The Λ weak decay constant α_- at low energies

University *of* Glasgow

Background

Λ BARYONS ($S = -1$, $I = 0$)

$\Lambda^0 = uds$

Λ $I(J^P) = 0(\frac{1}{2}^+)$

Mass $m = 1115.683 \pm 0.006$ MeV
$(m_\Lambda - m_{\bar{\Lambda}}) / m_\Lambda = (-0.1 \pm 1.1) \times 10^{-5}$ (S = 1.6)
Mean life $\tau = (2.632 \pm 0.020) \times 10^{-10}$ s (S = 1.6)
$(\tau_\Lambda - \tau_{\bar{\Lambda}}) / \tau_\Lambda = -0.001 \pm 0.009$
$c\tau = 7.89$ cm
Magnetic moment $\mu = -0.613 \pm 0.004\ \mu_N$
Electric dipole moment $d < 1.5 \times 10^{-16}$ e cm, CL = 95%

Decay parameters

$p\pi^-$	$\alpha_- = 0.642 \pm 0.013$	**2018**
$\bar{p}\pi^+$	$\alpha_+ = -0.71 \pm 0.08$	

Λ DECAY PARAMETERS

See the "Note on Baryon Decay Parameters" in the neutron Listings. Some early results have been omitted.

α_- FOR $\Lambda \to p\pi^-$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.642±0.013 OUR AVERAGE					
0.584±0.046	8500	ASTBURY	75	SPEC	
0.649±0.023	10325	CLELAND	72	OSPK	
0.67 ±0.06	3520	DAUBER	69	HBC	From Ξ decay
0.645±0.017	10130	OVERSETH	67	OSPK	Λ from $\pi^- p$
0.62 ±0.07	1156	CRONIN	63	CNTR	Λ from $\pi^- p$

α_+ FOR $\bar{\Lambda} \to \bar{p}\pi^+$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
−0.71 ±0.08 OUR AVERAGE					
−0.755±0.083±0.063	≈ 8.7k	ABLIKIM	10	BES	$J/\psi \to \Lambda\bar{\Lambda}$
−0.63 ±0.13	770	TIXIER	88	DM2	$J/\psi \to \Lambda\bar{\Lambda}$

M. Tanabashi et al. (Particle Data Group), Phys. Rev. D 98, 030001 (2018)

- The $\Lambda \to p\pi^-$ decay is a weak decay and preserves some of the polarisation of the Λ
- α_- is the parameter that tells us how much of the polarisation is transferred from the Λ onto the proton
  →"Self-analysing" decay
- In 2019 new BESIII result with huge discrepancy

2019

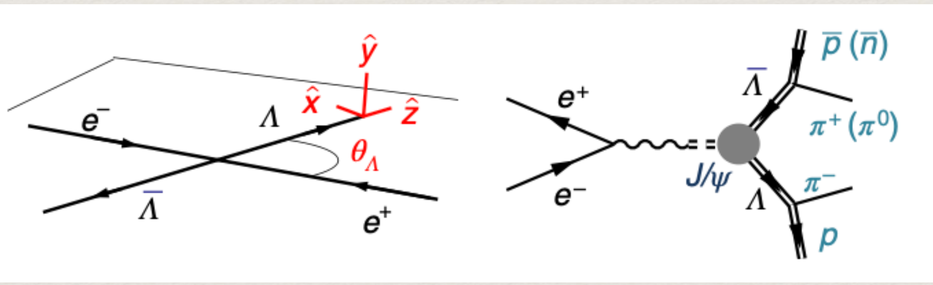
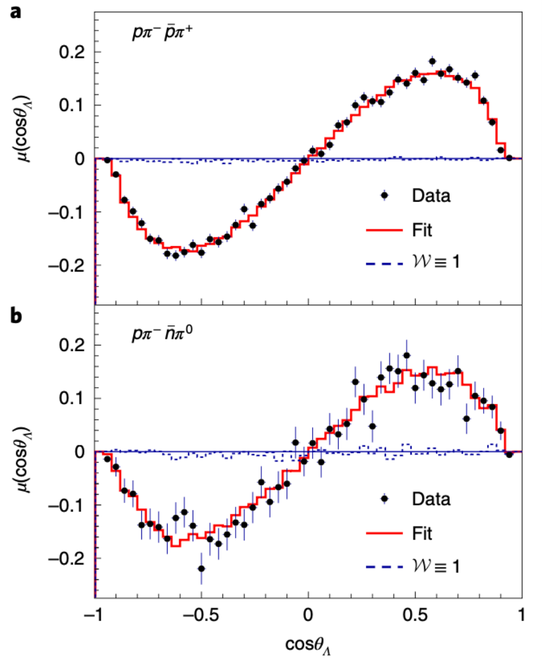


Table 1 | Summary of the results

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])



2019 - further work

D.G. Ireland et al

PHYSICAL REVIEW LETTERS **123,** 182301 (2019)

Kaon Photoproduction and the Λ Decay Parameter α_-

If the photon beam is circularly polarized we have

$$1 + \alpha_- \cos\theta_y P + (\alpha_- \cos\theta_x C_x + \alpha_- \cos\theta_z C_z)\, P_C^\gamma, \quad (2)$$

and if the photon beam is linearly polarized the distribution is

$$1 + \alpha_- \cos\theta_y P - \{\Sigma + \alpha_- \cos\theta_y T\}\, P_L^\gamma \cos 2\phi - \{\alpha_- \cos\theta_x O_x + \alpha_- \cos\theta_z O_z\}\, P_L^\gamma \sin 2\phi. \quad (3)$$

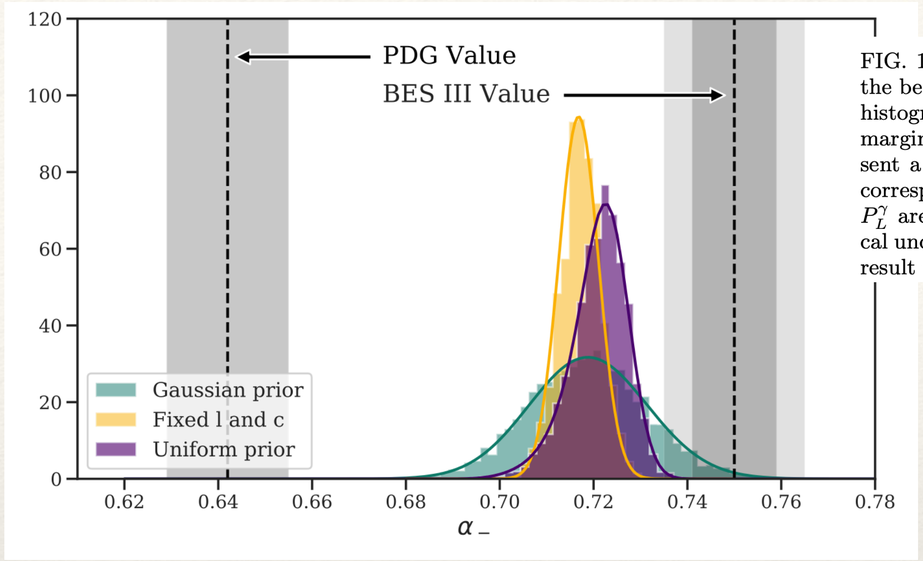


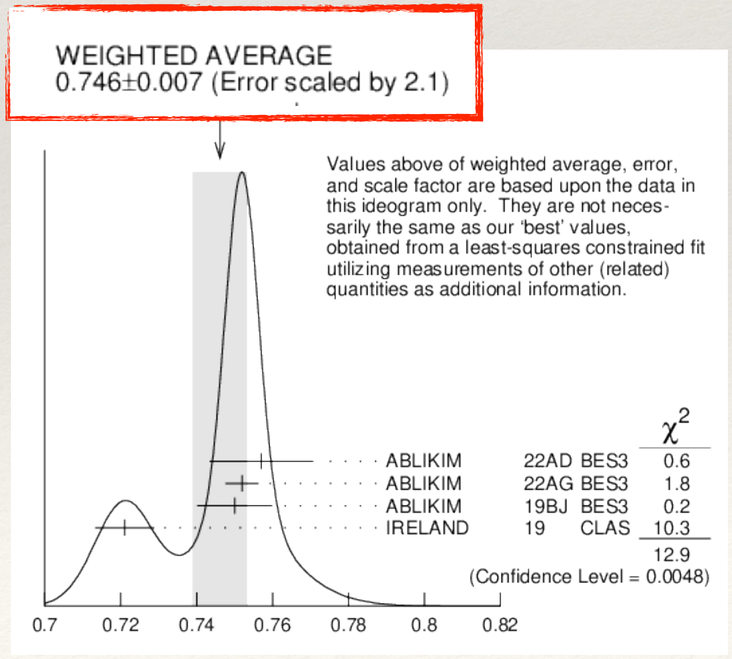
FIG. 1. Posterior densities for α_-, given different priors for the beam polarization calibration constants P_C^γ and P_L^γ. The histograms show the result of the MCMC sampling of the marginalized posterior densities while the solid lines represent a direct scan of the posteriors. For clarity, the results corresponding to the double width uniform priors for P_C^γ and P_L^γ are omitted. Dark grey vertical bands represent statistical uncertainty; the additional light grey bands on the BESIII result represent systematic uncertainty.

$$\alpha = 0.721(6)(5)$$

+ Fierz identities:

$$O_x^2 + O_z^2 + C_x^2 + C_z^2 + \Sigma^2 - T^2 + P^2 = 1$$
$$\Sigma P - C_x O_z + C_z O_x - T = 0$$

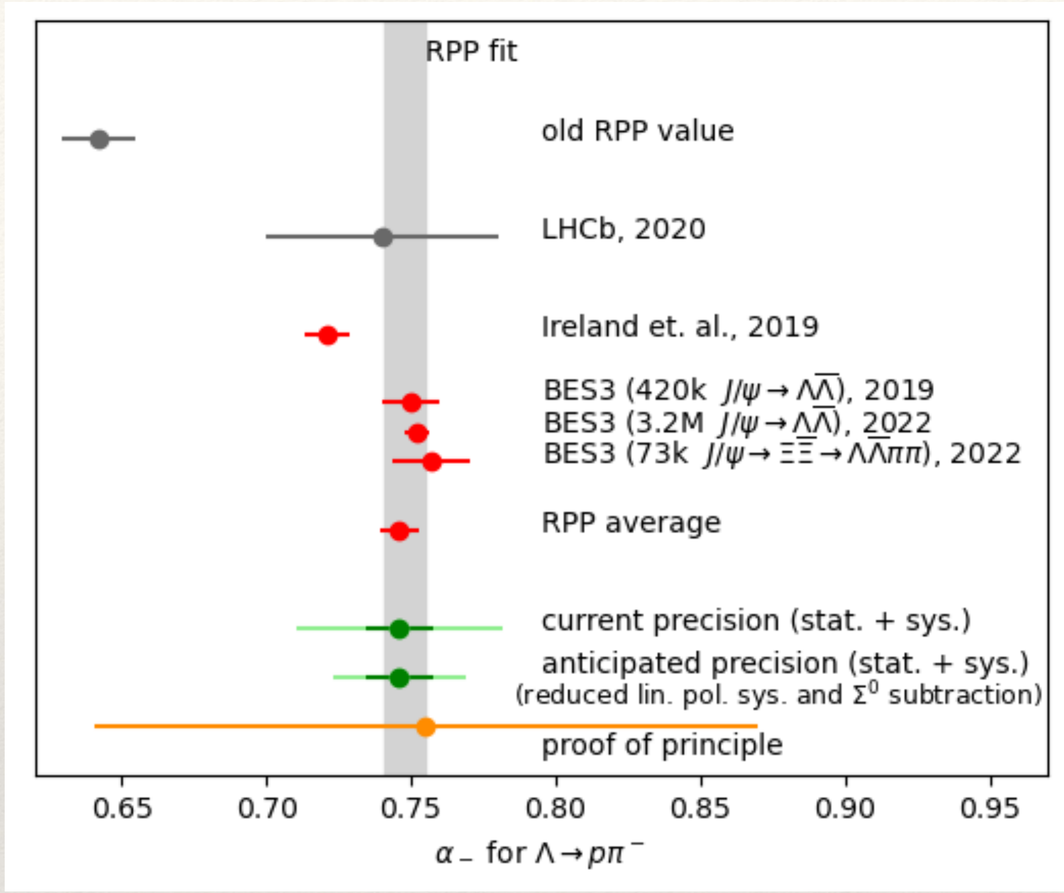
- Use data from three different publications from different beam times
- Extrapolate data to have data set with common kinematics
- Extract alpha from over-constrained set of equations
- Since then two more publications by BES3
- Old results ignored by PDG but slight tension between new results



What will we do in Hall D?

https://arxiv.org/abs/2405.01288

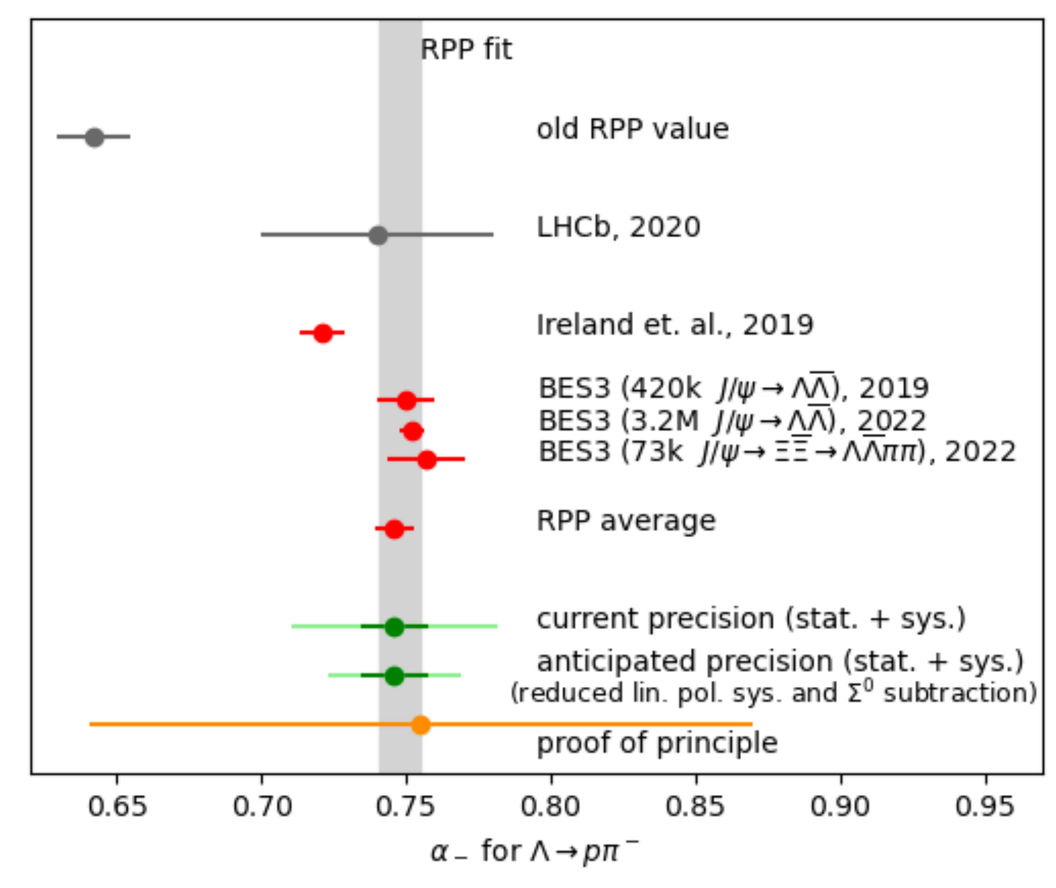
- We can use the same idea as Ireland et al but do it better!
  - No need to interpolate between results from different experiments with different kinematics
  - Measure P, Σ, T, O_x, O_z, C_x, C_z all simultaneously for $\gamma p \to K^+\Lambda$
    - Requirement: **Linear** + **circular** **polarization in Hall D simultaneously (elliptical polarization)**
  - Since we are over constrained by Fierz identities: leave $\alpha\_$ as free parameter
- In practice: directly fit amplitudes to data instead of constrained polarisation observables → automatically constrained
- **Approved by PAC52 as run group addition**



Main systematic for GlueX:
Photon beam linear polarization due to dominance of amplitudes depending on linear polarisation

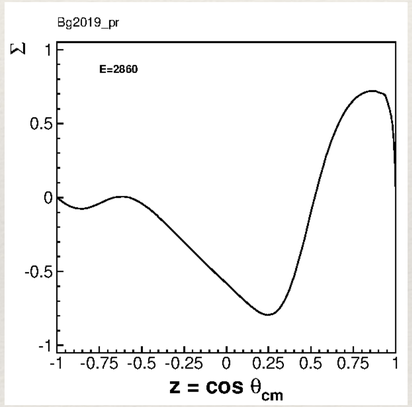
The advantage of lower energies

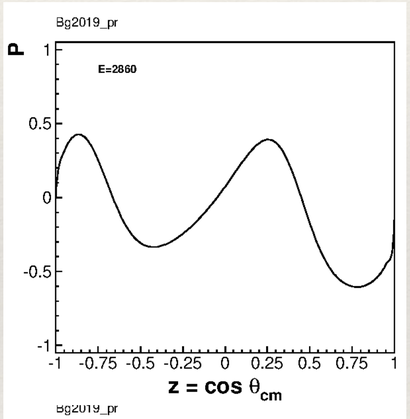
- Statistical precision:
  - Cross sections about factor 10 greater (SLAC: $\sigma \propto 1/E_\gamma^2$)
  - GlueX-II has about 220d left
    → we can double our statistics with ~3 weeks of running
    → a little over 60d would half our statistical uncertainty
  - Systematic uncertainty:
    - One would not expect to improve the systematic uncertainty on the determination of degree of linear polarisation
    - At low energies different polarisation observables would dominate
    - Access to more central events in CMS
    - *Potentially* less reliant on linear polarisation

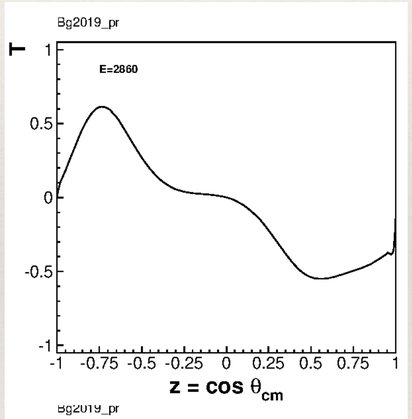


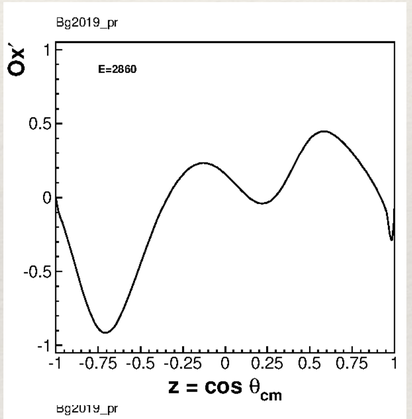
Preliminary study

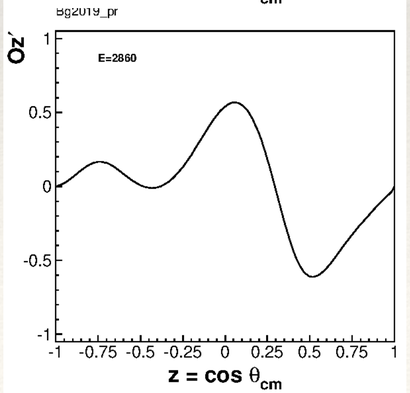
- Use BnGa partial-wave analysis results for $E_\gamma = 2860$ MeV and re-run proposal studies
  - Proposal : Σ: 0.9143 P: -0.4888 T: -0.5106 $O_{x'}$: -0.1856 $O_{z'}$: 0.2551 $C_{x'}$: 0.2886 $C_{z'}$: -0.0539
  - $\cos\theta = -0.9$: Σ: -0.0701 P: 0.4081 T: 0.3279 $O_{x'}$: -0.4011 $O_{z'}$: 0.0626 $C_{x'}$: -0.1440 $C_{z'}$: -0.8663
  - $\cos\theta = 0$: Σ: -0.5807 P: 0.0733 T: 0.0006 $O_{x'}$: 0.1596 $O_{z'}$: 0.5400 $C_{x'}$: -0.2374 $C_{z'}$: -0.5328
  - $\cos\theta = 0.9$: Σ: 0.7110 P: -0.5361 T: -0.4183 $O_{x'}$: 0.0451 $O_{z'}$: -0.1310 $C_{x'}$: -0.4291 $C_{z'}$: 0.4227

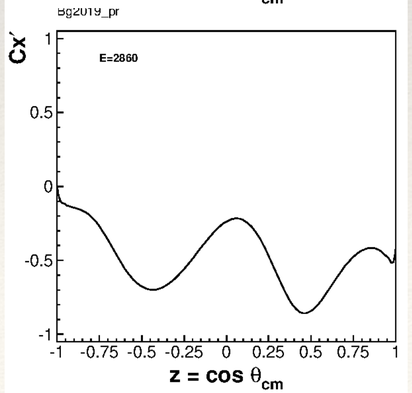


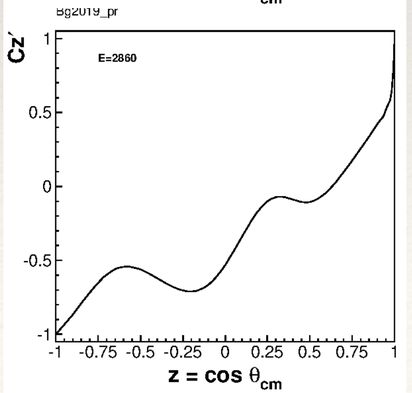








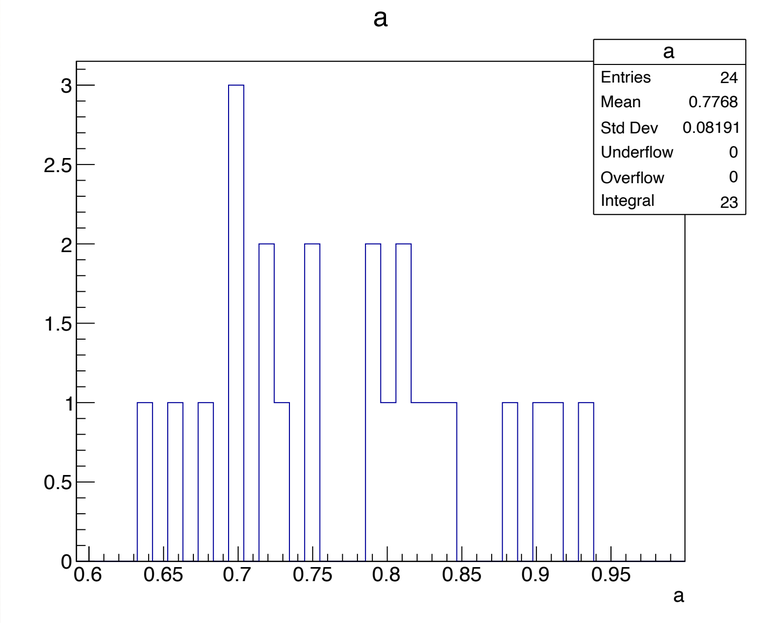


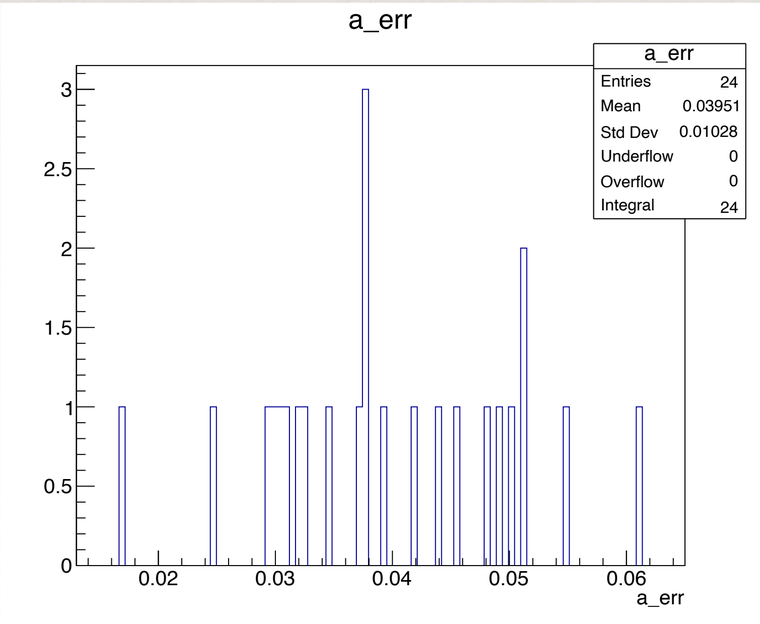


Preliminary study - 24 toys - results

Proposal values

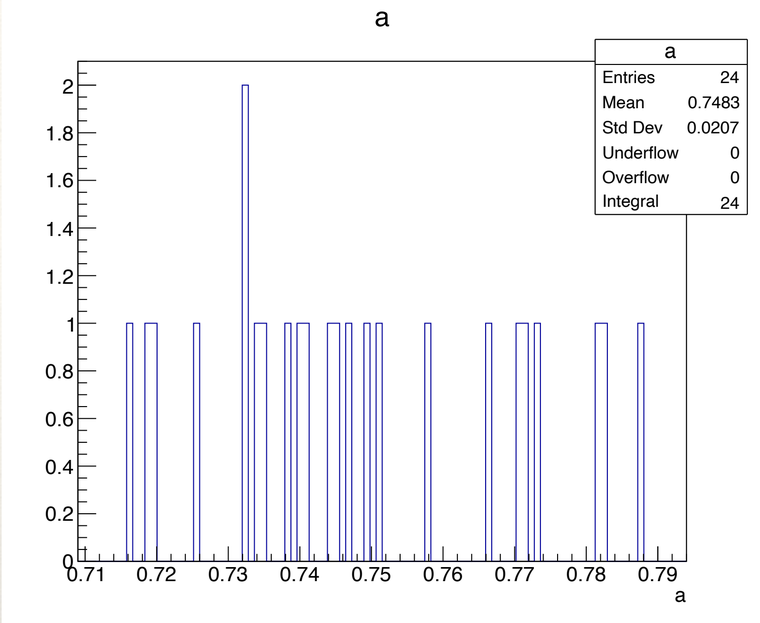
$\bar{a} \pm \overline{\Delta a} = 0.7768 \pm 0.0395$

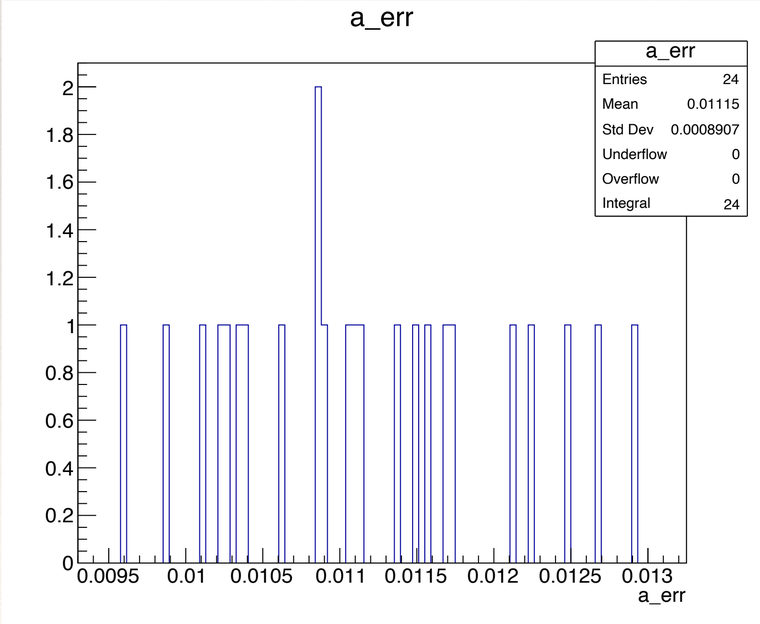




BnGa $\cos\theta = 0.9$

$\bar{a} \pm \overline{\Delta a} = 0.7483 \pm 0.0112$



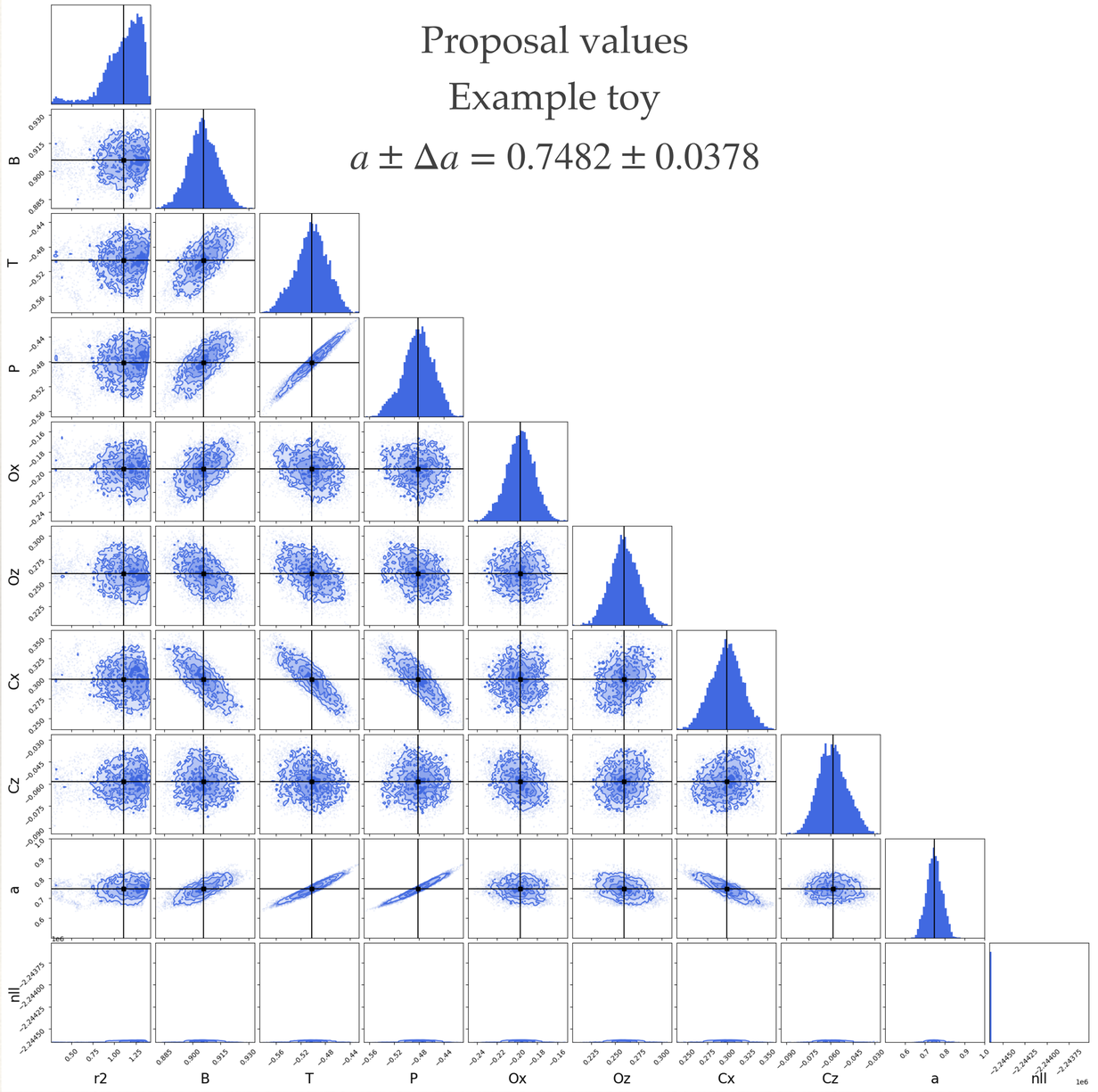


Preliminary study - 24 toys - results

Proposal values

Example toy

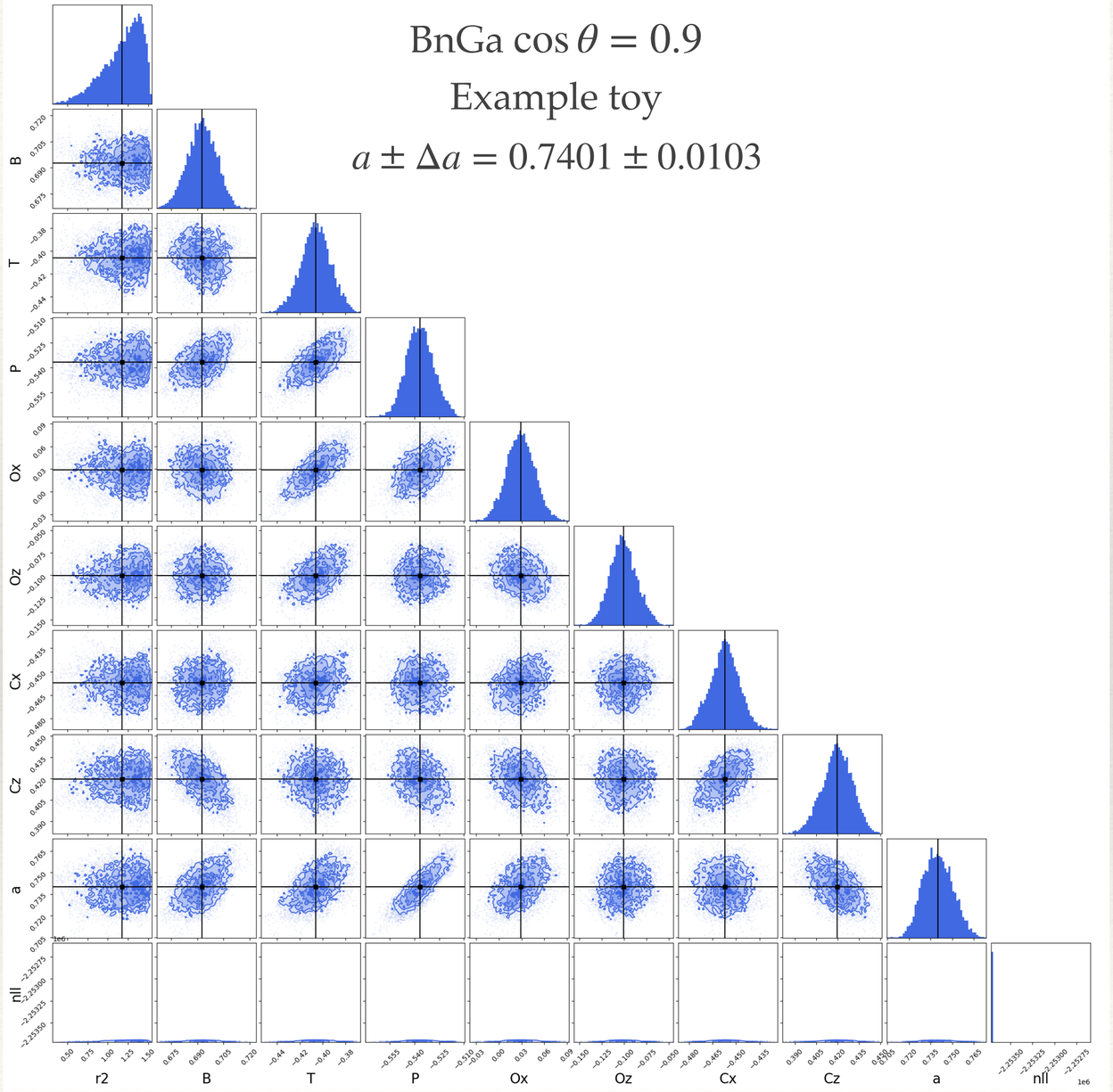
$a \pm \Delta a = 0.7482 \pm 0.0378$



BnGa $\cos\theta = 0.9$

Example toy

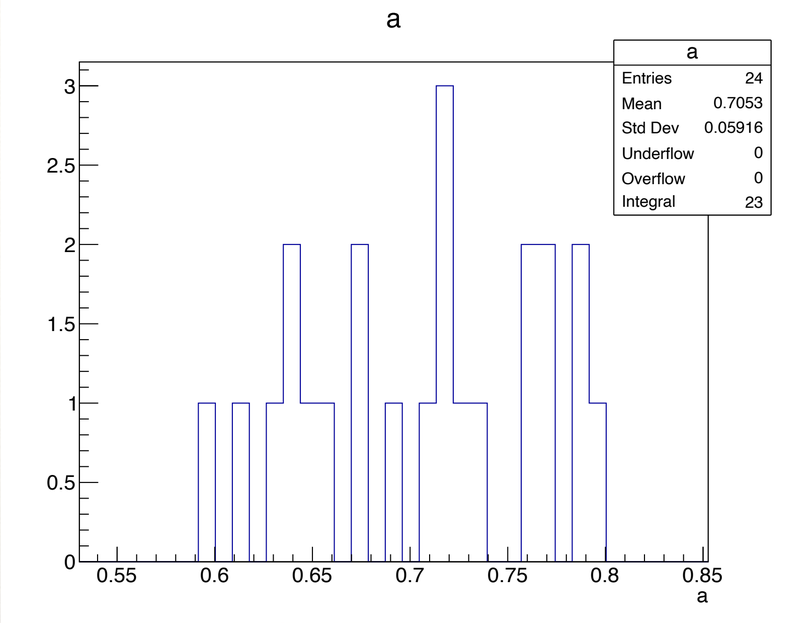
$a \pm \Delta a = 0.7401 \pm 0.0103$



Preliminary study - 24 toys with 1σ lin. pol. bias- results

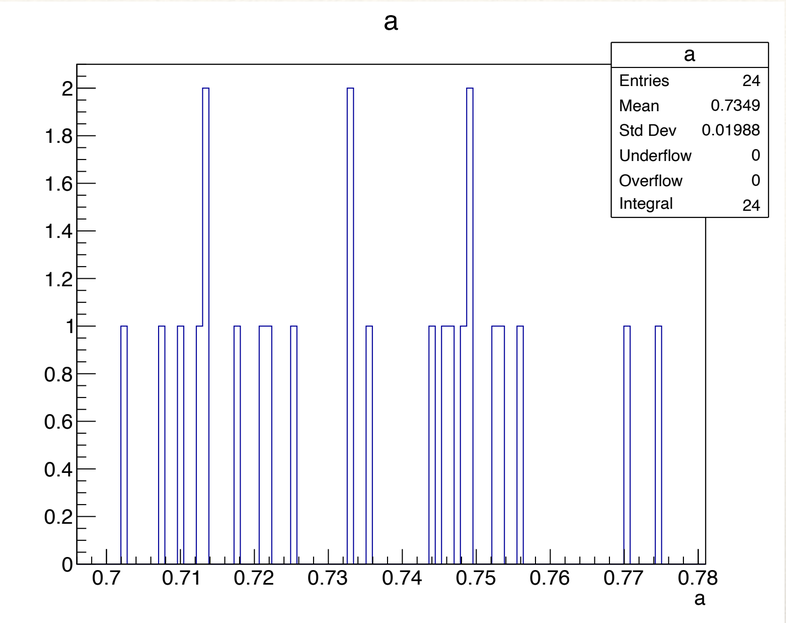
Proposal values

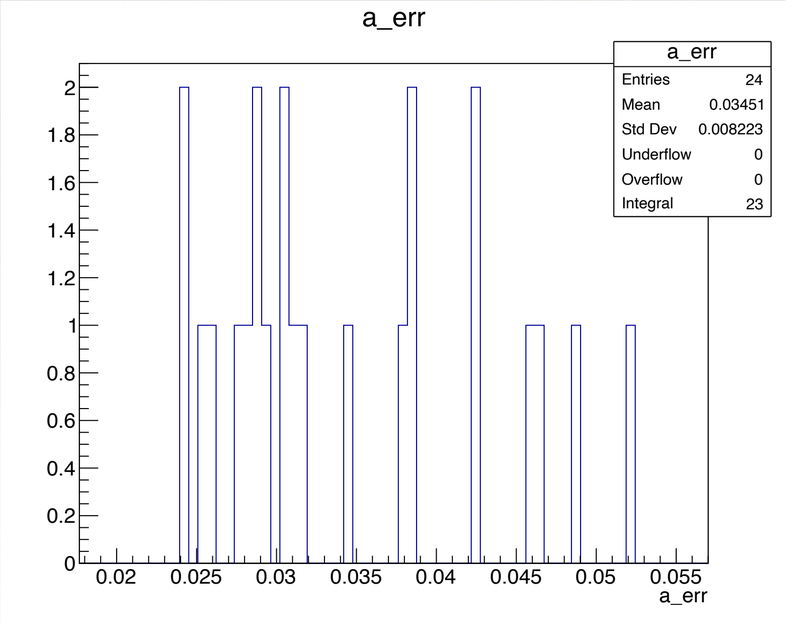
$\bar{a} \pm \overline{\Delta a} = 0.7053 \pm 0.0345$

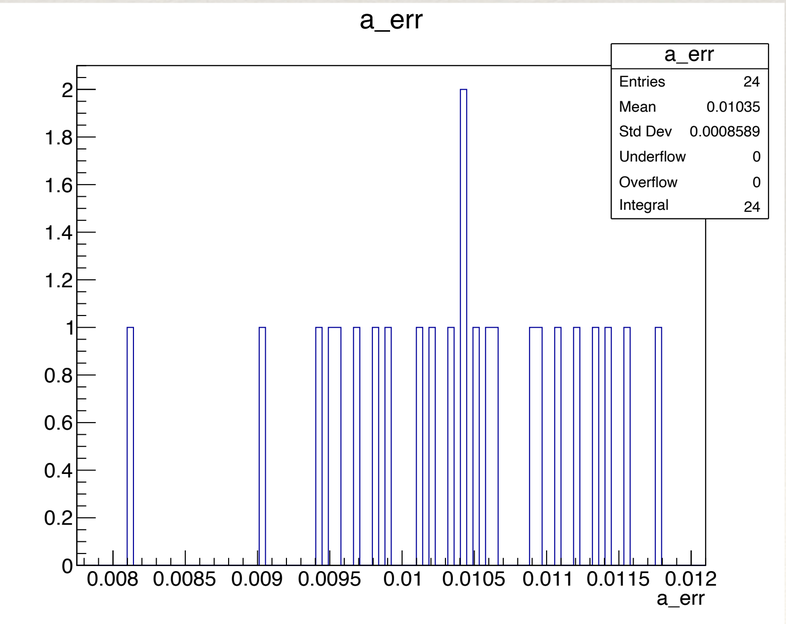


BnGa $\cos\theta = 0.9$

$\bar{a} \pm \overline{\Delta a} = 0.7349 \pm 0.0104$







Summary

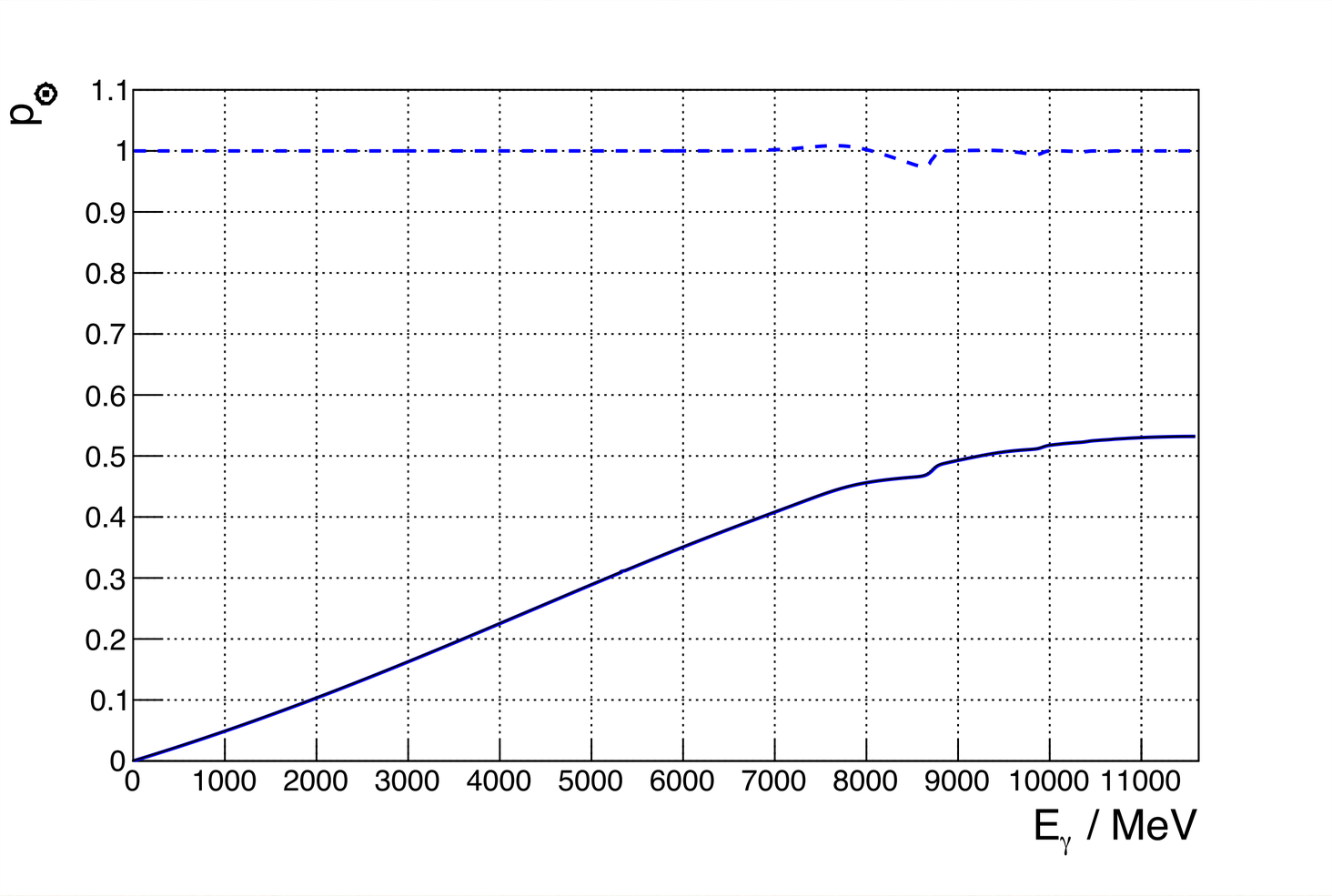
- $\alpha_$ is an important constant that recently saw large re-adjusting
- We will provide a “simple” single measurement of $\alpha_$ independent of the BESIII methodology and without the drawbacks of the Ireland et al measurement
  - run in parallel with remainder of GlueX-II

- At low energies we could
  - Quickly improve the statistical precision
  - Perform important systematic cross-checks
  - ~~*Potentially*~~ *Very likely* improve the systematics of the measurements significantly
    - Preliminary studies look very promising

Backup

Influence of linear polarization

- Effect of linear polarisation on circular polarisation is well understood and shown to be small for standard GlueX running conditions



Phys. Rev. Lett. 132.12 (2024)

2019 - a new BESIII result

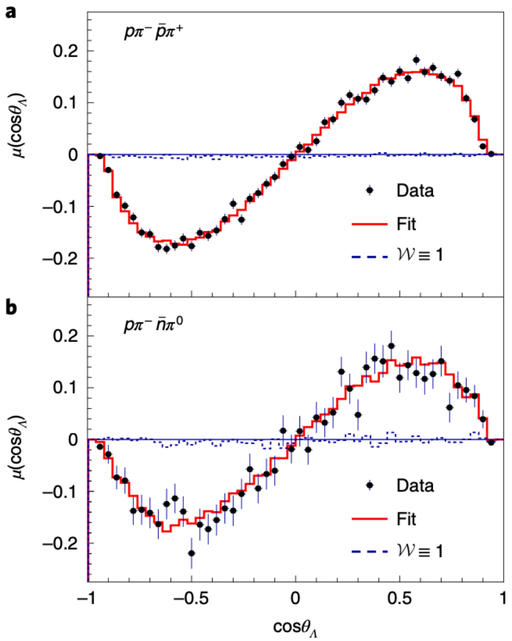
nature physics

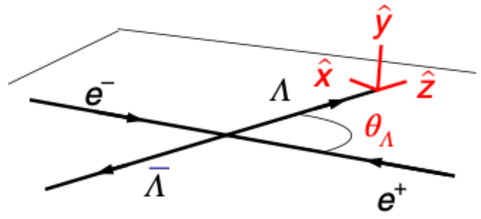
LETTERS

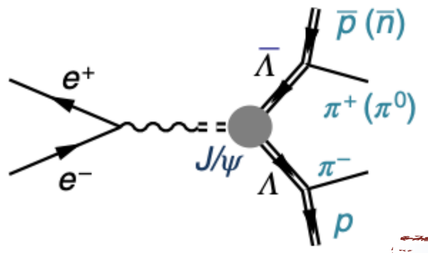
https://doi.org/10.1038/s41567-019-0494-8

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

The BESIII Collaboration*







New measurement: huge discrepancy

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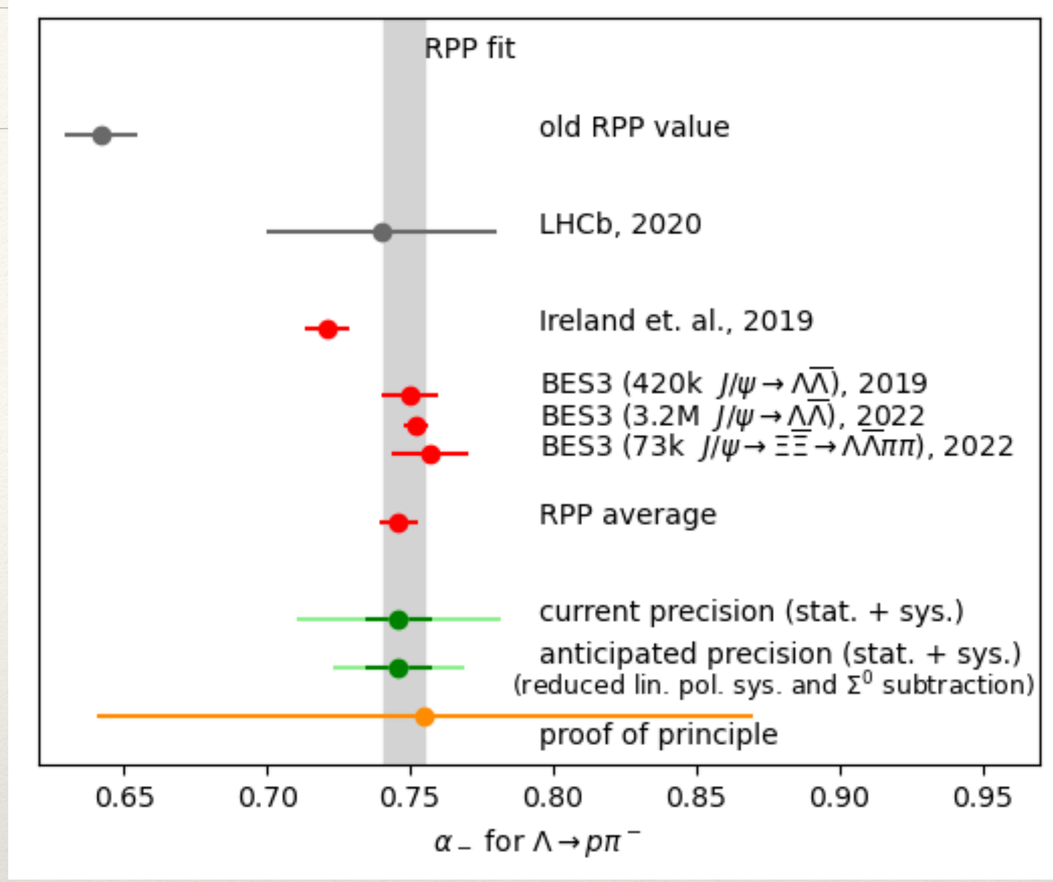
A projection from GlueX data

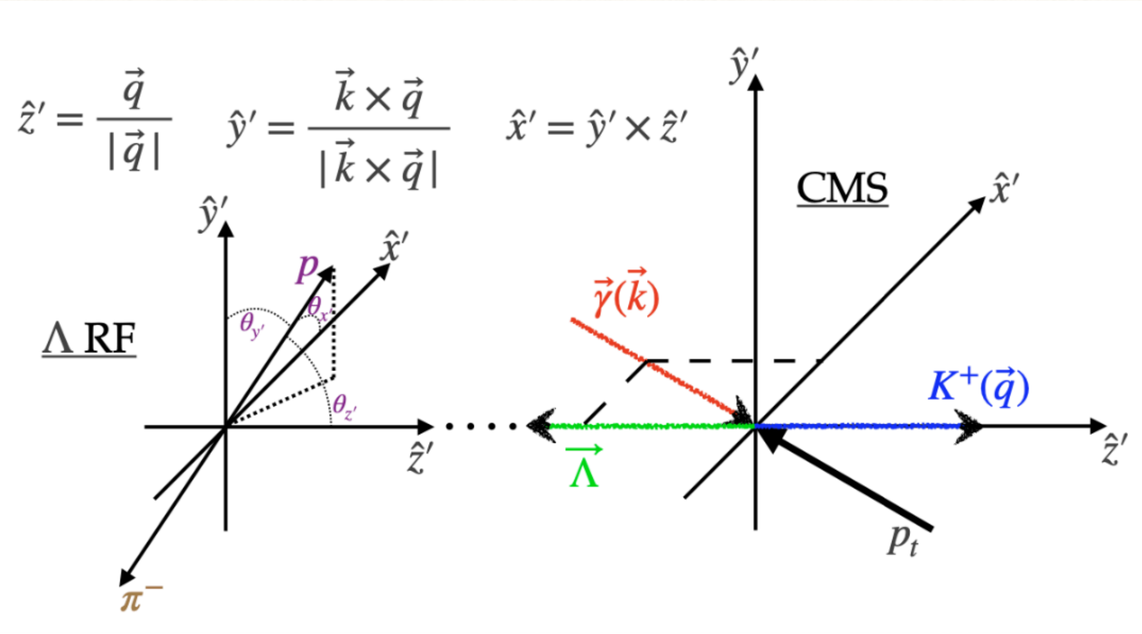
- Helicity bit was added to GlueX data stream ahead of Spring 2023 data taking
- Hall D happened to get 50-70% longitudinal polarization
  - Measured in Halls A/B and projected into Hall D via CEBAF Elegant model
- About 5% of data analysed for proof-of-concept (very preliminary, calibrations not complete yet)
- Identified ~8.6k $\gamma p \to K^+\Lambda$ events, used to extract $\alpha_- = 0.755 \pm 0.115$ (sys. only)
- Used this result together with MC studies to estimate achievable precision with remainder of GlueX-II running with ~80% longitudinal polarization → statistical precision comparable to previous results



- Anticipate some improvements to determination of linear polarization and subtraction of backgrounds
- Final anticipated uncertainties: 0.012 (stat) + 0.021 (sys)

	% uncertainty	% contribution	absolute contribution
Photon beam circular polarization	2%	<0.2%	<0.002
Photon beam linear polarization	<2%	<4%	<0.03
Acceptance	2%	2%	0.015
Σ contamination	<2.5%	<0.3%	<0.002
Total (current upper limit)		<4.5%	<0.034
Total (anticipated)		2.8%	0.021

Methodology



- Identify $\gamma p \to K^+\Lambda$, $\Lambda \to p\pi^-$
- Measure Φ, $\cos\theta_{x'}$, $\cos\theta_{y'}$, $\cos\theta_{z'}$
- Fit intensity function with $\alpha\_$ as free parameter, using transversity amplitudes

$$\frac{\mathrm{d}\sigma}{\mathrm{d}t} = |b_1|^2 + |b_2|^2 + |b_3|^2 + |b_4|^2$$
$$\Sigma\frac{\mathrm{d}\sigma}{\mathrm{d}t} = |b_1|^2 + |b_2|^2 - |b_3|^2 - |b_4|^2$$
$$T\frac{\mathrm{d}\sigma}{\mathrm{d}t} = |b_1|^2 - |b_2|^2 - |b_3|^2 + |b_4|^2$$
$$P\frac{\mathrm{d}\sigma}{\mathrm{d}t} = |b_1|^2 - |b_2|^2 + |b_3|^2 - |b_4|^2$$
$$O_{x'}\frac{\mathrm{d}\sigma}{\mathrm{d}t} = -2\,\mathrm{Re}(b_1 b_4^* - b_2 b_3^*)$$
$$O_{z'}\frac{\mathrm{d}\sigma}{\mathrm{d}t} = -2\,\mathrm{Im}(b_1 b_4^* + b_2 b_3^*)$$
$$C_{x'}\frac{\mathrm{d}\sigma}{\mathrm{d}t} = 2\,\mathrm{Im}(b_1 b_4^* - b_2 b_3^*)$$
$$C_{z'}\frac{\mathrm{d}\sigma}{\mathrm{d}t} = -2\,\mathrm{Re}(b_1 b_4^* + b_2 b_3^*)$$

$$I = 1 + \alpha_- \cos\theta_{y'} P - P_\gamma \cos(2\Phi)(\Sigma + \alpha_- \cos\theta_{y'} T) - P_\gamma \sin(2\Phi)(\alpha_- \cos\theta_{x'} O_{x'} + \alpha_- \cos\theta_{z'} O_{z'}) - P_\odot(\alpha_- \cos\theta_{x'} C_{x'} + \alpha_- \cos\theta_{z'} C_{z'})$$