Regge trajectories of strange resonances and the non-ordinary nature of the κ

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Index

Motivation

- Interest in identification of non-ordinary Quark Model states.
- Easy if quantum numbers are not qqbar
- Not so easy for cryptoexotics like light scalars. Particularly the σ and κ-mesons existence and nature has been debated for several decades.
- Hard to tell what a non-ordinary resonance is.

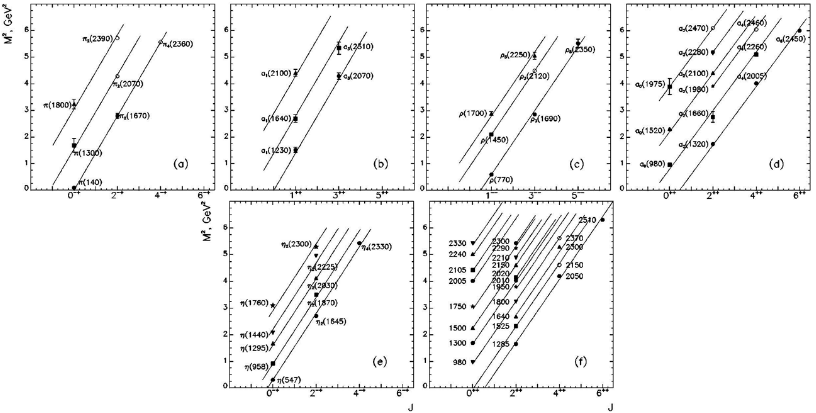


Figure: Anisovich-Anisovich-Sarantsev-PhysRevD.62.05150

- For ordinary resonances: All hadrons are classified in linear (J, M^2) trayectories.

Regge Theory

- σ and κ-mesons are not included in these plots.
- The σ-meson cannot be included because it has no possible partner in this classification.
- The κ resonance is not even mentioned as it still needs confirmation according to the PDG.

Regge poles

- The contribution of a single pole to a partial wave is

$$f(J,s) = f_{background} + \frac{\beta(s)}{J-\alpha(s)} \approx \frac{\beta(s)}{J-\alpha(s)} \quad (1)$$

- $\alpha(s)$ is the position of the pole, whereas $\beta(s)$ is the residue.
- Unitarity condition on the real axis implies

$$Im\alpha(s) = \rho(s)\beta(s) \quad (2)$$

- The analytical properties of $\beta(s)$ implies

$$\beta(s) = \frac{\hat{s}^{\alpha(s)}}{\Gamma(\alpha(s)+3/2)}\gamma(s) \quad (3)$$

- The trajectory and residue should satisfy these integral equations:

$$\mathrm{Re}\,\alpha(s) = \alpha_0 + \alpha' s + \frac{s}{\pi} PV \int_{4m^2}^{\infty} ds' \frac{\mathrm{Im}\alpha(s')}{s'(s'-s)}, \tag{4}$$

$$\mathrm{Im}\,\alpha(s) = \frac{\rho(s) b_0 \hat{s}^{\alpha_0+\alpha' s}}{|\Gamma(\alpha(s)+\frac{3}{2})|} \exp\Bigg(-\alpha' s[1-\log(\alpha' s_0)] + \frac{s}{\pi} PV \int_{4m^2}^{\infty} ds' \frac{\mathrm{Im}\alpha(s') \log\frac{\hat{s}}{\hat{s}'} + \arg\Gamma\left(\alpha(s')+\frac{3}{2}\right)}{s'(s'-s)}\Bigg), \tag{5}$$

$$\beta(s) = \frac{b_0 \hat{s}^{\alpha_0+\alpha' s}}{\Gamma(\alpha(s)+\frac{3}{2})} \exp\Bigg(-\alpha' s[1-\log(\alpha' s_0)] + \frac{s}{\pi} \int_{4m^2}^{\infty} ds' \frac{\mathrm{Im}\alpha(s') \log\frac{\hat{s}}{\hat{s}'} + \arg\Gamma\left(\alpha(s')+\frac{3}{2}\right)}{s'(s'-s)}\Bigg), \tag{6}$$

- Constants fixed by forcing the amplitude to have THE POLE AND RESIDUE OF THE DESIRED RESONANCE

$\rho(770)$ resonance

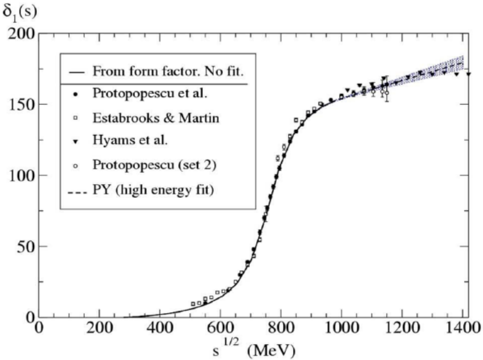


Figure: García-Martín et al.-Phys.Rev. D83 (2011) 074004

- Parameters obtained using a dispersive formalism (Roy-Steiner equations).
- $M_{K^*} = 763 \pm 2$ MeV and $\Gamma_{K^*} = 146 \pm 2$ MeV, with $|g| = 6.01 \pm 0.07$.

$\rho(770)$ resonance

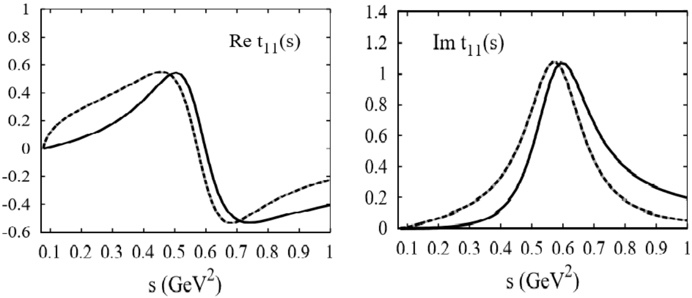


Figure: Carrasco et al.-Phys.Lett. B749 (2015) 399-406

- We (black) recover a fair representation of the partial wave, in agreement with the GKPY amplitude (red)
- Neglecting the background vs. Regge pole gives a 10-15% error.

$\rho(770)$ resonance

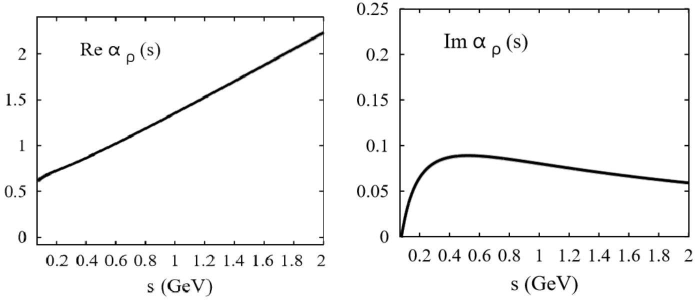


Figure: Carrasco et al.-Phys.Lett. B749 (2015) 399-406

- It is almost a linear regge trajectory.
- This is a prediction for the whole tower of $\rho(770)$ Regge partners: $\rho(1690), \rho(2350)$...
- Intercept $\alpha_0 = 0.52 \pm 0.002$, and Slope $\alpha' = 0.902 \pm 0.004\text{GeV}^{-2}$.

$K^*(892)$ resonance

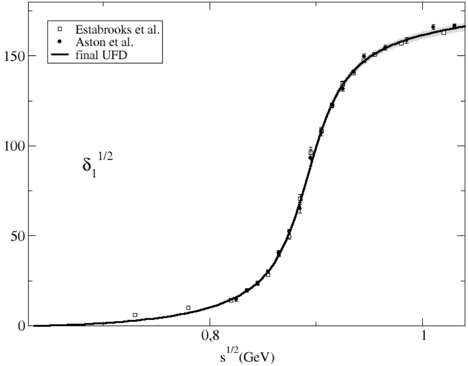


Figure: Peláez-Rodas-Phys.Rev. D93 (2016) no.7, 074025

- We use as input the parameters obtained using a dispersive formalism.
- $M_{K^*} = 892 \pm 1$ MeV and $\Gamma_{K^*} = 58 \pm 2$ MeV, with $|g| = 6.02 \pm 0.06$.

$K^*(892)$ resonance

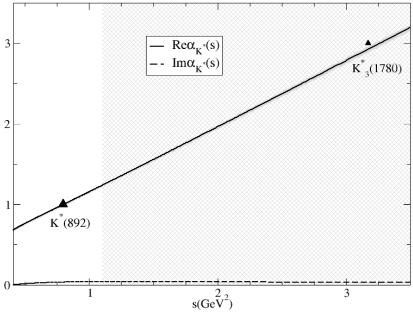
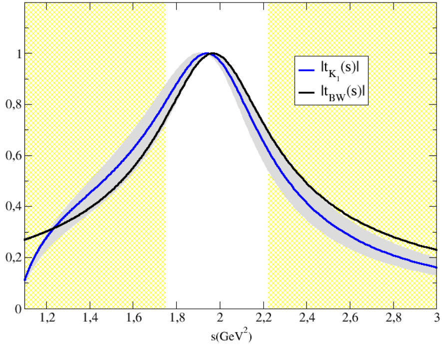


Figure: Carrasco et al.-Phys.Lett. B749 (2015) 399-406

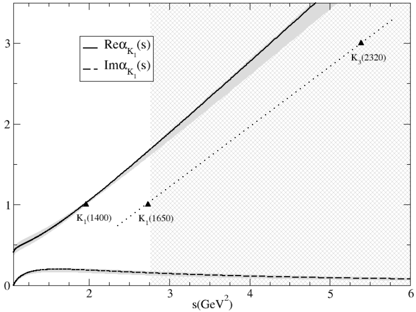
- It is almost a linear regge trajectory.
- It is a prediction, not a fit.
- Consistent with the fits in the literature.
- Intercept $\alpha_0 = 0.32 \pm 0.01$, and Slope $\alpha' = 0.83 \pm 0.01 \mathrm{GeV}^{-2}$.

$K_1(1400)$ resonance



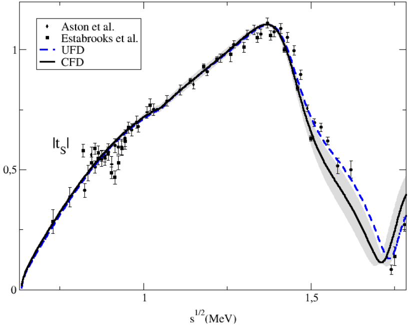
- Very elastic to $K^*(892)\pi$ with $BR = 94 \pm 6\%$.
- The $K_1(1400)$ is a clear resonance, we use a Breit-Wigner description.
- The result obtained with our method is compatible near the pole.

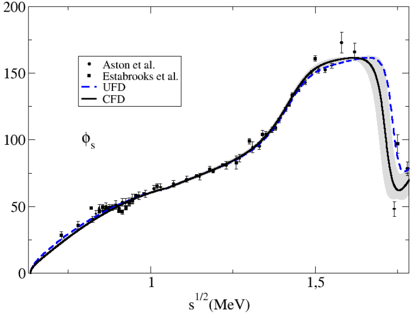
$K_1(1400)$ resonance



- It is almost linear.
- There is no partner, but we can compare our trajectory with other fits in the same energy region.
- Intercept $\alpha_0 = -0.72^{+0.13}_{-0.03}$, and Slope $\alpha' = 0.90 \pm 0.01\text{GeV}^{-2}$.

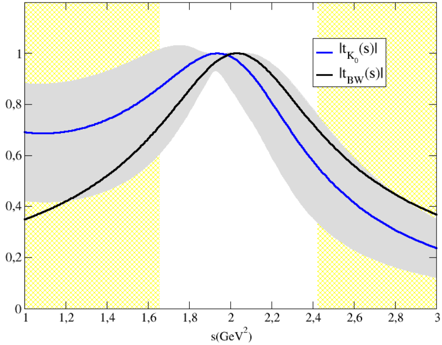
$K_0^*(1430)$ resonance





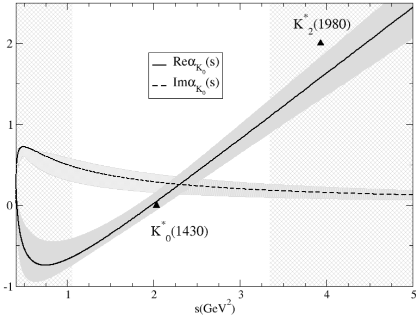
- Very elastic to $K\pi$ with $BR = 93 \pm 10\%$.
- There are 2 resonances in this region, but we neglect the contribution of the κ for the $K_0^*(1430)$ calculation.

$K_0^*(1430)$ resonance



- Solution obtained with the method.
- Many models predict quark-antiquark with sizable mixing to $K\pi$.
- The result obtained with our method is compatible near the pole.

$K_0^*(1430)$ resonance



- It is almost linear, the method does not describe properly the scattering lengths (there are 2 poles).
- Intercept $\alpha_0 = -1.15^{+0.23}_{-0.15}$, and Slope $\alpha' = 0.81 \pm 0.1\text{GeV}^{-2}$.

Non-ordinary resonances

- For non-ordinary resonances one expects the regge trajectories to be non-linear.
- We are interested in the σ and the κ, considered as non-usual resonances.
- Our method cannot predict the compositeness of a resonance, but it shows when a resonance its a non-ordinary candidate.

$\sigma / f_0(500)$ resonance

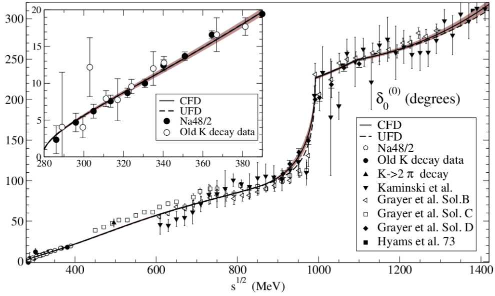
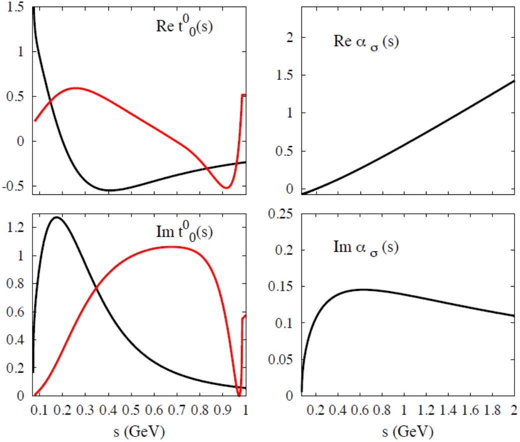


Figure: García-Martín et al.-Phys.Rev. D83 (2011) 074004

- Candidate for non-ordinary behavior.
- Huge width, there is no resonant behavior in the partial wave.
- The parameters of the resonance are obtained using Roy-Steiner equations.
- $M_\sigma = 457^{+14}_{-15}$ MeV, $\Gamma_\sigma = 558^{+22}_{-14}$ MeV, $|g| = 3.59^{+0.11}_{-0.13}$ GeV.

$\sigma / f_0(500)$ resonance



- Fair agreement in the resonant region.
- If we impose a linear regge trajectory the result spoils the data description.

$\sigma/f_0(500)$ resonance

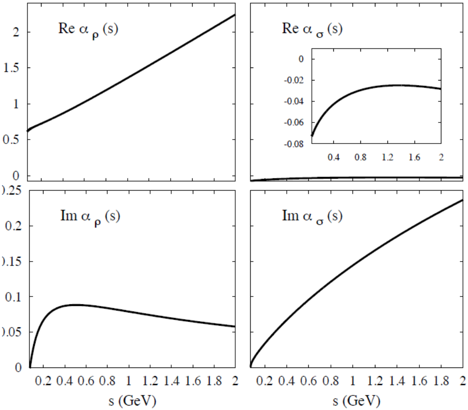


Figure: Londergan et al.-Phys.Lett. B729 (2014) 9-14

- We compare the results of the σ with the usual linear regge trajectory of the ρ.

$\sigma/f_0(500)$ resonance

- Not a linear regge trajectory, σ has no partners. The σ trajectory is **NOT** ordinary
- The slope is 2 orders of magnitude smaller than the usual slope for ordinary resonances.
- Intercept $\alpha_0 = -0.090^{+0.004}_{-0.012}$, and Slope $\alpha' = 0.002^{+0.050}_{-0.001}\text{GeV}^{-2}$.

κ resonance

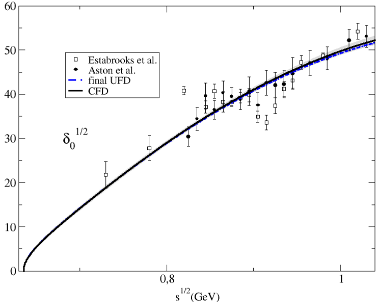
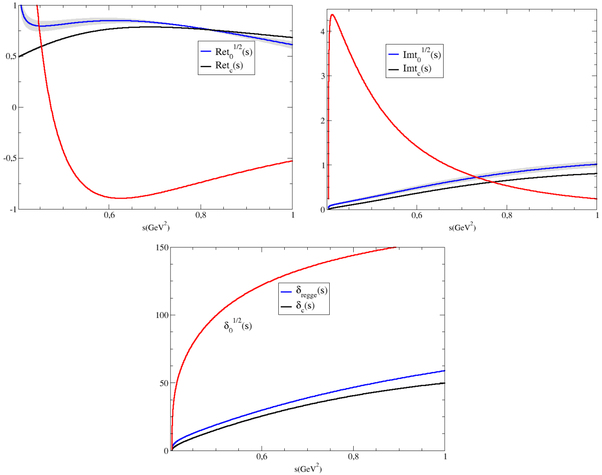


Figure: Peláez-Rodas-Phys.Rev. D93 (2016) no.7, 074025

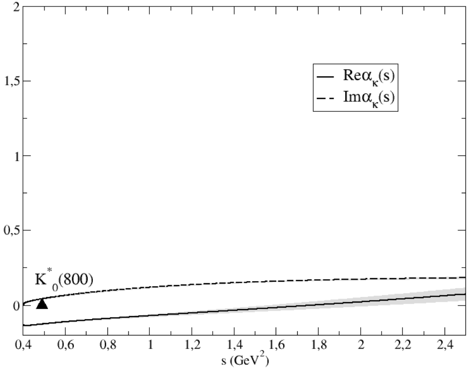
- Cryptoexotic candidate.
- The parameters of the resonance are taken from a dispersive analysis.
- Even broader than the σ.
- $M_\kappa = 680 \pm 15$ MeV, $\Gamma_\kappa = 668 \pm 15$ MeV, $|g| = 4.99 \pm 0.08$ GeV.

κ resonance



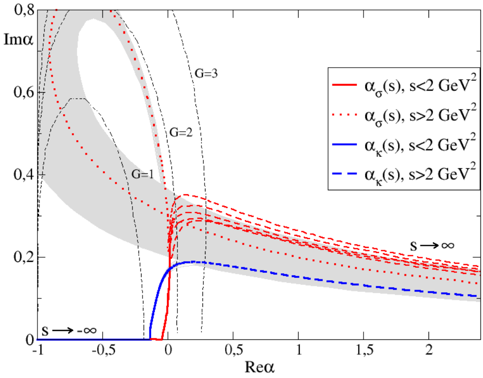
- Again if we impose a linear regge trajectory the result does not describe the data.

κ resonance



- Trajectory very far from real, very small real part.
- The slope its almost 5 times smaller than usual.
- Intercept $\alpha_0 = -0.28 \pm 0.02$, and Slope $\alpha' = 0.16 \pm 0.03 \text{GeV}^{-2}$.

- If a resonance is not ordinary, what then
- We cannot obtain the compositeness of a resonance using this method...
- But we can obtain some qualitative results for these 2 resonances.



- Striking similarity with Yukawa potentials at low energy: $V(r) = Gaexp(r/a)/r$.
- Similar order of magnitude for range: $a_{\pi\pi} = 0.5\ \text{GeV}^{-1}$ and $a_{\pi K} = 0.32\ \text{GeV}^{-1}$.
- We obtain that $a_{\pi\pi}/a_{\pi K} \approx \mu_{\pi K}/\mu_{\pi\pi}$.

Summary

- We **Calculate** the regge trajectories from a dispersive analysis, including the width.
- Regge trajectory from pole position and residue of isolated resonance.
- With this method $\rho(770)$,$f_2(1270)$, $f_2'(1525)$, $K^*(892)$, $K_1(1400)$ and $K_0^*(1430)$ trajectories come out linear. With a usual slope of 0.8-0.9.
- σ and κ trajectories are non-linear:
    - Trajectory slope much smaller.
    - Not possible partners.
    - If forced to be linear, data description ruined.
    - Some similarities with Yukawa potentials at low energies.

Thank you for your atention!