Results and future prospects from LHCb

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Hadron Spectroscopy with Strangeness 2024

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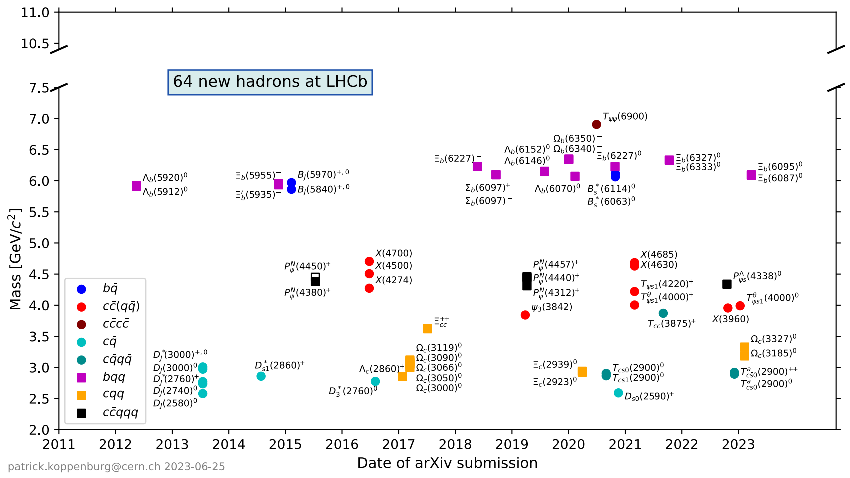
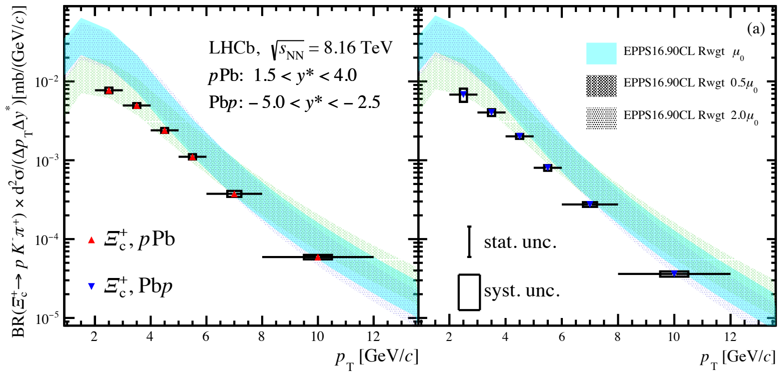
VIA VERITAS VITA

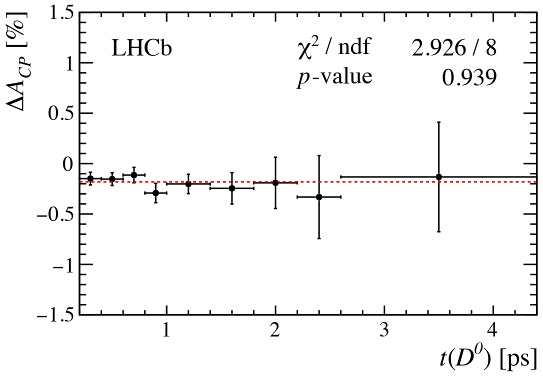
LHCb Original

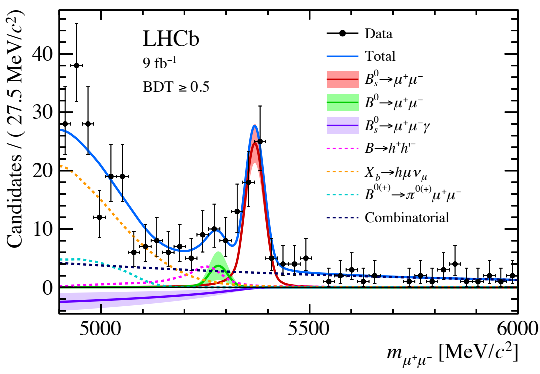
Original
2009-2018

- Hugely successful experiment, > 600 publications
- Significant discoveries
  - CPV observed in new systems
  - Rare decays
  - 64 of 72 new hadrons discovered at the LHC
- Broad physics programme
  - World leading for core topics, but also
    - Heavy ions
    - Fixed target
    - Electroweak
    - Dark Sector









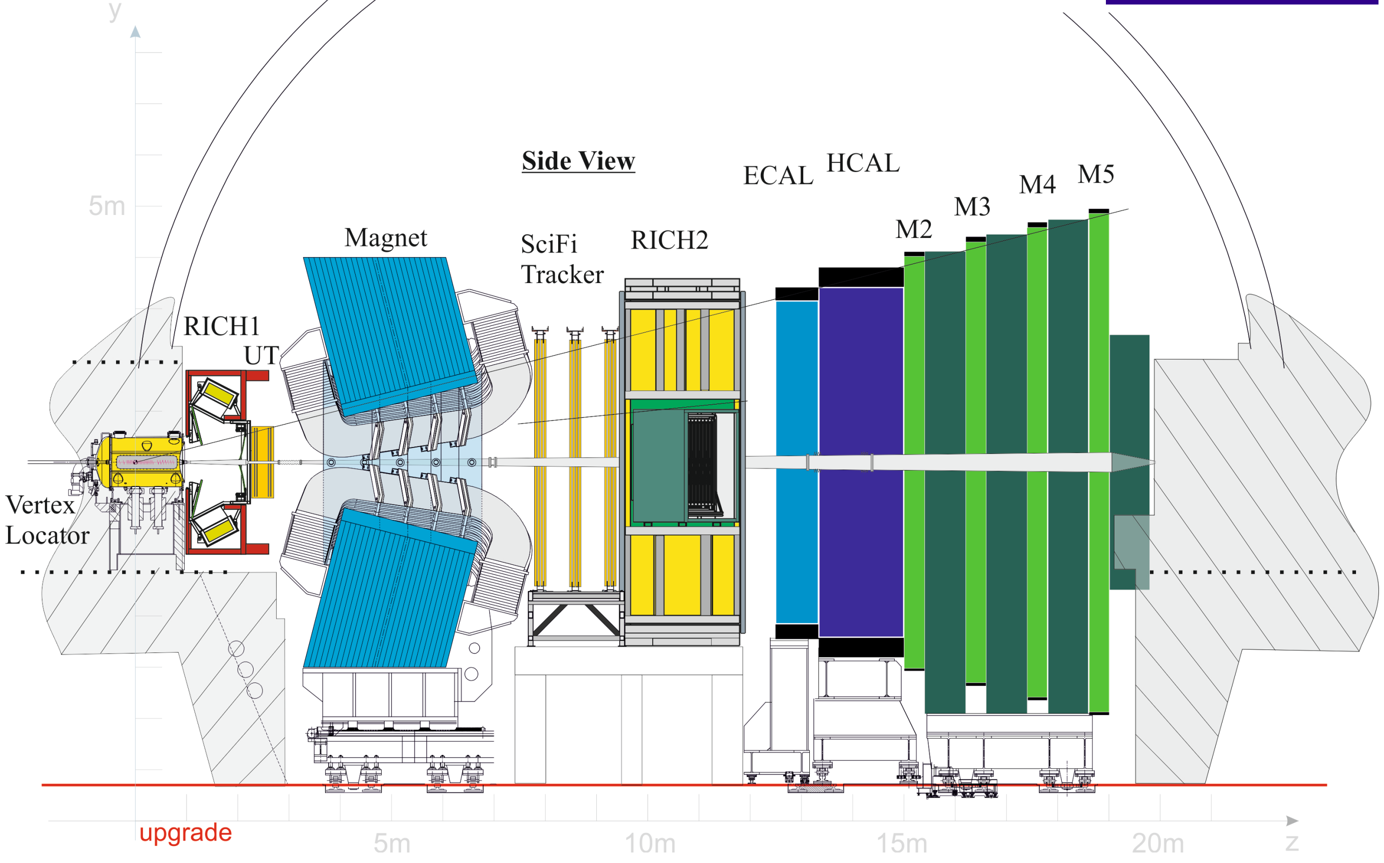
LHCb Upgrade I

- Major project achieved on budget
  - All sub detectors installed
  - Commissioning to detector and dataflow ongoing
  - Detector performance studies underway
  - 90% of channels upgraded
  - Replaced readout electronics
  - Operate at 30 MHz
  - Peak luminosity x5 w.r.t. Run 1

$$2 \times 10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$$

Upgrade I

2022-2032

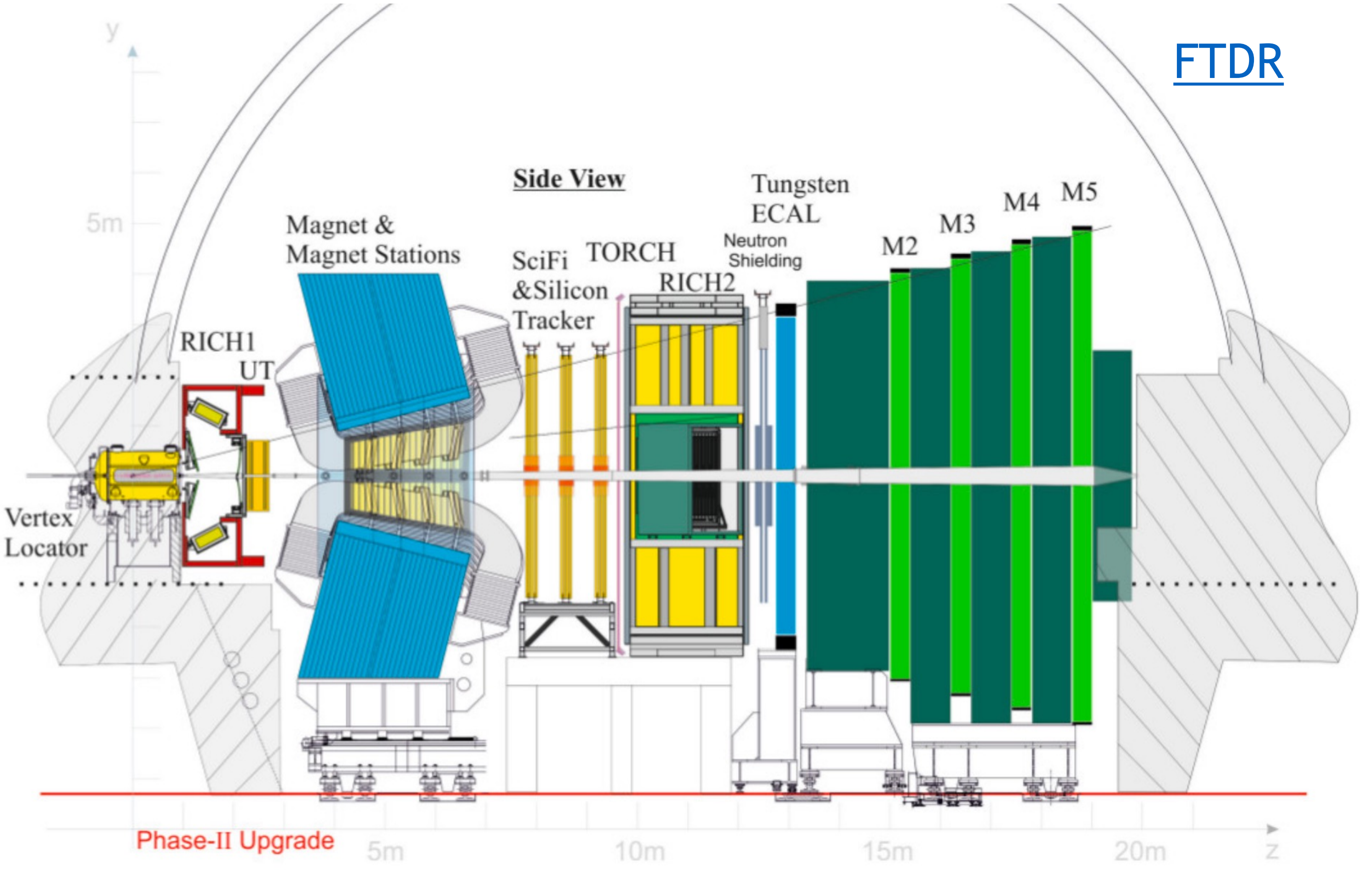


LHCb Upgrade II

LHCb *Upgrade II* *2033-*

FTDR

- Complete new detector required
  - Vertexing: Pixel detector with timing
  - Hadron PID: RICH with timing and better resolution, TORCH for low momentum tracks
  - Tracking: New magnet stations and pixel mighty tracker
  - Calorimeter: Better resolution and timing information
  - Muon system: New technologies for high occupancy regions

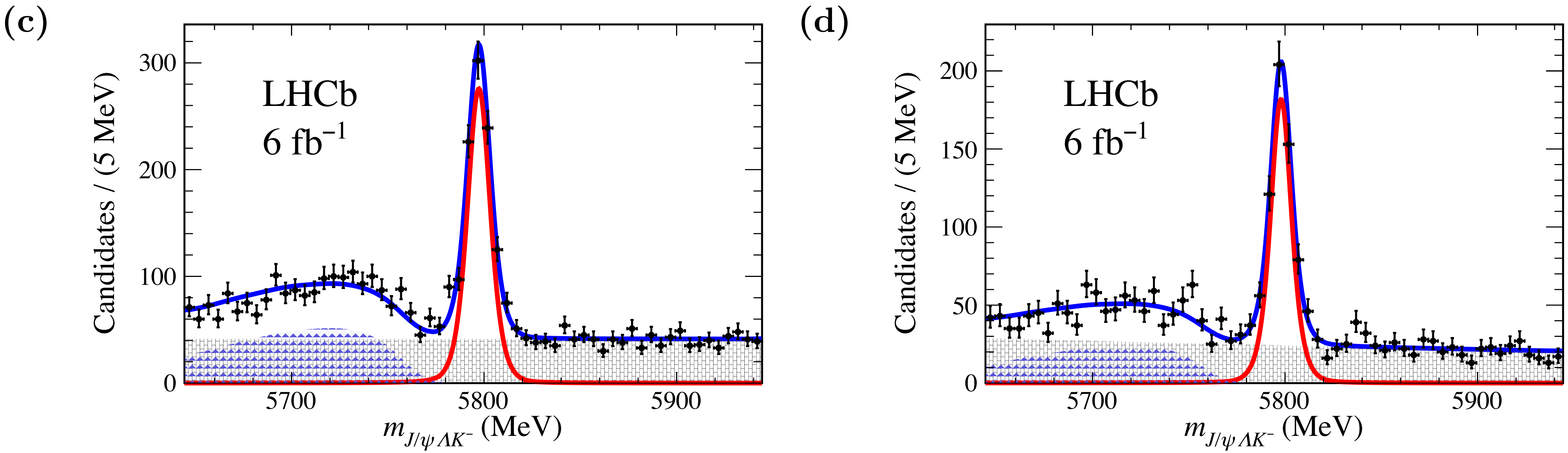


Measurement of excited Ξ baryons

- Real paper title was actually
  - Light/strange spectroscopy at LHCb is not often the intended goal of a particular study
  - Typically spin-offs or something that is necessary to model in other searches

Evidence of a $J/\psi\Lambda$ structure and observation of excited Ξ^- states in the $\Xi_b^- \to J/\psi\Lambda K^-$ decay

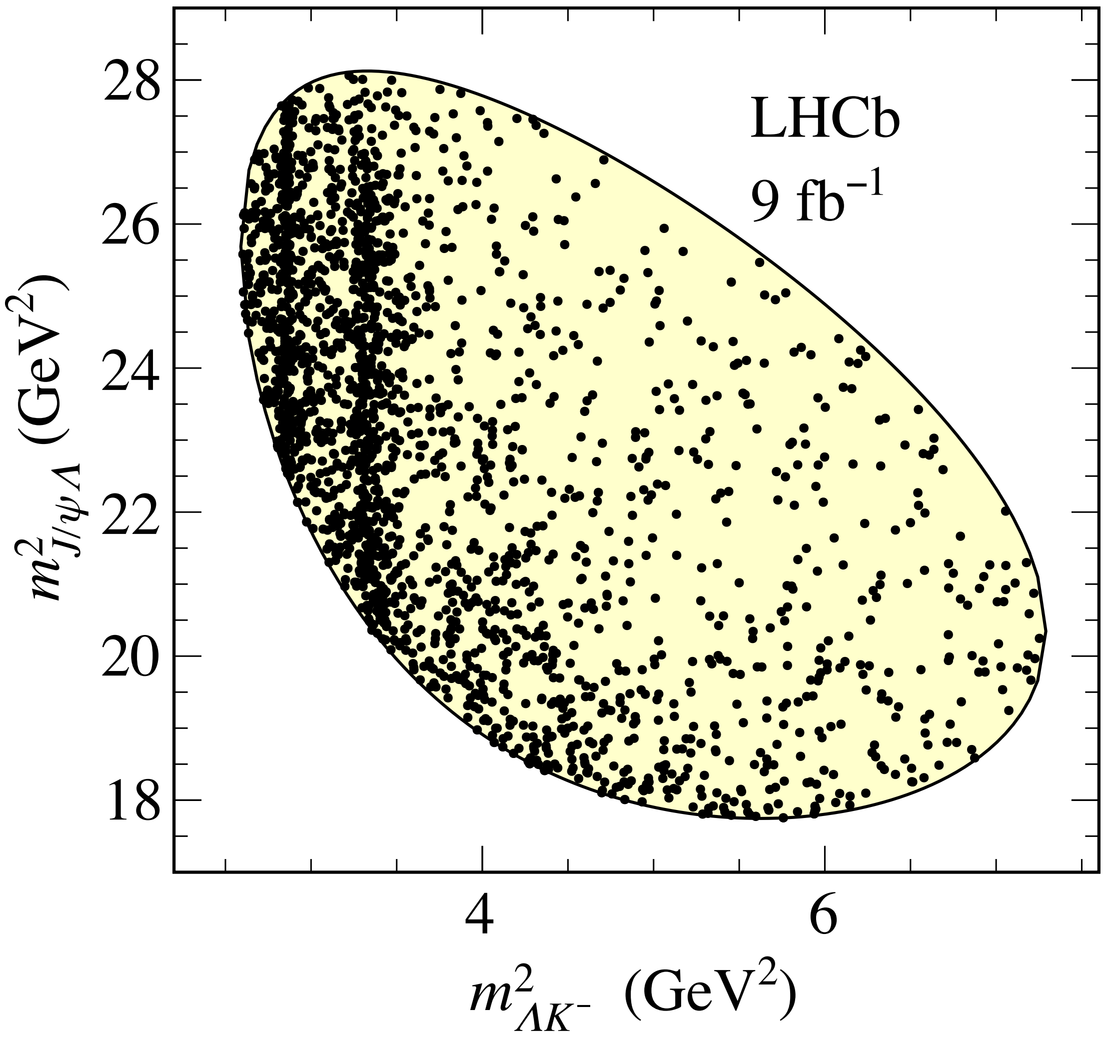
- Full LHCb dataset (9 fb^{-1})



Measurement of excited Ξ baryons

- Following the mass fits
  - Select events in a 15 MeV window around the signal peaks.
  - Signal yield: 1750 ± 50
  - sWeight to subtract the background

- Search for pentaquarks in $m^2(J/\psi\Lambda)$
  - Main aim of the analysis
- Model Ξ resonances in $m^2(\Lambda K^-)$
  - Necessary to achieve the above
  - New results would be a bonus!



Measurement of excited Ξ baryons

- First step is to describe the ΛK^- projection correctly
  - If this doesn't fit well in the other projections, add exotic candidates in other channels

State	M_0 (MeV)	Γ_0 (MeV)	LS couplings	J^P examined
$\Xi(1690)^-$	1690 ± 10	< 30	4 (6)	$(1/2, 3/2)^{\pm}$
$\Xi(1820)^-$	1823 ± 5	24^{+15}_{-10}	3 (6)	$3/2^-$
$\Xi(1950)^-$	1950 ± 15	60 ± 20	3 (6)	$(1/2, 3/2, 5/2)^{\pm}$
$\Xi(2030)^-$	2025 ± 5	20^{+15}_{-5}	3 (6)	$5/2^{\pm}$
NR ΛK^-	-	-	4 (4)	$1/2^-$

This left a peak clearly unaccounted for in $m^2(J/\psi\Lambda)$

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State
$\Xi(1690)^-$
$\Xi(1820)^-$
$\Xi(1950)^-$
$\Xi(2030)^-$
NR ΛK^-

$\Xi(1690)$		***
$\Xi(1820)$	$3/2^-$	***
$\Xi(1950)$		***
$\Xi(2030)$	$\frac{5}{2}^?$	***

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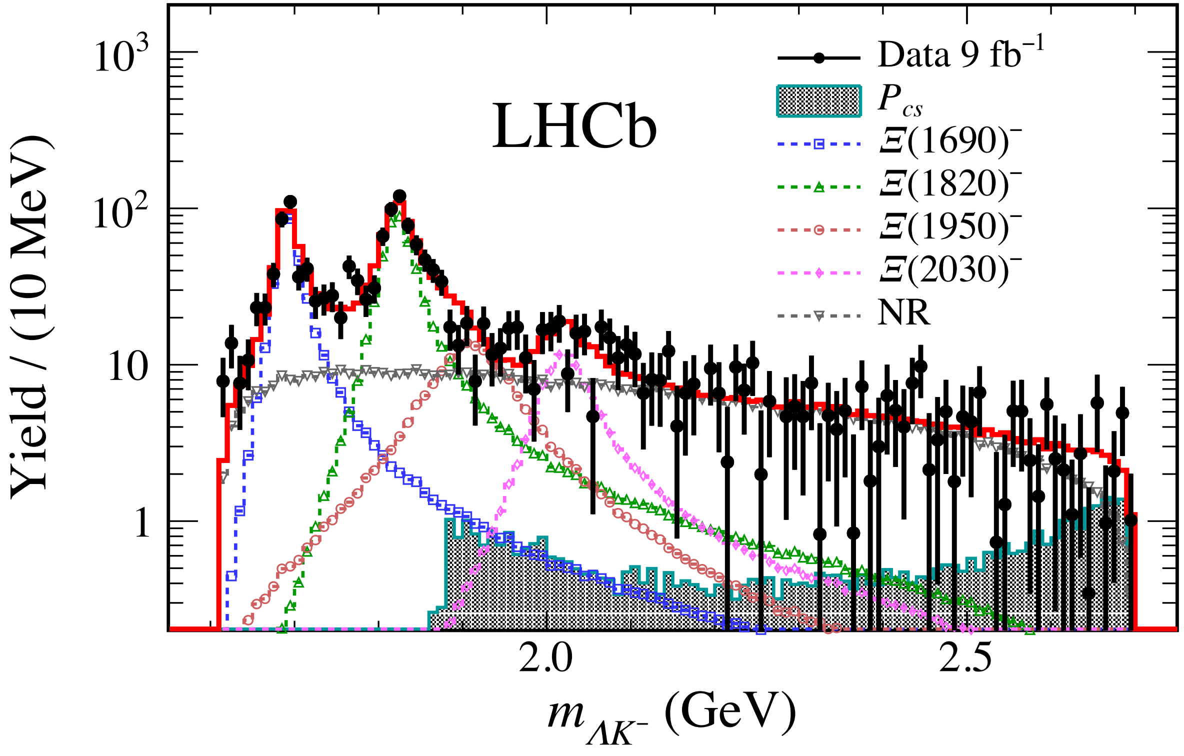
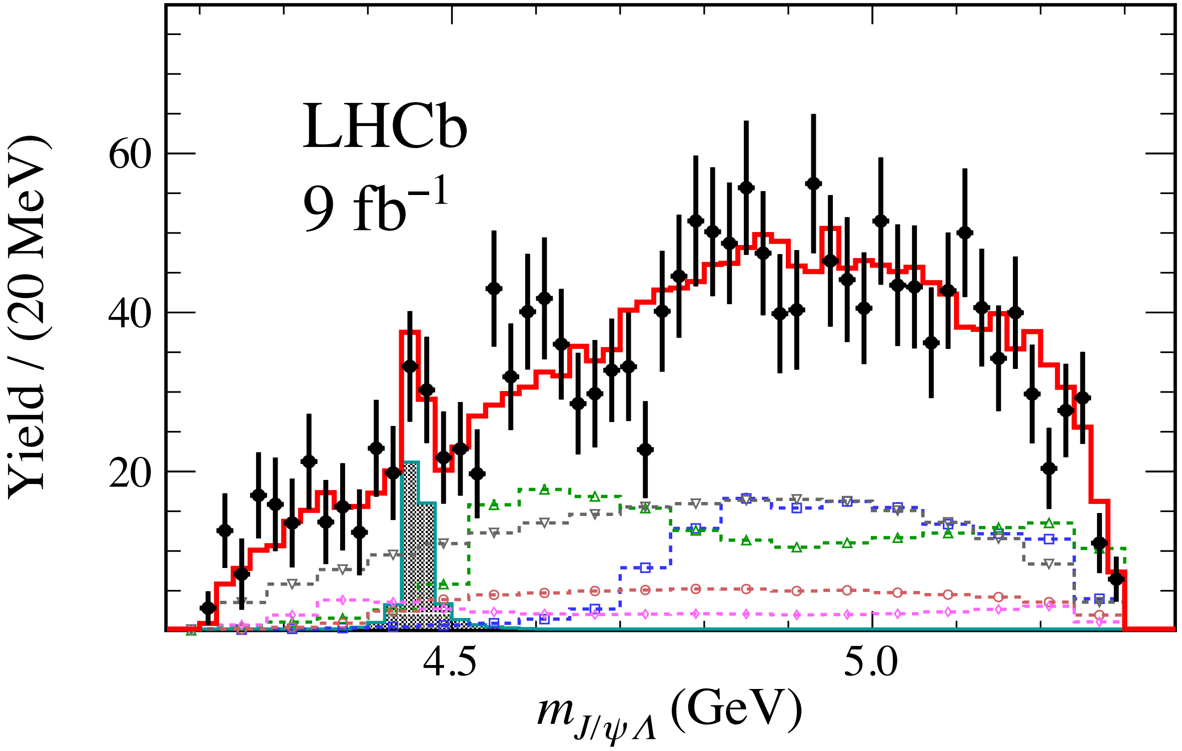
Measurement of excited Ξ baryons

- Add a pentaquark state in the $J/\psi\Lambda$ channel
  - If this doesn't fit well in the other projections, add exotic candidates in other channels





Measurement of excited Ξ baryons

- Add a pentaquark state in the $J/\psi\Lambda$ channel
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State	M_0 (MeV)	Γ_0 (MeV)	FF (%)
$P_{cs}(4459)^0$	$4458.8 \pm 2.9\,^{+4.7}_{-1.1}$	$17.3 \pm 6.5\,^{+8.0}_{-5.7}$	$2.7\,^{+1.9}_{-0.6}\,^{+0.7}_{-1.3}$
$\Xi(1690)^-$	$1692.0 \pm 1.3\,^{+1.2}_{-0.4}$	$25.9 \pm 9.5\,^{+14.0}_{-13.5}$	$22.1\,^{+6.2}_{-2.6}\,^{+6.7}_{-8.9}$
$\Xi(1820)^-$	$1822.7 \pm 1.5\,^{+1.0}_{-0.6}$	$36.0 \pm 4.4\,^{+7.8}_{-8.2}$	$32.9\,^{+3.2}_{-6.2}\,^{+6.9}_{-4.1}$
$\Xi(1950)^-$	1910.6 ± 18.4	105.7 ± 23.2	$11.5\,^{+5.8}_{-3.5}\,^{+49.9}_{-9.4}$
$\Xi(2030)^-$	2022.8 ± 4.7	68.2 ± 8.5	$7.3\,^{+1.8}_{-1.8}\,^{+3.8}_{-4.1}$
NR	—	—	$35.8\,^{+4.6}_{-6.4}\,^{+10.3}_{-11.2}$

Measurement of excited Ξ baryons

- Results for the Ξ resonances
  - Precise measurements of the mass and width of two states

$$M(\Xi(1690)^-) = 1692.0 \pm 1.3\,^{+\,1.2}_{-\,0.4}\,\text{MeV}, \quad \Gamma(\Xi(1690)^-) = 25.9 \pm 9.5\,^{+\,14.0}_{-\,13.5}\,\text{MeV},$$
$$M(\Xi(1820)^-) = 1822.7 \pm 1.5\,^{+\,1.0}_{-\,0.6}\,\text{MeV}, \quad \Gamma(\Xi(1820)^-) = 36.0 \pm 4.4\,^{+\,7.8}_{-\,8.2}\,\text{MeV}.$$

  - Spin-parity measurements will require more data
  - Run 3 data sample should have 10 times the number of signal events

- Evidence for a new pentaquark state

Mass $4458.8 \pm 2.9\,^{+4.7}_{-1.1}\,\text{MeV}$ Width $17.3 \pm 6.5\,^{+8.0}_{-5.7}\,\text{MeV}$

  - Significance of 3.1 sigma

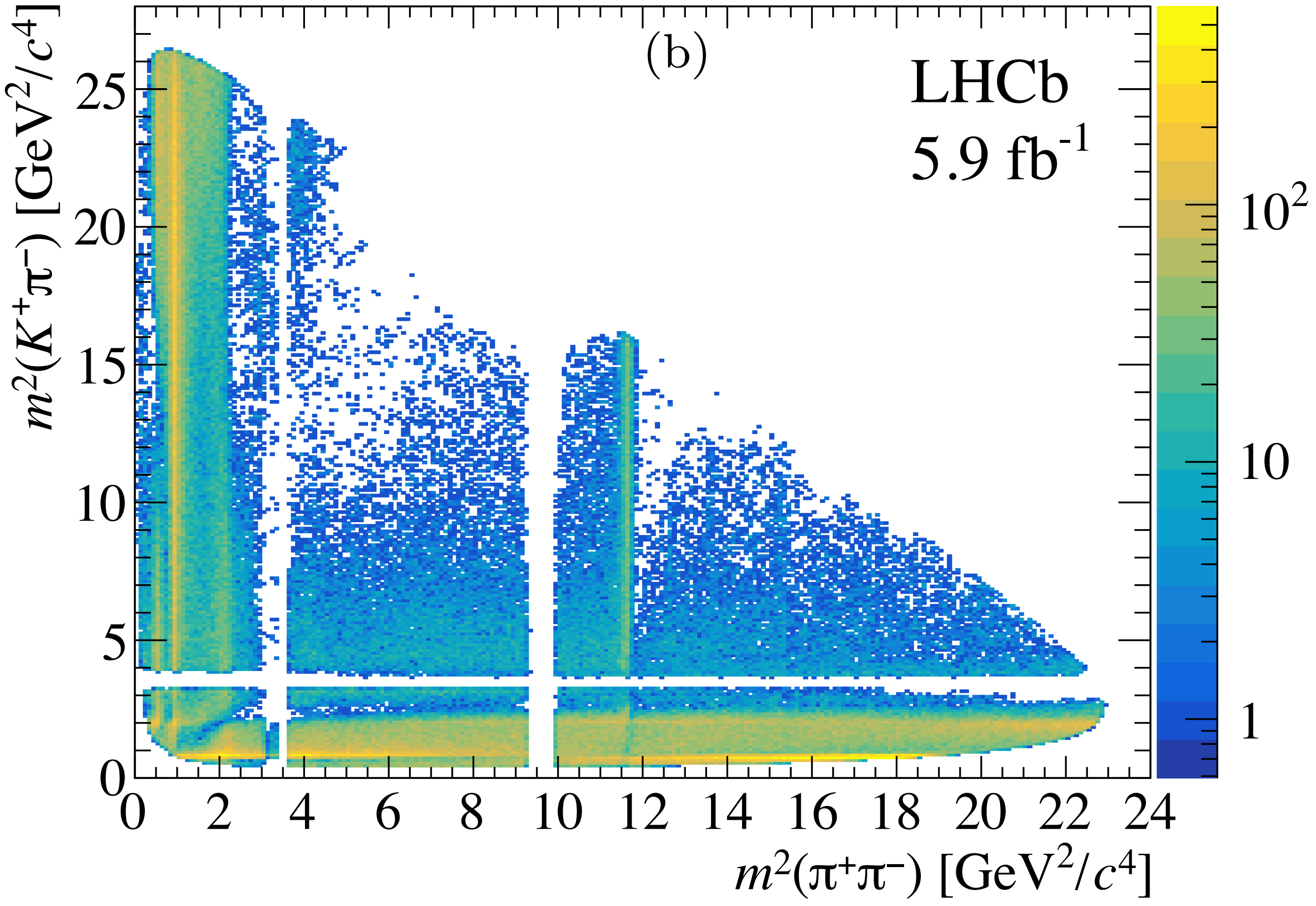
Future prospects

- Workshop outlines 4 different areas
  - excited kaons
  - strangeonia
  - hyperon resonances
  - the nature of Lambda(1405)

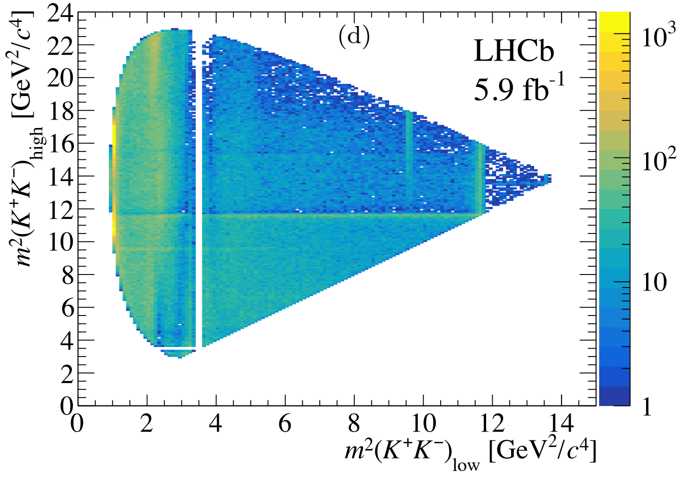
- In principle I think LHCb could contribute to all of them…
  - Excited kaons appear in many channels, where to look?
  - Producing them in B-hadron decays provides extremely clean samples
  - … but limits the production of the heavier states

Future prospects

- Large samples of $B^+ \to K^+\pi^+\pi^-$
  - Run 2 data gives ~500k events
  - No amplitude analysis yet
  - Rich structures visible up to around 2.2-2.3 GeV



- Can also access KK



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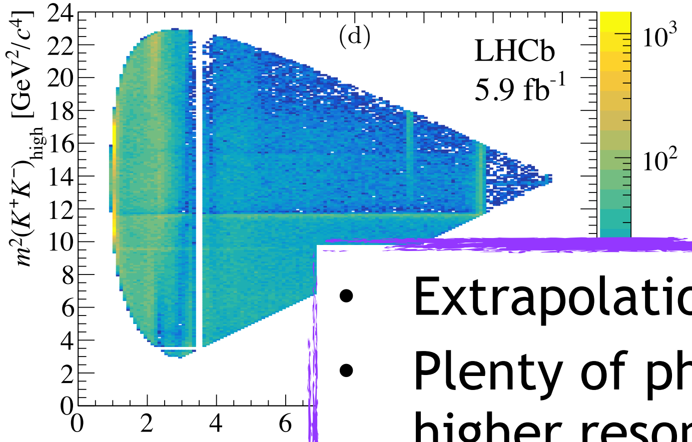
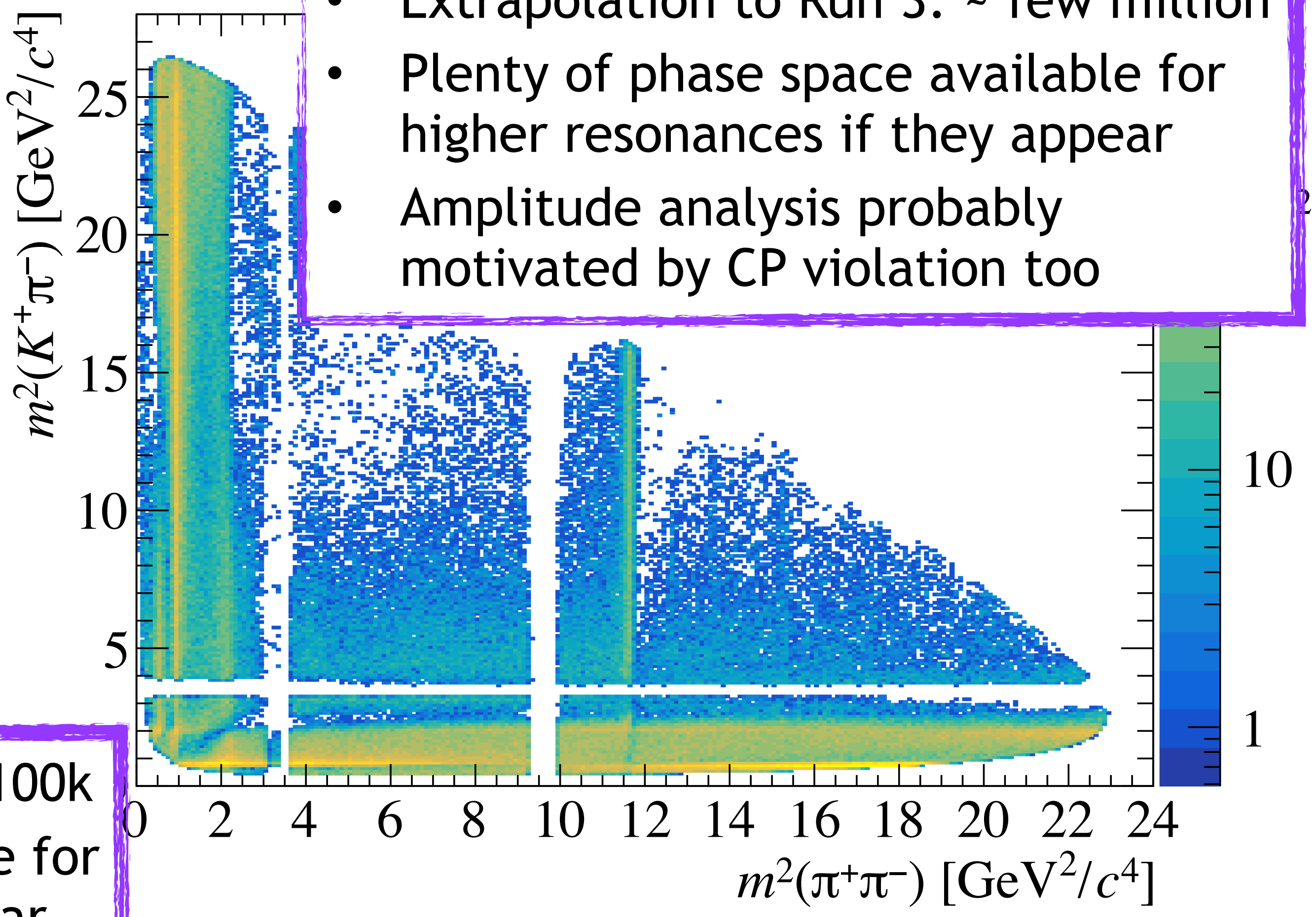


- Extrapolation to Run 3: ~ few 100k
- Plenty of phase space available for higher resonances if they appear

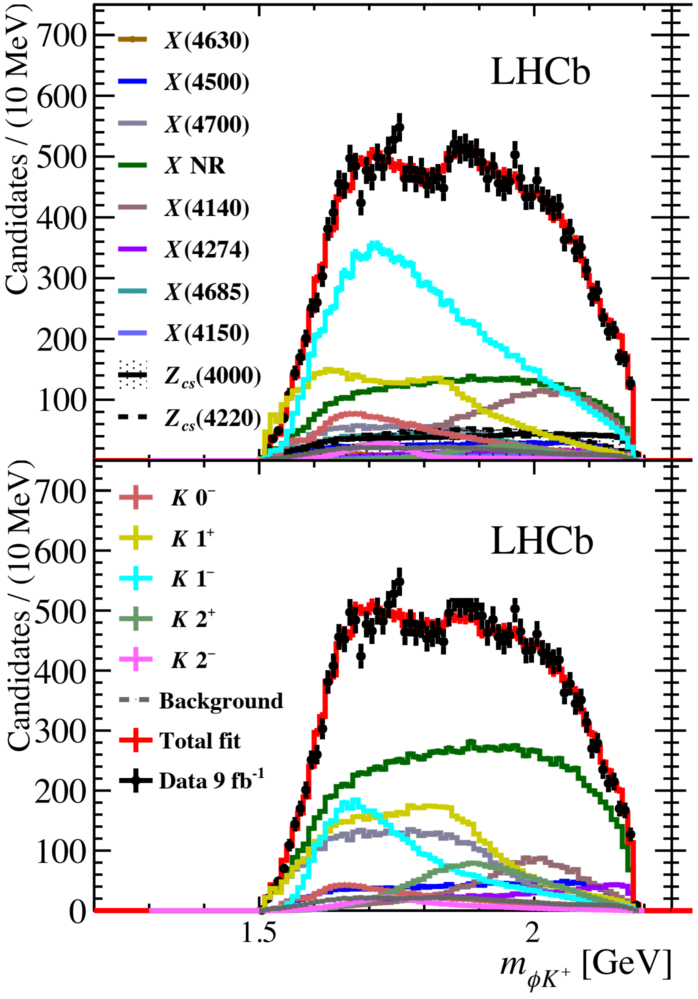


- Extrapolation to Run 3: ~ few million
- Plenty of phase space available for higher resonances if they appear
- Amplitude analysis probably motivated by CP violation too

Future prospects

- Large samples of $B^+ \to J/\psi\phi K^+$
  - Run 1+2 data gives ~24k events
  - No amplitude analysis yet
  - Rich structures visible up to around 2.2-2.3 GeV

J^P		Contribution	Significance $[\times\sigma]$	M_0 [MeV]	Γ_0 [MeV]	FF [%]
1^+	2^1P_1	$K(1^+)$	4.5 (4.5)	$1861 \pm 10\,^{+16}_{-46}$	$149 \pm 41\,^{+231}_{-23}$	
	2^3P_1	$K'(1^+)$	4.5 (4.5)	$1911 \pm 37\,^{+124}_{-48}$	$276 \pm 50\,^{+319}_{-159}$	
	1^3P_1	$K_1(1400)$	9.2 (11)	1403	174	$15 \pm 3\,^{+3}_{-11}$
2^-	1^1D_2	$K_2(1770)$	7.9 (8.0)	1773	186	
	1^3D_2	$K_2(1820)$	5.8 (5.8)	1816	276	
1^-	1^3D_1	$K^*(1680)$	4.7 (13)	1717	322	$14 \pm 2\,^{+35}_{-8}$
	2^3S_1	$K^*(1410)$	7.7 (15)	1414	232	$38 \pm 5\,^{+11}_{-17}$
2^-	2^3P_2	$K_2^*(1980)$	1.6 (7.4)	$1988 \pm 22\,^{+194}_{-31}$	$318 \pm 82\,^{+481}_{-101}$	$2.3 \pm 0.5 \pm 0.7$



Future prospects

- Large samples of $B^+ \to J/\psi \phi K^+$
  - Run 1+2 data gives ~24k events
  - No amplitude analysis yet
  - Rich structures visible up to around 2.2-2.3 GeV

- Extrapolation to Run 3: ~100k
- Likely still well motivated by exotic searches

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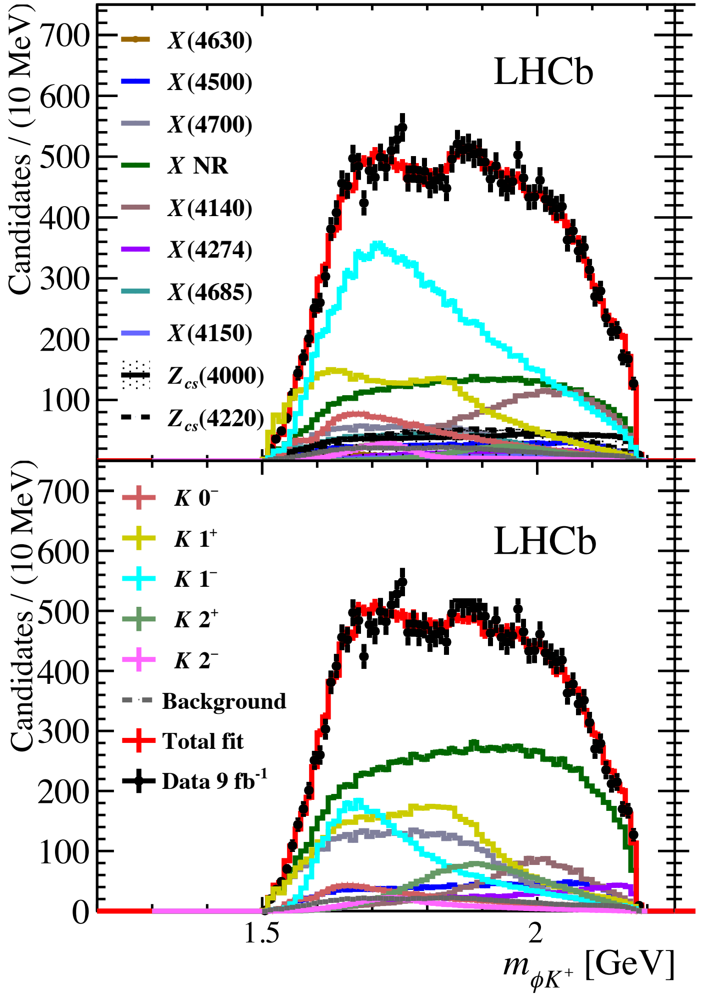

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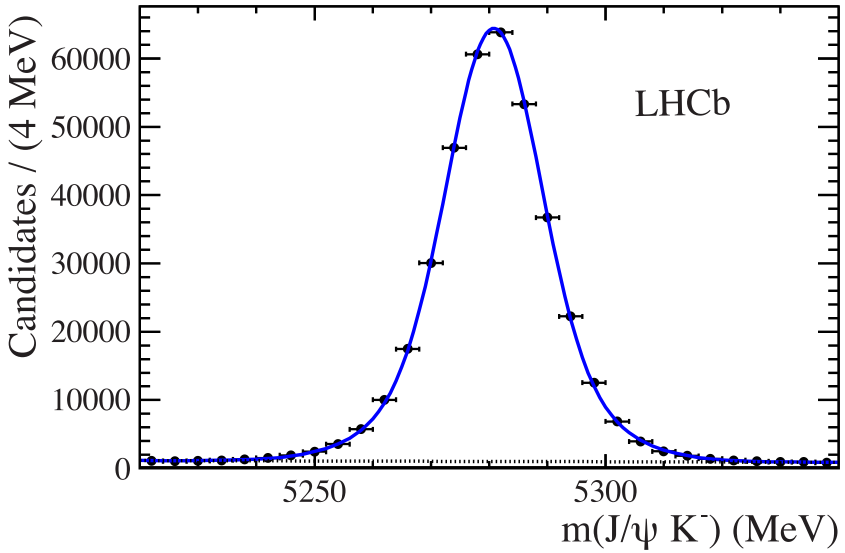
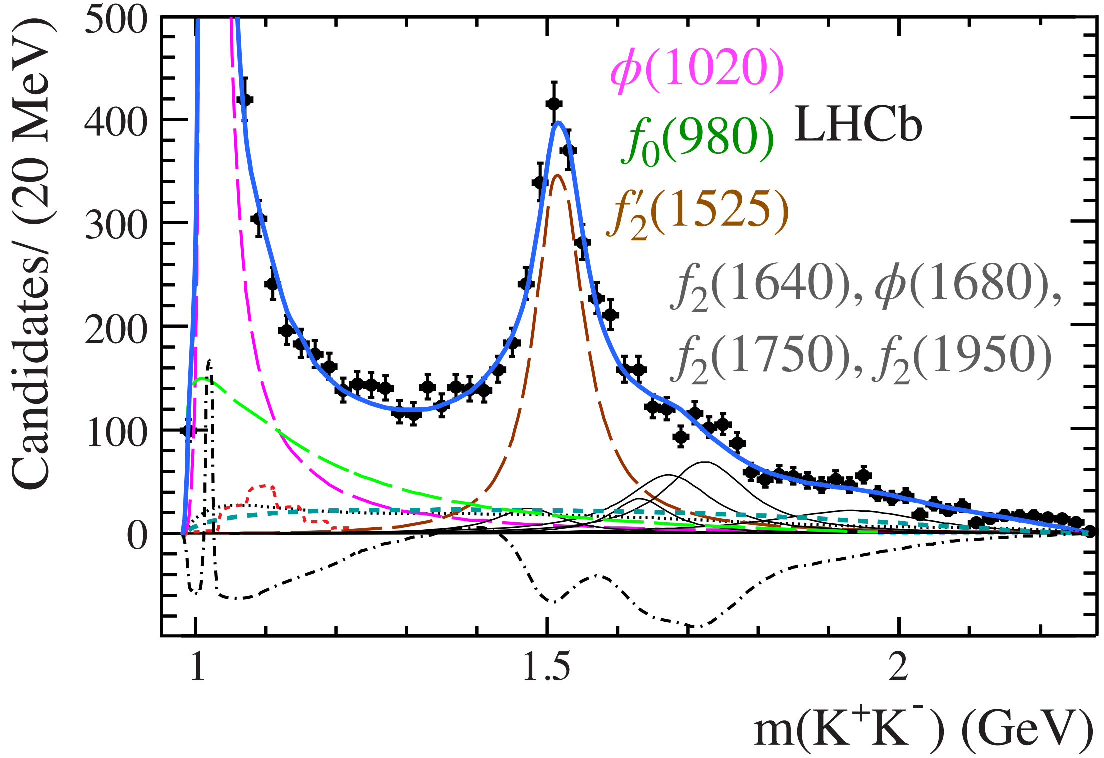
  - the nature of Lambda(1405)

- In principle I think LHCb could contribute to all of them…
  - Strangeonia can appear in many decays, where to look?
  - Producing them in B-hadron decays provides extremely clean samples
    - Challenge is to separate them from eachother

Future prospects

- Amplitude analysis of $\bar{B}_s^0 \to J/\psi K^+ K^-$
  - Just the 2011 dataset
  - ~350k signal candidates, > 97% purity
    - Most of those in the $\phi(1020)$ region
    - Visible structures up to ~2 GeV though





World leading measurements

$$m_{f_2'(1525)} = 1522.2 \pm 2.8^{+5.3}_{-2.0}\ \text{MeV},$$
$$\Gamma_{f_2'(1525)} = 84 \pm 6^{+10}_{-\ 5}\ \text{MeV}.$$

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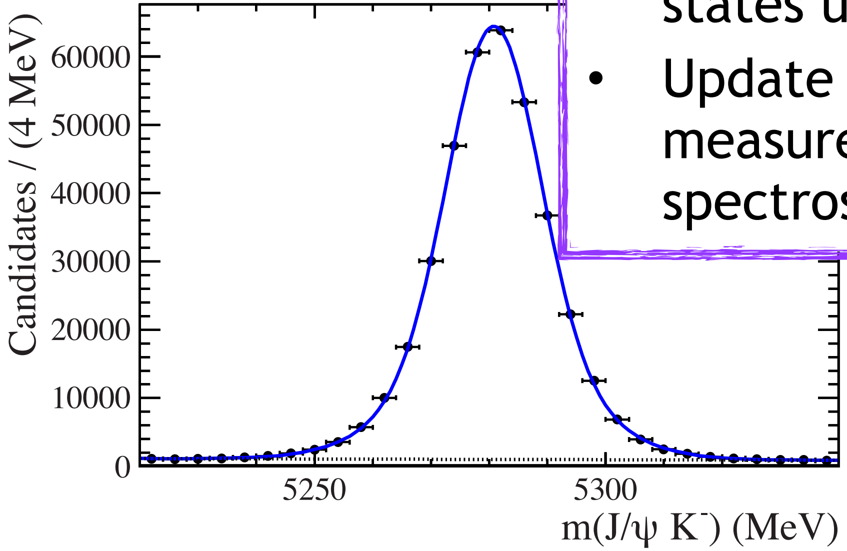

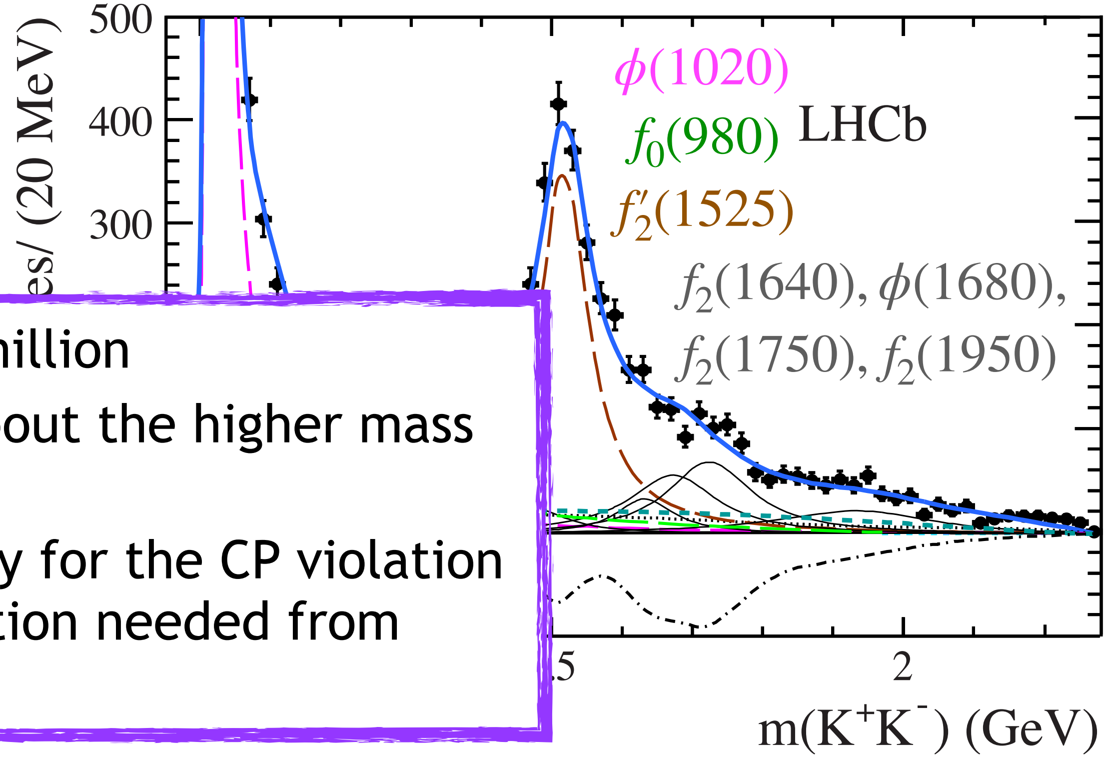

- Extrapolation to Run 3: ~ 15 million
- Should be able to say more about the higher mass states up to ~2.1 GeV
- Update might not be necessary for the CP violation measurement - strong motivation needed from spectroscopy side!

World leading measurements

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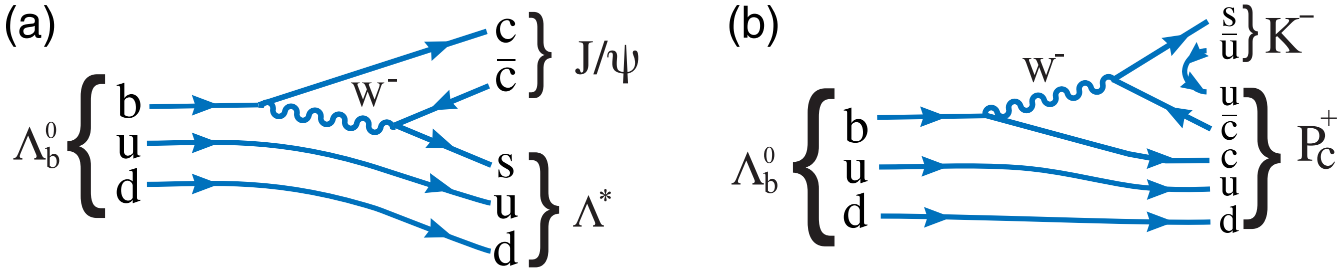
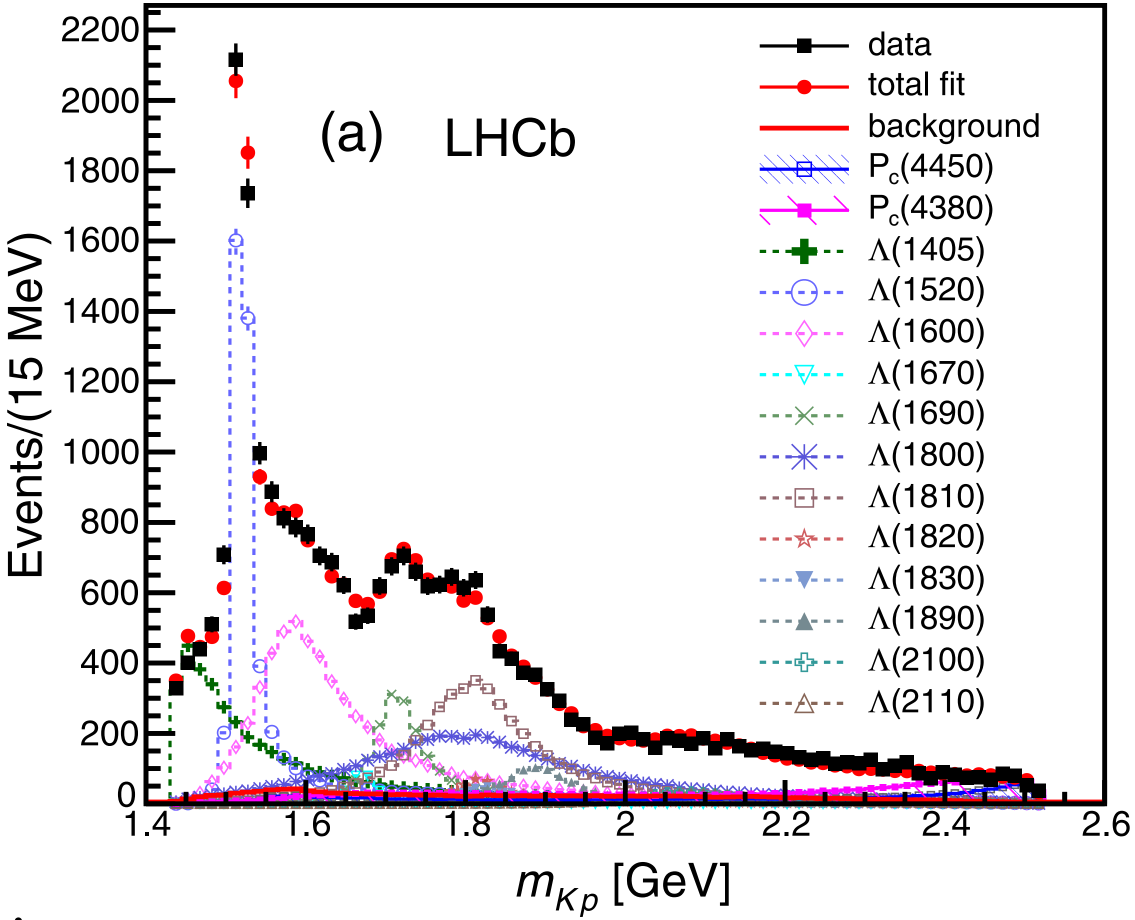
- In principle I think LHCb could contribute to all of them…
  - Hyperon states are produced in high numbers in b-hadron decays
    - Some more easily than others though (the Δ and Σ baryons are suppressed in b-decays)
  - Should have large samples of the Λ baryon family
    - Are they large enough?
    - If not, are they complimentary enough?

Future prospects

- Analysis of $\Lambda_b^0 \to J/\psi K^- p$ decays
  - This is the pentaquark discovery channel
  - The Λ family dominate the phase-space



- There are 26k signal events (Run 1)
  - 95% purity
  - Clean laboratory to study Λ states if motivated
  - Could measure masses, widths and spin-parity



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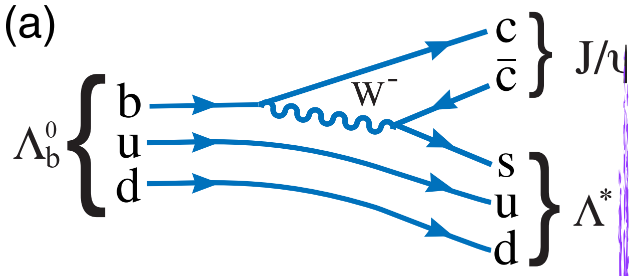

- Extrapolation to Run 3: up to 1 million
- Phase-space again running out by 2.5 GeV
- Full Run 2 analysis of this channel already very challenging. Run 3 analysis would be even more so - can we motivate things even more?

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  - 95% purity
  - Clean laboratory to study Λ states if motivated
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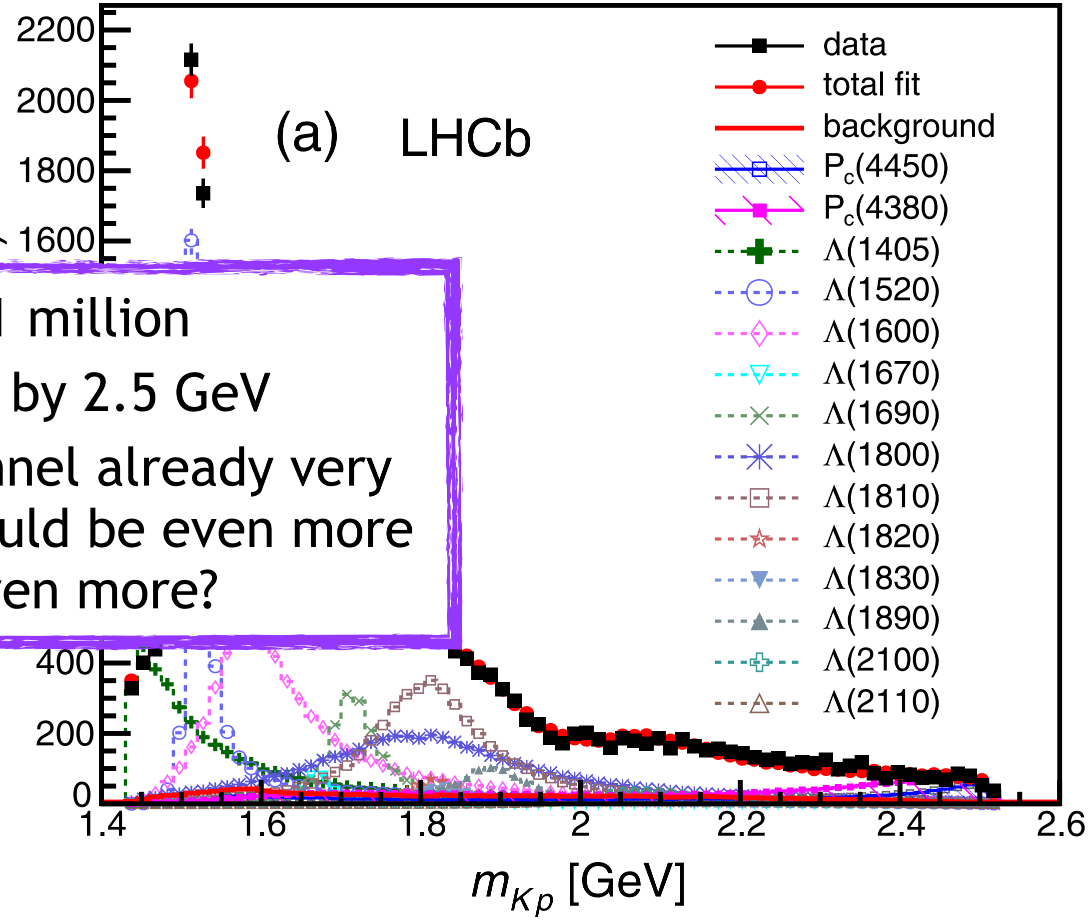

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- In principle I think LHCb could contribute to all of them…
  - Nature of the $\Lambda(1405)$ looks more challenging though
  - Too light* to decay to pK so requires reconstruction using neutrals
    - Not one of LHCb’s strong points… though Upgrade 2 might help
    - New calorimeter and enormous data samples
  - *Broad enough to leak into some Dalitz plots… can we do anything there?

Summary

- LHCb has large data samples that contain plenty of strangeness
- To date, not often the intended target for an analysis
- LHCb Upgrade and LHCb Upgrade II promise huge data sets for the foreseeable future

- Interested to hear thoughts on places we could have maximum impact