B→hh status

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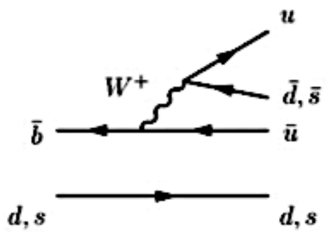
on behalf of the LHCb collaboration

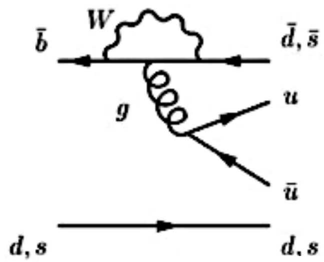
Implications of LHCb measurements and future prospects workshop
16 October 2013

Why do we want to study these decays?

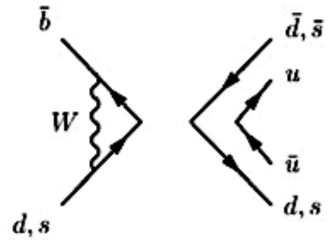
Sensitive to New physics contributions
Loop level determination of weak phase γ
and mixing phases ϕ_s, ϕ_d.
Test U-spin symmetry.
Contribution to Acp Kπ-puzzle.



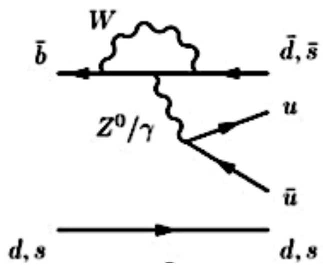
Tree



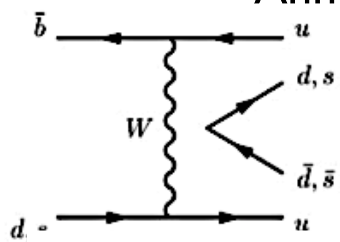
Penguin



Penguin Annihilation



Electroweak Penguin



Exchange

What channels can we use?

$B_d \to K\pi$*, $B_d \to \pi\pi$*, $B_d \to KK$, $B_d \to pK$,
$B_s \to \pi K$*, $B_s \to \pi\pi$, $B_s \to KK$*,
$B_s \to pK$, $\Lambda_b \to p\pi$, $\Lambda_b \to pK$ etc.

What information can we get?

Branching Ratios*
Time-integrated *CP* asymmetries (A_{cp})*
Time-dependent *CP* asymmetries (A(t))*
Effective lifetime
Triple decay asymmetries and polarization amplitudes

$$A_{CP} = \frac{\Gamma_{\bar{B}\to\bar{f}} - \Gamma_{B\to f}}{\Gamma_{\bar{B}\to\bar{f}} + \Gamma_{B\to f}}$$

$$A(t) = \frac{\Gamma_{\bar{B}\to f}(t) - \Gamma_{B\to f}(t)}{\Gamma_{\bar{B}\to f}(t) + \Gamma_{B\to f}(t)}$$

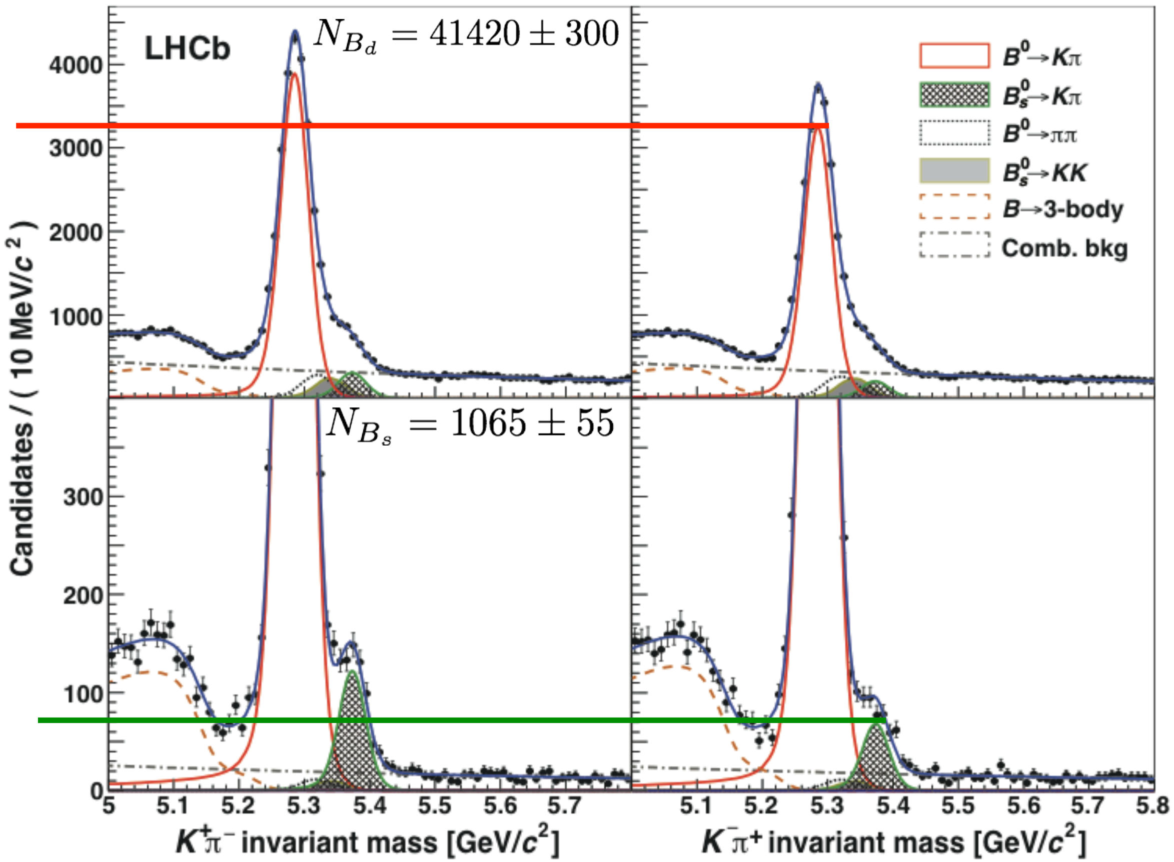
* In this talk

$\mathcal{L}$ = 1 fb^{-1}

$B_d \to K\pi$, $B_s \to \pi K$ Time-integrated *CP* asymmetries

Phys. Rev. Lett.110 (2013) 221601

Raw Asymmetries



$$A_{\mathrm{raw}}\left(B^0 \to K^+\pi^-\right) = -0.091 \pm 0.006$$

$$A_{\mathrm{raw}}\left(B_s^0 \to K^-\pi^+\right) = 0.28 \pm 0.04$$

Event selection is cut –based and tuned to have better sensitivities for the *CP* violation variables. Exclusive event samples selected under $\pi\pi$, $K\pi$, KK, pK, $p\pi$ daughter mass hypothesis.

PID calibration is performed on data using $D^* \to D0(K\pi)\pi$ and $\Lambda_b \to p\pi$ decays.

Maximum Likelihood fit is performed simultaneously to all the samples (additional samples are fixing the cross-feed backgrounds contributions under the signal peaks). The measured observable is

$$A_{\mathrm{raw}} = \frac{N_{K^-\pi^+} - N_{K^+\pi^-}}{N_{K^-\pi^+} + N_{K^+\pi^-}}$$

The extracted asymmetries are, in fact, "raw" asymmetries (depend on the *B* production asymmetries and detection asymmetries).

Corrections

We correct raw results using the following formula:

$$A_{CP} = A^{\mathrm{raw}} - A_{\Delta}$$

$$A_{\Delta} = \underline{\zeta A_D} - \underline{\kappa A_P}$$

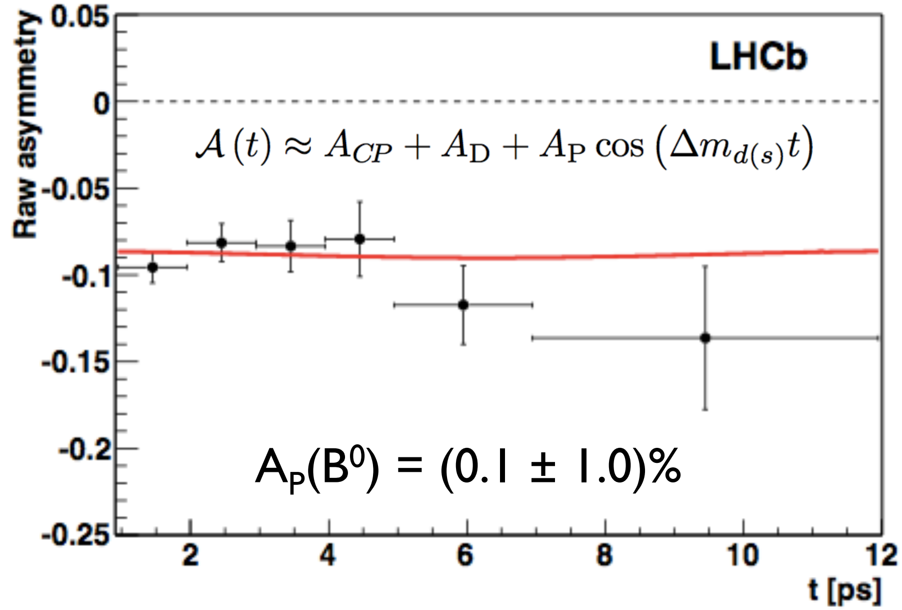
Detection asymmetry part: estimated from the tagged and untagged decays of $D \rightarrow hh$, ζ=+1 for B_d and ζ=-1 for B_s.

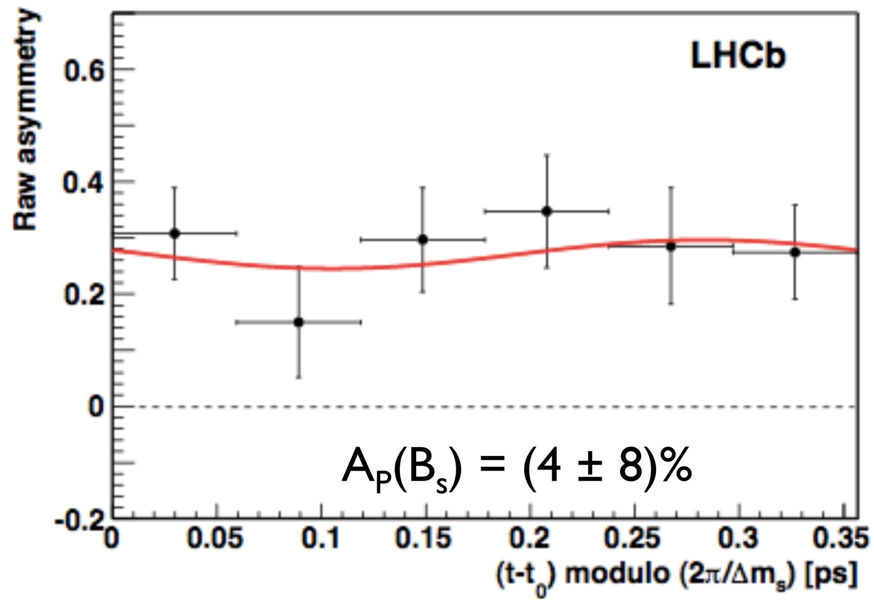
$A_D(B_d \rightarrow K\pi) = (-1.15 \pm 0.23)\%$
$A_D(B_s \rightarrow K\pi) = (-1.22 \pm 0.21)\%$

Production asymmetry part: determined from fits to untagged decay time spectra, κ takes mixing into account.

$$A_{\Delta}(B_d) = (-1.12 \pm \underline{0.23} \pm \underline{0.30})\%$$

$$A_{\Delta}(B_s) = (1.09 \pm \underline{0.21} \pm \underline{0.26})\%$$





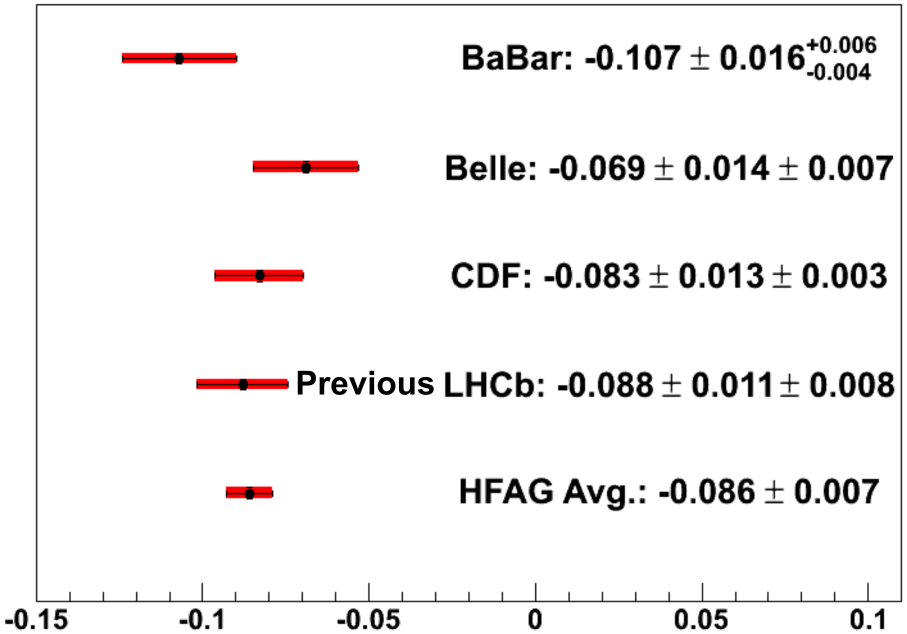
Results

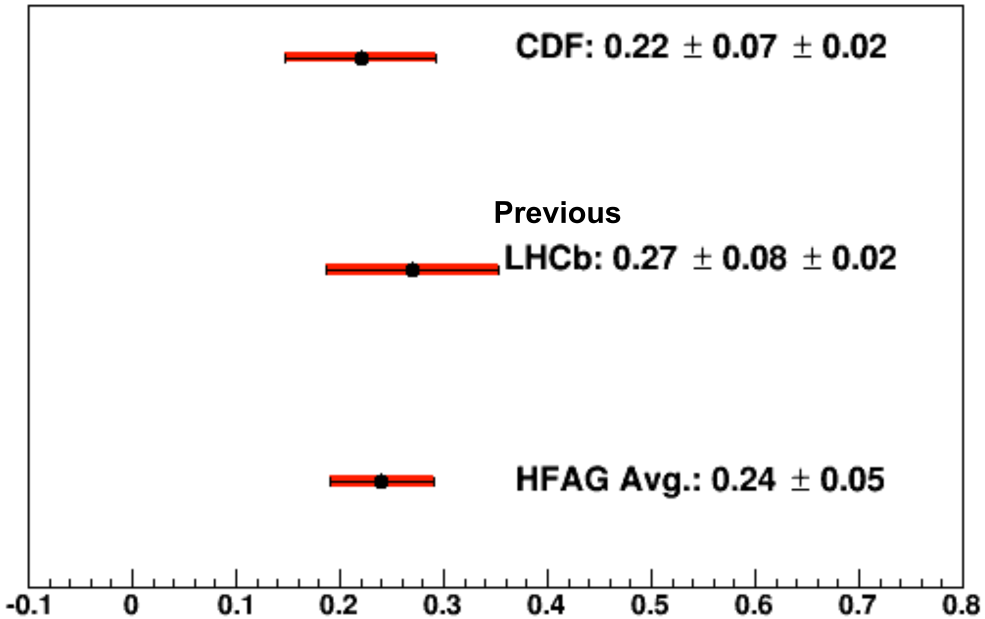
Most precise to date (10.5 σ significance):

$$A_{CP}(B^0 \to K^+\pi^-) = -0.080 \pm 0.007\,(\text{stat}) \pm 0.003\,(\text{syst})$$

First observation of CP violation in B_s (6.5 σ significance):

$$A_{CP}(B_s^0 \to K^-\pi^+) = 0.27 \pm 0.04\,(\text{stat}) \pm 0.01\,(\text{syst}).$$





$\mathcal{L}$ = 1 fb^{-1} (2011)
2 fb^{-1} (2012)

$B \to K_s h$ Time-integrated *CP* asymmetries

Preliminary
LHCB-PAPER-2013-043
arXiv: 1308.1277

Raw Asymmetries

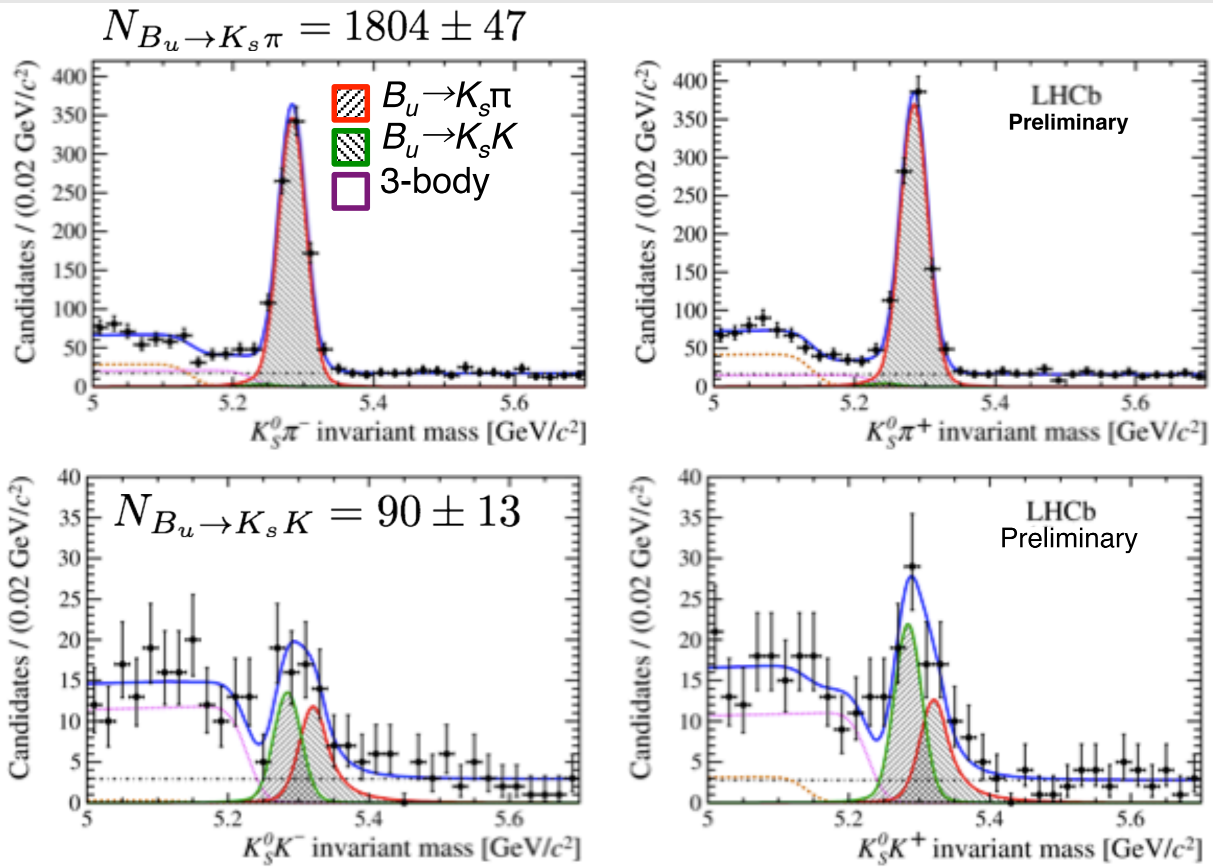
Event selection is Boosted-Decision Tree based and tuned to have better sensitivities for the *CP* violation variables in each channel.

PID calibration is performed on data using
$D^* \to D0(K\pi)\pi$ decays.

Selection efficiencies from Monte Carlo

Correction of raw asymmetries:
Production and detection asymmetry:
taken from $B^+ \to J/\Psi K^+$ decays.
Ks related:

- *CP* violation in K_S
- K_S regeneration from K_L interaction with the detector



We obtain

$$A_{\mathrm{raw}}(B^+ \to K_s\pi^+) = -0.032 \pm 0.025$$

$$A_{\mathrm{raw}}(B^+ \to K_sK^+) = -0.23 \pm 0.14$$

Branching Fractions and results

Full results of the study are

$$\frac{\mathcal{B}(B^+ \to K^0_S K^+)}{\mathcal{B}(B^+ \to K^0_S \pi^+)} = 0.064 \pm 0.009\ (\text{stat.}) \pm 0.004\ (\text{syst.}),$$

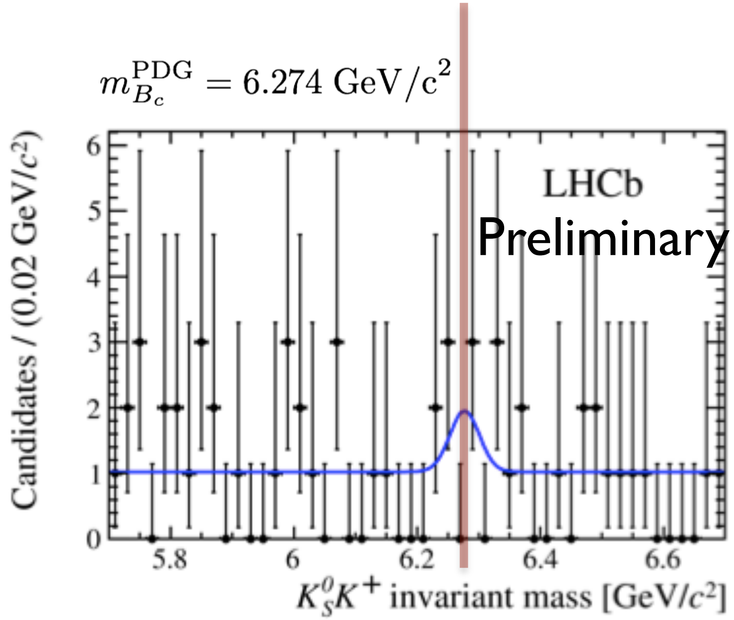
$$\mathcal{A}^{CP}(B^+ \to K^0_S \pi^+) = -0.022 \pm 0.025\ (\text{stat.}) \pm 0.010\ (\text{syst.}),$$

$$\mathcal{A}^{CP}(B^+ \to K^0_S K^+) = -0.21 \pm 0.14\ (\text{stat.}) \pm 0.01\ (\text{syst.}).$$

	BaBar, 10^{-2}	Belle, 10^{-2}
$A^{CP}(B^+ \to K_s \pi)$	-2.9±3.9±1.0	-1.1±2.1±0.6
$A^{CP}(B^+ \to K_s K)$	10±26±3	1.4±16.8±0.2

We also search for the $B_c \to K_s K$ decays (using 1 fb^{-1}) with retuned BDT selection. We find 2.8 signal events. Feldman-Cousin's method has been used to estimate confidence intervals.

$$\frac{f_c}{f_u} \cdot \frac{\mathcal{B}(B_c^+ \to K^0_S K^+)}{\mathcal{B}(B^+ \to K^0_S \pi^+)} < 5.8 \times 10^{-2}$$



$\mathcal{L}$ = 1 fb^{-1}

$B_d \to \pi\pi$, $B_s \to KK$ Time-dependent *CP* asymmetries

Preliminary
LHCB-PAPER-2013-040
arXiv:1308.1428

Formalism for time-dependence and tagging

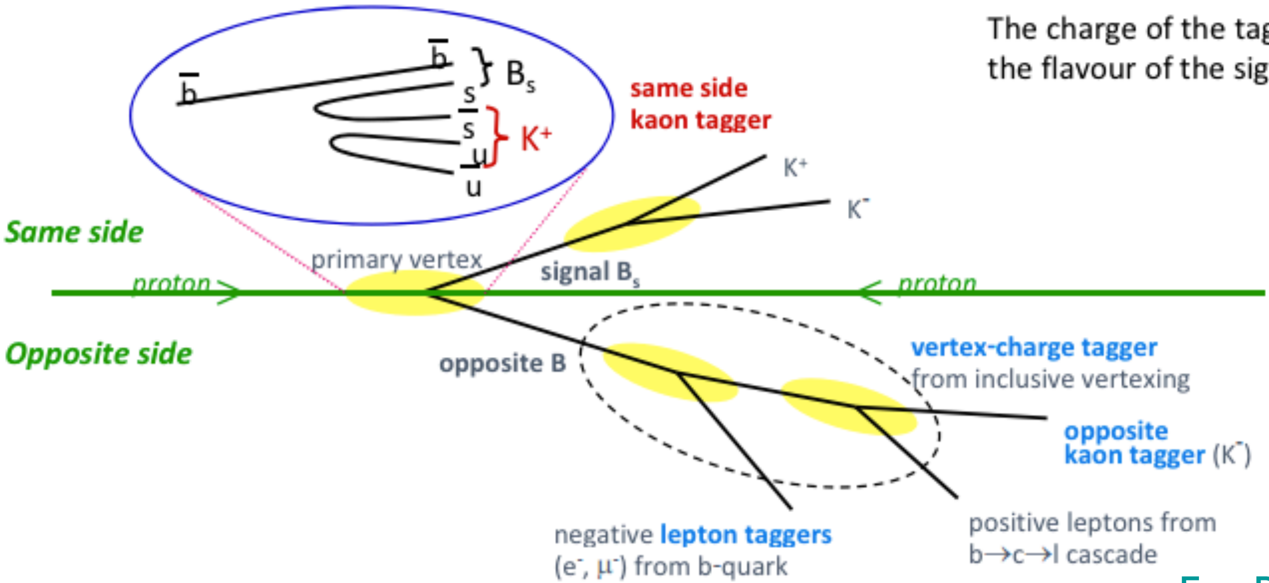
CP asymmetry as a function of time for neutral *B* mesons decaying to a CP eigenstate *f* is given by

$$\mathcal{A}(t) = \frac{\Gamma_{\bar{B}^0_{(s)}\to f}(t) - \Gamma_{B^0_{(s)}\to f}(t)}{\Gamma_{\bar{B}^0_{(s)}\to f}(t) + \Gamma_{B^0_{(s)}\to f}(t)} = \frac{-C_f \cos(\Delta m_{d(s)} t) + S_f \sin(\Delta m_{d(s)} t)}{\cosh\left(\frac{\Delta\Gamma_{d(s)}}{2} t\right) - A_f^{\Delta\Gamma} \sinh\left(\frac{\Delta\Gamma_{d(s)}}{2} t\right)}$$

with $\Delta m_{d(s)} = m_{d(s),\mathrm{H}} - m_{d(s),\mathrm{L}}$ and $\Delta\Gamma_{d(s)} = \Gamma_{d(s),\mathrm{L}} - \Gamma_{d(s),\mathrm{H}}$ mass and width difference of mass eigenstat

To obtain C_f and S_f, we need to tag initial flavour of *B* meson.

In this analysis, we exploit the decay products of the other b hadron: lepton (e or μ); kaon; overall charge of secondary vertex ("opposite side" taggers).



The charge of the tagger tags the flavour of the signal B.

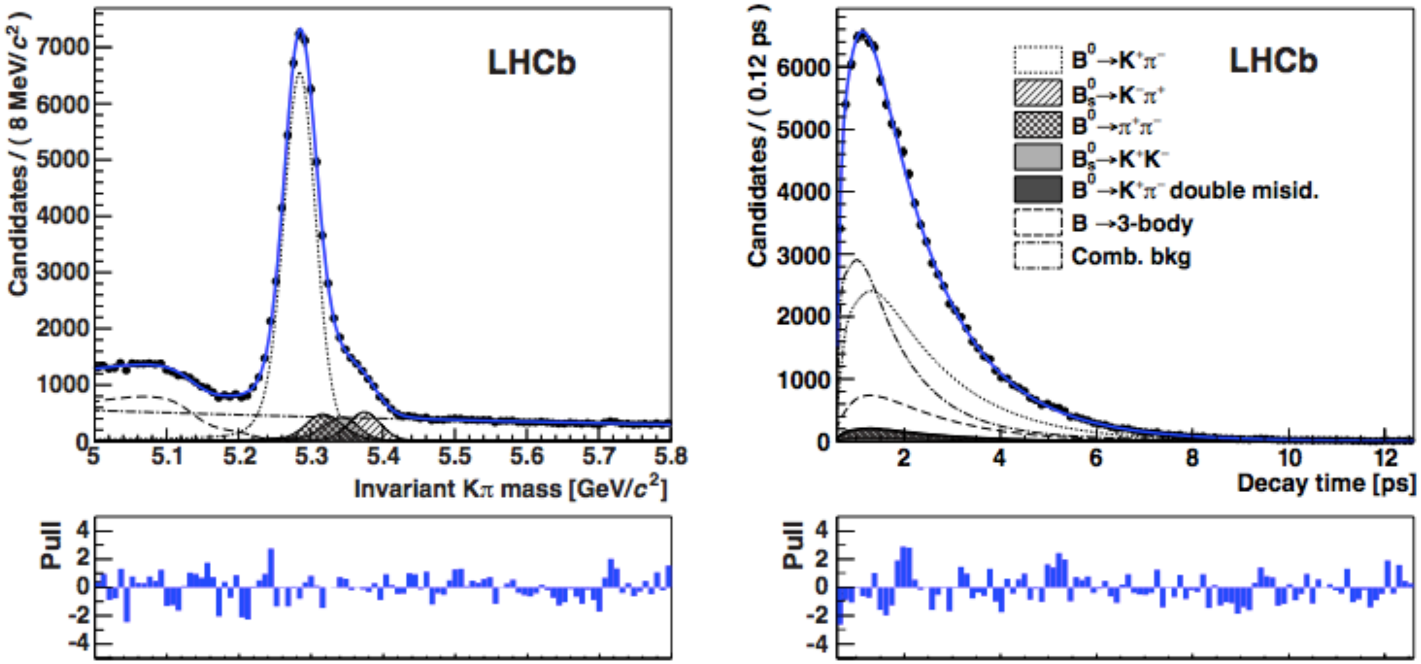
Eur. Phys. J. 72 (2012), 2022.

Tagging performance: mistag rate, ω_{mistag} , tagging efficiency, $\varepsilon_{\mathrm{tag}}$.

Neural Network determines ω_{mistag}, which is than calibrated on the data sample

Tagging and Decay time studies

Samples divided into categories of predicted mistag. Simultaneous invariant mass and decay fit with $B \to K\pi$ decays to calibrate the neural network performance.



Calibration of flavour tagging response: ε =(2.45 ± 0.25)%

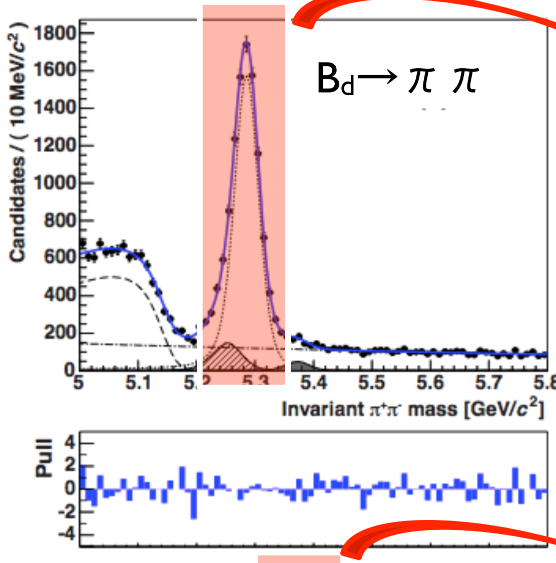
We also obtain production asymmetry $A_P(B^0)$ = (0.6 ± 0.9)% and $A_P(B_s^0)$ = (7 ± 5)%

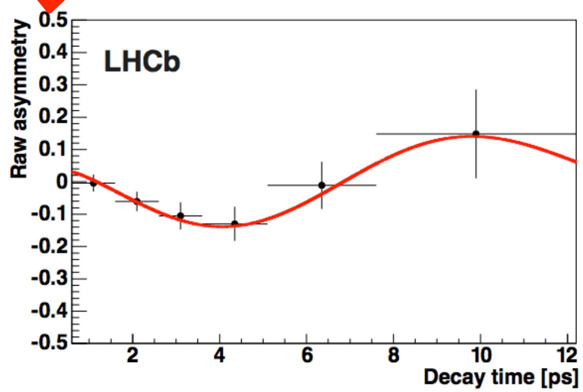
For Bs→*KK* study, the decay time resolution plays important role (as it is comparable to oscillation period). We estimate this quantity using Y(nS), J/Ψ, and $\Psi(2S) \to \mu\ \mu$ data and Monte Carlo samples: $\sigma_t = 50 \pm 5$ fs

Time-Dependent Results

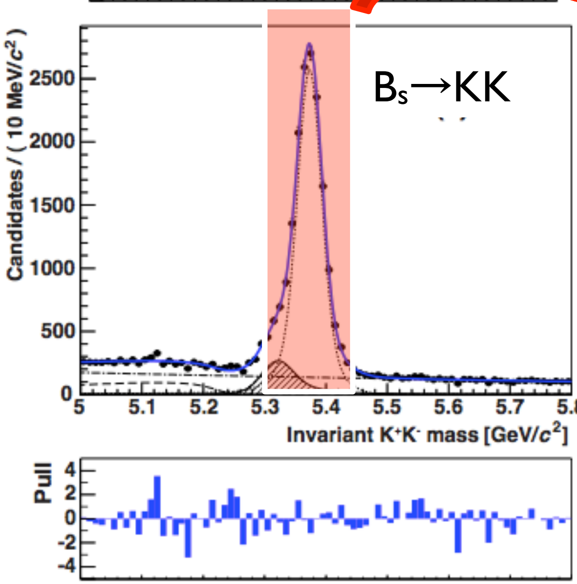
We perform a 2D Maximum Likelihood fit to mass and time.

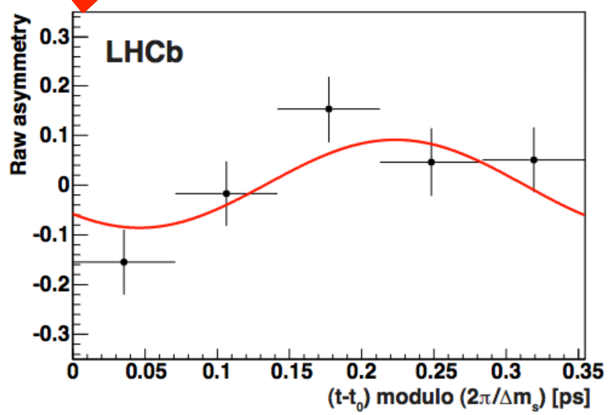
Tagging parameters and production asymmetry are propagated from $K\pi$ fit using gaussian priors



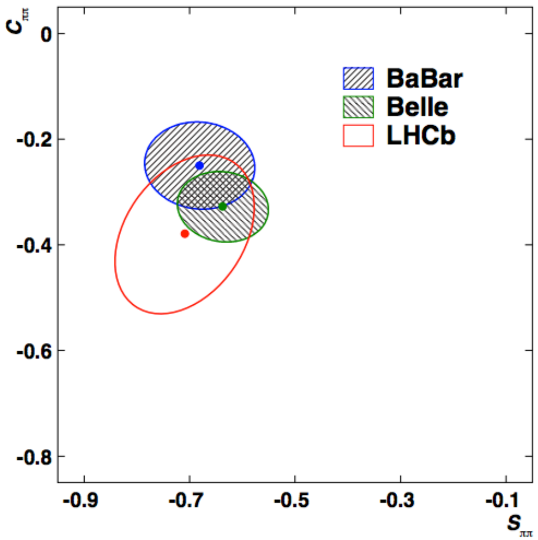


$$C_{\pi\pi} = -0.38 \pm 0.15 \pm 0.02,$$
$$S_{\pi\pi} = -0.71 \pm 0.13 \pm 0.02,$$
$$\rho(C_{\pi\pi}, S_{\pi\pi}) = 0.38$$





$$C_{KK} = 0.14 \pm 0.11 \pm 0.03,$$
$$S_{KK} = 0.30 \pm 0.12 \pm 0.04,$$
$$\rho(C_{KK}, S_{KK}) = 0.02$$



Our results are in agreement with previous studies by BaBar and Belle in $B_d \rightarrow \pi\ \pi$

Experiment	$C_{\pi\pi}$	$S_{\pi\pi}$	$\rho(C_{\pi\pi}, S_{\pi\pi})$
BaBar	$-0.25 \pm 0.08 \pm 0.02$	$-0.68 \pm 0.10 \pm 0.03$	-0.06
Belle	$-0.33 \pm 0.06 \pm 0.03$	$-0.64 \pm 0.08 \pm 0.03$	-0.10

$B_s \rightarrow KK$ is the first time measurement.

Taking into account U-spin symmetry we are able to obtain CKM angle γ using our experimental results (see talk by Paolo Gandini). Some other useful relations can be tested using also the time-integrated analysis.

In case of exact U-spin symmetry: $$\Delta = \frac{A_{CP}(B^0 \to K^+\pi^-)}{A_{CP}(B_s^0 \to K^-\pi^+)} + \frac{\mathcal{B}(B_s^0 \to K^-\pi^+)}{\mathcal{B}(B^0 \to K^+\pi^-)}\frac{\tau_d}{\tau_s} = 0$$

Using LHCb results for branching ratios [JHEP 10 (2012) 037]: $\Delta = -0.02 \pm 0.05 \pm 0.04$

Moreover, time-integrated and time-dependent results are related:

$C(B_d \rightarrow \pi\ \pi) = -0.38 \pm 0.15 \pm 0.02 \sim -A_{CP}(B_s \rightarrow \pi K) = -0.27 \pm 0.04 \pm 0.01$

$C(B_s \rightarrow KK) = 0.14 \pm 0.11 \pm 0.03 \sim -A_{CP}(B_d \rightarrow K\pi) = 0.080 \pm 0.007 \pm 0.003$

$\mathcal{L}$=0.9 fb^{-1}

Evidence of baryonic decays $B \to p\bar{p}$

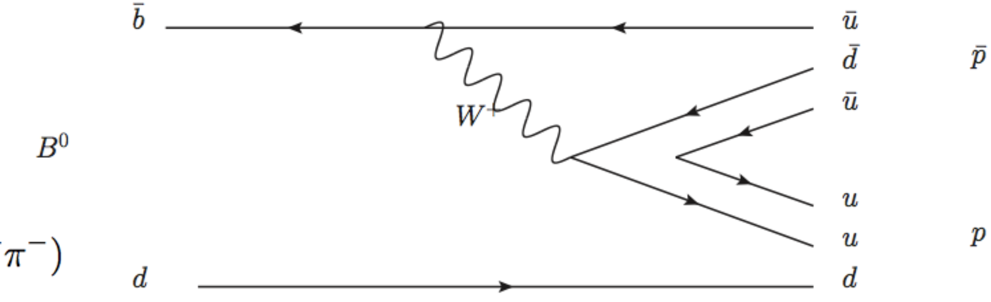
J. High Energy Phys. 10 (2013) 005

Analysis results

The decay has never been observed before.

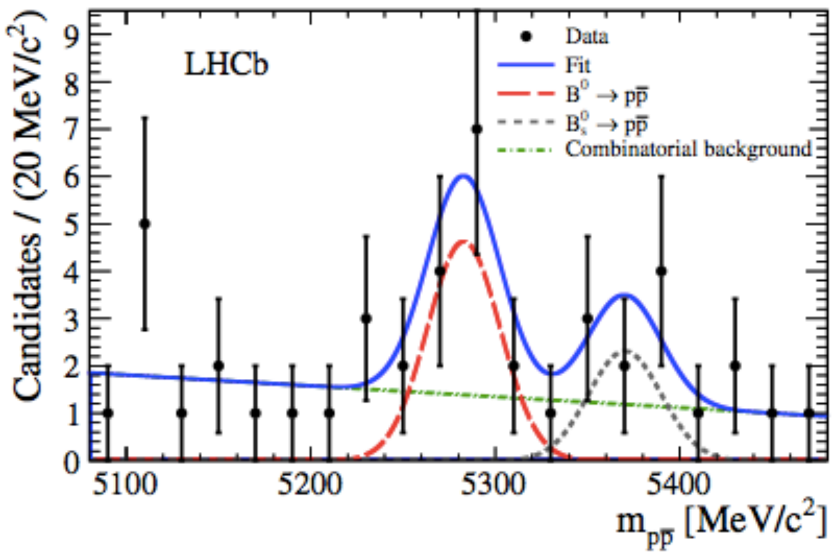
All theory predictions point to branching fraction ~ 10^{-7}.

We measure the ratio of decays of interest to $B \to K\pi$



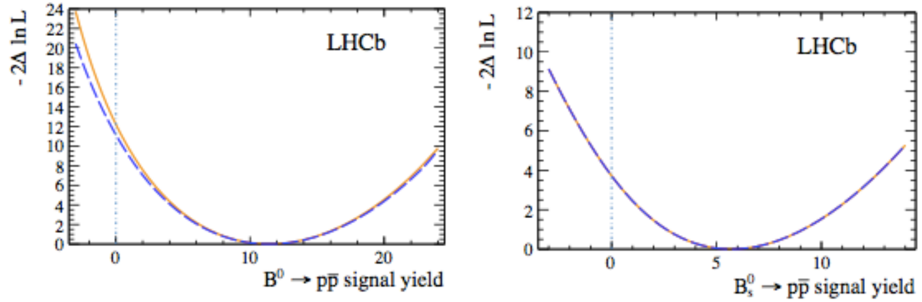
$$\mathcal{B}(B^0 \to p\bar{p}) = \frac{N(B^0 \to p\bar{p})}{N(B^0 \to K^+\pi^-)} \cdot \frac{\epsilon_{B^0 \to K^+\pi^-}}{\epsilon_{B^0 \to p\bar{p}}} \cdot \mathcal{B}(B^0 \to K^+\pi^-)$$

Efficiency is taken from simulated events, other quantities are measured by LHCb



First evidence of $B_d \to p\bar{p}$

Likelihood scans



Using Feldman-Cousins approach

$$\mathcal{B}(B^0 \to p\bar{p}) = (1.47\,^{+0.62}_{-0.51}\,^{+0.35}_{-0.14}) \times 10^{-8} \quad \text{at} \quad 68.3\% \quad \text{CL}$$

$$\mathcal{B}(B^0 \to p\bar{p}) = (1.47\,^{+1.09}_{-0.81}\,^{+0.69}_{-0.18}) \times 10^{-8} \quad \text{at} \quad 90\% \quad \text{CL}$$

$$\mathcal{B}(B_s^0 \to p\bar{p}) = (2.84\,^{+2.03}_{-1.68}\,^{+0.85}_{-0.18}) \times 10^{-8} \quad \text{at} \quad 68.3\% \quad \text{CL}$$

$$\mathcal{B}(B_s^0 \to p\bar{p}) = (2.84\,^{+3.57}_{-2.12}\,^{+2.00}_{-0.21}) \times 10^{-8} \quad \text{at} \quad 90\% \quad \text{CL}$$

Summary

LHCb have provided several results in the field:

Time integrated $B \to K\pi$:

- $B_d \to K\pi$: world's best (10σ) significance of the direct *CP* asymmetry.
- $B_s \to \pi K$: first observation of direct *CP* asymmetry (6σ).
- $B_u \to K_s h$: world leading measurement

Time dependent $B \to \pi\pi/KK$:

- $B_d \to \pi\pi$: measurement in agreement with B-factories results.
- $B_s \to KK$: first ever measurement in this channel

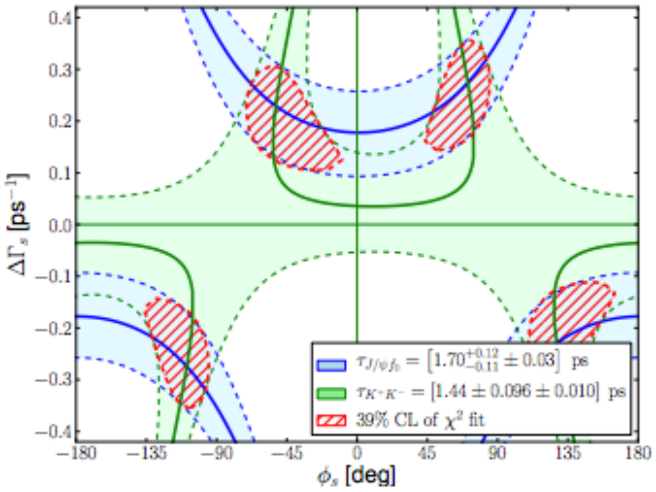
Rare decays:

- $B_d \to p\bar{p}$ first evidence of the decay.
- $B_c \to K_s K$ first upper limit in sector.

$\mathcal{L}$=1.0 fb^{-1}

$B_s \rightarrow KK$ Effective Lifetime Measurement

Physics Letters B 716 (2012) 393–400



Comparison between *CP* even and *CP* odd lifetimes is useful to constrain the *CP* violation parameters

Fleischer, Knegjens Eur.Phys.J. C71 (2011) 1789

The untagged decay time distribution can be written as:

$$\Gamma(t) \quad \propto \quad (1 - \mathcal{A}_{\Delta\Gamma_s})\, e^{-\Gamma_L t} + (1 + \mathcal{A}_{\Delta\Gamma_s})\, e^{-\Gamma_H t}\,.$$

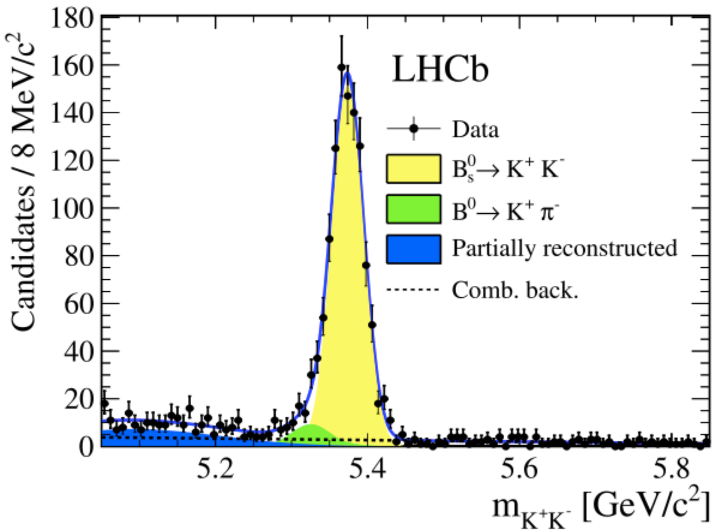
In this case, fitting the decay time with a single exponential gives an effective lifetime defined as:

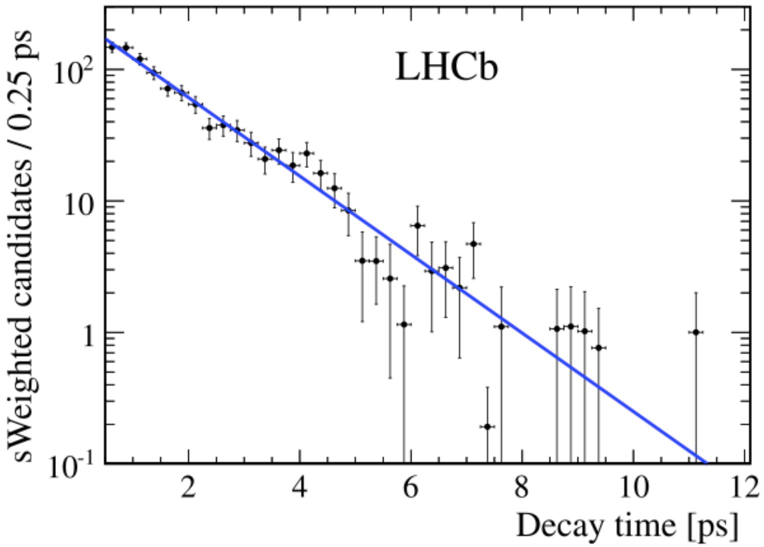
$$\tau_{KK} = \tau_{B_s^0} \frac{1}{1 - y_s^2} \left[\frac{1 + 2\mathcal{A}_{\Delta\Gamma_s} y_s + y_s^2}{1 + \mathcal{A}_{\Delta\Gamma_s} y_s} \right]$$

with $\quad y_s \equiv \dfrac{\Delta\Gamma_s}{2\Gamma_s},$

Analysis steps:

- two consecutive Neural Network NeuroBayes® selections applied:
    1. based on the kinematic variables
    2. the kinematic information is combined with the PID
- only events with τ>0.5 ps are considered
- mass fit is used to extract sWeights for the signal decay time distribution





$$\tau_{KK} = 1.455 \pm 0.046\,(\text{stat.}) \pm 0.006\,(\text{syst.})\ \text{ps},$$

Which can be compared to the SM predictions:

$$\tau_{KK}^{\text{SM}} = 1.40 \pm 0.02\ \text{ps}$$