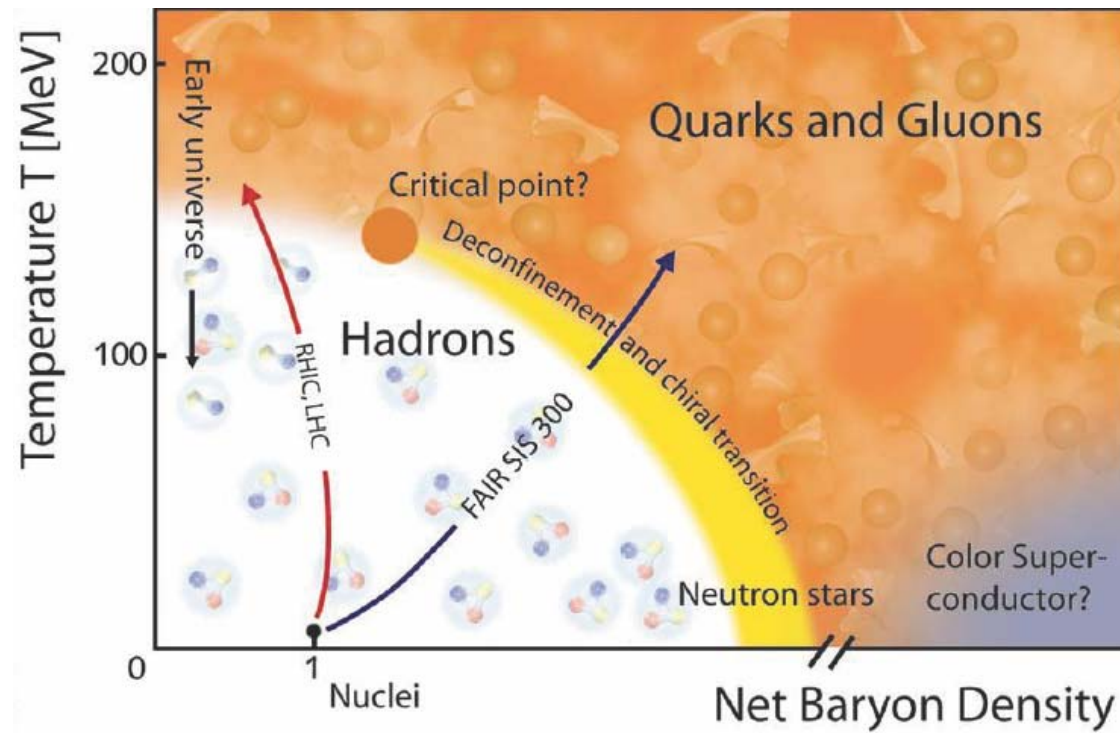


HADRONIC PHYSICS IN SPAIN

NUPECC meeting

Madrid (Spain), March 7, 2008

Hadronic physics aims at understanding the properties of hadrons and their mutual interactions from **QCD** (the theory governing the dynamics of quarks, the constituents of hadrons). This is an ambitious goal and the field is compartmented into several subfields that basically study the phases and structures of QCD at their various levels of complexity.



Typical topics in hadronic physics:

Chiral Perturbation Theory

Effective Field Theory

Exotic Hadrons

Hadron Properties from Lattice QCD

Spectroscopy of light and heavy quark hadrons

Quarkonia

Glueballs, hybrids and multiquarks

Hadrons in matter

Heavy ion collisions

-
-
-



Members:

permanent: A. Parreño, A. Polls, A. Ramos

other: V. Magas (RyC), B. Juliá-Díaz (JdIC), I. Vidaña (JdIC), E. van Dalen (pdoc),
C. Chumillas (doc), E. Jiménez-Tejero (doc)

Topics:

- ✓ Hadron-Hadron interactions (with effective chiral lagrangians
or lattice QCD simulations)
- ✓ Hadron spectroscopy (with light and heavy flavors)
- ✓ Hadron production with EM probes
- ✓ Hypernuclear physics
- ✓ Hadrons in the nuclear medium at finite temperature
- ✓ Relativistic Heavy Ion Collisions

Colaborations:

Valencia, Granada, Frankfurt, GSI, Bergen, Saclay, Tuebingen, Kiev, Torino, Catania,
Calabria, Padova, Michigan, NPLQCD-USA, Blacksburg, Argonne, Jlab, Pittsburgh, La Plata

Members:

- permanent:** E. Amaro, C. García-Recio, J. Nieves, E. Romera,
E. Ruiz-Arriola, L.L. Salcedo
- other:** M. Valverde (pdoc), A. Calle (doc)

Topics:

- ✓ Hadron-Hadron interactions (chiral symmetry, non-perturbative methods...)
- ✓ Heavy baryons: spectroscopy and semileptonic decays
(from quark modes or Lattice QCD)
- ✓ Hadronic systems in a dense medium at finite temperature
- ✓ Dispersion of electroweak probes off nuclei
(hadron production or quasielastic scattering)
- ✓ Hypernuclear physics

Colaborations:

Valencia, Salamanca, UCMadrid, Barcelona, Sevilla, UK-QCD, Cracow, Torino, Juelich,
Bonn, Frankfurt, MIT, Ohio, BNL, Idaho, Osaka, T2K(exp)

Members:

permanent: J.M. Udías, E. Moya

other: C. Fernández-Ramírez (pdoc), C. Pérez (JdIC)

Topics:

- ✓ π (and η) EM production in nucleons and nuclei
- ✓ EM properties of the nucleon, the Δ and other resonances
- ✓ Strange form factors of the nucleon
- ✓ Nuclear response functions to electroweak probes
(using scaling and superscaling)

Colaborations:

Granada, Sevilla, Madrid (IEM-CSIC), Torino, MIT

(Members of R³B, EXL and ELISE collaborations at FAIR/GSI)

Particle Physics and Nuclear theory group (UNIVERSITY OF MURCIA)

Members:

permanent: J.A. Oller, L. Roca

other: M. Albaladejo (doc), J.M. Alarcón (doc).

Topics:

- ✓ Hadron-Hadron interactions (with effective chiral lagrangians and non-perturbative methods)
- ✓ Hadron spectroscopy
- ✓ Mesons in a medium and nuclear matter from effective field theories

Colaborations:

Valencia, Barcelona, Granada, Buenos Aires

Members:

permanent: F. Fernández, E. Hernández, D. Rodríguez-Entem, A. Valcarce

other: J.M. Verde-Velasco (pdoc)

Topics:

- ✓ Baryon-Baryon interactions (from quark model and effective theories)
- ✓ Hadron spectroscopy
- ✓ Electroweak transitions of heavy mesons and baryons
- ✓ π production in neutrino-nucleon and neutrino-nucleus reactions

Colaborations:

Granada, Valencia, Madrid, Grenoble, Jerusalem, Mexico, Seattle

Hadron Physics and Quark Model group (UNIVERSITY OF VALENCIA)

Members:

permanent: P. González, S. Noguera, V. Vento

other: J. Vijande (JdIC), A. Courtoy (doc), T. Fernández-Caramés (doc)

Topics:

- ✓ Hadron-Hadron interactions
- ✓ Hadron spectroscopy
- ✓ Deep inelastic scattering (GPD, TDA)
- ✓ Deconfinement.

Colaborations:

Salamanca, Paris

Members:

permanent: E. Oset, M. J. Vicente-Vacas

other: L. Alvarez-Ruso (pdoc), K. Khemchandani (pdoc), L. Geng (pdoc),
D. Gamermann (doc), A. Martínez-Torres (doc), J. Martin-Camalich (doc),
R. Molina (doc), I. Ruiz (doc)

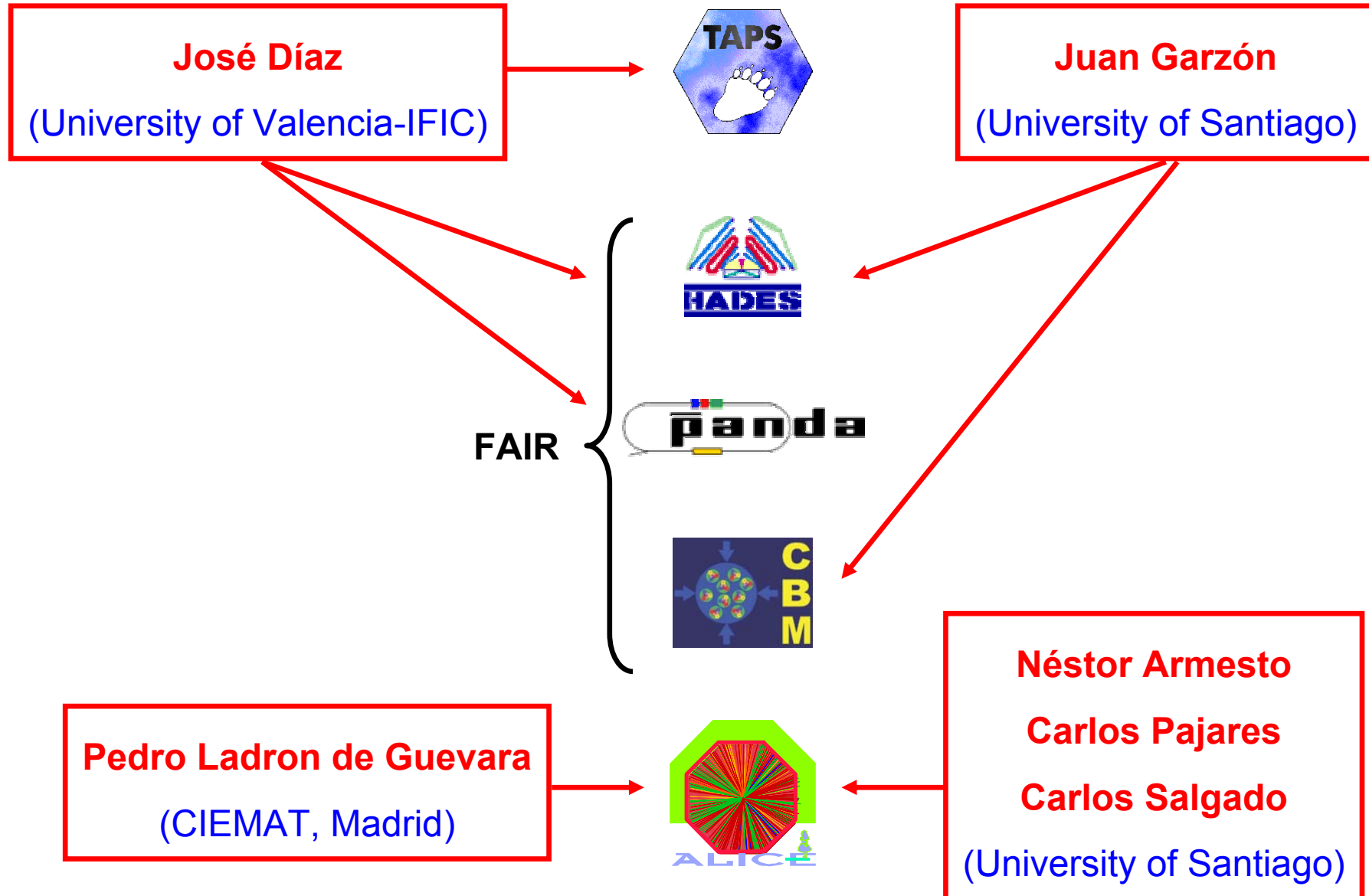
Topics:

- ✓ Dynamically generated three-hadron resonances
- ✓ Hadrons in nuclei
- ✓ Neutrino-nucleus reactions
- ✓ Chiral perturbation theory with Δ states
- ✓ Charmed hadron physics

Colaborations:

Granada, Murcia, Barcelona, Madrid, Juelich, Osaka, Nara, Kyoto

EXPERIMENTAL HADRONIC PHYSICS in Spain

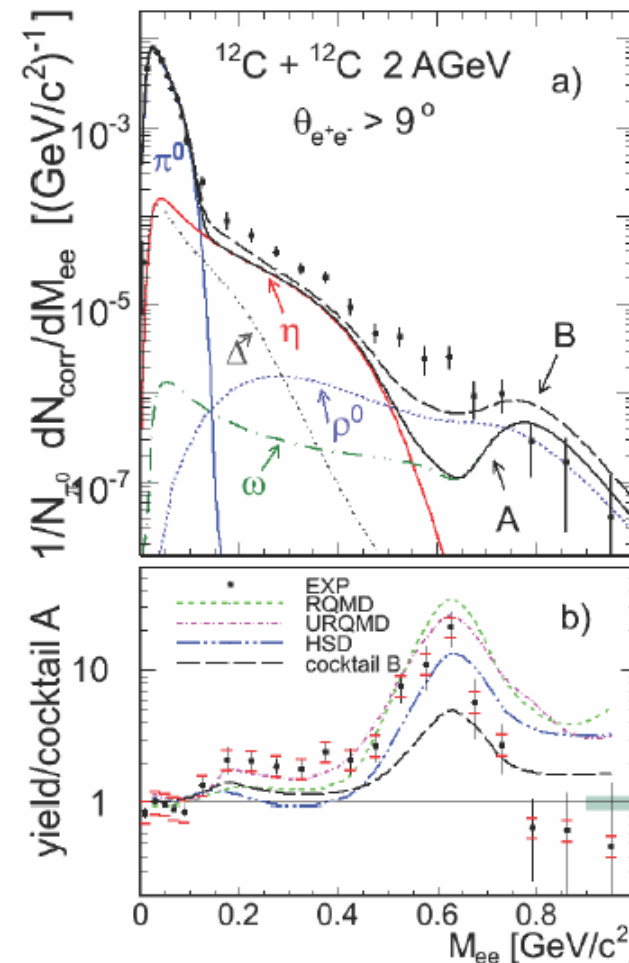


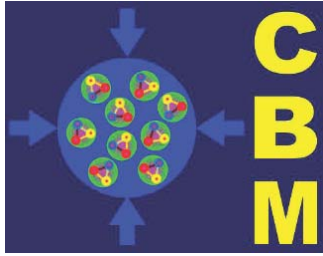


The High-Acceptance DiElectron Spectrometer HADES investigates the properties of the short-lived vector meson properties inside nuclear matter at normal and high densities by high resolution lepton pair (e^+, e^-) decay measurements. These extreme conditions are achieved by heavy ion collisions from 1 few AGeV (SIS@GSI) of up to 10 AGeV (FAIR@GSI).

Invariant mass spectra of e^+e^- pairs from HADES at SIS-GSI. There is an excess of dileptons with respect free-meson contributions around $0.6 \text{ GeV}/c^2$.

G. Agakichiev et al., Phys. Rev. Lett 89 (2007) 052302





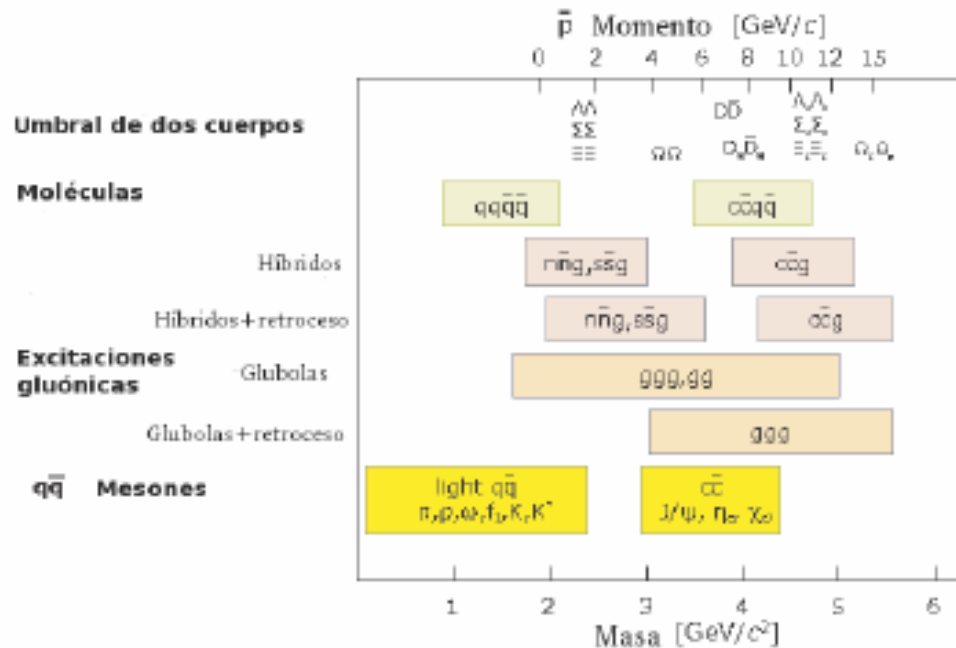
The CBM (Compressed Baryonic Matter) detector is a more sophisticated version of the HADES detector and will measure heavy-ion collisions up to 35 AGeV, achieving densities of 8-10 times nuclear matter density.

It will also allow to explore:

- chiral restoration
- the critical point of the QCD-phase diagram
- properties of mesons containin charm: D, J/Ψ, ...



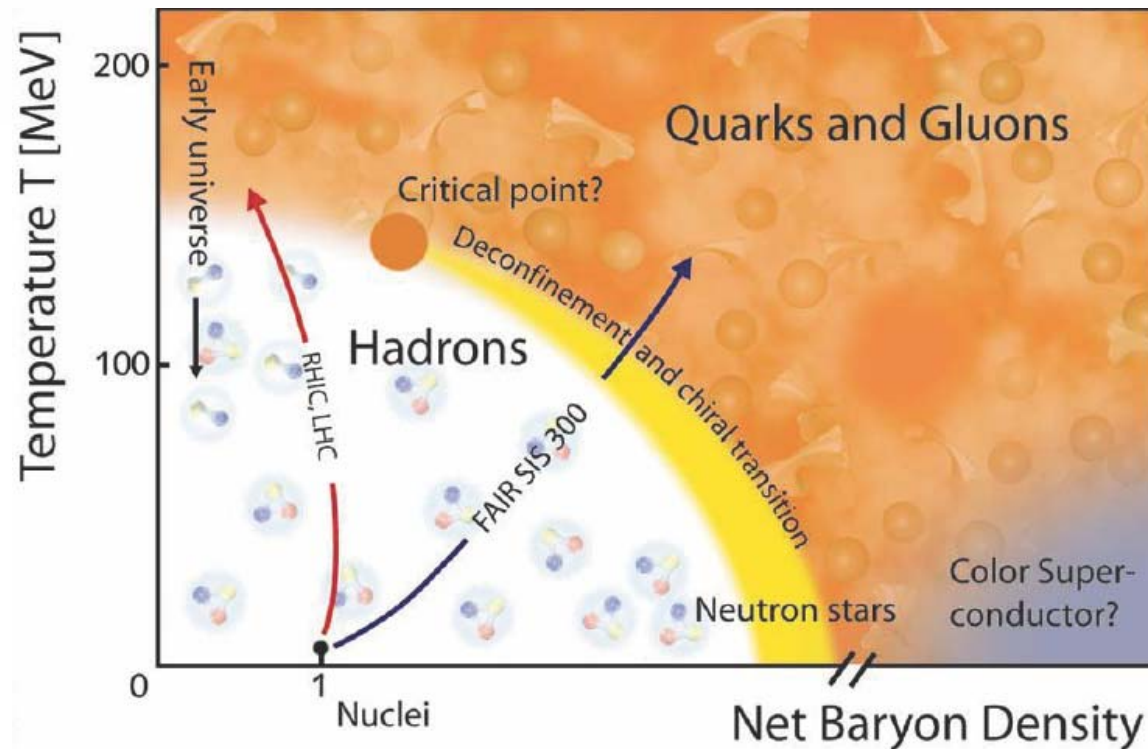
→ antiproton-proton and antiproton-nucleus collisions



- ✓ Exotic Hadrons (Glueballs and Hybrids)
- ✓ Charm in Nuclei
- ✓ Charmonium
- ✓ Hypernuclei (S=-2)
- ✓ D- and D_S-physics



The ALICE Collaboration is building a dedicated heavy-ion detector to study the physics of strongly interacting matter at extreme energy densities, where the formation of a new phase of matter, the quark-gluon plasma, is expected. The existence of such a phase and its properties are key issues in QCD for the understanding of confinement and of chiral-symmetry restoration.



Some THEORY highlights

HADRON SPECTROSCOPY and HADRON-HADRON INTERACTIONS

Many spanish groups have made significant contributions in building up unitary (non-perturbative) extensions of chiral perturbation theory in coupled channels, with two purposes:

1. to extend the limit of applicability of χ PT to higher energies
2. to study resonances

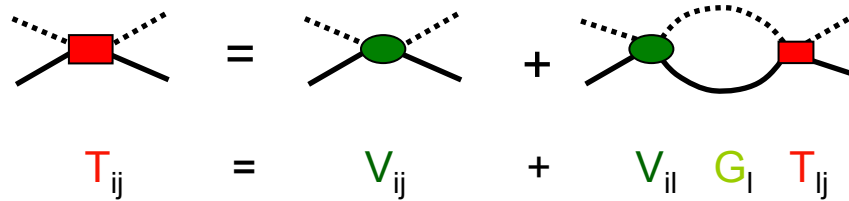
Barcelona, Granada, Murcia, Valencia

→ As a result, it is found that some of the observed resonances are generated dynamically through the multiple scattering of meson-meson (or baryon-meson) pairs in coupled channels. Their properties might be very different from the Quark Model predictions.

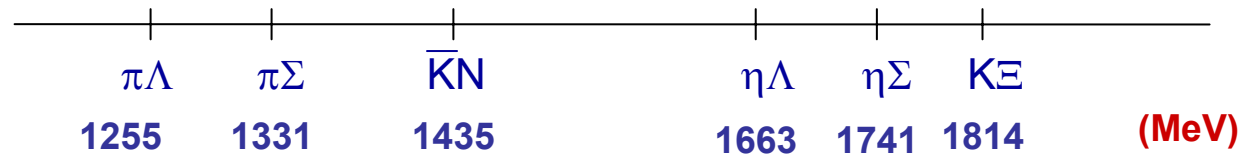
Example: The $\Lambda(1405)$

chiral lagrangian
+
unitarization

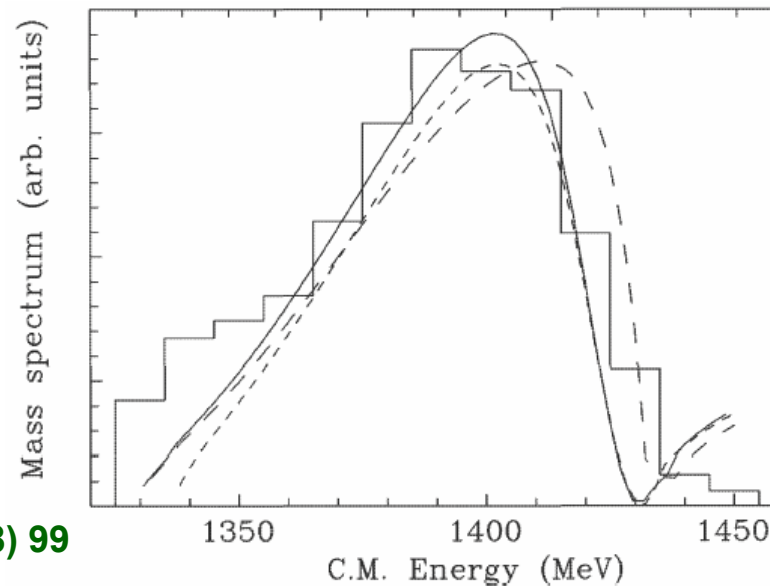
$$\mathcal{L}_1 \sim \langle \bar{B} i \gamma^\mu \frac{1}{4f^2} [(\Phi \partial_\mu \Phi - \partial_\mu \Phi \Phi) B - B(\Phi \partial_\mu \Phi - \partial_\mu \Phi \Phi)] \rangle \longrightarrow \text{s-wave}$$



in coupled channels

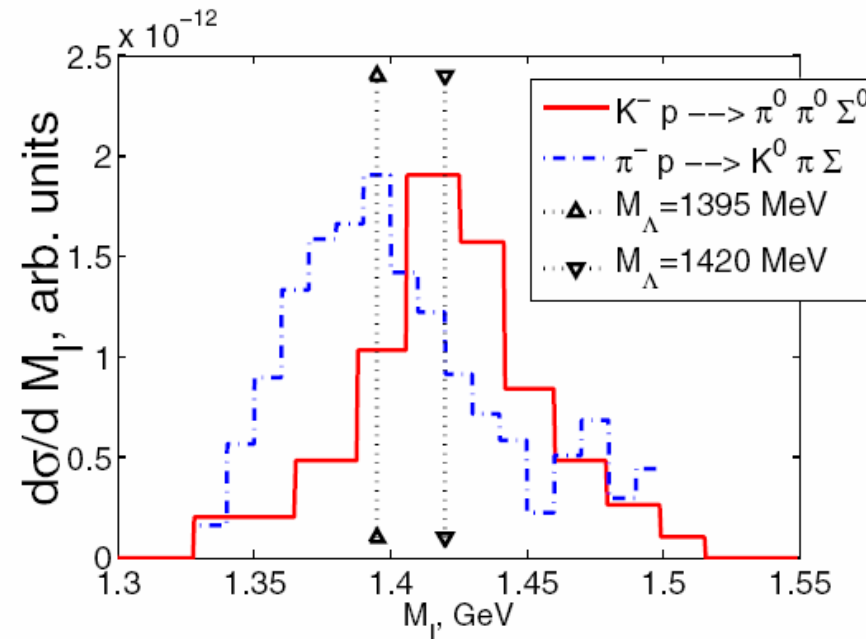


generates the $\Lambda(1405)$ located 27 MeV below the K-p threshold



Moreover, within the chiral models, the $\Lambda(1405)$ appears as a **superposition of two poles** in the complex plane, located at different energies and having different widths and different couplings to $\pi\Sigma$ and KN states. Therefore, **the observed properties of the $\Lambda(1405)$ will depend on the mechanism (reaction) that initiates the formation of the resonance.**

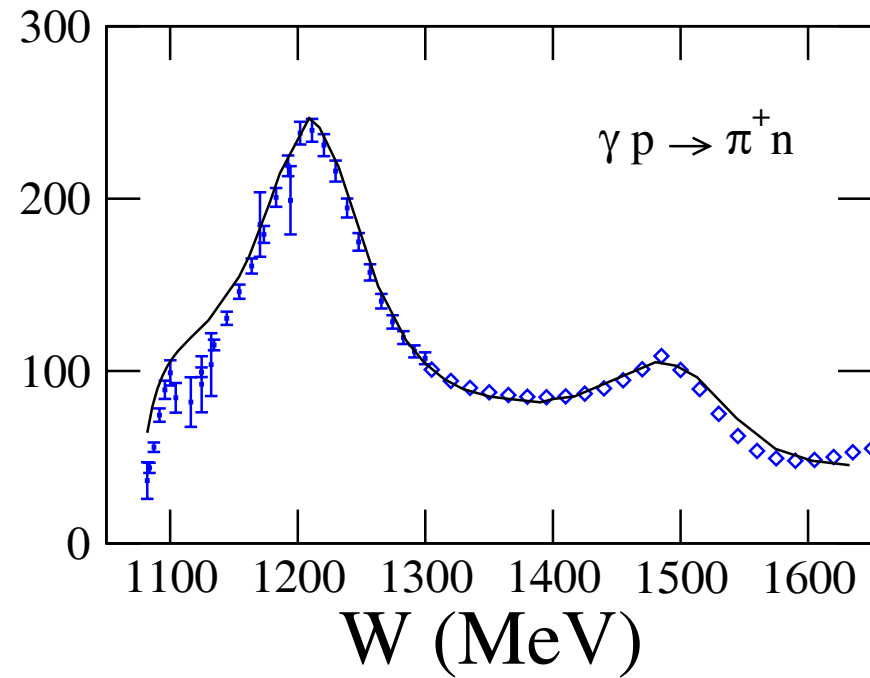
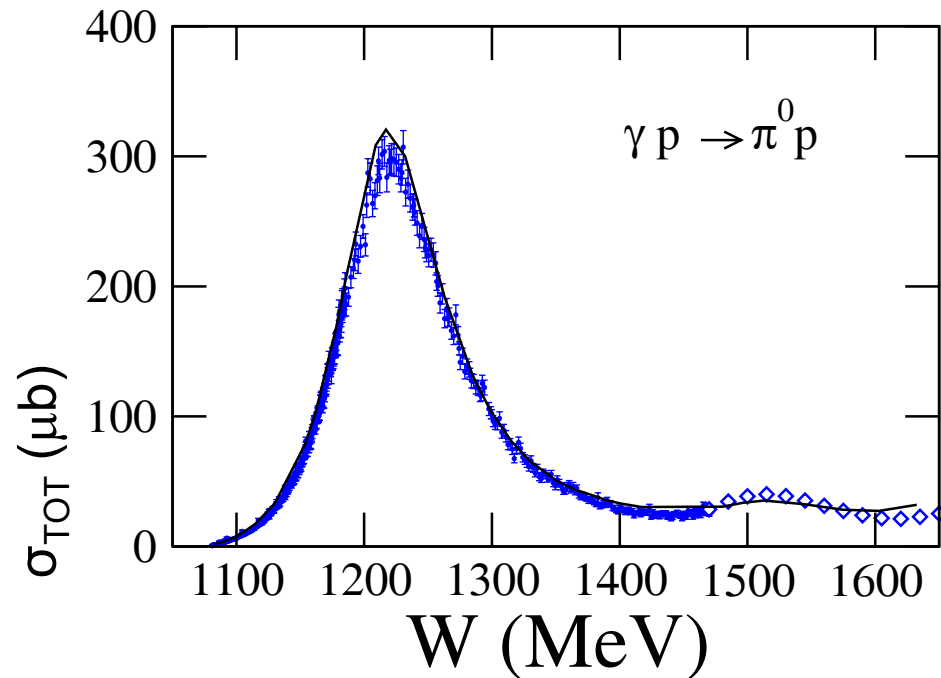
The experiments confirm the two-pole structure of the $\Lambda(1405)$ predicted by the chiral models!



V. K. Magas, E. Oset and A. Ramos,
Phys. Rev. Lett. 95, 052301 (2005)

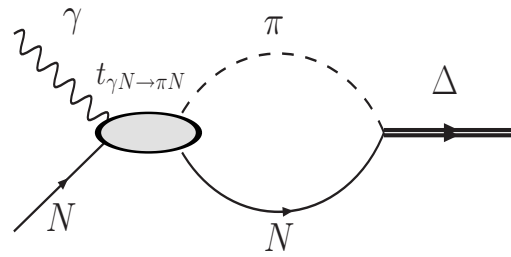
EXTENSIONS and related work ...

1) Combine a meson-baryon coupled channel approach with the well established PDG explicit resonances → excellent fits!

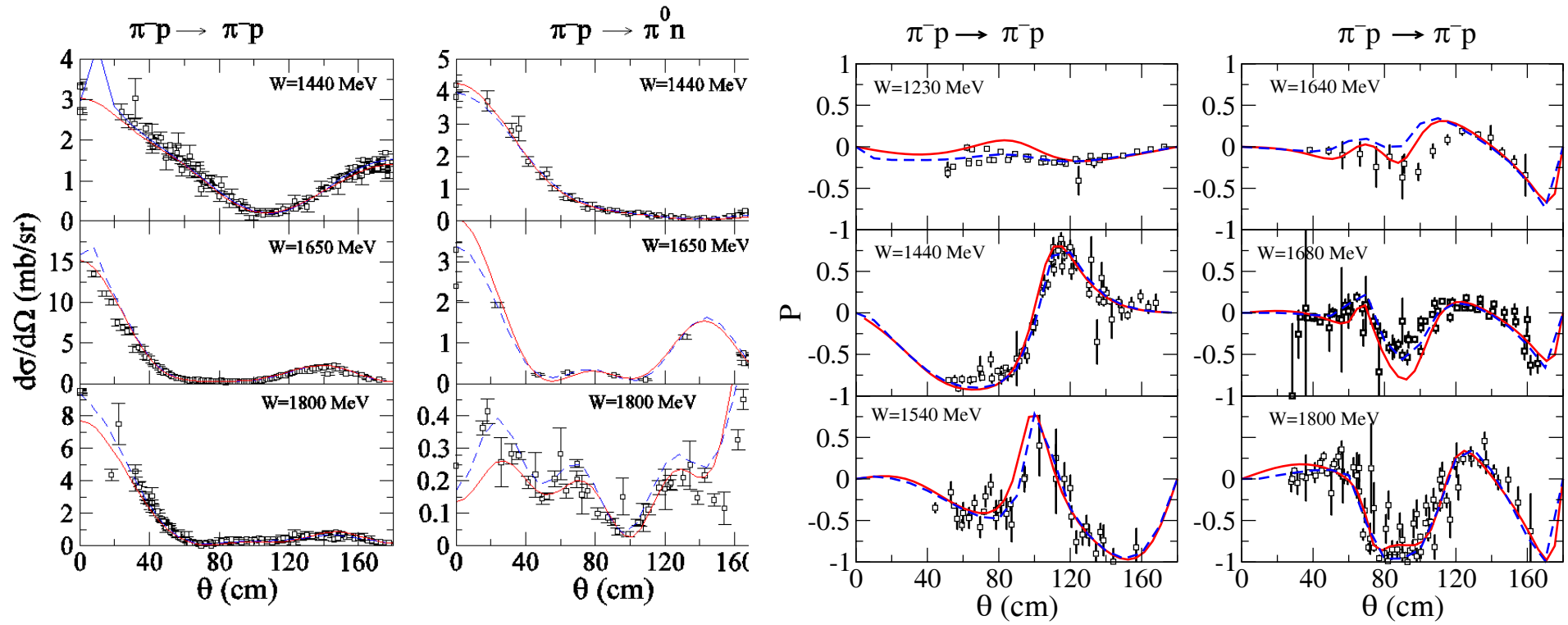


Total cross sections for single pion production in the N^* resonance region. The model contains πN , ηN , $\pi\pi N$ ($\pi\Delta$, σN , ρN) channels and 16 explicit resonance states. In the next slide we show the quality of the strong part of the model.

B. Julia-Diaz, A. Matsuyama, T.-S.H. Lee, T. Sato, L.C. Smith, submitted *Phys. Rev. C* (2008)



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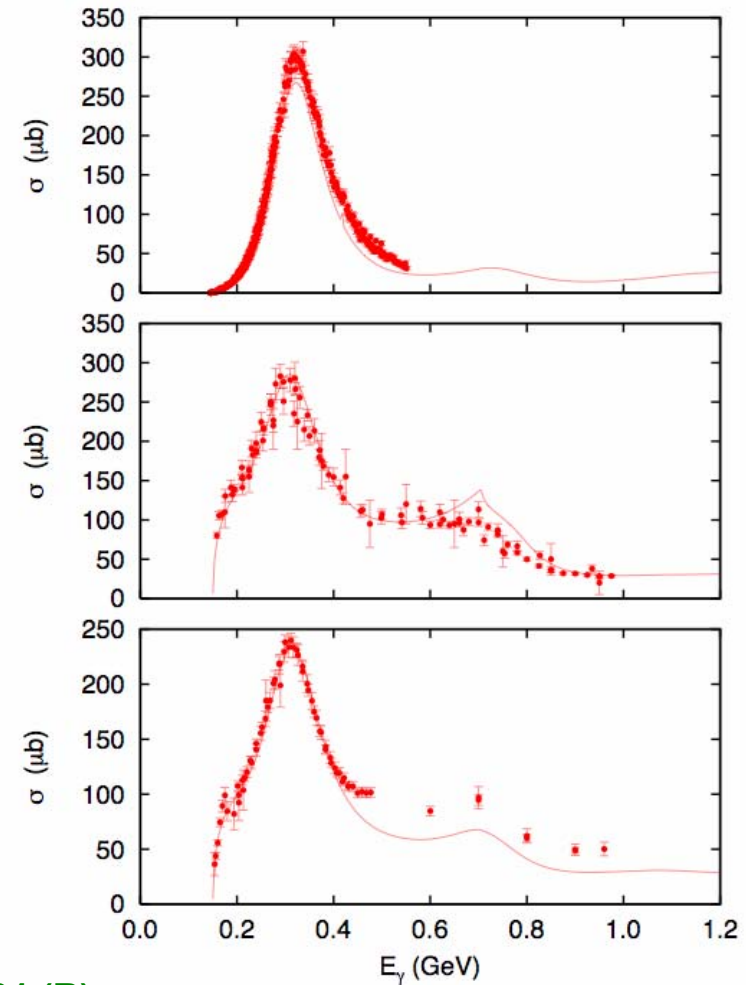


B. Julia-Diaz, A. Matsuyama, T.-S.H. Lee, T. Sato, *Phys. Rev. C* 76, 065201 (2007)

D. Arndt et al, SAID , gwdac.phys.gwu.edu

2) Take a simpler model (no coupled-channels) but improve on the coupling of spin-3/2 resonances.

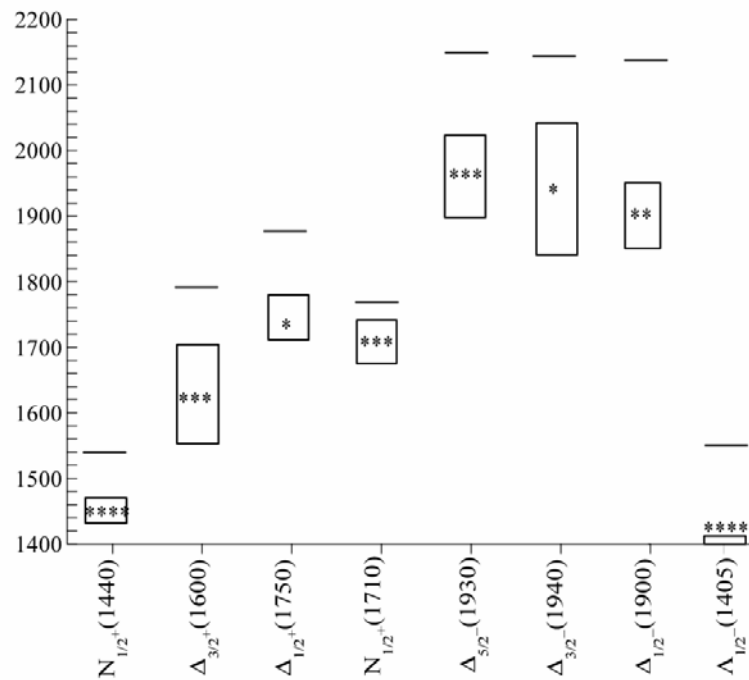
- Up to 1.2 GeV of photon energy (all spin-1/2 and spin-3/2 four-stars resonances up to 1.8 GeV)
- Chiral symmetry
- Consistent spin-3/2 treatment
- Crossing symmetry
- Gauge invariance
- Fair description of data



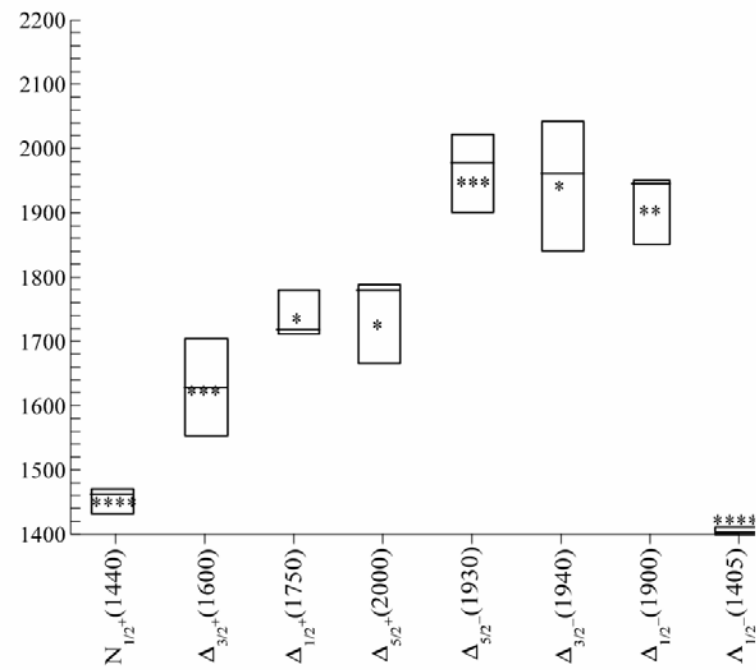
C. Fernández-Ramírez, E. Moya de Guerra, J.M. Udías,
Ann. Phys. (N.Y.) 321 (2006) 1408; PRC 73 (2006) 042201 (R)

3) Couple the S-wave meson-baryon channels to 3q-states \rightarrow it plays a key role to match poor quark model predictions for some baryon resonance masses with data!

THRESHOLD EFFECTS IN THE LIGHT-QUARK BARYON SPECTRUM



Solid lines: 3q mass predictions. Boxes: data.



Solid lines: (3q + meson-baryon) mass predictions.

P. González, J. Vijande and A. Valcarce, sent to Phys. Rev. C for publication.

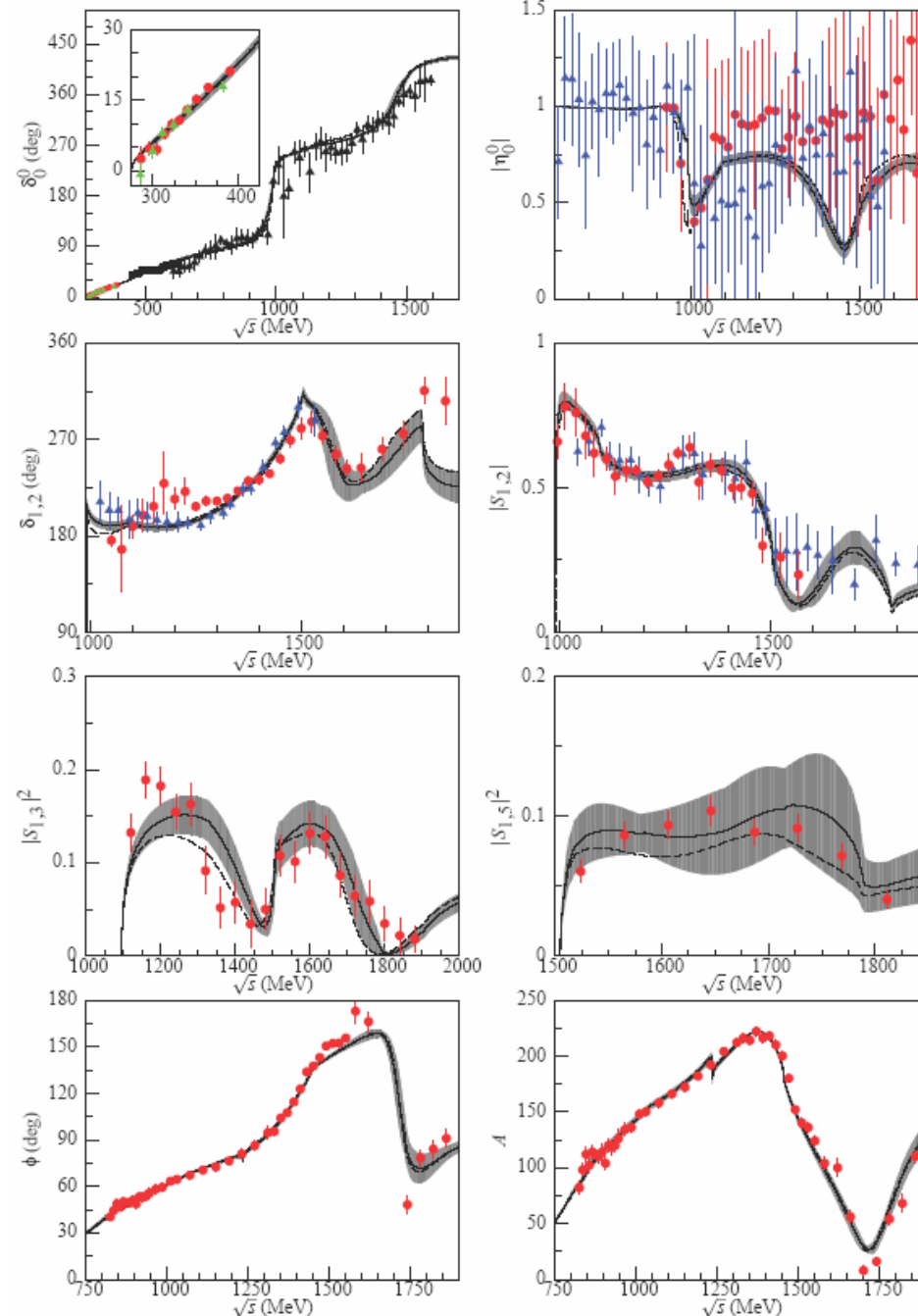
$\pi\pi$ scattering observables

4) Include multipion channels
(in the form of $\sigma\sigma\Box\dots$)

Based on the chiral suppression of the coupling of a scalar glueball to $q\bar{q}$, overwhelming reasons are given in this work to identify the $f_0(1500)$ and $f_0(1710)$ resonances as **glueballs**.

M. Albaladejo and J. A. Oller,
"Identification of a Scalar Glueball,"
arXiv:0801.4929 [hep-ph];

M. Albaladejo, J. A. Oller and C. Piqueras,
"S-wave meson scattering up to $s^{1/2} < 2$
GeV from chiral Lagrangians,"
arXiv:0711.1977 [hep-ph].



5) Three-hadron quasi-bound states (resonances) from Faddeev equations

The X(2175) resonance recently discovered at BABAR and BES is reproduced as a resonant state of the three body system ($\Phi K \bar{K}$) using Faddeev equations with meson-meson interactions derived from chiral Lagrangians. It decays predominantly into Φ and $f_0(980)$.

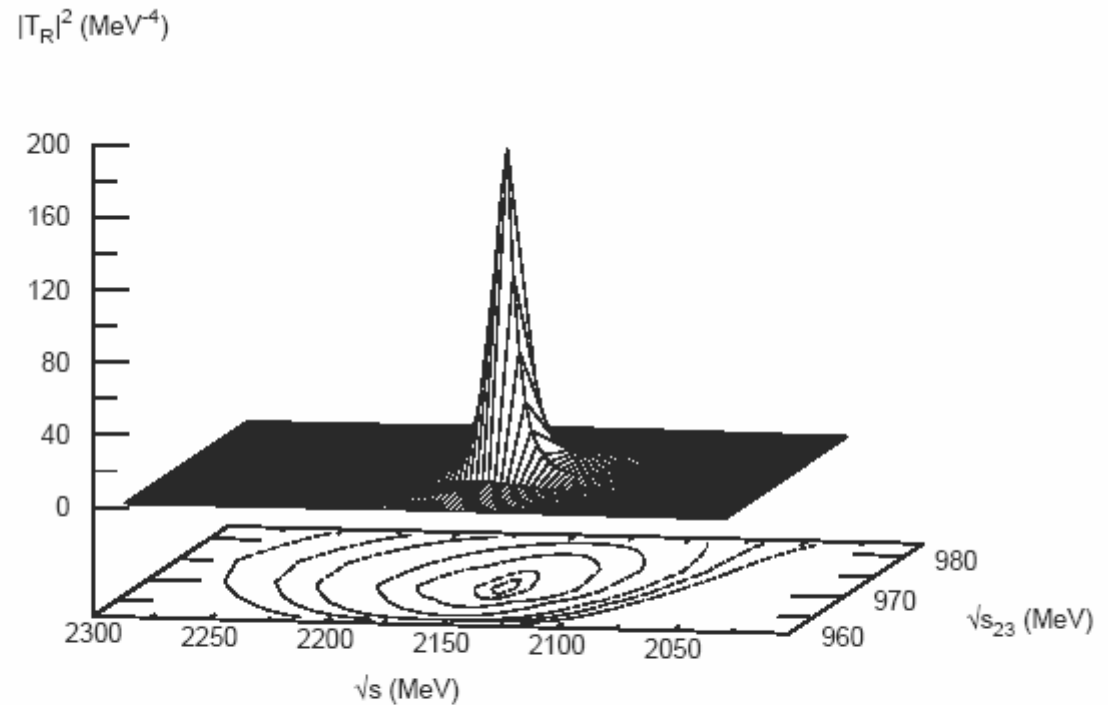


Figure 1: The $\phi K \bar{K}$ squared amplitude in the isospin 0 configuration.

A. Martínez Torres, K. P. Khemchandani, L. S. Geng, M. Napsuciale, and E. Oset,
arXiv:0801.3635 [nucl-th]

Several groups are extending the method to the **charm** degree of freedom to interpret the data from BELLE, Babar, BES, CLEO ... but also in preparation for the forthcoming experiments at FAIR that will be sensitive to the in-medium properties of hadrons with charm.

Valencia → dynamically generated open charm and hidden charm

Barcelona meson resonances from meson-meson coupled channel dynamics

Barcelona → dynamically generated charmed baryon resonances within

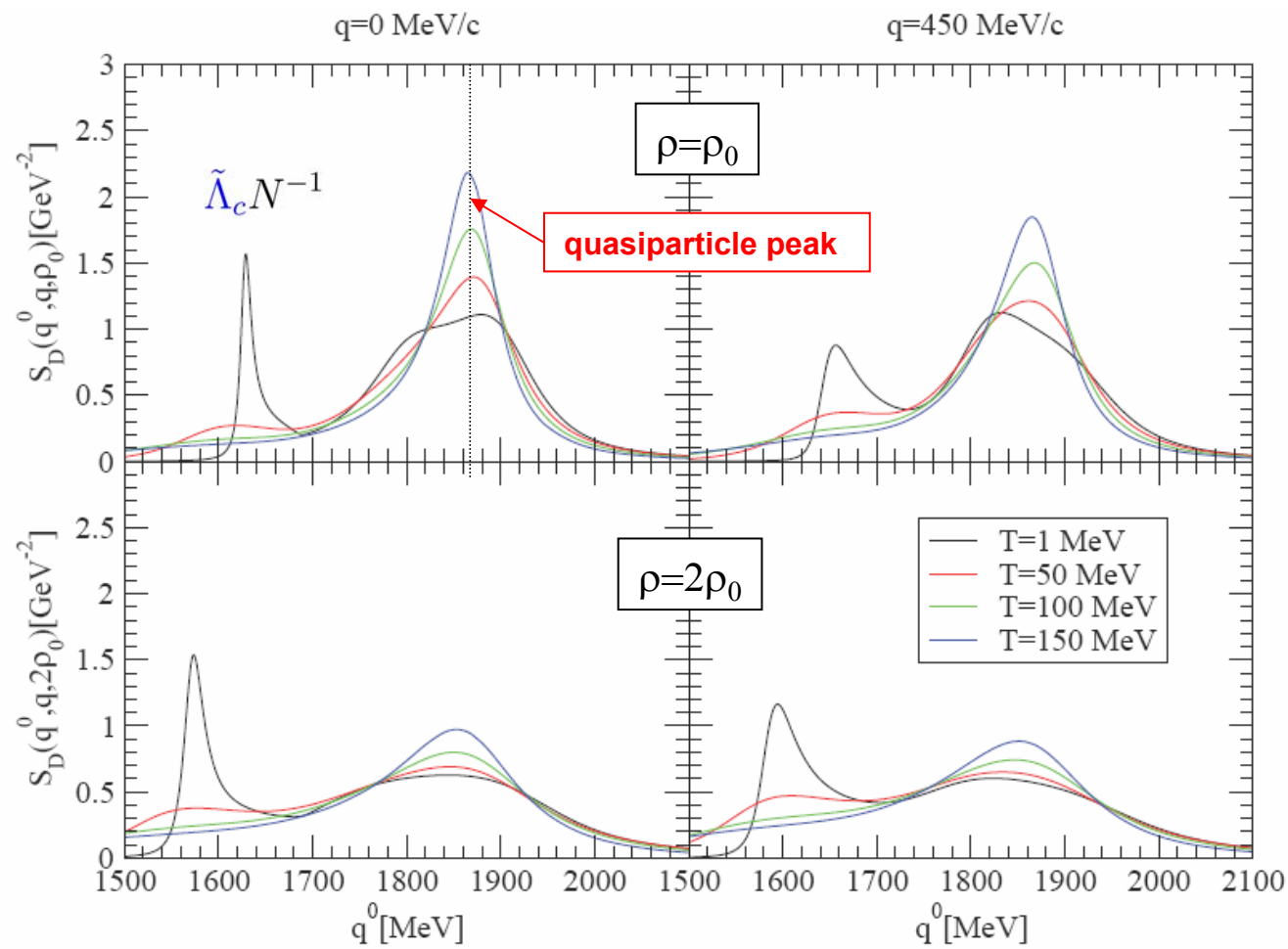
Frankfurt a SU(4) model → D-meson properties in hot and dense medium

Granada → dynamically generated charmed baryon resonances within

Barcelona a SU(8) model (based on heavy-quark spin symmetry)

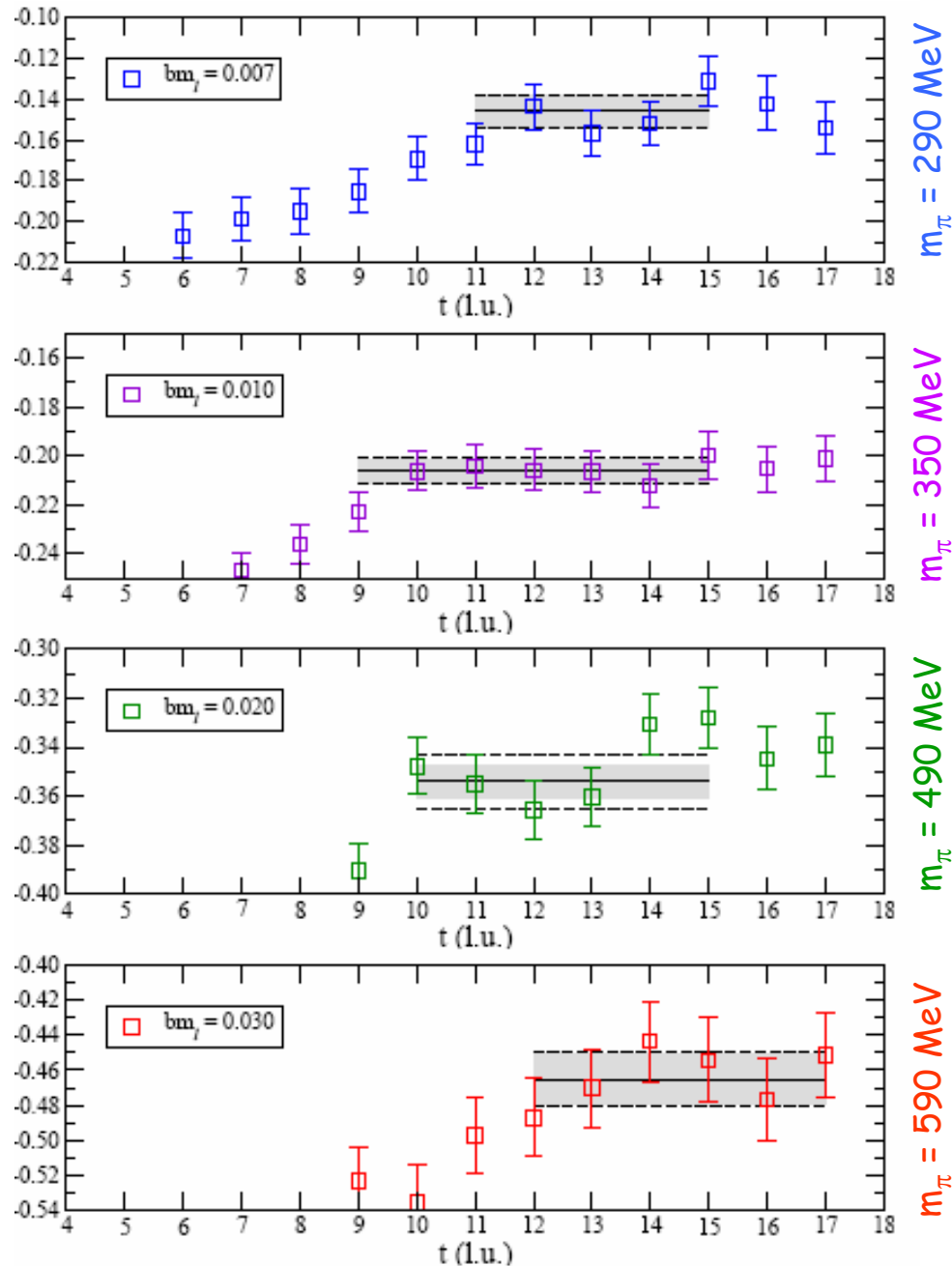
Salamanca → quark model charmed baryon and meson resonances

D-meson spectral function ($\rho=\rho_0$ and $2\rho_0$)



L. Tolos, A. Ramos and T. Mizutani, Phys.Rev.C77 (2008) 015207

HADRON-HADRON INTERACTIONS from LATTICE QCD



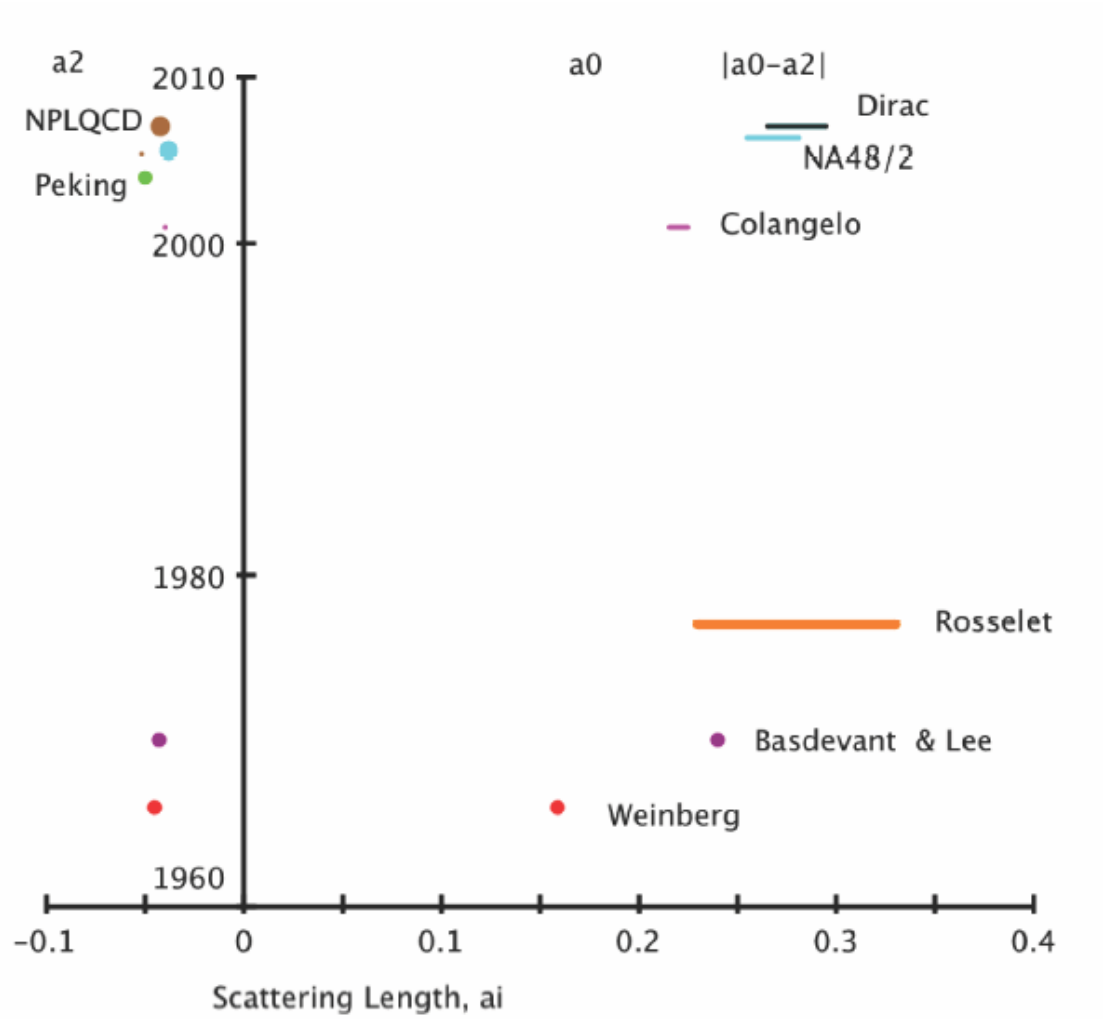
$\pi^+ \pi^+$ scattering

combined with χ PT

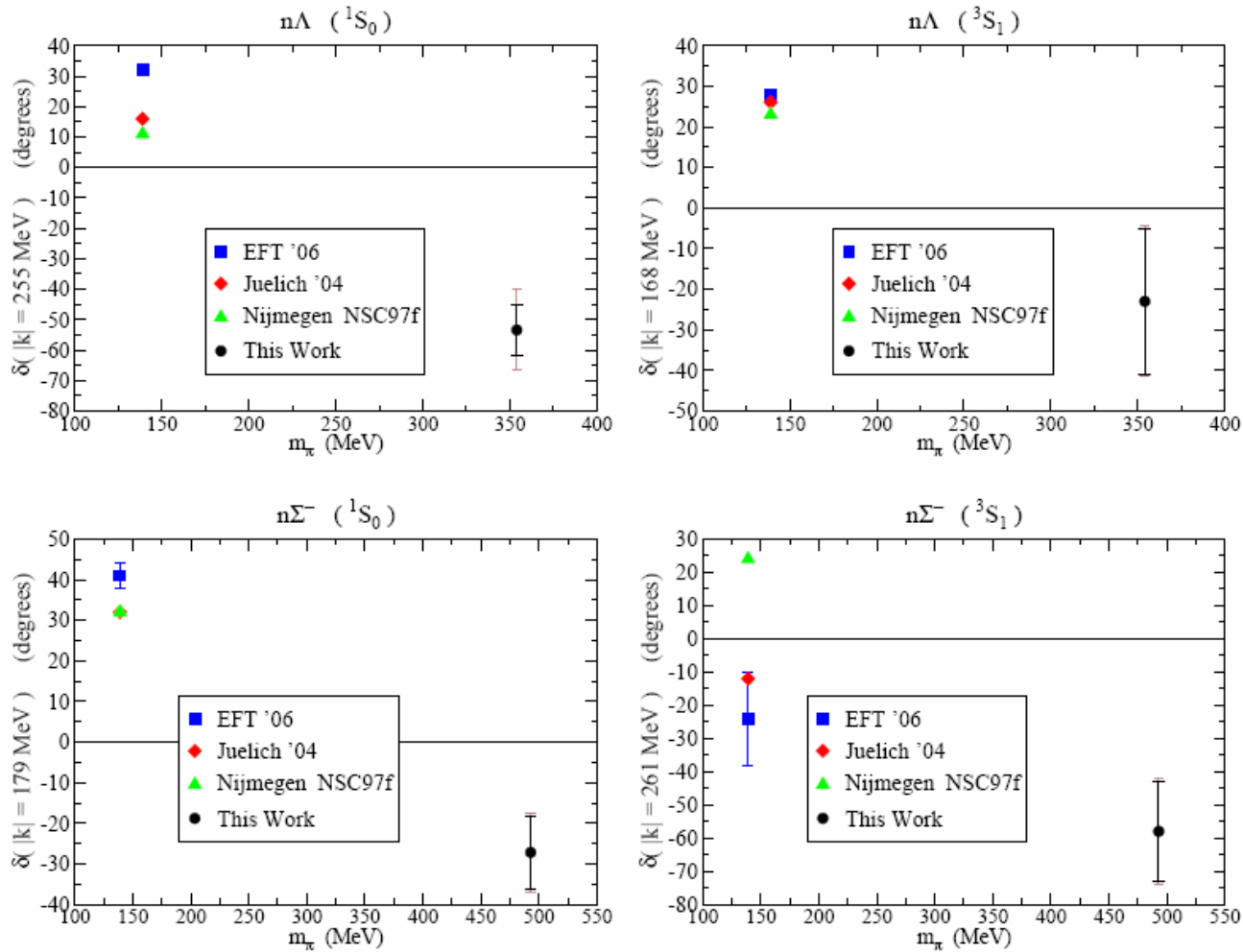
$$m_\pi a_{\pi\pi}^{I=2} = -0.04330 \pm 0.00042$$

A. Parreño with the NPLQCD collaboration,
Phys.Rev.D77(2008) 014505

(DIRAC measures a combination
a0-a2)



Lattice QCD is especially interesting for the study of hadronic interactions in the strange sector (e.g. ΥN scattering), where the instability of the particle makes experiments hard to perform.



Goal: produce stable results for smaller values of m_π

By NPLQCD Collaboration, Nucl.Phys.A794(2007) 62-72.

The spanish **theory groups** have been and are very active in contributing to the progress of Hadronic physics. The groups are well integrated in the International circuit, participating in the big european projects (e.g. HadronPhysics) and providing support to the ongoing and future experiments, with an especial focus to the FAIR physics program.

The **experimental groups** working on hadronic physics projects are still very limited. However, many spanish citizens are involved in experimental collaborations (MAINZ, GSI, Heidelberg, Nantes, Caen) and could be the seed for an eventual growing of the experimental groups.

Thank you for your attention!