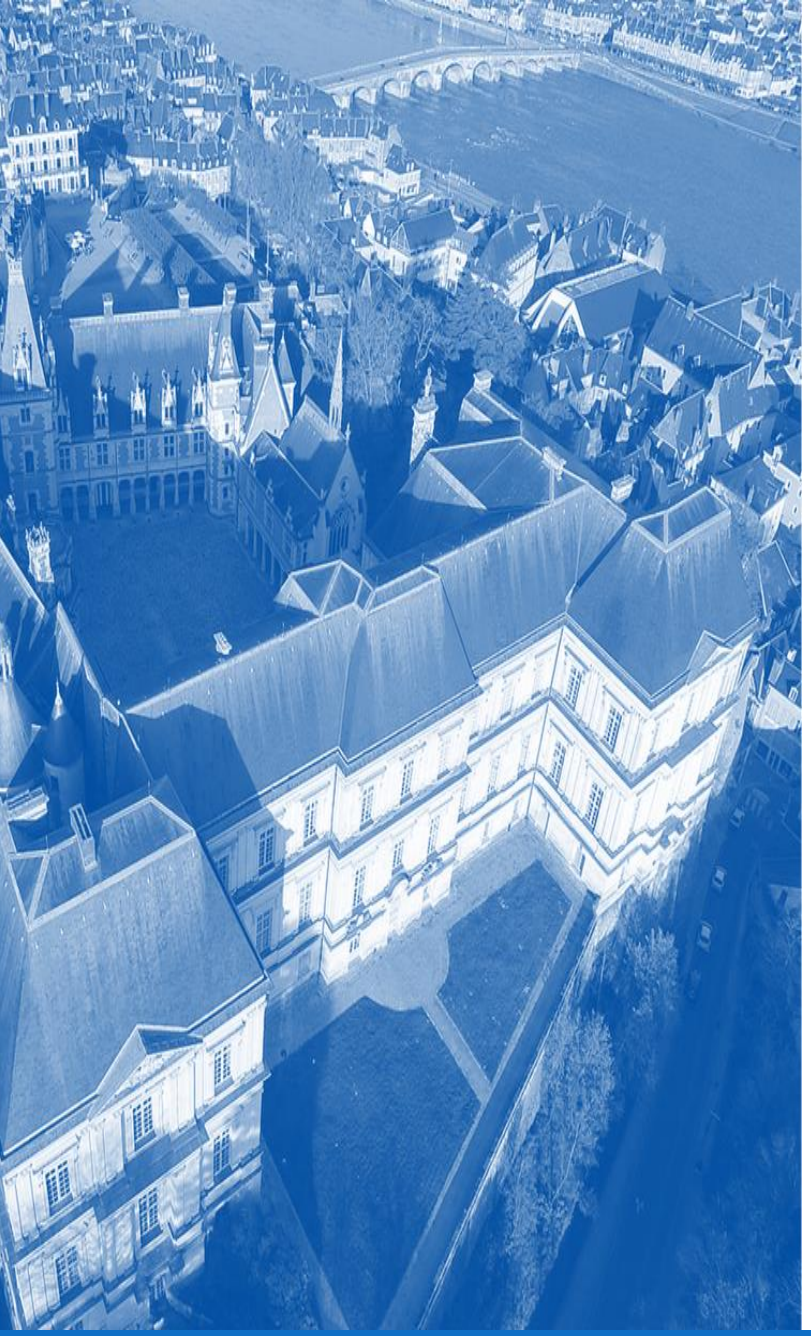

HF production and properties @ ATLAS & CMS

EDUARD DE LA CRUZ BURELO*

FOR THE ATLAS AND CMS COLLABORATIONS

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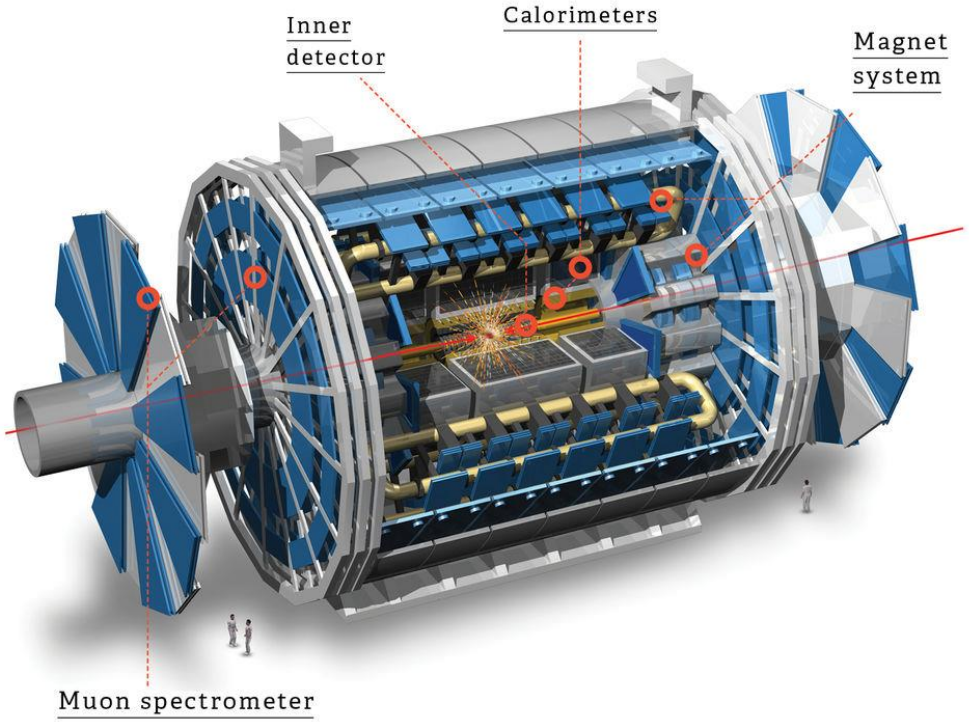
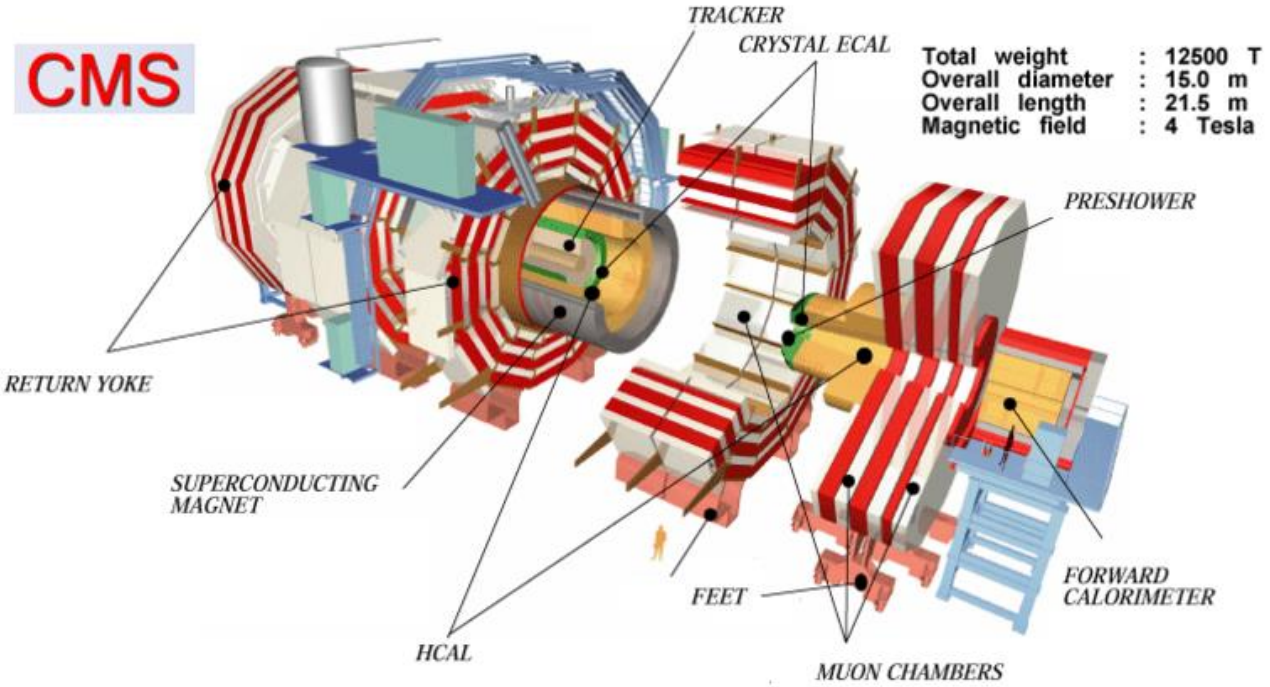
The detectors

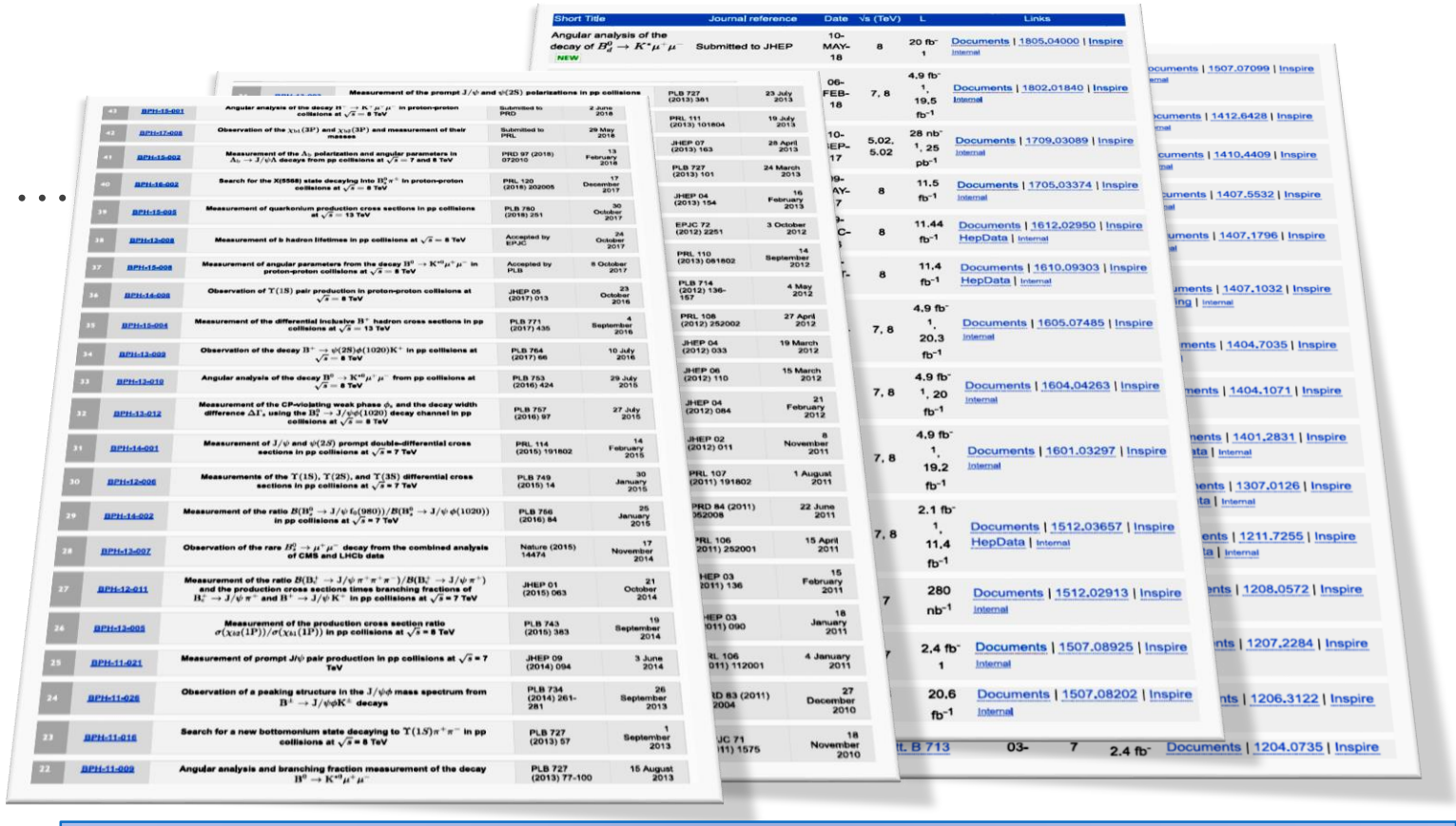




Some taste on HF production at ATLAS and CMS

74 results from both experiments, some of them …

- Quarkonium cross sections (CMS & ATLAS)
- Polarization of the Λ_b^0 (CMS and ATLAS)
- Study of $B_d^0 \rightarrow K^* \mu^+ \mu^-$ (ATLAS)
- Search for $X^+(5558) \rightarrow B_s \pi^+$ (CMS and ATLAS)
- Lifetime of B hadrons (CMS)



All heavy flavor results from ATLAS and CMS can be found at:

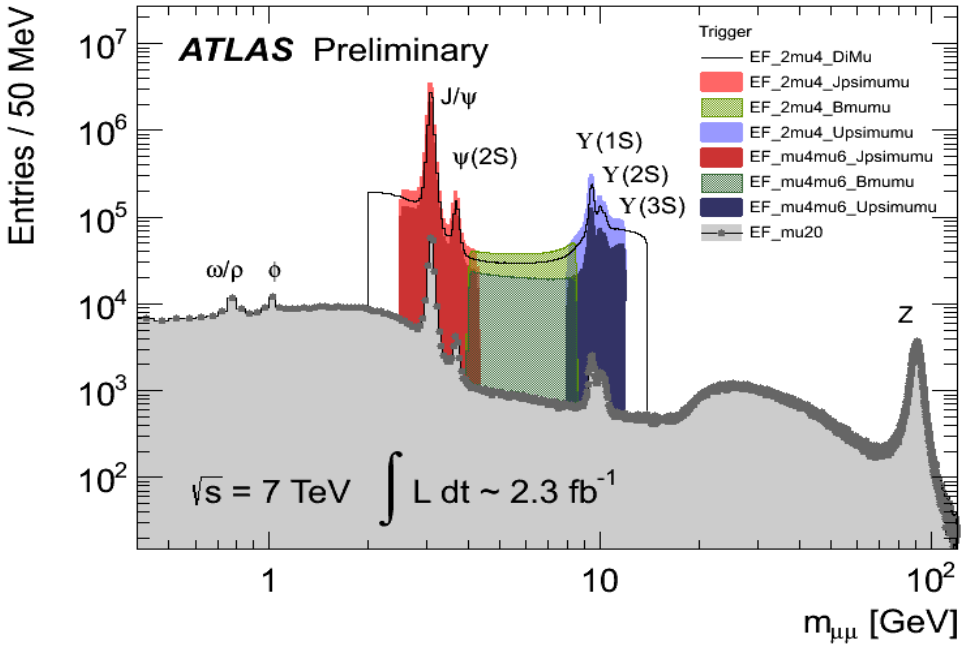
- https://twiki.cern.ch/twiki/bin/view/AtlasPublic/BPhysPublicResults
- https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsBPH

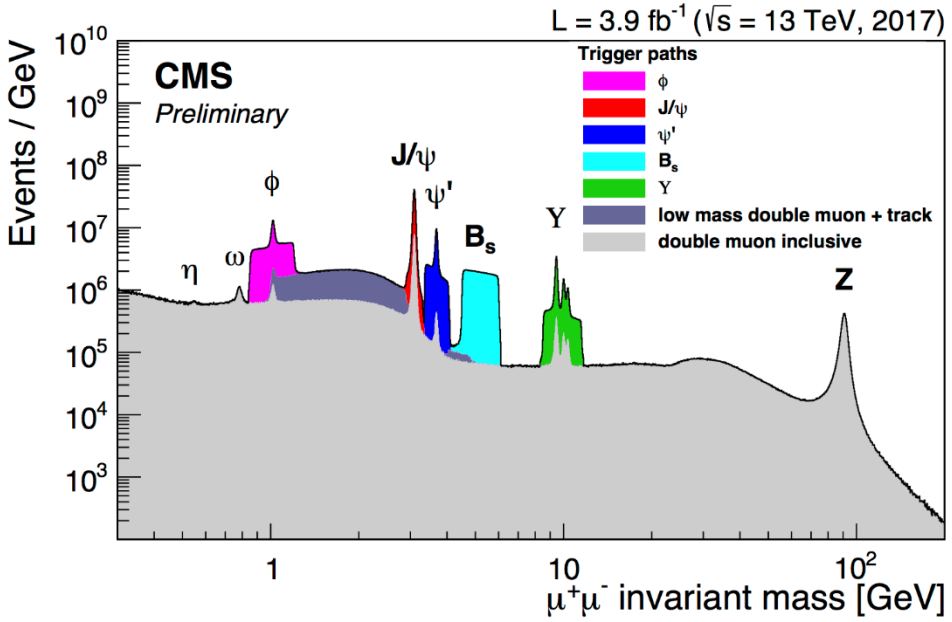
b physics triggers

ATLAS & CMS use dimuon triggers for b and charm physics. In general :

- Quarkonia: $J/\psi \to \mu\mu, \Upsilon \to \mu\mu$
- Exclusive decays: $B \to J/\psi(\mu\mu) + X$
- Rare decays: $B \to \mu\mu + X$

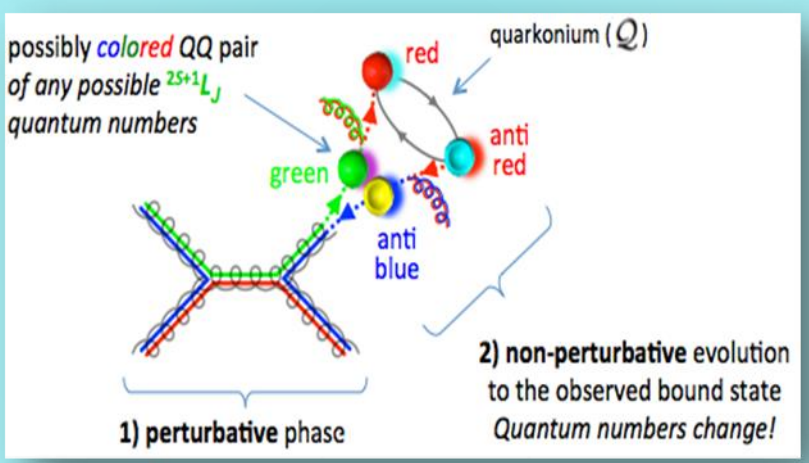
Minimum differences between ATLAS and CMS.





Quarkonium production @ CMS

Well established framework: NRQCD ~ factorizes short-dist. (SDCs, perturbative calculations) and universal long-dist. (LDMEs, from fits to data) contributions.



Contrary to expectations, LHC measurements indicate **quarkonia are produced unpolarized** ⇒ important to add more data to constrain LDMEs.

For J/ψ, ψ' and Υ(nS) (n=1,2,3) @13 TeV, **CMS measures**:

prompt signal events (cannot distinguish feed-down decays of heavier $c\bar{c}$)

Acceptance

$$\mathcal{B}(\mathcal{Q} \to \mu^+\mu^-)\,\frac{\mathrm{d}^2\sigma}{\mathrm{d}p_\mathrm{T}\,\mathrm{d}y} = \frac{N(p_\mathrm{T}, y)}{\mathcal{L}\Delta y \Delta p_\mathrm{T}} \left\langle \frac{1}{\epsilon(p_\mathrm{T}, y)\mathcal{A}(p_\mathrm{T}, y)} \right\rangle$$

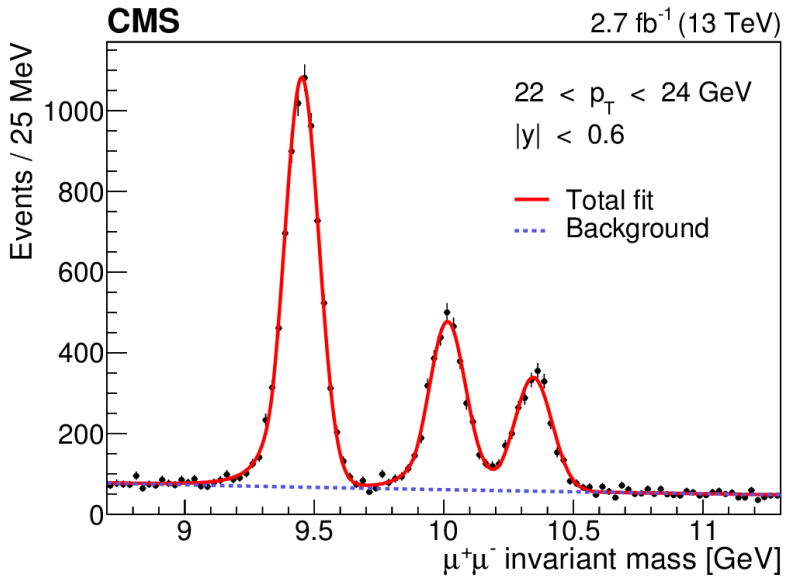
Integrated lumi

y and p_T bin widths
($|y| < 1.2$, p_T = 20 - 150 (130) GeV)

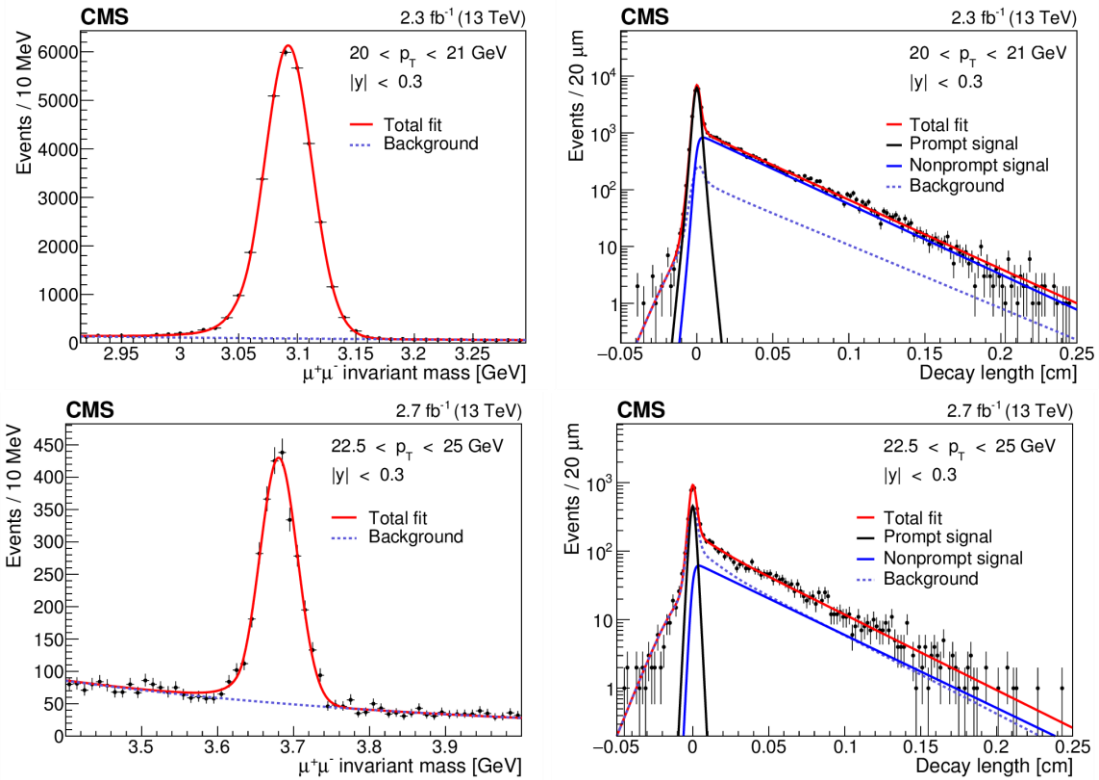
Reconstruction efficiency

CMS yields and prompt fraction

- **UML fits to $M_{\mu\mu}$ ($M_{\mu\mu}$-ct) in each y-p_T bin (for J/ψ and ψ'):**



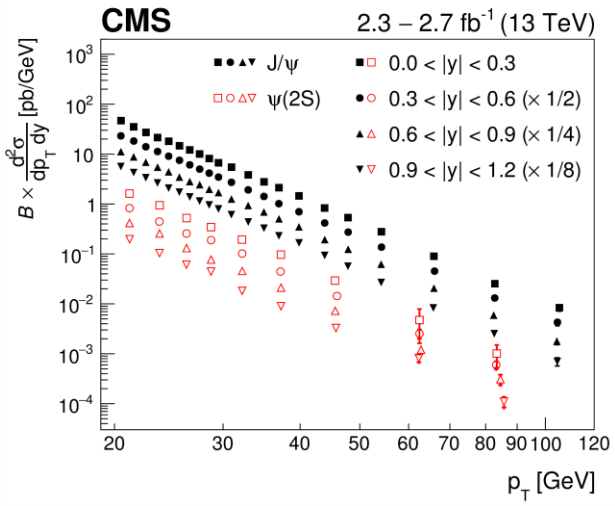
- Each: CB icomposed of a Gaussian core.
- Means: fixed · common factor.
- Widths: ~common.
- CB params: constrained to the fit of the pT-integrated distribution.
- Bkg.: exponential.

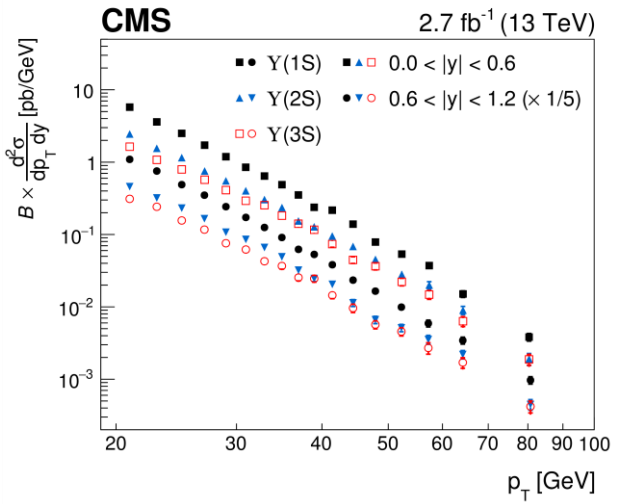


- CB (+ Gauss. J/ψ) + exponential bkg.
- Mean and CB params. constrained to p_T-int.

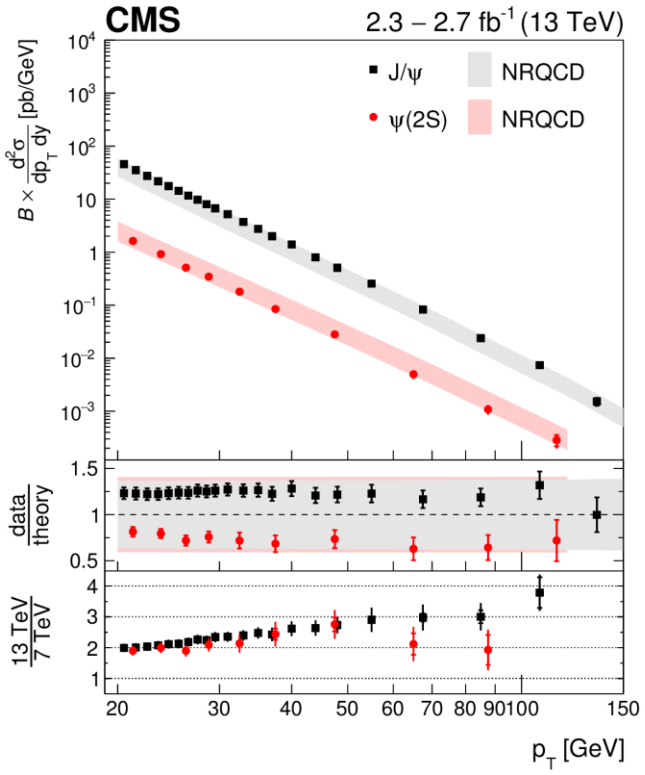
- Prompt = Res. (R): event-by-event-scaled double-Gauss.
- Non-prompt: Exp ⊗ R.
- Bkg.: R' + exp ⊗ R'.

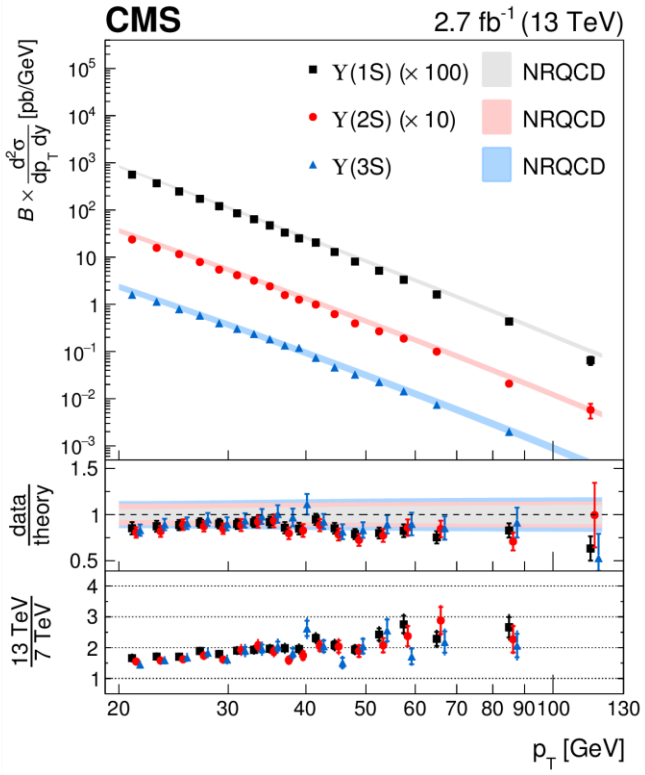
CMS results

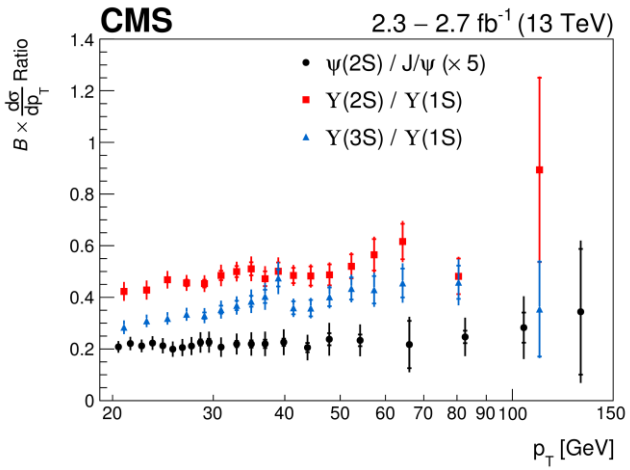




Shapes consistent across *y* region: **can *integrate over y***.







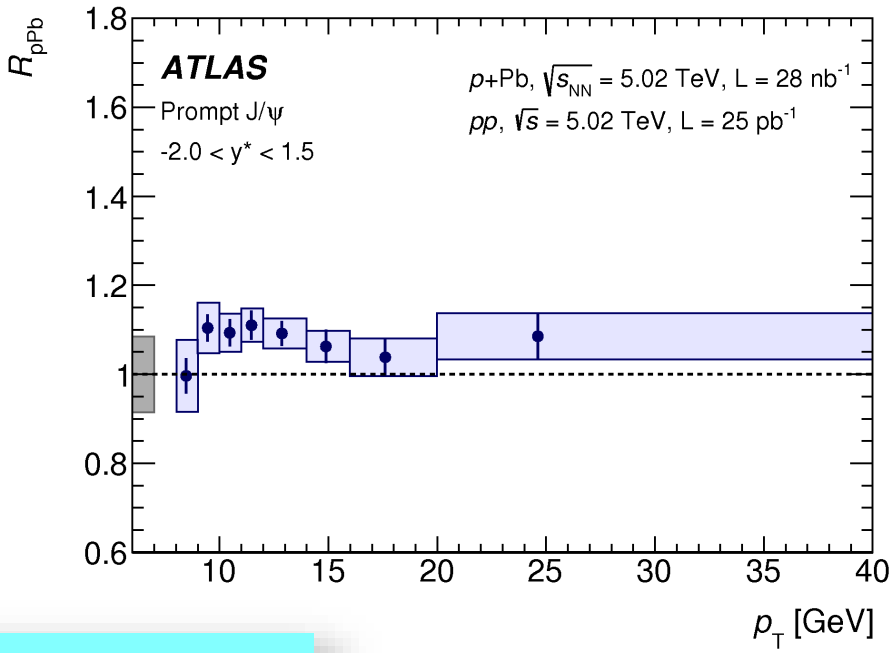
- NLO NRQCD predictions in agreement with data.
- As expected from evolution of PDFs, cross sections increase with energy.
- **These measurements should reduce theoretical uncertainties from the extraction of LDMEs.**

PLB 780, 251 (2018)

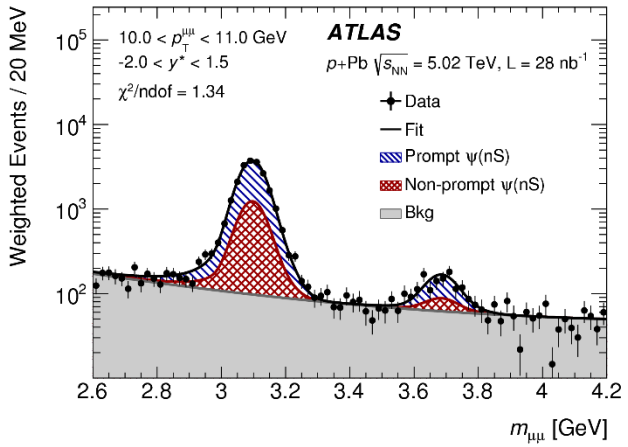
ATLAS quarkonium production in HI and pp collisions

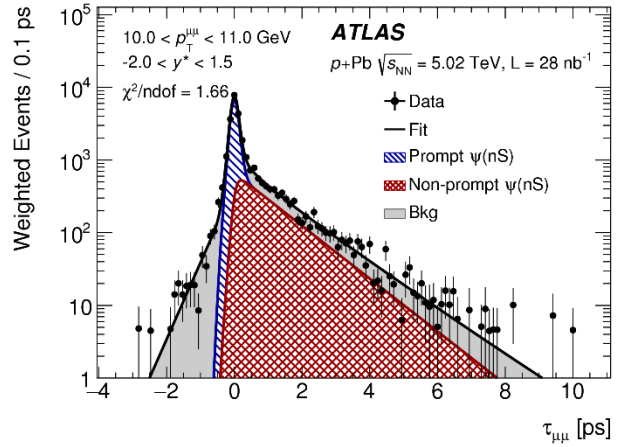
The main goal is to study the modification of J/ψ, ψ′, and Υ(nS) (n=1,2,3) in p+Pb collisions wrt to their production in pp collisions.

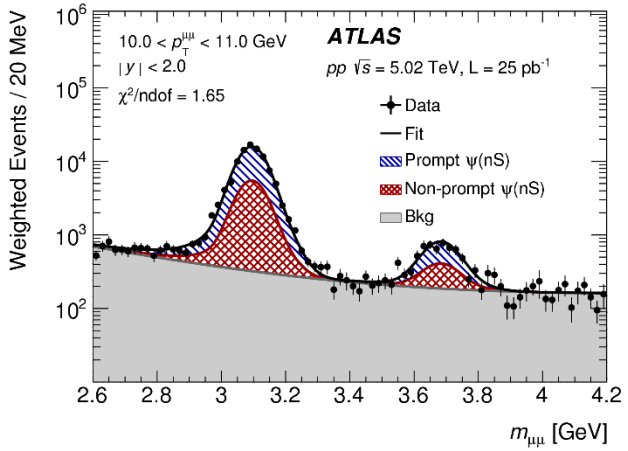
Eur. Phys. J. C. 78 (2018) 171

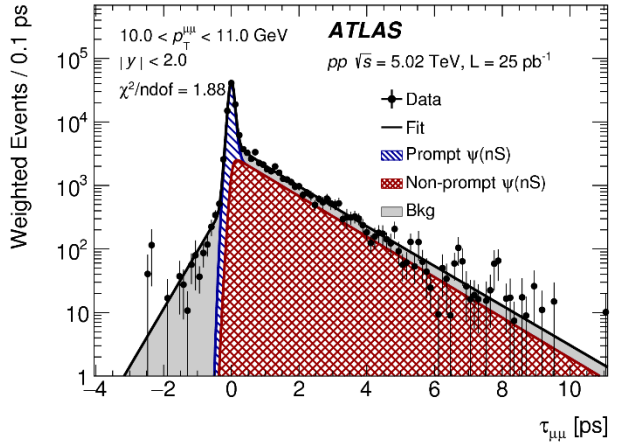


$$R_{p\mathrm{Pb}} = \frac{1}{208}\frac{\sigma^{O(nS)}_{p+\mathrm{Pb}}}{\sigma^{O(nS)}_{pp}},$$

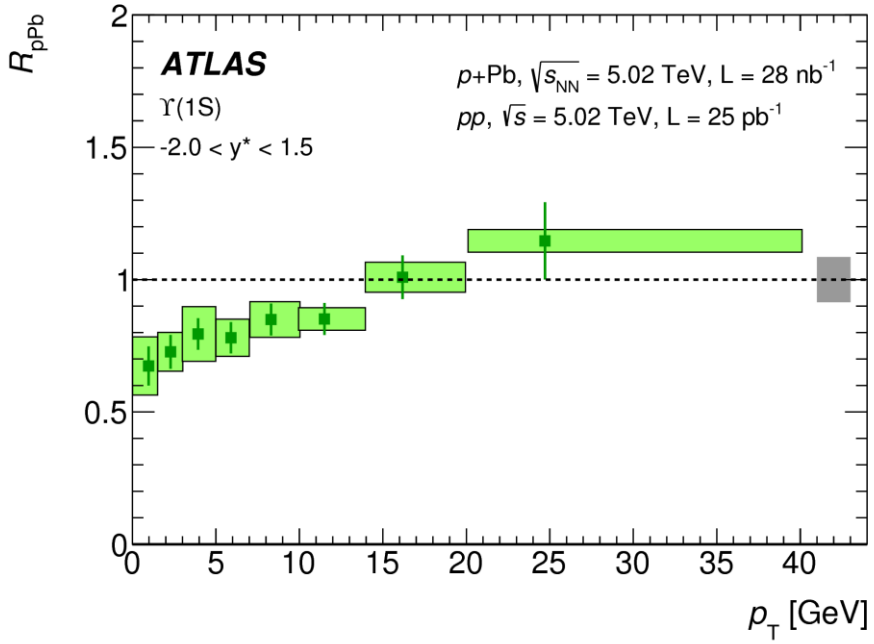


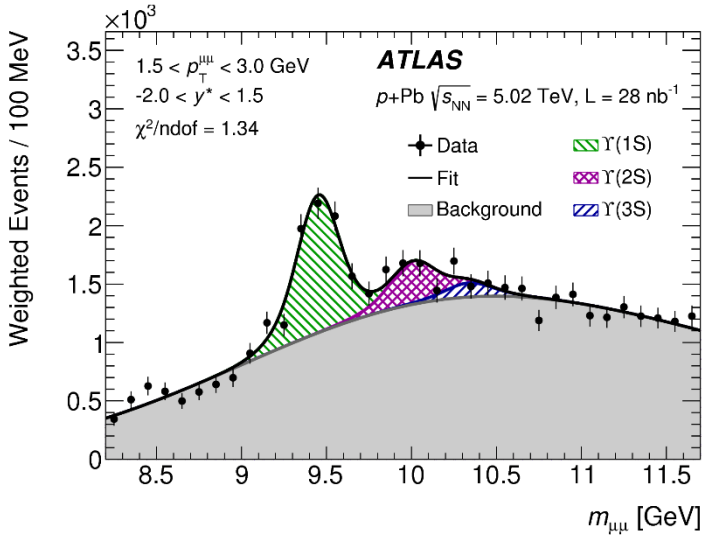


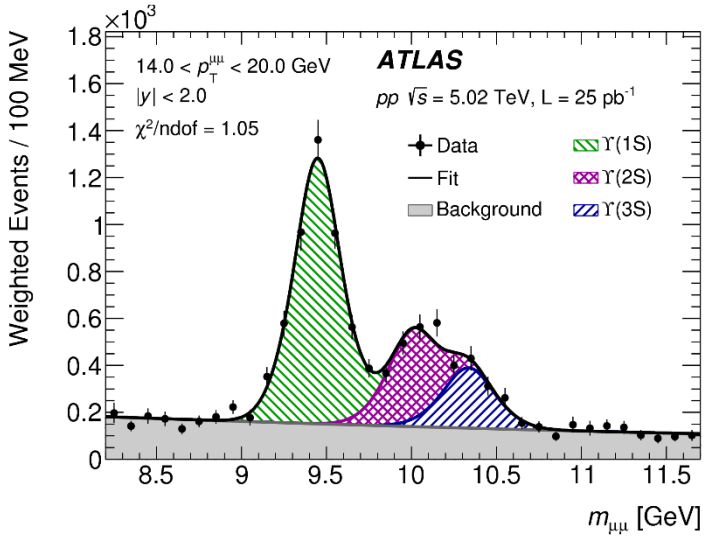


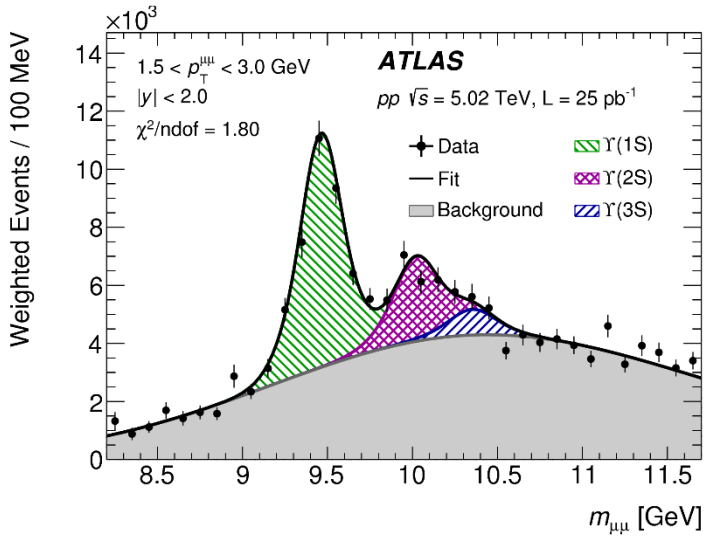


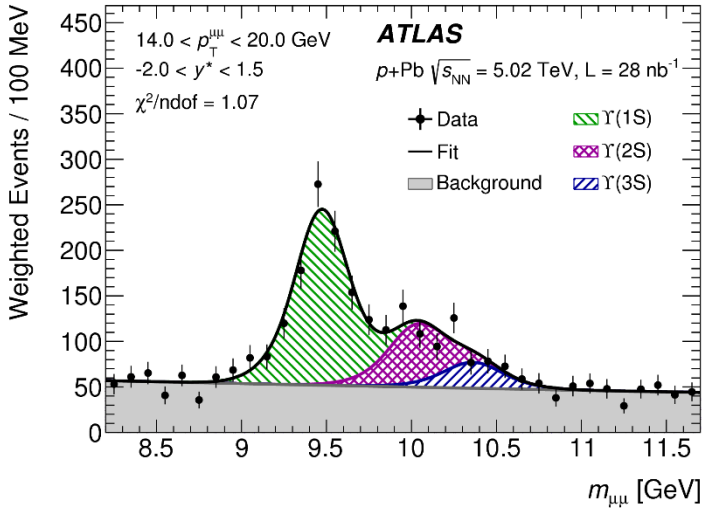
ATLAS quarkonium production in HI and pp collisions



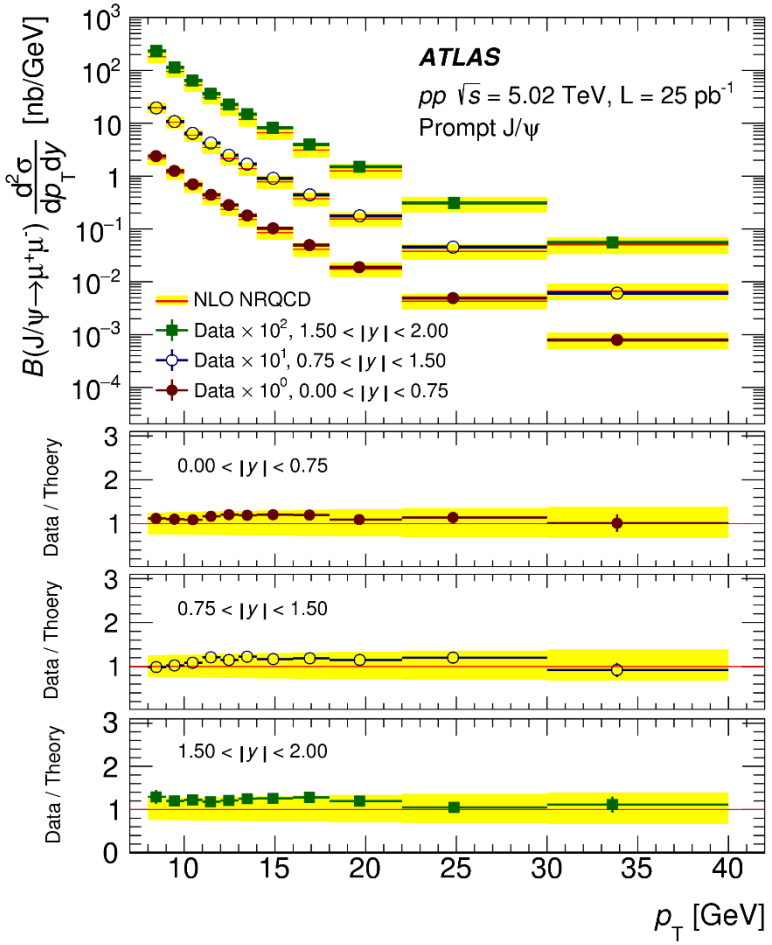


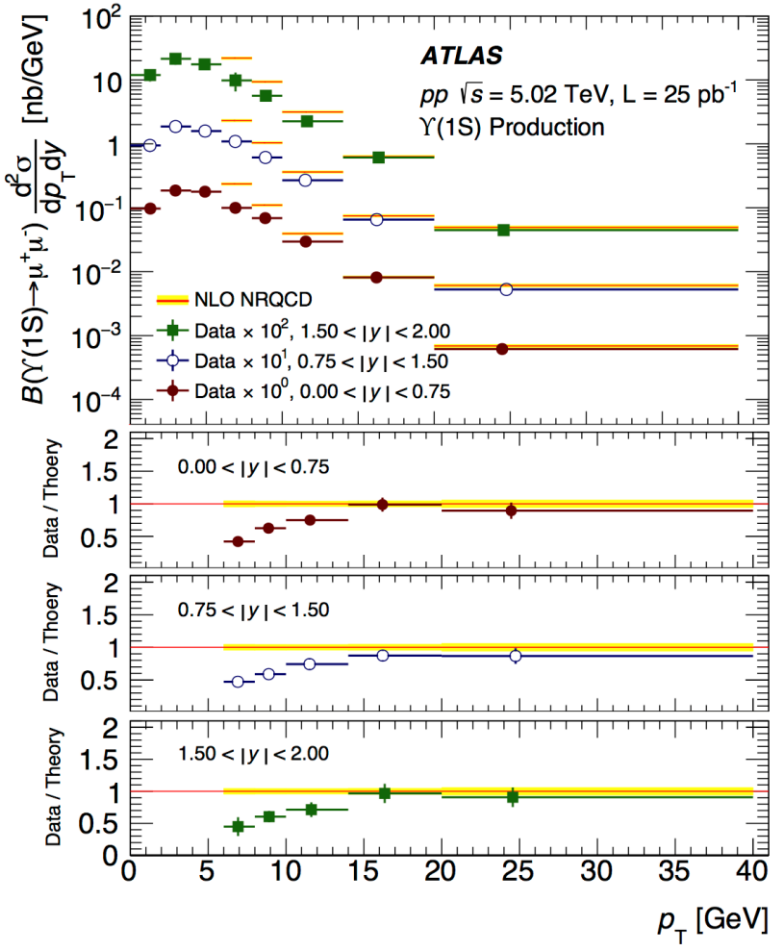


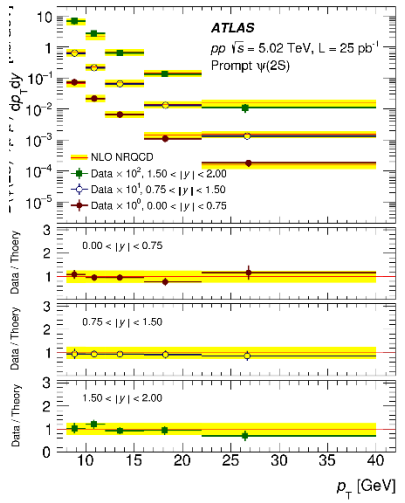


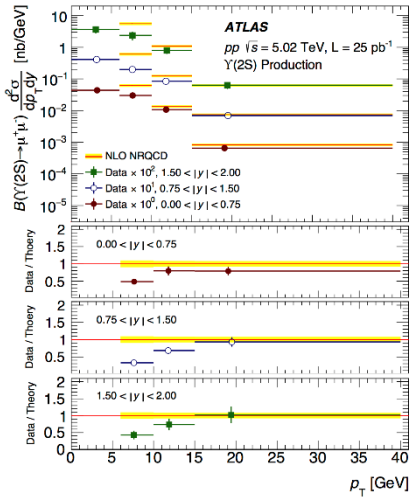


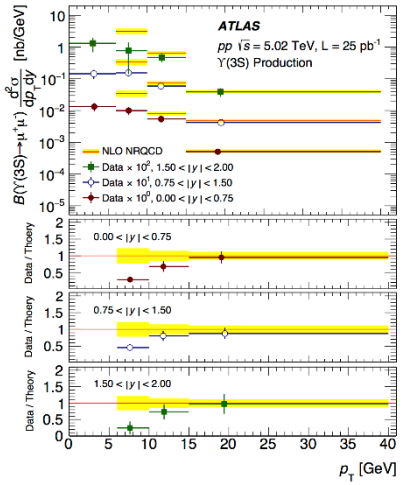
ATLAS quarkonium production in HI and pp collisions











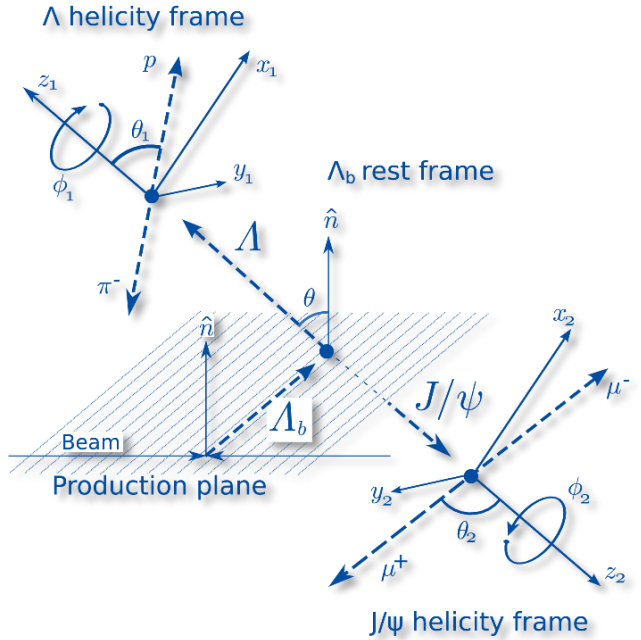
CMS Helicity study of $\Lambda_b^0 \to J/\psi\,\Lambda$ decays

HQET: A large fraction of *transverse b*-polarization remains after hadronization.

This analysis: $\Lambda_b \to J/\psi\Lambda$ 5D angular decay function [*Kramer & Simma, NPB-P.S. 50, 125 (1996)*] is partially integrated:

$$\frac{\mathrm{d}^3\Gamma}{\mathrm{d}\cos\theta_\Lambda\,\mathrm{d}\cos\theta_\mathrm{p}\,\mathrm{d}\cos\theta_\mu}(\theta_\Lambda,\theta_\mathrm{p},\theta_\mu) = \int_{-\pi}^{\pi}\int_{-\pi}^{\pi}\frac{\mathrm{d}^5\Gamma}{\mathrm{d}\cos\theta_\Lambda\,\mathrm{d}\Omega_\mathrm{p}\,\mathrm{d}\Omega_\mu}(\theta_\Lambda,\theta_\mathrm{p},\theta_\mu,\varphi_\mathrm{p},\varphi_\mu)\mathrm{d}\varphi_\mathrm{p}\,\mathrm{d}\varphi_\mu$$
$$\sim \sum_{i=1}^{8} u_i\left(|T_{\lambda_1\lambda_2}|^2\right) v_i(P,\alpha_\Lambda) w_i(\theta_\Lambda,\theta_\mathrm{p},\theta_\mu).$$

α_Λ: asymmetry param. in $\Lambda \to p\pi^-$ decay (fixed to PDG 0.62 ± 0.013).



- ***P***: Λ_b polarization.
- **Asymmetry param. in $\Lambda_b \to J/\psi\Lambda$** →
- Long. polarization of the Λ →
- J/ψ long./transv. pol. Parameter →

$$1 = |T_{++}|^2 + |T_{+0}|^2 + |T_{-0}|^2 + |T_{--}|^2,$$
$$\alpha_1 = |T_{++}|^2 - |T_{+0}|^2 + |T_{-0}|^2 - |T_{--}|^2,$$
$$\alpha_2 = |T_{++}|^2 + |T_{+0}|^2 - |T_{-0}|^2 - |T_{--}|^2,$$
$$\gamma_0 = |T_{++}|^2 - 2|T_{+0}|^2 - 2|T_{-0}|^2 + |T_{--}|^2$$

- $P^{(\mathrm{LHCb})}$ = 0.06 ± 0.07 ± 0.02
- $P^{(\mathrm{HQET})}$ = 0.1 - 0.2
- $\alpha_1^{(\mathrm{LHCb})} = -\alpha_b^{(\mathrm{LHCb})}$ = -0.05 ± 0.17 ± 0.07
- Many theoretical predictions for α_1:
  - 0.1 - 0.2 (PQCD, factorization, several quark models).
  - -0.78 (HQET).

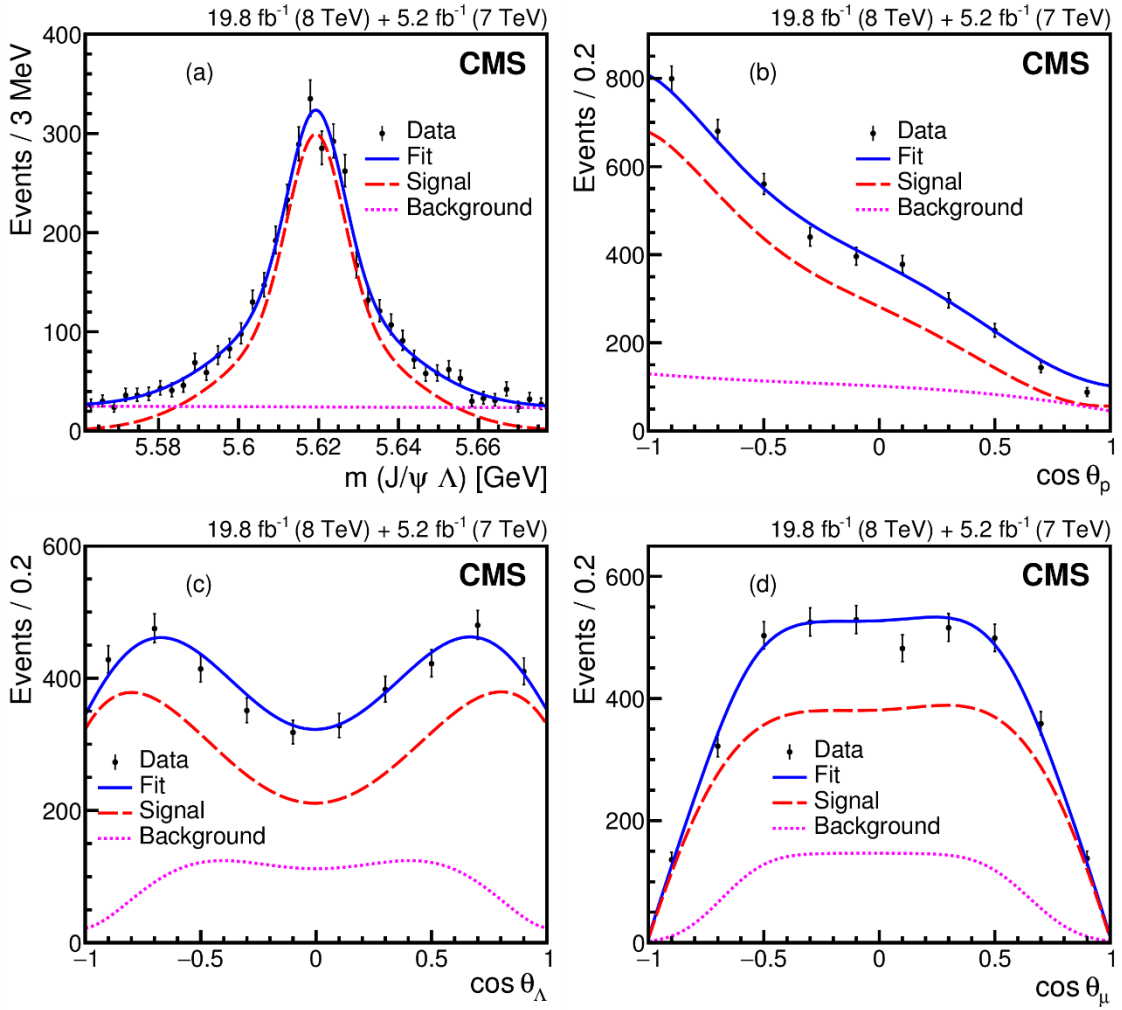
CMS Helicity study of $\Lambda_b^0 \to J/\psi\,\Lambda$ decays

Simultaneous 3D UML fit to Λ_b^0 and $\overline{\Lambda_b^0}$ in 7 and 8 TeV data assuming CP conservation

$$P = 0.00 \pm 0.06\,(\text{stat}) \pm 0.06\,(\text{syst}),$$
$$\alpha_1 = 0.14 \pm 0.14\,(\text{stat}) \pm 0.10\,(\text{syst}),$$
$$\alpha_2 = -1.11 \pm 0.04\,(\text{stat}) \pm 0.05\,(\text{syst}),$$
$$\gamma_0 = -0.27 \pm 0.08\,(\text{stat}) \pm 0.11\,(\text{syst}),$$

The measurements are consistent with LHCb results and theoretical predictions.

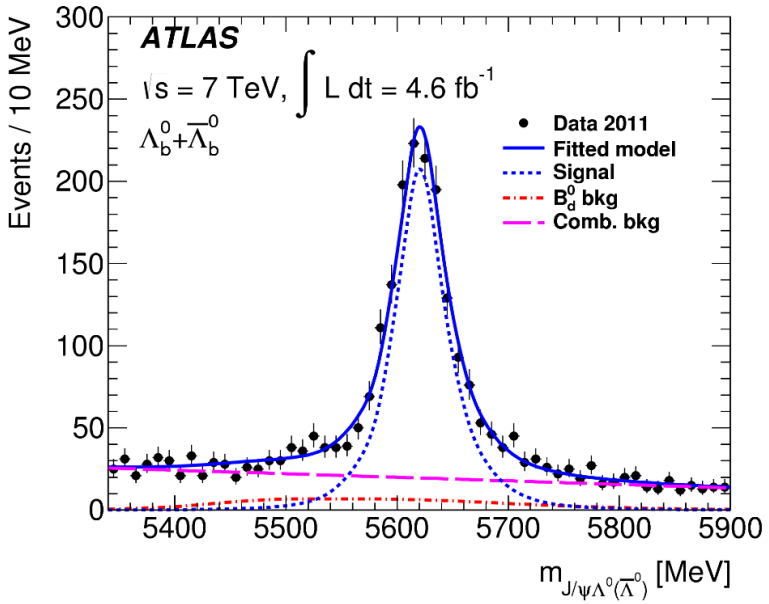
PRD 97 (2018) 072010

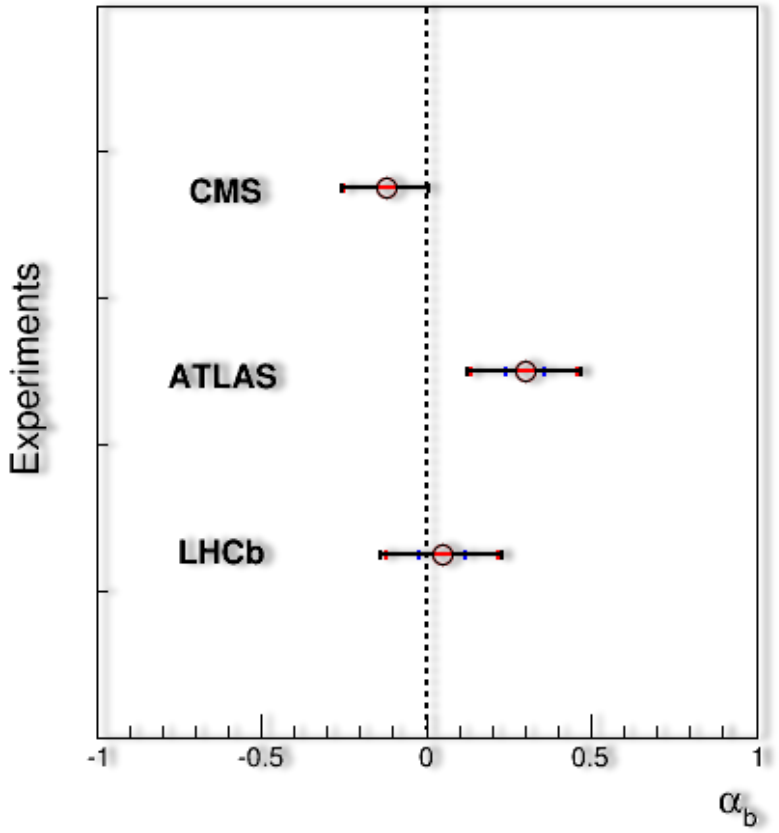


ATLAS Helicity study of $\Lambda_b^0 \to J/\phi\,\Lambda$ decays

- Study performed by ATLAS with dataset at 7 TeV
- Assume zero polarization.
- Assume CP conservation.

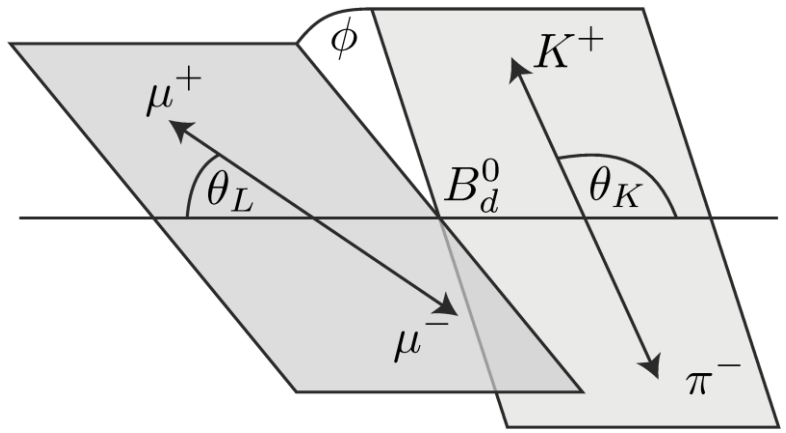
$$\alpha_b = 0.30 \pm 0.16\ (stat) \pm 0.06\ (syst)$$





Phys. Rev. D. 89, 092009

ATLAS angular analysis of $B^0 \to K^{*0}\mu^+\mu^-$

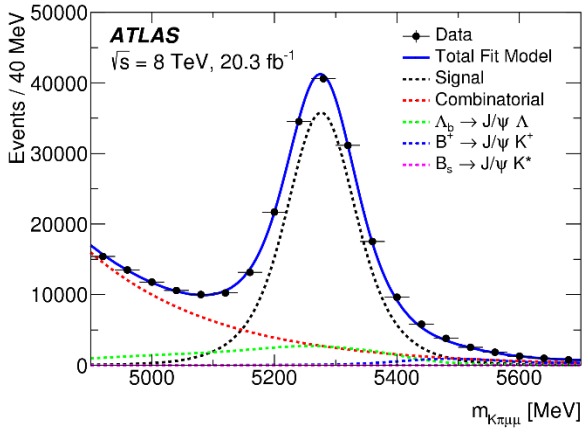


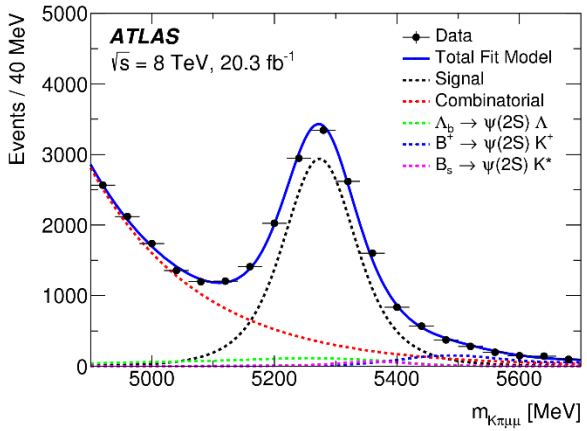
$$\frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2}\frac{\mathrm{d}^4\Gamma}{\mathrm{d}\cos\theta_L\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi\,\mathrm{d}q^2} = \frac{9}{32\pi}\Bigg[\frac{3(1-F_L)}{4}\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1-F_L}{4}\sin^2\theta_K\cos 2\theta_L$$
$$-F_L\cos^2\theta_K\cos 2\theta_L + S_3\sin^2\theta_K\sin^2\theta_L\cos 2\phi$$
$$+S_4\sin 2\theta_K\sin 2\theta_L\cos\phi + S_5\sin 2\theta_K\sin\theta_L\cos\phi$$
$$+S_6\sin^2\theta_K\cos\theta_L + S_7\sin 2\theta_K\sin\theta_L\sin\phi$$
$$+S_8\sin 2\theta_K\sin 2\theta_L\sin\phi + S_9\sin^2\theta_K\sin^2\theta_L\sin 2\phi\Bigg|.$$

This is a FCNC decay cannel on which LHCb has reported a potential hint on a deviation of 3.4 sigmas from the SM calculations.

$$P_1 = \frac{2S_3}{1-F_L}$$
$$P_2 = \frac{2}{3}\frac{A_{\mathrm{FB}}}{1-F_L}$$
$$P_3 = -\frac{S_9}{1-F_L}$$
$$P'_{j=4,5,6,8} = \frac{S_{i=4,5,7,8}}{\sqrt{F_L(1-F_L)}}.$$

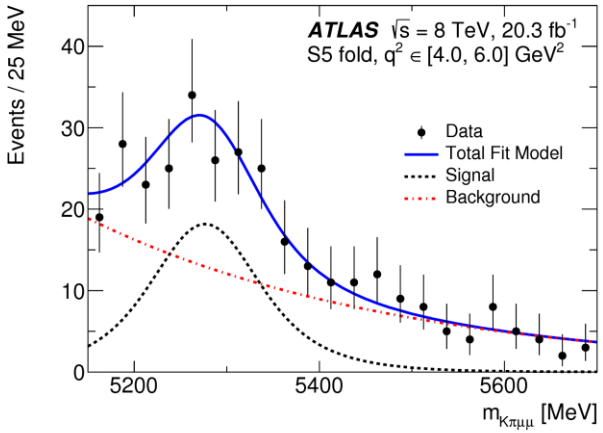
ATLAS angular analysis of $B^0 \to K^{*0}\mu^+\mu^-$

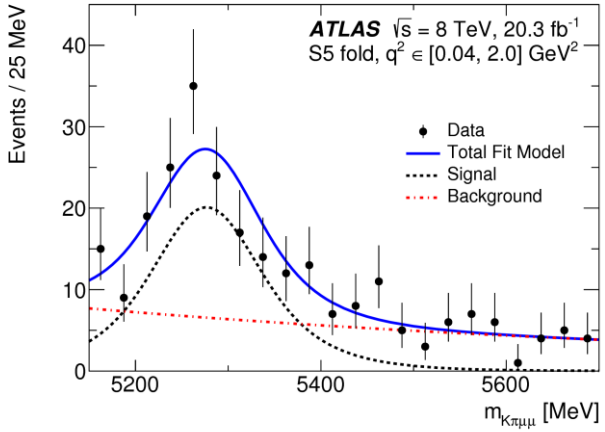


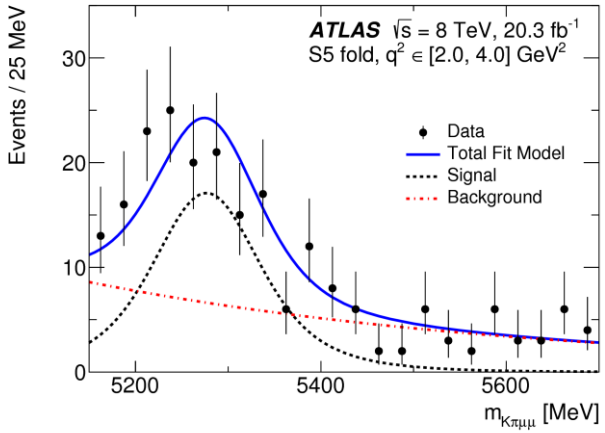


Control samples

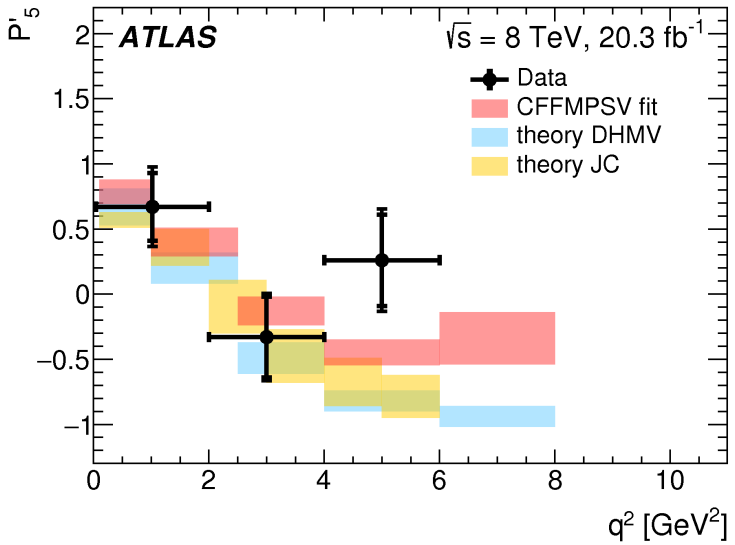
q^2 [GeV^2]	n_{signal}	$n_{\text{background}}$
[0.04, 2.0]	128 ± 22	122 ± 22
[2.0, 4.0]	106 ± 23	113 ± 23
[4.0, 6.0]	114 ± 24	204 ± 26
[0.04, 4.0]	236 ± 31	233 ± 32
[1.1, 6.0]	275 ± 35	363 ± 36
[0.04, 6.0]	342 ± 39	445 ± 40

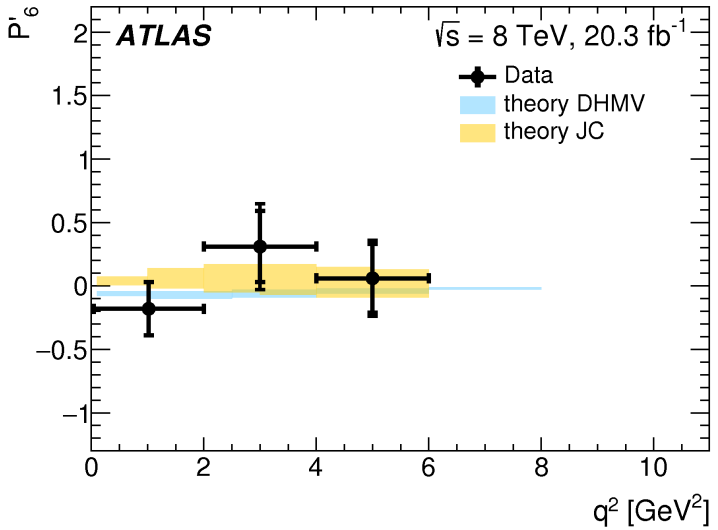


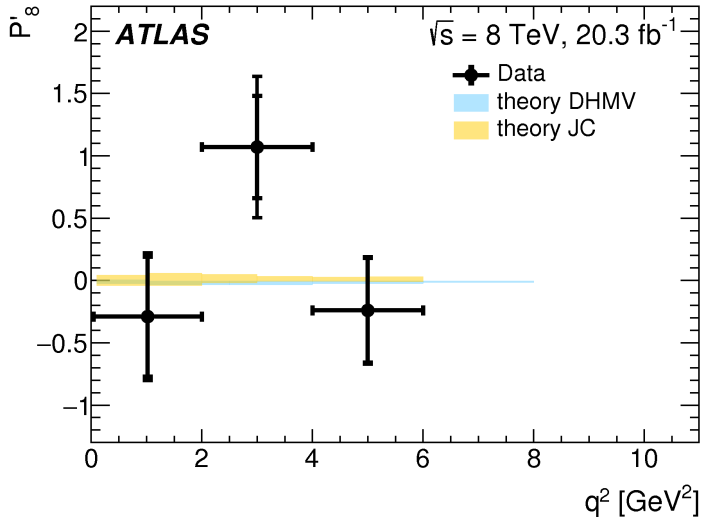


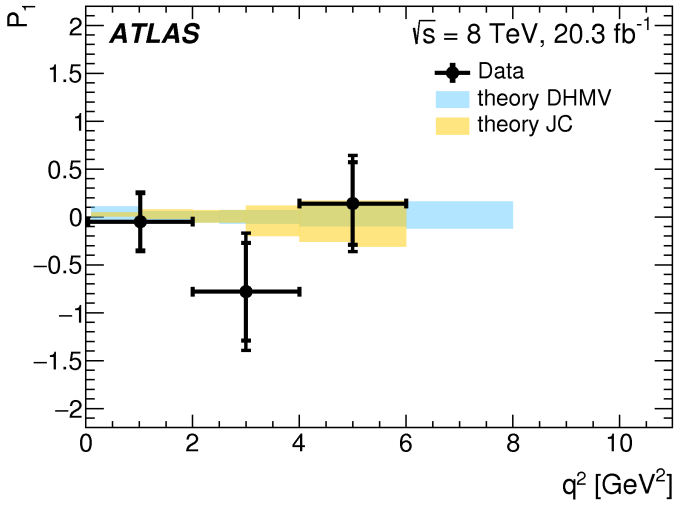


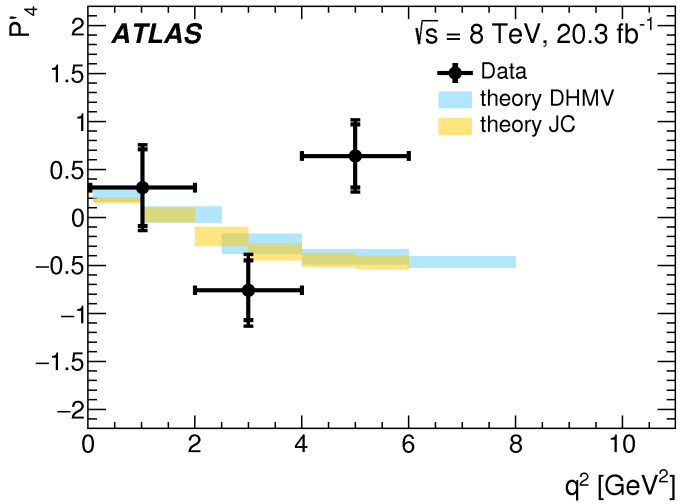
ATLAS angular analysis of $B^0 \to K^{*0}\mu^+\mu^-$









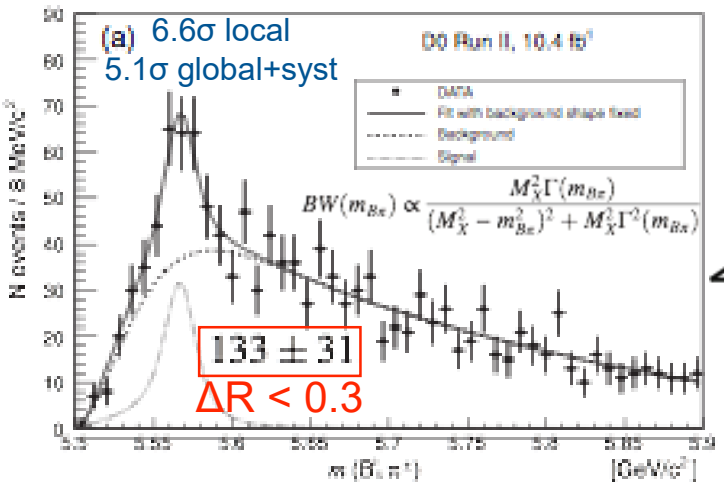


All results are compatible within 3 s.d. with different predictions, and are compatibles with results from the LCHb, CMS, and Belle experiments.

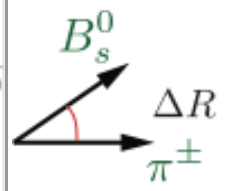
Submitted to JHEP

Search for $X^+(5568) \to B_s\pi^+$

- DZero reported the observation of a tetraquark candidate in $X^+(5568) \to B_s\pi^+$
- LHCb reported a non-confirmation result of these candidate.
- CMS and ATLAS has recollected several thousands of $B_s \to J/\psi\,\phi$ decays on what to look for.



$$M_X = 5567.8 \pm 2.9\,^{+0.9}_{-1.9}\,\text{MeV}$$
$$\Gamma_X = 21.9 \pm 6.4\,^{+5.0}_{-2.5}\,\text{MeV}$$
Strong decay!
$$N_X = 133 \pm 31 \pm 15\,\text{cand.}$$



Loosely Bound Hadronic Molecule?

Not favored due to mass far from B-K thresh.

Tetraquark?

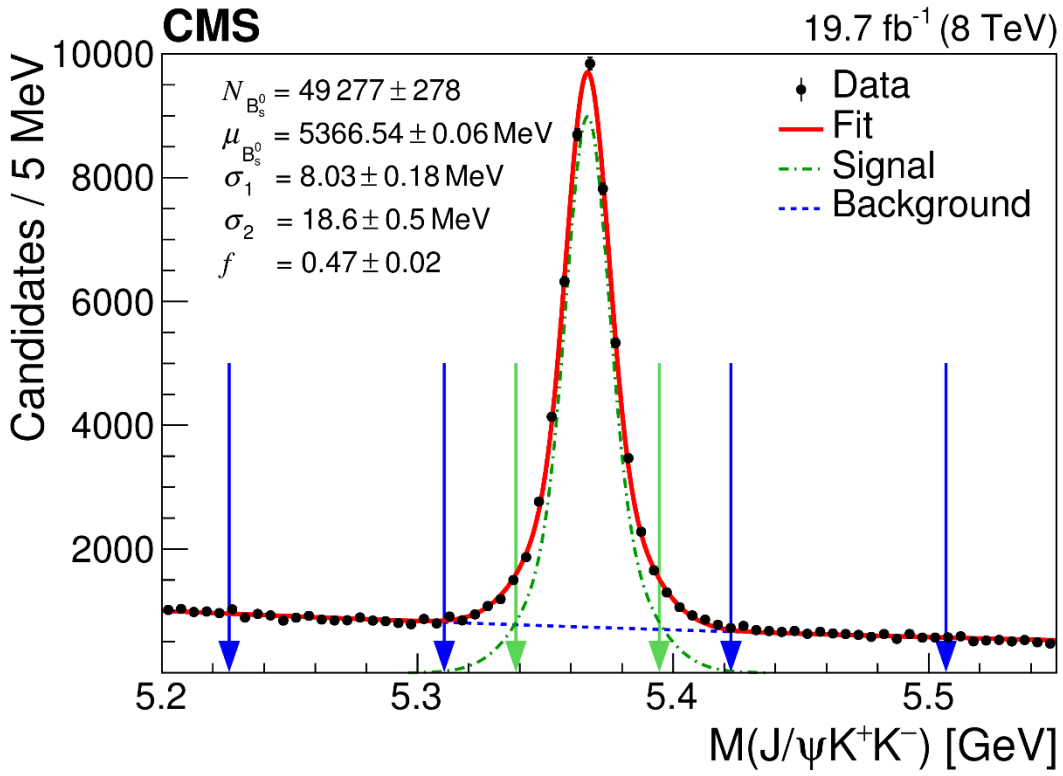
Possible, but theory predicts more states

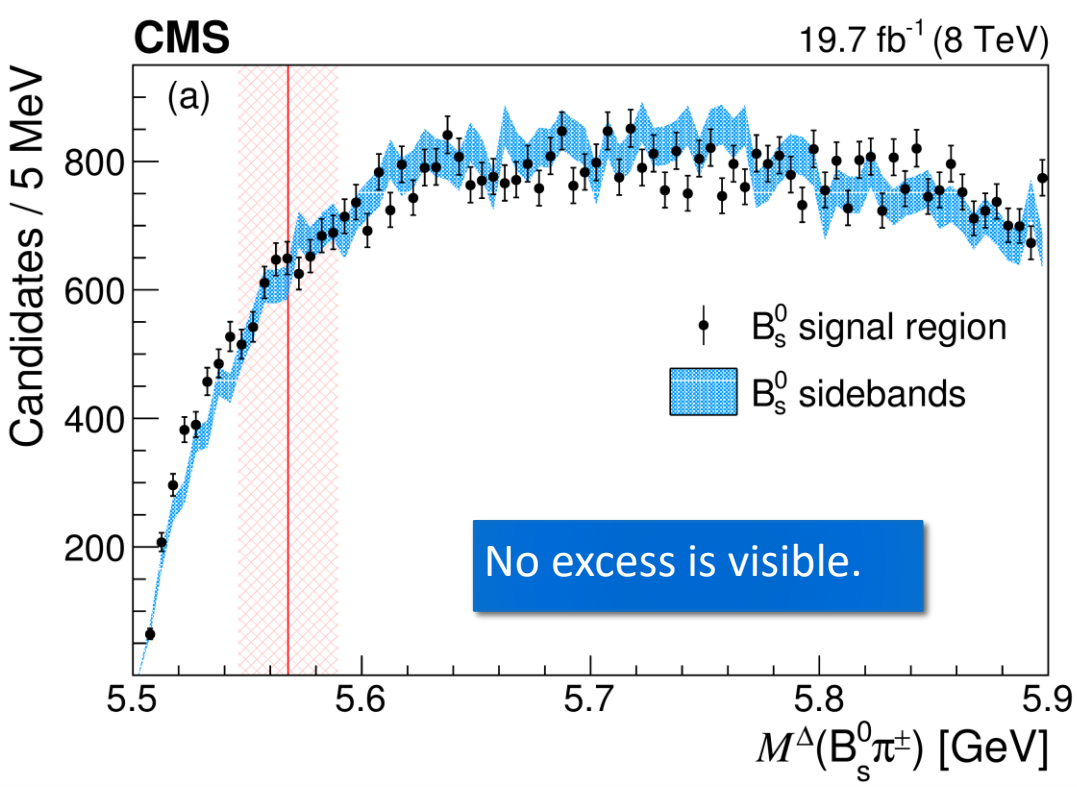
- If $X(5568)^- \to B_s^0\pi^-$ then $J^P = 0^+$
- If $X(5617)^- \to B_s^{0*}\pi^-$ $\hookrightarrow B_s^0\gamma$ miss! then $J^P = 1^+$

$$\rho_X \equiv \frac{\sigma(pp \to X(5558) + anything) \times B(X(5558) \to B_s\pi^\pm)}{\sigma(pp \to B_s + anything)} = \frac{N_X}{N_{B_s}} \frac{\varepsilon_{B_s}}{\varepsilon_X}$$

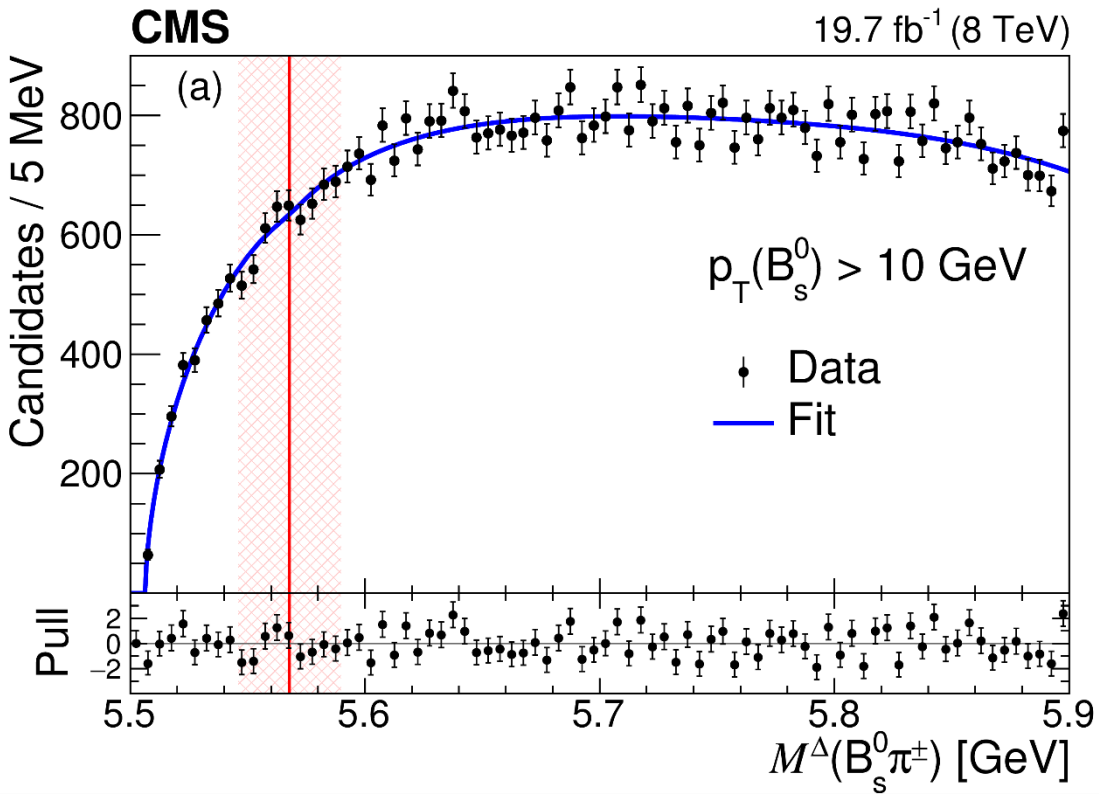
CMS search for $X^+(5568) \to B_s\pi^+$

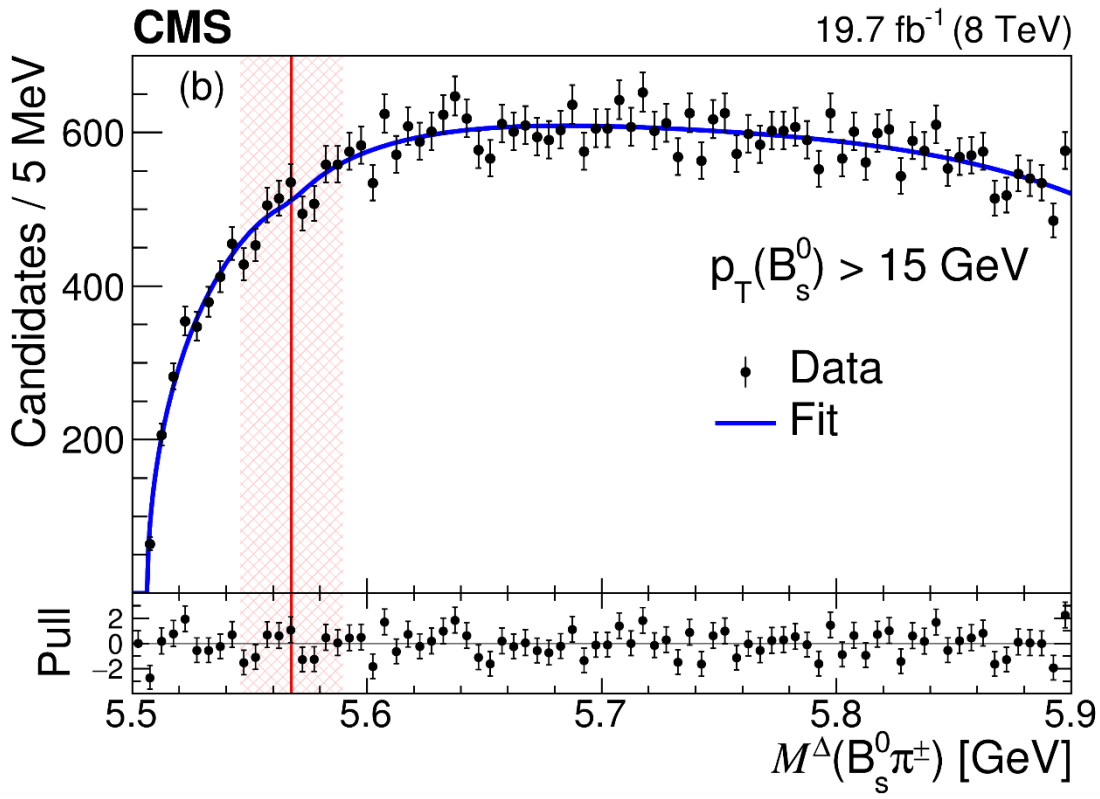
Search for resonances in the $B_s\,\pi^{\pm}$ invariant mass spectrum: B_s (→J/ψφ(1020)) + prompt pion.



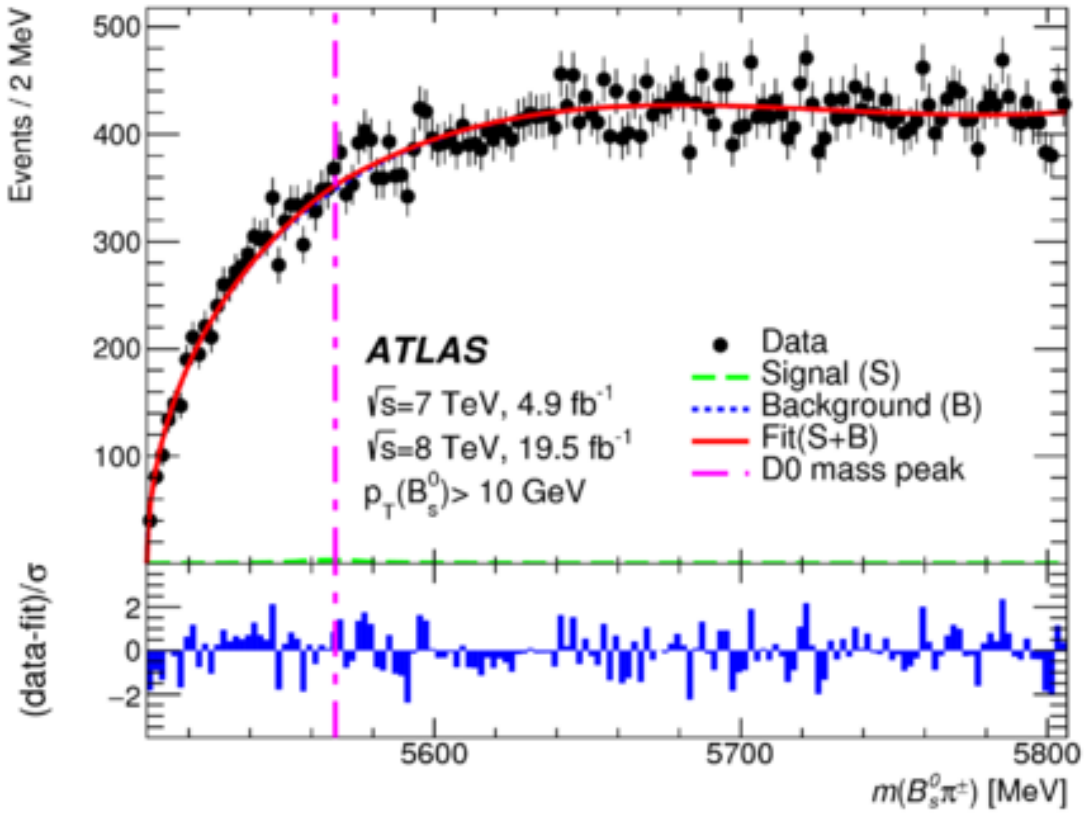


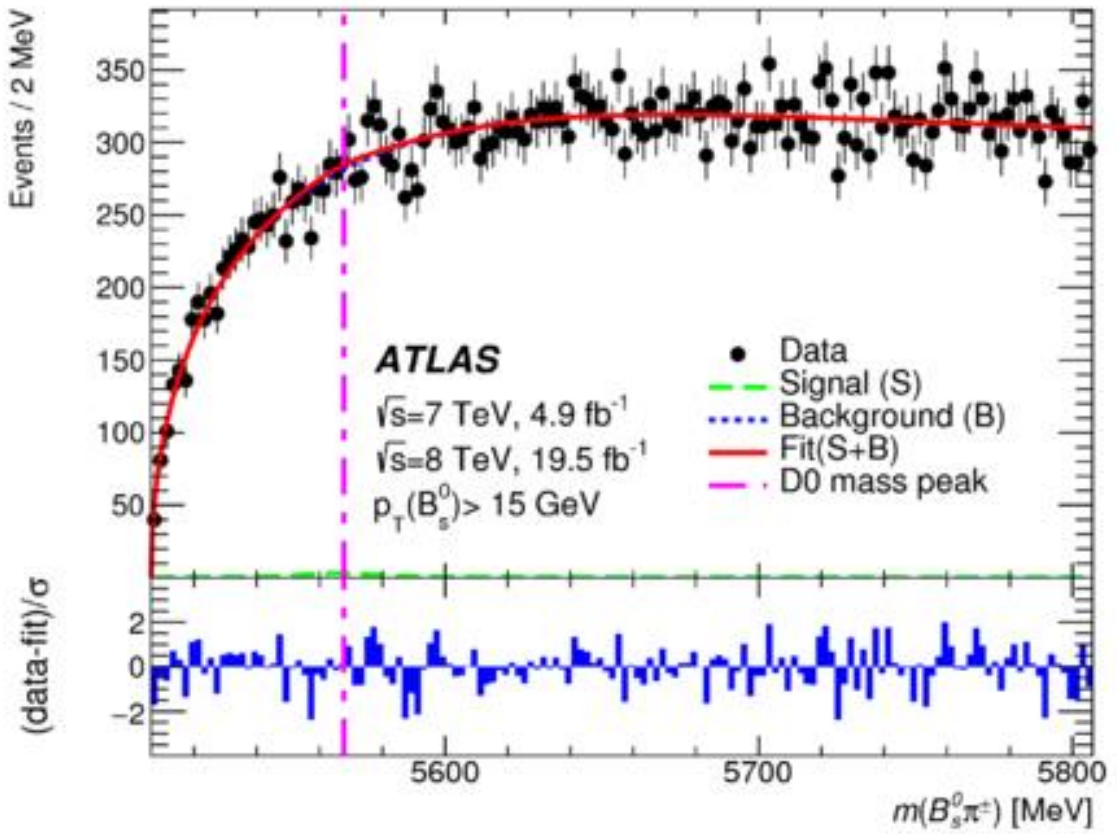
Fit to CMS data



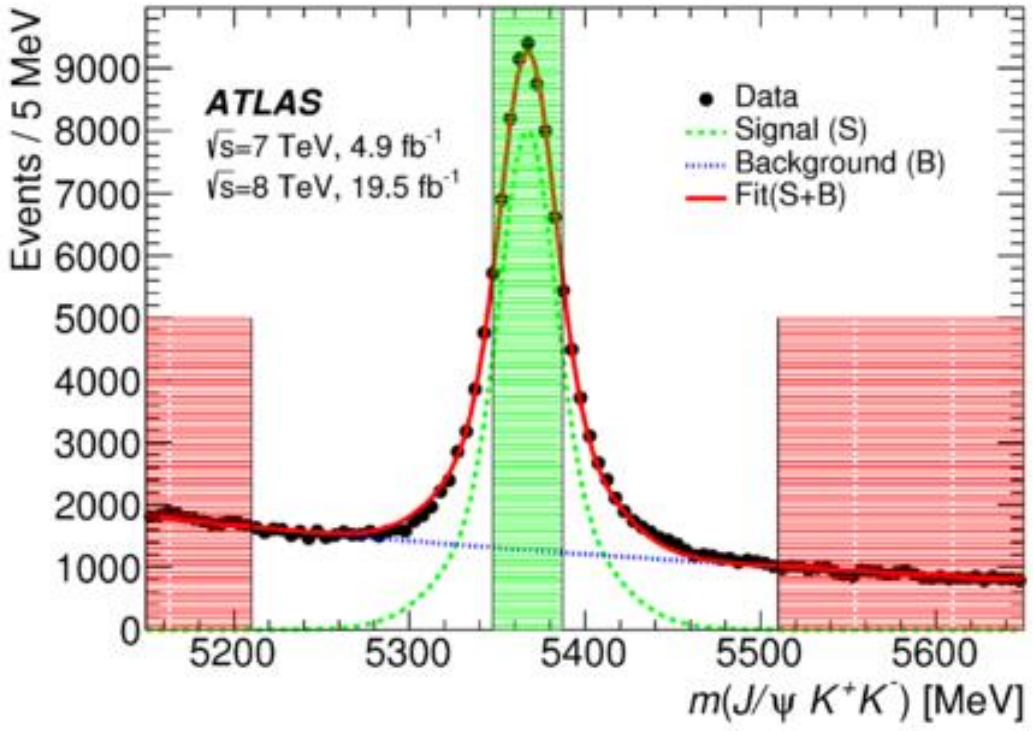


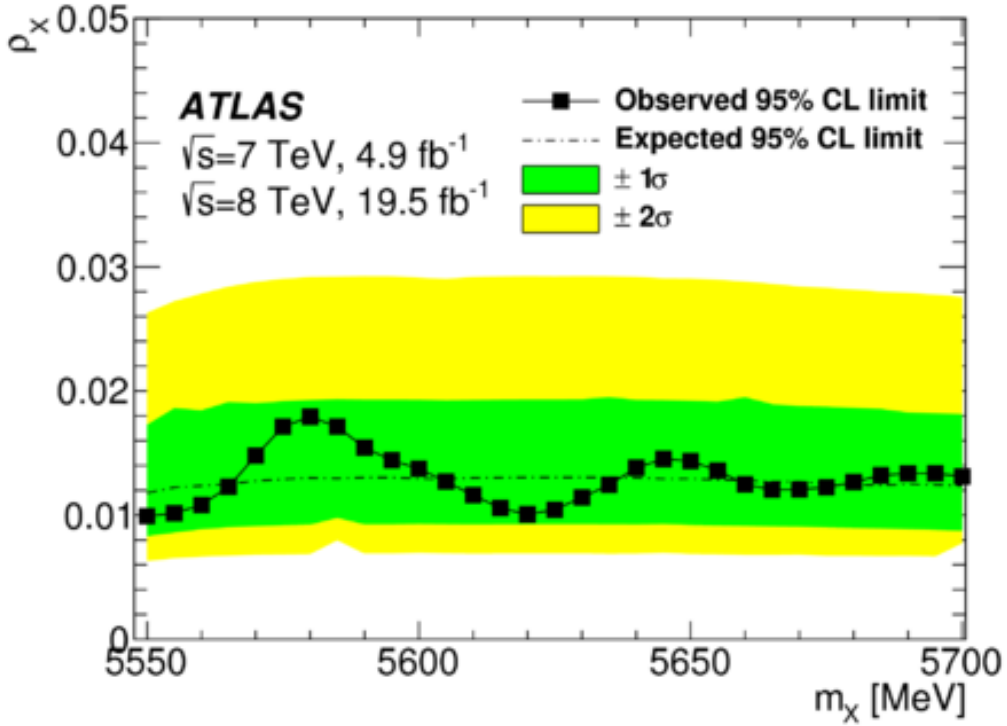
ATLAS search for $X^+(5568) \rightarrow B_s\pi^+$





ATLAS search for $X^+(5568) \to B_s\pi^+$





Summary of the search for $X^+(5568) \to B_s\pi^+$

- CMS and ATLAS find not significant structure in M($B_s\pi^{\pm}$) for masses up to 5.9 GeV, disfavoring predictions of tetraquark models.
- No signal found despite trying different kinematic & quality cuts, variants of bkg. modeling and fit regions.

CMS:

$\rho_X < 1.1\%$ @95% $C.L.$ for pT(Bs)>10 GeV

$\rho_X < 1.0\%$ @95% $C.L.$ for pT(Bs)>15 GeV

PRL 120, 202005 (2018)

ATLAS:

$\rho_X < 1.5\%$ @95% $C.L.$ for pT(Bs)>10 GeV

$\rho_X < 1.6\%$ @95% $C.L.$ for pT(Bs)>15 GeV

PRL 120, 202007 (2018)

More recently (pub. last weeka)

CDF: ρ < 6.7% for $p_T(B_s)$ > 10 GeV & |y| ≲ 1 does not favor D0 results [PRL 120, 202006 (2018)]

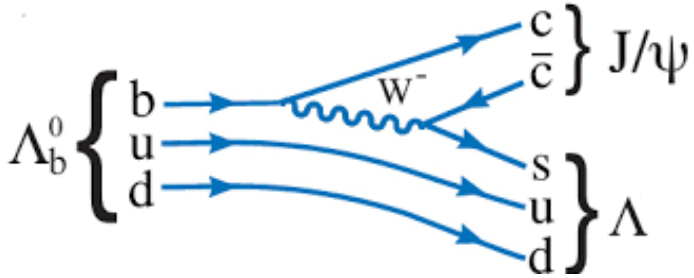
$\rho_X^{DZero} = 8.6 \pm 1.9\,(stat) \pm 1.4\,(syst.)$ % *hadronic*

$\rho_X^{DZero} = 7.3^{+2.8}_{-2.4}\,(stat)^{+0.6}_{-1.7}(syst.)$ % *Semileptonic*

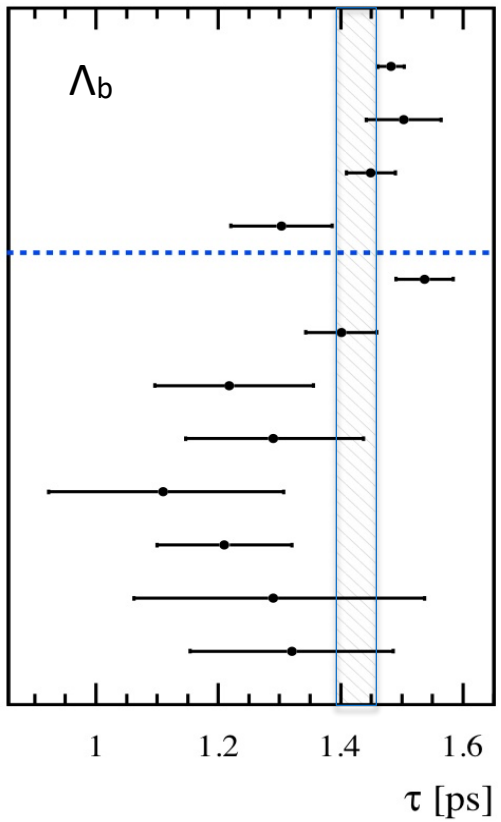
See A. Druskoi presentation.

D0: reconfirms with 6.7σ using B_s semileptonic decays [PRD 97, 092004 (2018)]

b hadron lifetimes

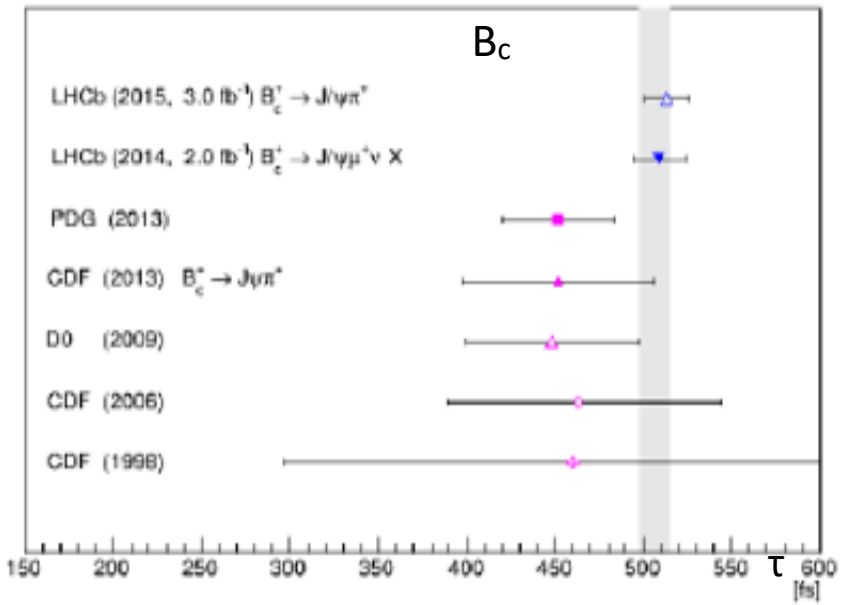


- B-lifetimes determine importance of non-spectator contributions.
- Discrepancies among previous measurements of, e.g., Λ_b & B_c^+ lifetimes:



Experiment
LHCb (2013) [$J/\psi pK^-$]
CMS (2012) [$J/\psi\Lambda$]
ATLAS (2012) [$J/\psi\Lambda$]
D0 (2012) [$J/\psi\Lambda$]
CDF (2011) [$J/\psi\Lambda$]
CDF (2010) [$\Lambda_c^+\pi^-$]
D0 (2007) [$J/\psi\Lambda$]
D0 (2007) [Semileptonic decay]
DLPH (1999) [Semileptonic decay]
ALEP (1998) [Semileptonic decay]
OPAL (1998) [Semileptonic decay]
CDF (1996) [Semileptonic decay]

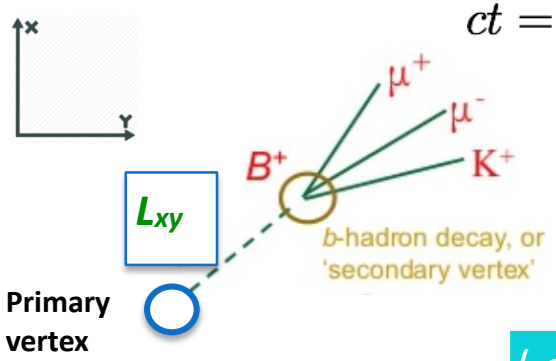
http://www.quantumdiaries.org/tag/b-physics/



LHCb results significantly larger than Tevatron measurements

Measurement strategy

$$ct = cL_{xy}\frac{M_B^{(\mathrm{PDG})}}{p_{\mathrm{T}}}$$



(ct > 200 μm)

Measurements **based on reconstruction of** the transverse decay length L_{xy} and UML fits of reco. mass (M), ct and σ_{ct} of the b hadrons:

$$B^+, B^0, B_s, \Lambda_b^0$$

$B^+ \to J/\psi K^+$: reference mode, for evaluation of syst. uncertainties.

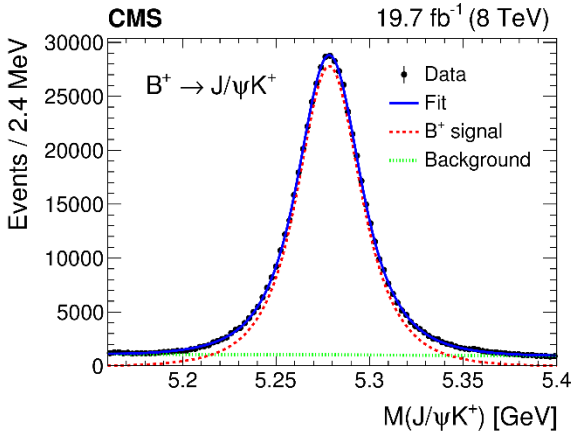
For the Bc meson, we use a ratio technique:

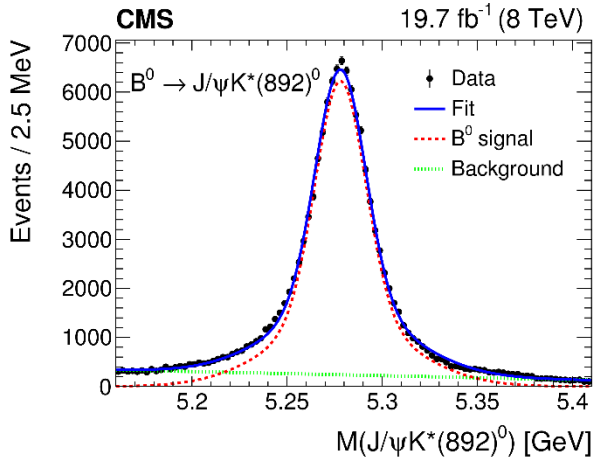
$$R(ct) \equiv \frac{N_{B_c^+}(ct)}{N_{B^+}(ct)} \approx R_\varepsilon(ct)exp(-\Delta\Gamma t)$$

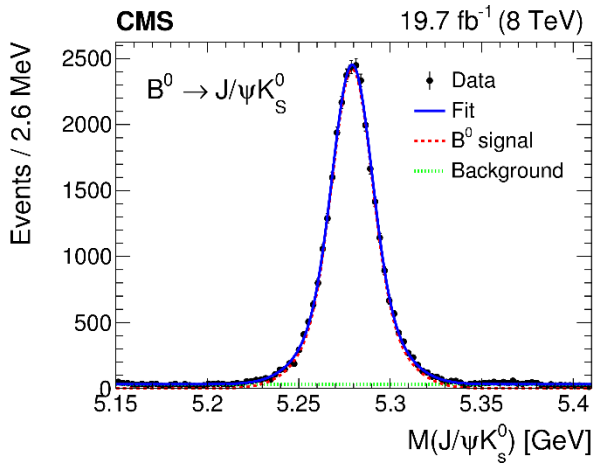
$$\Delta\Gamma \equiv \Gamma_{\mathrm{B_c^+}} - \Gamma_{\mathrm{B^+}} = \frac{1}{\tau_{\mathrm{B_c^+}}} - \frac{1}{\tau_{\mathrm{B^+}}}.$$

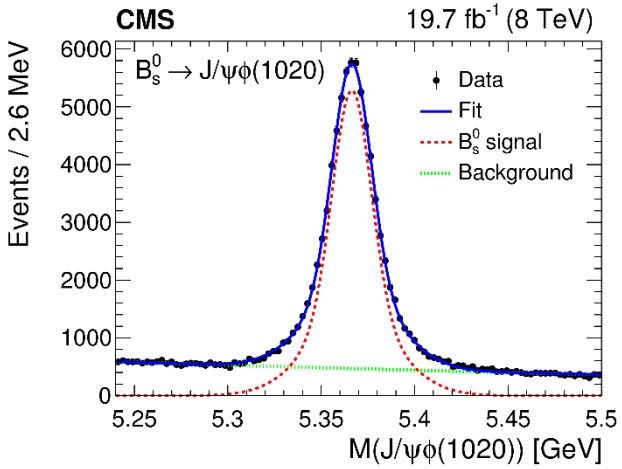
$$\mathrm{PDF} = f_S M_S(M) T_S(ct) E_S(\sigma_{ct}) + (1 - f_S) M_B(M) T_B(ct) E_B(\sigma_{ct})$$

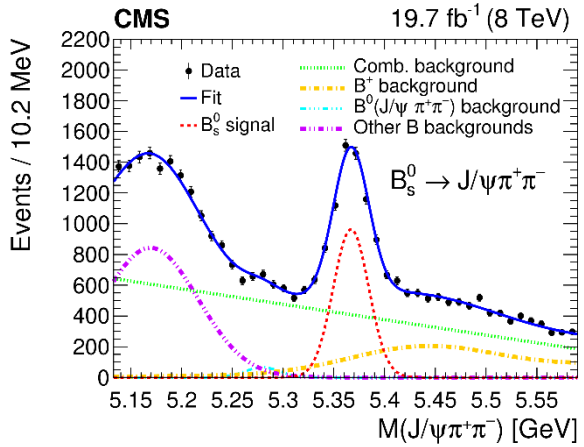
Mass distributions of b hadrons

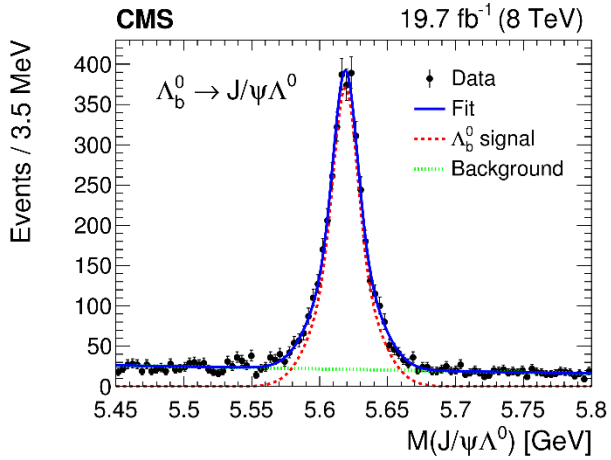


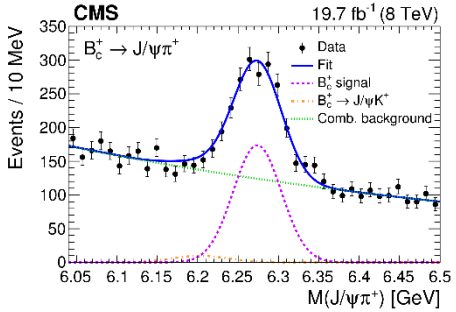


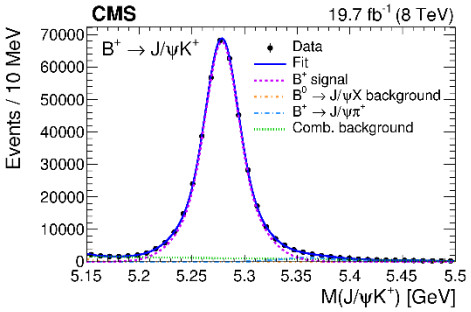












Lifetime results

$c\tau_{B^0 \to J/\psi K^*(892)^0} = 453.0 \pm 1.6\ (stat) \pm 1.8\ (syst)\ \mu m$

$c\tau_{B^0 \to J/\psi K^0_S} = 457.0 \pm 2.7\ (stat) \pm 2.8\ (syst)\ \mu m$

} $c\tau_{B^0} = 454.1 \pm 1.4\ (stat) \pm 1.7\ (syst)\ \mu m$

vs. 455.7 ± 1.2 µm (HFAG)

$c\tau_{B^0_s \to J/\psi \pi^+\pi^-} = 502.7 \pm 10.2\ (stat) \pm 3.4\ (syst)\ \mu m$ vs. 495 ± 10 (LHCb), 510 ± 36 (CDF), 508 ± 45 µm (D0)

$c\tau_{B^0_s \to J/\psi \phi(1020)} = 443.9 \pm 2.0\ (stat) \pm 1.5\ (syst)\ \mu m$ vs. 443.4 ± 3.6 µm (HFAG)

$c\tau_{\Lambda^0_b} = 442.9 \pm 8.2\ (stat) \pm 2.8\ (syst)\ \mu m$ vs. 440.7 ± 3.0 µm (HFAG)

$c\tau_{B^+_c} = 162.3 \pm 7.8\ (stat) \pm 4.2\ (syst) \pm 0.1\ (\tau_{B^+})\ \mu m$ vs. 152.0 ± 2.7 µm (HFAG)

Precision from each channel is as good as or better than previous measurements.

Accepted by EPJC (arXiv:1710.08949)

$\tau_{\Lambda^0_b}/\tau_{B^0 \to J/\psi K^*(892)^0} = 0.978 \pm 0.018(stat) \pm 0.006(syst)$ vs. 0.967 ± 0.007 (HFAG)

$\tau_{B^0_S \to J/\psi \phi(1020)}/\tau_{B^0 \to J/\psi K^*(892)^0} = 0.980 \pm 0.006(stat) \pm 0.003(syst)$ vs. 0.993 ± 0.004 (HFAG)

Ratios compatible with the current W.A. values (≲1.5σ)

Combination of theses results leads to:

$\Gamma_d = 0.662 \pm 0.003(\text{stat}) \pm 0.003(syst) ps^{-1}$

$\Delta\Gamma_d = 0.023 \pm 0.015(\text{stat}) \pm 0.016(syst) ps^{-1}$

$\Delta\Gamma_d/\Gamma_d = 0.034 \pm 0.023(\text{stat}) \pm 0.024(syst)$ vs. -0.002 ± 0.010 (HFAG)

$c\tau_L(B_s) = 420.4 \pm 6.2\ \mu m$ vs. 423.6 ± 1.8 µm (HFAG)

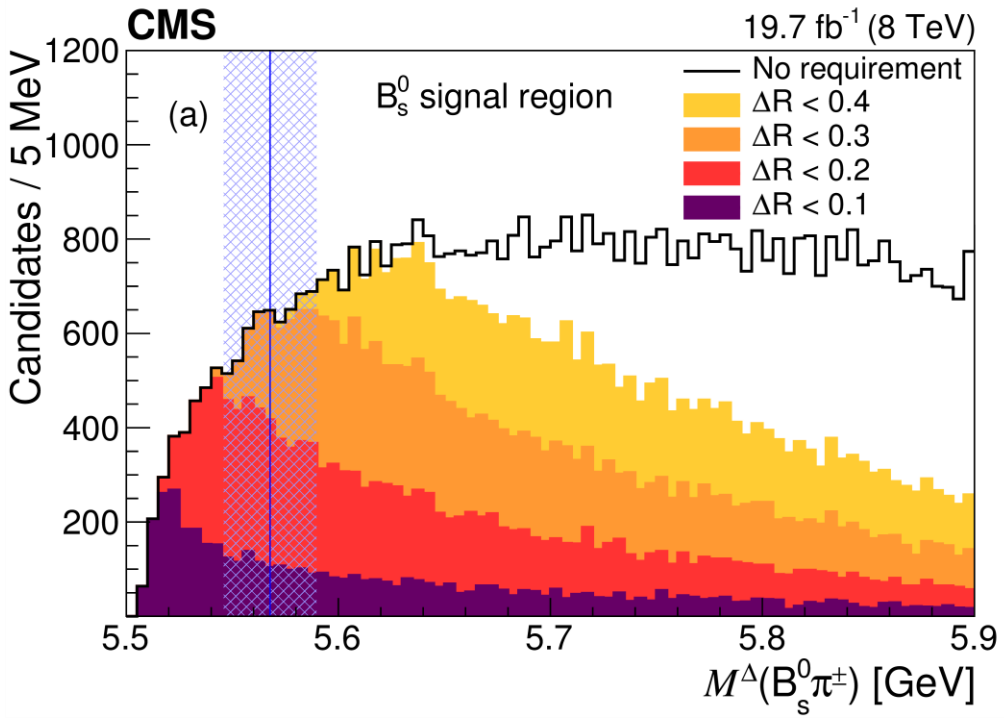
All results are in agreement with current W.A. values and with HQE predictions and other theoretical models

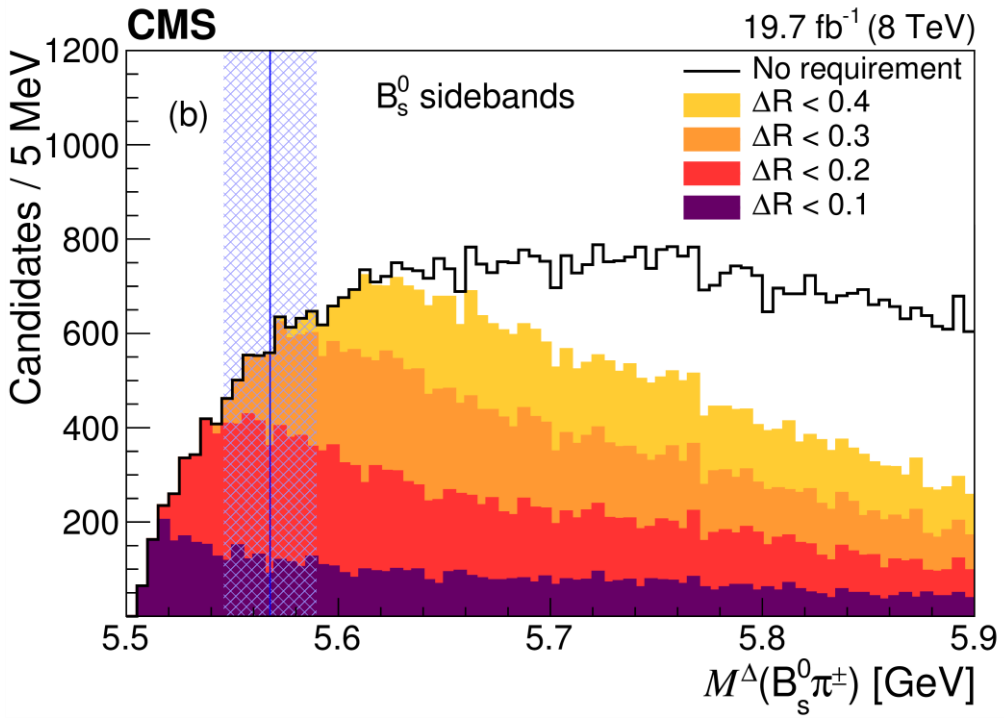
Conclusion and prospects

- Data sets of 8 TeV are still producing important results, in addition to the analysis of data at 13 TeV.
- ATLAS and CMS are profiting of their trigger on dimuons, suitable for studies on rare decays of b-hadrons, so new results on that line will come soon, in addition to properties and other observations.
- CMS and ATLAS can not confirm the peaking structure observed by Dzero.
- Both experiments, ATLAS and CMS have a strong opportunities on the study of heavy hadron.
- ATLAS and CMS has produced much more results than what can fit in this talk.

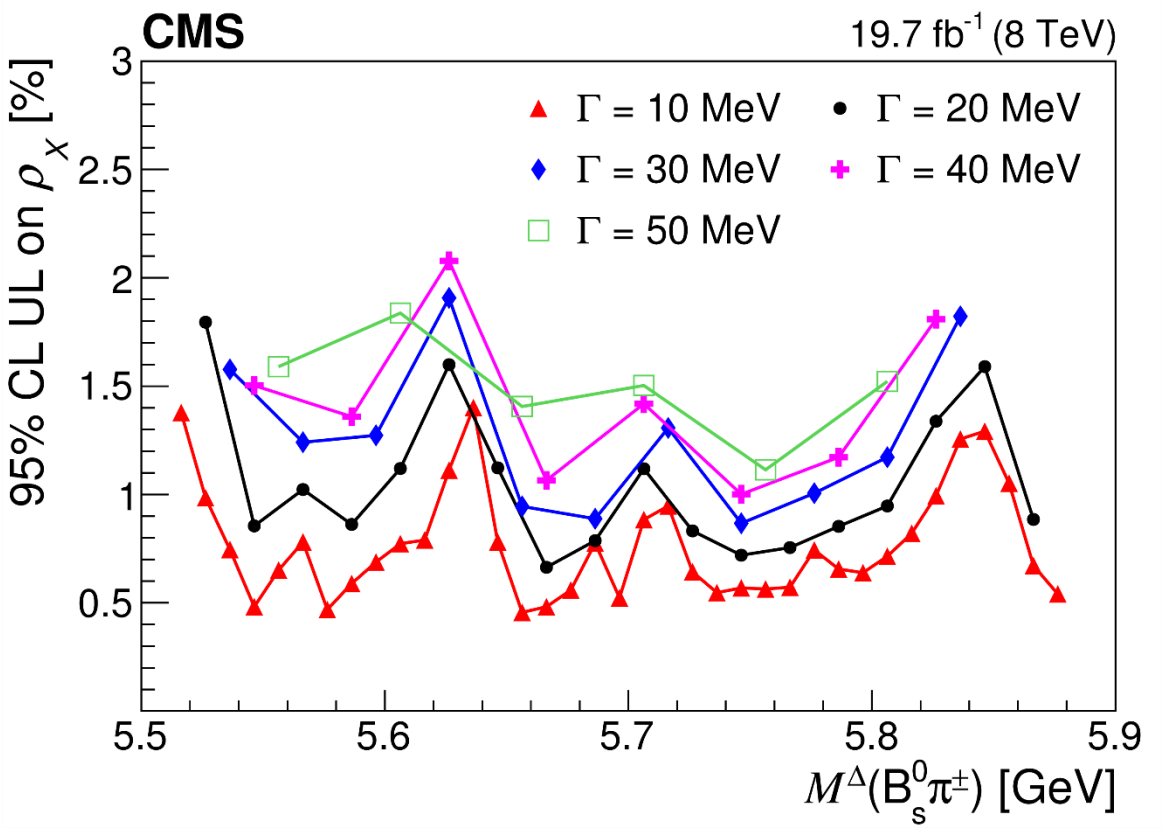
Backups

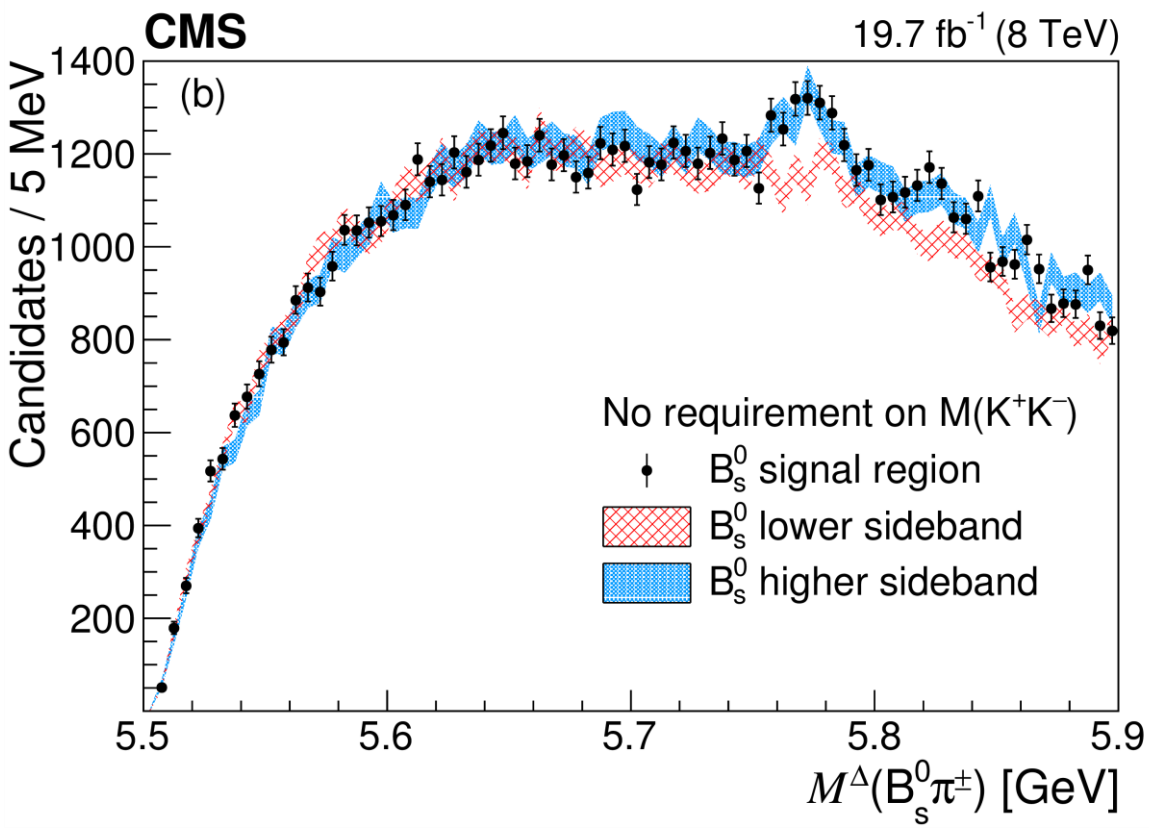
CMS search for $X^+(5568) \to B_s\pi^+$



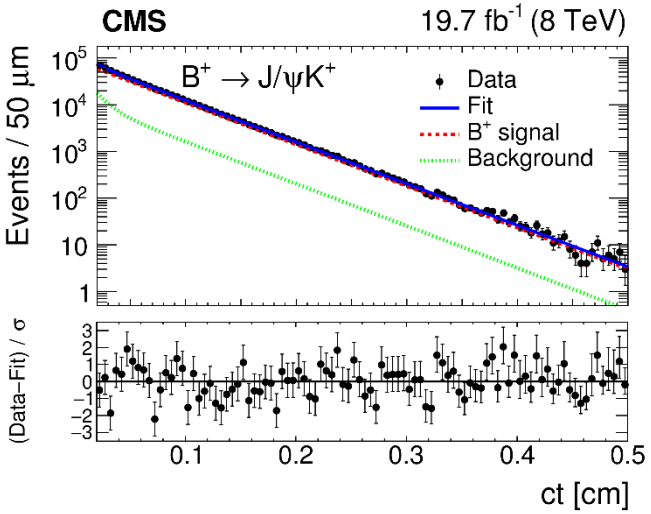


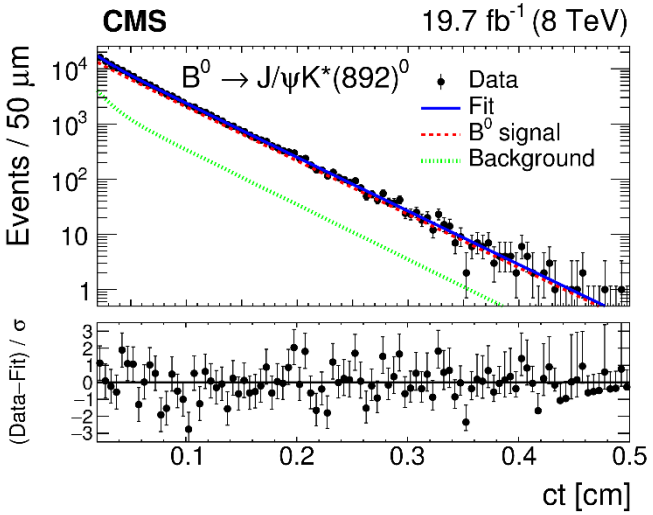
CMS search for $X^+(5568) \to B_s\pi^+$

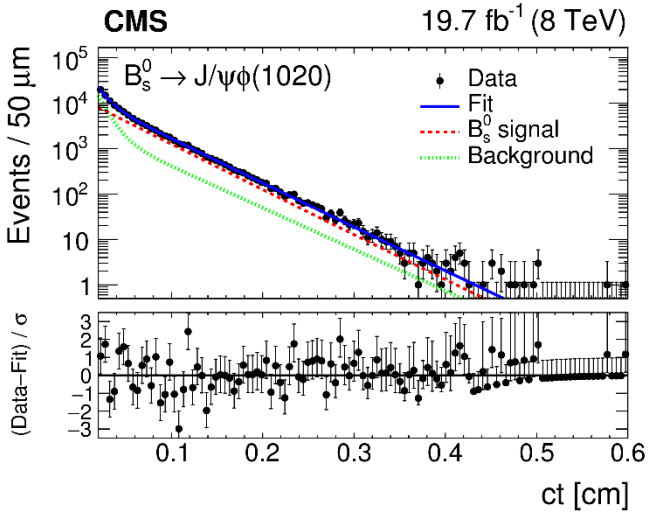


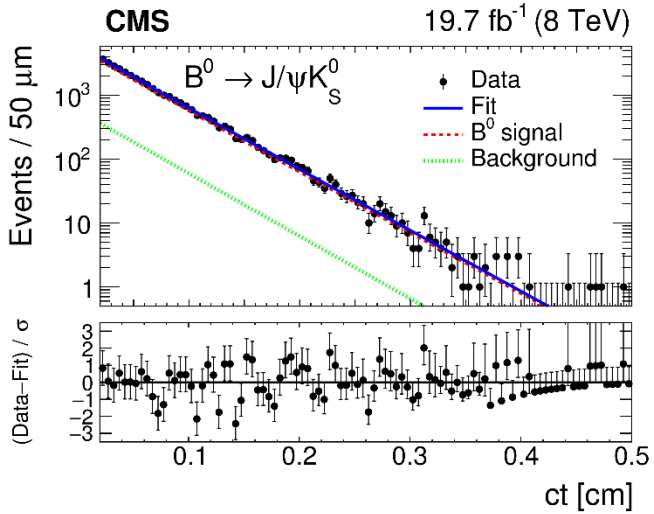


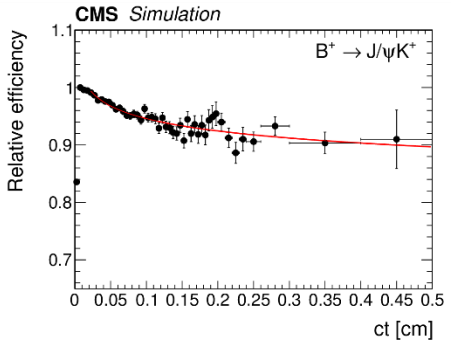
Efficiencies and lifetime fits

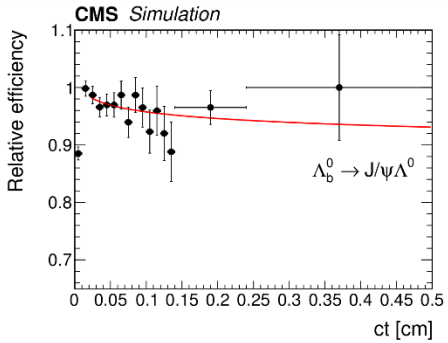


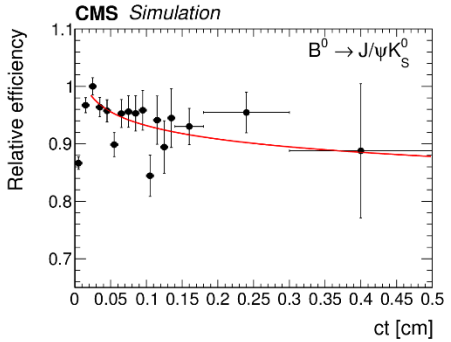


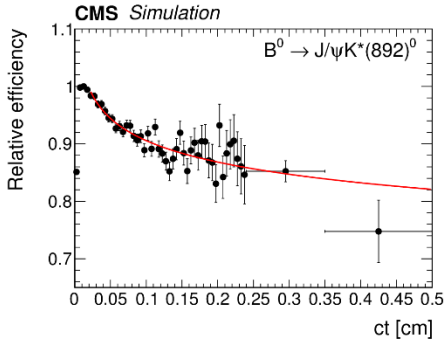


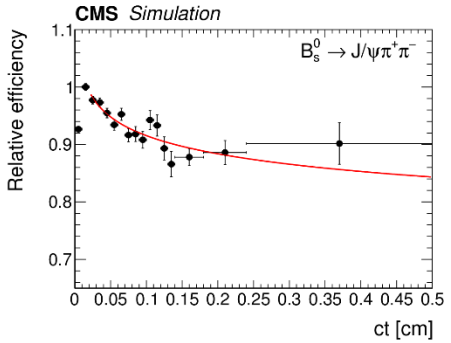


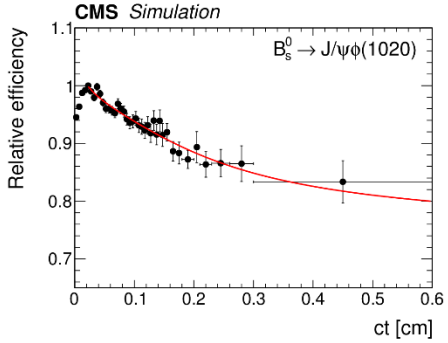












Lifetime fits