Master Thesis Presentation

"Long-distance contributions in rare semileptonic B decays"
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Physics Division, Theory Group
Lawrence Berkeley National Laboratory (LBNL) & UC Berkeley

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- Long-distance contributions can create large theoretical uncertainties: They should be better understood.
- Difficult to be calculated: **non-perturbative** character.

Theoretical Framework: EFTs

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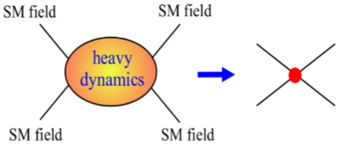

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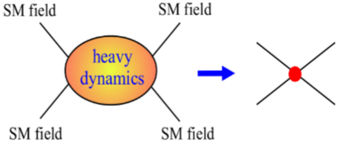

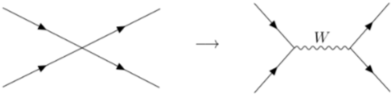

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$$\frac{4G_F}{\sqrt{2}} J_\mu J^\mu \to \frac{g^2 J^\mu J_\mu}{q^2 - M_W^2 + i\epsilon}$$

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$$\mathcal{M} = \frac{G_F}{\sqrt{2}} \frac{\alpha_{em}}{\pi} V_{tb} V_{ts}^* \Big[16\pi^2 \bar{\ell}\gamma^\mu \ell p_\mu \mathcal{H}_{c\bar{c}}(q^2) + \mathcal{F}(C_7, C_9, C_{10}) \Big] \,. \tag{2}$$

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We calculate them from data using dispersion relations.

Hadronic dispersion relations

Subtracted dispersion relation for the hadronic contributions

$$\Delta\mathcal{H}_{c\bar{c}}(q^2) \equiv \frac{q^2}{\pi}\int_{s_0}^{\infty} ds \frac{\rho_{c\bar{c}}(s)}{s(s-q^2)}\,, \qquad \rho_{c\bar{c}}(s) = \frac{1}{\pi} Im[\mathcal{H}_{c\bar{c}}(s)]\,. \quad (3)$$

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Dominant contributions to $\rho_{c\bar{c}}$ come from **One-Particle** and **Two-Particle** intermediate hadronic states $\rho_{c\bar{c}}(s) = \rho_{c\bar{c}}^{1P}(s) + \rho_{c\bar{c}}^{2P}(s)$

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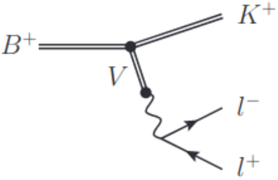

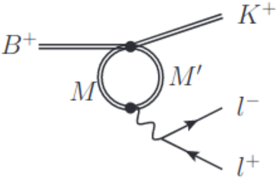

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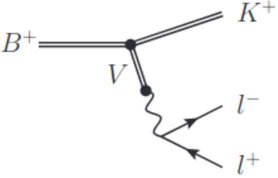

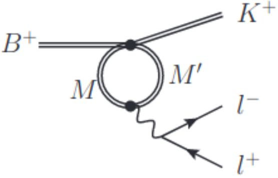

We want to have a quantitative estimate of these contributions.

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$$\mathcal{B}(B \to KV_j) \times \mathcal{B}(V_j \to \ell^+\ell^-) = \tau_B \frac{G_F^2\alpha^2|\lambda_t|^2}{128\pi^5} \times \int_{4m_{\ell^2}}^{(m_B - m_K)^2} dq^2 k(q^2)^3[\beta(q^2) - \frac{1}{3}\beta(q^2)^3]\left|f_+(q^2)\right|^2 |\eta_j|^2 \left|\frac{q^2}{m_j^2}A_j^{1P}(q^2)\right|^2 . \tag{5}$$

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Two-Particle Intermediate Hadronic Contributions

Proceeding in a similar way, the 2P contribution is

$$\Delta\mathcal{H}_{2P}(q^2) = \sum_j \eta_j e^{i\delta_j} A_j^{2P}(q^2), \quad A_j^{2P}(q^2) = \frac{q^2}{\pi}\int_{s_0^j}^{\infty} \frac{ds}{s}\frac{\rho_j(s)}{(s-q^2)} . \quad (6)$$

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Compatible with $\eta_{D,\bar{D}} \lesssim \mathcal{O}(1)$ (perturbative arguments).

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- LHC Run 3 coming soon! Hope to collect more data and clarify whether the LFU violations is a statistical fluctuation or not.

Projects beyond my Master Thesis

During my studies: Co-authored two publications on the search for the QCD critical point [1] [2]

[1] N. G. Antoniou, N. Davis, F. K. Diakonos, G. Doultsinos, **N. Kalntis**, *et al.* "Decoding the QCD critical behaviour in A + A collisions." *Nuclear Physics A* 1003, 122018 (2020)

[2] N. G. Antoniou, F. K. Diakonos, **N. Kalntis** and A. Kanargias, "Higher cumulants of baryon number in critical QCD." *Nuclear Physics A* 986, 167-174 (2019)

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- Future: Integration of CTs and extension to the non-abelian case (under progress).

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Thank you very much for your time!

Additional/Explanatory Slides!

Conclusions

One-Particle and Two-Particle States	η value
J/Ψ	$(1.791 \pm 1.231) \times 10^4$
$\Psi(2s)$	$(1.834 \pm 1.346) \times 10^3$
$\Psi(3770)$	4.358 ± 0.389
$\Psi(4040)$	1.538 ± 0.622
DD	$\leq 0.247 \pm 0.216$
DD^*	$\leq 1.014 \pm 0.358$

One - and Two-Particle Intermediate Hadronic Contributions

$$\rho^{1P} \propto \mathcal{M}_1(B \to KV)\mathcal{M}_2(V \to \ell\ell)\,. \tag{9}$$

$$\rho^{2P} \propto \int \frac{d^4\ell_1 d^4\ell_2}{E_1 E_2}\delta^4(s-\ell_1-\ell_2)\mathcal{M}_1(B \to KMM^{'})\mathcal{M}_2(MM^{'} \to \ell\ell)\,. \tag{10}$$

DD case:

$\mathcal{M}_1(B \to KDD) = \alpha_1 + \beta_1 p \cdot q + \gamma p \cdot \ell_1$,

$(-ie)(\ell_1 - \ell_2)^\mu$: γDD vertex (scalar QED)

DD^* case:

$\mathcal{M}_1(B \to KDD^*) = \beta p \cdot \epsilon(D^*)$,

$C\ \epsilon(D^*)^\mu$: γDD^* vertex.

Theoretical Framework: Long-distance contributions

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$$i \int d^4x e^{iq\cdot x} \langle K(p)| \, T[J^{em}_{\mu}(x), C_1\mathcal{O}^c_1(0) + C_2\mathcal{O}^c_2(0)] \, |B(p+q)\rangle \qquad (11)$$

$$= \mathcal{H}_{c\bar{c}}(q^2)((p\cdot q)q_{\mu} - q^2 p_{\mu}) \, . \qquad (12)$$

One-Particle Intermediate Hadronic Contributions

The leading contribution to $\rho_{c\bar{c}}(s)$ is given by the one-particle intermediate hadronic states, with $c\bar{c}$ valence quarks (charmonium resonances: J/Ψ and its excited states $\Psi(2s)$, ...).

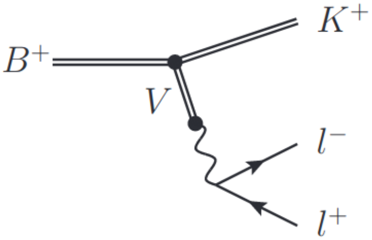

Figure: One-particle intermediate hadronic states.

Two-Particle Intermediate Hadronic Contributions

The next-to-leading contribution to $\rho_{c\bar{c}}(s)$ is given by the two-particle intermediate hadronic states (one-loop).

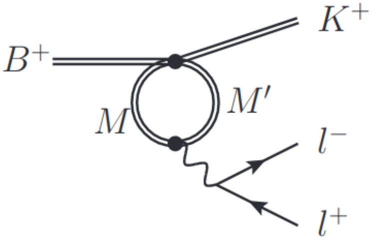

Figure: Two-particle intermediate hadronic states.

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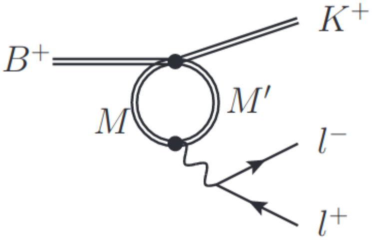

Figure: Two-particle intermediate hadronic states.

Most important contributions are from DD and the D^*D mesons in the loop (D: scalar bosons, D^*: vector bosons).

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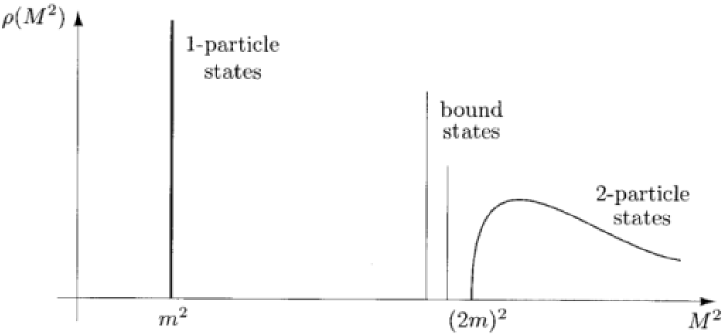
Integral weights lower energies more heavily and lessens the influence of the high energy region.

Spectral function



$$\rho(M^2) = Z\delta(M^2 - m^2) + \sigma(M^2)\theta(M^2 - s_0)\,. \tag{15}$$

$$\mathcal{H}(s) \propto \frac{1}{\pi}\int_0^\infty ds' \frac{\rho(s')}{s' - s - i\epsilon}, = \frac{\rho_0}{m^2 - s - i\epsilon} + \int_{s_0}^\infty ds' \frac{\sigma(s')}{s' - s - i\epsilon}\,. \tag{16}$$