Measuring the $B^0_{d,s} \rightarrow K_s^0 h^{+/-} h^{-/+}$ Relative Branching Fractions at the LHCb experiment

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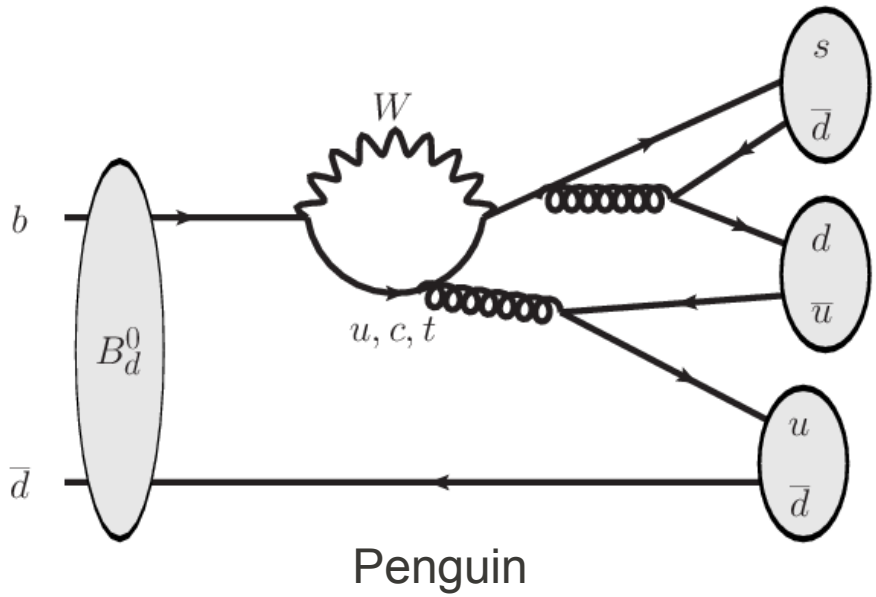
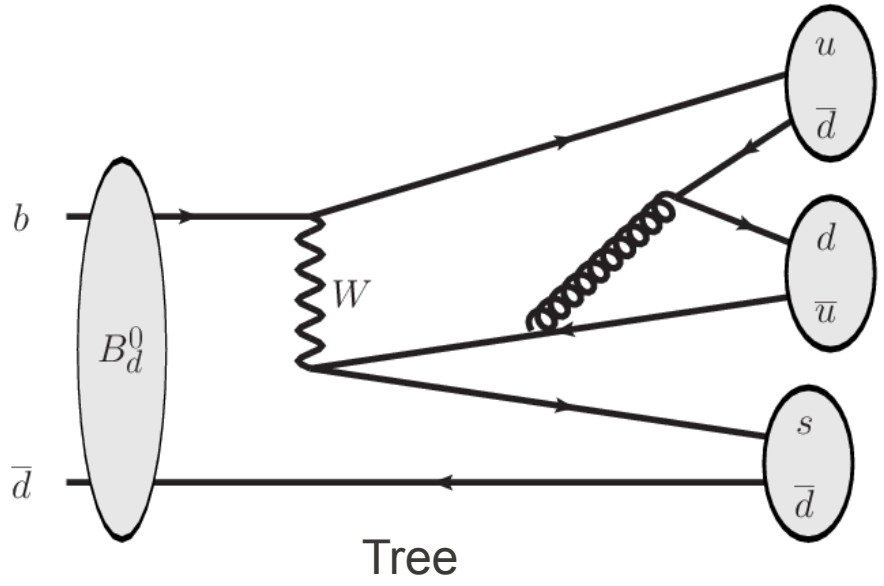
$B \rightarrow K_s hh$ Decay Mode

- Part of the Charmless 3-Body B decay family.
- Can proceed via Penguin loops or Tree diagrams.
- Relative phase between these diagrams is the CKM angle γ.



Penguin



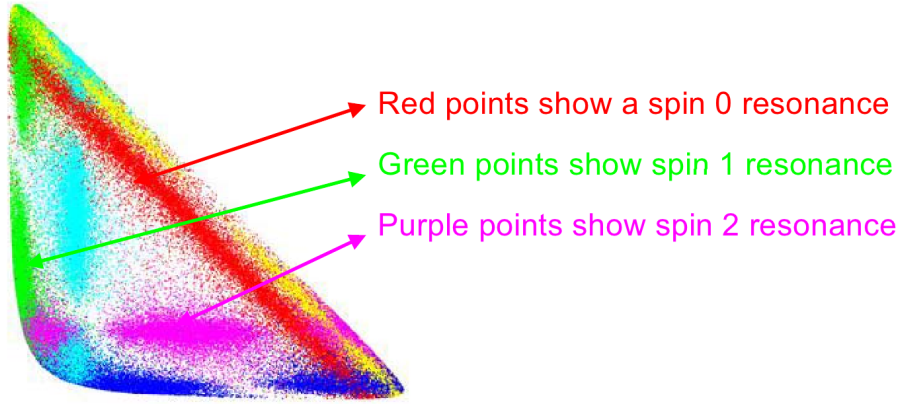
Tree

- Tree+loop diagram contributions are of similar magnitude making the interference easier to measure.

Physics Potential

- Potential for competitive relative branching fraction (BF) measurements/limits (+ possible discoveries) in 5 modes.
- β^{eff} angle extraction is possible from Dalitz Plot (DP) analysis.

$$d\Gamma = \frac{1}{(2\pi)^3}\frac{1}{32M^3}\overline{|\mathcal{A}|^2}dm^2_{ab}dm^2_{bc}$$



Toy Monte Carlo Dalitz Plot showing several resonance spin states

- Constraints on γ from $B_s \to K_S \pi\pi$ and $B_s \to K\pi\pi^0$ DP analyses (see slide 11).
- Due to the loop in the penguin diagram, New Physics (NP) particles can enter into the decays and cause deviations from expected values.

Current Goals

- Search for the 3 unobserved $B_s \rightarrow K_s$ hh modes
- Confirmation (or otherwise?) of $B_d \rightarrow K_s$ Kπ seen at BaBar.
- Measurement of these branching fractions (BF) relative to the well established $B_d \rightarrow K_s$ ππ mode seen at the B-factories.

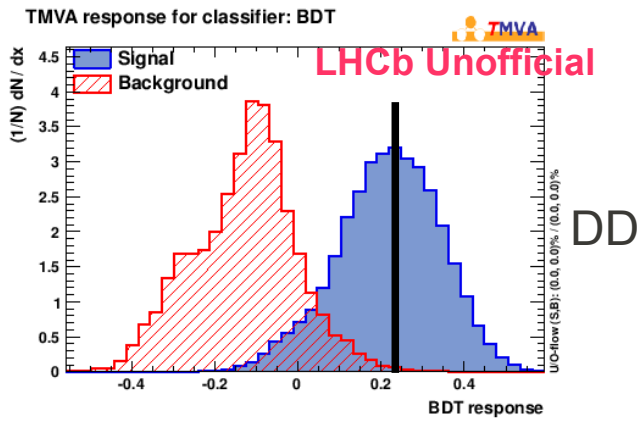
Decay Mode	Branching Fraction (10^{-6})		
	BaBar	Belle	World Average
$B^0_d \rightarrow K^0\pi^+\pi^-$	50.2 ± 2.3	47.5 ± 4.4	49.6 ± 2.0
$B^0_d \rightarrow K^0K^\pm\pi^\mp$	6.4 ± 1.2	< 18	6.4 ± 1.2
$B^0_d \rightarrow K^0K^+K^-$	23.8 ± 2.6	28.3 ± 5.2	24.7 ± 2.3

Current values of measured B_d modes from Heavy Flavour Averaging Group

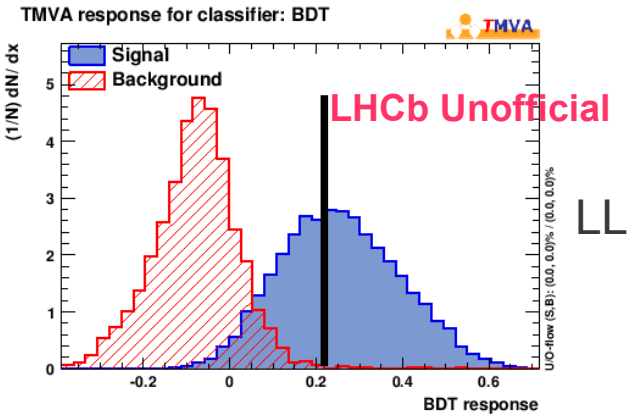
Selection of Candidates - BDT

- Using TMVA package to create Boosted-Decision-Tree (BDT) selectors from discriminating variables. Treat K_s DD/LL candidates separately (K_s DD candidates have no daughter pion hits in the VELO sub detector).
- 2010 Data used for the training of BDT, with 2-Body charm resonances and some $\Lambda_{b,c}$ mass combinations vetoed.

Description
B transverse momentum
B IP significance w.r.t PV
B pointing angle
B vertex fit χ^2
B flight distance significance w.r.t PV
hadron IP significance w.r.t PV
K^0_S vertex fit χ^2
K^0_S flight distance significance w.r.t PV
K^0_S IP significance w.r.t PV



DD



LL

	BDT Cut	ϵ Signal	ϵ Background
$B^0_s \to K^0_S\pi^+\pi^-$ (LL)	0.21	0.63	0.003
$B^0_s \to K^0_S\pi^+\pi^-$ (DD)	0.25	0.42	0.002

Selection of Candidates – PID & Vetoes

- RICH detector information (mostly) used to calculate Delta-log-likelihood (DLL) PID variables for charged tracks.
- Use cuts on DLL variables to distinguish pions and kaons.

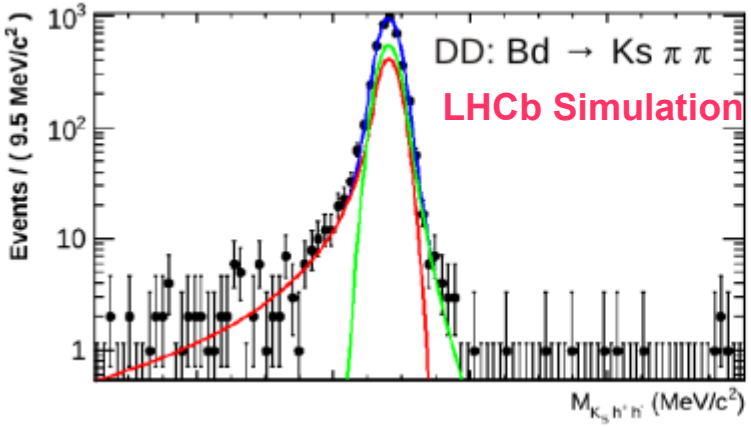
Track	π	K
Kaon PID Requirement	$\mathrm{DLL}_{K\pi} < 0$	$\mathrm{DLL}_{K\pi} > 5$
Proton PID Requirement	$\mathrm{DLL}_{p\pi} < 10$	$(\mathrm{DLL}_{p\pi} - \mathrm{DLL}_{K\pi}) < 10$

- Charmonium $\rightarrow \mu^+\mu^-$ removed using a cut on muon ID.
- Charmed resonances vetoed with cuts on track mass combinations.
- Fewer than 1% of events contain multiple candidates. A single candidate is selected using an arbitrary (but reproducible) selection algorithm.

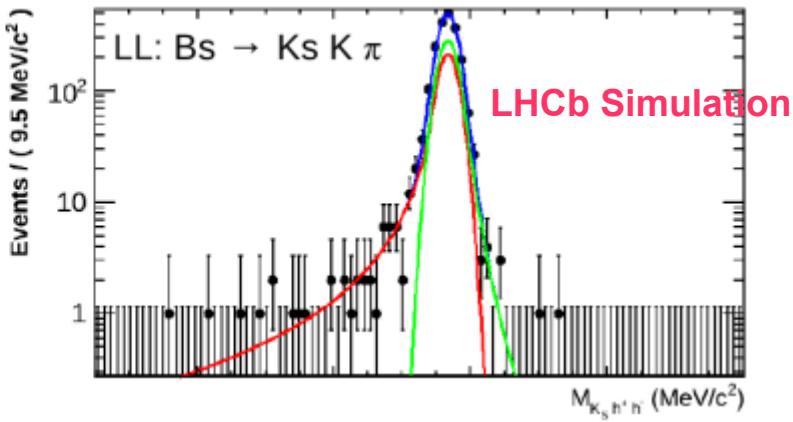
Simultaneous Fit - Signal

- Simultaneous fit of all 6 modes (3 hh combinations and both DD & LL) so that cross feeds can be taken into account. Fit commissioned on ~250pb^{-1} of 2011 Data (about 1/5th of the full dataset).
- Signal Fit:
  - 2 Crystal Ball functions with the same mean value and resolution and different tails
  - Simultaneous fit of all simulated (MC) signals, with same tail parameters, the same fraction of the second CB and the same B_d and B_s mean values.

Tests of the Signal fits on selected simulated candidates



$B_d \rightarrow K_s\pi\pi$ (DD)

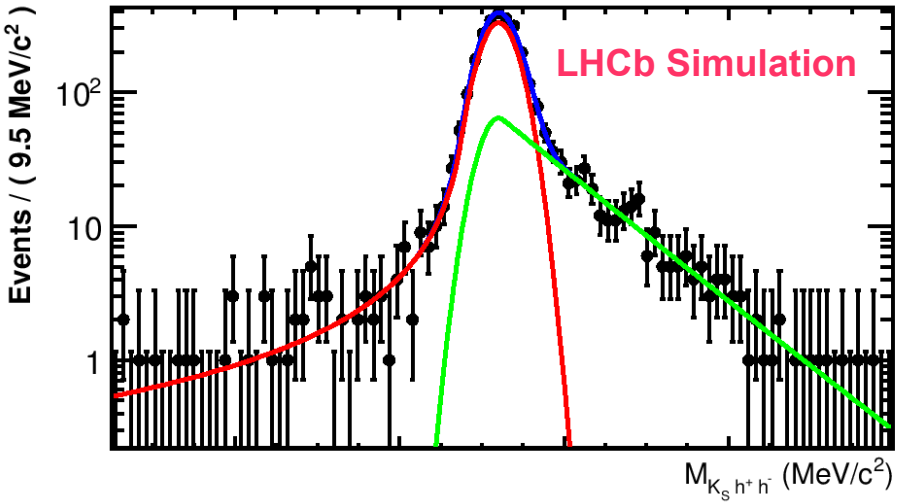


$B_s \rightarrow K_sK\pi$ (LL)

Simultaneous Fit – Cross Feed + Combinatorial

- Cross Feed Fit:
  - 2 Crystal Ball functions again, with same mean + resolutions but different tail parameters.

Tests of the Cross Feed fits on selected simulated candidates



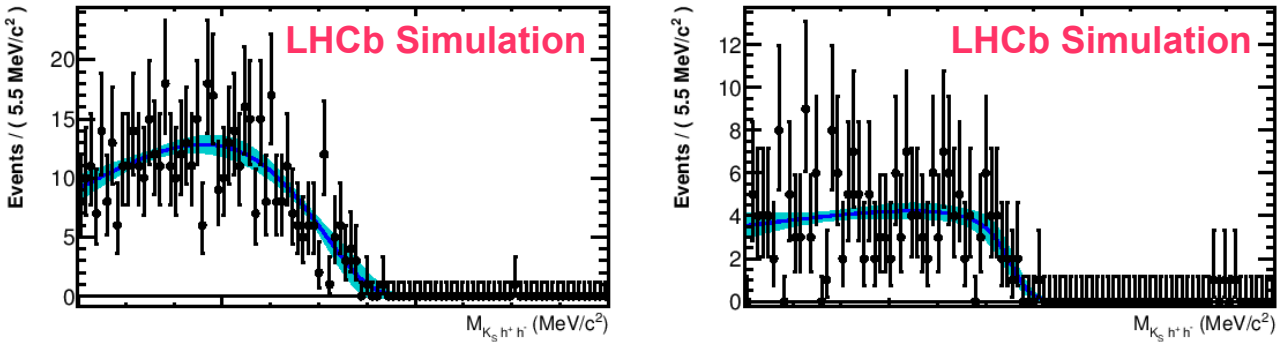
$B_d \rightarrow K_s \pi\pi$ events with $K\pi$ mass hypothesis

- Combinatorial Background:
  - Fitted with exponential.

Simultaneous Fit – Partially Reconstructed Backgrounds

- Partially Reconstructed Backgrounds:
  - Generalised ARGUS function convoluted with Gaussian resolution
- Examples:
  - $B_d \rightarrow K_s \pi\pi\gamma$ photon not reconstructed.
  - $B \rightarrow K^*(K_s\pi)\ \rho(\pi\pi)$ pion from 4-body VV mode not reconstructed.
  - $B^- \rightarrow D^0(K_s\pi\pi)\ K^-$ pion not reconstructed.
  - + others...

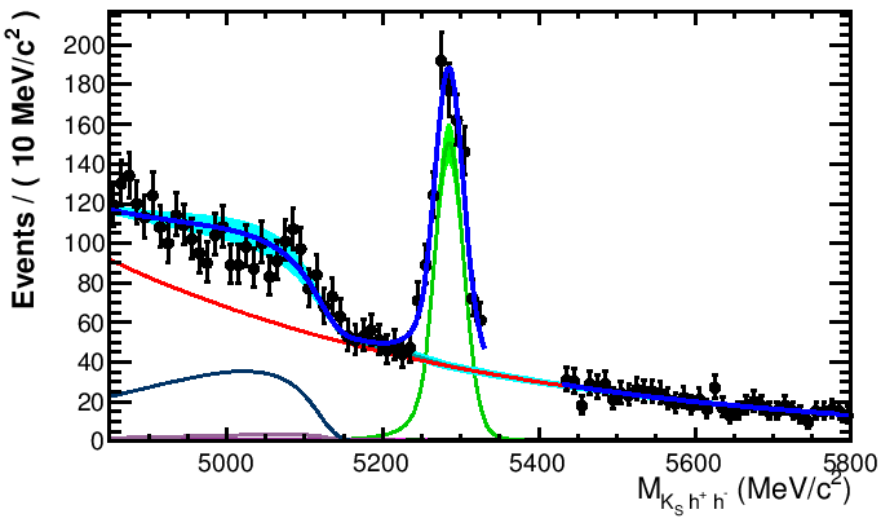
Tests of the partially reconstructed fits on selected simulated candidates



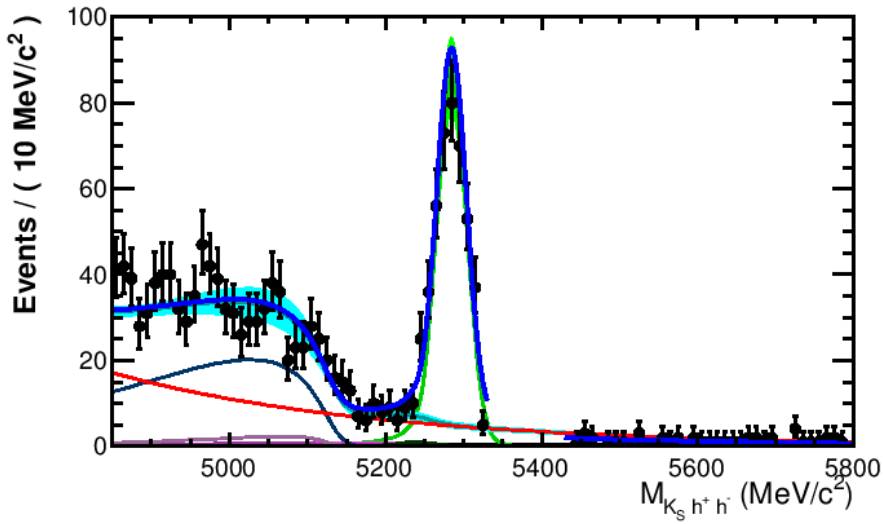
$B^- \rightarrow D^0\ K^-$ events reconstructed as $K_s\ K\pi$: left DD, right LL

Fit Performance

- On the full 2011 dataset with blinded B_s mass region, we obtained these fit results for $B_d \rightarrow K_s \pi\pi$



DD



LL

- Good performance of fit. Observe yields of ~750 in DD, ~440 in LL
- Ratio of $B_d \rightarrow K_s KK$ and $B_d \rightarrow K_s \pi\pi$ in excellent agreement with expectation.

Current Status + Future Goals

- Extraction of efficiencies from data, extraction of yields and evaluation of systematic uncertainties are under way.
- Calculation of relative BFs/upper limits on blinded modes beginning very soon. Working towards a preliminary result for late May (FPCP).
- Then a paper result to follow shortly afterwards.
- Future:
  - Dalitz Plot analyses of $B_d \to K_s\pi\pi$ (KK) and $B_s \to K_s K\pi$
- Longer Term:
  - Time dependent Dalitz Plot analyses of B_d modes for β^{eff} extraction
  - Time dependent Dalitz Plot analysis of $B_s \to K_s K\pi$ mode for evaluation of β_s^{eff}
  - $B_s \to K_S \pi\pi$ and $B_s \to K\pi\pi^0$ Dalitz Plot analyses to extract relative phase of $B \to K^*\pi$ and $B \to \rho K$ decays. Isospin analysis gives a constraint on γ.

Backup Slides

PDF Functions

- Crystal Ball:
  - $t = m\text{-}\mu$
  - μ and σ are mean and resolution of Gaussian part.
  - Sign of α governs left/right handedness of tail, *n* governs power law of tail decrease.

$$CB(t) = \mathcal{N} \cdot \begin{cases} \exp(-t^2/2\sigma^2) & \text{if } t/\sigma > -\alpha \\ (\frac{n}{|\alpha|})^n \exp(-\alpha^2/2)(\frac{n-\alpha^2}{|\alpha|} - \frac{t}{\sigma}) & \text{if } t/\sigma \leq -\alpha, \end{cases}$$

- ARGUS:
  - $m<m_t$ (threshold mass value)
  - c controls curvature
  - p controls falling of slope.

$$A(m : m_t, c, p) = \frac{2^{-p} c^{2(p+1)}}{\Gamma(p+1) - \Gamma(p+1, c^2/2)} \cdot \frac{m}{m_t^2}(1 - \frac{m^2}{m_t^2})^p \exp\left[-\frac{1}{2}c^2(1 - \frac{m^2}{m_t^2})\right]$$

Simultaneous Fit – Signal + Cross Feed

- Simultaneous fit of both DD & LL samples, 6 distributions with 37 parameters.

- Signal:
  - Shape from MC.
  - $B_{d,s}$ masses floated: requested to be the same for all distributions.
  - $B_d \rightarrow K_s \pi\pi$ resolutions (DD and LL) floated.
  - All the other resolutions are scaled according to Monte Carlo (MC).
- Cross Feeds: $K_s \pi\pi$ and $K_s KK$ vs. $K_s K\pi$ and vice versa.
  - Shapes from MC
  - Yields Gaussian constrained with the mode yields.

Simultaneous Fit – Backgrounds

- Partially reconstructed backgrounds:
  - Shapes from MC
  - All the relative yields of the partially reconstructed backgrounds respect to the signal.
  - (B_d or B_s) are the same in DD and LL.
  - Most of the yields are Gaussian constraints with errors coming from Branching fractions.
  - Charm contribution to K_s KK extracted from data.
- Combinatoric background:
  - Exponential shape, parameter floated in the fit.
  - Same shape for all decay modes.
  - different shape for DD and LL.