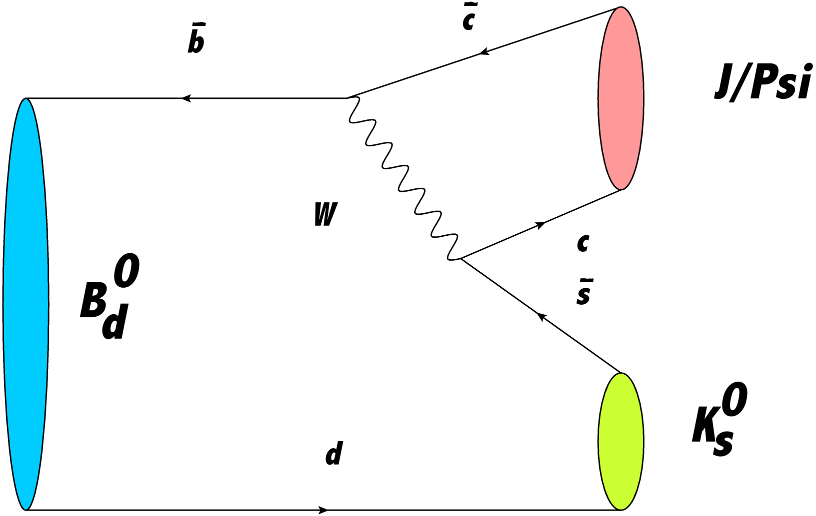
Measurement of sin(2β) in the decay $B_d^0 \longrightarrow J/\Psi K_s^0$

Johannes Mayer, Patrick Fahner

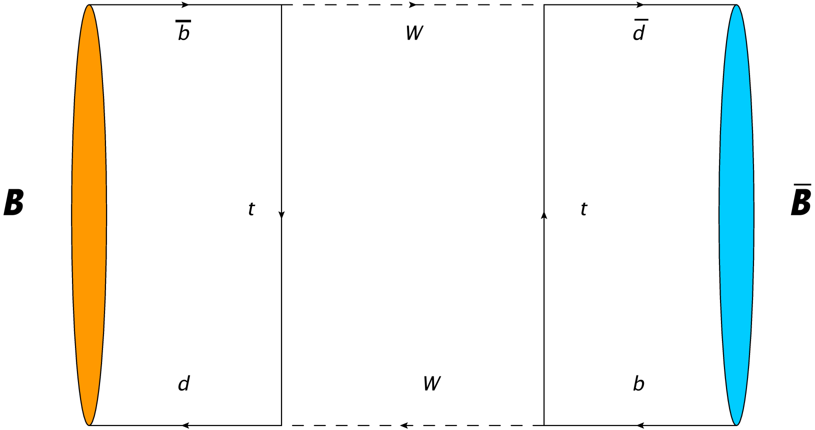
LHCb, Physikalisches Institut
Heidelberg University

27. Mai 2013

Decay $B_d^0 \longrightarrow J/\Psi K_s^0$



$B_d^0 - \bar{B}_d^0$-Mixing



Time-dependent asymmetry

$$\mathcal{A}_{J/\Psi K_s^0}(t) = \frac{\Gamma(\bar{B}_d^0 \to J/\Psi K_s^0) - \Gamma(B_d^0 \to J/\Psi K_s^0)}{\Gamma(\bar{B}_d^0 \to J/\Psi K_s^0) + \Gamma(B_d^0 \to J/\Psi K_s^0)} \tag{1}$$

$$= S_{J/\Psi K_s^0} \sin(\Delta m_d t) - C_{J/\Psi K_s^0} \cos(\Delta m_d t) \tag{2}$$

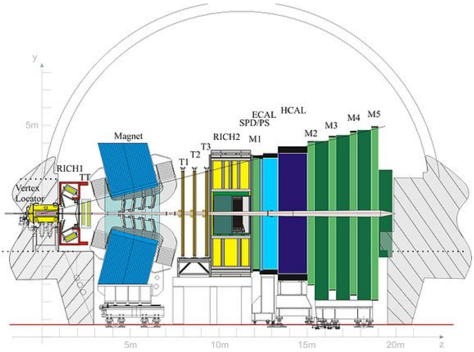
sine - term

- interference between direct decay and decay after mixing
- $S_{J/\Psi K_s^0} = \sin(2\beta)$

cosine - term

- interference between decay amplitudes or CPV in mixing
- here: $C_{J/\Psi K_s^0} \approx 0$

LHCb-detector



Tracks

- Long Tracks: VELO + T Stations (Johannes)
- Downstream Tracks: TT + T Stations (Patrick)

Cuts

	Long Tracks	Downstream Tracks
candidates	10842	57153
S/B	18.0	4.0
cuts		
$\frac{\chi^2_{Track}}{nDof}(\mu)$	< 2.5	< 3
$p_T(K^0_s)$	> 1000 MeV	—
$\frac{\chi^2_{Track}}{nDof}(\pi)$	< 1.5	< 3
$\frac{\tau}{\sigma_\tau}(K^0_s)$	> 15	> 5
decay length sig. (K^0_s)	> 25	> 5
$\lvert M(\pi^+\pi^-) - M(K^0_s)\rvert$	< 7 MeV	< 22 MeV

New in 2012: Ghost probability. We choose ghost prob < 0.5.

Fit strategy

- Unbinned Maximum Likelihood Fit
- sFit: Maximise modified likelihood function

$$\textit{test} \tag{3}$$

- sWeigths calculated with sPlot-technique

$$\mathcal{P}_{meas} = \underbrace{\epsilon(t)}_{=1,\text{later more}} \mathcal{P}_{sig}(t') \otimes \mathcal{R}(t-t') \tag{4}$$

Mean dacay time resolution

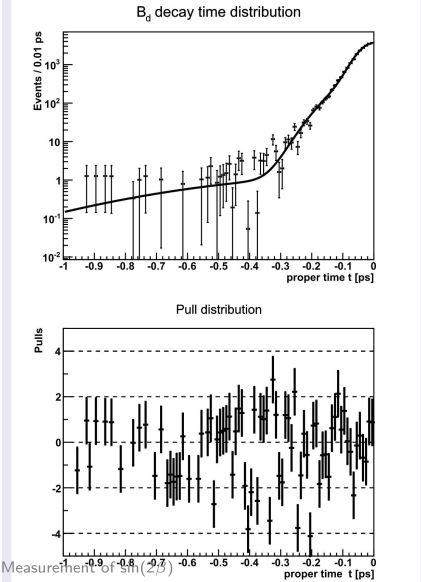
Resolution model

$$\mathcal{R}(t) = \sum_{i=0}^{3} \frac{f_i}{2\pi\sigma_i} e^{-\frac{t^2}{2\sigma^2}} \tag{5}$$

Perform sFit with reonstructed J/Ψ mass as discriminating variable

Mean dacay time resolution

Downstream Tracks



Long Tracks

Resolution

Parameter		long tracks	downstream tracks
σ_1	(ps)	0.117±0.016	0.480±0.070
σ_2	(ps)	0.061±0.037	0.04396±0.00094
σ_3	(ps)	0.037±0.003	0.0932±0.0034
f_1		0.054±0.032	0.00329±0.00099
f_2		0.294±0.138	0.739±0.027

nominal fit

mass fit - parameterisation

Signal

$$\mathcal{P}_{m;S}(m;\vec{\lambda}_{m;S}) = f_{S,m}\mathcal{G}(m;m_{B_d^0},\sigma_{m,1}) + \mathcal{G}(m;m_{B_d^0},\sigma_{m,2}) \quad (6)$$

Background

$$\mathcal{P}_{m;B}(m;\vec{\lambda}_{m;B}) = \frac{1}{\mathcal{N}_{m;B}} e^{-\alpha_m m} \quad (7)$$

Total mass p.d.f.

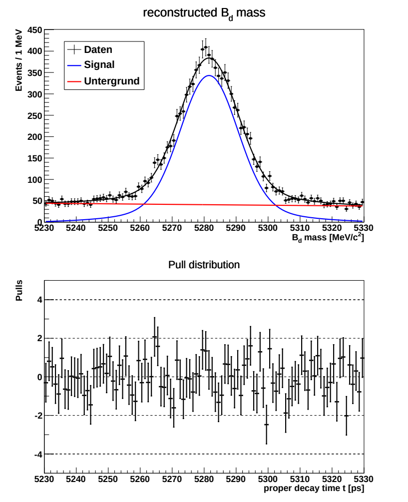
$$\mathcal{P}_m(m;\vec{\lambda}_m) = f_{sig}\mathcal{P}_{m;S}(m;\vec{\lambda}_{m;S}) + (1-f_{sig})\mathcal{P}_{m;B}(m;\vec{\lambda}_{m;B}) \quad (8)$$

nominal fit

mass fit

Long Tracks

Downstream Tracks



nominal fit

Probability density function

$$\mathcal{P}_{\mathrm{meas}}(t,d,\omega) \propto e^{-t/\tau}\left\{1 - d\mu(1-2\omega) - d\Delta p_0 - \left[d(1-2\omega) - \mu(1 - d\Delta p_0)\right] S_{J/\Psi K^0_s} \sin(\Delta m_d t)\right\} \quad (9)$$

- d: tagging decision
- $\mu = A_P = \frac{R_{\bar{B}^0_d} - R_{B^0_d}}{R_{\bar{B}^0_d} + R_{B^0_d}}$ production asymmetry
- ω: calibrated mistag probability

$$(\eta^{OS}) = p_1(\eta^{OS} - \left\langle \eta^{OS} \right\rangle) + p_0 \quad (10)$$

  p_0, p_1: calibration parameters
  η^{OS}: predicted mistag probability
- Δp_0: tagging calibration asymmetry
- Δm_d: mixing frequency

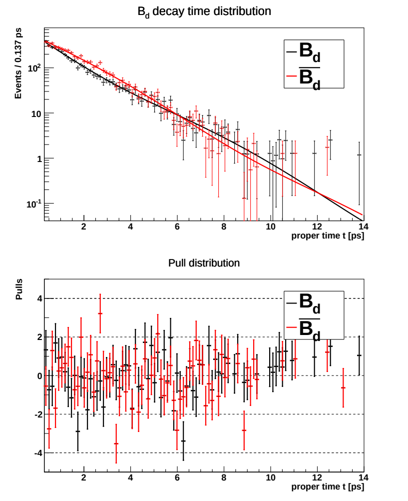
Fit results

- floating parameters: $S_{J/\Psi K_s^0}$, τ, Δm_d
- constrained parameters: $\mu = -0.015 \pm 0.013$, $p_0 = 0.382 \pm 0.003$, $p_1 = 0.981 \pm 0.024$, $\Delta p_0 = 0.0045 \pm 0.0053$
- fixed parameters: $\left\langle \eta^{OS} \right\rangle = 0.382$, resolution parameters
- signal events: ??? (long) // 8585 (downstream) [2011: 8600 total]

Fit results

Long Tracks

Downstream Tracks



fit results

Parameter	long	downstream
$S_{J/\Psi K_s^0}$	$\pm$	0.565$\pm$0.069
τ	$\pm$	1.516$\pm$0.039
Δm_d	$\pm$	0.521$\pm$0.039

Systematic errors

- Fit Bias due to fit method
- Tagging calibration
- Time acceptance
- Correlation mass $\leftrightarrow$ decay time
- Time resolution

Systematic Errors

Fit Bias

Generate Toy MC with ??? (long) / 13000 events an parameters derived from nominal fit (except $S_{J/\Psi K_s^0} = 0.75$)

Long Tracks

Downstream Tracks

Systematic errors
Tagging calibration

Vary Tagging calibration parameters $p_0, p_1 \pm$ their systematic uncertainties

1. in the nominal fit
2. in the generation of Toy MC, but fit with original values

Note: Systematic studies on used tagging calibration hasn't finished yet $\longrightarrow$ no official value. We use largest differences in channels so far:

$$\delta p_0^{stat.} = 0.019, \qquad \delta p_1^{stat.} = 0.07$$

Systematic errors

Tagging calibration

Choose highest difference from nominal fit / toy as estimate for the systematic uncertainty

- Long tracks:
- Downstream tracks:

Note: Estimates very large due to large $\delta p_0^{stat.}$, $\delta p_1^{stat.}$ compared to other calibrations (systematic studies of calibration need to be finished)

Systematic errors
Time acceptance

Note: just a cross-check, no in-depth analysis

Determination of an acceptance function

- no separation between $B_d^0$and $\overline{B_d^0}$
  $\Rightarrow$ simple exponential decay
- neglect lifetime cut ($t > 0.3$ps)
- contributions to acceptance:
  - turn-on-effect
  - decreasing acceptance for higher lifetimes due to VELO geometry

Systematic errors

Time acceptance

Fit p.d.f

$$\mathcal{P}_{acc}(t) \propto \underbrace{e^{-t/\tau}}_{\text{exp. decay}} \cdot \underbrace{\frac{2}{\pi}\arctan[t \cdot \exp(at+b)]}_{\text{turn-on-effect}} \cdot \underbrace{(1+\beta t)}_{\substack{\text{higher lifetimes} \\ (\beta<0)}}$$

Note: τ will be constrained to the PDG value
$\tau = 1,519 \pm 0,007\mathrm{ps}$.

Systematic errors

Time acceptance

Long Tracks

Downstream Tracks

Systematic errors

Time acceptance

Table : Fit results for exponential decay fit with acceptance function. τ was constrained to the PDG value $\tau = 1,519 \pm 0,007\mathrm{ps}$

parameter	long	long
τ	$\pm$	1.519$\pm$0.007
a	$\pm$	44.1$\pm$5.7
b	$\pm$	-7.4$\pm$1.1
β	$\pm$	-0.0056$\pm$0.0085

Toy MC Study

- generate with acceptance function
- use parameters mentioned above
- fit without acceptance function

No significant difference to fit bias!

$$\mu_{fit} = 0.059 \pm 0.007 \quad \text{vs.} \quad \mu_{acc} = 0.063 \pm 0.007$$

Systematic errors
Correlation mass $\leftrightarrow$ decay time

Systematic errors

Resolution

Systematic errors
Summary

effect	long	downstream
fit method		
tagging calibration		
time acceptance		
mass $\leftrightarrow$ decay time		
resolution		
total		

Conclusion