Measurement of the weak decay $\Lambda \to p\pi^-$ constant α_-

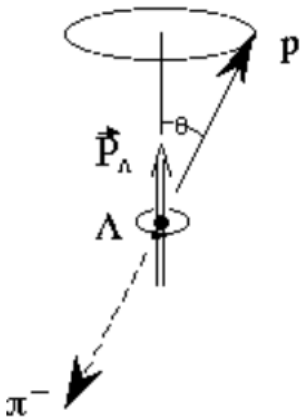
Run group proposal to run with E12-12-002A (GlueX-II)

Presented on behalf of: P. Hurck, D. Glazier, K. Livingston, F. Afzal, A. Thiel, Y. Wunderlich, V. Crede, M. Dalton

Endorsed by the GlueX Collaboration

- Running with the remaining part of GlueX-II - 118 PAC days
- Does not require any new equipment or configuration
- Does require a longitudinal electron beam polarization in Hall D:
  a matter of scheduling - optimization of the polarization for all halls,
  typically feasible by a selection of the linac energy and the initial spin rotation

Asymmetry parameter of the weak decay $\Lambda \to p\pi^-$



$$\frac{dN}{d\Omega} \propto (1 + P_\Lambda \alpha_- \cos\theta)$$

- P_Λ - polarization of Λ
- α_- - the decay asymmetry parameter
  - The asymmetry is parity-violating
  - Interference of S and P-waves (weak decays violate P)
  - Decays of unpolarized Λ produce longitudinally polarized protons $P = \alpha_-$
  - α_- was measured in many experiments since 1960-s; it has been used as an ingredient in many other polarization measurements
    A considerable revision of the measured value occurred in 2019

History of measurements and the current status

Measurements before 2019

Mostly measuring the final proton polarization

PDG 2018

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 $\pi^- p$

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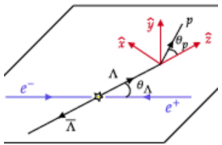
New precision measurements

BESIII $e^- + e^+ \to J/\psi\,(m = \pm 1)$

$J/\psi \to \Lambda\bar{\Lambda}$; $\Xi\bar{\Xi}$



Ablikam et al, Nature Phys. 15 (2019), PRL 129 (2022)

$$\alpha_- = 0.7519 \pm 0.0036 \pm 0.0024$$

$$\alpha_+ = -0.7559 \pm 0.0030 \pm 0.0024$$

CLAS data $\gamma p \to K^+\Lambda$ used

Ireland et al, PRL 123, 182301 (2019)

Beam circular and linear polarization

Formalism for pseudoscalar photoproduction

$$\alpha_- = 0.721 \pm 0.006 \pm 0.005$$

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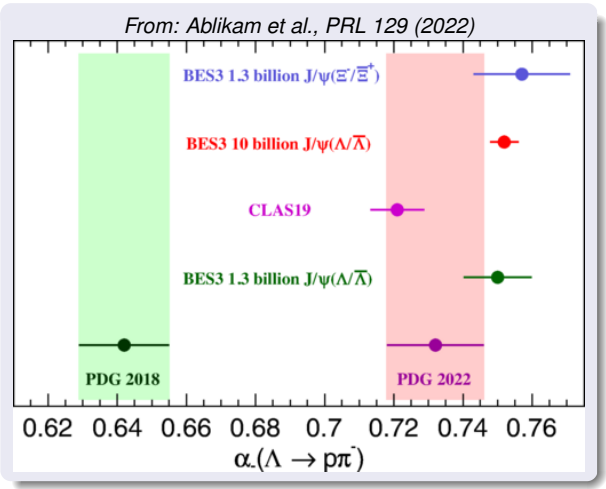

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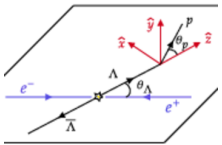

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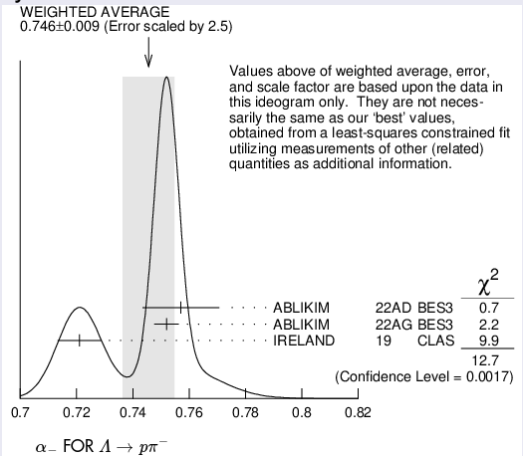
Recent PDG: best value for α

Only the BESIII and CLAS results are considered



Tension between the BESIII and CLAS results is $\approx 3.5\sigma$

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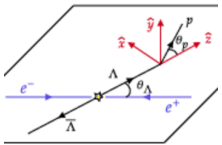
$\psi \to \Lambda\bar{\Lambda}$; $\Xi\bar{\Xi}$



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Measurement methodology for $\gamma p \to K^+\Lambda^0,\ \ \Lambda^0 \to p\pi^-$ reaction

Ireland et al, PRL 123, 182301 (2019) and references therein

Beam polarization

P_L - linear
P_C - circular

CM frame

$\vec{k}$ - photon momentum
$\vec{q}$ - Λ momentum
Φ - angle between the linear polarization and reaction planes

Λ^0 rest frame

$$\vec{z} = \frac{\vec{q}}{|\vec{q}|},\quad \vec{y} = \frac{\vec{k}\times\vec{q}}{|\vec{k}\times\vec{q}|},\quad \vec{x} = \vec{y}\times\vec{z}$$

$\vec{p}$ - proton momentum
$\cos\theta_x = \vec{p}\cdot\vec{x}/|p|,\ \ \cos\theta_y = ...$

$$\begin{aligned} I(W,t) = 1 &+ \alpha_- \cos\theta_y P \\ &- P_L \cos(2\Phi)(\Sigma + \alpha_- \cos\theta_y T) \\ &- P_L \sin(2\Phi)\,\alpha_-(\cos\theta_x O_x + \cos\theta_z O_z) \\ &- P_C\,\alpha_-(\cos\theta_x C_x + \cos\theta_z C_z) \end{aligned}$$

$\Phi, \cos\theta_x, \cos\theta_y, \cos\theta_z$ are measured
Unknown: α_- and 7 polarization observables (P.O.):
$P, \Sigma, T, O_x, O_z, C_x, C_z$ may depend on W, t
Fit data in (W, t) bins and extract α_-

Constraints - Fierz identities:

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

Ireland et al., 2019

- Used published CLAS results on different sets of P.O. extracted in different (W, t) areas
- Only 5 P.O. measured in the common (W, t) area
- Interpolation or extrapolation used

Proposed measurement in Hall D with GlueX-II

- Use $\gamma p \to K^+\Lambda^0,\ \ \Lambda^0 \to p\pi^-$, similar to *Ireland 2019*.
- Expected improvements: better understanding of the systematic errors

Pilot measurement in Hall D

- 2023: beam helicity signal added to DAQ
- GlueX-II 2023 run, 5% of data analyzed (1.5 PAC days equiv.), 8.5k $K^+\Lambda$
- Longitudinal electron polarization of $\sim$70% projected from Halls A/C measurements
- The photon beam elliptical polarization is derived from the electron beam longitudinal polarization and the linear polarization measurement
- Fit results: $\alpha_- = \ 0.75 \pm 0.11(stat)$
- Used to project the statistical error

Projection to the proposed measurement

- Assume electron polarization of $\mathrm{P_e}$ $\sim$80%
- $\delta(\alpha_-)(stat)$ would double for $\mathrm{P_e}$ $\sim$40%
- Weak impact from the $\delta(\mathrm{P_e})$ on $\delta(\alpha_-)(syst)$
- Anticipating improvements in measuring $\mathrm{P_L}$
- Projected: $\alpha_- = ? \pm 0.012 \pm 0.021$

Systematic error budget

	δ	contib. to $\delta(\alpha_-)$	
		%	absolute
Photon beam circular $\mathrm{P_C}$	2%	<0.2%	<0.002
Photon beam linear $\mathrm{P_L}$	<2%	<4%	<0.03
Acceptance	2%	2%	0.015
Σ^0 contamination	<2.5%	<0.3%	<0.002
Total (current upper limit)		<4.5%	<0.034
Total (anticipated)		<2.8%	<0.021

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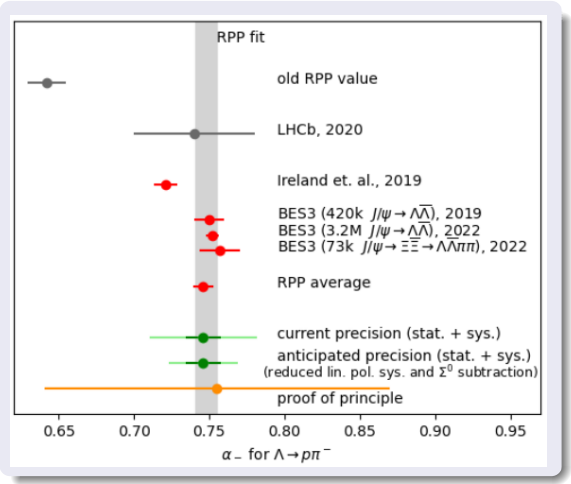

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Summary

- α_- is an important constant and an ingredient for other polarization measurements
- The measurement in Hall D would be independent of the BESIII methodology and without drawback of the *Ireland et al, 2019* measurement
- It will run in parallel with the remainder of GlueX-II
- **The only requirement is a longitudinal electron beam polarization.**
  With the regular diamond radiator it will provide an elliptical polarisation of the photon beam
- The photon beam elliptical polarization also enables:
  - Measurements of third components of SDMEs and additional constraints for amplitude analysis (core GlueX program)
  - Σ weak decay asymmetry measurement
  - Others...

BACKUP

Influence of Coherent Radiation on Circular Polarization

The effect is small and well predicted.
The calculation is done for $P_e = 53\%$.