ATLAS/CMS: B production

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(On behalf of CMS/ATLAS collaboration)

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Introduction

The b-hadron production has been predicted with NLO accuracy for more than twenty years. However, the dependence on the factorization, renormalization scales, m_b results in theoretical uncertainties of up to 40%.

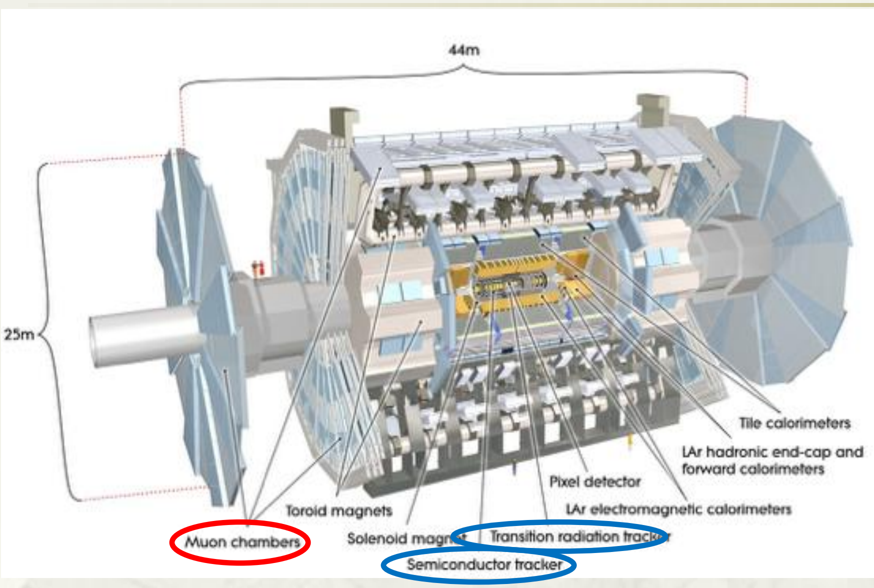
The large production cross--sections for B hadron particles in pp collisions at LHC energies provides opportunities for testing the Standard Model picture of flavor dynamics.

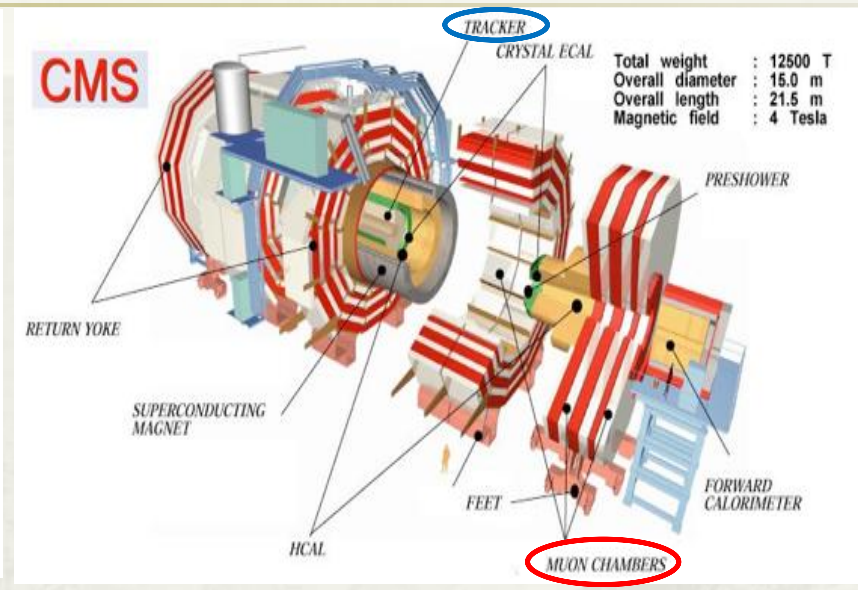
Motivation:

- Test of perturbative & non-- - perturbative QCD models for B hadrons production/fragmentation.
- Study dynamics of heavy quarks inside hadrons, decay models and spectroscopy.
- Heavy flavored hadrons are profusely produced at the LHC. It is possible to study/search for some quarkonium-- - like exotic states and new physics.

CMS and ATLAS

General Purpose Detectors running on LHC





	ATLAS	CMS
Axial Magnetic field	2 T	3.8 T
Track momentum resolution σ/p^{T2} [GeV]$^{-1}$	~0.05%p_T + 0.015	~0.015%p_T + 0.005
Lifetime resolution	~100 fs	~70 fs
ID tracking $\|\eta_{max}\|$	2.5	2.5
Muon System $\|\eta_{max}\|$	2.7	2.4

precision tracking

- good momentum, impact parameter and vertex resolutions
- good b-tagging capability

robust muon identification

- muon detection down to low p_T, low mis-identification rates

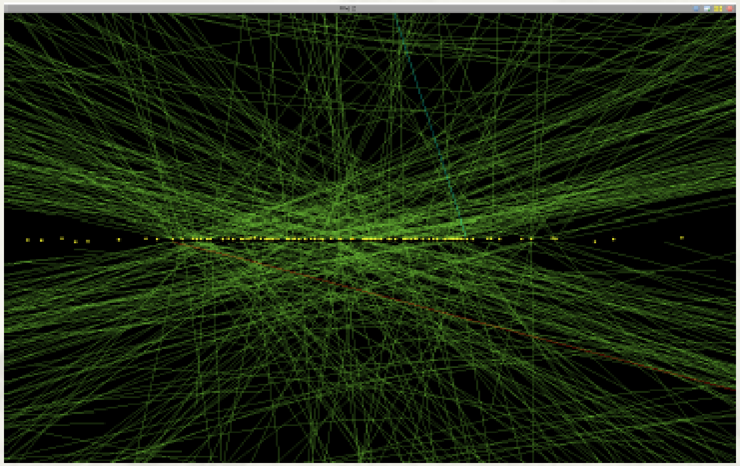
ATLAS and CMS fully exploit the highest HF production rates and highest LHC luminosities, and access regimes and phase space, complementary to B factories, Tevatron, and LHCb.

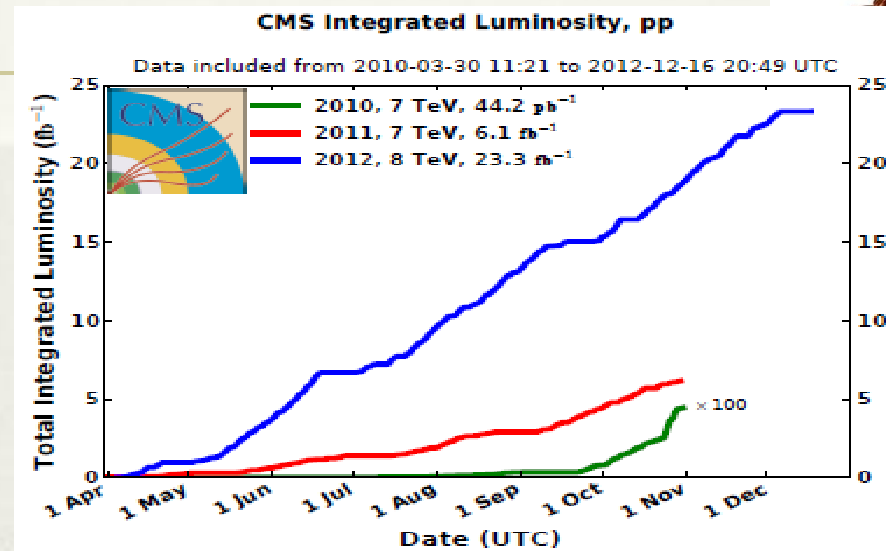
Data and trigger system

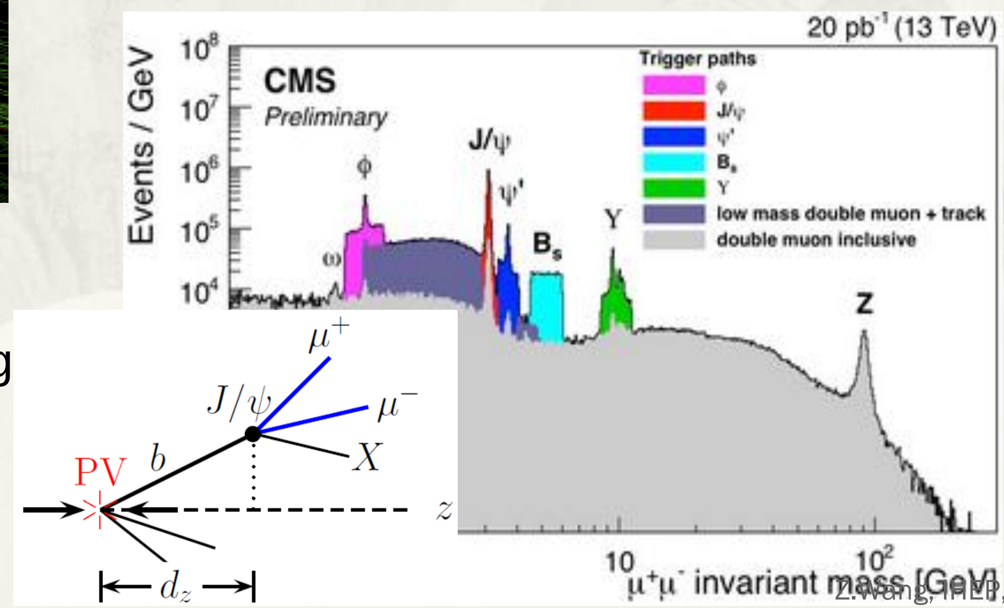
proton proton collision

- $\sqrt{s} = 7$ TeV , $\mathcal{L} = \ 5$ fb^{-1} (2011 run)
- $\sqrt{s} = 8$ TeV , $\mathcal{L} = 20$ fb^{-1} (2012 run)

$< \mu >_{2011} = 8$ PV, $< \mu >_{2012} = 21$ PV







Trigger selection for heavy flavour studies is mostly based on di-muon signature. Collect data at increasing instantaneous luminosity.

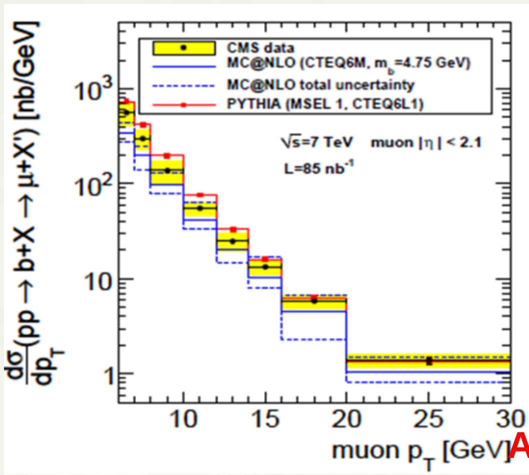
- muon p_T threshold (4 or 6 GeV)
- di-muon vertex reconstruction
- invariant mass window

Inclusive b production

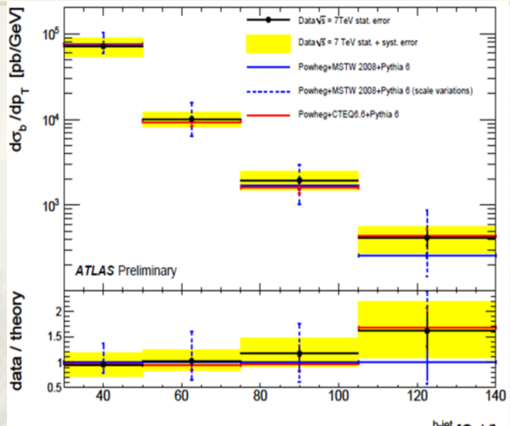
Early inclusive b production measurements are performed at ATLAS and CMS, data sample ~nb^{-1} to several ~pb^{-1}.

Inclusive b-hadron with muon 7 TeV, 85 nb^{-1}	**CMS**: JHEP 03 (2011) 090,
Inclusive bbarX$\to\mu\mu X'$ 7 TeV, 27.9 pb^{-1},	**CMS**: JHEP 06 (2012) 110,
Inclusive b-jet production 7 TeV, 34 pb^{-1},	**CMS**: JHEP 04 (2012) 084,
b-hadron ($D^{*+}\mu^{-}X$) 7 TeV, 3.3 pb^{-1}	**ATLAS**: Nucl. Phys. B 864 (2012) 341,
b di-jets 7 TeV, 3.3 pb^{-1},	**ATLAS**: Nucl. Phys. B 864 (2012) 341,

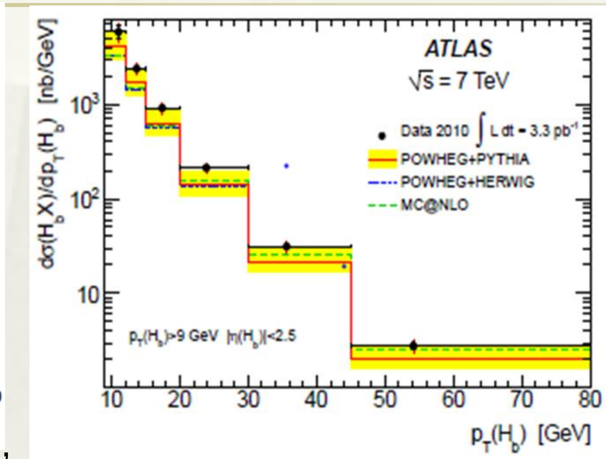
Inclusive b production



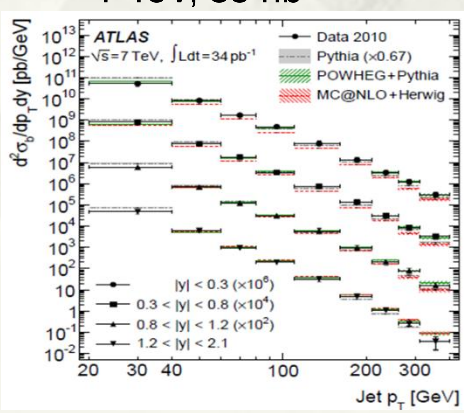
CMS: JHEP 03 (2011) 090,
7 TeV, 85 nb^{-1}



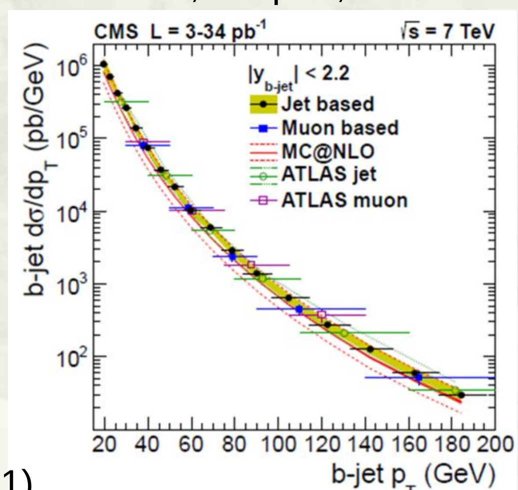
ATLAS: ATLAS-CONF-2011-057,
7 TeV, 4.8 pb^{-1},



ATLAS: Nucl. Phys. B 864 (2012) 341, 7 TeV, 3.3 pb^{-1},



ATLAS: Eur. Phys. J. C 71 (2011) 1846, 7 TeV, 34 pb^{-1},



CMS: JHEP 04 (2012) 084,
7 TeV, 34 pb^{-1},

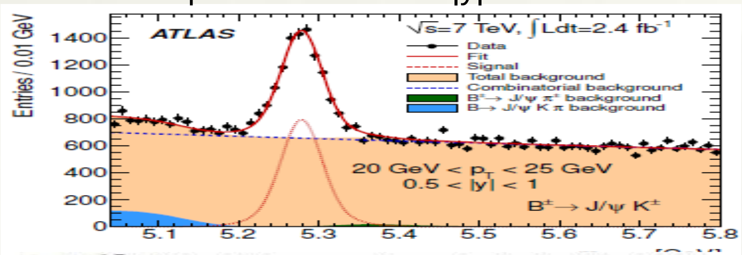
Production Cross Sections are measured with few data in early ATLAS/CMS run.

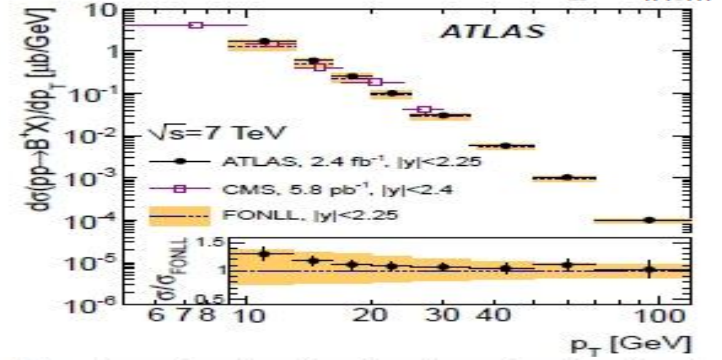
Differential Cross Sections are consistent with NLO predictions.

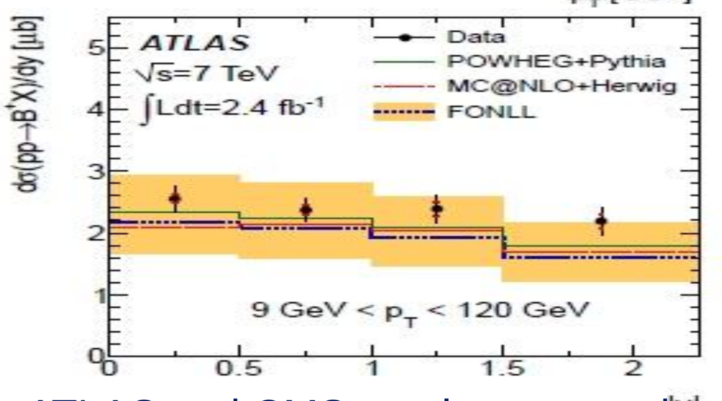
B^+ production

$B^+ \rightarrow J/\psi K^+ \rightarrow \mu^+\mu^- K^+$

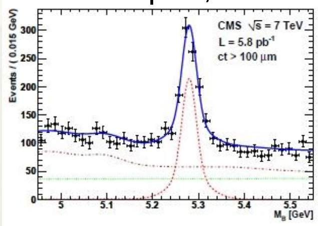
ATLAS **JHEP 1310 (2013) 042**. 7 TeV, 2.4 fb^{-1},
9 GeV < p^T < 120 GeV and |y| < 2.25

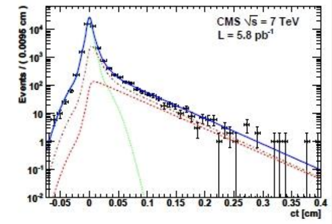


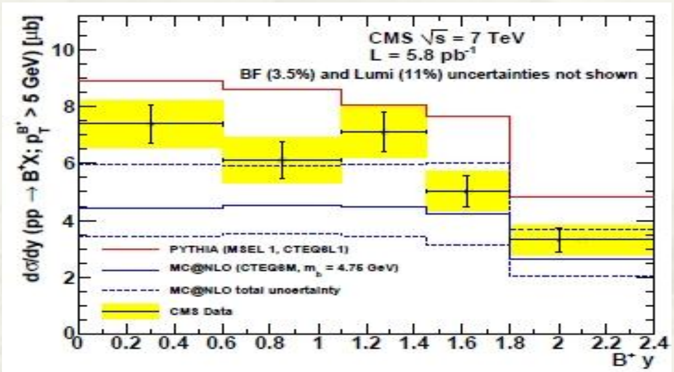


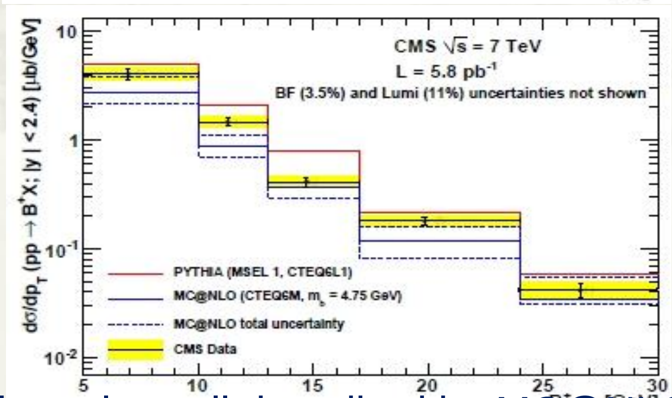


CMS **Phys.Rev.Lett. 106 (2011) 112001**
7 TeV 5.8 pb^{-1},







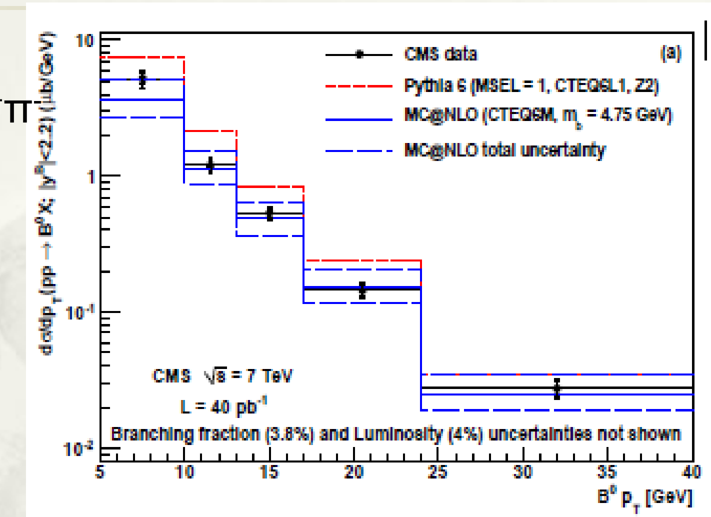


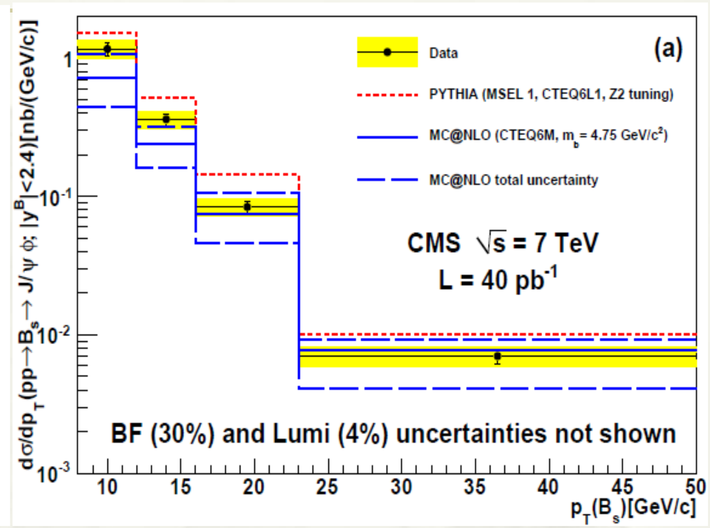
ATLAS and CMS results are consistent, and results well described by MC@NLO calculations

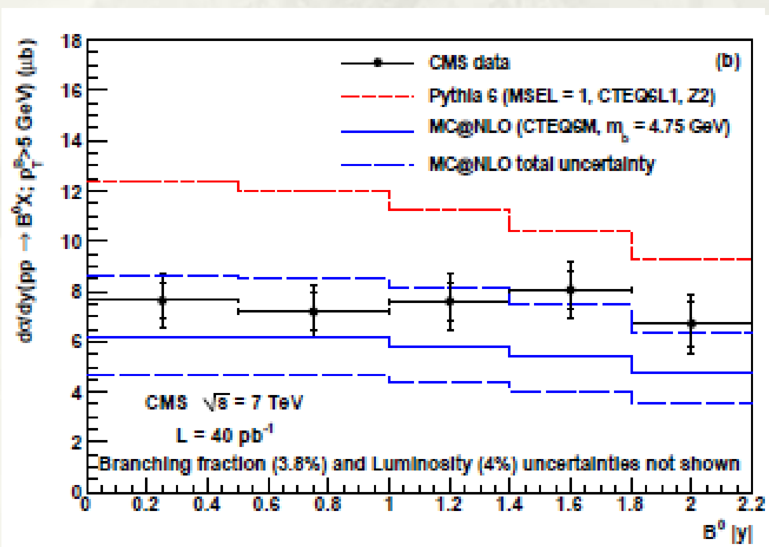
B^0, B_s production

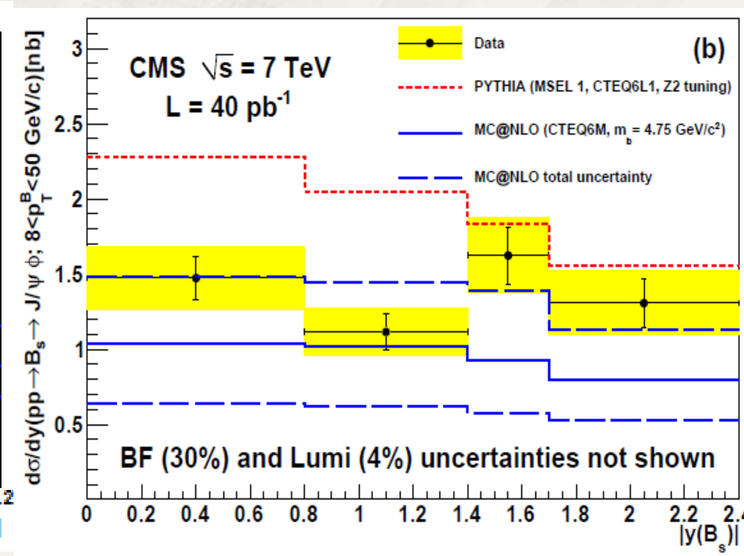
$B^0 \rightarrow J/\psi\ K^{0*} \rightarrow \mu^+\mu^-\ K^+\pi^-$
$B_s \rightarrow J/\psi\ \phi \rightarrow \mu^+\mu^-\ K^+K^-$

CMS
Phys. Rev. Lett. 106 (2011) 252001
7 TeV, using 40 pb^{-1},
5 GeV < p^T, |y| < 2.2







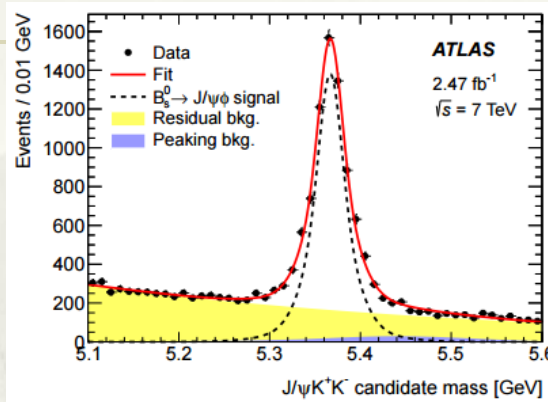


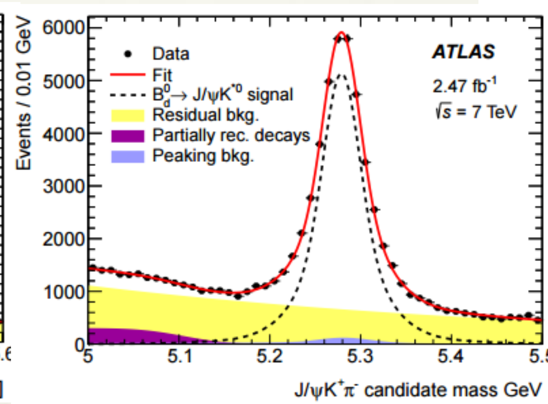
CMS
Phys. Rev. D 84 (2011) 052008
7 TeV, 40 pb^{-1},
8 GeV<p^T<50 GeV
|y|< 2.4

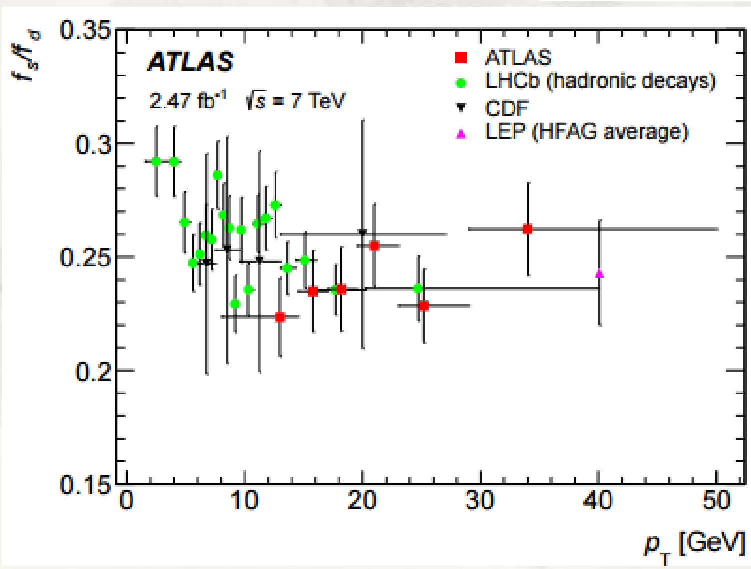
B^0, B_s production

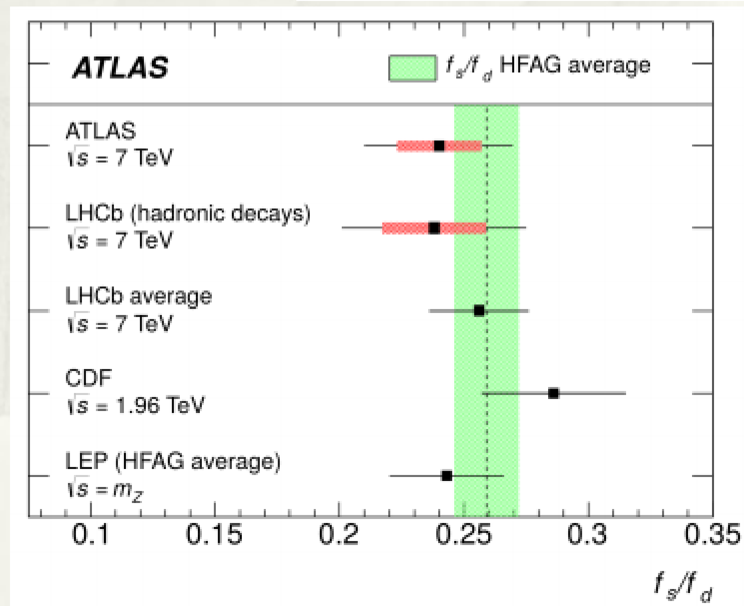
ATLAS
Submttted to Phys. Rev. Lett.
arXiv:1507.08925

$B^0 \to J/\psi K^{0*} \to \mu^+\mu^- K^+\pi^-$
$B_s \to J/\psi \varphi \to \mu^+\mu^- K^+K^-$









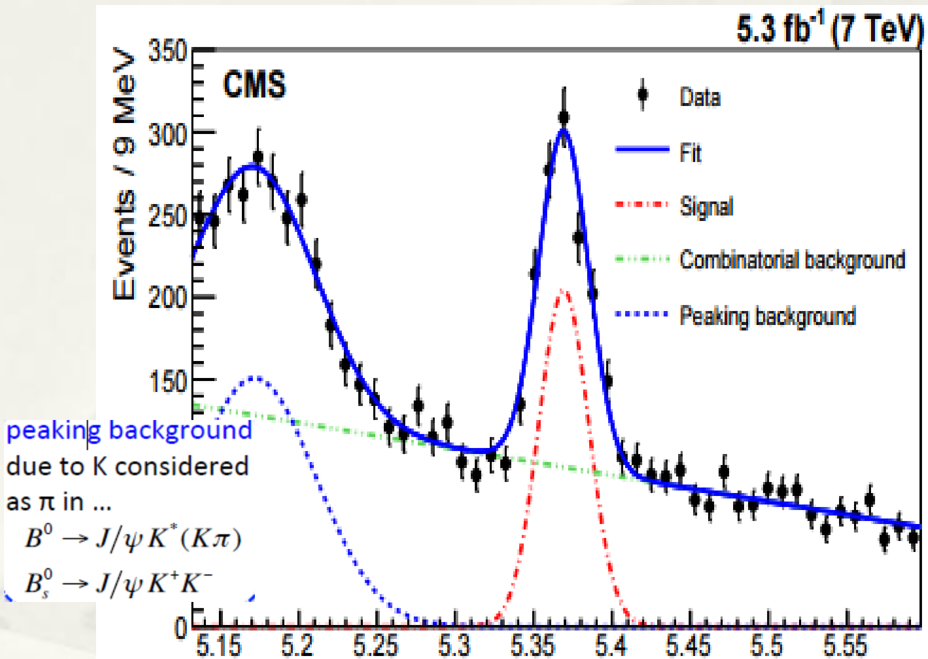
Ratio of b-quark fragmentation fractions

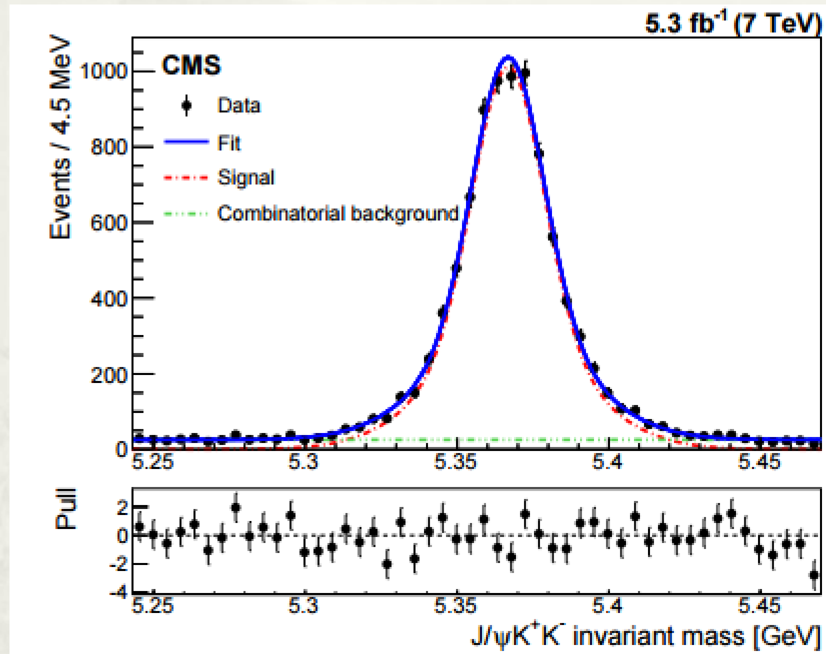
$$\frac{f_s}{f_d}\frac{\mathcal{B}(B_s^0 \to J/\psi\phi)}{\mathcal{B}(B_d^0 \to J/\psi K^{*0})} = 0.199 \pm 0.004(\text{stat}) \pm 0.010(\text{sys}).$$

$B^0_s \to J/\psi\ f^0(980),\ \ J/\psi\phi$

CMS

Submttted to Phys. Lett. B,   arXiv:1501.06089





$$R(f^0/\phi)\quad \frac{\mathcal{B}(B^0_s \to J/\psi\, f_0)\mathcal{B}(f_0 \to \pi^+\pi^-)}{\mathcal{B}(B^0_s \to J/\psi\, \phi)\mathcal{B}(\phi \to K^+K^-)} = 0.140 \pm 0.013\,(\text{stat}) \pm 0.018\,(\text{syst}).$$

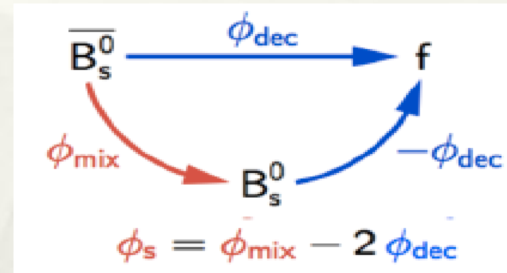
The result is consistent with the theoretical prediction of about 0.2

PRD 79 (2009) 074024

$B_s \to J/\psi\phi$

'golden' mode to explore CP violation,
flavor non-specific, experimentally clean final state

CPV arises in interference between direct decay and decay after oscillation

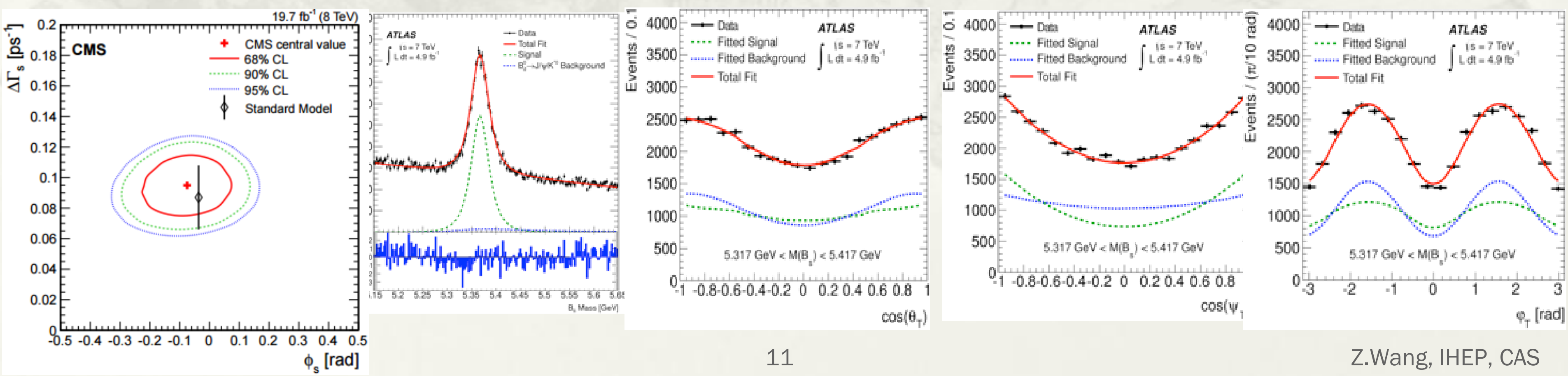


- Precise theoretical prediction of CPV phase φ_S within SM: $\varphi_S(SM) \sim -2\beta_S = -0.036 \pm 0.002$ rad
- Sensitive to new physics effects

$$\phi_s = \phi_s^{SM} + \phi_s^{NP}$$

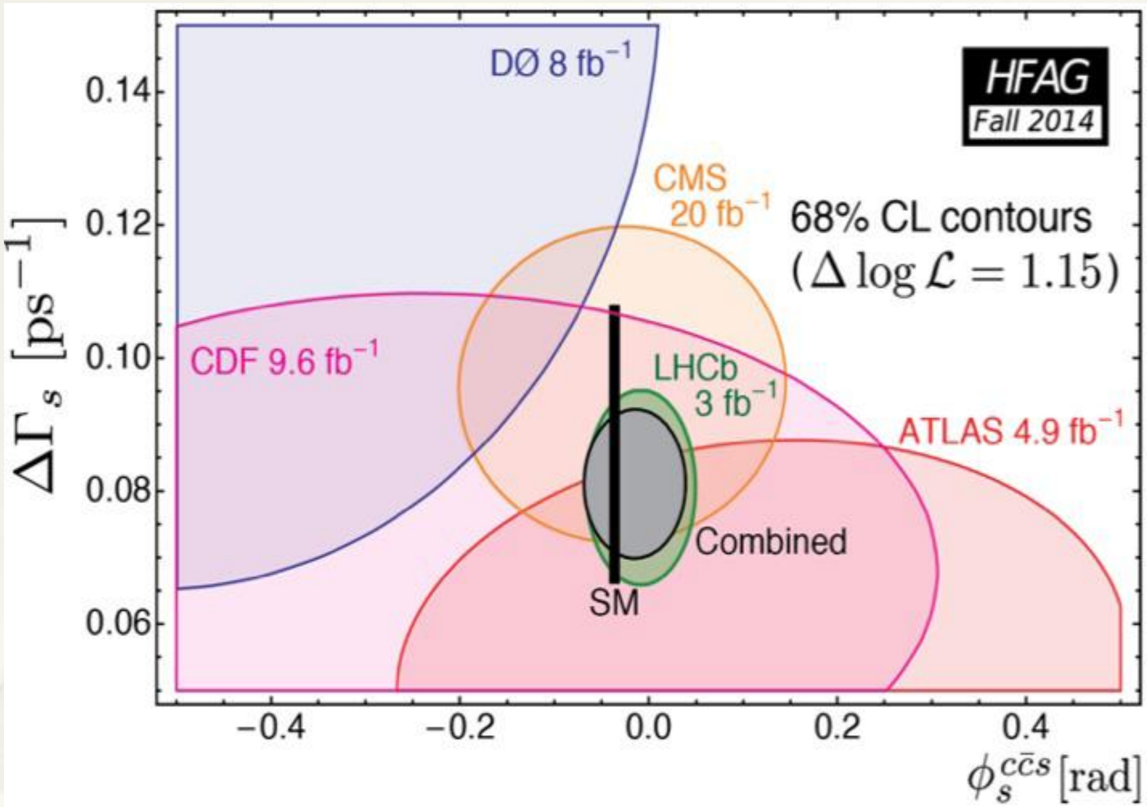
$$\frac{d^4\Gamma(B_s(t))}{d\Theta dt} = X(\Theta, \alpha, t) = \sum_{i=1}^{10} O_i(\alpha, t).g_i(\Theta)$$

$$O_i(\alpha, t) = N_i e^{-\Gamma_s t}\left[a_i \cosh(\frac{1}{2}\Delta\Gamma_s t) + b_i \sinh(\frac{1}{2}\Delta\Gamma_s t) + c_i \cos(\Delta m_s t) + d_i \sin(\Delta m_s t)\right]$$



Z.Wang, IHEP, CAS

ϕ_s world summary



ATLAS: Phys. Rev. D 90 (2014)
CMS: Submitted to Phys. Lett. B, arXiv:1507.07527

LHCB: PRL 114, 041801

CP-violating weak phase φ_s
The decay width difference $\Delta\Gamma_s$

$\Delta\Gamma_S$ is confirmed to be non-zero.

These accurate measurements are in good agreement with SM predictions.

Experiment	$\Delta\Gamma_s$ (ps^{-1})	ϕ_s (rad)
ATLAS (4.9/fb)	0.053±0.021 ±0.010	0.12±0.25±0.05
CMS (20/fb)	0.095±0.013± 0.007	−0.075±0.097±0.031
LHCb (3/fb)	0.0805±0.0091±0.0032	-0.058±0.049±0.006

$B_s \to J/\psi\Phi$

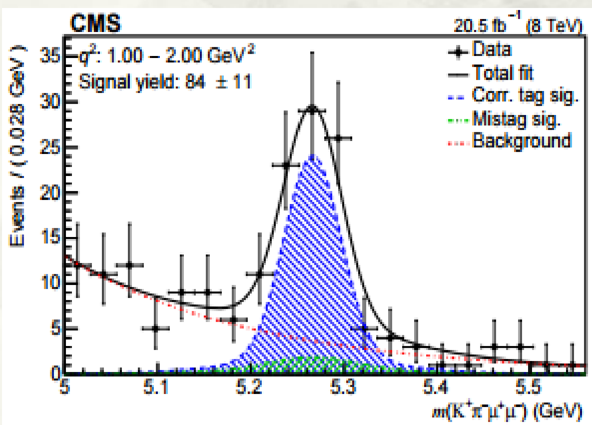
$B_s \to J/\psi KK,\ J/\psi\pi\pi,\ \Phi\Phi$

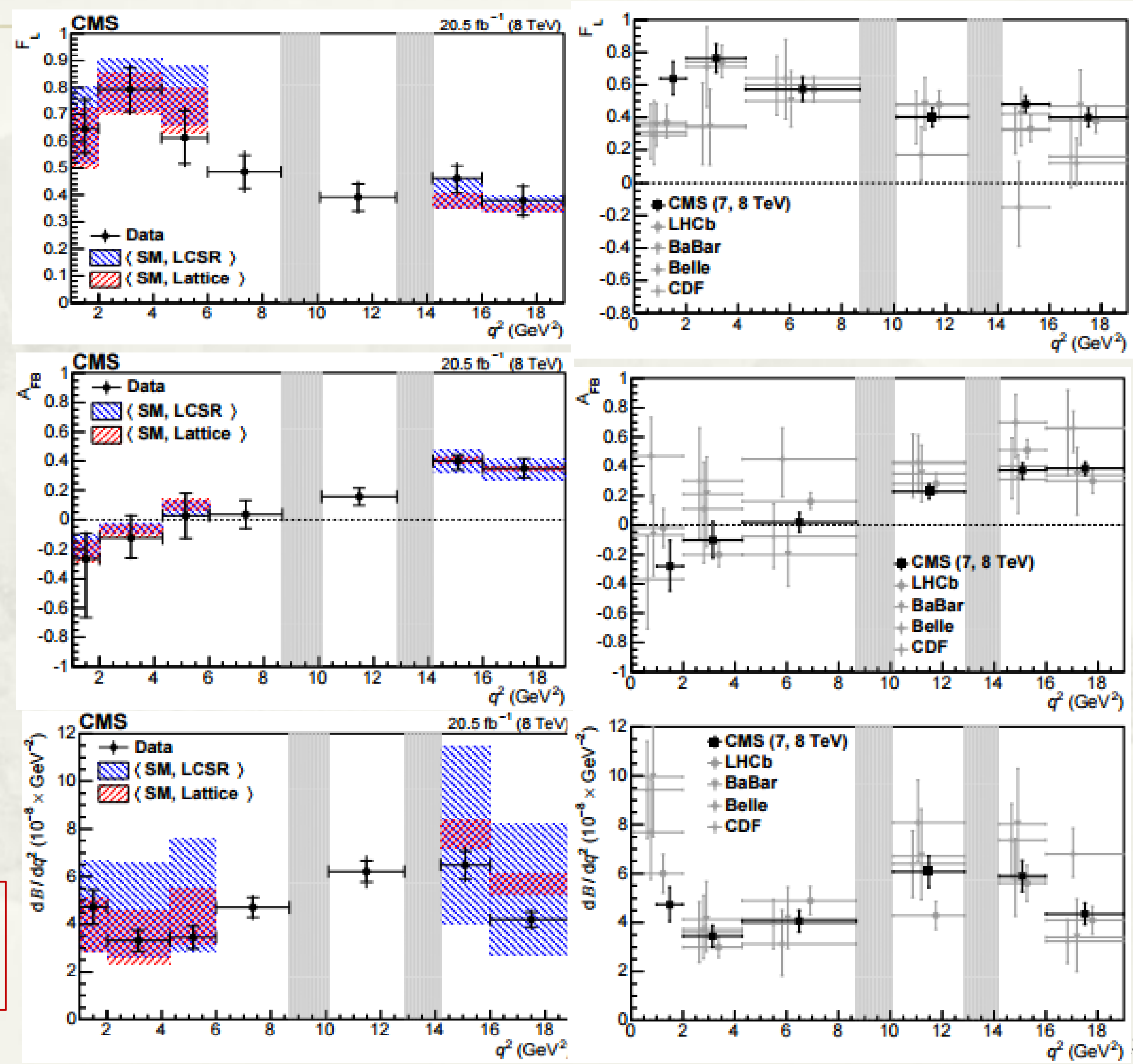
Angular analysis of $B^0 \to K^{0*} \mu^+\mu^-$

CMS

Submtted to Phys. Lett. B
arXiv:1507.08126, 8 TeV, 20.5 fb^{-1}

A_{FB}: forward-backward asymmetry of muons,
F_L: K^{*0} longitudinal polarization fraction,
dB/dq^2: differential branching fraction (as a function of the di-μ inv. mass squared)





In good agreement with standard model predictions

Peaking Structures in $B^{\pm} \to J/\psi\phi K^{\pm}$

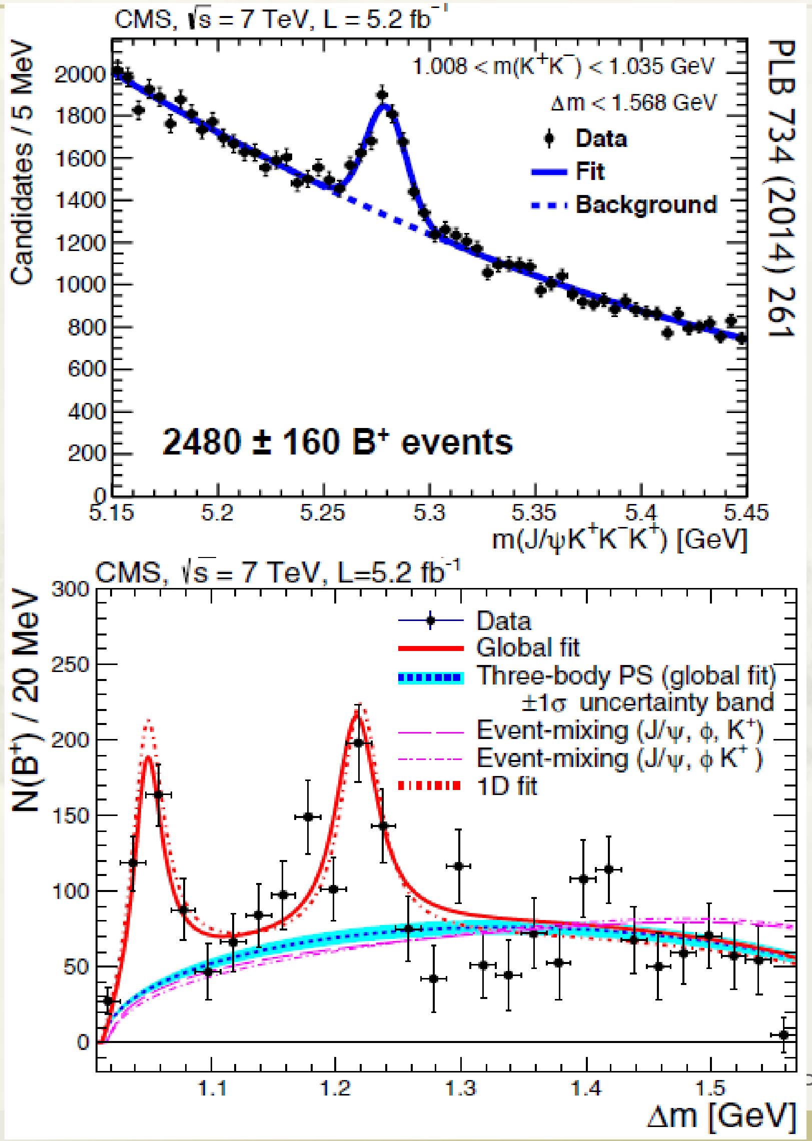
CMS: PLB 734 (2014) 261

$B^{\pm} \to J/\psi + \phi + K^{\pm}$, $\phi \to K^+K^-$

2 peaking structures in $\Delta m = m(\mu^+\mu^- K^+K^-) - m(\mu^+\mu^-)$ spectrum:

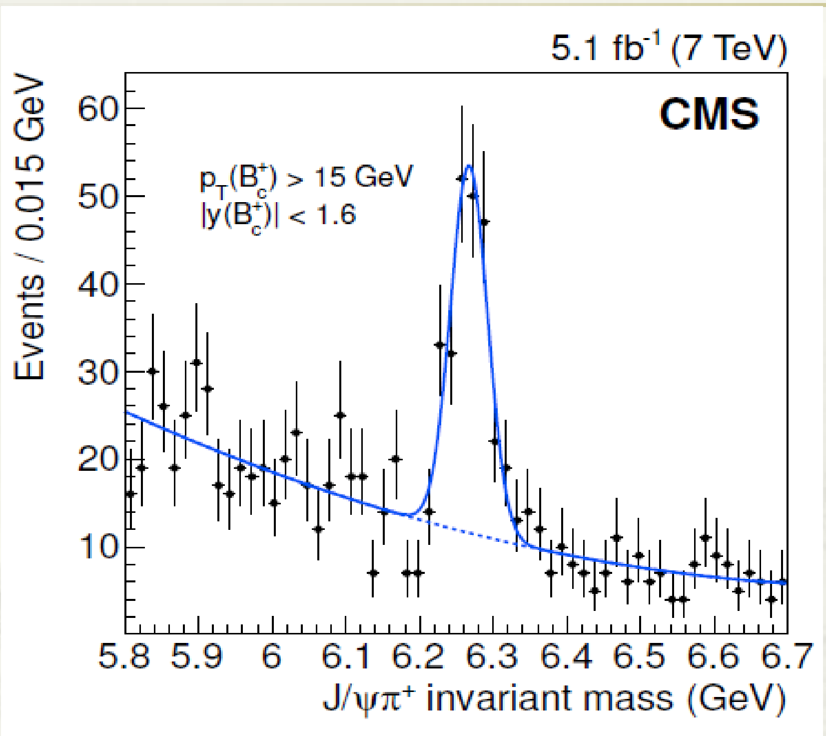
$m_1 = 4148.0 \pm 2.4$ (stat.) ± 6.3 (syst.) MeV
$\Gamma_1 = 28^{+15}_{-11}$ (stat.) ± 19 (syst.) MeV
Significance > 5σ Consistent with Y(4140) reported by CDF

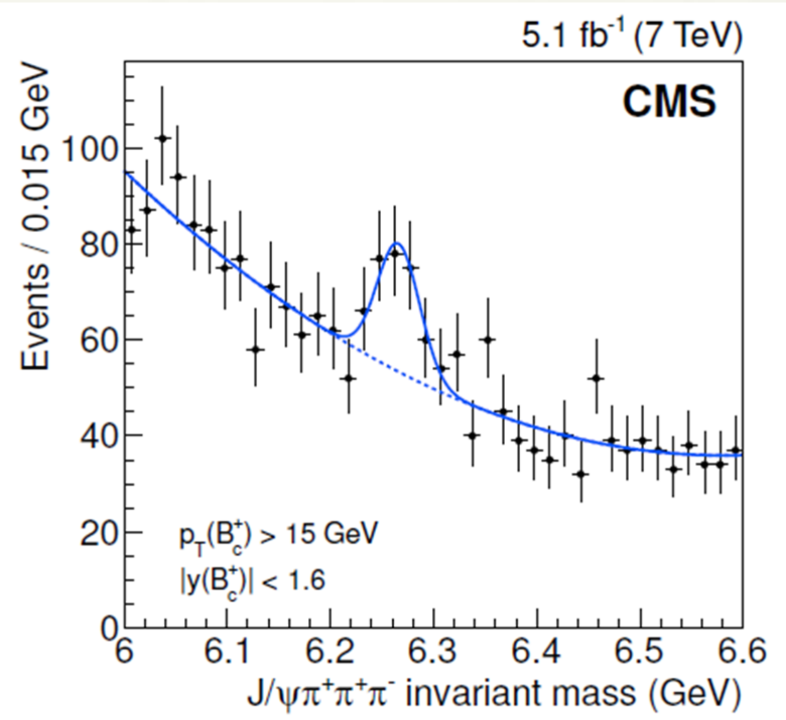
$m_2 = 4313.8 \pm 5.3$ (stat.) ± 7.3 (syst.) MeV
$\Gamma_2 = 38^{+30}_{-15}$ (stat.) ± 16 (syst.) MeV



B_c production

CMS JHEP **1501 (2015) 063**



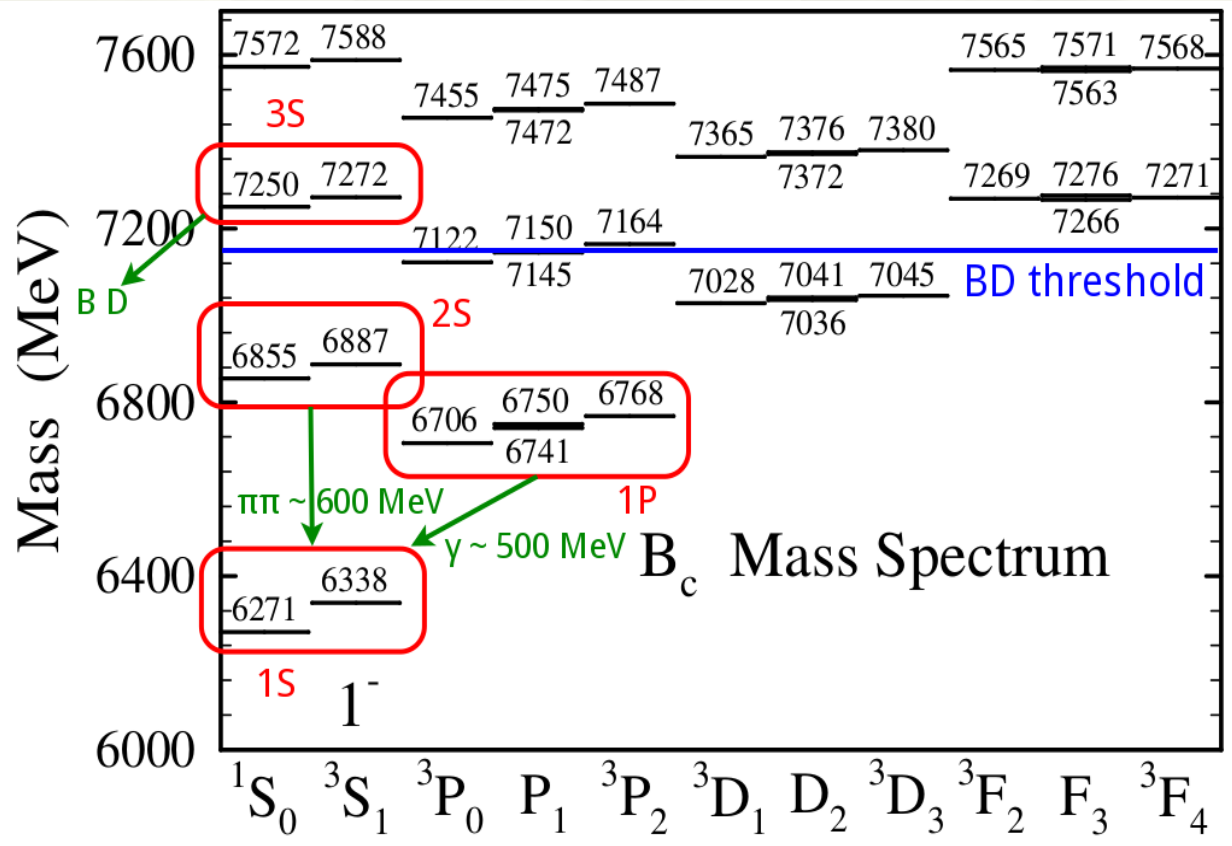


$$R_{c/u} = \frac{\sigma(B_c^+)\times Br(B_c^+ \to J/\psi\pi^+)}{\sigma(B^+)\times Br(B^+ \to J/\psi K^+)} = \left[0.48 \pm 0.05(stat) \pm 0.03(syst) \pm 0.05(\tau_{B_c})\right]\%$$

$$R_{B_c} = \frac{Br(B_c^+ \to J/\psi\pi^+\pi^+\pi^-)}{Br(B_c^+ \to J/\psi\pi^+)} = 2.55 \pm 0.80(stat) \pm 0.33(syst)^{+0.04}_{-0.01}(\tau_{B_c})$$

Excited B_c search

- No excited states of B^+_c reported previously.
- The spectrum and properties of B^+_c family are predicted by non-relativistic potential models, perturbative QCD and lattice calculations.



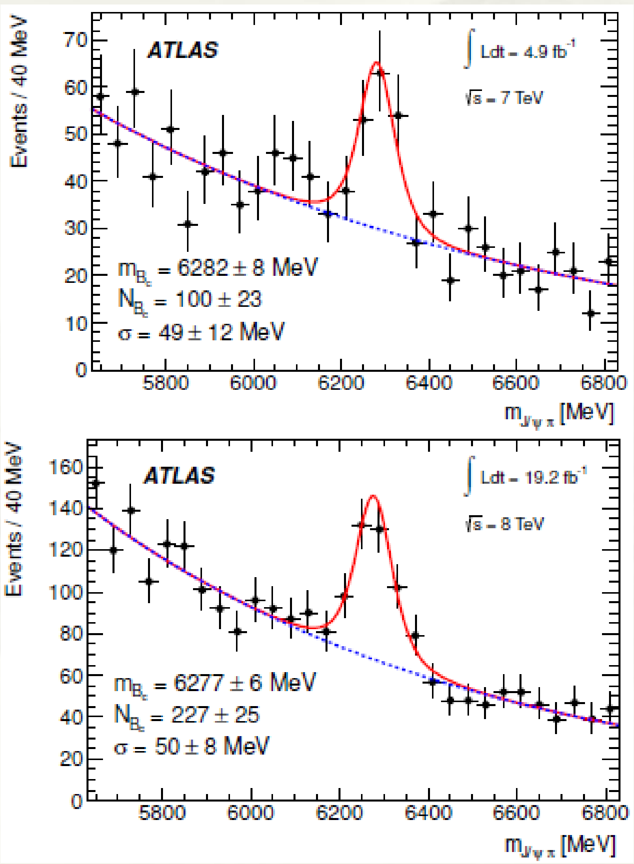
Phys. Rev. D 70 (2004) 054017

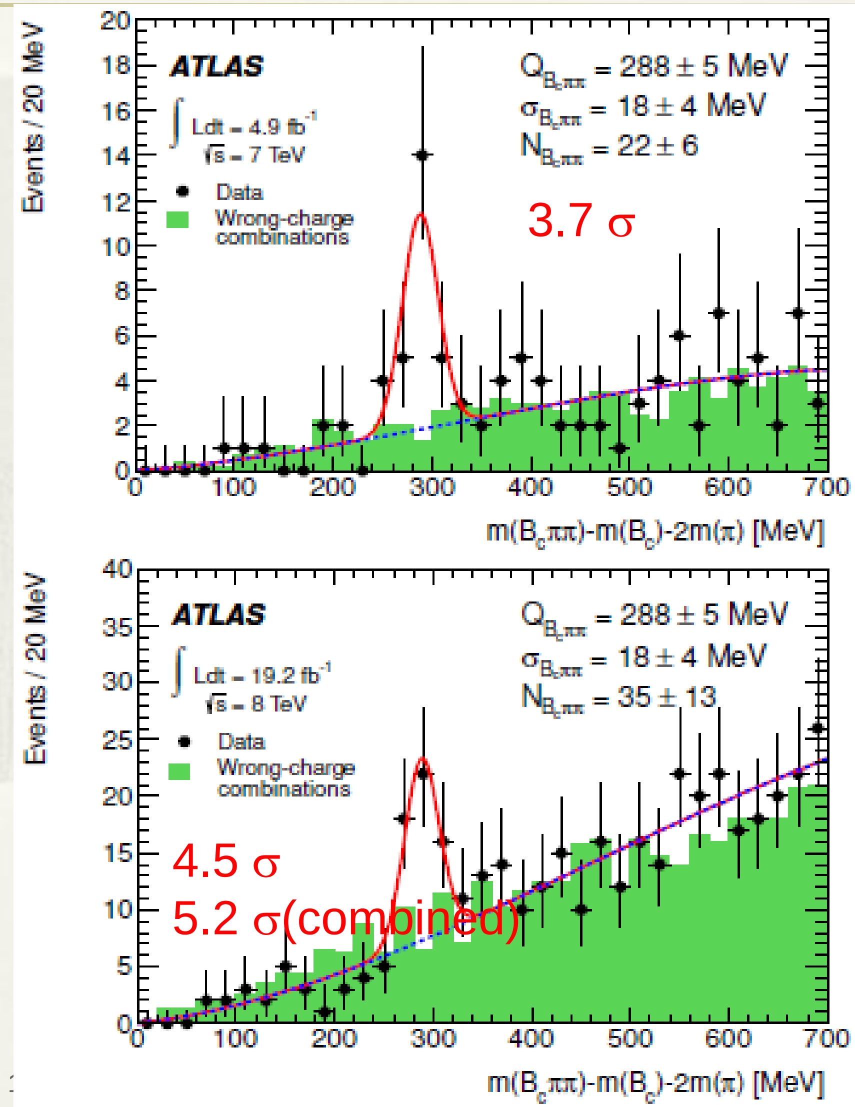
$B_c(2S)$ observation

ATLAS Phys. Rev. Lett. 113 (2014) 21, 212004

$$B_c^+(2S) \to B_c^+(1S)\pi^+\pi^-$$

$$Q_{B_c^+\pi\pi} = m(B_c^+\pi^+\pi^-) - m(B_c^+) - 2m(\pi^+)$$





Q = 288.3±3:5 (stat.)±4.1 (syst.) MeV

M = 6842 ± 4 (stat.) ± 5 (syst.) MeV,

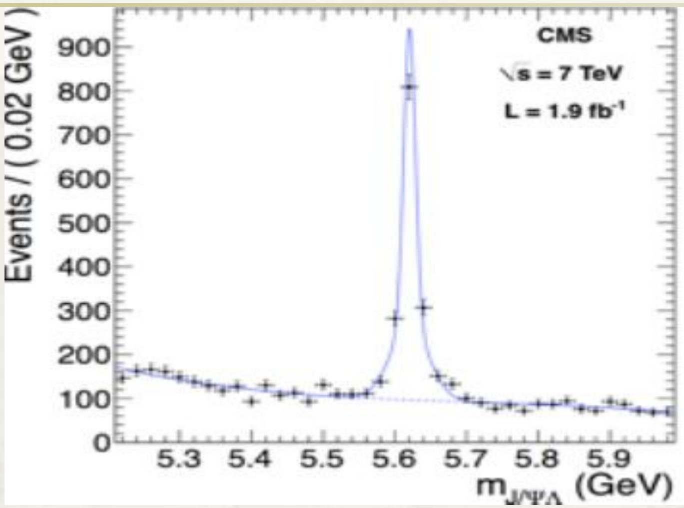
Λ_b production

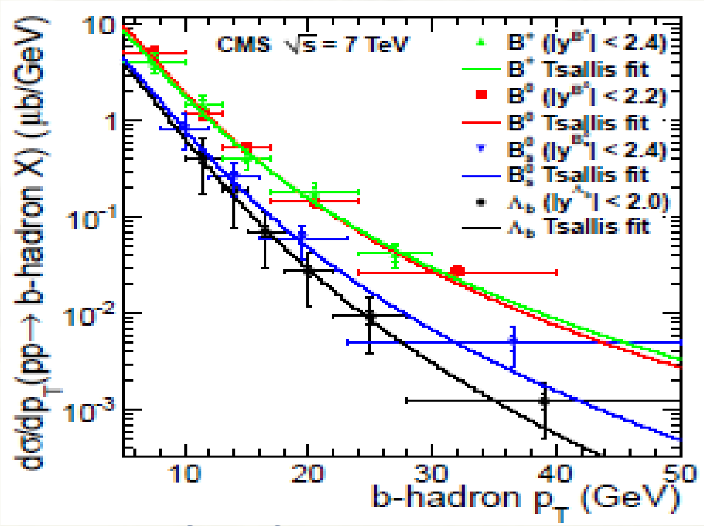
CMS Phys. Lett. B 714 (2012) 136   7 TeV, 1.9 fb^{-1}

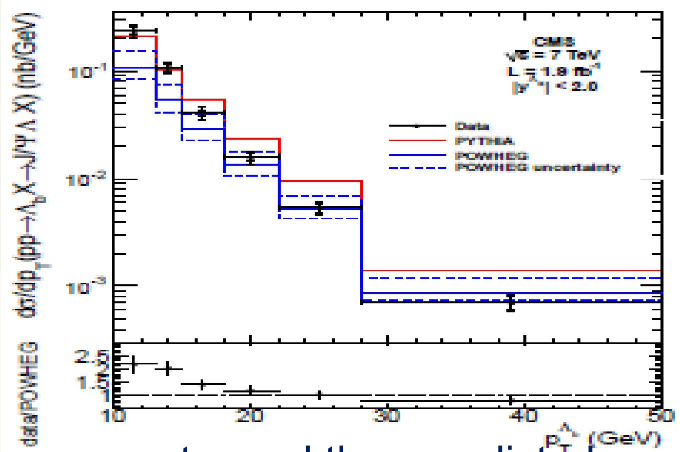
explore the baryon decay
$\Lambda_b \to J/\psi(\mu\mu)\Lambda^0(p\pi)$

- measure Λ_b properties
- production cross section

$\sigma = 1.16 \pm 0.06 \pm 0.12$ nb
(7 TeV, p_T>10 GeV, |y|<2)







p_T distribution falls faster than measured *b*-mesons spectra and than predicted spectra from NLO MC POWHEG and leading-order MC PYTHYA.

Cross-section ratio $\sigma(\overline{\Lambda}_b^0)/\sigma(\Lambda_b^0)$ consistent with 1 and constant vs p_T, and rapidity |y|.

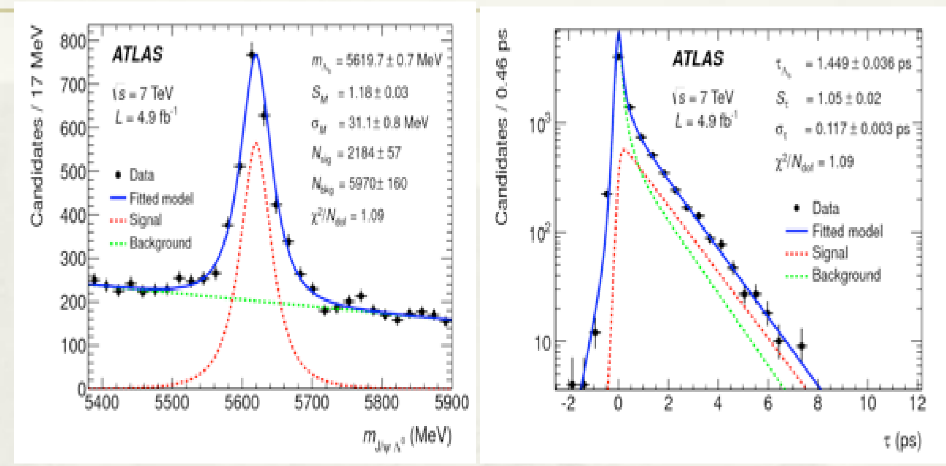
Λ_b production

- **mass and lifetime**

ATLAS $m = 5619.7 \pm 0.7 \pm 1.1$ MeV

$\tau = 1.449 \pm 0.036 \pm 0.017$ ps

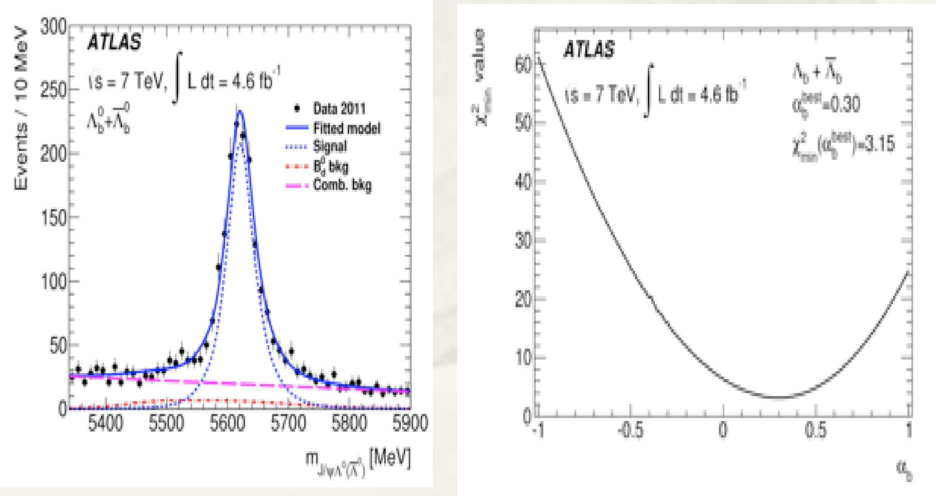
CMS $\tau = 1.503 \pm 0.052 \pm 0.031$ ps



ATLAS: Phys. Rev. D 87, 032002 (2013)

- **Parity violating asymmetry parameter α_b and the helicity amplitudes**

ATLAS $a_b = 0 .30 \pm 0.16 \pm 0.06$
(assume CP conservation)



ATLAS: Phys. Rev. D 89, 092009 (2014)

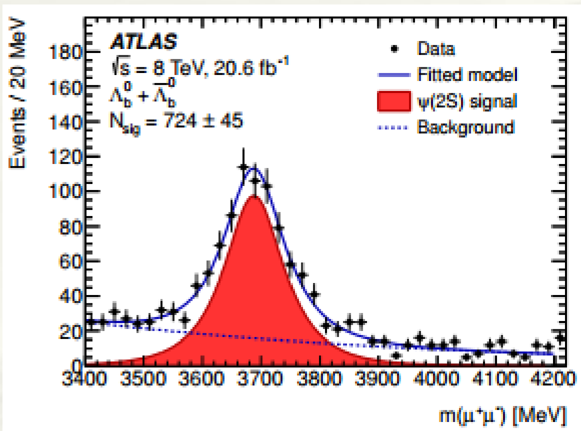
- Perturbative quantum chromodynamics (pQCD): α_b = -0.17 to -0.14 (PRD 65, 074030 (2002))
- Heavy quark effective theory (HQET): α_b = 0.78 (PLB 614, 165 (2005))

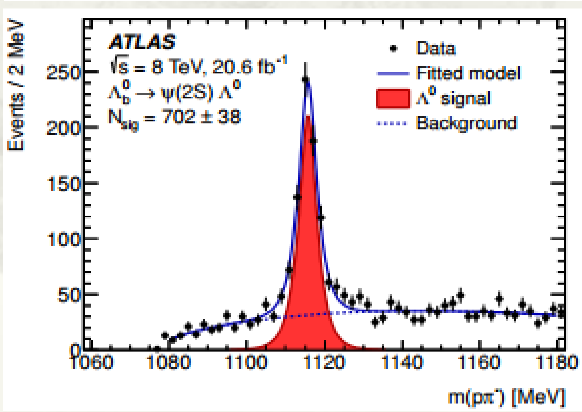
$\Lambda_b : \psi(2S)+\Lambda^0$

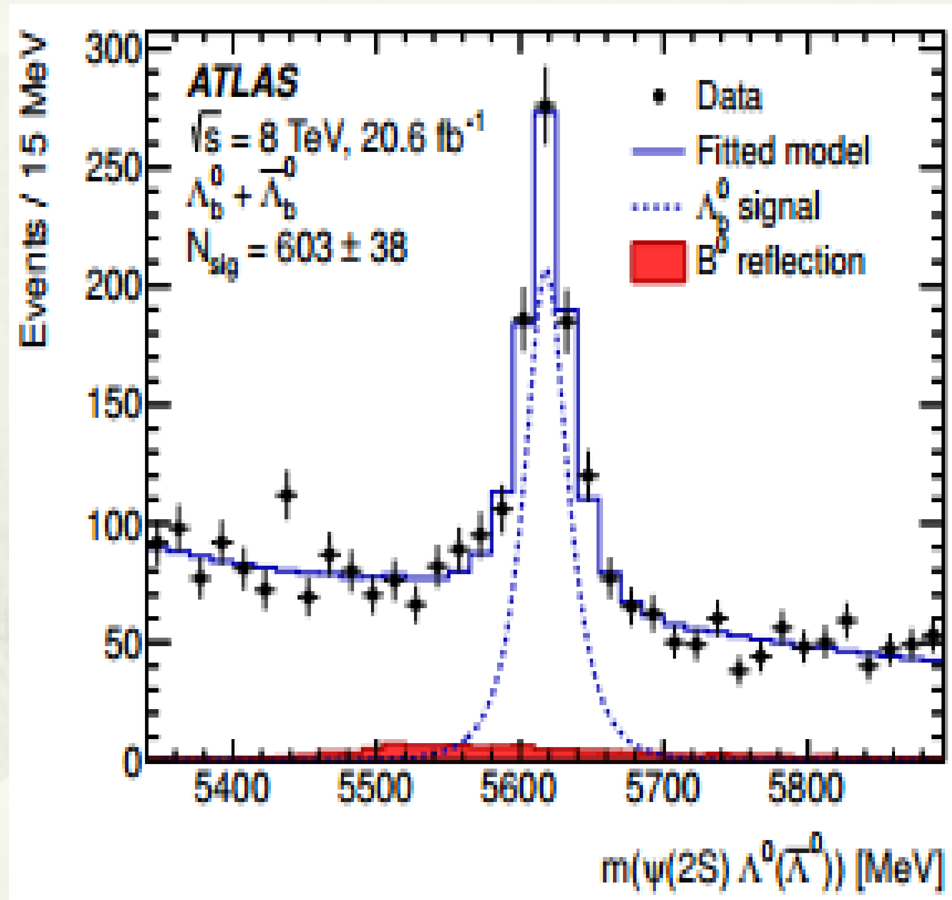
ATLAS

Submttted to Phys. Lett. B

arXiv:1507.08202







$$\frac{\Gamma(\Lambda_b^0 \to \psi(2S)\Lambda^0)}{\Gamma(\Lambda_b^0 \to J/\psi\,\Lambda^0)} = 0.501 \pm 0.033(\text{stat}) \pm 0.016(\text{syst}) \pm 0.011(\mathcal{B}),$$

Ξ_b^{*0} observation

CMS: PRL 108, 252002 (2012)

$\Xi_b^{*0} \to \Xi_b^- \pi^+$
$\to \Xi_c^- J/\psi\, \pi^+$
$\to \Lambda^0 \pi^- J/\psi\, \pi^+$
$\to \mu^+\mu^- p^+ \pi^-\pi^-\pi^+$

Complex cascade decay topology

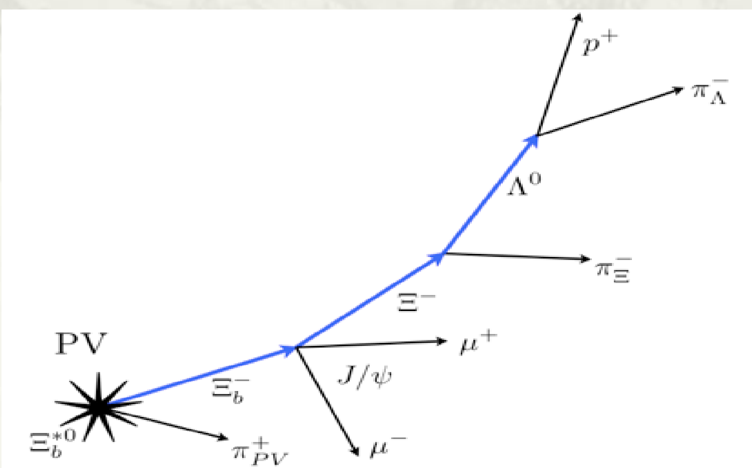
- 4 displaced vertices
- 6 final state tracks

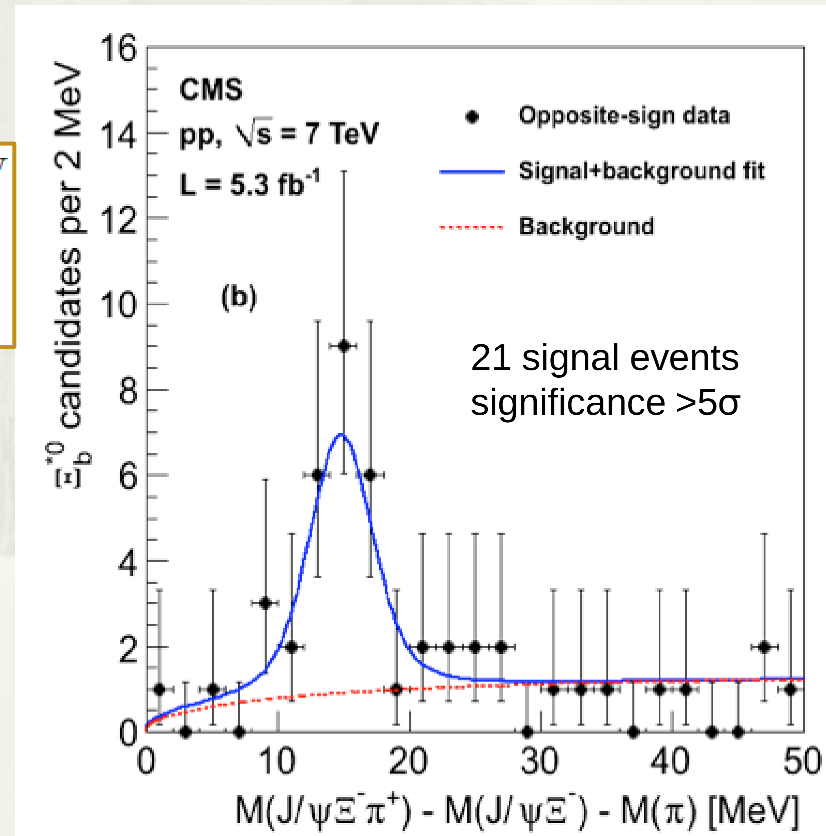
- CMS observes new baryon state: Ξ_b^{*0}
- note: LHCb just reported two charged additions to the Ξ_b family: $\Xi_b^{'-}$, Ξ_b^{*-}

$$\delta m = m(\Xi_b^{*0}) - m(\Xi_b^-) - m_{\pi^+} = 14.84 \pm 0.74 \pm 0.28 \text{ MeV}$$

$$m(\Xi_b^{*0}) = 5945.0 \pm 0.7 \pm 0.3 \pm 2.7(\text{PDG}) \text{ MeV}$$

$$\Gamma(\Xi_b^{*0}) = 2.1 \pm 0.74 \text{ MeV}$$

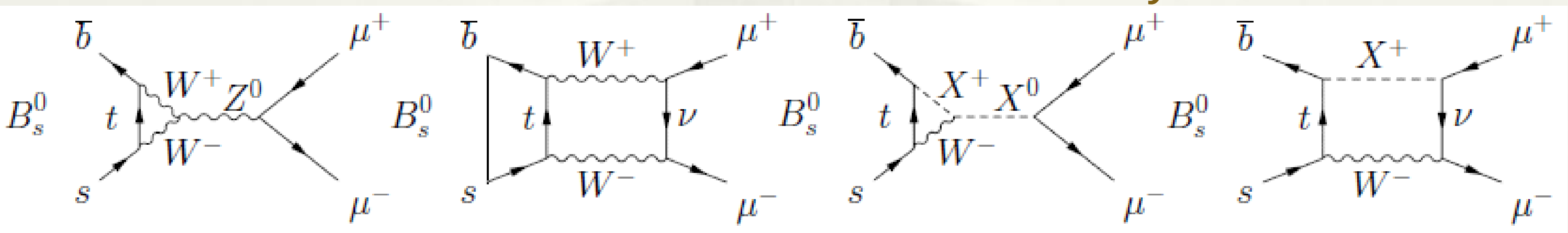




21 signal events
significance >5σ

$B_{s,d} \to \mu\mu$ search: motivation

Standard model   Beyond SM



Highly suppressed decay in SM

Forbidden ar tree level →FCNC transitions only possible through penguin or box diagram.
Cabibbo $|V_{td}| < |V_{ts}|$ and helicity suppressed

SM predictions

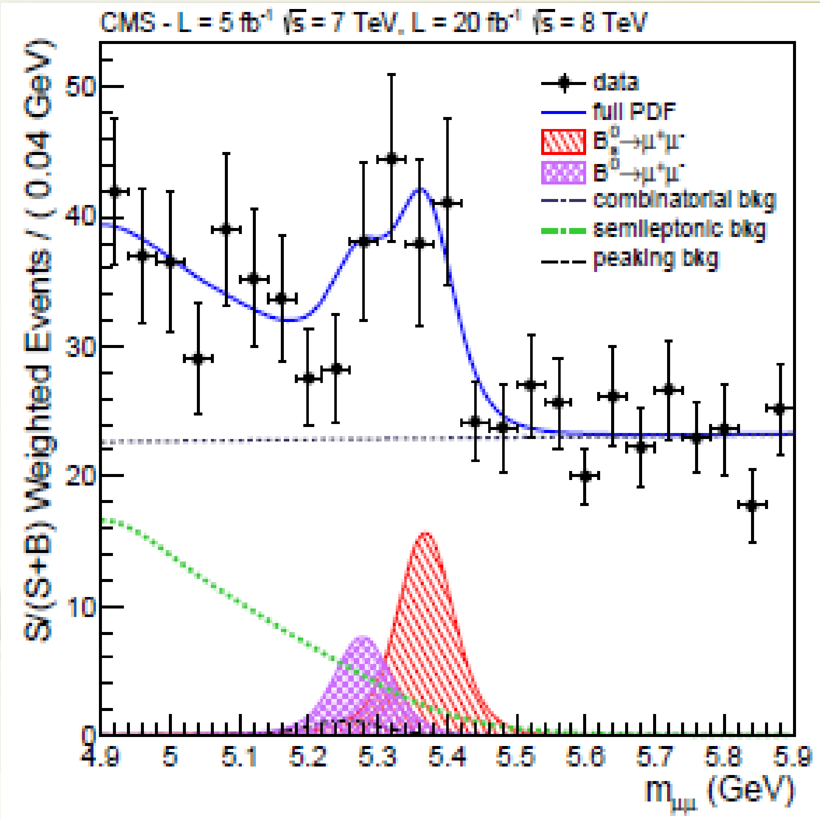
$BR(B^0 \to \mu^+\mu^-) = (1.06 \pm 0.09) \times 10^{-10}$
$BR(B_s^0 \to \mu^+\mu^-) = (3.66 \pm 0.23) \times 10^{-9}$ (PRL112, 101801, 2014)

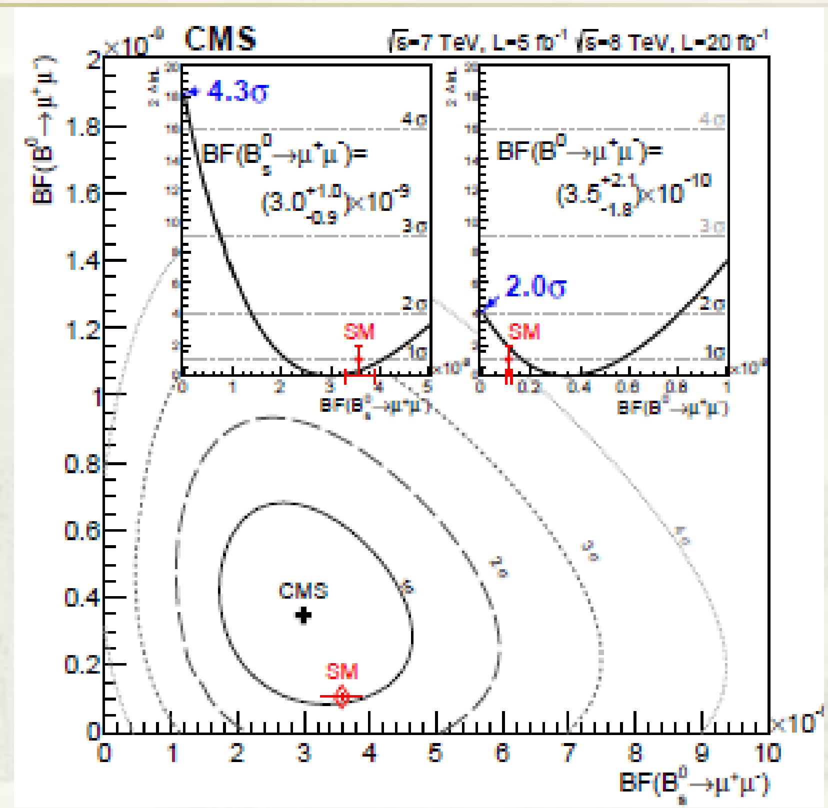
Sensitivity to NP

2HDM and $m(H^+)$ MSSM tan β
Leptoquarks 4^{th} generation top

$B_{s,d} \to \mu\mu$ search

CMS: PRL 111 (2013) 101804





$$\mathcal{B}(B_s \to \mu\mu) = (3.0^{+0.9}_{-0.8}(stat.)^{+0.6}_{-0.4}(syst.)) \cdot 10^{-9} \quad S=4.3\sigma \ (\text{Exp. } 4.8)$$

$$\mathcal{B}(B_d \to \mu\mu) < 1.1 \cdot 10^{-9} \ (95\% \text{ C.L.})$$

ATLAS: $BR(B^0_s \to \mu^+\mu^-) < 2.2(1.9) \times 10^{-8}$ at 95% (90%)
Physics Letters B 713 (2012) 387–407

$B_{s,d}$: CMS + LHCb

CMS+LHCb: Nature 522 (2015) 68

Data: 25 fb^{-1} (CMS) and 3 fb^{-1} (LHCb)

Selection: BDT with 20 categories, 12 CMS categories which depend on $\sqrt{s}$, detector region, and BDT ranges + 8 LHCb categories which depend on BDT ranges

Common parameters: hadronisation fraction $f_d = f_s$, $B(B^{\pm} \to J/\psi K^{\pm})$

$$\mathcal{B}(B_s \to \mu\mu) = (2.8^{+0.7}_{-0.6}) \cdot 10^{-9} \quad S=6.2\sigma \text{ (Exp: } 7.4\sigma)$$

$$\mathcal{B}(B_d \to \mu\mu) = (3.9^{+1.6}_{-1.4}) \cdot 10^{-10} \quad S=3.0\sigma \text{ (Exp: } 0.8\sigma)$$

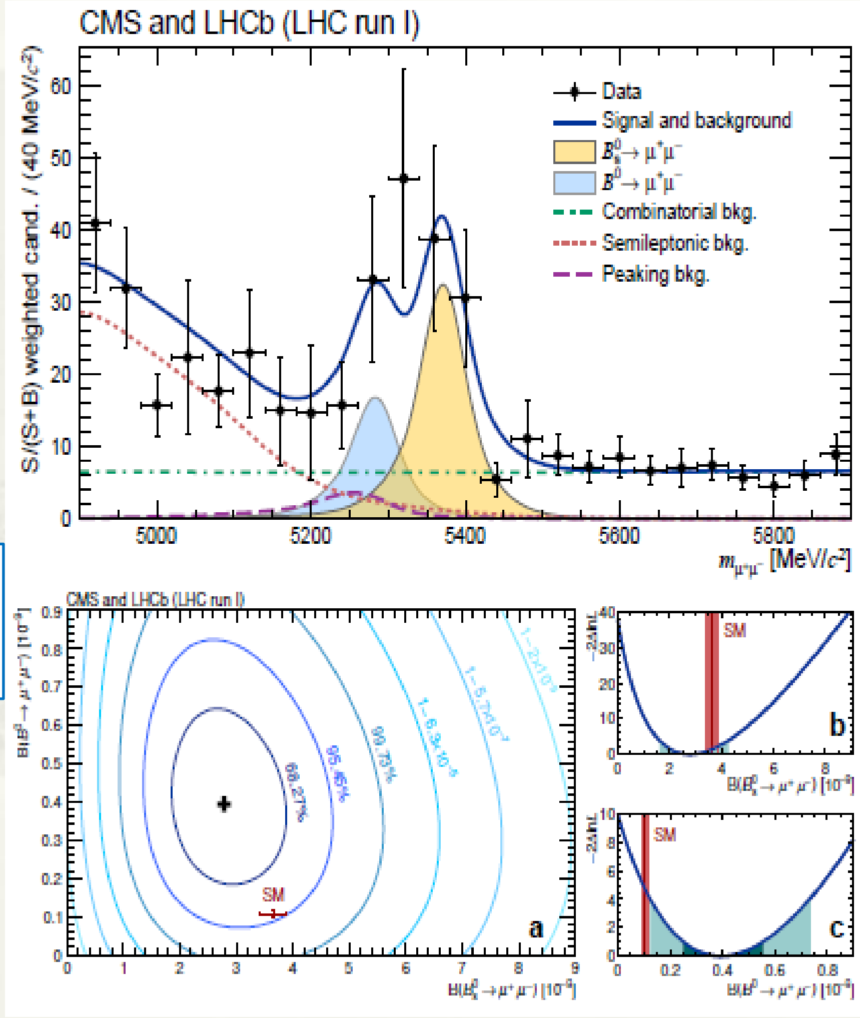
Measurement of the ratio

$R = BR(B^0 \to \mu^+\mu^-) / BR(B_s^0 \to \mu^+\mu^-)$

$= 0.14^{+0.08}_{-0.06}$

Compatible with the SM prediction

$R = 0.0295^{+0.0028}_{-0.0025}$ at the 2.3σ level



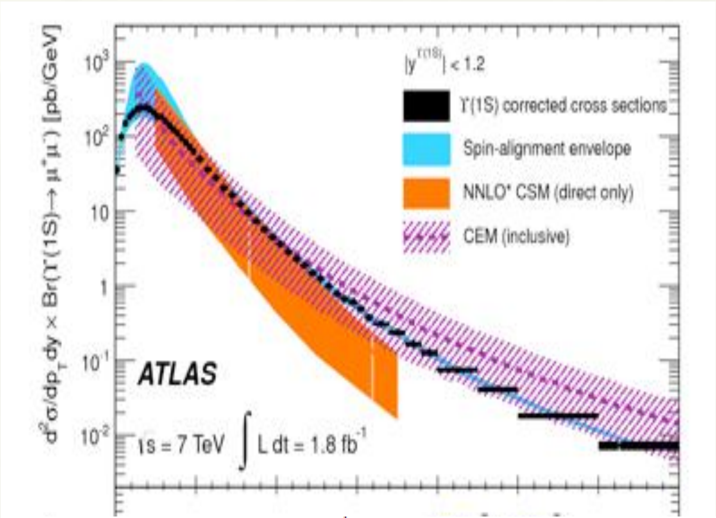
Confidence intervals

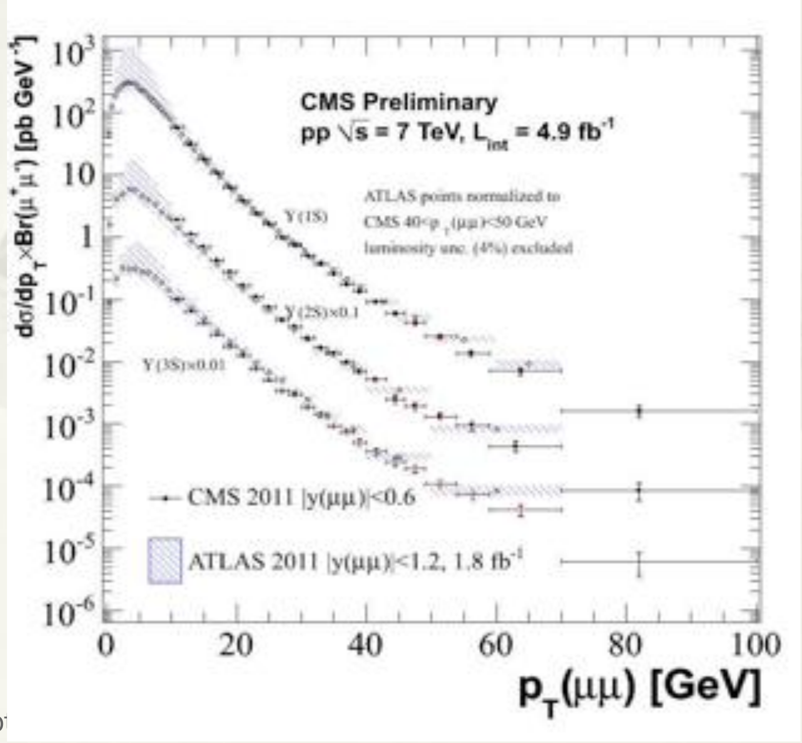
Υ(nS) cross section

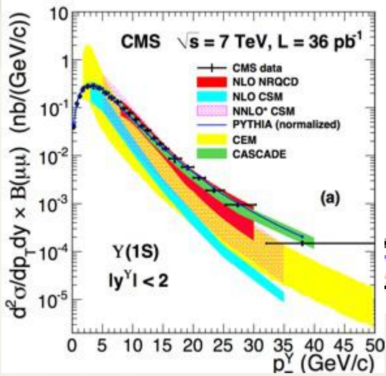
ATLAS: Phys. Rev. D 87, 052004 (2013); CMS: Phys. Lett. B 749 (2015) 14

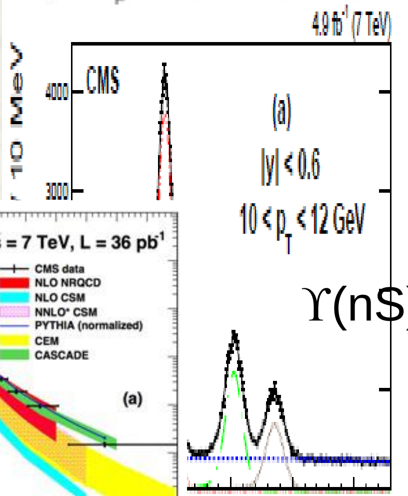
S-wave measurements for $0 < p_T < 100$ GeV

➢high-p_T reach allows to probe models with increasing precision
➢Tevatron and LHCb data limited to $p_T < 15$ GeV

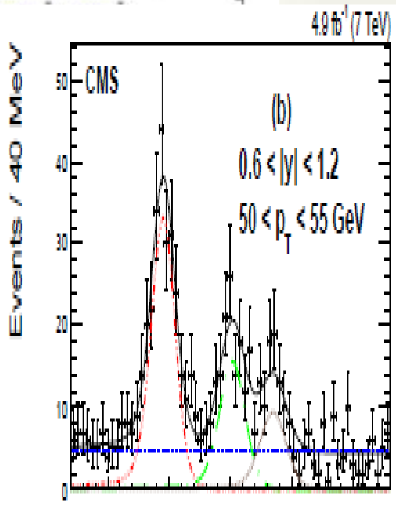








Υ(nS)



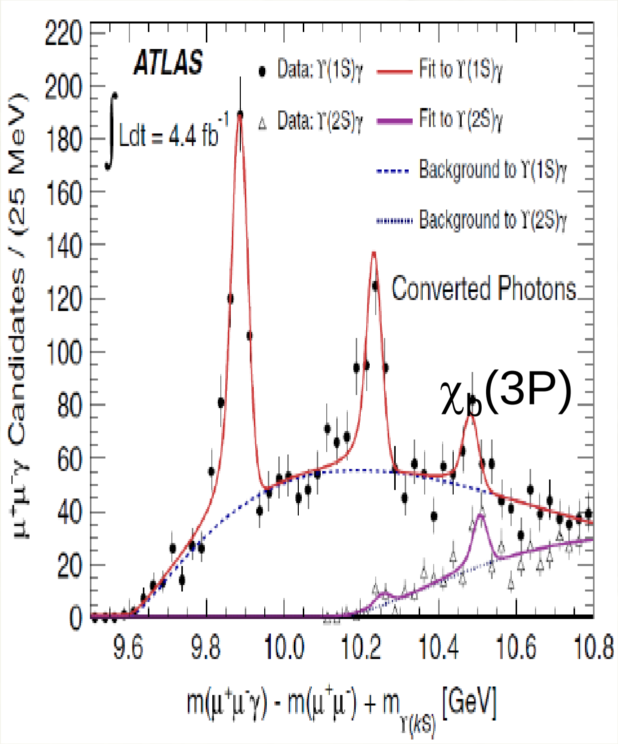
P-wave bottomonia

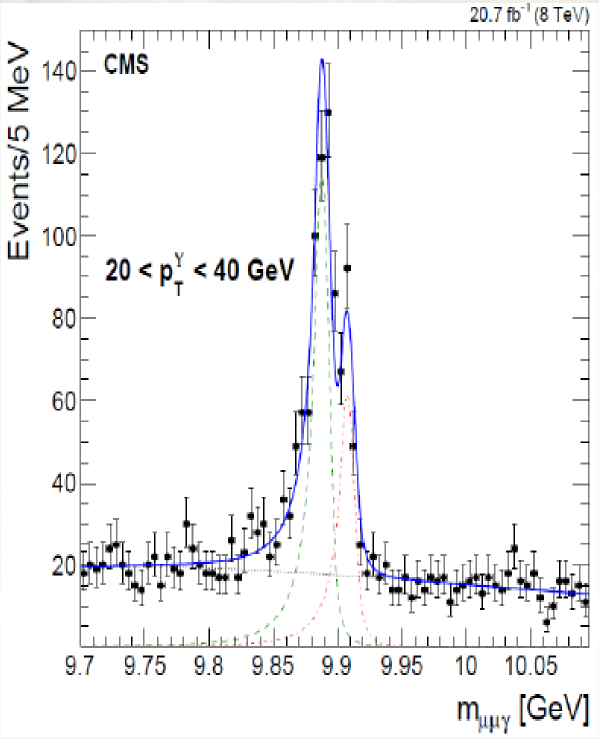
radiative decays $\chi_b \to \Upsilon(nS)\gamma$ are explored to reconstruct P-wave bottomonia.

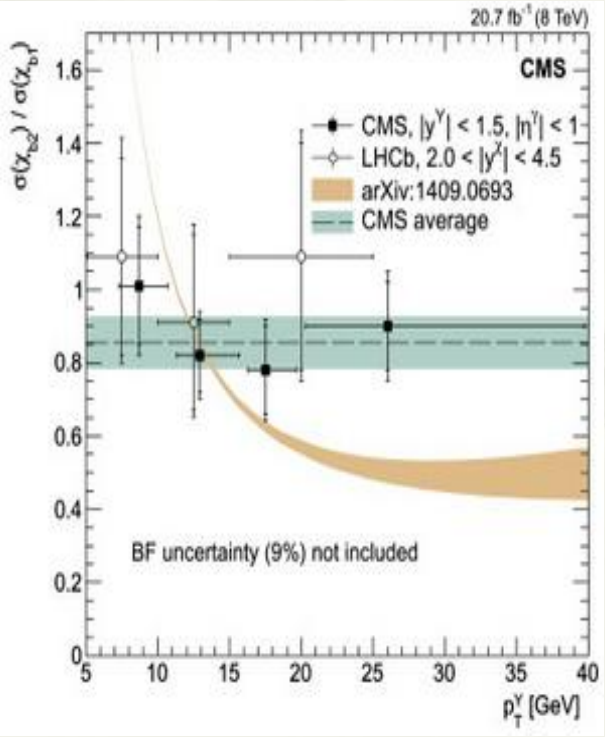
- Photons reconstructed by e^+e^- or detected in calorimeters

- χ_b (3P) first observed by ATLAS
- χ_{b2}(1P)/χ_{b1}(1P) production ratio measured

ATLAS: P.R.L 108 (2012) 152001
CMS: P.L.B 743 (2015) 383–402





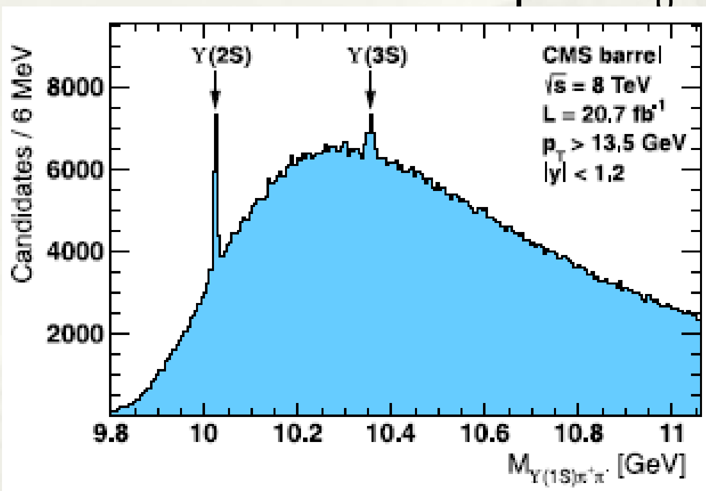


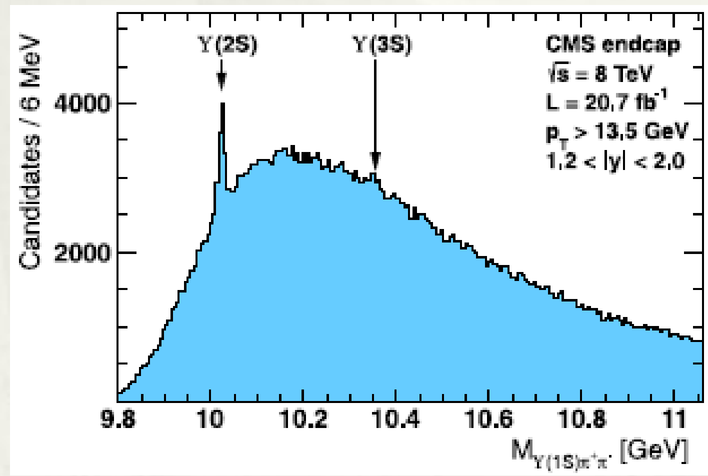
$\Upsilon(1S)\pi^+\pi^-$

CMS Phys. Lett. B 727 (2013) 57 (8 TeV, 20/fb)

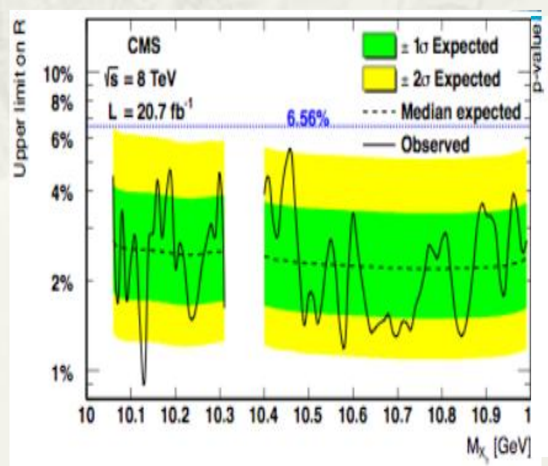
Exotic resonance X(3872) discovered in the final state $J/\psi\pi^+\pi^-$

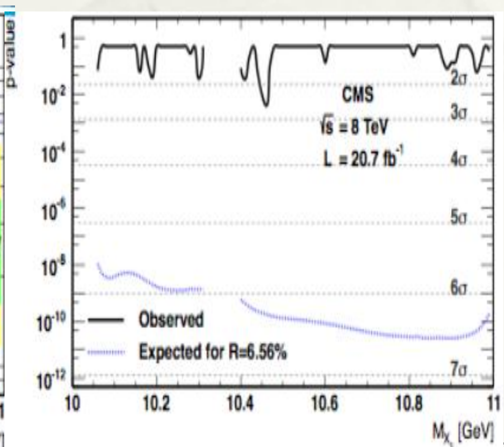
A bottomonium counterpart X_b may exist and decays into $\Upsilon(1S)\,\pi^+\pi^-$





$$R = \frac{N^{obs}_{X_b}}{N^{obs}_{\Upsilon(2S)}} \frac{\epsilon_{\Upsilon(2S)}}{\epsilon_{X_b}}$$

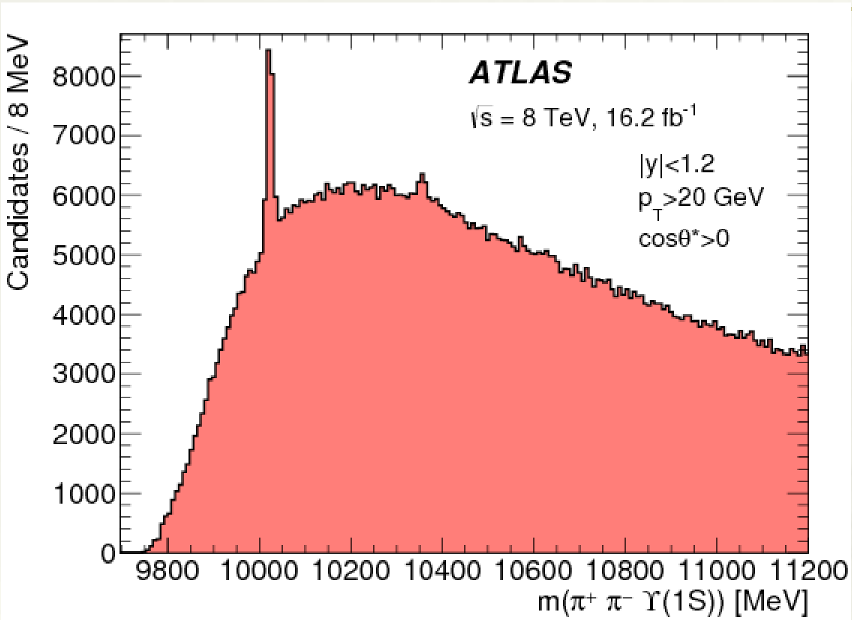


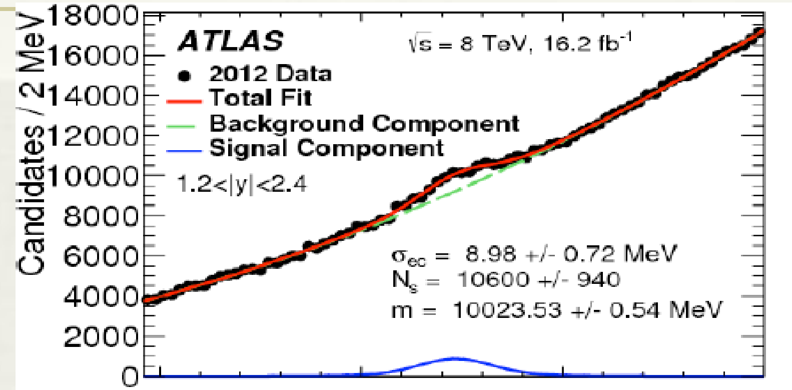


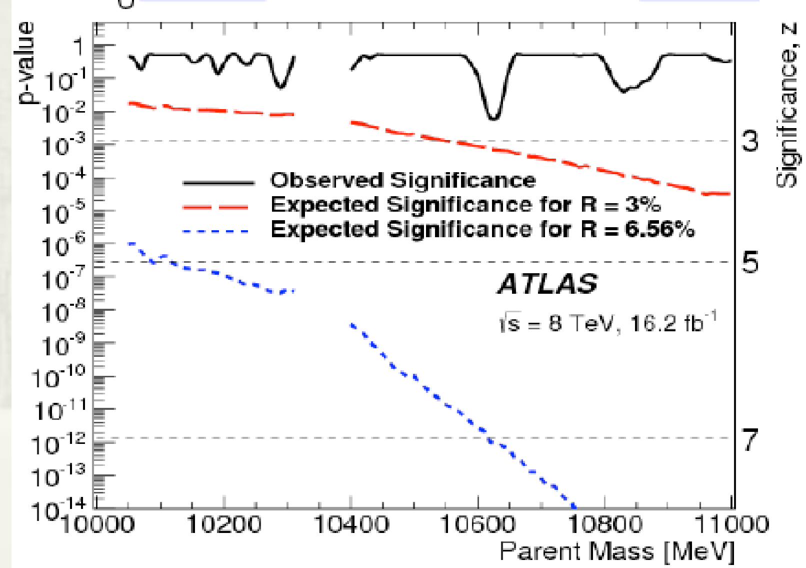
- No structure apart from $\Upsilon(2S)$ and $\Upsilon(3S)$
- No significant excess is observed
- At 95% CL, Upper limit on the cross sections*branching fractions ratio: 0.9 - 5.4 %

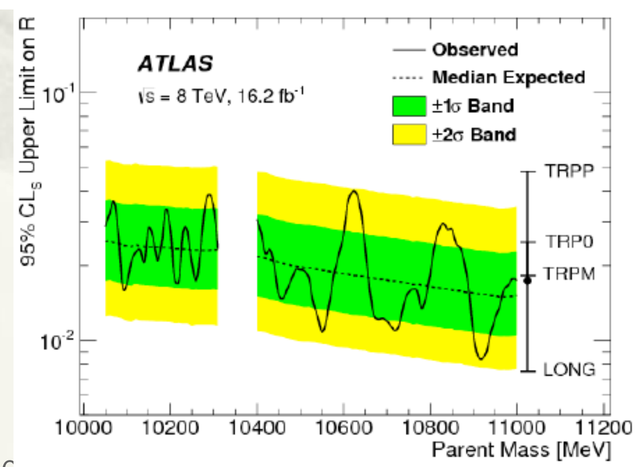
X_b @ATLAS

ATLAS: Phys. Lett. B 740 (2015) 199









No significant excess found, set upper limit.
95% CL upper limit on R: 0.8~4%

Summary

CMS and ATLAS collaborations extensively measured inclusive and exclusive productions with LHC run-I data. Gave significant contribution in the study of rare decays. Stringent test of the Standard Model prediction, Great effect on New Physics searches

Achievements include:

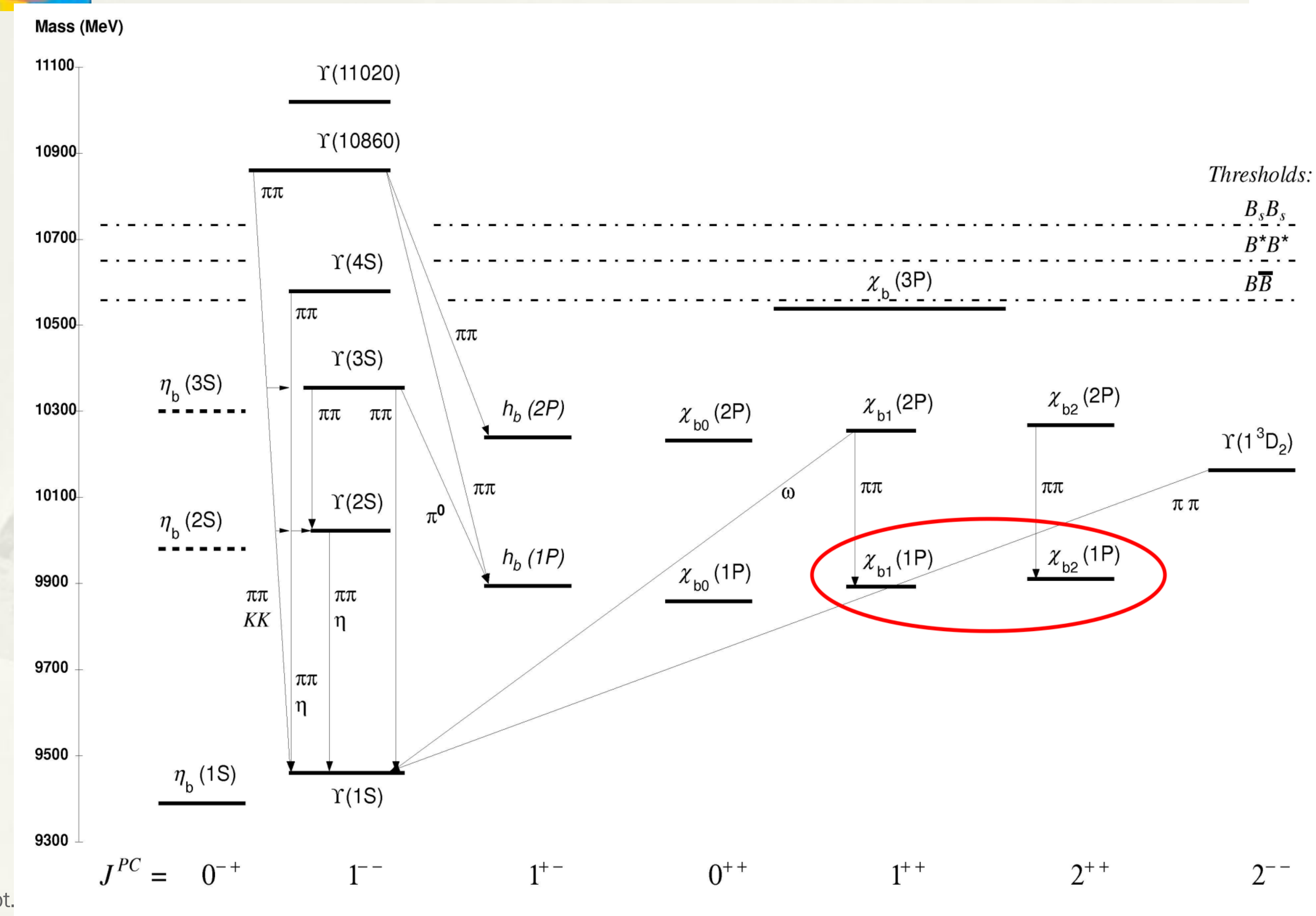
- Precision measurements of b hadron production and decay properties,
- Spectroscopy: observation of new meson and baryon states and decay modes,
- rare processes: observation of the long-sought $B_s \to \mu\mu$ decay.

higher energy, luminosity and pileup of coming LHC runs will bring both challenges and new possibilities to B physics studies

Thanks !

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

HF Physics talks in the parallel meeting.



Mass (MeV)
11100
10900
10700
10500
10300
10100
9900
9700
9500
9300
ϒ(11020)
ϒ(10860)
ϒ(4S)
ϒ(3S)
ϒ(2S)
ϒ(1S)
η_b (3S)
η_b (2S)
η_b (1S)
h_b (2P)
h_b (1P)
χ_b0 (2P)
χ_b0 (1P)
χ_b (3P)
χ_b1 (2P)
χ_b1 (1P)
χ_b2 (2P)
χ_b2 (1P)
ϒ(1 3D2)
ππ
KK
η
π0
ω
π π
Thresholds:
BsBs
B*B*
BB̄
J^PC = 0−+ 1−− 1+− 0++ 1++ 2++ 2−−

