Three-body B decays in perturbative QCD

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Motivation

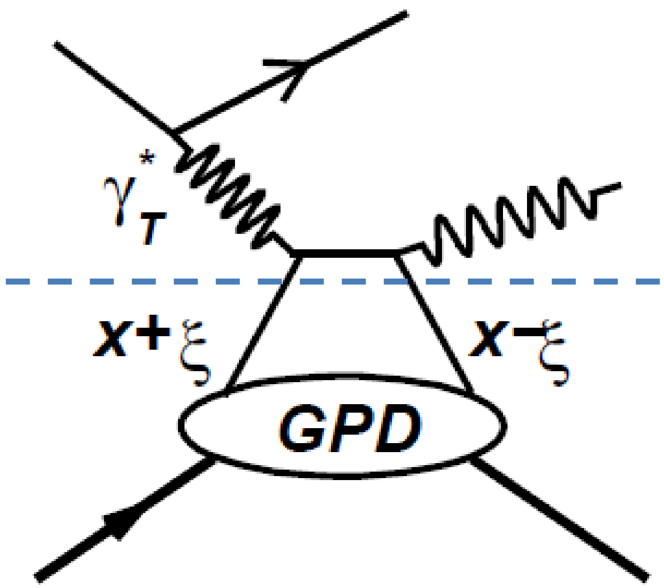
- B decays involve multiple (EW and QCD) scales, demanding use of effective theory
- Involve both weak and strong dynamics
- Suitable for probing CP violation and new physics
- Also suitable for study of hadron physics
- Focus on time-like version of generalized parton distribution (GPD)---two-hadron distribution amplitude (DA)

see Dong and Song's talks this afternoon

GPD vs two-hadron DA

Factorization of GPD

- GPD can be factorized from forward Compton scattering, in which hand-bag diagram dominates



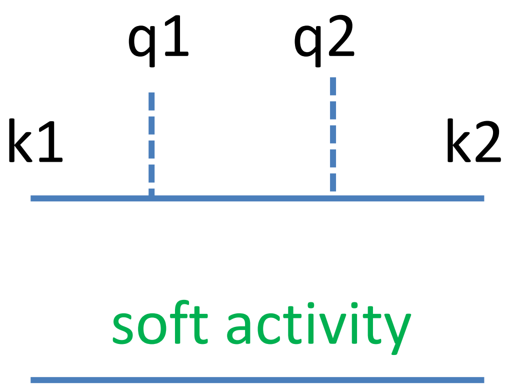
hard scattering

$\otimes$

collinear (IR) dynamics

Hand-bag diagram

- In forward region hand-bag diagram dominates
- In non-forward region both diagrams (two photons attach to the same quark and two gluons attach to different quarks) are same order of magnitude



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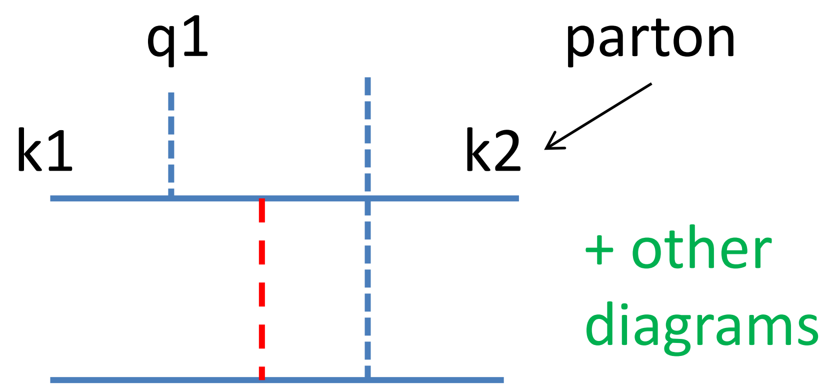


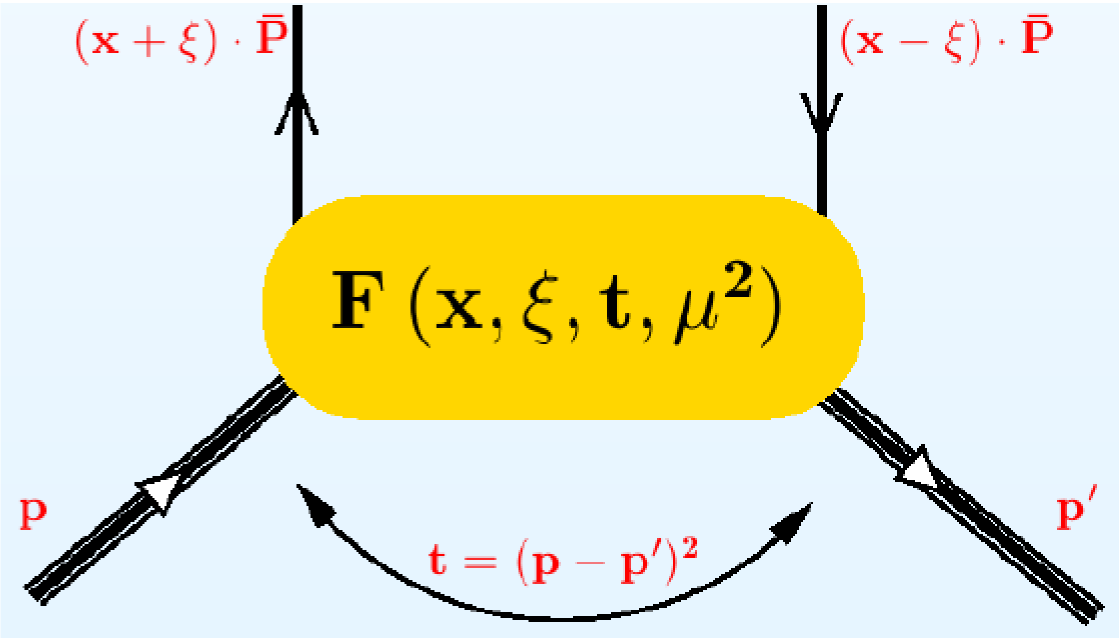
k1 // k2, k1 and k2 on shell
no need of hard gluon

k1+q1 off-shell, need hard gluon
to make k2 on shell

Definition of GPD

$$\frac{1}{2}\int \frac{dz^-}{2\pi} e^{ix\bar{P}^+z^-} \langle p'|\bar{q}(-\frac{1}{2}z)\gamma^+ q(\frac{1}{2}z)|p\rangle|_{z^+=0,\mathbf{z}=0}$$

$$= \quad \frac{1}{2\bar{P}^+}\left[H^q(x,\xi,t,\mu^2)\bar{u}(p')\gamma^+u(p) + E^q(x,\xi,t,\mu^2)\bar{u}(p')\frac{i\sigma^{+\alpha}\Delta_\alpha}{2m_N}u(p)\right]$$



$$\Delta = p' - p$$

$$t = (p' - p)^2$$

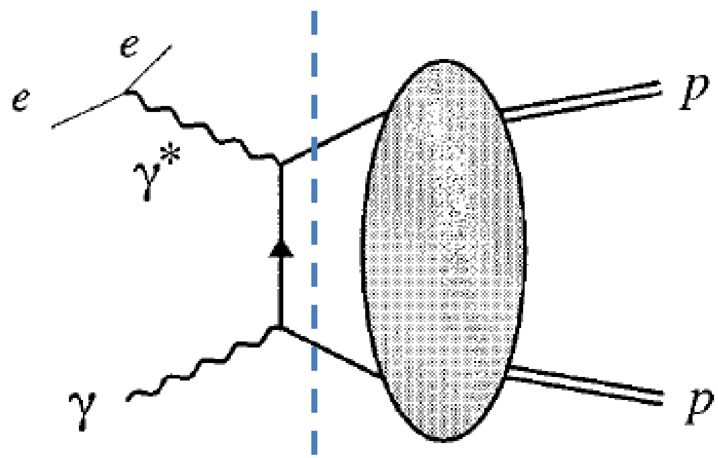
$$\bar{P}^+ = (p' + p)/2$$

skewness

$$\xi = \frac{p - p'}{p + p'}$$

Two-hadron DA

- Two-hadron DA is time-like version of GPD
- Factorized from process when p and p' almost collimate, and "hand-bag" diagram dominates
- As hard gluon attaches to the bubble, p and p' open a large angle



collinear dynamics

Importance of two-hadron DA

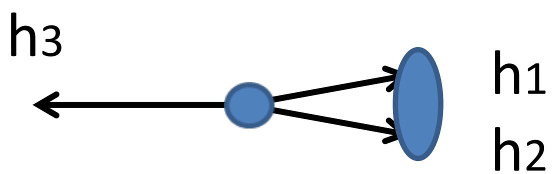
- Two-hadron DA can appear in multi-particle production in e+e- annihilation

$$e^+e^- \to h_1h_2h_3$$

- and in 3-body B decays Chen, Li 2003

$$B \to h_1h_2h_3$$

Two-hadron DA



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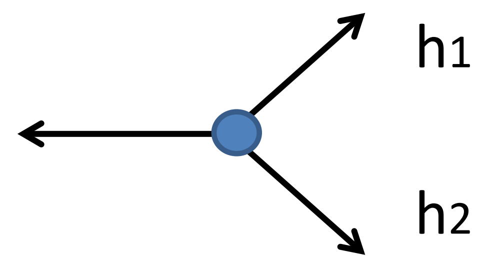


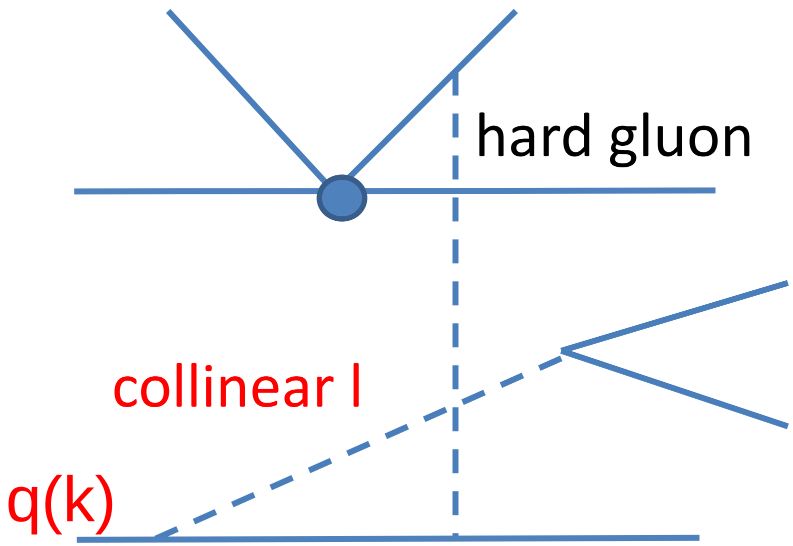
one hard gluon, one soft gluon
as two hadrons collimate

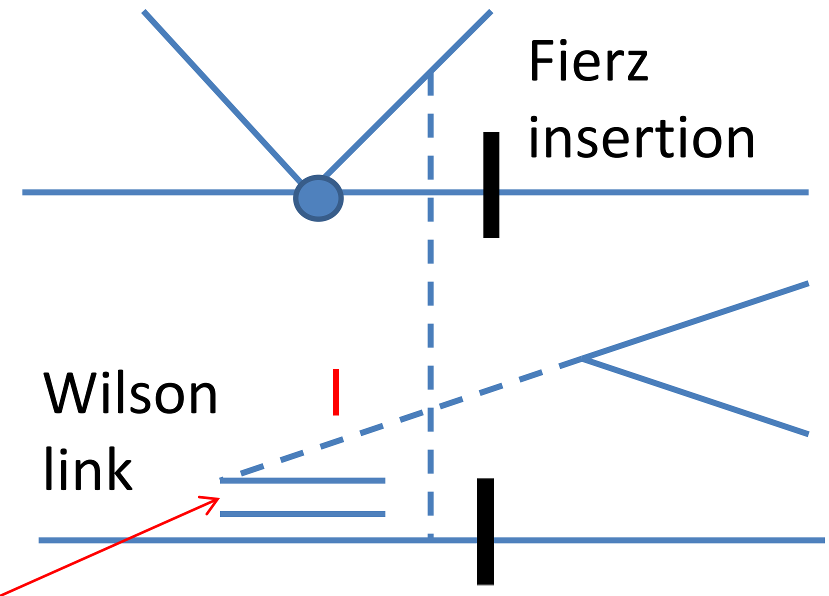
two hard gluons
power suppressed

Factorization & definition of two-hadron DA

Factorization

- Similar to collinear factorization for ordinary hadron DA based on eikonalization and Ward identity for summing collinear attachments





$$\bar{q}(k)\frac{\gamma^{\alpha}(\not{k}+\not{l})}{(k+l)^{2}} \approx \bar{q}(k)\frac{k^{\alpha}}{k\cdot l}$$

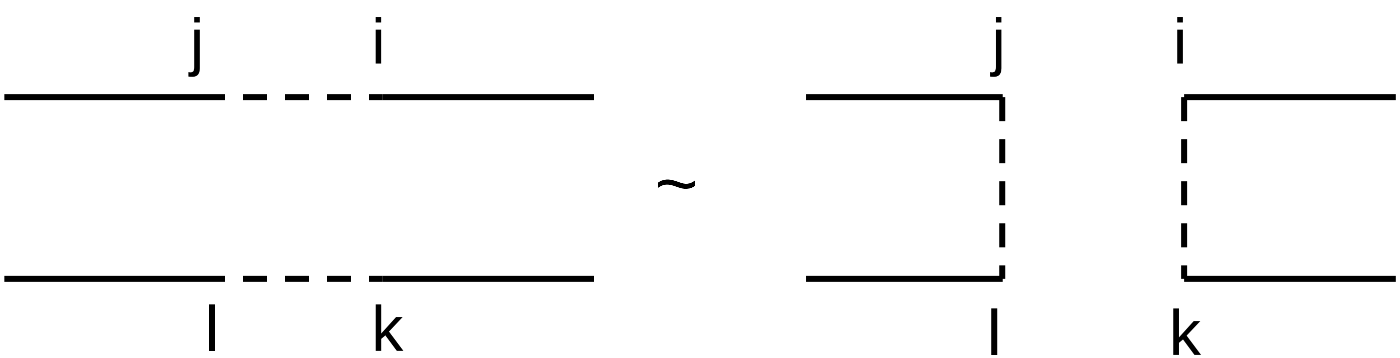
as two hadrons collimate
it is collinear gluon

Fierz transformation

- Insert Fierz identity to break fermion flow

$$
\begin{aligned}
I_{ij} I_{lk} \; = \; & \frac{1}{4} I_{ik} I_{lj} + \frac{1}{4} (\gamma^{\alpha})_{ik} (\gamma_{\alpha})_{lj} + \frac{1}{8} (\sigma^{\alpha\beta})_{ik} (\sigma_{\alpha\beta})_{lj} \\
& + \frac{1}{4} (\gamma^{5} \gamma^{\alpha})_{ik} (\gamma_{\alpha} \gamma^{5})_{lj} + \frac{1}{4} (\gamma^{5})_{ik} (\gamma^{5})_{lj}
\end{aligned}
$$

- First 3 projectors contribute to pion pair, leading to 3 di-pion DAs



Isospin

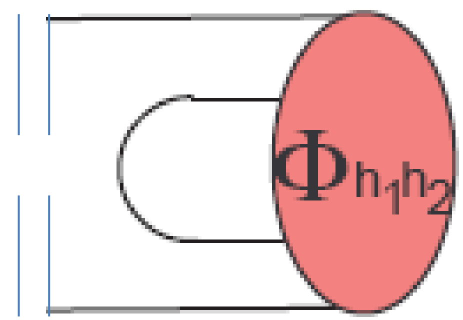
- Two pions form isospins I = 0, 1, 2
- For two-hadron DA, nonlocal operators formed by two light quarks have I = 0, 1
- For $\pi^+\pi^-$ pair, consider nonlocal operators

$$I = 0, \overline{\psi}\,\Gamma_i (1/2)\psi,$$

$$I = 1, \overline{\psi}\,\Gamma_i (\sigma^3/2)\psi$$

$$\Gamma_i = I, \gamma^\alpha, or\ \sigma^{\alpha\beta}$$

Wilson lines for gauge invariance



- Match C-parity of pion state and quark current: I = 0, S-wave (even); I = 1, P-wave (odd)

Definition

$$T = \sigma^3/2, \quad I = 1$$
$$T = 1/2, \quad I = 0$$

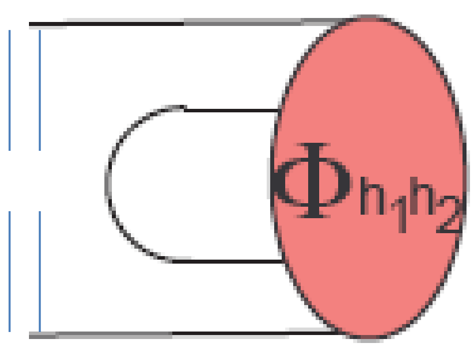
- Di-pion DAs for vector, scalar, tensor currents

$$\Phi_v(z,\zeta,w^2) = \frac{1}{2\sqrt{2N_c}} \int \frac{dy^-}{2\pi} e^{-izP^+y^-} \langle \pi^+(P_1)\pi^-(P_2)|\bar{\psi}(y^-)\ \not{n}_- T\psi(0)|0\rangle \ ,$$

$$\Phi_s(z,\zeta,w^2) = \frac{1}{2\sqrt{2N_c}} \frac{P^+}{w} \int \frac{dy^-}{2\pi} e^{-izP^+y^-} \langle \pi^+(P_1)\pi^-(P_2)|\bar{\psi}(y^-)T\psi(0)|0\rangle \ ,$$

$$\Phi_t(z,\zeta,w^2) = \frac{1}{2\sqrt{2N_c}} \frac{f_{2\pi}^{\perp}}{w^2} \int \frac{dy^-}{2\pi} e^{-izP^+y^-} \langle \pi^+(P_1)\pi^-(P_2)|\bar{\psi}(y^-)i\sigma_{\mu\nu}n_-^{\mu}P^{\nu}T\psi(0)|0\rangle$$

$$P = p_1 + p_2, \quad \varsigma = p_1^+/P^+$$



z

quark momentum fraction

pi+ momentum fraction, corresponding to ξ in GPD

ω^2 invariant mass, corresponding to t in GPD

GPD vs. Two-hadron DA

- GPD and two-hadron DA have similarity, such as normalization to form factors

$$\int_0^1 dx\, H^q(x,\xi,t,\mu^2) = F_1^q(t)$$ Dirac

turn nonlocal operator
Into local operator

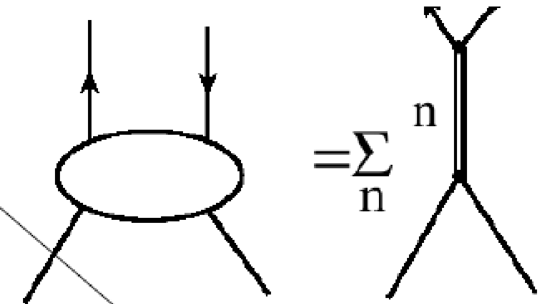
$$\int_0^1 dx\, E^q(x,\xi,t,\mu^2) = F_2^q(t)$$ Pauli

$$\int_0^1 dz \Phi_{\parallel}^{I=1}(z,\zeta,w^2) = (2\zeta-1)F_\pi(w^2)$$ electromagnetic

$$\int_0^1 dz \Phi_{\perp}^{I=1}(z,\zeta,w^2) = (2\zeta-1)F_t(w^2)$$ tensor

Partial wave decomposition

It is an expansion in terms of the relative orbital momentum and eigenfunctions of the QCD evolution operator:



$$H^q(x,\xi,t,\mu^2) = \sum_{\substack{n=1 \\ \text{odd}}}^{\infty} \sum_{\substack{l=0 \\ \text{even}}}^{n+1} B^i_{nl}(t,\mu^2)\,\theta\left(\xi - |x|\right)\left(1 - \frac{x^2}{\xi^2}\right) C_n^{3/2}\left(\frac{x}{\xi}\right) P_l\left(\frac{1}{\xi}\right)$$

$$E^q(x,\xi,t,\mu^2) = \sum_{\substack{n=1 \\ \text{odd}}}^{\infty} \sum_{\substack{l=0 \\ \text{even}}}^{n+1} C^i_{nl}(t,\mu^2)\,\theta\left(\xi - |x|\right)\left(1 - \frac{x^2}{\xi^2}\right) C_n^{3/2}\left(\frac{x}{\xi}\right) P_l\left(\frac{1}{\xi}\right)$$

generalized form factors with known QCD evolution

Gegenbauer polynomials

Legendre polyn.

$$\Phi(z,\zeta,w^2) = 6z(1-z)\sum_{n=0}^{\infty}\sum_{l=0}^{n+1} B_{nl}(w^2)C_n^{3/2}(2z-1)C_l^{1/2}(2\zeta-1)$$

Resonant contribution

- Two-hadron DA receives contributions from various resonances   Pire, hep-ph/0202231

interference

$$\Phi^{I=0}(z,\zeta,m_{2\pi}) = 10z(1-z)(2z-1)\,R_\pi$$

$$\left[-\frac{3-\beta^2}{2}\,e^{i\delta_0(m_{2\pi})}\;|BW_{f_0}(m_{2\pi}^2)| + \beta^2\;e^{i\delta_2(m_{2\pi})}\;|BW_{f_2}(m_{2\pi}^2)|\;P_2(\cos\theta)\right]$$

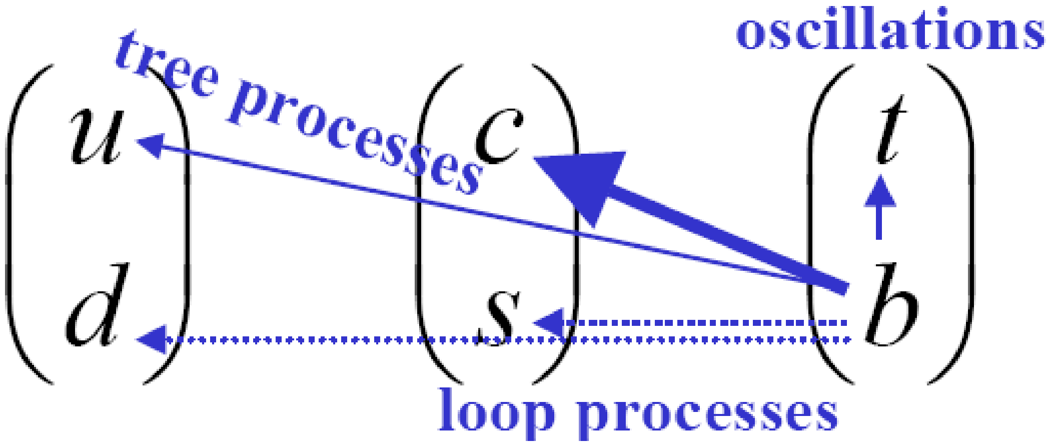
more strong phase

$$BW_{f_{0/2}}(m_{2\pi}^2) = \frac{m_{f_{0/2}}^2}{m_{f_{0/2}}^2 - m_{2\pi}^2 - i\,m_{f_{0/2}}\Gamma_{f_{0/2}}}$$

- BW ~ $1/\omega^2$ asymptotically, nonresonant contribution

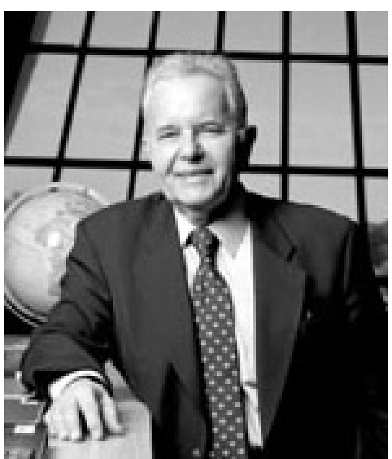
Basics of B decay theory

Cabbibo-Kobayashi-Maskawa Matrix



(Wolfenstein parametrization)

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$



$$; \begin{pmatrix} 0.97 & 0.23 & 0.004 \\ -0.23 & 0.97 & 0.04 \\ 0.004 & -0.04 & 1 \end{pmatrix}$$

Weak phase, ~~CP~~

(magnitudes only)

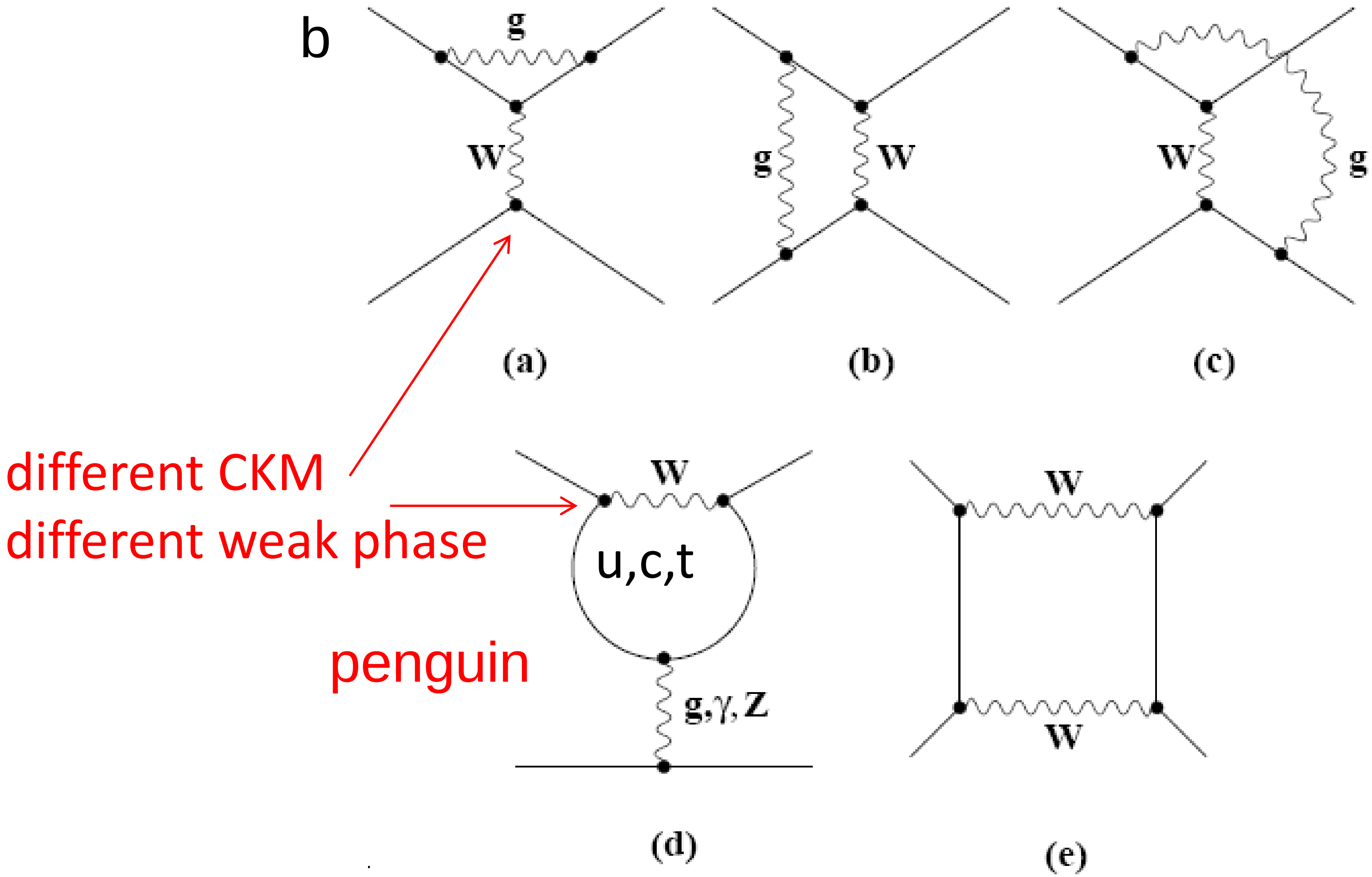
Effective Hamiltonian

- B decays involve multi-scales. First derive effective Hamiltonian by integrating out m_W
- Dynamics of scale m_W is organized into Wilson coefficient C_i
- The rest lower than m_W goes into 4-fermion operators O_i
- $H = V_{CKM} \Sigma_i C_i(\mu) O_i(\mu)$ Buras,Buchalla, 1995

$$O_1 = (\bar{d}b)_{V-A}(\bar{c}u)_{V-A} \qquad O_2 = (\bar{c}b)_{V-A}(\bar{d}u)_{V-A}$$

- Their μ (factorization scale) dependencies cancel.

Diagrams at scale m_W



CP violation

- Thumb only on the right---P violation
- Thumbs on the right of right hand, and on the left of left hand---CP conservation
- Nature gives L to particle and R to antiparticle

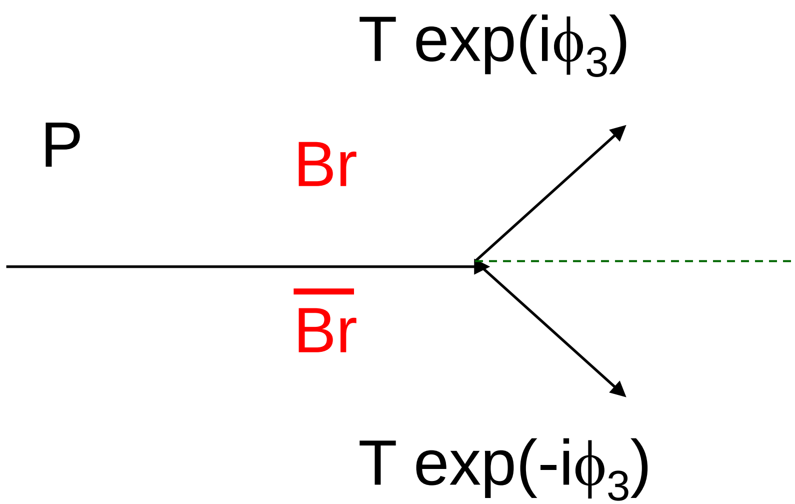
thousand-hand Guan Yin

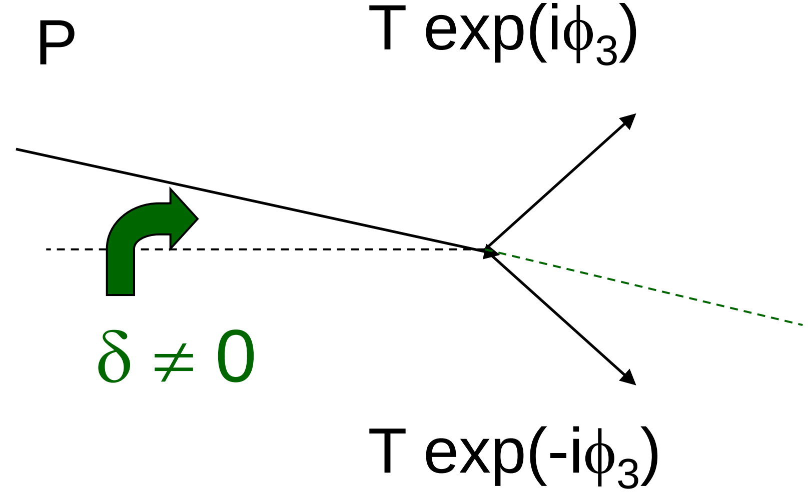
- CP conserved here?
- If she loses one arm, ~~CP~~ at 10^{-3}

anti-particle particle

Direct CP violation

- Require tree (T) and penguin (P) contributions, weak and strong phases
- Weak phase from CKM, (part of) strong phase from two-hadron DA





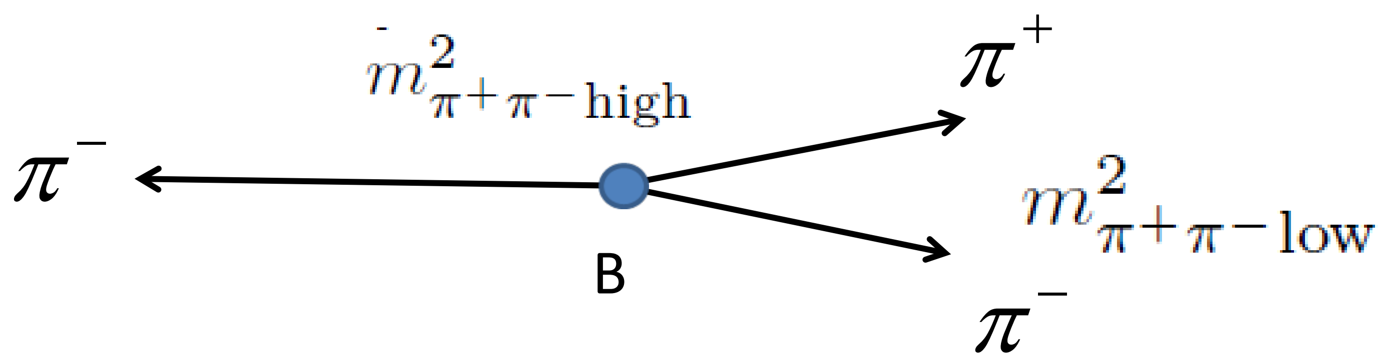
If strong phase $\delta=0$

$\overline{Br} = Br$, no direct $\cancel{CP}$

$Br \neq \overline{Br}$ direct $\cancel{CP}$

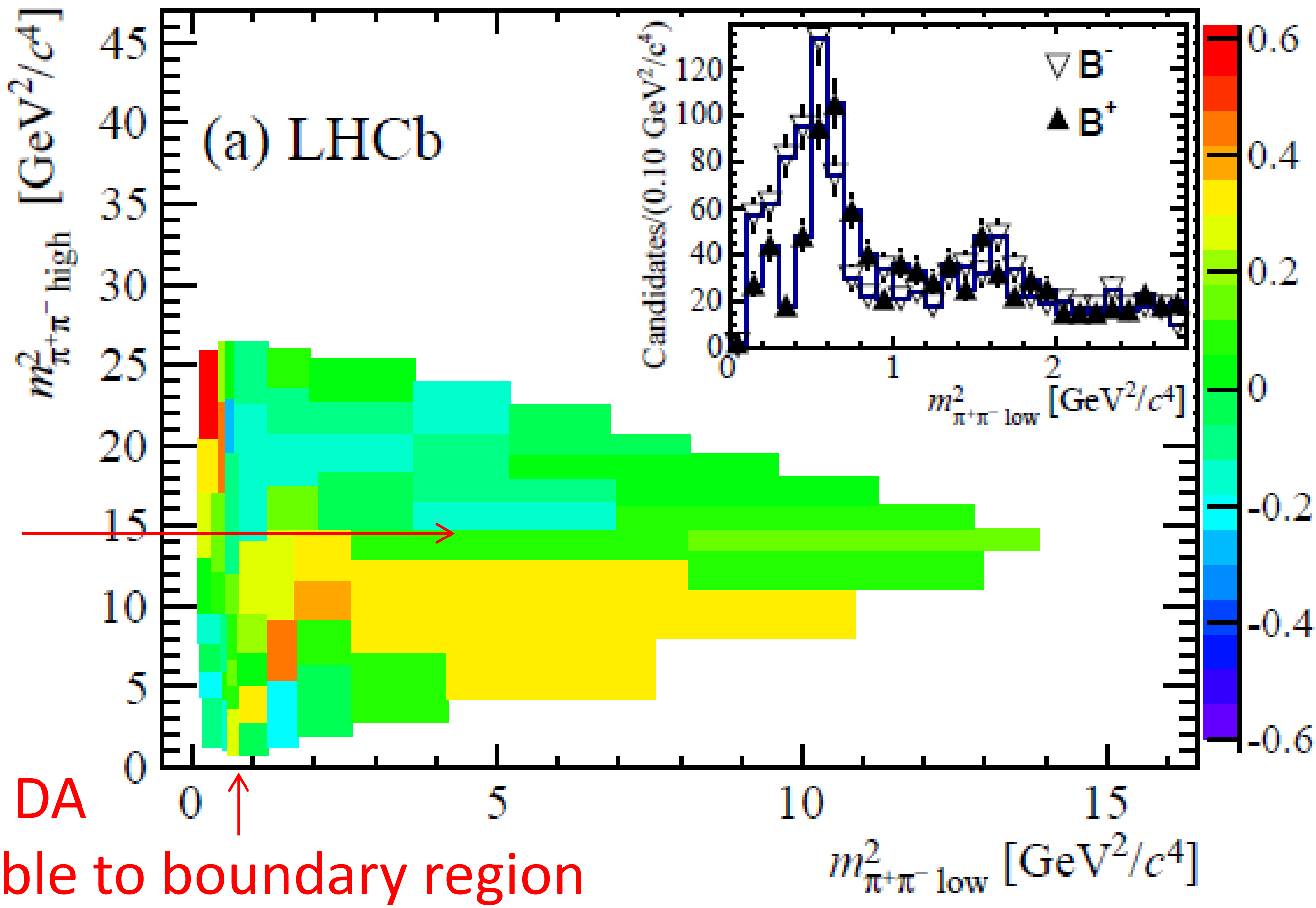
Three-body hadronic B decays

Wang, Li 2016



Dalitz plot

- LHCb has measured CP asymmetries in whole Dalitz plot for $B^- \to \pi^+\pi^-\pi^-$



genuine 3-body decay

di-pion DA applicable to boundary region

Di-pion DAs up to twist 3

- P-wave $T = \sigma^3/2, \quad \Phi \propto \bar{u}\Gamma u - \bar{d}\Gamma d$

$$\phi_{\pi\pi}^{I=1} = \frac{1}{\sqrt{2N_c}} \left[\not{p}\, \phi_{v\nu=-}^{I=1}(z,\zeta,w^2) + w\phi_s^{I=1}(z,\zeta,w^2) + \frac{\not{p}_1\not{p}_2 - \not{p}_2\not{p}_1}{w(2\zeta-1)} \phi_{t\nu=+}^{I=1}(z,\zeta,w^2) \right]$$

Gegenbauer moments to be determined

$$\phi_{v\nu=-}^{I=1}(z,\zeta,w^2) \equiv \phi^0(z,\zeta,w^2) = \frac{3F_\pi(w^2)}{\sqrt{2N_c}} z(1-z) \left[1 + a_2^0 C_2^{3/2}(1-2z)\right] P_1(2\zeta-1) \,,$$

$$\phi_s^{I=1}(z,\zeta,w^2) \equiv \phi^s(z,\zeta,w^2) = \frac{3F_s(w^2)}{2\sqrt{2N_c}} (1-2z) \left[1 + a_2^s \left(1 - 10z + 10z^2\right)\right] P_1(2\zeta-1)$$

$$\phi_{t\nu=+}^{I=1}(z,\zeta,w^2) \equiv \phi^t(z,\zeta,w^2) = \frac{3F_t(w^2)}{2\sqrt{2N_c}} (1-2z)^2 \left[1 + a_2^t C_2^{3/2}(1-2z)\right] P_1(2\zeta-1) \,,$$

Form factor inputs

- Form factor input from e+e- annihilation data based on universality of di-pion DA

BaBar 2012

$\rho - \omega$ mixing

$$F_\pi(w^2) = \Big[\mathrm{GS}_\rho(w^2, m_\rho, \Gamma_\rho) \frac{1 + c_\omega \mathrm{BW}_\omega(w^2, m_\omega, \Gamma_\omega)}{1 + c_\omega}$$

Gounaris-Sakurai model

$$+ \sum c_i \mathrm{GS}_i(w^2, m_i, \Gamma_i) \Big] \left(1 + \sum c_i\right)^{-1}$$

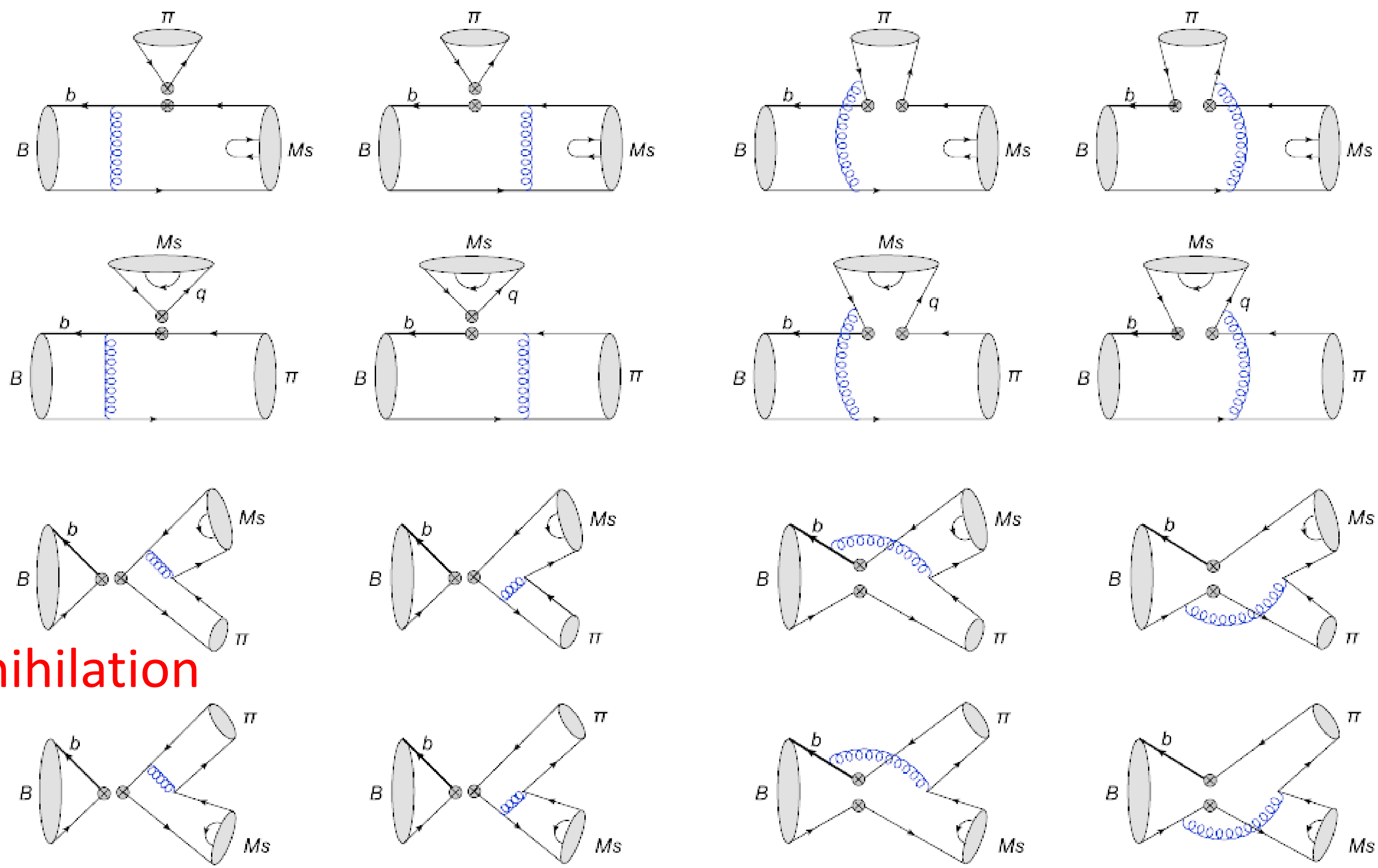
Breit-Wigner function

$$i = \rho'(1450),\ \rho''(1700) \text{ and } \rho'''(2254)$$

Feynman diagrams

- Calculate 16 diagrams (similar to 2-body decays)

nonfactorizable



annihilation

Results

- Fitted P-wave Gegenbauer moments

$$a_2^0 = 0.25,\ a_2^s = 0.75, \text{ and } a_2^t = -0.60$$

		Results	Data [98]
$K^+\pi^+\pi^-$	$\mathcal{B}\ (10^{-6})$	$3.42^{+0.78}_{-0.55}(\omega_B)^{+0.44}_{-0.39}(a_2^t)^{+0.39}_{-0.38}(m_0^K)^{+0.39}_{-0.32}(a_2^0)^{+0.29}_{-0.28}(a_2^s)$	3.7 ± 0.5
	$\mathcal{A}_{CP}$	$0.43^{+0.04}_{-0.05}(\omega_B) \pm 0.06(a_2^t) \pm 0.03(m_0^K) \pm 0.03(a_2^0) \pm 0.01(a_2^s)$	0.37 ± 0.10
$K^0\pi^+\pi^0$	$\mathcal{B}\ (10^{-6})$	$7.43^{+1.92}_{-1.31}(\omega_B)^{+1.65}_{-1.42}(a_2^t)^{+0.88}_{-0.91}(m_0^K)^{+0.60}_{-0.62}(a_2^0)^{+0.53}_{-0.47}(a_2^s)$	8.0 ± 1.5
	$\mathcal{A}_{CP}$	$0.15^{+0.02}_{-0.01}(\omega_B)^{+0.04}_{-0.05}(a_2^t) \pm 0.01(m_0^K)^{+0.01}_{-0.00}(a_2^0) \pm 0.00(a_2^s)$	-0.12 ± 0.17
$K^+\pi^-\pi^0$	$\mathcal{B}\ (10^{-6})$	$6.51^{+1.71}_{-1.12}(\omega_B)^{+0.58}_{-0.61}(a_2^t)^{+0.78}_{-0.77}(m_0^K)^{+0.67}_{-0.64}(a_2^0)^{+0.39}_{-0.47}(a_2^s)$	7.0 ± 0.9
	$\mathcal{A}_{CP}$	$0.31^{+0.00}_{-0.01}(\omega_B)^{+0.09}_{-0.08}(a_2^t)^{+0.03}_{-0.02}(m_0^K) \pm 0.01(a_2^0) \pm 0.02(a_2^s)$	0.20 ± 0.11
$K^0\pi^+\pi^-$	$\mathcal{B}\ (10^{-6})$	$3.76^{+1.09}_{-0.74}(\omega_B)^{+0.73}_{-0.60}(a_2^t)^{+0.52}_{-0.47}(m_0^K)^{+0.28}_{-0.25}(a_2^0)^{+0.26}_{-0.23}(a_2^s)$	4.7 ± 0.6
	$\mathcal{A}_{CP}$	$0.06^{+0.01}_{-0.02}(\omega_B)^{+0.00}_{-0.01}(a_2^t) \pm 0.00(m_0^K)^{+0.00}_{-0.01}(a_2^0) \pm 0.00(a_2^s)$	$-$

Summary

- Two-hadron DA, time-like version of GPD, contains rich strong dynamics
- Include both resonant and nonresonant contributions to 3-body B decays at the same time, providing strong phase required by direct CP violation
- Need precise determination of various two-hadron DAs (PP, PV, VV pairs; S, P, D waves, twits-2, 3; …)
- Future goal: predict direct CP violation of 3-body B decays in localized regions of phase space

Back-up slides

Motivation

- Recent LHCb data of direct CP asymmetries in localized regions of phase space

$$A_{CP}^{\text{region}}(K^+K^-K^-) = -0.226 \pm 0.020 \pm 0.004 \pm 0.007,$$

for $m^2_{K^+K^-\text{high}} < 15\ \text{GeV}^2$ and $1.2 < m^2_{K^+K^-\text{low}} < 2.0\ \text{GeV}^2$

$$A_{CP}^{\text{region}}(K^-\pi^+\pi^-) = 0.678 \pm 0.078 \pm 0.032 \pm 0.007$$

for $m^2_{K^-\pi^+\text{high}} < 15\ \text{GeV}^2$ and $\underline{0.08 < m^2_{\pi^+\pi^-\text{low}} < 0.66\ \text{GeV}^2}$

$$A_{CP}^{\text{region}}(K^+K^-\pi^-) = -0.648 \pm 0.070 \pm 0.013 \pm 0.007$$

for $m^2_{K^+K^-} < 1.5\ \text{GeV}^2$

rho resonance

$$A_{CP}^{\text{region}}(\pi^+\pi^-\pi^-) = 0.584 \pm 0.082 \pm 0.027 \pm 0.007$$

for $m^2_{\pi^+\pi^-\text{high}} > 15\ \text{GeV}^2$ and $\underline{m^2_{\pi^+\pi^-\text{low}} < 0.4\ \text{GeV}^2}$

Isospin of pion pair

$$I = 2$$

$$I_z = 2 \qquad |\pi^+\rangle|\pi^+\rangle$$

$$I_z = 1 \qquad |\pi^+\rangle|\pi^0\rangle + |\pi^0\rangle|\pi^+\rangle$$

$$I_z = 0 \qquad |\pi^+\rangle|\pi^-\rangle + 2|\pi^0\rangle|\pi^0\rangle + |\pi^-\rangle|\pi^+\rangle$$

$$I_z = -1 \qquad |\pi^0\rangle|\pi^-\rangle + |\pi^-\rangle|\pi^0\rangle$$

$$I_z = -2 \qquad |\pi^-\rangle|\pi^-\rangle$$

$$\mathcal{C}\,|\pi^+\pi^-\rangle = (-1)^L\,|\pi^+\pi^-\rangle$$

$$I = 1$$

$$I_z = 1 \qquad |\pi^+\rangle|\pi^0\rangle - |\pi^0\rangle|\pi^+\rangle$$

$$I_z = 0 \qquad \boxed{|\pi^+\rangle|\pi^-\rangle - |\pi^-\rangle|\pi^+\rangle}$$

$$I_z = -1 \qquad |\pi^0\rangle|\pi^-\rangle - |\pi^-\rangle|\pi^0\rangle$$

correspond to l = 1, 3
P wave…

correspond to l = 0, 2,
S, D waves…

$$I = 0$$

$$I_z = 0 \qquad \boxed{|\pi^+\rangle|\pi^-\rangle + |\pi^-\rangle|\pi^+\rangle} - |\pi^0\rangle|\pi^0\rangle$$

C-parity

- C-parity (charge parity) for mesonic state is equivalent to parity

$$C\,|\pi^+\pi^-\rangle = (-1)^L\,|\pi^+\pi^-\rangle$$

- C-parity for quark fields (spinors)

$$\psi^{(c)} = C\psi^\star \qquad C = i\gamma^2$$

$$C^\dagger\gamma^\mu C = -(\gamma^\mu)^\star$$

- C-parity is odd for vector and tensor currents, and even for scalar current

Kinematics

- Meson momenta in light-cone coordinates

$$p_B = \frac{m_B}{\sqrt{2}}(1, 1, 0_{\mathrm{T}}), \quad p = \frac{m_B}{\sqrt{2}}(1, \eta, 0_{\mathrm{T}}), \quad p_3 = \frac{m_B}{\sqrt{2}}(0, 1-\eta, 0_{\mathrm{T}})$$

- Two-hadron invariant mass

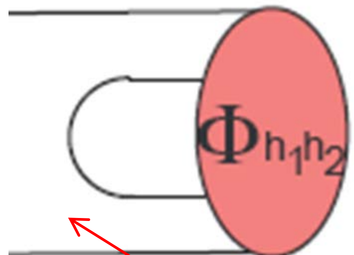
$$\omega^2 = p^2 \qquad p = \underset{\text{pi+}}{p_1} + \underset{\text{pi-}}{p_2} \qquad \eta = \frac{\omega^2}{m_B^2}$$

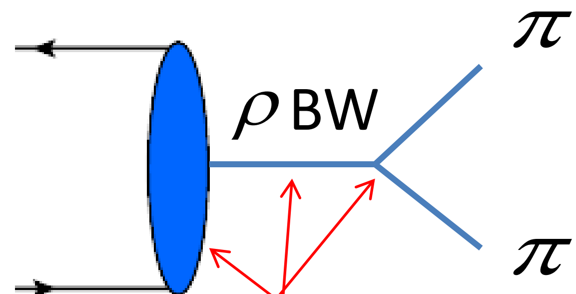
- pi+ momentum fraction

$$p_1^+ = \underset{\substack{\uparrow \\ \text{pion momentum fraction}}}{\zeta}\frac{m_B}{\sqrt{2}}, \quad p_1^- = (1-\zeta)\eta\frac{m_B}{\sqrt{2}}, \quad p_2^+ = (1-\zeta)\frac{m_B}{\sqrt{2}}, \quad p_2^- = \zeta\eta\frac{m_B}{\sqrt{2}}$$

Consistency with pole model

- Consistency between di-pion DA and pole model





$$P_1(\zeta) = 2\zeta - 1 \leftrightarrow \varepsilon_\rho \cdot (p_1 - p_2)$$

$$F_\pi^\rho(w^2) \approx \frac{g_{\rho\pi\pi} w f_\rho}{D_\rho(w^2)}$$

- At twist 3

$$F_{s,t}^\rho(w^2) \approx g_{\rho\pi\pi} w f_\rho^T / D_\rho(w^2)$$

- Form factor ratio

$$F_{s,t}(w^2) \approx (f_\rho^T / f_\rho) F_\pi(w^2)$$

Consistency with 2-body formalism

- BRs are close between 3-body and 2-body formalism, direct CPAs differ s bit
- CPA from 3-body more consistent with data

$$K^+\rho^0 \quad \begin{cases} \mathcal{B} = (3.52^{+0.67}_{-0.45}(\omega_B)^{+0.40}_{-0.34}(a_2^t)^{+0.42}_{-0.38}(m_0^K)^{+0.47}_{-0.43}(a_2^0)^{+0.25}_{-0.24}(a_2^s)) \times 10^{-6}\,, \\ \mathcal{A}_{CP} = 0.55^{+0.02}_{-0.04}(\omega_B)^{+0.09}_{-0.08}(a_2^t) \pm 0.03(m_0^K)^{+0.00}_{-0.01}(a_2^0) \pm 0.01(a_2^s)\,, \end{cases}$$

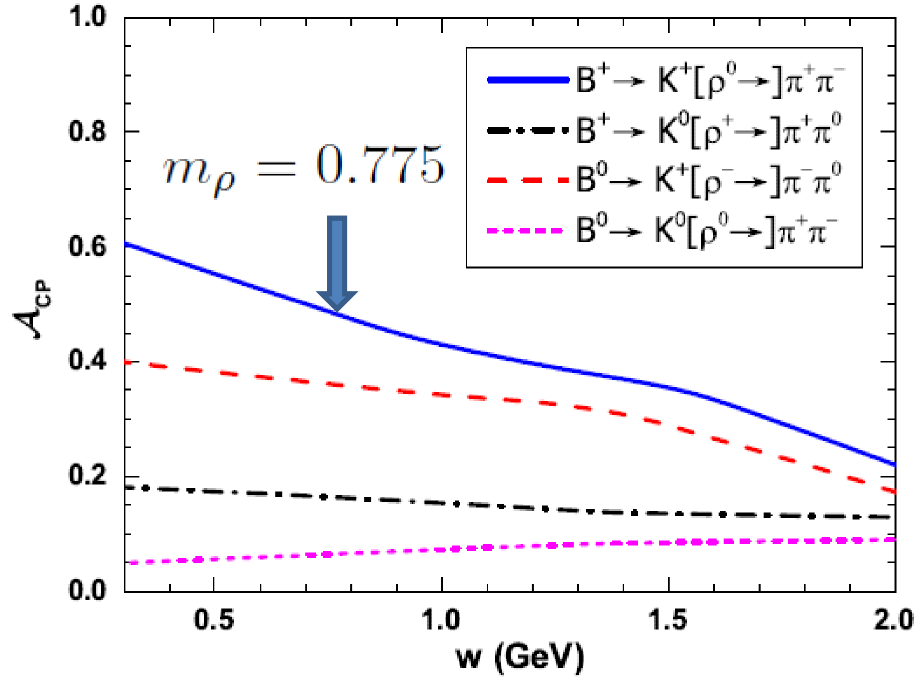
$$K^0\rho^+ \quad \begin{cases} \mathcal{B} = (7.66^{+1.79}_{-1.19}(\omega_B)^{+1.69}_{-1.44}(a_2^t)^{+1.04}_{-0.95}(m_0^K)^{+0.84}_{-0.73}(a_2^0)^{+0.43}_{-0.41}(a_2^s)) \times 10^{-6}\,, \\ \mathcal{A}_{CP} = 0.22 \pm 0.03(\omega_B)^{+0.03}_{-0.05}(a_2^t) \pm 0.01(m_0^K) \pm 0.00(a_2^0) \pm 0.00(a_2^s) \end{cases}$$

$$K^+\rho^- \quad \begin{cases} \mathcal{B} = (6.92^{+1.58}_{-1.04}(\omega_B)^{+0.67}_{-0.53}(a_2^t)^{+0.86}_{-0.81}(m_0^K)^{+0.91}_{-0.80}(a_2^0)^{+0.42}_{-0.40}(a_2^s)) \times 10^{-6}\,, \\ \mathcal{A}_{CP} = 0.34^{+0.00}_{-0.01}(\omega_B)^{+0.13}_{-0.12}(a_2^t)^{+0.03}_{-0.02}(m_0^K)^{+0.01}_{-0.02}(a_2^0)^{+0.01}_{-0.02}(a_2^s)\,. \end{cases}$$

$$K^0\rho^0 \quad \begin{cases} \mathcal{B} = (4.01^{+1.07}_{-0.71}(\omega_B)^{+0.70}_{-0.63}(a_2^t)^{+0.55}_{-0.50}(m_0^K)^{+0.40}_{-0.35}(a_2^0) \pm 0.19(a_2^s)) \times 10^{-6} \\ \mathcal{A}_{CP} = 0.04 \pm 0.01(\omega_B) \pm 0.00(a_2^t) \pm 0.00(m_0^K)^{+0.00}_{-0.01}(a_2^0) \pm 0.00(a_2^s) \end{cases}$$

More results

- Differential distribution of CPA
- CPA of $K^+\rho^0$ would be overestimated in 2-body formalism



- Predictions

$K^+\rho'^0 \to K^+\pi^+\pi^-$	$\mathcal{B}\ (10^{-7})$	$4.32^{+1.17}_{-0.99}(\omega_B)^{+0.81}_{-0.79}(a_2^t)^{+0.59}_{-0.64}(a_2^s)^{+0.40}_{-0.46}(m_0^K)^{+0.13}_{-0.17}(a_2^0)$
	$\mathcal{A}_{CP}$	$0.32^{+0.06}_{-0.04}(\omega_B) \pm 0.03(a_2^t)^{+0.01}_{-0.02}(a_2^s)^{+0.02}_{-0.01}(m_0^K) \pm 0.01(a_2^0)$
$K^0\rho'^+ \to K^0\pi^+\pi^0$	$\mathcal{B}\ (10^{-7})$	$10.37^{+3.72}_{-2.36}(\omega_B)^{+3.14}_{-2.71}(a_2^t)^{+1.26}_{-1.03}(a_2^s)^{+1.13}_{-0.92}(m_0^K)^{+0.42}_{-0.37}(a_2^0)$
	$\mathcal{A}_{CP}$	$0.12 \pm 0.02(\omega_B)^{+0.02}_{-0.01}(a_2^t)^{+0.03}_{-0.02}(a_2^s) \pm 0.01(m_0^K) \pm 0.01(a_2^0)$
$K^+\rho'^- \to K^+\pi^-\pi^0$	$\mathcal{B}\ (10^{-7})$	$7.61^{+2.37}_{-1.90}(\omega_B)^{+1.32}_{-1.03}(a_2^t)^{+1.17}_{-0.88}(a_2^s)^{+0.86}_{-0.75}(m_0^K)^{+0.26}_{-0.22}(a_2^0)$
	$\mathcal{A}_{CP}$	$0.27^{+0.02}_{-0.01}(\omega_B) \pm 0.06(a_2^t)^{+0.00}_{-0.01}(a_2^s) \pm 0.02(m_0^K) \pm 0.01(a_2^0)$
$K^0\rho'^0 \to K^0\pi^+\pi^-$	$\mathcal{B}\ (10^{-7})$	$4.84^{+1.82}_{-1.32}(\omega_B)^{+1.11}_{-1.05}(a_2^t) \pm 0.50(a_2^s)^{+0.48}_{-0.46}(m_0^K)^{+0.14}_{-0.16}(a_2^0)$
	$\mathcal{A}_{CP}$	$0.08^{+0.00}_{-0.01}(\omega_B)^{+0.02}_{-0.00}(a_2^t) \pm 0.01(a_2^s) \pm 0.01(m_0^K) \pm 0.01(a_2^0)$