Reconstruction of Dalitz Plots in QCD Factorization for $B \to \pi\pi\pi$ decays – Status Report

Susanne Kränkl

Universität Siegen
Theoretische Physik I

in collaboration with
Javier Virto and Thomas Mannel

Siegen, 08.12.2014

DFG FOR 1873

Dalitz plot (DP) analysis of non-leptonic three-body B decays

Interest

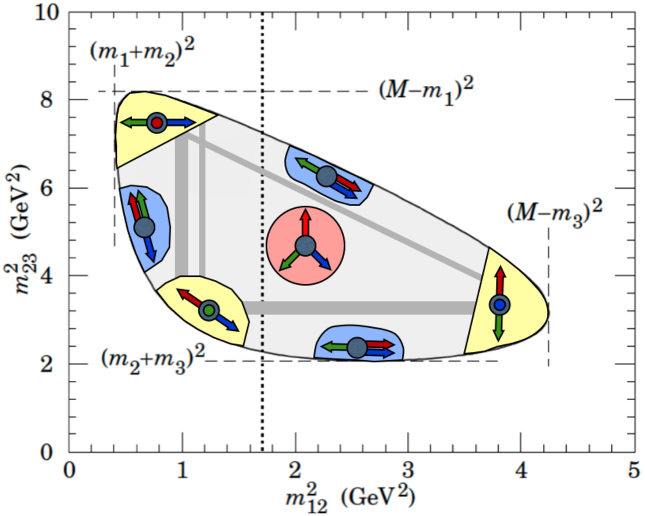
- Phenomenological aspects: UT angles, CP violation, New Physics?
- A lot of experimental data available (Babar, Belle, LHCb)
- B decays are dominated by non-resonant (NR) contributions $BR_{NR} \gtrsim 70\% BR$

Advantages of QCD factorization

- Model-independent analysis
- May provide a combined description of R and NR contributions

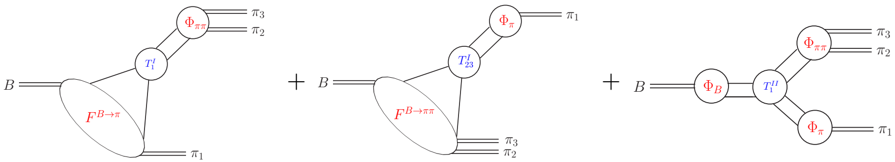
Outline

- Identify regions in the DP where EFTs are applicable
- Proof of factorization (at leading power, leading order in α_s)
- Try to reconstruct the DP in the full face space



- Center
- Edges (collinear)
- Corners (soft)

use abbreviation
$s_{12} = m_{12}^2 / m_B^2$



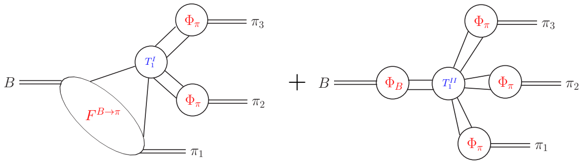
Edges and corners ($s_{12} \ll 1$)

$$\langle \pi_1\pi_2\pi_3|\mathcal{O}_i|B\rangle_{s_{12}\ll 1} = T_3^I \otimes F^{B\to\pi_3} \otimes \Phi_{\pi_1\pi_2} + T_{12}^I \otimes F^{B\to\pi_1\pi_2} \otimes \Phi_{\pi_3} + T_3^{II} \otimes \Phi_B \otimes \Phi_{\pi_3} \otimes \Phi_{\pi_1\pi_2}$$

Specator interaction @ NLO in α_s

$F^{B\to\pi}$, $F^{B\to\pi\pi}$: form factors
ϕ_π, ϕ_B, $\phi_{\pi\pi}$: light-cone distribution amplitudes
} soft part, non-perturbative

T_{ij} : hard scattering kernel   hard part, perturbative



Center ($s_{12} \sim 1$)

$$
\begin{aligned}
\langle \pi_1 \pi_2 \pi_3 | \mathcal{O}_i | B \rangle_{s_{12}\sim 1/3} &= T_1^I \otimes F^{B\to\pi_1} \otimes \Phi_{\pi_2} \otimes \Phi_{\pi_3} + T_2^I \otimes F^{B\to\pi_2} \otimes \Phi_{\pi_1} \otimes \Phi_{\pi_3} \\
&+ T_3^I \otimes F^{B\to\pi_3} \otimes \Phi_{\pi_1} \otimes \Phi_{\pi_2} \\
&+ T^{II} \otimes \Phi_B \otimes \Phi_{\pi_1} \otimes \Phi_{\pi_2} \otimes \Phi_{\pi_3}
\end{aligned}
$$

Specator interaction @ NLO in α_s

- Generalized form factor and distribution amplitude further factorize:
  - $$F^{B\to\pi_1\pi_2}|_{s_{12}\sim 1} = T_1^I \otimes F^{B\to\pi_1} \otimes \Phi_{\pi_2} + T_2^I \otimes F^{B\to\pi_2} \otimes \Phi_{\pi_1} + T_{12}^{II} \otimes \Phi_B \otimes \Phi_{\pi_1} \otimes \Phi_{\pi_2}$$
  - $\Phi_{\pi_1\pi_2} \sim \Phi_{\pi_1} \otimes \Phi_{\pi_2}$
- Existance of factorizable contributions that are of leading power in center but power suppressed at corners/edges (and vice vera)
- Scaling

@ Center

$$\mathcal{A}^{s_{12}\sim 1/3} \sim G_F f_\pi^2\, \alpha_s(m_B\sqrt{s_{12}})$$

@ Edges

$$\mathcal{A}^{s_{12}\ll 1}_{\Phi_{\pi\pi}} \sim G_F m_B^2$$

$$\mathcal{A}^{s_{12}\ll 1}_{F^{B\to\pi\pi}} \sim G_F f_\pi\, m_B$$

Merging egdes and center

$$\Phi_{\pi\pi} \to\sim f_\pi^2/(m_B^2 s_{12}) \cdot \alpha_s(m_B\sqrt{s_{12}})$$

Diehl, Feldmann, Kroll, Vogt, 2000

$$F^{B\to\pi\pi} \to \sim f_\pi \alpha(m_B\sqrt{s_{12}})$$

$$\mathcal{A}^{s_{12}\ll 1}_{\Phi_{\pi\pi}, F^{B\to\pi\pi}} \xrightarrow{s_{12}\sim 1/3} \mathcal{A}^{s_{12}\sim 1/3}$$

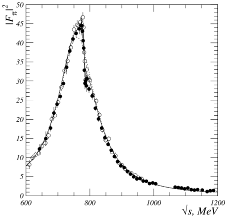
$$\mathcal{A}^{s_{12}\sim 1/3} \xrightarrow{s_{12}\sim(\Lambda/m_B)^2} \mathcal{A}^{s_{12}\ll 1}_{\Phi_{\pi\pi}}$$

UNIVERSITÄT SIEGEN

Generalized distribution amplitude $\Phi_{\pi\pi}$ Diehl at al, 1998

$$(\Phi_{\pi\pi})^{ij,ab}_{\alpha\beta}(z,n_+,k_2,k_3) = \frac{k_{23}^+}{2\pi}\int dx^- e^{iz(k_{23}^+ x^-)}\langle\pi^a(k_2)\pi^b(k_3)|\bar{q}^i_\alpha(x^- n_-)q^j_\beta(0)|0\rangle$$

- related to the single pion DA ϕ_π by the soft pion theorem
- contains hadronic resonances
- can be related to time-like form factor F_π of the pion



Melikhov at al, 2004

Generalized form factor $F^{B\to\pi\pi}$

Faller, Feldmann, Khodjamirian, Mannel, 2013

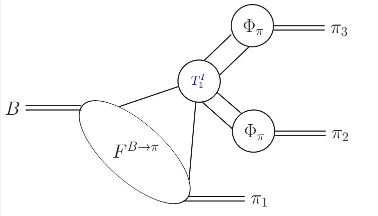
$$F^{ab}_{ij,\alpha\beta}(k_1,k_2,k_3) \equiv \langle\pi^a(k_2)\pi^b(k_3)|\bar{q}_{j\beta}b_\alpha|B_i(p)\rangle$$

- can be related to $\Phi^{\pi\pi}$ Hambrock, Khodjamirian, P2

UNIVERSITÄT SIEGEN

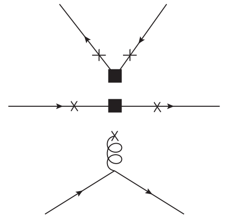
- Focus on $B \to \pi\pi\pi$ decays
- Use usual operators basis
  current-current: Q_1, Q_2, penguin: $Q_3 \ldots, Q_6$

@ center



$+$ permutations

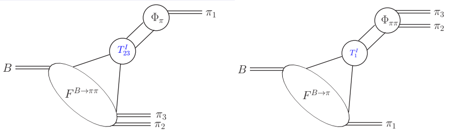
$T_1^I \to$



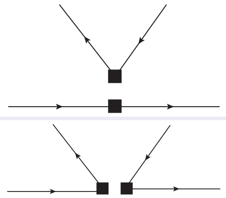
- No endpoint divergences for current-current operators
- Inclusion of penguin operators WIP

UNIVERSITÄT SIEGEN

@ edges/corners



$T^I_{23},\ T^I_1 \rightarrow$

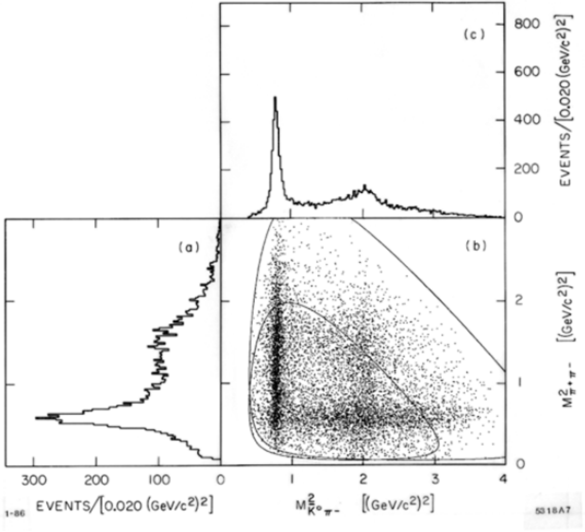


- go to physical basis: π^+, π^-, π^0

$$\mathcal{A}(\bar{B}^0 \to \pi^0\pi^+\pi^-)_{s_{+-}\ll 1} = G_F f_\pi m_\pi N_c\, c_2 \left[i F_t{}^0(s_{0+}, s_{+-}) + i F_t{}^1(s_{0+}, s_{+-}) \right] + G_F m_B^2 \xi_\pi(E_0) N_c^2\, c_2\, (s_{0+} - s_{0-}) F_\pi(s_{+-})$$

$$\mathcal{A}(\bar{B}^0 \to \pi^0\pi^+\pi^-)_{s_{0+}\ll 1} = 2 G_F f_\pi m_\pi N_c\, c_1\, i F_t{}^1(s_{0-}, s_{0+})$$

$$\mathcal{A}(\bar{B}^0 \to \pi^0\pi^+\pi^-)_{s_{0-}\ll 1} = G_F m_B^2 \xi_\pi(E_+) N_c^2\, c_1\, (s_{+-} - s_{0+}) F_\pi(s_{0-})$$



$$\Gamma_{\text{2-body}} \sim G_F^2 f_\pi^2 m_B^3 \longleftrightarrow \Gamma^{s_{12}\ll 1}_{\text{3-body},\ \Phi_{\pi\pi}} \sim G_F^2 m_B^5$$

UNIVERSITÄT SIEGEN

Outlook

- Calculation of BR^{center} and $BR^{\text{edges/corners}}$

  $\rightarrow$ compare with experimental result
- Understand scaling of edges: Why $\mathcal{A}_{F^{\pi\pi}} < \mathcal{A}_{\Phi^{\pi\pi}}$?

  $\rightarrow$ analyize perturbative limits of $F_{\pi\pi}$ and $\Phi_{\pi\pi}$
- Try to understand resonances as two-body decays within the three-body framework

Future work

- Extend analysis to other three-body decays ($K^{\pm} \rightarrow K^{+}K^{-}\pi^{\pm}, \ldots$)
- Go beyond leading order analysis