b-hadron production and decays at the LHC: selected highlights

The pillars of our search for new physics: QCD at work

- ❑b-hadron production
- ❑Hadronic decays
- ❑Exotic final states

Highlights of a very extensive experimental program, apologies for nice results not covered here

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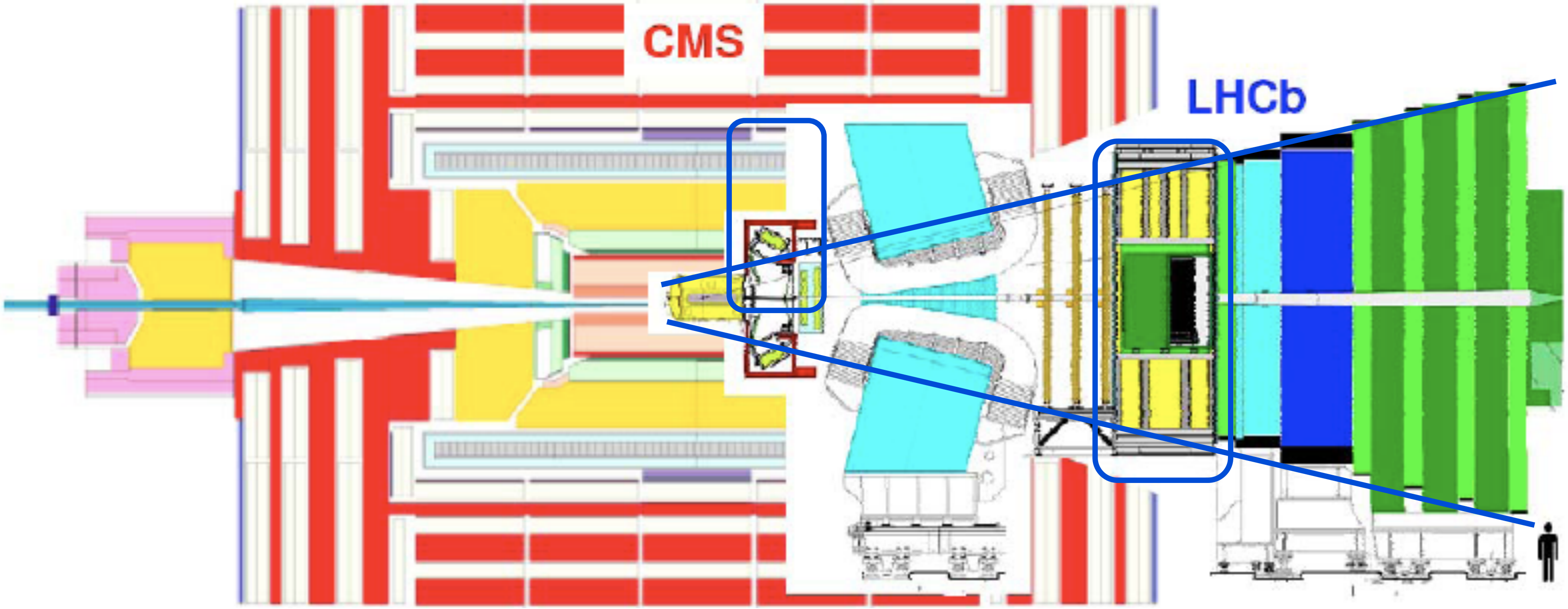
Starting a new era: the dawn of LHC

ATLAS and **CMS** are general purposed detectors, b-physics capabilities based on vertexing and good lepton ID.

Important new addition: LHCb first dedicated detector to pursue search for new physics in beauty and charm decays. Important LHCb features:

- ✓ particle detection in the forward region (down to beam-pipe)
- ✓ special particle identification capability in particular for hadrons due to RICH detector
- ✓ precise vertexing (also ATLAS & CMS)

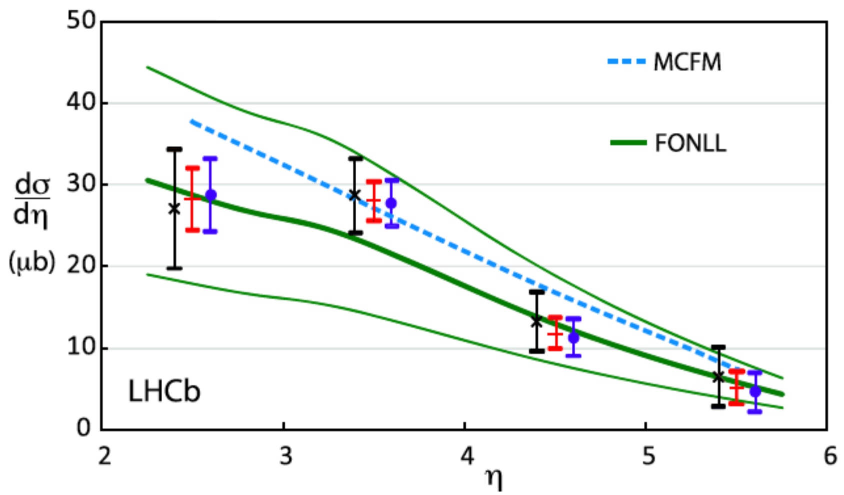


B PRODUCTION

b-hadron cross section from semileptonic decays

LHCb measured $\sigma(pp \to b\bar{b}X)$ from $D^0\mu\nu X$

Phys.Lett.B694:209-216,2010



η	σ(μb) Theory I	σ(μb) Theory II	Measured σ(μb)	Measured σ(μb)
2,6	89.0	70.2	75.3 ± 5.4 ± 13.0	**89.6± 6.4± 15.3**
All	332	253	284 ± 20 ± 49	**338.0± 23.8± 57.7**

LEP b-fractions

CDF b-fractions

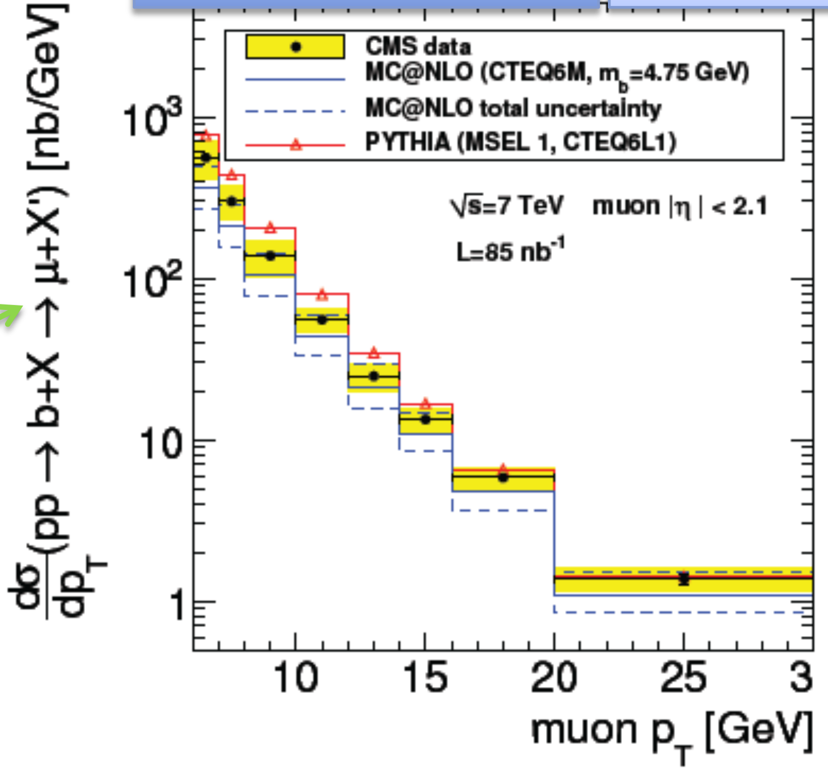
CMS studies μ with high p_T relative to jet axis

$\sigma_{vis} = (1.32 \pm 0.01(stat) \pm 0.30(sys) \pm 0.15(lumi))\mu b$

$\sigma_{Phythia} = 1.8\mu b$

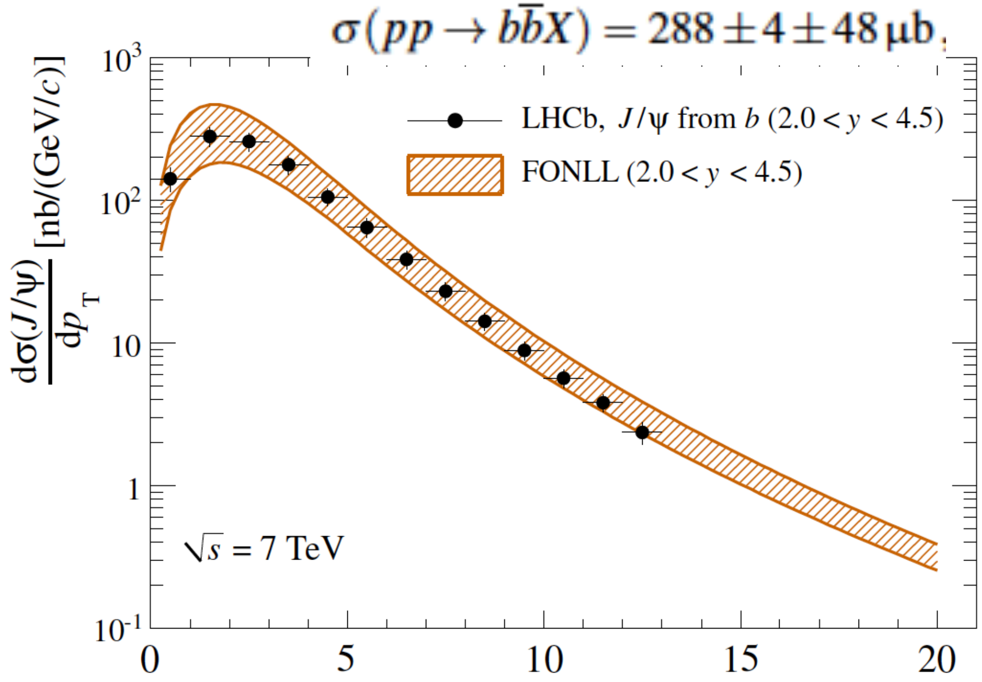
$\sigma_{MC@NLO} = (0.95^{+0.41}_{-0.21}(scale) \pm 0.09(m_b) \pm 0.05(pdf))\mu b$

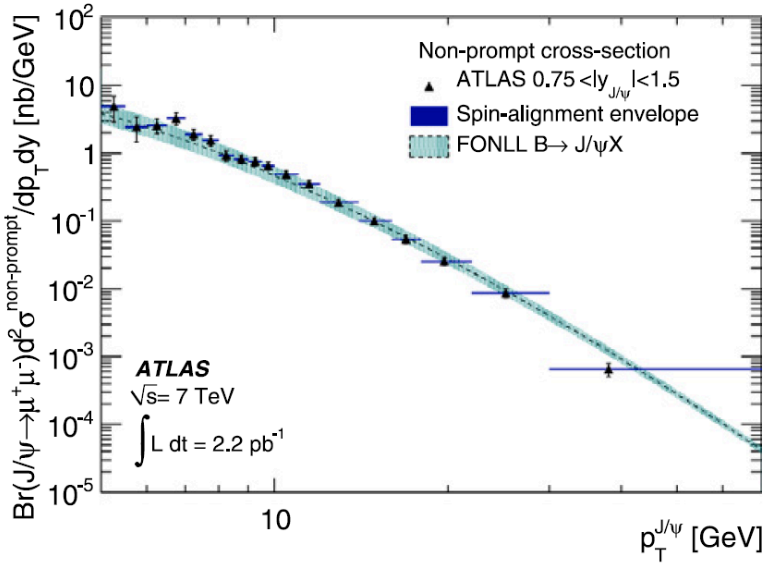
Disagreement with MC@NLO highest at low muon p_T



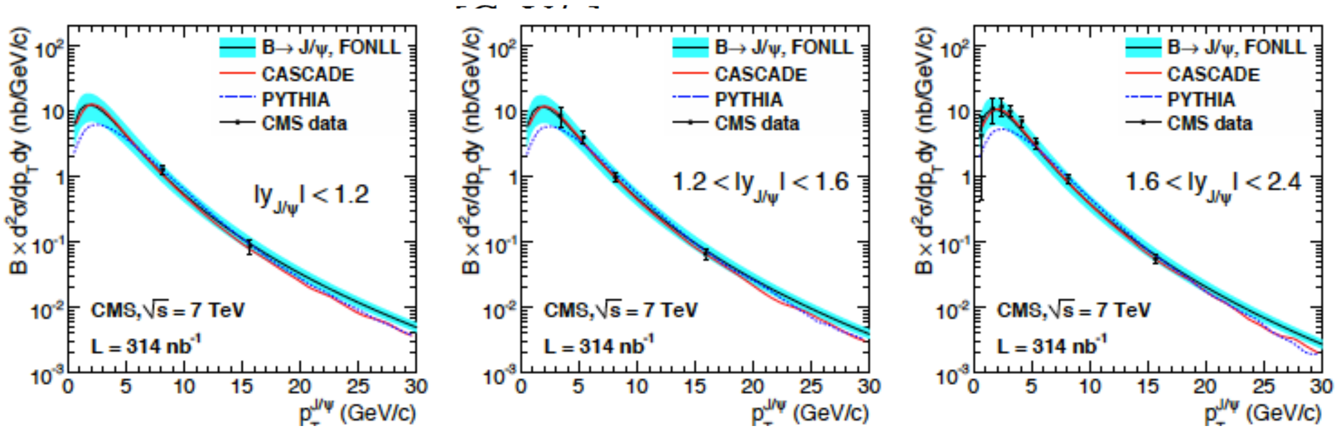
Non prompt Inclusive J/ψ

LHCb Eur.Phys.J.C71:1645,2011

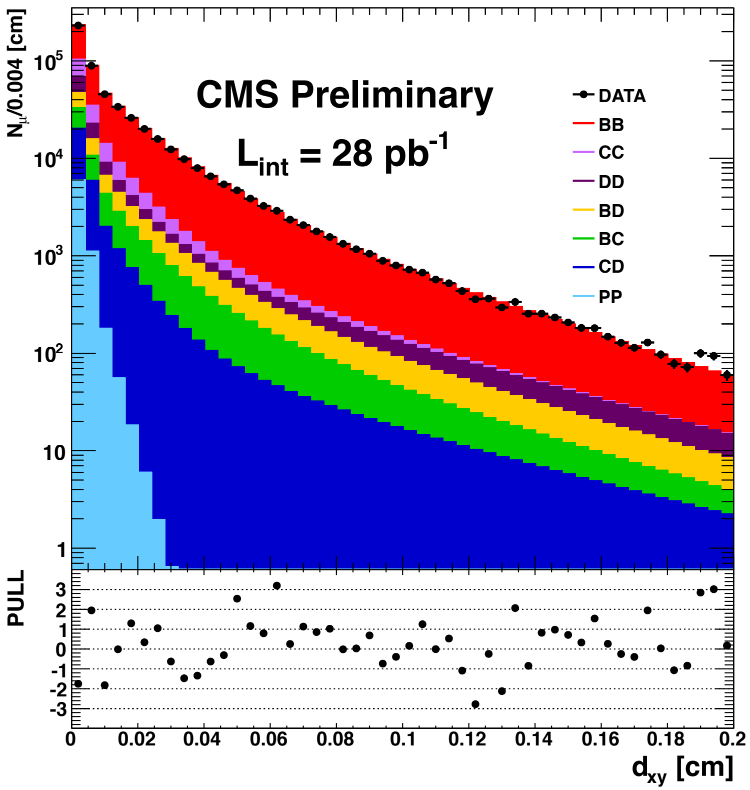


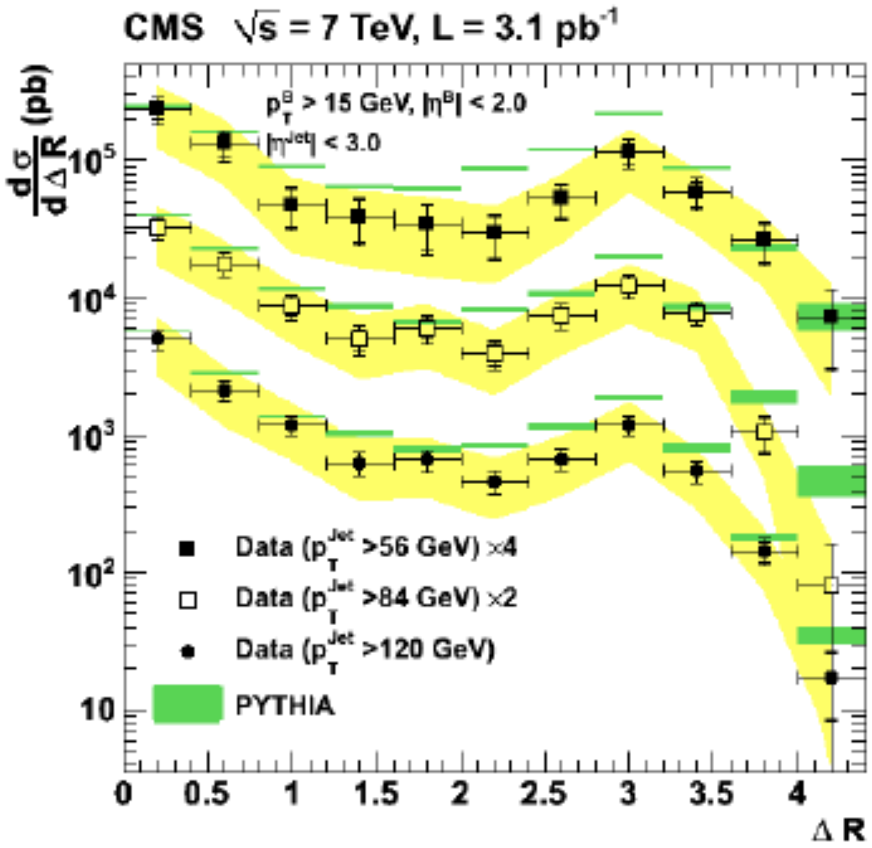


CMS $\mathcal{L}$=314 nb^{-1}



b and $\bar{b}$





$$\sigma(pp \to b\bar{b}X \to \mu\mu Y) = 26.18 \pm 0.14\,(\text{stat.}) \pm 2.82\,(\text{syst.}) \pm 1.05\,(\text{lumi.})\ \text{nb}$$

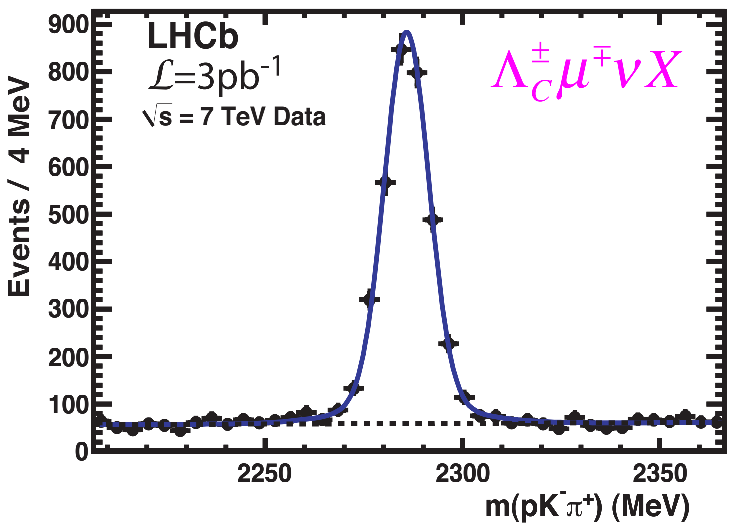
2 μ in η<2.1

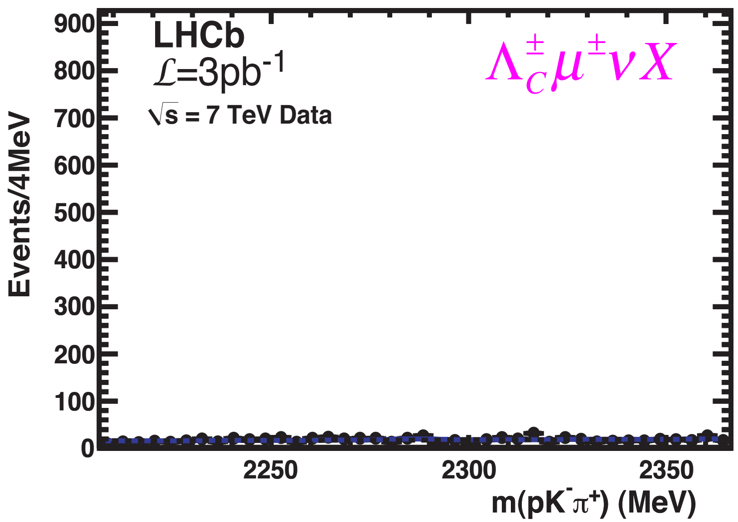
$$\sigma_{MC@NLO}(pp \to b\bar{b}X \to \mu\mu Y) = 19.95 \pm 0.46\,(\text{stat.})\ ^{+4.68}_{-4.33}\,(\text{syst.})\ \text{nb.}$$

Production cross section as a function of the angular separation ΔR in the φη plane

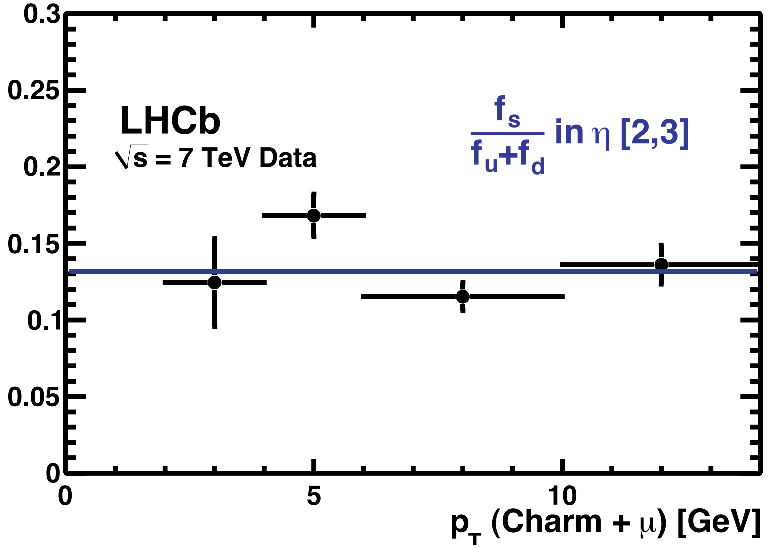
b-hadron production fractions

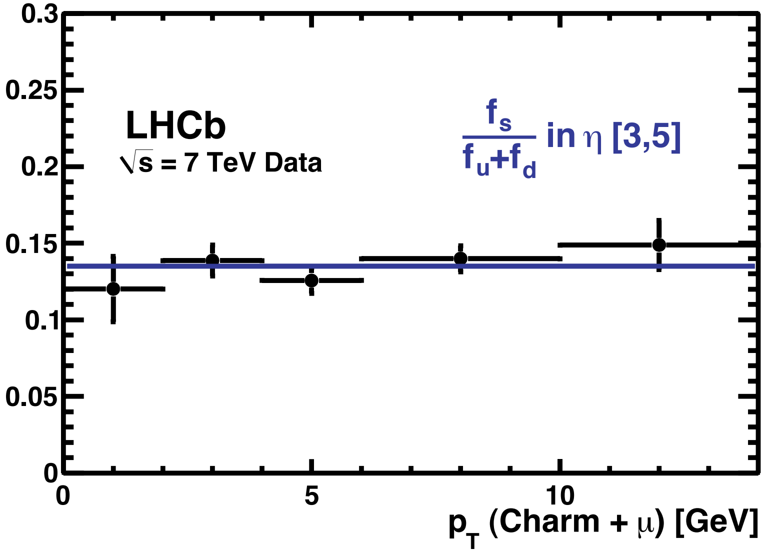
- b-fractions measured from charm-μ final states:
  - ❑ B^0+B^+ mostly $D^0\mu\nu$+$D^+\mu\nu$
  - ❑ B_s mostly $D_s\mu\nu$
  - ❑ Λ_b mostly $\Lambda_c\mu\nu$
- taking into account all the possible cross-feeds:
  - ❑ $D^{0,\pm}K\mu\nu$ (B^0,B^+,B_s)
  - ❑ D_sK (B^0,B^+, B_s)
  - ❑ $D^0p(n)$ (B^0,B^+, Λ_b)





$f_s/(f_u+f_d) = 0.134 \pm 0.004^{+0.012}_{-0.011}$





Systematic error breakdown

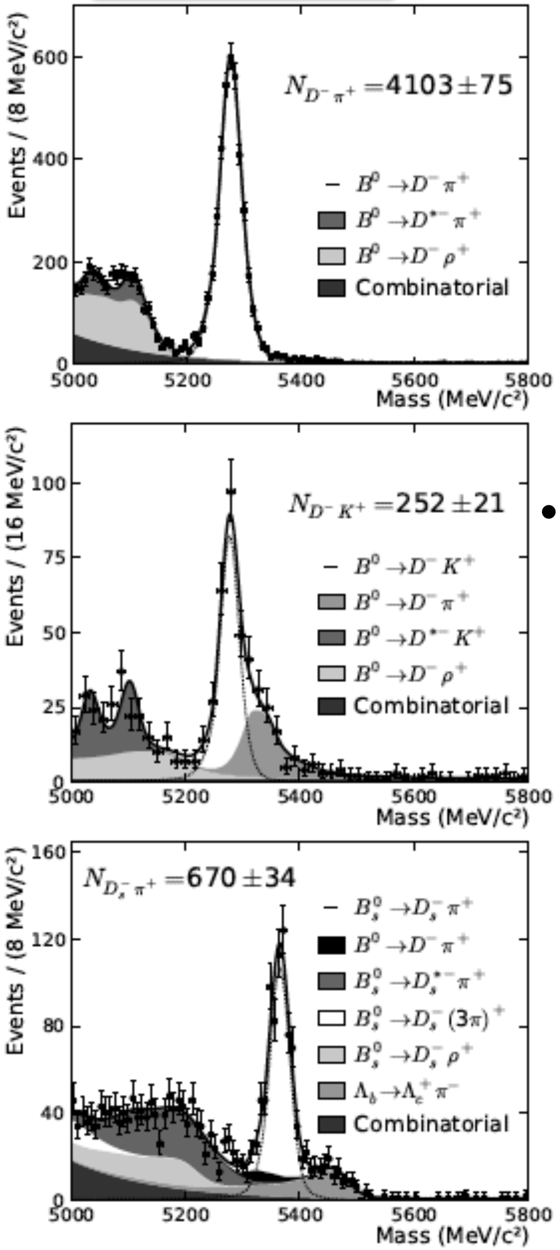
Source	Error (%)
Bin dependent errors	1.0
Charm hadron branching fractions	5.5
B_s semileptonic decay modeling	3.0
Backgrounds	2.0
Tracking efficiency	2.0
Lifetime ratio	1.8
PID efficiency	1.5
$\overline{B}^0_S \to D^0 K^+ X \mu^- \overline{\nu}$	$^{+4.1}_{-1.1}$
$(B^-, \overline{B}^0) \to D_s^+ K X \mu^- \overline{\nu}$	2.0
Total	$^{+8.6}_{-7.7}$

LEP: 0.128 ± 0.012
Tevatron: 0.156 ± 0.026 (HFAG)

***$f_s/(f_u+f_d)$* doesn't depend on η or p_T (charm+μ)**

LHCb determination of f_s/f_d

arXiv:1106.4435.



$$\frac{f_s}{f_d}(D_s\mu\nu X) = 0.268 \pm 0.008^{+0.024}_{-0.022}$$

LHCb has two other measurements:

$$\frac{BF(B_s^0 \to D_s^-\pi^+)}{BF(B^0 \to D^-K^+)} = 0.250 \pm 0.024(stat) \pm 0.017(syst) \pm 0.017(theor)$$

$$\frac{BF(B_s^0 \to D_s^-\pi^+)}{BF(B^0 \to D^-\pi^+)} = 0.256 \pm 0.014(stat) \pm 0.019(syst) \pm 0.026(theor)$$

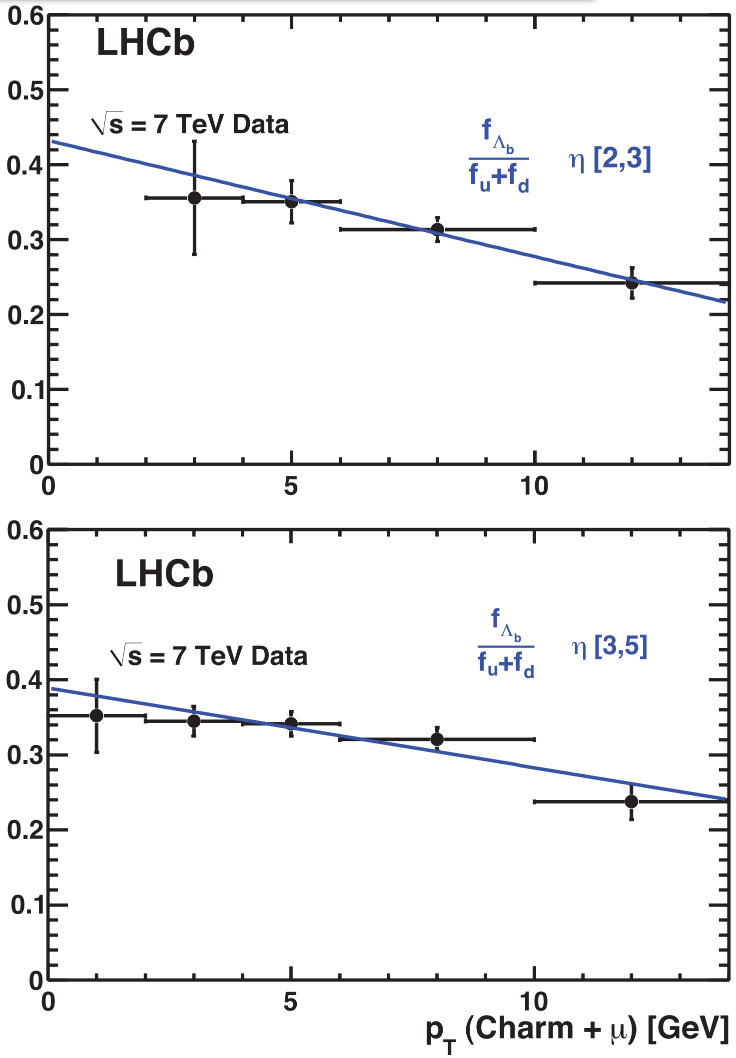
- We average the 3 LHCb measurements to get [LHCb-CONF-2011-34]

$$\left\langle \frac{f_s}{f_d} \right\rangle = 0.267^{+0.021}_{-0.020}$$

Source	Error(%)
Statistical	2.8
Experimental Sys (symme)	3.3
$B_s \to D_s K X \mu\nu$	+3.0 -0.8
$\mathcal{B}(D^+ \to K^-\pi^+\pi^-)$	2.2
$\mathcal{B}(D_s \to K^-K^+\pi^-)$	4.9
B lifetimes	1.5
$\mathcal{B}(B^0/B^+ \to D_s K^-)$	1.5
Theory	1.9

The fraction $f_{\Lambda_b}/(f_u + f_d)$

LHCb-CONF-2011-028

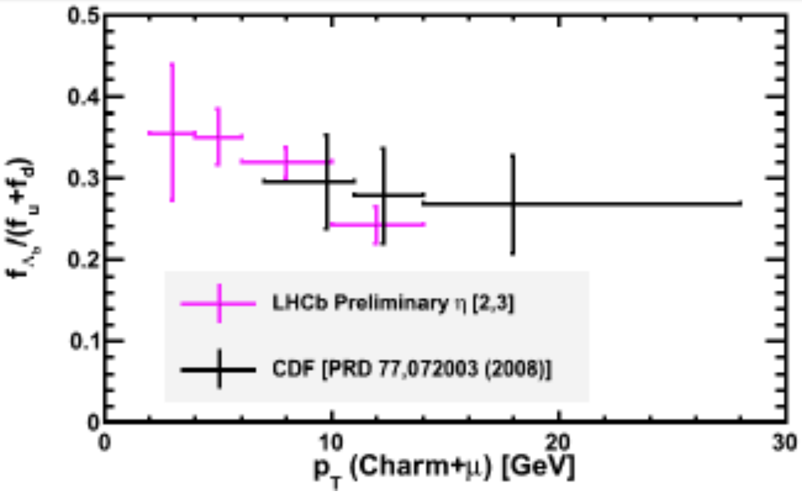


$f_{\Lambda b}/(f_u+f_d)$ depends on p_T

If we fit with straight line, we get

$$\frac{f_{\Lambda_b}}{f_u + f_d} = (0.404 \pm 0.017 \pm 0.027 \pm 0.105)\times \left[1-(0.031\pm 0.004 \pm 0.003)\times p_T\ /\mathrm{GeV}\right]$$

Systematic error on the scale 26% from $\mathcal{B}(\Lambda_c \to pK\pi)$

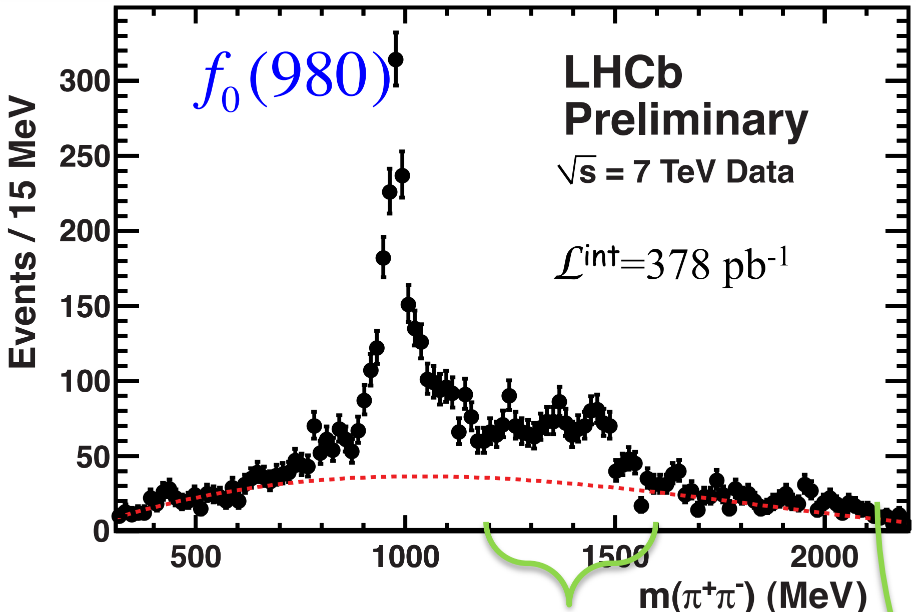


CDF value $(0.281\pm0.012^{+0.011}_{-0.056}{}^{+0.128}_{-0.086})$ $\langle p_T \rangle_{\mathrm{CDF}} \approx 14.1\,\mathrm{GeV}$

LEP value 0.110 ± 0.035 $\langle p_T \rangle_{\mathrm{LEP}} \approx 40\,\mathrm{GeV}$

Selected topics in hadronic B decays

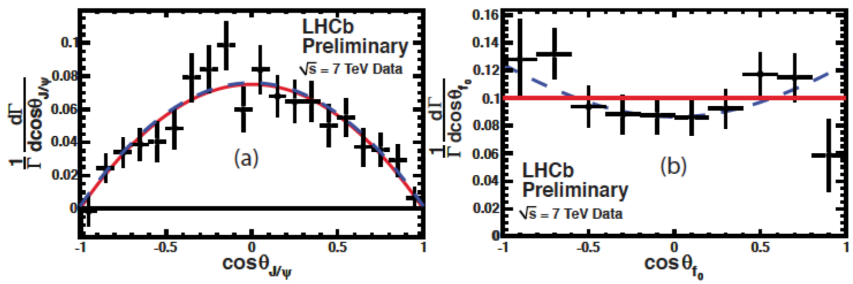
$B_s \to J/\psi f_0$ at LHCb



$$R_{eff}^{f_0} \equiv \frac{N_{corr}(J/\psi f_0)}{N_{corr}(J/\psi\phi)} = (21.7 \pm 1.1 \pm 1.0)\%$$

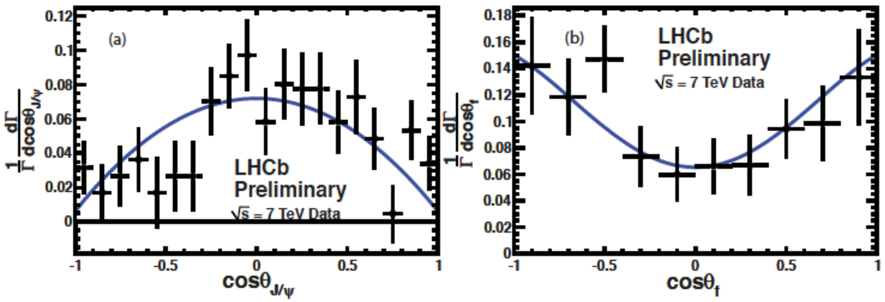
Existence of decay predicted by Stone & Zhang, with $R_{th}^{f_0} \approx 20\%$

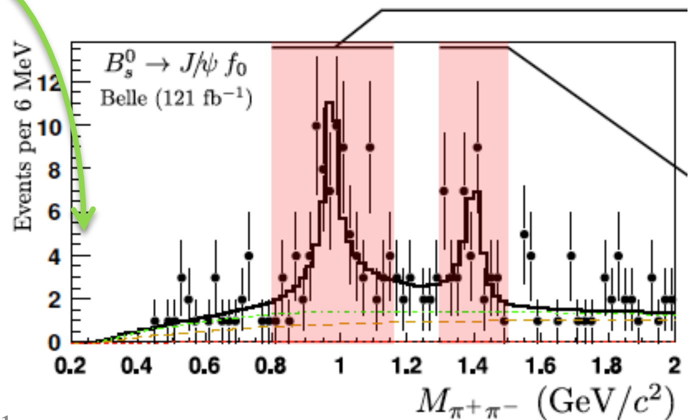
Phys.Rev. D79 (2009) 074024



Cutting on m($\pi^+\pi^-$)= (1200,1600) significant D-wave component

f_0 mass region $\approx$ s-wave

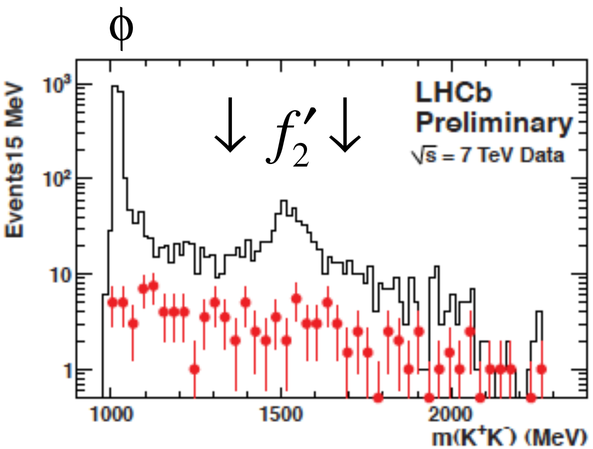


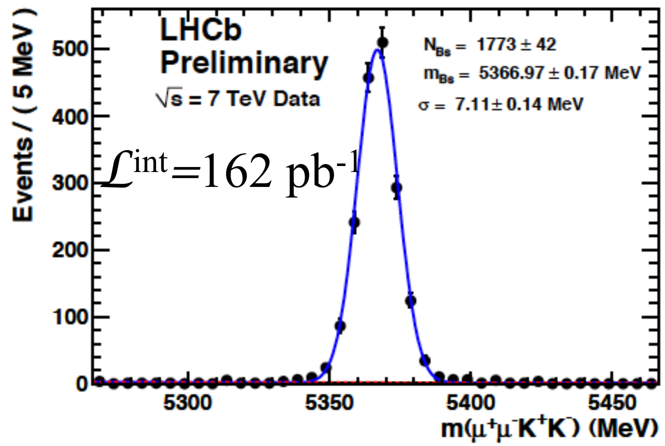


Inconsistent with Belle evidence for $f_0(1370)$

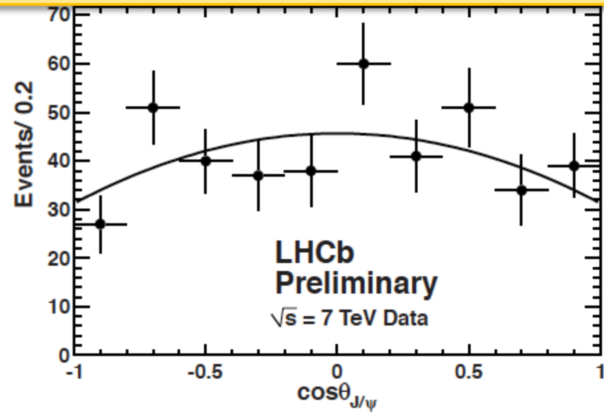
Study of $B_s^0 \to J/\psi K^+K^-$ and first observation of $B_s^0 \to J/\psi f_2'(1525)$

Selecting events with K^+K^- within ±20 MeV of the ϕ mass, we obtain the normalization $J/\psi\phi$ signal





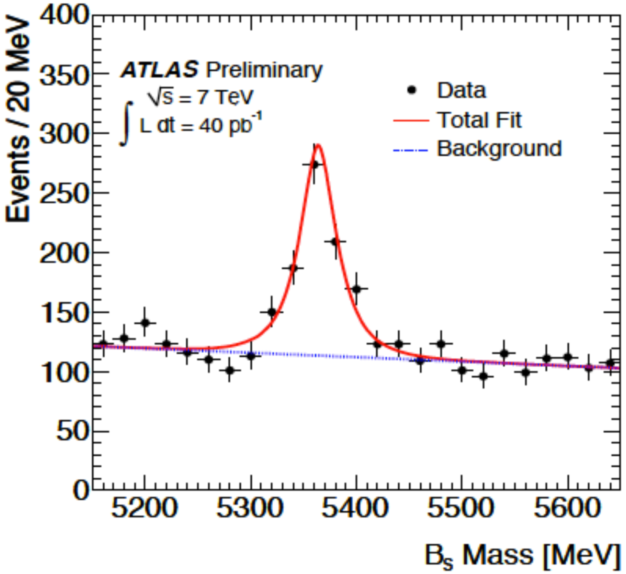
Angular analysis shows consistency with spin 2

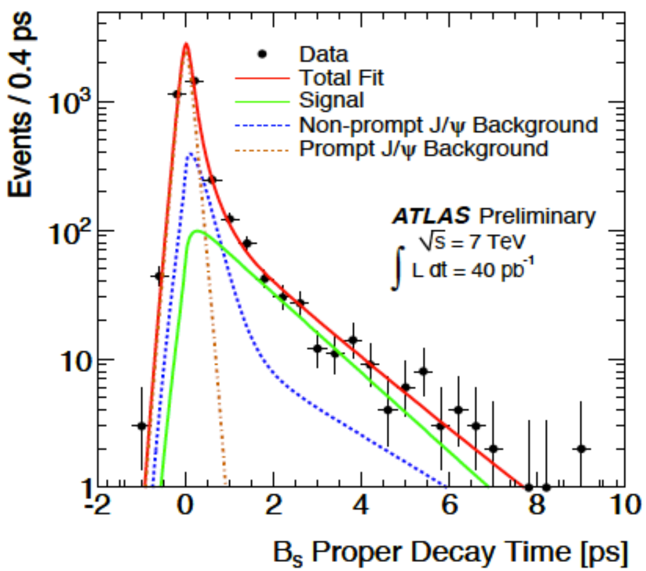


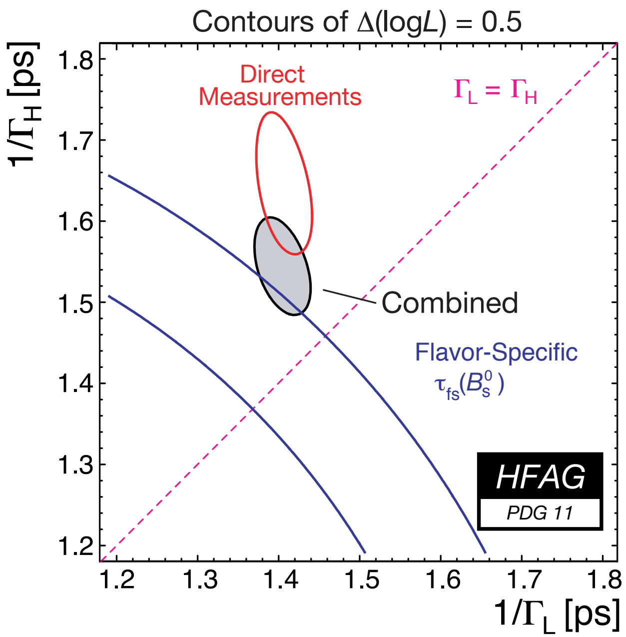
$$R_{eff}^{f_2'} \equiv \frac{N_{corr}(B_s^0 \to J/\psi f_2')}{N_{corr}(B_s^0 \to J/\psi \phi)} = (19.4 \pm 1.8 \pm 1.1)\%$$

More opportunities for CPV measurements!

From ATLAS: B_s lifetime in $J/\psi\phi$

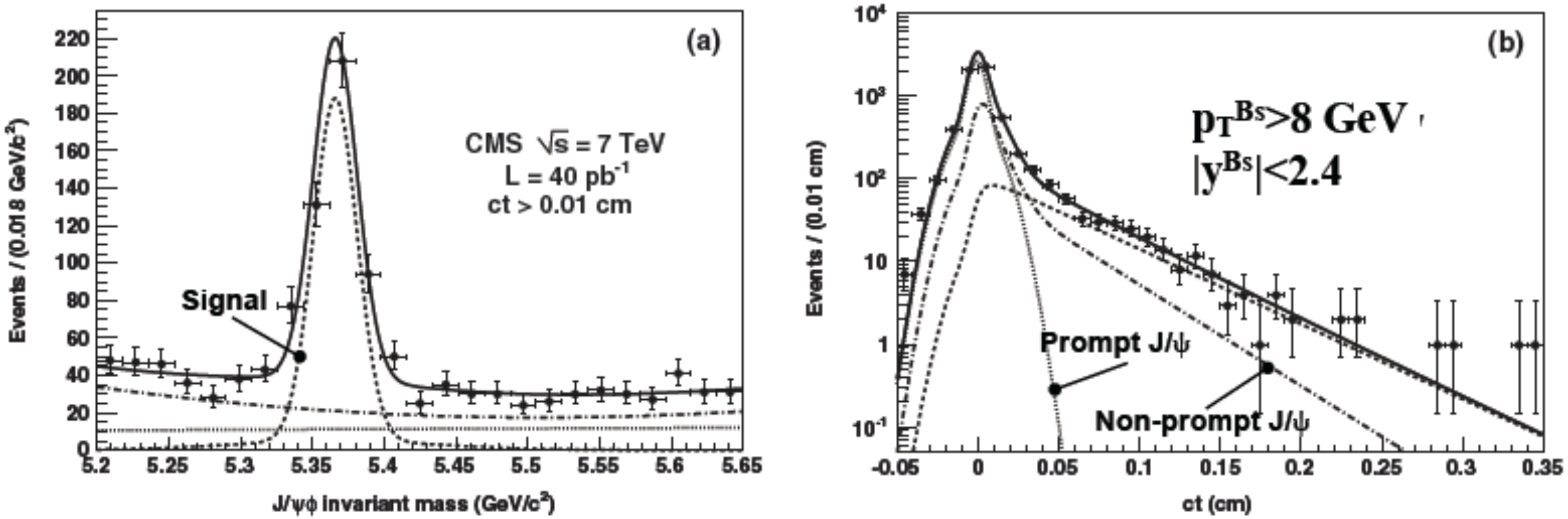






Simultaneous fit of mass and proper time gives τ_{Bs}=(1.41±0.08±0.05) ps

CMS studies of $B_s \to J/\psi\phi$



About 550 candidates from combined mass and lifetime fit in 40 pb^{-1} $c\tau=(478\pm26)\ \mu m$ $[\tau=(1.59\pm0.087)ps]$

First published result B_s production cross section

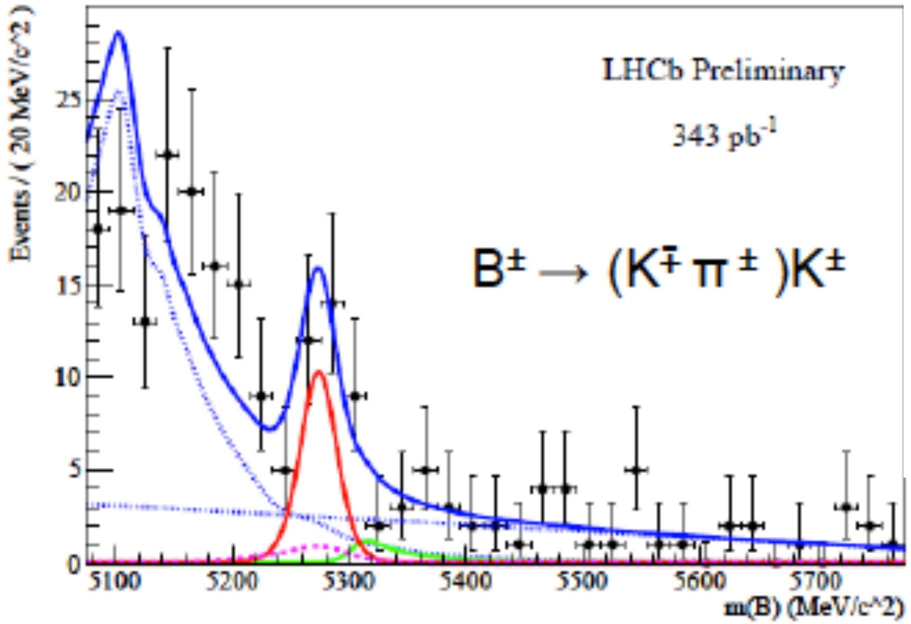
$pp\to B_sX\to J/\psi\phi X$, $p_T^B>8$ GeV, $|y^B|<2.4$

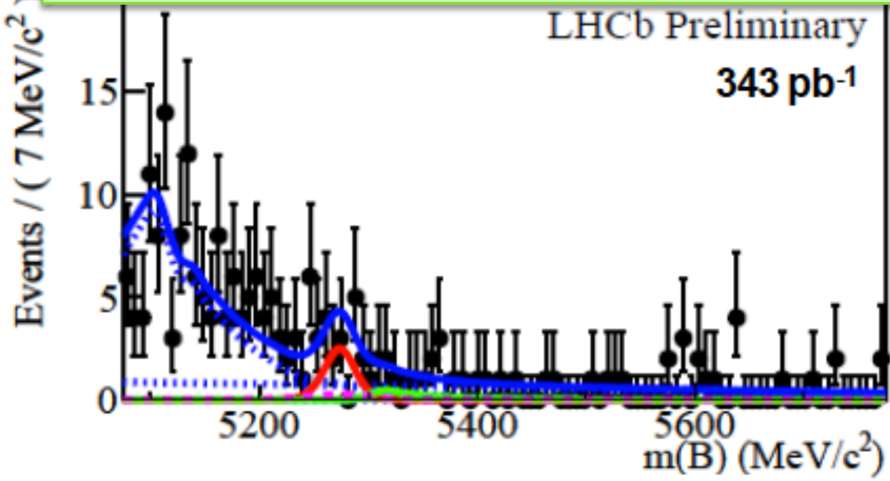
$6.9 \pm 0.6(\mathrm{stat}) \pm 0.5(\mathrm{syst}) \pm 0.3(\mathrm{lumi})$ nb	**Measured visible cross section**
$4.57^{+1.93}_{-1.71}(\mathrm{scale}) \pm 1.37(\mathrm{B.F.})$ nb	**MC@NLO**
$9.39 \pm 2.82(\mathrm{B.F.})$ nb	**Pythia**

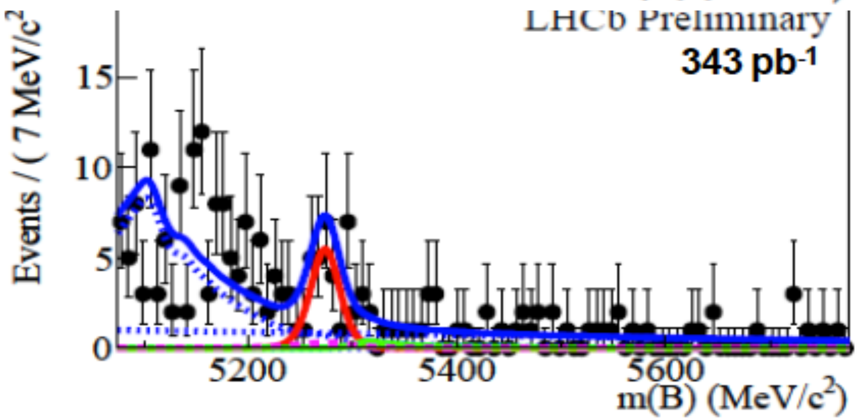
Evidence for $B^{\mp} \rightarrow K^{\pm}\pi^{\mp}K^{\mp}(ADS)$

Atwood, Dunietz, Soni **Phys.Rev. D63 (2001) 036005**

LHCb-CONF-2011-044







Ratio to favored mode:

$$R_{ADS}^{DK}(LHCb) = (1.66 \pm 0.39 \pm 0.24) \times 10^{-2}$$

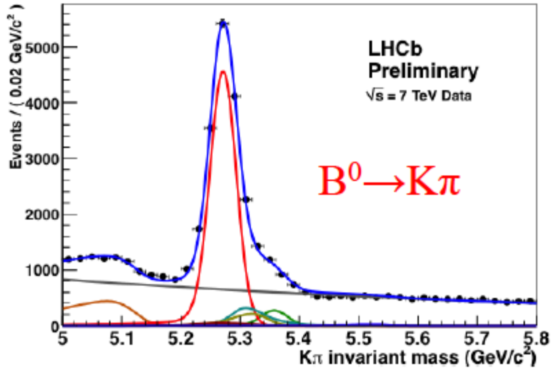
$$R_{ADS}^{DK}(WA - noLHCb) = (1.6 \pm 0.3) \times 10^{-2}$$

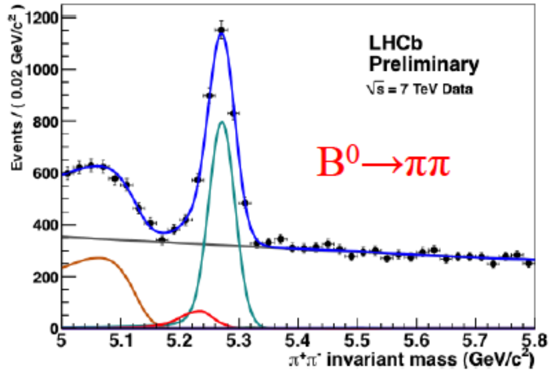
$$A_{ADS}^{DK}(LHCb) = -(0.39 \pm 0.17 \pm 0.02)$$

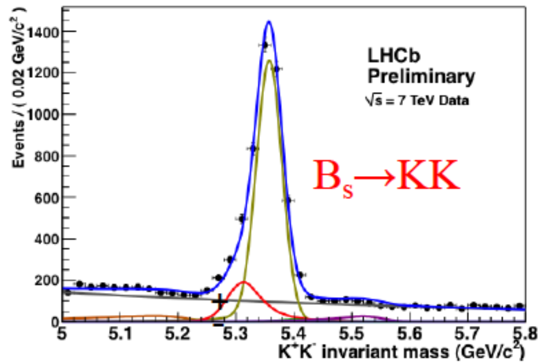
$$A_{ADS}^{DK}(WA - noLHCb) = -(0.58 \pm 0.21)$$

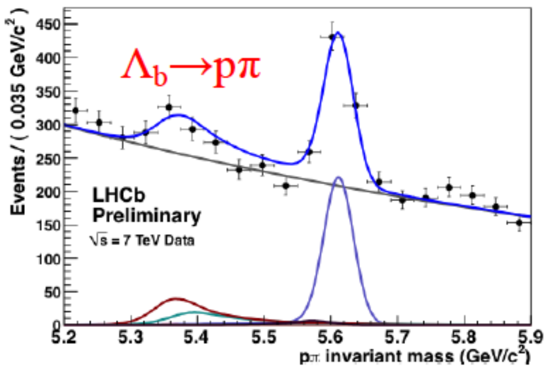
Non leptonic 2 body B decays

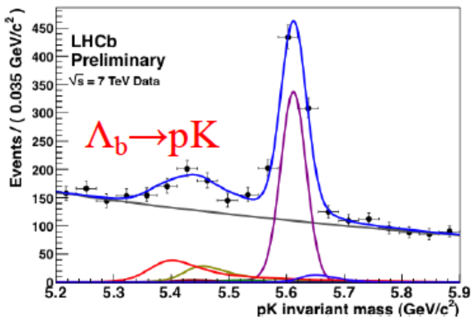
- Important tests of CKM framework & interplay between QCD effects and weak interactions [many theoretical methods proposed to tackle this]
- $B_{(s)} \rightarrow \pi\pi$, πK, KK extensively studied in the last 10 years, great body of experimental knowledge and growing! (new PID power of LHCb RICH)

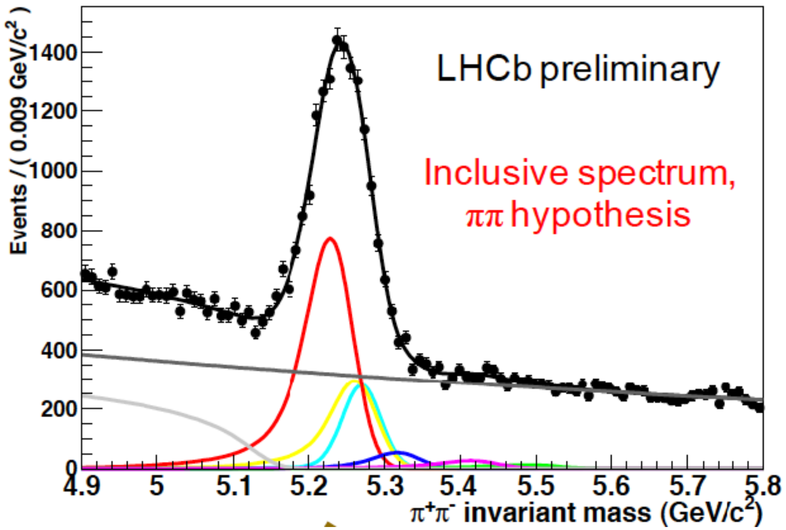








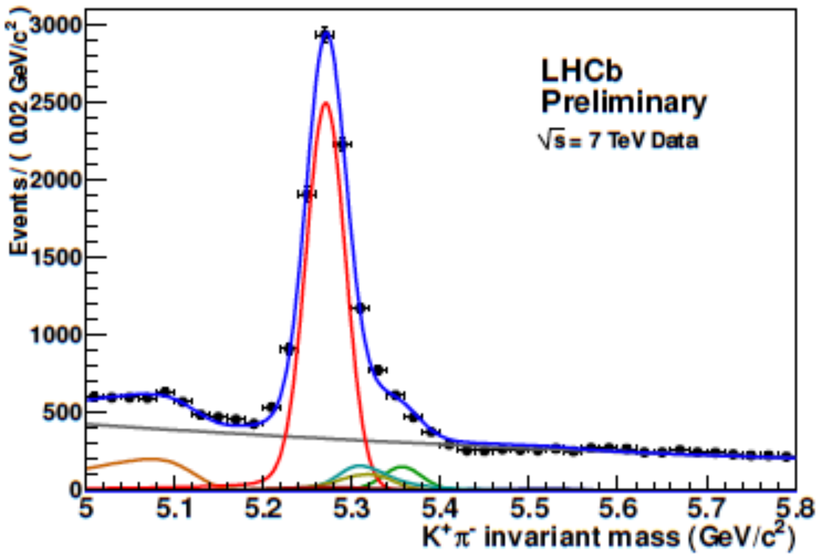


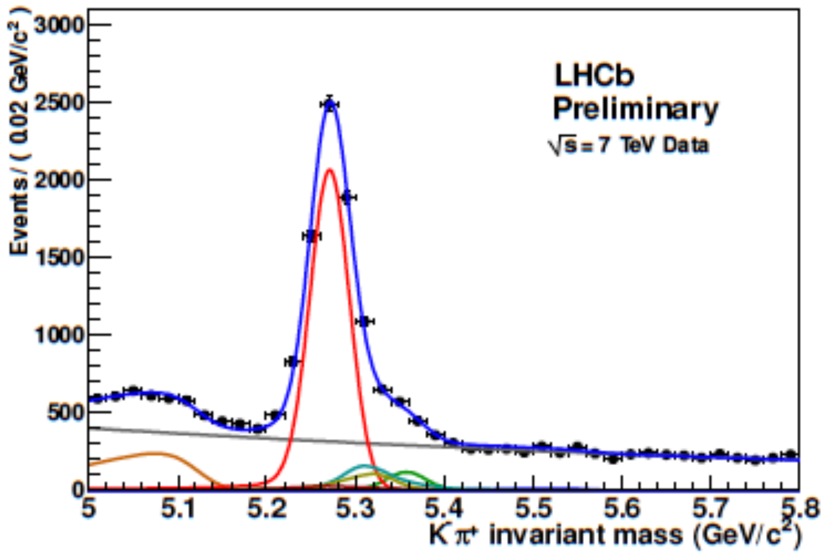


Direct CP Violation (see L. Zhang talk)

$$A_{CP}(B^0 \to K\pi) = -0.088 \pm 0.011 \pm 0.008$$

$$A_{CP}(B^0 \to K\pi) = -0.098^{+0.012}_{-0.011} \quad (HFAG)$$



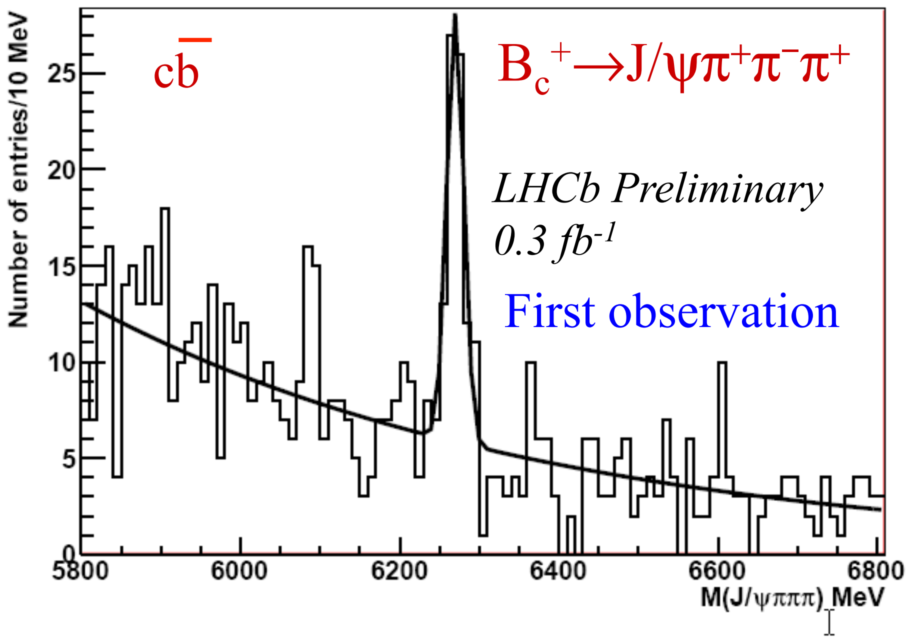


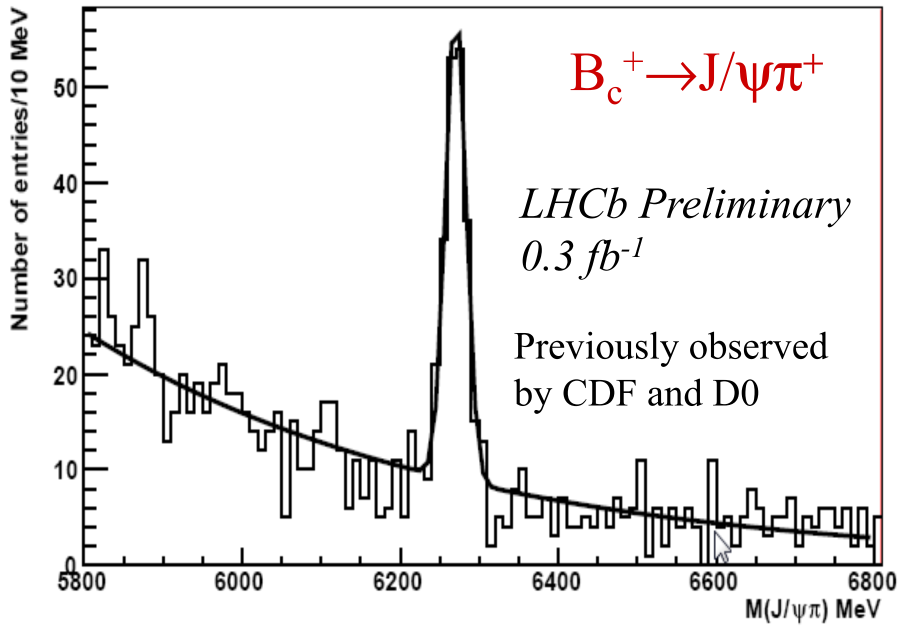
$$A_{CP}(B_s^0 \to \pi K) = -0.27 \pm 0.08 \pm 0.02$$

First evidence for direct CPV in $B_s \to \pi K$ decays

First observation of $B_c^+ \to J/\psi\pi^+\pi^-\pi^+$

Only 3rd B_c^+ decay mode ever observed





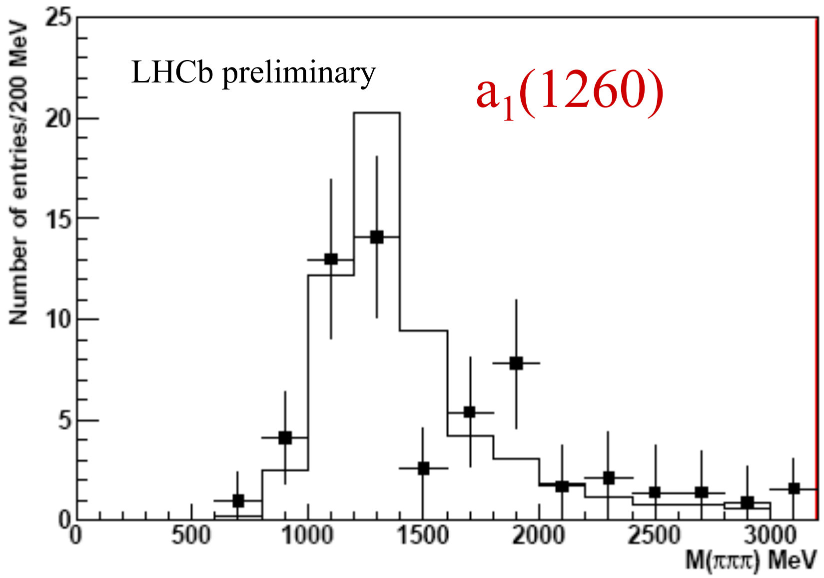
58.2±9.6 events
6268.4±1.7 MeV (uncalibrated)
σ=9.7±1.6 MeV
6.8σ

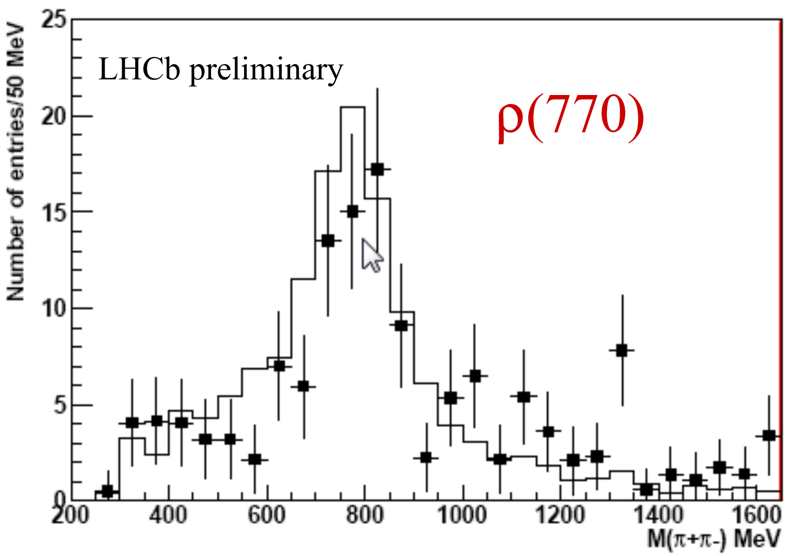
163.1±15.7 events
6270.3±1.4 MeV (uncalibrated)
σ=12.7±1.6 MeV
11σ

$$\mathcal{B}(B_c^+ \to J/\psi\pi^+\pi^+\pi^-)/\mathcal{B}(B_c^+ \to J/\psi\pi^+) = \mathbf{3.0 \pm 0.6 \pm 0.4}$$

Consistent with theoretical prediction of 2.1±0.3 (ff uncertainty)
A.K.Likhoded,A.V.Luchinsky PRD81, 014015(2010)

$B_c \to J/\psi\pi\pi\pi$ resonant substructure

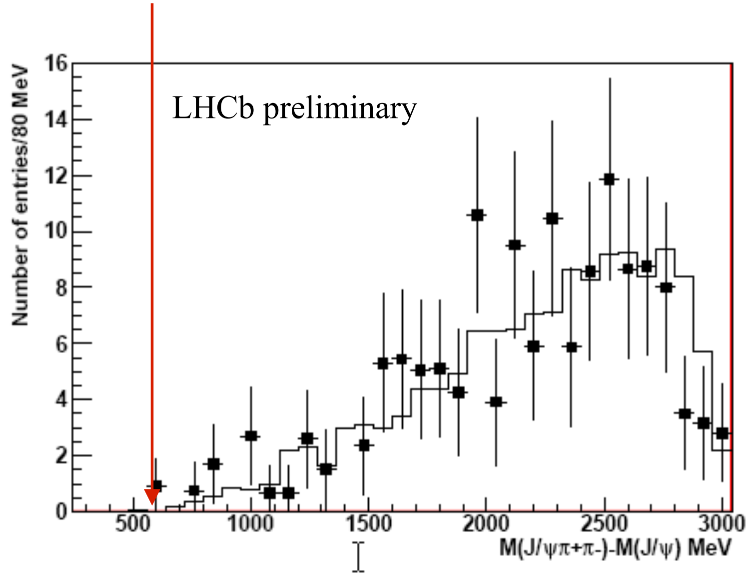




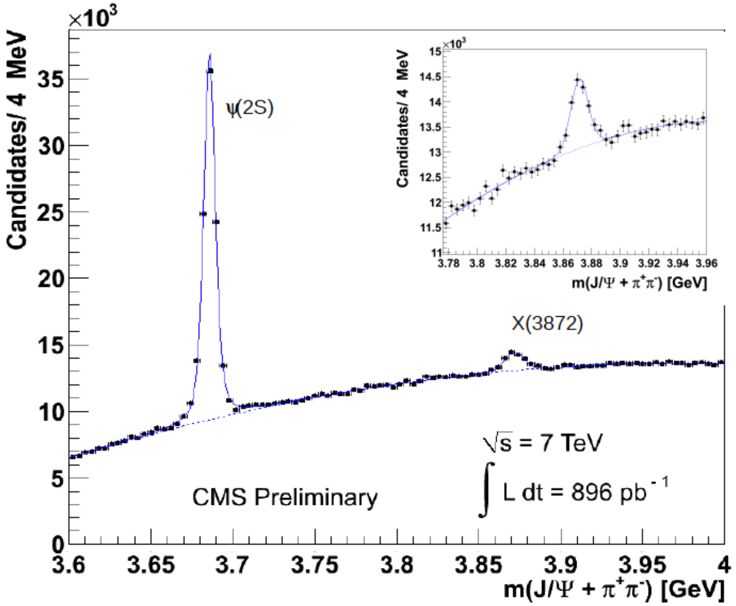
Sideband subtracted signal in the real data

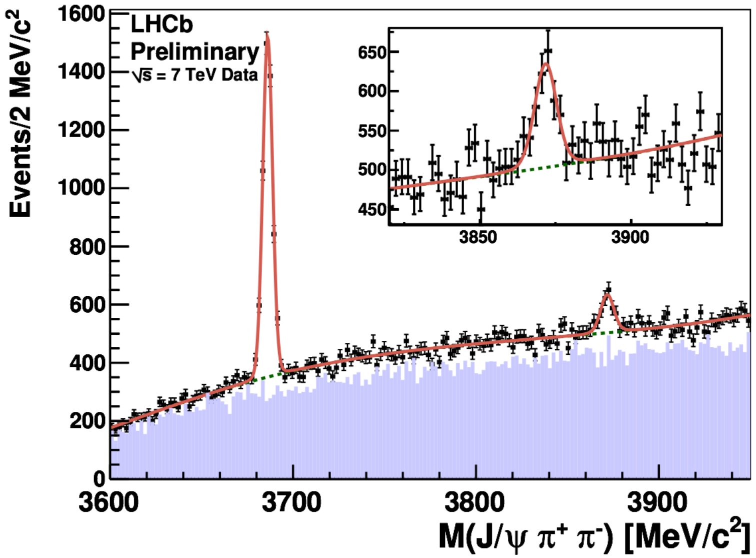
MC $B_c \to J/\psi\, a_1(1260)$, $a_1(1260) \to \rho(770)\pi$

No $B_c \to \psi(2S)\pi^-$ observed



Venturing into exotica: studies of the X(3872)

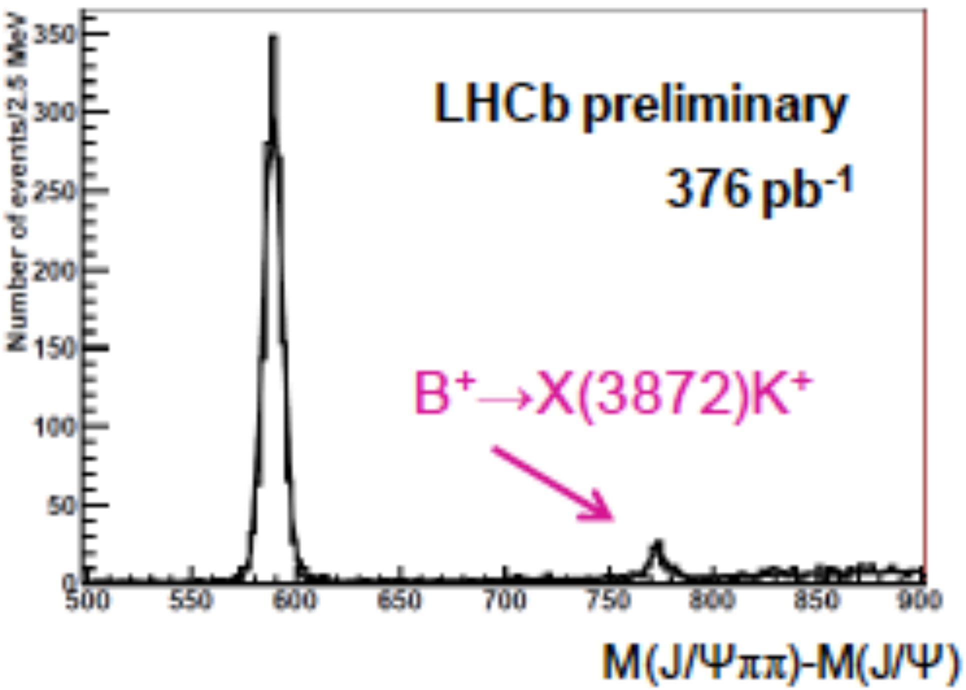




- Discovered by Belle in 2003, confirmed by CDF. D0, BaBar, started "gold rush" of exotic QCD states.
- CMS measures ratio of inclusive X(3872) to ψ(2S) production in J/ψππ channel
- LHCb determines mass precisely [LHCb CONF-2011-021]

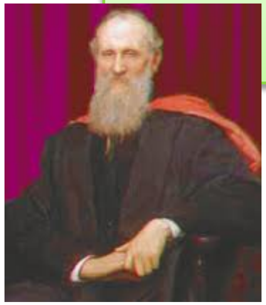
$M_{X(3872)}$=3871.96±0.46±0.10 MeV
Using 585 ± 71 candidates from 35 pb^{-1} of data collected in 2010

Seeking to shed more light on the X(3872)



- Quantum numbers not yet firmly established
  - 1^{++} or 2^{-+}
- Use $B^+ \to X(3872)K^+$ to choose right assignment
- DD* molecule or tetraquark?

Concluding remark



In 1900, Lord Kelvin famously stated, "There is nothing new to be discovered in physics now. All that remains is more and more precise measurement."

Five years later, Albert Einstein published his paper on special relativity, which challenged the very simple set of rules laid down by Newtonian mechanics

Rich phenomenology being explored may provide key to new paradigm shift!

The end