Production and decay of heavy flavour baryons

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on behalf of the LHCb collaboration
presenting also result from Atlas and CMS

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Outline

- Introduction to $b$-baryon physics
- Experimental results
- Conclusions
Introduction to $b$-baryon physics
Physics motivations

- At LHC $b$-baryons are produced in unprecedented quantities → opens a new field in flavour physics for precision measurements
  
  - Most precise measurement of $|V_{ub}|$ using $\Lambda_b^0 \rightarrow p\mu^-\bar{\nu}_\mu$ decays [arXiv:1504.01568]

- Mass, lifetimes and branching ratios measurements

- $b$-baryon physics is a relatively unexplored territory:
  
  - search for physics beyond the Standard Model (SM) in rare decays and $CP$ violation

  - useful QCD laboratory in different energy regime with respect to light baryons. Experimental anchor point for QCD models
Beautiful baryons

- Baryons are fermions composed by 3 quarks
- State function antisymmetric under exchange of equal-mass quarks
  \[ |qqq⟩_A = |\text{color}⟩_A × |\text{space, spin, flavour}⟩_S \]
- \( SU(4) \) multiplets for baryons made of \((u,d,s,b)\) quarks
  - \( B= \) bottomness, \( Y= \) hypercharge, \( I_3= \) Isospin z-component
  - \( SU(4) \) symmetry heavily broken - large \( b \)-quark mass
  - particles in \( SU(4) \) multiplets have same spin and parity
**b-baryons states**

- **b-baryons** \((bq_1 q_2)\) as QCD laboratory:
  - \(m_b \gg m_{q_1 q_2}\) simplified dynamics
  - \(b\) quark in the limit \(m_b \to \infty\) effective static colour field \((m_b \sim 4.8\text{GeV})\)
  - heavy baryon properties determined by dynamics of diquark system in \(b\)-quark color field
  - Ground state baryons \((L = 0)\) with spin-parity \(J^P = 1/2^+, 3/2^+\) characterised by the spin-parity of the diquark system \(j^P = 0^+, 1^+\)

\[
\begin{align*}
S, J & \quad \ell' \\
\ell & \quad q_2 \\
q_1 & \quad b \\
\text{Ground state} & \quad (L = 0)
\end{align*}
\]

\[
\begin{align*}
J^P = 0^+, 1^+ & \quad j = L + s \\
L = 0 & \quad (L = 0)
\end{align*}
\]

\[
\begin{align*}
\begin{array}{cccc}
-1/2 & 0 & +1/2 \\
-1 & -1/2 & 0 & +1/2 & +1
\end{array}
& \quad I \\
\begin{array}{c}
S = 0 \\
S = -1 \\
S = -2
\end{array}
\end{align*}
\]

\[
\begin{align*}
\begin{array}{c}
\Lambda_b^{0}\hphantom{_{udb}} & \text{S}=0 \\
\Sigma_b^{-}\hphantom{_{dub}} & \text{S}=-1 \\
\Sigma_b^{0}\hphantom{_{ub}} & \text{S}=-2 \\
\Xi_b^{-}\hphantom{_{dub}} & \\
\Xi_b^{0}\hphantom{_{ub}} & \\
\Xi_b^{'-}\hphantom{_{dub}} & \\
\Xi_b^{'0}\hphantom{_{ub}} & \\
\Omega_b^{-}\hphantom{_{ssb}} & \\
\Omega_b^{0}\hphantom{_{ssb}} & \\
\Omega_b^{'+}\hphantom{_{ssb}} & \\
\Omega_b^{'+}\hphantom{_{ssb}} & \\
\end{array}
\end{align*}
\]

\[
\begin{align*}
J^P = \frac{1}{2} & \quad (J^P = \frac{3}{2} \text{ not shown})
\end{align*}
\]
**b-baryon rare decays**

- Access to $|V_{ub}|$ CKM element, form factors $f(\Lambda_b \rightarrow p)$ determined by Lattice QCD. Experimentally very challenging, achieved unprecedented precision

  ![LHCb](https://lhcb.cern.ch)

  $$|V_{ub}| = (3.27 \pm 0.23) \times 10^{-3}$$


- Angular analysis of $b$-baryon flavour-changing neutral current decays, e.g. $b \rightarrow s$ transitions, is sensitive to physics beyond Standard Model (SM)

  ![LHCb](https://lhcb.cern.ch)


  See Christian Linn talk for more details

- Angular analysis of $b$-baryon flavour-changing neutral current decays, e.g. $b \rightarrow s$ transitions, is sensitive to physics beyond Standard Model (SM)

  ![LHCb](https://lhcb.cern.ch)

  See Greg Ciazerek talk for more details
Experimental results
$b$-baryon production

- Production cross-section strongly depends on $p_T$ of $b$-hadron:
  - different $b$-quark fragmentation function ratio $f_{\Lambda_b^0}/f_d$ measured at LEP and at LHC, where $f_{\Lambda_b^0} = P(b \rightarrow \Lambda_b^0)$ and $f_d = P(b \rightarrow B_d^0)$
  - measurement of $f_{\Lambda_b^0}/f_d$ vs $p_T$ of $b$-quark is cleaner to interpret.
  Expected a slow dependence in that case

\[ f_{\Lambda_b^0}/f_d \]

Note: LEP average not included in the fit. LHCb measurements are not independent

![Graph showing $f_{\Lambda_b^0}/f_d$ vs $p_T$ b-hadron (GeV/c)]
Production kinematic dependence

- Use clean $\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-$ (45K), $\bar{B}^0 \rightarrow D^+ \pi^-$ (106K) exclusive decays to measure dependance of $f_{\Lambda_b^0} / f_d$ on $b$-hadron kinematics, e.g. $p_T$, pseudorapidity $\eta$.

- Measure

\[
\frac{f_{\Lambda_b^0}}{f_d}(x) = \frac{B(\bar{B}^0 \rightarrow D^+ \pi^-)}{B(\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-)} \times \frac{B(D^+ \rightarrow K^- \pi^+ \pi^+)}{B(\Lambda_c^+ \rightarrow pK^- \pi^+)} \times \mathcal{R}(x)
\]

where

\[
\mathcal{R}(x) = \frac{N_{\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-}(x)}{N_{\bar{B}^0 \rightarrow D^+ \pi^-}(x)} \times \frac{\varepsilon_{\bar{B}^0 \rightarrow D^+ \pi^-}(x)}{\varepsilon_{\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-}(x)} , \quad \text{and} \quad x = p_T, \eta
\]

Data sample 1fb$^{-1}$ at 7 TeV - JHEP08(2014)143
Production kinematic dependence

- Absolute value of $f_{\Lambda_b^0}/f_d$ from LHCb semileptonic analysis

- obtain most precise branching ratio measurement of $b$-baryon to date (8% precision)

$$B\left(\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-\right) = \left(4.30 \pm 0.03 \pm 0.12^{+0.26}_{-0.21} \times 10^{-3}\right)$$

Exponential dependence vs $p_T$  
Linear dependence vs $\eta$
$\Lambda^0_b$ production cross-section

- Measurement of differential production cross-section for $\Lambda^0_b$ using $\Lambda^0_b \rightarrow J/\psi \Lambda$ decays with $J/\psi \rightarrow \mu^+\mu^-$, $\Lambda \rightarrow p\pi^-$

PLB 714 (2012) 136–157

- $p_T$ distribution falls faster than measured $b$-mesons spectra and than predicted spectra from NLO MC POWHEG and leading-order MC PYTHIA
- Cross-section ratio $\sigma(\Lambda^0_b)/\sigma(\Lambda^0_b)$ consistent with 1 and constant vs $p_T$, and rapidity $|y|$
Observation of $\Xi^*_b^0$

- New resonant state compatible with $\Xi^*_b^0$ ($usb$) $J^P = \frac{3}{2}^+$, $j = 1$
- Signal reconstruction involves three secondary vertices, $\Xi^-$, $\Xi^-$, $\Lambda$ and a dimuon pair
- Theory predicts $m(\Xi'_b^0) - m(\Xi_b^-) < m_{\pi^+}$ no strong decay $\Xi'_b^0 \rightarrow \Xi^- \pi^+$ consistent with experimental results

$\delta m = m(\Xi^*_b^0) - m(\Xi_b^-) - m_{\pi^+} = 14.84 \pm 0.74 \pm 0.28$ MeV
$m(\Xi_b^-) = 5945.0 \pm 0.7 \pm 0.3 \pm 2.7$ (PDG) MeV
$\Gamma(\Xi^*_b^0) = 2.1 \pm 0.74$ MeV

PRL 108, 252002 (2012)
Two new $\Xi_b^-\pi^-$ baryon resonances

- Study $\Xi_b^0\pi^-\pi^+$ mass spectrum: 2 new resonances consistent with

\begin{align*}
\Xi_b^- (dsb) & \quad J^P = \frac{1}{2}^+, \sigma = 1 \\
\Xi_b^{*-} (dsb) & \quad J^P = \frac{3}{2}^+, \sigma = 1
\end{align*}

\[
\delta m(\Xi_b^-) = 3.653 \pm 0.018 \pm 0.006 \text{ MeV}/c^2 \\
\Gamma(\Xi_b^-) < 0.08 \text{ MeV at 95\% C.L.}
\]

3fb$^{-1}$ data at 7-8 TeV - PRL 114, 062004 (2015)
$\Xi_b^-$ helicity angle distributions

- Flat distribution if $J=1/2$ or $J>1/2$ but zero longitudinal polarisation

- Cannot determine $J$ value. However, data are consistent with quark model predictions $J=1/2$ and $J=3/2$ (if not or weakly polarised)

$\pi^- b \rightarrow \Xi_b^-$

Helicity angle definition

$\cos(\theta_h) = \frac{1}{2}$

$\theta_h = 0 \pm 0.11$

$\Xi^+_c \rightarrow \Xi_b^{(*)} \rightarrow \Xi_b^0 \rightarrow \pi^- b$

PRL 114, 062004 (2015)
\( \Xi_b^0 \) lifetime and mass measurements

- Measure lifetime relative to \( \Lambda_b^0 \) and mass difference \( m(\Xi_b^0) - m(\Lambda_b^0) \)

\[
\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^- , \Lambda_c^+ \rightarrow pK^- \pi^+ \\
\Xi_b^0 \rightarrow \Xi_c^+ \pi^- , \Xi_c^+ \rightarrow pK^- \pi^+ 
\]

- Ratio of efficiency corrected yields vs time

\[
\frac{N_{\Xi_b^0}(t)}{N_{\Lambda_b^0}(t)} = e^{(1/\tau_{\Lambda_b^0} - 1/\tau_{\Xi_b^0})t}
\]

Lifetime ratio from a fit using exponential function
\( \Xi^0_b \) lifetime and mass measurements

- **Measure** \( \frac{\tau_{\Xi^0_b}}{\tau_{\Lambda^0_b}} = 1.006 \pm 0.018 \pm 0.010 \) first measurement

- **Measure** \( m(\Xi^0_b) - m(\Lambda^0_b) = 172.44 \pm 0.39 \pm 0.17 \text{ MeV}/c^2 \) \( \times 4 \) precision improvement

- **Measure** relative production rate

\[
\frac{f_{\Xi^0_b}}{f_{\Lambda^0_b}} \cdot \frac{\mathcal{B}(\Xi^0_b \to \Xi^+_c \pi^-)}{\mathcal{B}(\Lambda^0_b \to \Lambda^+_c \pi^-)} \cdot \frac{\mathcal{B}(\Xi^+_c \to pK^-\pi^+)}{\mathcal{B}(\Lambda^+_c \to pK^-\pi^+)} = (1.88 \pm 0.04 \pm 0.03) \times 10^{-2}
\]

assuming naive Cabibbo factors

\[
\mathcal{B}(\Xi^0_b \to \Xi^+_c \pi^-)/\mathcal{B}(\Lambda^0_b \to \Lambda^+_c \pi^-) \approx 1 \quad \mathcal{B}(\Xi^+_c \to pK^-\pi^+)/\mathcal{B}(\Lambda^+_c \to pK^-\pi^+) \approx 0.1
\]

obtain \( f(\Xi^0_b)/f(\Lambda^0_b) \approx 0.2 \)

\( \Lambda^0_b \) lifetime measurements

- \( \tau_{\Lambda^0_b} = 1.479 \pm 0.009 \pm 0.010 \text{ ps} \)
- \( \tau_{\Lambda^0_b} = 1.449 \pm 0.036 \pm 0.017 \text{ ps} \)

\( \Lambda^0_b \) mass measurements

- \( m_{\Lambda^0_b} = 5619.36 \pm 0.26 \text{ MeV} \)
- \( m_{\Lambda^0_b} = 5619.7 \pm 0.7 \pm 1.1 \text{ MeV} \)
$\Xi_b^-$ lifetime and mass measurements

- Measure lifetime relative to $\Lambda_b^0$ and mass difference $m(\Xi_b^-) - m(\Lambda_b^0)$

$\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-$, $\Lambda_c^+ \rightarrow pK^- \pi^+$

$\Xi_b^- \rightarrow \Xi_c^0 \pi^-$, $\Xi_c^0 \rightarrow pK^- K^- \pi^+$

![Graph showing $\Lambda_c^+$ decay](image1.png)

$\Lambda_c^+ \rightarrow pK^- \pi^+$

$\Xi_c^0 \rightarrow pK^- K^- \pi^+$

$3$ fb$^{-1}$ data at 7-8 TeV - PRL 113, 242002 (2014)

$\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-$, $\Lambda_c^+ \rightarrow pK^- \pi^+$

$\Xi_b^- \rightarrow \Xi_c^0 \pi^-$, $\Xi_c^0 \rightarrow pK^- K^- \pi^+$

$LHCb$

Candidates / (5 MeV/c$^2$)

$5400$ $5500$ $5600$ $5700$ $5800$

$M(\Lambda_c^+ \pi^-)$ [MeV/c$^2$]

$1799 \pm 46$

$(220.5 \pm 0.5) \times 10^3$
### $\Xi_b$ lifetime and mass results

- **Ratio of efficiency vs decay time**

- **Ratio of efficiency corrected yields vs decay time**

### Results

- **Measure**
  
  \[
  M(\Xi_b^-) - M(\Lambda_b^0) = 178.36 \pm 0.46 \pm 0.16 \text{ MeV}/c^2 \]
  
  \[
  \frac{\tau_{\Xi_b^-}}{\tau_{\Lambda_b^0}} = 1.089 \pm 0.026 \pm 0.011
  \]

- **Using LHCb results relative to $\Xi_b^0$ we obtain**

  \[
  M(\Xi_b^-) - M(\Xi_b^0) = 5.92 \pm 0.60 \pm 0.23 \text{ MeV}/c^2 \]
  
  \[
  \frac{\tau_{\Xi_b^-}}{\tau_{\Xi_b^0}} = 1.083 \pm 0.032 \pm 0.016
  \]

- **Results consistent with predictions from heavy quark expansion (HQE)**

  \[
  \frac{\tau_{\Xi_b^-}}{\tau_{\Lambda_b^0}} = 1.19^{+0.07}_{-0.06} \quad \frac{\tau_{\Xi_b^-}}{\tau_{\Xi_b^0}} = 1.05 \pm 0.07 \quad M(\Xi_b^-) - M(\Xi_b^0) = 6.24 \pm 0.21 \text{ MeV}/c^2
  \]
Observation of $\Lambda_b^0 \to J/\psi p\pi^-$ decay

- Large interference between tree and penguin amplitudes.

Measure relative BR wrt $\Lambda_b^0 \to J/\psi pK^-$ and search for CPV

$\Lambda_b^0 \to J/\psi p\pi^- $ tree $\propto V_{cb} V_{cd} \sim \lambda^3$

$\Lambda_b^0 \to J/\psi p\pi^- $ penguin $\propto V_{tb} V_{td} \sim \lambda^3$ ($|V_{us}| = \lambda$)

$\Lambda_b^0 \to J/\psi p\pi^-$

$m_{J/\psi \pi^\pm}$ [MeV/c$^2$]

$\Lambda_b^0 \to J/\psi pK^-$

$m_{J/\psi \pi^\pm}$ [MeV/c$^2$]
Search for CP violation

- Measurement of $\Delta A_{CP}$ cancel production and proton reconstruction asymmetries

$$A_{raw}(\Lambda_b^0 \to J/\psi p h^-) = A_{CP}(\Lambda_b^0 \to J/\psi p h^-) + A_{prod}(\Lambda_b^0) - A_{reco}(h^+) + A_{reco}(p)$$

$$\Delta A_{CP} = A_{raw}(\Lambda_b^0 \to J/\psi p\pi^-) - A_{raw}(\Lambda_b^0 \to J/\psi pK^-)$$

$$= A_{CP}(\Lambda_b^0 \to J/\psi p\pi^-) - A_{CP}(\Lambda_b^0 \to J/\psi pK^-) + A_{reco}(\pi^+) - A_{reco}(K^+)$$

$$(5.7 \pm 2.4 \pm 1.2)^0_0 \% \quad 2.2\sigma \text{ from zero}$$

- No indications of large local CP asymmetries in Dalitz plane

- Rich resonant structure in $m(p\pi^-)$, no evidence for exotics in $m(J/\psi p), m(J/\psi\pi^-)$

- BR compatible with expected value 0.08: CKM x phase space factor

$$\frac{B(\Lambda_b^0 \to J/\psi p\pi^-)}{B(\Lambda_b^0 \to J/\psi pK^-)} = 0.0824 \pm 0.0025 \text{ (stat)} \pm 0.0042 \text{ (syst)}$$
Search for $\Lambda_{b}^{0} \rightarrow \Lambda \eta^{(')}$ decays

- $b$-baryons decays to final states with $\eta$, $\eta'$ not yet observed. From BR measurements determine $\eta - \eta'$ mixing

Consider $\eta$, $\eta'$ as admixture of light strange $|\eta_s\rangle = |s\bar{s}\rangle$ quark states, and gluons $|gg\rangle$:

$$|\eta'\rangle \simeq \cos \phi_G \sin \phi_P |\eta_q\rangle + \cos \phi_G \cos \phi_P |\eta_s\rangle + \sin \phi_G |gg\rangle$$
$$|\eta\rangle \simeq \cos \phi_P |\eta_q\rangle - \sin \phi_P |\eta_s\rangle$$

- Mixing parameters determined in $B_{(s)}^{0} \rightarrow J/\psi \eta^{(')}$ decays

$$\phi_P = (43.5^{+1.5}_{-2.8})^\circ \quad \phi_G = (0 \pm 25)^\circ$$

arXiv:1505.03295 Submitted to JHEP
Analysis strategy and event selection

- Measure BR of $\Lambda_b \rightarrow \Lambda \eta'_{\pi^+ \pi^-} (\gamma, \eta, \gamma)$ and $\Lambda_b \rightarrow \Lambda \eta_{\pi^+ \pi^-}$ relative to $B^0 \rightarrow K^0_S \eta'_{\pi^+ \pi^-}$
- Long lived $K^0_S \rightarrow \pi^+ \pi^-$ and $\Lambda \rightarrow p\pi^-$ are divided in Long and Downstream categories if produce hits in the vertex detector or not. Different track resolution and selection optimisation

- Full decay chain refitted, primary vertex with tracks not from $b$-hadron decays, fix to nominal value the mass of $\Lambda, K^0_S, \eta, \eta'$

$\sigma(m) = 30.0 \pm 1.5 \text{ MeV}/c^2$

$\sigma(m) = 29.4 \pm 1.3 \text{ MeV}/c^2$
Fit results

\[ \Lambda_b \to \Lambda\eta'_{\pi^+\pi^-\gamma} \quad 1.0 \pm 4.4 \]

\[ \Lambda_b \to \Lambda\eta'_{\pi^+\pi^-\eta\gamma\gamma} \quad -4.2 \pm 2.3 \]

\[ \Lambda_b \to \Lambda\eta_{\pi^+\pi^-\pi^0} \quad 5.3 \pm 3.8 \quad 3\sigma \text{ significance} \]

- Measure ratio of BR and use known \( \mathcal{B}(B^0 \to K^0_S\eta') \)
  \[
  \frac{\mathcal{B}(\Lambda_b^0 \to \Lambda\eta')}{\mathcal{B}(B^0 \to K^0\eta')} < 0.047 \text{ at } 90\% \text{ CL} \\
  \frac{\mathcal{B}(\Lambda_b^0 \to \Lambda\eta)}{\mathcal{B}(B^0 \to K^0\eta')} = 0.142^{+0.11}_{-0.08} \quad 68\% \text{ CL} \\
  \mathcal{B}(\Lambda_b^0 \to \Lambda\eta) = (9.3^{+7.3}_{-5.3}) \times 10^{-6} \]

3fb\(^{-1}\) data at 7-8 TeV - arXiV:1505.03295, submitted to JHEP
$|V_{ub}|$ measurement with $\Lambda_b^0 \rightarrow p\mu^-\bar{\nu}_\mu$

- Normalise yields to $\Lambda_b^0 \rightarrow \Lambda_c^+ \mu^-\bar{\nu}_\mu$, $V_{cb}$ mediated decay, cancel many systematic uncertainties.
- Apply tight vertex cut, PID on proton and muon, track isolation to reject 90% of background (using boosted decision tree).
- Use corrected mass to reconstruct the signal and retain events with $\sigma (M_{corr}) < 100$ MeV.
  
  $$M_{corr} = \sqrt{p_{\perp}^2 + M_{p\mu}^2 + p_{\perp}}$$

- Use $\Lambda_b^0$ flight direction and mass to determine $q^2$ with two-fold ambiguity (neutrino). Require both solutions $>15$ GeV$^2$, minimise migration to low $q^2$.

See Greg Ciezarek talk for more details.
Measure:

\[ |V_{ub}|^2 = \frac{B(\Lambda_b^0 \rightarrow p\mu^-\bar{\nu}_\mu)_{q^2>15 GeV^2}}{B(\Lambda_b^0 \rightarrow \Lambda_c^+ \mu^-\bar{\nu}_\mu)_{q^2>7 GeV^2}} \times R_{FF} \]

world average: \((39.5 \pm 0.8) \times 10^{-3}\)
measured: \((1.00 \pm 0.04 \pm 0.08) \times 10^{-2}\)
LQCD [1]: 0.68 \pm 0.07


Most precise measurement:

\[ |V_{ub}| = (3.27 \pm 0.15 \pm 0.17 \pm 0.06) \times 10^{-3} \]

Background contributions estimated using ad hoc control samples

Largest exp. uncertainty from \(B(\Lambda_c^+ \rightarrow pK^+\pi^-)\)

Combinatorial
Mis-identified
\(D^0\mu^+\bar{\nu}\)
\(\Lambda_c^0\mu^+\bar{\nu}\)
\(\Lambda_c^+\mu^+\bar{\nu}\)
\(N^+\mu^+\bar{\nu}\)
\(p\mu^+\bar{\nu}\)

Combinatorial

LHCb

17687 \pm 733

LHCb

34255 \pm 571
$|V_{ub}|$ puzzle

~3.5$\sigma$ tension between exclusive and inclusive measurements

LHCb measurement does not support explanation based on right handed current added to SM

Inclusive

Exclusive ($B \rightarrow \pi l \nu$)

LHCb ($\Lambda^0_b \rightarrow \mu \nu$)

PDG 2014

arXiv:1501.05373 (RBC/UKQCD)

arXiv:1503.07839 (FNAL/MILC)

arXiv:1503.01421 (RBC/UKQCD)
Conclusions

- At the LHC, $b$-baryons represent a new field in flavour physics for precision measurements. However, it is a relatively new territory for experiments and theory.

- Precision measurements of mass, lifetimes and BR provide experimental anchor points for theory and QCD models. Rare decays and CPV are sensitive to physics beyond SM.

- $|V_{ub}|$ measurement using $\Lambda_b$ is an outstanding example of advancement of both experimental techniques and LQCD calculations, providing a stringent test of SM. Others are foreseen.

- Be prepared to be surprised by $b$-baryon physics in the near future!
Backup slides
Parity violation in $\Lambda_b^0 \rightarrow J/\psi\Lambda$

- Parity violation is not maximal in hadron weak decays and depends on hadron constituents. In $b$-baryons can be predicted by perturbative QCD (pQCD) and heavy quark effective theory (HQET).

$\Lambda_b^0$ polarisation allowed only to be perpendicular to production plane, due to parity conservation in pp strong interaction.

Use 4 helicity amplitudes to describe the $\Lambda_b^0 \rightarrow J/\psi\Lambda$ decay:

$$A(\lambda_\Lambda, \lambda_{J/\psi}) : a_+ = A(1/2, 0), a_- = A(-1/2, 0),$$

$$b_+ = A(-1/2, -1), b_- = A(1/2, 1)$$
Parity violation results

- \( <P> = 0 \) in a symmetric interval in pseudorapidity

- Assume CP conservation and extract \( \alpha \) from a simplified angular analysis with 5 independent parameters

\[
\alpha = |a_+|^2 - |a_-|^2 + |b_+|^2 - |b_-|^2
\]

\[
= 0.30 \pm 0.16 \pm 0.06
\]

- Consistent with LHCb measurement

\[
\alpha = 0.05 \pm 0.17 \pm 0.07
\]

but not with pQCD \([-0.17, -0.14]\) and HQET predictions 0.78

- LHCb measured \( P = 0.06 \pm 0.07 \pm 0.02 \)
LHCb detector

Tracker Turicensis (TT)

VELO

T Stations
LHCb tracking system

TT: 500μm thick, single sided Si strip detector, pitch~100-200μm, vertical and stereo angle strips arrangement (x-u-v-x)=(0°,-5°,+5°,0°)

- Tracker Turicensis~8.4 m² Si
- Inner Tracker~4.0 m² Si
- VELO Tracker Turicensis~8.4 m² Si
- Inner Tracker~4.0 m² Si
- Outer Tracker
- Gas drift time detector Argon (70%), CO₂ (30%)
- 200μm position resolution
- B field bending power 3.7Tm
Track definitions at LHCb

Ghost track = is a fake track. For example it can be formed by matching a real track segment in the VELO (VELO seed) with a real track segment in the downstream tracker (T seed)