Global Analysis of charmless two body B/Bs decays in pQCD Approach

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Summary

Motivation

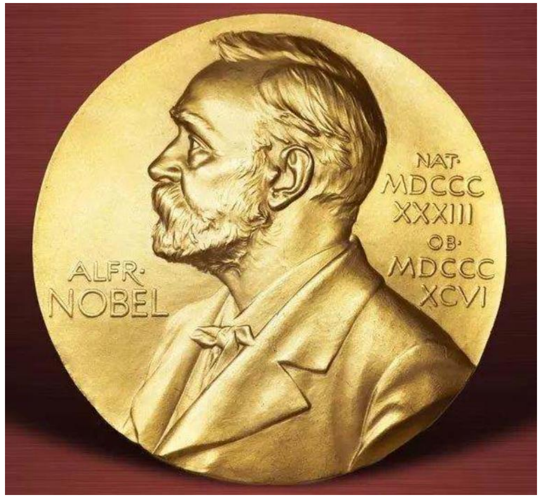
1999 —— 2008
SLAC(Babar)

2009 ——
CERN(LHCb)

KEKB(Belle)
1999 —— 2010

KEKB(Belle-II)
2018 ——

- The measurement of CP violation in B decay has led to Nobel Prize in 2008.
- With the operation of more advanced experiments, the B physics has entered the era of high precision.



Experiments that start from 2008

LHCb

Experiments that start collecting results recently

Belle II

Motivation

1999 —— 2008
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2009 ——
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1999 —— 2010

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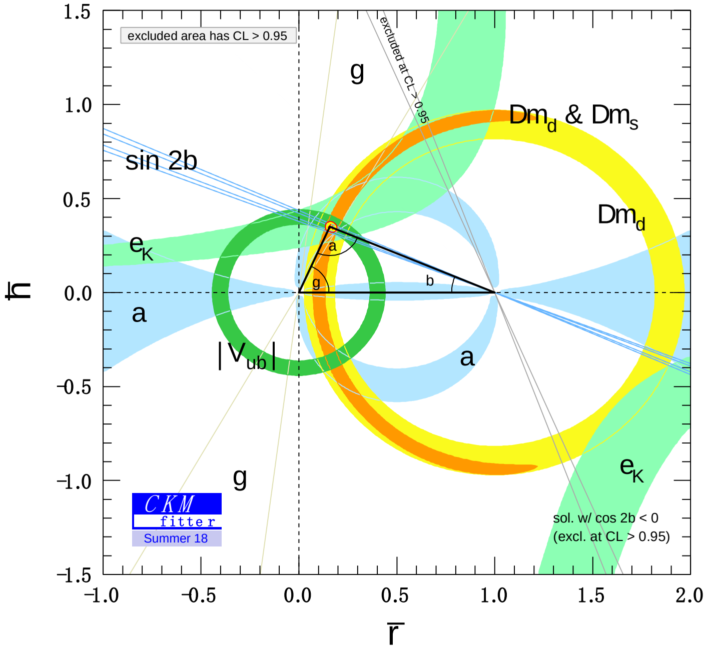
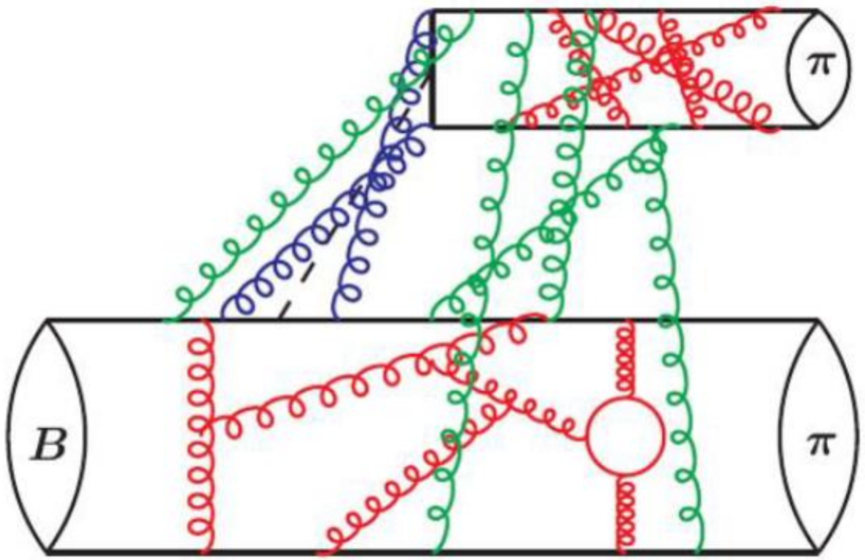
2018 ——



- **B meson decay is an ideal place to study CKM phase angle and CP violation.**
- **The precision test of Standard Model (SM) will help us to find new physics or search new particles indirectly**

Motivation



Complicated ! ! !

PHYSICAL REVIEW D **76,** 074018 (2007)

Charmless nonleptonic B_s decays to PP, PV, and VV final states in the perturbative QCD approach

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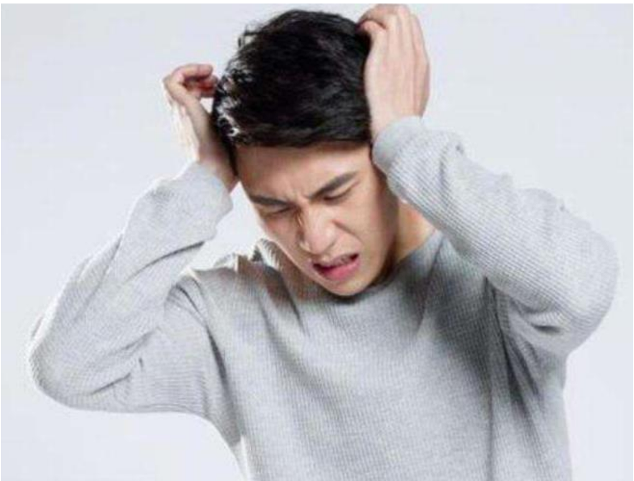
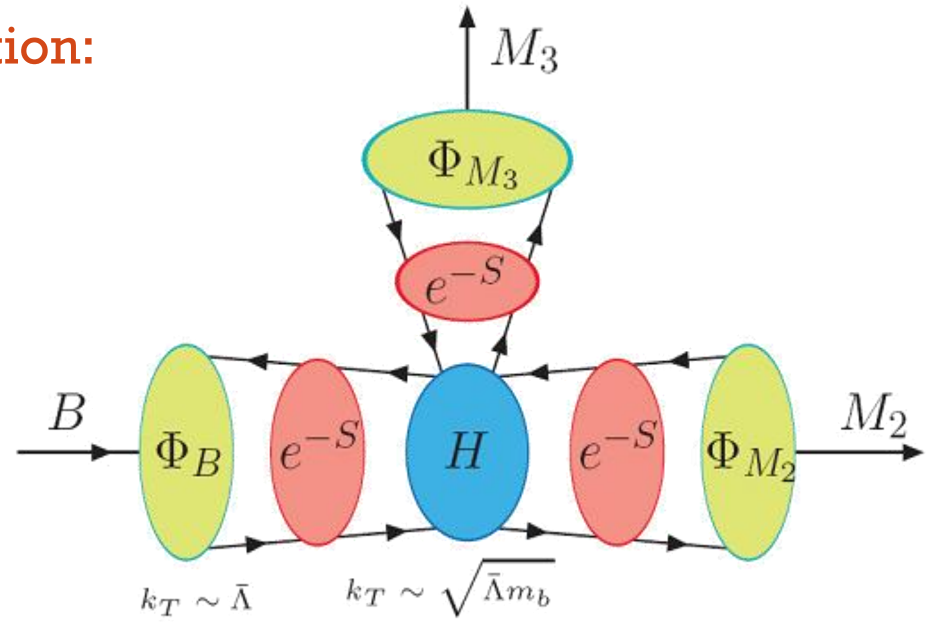
charmless two-body decays
B->PP: 34
B->VP: 62
B->VV: 34



How to simplify?

Auto calculation

k_T factorization:



Other approaches:

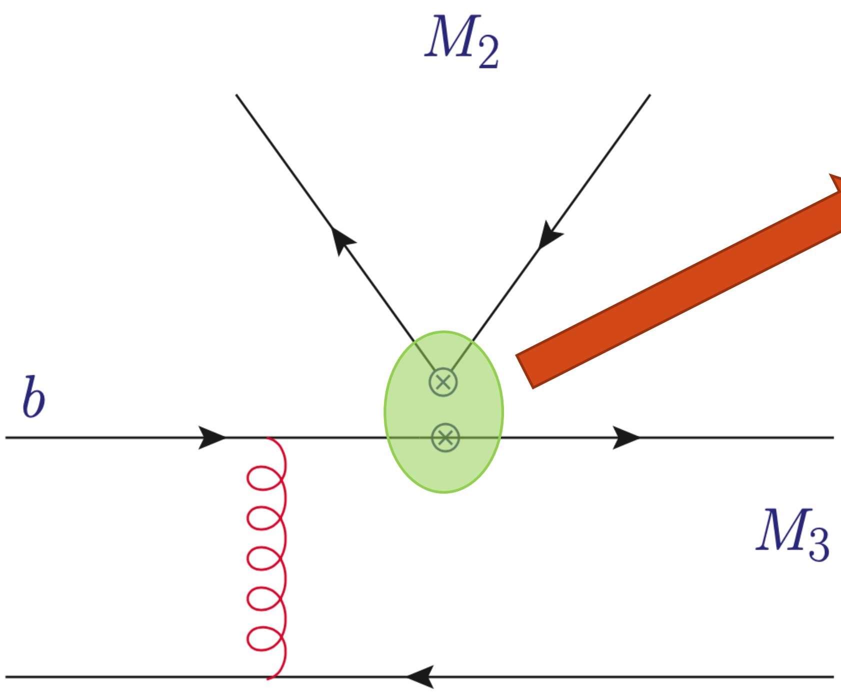
- QCD factorization
- SCET factorization
- ……

$$A \sim \int d^3k_1\, d^3k_2\, d^3k_3\, \mathrm{Tr}\left[\, C(t)\, \Phi_B(k_1)\, \Phi_1(k_2)\, \Phi_2(k_3)\, H(k_1,k_2,k_3,t)\,\right]$$

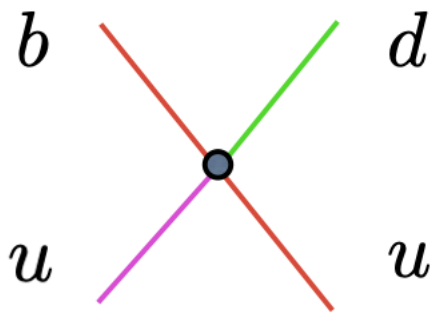
Factorization: A process → Several parts

The key point is how to modular calculate these parts of different processes, especially the hard kernel.

Auto calculation



Factorizable emission diagram



Fermi 4-quark interaction

$$\mathcal{H}_{eff} = \frac{G_F}{\sqrt{2}} \Big\{ \sum_{q=u,c} \underbrace{V_{qb} V_{qD}^*}_{\text{CKM}} \big[C_1 O_1^q + \underbrace{C_2}_{\text{Wilson coefficients}} O_2^q \big] - V_{tb} V_{tD}^* \big[\sum_{i=3}^{10} C_i O_i \big] \Big\} + \text{H.c.},$$

Current operator: $O_1^q = (\bar{q}_\alpha b_\beta)_{V-A} (\bar{D}_\beta q_\alpha)_{V-A},$

- For each two body B decay process, we have factorizable/non-factorizable emission/annihilation diagrams(totally 16 diagrams).
- Each diagram has $C_1 O_1 \sim C_{10} O_{10}$ contributions.

Auto calculation

The formulas of $\langle M_2 M_3|\mathcal{H}_{eff}|B\rangle$ are different process by process.

We introduce a systematical approach with SU(3) matrix elements to calculate these formulas.

Matrix definition:

$$B^- = (1,0,0), \quad \cdots\cdots \qquad \delta_u = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}, \quad \Lambda^d = \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix}, \quad \cdots\cdots$$

$$M_{\pi^+} = M_{\rho^+} = \begin{array}{c} \begin{array}{ccc} \bar{u} & \bar{d} & \bar{s} \end{array} \\ \begin{pmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \end{array} \begin{array}{c} \\ u \\ d \\ s \end{array} \cdots\cdots$$

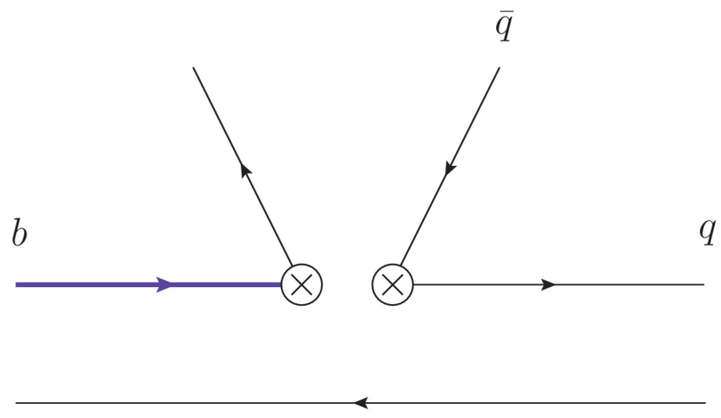
Then the contributions of Wilson coefficients C_1, C_2 can be represented as:

$$A_u(B \to M_2 M_3) = [F_e(a_1) + M_e(C_1)]\, B M_3 \delta_u M_2 \Lambda_f$$

$$+ \ [F_e(a_2) + M_e(C_2)]\, B M_3 \Lambda_f Tr[\delta_u M_2]$$

$C_2 + 1/3 C_1$

factorizable non-factorizable



Global fit

- **A specific process of two-body B meson decay is very complex to calculate(20 mins each). Several days will be cost to finish only once fit.**
- **To be capable of fitting Gegenbauer moments of light meson, a database of different orders of Gegenbauer moments should be established.(once fit with several mins)**

The distribution amplitude of Pseudo-scalar meson(twist-2 part):

$$\phi_P(x) = \frac{f_P}{2\sqrt{2N_c}} 6x(1-x)\left[1 + a_1 C_1^{3/2}(1-2x) + a_2 C_2^{3/2}(1-2x) + a_4 C_4^{3/2}(1-2x)\right]$$

The Gegenbauer moments of a light meson are linear independence to each other, so:

$$\langle M_2(a_2+a_4) M_3(a_2)|\mathcal{H}_{eff}|B\rangle$$
$$= a_{2,M_2} a_{2,M_3} \langle M_2 M_3|\mathcal{H}_{eff}|B\rangle_{22} + a_{4,M_2} a_{2,M_3} \langle M_2 M_3|\mathcal{H}_{eff}|B\rangle_{42}$$

Then the full amplitude can be reconstructed by database as:

$$A = \sum_{n,m=1} a_n \cdot a_m \cdot \underline{M_{nm}}$$

Database of different Gegenbauer moments

Global fit

Least-Squares Fitting (lsq)

- The lsq method minimizes the summed χ^2 of residuals to obtain the coefficient estimates.
- The summed square of residuals is defined as :

experimental data

$$\chi^2 = \sum_{i=1}^{n} \frac{(y_i - \hat{y}_i)^2}{\sigma_y^2}$$

fitted data

Bayesian analysis

- In order to stabilize a complicate non-linear lsq fit, one can use bayesian analysis.
- The modified expression of summed square of residuals is defined by:

$$\chi_m^2 = \chi^2 + \chi_{prior}^2, \quad \chi_{prior}^2 = \sum_{n} \frac{(a_n - \tilde{a}_n)^2}{\tilde{\sigma}_{a_n}^2},$$

fit parameter (Gegenbaue)

Refers to QCDSR[1]

$\tilde{a}_n \pm \tilde{\sigma}_{a_n}^2$ is choosen by physical background at reasonable range.

[1]. Ball P, Zwicky R, Phys. Rev. D 71, 014015 (2006)

Global fit

What we want to fit ?

Fit parmeters : γ

CKM phase angle

$$(\underbrace{a_{2\pi},\, a_{4\pi},\, a_{1K},\, a_{2K},\, a_{4K},}_{twist2\quad (pseudoscalar\ meson)}\quad \underbrace{a_{2\rho},\, a_{1K*},\, a_{2K*},}_{twist2\quad (vector\ meson)}$$

$$\underbrace{a^T_{2\pi}, a^T_{2\pi} a^T_{2K}, a^T_{2K}}_{twist3\quad (pseudoscalar\ meson)}\ ),$$

Why we want to fit ?

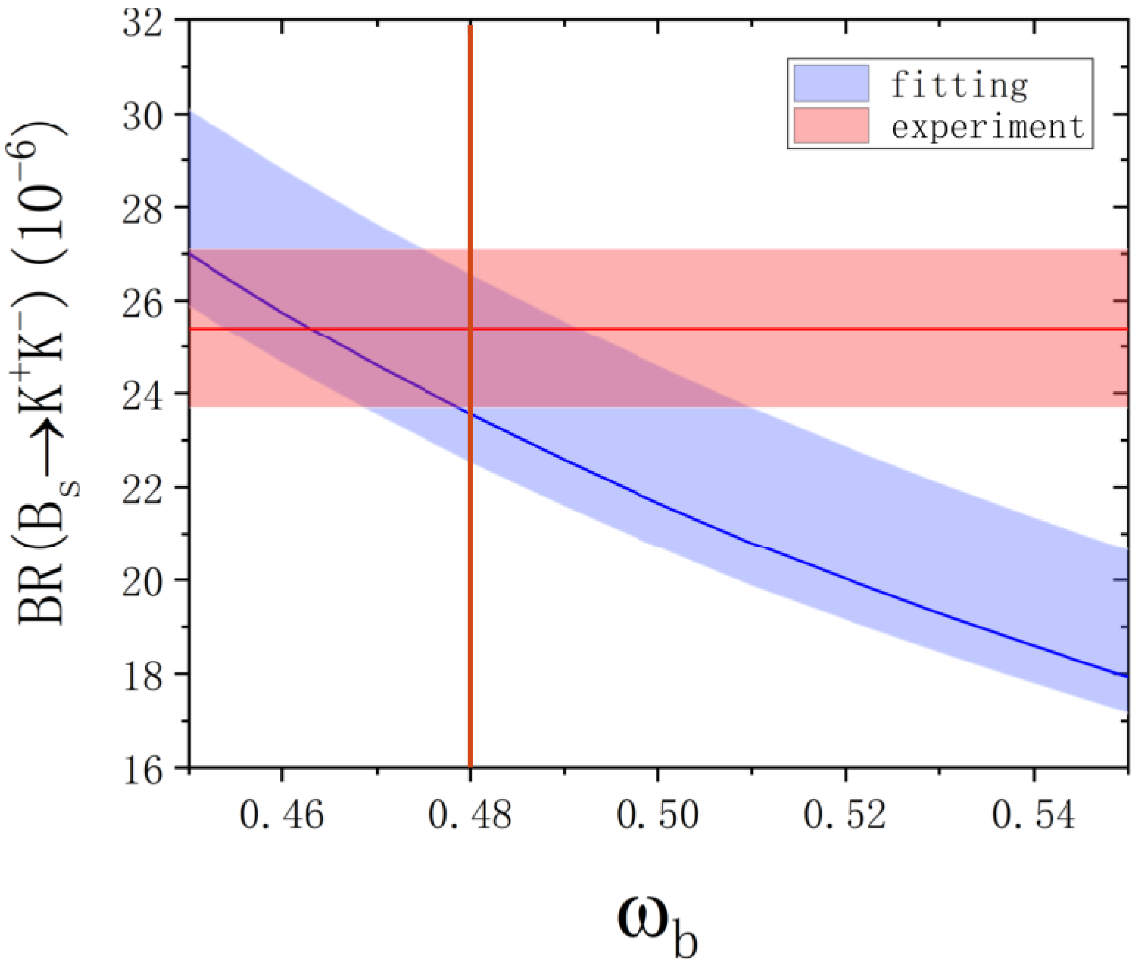
- a_{1K} and a_{1K^*} marked the symmetry breaking of up (down) quark and strange quark.
- CKM phase angle γ is sensitive to new physics and CP violation.

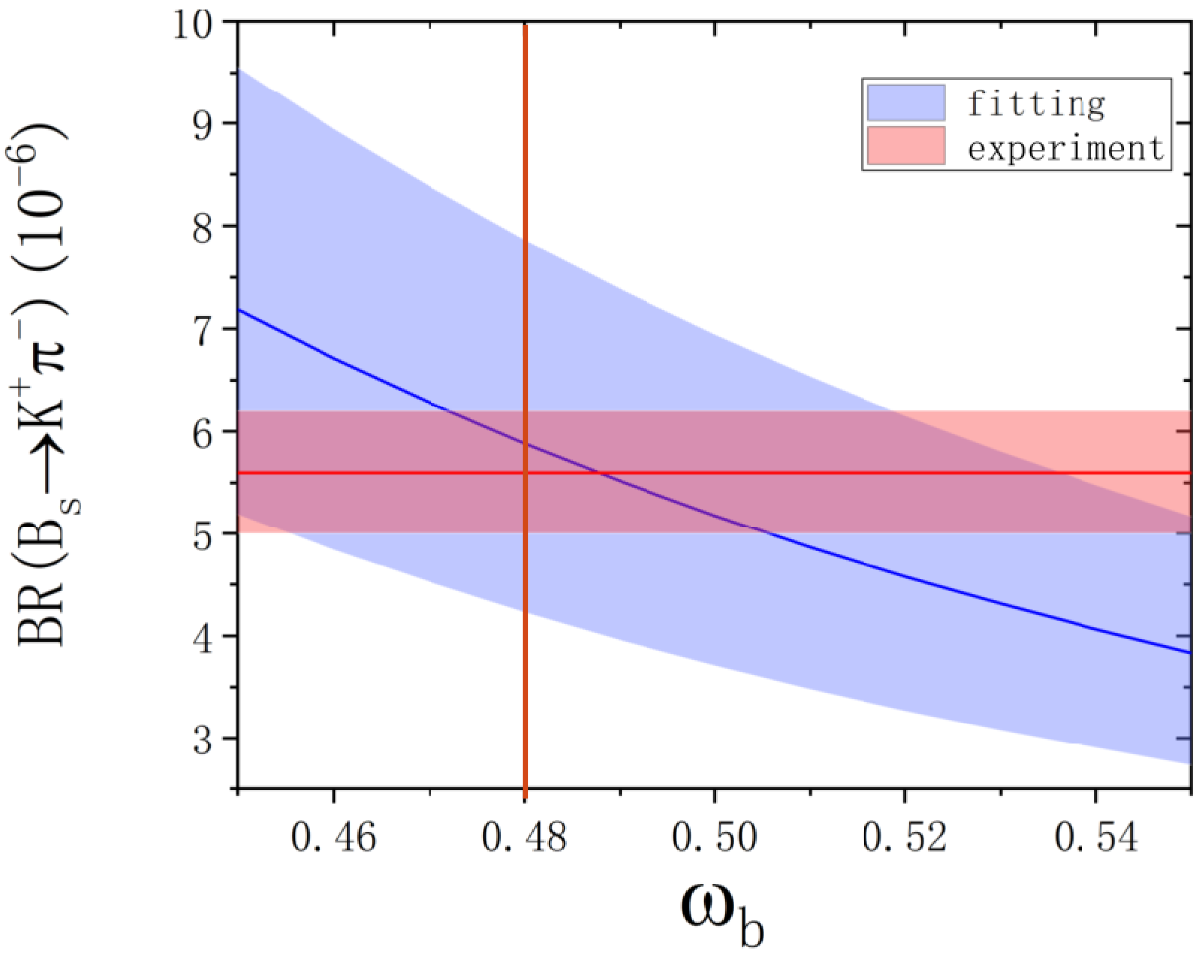
Global fit

Since the influence of ω_b in two body B_s decay depends on specific process, we can not extract ω_b by fitting Gegenbauer coefficients database.

Method of extracting ω_b in two body B_s decay:

We compare the experimental data with pQCD prediction of running ω_b.





Global fit

Channel	Experimental data		This work	
	Branching ratio(10^{-6})	$A_{CP}(\%)$	Branching ratio(10^{-6})	$A_{CP}(\%)$
$B_s \to K^+K^{*-}/K^-K^{*+}$	11.2 ± 2.2	–	14.4 ± 0.7	$-33.3 \pm 1.4/55.2 \pm 2.7$
$B_s \to K^0\bar{K}^{*0}/\bar{K}^0K^{*0}$	16 ± 4	–	14.07 ± 0.76	0 ± 0
$B^- \to \rho^-\pi^0$	10.9 ± 1.4	2 ± 11	8.73 ± 0.26	24.6 ± 2.5
$B^- \to \pi^0K^{*-}$	6.8 ± 0.9	-39 ± 21	3.49 ± 0.19	-33.2 ± 1.8
$B^0 \to \rho^0\bar{K}^0$	3.4 ± 1.1	4 ± 20	3.05 ± 0.38	2.62 ± 0.68
$B^0 \to \pi^0\bar{K}^{*0}$	3.3 ± 0.6	-15 ± 11	1.675 ± 0.098	-7.31 ± 0.44
$B^0 \to \pi^-\rho^+/\pi^+\rho^-$	23 ± 2.3	$13 \pm 8/6 \pm 8$	21.35 ± 0.57	$-25.5 \pm 1.5/9 \pm 1.2$
$B_s \to K^-K^+$	25.4 ± 1.7	-14 ± 11	23.1 ± 1.3	-8.2 ± 2.4
$B_s \to \pi^-\pi^+$	0.68 ± 0.08	–	0.739 ± 0.075	-1.6 ± 0.39
$B_s \to K^0\bar{K}^0$	20 ± 6	0 ± 0	24.4 ± 1.4	0 ± 0
$B_s \to \pi^-K^+$	5.6 ± 0.6	22.1 ± 1.5	5.43 ± 0.55	22.3 ± 1.2
$B^- \to K^0K^-$	1.31 ± 0.17	4 ± 14	1.386 ± 0.075	20.2 ± 2.6
$B^- \to \pi^0K^-$	12.9 ± 0.5	3.7 ± 2.1	12.86 ± 0.23	-6.5 ± 0.58
$B^- \to \bar{K}^0\pi^-$	23.7 ± 0.8	-1.7 ± 1.6	22.88 ± 0.45	-2.84 ± 0.23
$B^0 \to \bar{K}^0K^0$	1.21 ± 0.16	-60 ± 70	1.172 ± 0.077	0 ± 0
$B^0 \to \bar{K}^0\pi^0$	9.9 ± 0.5	0 ± 13	8.87 ± 0.21	-3.84 ± 0.48
$B^0 \to K^-\pi^+$	19.6 ± 0.5	-8.4 ± 0.6	20.09 ± 0.37	-8.25 ± 0.36
$B^0 \to \pi^-\pi^+$	5.12 ± 0.19	31 ± 4	5.29 ± 0.17	23.8 ± 2.1

over 5 sigma error data

Global fit

CKM phase angle γ: 75.1$\pm$2.9

Our fitted Gegenbauer moments of pseudoscalar meson and vector meson:

Gegenbauer moments		$a_{2\pi}$	$a_{4\pi}$	$a_{2\pi}^{P}$	$a_{2\pi}^{T}$		$a_{2\rho}$
Fitting results		**0.592$\pm$0.067**	**-0.370 $\pm$0.095**	**1. 12 $\pm$0.13**	**-0.49$\pm$0.34**		**0191.$\pm$0.091**
Gegenbauer moments	a_{1K}	a_{2K}	a_{4K}	a_{2K}^{P}	a_{2K}^{T}	a_{1K*}	a_{2K*}
Fitting results	**0.345$\pm$0.0078**	**0.261$\pm$0.081**	**-0.398$\pm$0.048**	**~0**	**~0**	**~0**	**0.1$\pm$0.027**

Twist-2 Gegenbauer moments calculated by QCD sum rules[1]:

Gegenbauer moments		$a_{2\pi}$	$a_{4\pi}$		$a_{2\rho}$
Fitting results		**0.25$\pm$0.15**	**-0.015$\pm$0.025**		**0.15 $\pm$0.07**
Gegenbauer moments	a_{1K}	a_{2K}	a_{4K}	a_{1K*}	a_{2K*}
Fitting results	**0.06 $\pm$0.03**	**0.25$\pm$0.15**	**—**	**0.03$\pm$0.02**	**0.11 $\pm$0.09**

[1]. Ball P, Zwicky R, Phys. Rev. D 71, 014015 (2006)

Global fit

Another part of processes predicted by pQCD approach with fitted Gegenbauer moments:

Channel	Experimental data	Previous pQCD prediction (LO)	Our results
	Branching ratio(10^{-6})	Branching ratio(10^{-6})	Branching ratio(10^{-6})
$B^- \to \pi^- \overline{K}^{*0}$	**10.1±0.8**	**5.5 [1]**	**5.06±0.23**
$B^- \to \rho^- \overline{K}^0$	**7.3 ±1.2**	**3.6 [1]**	**3.4±0.59**
$B^- \to \rho^0 K^-$	**3.7±0.5**	**2.5 [1]**	**2.3±0.43**
$B^0 \to \pi^+ K^{*-}$	**7.5±0.4**	**5.1 [1]**	**4.86±0.28**
$B^0 \to \pi^0 \rho^0$	**2.0±0.5**	**0.15[2]**	**0.0496±0.0068**
$B^0 \to K^- \rho^+$	**7.0±0.9**	**4.7 [1]**	**4.43±0.64**
$B^0 \to K^- K^+$	**0.078±0.015**		**0.127±0.002**
$B_s \to \pi^- K^{*+}$	**2.9±1.1**	**7.6[3]**	**10.32±0.25**

These channels are not predicted well in leading order by pQCD approach.

[1]. H. n. Li and S. Mishima, Phys. Rev. D 74, 094020 (2006) **[2]**. Z. Rui, X. Gao and C. D. Lu, Eur. Phys. J. C 72, 1923 (2012)
[3]. A. Ali, G. Kramer, et al, Phys. Rev. D 76, 074018 (2007)

Summary

- We establish a database of B/Bs charmless two body decays by an automated program. Branching ratios and CPVs of different processes can be easily derived by this database.

- Based on this database, we fit the CKM phase angle γ and Gegenbauer moments of light mesons.

- With the fitted parameters, we give the pQCD predictions of branching ratios and CPVs of several processes. Some processes can not be predicted well at leading order.

Thank You !