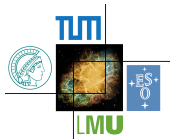


Precision extraction of $\phi_{d,s}$ (and some comments on α)

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Extracting weak phases in hadronic decays

UT angles extracted from non-leptonic decays

➡ Hadronic matrix elements (MEs) main theoretical difficulty!

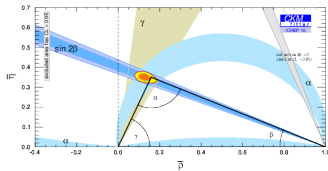
Options:

- Lattice: not (yet) feasible for (most) 3-meson MEs
 - Other non-perturbative methods, e.g. QCDSR: idem, precision
 - Factorization: applicability, power corrections [but see Frings+'15]
 - 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

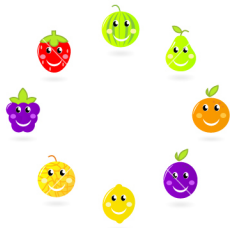
Here: Discuss SU(3) in $B \rightarrow J/\psi M$
Some comments on the extraction of α



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 be included (all orders): tensor (octet) $\sim m_s$
[Savage'91, Gronau et al.'95, Grinstein/Lebed'96, Hinchliffe/Kaeding'96]

Main questions:

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

Isospin breaking: from $m_d - m_u \ll \Lambda_{\text{QCD}}$, $\alpha_{\text{em}} \rightarrow \mathcal{O}(\%)$

BR measurements and isospin violation [MJ'16]

- Affects **every** BR measurement for $B_{d,u}$ decays
- ➡ Also isospin analysis in $B \rightarrow \pi\pi$

Branching ratio measurements require normalization. . .

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

Assumptions entering this normalization:

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

Both approaches problematic:

- Potential large isospin violation in $\Upsilon \rightarrow BB$ [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 $r_{+0} = 1.035 \pm 0.038$
- ➡ Isospin asymmetry $B \rightarrow J/\psi K$: $A_I = -0.006 \pm 0.024$

Improvable with existing+coming data, $N_{B\bar{B}}$ one issue

$B \rightarrow J/\psi M$ decays - basics [see also previous talks + this morning]



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

- 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]
- Fantastic precision expected at LHC and Belle II
- Subleading contributions must be controlled:
Apparent phase $\tilde{\phi} = \phi_{SM}^{mix} + \Delta\phi_{NP}^{mix} + \Delta\phi_{pen}(SM+NP)$

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

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

➡ ... but “corrections” are large ($\mathcal{O}(1)$): $\Lambda_{\text{QCD}}/(\alpha_s m_{c,b})$

$B \rightarrow J/\psi M$ formally factorizes for $N_C \rightarrow \infty \dots$ [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 $C_8 \sim 17C_0!$

$BR(B \rightarrow J/\psi M)$ remains uncalculable

N.B.: No justification to assume $\frac{F_{B \rightarrow K}}{F_{B \rightarrow \pi}}$ for $SU(3)$ breaking

Factorization for P/T : [Frings+'15, talk by U.Nierste@CKM'16]

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

Factorization in $B \rightarrow \pi\pi, \rho\rho, \rho\pi$:

- Factorizes again, $\mathcal{O}(\alpha_s^n)$ corrections calculable
- ➡ Λ_{QCD}/m_b sizable, issue e.g. colour-suppression in $B \rightarrow \pi\pi$

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

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

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 $b \rightarrow d$
- Extract $\phi = \phi_{\text{SM}}^{\text{mix}} + \Delta\phi_{\text{NP}}^{\text{mix}}$ and $\Delta\phi_{\text{pen}}$
- Issue: Dependence of $\Delta\phi_{\text{pen}}$ on SU(3) breaking



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

➔ Determines model-independently SU(3) breaking in A_c : $\sim 20\%$

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

➔ 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 $x \sim \delta^n \rightarrow x \leq \delta^{(2n-1)/2}$

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

A word on (strong) meson mixing

Neutral singlets and octets can **mix** under QCD

➡ Complicates SU(3) analysis

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

$B \rightarrow J/\psi V$: ϕ central mode \rightarrow mixing important

For $N_C \rightarrow \infty$ 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) \rightarrow SU(3) breaking dominant

➡ eigenstates according to strangeness content

➡ $\mathcal{O}(1)$ effect, no expansion

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

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

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

Annihilation is important!

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

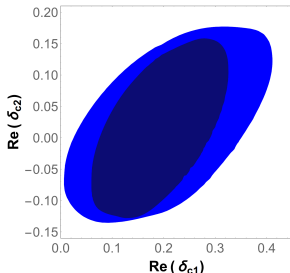
In $B \rightarrow J/\psi M$ three annihilation contributions:

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

$SU(3)$ breaking in $B \rightarrow J/\psi P$ [MJ('18), preliminary]

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

- PDG uncertainties applied
 - ➡ Experimental issue: $R_{\pi K}$
- Excellent fit ($\chi^2/\text{dof} \leq 1$)
 - ➡ 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

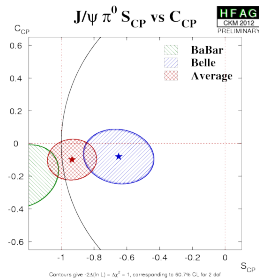
Remaining weaker approximations:

- $SU(3)$ 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!)
- $A(B_s \rightarrow J/\psi\pi^0) = 0$: testable (challenging)

“Penguins” in $B \rightarrow J/\psi P$ [MJ('18), preliminary]

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

- PDG uncertainties applied
 - ➡ Experimental issue: $S(B \rightarrow J/\psi\pi^0)$
- 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 $B_s \rightarrow J/\psi K$ possible with cancellations
 - ➡ Exp. progress important!

$ P, A/T $	$\phi/^\circ$
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

Additional comments on the extraction of α

α is determined using **isospin analyses** in $B \rightarrow \pi\pi, \rho\rho, \rho\pi$

➡ EW penguins (w/ $\Delta I = 3/2$) often neglected

➡ Works very well [see talks by M.Bona and L. Vale Silva]

A couple of (semi-)experimental issues:

- f_L in $\rho\rho$ (Belle vs. BaBar+LHCb)
- α from $B \rightarrow \rho\pi$ ([Charles+'17])

Potential qualitative experimental improvements: **reduce degeneracies**

- Time-dependent CP asymmetry in $B \rightarrow \rho^0\rho^0$! (so far only BaBar)
- Time-dependent CP asymmetry in $B \rightarrow \pi^0\pi^0$ (C_{00}, S_{00} ?!)

Potential improvements on the theory side? [partly Charles+'17]

- Inclusion of EWP (mostly trivial, already sometimes included)
- Main issue: **isospin-breaking effects** (also finite Γ_ρ)
 - Partly from data (e.g. $\pi^0 - \eta^{(\prime)}$ mixing) $\rightarrow \mathcal{O}(\%)$
 - Partly rough estimates $\rightarrow \mathcal{O}(\%)$
 - Potentially enhanced: isospin breaking in $\Upsilon(4S)$ decay \rightarrow include!

Conclusions

Smallness of NP poses new challenges to CPV interpretation

- SU(3) with breaking enables model-independent analyses
 - ➡ Corrections on top of λ^2 suppression \rightarrow small
- High precision \rightarrow Control penguins *and* annihilation
- QCD-mixing of mesons complicates $B \rightarrow J/\psi V$ analysis
 - ➡ Nevertheless possible (no SU(3) breakdown), w.i.p.
- Interplay with SU(3) breaking
 - ➡ careful interpretation of BR data necessary
- SU(3)-breaking in penguins difficult to include
 - ➡ presently irrelevant, ultimate numerical impact?

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

Extraction of α :

- Experimental prospects good, qualitative progress possible
- Isospin breaking main theory issue, partly from data (like $\Upsilon \rightarrow B\bar{B}$)

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

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

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

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

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

Table : Topological amplitudes contributing to $B \rightarrow J/\psi P$ 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 $B \rightarrow J/\psi P$ decays with $b \rightarrow d$ transitions ($b \rightarrow s$ 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.

Reparametrization invariance and NP sensitivity

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

Reparametrization invariance:

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

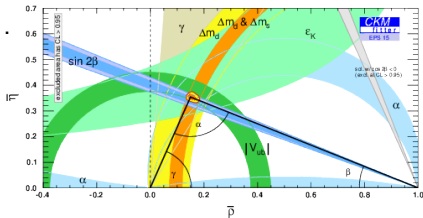
Transformation changes weak phase, but not form of amplitude

- ➡ 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 $B \rightarrow J/\psi P$ or $B \rightarrow DD$
 - 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
 - ➔ $|V_{ub}|, |V_{cb}|, \alpha(\phi_2), \beta(\phi_1), \dots$
- NP searches, specifically isospin asymmetries



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

➔ $A_I(J/\psi K, D_s D, K^* \gamma \dots)$

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

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

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

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

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

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

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

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 $\Gamma(B^+ \rightarrow J/\psi K^+) \equiv \Gamma(B^0 \rightarrow J/\psi K^0)$)
- ➡ 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

$$N_s = 2N_{B\bar{B}} f_{00} \epsilon_s \text{BR}(B^0 \rightarrow X^0)$$

$$N_d = N_{B\bar{B}} f_{00} \epsilon_d \text{BR}(B^0 \rightarrow X^0)^2$$

$$f_{00} = \frac{C N_s^2}{4N_d N_{B\bar{B}}} \stackrel{\text{BaBar}}{=} 0.487 \pm 0.010 \pm 0.008 \quad (D^* \ell \nu, \text{part.rec.})$$

- 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: $BR(\Upsilon(4S) \rightarrow \text{non-}B\bar{B}) \leq 4\%$ [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]

$$r_{+0} = 1.035 \pm 0.037$$

- **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 $B^0 \rightarrow D^{*-}(\bar{D}^0\pi^-)\ell^+\nu$
 - r_{+0} from inclusive modes
 - Limit on non- $B\bar{B}$ decay modes of the $\Upsilon(4S)$
2. Potential of $B^{+,0} \rightarrow \bar{D}^{*0,-}(\bar{D}^{0,-}\pi^0)\ell^+\nu$: [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!