HEP in Madagascar

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on behalf of the

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PHE
Physique des Hautes Energies
Université d'Antananarivo

HEP-Phenomenology
QCD Laplace Sum Rules

M.A. Shifman, A.I. Vainshtein, V.I. Zhakarov, Nucl. Phys. B 147 (1979)

P. Pascual and R. Tarrach, "*QCD: renormalization for practitioner*", Springer (1984)

L. J. Reinders, H. Rubinstein and S. Yazaki, "*Hadron Properties from QCD Sum Rules*", Phys. Rept. 127 (1985)

S. Narison, "*QCD Spectral Sum Rules*", World Sci. Lect. Notes Phys. 26 (1989)

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B.L. Ioffe, "QCD at Low Energies", Prog. Part. Nucl. Phys. 56 (2006)

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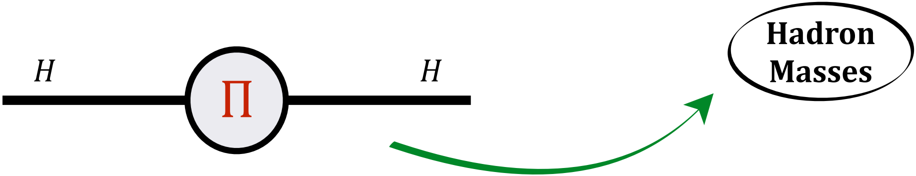
2-point Spectral Function



QCD Sum Rules

We evaluate the two-point spectral function to obtain the mass of the hadronic state *H*:

$$\Pi(q^2) = i \int d^4x \, e^{-iq\cdot x} \langle 0 | T \left[\mathcal{O}_H^J(x) \mathcal{O}_H^{J\,\dagger}(0) \right] | 0 \rangle$$

Quark-Hadron Duality

QCD side

- quark and gluon fields
- Inverse Laplace Transform
- condensates up to dim 5-7
- NLO calculation
- spectral functions

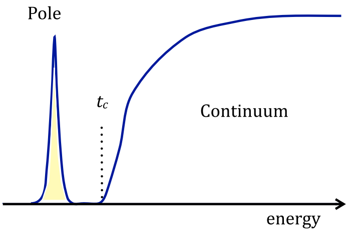
HADRONIC side

- phenomenology
- hadronic fields
- complete set of intermediate states
- decay constants
- spectral functions

Our Method

Finite Energy in QCD Laplace Sum Rules

$$\mathcal{L}_n(\tau,\mu) = \int_{(m_c+m_s)^2}^{t_c} dt\, t^n\, e^{-t\tau} \cdot \frac{1}{\pi}\mathrm{Im}\,\Pi(t,\mu)$$



Usual Ansatz:

"one resonance" + $\theta(t-t_c) \times$ *QCD continuum*

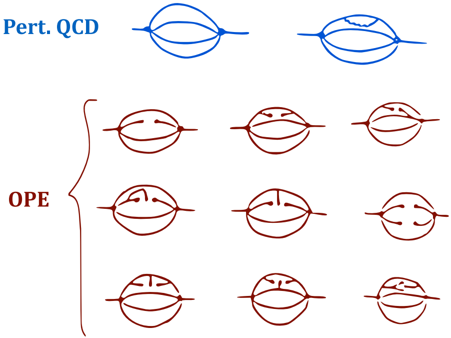
$$\mathrm{Im}\,\Pi \simeq f_H^2\, M_H^8\, \delta(t-M_H^2) + \Theta(t-t_c) \text{ ``Continuum''}$$

where the **coupling constants** are defined as

$$\langle 0|\mathcal{O}_H|H\rangle = f_H\, M_H^4$$
$$\langle 0|\mathcal{O}^\mu_{H^*}|H^*\rangle = \epsilon^\mu f_{H^*}\, M_{H^*}^5$$

- continuum comes from the discontinuity of the Feynmann diagrams
- different tests of this ansatz from complete hadronic data have shown that it can reproduce with high-precision these complete data
- it has been also successfully tested in the large-*Nc* limit of QCD

Our Method



- We get **OPE convergence** for $d = 6$ condensates.
- Higher dimension condensates are not indicated to improve convergence due to the **violation of factorization.**
- As τ, t_c, μ are free external parameters, we use **stability criteria** to extract the lowest ground state mass and coupling.
- **NLO PT corrections** are included as the convolution of the two spectral function built from two quark bilinear currents.
- NLO corrections are important to justify the use of MS running mass for the **heavy quark mass**.

A. Pich and E. de Rafael, *Phys. Lett.* **B158** (1985) 477.
S Narison and A. Pivovarov *Phys Lett* **B327** (1994) 341.

Our Method

Finite Energy in QCD Laplace Sum Rules

$$\mathcal{L}_n(\tau,\mu) \;=\; \int_{(m_c+m_s)^2}^{t_c} dt\; t^n\, e^{-t\tau} \cdot \frac{1}{\pi}\mathrm{Im}\,\Pi(t,\mu)$$

We extract the **lowest ground state mass** for the tetraquark and molecular states by using the ratio of the moments

$$M_H^2 \;\simeq\; \frac{\mathcal{L}_1}{\mathcal{L}_0}$$

Main papers

Int. J. Mod. Phys. A 31, 1650093 (2016)	Nature of the X(5568) : A critical Laplace sum rule analysis at N2LO.
Int. J. Mod. Phys. A 31, 1650196 (2016)	XYZ-like spectra from Laplace sum rule at N2LO in chiral limit.
Int. J. Mod. Phys. A 33, 1850082 (2018)	XYZ-SU(3) breaking from Laplace sum rules at higher orders.
Phys. Lett. B 787, 111-123 (2018)	Scalar meson contributions to a_μ from light-by-light scattering.
Phys. Rev. D 102, 094001 (2020)	Doubly-hidden scalar heavy molecules and tetraquarks states from QCD at NLO.
Nucl. Phys. A 1007, 122113 (2021)	$X_{0,1}(2900)$ and $(D^- K^+)$ invariant mass from QCD Laplace sum rules at NLO.
Phys. Rev. D 103, 074015 (2021)	Z_c-like spectra from QCD Laplace sum rules at NLO.

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