# Search for excited $\Omega_c^0$ states in $\Omega_b^- \to \Xi_c^+ K^- \pi^-$ decays

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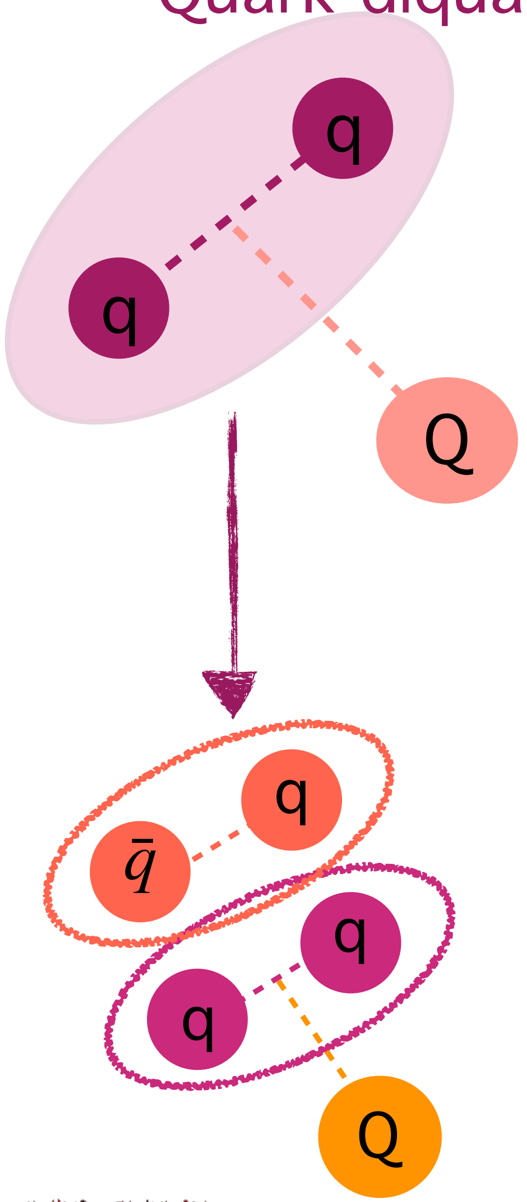
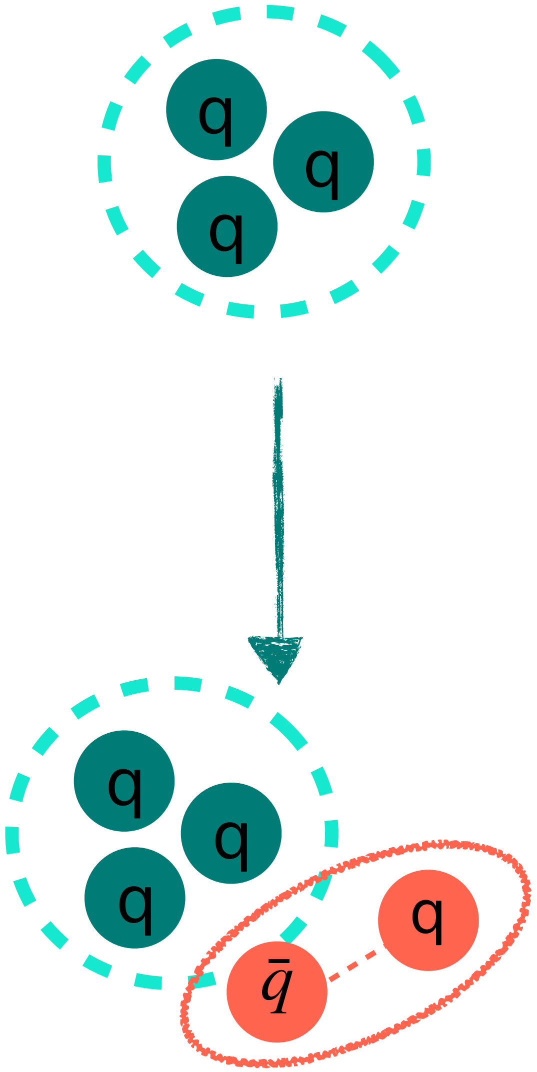
# Introduction

How are baryons formed?

Quark-diquark: Q qq



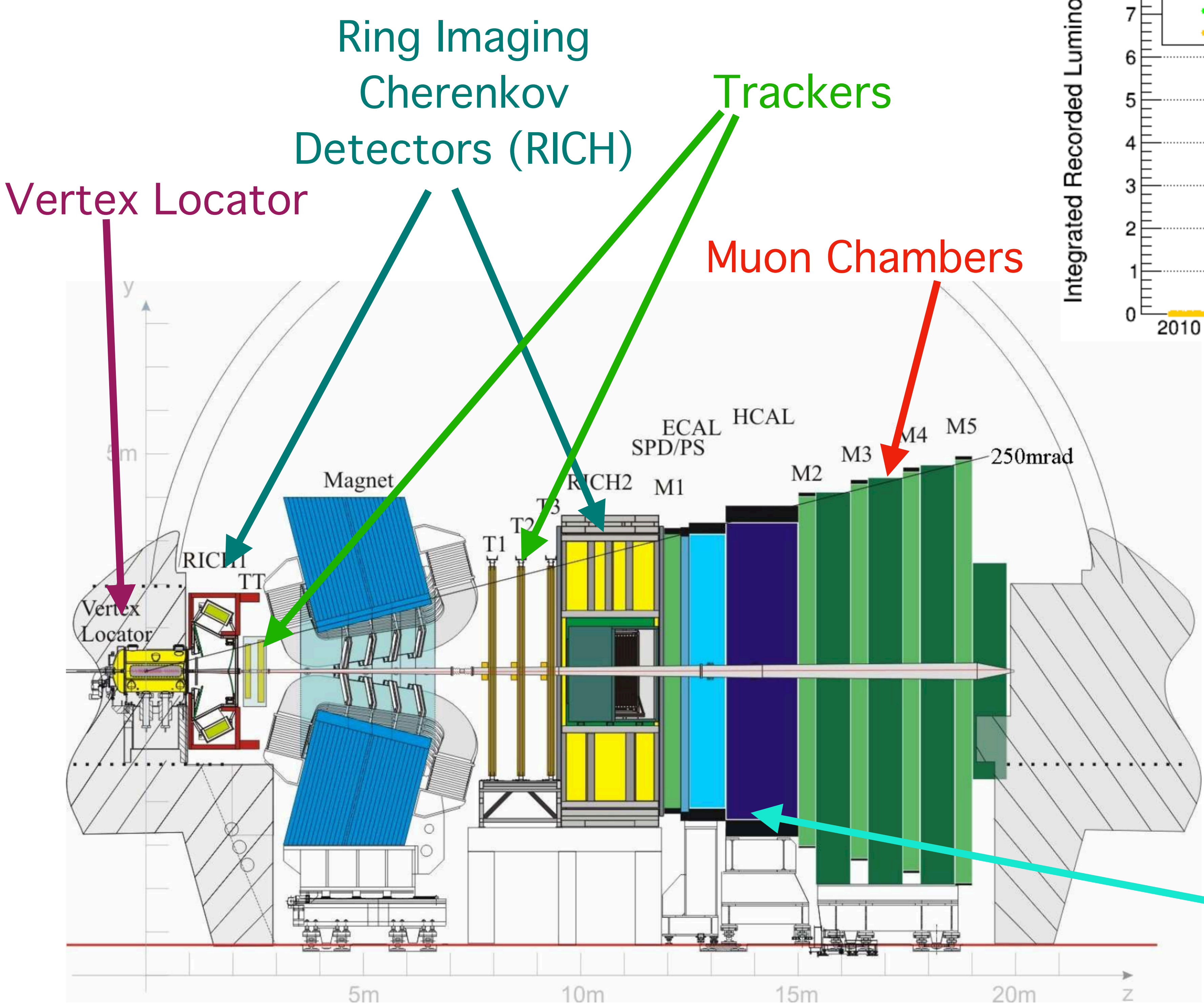

Three valence quarks: qqq

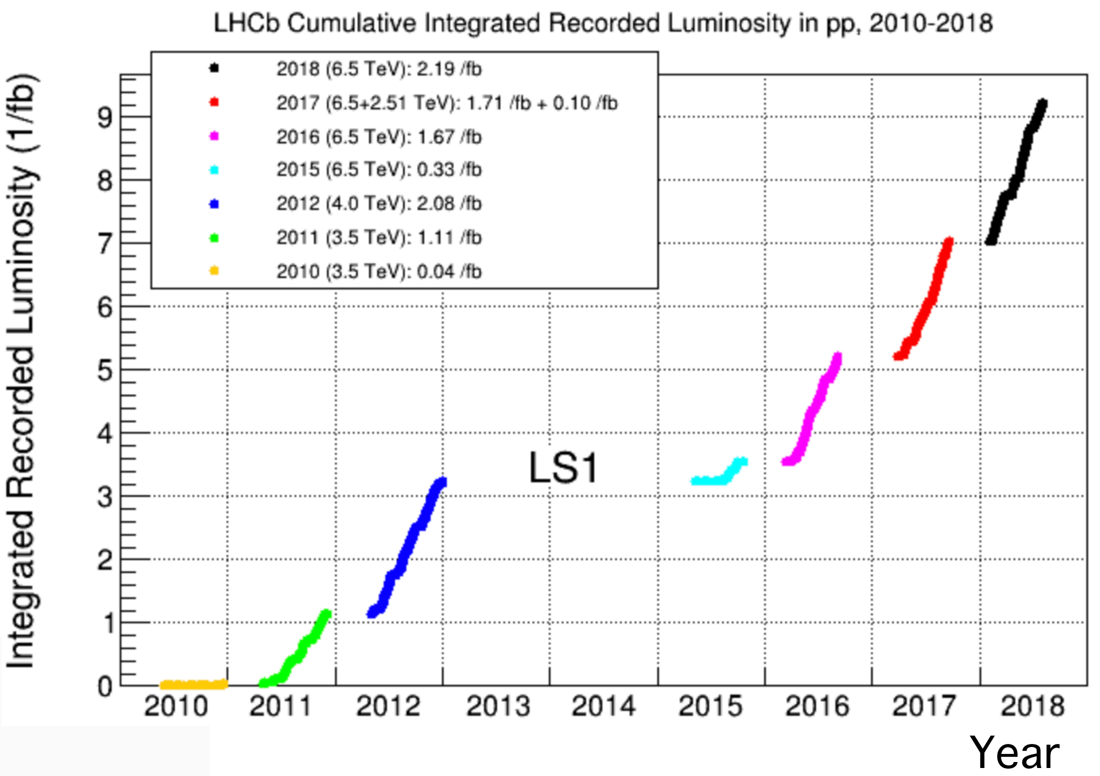



Huge interest in gaining a deeper understanding of the hadronic structure!

Studying conventional hadron spectroscopy should shed light on exotic hadron spectroscopy - so we can understand how tetraquarks and pentaquarks are formed.

# LHCb Detector




- Single-arm forward spectrometer.
- Extremely good particle identification.

# Motivation

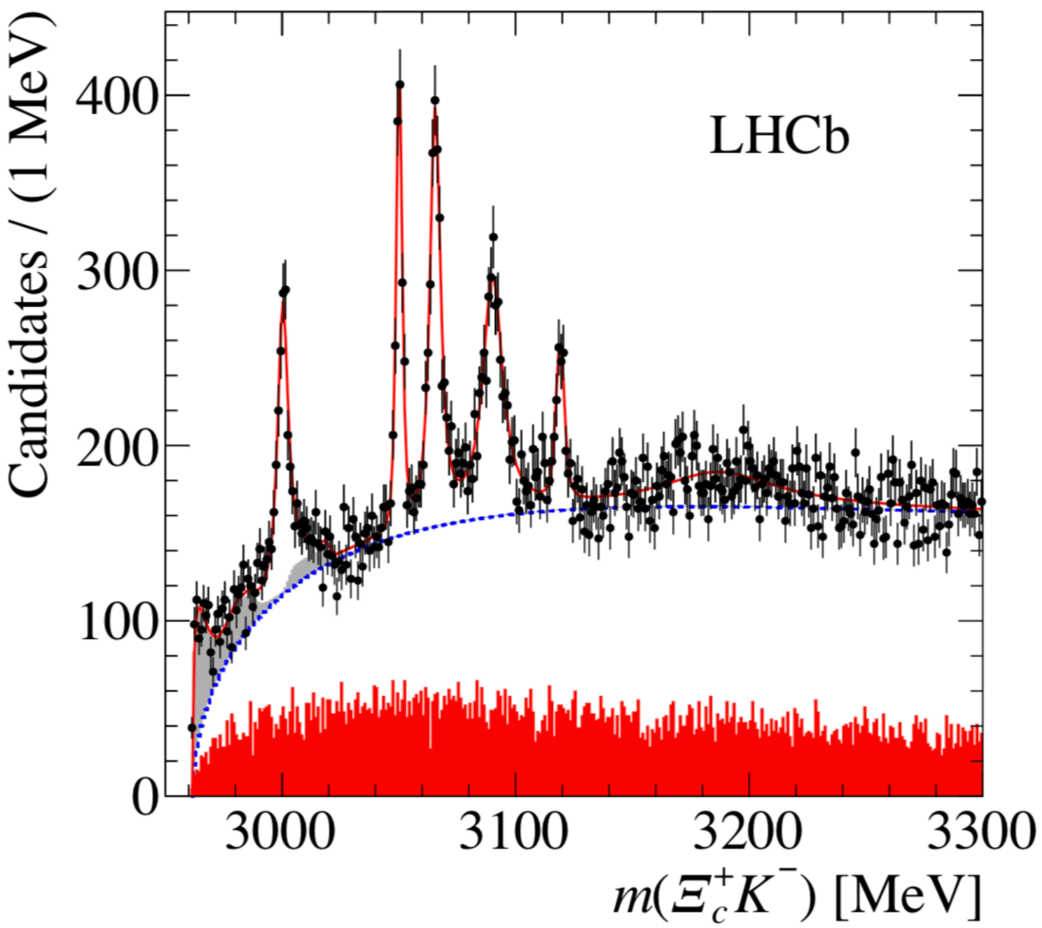
- Recent observation of five new resonances of $\Omega_c^0$ (css) decaying as $\Omega_c^{**0} \to \Xi_c^+ K^-$: Now cited over 175 times!

- Some of these new narrow states may be evidence of pentaquarks.

- These resonances were found in the prompt production.

- The quantum numbers of these states are currently unknown.

arxiv:1703.04639



# Quantum Numbers

- Different models predict very different quantum numbers.

| State | [20] | [21] | [22] | [24] | [30] | [26] | [28] | [29] | [33] | [27] | This work |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $\Omega_c(3000)$ | | $1/2^-$ | $1/2^-$ $(3/2^-)$ | $1/2^-$ | $1/2^-$ | $1/2^-$ | $1/2^-$ | $1/2^+$ or $3/2^+$ | $1/2^-$ | | $1/2^-$ |
| $\Omega_c(3050)$ | | $1/2^-$ | $1/2^-$ $(3/2^-)$ | $1/2^-$ | $5/2^-$ | $3/2^-$ | $1/2^-$ | $5/2^+$ or $7/2^+$ | $3/2^-$ | | $3/2^-$ |
| $\Omega_c(3066)$ | $1/2^+$ | $1/2^+$ or $1/2^-$ | $3/2^-$ $(5/2^-)$ | $3/2^-$ | $3/2^-$ | $5/2^-$ | $3/2^-$ | $3/2^-$ | $1/2^+$ | | $3/2^-$ |
| $\Omega_c(3090)$ | | | $3/2^-$ $(1/2^+)$ | $3/2^-$ | $1/2^-$ | $1/2^+$ | $3/2^-$ | $5/2^-$ | $1/2^+$ | | $5/2^-$ |
| $\Omega_c(3119)$ | $3/2^+$ | $3/2^+$ | $5/2^-$ $(3/2^+)$ | $5/2^-$ | $3/2^-$ | $3/2^+$ | $5/2^-$ | $5/2^+$ or $7/2^+$ | $3/2^+$ | $1/2^-$ | $1/2^+$ or $3/2^+$ |

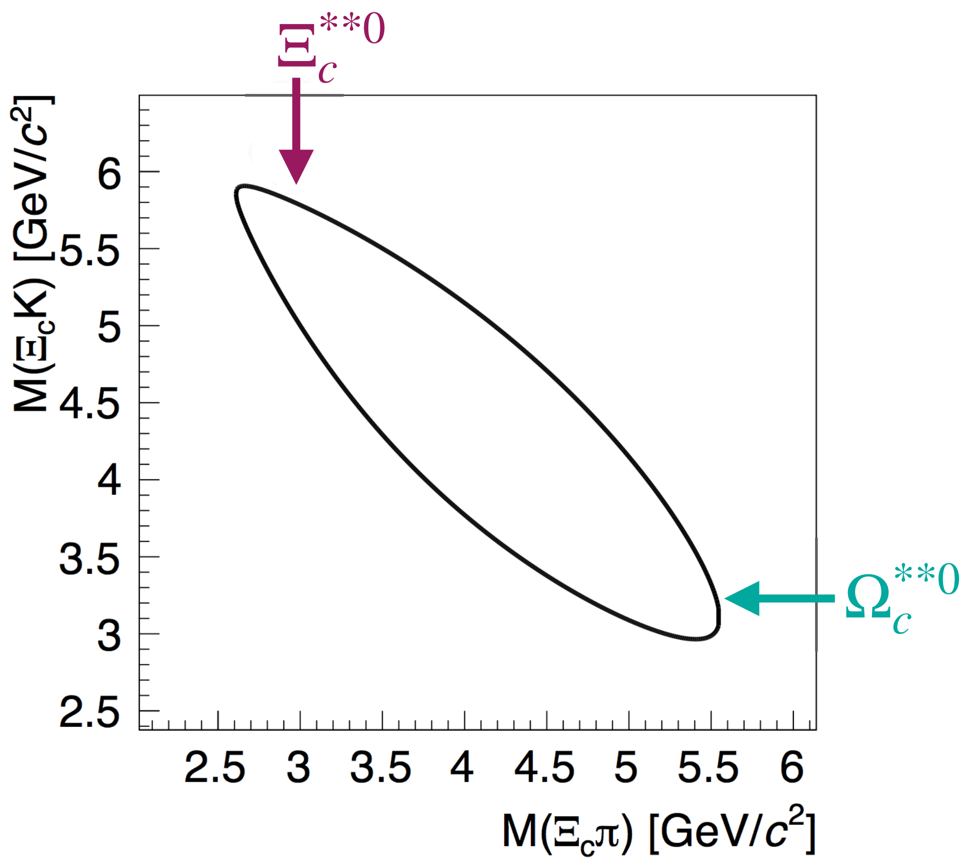
PhysRevD.95.116010

- The measurement of the quantum numbers can not be done in the prompt analysis due to the unknown polarisation of the $\Omega_c^{**0}$ states.
- A way to determine the quantum numbers is from studying the decay of a known hadron ($\Omega_b^-$) into these excited states.

# Main Goals

- Observation of a new decay mode $\Omega_b^- \to \Xi_c^+ K^- \pi^-$.
- First observation of the excited $\Omega_c^0$ states from $\Omega_b^-$ decays.
- Measurement of their quantum numbers.

# Method




- The decay of interest: $\Omega_b^- \to \Xi_c^+ K^- \pi^-$.

$$\Omega_b^- \to \Omega_c^{**0}\pi^-$$
$$\hookrightarrow \Xi_c^+ K^-$$
$$\hookrightarrow p^+ K^- \pi^+$$

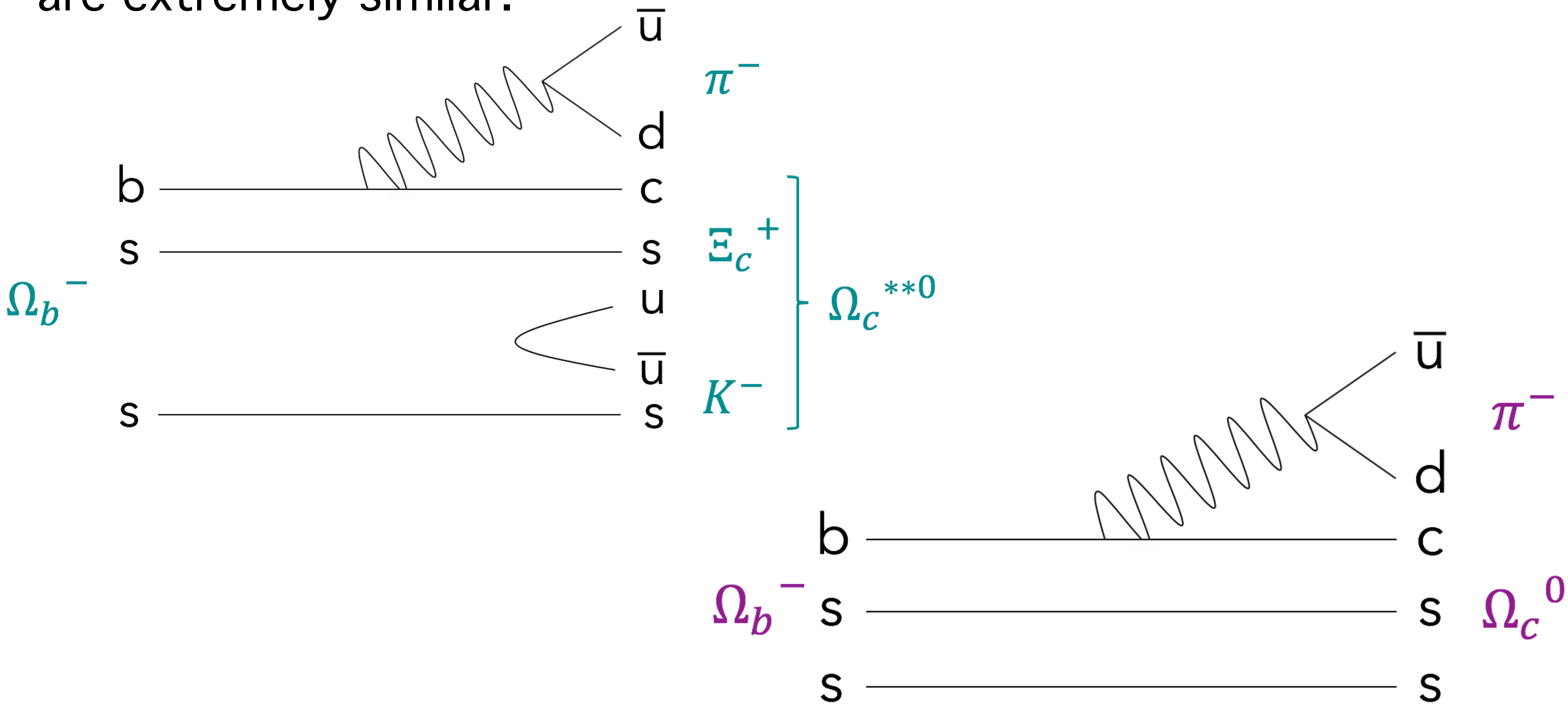
- There will be no resonances from $K^-\pi^-$, however there are resonances possible from $\Xi_c^+\pi^-$ ($\Xi_c^{**0}$) but these will populate different areas in the phase space than $\Xi_c^+ K^-$.

- First a similar decay will be studied, $\Omega_b^- \to \Omega_c^0 \pi^-$, this decay has been observed previously.

$$\Omega_b^- \to \Omega_c^0 \pi^-$$
$$\hookrightarrow p^+ K^- K^- \pi^+$$

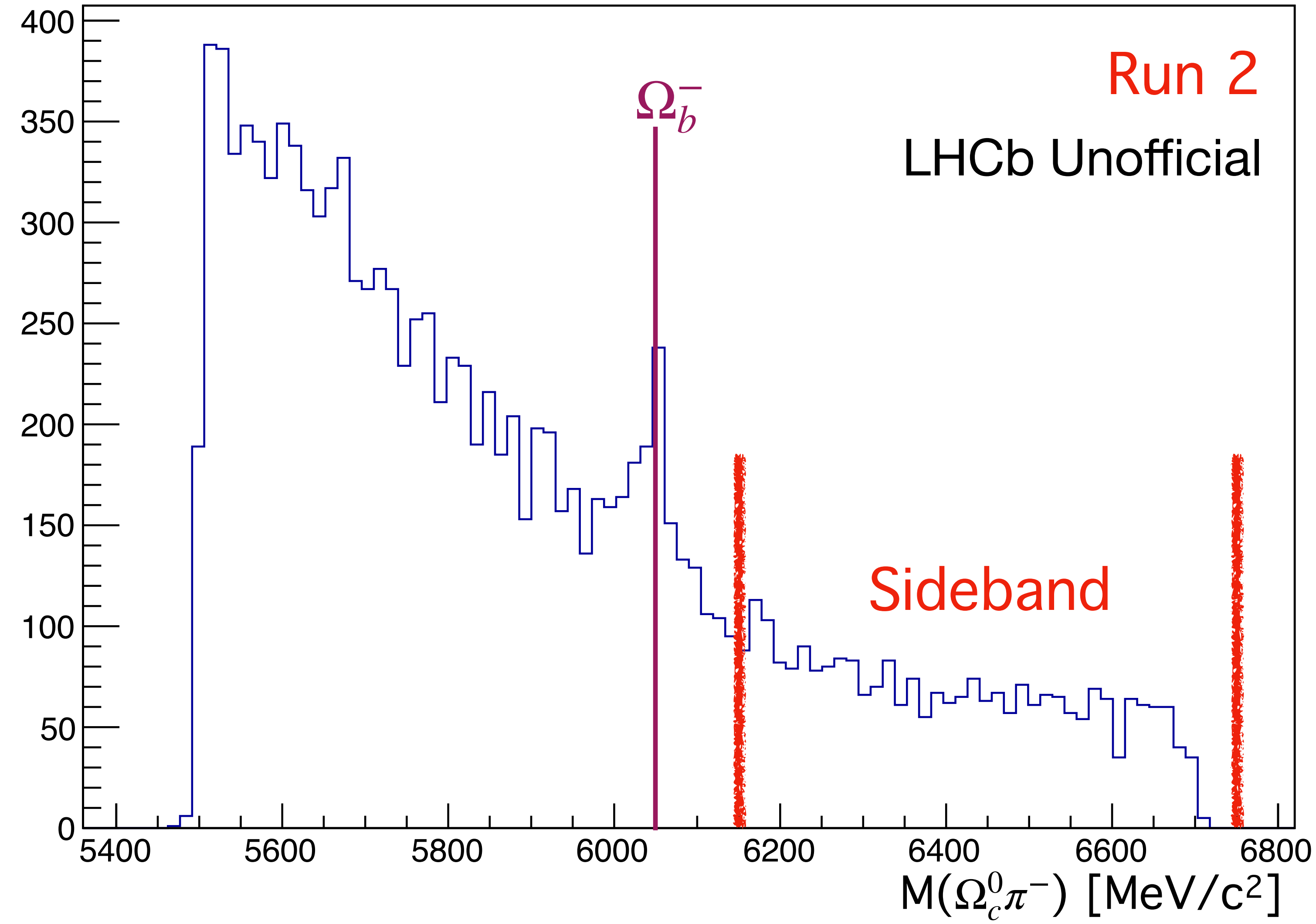
# Data

- Topology of final states (number and type of tracks) of both decays are extremely similar.



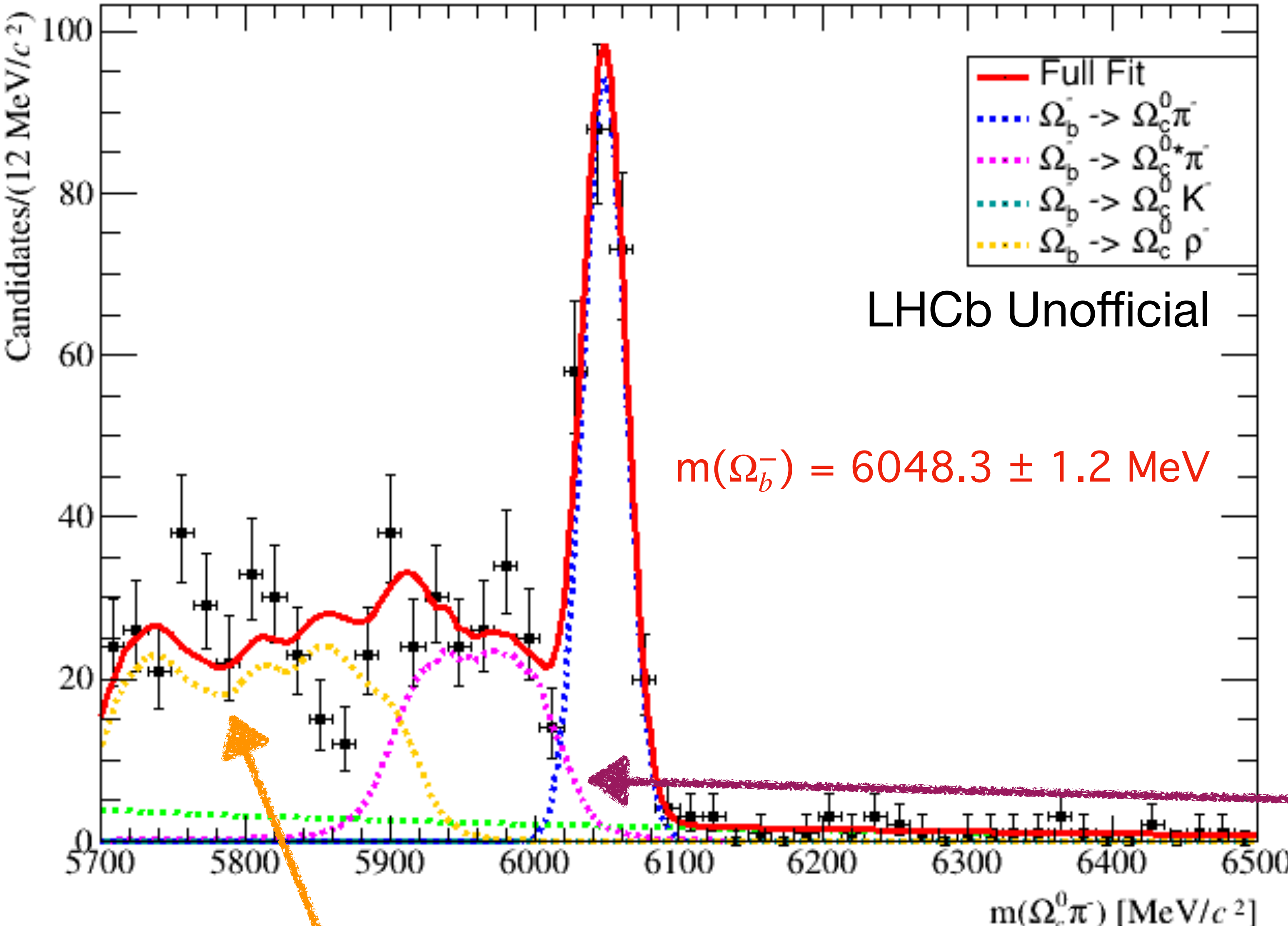
# $\Omega_b^- \to \Omega_c^0 \pi^-$: Event Selection

- Initial cuts applied to a variety of variables, these include:
  - PID of final state particles.
  - Mass of $\Omega_c^0$.
  - Transverse momentum.




- A multivariate analysis technique is implemented to reduce background.
- MC is used for the signal sample and sideband for the background sample.
- A boosted decision tree (BDT) has been used for the selection of events and the cut on the BDT is optimised.

# $\Omega_b^- \to \Omega_c^0 \pi^-$: Fitting




$\Omega_b^- \to \Omega_c^0 \rho^-$
$\hookrightarrow \pi^- \pi^0$

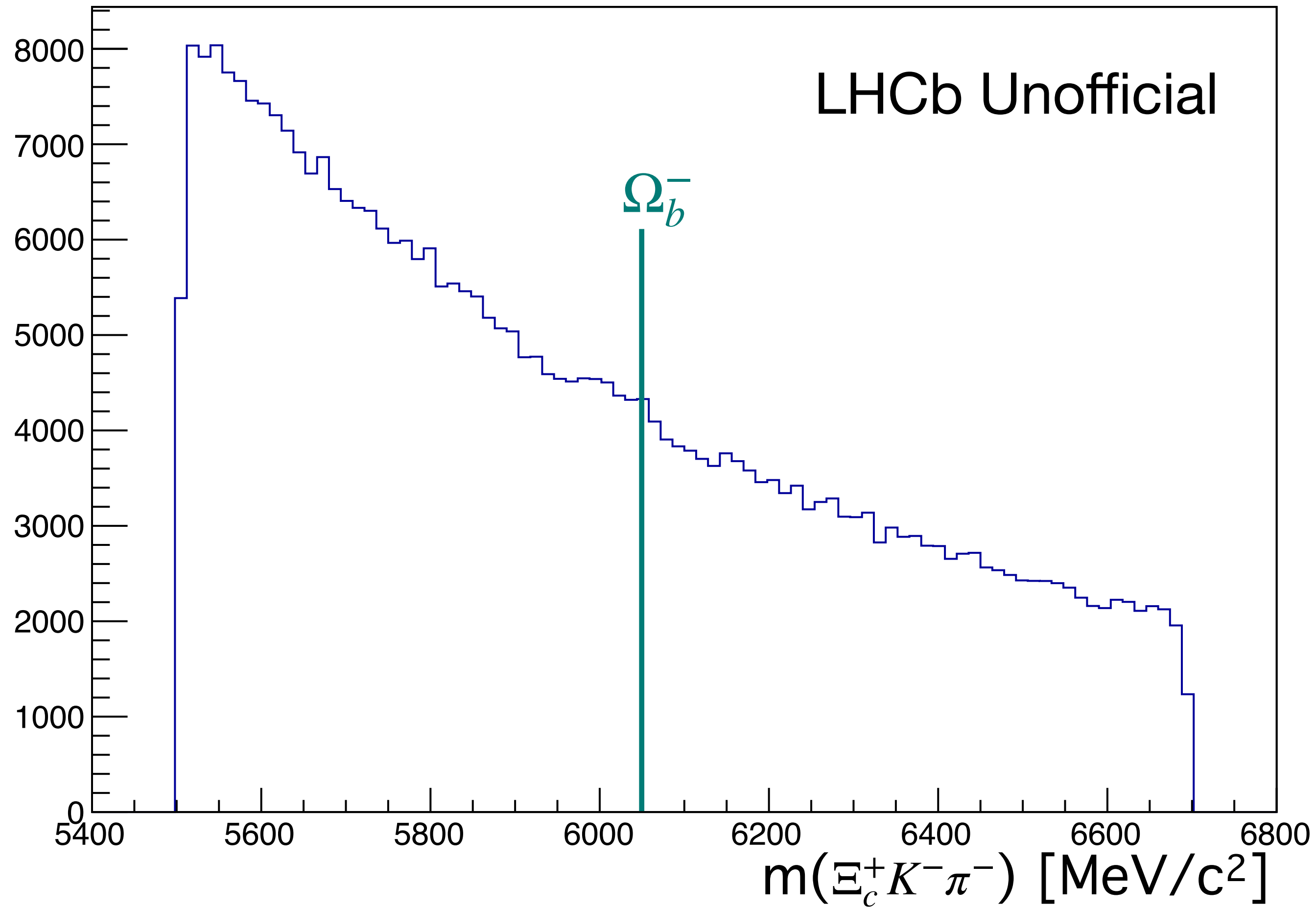
| Decay | Yield |
|---|---|
| $\Omega_b^- \to \Omega_c^0 \pi^-$ | 224.7 ± 16.0 |
| $\Omega_b^- \to \Omega_c^{*0} \pi^-$ | 180.8 ± 16.7 |
| $\Omega_b^- \to \Omega_c^0 \rho^-$ | 283.7 ± 21.1 |
| $\Omega_b^- \to \Omega_c^0 K^-$ | - |

$\Omega_b^- \to \Omega_c^{*0} \pi^-$
$\hookrightarrow \Omega_c^0 \gamma$

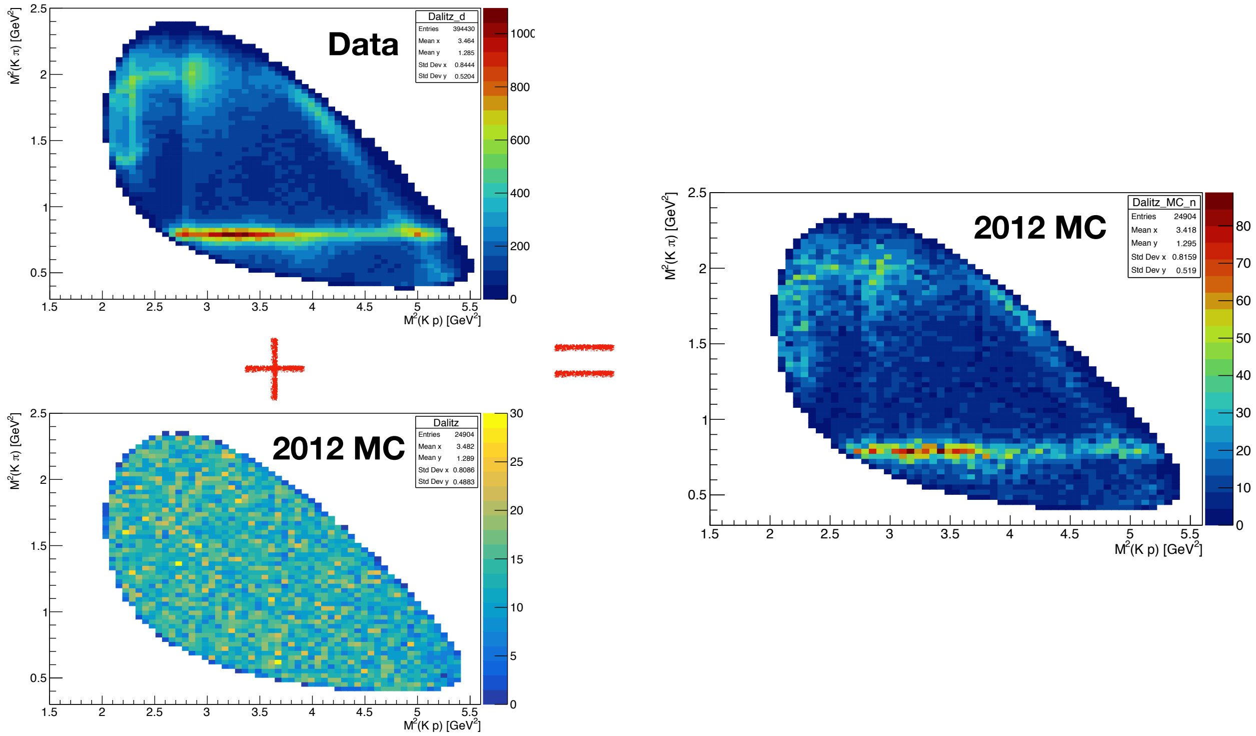
This peak is shifted down due to the photon not being reconstructed.

# $\Omega_b^- \to \Omega_c^{**0}(\to \Xi_c^+ K^-)\pi^-$

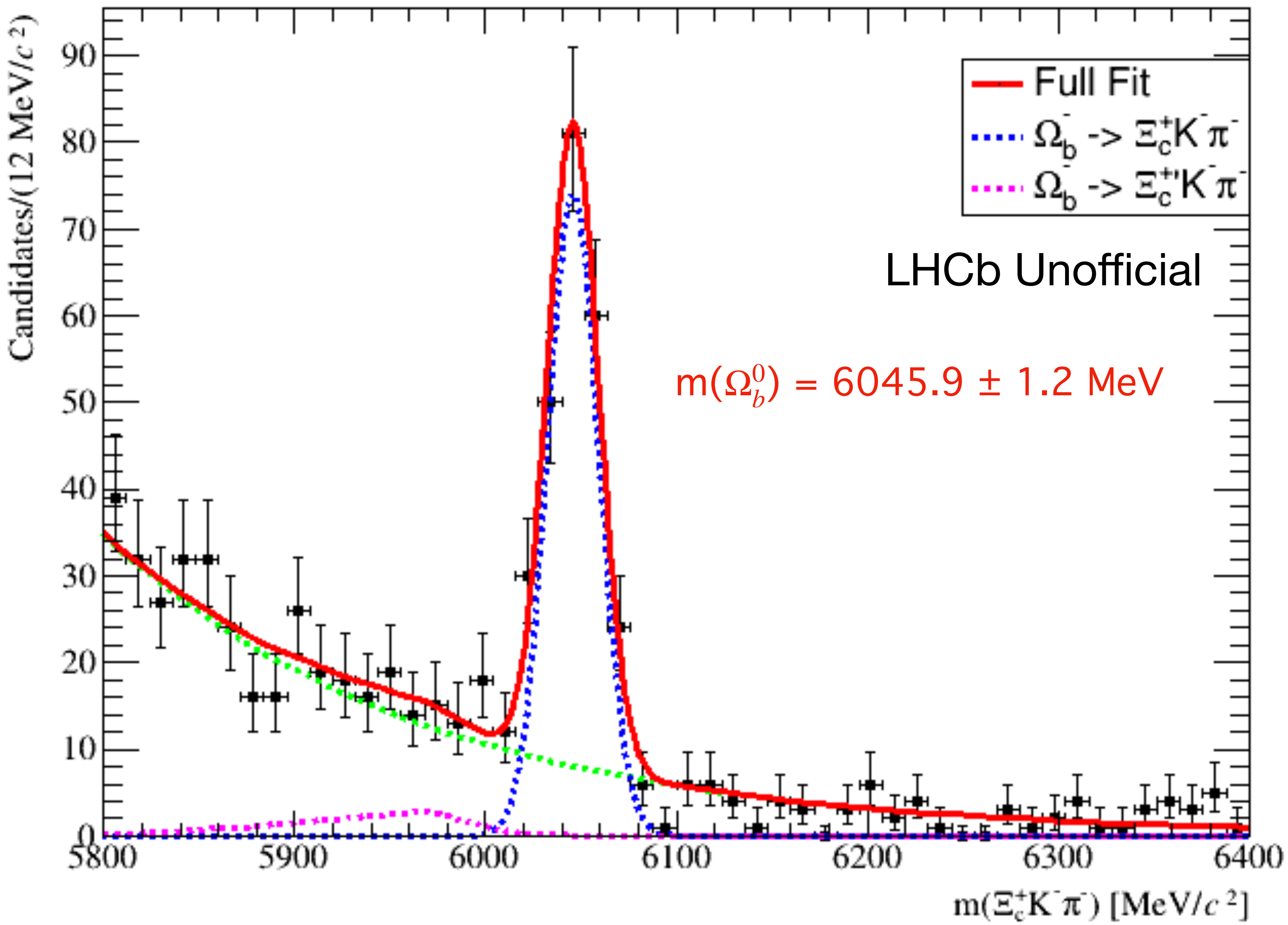
- Can now move onto the decay of interest.
- The analysis strategy performed on $\Omega_b^- \to \Omega_c^0\pi^-$ can now be applied to this decay mode.
- A BDT is used for the selection of signal events.




- The $\Xi_c^+$ Dalitz plot in MC is reweighted according to data.



# $\Omega_b^- \to \Omega_c^{**0}(\to \Xi_c^+ K^-)\pi^-$: Fitting $\Omega_b^-$ Mass

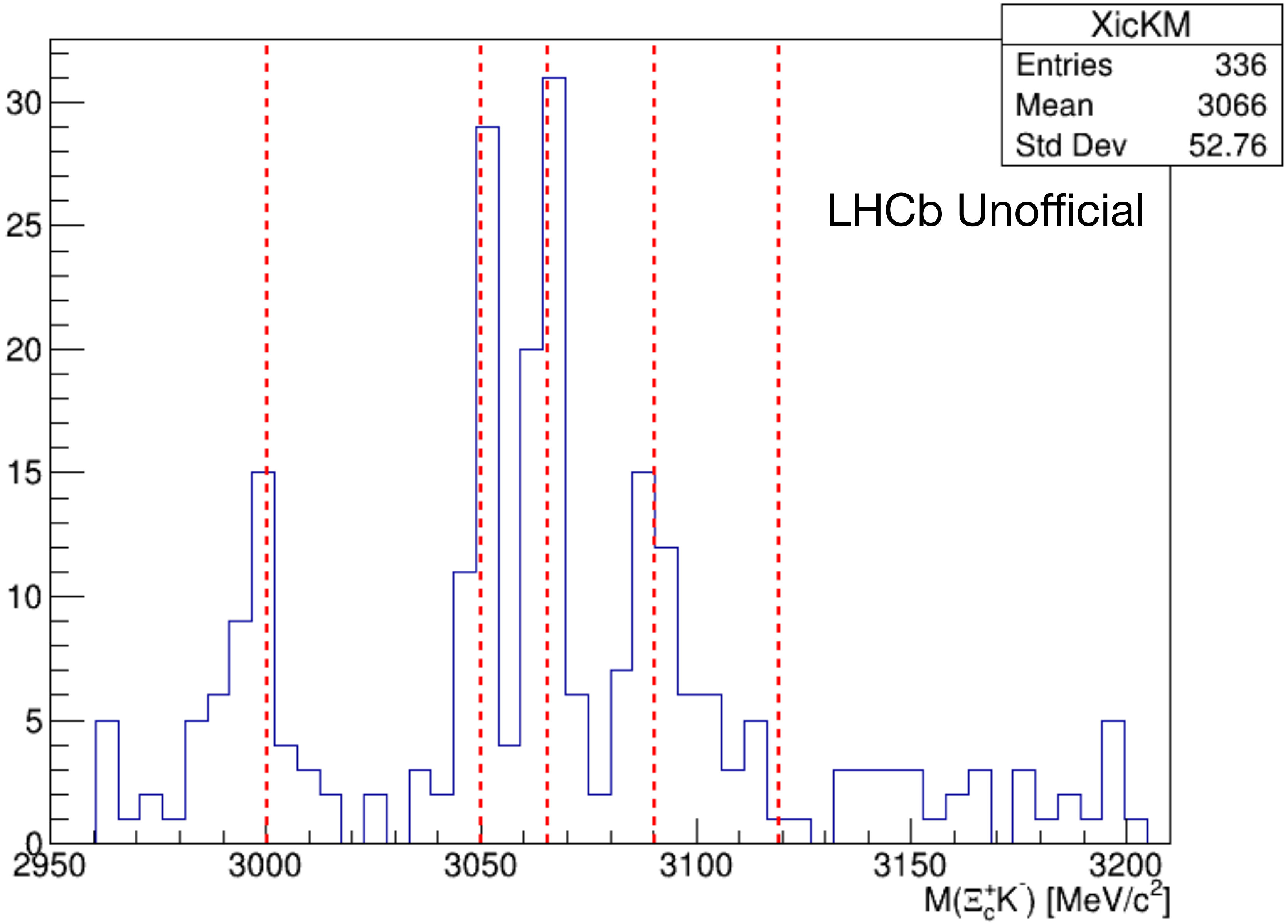



| Decay | Yield |
|---|---|
| $\Omega_b^- \to \Xi_c^+ K^- \pi^-$ | 208.7 ± 16.5 |
| $\Omega_b^- \to \Xi_c^{\prime +} K^- \pi^-$ | 26.0 ± 21.5 |

- Using 9fb[-1].
- Candidates within $3\sigma$ of the measured value of the $\Omega_b^-$ mass are used for the search of the excited $\Omega_c^0$ states.

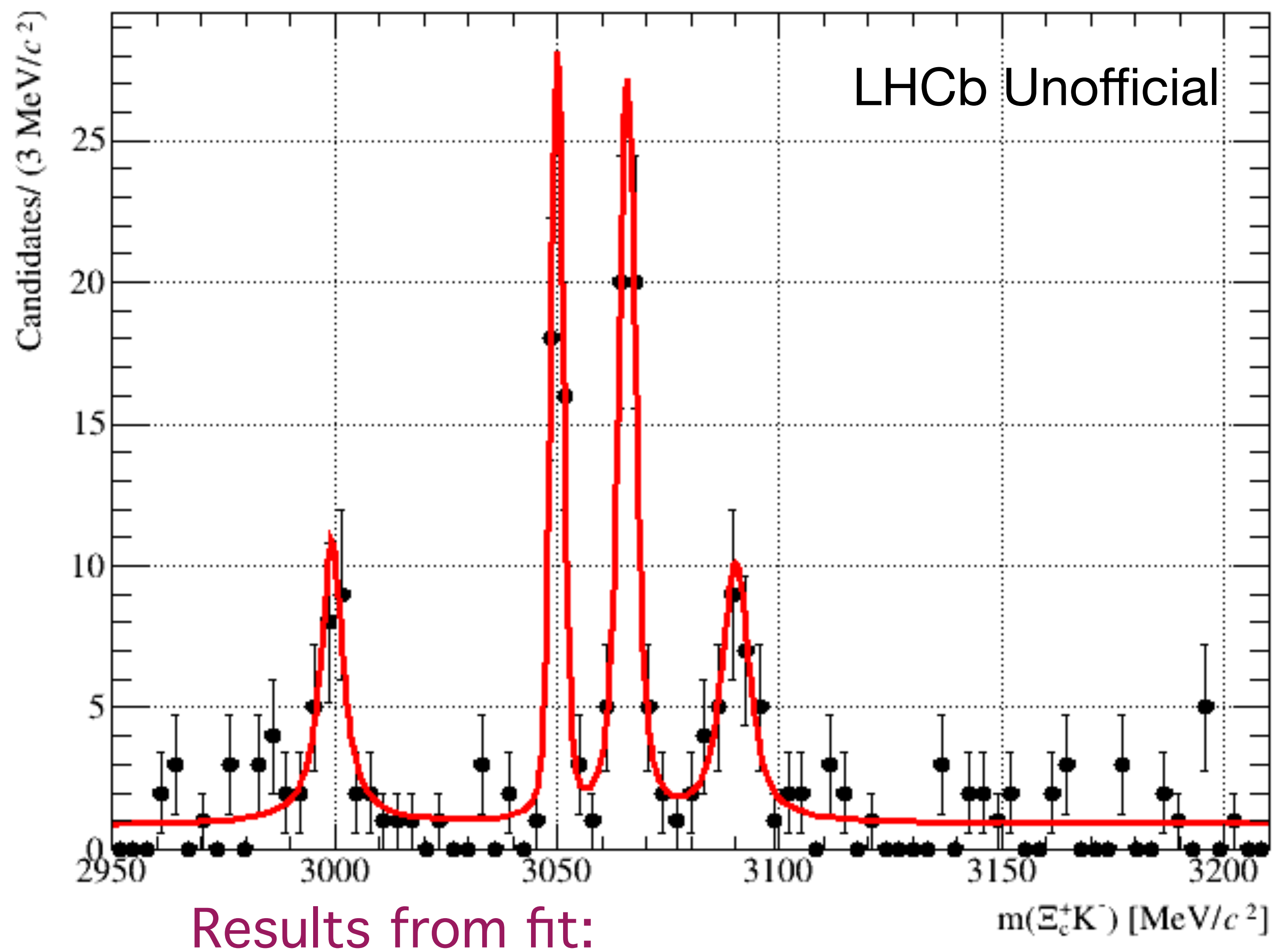
# $\Omega_b^- \to \Omega_c^{**0}(\to \Xi_c^+ K^-)\pi^-$: m($\Xi_c^+ K^-$)

- Additional $\Omega_b^-$ mass constraint to improve mass resolution in the $\Xi_c^+ K^- \pi^-$ phase space.
- 4 out of the 5 states observed previously can be seen.



# m($\Xi_c^+ K^-$): Fitting

- Fitted with a relativistic Breit Wigner (s-wave) convolved with a Gaussian (for detector resolution).
- Background is currently modelled as a flat line.
- Errors are statistical.

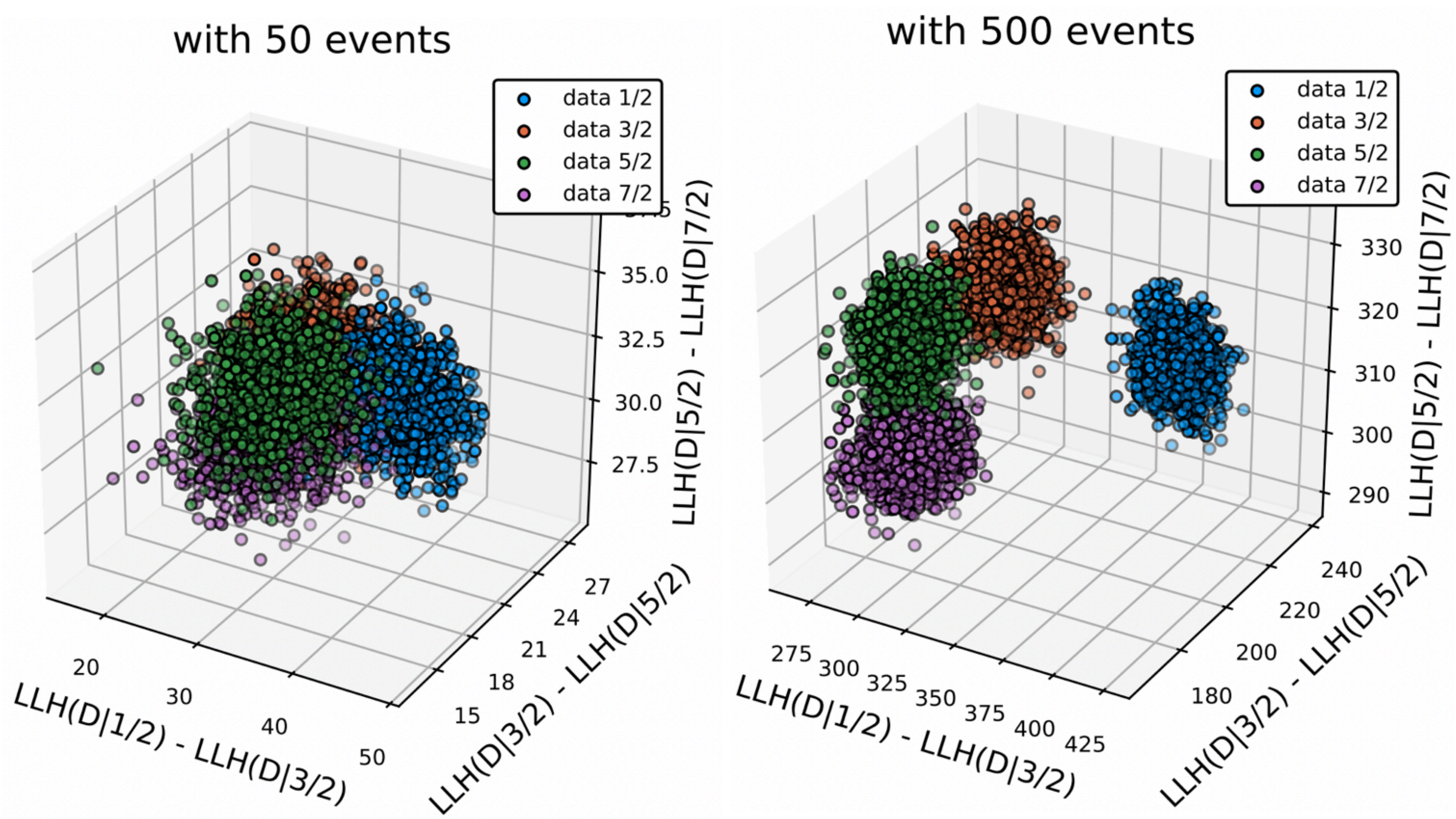


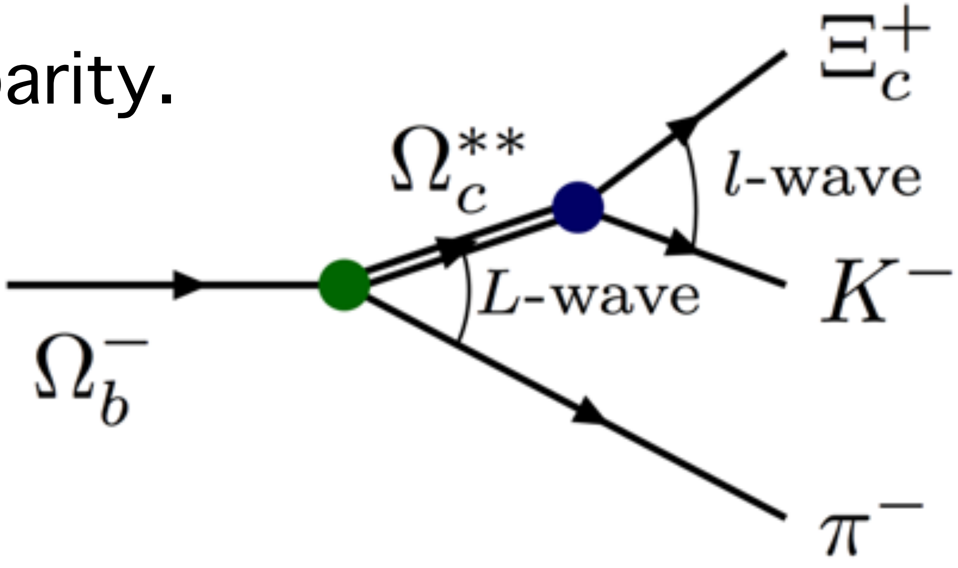

Results from 2017 paper: Results from fit:

| Resonance | Mass [MeV] | $\Gamma$ [MeV] | Mass [MeV] | $\Gamma$ [MeV] | Yield |
|---|---|---|---|---|---|
| $\Omega_c(3000)^0$ | 3000.4 ± 0.2 | 4.5 ± 0.6 | 2999.5 ± 0.9 | 5.6 ± 2.1 | 28.3 ± 7.2 |
| $\Omega_c(3050)^0$ | 3050.2 ± 0.1 | 0.8 ± 0.2 | 3050.2 ± 0.3 | 1.0 ± 1.0 | 34.7 ± 6.5 |
| $\Omega_c(3065)^0$ | 3065.6 ± 0.1 | 3.5 ± 0.4 | 3065.9 ± 0.4 | 2.4 ± 0.9 | 50.0 ± 8.2 |
| $\Omega_c(3090)^0$ | 3090.2 ± 0.3 | 8.7 ± 1.0 | 3090.3 ± 0.9 | 5.4 ± 2.5 | 30.0 ± 7.5 |

# Angular Analysis

- The spin of the $\Omega_c^{**0}$ states can be probed by studying angular distributions of the $\Omega_b^- \to \Xi_c^+ K^- \pi^-$ decay.
- A six dimensional analysis can be sensitive to quantum numbers of states even with 50 events.
- MC toys show discrimination between spin parity.




- Validation ongoing: $\Xi_b^- \to \Lambda_c^+ K^- \pi^-$

Dalitz-plot decomposition for three-body decays: arxiv:1910.04566

# Summary

- First observation of a new decay mode; $\Omega_b^- \to \Xi_c^+ K^- \pi^-$.
- Observation of $\Omega_c^{**0}$ from $\Omega_b^-$ decays.
- Shown that the $\Omega_c^{**0}$ states are not partially reconstructed decays.

- More results will be reported in this analysis:
    - First observation of $\Omega_b^- \to \Omega_c^{*0} \pi^-$.
    - Measurement of the branching ratios.
    - Precise measurement of the $\Omega_b^-$ mass.

Results from this analysis:

$\Omega_c^0 \pi^-$ : m($\Omega_b^-$) = 6048.3 ± 1.2 (stat) MeV

$\Xi_c^+ K^- \pi^-$ : m($\Omega_b^0$) = 6045.9 ± 1.2 (stat) MeV

PDG Mass:

| *VALUE* (MeV) | *DOCUMENT ID* | | *TECN* |
|---|---|---|---|
| **6046.1± 1.7 OUR AVERAGE** | | | |
| 6045.1± 3.2± 0.8 | [1] AAIJ | 16O | LHCB |
| 6047.5± 3.8± 0.6 | [2] AALTONEN | 14B | CDF |
| 6046.0± 2.2± 0.5 | [3] AAIJ | 13AV | LHCB |

# Thanks for Listening!!