Heavy flavour physics at LHCb

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on behalf of the LHCb collaboration

Aspen Winter Conference

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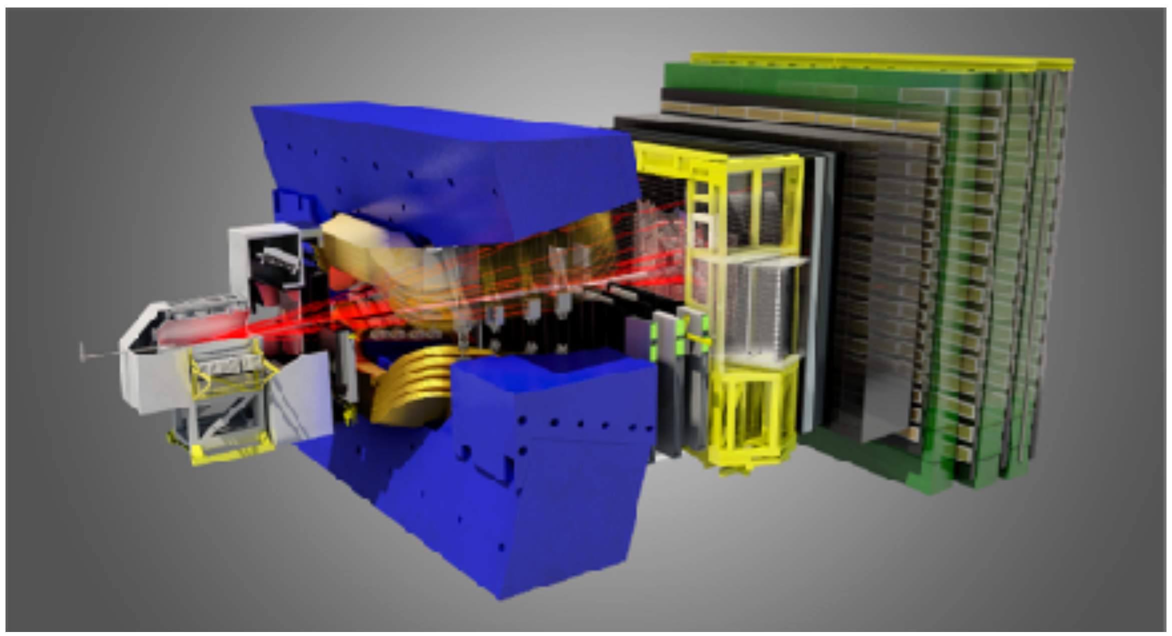
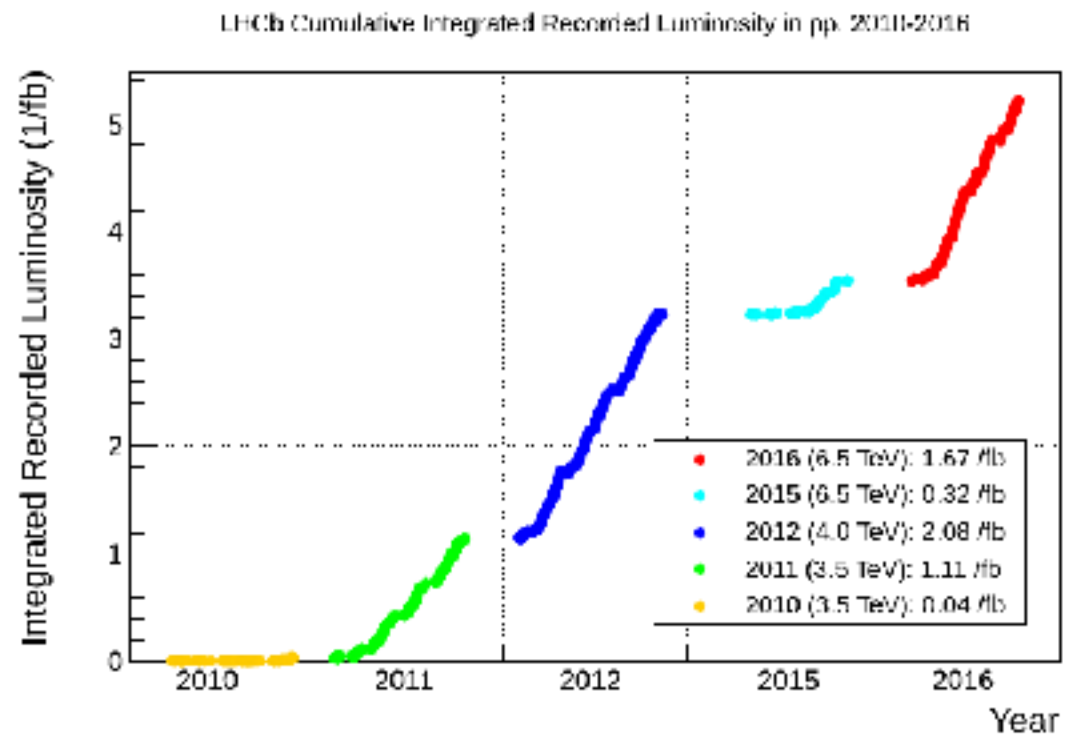
Universität Zürich[UZH]

LHCb status

- LHC experiment focussed on heavy flavour physics.
    - We do plenty more than this though - remember Mike's talk [here].

JINST 3 (2008) S08005





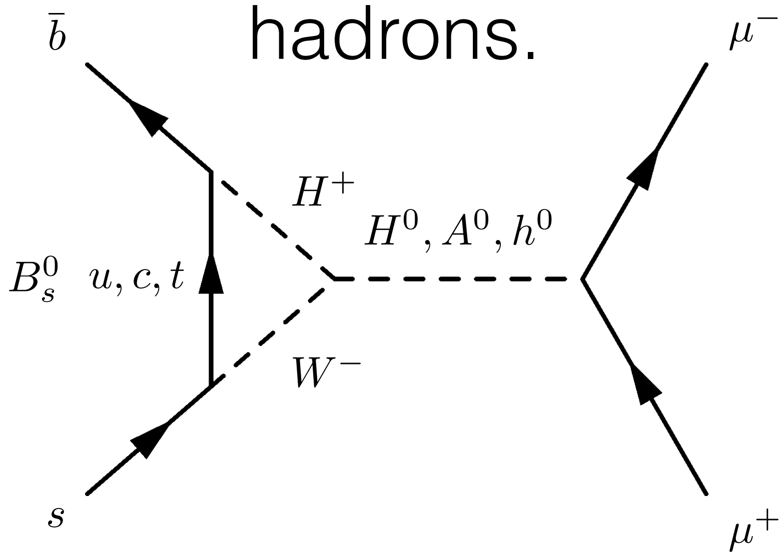
- Collected ~2.0fb^{-1} so far in the LHC run II (2015-2016).
    - In run II, calibration/alignment performed online to allow trigger objects to be used directly in analysis.
    - Hope to collect another 1.5fb^{-1} in 2017 - looking forward to the restart!

Quark flavour physics

- Quark flavour physics is the study of how different flavours of quarks interact.

Two main avenues in this field:

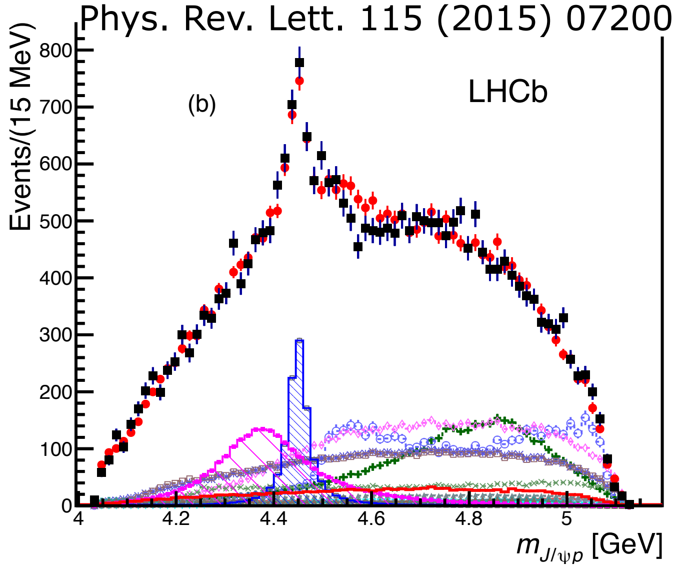
Indirectly search for New Physics	Study QCD
• Measure decays of ground-state hadrons.	• Always have some QCD uncertainty in SM predictions.



- Compare measurements with SM predictions.
- Precise tests of SM (CKM unitarity).
- Find new sources of CPV.

- Make auxiliary measurements to verify QCD effective theories (HQET).
- Study nature of bound states (spectroscopy)

Phys. Rev. Lett. 115 (2015) 072001



- And maybe find something exotic!

Quark [obscured] physics

TODAY

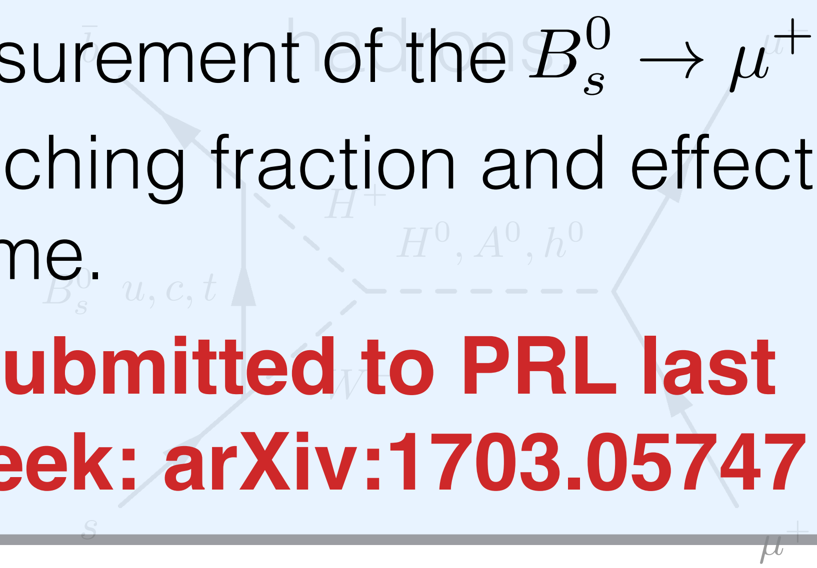
- Quark flavour physics is [obscured] different flavours of quarks interact.

Two ma[obscured]s field:

Indirectly search for New P[obscured]

Study QCD

- Measure decays of ground-state hadrons



Measurement of the $B_s^0 \to \mu^+\mu^-$ branching fraction and effective lifetime.

Submitted to PRL last week: arXiv:1703.05747

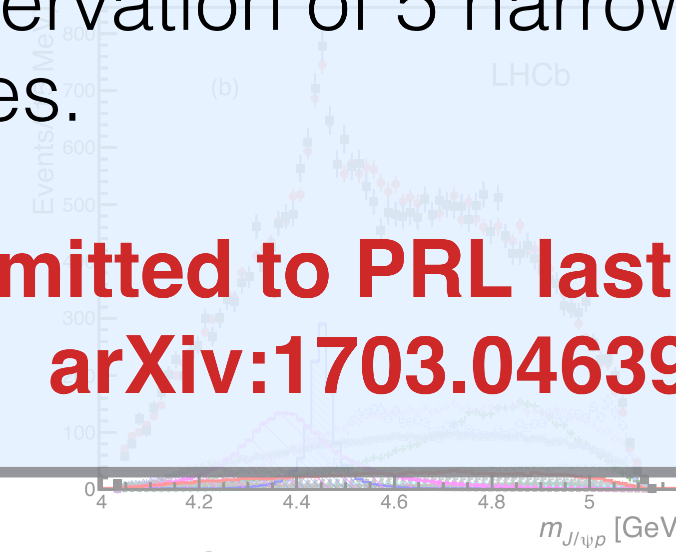
- Compare measurements with SM predictions.
- Test CKM matrix unitarity.
- Find new sources of CPV.

- Always have some QCD uncertainty [obscured]

Measurement of the B_s^0 and D_s^0 lifetimes.

LHCb-PAPER-2017-004: Presented for the first time at Lake Louise 2017

- Make auxiliary measurements to verify QCD effective theories (HQET).
- Study nature of bound states (spectroscopy)



Observation of 5 narrow Ω_c^0 states.

Submitted to PRL last week: arXiv:1703.04639.

- And maybe find something exotic!

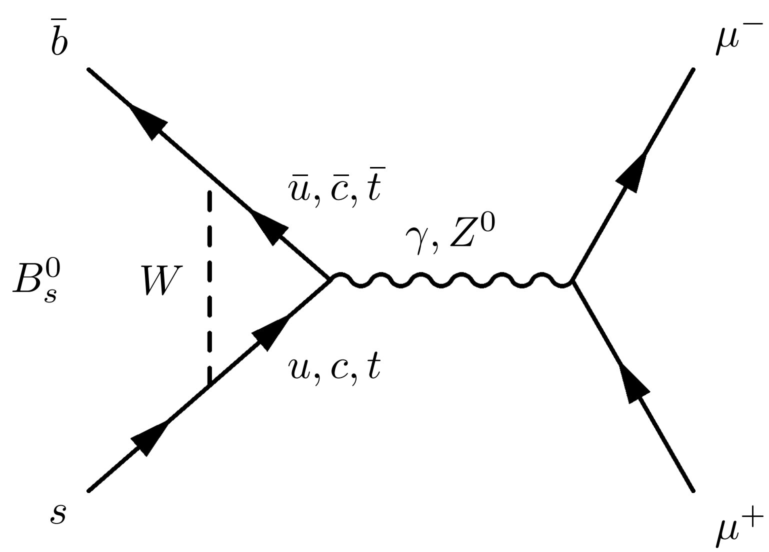
$$B^0_{(s)} \to \mu^+\mu^-$$

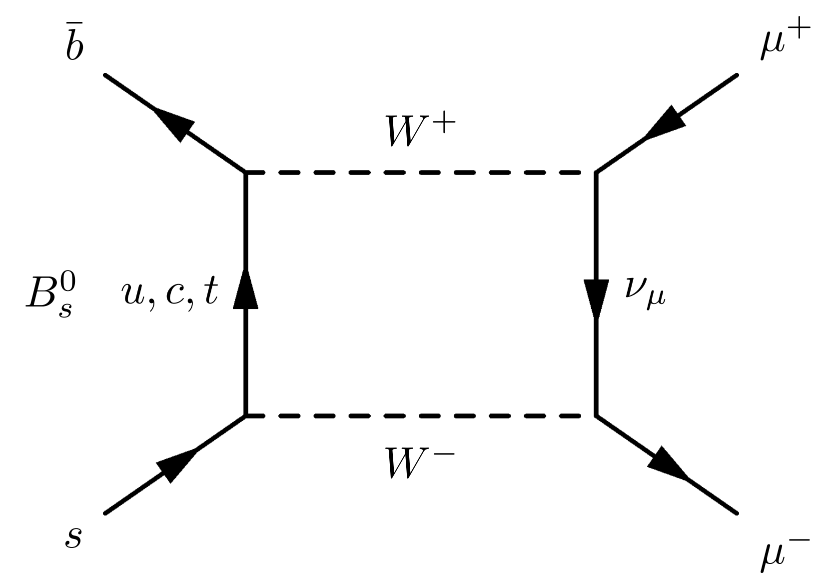
arXiv:1703.05747

The decay $B^0_{(s)} \to \mu^+\mu^-$

- One in every billion B_s^0 mesons decays into two muons

- For example, like this: Or this:





- The two things that make this decay special are:
  - Doubly suppressed (Helicity and GIM)
  - Good theoretical uncertainty (Lattice QCD needed for B meson decay constant).

arXiv:1703.05747

$B^0_{(s)} \to \mu^+\mu^-$ analysis in a nutshell

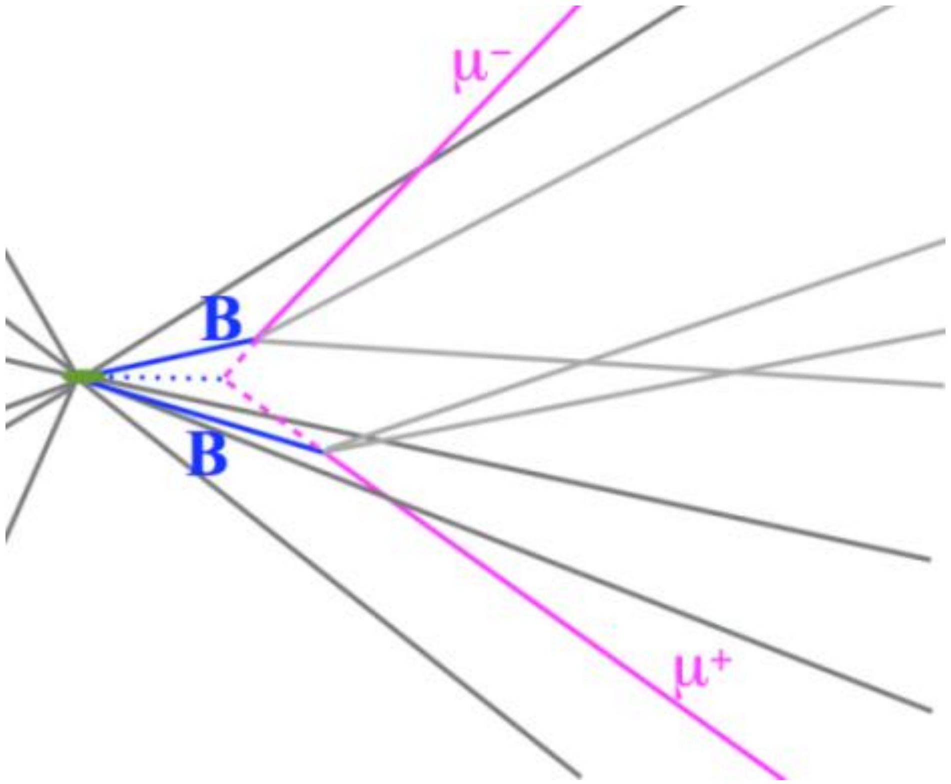
- Main challenge is to deal with huge background from random combinations of muons from different B decays.

  - $\mathcal{B}(B \to \mu X)$ ~ 10%, $\mathcal{B}(B^0_s \to \mu^+\mu^-)$ ~ 10^{-9}.

- Train multivariate selection to remove this.

- Dangerous peaking backgrounds from B—>hh and B—>μh.

- Normalise signal yield to $B^+ \to J/\psi K^+$ and $B^0 \to K^+\pi^-$ with the ratio of B_s/B^+ production fractions.



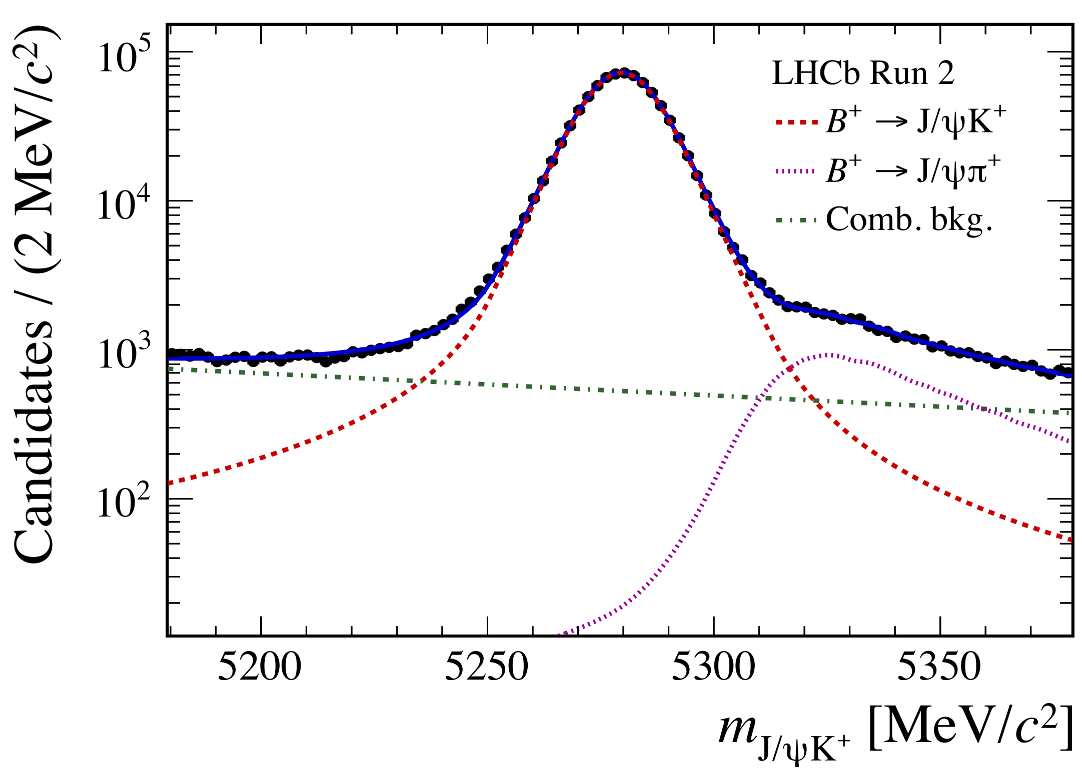
- Fit dimuon mass in bins of the multivariate response.

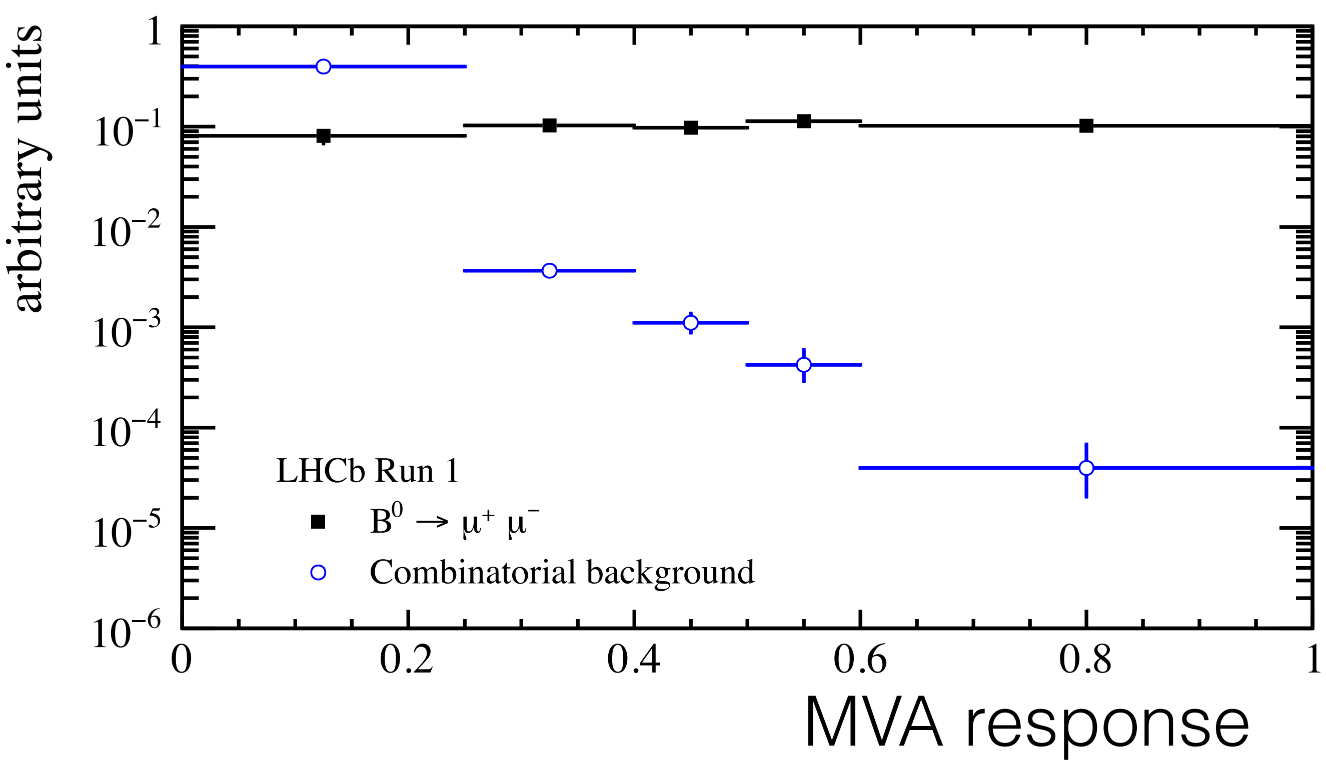
arXiv:1703.05747

New $B^0_{(s)} \to \mu^+\mu^-$ measurement

Nature 522, 68-72

- Update run 1 result (used in LHCb-CMS combination) to include 2015+2016 data.
- Significantly improve isolation algorithm (important input to MVA).
- Improve treatment of peaking backgrounds (look in data for mis-identified muons).



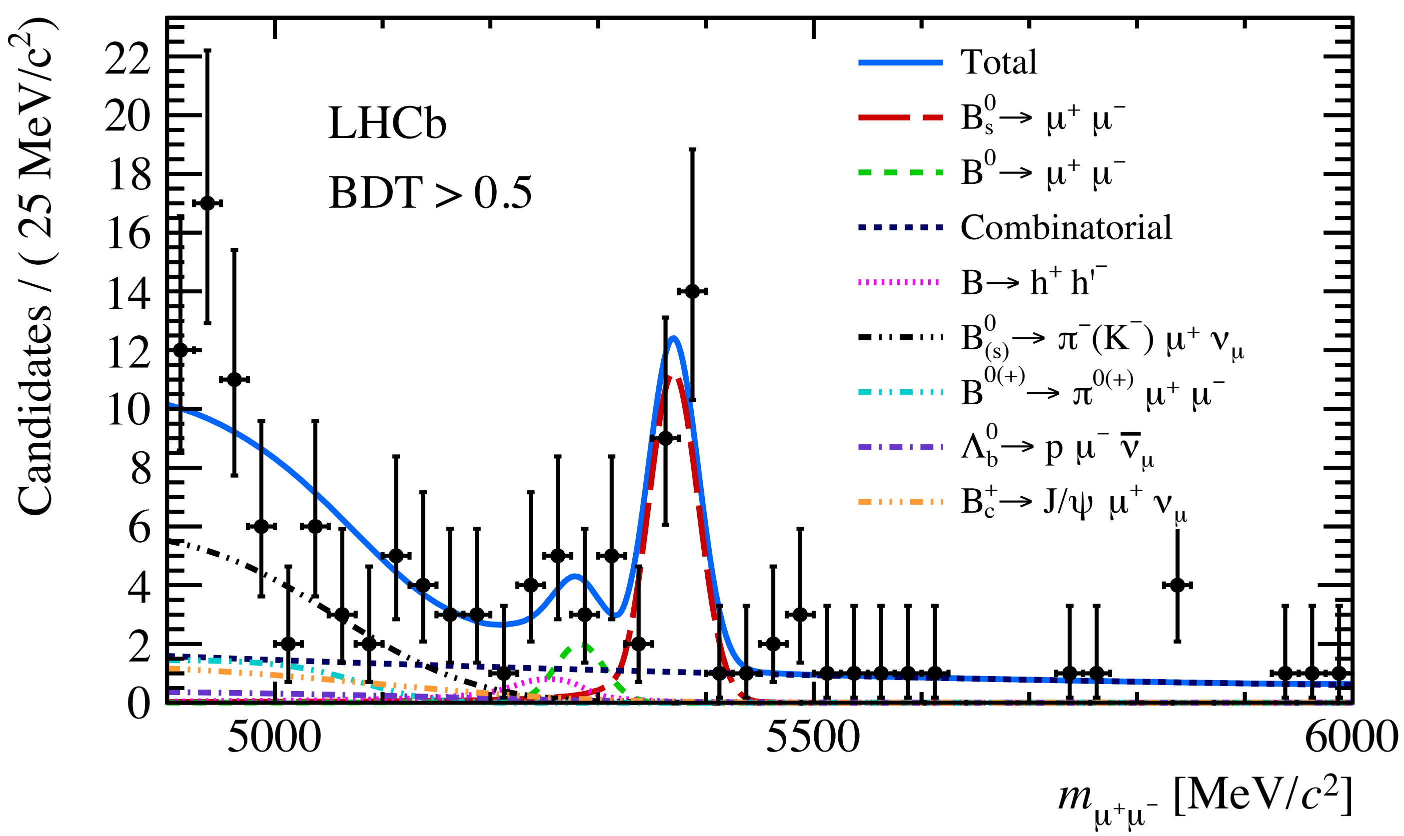


arXiv:1703.05747

Dimuon mass fit

- Fit dimuon mass to determine signal yield, accounting for all different backgrounds.

- Yields of peaking backgrounds checked by looking at data without muon ID - consistent results.



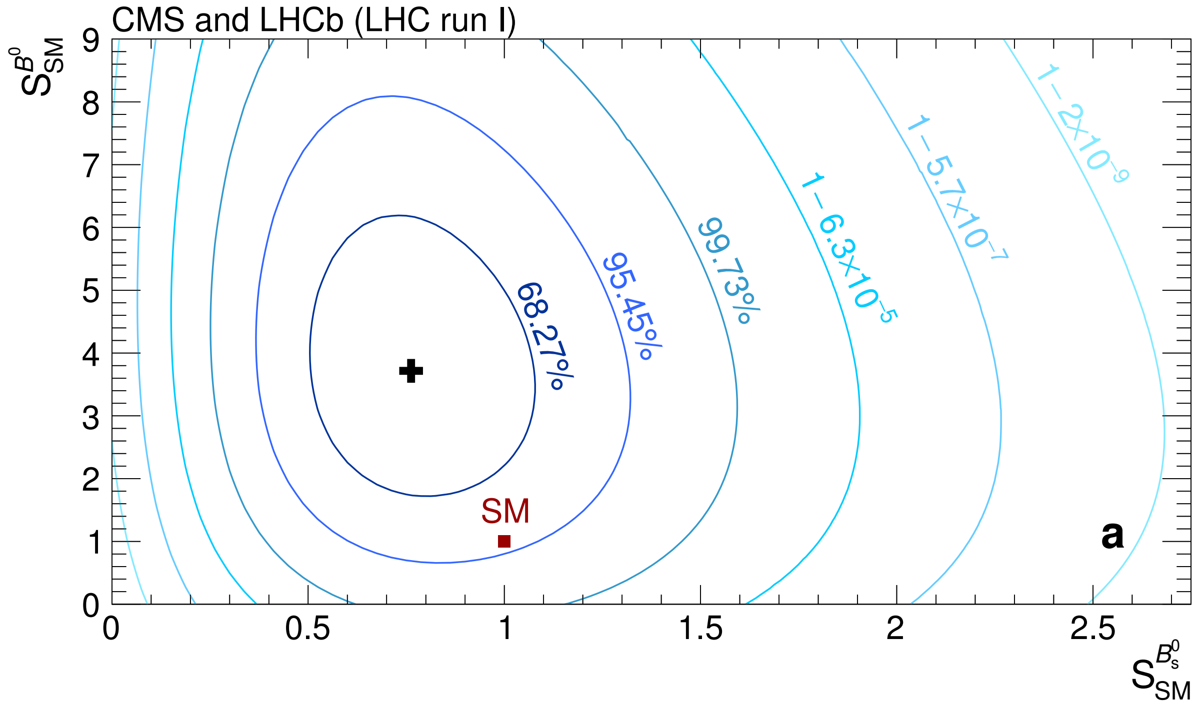
Signal **not** S/B weighted

- Much less background this time, mainly due to isolation improvements.

New $B^0_{(s)} \to \mu^+\mu^-$ results

- Using ratio of signal and normalisation yields and their efficiencies from simulation, determine branching fractions.

Nature 522, 68–72



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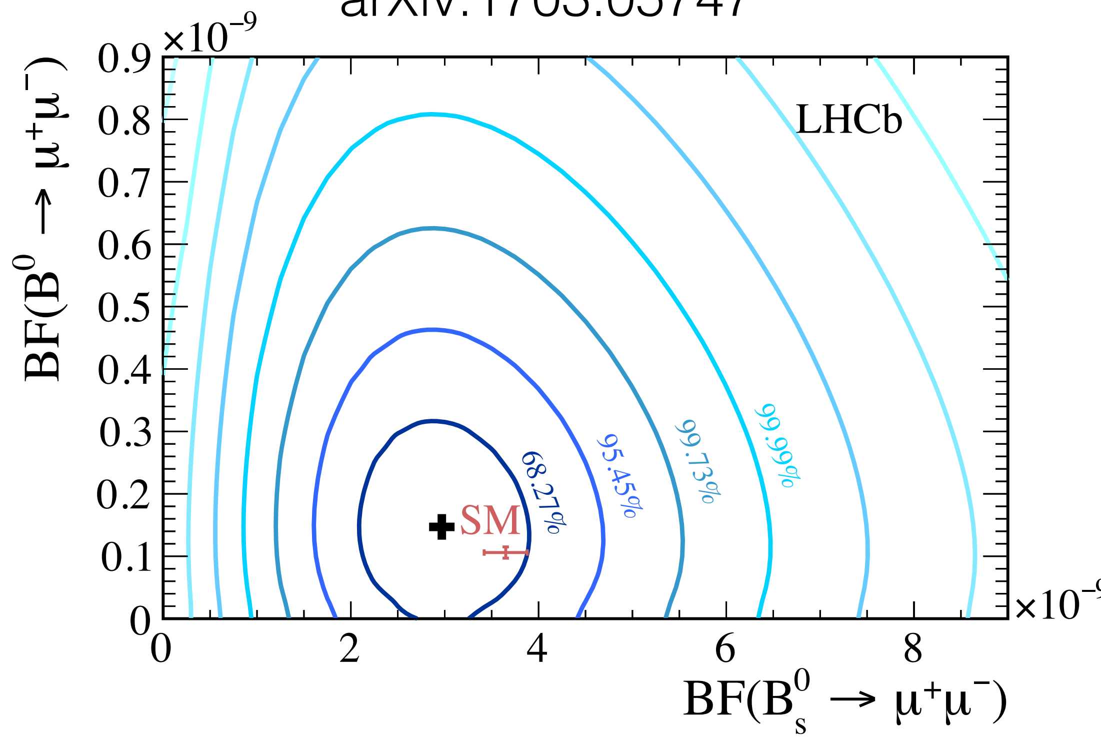


- In general results consistent with the SM.
- Also measure effective lifetime: $\tau(B^0_s \to \mu^+\mu^-) = 2.04 \pm 0.44 \pm 0.05\,\mathrm{ps}$, not yet enough data to be sensitive to NP.

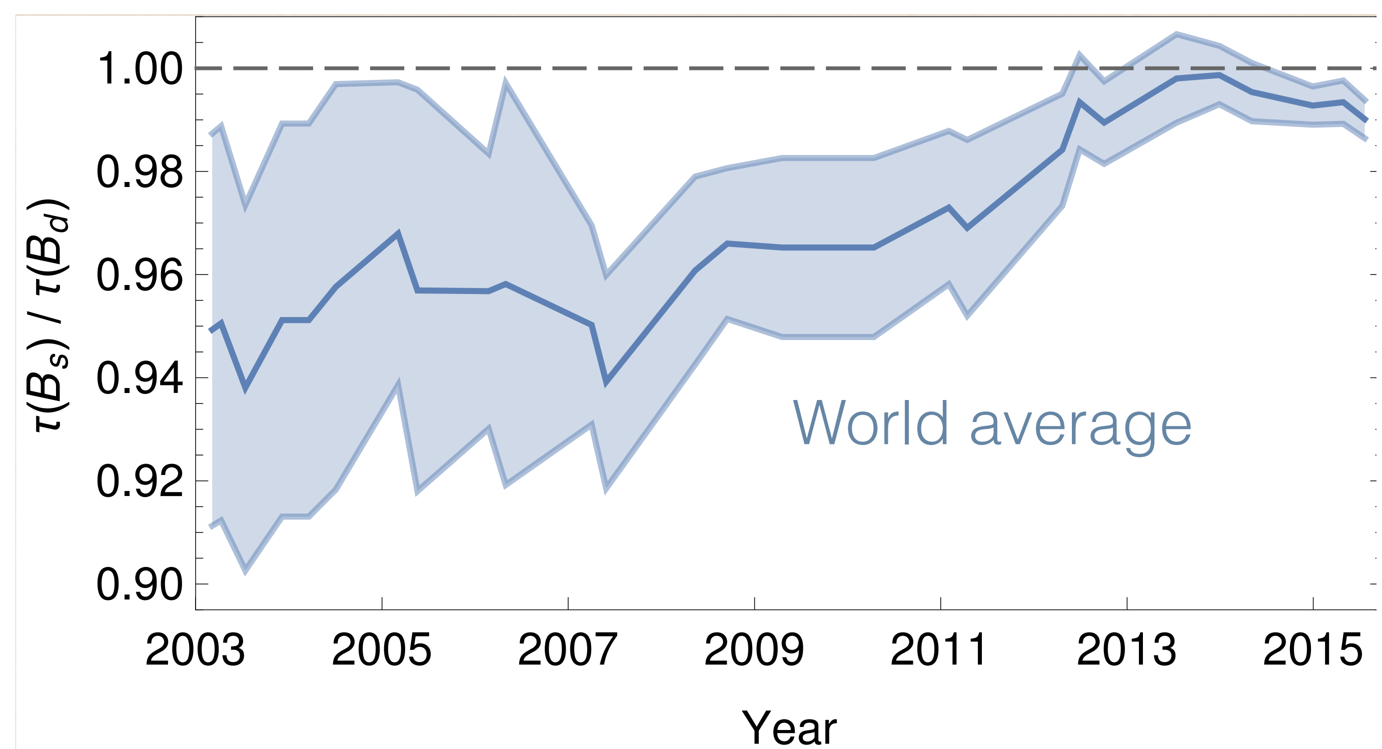
Measurement of the B_s^0 and D_s^+ lifetimes

The importance of the B_s^0 lifetime

- When calculating SM observables of heavy flavour decays - common approximation: set the heavy quark masses to infinity (HQET).
- Another assumption: quark-hadron duality - if average over large number of states, you can use a quark-level calculation to approximate the hadronic.
- Testing these frameworks of utmost importance - lifetimes of b-hadrons are excellent place to do this.

HQET predicts that the Bs and B0 lifetimes should be the same, previous results (e.g. [1]) have indicated otherwise.

Plot from A. Lenz



[1] D0 Collab. Phys. Rev. Lett. 114 (2015)

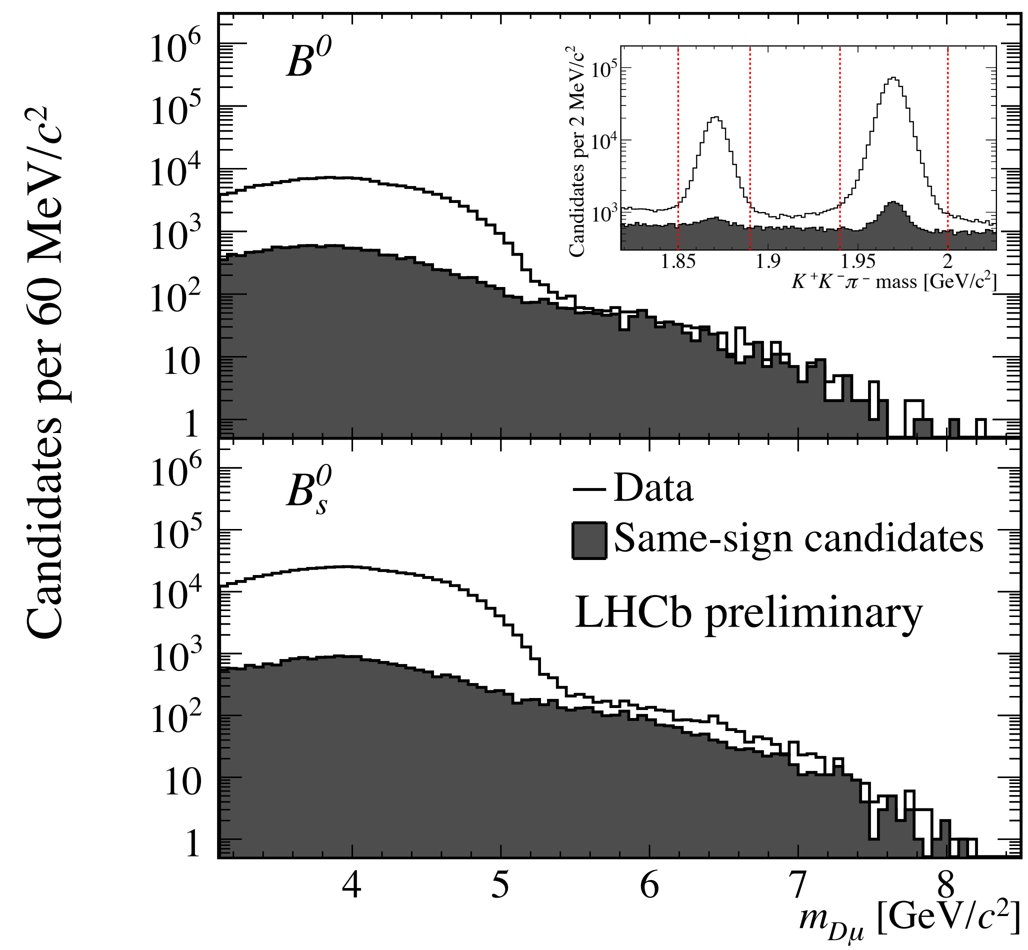
Recent measurement at LHCb

- Use flavour specific ‘semi-leptonic’ decays $B_s^0 \to D_s^{(*)+} \mu\nu$.

- Normalise to the well known B^0 lifetime using $B^0 \to D^{(*)+} \mu\nu$ decays.

- Use the same charm final state of $K^+K^-\pi^+$ for both D$^+$ and D$_s^+$.

- Correct for missing neutrino using the k-factor technique.



- Determine time acceptance using simulation.

- Fit corrected mass in bins of decay time to determine lifetime ratio.

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Corrected mass fit

- Corrected mass defined as:

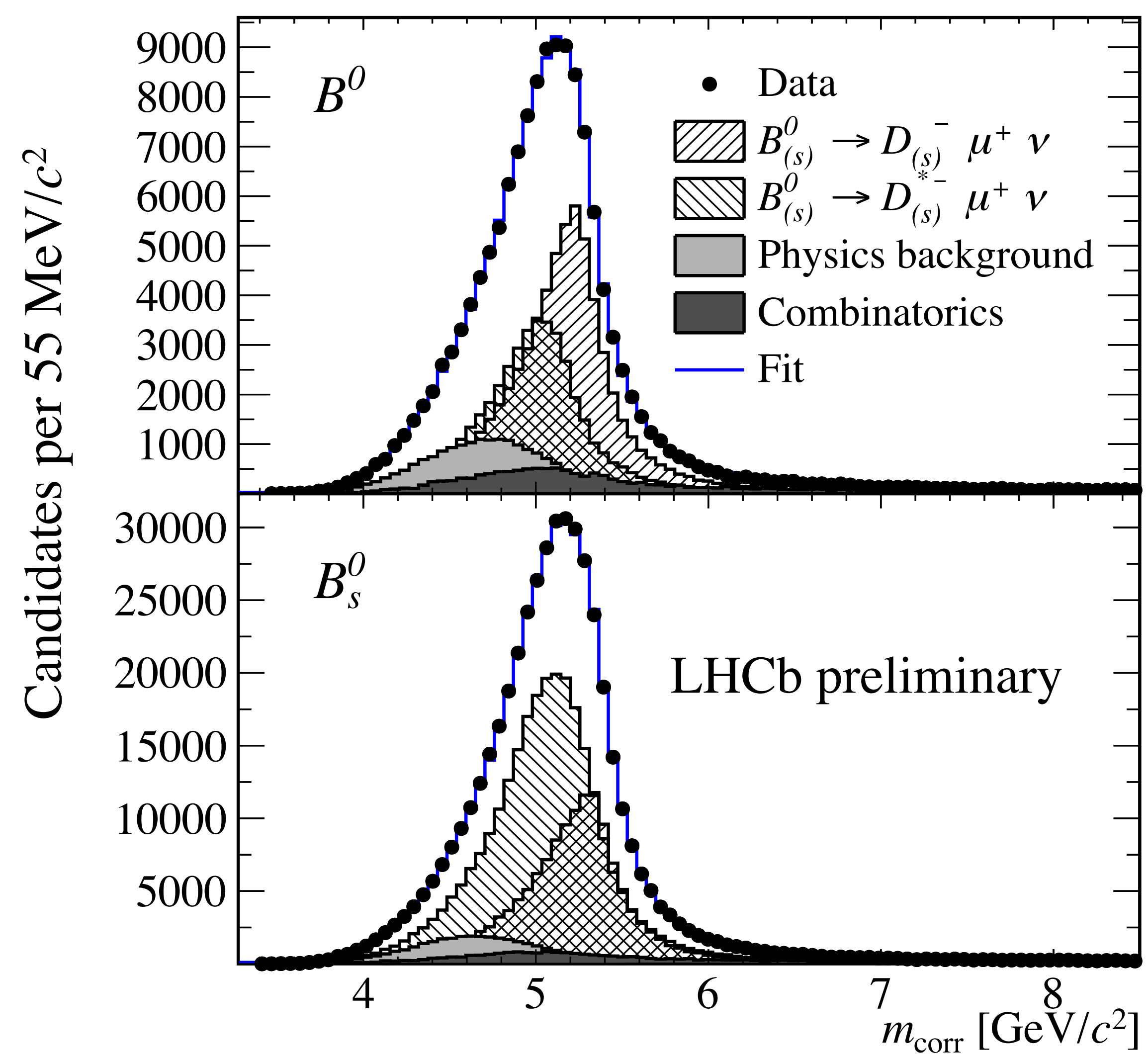
$$m_{\mathrm{corr}} = \sqrt{m_{\mathrm{vis}}^2 + p_{\perp}^2} + p_{\perp}$$

Mass of visible decay products

Momentum perpendicular to B direction.

- Only ground and first excited states of charm meson considered as signal.

- B^0 sample much more separated than B_s^0 due to soft D_s^{*+} decay mode.



Decay time fit

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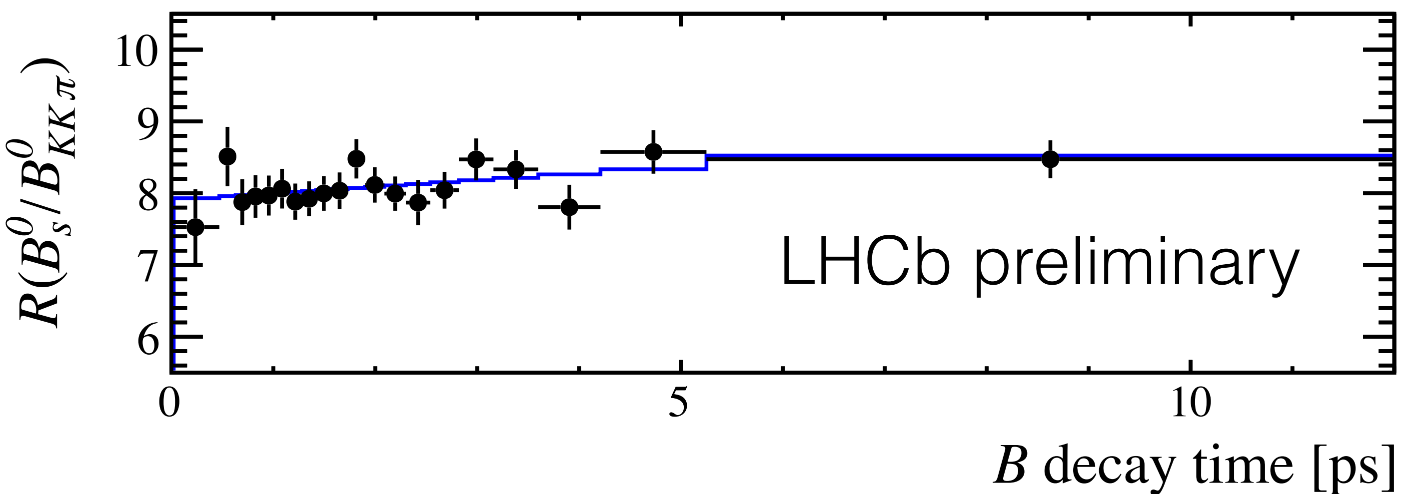
- Correct for acceptance in simulation (almost flat after re-weighting due to D^+/D^+_s lifetime difference).



- Cross-check using more abundant $D^+ \to K^-\pi^+\pi^+$ decay mode and find consistent results.

- No significance difference in decay widths found:

$$\Delta_\Gamma(B) = -0.0115 \pm 0.0053\,(\mathrm{stat}) \pm 0.0041\,(\mathrm{syst})\,\mathrm{ps}^{-1}$$

- Also measure the difference in D^+/D^+_s lifetimes:

$$\Delta_\Gamma(D) = 1.0131 \pm 0.0117\,(\mathrm{stat}) \pm 0.0065\,(\mathrm{syst})\,\mathrm{ps}^{-1}$$

- Systematics dominated by:
  - Composition of signal (e.g. knowledge of form factors)
  - Decay time acceptance (production kinematics)

Results

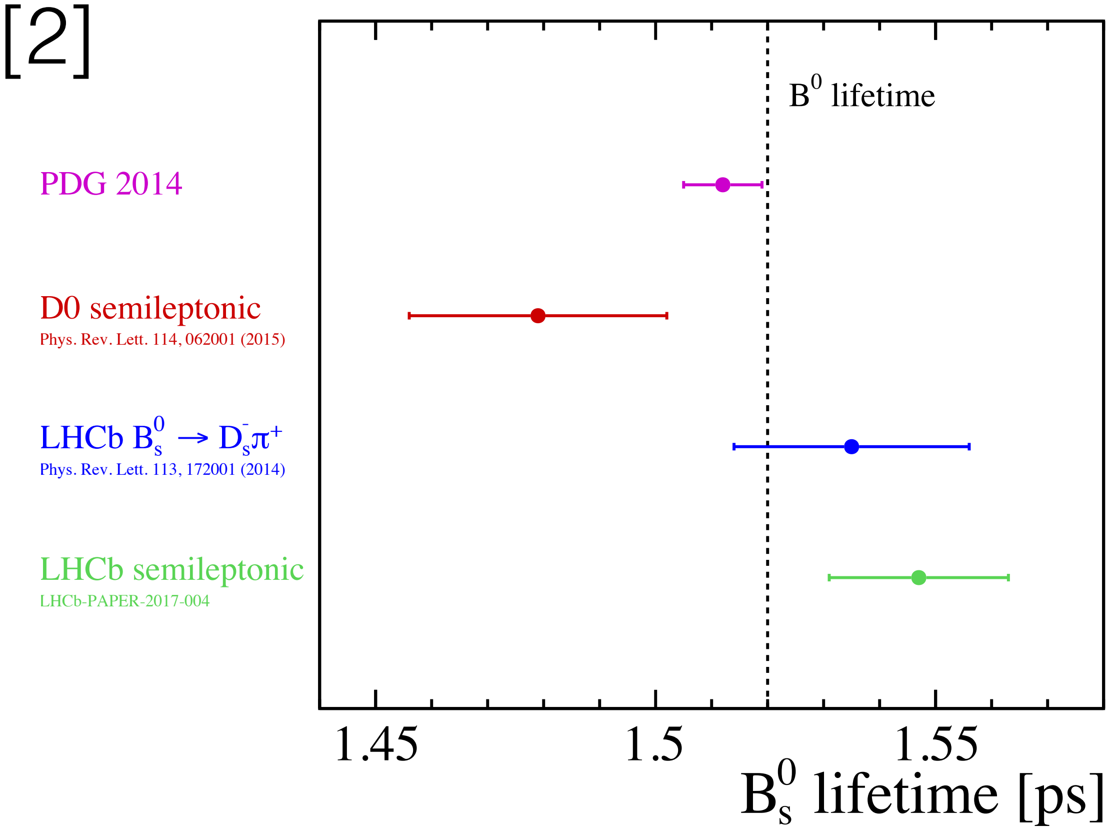
LHCb-PAPER-2017-004

- B_s^0 and D_s^+ lifetimes are found to be:

$$1.547 \pm 0.013\,(\text{stat}) \pm 0.010\,(\text{syst}) \pm 0.004\,(\tau_B)\ \text{ps},$$
$$0.5064 \pm 0.0030\,(\text{stat}) \pm 0.0017\,(\text{syst}) \pm 0.0017\,(\tau_D)\ \text{ps}$$

- These are the world's most precise.

- The B_s^0 lifetime is in agreement with HQET theory and LHCb's previous measurement with fully reconstructed decays [1], but is in tension from results from D0 [2]



[1] LHCb Collab. Phys. Rev. Lett. 113, (2014)

[2] D0 Collab. Phys. Rev. Lett. 114 (2015)

Observation of five narrow Ω_c^0 states

arXiv:1703.04639

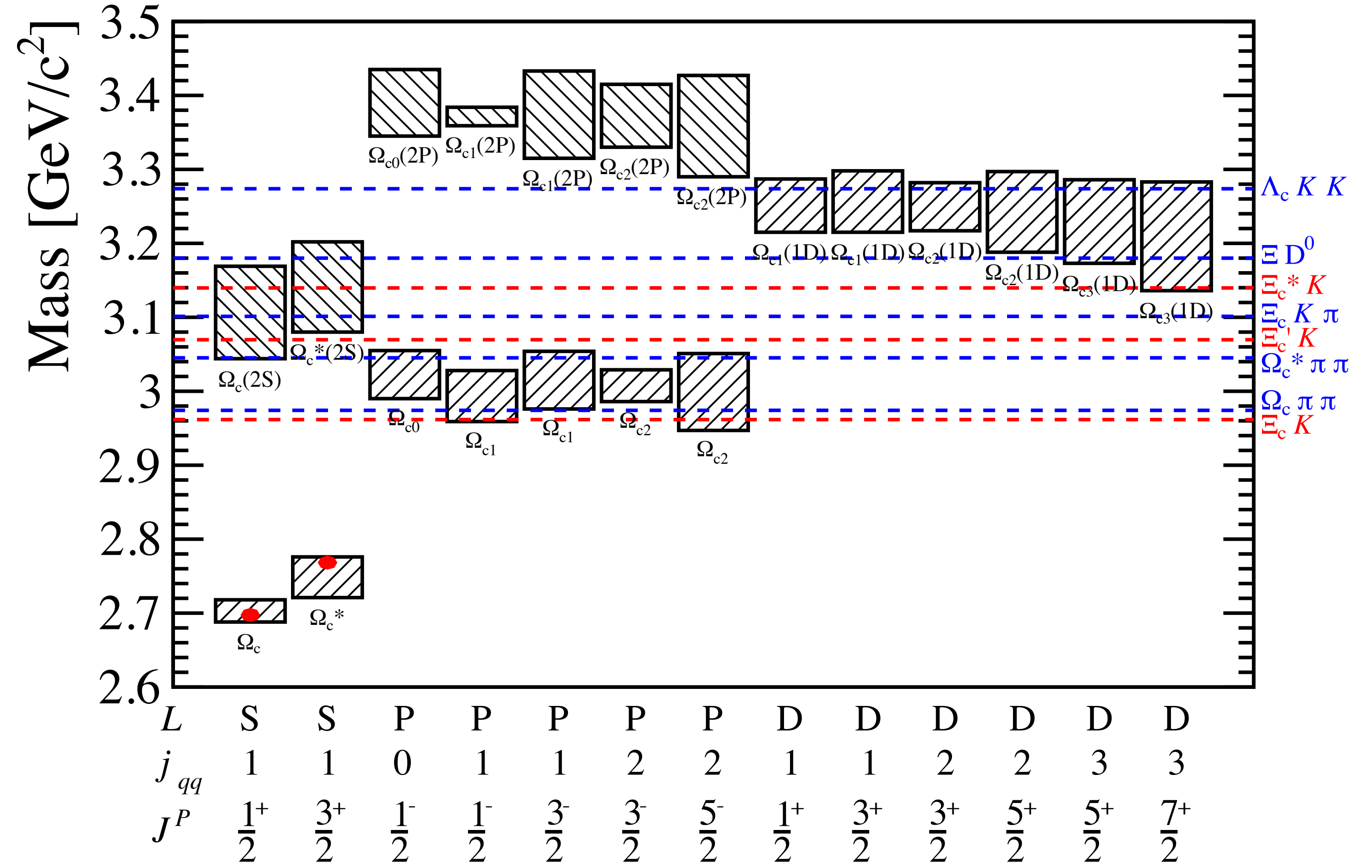
Ω_c^0 spectrum

- Spectroscopy another important way to improve our understanding of QCD and test HQET.

- The Ω_c^0 baryon has quark content css and their spectrum is almost completely unknown - only two have been found previously.

- Predictions of the masses in boxes here are from Refs[1-7].

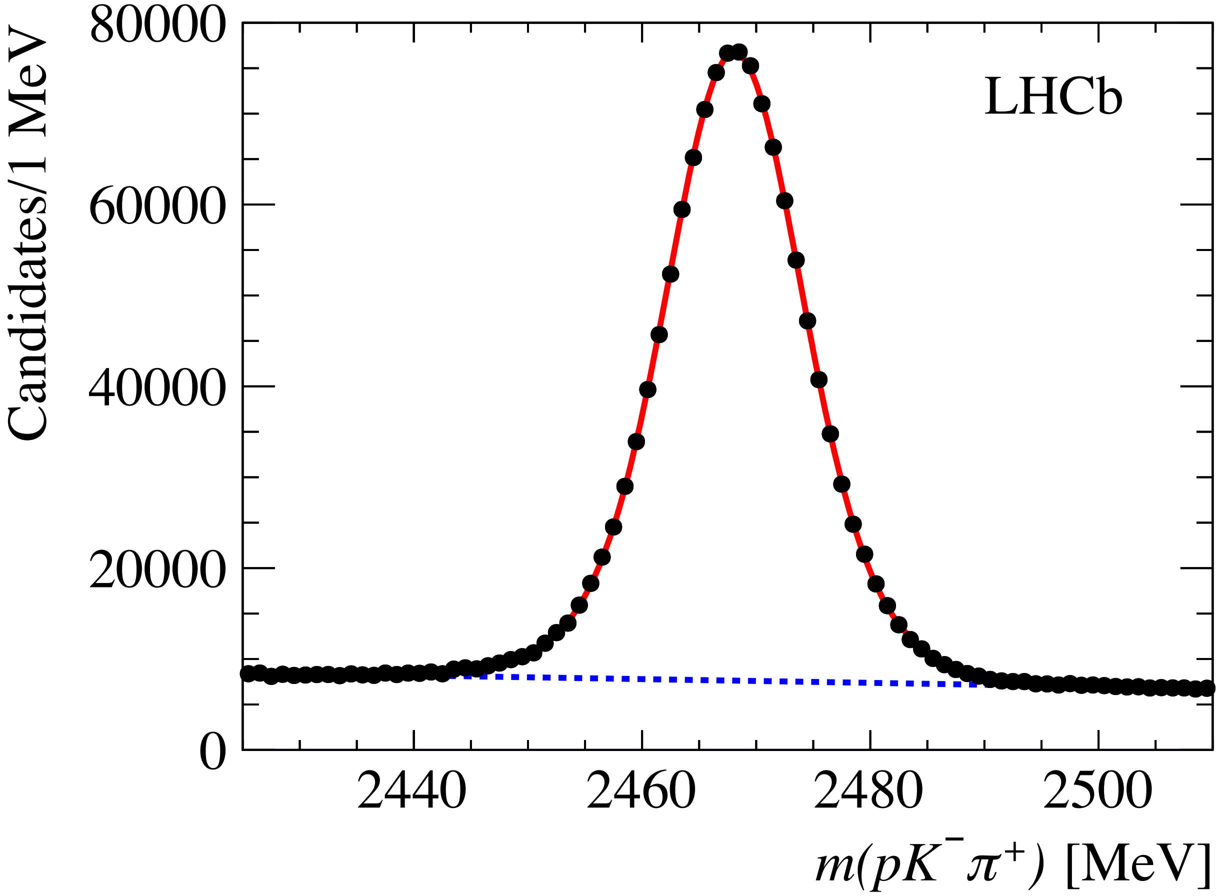
- In the LHCb analysis, look for the decay mode $\Omega_c^0 \to \Xi_c^+ K^-$ using 2011,2012 and 2015 data.



[1] Phys. Lett. B659 (2008) [2] Int. J. Mod. Phys. A23 (2008) 2817 [3] Phys. Rev. D84 (2011) 014025
[4] J. Phys. G34 (2007) 961 [5] Eur. Phys. J. A37 (2008) 217 [6] Eur. Phys. J. A28 (2006) [7] Chin. Phys. C40 (2016) 123102

Selection of Ξ_c^+ candidates

- First select Ξ_c^+ candidates.
- Selection uses a likelihood ratio approach.
- Useful variables include vertex quality, flight significance and particle ID of proton.



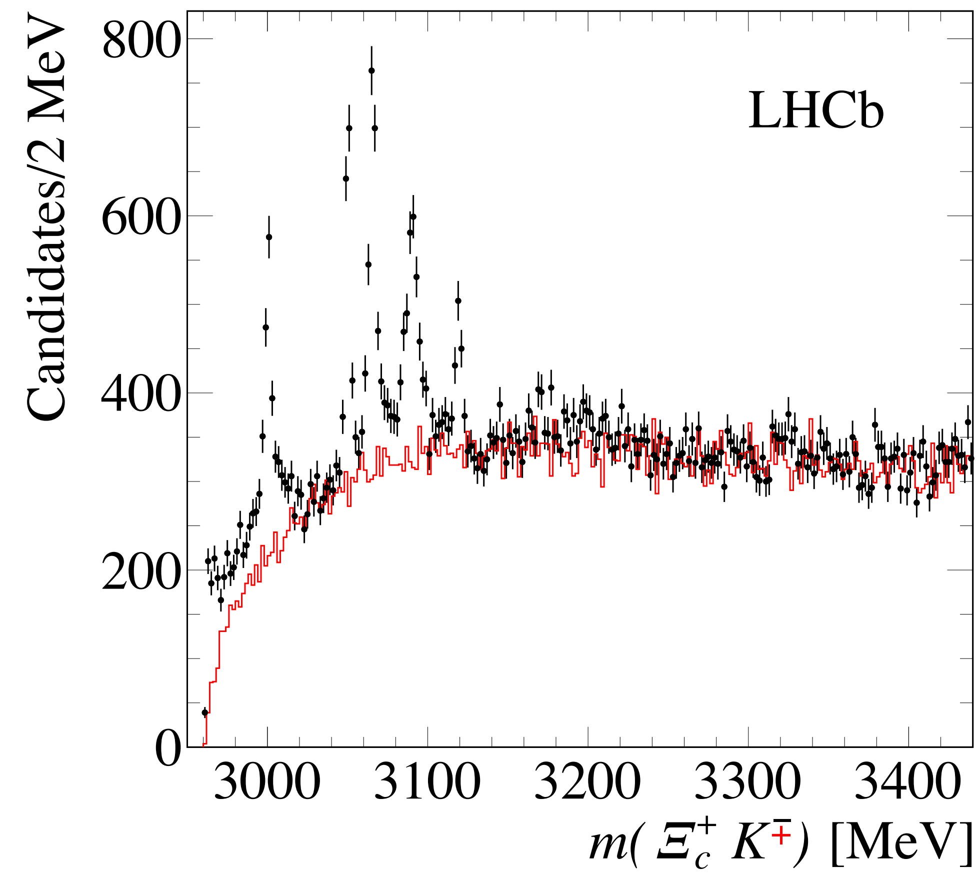
- Fit to looser selection criteria used to determine kinematic/geometric properties of the signal (production not so well known).
- After full selection see 1M signal at around 83% purity.

arXiv:1703.04639

Add a kaon to look for Ω_c^0

- Combine a kaon which has a good PID response and vertex quality.

- Also require pT > 4.5 GeV for Ω_c^0 candidate.



- Opposite sign spectrum looks very peaky!
- No such structure seen in same-sign data.
- Checked pion hypothesis - no narrow structures seen.

Where $m(\Xi_c^+ K^-) = m([pK^-\pi^+]_{\Xi_c^+} K^-) - m([pK^-\pi^+]_{\Xi_c^+}) + m_{\Xi_c^+}$

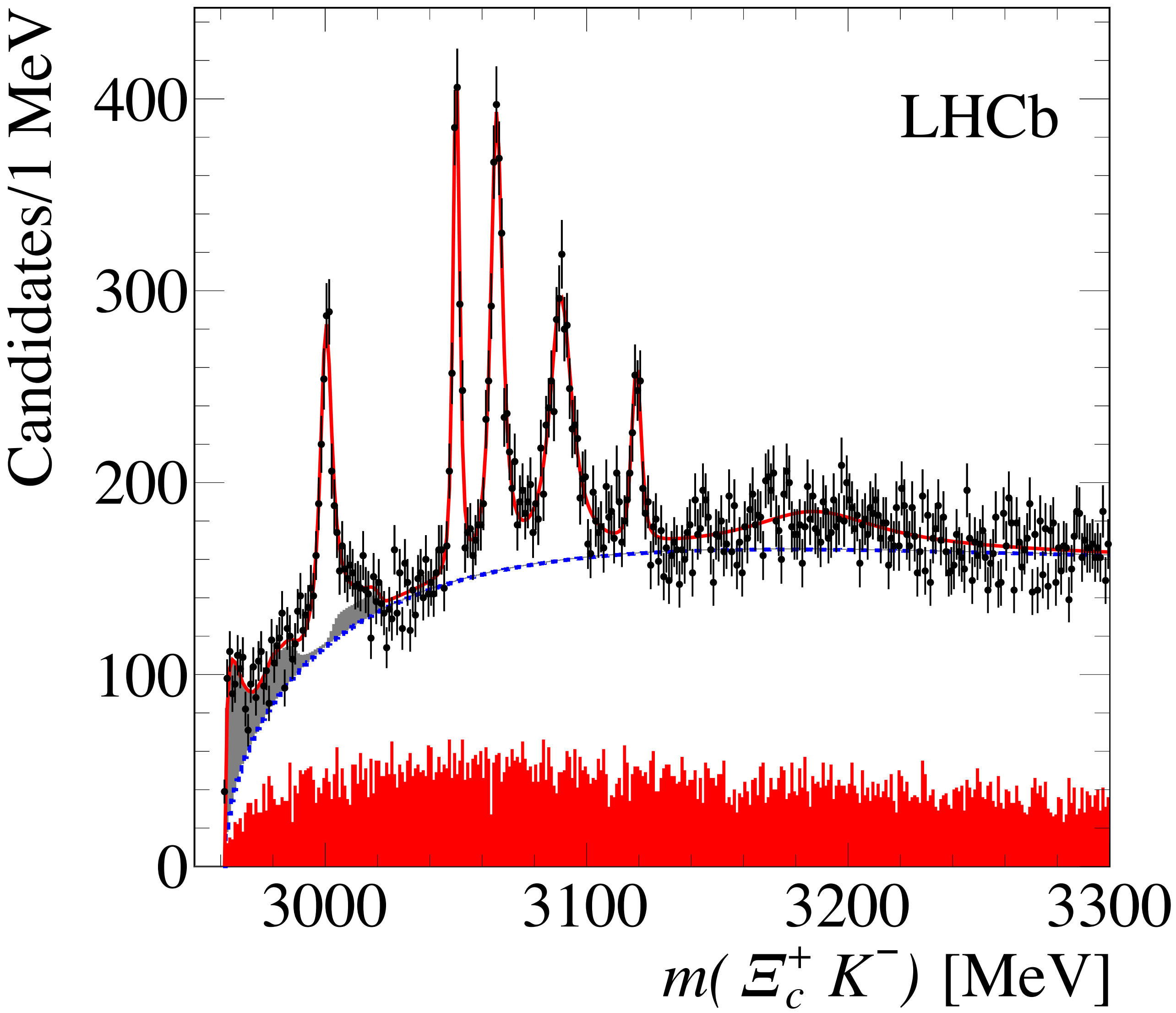
Fit spectrum

- Fit data to determine significance and mass/widths of the new states

- Parameterise signal peaks with relativistic Breit-Wigner functions.

- Feed-down from other Ω_c^0 decay modes shown in grey.

- Background parameterisation inspired by same-sign data.

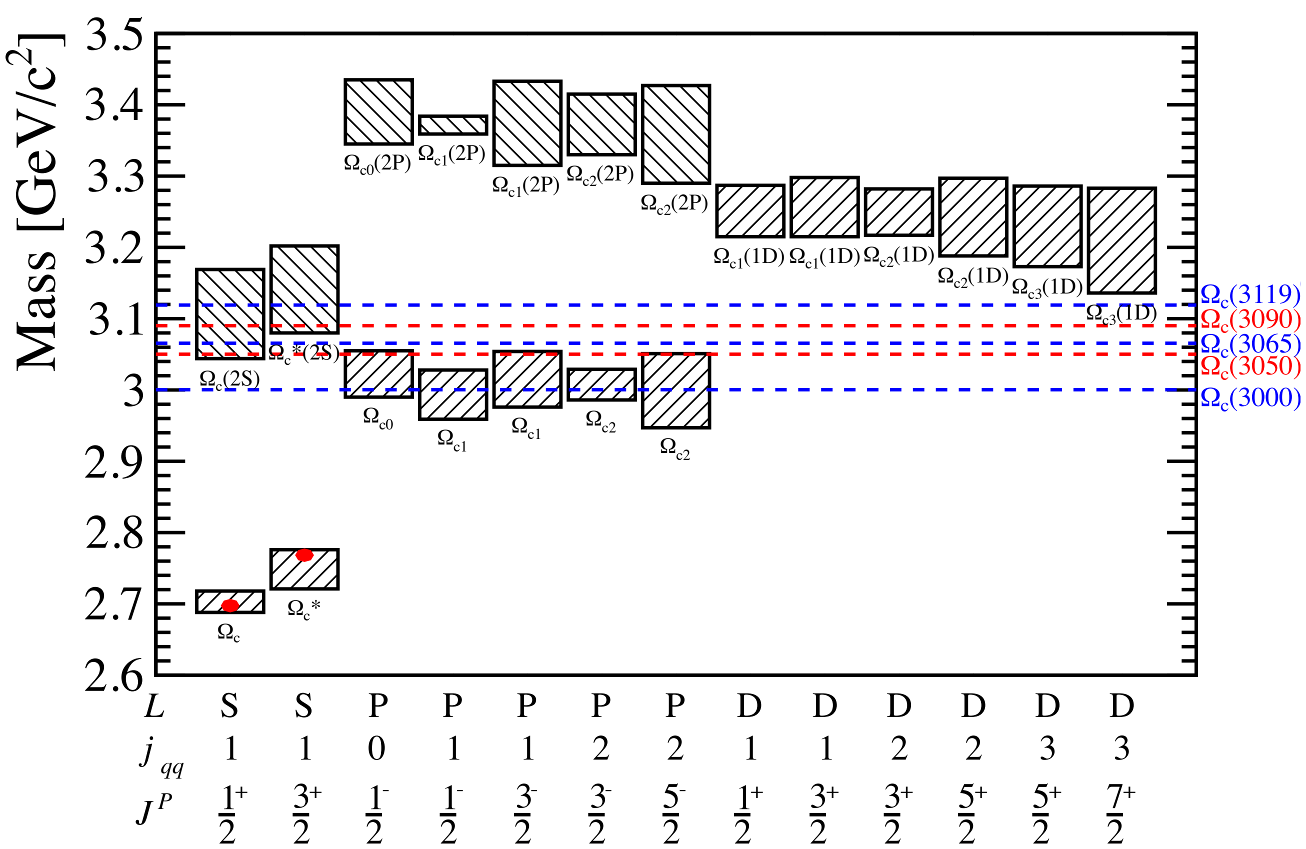


- **Five** states observed with over 10 significance! (record for a single analysis?).

- Also see a broad structure around 3200 - single or multiple states??

arXiv:1703.04639

Mass results



- Systematics include:
  - Alternate background model
  - Vary Blatt-Weisskopf factors.
  - Mass scale/resolution.
  - Possibility of interference.
  - Description of broad structure.

- Masses seem broadly consistent with predictions.
- For the widths, see the paper: arXiv:1703.04639.
- Dramatic increase in experimental knowledge in this area.

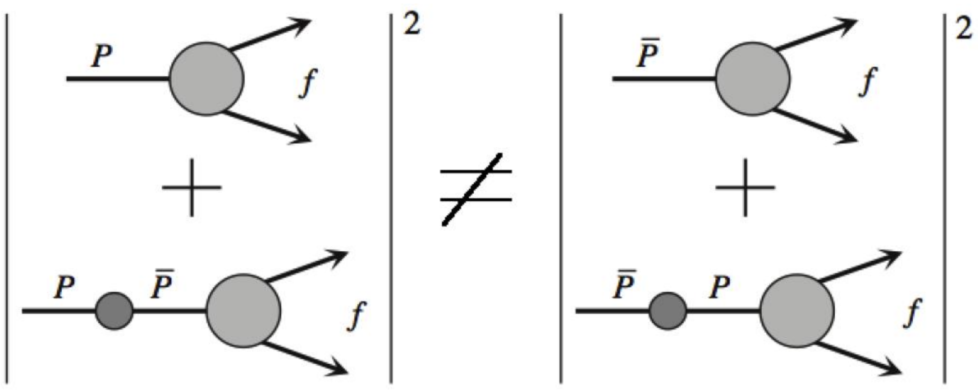
Summary

- LHCb very pleased with the run II dataset so far.
    - We are now publishing heavy flavour results with it.
- I just gave a very small and biased taste of what's come out recently.
    - $B_{(s)}^0$—>μμ update [arXiv:1703.05747]
    - B_s^0 and D_s^+ lifetimes [LHCb-PAPER-2017-004]
    - Observation of five narrow Ω_c^0 states [arXiv:1703.05747].

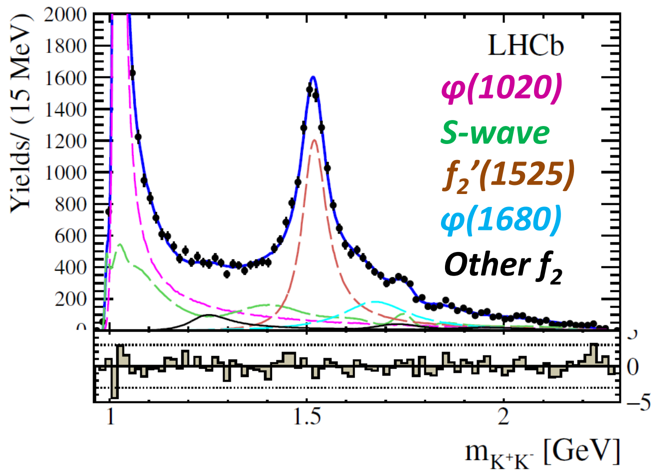
Summary

- I did not talk about the latest CP violation studies, a central theme of heavy flavour physics.

  - For example, new result on ϕ_s with $B_s^0 \longrightarrow J/\psi K^+K^-$ with $m_{KK} > m_\phi$.

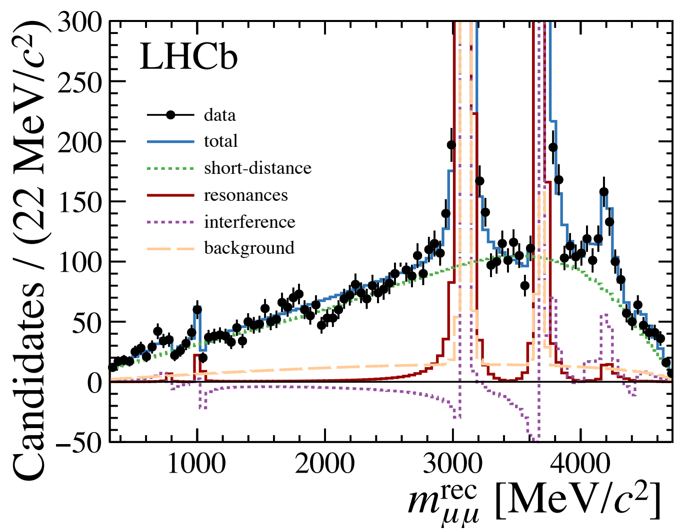


LHCb-PAPER-2017-008

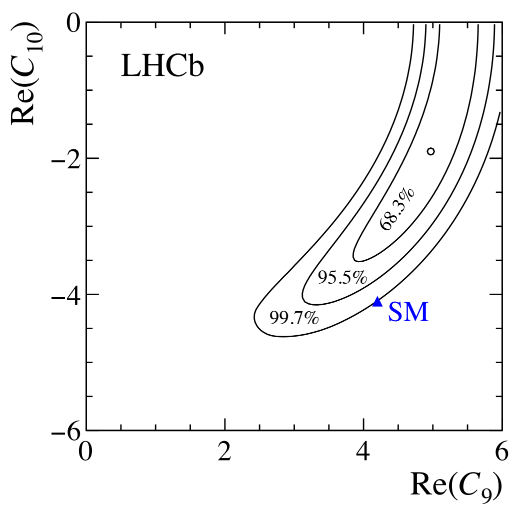


$\phi_s = 0.12 \pm 0.11 \pm 0.03$

I also did not discuss our anomalies in SL decays - discussed by Zoltan.



Recent update on this from Eur. Phys. J. C (2017) 77: 161.

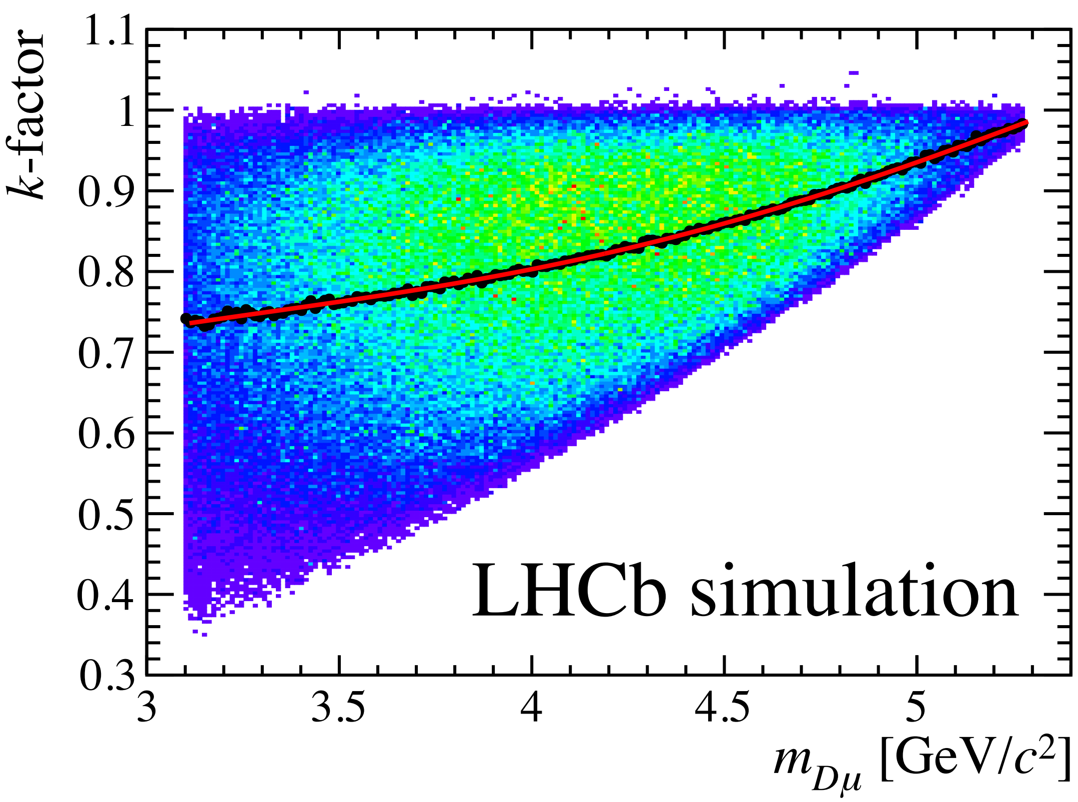


- If you are interested in more, take a look at our public results pages [here]

k-factor technique

LHCb-PAPER-2017-004

- To determine the decay time, need to know flight distance and B momentum: $\tau = m_B L / p_B$.
- At each point of visible mass $m_{D\mu}$, use simulation to relate visible B momentum to total B momentum (k-factor).



- The k-factor response depends on exactly which semileptonic decay you are looking at.
- Therefore, need to determine relative amounts of $B \to D$ vs $B \to D^*$ in data.