Isospin amplitudes in b-baryon spectroscopy at LHCb

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Introduction

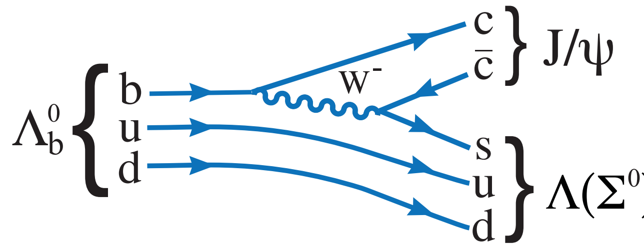
- Isospin is a strong interaction symmetry between u & d quarks. Weak interactions do not conserve isospin
- In $K\rightarrow\pi\pi$ decays the final state with I=0 >> I=2. $|A_0|/|A_2|$= 22.45±0.06, can be explained as a strong interaction effect by recent lattice calc RBC/UKQCD, 19.9±2.3±4.4 [arXiv:2004.09440], but Buras et al [arXiv:1401.1385] claim their analytical calc 16.0±0.15 doesn't agree & there could be New Physics
- We start by studying $\Lambda_b \rightarrow J/\psi\ \Lambda$ versus $\Lambda_b \rightarrow J/\psi\ \Sigma^0$

  Isospin: 0 0 0 0 0 1

  We take $I(\Lambda_b)$=0 from quark model, never measured

What we could learn

- Feynman diagram at leading order:



- $b \to c\bar{c}\bar{s}$ operator does not change isospin, so we expect Λ mode to be >> Σ mode [I(b)=I(c)=I(s)=0]
- If J/ψ Λ mode is >> J/ψ Σ, then Λ_b is I=0
- Some analyses have assumed that only the smallest isospin changing amplitude is present. Ex: In the pentaquark analysis of $\Lambda_b \to J/\psi\ pK^-$, it was assumed that the pK^- formed a Λ^*, rather than a Σ^* [arXiv:1507.03414] Can we justify this? Apply this to other analyses?
- Can we detect an I=1 New Physics amplitude?

Other possible findings

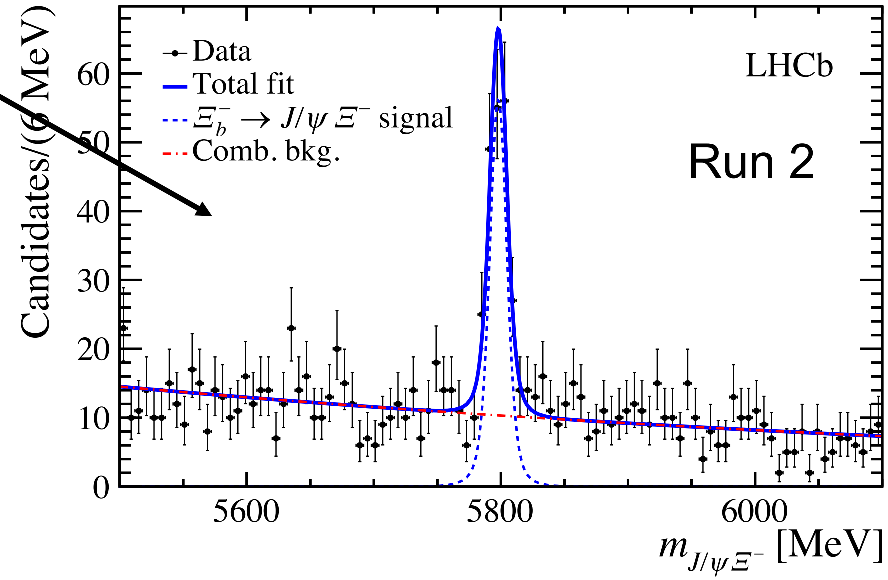
- In general I-spin breaking is at the level of 1% in rate, but if the ud in the Λ_b are in a tightly bound I=0 diquark, this breaking will vanish. So we test the diquark model
- $\Lambda-\Sigma$ wavefunction mixing is at the level of ~0.01 in amplitude, several predictions, including lattice [arXiv:1911.02186], we could measure this with enough sensitivity

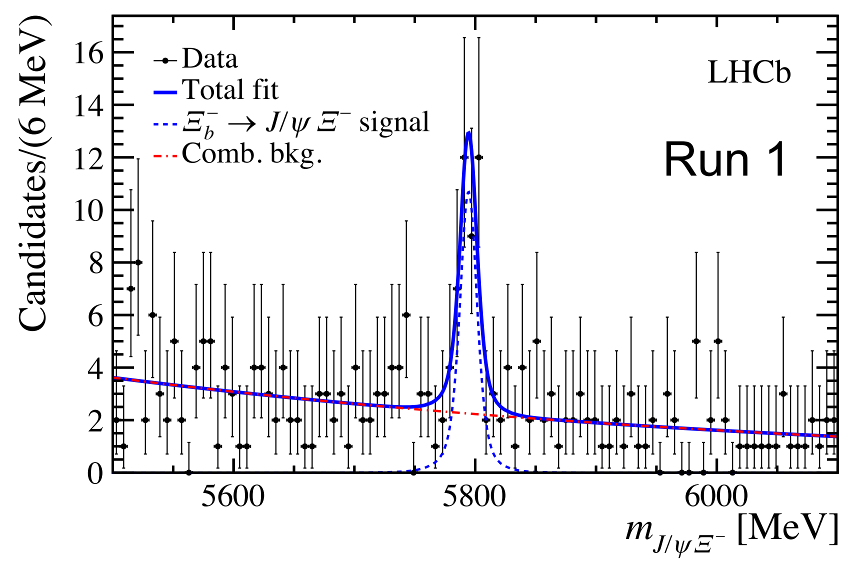
Data analysis

- Reconstruct the $J/\psi\ \Lambda$ mass distribution for J/ψ & Λ that form a vertex detached from the pp collision point. A BDT is used to reduce bkgrd
- $\Lambda_b \to J/\psi\ \Sigma^0$, $\Sigma^0 \to \gamma\Lambda$ is looked for without reconstructing the γ, because of its low energy & related low detection efficiency; $M(J/\psi\ \Lambda)$ a satellite bump just below the Λ_b mass
- Other significant backgrounds are $\Lambda_b \to J/\psi\ \Lambda^*$, $\Lambda^* \to \pi^0\Sigma^0$, & $\Xi_b \to J/\psi\ \Xi$, $\Xi \to \pi\ \Lambda$. We fully reconstruct the latter in the charged Ξ_b^- mode
- Runs 1 (3.0/fb) & 2 (5.5/fb) analyzed separately

$\Xi_b^- \rightarrow J/\psi\ \Xi^-$

- This we fully reconstruct
- Determining the yields, from the fits, we simulate the size & shape of the $J/\psi\ \Lambda$ mass spectrum
- The $J/\psi\ \Lambda^*$ shapes are simulated, no normalization is possible
- For details see [arXiv:1912.02110]





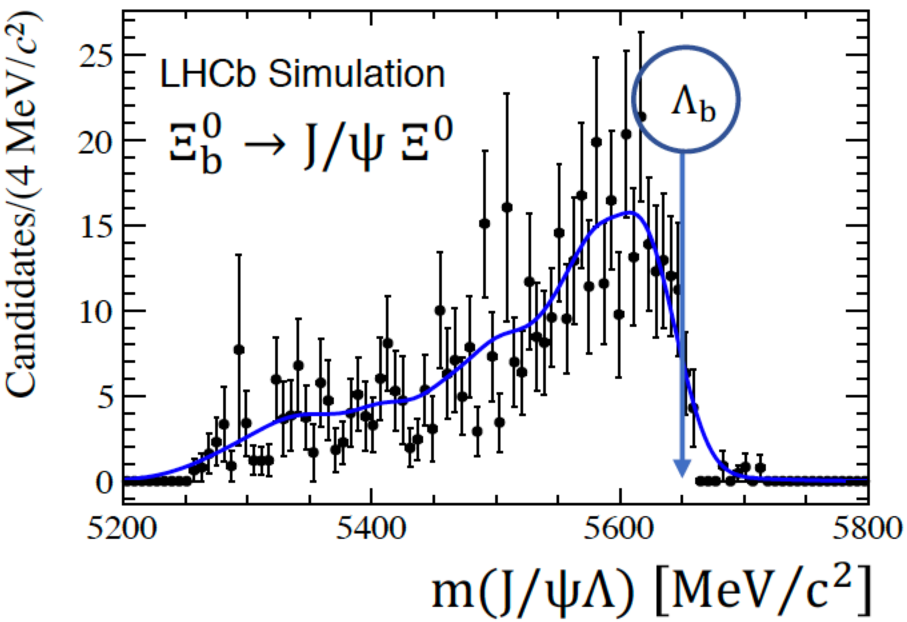
Shapes

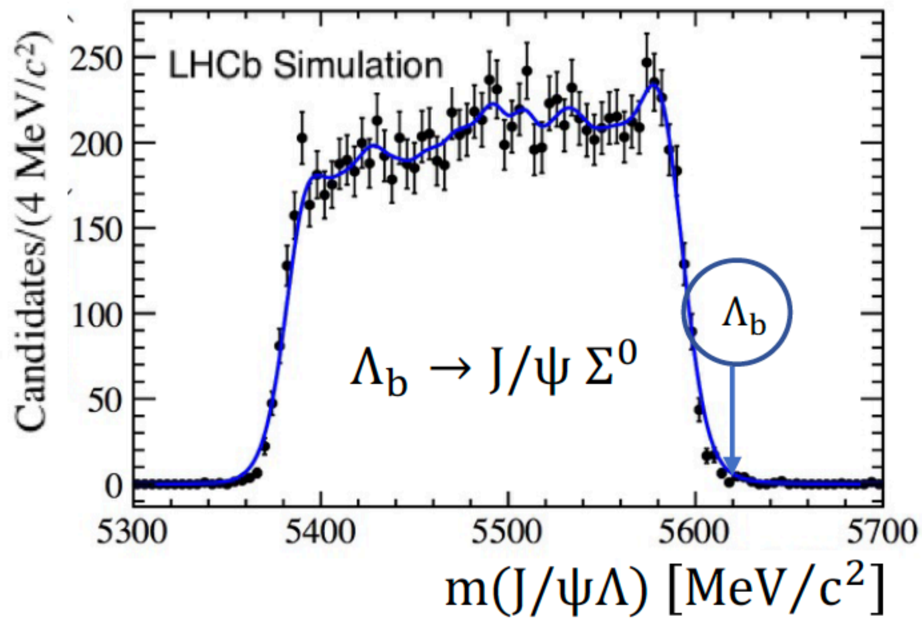
- Shape simulated

Normalization measured

Shape simulated

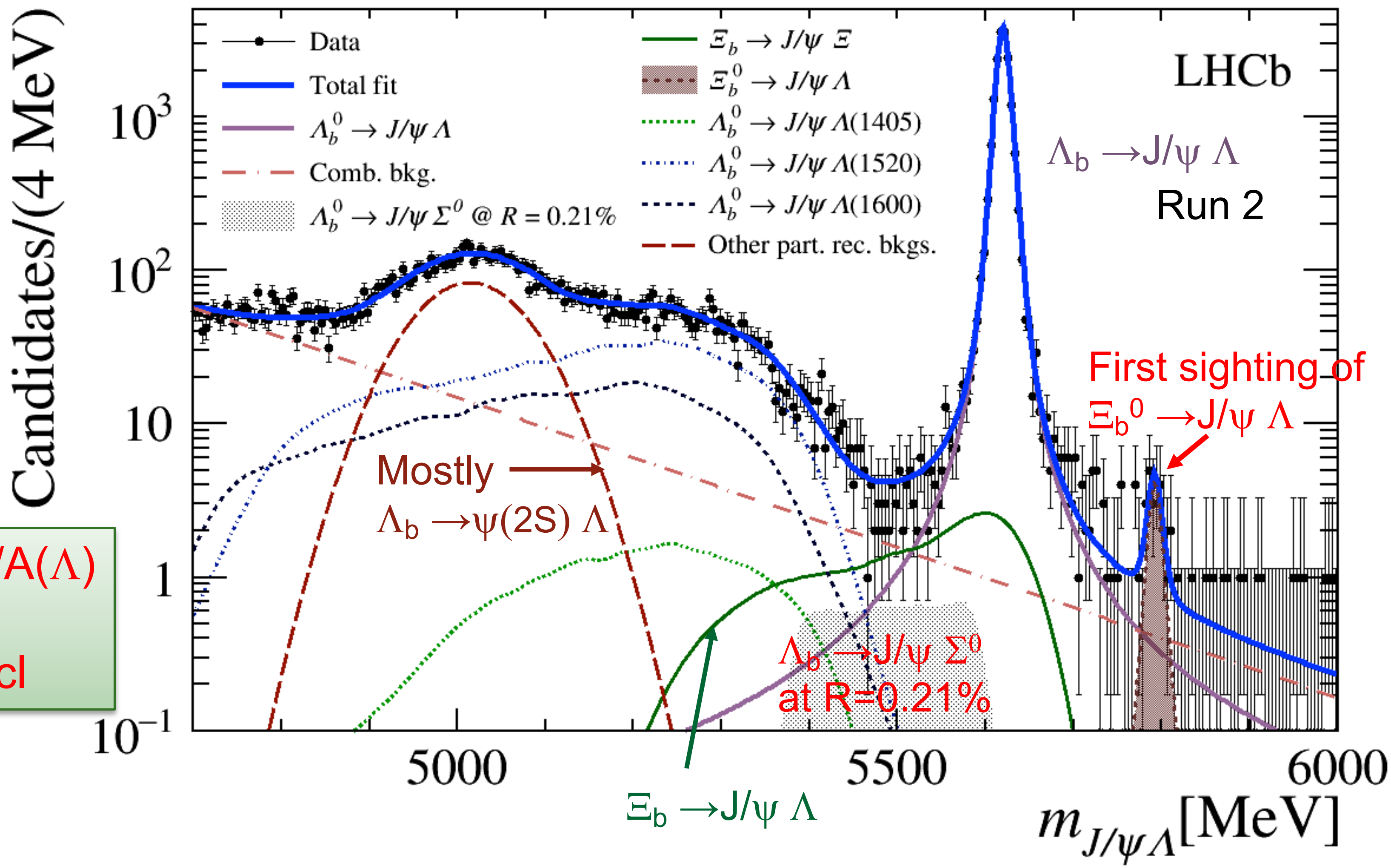
What we want to find





Title in red

Λ_b results



$R \equiv A(\Sigma)/A(\Lambda)$
<0.21%
@95% cl

R in detail

- $R \equiv \frac{|A_1|^2}{|A_0|^2} = \frac{B(\Lambda_b^0 \to J/\psi \Sigma^0)}{B(\Lambda_b^0 \to J/\psi \Lambda)} \Phi$, where Φ is a phase space factor = 1.058

- $$R \equiv \frac{|A_1|^2}{|A_0|^2} = \frac{\#(\Lambda_b^0 \to J/\psi \Sigma^0) \cdot \epsilon_{J/\psi \Sigma^0}}{\#(\Lambda_b^0 \to J/\psi \Lambda) \cdot \epsilon_{J/\psi \Lambda}} \Phi$$

- *R* is determined by a joint fit to the Run 1 & Run 2 $J/\psi\ \Lambda$ mass distribution including the systematic uncertainties using Gaussian constraints; they are mainly relative final state efficiencies ~2% & $\Xi_b \to J/\psi\ \Xi$ background normalizations ~10%

Fit yields

Parameter	Shared value	Run 1 value	Run 2 value
$\mathcal{R}$	<0.21% @ 95% cl	–	–
$N_{\Lambda_b^0 \to J/\psi \Lambda}$	–	4417 ± 66	$16\,970 \pm 130$
$N_{\Xi_b \to J/\psi \Xi}$	–	23.3 ± 5.7	139.7 ± 21.9
$N_{\Xi_b^0 \to J/\psi \Lambda}$	–	6.2 ± 3.0	17.8 ± 5.1

Synopsis of Λ_b result

$\left|\frac{A_1}{A_0}\right|$

10

5 — Λ_b is I=1, or New Physics

2

1 — No preference for I=0 or I=1 amplitudes

0.5

0.2

0.1 — Expected from u-d mass diff if not diquark

0.05

Measured <0.046@95% cl

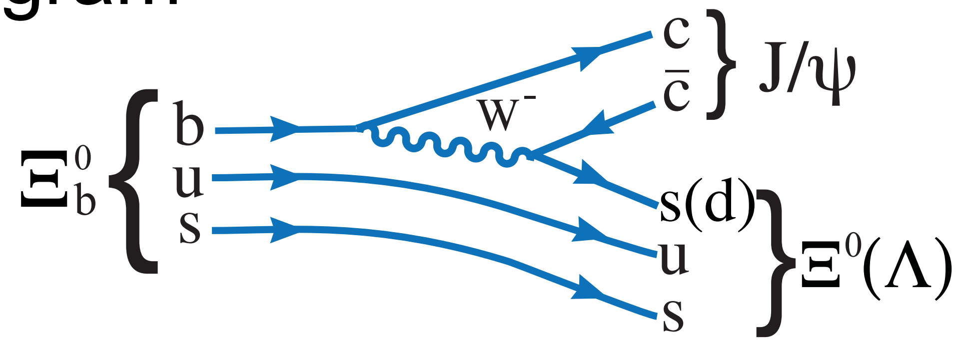
0.02

0.01 — Expected from Λ-Σ mixing

0.005

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

- Lowest order diagram



- By assuming $\Gamma(\Xi_b^0 \to J/\psi \Xi^0)$=$\Gamma(\Xi_b^- \to J/\psi \Xi^-)$, we also measure

$$R_{\Xi_b} \equiv \frac{B(\Xi_b^0 \to J/\psi \Lambda)}{B(\Xi_b^0 \to J/\psi \Xi^0)} = (8.2 \pm 2.1 \pm 0.9) \times 10^{-3}$$

- Next, amplitude analysis

$|A_0| / |A_{1/2}|$

- $\Xi_b^0 \rightarrow J/\psi\ \Lambda$ versus $\Xi_b^0 \rightarrow J/\psi\ \Xi^0$

Isospin: ½ 0 0 (A_0) ½ 0 ½ $(A_{1/2})$

- So $\frac{|A_0|}{|A_{1/2}|} = \frac{|V_{cd}|}{|V_{cs}|}\sqrt{\frac{B(\Xi_b^0 \rightarrow J/\psi \Lambda)}{B(\Xi_b^0 \rightarrow J/\psi \Xi^0)\Phi_{\Xi_b}}}$=0.37±0.06±0.02

- Theoretical expectation based on SU(3)$_F$:

  Λ_b, Ξ_b^0, & Ξ_b^- form an $\bar{3}$, while the Λ & Ξ form an 8.

Dery et al. [arXiv:2001.05397] predict $\frac{|A_0|}{|A_{1/2}|} = \frac{1}{\sqrt{6}} = 0.41$, with a 20% uncertainty due to SU(3)$_F$ breaking; the $1/\sqrt{6}$ is an SU(3) Clebsch Gordon coefficient

Conclusions

- Λ_b isospin is 0, as the quark model says
- The u & d in Λ_b almost certainly form a diquark
- In the pentaquark analysis of $\Lambda_b \to J/\psi\ pK^-$, it was assumed that the pK^- formed a Λ^*, rather than a Σ^*. This now is justified
- There is no preference for the I=1/2 amplitude in $\Xi_b^0 \to J/\psi\ \Xi^0$ over the I=0 amp in $\Xi_b^0 \to J/\psi\ \Lambda$
  Similar to results on $B \to \pi\pi$: $|A_0/A_2| \approx 1.0$
  [arXiv:1203.3131], unlike $D \to \pi\pi$: $|A_0/A_2| \approx 2.5$
  [arXiv:1402.1164], and $K \to \pi\pi$: $|A_0/A_2| = 22.5$

The End

Paper published: Aaij et al., LHCb collaboration, *Phys. Rev. Lett.* 124 (2020) 11, 111802 [arXiv:1912.02110]

Backups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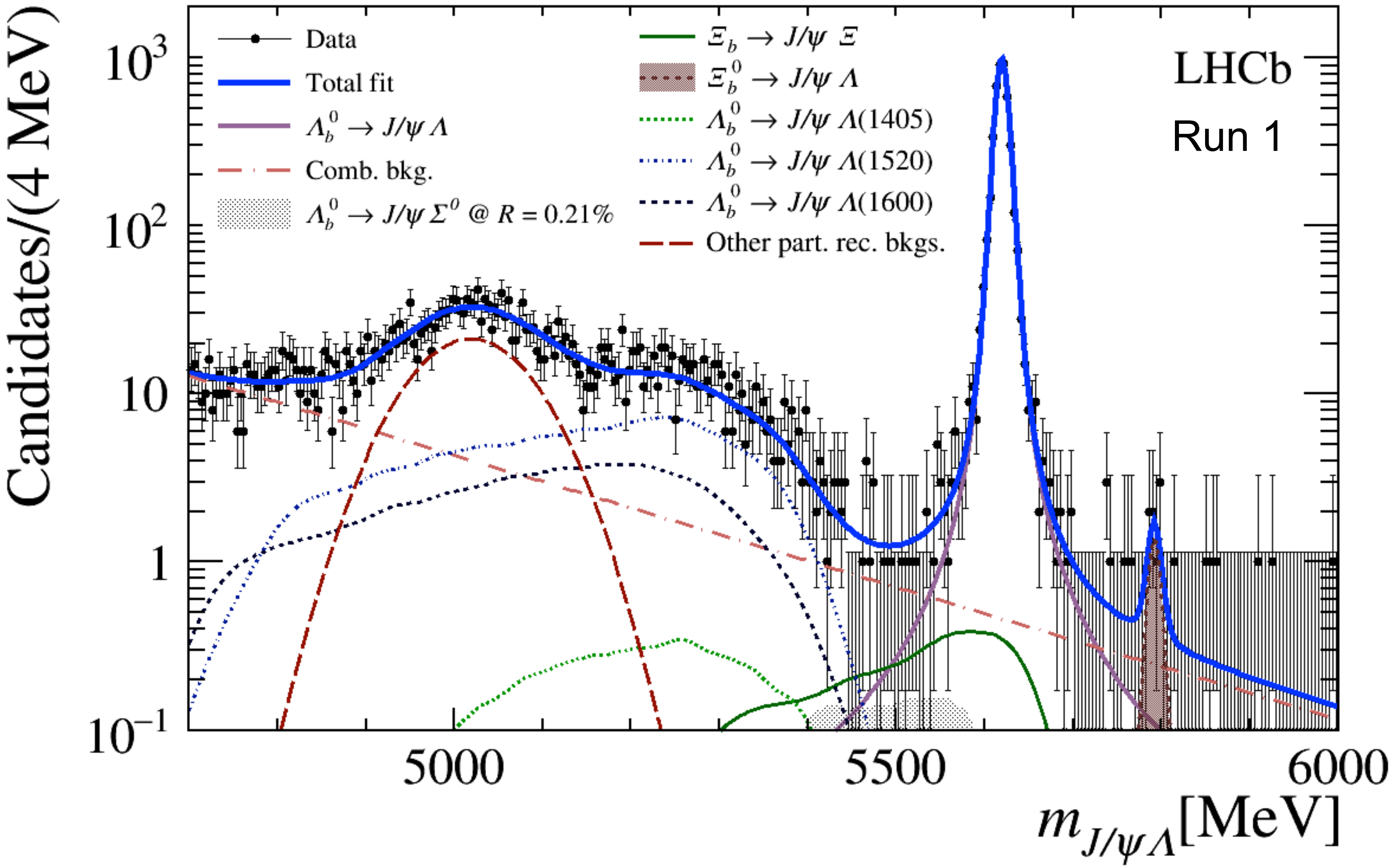
M(J/ψ Λ) Run 1


Candidates/(4 MeV)
10^3
10^2
10
1
10^{-1}
Data
Total fit
$\Lambda_b^0 \to J/\psi\,\Lambda$
Comb. bkg.
$\Lambda_b^0 \to J/\psi\,\Sigma^0$ @ $R = 0.21\%$
$\Xi_b \to J/\psi\,\Xi$
$\Xi_b^0 \to J/\psi\,\Lambda$
$\Lambda_b^0 \to J/\psi\,\Lambda(1405)$
$\Lambda_b^0 \to J/\psi\,\Lambda(1520)$
$\Lambda_b^0 \to J/\psi\,\Lambda(1600)$
Other part. rec. bkgs.
LHCb
Run 1
5000
5500
6000
$m_{J/\psi\Lambda}$[MeV]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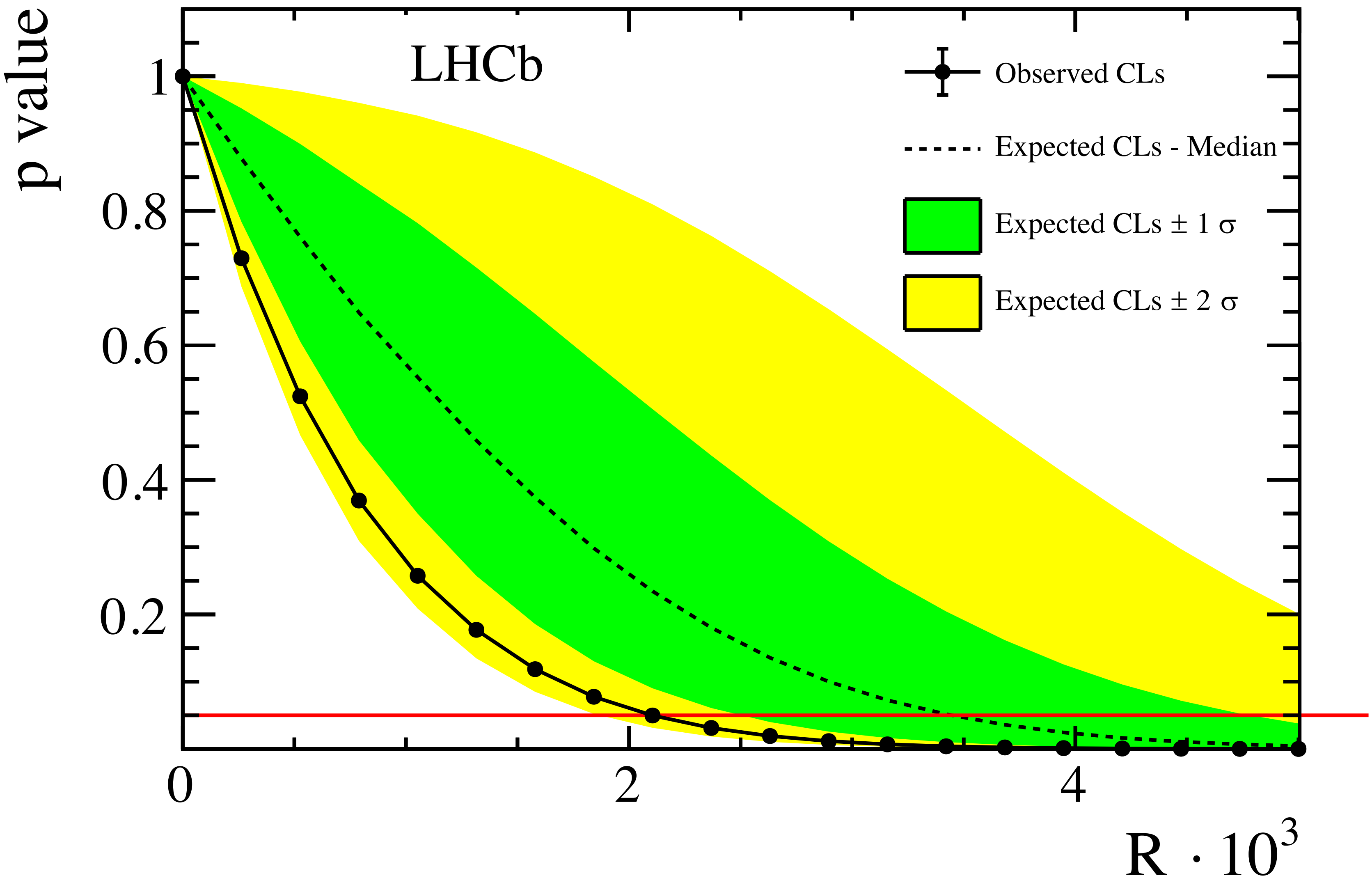
CL_s


LHCb
p value
1
0.8
0.6
0.4
0.2
0
2
4
R · 10^3
Observed CLs
Expected CLs - Median
Expected CLs ± 1 σ
Expected CLs ± 2 σ

Isospin breaking

- PDG new: 84.2 Flavor symmetry (Dave Robinson and Charles Wohl)
- Just as for the light mesons and baryons, approximate flavor SU(3) symmetry of the light
- quarks – the u, d, and s – is expected to relate matrix elements of charmed baryons belonging
- to the same multiplet, up to corrections of order $(m_s - m_d)/\Lambda_{QCD}$ ~20%. (Similarly, isospin
- relations should hold to the percent level.) This includes Gell-Mann-Okubo mass relations, as well
- as relations between matrix elements for charmed baryon multibody decays. These relations may
- be constructed order-by-order in the appropriate symmetry breaking parameters.
-
- Isospin-breaking in ε′/ε: Impact of η_0 at the Dawn of the 2020s, Andrzej J. Buras, Jean-Marc Gerard
- (May 18, 2020) e-Print: 2005.08976
- Abstract
- For direct CP-violation in K->pi pi decays, the usual isospin-breaking effects at
- the percent level are amplified by the dynamics behind the Delta I = 1/2 rule…
-
- Dery, Ghosh, Grossman and Schacht arXiv:2001.05397 SU(3)F Analysis for Beauty Baryon Decays
- “and we generically expect the size of isospin and
- SU(3)F breaking to be ~1% and ~20%, respectively (first line after equation 39)

$\sigma(\Xi_b^0)/\sigma(\Xi_b^-)$

- Nominally these would be equal due to isospin conservation in their production
- However the $\Xi_b'(5935)^0$ is not massive enough to decay into $\Xi_b^-\pi^+$, so it always decays in a Ξ_b^0
- After accounting for all the measured excited states, this results in

$\sigma(\Xi_b^0)/\sigma(\Xi_b^-)$ = 1.37±0.09, uncertainty due to measurement errors