Theoretical status of non-leptonic heavy meson decays

Rahul Sinha

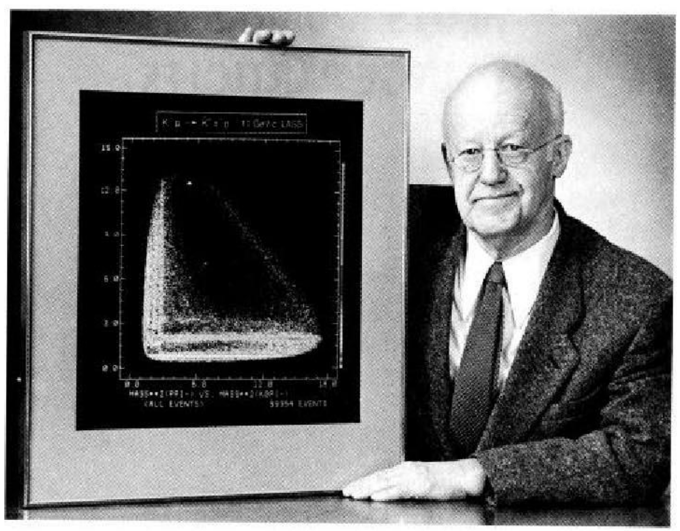
The Institute of Mathematical Sciences

Chennai, INDIA

Thanks to Hai-Yang Cheng, Hsiang-nan Li, Tom Browder ….
for many valuable inputs

- *Largely talk of hadronic three body decay of heavy mesons.*
- *Personal selection of topics…*
  - *D decay barely covered. Jernej Kamenik* *27th* (M)
  - *Alas, baryonic decay modes also left out. Marcello Rotondo* *26th (M)*
- *Not a comprehensive review. Mainly results and some concepts*
- *Dalitz plots present status …. So much effort by the community that perhaps in future FPCP dedicated talk on it.*

Tribute to Richard Henry Dalitz



Source: **Bill Dunwoodie's slide**

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Workshop on 3-Body Charmless B Decays
LPHNE, Paris Feb. 1-3, 2006

Dalitz Plots-three body decays

- *The new mantra in hadronic heavy flavor decays is the Dalitz plot or three body decays of heavy mesons.*
- *Largely driven by "Measurements of CP violation in the three-body phase space of charmless $B^{\pm}$ decays"*
    - *LHCb collaboration*, PHYSICAL REVIEW D 90, 112004 (2014)

$$A_{CP}(B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}) = +0.025 \pm 0.004 \pm 0.004 \pm 0.007 \quad 2.8\sigma$$

$$A_{CP}(B^{\pm} \to K^{\pm}K^{+}K^{-}) = -0.036 \pm 0.004 \pm 0.002 \pm 0.007 \quad 4.3\sigma$$

$$A_{CP}(B^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}) = +0.058 \pm 0.008 \pm 0.009 \pm 0.007 \quad 4.2\sigma$$

$$A_{CP}(B^{\pm} \to \pi^{\pm}K^{+}K^{-}) = -0.123 \pm 0.017 \pm 0.012 \pm 0.007 \quad 5.6\sigma$$

Three-body hadronic decays of heavy mesons constitute a large fraction of the branching fraction. BaBar, Belle and LHCb, measured branching ratios and CP asymmetries for a large number of B 3-body hadronic modes.

Literature on 3-body decays (partial list)

Cheng, Chua, Soni [0704.1049]*

Zhang, Guo, Yang [1303.3676]

Bhattacharya, Gronau, Rosner [1306.2625]

Xu, Li, He [1307.7186]

Bediaga, Frederico, Lourenco [1307.8164]

Gronau [1308.3448]

Cheng, Chua [1308.5139] *

Zhang, Guo, Yang [1308.5242]

Lesniak, Zenczykowski [1309.1689]

Di Salvo [1309.7448]

Xu, Li, He [1311.3714]

Cheng, Chua [1401.5514]*

Ying Li [1401.5948]*

Bhattacharya, Gronau, Imbeault, London, Rosner [1402.2909]

Wang, Hu, Li, Lu [1402.5280]*

Ying Li [1402.6052]*

He, Li, Xu [1410.0476]

Kränkl, Mannel , Virto [arXiv:1505.04111]*

Sincere apologies to those whose papers I have missed mentioning here …

Why study three body decay modes?

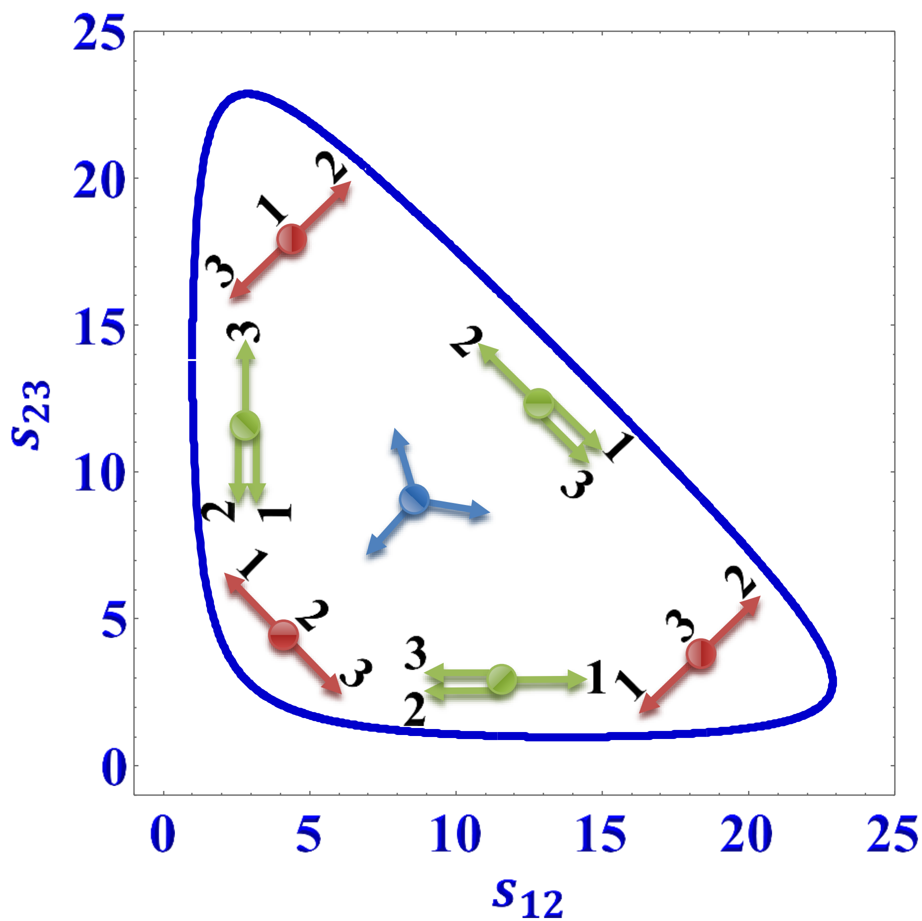
- Experimentally established that charmless 3-body decays more abundant than 2-body decays
- 3-body decays are more challenging to understand theoretically.
- Description is still at modelling stage. QCD based approach for various regions needed.
- Many phenomenological applications. Well known ones are study of CP violation and measurement of weak phase. Discuss some applications in detail later.
- CP violation helped by two additional sources for strong phase arising from long-distance effects involving hadron-hadron interactions in the final state:

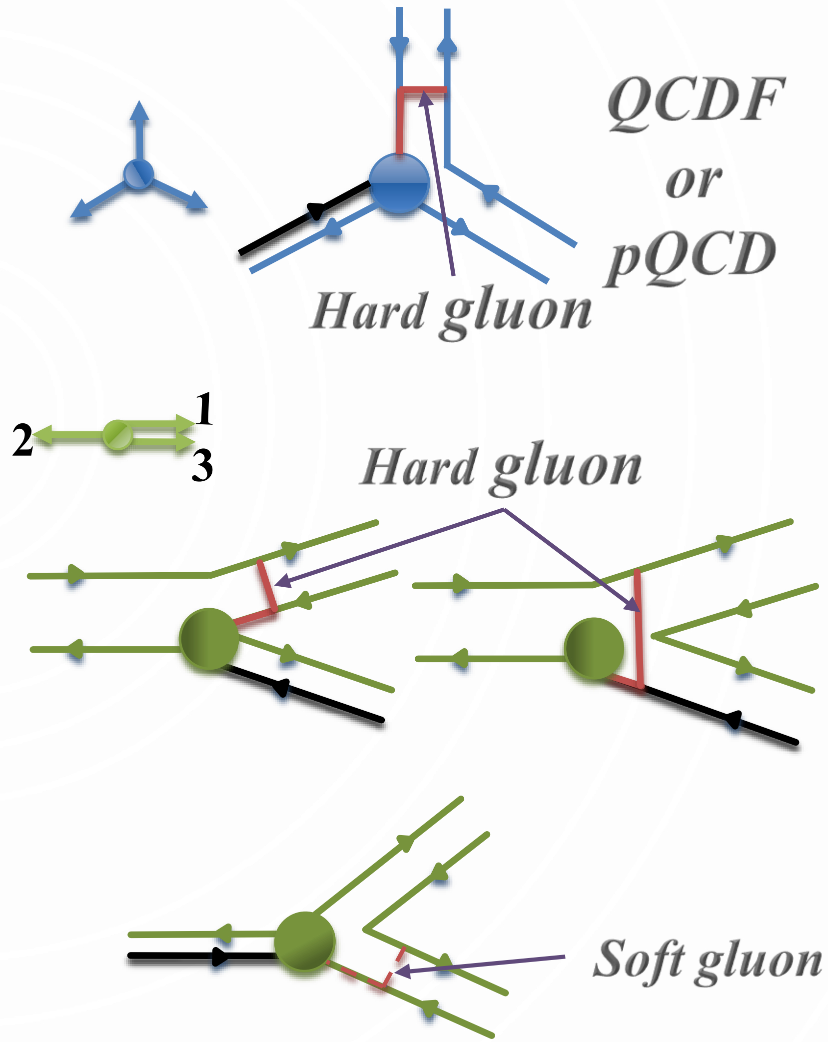
1. *Interference between intermediate states of the decay can introduce large strong-phase differences inducing local CP asymmetries in the phase space.*
2. *Another mechanism is final-state $KK \leftrightarrow \pi\pi$ rescattering – occur between decay channels having the same flavor quantum numbers.*

- *In general learn about role of hadronic long-distance effects and final-state interactions in unitarized description.*
- *Large non-resonant fractions in penguin-dominated B decay modes, where as, non-resonant signal is less than 10% in D decays.*
- *Significant effort in trying underway to understand 3-body charmless decays.*

Regions on the Dalitz Plot

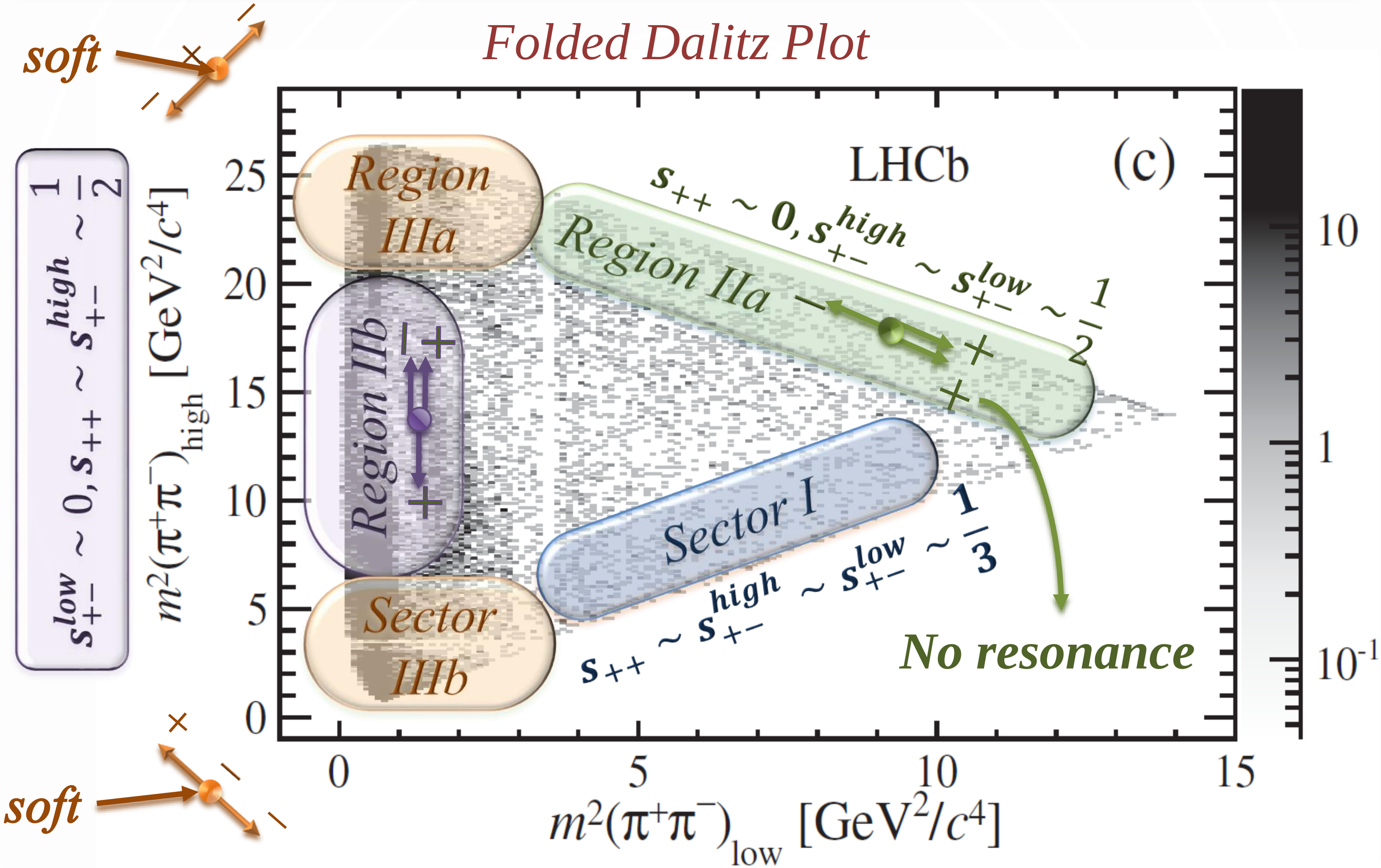
Hadronic three body decays of B

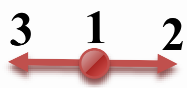




Regions on the Dalitz Plot

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





Region with soft meson emission can be explored using Heavy meson chiral perturbation theory (HMChPT). Particle 2 and 3 hard but 1 can be soft.

Description of 2 body charmless hadronic B mesons -several competing approaches-QCDF, pQCD, and SCET.

3-body decays much more complicated.

- *Decay described in terms of two invariants. Talk of differential decay rate.*
- *Three body decays of B mesons both resonant and non resonant contributions in general.*
- *Important to pin down the mechanism responsible for large local CP asymmetries.*

❑ *Correlation seen by* LHC*b*: $A_{CP}(K^-K^+K^-) \approx -A_{CP}(K^-\pi^+\pi^-)$, $A_{CP}(\pi K^+K^-) \approx -A_{CP}(\pi\pi^+\pi^-)$,

Conjectured that CPT theorem & final-state rescattering of $\pi^+\pi^- \leftrightarrow K^+K^-$ *may play important roles*

I. Bediaga, T. Frederico, O. Lourenço, Phys. Rev. D 89, 094013 (2014)

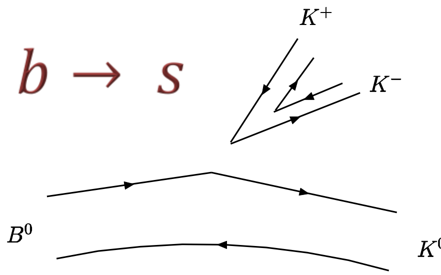
HMChPT approach to 3-body decay

Assuming factoriziation the resulting local correlators are computed in the framework of Heavy-Meson Chiral Perturbation Theory (HMChPT)

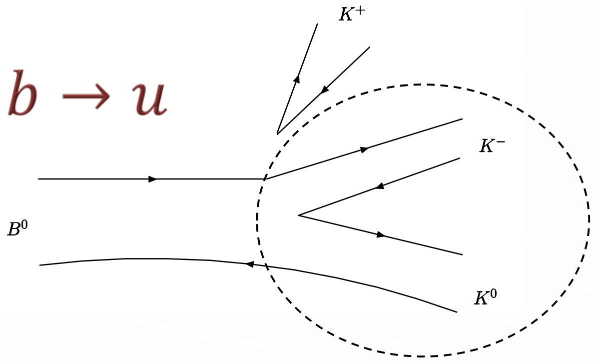
Under factorization approximation, three factorizable amplitudes for $B^0 \to K^+K^-K^0$

- *current-induced process:* $\langle B^0 \to K^0\rangle\langle 0 \to K^+K^-\rangle$
- *transition process:* $\langle B^0 \to K^-K^0\rangle\langle 0 \to K^+\rangle$
- *annihilation process:* $\langle B^0 \to 0\rangle\langle 0 \to K^+K^-K^0\rangle$

$b \to s$



$b \to u$



- *H.-Y. Cheng, C.-K.Chua,*
  Phys. Rev. D 88, 114014 (2013)
  Phys. Rev. D 89, 074025 (2014)

- *NR rates for tree-dominated* $B \to KK\pi$, $\pi\pi\pi$ *will become too large ,e.g.,* $Br(B^- \to K^+K^-\pi^-)_{NR} = 33\times10^{-6}$ *larger than total BF,* 5×10^{-6} $\Rightarrow$ *HMChPT is applicable only to soft mesons !*

- *Ways of improving the use of HMChPT have been suggested before.* *Fajfer et al; Yang, HYC,…*

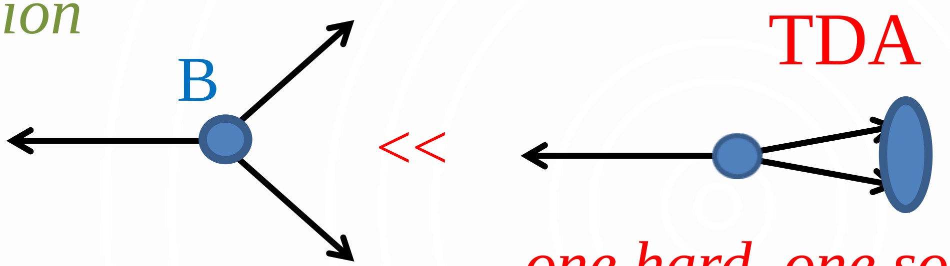
- *Write tree-induced NR amplitude as* $A^{HMChPT}_{transition}\; e^{-\alpha_{NR}\, p_B\cdot(p_1-p_2)}\; e^{i\varphi_{12}}$
- *HMChPT is recovered in soft meson limit,* $p_1, p_2 \to 0$
- *The parameter* $\alpha_{NR} \gg \frac{1}{2m_B\Lambda_\chi}$ *is constrained from* $B^- \to \pi^+\pi^-\pi^-$
- *NR rates: mostly from* $b \to s$ *(via* $\langle \bar{K}K|\bar{s}s|0\rangle$*) and a few percentages from* $b \to u$ *transitions*
- Resonant:
  - $B^0 \to f_0K^0 \to K^+K^-K^0$, $f_0 = f_0(980), f_0(1500), f_0(1710), \ldots$
  - $B^0 \to VK^0 \to K^+K^-K^0$, $V = \rho, \omega, \phi, \ldots$

- *Three-body B decays receive sizable NR contributions governed by the matrix elements of scalar densities.*

- *U-spin symmetry relating* $\langle K\pi|\bar{s}d|0\rangle$ *to* $\langle \bar{K}K|\bar{s}s|0\rangle$ *badly broken.*

pQCD approach to 3-body decays

- *Approach to 3-body B decays based on kT factorization theorem with two-hadron distribution amplitude (TDA) for dominant region*



two hard-gluon power suppressed

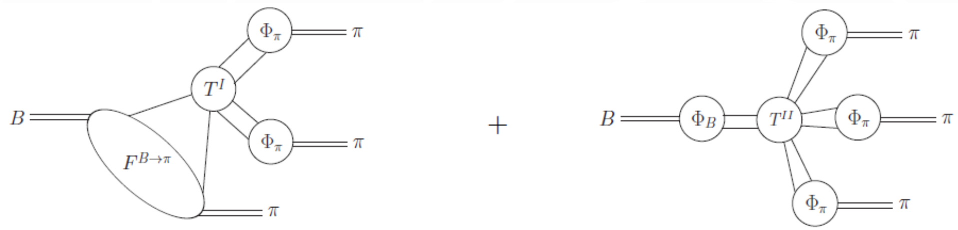
one hard, one soft gluon, two hadrons collimate, dominant

- *Short-distance and rescattering P-wave phases are equally important for predicting A_{CP}.*
- *Can explain and predict direct CP asymmetries of 3π and $K\pi\pi$ in various localized regions of phase space.*

W.-F. Wang, H.-C Hu, H.-n Li and C.-D. Lü, Phys. Rev. D 89, 074031 (2014)

QCDF approach to $B \to \pi^+\pi^-\pi^+$ decays

- *In the limit of very heavy b-quark, Region-I of the Dalitz plot can be described in terms of the $B \to \pi$ form factor and the B and π light-cone distribution amplitudes*



Factorization formula

- *Power $\left(\frac{1}{m_b^2}\right)$ & α_s suppressed with respect to two-body.*
- *At leading order/power/twist all convolutions finite ⇒ factorization*
- *The edges of the Dalitz plot, on the other hand, require different non-perturbative input: the $B \to \pi\pi$ form factor and the two-pion distribution amplitude.*
- *$(\pi^-\pi^-)$ edge -No resonances ⇒ perturbative result reasonable.*
- *For realistic B-meson masses no perturbative centre in the Dalitz plot, but systematic description might be possible in the context of two-pion states.*

S. Kränkl, T. Mannel , J. Virto [arXiv:150l5.04111]

Two & Three body decays using SU(3)

Study of $B \to PP,\ VP,\ PPP$ *decays in the framework of flavor symmetry*

- *Study fully symmetric final states in* $B \to PPP$, $P = \pi, K$. *Relations between fully symmetric final states in the* SU(3) *limit.*

$$\sqrt{2}\mathcal{A}(B^+ \to K^+\pi^+\pi^-)_{FS} = \mathcal{A}(B^+ \to K^+K^+K^-)_{FS}$$

$$\sqrt{2}\mathcal{A}(B^+ \to \pi^+K^+K^-)_{FS} = \mathcal{A}(B^+ \to \pi^+\pi^+\pi^-)_{FS}$$

Bhattacharya, Gronau, Imbeault, London, and Rosner, Phys. Rev. D 89, 074043 (2014).

- *Update on* $B \to PP, VP$ *using* SU(3).
  - *Extraction of W-exchange and penguin-annihilation amplitudes for the first time.*
  - *Larger than expected color suppressed tree and strong phases*
  - *Predict large BR* $\sim 10^{-6}$ *for* $B_s^0 \to \phi\pi^0$.
  - *Identify few observables to be determined experimentally in order to discriminate among theory calculations*

H. Y. Cheng, C.W. Chiang, and A. L. Kuo, Phys. Rev. D 91, 014011 (2015).

- SU(3) *in D decays: From* 30% *symmetry breaking to* 10^{-4} *precision. Identify a class of* U-*spin related decays D*→ P^+P^-, P^+V^-, V^+P^-. *Symmetry-breaking terms affect relations at* $\mathcal{O}(4)$ *U-spin breaking.*

$$R_1 \equiv \frac{|A(D^0 \to K^+\pi^-)|}{|A(D^0 \to \pi^+K^-)|\tan^2\theta_C},$$

$$\epsilon_1 = \frac{\langle \pi^+K^-|H_{\text{eff}}^{CF}|D^0\rangle^{(1)}}{\langle \pi^+K^-|H_{\text{eff}}^{CF}|D^0\rangle^{(0)}}$$

$$R_2 \equiv \frac{|A(D^0 \to K^+K^-)|}{|A(D^0 \to \pi^+\pi^-)|},$$

$$\epsilon_2 = \frac{\langle K^+K^-|H_{\text{eff}}^{SCS}|D^0\rangle^{(1)}}{\langle K^+K^-|H_{\text{eff}}^{SCS}|D^0\rangle^{(0)}}$$

$$R_3 \equiv \frac{|A(D^0 \to K^+K^-)| + |A(D^0 \to \pi^+\pi^-)|}{|A(D^0 \to \pi^+K^-)|\tan\theta_C + |A(D^0 \to K^+\pi^-)|\tan^{-1}\theta_C},$$

$$R_4 \equiv \sqrt{\frac{|A(D^0 \to K^+K^-)||A(D^0 \to \pi^+\pi^-)|}{|A(D^0 \to \pi^+K^-)||A(D^0 \to K^+\pi^-)|}}.$$

$$\Delta R \equiv R_3 - R_4 + \frac{1}{8}[(\sqrt{2R_1 - 1} - 1)^2 - (\sqrt{2R_2 - 1} - 1)^2]$$

$$= \mathcal{O}(\epsilon_1^4, \epsilon_2^4).$$

M. Gronau, Phys. Rev. D 91, 076007 (2015)

- *Extraction of the CP-violating phase* γ *using* $B \to K\pi\pi$ *and* $B \to KK\bar{K}$ *decays. Analysis based on fully symmetric state.*

B. Bhattacharya, M. Imbeault, and D. London, Phys. Lett. B728, 206 (2014)

- *Relations among several fully symmetric B→PPP amplitudes are not affected by first-order SU(3) breaking effects due to a nonzero strange quark mass, and also some not affected by first order isospin breaking effects. These relations, therefore, hold to good precisions.*

  X. G. He, G. N. Li, and D. Xu, Phys. Rev. D 91, 014029 (2015).

- *Complete set of isospin, U-spin, and SU(3) relations among the CP asymmetries in 2-body $B \to PP$ and $B \to PV$ decays.*
  - *Effects of first order symmetry breaking. SU(3) breaking found to have reasonable size for appropriately normalized observables.*
  - *Derive sum rules among δ_{CP}:*

$$\delta_{\rm CP}[B_\mu \to P_\alpha P_\beta] = \left(\left|\overline{\mathcal{A}}_{\mu\to\alpha\beta}\right|^2 - \left|\mathcal{A}_{\mu\to\alpha\beta}\right|^2\right) \times \begin{cases} 1\,, & P_\alpha \neq P_\beta \\ 1/2\,, & P_\alpha = P_\beta \end{cases}$$

$B \to PP$ 19 ($B \to PV$ 32) linearly independent sum rules in δ_{CP}

Y. Grossman, Z. Ligeti, and D. J. Robinson, JHEP 01 (2014) 066.

- *BaBar measurement of CP violation in $B^+ \to K^*(892)\pi^0$ from a Dalitz plot analysis of $B^+ \to K_S^0\pi^+\pi^0$ decays* *pQCD Li, Mishima*

Partial list of other papers on hadronic decays of B &D mesons

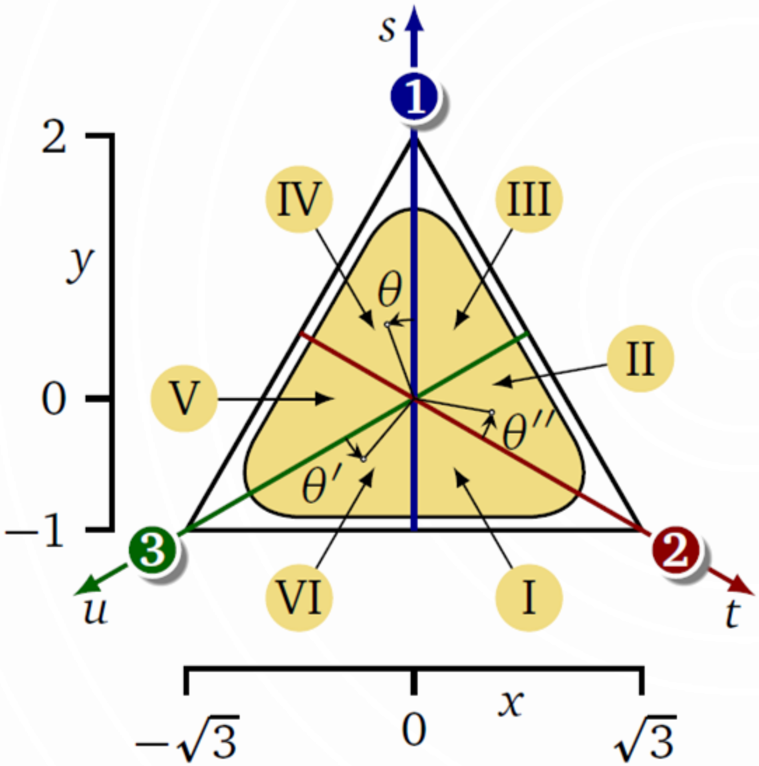
- *Branching ratios and direct CP asymmetries in D → PV decays, Q. Qin, H.-n Li, C.-D. Lü, and F.-S. Yu, Phys. Rev. D 89, 054006 (2014)*
- *Improved Estimates of The $B_s \to V\,V$ Decays in Perturbative QCD Approach, Z. T. Zou, A. Ali, C. D. Lu, X. Liu and Y. Li Phys. Rev. D91 (2015) 054033 (2015)*
- *Non-leptonic decays of Charmed mesons into two Pseudoscalars, A. Biswas, N. Sinha, G. Abbas, arXiv:1503.08176*
- *Model-Independent Analysis of CP Violation in Charmed Meson Decays, R. Dhir, C.S. Kim, S. Oh., arXiv:1504.02556*
- *Probing spectator scattering and annihilation corrections in $B_s \to PV$ decays, Q. Chang, X. Hu, J. Sun, Y. Yang, Phys.Rev. D91 (2015) 7, 074026*
- *Topological amplitudes in D decays to two pseudoscalars: a global analysis with linear SU(3)_F breaking, S. Muller, U. Nierste, S. Schacht, arXiv: 1503.06759*
- *Dalitz plot studies in hadronic charm decays, L. Lesniak, arXiv: 1411.1665*

⋮

Sorry could not complete the list. Will do so after the talk and update.

Studying symmetries using Dalitz Plots

The Dalitz plot distribution can be described in terms of barycentric rectangular and polar coordinate systems.



$$\theta = \theta' + \tfrac{2\pi}{3} = \theta'' + \tfrac{4\pi}{3}.$$

The barycentric rectangular (x, y) and polar (r, θ) coordinates are related to one another by:

$$s = \frac{M^2}{3}\left(1 + y\right) = \frac{M^2}{3}\left(1 + r\cos\theta\right),$$

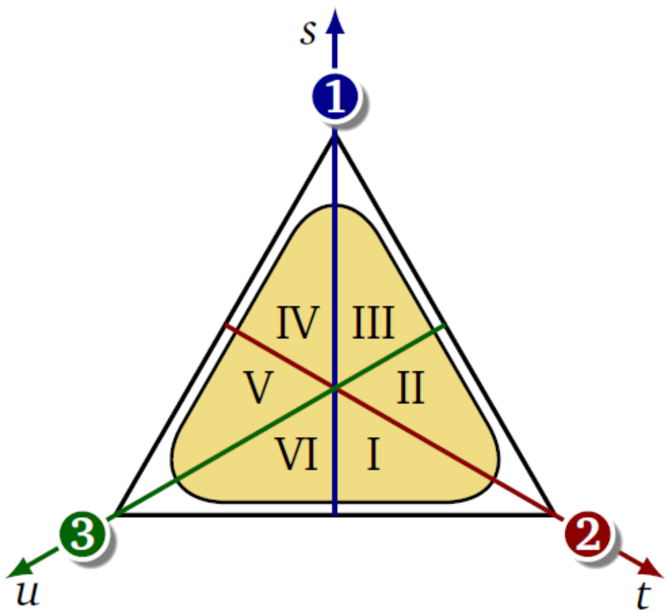
$$t = \frac{M^2}{6}\left(2 + \sqrt{3}x - y\right)$$

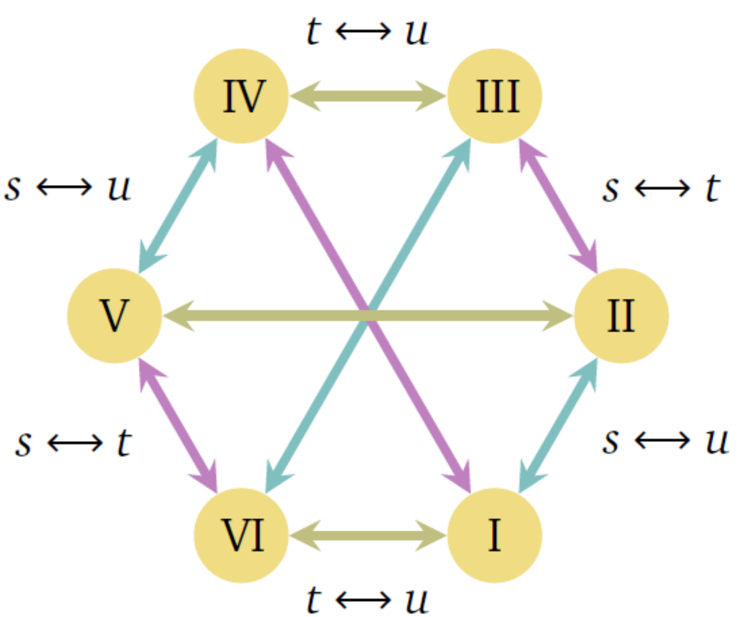
$$= \frac{M^2}{3}\left(1 + r\cos\left(\frac{2\pi}{3} + \theta\right)\right),$$

$$u = \frac{M^2}{6}\left(2 - \sqrt{3}x - y\right)$$

$$= \frac{M^2}{3}\left(1 + r\cos\left(\frac{2\pi}{3} - \theta\right)\right).$$

The sextants of the Dalitz plot are related to one another via exchange of a pair of the Mandelstam-like variables.





Dalitz plot would to be symmetric under exchange of two particles, say 2 and 3, i.e. also under $t \leftrightarrow u$, iff

- *particles 2 and 3 are equally massive, and*
- *they exist in even partial wave states.*

Physicist A chooses to apply isospin:

$$\pi^0 \leftrightarrow \pi^+ \Rightarrow t \leftrightarrow u$$

Concludes that the amplitude has two components: symmetric and anti-symmetric along the $t = u$ axis.

Physicist B chooses to apply U-spin:

$$K^0 \leftrightarrow \pi^0 \Rightarrow s \leftrightarrow t$$

Concludes that the amplitude has two components: symmetric and anti-symmetric along the $s = t$ axis.

Decay amplitude given by

$$\mathscr{A}(s,t,u) = \mathscr{A}_{SS}(s,t,u) + \mathscr{A}_{AA}(s,t,u)$$

Final state			Kind of $SU(2)$ exchange	
M_1	M_2	M_3	$M_1 \leftrightarrow M_2$	$M_2 \leftrightarrow M_3$
K^0	π^0	π^+	U-spin	Isospin
K^+	π^0	π^-	V-spin	Isospin
K^+	π^0	$\bar{K}^0$	V-spin	U-spin
π^+	π^0	$\bar{K}^0$	Isospin	U-spin

If both isospin and U-spin are individually good symmetries Dalitz Plot must obey the symmetries concluded by the two physicists. But that is impossible unless the amplitude is either

- *symmetric under both*

  $s \leftrightarrow t$ *and* $t \leftrightarrow u$,
- *antisymmetric under both*

  $s \leftrightarrow t$ *and* $t \leftrightarrow u$

Distribution function has two parts f_S and f_A

$$f_S(s,t,u) \propto |\mathscr{A}_{SS}(s,t,u)|^2 + |\mathscr{A}_{AA}(s,t,u)|^2$$

$$f_A(s,t,u) \propto 2\,\mathrm{Re}\Big(\mathscr{A}_{SS}(s,t,u)\cdot\mathscr{A}^*_{AA}(s,t,u)\Big)$$

The various sextants of the Dalitz plot have a characteristic alternate distribution pattern

$$f_I = f_{III} = f_V = f_S(s,t,u) + f_A(s,t,u) \qquad \Sigma^i_j(r,\theta) = f_i + f_j$$

$$f_{II} = f_{IV} = f_{VI} = f_S(s,t,u) - f_A(s,t,u) \qquad \Delta^i_j(r,\theta) = f_i - f_j$$

Probe the nature of SU(3) *breaking and quantitatively measure* SU(3) *breaking*

$$\mathbb{A}_1 = \left|\frac{\Sigma^I_{VI}-\Sigma^{III}_{IV}}{\Sigma^I_{VI}+\Sigma^{III}_{IV}}\right| + \left|\frac{\Sigma^{III}_{IV}-\Sigma^V_{II}}{\Sigma^{III}_{IV}+\Sigma^V_{II}}\right| + \left|\frac{\Sigma^V_{II}-\Sigma^I_{VI}}{\Sigma^V_{II}+\Sigma^I_{VI}}\right| + \left|\frac{\Delta^I_{VI}-\Delta^{III}_{IV}}{\Delta^I_{VI}+\Delta^{III}_{IV}}\right| + \left|\frac{\Delta^{III}_{IV}-\Delta^V_{II}}{\Delta^{III}_{IV}+\Delta^V_{II}}\right| + \left|\frac{\Delta^V_{II}-\Delta^I_{VI}}{\Delta^V_{II}+\Delta^I_{VI}}\right|,$$

$$\mathbb{A}_2 = \left|\frac{\Sigma^V_{IV}-\Sigma^I_{II}}{\Sigma^V_{IV}+\Sigma^I_{II}}\right| + \left|\frac{\Sigma^I_{II}-\Sigma^{III}_{VI}}{\Sigma^I_{II}+\Sigma^{III}_{VI}}\right| + \left|\frac{\Sigma^{III}_{VI}-\Sigma^V_{IV}}{\Sigma^{III}_{VI}+\Sigma^V_{IV}}\right| + \left|\frac{\Delta^V_{IV}-\Delta^I_{II}}{\Delta^V_{IV}+\Delta^I_{II}}\right| + \left|\frac{\Delta^I_{II}-\Delta^{III}_{VI}}{\Delta^I_{II}+\Delta^{III}_{VI}}\right| + \left|\frac{\Delta^{III}_{VI}-\Delta^V_{IV}}{\Delta^{III}_{VI}+\Delta^V_{IV}}\right|,$$

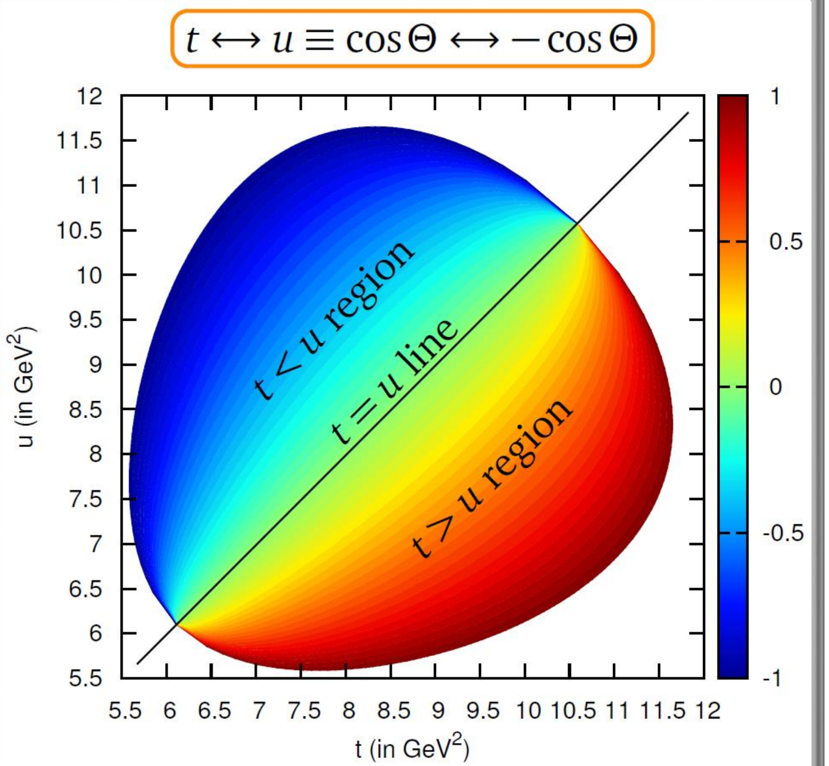
$$\mathbb{A}_3 = \left|\frac{\Sigma^I_{IV}-\Sigma^{III}_{II}}{\Sigma^I_{IV}+\Sigma^{III}_{II}}\right| + \left|\frac{\Sigma^{III}_{II}-\Sigma^V_{VI}}{\Sigma^{III}_{II}+\Sigma^V_{VI}}\right| + \left|\frac{\Sigma^V_{VI}-\Sigma^I_{IV}}{\Sigma^V_{VI}+\Sigma^I_{IV}}\right| + \left|\frac{\Delta^I_{IV}-\Delta^{III}_{II}}{\Delta^I_{IV}+\Delta^{III}_{II}}\right| + \left|\frac{\Delta^{III}_{II}-\Delta^V_{VI}}{\Delta^{III}_{II}+\Delta^V_{VI}}\right| + \left|\frac{\Delta^V_{VI}-\Delta^I_{IV}}{\Delta^V_{VI}+\Delta^I_{IV}}\right|.$$

D. Sahoo, R. Sinha and N. G. Deshpande, Phys. Rev. D 91, 076013 (2015)

CP violation in D on "a" Dalitz plot

Consider Dalitz plot of $B \rightarrow K D^0 \overline{D}^0$.

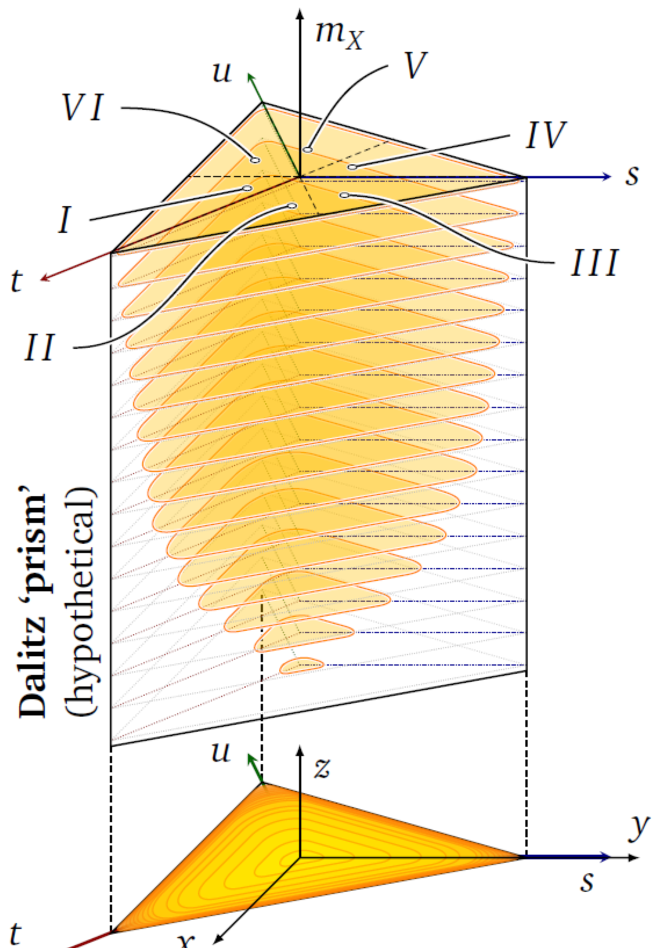
- Assume there is no direct CP violation in the $D^0 - \overline{D}^0$ system and the D mesons are reconstructed from daughter particles of definite CP f^{CP}. Let us say they are reconstructed in $f^+ = \{K^+K^-, \pi^+\pi^-\}$.
- Hence both the D mesons must have been in same state D_1. $D_1 D_1$ two identical particles and Bose symmetry demands that the Dalitz plot must be fully symmetric under exchange of D mesons.
- Any difference must be a signature of CP asymmetry



D. Sahoo, R. Sinha, N. G. Deshpande and S.Pakvasa, Phys. Rev. D89, 071903(R) (2014)

Dalitz Prism

The Dalitz prism can handle gargantuan amount of data enabling precise measurements of the violations.



- Very precise measurements essential to study violations of **CP**, **CPT** and Bose symmetries require analysis of a huge number of events.
- Dalitz prism combines data from the continuum with data from many resonances. This enhances the statistics immensely.
- We just need the projection of the Dalitz prism at its base to do our analysis.

D. Sahoo, R. Sinha, N. G. Deshpande, Phys. Rev. D91, 051901(R) (2015)

What is wrong with C?

After redefinitions the amplitudes for $B \to K\pi$ may be written as

$$
\begin{aligned}
A^{0+} &\equiv A(B^+ \to K^0\pi^+) = e^{i\gamma}A - P, \\
\sqrt{2}A^{+0} &\equiv A(B^+ \to K^+\pi^0) = -\Big[e^{i\gamma}(T + C + A) \\
&\qquad - (P + P_{EW} + P_{EW}^C)\Big], \\
A^{+-} &\equiv A(B^0 \to K^+\pi^-) = -\Big[e^{i\gamma}T - (P + P_{EW}^C)\Big], \\
\sqrt{2}A^{00} &\equiv A(B^0 \to K^0\pi^0) = -\left[e^{i\gamma}C + (P - P_{EW})\right]
\end{aligned}
$$

Consider a general NP contribution to P_{EW}: $P_{EW} \to P_{EW} + Ne^{i\phi}$

One can express $Ne^{i\phi} = N_1 + N_2e^{i\gamma}$

Any complex number can be written in terms of two other pieces with arbitrary phases – reparametrization invariance (RI)

M. Imbleaut, D. London, C. Sharma, N. Sinha and R. Sinha Physics Letters B 653 (2007) 254–258

$$
\begin{aligned}
A^{0+} &\equiv A(B^+ \to K^0\pi^+) = e^{i\gamma}A - P, \\
\sqrt{2}A^{+0} &\equiv A(B^+ \to K^+\pi^0) = -\Big[e^{i\gamma}(T + C + A) - (P + P^{EW} + P_C^{EW})\Big] + Ne^{i\phi}, \\
&= -\Big[e^{i\gamma}(T + C - N_2 + A) - (P + P^{EW} + N_1 + P_C^{EW})\Big], \\
A^{+-} &\equiv A(B^0 \to K^+\pi^-) = -\Big[e^{i\gamma}T - (P + P_C^{EW})\Big], \\
\sqrt{2}A^{00} &\equiv A(B^0 \to K^0\pi^0) = -\left[e^{i\gamma}C + (P - P^{EW})\right] + Ne^{i\phi} \\
&= -\left[e^{i\gamma}(C - N_2) + (P - P^{EW} - N_1)\right]
\end{aligned}
$$

Redefine: $\hat{C} = C - N_2, \hat{P}_{EW} = P_{EW} + N_1$

Reduce to the same form as without NP. Both C and P_{EW} *get affected simultaneously even though NP only in* P_{EW}*.*

We find that the following pairs of (suitably-redefined) amplitudes are simultaneously affected by NP

- $P_{EW} \leftrightarrow C$
- $P_{EW}^{C} \leftrightarrow T$
- $P \leftrightarrow A$

No clean signal of NP, unless you have a reliable estimate of the amplitudes in SM.

Hint of large C only meaningful signal of NP in $\boldsymbol{P_{EW}}$

Conclusions & Outlook

- *Much more effort both theory and experiment expected using Dalitz plot over the coming years.*
- *Three body final states are just beginning to get described. Theoretical effort will be boosted by rich data from LHCb run 2 and Belle II.*
- *Goal is to have a systematic factorization of three-body decays over regions in the Dalitz plot*
- *Possible that new flavour-changing interactions may be dominantly in purely hadronic transitions. Smart creative approaches needed.*
- *Large C could be an indication of New Physics, but how do we make sure what the reason is?*