CP violation in the B_s->$\phi\phi$ decay at LHCb

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IOP, 8-10 April 2013

Outline

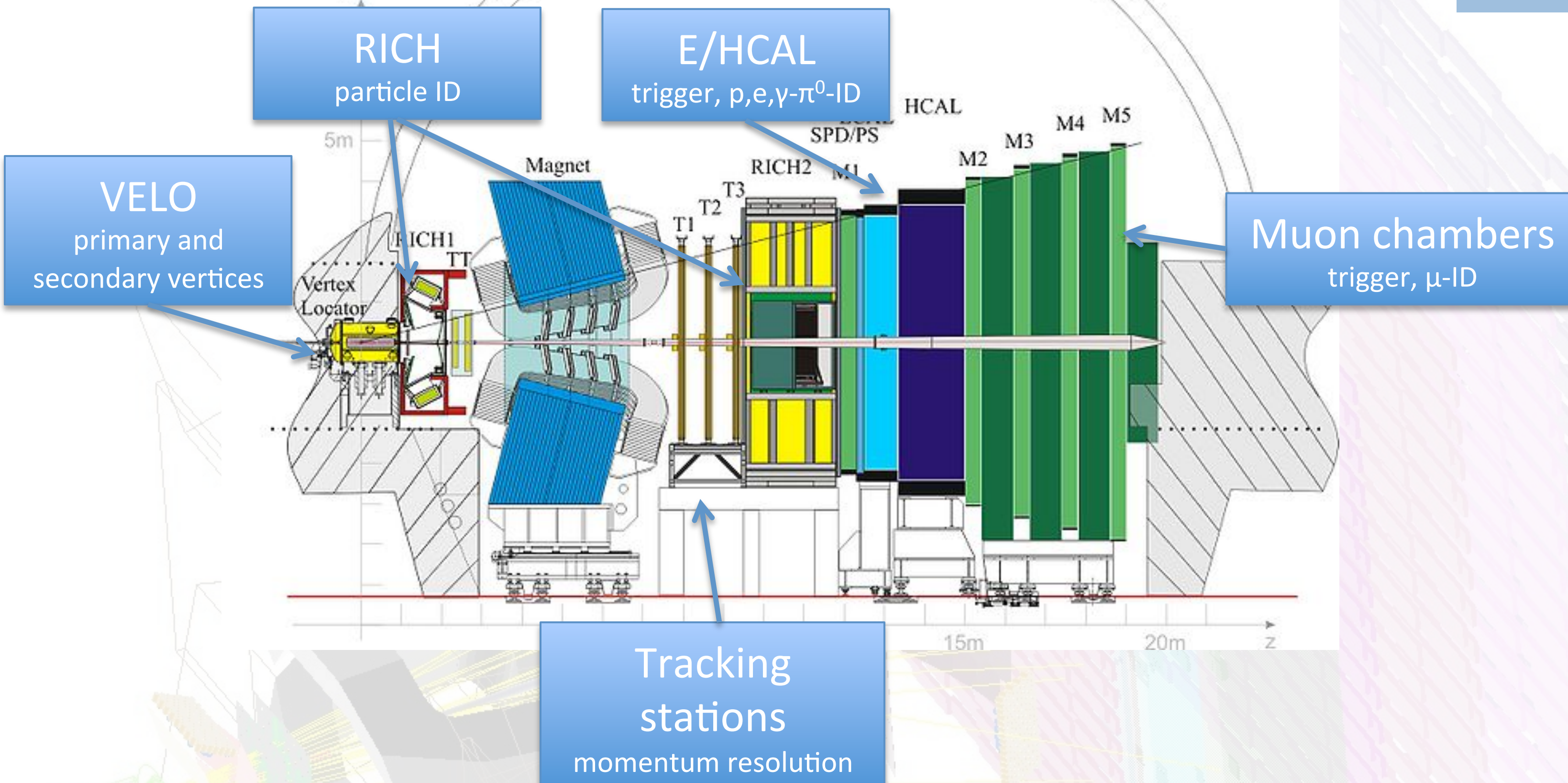
LHCb detector

Phenomenology and New Physics

B_s->ϕϕ analysis ingredients

Results New for 2013
LHCb-PAPER-2013-007, arXiv:1303.7125

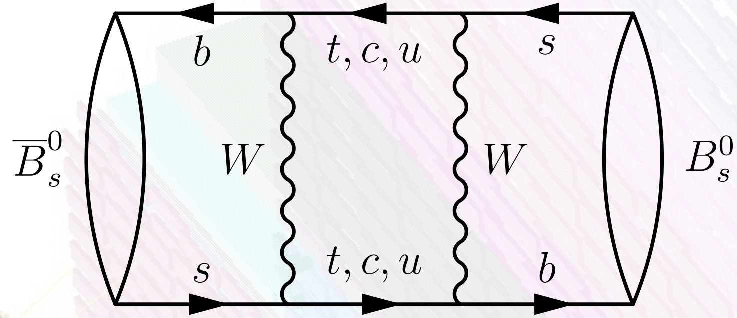
LHCb Detector



- LHCb is a forward arm spectrometer (pseudo-rapidity range: $2 < \eta < 5$),
- Accurate decay time resolution through vertex locator (VELO),
- Accurate particle ID provided by RICH detectors.

Why B_s Physics?

<u>Mixing</u>

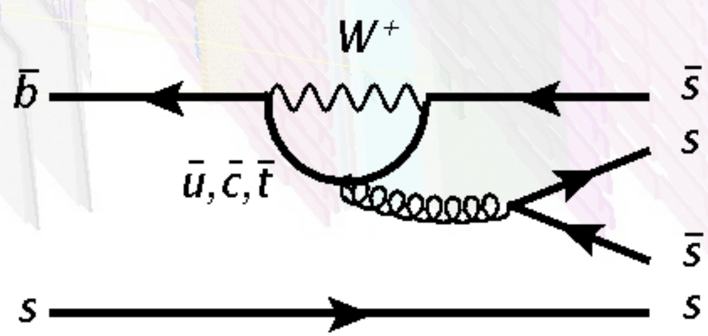


There could be new physics contributions, that would manifest as new contributions in B_s mixing diagrams (arXiv:1008.1593)

Large effects are ruled out through existing measurements of $B_s \to J/\psi\phi$

<u>Decay</u>

New contributions could also appear in penguin diagrams (hep-ph/0007328, arXiv:1212.6486v1).



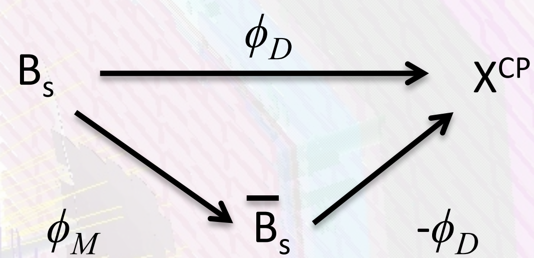
Loop suppressed ➔ need large datasets to measure

Now becoming accessible.

Why B_s->ϕϕ?

B_s->ϕϕ is an example of a flavour changing neutral current interaction (FCNC) b->sss => can only occur through penguin diagrams and higher orders.

Measure ϕ_s, defined as the CP violation interference between mixing and decay:



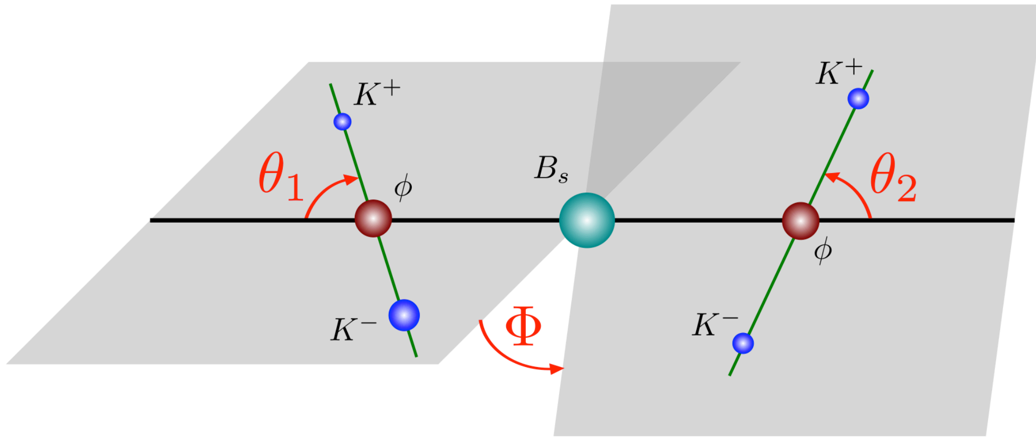
I.e. $\phi_s = \phi_M - 2\phi_D$

⇒ B_s->ϕϕ is sensitive to new physics in mixing and decay as both Bs and Bs can decay to ϕϕ.

In Bs->ϕϕ, resulting from a b->s$\bar{s}$s transition, the SM prediction is 0.00±0.02 rad

Analysis Details

B_s->ϕϕ is a P->VV decay => Final state a mixture of CP-even and CP-odd eigenstates ➔ need angular analysis to disentangle them.



To obtain greatest sensitivity to CP violation, need to be able to resolve Bs oscillations => requires observation of the B_s decay time.

Therefore analysis requires good understanding of efficiencies as a function of decay time and angular observables:

- Selections such as impact parameter give lower efficiency at short decay times.
- Shape of LHCb detector means high values of $|\cos\theta_i|$ are less efficient.

These are taken from simulation.

Analysis Details

- PDF has 15 terms (6 P-wave and 9 S-wave).
- $F(t,\cos\theta_1,\cos\theta_2,\Phi) = \Sigma_i K_i(t) f_i(\cos\theta_1,\cos\theta_2,\Phi)$, where:

i	K_i	f_i
1	$\lvert A_0(t)\rvert^2$	$4\cos^2\theta_1\cos^2\theta_2$
2	$\lvert A_\parallel(t)\rvert^2$	$\sin^2\theta_1\sin^2\theta_2(1+\cos 2\Phi)$
3	$\lvert A_\perp(t)\rvert^2$	$\sin^2\theta_1\sin^2\theta_2(1-\cos 2\Phi)$
4	$Im(A_\parallel^*(t)A_\perp(t))$	$-2\sin^2\theta_1\sin^2\theta_2\sin 2\Phi$
5	$Re(A_\parallel^*(t)A_0(t))$	$\sqrt{2}\sin 2\theta_1\sin 2\theta_2\cos\Phi$
6	$Im(A_0^*(t)A_\perp(t))$	$-\sqrt{2}\sin 2\theta_1\sin 2\theta_2\sin\Phi$
7	$\lvert A_{SS}(t)\rvert^2$	$\frac{4}{9}$
8	$\lvert A_S(t)\rvert^2$	$\frac{4}{3}(\cos\theta_1+\cos\theta_2)^2$
9	$Re(A_S^*(t)A_{SS}(t))$	$\frac{8}{3\sqrt{3}}(\cos\theta_1+\cos\theta_2)$
10	$Re(A_0(t)A_{SS}^*(t))$	$\frac{8}{3}\cos\theta_1\cos\theta_2$
11	$Re(A_\parallel(t)A_{SS}^*(t))$	$\frac{4\sqrt{2}}{3}\sin\theta_1\sin\theta_2\cos\Phi$
12	$Im(A_\perp(t)A_{SS}^*(t))$	$-\frac{4\sqrt{2}}{3}\sin\theta_1\sin\theta_2\sin\Phi$
13	$Re(A_0(t)A_S^*(t))$	$\frac{8}{\sqrt{3}}\cos\theta_1\cos\theta_2(\cos\theta_1+\cos\theta_2)$
14	$Re(A_\parallel(t)A_S^*(t))$	$\frac{4\sqrt{2}}{\sqrt{3}}\sin\theta_1\sin\theta_2(\cos\theta_1+\cos\theta_2)\cos\Phi$
15	$Im(A_\perp(t)A_S^*(t))$	$-\frac{4\sqrt{2}}{\sqrt{3}}\sin\theta_1\sin\theta_2(\cos\theta_1+\cos\theta_2)\sin\Phi$

P-wave (ϕϕ) (rows 1–6)

CP-even S-wave (f0f0) (row 7)

CP-odd S-wave (ϕf0) (row 8)

f0f0– ϕf0 interference (row 9)

ϕϕ-f0f0 interference (rows 10–12)

ϕϕ-ϕf0 interference (rows 13–15)

With this, can fit for:
Polarisation fractions A_i, CP-conserving strong phases, δ_i, and CP-violating phase, ϕ_s

Analysis Ingredients

Example time dependent term:

Flavour-tagging

B_s oscillation frequency

$$\Im(A_{\parallel}(t)^* A_{\perp}(t)) = |A_{\parallel}||A_{\perp}|\{(1-2\omega)e^{-\Gamma_s t}[\sin\delta_1 \cos(\Delta m_s t) - \cos\delta_1 \sin(\Delta m_s t)\cos\phi_s] - \frac{1}{2}\cos\delta_1 (e^{-\Gamma_{\rm H} t} - e^{-\Gamma_{\rm L} t})\sin\phi_s\}$$

B_s decay rates

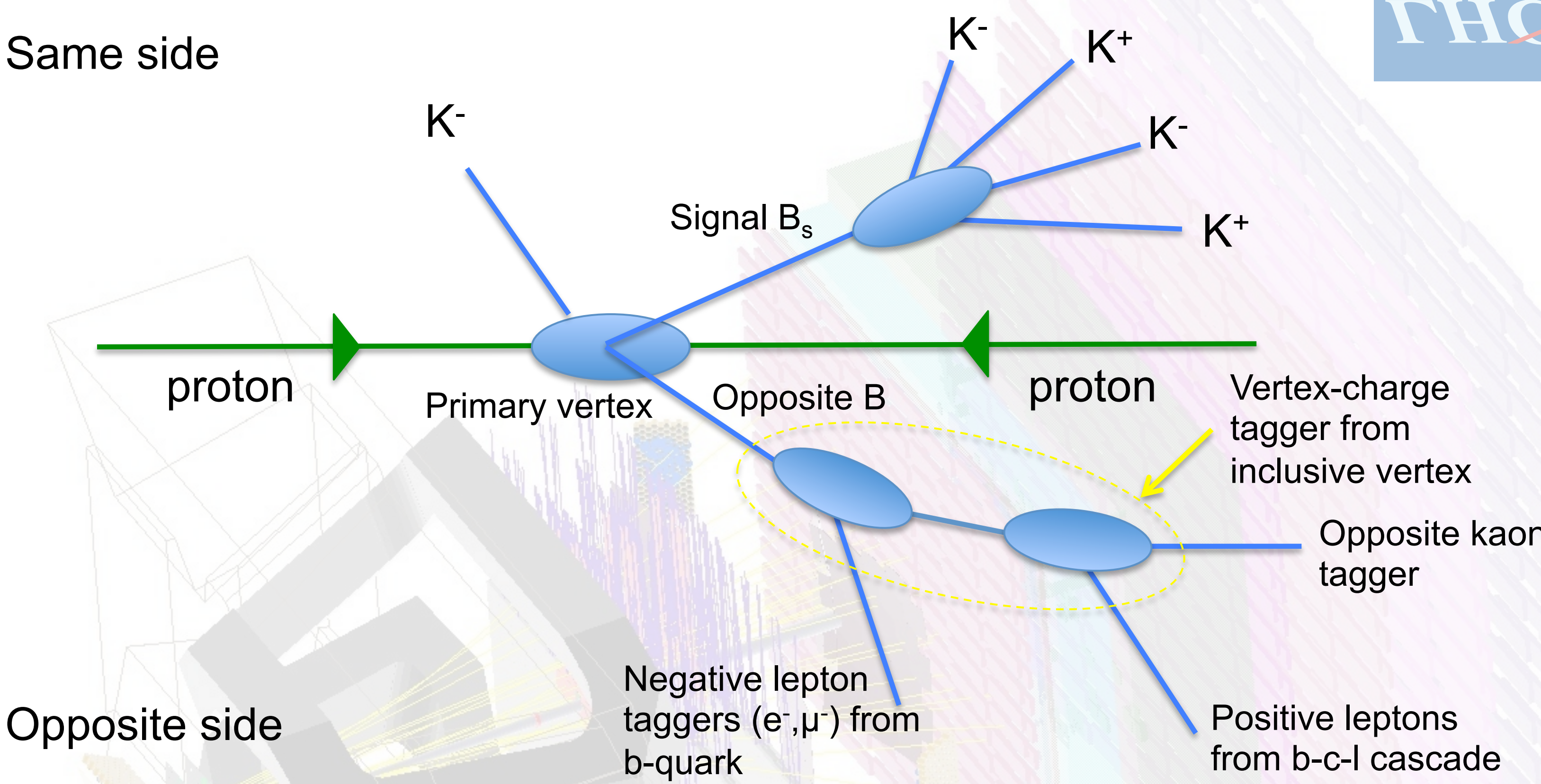
B_s decay rates ($\Gamma_s=[\Gamma_H+\Gamma_L]/2$ & $\Delta\Gamma_s=\Gamma_L-\Gamma_H$): Gaussian constraints to the values measured in the Bs->J/ψϕ decay (LHCb-PAPER-2013-002).

Time resolution: Convolve our PDF with Gaussian function of width 40fs, where the width is found from simulation.

B_s oscillation frequency: Gaussian constraint to LHCb value (LHCb-CONF-2011-050)

Flavour-tagging: Opposite side and same-side algorithms used (explained soon).

Analysis Ingredients: Flavour-tagging



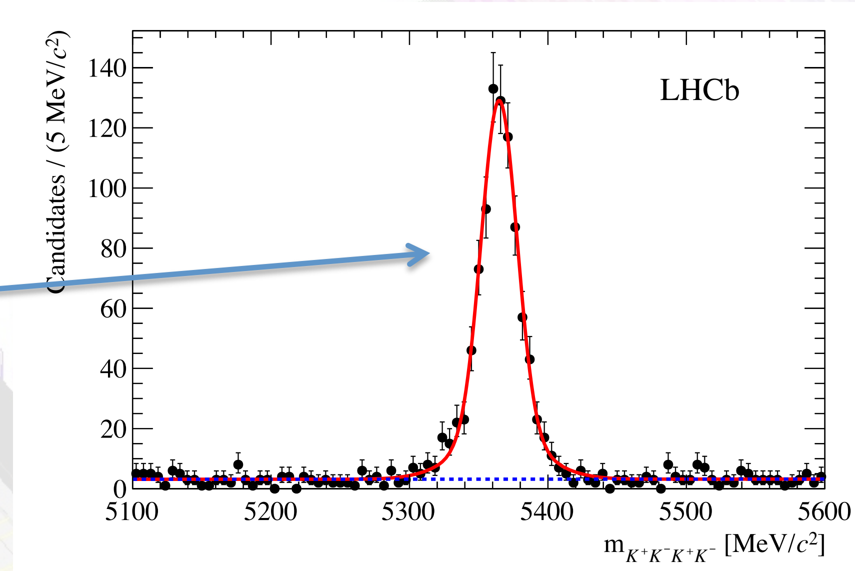
Event-by-event incorrect tag probability calibrated mainly from $B^+ \to J/\psi K^+$ (OS) and $B_s \to D_s\pi$ (SSK) => calibration parameters constrained in fitting.

Total tagging power = $\varepsilon(1-2\omega)^2 = (3.20 \pm 0.48)\%$

Results: Dataset

880 events observed in $K^+K^-K^+K^-$ final state using 1.0 fb^{-1} LHCb data.

Very clean signal given fully hadronic final state



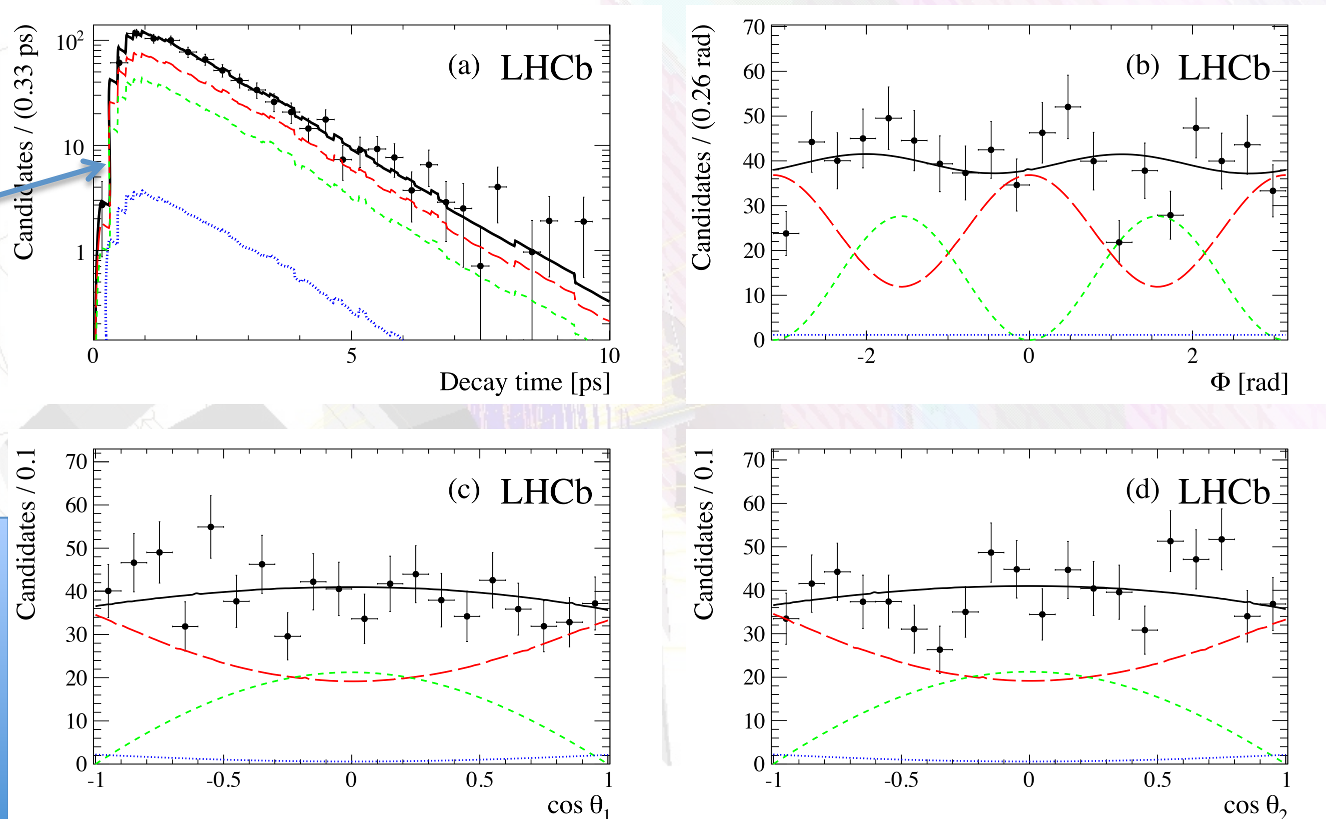
Events triggered mainly by looking for good quality tracks consistent with ϕ mass and exploiting general kinematics of B decays.
Multivariate offline selections use kinematic variables and track quality to separate signal from background.

Low contamination from reflections from B^0->ϕK* due to small width of the ϕ resonance.

Results: Projections on to Observables

- Shown below are data and corresponding fit projected on to each of the phase space observables.
- Can separate fit by CP eigenstate.

Time biasing selections cause low efficiency at short lifetimes



Projections background subtracted and include acceptances

Total

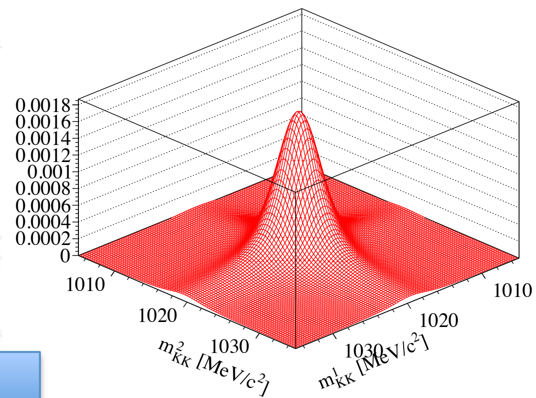
CP-even

CP-odd

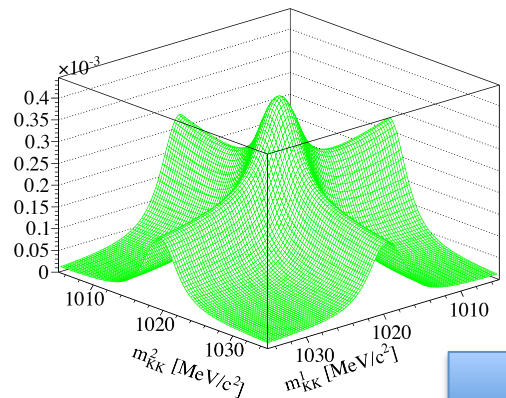
S-wave

Results: S-wave Crosscheck

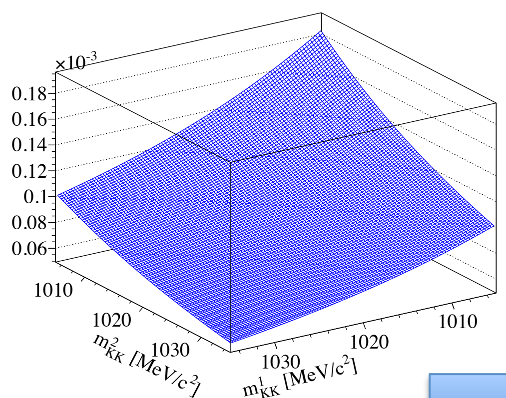
Although measured in angular and time dependent fit, also possible to measure S-wave using m_{KK} lineshapes (relativistic Breit-Wigner shape for P-wave, Flatté for S-wave).
=> Do a 2D fit to m_{KK} vs. m_{KK} as a sanity check (ignores interferences)



ϕϕ



ϕf_0



$f_0 f_0$

=> Find total S-wave fraction of (2.12±1.17)%

Results: ϕ_s

Parameter	Value	$\sigma_{\text{stat.}}$	$\sigma_{\text{syst.}}$
ϕ_s 68 % C.L: [rad]	$(-2.37, -0.92)$		0.22
$\lvert A_0\rvert^2$	0.329	0.033	0.017
$\lvert A_\perp\rvert^2$	0.358	0.046	0.018
$\lvert A_S\rvert^2$	0.016	$^{+0.024}_{-0.012}$	0.009
δ_1 [rad]	2.19	0.44	0.12
δ_2 [rad]	-1.47	0.48	0.10
δ_S [rad]	0.65	$^{+0.89}_{-1.65}$	0.33

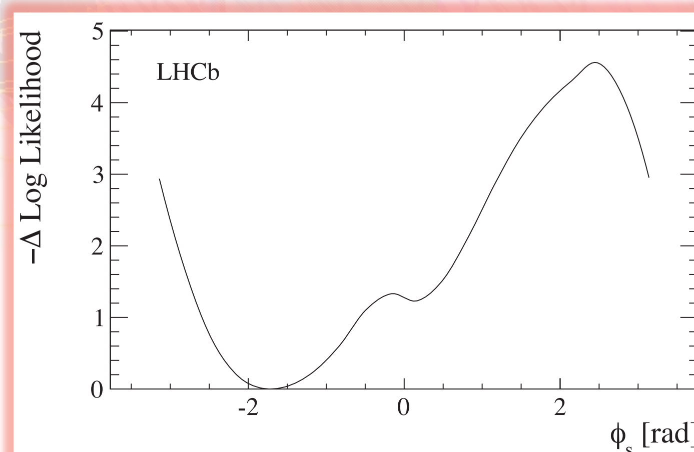
The dominant systematic uncertainties arise from time acceptance and S-wave

Statistical likelihood for ϕ_s shows non-parabolic behaviour ➔ only a 68% C.L. is quoted.

Small dataset ➔ Feldman Cousins analysis is used to provide a coverage corrected 68% C.L. including systematic uncertainties of

ϕ_s in the interval [-2.46,-0.76] rad

The p-value of the Standard Model hypothesis is 16%.



Summary

- A first time-dependent tagged analysis of CP violation in the interference between mixing and decay for the B_s->ϕϕ decay yields a 68% C.L of:

[-2.46,-0.76] rad

- The p-value of the Standard Model hypothesis is 16%.

- Still $2fb^{-1}$ of 2012 LHCb data yet to analyse => eager to see what awaits with the full combined 2011+2012dataset.