Northern Illinois University

PHYS 684 Final Project

Observation of the doubly charmed baryon decay $\Xi_{cc}^{++} \rightarrow \Xi_c'^{+} \pi^{+}$

LHCb collaboration

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Overview

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- Ξ_{cc}^{++} decay analysis
- $\Xi_{cc}^{++} \rightarrow \Xi'^{+}_{c} \pi^{+}$ decay event selection
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Introduction

Introduction to the LHCb detector:[1]

- The LHCb detector is a single-arm forward spectrometer designed for the study of particles containing b or c quarks.
- The detector includes a high-precision tracking system which provides a measurement of the momentum, p, of charged particles.

[1] LHCb collaboration, A. A. Alves Jr. et al., The LHCb detector at the LHC, JINST 3 (2008) S08005.

Introduction

Introduction to the online event selection:[2]

- The online event selection is performed by a trigger, which consists of one hardware stage and two software stages.
- At the first software stage, tracks with a large impact parameter significance is required.
- At the second software stage, an alignment and calibration of the detector is performed in near real-time.

[2] R. Aaij et al., The LHCb trigger and its performance in 2011, JINST 8 (2013) P04022, arXiv:1211.3055.

Introduction

Introduction to the simulation framework:

- Simulation samples are used to model the effects of the detector acceptance and to estimate the efficiencies of the selection requirements.
- Simulated events are generated with a Ξ_{cc}^{++} mass of 3621MeV/c^2 and a lifetime of 256fs.

Ξ_{cc}^{++} decay analysis

Previous Ξ_{cc}^{++} decay LHCb analysis:

- In 2017, the LHCb collaboration reported the first observation of the doubly charmed baryon Ξ_{cc}^{++}.[3]
- In 2018, this observation has been confirmed using the $\Xi_{cc}^{++} \rightarrow \Xi_c^+ \pi^+$ decay mode.[4]

Difference: Ξ_c^+ (dsc) Ξ'^{+}_c (usc)

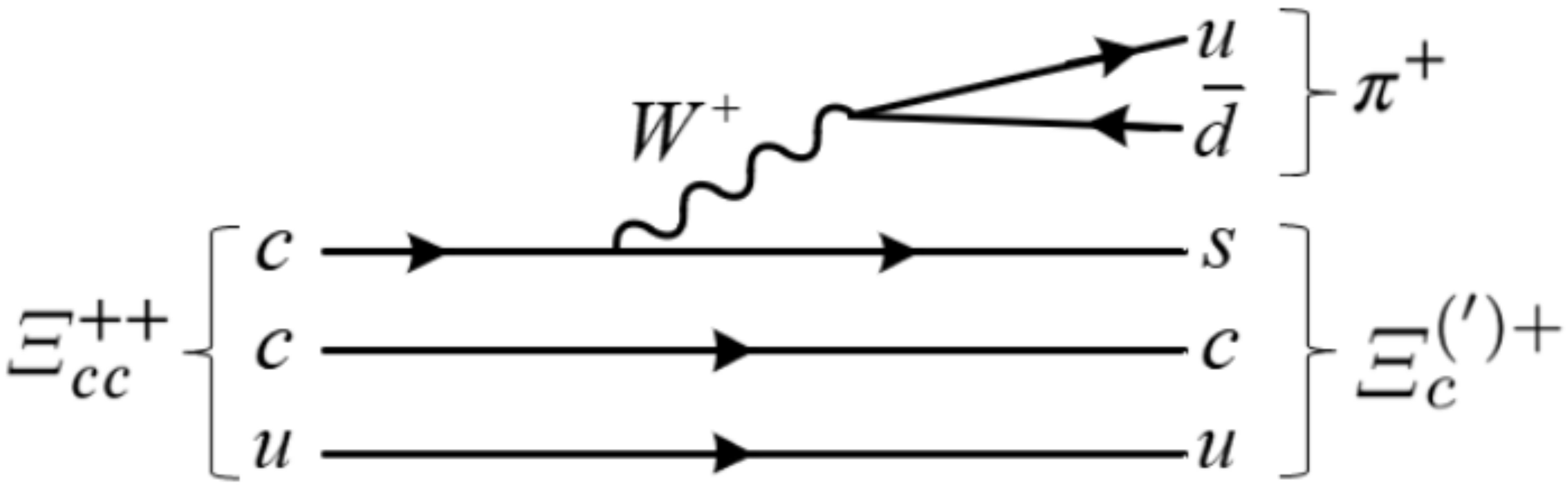
[3] LHCb collaboration, R. Aaij et al., Observation of the doubly charmed baryon Ξ_{cc}^{++}, Phys. Rev. Lett. 119 (2017) 112001, arXiv:1707.01621.

[4] LHCb collaboration, R. Aaij et al.,First observation of the doubly charmed baryon decay $\Xi_{cc}^{++} \rightarrow \Xi_c^+ \pi^+$, Phys. Rev. Lett. 121 (2018) 162002, arXiv:1807.01919.

Ξcc++ decay analysis

The first Ξcc++→Ξ′c+ π+ decay model:

- The first model assumes a (cu)c configuration, where the single c quark decays and the diquark remains a spectator.

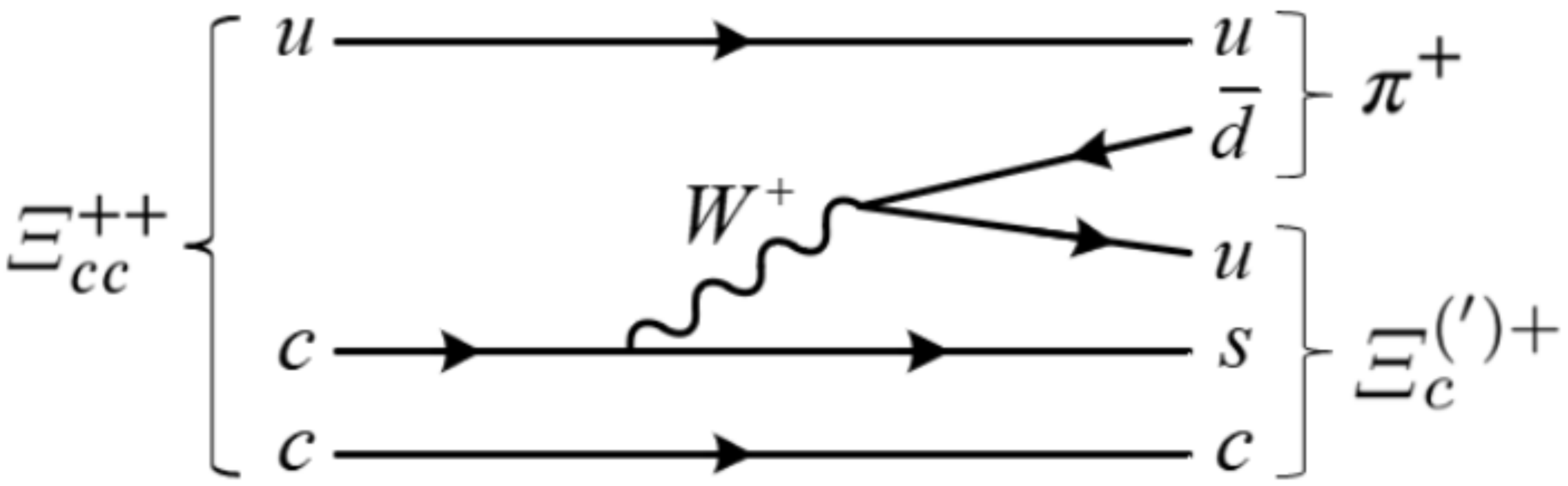


External W-emission diagram

Ξcc++ decay analysis

The second Ξcc++→Ξ′c+ π+ decay model:

- The second model takes the (cc)u configuration with the diquark system breaking apart, leading to a (cc)u → c(su).



Internal W-emission diagram

$\Xi_{cc}^{++} \to \Xi'^{+}_{c} \pi^{+}$ decay event selection

- The event selection of the $\Xi_{cc}^{++} \to \Xi'^{+}_{c} \pi^{+}$ decays are further split into two disjoint subsamples.
- The first contains events that are triggered by at least one of the Ξ_c^{+} decay products with high transverse energy deposited in the calorimeters, and is referred to as triggered on signal (TOS).
- The second consists of events that are exclusively triggered by particles unrelated to the signal decay products, and are referred to as exclusively triggered independently of signal (TIS).

Relative branching fraction measurement

To measure the branching fraction of the signal decay, both the relative signal yields and efficiencies must be determined, as defined below:

$$\frac{\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^{\prime +}\pi^+)}{\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^{+}\pi^+)} = \frac{N_{\Xi_c^{\prime +}}}{N_{\Xi_c^{+}}} \times \frac{\epsilon_{\Xi_c^{+}}}{\epsilon_{\Xi_c^{\prime +}}}$$

$N_{\Xi'c+}$ is the signal yield of the $\Xi cc{+}{+} \rightarrow \Xi' c{+}\ \pi{+}$ decay, and $\varepsilon_{\Xi'c+}$ is efficiency.

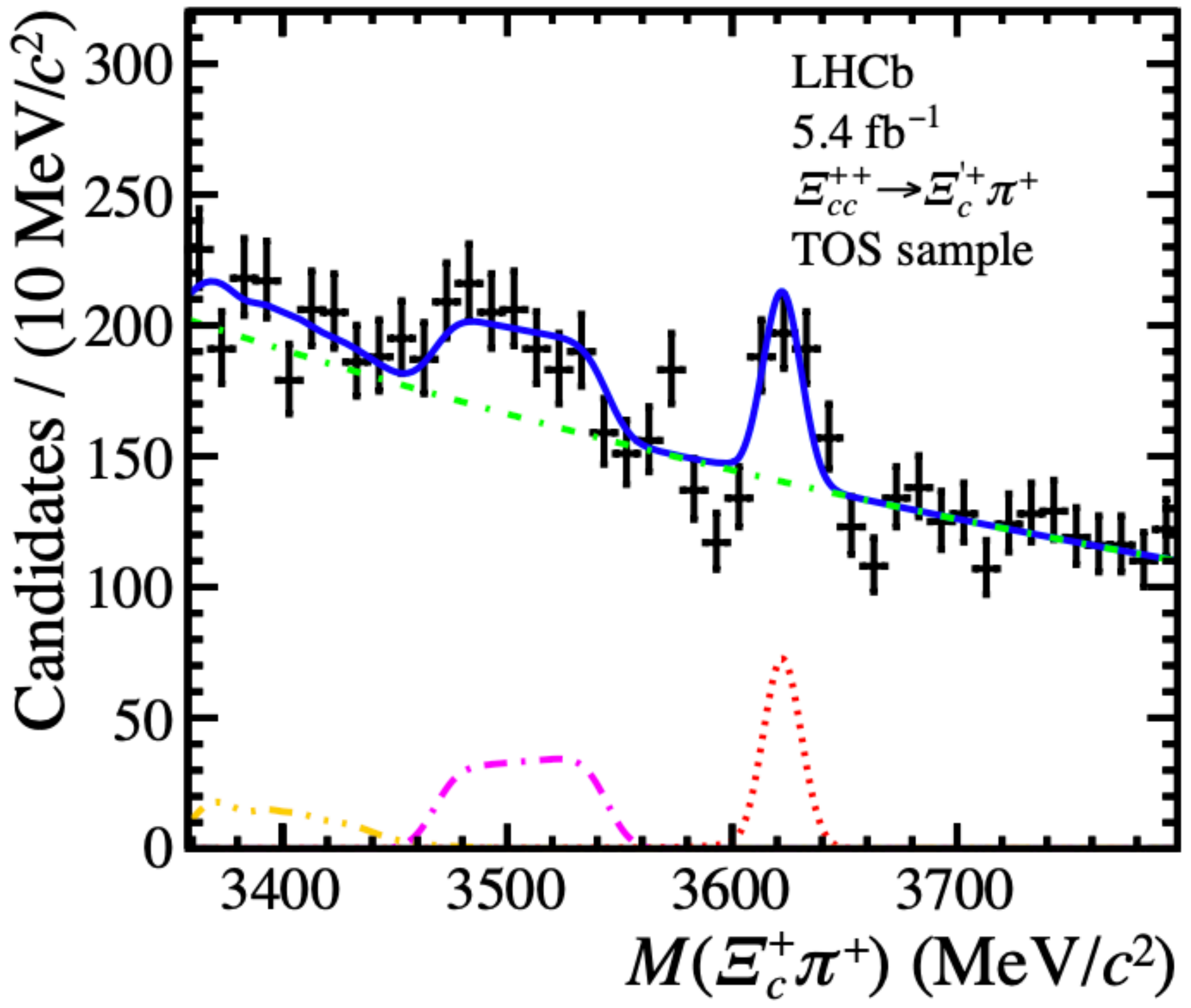
The signal yield is determined by the $\Xi c{+}\ \pi{+}$ invariant-mass spectrum. The efficiencies are found to be negligible.

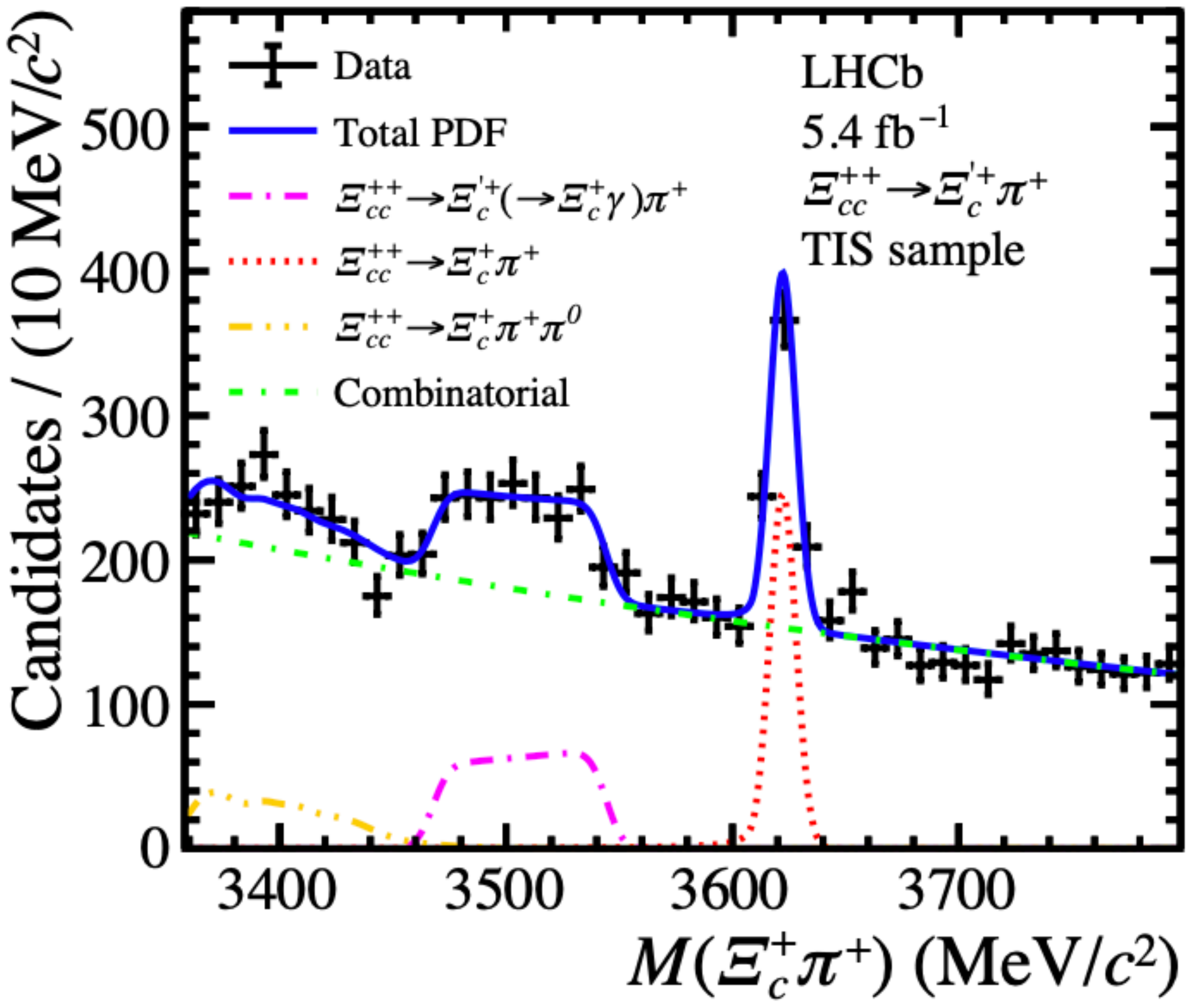
Relative branching fraction measurement

Invariant-mass spectrum:

The peaking structure around 3620 MeV/c2

The box-like enhancement between 3480 and 3560 MeV/c2





Relative branching fraction measurement

Maximum-likelihood fit model:

An unbinned maximum-likelihood fit is performed simultaneously to the invariant-mass distribution:

$$M(\Xi_c^+ \pi^+) \equiv m(\Xi_c^+ \pi^+) - m(\Xi_c^+) + m_0(\Xi_c^+)$$

Here, $m(\Xi_c^+ \pi^+)$ and $m(\Xi_c^+)$ are the reconstructed invariant masses of the Ξ_{cc}^{++} and Ξ_c^+ candidates, and $m_0(\Xi_c^+)$ is the known Ξ_c^+ mass.[5]

[5] Particle Data Group, P. A. Zyla et al., Review of particle physics, Prog. Theor. Exp. Phys. 2020 (2020) 083C01.

Relative branching fraction measurement

The signal yields determined from the fit, along with the relative yields, are listed in Table 1, where the quoted uncertainties are statistical only.

Table 1: Yields of the signal and normalisation decay modes, and the relative yields.

Category	$\Xi_{cc}^{++} \to \Xi_c'^{+}\pi^+$	$\Xi_{cc}^{++} \to \Xi_c^{+}\pi^+$	$N_{\Xi_c'^+}/N_{\Xi_c^+}$
TOS	262 ± 53	159 ± 32	1.64 ± 0.39
TIS	494 ± 63	379 ± 32	1.30 ± 0.18

Systematic uncertainties

The systematic uncertainties are arising from determinations of the relative signal yields and efficiencies in Table 2.

Table 2: Relative systematic uncertainties on the branching fraction ratio $\frac{\mathcal{B}(\Xi_{cc}^{++}\to\Xi_c^{\prime +}\pi^+)}{\mathcal{B}(\Xi_{cc}^{++}\to\Xi_c^{+}\pi^+)}$

Source	TOS [%]	TIS [%]
Signal model	4.9	0.8
normalisation model	3.7	3.8
Combinatorial background	0.6	3.1
Partially reconstructed background	3.7	1.5
Mass window	11.0	3.9
Simulated sample size	4.5	3.6
Lifetime and kinematic corrections	0.5	1.8
Hardware trigger	0.0	1.6
Particle identification	0.5	0.7
Sum in quadrature	13.9	7.9

Systematic uncertainties

Measure the branching fraction of the signal decay:

$$\frac{\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^{\prime +}\pi^+)}{\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^{+}\pi^+)} = \frac{N_{\Xi_c^{\prime +}}}{N_{\Xi_c^{+}}} \times \frac{\epsilon_{\Xi_c^{+}}}{\epsilon_{\Xi_c^{\prime +}}}$$

$N_{\Xi'c+}$ is the signal yield, $\varepsilon_{\Xi'c+}$ is efficiency.

As the signal and normalisation decay modes have the same final states and very similar kinematic distributions, other systematic sources like the tracking efficiency mostly cancel in the ratio and found to be negligible.

Results and summary

- Including all systematic uncertainties, the measured relative branching fraction in the TOS and TIS samples are $1.81 \pm 0.43 \pm 0.25$ and $1.34 \pm 0.19 \pm 0.1$.
- The combination of the two measurements is performed using the best linear unbiased estimator. In the combination, some uncertainties are assumed to be 100% correlated between the TOS and TIS samples, while the other uncertainties are taken to be uncorrelated. [6]

[6] R. Nisius, BLUE: combining correlated estimates of physics observables within ROOT using the Best Linear Unbiased Estimate method, SoftwareX 11 (2020) 100468, arXiv:2001.10310.

Results and summary

- The combined result is:

$$\frac{\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^{\prime +} \pi^+)}{\mathcal{B}(\Xi_{cc}^{++} \to \Xi_c^{+} \pi^+)} = 1.41 \pm 0.17 \pm 0.10$$

- In summary, a new decay mode of the doubly charmed baryon $\Xi_{cc}^{++} \to \Xi_c^{\prime +} \pi^+$ is observed by the LHCb experiment. The relative branching fraction between the $\Xi_{cc}^{++} \to \Xi_c^{\prime +} \pi^+$ and $\Xi_{cc}^{++} \to \Xi_c^{+} \pi^+$ decays is measured for the first time.

Rererences

- [1] LHCb collaboration, A. A. Alves Jr. et al., The LHCb detector at the LHC, JINST 3 (2008) S08005.
- [2] R. Aaij et al., The LHCb trigger and its performance in 2011, JINST 8 (2013) P04022, arXiv:1211.3055.
- [3] LHCb collaboration, R. Aaij et al., Observation of the doubly charmed baryon Ξ_{cc}^{++}, Phys. Rev. Lett. 119 (2017) 112001, arXiv:1707.01621.
- [4] LHCb collaboration, R. Aaij et al.,First observation of the doubly charmed baryon decay $\Xi_{cc}^{++} \to \Xi_c^{\prime +} \pi^+$, Phys. Rev. Lett. 121 (2018) 162002, arXiv:1807.01919.
- [5] Particle Data Group, P. A. Zyla et al., Review of particle physics, Prog. Theor. Exp. Phys. 2020 (2020) 083C01.
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Thank you!