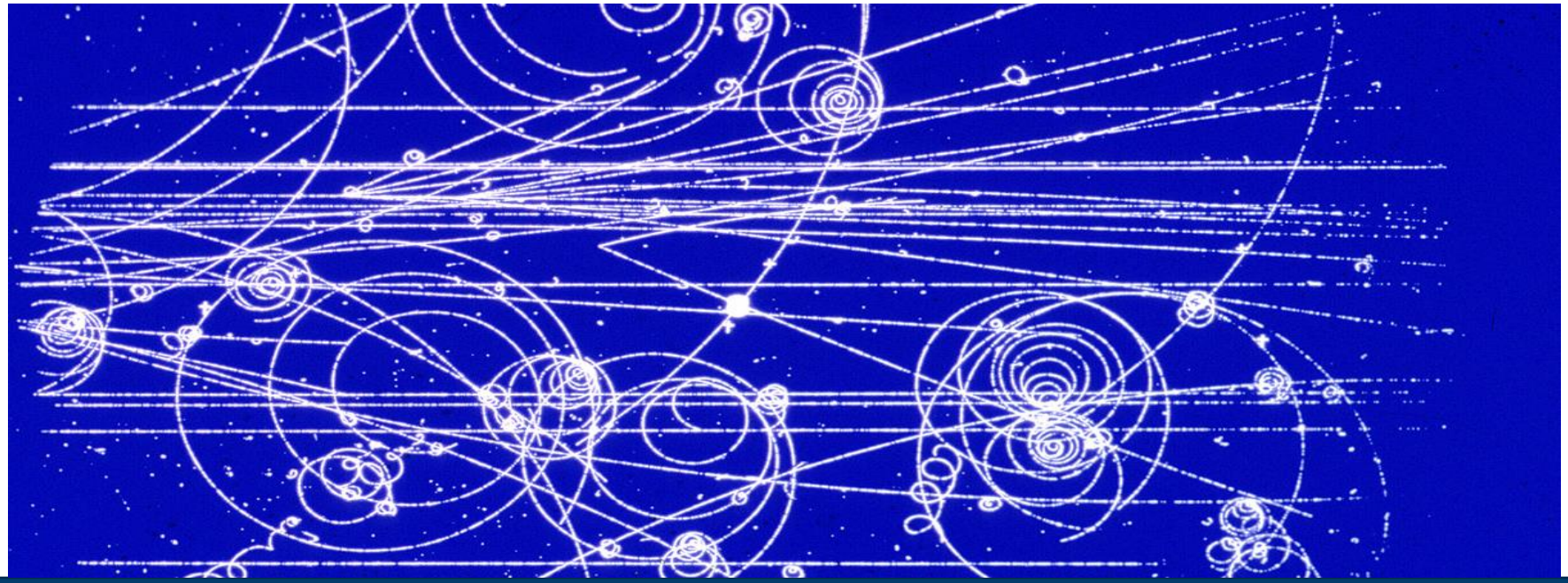


Study to Determine the Quantum Numbers of Ξ Resonances with PAWIAN

November 6th 2019| P̄ANDA CM 19/3 GSI | Jenny Pütz

Mitglied der Helmholtz-Gemeinschaft

p̄anda

JÜLICH Forschungszentrum

Motivation

Partial Wave Analysis

- Up to know: worked on analysis of $\bar{p}p \rightarrow \bar{\Xi}^{+}\Xi^{*-}$ with $\Xi^{*-} \rightarrow \Lambda K^{-}$ (& c.c.) [1)]
- Quantum number of most Ξ resonances unknown or only estimated
- No experimental data and theoretical predictions
- PWA: possibility to determine those quantum numbers

Table 1. The status of the Ξ resonances. Only those with an overall status of *** or **** are included in the Baryon Summary Table.

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

PDG2014

1) See plenary talk and talk in Hyperon Session at CM 18/3

What is PAWIAN?

- **PA**rtial **W**ave **I**nteractive **AN**alysis software
- Different spin formalisms and dynamics
- Event-based maximum likelihood fit (MINUIT2)
- Generates events based on user-defined decay model or on fit results obtained with real data

For further information: https://panda-wiki.gsi.de/foswiki/bin/view/PWA/PawianPwaSoftware

Strategy

- Is it possible to reconstruct the input values?
- Event Generation:
  - 1 data set of 10000 events for $\bar{\Xi}\Lambda K^-$
  - 2 data sets of 3000 events for each resonance
- $p_{\bar{p}}$= 4.6 GeV/c and L_{max}=0,1 for each data set
- Different quantum numbers generated for Ξ(1690)⁻ and Ξ(1820)⁻

$$^1/_2{}^-,\ ^1/_2{}^+,\ ^3/_2{}^-,\ ^3/_2{}^+$$

- Fit all hypotheses to each generated data set
- At later stage: included crossed channel $\bar{\mathrm{p}}\mathrm{p} \rightarrow \bar{\Lambda}(1890)\Lambda$

How are Results Compared?

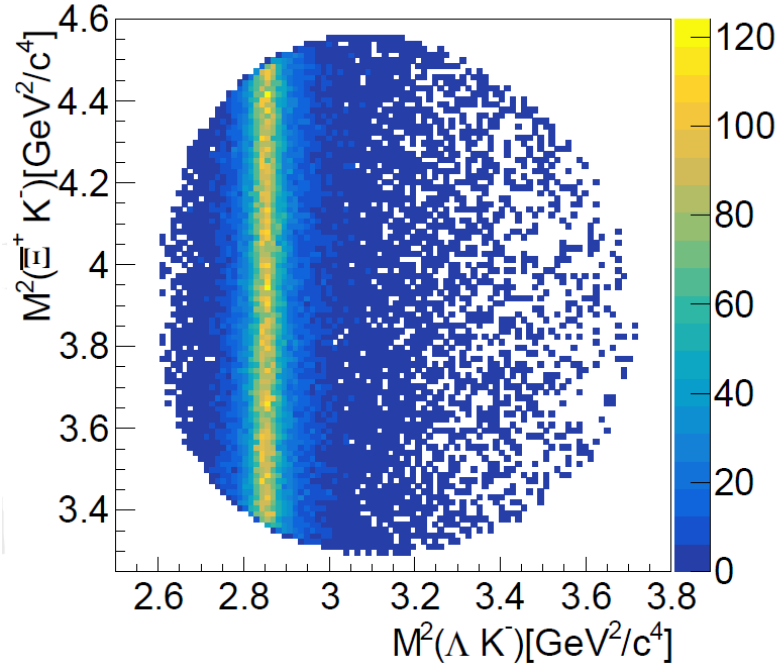
- Different criteria used: BIC and AIC
- BIC: Bayesian information criterion
  - model selection among a finite set of models
- AIC: Akaike information criterion
  - Estimates quality of model relative to set of models
- In both cases, model with lowest value is preferred

- Final selection based on : $\Delta\mathrm{AIC} = \mathrm{AIC}_i - \mathrm{AIC}_{min}$
- $\Delta\mathrm{AIC} < 2$: evidence for the model; $\Delta\mathrm{AIC} > 10$: model unlikely
- Special case: AIC and BIC show different tendencies => AIC+BIC

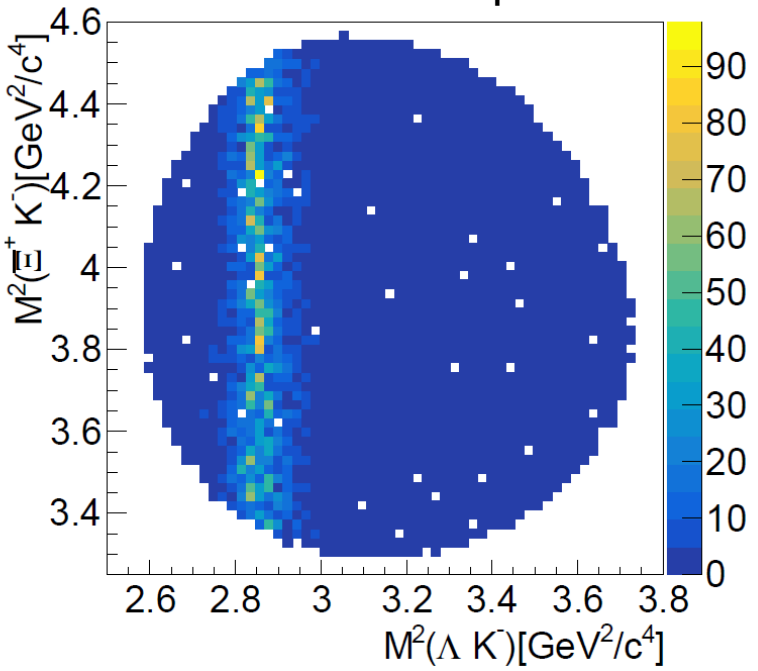
Single Resonances

$\Xi(1690)^-$ $(L_{max}= 0)$

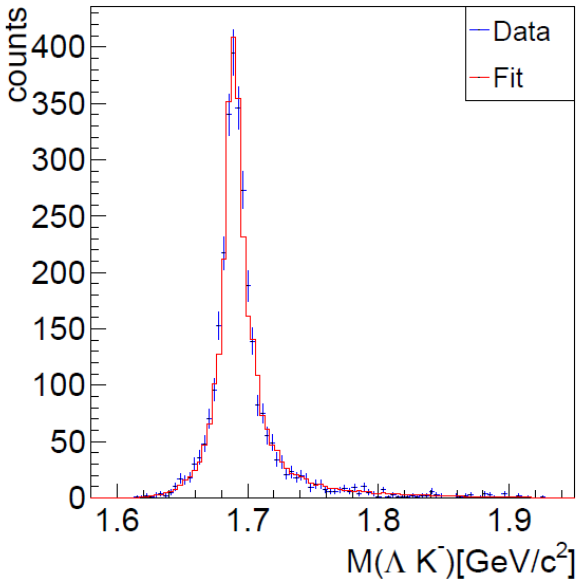
Generated ½⁺ Sample

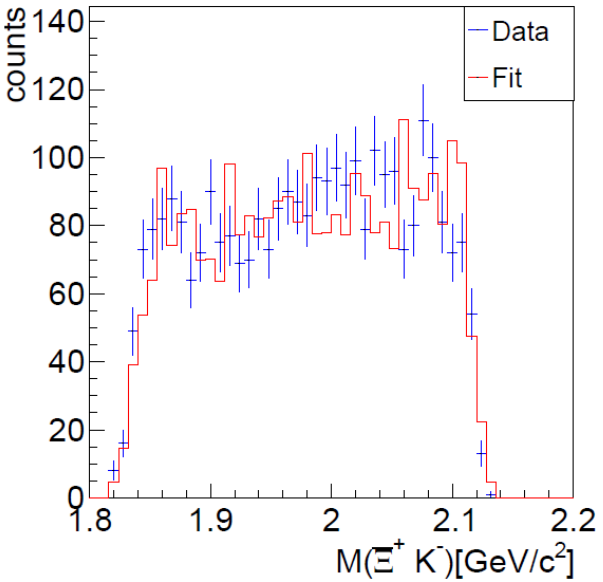


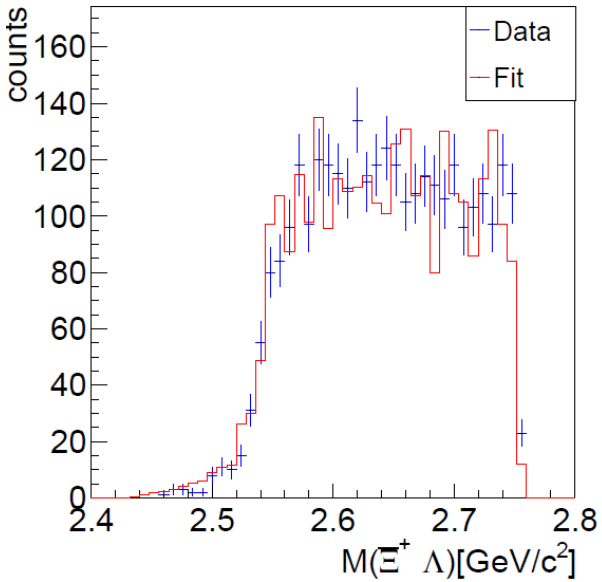
Fitted ½⁺ Sample



$\Xi(1690)^-$ $(L_{max} = 0)$



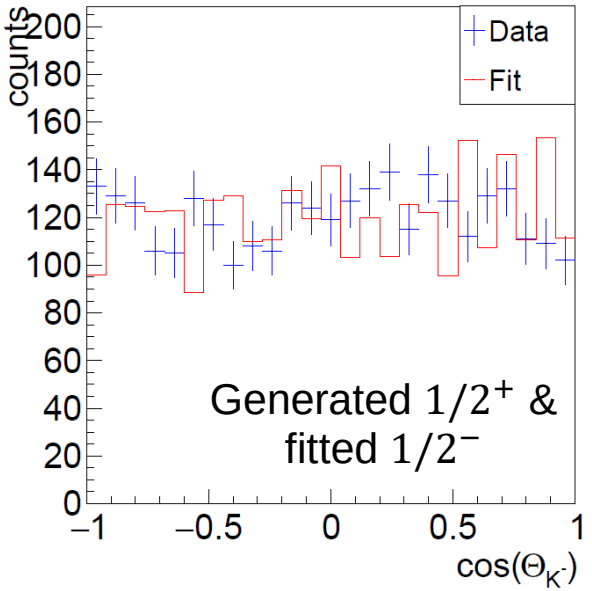


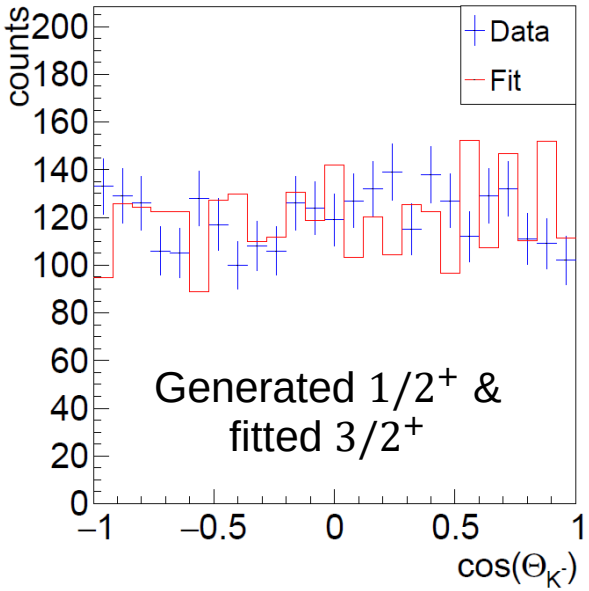


<u>In all tested cases:</u>
generated hypothesis preferred by fit!

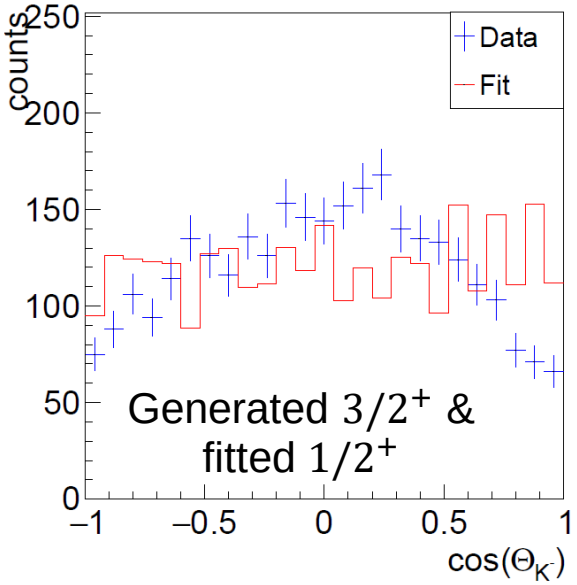
generated hypothesis	fit hypothesis	NLL	BIC	AIC	ΔBIC	ΔAIC
$1/2^+$	$1/2^+$	-3,989.3	-7,930.5	-7,966.5	0	0
	$1/2^-$	-3,970.3	-7,893.7	-7,929.8	36.8	36.7
	$3/2^+$	-3,963.3	-7,862.6	-7,910.6	67.9	55.9
	$3/2^-$	-3,928.9	-7,793.8	-7,841.9	136.7	124.6

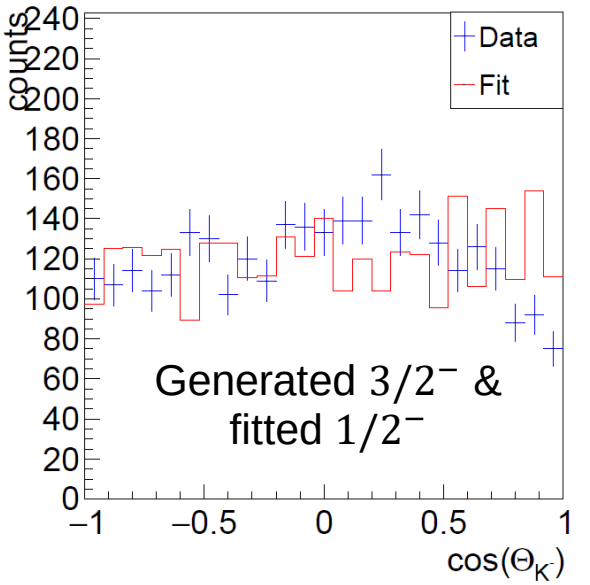
$\Xi(1690)^-$ $(L_{max}= 0)$



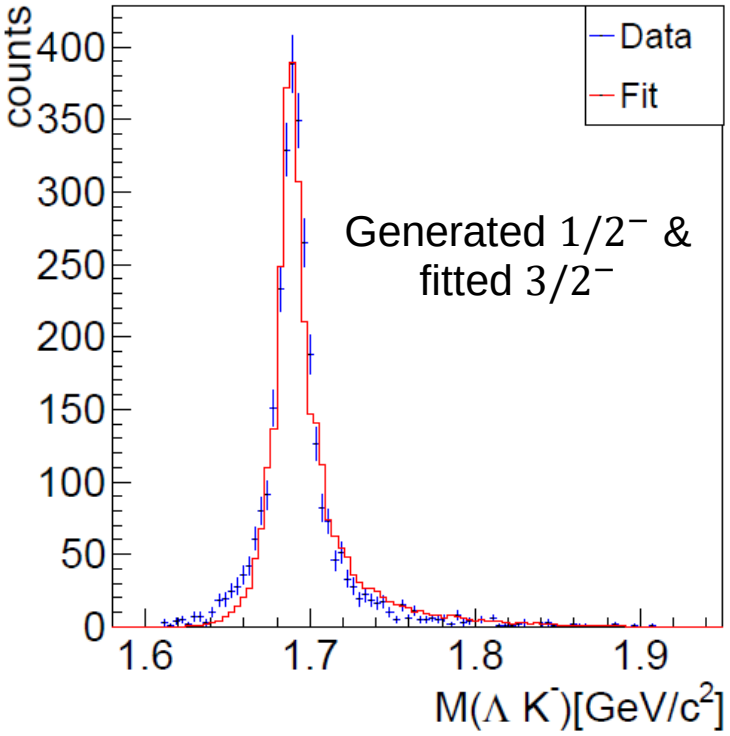


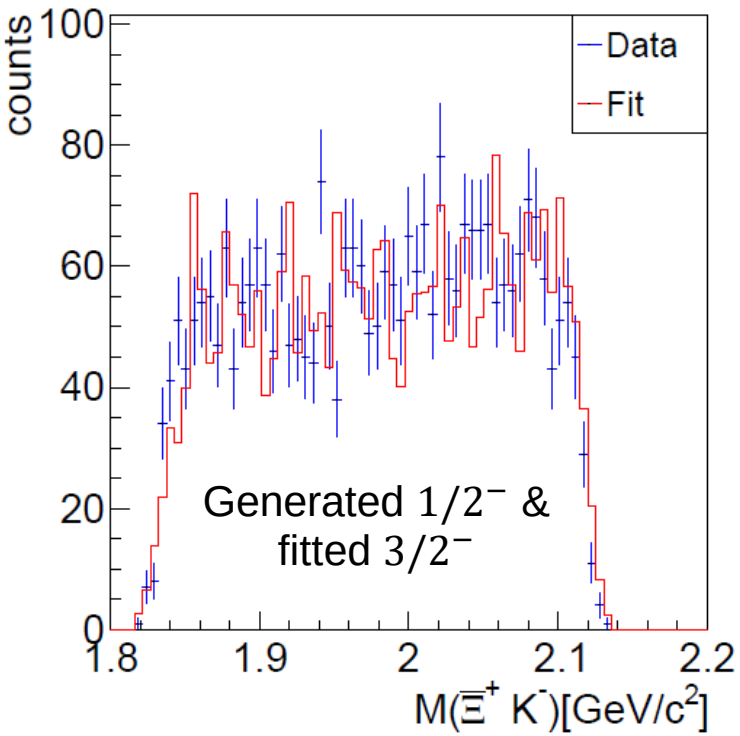
not caused by statistical effects





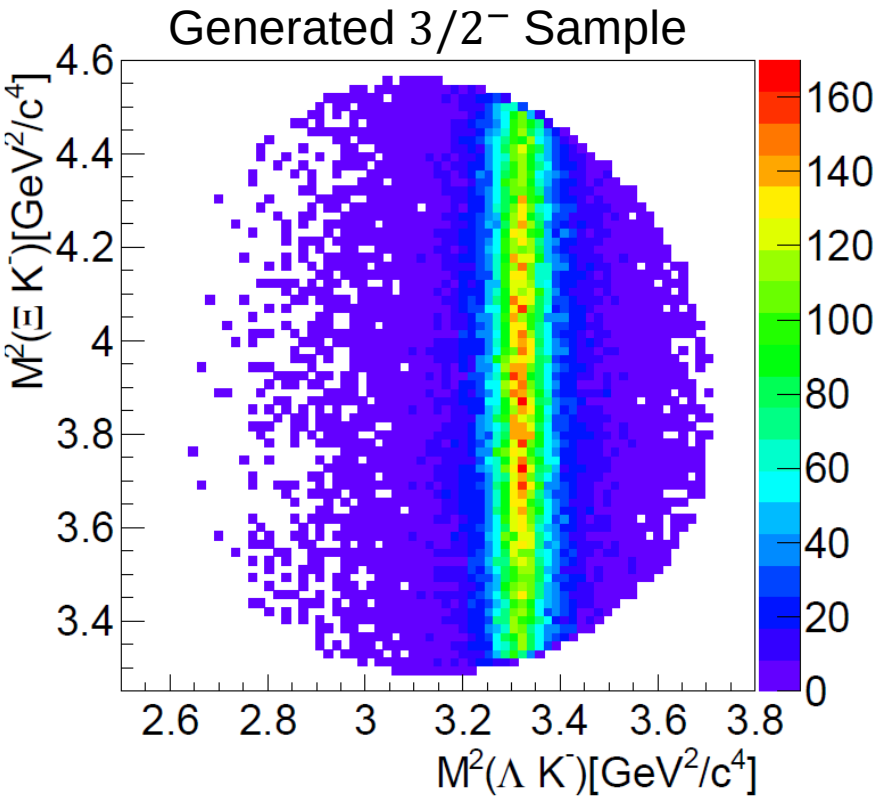
$\Xi(1690)^-$ $(L_{\max} = 1)$

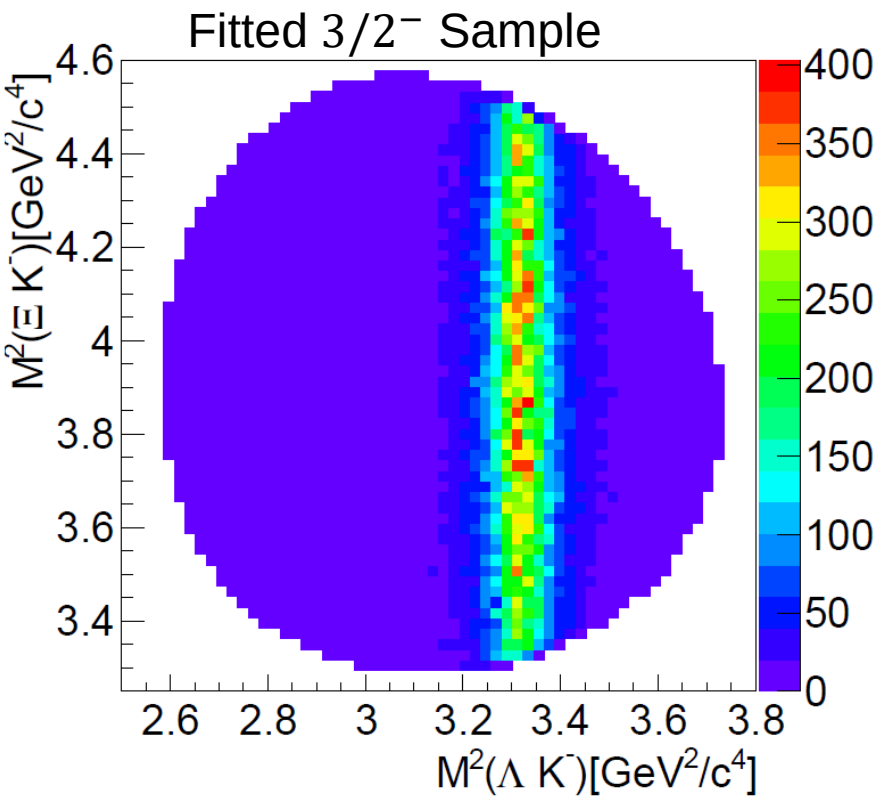




- True hypothesis preferred by fit in each case
- Similar fitted angular distributions as for $L_{\max} = 0$

$\Xi(1820)^-$ $(L_{\max} = 0)$



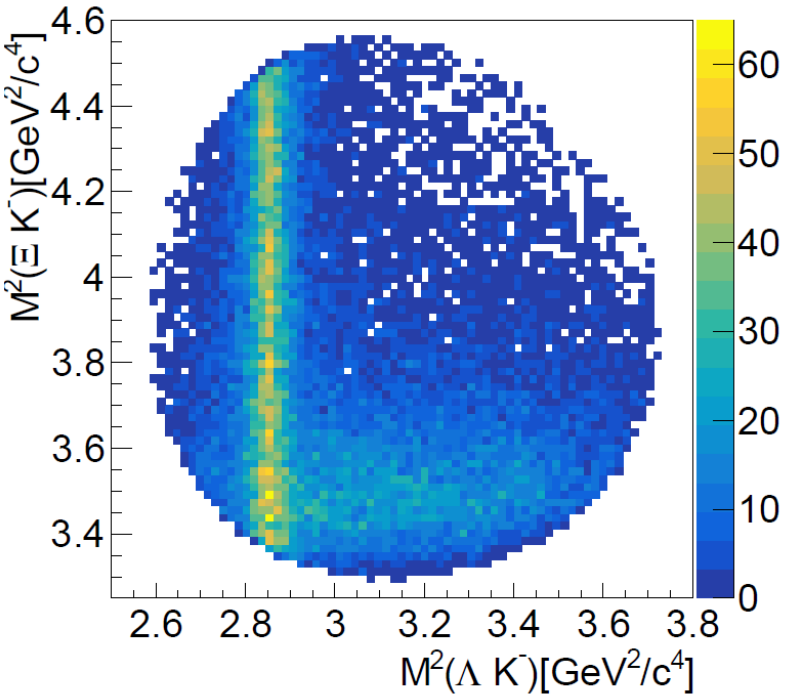


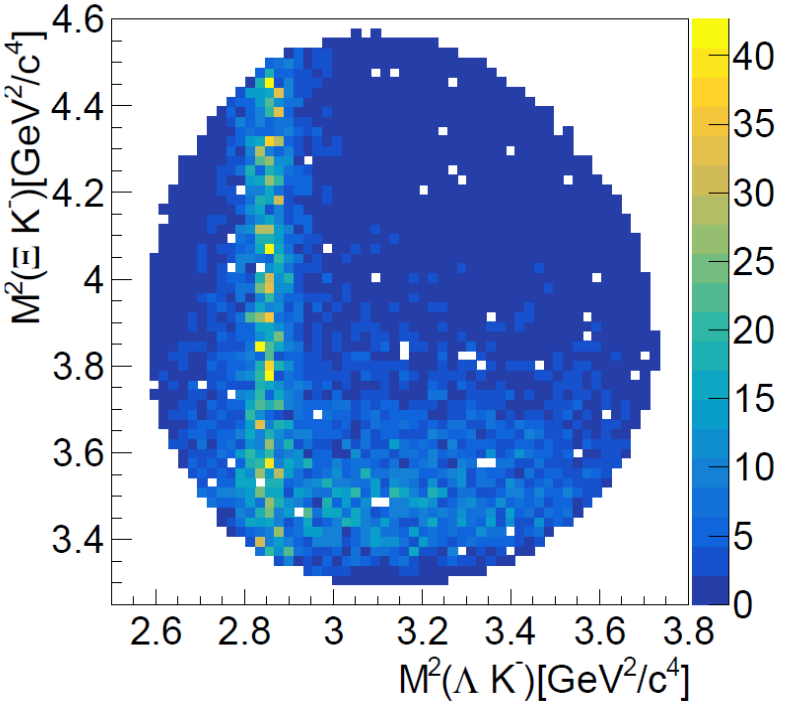
generated hypothesis	fit hypothesis	NLL	BIC	AIC	ΔBIC	ΔAIC
$1/2^+$	$1/2^+$	-3,010.5	-6,092.9	-6,128.9	0	0
	$1/2^-$	-3,059.8	-6,071.5	-6,107.5	21.4	12.4
	$3/2^+$	-3,071.1	-6,078.1	-6,126.6	14.8	2.3
	$3/2^-$	-3,055.1	-6,046.2	-6,094.3	46.7	34.6

For $L_{\max} = 1$ even harder to distinguish

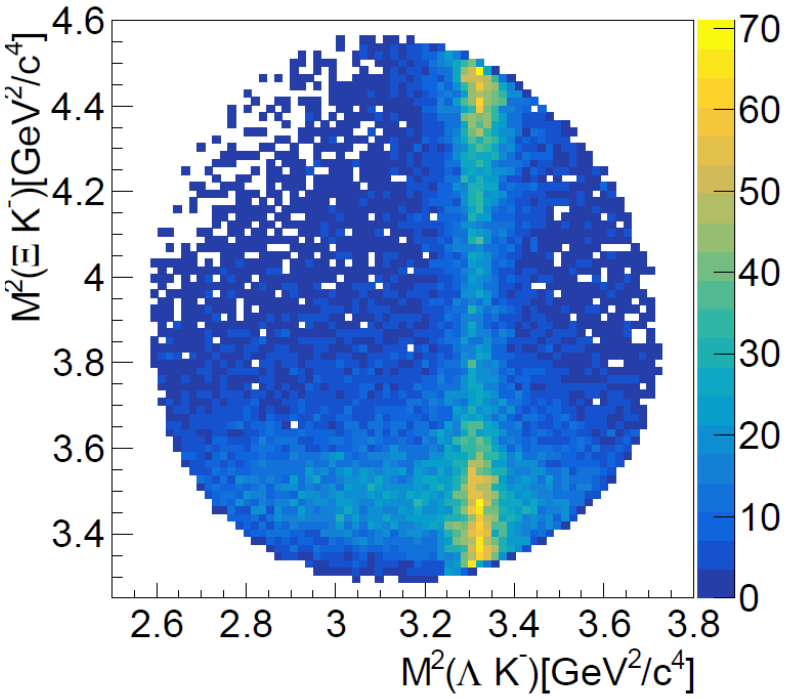
Crossed Channel

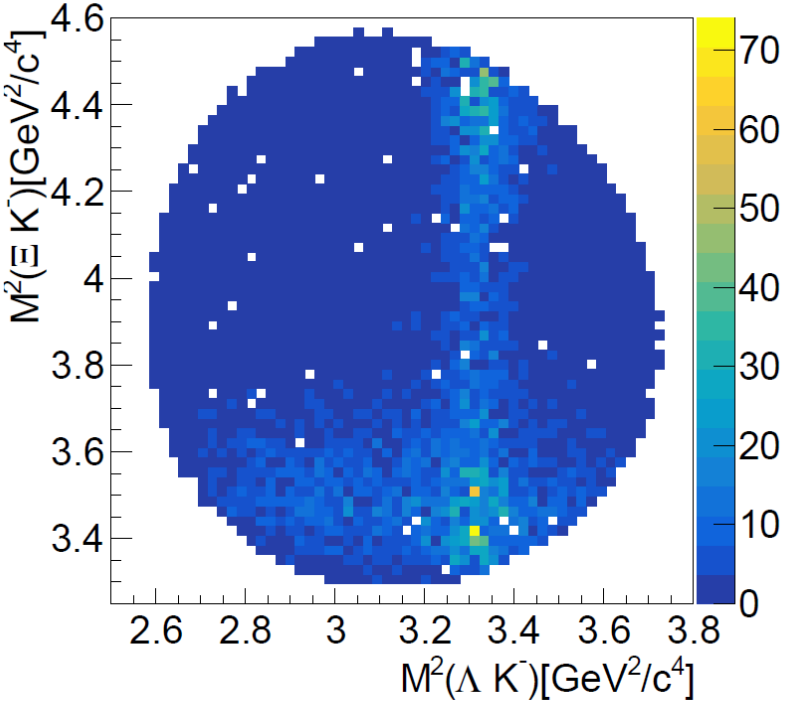
$\Xi(1690)^-$ $(L_{\mathrm{MAX}} = 1)$





$\Xi(1820)^-$ $(L_{\mathrm{MAX}} = 0)$





Summary & Outlook

- Performed test to reproduce quantum numbers
- “Single” resonances: promising
- Included crossed channel: $\bar{\mathrm{p}}\mathrm{p} \rightarrow \overline{\Lambda}(1890)\Lambda$
- Statistics is limiting factor

- Systematic studies with higher statistics needed
- Combined sample for both Ξ resonances
- Same test should be done for charge conjugate particles

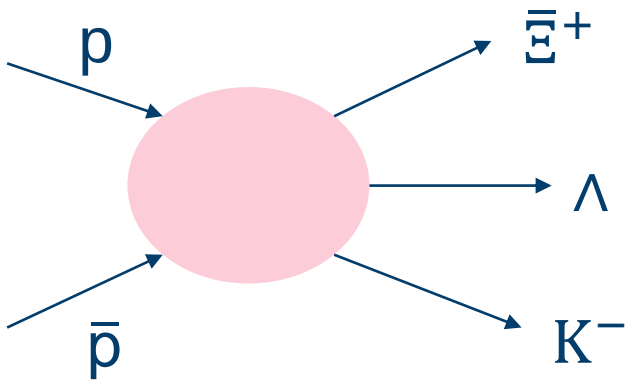
Thank you for your attention

Backup

Reminder

Partial Wave Analysis

- Partial Wave Analysis (PWA): tool to extract complex amplitudes of process
- In case of low energies → process dominated by resonances
- PWA gives possibility to determine:
  - Mass & width
  - Spin & Parity



Event Generation

Maximum Angular Momentum of $\bar{p}p$

- Beam momentum of 4.6 GeV/c² corresponds to a momentum in center-of-mass frame of:
  - $p_{\mathrm{cm}} \approx 600\ \mathrm{MeV/c}$ for $\Xi(1690)^- \rightarrow L_{\mathrm{max}} = 3$
  - $p_{\mathrm{cm}} \approx 410\ \mathrm{MeV/c}$ for $\Xi(1820)^- \rightarrow L_{\mathrm{max}} = 2$

BIC and AIC

- **Bayesian information criterion (BIC):**

  is a criterion for model selection among a finite set of models; the model with the lowest BIC is preferred.

$$BIC = 2 \cdot (-LHH) + k \cdot \ln(n)$$

  with LHH: maximal loglikelihood value, k: number of free fit parameters and n: number of events in the sample

- **Akaike information criterion (AIC):**

  is a measure of the relative quality of statistical models for a given set of data. Given a collection of models for the data, AIC estimates the quality of each model, relative to each of the other models

$$AIC = 2k + 2 \cdot (-LLH)$$

Helicity Frame

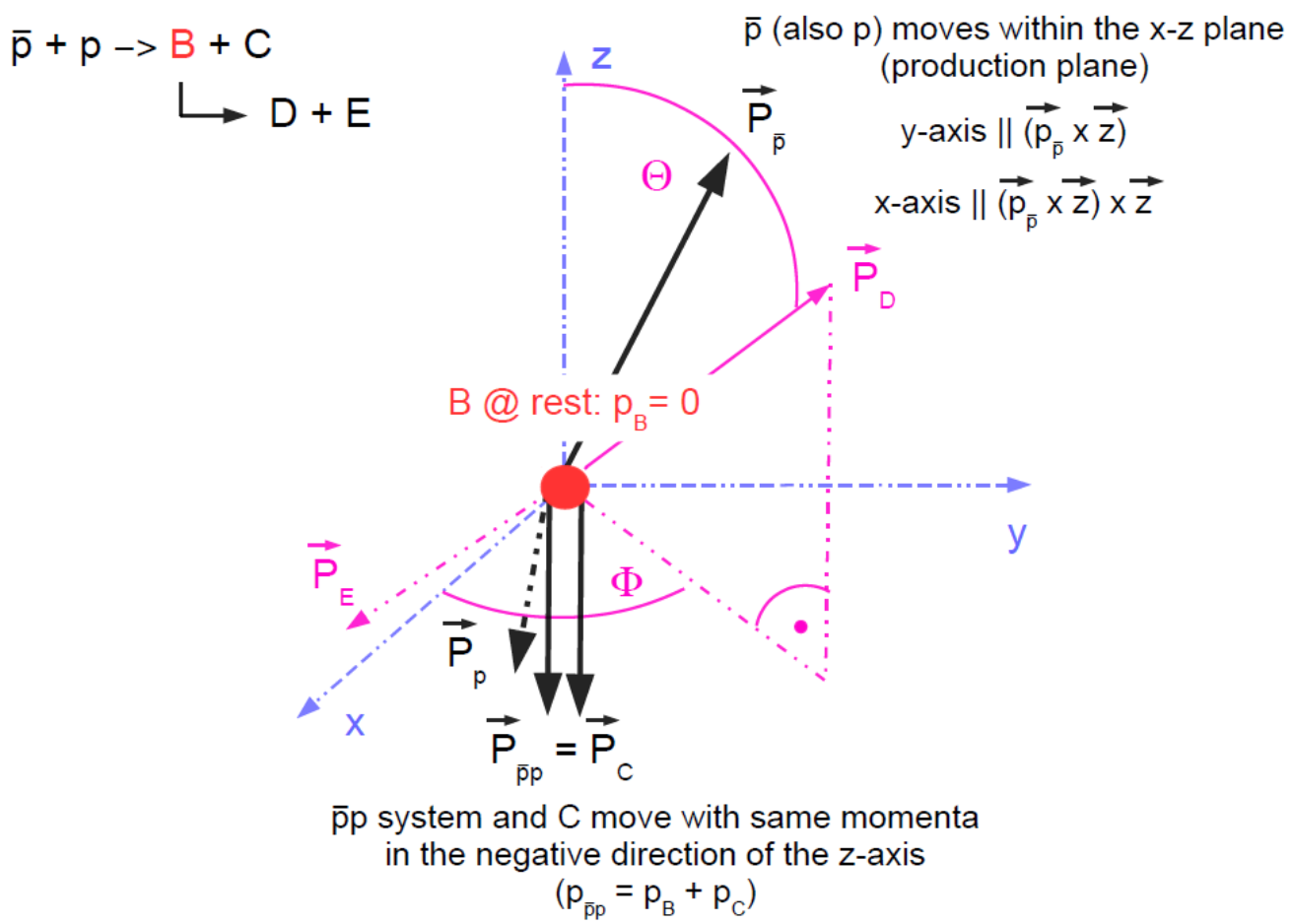


Image from Bertram Kopf

Gottfried-Jackson Frame

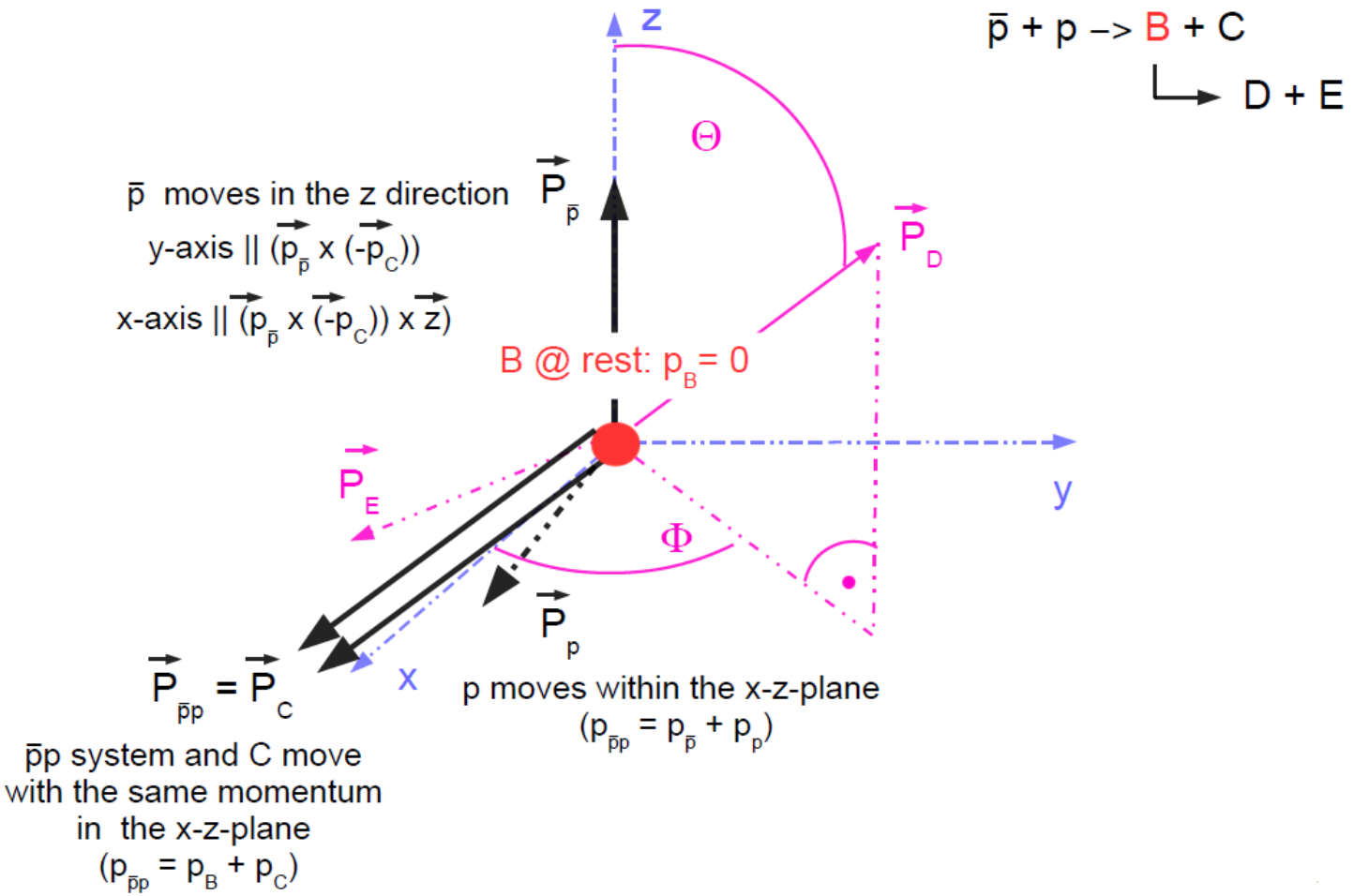


Image from Bertram Kopf

$\Xi(1690)^-$ $(L_{\max} = 0)$

Table 6.3: Results of the different generated and fitted hypotheses for $\Xi(1690)^-$. The maximal orbital angular momentum is set to $L_{\max} = 0$.

generated hypothesis	fit hypothesis	NLL	BIC	AIC	ΔBIC	ΔAIC	AIC + BIC	N_{par}
$1/2^+$	$1/2^+$	-3,989.3	-7,930.5	-7,966.5	0	0	-15,897.0	6
	$1/2^-$	-3,970.3	-7,893.7	-7,929.8	36.8	36.7	-15,823.5	6
	$3/2^+$	-3,963.3	-7,862.6	-7,910.6	67.9	55.9	-15,773.2	8
	$3/2^-$	-3,928.9	-7,793.8	-7,841.9	136.7	124.6	-15,645.7	8
$1/2^-$	$1/2^+$	-4,010.9	-7,973.7	-8,009.7	76.9	77.2	-15,983.4	6
	$1/2^-$	-4,049.4	-8,050.6	-8,086.9	0	0	-16,137.5	6
	$3/2^+$	-4,011.9	-7,958.0	-8,006.1	92.6	80.8	-15,964.1	8
	$3/2^-$	-3,865.9	-7,667.8	-7,715.9	382.8	371.0	-15,383.7	8
$3/2^+$	$1/2^+$	-4,115.2	-8,182.4	-8,218.5	147.8	159.8	-16,400.9	6
	$1/2^-$	-4,105.3	-8,162.5	-8,198.6	167.7	179.7	-16,361.1	6
	$3/2^+$	-4,197.1	-8,330.2	-8,378.3	0	0	-16,708.5	8
	$3/2^-$	-4,132.8	-8,201.6	-8,249.6	128.6	128.7	-16,451.2	8
$3/2^-$	$1/2^+$	-3,740.0	-7,431.9	-7,467.9	101.0	113.6	-14,899.8	6
	$1/2^-$	-3,658.3	-7,268.6	-7,304.6	264.8	276.9	-14,573.2	6
	$3/2^+$	-3,762.9	-7,461.8	-7,509.9	71.6	71.6	-14,971.7	8
	$3/2^-$	-3,798.7	-7,533.4	-7,581.5	0	0	-15,114.9	8

$\Xi(1690)^-$ ($L_{max}= 1$)

Table 6.4: Results of the different generated and fitted hypotheses for $\Xi(1690)^-$. The maximal orbital angular momentum is set to $L_{max} = 1$.

generated hypothesis	fit hypothesis	NLL	BIC	AIC	ΔBIC	ΔAIC	AIC + BIC	N_{par}
$1/2^+$	$1/2^+$	-4,259.2	-8,359.7	-8,479.9	0	0	-16,839.6	20
	$1/2^-$	-4,249.4	-8,338.6	-8,458.7	21.1	21.2	-16,797.3	20
	$3/2^+$	-4,282.5	-7,862.6	-7,910.6	497,1	569,3	-15,773.2	30
	$3/2^-$	-4,186.7	-8,324.8	-8,505.0	34.9	25.1	-16,829.8	30
$1/2^-$	$1/2^+$	-4,233.7	-8,307.2	-8,427.3	37.3	37.5	-16,734.5	20
	$1/2^-$	-4,252.3	-8,344.5	-8,464.8	0	0	-16,809.3	20
	$3/2^+$	-4,254.0	-8,267.8	-8,447.9	76.7	16.9	-16,715.7	30
	$3/2^-$	-4,124.4	-8,008.6	-8,188.8	335.9	276.0	-16,197.4	30
$3/2^+$	$1/2^+$	-4,158.2	-8,156.2	-8,276.3	189.3	243.3	-16,432.5	20
	$1/2^-$	-4,146.0	-8,131.8	-8,252.0	213,7	267.6	-16,383.8	20
	$3/2^+$	-4,288.8	-8,345.5	-8,519.6	0	0	-16,865.1	30
	$3/2^-$	-4,230.1	-8,219.9	-8,400.1	125.6	119.5	-16,620.0	30
$3/2^-$	$1/2^+$	-3,870.5	-7,580.8	-7,700.9	309.8	369.8	-15,281.7	20
	$1/2^-$	-3,802.6	-7,445.0	-7,565.1	445.6	505.6	-15,010.1	20
	$3/2^+$	-4,013.9	-7,795.6	-7,969.8	95	100.9	-15,765.4	30
	$3/2^-$	-4,065.4	-7,890.6	-8,070.7	0	0	-15,961.3	30

$\Xi(1820)^-$ $(L_{max}= 0)$

Table 6.5: Results of the different generated and fitted hypotheses for $\Xi(1820)^-$. The maximum orbital momentum is set to $L_{max} = 0$.

generated hypothesis	fit hypothesis	NLL	BIC	AIC	ΔBIC	ΔAIC	AIC + BIC	N_{par}
$1/2^+$	$1/2^+$	-3,010.5	-6,092.9	-6,128.9	0	0	-12,221.8	6
	$1/2^-$	-3,059.8	-6,071.5	-6,107.5	21.4	12.4	-12,179.0	6
	$3/2^+$	-3,071.1	-6,078.1	-6,126.6	14.8	2.3	-12,204.7	8
	$3/2^-$	-3,055.1	-6,046.2	-6,094.3	46.7	34.6	-12,140.5	8
$1/2^-$	$1/2^+$	-2,985.1	-5,922.1	-5,958.1	23.1	23	-11,880.2	6
	$1/2^-$	-2,996.6	-5,945.2	-5,981.2	0	0	-11,926.4	6
	$3/2^+$	-2,985.6	-5,907.1	-5,955.2	38.1	26	-11,862.3	8
	$3/2^-$	-2,951.0	-5.837.9	-5,886.0	107.3	95.2	-11,723.9	8
$3/2^+$	$1/2^+$	-3,033.9	-6,019.8	-6,055.8	243.6	255.6	-12,075.6	6
	$1/2^-$	-3,034.0	-6,019.7	-6,056.0	243.7	255.6	-12,075.7	6
	$3/2^+$	-3,163.7	-6,263.4	-6,311.4	0	0	-12,574.8	8
	$3/2^-$	-3,139.9	-6,215.8	-6,263.8	47.6	47.6	-12,479.6	8
$3/2^-$	$1/2^+$	-3,271.4	-6,536.5	-6,541.5	54.9	56.5	-13,078.0	6
	$1/2^-$	-3,254.9	-6,503.5	-6,508.5	87.9	89.5	-13,012.0	6
	$3/2^+$	-3,292.2	-6,576.1	-6,582.7	15.3	15.3	-13,158.8	8
	$3/2^-$	-3,299.8	-6,591.4	-6,598.0	0	0	-13,189.4	8

$\Xi(1820)^-$ ($L_{max}= 1$)

Table 6.6: Results of the different generated and fitted hypotheses for $\Xi(1820)^-$. The maximum orbital momentum is set to $L_{max} = 1$.

generated hypothesis	fit hypothesis	NLL	BIC	AIC	ΔBIC	ΔAIC	AIC + BIC	N_{par}
$1/2^+$	$1/2^+$	-3,170.1	-6,180.0	-6,300.1	0	0	-12,480.1	20
	$1/2^-$	-3,169.6	-6,179.1	-6,299.4	0.9	0.8	-12,478.4	20
	$3/2^+$	-3,179.0	-6,117.9	-6,298.1	62.1	2.0	-12,416.0	30
	$3/2^-$	-3,166.1	-6,092.9	-6,272.3	87.1	27.8	-12,365.2	30
$1/2^-$	$1/2^+$	-3,082.4	-6,004.6	-6,124.7	24.2	24.2	-12,129.3	20
	$1/2^-$	-3,094.5	-6,028.8	-6,148.9	0	0	-12,177.7	20
	$3/2^+$	-3,089.6	-5,939.0	-6,119.2	89.8	29.7	-12,058.2	30
	$3/2^-$	-3,054.3	-5.868.5	-6,048.7	160.3	100.2	-11,917.2	30
$3/2^+$	$1/2^+$	-3,092.4	-6,024.7	-6,144.8	306.3	366.4	-12,169.5	20
	$1/2^-$	-3,089.7	-6,019.3	-6,139.4	311.7	371.8	-12,158.7	20
	$3/2^+$	-3,285.6	-6,331.0	-6,511.2	0	0	-12,842.2	30
	$3/2^-$	-3,265.8	-6,291.4	-6,471.6	39.6	39.6	-12,763.0	30
$3/2^-$	$1/2^+$	-3,404.4	-6,648.7	-6,768.8	256.8	316.8	-13,417.5	20
	$1/2^-$	-3,392.7	-6,625.1	-6,745.3	280.4	340.3	-13,370.4	20
	$3/2^+$	-3,556.7	-6,873.3	-7,053.5	32.2	32.1	-13,926.8	30
	$3/2^-$	-3,572.8	-6,905.5	-7,085.6	0	0	-13,991.1	30

$\Xi(1690)^-$ ($L_{max}= 1$) cross channel

Table 6.7: Results of the different generated and fitted hypotheses for $\Xi(1690)^-$ including the reaction $\bar{p}p \to \bar{\Lambda}(1890)\Lambda$. The chosen maximum orbital momentum is $L_{max} = 1$.

generated hypothesis	fit hypothesis	NLL	BIC	AIC	ΔBIC	ΔAIC	AIC + BIC	N_{par}
$1/2^+$	$1/2^+$	-1,627.6	-2,838.9	-3,151.2	0	4.8	-5,990.1	52
	$1/2^-$	-1,622.5	-2,828.7	-3,141.1	10.2	14.9	-5,969.8	52
	$3/2^+$	-1,640.0	-2,783.5	-3,156.0	55.3	0	-5,939.8	62
	$3/2^-$	-1,636.8	-2,777.1	-3,149.5	61.7	6.5	-5,926.6	62
$1/2^-$	$1/2^+$	-1,673.1	-2,929.9	-3,242.3	5.6	7.2	-6,172.2	52
	$1/2^-$	-1,675.9	-2,935.5	-3,247.8	0	1.7	-6,183.3	52
	$3/2^+$	-1,686.7	-2,877.1	-3,249.5	58.4	0	-6,126.6	62
	$3/2^-$	-1,675.5	-2,854.7	3,227.1	80.8	22.4	-6,081.8	62
$3/2^+$	$1/2^+$	-1,811.8	-3,207.3	-3,519.6	106.5	166.6	-6,726.9	52
	$1/2^-$	-1,812.8	-3,209.2	-3,521.5	104.6	164.7	-6,730.7	52
	$3/2^+$	-1,905.1	-3,313.8	-3,686.2	0	0	-7,000.0	62
	$3/2^-$	-1,903.4	-3,310.4	-3,682.8	3.4	3.4	-6,993.2	62
$3/2^-$	$1/2^+$	-1,626.0	-2,835.5	-3,147.9	132.4	192.5	5,983.4	52
	$1/2^-$	-1,620.4	-2,824.5	-3,136.8	143.4	203.5	-5,961.3	52
	$3/2^+$	-1,716.6	-2,936.9	-3,309.3	31	31	-6,246.2	62
	$3/2^-$	-1,732.1	-2,967.8	-3,340.3	0	0	-6,308.1	62

$\Xi(1820)^-$ ($L_{max}= 0$) crossed channel

Table 6.8: Results of the different generated and fitted hypothesis for $\Xi(1820)^-$ including the reaction $\bar{p}p \rightarrow \bar{\Lambda}(1890)\Lambda$. The chosen maximum orbital momentum is $L_{max} = 0$.

generated hypothesis	fit hypothesis	NLL	BIC	AIC	ΔBIC	ΔAIC	AIC + BIC	N_{par}
$1/2^+$	$1/2^+$	-1,320.8	-2,513.6	-2,609.7	0	0	-5,123.3	16
	$1/2^-$	-1,318.3	-2,508.6	-2,604.7	5.0	5.0	5,113.3	16
	$3/2^+$	-1,318.5	-2492.8	-2600.9	20.8	8.8	-5,093.7	18
	$3/2^-$	-1,316.5	-2,488.8	-2,596.9	24.8	12.8	-5,085.7	18
$1/2^-$	$1/2^+$	-1,531.5	-2,935.0	-3,031.1	12.1	12.8	-5,966.1	16
	$1/2^-$	-1,537.6	-2,947.1	-3,043.2	0	0.7	-5,990.3	16
	$3/2^+$	-1,533.9	-2,923.7	-3,301.9	23.4	12	-5,955.6	18
	$3/2^-$	-1,539.9	-2,935.8	-3,043.9	11.3	0	-5,979.7	18
$3/2^+$	$1/2^+$	-1,448.8	-2,769.6	-2,865.7	67.1	79.1	-5,635.3	16
	$1/2^-$	-1,453.9	-2,779.7	-2,875.8	57.0	69.0	-5,655.5	16
	$3/2^+$	-1,490.4	-2,836.7	-2,944.8	0	0	-5,781.5	18
	$3/2^-$	-1,489.4	-2,834.8	-2,942.9	1.9	1.9	-5,777.7	18
$3/2^-$	$1/2^+$	-1,492.3	-2,856.4	-2,952.5	200.6	213.5	-5,808.9	16
	$1/2^-$	-1,510.5	-2,892.9	-2,889.0	164.1	176.1	-5,781.9	16
	$3/2^+$	-1,594.7	-3,045.2	-3,153.3	11.8	11.8	-6,198.5	18
	$3/2^-$	-1,600.5	-3,057.0	-3,165.1	0	0	-6,222.1	18