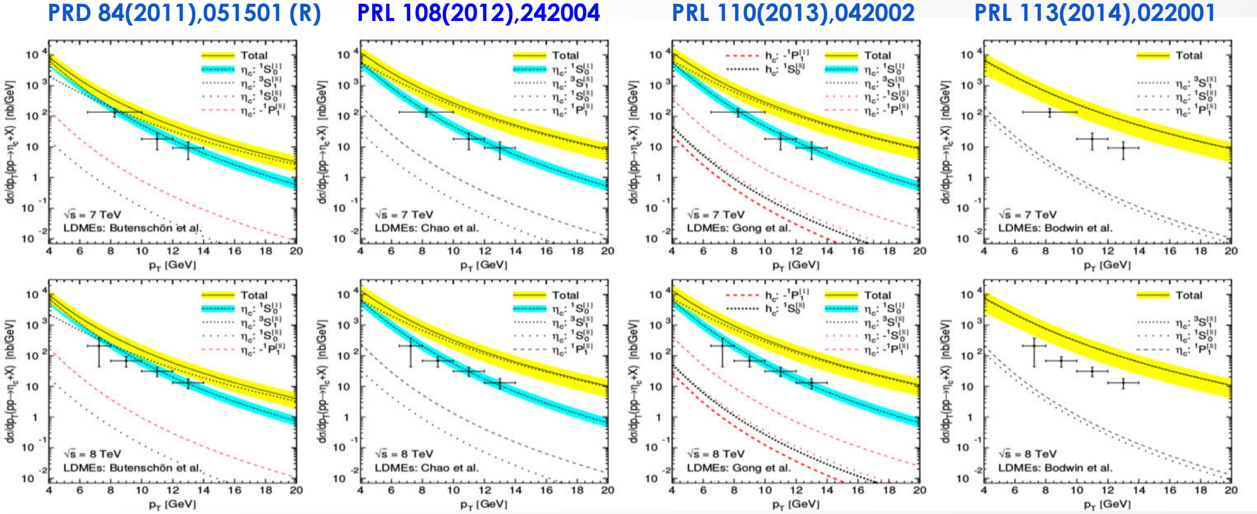
η_c production challenges NRQCD

η_c LDMEs determination:

- determined from known HQSS relation for J/ψ
- direct projection to LHCb data

$$\langle O_1^{\eta_c}(^1S_0)\rangle = \frac{1}{3}\langle O_1^{J/\psi}(^3S_1)\rangle,$$
$$\langle O_8^{\eta_c}(^1S_0)\rangle = \frac{1}{3}\langle O_8^{J/\psi}(^3S_1)\rangle,$$
$$\langle O_8^{\eta_c}(^3S_1)\rangle = \langle O_8^{J/\psi}(^1S_0)\rangle,$$
$$\langle O_8^{\eta_c}(^1P_1)\rangle = 3\langle O_8^{J/\psi}(^3P_0)\rangle.$$

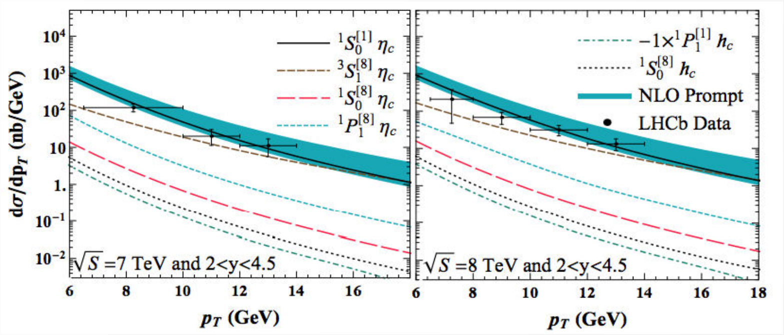
PRD 84(2011),051501 (R) PRL 108(2012),242004 PRL 110(2013),042002 PRL 113(2014),022001



=► LHCb data are entirely described by **CS** contribution

- Recent progress in theoretical description:

PRL 114(2015), 092005



using constraints from **fits to J/ψ production measurements and fit to η_c production measurement**, upper limit on CO LMDE extracted:

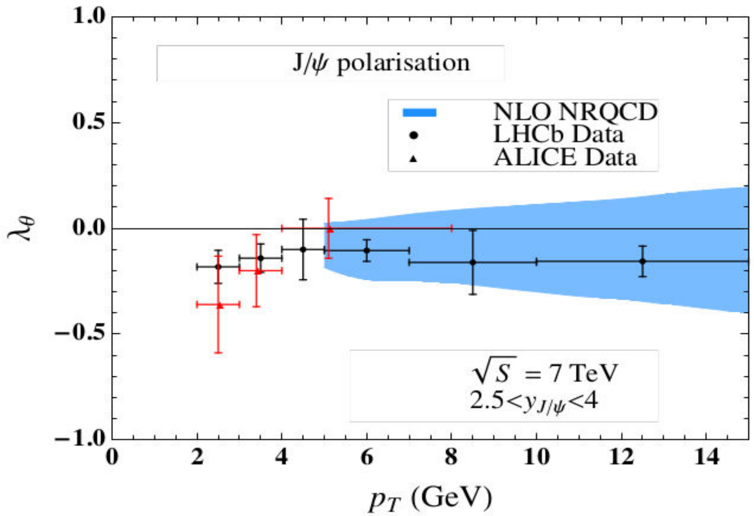
$$0 < O_8^{\eta_c}(^3S_1) < 1.46 \times 10^{-3}\,\mathrm{GeV}^3$$

η_c production challenges NRQCD

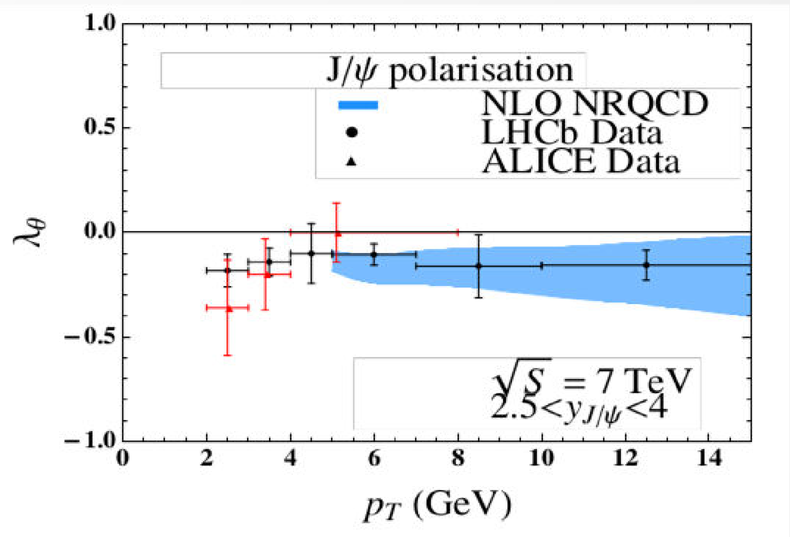
UL on $O^{\eta_c}(^3S_1^{[8]})$ ⇒ new constraint on J/ψ polarization

PRL 114(2015), 092005

Without η_c measurements



With η_c measurements



Outcome:

- *progress in data* description
- tension with CDF data
- two large CO contributions cancel each other ⇒ hierarchy problem ⇒ Soft Gluon Fragmentation, etc.?
- joint study of hadroproduction and production in inclusive *b*-decays?

Prospects:

- Theory fits to be updated with Run II measurement
- Similarly measure $\eta_c(2S)$ prompt production using new dedicated trigger lines

J/ψ and η_c production in inclusive b-decays

Usachov,Kou, Barsuk, LAL-17-051

- From **EPJC 75 (2015) 311** and **Chin. Phys. C40 (2016) 100001:**

$$\frac{\mathcal{B}(b \to \eta_c(1S)^{direct} X)}{\mathcal{B}(b \to J/\psi^{direct} X)} = 0.691 \pm 0.090 \pm 0.024 \pm 0.103.$$

- Relation between LDME from HQSS:

$$\langle O_1^{\eta_c}(^1S_0)\rangle = \frac{1}{3}\langle O_1^{J/\psi}(^3S_1)\rangle,$$
$$\langle O_8^{\eta_c}(^1S_0)\rangle = \frac{1}{3}\langle O_8^{J/\psi}(^3S_1)\rangle,$$
$$\langle O_8^{\eta_c}(^3S_1)\rangle = \langle O_8^{J/\psi}(^1S_0)\rangle,$$
$$\langle O_8^{\eta_c}(^1P_1)\rangle = 3\langle O_8^{J/\psi}(^3P_0)\rangle.$$

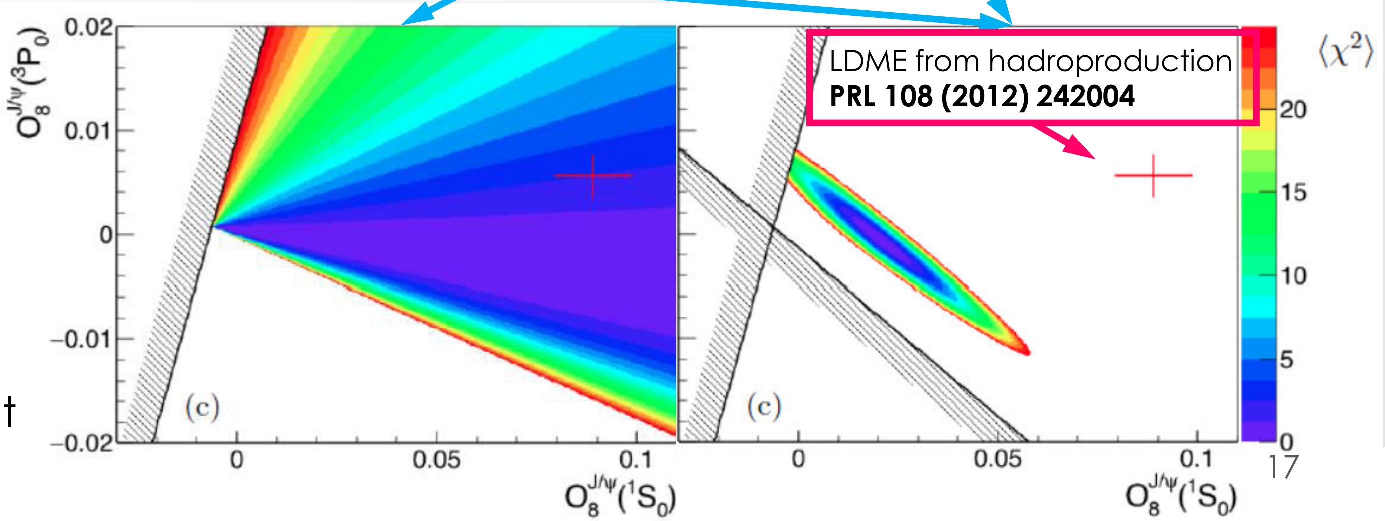
- Branching fractions calculated in **Beneke, Maltoni, Rothstein, PRD 59 (1999) 054003**

- **Fit two LDME to measurements**
- Consecutively fix two remaining LDME from **Chao et al., PRL 108 (2012) 242004**

$$\langle O_8^{J/\psi}(^3S_1)\rangle = 0.003\,\mathrm{GeV}^3$$
$$\langle O_8^{J/\psi}(^3S_1)\rangle = 1.16\,\mathrm{GeV}^3$$

- Two independent measurements (constraints) important

$$\frac{\mathcal{B}(b \to \eta_c(1S)^{direct} X)}{\mathcal{B}(b \to J/\psi^{direct} X)} \qquad \mathcal{B}(b \to J/\psi^{direct} X)$$

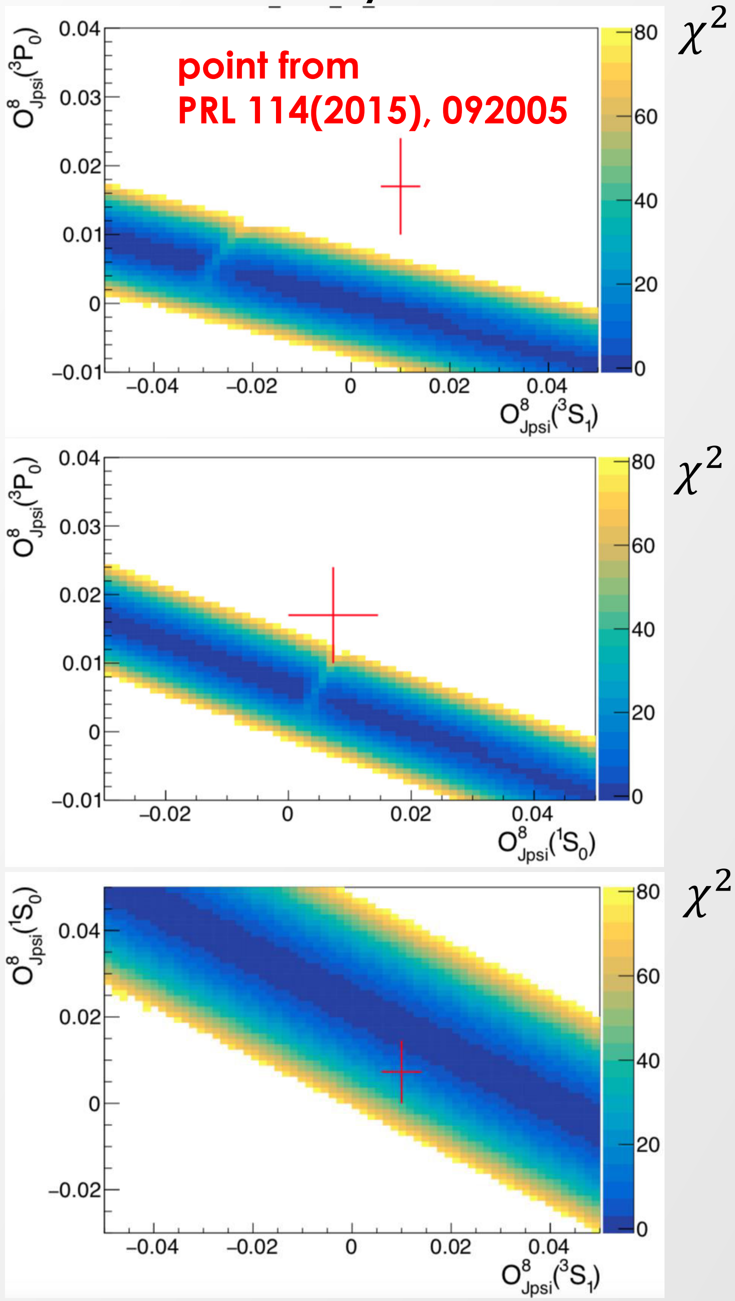


Theory fits to J/ψ and η_c production in inclusive b-decays

- Compare determination of LDMEs from hadroproduction and from b-decays

- Understanding of theoretical uncertainties crucial to make a comparison.

Estimate with theory errors included

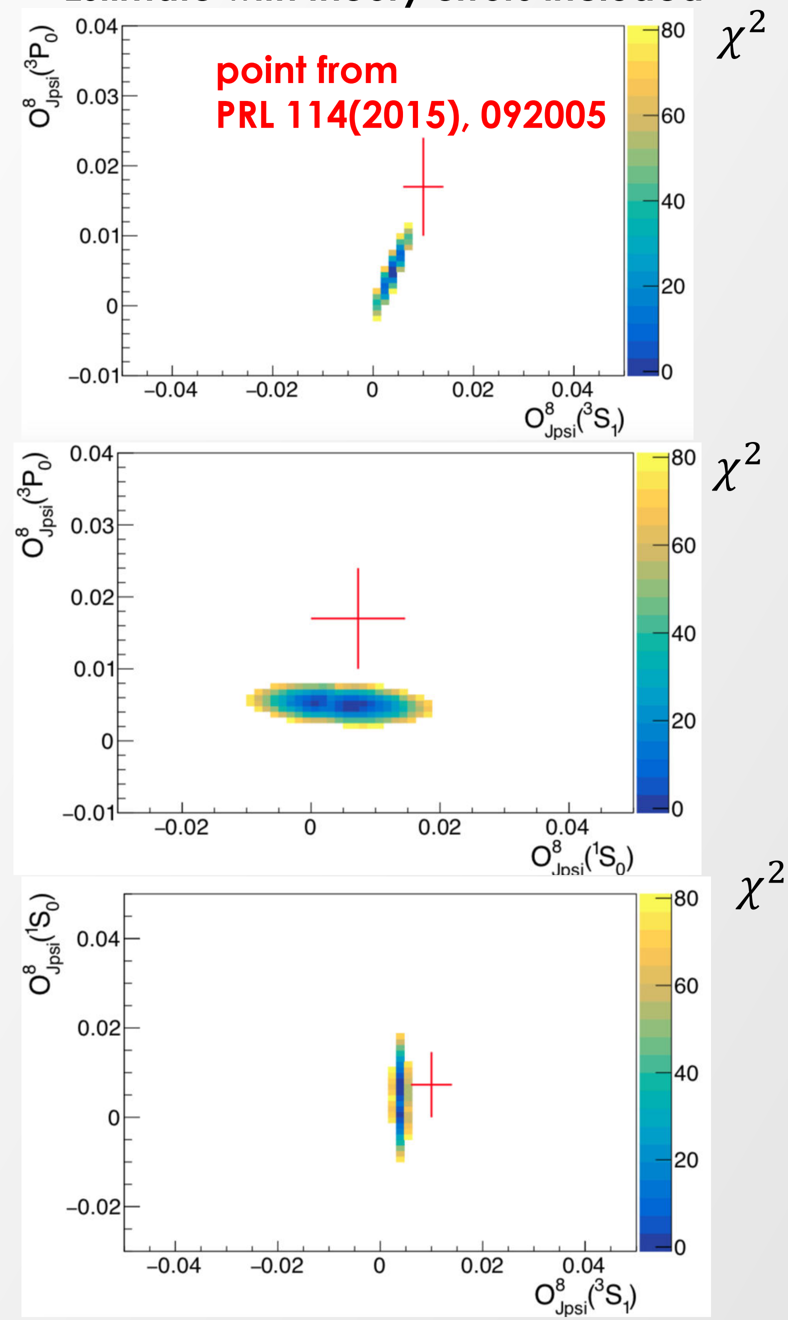


Joint fits to J/ψ and η_c production in inclusive b-decays and prompt production

- Compare determination of LDMEs from hadroproduction and from b-decays

- Understanding of theoretical uncertainties crucial to make a comparison.

Estimate with theory errors included



Combining charmonium production measurements

- Understanding of theoretical uncertainties crucial to make comparisons.
- **Theory calculations** should be revisited, higher order corrections maybe needed.

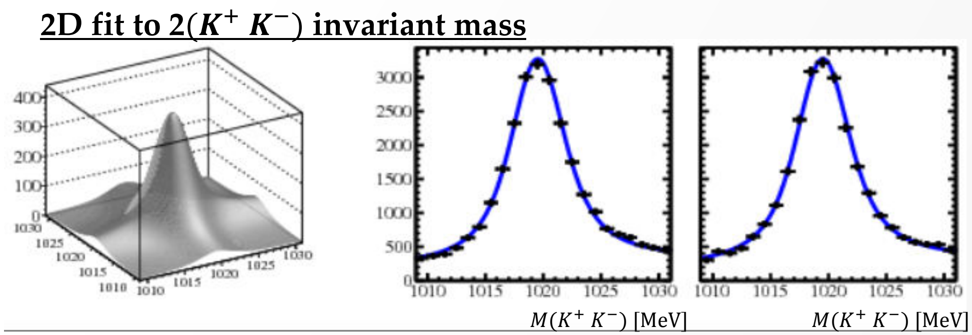
- This technique constrains theory using **simultaneously** results on **charmonia hadroproduction and** on **charmonia from b-inclusive decays** under **assumptions of factorization, universality and HQSS**, with **different charmonium states.**

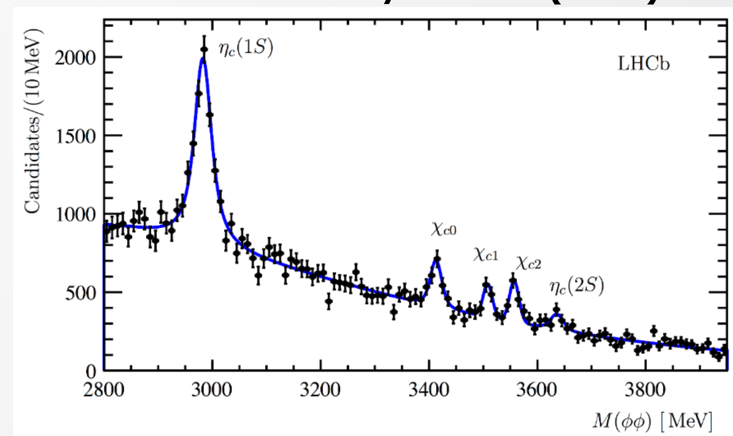
- Alternatively, once hadroproduction and production in b-decays measured for charmonium states with linked LDMEs, the above **assumptions can be tested quantitatively**.

$\chi_{c0,1,2}$ production in inclusive b-decays using $\chi_{c0,1,2} \rightarrow \phi\phi$

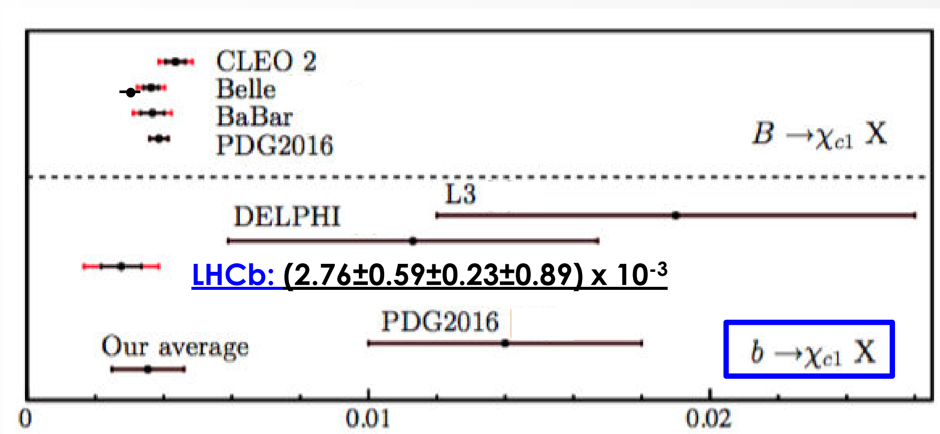
Eur.Phys.J. C77 (2017) 609

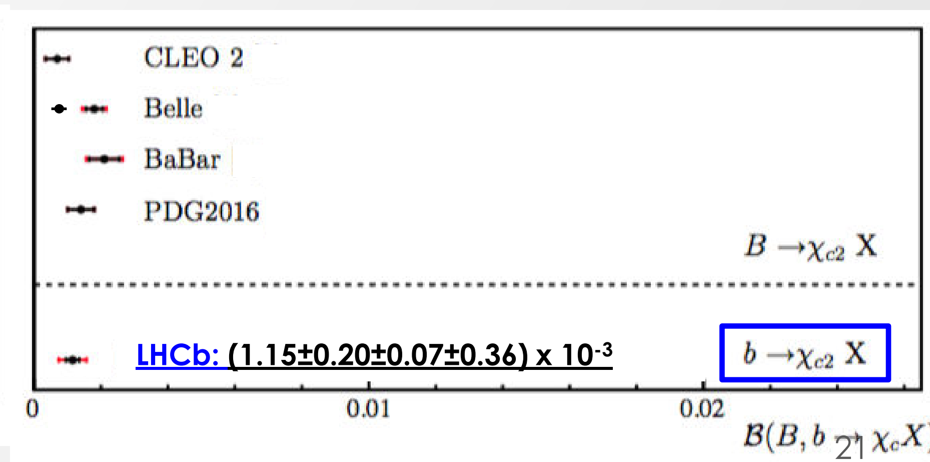
- Charmonium reconstructed via **decays to φφ**; true φφ combinations using 2D fit technique





- First measurement of χ_{c0} production in b-hadron decays: **BR(b→χ_{c0}X)=(3.02±0.47±0.23±0.94)x10^{-3}**
- Most precise measurements of χ_{c1} and χ_{c2} production in b-decays, consistent with B-factories





$\chi_{c0,1,2}$ production in inclusive b-decays using $\chi_{c0,1,2} \to \phi\phi$

Usachov, Kou, Barsuk, LAL-17-051

- From **Eur.Phys.J. C77 (2017) 609** and **Chin. Phys. C40 (2016) 100001:**

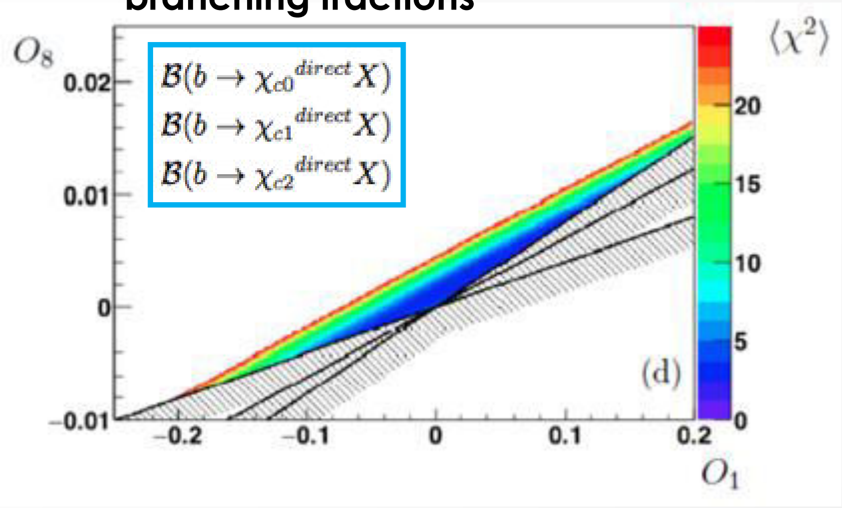
$$\mathcal{B}(b \to \chi_{c0}{}^{direct} X) = (2.74 \pm 0.47 \pm 0.23 \pm 0.94_{\mathcal{B}}) \times 10^{-3}$$
$$\mathcal{B}(b \to \chi_{c1}{}^{direct} X) = (2.49 \pm 0.59 \pm 0.23 \pm 0.89_{\mathcal{B}}) \times 10^{-3}$$
$$\mathcal{B}(b \to \chi_{c2}{}^{direct} X) = (0.89 \pm 0.20 \pm 0.07 \pm 0.36_{\mathcal{B}}) \times 10^{-3}$$

- Relation between LDME from HQSS:

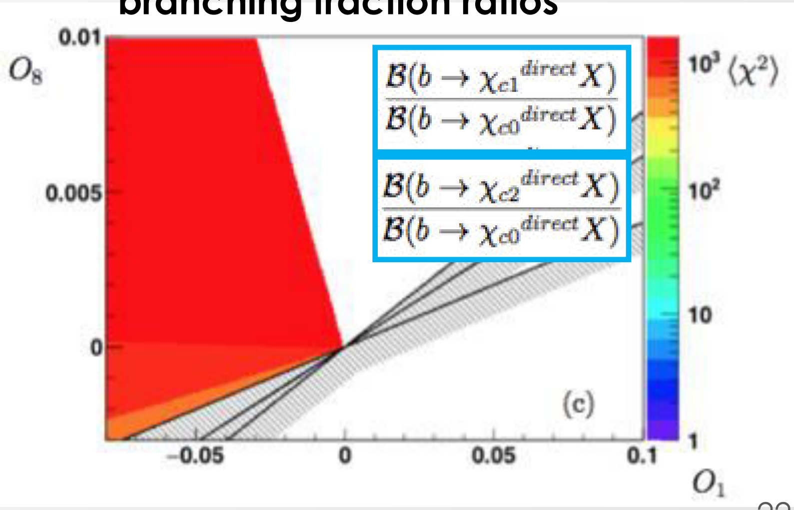
$$O_1 \equiv \langle O_1^{\chi_{c0}}(^3P_0)\rangle / m_c^2,$$
$$O_8 \equiv \langle O_8^{\chi_{c0}}(^3S_1)\rangle,$$
$$\langle O_1^{\chi_{cJ}}(^3P_J)\rangle / m_c^2 = (2J+1) O_1,$$
$$\langle O_8^{\chi_{cJ}}(^3S_1)\rangle = (2J+1) O_8.$$

- Branching fractions calculated in **Beneke, Maltoni, Rothstein, PRD 59 (1999) 054003**

Fit to three measurements of branching fractions



Fit to two measurements of branching fraction ratios



$\eta_c(2S)$ production in inclusive b-decays using $\eta_c(2S) \to \phi\phi$

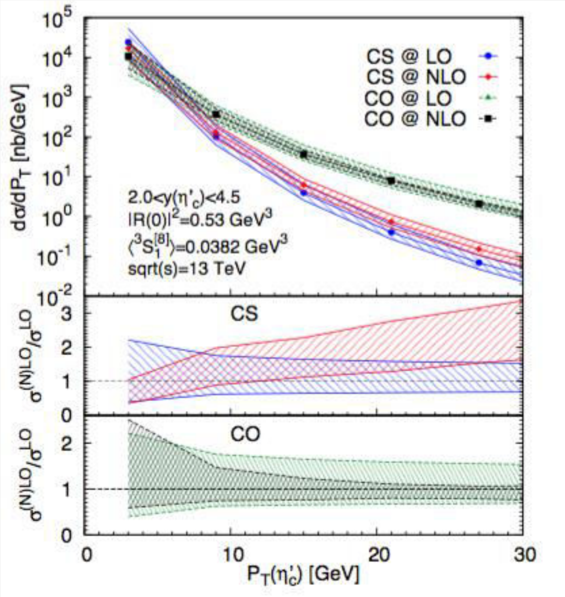
Eur.Phys.J. C77 (2017) 609

- First measurement of $\eta_c(2S)$ production in b-decays; first evidence for $\eta_c(2S) \to \phi\phi$

$$\frac{\mathcal{B}(b \to \eta_c(2S)X) \times \mathcal{B}(\eta_c(2S) \to \phi\phi)}{\mathcal{B}(b \to \eta_c(1S)X) \times \mathcal{B}(\eta_c(1S) \to \phi\phi)} = 0.040 \pm 0.011 \pm 0.004$$

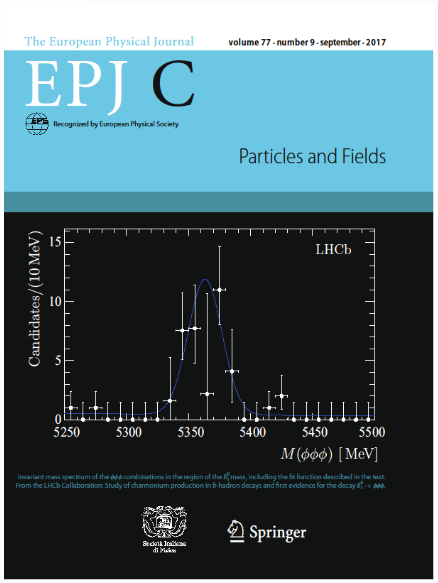
- Important to measure $\eta_c(2S)$ hadroproduction, recent theory prediction; dedicated trigger in 2018

Lansberg, Shao, Zhang
arXiv:1711.00265

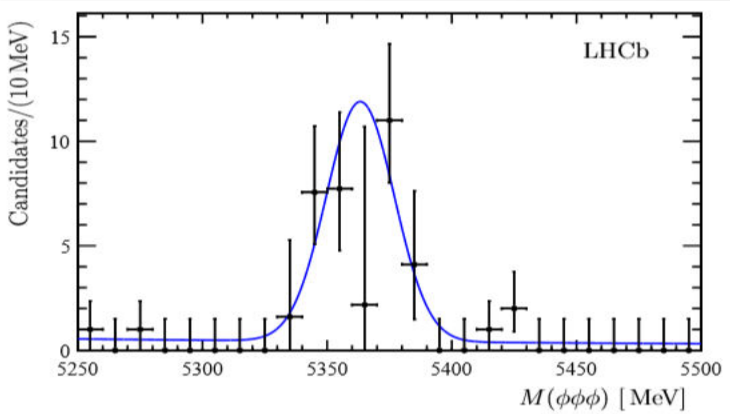


- Limits on production of X(3872), X(3915), $\chi_{c0}(2P)$ in b-decays

$$\mathcal{B}(b \to X(3872)X) \times \mathcal{B}(X(3872) \to \phi\phi) < 4.5\ (3.9) \times 10^{-7},$$
$$\mathcal{B}(b \to X(3915)X) \times \mathcal{B}(X(3915) \to \phi\phi) < 3.1\ (2.7) \times 10^{-7},$$
$$\mathcal{B}(b \to \chi_{c2}(2P)X) \times \mathcal{B}(\chi_{c2}(2P) \to \phi\phi) < 2.8\ (2.3) \times 10^{-7}.$$



First evidence of Bs→ φφφ decays



$$\mathcal{B}(B_s^0 \to \phi\phi\phi) = (2.15 \pm 0.54 \pm 0.28 \pm 0.21_{\mathcal{B}}) \times 10^{-6}.$$

+ φ polarization studies

$\eta_c(1S)$ branching fractions

- Indirect determination:

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from known B^0_s and η_c yields Λ^0_b fragmentation fraction $f_{\Lambda^0_b}$ momentum dependence and

$$\mathcal{B}(B^0_s \to \phi\phi) = (1.84 \pm 0.05 \pm 0.07 \pm 0.11_{f_s/f_d} \pm 0.12_{\text{norm}}) \times 10^{-5}$$
$$\mathcal{B}(b \to J/\psi X) = (1.16 \pm 0.10)\%$$
$$\frac{\mathcal{B}(b\to\eta_c(1S)X)\times\mathcal{B}(\eta_c(1S)\to p\bar{p})}{\mathcal{B}(b\to J/\psi X)\times\mathcal{B}(J/\psi\to p\bar{p})} = 0.302 \pm 0.042$$
$$\mathcal{B}(J/\psi \to p\bar{p}) = (2.120 \pm 0.029) \times 10^{-3}$$
$$f_s/f_d = 0.259 \pm 0.015$$

estimated branching fractions ratio

$$\frac{\mathcal{B}(\eta_c(1S) \to \phi\phi)}{\mathcal{B}(\eta_c(1S) \to p\bar{p})} = 1.79 \pm 0.14 \pm 0.09 \pm 0.10_{f_s/f_d} \pm 0.03_{f_{\Lambda^0_b}} \pm 0.29_{\mathcal{B}}$$

significantly larger than the value determined from PDG:

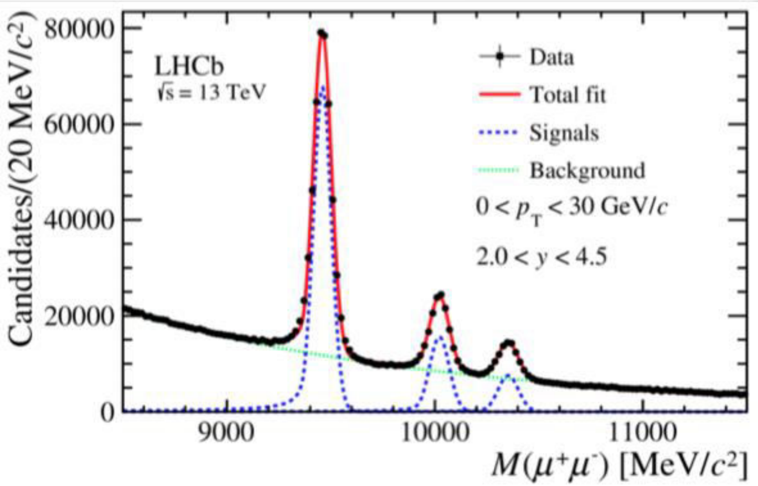
$$\frac{\mathcal{B}(\eta_c(1S)\to\phi\phi)}{\mathcal{B}(\eta_c(1S)\to p\bar{p})} = 1.17 \pm 0.18$$

Other decays of charmonia for production studies

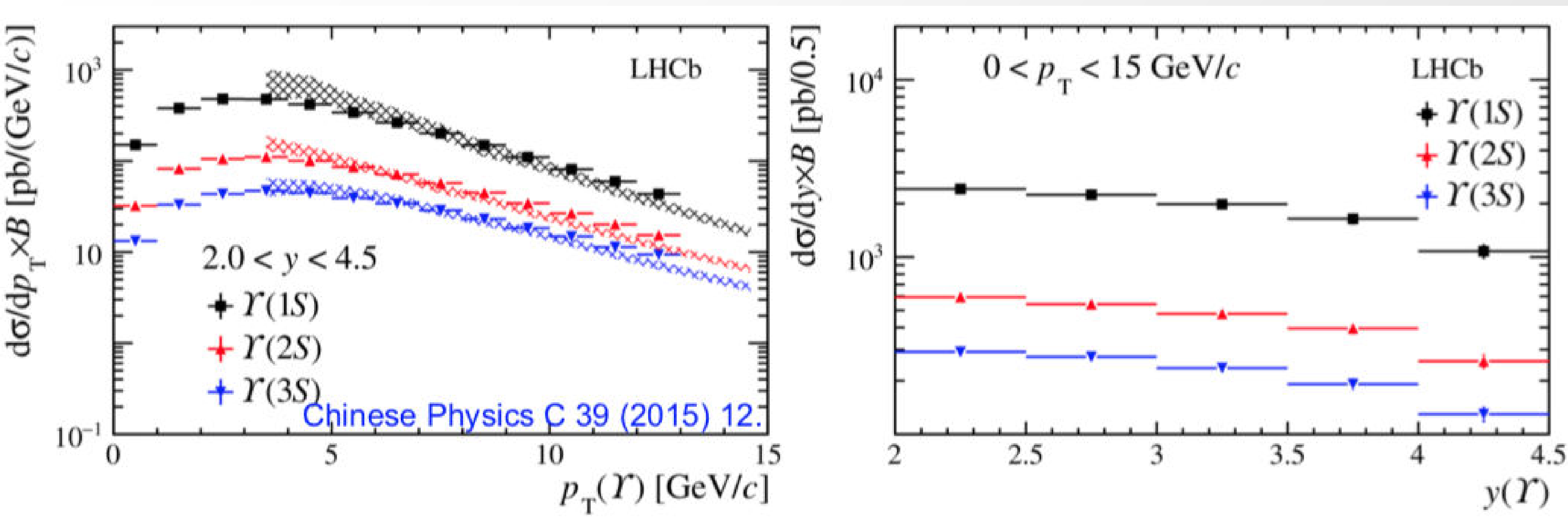
	$\mu\mu$	$J/\psi\,\gamma$	$p\bar{p}$	$\phi\phi$	$p\bar{p}\pi^+\pi^-$	$\phi f_0(980)$	$\phi f_2(1545)$	baryons $\Lambda\Lambda, \Xi\Xi, \Sigma\Sigma, \Lambda^*\Lambda^*$
$\eta_c(1S)$	forb.	-	**0.15%**	0.18%	0.5%			~0.1%
J/ψ	6%	-	0.2%	forb.	0.6%	0.03%	~0.1%	~0.1%
χ_{c0}	forb.	1.3%	0.02%	**0.08%**				~0.04%
χ_{c1}	forb.	**34%**	0.01%	**0.04%**	0.05%			~0.01%
h_c	forb.		?	forb.	?			?
χ_{c2}	forb.	**19%**	0.1%	**0.01%**	0.1%			~0.01%
$\eta_c(2S)$	forb.		?	**?**	?			?
$\psi(2S)$	0.8%		0.03%	forb.	0.06%			~0.02%

$\eta_c(1S)\,\gamma$ - is a promising channel to study h_c

Υ production at 13 TeV at LHCb using Υ → *μμ*

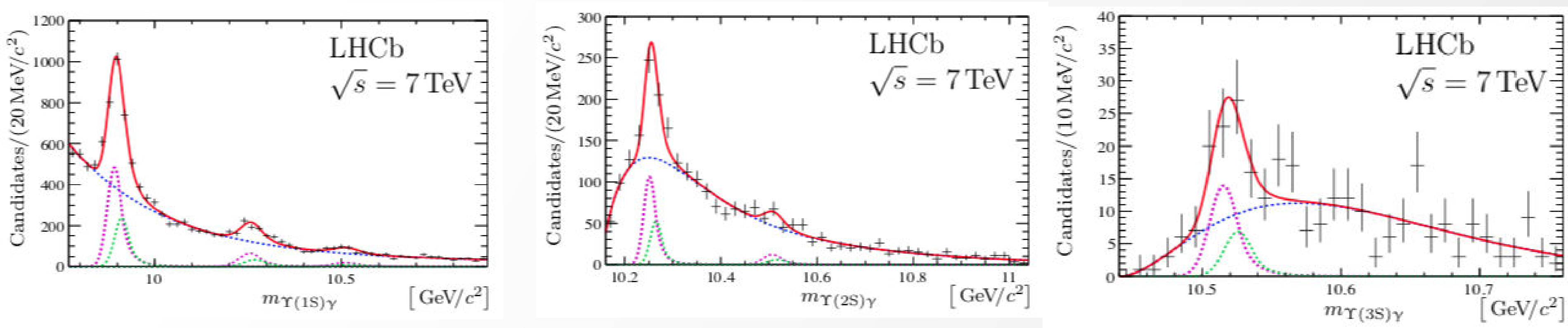


- clean signal from Υ(1S), Υ(2S), Υ(3S)

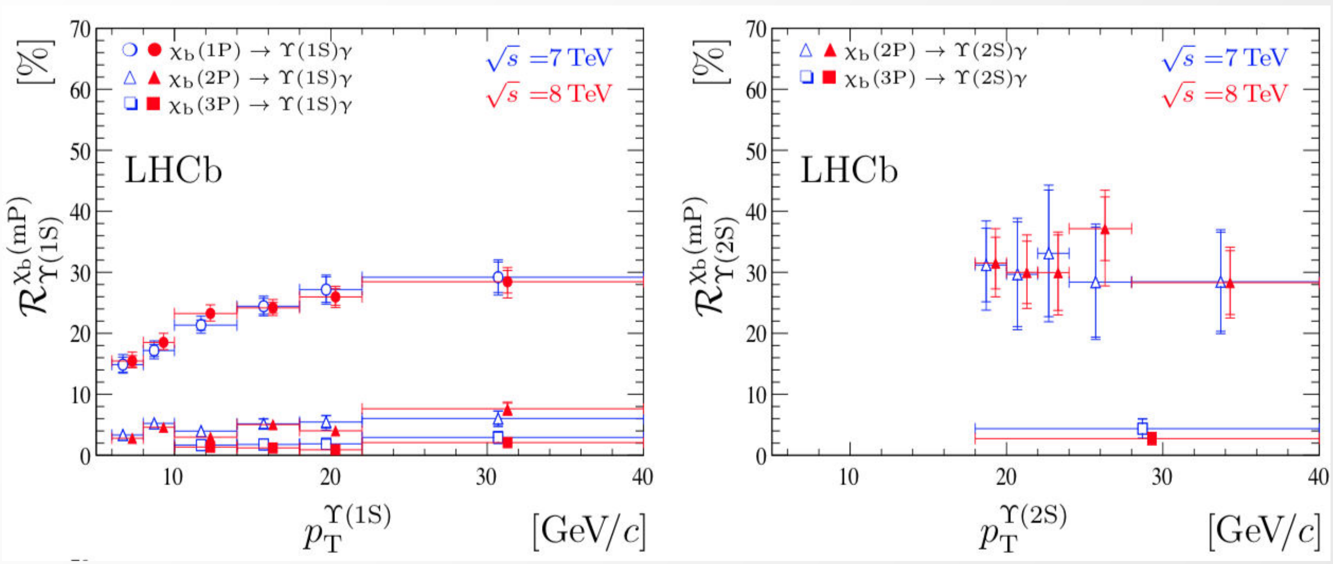


- **Double differential production cross-section has been measured**
- Similar studies at other LHC experiment

χ_b production at LHCb



- clean signal from χ_b(1P), χ_b(2P) and χ_b(3P)
- **χ_b(3P)** – first particle discovered at LHC



- **p_T - differential production cross-section measured relative to ϒ(1S), ϒ(2S) and ϒ(3S)**
- Search for $\chi_b \rightarrow \Upsilon\mu\mu$?

Summary

- Comprehensive model still missing to describe **Heavy Flavor (e.g. charmonium) production**
- J/ ψ (and ψ(2S)) hadroproduction has been measured at many LHC and Tevatron experiments. J/ ψ production is well described by CO model
- LHCb results allow to perform **powerful tests of QCD** and constrain theory:
  - joint study of charmonium hadroproduction and production in decays
  - $\eta_c(1S)$ prompt production measurement constrains CO LDMEs
- Current progress:
  - first observations of $\chi_{c1,2} \to \boldsymbol{J/\psi\mu\mu}$ decay modes
  - $\chi_{c0,1,2}$ production in b-decays measured at LHCb using decays to $\varphi\varphi$
  - first evidence of $\eta_c(2S)$ production in b-decays
- Other charmonium states can be studied via hadronic decays:
  - $\boldsymbol{h_c}$ and $\boldsymbol{\eta_c(2S)}$ production
  - decays to $\boldsymbol{\Lambda^* \Lambda^*}$, $\boldsymbol{\Lambda\Lambda}$, $\boldsymbol{\Xi\Xi}$, $\boldsymbol{\Sigma\Sigma}$, $\boldsymbol{p\bar{p}\pi^+\pi^-}$ final states

- ϒ and $\boldsymbol{\chi_b}$**(3P)** hadroproduction has been measured at LHC
- $\boldsymbol{\chi_b}$**(3P)** – first particle discovered at LHC

Status of charmonia production measurements

	Prompt hadroproduction	$BR(B^0 \vert B^{\pm} \vert b-baryons \to (c\bar{c})X)$	$BR(B^0 \vert B^{\pm} \to (c\bar{c})X)$
$\eta_c(1S)$	LHCb - $p\bar{p}$	$(4.88 \pm 0.96) \times 10^{-3}$ LHCb - $p\bar{p}$	-
J/ψ	LHCb, ATLAS, CMS -$\mu\mu$	$(1.16 \pm 0.10) \times 10^{-3}$ LEP - ll	$(1.094 \pm 0.032) \times 10^{-2}$ direct : $(7.8 \pm 0.4) \times 10^{-3}$ BABAR, CLEO - ll
χ_{c0}	-	$(1.66 \pm 0.26 \pm 0.13 \pm 0.40B) \times 10^{-3}$ *LHCb -$\phi\phi$	-
χ_{c1}	ATLAS, LHCb, CMS -$J/\psi\,\gamma$	$(1.4 \pm 0.4) \times 10^{-2}$ LEP - $J/\psi\,\gamma$ $(1.41 \pm 0.30 \pm 0.12 \pm 0.36B) \times 10^{-3}$ *LHCb -$\phi\phi$	$(3.86 \pm 0.27) \times 10^{-3}$ direct: $(3.24 \pm 0.25) \times 10^{-3}$ BABAR, Belle, CLEO -$J/\psi\,\gamma$
h_c	-	-	-
χ_{c2}	ATLAS, LHCb, CMS -$J/\psi\,\gamma$	$(0.63 \pm 0.11 \pm 0.05 \pm 0.15B) \times 10^{-3}$ *LHCb -$\phi\phi$	$(1.4 \pm 0.4) \times 10^{-3}$ direct: $(1.65 \pm 0.31) \times 10^{-3}$ BABAR, Belle -$J/\psi\,\gamma$
$\eta_c(2S)$	-	*LHCb -$\phi\phi$ BR($\eta_c(2S) \to \phi\phi$) was not measured	-
$\psi(2S)$	LHCb, ATLAS, CMS -$\mu\mu$	$(2.83 \pm 0.29) \times 10^{-3}$ LHCb, CMS - $\mu\mu$	$(3.07 \pm 0.21) \times 10^{-3}$ BABAR, CLEO - ll

* preliminary

Limited information about charmonia production