Kaon Photoproduction and the Λ Weak Decay Parameter

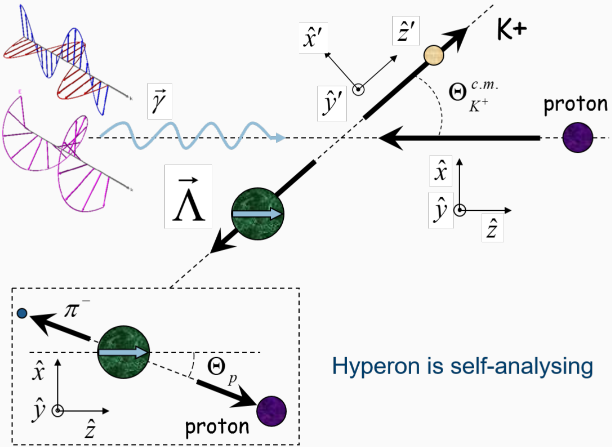
CLAS HSWG meeting

D.G. Ireland

15 November, 2018

Kaon Photoproduction

Kaon Photoproduction - $K\Lambda$ example



Hyperon is self-analysing

The Recent BESIII Result

arXiv paper...

Polarization and Entanglement in Baryon-Antibaryon Pair Production in Electron-Positron Annihilation

M. Ablikim[1], M. N. Achasov[10,d], S. Ahmed[15], M. Albrecht[4], M. Alekseev[55A,55C], A. Amoroso[55A,55C], F. F. An[1], Q. An[52,42], Y. Bai[41], O. Bakina[27], R. Baldini Ferroli[23A], Y. Ban[35], K. Begzsuren[25], D. W. Bennett[22], J. V. Bennett[5], N. Berger[26], M. Bertani[23A], D. Bettoni[24A], F. Bianchi[55A,55C], E. Boger[27,b], I. Boyko[27], R. A. Briere[5], H. Cai[57], X. Cai[1,42], A. Calcaterra[23A], G. F. Cao[1,46], S. A. Cetin[45B], J. Chai[55C], J. F. Chang[1,42], W. L. Chang[1,46], G. Chelkov[27,b,c], G. Chen[1], H. S. Chen[1,46], J. C. Chen[1], M. L. Chen[1,42], P. L. Chen[53], S. J. Chen[33], X. R. Chen[30], Y. B. Chen[1,42], W. Cheng[55C], X. K. Chu[35], G. Cibinetto[24A], F. Cossio[55C], H. L. Dai[1,42], J. P. Dai[37,h], A. Dbeyssi[15], D. Dedovich[27], Z. Y. Deng[1], A. Denig[26], I. Denysenko[27], M. Destefanis[55A,55C], F. De Mori[55A,55C], Y. Ding[31], C. Dong[34], J. Dong[1,42], L. Y. Dong[1,46], M. Y. Dong[1,42,46], Z. L. Dou[33], S. X. Du[60], P. F. Duan[1], J. Z. Fan[44], J. Fang[1,42], S. S. Fang[1,46], Y. Fang[1], R. Farinelli[24A,24B], L. Fava[55B,55C], S. Fegan[26], F. Feldbauer[4], G. Felici[23A], C. Q. Feng[52,42], E. Fioravanti[24A], M. Fritsch[4], C. D. Fu[1], Q. Gao[1], X. L. Gao[52,42], Y. Gao[44], Y. G. Gao[6], Z. Gao[52,42], B. Garillon[26], I. Garzia[24A], A. Gilman[49], K. Goetzen[11], L. Gong[34], W. X. Gong[1,42], W. Gradl[26], M. Greco[55A,55C], L. M. Gu[33], M. H. Gu[1,42], Y. T. Gu[13], A. Q. Guo[1], L. B. Guo[32], R. P. Guo[1,46], Y. P. Guo[26], A. Guskov[27], Z. Haddadi[29], S. Han[57], X. Q. Hao[16], F. A. Harris[47], K. L. He[1,46], F. H. Heinsius[4], T. Held[4], Y. K. Heng[1,42,46], Z. L. Hou[1], H. M. Hu[1,46], J. F. Hu[37,h], T. Hu[1,42,46], Y. Hu[1], G. S. Huang[52,42], J. S. Huang[16], X. T. Huang[36], X. Z. Huang[33], Z. L. Huang[31], T. Hussain[54], W. Ikegami Andersson[56], M. Irshad[52,42], Q. Ji[1], Q. P. Ji[16], X. B. Ji[1,46], X. L. Ji[1,42], H. L. Jiang[36], X. S. Jiang[1,42,46], X. Y. Jiang[34], J. B. Jiao[36], Z. Jiao[18], D. P. Jin[1,42,46], S. Jin[33], Y. Jin[48], T. Johansson[56], A. Julin[49], N. Kalantar-Nayestanaki[29], X. S. Kang[34], M. Kavatsyuk[29], B. C. Ke[1], I. K. Keshk[4], T. Khan[52,42], A. Khoukaz[50], P. Kiese[26], R. Kiuchi[1], R. Kliemt[11], L. Koch[28], O. B. Kolcu[45B,f], B. Kopf[4], M. Kornicer[47], M. Kuemmel[4], M. Kuessner[4], A. Kupsc[56], M. Kurth[1], W. Kühn[28], J. S. Lange[28], P. Larin[15], L. Lavezzi[55C], S. Leiber[4], H. Leithoff[26], C. Li[56], Cheng Li[52,42], D. M. Li[60], F. Li[1,42], F. Y. Li[35], G. Li[1], H. B. Li[1,46], H. J. Li[1,46], J. C. Li[1], J. W. Li[40], K. J. Li[43], Kang Li[14], Ke Li[1], Lei Li[3], P. L. Li[52,42], P. R. Li[46,7], Q. Y. Li[36], T. Li[36], W. D. Li[1,46], W. G. Li[1], X. L. Li[36], X. N. Li[1,42], X. Q. Li[34], Z. B. Li[43], H. Liang[52,42], Y. F. Liang[39], Y. T. Liang[28], G. R. Liao[12], L. Z. Liao[1,46], J. Libby[21], C. X. Lin[43], D. X. Lin[15], B. Liu[37,h], B. J. Liu[1], C. X. Liu[1], D. Liu[52,42], D. Y. Liu[37,h], F. H. Liu[38], Fang Liu[1], Feng Liu[6], H. B. Liu[13], H. L Liu[41], H. M. Liu[1,46], Huanhuan Liu[1], Huihui Liu[17], J. J. Liu[1], J. B. Liu[52,42], J. Y. Liu[1,46], K. Y. Liu[31], Ke Liu[6], L. D. Liu[35], Q. Liu[46], S. B. Liu[52,42], X. Liu[30], Y. B. Liu[34], Z. A. Liu[1,42,46], Zhiqing Liu[26], Y. F. Long[35], X. C. Lou[1,42,46], H. J. Lu[18], J. G. Lu[1,42], Y. Lu[1], Y. P. Lu[1,42], C. L. Luo[32], M. X. Luo[59], P. W. Luo[43], T. Luo[9,j], X. L. Luo[1,42], S. Lusso[55C], X. R. Lyu[46], F. C. Ma[31], H. L. Ma[1], L. L. Ma[36], M. M. Ma[1,46], Q. M. Ma[1], X. N. Ma[34], X. Y. Ma[1,42], Y. M. Ma[36], F. E. Maas[15], M. Maggiora[55A,55C], S. Maldaner[26], Q. A. Malik[54], A. Mangoni[23B], Y. J. Mao[35], Z. P. Mao[1], S. Marcello[55A,55C], Z. X. Meng[48], J. G. Messchendorp[29], G. Mezzadri[24A], J. Min[1,42], T. J. Min[33], R. E. Mitchell[22], X. H. Mo[1,42,46], Y. J. Mo[6], C. Morales Morales[15], N. Yu. Muchnoi[10,d], H. Muramatsu[49], A. Mustafa[4], S. Nakhoul[11,g], Y. Nefedov[27], F. Nerling[11,g], I. B. Nikolaev[10,d], Z. Ning[1,42], S. Nisar[8], S. L. Niu[1,42], X. Y. Niu[1,46], S. L. Olsen[46], Q. Ouyang[1,42,46], S. Pacetti[23B], Y. Pan[52,42], M. Papenbrock[56], P. Patteri[23A], M. Pelizaeus[4], J. Pellegrino[55A,55C], H. P. Peng[52,42]

$\Lambda - \bar{\Lambda}$ Production

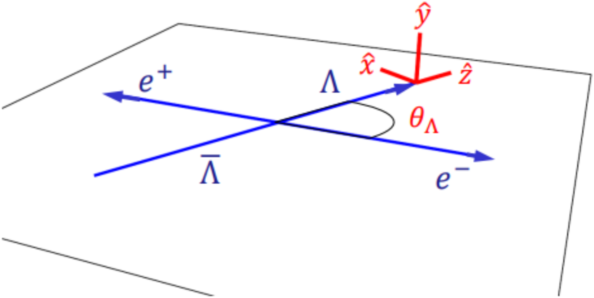


FIG. 1. Kinematics of the reaction $e^+e^- \to J/\psi \to \Lambda\bar{\Lambda}$ in the overall center-of-mass system. The Λ particle is emitted in the $\hat{z}$ direction at an angle θ_Λ with respect to the e^- direction, and the $\bar{\Lambda}$ is emitted in the opposite direction. The hyperons are polarized in the direction perpendicular to the reaction plane ($\hat{y}$). The hyperons are reconstructed, and the polarization is determined by measuring their decay products: (anti-)nucleons and pions.

$\Lambda - \bar{\Lambda}$ Production

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

Λ Weak Decay Parameter

TABLE I. Summary of the results: the $J/\psi \to \Lambda\bar{\Lambda}$ angular distribution parameter α_ψ, the phase $\Delta\Phi$, the asymmetry parameters for the $\Lambda \to p\pi^-$ (α_-), $\bar{\Lambda} \to \bar{p}\pi^+$ (α_+) and $\bar{\Lambda} \to \bar{n}\pi^0$ ($\bar{\alpha}_0$) decays, the CP asymmetry A_{CP}, and the ratio $\bar{\alpha}_0/\alpha_+$. The first uncertainty is statistical, and the second one is systematic.

Parameters	This work	Previous results
α_ψ	$0.461 \pm 0.006 \pm 0.007$	0.469 ± 0.027 [25]
$\Delta\Phi$	$(42.4 \pm 0.6 \pm 0.5)^\circ$	–
α_-	$0.750 \pm 0.009 \pm 0.004$	0.642 ± 0.013 [27]
α_+	$-0.758 \pm 0.010 \pm 0.007$	-0.71 ± 0.08 [27]
$\bar{\alpha}_0$	$-0.692 \pm 0.016 \pm 0.006$	–
A_{CP}	$-0.006 \pm 0.012 \pm 0.007$	0.006 ± 0.021 [27]
$\bar{\alpha}_0/\alpha_+$	$0.913 \pm 0.028 \pm 0.012$	–

Λ Weak Decay Parameter

TABLE I. Summary of the results: the $J/\psi \to \Lambda\bar{\Lambda}$ angular distribution parameter α_ψ, the phase $\Delta\Phi$, the asymmetry parameters for the $\Lambda \to p\pi^-$ (α_-), $\bar{\Lambda} \to \bar{p}\pi^+$ (α_+) and $\bar{\Lambda} \to \bar{n}\pi^0$ ($\bar{\alpha}_0$) decays, the CP asymmetry A_{CP}, and the ratio $\bar{\alpha}_0/\alpha_+$. The first uncertainty is statistical, and the second one is systematic.

Parameters	This work	Previous results
α_ψ	$0.461 \pm 0.006 \pm 0.007$	0.469 ± 0.027 [25]
$\Delta\Phi$	$(42.4 \pm 0.6 \pm 0.5)^\circ$	–
α_-	$0.750 \pm 0.009 \pm 0.004$	0.642 ± 0.013 [27]
α_+	$-0.758 \pm 0.010 \pm 0.007$	-0.71 ± 0.08 [27]
$\bar{\alpha}_0$	$-0.692 \pm 0.016 \pm 0.006$	–
A_{CP}	$-0.006 \pm 0.012 \pm 0.007$	0.006 ± 0.021 [27]
$\bar{\alpha}_0/\alpha_+$	$0.913 \pm 0.028 \pm 0.012$	–

Consequences for Observables from g8 and g1c?

Fierz Identity for LUY plus CUY

Experimental Polarization Configurations:

LUY: Linear photon beam; unpolarized target; measured recoil

Intensity:

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

CUY: Circularly photon beam; unpolarized target; measured recoil

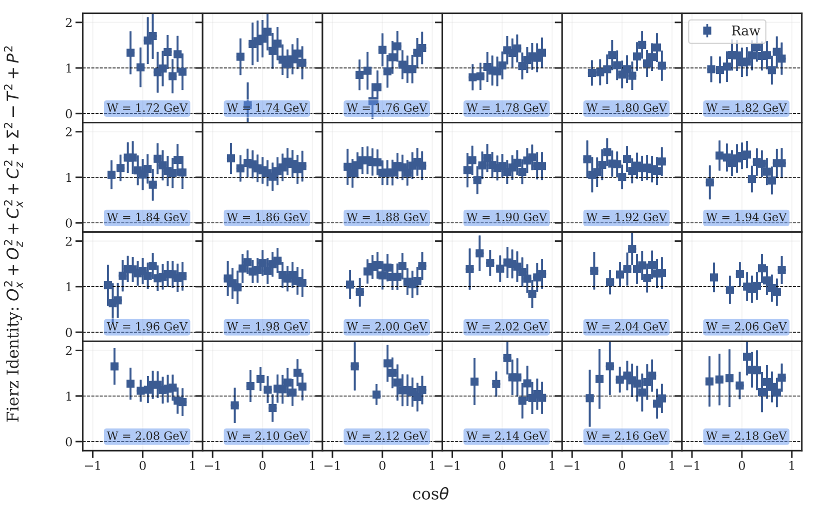
Intensity:

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

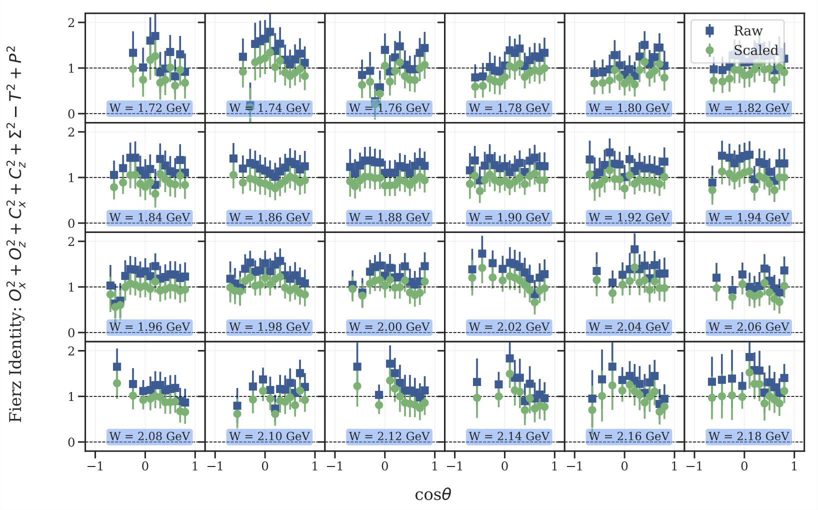
Fierz identity connecting two experiments:

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

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 $3 \times \sigma$

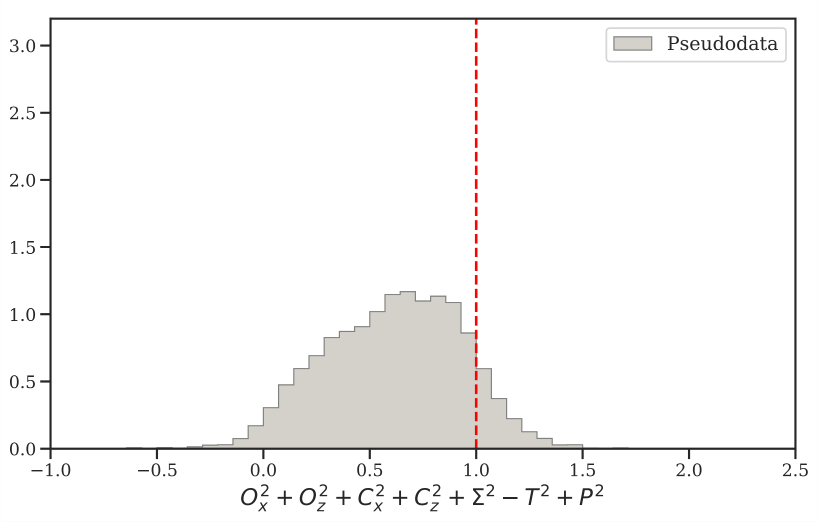
Writing

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

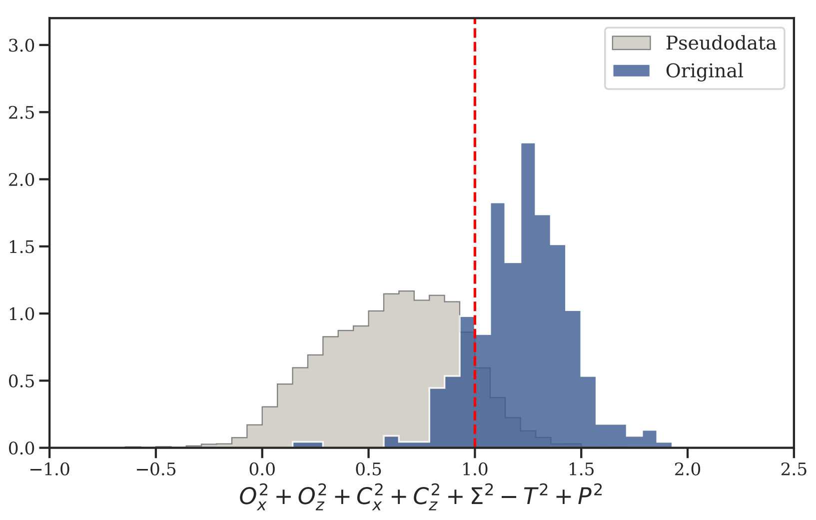
Also define pull as

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

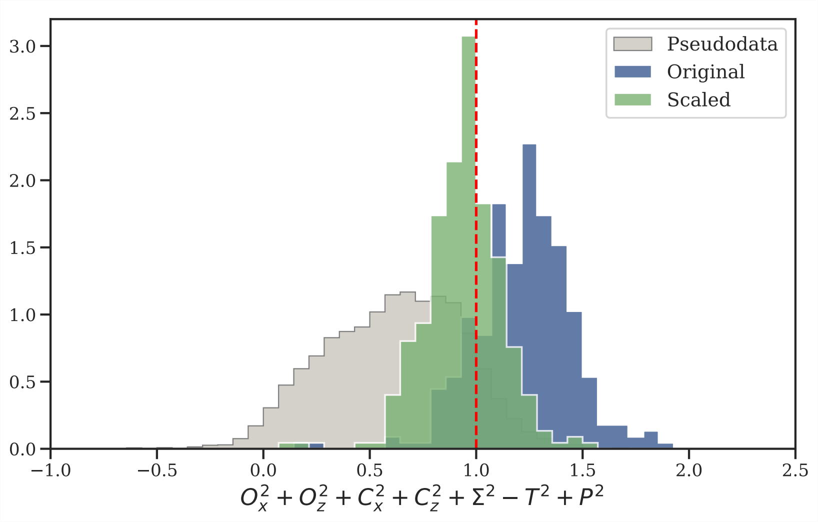
Key Result: Histogram of Fierz Identities



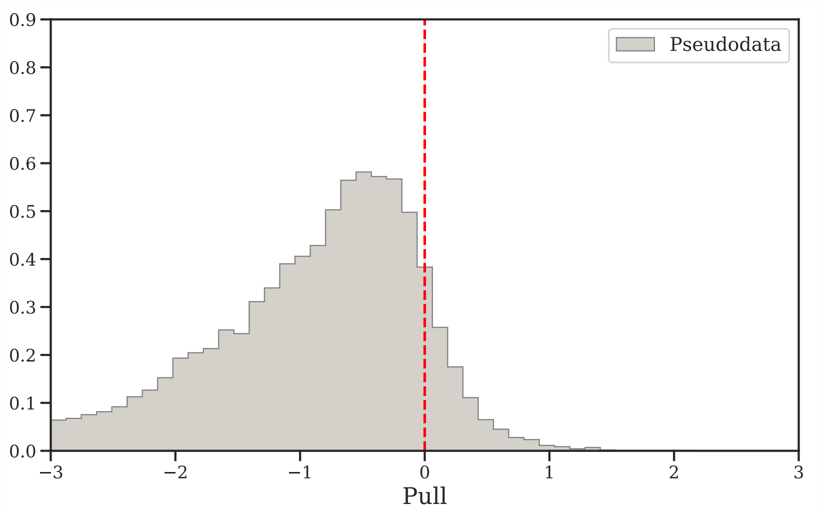
Key Result: Histogram of Fierz Identities



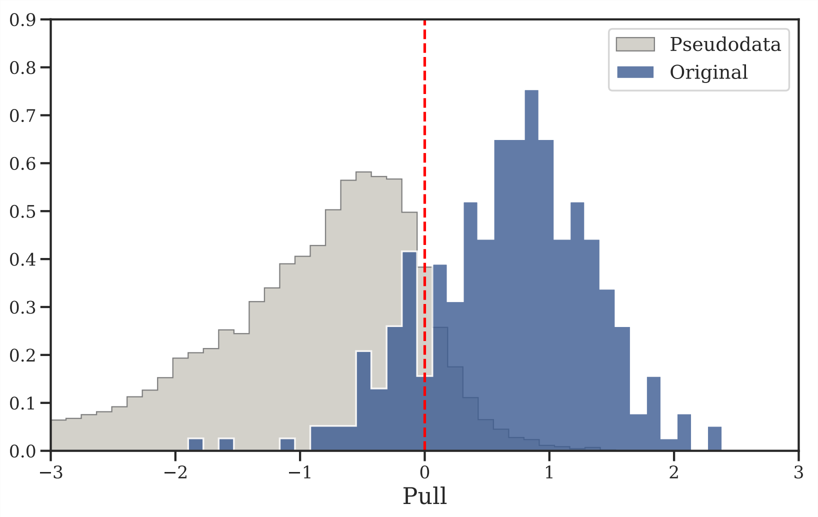
Key Result: Histogram of Fierz Identities



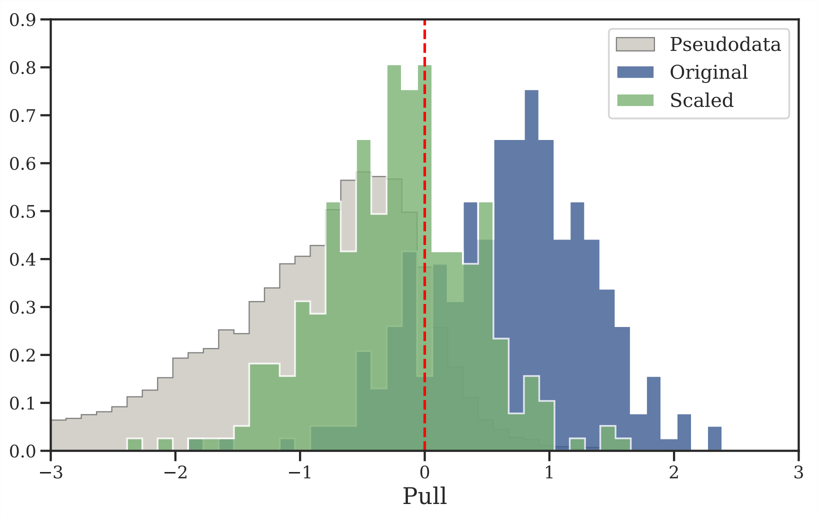
Key Result: Pulls of Fierz Identities



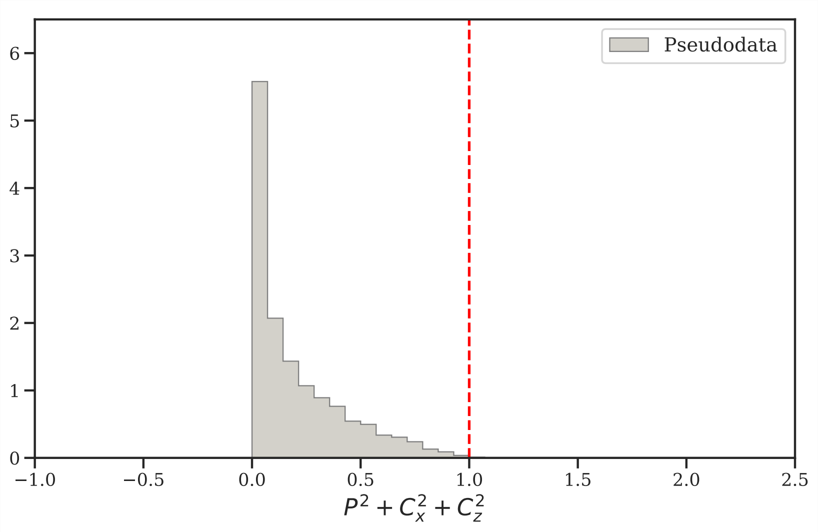
Key Result: Pulls of Fierz Identities



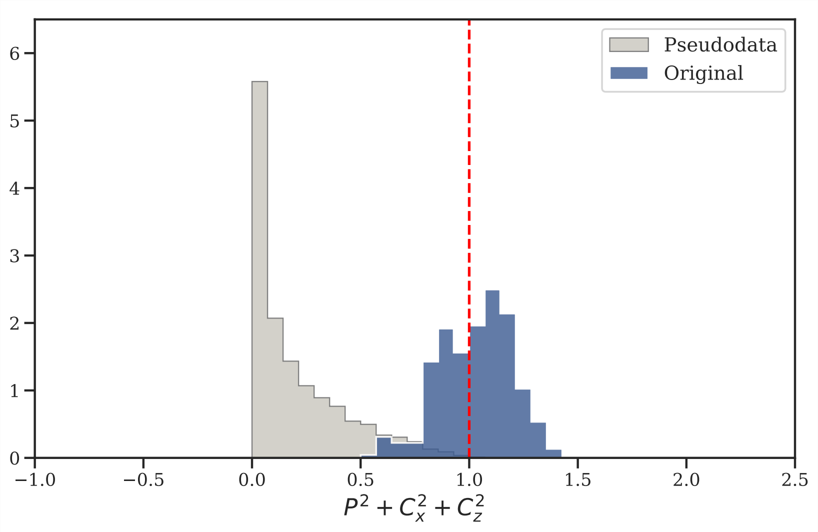
Key Result: Pulls of Fierz Identities



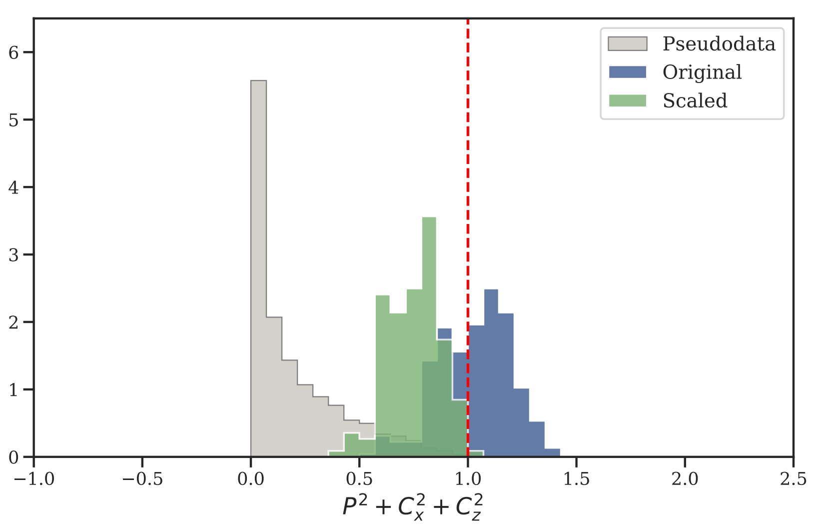
Key Result: Λ Polarization from CLAS Data



Key Result: Λ Polarization from CLAS Data



Key Result: Λ Polarization from CLAS Data



Consequences for Fitting Observables from g8 and g1c?

Using New Weak Decay Parameter for Jülich-Bonn Fits

Observable (# data points)	χ^2/n (JüBo2017) unscaled	χ^2/n (JüBo2017) scaled	χ^2/n (Refit) unscaled	χ^2/n (Refit) scaled
$d\sigma/d\Omega$ (421)	2.65	2.65	1.11	0.96
Σ (314)	5.00	5.00	2.55	2.48
T (314)	1.96	3.00	1.75	1.29
P (410)	1.49	0.91	1.84	1.28
C_x (82)	1.99	1.56	2.15	1.30
C_z (85)	1.95	1.12	1.58	1.34
O_x (314)	1.63	2.00	1.44	1.18
O_z (314)	1.62	1.64	1.34	1.23
all (2254)	2.33	2.38	1.67	1.37

Measuring α_- from g8 and g1c data?

Likelihood Function

Define function

$$\mathcal{F}(a,l,c) = a^2 l^2 \left(\mathbf{O_x}^2 + \mathbf{O_z}^2 - \mathbf{T}^2\right) + a^2 c^2 \left(\mathbf{C_x}^2 + \mathbf{C_z}^2\right) + l^2 \mathbf{\Sigma}^2 + a^2 \mathbf{P}^2,$$

where a, l, c are the relative calibrations (i.e. systematics) for α_-, linear photon polarization and circular polarization, resp.

Likelihood of obtaining data $\mathcal{O}_i$ in i-th bin, given a, l, c is

$$\mathcal{P}_i\left(\mathcal{O}_i \mid a,l,c\right) = \frac{1}{\sqrt{2\pi}} \frac{1}{\sigma_F} \exp\left(\frac{\mathcal{F}(a,l,c) - 1}{\sigma_F}\right)^2,$$

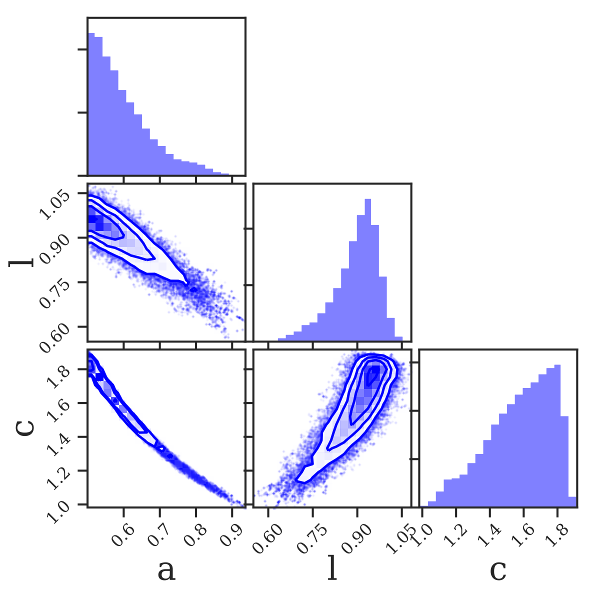
assuming observables are independent and identically distributed (gaussian).

For observables from N bins:

$$\mathcal{P}_{tot}\left(\{\mathcal{O}_i\} \mid a,l,c\right) = \prod_{i=1}^{N} \mathcal{P}_i\left(\mathcal{O}_i \mid a,l,c\right)$$

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

Likelihood Function



- Use Markov Chain Monte Carlo
- Most probable values not reasonable!

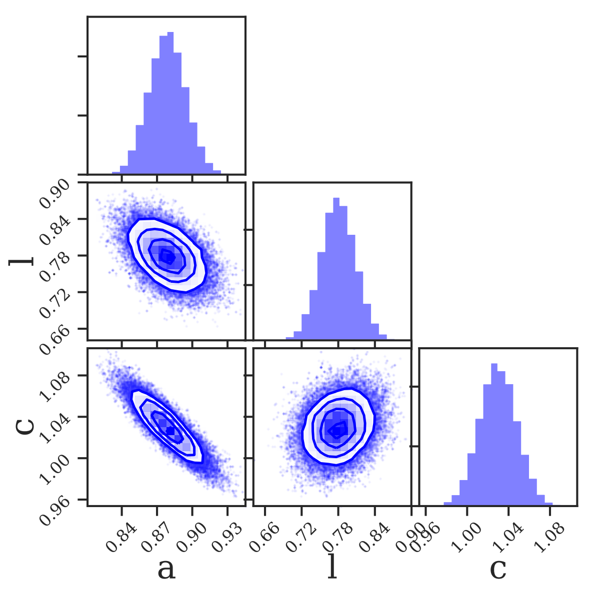
Include knowledge of calibrations

Calculate posterior PDF from likelihood and prior:

$$\mathcal{P}_i\left(a, l, c \mid \mathcal{O}_i\right) \propto \mathcal{P}_i\left(\mathcal{O}_i \mid a, l, c\right) \mathcal{P}_i\left(a, l, c\right)$$

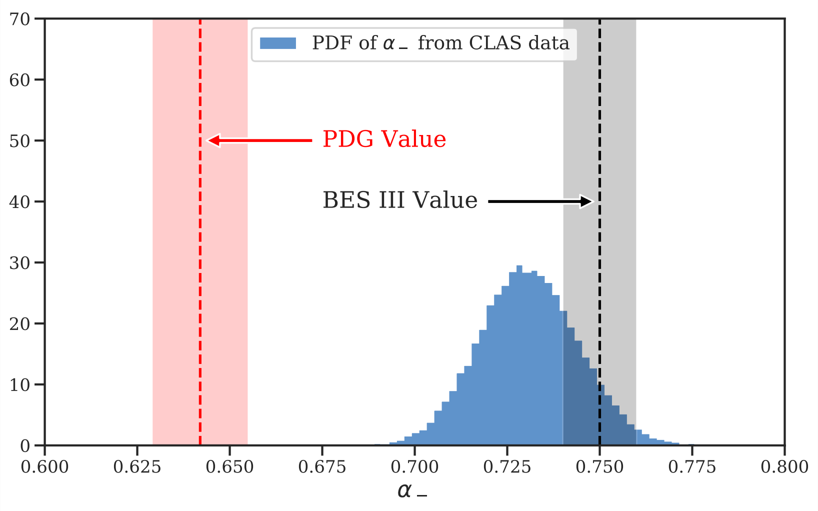
- Impose $\alpha_- \geq 0$
- Quoted systematic uncertainties in P_γ^L are 3-6% (use 5)
- Quoted systematic uncertainties in P_γ^C are 2% (use 2%)
- Which PDF to use? Gaussian $\mathcal{N}(1, \sigma)$? Uniform $\mathcal{U}(1-\sigma, 1+\sigma)$?

Gaussian Prior

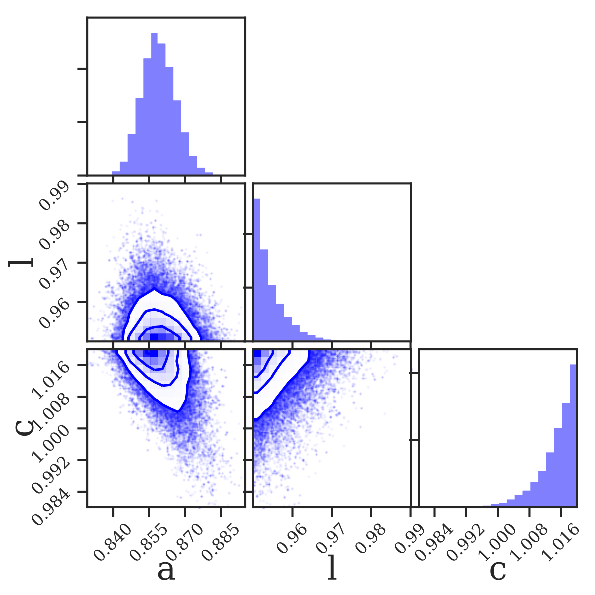


- Posterior looks nice!
- Most probable value of *l* questionable!

PDF for α_- (gaussian prior and marginalize over l and c)

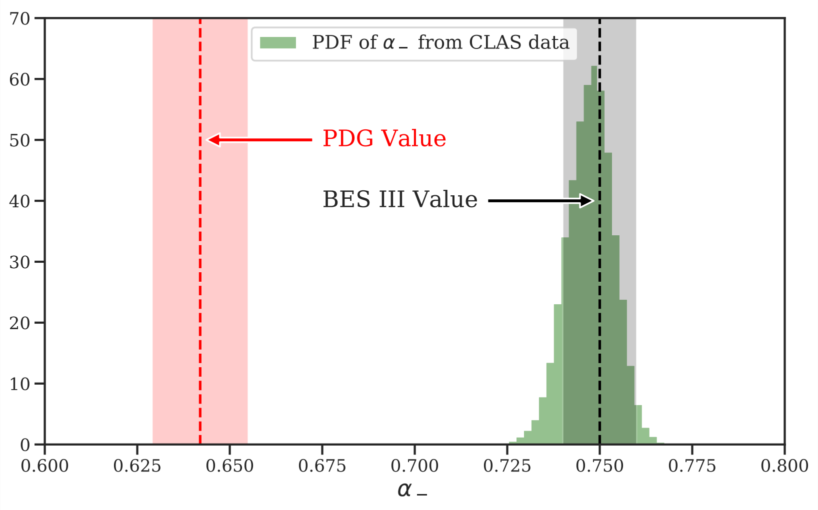


Uniform Prior



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

PDF for α_- (uniform prior and marginalize over l and c)



Conclusions

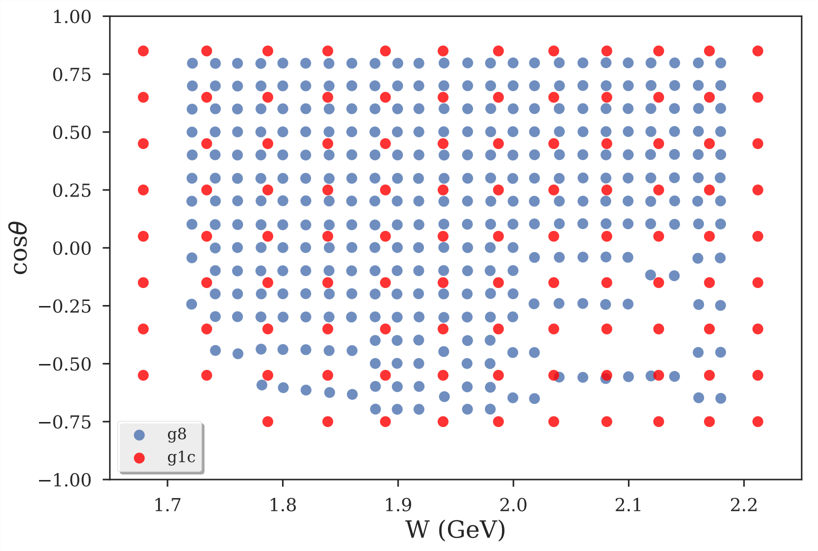
Conclusions

Source	Value
PDG	0.642 ± 0.013
BES III	$0.750 \pm 0.009 \pm 0.004$
CLAS	0.747 ± 0.006 (uniform)
	0.731 ± 0.014 (gaussian)

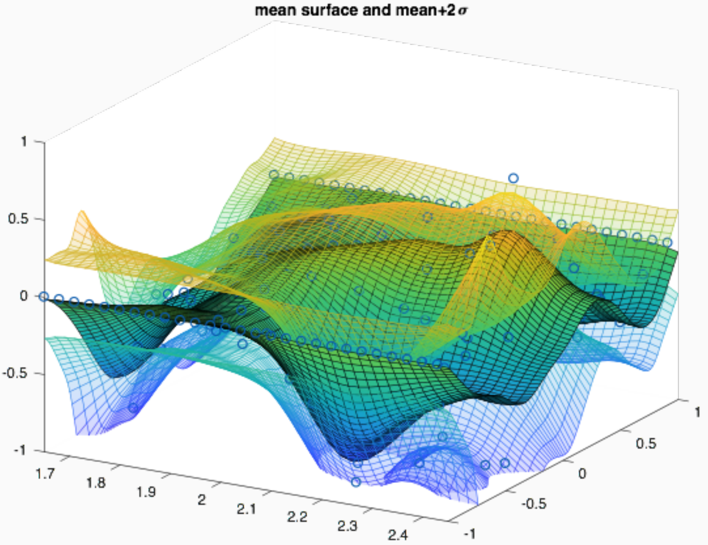
- New BES III result for α_- is 17% higher than PDG value
- Affects all recoil observables relying on Λ weak decay
- CLAS data corroborates BES result
- Previous physics interpretations are $\sim$ safe
- Preliminary calculation shows CLAS data can independently determine α_-
- More checks and cross-validation to do...

Backup Slides

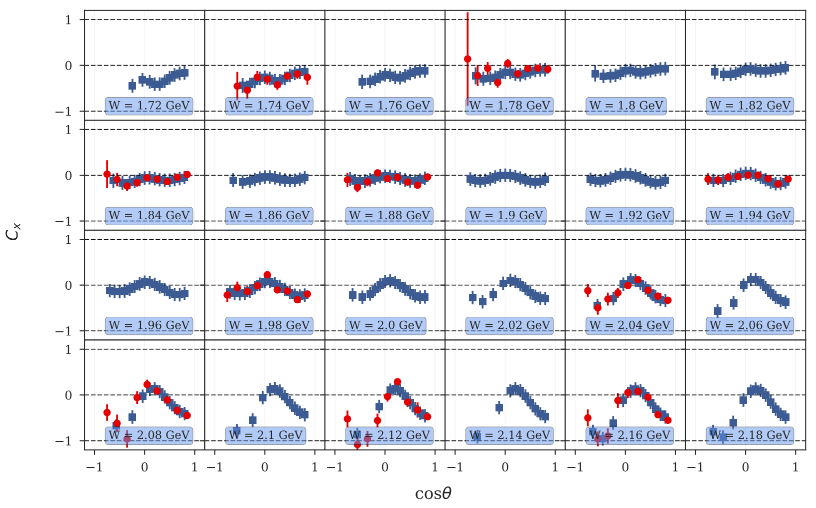
g8 $K - \Lambda$ Coverage



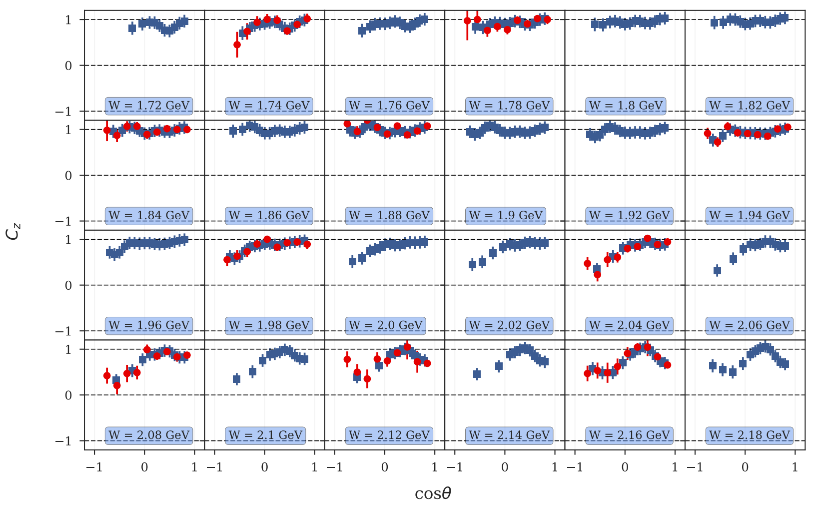
Gaussian Process Interpolation



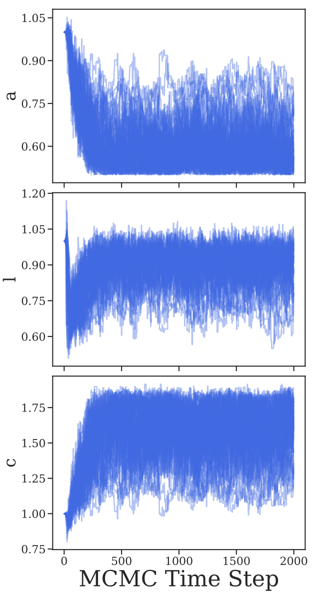
Using Gaussian Process to Interpolate g1c to g8 Bins: C_x



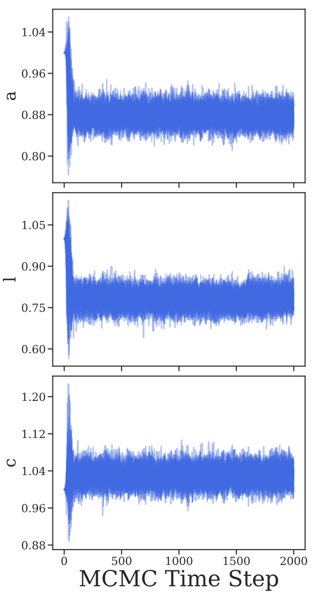
Using Gaussian Process to Interpolate g1c to g8 Bins: C_z



MCMC Chain - no prior



MCMC Chain - gaussian prior



MCMC Chain - uniform prior