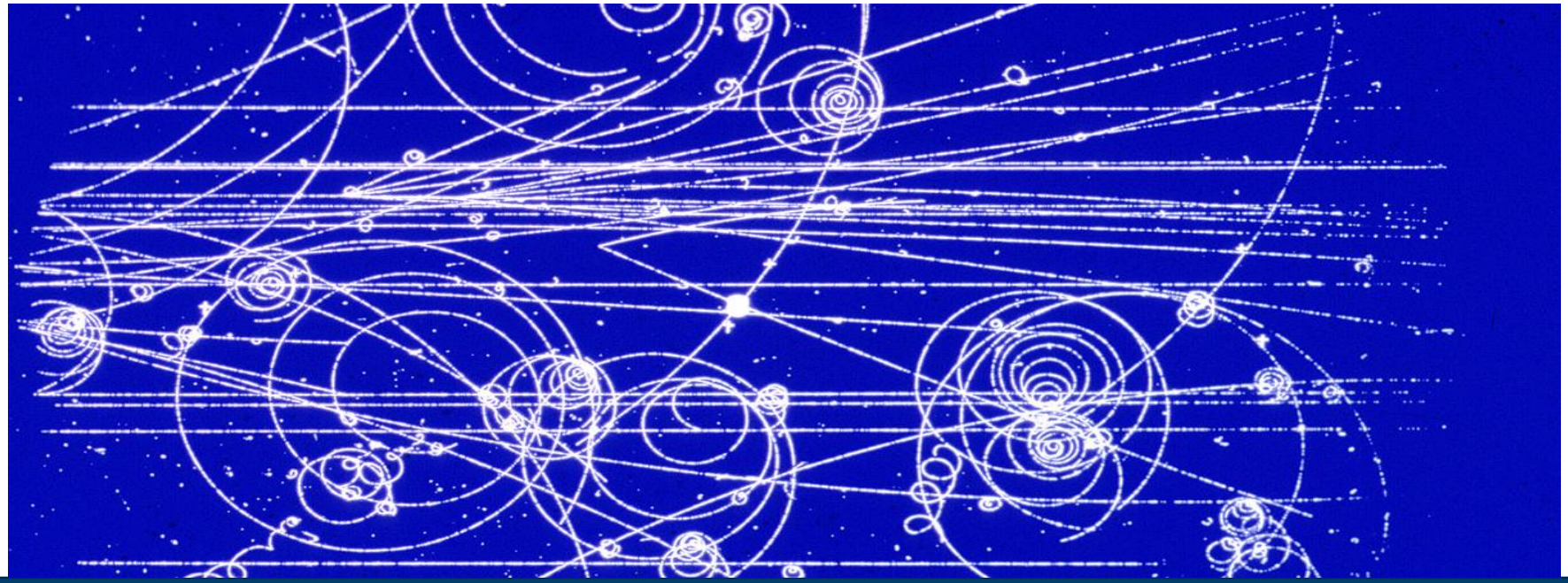


First Results with PAWIAN

June 25th 2019| P̄ANDA CM 19/2 GSI | Jennifer Pütz

Outline

- Motivation
- Introduction
- Test on Quantum Numbers
- Summary & Outlook

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.

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

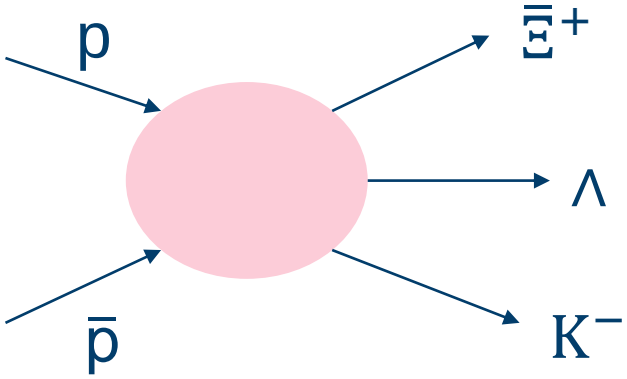
PDG2014

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

Introduction

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



Introduction

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

First Steps of PWA

Test of Quantum Numbers

- 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
- Different quantum numbers generated for $\Xi(1690)^-$ and $\Xi(1820)^-$

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

- Included crossed channel $\bar{\mathrm{p}}\mathrm{p} \rightarrow \bar{\Lambda}(1890)\Lambda$
- Fit all hypotheses to each generated data set

How are Results Compared?

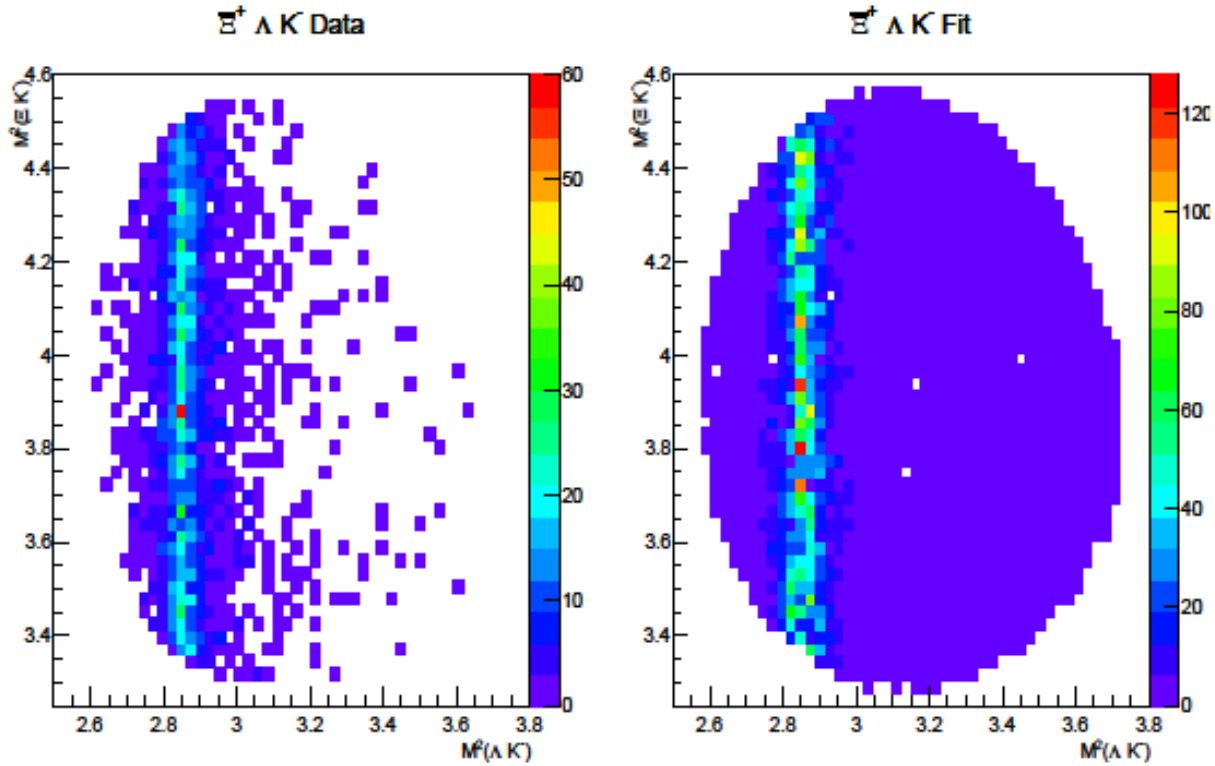
- Different criteria used: BIC and AIC
- BIC: Bayesian information criterion
  - Criterion for model selection among a finite set of models; (lowest BIC is preferred)
- AIC: Akaike information criterion
  - Estimates the quality of each model relative to each of the other model
- Model selection based 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

Ξ(1690)⁻

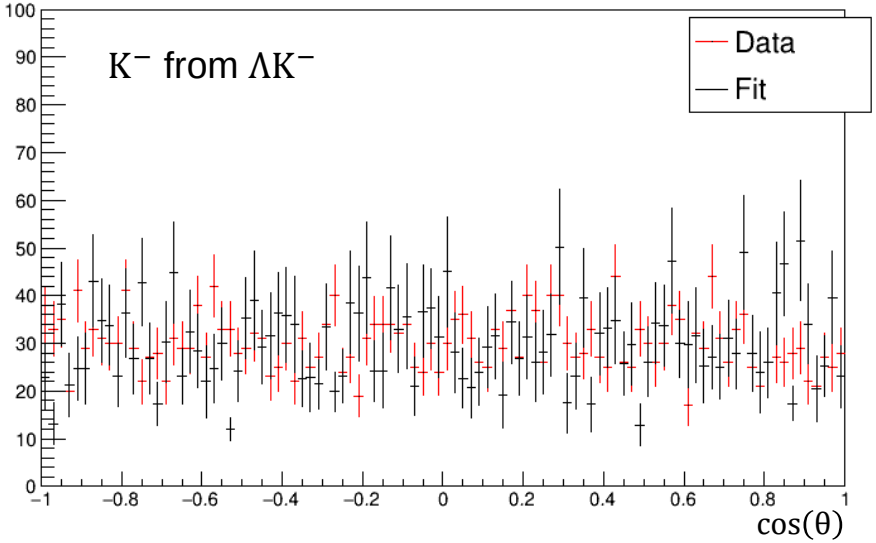
Hyp ½+	BIC	AIC	AIC + BIC	Free param
½⁺	**-8359.7**	**-8479.9**	**-17,438.6**	20
½⁻	-8338.6	-8458.7	-16,797.3	20
3/2⁺	-7862.6	-7910.6	-15,773.2	30
3/2⁻	-8324.8	-8505.0	-16,829.8	30

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

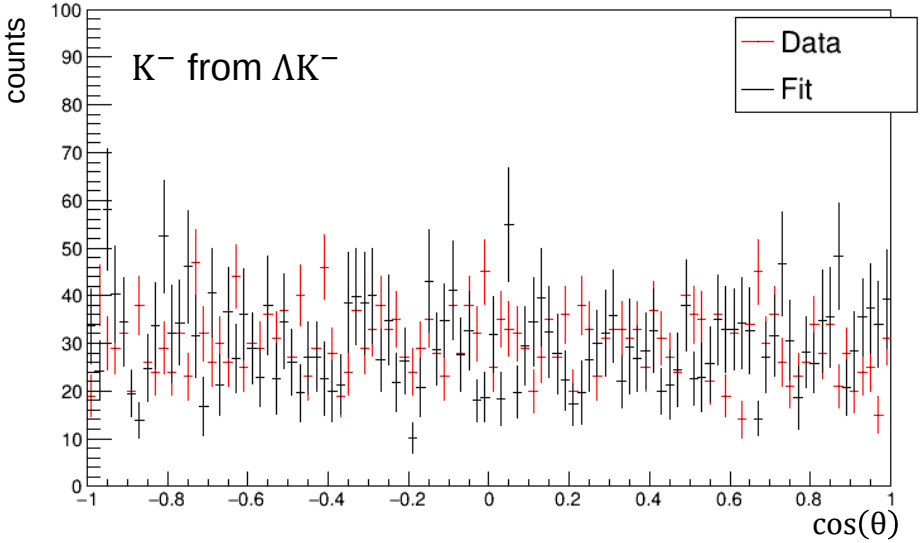


$\Xi(1690)^-$ Hyp $1/2^+$ Tested Hyp$1/2^+$

Helicity frame

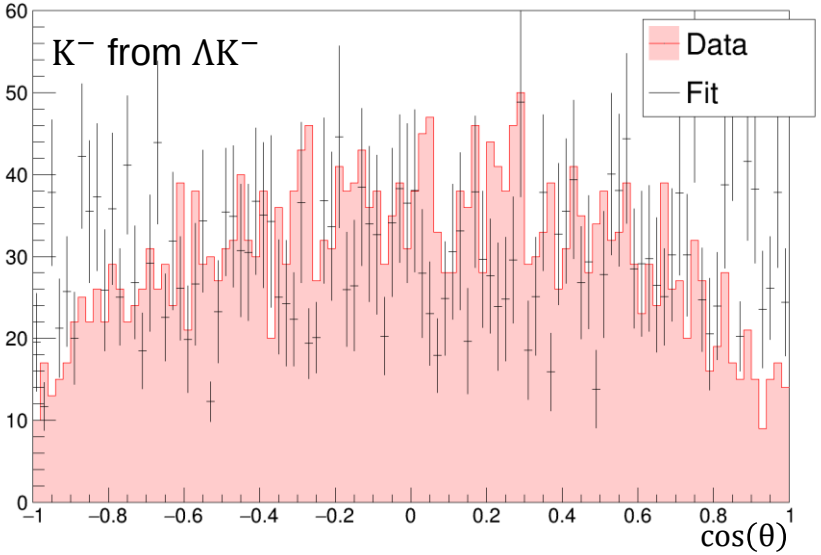


GJ frame

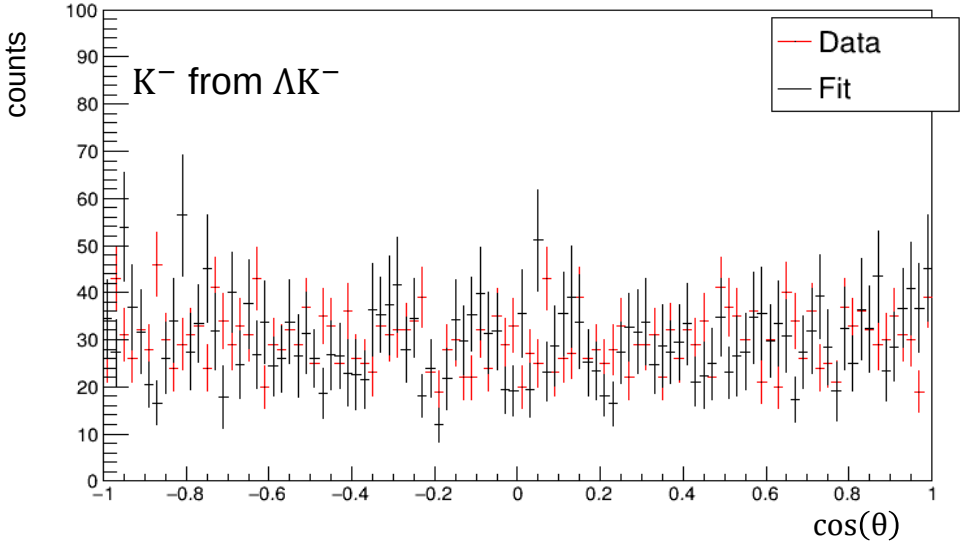


$\Xi(1690)^-$ Hyp $3/2^+$ Tested Hyp$1/2^-$

Helicity frame



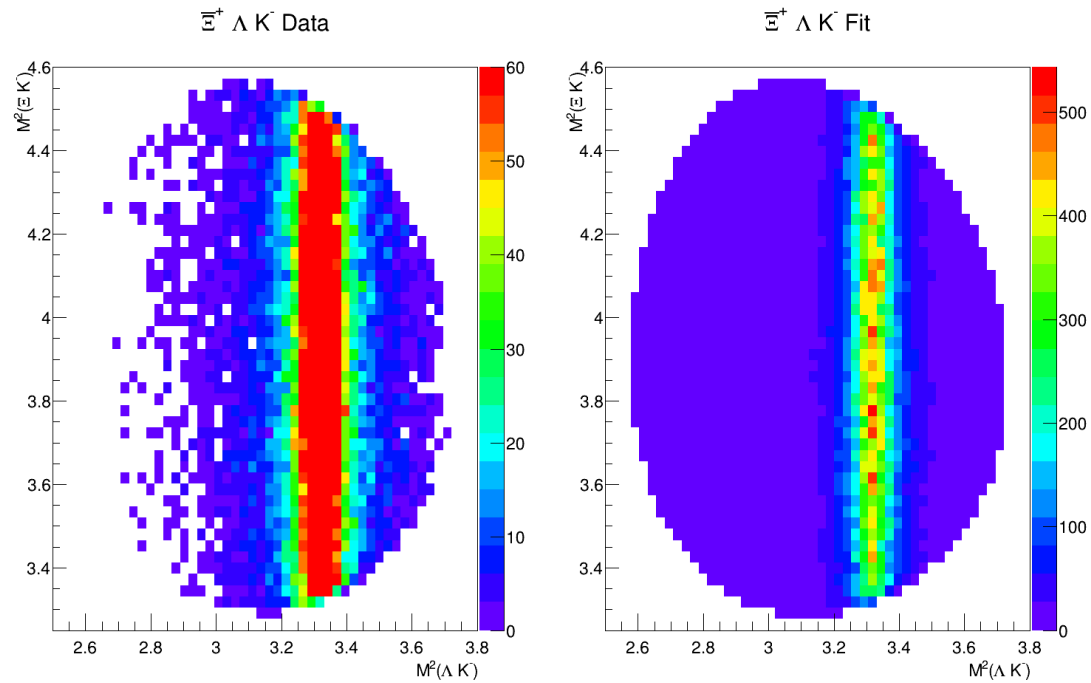
GJ frame



Ξ(1820)⁻

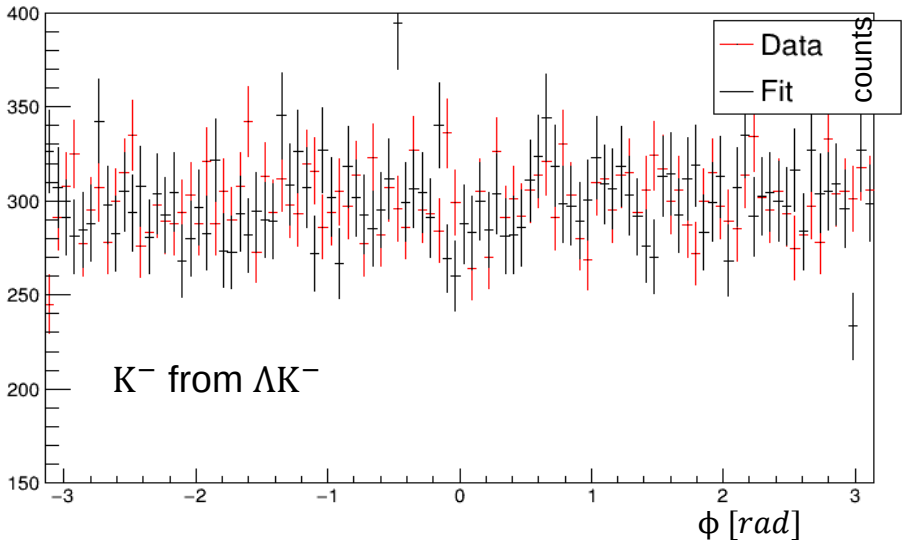
Hyp ½+	BIC	AIC	ΔAIC	Free param
½⁺	**-6092.9**	**-6128.9**	**0**	6
½⁻	-6071.5	-6107.5	21.4	6
3/2⁺	-6078.1	-6126.6	2.3	8
3/2⁻	-6047.2	-6094.2	34.7	8

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

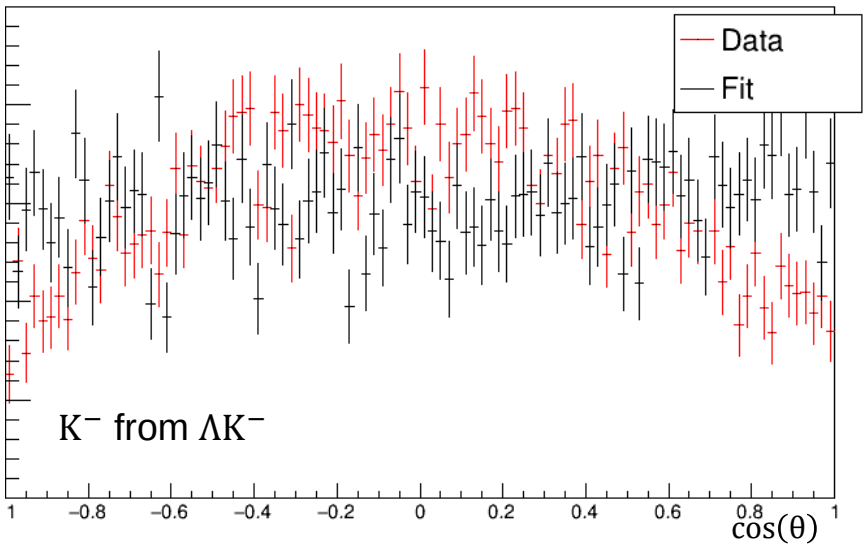


Ξ(1820)⁻ Hyp 3/2⁻ Tested Hyp1/2⁻

Helicity frame



Helicity frame

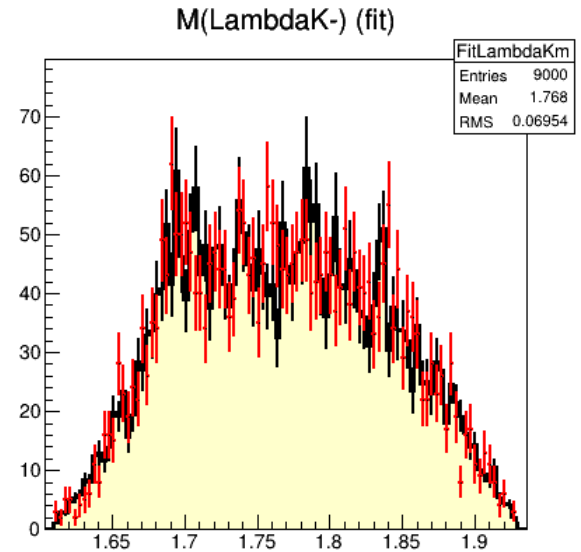


Crossed Channel

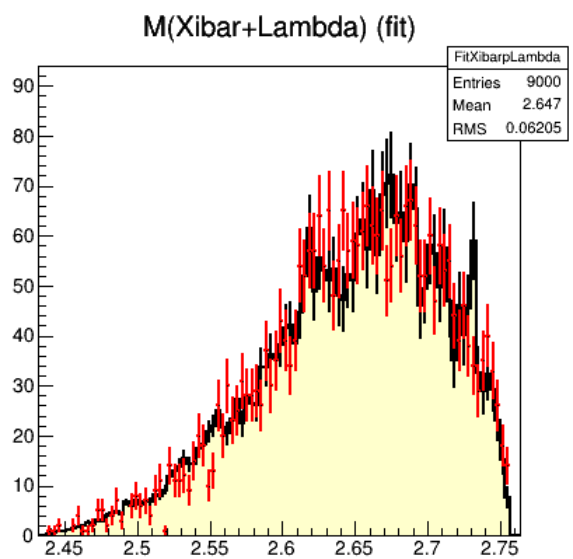
$\Xi(1690)^-$

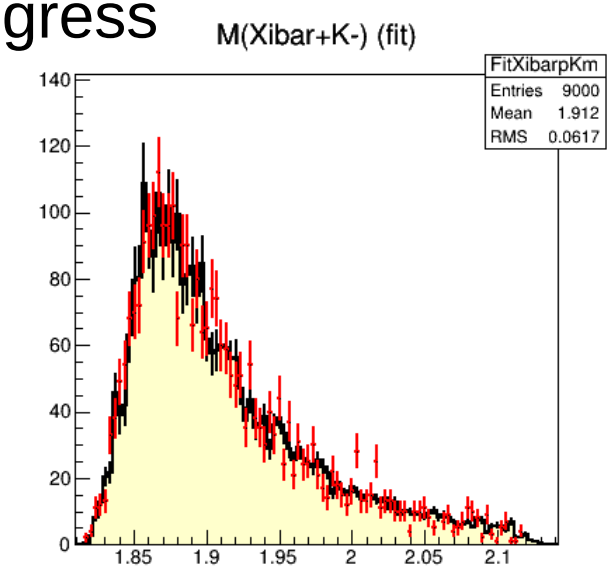
With Crossed Channel

Hyp ½+	BIC	AIC	ΔAIC	Free param
½⁺	**-2874.1**	**-3186.4**	**0**	52
½⁻	-2871.5	-3183.9	2.5	52
3/2⁺	-2783.8	-3156.2	30.2	62
3/2⁻	-2788.7	-3161.1	25.3	62



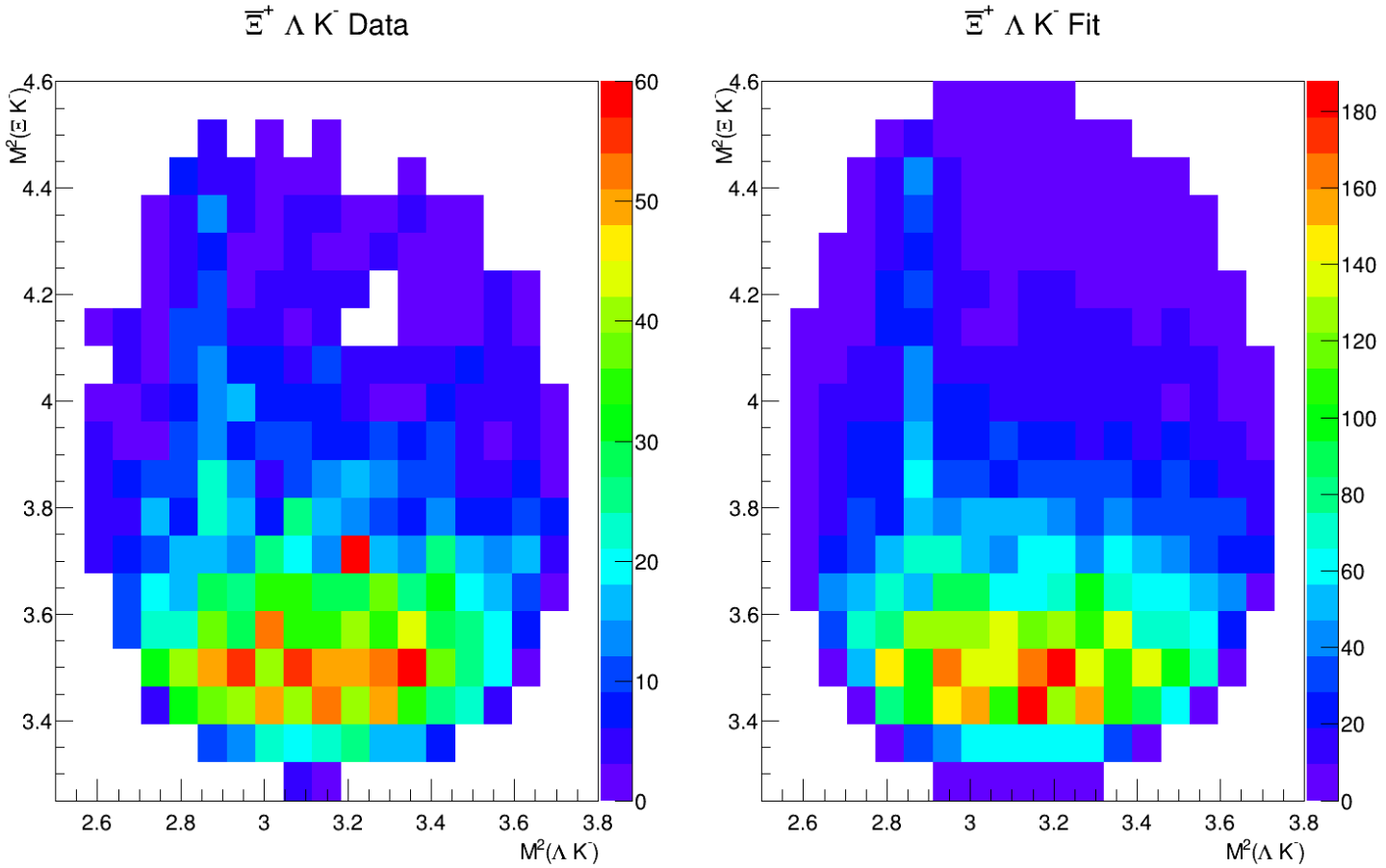
Work in progress





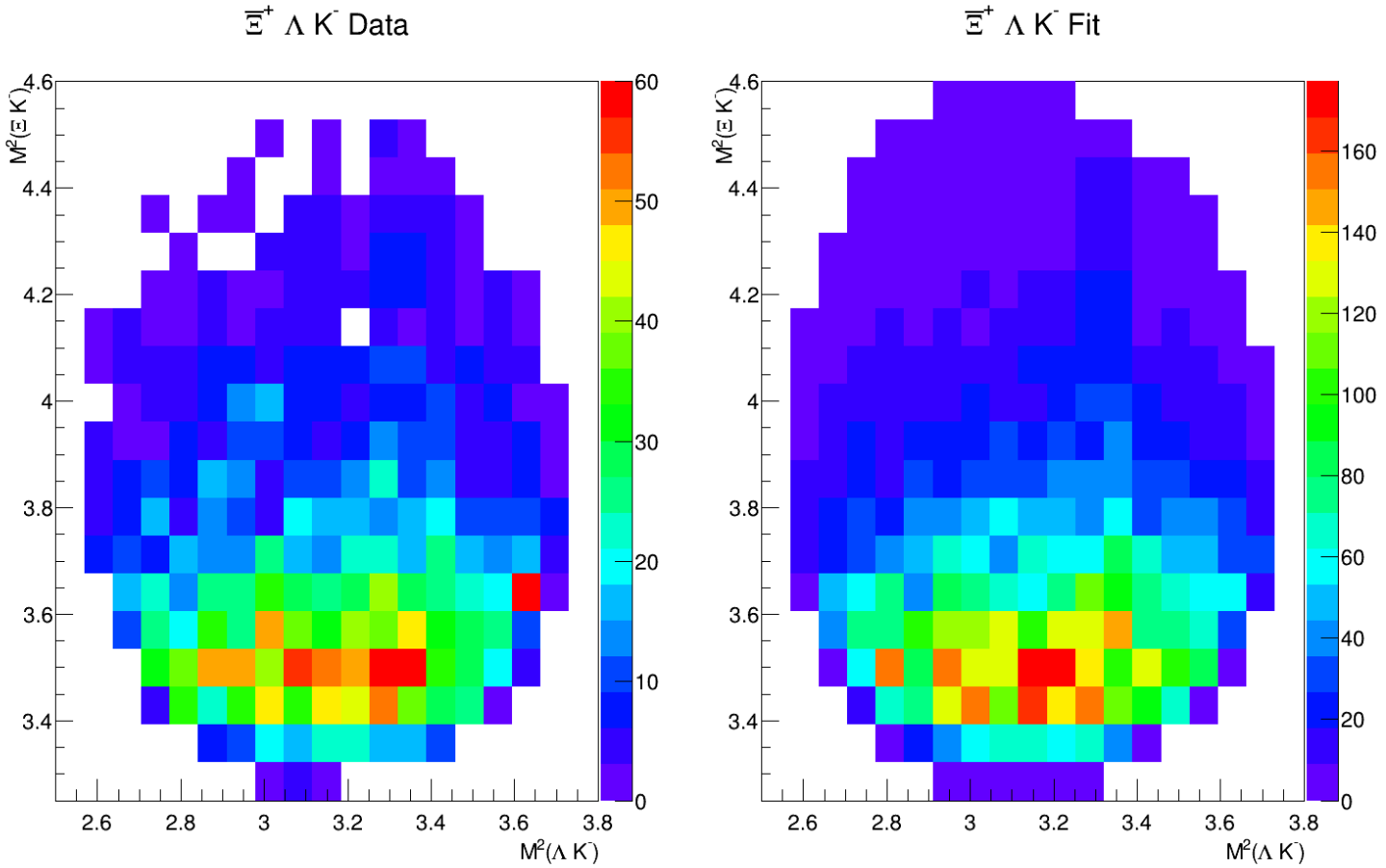
$\Xi(1690)^-$ Hyp $1/2^+$ Tested Hyp$1/2^+$

With Crossed Channel



Ξ(1820)⁻ Hyp 3/2⁻ Tested Hyp3/2⁻

With Crossed Channel



Summary & Outlook

- Performed test to reproduce quantum numbers
- “Single” resonances: promising
- Included crossed channel: $\bar{\mathrm{p}}\mathrm{p} \rightarrow \bar{\Lambda}(1890)\Lambda$
- Ratio between $\bar{\Lambda}(1890)$ and Ξ resonance seems to complicate reproduction of input
- Scaled contribution of Ξ resonance and Λ resonance

- Finishing analysis for $\Xi(1690)^-$ and $\Xi(1820)^-$ including crossed channel (looks promising)

Backup

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

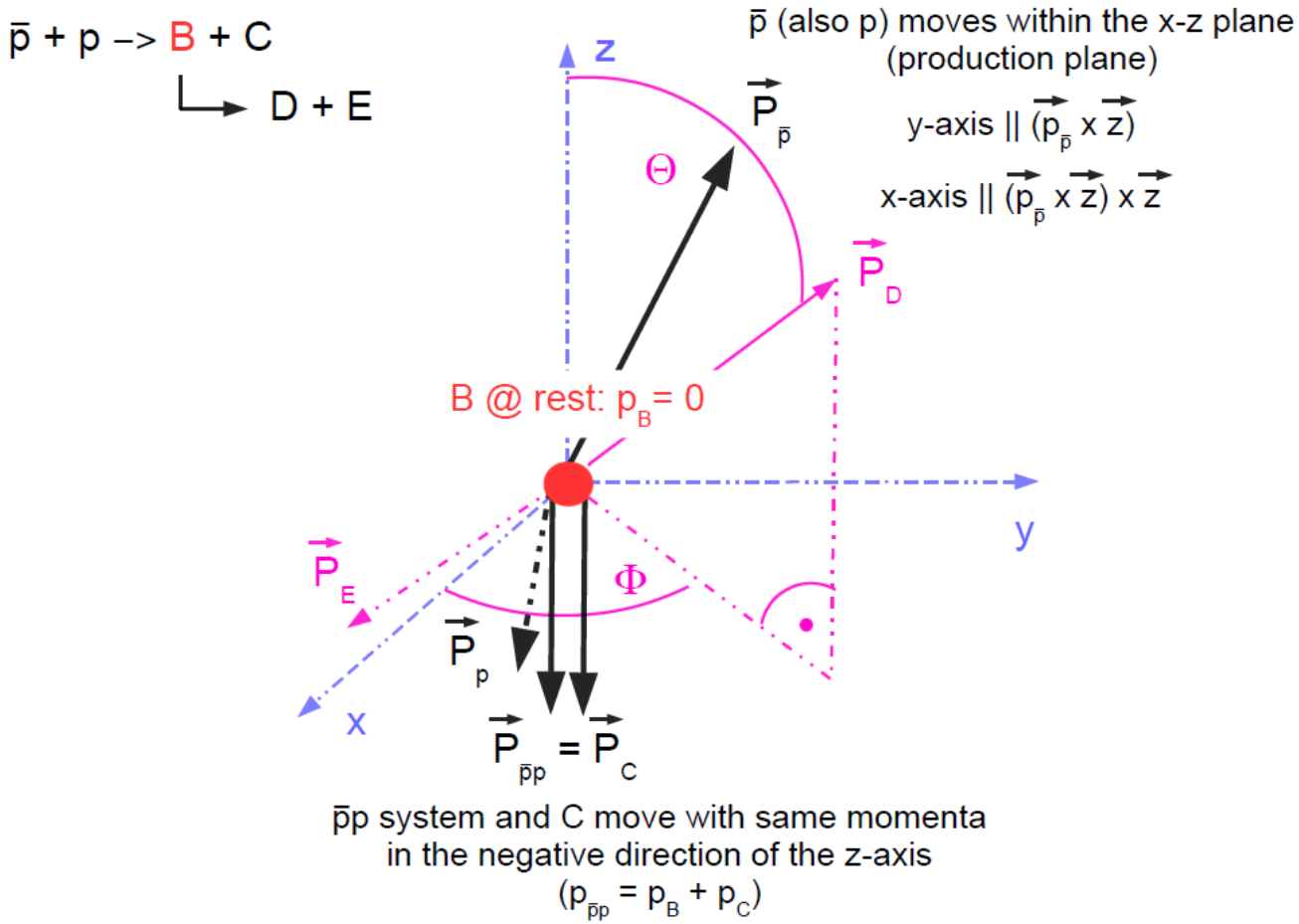


Image from Bertram Kopf

Gottfried-Jackson Frame

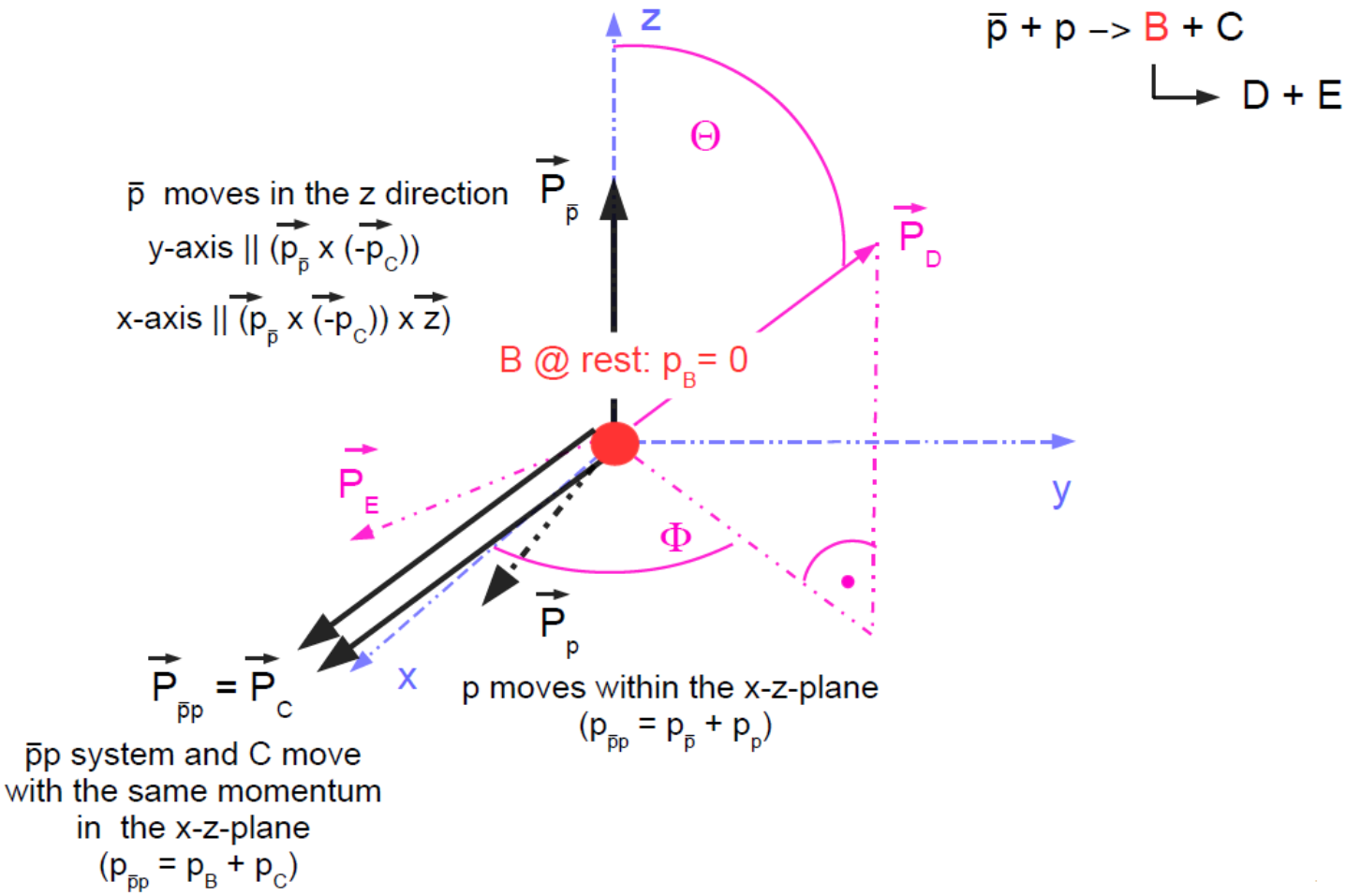


Image from Bertram Kopf

$\Xi(1690)^-$

Hyp ½+	BIC	AIC	AIC + BIC	Free param
½⁺	**-8359.7**	**-8479.9**	**-17,438.6**	20
½⁻	-8338.6	-8458.7	-16,797.3	20
3/2⁺	-7862.6	-7910.6	-15,773.2	30
3/2⁻	-8324.8	-8505.0	-16,829.8	30

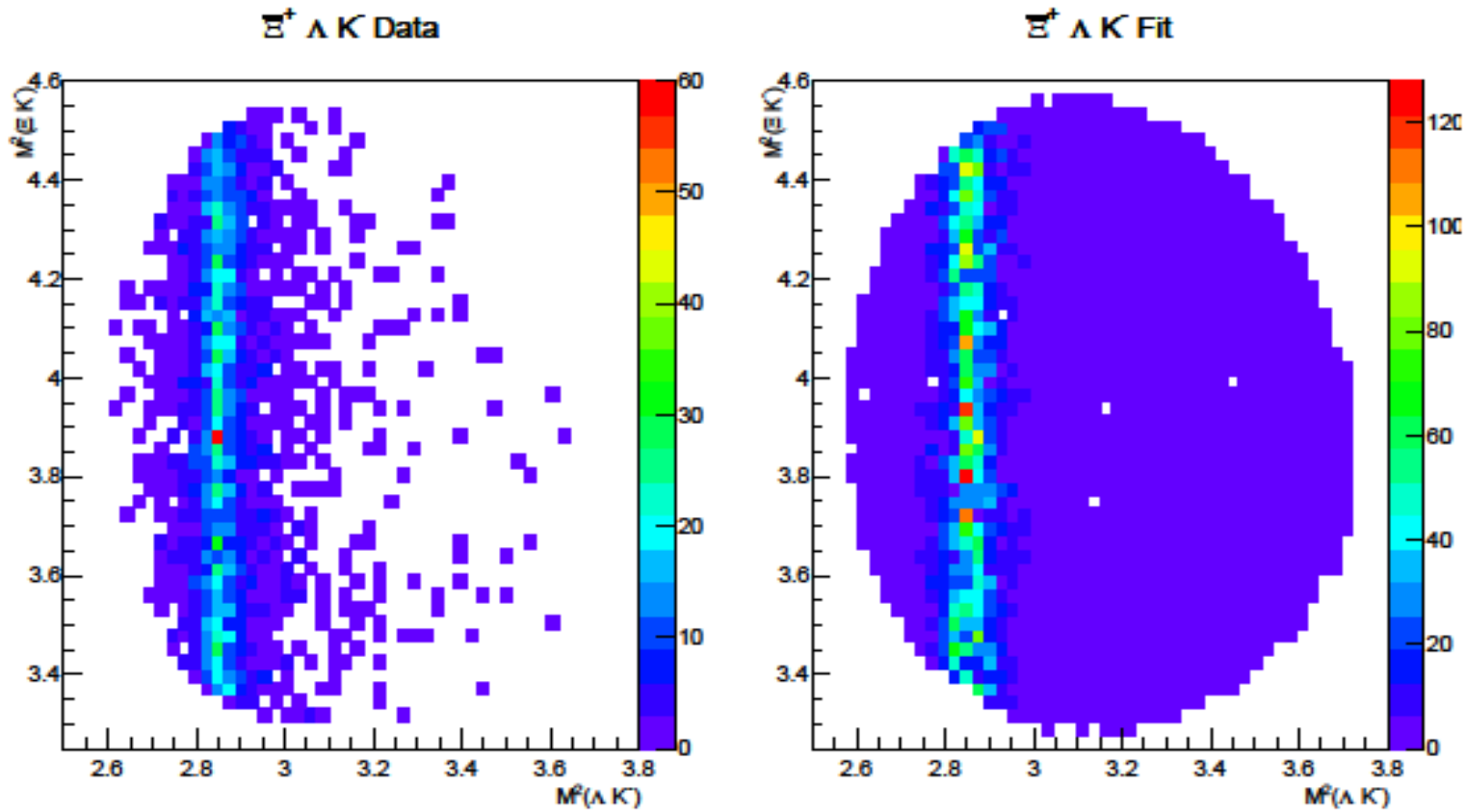
Hyp ½-	BIC	AIC	ΔAIC	Free param
½⁺	-8307.2	-8427.3	37.5	20
½⁻	**-8344.5**	**-8464.8**	**0**	20
3/2⁺	-8267.8	-8447.9	16.9	30
3/2⁻	-8008.6	-8188.8	276.0	30

Hyp 3/2+	BIC	AIC	ΔAIC	Free param
½⁺	-8156.2	-8276.3	243.3	20
½⁻	-8131.8	-8252.0	276.6	20
3/2⁺	**-8345.5**	**-8519.6**	**0**	30
3/2⁻	-8219.9	-8400.1	119.5	30

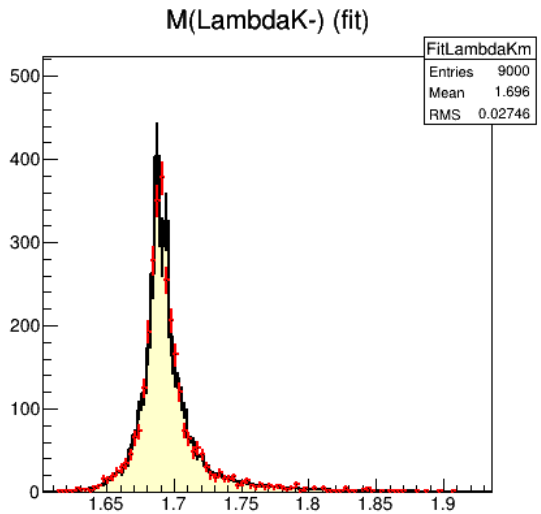
Hyp 3/2-	BIC	AIC	ΔAIC	Free param
½⁺	-7580.8	-7700.9	369.8	20
½⁻	-7445.0	-7565.1	505.6	20
3/2⁺	-7795.6	-7969.8	100.9	30
3/2⁻	**-7890.6**	**-8070.7**	**0**	30

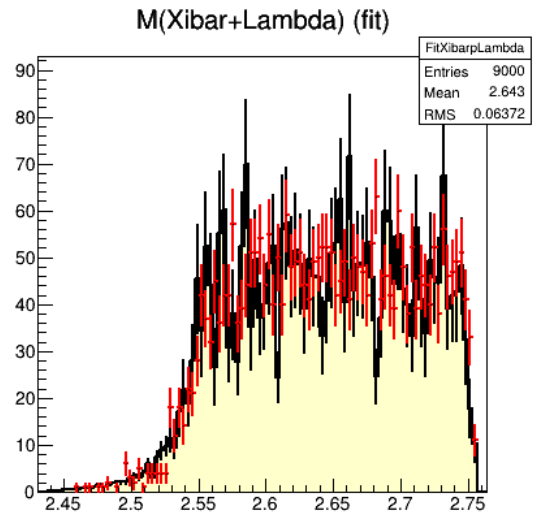
*) special case: use BIC+AIC for comparison

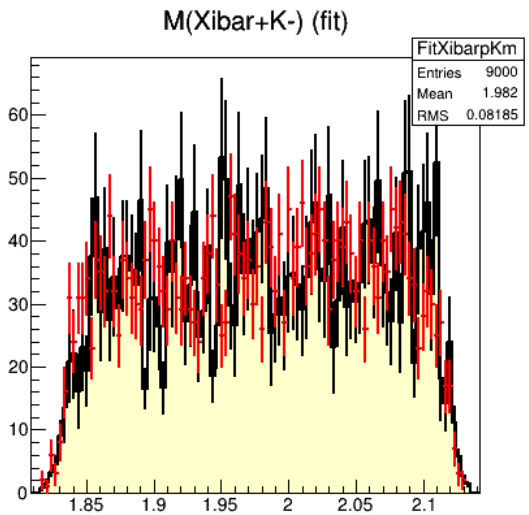
$\Xi(1690)^-$ HYP $1/2^+$ Tested Hyp$1/2^+$



$\Xi(1690)^-$ HYP $1/2^+$ Tested Hyp$1/2^+$







$\Xi(1820)^-$

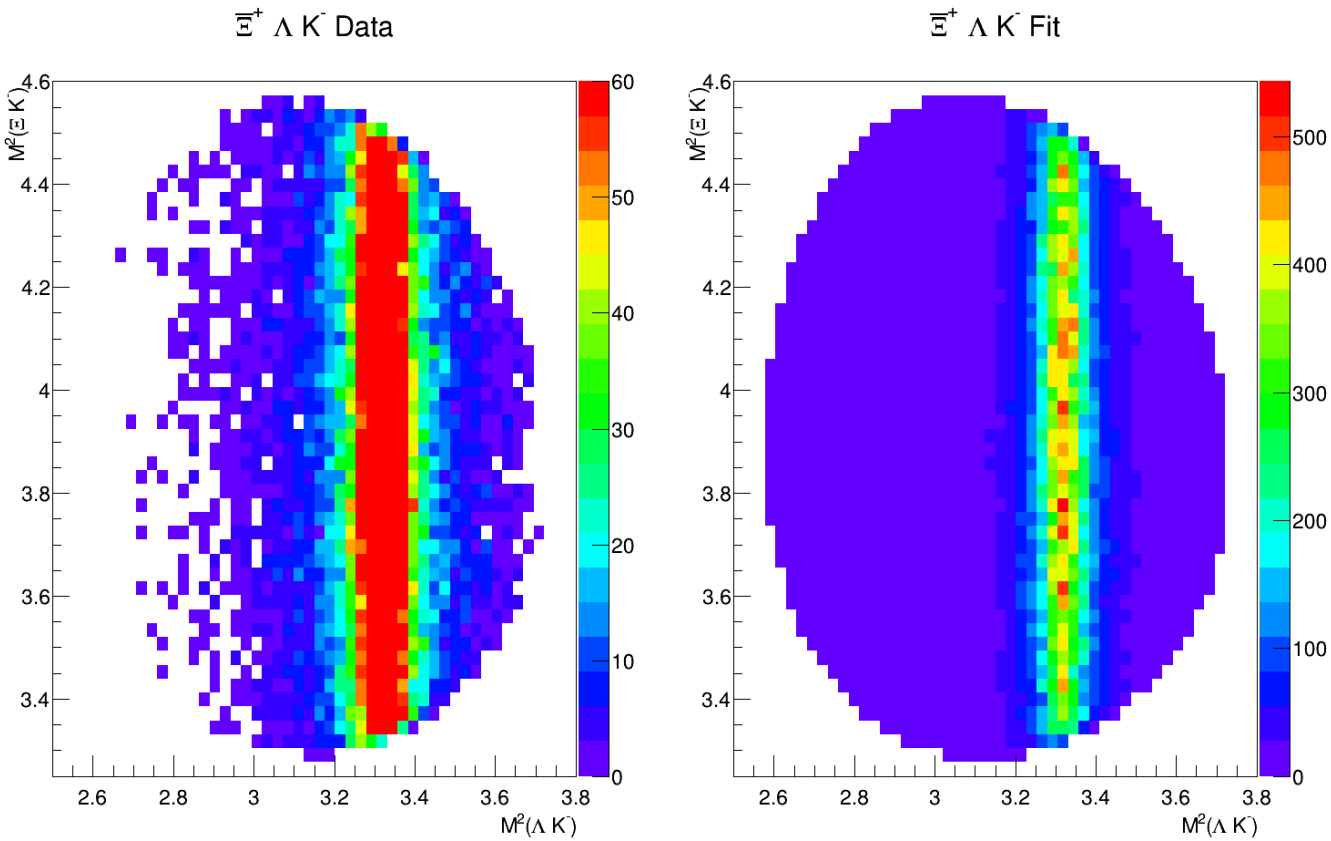
Hyp ½+	BIC	AIC	ΔAIC	Free param
$\frac{1}{2}^+$	**-6092.9**	**-6128.9**	**0**	6
$\frac{1}{2}^-$	-6071.5	-6107.5	21.4	6
$3/2^+$	-6078.1	-6126.6	2.3	8
$3/2^-$	-6047.2	-6094.2	34.7	8

Hyp ½-	BIC	AIC	ΔAIC	Free param
$\frac{1}{2}^+$	-5922.1	-5958.2	23	6
$\frac{1}{2}^-$	**-5945.2**	**-5981.2**	**0**	6
$3/2^+$	-5907.1	-5955.2	26	8
$3/2^-$	-5837.9	-5886.0	95.2	8

Hyp 3/2+	BIC	AIC	ΔAIC	Free param
$\frac{1}{2}^+$	-6019.8	-6055.8	255.6	6
$\frac{1}{2}^-$	-6019.7	-6056.0	255.4	6
$3/2^+$	**-6263.4**	**-6311.4**	**0**	8
$3/2^-$	-6215.8	-6263.8	47.6	8

Hyp 3/2-	BIC	AIC	ΔAIC	Free param
$\frac{1}{2}^+$	-65365	-65415	565	6
$\frac{1}{2}^-$	-65035	-65085	895	6
$3/2^+$	-65761	-65827	153	8
$3/2^-$	**-65914**	**-65980**	**0**	8

Ξ(1820)⁻ HYP 3/2⁻ Tested Hyp3/2⁻



$\Xi(1820)^-$

With Crossed Channel

Hyp 3/2+	BIC	AIC	ΔAIC	Free param
½⁺	-2396.1	-2492.2	202.7	16
½⁻	-2396.4	-2492.5	202.4	16
3/2⁺	**-2586.8**	**-2694.9**	**0**	18
3/2⁻	-2577.8	-2685.9	9	18

Hyp 3/2-	BIC	AIC	AIC + BIC	Free param
½⁺	**-2613.5**	**-2709.6**	**-5323.1**	16
½⁻	-2612.6	-2708.8	-5321.4	16
3/2⁺	-2534.8	-2642.9	-5177.7	18
3/2⁻	-2603.1	-2711.3	-5314.4	18

Work in progress

Ξ(1820)⁻ HYP 3/2⁻ Tested Hyp3/2⁻

With Crossed Channel