Hadron spectroscopy results from LHCb

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(on behalf of the LHCb collaboration)

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European Research Council

THE UNIVERSITY OF WARWICK

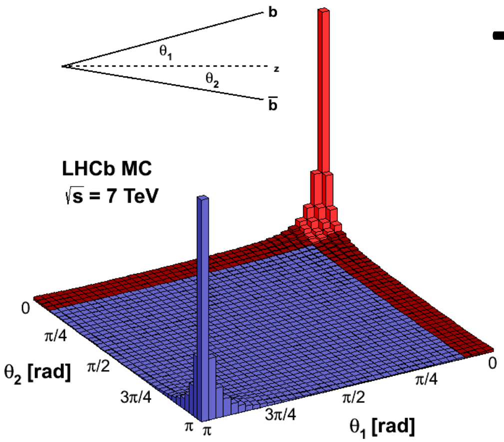
Overview

- Introduction to LHCb
- Experimental results
  - Light mesons
  - Charm
  - Charmonium(-like)
  - Beauty
  - Baryons
- Future prospects
- Conclusion

The LHCb experiment

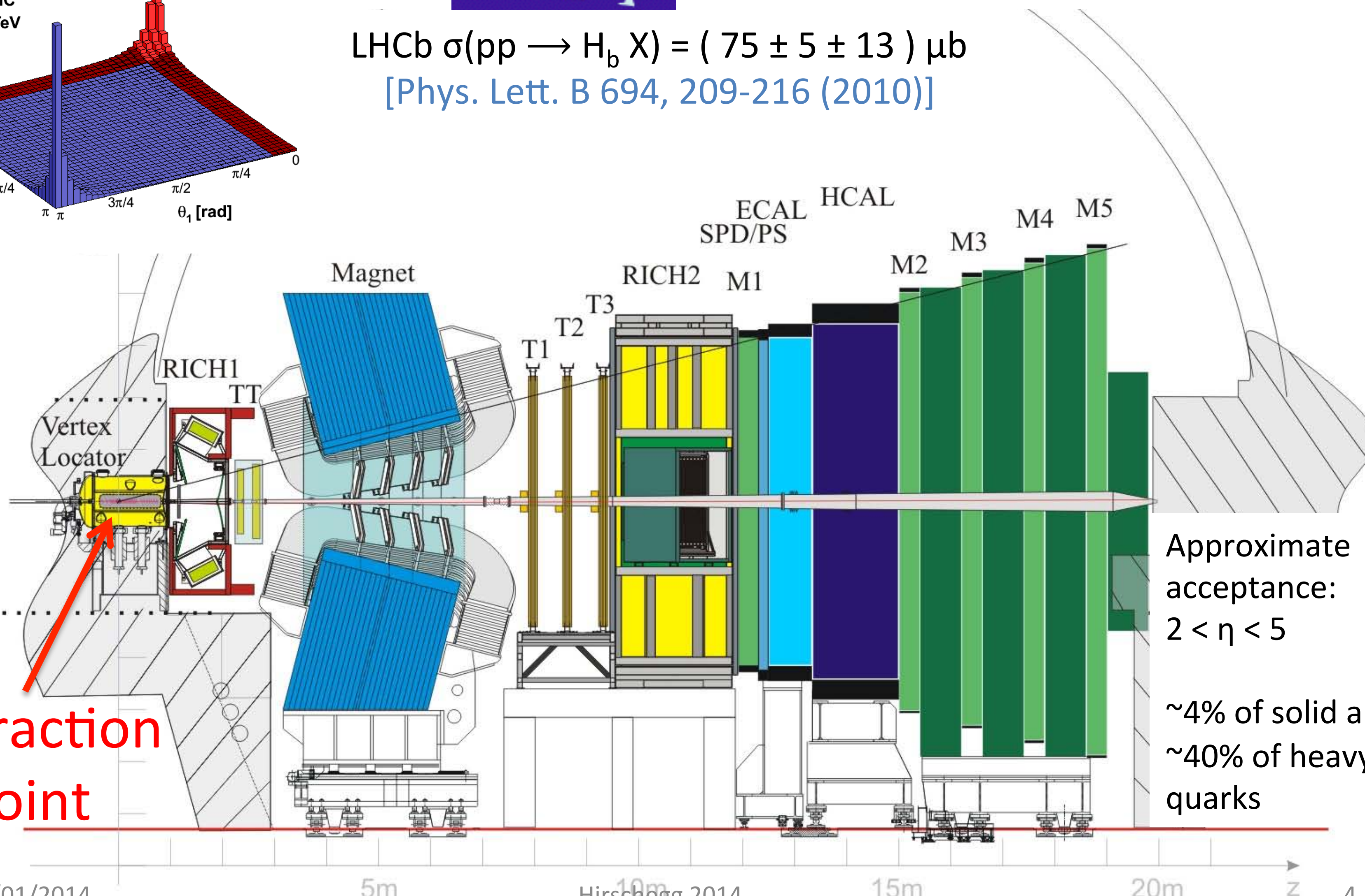
- Primary goal of LHCb is to make precision tests of the Standard Model in order to discover or exclude New Physics models
- Physics programme is broad:
  – Core measurements of CP-violation and rare decays
  – Plus spectroscopy & hadronic physics, EW physics, etc.
- Knowledge from latter parts, which are very interesting in themselves(!), are also key to better precision/accuracy in core programme

The LHCb detector



LHCb $\sigma(pp \longrightarrow H_b X) = (75 \pm 5 \pm 13)\ \mu b$

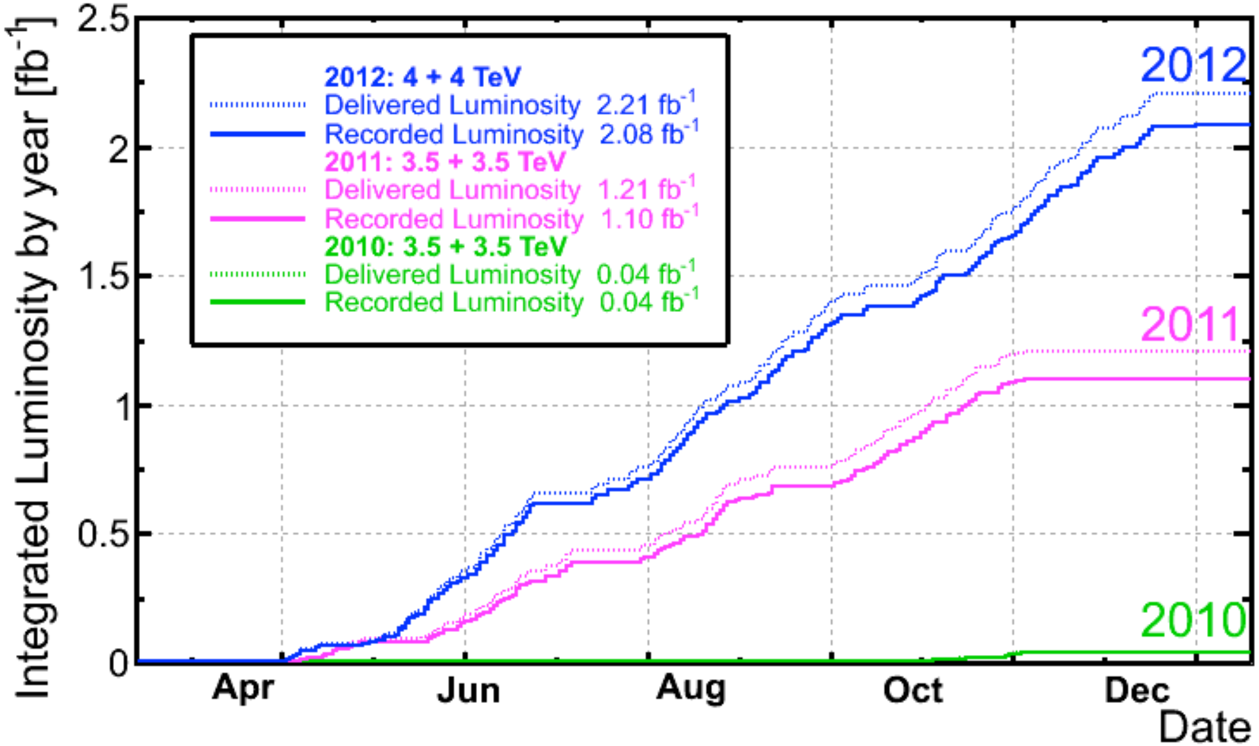
[Phys. Lett. B 694, 209-216 (2010)]

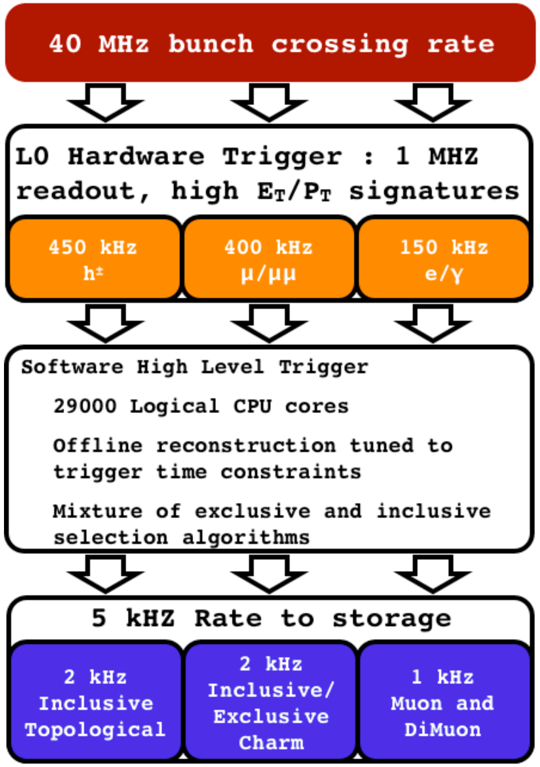


Approximate acceptance:
$2 < \eta < 5$

~4% of solid angle
~40% of heavy quarks

data samples





- 2011: √s = 7 TeV, L ≈ 1 fb^{-1}
- 2012: √s = 8 TeV, L ≈ 2 fb^{-1}

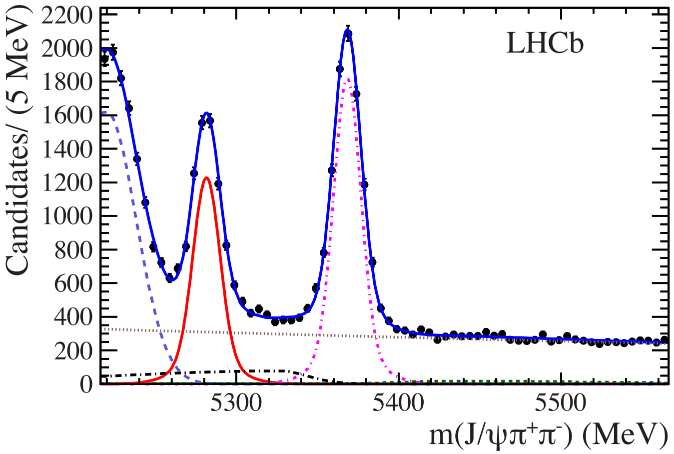
- ❑ Trigger Efficiencies:
  - ❑ ~30% efficient for multi-body hadronic
  - ❑ ~90% efficient for di-muons

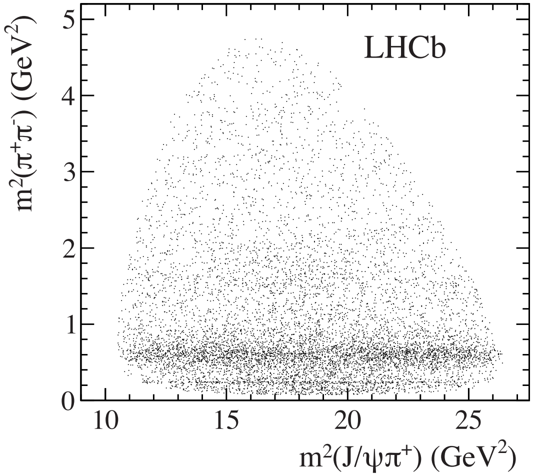
Light mesons

Phys. Rev. D87 (2013) 052001

Mixing angle of $f_0(980)$

- Analysis of the resonant structures in $B^0 \longrightarrow J/\psi\pi^+\pi^-$ decays
- Modified Dalitz-plot fit including also the J/ψ decay angle and accounting for different helicity states of intermediate resonances
- Model includes contributions from $\rho(770)$, $\omega(782)$, $f_0(980)$, $f_2(1270)$, $\rho(1450)$ and $f_0(500)$
- Efficiency variation taken into account as a function of DP and J/ψ decay angle, including correlations

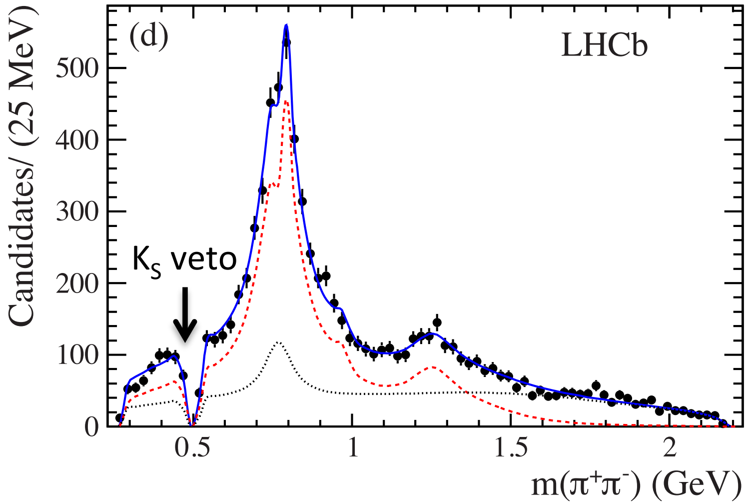


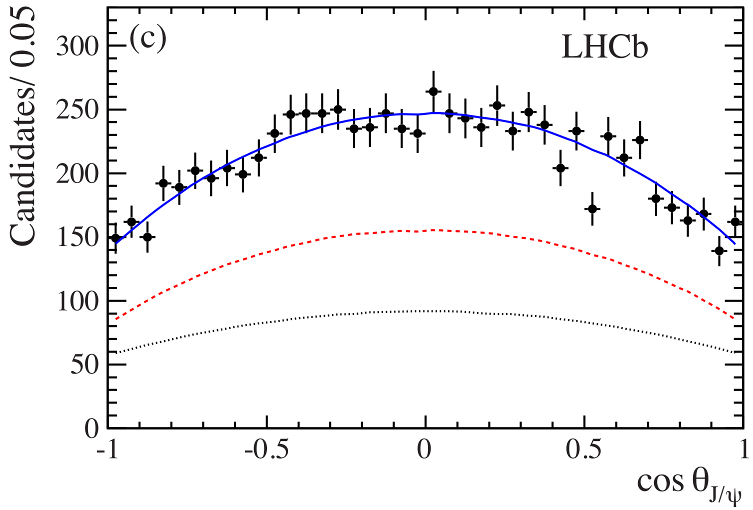


Phys. Rev. D87 (2013) 052001

Mixing angle of $f_0(980)$

- Largest contribution from $\rho(770)$ [63%]
- Smaller but significant contributions from $f_0(500)$ [16%] and $f_2(1270)$ [9%]
- Evidence of $\omega(782)$ [0.6%] and $\rho(1450)$ [5.3%]
- Significance of $f_0(980)$ [1.5%] only 2.5σ





Phys. Rev. D87 (2013) 052001

Mixing angle of $f_0(980)$

- Interpreting $f_0(500)$ and $f_0(980)$ as mixtures of underlying states:

$$\left|f_0(980)\right\rangle = \sin\varphi_m \frac{1}{\sqrt{2}}\left(\left|u\bar{u}\right\rangle + \left|d\bar{d}\right\rangle\right) + \cos\varphi_m \left|s\bar{s}\right\rangle$$

$$\left|f_0(500)\right\rangle = \cos\varphi_m \frac{1}{\sqrt{2}}\left(\left|u\bar{u}\right\rangle + \left|d\bar{d}\right\rangle\right) - \sin\varphi_m \left|s\bar{s}\right\rangle$$

- In this decay, only the $d\bar{d}$ part contributes, so

$$\tan^2\varphi_m = \frac{\mathrm{BF}\left(B^0 \to J/\psi\, f_0(980)\right)}{\mathrm{BF}\left(B^0 \to J/\psi\, f_0(500)\right)} \frac{\Phi(500)}{\Phi(980)}$$

- Where the last term is a ratio of phase space factors
- Using the information from the fit and external information on the f_0 decay BFs we find

$$\tan^2\varphi_m = \frac{\mathrm{BF}\left(B^0 \to J/\psi\, f_0(980)\right)}{\mathrm{BF}\left(B^0 \to J/\psi\, f_0(500)\right)} \frac{\Phi(500)}{\Phi(980)} < 0.35 @ 90\%\mathrm{CL}$$

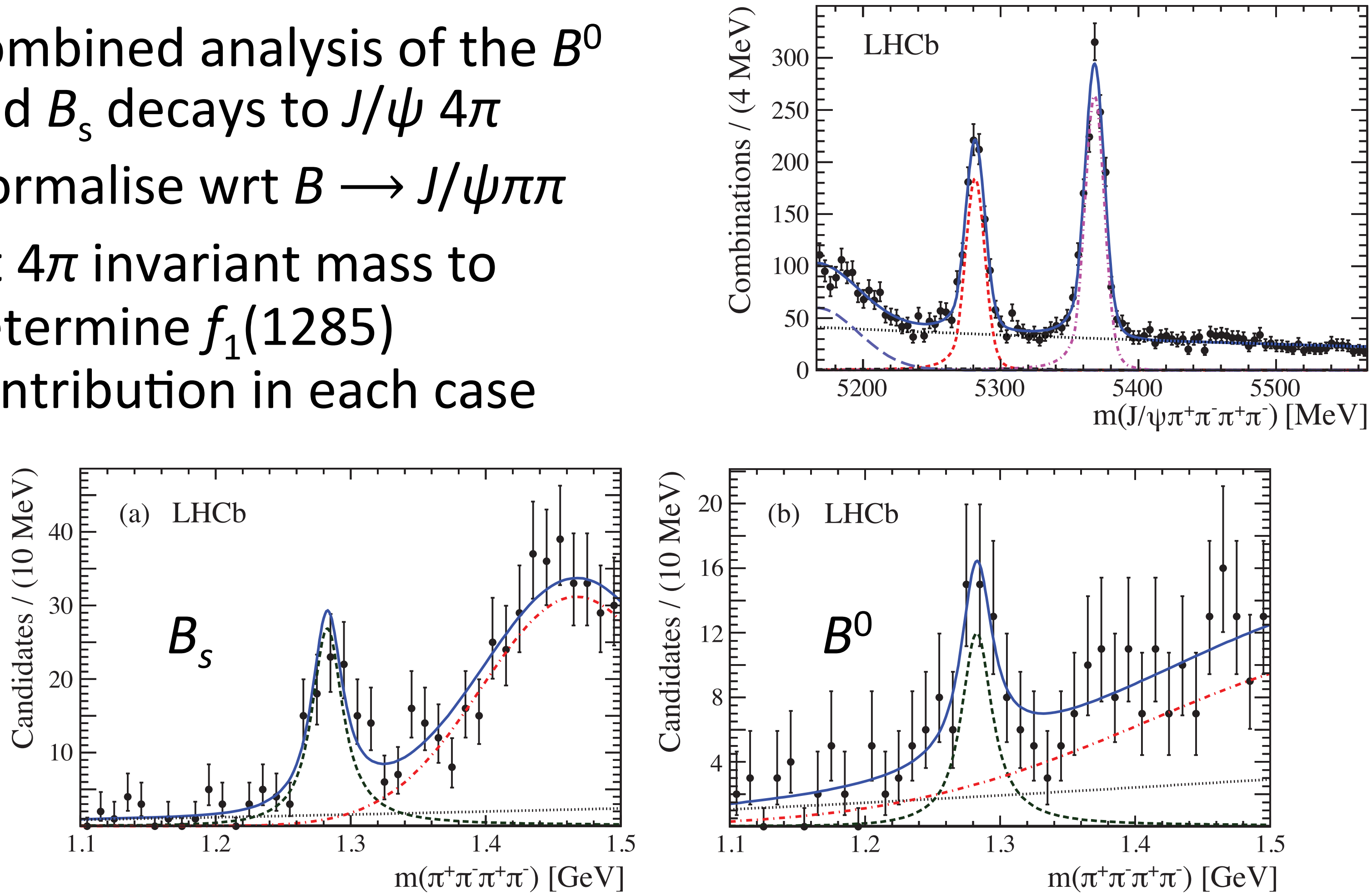
$$\left|\varphi_m\right| < 31^\circ @ 90\%\mathrm{CL}$$

3 fb^{-1} (2011+2012)

arXiv:1310.2145 [hep-ex]
To appear in Phys. Rev. Lett.

Mixing angle of $f_1(1285)$

- Combined analysis of the B^0 and B_s decays to $J/\psi\ 4\pi$
- Normalise wrt $B \longrightarrow J/\psi\pi\pi$
- Fit 4π invariant mass to determine $f_1(1285)$ contribution in each case



3 fb^{-1} (2011+2012)

arXiv:1310.2145 [hep-ex]
To appear in Phys. Rev. Lett.

Mixing angle of $f_1(1285)$

- Similar interpretation as with $f_0(500)$ and $f_0(980)$
  - $f_1(1285)$ and as yet unidentified mixing partner
- Here use $f_1(1285)$ information from B^0 and B_s decays:

$$\tan^2\varphi_m = \frac{1}{2}\frac{\mathrm{BF}\left(B_s^0 \to J/\psi\, f_1(1285)\right)}{\mathrm{BF}\left(B^0 \to J/\psi\, f_1(1285)\right)}\frac{\tau_0}{\tau_s}\frac{|V_{cd}|^2}{|V_{cs}|^2}\frac{\Phi_0}{\Phi_s} = 0.1970 \pm 0.053\,^{+0.014}_{-0.012}$$

- The resulting mixing angle is:

$$|\varphi_m| = \left(24.0\,^{+3.1}_{-2.6}\,^{+0.6}_{-0.8}\right)^\circ$$

- The observed ratio of branching fractions disfavours the tetraquark interpretation of the $f_1(1285)$

[Phys. Rev. Lett. 111 (2013) 062001]

Charm

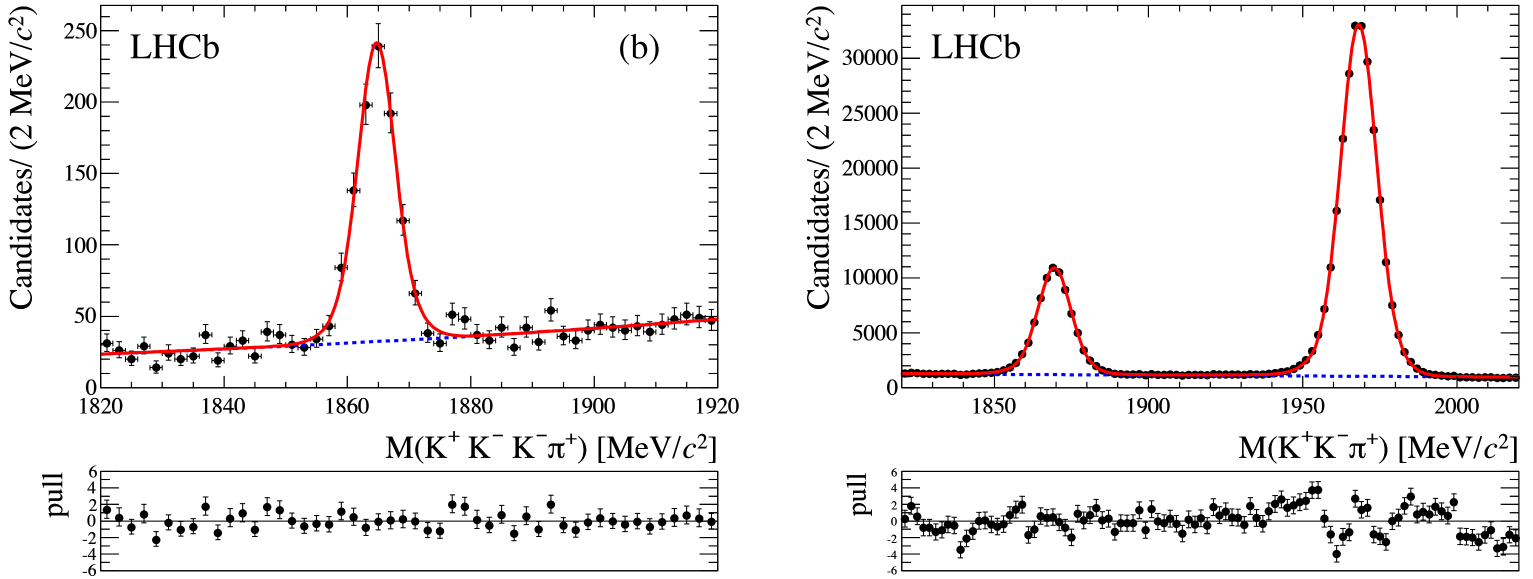
D meson masses

- *D* meson masses not so precisely known as *B*'s
- Precision on world averages of m(D^0), m(D^+) and m(D_s) are 0.2, 0.4 and 1.4 MeV/c^2 [PDG 2012 Averages]
- Mass splittings slightly better known:
  - m(D^+) – m(D^0) = 4.76 ± 0.28 MeV/c^2
  - m(D_s) – m(D^+) = 98.85 ± 0.25 MeV/c^2
- Much interest in more precise measurements:
  - Nature of *X*(3872) – is its mass above or below m(D^0) + m(D^{*0}) threshold
  - Largest systematic uncertainty on the B_c mass measurement in decay to $J/\psi\ D_s$

J. High Energy Phys. 06 (2013) 065

D meson masses

- Use $D^0 \longrightarrow 3K\pi$ to measure D^0 mass
  - Low Q-value, reduced systematics due to detector momentum-scale
- Use $D_{(s)}^+ \longrightarrow KK\pi$ (and $D^0 \longrightarrow KK\pi\pi$) to measure mass splittings
  - The different D^0 decay is used due to its more similar Q-value to the $D_{(s)}^+$ decay



J. High Energy Phys. 06 (2013) 065

D meson masses

- Results for mass and mass splittings are:

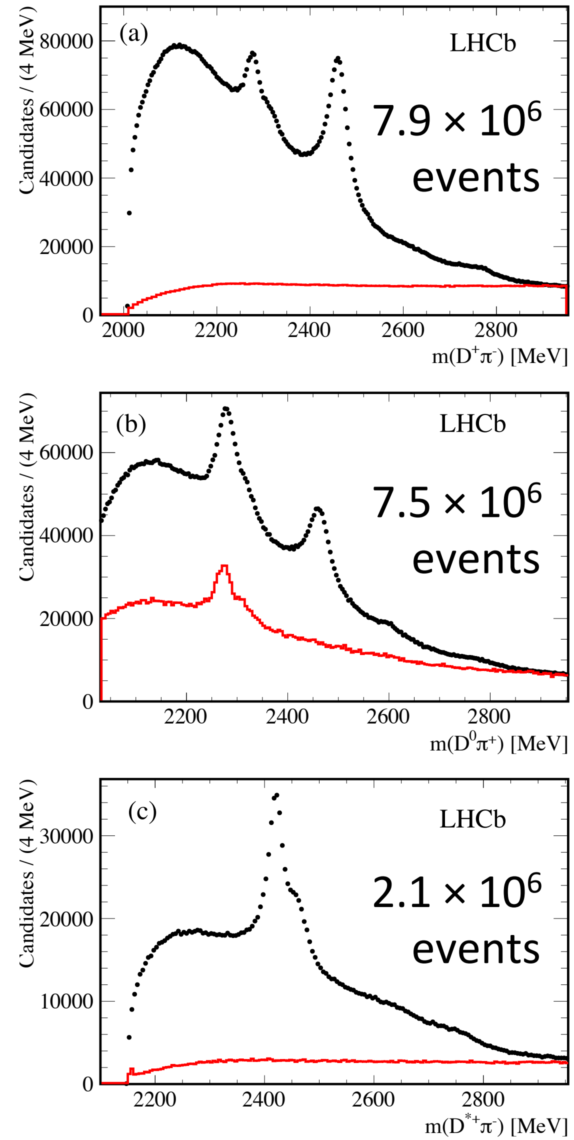
$$
\begin{aligned}
M(D^0) &= 1864.75 \pm 0.15\,(\text{stat}) \pm 0.11\,(\text{syst})\ \text{MeV}/c^2, \\
M(D^+) - M(D^0) &= 4.76 \pm 0.12\,(\text{stat}) \pm 0.07\,(\text{syst})\ \text{MeV}/c^2, \\
M(D_s^+) - M(D^+) &= 98.68 \pm 0.03\,(\text{stat}) \pm 0.04\,(\text{syst})\ \text{MeV}/c^2.
\end{aligned}
$$

- Dominant systematic uncertainty is from the knowledge of the detector momentum scale
- Combining with PDG values, can determine more precise value for D_s mass:

$$M(D_s^+) = 1968.19 \pm 0.20 \pm 0.14 \pm 0.08\,\text{MeV}/c^2,$$

Excited *D* meson states

- Search for D_J states decaying to $D^+\pi^-$, $D^0\pi^+$ and $D^{*+}\pi^-$
  - $D^+ \longrightarrow K^-\pi^+\pi^+$, $D^0 \longrightarrow K^-\pi^+$ and $D^{*+} \longrightarrow D^0\pi^+$
- *D* candidates required to be produced at primary collision vertex to reduce contributions from *b*-hadron decays
- $D^+\pi^-$ and $D^0\pi^+$ spectra contain cross feed from the decay of $D_1(2420)$ or $D_2^*(2460)$ to $D^*\pi$ where the π^0 or γ from the D^* decay is lost
- The wrong-sign spectra are also studied as cross-checks
  - (Shown in red)



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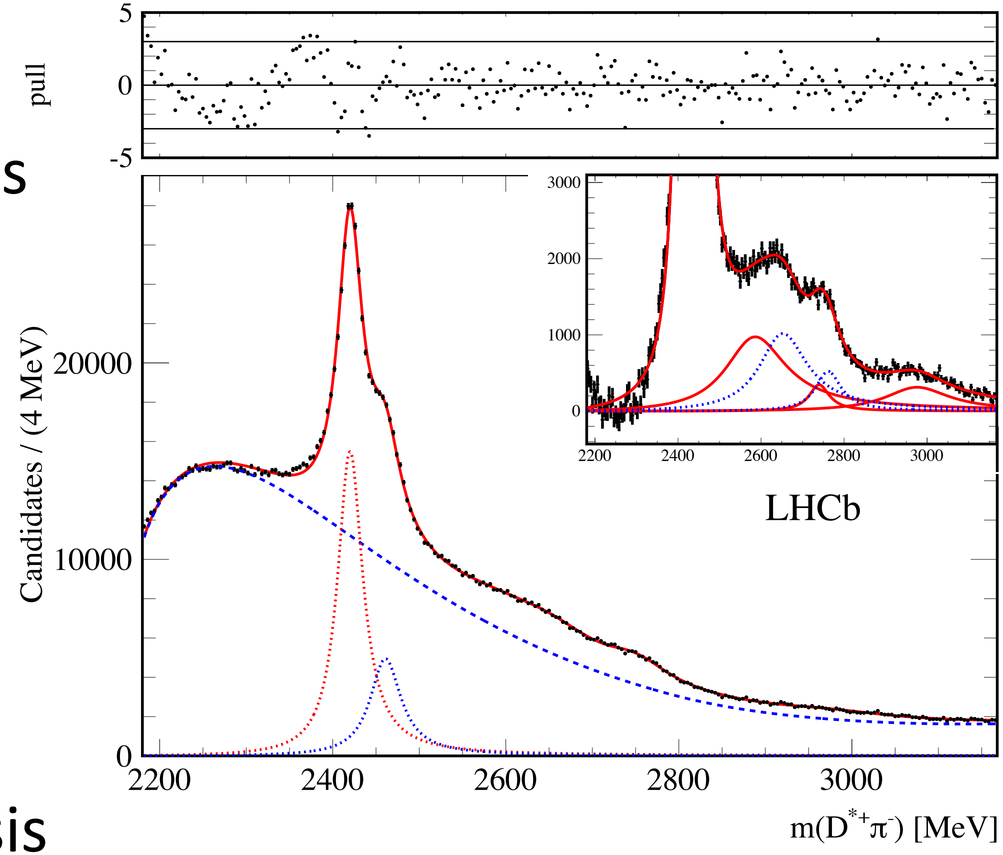
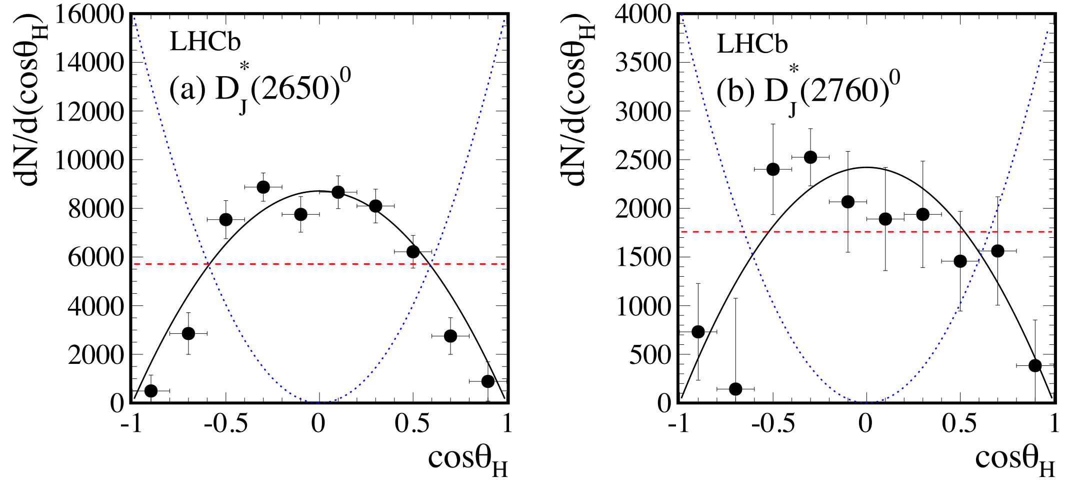
Excited *D* meson states

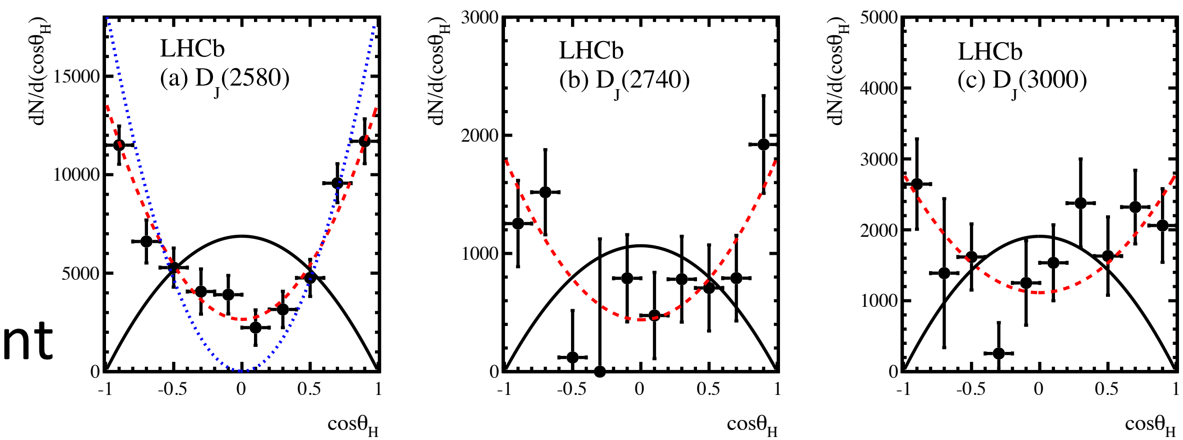
- First examine the $D^{*}\pi$ spectrum
- Fit includes contributions from well established $D_1(2420)$ and $D_2^*(2460)$ plus 5 further states:
  - $D_J(2580)$, $D_J(2650)$, $D_J(2740)$, $D_J(2760)$, $D_J(3000)$
- Three-body final state allows spin-parity analysis



Excited *D* meson states

- Use angle between two pions in the rest frame of the $D^{*}\pi$ system (θ_H)
  - Natural parity:
    - $\sin^2(\theta_H)$
  - Unnatural parity:
    - $1 + h\cos^2(\theta_H)$
- Fit mass spectrum in bins of $\cos(\theta_H)$ to determine yields of each contribution
- Use the $\cos(\theta_H)$ distribution to make spin-parity assignment





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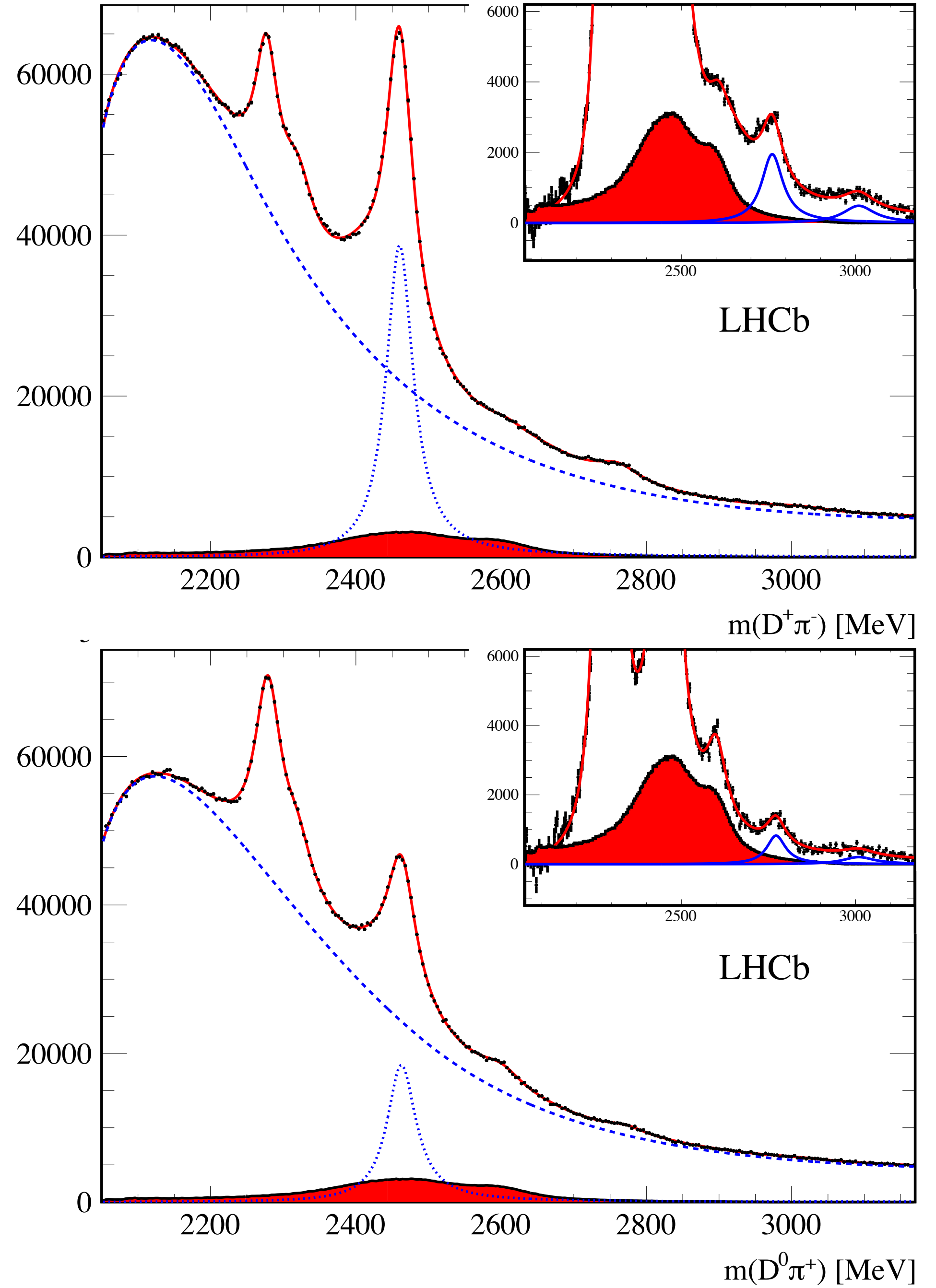
- Use the $D^{*}\pi$ results to include a cross feed component into the $D\pi$ spectra (solid red histo)
- Expect contributions from the natural parity states $D_J(2650)$ and $D_J(2760)$
- The $D_J(2760)$ is clearly present but the fit to the $D_J(2650)$ is complicated by the cross feeds
- Mass and width measurements of $D_J(2650)$ are therefore reported only from the $D^{*}\pi$ fit
- Fits also require a broad structure around 3000 MeV



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Excited *D* meson states

Resonance	Final state	Mass (MeV)	Width (MeV)	Yields $\times 10^3$	Significance (σ)
$D_1(2420)^0$	$D^{*+}\pi^-$	$2419.6 \pm 0.1 \pm 0.7$	$35.2 \pm 0.4 \pm 0.9$	$210.2 \pm 1.9 \pm 0.7$	
$D_2^*(2460)^0$	$D^{*+}\pi^-$	$2460.4 \pm 0.4 \pm 1.2$	$43.2 \pm 1.2 \pm 3.0$	$81.9 \pm 1.2 \pm 0.9$	
$D_J^*(2650)^0$	$D^{*+}\pi^-$	$2649.2 \pm 3.5 \pm 3.5$	$140.2 \pm 17.1 \pm 18.6$	$50.7 \pm 2.2 \pm 2.3$	24.5
$D_J^*(2760)^0$	$D^{*+}\pi^-$	$2761.1 \pm 5.1 \pm 6.5$	$74.4 \pm 3.4 \pm 37.0$	$14.4 \pm 1.7 \pm 1.7$	10.2
$D_J(2580)^0$	$D^{*+}\pi^-$	$2579.5 \pm 3.4 \pm 5.5$	$177.5 \pm 17.8 \pm 46.0$	$60.3 \pm 3.1 \pm 3.4$	18.8
$D_J(2740)^0$	$D^{*+}\pi^-$	$2737.0 \pm 3.5 \pm 11.2$	$73.2 \pm 13.4 \pm 25.0$	$7.7 \pm 1.1 \pm 1.2$	7.2
$D_J(3000)^0$	$D^{*+}\pi^-$	2971.8 ± 8.7	188.1 ± 44.8	9.5 ± 1.1	9.0
$D_2^*(2460)^0$	$D^+\pi^-$	$2460.4 \pm 0.1 \pm 0.1$	$45.6 \pm 0.4 \pm 1.1$	$675.0 \pm 9.0 \pm 1.3$	
$D_J^*(2760)^0$	$D^+\pi^-$	$2760.1 \pm 1.1 \pm 3.7$	$74.4 \pm 3.4 \pm 19.1$	$55.8 \pm 1.3 \pm 10.0$	17.3
$D_J^*(3000)^0$	$D^+\pi^-$	3008.1 ± 4.0	110.5 ± 11.5	17.6 ± 1.1	21.2
$D_2^*(2460)^+$	$D^0\pi^+$	$2463.1 \pm 0.2 \pm 0.6$	$48.6 \pm 1.3 \pm 1.9$	$341.6 \pm 22.0 \pm 2.0$	
$D_J^*(2760)^+$	$D^0\pi^+$	$2771.7 \pm 1.7 \pm 3.8$	$66.7 \pm 6.6 \pm 10.5$	$20.1 \pm 2.2 \pm 1.0$	18.8
$D_J^*(3000)^+$	$D^0\pi^+$	3008.1 (fixed)	110.5 (fixed)	7.6 ± 1.2	6.6

- Tentative spin parity assignments made comparing measured parameter values and results of spin-parity analysis
- $D_J(2580)$: 2S state with $J^P = 0^-$
- $D_J(2650)$: 2S state with $J^P = 1^-$
- $D_J(2760)$: 1D state with $J^P = 1^-$
- $D_J(2740)$: 1D state with $J^P = 2^-$ (although the measured and predicted mass do not agree well)

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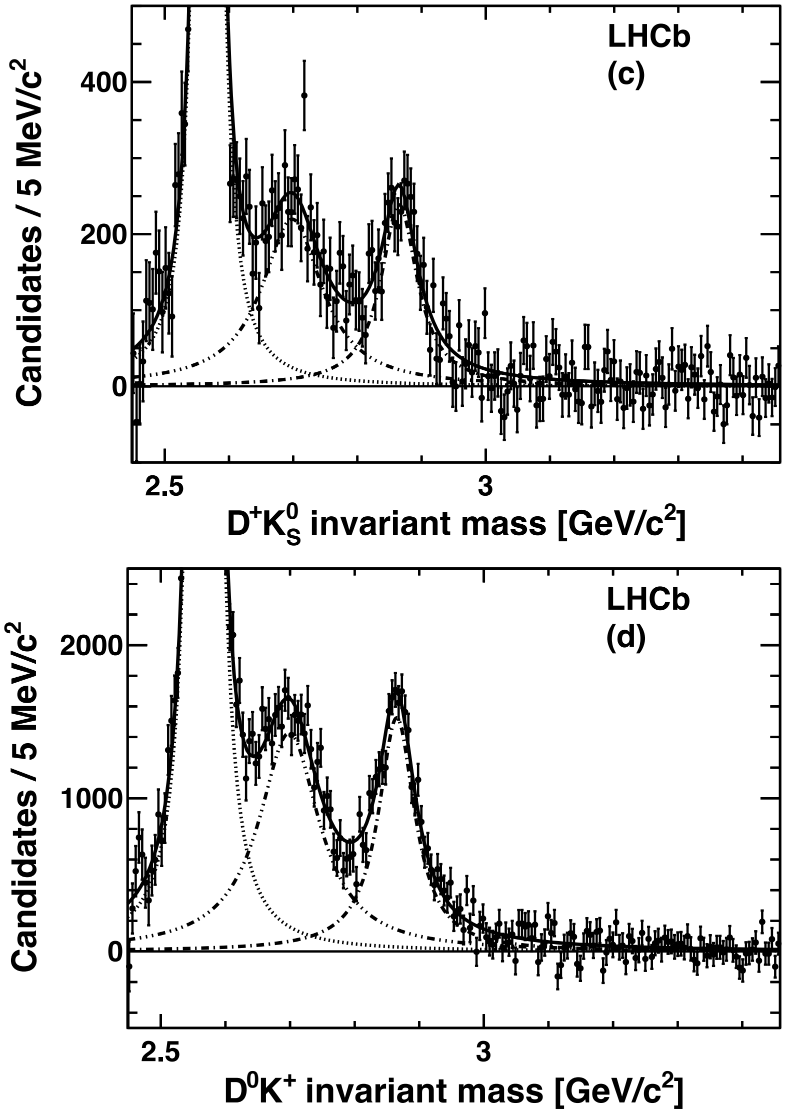
Excited D_s meson states

- Similar study of D_{sJ} states decaying to $D^+K^0_S$ and D^0K^+
- Confirms the existence of $D_{s1}^*(2700)$ and $D_{sJ}^*(2860)$ states seen by the *B*-factory analyses
  - First observations of these states in hadronic interactions
- Measure their parameters to be consistent with *B*-factory measurements:

$$m(D^*_{s1}(2700)^+) = 2709.2 \pm 1.9(\text{stat}) \pm 4.5(\text{syst})\ \text{MeV}/c^2,$$
$$\Gamma(D^*_{s1}(2700)^+) = 115.8 \pm 7.3(\text{stat}) \pm 12.1(\text{syst})\ \text{MeV}/c^2,$$
$$m(D^*_{sJ}(2860)^+) = 2866.1 \pm 1.0(\text{stat}) \pm 6.3(\text{syst})\ \text{MeV}/c^2,$$
$$\Gamma(D^*_{sJ}(2860)^+) = 69.9 \pm 3.2(\text{stat}) \pm 6.6(\text{syst})\ \text{MeV}/c^2.$$



Charmonium(-like)

Phys. Rev. Lett. 111 (2013) 112003

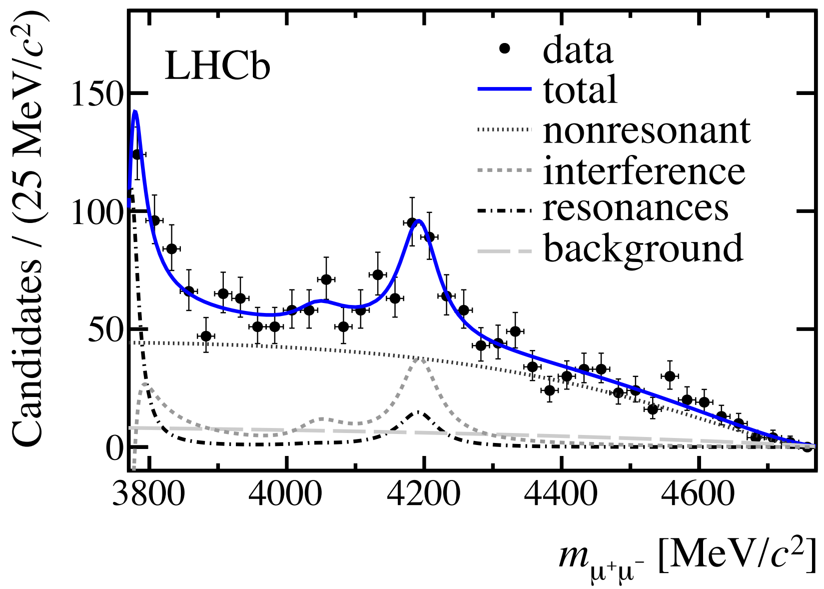
$B^+ \longrightarrow \psi(4160)\, K^+$

- $B^+ \longrightarrow K^+\mu^+\mu^-$ decays used to probe contributions to the loop processes from new physics amplitudes
- Important to understand the tree-level contributions via vector charmonium resonances
- Dedicated analysis of the decays $B^+ \longrightarrow K^+\mu^+\mu^-$ above open-charm threshold
- Require highly displaced vertex to remove combinatorial backgrounds
- Backgrounds from *B* decays reduced with strong particle identification criteria and vetoes on misidentified μ^-K^+ combinations
- Fit to the *B*-candidate invariant mass used to estimate background level

Phys. Rev. Lett. 111 (2013) 112003

$B^+ \longrightarrow \psi(4160)\ K^+$

- $\mu^+\mu^-$ invariant mass resolution improved using constraints on the vertex fit:
  - Candidate invariant mass constrained to nominal *B* mass
  - Candidate momentum must point back to associated primary vertex
- Fit includes terms for:
  - Vector and axial vector nonresonant
  - Vector resonances (including $\psi(3770)$ – on far left of plot)
  - Interference between the resonances and vector NR

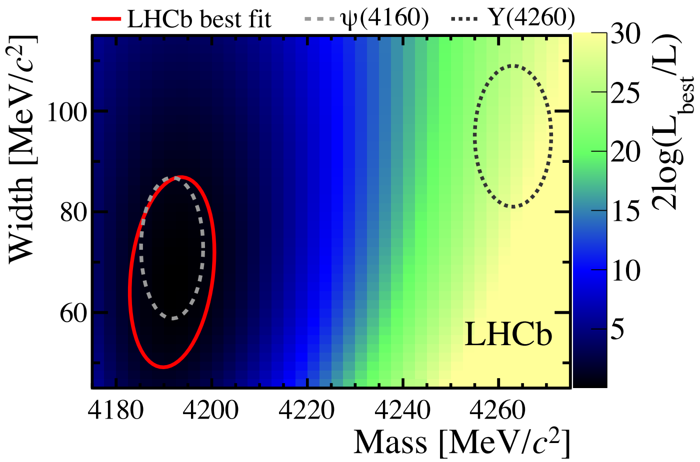


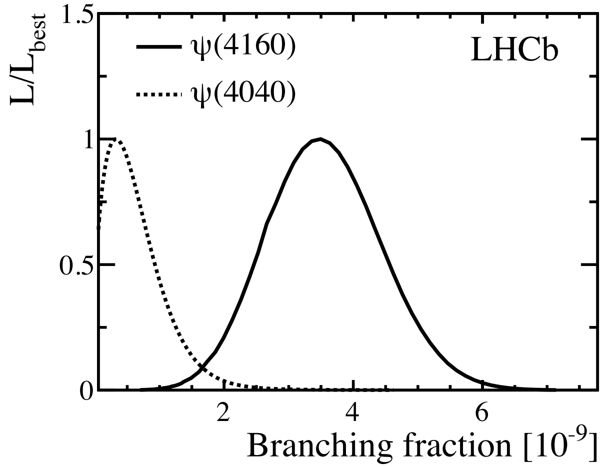
- Contributions for $\psi(4160)$ and $\psi(4040)$ are included
- $\psi(4160)$ is observed with significance > 6σ
- Signal yield for $\psi(4040)$ is not significant

Phys. Rev. Lett. 111 (2013) 112003

$B^+ \longrightarrow \psi(4160)\ K^+$

- First observations of the decays $B^+ \longrightarrow \psi(4160)K^+$ and $\psi(4160) \longrightarrow \mu^+\mu^-$
- Mass and width are consistent with previous measurements
- Branching fraction: $(5.1 \pm 1.3 \pm 3.0) \times 10^{-4}$ assuming lepton universality
- Contribution from $\psi(4160)$ is ~20% of total signal in low-recoil region – larger than theoretical estimates





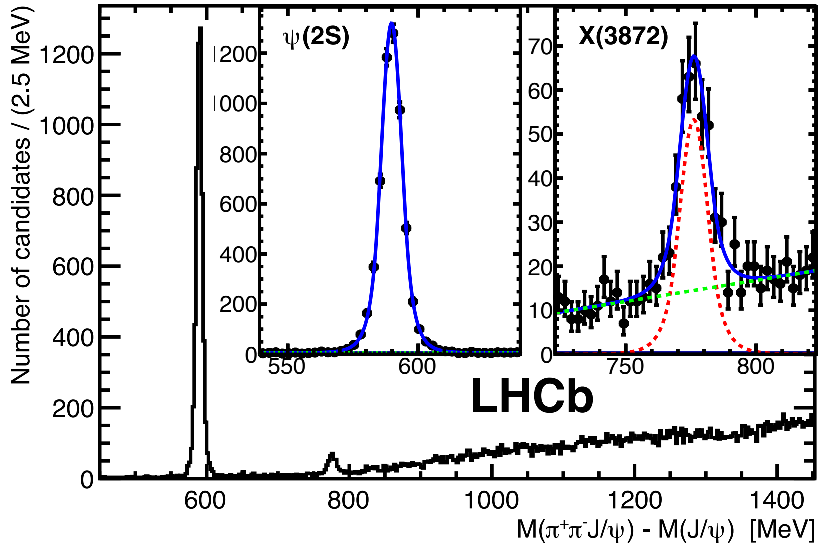
Properties of $X(3872)$

- The nature of the $X(3872)$ particle remains unclear over 10 years after its discovery by Belle
- Possibilities include conventional charmonium or exotic states like tetra-quarks or D^*D molecules
  - Including latest m(D^0) result (presented earlier) in determination of $X(3872) = D^*D$ molecule binding energy gives $E_B = 0.09 \pm 0.28$ MeV/c^2
  - i.e. if it is a molecular bound state it is very loosely bound
- Its quantum numbers are important inputs to the puzzle
  - Possible values reduced to $J^{PC} = 1^{++}$ or 2^{-+} by a 3D angular analysis by the CDF collaboration
- LHCb have performed the first 5D angular analysis of the decay chain $B^+ \longrightarrow X(3872)K^+$, $X(3872) \longrightarrow J/\psi\pi\pi$, $J/\psi \longrightarrow \mu\mu$
  - The similar decay substituting the $\psi(2S)$ for the $X(3872)$ is used as a control sample for many aspects of the analysis

Phys. Rev. Lett. 110 (2013) 222001

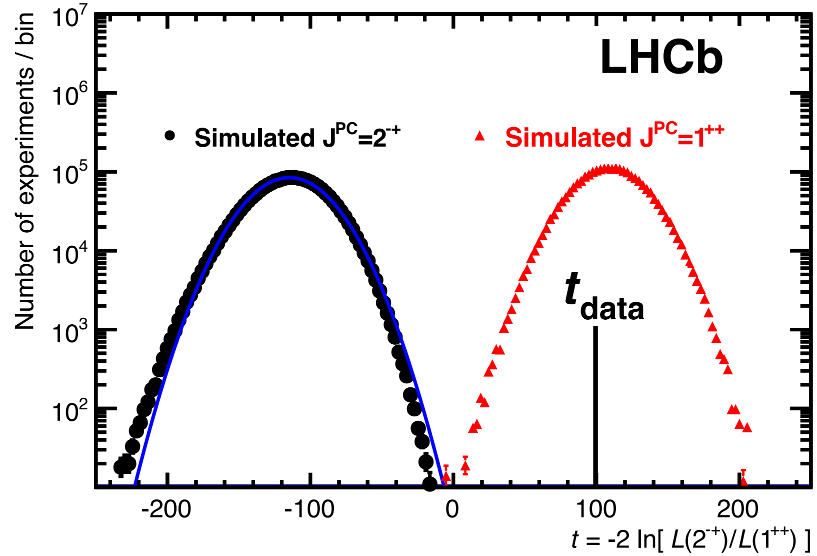
Properties of *X*(3872)

- Likelihood ratio constructed using the PDFs of the 5D angular space:
  - *X*, J/ψ and $\pi\pi$ helicity angles
  - angle between *X* and J/ψ decay planes
  - angle between *X* and $\pi\pi$ decay planes
- Angular distributions are constructed in the helicity formalism
  - 2 free parameters are floated in the fit to data



- 2^{-+} hypothesis is excluded at 8.4σ
- Angular parameters agree well with Belle values and values obtained from fitting 1^{++} simulation

- This result rules out the *X*(3872) being the $\eta_{c2}(1^1D_2)$ conventional charmonium state



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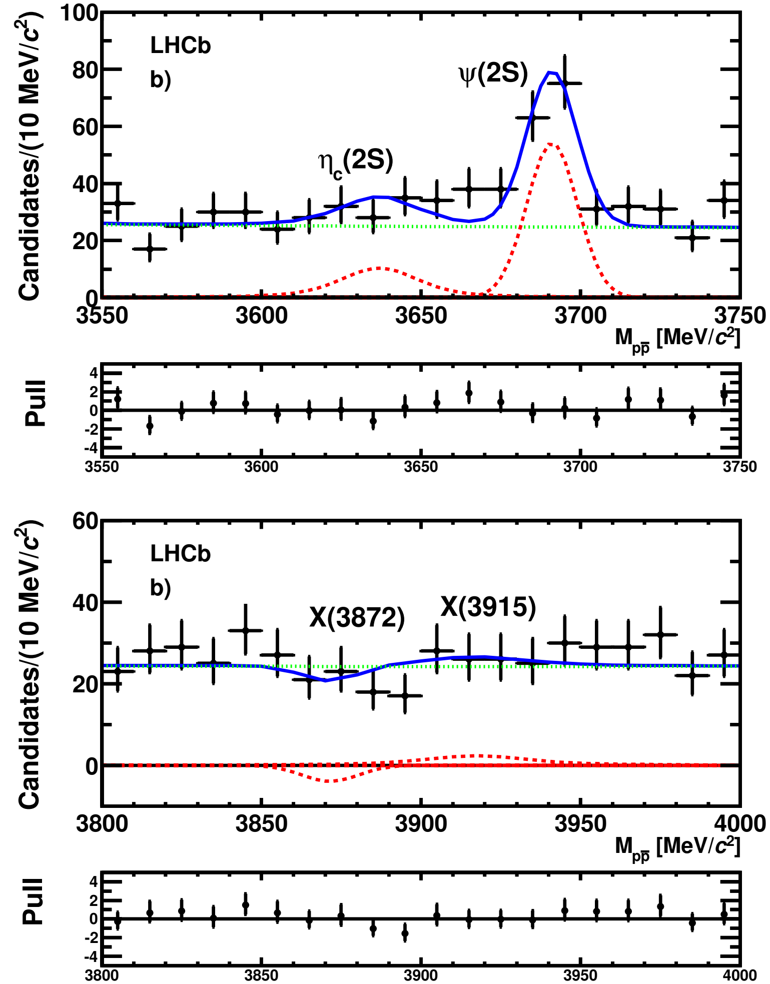
Eur. Phys. J. C 73 (2013) 2462

Properties of *X*(3872)

- A separate analysis of $B^+ \longrightarrow p\bar{p}K^+$ decays places limits on branching fraction of $X(3872) \longrightarrow p\bar{p}$
- Fits are performed to the ppbar invariant mass spectrum, including background, nonresonant and resonant terms
- No significant signal is observed for the *X*(3872) decay and a limit is placed on the BF of:

$$\frac{\mathcal{B}(X(3872)\to p\bar{p})}{\mathcal{B}(X(3872)\to J/\psi\pi^+\pi^-)} < 2.0\times 10^{-3}$$

- This value is in tension with some predictions based on the molecular interpretation of the state [Phys. Rev. D77 (2008) 034019]

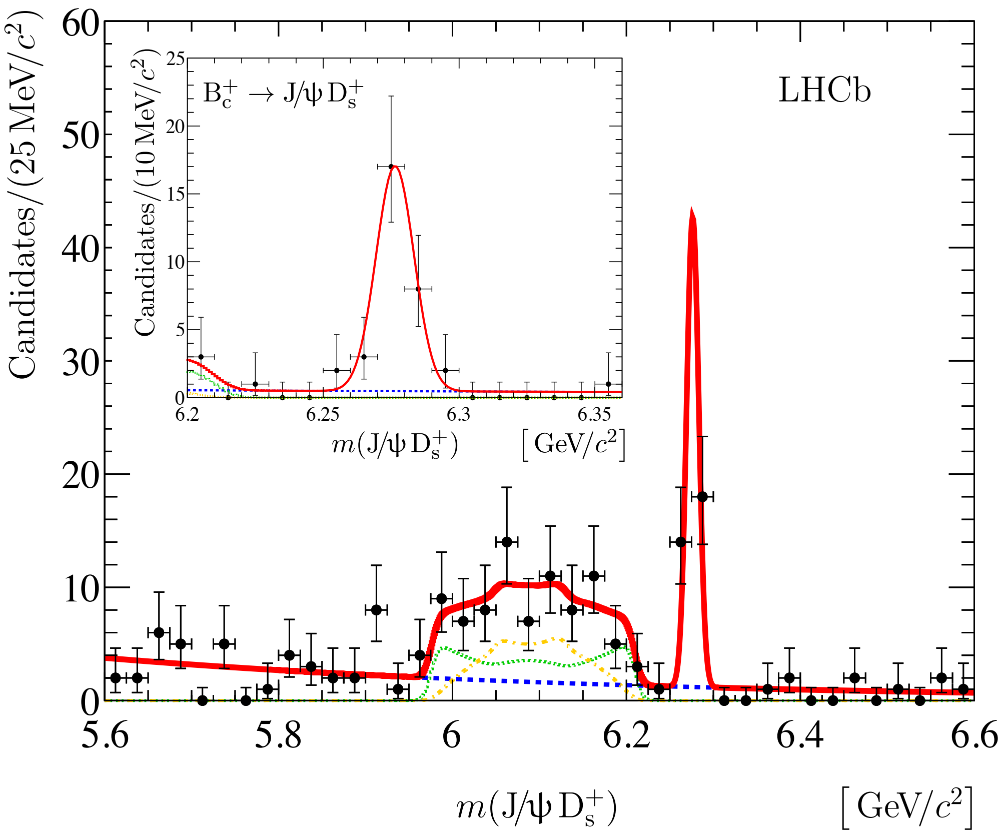


B_c properties

Mass of the B_c meson

- Properties of B_c meson are still rather poorly determined
- Lifetime is rather shorter than other B mesons
  - Indicates importance of charm quark in the weak decay
  - See also recent LHCb observation of $B_c \longrightarrow B_s\,\pi$

  [Phys. Rev. Lett. 111 (2013) 181801]
- Recent observation of B_c decays to $J/\psi\ D_s$ provide a way to reduce the systematic uncertainty on the mass measurement
- Obtains a yield of 29 signal events



Phys. Rev. D87 (2013) 112012

Mass of the B_c meson

- Mass determination makes use of recent improvement in D_s mass measurement (discussed earlier)
- Also helped by low Q-value for the decay
- Dominant systematics from knowledge of momentum scale and detector material
- Mass determined to be:

$$m(B_c) = 6276.28 \pm 1.44 \pm 0.36\ \mathrm{MeV}/c^2$$

- Uncertainties on momentum scale and D_s mass largely cancel in the mass difference:

$$m(B_c) - m(D_s) = 4307.97 \pm 1.44 \pm 0.20\ \mathrm{MeV}/c^2$$

Baryons

arXiv:1310.2538 [hep-ex]
Submitted to JHEP

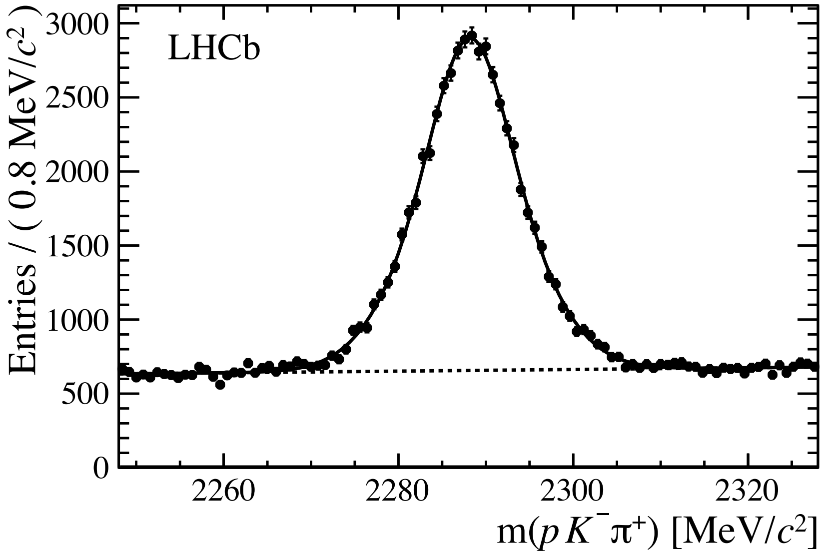
Search for Ξ_{cc}^+ baryon

- Signals claimed by SELEX collaboration for Ξ_{cc}^+ decaying to both $\Lambda_c^+ K^- \pi^+$ and $D^+ p K^-$
- In contrast, *B*-factories and FOCUS have found no evidence

- Search for Ξ_{cc}^+ decaying to $\Lambda_c^+ K^- \pi^+$
- Production cross-section determined relative to that of Λ_c^+

$$R \equiv \frac{\sigma\left(\Xi_{cc}^{+}\right) \mathrm{BF}\left(\Xi_{cc}^{+} \to \Lambda_c^{+} K^{-} \pi^{+}\right)}{\sigma\left(\Lambda_c^{+}\right)}$$

- Both the Ξ_{cc}^+ and Λ_c^+ candidates are required to have vertices displaced from the primary collision vertex

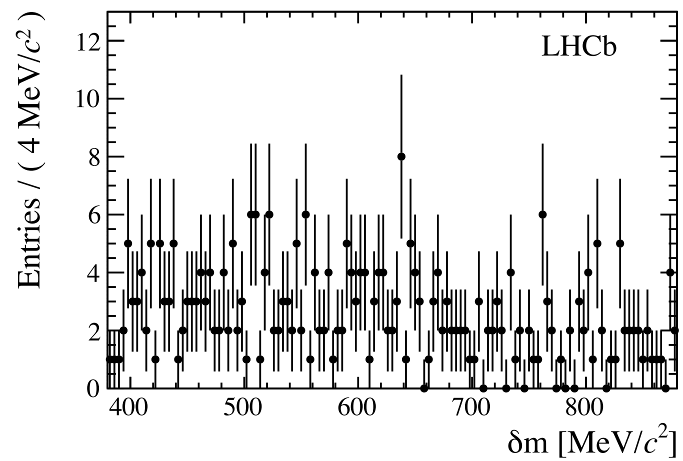


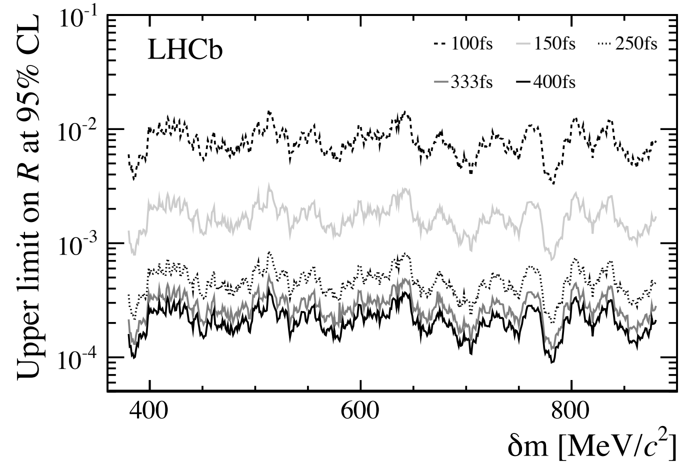
- The Λ_c^+ is reconstructed decaying to $pK^-\pi^+$ and same Λ_c^+ selection is applied in both signal & normalisation modes
- Λ_c^+ candidate invariant mass required to be within 2273 – 2303 MeV/c^2 window

arXiv:1310.2538 [hep-ex]
Submitted to JHEP

Search for Ξ_{cc}^{+} baryon

- Search is performed at 1 MeV steps in 10 MeV windows of the mass difference:
  $\delta m = m([pK^-\pi^+]\,K^-\pi^+) - m(pK^-\pi^+) - m(K^-) - m(\pi^+)$
- Events outside window used to subtract background (two different methods used as cross-check)
- Ratios of efficiencies calculated using simulation and correcting for known data/simulation differences
  - Variation as a function of lifetime and δm determined by reweighting
- No significant signals seen and upper limits on R are determined as a function of lifetime and δm
- The current results neither confirm nor exclude the SELEX observation





Phys. Rev. Lett. 110 (2013) 182001

Masses of Λ_b, Ξ_b^- and Ω_b^-

- Previous measurements of the Ω_b^- mass by CDF and D0 differ by more than 6σ
- The b-baryons are reconstructed in their decays to $J/\psi\ \Lambda$, $J/\psi\ \Xi^-$ and $J/\psi\ \Omega^-$, respectively
- The subsequent decays $\Xi^- \longrightarrow \Lambda\pi^-$ and $\Omega^- \longrightarrow \Lambda K^-$ are considered
- These decay chains contain several long-lived particles and hence have a characteristic event topology

Phys. Rev. Lett. 110 (2013) 182001

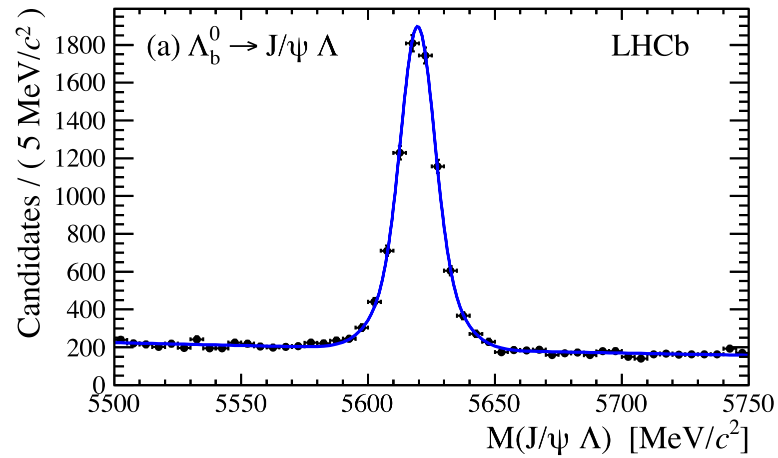
Masses of Λ_b, Ξ_b^- and Ω_b^-

- Masses measured with much improved precision
- Measurement of M(Ω_b^-) in agreement with CDF but not D0
- Mass differences also measured:

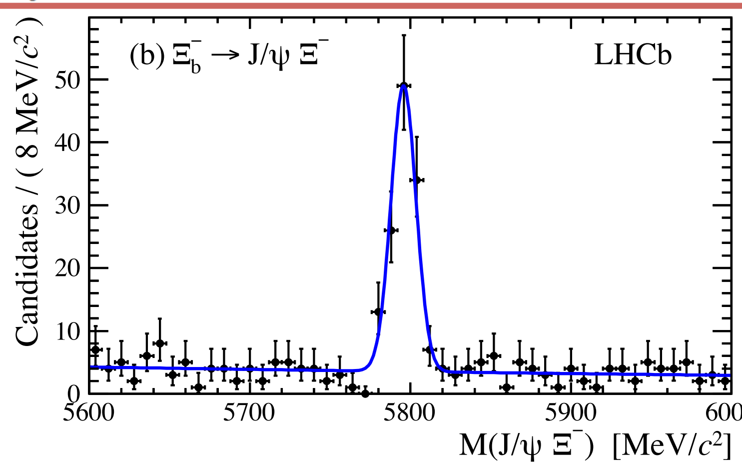
$$M(\Xi_b^-) - M(\Lambda_b^0) = 176.2 \pm 0.9\,(\text{stat}) \pm 0.1\,(\text{syst})\ \text{MeV}/c^2,$$
$$M(\Omega_b^-) - M(\Lambda_b^0) = 426.4 \pm 2.2\,(\text{stat}) \pm 0.4\,(\text{syst})\ \text{MeV}/c^2.$$

- Largest systematic uncertainties from momentum scale mostly cancel but those from hyperon masses remain

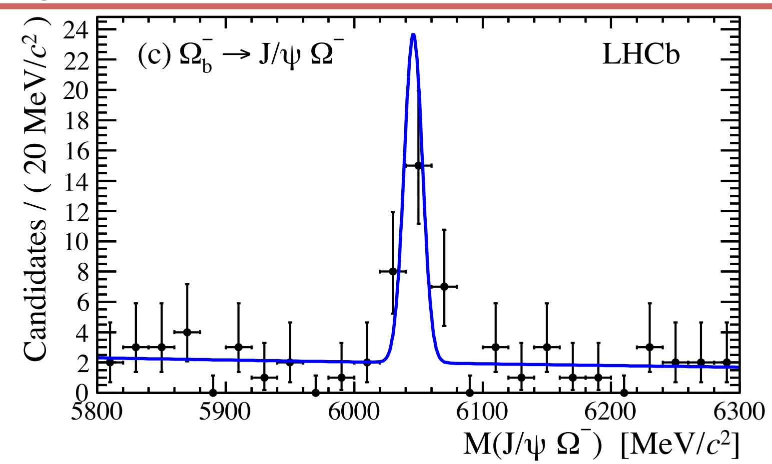
$$M(\Lambda_b^0) = 5619.53 \pm 0.13\,(\text{stat}) \pm 0.45\,(\text{syst})\ \text{MeV}/c^2$$



$$M(\Xi_b^-) = 5795.8 \pm 0.9\ (\text{stat}) \pm 0.4\ (\text{syst})\ \text{MeV}/c^2$$



$$M(\Omega_b^-) = 6046.0 \pm 2.2\ (\text{stat}) \pm 0.5\ (\text{syst})\ \text{MeV}/c^2$$

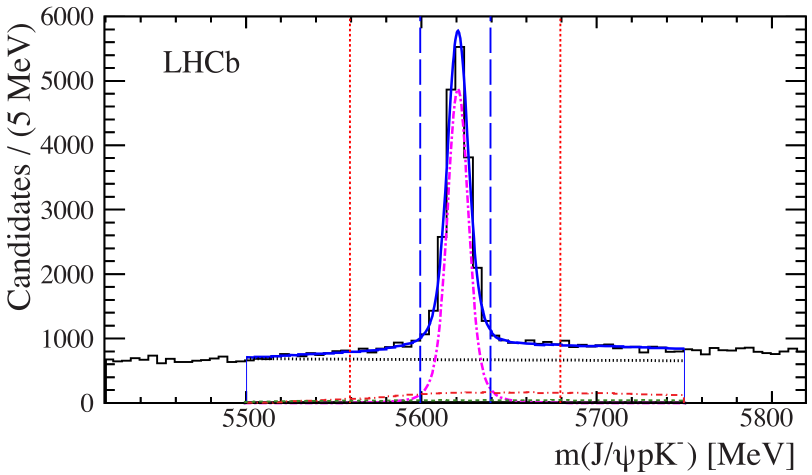


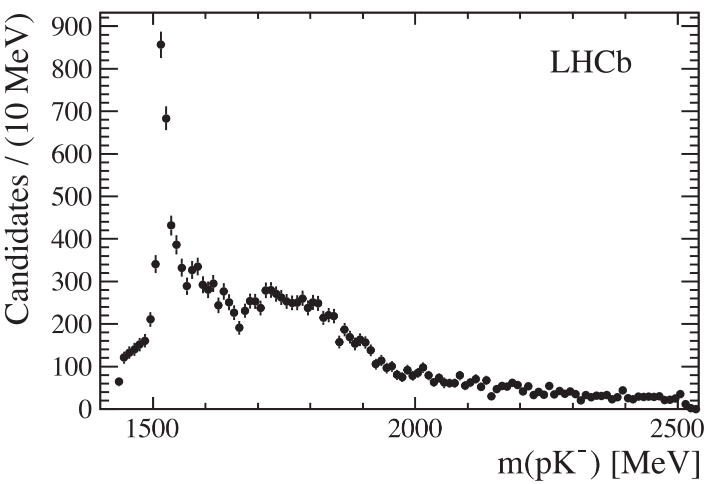
Phys. Rev. Lett. 111 (2013) 102003

Lifetime of Λ_b

- Previous measurements of the Λ_b lifetime found much smaller values than expected from HQE
- More recent measurements by ATLAS, CMS, CDF and D0 indicate larger values
- A precision measurement is needed to resolve the discrepancy
- This analysis uses decay $\Lambda_b \longrightarrow J/\psi\ p\ K^-$

- Measurement is made relative to B^0 lifetime in its decay to $J/\psi\ \pi^+ K^-$ (in region of $K^*(892)$ resonance)
- Topological and kinematic similarities allows cancellation of several systematic uncertainties
- Simulation reweighted to account for dynamics of Λ_b decay





Phys. Rev. Lett. 111 (2013) 102003

Lifetime of Λ_b

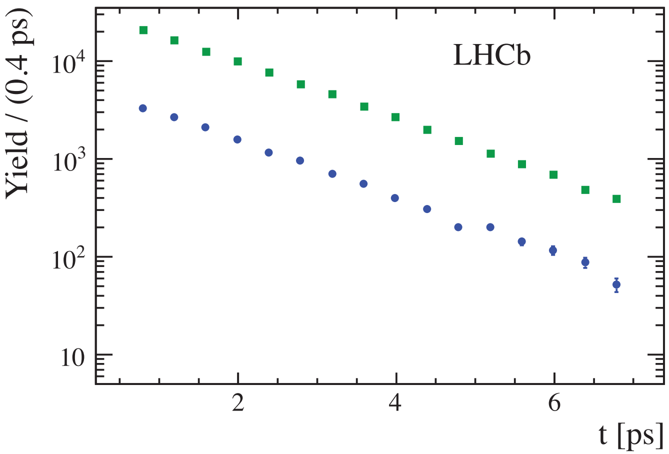
- Signal yield determined in bins of decay time distribution for both $\Lambda_b \longrightarrow J/\psi p K^-$ and $B^0 \longrightarrow J/\psi \pi^+ K^-$
- Yield ratio fitted allowing for differences in acceptance as a function of decay time
- Lifetime ratio:

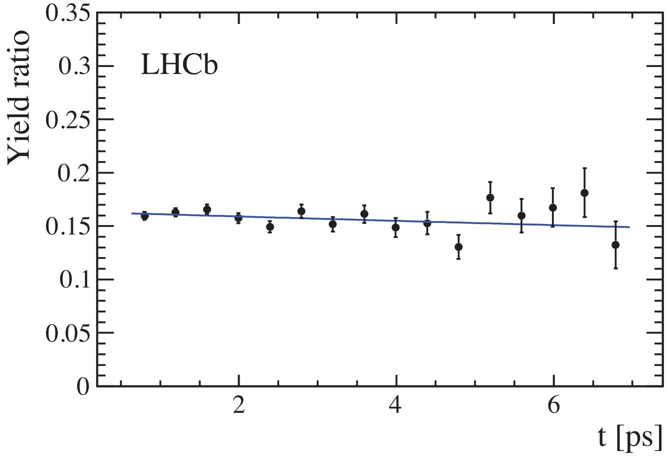
  0.976 ± 0.012 ± 0.006

- Using the world average B^0 lifetime (1.519 ± 0.007 ps):

  $\tau(\Lambda_b)$ = 1.482 ± 0.018 ± 0.012 ps

- Central value of ratio differs from unity by only few %
  - Indeed, is less than 2σ from unity
  - In agreement with HQE



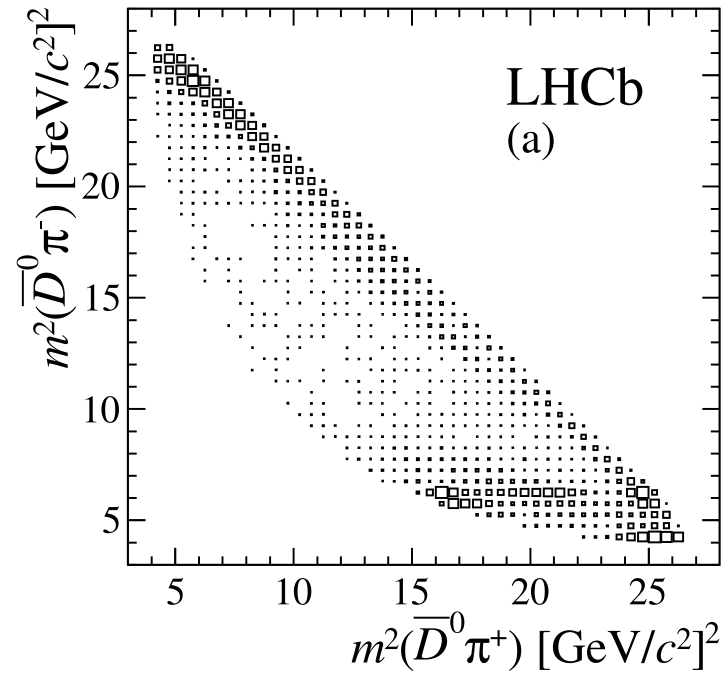


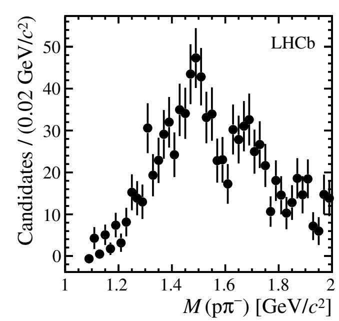
Conclusion

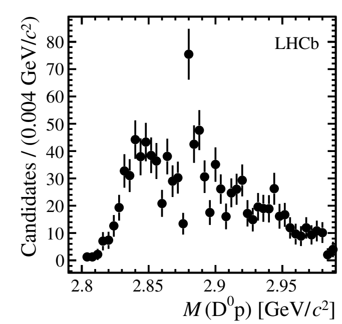
Future prospects

- Input on the f_0 mixing angle can also come from final states such as $D^0\pi\pi$
- Dalitz plot analyses of $D^{(*)}hh$ final states can also provide input on excited charm states, in particular determining their spin
- Charmless b-hadron decays can provide much input into light meson/baryon spectroscopy
  - In particular $B^+ \longrightarrow 3h$ and $p\bar{p}h$
  - Understanding the large CP-violation will require precise understanding of Dalitz-plot structure
- Charm baryons can also be studied in B decays such as those to $Dp\pi$ and DpK
- B_c and b-baryon lifetime measurements in the pipeline

Phys. Rev. D 87 (2013) 112009







arXiv:1311.4823 [hep-ex]

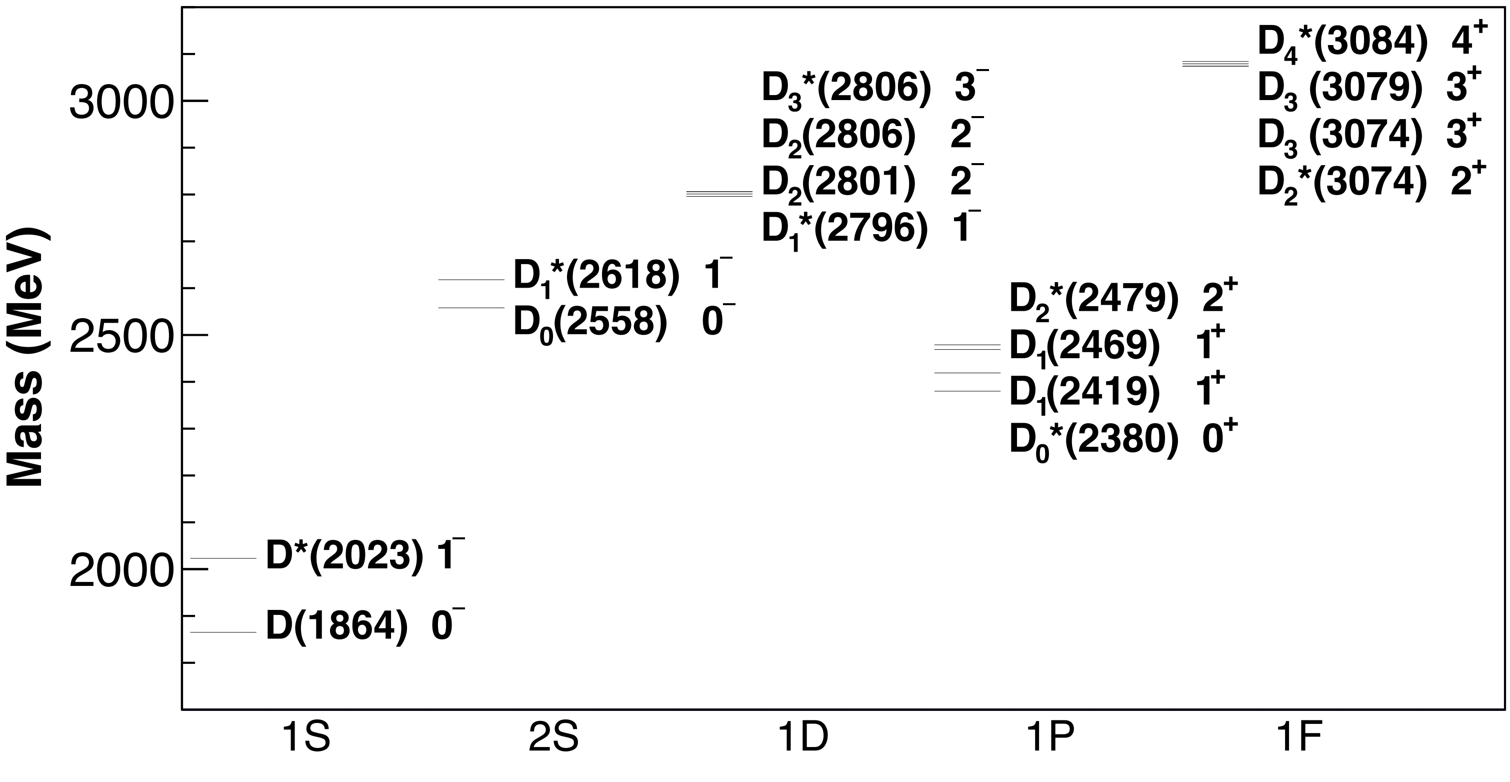
Summary

- A wealth of hadron spectroscopy results from LHCb in the last year
- Improved precision possible for some of the measurements using the combined 2011 + 2012 (1 fb^{-1} + 2 fb^{-1}) dataset
- Many more exciting results in the pipeline
- Watch this space!

Backup Slides

J. High Energy Phys. 09 (2013) 145

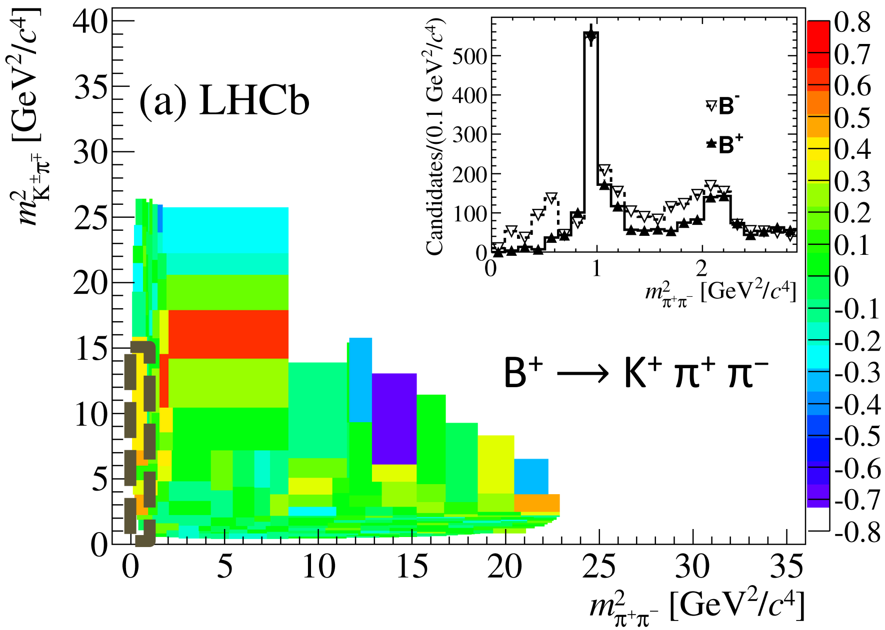
Excited *D* meson states

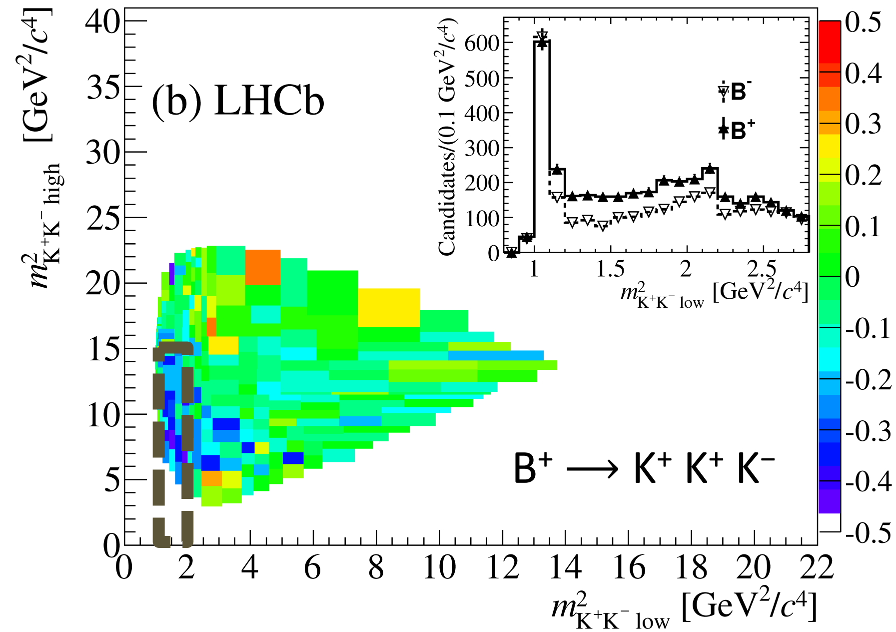


Modified Godfrey-Isgur mass predictions [Phys. Rev. D32 (1985) 189].
The spectrum is scaled such that the ground state coincides with the D^0 mass.

Phys. Rev. Lett. 111 (2013) 101801

CPV in $B^+ \longrightarrow K^+ h^+ h^-$





A_{CP}(local) = 0.678 ± 0.078 ± 0.032 ± 0.007

A_{CP}(local) = −0.226 ± 0.020 ± 0.004 ± 0.007

- Study variation of A_{raw} over Dalitz plot
- Some areas of phase space have very large asymmetries, e.g. region around ρ^0 resonance in $B^+ \longrightarrow K^+ \pi^+ \pi^-$ but also regions not clearly associated with a resonance, particularly in $B^+ \longrightarrow K^+ K^+ K^-$

Phys. Rev. Lett. 112 (2014) 011801

CPV in $B^+ \longrightarrow \pi^+ h^+ h^-$

- Again, asymmetries have opposite sign between the two modes
- Large localised asymmetries, not clearly associated with a narrow resonance

$A_{CP}(\text{local}) = 0.584 \pm 0.082 \pm 0.027 \pm 0.007$

$A_{CP}(\text{local}) = -0.648 \pm 0.070 \pm 0.013 \pm 0.007$