FUDAN UNIVERSITY 復旦大學

Observation of new hyperons at Belle

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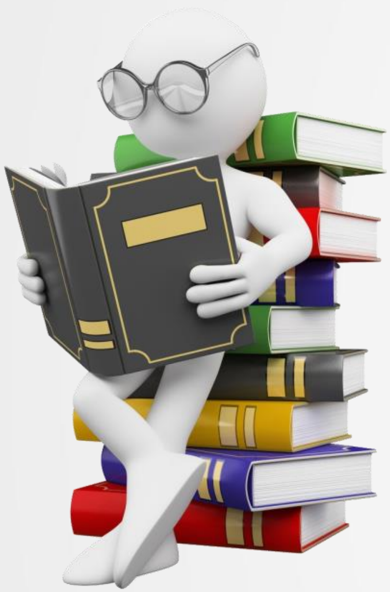
Outline

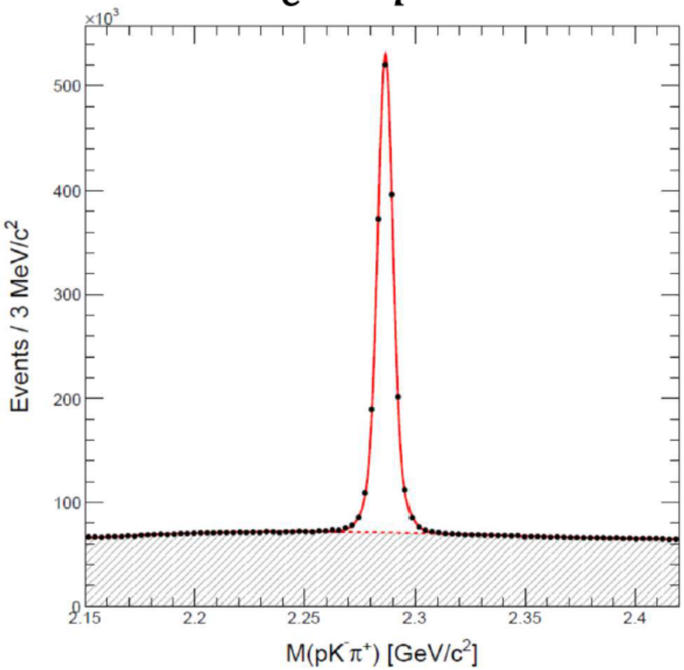


- A new Λ excited state ?
- Observation of $\Xi(1620)^0$
- Observation of an excited Ω^- baryon
- Search for $\Omega(2012) \to K\Xi(1530)$

Although Belle stopped data taking more than ten years ago and BelleII has already started data taking, Belle is still producing many excited results.

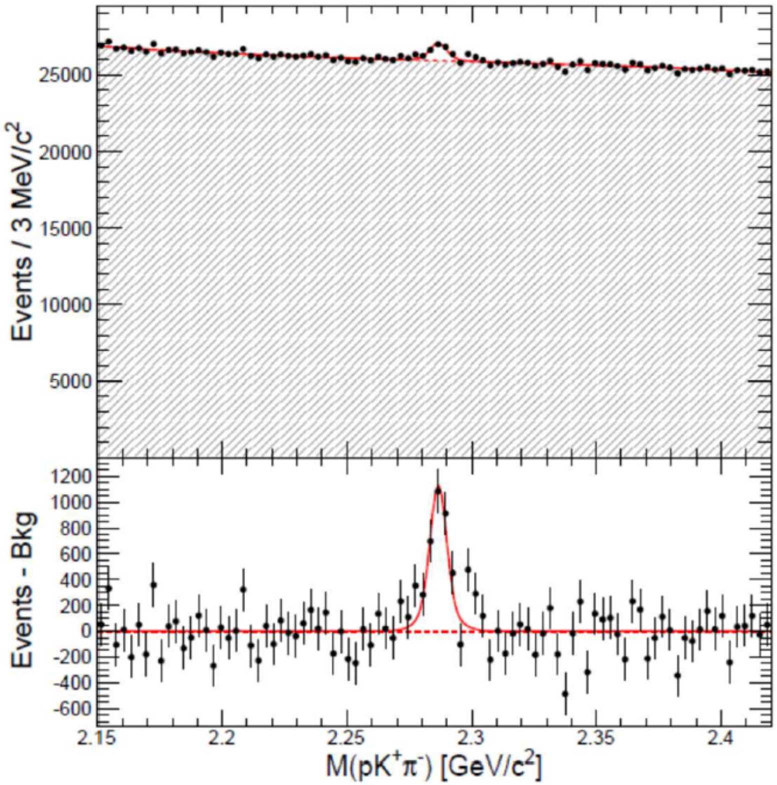
DCS decay $\Lambda_c^+ \to p\, K^+ \pi^-$

CF: $\Lambda_c^+ \to pK^-\pi^+$



$(1.452 \pm 0.015) \times 10^6$ events

DCS: $\Lambda_c^+ \to pK^+\pi^-$



Significant signal observed!

(significance 9.4σ)

3587±380 events

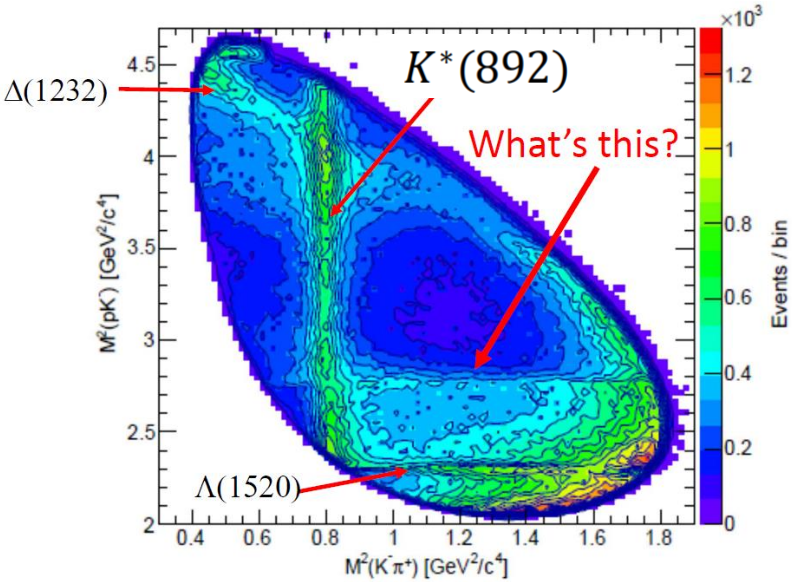
[PRL117, 011801]

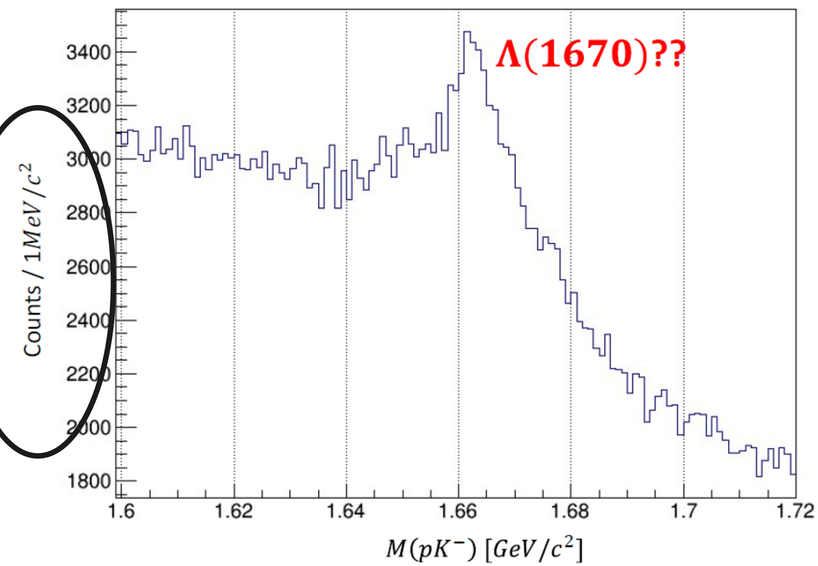
$$BR(\Lambda_c^+ \to pK^+\pi^-) = (1.61 \pm 0.23^{+0.07}_{-0.08}) \times 10^{-4}$$

The first observation of DCS in Baryons.

A new Λ excited state ?

Dalitz plot: $\Lambda_c^+ \to pK^-\pi^+$ [PRL117.011801]





- The peak position is ~1663 MeV, near the Λη threshold (1663.5 MeV)
- Width is ~10 MeV, significantly narrower than Λ, Σ resonances in this region
  - Λ(1670): 25-50 MeV
  - Σ(1660): 40-200 MeV
  - Σ(1670): 40-80 MeV
  - Λ(1690): ~60 MeV
- 2 independent groups claim there is a new narrow Λ^* resonance at this energy with J=3/2
  - Kamano et al. [PRC90.065204, PRC92.025205]
    $J^P=3/2^+$ (P_{03}), M=1671+2-8 MeV, Γ=10+22-4 MeV
  - Liu & Xie [PRC85.038201, PRC86.055202]
    $J^P=3/2^-$ (D_{03}), M=1668.5±0.5 MeV, Γ=1.5±0.5 MeV
- The reason is the same
  - From $K^-p \to \Lambda\eta$ measurement near the threshold by Crystal Ball collaboration at BNL [PRC64.055205]
  - Especially the angular distribution → Model independent
- There is no state in quark models
  - It must be an exotic
  - $uds s\bar{s}$ pentaquark??

Observation of $\Xi^0(1620)$ and evidence for $\Xi^0(1690)$

PRL 122, 072501 (2019)

List of Ξ(S=-2) particles from PDG

Particle	J^P	Overall status	Status as seen in — $\Xi\pi$	ΛK	ΣK	$\Xi(1530)\pi$	Other channels
$\Xi(1318)$	1/2+	****					Decays weakly
$\Xi(1530)$	3/2+	****	****				
$\Xi(1620)$	½-?	*	*				
$\Xi(1690)$		***		***	**		
$\Xi(1820)$	3/2−	***	**	***	**	**	
$\Xi(1950)$		***	**	**		*	
$\Xi(2030)$		***		**	***		
$\Xi(2120)$		*		*			
$\Xi(2250)$		**					3-body decays
$\Xi(2370)$		**					3-body decays
$\Xi(2500)$		*		*	*		3-body decays

**** Existence is certain, and properties are at least fairly well explored.
*** Existence ranges from very likely to certain, but further confirmation is desirable and/or quantum numbers, branching fractions, *etc.* are not well determined.
** Evidence of existence is only fair.
* Evidence of existence is poor.

- NOT much is known about Ξ^*
- Not found ½-? With L =1
- **$\Xi(1620)$** and **$\Xi(1690)$** are candidates
- $\Xi\pi$ is possible mode

Status of the $\Xi(1620)$

One star:

Evidence of existence is poor

E. Briefel, PRD 16, 2706 (1977)

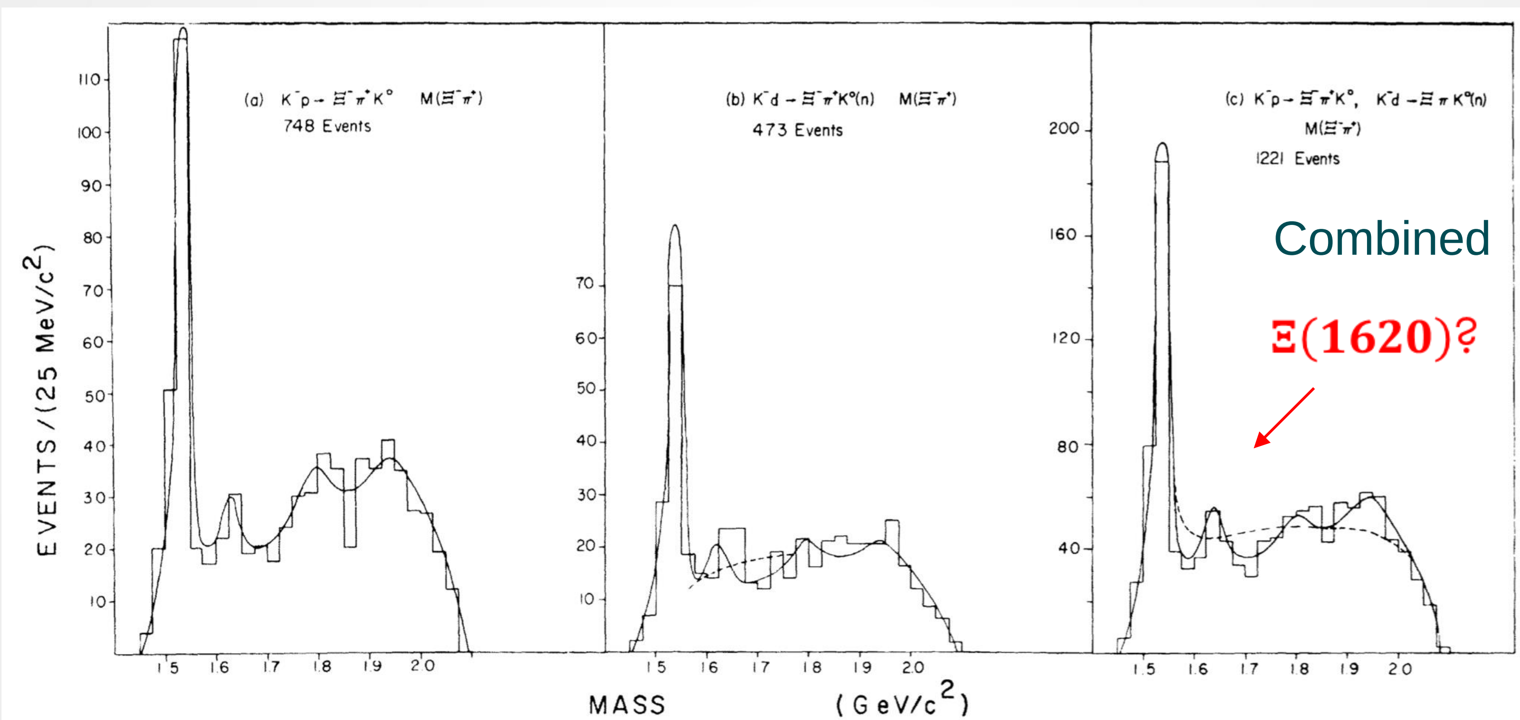
The data for this analysis came from two separate exposures, consisting of ~10^6 pictures each, of the BNL 31-in. bubble chamber to a separated beam of 2.87-GeV/c K^- mesons. During the first

But !!

J.K.Hassall says "no evidence"

In NPB189 (1981) 397

the Argonne 12 foot bubble chamber



The $\Xi^-\pi^+$ effective-mass distributions for the reaction $K^-p \to \Xi^-\pi^+K^0$

Search for $\Xi^0(1620)$ and $\Xi^0(1690)$ at Belle

PRL 122, 072501 (2019)

Search for $\Xi^0(1620)$ and $\Xi^0(1690)$ at Belle in below channel: $\Xi_c^+ \to \Xi^{*0}\pi^+$, $\Xi^{*0} \to \Xi^-\pi^+$

Data set:

Total 980fb^{-1}

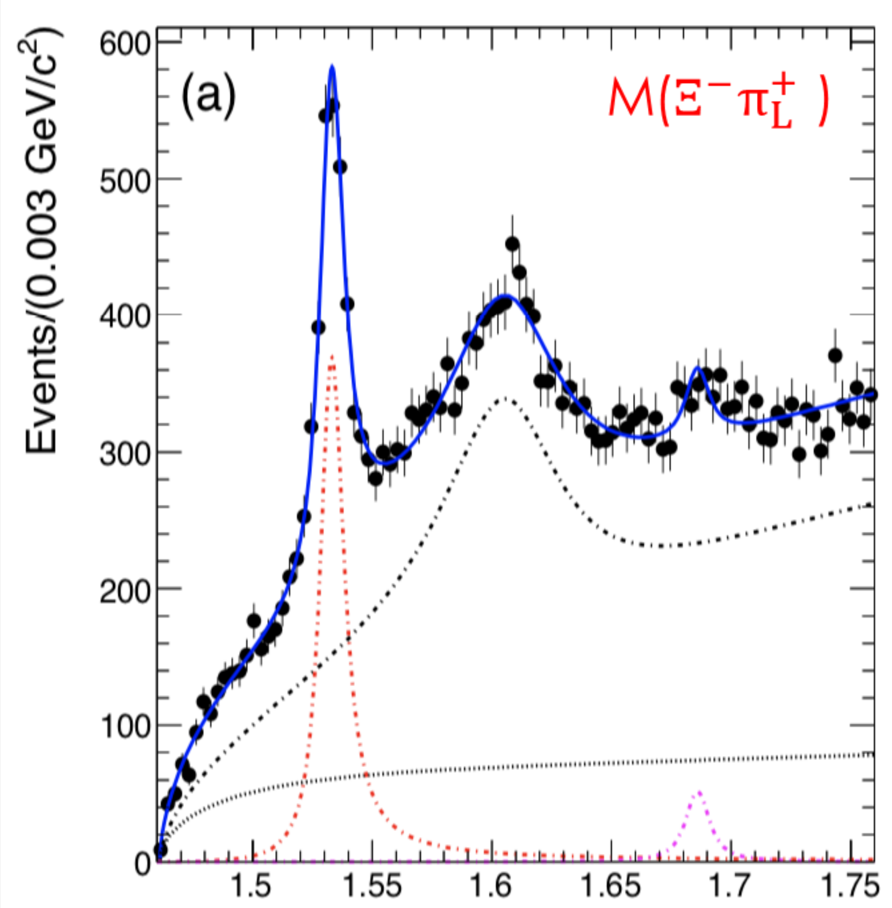
Data sample	Luminosity(fb^{-1})	Data sample	Luminosity(fb^{-1})
$\Upsilon(1S)$	5.74	$\Upsilon(2S)$	24.91
$\Upsilon(3S)$	2.9	e^+e^- at $\sqrt{s}$=10.52GeV	89.5
e^+e^- at $\sqrt{s}$=10.58GeV	711.0	e^+e^- at $\sqrt{s}$=10.867GeV	121.4

Crucial Selection criteria:

- To purify the Ξ_c^+ samples, the scaled momentum $x_p = \frac{p_{CM}}{\sqrt{\frac{1}{4}s - m(\Xi_c^+)^2}} < 0.5$
- The retained Ξ^- candidates are combined with the lower and higher momentum pions, as labeled π_L^+ and π_H^+.
- A vertex fit is applied to the $\Xi_c^+ \to \Xi^-\pi^+\pi^+$ decay, and the $\chi^2 < 50$

Observation of $\Xi^0(1620)$ and evidence for $\Xi^0(1690)$

PRL 122, 072501 (2019)



In the simultaneous fit

- The $\Xi^0(1530)$ and $\Xi^0(1690)$ signals are modeled with P- and S-wave relativistic BW functions.
- The $\Xi^0(1620)$ signal is modeled with the S-wave relativistic BW function.
- The interference between $\Xi^0(1620)$ and the S-wave non-resonant process is taken into account.
- The combinatorial backgrounds are described by a threshold.

$\Xi^0(1620)$ **state**	
Mass (MeV/c²)	$1610.4 \pm 6.0^{+5.9}_{-3.5}$
Width (MeV)	$59.9 \pm 4.8^{+2.8}_{-3.0}$

When the S-wave (P-wave) relativistic BW with fixed mass and width is used as the fitting function, the significance for $\Xi^0(1690)$ is 4.6σ (4.0σ).

Observation of an excited Ω^- baryon

PRL 121, 052003 (2018)

Ω^- = s s s (S=-3, I=0)

1. Ω^- excited states have proved difficult to find

- Only one excited Ω^- state, $\Omega(2250)$, has been confirmed until now.
- In addition, evidence for two other states of Ω^- was reported.
- The masses of these excited Ω^- are much higher than the ground state (>600MeV).

2. $\Omega^{*-} \to \Omega^- + \pi^0$ is highly suppressed since Ω^- has isospin zero

3. Preferred modes

- $\mathbf{\Omega^{*-} \to \Xi^- + K^0_S}$ ✓
- $\mathbf{\Omega^{*-} \to \Xi^0 + K^-}$ ✓
- Low-lying states
- Analogous to $\Omega_c^0 \to \Xi_c^+ K^-$

[R. Aaij et al. PRL 118, 182001 (2017)]
[J. Yelton et al. PRD 97, 051102 (2018)]

Data sample	Luminosity(fb^{-1})	Events ($\times 10^8$)
$\Upsilon(1S)$	5.7	1.02
$\Upsilon(2S)$	24.9	1.58
$\Upsilon(3S)$	2.9	-

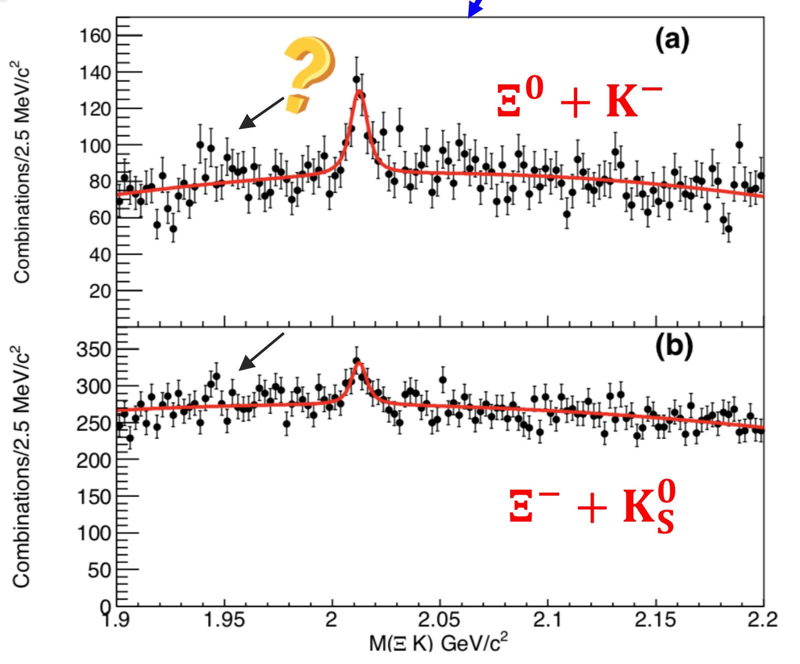
- Decays of these narrow resonances proceed via gluons.
- Production of baryon is enhanced.

Observation of an excited Ω^- baryon

Results & Summary

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

Data	Mode	Mass (MeV/c^2)	Yield	Γ(MeV)	χ^2/d.o.f.	n_σ
$\Upsilon(1S, 2S, 3S)$	$\Xi^0 K^-$, $\Xi^- K^0_S$ (simultaneous)	2012.4 ± 0.7	242 ± 48, 279 ± 71	$6.4^{+2.5}_{-2.0}$	227/230	8.3
$\Upsilon(1S, 2S, 3S)$	$\Xi^0 K^-$	2012.6 ± 0.8	239 ± 53	6.1 ± 2.6	115/114	6.9
$\Upsilon(1S, 2S, 3S)$	$\Xi^- K^0_S$	2012.0 ± 1.1	286 ± 87	6.8 ± 3.3	101/114	4.4
Other	$\Xi^0 K^-$	2012.4 (Fixed)	209 ± 63	6.4 (Fixed)	102/116	3.4
Other	$\Xi^- K^0_S$	2012.4 (Fixed)	153 ± 89	6.4 (Fixed)	133/116	1.7



PRL 121, 052003 (2018)

- The gap in the spectrum between the ground state and this excited state (~340 MeV) is smaller than in other Ω^- excited states, which is closer to the negative-parity orbital excitations of many other baryons.
- The narrow width observed implies that the quantum number $J^P = \frac{3}{2}^-$ is preferable.

Theoretical interpretation for the $\Omega^*(2012)$

It is generally accepted that $\Omega^*(2012)$ is 1P orbital excitation of the ground state Ω baryon with the three strange quarks, whose quantum numbers are $J^P = \frac{3}{2}^-$.

Notably, the newly observed $\Omega^*(2012)$ is revealed as a KΞ(1530) hadronic molecule.
[PRD 98, 054009 (2018),
PRD 98, 056013 (2018),
arXiv:1807.02145,
arXiv:1807.06485,
arXiv:1807.06485,
......]
The $K\Xi\pi$ three-body component is largely dominant.

From PRD 98, 056013 (2018)

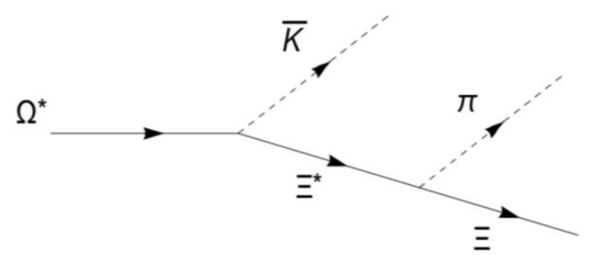


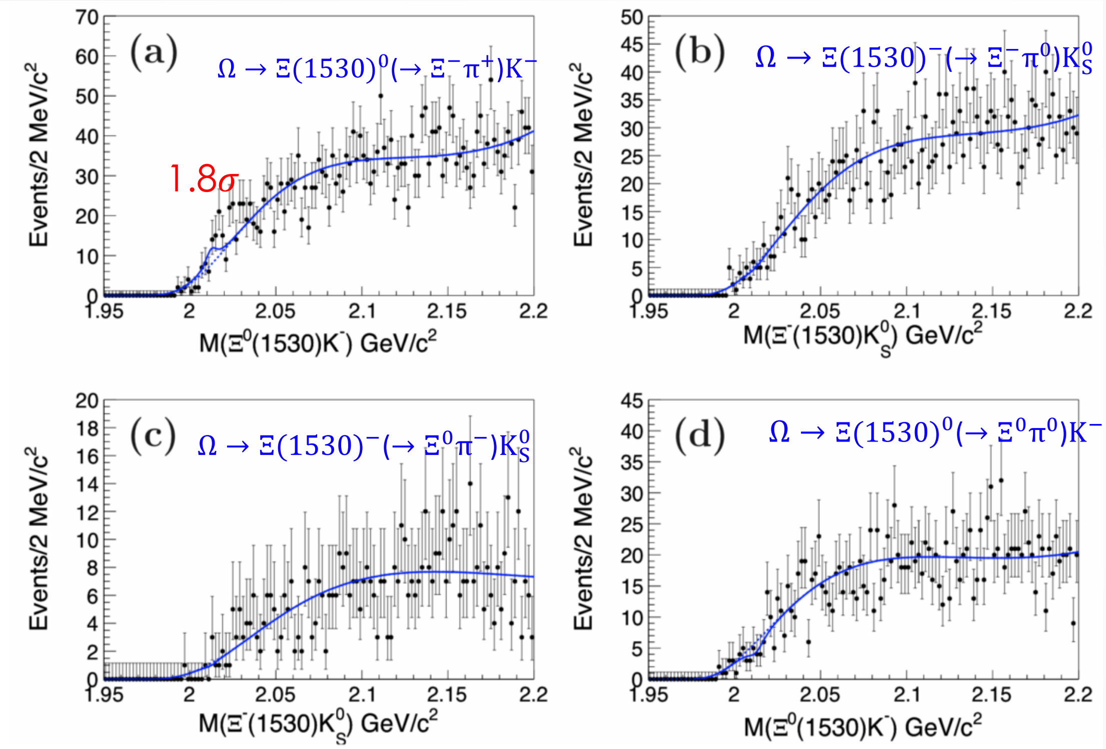
FIG. 1: The three-body decays of $\Omega(2012)$ in the $K\Xi(1530)$ molecular picture.

Mode	$J^P = \frac{3}{2}^-$ $\Omega(2012)$ $(K\Xi(1530))$	
	Widths (MeV)	Branch Ratio(%)
$K\Xi$	0.4	14.3
$K\pi\Xi$	2.4	85.7
Total	2.8	100.0

Search for Ω(2012) → KΞ(1530) → KπΞ

We use the same data samples to search for Ω(2012) → KΞ(1530) → KπΞ in the decay of the narrow resonances Υ(1S), Υ(2S), and Υ(3S).

arxiv: 1906.00194



No clear Ω(2012) signals are observed.
We give the upper limits on the ratios of the branching fractions at 90% C.L. as below.

$$R^{\Xi^-\pi^+K^-}_{\Xi^-\bar{K}^0} = \frac{\mathcal{B}(\Omega \to \Xi(1530)^0(\to \Xi^-\pi^+)K^-)}{\mathcal{B}(\Omega \to \Xi^-\bar{K}^0)} < 9.3\%$$

$$R^{\Xi^-\pi^0\bar{K}^0}_{\Xi^-\bar{K}^0} = \frac{\mathcal{B}(\Omega \to \Xi(1530)^-(\to \Xi^-\pi^0)\bar{K}^0)}{\mathcal{B}(\Omega \to \Xi^-\bar{K}^0)} < 81.1\%$$

$$R^{\Xi^0\pi^-\bar{K}^0}_{\Xi^0K^-} = \frac{\mathcal{B}(\Omega \to \Xi(1530)^-(\to \Xi^0\pi^-)\bar{K}^0)}{\mathcal{B}(\Omega \to \Xi^0K^-)} < 21.3\%$$

$$R^{\Xi^0\pi^0K^-}_{\Xi^0K^-} = \frac{\mathcal{B}(\Omega \to \Xi(1530)^0(\to \Xi^0\pi^0)K^-)}{\mathcal{B}(\Omega \to \Xi^0K^-)} < 30.4\%$$

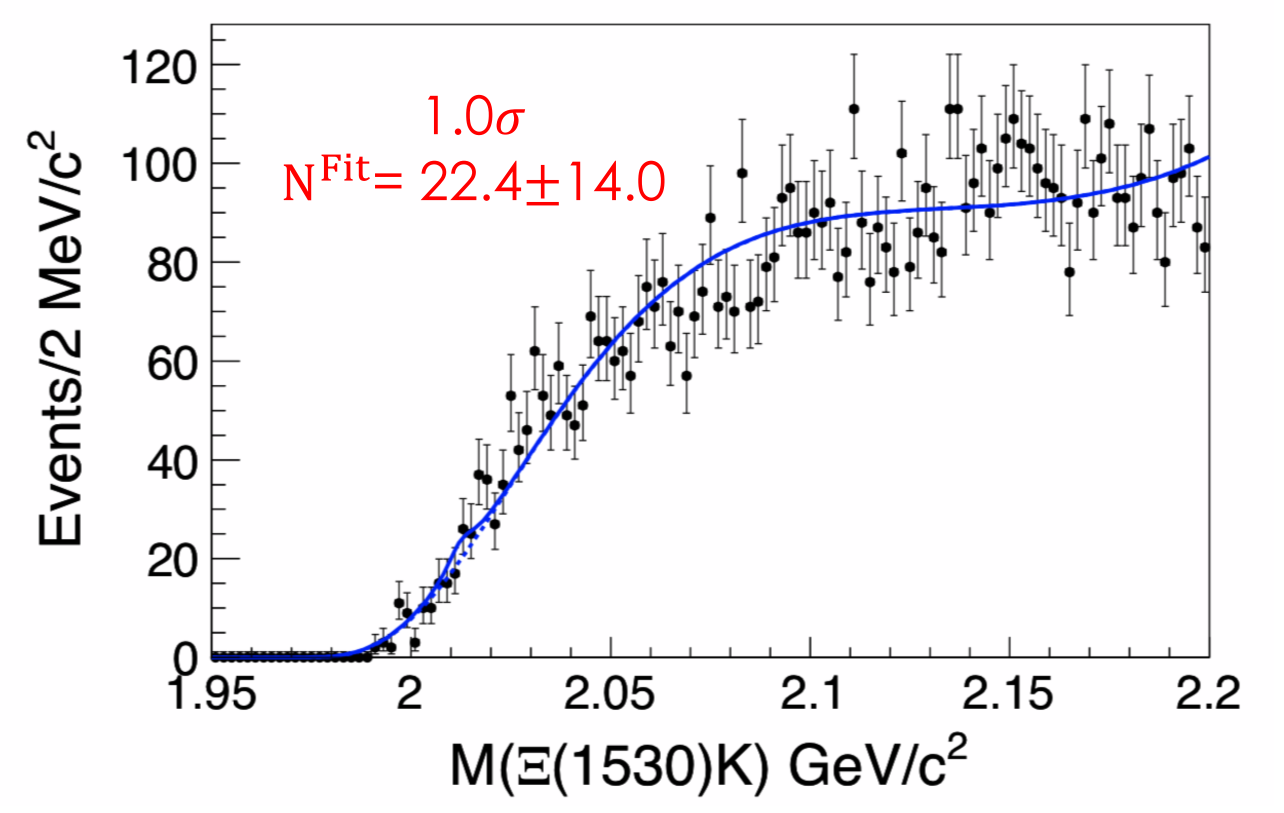
$$R^{\Xi^-\pi^+K^-}_{\Xi^0K^-} = \frac{\mathcal{B}(\Omega \to \Xi(1530)^0(\to \Xi^-\pi^+)K^-)}{\mathcal{B}(\Omega \to \Xi^0K^-)} < 7.8\%$$

$$R^{\Xi^0\pi^-\bar{K}^0}_{\Xi^-\bar{K}^0} = \frac{\mathcal{B}(\Omega \to \Xi(1530)^-(\to \Xi^-\pi^0)\bar{K}^0)}{\mathcal{B}(\Omega \to \Xi^-\bar{K}^0)} < 25.6\%$$

Mode	N^{Fit}	N^{UL}
$\Omega \to \Xi(1530)^0(\to \Xi^-\pi^+)K^-$	22.5±12.9	41.0
$\Omega \to \Xi(1530)^-(\to \Xi^-\pi^0)K^0_S$	-3.5±11.6	16.6
$\Omega \to \Xi(1530)^-(\to \Xi^0\pi^-)K^0_S$	-1.0±3.6	7.2
$\Omega \to \Xi(1530)^0(\to \Xi^0\pi^0)K^-$	-12.0±9.8	13.2

Search for $\Omega(2012) \to K\Xi(1530) \to K\pi\Xi$

A simultaneous fit to all three-body decay modes is performed.



$$R^{\Xi\pi K}_{\Xi K} = \frac{\mathcal{B}(\Omega\to\Xi(1530)(\to\Xi\pi)K)}{\mathcal{B}(\Omega\to\Xi K)} = (6.0\pm3.7(\text{stat.})\pm1.3(\text{syst.}))\%$$

$$R^{\Xi\pi K}_{\Xi K} = \frac{\mathcal{B}(\Omega\to\Xi(1530)(\to\Xi\pi)K)}{\mathcal{B}(\Omega\to\Xi K)} < 11.9\% \text{ at } 90\% \text{ C.L.}$$

Summary

- Although Belle has stopped data taking for ~10 years ago, we are still producing exciting results for hyperons.
- Belle II started data taking on 25 March with its full detector.
- Belle II will reach 50 ab^{-1} by 2027, which will provide greater sensitivity and precise measurements in hadron physics

Belle II physics book (arXiv:1808.10567):
https://arxiv.org/abs/1808.10567

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Thanks for your attention

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