New ideas on CKM angle α (ϕ_2) measurements

11th International Workshop on the CKM Unitarity Triangle

J. Dalseno
jeremypeter.dalseno [AT] usc.es

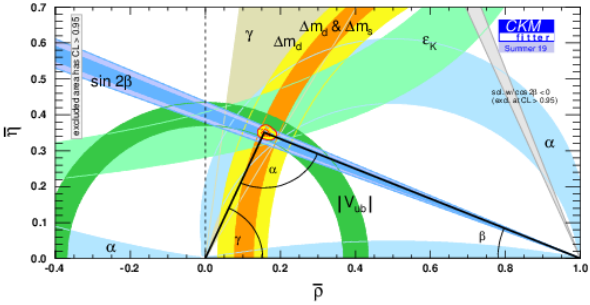
24 November 2021

Introduction

α (ϕ_2) is now the least known input to fits of the Unitarity Triangle

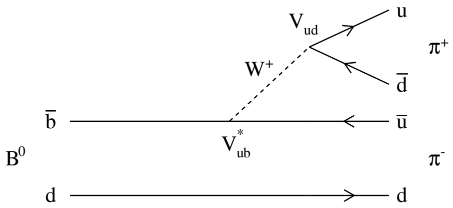
Fantastic opportunity to experimentally impact New Physics searches

Unitarity Triangle (UT)



α is the apex angle of the UT, but something of a misnomer

Introduction



Sensitivity arises from mixing-induced interference in $b \to u$ transitions

Time-dependent, flavour-tagged analysis

  "α": $-2\beta - 2\gamma$

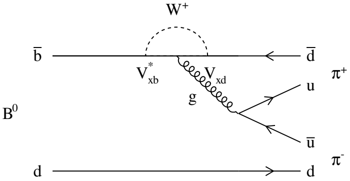
Solution between $[0, \pi]$, expression becomes $\pi - \beta - \gamma$

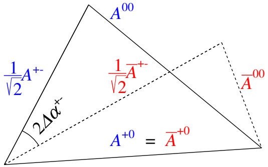
  Could be identified as α if unitarity is conserved

Distinction doesn't matter in Standard Model fits of the UT

Important when searching for a New Physics amplitude in mixing

Introduction





- Theoretically dirtiest of all weak phases at base level
- Significant effort required to clean up
- Primary source of distortion from gluonic penguin amplitudes
  - Mixing-induced CP violation parameter: $\mathcal{S}_{CP}^{+-} \propto \sin(2\alpha + 2\Delta\alpha^{+-})$
- Remove with isospin at the expense of involving additional channels
  - M. Gronau and D. London, Phys. Rev. Lett. **65**, 3381 (1990)
- Bose-Einstein: $I = 1$ forbidden
- In $B^{+} \to \pi^{+}\pi^{0}$, minimum of $I = 2$ from I_3
  - Gluon in penguin means $I = 2$ can't be reached, therefore forbidden
- Isospin triangle relations must share the same base
- 5 sides, 5 observables, enough degrees of freedom to constrain $2\Delta\alpha^{+-}$
  - $\mathcal{B}^{+0}$, $\mathcal{B}^{+-}$, $\mathcal{B}^{00}$, $\mathcal{A}^{+-}$, $\mathcal{A}^{00}$

Introduction

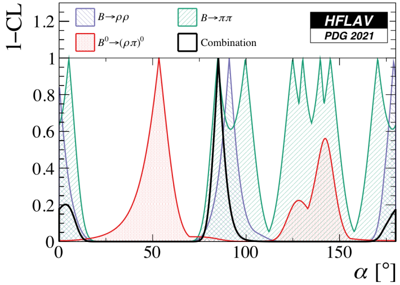
4-fold ambiguity from triangle orientation $\times$ 2-fold in α from $\mathcal{S}_{CP}^{+-}$

Constraint dominated by $B \to \rho\rho$

Some sensitivity from $B^0 \to (\rho\pi)^0$

Input from $B^0 \to a_1^{\pm}\pi^{\mp}$ possible, but not included

World-average



HFLAV: $\alpha = (85.2^{+4.8}_{-4.3})^\circ$

Introduction

Various other sources of α bias

Theoretical side: presence of residual $I = 1$ amplitudes

Cannot continue to ignore these for much longer

Some can be eliminated experimentally, others apparently not

Electroweak penguin amplitudes

- $\Delta\alpha \sim 1^\circ$ in $B \to \pi\pi$, $\rho\rho$ and $B^0 \to (\rho\pi)^0$
  - M. Gronau and J. Zupan, Phys. Rev. D **71**, 074017 (2005)

π^0–η–η' mixing and ρ^0–ω–ϕ mixing

- $\Delta\alpha \sim 1^\circ$ in $B \to \pi\pi$, order of magnitude smaller in $B^0 \to (\rho\pi)^0$
  - M. Gronau and J. Zupan, Phys. Rev. D **71**, 074017 (2005)
- Experimentally manageable in $B \to \rho\rho$
  - M. Gronau and J. Rosner, Phys. Lett. B **766**, 345 (2017)

Invariant mass difference in $B \to \rho\rho$ from finite ρ width

- Experimentally manageable
  - F. Falk, Z. Ligeti, Y. Nir and H. Quinn, Phys.Rev. D **69**, 011502 (2004)

Outline

Experimental sources of bias and limitations to α precision

We also have the capacity to address some of these

"New ideas": eliminating or reducing dominant systematic uncertainties

1. Solution degeneracies in α
   — $B \to \rho\rho$
   — Amplitude analysis
2. Precision SU(3)
   — $B^0 \to a_1^{\pm}\pi^{\mp}$
3. Systematic correlations-induced bias
   — $B \to \rho\rho$ and $B^0 \to (\rho\pi)^0$
4. Systematically limited branching fractions
   — $B \to \pi\pi$ and $B \to \rho\rho$
   — Rescaled isospin triangles
   — New LHCb prospect

$B^0 \to (\rho\pi)^0$

Time-dependent, flavour-tagged, amplitude analysis of $B^0 \to \pi^+\pi^-\pi^0$

Isospin argument applied only to the strong penguin amplitudes

Dalitz plot contains degrees of freedom to model tree and penguin

Measure α without ambiguity in a single analysis

A. Snyder and H. Quinn, Phys. Rev. **D 48**, 2139 (1993)

Tree and penguin amplitudes highly correlated, difficult to converge fit

Remove free complex isobar coefficients of the model

Expand $|A|^2$, free real independent parameter for each cross term

Greatly expand parameters space from 11 to 27 bilinear coefficients

H. Quinn and J. Silva, Phys. Rev. D **62**, 054002 (2000)

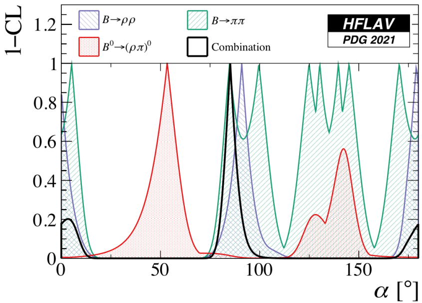
To avoid explosion of parameters, same P/T for $\rho(1450)$ and $\rho(1700)$

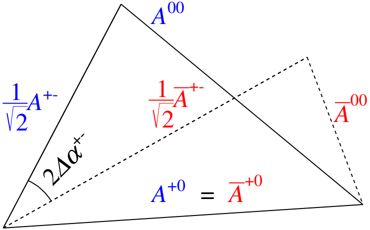
Similarly difficult to add additional resonances to $\pi^+\pi^-$ distribution

Future of this method unclear going forwards, look for another way

$B \to \rho\rho$

World-average





Only 2 visible solutions in $B \to \rho\rho$

$\mathcal{B}^{00}$ very small, isospin triangles flat, $2\Delta\alpha^{+-} \sim 0$

$\mathcal{S}_{CP}^{00}$ sets triangle orientation, 2 solutions remain

In any case, $2\Delta\alpha^{+-} \sim 0$ known without ambiguity

Remaining ambiguity only from $\mathcal{S}_{CP}^{+-} \propto \sin(2\alpha + 2\Delta\alpha^{+-})$

Amplitude analysis is needed

$B^0 \to \rho^+\rho^-$

Time-dependent (t), flavour-tagged (q) rate

$$\Gamma(t,q) \propto e^{-t/\tau_d} \Big[(|A|^2 + |\bar{A}|^2) \\ -q(|A|^2 - |\bar{A}|^2)\cos\Delta m_d t + 2q\Im(\bar{A}A^*)\sin\Delta m_d t \Big]$$

A: Decay amplitude, dependent on phase space position, Φ_4

Sum of intermediate contributions, i

$$A = \sum_i A_i(\Phi_4), \qquad \bar{A} = \sum_i \lambda^i_{CP} A_i(\Phi_4)$$

A_i contains only strong dynamics, while weak phase contained in λ^i_{CP}

$B^0 \to \rho^+\rho^-$

- Dominates, interference from higher ρ and a_1 resonances, α sensitive
- CP-violation parameter factorises, $\lambda^i_{CP} \to \lambda_{CP} = e^{2i\alpha}$
- $\Im(\bar{A}A^*) = \Im(\lambda_{CP}AA^*) = \Im\lambda_{CP}|A|^2 = \sin 2\alpha$

2 solutions remain, despite amplitude analysis

$B^0 \to \rho^0 \rho^0$

How about $B^0 \to \rho^0 \rho^0$ instead

Colour-suppressed, interferes with $B^0 \to a_1^\pm \pi^\mp$ which is not

- Order of magnitude larger branching fraction harshly suppressed by analysis
- Achieved at great cost to the $B^0 \to \rho^0 \rho^0$ yield
- More difficult to understand systematics from a_1 hadronic uncertainty

But, $B^0 \to a_1^\pm \pi^\mp$ has a known penguin contribution

Predicted by theory

- H.-Y. Cheng and K.-C Yang, Phys. Rev. **D 76**, 114020 (2007)

3σ confirmation from experiment

- Belle Collab., Phys.Rev. **D 86**, 092012 (2012)

Theory and experiment in excellent agreement

Amplitude analysis in charmless $B^0 \to \rho^0 \rho^0$ and $B^0 \to a_1^\pm \pi^\mp$ regions

With enough data, penguin in $B^0 \to a_1^\pm \pi^\mp$ prevents factorisation of λ^i_{CP}

Instead of $\mathcal{S}^{00}_{CP}$, directly measure effective α^{00} without ambiguity

Extended $B \to \rho\rho$ isospin analysis

Implications for the SU(2) isospin triangle analysis

$$A^{+0} = \frac{1}{\sqrt{2}} A^{+-} + A^{00}, \qquad \bar{A}^{+0} = \frac{1}{\sqrt{2}} \bar{A}^{+-} + \bar{A}^{00}$$

Parameterise isospin amplitudes as per the usual approach

J. Charles, O. Deschamps, S. Descotes-Genon and V. Niess,
Eur. Phys. J. **C 77** (2017) 574

Build physics observables from amplitudes

$$\frac{1}{\tau_B^{i+j}} \mathcal{B}^{ij} = \frac{|\bar{A}^{ij}|^2 + |A^{ij}|^2}{2}, \; \mathcal{A}_{CP}^{ij} = \frac{|\bar{A}^{ij}|^2 - |A^{ij}|^2}{|\bar{A}^{ij}|^2 + |A^{ij}|^2}, \; \mathcal{S}_{CP}^{ij} = \frac{2\Im(\bar{A}^{ij} A^{ij*})}{|\bar{A}^{ij}|^2 + |A^{ij}|^2}$$

Simply replace $B^0 \to \rho^0 \rho^0$ parameters

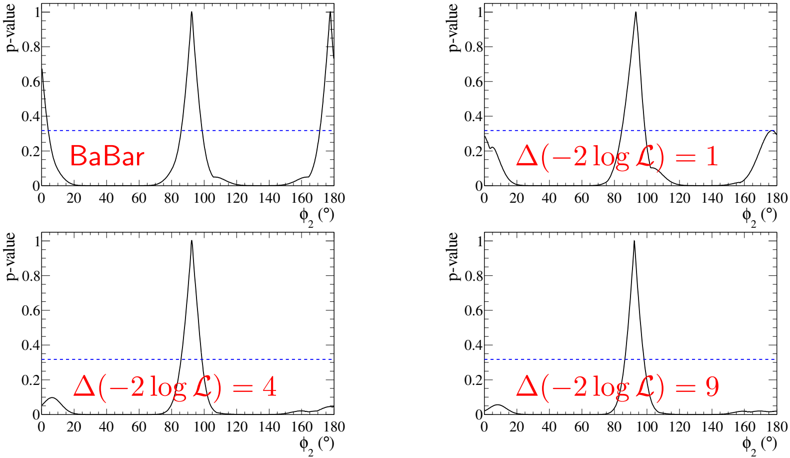
$$\mathcal{A}_{CP}^{00} \to |\lambda_{CP}^{00}| = \left| \frac{\bar{A}^{00}}{A^{00}} \right|, \qquad \mathcal{S}_{CP}^{00} \to \alpha^{00} = \frac{\arg(\bar{A}^{00} A^{00*})}{2}$$

Extended $B \to \rho\rho$ isospin analysis performance

Begin with BaBar input, Phys. Rev. Lett. **102**, 141802 (2009)

Assume 2 solutions for α^{00} are resolved with increasing significance

Insert α^{00} likelihood profile into fit χ^2



Method can work providing 2 solutions for α^{00} distinguished in $-2\log\mathcal{L}$

Prospects for resolving α^{00} solutions

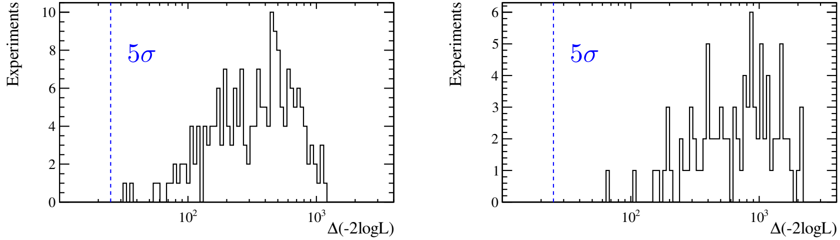
Method relies on penguin from $B^0 \to a_1^\pm \pi^\mp$, not the dominant tree

Estimate amount of data needed for penguin to play significant role

Generate pseudoexperiments based on current experimental results

Critical variable is $\Delta(-2\log\mathcal{L})$ between α^{00} solutions

LHCb Run 3: Effective Yield ~ 15000 Belle II: Effective Yield ~ 30000



Effective yield accounts for flavour-tagging penalties

Spread includes hadronic model systematic uncertainty

Method should be viable within the next few years of data taking

J. Dalseno, JHEP **11** (2018) 193 [INSPIRE]

Outline

Experimental sources of bias and limitations to α precision

We also have the capacity to address some of these

"New ideas": eliminating or reducing dominant systematic uncertainties

1. Solution degeneracies in α
   — $B \to \rho\rho$
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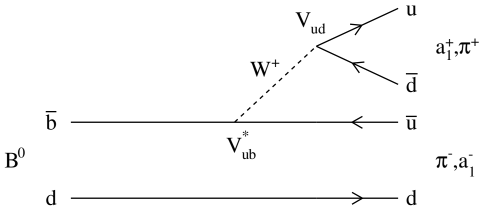
$B^0 \to a_1^{\pm}\pi^{\mp}$



- Quasi-two-body time-dependent flavour-tagged analysis
- Sensitive to algebraic average of effective α^+ and α^- (4 solutions)
- SU(2) solutions not practical, amplitude analysis of $B^0 \to (a_1\pi)^0$
- Measure $B^{+0} \to K_{1A}^{0+}\pi^{+-}$ and $B^{+0} \to K^{0+}a_1^{+-}$ branching fractions
  - K_{1A} is the ${}^3P_1$ partner of the a_1
- $|\Delta\alpha|$ from SU(3) analysis ($\times 2$ solutions)
  - M. Gronau and J. Zupan, Phys. Rev. **D 73**, 057502 (2006)
- But since we have the $B^0 \to a_1^{\pm}\pi^{\mp}$ amplitude, so we can do more
  - J. Dalseno, JHEP **10** (2019) 191 [INSPIRE]

$B^0 \to a_1^\pm \pi^\mp$

$B^0 \to a_1^+ \pi^-$ and $a_1^- \pi^+$ distinguished in $B^0 \to \rho^0 \rho^0$ amplitude analysis

- Otherwise, they don't really overlap and thus do not interfere

Effective α^+ and α^- separately resolved with same significance as α^{00}

- Already, only 2 solutions remain from SU(3) analysis to constrain $|\Delta\alpha|$

Study impact on SU(3) analysis with pure penguin (B^+) modes

$$B^0 \to a_1^+ \pi^- : A_d^+ = T^+ e^{+i\gamma} + P^+,\ \bar{A}_d^+ = T^+ e^{-i\gamma} + P^+,\ \lambda_{CP}^+ = \frac{\bar{A}_d^+}{A_d^+} e^{-2i\beta}$$

$$B^0 \to a_1^- \pi^+ : A_d^- = T^- e^{+i\gamma} + P^-,\ \bar{A}_d^- = T^- e^{-i\gamma} + P^-,\ \lambda_{CP}^- = \frac{\bar{A}_d^-}{A_d^-} e^{-2i\beta}$$

$$B^+ \to K_{1A}^0 \pi^+ : A_s^+ = -\frac{1}{\bar{\lambda}} \frac{f_{K_1}}{f_{a_1}} P^+$$

$$B^+ \to K^0 a_1^+ : A_s^- = -\frac{1}{\bar{\lambda}} \frac{f_K}{f_\pi} P^-$$

Factorisable SU(3) breaking, $\bar{\lambda} = |V_{us}/V_{ud}|$, f_i: decay constants

8 free parameters: $T^\pm$ (tree), $P^\pm$ (penguin) and α, fix $\arg(T^+) = 0$

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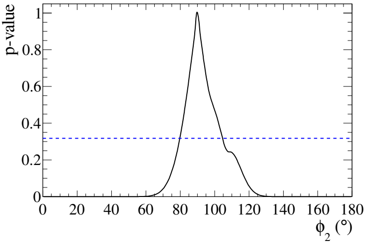
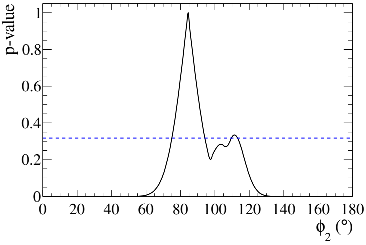
$B^0 \to a_1^{\pm}\pi^{\mp}$

- 9 physical observables
  - 4 branching fractions, $2\mathcal{B}_i/\tau_B = |\bar{A}_i|^2 + |A_i|^2$
  - 4 CP-violating parameters, $\lambda_{CP}^{\pm}$
  - 1 strong phase difference, $\arg(A_d^-/A_d^+)$
- Unlikely, but consider if B factories could have resolved $\alpha^{\pm}$
  - Set to theoretical values with scaled Belle uncertainties
- Take BaBar branching fractions for SU(3)-related B^+ channels
  - $B \to K_{1A}\pi$: BaBar Collab. Phys. Rev. **D 81**, 052009 (2010)
  - $B \to a_1 K$: BaBar Collab. Phys. Rev. Lett. **100**, 051803 (2008)

Most probable $\mathcal{B}(B^+ \to K^0_{1A}\pi^+)$



Mean $\mathcal{B}(B^+ \to K^0_{1A}\pi^+)$



Resolving α in $B^0 \to a_1^\pm \pi^\mp$

Huge improvement over 8 distinct solutions with 1st generation errors

$B^0 \to a_1^\pm \pi^\mp$ observables came from amplitude analysis

- $A_d^\pm$, $\bar{A}_d^\pm$ amplitudes fully constrained

Still room for improvement in the $b \to s$ penguin system

$$K_{1A}^0 \pi^+ : A_s^+ = -\frac{1}{\bar{\lambda}} \frac{f_{K_1}}{f_{a_1}} P^+, \qquad K^0 a_1^+ : A_s^- = -\frac{1}{\bar{\lambda}} \frac{f_K}{f_\pi} P^-$$

Branching fractions essentially give the magnitude of $P^\pm$

However, $B^+ \to K_{1A}^0 \pi^+$ and $B^+ \to K^0 a_1^+$ share the same final state

Like $B^0 \to a_1^\pm \pi^\mp$, won't overlap very much

Add intermediary $B^+ \to K^{*+} \rho^0$, combined charmless amplitude analysis

- Strong phase difference between $B^+ \to K_{1A}^0 \pi^+$ and $K^0 a_1^+$ gives $\arg(A_s^- / A_s^+)$

8 free parameters for 10 physical observables

- Overconstrained, enables deeper studies

SU(3) breaking in $B^0 \to a_1^\pm \pi^\mp$

Factorisable SU(3)-breaking parameters already accounted for

Non-factorisable SU(3) breaking an additional source of uncertainty

- Other diagrams, theoretical uncertainties, other unknown effects

Additional real factors, $F^\pm_{\mathrm{SU}(3)}$

Unity in the limit of no non-factorisable SU(3)-breaking

$$K^0_{1A}\pi^+ : A_s^+ = -\frac{F^+_{\mathrm{SU}(3)}}{\bar{\lambda}}\frac{f_{K_1}}{f_{a_1}}P^+, \qquad K^0 a_1^+ : A_s^- = -\frac{F^-_{\mathrm{SU}(3)}}{\bar{\lambda}}\frac{f_K}{f_\pi}P^-$$

8 free parameters for 10 physical observables

Might be able to get sensitivity to non-factorisable SU(3)-breaking

If so, irreducible systematic uncertainty absorbed into α constraint

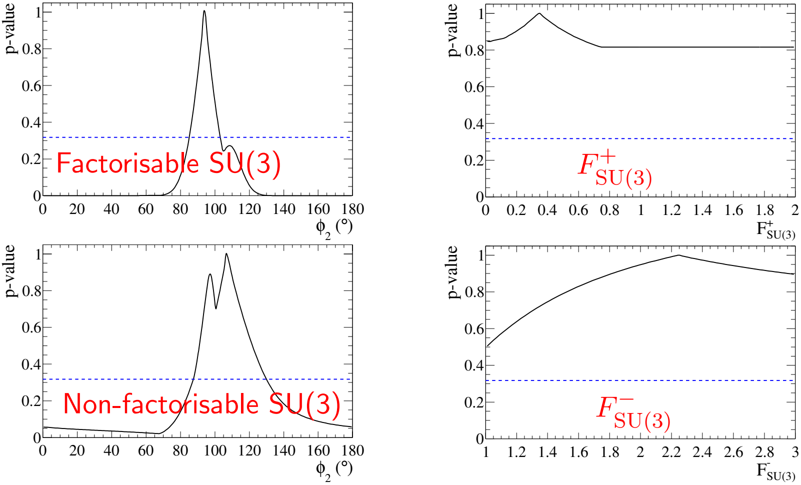
- More sustainable analysis

All analyses with fully charged tracks

- LHCb-friendly approach

SU(3) breaking in $B^0 \to a_1^{\pm}\pi^{\mp}$

Best case scenario at $\arg(P_s^-/P_s^+) = 45°$, otherwise unknown for now



Already emerging sensitivity to SU(3)-breaking, costs α precision

Consensus on the K_1 mixing angle potentially an outstanding issue

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   — New LHCb prospect

$B \to \rho\rho$

Quite familiar by now with sources of α bias from theory

Approach to α combination can also induce experimental-side distortions

- *eg.* 3 $B \to \rho\rho$ channels similar, share common analysis strategies
- Systematic correlations not just within, but between analyses

Apart from $B^0 \to \rho^0\rho^0$ at LHCb, quasi-two-body approach standard

Amplitude analysis in $B \to \rho\rho$ most likely unavoidable in the future

- Interference otherwise an irreducible systematic, limits precision

In any case, already fit the ρ mass also for non-interfering backgrounds

Important because model systematic uncertainty quite sizeable

For dominant vector resonances, mostly from their own pole parameters

- Breit-Wigner phase varies most rapidly at the pole
- Variations manipulate interference pattern in most interesting region

Cannot individually release ρ pole parameters in each analysis

- Meaning of the ρ would be unclear in the α combination

Release in combined analysis of 3 $B \to \rho\rho$ channels impractical

Practically irreducible, check what happens without shared systematics

Correlated ρ pole systematics

Generate $B \to \rho\rho$ according to estimated yields at Belle II

- Account for flavour-tagging dilution

Relative strong phases between $B \to \rho\rho$ polarisations unknown

- Can reverse engineer from known branching fractions with 2-fold ambiguity
- Pick between solutions at random

Conduct the 3 $B \to \rho\rho$ amplitude analyses

Estimate model systematic uncertainty from ρ pole parameters

Generate variations from according to correlation matrix

	$m_0(\rho^+)$	$\Gamma_0(\rho^+)$	$m_0(\rho^0)$	$\Gamma_0(\rho^0)$
$m_0(\rho^+)$	$+1$			
$\Gamma_0(\rho^+)$	0	$+1$		
$m_0(\rho^0)$	$+1$	0	$+1$	
$\Gamma_0(\rho^0)$	0	$+1$	0	$+1$

At fundamental level, charged and neutral ρ are the same

Correlated ρ pole systematics scenarios

Apply variations, construct model systematic covariance matrices

- 9 branching fractions, 12 CP-violation parameters

Perform α constraint under 3 scenarios considered

Current: Model systematic correlations ignored

- Model uncertainty correlation matrix set to the identity

Expected: Every analysis handles own model systematic correlations

- ρ pole parameter variations unique to each analysis

Proposed: Shared handling of model systematic correlations

- Common set of ρ pole parameter variations

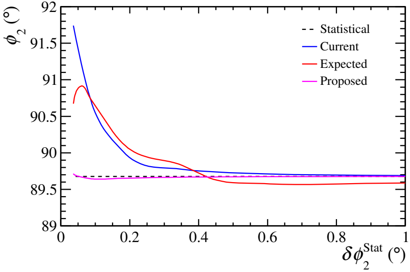
J. Dalseno, JHEP **10** (2021) 110 [INSPIRE]

Correlated ρ pole systematics results

Model uncertainty irreducible, so does not scale with data sample size

Assess impact relative to statistical uncertainty

Plot α as a function of its statistical error



Ignore model systematic and scale statistical uncertainty as null test

- Dashed line: α does not drift

Common handling of model systematic uncertainty shown in pink

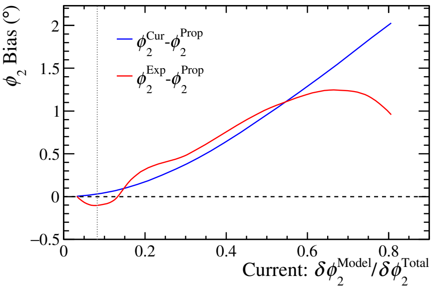
Limited α drift as statistical uncertainty scales

- Shared model systematics procedure is applied correctly

Correlated ρ pole systematics results

Investigate performance relative to Proposed practice

Plot α bias as function of model uncertainty strength



Bias in α up to 1° as model uncertainty dominates

No obvious trend in Expected practice

- Each analysis handling their own systematic correlations is dangerous

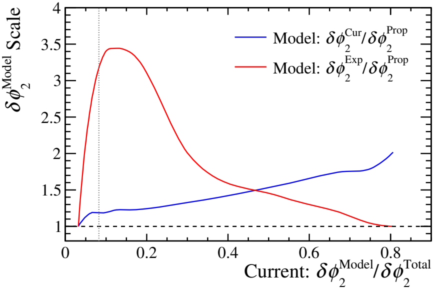
Vertical dashed line is estimated Belle II projection

- Bias at the level of 0.1° assuming $B \to \rho\rho$ models

Correlated ρ pole systematics results

Investigate performance relative to Proposed practice

Plot model uncertainty penalty through incorrect systematics handling



Belle II projection shown as vertical dashed line

- Ignoring model correlations: model uncertainty 1.2 times larger
- Individual model correlations: model uncertainty over 3 times larger
- Assuming $B \to \rho\rho$ models

Bookkeeping is essential to keeping α bias and model uncertainties down

Correlated model systematics between systems

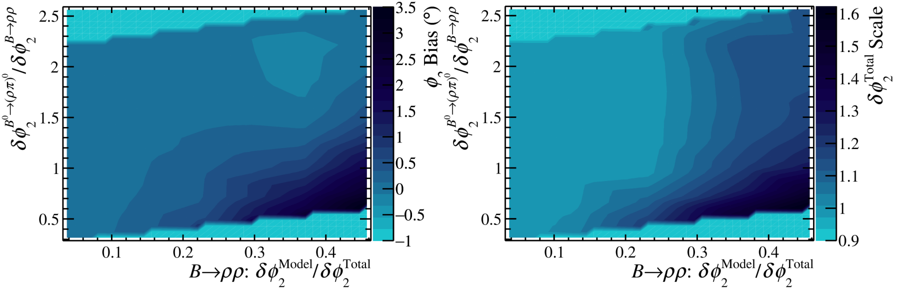
Logic extends to systematic correlations between systems constraining α

$B^0 \to (\rho\pi)^0$ also models the ρ resonances, extend study

Consider 2 scenarios

- Each system handles their own model correlations
- Model variations shared between $B \to \rho\rho$ and $B^0 \to (\rho\pi)^0$ systems

$B \to \rho\rho$ model strength and relative $B^0 \to (\rho\pi)^0$ α uncertainty unknown



α bias and uncertainty penalties also seen

- If $B^0 \to (\rho\pi)^0$ dominates while $B \to \rho\rho$ model uncertainty significant

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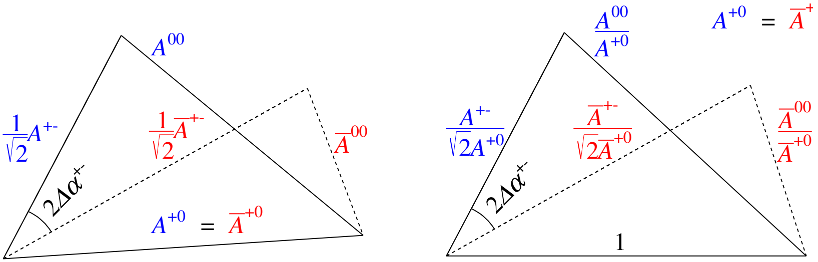
   — Rescaled isospin triangles
   — New LHCb prospect

Rescaled isospin triangles

- Branching fractions of α-sensitive $B \to hh$ decays systematically limited
  - Limited prospects for improvement at Belle II, $\delta N_{B\bar{B}} \sim 1.4\%$
  - More difficult to impact α uncertainty
- Need to adjust thinking, reexamine isospin triangles
- J. Dalseno, arXiv:2110.08183 [hep-ph] [INSPIRE]

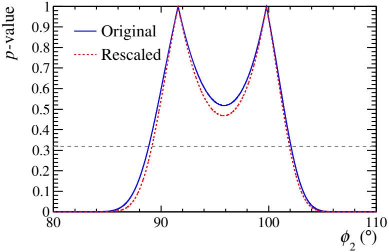
Original　　　　　　　　　　　　　Rescaled



- Like UT, only 2 parameters required to constrain triangle
- Original isospin argument has 5, can reduce by 1
- For α purposes, base length is nuisance, need $2\Delta\alpha^{+-}$, scale away

$B \to \pi\pi$ rescaled

- Constrain amplitude ratios instead
  - Minor improvement to theoretical uncertainties, however mostly unchanged
- No longer require measurements of absolute branching fractions
- Only relative branching fractions required
  - Systematically a lot cleaner
- $\mathcal{B}^{+0}$, $\mathcal{B}^{+-}$, $\mathcal{B}^{00}$ $\quad\to\quad$ $\mathcal{B}^{+-}/\mathcal{B}^{+0}$, $\mathcal{B}^{00}/\mathcal{B}^{+0}$
- Repeat projection from Belle II physics book, remove $\delta N_{B\bar{B}}$



- Leading edge in α constraint improved by 0.3°
- Efficiency-related systematics of common particles also cancel in ratio

$B \to \rho\rho$ rescaled

- Also applies to $B \to \rho\rho$, becomes especially interesting for LHCb
- Absolute branching fractions at LHCb require normalisation channel
- Inherit Belle II uncertainties as baseline
  - Ordinarily, α measurement not competitive by design
- Measurement of relative branching fractions removes Belle II dependency
- $B \to \pi\pi$ remains impossible at LHCb, but what about $B \to \rho\rho$
- At first glance, $B^0 \to \rho^+\rho^-$ has 2 neutral π^0 mesons
- Difficult, but is the colour-favoured channel, large branching fraction
- LHCb well known to be able to handle a single π^0
- Can cleanup further with π^0 Dalitz or photon conversion requirement
- But surely, flavour-tagging inefficiency at LHCb kills the prospects
- Well not quite, recall history of $B \to \rho\rho$ at Belle

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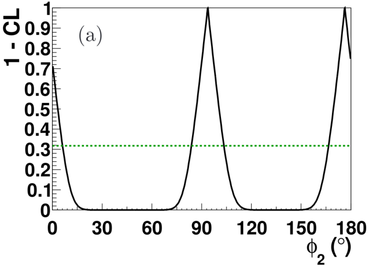
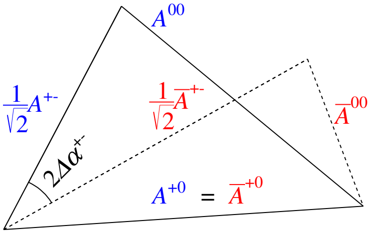
$B \to \rho\rho$ rescaled

Good constraint despite no CP-violation measurement in $B^0 \to \rho^0\rho^0$

Phys. Rev. D **93**, 032010 (2016)





Key is that $\mathcal{B}^{00}$ much smaller than $\mathcal{B}^{+0}$

CP violation in $B^0 \to \rho^+\rho^-$ well known, sensitivity to α

Unlike $B \to \pi\pi$, isospin triangles are flat, $\mathcal{A}_{CP}^{00}$ can't do all that much

Converse must also be true

CP violation in $B^0 \to \rho^0\rho^0$ will be well known at LHCb, α sensitivity

Don't need to know $\mathcal{A}_{CP}^{+-}$, no flavour-tagging penalty

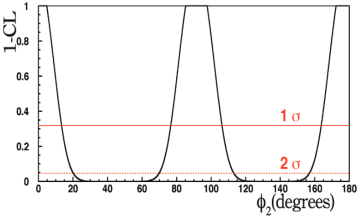
$B \to \rho\rho$ rescaled

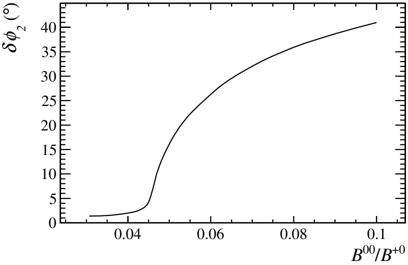
Method ultimately relies on smallness of $\mathcal{B}^{00}/\mathcal{B}^{+0}$

Ambiguities were present when this used to be larger at Belle

Determine fail point, plot α uncertainty as function of $\mathcal{B}^{00}/\mathcal{B}^{+0}$

Phys. Rev. D **78**, 111102 (2008)





Based on current central values, fail point at $\mathcal{B}^{00}/\mathcal{B}^{+0} \sim 0.045$

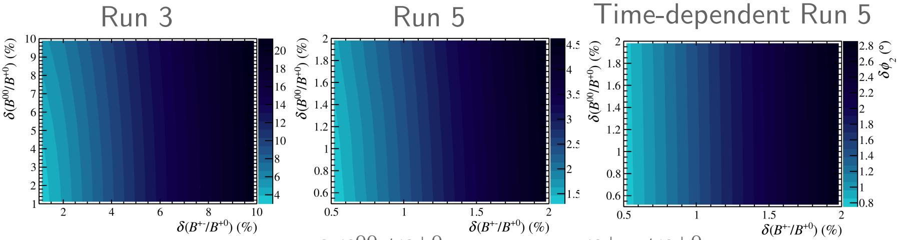
Current value is $\mathcal{B}^{00}/\mathcal{B}^{+0} \sim 0.03$, safe from experimental fluctuations

Method very promising in that respect

New systematic f_u/f_d, similar to b-hadron fraction in $\Upsilon(4S)$ at Belle II

$B \to \rho\rho$ rescaled

Project performance at LHCb, scan $\mathcal{B}^{+-}/\mathcal{B}^{+0}$ vs $\mathcal{B}^{00}/\mathcal{B}^{+0}$ error space



Uncertainty independent of $\mathcal{B}^{00}/\mathcal{B}^{+0}$, driven by $\mathcal{B}^{+-}/\mathcal{B}^{+0}$

Consider 500 effective $B^0 \to \rho^+\rho^-$ events in Run 3 with systematics

- Just 1% of 1% of 4-charged pion charmless rate
- α uncertainty already competitive with BaBar and Belle
- Motivates optimisation of ECAL upgrade for longitudinal polarised $\rho^\pm$

Relative branching fractions uncertainties limited to $\sim 0.5\%$ at LHCb

- $\delta\alpha \sim 1.4^\circ$

At these yields, time-dependent flavour-tagged analysis becomes possible

- Events at the level of Run 1 $B^0 \to J/\psi K^0_S$ with electrons
- $\delta\alpha \sim 0.8^\circ$

Summary

- Sub-degree precision in α possible in the near future
- Innovation on experimental side important to realising this goal
- Amplitude analysis in $B \to \rho\rho$
  - Properly handle interference effects, model $I = 1$, resolve α ambiguities
  - J. Dalseno, JHEP **11** (2018) 193 [INSPIRE]
- Opens the possibility for precision SU(3) measurement in $B^0 \to a_1^{\pm}\pi^{\mp}$
  - Non-factorisable SU(3) can be constrained with amplitude analysis
  - Consensus on K_1 mixing angle motivated
  - J. Dalseno, JHEP **10** (2019) 191 [INSPIRE]
- Rigorous, coordinated bookkeeping surrounding systematic correlations
  - Bias in α reduced and uncertainty improved
  - J. Dalseno, JHEP **10** (2021) 110 [INSPIRE]
- Relative branching fraction measurements
  - Eliminate and reduce dominant branching fractions systematics
  - LHCb can finally enter the fray in $B \to \rho\rho$
  - b-hadron fraction in $\Upsilon(4S)$ at Belle II, and f_u/f_d at LHCb motivated
  - J. Dalseno, arXiv:2110.08183 [hep-ph] [INSPIRE]