Search for the decay $\Lambda_b^0 \rightarrow \Lambda\eta'$ at LHCb

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LHCb

- ✓ Physics motivation.
- ✓ Selection.
- ✓ Results

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Introduction

- Searching for the rare decay $\Lambda_b^0 \to \Lambda\eta'$.
  - Not yet observed.
  - Λ_b^0 (udb) decaying to Λ (uds) is FCNC.
  - Investigate phenomena of η-η' mixing.
- Using $B^0 \to K_S^0\eta'$ as a control channel.
  - Use to optimise selection.
  - Measure relative branching fractions.
- Reconstruct the decays:
  - $\eta' \to \pi^+\pi^-\gamma$ (29.1%)
  - $K_S^0 \to \pi^+\pi^-$ (69.2%)
  - $\Lambda \to p\pi^-$ (63.9%)
- Results presented in LHCb-CONF-2013-010
- Using 2012 dataset: $2\,\text{fb}^{-1}$

η–η' mixing

- Investigate the phenomena of η–η' mixing.
- $\eta^{(\prime)}$ mass eigenstates described by mixing of flavour eigenstates.

$$|\eta_q\rangle = \frac{1}{\sqrt{2}}|u\bar{u} + d\bar{d}\rangle$$

$$|\eta_s\rangle = |s\bar{s}\rangle$$

$$\begin{pmatrix} |\eta\rangle \\ |\eta'\rangle \end{pmatrix} = \begin{pmatrix} \cos\phi_{\mathrm{p}} & -\sin\phi_{\mathrm{p}} \\ \sin\phi_{\mathrm{p}} & \cos\phi_{\mathrm{p}} \end{pmatrix} \begin{pmatrix} |\eta_q\rangle \\ |\eta_s\rangle \end{pmatrix}.$$

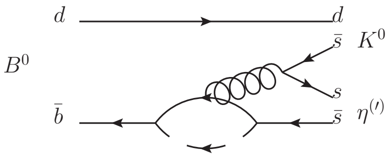
- Introduce gluonic component to η' wavefunction.

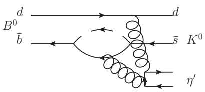
$$|\eta\rangle \approx \cos\phi_{\mathrm{p}}|\eta_q\rangle - \sin\phi_{\mathrm{p}}|\eta_s\rangle$$

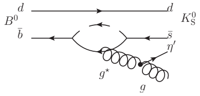
$$|\eta'\rangle \approx \cos\phi_{\mathrm{G}}\sin\phi_{\mathrm{p}}|\eta_q\rangle + \cos\phi_{\mathrm{G}}\cos\phi_{\mathrm{p}}|\eta_s\rangle + \sin\phi_{\mathrm{G}}|\mathrm{gg}\rangle.$$

- Has interesting consequences for branching fractions.

Branching Fractions







- Extra Feynman Diagrams available for η' decays
  - Higher branching ratio

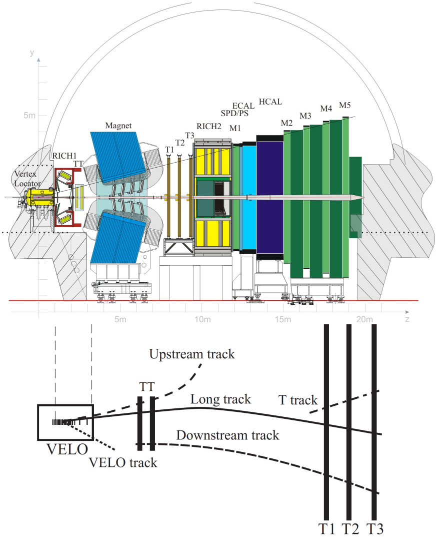
$$\mathcal{B}(B^0 \to K^0\eta') = (66 \pm 4) \times 10^{-6}$$

$$\mathcal{B}(B^0 \to K^0\eta) = (1.23^{+0.27}_{-0.24}) \times 10^{-6}$$

- Measure relative branching ratio of $B \to X\eta'$ to $B \to X\eta$ decays.
- Many different decays needed to measure ϕ_{p} and ϕ_{G}
- No baryonic decay yet observed.

Expected: $\mathcal{B}(\Lambda_b^0 \to \Lambda\eta') \approx (3 - 19) \times 10^{-6}$ arxiv:hep-ph/0305031

LHCb detector

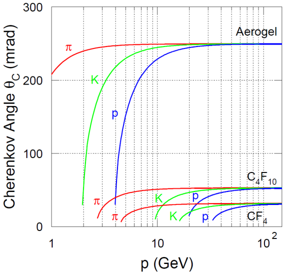


- LHCb detector is a forward arm spectrometer.
  - VELO allows for precise tracking.
  - RICH used for Particle ID.
- K^0_S and Λ have relatively long lifetimes ($\approx 10^{-10}s$, $c\tau \approx 50\,\mathrm{cm}$)
  - Categorised according to where they decay in detector: LL (upstream of VELO) or DD (downstream of VELO)

Selection

Selection consists of several stages:

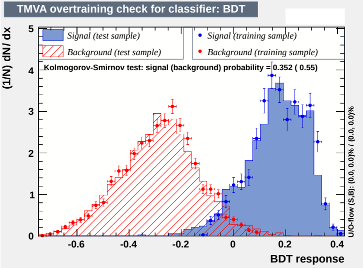
- Loose preselection.
    - Kinematic selection.
    - Cuts down combinatoric background.
- Multivariate selection.
    - Boosted Decision Tree (BDT).
    - Achieve maximum separation.

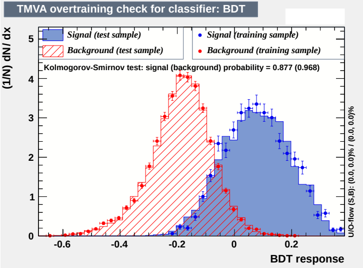


- Particle Identification (PID) Selection
    - Reduce background from misidentified kaons and protons.
    - Uses excellent performance of the RICH detectors.
    - Cut on the difference in log-likelihood between kaon or proton and pion hypothesis: $\mathrm{DLL}_{K\pi}$, $\mathrm{DLL}_{p\pi}$

Multivariate Selection

- Training a BDT using B^0 Monte Carlo and data sidebands.
  - Takes many variables with low discriminating power.
  - Combines them into one powerful discriminant (BDT response).

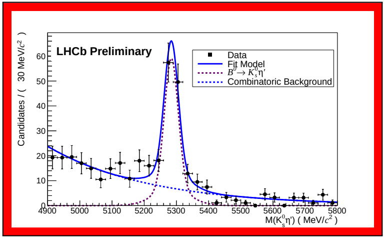
LL 

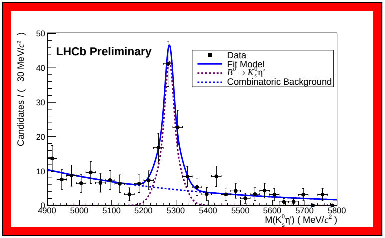
DD 

- Use this BDT as a proxy and apply to Λ_b^0 selection.

Mass fits to B^0

- Selection applied to data and fit performed to reweighted B^0 mass.
- Background fit with exponential.
- Signal fit with two gaussians with a common mean, with ratio $\frac{\sigma_1}{\sigma_2}$ and $\frac{N_1}{N_2}$ fixed to Monte Carlo values.
- Yield and width of narrowest gaussian and mean allowed to float.

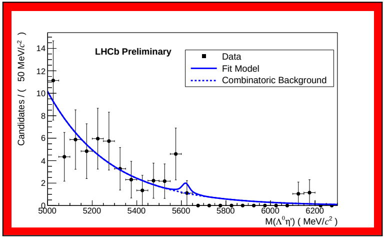




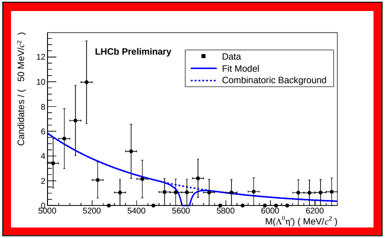
N(LL)$=125 \pm 13(14.8\sigma)$ N(DD)$=75 \pm 12(11.7\sigma)$

Mass fits to Λ_b^0

- After unblinding, no significant signal is observed.
- Signal and background are fit in the same way as B^0.
- All parameters in signal model fixed to MC values. Yield left to float.
- Number of events extracted from fit used to place a limit on branching fraction.



N(LL)=1



N(DD)=–3

Systematic Uncertainties

- Systematic uncertainties on the ratio of branching fractions

$$R = \frac{\mathcal{B}(\Lambda_b^0 \to \Lambda^0 \eta')}{\mathcal{B}(B^0 \to K^0 \eta')} = \frac{N_{\rm S}(\Lambda_b^0)}{N_{\rm S}(B^0)} \times \frac{\epsilon_{\rm tot}(B^0)}{\epsilon_{\rm tot}(\Lambda_b^0)} \times \frac{f_d}{f_\Lambda} \times \frac{0.5 \times \mathcal{B}(K_{\rm S}^0 \to \pi^+\pi^-)}{\mathcal{B}(\Lambda^0 \to p\pi)}$$

- Uncertainty on f_d/f_λ measured by LHCb to be 27%.
- Uncertainty on efficiencies just statistical uncertainty (24/22%).
- 6/4% uncertainty due to difference in B^0 and Λ_b^0 BDT response.
- PID uncertainty calculated by comparing efficiency with single bin efficiency.
- 9% uncertainty due to fit model used.
  - Yield extracted using different models for signal and background.

Systematics II

- Summary of systematic uncertainties.
  - Total of 40%

Systematic effect	**Unc. (LL)**	**Unc. (DD)**
BF of K_{S}^{0} and Λ^{0}	0.008	
Ratio of production fractions	0.27	
BDT Response	0.06	0.04
Ratio of ϵ_{sel}	0.24	0.22
ϵ_{PID}	0.013	
Fit model	0.09	0.09
Total	**0.4**	**0.4**

Confidence Limits

- Use Feldman-Cousins method to calculate upper limit on ratio of branching fractions.
- Using number of Λ_b^0 candidates extracted from the fit.
- Systematic uncertainties accounted for in probabilities.
- Combine LL and DD selections.

$$R = \frac{\mathcal{B}(\Lambda_b^0 \to \Lambda\eta')}{\mathcal{B}(B^0 \to K_S^0\eta')} < 9.6 \times 10^{-2} \text{ at } 90\% \text{ CL}$$

- Use known $\mathcal{B}(B^0 \to K^0\eta') = (66 \pm 4) \times 10^{-6}$

$$\mathcal{B}(\Lambda_b^0 \to \Lambda\eta') < 6.3 \times 10^{-6} \text{ at } 90\% \text{ CL}$$

Conclusions

- Searching for $\Lambda_b^0 \to \Lambda\eta'$ ($\eta' \to \pi^+\pi^-\gamma$).
- B^0 signal used as a control chanel and is well established.
- No significant Λ_b^0 observed.
- Present a limit on branching fraction.

$$\mathcal{B}(\Lambda_b^0 \to \Lambda\eta') < 6.3 \times 10^{-6} \text{ at } 90\% \text{ CL}$$

Outlook: Update for publication

- Add in the 2011 dataset ($1\,\text{fb}^{-1}$).
- Include $\eta' \to \pi^+\pi^-\eta$
- Search for $\Lambda_b^0 \to \Lambda\eta$
- Will be sensitive to full theoretical range.

Watch this space!

Back-Up Slides

BDT Selection

- Variables used in training

Particle	**Variables**
B^0 (Λ_b^0)	p_{T}, $\log(\chi^2_{\mathrm{VS}})$, $\log(\chi^2_{\tau_{B^0}})$, $\log(1 - \cos(\mathrm{DIRA}))$, Decay χ^2_{vtx}
K^0_{S} (Λ)	p, $\log(\chi^2_{\mathrm{IP}})$, $\log(\chi^2_{\mathrm{VS}})$
η'	p_{T}, $\log(\chi^2_{\mathrm{IP}})$
γ	$\log(E_{\mathrm{T}})$

- Cut on BDT response chosen by optimising Punzi FoM:

$$\mathrm{FoM} = \frac{\epsilon_{\mathrm{MVA}}}{\frac{a}{2} + \sqrt{B}}$$

Confidence Limits

Feldman-Cousins method used to calculate upper limit.

- Add values of Nfit into the confidence regions according to likelihood ratio

$$R_L = \frac{P(\mathrm{Nfit}|\mu)}{P(\mathrm{NFit}|\mu_{\mathrm{best}})}$$

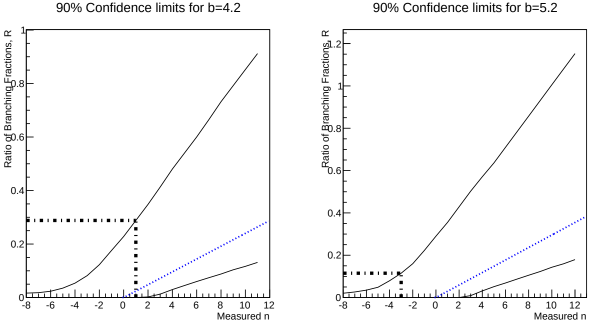
- P is a Gaussian probability described by systematic uncertainty and statistical uncertainty on the fit.
- μ_{best} is value of μ which maximises P, μ_{best}=max(0,Nfit)
- Nfit added until P(Nfit$|\mu$) exceeds confidence limit (90%)

$$\int_{n_{lo}}^{n_{hi}} P(\mathrm{Nfit}|\mu) dn \geq 0.9$$

- Scan over values of μ to build confidence belts.

Limits

- Use this method and the number of Λ_b^0 events extracted from the fit to place a limit on ratio of branching fractions.



R(LL) $<$ 0.288   R(DD) $<$ 0.160 at 90% CL

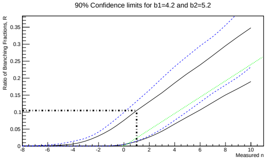
Combined limits

- Combined limit obtained by adding Nfit_1 and Nfit_2 by likelihood ratio

$$R_L = \frac{P(\mathrm{Nfit}_1|\mu_1)}{P(\mathrm{Nfit}_1|\mu_{\mathrm{best}})} \times \frac{P(\mathrm{Nfit}_2|\mu_2)}{P(\mathrm{Nfit}_2|\mu_{\mathrm{best}})}$$

- Combined probability needs to take into account:
  - Correlations in uncertainties (assumed to be 100%).
  - Different μ_1 and μ_2 for LL and DD.

$$P(\mathrm{Nfit}_1 \& \mathrm{Nfit}_2) = P(\mathrm{Nfit}_1) \times P(\mathrm{Nfit}_2|\mathrm{Nfit}_1) > 0.9$$



$$R = \frac{\mathcal{B}(\Lambda_b^0 \to \Lambda^0 \eta')}{\mathcal{B}(B^0 \to K^0 \eta')} < 9.6 \times 10^{-2} \text{ at 90\% CL}$$

$$\mathcal{B}(\Lambda_b^0 \to \Lambda^0 \eta') < 6.3 \times 10^{-6} \text{ at 90\% CL}$$