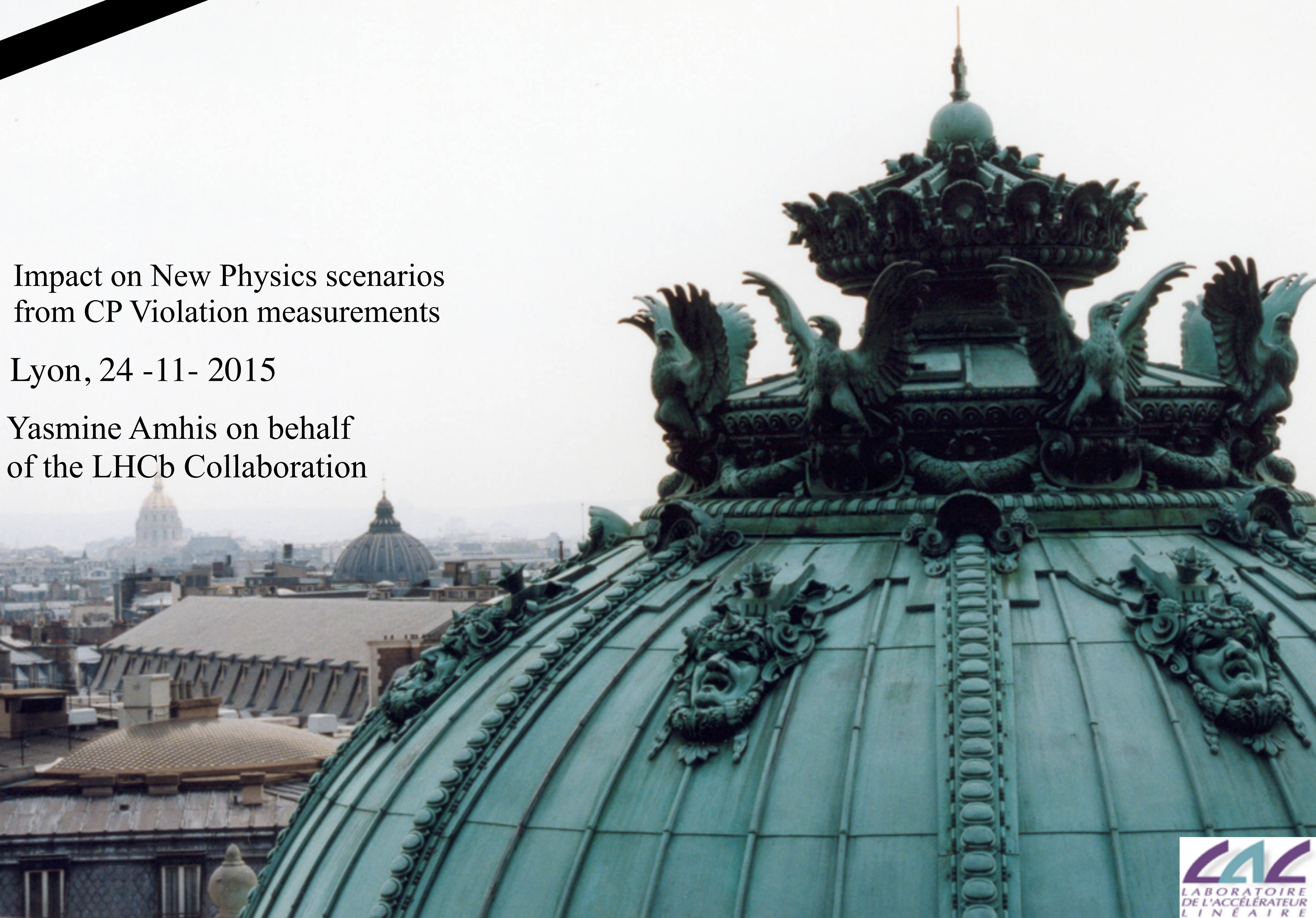
Impact on New Physics scenarios from CP Violation measurements

Lyon, 24 -11- 2015

Yasmine Amhis on behalf
of the LHCb Collaboration



High p_T questions

- What is the mechanism of electroweak symmetry breaking?
- What separates the electroweak scale from the Planck scale?
- What happened at the electroweak phase transition?
- What are the dark matter particles?
- How was the baryon asymmetry generated?

Flavor questions

- The Standard Model flavor puzzle:
  Why are the flavor parameters small and hierarchical?
  (Why) are the neutrino flavor parameters different?
- The New Physics flavor puzzle:
  If there is NP at the TeV scale, why are FCNC so small?
  The solution $\Longrightarrow$ Clues for the subtle structure of the NP
- Are the two puzzles related?

Y.Nir CERN
Flavour Physics Seminars.

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Flavour Physics Seminars.

Indirect Searches – Model Independent Searches
Four examples of how to look for New Physics

How can New Physics affect angular observables ?

How can New Physics enhance a suppressed decay ?

How can New Physics affect an oscillation ?

How can New Physics affect CP violation ? $\sin 2\beta, \phi_s$

Classification of CP Violating effects

A large set of NP models predict the existence
of new CP Violating phases

CPV in decay

CPV in mixing

CPV in the
interference
mixing & decay

What is the Standard Model telling us ?

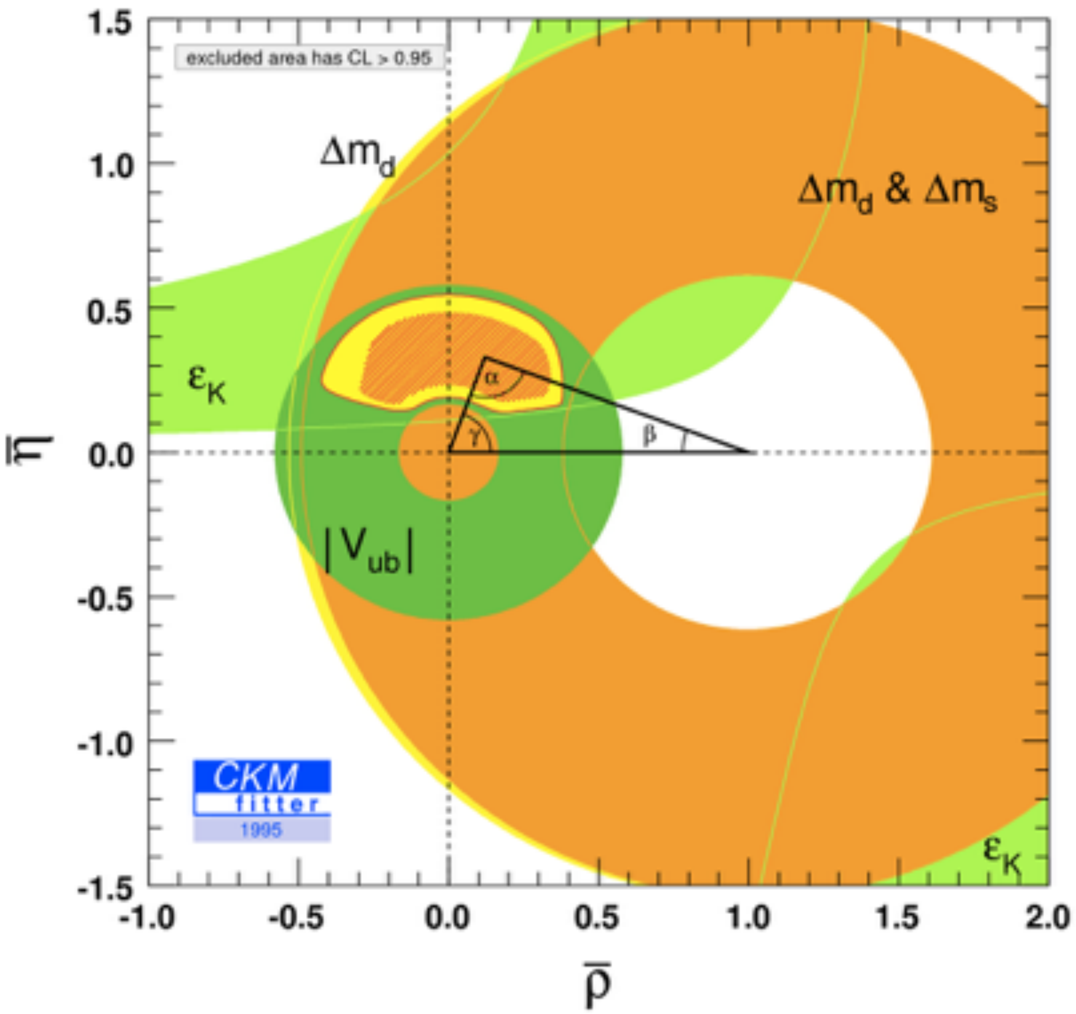
$$V_{\mathrm{CKM}} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

$$\begin{pmatrix} 1-\frac{1}{2}\lambda^2-\frac{1}{8}\lambda^4 & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda+\frac{1}{2}A^2\lambda^5[1-2(\rho+i\eta)] & 1-\frac{1}{2}\lambda^2-\frac{1}{8}\lambda^4(1+4A^2) & A\lambda^2 \\ A\lambda^3[1-(1-\frac{1}{2}\lambda^2)(\rho+i\eta)] & -A\lambda^2+\frac{1}{2}A\lambda^4[1-2(\rho+i\eta)] & 1-\frac{1}{2}A^2\lambda^4 \end{pmatrix}$$

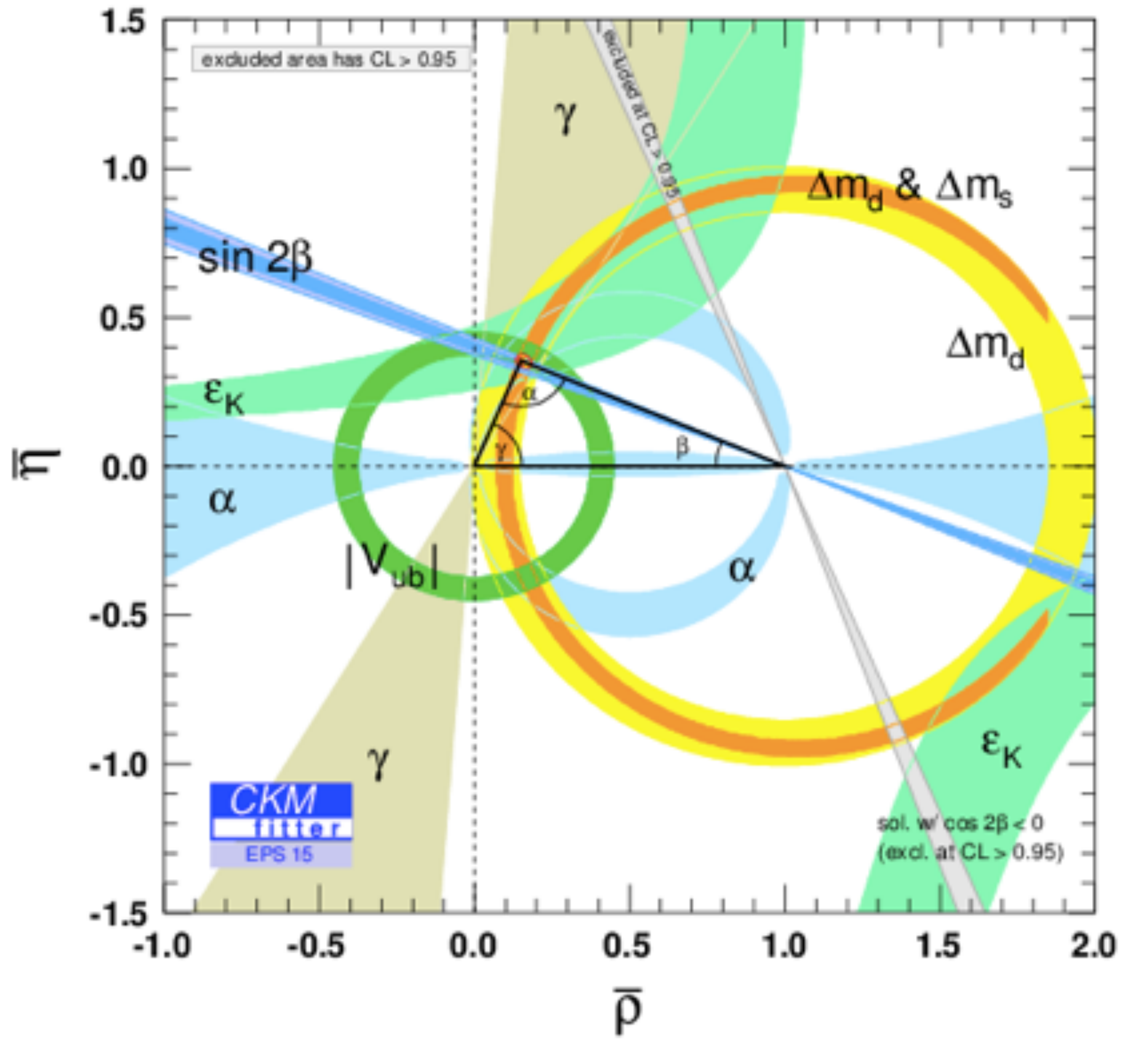
We have to constrain as much as possible all the parameters

What is real life telling us ?

1995



2015



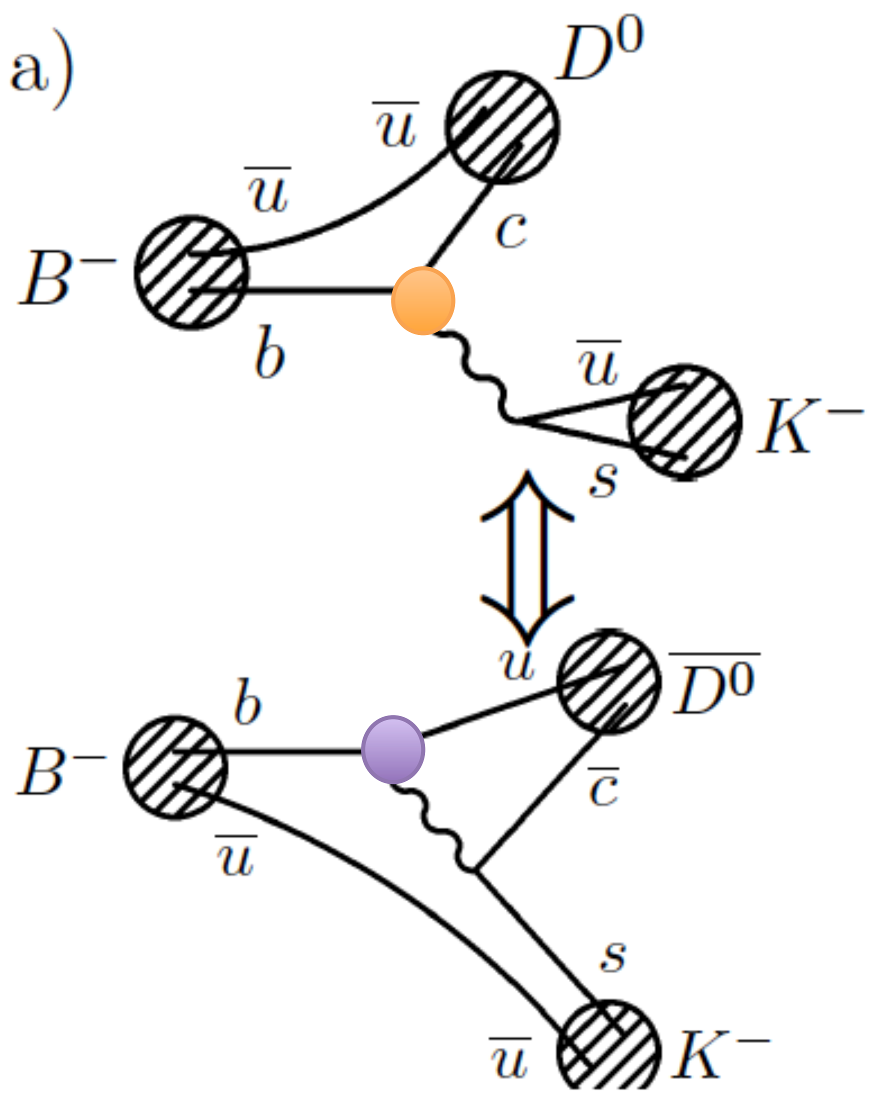
The CKM mechanism seems to work

What is New Physics telling us?

Where shall we start ?

Measure theoretically clean observables

Measurement of γ



The weak phase γ can be measured
in the interference of b→c and b→u decays.

$$\gamma = \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$

Measurement of γ

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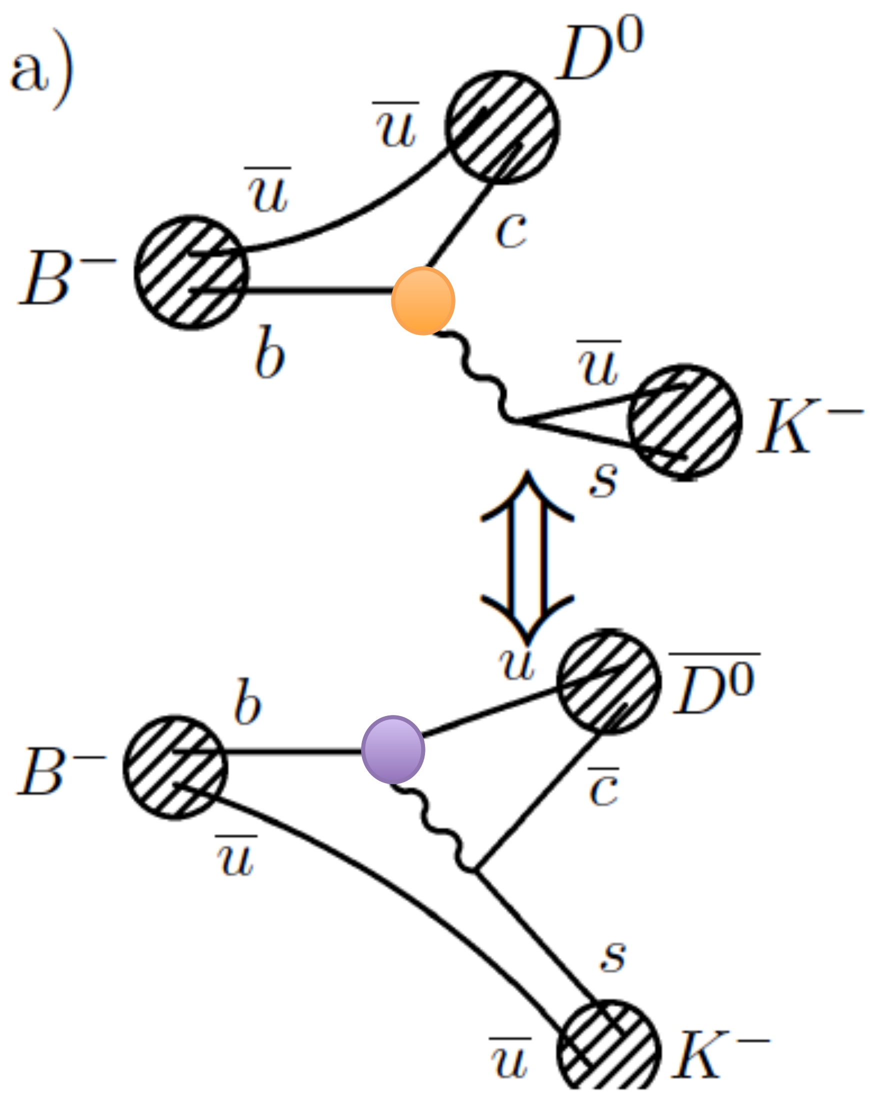


$$
\begin{aligned}
A(B^- \to D^0 K^-) &= a \\
&\downarrow CP \\
\bar{A}(B^+ \to \bar{D}^0 K^+) &= a
\end{aligned}
$$

$$\gamma = \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$

$$
\begin{aligned}
A(B^- \to \bar{D}^0 K^-) &= a e^{-i\gamma} r_B e^{i\delta_B} \\
&\downarrow CP \\
\bar{A}(B^+ \to D^0 K^+) &= a e^{+i\gamma} r_B e^{i\delta_B}
\end{aligned}
$$

$B^+ \to Dh^+$, $D \to hh$, GLW/ADS, $1\,\mathrm{fb}^{-1}$

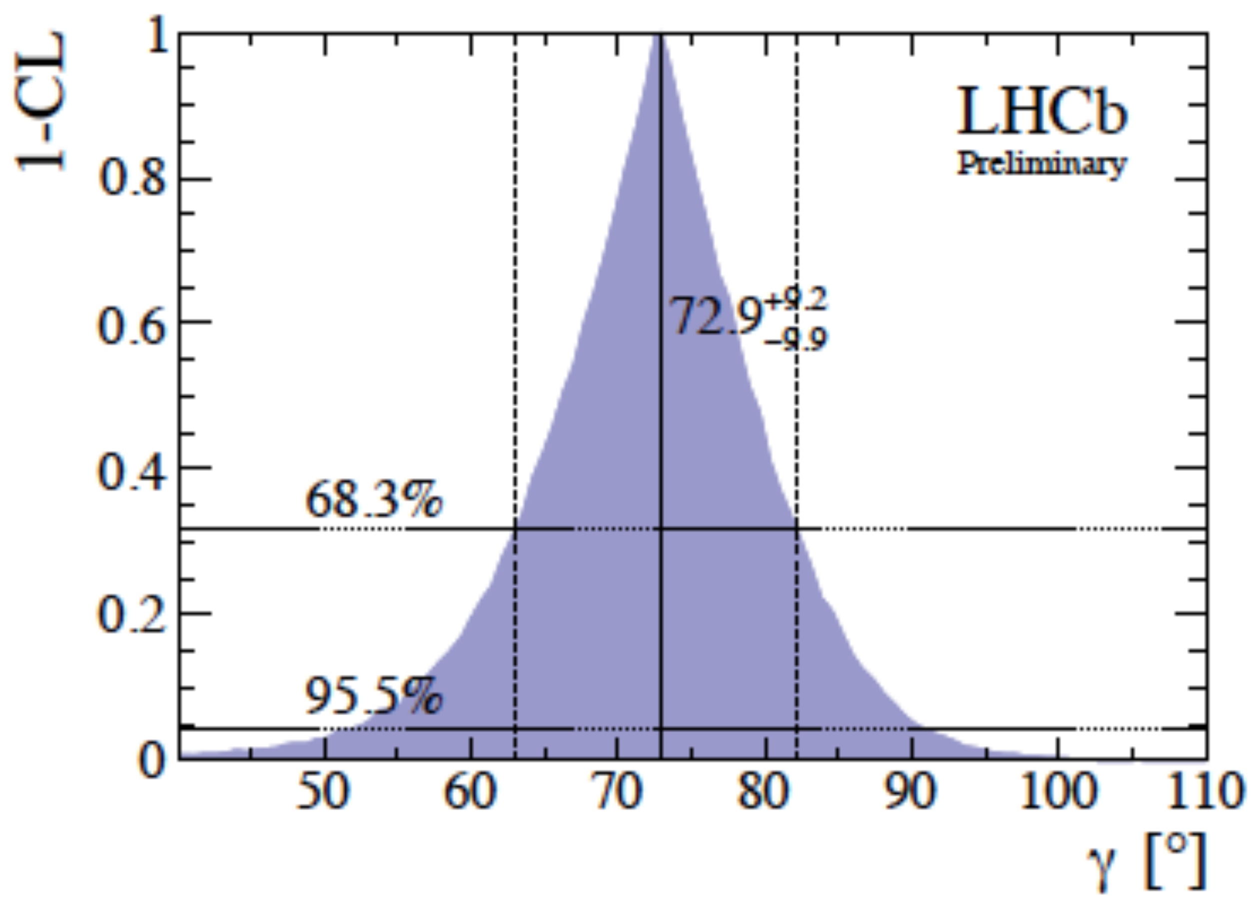
$B^+ \to Dh^+$, $D \to K\pi\pi\pi$, ADS, $1\,\mathrm{fb}^{-1}$

$B^+ \to DK^+$, $D \to K^0_S hh$, model-independent GGSZ, $3\,\mathrm{fb}^{-1}$

$B^+ \to DK^+$, $D \to K^0_S K\pi$, GLS, $3\,\mathrm{fb}^{-1}$

$B^0 \to DK^{*0}$, $D \to hh$, GLW/ADS, $3\,\mathrm{fb}^{-1}$

$B^0_s \to D_s^{\mp}K^{\pm}$, time-dependent, $1\,\mathrm{fb}^{-1}$



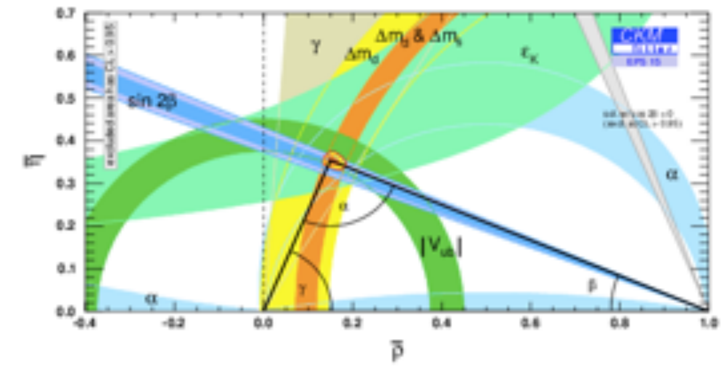
Other measurements
and updates
will be added soon !

LHCb-CONF-2014-004

What about $|V_{ub}|$?

$$V_{\rm CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

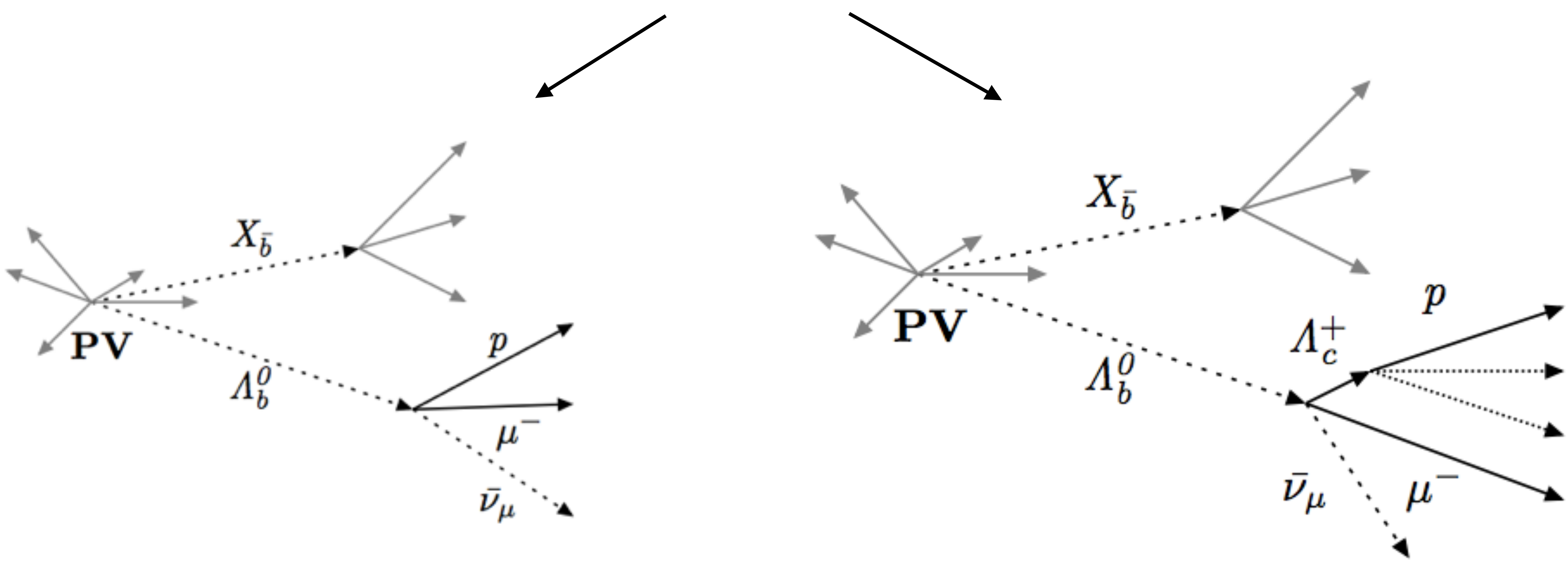
Measurement of V_{ub} [3 fb^{-1}]



What we measure :

$$\frac{|V_{ub}|^2}{|V_{cb}|^2} = \frac{\mathcal{B}(\Lambda_b^0 \to p\mu^-\overline{\nu}_\mu)}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+\mu^-\overline{\nu}_\mu)} R_{\mathrm{FF}}$$

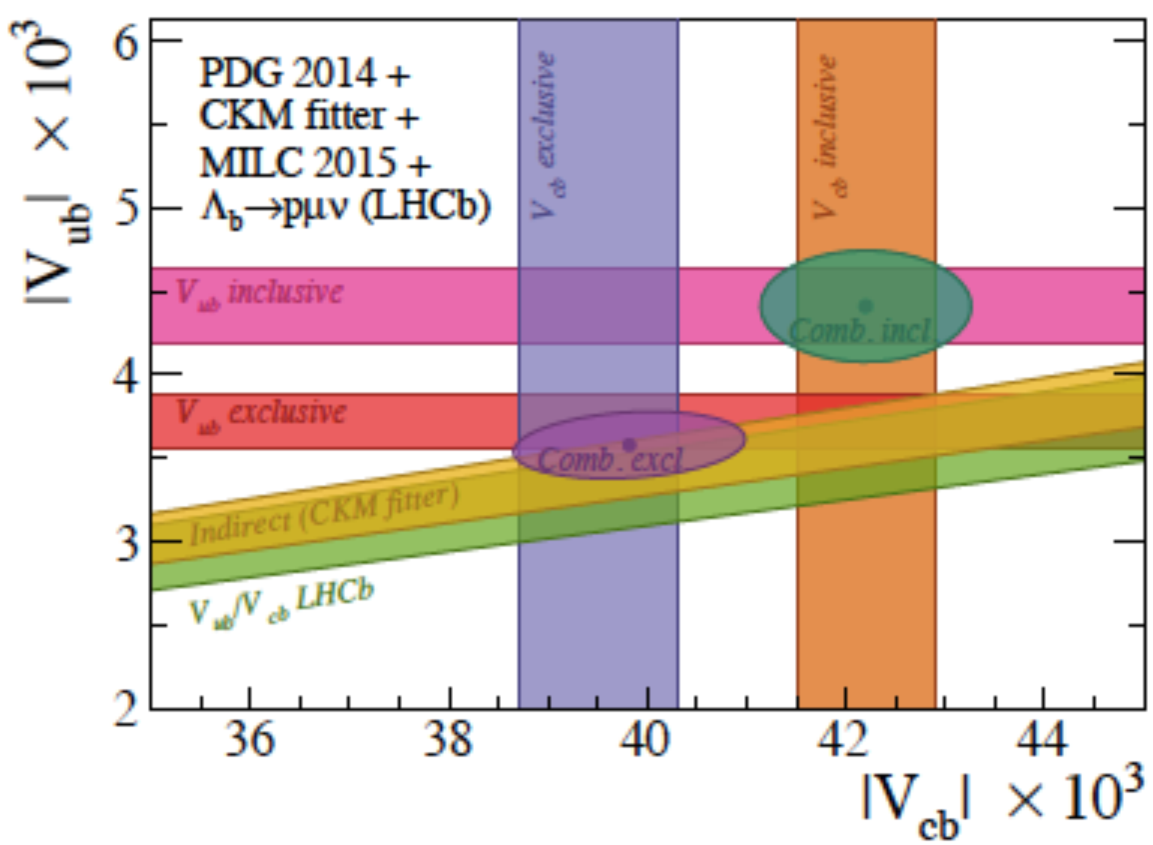
Topologies

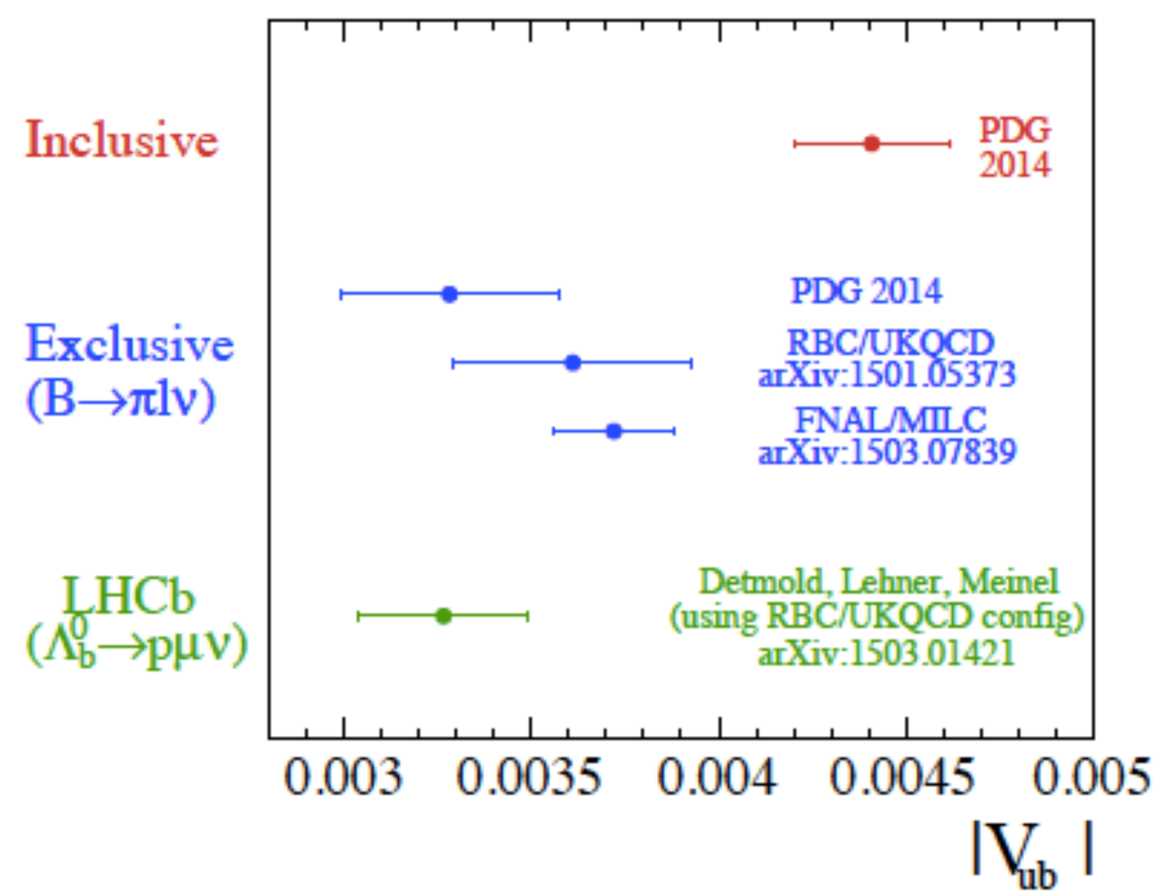


Result :

$$|V_{ub}| = (3.27 \pm 0.15 \pm 0.17 \pm 0.06) \times 10^{-3}$$

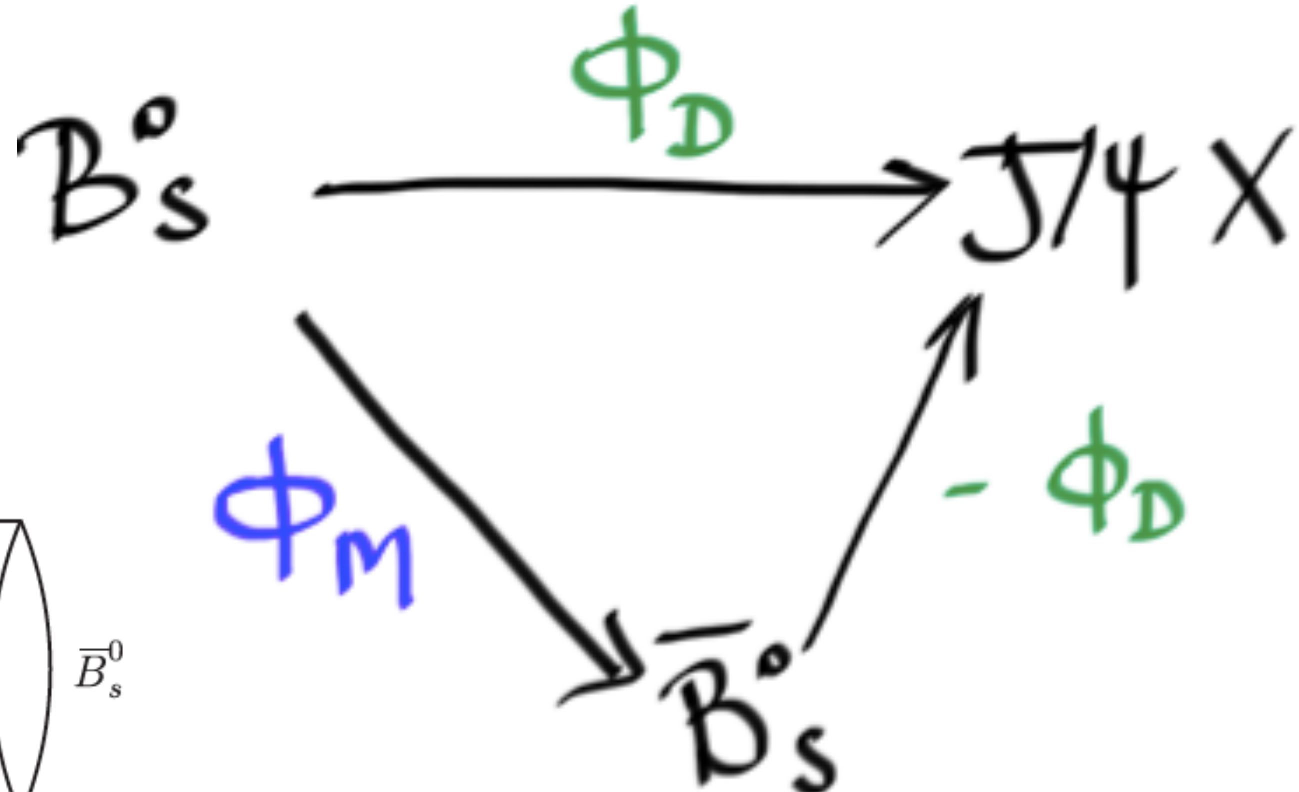
stat LQCD V_{cb}



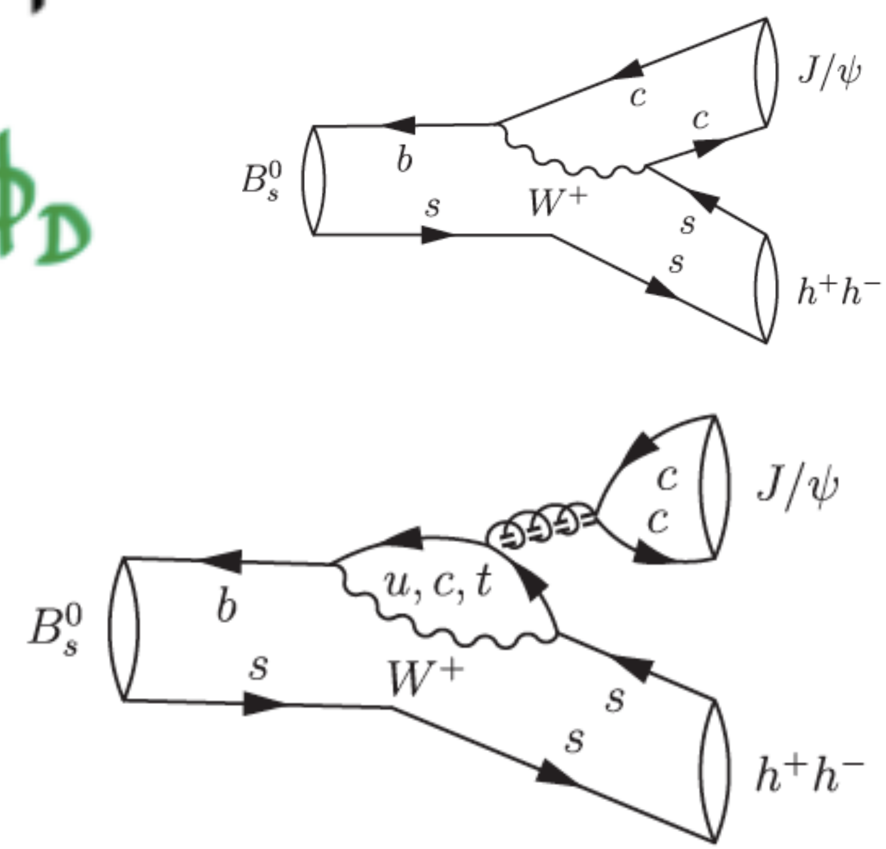


[Nature Physics 3415 (2015)] [3 fb^{-1}]

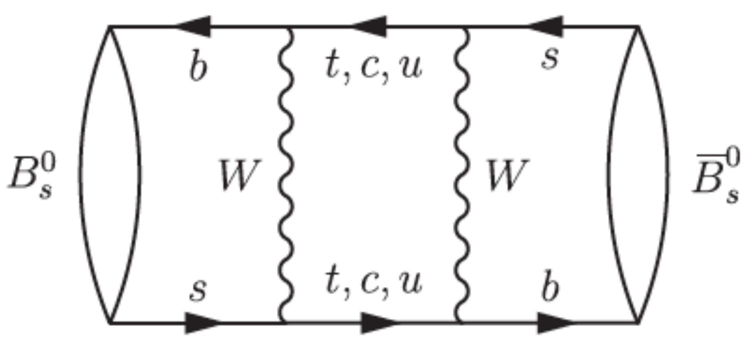
Φ_s from $b \to ccs$ transitions



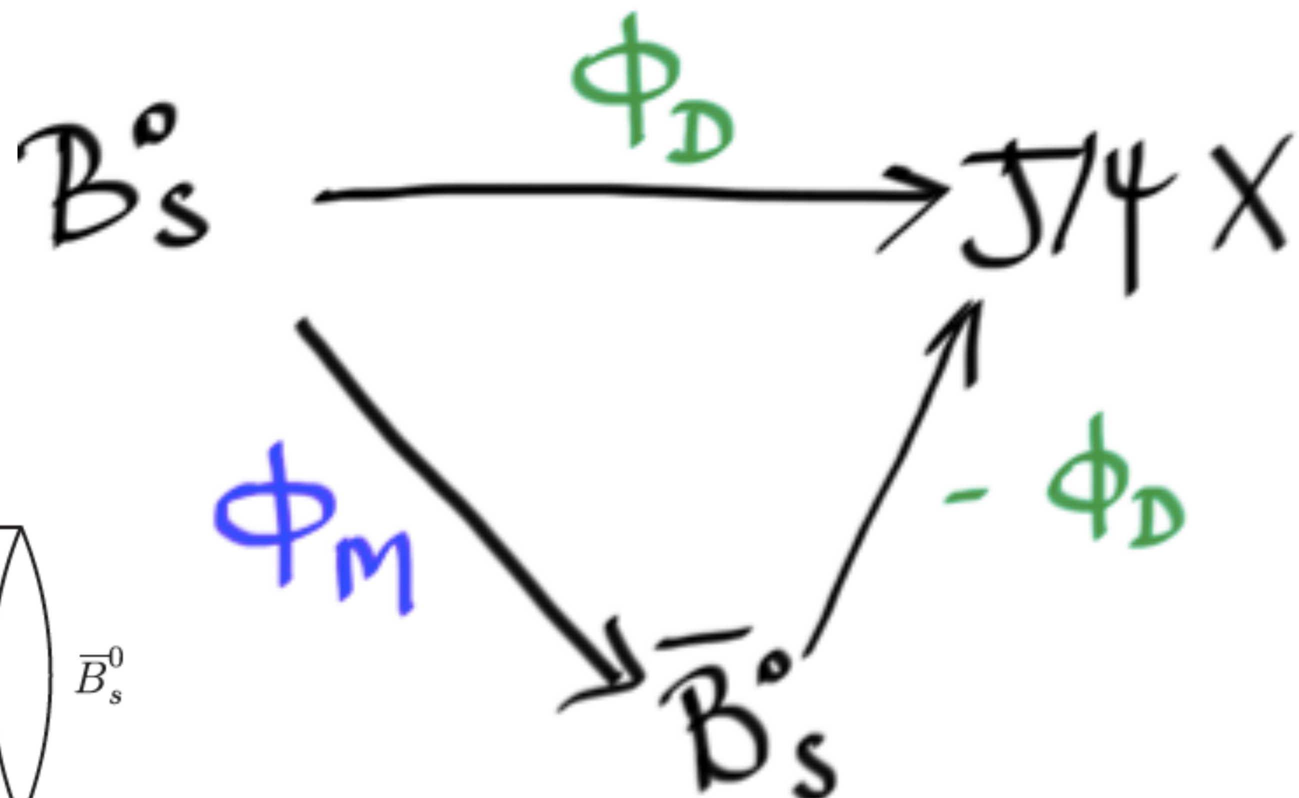
Decay



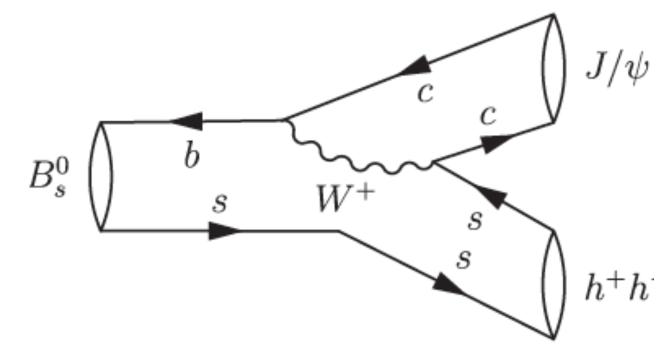
Mixing



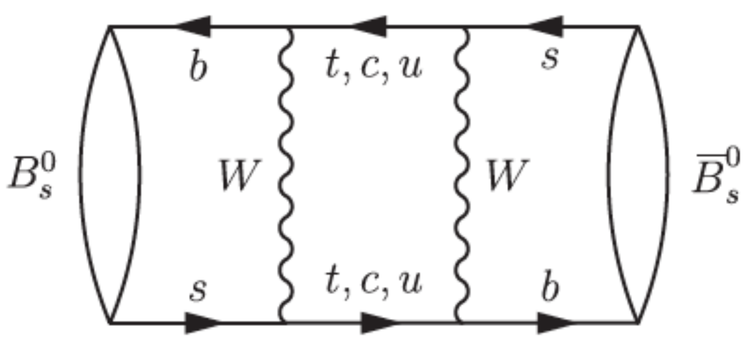
Φ_s from $b \to ccs$ transitions

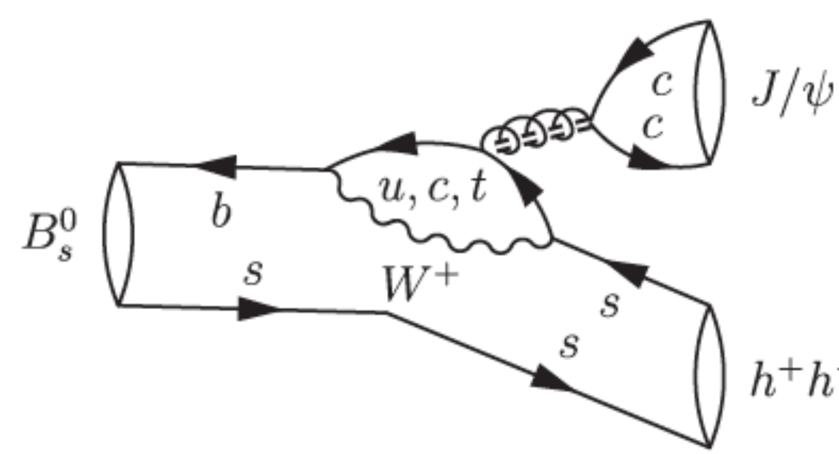


Decay



Mixing



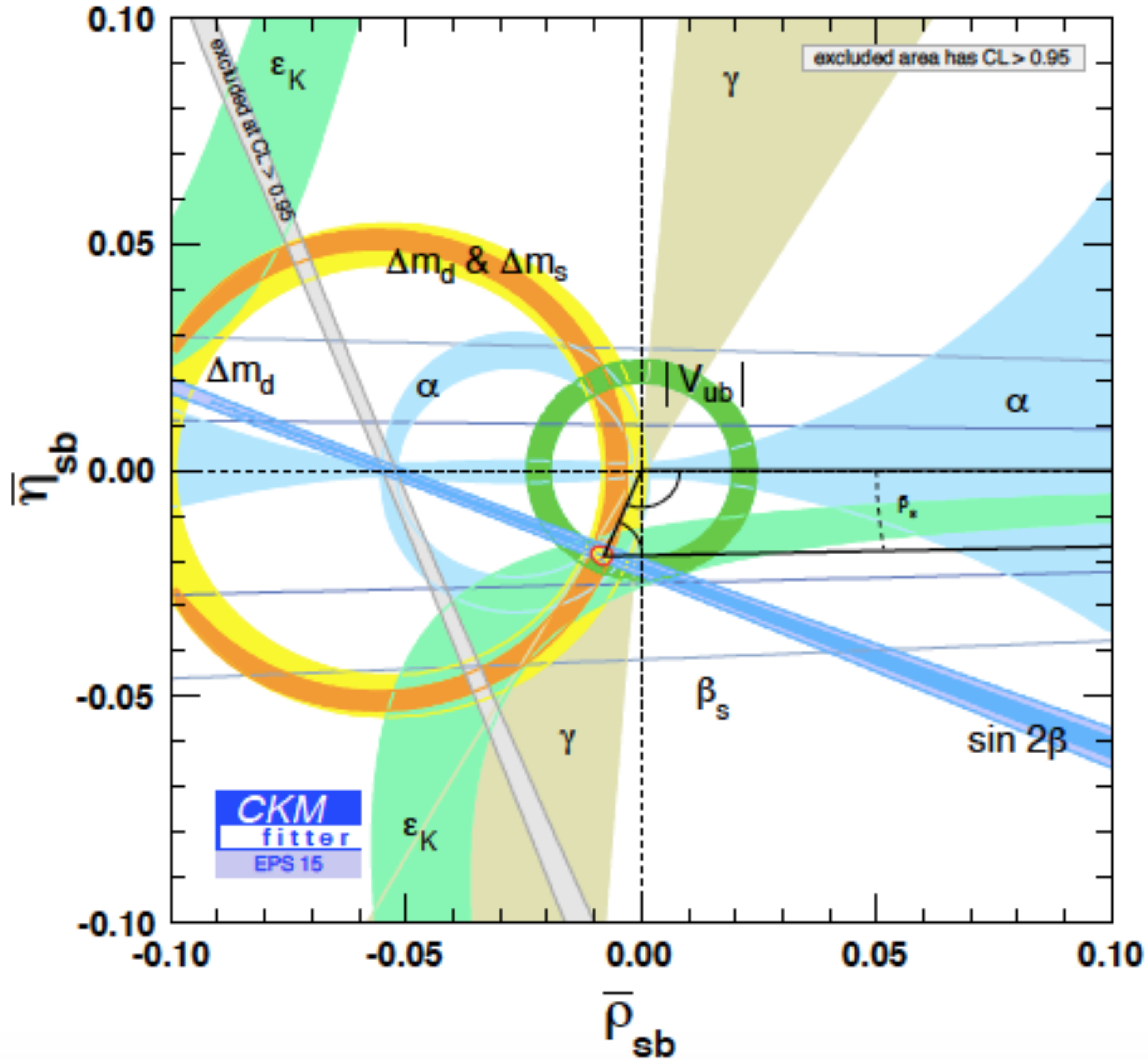


$$\phi_s = \phi_s^{SM} + \phi_s^{NP}$$

$\phi_s^{SM} = \phi_M$ Predicted to be very small in the SM

Phys. Rev D84 (2001) 033005

The other triangle



What do we measure ?

$$\mathcal{A}_{CP}(t) = \frac{\Gamma\left(\overline{B}_q^0(t) \to f\right) - \Gamma\left(B_q^0(t) \to f\right)}{\Gamma\left(\overline{B}_q^0(t) \to f\right) + \Gamma\left(B_q^0(t) \to f\right)} = \frac{\mathcal{S}_f \sin\left(\Delta m t\right) - \mathcal{C}_f \cos\left(\Delta m t\right)}{\cosh\left(\frac{\Delta\Gamma t}{2}\right) + \mathcal{A}_{\Delta\Gamma} \sinh\left(\frac{\Delta\Gamma t}{2}\right)}$$

$$\Delta m = m_{\mathrm{H}} - m_{\mathrm{L}} \qquad \Delta\Gamma = \Gamma_{\mathrm{L}} - \Gamma_{\mathrm{H}}$$

Mixing parameters

$$\mathcal{S}_f = \frac{2\Im(\lambda_f)}{1+|\lambda_f|^2}\,, \quad \mathcal{C}_f = \frac{1-|\lambda_f|^2}{1+|\lambda_f|^2}\,, \quad \mathcal{A}_{\Delta\Gamma} = -\frac{2\Re(\lambda_f)}{1+|\lambda_f|^2}$$

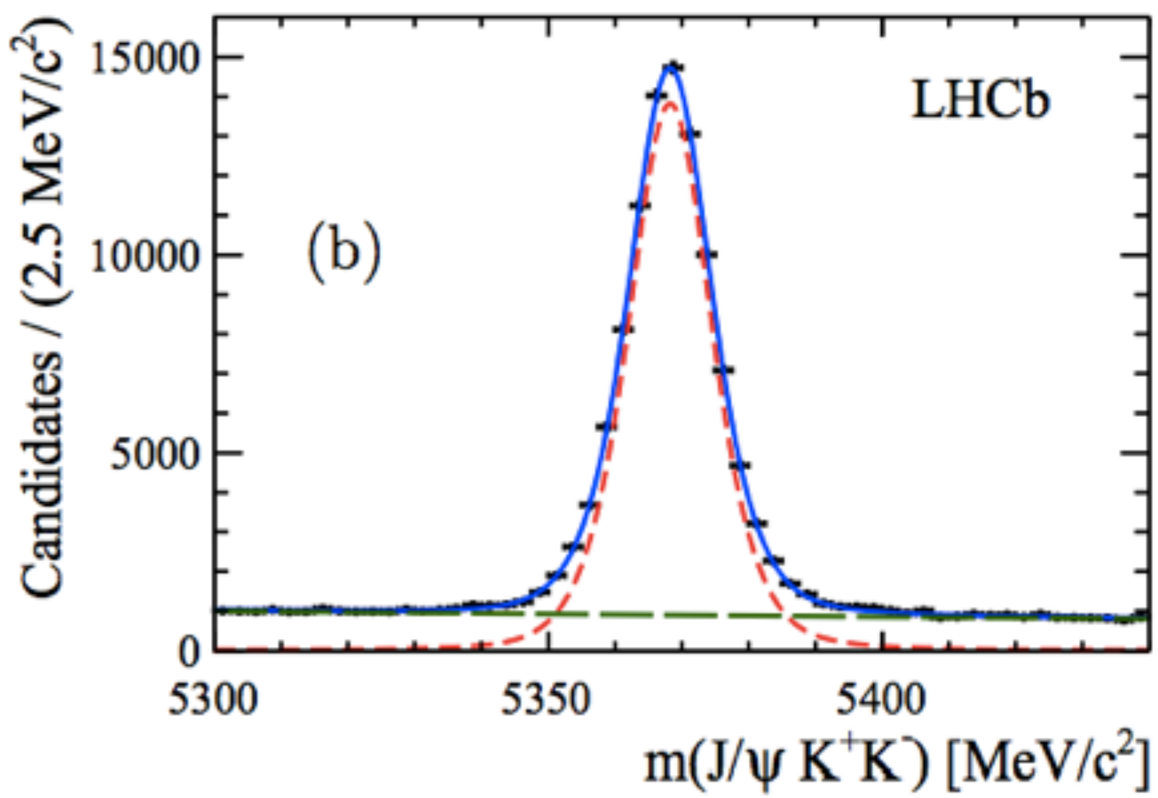
$$\lambda_f = \eta_f \frac{q}{p} \frac{A(\overline{B}_q^0(t) \to f)}{A(B_q^0(t) \to f)} = \eta_f |\lambda_f| e^{i\phi_q}$$

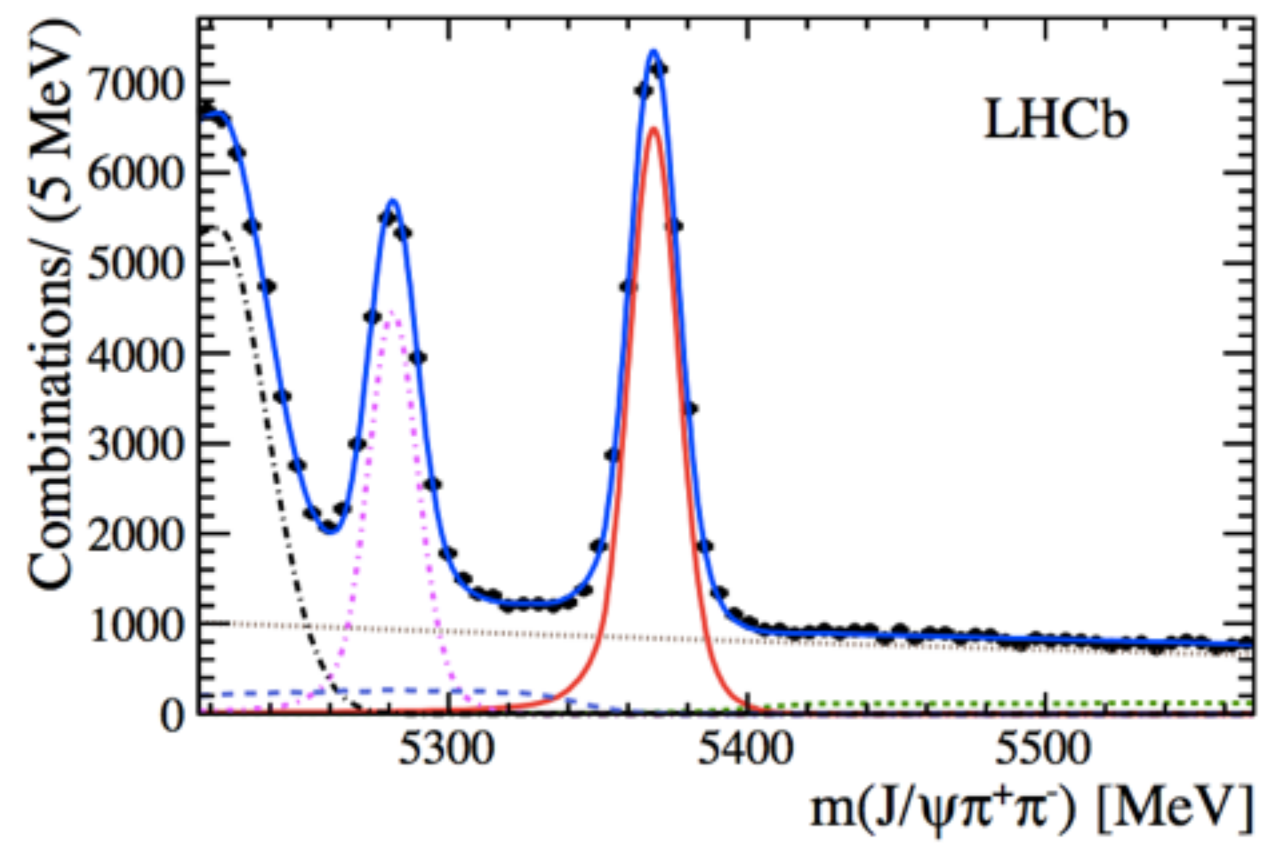
CP observables

$$\mathcal{S}_f = -\eta_f \frac{2|\lambda_f|\sin(\phi_q)}{1+|\lambda_f|^2}\,, \quad \mathcal{A}_{\Delta\Gamma} = \eta_f \frac{2|\lambda_f|\cos(\phi_q)}{1+|\lambda_f|^2}$$

Measurement of Φ_s in $B_s \to J/\psi\, h^+h^-$ [3 fb^{-1}]

The golden modes



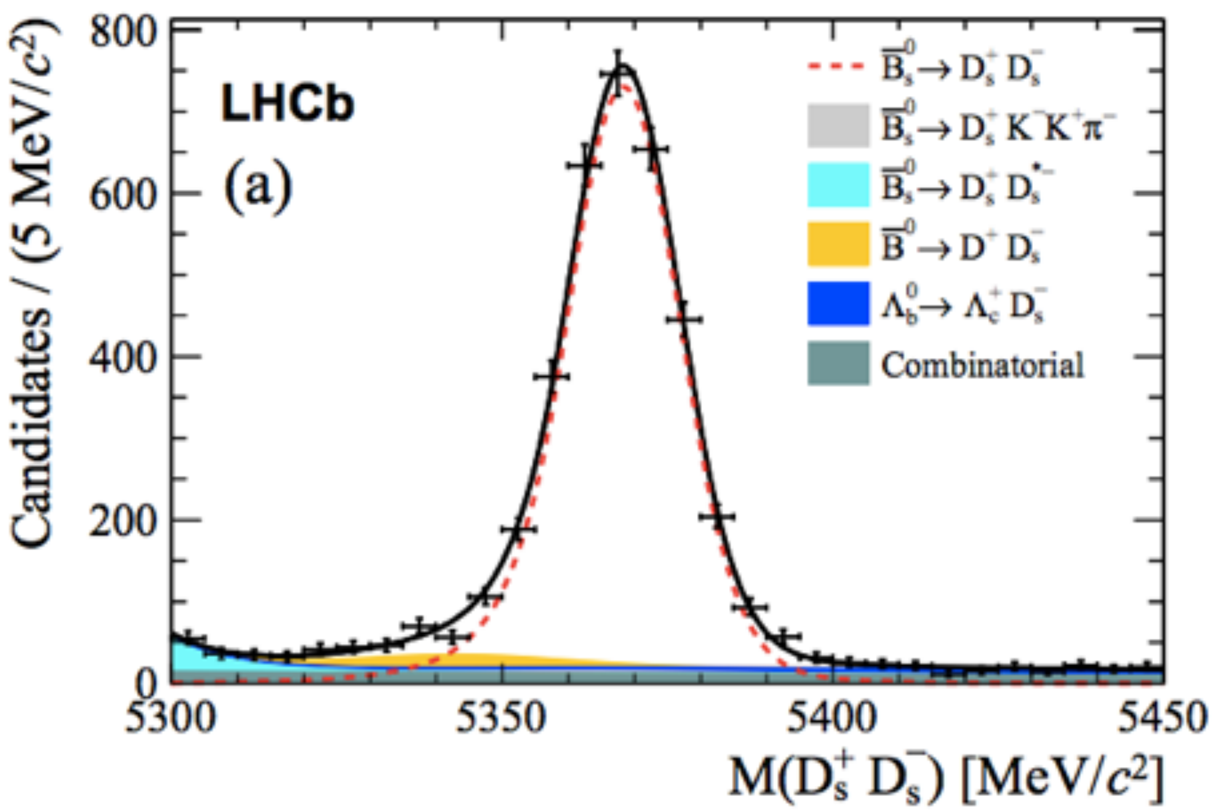


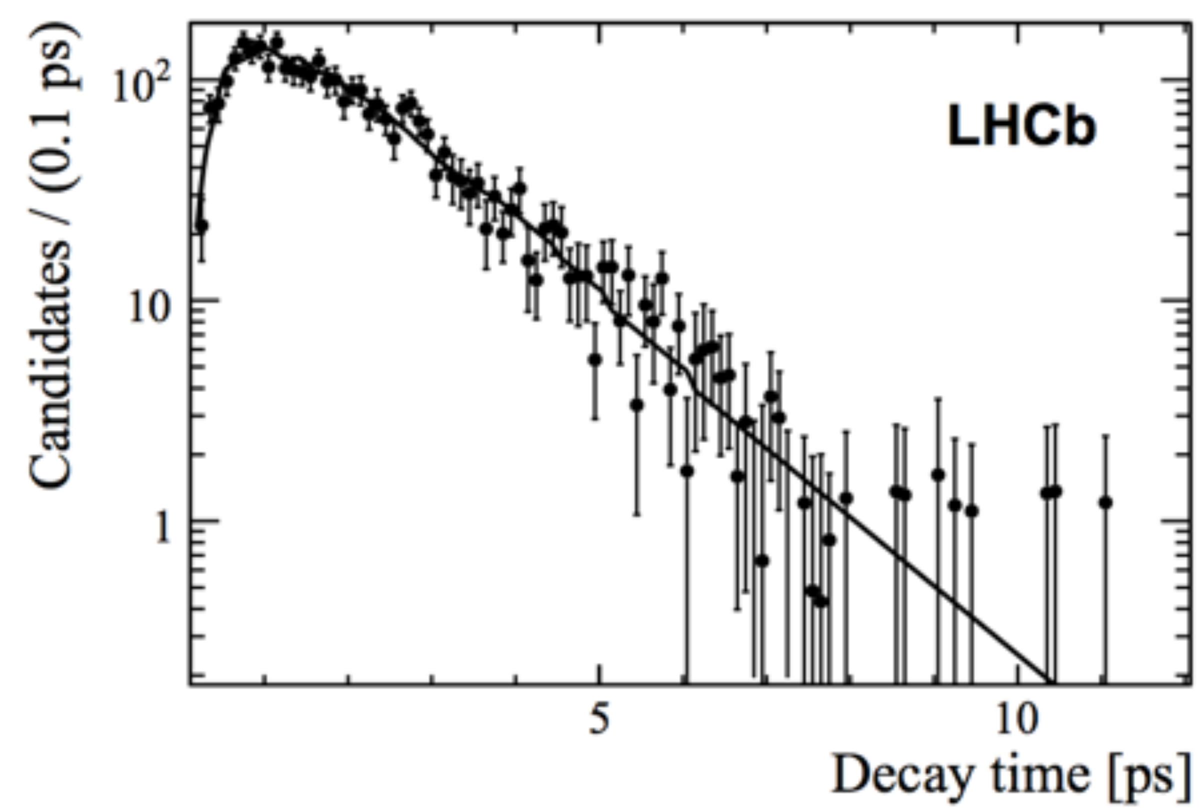
Use angular analysis to separate the *CP* components.

[Phys. Rev. Lett. 114 041801 (2015)]

[Phys. Lett. B 736 (2014) 186]

Measurement of Φ_s in $B_s \to D_s D_s$ [3 fb^{-1}]





CP-even final state

Phys. Rev. Lett. 113 (2014) 211801

$B_s^0 \to J/\psi K^+K^-$ and $B_s^0 \to J/\psi \pi^+\pi^-$

$\phi_s^{c\bar{c}s} = -0.010 \pm 0.039\,\text{rad}$

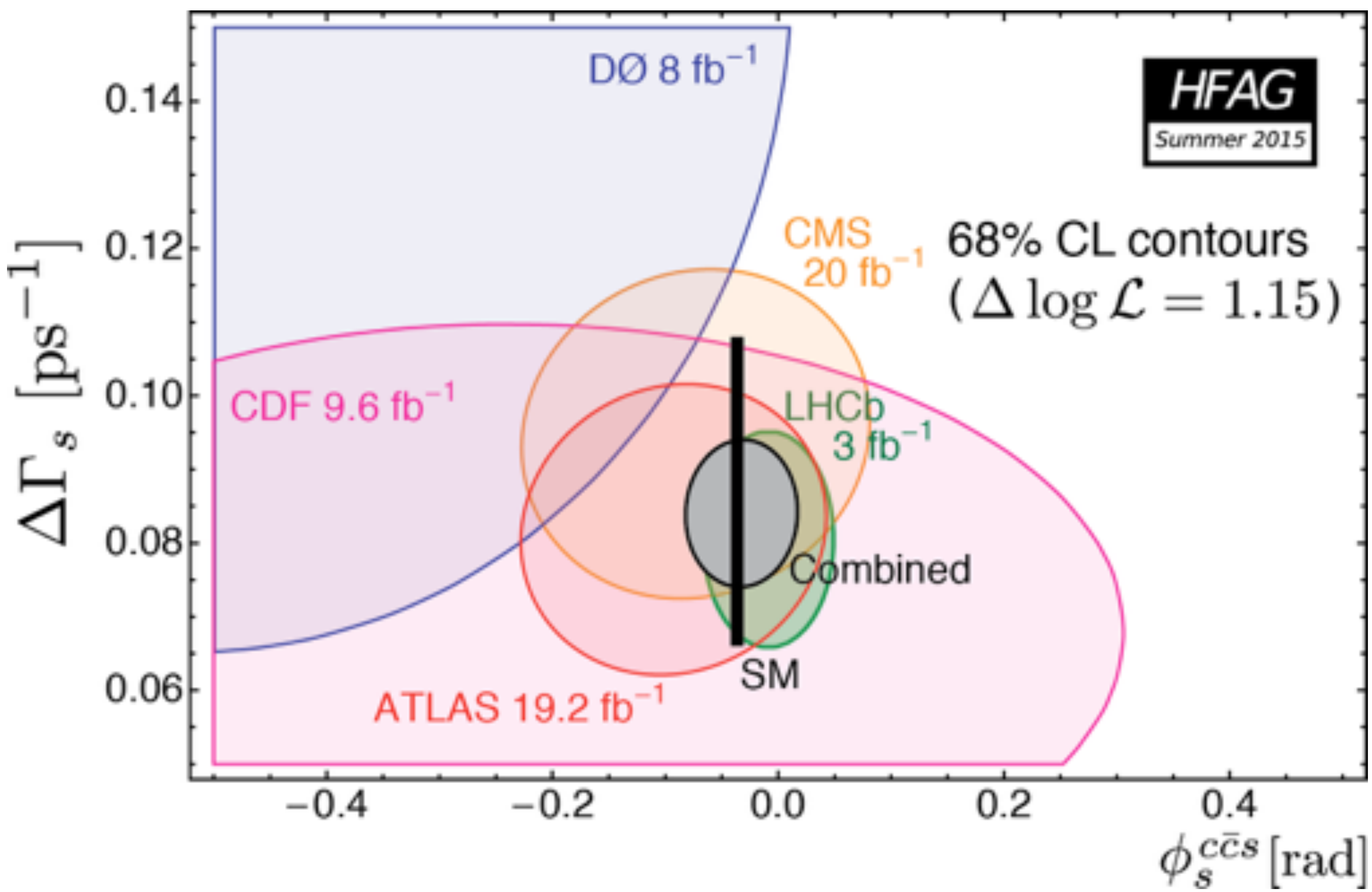
stat+syst

The big picture

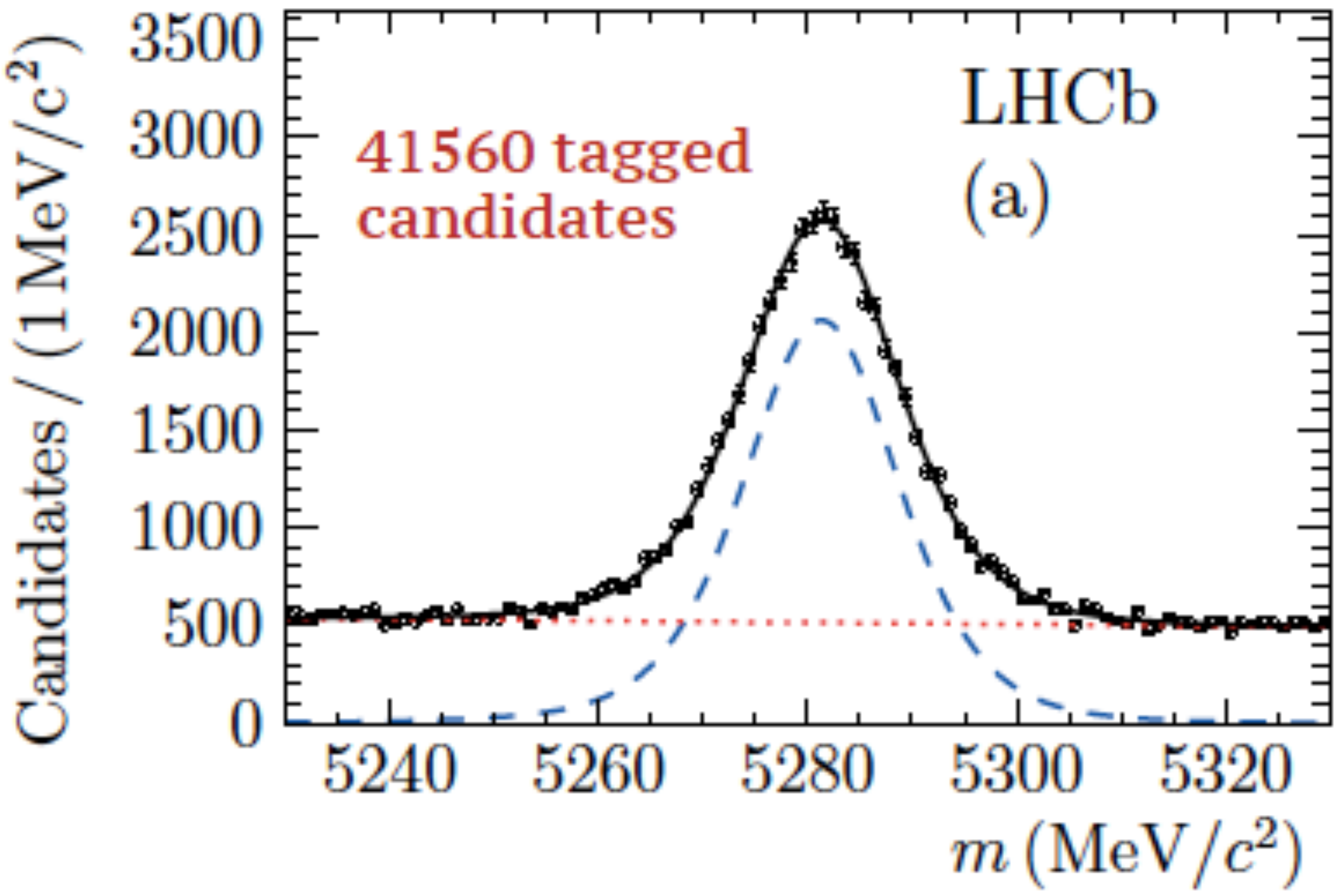
$B_s^0 \to D_s^+ D_s^-$

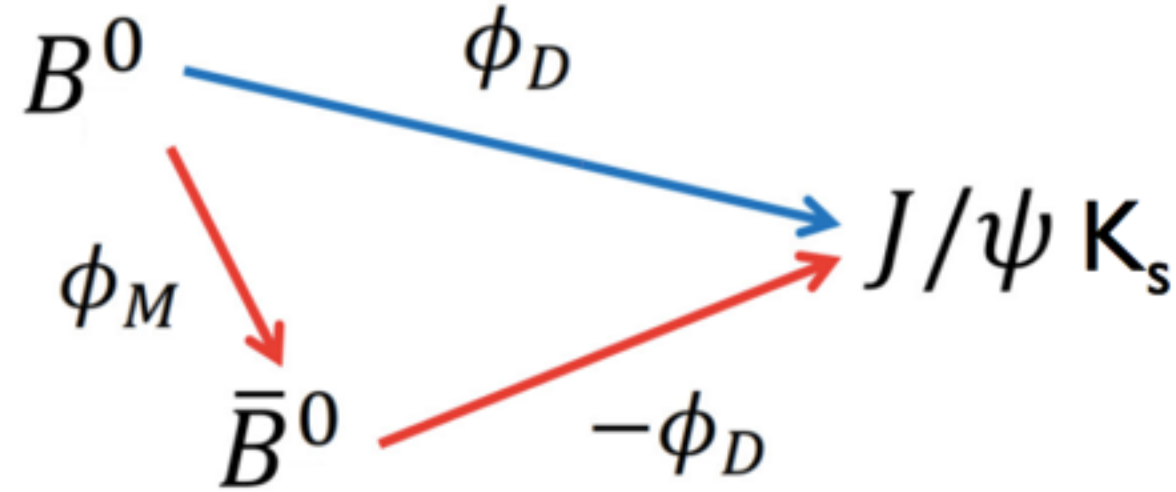
$\phi_s^{c\bar{c}s} = +0.02 \pm 0.17 \pm 0.02\,\text{rad}$

stat syst



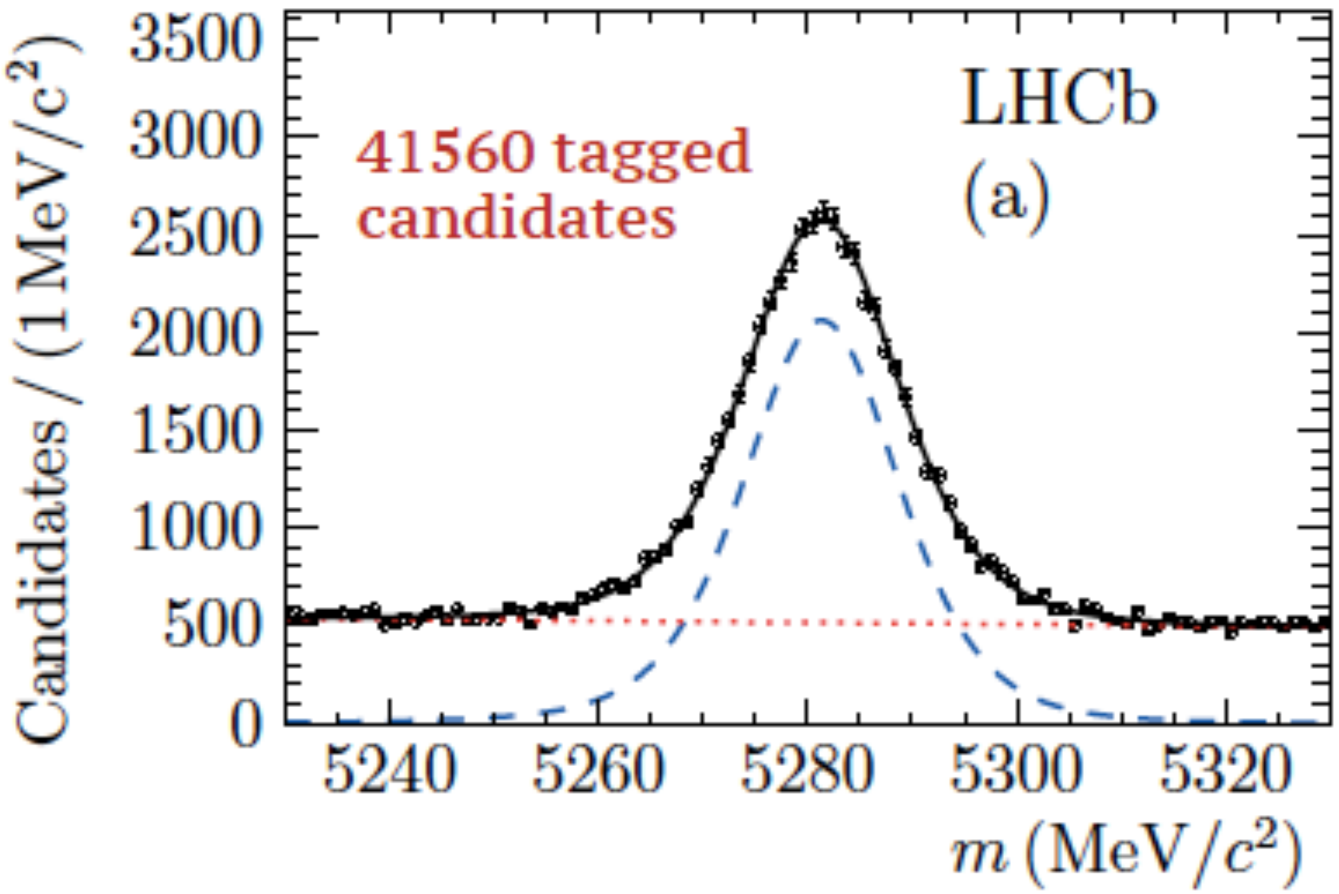
Measurement of CPV in B→ J/ψ K_s [3 fb^{-1}]

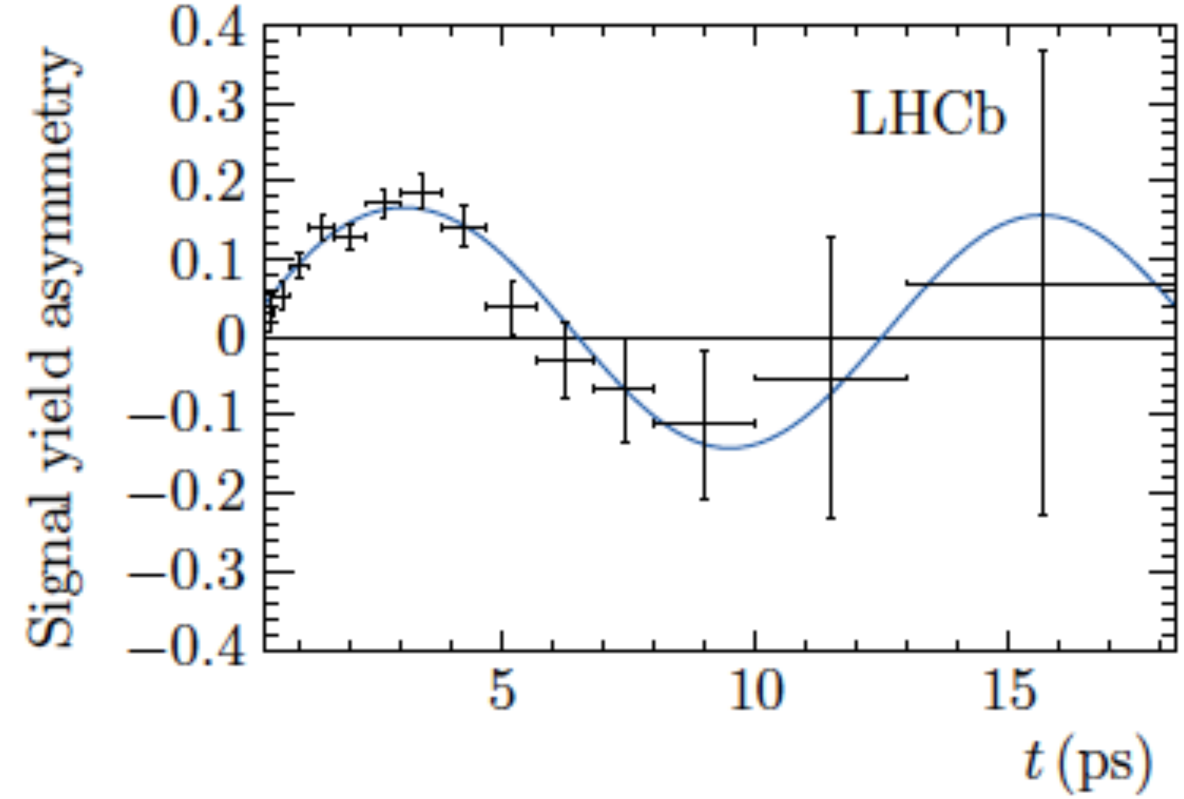




Phys. Rev. Lett. 115, 031601 (2015)]

Measurement of CPV in $B \to J/\psi K_s$ [3 fb^{-1}]





$$S = \quad 0.731 \pm 0.035\,(\text{stat}) \pm 0.020\,(\text{syst}),$$
$$C = -0.038 \pm 0.032\,(\text{stat}) \pm 0.005\,(\text{syst}).$$

Phys. Rev. Lett. 115, 031601 (2015)]

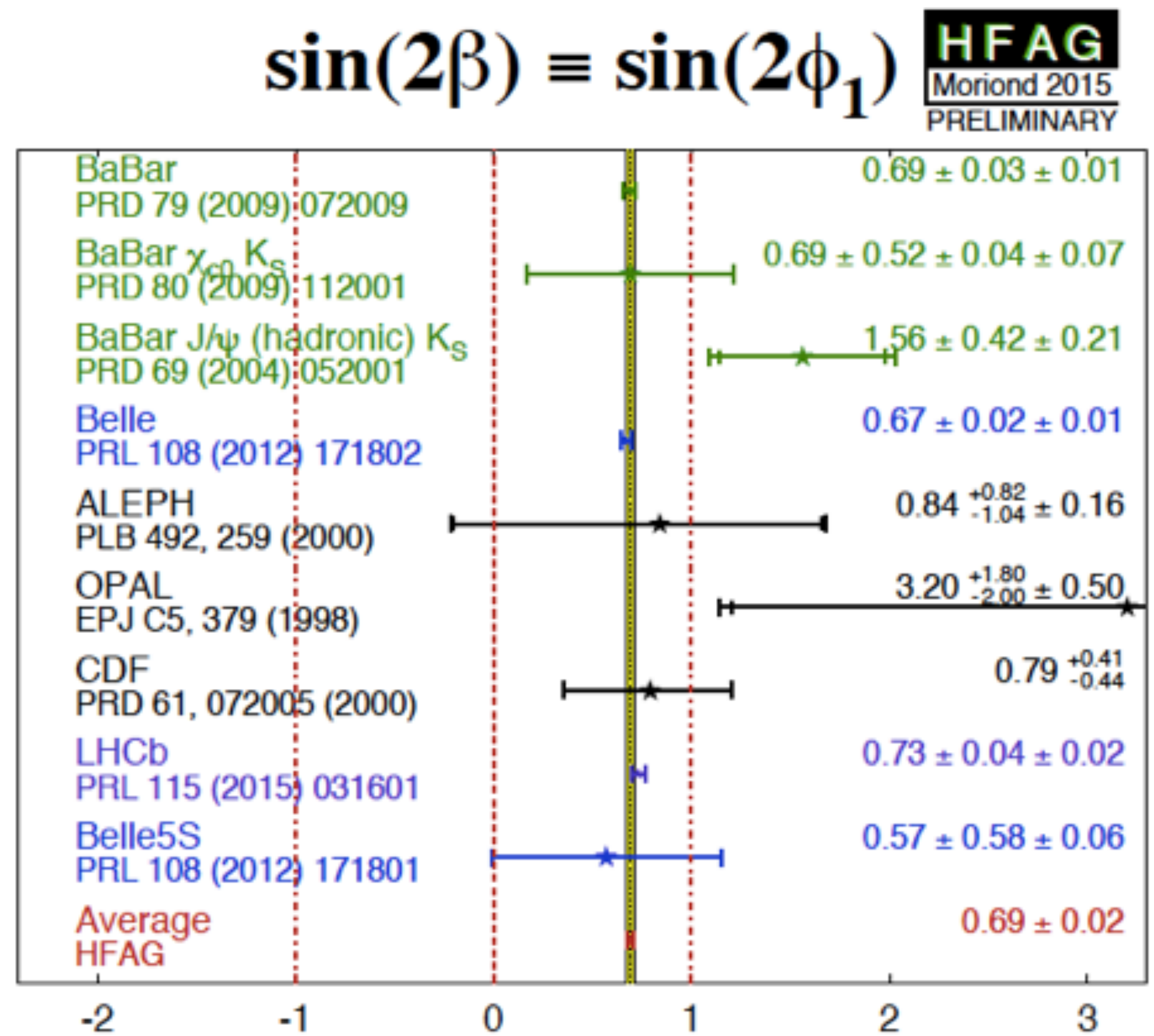
An other big picture

World average: [HFAG]

$$\sin(2\beta)^{\text{exp}} = 0.691 \pm 0.017$$

Expectation from global fit: [CKMFitter]

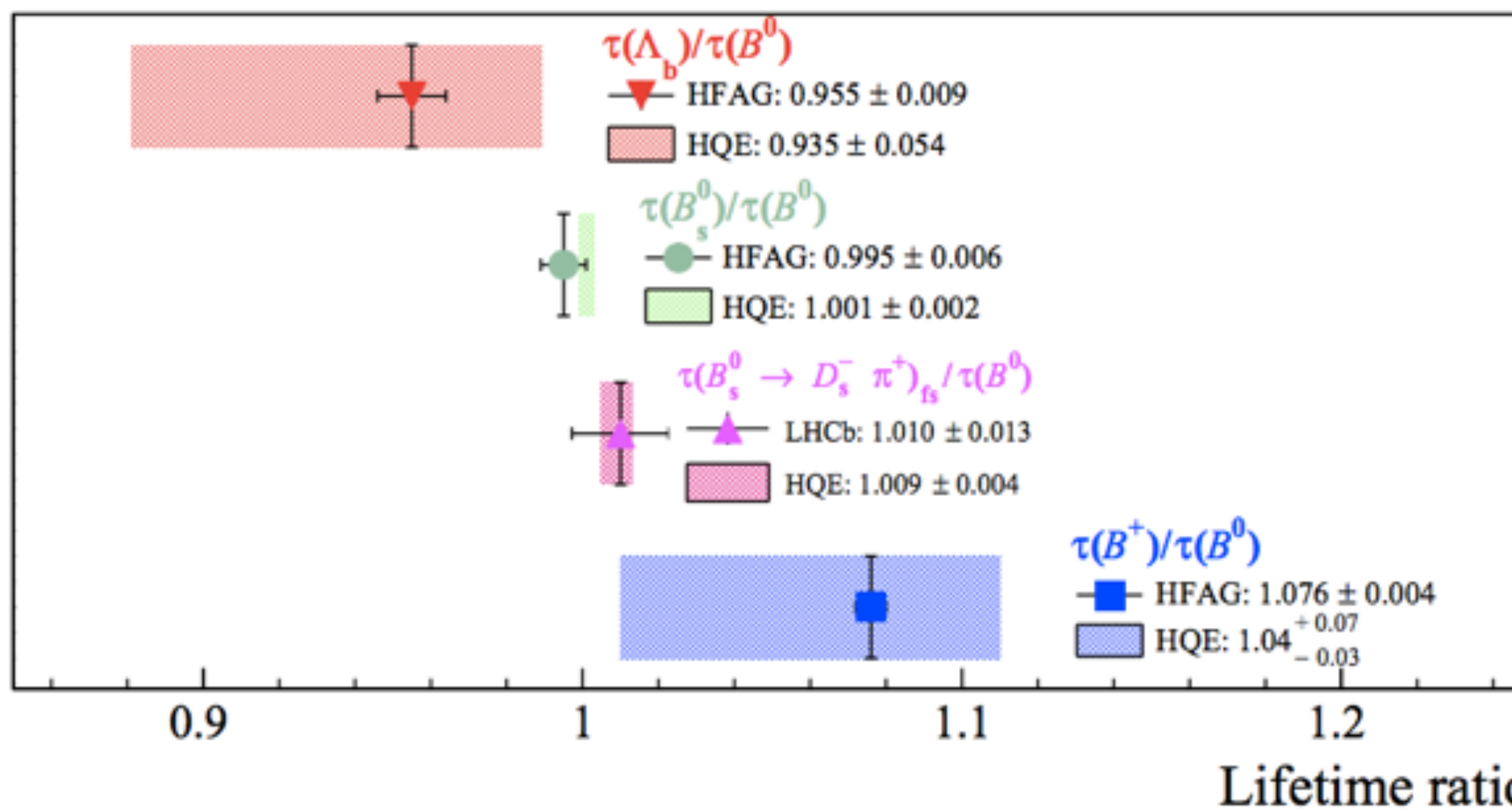
$$\sin(2\beta)^{\text{SM}} = 0.748^{+0.030}_{-0.032}$$



Very precise lifetime measurements

Ratio	Value
$\tau_{B^+}/\tau_{B^0\to J/\psi K^*(892)^0}$	$1.074 \pm 0.005 \pm 0.003$
$\tau_{B_s^0}/\tau_{B^0\to J/\psi K^*(892)^0}$	$0.971 \pm 0.009 \pm 0.004$
$\tau_{\Lambda_b^0}/\tau_{B^0\to J/\psi K^*(892)^0}$	$0.929 \pm 0.018 \pm 0.004$
τ_{B^+}/τ_{B^-}	$1.002 \pm 0.004 \pm 0.002$
$\tau_{\Lambda_b^0}/\tau_{\overline{\Lambda}_b^0}$	$0.940 \pm 0.035 \pm 0.006$
$\tau_{B^0\to J/\psi K^*(892)^0}/\tau_{\overline{B}^0\to J/\psi \overline{K}^*(892)^0}$	$1.000 \pm 0.008 \pm 0.009$

Useful test of HQE

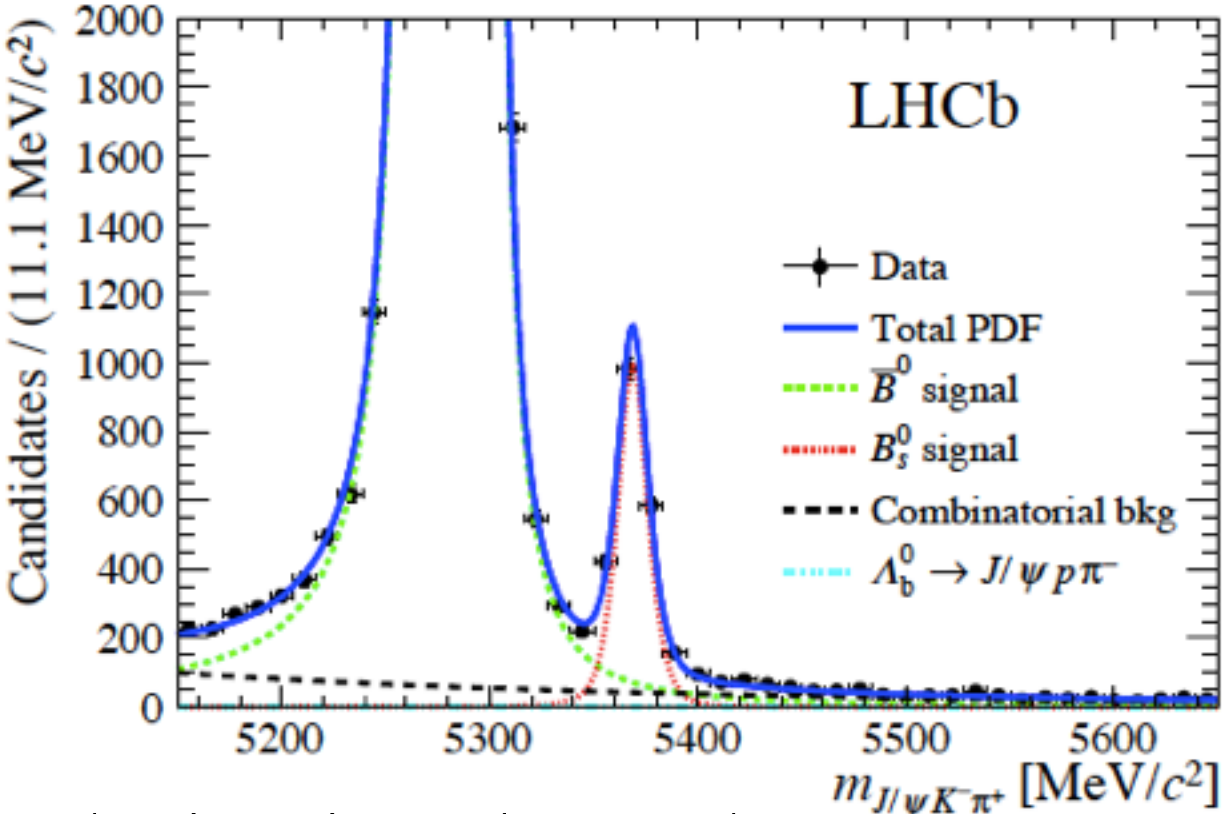


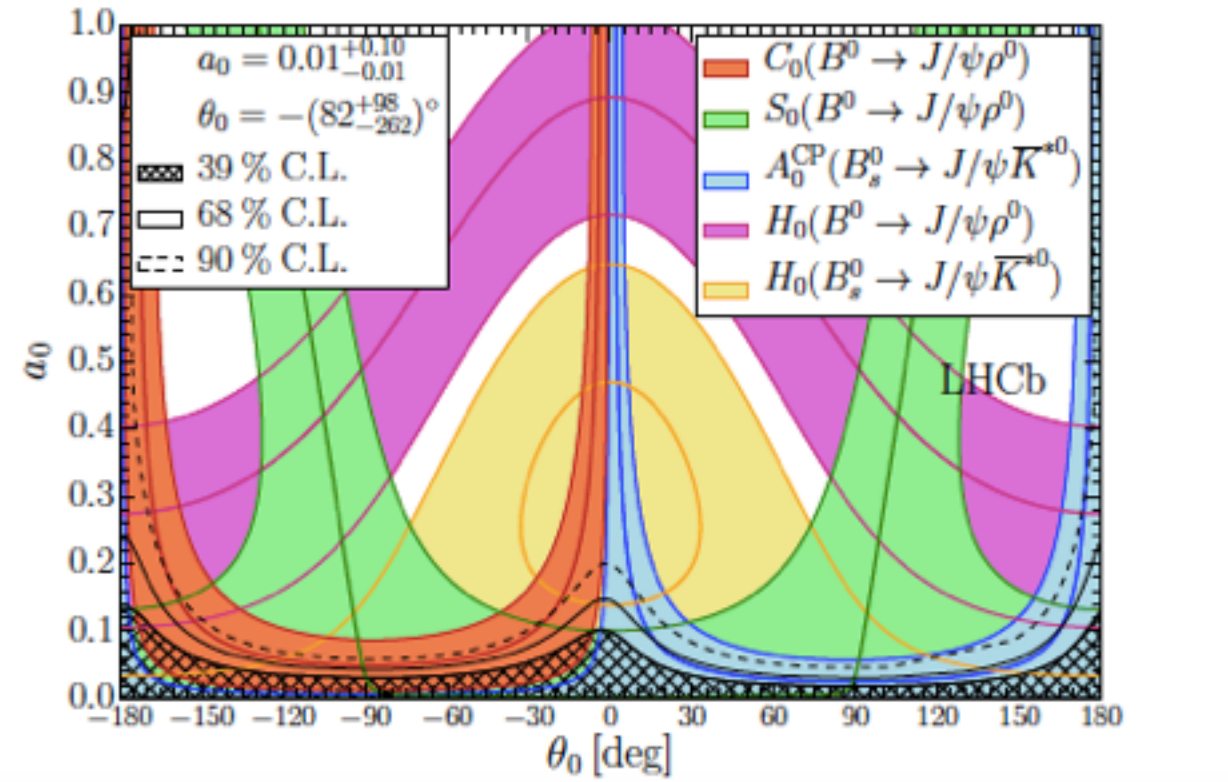
JHEP04(2014)114 [1 fb^{-1}]

How do we constrain the penguins ?

Proposal : arXiv:1412.6834

$$A\left(B_s^0 \to J/\psi \overline{K}^{*0})_i\right) = -\lambda \mathcal{A}_i \left[1 - a_i e^{i\theta_i} e^{i\gamma}\right]$$





Polarization dependent

$$\Delta\phi_{s,0}^{J/\psi\,\phi} = 0.000^{+0.009}_{-0.011}\,(\text{stat})^{+0.004}_{-0.009}\,(\text{syst})\ \text{rad}$$

$$\Delta\phi_{s,\parallel}^{J/\psi\,\phi} = 0.001^{+0.010}_{-0.014}\,(\text{stat})^{+0.007}_{-0.008}\,(\text{syst})\ \text{rad}$$

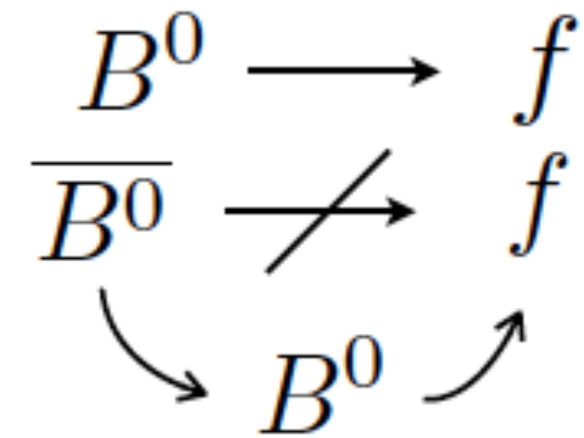
$$\Delta\phi_{s,\perp}^{J/\psi\,\phi} = 0.003^{+0.010}_{-0.014}\,(\text{stat})^{+0.007}_{-0.008}\,(\text{syst})\ \text{rad}$$

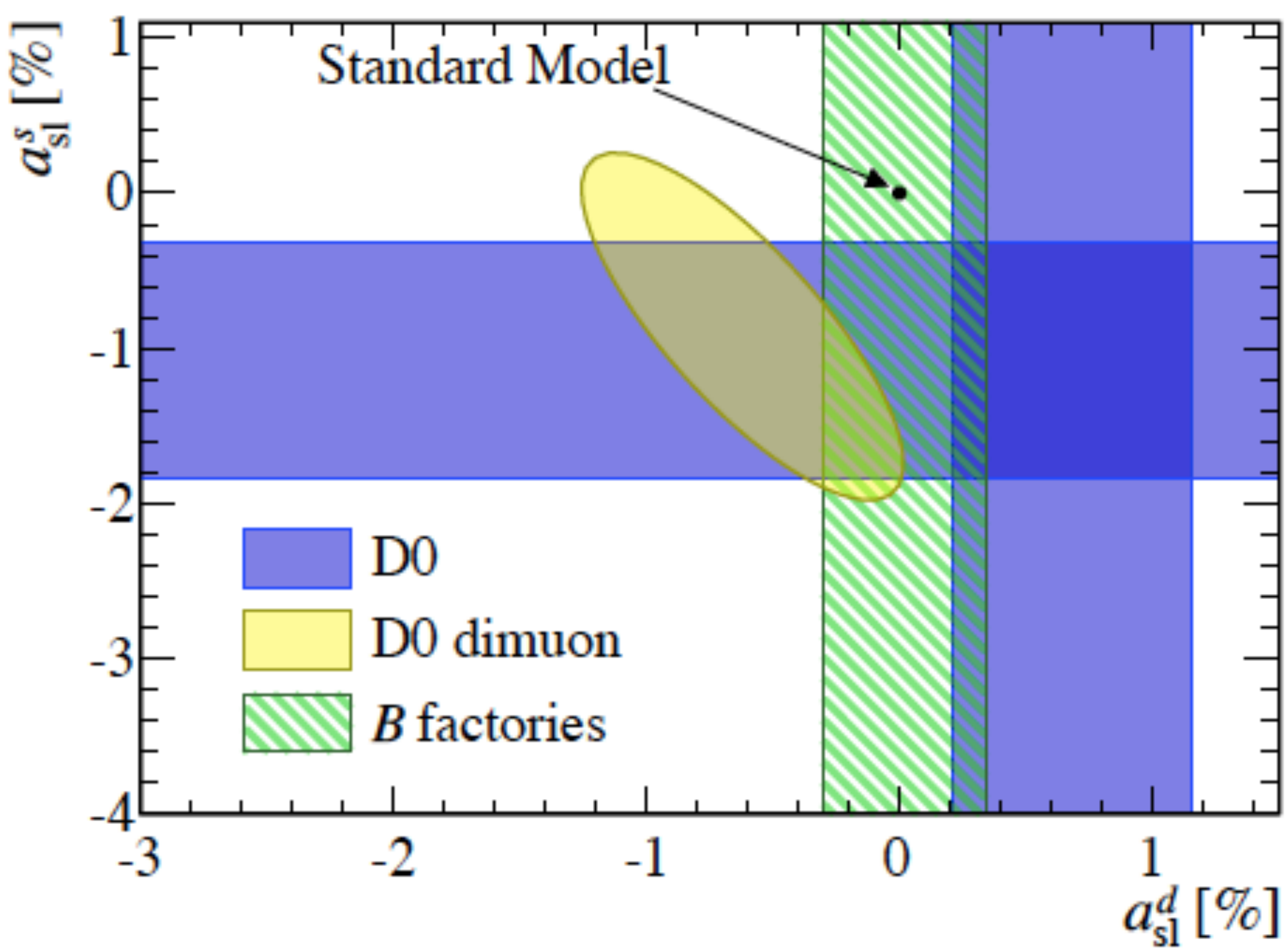
The penguins are small!

arXiv:1509.00400 [3 fb^{-1}]
Phys. Lett. B742 (2015) 38 [3 fb^{-1}]

More CP asymmetries

$$a_{\rm sl} = \frac{N(\bar{B}\to B \to f) - N(B\to \bar{B} \to \bar{f})}{N(\bar{B}\to B \to f) + N(B\to \bar{B} \to \bar{f})}$$



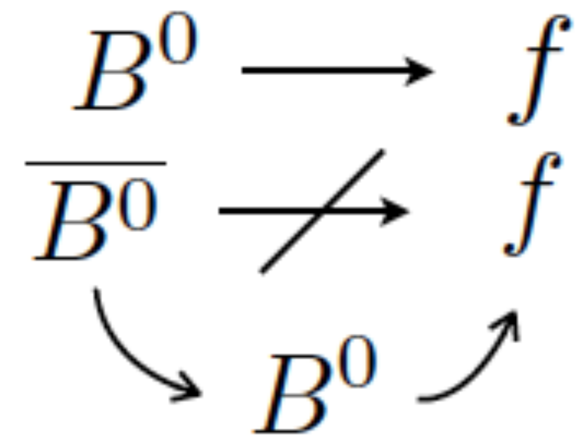


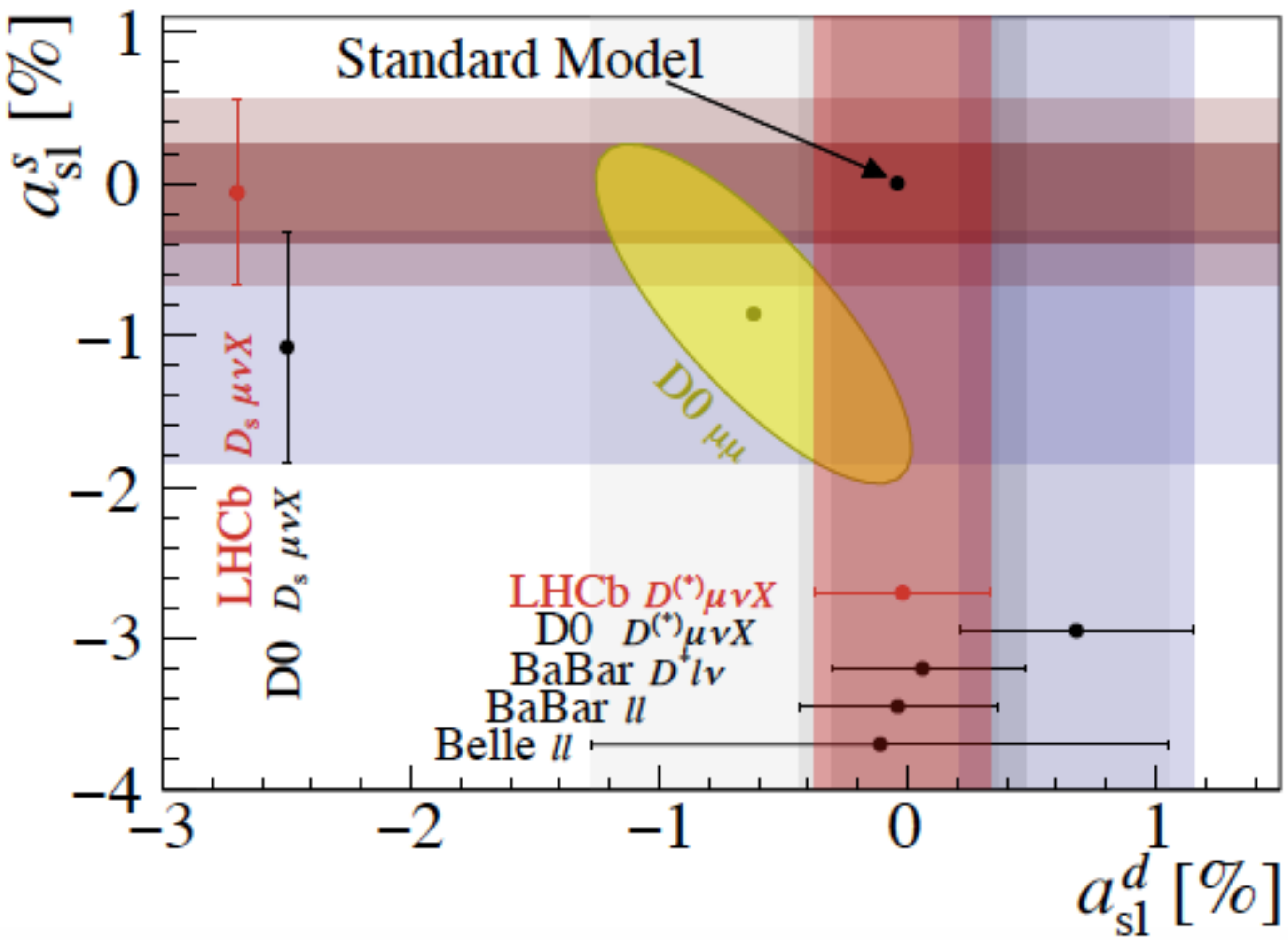
Phys. Rev. Lett. 114 (2015) 041601 [3 fb^{-1}]

Phys. Lett. B 728 (2014) 607-615 [1 fb^{-1}]

More CP asymmetries

$$a_{\mathrm{sl}} = \frac{N(\bar{B}\to B \to f) - N(B\to\bar{B} \to \bar{f})}{N(\bar{B}\to B \to f) + N(B\to\bar{B} \to \bar{f})}$$



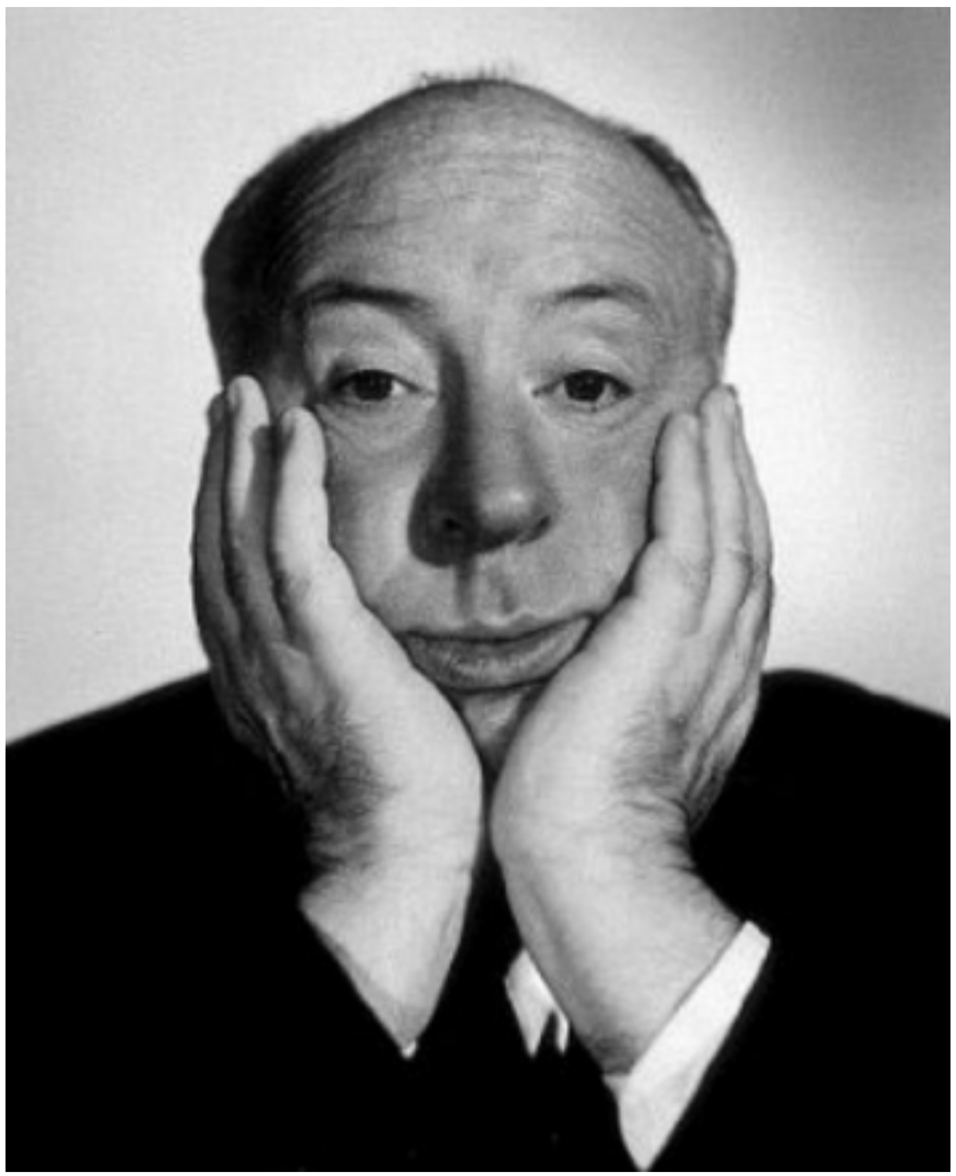


LHCb measurements very consistent with the SM.

Phys. Rev. Lett. 114 (2015) 041601 [3 fb^{-1}]

Phys. Lett. B 728 (2014) 607-615 [1 fb^{-1}]

Conclusion

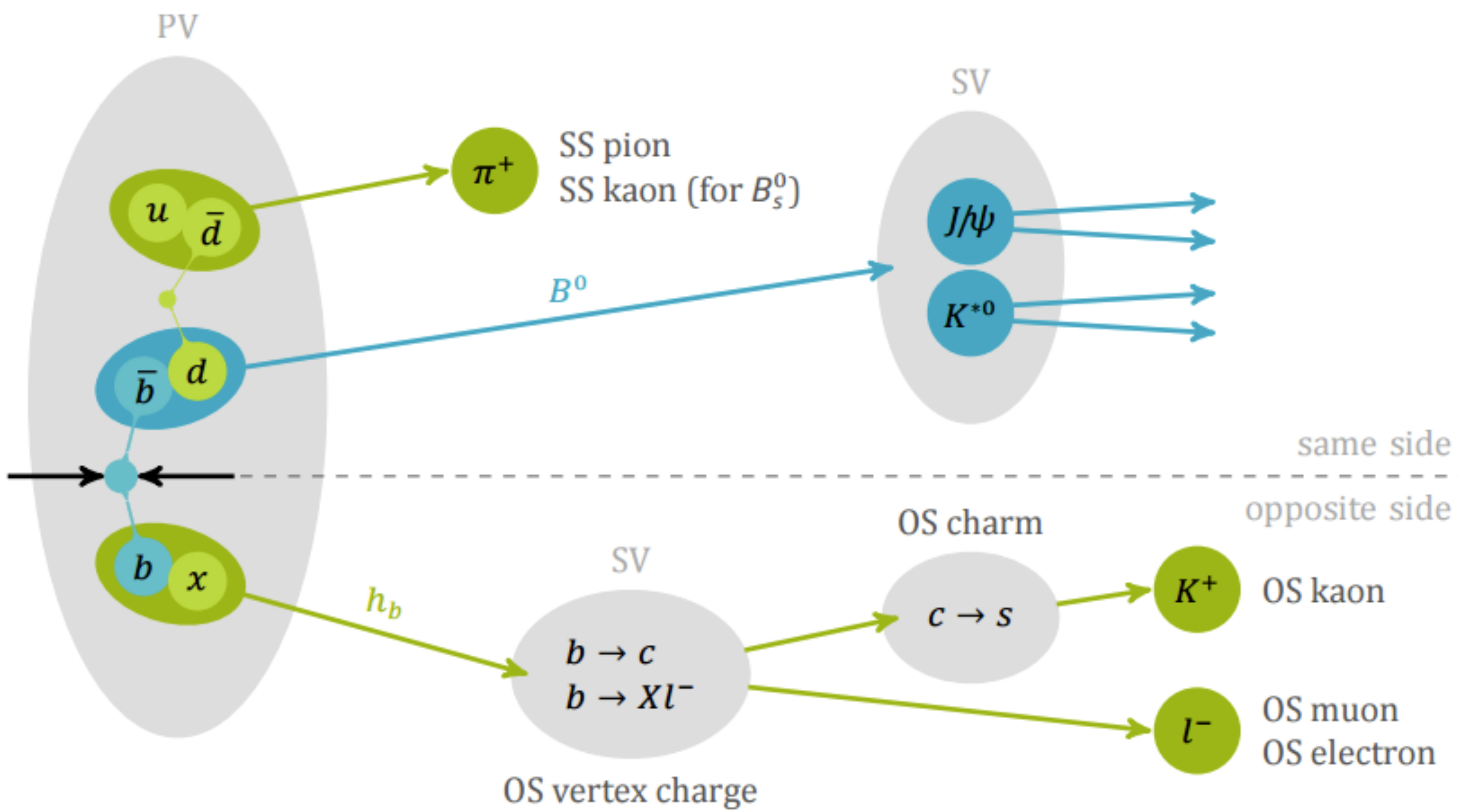


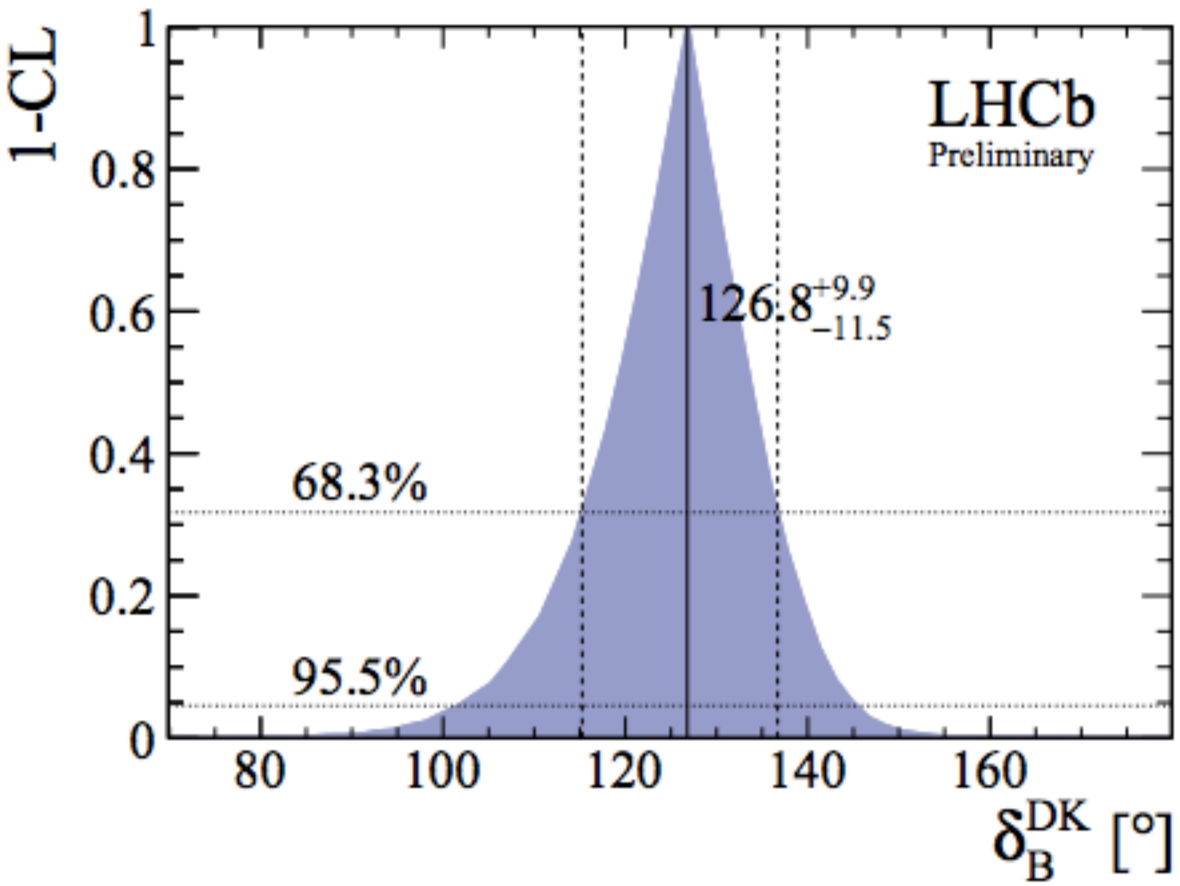
The measurements of CP observables are reaching very high precision.

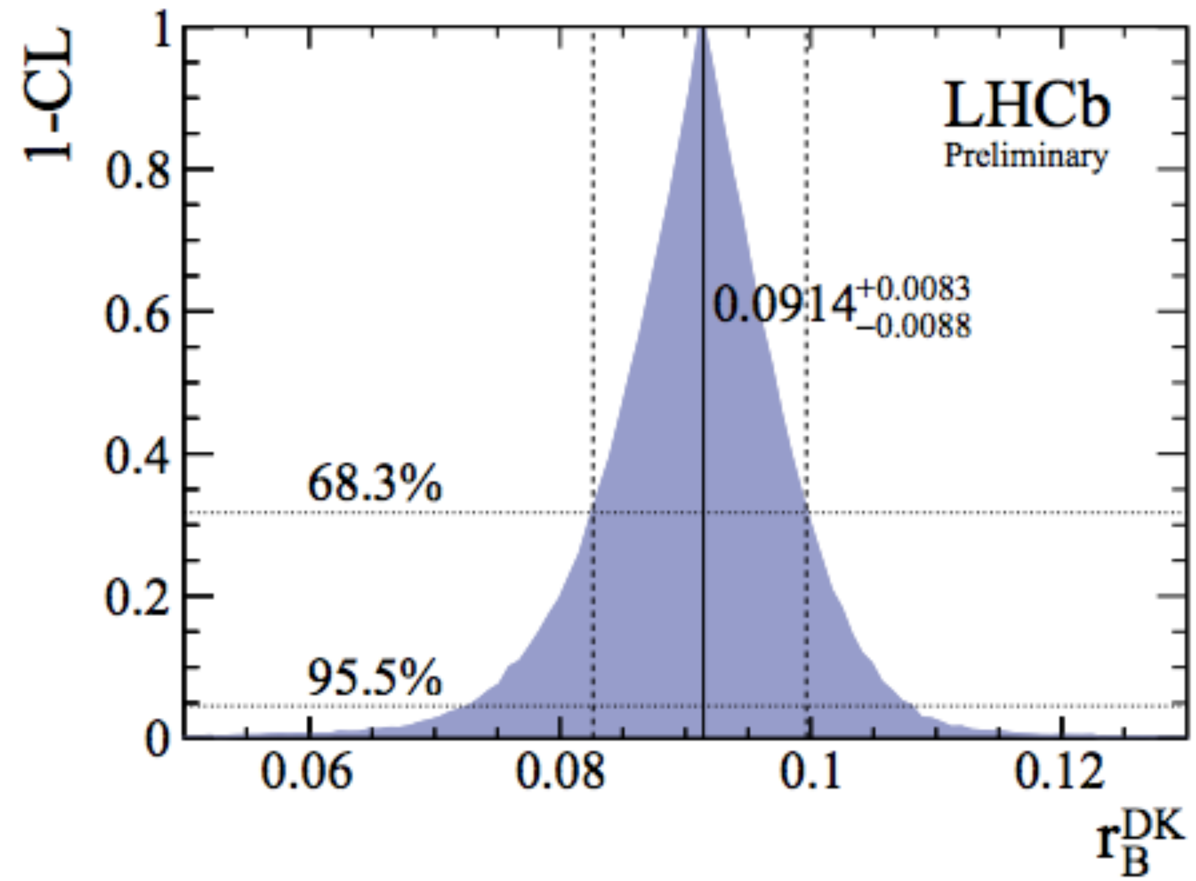
LHCb will continue to collect data and push further the precision of the measurements as well as add additional modes

No clear sign of New Physics contributions.

Backup slides


PV
SV
SS pion
SS kaon (for B_s^0)
π^+
u
$\bar{d}$
B^0
J/ψ
K^{*0}
$\bar{b}$
d
same side
opposite side
OS charm
SV
b
x
h_b
$c \to s$
K^+
OS kaon
$b \to c$
$b \to Xl^-$
l^-
OS muon
OS electron
OS vertex charge


1-CL
LHCb
Preliminary
$126.8^{+9.9}_{-11.5}$
68.3%
95.5%
δ_B^{DK} [°]


1-CL
LHCb
Preliminary
$0.0914^{+0.0083}_{-0.0088}$
68.3%
95.5%
r_B^{DK}

GGSZ (Giri, Grossman, Sofer, Zupan) :

Use quasi 2-body *CP* eigenstate of the *D* to be resolved in the Dalitz plane. $D \longrightarrow K_s \pi\pi$. So far the most precise gamma determination.

ADS (Atwood, Dunietz, Soni):

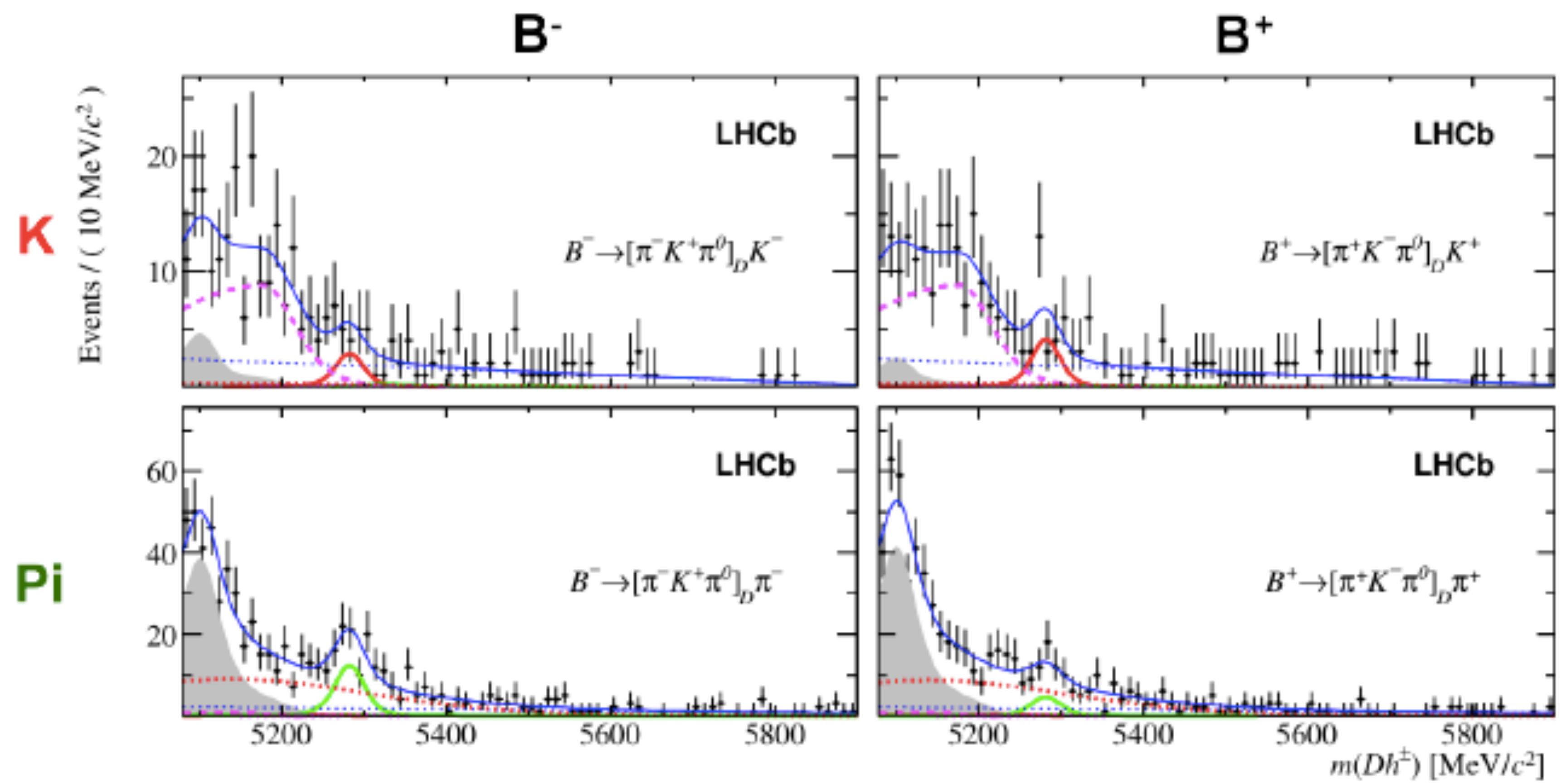
Use *anti-*D^0 $K^+ \pi^-$ for $b \longrightarrow u$ transitions (*Cabibbo allowed*) and $D^0 \longrightarrow K^- \pi^+$ (*Doubly Cabibbo Suppressed*) for $b \longrightarrow c$ transitions. One has to know strong phases from *D* decays.

GLW (Gronau, London, Wyler):

Search for *D* mesons in *CP* eigenstates eg : $D \longrightarrow KK$ and $D \longrightarrow \pi\pi$

[PHYS. REV. D91 (2015) 112014]

ADS-like modes



$B \to DK$ signal significance 2.8 σ
$B \to D\pi$ signal significance 5.3 σ
$\Rightarrow$ First Observation

$$R^{K\pi\pi^0}_{ADS(K)} = 0.0140 \pm 0.0047 \pm 0.0021$$

$$R^{K\pi\pi^0}_{ADS(\pi)} = 0.00235 \pm 0.00049 \pm 0.00006$$

$$A^{K\pi\pi^0}_{ADS(K)} = -0.020 \pm 0.27 \pm 0.04$$

$$A^{K\pi\pi^0}_{ADS(\pi)} = 0.438 \pm 0.190 \pm 0.011$$

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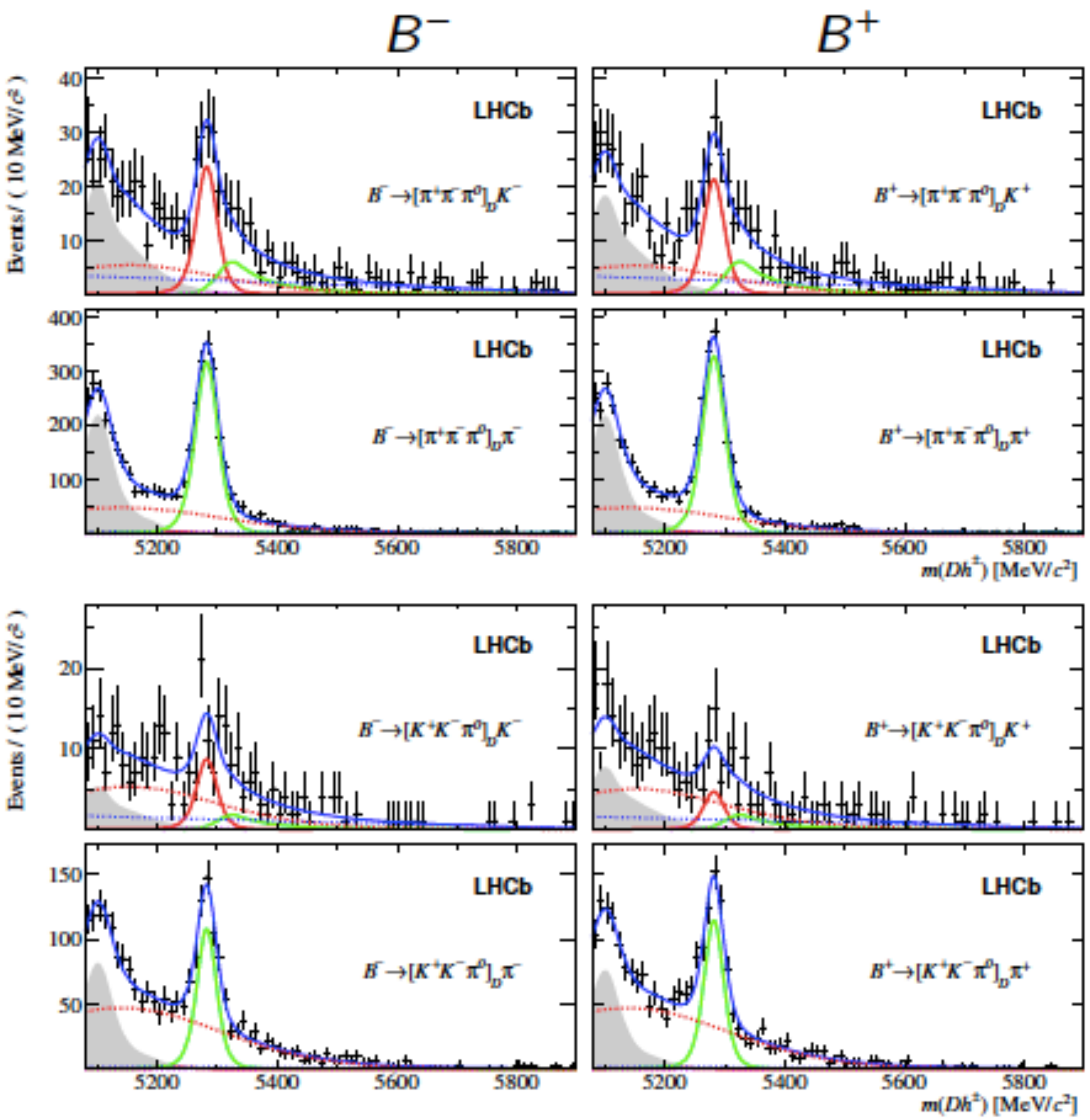
GLW-like modes



B→ DK
B→ Dπ

$B \to D(KK\pi^0)\pi$ signal significance > 10.0σ
$B \to D(KK\pi^0)K$ First evidence (4.5 σ)

$$R^{KK\pi^0}_{qGLW} = 0.95 \pm 0.22 \pm 0.05$$
$$R^{\pi\pi\pi^0}_{qGLW} = 0.98 \pm 0.11 \pm 0.05$$
$$A^{KK\pi^0}_{qGLW(K)} = 0.30 \pm 0.20 \pm 0.02$$
$$A^{\pi\pi\pi^0}_{qGLW(K)} = 0.054 \pm 0.091 \pm 0.011$$
$$A^{KK\pi^0}_{qGLW(\pi)} = -0.030 \pm 0.040 \pm 0.005$$
$$A^{\pi\pi\pi^0}_{qGLW(\pi)} = -0.016 \pm 0.020 \pm 0.004$$