Hadronic and QCD theory group at IPARCOS

The project

<u>Research Grant: </u>PID2019-106080GB-C21

Hadronic Physics and Quantum Chromodynamics (QCD): from low energies to LHC

Part of
<u>UCM group</u>:
Effective Theories, Particle Physics and Cosmology
("Excellent" in UCM evaluation 10/5/2023)

UCM node of <u>EU's Horizon2020</u>
STRONG2020 (Grant Agreement No. 824093).

GOBIERNO DE ESPAÑA
MINISTERIO DE ECONOMÍA, INDUSTRIA Y COMPETITIVIDAD

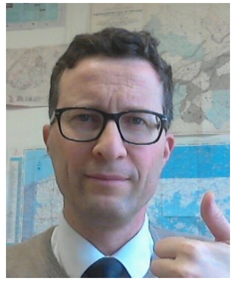
STRONG-2020

Hadronic and QCD theory group at IPARCOS-UCM

The people

Profs.:

Ángel Gómez Nicola



Felipe J. Llanes Estrada (1/2)

Ignazio Scimemi (PI)

Clara M. Peset (PAD, since 9/21)

José R. Peláez (PI)

Researchers:

Jacobo Ruiz de Elvira (RyC, since 12/21)

Alexey Vladimirov (Talento CAM, since 5/22)

María Pía Zurita (Talento CAM, since 2/23)

Patricia C. Magalhaes (Mª Zambrano, 6/22-7/23)

New Doctors in 2023: Alexandre Salas and Eva Lope (Both supervised by F.J. Llanes)

9 On-going PhDs:

- Alejandro Canoa (JRP, JRE)
- Oscar del Río (IS)
- Rafael Fernández (IS)
- Juan J. Gálvez (FJLL)
- Patricia A. Gutiérrez (IS)
- Sara Piloñeta (AV)
- Pablo Rabán (JRP, JRE)
- Alba Reyes (JRP)
- A. Vioque (PA), (AGN)

+ half a dozen TFMs, several of them now in doctorate program with us

Hadronic and QCD theory group at IPARCOS-UCM

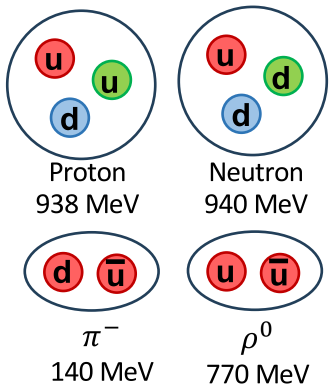
The issues to address

IPARCOS

Electrons have "electric" charge and interact through photons → Quantum Electrodynamics, QED

Quarks have "color" charge and interact through **gluons** → Quantum Chromodynamics, **QCD**

- **QCD** is very strong and binding at long distances/low energies (<1-2 GeV) In that regime, quarks and gluons are not seen as free states. They form color-neutral **hadrons** that still interact strongly.
- **In the hadron realm QCD** is highly non-linear (non Abelian gauge theory) and very non-perturbative in the usual coupling expansion.



The issues to address

For many decades **large simplifications of QCD or simple models** (like the quark model above) were used to describe:

1) Hadrons in terms of quarks and gluons,
2) Identify and understand the hadron spectrum and properties
3) Their dynamics at high temperatures (heavy ion collisions)
4) Their behavior at high densities (i.e, neutron stars)

Hadronic and QCD theory group at IPARCOS

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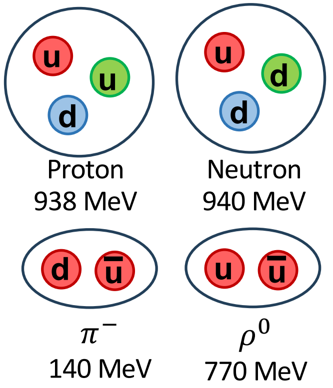

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How we address the issues

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How do we address these issues?

Effective field theories:

QCD in specific regimes where other systematic expansions can be performed
low-energy, collinear cases, soft particle emission, non-relativistic, heavy masses, etc.

and/or

Dispersion/analyticity theory:

First principles constraints on analyticity due to causality, unitarity, etc…

Another issue to address

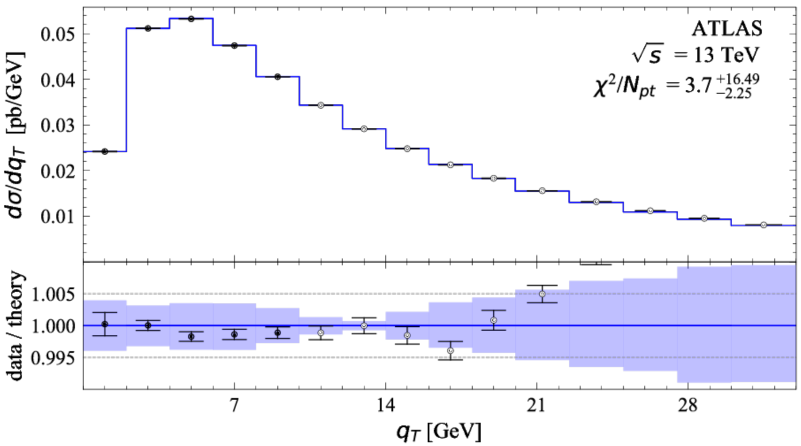
5) Developing/combining these techniques. Search for further applications

1) Hadrons in terms of quarks and gluons

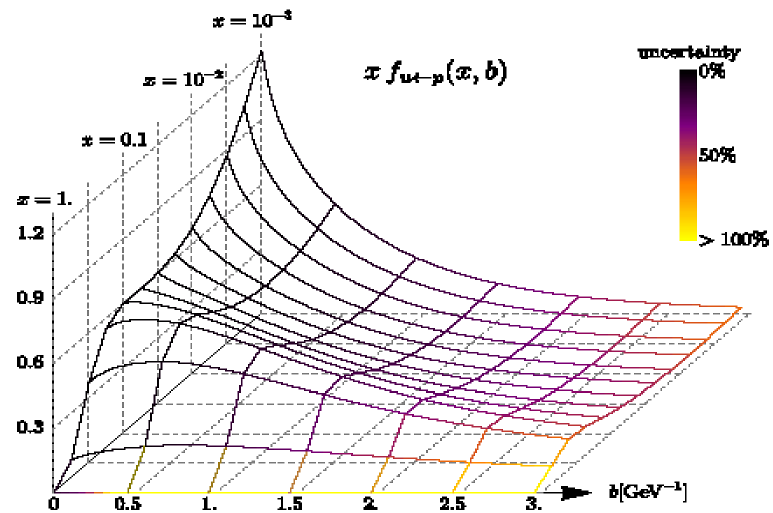
5) Developing/combining these techniques.

- Studying the motion of **quarks and gluons inside a proton** combining QCD perturbative calculations, effective field theories, high precision computing and data analysis. Also exploring the possibilities of lattice theory, jets and heavy quark cases.

- First group in the world to work out a global extraction of **transverse momentum distributions (TMD)** to the fourth perturbative order (N4LL) in QCD. Development of higher order expansions.



Example of the description of the most precise data for qT-spectrum of Z-boson (ATLAS detector, LHC). Emphasize the precision of the theory <0.5%.



Distribution of u-quark with respect to x (longitudinal momentum), and b (transverse position), extracted at N4LL

1) Hadrons in terms of quarks and gluons

5) Developing/combining these techniques.

- **I. Scimemi** has specialized in the TMD jet substructures and heavy quark measurements.

- **P. Zurita** is specialized in collinear quark/gluon densities (PDFs), the study of initial and final state, in proton/vacuum and in the nuclear medium. TMDs, machine learning for PDFs.

- **A. Vladimirov** has worked on the problems of lattice QCD, making the first direct confirmation of universality of the soft-gluon evolution, together with the Regensburg lattice group.

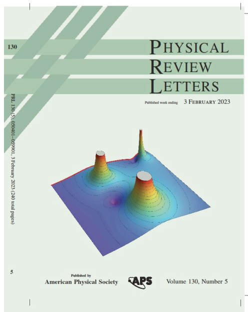
He was granted a ``Europa Excelencia" 2-yr Grant given to ERC positively reviewed projects that entered the final list, and recommended for funding, but not funded due to funds limits. Title: "*New frontiers in nucleon tomography*". Analysis of the most recent polarized-scattering data, including power corrections.

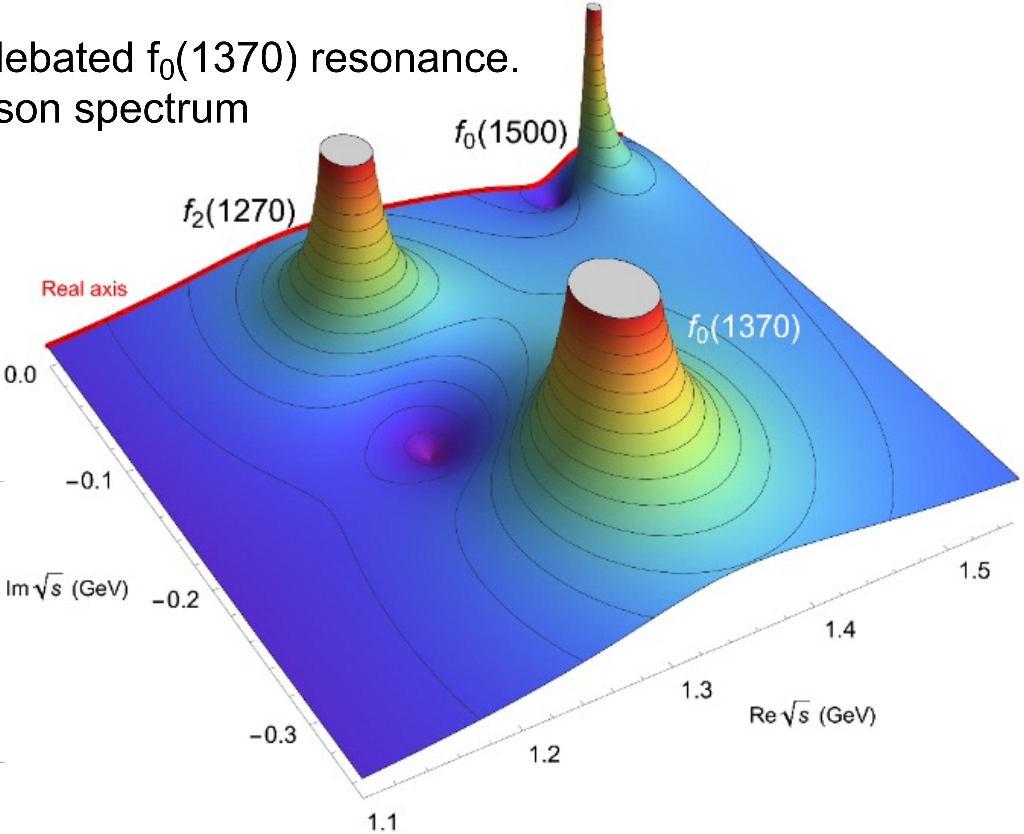
Hadron Spectrum: J.R.Peláez, J. Ruiz de Elvira and collaborators

Using dispersion Theory and analyticity on data

- Proposed decay branching ratio rigorous definition for resonances near threshold. *Phys.Lett.B844(2023)138070*,

- Dispersive determination of the long-debated $f_0(1370)$ resonance.
  Key to understand the light-scalar meson spectrum
  Phys.Rev.Lett.130(2023)5 051902,
  Cover of the journal issue.





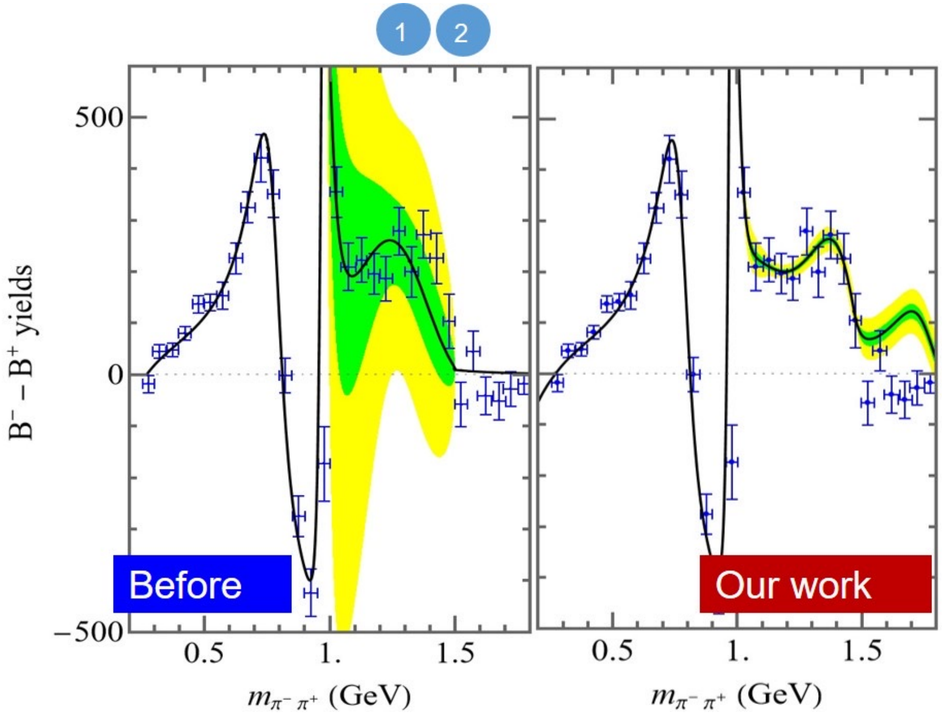
2) Identify and understand the hadron spectrum and properties

5) Developing/combining these techniques.

Hadron Properties. CP violation@LHCb

J.R.Pelaez, P. Magalhaes and collaborators

Reanalysis of CP violation of B-meson decays into three light mesons, using our dispersive $\pi\pi \to KK$ parameterizations. LHCb is adopting our approach in their ongoing analyses.
Phys. Rev. Lett, 130(2023) 20,201901



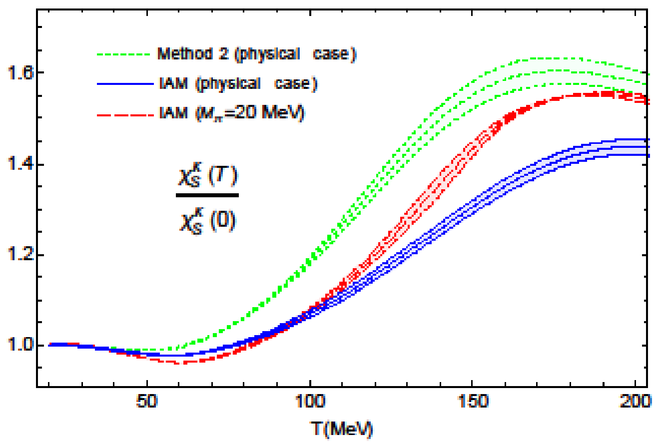
CP asymmetry in B → K π π @ LHCb
Before and after using our parameterization as a function of the 2-pion invariant mass

3) Hadron dynamics at high temperatures

A. Gómez Nicola, J. Ruiz de Elvira, A. Vioque

Study of QCD and Hadron Physics under **extreme conditions of temperature and chemical potentials**, around the so called QCD phase diagram.

- Calculation of pion-kaon scattering at finite temperature and the role of the $K_0^*(700)$ resonance for the restoration of symmetries broken in the observed hadron spectrum, such as the chiral and $U_A(1)$ symmetries. Results are consistent with lattice simulations.
JHEP 08 (2023) 148

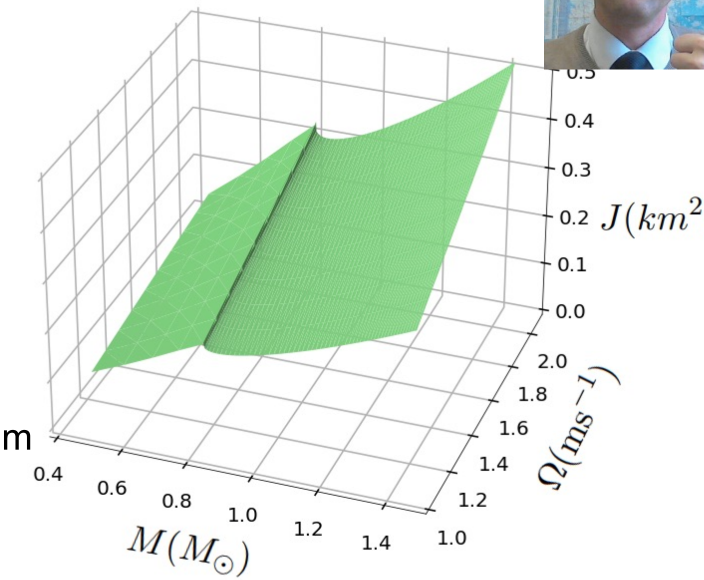


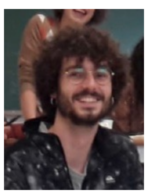
Strange chiral susceptibility evolution with temperature

4) Hadron behavior at high densities (neutron stars)
5) Developing these techniques. Further applications
The Astrophysics/Cosmology connection

- **<u>Neutron Stars:</u> F. J. Llanes Estrada, Eva Lope Oter, & Pablo Navarro**
  Finite density phase transition in QCD → **ridge in astrophysical properties**.

If strongly interacting matter presents a first order phase transition from hadronic to quark matter (or anything exotic) within **neutron stars**, diagrams with three observables **present a ridge**. Some day, accessible with astrophysics data. Annals of Physics (2023). **Eva Lope PhD 2023**





Example:
M=mass, Ω=angular velocity, J=angular momentum

- <u>**Flow Oriented Perturbation Theory**</u>

Alexandre Salas-Bernárdez, Michael Borinsky, Zeno Capatti, Eric Laenen, e-Print: 2310.09708 [hep-th]

- **<u>Effective Theories for dark matter:</u> C. Peset**

Applied non-relativistic effective theory techniques developed for QCD problems to the computation of the most precise prediction of dark matter annihilation into gamma rays. In particular for electroweak-like dark matter. *JHEP* 01 (2023) 171

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2023 Publications

1- R. Álvarez Garrote, J. Cuervo, **J.R. Peláez y P.C. Magalhães.** Physical Review Letters 130 (2023) 20, 201901.

2- **J.R. Peláez, A.Rodas y J. Ruiz de Elvira.** f0(1370) Phys.Rev.Lett. 130 (2023) 5, 051902 ***Portada del número.***

3- V. Burkert, V. Crede, E. Klempt, K.V. Nikonov, J.A. Oller, **J.R. Peláez, J. Ruiz de Elvira,** et al.. Physics Letters B 844 (2023) 138070.

4.-Martin Beneke, Stefan Lederer, **Clara Peset**, JHEP 01 (2023) 171.

5.-Hai-Tao Shu, Maximilian Schlemmer, Tobias Sizmann, **Alexey Vladimirov,** Lisa Walter et al. *Phys.Rev.D* 108 (2023) 7, 074519.

6.-Markus Diehl, Florian Fabry, **Alexey Vladimirov,** *JHEP* 05 (2023) 067.

7.-V.D. Burkert, L. Elouadrhiri, A. Afanasev, J. Arrington, M. Contalbrigo, **Alexey Vladimirov,** et al. *Prog.Part.Nucl.Phys.* 131 (2023) 104032.

8.-Simone Rodini, **Alexey Vladimirov,**. *JHEP* 09 (2023) 117.

9.-Malin Horstmann, Andreas Schafer, **Alexey Vladimirov,** *Phys.Rev.D* 107 (2023) 3, 034016.

10.-**P. A. Gutierrez Garcia,** Miguel G. Echevarría, **Ignazio Scimemi** *Phys.Lett.B* 840 (2023) 137881

11.- Guillermo Benito-Calviño, Javier García-Olivares, **Felipe J. Llanes-Estrada**. e-Print:2209.13225 [hep-ph]

12.- Noe Demazure, Víctor González Sebastián, **Felipe J. Llanes-Estrada.** Few Body Syst. 64 (2023) 3, 57

13.- Pablo Navarro Moreno, **Felipe J. Llanes-Estrada**, **Eva Lope-Oter**, Annals Phys. 459 (2023) 169487

14.- Michael Borinsky, Zeno Capatti, Eric Laenen, **Alexandre Salas-Bernárdez.** JHEP 01 (2023) 172.

15.- **A.Gómez Nicola**, **J.Ruiz de Elvira, A.Vioque-Rodríguez,** JHEP 08 (2023) 148.

16.-**Oscar del Rio, Alexey Vladimirov,**, accepted by JHEP, e-Print:2304.14440 [hep-ph]

17.-Miguel G. Echevarría, **Samuel F. Romera, Ignazio Scimemi,** accepted in JHEP, e-Print: 2308.12356 [hep-ph].

18.-**Alexey Vladimirov,** accepted by JHEP, e-Print:2307.13054 [hep-ph]

19.-**Rafael F. del Castillo,** M. Jaarsma, **I. Scimemi,** W. Waalewijn,, accepted by JHEP, e-Print:2307.13025 [hep-ph]

20.- V. Moos, **I. Scimemi, A. Vladimirov, P. Zurita**,, accepted by JHEP, e-Print:2305.07473 [hep-ph]