Measurement of the Ω(2012) Baryon at the LHC

Anders Knospe
Lehigh University
ALICE Collaboration
13 November 2025

Measurement of the Ω(2012) Baryon at the LHC

This presentation was supposed to be delivered by Anders Knospe, on behalf of ALICE

Anders Knospe
Lehigh University
ALICE Collaboration

13 November 2025

Measurement of the Ω(2012) Baryon at the LHC

This presentation was supposed to be delivered by Anders Knospe, on behalf of ALICE

It is now being delivered by Adrian Fereydon Nassirpour, on behalf of Anders Knospe, on behalf of ALICE

Adrian Fereydon Nassirpour on behalf of:

Anders Knospe

Lehigh University

ALICE Collaboration

13 November 2025

This is to say, if you have analysis specific questions I am unable to answer, please reach Anders at: anders.knospe@cern.ch

Measurement of the Ω(2012) Baryon at the LHC

This presentation was supposed to be delivered by Anders Knospe, on behalf of ALICE

It is now being delivered by Adrian Fereydon Nassirpour, on behalf of Anders Knospe, on behalf of ALICE

Adrian Fereydon Nassirpour on behalf of:

Anders Knospe

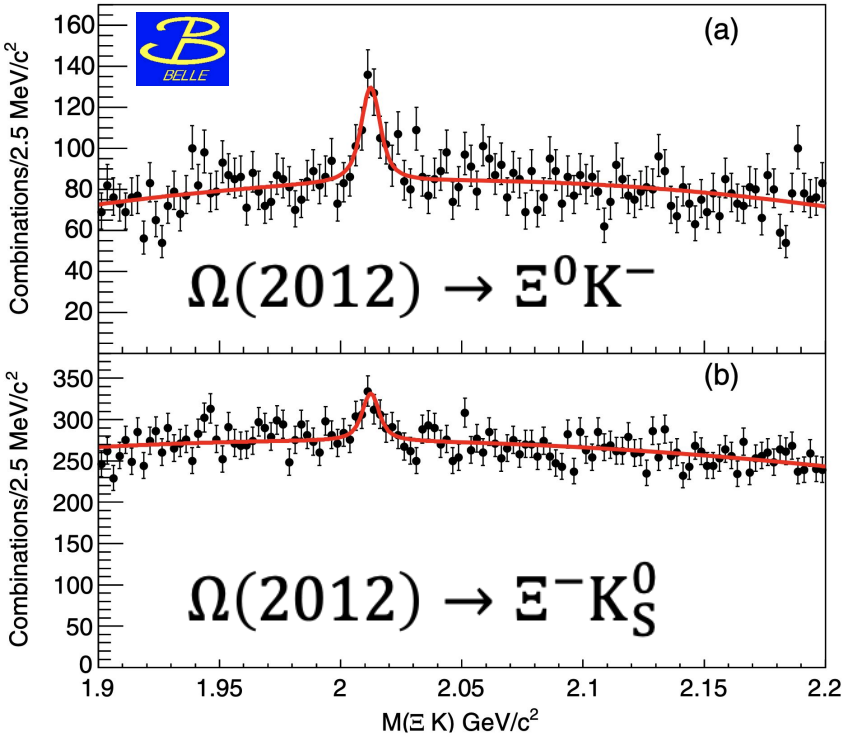
Lehigh University

ALICE Collaboration

13 November 2025

Discovery by Belle

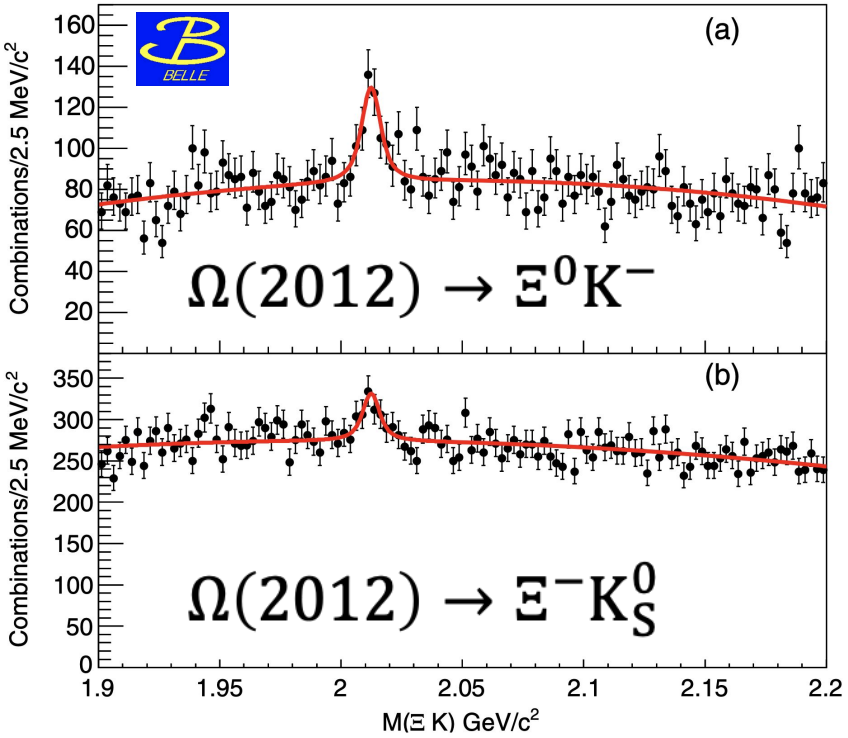
- In 2018, Belle discovered the Ω(2012) baryon, an excited Ω (*sss*) state.
  - Seen in decays of Y mesons produced in e^-e^+ collisions at the KEKB collider.
  - Observed two-body decays: $\Xi^0 K^-$ & $\Xi^- K^0_S$



PRL **121** 052003 (2018)

Discovery by Belle

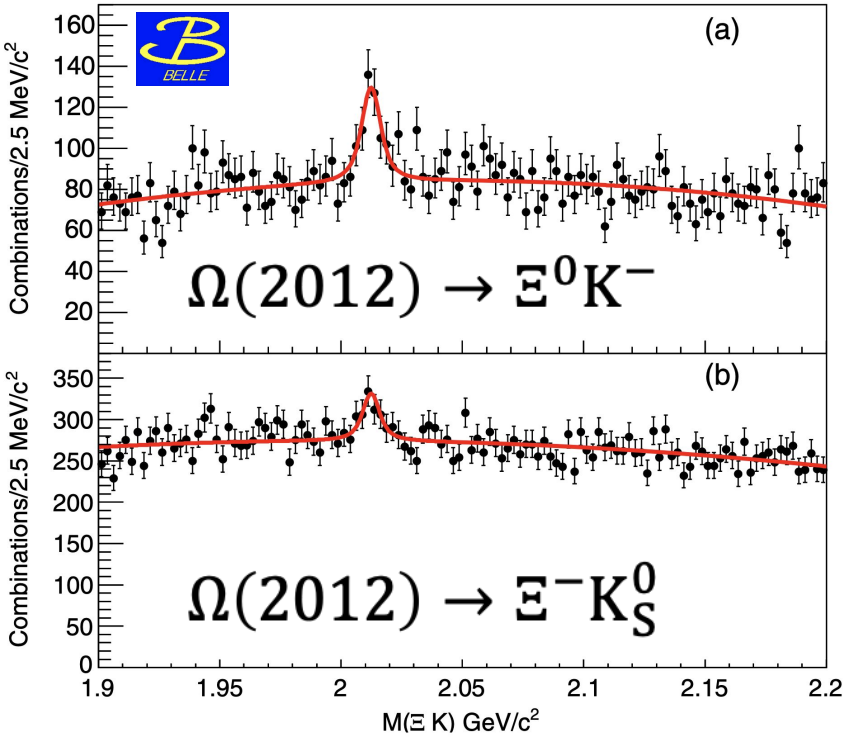
- In 2018, Belle discovered the Ω(2012) baryon, an excited Ω (*sss*) state.
  - Seen in decays of Y mesons produced in e^-e^+ collisions at the KEKB collider.
  - Observed two-body decays: $\Xi^0 K^-$ & $\Xi^- K^0_S$
  - Significance of 7.2σ
  - Mass: 2012.4 ± 0.7 (stat.) ± 0.6 (sys.) MeV/c^2
  - Width: $6.4^{+2.5}_{-2.0}$ (stat.) 1.6 (sys.) MeV/c^2



PRL **121** 052003 (2018)

Discovery by Belle

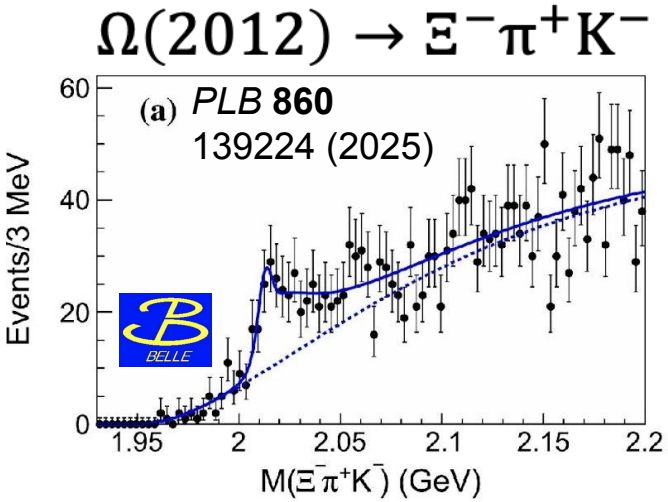
- In 2018, Belle discovered the Ω(2012) baryon, an excited Ω (*sss*) state.
  - Seen in decays of Y mesons produced in e^-e^+ collisions at the KEKB collider.
  - Observed two-body decays: $\Xi^0 K^-$ & $\Xi^- K_S^0$
  - Significance of 7.2σ
  - Mass: 2012.4 ± 0.7 (stat.) ± 0.6 (sys.) MeV/c^2
  - Width: $6.4^{+2.5}_{-2.0}$ (stat.) 1.6 (sys.) MeV/c^2
- Width is fairly narrow for a strongly decaying resonance.
  - If Ω(2012) has negative parity, the narrow width suggests that Ω(2012) should be spin $\frac{3}{2}$ (*d*-wave decay, not *s*).



PRL **121** 052003 (2018)

Subsequent Measurements by Belle

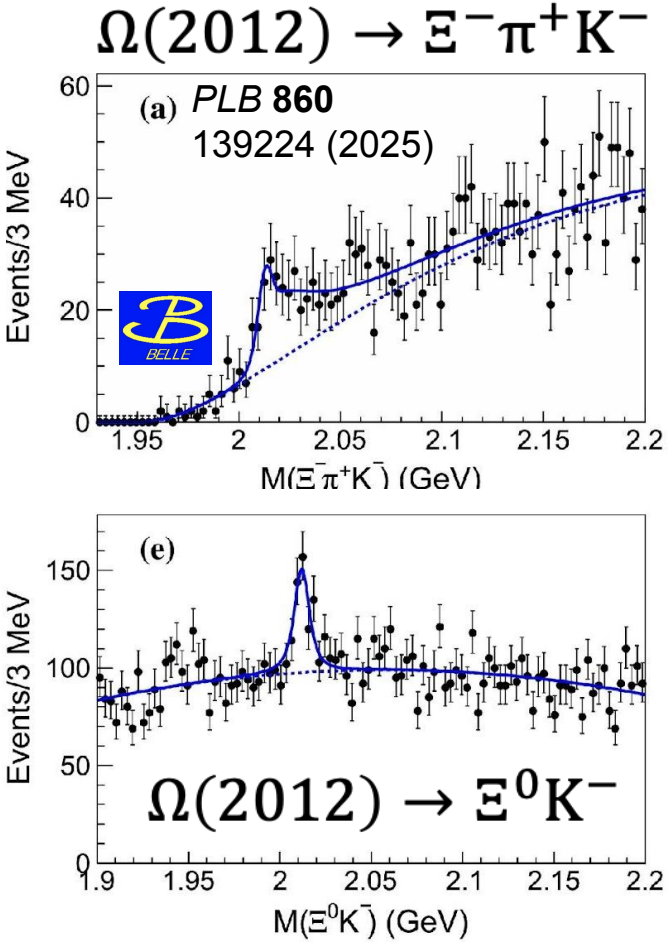
- In a later measurement, Belle discovered three-body decays: $\Omega(2012) \to \Xi(1530)\overline{\mathrm{K}} \to \Xi\pi\overline{\mathrm{K}}$.
  - Significance of 5.2σ



Subsequent Measurements by Belle

- In a later measurement, Belle discovered three-body decays: $\Omega(2012) \rightarrow \Xi(1530)\overline{\mathrm{K}} \rightarrow \Xi\pi\overline{\mathrm{K}}$.
  - Significance of 5.2σ

- Similar mass measurement:



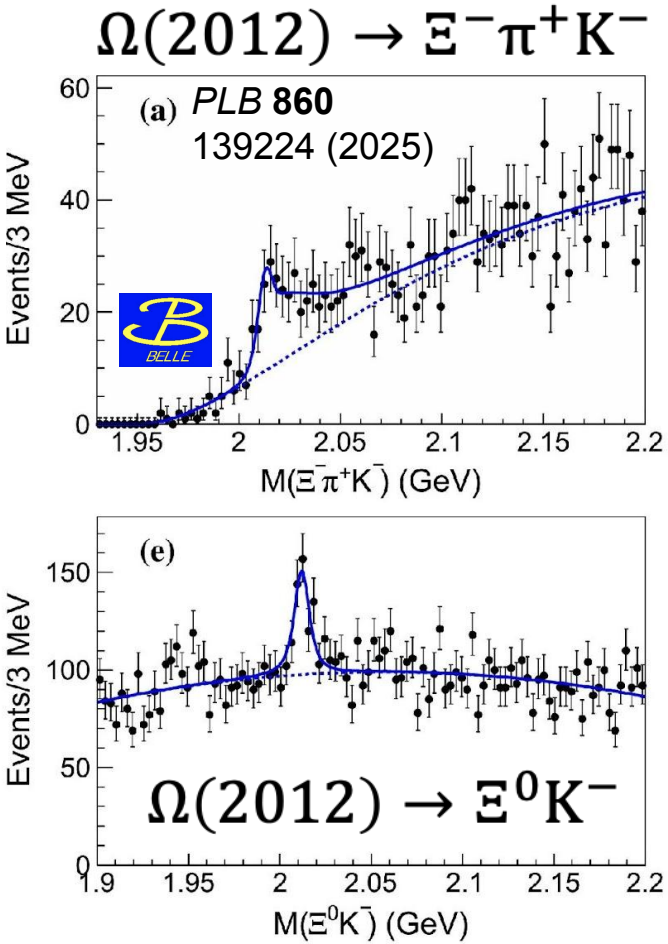
Subsequent Measurements by Belle

- In a later measurement, Belle discovered three-body decays: $\Omega(2012) \to \Xi(1530)\overline{\mathrm{K}} \to \Xi\pi\overline{\mathrm{K}}$.
  - Significance of 5.2σ
- Measured the effective couplings to $\Xi(1530)\overline{\mathrm{K}}$ and $\Xi\overline{\mathrm{K}}$.
- Ratio of branching fractions:

$$\mathcal{R}^{\Xi\pi\overline{\mathrm{K}}}_{\Xi\overline{\mathrm{K}}} \equiv \frac{\mathcal{B}[\Omega(2012)\to\Xi\pi\overline{\mathrm{K}}]}{\mathcal{B}[\Omega(2012)\to\Xi\overline{\mathrm{K}}]}$$

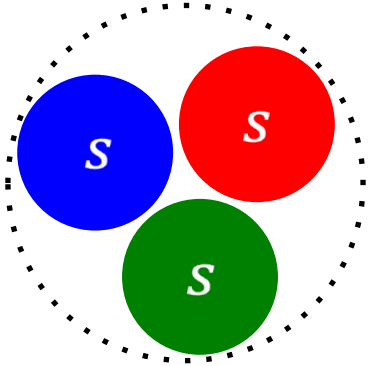
$$= 0.99 \pm 0.26\,(\mathrm{stat.}) \pm 0.06\,(\mathrm{sys.})$$

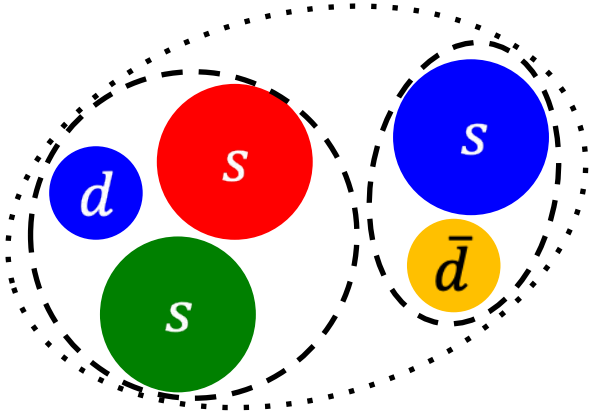
  - Similar branching fractions for the two- and three-body decays.
- Similar mass measurement:



Ω(2012) Structure

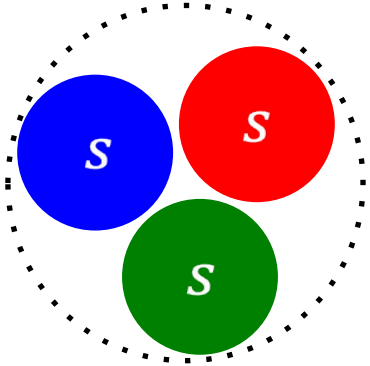
- Extensive theoretical work on understanding the structure of Ω(2012).
- Some studies conclude that it is a regular 3-valence-quark baryon.
  - Possibly a *p*-wave excitation.

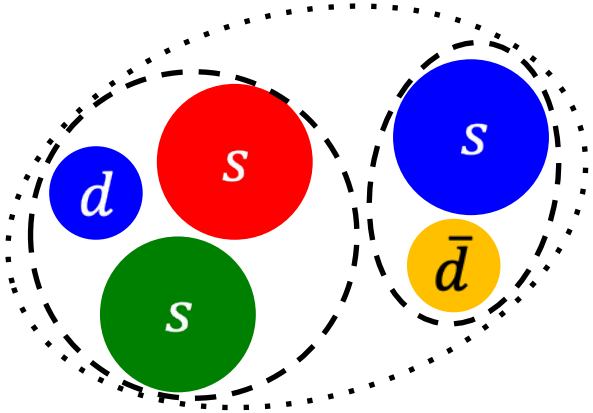




$\Omega(2012)$ Structure

- Extensive theoretical work on understanding the structure of $\Omega(2012)$.
- Some studies conclude that it is a regular 3-valence-quark baryon.
  - Possibly a *p*-wave excitation.
- Other studies explore the possibility that it is a hadron molecule.
  - The $\Omega(2012)$ mass is just below the summed masses of $\Xi(1530)$ and K: is $\Omega(2012)$ a $\Xi(1530)\overline{\mathrm{K}}$ bound state?
  - Some studies explored mixing of $\Xi(1530)\overline{\mathrm{K}}$ with $\Xi\overline{\mathrm{K}}$, $\Omega\eta$, and/or 3-quark components.

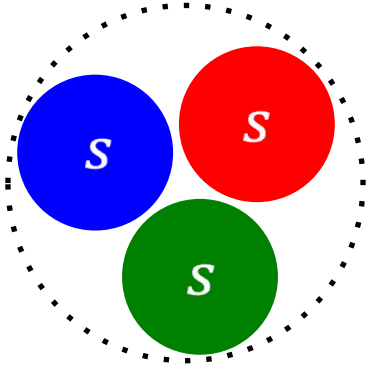


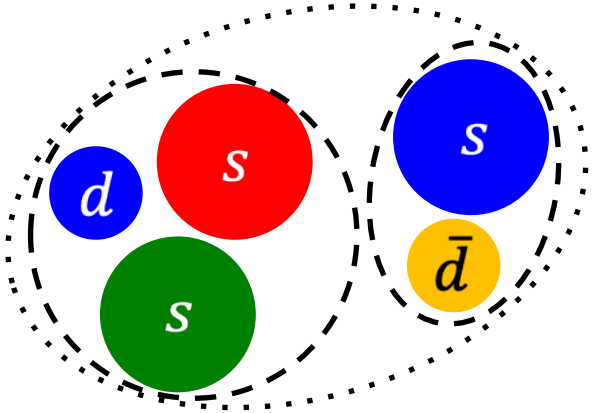


$\Omega(2012)$ Structure

- Extensive theoretical work on understanding the structure of $\Omega(2012)$.
- Some studies conclude that it is a regular 3-valence-quark baryon.
  - Possibly a *p*-wave excitation.
- Other studies explore the possibility that it is a hadron molecule.
  - The $\Omega(2012)$ mass is just below the summed masses of $\Xi(1530)$ and K: is $\Omega(2012)$ a $\Xi(1530)\overline{\mathrm{K}}$ bound state?
  - Some studies explored mixing of $\Xi(1530)\overline{\mathrm{K}}$ with $\Xi\overline{\mathrm{K}}$, $\Omega\eta$, and/or 3-quark components.

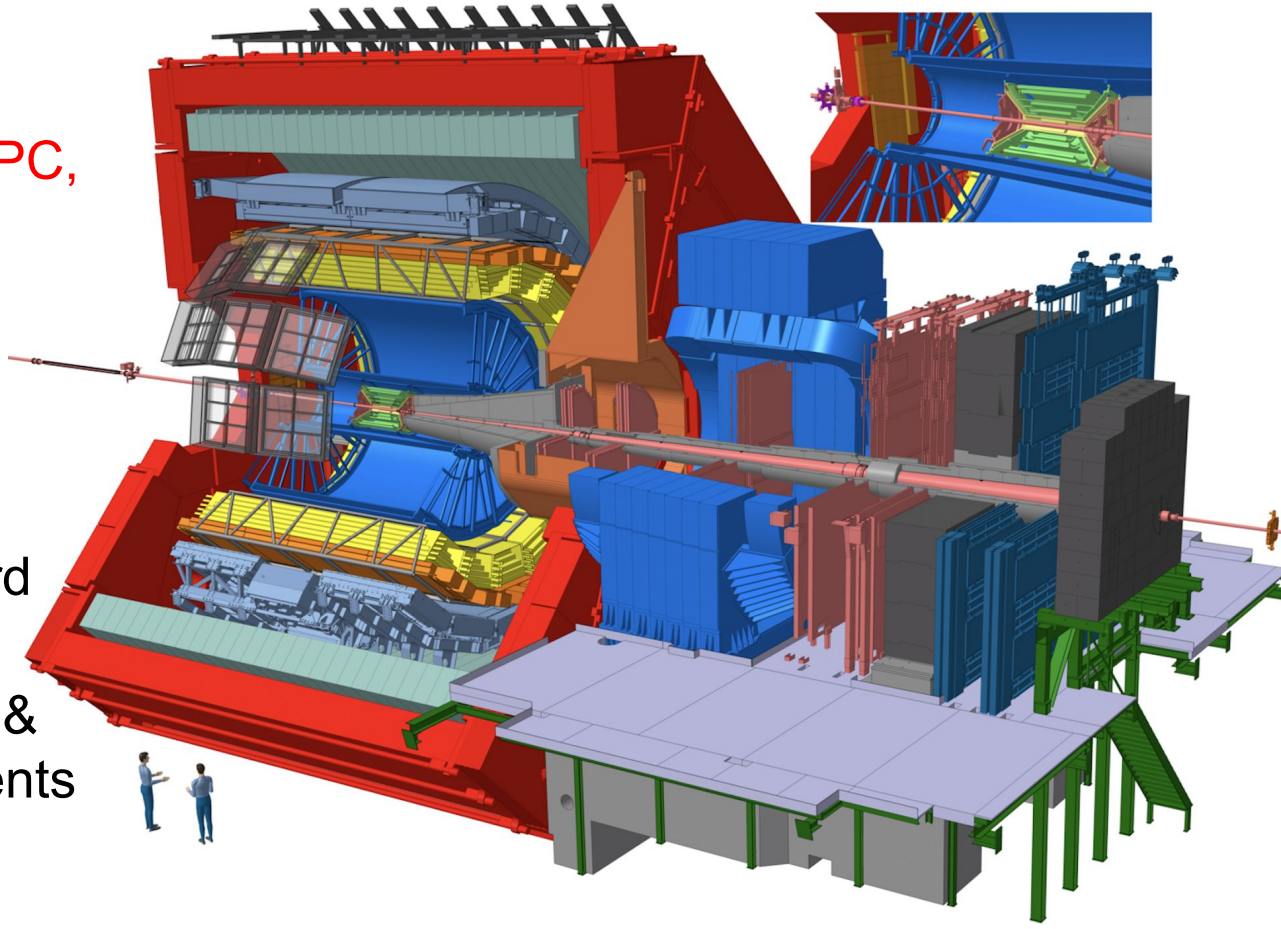
Hadron molecule interpretation is consistent with Belle's observation of the three-body decays.





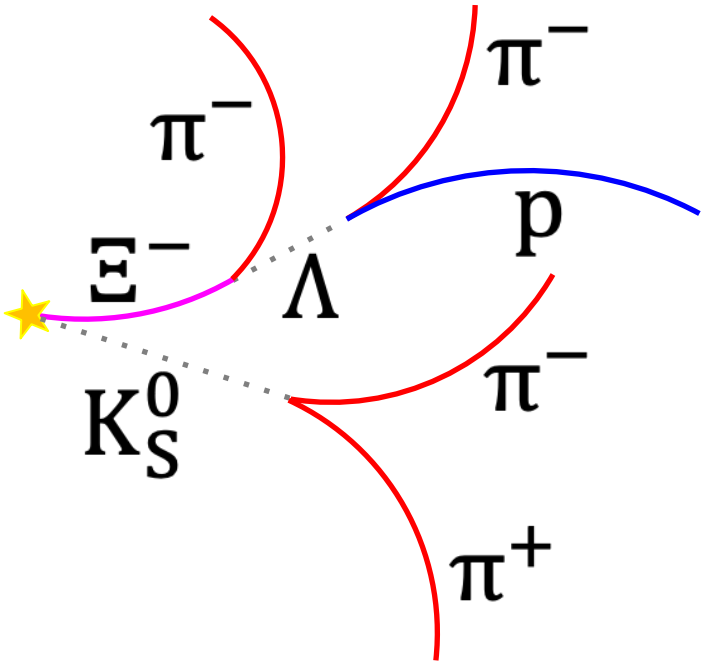
ALICE Detector

- ALICE at the LHC has observed the Ω(2012).
- Main tracking: ITS & TPC, TRD
- Particle ID: ITS, TPC, TOF, TRD, HMPID
- Outer: Calorimeters, Cherenkov detectors
- Muon system at forward rapidities
- V0 detector: triggering & multiplicity measurements
- ZDC: forward energy



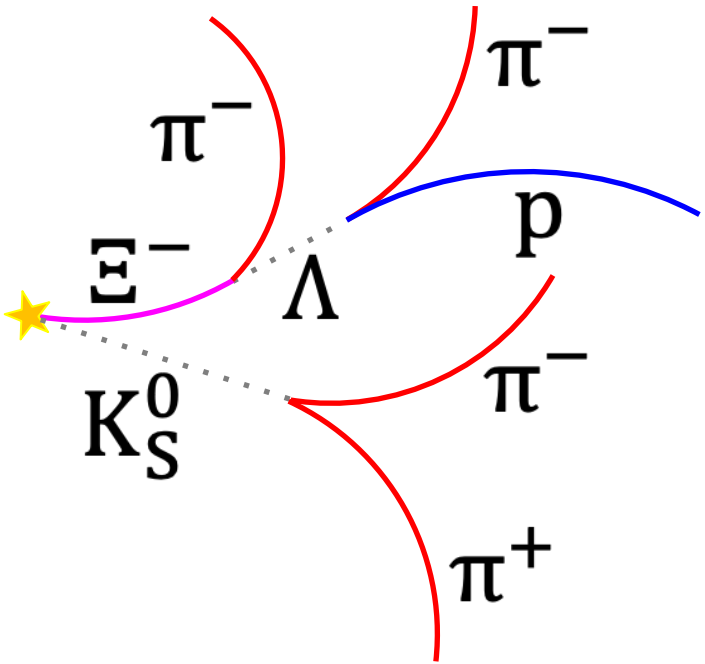
Data Set

- ALICE measurement uses large sample of 10^9 pp collisions at $\sqrt{s}$ = 13 TeV
  - Recorded in LHC Run 2: 2016–2018



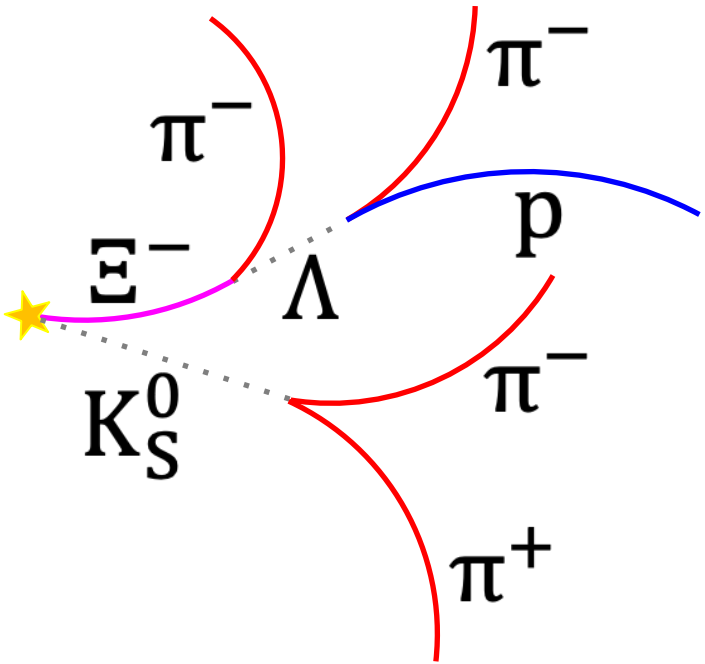
Data Set

- ALICE measurement uses large sample of 10^9 pp collisions at $\sqrt{s}$ = 13 TeV
  - Recorded in LHC Run 2: 2016–2018
- Uses High-Multiplicity (HM) Trigger:
  - Selects events with the 0–0.1% highest charged-particle multiplicities in the V0 detectors (forward-rapidity scintillators).
  - HM data sample has a mean charged-particle multiplicity about 6 times larger than minimum-bias pp sample at this energy.



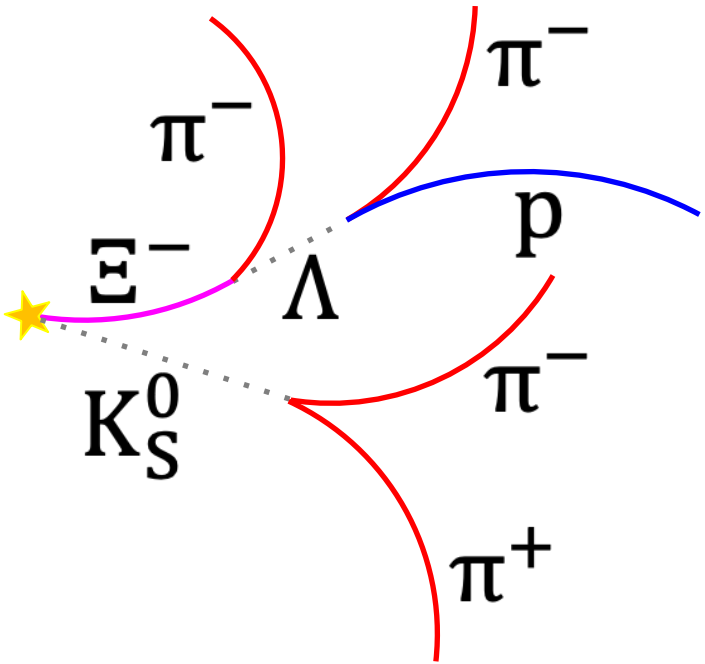
Data Set

- ALICE measurement uses large sample of 10^9 pp collisions at $\sqrt{s}$ = 13 TeV
  - Recorded in LHC Run 2: 2016–2018
- Uses High-Multiplicity (HM) Trigger:
  - Selects events with the 0–0.1% highest charged-particle multiplicities in the V0 detectors (forward-rapidity scintillators).
  - HM data sample has a mean charged-particle multiplicity about 6 times larger than minimum-bias pp sample at this energy.
  - Takes advantage of **strangeness enhancement** effect: strange particle production is enhanced in more active collisions (nucleus-nucleus, HM pp) in comparison to minimum-bias pp.



Data Set

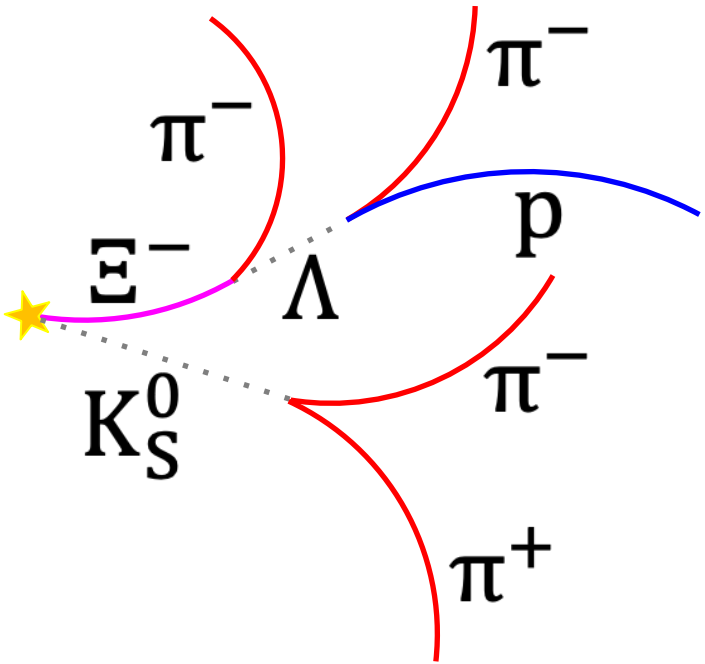
- ALICE measurement uses large sample of 10^9 pp collisions at $\sqrt{s}$ = 13 TeV
  - Recorded in LHC Run 2: 2016–2018
- Uses High-Multiplicity (HM) Trigger:
  - Selects events with the 0–0.1% highest charged-particle multiplicities in the V0 detectors (forward-rapidity scintillators).
  - HM data sample has a mean charged-particle multiplicity about 6 times larger than minimum-bias pp sample at this energy.
  - Takes advantage of **strangeness enhancement** effect: strange particle production is enhanced in more active collisions (nucleus-nucleus, HM pp) in comparison to minimum-bias pp.



Luminosity equivalent to approximately 36.6 ± 2.0 pb−1

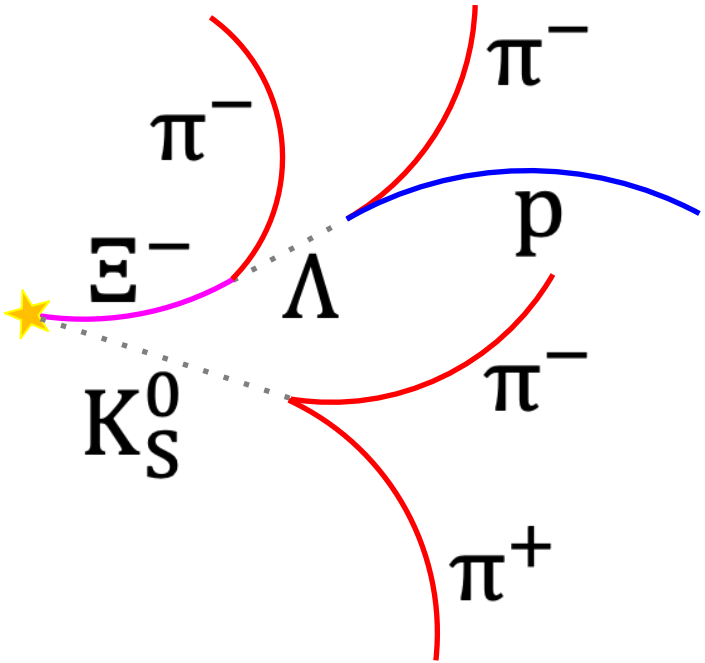
Decay Reconstruction

- ALICE measures $\Omega(2012) \rightarrow \Xi^{-}\mathrm{K}^{0}_{S}$ decays.
- ALICE reconstructs tracks with combination of ITS and TPC.



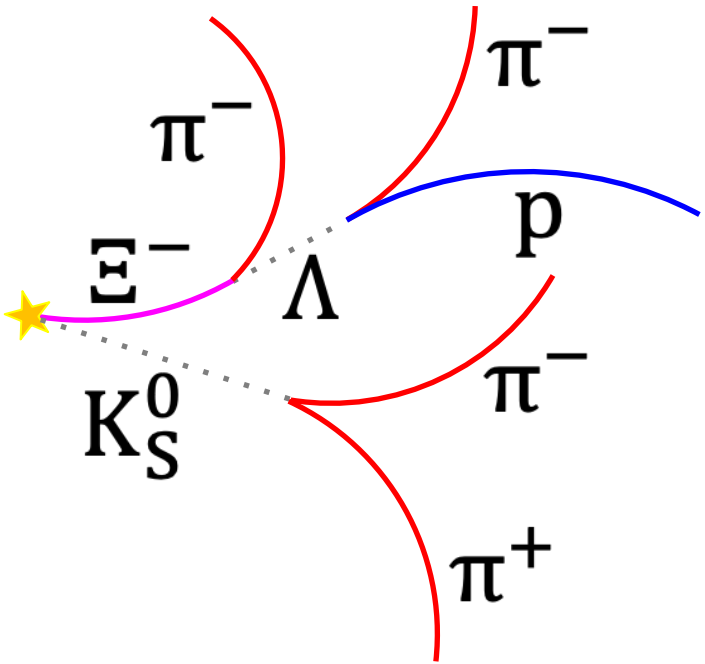
Decay Reconstruction

- ALICE measures $\Omega(2012) \rightarrow \Xi^{-}\mathrm{K}^{0}_{\mathrm{S}}$ decays.
- ALICE reconstructs tracks with combination of ITS and TPC.
- Pion and proton tracks are identified through their specific energy loss d*E*/d*x* in the TPC.



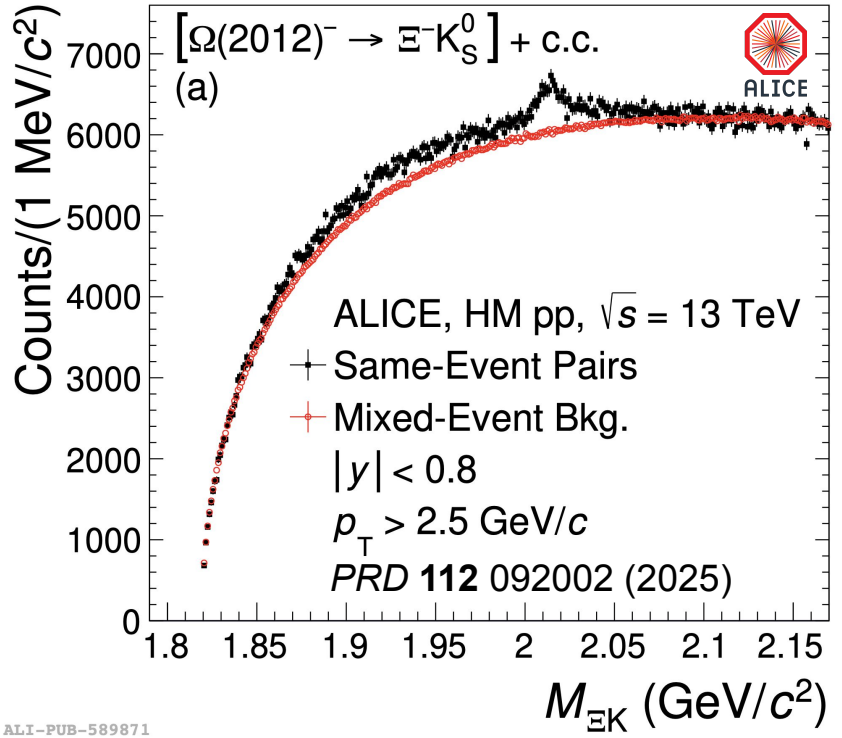
Decay Reconstruction

- ALICE measures $\Omega(2012) \rightarrow \Xi^{-}\mathrm{K}^{0}_{\mathrm{S}}$ decays.
- ALICE reconstructs tracks with combination of ITS and TPC.
- Pion and proton tracks are identified through their specific energy loss d*E*/d*x* in the TPC.
- V^0 and cascade candidates are reconstructed through invariant-mass analysis plus topological cuts
  - Selections on decay radius, DCA between daughters, DCA to primary vertex, pointing angle



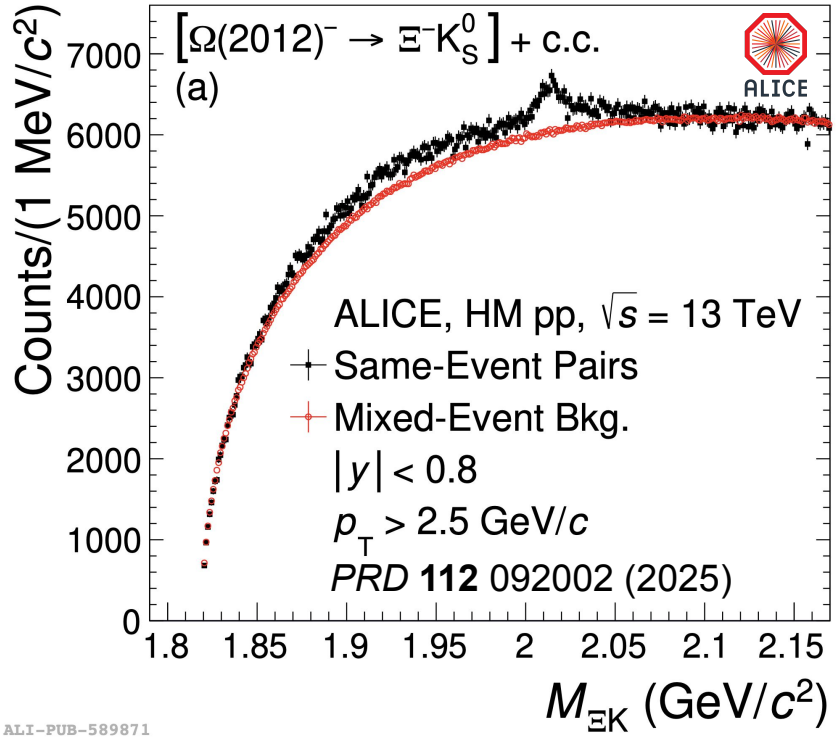
Data Analysis

- An Ω(2012) peak is clearly visible atop a combinatorial background.
  - Signal-to-background ratio = 0.033.
  - Peak significance = 15σ.



Data Analysis

- An Ω(2012) peak is clearly visible atop a combinatorial background.
  - Signal-to-background ratio = 0.033.
  - Peak significance = 15σ.
- Two ways to deal with background:
  - Event mixing is used to estimate the combinatorial background → subtract from same-event distribution → parameterize residual background with polynomial.
  - Parameterize entire background with function.

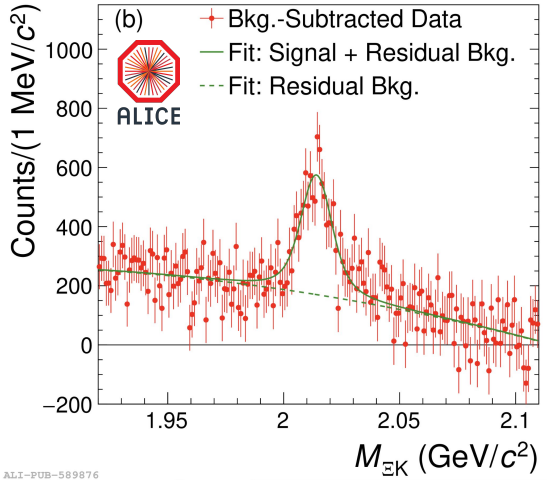


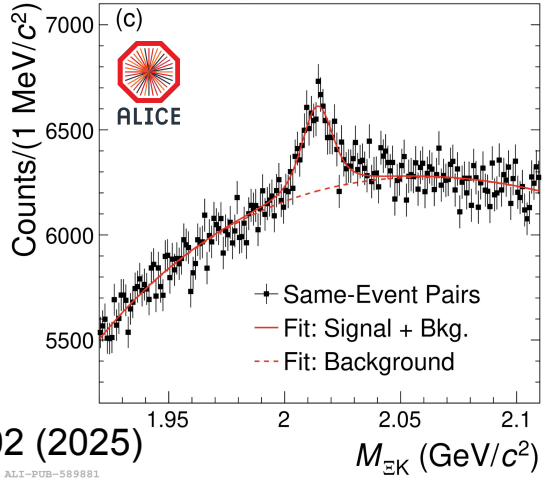
ALI-PUB-589871

Data Analysis

- An Ω(2012) peak is clearly visible atop a combinatorial background.
  - Signal-to-background ratio = 0.033.
  - Peak significance = 15σ.
- Two ways to deal with background:
  - Event mixing is used to estimate the combinatorial background → subtract from same-event distribution → parameterize residual background with polynomial.
  - Parameterize entire background with function.
- Peak is described with a Voigt function:
  - Convolution of Breit-Wigner distribution and a Gaussian (detector effects).

$$O(\sigma_{Gaus}) \approx O(\Gamma_{BW})$$



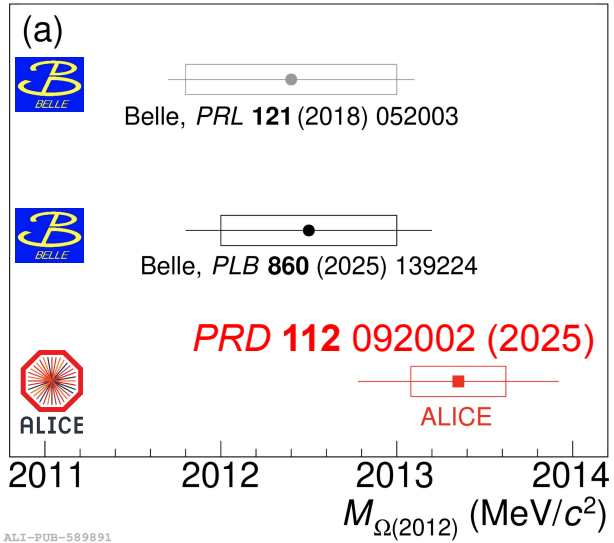


PRD **112** 092002 (2025)

Mass and Width

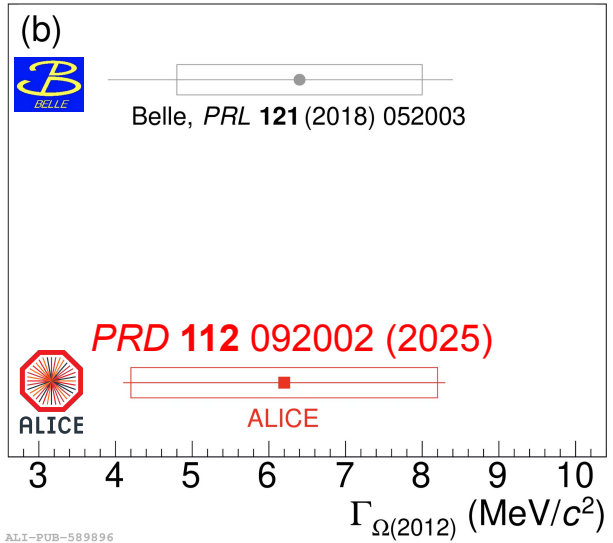
- ALICE Ω(2012) mass value is consistent with Belle values, but with smaller uncertainties.

M = 2013.35 ± 0.57 (stat.) ± 0.27 (sys.) MeV/c^2



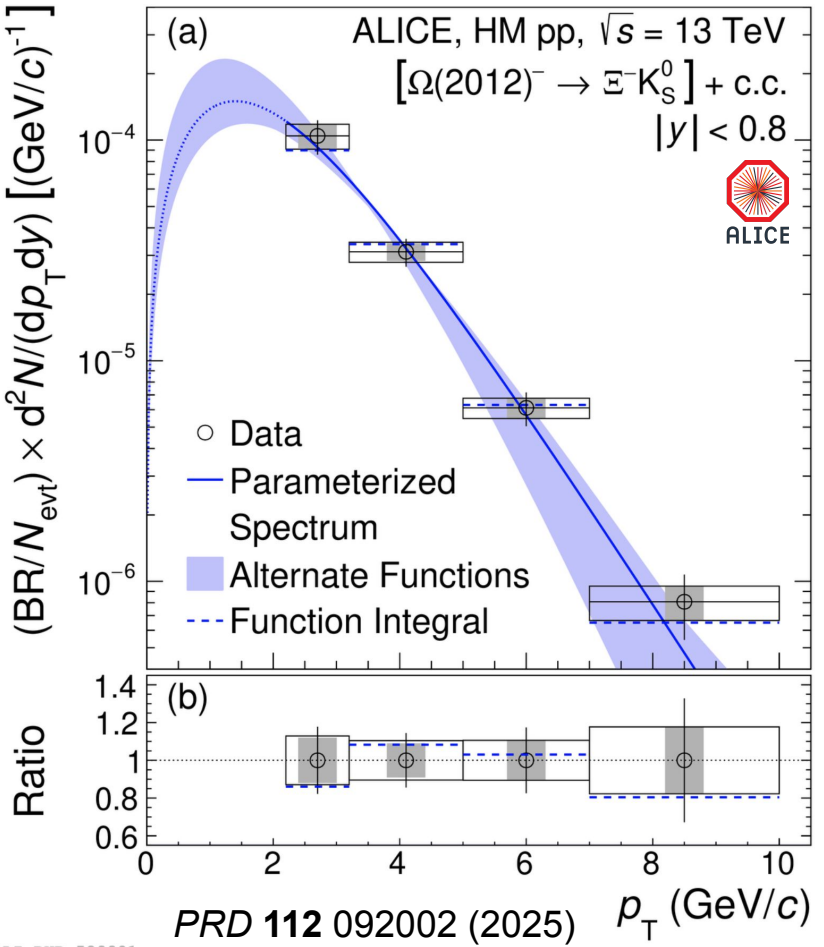
- ALICE Ω(2012) width value is consistent with Belle value.
  - Confirmation of the narrow width for this resonance → support for the $J^P = \frac{3}{2}^-$ hypothesis.

Γ = 6.2 ± 2.1 (stat.) ± 2.0 (sys.) MeV/c^2



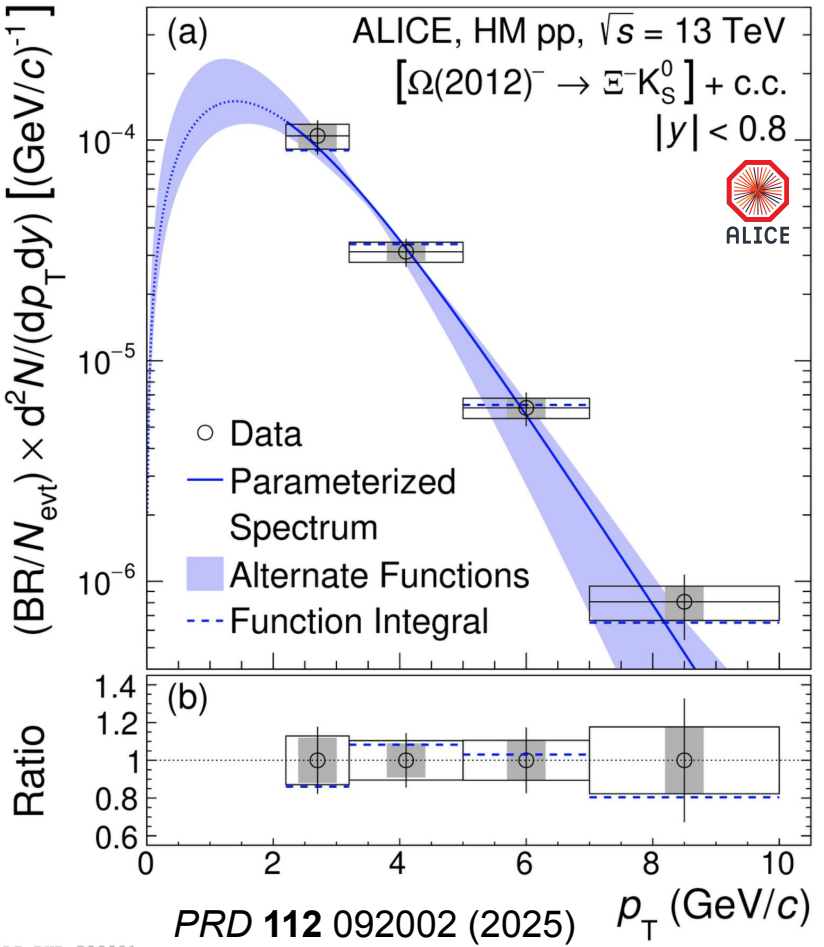
Yields

- Analysis procedure repeated in four p_T intervals covering $2.2 \leq p_T \leq 10$ GeV/c.
  - Very low acceptance × efficiency for $p_T < 2.2$ GeV/c → no visible signal.
  - **First measurement** of Ω(2012) yield and p_T spectrum.



Yields

- Analysis procedure repeated in four p_T intervals covering $2.2 \leq p_T \leq 10$ GeV/c.
  - Very low acceptance × efficiency for $p_T < 2.2$ GeV/c → no visible signal.
  - **First measurement** of Ω(2012) yield and p_T spectrum.

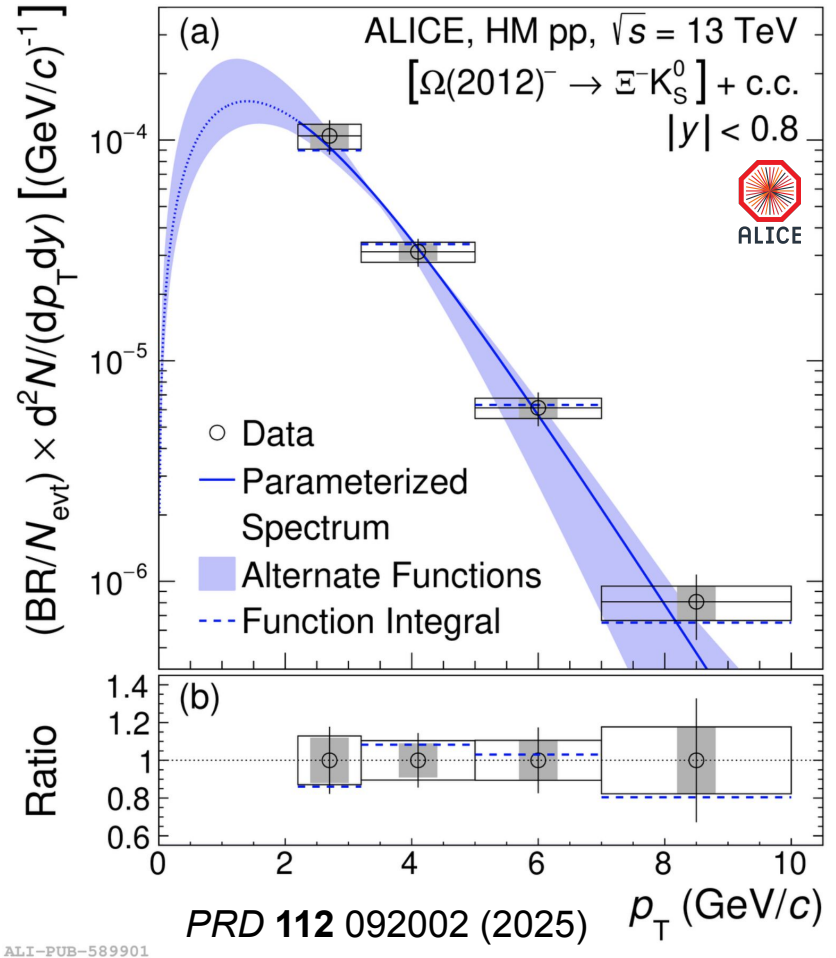


Yields

- Analysis procedure repeated in four p_T intervals covering $2.2 \leq p_T \leq 10$ GeV/c.
  - Very low acceptance × efficiency for $p_T < 2.2$ GeV/c → no visible signal.
  - **First measurement** of Ω(2012) yield and p_T spectrum.
- Lévy-Tsallis distribution used to extrapolate yield down to $p_T = 0$.
  - Shape of this distribution is set by m_T scaling from the ground-state Ω p_T spectrum.

$$BR \times \frac{dN}{dy} = \left[4.2 \pm 0.3\ (\text{stat.})\ ^{+1.5}_{-0.6}\ (\text{sys.})\right] \times 10^{-4}$$

$$\langle p_T \rangle = 2.15 \pm 0.08\ (\text{stat.})\ ^{+0.14}_{-0.26}\ (\text{sys.})\ \text{GeV}/c$$



Branching Fractions

- Use ALICE Ω(2012) yield value to estimate the decay branching fractions:

$$\mathcal{B}(\to \Xi^{-}\overline{\mathrm{K}}^{0}) = \frac{2\times\mathcal{B}(\to \Xi^{-}\mathrm{K}^{0}_{\mathrm{S}})\times\Omega(2012)_{\mathrm{ALICE}}}{\Omega_{\mathrm{ALICE}}} \times \frac{\Omega_{\mathrm{STM}}}{\Omega(2012)_{\mathrm{STM}}} = 0.28^{+0.12}_{-0.07}$$

Branching Fractions

- Use ALICE Ω(2012) yield value to estimate the decay branching fractions:

1.) Measure Ω(2012) yield in HM pp collisions.
Not corrected for branching fraction.

$$\mathcal{B}(\to \Xi^{-}\overline{\mathrm{K}}^{0}) = \frac{2\times\mathcal{B}(\to \Xi^{-}\mathrm{K}^{0}_{\mathrm{S}})\times\Omega(2012)_{\mathrm{ALICE}}}{\Omega_{\mathrm{ALICE}}} \times \frac{\Omega_{\mathrm{STM}}}{\Omega(2012)_{\mathrm{STM}}} = 0.28^{+0.12}_{-0.07}$$

Branching Fractions

- Use ALICE Ω(2012) yield value to estimate the decay branching fractions:

1.) Measure Ω(2012) yield in HM pp collisions.
Not corrected for branching fraction.

2.) Estimate ground-state Ω yield in HM pp collisions.
Use ALICE measurements of Ω yields in pp & p–Pb collisions as functions of multiplicity.

Only half of $K^0/\overline{K}^0$ decay as K^0_S.

$$\mathcal{B}(\to \Xi^-\overline{K}^0) = \frac{2\times\mathcal{B}(\to \Xi^- K^0_S)\times\Omega(2012)_{\mathrm{ALICE}}}{\Omega_{\mathrm{ALICE}}} \times \frac{\Omega_{\mathrm{STM}}}{\Omega(2012)_{\mathrm{STM}}} = 0.28^{+0.12}_{-0.07}$$

Branching Fractions

- Use ALICE Ω(2012) yield value to estimate the decay branching fractions:

1.) Measure Ω(2012) yield in HM pp collisions.
Not corrected for branching fraction.

2.) Estimate ground-state Ω yield in HM pp collisions.
Use ALICE measurements of Ω yields in pp & p–Pb collisions as functions of multiplicity.

3.) Estimate $\frac{\Omega(2012)}{\Omega}$ yield ratio using statistical-thermal model.
In absence of feed-down:

$$\frac{\Omega(2012)_{\mathrm{SM}}}{\Omega_{\mathrm{SM}}} = \frac{2J_{\Omega(2012)}+1}{2J_{\Omega}+1} \times \frac{M^2_{\Omega(2012)}}{M^2_{\Omega}} \times \frac{K_2\left(M_{\Omega(2012)}/T\right)}{K_2(M_{\Omega}/T)}$$

Chemical freeze-out temperature T is extracted from thermal-model fits to other ALICE particle yield measurements in this multiplicity region.
And assume $J_{\Omega(2012)} = \frac{3}{2}$.

Only half of $\mathrm{K}^0/\overline{\mathrm{K}}^0$ decay as $\mathrm{K}^0_{\mathrm{S}}$.

$$\mathcal{B}(\to \Xi^-\overline{\mathrm{K}}^0) = \frac{2\times\mathcal{B}\left(\to \Xi^-\mathrm{K}^0_{\mathrm{S}}\right)\times\Omega(2012)_{\mathrm{ALICE}}}{\Omega_{\mathrm{ALICE}}} \times \frac{\Omega_{\mathrm{STM}}}{\Omega(2012)_{\mathrm{STM}}} = 0.28^{+0.12}_{-0.07}$$

Branching Fractions

- Use ALICE Ω(2012) yield value to estimate the decay branching fractions:

Ratio of two-body branching fractions measured by Belle:

$$\frac{\mathcal{B}(\to \Xi^0 \mathrm{K}^-)}{\mathcal{B}(\to \Xi^- \overline{\mathrm{K}}^0)} = 1.2 \pm 0.3$$

Estimated from ALICE Ω(2012) yield value:

$$\mathcal{B}(\to \Xi^- \overline{\mathrm{K}}^0) = 0.28^{+0.12}_{-0.07}$$

Estimates of other two-body branching fractions:

$$\mathcal{B}(\to \Xi^0 \mathrm{K}^-) = 0.34^{+0.16}_{-0.12}$$

$$\mathcal{B}(\to \Xi \overline{\mathrm{K}}) = 0.62^{+0.27}_{-0.17}$$

Branching Fractions

- Use ALICE Ω(2012) yield value to estimate the decay branching fractions:

Ratio of two-body branching fractions measured by Belle:

$$\frac{\mathcal{B}(\to \Xi^0 K^-)}{\mathcal{B}(\to \Xi^- \bar{K}^0)} = 1.2 \pm 0.3$$

Estimated from ALICE Ω(2012) yield value:

$$\mathcal{B}(\to \Xi^- \bar{K}^0) = 0.28^{+0.12}_{-0.07}$$

Estimates of other two-body branching fractions:

$$\mathcal{B}(\to \Xi^0 K^-) = 0.34^{+0.16}_{-0.12}$$

$$\mathcal{B}(\to \Xi \bar{K}) = 0.62^{+0.27}_{-0.17}$$

Ratio of two- & three-body branching fractions measured by Belle:

$$\mathcal{R}^{\Xi\pi\bar{K}}_{\Xi\bar{K}} \equiv \frac{\mathcal{B}(\to \Xi\pi\bar{K})}{\mathcal{B}(\to \Xi\bar{K})} = 0.99 \pm 0.27$$

If all Ω(2012) decays are either $\Xi\pi\bar{K}$ or $\Xi\bar{K}$, the Belle $\mathcal{R}^{\Xi\pi\bar{K}}_{\Xi\bar{K}}$ value implies that

$$\mathcal{B}(\to \Xi\bar{K}) = 0.50^{+0.08}_{-0.06}$$

Branching Fractions

- Use ALICE Ω(2012) yield value to estimate the decay branching fractions:

Ratio of two-body branching fractions measured by Belle:

$$\frac{\mathcal{B}(\to \Xi^0 K^-)}{\mathcal{B}(\to \Xi^- \bar{K}^0)} = 1.2 \pm 0.3$$

Estimated from ALICE Ω(2012) yield value:

$$\mathcal{B}(\to \Xi^- \bar{K}^0) = 0.28^{+0.12}_{-0.07}$$

Estimates of other two-body branching fractions:

$$\mathcal{B}(\to \Xi^0 K^-) = 0.34^{+0.16}_{-0.12}$$

$$\mathcal{B}(\to \Xi \bar{K}) = 0.62^{+0.27}_{-0.17}$$

Ratio of two- & three-body branching fractions measured by Belle:

$$\mathcal{R}^{\Xi\pi\bar{K}}_{\Xi\bar{K}} \equiv \frac{\mathcal{B}(\to \Xi\pi\bar{K})}{\mathcal{B}(\to \Xi\bar{K})} = 0.99 \pm 0.27$$

If all Ω(2012) decays are either $\Xi\pi\bar{K}$ or $\Xi\bar{K}$, the Belle $\mathcal{R}^{\Xi\pi\bar{K}}_{\Xi\bar{K}}$ value implies that

$$\mathcal{B}(\to \Xi\bar{K}) = 0.50^{+0.08}_{-0.06}$$

If we redo this calculation assuming that $J_{\Omega(2012)} = \frac{1}{2}$, we find that $\mathcal{B}(\to \Xi\bar{K}) > 0.9$, which is inconsistent with Belle measurements.
Even stronger support for the $J_{\Omega(2012)} = \frac{3}{2}$ hypothesis.

Summary

- ALICE has observed the Ω(2012) baryon discovered by Belle.
- Our measurements of the mass and width are consistent with Belle's values.
  - ALICE mass value has smaller uncertainties.
- First measurement of Ω(2012) yields and p_T spectra.
- First estimates of **absolute** branching fractions for two-body Ω(2012) decays.
- Narrow width and branching fraction measurements support the spin $\frac{3}{2}$ hypothesis for Ω(2012).