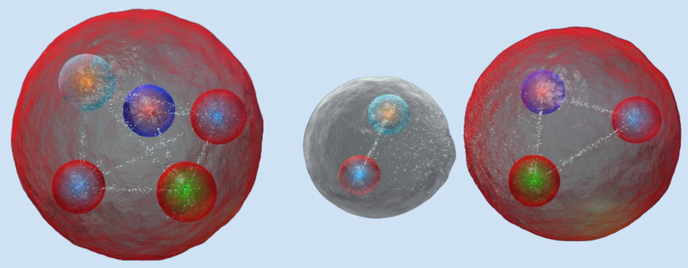
PhD Open Days

Pentaquark spectroscopy - Why is it so exotic?

PhD program in Physics

Luis Raul Torres Rojas *raul.torres@tecnico.ulisboa.pt*



What bind us together is QCD!

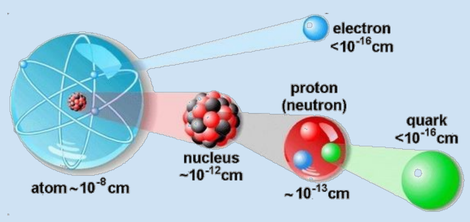


Fig 1. From atoms to quarks.

Nuclei core of Mendeleev's elements table are formed by *protons* and *neutrons* which are a subtype of *hadrons* named *baryons.* Ordinary hadrons are *mesons*, made of quark-antiquark pairs, and *baryons,* made of three quarks.

The theory describing how hadrons are formed is called *Quantum chromodynamics* with *quarks* and *gluons* as their building blocks.

Gluons are another fundamental particle which mediates the strong interaction between quarks.

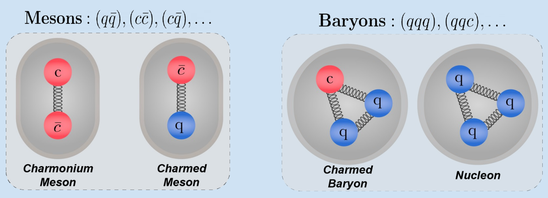


Fig 2. Ordinary hadrons.

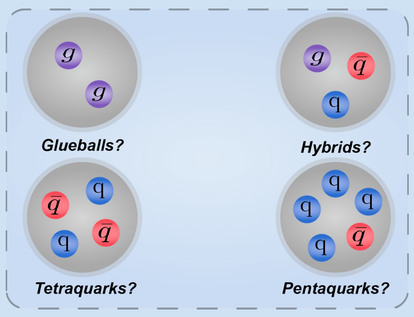


Fig 3. Exotic hadrons.

Mass generation for light hadrons, like protons and neutrons, comes 99% from QCD and the remaining is due to *Higgs mechanism.* ***QCD bind us together!.*** But that's not the full story! QCD predicts the existence of glueballs, hybrids and multiquark states, i.e., tetraquarks, **pentaquarks** and so on!.

New Zoo of exotic particles are on the way!

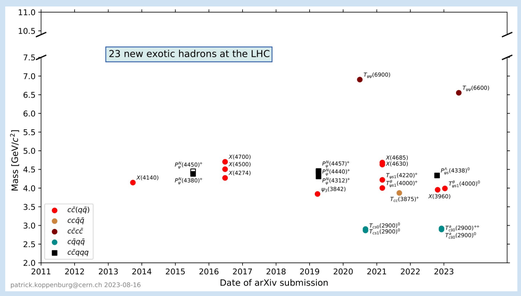


Fig 4. New exotic hadrons in LHC.

Only five pentaquark candidates and 18 tetraquark candidates in the recent 10 years! Only pentaquark states with charmonium quark content have been measured so far. No Θ(uuddcbar) seen.

Pentaquarks : $(c\bar{c}qqq), (\bar{c}qcqq), \ldots$

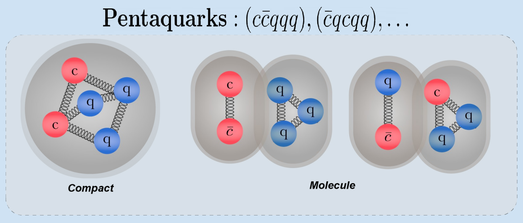


Fig 5. Pentaquarks in five-body and two-body picture.

Theoretical methods

- Amplitude analyses.
- Lattice QCD.
- Phenomenological models.
- Effective theories (ChPT,...).

Functional methods

- ***Dyson Schwinger & Bethe Salpeter equations.***
- Functional Renormalization Group, etc.

Pentaquark Five Body Equation in

Bethe Salpeter/ Dyson Schwinger approach

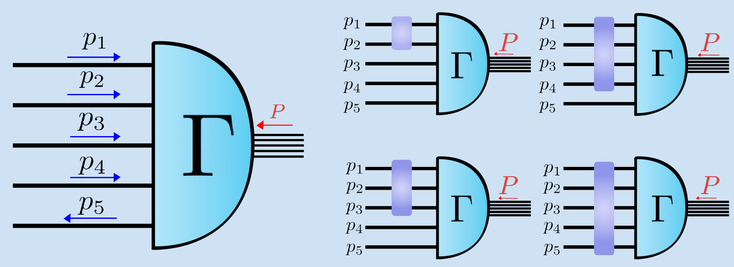


Fig 6. Five-body Pentaquark with 2-, 3-,4-, 5- body interaction kernel..

The Five-Body *Pentaquark Bethe Salpeter Equation* choose dynamically which type of structure is dominant and is an *exact equation*. The interaction kernel contains all possible ways the quark-core could self-interact. We restrict ourselves to 2-body kernels. The Bethe Salpeter Equation is simply:

$$\Gamma = K G_0 \Gamma.$$

Where *K* is kernel, G_0 product of propagators and Γ the amplitude.

Molecule with hadronic exchange - Preliminary results!

A practical simplification to solve the *pentaquark* system is describing it as a *'molecule'*. We solve the two-body Bethe Salpeter Equation (uudccbar) with a Σc and proton combination in a couple channel system.

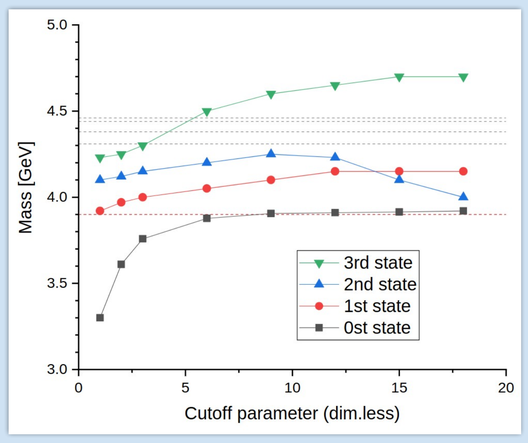


Fig 7. Two-body Pentaquark result.

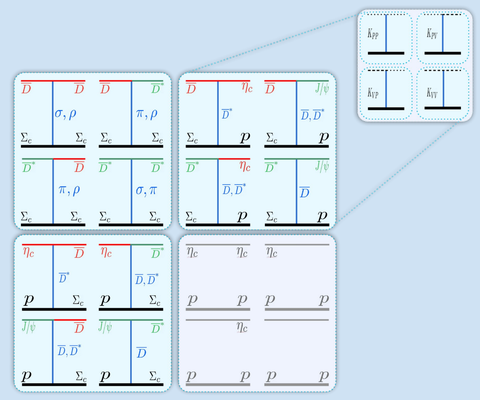


Fig 8. Two-body Pentaquark couple channel system.

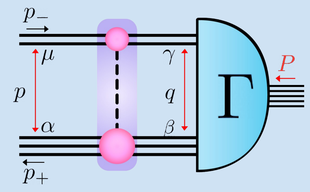


Fig 9. Two-body Pentaquark (Molecule).

The Two-Body Pentaquark Bethe Salpeter Equation in a coupled channel system is

$$\Gamma_a = K_{ab} G_b \Gamma_b.$$

References

- *Eichmann, Sanchis-Alepuz, Williams, Alkofer, Fischer (2016). Baryons as relativistic three-quark bound states. Prog. Rev D94 (2016)9, 094033.*
- *Wallbott, Paul C., Eichmann, Fischer (2020). Disentangling different structures in heavy-light four-quark states. Physical Review D 101 (2020)5, 054015.*
- *Wallbott, Paul C., Eichmann, Fischer (2019). X (3872) as a four-quark state in a Dyson-Schwinger/Bethe-Salpeter approach. Physical Review D 100 (2019)9, 094001.*

Meet our group!

TÉCNICO LISBOA

Gernot Eichmann, Teresa Peña

PhD Program in Physics

LIP REPÚBLICA PORTUGUESA fct Fundação para a Ciência e a Tecnologia

OE,FCT-Portugal, CERN/FIS-PAR/0023/2021

phdopendays.tecnico.ulisboa.pt