CKM and CP Constraints from B-Decays

Shohei Nishida

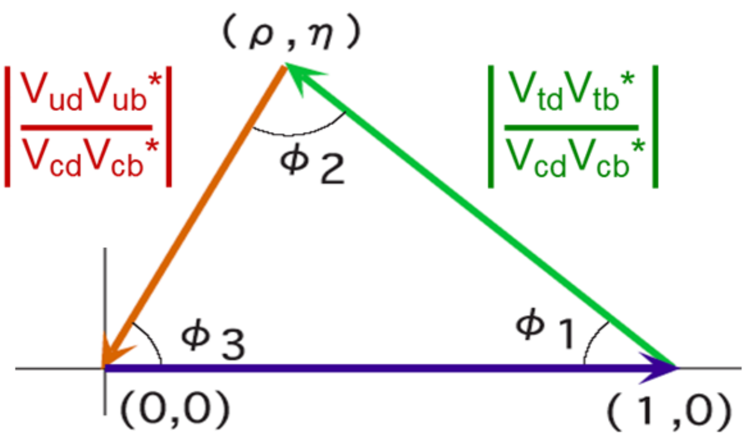
KEK

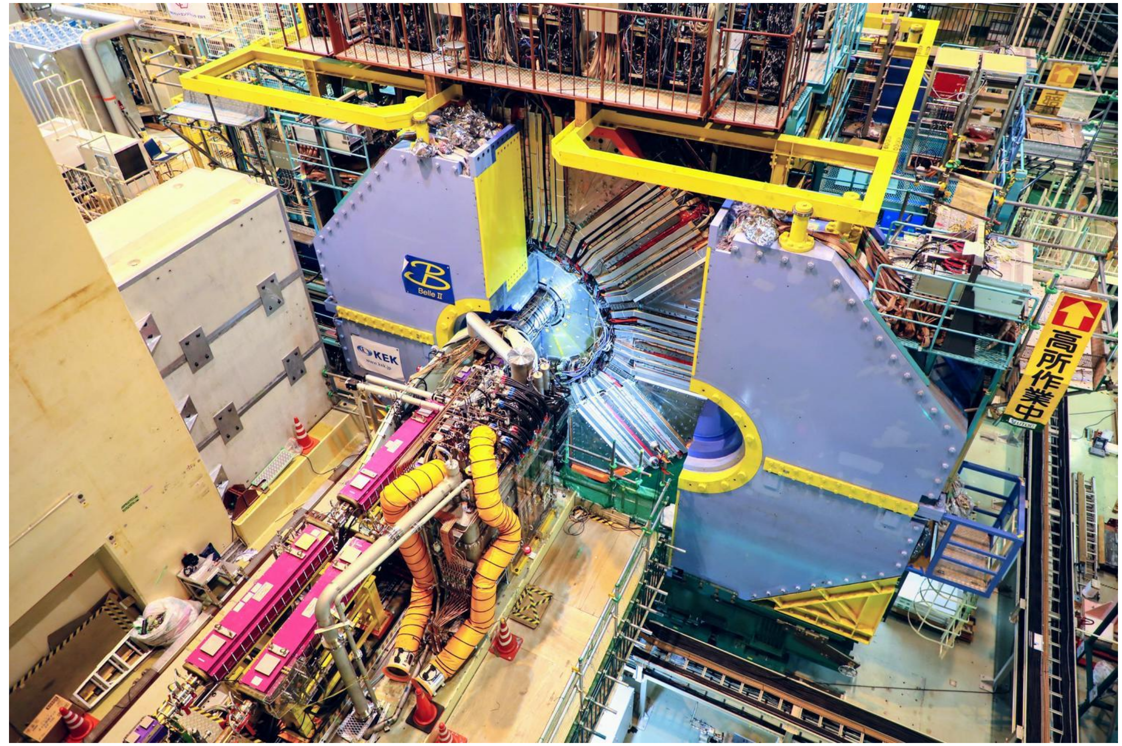
Lepton Photon 2019

Aug. 9, 2019

Contents

- ϕ_1 / β
- ϕ_s
- ϕ_3 / γ
- $|V_{cb}|$
- CP Asymmetry in $B^+ \to \pi^+K^+K^-, \pi^+\pi^-\pi^+$





Unitarity Triangle

Kobayashi-Maskawa theory

Complex phase in the quark mixing matrix

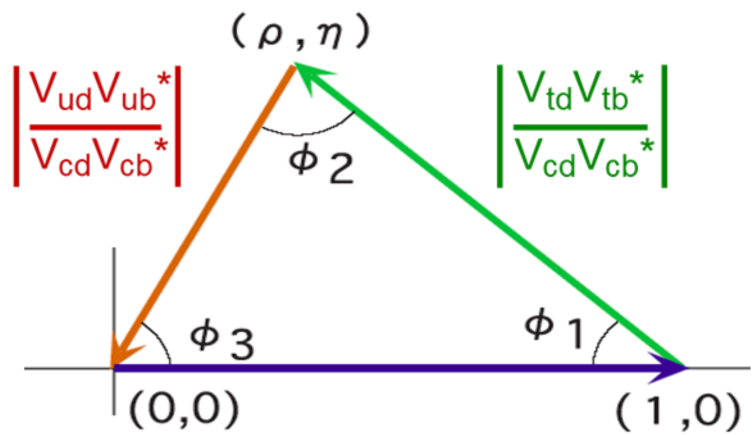
→ CP violation in the Standard Model (SM)

CKM (Cabibbo-Kobayashi-Maskawa) Matrix

$$V=\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

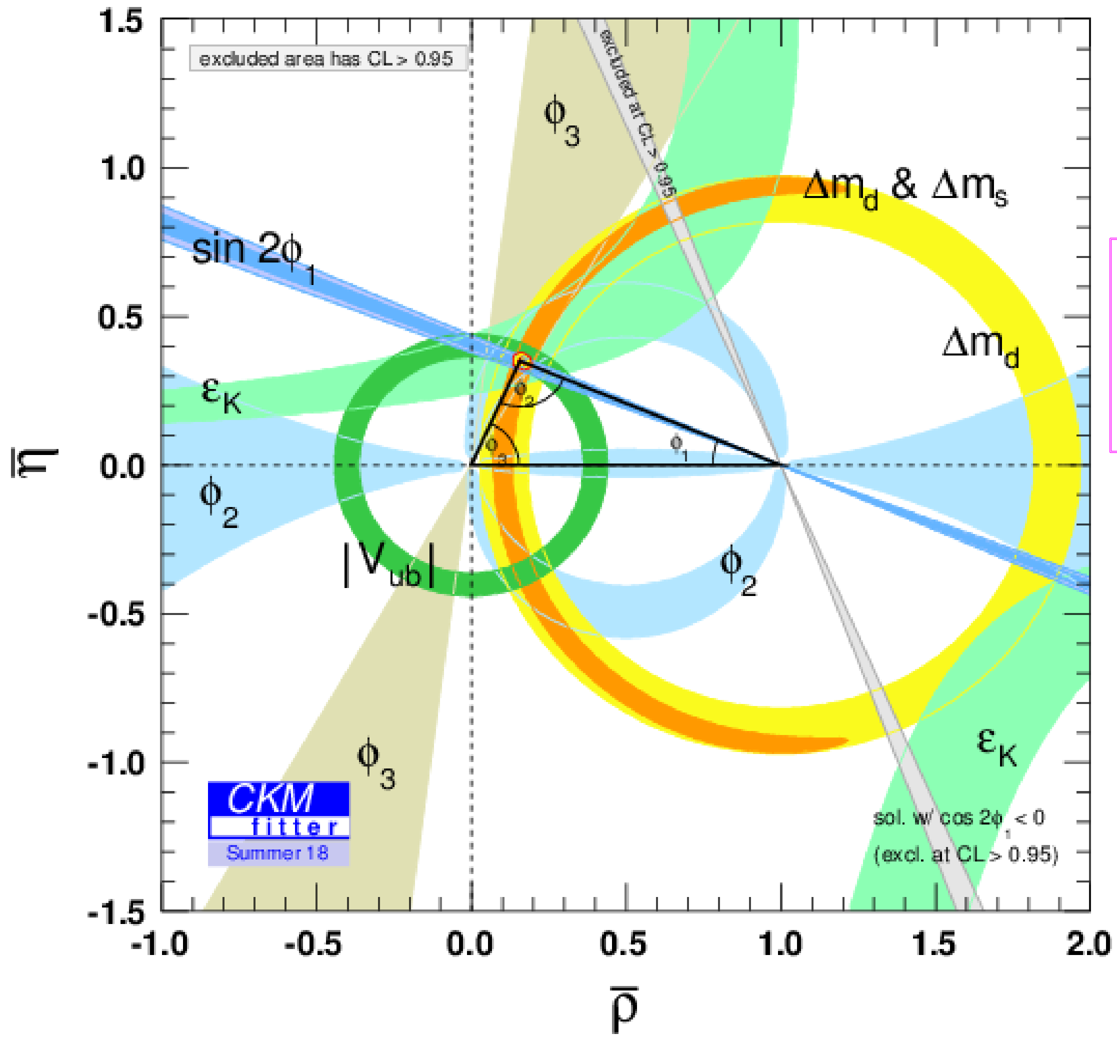
From the unitarity of the matrix:

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

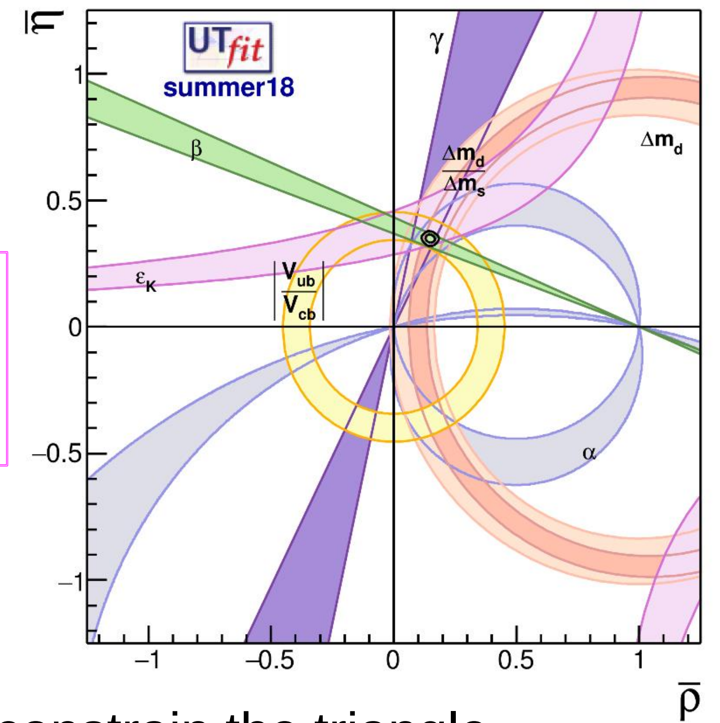


$\phi_1 = \beta$
$\phi_2 = \alpha$
$\phi_3 = \gamma$

Unitarity Triangle



$\phi_1 = \beta$
$\phi_2 = \alpha$
$\phi_3 = \gamma$



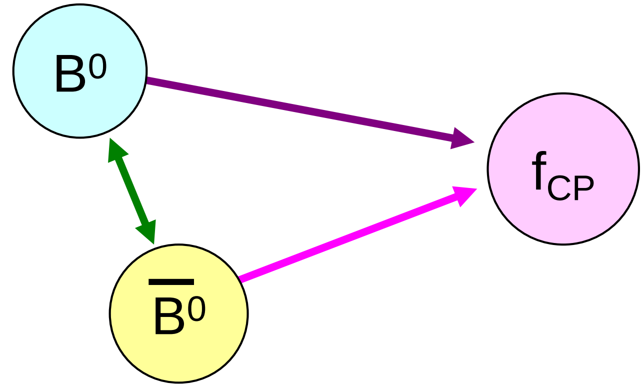
- Overconstrain the triangle
  $\rightarrow$ test of the SM

- Measurements generally consistent.
- Still room for O(10%) New Physics effect.

Time dependent CP Asymmetry

Mixing-induced CP asymmetry

- B^0 and $\bar{B}^0$ decay to a common CP eigenstate f_{CP}.
- CP violation appears as a decay time difference.



$$A_{CP}(\Delta t) = \frac{\Gamma(\bar{B}^0(\Delta t) \to f_{CP}) - \Gamma(B^0(\Delta t) \to f_{CP})}{\Gamma(\bar{B}^0(\Delta t) \to f_{CP}) + \Gamma(B^0(\Delta t) \to f_{CP})}$$

$$= S \sin(\Delta m \Delta t) + A \cos(\Delta m \Delta t)$$

$S = -\xi \sin(2\phi_1)$ for $B \to J/\psi K_{S/L}$

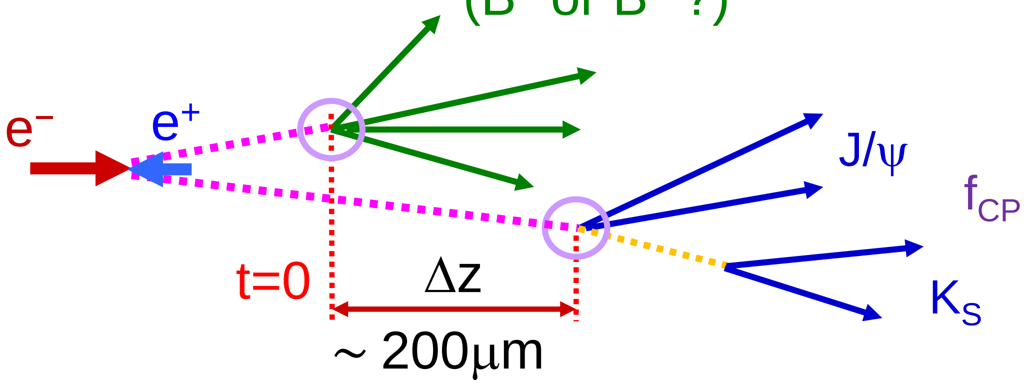
S : mixing induced CPV

A : direct CPV (=−C)

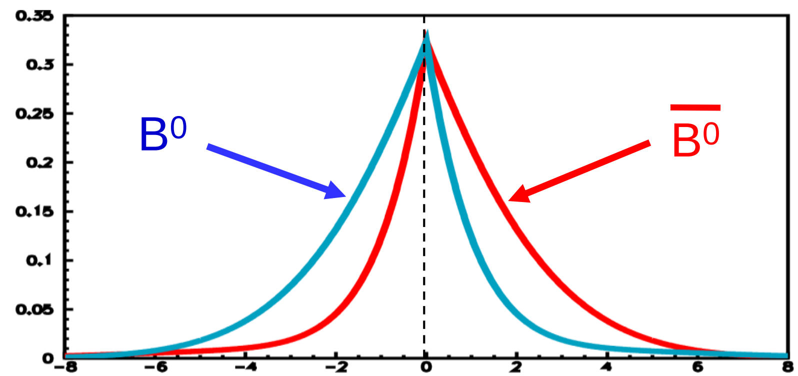
Belle/BaBar

Flavor-tag (B^0 or $\bar{B}^0$?)

ε_{eff} ~30%



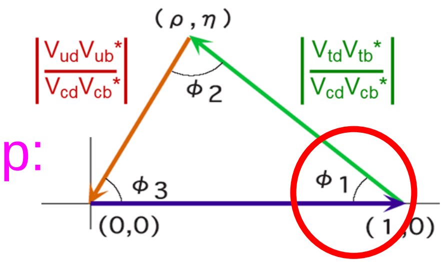
measure position instead of time



$\Delta t \sim \Delta z / c\beta\gamma$

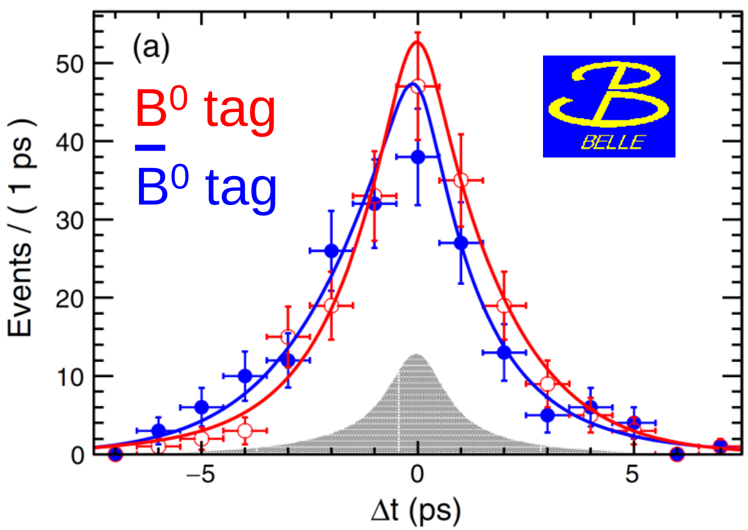
Measurement of ϕ_1 (β)

- $\sin(2\phi_1)$ has been measured precisely with $b \to c\bar{c}s$ tree process
  $\sin(2\phi_1) = 0.699 \pm 0.017$ (HFLAV)
- Measurement of $\sin(2\phi_1)$ using other processes with penguin loop:
  ✓ To probe non-SM contribution in the penguin loop.
- Recent results from Belle: $B \to J/\psi\,\pi^0$, $\pi^0\pi^0 K_S$ with 711 fb^{-1}



$B \to J/\psi\,\pi^0$ (tree + penguin) [PRD98 (2018) 112008]

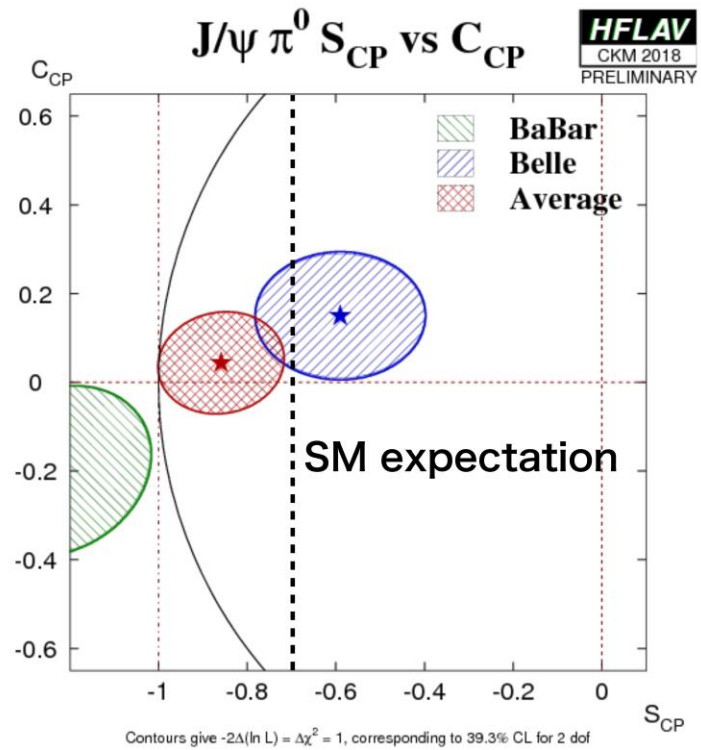
Understanding of penguin contribution could improve the uncertainty of $\sin(2\phi_1)$



$S = -\sin(2\phi_1)$ in SM

$S = -0.59 \pm 0.19 \pm 0.03$

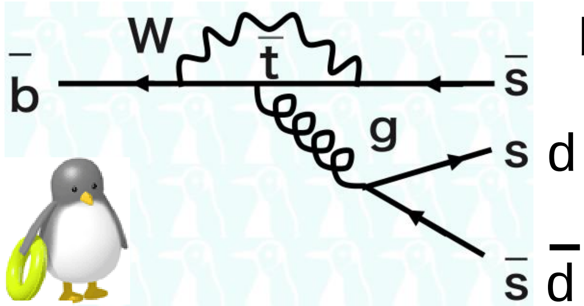
$A = -C$
$= 0.15 \pm 0.14 \,{}^{+0.04}_{-0.03}$

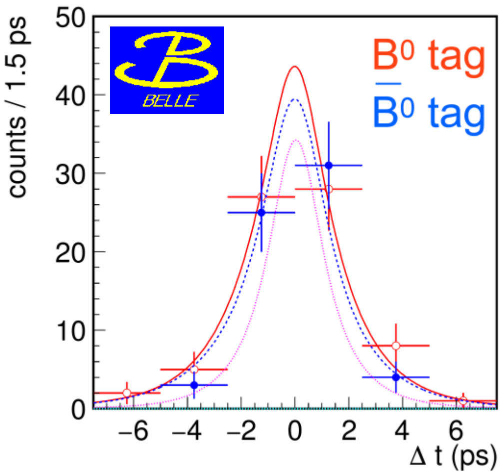


Measurement of ϕ_1 (β)

$B \rightarrow \pi^0 \pi^0 K_S$

[PRD99 (2019) 011102]



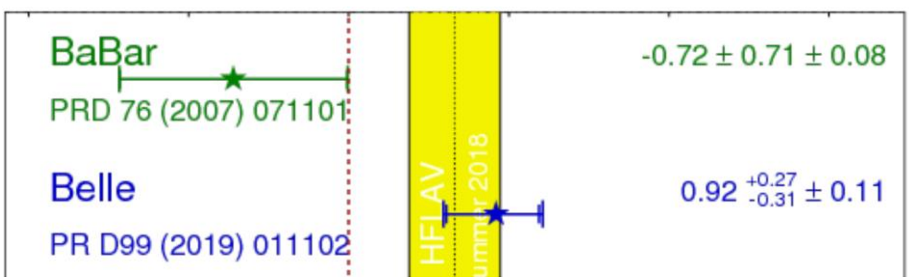


New result from Belle is coming soon

$S = -\sin(2\phi_1)$ in SM

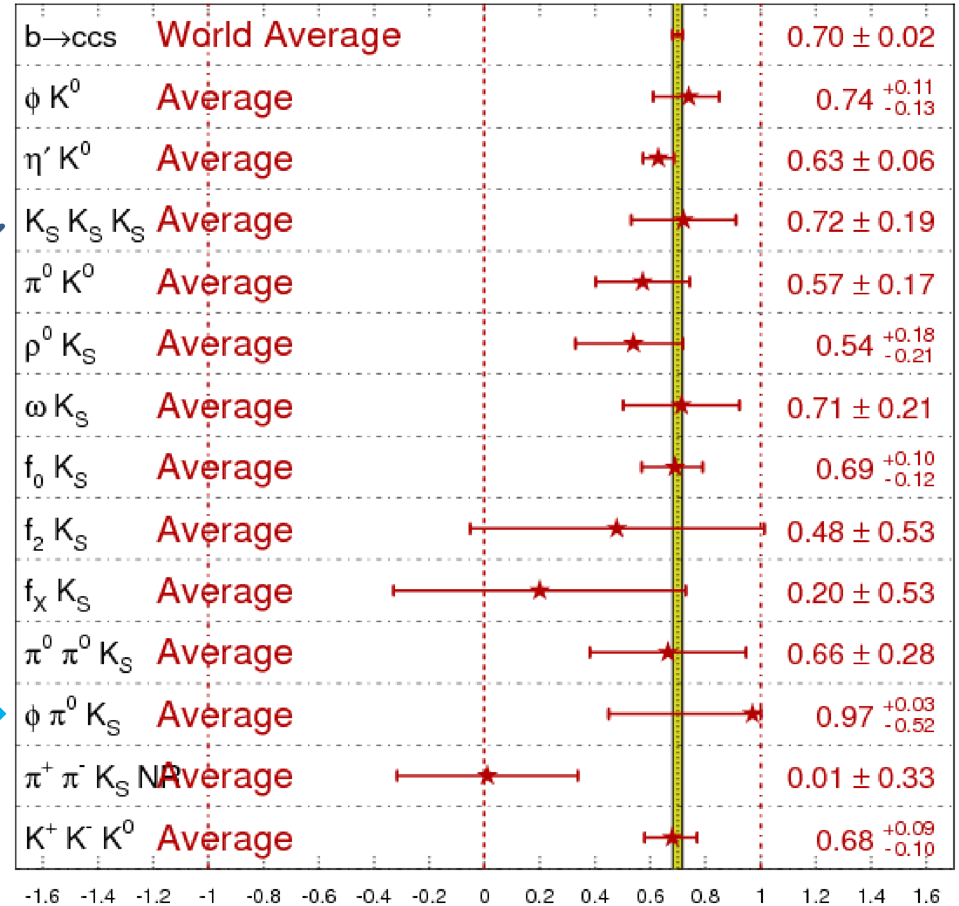
$S = -0.92^{+0.27}_{-0.31}{}^{+0.10}_{-0.11}$

$A = 0.28 \pm 0.21 \pm 0.04$



$b \rightarrow s\bar{q}q$ $\sin(2\beta^{eff}) \equiv \sin(2\phi_1^{eff})$

HFLAV Summer 2018 PRELIMINARY

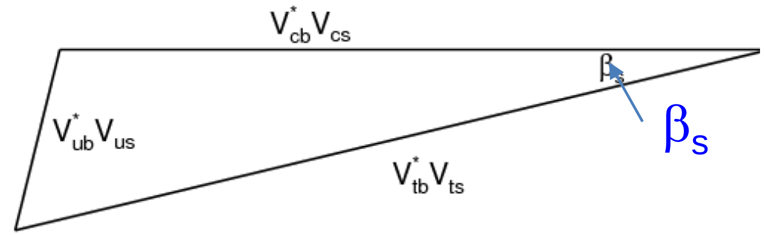


Study items at Belle II

ϕ_s

Another combination of the unitarity of the CKM matrix makes a squashed triangle.

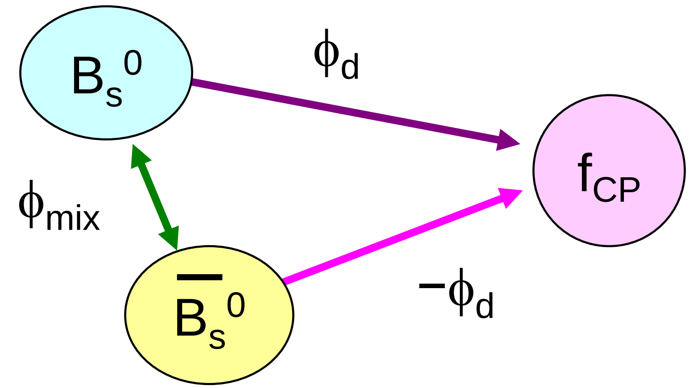
$$V_{us}V_{ub}^* + V_{cs}V_{cb}^* + V_{ts}V_{tb}^* = 0$$



- β_s can be measured in mixing-induced CP violation in B_s decays like $B_s \to J/\psi\ \phi$.

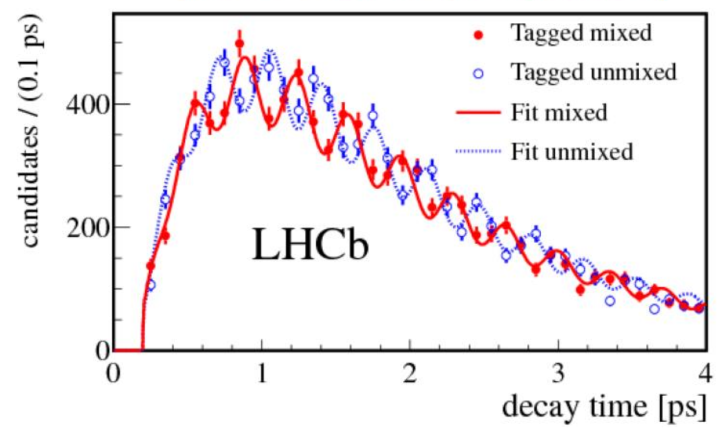
$$\phi_s = \phi_{mix} - 2\ \phi_d = -2\ \beta_s \quad \text{(in SM)}$$

$$\phi_s = -36.8^{+1.0}_{-0.7}\ \text{mrad} \quad \text{(SM)}$$



- Experimental technique
  - ✓ excellent time resolution (<100fs) necessary because of fast B_s oscillation,
    - ➢ Cannot be studied at B-factories due to small boost factor.
  - ✓ flavor tagging
  - ✓ angular distribution to extract CP eigenstate.

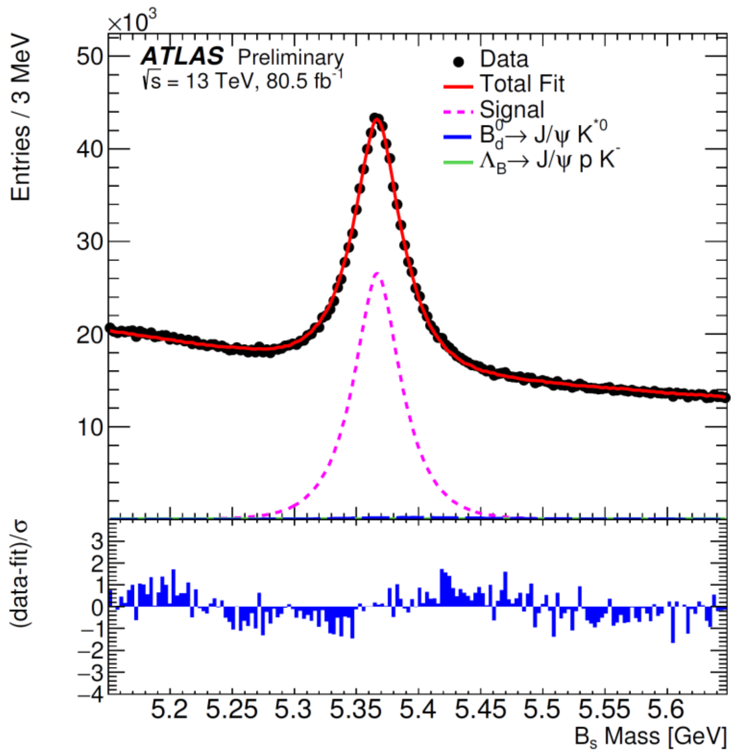
[New J. Phys. 15 (2013) 053021]

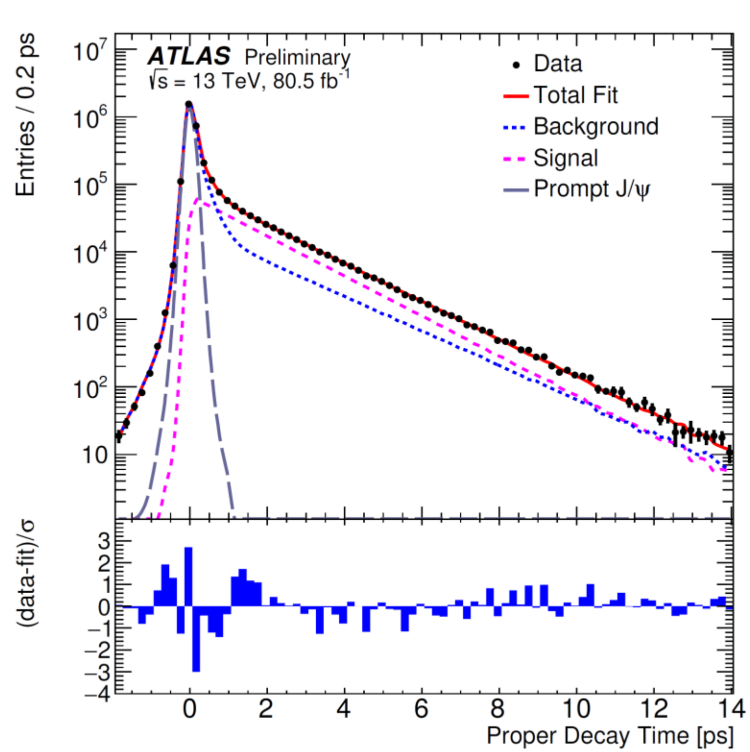


ϕ_s from ATLAS

[ATL-CONF-2019-009]

- $B_s \to J/\psi\ \phi$
- Previous result from ATLAS was based on 19.2 fb^{-1} at 7-8 TeV (Run1).
- New measurement with 80.5 fb^{-1} at 13 TeV (Run2).
- Flavor tagging (of the other side b-hadron) using weighted sum of the charge in a cone around a lepton or in a jet. Calibrated with $B^+ \to J/\psi\ K^+$.





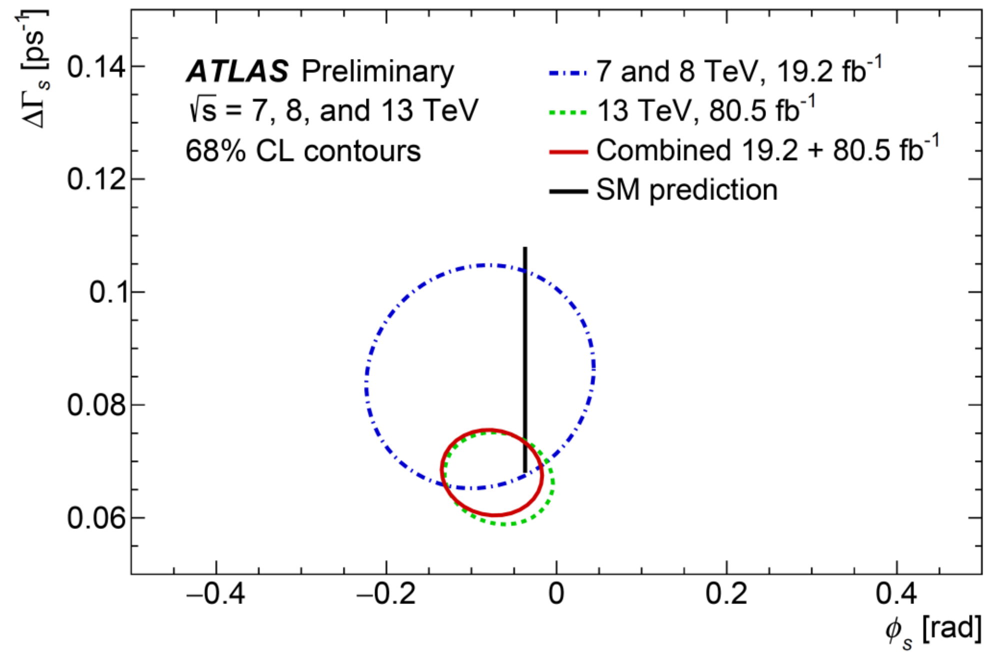
ϕ_s from ATLAS

Physical values obtained from 80.5 fb^{-1}

Parameter	Value	Statistical uncertainty	Systematic uncertainty
ϕ_s[rad]	−0.068	0.038	0.018
$\Delta\Gamma_s$[ps^{-1}]	0.067	0.005	0.002
Γ_s[ps^{-1}]	0.669	0.001	0.001
$\lvert A_{\parallel}(0)\rvert^2$	0.219	0.002	0.002
$\lvert A_0(0)\rvert^2$	0.517	0.001	0.004
$\lvert A_S(0)\rvert^2$	0.046	0.003	0.004
$\delta_\perp$ [rad]	2.946	0.101	0.097
$\delta_\parallel$ [rad]	3.267	0.082	0.201
$\delta_\perp - \delta_S$ [rad]	−0.220	0.037	0.010

Γ_s, $\Delta\Gamma_s$	decay with and decay width difference
ϕ_s ($\approx 2\beta_s$)	CP violating phase
$\lvert A_0\rvert^2$, $\lvert A_{\parallel}\rvert^2$	CP state amplitudes
$\delta_\parallel$, $\delta_\perp$	Strong phases
$\lvert A_S\rvert^2$, δ_S	S-wave parameters

Syst. for ϕ_s is mainly from tagging



Combined with 19.2 fb^{-1} data @ 7,8 TeV

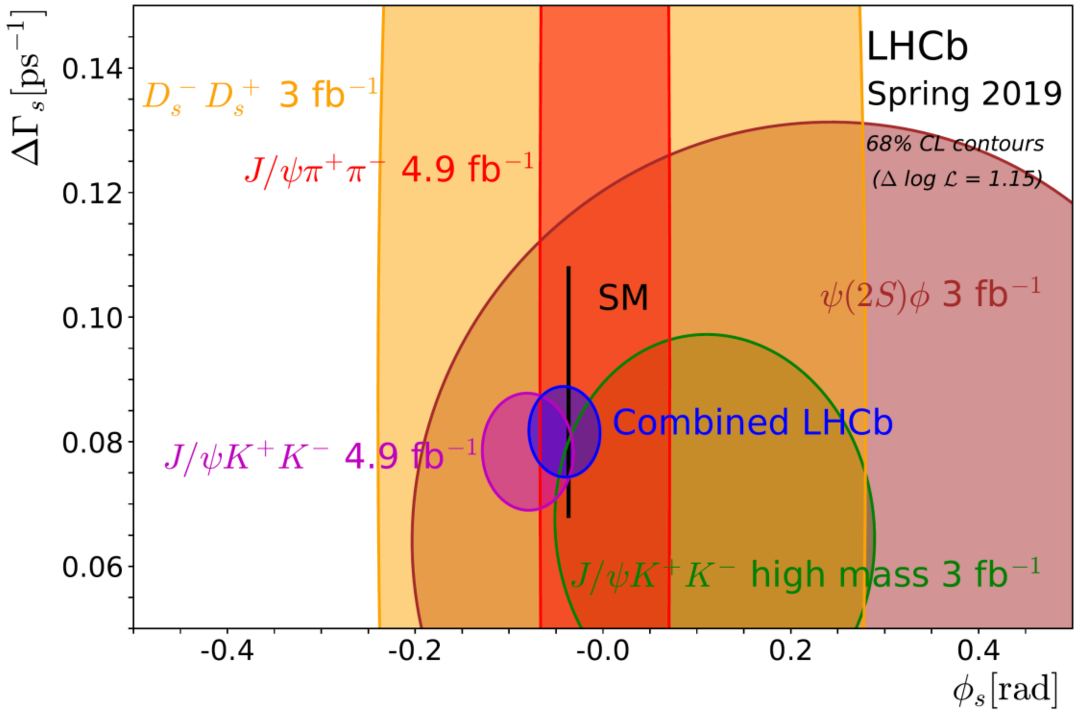
ϕ_s = − 0.076 ± 0.034 ± 0.019 mrad

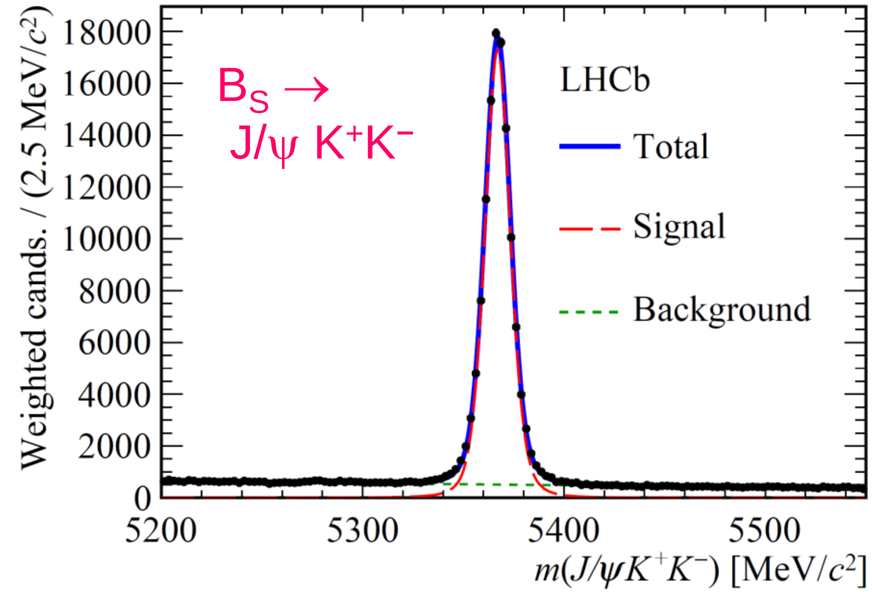
$\Delta\Gamma_s$ = 0.068 ± 0.004 ± 0.003 ps^{-1}

ϕ_s from LHCb

[arXiv:1906.08356, arXiv:1903.05530]

- $B_S \to J/\psi\ K^+K^-$ and $B_S \to J/\psi\ \pi^+\pi^-$.
- 1.9 fb^{-1} from LHC Run2.
- $B_S \to J/\psi\ K^+K^-$ around ϕ region.





$B_S \to J/\psi\ K^+K^-$

$\phi_s = -84 \pm 41 \pm 6$ mrad

$B_S \to J/\psi\ \pi^+\pi^-$

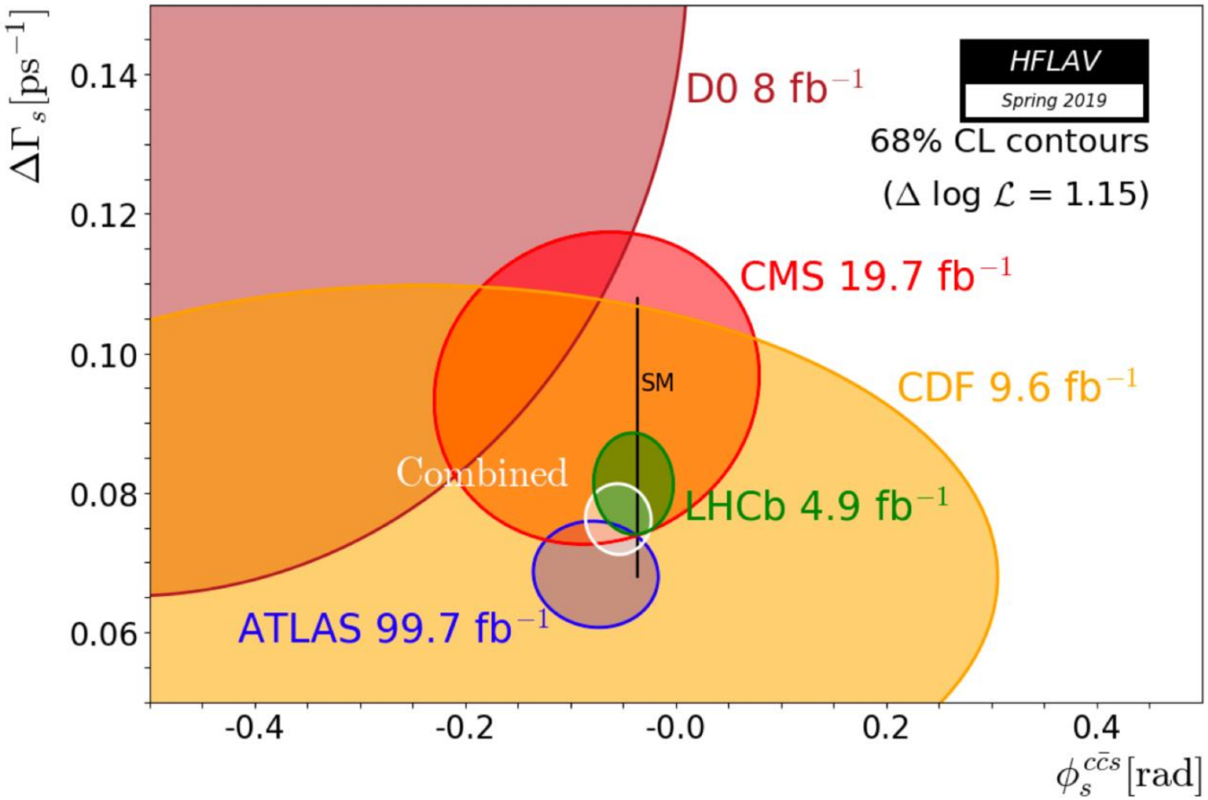
$\phi_s = -57 \pm 60 \pm 11$ mrad

LHCb combined

$\phi_s = -41 \pm 25$ mrad

[Parallel Talk by C.Santamarina on Thursday]

Combined ϕ_s



SM prediction

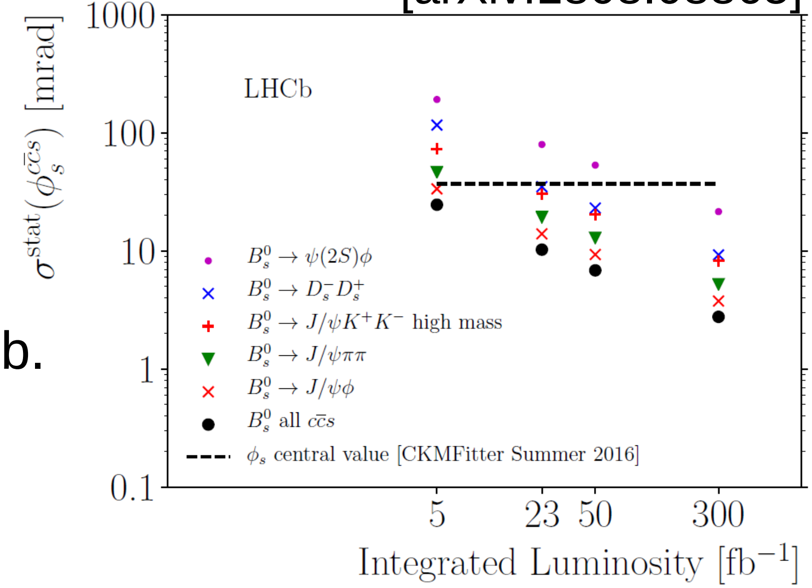
$$\phi_s = -36.8^{+1.0}_{-0.7} \text{ mrad}$$

(CKMFitter)

HFLAV (exp. average)

$$\phi_s = -55 \pm 21 \text{ mrad}$$

[arXiv:1808.08865]

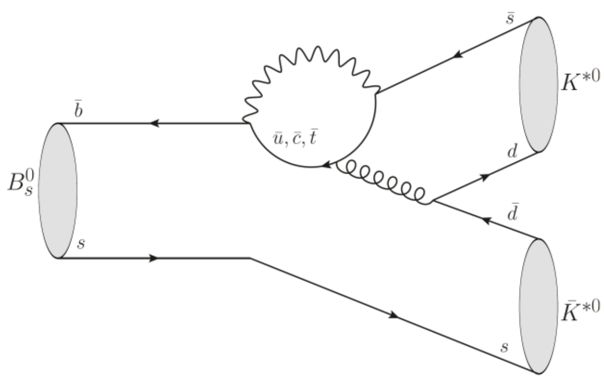


- Improved measurements from ATLAS and LHCb.
- Exp. error still one order larger than the SM.
- Measurements are limited by statistics. Further improvement is expected at HL-LHC.

ϕ_s from Loop Diagram

- Measure ϕ_s in other processes through loop diagram.
- Good probes for New Physics: heavy NP particles in the loop.

$B_S \rightarrow (K^+\pi^-)(K^-\pi^+)$

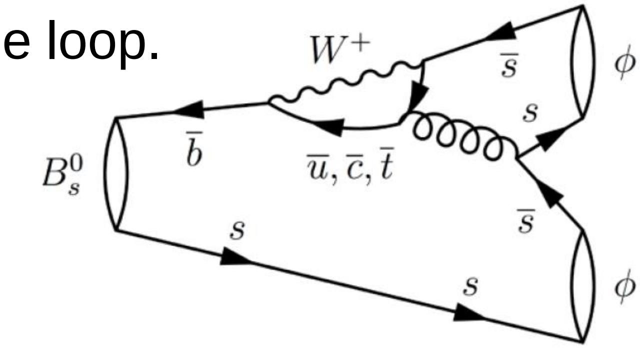


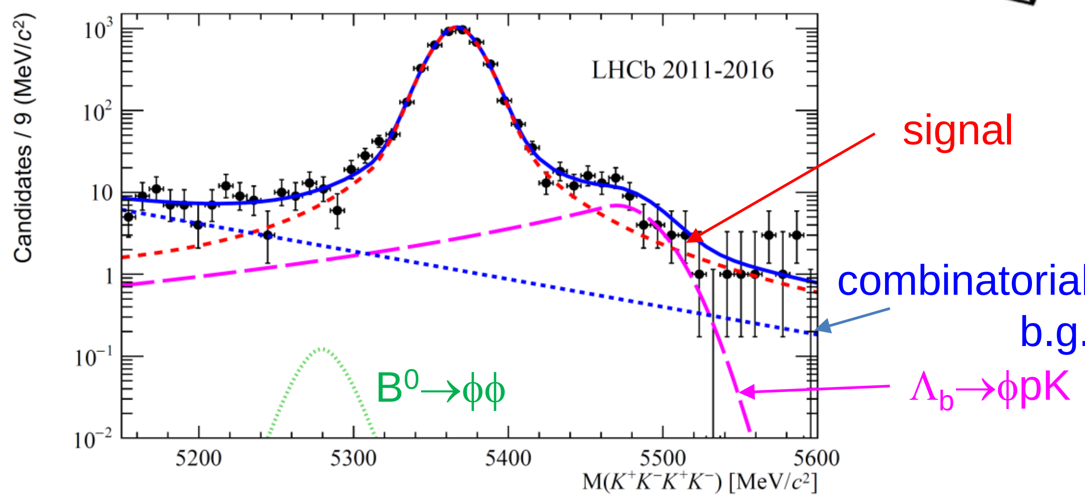
3.0 fb^{-1} at 7, 8 TeV

$\phi_s(dd) = -0.10 \pm 0.13 \pm 0.14$ rad

[JHEP03 (2018) 140]

$B_S \rightarrow \phi\phi$





$\phi_s = -55 \pm 21$ mrad (HFLAV) for $b \rightarrow ccs$

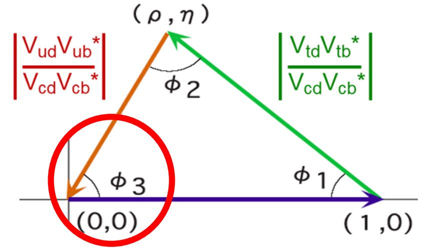
$\phi_s(sss) = -73 \pm 115 \pm 27$ mrad

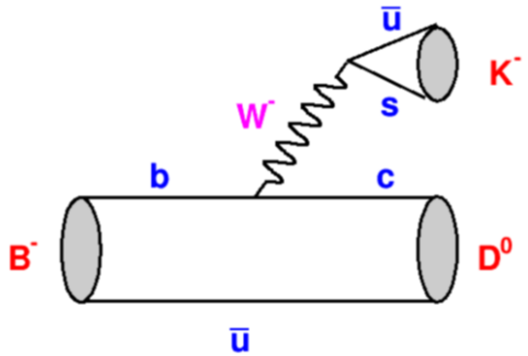
[Parallel Talk by C.Santamarina on Thursday]

[arXiv:1907.10003]

ϕ_3 / γ

- ϕ_3 / γ can be measured using the interference $B \to D K$ and $B \to \bar{D} K$.
  - ✓ Not necessarily $B \to D K$. $B \to D K^*$ etc. are fine.

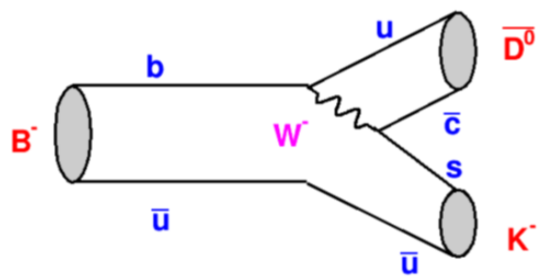




color favored

$B^- \to D^0 K^- \approx V_{cb} V_{us}^*$

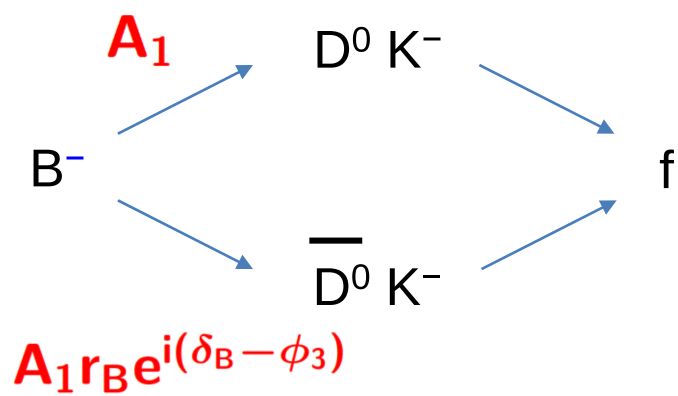
$\mathbf{A_1}$



color suppressed

$B^- \to \bar{D}^0 K^- \approx V_{ub} V_{cs}^*$

$\mathbf{A_1 r_B e^{i(\delta_B - \phi_3)}}$



- Only tree contributions: theoretically clean.
- Several decay modes (final states) possible to extract ϕ_3 / γ.
- Amplitude ratio r_B and strong phase δ_B are mode-dependent.
  - ✓ sensitivity depends on modes.

ϕ_3 / γ

- GLW (Gronau-London-Wyler) [PLB 253 (1991) 483, PLB 265 (1991) 172]
  - ✓ $B^{\pm} \to D^0_{CP} K^{\pm}$
  - ✓ Use CP eigenstate of D meson.
- ADS (Atwood-Dunietz-Soni) [PRL 78, 3357 (1997), PRD 63. 036005 (2001)]
  - ✓ Enhancement of CP violation by using doubly Cabibbo suppressed decays.
- GGSZ (Giri-Grossmann-Soffer-Zupan) [PRD 68. 054018 (2003)]
  - ✓ 3 (or multi-) body final state.
  - ✓ Different amplitude and strong phase in different region of Dalitz plot.
- GLS (Grossmann-Ligeti-Soffer) [PRD 67. 071301 (R) (2003)]
  - ✓ Singly Cabibbo suppressed D decay ($K_S K \pi$)

ϕ_3 / γ from Belle

- Binned Dalitz plot analysis using $B^- \to D^0 K^-$, $D^0\pi^-$ with $D^0 \to K_S\pi^+\pi^-\pi^0$.
  - ✓ Model-independent formalism
  - ✓ $D^0 \to K_S\pi^+\pi^-$ is the primary mode for such studies, but $D^0 \to K_S\pi^+\pi^-\pi^0$ has twice larger branching fraction (5.2%).
  - ✓ $r_B(DK) \sim 0.1$ and $r_B(D\pi) \sim 0.005$ while $B(B^- \to D^0\pi^-) \sim 10 \times B(B^- \to D^0K^-)$. $B^- \to D^0\pi^-$ is not sensitive to ϕ_3, but serves as a control mode.

For the B^- decay,

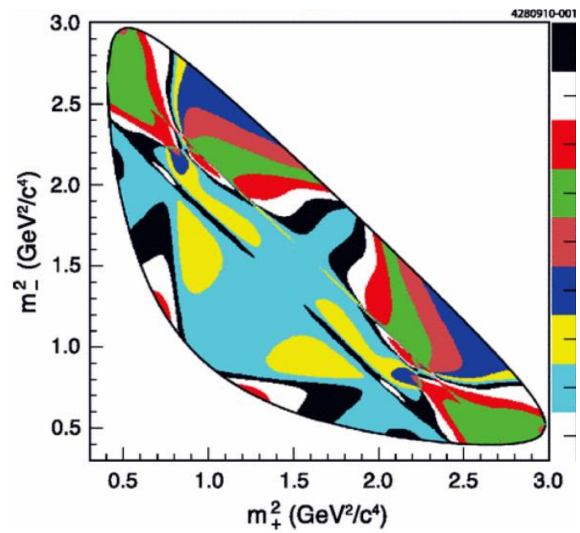
$$\Gamma_i^- = K_i + r_B^2 \bar{K}_i + 2\sqrt{K_i \bar{K}_i}(c_i x_- + s_i y_-)$$

$$\mathbf{x}_\pm = r_B \cos(\delta_B \pm \phi_3);\ \mathbf{y}_\pm = r_B \sin(\delta_B \pm \phi_3)$$

$\mathbf{c_i}$, $\mathbf{s_i}$ - cosine and sine of the strong phase difference between D^0 and $\bar{D}^0$

Input from CLEO-c or BESIII

$\mathbf{K_i}$ and $\bar{\mathbf{K}}_i$ - fraction of flavour-tagged D events

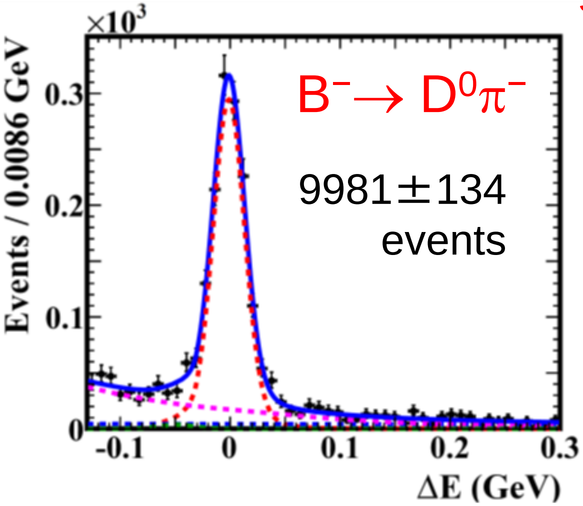


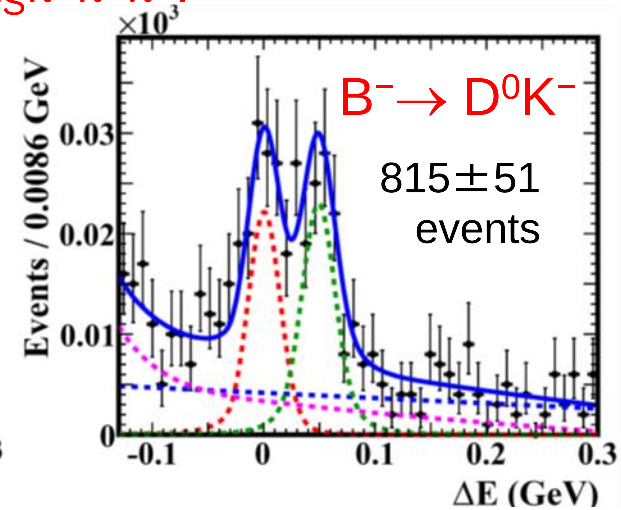
Dalitz plot binning for $K_S^0\pi^+\pi^-$.

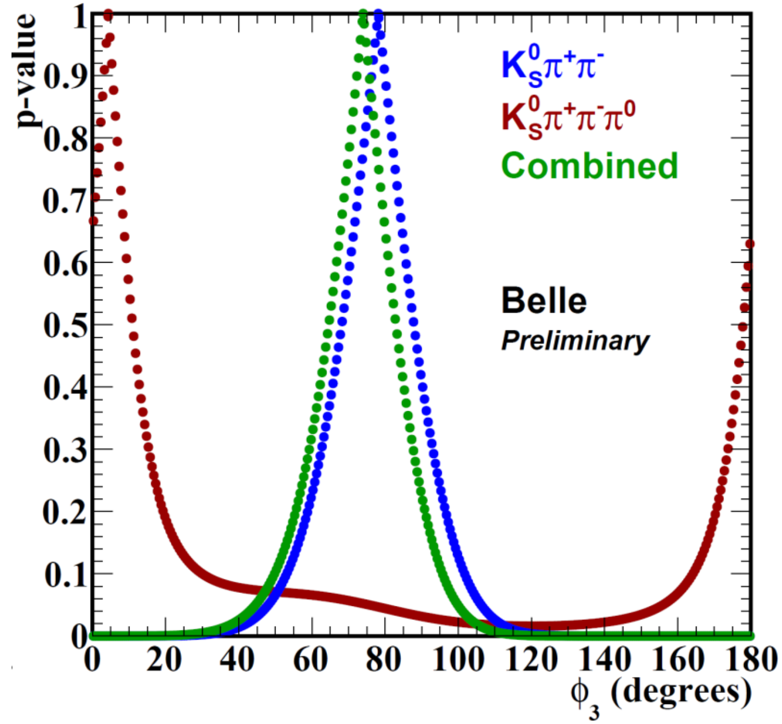
PRD**82**, 112006(2010)

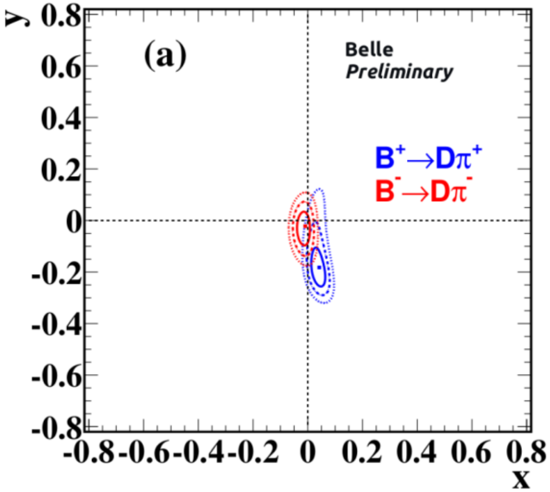
ϕ_3 / γ from Belle

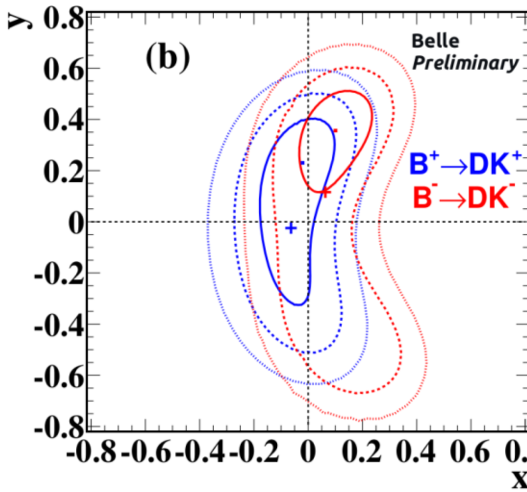
$D^0 \to K_S \pi^+ \pi^- \pi^0$.











ϕ_3 from Belle

$(78^{+14}_{-15})^\circ \Rightarrow (74^{+13}_{-14})^\circ$

with this measurement

First measurement!

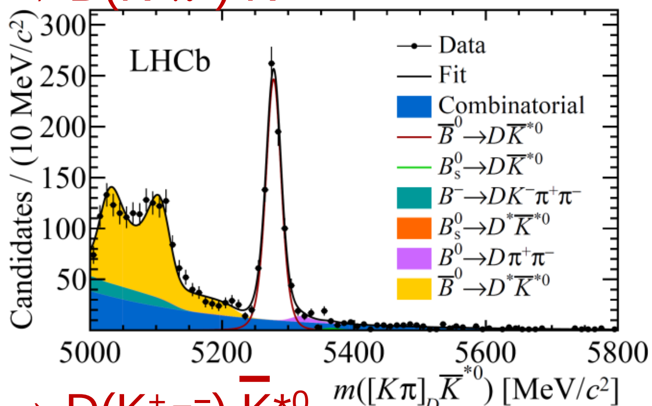
Promising at Belle II (estimation: 4.4° at 50 ab^{-1})

ϕ_3 / γ from LHCb

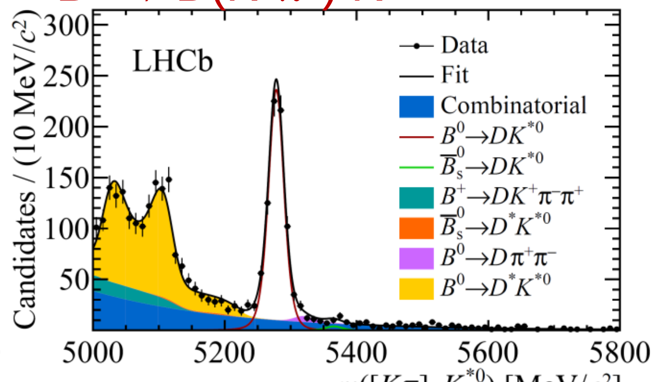
- Updated γ (=ϕ_3) measurement by LHCb with ADS/GLW method.
- $B^0 \to DK^{*0}$ with $D \to K^+\pi^-$, K^+K^-, $\pi^+\pi^-$, $K^+\pi^-\pi^+\pi^-$, $\pi^+\pi^-\pi^+\pi^-$ (+c.c.).
- 4.8 fb^{-1} at 7, 8, 13 TeV (Run1+2)

[arXiv:1905.08297]

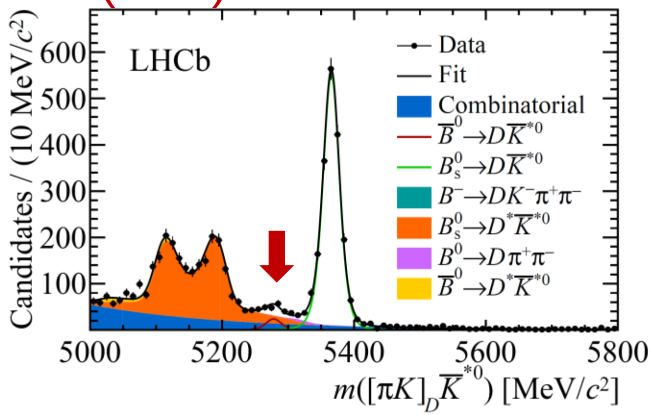
$\bar{B}^0 \to D(K^-\pi^+)\bar{K}^{*0}$



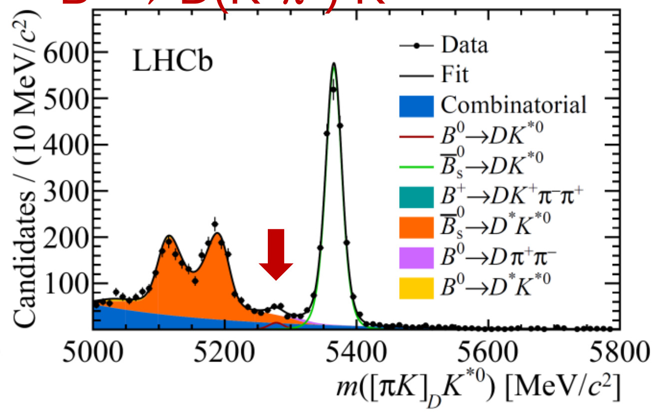
$B^0 \to D(K^+\pi^-)K^{*0}$



$\bar{B}^0 \to D(K^+\pi^-)\bar{K}^{*0}$

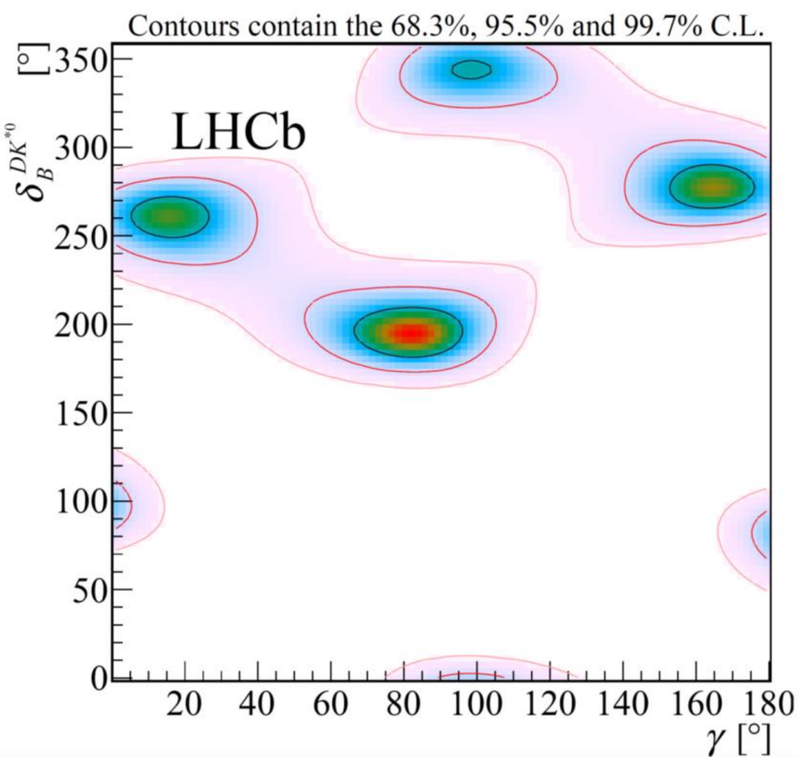


$B^0 \to D(K^-\pi^+)K^{*0}$

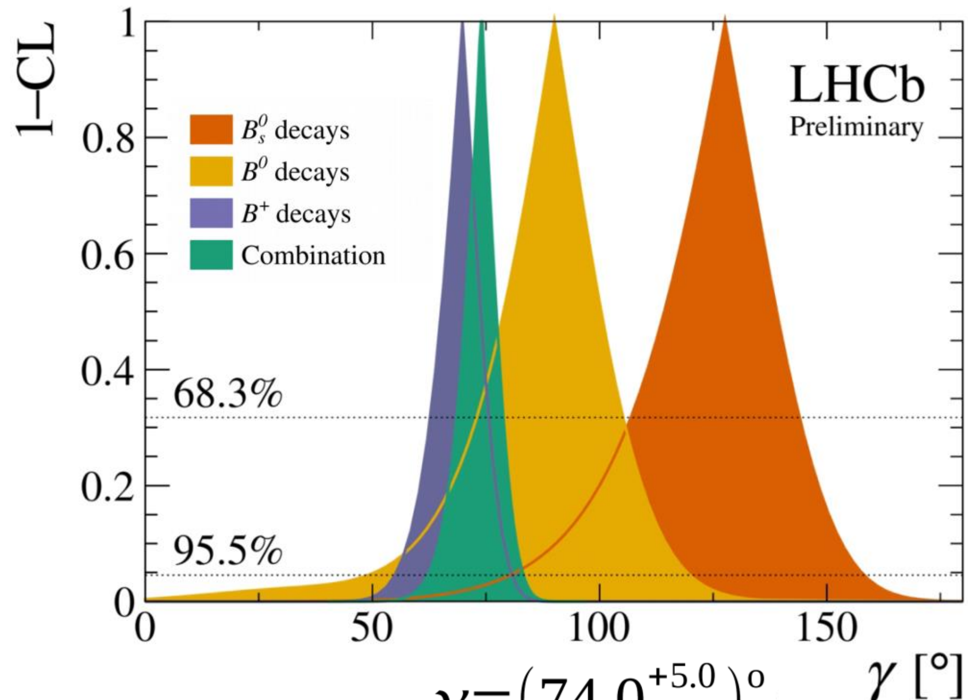


ϕ_3 / γ from LHCb

Contour from this result



LHCb 2018



$$\gamma = \left(74.0^{+5.0}_{-5.8}\right)^{\circ}$$

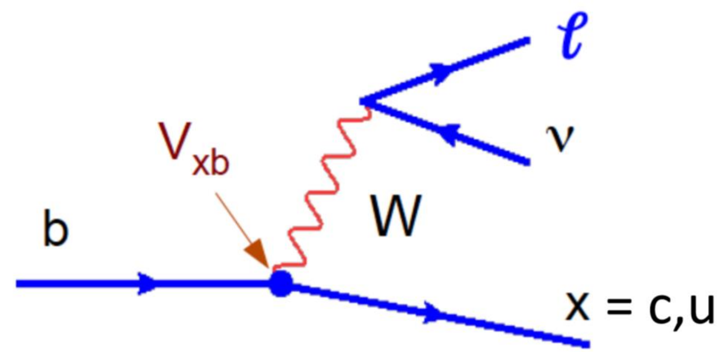
Expect to improve the error slightly.

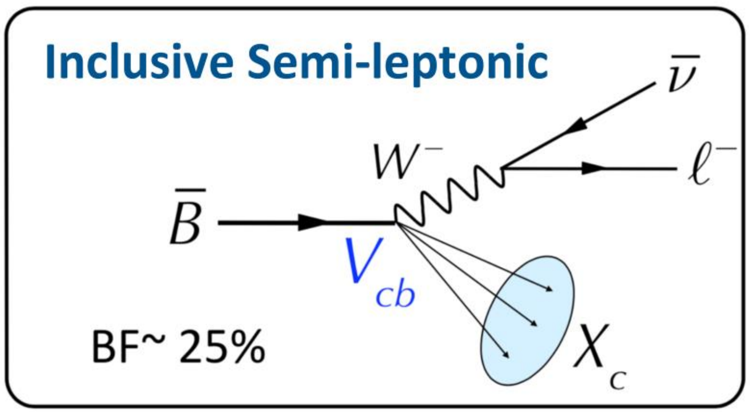
HFLAV	$(71.1^{+4.6}_{-5.3})^{\circ}$
CKM fit	$(65.8^{+1.0}_{-1.7})^{\circ}$

$|V_{ub}|$ and $|V_{cb}|$

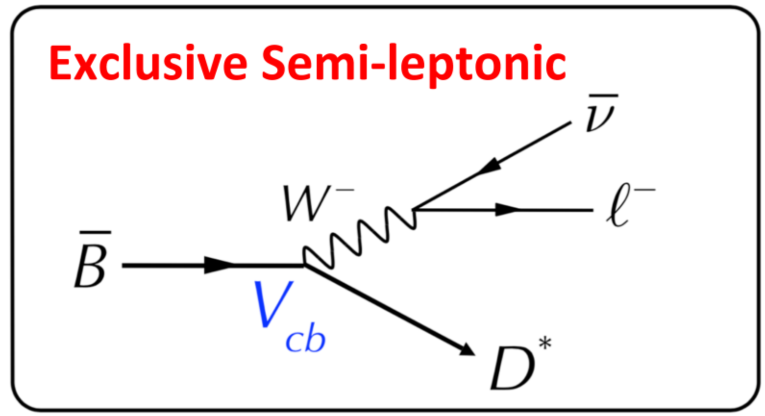
- $|V_{ub}|$ and $|V_{cb}|$ can be measured using semi-leptonic decays $b \to u\ell\nu$, $c\ell\nu$.

- Two approaches: inclusive and exclusive





do not specify hadron state



specify hadrons (experimentally clean)

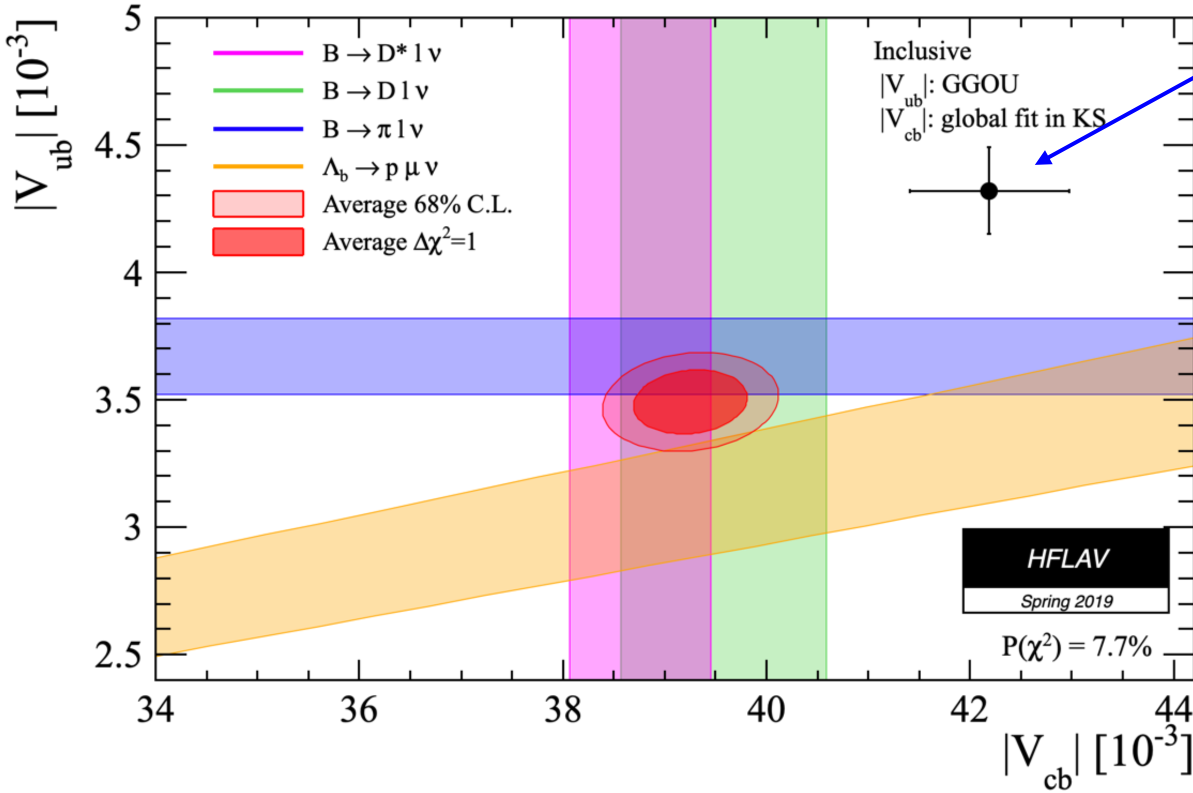
- QCD corrections to parton level decay rate
- Operator Product Expansion (OPE) in α_S and Λ/m_b

- QCD contributions parametrized in form factors
- Lattice QCD (high q^2) or LCSR (low q^2)

$|V_{ub}|$ and $|V_{cb}|$

Tension between inclusive and exclusive

exclusive measurements (2019 spring)



average for inclusive

$|V_{cb}| = (42.19 \pm 0.78) \times 10^{-3}$ (inclusive)

$|V_{cb}| = (39.25 \pm 0.56) \times 10^{-3}$ (exclusive)

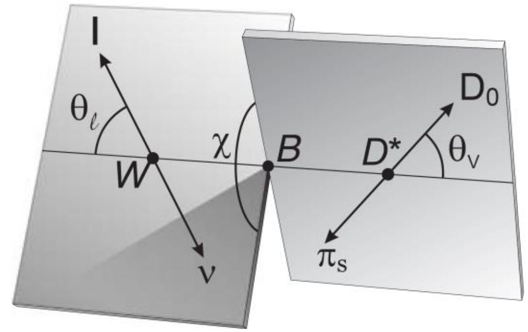
$|V_{ub}| = (4.32 \pm 0.17) \times 10^{-3}$ (inclusive)

$|V_{ub}| = (3.49 \pm 0.13) \times 10^{-3}$ (exclusive)

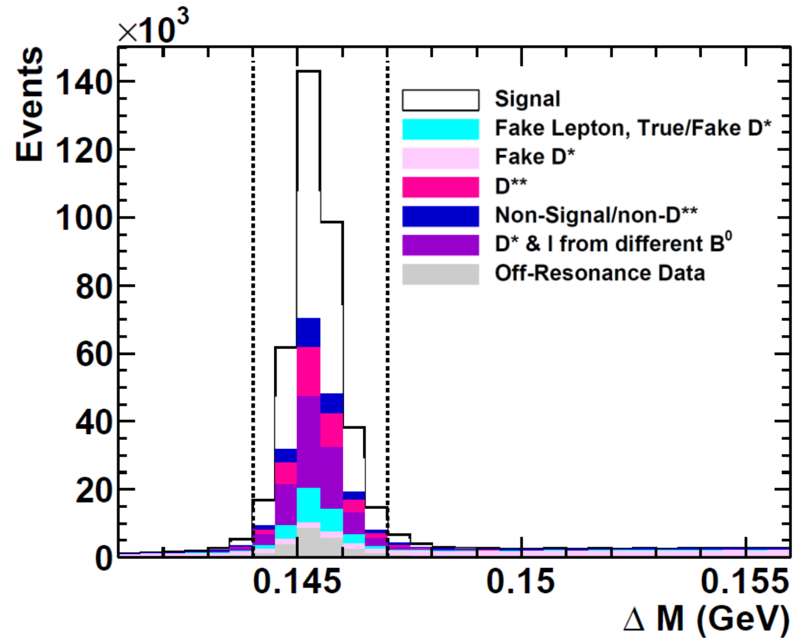
$|V_{cb}|$ from $B \to D^*\ell\nu$

- New result of untagged analysis of $B \to D^*\ell\nu$ by Belle.
- Simultaneous fit to $\cos\theta_\ell$, $\cos\theta_V$, χ, w (hadronic recoil) to extract form factors and $F(1)\,|V_{cb}|$.
- Two form factor parametrization, CLN [NPB530, 153 (1998)] and BGL [PRL74, 463 (1995)] are used.
  - ✓ CLN was mainly used in previous measurements.

[arXiv:1809.03290 to appear in PRD]



$N(B\to D^*e\nu) = 90738$
$N(B\to D^*\mu\nu) = 89082$

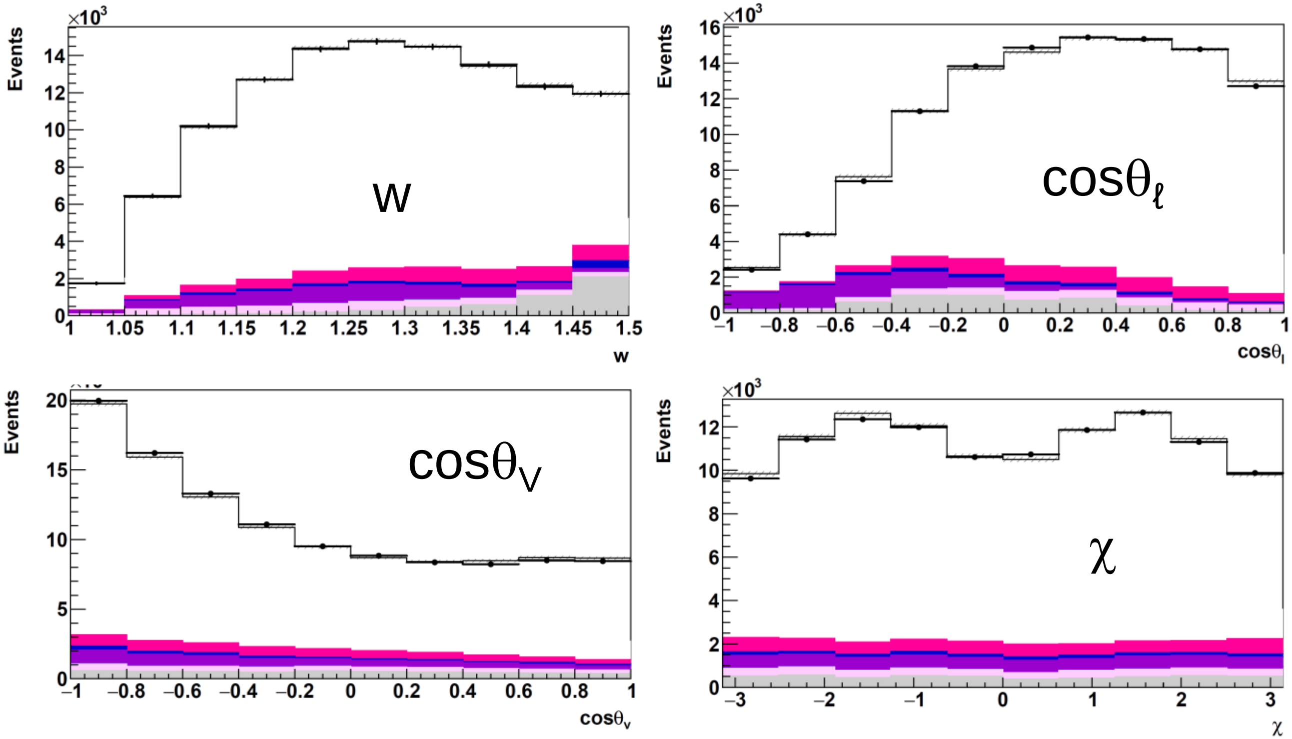


Bonus: Lepton Flavor Universality test

$$\frac{\mathcal{B}(B^0 \to D^{*-}e^+\nu)}{\mathcal{B}(B^0 \to D^{*-}\mu^+\nu)} = 1.01 \pm 0.01 \pm 0.03$$

$|V_{cb}|$ from $B \to D^*\ell\nu$

Fit for BGL parametrizations for $B \to D^*\mu\nu$



world average

$|V_{cb}| = (42.19 \pm 0.78) \times 10^{-3}$ (inclusive)

$|V_{cb}| = (39.25 \pm 0.56) \times 10^{-3}$ (exclusive)

(including this result)

In the preliminary result, the tension seemed to be solved by BGL parametrization, but actually not.

CLN: $|V_{cb}| = (38.4 \pm 0.2 \pm 0.6 \pm 0.6) \times 10^{-3}$

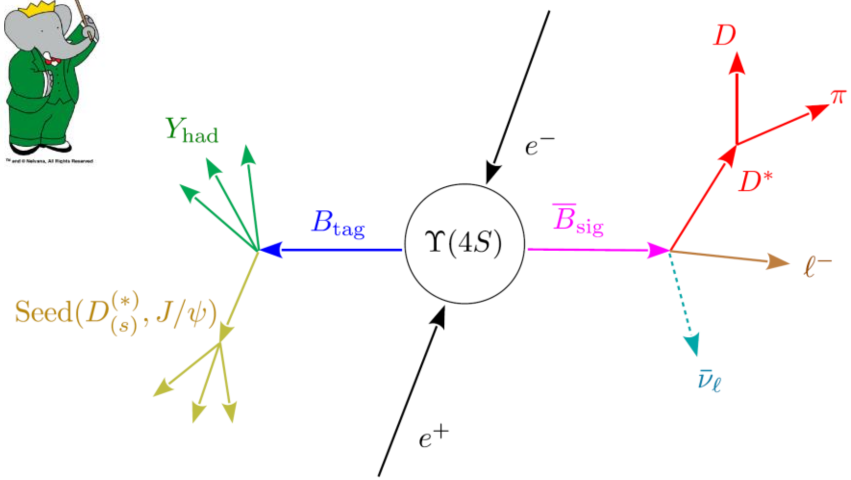
BGL: $|V_{cb}| = (38.3 \pm 0.3 \pm 0.7 \pm 0.6) \times 10^{-3}$

Tension still persists.

$|V_{cb}|$ from $B \to D^*\ell\nu$

- BaBar performed full 4-d analysis using 426 fb^{-1} data set.
- Hadronic B_{tag} reconstruction with 2968 modes (more modes than before for higher efficiency).

[arXiv:1903.10002]



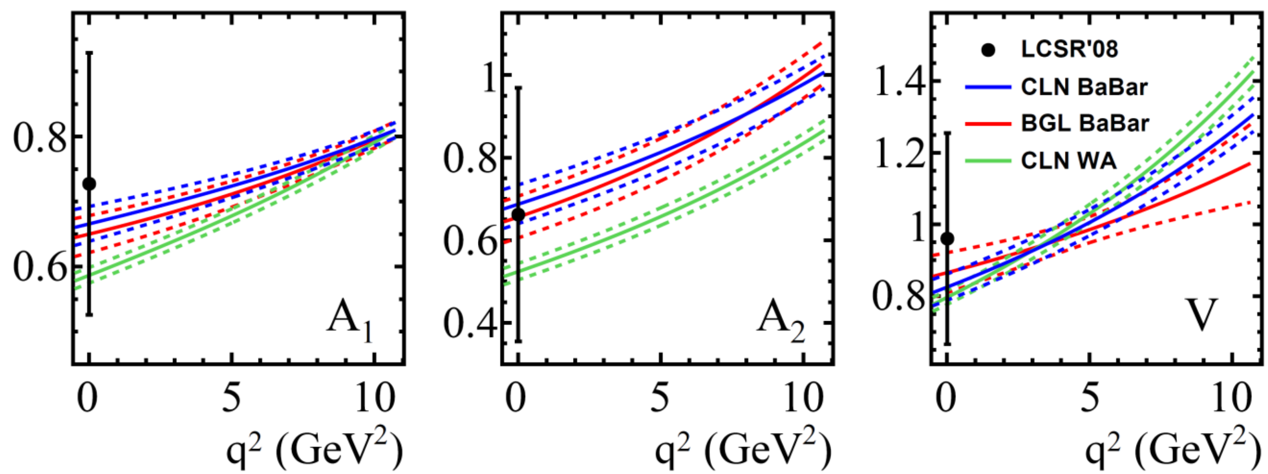
	$\|V_{cb}\| \times 10^3$
BGL	38.36 ± 0.90
CLN	38.40 ± 0.84

Tension still persists.

world average

$|V_{cb}| = (42.19 \pm 0.78) \times 10^{-3}$ (inclusive)
$|V_{cb}| = (39.25 \pm 0.56) \times 10^{-3}$ (exclusive)

Form Factor

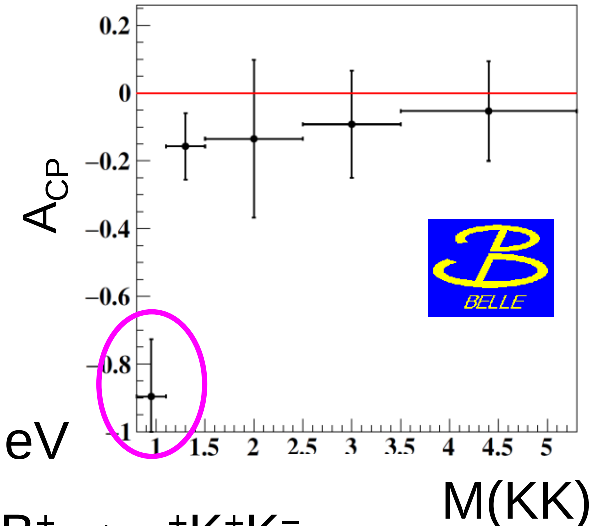


CPV in $B^+ \to \pi^+K^+K^-$, $\pi^+\pi^-\pi^+$

- Large local CP asymmetry in the phase space was found by LHCb and Belle in the decay $B^+ \to \pi^+K^+K^-$.
  - ✓ $A_{CP} = -0.123 \pm 0.017 \pm 0.012 \pm 0.007$ (LHCb)

    [PRD90, 112004 (2014)]

[PRD96, 031101(R) (2017)]

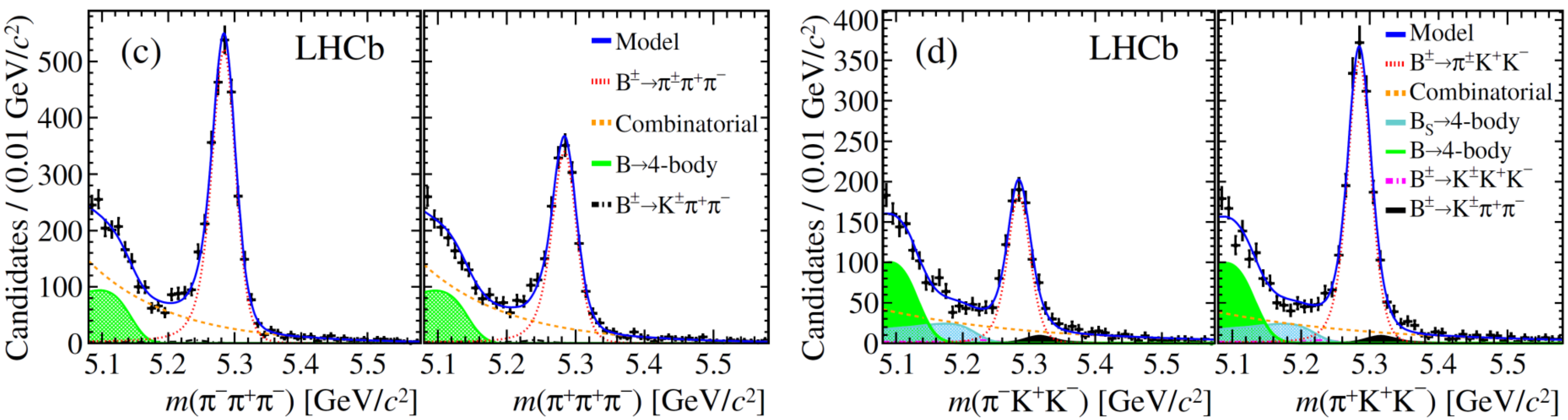


- Amplitude analysis of $B^+ \to \pi^+K^+K^-$ and $B^+ \to \pi^+\pi^-\pi^+$ by LHCb.

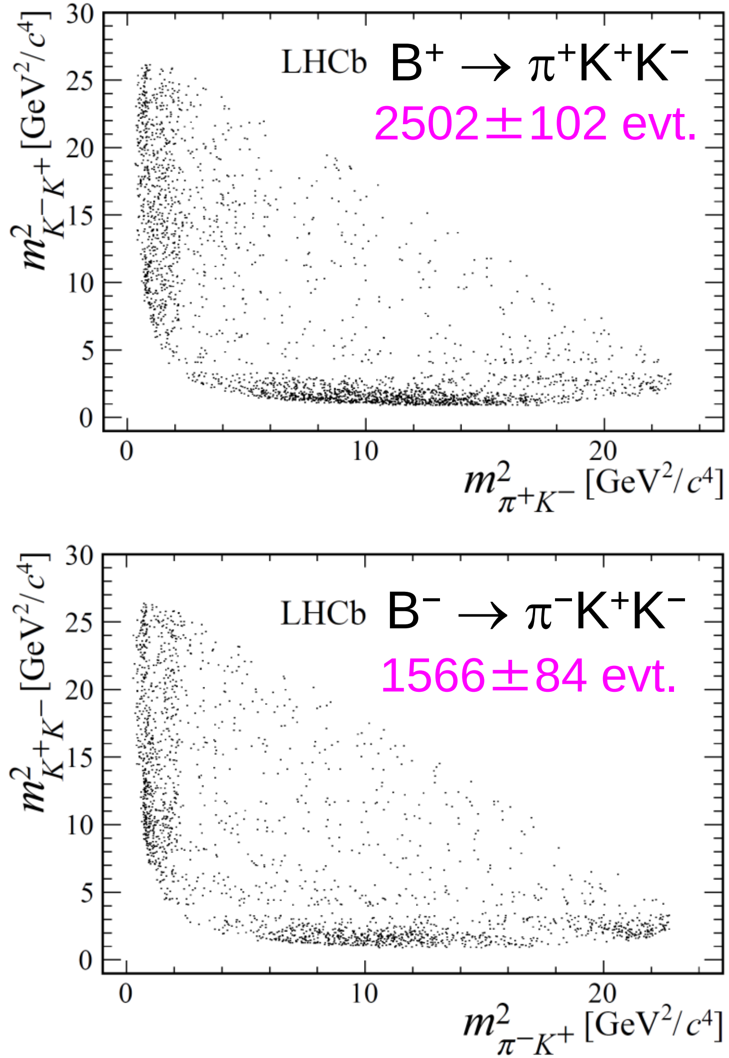
  [Parallel Talk by C.Santamarina on Thursday]

Mass distributions for B^- and B^+ at $1.0 < M(KK/\pi\pi) < 1.5$ GeV

$B^- \to \pi^-\pi^-\pi^+$ $B^+ \to \pi^+\pi^-\pi^+$ $B^- \to \pi^-K^+K^-$ $B^+ \to \pi^+K^+K^-$



CPV in $B^+ \to \pi^+K^+K^-$



3.0 fb^{-1} at Run 1 [arXiV:1905.09244]

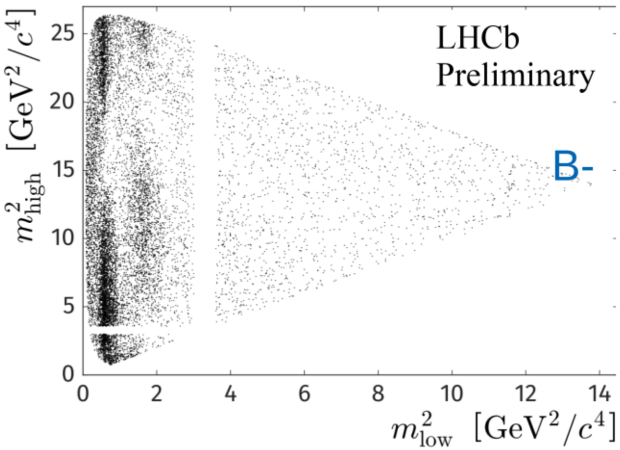
Contribution	Fit Fraction(%)	A_{CP}(%)
$K^*(892)^0$	$7.5 \pm 0.6 \pm 0.5$	$+12.3 \pm 8.7 \pm 4.5$
$K_0^*(1430)^0$	$4.5 \pm 0.7 \pm 1.2$	$+10.4 \pm 14.9 \pm 8.8$
Single pole	$32.3 \pm 1.5 \pm 4.1$	$-10.7 \pm 5.3 \pm 3.5$
$\rho(1450)^0$	$30.7 \pm 1.2 \pm 0.9$	$-10.9 \pm 4.4 \pm 2.4$
$f_2(1270)$	$7.5 \pm 0.8 \pm 0.7$	$+26.7 \pm 10.2 \pm 4.8$
Rescattering	$16.4 \pm 0.8 \pm 1.0$	$-66.4 \pm 3.8 \pm 1.9$
$\phi(1020)$	$0.3 \pm 0.1 \pm 0.1$	$+9.8 \pm 43.6 \pm 26.6$

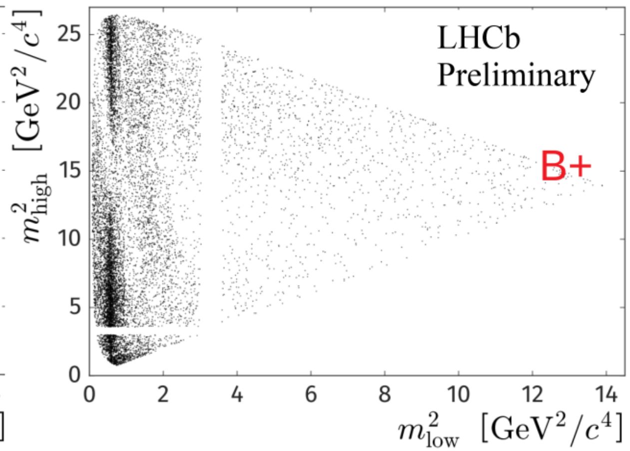
- Fit to 5 resonances + non-resonant + ππ↔KK rescattering.
- Large CP asymmetry comes from the rescattering component.
  - ✓ Can explain the previous result.

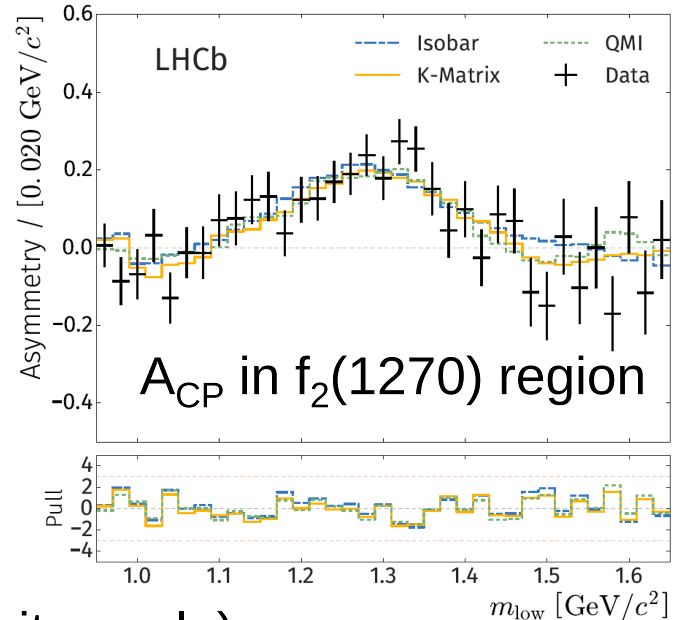
[Parallel Talk by C.Santamarina on Thursday]

CPV in $B^+ \to \pi^+\pi^-\pi^+$

3.0 fb^{-1} at 7-8 TeV (Run1) [LHCb-PAPER-2019-017, LHCb-PAPER-2019-018]







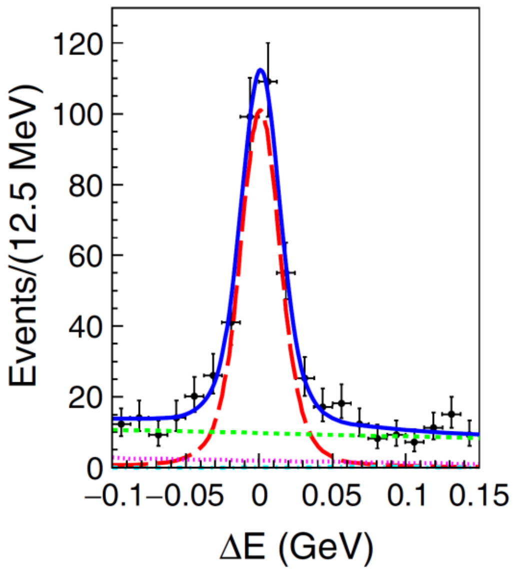
- Large CP asymmetries found in
  - ✓ $f_2(1270)$ component.
  - ✓ $\rho(770)$-scalar interference (in projection to helicity angle).
  - ✓ S-wave components (with three approaches).

[Parallel Talk by C.Santamarina on Thursday]

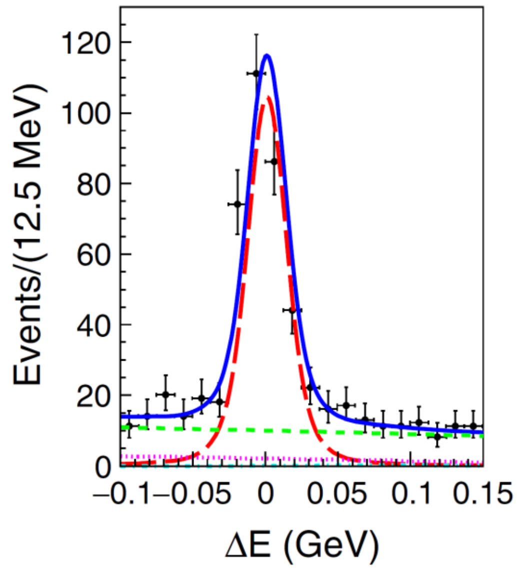
More study can be done with LHCb Run2 data.

CPV in $B^+ \to K_S K_S K^+$

$B^+ \to K_S K_S K^+$



$B^- \to K_S K_S K^-$



[PRD99 (2019) 031102]

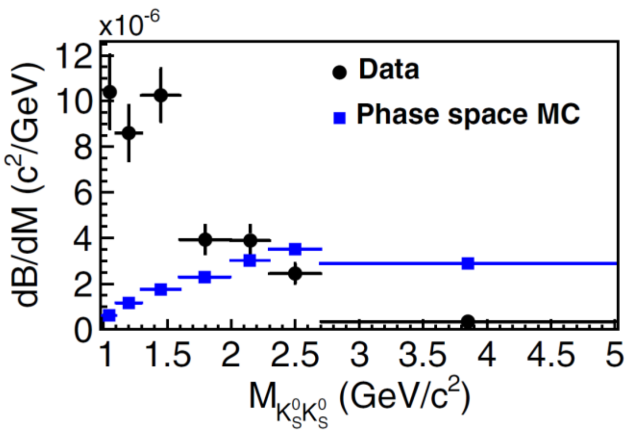
Belle 711 fb^{-1}

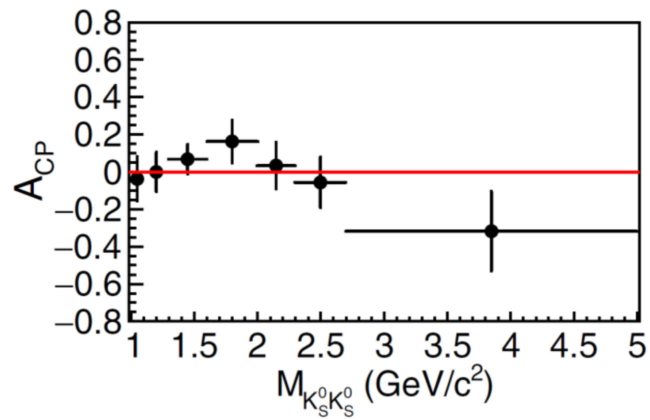
Not an amplitude analysis

$\mathcal{B}(B^+ \to K_S K_S K^+) = (6.5 \pm 2.6 \pm 0.4) \times 10^{-7}$

$A_{CP}(B^+ \to K_S K_S K^+) = (+1.6 \pm 3.9 \pm 0.9)\%$

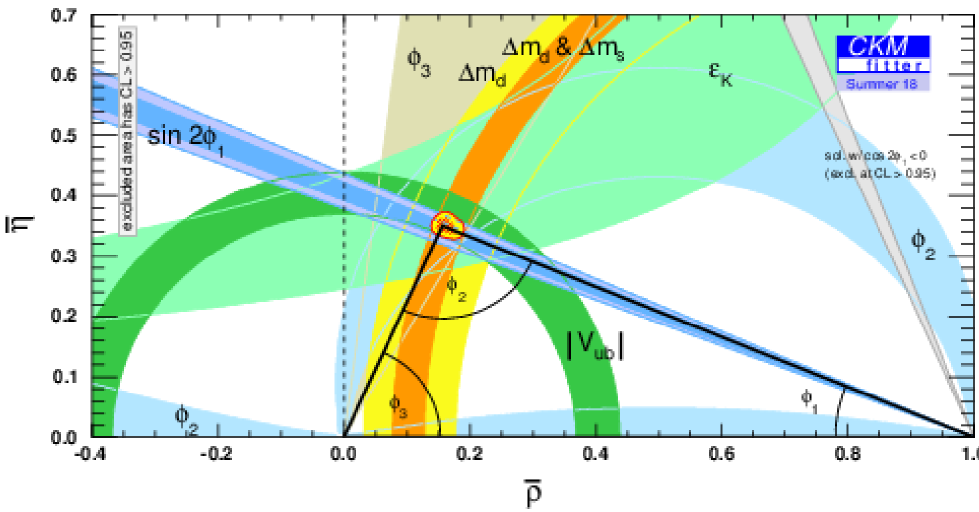
$\mathcal{B}(B^+ \to K_S K_S \pi^+) < 8.7 \times 10^{-7}$





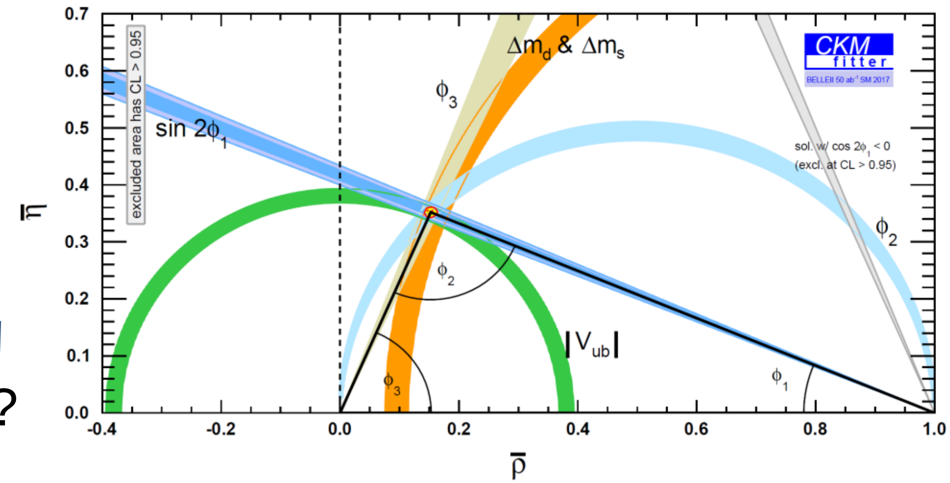
Conclusion

- Updates on ϕ_3 / γ, $|V_{cb}|$, ϕ_s.
- CP Asymmetry in $B^+ \to \pi^+K^+K^-$, $\pi^+\pi^-\pi^+$.

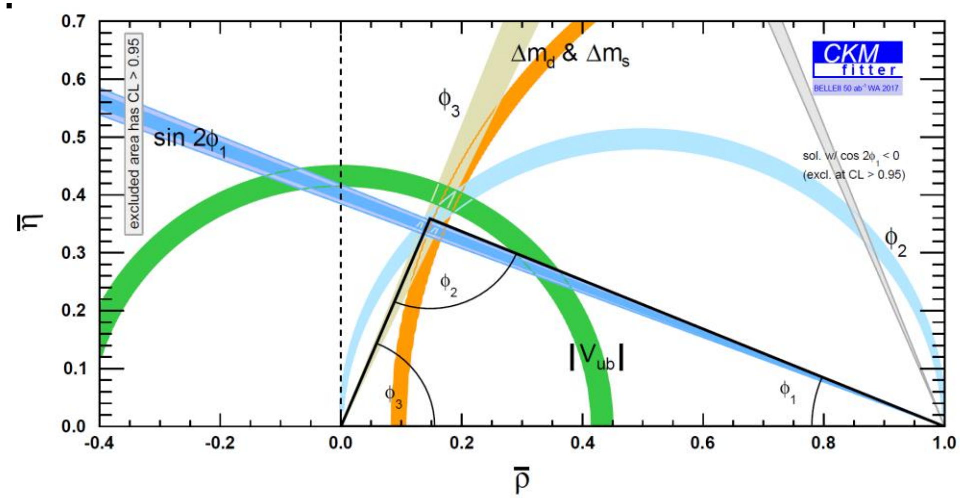


?

?



Belle II 50 ab^{-1} [arXiv:1808.10567]

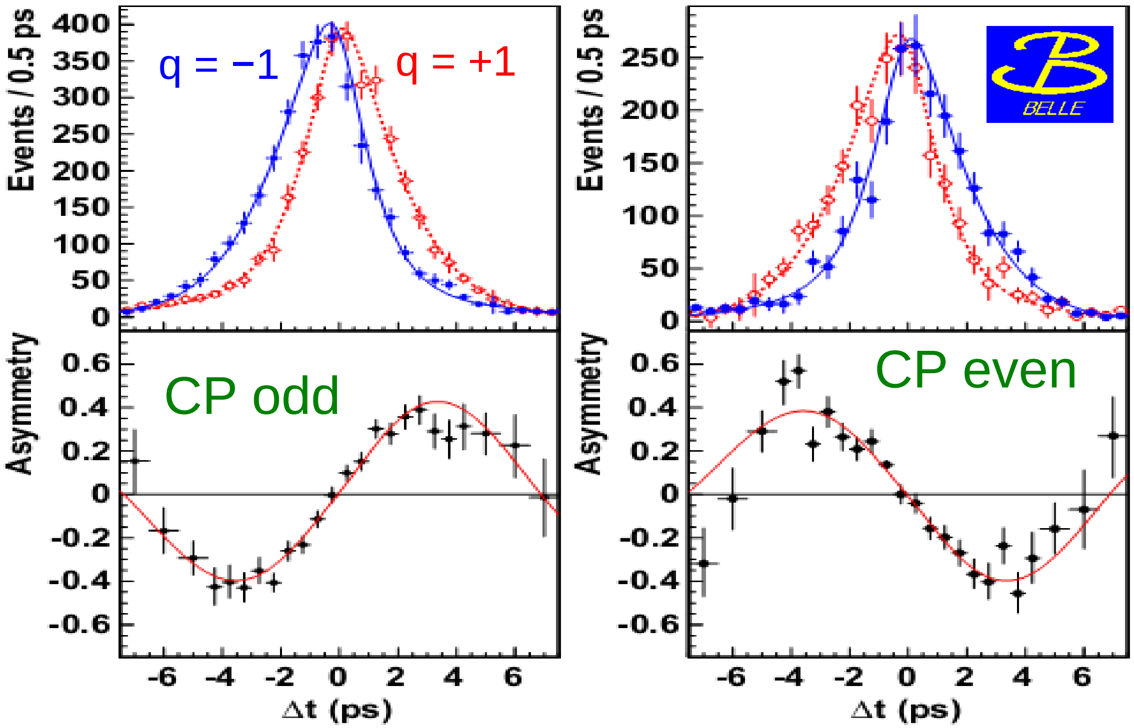


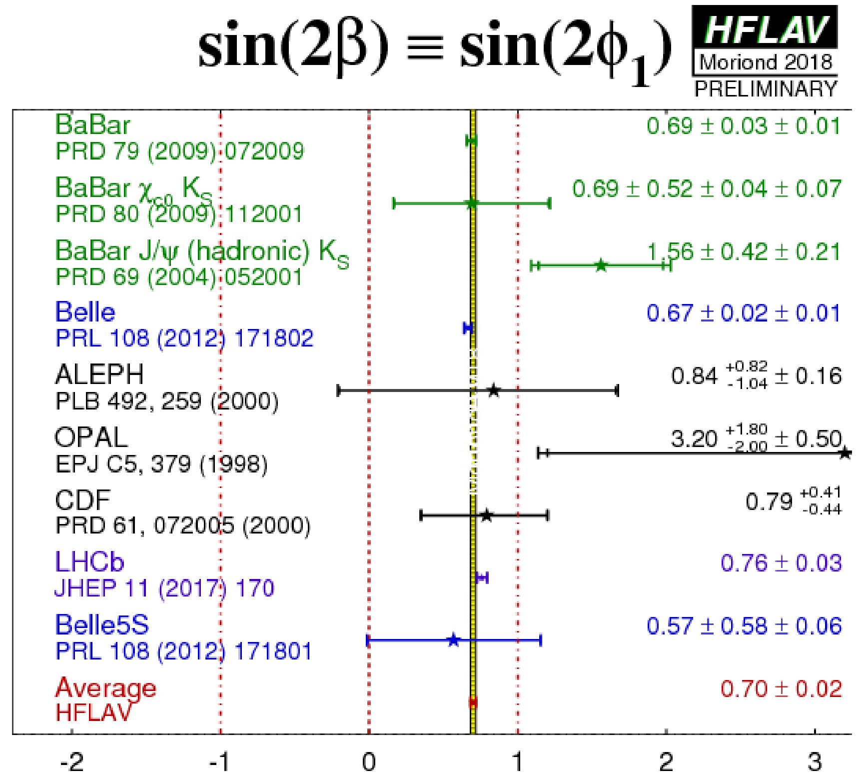
- More results from LHCb are expected.
- Belle II started, will join the game.

[Talk by T.Browder on Monday]

Backup

Measurement of ϕ_1 (β)





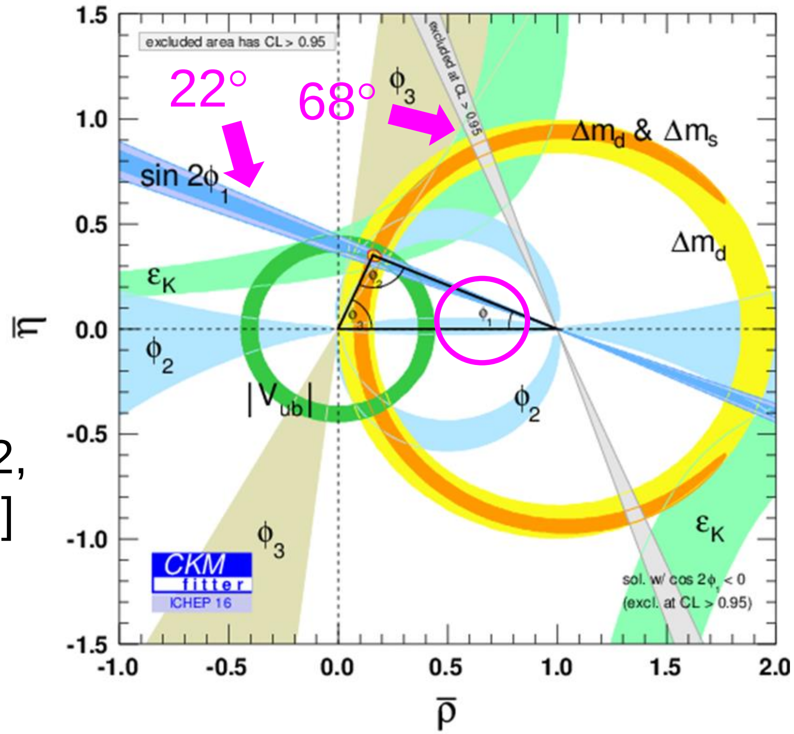
$\sin(2\phi_1) = 0.667 \pm 0.023 \pm 0.012$

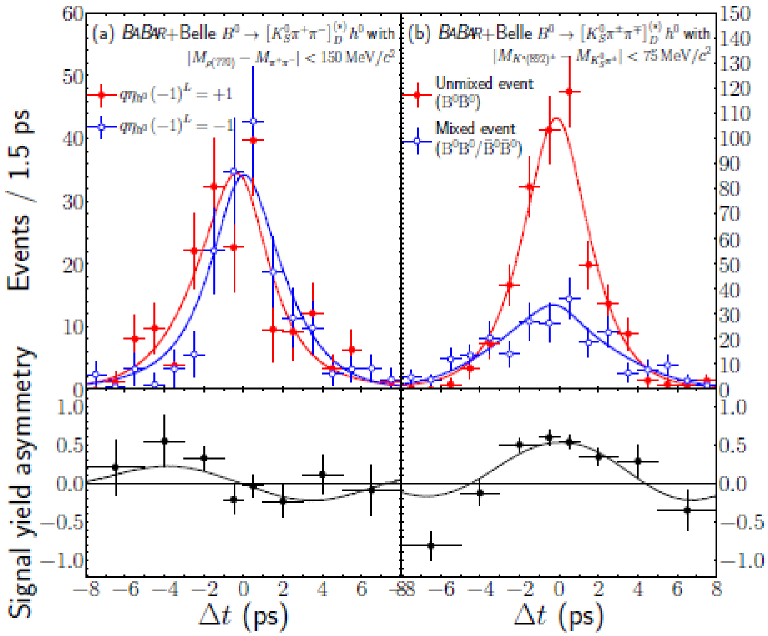
$A = 0.006 \pm 0.016 \pm 0.012$

[PRL 108, 171802 (2012)]

cos(2β) in $B \to D^{(*)}h^0$

- $\sin 2\beta$ is precisely measured, but trigonometric ambiguity exists for β.
- Time-dependent Dalitz analysis of $B \to D^{(*)}h^0$, $D \to K_S\pi^+\pi^-$ ($h = \pi^0, \eta, \omega$) can resolve it.
- Joint Babar + Belle analysis.
  - ✓ 471 + 772 M $B\bar{B}$





(two different region in Dalitz plane)

[arXiv:1804.06152, arXiv:1804.06153]

$$\sin(2\beta) = 0.80 \pm 0.14\,(\text{stat.}) \pm 0.06\,(\text{syst.}) \pm 0.03\,(\text{model})$$

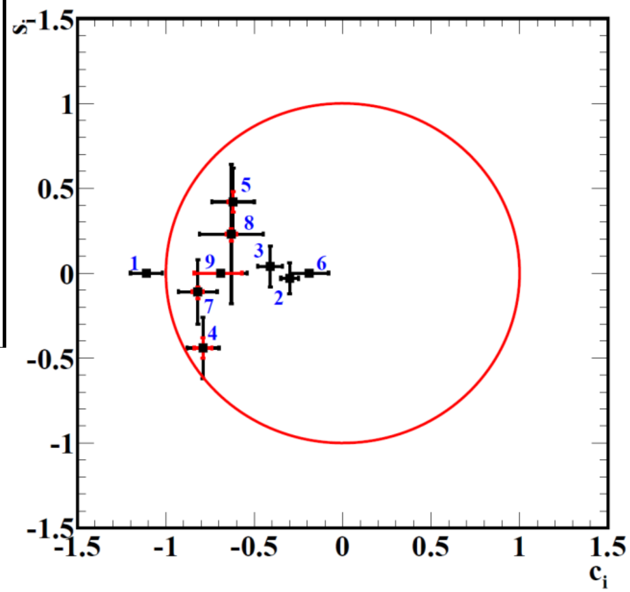
$$\cos(2\beta) = 0.91 \pm 0.22\,(\text{stat.}) \pm 0.09\,(\text{syst.}) \pm 0.07\,(\text{model})$$

$$\beta = \left(22.5 \pm 4.4\,(\text{stat.}) \pm 1.2\,(\text{syst.}) \pm 0.6\,(\text{model})\right)^0$$

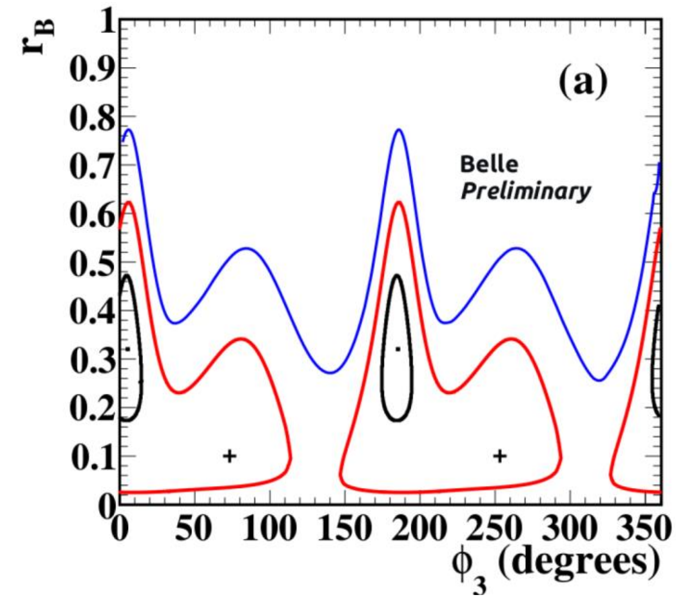
- First evidence of $\cos 2\beta > 0$.

ϕ_3 / γ

Bin	Bin region
1	$m(\pi^+\pi^-\pi^0) \approx m(\omega)$
2	$m(K^0_S\pi^-) \approx m(K^{*-})$ & $m(\pi^+\pi^0) \approx m(\rho^+)$
3	$m(K^0_S\pi^+) \approx m(K^{*+})$ & $m(\pi^-\pi^0) \approx m(\rho^-)$
4	$m(K^0_S\pi^-) \approx m(K^{*-})$
5	$m(K^0_S\pi^+) \approx m(K^{*+})$
6	$m(K^0_S\pi^0) \approx m(K^{*0})$
7	$m(\pi^+\pi^0) \approx m(\rho^+)$
8	$m(\pi^-\pi^0) \approx m(\rho^-)$
9	Remainder



c_i and s_i results in 9 bins using CLEO-c data



ϕ_s from ATLAS

Systematic Uncertainties

	ϕ_s [rad]	$\Delta\Gamma_s$ [ps^{-1}]	Γ_s [ps^{-1}]	$\lvert A_\parallel(0)\rvert^2$	$\lvert A_0(0)\rvert^2$	$\lvert A_S(0)\rvert^2$	$\delta_\perp$ [rad]	$\delta_\parallel$ [rad]	$\delta_\perp - \delta_S$ [rad]
Tagging	1.7×10^{-2}	0.4×10^{-3}	0.3×10^{-3}	0.2×10^{-3}	0.2×10^{-3}	2.3×10^{-3}	1.9×10^{-2}	2.2×10^{-2}	2.2×10^{-3}
Acceptance	0.7×10^{-3}	$<10^{-4}$	$<10^{-4}$	0.8×10^{-3}	0.7×10^{-3}	2.4×10^{-3}	3.3×10^{-2}	1.4×10^{-2}	2.6×10^{-3}
ID alignment	0.7×10^{-3}	0.1×10^{-3}	0.5×10^{-3}	$<10^{-4}$	$<10^{-4}$	$<10^{-4}$	1.0×10^{-2}	7.2×10^{-3}	$<10^{-4}$
S–wave phase	0.2×10^{-3}	$<10^{-4}$	$<10^{-4}$	0.3×10^{-3}	$<10^{-4}$	0.3×10^{-3}	1.1×10^{-2}	2.1×10^{-2}	8.3×10^{-3}
Background angles model:									
Choice of fit function	1.8×10^{-3}	0.8×10^{-3}	$<10^{-4}$	1.4×10^{-3}	0.7×10^{-3}	0.2×10^{-3}	8.5×10^{-2}	1.9×10^{-1}	1.8×10^{-3}
Choice of p_T bins	1.3×10^{-3}	0.5×10^{-3}	$<10^{-4}$	0.4×10^{-3}	0.5×10^{-3}	1.2×10^{-3}	1.5×10^{-3}	7.2×10^{-3}	1.0×10^{-3}
Choice of mass interval	0.4×10^{-3}	0.1×10^{-3}	0.1×10^{-3}	0.3×10^{-3}	0.3×10^{-3}	1.3×10^{-3}	4.4×10^{-3}	7.4×10^{-3}	2.3×10^{-3}
Dedicated backgrounds:									
B_d^0	2.3×10^{-3}	1.1×10^{-3}	$<10^{-4}$	0.2×10^{-3}	3.1×10^{-3}	1.4×10^{-3}	1.0×10^{-2}	2.3×10^{-2}	2.1×10^{-3}
Λ_b	1.6×10^{-3}	0.4×10^{-3}	0.2×10^{-3}	0.5×10^{-3}	1.2×10^{-3}	1.8×10^{-3}	1.4×10^{-2}	2.9×10^{-2}	0.8×10^{-3}
Fit model:									
Time res. sig frac	1.4×10^{-3}	1.1×10^{-3}	$<10^{-4}$	0.5×10^{-3}	0.6×10^{-3}	0.6×10^{-3}	1.2×10^{-2}	3.0×10^{-2}	0.4×10^{-3}
Time res. p_T bins	3.3×10^{-3}	1.4×10^{-3}	0.1×10^{-2}	$<10^{-4}$	$<10^{-4}$	0.5×10^{-3}	6.2×10^{-3}	5.2×10^{-3}	1.1×10^{-3}
Total	1.8×10^{-2}	0.2×10^{-2}	0.1×10^{-2}	0.2×10^{-2}	0.4×10^{-2}	0.4×10^{-2}	9.7×10^{-2}	2.0×10^{-1}	0.1×10^{-1}

Uncertainty in the calibration of the B_s-tag probability; MC statistical uncertainty included in fit stat. error

Alternative detector acceptance fit-functions and binning determined from MC

Radial expansion uncertainties determined from their effect on tracks d_0 in the data

Background angles model (fixed in UML fit) extracted from data with varying sidebands size and binning

Uncertainties of relative fraction; fit-model and P-wave contribution

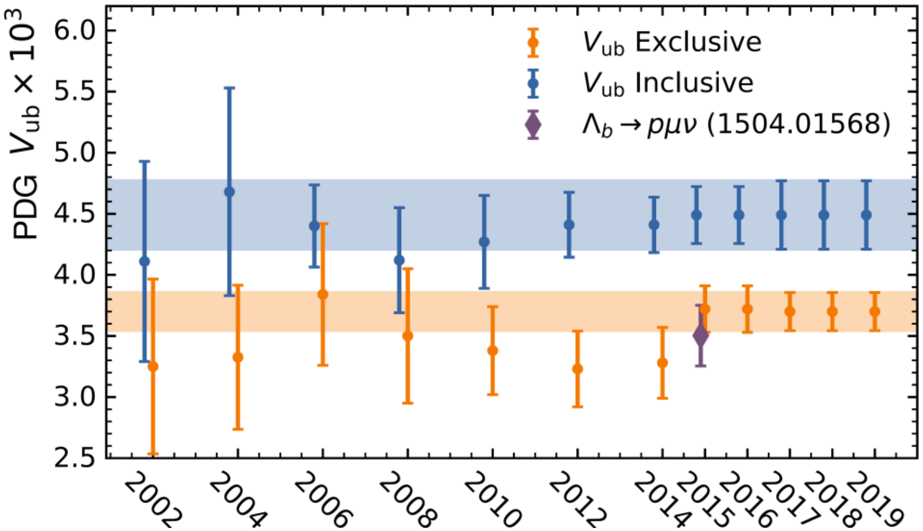
Uncertainties of relative fraction; fit-model and contributions from $\Lambda b \to J/\psi \Lambda^*$ decays

Toy-MC studies; pulls of the default fit model, default fit on toy-data generated with modified PDFs

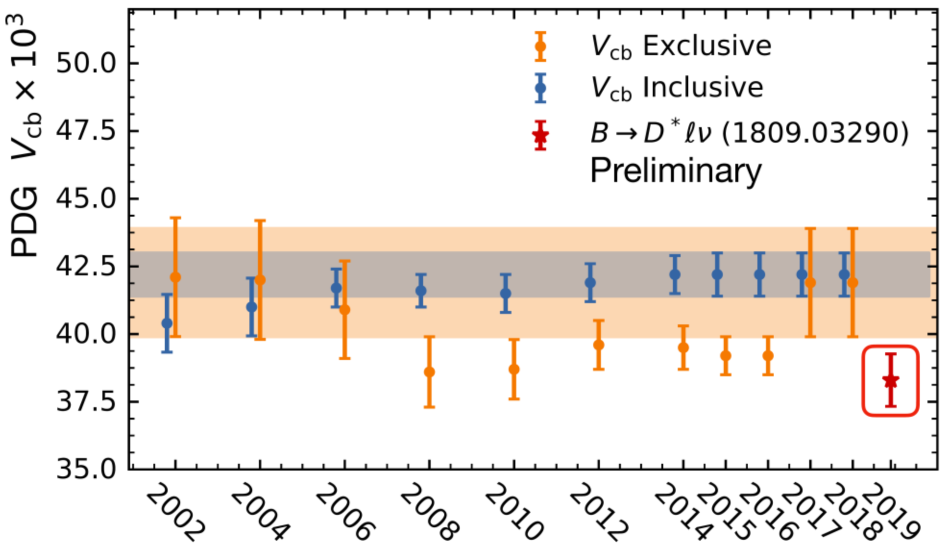
slides from A.E

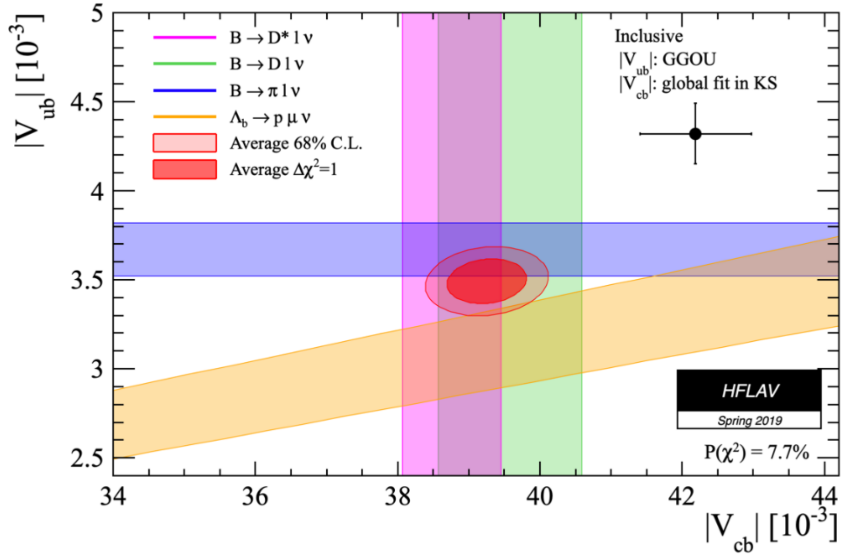
$|V_{ub}|$ and $|V_{cb}|$

$|V_{ub}|$

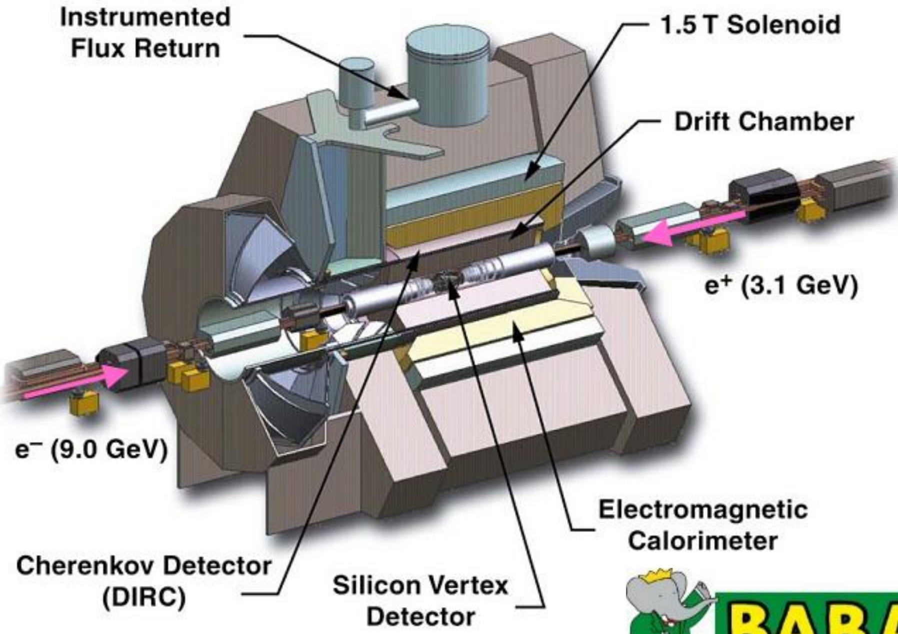


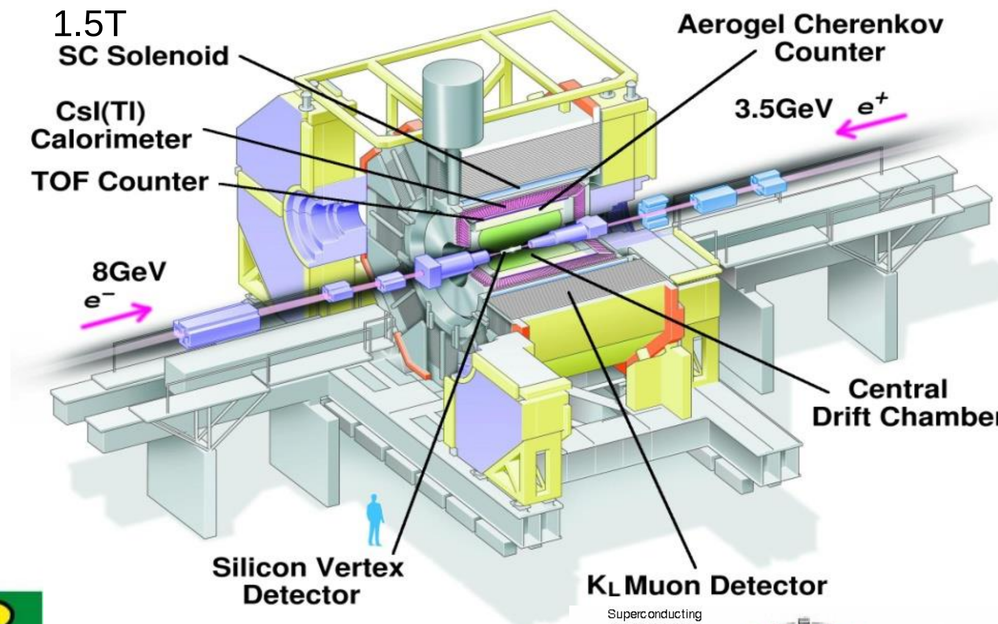
$|V_{cb}|$

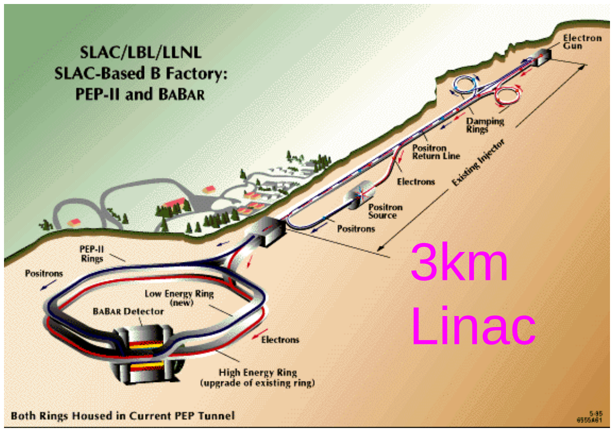




Two B Factories





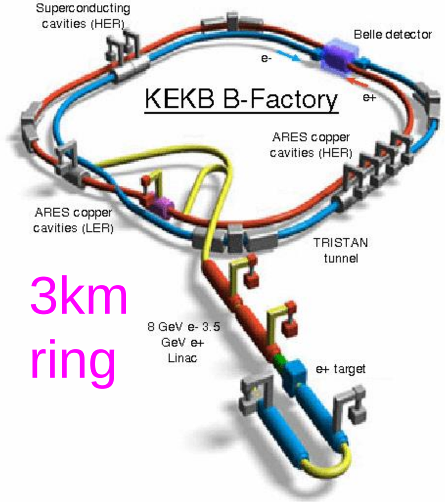


BaBar @ PEP-II

9 GeV e⁻ +
3.1 GeV e⁺

Belle @ KEKB

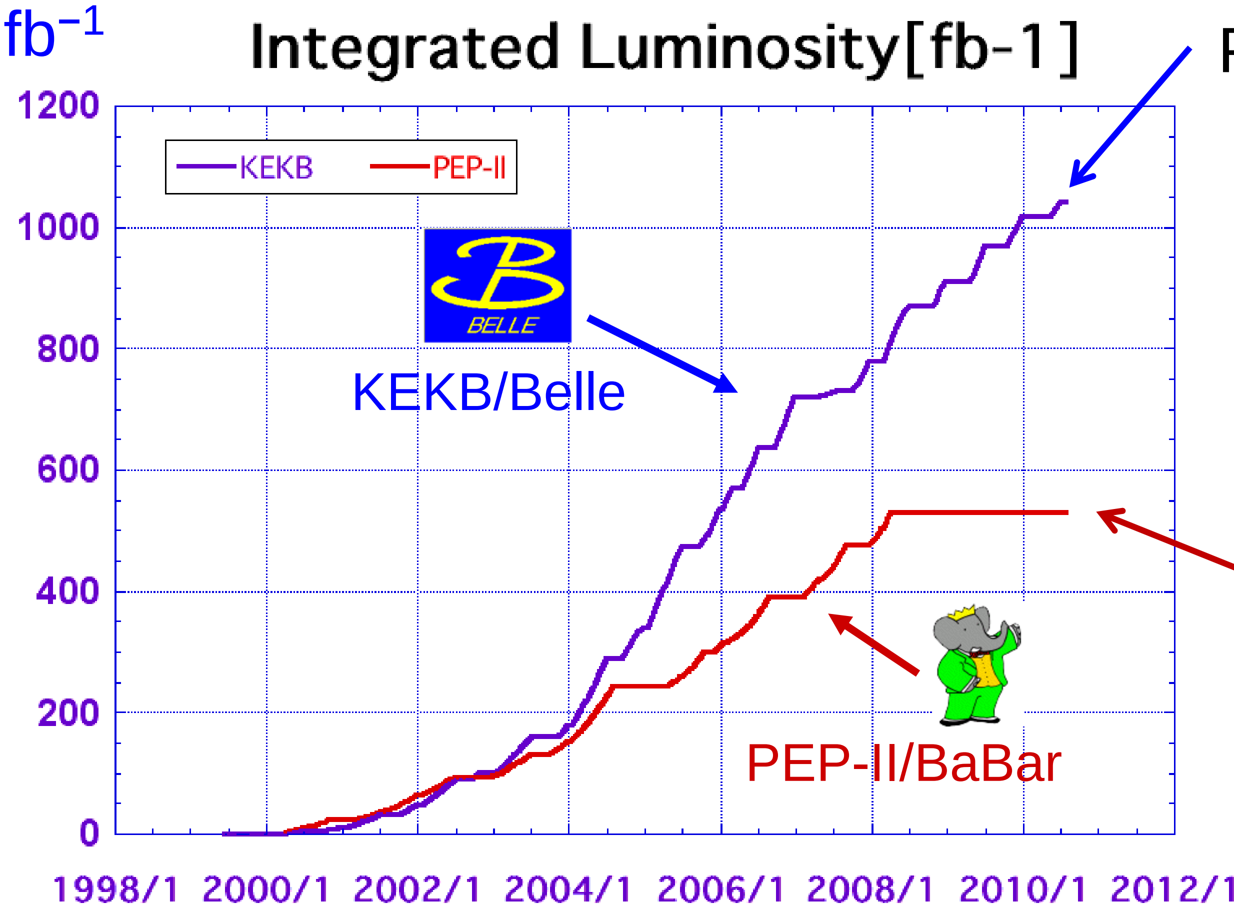
8 GeV e⁻ +
3.5 GeV e⁺



B Factory Luminosity

$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$ (σ=1.1nb)

$1\ fb^{-1} \sim 10^6\ B\bar{B}$ @ $\Upsilon(4S)$



These data are taken till 2010.

KEKB/Belle

Total ~1040 fb^{-1}

Peak $2.11 \times 10^{34}\ cm^{-2}\ s^{-1}$

On resonance:
- $\Upsilon(5S)$: 121 fb^{-1} ← B_s
- $\Upsilon(4S)$: 711 fb^{-1}
- $\Upsilon(3S)$: 3 fb^{-1}
- $\Upsilon(2S)$: 24 fb^{-1}
- $\Upsilon(1S)$: 6 fb^{-1}

Off resonance, scan:
~ 100 fb^{-1}

PEP-II/BaBar

Total 550 fb^{-1}

Peak $1.21 \times 10^{34}\ cm^{-2}\ s^{-1}$

On resonance:
- $\Upsilon(4S)$: 433 fb^{-1}
- $\Upsilon(3S)$: 30 fb^{-1}
- $\Upsilon(2S)$: 14 fb^{-1}

Off resonance:
~ 54 fb^{-1}