$\sin 2\beta$ from $B \to J/\psi K$

Martin Jung

Talk at CKM 2016
1st of December 2016, Mumbai, India

Extracting weak phases in hadronic decays

UT angles extracted from non-leptonic decays

➥ Hadronic matrix elements (MEs) main theoretical difficulty!

Options:

- Lattice: not (yet) feasible for (most) 3-meson MEs
- Other non-perturbative methods, e.g. QCDSR: idem, precision
- Factorization: applicability, power corrections [but see Uli's talk]
- Symmetry methods: limited applicability or precision

➥ New/improved methods necessary!

UT angles extracted by avoiding direct calculation of MEs

➥ Revisit approximations for precision analyses

➥ Necessary due to apparent smallness of NP

Here: Improve SU(3) analysis in $B \to J/\psi M$

Flavour SU(3) and its breaking

SU(3) flavour symmetry ($m_u = m_d = m_s$)...

- does not allow to calculate MEs, but relates them (WE theorem)
- provides a model-independent approach
- allows to determine MEs from data
  ➥ improves "automatically"!
- includes final state interactions

flavour octet

SU(3) breaking...

- is sizable, $\mathcal{O}(20-30\%)$
- can systematically be included: tensor (octet) $\sim m_s$
  [Savage'91,Gronau et al.'95,Grinstein/Lebed'96,Hinchliffe/Kaeding'96]
  ➥ even to arbitrary orders [Grinstein/Lebed'96]

Main questions:

- How large is the SU(3)-expansion parameter?
- Is the number of reduced MEs tractable?

$B \to J/\psi M$ decays - basics

$B_d \to J/\psi K$, $B_s \to J/\psi\phi$:

- Amplitude $A = \lambda_{cs} A_c + \lambda_{us} A_u$
- Clearly dominated by A_c [Bigi/Sanda '81]
- Very clear experimental signature
- Subleading terms:
  - Doubly Cabibbo suppressed
  - Penguin suppressed
  - ➥ Estimates $|\lambda_{us} A_u|/|\lambda_{cs} A_c| \lesssim 10^{-3}$
    [Boos et al.'03, Li/Mishima '04, Gronau/Rosner '09]

The golden modes of B physics: $|S| = \sin\phi$

However:

- Quantitative calculation still unfeasible [but see Frings+'15 → Uli]
- Fantastic precision expected at LHC and Belle II
- ➥ Subleading contributions should be controlled:
  Apparent phase $\tilde{\phi} = \phi_{\rm SM}^{\rm mix} + \Delta\phi_{\rm NP}^{\rm mix} + \Delta\phi_{\rm pen\,(SM+NP)}$

Including $|A_u| \neq 0$ – Penguin Pollution

$$\boxed{A_u \neq 0 \;\Rightarrow\; S \neq \sin\phi,\; A_{\rm CP}^{\rm dir} \neq 0}$$

Idea: U-spin-related modes constrain A_u [Fleischer'99, Ciuchini et al.'05,'11, Faller/Fleischer/MJ/Mannel'09, ...]

- Increased relative penguin influence in $b \to d$
- Extract $\phi = \phi_{\rm SM}^{\rm mix} + \Delta\phi_{\rm NP}^{\rm mix}$ and $\Delta\phi_{\rm pen}$
- Issue: Dependence of $\Delta\phi_{\rm pen}$ on SU(3) breaking

Using full SU(3) analysis: [MJ'12]

➥ Determines model-independently SU(3) breaking: $\sim 20\%$

Improved extraction of $\phi_d (\to \Delta\phi_{\rm NP}^{\rm mix})$ and $\Delta\phi_{\rm pen}$

➥ Correction to an already very small effect

Power counting

SU(3) breaking typically $\mathcal{O}(20-30\%)$

Several other suppression mechanisms involved:

- CKM structure (λ, but also $R_u \sim 1/3$)
- "Topological suppression: penguins and annihilation
- $1/N_C$ counting

All these effects should be considered!

- Combined power counting in $\delta \sim 30\%$ for all effects
- Neglect/Constrain only multiply suppressed contributions
- Numerically: contribution $x \sim \delta^n \rightarrow x \leq \delta^{(2n-1)/2}$

$\boxed{\text{Yields predictive frameworks with weaker assumptions!}}$

- Uses full set of observables for related decays
- Assumptions can be checked within the analysis
  - ΔA_{CP}, $\Delta\Delta S$ sensitive to $SU(3)$ breaking for penguins

BR measurements and isospin violation [MJ'16]

Again: detail due to high precision and small NP

➥ Not specific to $B \to J/\psi M$!

Branching ratio measurements require normalization...

- B factories: depends on $\Upsilon \to B^+B^-$ vs. $B^0\bar{B}^0$
- LHCb: normalization mode, usually obtained from B factories

Assumptions entering this normalization:

- PDG: assumes $r_{+0} \equiv \Gamma(\Upsilon \to B^+B^-)/\Gamma(\Upsilon \to B^0\bar{B}^0) \equiv 1$
- LHCb: assumes $f_u \equiv f_d$, uses $r_{+0}^{\mathrm{HFAG}} = 1.058 \pm 0.024$

Both approaches problematic:

- Potential large isospin violation in $\Upsilon \to BB$ [Atwood/Marciano'90]
- Measurements in r_{+0}^{HFAG} assume isospin in exclusive decays
  ➥ This is one thing we want to test!

➥ Avoiding this assumption yields $r_{+0} = 1.027 \pm 0.037$

➥ Isospin asymmetry $B \to J/\psi K$: $A_I = -0.009 \pm 0.024$

A word on (strong) meson mixing

Neutral singlets and octets can mix under QCD

➥ Complicates SU(3) analysis

$B \to J/\psi P$: η, η' not necessary to determine ϕ_d

$B \to J/\psi V$: ϕ central mode

➥ Meson mixing has to be dealt with

For $N_C \to \infty$ in the SU(3) limit: degenerate $P_{1,8}$ and $V_{1,8}$

➥ Relative size of corrections determines mixing angle

➥ Large mixing does not mean breakdown of SU(3)!

η, η': large correction to $1/N_C$ from anomaly (singlet)

➥ η, η' remain approximate SU(3) eigenstates

ϕ, ω: $1/N_C$ effects small (OZI) $\to$ SU(3) breaking dominant

➥ eigenstates according to strangeness content, large mixing

Only the octet part can be controlled by K^* and ρ!

➥ Data for ω necessary to control singlet in SU(3)

Annihilation contributions in $B \to J/\psi M$

Annihilation is important!

- Suppression unclear for heavy final states
  - ➥ $\sim 20\%$ in $A_c(B \to DD)$ [MJ/Schacht'15]
- Determines singlet contributions in $B_s \to J/\psi\phi$
- Affects extraction of $\eta - \eta'$ mixing angle from $B_{d,s} \to J/\psi\eta^{(\prime)}$
- Its neglect in A_u correlates e.g. $B^- \to J/\psi\pi^-$ and $B^0 \to J/\psi K^0$ directly
  - ➥ Overly "precise" predictions for CP asymmetries

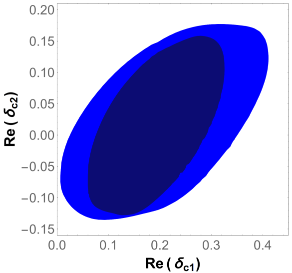
In $B \to J/\psi M$ three annihilation contributions:

- Annihilation in A_c, taken into account where appropriate
- Two annihilation contributions in A_u, $a_2 \sim a_1/N_C$
  - ➥ $a_2 \ll 1 \to BR(B_s \to J/\psi\pi^0, \rho^0) \approx 0$
    $BR(B_s \to J/\psi\rho) \leq 3.6 \times 10^{-6}\,(90\%\mathrm{CL})$
  - ➥ No improvement from inclusion (unlike [Ligeti/Robinson'15])
  - ➥ Only leading contribution included later

$SU(3)$ breaking in $B \to J/\psi P$ [MJ('16), preliminary]

Fit to $\mathbf{B_{d,u,s} \to J/\psi(K,\pi)}$ data (including correlations)

- PDG uncertainties applied
  - ➥ Experimental issue: $R_{\pi K}$
- Excellent fit $(\chi^2/\mathrm{dof} \leq 1)$
  - ➥ Bad fit w/o SU(3) breaking
- SU(3) breaking $\leq 55\%$ allowed
  - ➥ Real SU(3) breaking $\lesssim 30\%$



1. $SU(3)$-breaking parameters perfectly within expectations
2. Strong correlation between $Re(\delta C_1)$ and $Re(P)$:
   - ➥ Cancellations for large P
   - ➥ Assumption on SU(3) breaking affects penguin shift

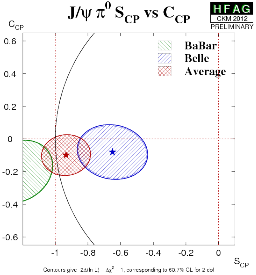
Remaining weaker approximations:

- SU(3) breaking for A_c, only (but to all orders for $P = \pi, K$!)
- EWPs with $\Delta I = 1, 3/2$ neglected in $\mathcal{A}_c$ (tiny!)
- $A(B_s \to J/\psi \pi^0) = 0$: testable (challenging)

"Penguins" in $B \to J/\psi P$ [MJ('16), preliminary]

Fit to $B_{d,u,s} \to J/\psi(K,\pi)$ data (including correlations)

- PDG uncertainties applied
  - Experimental issue: $S(B \to J/\psi\pi^0)$
- Annihilation included
  - $P/T, A/T \leq (100, 55, 16)\%$
- Pen. + Ann. consistent with 0



1. No significant $\mathcal{A}_u$ anywhere
   - no motivation for enhanced P, A_u
2. ϕ_d stable even with enhancements
3. Large CP asymmetries in $B_s \to J/\psi K$ possible with cancellations
   - Exp. progress important!

$\lvert P, A/T \rvert$	$\phi/^\circ$
100% (PDG)	22.2 ± 0.9
55% (PDG)	22.1 ± 0.8
55% (Belle)	22.0 ± 0.7
16% (PDG)	22.0 ± 0.8
0	21.7 ± 0.7

Conclusions

- Smallness of NP poses new challenges to CPV interpretation
- SU(3) with breaking enables model-independent analyses
- Combined power counting of small effects necessary

- High precision $\rightarrow$ Control penguins *and* annihilation
  - Possible for ϕ_d by $B \rightarrow J/\psi P$ $|\Delta\phi| \leq 0.6^\circ$ (95% CL)
  - $B \rightarrow J/\psi \pi^0$ and $B_s \rightarrow J/\psi K$ central
- Interplay with SU(3) breaking
  - careful interpretation of BR data necessary
- Results will improve with coming data, penguins tamed

- QCD-mixing of mesons complicates $B \rightarrow J/\psi V$ analysis
  - Nevertheless possible, work in progress

$b \rightarrow c\bar{c}s$ modes remain "golden"!

Input Values for $B \to J/\psi P$ Decays: BRs

Observable	Value	Ref./Comments
$\frac{1}{c_-}\mathrm{BR}(B^- \to J/\psi K^-)$	$(10.27 \pm 0.31) \times 10^{-4}$	
$\frac{1}{c_-}\mathrm{BR}(B^- \to J/\psi \pi^-)$	$(0.38 \pm 0.07) \times 10^{-4}$	
$\frac{\mathrm{BR}(B^- \to J/\psi \pi^-)}{\mathrm{BR}(B^- \to J/\psi K^-)}$	0.040 ± 0.004	scaling factor 3.2
	0.0386 ± 0.0013	Excluding BaBar
	0.052 ± 0.004	Excluding LHCb
$\frac{1}{c_0}\mathrm{BR}(\bar{B}^0 \to J/\psi \bar{K}^0)$	$(8.73 \pm 0.32) \times 10^{-4}$	
$r\,\frac{\mathrm{BR}(B^- \to J/\psi K^-)}{\mathrm{BR}(\bar{B}^0 \to J/\psi \bar{K}^0)}$	1.090 ± 0.045	correlations neglected
$\frac{1}{c_0}\mathrm{BR}(\bar{B}^0 \to J/\psi \pi^0)$	$(0.176 \pm 0.016) \times 10^{-4}$	scaling factor 1.1
$\frac{f_s}{f_d}\,\frac{\mathrm{BR}(\bar{B}_s \to J/\psi K_S)}{\mathrm{BR}(\bar{B}^0 \to J/\psi K_S)}$	0.0112 ± 0.0006	$f_s/f_d = f_s/f_d\vert_{\mathrm{LHCb}}$
$\frac{\mathrm{BR}(\bar{B}_s \to J/\psi K_S)}{\mathrm{BR}(\bar{B}^0 \to J/\psi K_S)}$	0.038 ± 0.009	uses $f_s/f_d = f_s/f_d\vert_{\mathrm{Tev}}$
$\frac{1}{c_0}\mathrm{BR}(\bar{B}^0 \to J/\psi \eta)$	$0.123 \pm 0.019 \times 10^{-4}$	
$\mathrm{BR}(\bar{B}_s \to J/\psi \eta)$	$(5.1 \pm 1.1) \times 10^{-4}$	
$R_s = \frac{\mathrm{BR}(\bar{B}_s \to J/\psi \eta')}{\mathrm{BR}(\bar{B}_s \to J/\psi \eta)}$	0.73 ± 0.14	$\rho(BR, R_s) = -23\%$
R_s	0.902 ± 0.084	$\rho(R_s, R) = 1\%$
$R = \frac{\mathrm{BR}(\bar{B}^0 \to J/\psi \eta')}{\mathrm{BR}(\bar{B}^0 \to J/\psi \eta)}$	1.11 ± 0.48	$\rho(R, R_\eta) = -73\%$
$\frac{f_d}{f_s} R_\eta = \frac{f_d}{f_s}\,\frac{\mathrm{BR}(\bar{B}^0 \to J/\psi \eta)}{\mathrm{BR}(\bar{B}_s \to J/\psi \eta)}$	0.072 ± 0.024	$\rho(R_\eta, R_s) = 9\%$

Input Values for $B \to J/\psi P$ Decays: CP Asymmetries

Observable	Value	Ref./Comments
$\mathcal{A}_{\rm CP}(B^- \to J/\psi K^-)$	0.003 ± 0.006	
$\mathcal{A}_{\rm CP}(B^- \to J/\psi \pi^-)$	0.001 ± 0.028	
$-\eta_{\rm CP}\mathcal{S}_{\rm CP}(\bar{B}^0 \to J/\psi K_{S,L})$	0.687 ± 0.019	
$\mathcal{A}_{\rm CP}(\bar{B}^0 \to J/\psi K_{S,L})$	0.016 ± 0.017	$\rho(\mathcal{S}_{\rm CP}, \mathcal{A}_{\rm CP}) = -15\%$
$\mathcal{S}_{\rm CP}(\bar{B}^0 \to J/\psi \pi^0)$	-0.94 ± 0.29	
	-0.65 ± 0.22	Belle only
$\mathcal{A}_{\rm CP}(\bar{B}^0 \to J/\psi \pi^0)$	0.13 ± 0.13	
	0.08 ± 0.17	Belle only
$\mathcal{S}_{\rm CP}(\bar{B}_s \to J/\psi K_S)$	-0.08 ± 0.41	
$\mathcal{A}_{\rm CP}(\bar{B}_s \to J/\psi K_S)$	0.28 ± 0.42	
$\mathcal{A}_{\Delta\Gamma}(\bar{B}_s \to J/\psi K_S)$	$0.49^{+0.77}_{-0.65} \pm 0.06$	
$f_s/f_d\|_{\rm LHCb}$	0.259 ± 0.015	
y_s	0.0611 ± 0.0037	
$r = f_{+-}/f_{00}$	1.027 ± 0.037	

Data in both tables: PDG, HFAG, LHCb, Belle, BaBar

Topological amplitudes in $B \to J/\psi P$

Mode	C	E^c	$\tilde{P}_2$	A^u	PA	E^u
$\bar{B}^0 \to J/\psi \bar{K}^0$	1	0	1	0	0	0
$\bar{B}^0 \to J/\psi \pi^0 \times\sqrt{2}$	1	0	1	0	0	-1
$B^- \to J/\psi K^-$	1	0	1	1	0	0
$B^- \to J/\psi \pi^-$	1	0	1	1	0	0
$\bar{B}_s \to J/\psi K^0$	1	0	1	0	0	0
$\bar{B}_s \to J/\psi \pi^0 \times\sqrt{2}$	0	0	0	0	0	-1
$\bar{B}^0 \to J/\psi \eta_8 \times\sqrt{6}$	-1	0	-1	0	0	-1
$\bar{B}^0 \to J/\psi \eta_1 \times\sqrt{3}$	1	$\sqrt{3}$	1	0	3	1
$\bar{B}_s \to J/\psi \eta_8 \times\sqrt{6}$	2	0	2	0	0	-1
$\bar{B}_s \to J/\psi \eta_1 \times\sqrt{3}$	1	$\sqrt{3}$	1	0	3	1

Table : Topological amplitudes contributing to $B \to J/\psi P$ in the $SU(3)$ limit.

Power counting explicit

Contribution	CKM	$1/N_C$	Pen.	Ann.	Π
C	1	1	1	1	1
A^c	1	δ	1	δ	δ^2
$\tilde{P}_2$	R_u	δ	δ	1	$R_u \times \delta^2$
$\tilde{P}_4$	R_u	δ^2	δ	δ	$R_u \times \delta^4$
A_1^u	R_u	1	1	δ^2	$R_u \times \delta^2$
A_2^u	R_u	δ	1	δ^2	$R_u \times \delta^3$

Table : Relative power counting for the contributions to $B \to J/\psi P$ decays with $b \to d$ transitions ($b \to s$ transitions receive an additional factor of λ^2 in the contributions to $\mathcal{A}_u$). There is an additional factor of δ for the SU(3) corrections to a given amplitude.

Factorization in $B \to J/\psi M$

$B \to J/\psi M$ *formally* factorizes for $m_{c,b} \to \infty$... [BBNS'00]

➥ ...but corrections are large: $\Lambda_{\rm QCD}/(\alpha_s m_{c,b})$

$B \to J/\psi M$ *formally* factorizes for $N_C \to \infty$... [Buras+'86]

➥ ...but corrections are large: $A_c \sim C_0 v_0 + C_8(v_8 - a_8)$ [Frings+'15]
Non-factorizable $a_8, v_8 \sim v_0/N_C$, but $C_8 \sim 17 C_0$!

$BR(B \to J/\psi M)$ remains uncalculable
N.B.: No reason to assume $F_{B\to K}/F_{B\to\pi}$ for $SU(3)$ breaking

Factorization for P/T: [Frings+'15 → see Uli's talk Tuesday]

- $\mathcal{A}(B \to J/\psi M) = \lambda_{cs} A_c + \lambda_{us} A_u$, A_u "penguin pollution"

➥ $A_u \sim p + a$, includes penguin and annihilation contributions
No annihilation in $B_d \to J/\psi K$, but in $B_s \to J/\psi \phi$

- $p = \sum_j \langle J/\psi M|\mathcal{O}_j^u|B\rangle = \sum_k \langle J/\psi M|\mathcal{O}_k^c|B\rangle + \mathcal{O}(\Lambda/m_{J/\psi})$
- Estimating $\langle J/\psi M|\mathcal{O}_k^c|B\rangle$ in $1/N_C$ yields $\Delta\phi_{d,s}|_p \lesssim 1^\circ$

Reparametrization invariance and NP sensitivity

$$\mathcal{A} = \mathcal{N}(1 + r\, e^{i\phi_s} e^{i\,\phi_w}) \to \tilde{\mathcal{N}}(1 + \tilde{r}\, e^{i\tilde{\phi}_s} e^{i\tilde{\phi}_w})$$

Reparametrization invariance:

[London et al.'99,Botella et al.'05,Feldmann/MJ/Mannel'08]

Transformation changes weak phase, but not form of amplitude

➥ Sensitivity to (subleading) weak phase lost (presence visible)

- $\phi_w = \gamma$ in given analyses
- Usually broken by including symmetry partners
  - ➥ Proposals to extract γ in $B \to J/\psi P$ or $B \to DD$
- However: partially restored when including SU(3) breaking! [MJ/Schacht'14]
  - ➥ Reason for large range for γ observed in [Gronau et al.'08]
  - ➥ Extracted phase fully dependent on SU(3) treatment

➥ NP phases in $\mathcal{A}$ not directly visible

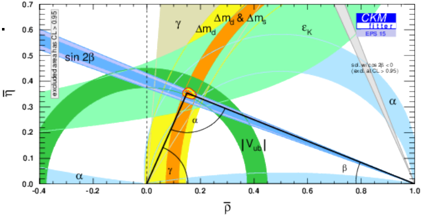
➥ NP tests remain possible

➥ Addition of new terms, e.g. $A_c^{\Delta I=1}$ additional option

(Absolute) BR measurements for B mesons

BR measurements are important for...

- fundamental parameters
  ➥ $|V_{ub}|, |V_{cb}|, \alpha(\phi_2), \beta(\phi_1), \ldots$
- NP searches, specifically isospin asymmetries



$$A_I(X) = \frac{\bar{\Gamma}(B^0 \to X_d^0) - \bar{\Gamma}(B^+ \to X_u^+)}{\bar{\Gamma}(B^0 \to X_d^0) + \bar{\Gamma}(B^+ \to X_u^+)}$$

➥ $A_I(J/\Psi K, D_s D, K^*\gamma \ldots)$

BR measurements require normalization:

- $N_{B\bar{B}} \times f_{+-,00}$ for B factories
- LHCb: ratios of BRs, absolute measurements from B factories

Determination of $f_{+-,00}$ affects all BR measurements

$\Gamma(\Upsilon \to B^+B^-) = \Gamma(\Upsilon \to B^0\bar{B}^0)$?

Isospin limit: $\Gamma(\Upsilon \to B^+B^-) = \Gamma(\Upsilon \to B^0\bar{B}^0)$

➥ Naively corrections $\mathcal{O}(\%)$

However: corrections parametrically enhanced $\sim \pi/v \approx 50$

➥ Potentially [Atwood/Marciano'90,Kaiser+'02]

$$r_{+0} \equiv f_{+-}/f_{00} = \Gamma(\Upsilon \to B^+B^-)/\Gamma(\Upsilon \to B^0\bar{B}^0) \sim 1.2!$$

Then again. . .

- Smaller enhancement due to meson & vertex structure [Byers/Eichten,Lepage'90,Dubynskiy+'07]
- Experimentally $r_{+0} \sim 1.05$ [HFAG'14]

Two lessons:
Assumption of $r_{+0} \equiv 1$ not justified for precision results!
$r_{+0} - 1 \sim \mathcal{O}(\%) \sim$ "standard" isospin breaking

Testing isospin in B decays

Simplest case: test $\Gamma_+ \stackrel{!}{=} \Gamma_0$ for some decay

Experimentally: observe $N_{+(0)}$ charged (neutral) decays,

$$\Gamma_+ - \Gamma_0 \sim \frac{1}{N_{B\bar{B}}}\left[\frac{N_+}{f_{+-}} - \frac{N_0}{f_{00}}\right] .$$

- With assumption on r_{+0}, $\Gamma_+ - \Gamma_0$ can be determined
- With assumption on $\Gamma_+ - \Gamma_0$, r_{+0} can be determined

➥ Precision tests: we have to avoid both assumptions!

Literature:

- PDG: assumes $r_{+0} \equiv 1$ for their BR values
- LHCb: uses $f_u \equiv f_d$, but takes r_{+0} from HFAG
- HFAG: $r_{+0} = 1.058 \pm 0.024$, assuming $\Gamma_+ \equiv \Gamma_0$ in 6/7 cases (specifically $\Gamma(B^+ \to J/\psi K^+) \equiv \Gamma(B^0 \to J/\psi K^0)$)

➥ Not suited for precision tests!

Measuring r_{+0} w/o isospin assumption

Avoiding isospin assumptions altogether: [MARK III Coll.'86, BaBar'05]
Compare singly- and doubly-tagged events in the same final state

$$\begin{aligned} N_s &= 2N_{B\bar{B}}\, f_{00}\, \epsilon_s\, \mathrm{BR}(B^0 \to X^0) \\ N_d &= N_{B\bar{B}}\, f_{00}\, \epsilon_d\, \mathrm{BR}(B^0 \to X^0)^2 \\ f_{00} &= \frac{C\, N_s^2}{4 N_d N_{B\bar{B}}} \stackrel{\mathrm{BaBar}}{=} 0.487 \pm 0.010 \pm 0.008 \;\; (D^* \ell \nu, \mathrm{part.rec.}) \end{aligned}$$

- Could be significantly improved with full BaBar dataset
- Should be done with Belle I data!
  - Issue: $N_{B\bar{B}}$ less precise, but comparable precision possible
- Has to be improved by Belle II for precision BR measurements
  - Off-resonance data below $\Upsilon(4S)$ important

Determination of r_{+0} for isospin tests

Second option: use $\Gamma_+ \equiv \Gamma_0$ for inclusive decays [Gonau+'06]

- Isospin-breaking additionally suppressed by $1/m_b^2$
- $r_{+0} = 1.01 \pm 0.03 \pm 0.09\,(X_c^{+0}\ell\nu)$ [Belle'03]
  ➥ $r_{+0} = 1.00 \pm 0.03 \pm 0.04$ (updated inputs)
  Further significant reduction of systematics possible?

$f_{+-} + f_{00} \stackrel{!}{=} 1$?

- Measurement: $BR(\Upsilon(4S) \to \mathrm{non-}B\bar{B}) \leq 4\%$ [CLEO'96]
- No non-$B\bar{B}$ mode observed with BR$\geq 10^{-4}$ [HFAG]

➥ $f_{+-} + f_{00} = 1$ assumed in the following

➥ Main assumption here, needs experimental confirmation!

Averaging the two values for r_{+0} w/o isospin bias: [MJ'16]

$$r_{+0} = 1.027 \pm 0.037$$

- Only this value that can be used for isospin asymmetries
- Improvable with existing data, Belle II has to do better!
- Implies a $\sim 2\%$ lower bound for BR precision at the moment

Potential for Belle II

1. Belle II can significantly improve the existing measurements
   - Singly- vs. doubly-tagged $B^0 \to D^{*-}(\bar{D}^0\pi^-)\ell^+\nu$
   - r_{+0} from inclusive modes
   - Limit on non-$B\bar{B}$ decay modes of the $\Upsilon(4S)$
2. Potential of $B^{+,0} \to \bar{D}^{*0,-}(\bar{D}^{0,-}\pi^0)\ell^+\nu$): [MJ'16]
   - Lower reconstruction efficiency
     ➥ countered by high luminosity
   - First direct measurement of f_{+-}
     ➥ enables test of $f_{+-} + f_{00} \simeq 1$ (main assumption so far)
   - Allows for measuring r_{+0} as a double-ratio
     ➥ $N_{B\bar{B}}$ cancels together with other systematic uncertainties

Precision challenge met by Belle II
New measurements to test assumptions
Isospin tests with $A_I \sim \mathcal{O}(\leq \%)$ become possible!

Implications for $B \to J/\psi K$

Present averages have uncertainties around 3% [PDG]

- For $c_0/c_+ \equiv r_{+0} = 1$, $A_I(J/\Psi K) = -0.044 \pm 0.024$
  Discussed e.g. in [Feldmann+'08,MJ/Mannel'09,MJ'12,Ligeti/Robinson'15]

Additional measurement [BaBar'04] , updated inputs:

$$r_{+0}\mathrm{BR}(B^+ \to J/\psi K^+)/\mathrm{BR}(B^0 \to J/\psi K^0) = 1.090 \pm 0.045$$

This yields the averages (accidentally small correlations): [MJ'16]

$$\begin{aligned}
\mathrm{BR}(B^+ \to J/\psi K^+) &= (9.95 \pm 0.32) \times 10^{-4} \ [\mathrm{PDG}: (10.27 \pm 0.31)] \\
\mathrm{BR}(B^0 \to J/\psi K^0) &= (9.08 \pm 0.31) \times 10^{-4} \ [\mathrm{PDG}: (8.73 \pm 0.32)] \\
A_I(J/\Psi K) &= -0.009 \pm 0.024 \ \text{(SM expectation } \lesssim 1\%)
\end{aligned}$$

- Errors basically unchanged. No sign of an isospin asymmetry!
  - Relevant in penguin pollution analyses [MJ'12,('16),Ligeti/Robinson'15]
    - Improvement important for precision in $\beta(\phi_1)$
  - Note: also $A_I(J/\Psi\pi)[\overset{!}{\sim} 20 \times A_I(J/\Psi K)]$ compatible with 0
  - Side effect: $A_I(J/\Psi K)$ can be used to determine f_u/f_d at LHCb

Consequences for other decay modes

Possible violation of quasi-isospin sum rule in $\bar{B}^{0,-} \to D_s^- D^{+,0}$ [LHCb'13, MJ/Schacht'14]

- possibly affected by f_u/f_d, extraction via $A_I(J/\Psi K)$

$B \to K^*\gamma$:
Isospin asymmetry including production asymmetry:

$$A_I(K^*\gamma) = 0.042 \pm 0.032$$

- Smaller shift (r_{+0} included in one of the measurements)

$B \to X_s\gamma$:
Expected to be ~ 0 (as for $B \to X_c\ell\nu$),

$$A_I(X_s\gamma) = -0.001(58)(5)(19)\ (\mathrm{stat})(\mathrm{syst})(r_{+0})$$

- r_{+0} dominating systematic uncertainty!

Determination of V_{cb}: In principle relevant
However: effect small for $\Gamma_+ + \Gamma_0$, also $|V_{cb}| \sim \sqrt{BR}$

- Only important for non-averaged determinations