STRONG 2020

Probing baryon weak decays - from experiment to lattice QCD

6–7 Mar 2023
Warsaw, Pasteura 7

NCBJ ŚWIERK

Artur Ukleja
Varvara Batozskaya

Patrik Adlarson
Johan Bijnens
Lars Eklund
Andrzej Kupsc
Stefan Leupold

Weak decays of strange and charm baryons:

novel sensitive experimental methods:
decay parameters, form factors, tests of fundamental symmetries
present/future results from BESIII, LHCb, Belle-II,...

Interpretation of the results, theory predictions needed

Purpose of this meeting:
motivate theory-phen efforts **for baryon decays**
understand status/prospects of LQCD calculations
Common EU theory-phen-exp applications?

Example: hyperon vs kaon non leptonic decays

Direct CP violation in K^0 decays

(I) $K^0 \to \pi^+\pi^-$ (II) $K^0 \to \pi^0\pi^0$

Two weak transitions needed
$|\Delta I| = \frac{1}{2}$ and $|\Delta I| = \frac{3}{2}$

$K^0 \to \pi^+\pi^-$ $\quad \mathcal{A}_I = A_0 \exp(i\xi_0 + i\delta_0) + A_2 \exp(i\xi_2 + i\delta_2)$

$\bar{K}^0 \to \pi^+\pi^-$ $\quad \bar{\mathcal{A}}_I = A_0 \exp(-i\xi_0 + i\delta_0) + A_2 \exp(-i\xi_2 + i\delta_2)$

$(\pi\pi)_{I=0,2}$

$$\mathrm{Re}(\epsilon') := \frac{1}{2}\frac{|\mathcal{A}_I|^2 - |\bar{\mathcal{A}}_I|^2}{|\mathcal{A}_I|^2 + |\bar{\mathcal{A}}_I|^2} \approx (\xi_0 - \xi_2)\sin(\delta_0 - \delta_2)\frac{A_2}{A_0}$$

Exp. avg PDG

$\mathrm{Re}(\epsilon'/\epsilon) = (16.6 \pm 2.3) \cdot 10^{-4}$

$|\epsilon| = (2.228 \pm 0.011) \times 10^{-3}$

$3.7(5)\times10^{-6} \approx (\xi_0 - \xi_2)\sin 47.7° \frac{1}{22}$

$(\xi_0 - \xi_2) \approx 10^{-4}$ rad

$(21.7 \pm 8.2) \times 10^{-4}$ Lattice QCD (RBC,UKQCD) *PRD* 102 (2020) 054509

Hyperon decays

Two amplitudes already for $|\Delta I| = \frac{1}{2}$ transitions

$$\left.\begin{array}{ll} \Lambda(dsu) & A(\Lambda \to p\pi^-) \\ \Xi^-(dss) & A(\Xi^- \to \Lambda\pi^-) \end{array}\right\} = S\sigma_0 + P\,\boldsymbol{\sigma}\cdot\hat{\mathbf{n}}$$

P (parity even) – p-wave final state

S (parity odd) – s-wave final state

$$S = |S|\exp(i\xi_S)\exp(i\delta_S)$$

$$P = |P|\exp(i\xi_P)\exp(i\delta_P)$$

Strong interaction in final state

weak CP-odd phases

Observables: decay width and two decay parameters

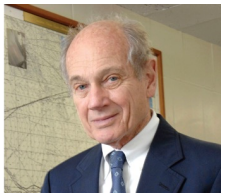
$$\alpha = \frac{2\,\mathrm{Re}(S^*P)}{|S|^2+|P|^2} \qquad \beta = \frac{2\mathrm{Im}(S^*P)}{|P|^2+|S|^2}$$

$$\beta = \sqrt{1-\alpha^2}\sin\phi$$

$$\gamma = \sqrt{1-\alpha^2}\cos\phi$$

α, β, γ measurements for $\Lambda \to p\pi^-$

James Cronin
1931-2016



Oliver Overseth
1928-2008

PHYSICAL REVIEW VOLUME 129, NUMBER 4 15 FEBRUARY 1963

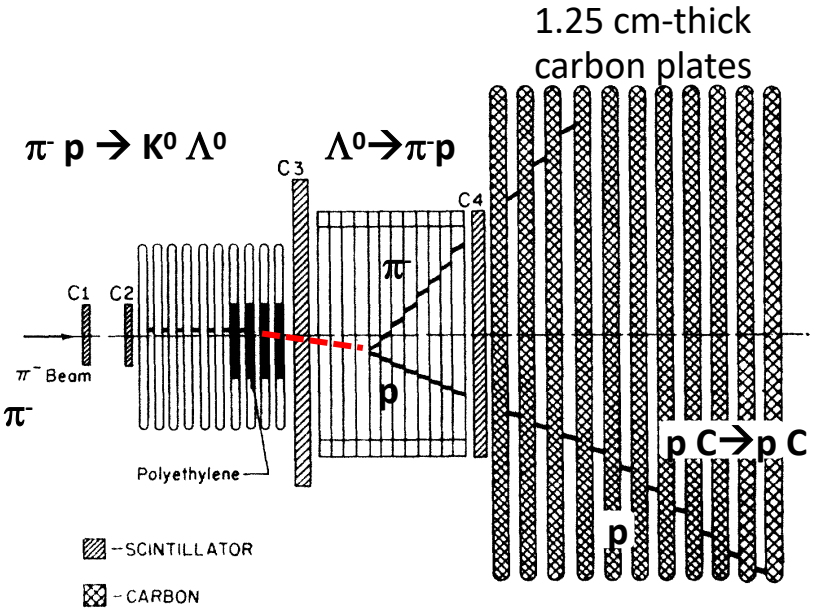
Measurement of the Decay Parameters of the Λ^0 Particle*

JAMES W. CRONIN AND OLIVER E. OVERSETH†
Palmer Physical Laboratory, Princeton University, Princeton, New Jersey
(Received 26 September 1962)

The decay parameters of $\Lambda^0 \to \pi^- + p$ have been measured by observing the polarization of the decay protons by scattering in a carbon-plate spark chamber. The experimental procedure is discussed in some detail. A total of 1156 decays with useful proton scatters was obtained. The results are expressed in terms of polarization parameters, α, β, and γ given below:

$$\alpha = 2\,\mathrm{Re}sp^*/(|s|^2+|p|^2) = +0.62\pm0.07,$$
$$\beta = 2\,\mathrm{Im}sp^*/(|s|^2+|p|^2) = +0.18\pm0.24,$$
$$\gamma = (|s|^2-|p|^2)/(|s|^2+|p|^2) = +0.78\pm0.06,$$

where s and p are the s- and p-wave decay amplitudes in an effective Hamiltonian $s+p\boldsymbol{\sigma}\cdot\mathbf{p}/|\mathbf{p}|$, where $\mathbf{p}$ is the momentum of the decay proton in the center-of-mass system of the Λ^0, and $\boldsymbol{\sigma}$ is the Pauli spin operator. The helicity of the decay proton is positive. The ratio $|p|/|s|$ is $0.36^{+0.05}_{-0.06}$ which supports the conclusion that the $K\Lambda N$ parity is odd. The result $\beta = 0.18\pm0.24$ is consistent with the value $\beta = 0.08$ expected on the basis of time-reversal invariance.



no H_2 target, no magnet;
use kinematics and proton's range in carbon to infer E_p

$$P_p = \frac{(\alpha + P_\Lambda \cos\theta)\hat{z}' + \beta P_\Lambda \hat{x}' + \gamma P_\Lambda \hat{y}'}{1 + \alpha P_\Lambda \cos\theta}$$

$$\alpha_\Lambda = 0.62(7)$$

Slide from Steve Olsen

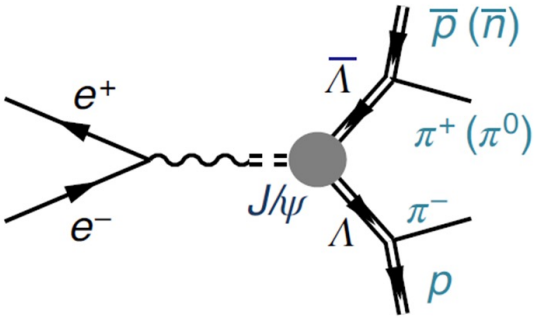
nature physics
LETTERS
https://doi.org/10.1038/s41567-019-0494-8

$e^+e^- \to J/\psi \to \Lambda\bar{\Lambda}$

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

The BESIII Collaboration*

Nature Phys. 15 (2019) 631



Phys.Rev.Lett. 129 (2022) 131801

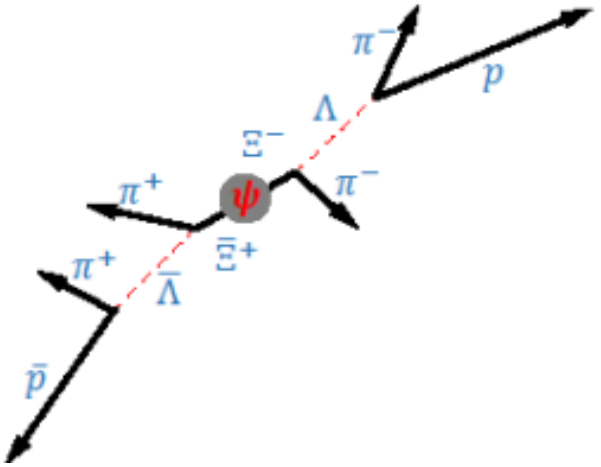
$e^+e^- \to J/\psi \to \Xi^-\bar{\Xi}^+$

Article | Open Access | Published: 01 June 2022

Probing CP symmetry and weak phases with entangled double-strange baryons

The BESIII Collaboration

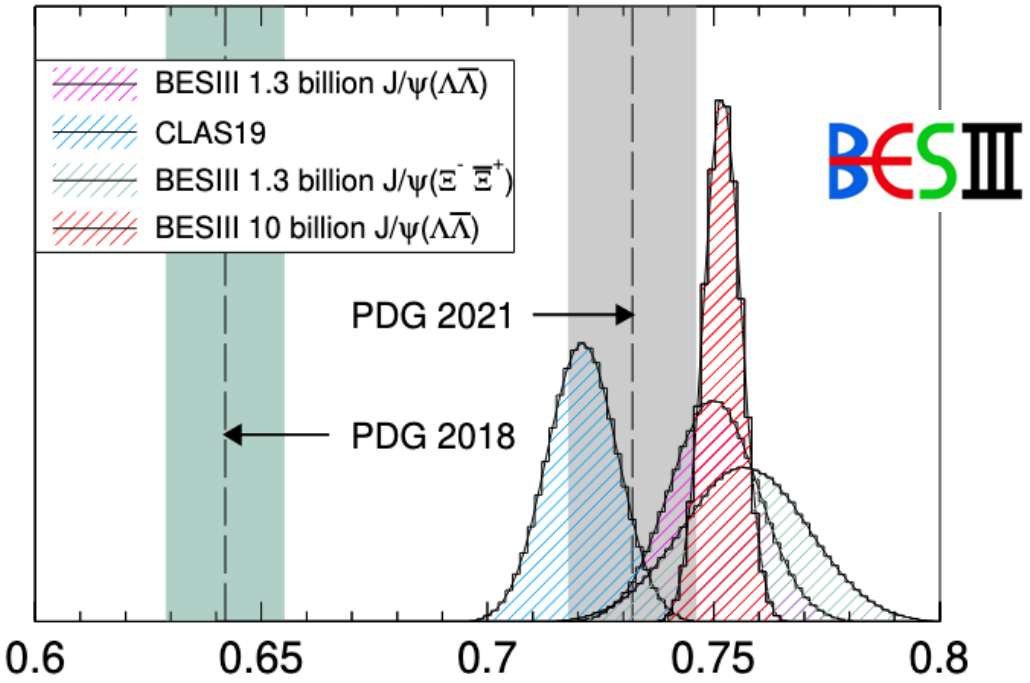
Nature **606**, 64–69 (2022) | Cite this article



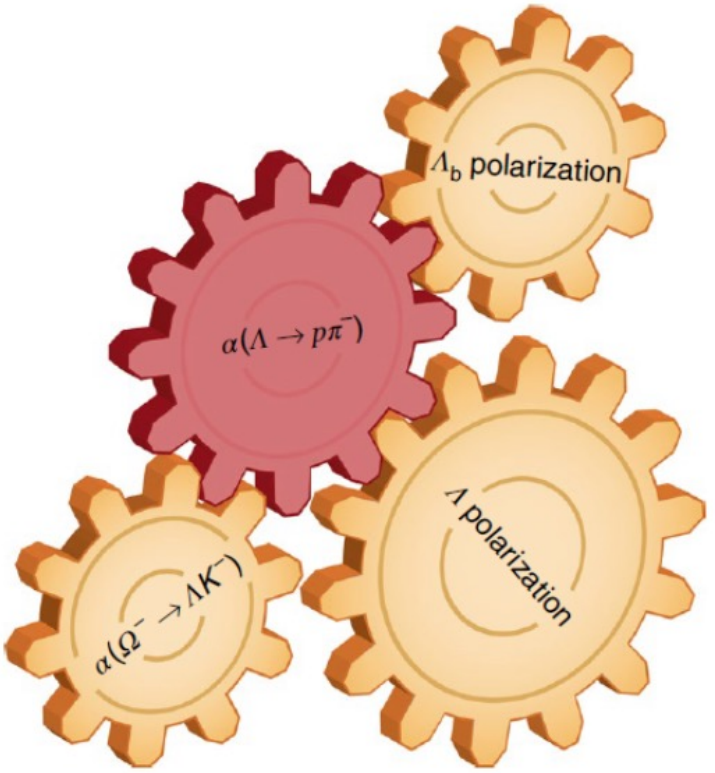
Methods:

Fäldt, AK PLB 772 (2017) 16
Perotti, Fäldt, AK, Leupold, Song PRD99 (2019)056008
Adlarson, AK PRD 100 (2019) 114005
Salone,Adlarson,Batozskaya, AK,Leupold,Tandean PRD 105 (2022) 116022
Batozskaya, AK, Salone,Wiechnik 2302.07665 [hep-ph]

Decay parameters



$\alpha(\Lambda \rightarrow p\pi^-)$



news & views

PARTICLE PHYSICS

Anomalous asymmetry

A measurement based on quantum entanglement of the parameter describing the asymmetry of the Λ hyperon decay is inconsistent with the current world average. This shows that relying on previous measurements can be hazardous.

Ulrik Egede

CPV tests in hyperon decays

$$\Xi^- \to \Lambda\pi^- \qquad\qquad \bar{\Xi}^+ \to \bar{\Lambda}\pi^+$$

$$S = |S|\exp(i\xi_S + i\delta_S) \qquad \bar{S} = |S|\exp(-i\xi_S + i\delta_S)$$

$$P = |P|\exp(i\xi_P + i\delta_P) \qquad \bar{P} = -|P|\exp(-i\xi_P + i\delta_P)$$

CP-odd phases

$$A_{CP} := \frac{\alpha + \bar{\alpha}}{\alpha - \bar{\alpha}} \text{ and } B_{CP} := \frac{\beta + \bar{\beta}}{\alpha - \bar{\alpha}} \qquad \Phi_{CP} = \frac{\phi + \bar{\phi}}{2}$$

$$A_{\rm CP} = -\frac{\sqrt{1-\alpha^2}}{\alpha}\sin\phi\tan(\xi_P - \xi_S)$$

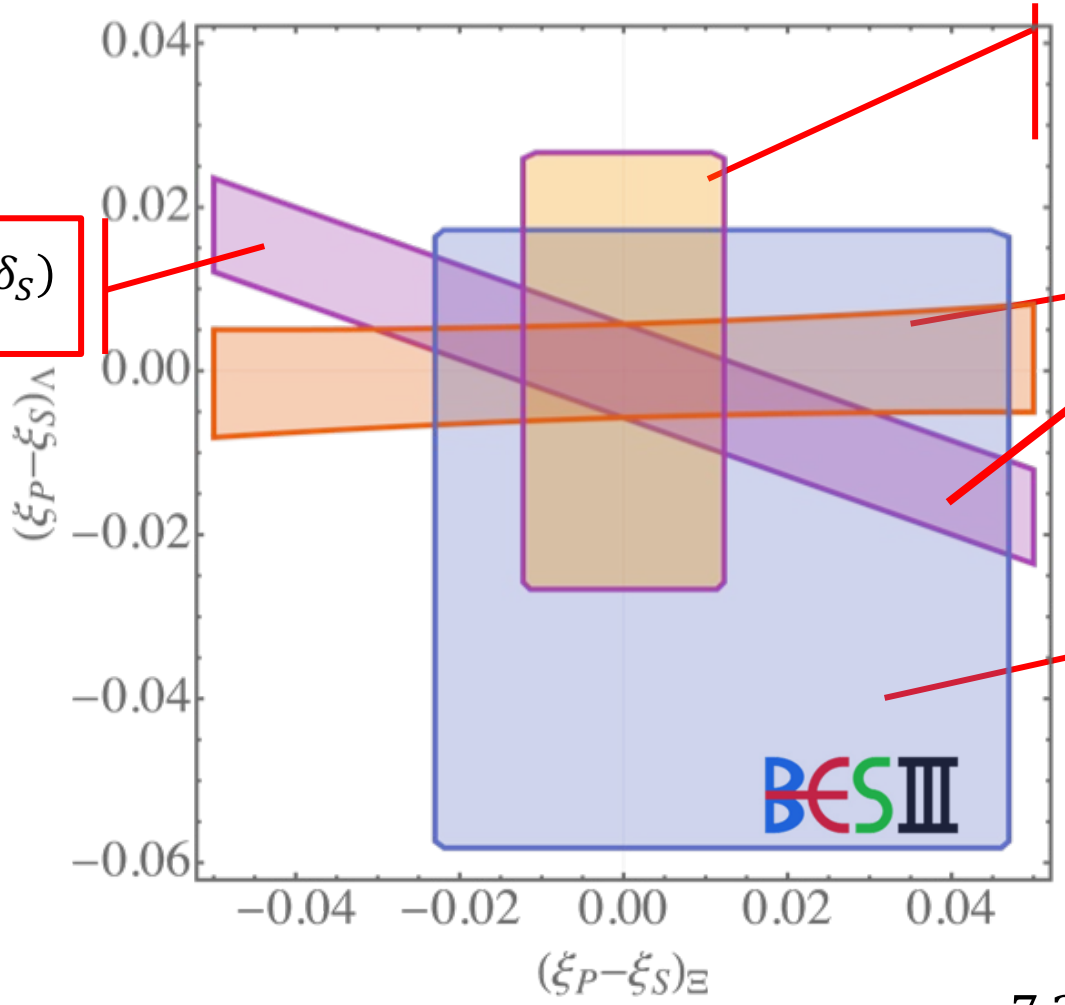
$$= -\tan(\delta_P - \delta_S)\tan(\xi_P - \xi_S)$$

$$B_{\rm CP} = \tan(\xi_P - \xi_S)\ ,$$

$$\Phi_{\rm CP} = \frac{\alpha}{\sqrt{1-\alpha^2}}\cos\phi\tan(\xi_P - \xi_S)$$

$|\Delta I| = \frac{1}{2}$ limit

Hyperon weak phases



$\Lambda\pi$ $(\delta_P - \delta_S)$ theory

BESIII projection

HyperCP

1.2×10^8 Ξ^- 4.1×10^7 $\bar{\Xi}^+$

BESIII

Nature 606 (2022) 64

+BES22Λ

7.3×10^4 Ξ^- $\bar{\Xi}^+$ and 3.2×10^6 $\Lambda\bar{\Lambda}$

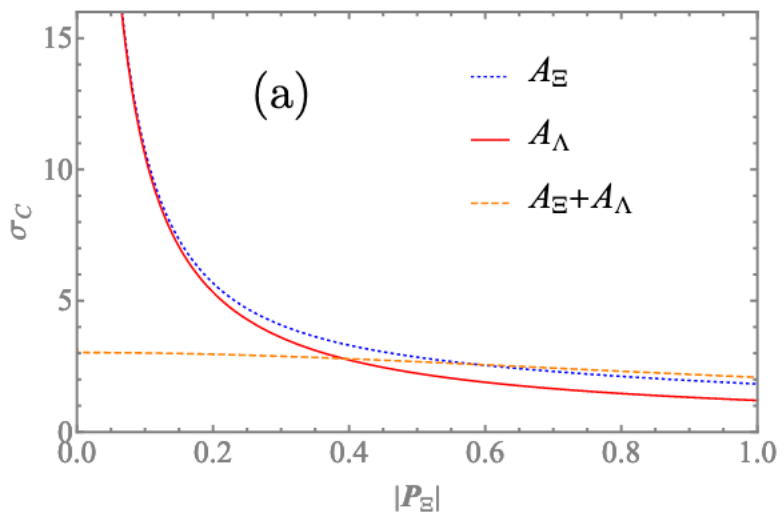
$$-3.8\times10^{-4} < (\xi_P - \xi_S)^{\mathrm{SM}}_{\Xi} < -0.4\times10^{-4}$$

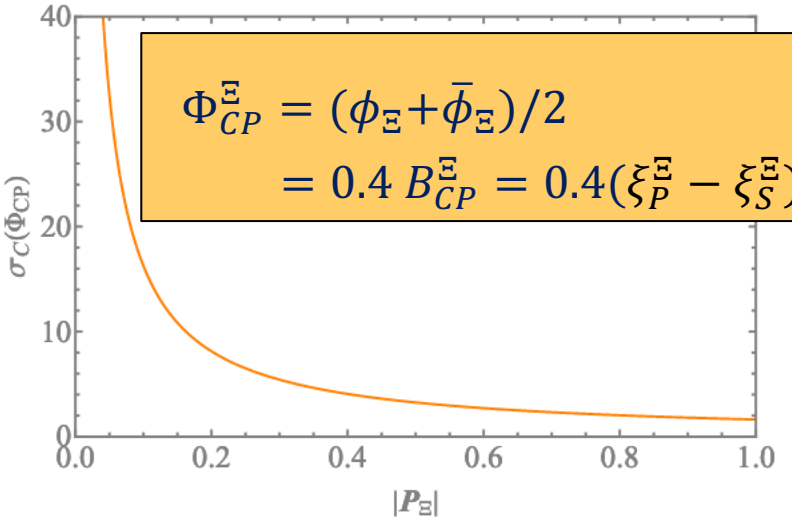
$$-2.4\times10^{-4} < (\xi_P - \xi_S)^{\mathrm{SM}}_{\Lambda} < -2.0\times10^{-4}$$

HyperCP PRL 93 (2004) 262001

HyperCP measurements

$\Xi^- \to \Lambda\pi^- \to p\pi^-\pi^-$+c.c

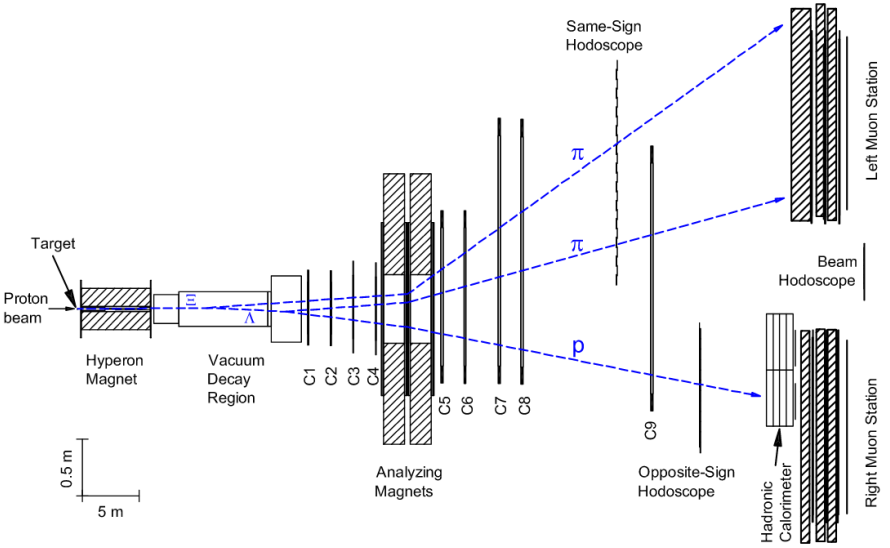




$$\Phi_{CP}^{\Xi} = (\phi_\Xi + \bar{\phi}_\Xi)/2 = 0.4\, B_{CP}^{\Xi} = 0.4(\xi_P^{\Xi} - \xi_S^{\Xi})$$

$$A_\Xi + A_\Lambda = (0.0 \pm 5.1 \pm 4.4)\times 10^{-4}$$

HyperCP PRL 93 (2004) 262001



1.2×10^8 Ξ^- **4.1×10^7** $\bar{\Xi}^+$

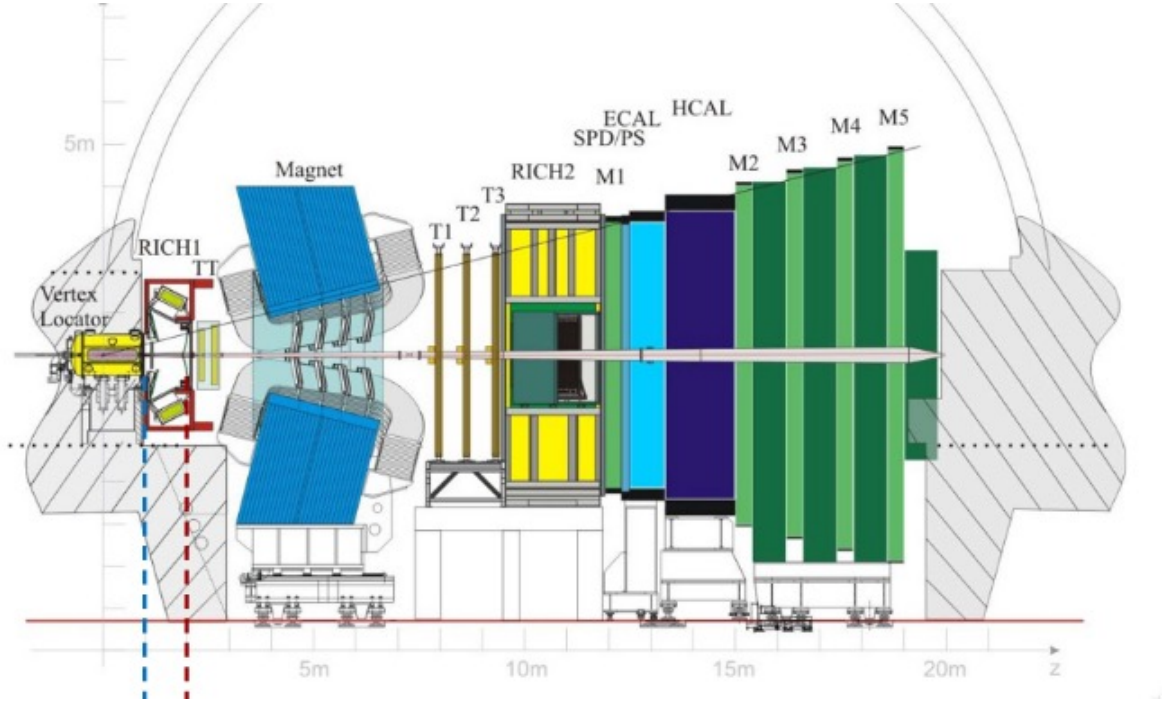
Ξ^- Polarization (3.7%)

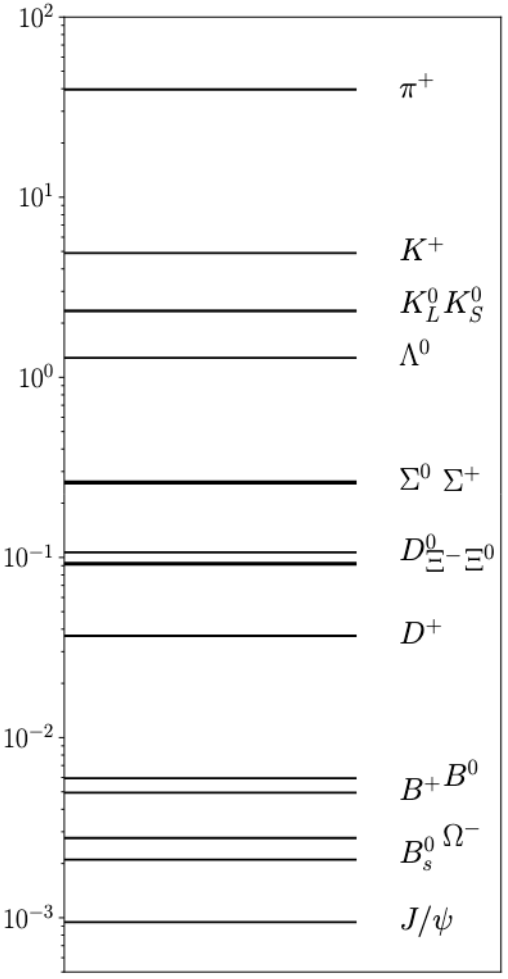
Improved **HyperCP** measurement at LHCb?

$$\Xi^- \to \Lambda\pi^- \to p\pi^-\pi^- + \text{c.c}$$

$\Xi^-(\bar{\Xi}^+)$ **Polarization (** 60%)
nearly symmetric acceptance

LHCb





#particles per pp interaction
(√s = 13 TeV at LHCb

JHEP05(2019)048

We would like to understand prospects for calculating properties of weak baryon decays (in particular from the lattice)

The main topics for the discussion:

- strange, charm (beauty?) baryon decays: (non-leptonic, semileptonic, radiative)
- static properties (magnetic dipole moments)
- tests of fundamental symmetries CPV

Ideas for new projects and future collaborations