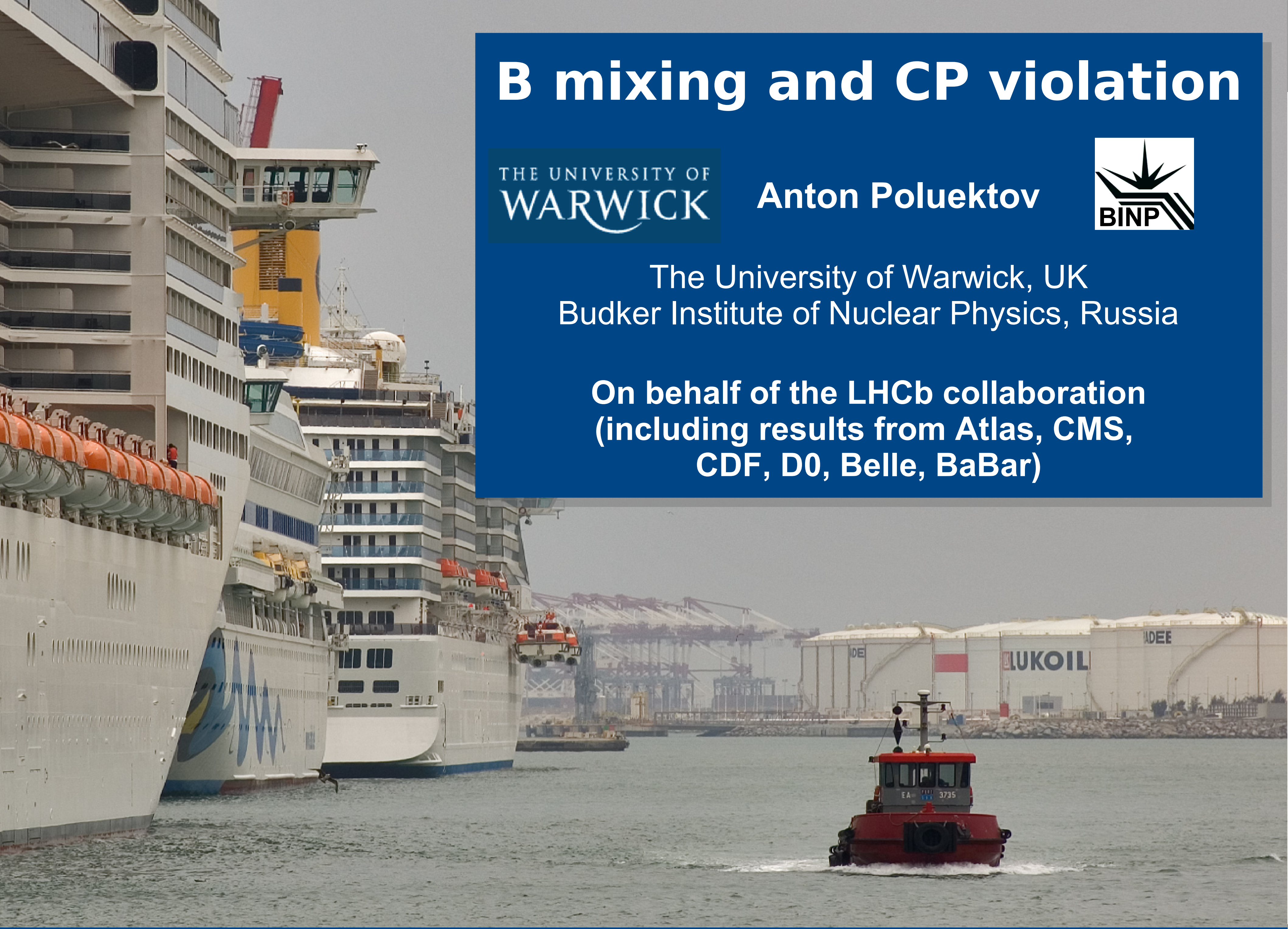


B mixing and CP violation

Anton Poluektov

The University of Warwick, UK
Budker Institute of Nuclear Physics, Russia

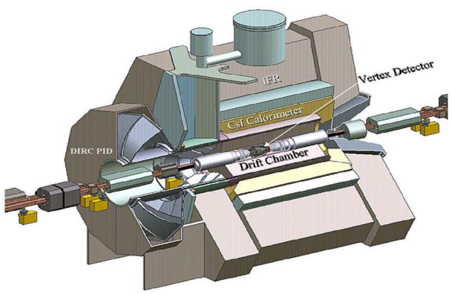
On behalf of the LHCb collaboration (including results from Atlas, CMS, CDF, D0, Belle, BaBar)

Overview of results

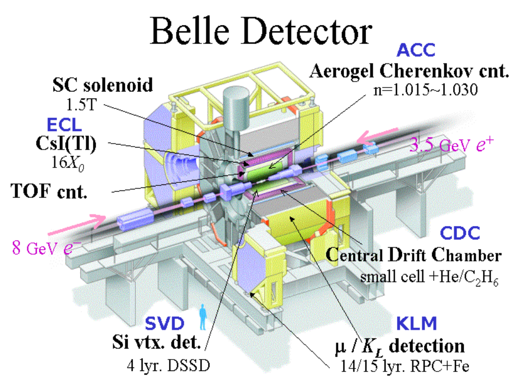
- B meson mixing parameters and CP violation in mixing
  - B^0, B_s oscillation frequency Δm
  - Semileptonic asymmetry
- Direct CP violation in B decays
  - Charmed B decays, measurement of γ
  - Charmless B decays
- Mixing-induced indirect CP violation in B^0 and B_s
  - $\sin 2\beta$ from $B^0 \to J/\psi K_S$
  - φ_s from $B_s \to J/\psi\varphi$
  - $B_s \to \varphi\varphi$

B physics at e^+e^- and proton machines

Electron-positron colliders (B factories)



BaBar (PEP-II, SLAC)



Belle (KEKB, KEK)

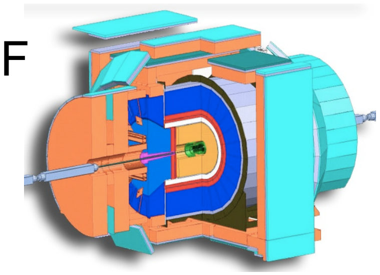
Production of $b\bar{b}$ pairs at threshold

- Clean environment
- Efficient reconstruction of neutral modes
- Efficient flavour tagging

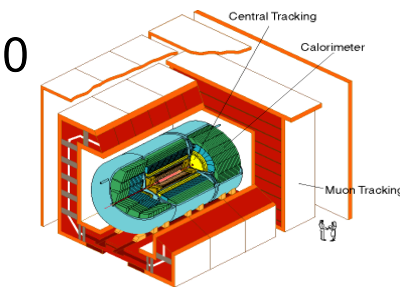
- Low production cross-section (especially B_s)
- Small boost (artificially by asymmetric energies), low time resolution

Hadron colliders (Tevatron, LHC)

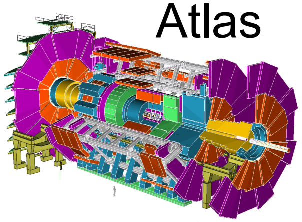
CDF

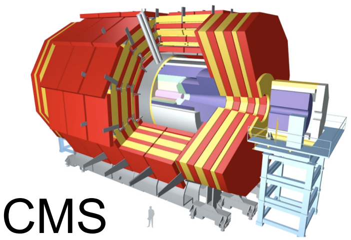


D0

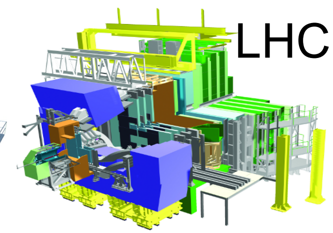


Atlas





CMS



LHCb

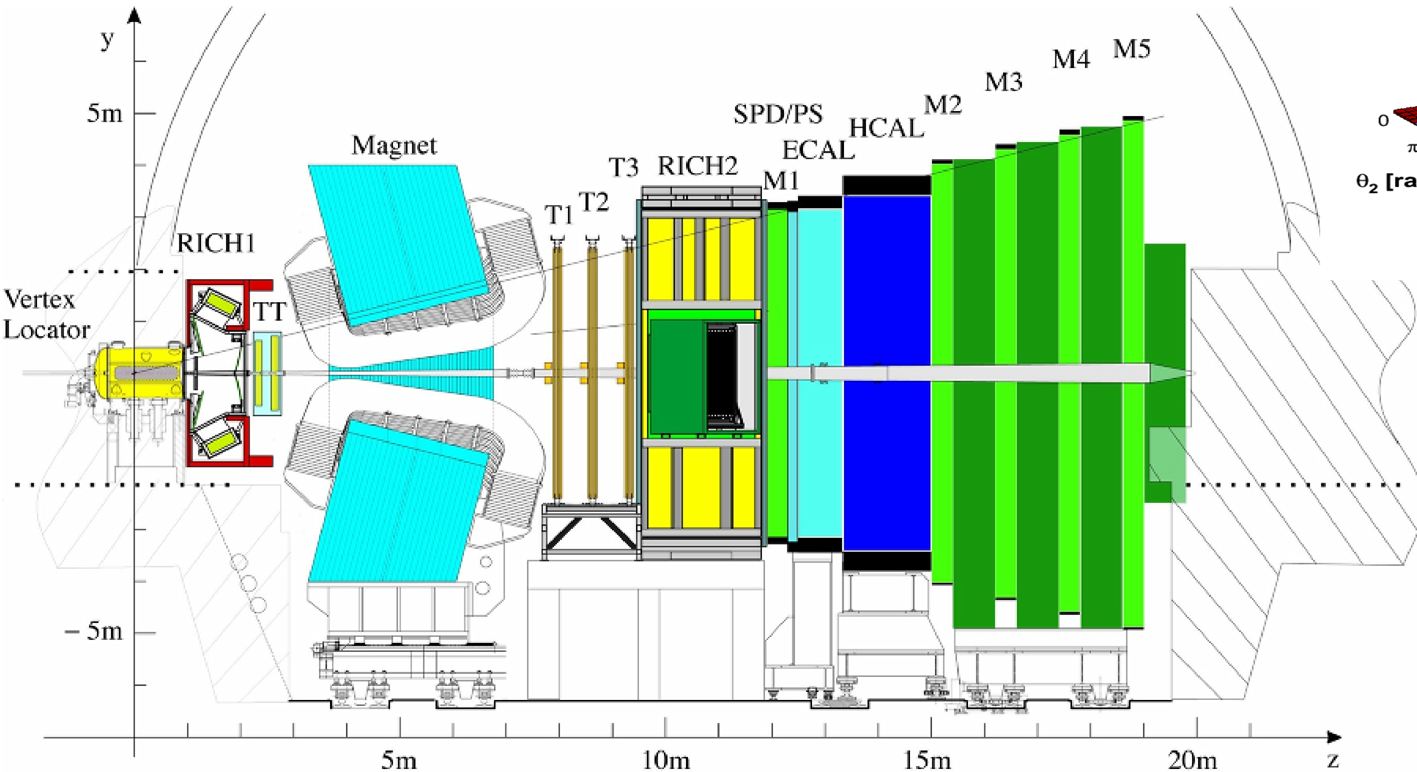
Production of $b\bar{b}$ pairs in proton collisions

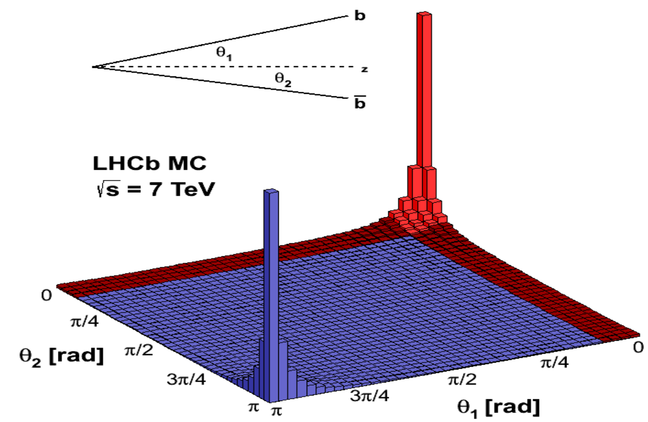
- Forward production, large boost
- All sorts of b hadrons produced (B^0, B^+, B_s, B_c, Λ_b, B^*, ...)
- Large production cross-section

- Busy events, hard to reconstruct neutral modes.
- Lower flavour tagging power

LHCb

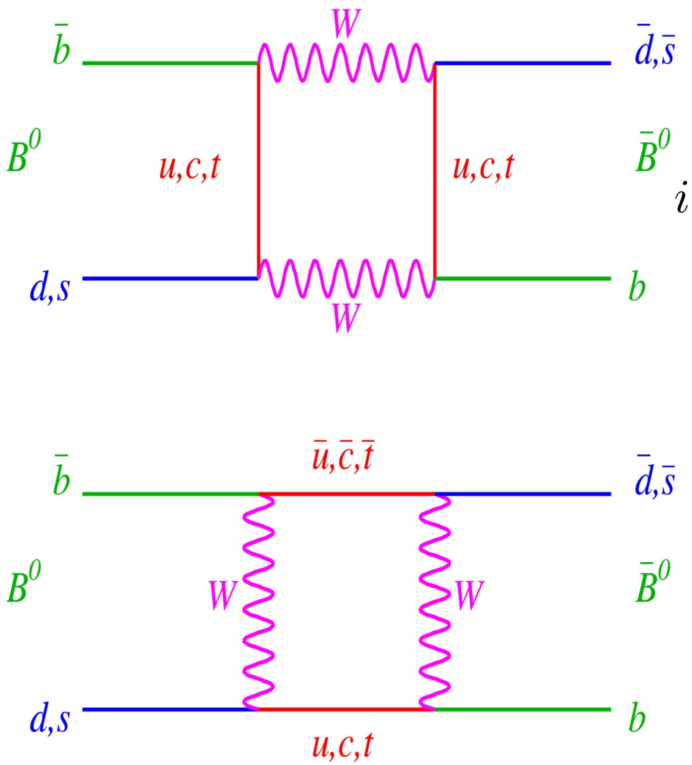
One-arm spectrometer optimised for studies of B and D decays. Forward geometry: $2<\eta<5$





- Good vertexing - Measure B_d and B_s oscillations, reject prompt background
- Particle identification - Flavour tagging, misID background
- Calorimetry - Reconstruction of neutral particles (γ, π^0)
- Efficient trigger, including hadronic modes

B mixing and CP violation in mixing



Neutral B mesons (B^0, B_s) oscillate:

$$i\frac{\partial}{\partial t}\begin{pmatrix} B^0(t) \\ \overline{B}^0(t) \end{pmatrix} = \left[\begin{pmatrix} M_{11} & M_{12} \\ M_{12}^* & M_{22} \end{pmatrix} - \frac{i}{2}\begin{pmatrix} \Gamma_{11} & \Gamma_{12} \\ \Gamma_{12}^* & \Gamma_{22} \end{pmatrix}\right]\begin{pmatrix} B^0(0) \\ \overline{B}^0(0) \end{pmatrix}$$

Mass eigenstates ≠ flavour eigenstates

Unlike K^0 system, width difference $\Delta\Gamma$ is small.

$$|B_{L,H}\rangle = p|B^0\rangle \pm q|\overline{B}^0\rangle, \text{ where } \frac{q}{p} = \sqrt{\frac{M_{12}^* - \frac{i}{2}\Gamma_{12}^*}{M_{12} - \frac{i}{2}\Gamma_{12}}}$$

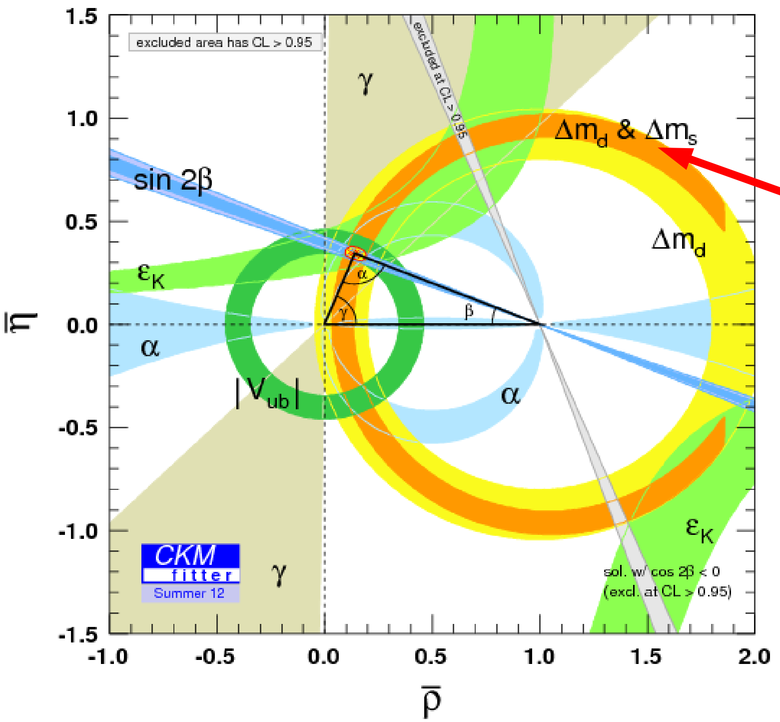
B^0: oscillation period ~ lifetime

$$\begin{aligned} \Gamma_d &\simeq 0.7\ \text{ps}^{-1} \\ \Delta m_d &\simeq 0.5\ \text{ps}^{-1} \\ \Delta\Gamma_d &\ll 0.1\ \text{ps}^{-1} \end{aligned}$$

B_s: oscillation period ≪ lifetime

$$\begin{aligned} \Gamma_s &\simeq 0.7\ \text{ps}^{-1} \\ \Delta m_s &\simeq 18\ \text{ps}^{-1} \\ \Delta\Gamma_s &\simeq 0.1\ \text{ps}^{-1} \end{aligned}$$

B mixing and CP violation in mixing



Measurements of B mixing parameters and CP violation provide important inputs:

- $\Delta m_d/\Delta m_s$ constrains the apex of the Unitarity Triangle
- $\Delta\Gamma$ is small and can be affected by NP.
- CP violation in mixing is also a good null-test of the SM. Can be accessed in the asymmetries of flavour-specific final states:

$$a_{sl}^{d(s)} \equiv \frac{\Gamma(\overline{B}^0_{(s)} \to \mu^+ D^-_{(s)}) - \Gamma(B^0_{(s)} \to \mu^- D^+_{(s)})}{\Gamma(\overline{B}^0_{(s)} \to \mu^+ D^-_{(s)}) + \Gamma(B^0_{(s)} \to \mu^- D^+_{(s)})} = \frac{1-|q/p|^2}{1+|q/p|^2}$$

Theory prediction:

$$a_{sl}^s = (2.0 \pm 0.6) \times 10^{-5}$$
$$a_{sl}^d = (-4.8 \pm 1.1) \times 10^{-4}$$

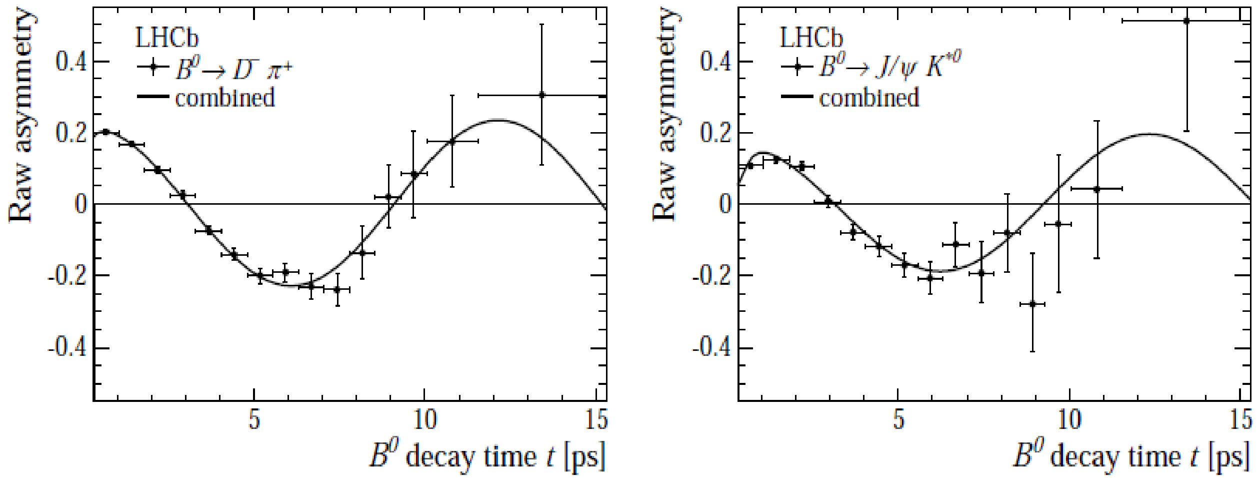
A. Lenz and U. Nierste JHEP 06 (2007) 072

B^0, B_s oscillation frequency (Δm_d, Δm_s)

1 fb^{-1} sample, 2011

- Flavor-tagged $B^0 \to D^- \pi^+$ and $B^0 \to J/\psi K^{*0}$
  Measure time-dependent mixed/unmixed asymmetry

LHCb, PLB 719 (2013) 318

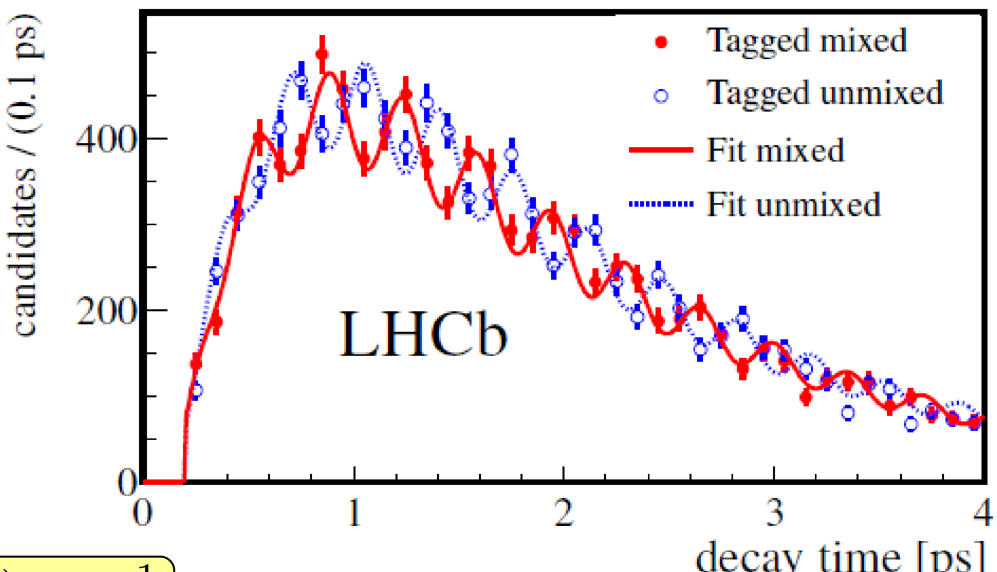


$$\Delta m_d = 0.5156 \pm 0.0051(\text{stat}) \pm 0.0033(\text{syst})\ \text{ps}^{-1}$$

HFAG(2012): $0.507 \pm 0.004\ \text{ps}^{-1}$

- $B_s \to D_s^- \pi^+$
  combine $D_s^- \to \varphi\pi$, K^*K, $KK\pi$, $K\pi\pi$, $\pi\pi\pi$ modes

LHCb, arXiv:1304.4741



World-best measurement

$$\Delta m_s = 17.768 \pm 0.023(\text{stat}) \pm 0.006(\text{syst})\ \text{ps}^{-1}$$

Semileptonic asymmetry

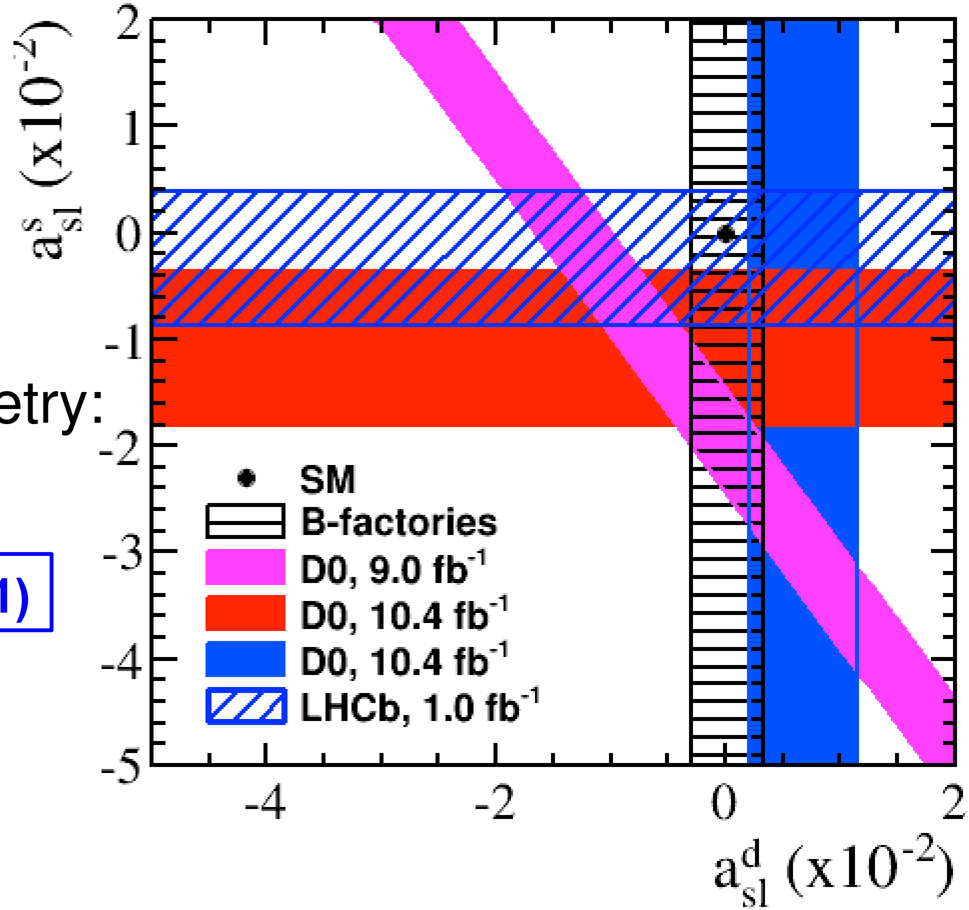
- D0: measure like-sign dimuon asymmetry

$$A^b_{sl} \equiv \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}} \simeq 0.6a^d_{sl} + 0.4a^s_{sl}$$

evidence (3.9σ) of anomalous asymmetry:

$$A^b_{sl} = (-0.787 \pm 0.172 \pm 0.093)\%$$

D0, PRD 84 052007 (2011)



- LHCb: difficult to measure A^b_{sl} due to asymmetric initial state. For B_s, fast oscillations cancel the production asymmetry

$$A_{\rm raw} \equiv \frac{N(D_s^- \mu^+) - N(D_s^+ \mu^-)}{N(D_s^- \mu^+) + N(D_s^+ \mu^-)} = \frac{a^s_{\rm sl}}{2} + \left[a_p - \frac{a^s_{\rm sl}}{2}\right] \frac{\int e^{-\Gamma_s t} \cos(\Delta M_s t)\epsilon(t)dt}{\int e^{-\Gamma_s t} \cosh(\Delta \Gamma_s t/2)\epsilon(t)dt}$$

$$a^s_{sl} = (-0.24 \pm 0.54(\mathrm{stat}) \pm 0.33(\mathrm{syst}))\%$$

LHCb-CONF-2012-022

This and other measurements are well consistent with SM

Direct CP violation

- Asymmetry in decay amplitudes

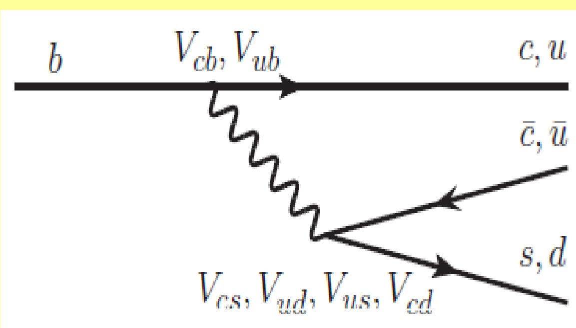
$$\Gamma_f = |\mathcal{M}(B \to f)|^2, \qquad \Gamma_{\overline{f}} = |\mathcal{M}(\overline{B} \to \overline{f})|^2 \qquad A = \frac{\Gamma_f - \Gamma_{\overline{f}}}{\Gamma_f + \Gamma_{\overline{f}}}$$

  The only possibility for charged B mesons

- Interference between two different diagrams is needed for CP violation

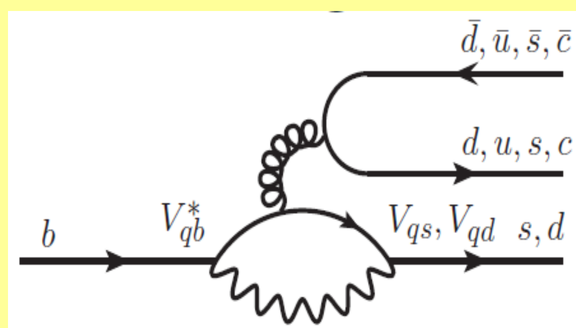
- Two possible types of transitions:

Tree

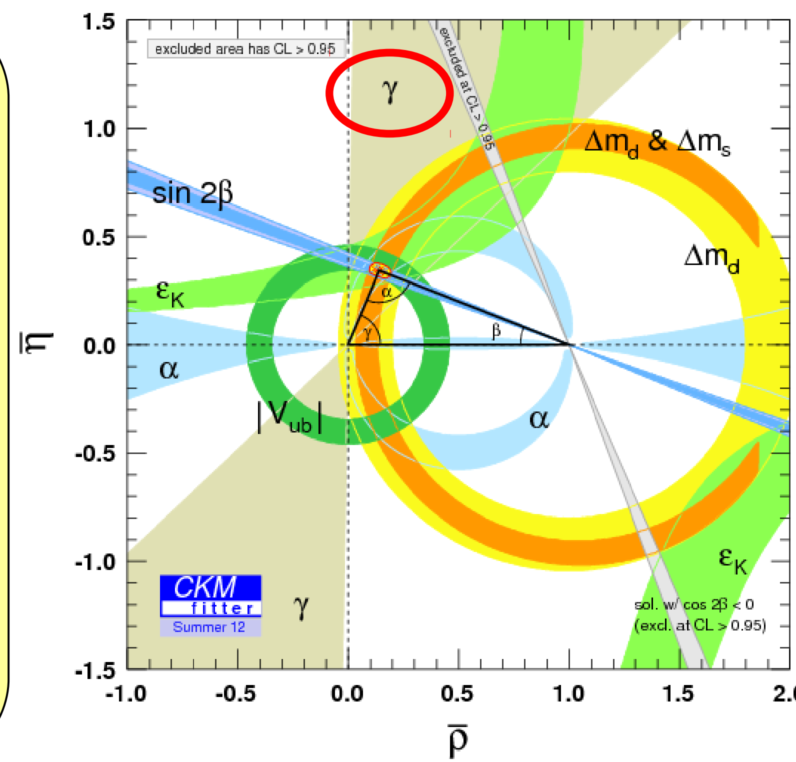


b→c transitions
Final states with open charm
Probe CKM angle γ
Not affected by NP

QCD penguin



Charmless final states
Potentially contain information on γ.
Can be affected by NP (loops!)



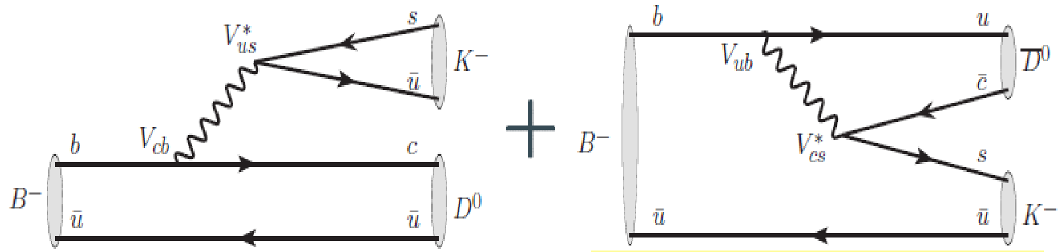
Measurement of γ: B→DK, D→hh

LHCb, PLB 713 (2012) 351

Access CKM phase γ through interference of $V_{cb}V^*_{us}$ and $V_{cs}V^*_{ub}$ amplitudes.

- GLW mode: D→KK, ππ
- ADS mode: fav. B→DK, sup. D→πK
  and sup. B→DK, fav. D→Kπ

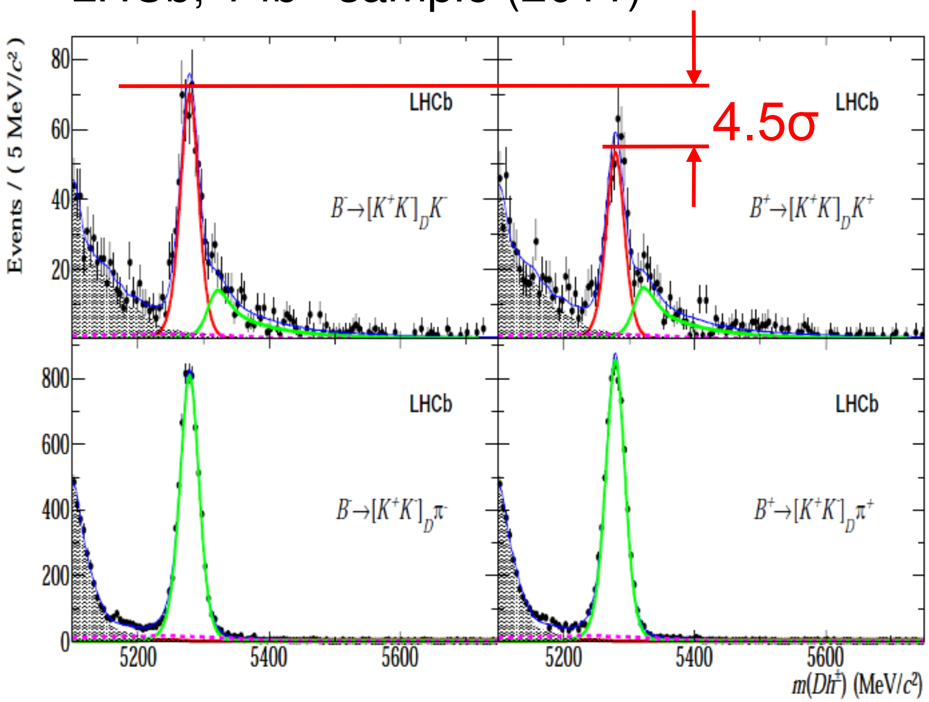
$B^- \to D^0 K^-$: + $B^- \to \overline{D}^0 K^-$:

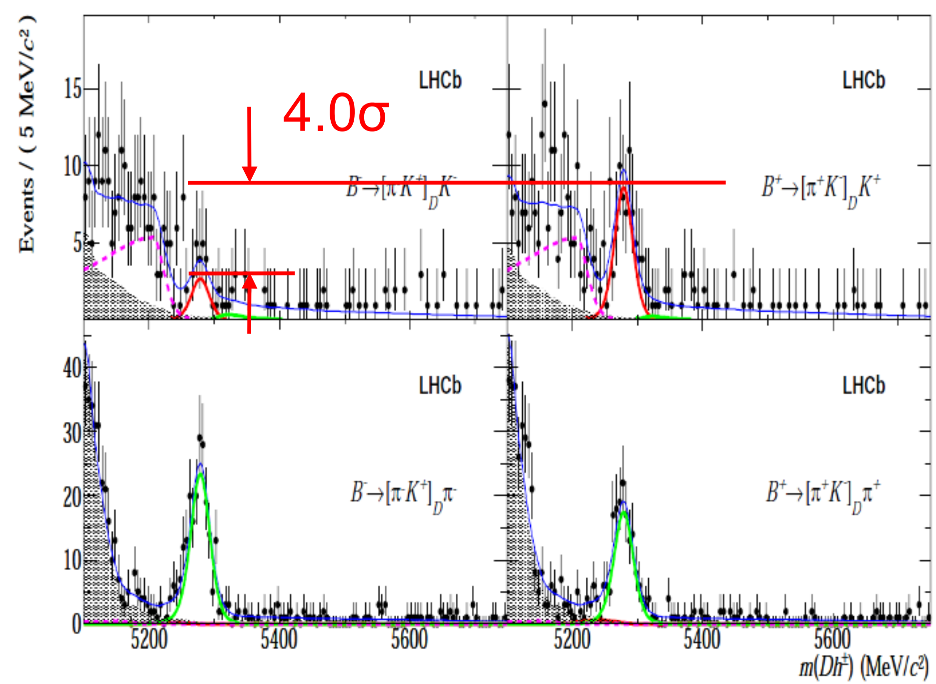


$A \sim V_{cb}V^*_{us} \sim A\lambda^3$

$A \sim V_{ub}V^*_{cs} \sim A\lambda^3(\rho - i\eta)$

LHCb, 1 fb⁻¹ sample (2011)



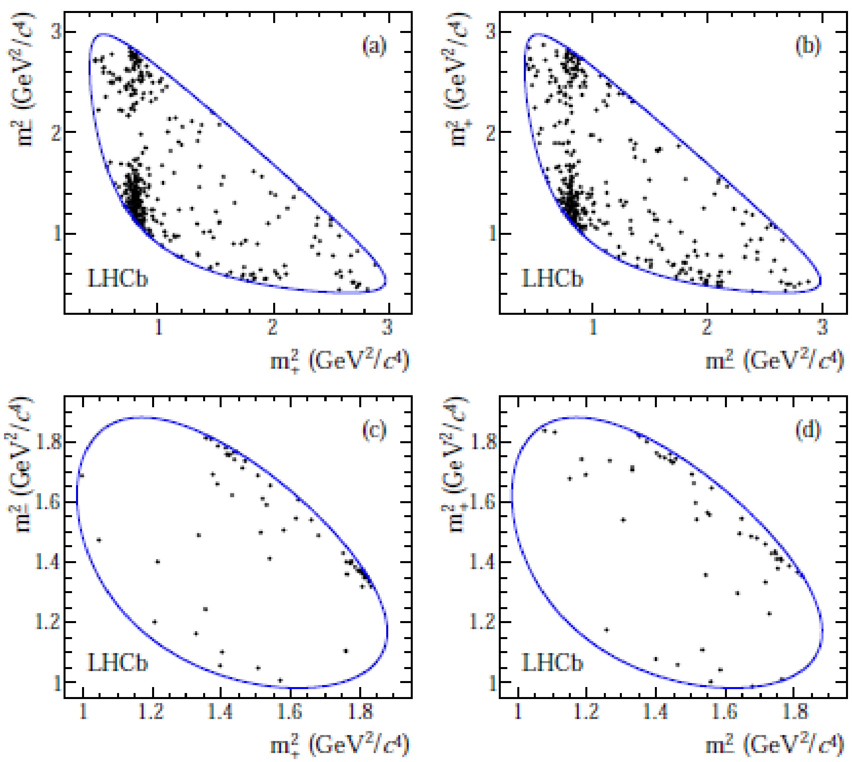


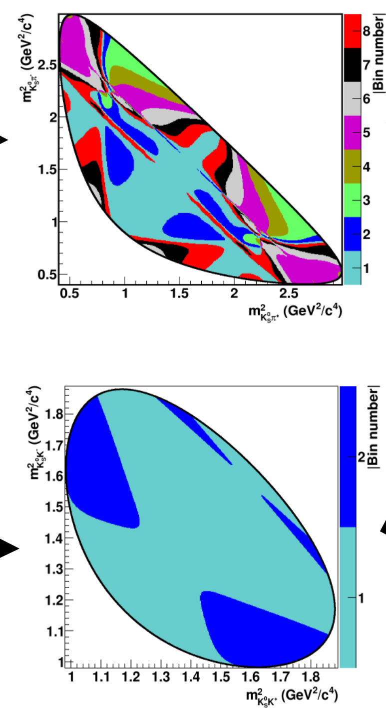
5.8σ observation of CP violation in the combination of B→D(hh)K modes

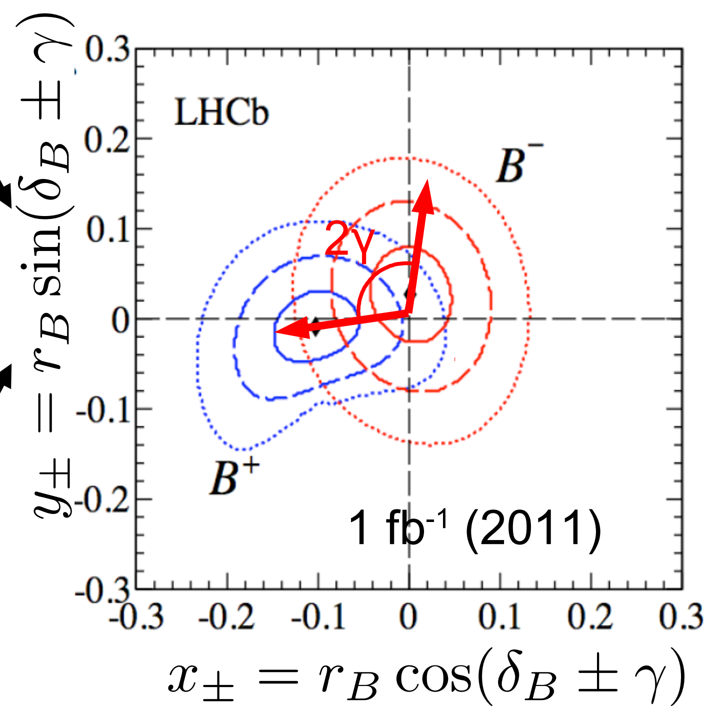
Measurement of γ: $B \to DK$, $D \to K_S h^+ h^-$

- Measure differences in Dalitz distributions of $D \to K_S h^+ h^-$ ($h = \pi$ or K)
- Model-independent binned Dalitz analysis
  - Use threshold $D\bar{D}$ data (CLEO) to constrain hadronic parameters in bins of phase space. 10-20% precision loss, but no amplitude model uncertainty.

LHCb, PLB 718 (2012) 43



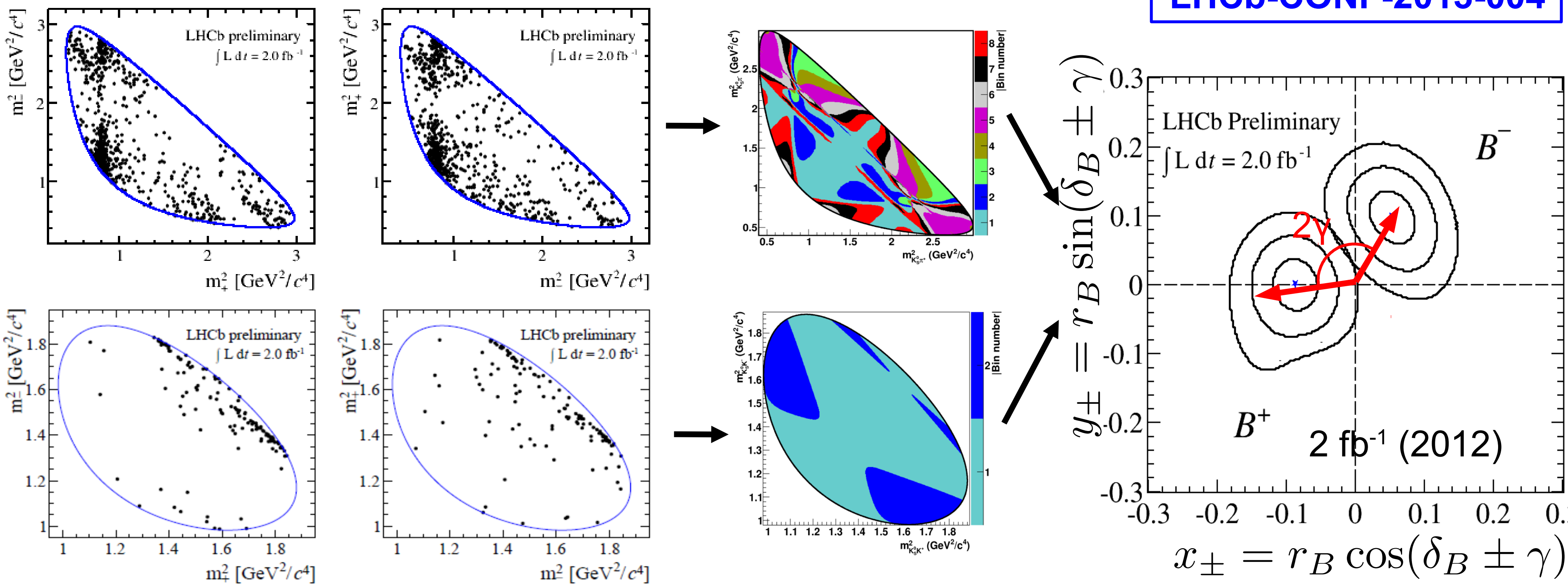




Measurement of γ: $B \to DK$, $D \to K_S h^+ h^-$

- Measure differences in Dalitz distributions of $D \to K_S h^+ h^-$ ($h = \pi$ or K)
- Model-independent binned Dalitz analysis
  - Use threshold $D\bar{D}$ data (CLEO) to constrain hadronic parameters in bins of phase space. 10-20% precision loss, but no amplitude model uncertainty.

LHCb-CONF-2013-004



Measurement of γ: combination

LHCb-CONF-2013-006

- B→DK modes share other common parameters in addition to γ ⇒ combination is more precise than simple average
- Latest LHCb combination:
  - B→DK, D→$K_S$hh, 2011 and 2012 data
  - B→DK, D→hh', 2011 data
  - B→DK, D→Kπππ

LHCb, arXiv:1303.4646

$$\gamma = (67.2^{+12.4}_{-11.5})^\circ$$

See talk by M. Schlupp at HF1 section for details

World-best measurement of γ.
Good agreement with combinations from BaBar

$$\gamma = (69^{+17}_{-16})^\circ$$

PRD 87, 052015 (2013)

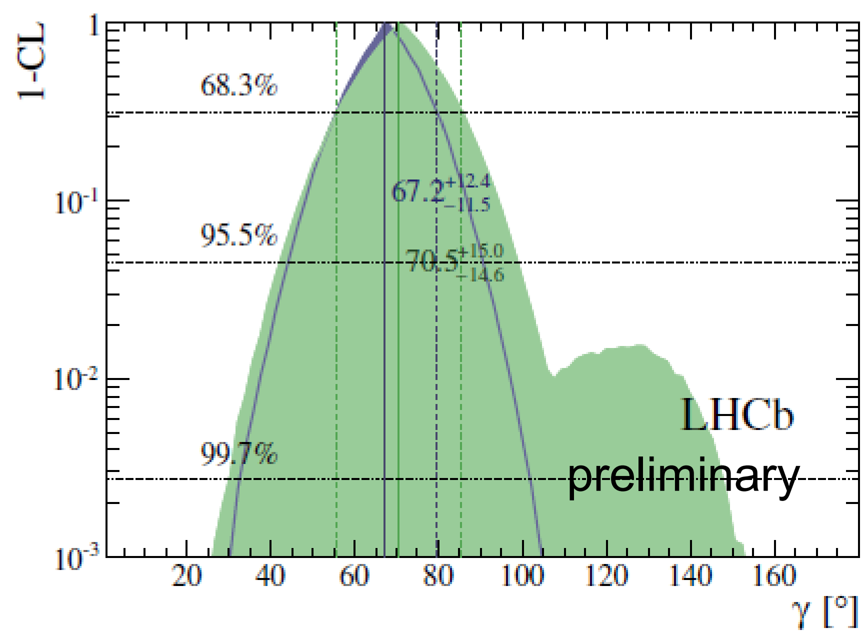
and Belle

$$\gamma = (68^{+15}_{-14})^\circ$$

arXiv:1301.2033

Indirect constraint from other CKM measurements (CKMfitter):

$$\gamma = (68 \pm 4)^\circ$$



CP violation in $B_s \to K\pi$

See talk by C. Santamarina Rios at HF1 section for details

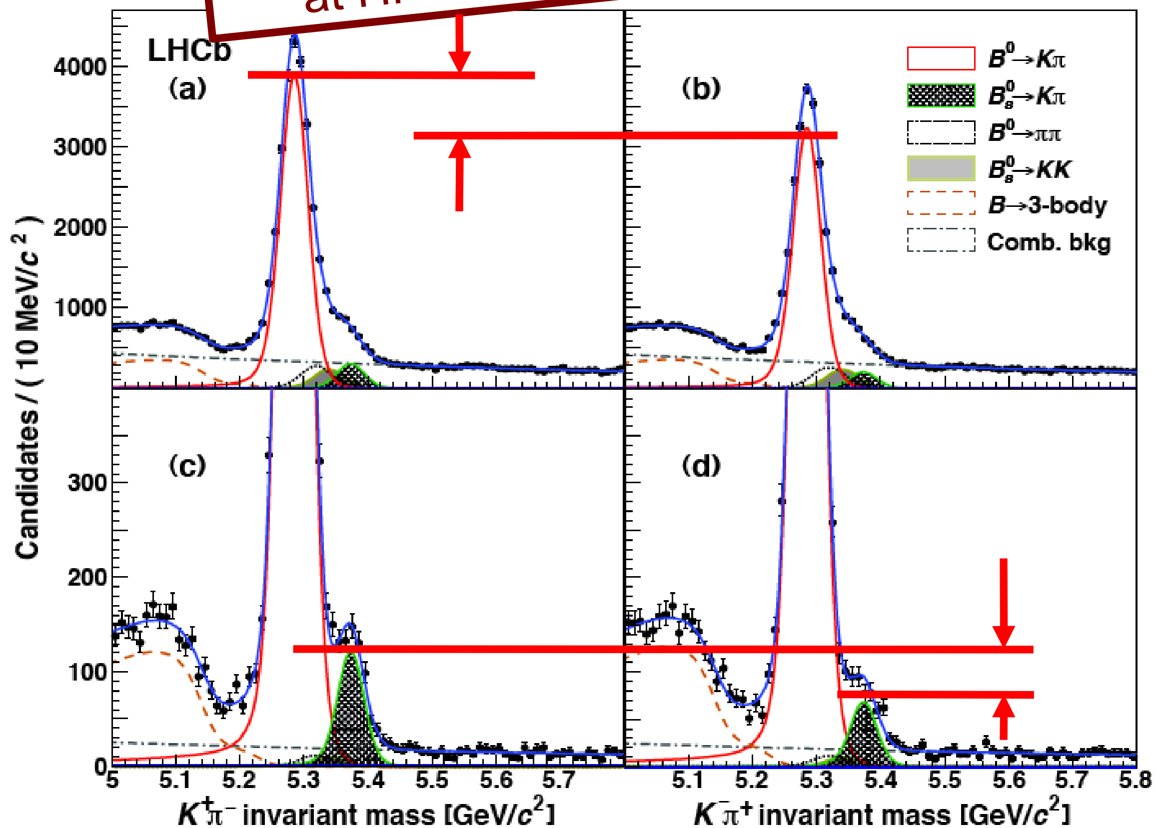
LHCb, 1 fb^{-1} (2011)

- Flavour-specific decay $B_{(s)} \to K\pi$
- Previous measurements:
  CDF: **CDF public note 10726**

$$A_{CP}(B_s^0 \to K\pi) = 0.22 \pm 0.07 \pm 0.02$$

HFAG average (B factories, CDF):

$$A_{CP}(B^0 \to K\pi) = -0.086 \pm 0.007$$



First observation (>5σ) of CP violation in B_s system **LHCb-PAPER-2013-018**

$$A_{CP}(B_s^0 \to K\pi) = \frac{\Gamma(\overline{B}_s^0 \to K^+\pi^-) - \Gamma(B_s^0 \to K^-\pi^+)}{\Gamma(\overline{B}_s^0 \to K^+\pi^-) + \Gamma(B_s^0 \to K^-\pi^+)} = 0.27 \pm 0.04 \pm 0.01$$

The most precise single measurement of CP violation in B^0 system

$$A_{CP}(B^0 \to K\pi) = \frac{\Gamma(\overline{B}^0 \to K^-\pi^+) - \Gamma(B^0 \to K^+\pi^-)}{\Gamma(\overline{B}^0 \to K^-\pi^+) + \Gamma(B^0 \to K^+\pi^-)} = -0.080 \pm 0.007 \pm 0.003$$

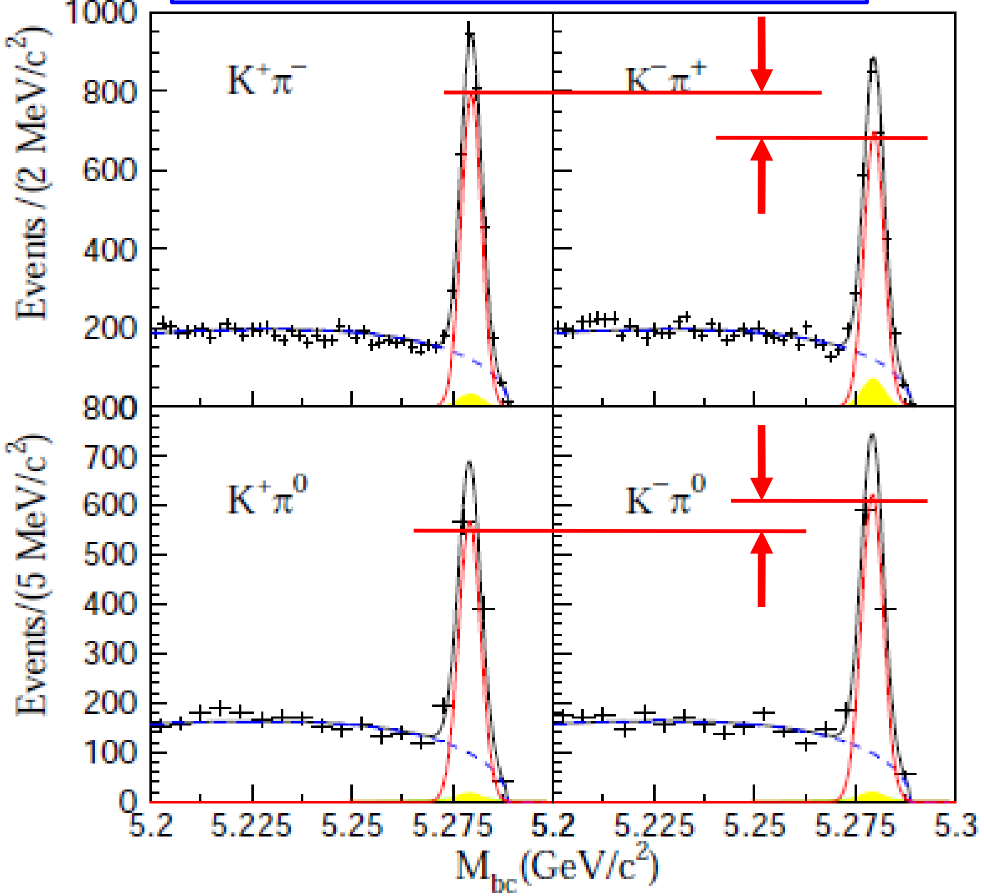
CP violation in B→Kπ

- B factories can measure both isospin combinations: $B^0 \to K\pi$ and $B^+ \to K\pi$
- New measurement by Belle, 772M $b\bar{b}$ pairs
- Difference in CPV for B^0 and B^+ confirmed

$$A_{CP}(B^0 \to K\pi) = -0.069 \pm 0.014 \pm 0.007$$

$$A_{CP}(B^+ \to K\pi^0) = +0.043 \pm 0.024 \pm 0.002$$

Belle, PRD 87, 031103 (2013)



HFAG world average:

$$\Delta A_{CP}(B \to K\pi) = +0.124 \pm 0.022$$

5.6σ significance

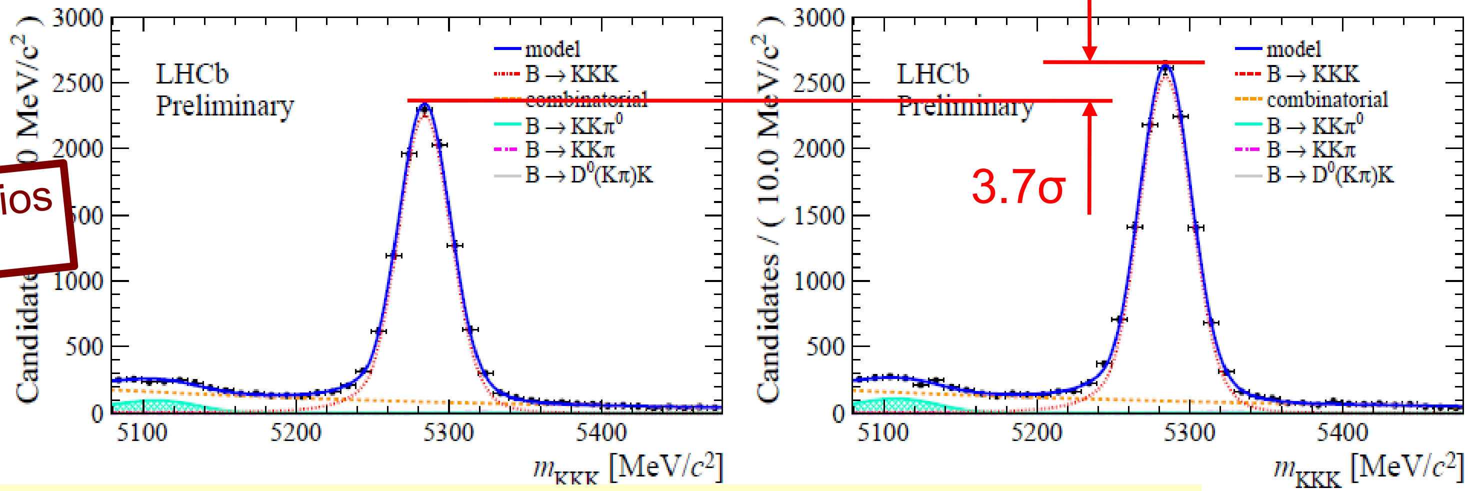
"ΔA_{CP} puzzle" in B decays. Can be explained by enhanced colour-suppressed tree, or NP in the EW penguin.

CP violation in 3-body charmless B decays

LHCB-CONF-2012-018

LHCB-CONF-2012-028

See talk by C. Santamarina Rios at HF1 section for details



Integrated asymmetry (full phase space):

$$A_{CP}(B^\pm \to K^\pm\pi^+\pi^-) = +0.034 \pm 0.009(\text{stat}) \pm 0.004(\text{syst}) \pm 0.007(J/\psi K^\pm),$$

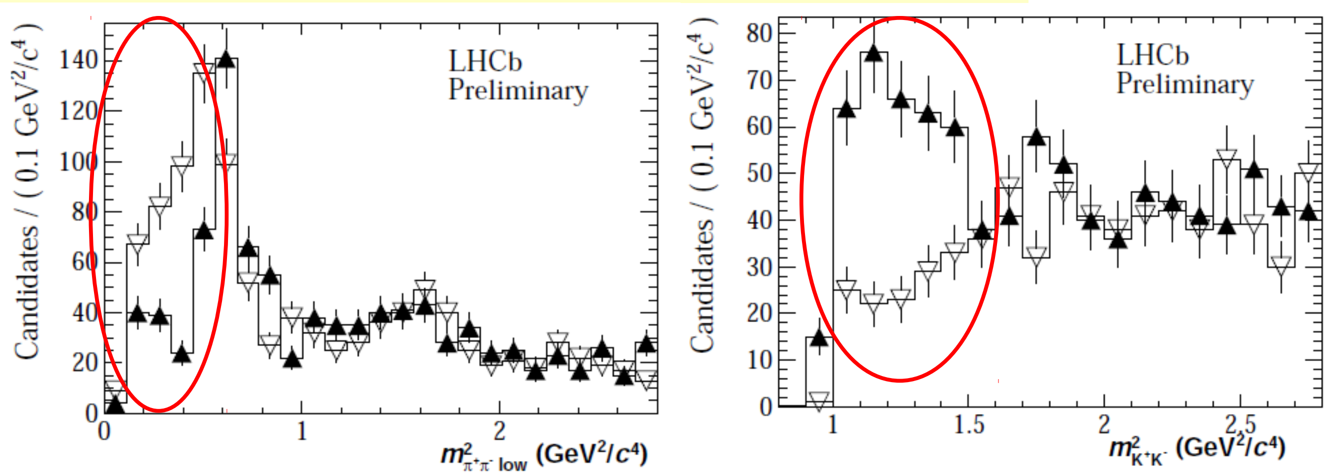
$$A_{CP}(B^\pm \to K^\pm K^+ K^-) = -0.046 \pm 0.009(\text{stat}) \pm 0.005(\text{syst}) \pm 0.007(J/\psi K^\pm)$$

$$A_{CP}(B^\pm \to \pi^\pm\pi^+\pi^-) = +0.120 \pm 0.020(\text{stat}) \pm 0.019(\text{syst}) \pm 0.007(J/\psi K^\pm),$$

$$A_{CP}(B^\pm \to K^+ K^-\pi^\pm) = -0.153 \pm 0.046(\text{stat}) \pm 0.019(\text{syst}) \pm 0.007(J/\psi K^\pm)$$

Asymmetry is mostly in the low-q^2 region of phase space not associated to resonances

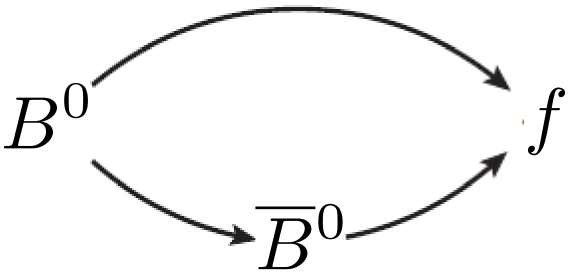
Amplitude analysis and more theory input is required



Mixing-induced indirect CP violation

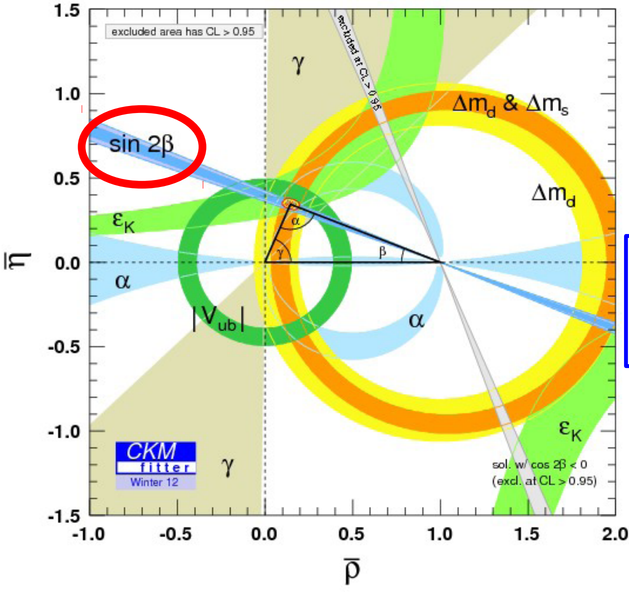
- Even in the absence of CP violation in mixing ($|q/p|=1$) and decay ($|A_f/\bar{A}_f|=1$), CP violation is possible in the interference of decays with and without mixing

if $Im\left(\frac{q}{p}\frac{\overline{A}_f}{A_f}\right) \neq 0$



Can be measured in time-dependent asymmetry:

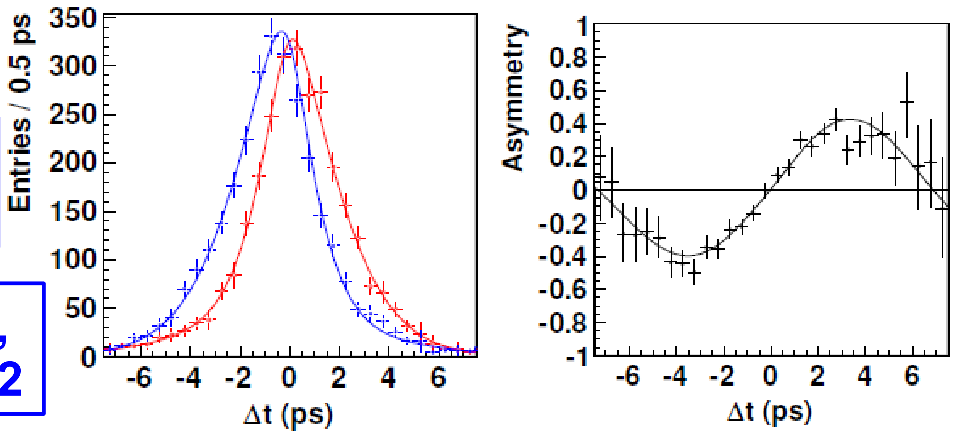
$$\frac{\Gamma(\overline{B}^0 \to f_{CP}) - \Gamma(B^0 \to f_{CP})}{\Gamma(\overline{B}^0 \to f_{CP}) + \Gamma(B^0 \to f_{CP})}(\Delta t) = S_{f_{CP}} \sin(\Delta m_d \Delta t) + A_{f_{CP}} \cos(\Delta m_d \Delta t)$$



$B^0 \to J/\psi K_S$: $S=\sin(2\beta)$. Precisely measured by B factories

BaBar, PRD 79(2009)072009

Belle, PRL 108(2012)171802



$\sin 2\beta$ from $B^0 \to J/\psi K_S$

Well measured by B factories (Belle, BaBar)

Difficult at hadronic machines because of lower tagging power

- LHCb, 1 fb^{-1} sample
- ~8200 flavor-tagged decays
- First significant measurement of $\sin 2\beta$ at hadron collider

See talk by R. Aaij at HF2 section for details

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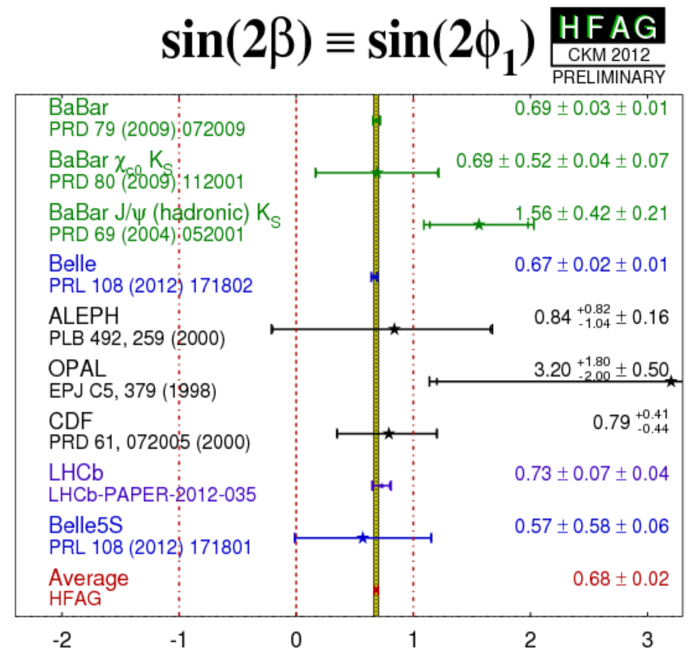
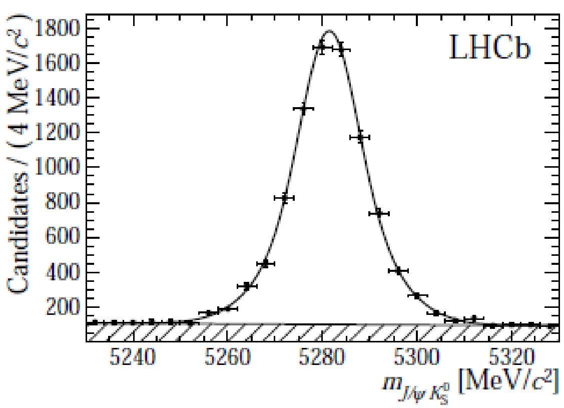
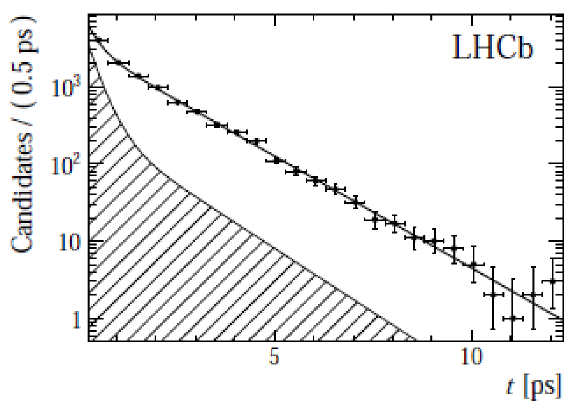
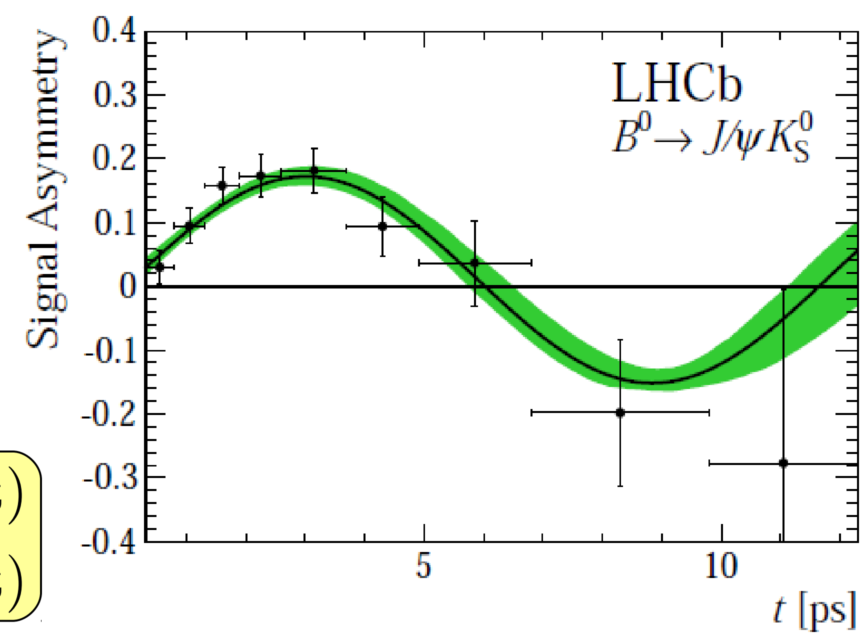




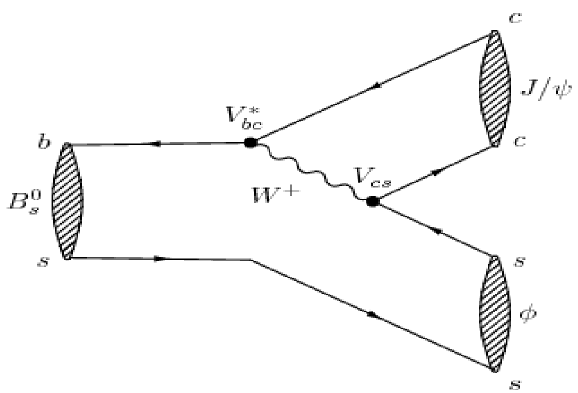


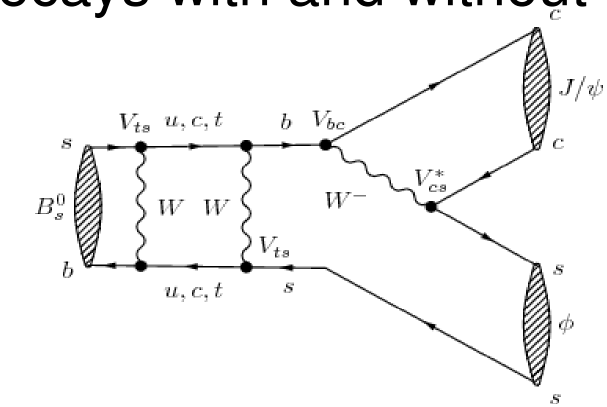


$$S(J/\psi K_S^0) = 0.73 \pm 0.07(\text{stat}) \pm 0.04(\text{syst})$$
$$C(J/\psi K_S^0) = 0.03 \pm 0.09(\text{stat}) \pm 0.01(\text{syst})$$

B_s mixing phase φ_s from $B_s \to J/\psi\varphi$

Interference of $B_s \to J/\psi\varphi$ decays with and without mixing



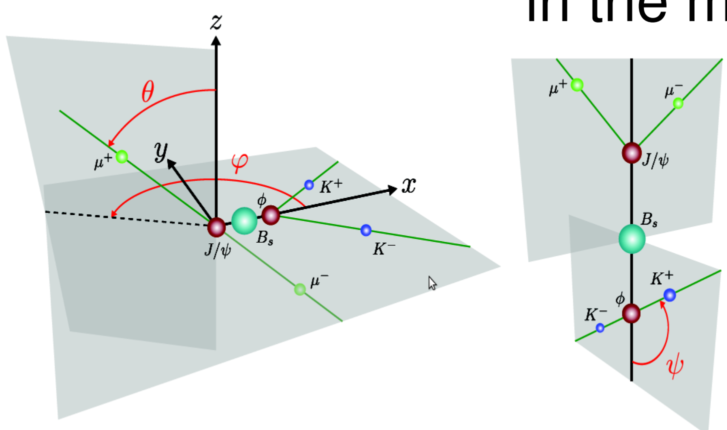


In SM, small phase difference:

$$\phi_s = -0.036 \pm 0.002$$

Possible NP effects in the mixing loop

$P \to VV$ decay:
both CP-odd and CP-even amplitudes contribute
Angular analysis (3 angles) to separate their contributions



D0, PRD 85, 032006 (2012)

$$\begin{aligned} \phi_s &= -0.55^{+0.38}_{-0.36} \text{ rad} \\ \tau_s &= 1.443^{+0.038}_{-0.035} \text{ ps} \\ \Delta\Gamma_s &= 0.163^{+0.065}_{-0.064} \text{ ps}^{-1} \end{aligned}$$

SM p-value: 29.8%

CDF, PRL 109, 171802 (2012)

$$\begin{aligned} \phi_s &\in (-0.06, 0.30) \text{ rad} \\ \tau_s &= 1.528 \pm 0.019 \pm 0.009 \text{ ps} \\ \Delta\Gamma_s &= 0.068 \pm 0.026 \pm 0.009 \text{ ps}^{-1} \end{aligned}$$

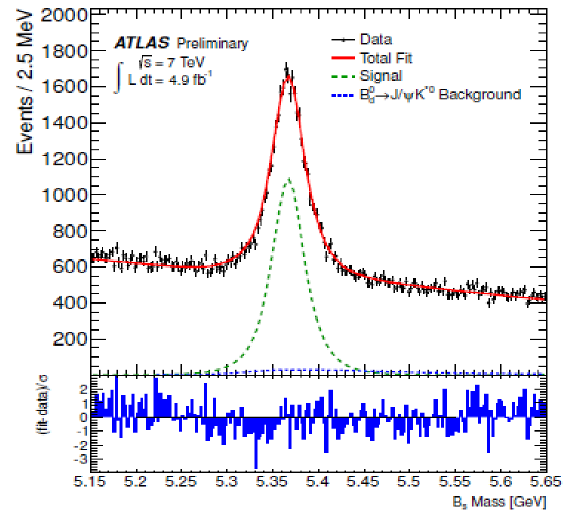
$B_s \to J/\psi\varphi$: LHC

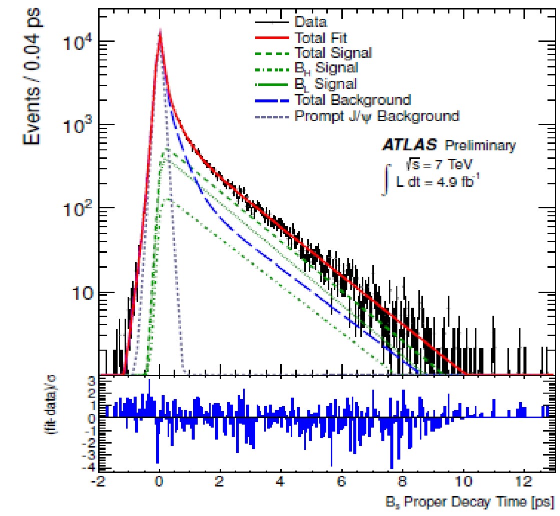
ATLAS-CONF-2013-039

Atlas, 4.9 fb^{-1} sample (2011)

$$\phi_s = 0.12 \pm 0.25 \pm 0.11 \text{ rad}$$
$$\Gamma_s = 0.677 \pm 0.007 \pm 0.003 \text{ ps}^{-1}$$
$$\Delta\Gamma_s = 0.053 \pm 0.021 \pm 0.009 \text{ ps}^{-1}$$

See talk by S. Leontsinis at HF1 section for details



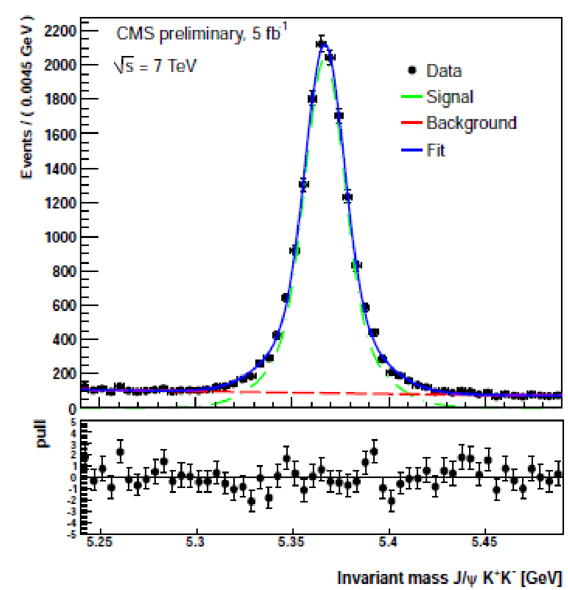


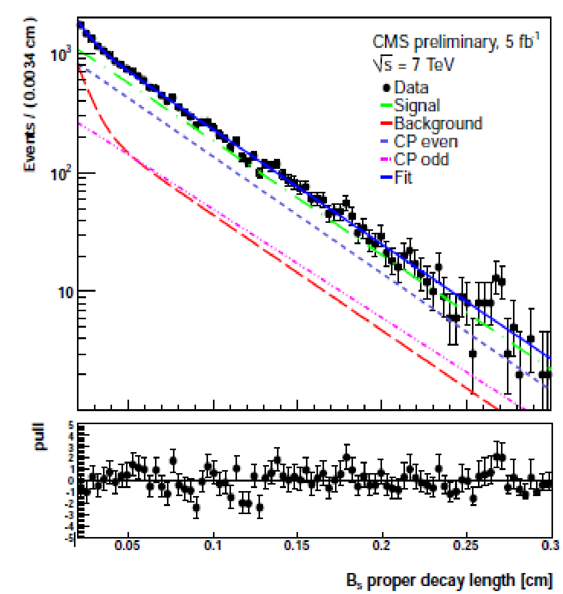
CMS-PAS-BPH-11-006

Untagged $B_s \to J/\psi\ \varphi$ analysis.

Competitive precision on width difference $\Delta\Gamma_s$, but not sensitive to φ_s

$$\Delta\Gamma_s = 0.048 \pm 0.024 \pm 0.003 \text{ ps}^{-1}$$



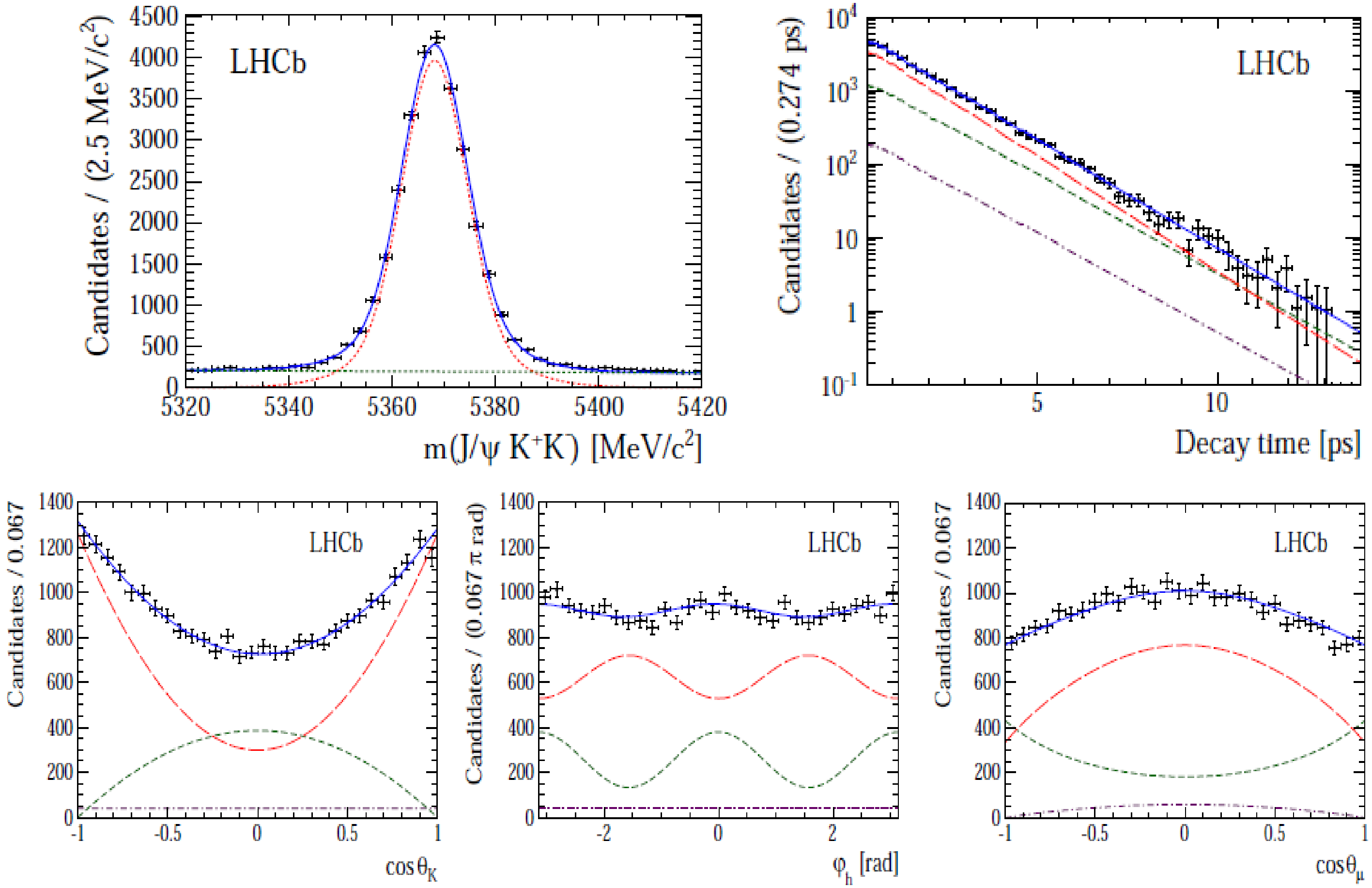


$B_s \to J/\psi\varphi$: LHCb

LHCb, arXiv:1304.2600

LHCb, 1 fb^{-1} sample (2011)

See talk by R. Aaij at HF2 section for details



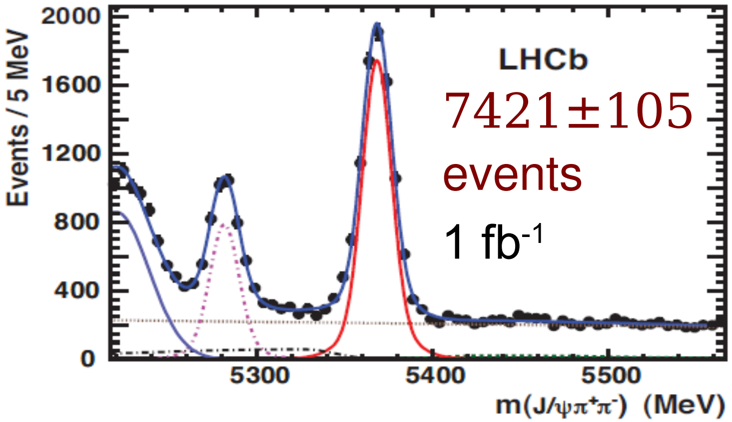
World's most precise measurement of φ_s

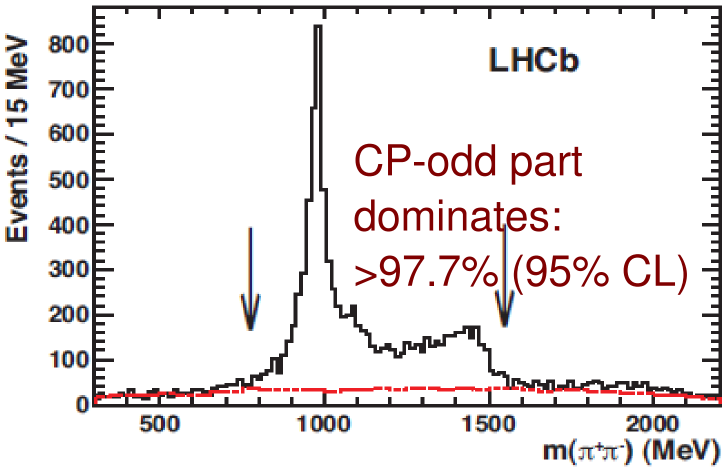
Well consistent with SM

$$\phi_s = 0.07 \pm 0.09 \pm 0.01 \text{ rad}$$
$$\Gamma_s = 0.663 \pm 0.005 \pm 0.006 \text{ ps}^{-1}$$
$$\Delta\Gamma_s = 0.100 \pm 0.016 \pm 0.003 \text{ ps}^{-1}$$

φ_s: $B_s \to J/\psi\pi^+\pi^-$ and combined

Similar measurement with $B_s \to J/\psi\pi^+\pi^-$
Dominated by single CP-odd amplitude, no angular analysis needed.



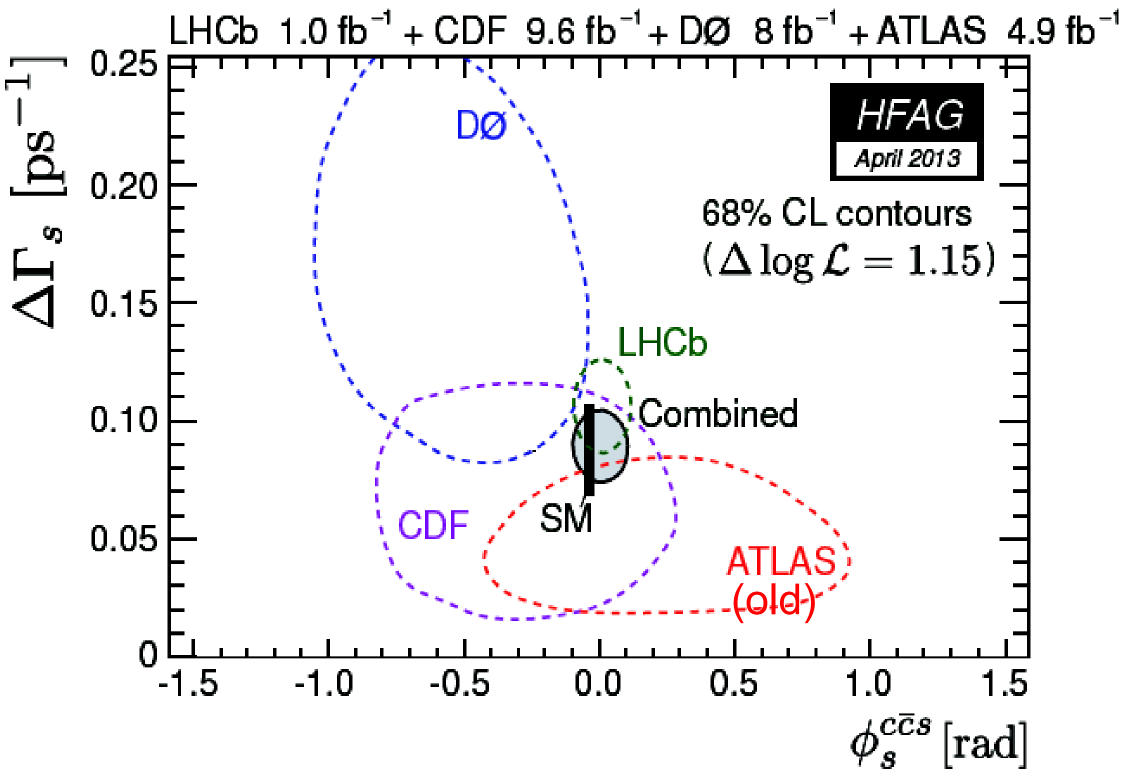


$$\phi_s = -0.14^{+0.17}_{-0.16} \pm 0.01 \text{ rad}$$

LHCb, PLB 707 (2012) 497

LHCb-only combination:

$$\begin{aligned} \phi_s &= 0.01 \pm 0.07 \pm 0.01 \text{ rad} \\ \Gamma_s &= 0.661 \pm 0.004 \pm 0.006 \text{ ps}^{-1} \\ \Delta\Gamma_s &= 0.106 \pm 0.011 \pm 0.007 \text{ ps}^{-1} \end{aligned}$$



HFAG average:

$$\begin{aligned} \phi_s &= 0.013^{+0.083}_{-0.090} \text{ rad} \\ \Delta\Gamma_s &= 0.089^{+0.011}_{-0.013} \text{ ps}^{-1} \end{aligned}$$

$B_s \to \varphi\varphi$

$b \to s\bar{s}s$ penguin. In SM, the weak phase is small: $\phi_s < 0.02$

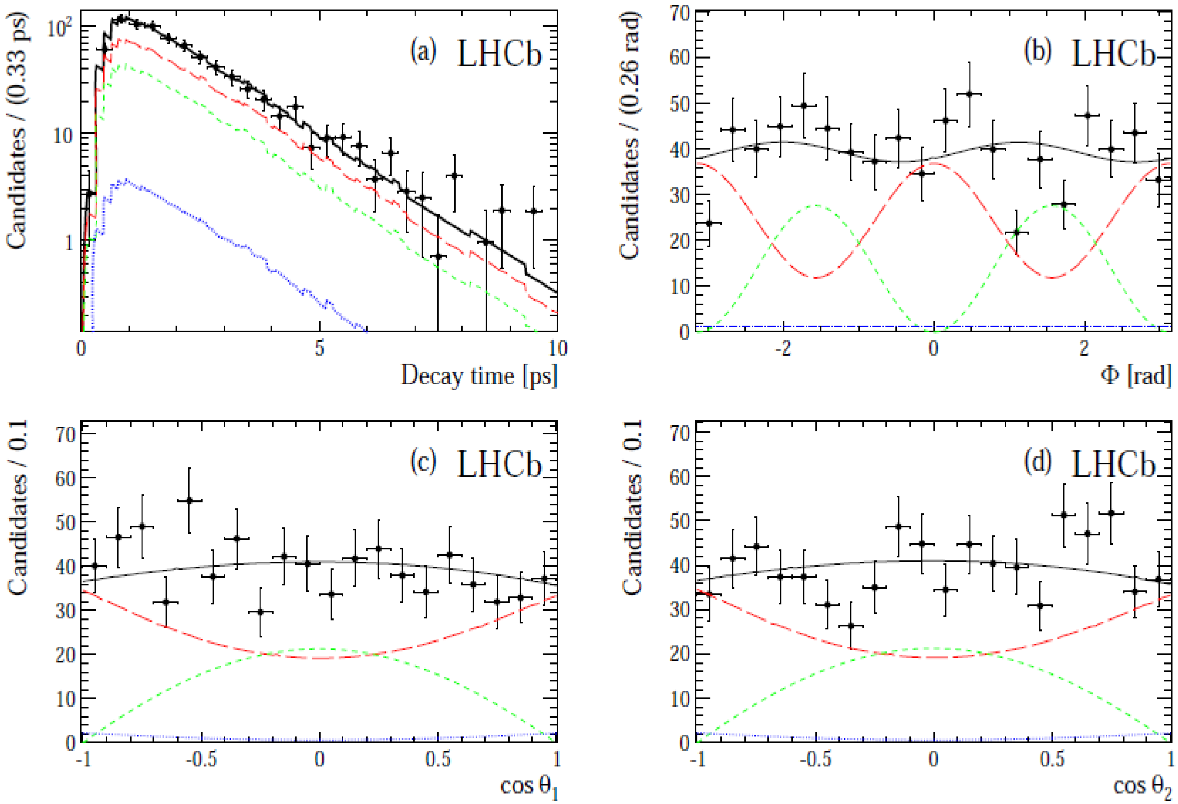
Can be affected by NP in the penguin loop.

See talk by C. Santamarina Rios at HF1 section for details

First measurement performed by CDF: **PRL 107, 261802 (2011)**

- LHCb, 1 fb^{-1} sample (2011)
- 880±31 $B_s \to \varphi(KK)\varphi(KK)$ decays
- KK can be vector (φ) or scalar (f_0, non-res) $\Rightarrow$ 5 polarisation amplitudes. Angular analysis.

LHCb, arXiv:1303.7125



$\phi_s \in [-2.46, -0.76]$ rad at 68% CL

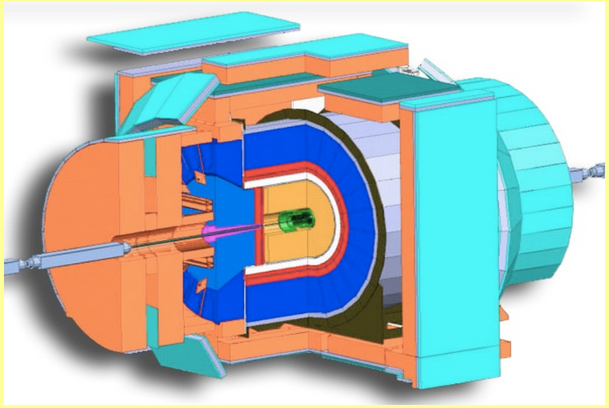
SM p-value is 16%

Summary

- Parameters of B meson mixing and CP violation in B sector probe NP in various ways. However, all measurements do not contradict SM so far.
- B^0 and B^+ systems have been studied by B factories for more than a decade. New results are appearing.
- Many new measurements by LHCb. Interesting results from Atlas and CMS with some leptonic modes.
  - B_s weak phase φ_s (D0, CDF, Atlas, LHCb)
  - First observation of direct CPV in B_s decays (LHCb)
  - Measurement of γ (LHCb)
- Most LHCb analyses are on 1 fb^{-1} (2011). Expect exciting new results soon when another 2 fb^{-1} (2012) are added. Other experiments are competitive in many cases:
  - B factories: B^0 modes with flavour tagging, modes with neutrals.
  - Tevatron: measurements relying on symmetric initial state.
  - CMS, Atlas: final states with leptons.

Backup

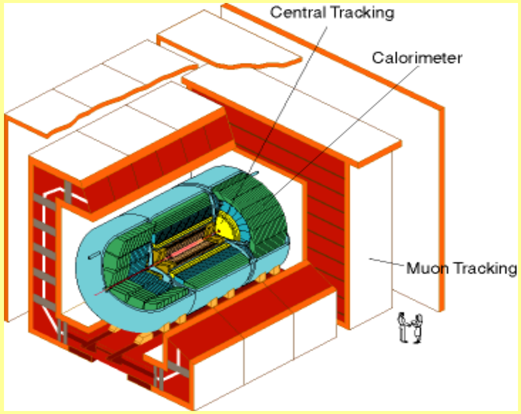
B physics at hadron colliders



Tevatron

$p\bar{p}$ at $\sqrt{s}$ = 1.96 TeV
No production asymmetries:
helps in CP violation studies

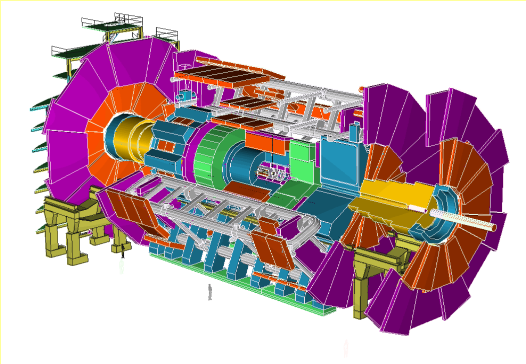
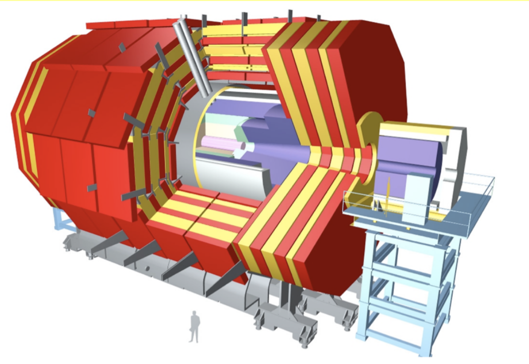
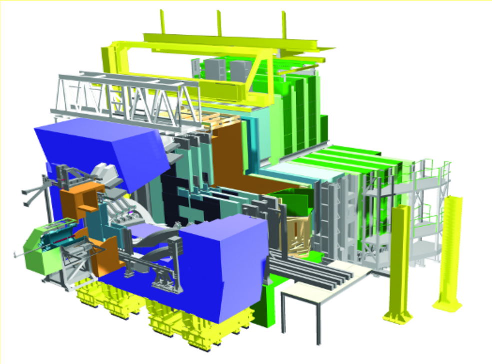
CDF **D0**



LHC

pp at $\sqrt{s}$ = 7-8 TeV
Atlas, CMS: central detectors
Full LHC luminosity, leptonic triggers

LHCb
Forward one-arm spectrometer
Optimised for B physics
(vertexing, PID)
Lepton and hadron triggers

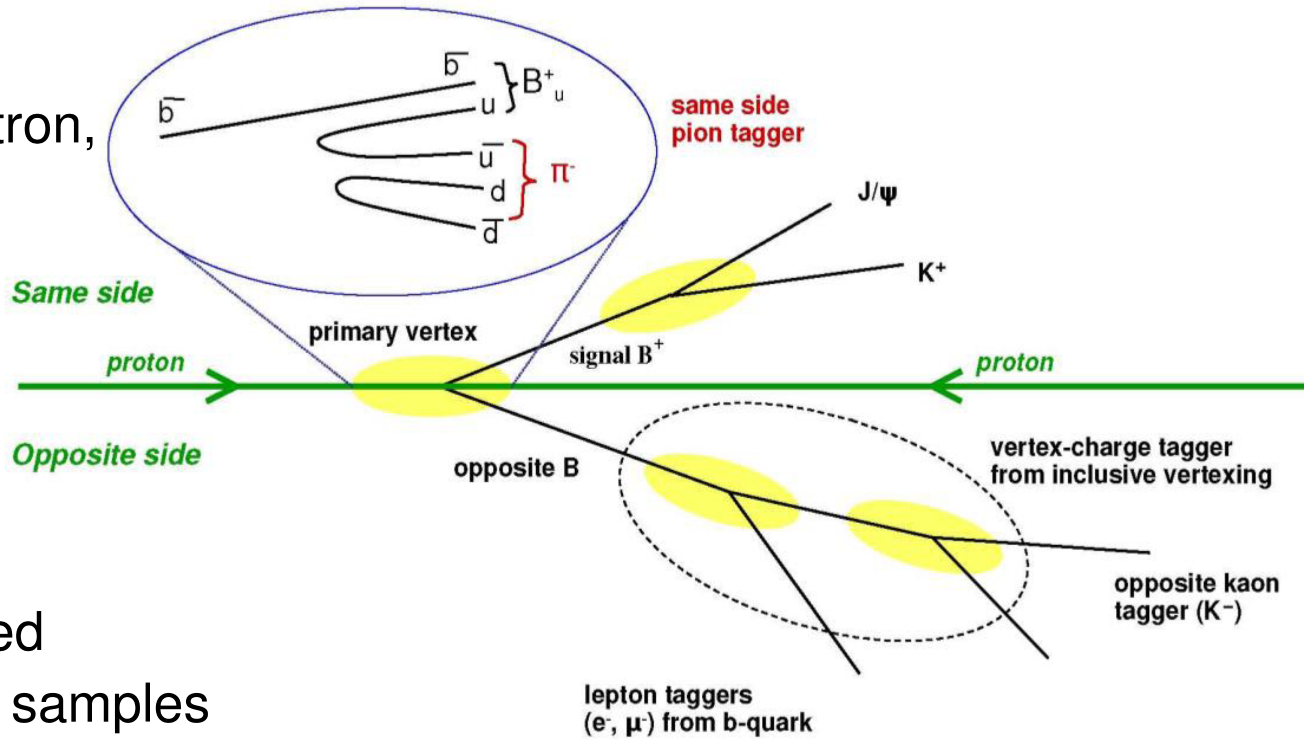




Flavour tagging at LHCb

LHCb-PAPER-2011-027

Use information from

- Opposite side:
  Charge of kaon, muon, electron, charge of tracks from the secondary vertex
- Same side:
  Charge of associated kaon track



Tagging performance calibrated on data: $B \to J/\psi K$ and $B_s \to D_s \pi$ samples

Flavour tagging performance in $B_s \to J/\psi\varphi$ analysis:

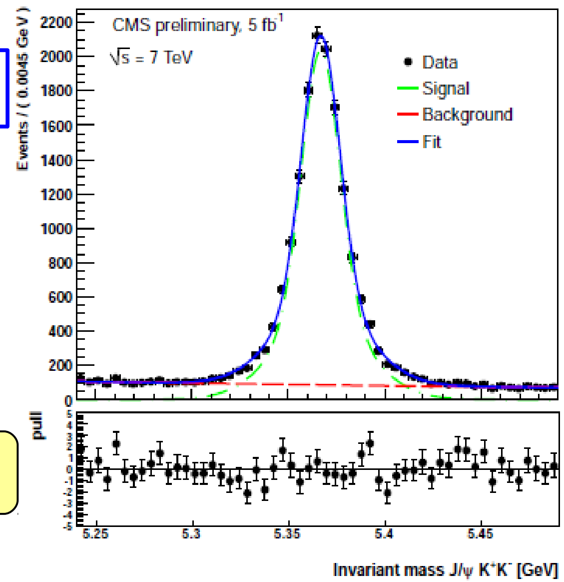
	Opposite side	Same side	Combined
Mistag probability ω	36.83 %	35.27%	35.9%
Tagging efficiency ε_{tag}	33.00 %	10.26%	39.36%
Tagging power $\varepsilon_{tag}(1-2\omega)^2$	(2.29 ± 0.06) %	(0.89 ± 0.17) %	(3.13 ± 0.23)%

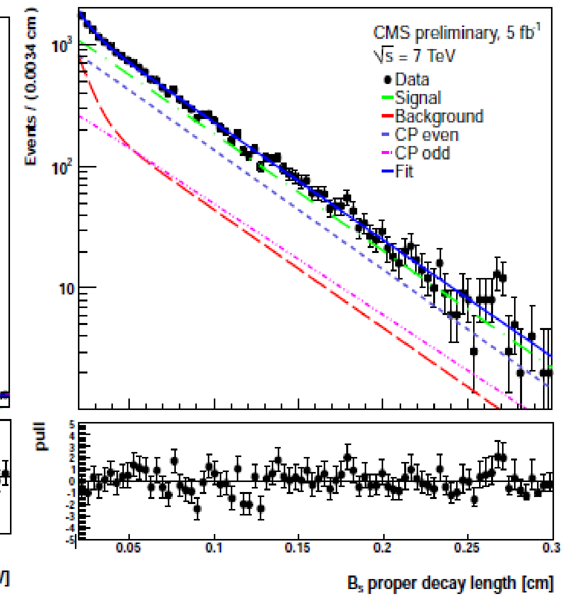
B_s lifetime difference $\Delta\Gamma_s$

Mass eigenstates in SM are nearly CP eigenstates. Lifetime difference can be probed with untagged events

- $B_s \to J/\psi\ \varphi$ **CMS-PAS-BPH-11-006**
  Mixture of CP-odd and CP-even states, can be separated with angular analysis

$$\Delta\Gamma_s = 0.048 \pm 0.024 \pm 0.003\ \mathrm{ps}^{-1}$$





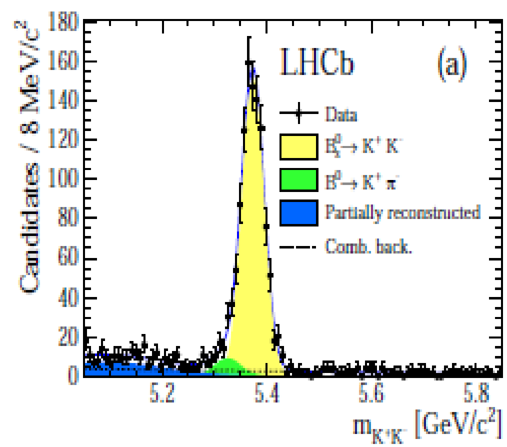
- $B_s \to K^+K^-$: CP-even state, effective lifetime

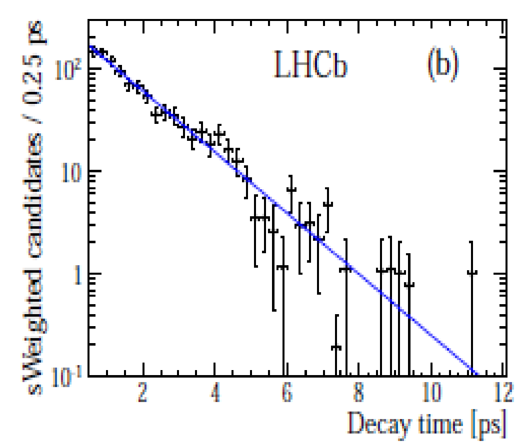
$$\tau_{KK} \simeq \tau_{B_s}\left(1 + \mathcal{A}_{\Delta\Gamma_s}\frac{\Delta\Gamma_s}{2\Gamma_s}\right)$$

  almost equal to $1/\Gamma_L$
  can be affected by NP in B decay loop

LHCb, PLB 716 (2012) 393

$$\tau_{KK} = 1.455 \pm 0.046 \pm 0.006\ \mathrm{ps}$$



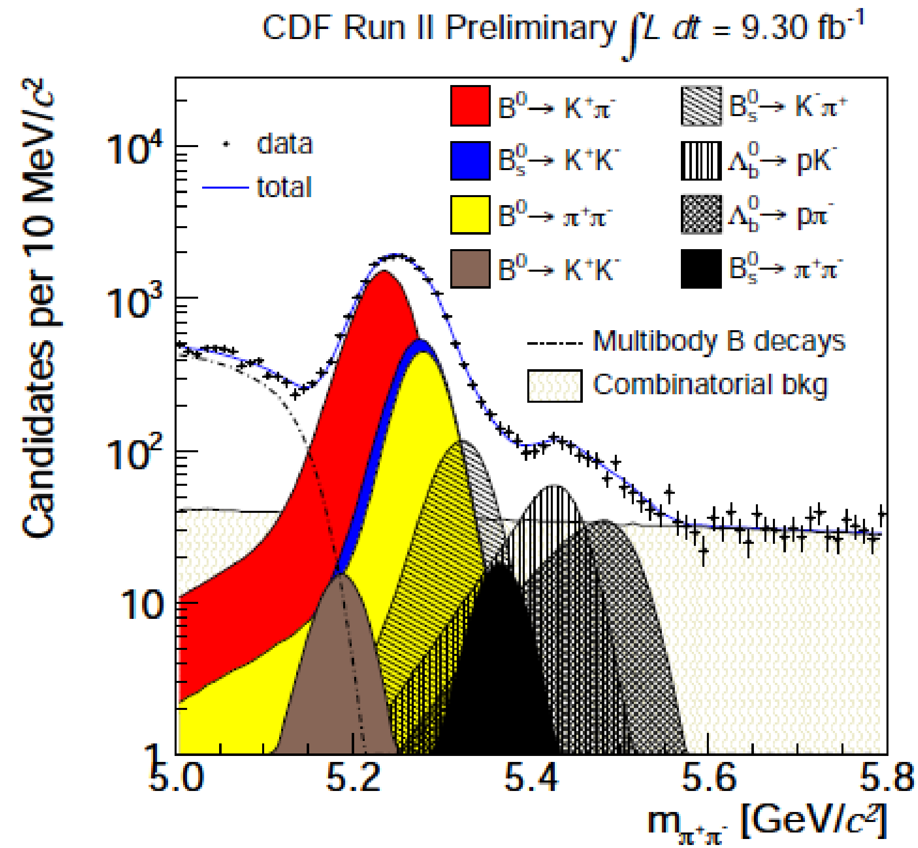


$$(1.40 \pm 0.02)\ \text{in SM}$$

CP violation in B hadrons→hh'

CDF public note 10726

- CDF, 9.3 fb^{-1} sample.
- Consider B^0, B_s, $\Lambda_b \to hh'$ ($h=\pi,K,p$)
- Use kinematic and dE/dx (PID) measurements to separate final state hadrons (π,K,p)

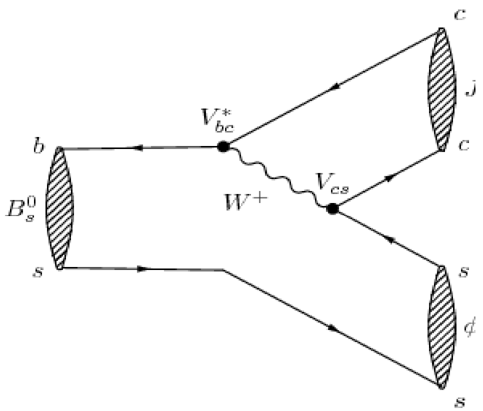


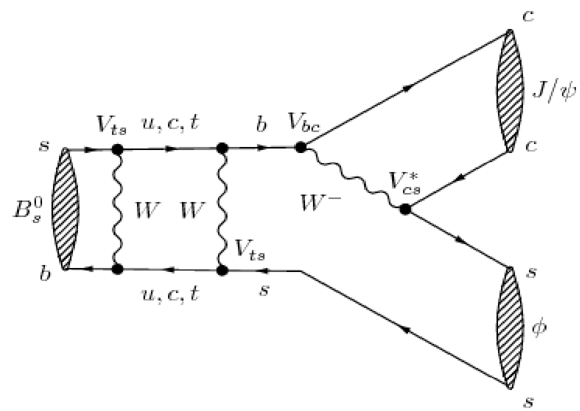
$$\begin{aligned}
\mathcal{A}_{CP}(B^0 \to K^+\pi^-) &= -0.083 \pm 0.013\ (stat.) \pm 0.003\ (syst.),\\
\mathcal{A}_{CP}(B_s^0 \to K^-\pi^+) &= +0.22 \pm 0.07\ (stat.) \pm 0.02\ (syst.),\\
\mathcal{A}_{CP}(\Lambda_b^0 \to p\pi^-) &= +0.07 \pm 0.07\ (stat.) \pm 0.03\ (syst.),\\
\mathcal{A}_{CP}(\Lambda_b^0 \to pK^-) &= -0.09 \pm 0.08\ (stat.) \pm 0.04\ (syst.)
\end{aligned}$$

3.0σ CPV in $B_s \to K\pi$
6.4σ CPV in $B^0 \to K\pi$
No CPV in Λ_b

HFAG: $A_{CP}(B^0 \to K\pi) = -0.086 \pm 0.007$

B_s mixing phase φ_s from $B_s \to J/\psi\varphi$





Interference of $B_s \to J/\psi\varphi$ decays with and without mixing

In SM, small phase difference:

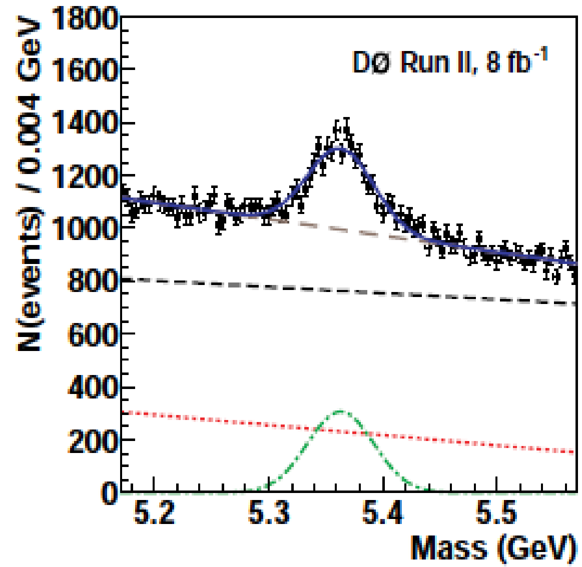
$$\varphi_s = -0.036 \pm 0.002$$

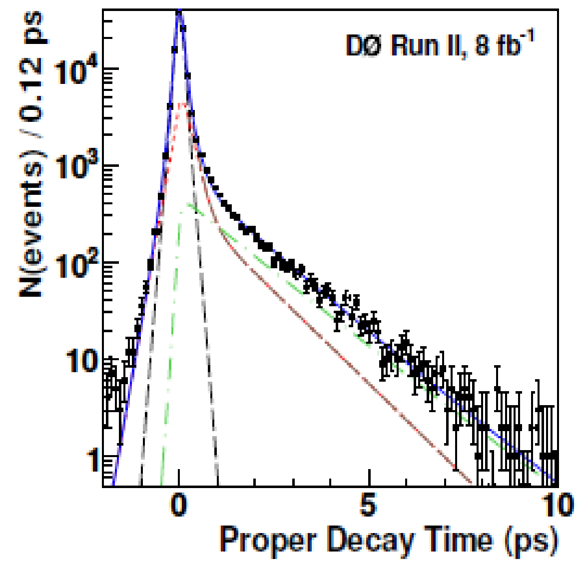
D0, PRD 85, 032006 (2012)

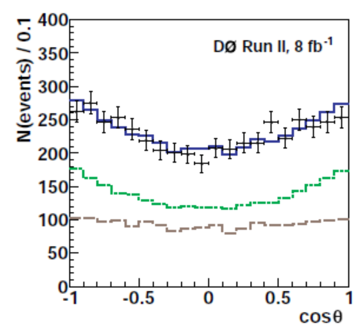
D0, 8 fb^{-1} sample

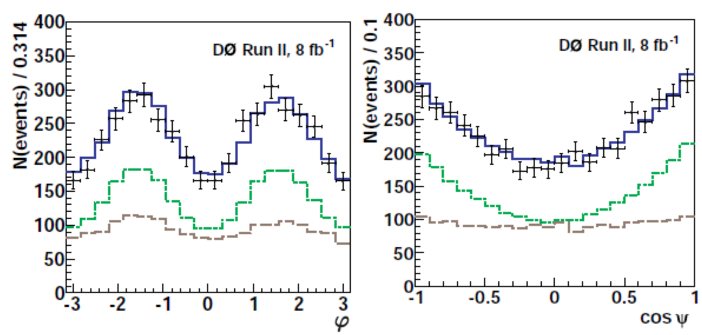
$$\phi_s = -0.55^{+0.38}_{-0.36} \text{ rad}$$
$$\tau_s = 1.443^{+0.038}_{-0.035} \text{ ps}$$
$$\Delta\Gamma_s = 0.163^{+0.065}_{-0.064} \text{ ps}^{-1}$$

SM p-value: 29.8%

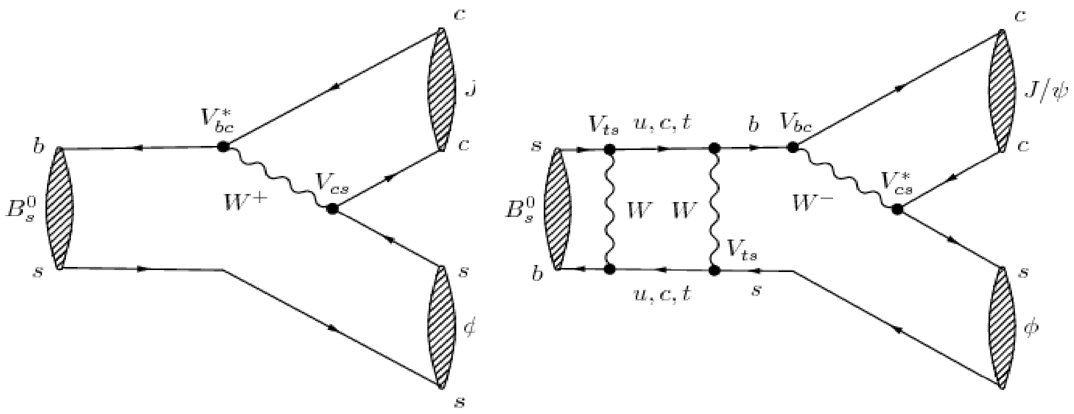








B_s mixing phase φ_s from $B_s \to J/\psi\varphi$



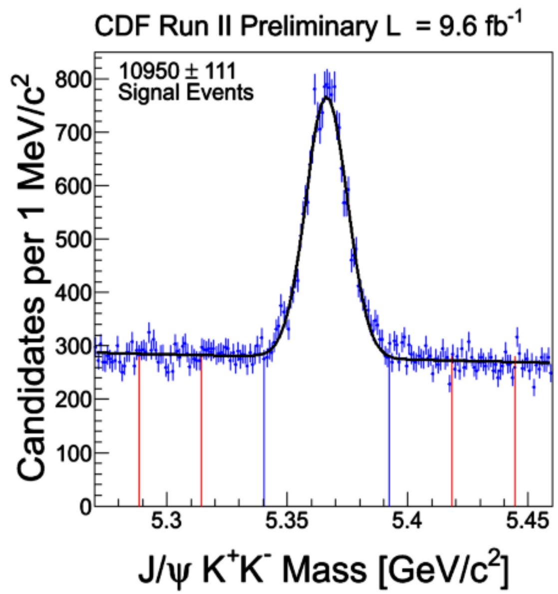
Interference of $B_s \to J/\psi\varphi$ decays with and without mixing

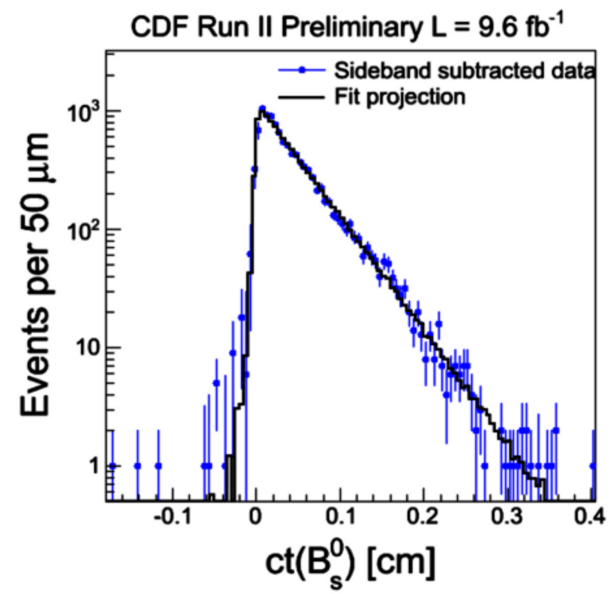
In SM, small phase difference:

$$\varphi_s = -0.036 \pm 0.002$$

CDF, PRL 109, 171802 (2012)

CDF, 9.6 fb^{-1} sample





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$$\tau_s = 1.528 \pm 0.019 \pm 0.009\ \text{ps}$$
$$\Delta\Gamma_s = 0.068 \pm 0.026 \pm 0.009\ \text{ps}^{-1}$$