Time integrated and time dependent asymmetries in $B \to hh'$ ($h=K,\pi,p$) decays at LHCb including

First observation of CPV in the B_s system !

Aurélien MARTENS (LPNHE Paris)
on behalf of the LHCb Collaboration

The LHCb experiment in a nutshell

LHCb-Roadmap

Excellent tracking (Time, impact parameter, mass resolutions)

Rich performance

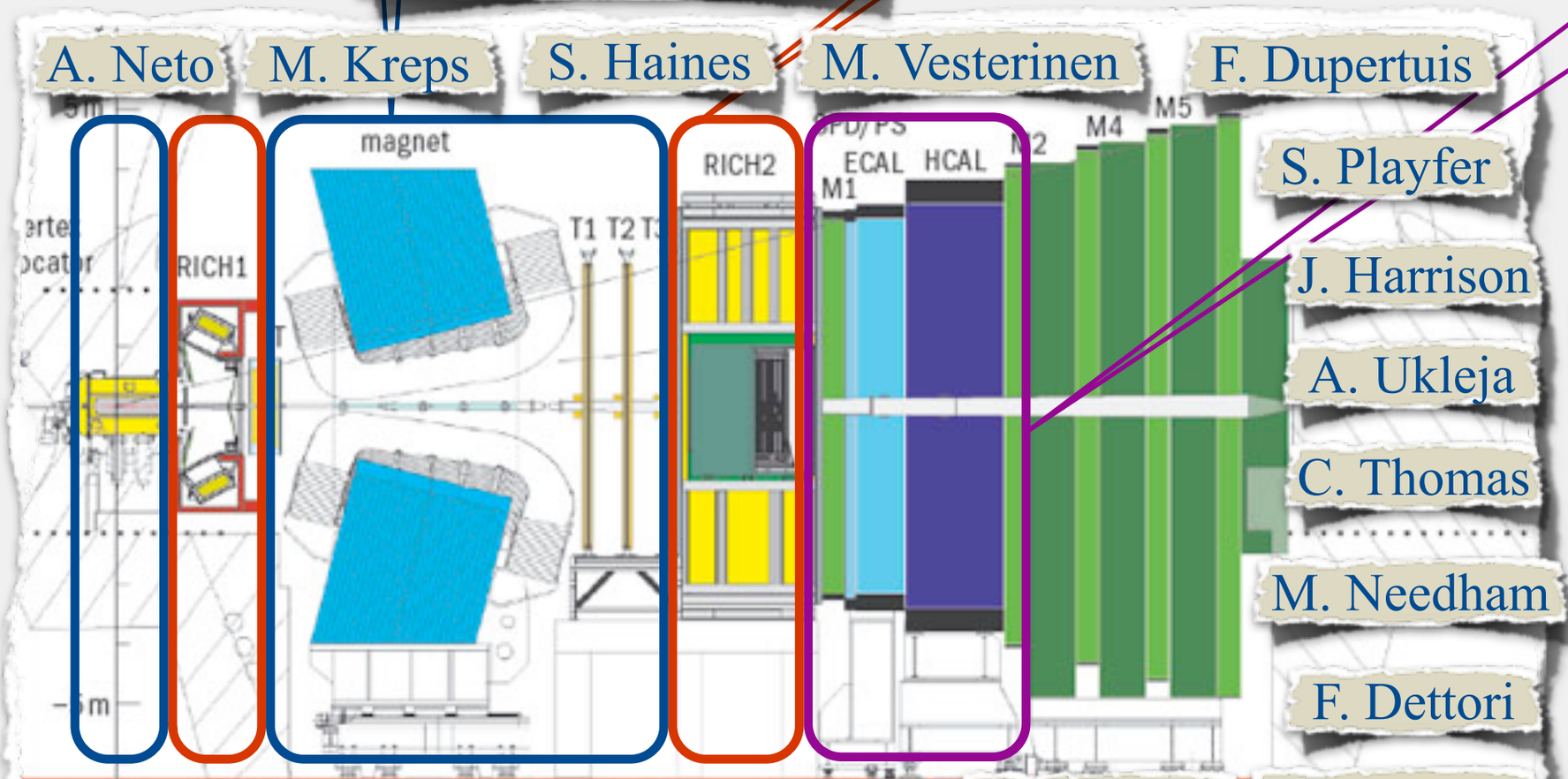
Excellent Particle Indentification (including low momenta for flavour tagging)

High trigger efficiency

Trigger performance

Many other talks...

A. Neto M. Kreps S. Haines M. Vesterinen F. Dupertuis



M. Schiller P. Cartelle M.Martinelli G. Sabatino F. Machefert

S. Playfer

J. Harrison

A. Ukleja

C. Thomas

M. Needham

F. Dettori

$2010: \int L = 37 pb^{-1}$

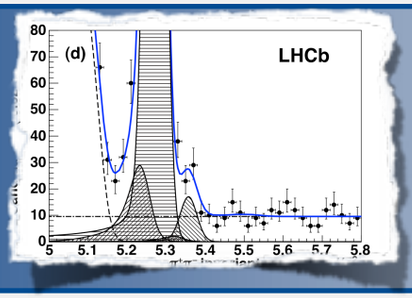
$2011: \int L = 1.0 fb^{-1}$

$2012: \int L = 2\ fb^{-1}$

...and posters !

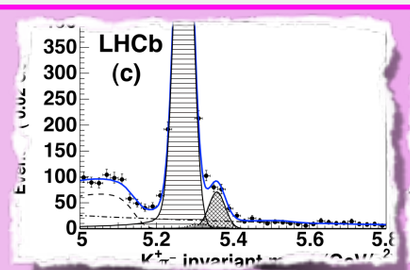
A. Falabella
M. Orlandea
D. Pinci

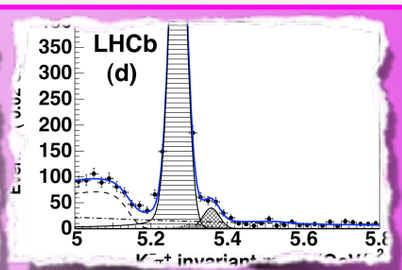
Overview of B→hh measurements



Branching fraction measurements

Time integrated CPV





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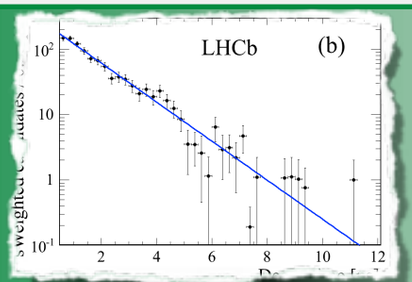
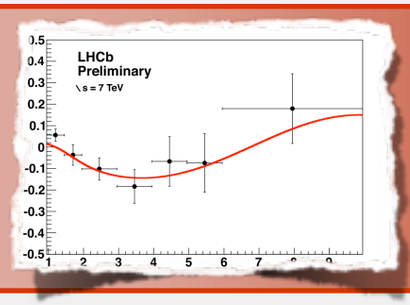


Effective lifetime measurement

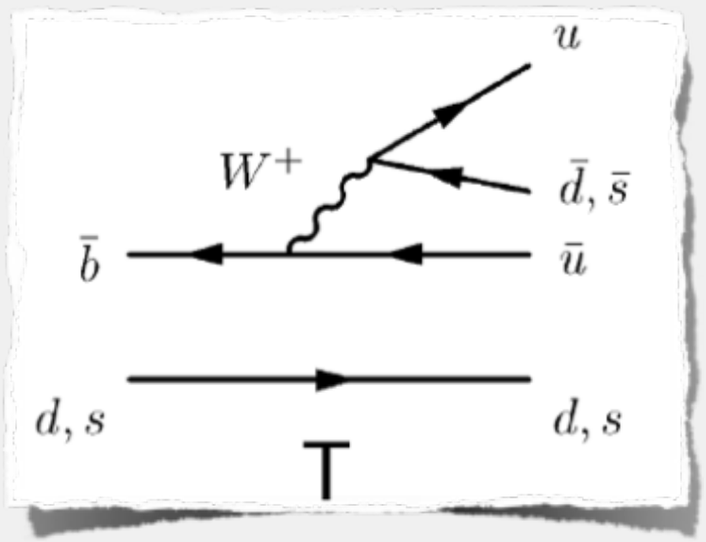
Time dependent CPV



LHCb Charmless B decays results: http://lhcbproject.web.cern.ch/lhcbproject/CDS/cgi-bin/bnoc.php

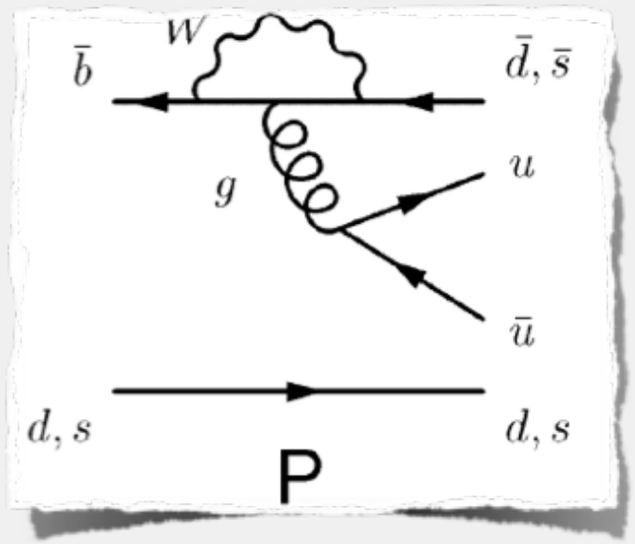
General strategy in 2-body decays

Decays sensitive to CKM angle γ, and mixing parameters and phases



Example of interfering diagrams

7 parameters for 4 observables if no additional hypothesis



Decays of interest, BR~10^{-7}→10^{-5}

LHCb-Roadmap
PLB 459 (1999) 306 [Fleisher]
JHEP 10 (2012) 029 [Ciuchini et al.]

U-spin relates hadronic parameters

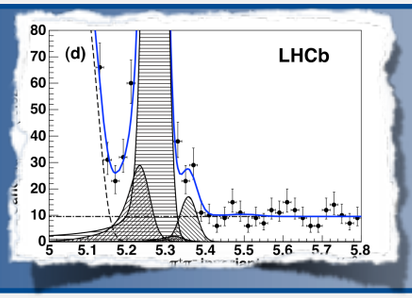
Decay mode	Contributing diagrams
$B^0 \to \pi^+\pi^-$	$T,\ P,\ PA,\ P^C_{EW},\ E$
$B^0 \to K^+\pi^-$	$T,\ P,\ P^C_{EW}$
$B^0_s \to \pi^+K^-$	$T,\ P,\ P^C_{EW}$
$B^0_s \to K^+K^-$	$T,\ P,\ PA,\ P^C_{EW},\ E$
$B^0 \to K^+K^-$	$PA,\ E$
$B^0_s \to \pi^+\pi^-$	$PA,\ E$

control U-spin assumption for spectator quark

control size of polluting diagrams

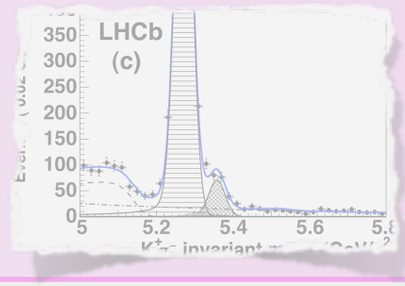
All the decay modes need to be studied together !

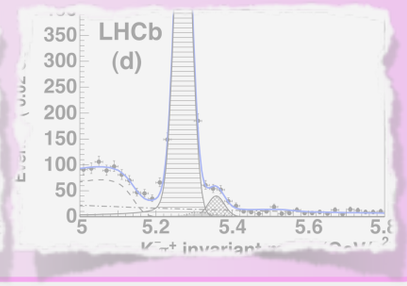
Overview of B→hh measurements



Branching fraction measurements

Time integrated CPV





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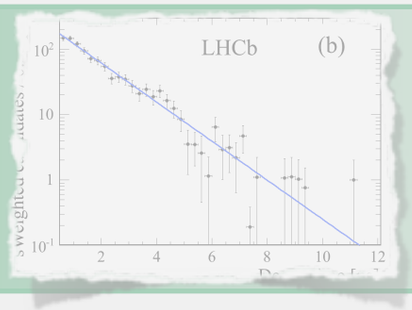
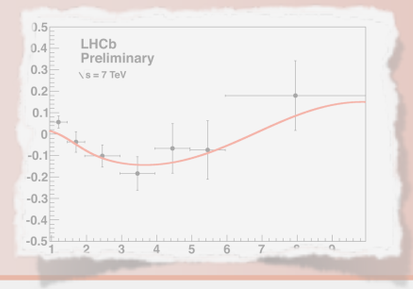


Effective lifetime measurement

Time dependent CPV



LHCb Charmless B decays results: http://lhcbproject.web.cern.ch/lhcbproject/CDS/cgi-bin/bnoc.php

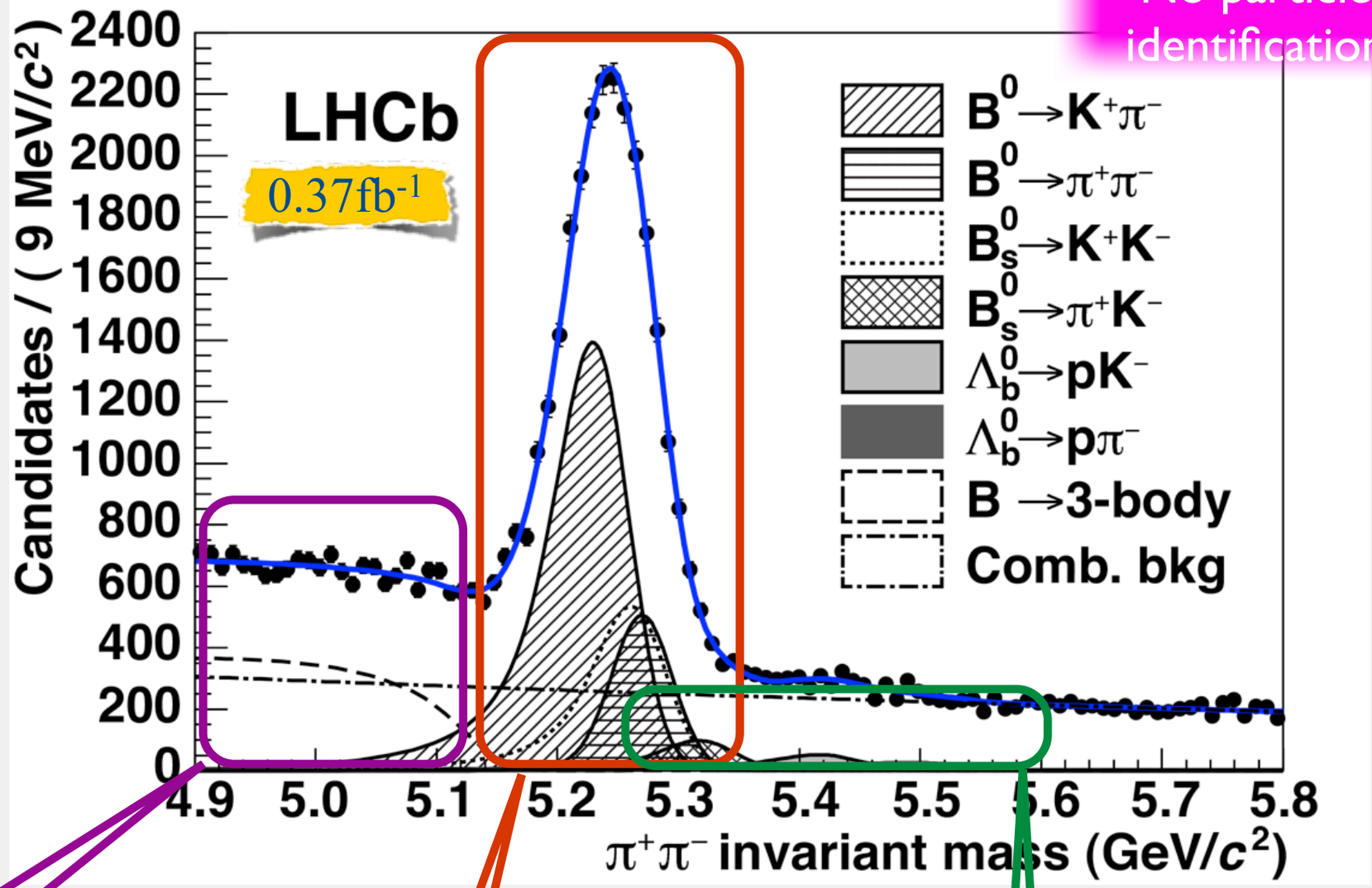
Topological and kinematic selection

JHEP 10 (2012) 037

Topological and kinematic selection

Track p_T [GeV/c]	>1.1
Track d_{IP} [μm]	>150
Track χ^2/ndf	<3
$\max(p_T^{h^+}, p_T^{h'^-})$ [GeV/c]	>2.8
$\max(d_{IP}^{h^+}, d_{IP}^{h'^-})$ [μm]	>300
d_{CA} [μm]	<80
d_{IP}^B [μm]	<60
p_T^B [GeV/c]	>2.2
$t_{\pi\pi}$ [ps]	>0.9

No particle identification



3 body charmless decays dominate lower mass sideband

Many 2 body decay modes to be separated

Suppressed signal contributions require tighter selections

Particle identification separation

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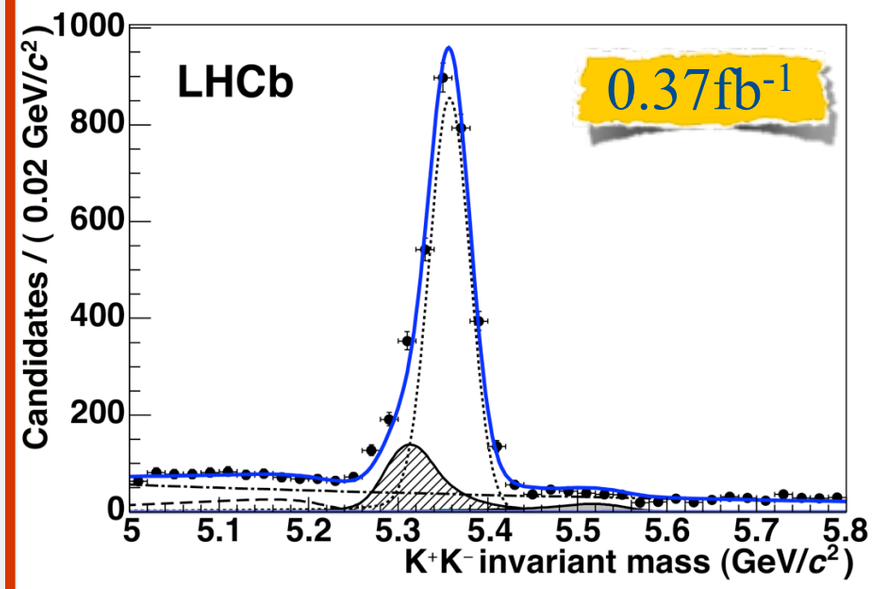
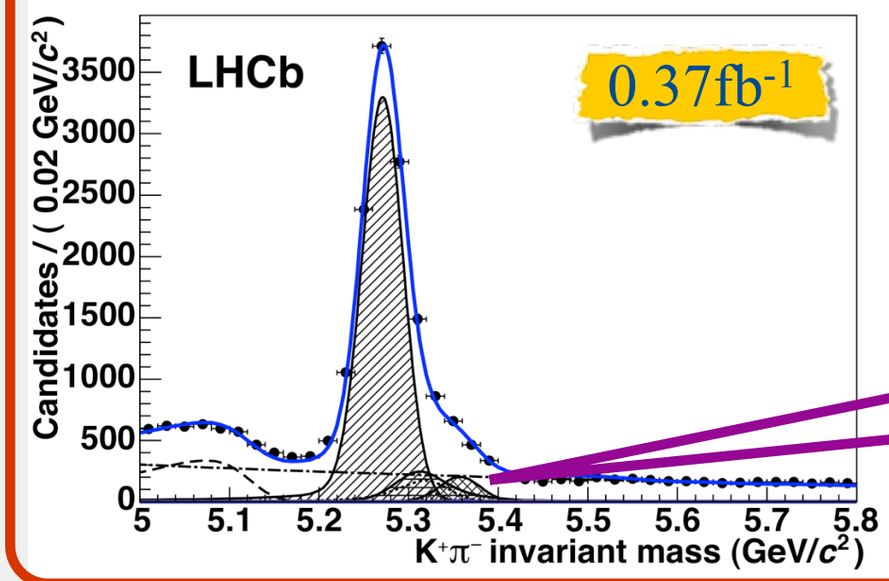


World's best

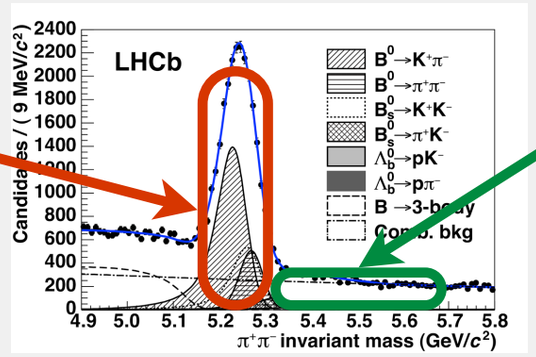
$$\frac{f_s}{f_d}\frac{\mathscr{B}(B_s^0 \to K^+K^-)}{\mathscr{B}(B^0 \to K^+\pi^-)}$$

$$= 0.316 \pm 0.009\ (\text{stat.}) \pm 0.019\ (\text{syst.})$$

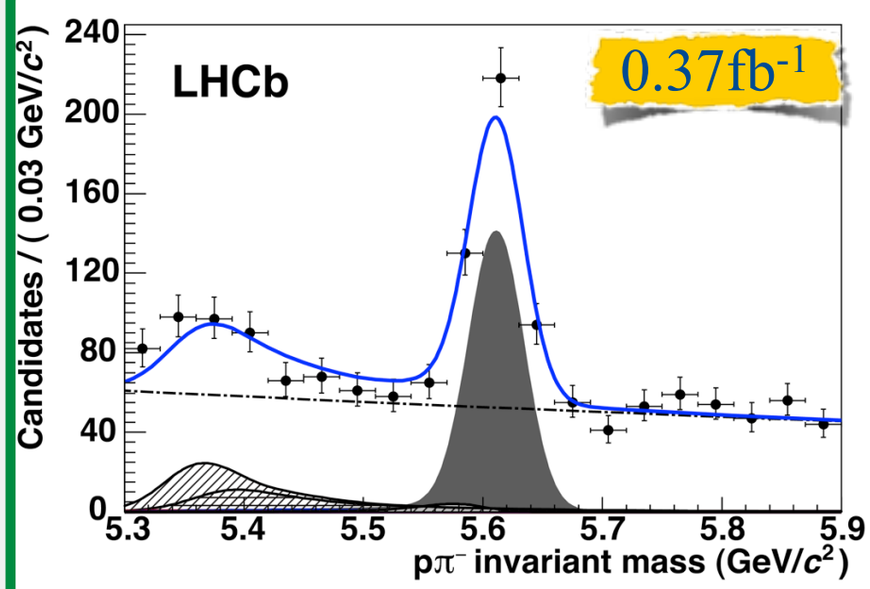


Adding Particle Identification (PID)

PID calibrated with large samples of D^* and Λ^0 decays



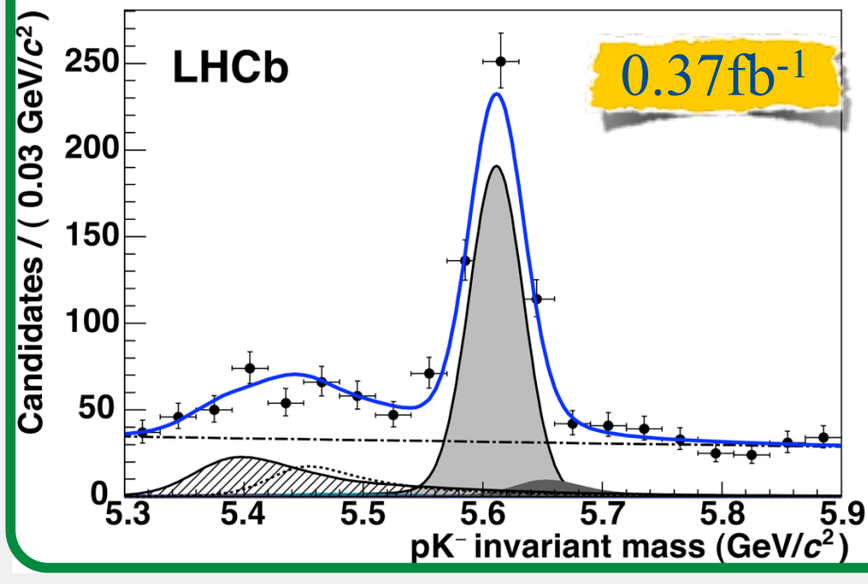
Tighter selection needed to observe the suppressed decays



World's best

$$\frac{\mathscr{B}(\Lambda_b^0 \to p\pi^-)}{\mathscr{B}(\Lambda_b^0 \to pK^-)}$$

$$= 0.86 \pm 0.08\ (\text{stat.}) \pm 0.05\ (\text{syst.})$$



Looking for $B_s \to \pi^+ K^-$

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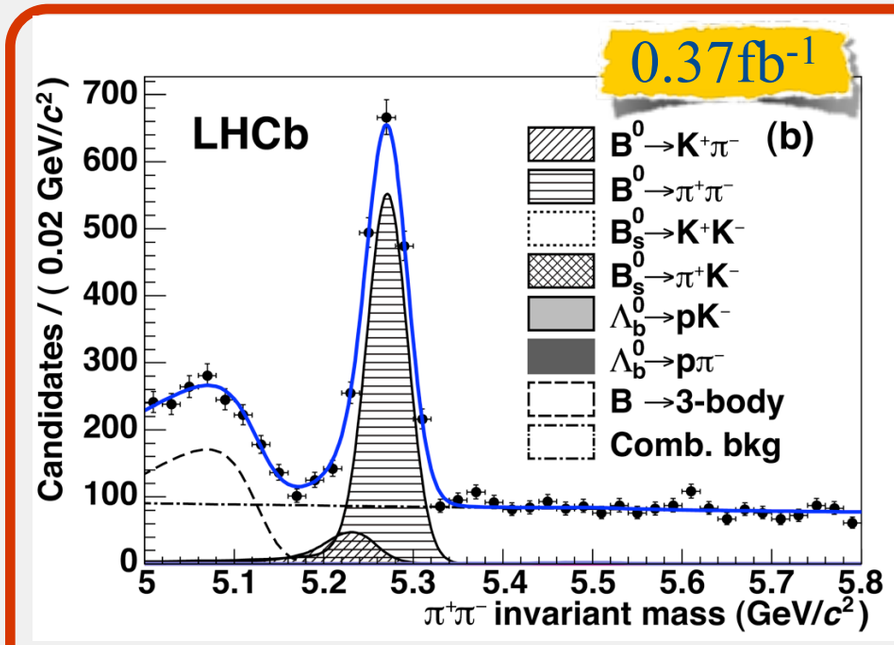
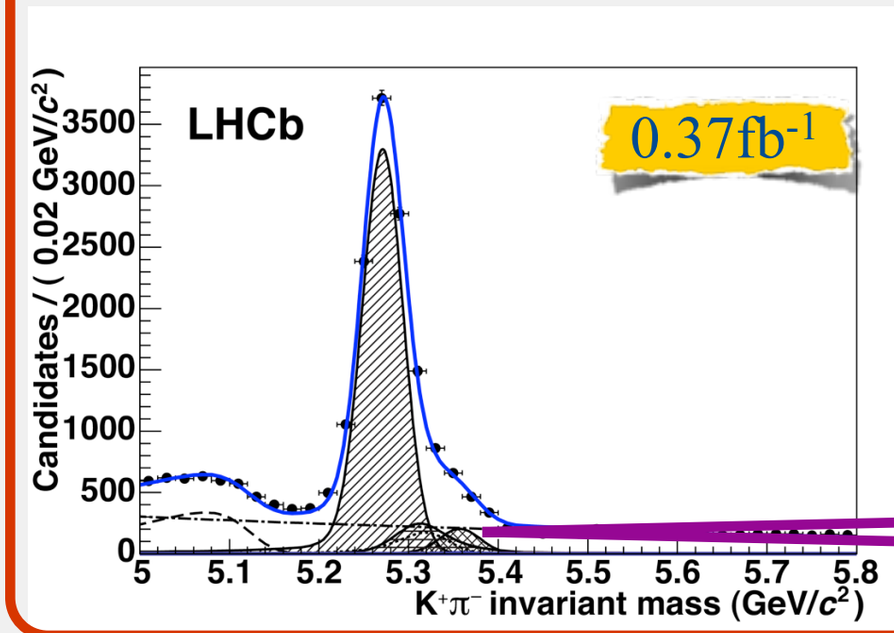


$$\frac{\mathcal{B}(B^0 \to \pi^+\pi^-)}{\mathcal{B}(B^0 \to K^+\pi^-)}$$

$$= 0.262 \pm 0.009\ (\text{stat.}) \pm 0.017\ (\text{syst.})$$



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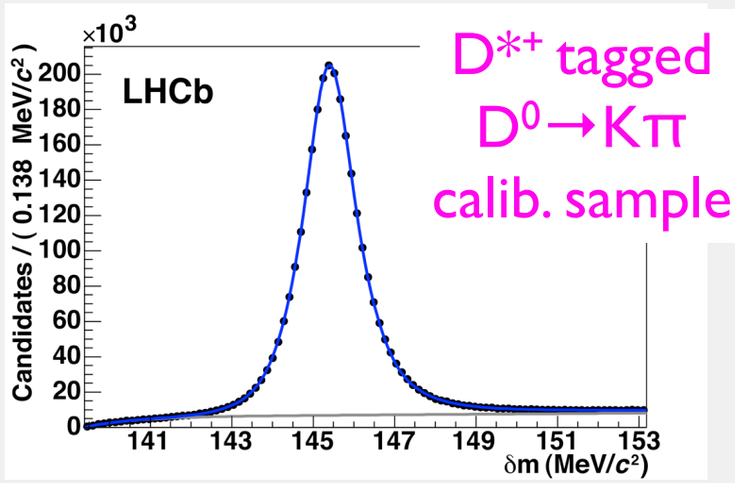
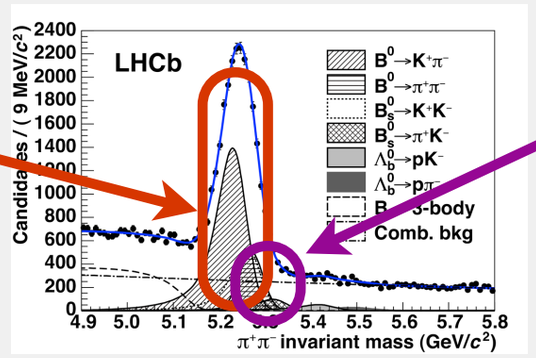


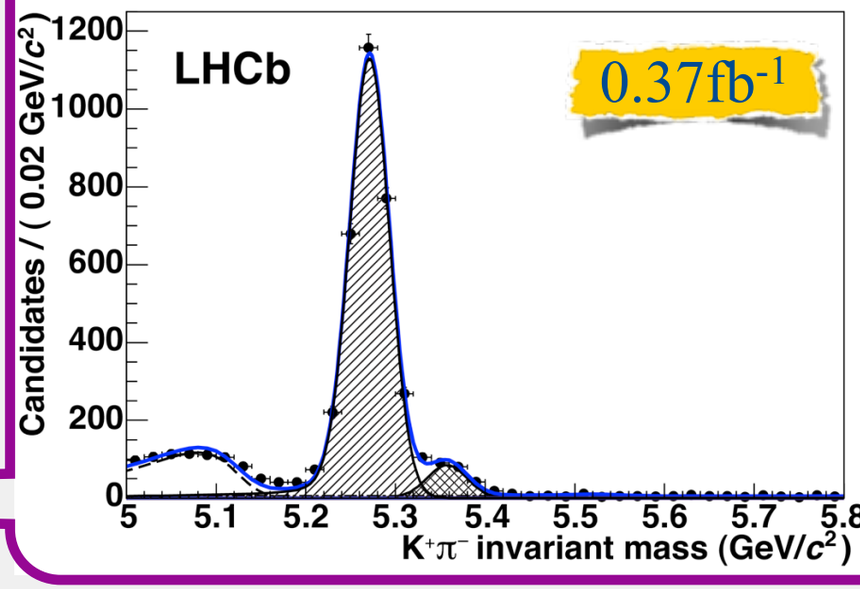


Tighter selection needed to observe the suppressed decays

World's best

$$\frac{f_s}{f_d}\frac{\mathcal{B}(B_s^0 \to \pi^+ K^-)}{\mathcal{B}(B^0 \to K^+\pi^-)}$$

$$= 0.074 \pm 0.006\ (\text{stat.}) \pm 0.006\ (\text{syst.})$$



and very suppressed modes

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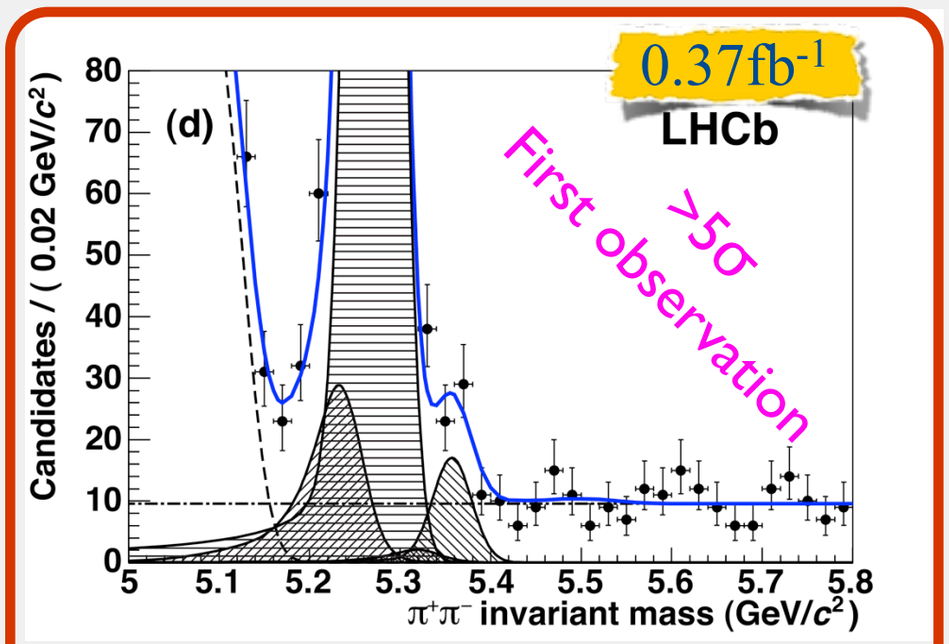
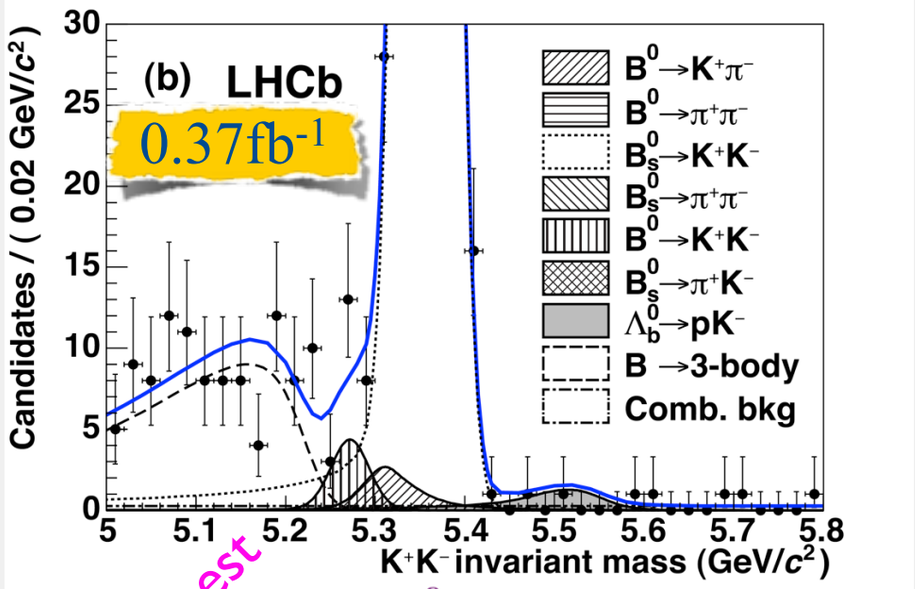


$$\frac{f_s}{f_d}\frac{\mathscr{B}(B_s^0 \to \pi^+\pi^-)}{\mathscr{B}(B^0 \to \pi^+\pi^-)}$$

$$= 0.050^{+0.011}_{-0.009}\,(\text{stat.}) \pm 0.004\,(\text{syst.})$$

Very tight selection

Plots are zoomed
Mind the scale



World's best

$$\frac{f_d}{f_s}\frac{\mathscr{B}(B^0 \to K^+K^-)}{\mathscr{B}(B_s^0 \to K^+K^-)}$$

$$= 0.018^{+0.008}_{-0.007}\,(\text{stat.}) \pm 0.009\,(\text{syst.})$$

Using the world average: HFAG

$$\mathscr{B}(B^0 \to K^+\pi^-) = (19.4 \pm 0.6) \times 10^{-6}$$

and LHCb's

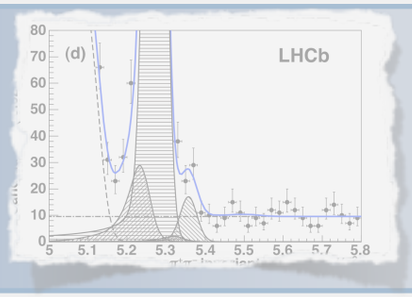
$$f_s/f_d = 0.267^{+0.021}_{-0.020}$$

PRD 85 (2012) 032008

$$\begin{aligned}
\mathscr{B}(B^0 \to \pi^+\pi^-) &= (\ 5.08 \pm 0.17\,(\text{stat.}) \pm 0.37\,(\text{syst.})) \times 10^{-6} \\
\mathscr{B}(B_s^0 \to K^+K^-) &= (23.0\ \ \pm 0.7\ \ (\text{stat.}) \pm 2.3\ \ (\text{syst.})) \times 10^{-6} \\
\mathscr{B}(B_s^0 \to \pi^+K^-) &= (\ 5.4\ \ \pm 0.4\ \ (\text{stat.}) \pm 0.6\ \ (\text{syst.})) \times 10^{-6} \\
\mathscr{B}(B_s^0 \to \pi^+\pi^-) &= (0.95^{+0.21}_{-0.17}\,(\text{stat.}) \pm 0.13\,(\text{syst.})) \times 10^{-6} \\
\mathscr{B}(B^0 \to K^+K^-) &= (0.11^{+0.05}_{-0.04}\,(\text{stat.}) \pm 0.06\,(\text{syst.})) \times 10^{-6}
\end{aligned}$$

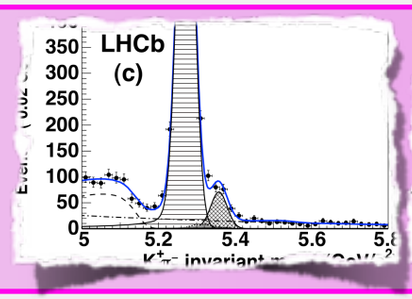
Systematics: signal model, FSR, cross-feeds, 3-body decays

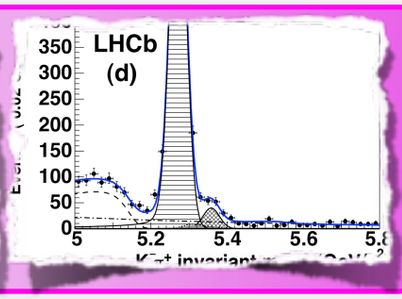
Overview of B→hh measurements



Branching fraction measurements

Time integrated CPV





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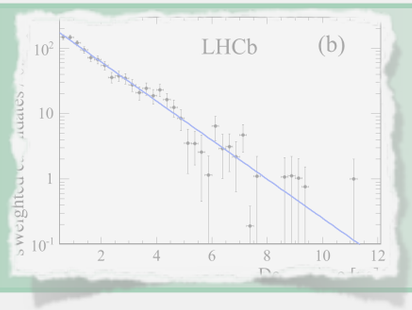
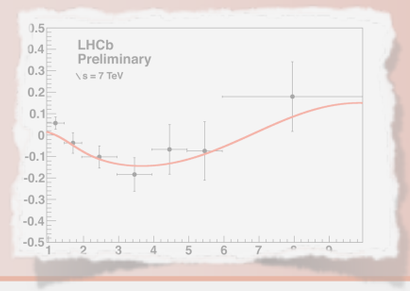


Effective lifetime measurement

Time dependent CPV



LHCb Charmless B decays results: http://lhcbproject.web.cern.ch/lhcbproject/CDS/cgi-bin/bnoc.php

Time integrated CPV

Goal:
Study CPV in flavour specific decays
$B^0 \to K^+\pi^-$ and $B_s \to K^-\pi^+$

$$\mathcal{A}_{CP}(B_s^0 \to K\pi) = \frac{\Gamma(\bar{B}_s^0 \to K^+\pi^-) - \Gamma(B_s^0 \to K^-\pi^+)}{\Gamma(\bar{B}_s^0 \to K^+\pi^-) + \Gamma(B_s^0 \to K^-\pi^+)}$$

$$\mathcal{A}_{CP}(B^0 \to K\pi) = \frac{\Gamma(\bar{B}^0 \to K^-\pi^+) - \Gamma(B^0 \to K^+\pi^-)}{\Gamma(\bar{B}^0 \to K^-\pi^+) + \Gamma(B^0 \to K^+\pi^-)}$$

Detection asymmetry

LHCB-PAPER-2013-018 in preparation

NEW

$$\mathcal{A}_{CP} = \mathcal{A}_{Raw} - (\mathcal{A}_{Det.} + \kappa \mathcal{A}_{Prod.})$$

HFAG

From HFAG transported to LHCb decay time acceptance

$\mathcal{A}_{CP}(KK) = -0.24 \pm 0.18\%$

Determined from large D decay samples

$$\mathcal{A}_{Raw}(K\pi) = \mathcal{A}_{D}(\pi_s) + \mathcal{A}_{D}(K\pi) + \mathcal{A}_{P}(D^*)$$

$$\mathcal{A}_{Raw}(KK) = \mathcal{A}_{CP}(KK) + \mathcal{A}_{D}(\pi_s) + \mathcal{A}_{P}(D^*)$$

$$\mathcal{A}_{D}(K\pi) - \mathcal{A}_{CP}(KK) = \mathcal{A}_{Raw}(K\pi) - \mathcal{A}_{Raw}(KK)$$

Kinematic reweighting to transport to B kinematics

$\mathcal{A}_{D}(K\pi) - \mathcal{A}_{CP}(KK) = -0.91 \pm 0.15\%$ (B^0 optimisation)

$\mathcal{A}_{D}(K\pi) - \mathcal{A}_{CP}(KK) = -0.98 \pm 0.11\%$ (B_s^0 optimisation)

$$\mathcal{A}_{Det.}(B^0) = -1.15 \pm 0.23\%$$

$$\mathcal{A}_{Det.}(B_s^0) = -1.22 \pm 0.21\%$$

Production asymmetry

LHCB-PAPER-2013-018 in preparation

NEW $\mathcal{A}_{CP} = \mathcal{A}_{Raw} - (\mathcal{A}_{Det.} + \kappa \mathcal{A}_{Prod.})$

Dilution from:
- mixing
- proper time acceptance

$\kappa_{B^0} = 0.303 \pm 0.005$

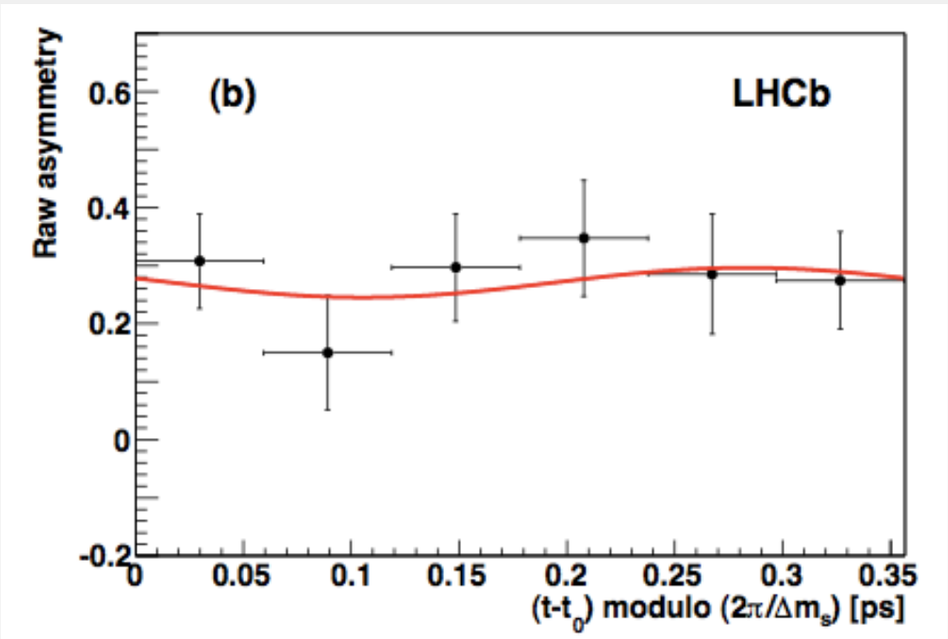
$\kappa_{B^0_s} = -0.033 \pm 0.003$

Determined from time dependence

$\mathcal{A}(t) \simeq \mathcal{A}_{CP} + \mathcal{A}_{Det.} + \mathcal{A}_{Prod.} \cos(\Delta m_{d(s)} t)$

$\mathcal{A}_{\text{Prod.}}(B^0) = 0.1 \pm 1.0\%$

$\mathcal{A}_{\text{Prod.}}(B^0_s) = 4 \pm 8\ \%$



In summary: corrections are small

$\mathcal{A}_{\text{Det.}} + \kappa \mathcal{A}_{\text{Prod.}}(B^0) = -1.12 \pm 0.23\ (\text{Det.}) \pm 0.30\ (\text{Prod.})\%$

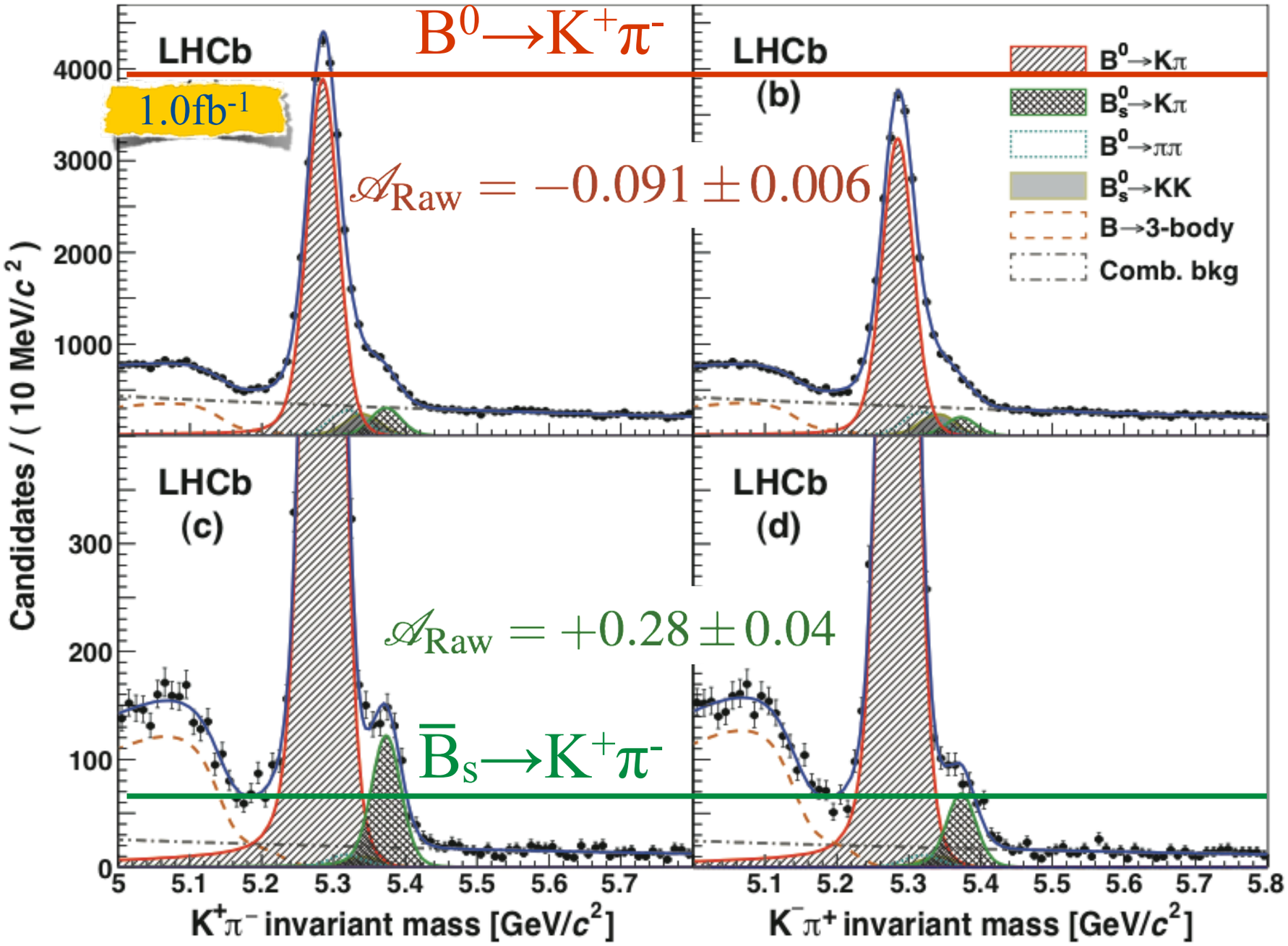
$\mathcal{A}_{\text{Det.}} + \kappa \mathcal{A}_{\text{Prod.}}(B^0_s) = 1.09 \pm 0.21\ (\text{Det.}) \pm 0.26\ (\text{Prod.})\%$

Raw asymmetry

LHCB-PAPER-2013-018 in preparation

NEW

$$\mathcal{A}_{CP} = \mathcal{A}_{Raw} - (\mathcal{A}_{Det.} + \kappa \mathcal{A}_{Prod.})$$



NEW

Final result

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$$\mathcal{A}_{CP}(B_s^0 \to K\pi) = \frac{\Gamma(\bar{B}_s^0 \to K^+\pi^-) - \Gamma(B_s^0 \to K^-\pi^+)}{\Gamma(\bar{B}_s^0 \to K^+\pi^-) + \Gamma(B_s^0 \to K^-\pi^+)}$$

>5σ observation

1.0fb^{-1}

$$= 0.27 \pm 0.04\,(\text{stat.}) \pm 0.01\,(\text{syst.})$$

$$\text{CDF result} = 0.22 \pm 0.07\,(\text{stat.}) \pm 0.02\,(\text{syst.})$$

CDF:Public-10726

Dominant systematic uncertainties:
B_s case: B invariant mass fit model
B_d case: production and detector asymmetries

First observation of CPV in the B_s system !

$$\mathcal{A}_{CP}(B^0 \to K\pi) = \frac{\Gamma(\bar{B}^0 \to K^-\pi^+) - \Gamma(B^0 \to K^+\pi^-)}{\Gamma(\bar{B}^0 \to K^-\pi^+) + \Gamma(B^0 \to K^+\pi^-)}$$

Most precise single measurement

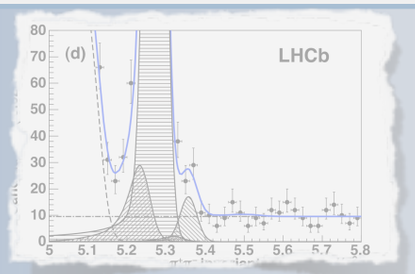
1.0fb^{-1}

$$= -0.080 \pm 0.007\,(\text{stat.}) \pm 0.003\,(\text{syst.})$$

$$\text{HFAG average} = -0.086 \pm 0.007$$

HFAG

Overview of B→hh measurements



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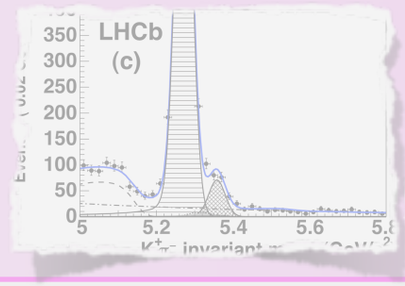
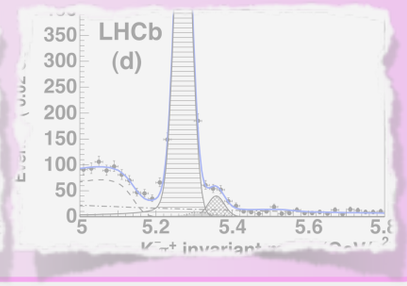
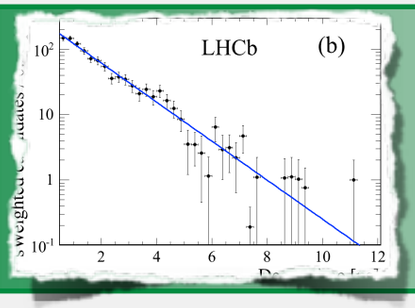
Time integrated CPV



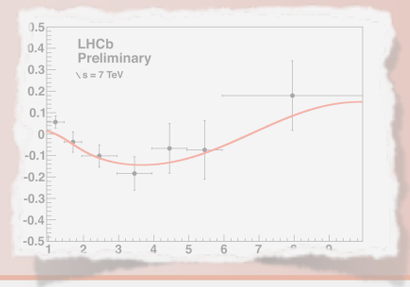


NEW



Effective lifetime measurement

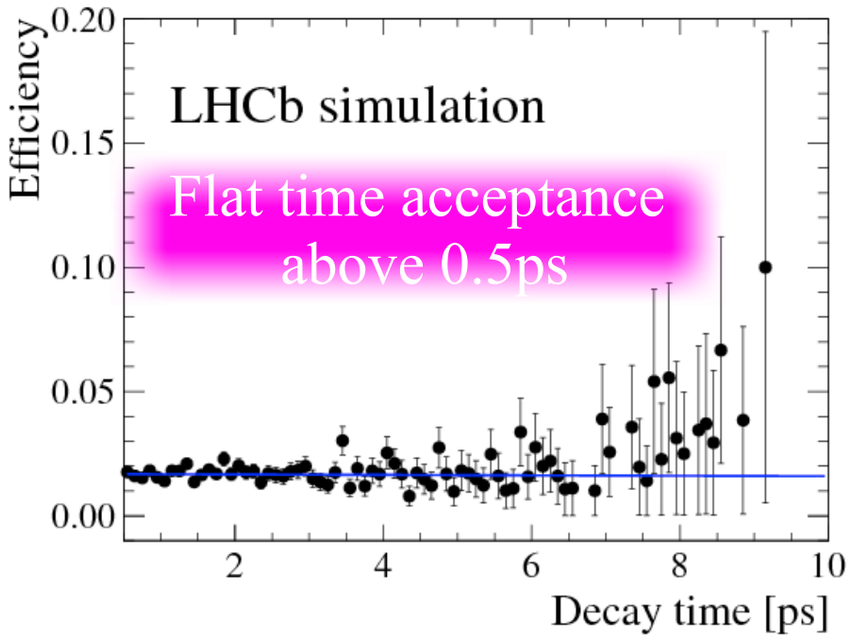
Time dependent CPV



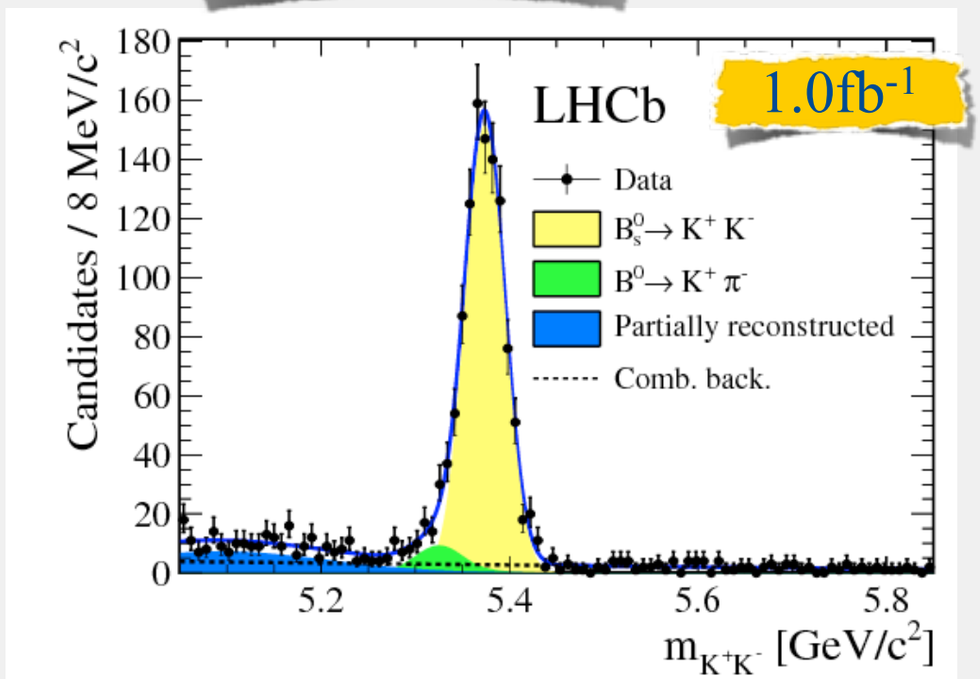
LHCb Charmless B decays results: http://lhcbproject.web.cern.ch/lhcbproject/CDS/cgi-bin/bnoc.php

Effective Lifetime in $B_s \to KK$

Phys. Lett. B 716 (2012) 393



trigger and selection: Neural Networks



$$\tau_{KK} = \tau_{B_s^0}(1 + \mathcal{A}_{\Delta\Gamma_s} y_s + O(y_s^2)) = 1.468 \pm 0.046\ (\text{stat.}) \pm 0.006\ (\text{syst.})\ \text{ps}$$

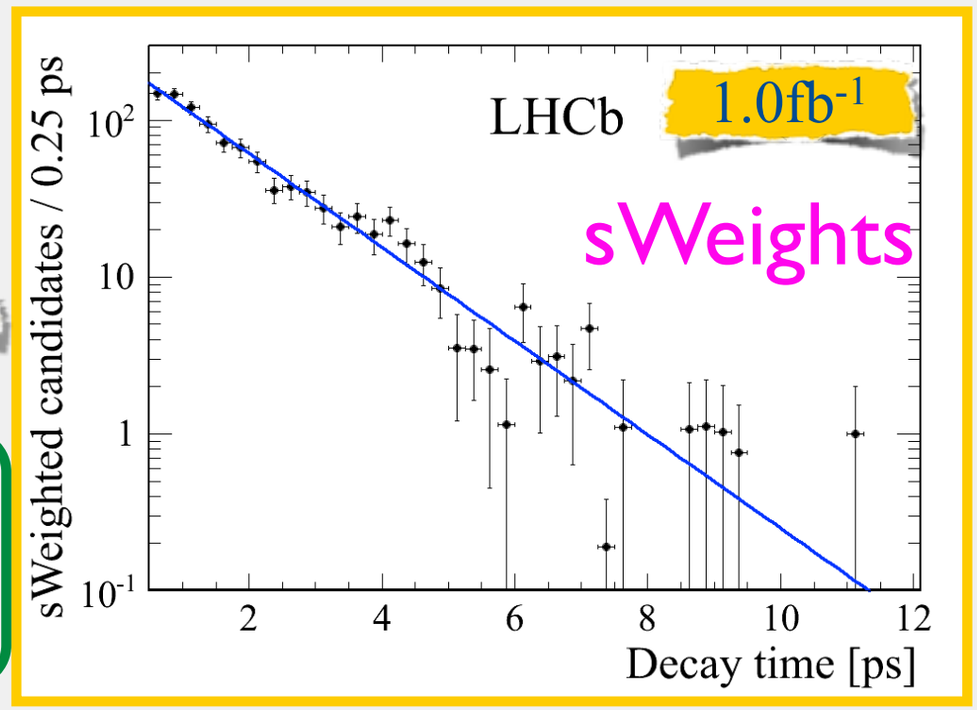
Dominant systematic: proper time reconstruction bias

Consistent with Standard Model prediction

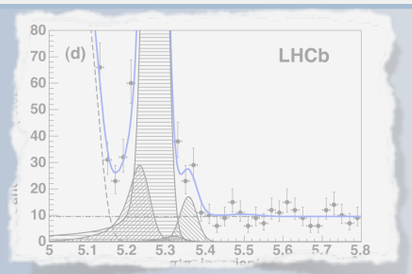
$$\tau_{KK} = 1.40 \pm 0.02\ \text{ps}$$ Eur. Phys. J. C 71 (2011) 1532

Consistent with independent 2010 data LHCb result:

$$\tau_{KK} = 1.440 \pm 0.096\ (\text{stat.}) \pm 0.008\ (\text{syst.}) \pm 0.003\ (\text{mod.})\ \text{ps}$$

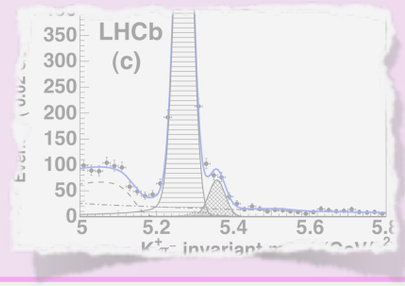


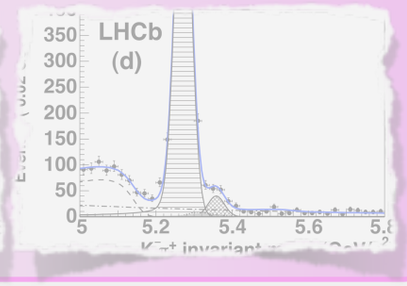
Overview of B→hh measurements



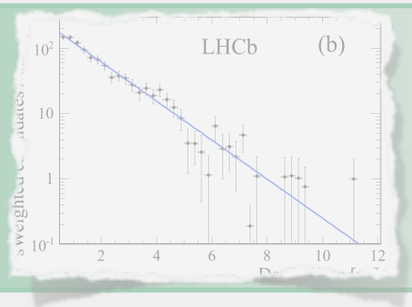
Branching fraction measurements

Time integrated CPV



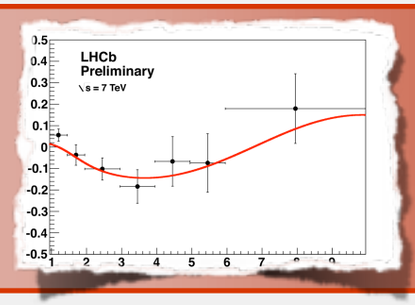


NEW



Effective lifetime measurement

Time dependent CPV



LHCb Charmless B decays results: http://lhcbproject.web.cern.ch/lhcbproject/CDS/cgi-bin/bnoc.php

Introduction

Goal:
Study CPV in non flavour specific decays
$B^0 \to \pi^+\pi^-$ and $B_s \to K^+K^-$

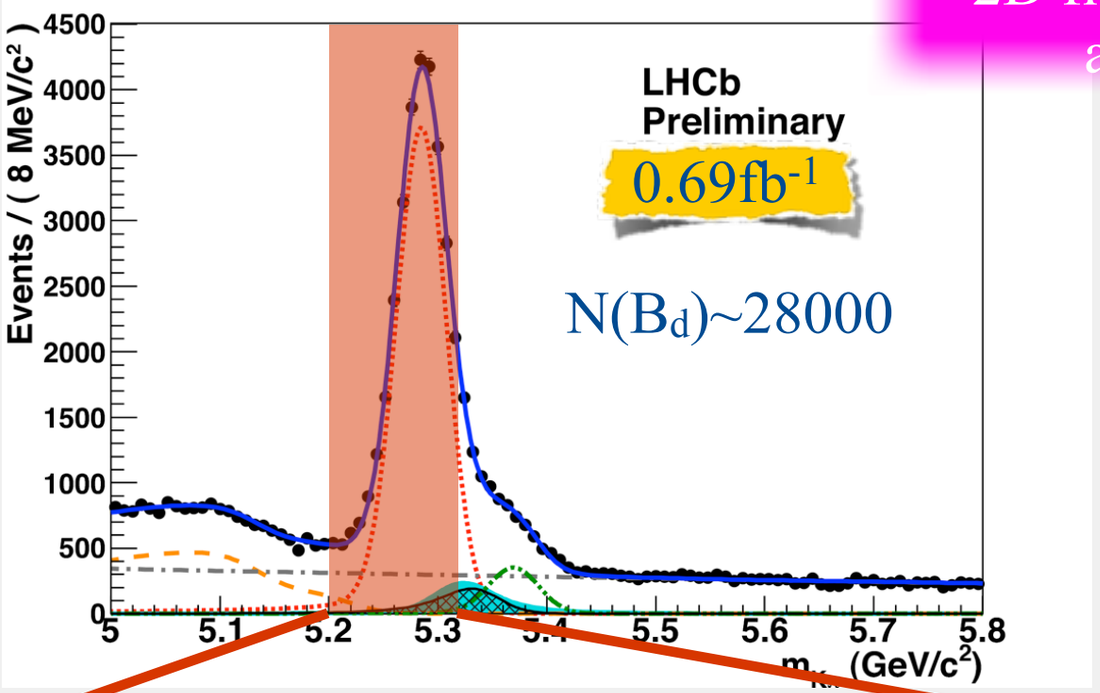
$$\mathcal{A}_{CP}(t) = \frac{\mathcal{A}_{dir.}\cos(\Delta m t) + \mathcal{A}_{mix.}\sin(\Delta m t)}{\cosh\left(\frac{\Delta\Gamma}{2}t\right) - \mathcal{A}_{\Delta\Gamma}\sinh\left(\frac{\Delta\Gamma}{2}t\right)}$$

Tagged time dependent analysis
calibrated with flavour specific $B^0 \to K^+\pi^-$

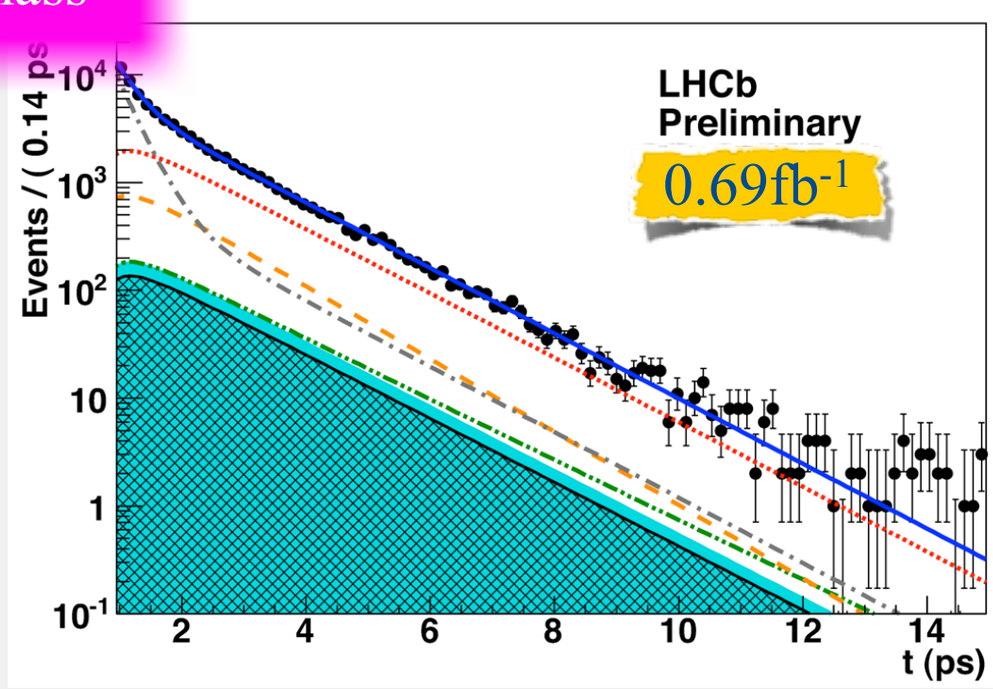
$B_d \to K\pi$ proxy: taggers calibration

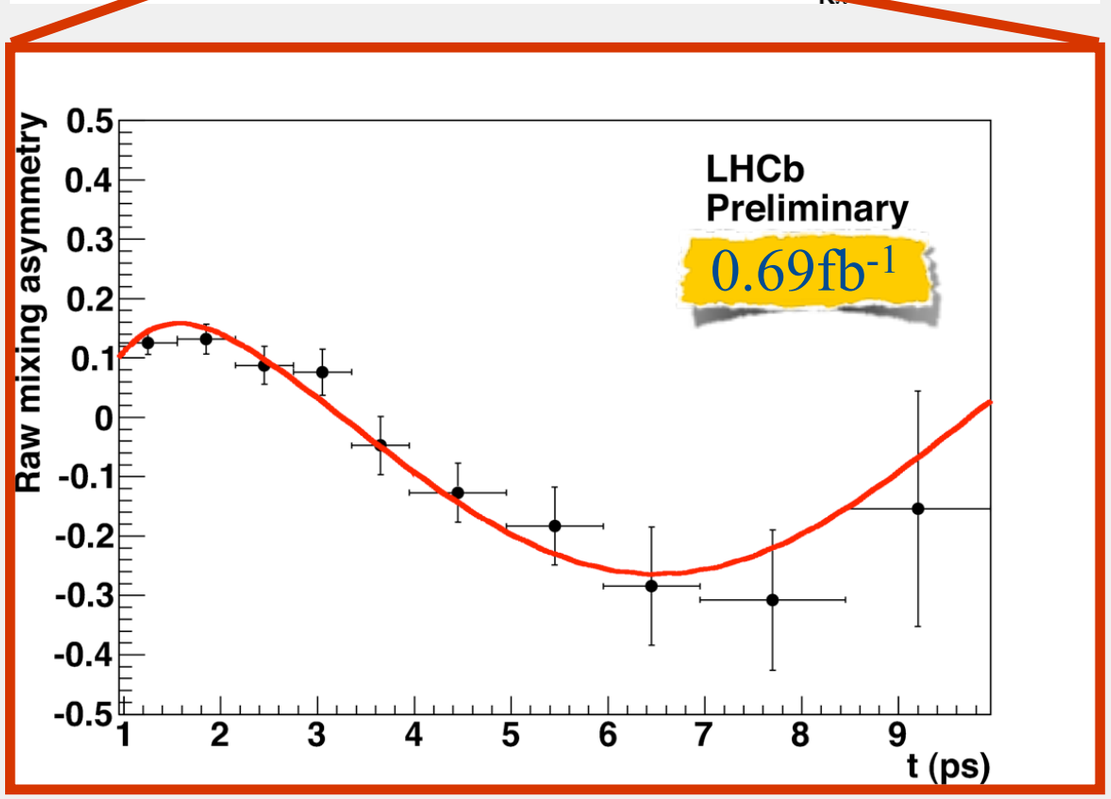
LHCb-CONF-2012-007

2D fit of invariant mass and decay time



Preliminary





EPJC 72 (2012) 2022 — Use of Opposite Side Taggers

input Δm_s from $B_s \to D_s\pi$ — PLB 709 (2012) 177

input $\Delta\Gamma_s$ from $B_s \to J/\Psi\Phi$ — PRL 108 (2012) 101803

$$\Delta m_d = 0.484 \pm 0.019\,\mathrm{ps}^{-1}$$
$$\tau_{B^0} = 1.509 \pm 0.011\,\mathrm{ps}$$

Agreement w/ WA

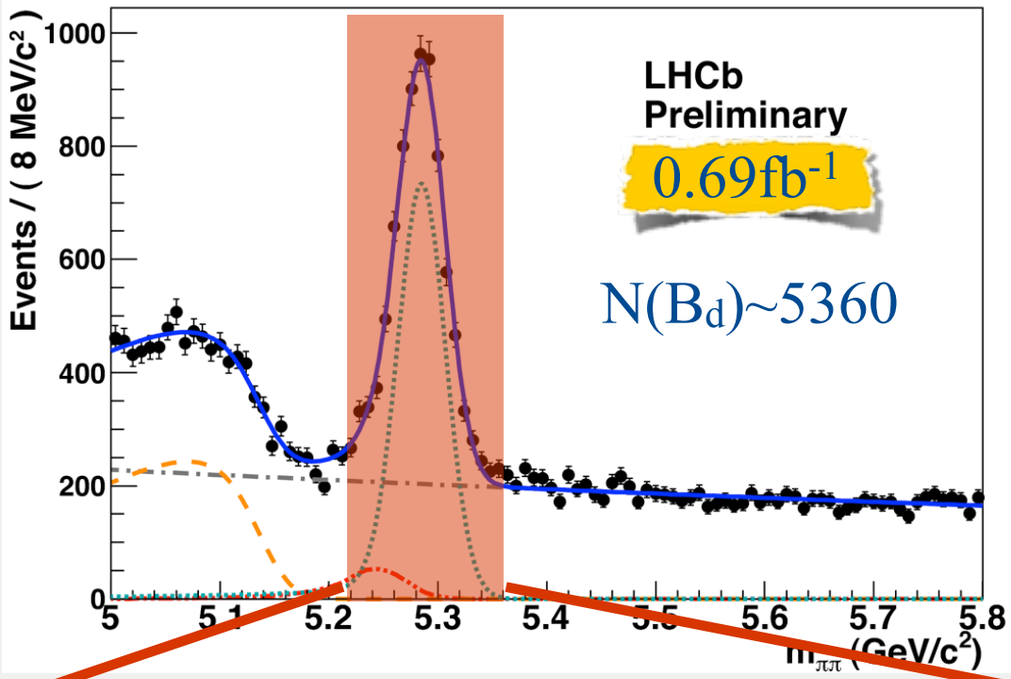
Input to $B_d \to \pi\pi$ and $B_s \to KK$ $\mathcal{A}_{\mathrm{Prod.}}(B^0) = -0.015 \pm 0.013$

$\mathcal{A}_{\mathrm{Prod.}}(B_s^0) = -0.03 \pm 0.06$

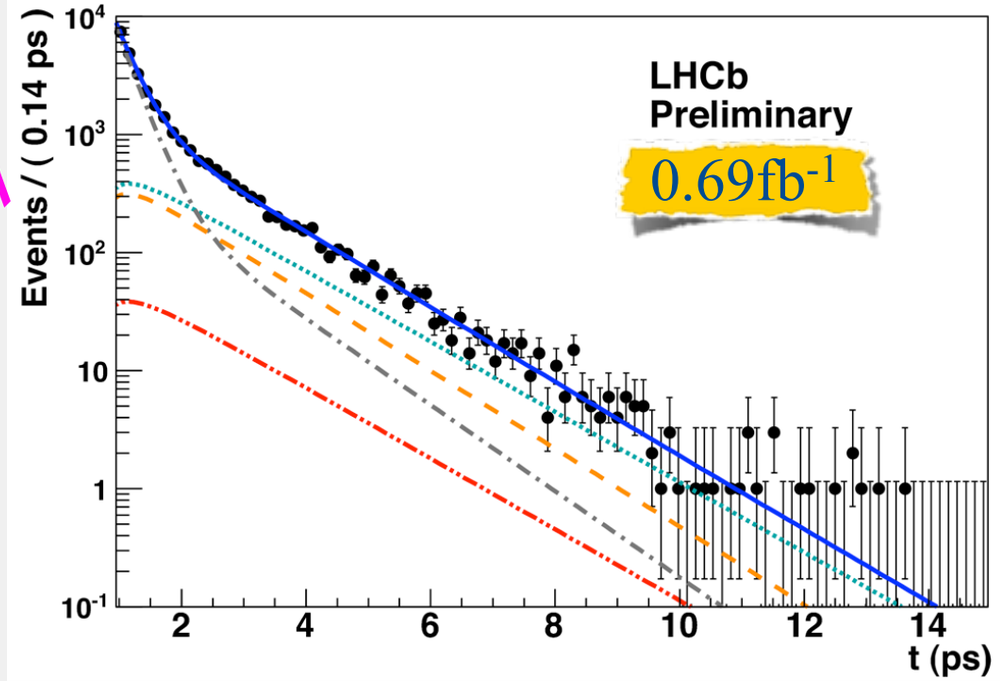
$$\varepsilon(1-2\omega)^2 = 2.3 \pm 0.1\%$$

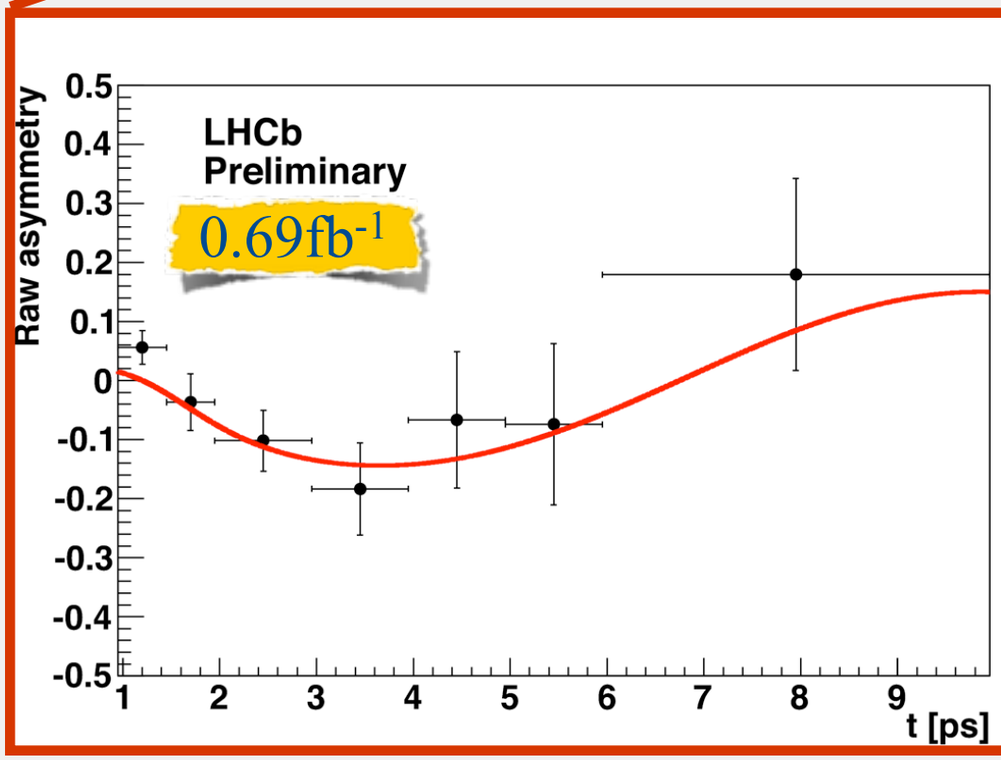
Result: $B_d \to \pi\pi$

LHCb-CONF-2012-007



Preliminary





LHCb-CONF-2011-010

B^0 mixing frequency from other LHCb analysis

$$\Delta m_d = 0.499 \pm 0.032\ (\text{stat.}) \pm 0.003\ (\text{syst.})\ \text{ps}^{-1}$$

Dominating systematic uncertainties:
input paremeters, signal model

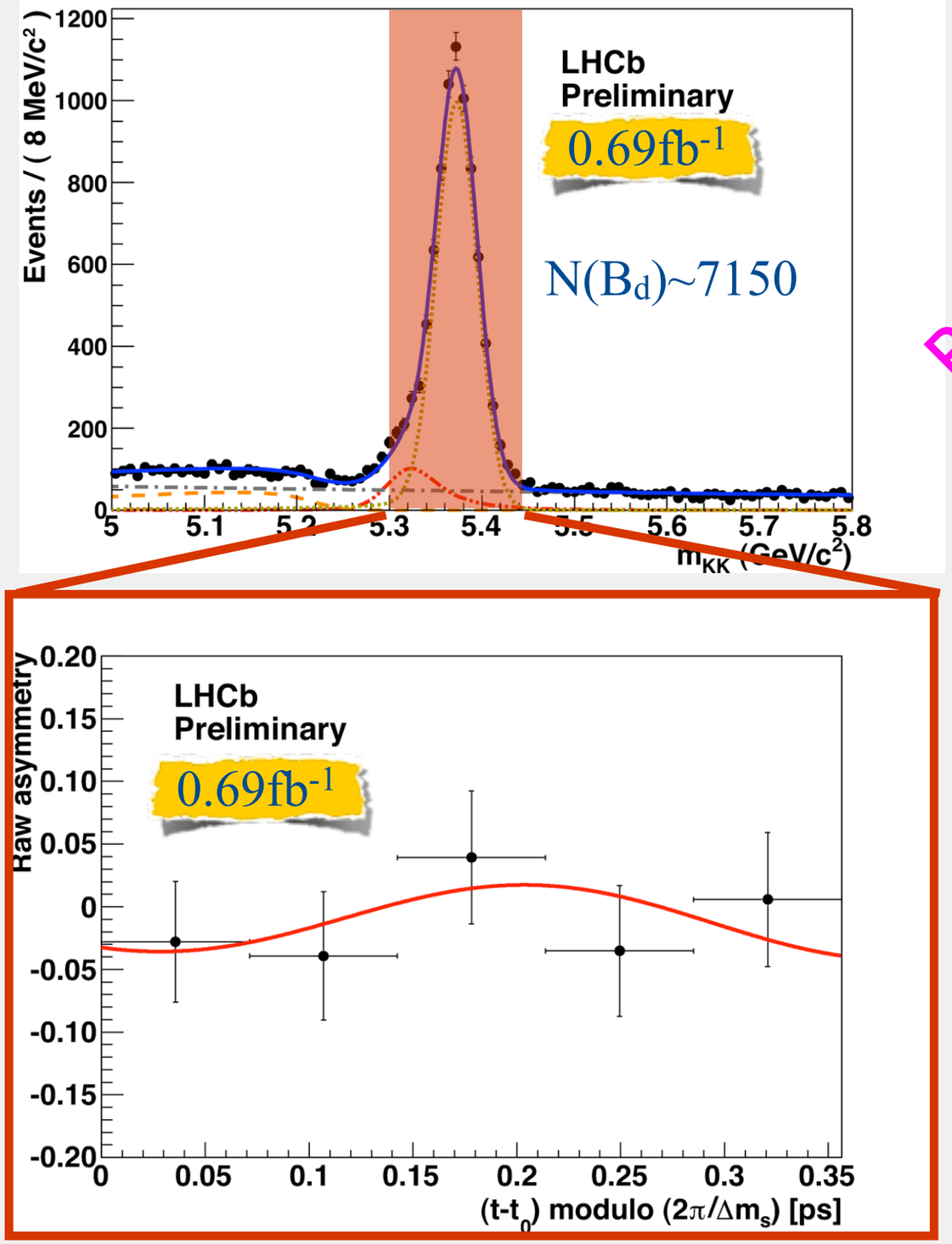
$$\mathcal{A}_{\text{dir.}} = 0.11 \pm 0.21\ (\text{stat.}) \pm 0.03\ (\text{syst.})$$

$$\mathcal{A}_{\text{mix.}} = -0.56 \pm 0.17\ (\text{stat.}) \pm 0.03\ (\text{syst.})$$

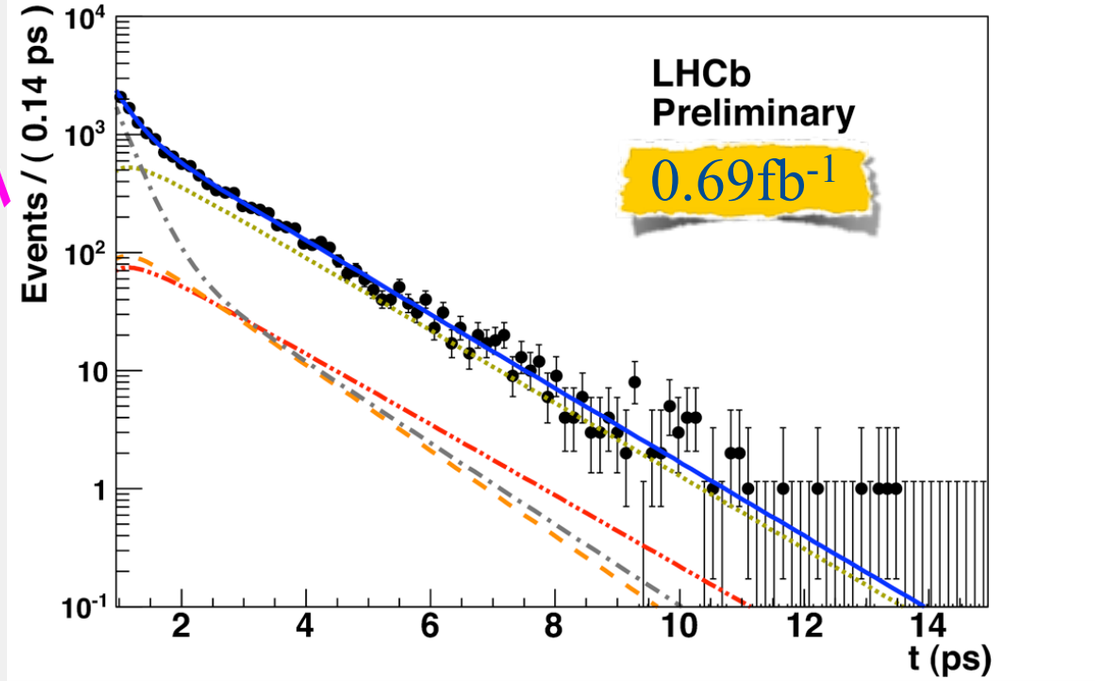
$$\text{corr.} = -0.34\ (\text{stat. only})$$

Result: $B_s \to KK$

LHCb-CONF-2012-007



Preliminary



input Δm_s from $B_s \to D_s \pi$ — PLB 709 (2012) 177
input $\Delta \Gamma_s$ from $B_s \to J/\Psi \Phi$ — PRL 108 (2012) 101803

Dominating systematic uncertainties:
input parameters, signal model

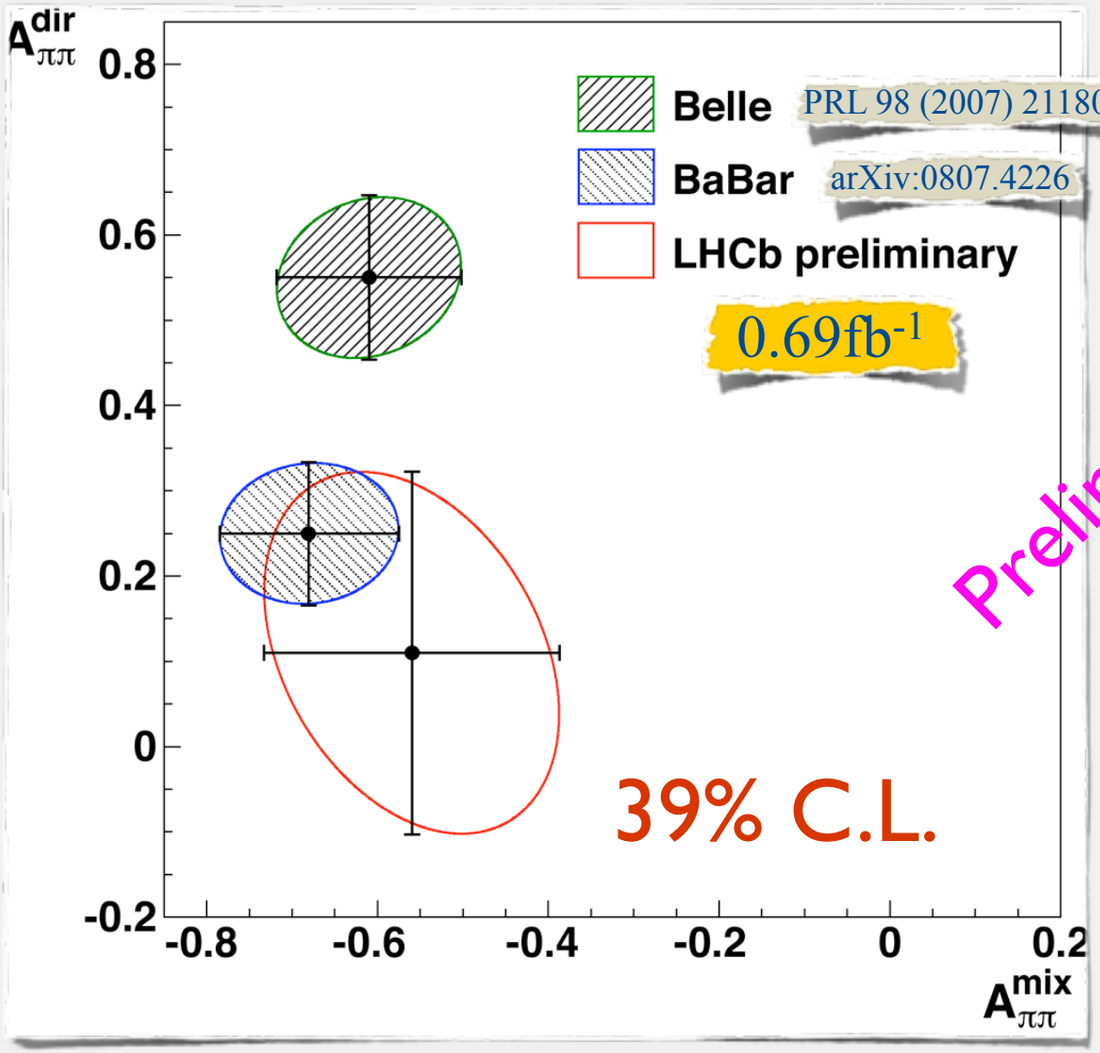
$$\mathcal{A}_{\text{dir.}} = 0.02 \pm 0.18\ (\text{stat.}) \pm 0.04\ (\text{syst.})$$

$$\mathcal{A}_{\text{mix.}} = 0.17 \pm 0.18\ (\text{stat.}) \pm 0.05\ (\text{syst.})$$

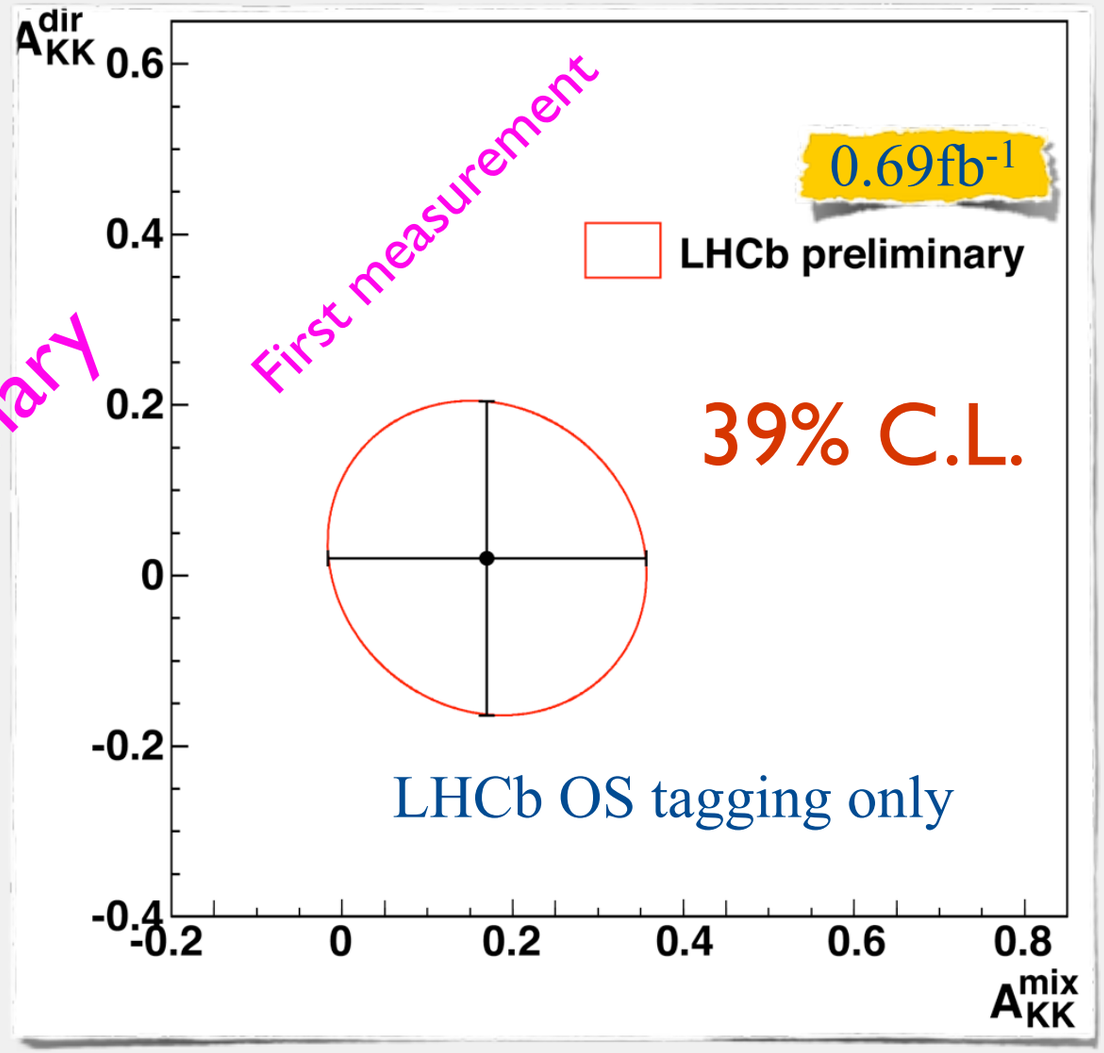
$$\text{corr.} = -0.10\ (\text{stat. only})$$

Summary of TD CPV results

LHCb-CONF-2012-007



Preliminary

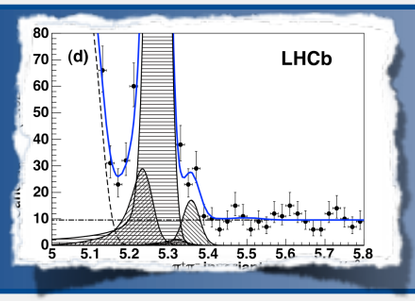


Improvements expected:

3fb^{-1} on tape

Same Side Tagging LHCb-CONF-2012-033

Conclusion and prospects

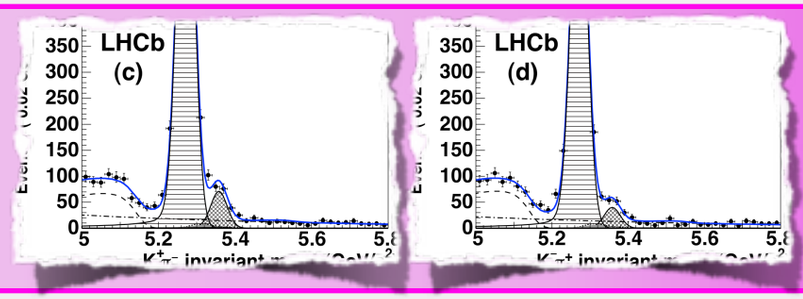


Branching fraction measurements
First observation of $B_s \to \pi\pi$

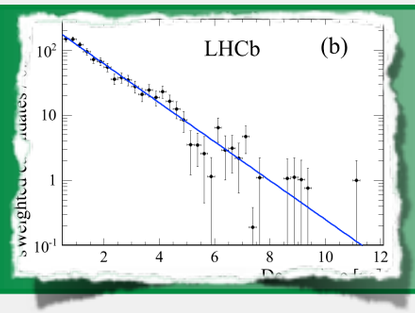
✔SM

Observation of Direct CPV in B_s system ($B_s \to K\pi$)

✔SM



NEW

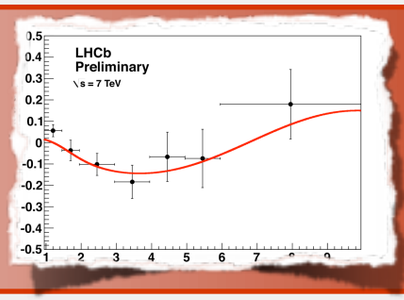


Effective lifetime measurement in $B_s \to KK$

✔SM

Tagged time dependent measurements in the $B_d \to \pi\pi$ and $B_s \to KK$

✔SM

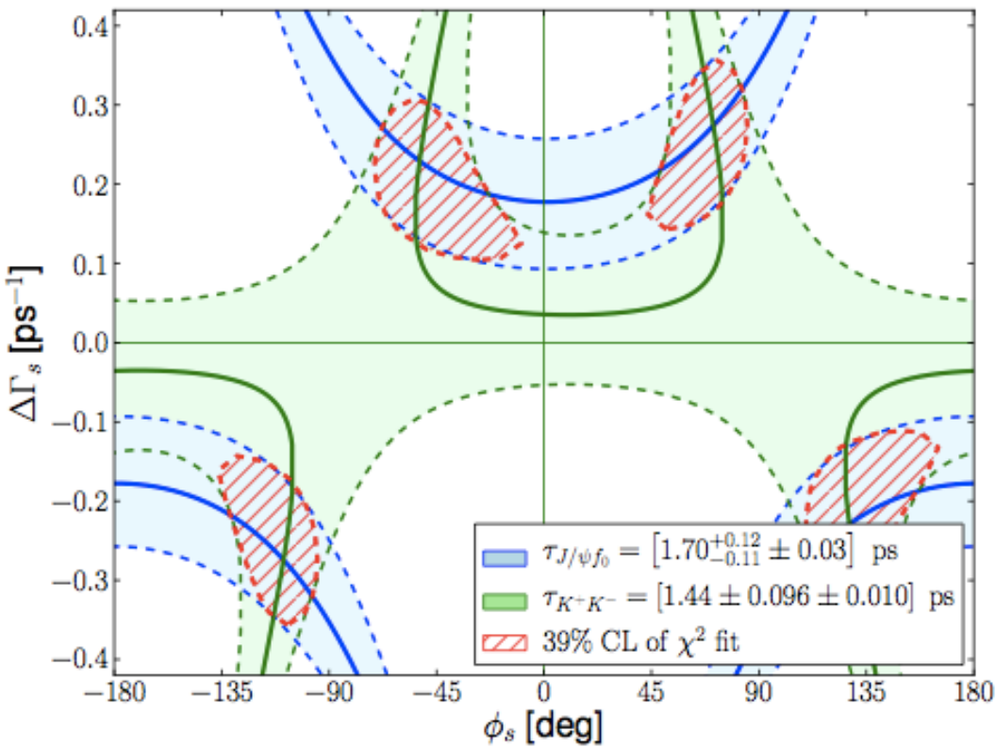


Improvements expected: $3fb^{-1}$ on tape, Same Side Tagging, Upgrade

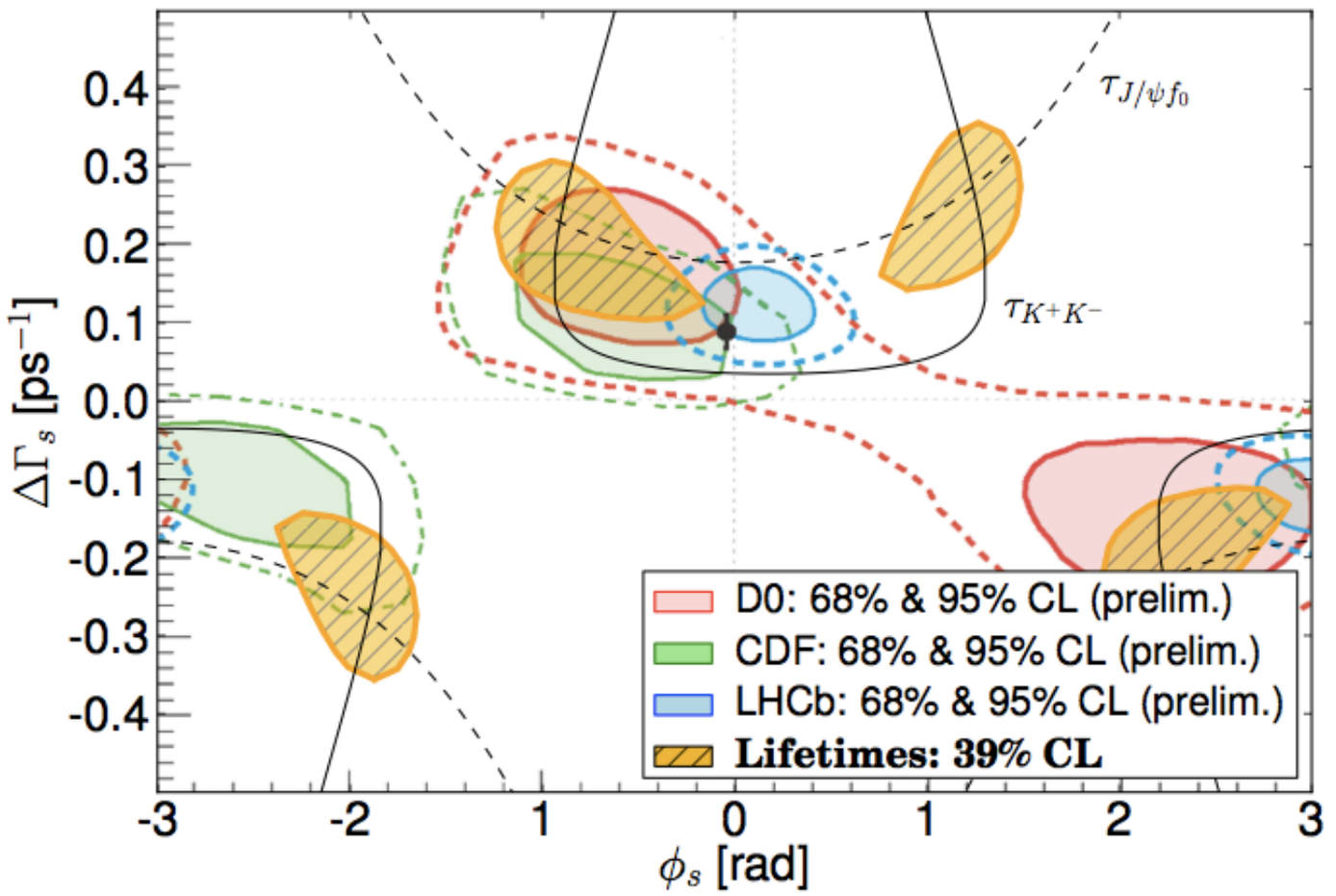
LHCb Charmless B decays results: http://lhcbproject.web.cern.ch/lhcbproject/CDS/cgi-bin/bnoc.php

Backup

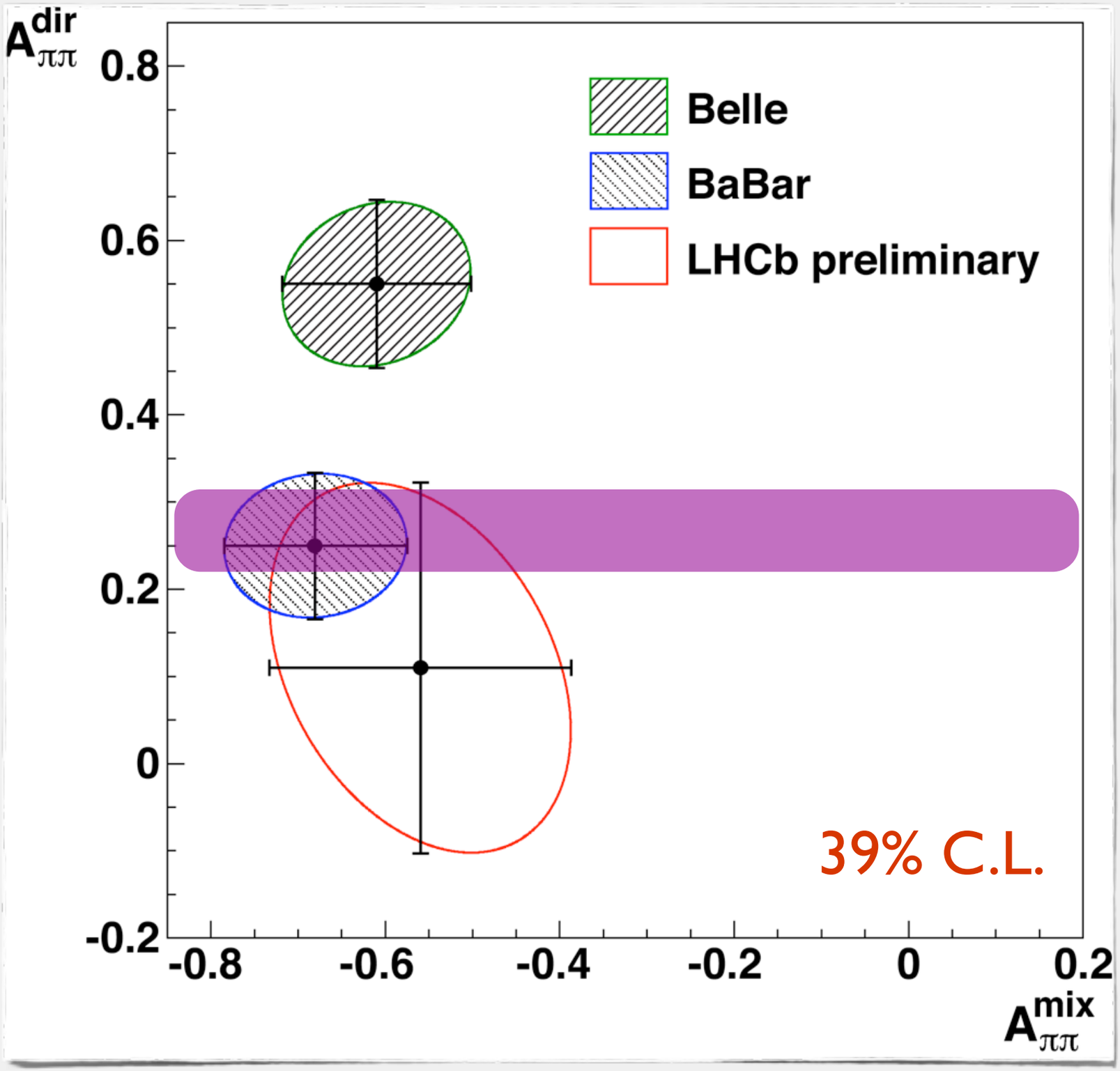
Impact of effective lifetime



Fleisher, Knegjens



B_s CPV and SM



Assuming SU(3)

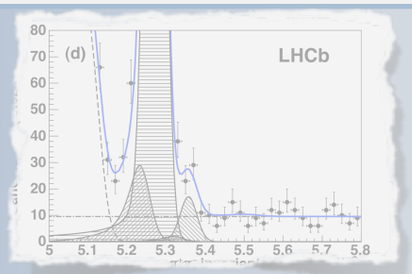
B_s CPV and SM (2)

$$\Delta = \frac{A_{CP}(B^0 \to K\pi)}{A_{CP}(B_s^0 \to K\pi)} + \frac{\mathcal{B}(B_s^0 \to K\pi)}{\mathcal{B}(B^0 \to K\pi)} \frac{\tau_d}{\tau_s} = 0,$$

$$\Delta = -0.02 \pm 0.05(stat.) \pm 0.04(syst.)$$

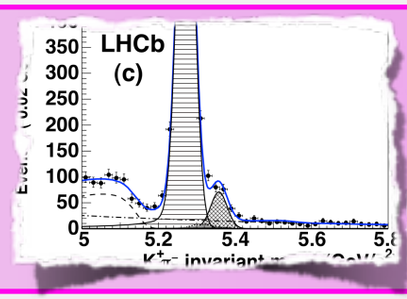
Previous TI CPV measurement

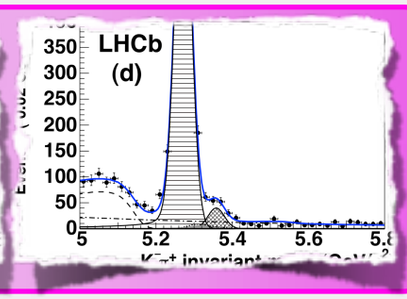
Overview of B→hh measurements

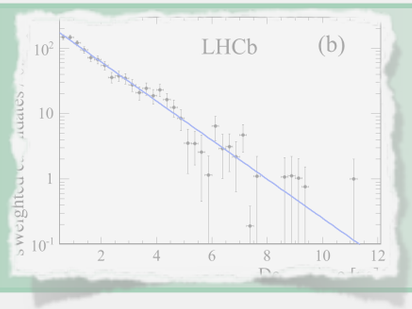


Branching fraction measurements

Time integrated CPV

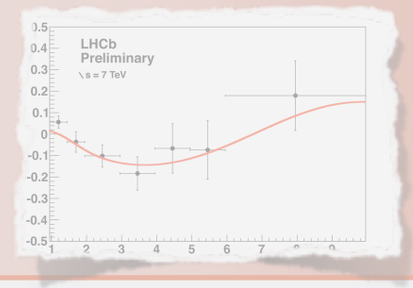






Effective lifetime measurement

Time dependent CPV



LHCb Charmless B decays results: http://lhcbproject.web.cern.ch/lhcbproject/CDS/cgi-bin/bnoc.php

Detection asymmetry

PRL 108 201061

$$\mathcal{A}_{CP} = \mathcal{A}_{Raw} - (\mathcal{A}_{Det.} + \kappa \mathcal{A}_{Prod.})$$

Determined from large D decay samples

$$\mathcal{A}_{Det.} = \mathcal{A}_{Int.} + \alpha \mathcal{A}_{Rec.}$$

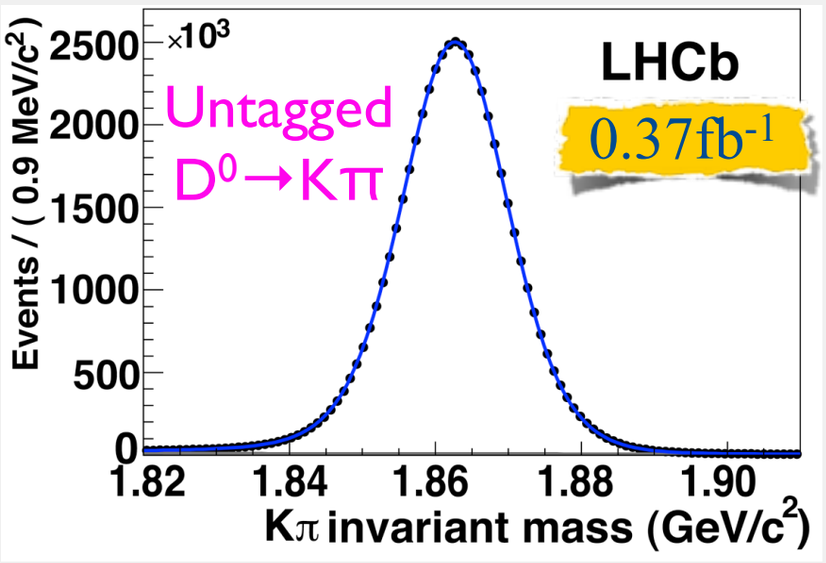
Strong interaction cross-sections

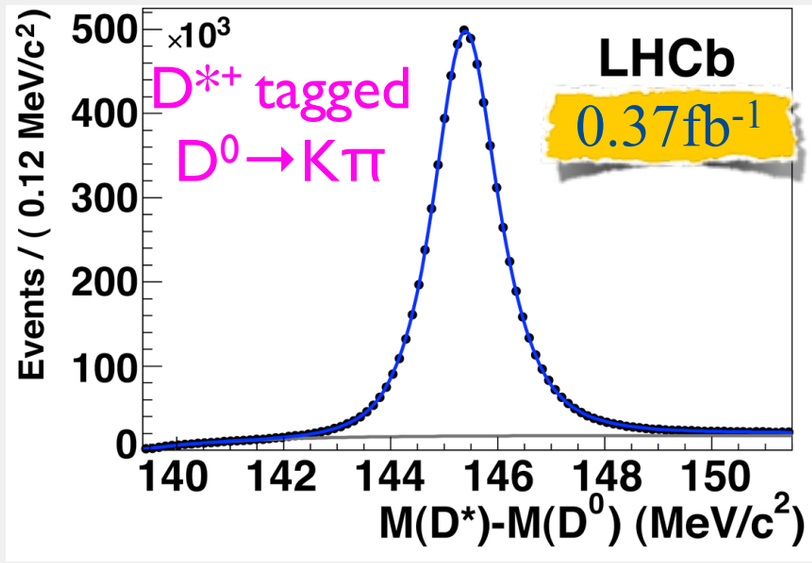
$$\mathcal{A}_{Int.} = -1.0 \pm 0.2\%$$

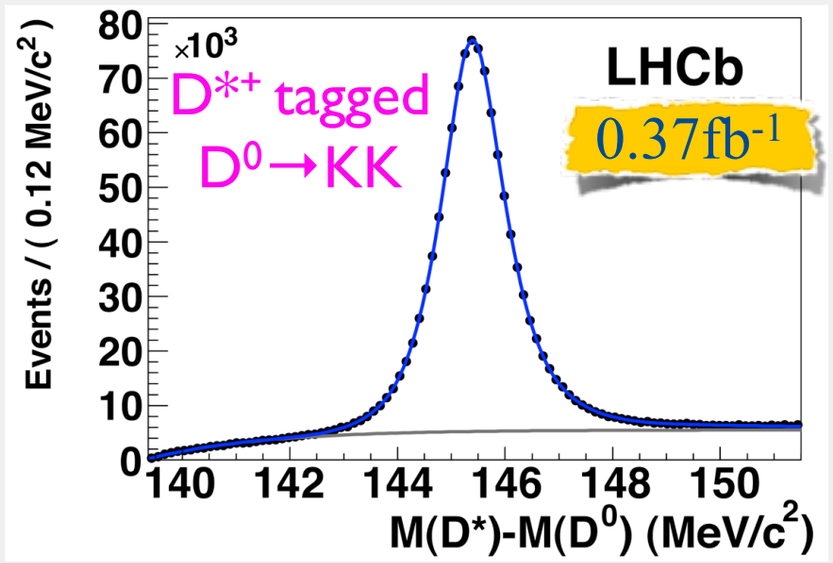
Reconstruction asymmetry

$$\mathcal{A}_{Rec.} = -0.18 \pm 0.02\%$$

Suppressed by magnetic field flip:
$\alpha = 0.20 \pm 0.1$







Production asymmetry

PRL 108 201061

$$\mathcal{A}_{CP} = \mathcal{A}_{Raw} - (\mathcal{A}_{Det.} + \kappa \mathcal{A}_{Prod.})$$

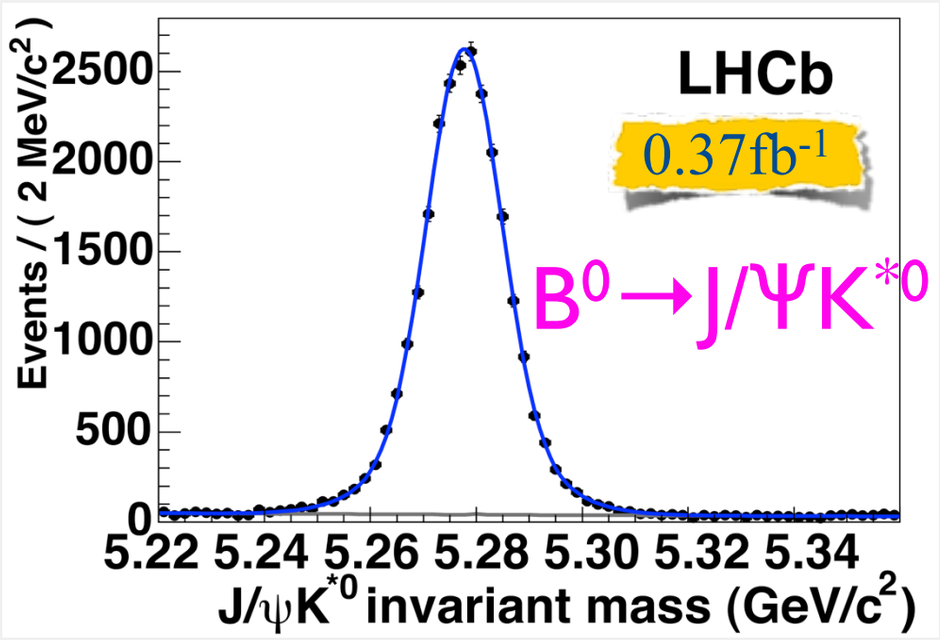
Dilution from:
- mixing
- proper time acceptance

$$\kappa_{B^0} = 0.303 \pm 0.005$$
$$\kappa_{B^0_s} = -0.033 \pm 0.003$$

Determined with $B^0 \to J/\Psi K^{*0}$ decays:
CPV at the level of 10^{-3}

$$\mathcal{A}_{Prod.} = 1.0 \pm 1.3\%$$

(Corrected for detection asymmety)



In summary: corrections are small

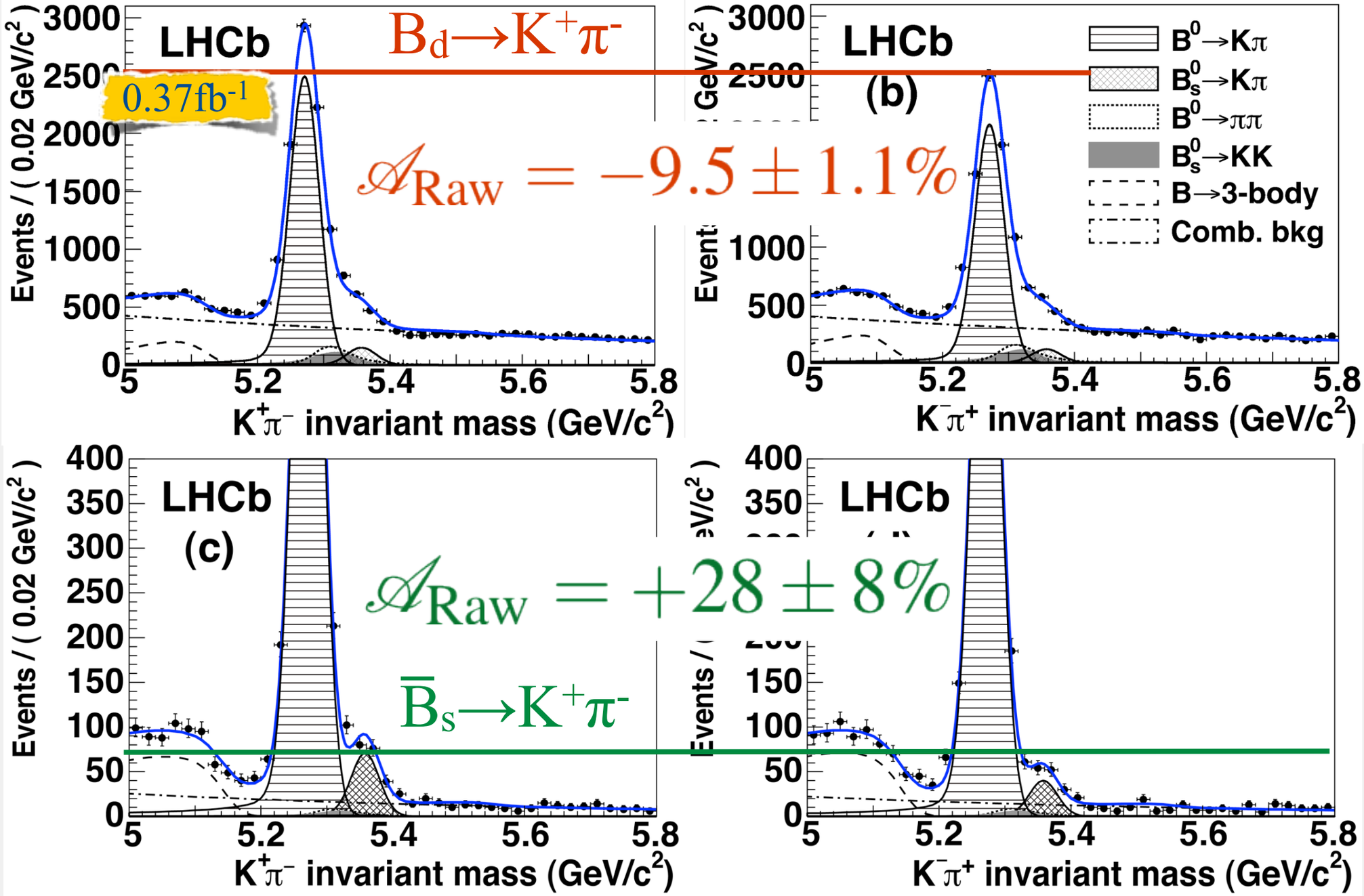
$$\mathcal{A}_{Det.} + \kappa \mathcal{A}_{Prod.} = -0.7 \pm 0.6\% (B^0)$$

$$\mathcal{A}_{Det.} + \kappa \mathcal{A}_{Prod.} = 1.0 \pm 0.2\% (B^0_s)$$

Raw asymmetry

PRL 108 201061

$$\mathcal{A}_{CP} = \mathcal{A}_{Raw} - (\mathcal{A}_{Det.} + \kappa \mathcal{A}_{Prod.})$$



Final result

PRL 108 201061

$$\mathcal{A}_{CP}(B_s^0 \to K\pi) = \frac{\Gamma(\bar{B}_s^0 \to K^+\pi^-) - \Gamma(B_s^0 \to K^-\pi^+)}{\Gamma(\bar{B}_s^0 \to K^+\pi^-) + \Gamma(B_s^0 \to K^-\pi^+)}$$

First >3σ evidence

0.37fb^{-1}

$$= 0.27 \pm 0.08\,(\text{stat.}) \pm 0.02\,(\text{syst.})$$

CDF result $= 0.39 \pm 0.15 \pm 0.08$ arXiv1103.5762

Dominant systematic uncertainties:

B_s case: B invariant mass fit model

B_d case: production and detector asymmetries

$$\mathcal{A}_{CP}(B^0 \to K\pi) = \frac{\Gamma(\bar{B}^0 \to K^-\pi^+) - \Gamma(B^0 \to K^+\pi^-)}{\Gamma(\bar{B}^0 \to K^-\pi^+) + \Gamma(B^0 \to K^+\pi^-)}$$

>6σ observation

0.37fb^{-1}

$$= -0.088 \pm 0.011\,(\text{stat.}) \pm 0.008\,(\text{syst.})$$

HFAG average $= -0.098^{+0.012}_{-0.011}$ HFAG