Measurements of isospin amplitudes in Λ_b^0 and Ξ_b^0 decays at LHCb

Arvind Venkat (arvenkat@syr.edu)
On behalf of the LHCb Collaboration

Phenomenology Symposium 2020
5 May 2020

PRL 124, 111802

Motivation

arXiv:1912.0211

- $\mathbf{K \to \pi\pi}$ decays: $\mathbf{\Delta I = 1/2}$ rule is a well known disparity in the isospin amplitudes A_0 and A_2
  - $R = \text{Re}\, A_2/\text{Re}\, A_0$

Experimental Measurement [1]	22.45 ± 0.06
Analytical Calculation [2]	16.0 ± 0.15
Lattice Calculation [1]	$19.9 \pm 2.3 \pm 2.4$
”no QCD” limit [2]	$\sqrt{2}$

← 31.1 ± 10.9 (OLD)

Note A_i is notated with final state isospin in subscript, on all slides

- $\Delta I = 1/2$ rule doesn’t translate easily to heavy flavour mesons (obtained from fits to data):
  - $D \to \pi\pi$[3] : $|A_0/A_2| \approx 2.5$ (O(1) enhancement)
  - $B \to \pi\pi$[4] : $|A_0/A_2| \approx 1.5$ (Close to “no QCD” limit)

[1] arXiv:2004.09440 – RBC, UKQCD

[2] arXiv:1401.1385 – Buras et. al.

[3] arXiv:1203.3131 – Franco et. al.

[4] arXiv:1402.1164 – Grinstein et. al.

Motivation

arXiv:1912.0211

- The Λ_b is predicted to be an iso-scalar by the quark model
  - Needs experimental support

- Isospin suppression commonly assumed in past analyses of Λ_b decays
  - Pentaquark analysis in $\Lambda_b \to J/\psi\ p\ K^-$ assumed suppression of $\Lambda_b \to J/\psi\ \Sigma^*$ w.r.t. $\Lambda_b \to J/\psi\ \Lambda^*$
  - Measurement of V_{ub} from $\Lambda_b \to p\mu\nu$ assumed suppression of $\Lambda_b \to N^*\mu\nu$

- Diquark structure of Λ_b
  - Baryons hypothesized to be built from a light diquark (ud) and a heavy quark.
  - If present, would be another suppression of isospin violation.
  - Commonly, isospin breaking is seen at ~1% in rate.

$\Lambda_b \to J/\psi\, \Lambda(\Sigma^0)\,, \Xi_b^0 \to J/\psi\, \Xi^0(\Lambda)$

arXiv:1912.0211

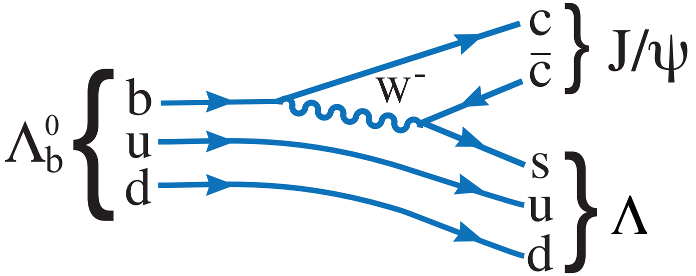
- Quark model assumes Λ_b as isospin 0, and Ξ_b^0 as isospin $1/2$

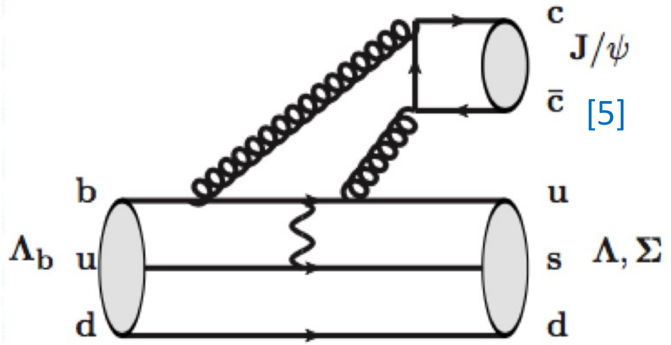
- $b \to c\bar{c}s$ is purely isospin 0
  - Naively, isospin breaking cannot be generated at tree level, if light quarks are just spectators
  - Isospin 1 final state could be generated through $\Lambda - \Sigma$ mixing, an exchange diagram, or through NP amplitudes
  - Tree diagram $\propto V_{cb}^* V_{cs} \sim\lambda^2$
  - Exchange diagram $\propto V_{ub}^* V_{us} \sim\lambda^4$

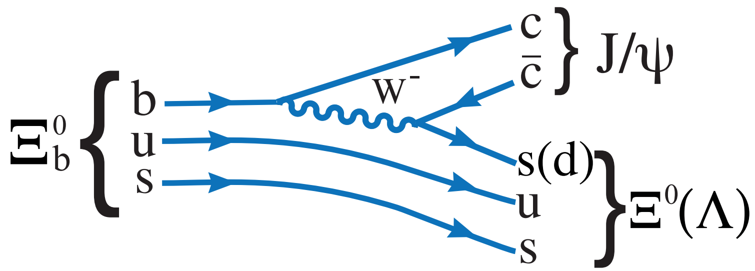
- $b \to c\bar{c}d$ changes isospin in Ξ_b^0 decay

- According to the quark model,
  - $\Lambda_b \to J/\psi\ \Lambda$ is purely $\Delta I = 0$ (A_0 amplitude)
  - $\Lambda_b \to J/\psi\ \Sigma^0$ is purely $\Delta I = 1$ (A_1 amplitude)
  - $\Xi_b^0 \to J/\psi\ \Xi^0$ is purely $\Delta I = 0$ ($A_{1/2}$ amplitude)
  - $\Xi_b^0 \to J/\psi\ \Lambda$ is purely $\Delta I = 1/2$ (A_0 amplitude)

- Neither $\Lambda_b \to J/\psi\Sigma^0$ nor $\Xi_b^0 \to J/\psi\Lambda$ had been observed before.







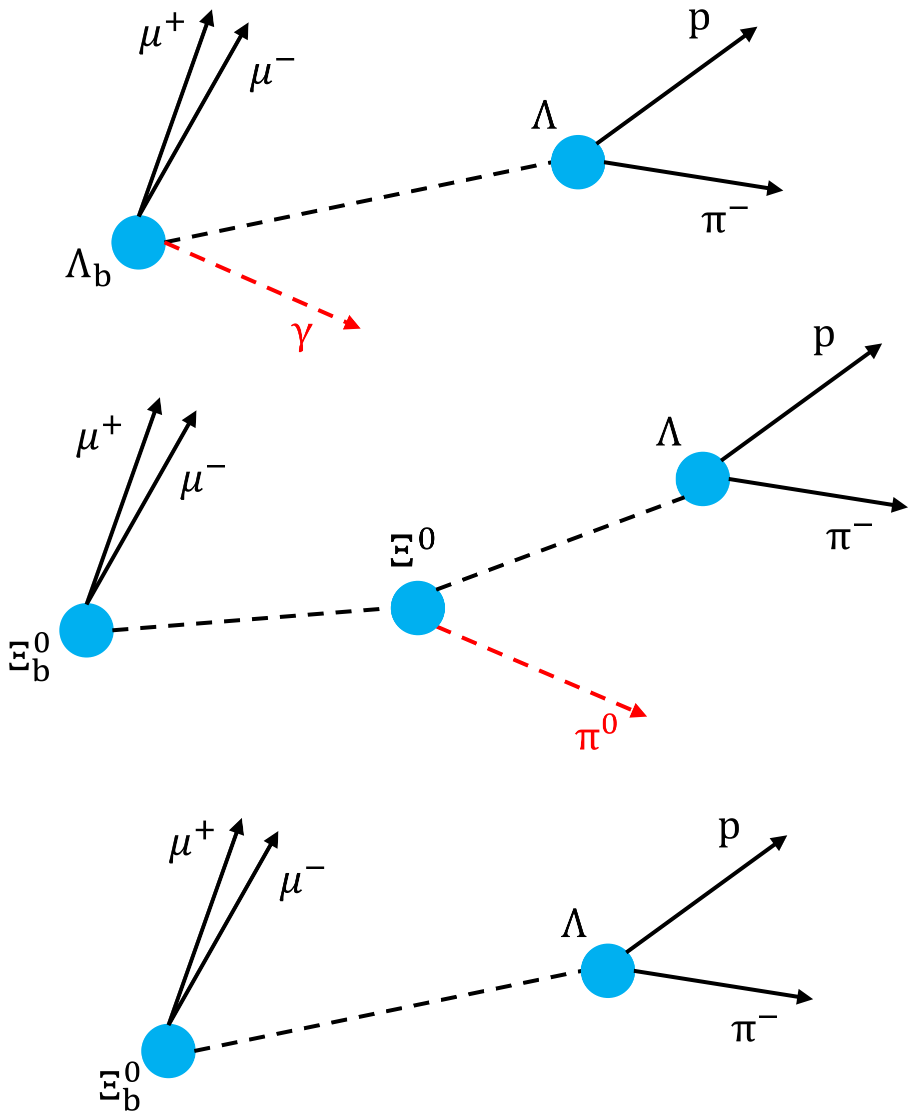
[5] arXiv:2001.05397 – Dery et. al.

Signal Decays

arXiv:1912.0211

- Our Λ_b signal decays are:
  - $\Lambda_b \rightarrow J/\psi\, \Lambda$
  - $\Lambda_b \rightarrow J/\psi\, \Sigma^0, \Sigma^0 \rightarrow \Lambda\gamma$
- Our Ξ_b^0 signal decays are
  - $\Xi_b^0 \rightarrow J/\psi\, \Xi^0,\ \Xi^0 \rightarrow \Lambda\pi^0$
  - $\Xi_b^0 \rightarrow J/\psi\, \Lambda$
- All four signal modes are reconstructed as $J/\psi\, \Lambda$
  - $J/\psi \rightarrow \mu^+\mu^-$
  - $\Lambda \rightarrow p\pi^-$
- We perform selections involving multivariate classifiers that exploit the isolation of the J/ψ in all our signal decays, using the full LHCb data-set (Run 1 + Run2)

Not reconstructed

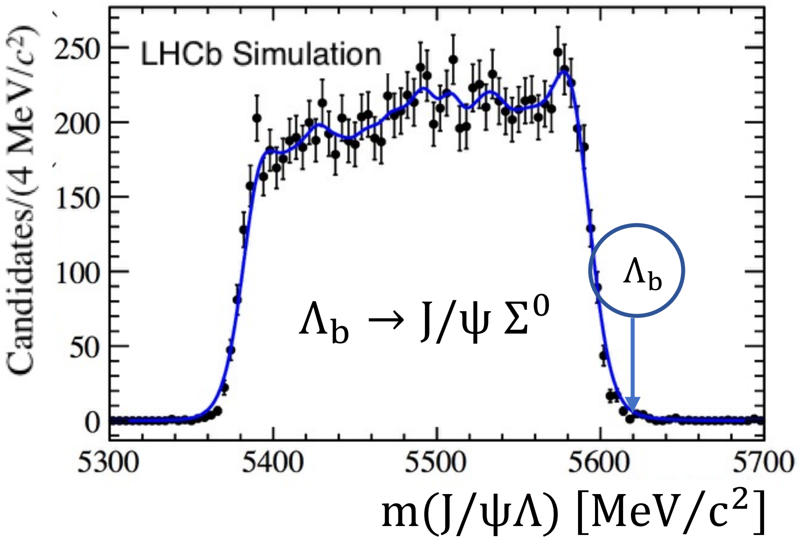


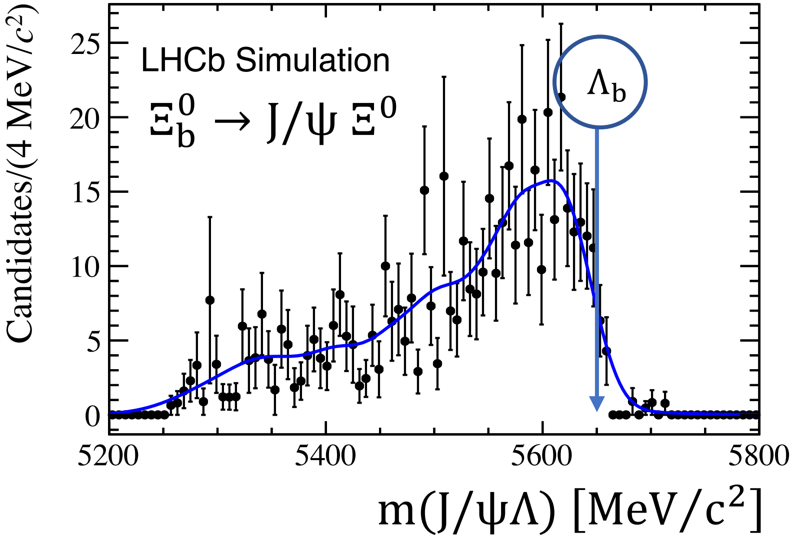
Signal Decays

arXiv:1912.0211

- Our Λ_b signal decays are:
  - $\Lambda_b \to J/\psi\,\Lambda$
  - $\Lambda_b \to J/\psi\,\Sigma^0, \Sigma^0 \to \Lambda\gamma$
- Our Ξ_b^0 signal decays are
  - $\Xi_b^0 \to J/\psi\,\Xi^0,\ \Xi^0 \to \Lambda\pi^0$
  - $\Xi_b^0 \to J/\psi\,\Lambda$
- All four signal modes are reconstructed as $J/\psi\,\Lambda$
  - $J/\psi \to \mu^+\mu^-$
  - $\Lambda \to p\pi^-$
- We perform selections involving multivariate classifiers that exploit the isolation of the J/ψ in all our signal decays , using the full LHCb data-set (Run 1 + Run2)

Not reconstructed





Observables of Interest

arXiv:1912.0211

- In the Λ_b decays:
  - $\mathcal{R}_{\Lambda_b} \equiv \frac{|A_1|^2}{|A_0|^2} = \frac{\mathcal{B}(\Lambda_b \to J/\psi\, \Sigma^0)}{\mathcal{B}(\Lambda_b \to J/\psi\, \Lambda)} \cdot \Phi_{\Lambda_b} = \frac{N_{corr}(\Lambda_b \to J/\psi\, \Sigma^0)}{N_{corr}(\Lambda_b \to J/\psi\, \Lambda)} \cdot \Phi_{\Lambda_b}$
- In the Ξ_b^0 decays:
  - $\mathcal{R}_{\Xi_b} \equiv \frac{\mathcal{B}(\Xi_b^0 \to J/\psi\, \Lambda)}{\mathcal{B}(\Xi_b^0 \to J/\psi\, \Xi^0)} = \frac{N_{corr}(\Xi_b^0 \to J/\psi\, \Lambda)}{N_{corr}(\Xi_b^0 \to J/\psi\, \Xi^0)}$
  - $\left|\frac{A_0}{A_{1/2}}\right| = \frac{1}{\lambda}\sqrt{\mathcal{R}_{\Xi_b}/\Phi_{\Xi_b}}$

N_{corr} - efficiency corr. yield

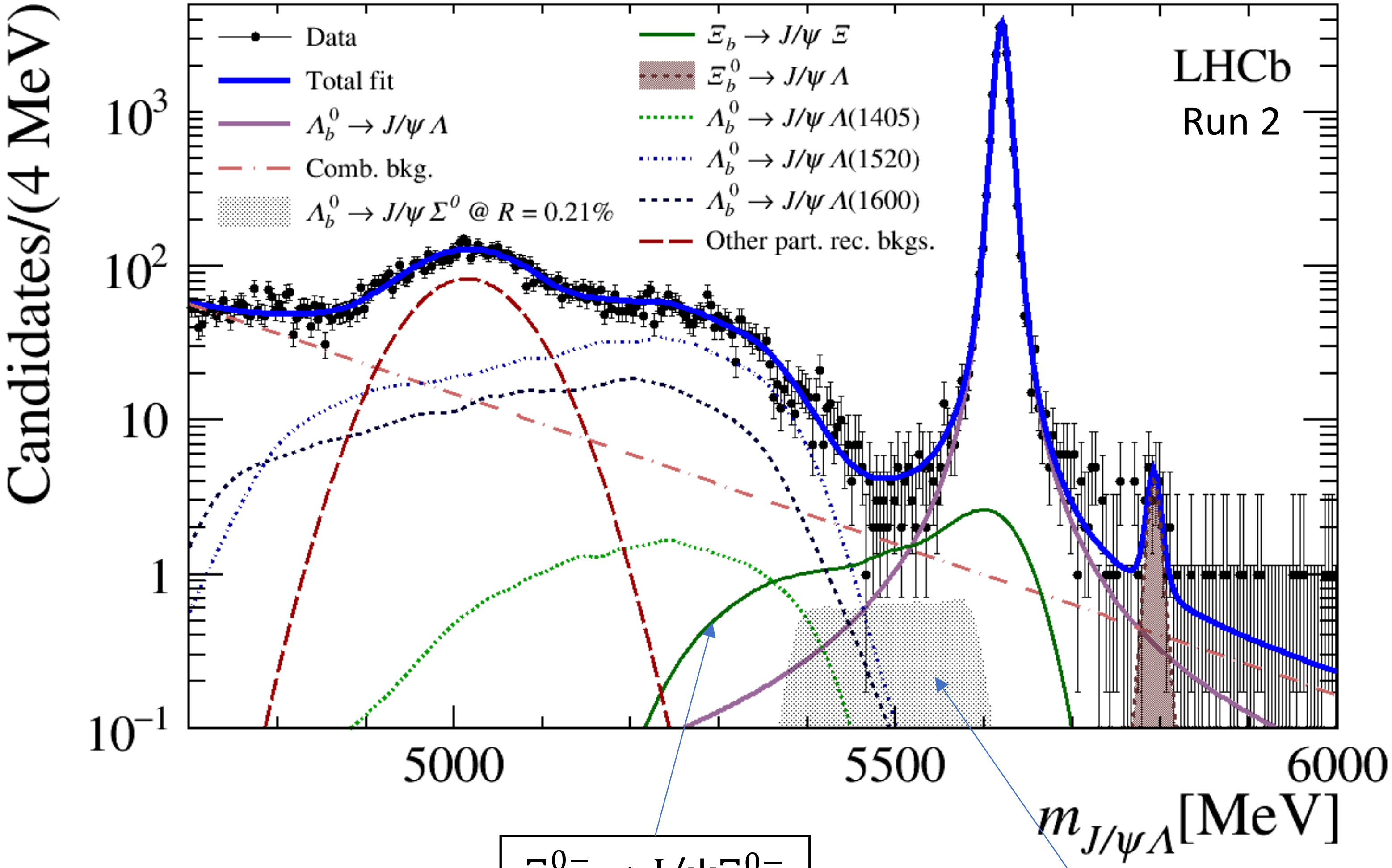
$\Phi_{\Lambda_b}, \Phi_{\Xi_b}$ – Phase space corr. factors

$\lambda = |V_{us}|/|V_{ud}|$ – CKM suppression

- We do not measure $\Xi_b^0 \to J/\psi\, (\Xi^0 \to \Lambda\pi^0)$ directly.
  - Instead we measure $\Xi_b^- \to J/\psi\, (\Xi^- \to \Lambda\pi^-)$ and use isospin to relate it to the Ξ_b^0 decay

Fits and Upper Limit

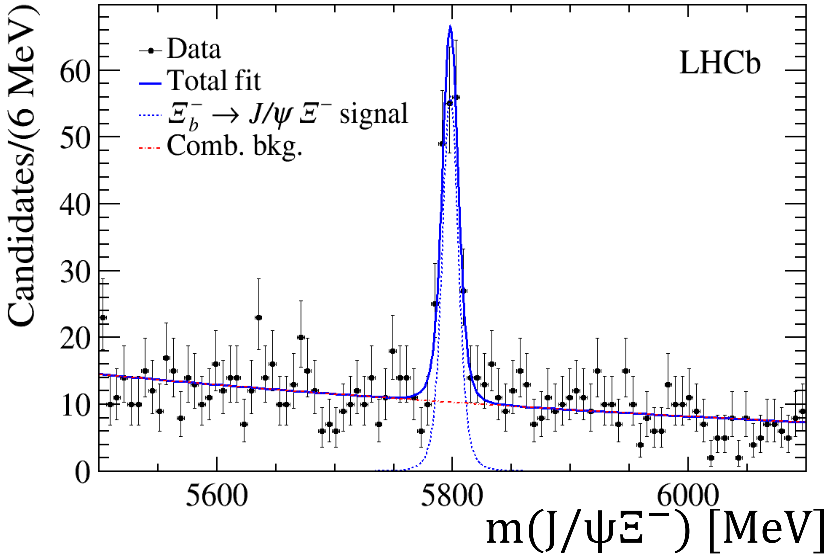
arXiv:1912.0211

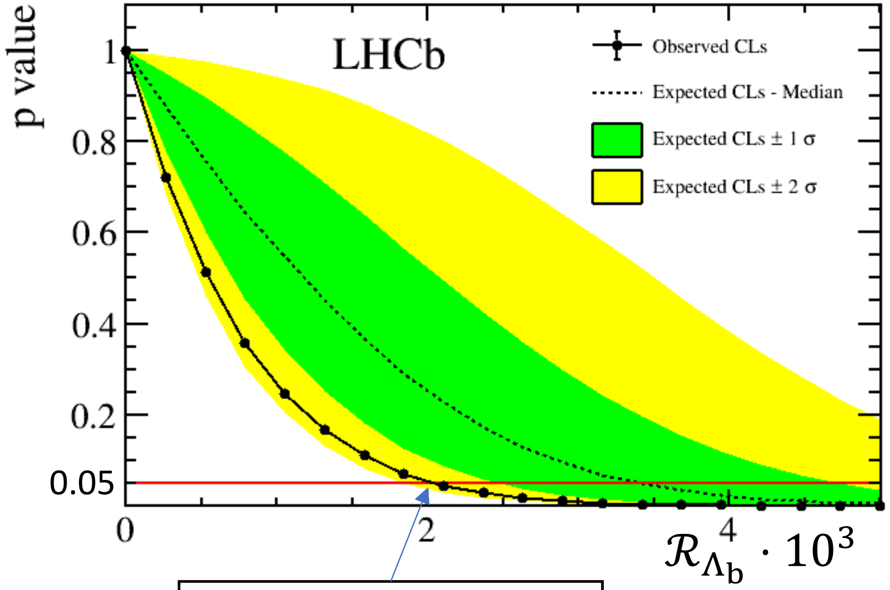


$\Xi_b^{0-} \to J/\psi\Xi^{0-}$

$\Lambda_b \to J/\psi\Sigma^0$
(artificially scaled to upper limit)

$\Xi_b^- \to J/\psi\ \Xi^-,\ \Xi^- \to \Lambda\pi^-, \Lambda \to p\pi^-$





95% CL Upper Limit

Results

arXiv:1912.0211

- $\mathcal{R}_{\Lambda_b} < \mathbf{2.1 \cdot 10^{-3}}$ @ 95% C.L.

  $\Rightarrow |A_1/A_0| = \sqrt{R} < \mathbf{1/21.8}$ @ 95% C.L.

- $\Xi_b^0 \rightarrow J/\psi\,\Lambda$: **First observation** of Cabibbo suppressed mode

  - Significance of observation : $\mathbf{5.6\,\sigma}$

  - $\mathcal{R}_{\Xi_b} \equiv \frac{\mathcal{B}(\Xi_b^0 \rightarrow J/\psi\,\Lambda)}{\mathcal{B}(\Xi_b^0 \rightarrow J/\psi\,\Xi^0)} = \mathbf{(8.2 \pm 2.1 \pm 0.9) \cdot 10^{-3}}$

    $\Rightarrow |A_0/A_{1/2}| = \mathbf{0.37 \pm 0.06 \pm 0.02}$

Interpretation – $SU(3)_F$ Analysis [5]

arXiv:1912.0211

- Dery et. al. perform a general $SU(3)_F$ analysis of baryonic $b \to c\bar{c}q \; (q = s, d)$

- $b \to c\bar{c}s$ decays: $\Lambda_b \to \Lambda\, J/\psi$ $\quad \Lambda_b \to \Sigma^0\, J/\psi$ $\quad \Xi_b^0 \to \Xi^0\, J/\psi$ $\quad \Xi_b^- \to \Xi^-\, J/\psi$
- $b \to c\bar{c}d$ decays: $\Xi_b^0 \to \Lambda\, J/\psi$ $\quad \Xi_b^0 \to \Sigma^0\, J/\psi$ $\quad \Lambda_b \to n\, J/\psi$ $\quad \Xi_b^- \to \Sigma^-\, J/\psi$

- From three separate assumptions:

  1. Working in the $SU(3)_F$ limit
  2. Λ and Σ^0 are isospin eigenstates (i.e. don't mix)
  3. $|V_{ub}^* V_{us} / V_{cb}^* V_{cs}| \to 0$

Predictions:

- $A(\Lambda_b \to J/\psi\, \Sigma^0) = 0$
- $\left|\dfrac{A(\Xi_b^0 \to \Lambda\, J/\psi)}{A(\Xi_b^0 \to \Xi^0 J/\psi)}\right| = \dfrac{1}{\sqrt{6}} \left|\dfrac{V_{cb}^* V_{cd}}{V_{cb}^* V_{cs}}\right|$

---

[5] arXiv:2001.05397 – DGGS

Interpretation – $SU(3)_F$ Analysis [5]

arXiv:1912.0211

- Isospin and $SU(3)_F$ breaking effects would lead at the same time to a deviation in $A(\Lambda_b \to \Sigma^0\, J/\psi)$ and $A(\Xi_b^0 \to \Lambda\, J/\psi)/A(\Xi_b^0 \to \Xi^0\, J/\psi)$

- $\Sigma^0 - \Lambda$ mixing:
  - $\left|\Lambda^0_{\text{phys}}\right\rangle = \cos\theta_m \left|\Lambda^0\right\rangle - \sin\theta_m \left|\Sigma^0\right\rangle$
  - $\left|\Sigma^0_{\text{phys}}\right\rangle = \sin\theta_m \left|\Lambda^0\right\rangle + \cos\theta_m \left|\Sigma^0\right\rangle$

- $\mathcal{R}_{\Lambda_b} \equiv \dfrac{A\left(\Lambda_b \to J/\psi\, \Sigma^0_{\text{phys}}\right)}{A\left(\Lambda_b \to J/\psi\, \Lambda^0_{\text{phys}}\right)} = \dfrac{\left\langle J/\psi\, \Sigma^0_{\text{phys}} \middle| H \middle| \Lambda_b \right\rangle}{\left\langle J/\psi\, \Lambda^0_{\text{phys}} \middle| H \middle| \Lambda_b \right\rangle} = \theta_m + \dfrac{\left\langle J/\psi\, \Sigma^0 \middle| H_1 \middle| \Lambda_b \right\rangle}{\left\langle J/\psi\, \Lambda^0 \middle| H_0 \middle| \Lambda_b \right\rangle} = \overset{\text{universal}}{\theta_m} + \theta_f^{\text{dyn}} = \theta_f$

- $\theta_m \sim \theta_f \sim 1° \;\Rightarrow \mathcal{R}_{\Lambda_b} = |\theta_f| \sim 0.02$

[5] arXiv:2001.05397 – DGGS

PRL 124, 111802

Comparison and Conclusions

arXiv:1912.0211

- DGGS prediction for $\left|\frac{A_0(\Xi_b^0 \to \Lambda\, J/\psi)}{A_{\frac{1}{2}}(\Xi_b^0 \to \Xi^0\, J/\psi)}\right| \approx 0.41$ agrees very well with our measurement of $(0.37 \pm 0.06 \pm 0.02)$.
  - DGGS expect a 20% correction from $SU(3)_F$ breaking effects.
  - Our measurement is not yet sensitive enough to probe size of these corrections.

- DGGS prediction for $\left|\frac{A_0(\Lambda_b \to \Lambda\, J/\psi)}{A_1(\Lambda_b \to \Sigma^0 J/\psi)}\right| \sim 0.02$ is close to our upper limit of $1/21.8 = 0.046$.
  - DGGS stress that a deviation from predicted value would point to isospin violation in the dynamical contribution to mixing.

PRL 124, 111802

Comparison and Conclusions

arXiv:1912.0211

- We have provided more support for the iso-scalar status of the Λ_b.
  - An isospin 1 component would be seen through the $\Delta I = 1$ channel.
  - In principle, could mix with the isospin 1 Σ_b^0.

- Experimental verification provided for the assumption of isospin suppression made in past analyses involving Λ_b.

- No isospin or $SU(3)_F$ breaking effects seen yet in Λ_b and Ξ_b decays.
  - With increasing statistics expected from Run 3 datasets, and additional channels to be probed, LHCb is well poised to make a first observation of isospin breaking in baryonic decays.

THANK YOU!!