Angular Analysis of $B_d \to J/\psi K^*$

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Overview

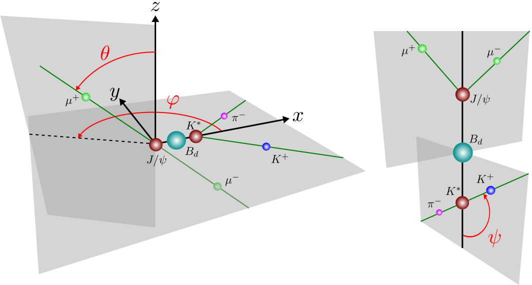
- Motivation
- LHCb Detector
- $B_d \to J/\psi K^*$ Analysis Method
- Results
- Conclusion

Motivation

- $B_d \to J/\psi K^*$ has already been measured accurately by BaBar, Belle and CDF
- It is an important control channel for $B_s \to J/\psi\phi$ which is key for measuring the CP violating phase ϕ_s
  - Similar angular distributions described by three transversity angles
  - Polarisation amplitudes measured by angular analysis
  - Verifies our understanding of detector effects
- It is self-tagging - the charge of the Kaon in the final state indicates the flavour of the B meson
  - Used to verify tagging methods used in LHCb
- With high statistics can measure direct CP violation and Cabibbo-supressed $B_s \to J/\psi K^*$

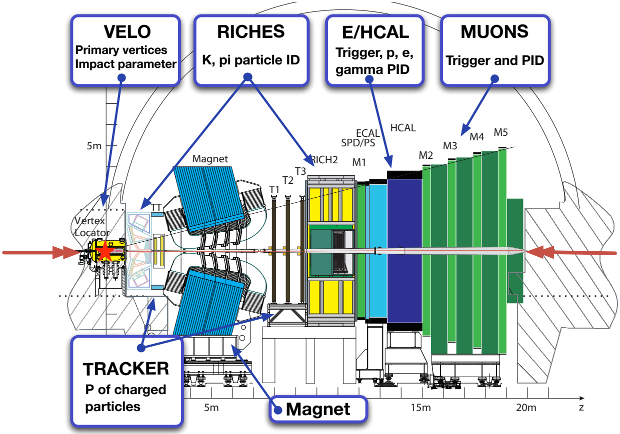
$B_d \to J/\psi K^*$

- Angular distribution described by 3 transversity angles θ, ϕ and ψ



- θ and ϕ are the polar and azimuthal angles of the μ^+ in the J/ψ rest frame
- ψ is the angle between the momentum of the K^+ and B in the rest frame of the K^*

LHCb Detector - Production of $b/\overline{b}$'s in forward direction



- VELO for precise vertexing
- RICH detectors identify charged particle (important for $K^* \rightarrow K^{\pm}\pi^{\mp}$)
- Muon detectors also vital for reconstruction of $J/\psi \rightarrow \mu^+\mu^-$ and triggering

Method

1. Select Data
   - Dataset from 2010 corresponding to $\mathcal{L} = 36pb^{-1}$
   - Lifetime unbiased trigger lines only - fully efficient for all B lifetimes
2. Unbinned maximum likelihood fit extracting physics parameters whilst understanding:
   - Lifetime and Angular Acceptance
   - Backgrounds
3. Systematic Uncertainties

Fit Procedure

- Unbinned Maximum Likelihood fit in B-mass m, proper time t, and decay angles $\Omega = (cos\theta, \phi, cos\psi)$
- Probability Density function consisting of signal $\mathcal{S}$ and background component $\mathcal{B}$:

$$\mathcal{P} = f_{sig}\mathcal{S}(m)\mathcal{S}(t,\Omega) + (1 - f_{sig})\mathcal{B}(m)\mathcal{B}(t,\Omega)$$

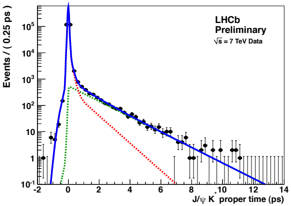
- Signal description given by differential decay rate:

$$\mathcal{S}(t,\Omega) = \frac{d\Gamma(B_d \to J/\psi K^*)}{d\Omega dt}$$

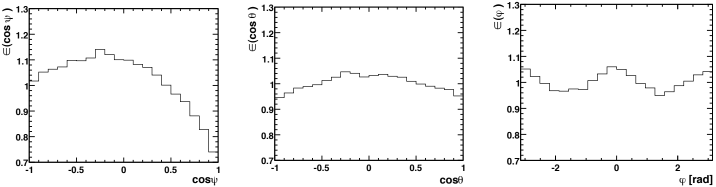
- Physics Parameters to extract:
  - Decay Width Γ_d, Polarization amplitudes $|A_{||}|^2$, $|A_{\perp}|^2$, $|A_0|^2$ and phases $\delta_{||}, \delta_{\perp}, \delta_0$
  - Including $|A_s|^2$ and δ_s for description of the $m_{K\pi}$ dependent S-wave component as well as the P wave.

Time Resolution and Angular Acceptance

- Finite proper time resolution model three Gaussian fit including all proper times (prompt excluded for final fit)



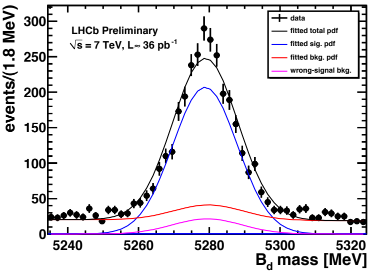
- Angular acceptance correction calculated from Monte Carlo using a 3D histogram in bins of the transversity angles Ω:

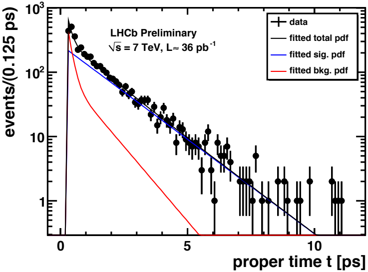


Background Description

- Sources of Background:
  - Random combinations of four tracks
  - Prompt J/ψ events combined with random tracks
  - True long-lived J/ψ from other $B_d \to J/\psi X$ decays
  - Long-lived combinatorial background
- Modelling the background
  - Cut on proper time at $t > 0.3ps$ removes most of the prompt background
  - Two long lived components modelled using sidebands of B mass
  - Angular dependence of the background has been described by a 3D histogram
  - Additional background component seen in Monte Carlo - 'wrong signal' which is reconstructed with wrong pion contributes $\approx 10\%$ of the background

Fit Results

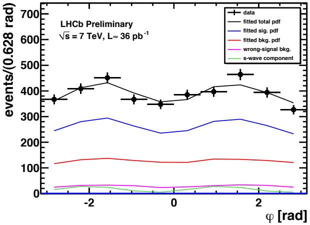


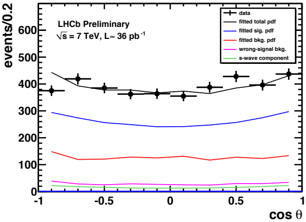


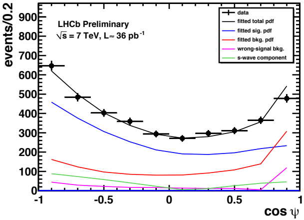
- Single Gaussian for mass signal
- Shallow exponential plus Gaussian for background

- Exponential for the signal
- Double exponential for the background

Transversity Angles







- Fitted signal
- Fitted background
- Wrong -signal background
- S-wave component

Results

- The following are the parameters from the final fit result with 2631 ± 51 signal candidates
- Within errors these are consistent with earlier measurements

Parameter	Result
Γ_d	$0.661 \pm 0.020 \pm 0.018$
$\lvert A_{\parallel} \rvert^2$	$0.252 \pm 0.020 \pm 0.016$
$\lvert A_{\perp} \rvert^2$	$0.178 \pm 0.022 \pm 0.017$
$\delta_{\parallel}$	$-2.87 \pm 0.11 \pm 0.10$
$\delta_{\perp}$	$3.02 \pm 0.10 \pm 0.07$
$\lvert A_s \rvert^2$	0.051 ± 0.022
δ_s	2.16 ± 0.15

Parameter	BaBar Result
Γ_d (PDG)	0.656 ± 0.017
$\lvert A_{\parallel} \rvert^2$	$0.211 \pm 0.010 \pm 0.006$
$\lvert A_{\perp} \rvert^2$	$0.233 \pm 0.010 \pm 0.005$
$\delta_{\parallel}$	$-2.93 \pm 0.08 \pm 0.04$
$\delta_{\perp}$	$2.91 \pm 0.05 \pm 0.03$

- There is an S-wave component of $5 \pm 2\%$

Systematic Uncertainties

- All systematic uncertainties considered are shown in the table below:

Systematic Effect	$\|A_{\|\|}\|^2$	$\|A_{\perp}\|^2$	$\delta_{\|\|}$	$\delta_{\perp}$
proper time acceptance	-	-	-	-
data/MC differences	0.008	0.006	0.07	0.05
statistical error of acceptance	0.002	0.001	-	0.01
wrong-signal fraction	0.004	0.001	-	0.01
background treatment	0.002	0.008	0.04	0.01
statistical error of background	0.008	0.005	0.02	0.01
mass model	0.010	0.002	0.01	0.01
s-wave treatment	0.001	0.013	0.05	0.05
sum	0.016	0.017	0.10	0.07

Summary

- The decay $B_d \to J/\psi K^*$ provides a valuable control sample for $B_s \to J/\psi\phi$ since it occurs via similar decay amplitudes which are already well measured
- The preliminary results presented here are consistent with previous results and therefore confirm that we understand our detector
- With data from 2010 and 2011, LHCb will improve the uncertainty on the results presented here and will go on to measure direct CP violation in $B_d \to J/\psi K^*$.

For more information see:
LHCb-Conf-2011-001
LHCb-Conf-2011-002

Backup

- The differential decay rate for $B_d \to J/\psi K^*$ is:

$$
\begin{aligned}
\frac{d^4\Gamma}{dtd\Omega} = e^{-\Gamma_d t}[f_1(\Omega)|A_0(0)|^2 + f_2(\Omega)|A_{\|}(0)|^2 \\
+ f_3(\Omega)|A_{\perp}(0)|^2 \\
\pm f_4(\Omega) sin(\delta_{\perp} - \delta_{\|})|A_{\|}(0)||A_{\perp}(0)| \\
+ f_5(\Omega) cos\delta_{\|}|A_0(0)||A_{\|}(0)| \\
\pm f_6(\Omega) sin\delta_{\perp}|A_0(0)||A_{\perp}(0)|]
\end{aligned}
$$

Selection

Decay mode	Cut parameter	Stripping value	Offline value
$J/\psi \rightarrow \mu\mu$	$\Delta ln\mathcal{L}_{\mu\pi}$	> 0	-
	$\chi^2_{\rm track}/{\rm nDoF}(\mu)$	< 5	< 4
	$min(pT(\mu^+), pT(\mu^-))$	-	$> 0.5 GeV$
	$\chi^2_{\rm vtx}/{\rm nDoF}(J/\psi)$	< 16	< 11
	$\lvert M(\mu^+\mu^-) - M_{J/\psi}$	$< 80 MeV$	-
	$\lvert M_{J/\psi(reco)} - M_{J/\psi(PDG)}\rvert/\sigma_{m_{J/\psi}}$	-	$< 1.4 \times 3$
	J/ψ mass constrained to PDG value		

Decay mode	Cut parameter	Stripping value	Offline value
$K^* \to K\pi$	$\Delta ln\mathcal{L}_{K\pi}$	> -2	> 0
	$\Delta ln\mathcal{L}_{Kp}$	-	> -2
	$\chi^2_{\mathrm{track}}/\mathrm{nDoF}(K,\pi)$	< 5	< 4
	$\mathrm{pT}(\mathrm{K}^{*0})$	$> 1\mathrm{GeV}$	-
	$\lvert M(K^+\pi^-) - M(K^*)\rvert$	$< 90 MeV$	$< 70 MeV$
	$\chi^2_{\mathrm{vtx}}/\mathrm{nDoF}(K^*)$	< 16	-
$B_d \to J/\psi K^*$	$M(B_d)$	$(5100, 5550) MeV$	$(5100, 5450) MeV$
	$pT(B_d)$	$> 2\mathrm{GeVc}$	-
	$\chi^2_{\mathrm{vtx}}/\mathrm{nDoF}(B_d)$	< 10	-
	$\chi^2_{\mathrm{DTF(B+PV)}}/\mathrm{nDoF}(B_d)$	-	< 5
	$IP\chi^2(B_d)$	-	< 25

Results with and withouth s-wave

Parameter	Result with S-wave	Result without S-wave
$\lvert A_{\parallel}\rvert^2$	0.252 ± 0.020	0.253 ± 0.020
$\lvert A_{\perp}\rvert^2$	0.178 ± 0.022	0.191 ± 0.019
$\delta_{\parallel}$	-2.87 ± 0.11	-2.82 ± 0.12
$\delta_{\perp}$	3.02 ± 0.10	3.07 ± 0.09
$\lvert A_s\rvert^2$	0.051 ± 0.022	-
δ_s	2.16 ± 0.15	-
Γ_d	0.659 ± 0.015	0.661 ± 0.015

Systematics on Γ_d

signal mass model	0.004
signal time model	0.074
bkg. mass model	0.039
bkg. time model	0.012
time resolution model	0.010
momentum scale	0.002
decay length scale	0.002
quadratic sum	0.082