School of Physics and Astronomy

Ion Feedback Monitoring of HPDs and $B_d \to J/\psi K^*$ for LHCb

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1 RICH and Hybrid Photon Detectors

1.1 Introduction

The Large Hadron Collider Beauty (LHCb) experiment is one of the four detectors on the Large Hadron Collider ring at CERN. It is the only asymmetric detector and is designed specifically for looking at particles containing b quarks and therefore has a high $b\bar{b}$ cross-section. The two Ring Imaging Cherenkov (RICH) subdetectors are part of the detector and provide charged particle identification using Cherenkov radiation. The Cherenkov photons are recorded by arrays of HPDs (Hybrid Photon Detectors) and rings are found using pattern recognition. The diameter of the ring along with the refractive index of the medium that the particle was travelling through, reveals it's velocity. This, along with the momentum of the particle deduced from the tracking stations, reveals the particle's mass. The HPDs have a high performance in Quantum Efficiency and resolution and recent data from proton-proton collisions has proven them to be very efficient. However, some of the HPDs have been shown to degrade over time and this has to be carefully monitored.

2 Ion Feedback

The HPDs consist of a vacuum inside a metal tube, sealed with a quartz window which is coated on the inside with a multialkali photocathode. When a photon enters the window it is converted to a photoelectron which is accelerated through a potential difference onto a reverse biased silicon sensor. If a photoelectron hits the sensor producing a charge pulse above a certain threshold it is classed as a 'hit' and a binary signal is read out. It has been found that in some HPDs there are an unusual number of clustered hits and as these HPDs age, a 'glowing' effect can occur where the HPD starts to produce it's own light. It was found that these HPDs have a degraded vacuum and an increased amount of residual gas molecules which are ionised by the photoelectrons. These are then accelerated onto the photocathode and this results in a delayed cascade of electrons which are accelerated onto the silicon sensor causing the clusters of hits. This is called Ion Feedback and as the effect increases the silicon bias currents become saturated and the HPDs become unusable. They can be repaired with a vacuum bake-out but this means removing them from the RICH detectors and sending them back to the manufacturer. The HPDs are closely monitored and it is possible to predict which ones will start to glow and when. This means that these candidates can be removed for repair when there is an intervention in LHCb.

To predict the degradation of the HPDs, timelines are produced of the raw Ion Feedback measurement. This can either be done while the HPDs are installed in the RICH or at the Photo-detector test facilities (PDTF) at Edinburgh. The first method is most important for deciding which HPDs to remove and replace during the intervention. It uses a continuous wave light source, and the integrated IFB rate is estimated. Predictions have been make for HPDs that will pass 5% IFB level before December 2011 for RICH 1 and RICH 2 and these are shown in Tables 1 and 2.

Table 1: RICH 1 repair candidates

HPD ID	RICH 1 Position	IFB measurement (%)	IFB fitting Gradient (% year)	Predicted Date 5% pass
H649005	D0_10	4.30	1.35	Glowing
H643005	D0_11	5.57	1.74	Already passed
H704001	U0_1	4.89	1.14	June 2010
H704016	U1_1	4.78	1.30	July 2010
H708006	D2_11	4.47	1.17	October 2010
H708013	U0_8	4.23	1.56	October 2010
H525005	D0_3	4.45	1.35	November 2010
H708003	D1_3	3.99	1.54	December 2010
H704008	D1_5	4.11	1.27	January 2011
H525006	U2_6	4.26	0.96	February 2011
H709002	D0_6	3.84	1.28	March 2011
H708022	U0_12	3.75	1.34	April 2011
H651007	D6_7	3.94	1.07	April 2011
H644002	U5_2	3.28	1.08	December 2011
H703003	D1_9	3.23	1.09	December 2011

In conclusion in RICH 1 there currently 2 HPDs over the 5% threshold, 6 more are predicted to pass 5% this year, and 7 more in 2011. In RICH 2 there is one HPD that has already passed 5%, 3 more predicted in 2010 and 10 more in 2011.

The majority of the HPDs have a low IFB measurement and show a slow steady increase (Figure 1). Some HPDs have a high Ion Feedback and show a faster increase. 38 HPDs in RICH 1 and 71 in RICH 2 show an increase in gradient between 2008 and 2009 (see Figure

Table 2: RICH 2 repair candidates

HPD ID	RICH 2 Position	IFB Measurement (%)	IFB Fitted Gradient (%/year)	Calculated Date 5% pass
H518004	A0_1	5.02	1.32	Already passed
H602006	C7_7	4.75	0.97	August 2010
H542003	A0_2	4.66	1.11	August 2010
H542008	A1_1	4.54	1.04	October 2010
H612002	A1_0	4.08	1.15	February 2011
H503004	C8_9	3.95	1.09	April 2011
H629002	A3_0	4.07	0.89	May 2011
H550009	A8_10	3.96	0.92	June 2011
H603002	C7_8	3.42	1.34	July 2011
H627024	A3_10	3.76	1.03	July 2011
H602002	C7_6	3.79	0.87	September 2011
H547001	A1_4	3.80	0.84	October 2011
H627003	A6_8	3.51	1.03	October 2011
H521001	C3_1	3.73	0.86	November 2011

2). It could be due to the ionisation of secondary electrons becoming more significant in the evolution. It was also thought that it could be due to the re-calibration that was carried out to the L0 boards at the end of 2008- but those boards that were calibrated generally do not correspond to those that have shown this increase. The reason for this increase is therefore still being investigated.

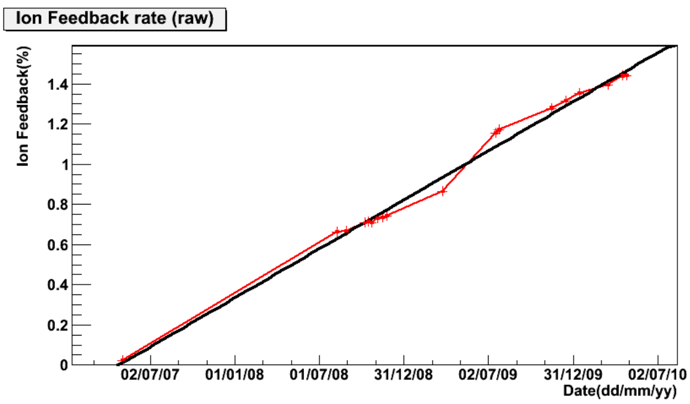


Figure 1: IFB timeline for H708023

2.1 Long Ion Feedback Runs

There have been several long Ion Feedback runs taken which show a so-far unexplained behaviour for many HPDs. These long runs can last as long as 24 hours, and the Raw Ion Feedback is measured in slices of 3 million events which corresponds to approximately 30 minutes of data taking. The standard IFB measurements are usually taken from the first 3 million events of a run only. It would be expected for these measurements to

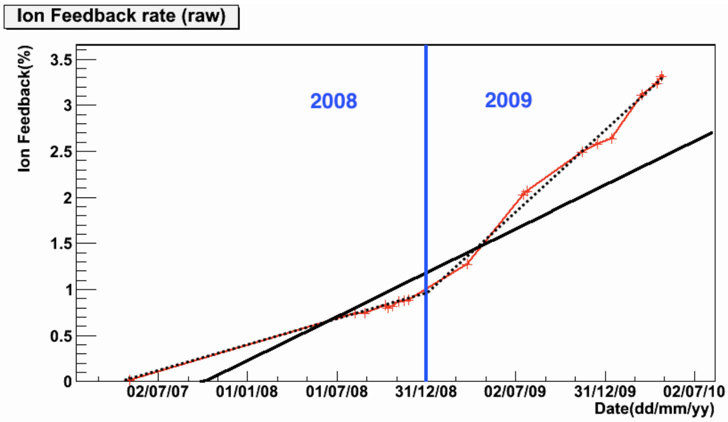


Figure 2: IFB timeline with increased gradient. The dotted and blue lines are just to guide the eye. The black line is a best fit line. This example is an extreme case.

be constant within errors, but in fact they can drift quite a lot over the course of the run- and can increase or decrease, or just fluctuate. These variations are far beyond any perceivable 'real' Ion Feedback variations. This suggests some instability of the system and this is currently under investigation. The IFB timelines discussed previously suggest that the measurements are usually similar between runs so this may be a gradual effect that only occurs when the system is running for a longer period of time.

For some HPDs the variation over a run seems to be correlated with the amount of light falling at that moment, but for others it is not. One HPD that always shows this correlation is D6_11 of RICH 1. The average cluster rate is the total number of clusters divided by the number of events- so gives a rough estimate of signal. The raw IFB trends and the average cluster rate for that HPD over one long run is shown in Figure 3.

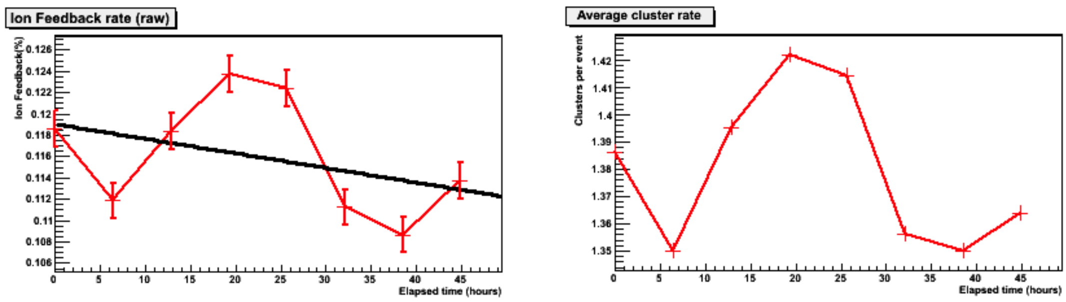


Figure 3: Raw IFB measurement and Average Cluster Rate for D6_11 for run 36569

The Ion Feedback gradient has been calculated for each run and this has been extrapolated to per year- so it can be compared with the other measurements. For each run the Raw IFB value has been plotted against the IFB gradient - to see if there is any correlation between HPDs with a high IFB and high variation over a run. Such a graph is shown in Figure 4. They all show a similar behaviour and it can be concluded that HPDs with a higher IFB are more likely to show this unstable behaviour. More investigation is needed so that the reason behind this behaviour is found and steps can be taken to ensure it is not a problem for taking data.

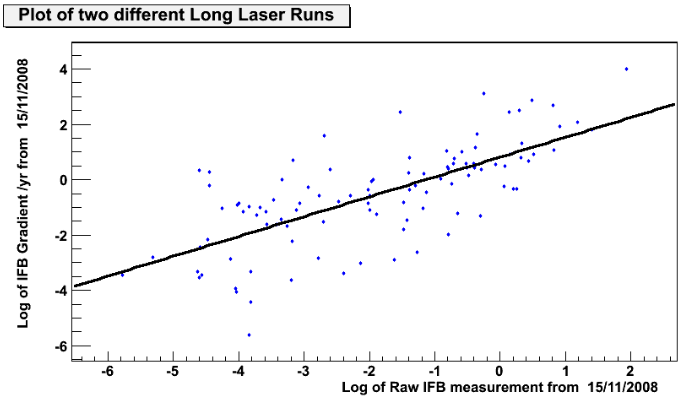


Figure 4: Logarithm of Raw IFB value plotted against logarithm of IFB gradient over a run

3 The Decay $B_d \to J/\psi K^*$

3.1 Introduction

This is a particularly useful control channel for the interesting decay $B_s \to J/\psi\phi$ due to certain similarities between them. $B_s \to J/\psi\phi$ is CP violating and sensitive to New Physics. The B meson can either decay directly or oscillate first before decaying. The mixing and decay amplitudes interfere and the time-dependent CP asymmetry measures the phase difference ϕ_s. This is predicted well by the Standard model but a precise measurement by LHCb may reveal New Physics.

Both $B_d \to J/\psi K^*$ and $B_s \to J/\psi\phi$ are pseudoscalar to vector-vector decays and have the same angular distribution. For each the final state is a admixture of CP-even and CP-odd states. The P-wave (l = 1) contribution is the CP-even part- i.e.the parity conserving part, while the S-wave is the (l = 0) parity violating part. These have different angular dependencies so it is possible to separate them using an angular analysis. The method for the measurement of these amplitudes in $B_d \to J/\psi K^*$ is very similar to the method used for extracting the CP violating phase ϕ_s from $B_s \to J/\psi\phi$ so it can be used to verify this important measurement.

$B_d \to J/\psi K^*$ is a colour-suppressed Cabibbo-favoured decay, and is seen in Figure 5. There is an internal W emission from a $b \to c$ transition, which associates with the $\bar{c}$ and d quarks to form colour singlets. The theoretical analysis of the decay is complex due to strong interaction effects but it is often used as a control channel. The large branching ratio is advantageous for this. The case where $K^* \to K^+\pi^-$ will only be looked at because the CP violation effects are small and the B^0 flavour is self- tagged by the charge of the final Kaon- which can be used to verify the other flavour tagging methods. (In the case where $K^* \to K_s\pi^0$ there will be time- dependent CP violation as it is a CP eigenstate). As a first step to my analysis of $B_d \to J/\psi\phi$ and related measurements I have begun some Monte Carlo analysis of $B_d \to J/\psi K^*$.

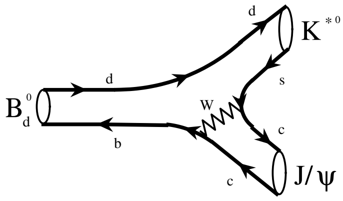


Figure 5: Feynman Diagram of $B_d \to J/\psi K^*$ decay [1]

Table 3: Previous Results of Polarisation amplitudes and arguments

Experiment	$\lvert A_0\rvert^2$	$\lvert A_\parallel\rvert^2$	$\lvert A_\perp\rvert^2$	$\delta_\parallel$	$\delta_\perp$
BaBar[2] $209fb^{-1}$	$0.556 \pm 0.009 \pm 0.010$	$0.211 \pm 0.010 \pm 0.006$	$0.233 \pm 0.010 \pm 0.005$	$-2.93 \pm 0.08 \pm 0.04$	$2.91 \pm -.05 \pm 0.03\pm$
Belle[3] $253fb^{-1}$	0.571 ± 0.15	0.216 ± 0.017	0.213 ± 0.017	-2.834 ± 0.134	2.878 ± 0.088
CDF [4] $1.3fb^{-1}$	$0.569 \pm 0.020 \pm 0.007$	-	$0.211 \pm 0.012 \pm 0.006$	$-2.96 \pm 0.08 \pm 0.03$	$2.97 \pm 0.06 \pm 0.01$
D0 [5] $2.8fb^{-1}$	0.587 ± 0.013	0.230 ± 0.013	-	-2.83 ± 0.06	-

3.2 Angular Analysis

There are three transversity angles used in this analysis - θ, φ and ψ and they are shown in Figure 6. Three complex polarization amplitudes are used to describe the angular dependent decay rates: A_0 represents the longitudinal polarization and $A_\parallel$ and $A_\perp$ for parallel and perpendicular transverse polarization. The relative contributions of these are calculated so that $|A_0|^2 + |A_\parallel|^2 + |A_\perp|^2 = 1$ and so one of them is arbitrary. The arguments of these amplitudes are the strong phases $\delta_0, \delta_\parallel$ and $\delta_\perp$. These amplitudes and arguments for $B_d \to J/\psi K^*$ are already measured with high precision from past experiments (see Table 3) - so by comparing the LHCb results with these, the method can be verified.

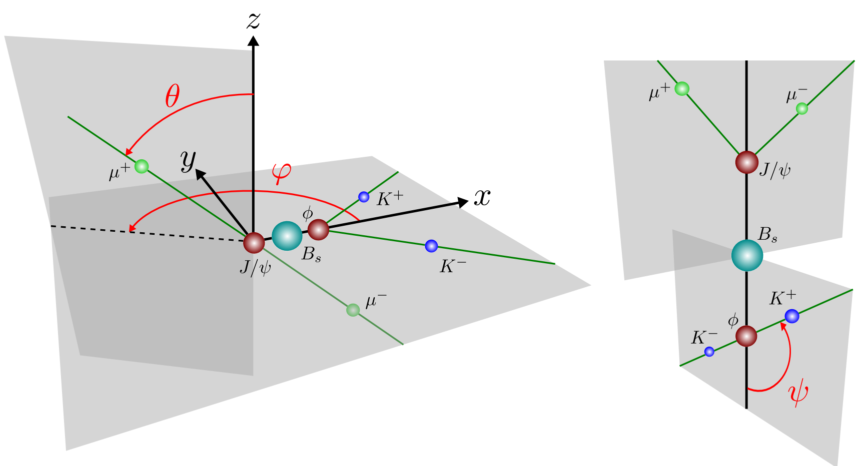


Figure 6: Transversity angles of $B_s \to J/\psi\phi$. For $B_d \to J/\psi\phi$ replace $\psi \to KK$ with $K^* \to K\pi$

3.3 Progress

The initial step towards the analysis of $B_d \to J/\psi K^*$ was to write a Probability Density Function (PDF) for the channel. This is a model for the channel describing the behaviour of the observables. It depends on the unknown physics parameters- the polarization amplitudes and strong phases- so these can be worked out from known observables. It includes a double gaussian time resolution because this has been shown to be a reasonable approximation [6]. The main PDF equation describing the time-independent angular distribution is below. $(f_1 - f_6)$ are angular expressions shown in [7]. I and R are the Imaginary and Real parts.

$$\frac{d^4\Gamma}{dtdcos\theta d\varphi dcos\psi} = e^{-\Gamma_d t}(f_1|A_0|^2+f_2|A_\parallel|^2+f_3|A_\parallel|^2-f_4 I(A_\perp A_\parallel^*)+f_5 R(A_0^* A_\parallel)\pm f_6 I(A_0^* A_\perp)) \quad (1)$$

Once this was written it was used to fit to the Monte Carlo data from 2009. This was done using a fitting tool written at Edinburgh called RapidFit. Firstly, toy studies were carried out to verify that the PDF behaved well. Toy studies are constructed from the PDF and then fitted back to the same PDF. This makes it quick and easy to see biases and correlations. The fit stability and statistical errors can be quantified using many toys studies. The results of the toy study are shown in Table 6. The MC09 data was selected using standard cuts already provided for $B_d \to J/\psi K^*$ for a lifetime unbiased selection (Table 5).

A fit was performed using the PDF described above as well another one that had already been written for the $B_s \to J/\psi\phi$ mass signal. There are six angular acceptance parameters that have to be included in the fit. These are worked out using a method described in [8].

A background was discovered at low lifetimes, which was clear from the time projection plot and the sidebands of the mass projection plots. It was concluded to be from prompt J/ψ production associated with another prompt track. This background was able to be fitted to by introducing a background PDF. The fit result is shown in Table 4 and fitted mass and time projections as well as the projections for each of the three transversity angles are shown in Figure 7. The values of the polarization amplitudes and arguments do not yet correspond to the known values and there is more work to do on this.

The next step in this analysis is to improve the fit and compare the measurements of the polarization amplitudes against their already well measured values to verify the method that has been used.

4 Future Plans

There is more useful work to be done on $B_d \to J/\psi K^*$ and this will lead on to an analysis of $B_s \to J/\psi\phi$ and the CP violating phase ϕ_s.

It will be important to look at the B_d and B_s production cross sections at LHCb. The production cross section is the ratio of the number of observed B candidates to the product of the detector acceptance, integrated luminosity, and branching ratio of the decay in question. These measurements examine the ability of perturbative QCD to predict absolute rates in hadronic collisions which are affected by large theoretical uncertainties. When there is enough data from the LHC I hope to carry out these measurements.

During the measurement for ϕ_s in $B_s \to J/\psi\phi$ an Opposite Side Tagger(OST) will be used. The OST technique determines the flavour of the 'other' B-hadron produced, so the one in

Table 4: Fit Result

Parameter	Fit result and error	σ from input
gamma	0.67333 ± 0.002112	9.2
Apara_sq	0.20375 ± 0.0024768	-15
Azero_sq	0.66165 ± 0.0019728	31
delta_para	0.081001 ± 0.024473	0.82
delta_perp	0.056165 ± 0.015601	0.44
deltaM	0.507 ± 0	nan
timeResolution1	0.022947 ± 0.0013878	-5.1
timeResolution2	0.076864 ± 0.0075696	2.2
timeResolution1Fraction	0.89145 ± 0.029804	6.4
angAccI1	0.9637 ± 0	nan
angAccI2	1.0768 ± 0	nan
angAccI3	1.0934 ± 0	nan
angAccI4	0.0032255 ± 0	nan
angAccI5	-0.030579 ± 0	nan
angAccI6	0.00015141 ± 0	nan
f_sig_m1	0.85321 ± 0.0021532	58
sigma_m1	14.535 ± 0.049694	24
sigma_m2	86.173 ± 1.15	34
m_Bs	5277.5 ± 0.052009	-11

question can be assumed to have the opposite flavour. It is very important to fully understand the tagging. The calibration and verification of this tagging method can be verified by using B_d mixing measurements. The oscillation frequency Δm_d and mass difference have been measured extremely accurately by BaBar and Belle and can be used to calibrate the OST. By fitting the flavour oscillations of the B_d mesons as a function of proper time, the mistag rate can be measured. This is another measurement I hope to carry out.

Recently $D0$ made a measurement of A^b_{sl}, the like-sign di-muon charge asymmetry in the B system [9]. Combining their result with that of CDF [10] they found that:

$$A^b_{sl} = \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}} = -(8.5 \pm 2.8) \times 10^{-3} \tag{2}$$

This is about 3σ away from the Standard Model prediction. The measurement was carried out blind to the flavour of the B meson and therefore received contributions from both B_s and B_d CP asymmetries. $D0$ also directly measured the contribution from the B_s meson alone:

$$a^s_{sl} = (-1.7 \pm 9.1) \times 10^{-3} \tag{3}$$

Despite the large error, this was used to calculate $|M^s_{12}|$ - the off-diagonal element of the mass matrix, $|\Gamma^s_{12}|$- the off-diagonal element of the decay matrix and ϕ_s- the relative phase between these two amplitudes [11]. Both $|\Gamma^s_{12}|$ and ϕ_s show a deviation from the Standard Model value as seen in Table 7. New physics that only adds a relative phase ϕ_s is unable to explain the CP asymmetry which means that there must be a contribution to $|\Gamma^s_{12}|$ as well.

It has recently been shown that there are two operators that could contribute to Γ^s_{12} by an order of 1 [11]. They would contribute 10% to the total lifetime of the B_s meson. There

Decay Mode	Cut
$J/\psi \rightarrow \mu^+\mu^-$	μ track maximum $\chi^2_{track}/nDoF < 5$ μ minimum $\Delta ln\mathcal{L}_{\mu\pi} > -5$ μ maximum $\Delta ln\mathcal{L}_{K\pi} > 5$ $\lvert M(\mu\mu)\rvert - \lvert M(J/\psi)\rvert < 42MeV$
$K^* \rightarrow K^+\pi^-$	K minimum $\Delta ln\mathcal{L}_{Kp} > -2$ K minimum $\Delta ln\mathcal{L}_{K\pi} > 0$ $\lvert M(\pi K)\rvert - \lvert M(K^*)\rvert < 70MeV$ $K^* p_T > 1GeV$ $K^*\chi^2_{vtx}/nDoF < 20$
$B_d \rightarrow J/\psi K^*$	$\lvert M(J/\psi K^*)\rvert - \lvert M(B_d)\rvert < 300MeV$ $B_d IP\chi^2 < 25$ $B_d\chi^2_{vtx}/nDoF < 5$ $B_d p_T > 2GeV$

Table 5: MC09 Selection Cuts

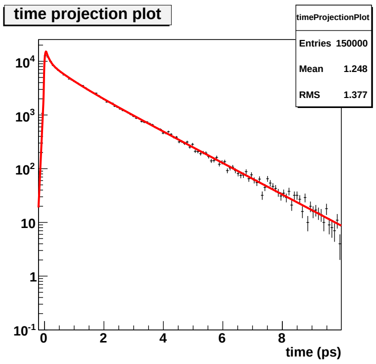
are large theoretical uncertainties on the current value anyway, due to large non-perturbative effects. The ratio of the proper lifetimes of B_s and B_d is much better predicted because the large non-perturbative effects mostly cancel out. An operator that gives a contribution to Γ^s_{12} of an order of 1 would give rise to a large lifetime difference- larger than theoretical uncertainty.

The B_d lifetime is precisely measured by the B factories and CDF at $1.52ps$ with an overall 1% error [12]. $D0$ measures a lower value of 1.41ps which is 3σ from the world average [5]. The B_s lifetime is measured at 1.50ps by CDF [13] and D0 [5] (at 2% and 4% accuracy respectively) and 1.47ps when LEP measurements are included [12] . For both the CDF and D0 measurements the statistical errors are larger than the systematic errors. Using the world average values, the value of the ratio τ_{B_s}/τ_{B_d} indicates a 2σ difference between the lifetime ratios. However the method for combining the systematics between different experiments and methods has not been verified.

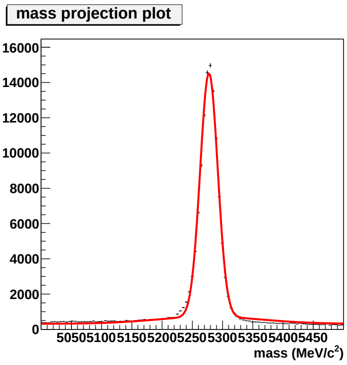
D0 has produced a result giving $\tau_{B_s}/\tau_{B_d} = 1.052 \pm 0.061(stat) \pm 0.015(stat)$ which is consistent with theoretical predictions and previous measurements, however it uses the inconsistent result for the B_d lifetime. The measurement of this ratio is important at LHCb as it could either support or constrain the existence of new physics in Γ^s_{12}. This is another measurement I would like to contribute to.

Parameter	Mean	Std. Dev	Pull mean	Pull Std. Dev
γ	$0.654 \pm 6.65e-05$	$0.0019 \pm 5.23e-05$	0.0176 ± 0.0320	0.935 ± 0.0246
$\lvert A_{\parallel}\rvert^2$	$0.240 \pm 9.68e-05$	$0.00284 \pm 7.85e-05$	0.0495 ± 0.0317	0.937 ± 0.0292
$\lvert A_0\rvert^2$	$0.600 \pm 7.23e-05$	$0.00213 \pm 5.61e-05$	-0.0616 ± 0.0324	0.966 ± 0.0242
$\delta_{\parallel}$	2.50 ± 0.0005	0.0170 ± 0.0004	-0.060 ± 0.0329	0.986 ± 0.0243
$\delta_{\perp}$	-0.171 ± 0.000445	0.0133 ± 0.0003	-0.064 ± 0.031	0.924 ± 0.0246
timeResolution1	0.030 ± 0.0002	0.005 ± 0.0002	-0.109 ± 0.032	0.974 ± 0.031
timeResolution2	0.060 ± 0.0001	0.004 ± 0.0001	0.029 ± 0.030	0.814 ± 0.027
timeResolutionFraction	0.494 ± 0.004	0.123 ± 0.0034	-0.025 ± 0.032	0.911 ± 0.0300
f_{m1}	0.548 ± 0.001	0.021 ± 0.001	-0.082 ± 0.032	0.995 ± 0.028
σ_{m1}	10.9 ± 0.005	0.144 ± 0.004	-0.088 ± 0.032	0.956 ± 0.027
σ_{m2}	18.4 ± 0.0061	0.181 ± 0.0055	-0.173 ± 0.032	0.992 ± 0.027
m_{Bs}	5279.5 ± 0.0015	0.0455 ± 0.0013	-0.0063 ± 0.0339	0.994 ± 0.0278

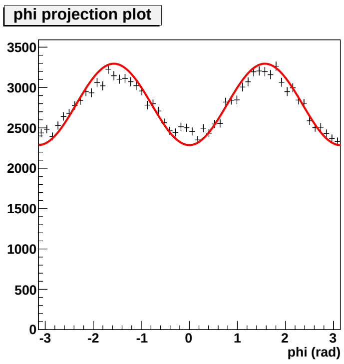
Table 6: Results of Toy Studies



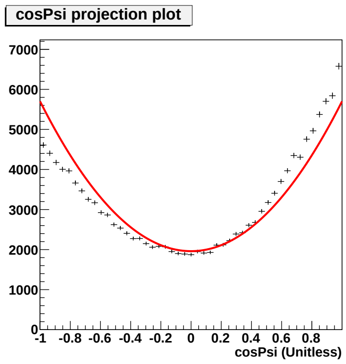
(a) Time Projection



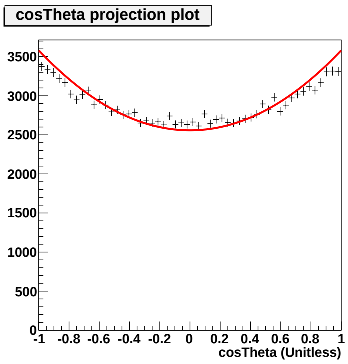
(b) Mass Projection



(c) ϕ Projection



(d) $cos(\psi)$ Projection



(e) $cos(\theta)$ Projection

Figure 7: Projection Plots

Parameter	Standard Model Prediction	Measured
$\lvert M_{12}^s \rvert$	$(9.8 \pm 1.1)ps^{-1}$	$(8.889 \pm 0.060)ps^{-1}$
$\lvert \Gamma_{12}^s \rvert$	$(0.049 \pm 0.012)ps^{-1}$	$(0.112 \pm 0.040)ps^{-1}$
ϕ_s	0.04 ± 0.01	-0.79 ± 0.024

Table 7: SM prediction compared to Measured value

5 Timetable

Task	Period
Monitoring of Ion Feedback	Ongoing until June 2011
Analysis of decay channel using 2010/11 data sample	Ongoing
Finish detector chapter	Before June 2011 (back in Edinburgh)
Theory Chapter	June - July 2011
HPD and Ion Feedback chapter	July- August 2011
Write-up decay channel analysis	August - December 2011
Editing	December 2011 - February 2012
Submit Thesis	February 2012

References

[1] M.Calvi, B.Khanji, G.Lanfranchi, O.Leroy, and S.Poss. Lifetime unbiased selection of $B_s \to J/\psi\phi$ and related control channels $B^0 \to J/\psi K^*$ and $B^+ \to J/\psi K^+$. *LHCb-2009-025*, 2009.

[2] The BaBar Collaboration. Measurement of Decay Amplitudes of $B \to (c\bar{c})K*$ with an Angular Analysis, for $(c\bar{c}) = J/\psi, \psi(2S)$ and $\chi_c 1$. *Phys.Rev.D 76, 031102*, 2007.

[3] The Belle Collaboration. Studies of CP violation in $B \to J/\psi K^*$ decays. *arXiv:hep-ex/0504030v2*, 2005.

[4] The CDF Collaboration. Angular Analysis of $B_s \to J/\psi\phi$ and $B^0 \to J/\psi K^*$ Decays and Measurement of $\Delta\Gamma_s$ and ϕ_s. *CDF note 8950*, 2007.

[5] D0 Collaboration. Measurement of the angular and lifetime parameters of the decays $B_d \to J/\psi K^{*0}$ and $B_s^0 \to J/\psi\phi$. *Phys.Rev.Lett.102, 032001*, 2009.

[6] P.Vankov and G.Raven. Proper-Time Resolution Modelling. *LHCb-2007-055*, 2006.

[7] C.Linn, U.Uwer, S.Hansmann-Menzemer, and C.Langenbruch. Time and angular dependent analysis of $B^0 \to J/\psi K^{*0}$ decays. *LHCb-2009-015*, 2009.

[8] T. Du Pree and G.Raven. Methods for Angular Analysis of $B \to J/\psi V$. *LHCb- 2009-024*, 2009.

[9] D0 Collaboration. Evidence for an anomalous like-sign dimuon charge asymmetry. *arXiv:1005.2757 [hep-ex]*, 2010.

[10] CDF Collaboration. Measurement of CP asymmetry in semileptionic B decays. *Note 9015*, 2007.

[11] C. Bauer and N.D.Dunn. Comment on new physics contributions to Γ_{12}^S. *arXiv:1006.1629v1 [hep=ph]*, 2010.

[12] C. Amsler et al. (Particle Data Group). PDG Summary Tables. *Physics Letters B667*, 2008.

[13] CDF Collaboration. Measurement of b hadron Lifetimes in the modes $B^+ \to J/\psi K^+$, $B^0 \to J/\psi K^{*0}$, $B^0 \to J/\psi K_s^0$ and $\lambda_b^0 \to J/\psi \lambda^0$, and measurement of the B^+/B^0 and λ_b^0/B^0 lifetime ratios. *CDF note 10071*, 2010.