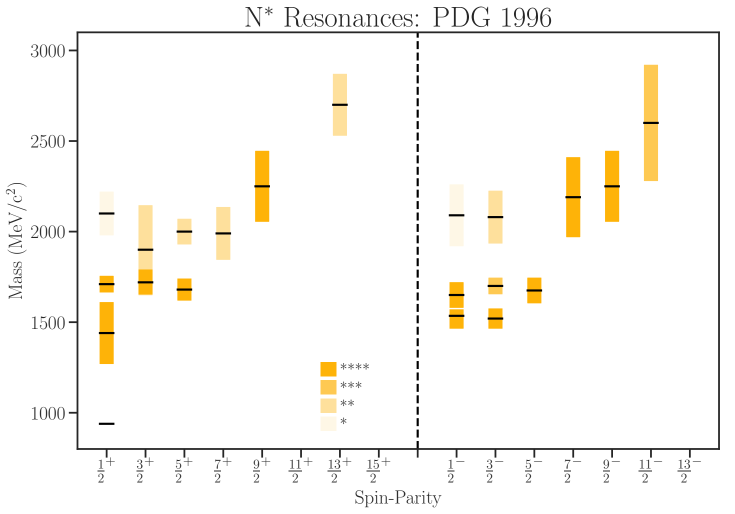
New Results in Strangeness Production with Polarization Observables

NSTAR 2019

D.G. Ireland

13 June, 2019

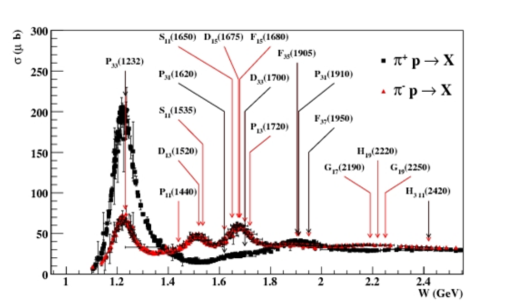
Light Baryon Spectrum - PDG 1996[1] List of N^* Resonances

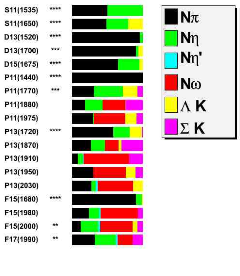


[1] R.M. Barnett et al. In: *Phys. Rev. D* 54 (1996), p. 1.

Resonance Hunting

Resonances found from πN scattering...





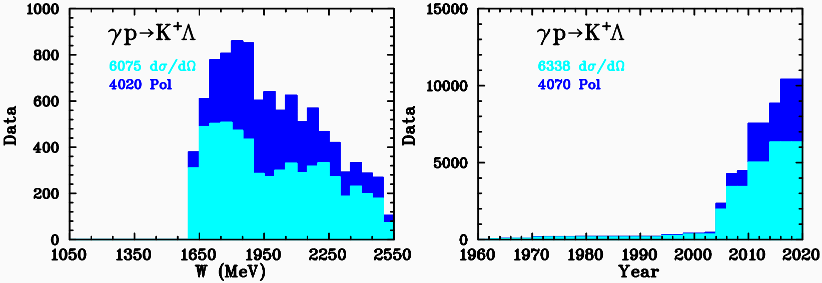
Coupling to other channels[2]?

---

[2]Simon Capstick and W. Roberts. "Strange decays of nonstrange baryons". In: *Phys. Rev. D* 58 (1998), p. 074011.

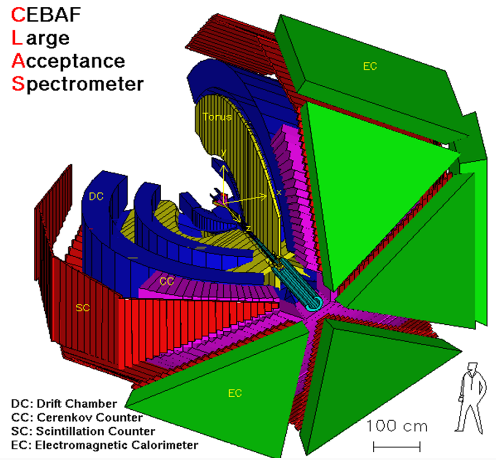
Kaon Photoproduction

Kaon Photoproduction - $K\Lambda$ Experimental Database



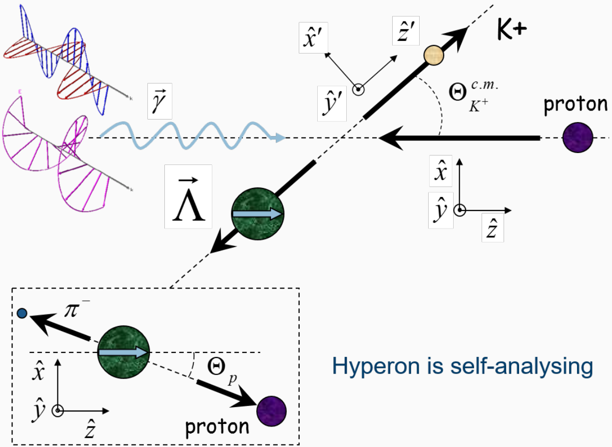
Accumulated $K\Lambda$ data points

Recent Experimental Data



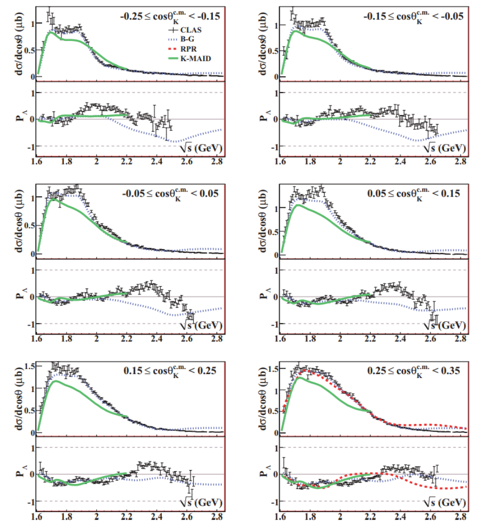
Data also from ELSA, GRAAL, LEPS, MAMI,...

Kaon Photoproduction - $K\Lambda$ example



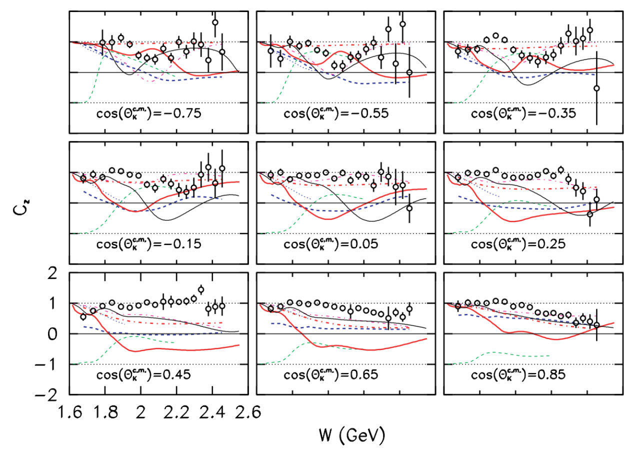
Hyperon is self-analysing

$\gamma p \to K^+\Lambda$: Cross-sections and Recoil Polarizations[3]



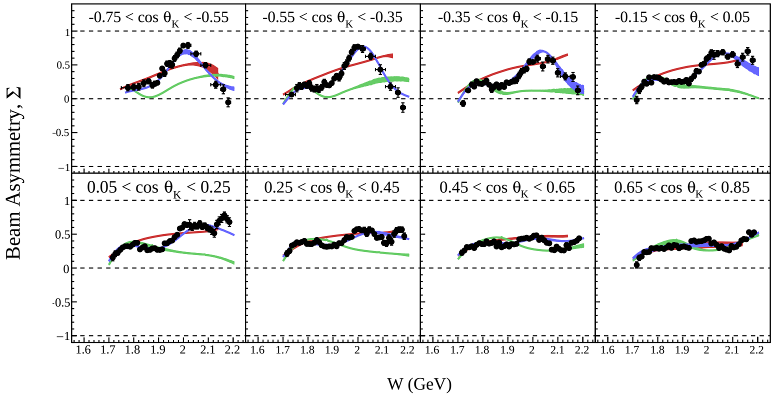
[3] M. E. McCracken et al. "Differential cross section and recoil polarization measurements for the $\gamma p \to K^+\Lambda$ reaction using CLAS at Jefferson Lab". In: *Physical Review C* 81 (2010), p. 025201.

$\gamma p \to K^+\Lambda$: Circular Beam-Recoil Observables[4]



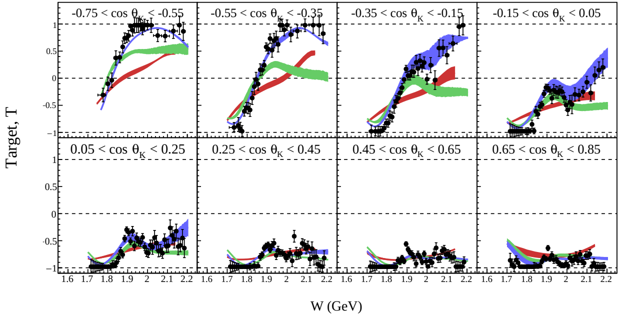
[4]RK Bradford et al. "First measurement of beam-recoil observables C_x and C_z in hyperon photoproduction". In: *Physical Review C* 75.3 (2007), p. 035205.

$\gamma p \to K^+\Lambda$: Beam Asymmetry[5]



[5] C. A. Paterson et al. "Photoproduction of Λ and Σ^0 hyperons using linearly polarized photons". In: *Phys. Rev. C* 93 (2016), p. 065201.

$\gamma p \to K^+\Lambda$: Comparison with Models

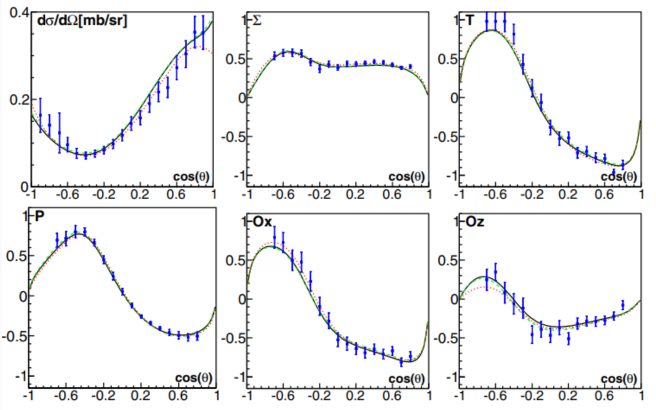


- Data Points: CLAS results;
- Red: ANL-Osaka calculations[6] (prediction);
- Green: Bonn-Gatchina 2014 fit[7] (BG2014-02, prediction);
- Blue: Bonn-Gatchina full re-fit with CLAS results;

[6]H. Kamano et al. "Nucleon resonances within a dynamical coupled-channels model of πN and γN reactions". In: *Phys. Rev. C* 88 (2013), p. 035209.

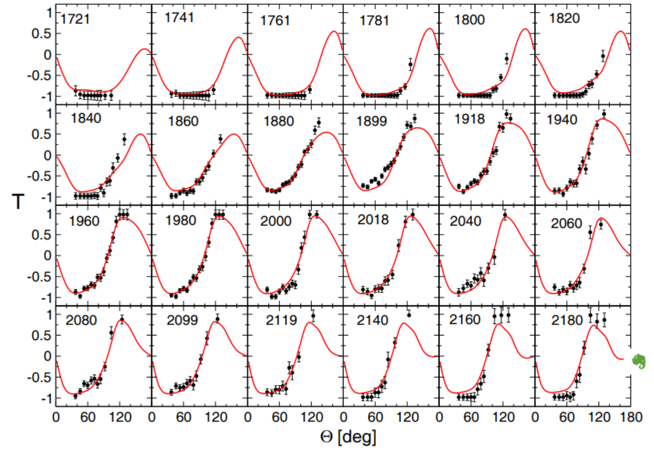
[7]E. Gutz et al. "High statistics study of the reaction $\gamma p \to p\pi^0\eta$". In: *Eur. Phys. J. A* 50 (2014), pp. 1–27.

$\gamma p \rightarrow K^+\Lambda$: L+P Model[8]



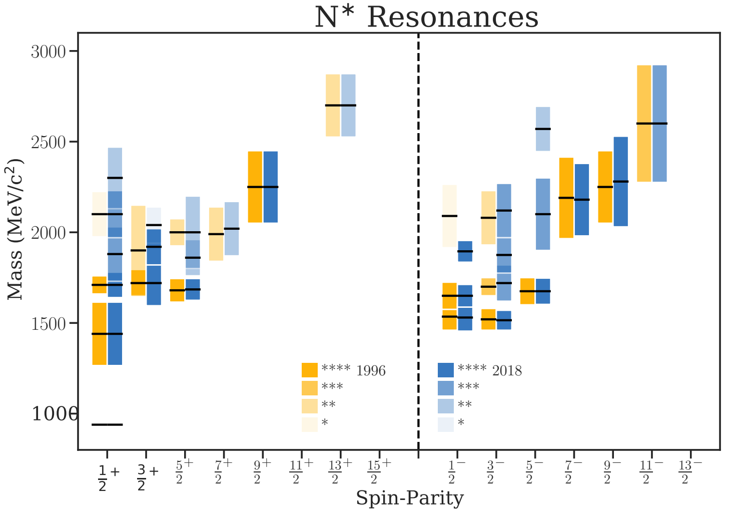
[8] A. V. Anisovich et al. “Strong Evidence for Nucleon Resonances near 1900 MeV”. In: *Phys. Rev. Lett.* 119.6 (2017), p. 062004.

$\gamma p \to K^+\Lambda$: Jülich-Bonn Coupled Channels[9]



[9] D. Rönchen, M. Döring, and U. -G. Meißner. "The impact of $K + \Lambda$ photoproduction on the resonance spectrum". In: *Eur. Phys. J. A* 54 (2018), p. 110.

Light Baryon Spectrum - PDG 2018[10] List of N^* Resonances



[10](Particle Data Group) Tanabashi, M. et al. "Review of Particle Physics". In: *Phys. Rev. D* 98.3 (Aug. 2018), p. 030001.

The Recent BESIII Result

Nature Physics paper[11]

nature physics

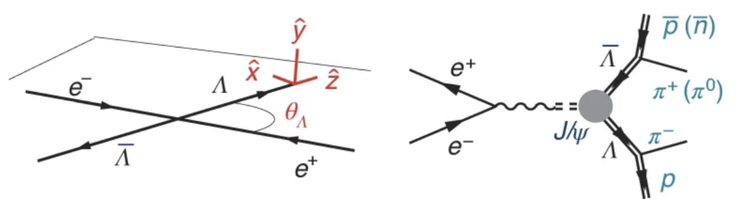
Letter | Published: 06 May 2019

Polarization and entanglement in baryon–antibaryon pair production in electron–positron annihilation

The BESIII Collaboration

[11] M. Ablikim et al. "Polarization and entanglement in baryon-antibaryon pair production in electron-positron annihilation". In: *Nature Physics* (May 2019), p. 1.

$\Lambda\bar{\Lambda}$ Production



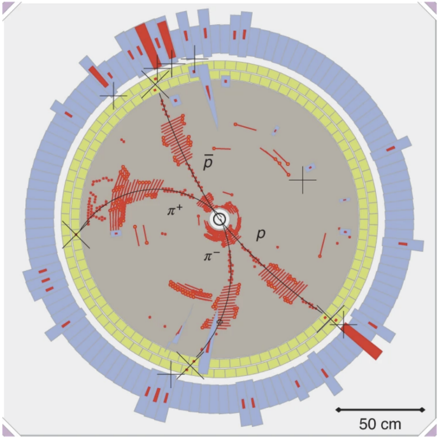
$\Lambda\bar{\Lambda}$ production process.

$$
\begin{aligned}
&\mathcal{W}(\xi;\alpha_\psi,\Delta\Phi,\alpha_-,\alpha_+)\\
&= 1+\alpha_\psi\cos^2\theta_\Lambda + \ \alpha_-\alpha_+\left[\sin^2\theta_\Lambda\left(n_{1,x}n_{2,x}-\alpha_\psi n_{1,y}n_{2,y}\right)\right.\\
&\left.+\left(\cos^2\theta_\Lambda+\alpha_\psi\right)n_{1,z}n_{2,z}\right]\\
&+\alpha_-\alpha_+\sqrt{1-\alpha_\psi^2}\cos(\Delta\Phi)\sin\theta_\Lambda\cos\theta_\Lambda\left(n_{1,x}n_{2,z}+n_{1,z}n_{2,x}\right)\\
&+\sqrt{1-\alpha_\psi^2}\sin(\Delta\Phi)\ \sin\theta_\Lambda\cos\theta_\Lambda\left(\alpha_-n_{1,y}+\alpha_+n_{2,y}\right)
\end{aligned}
$$

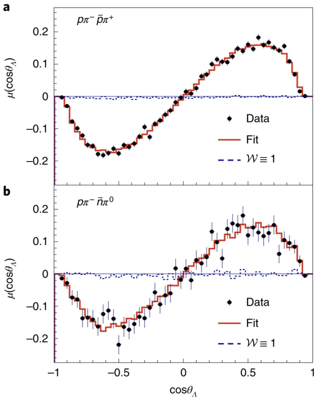
$\Lambda\bar{\Lambda}$ intensity distribution

$\Lambda\bar{\Lambda}$ Production

BES $\Lambda - \bar{\Lambda}$ event



Polarization signal...



$$\mu(\cos\theta_\Lambda) = \frac{\alpha_- - \alpha_2}{2} \frac{1 + \alpha_\psi \cos^2\theta_\Lambda}{3 + \alpha_\psi} P_y(\theta_\Lambda)$$

Λ Weak Decay Parameter- BES Results

Table 1 | Summary of the results

Parameters	This work	Previous results
α_ψ	$0.461 \pm 0.006 \pm 0.007$	0.469 ± 0.027 (ref. [14])
$\Delta\Phi$	$42.4 \pm 0.6 \pm 0.5°$	–
α_-	$0.750 \pm 0.009 \pm 0.004$	0.642 ± 0.013 (ref. [6])
α_+	$-0.758 \pm 0.010 \pm 0.007$	-0.71 ± 0.08 (ref. [6])
$\bar{\alpha}_0$	$-0.692 \pm 0.016 \pm 0.006$	–
A_{CP}	$-0.006 \pm 0.012 \pm 0.007$	0.006 ± 0.021 (ref. [6])
$\bar{\alpha}_0/\alpha_+$	$0.913 \pm 0.028 \pm 0.012$	–

Λ Weak Decay Parameter- BES Results

Table 1 | Summary of the results

Parameters	This work	Previous results
α_ψ	$0.461 \pm 0.006 \pm 0.007$	0.469 ± 0.027 (ref. [14])
$\Delta\Phi$	$42.4 \pm 0.6 \pm 0.5°$	–
α_-	$0.750 \pm 0.009 \pm 0.004$	0.642 ± 0.013 (ref. [6])
α_+	$-0.758 \pm 0.010 \pm 0.007$	-0.71 ± 0.08 (ref. [6])
$\bar{\alpha}_0$	$-0.692 \pm 0.016 \pm 0.006$	–
A_{CP}	$-0.006 \pm 0.012 \pm 0.007$	0.006 ± 0.021 (ref. [6])
$\bar{\alpha}_0/\alpha_+$	$0.913 \pm 0.028 \pm 0.012$	–

Λ Weak Decay Parameter- BES Results

Table 1 | Summary of the results

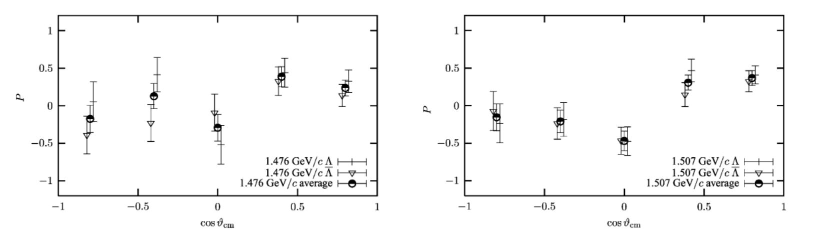
Parameters	This work	Previous results
α_ψ	$0.461 \pm 0.006 \pm 0.007$	0.469 ± 0.027 (ref. [14])
$\Delta\Phi$	$42.4 \pm 0.6 \pm 0.5°$	-
α_-	$0.750 \pm 0.009 \pm 0.004$	0.642 ± 0.013 (ref. [6])
α_+	$-0.758 \pm 0.010 \pm 0.007$	-0.71 ± 0.08 (ref. [6])
$\bar{\alpha}_0$	$-0.692 \pm 0.016 \pm 0.006$	-
A_{CP}	$-0.006 \pm 0.012 \pm 0.007$	0.006 ± 0.021 (ref. [6])
$\bar{\alpha}_0/\alpha_+$	$0.913 \pm 0.028 \pm 0.012$	-

$> 5\sigma$ **difference between new result and PDG[12].**

[12] (Particle Data Group) Tanabashi, M. et al. "Review of Particle Physics". In: *Phys. Rev. D* 98.3 (Aug. 2018), p. 030001.

So What?

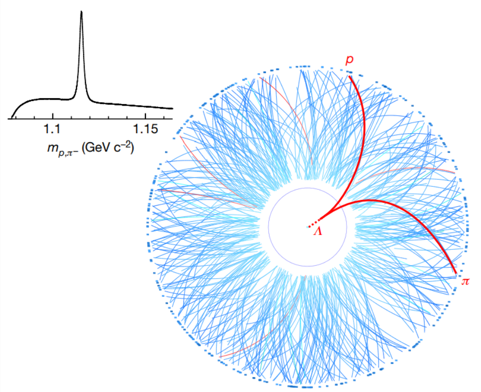
$p\bar{p} \to \Lambda\bar{\Lambda}$ Polarization[13]



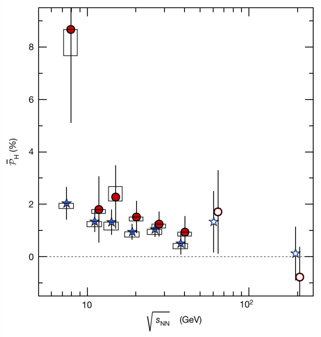
[13] E. Klempt et al. "Antinucleon nucleon interaction at low energy: Scattering and protonium". In: *Phys. Rept.* 368 (2002), pp. 119–316.

Global Λ hyperon polarization in nuclear collisions[14]

STAR Au-Au collision

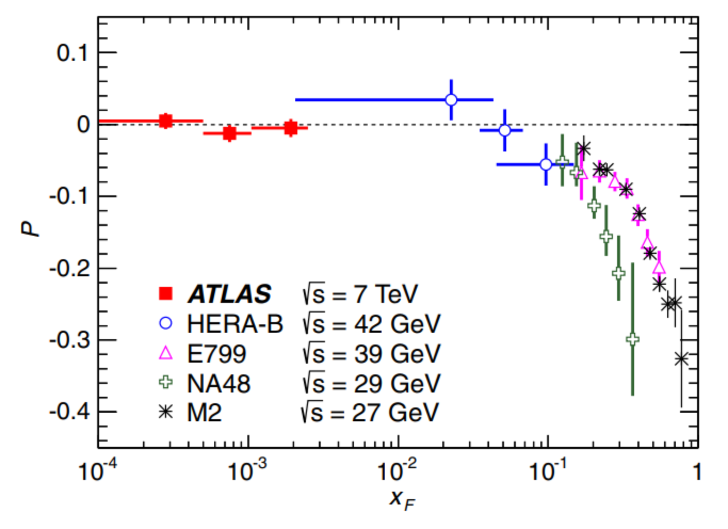


Average Λ ($\bar{\Lambda}$) polarization in collisions...



[14]The STAR Collaboration. "Global Λ hyperon polarization in nuclear collisions". In: *Nature* 548.7665 (2017), pp. 62–65.

$\Lambda(\bar{\Lambda})$ Transverse Polarization with ATLAS[15]



[15] ATLAS Collaboration, G. Aad, et al. "Measurement of the transverse polarization of Λ and $\bar{\Lambda}$ hyperons produced in proton-proton...". In: *Phys. Rev. D* 91 (2015),

Decay Parameters of Higher Mass States[16]

Ω^- DECAY PARAMETERS

$\alpha(\Omega^-)\,\alpha_-(\Lambda)$ FOR $\Omega^- \to \Lambda K^-$

Some early results have been omitted.

VALUE	*EVTS*
$\mathbf{0.0115 \pm 0.0015}$	**OUR AVERAGE**

Ξ^0 DECAY PARAMETERS

See the ``Note on Baryon Decay Parameters" in

$\alpha(\Xi^0)\,\alpha_-(\Lambda)$

This is a product of the $\Xi^0 \to \Lambda\pi^0$ and $\Lambda \to p\pi^-$ asy

VALUE	*EVTS*
$\mathbf{-0.261 \pm 0.006}$	**OUR AVERAGE**

[16] (Particle Data Group) Tanabashi, M. et al. "Review of Particle Physics". In: *Phys. Rev. D* 98.3 (Aug. 2018), p. 030001.

Consequences for Kaon Photoproduction Observables?

Fierz Identity for LUY plus CUY

Intensities for Experimental Polarization Configurations:

LUY: Linear photon beam; unpolarized target; measured recoil

$$1 + \alpha_- \cos\theta_y \mathbf{P} - \{\mathbf{\Sigma} + \alpha_- \cos\theta_y \mathbf{T}\} P_L^\gamma \cos 2(\alpha - \phi) + \{\alpha_- \cos\theta_x \mathbf{O_x} + \alpha_- \cos\theta_z \mathbf{O_z}\} P_L^\gamma \sin 2(\alpha - \phi)$$

CUY: Circularly photon beam; unpolarized target; measured recoil

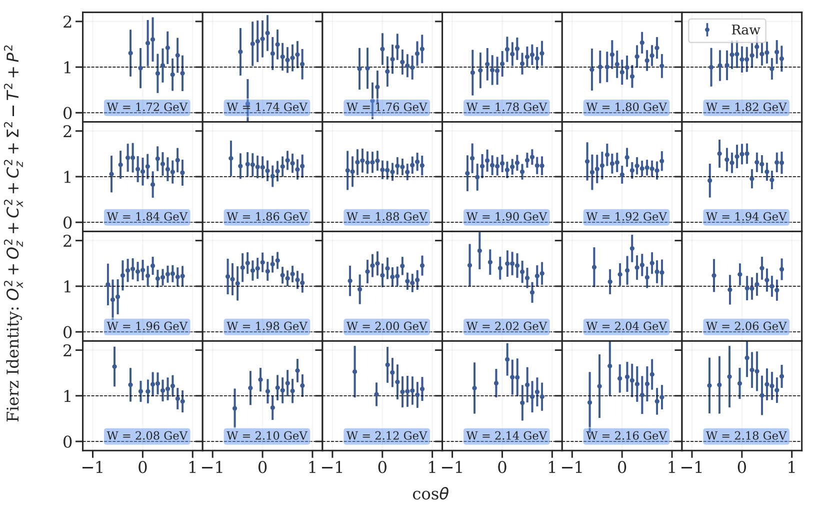
$$1 + \alpha_- \cos\theta_y \mathbf{P} + (\alpha_- \cos\theta_x \mathbf{C_x} + \alpha_- \cos\theta_z \mathbf{C_z}) P_C^\gamma$$

Fierz identities connecting two experiments:

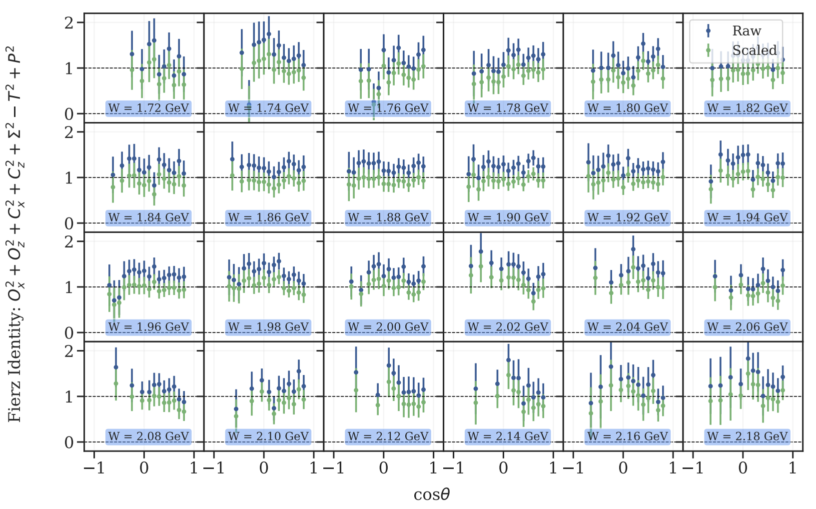
$$\mathbf{O_x}^2 + \mathbf{O_z}^2 + \mathbf{C_x}^2 + \mathbf{C_z}^2 + \mathbf{\Sigma}^2 - \mathbf{T}^2 + \mathbf{P}^2 = 1$$

$$\mathbf{\Sigma P} - \mathbf{C_x O_z} + \mathbf{C_z O_x} - \mathbf{T} = 0 \ .$$

Fierz Identity Values for Original Data



Fierz Identity Values for Scaled Data



Fierz Identities as a Statistical Ensemble

Generate pseudodata:

- Pick random point in amplitude space
- Calculate observables from amplitudes
- Treat observables as independent and adjust value by a random number sampled from $\mathcal{N}(0, \sigma)$,
- Single polarization observables have $\sigma \in [0.01, 0.05]$
- Double polarization observables have $3 \times \sigma$

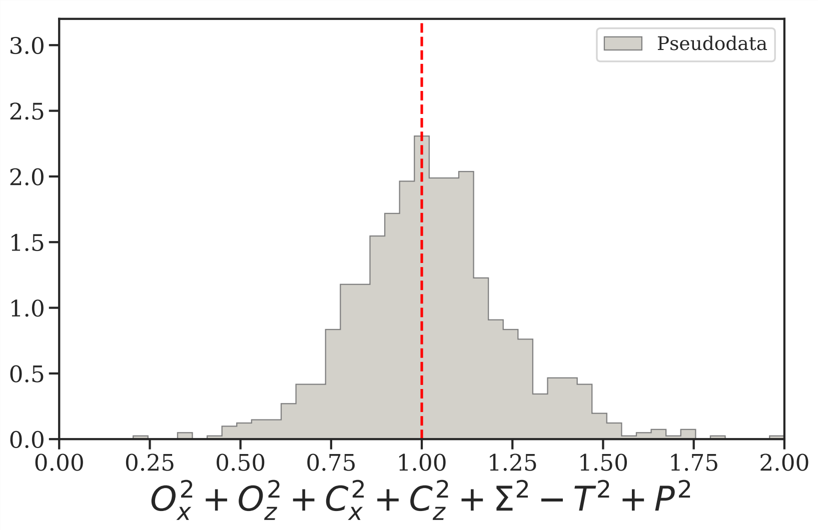
Writing

$$\mathcal{F} = \mathbf{O_x}^2 + \mathbf{O_z}^2 + \mathbf{C_x}^2 + \mathbf{C_z}^2 + \mathbf{\Sigma}^2 - \mathbf{T}^2 + \mathbf{P}^2$$

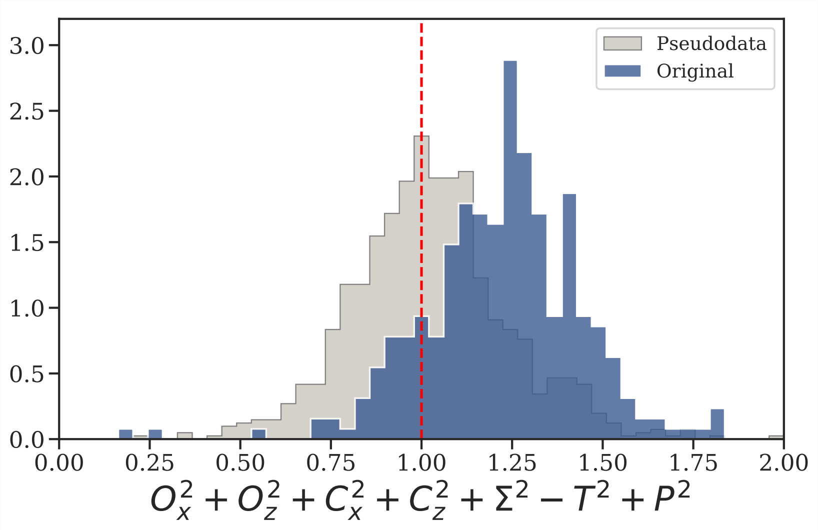
Also define pull as

$$\frac{\mathcal{F} - 1}{\sigma_F}$$

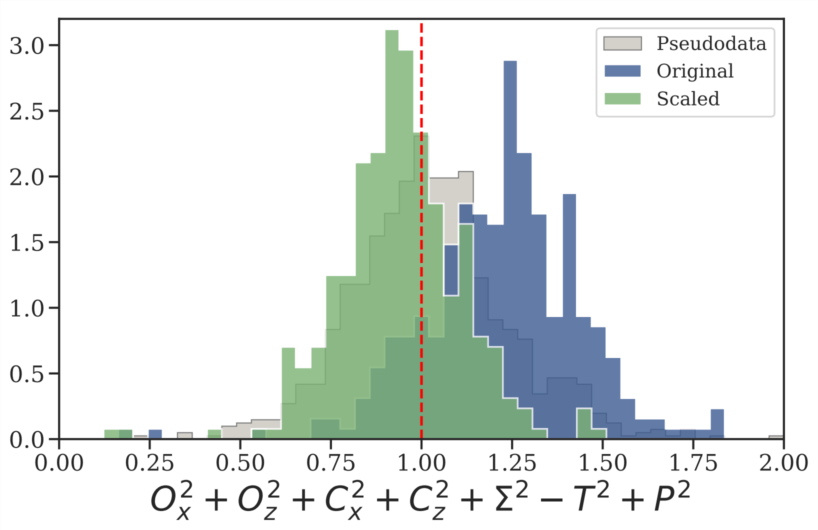
Key Result: Histogram of Fierz Identities



Key Result: Histogram of Fierz Identities



Key Result: Histogram of Fierz Identities



Estimate α_- from $K\Lambda$ data?

Parameter Estimation

Infer α_- from $K\Lambda$ data

with: M. Döring, D. I. Glazier, J. Haidenbauer, R. Murray-Smith, M. Mai and D. Rönchen[17].

Fierz Identities as Random Variables

$$\begin{aligned}\mathcal{F}_i^{(1)} =& a^2 l^2 \left(\mathcal{O}_{x,i}^2 + \mathcal{O}_{z,i}^2 - \mathcal{T}_i^2\right) + a^2 c^2 \left(\mathcal{C}_{x,i}^2 + \mathcal{C}_{z,i}^2\right) + l^2 \Sigma_i^2 + a^2 \mathcal{P}_i^2 \ ,\\ \mathcal{F}_i^{(2)} =& al\left[\Sigma_i \mathcal{P}_i - \mathcal{T}_i - ac(\mathcal{C}_{x,i}\mathcal{O}_{z,i} - \mathcal{C}_{z,i}\mathcal{O}_{x,i})\right] \ ,\end{aligned}$$

where $a = \alpha_-^{\mathrm{PDG}}/\alpha_-$ and c, l are relative calibrations (i.e. systematics) for circular and linear photon polarization, resp.

Instances of $\mathcal{F}_i^{(1)}$ and $\mathcal{F}_i^{(2)}$ for given a, c and l are $f_i^{(1)}$ and $f_i^{(2)}$

[17] D. G. Ireland et al. In: *arXiv:1904.07616* (2019).

Parameter Estimation

Likelihood Function

$$p_i(\mathfrak{O}_i|a,l,c) \propto \exp\left[-\left(\frac{f_i^{(1)}-1}{\sigma_{\mathcal{F}_i^{(1)}}}\right)^2 - \left(\frac{f_i^{(2)}}{\sigma_{\mathcal{F}_i^{(2)}}}\right)^2\right],$$

assuming observables are independent and identically distributed (gaussian). $\mathfrak{O}_i = \cup_{j=1}^{7}\mathcal{O}_{j,i}$ represents observables at point i

For observables from N bins:

$$\mathcal{P}(\mathfrak{O}|a,l,c) \propto \prod_{i=1}^{n} p_i(\mathfrak{O}_i|a,l,c)$$

where $\mathfrak{O} = \cup_{i=1}^{n}\mathfrak{O}_i$ represents entire data set.

i.e. the probability that the observables obey Fierz identity

Parameter Estimation

Include knowledge of calibrations

Calculate posterior PDF from likelihood and prior:

$$\mathcal{P}(a, l, c|\mathfrak{D}) \propto \mathcal{P}(\mathfrak{D}|a, l, c)\mathcal{P}(l, c) \ .$$

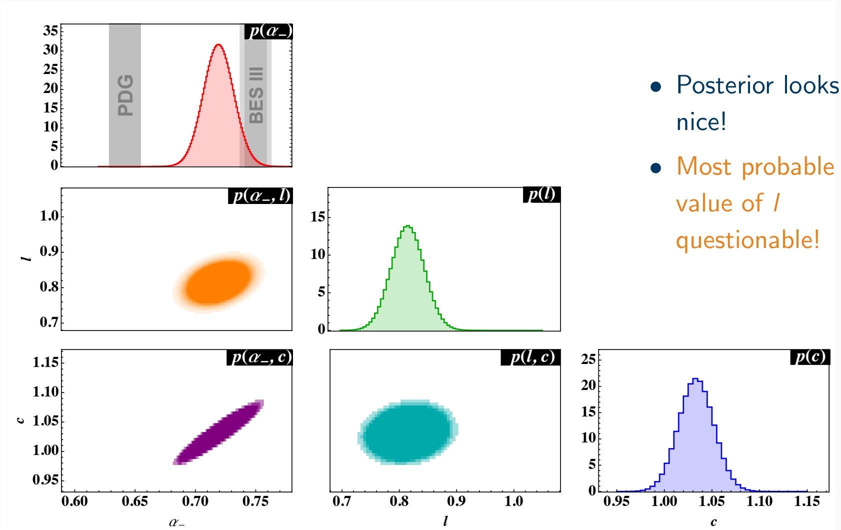
- Impose $\alpha_{-} \geq 0$
- Quoted systematic uncertainties in P_{γ}^{L} are 3-6% (use 5)
- Quoted systematic uncertainties in P_{γ}^{C} are 2% (use 2%)
- Which PDF to use? Gaussian $\mathcal{N}(1, \sigma)$? Uniform $\mathcal{U}(1-\sigma, 1+\sigma)$?

Posterior PDF

Function of a, c and l, $\mathcal{P}(a, l, c|\mathfrak{D})$, calculations done by

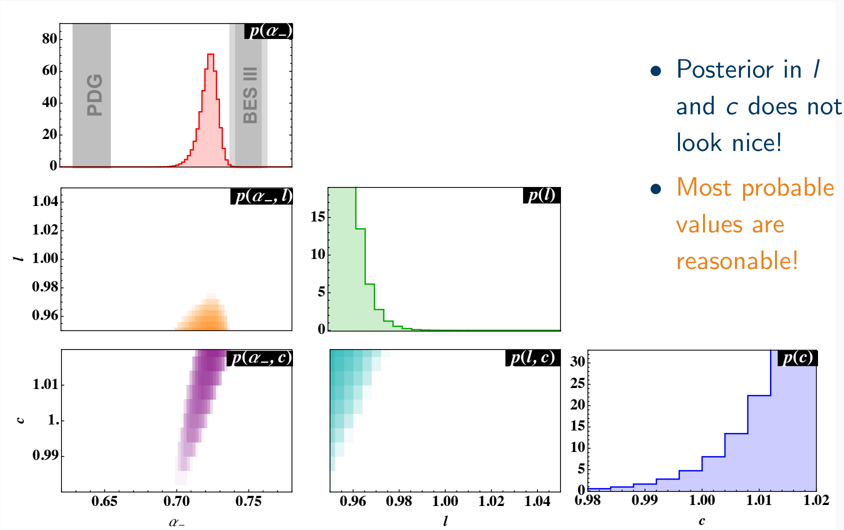
1. Markov Chain Monte Carlo (MCMC)
2. Direct calculation on $a - c - l$ grid

Gaussian Prior



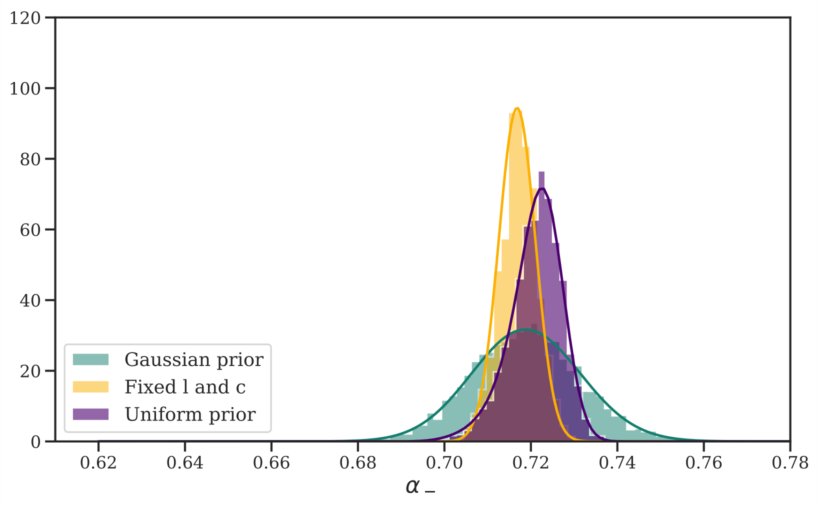
- Posterior looks nice!
- Most probable value of l questionable!

Uniform Prior

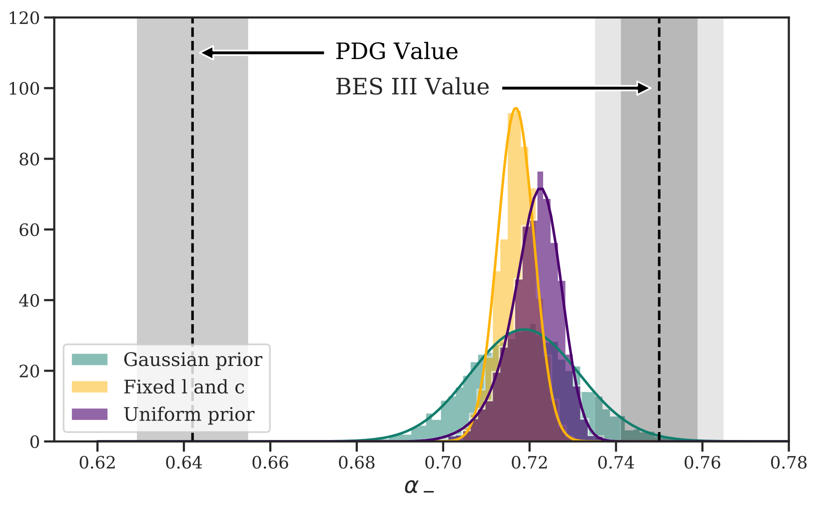


- Posterior in l and c does not look nice!
- Most probable values are reasonable!

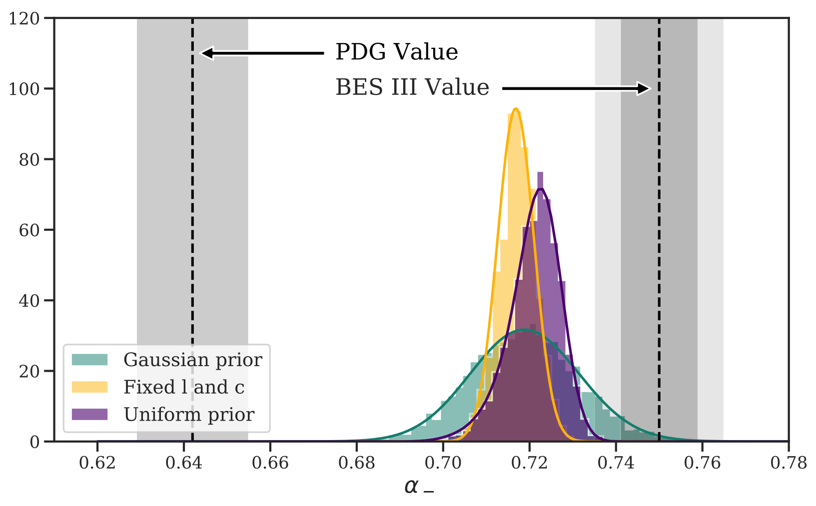
Posterior PDFs for α_- - Summary of results



Posterior PDFs for α_- - Summary of results



Posterior PDFs for α_- - Summary of results



$$\alpha_- = 0.721 \pm 0.006 \text{ (stat.) } \pm 0.005 \text{(sys.)}$$

Estimates of α_- - Summary of results

Source	Value	Prior Assumption P_γ^L, P_γ^C
PDG	0.642 ± 0.013	
BES III	$0.750 \pm 0.009 \pm 0.004$	
CLAS	0.719 ± 0.013	$\mathcal{N}(1.0, 0.05^2)$, $\mathcal{N}(1.0, 0.02^2)$
	0.721 ± 0.006 $(\star)$	$\mathcal{U}(0.95, 1.05)$, $\mathcal{U}(0.98, 1.02)$
	0.727 ± 0.007	$\mathcal{U}(0.90, 1.10)$, $\mathcal{U}(0.96, 1.04)$
	0.717 ± 0.004	Both fixed at 1.0
	$0.721 \pm 0.006 \pm 0.005$	Summary of our result

Consequences for Fitting Kaon Photoproduction Observables?

Refit of JüBo Coupled Channels Model

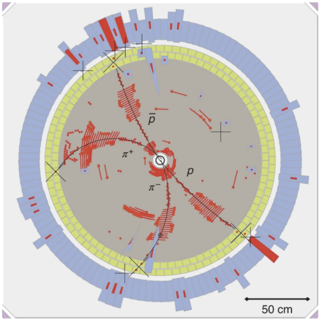
Observable (# data points)	χ^2/n (Refits) $\alpha_- = 0.642$	0.75	0.721
$d\sigma/d\Omega$ (421)	1.11	1.03	0.95
Σ (314)	2.55	2.61	2.56
T (314)	1.75	1.74	1.69
P (410)	1.84	1.66	1.62
C_x (82)	2.15	1.72	1.34
C_z (85)	1.58	1.83	1.62
O_x (314)	1.44	1.53	1.51
O_z (314)	1.34	1.58	1.49
all (2254)	1.67	1.66	1.59

Improved fit!

Conclusions

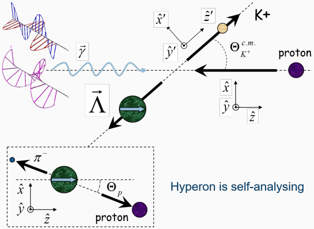
Summary

- New BES III result for α_- is 17% higher than PDG value



Summary

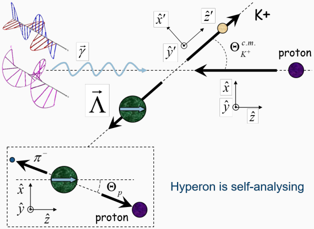
- New BES III result for α_- is 17% higher than PDG value
- Affects all recoil observables relying on Λ weak decay



Hyperon is self-analysing

Summary

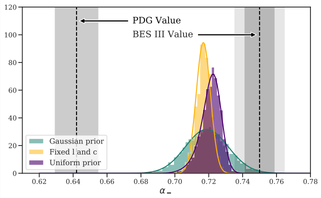
- New BES III result for α_- is 17% higher than PDG value
- Affects all recoil observables relying on Λ weak decay
- Kaon photoproduction data can independently determine α_-



Hyperon is self-analysing

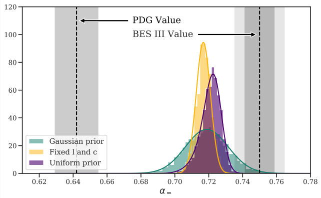
Summary

- New BES III result for α_- is 17% higher than PDG value
- Affects all recoil observables relying on Λ weak decay
- Kaon photoproduction data can independently determine α_-
- Our result: $\alpha_- = 0.721 \pm 0.006$ (stat.) ± 0.005(sys.)



Summary

- New BES III result for α_- is 17% higher than PDG value
- Affects all recoil observables relying on Λ weak decay
- Kaon photoproduction data can independently determine α_-
- Our result: $\alpha_- = 0.721 \pm 0.006$ (stat.) ± 0.005(sys.)
- Other analyses will have to be reviewed!

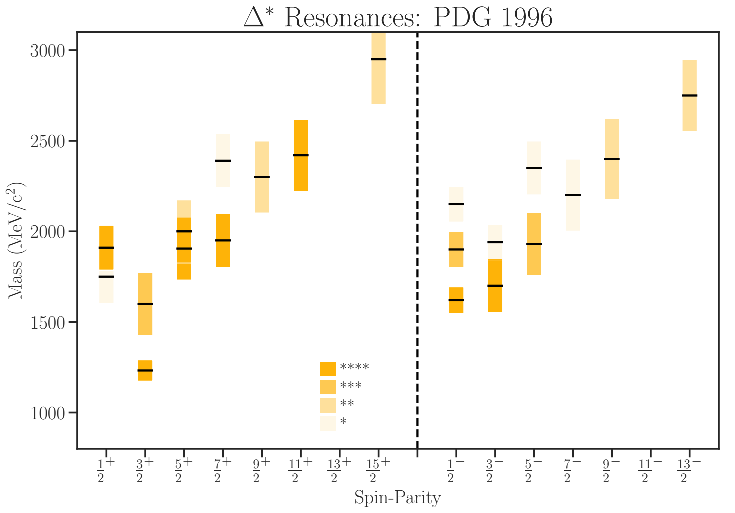


Details posted on arXiv[18]

[18] D. G. Ireland et al. In: *arXiv:1904.07616* (2019).

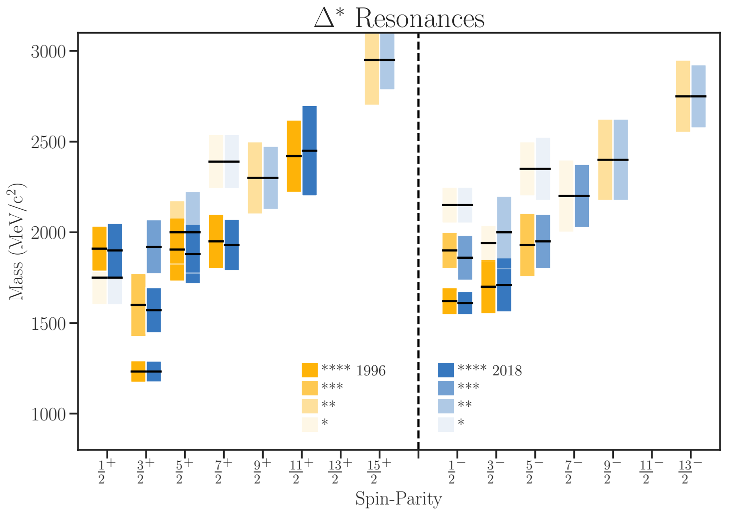
Backup Slides

Light Baryon Spectrum - PDG 1996[19] List of Δ Resonances



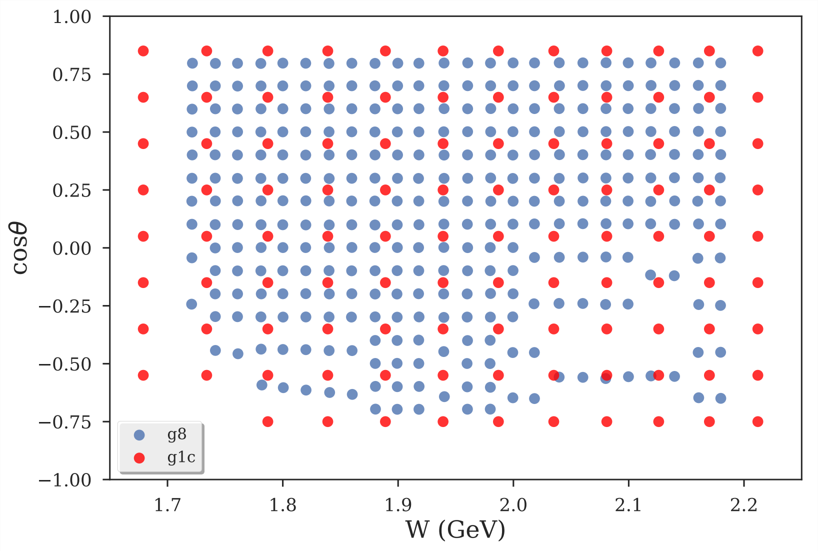
[19]R.M. Barnett et al. In: *Phys. Rev. D* 54 (1996), p. 1.

Light Baryon Spectrum - PDG 2018[20] List of Δ Resonances

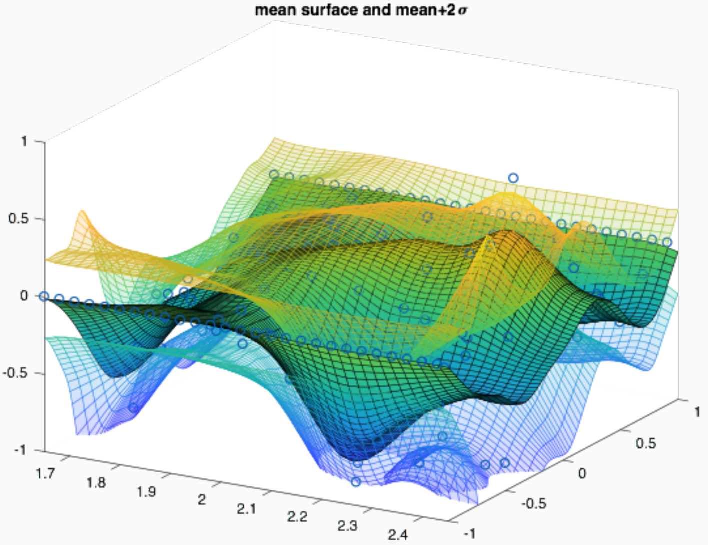


[20] (Particle Data Group) Tanabashi, M. et al. "Review of Particle Physics". In: *Phys. Rev. D* 98.3 (Aug. 2018), p. 030001.

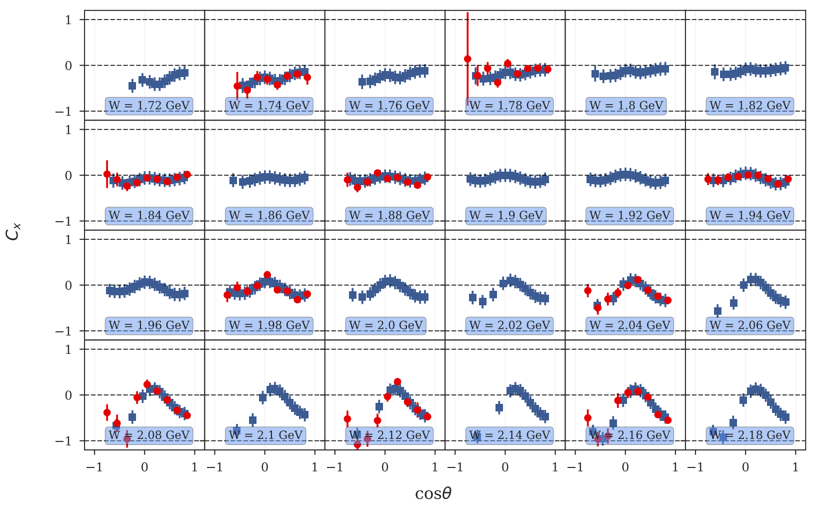
g8 $K - \Lambda$ Coverage



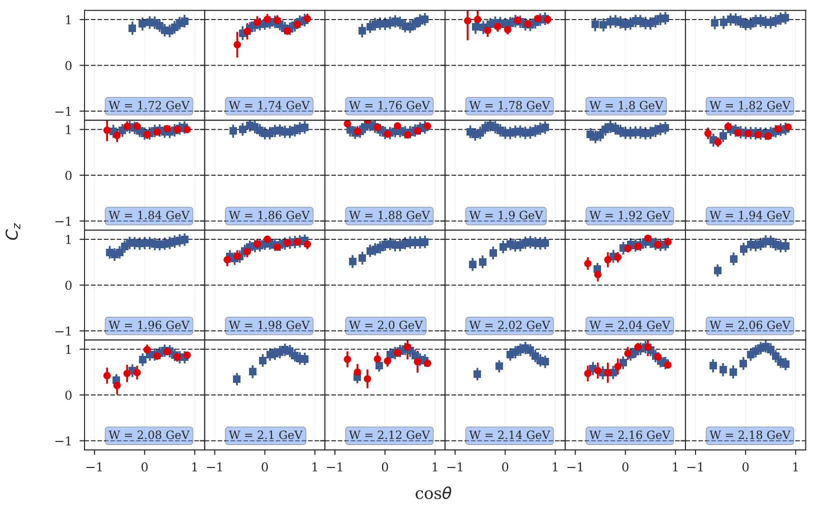
Gaussian Process Interpolation



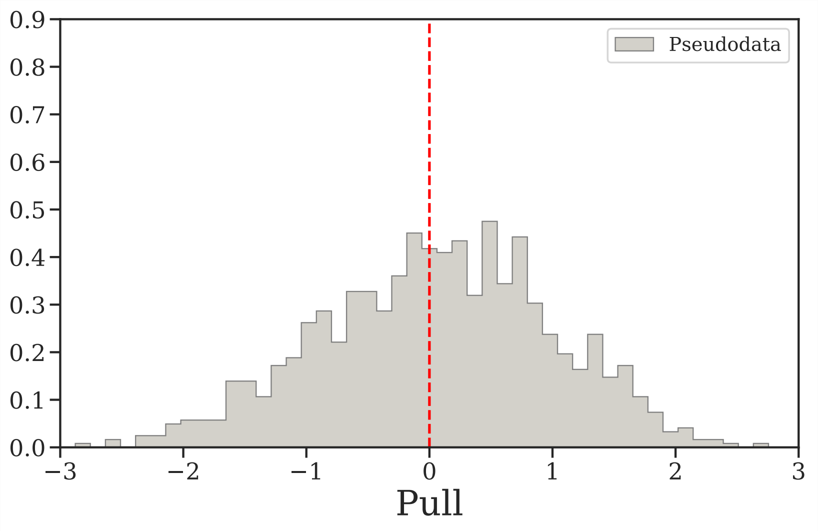
Using Gaussian Process to Interpolate g1c to g8 Bins: C_x



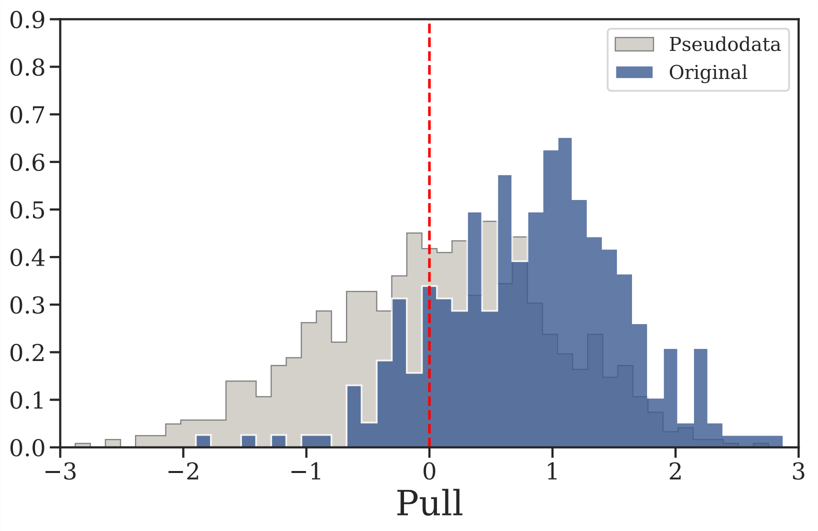
Using Gaussian Process to Interpolate g1c to g8 Bins: C_z



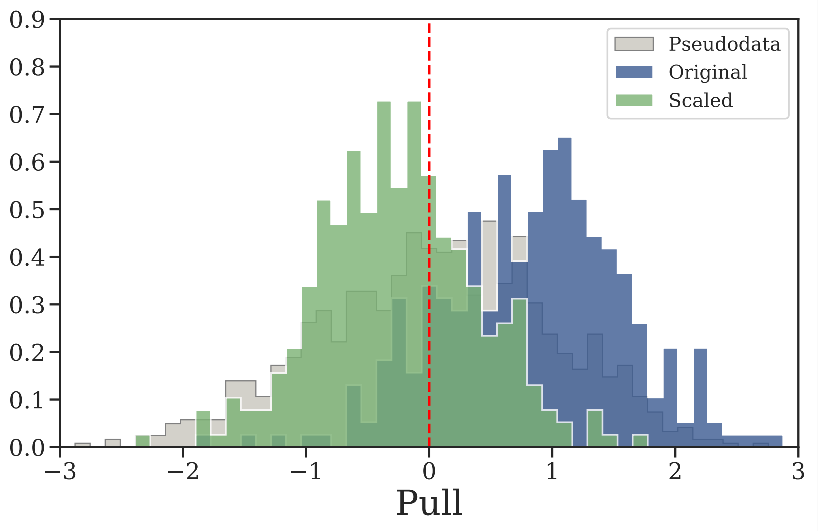
Key Result: Pulls of Fierz Identities



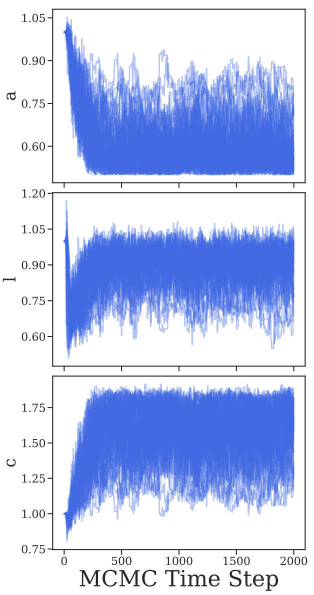
Key Result: Pulls of Fierz Identities



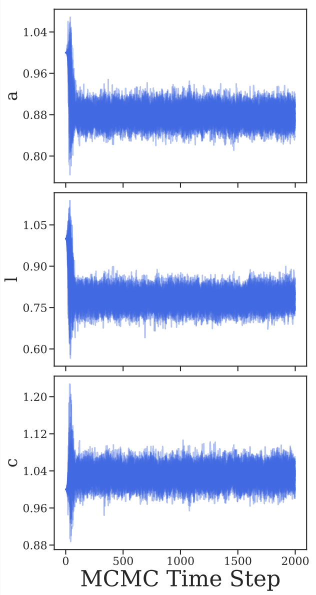
Key Result: Pulls of Fierz Identities



MCMC Chain - no prior



MCMC Chain - gaussian prior



MCMC Chain - uniform prior