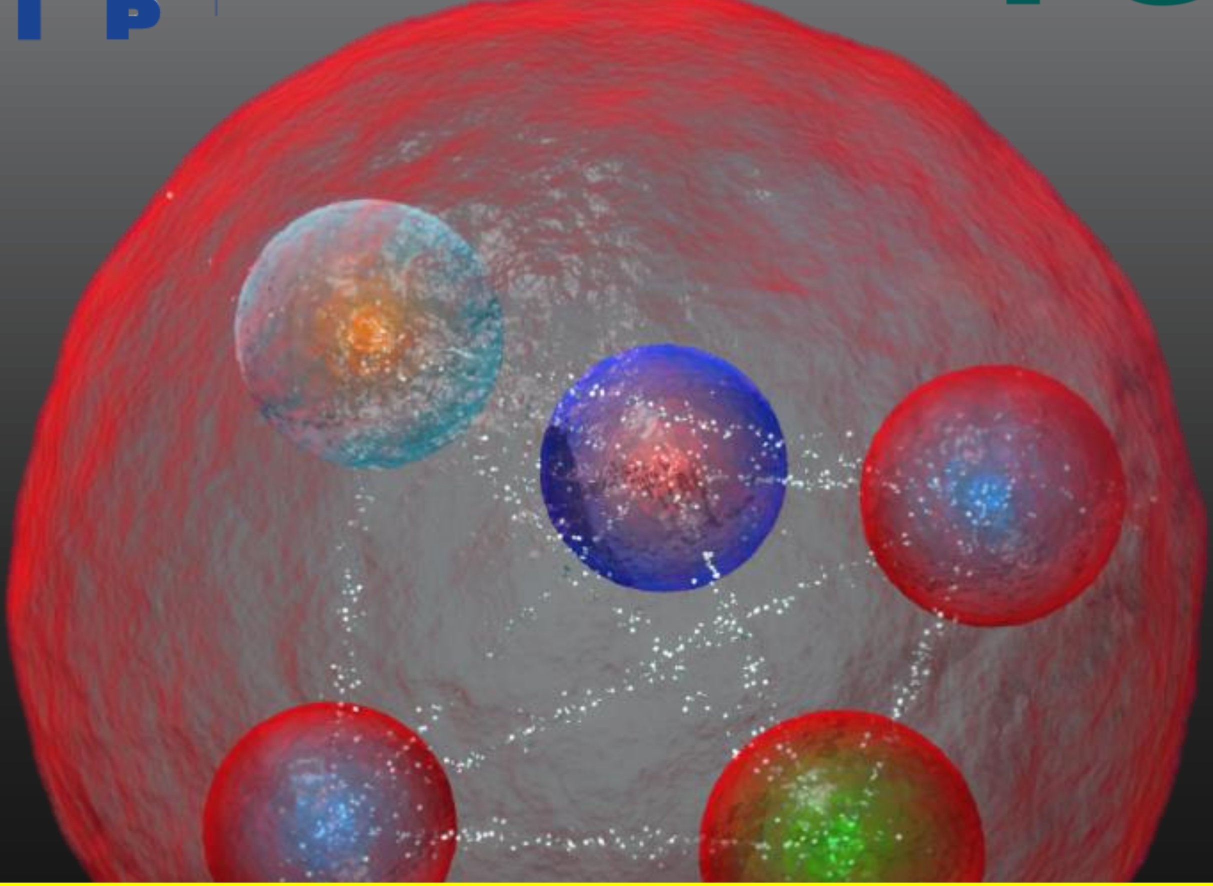
TÉCNICO LISBOA
LABORATÓRIO DE INSTRUMENTAÇÃO E FÍSICA EXPERIMENTAL DE PARTÍCULAS
Fundação para a Ciência e a Tecnologia
IDPASC



Pentaquarks in a Bethe-Salpeter approach

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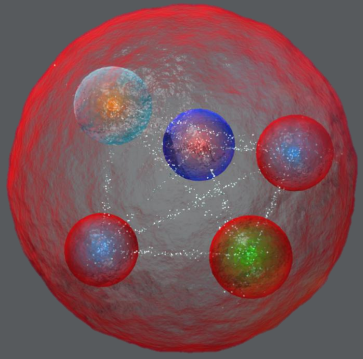
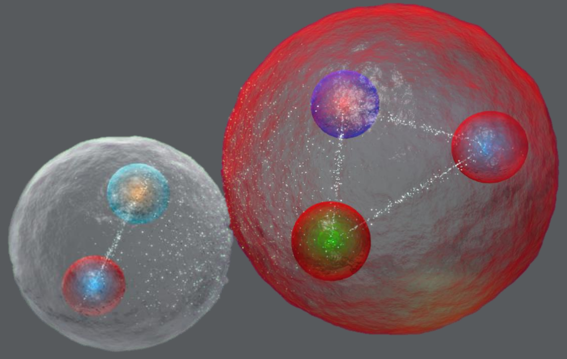
September 6th, 10th IDPASC School

Pentaquarks

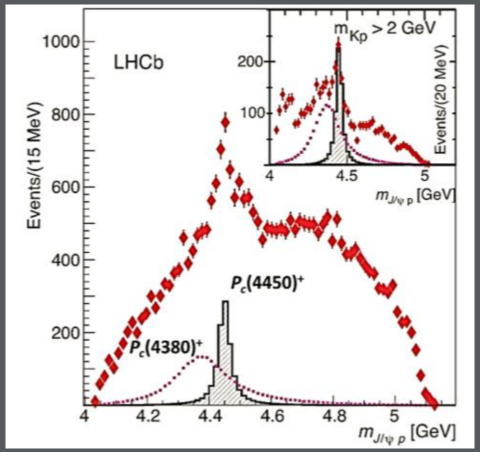


Bag of quarks

Pentaquarks are cousins of protons and neutrons, which are made of four quarks and one antiquark. Quarks cling to one another through the strong force so they cannot be isolated.



Molecule



BADALOV, Alexey, et al. Observation of J/ψp Resonances Consistent with Pentaquark States in Λ0b→ J/ψK− p Decays. *Physical Review Letters, 2015, Vol. 115, No. 7 (Agost)*, 2015.

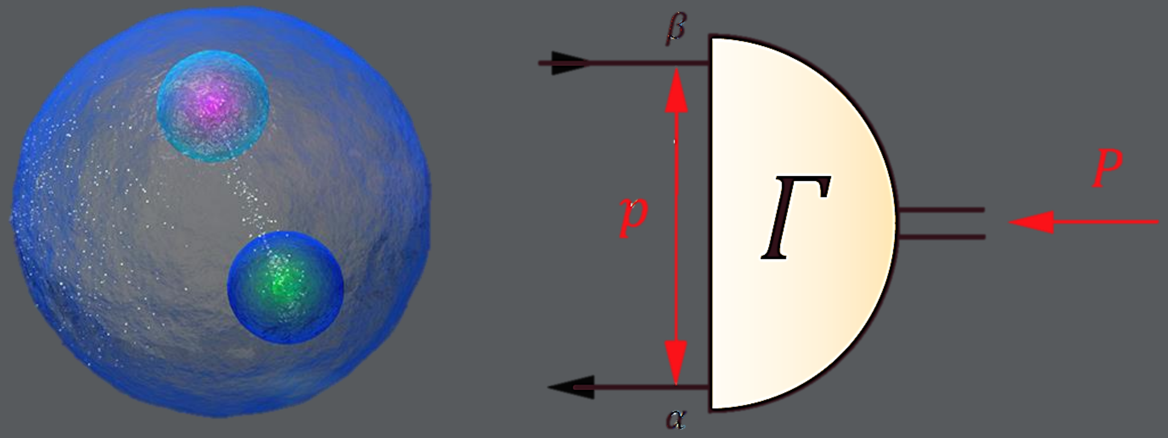
In 2015, **LHCb** reported signs of two pentaquarks with a mass of 4450 MeV, 4.74 times the mass of the proton and a lighter pentaquark at 4321 MeV.

Open question- structure of multiquarks: 1. Compact bags of four or five quarks; 2. Molecular picture

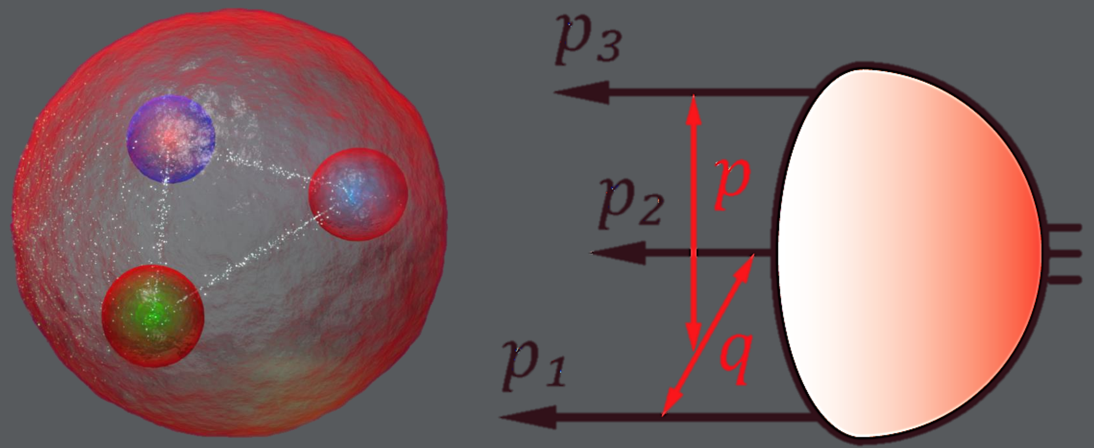
The goal of this project is to shed light on the spectrum and internal composition of such five-quark states with **functional methods**.

We need computer power!!!

Bethe-Salpeter approach – Bayons & Mesons



Mesons



Baryons

Quarks are almost always found in groups of three in particles known as **baryons** - including the proton and neutron - or in pairs called **mesons**, which consist of a quark and antiquark.

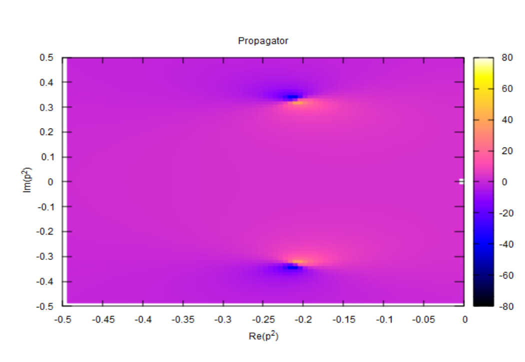
The objective is to solve pentaquarks directly from their **five-body BSEs**, delivering insight into their mass spectrum, resonance poles, their internal quark-gluon structure and their size whose knowledge is important for future experiments at the LHC and the other facilities.

First, we need to solve the DSE for the quark propagator, which is the fundamental ingredient in the subsequent pentaquark equations.

Dyson-Schwinger Equation

$$S^{-1}(p,\mu) = Z_2(\mu^2,\Lambda^2)\left(i\not{p} + m_0(\Lambda^2)\right) + \Sigma(p,\mu,\Lambda)$$

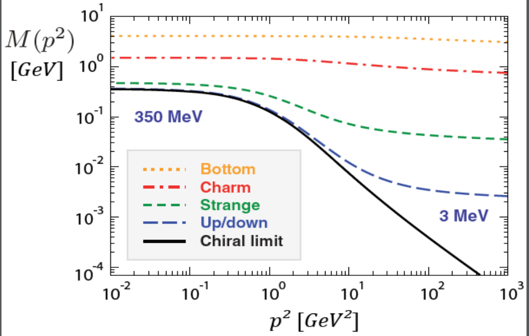
Quark propagator



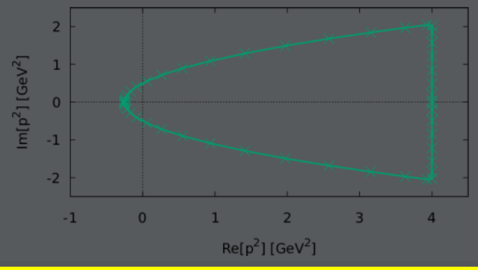
Quark up poles

They form an **infinite tower** of integral equations that couple Green's functions to one another in a hierarchical fashion.

To solve Five-body BSEs, we need them in the complex momentum plane using different methods **Directly, Schlessinger, Contour deformation, Cauchy and power method**.



Mass function RL



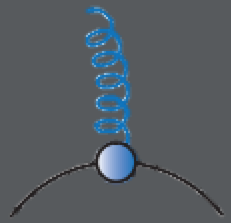
$$C_N(x) = \frac{p(x)}{q(x)} = \frac{f_1}{1+}\,\frac{a_1(x-x_1)}{1+}\,\frac{a_2(x-x_2)}{1+}\cdots\frac{a_{N-1}(x-x_{N-1})}{1}$$

Left, Cauchy method
Above, Schlessinger

Quark-Gluon Vertex, Constrains

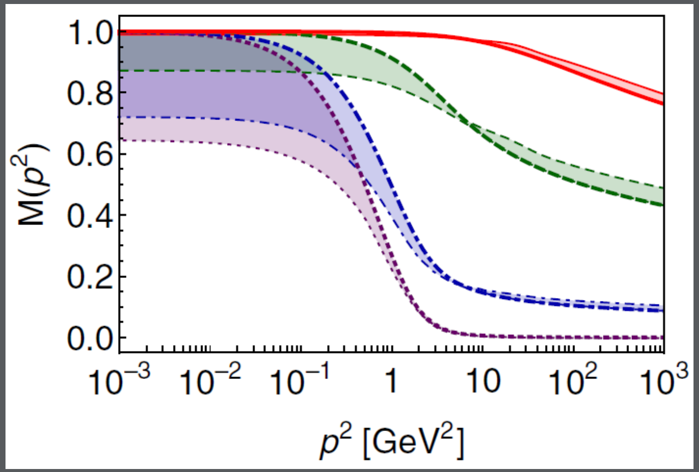
Since quark and gluon DSE form a **Infinite tower** of integral equations , this infinite set must be truncated by introducing physically reliable models of some suitable set of Green functions before a solution becomes tractable.

$$\Sigma(p,\mu,\Lambda) = -\frac{4g^2}{3} Z_{1F}(\mu^2,\Lambda^2) \int_q^{\Lambda} i\gamma^\mu \, S(q,\mu)\, D^{\mu\nu}(k,\mu) \boxed{\Gamma^\nu(l,k,\mu)}$$



The simplest choice is to replace the fully dressed fermión-boson vertex by its tree level counterpart, **Bare Vertex**. In construction a fermión boson vertex Ansatz, many efforts have been made over the past decades: **Ball-Chiu**, **Curtis-Penington**, **Kizilersu-Penington** and **Bashir Vertex**.

Sultan, M. A., Raya, K., Akram, F., Bashir, A., & Masud, B. (2021). Effect of the quark-gluon vertex on dynamical chiral symmetry breaking. *Physical Review D, 103*(5), 054036.



Mass function Bare, BC, CP, KP and BB

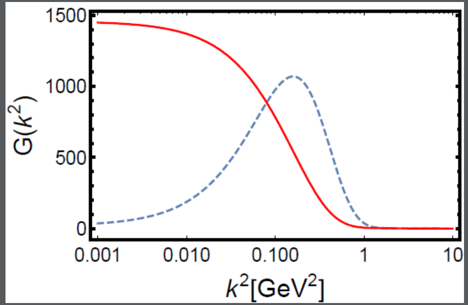
Effective Quark-Gluon interaction & Gluon Propagator

By virtue of the **RL truncation**, the entire framework rests upon a choice for **the effective coupling** $\alpha(k^2)$ .Rainbow-ladder represents the perturbative remainder of both the quark-gluon vertex and the qq kernel.

Several models for $\alpha(k^2)$ combining the UV limit with an ansatz in the infrared have been employed in the past and applied to detailed studies of meson physics. In the present study we implement the interaction of **Maris-Tandy and Qin-Chang.**

$$\frac{\alpha_s(q^2)}{q^2} = \frac{\pi D}{\omega^6} q^2 e^{-q^2/\omega^2} + \frac{\gamma_m \pi F(q^2)}{\frac{1}{2}\ln[\tau + (1 + q^2/\Lambda^2_{\text{QCD}})^2]}$$

Maris-Tandy model

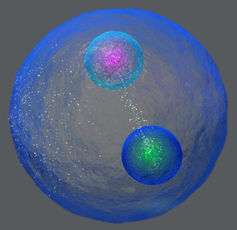


Blue: MT, Red: QC

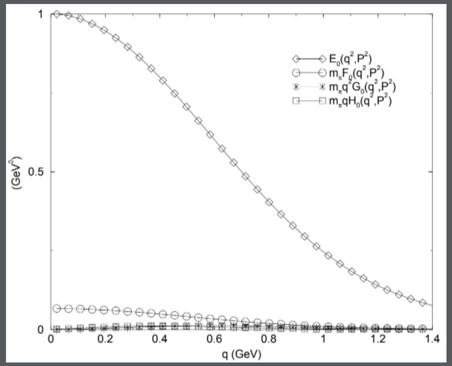
$$\frac{\alpha_s(q^2)}{q^2} = \frac{2\pi D}{\omega^4} e^{-q^2/\omega^2} + \frac{\gamma_m \pi F(q^2)}{\frac{1}{2}\ln[\tau + (1 + q^2/\Lambda^2_{\text{QCD}})^2]}$$

Qin-Chang model

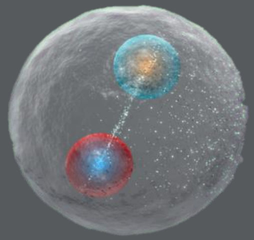
Work plan



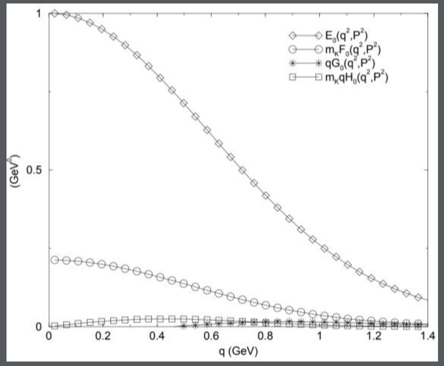
Pion $u\bar{d}$



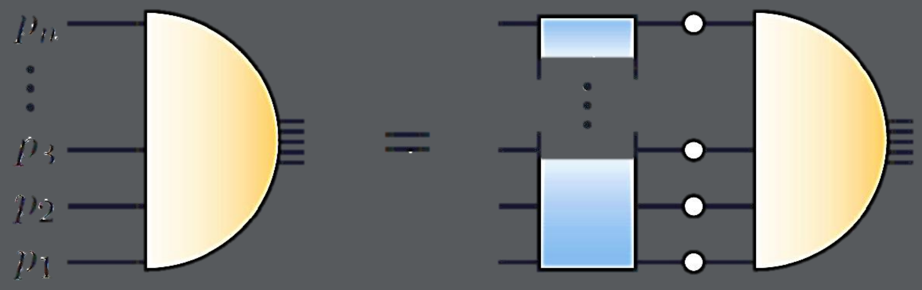
Pion Amplitude



Kaon $u\bar{s}$



Kaon Amplitude



Future work

- Work out the general tensor structure of the five-body amplitudes.
- Set up a parallelized numerical code for the five-body BSE for a general interaction kernel.
- Solve the five-body BSE for different quantum numbers and quark content.
- Set up a two-body version of the BSE
- Calculate structure observables of pentaquarks

Thanks for your attention!!!