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$B \to \pi\pi$ form factors from light cone sum rules

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QCD sum rules approach

The **QCD sum rule approach** is based on a twofold way of treating process-dependent **correlation functions** of quark-antiquark operators: (I) a correlation function is calculated in QCD operator product expansion, yielding a combined perturbative and power expansion, which contains universal input parameters encoding the nonperturbative quark-gluon interactions; (II) the same correlation function is related to the **hadronic matrix elements** via a dispersion relation. Mutually connected versions of QCD sum rules for different types of hadronic matrix elements include the **light-cone sum rules (LCSRs)** for hadronic form factors and **two-point sum rules** for the decay constants of hadrons. One employs two different types of correlation functions with, respectively, **distribution amplitudes (DAs) of hadrons** and QCD **vacuum condensates** as nonperturbative inputs.

$B \to \pi\pi$ form factors in LCSRs

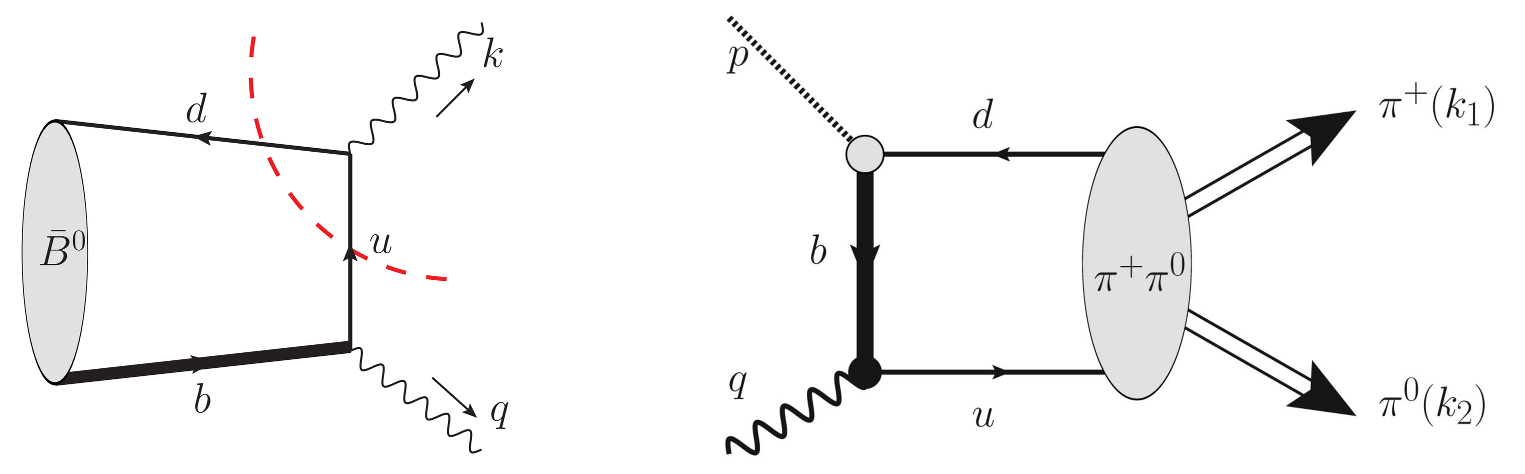

Illustration: Leading order diagram for the correlation functions used to derive QCD LCSRs for the form factors in $B \to \pi\pi\ell\bar{\nu}$ with the B (left) and dipion (right) DAs. See [1, 2, 3] for details.

With B meson distribution amplitude [1]

➜ **Correlation function:** $\bar{d}\gamma_\mu u$ interpolation current with the $b \to u$ weak current,

$F_{\mu\nu}(k,q) = i\int d^4x e^{ik\cdot x}\langle 0|\mathrm{T}\{\bar{d}\gamma_\mu u(x), \bar{u}\gamma_\nu(1-\gamma_5)b(0)\}|\bar{B}^0\rangle$.

➜ **QCD calculation:** $\mathbf{q^2 \ll m_B^2, |k^2| \gg \Lambda_{QCD}^2}$

long distant matrix element is defined by B meson light cone DAs;

short distant contribution is carried by internal free propagator.

➜ **Hadron dispersion relation:** $\pi^-\pi^0$ **interpolation**, (unitarity relation)

pion vector form factor $\langle\pi^-(k_1)\pi^0(k_2)|\bar{u}\gamma_\mu d|0\rangle = -\sqrt{2}(k_1-k_2)_\mu F_\pi(k^2)$,

$\Rightarrow$ convolution of F_π and $F_{B\to\pi\pi}$ in invariant mass s, $\Rightarrow$ impossible to solve analytically.

➜ **Quark-hadron duality and Borel transfer**

➜ **Resonance model for** $B \to \pi^-\pi^0$ **form factor** to fit the form factor.

an independent and apposite channel to study $B \to \rho, \rho'$ from factors in LCSRs;

how large of ρ contribution to $B \to \pi^-\pi^0$ form factor ?

With dipion distribution amplitude [2, 3]

➜ **Correlation function:** pseudoscalar heavy-light current j_5^B and weak current $j_{b\to u}^{(m)}$

$\Pi^{(m)}(q,k_1,k_2) = i\int d^4x e^{iqx}\left\langle \pi^-(k_1)\pi^0(k_2)|\mathrm{T}\left\{j_{b\to u}^{(m)}(x), j_5^B(0)\right\}|0\right\rangle$.

➜ **Analytical solution in terms of isospin-vector dipion DAs**

➜ $\mathbf{m = V - A}$: limit knowledge of dipion DAs $\Rightarrow$ only $F_{\perp,\parallel}(q^2,s)$ is available at $s = 4m_\pi^2$;

kinematic singularity $\Rightarrow$ $F_{t,0}(q^2,s)$ should be considered separately.

➜ $\mathbf{m = P}$: **for timelike-helicity form factor** $\mathbf{F_{t,0}}$

$B_{01}^{\parallel}(s) \simeq F_\pi(s)$ with B factory data, go to a large prediction $s \in [4m_\pi^2, 1.5\ \mathrm{GeV}^2]$.

➜ **Resonance model to estimate the** ρ **contribution**

Numerics

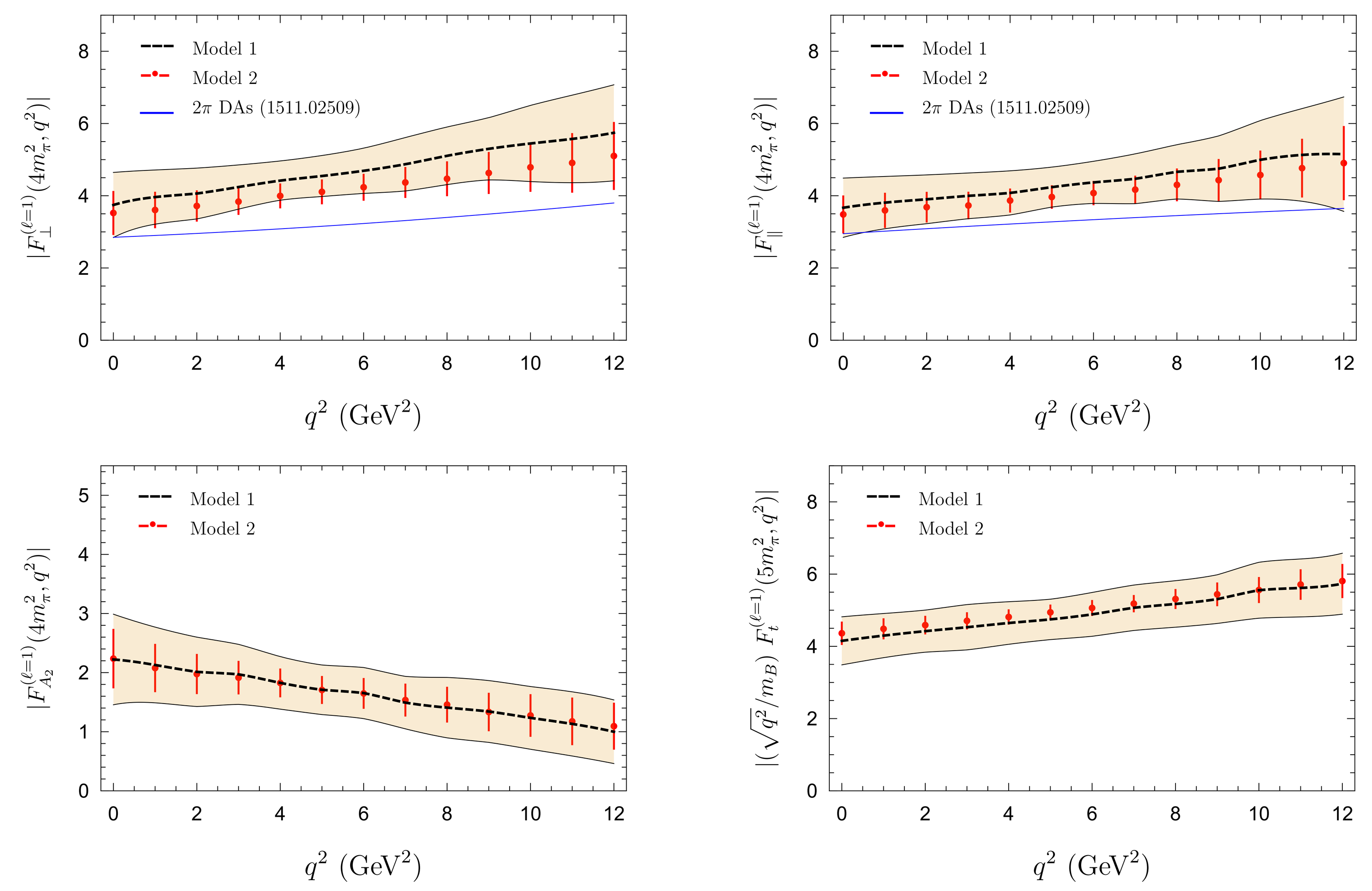

Figure.1: $\mathrm{B} \to \pi^-\pi^0$ transition form factors obtained with B meson LCDAs.

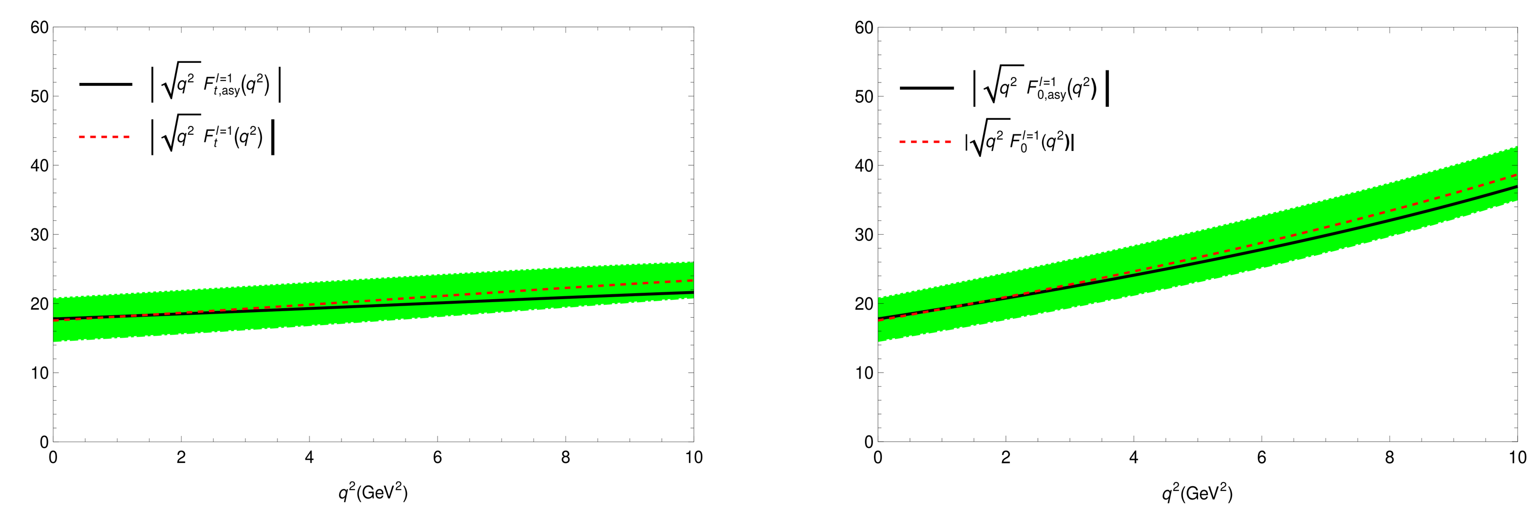

Figure.2: Timelike-helicity $\mathrm{B} \to \pi^-\pi^0$ transition form factors $\mathrm{F}_{t,0}$ obtained with diipon LCDAs.

Conclusion

- **Modele-I in Fig.1:** two resonances model, with using the $\mathrm{B} \to \rho$ form factor obtained from ρ meson LCSRs;
- **Modele-II in Fig.1:** three resonances model, with their relative size being the same as in pion vector form factor parameterized to describe data;
- **Fig.2:** Timelike-helicity form factors $\mathrm{F}_{t,0}$ are calculated separately to $\mathrm{F}_{\perp,\parallel}$ with diipon DAs, lowest expansion ($\mathrm{l}=1, \mathrm{n}=0$) gives almost the whole contribution;
- P-**wave contribution:** Only P-wave contribution with B meson DAs $\Leftarrow$ pion vector form factor; absolute dominate with diipon DAs ($> 95\%$);
- ρ **contribution:** $80\% - 90\%$ $\Rightarrow$ the residual deficit can be regarded as the finite-width effect in $\mathrm{B} \to \rho$ form factors, rethink the single pole assuming;
- k^2**-dependent evolution:** all four form factors with B meson DAs, only timlike-helicity form factors $\mathrm{F}_{t,0}(\mathrm{k}^2)$ with diipon DAs.

Outlooks

➜ Accuracy of OPE calculation: NLO correction & input parameters in B meson;

➜ light cone DAs of isospin-scalar diipon state and $\mathrm{K}\pi$ state;

➜ $\mathrm{B} \to \pi^0\pi^0$ to study B decay form factor with scalar final states;

➜ $\mathrm{B} \to \mathrm{K}\pi$ with $\mathrm{SU(3)}$ flavour violation final states $\Rightarrow$ $\mathrm{B} \to \mathrm{K}^*$ form factors.

References

[1] S. Cheng, A. Khodjamirian and J. Virto, "$B \to \pi\pi$ Form Factors from Light-Cone Sum Rules with B-meson Distribution Amplitudes", arXiv:1701.01633 [hep-ph].

[2] C. Hambrock and A. Khodjamirian, "Form factors in $\bar{B}^0 \to \pi\pi\ell\bar{\nu}_\ell$ from QCD light-cone sum rules", Nucl. Phys. B **905**, 373 (2016), arXiv:1511.02509 [hep-ph].

[3] S. Cheng, A. Khodjamirian and J. Virto, Timelike-helicity "$B \to \pi\pi$ form factor from light-cone sum rules with dipion Distribution Amplitudes", arXiv:1706.xxxxx [hep-ph].