Exotic multi-quark states and baryon spectroscopy workshop

25–27 June 2024, University of Bonn

Results of JRA7 - light and heavy quark hadron spectroscopy

M. Battaglieri and J. Nieves

IFIC
INSTITUT DE FÍSICA CORPUSCULAR

EXCELENCIA SEVERO OCHOA

VNIVERSITAT DE VALÈNCIA

CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

STRONG-2020

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824093

http://www.strong-2020.eu/

STRONG-2020

MAN

Management and Coordination

DISCO

Dissemination and Communication

TA

7 Transnational Access Research Infrastructures

VA

2 Virtual Access Infrastructures

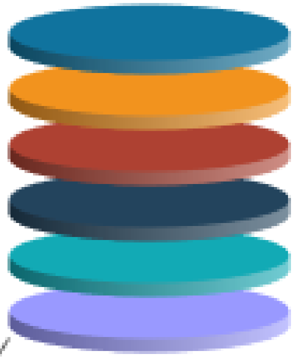
NA

7 Networking Activities

JRA

14 Joint Research Activities

32 Work Packages (WPs)



46 participating institutions (beneficiaries) in

- **16countries:**Austria,Belgium,Switzerland,Germany,Spain,Finland,France,Croatia, Ireland,Italy,Montenegro,Netherlands,Poland,Portugal,Sweden,United Kingdom

121otherInvolvedInstitutions(not receiving EU funding)

Courtesy by B. Erazmus

STRONG-2020 Kick-off meeting: October 23-25, 2019

Nantes, France: https://indico.in2p3.fr/event/19715/

STRONG-2020 Annual meeting: October 13-16, 2020

Online Meeting https://indico.in2p3.fr/event/20784/

STRONG-2020 Annual meeting: November 8-10, 2021

Nantes, France: https://indico.in2p3.fr/event/25163/

STRONG-2020 Annual meeting: October 18-20, 2022

Paris, France: https://indico.in2p3.fr/event/27767/

STRONG-2020 Annual meeting: November 20-22, 2023

CERN, Switzerland: https://indico.cern.ch/event/1264833/

Topical meetings organized by different project WPs can be found on the project Web site. EVENTS: MEETINGS

Courtesy by B. Erazmus

JRA7-Light and heavy-quark hadron spectroscopy (HaSP)

http://web.ge.infn.it/jstrong2020/

Study the spectrum of the hadrons

- new generation of experiments are running or are in preparation at CERN, Mainz, Bonn GSI, JLab, BESIII and Belle
- precise and abundant data requires an adequate analysis
- collaborative effort between experimental and theory: observables need to be interpreted using robust methods that rely only on the basic theoretical principles, and compared to the best solutions provided by the fundamental theory of the strong interaction via LQCD or systematic effective field theory expansions

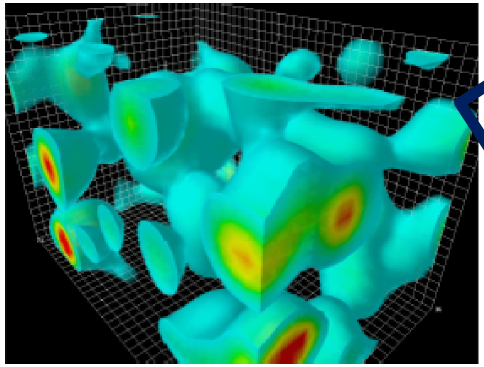
HaSP aims to coordinate the leading European institutions active in hadron spectroscopy to make progress in

- developing a theoretical, phenomenological and computational foundations for amplitudes
- establishment of best practices for accessing systematic uncertainties in analysis of hadron reaction data and interpretation of physics results

- **QCD** allows much richer hadron spectrum than **conventional** $q\bar{q}$ mesons and qqq baryons.

Exotic hadrons

glueballs	GG, GGG
multiquark states	$q\,q\,\bar{q}\,\bar{q}$, $q\,q\,q\,q\,\bar{q}$
hybrids	$q\,\bar{q}$ G, **$q\,q\,q$ G**, $q\,q\,\bar{q}\,\bar{q}$ G
molecular hadrons	$[D\bar{D}^*]$, $[\bar{D}^*\,\Sigma_c]$



Derek B. Leinweber – University of Adelaide

and temperature & density QCD phase-diagram

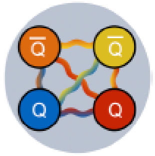
Discovery Exotic Mesons and/or Baryons

Design and build detectors
Collect data
Build observables
Fit data
Extract pole position,
…

Experiments Tools

(New and more precise) Data

Interpretation



Lattice QCD,
Constituent Models,
Effective Field Theories,
…

Theory

and temperature & density QCD phase-diagram

dispersive & analyticity techniques…

Task 1: Precision calculations in non-perturbative QCD (I)

QCD symmetries at the hadron level are used to construct EFT's able to describe the low energy hadronic phenomenology. Dispersion relations provide rigorous constraints to theoretical predictions that can be used to obtain accurate properties of excited states. Especially when combined with EFT’s, they provide a very powerful connection between the Hadronic and QCD realms

- QCD Effective Field Theories and unitarization methods and dispersive techniques: description of low energy hadronic phenomenology and properties of excited states **(C.Hanhart - FZJ)**
- Heavy hadrons decays: Dalitz-plot, EFT, exotic resonances nature, isospin or CP violations **(D.Rodriguez-Entem - USAL)**

Task 2: Precision calculations in non-perturbative QCD (II)

EFT techniques complement very efficiently LQCD simulations allowing precision spectroscopy of exotic and excited states and the treatment of states above thresholds in coupled-channel scattering analyses. Lattice and Green's function MCsimulations, combining chiral NN and 3N forces, will be also performed to study light and medium-heavy nuclei

- EFTs control extrapolations to physical kinematics covering regions not yet reachable in the lattice **(A.Parreño – UB – A.Lovato - ANL)**
- Precision spectroscopy of exotic and excited states in quarkonia using EFT combined with significant advancements in LQCD **(A.Vairo - TUM)**
- Heavy quarkonia in heavy-ion experiments and their suppressed production **(A.Vairo - TUM)**

Task 3: Meson Spectroscopy analysis of new and exotic states

Large number of “exotic” experimental discoveries, which did not fit the expectations of the quark model, as well as the unprecedented statistical precision have been obtained by COMPASS, LHCb, BESIII, Belle and other experiments. These discoveries occur especially in the open and hidden charm and bottom sectors, but some of them also correspond to the light quark sector. We propose to perform combined Partial Wave Analyses (PWAs) of the same final state measured in different experiments, making use of the theoretical tools developed in Tasks 1 and 2

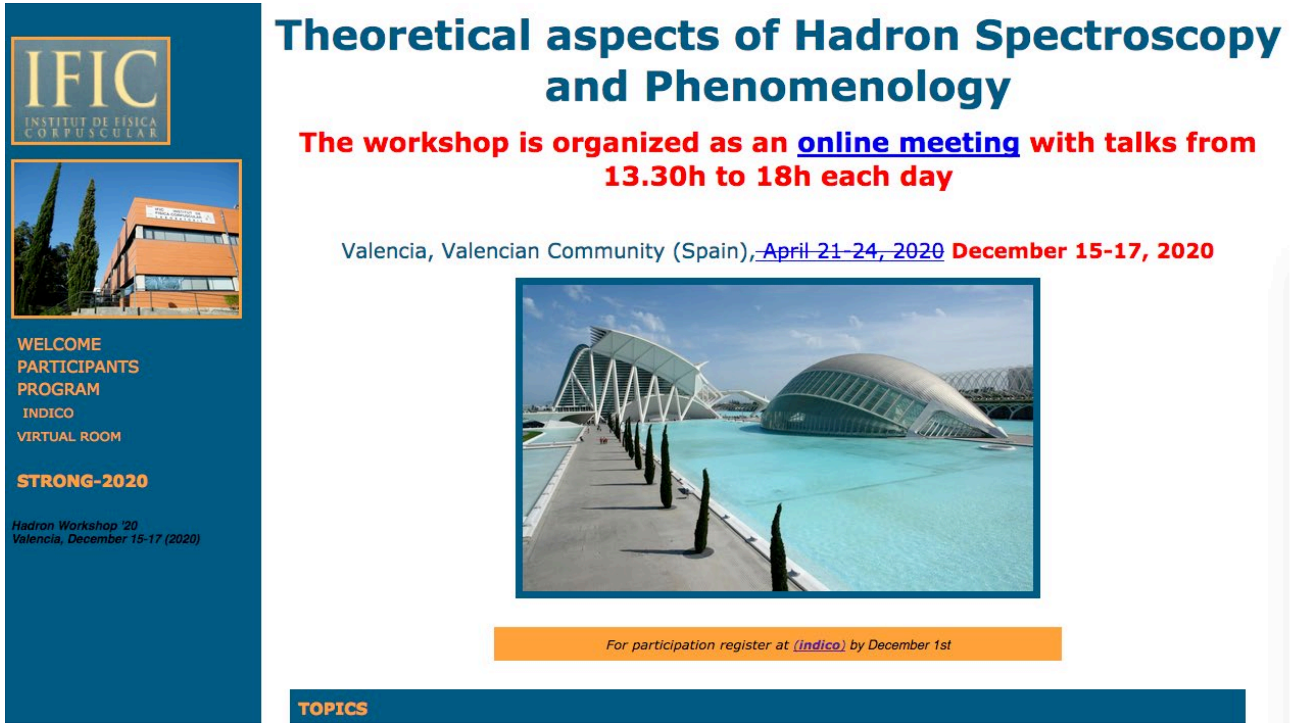
- Search for and study of light exotic mesons, charmonium and strangeonium **(V.Mathieu -UB)**
- Spectroscopy of low-lying scalars, strange mesons and strangeonia **(S.Schadmand - FZJ)**

Task 4: Baryon and multi-baryon spectroscopy

Baryon resonance parameters (e.g. mass, width, pole position) have been extracted so far by partial-wave analyses of scattering data. An intense effort has started to add information from photon-induced meson production at ELSA, JLAB and MAMI, from charmonium decays at BESIII and diffractive *pp* reactions at COMPASS

- Resonance parameter determination **(M.Ostrick – Mainz)**
- Diffractive and annihilation production and exotic baryons **(A.D’Angelo – URM-TV)**
- Di-baryon structure and parameter determination **(D. Watts – U. York)**

Topical Workshops



http://ific.uv.es/nucth/TH-WP25-H2020/

https://indico.ice.csic.es/event/24/

https://agenda.infn.it/event/27658/timetable/#20210914

STRONG2020 Hadron Spectroscopy (HaSP) General Workshop

13–16 de septiembre de 2022
Institute for Advanced Study of the Technische Universität München
Europe/Berlin zona horaria

Introduzca su término de búsq

- Vista general
- Scientific Program
- Cronograma
- Inscripción
- Lista de participantes
- Venue and Transportation
- Accomodation
- Conference Photo

This workshop is included in the activities of the working package WP25 (Light- and heavy-quark hadron spectroscopy) of the project STRONG-2020. It has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 824093.

This workshop is intended as an opportunity for the different groups working within the STRONG2020 project to share and report results. It is focused in particular on the experimental and theoretical aspects of hadron spectroscopy and phenomenology. This workshop is a follow-up of the 2021 online workshop hosted by the University of York and the 2020 Valencia workshop.

The major topics of the workshop cover:

1. Precision calculations in non-perturbative QCD: Effective Field Theories, analyticity, dispersion relations, and Lattice QCD
2. Hadron spectroscopy and exotic states
3. Production and decays of hadrons
4. Form factors, Low-energy constants, fundamental parameters of QCD, and spectroscopy of light nuclei

The workshop is organized in plenary presentation sessions, followed by discussion sessions to review novel ideas, plans, and proposals.

General Workshop

https://indico.ph.tum.de/event/6977/

DIARIVM

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Home | Indico | Venue | Practical information | Organization | Contact

The STRONG2020 HaSP school was planned for the end of the H2020 STRONG2020 European Network.

The STRONG-2020 project brings together many of the leading research groups and infrastructures involved today in the study of the strong interaction in Europe, and also exploits the innovation potential in applied research through the development of detector systems with applications beyond fundamental physics, e.g. for medical imaging and information technology. The Consortium includes 45 participant institutions, embracing 14 EU Member States, one International EU Interest Organization (CERN), and one EU candidate country. Together with host institutions of 21 other countries, without EU funds benefits, the project involves research in 36 countries. The project is structured in 32 Work Packages (WP): 7 Transnational Access Activities (TA), 2 Virtual Access Activities (VA), 7 Networking Activities (NA) and 14 Joint Research Activities (JRA). Furthermore, 2 WPs take care, respectively, of the "Management and Coordination" of the project and of "Communication and Outreach".

https://diarium.usal.es/strong2020/

Scientific Program

- **Effective Field Theories of QCD** (Introduction to non relativistic EFTs (HQET, NRQCD, pNRQCD) and chiral effective field theory. Quark-gluon plasma, heavy-ion collisions, thermal field theory, effective field theories at finite temperature)
- **Analysis tools for hadron physics** (Cross sections, Dalitz plot, helicity formalisms, S-Matrix constraints, reaction amplitude parametrization, hands-on with simulated data)
- **Hadron physics experiments** (Experimental Methods in Hadron Spectroscopy. Light Mesons with open and hidden strangeness. Mesons spin and parity determination procedure. Baryon spectroscopy in the light sector. Photo and electro-production of mesons on nucleon targets. Polarization observables and complete reactions. Experimental and statistical methods for data analysis. Applications to data: polarization observable and cross section extraction)

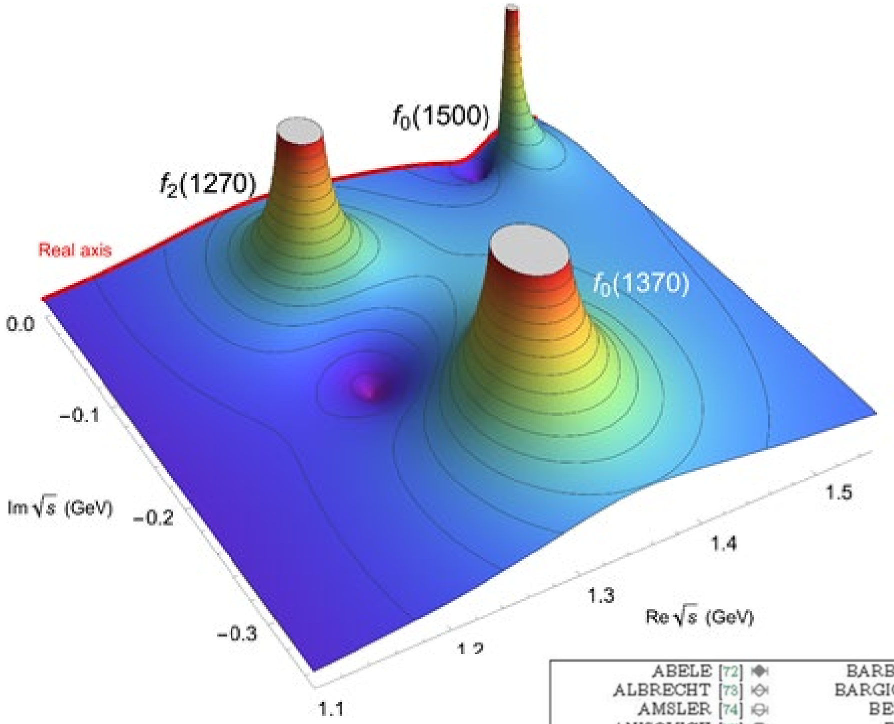
https://indico.ific.uv.es/event/6803/program

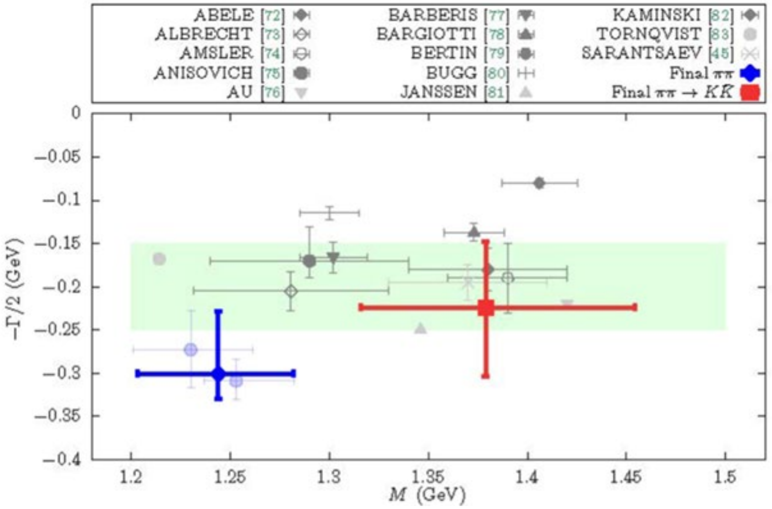
Confirmed speakers:

- Antonio Vairo (T.U. Munich)
- Jacopo Ghiglieri (CNRS, IN2P3)
- Vincent Mathieu (U. Barcelona)
- Miguel Albaladejo (IFIC Valencia)
- Annalisa D'Angelo (U. Roma and INFN
- Alessandra Filippi (INFN Torino)
- Derek Glazier (U. Glasgow)
- Lucilla Lanza (U. Rome Tor Vergata)
- Nickolas Zachariou (U. York)

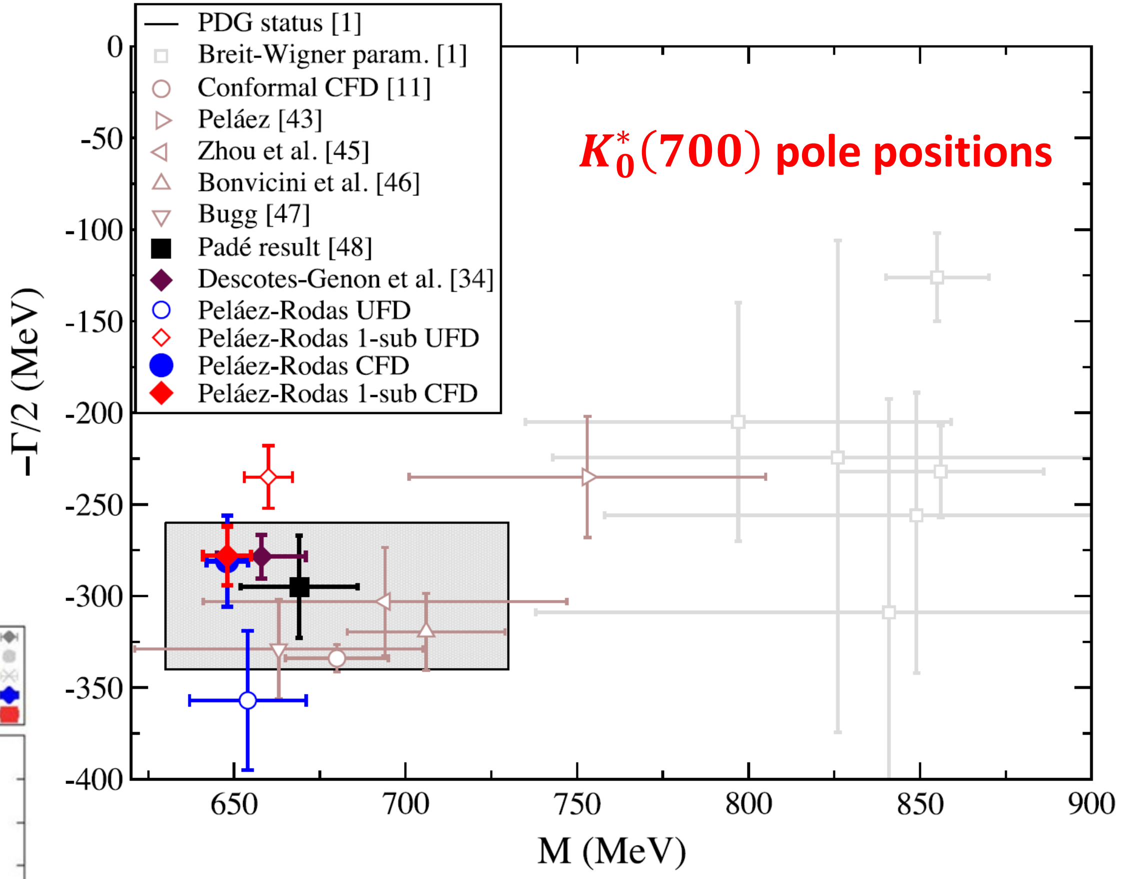
1. Effective Field Theories of QCD (A. Vairo, T.U. Munich).
   Speakers: A. Vairo (T.U. Munich) and J. Ghiglieri (CNRS, IN2P3).
2. Analysis tools for hadron physics (V. Mathieu, U. Barcelona).
   Speakers: V. Mathieu (U. Barcelona) and M. Albaladejo (IFIC Valencia).
3. Experimental methods in hadron spectroscopy (A. D'Angelo, U. Roma Tor Vergata & INFN Roma Tor Vergata).
   Speakers: A. D'Angelo (U. Roma Tor Vergata & INFN Roma Tor Vergata), A. Filippi (INFN Torino), D. Glazier (U. Glasgow), L. Lanza (U. Rome Tor Vergata) and N. Zachariou (U. York).

Progress in Task 1: development and application of EFTs and hadron decays



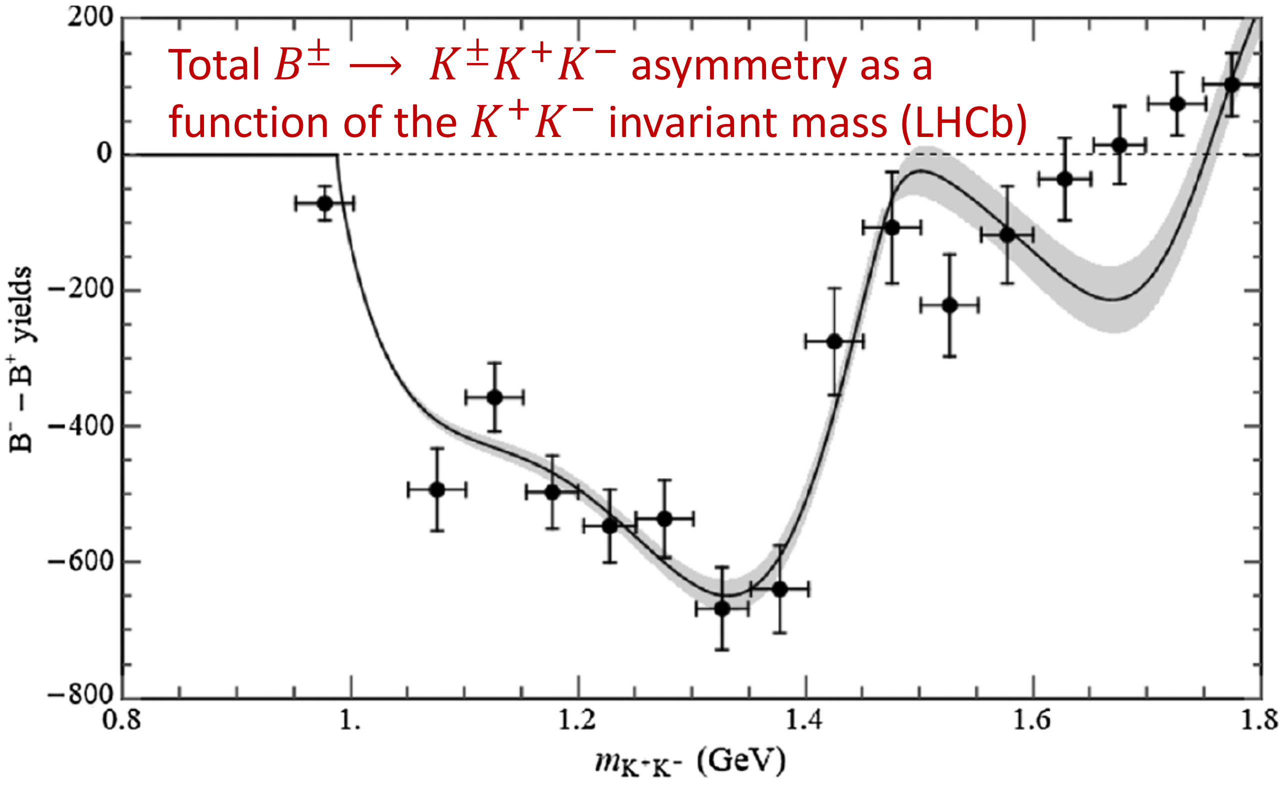


Determination of the f_0 (1370)pole position from dispersion relation,
J.R Pelaez, A. Rodas and J. Ruiz de Elvira Phys.Rev.Lett. 130 (2023) 051902



J.R.Peláez and A. Rodas, Phys. Rev. Lett. 124 (2020) 172001

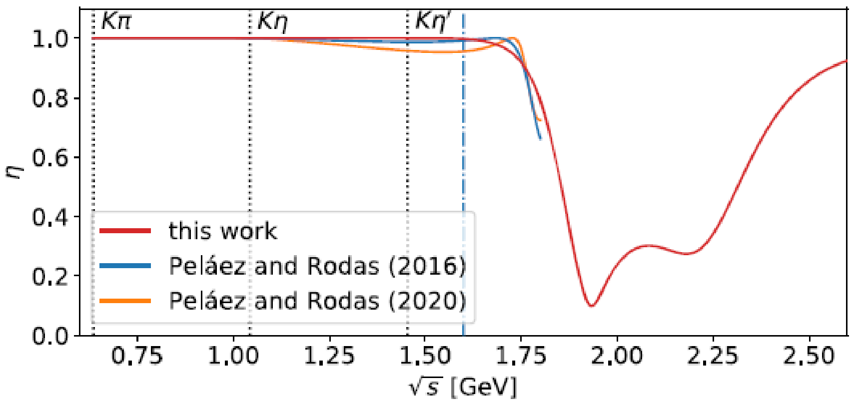
dispersive model-independent analysis of πK, $\pi\pi$ and $\pi\pi \to K\bar{K}$ partial-waves in the low energy region



On the scalar π K form factor beyond the elastic region, L. von Detten, F. Noël, C. Hanhart , M. Hoferichter , B. Kubis, *Eur.Phys.J.C* 81 (2021) 420

- includes inelastic effects via resonance exchange
- Fulfill all constraints from πK scattering and maintaining the correct analytic structure
- considers $\tau \longrightarrow K_S \pi \nu_\tau$
- extract the pole parameters of the $K_0^*(1430)$ and $K_0^*(1950)$

Dispersive $\pi\pi \rightarrow K\overline{K}$ Amplitude and Giant CP Violation in B to Three Light-Meson Decays at LHCb, R. Álvarez Garrote, J. Cuervo, P. C. Magalhães, and J. R. Peláez, Phys. Rev. Lett. (2023) 130 (2023) 201901



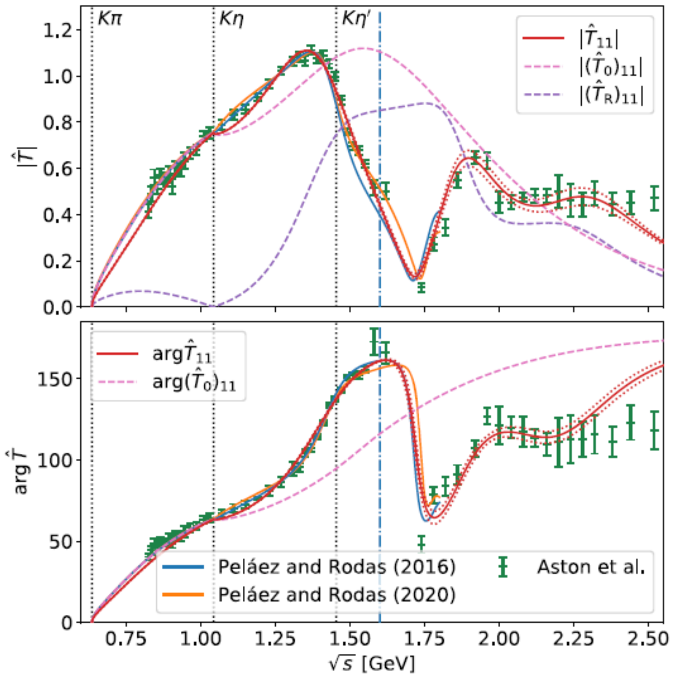
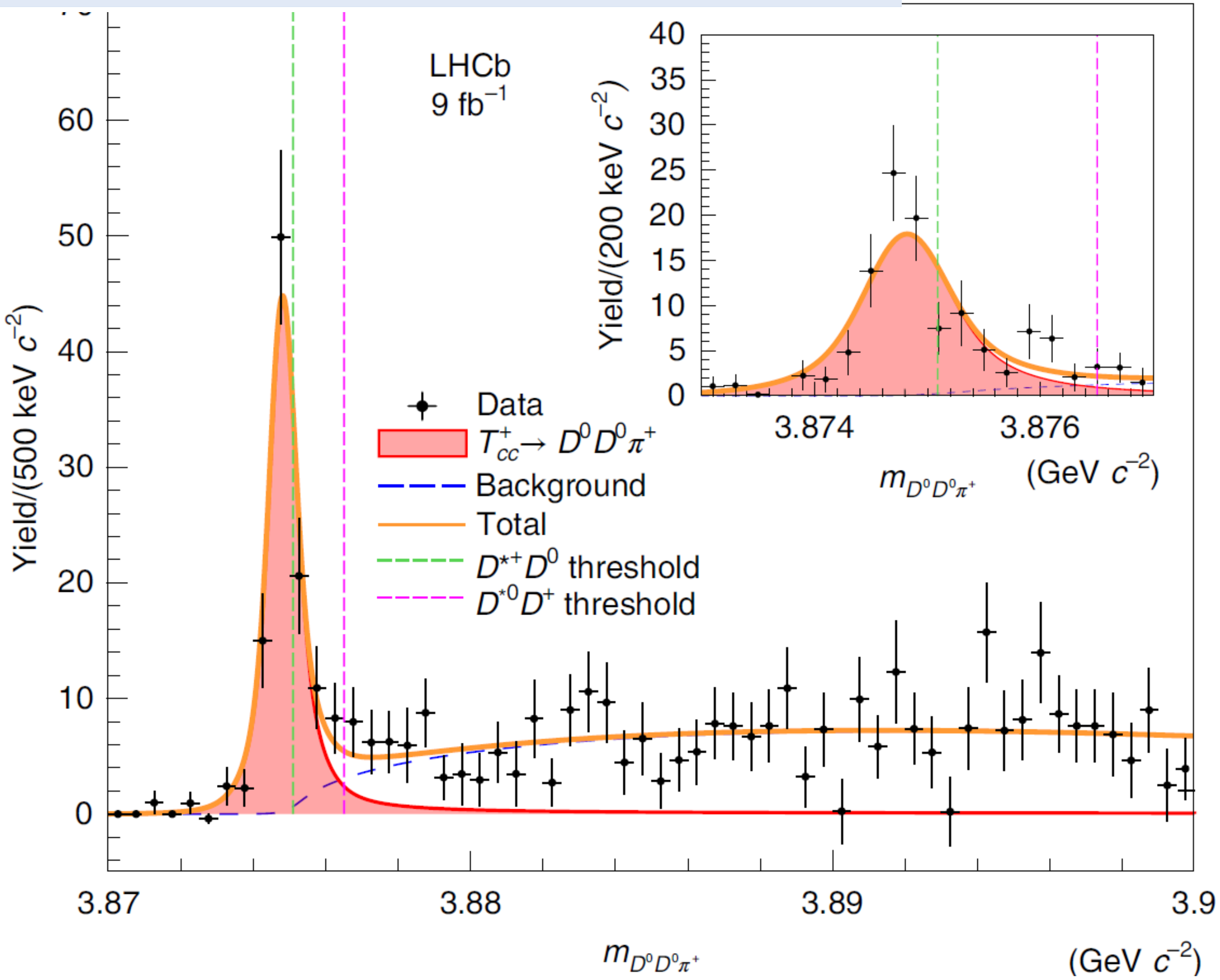


Table 1 | Parameters obtained from the fit to the $D^0D^0\pi^+$ mass spectrum: signal yield, N, BW mass relative to the $D^{*+}D^0$ mass threshold, δm_{BW}, and width, Γ_{BW}. The uncertainties are statistical only

Parameter	Value
N	117 ± 16
δm_{BW}	-273 ± 61 keV c^{-2}
Γ_{BW}	410 ± 165 keV

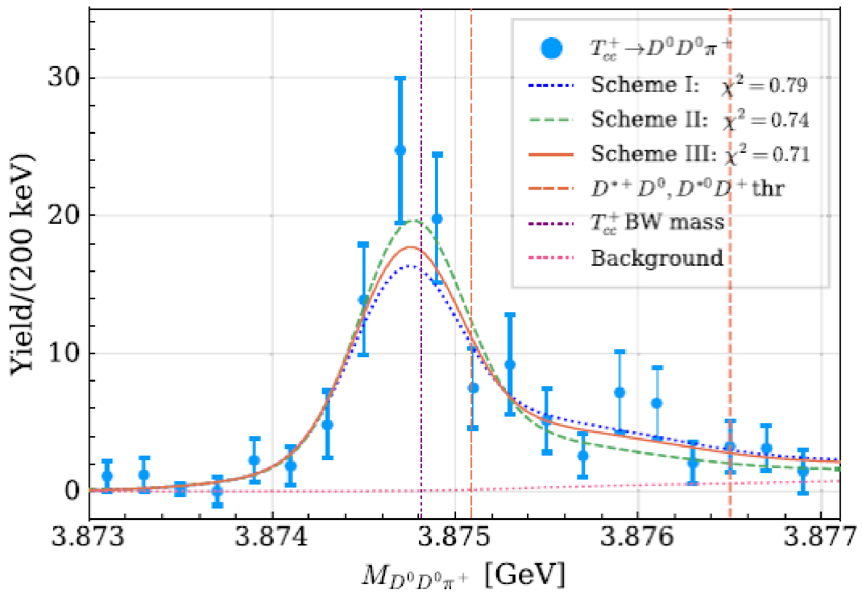
$T_{cc}^{+}(3875)$

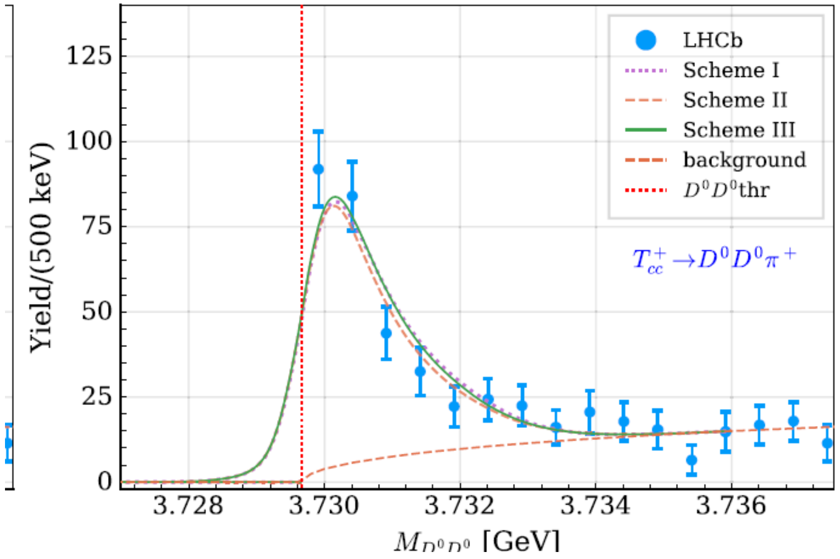


colorless compact tetraquark structure?
D^*D hadron-molecule?

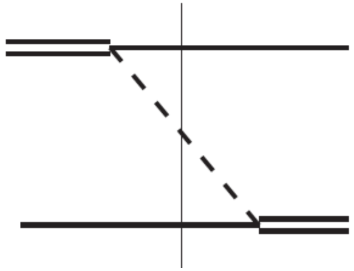
- molecular interpretation: A. Feijoo, W. H. Liang, and E. Oset, PRD 104 (2021) 114015 ; M.-J. Yan and M. P. Valderrama, PRD 105 (2022) 014007, M. Albaladejo, PLB 829 (2022) 137052 ,..., IFIC + Bochum + Moscow + Beijing+ Guangzhou+ Jülich, PRD 105 (2022) 014024 (full consistent treatment including OPE and three body effects)
- Isoscalar bound state in the DD^*_system using quark cluster model: T. F. Carames, A. Valcarce, and J. Vijande, PLB699 **(2011)** 291, or with potential modelled by meson exchanges X.-K. Dong, F.-K. Guo, and B.-S. Zou, Commun. Theor. Phys. 73 (2021) 125201…
- compact double-charm tetraquarks: J. P. Ader, J. M. Richard, and P. Taxil, PRD25 (1982) 2370 (1982),..., M. Karliner and S. Nussinov, JHEP 07 (2013)153 ....

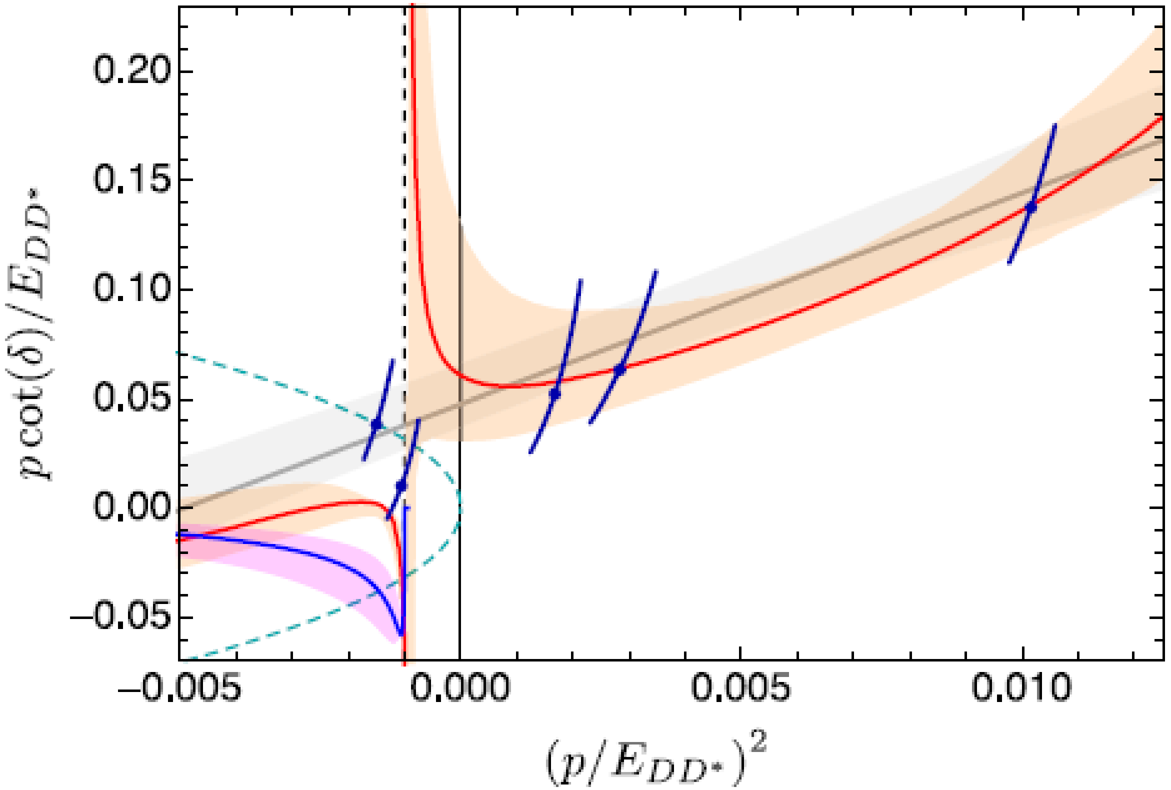
LHCb: Observation of an exotic narrow doubly charmed tetraquark, Nature Phys. 18 (2022) 751





Coupled-channel approach to T_{cc}^+ including three-body effects (OPE), M.L.-Du et al., PRD 105 (20229 014024





Role of Left-Hand Cut Contributions on Pole Extractions from Lattice Data: Case Study for $T_{cc}(3875)^+$, M.-L. Du et al, Phys. Rev. Lett. 131 (2023) 131903; Solving the left-hand cut problem in lattice QCD $T_{cc}(3875)^+$ from finite volume energy levels, L. Meng at al, Phys. Rev. D109 (2024) L071506

lattice data with unphysical pion masses for the T_{cc} cannot be analysed with the standard Lüscher method, since the left-hand cut is too close by.

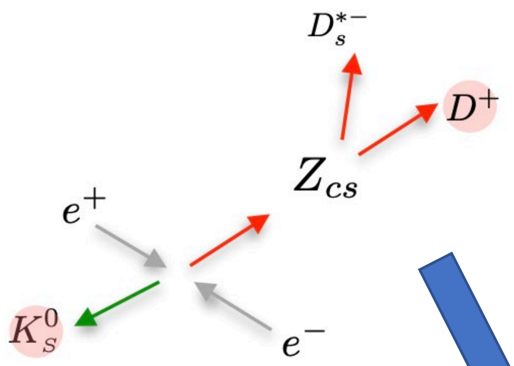
✴New exotic states observations and predictions

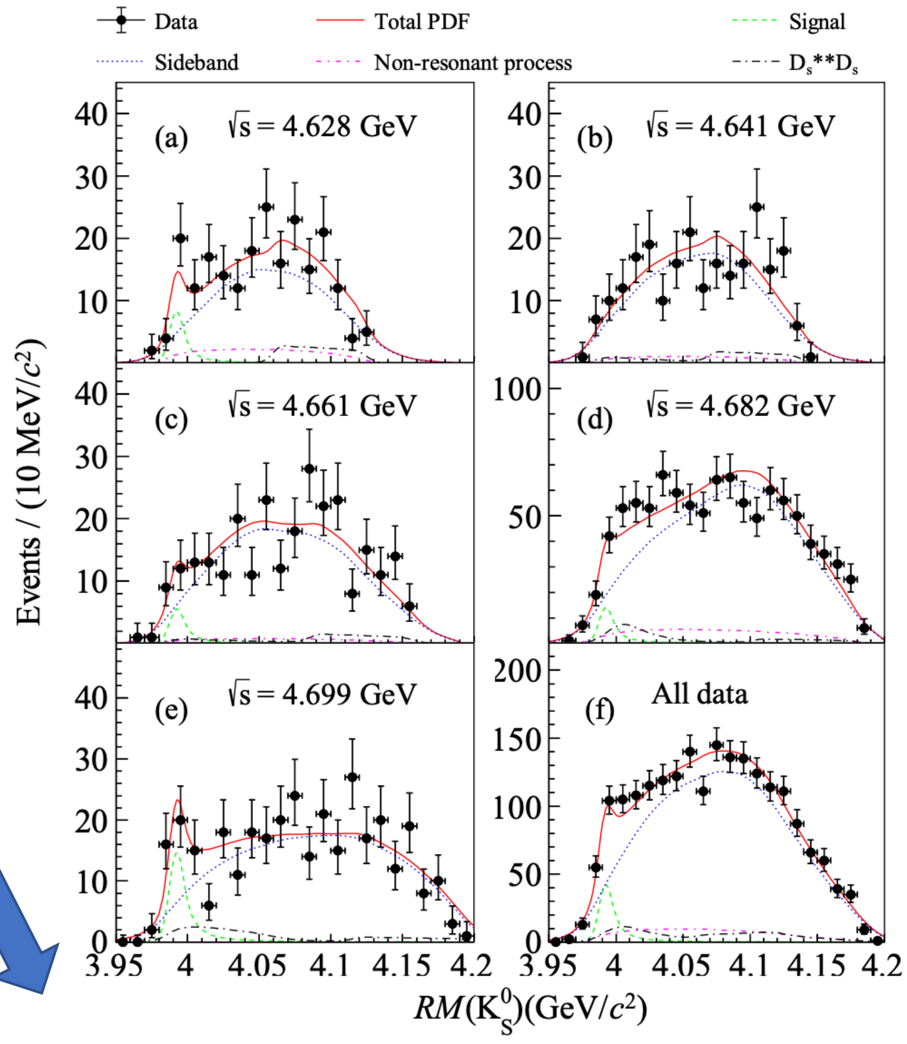
Observation of a new strange $\bar{c}c$-like state $Z_{cs}(3985)$ in e+ e- ⟶KDD*

by the Bochum group

from BESII collaboration

BESIII PRL129 (2022) 112003

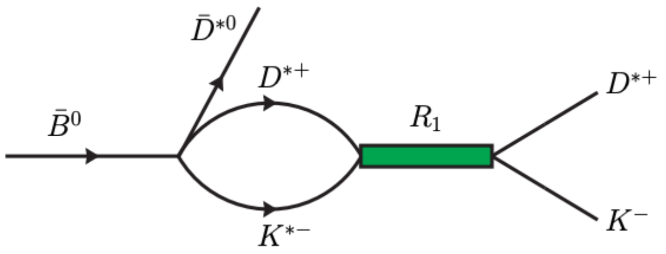


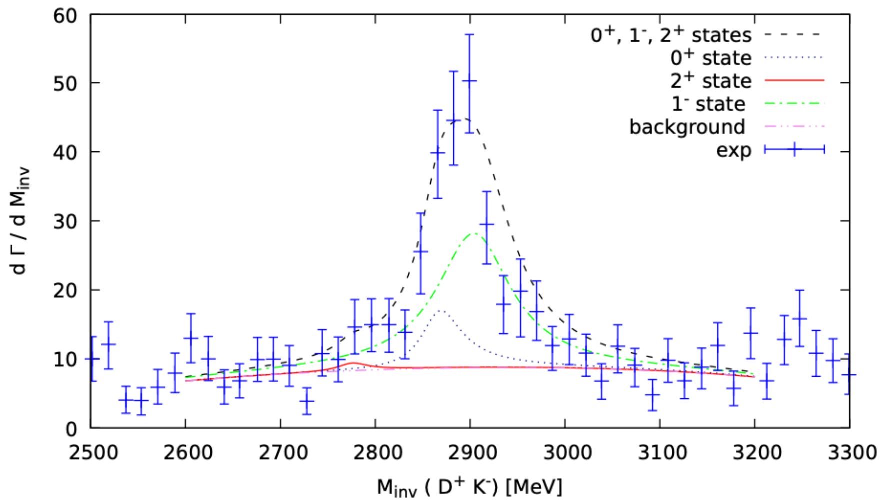


Theoretical prediction of R1, the X(2866) partner, and development of a method to find the spin-2 partner of the X(2866), both in DK final states in B meson decays by the Valencia group

Dai, Molina and Oset PLB832 (2022) 137219

Bayar and Oset PLB833 (2022) 137364

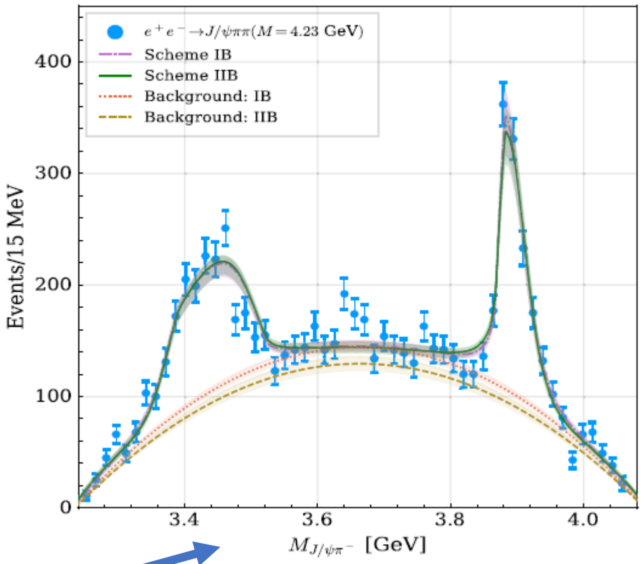


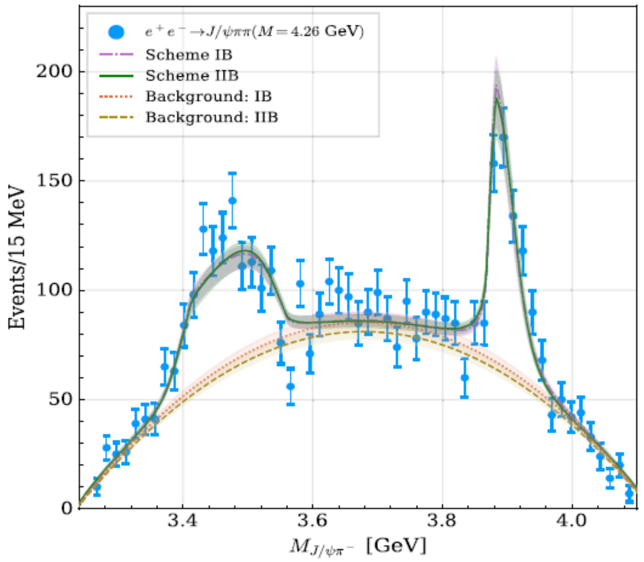


The strange partners of Z_c states: **Combined** analysis of the $Z_c(3900)$ and the $Z_{cs}(3985)$ exotic states

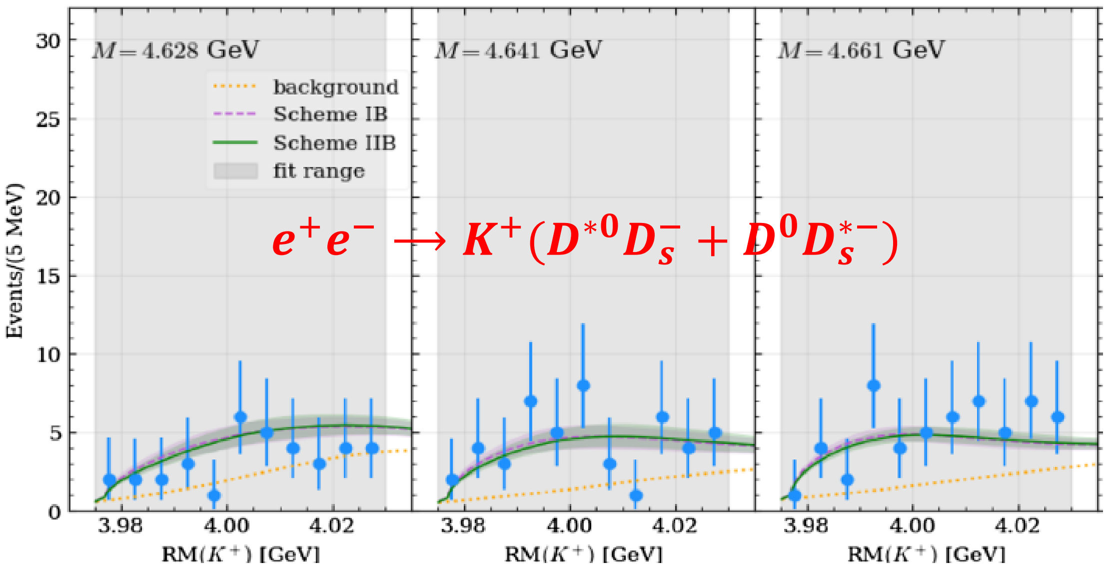
M.-L Du et al., Phys. Rev. D 105 (2022) 074018

$e^+e^- \longrightarrow J/\psi\pi\pi$



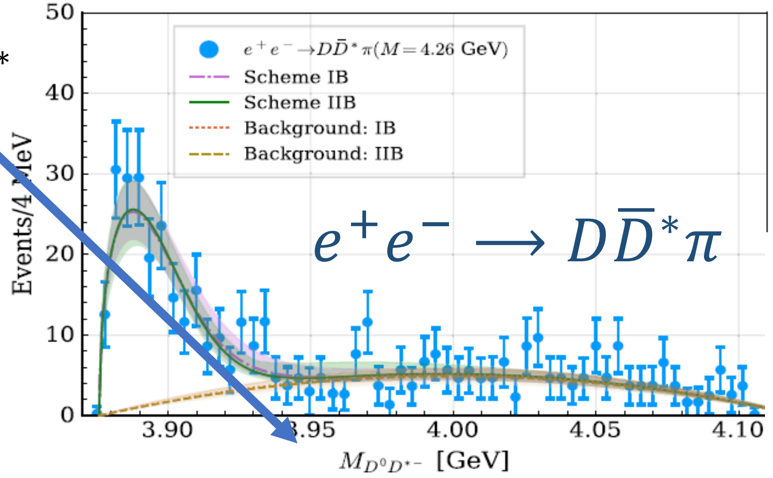


K^+ recoil mass distributions



$e^+e^- \longrightarrow K^+(D^{*0}D_s^- + D^0D_s^{*-})$

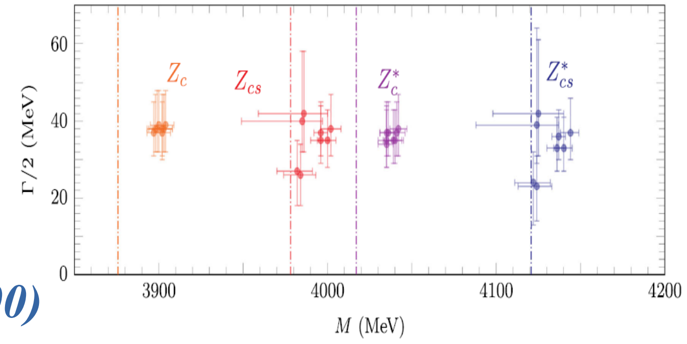
$J/\psi\pi$ and $D\bar{D}^*$ mass distributions

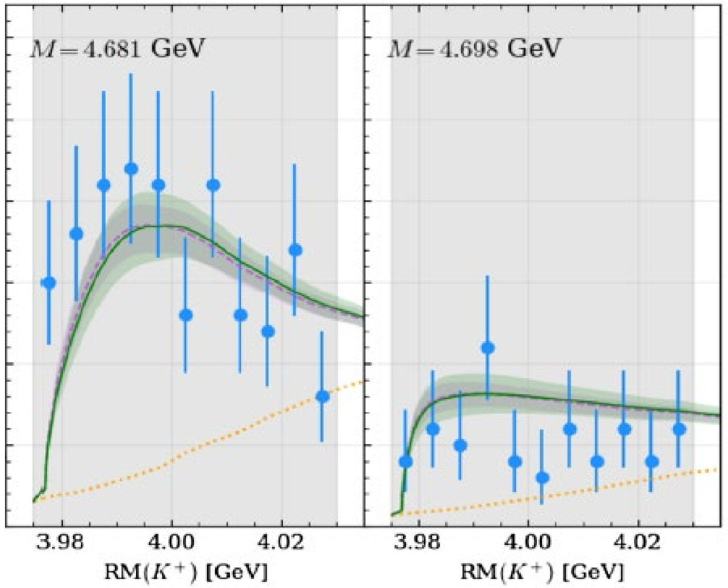


$e^+e^- \longrightarrow D\bar{D}^*\pi$

$D\bar{D}^*,\ J^{PC}(I) = 1^{+-}(1)$

$D\bar{D}_s^*,\ J^P(I) = 1^{\pm}(\frac{1}{2})$





Z_{cs} could be a virtual state or a resonance

Z_{cs} is probably the SU(3) flavor partner of Z_c(3900)

Z_{cs}^* should exist as its spin partner

other works ....

PHYSICAL REVIEW D **105**, 034014 (2022)

Is $Z_{cs}(3982)$ a molecular partner of $Z_c(3900)$ and $Z_c(4020)$ states?

V. Baru,[1,2] E. Epelbaum,[1] A. A. Filin,[1] C. Hanhart,[3] and A. V. Nefediev[4,5]

Physics Letters B 818 (2021) 136382
Contents lists available at ScienceDirect
Physics Letters B
www.elsevier.com/locate/physletb

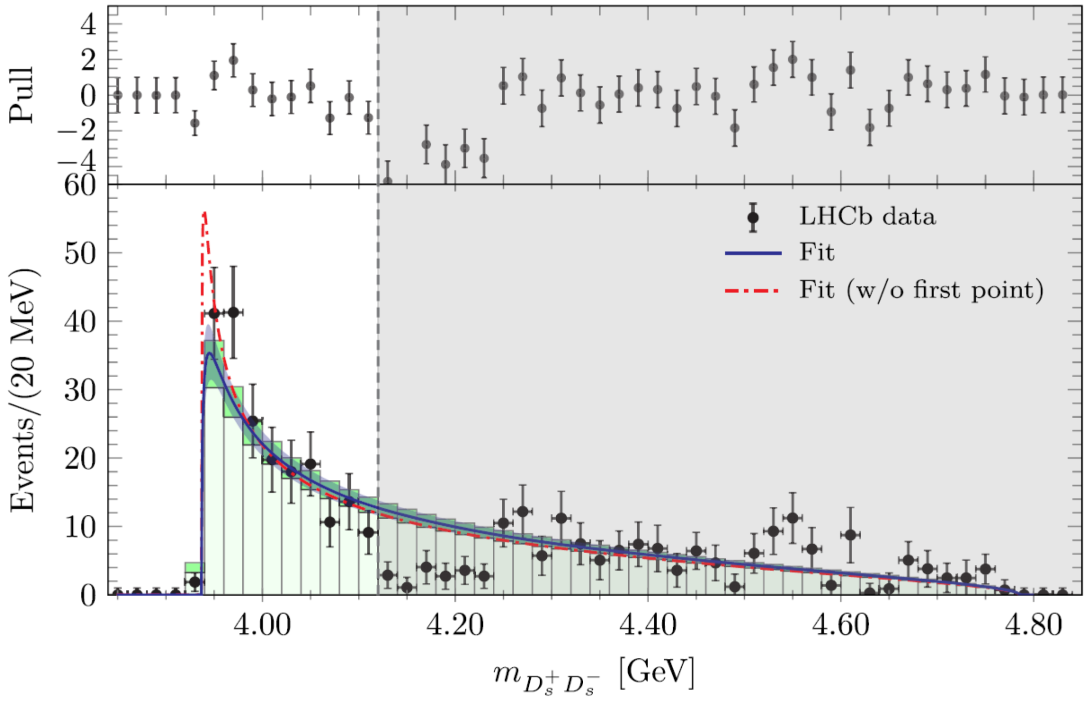
The strange partner of the Z_c structures in a coupled-channels model

Pablo G. Ortega[a,*], David R. Entem[b], Francisco Fernández[b]

Physics Letters B 814 (2021) 136120
Contents lists available at ScienceDirect
Physics Letters B
www.elsevier.com/locate/physletb

The $Z_{cs}(3985)$ as a threshold effect from the $\bar{D}_s^* D + \bar{D}_s D^*$ interaction

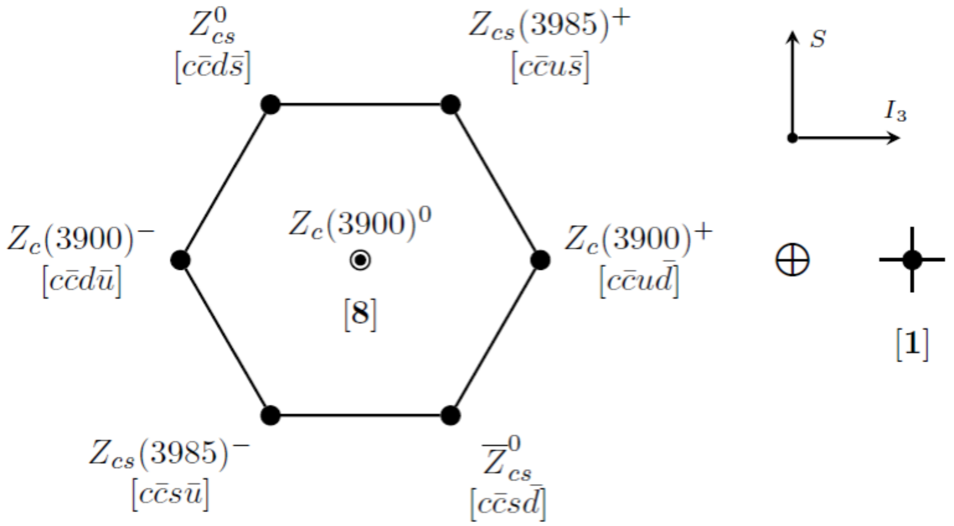
Natsumi Ikeno[a,b,*], Raquel Molina[b], Eulogio Oset[b]



New measurements have allowed determining the lowest-order LECs of the $D_{(s)}^{(*)}\bar{D}_{(s)}^{(*)}$ EFT based on HQSS

LHCb $B^+ \longrightarrow D_s^+ D_s^- K^+$

$D_s^+ D_s^-$ invariant mass



Establishing the heavy quark spin and light flavour molecular multiplets of the X(3872), Zc(3900), and X(3960), T. Ji et al., Phys.Rev.D 106 (2022) 094002. PREDICTION OF NEW EXOTIC STATES AND SU(3) CLASSIFICATION

$$\mathcal{L}_{4H} = -\frac{1}{4}\mathrm{Tr}[H^{a\dagger}H_b]\mathrm{Tr}[\bar{H}^c\bar{H}_d^\dagger](F_A\delta_a^b\delta_c^d + F_A^\lambda\vec{\lambda}_a^b\cdot\vec{\lambda}_c^d)$$
$$+\frac{1}{4}\mathrm{Tr}[H^{a\dagger}H_b\sigma^m]\mathrm{Tr}[\bar{H}^c\bar{H}_d^\dagger\sigma^m](F_B\delta_a^b\delta_c^d + F_B^\lambda\vec{\lambda}_a^b\cdot\vec{\lambda}_c^d).$$

and many other works on other exotic states…

Production of the $X(4014)$ as the spin-2 partner of $X(3872)$ in e^+e^- collisions — P.-P- Shi et al., *Chin.Phys.Lett.* 41 (2024) 031301

Predicting isovector charmonium-like states from $X(3872)$ properties — Z.-H. Zhang et al., 2404.11215

Can the two-pole structure of the $D_0^*(2300)$ be understood from recent lattice data? — A. Asokan et al., Eur.Phys.J.C 83 (2023) 850

Revisiting the nature of the P_c pentaquarks — M.-L. Du et al., *JHEP* 08 (2021) 157

Two states for the $\Xi(1820)$ resonance — R. Molina et al., 2309-03618

Double-Strangeness Molecular-Type Pentaquarks from Coupled-Channel Dynamics — J.A. Marsé-Valera et al., *Phys.Rev.Lett.* 130 (2023) 9

Theoretical interpretation of the $D_s^+ \to \pi^+\pi^0\eta$ decay and the nature of $a_0(980)$ — R. Molina et al., *Phys.Lett.B* 803 (2020) 135279

Article

Is the existence of a $J/\psi J/\psi$ bound state plausible?

X.-K. Dong et al., *Sci.Bull.* 66 (2021) 2462

X.-K. Dong et al., *Coupled-Channel Interpretation of the LHCb Double-J= Spectrum and Hints of a New State Near the J/ψ J/ψThreshold*, Phys. Rev. Lett. **126**, 132001 (2021)

spectroscopy of double-charmonium and double-bottomonium states

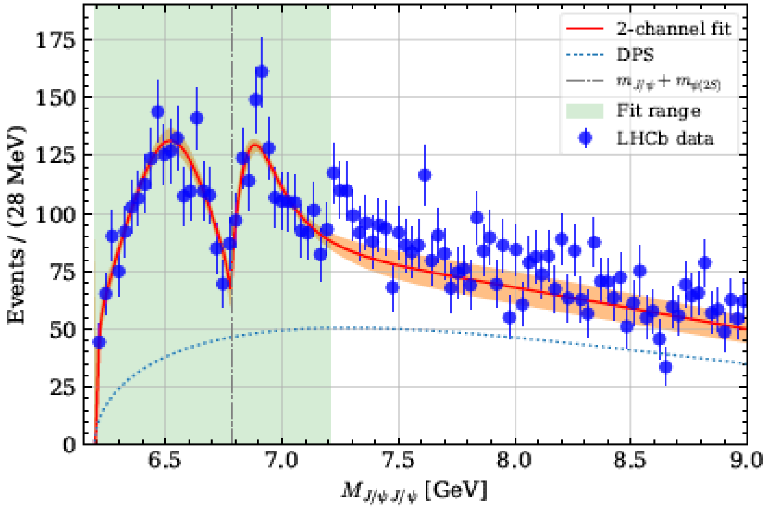
SciPost

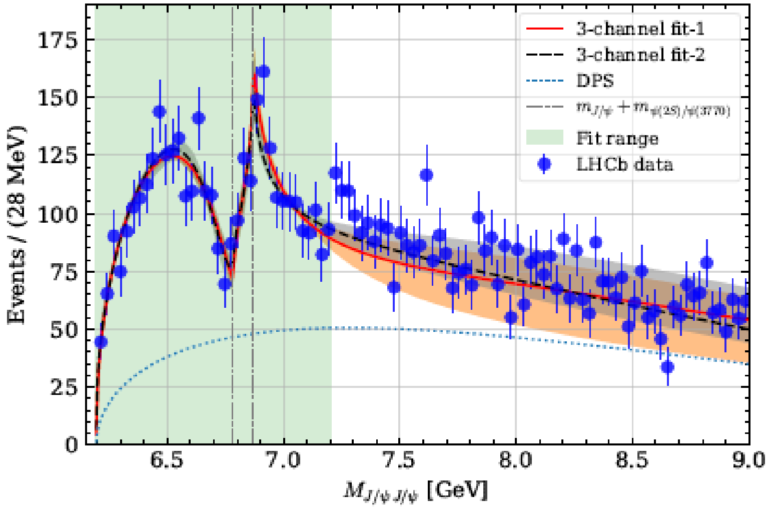
SciPost Phys. Proc. 6, 007 (2022)

Double-J/ψ system in the spotlight of recent LHCb data

V. Baru[1,2], X.-K. Dong[3,4], F.-K. Guo[3,4], C. Hanhart[5], A. Nefediev[6*] and B.-S. Zou[3,4,7]

consistent with unitarity: (i) with just two channels, J/ψJ/ψ and $\psi(2S)$J/ψ, as long as energy-dependent nteractions in these channels are allowed, or (ii) with three channels J/ψJ/ψ, $\psi(2S)$J/ψ and $\psi(3770)$J/ψ with just constant contact interactions. Both formulations hint at the existence of a near threshold state in the J/ψ J/ψ system with the quantum numbers $J^{PC} = 0^{++}$ or 2^{++} which we refer to as $X(6200)$.





Recently the LHCb Collaboration announced intriguing results on the double-J/ψ production in proton-proton collisions. A coupled-channel interpretation of the measured di-J/ψ spectrum is presented and a possible nature of the proposed near-threshold state $X(6200)$ is discussed.

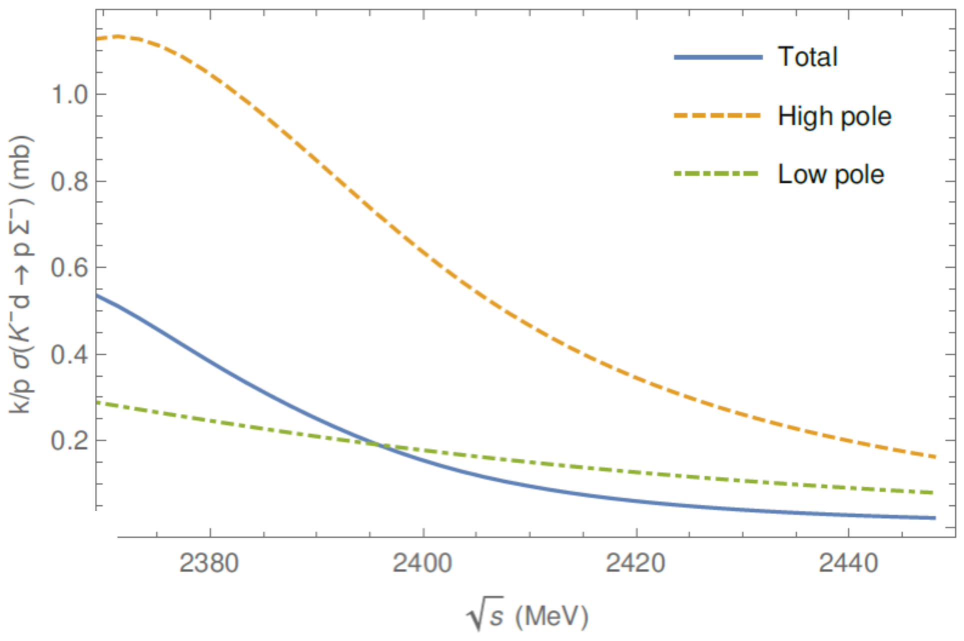
✴Sensitivity to non-perturbative effects to identify exotic quark configurations

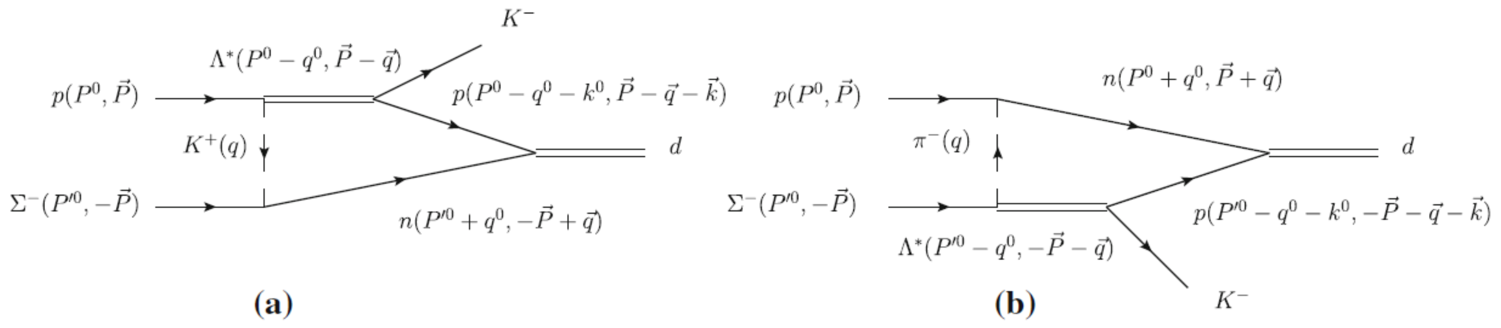
- Study of reactions disclosing the nature of the low-lying scalar mesons: different observables for the $D_s \to \pi^+\pi^0\eta$,$D^+ \longrightarrow \pi^+\eta\eta$,$D^+ \longrightarrow \pi^+\pi^0\eta$,$D^+ \longrightarrow K^-K^+K^+$, $D^0 \longrightarrow K^-\pi^0\eta$, $J/\psi \to \gamma\pi\pi, \gamma\pi\eta$, $a_1(1260) \longrightarrow \pi f_0(500)$, reactions to test the nature of the scalar mesons ($f_0(500)$, $f_0(980)$, $a_0(980)$ ...), [f. i. R. Molina, M. Döring, W. H. Liang, E. Oset, *Eur.Phys.J.C* 81 (2021) 782,…]

- Study of hadron molecules from the weak decay of heavy hadrons: double pole structure of the $K_1(1270)$ resonance, analyzed in the $\bar{B} \longrightarrow J/\psi\rho\bar{K}$, $\bar{B} \longrightarrow J/\psi\, K^*\pi$ and $D^+ \longrightarrow \nu e^+VP$ decays [L. Roca, W.H. Liang, E. Oset, Phys.Lett. B824 (2022) 136827

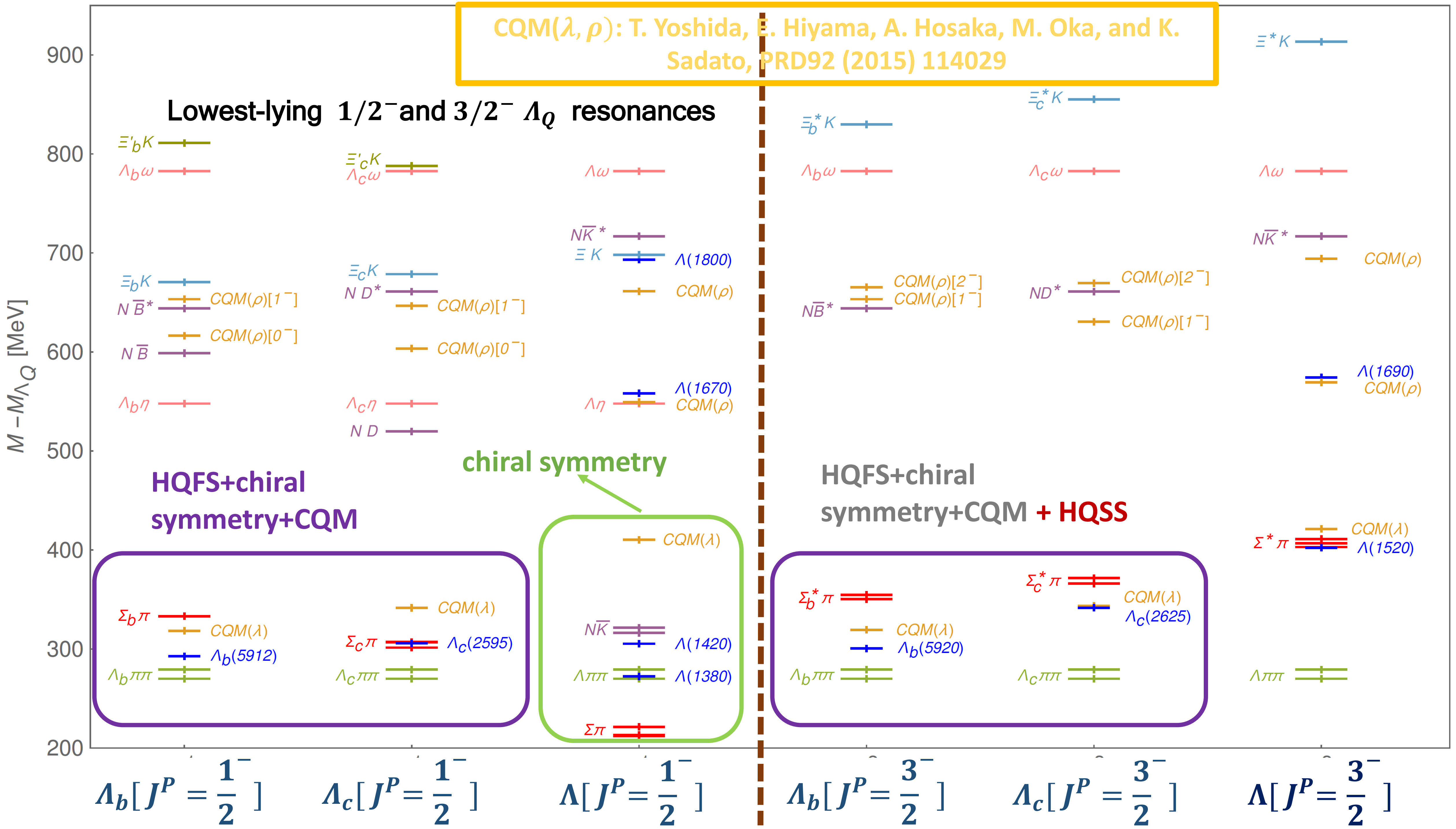
- Characteristics of some reactions in base to triangle singularities (TS) and making predictions of reactions where peaks associated to TS appear, to avert claims of discovery of new resonances when the experiments are performed

*sensitivity of the $K^-d \longrightarrow p\Sigma^-$ reaction to the properties of the $\Lambda(1405)$ resonance, which enhances the contribution of a **triangle-diagram mechanism** that dominates the reaction close to threshold*

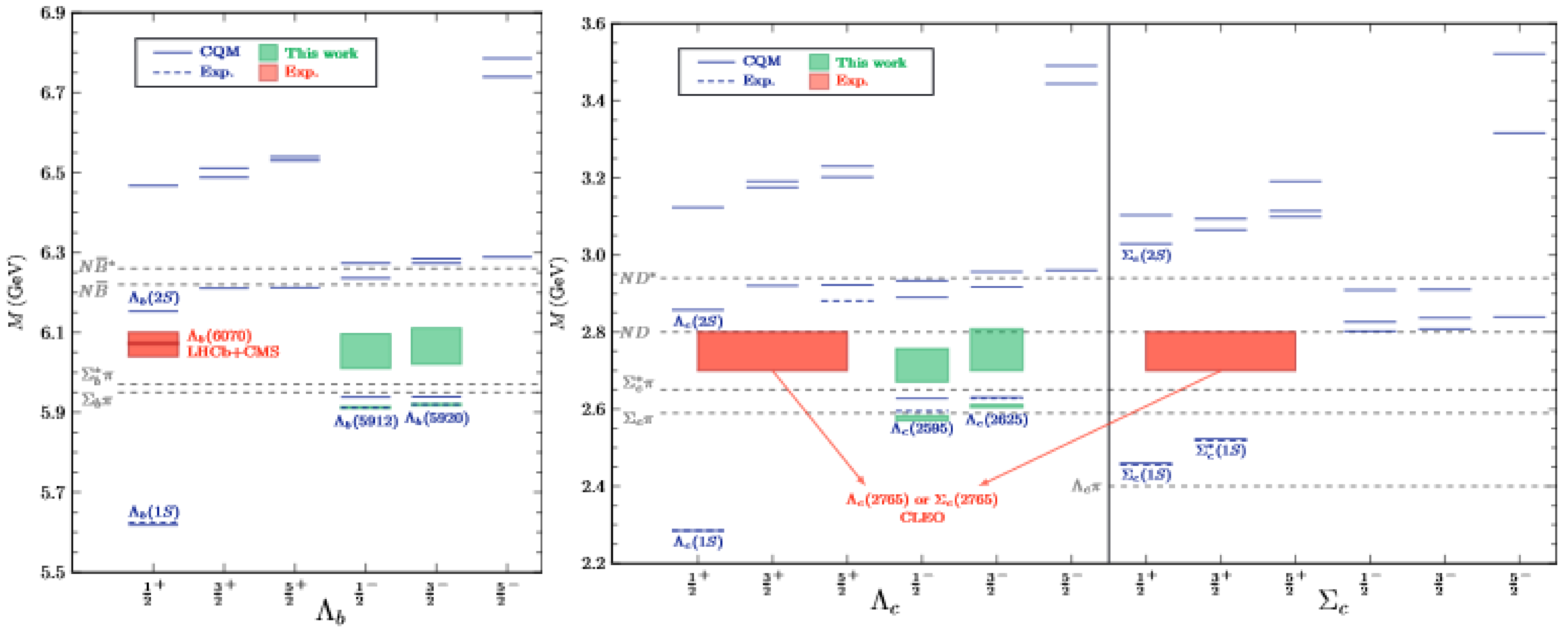




A. Feijoo, R. Molina, L.R. Dai, E. Oset
Eur.Phys.J.C 82 (2022) 11, 1028



CQM(λ, ρ): T. Yoshida, E. Hiyama, A. Hosaka, M. Oka, and K. Sadato, PRD92 (2015) 114029
Lowest-lying 1/2⁻ and 3/2⁻ Λ_Q resonances
M − M_{Λ_Q} [MeV]
900
800
700
600
500
400
300
200
Ξ'_b K
Λ_b ω
Ξ_b K
CQM(ρ)[1⁻]
N B̄*
CQM(ρ)[0⁻]
N B̄
Λ_b η
Σ_b π
CQM(λ)
Λ_b(5912)
Λ_b ππ
Ξ'_c K
Λ_c ω
Ξ_c K
N D*
CQM(ρ)[1⁻]
CQM(ρ)[0⁻]
Λ_c η
N D
CQM(λ)
Σ_c π
Λ_c(2595)
Λ_c ππ
Λ ω
N K̄*
Ξ K
Λ(1800)
CQM(ρ)
Λ(1670)
Λ η
CQM(ρ)
CQM(λ)
N K̄
Λ(1420)
Λ ππ
Λ(1380)
Σ π
Ξ*_b K
Λ_b ω
CQM(ρ)[2⁻]
CQM(ρ)[1⁻]
N B̄*
Σ*_b π
CQM(λ)
Λ_b(5920)
Λ_b ππ
Ξ*_c K
Λ_c ω
ND*
CQM(ρ)[2⁻]
CQM(ρ)[1⁻]
Σ*_c π
CQM(λ)
Λ_c(2625)
Λ_c ππ
Ξ* K
Λ ω
N K̄*
CQM(ρ)
Λ(1690)
CQM(ρ)
CQM(λ)
Σ* π
Λ(1520)
Λ ππ
chiral symmetry
HQFS+chiral symmetry+CQM
HQFS+chiral symmetry+CQM + HQSS
Λ_b[J^P = 1/2⁻]
Λ_c[J^P = 1/2⁻]
Λ[J^P = 1/2⁻]
Λ_b[J^P = 3/2⁻]
Λ_c[J^P = 3/2⁻]
Λ[J^P = 3/2⁻]



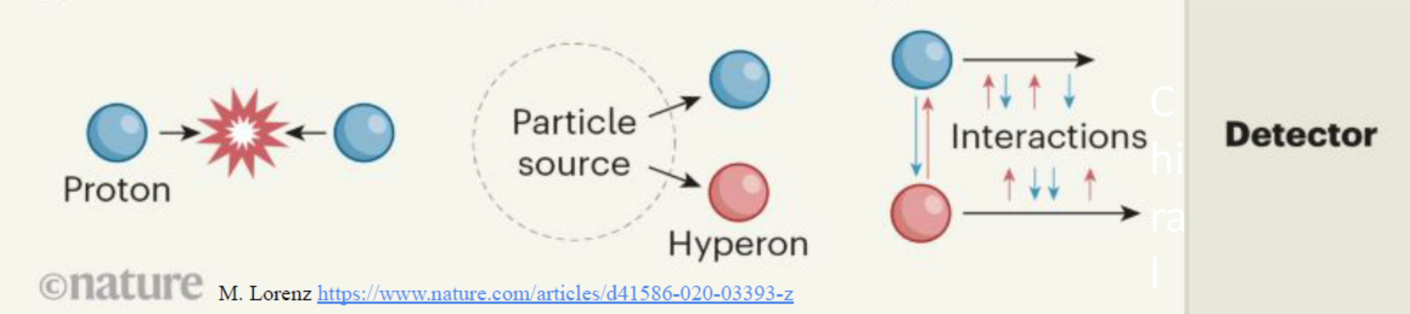
Lowest-lying $1/2^{-}$ and $3/2^{-}$ Λ_Q resonances: From the strange to the bottom sectors, *Prog.Part.Nucl.Phys.* 137 (2024) 104118

special attention to the interplay between the constituent quark-model and chiral baryon-meson degrees of freedom

Femtoscopy method in nucleus-nucleus collisions

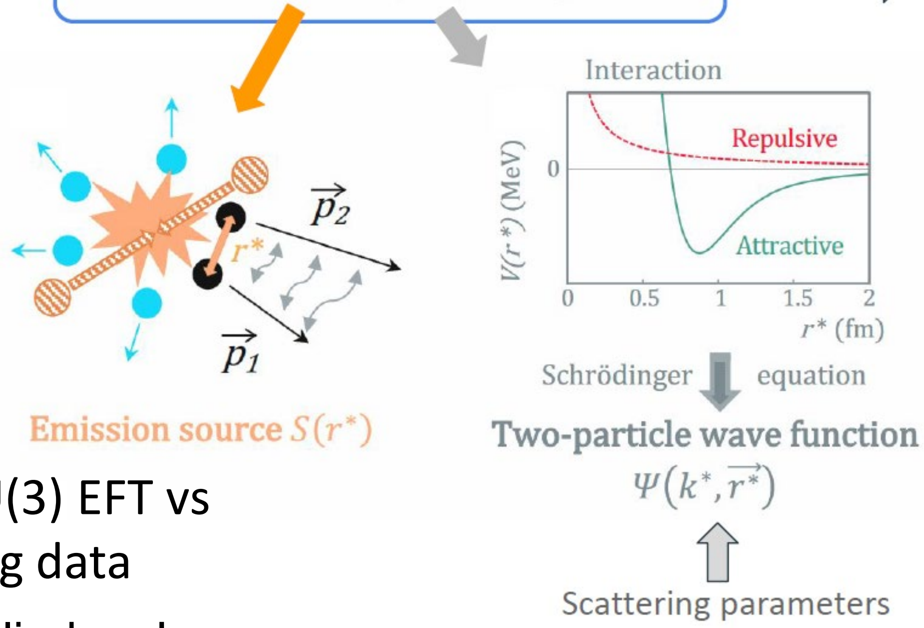
Measurement of the correlation function of two particles emitted a nucleus-nucleus collision

$$C(\overrightarrow{p_a}, \overrightarrow{p_b}) = \frac{P(\overrightarrow{p_a}, \overrightarrow{p_b})}{P(\overrightarrow{p_a})P(\overrightarrow{p_b})}$$

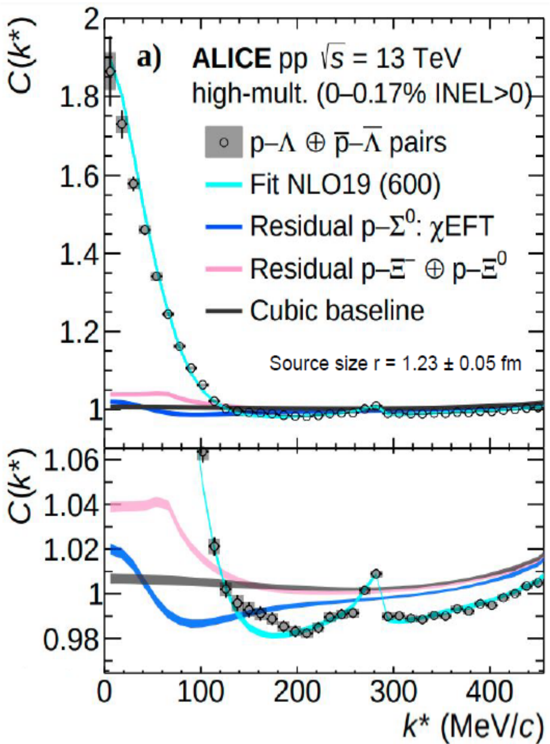


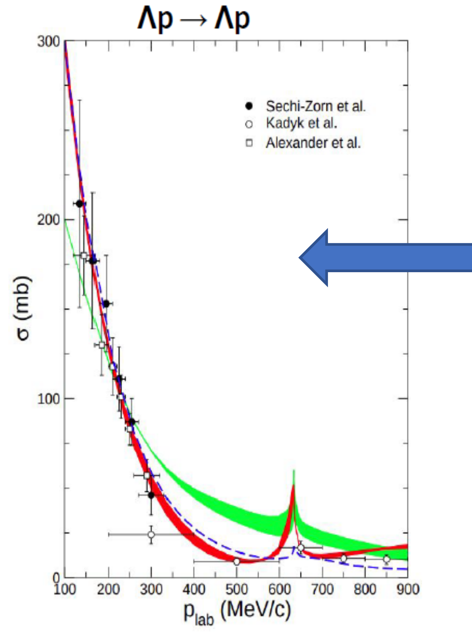
Theoretical correlation

$$C(k^*) = \int S(r^*)\, \left|\Psi(k^*, \overrightarrow{r^*})\right|^2 d^3r^*$$



p–Λ interaction





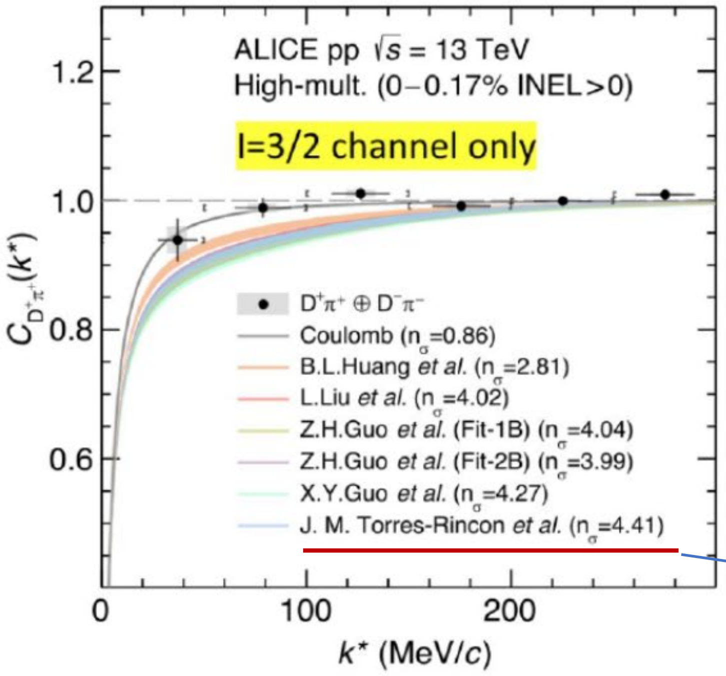
ALICE Coll. Phys.Lett.B 833 (2022) 137272

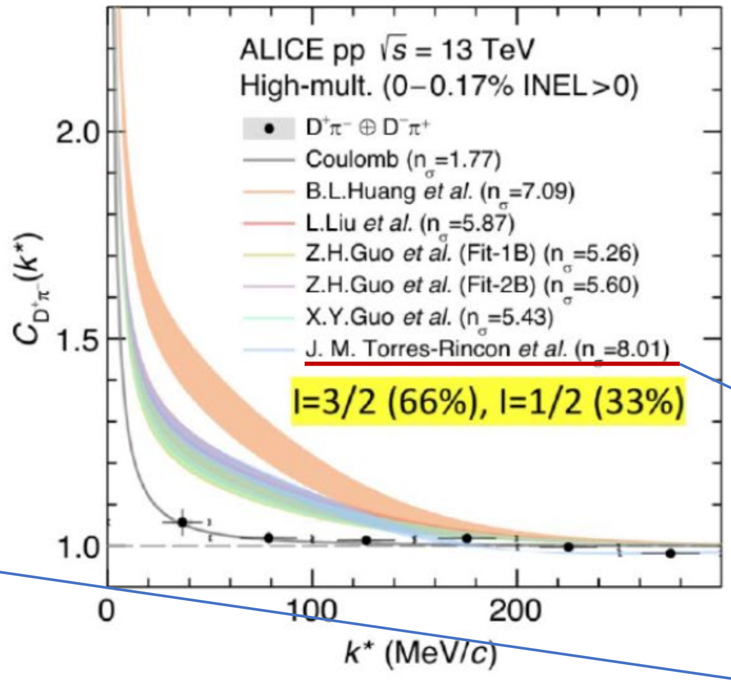
Theory: Haidenbauer et al., Eur. Phys. J. A 56 (2020)

Chiral SU(3) EFT vs scattering data

LO: H. Polinder, J. Haidenbauer, U. Meißner, Nucl. Phys. A779 (2006) 244.
NLO: J. Haidenbauer et al., Nucl. Phys. A915 (2013) 24.

Courtesy by O. Vazquez Doce



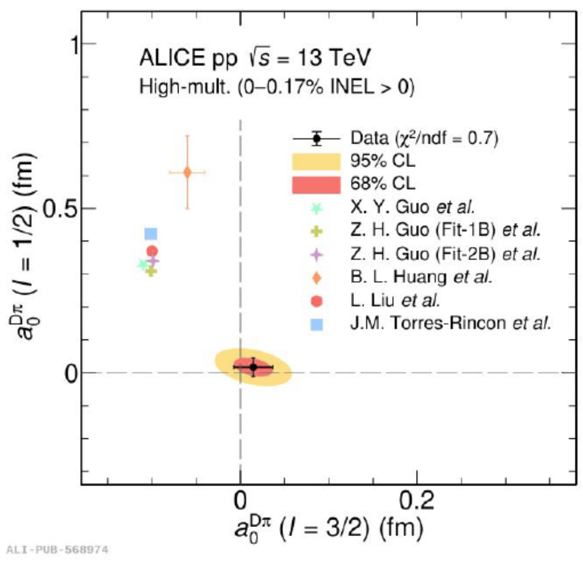


$D^+\pi^- \oplus D^-\pi^+$ Correlation Functions

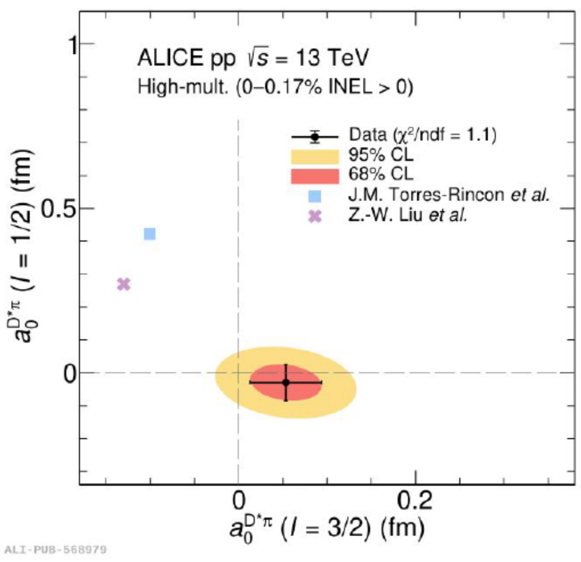
O. Vazquez Doce @ "Present and future perspectives in hadron physics", Frascati (INFN), June'24

Phys. Rev. D 108 (2023) 9, 096008

$D\pi$



$D^*\pi$



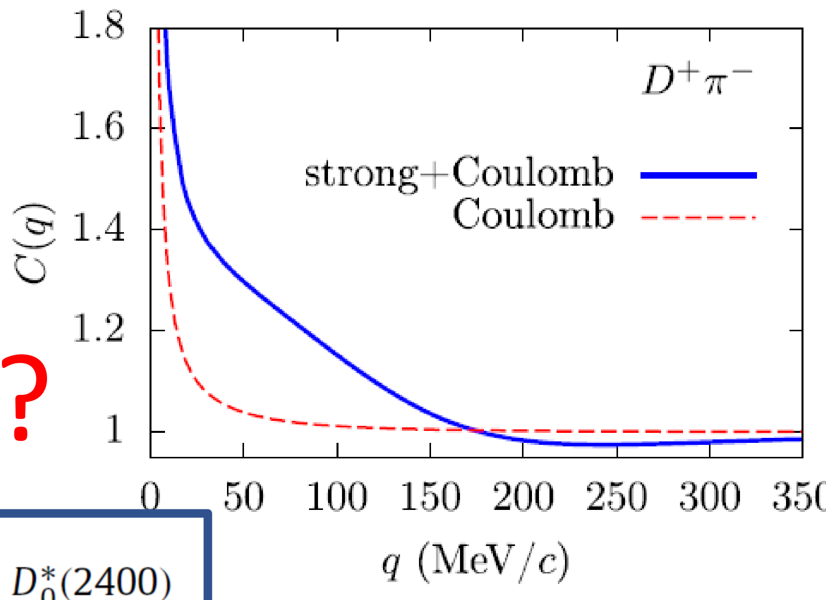
Small scattering lengths:

- compatible with Coulomb-only assumption
- theory overestimates interaction strength

Scattering lengths similar for Dπ and D*π:

- heavy-quark spin symmetry

??



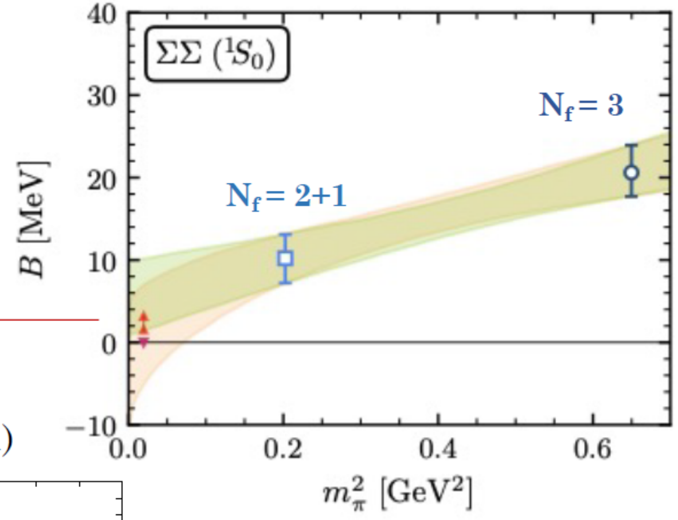
Two-pole structure of the $D_0^*(2400)$

Progress in Task 2.1: Hadron resonances, form factors, LECs, fundamental parameters of QCD, and light nuclei spectroscopy

NPLQCD

Recent work

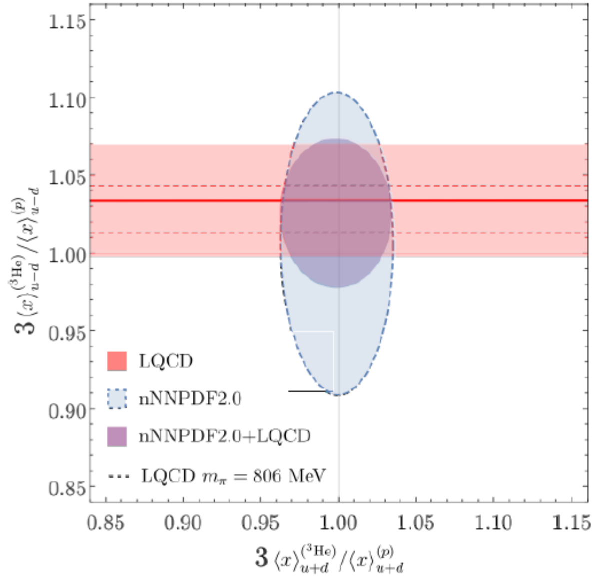
Baryon-Baryon interactions, strangeness from 0 to -4
Phys. Rev. D 103, 054508 (2021) @ m_π ~450 MeV



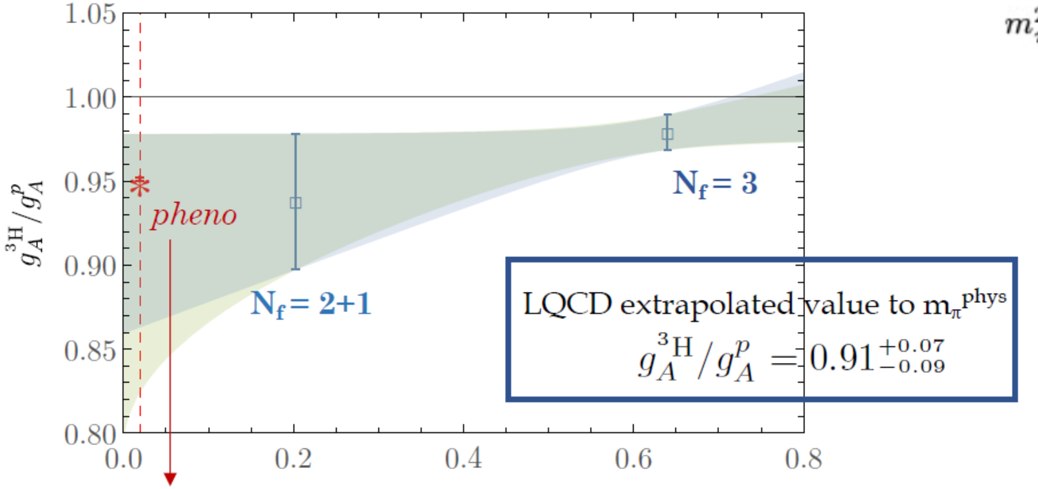
NSC97, χEFT @ NLO

Nuclear matrix elements from LQCD
Phys. Rept. **900**, 1 (2020)

Momentum fraction of ^{3}He
Phys. Rev. Lett. 126, 202001 (2021)



^{3}H axial charge
Phys. Rev. D 103, 074511 (2021)

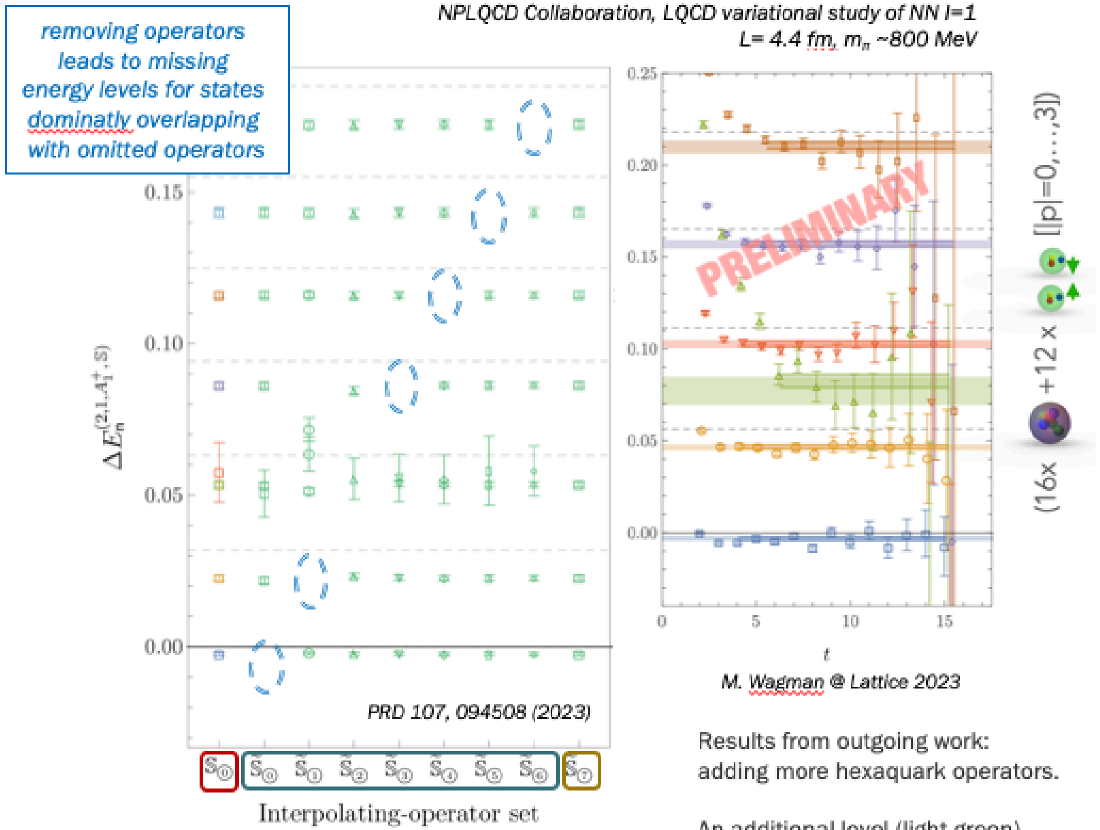


Baroni et al, PRC 94, 024003 (2016); PRC95 059902 (2017)

$g_A^{^3\mathrm{H}}/g_A^p = 0.9511(13)$

- Lattice-QCD variational study of nucleon-nucleon interactions (S. Amarasinghe et al., PRD 107 (2023) 094508) is extended by considering an additional volume and a complete basis of dibaryon and local hexaquark operators (W. Detmold et al, 2404.12039 [hep-lat])

- The combination of dibaryon and hexaquark operators provides strong evidence for the presence of an additional energy level in both the deuteron and dineutron channels.
- Ongoing work focuses on studying Octet Baryon - Octet Baryon scattering at m_π = 170 MeV and controlling lattice artifacts.

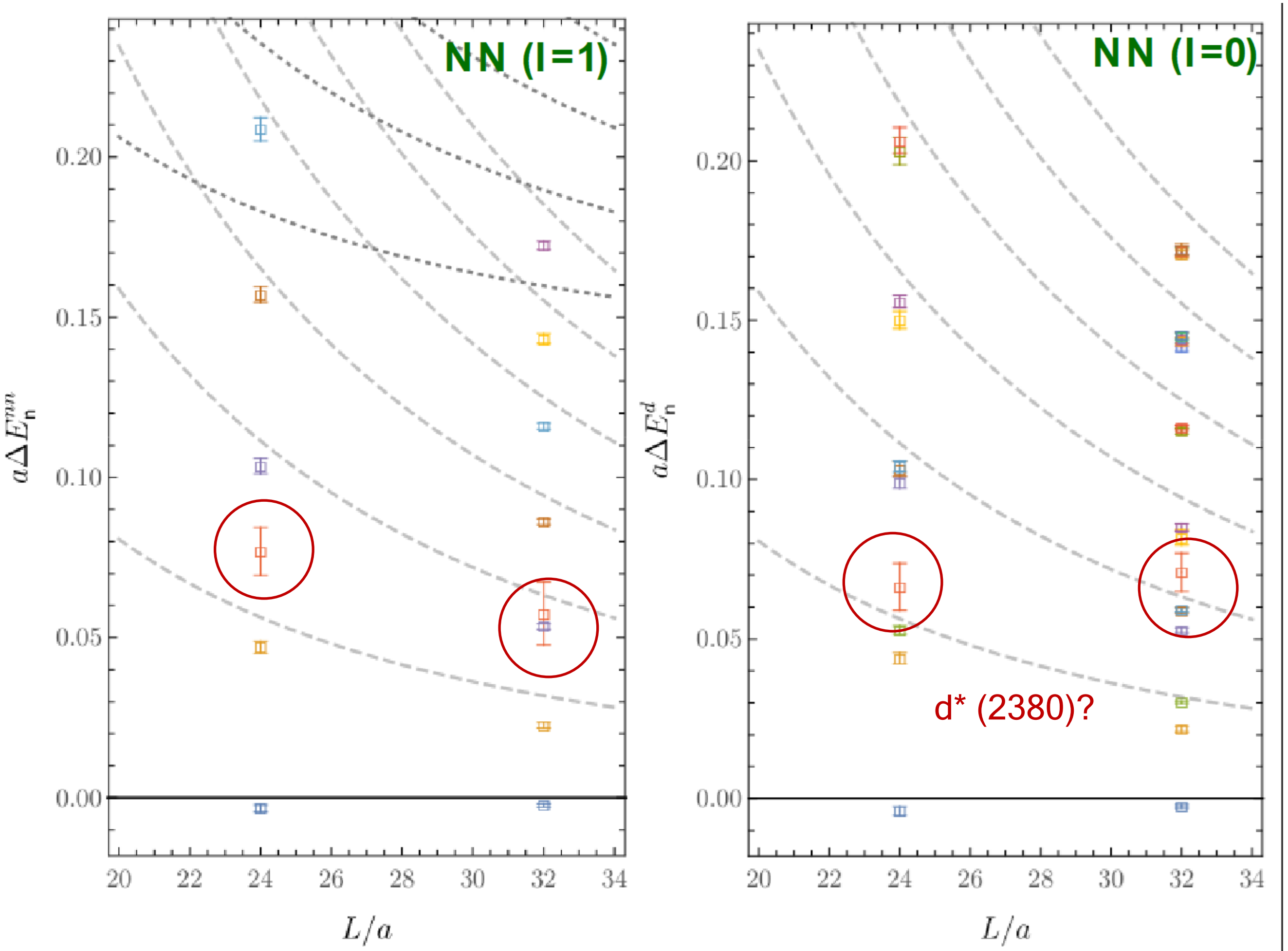


Results from outgoing work: adding more hexaquark operators.

An additional level (light green) appears with overlap onto hexaquark operators

S_0 contains hexaquark and dibaryons ops with different relative momentum

Set taking out a dibaryon op with a given value of the relative momentum



$m_\pi \sim 800\text{MeV}, \; b = 0.1453 \text{ fm}$

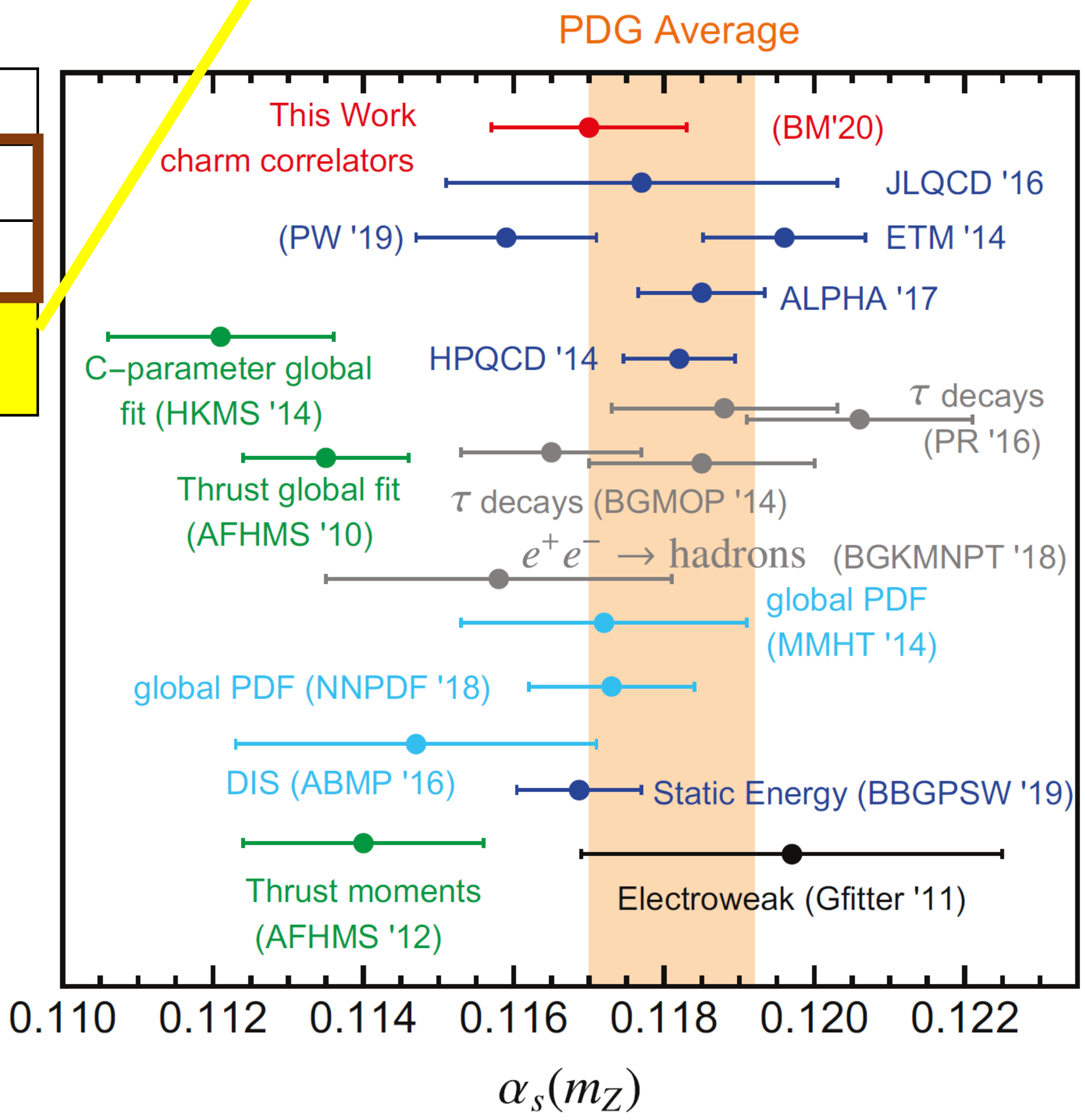
$L_S^3 \times L_T = 32^3 \times 48$ and $24^3 \times 48$

NPLQCD

Using LQCD, EFTs and data ⇒strong coupling constant α_s

input	$\alpha_s(M_Z)$
static energy	$0.11660^{+0.00110}_{-0.00056}$
singlet free energy at finite temperature	$0.11638^{+0.00095}_{-0.00087}$
dimensionless ratios of roots of the moments charm- and bottom-quark correlators (sum-rules)	0.1170 ± 0.0014

D. Boito and V. Mateu
JHEP 03 (2020) 094



LQCD & EFT and data:, PRD102 074503

Determination of the QCD coupling from the static energy and the free energy, TUMLQCD, A. Bazavov et al., PRD100 114511

- from the static energy at three-loop accuracy
- for the singlet free energy at finite temperature up to distances as small as 0.0081 fm

- **NUCLEAR STRUCTURE WITH CHIRAL FORCES**
- Study of neutron matter with chiral-EFT potentials: benchmark calculations of the energy per particle of pure neutron matter as a function of the baryon density
- Nuclear energy density functional from ab initio calculations
- Nuclei with up to A=6 nucleons with artificial neural network wave functions **(quantum computing and machine-learning techniques)**
- Ab initio calculation of medium-mass and heavy nuclei based on chiral EFT NN+3N forces

INFN, ARGONNE, FERMILAB, JLAB,UB,DARMSTADT: PRC101 045801, PRC104 024315, PRC 106 (2022) 034309, Few Body Syst. 63 (2022)

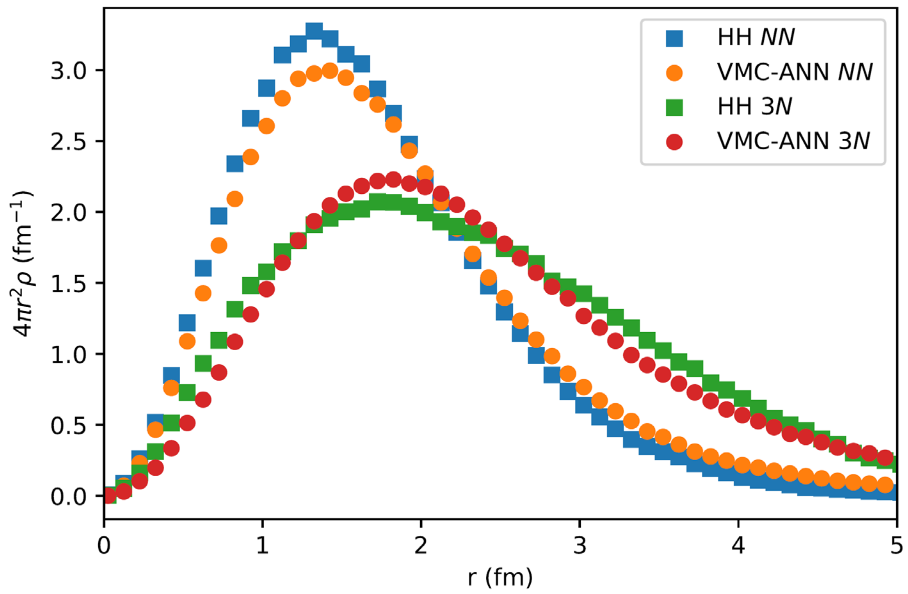


Fig. 3 VMC-A
force only or th

Table 1 Ground-state energies and charge radii for selected $A \leq 6$ nuclei obtained from the ANN and HH methods using as input the leading-order pionless-EFT Hamiltonian with and without the 3N force. We report also the experimental binding-energies from Ref. [50] and the charge radius taken from Refs. [51,52,53,54,55,56].

Nucleus	Potential	ANN		HH		Exp.	
		E (MeV)	r_{ch} (fm)	E (MeV)	r_{ch} (fm)	E (MeV)	r_{ch} (fm)
^{2}H	NN	−2.242(1)	2.120(5)	−2.242	2.110(2)	−2.225	2.128
^{3}H	NN	−9.511(1)	1.658(4)	−9.744	1.656(4)	−8.475	1.755(86)
	$3N$	−8.232(1)	1.750(3)	−8.475	1.747(6)		
^{3}He	NN	−8.800(1)	1.845(3)	−9.035	1.848(6)	−7.718	1.964(1)
	$3N$	−7.564(1)	1.961(3)	−7.811	1.969(8)		
^{4}He	NN	−36.841(1)	1.484(3)	−37.06	1.485(4)	−28.30	1.678
	$3N$	−27.903(1)	1.643(2)	−28.17	1.646(4)		
^{6}He	NN	−37.25(4)	1.895(2)	−37.96(8)	1.71(1)	−29.27	2.05(1)
	$3N$	−27.46(2)	> 4.89(1)	−27.41(8)	> 2.73		
^{6}Li	NN	−42.04(1)	2.248(3)	−42.51(5)	2.09(2)	−31.99	2.54(3)
	$3N$	−30.82(3)	3.049(2)	−31.00(8)	> 2.74		

CHARMED, STRANGE MESONS
($C = \pm1$, $S = \pm1$)
(including possibly non-$q\bar{q}$ states)
$D_s^+ = c\bar{s}$, $D_s^- = \bar{c}s$, similarly for D_s^*'s

PDGID:M172 JSON INSPIRE

$D_{s0}^*(2317)^\pm$

$I(J^P) = 0(0^+)$ J, P need confirmation.

produced in a nuclear medium environment

AUBERT 2006P and CHOI 2015A do not observe neutral and doubly charged partners of the $D_{s0}^*(2317)^+$. See the review on "Heavy Non-$q\bar{q}$ Mesons."

$D_{s0}^*(2317)^\pm$ MASS	2317.8 ± 0.5 MeV
$m_{D_{s0}^*(2317)^\pm} - m_{D_s^\pm}$	349.4 ± 0.5 MeV
$D_{s0}^*(2317)^\pm$ WIDTH	< 3.8 MeV CL=95.0%

$D_{s0}^*(2317)^\pm$ DECAY MODES

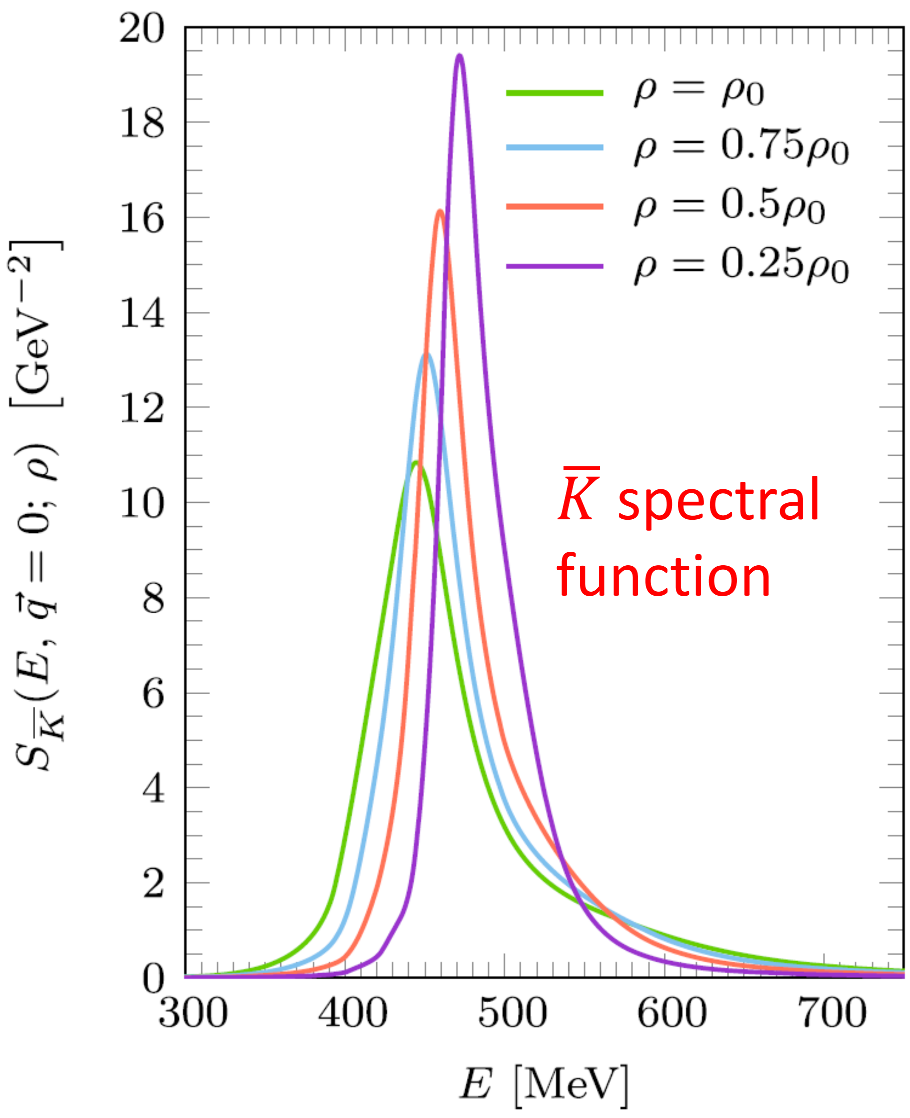
$D_{s0}^*(2317)^-$ modes are charge conjugates of modes below.

Mode		Fraction (Γ_i/Γ)	Scale Factor/ Conf. Level	P(MeV/c)
Γ_1	$D_s^+\pi^0$	$(100^{+0}_{-20})\%$		298
Γ_2	$D_s^+\gamma$	$< 5\%$	CL=90%	323
Γ_3	$D_s^*(2112)^+\gamma$	$< 6\%$	CL=90%	
Γ_4	$D_s^+\gamma\gamma$	$< 18\%$	CL=95%	323
Γ_5	$D_s^*(2112)^+\pi^0$	$< 11\%$	CL=90%	
Γ_6	$D_s^+\pi^+\pi^-$	$< 4 \times 10^{-3}$	CL=90%	194
Γ_7	$D_s^+\pi^0\pi^0$	not seen		205

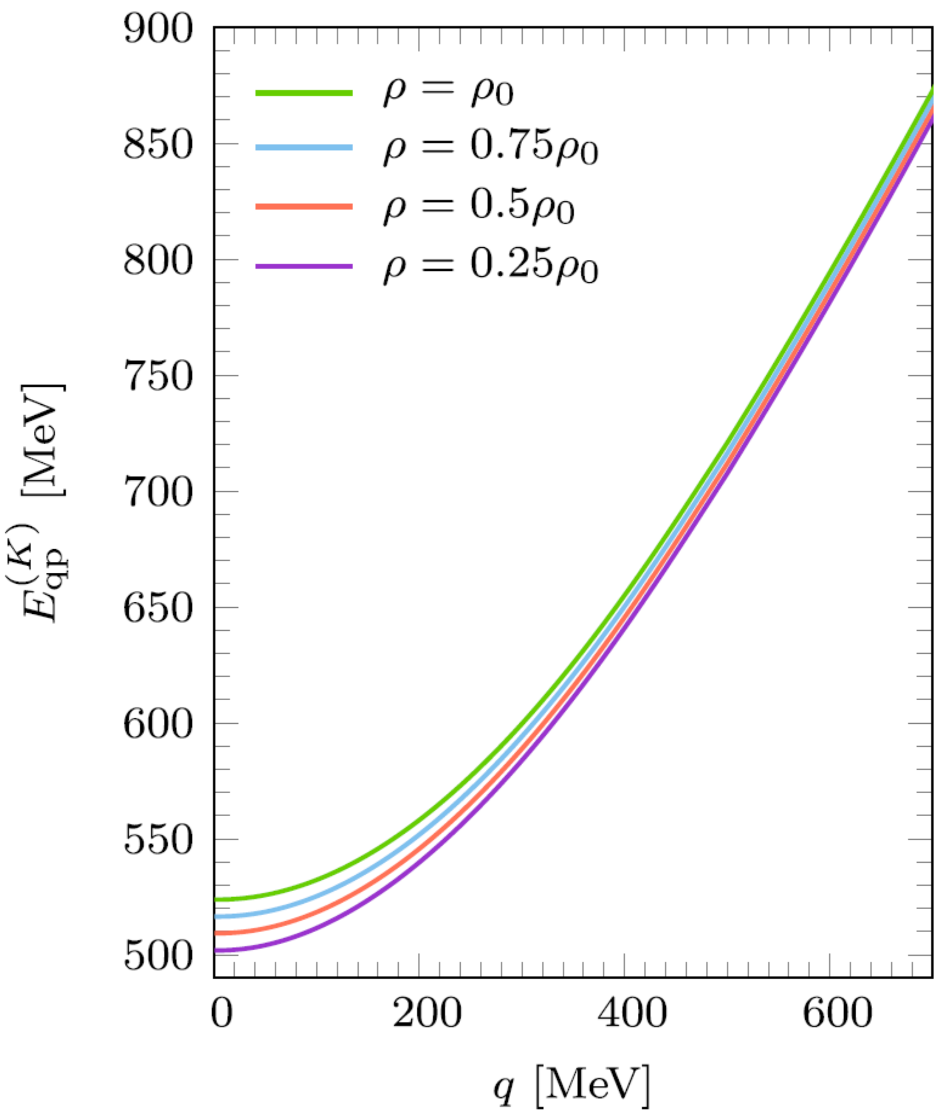
Isoscalar $J^P = 0^+$ exotic resonance $D_{s0}^*(2317)^\pm$

- quark content: $c\bar{s}$, $\bar{c}s$
- it cannot be accommodated in CQMs: around 100 MeV lighter than expected
- Molecular picture $D\bar{K}$ and $\bar{D}K$

KN and $\bar{K}N$ interactions very different!



$\bar{K}N \to \bar{K}N$: it appears strong hyperon resonances like $\Lambda(1405), \Lambda(1670)$, etc..



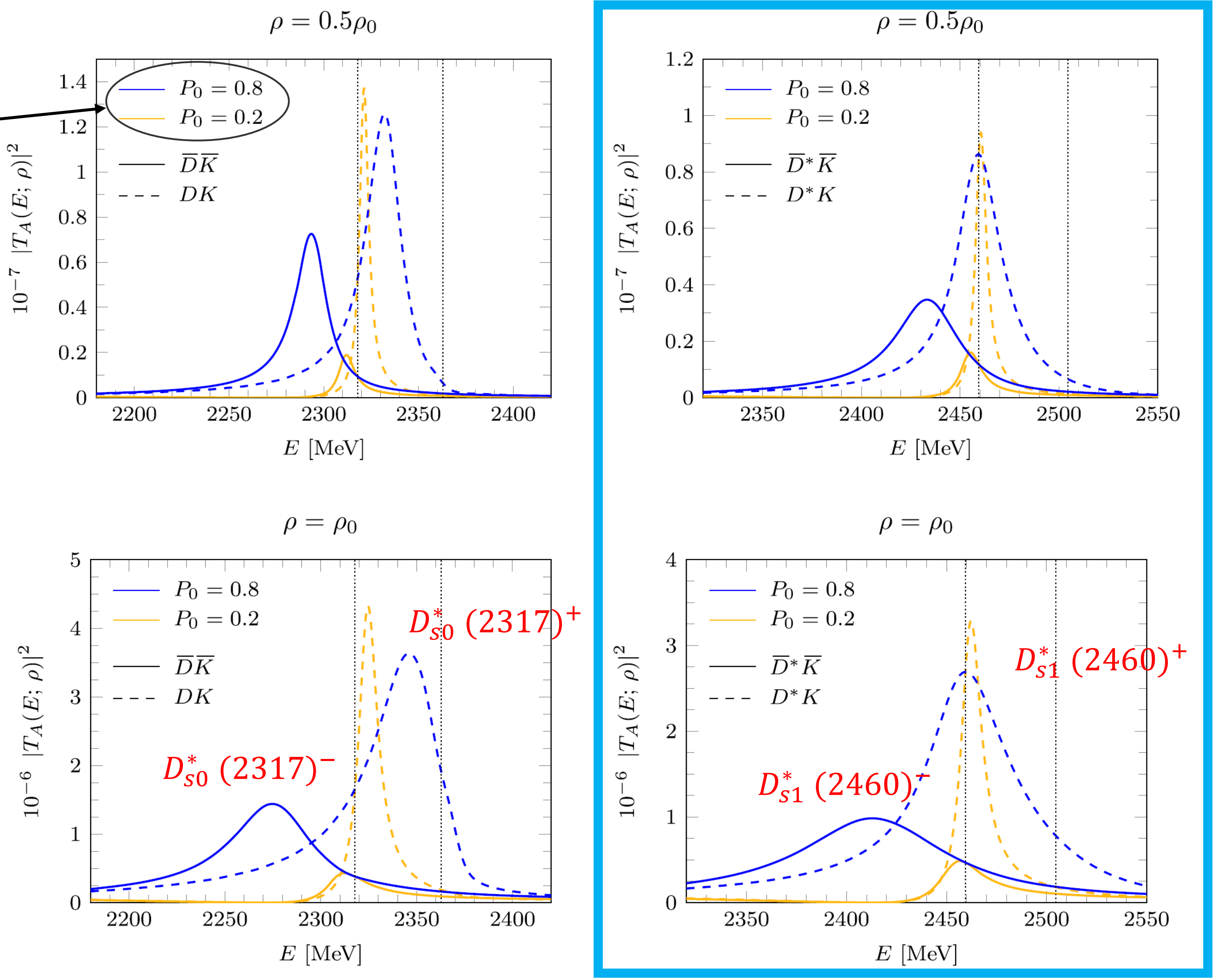
$$S_K(E, q; \rho) \approx \frac{\delta\left(E - E_{\rm qp}(q;\rho)\right)}{2E_{\rm qp}(q;\rho)}$$

Kaon spectral function in the nuclear medium behaves like a delta function, with a small modification (density-dependent) of the quasi-particle energy $E_{qp}^{(K)}$

KN: $\bar{s}\ell_1\ell_2\ell_3\ell_4$ resonance would be a pentaquark. Interaction very weak

two molecular probabilities

Line-shapes for different densities and molecular probabilities

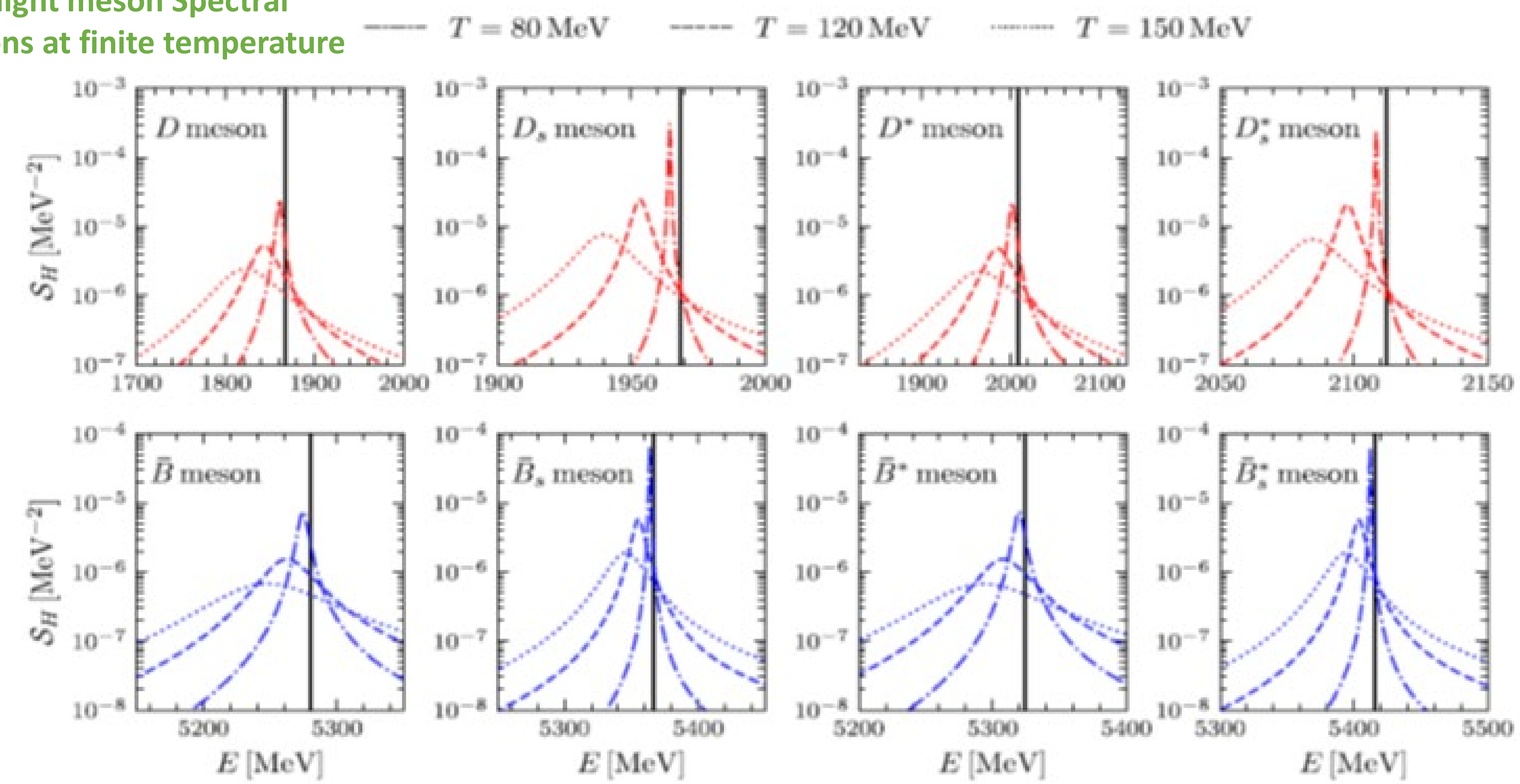


HQSS partner $D_{s1}^*(2460)^{\pm}$ isoscalar $J^P = 1^+$

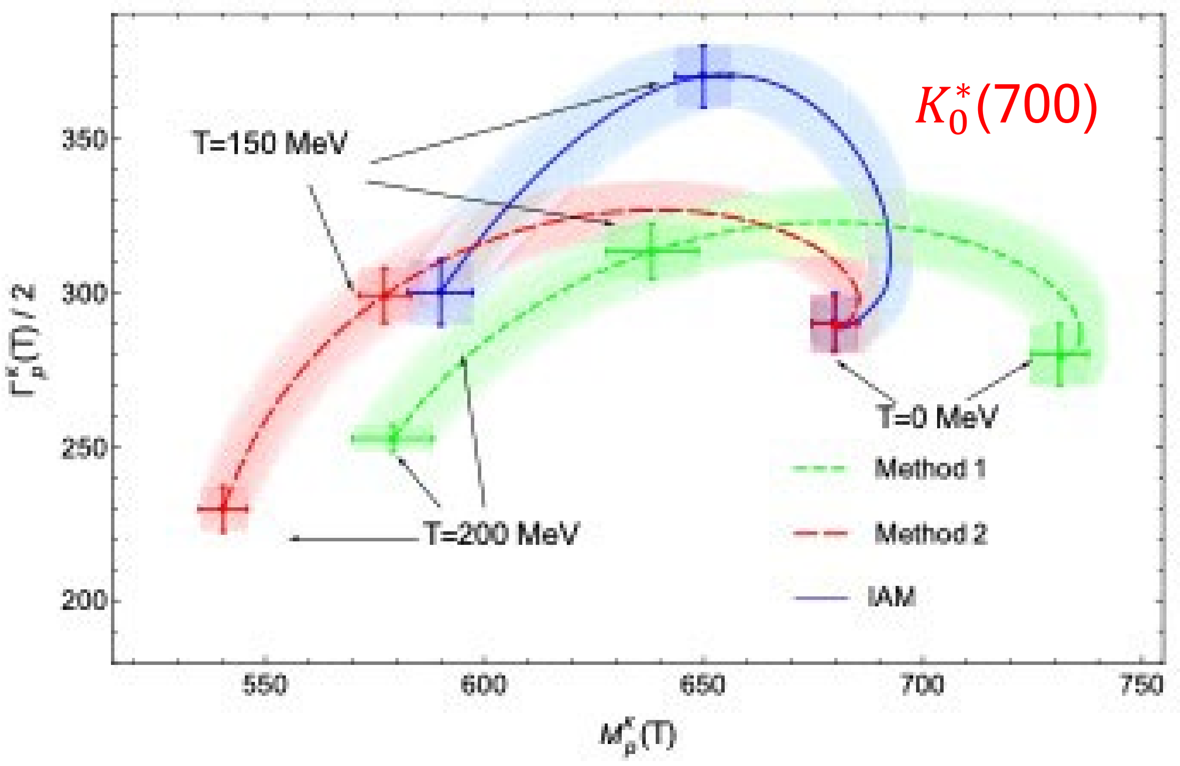
D^*K and $\overline{D}^*\overline{K}$ molecules

Phys. Lett. B 853 (2024) 138656

Heavy-light meson Spectral Functions at finite temperature



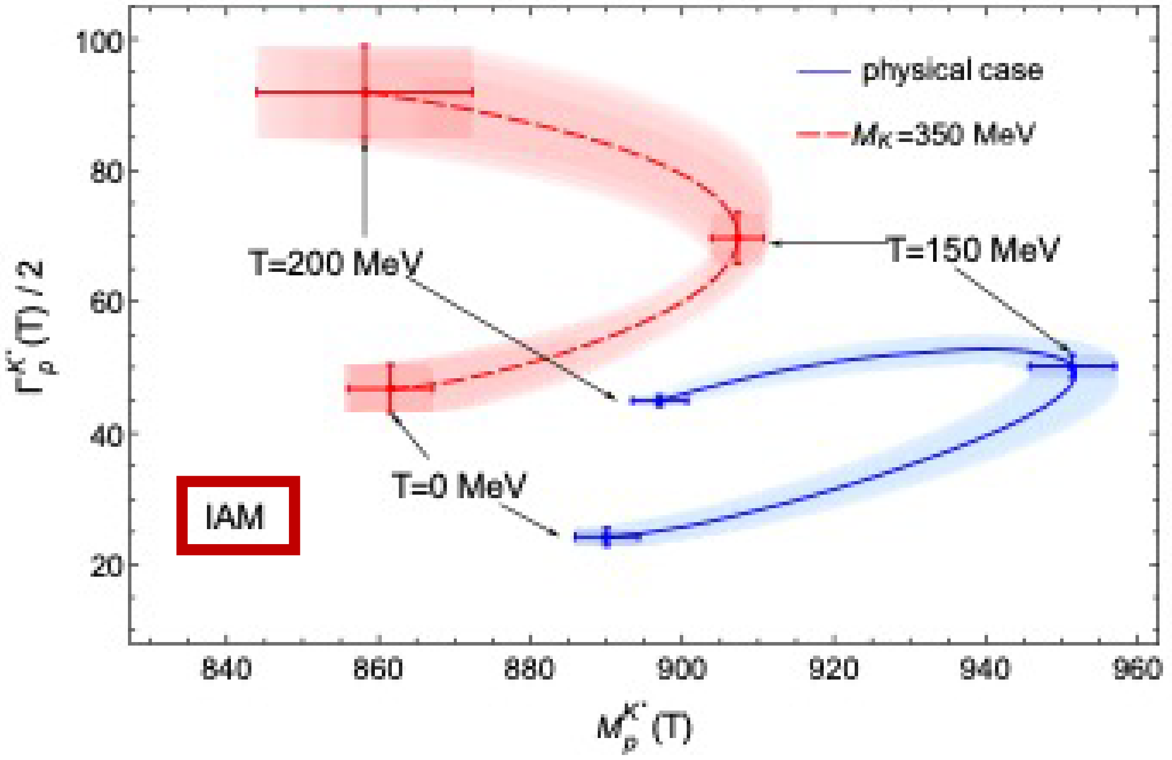
Engagement of young researchers:Gloria Montaña (PhD U. Barcelona) was the 2023 recipient of the APS PhD dissertation award in Hadronic Physics *"For outstanding progress in understanding the properties of heavy mesons in hot matter with the combination of non-perturbative hadronic theories and finite-temperature field theories"*
https://www.aps.org/funding-recognition/award/dissertation-award-hadronic-physics



Temperature dependence of the pole position of the K_0^*(700) and K^* (892) resonances when increasing the temperature T from 0 to 200 MeV

Computed pion-kaon scattering amplitude and the $K_0^*(700)$ and $K^*(892)$ resonances at finite temperature [A. Gómez Nicola, J. Ruiz de Elvira and A. Vioque-Rodríguez,JHEP 08 (2023) 148]

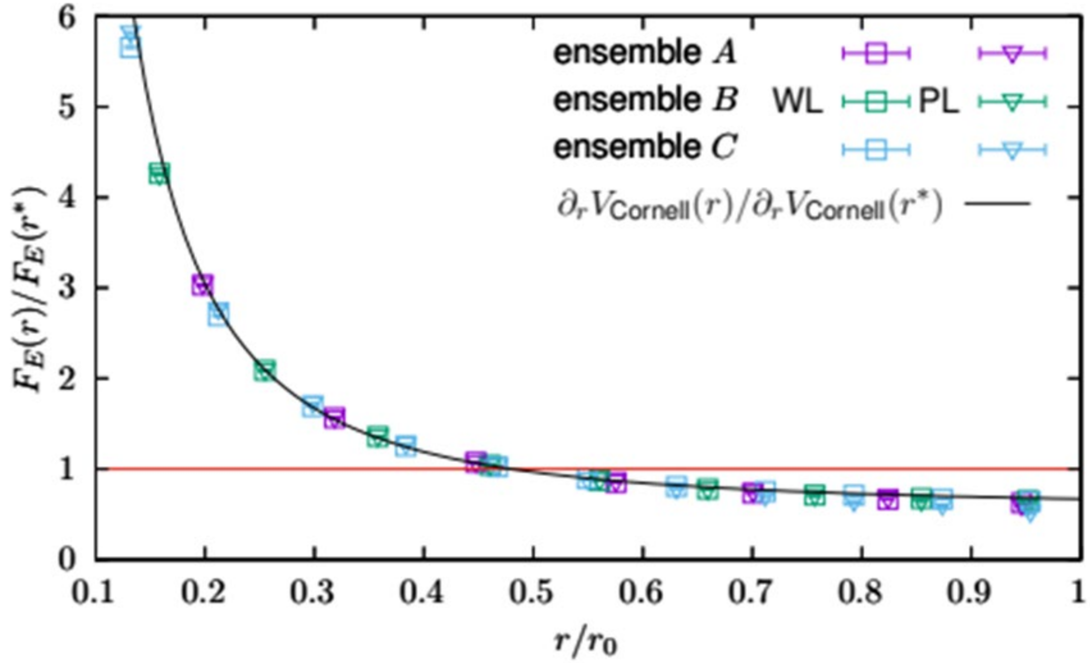
$K^*(892)$



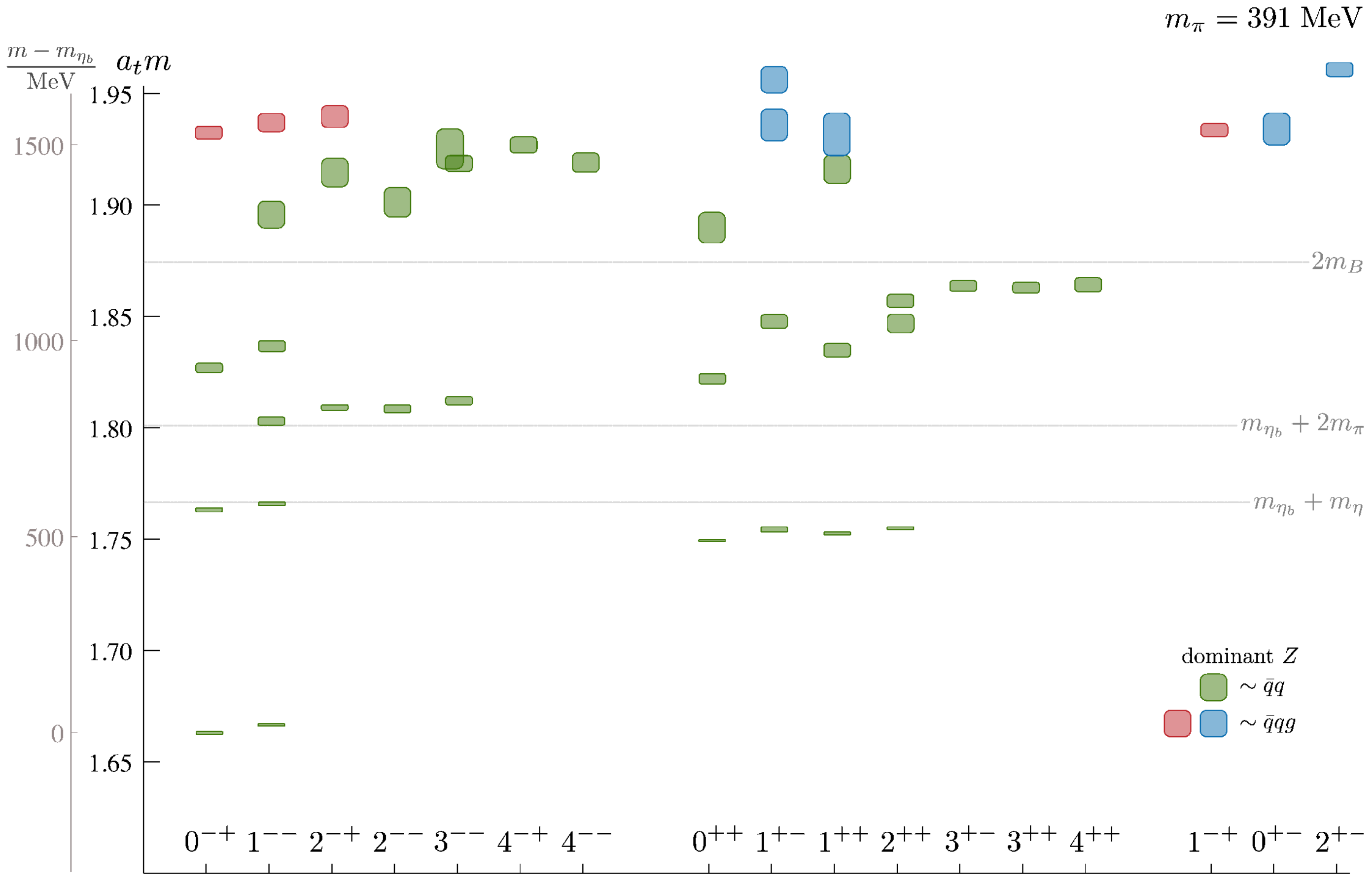
Progress in Tasks 2.2 and 2.3 : heavy-quark, hybrid and tetraquark potentials & Computation of matrix elements for in medium quarkonium evolution

N. Brambilla, V. Leino, O. Philipsen, C. Reisinger, A. Vairo, M. Wagner, Phys.Rev.D 105 (2022) 054514

S. Ryan et al [Hadron Spectrum coll.] JHEP 02 (2021) 214

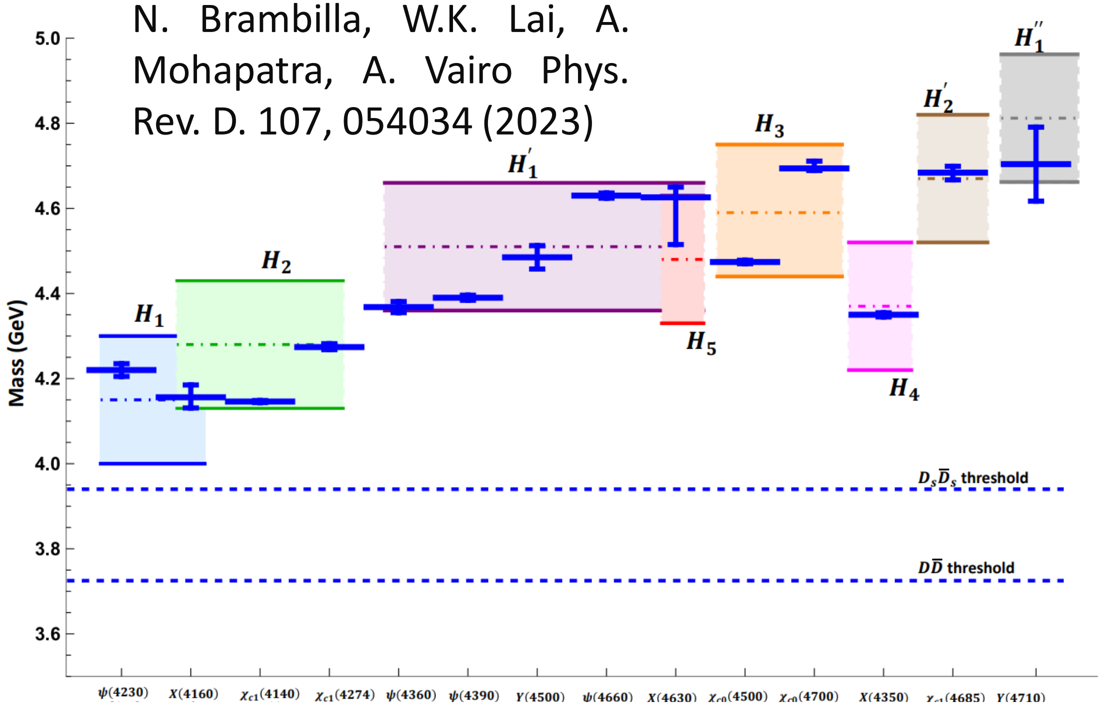


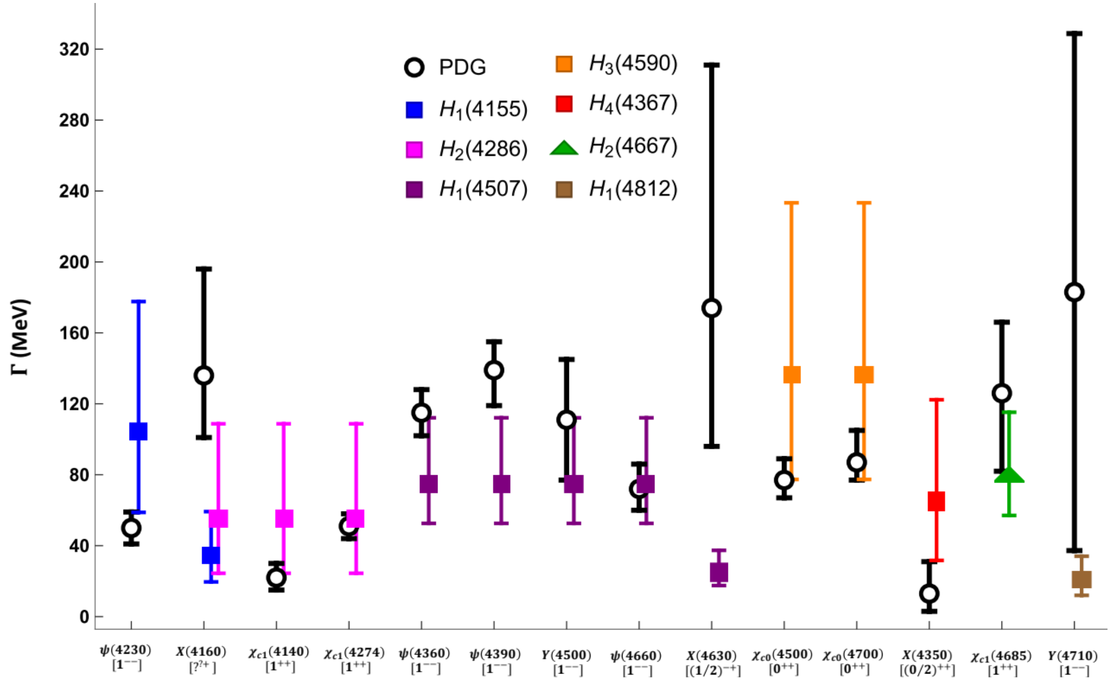
Lattice gauge theory computation of the static force between a static quark and a static antiquark. The approach is based on expectation values of Wilson loops or Polyakov loops with chromoelectric field insertions.

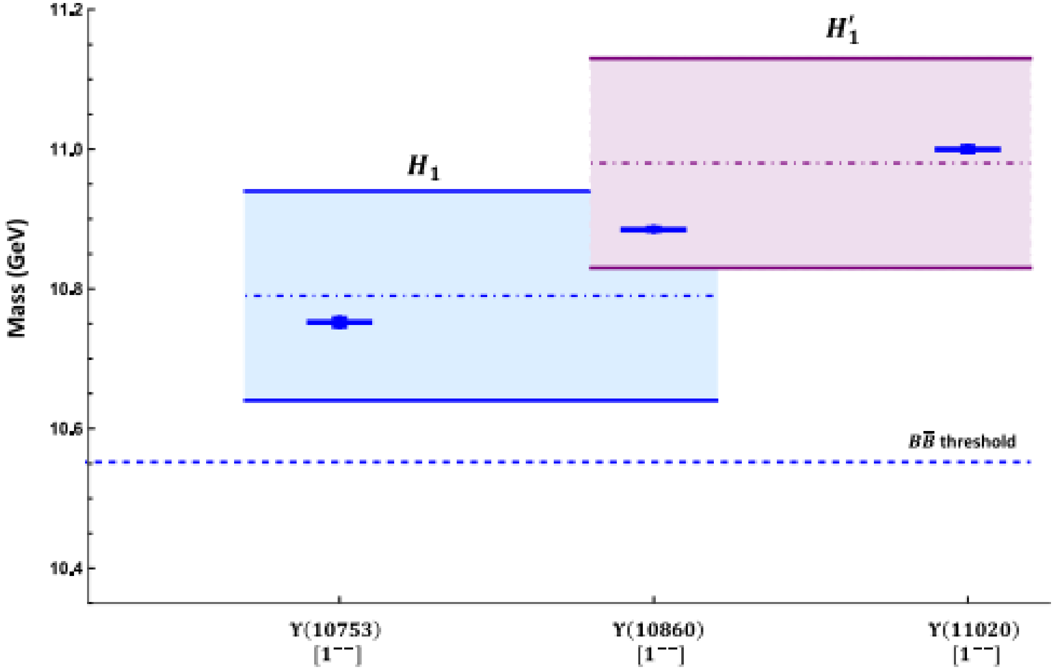


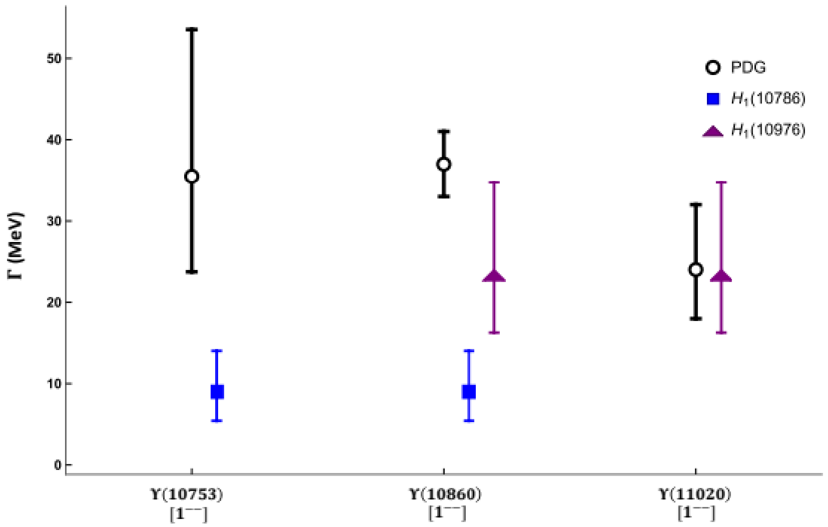
For the first time the excited and exotic bottomonium spectrum (including hybrids) has been determined by a fully relativistic and unquenched lattice calculation.

N. Brambilla, W.K. Lai, A. Mohapatra, A. Vairo Phys. Rev. D. 107, 054034 (2023)









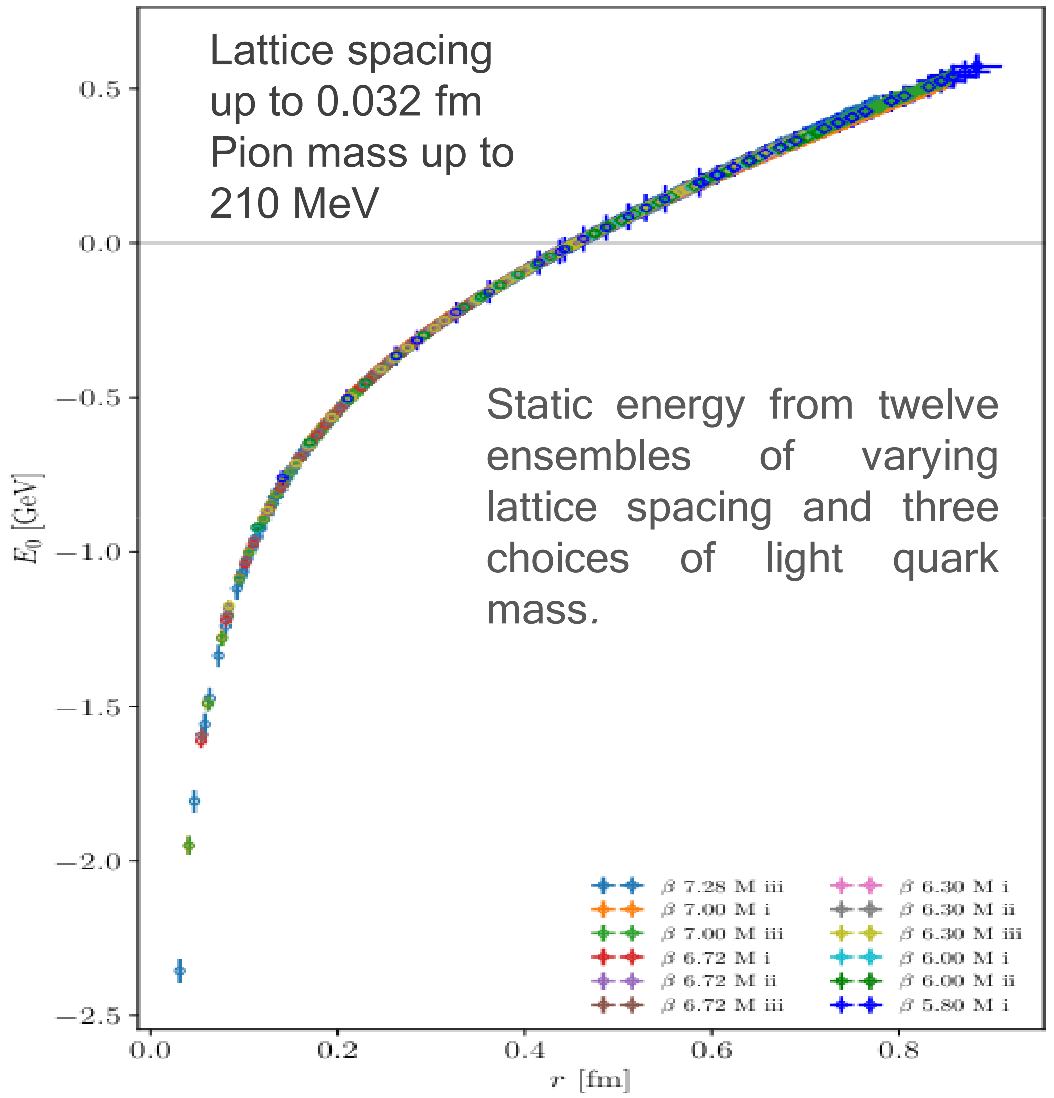
Hybrid spectrum and widths vs observed exotics in the charmonium and bottomonium sector calculated the framework of nonrelativistic effective field theories

- Precise extraction of α_s using a Lattice-QCD calculation of the QCD static energy and comparing it to a perturbative calculation of the same quantity in QCD at NNNLL [TUMQCD Collab, N. Brambilla et al., Phys. Rev. D 107 (2023) 074503].

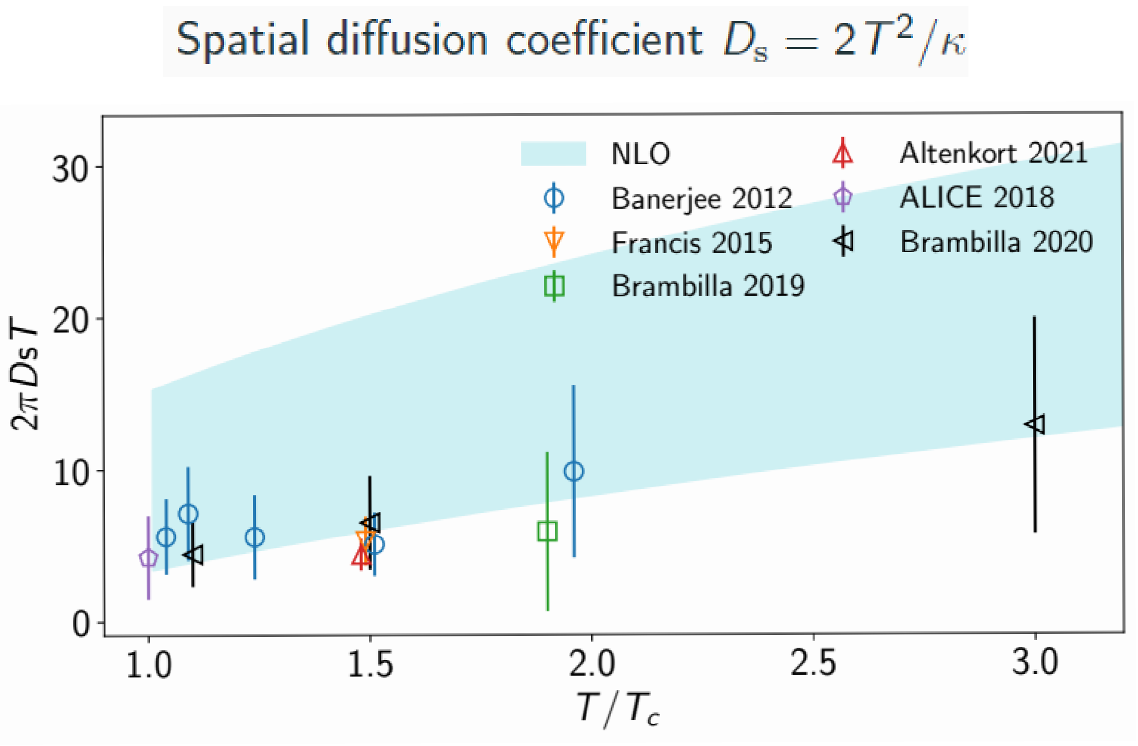
- Understanding how to establish a systematic approach for calculating the matching from the gradient-flow scheme to the MS scheme in the limit of small flow time for off-light cone Wilson-line operators This will be crucial to use the lattice gradient flow calculations of the low energy correlators in the nonrelativistic effective field theories for quarkonium and exotics: N. Brambilla and X. P. Wang, **JHEP in print**,

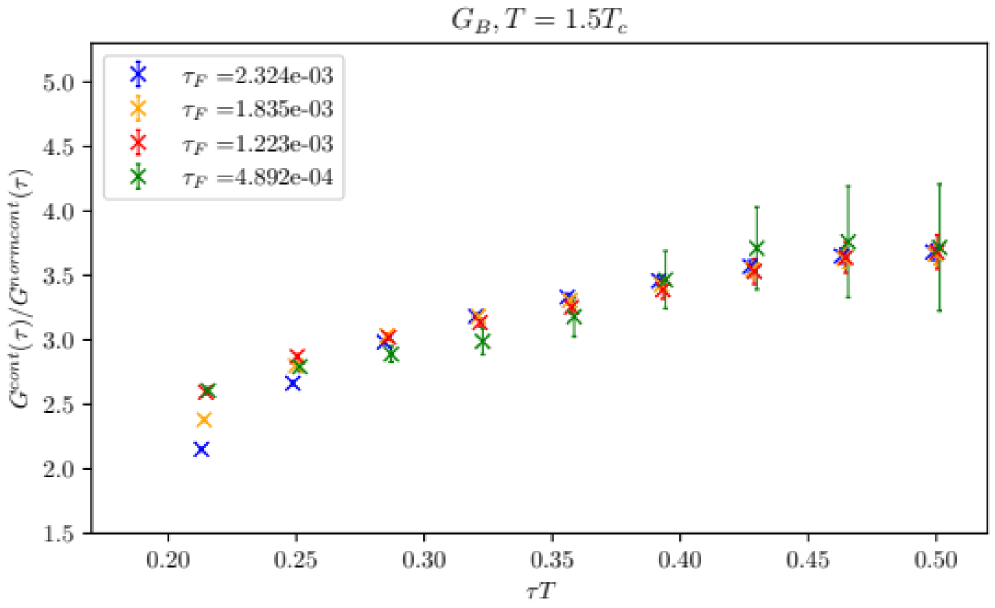
- Calculating the generalized Wilson loop containing the QCD force on the lattice using gradient flow: this is an important preliminary result that open the possibility to calculate on the lattice all correlators emerging in the nonrelativistic effective field theory, including pNRQCD and BOEFT: N.Brambilla, V.Leino, J. Mayer-Steudte and A. Vairo, **PRD in print**.

Static energy from (2+1+1)-Flavor lattice QCD



- The heavy quark and quarkonium behavior in a quark gluon plasma is governed by transport coefficients that can be computed non-perturbatively on lattice QCD
- The heavy quark **diffusion coefficient** was computed in a wide temperature range in N. Brambilla et al. PRD 102 (2020). The fitted temperature dependence is found to be compatible with the NLO perturbative result
- Currently we are running measurements of the 1/M corrections to the diffusion coefficient on the lattice. These come from the chromomagnetic correlators GB



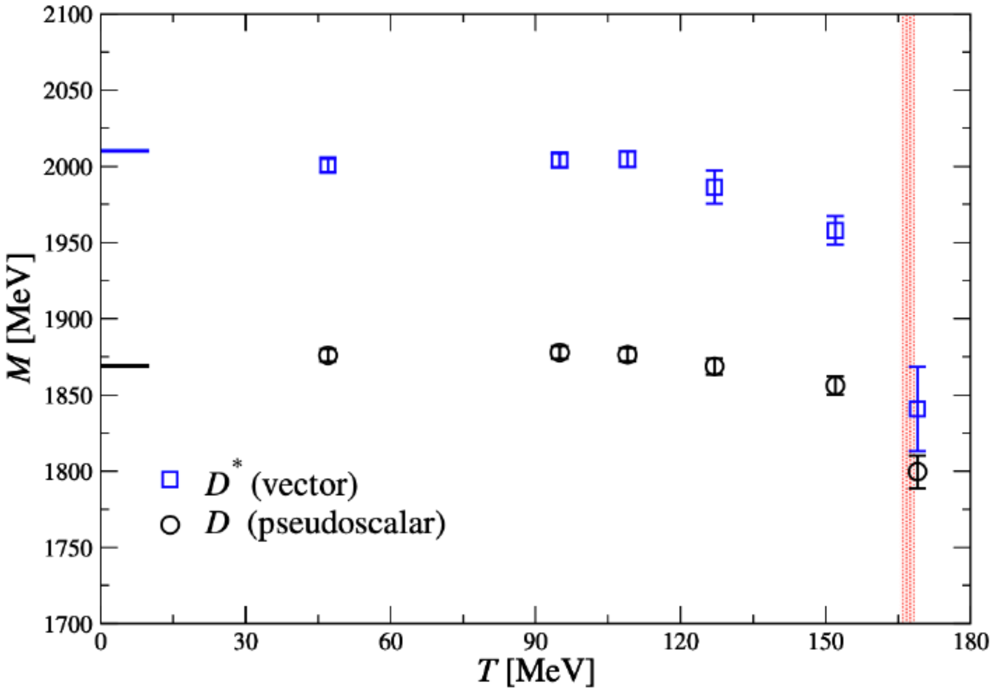


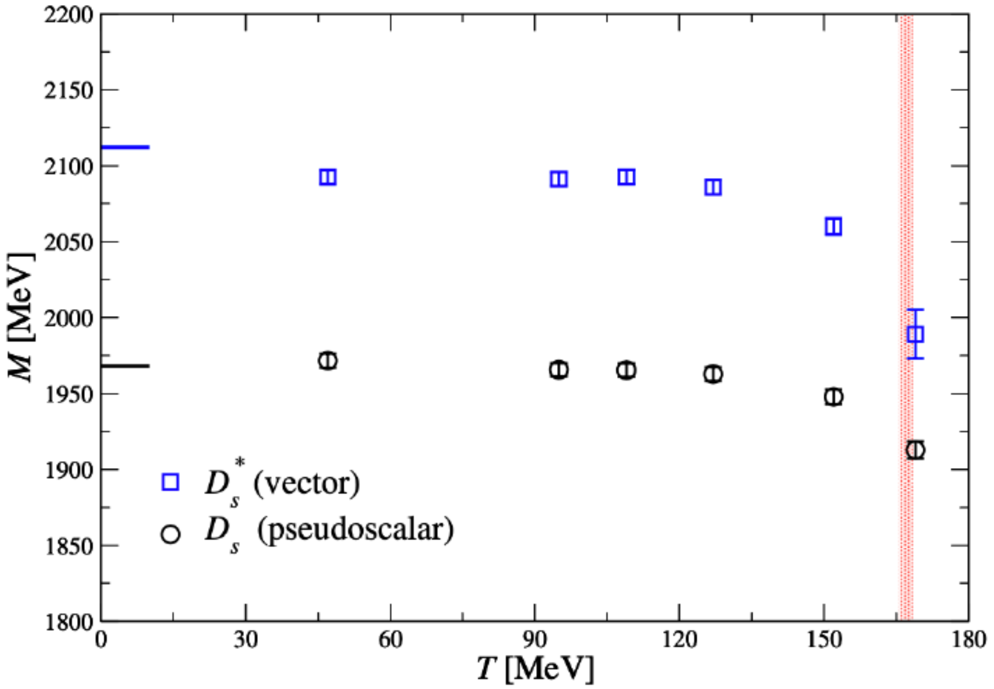
Thermal modification of hadrons on lattice

G. Aarts, C. Allton, R. Bignell, T. J. Burns, S. C. García-Mascaraque, S. Hands, B. Jäger, S. Kim, , S. M. Ryan, J.-I. Skullerud – arXiv:2209.14681 [hep-lat]

SPECTROSCOPY AT T>0 WITH HEAVY QUARKS

- 2+1 dynamic fermions (full QCD) @ m_π = 239 MeV
- T < Tc (~150 MeV)





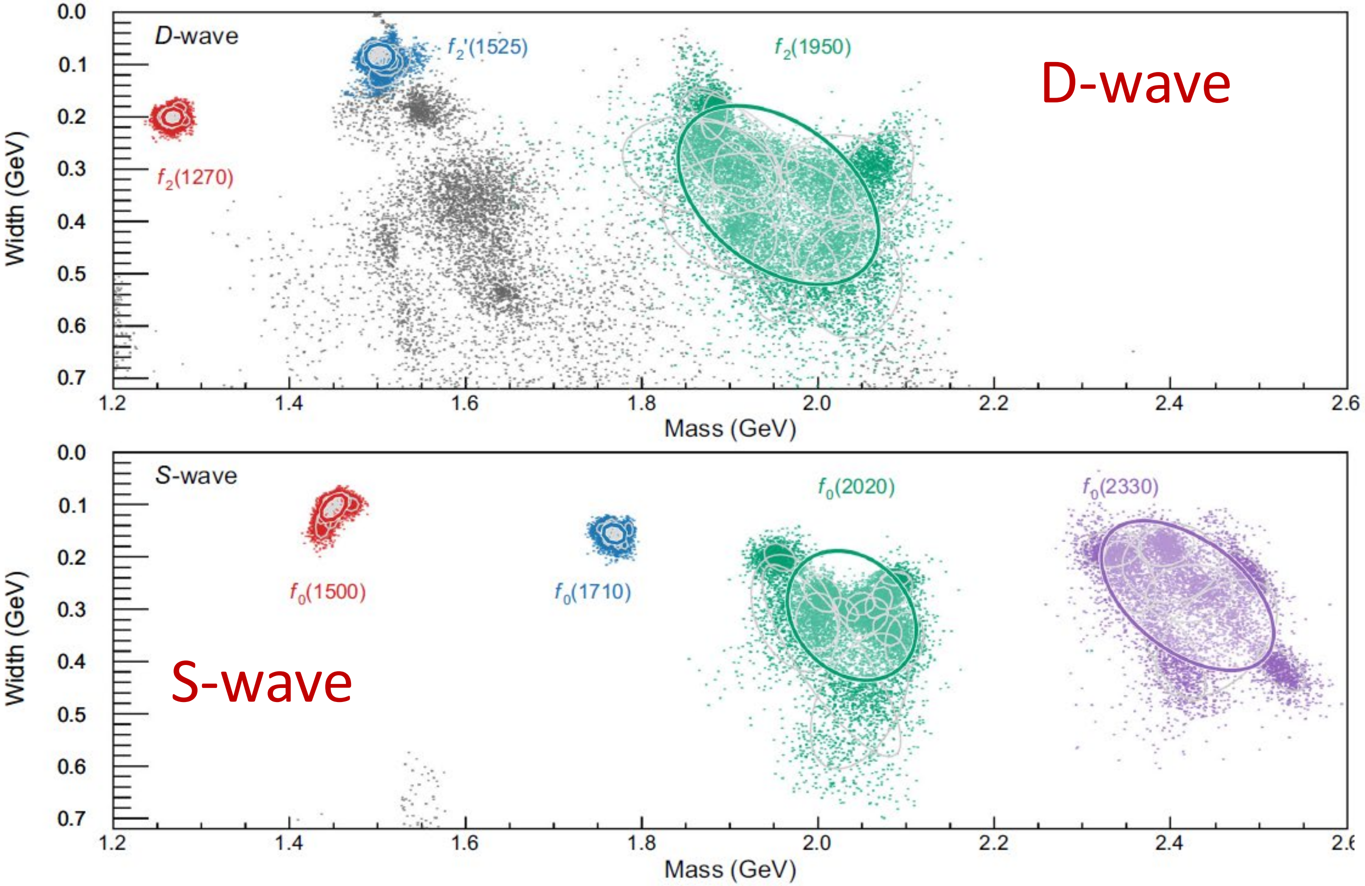
- D and Ds mesons in the hadronic phase
- Approaching thermal crossover : thermal modification of hadrons (as expected in QGP)

	J^P	PDG	T[MeV]= 47	95	109	127	152	169
D	0^-	1869.65(5)	1876(4)	1878(4)	1876(4)	1869(5)	1856(6)	1800(11)
D^*	1^-	2010.26(5)	2001(4)	2004(4)	2005(5)	1986(11)	1958(9)	1841(28)
D_s	0^-	1968.34(7)	1972(5)	1966(4)	1965(4)	1963(4)	1948(5)	1913(6)
D_s^*	1^-	2112.2(4)	2092(4)	2091(5)	2092(5)	2086(5)	2060(6)	1989(16)

Progress in Task 3: Meson Spectroscopy analysis of new and exotic states

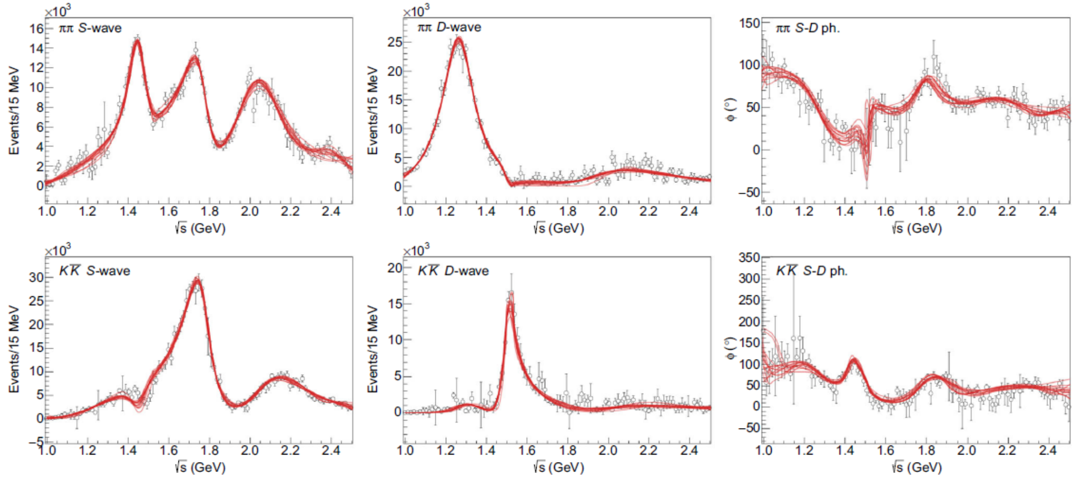
✶Development and application of new analysis tools

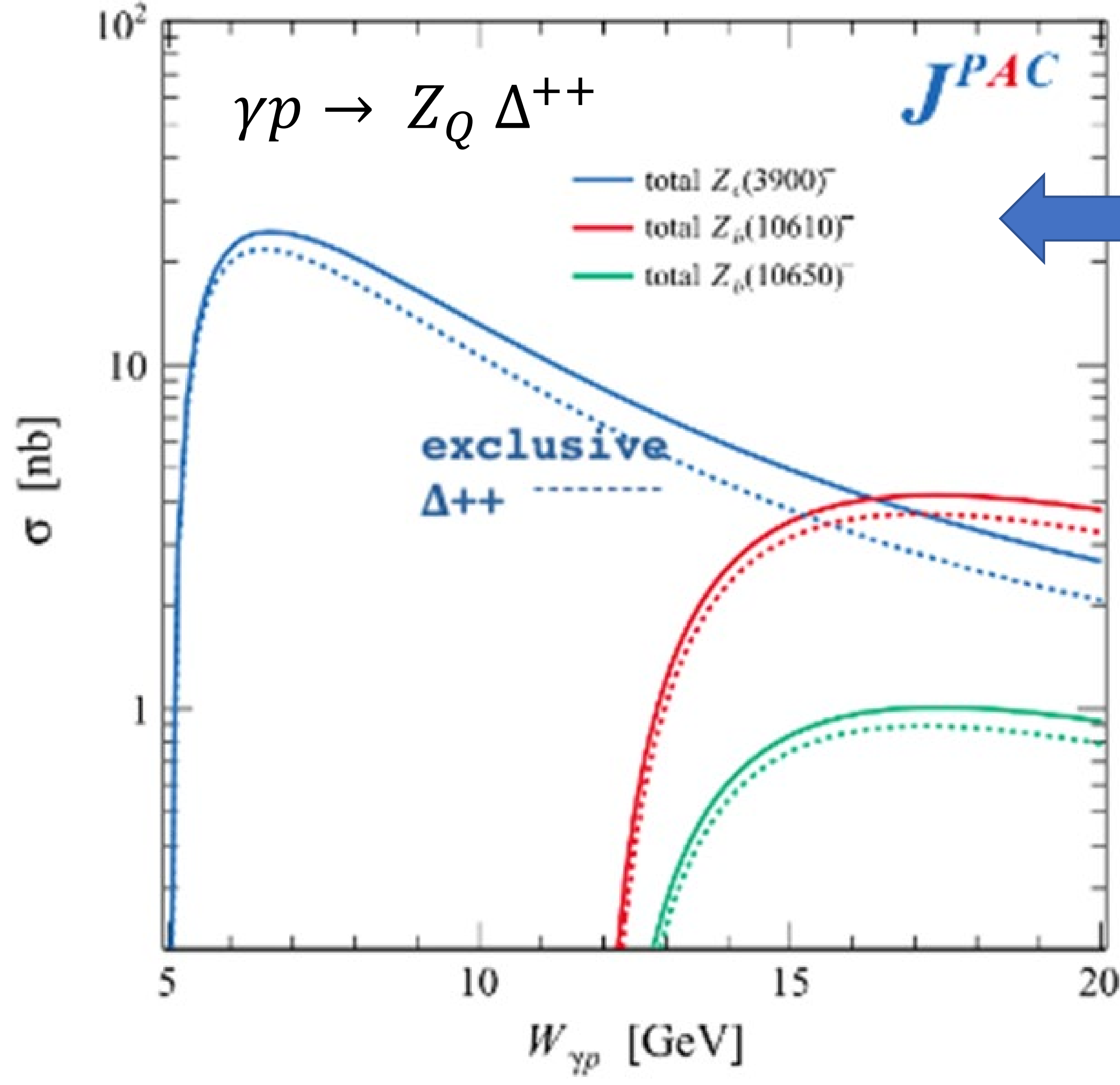
Determination of the scalar and tensor pole positions from J/psi radiative decays by JPAC, A.Rodas et al EPJ82 (2022), 1



$J/\psi \longrightarrow \gamma\pi^0\pi^0$ and $J/\psi \longrightarrow \gamma K_S^0 K_S^0$

Abstract We perform a systematic analysis of the $J/\psi \to \gamma\pi^0\pi^0$ and $\to \gamma K_S^0 K_S^0$ partial waves measured by BESIII. We use a large set of amplitude parametrizations to reduce the model bias. We determine the physical properties of seven scalar and tensor resonances in the 1–2.5 GeV mass range. These include the well known $f_0(1500)$ and $f_0(1710)$, that are considered to be the primary glueball candidates. The hierarchy of resonance couplings determined from this analysis favors the latter as the one with the largest glueball com-





✓ Support to phenomenological analysis (PWA)

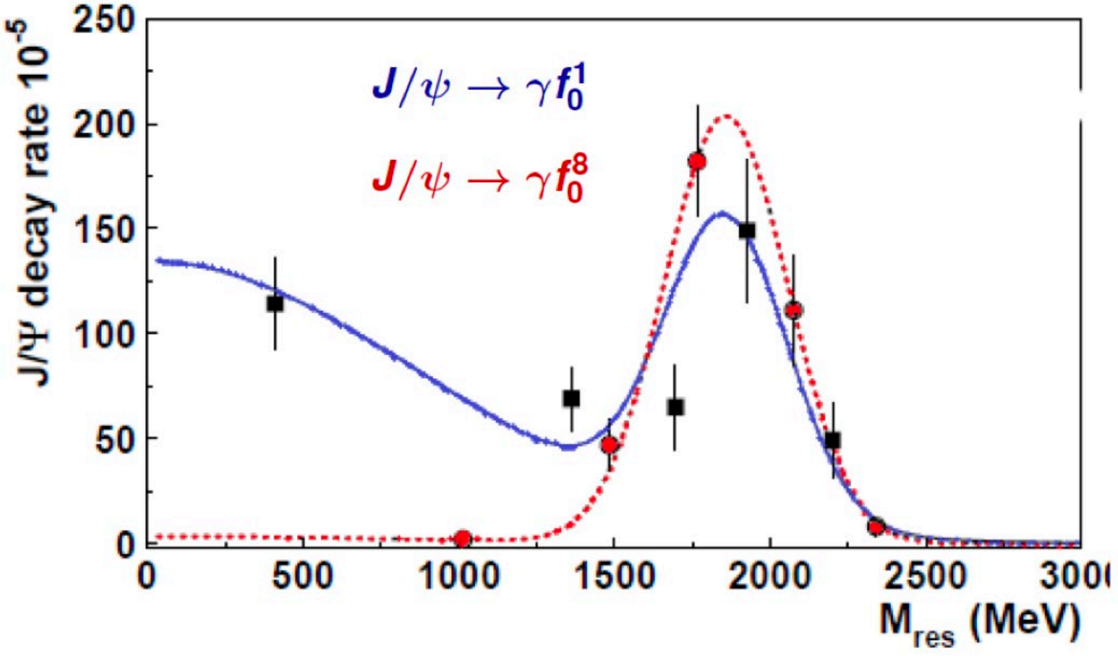
Predictions for JLab and EIC

M. Albaladejo et al. (JPAC Collaboration)
Phys.Rev.D 102 (2020) 114010

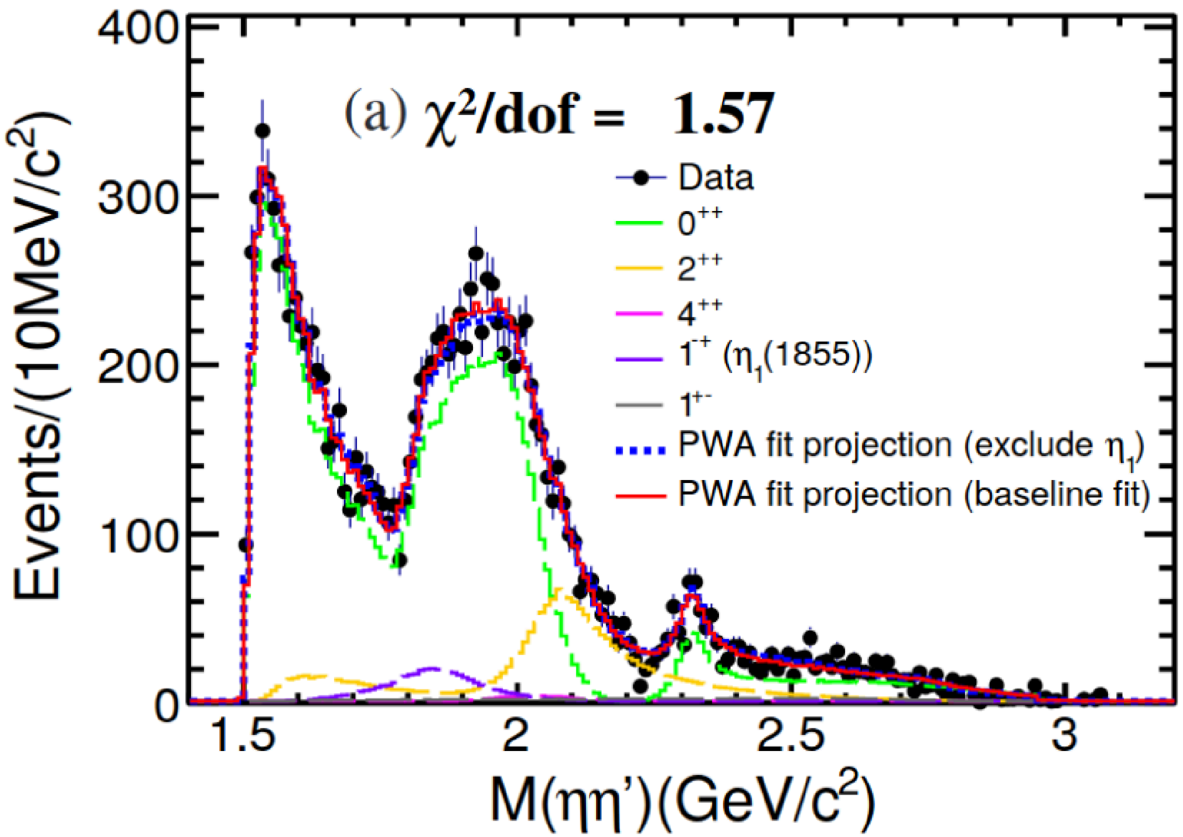
included in the ElSpectro MC generator. JPAC collaboration with the Glasgow group (D. Glazier et al)

…also proved that there are no mathematical ambiguities in partial-wave analysis of two mesons produced with a linearly polarized photon beam. Monte Carlo simulations to illustrate results. JPAC (W. Smith et al), PRD 108 (2023) 076001

- Data-driven dispersive analysis of the $\pi\pi$ and πK scattering
  - application to a vast experimental or lattice data with a broad (or coupled-channel) resonance of non-genuine QCD nature
- On the scalar πK form factor beyond the elastic region
  - formalism combining low energy elastic description with high energy resonance exchange
- ALICE completed a measurement of $f_0(980)$ in pp collisions at 13 TeV at LHC
- Exotic meson program at JLab - unique data sets with unprecedented statistical precision
  - CLAS12/MesonEx: light-quark mesons and search for exotics
  - GlueX: hybrid search in double meson production
  - studying production mechanisms and moments, developing PWA in parallel



Scalar isoscalar mesons and the **scalar glueball** from radiative J/ψ decays
A.V.Sarantsev, I.Denisenko, U.Thoma, E.Klempt PLB 816, 136227



Observation of new exotic candidates by **INFN Ferrara group from BESIII collaboration**

$\eta_1(1855)$ in $\eta'\eta$

$f_0(2480)$ in $\eta'\eta'$

$X(2600)$ in $\pi\pi\eta'$

PRD105(2022) 072002 & PRL129 (2022) 042001

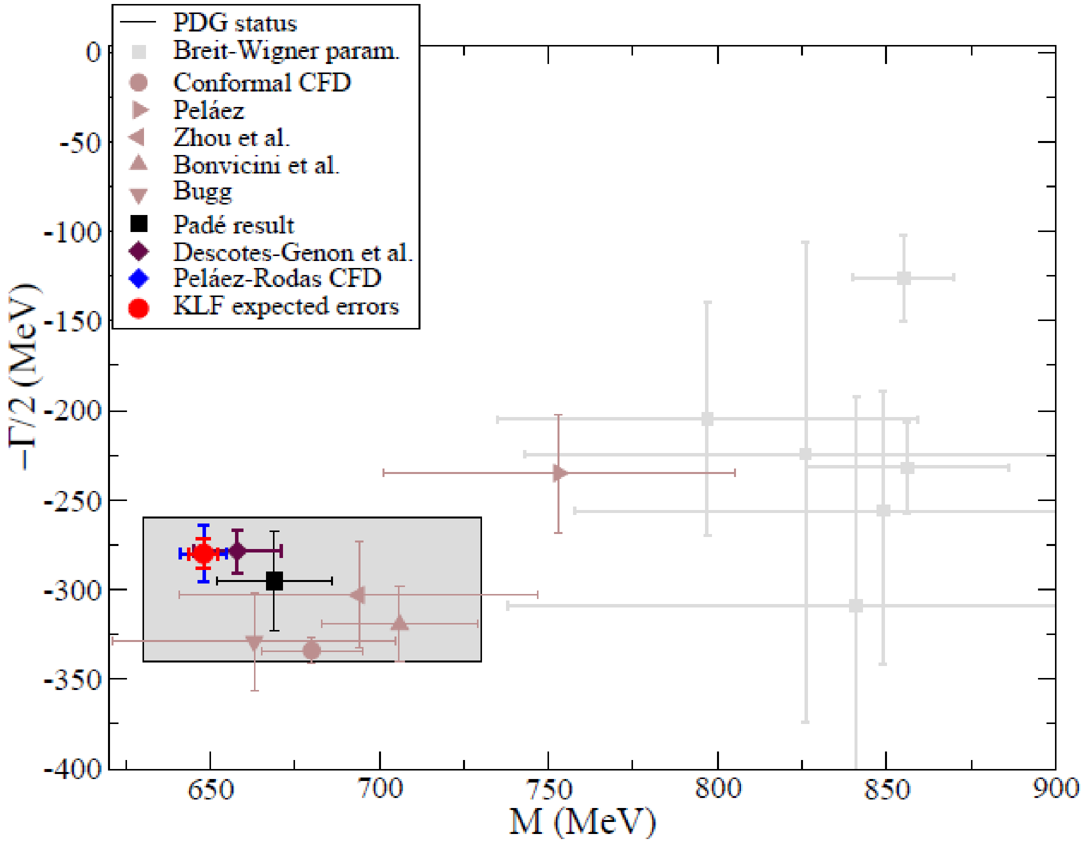


Figure 2: Expected precision on the $\kappa/K_0^*(700)$ pole parameters for 100 days of running time. The uncertainties of KLF prediction are presented in a red color within the blue error bars obtained without KLF data. The shadowed rectangle stands for PDG2018 uncertainties. (see Section 4.2 and Appendix A.4 for details).

KLF Collaboration.

Strange Hadron Spectroscopy with Secondary KL Beam in Hall D

Jlab C12-19-001 proposal (arXiv:2008.08215)

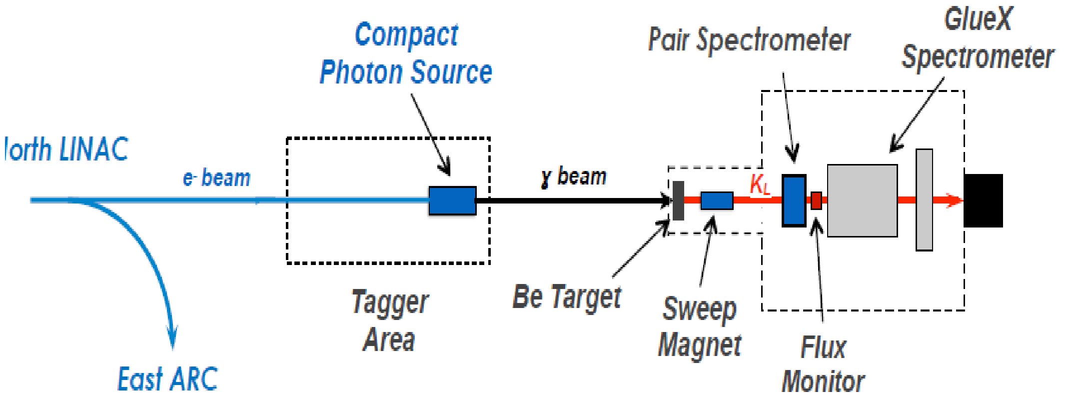


Figure 1: A diagram of the Jefferson Lab KLF, highlighting the K_L beamline elements.

Approval of K_{long} beam facility at JLab: extensive study of strange baryonic excitations and of mesons with strange content, search and characterization of the κ/K*(700) scalar, in its overlap with the $\sigma/f_0(500)$ and the $f_0(980)$, and of other strange excited resonances

Progress in Tasks 4.1 and 4.2: Baryon Spectroscopy

New PA and theory results:

✓ Theory/experiment collaboration to extend PWA

- Jülich-Bonn-WashingtonDC:
  - Composition of N* and Δ resonances via coupled-channel dynamics, Y.-F. Wang, PRC 109 (2024) 015202
  - Inclusion of KΛ electroproduction data, M. Mai et al., Eur.Phys.J.A 59 (2023) 286
  - Heavy meson–heavy baryon coupled-channel interactions, Z.-L. Wang Eur, Phys. J C82 (2022) 497
  - **New interactive webpage**: https://jbw.phys.gwu.edu/

- Laurent+Pietarinen PWA of kaon photoproduction
  A. Švarc and R. L. Workman PRC 108 (2023) 014615

- Meson photoproduction interpreted by Regge phenomenology
  I.I. Strakovsky et al., Phys.Rev.C 107 (2023) 1, 015203

- Truncated PWA for η-photoproduction via Bayesian Statistics;
  P. Kroenert et al., Phys. Rev. C 109 (2024) 045206

Review articles

Physics Reports 1001 (2023) 1–66

Contents lists available at ScienceDirect

Physics Reports

journal homepage: www.elsevier.com/locate/physrep

ELSEVIER

Towards a theory of hadron resonances

Maxim Mai [a,c], Ulf-G. Meißner [a,b,d,*], Carsten Urbach [a]

Review of the state of the art of our understanding of the spectrum of excited strongly interacting particles and discuss methods that allow for
a systematic and model-independent calculation of the hadron spectrum. These are lattice QCD and effective field theories.

Progress in Particle and Nuclear Physics 125 (2022) 103949

Contents lists available at ScienceDirect

Progress in Particle and Nuclear Physics

journal homepage: www.elsevier.com/locate/ppnp

ELSEVIER

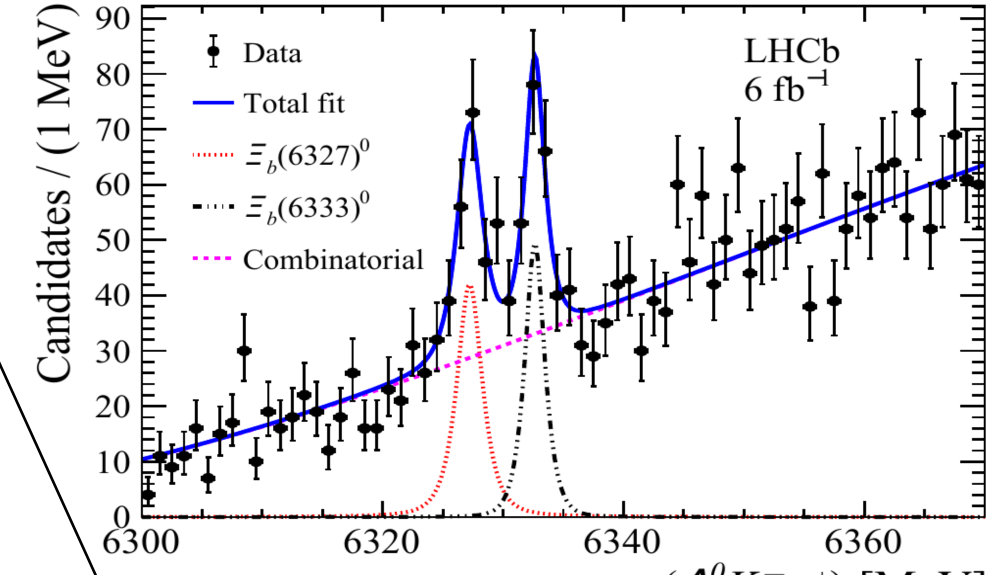
Review

Light Baryon Spectroscopy

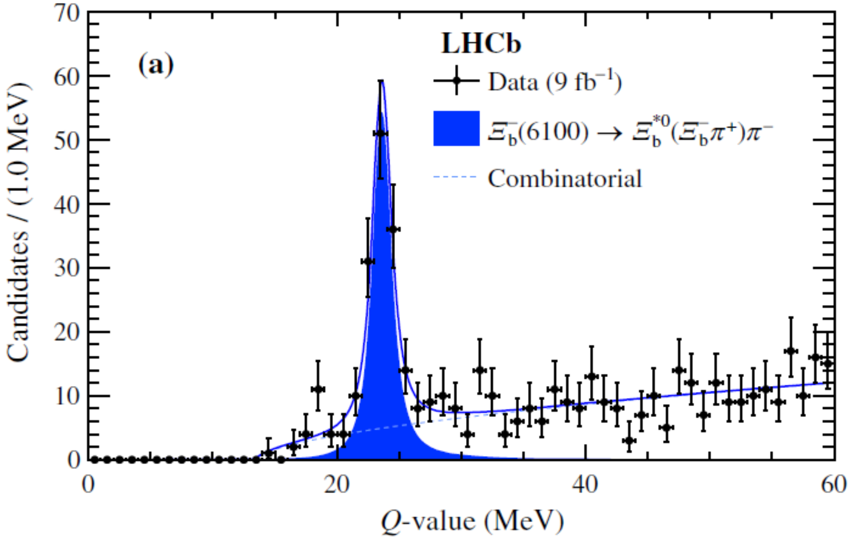
A. Thiel [*], F. Afzal, Y. Wunderlich

Compendium of experimental results, as well as a review of the theoretical methods of amplitude analysis used to analyze the data. ***The most significant datasets are presented in detail and are listed*** *in combination with a full set of the relevant references*

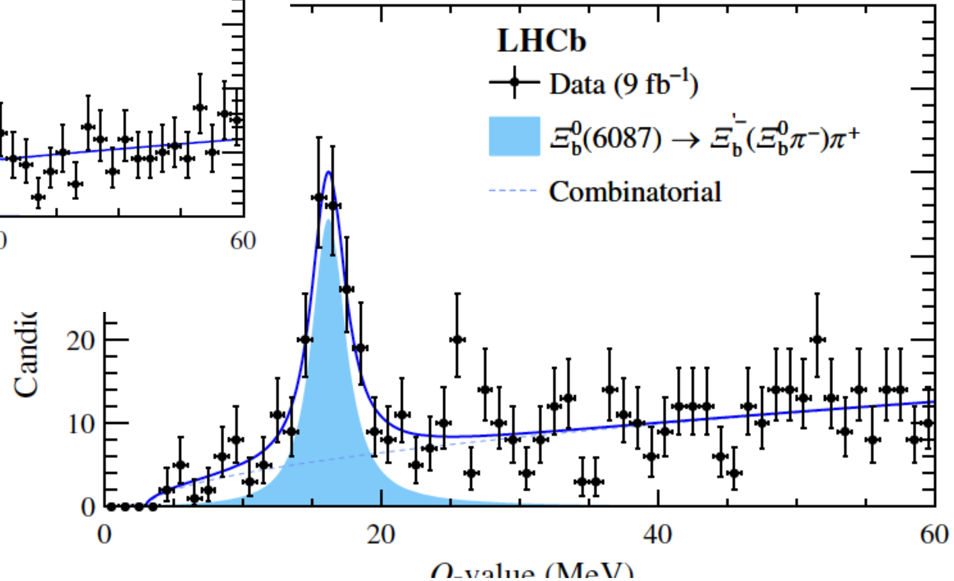
- **Heavy Baryons**
  - Observation of new excited Ξ_b^0 states
  - Observation of excited Ω_c^0 baryons (LHCb, arXiv:2107.03419)
  - Evidence for a new structure in the $J/\psi p$ (LHCb, arXiv:2108.04720)
  - Lifetimes of Ω_c^0 and Ξ_c^0 (LHCb, arXiv:2109.01334, 2302.04733)

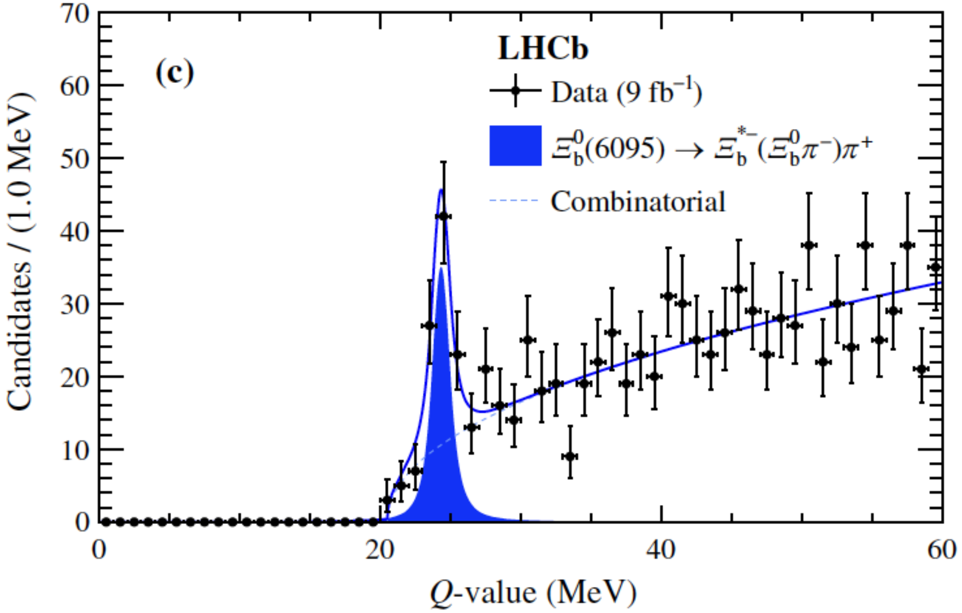


PRL 128 (2022) 162001



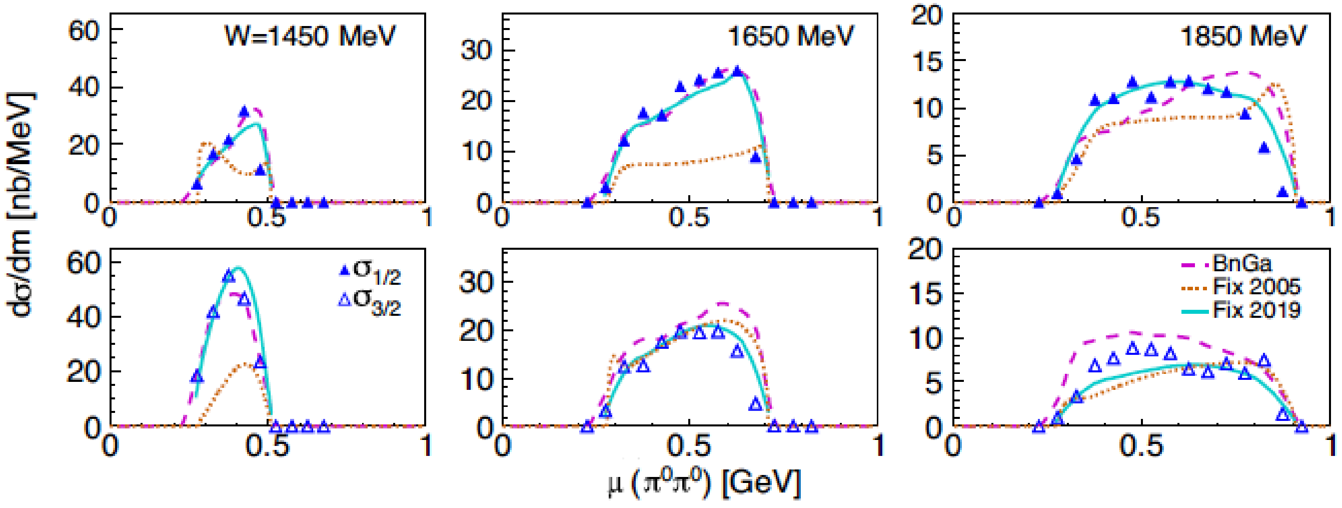
PRL. 131 (2023) 171901

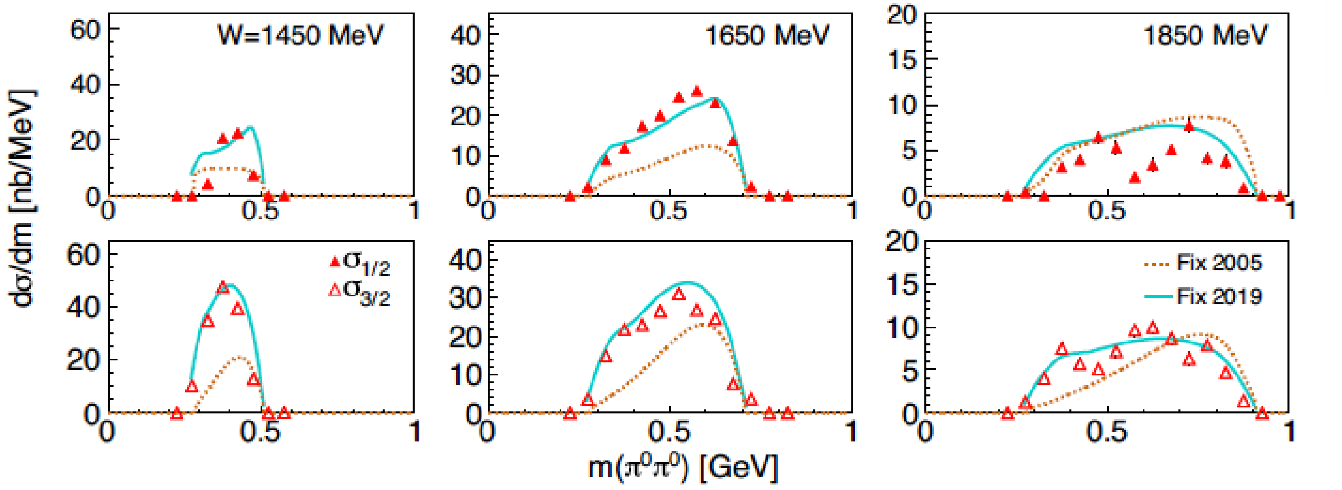




- ❑ Published measurements of spin dependent π, η, $\pi\pi$, and πη photoproduction from ELSA and MAMI.
- ❑ CBELSA/TAPS Collaboration: partial wave analysis of $\vec{\gamma}\vec{p} \longrightarrow \eta p$ [*Phys.Lett.B* 803 (2020) 135323]; **new EtaMAID** model published; the large difference in the $N\eta$-branching ratio between the *N(1535)1/2⁻* and the *N(1650)1/2⁻* almost disappeared in the new BnGa analysis result.
- ❑ Simultaneous measurement of G and E with elliptically polarized photon beam at MAMI
- ❑ New single-energy partial-wave analyses [H. Osmanović et al., Phys. Rev C 104 (2021) 034605; A. Švarc Phys. Rev. C 104 (2021) 014605]

The results reveal for the first time the helicity- and isospin-dependent structure of the $\gamma N \longrightarrow N\pi^0\pi^0$ reaction.



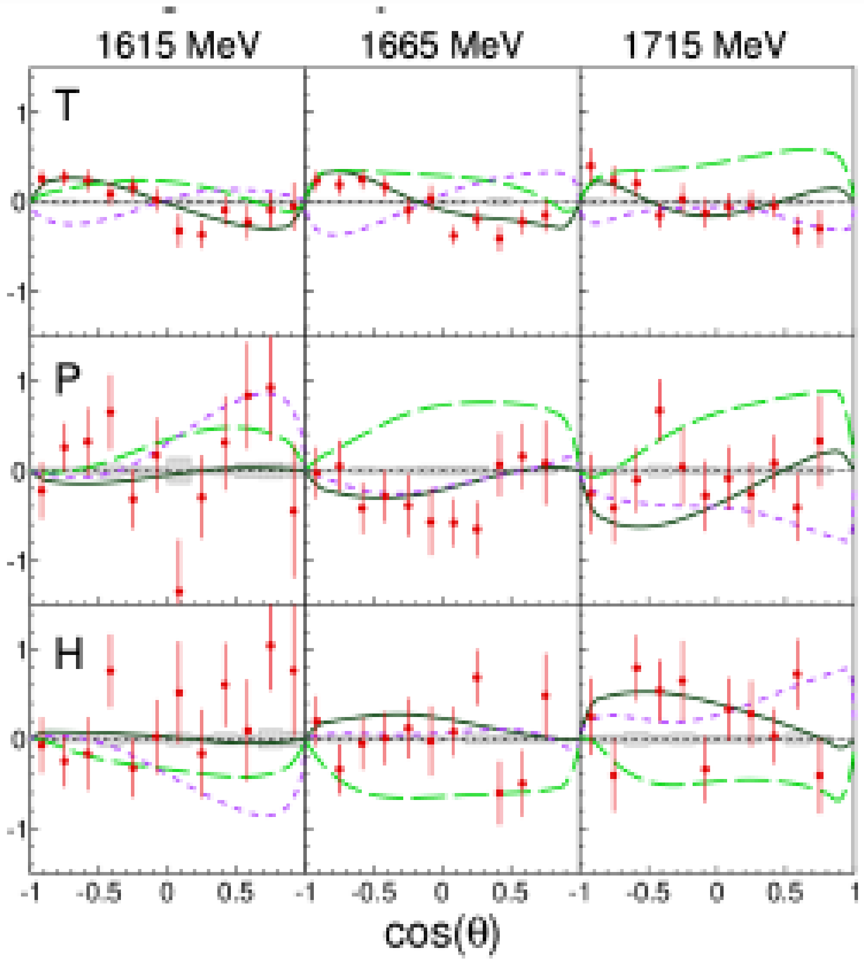


M. M. Dieterle *et al.*(A2 Collaboration)., Phys. Rev. Lett.125, 062001

η-photoproduction off neutron

$\vec{\gamma}\,\vec{d} \rightarrow \eta\, n\, (p)$

H. Schmieden @ "Strong2020 Annual Meeting", Frascati (INFN), June'24



N. Jermann (CBELSA/TAPS)
EPJA 59 (2023) 10, 232

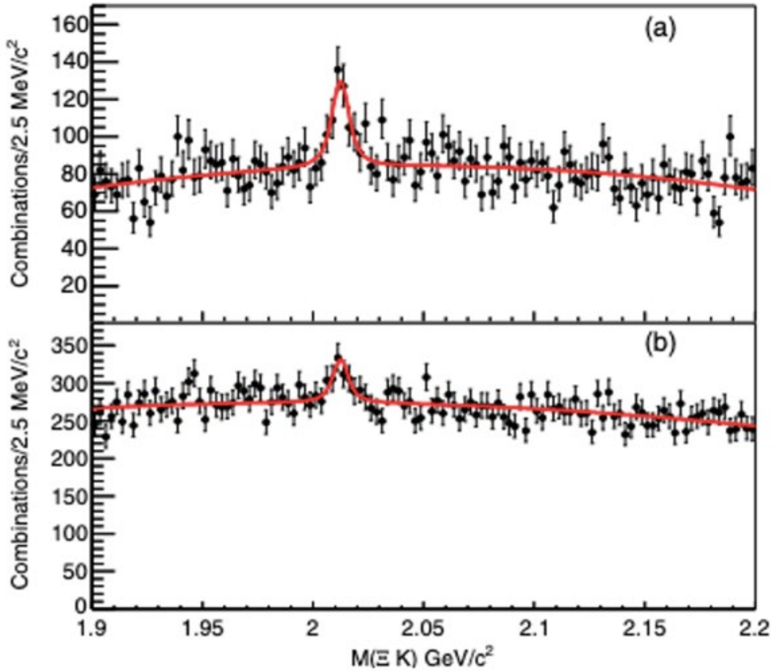
Predictions:

BnGa: interference in the $1/2^-$-wave

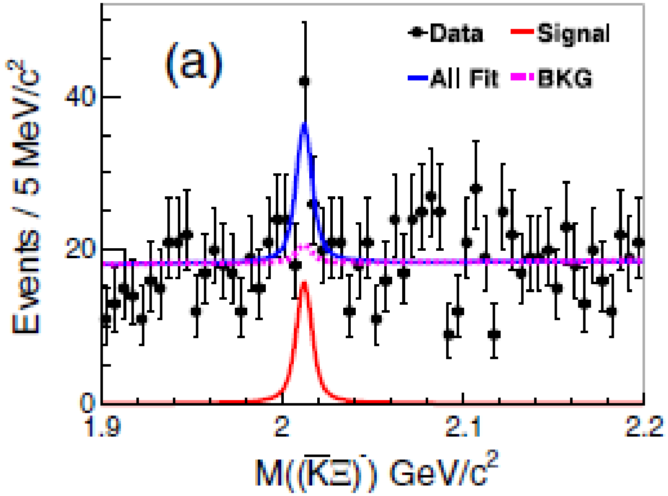
BnGa: structure explained by narrow $N(1685)1/2^+$

MAID: $N(1535)1/2^-$ $N(1710)1/2^+$

BnGa PWA fits including new double-polarisation data: narrow $1/2^+$ state ***not*** needed



PRD 104 (2021) 052005



Ω (2012) production at BELLE

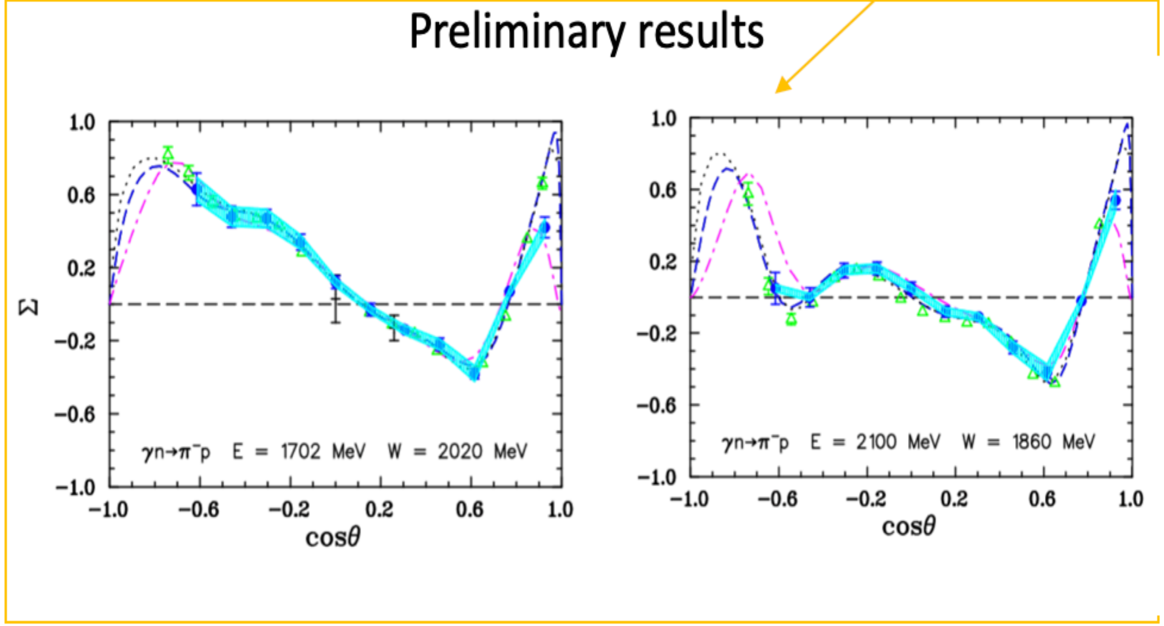
$\vec{\gamma}\vec{n}(p) \rightarrow \pi^- p(p)$ – photoproduction on a polarized HD target

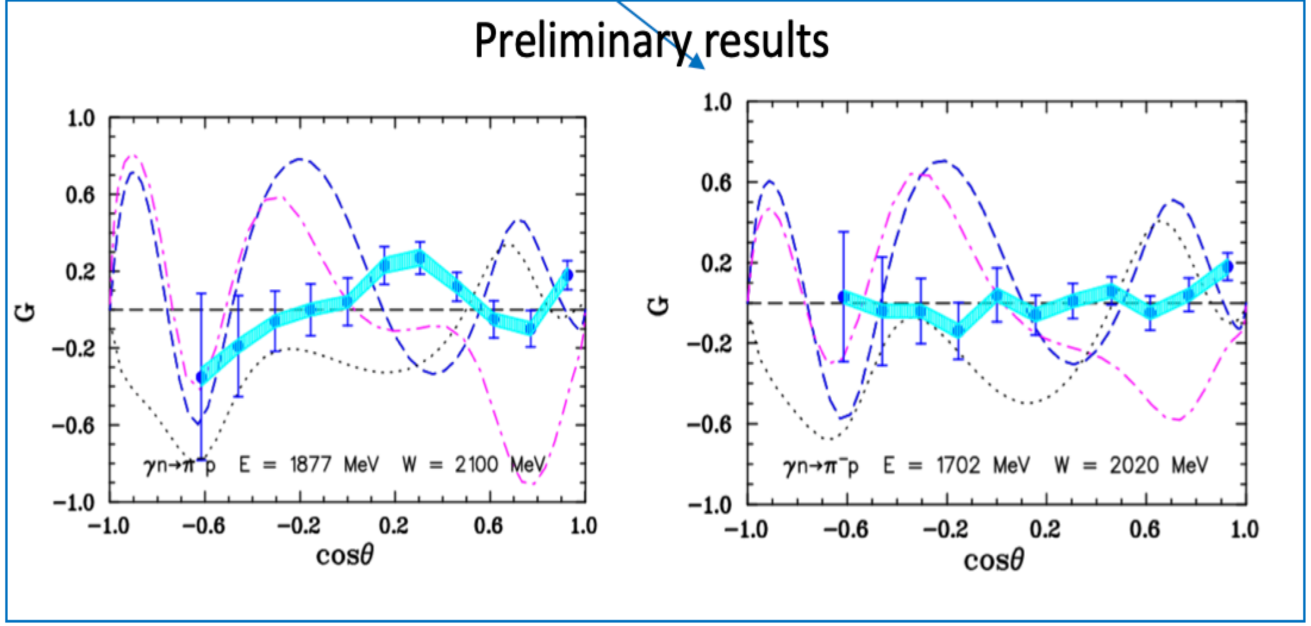
Measurements of Σ and G polarization observables

HD-ice frozen-spin polarized target polarized n

$$\frac{d\sigma(P_\gamma, P_D)}{d\Omega} = \frac{d\sigma_0}{d\Omega}\left(1 - P_\gamma^L \Sigma(\theta; W) cos(2\phi_\gamma) + P_\gamma^L P_D^V G(\theta; W) sin(2\phi_\gamma)\right)$$

Charged Pion Photo-Production from Polarized Neutrons at Jefferson Lab





SAID SM22 PION-MAID 2021 Bonn-Ga 2022-2

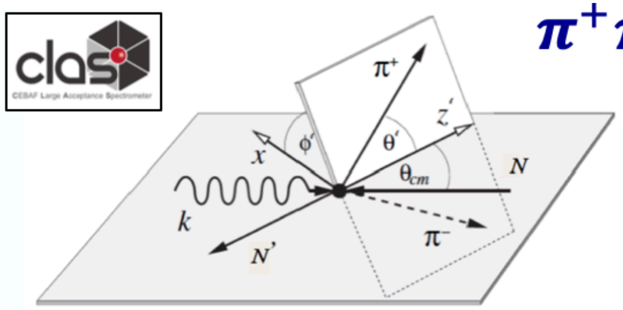
Preliminary results by: Haiyun Lu for the g14 analysis group

✶**New (polarisation) observables**

✓ Spin observables in baryon sector

$\pi^+\pi^-$ photoproduction – polarized p target

Measurements of polarization observables

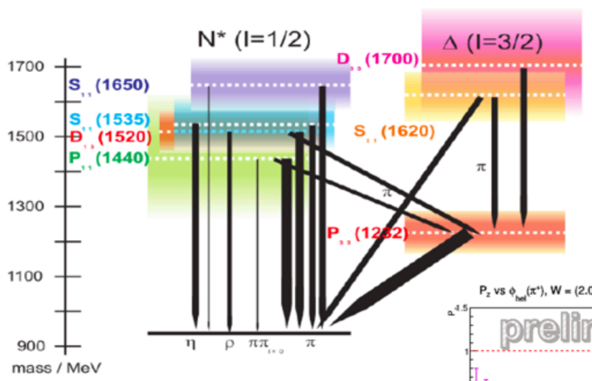


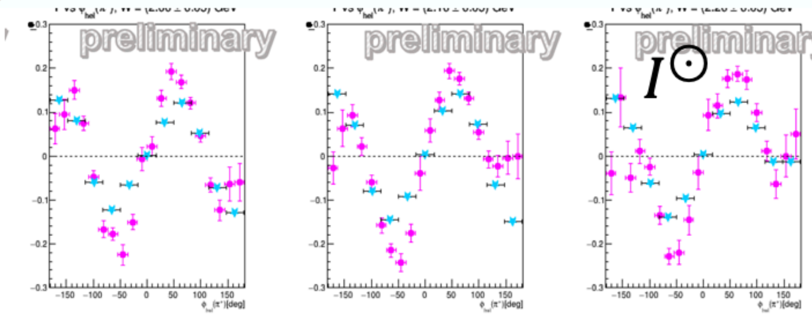
$$\frac{d\sigma}{dx_i} = \sigma_0\{(1 + \Lambda_z \cdot \mathbf{P_z}) + \delta_\odot(\mathbf{I}^\odot + \Lambda_z \cdot \mathbf{P}_z^\odot)\}$$

HD-ice frozen-spin polarized target

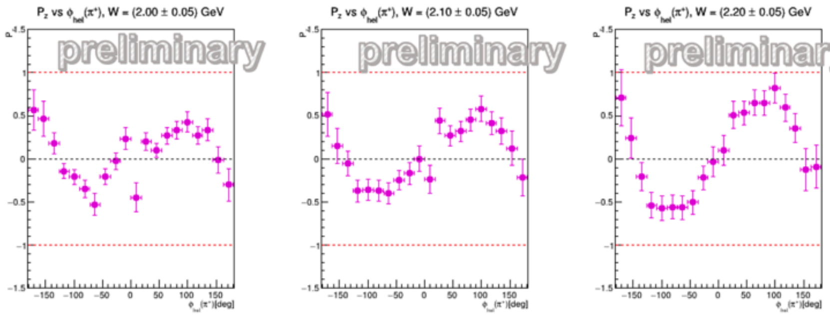
polarized p

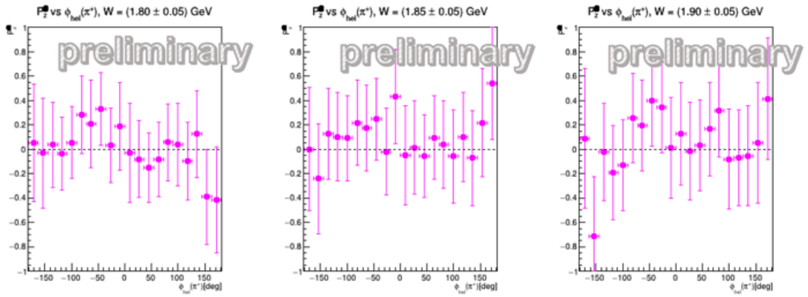
Possible two-steps de-excitation process of baryonic resonances





Blue points from S. Strauch et al., CLAS Coll., PR **C71** (2005), 055201





Preliminary results by: Alessandra Filippi for the g14 analysis group

✶New (polarisation) observables

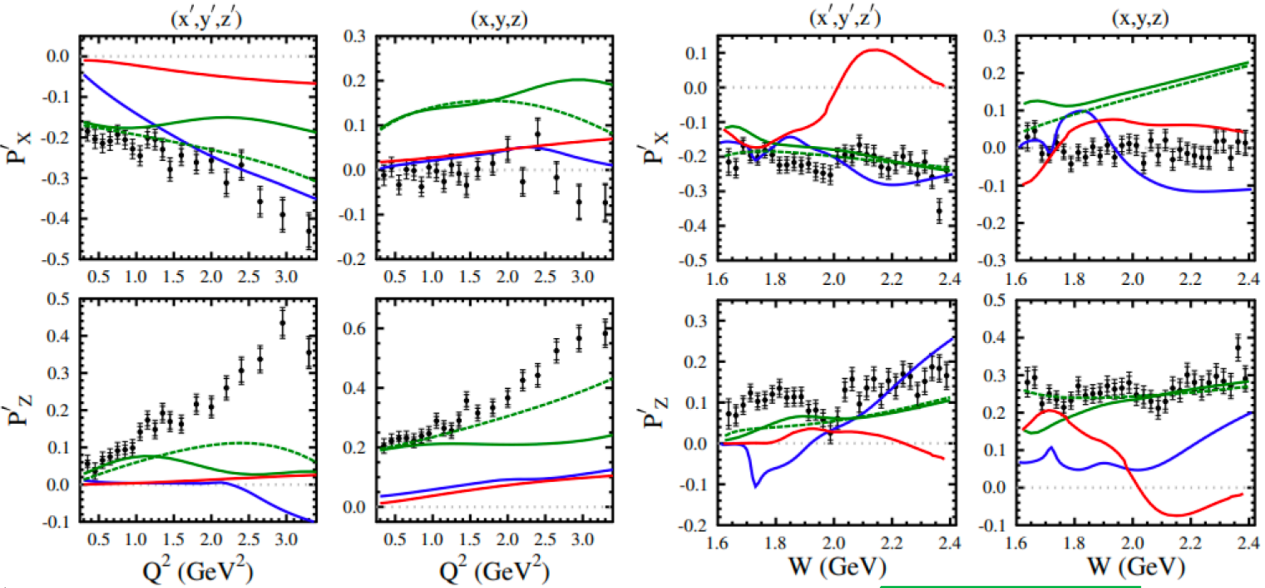
KY electro – production – Transfer polarization Asymmetry

$$A = \frac{N^+ - N^-}{N^+ + N^-} = \nu_Y \alpha_\Lambda P_b \mathcal{P}'_Y \cos\theta_p^{RF}$$

PHYSICAL REVIEW C **105**, 065201 (2022)

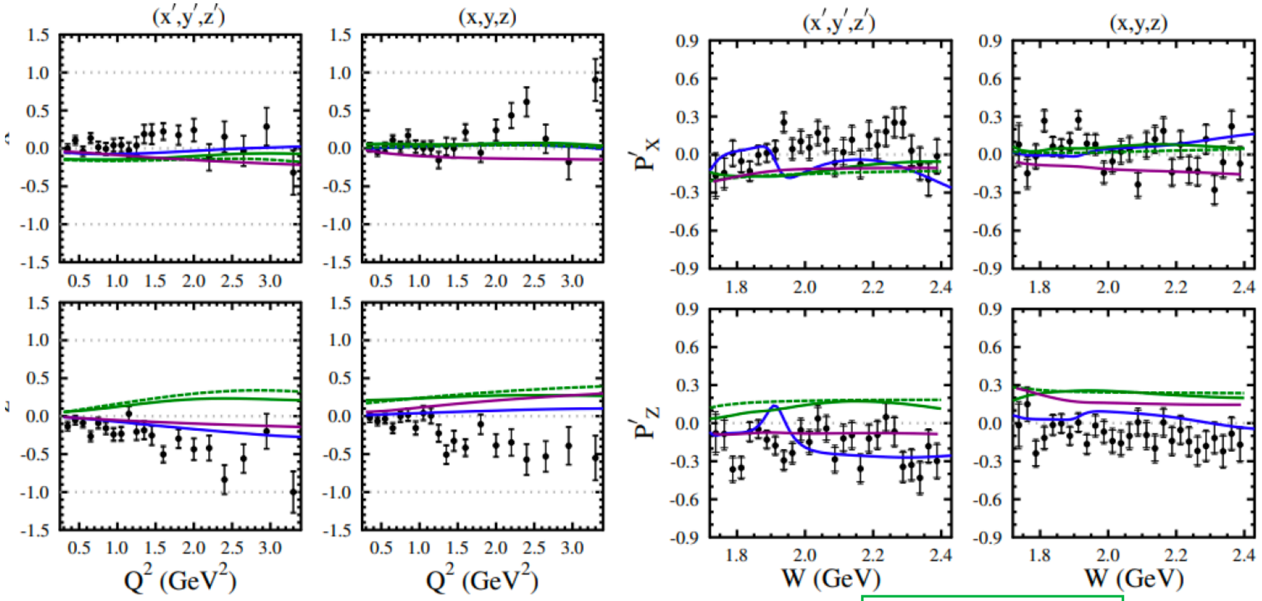
Beam-recoil transferred polarization in K^+Y electroproduction in the nucleon resonance region with CLAS12

Λ Polarization Asymmetry



6.535 GeV

Σ⁰ Polarization Asymmetry



6.535 GeV

Lucilla Lanza & Dan Carman for the RG-K analysis group

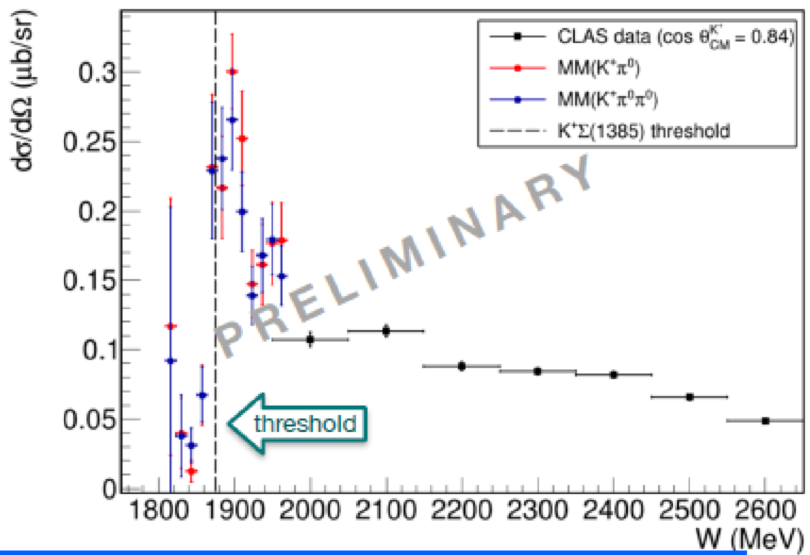
$\gamma\, p \rightarrow K^{+}\, \Sigma^{0*}(1385)$ photoproduction

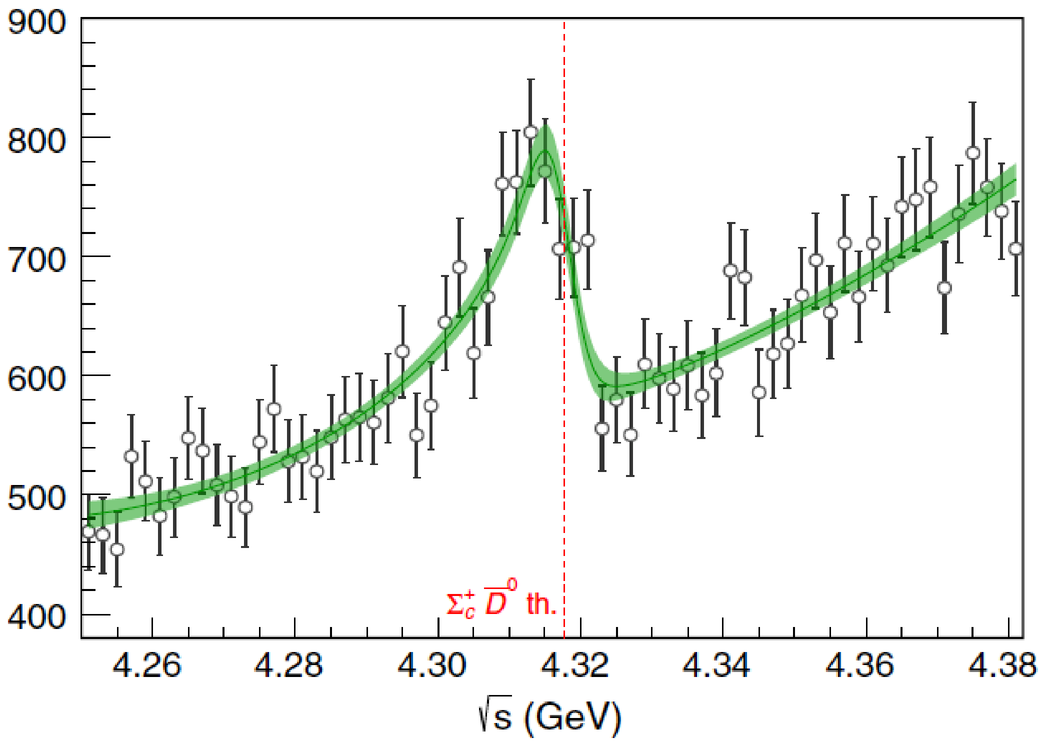
C. Fernández-Ramírezet al. (JPAC)
Phys. Rev. Lett.123, 092001

$\gamma\, p \rightarrow K^{+}\, \Sigma^{*}(1385)$ at $\Sigma^{*}(1385)$ threshold

M. Jena Masters thesis (Bonn 2024), data preliminary

- Differential cross section for $\cos\theta^{K}_{\mathrm{CM}} > 0.9$
- First data from threshold
- large peak at $W \approx 1900$ MeV





The BGOOD experiment at ELSA

- multi-quark structures in the baryon uds sector ?

Data analysis and Interpretation: modeling of the resonant contributions to the inclusive electron scattering observables, studied properties of the hidden-charm pentaquark-like resonances first observed by the LHCb Collaboration in 2015; studied the nature of the new signal reported by LHCb in the $J/\psi p$ spectrum using S-matrix

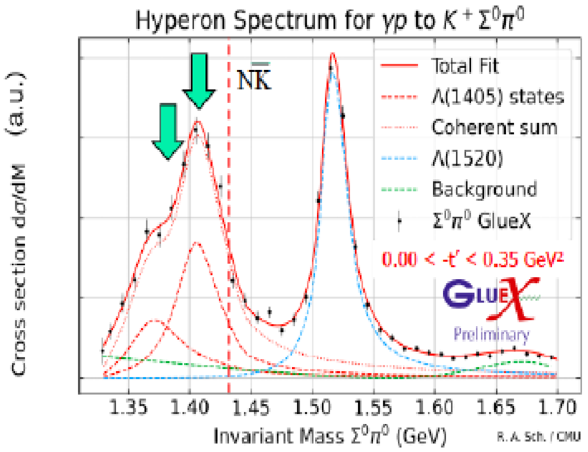
PHYSICAL REVIEW LETTERS **130,** 071902 (2023)

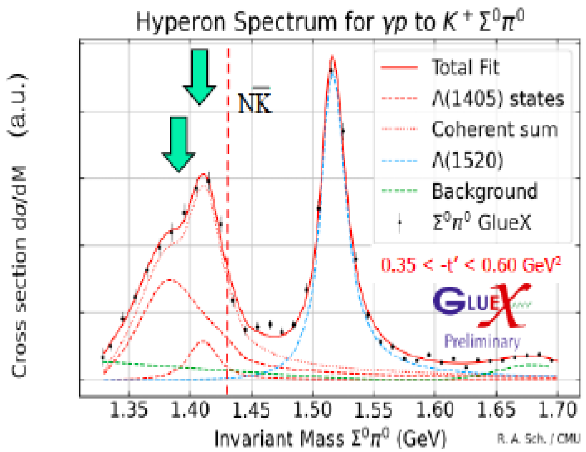
Results on the Λ(1405)

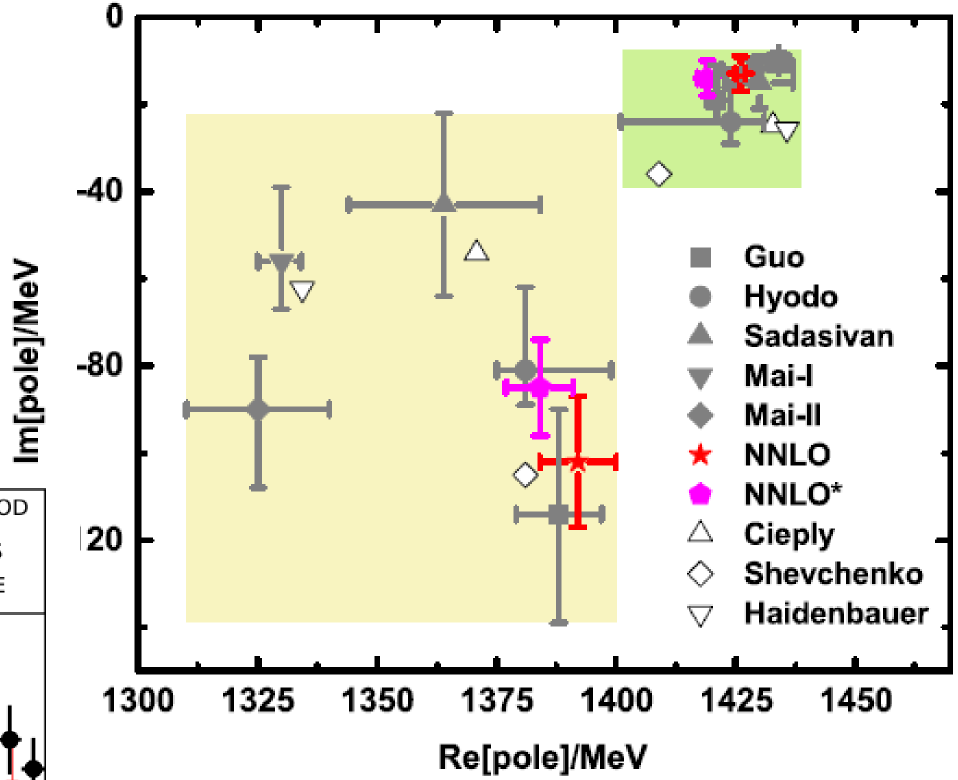
- New data from GlueX arXiv:2209.06230

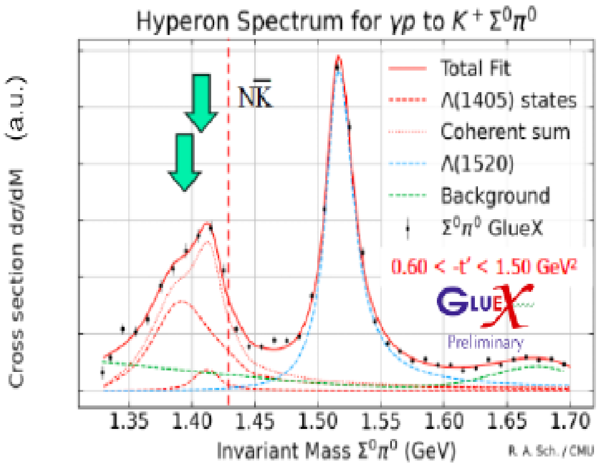
Cross-Channel Constraints on Resonant Antikaon-Nucleon Scattering

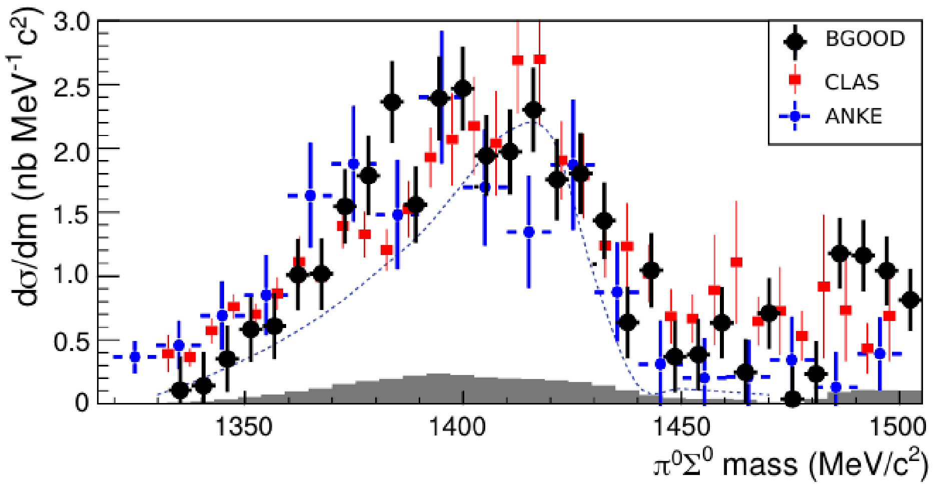
Jun-Xu Lu,[1,2] Li-Sheng Geng,[3,2,4,5,*] Michael Doering,[6,7] and Maxim Mai[8,6]











BGO-OD at ELSA Phys. Lett.B 833 (2022) 137375

The two-pole structure of Λ(1405) persist up to one-loop order reinforcing the existence of two-pole structures in dynamically generated states.

KLF Collaboration.

Strange Hadron Spectroscopy with Secondary KL Beam in Hall D

Jlab C12-19-001 proposal (arXiv:2008.08215)

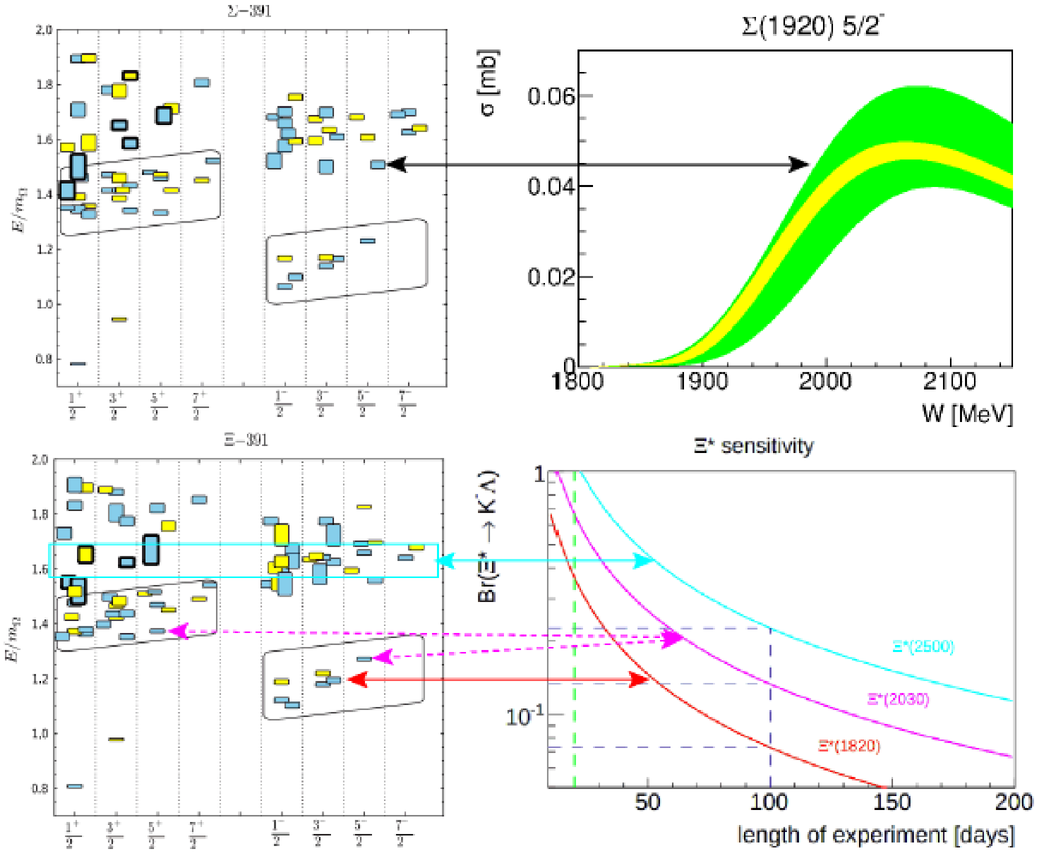


Figure 1: Example of comparison between expected KLF measurements (right) and Lattice QCD predictions for the hyperon spectrum [24] (left), see Section 4.1, Appendix A.3 and Ref. [25] of the text for details.

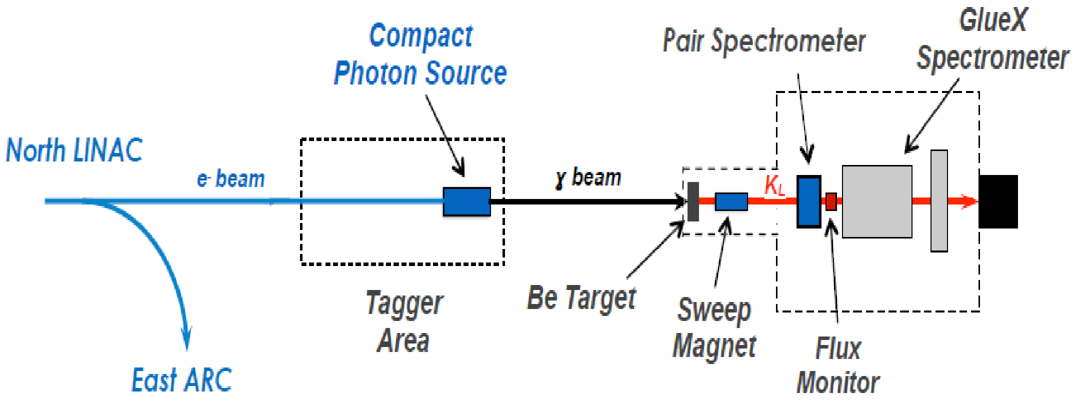
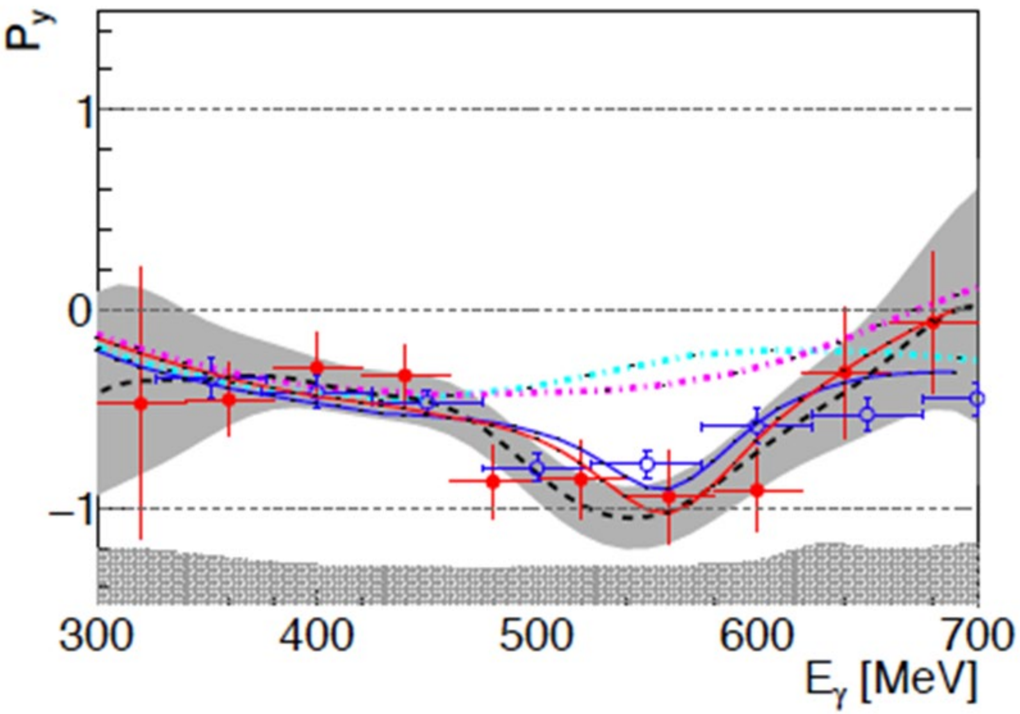
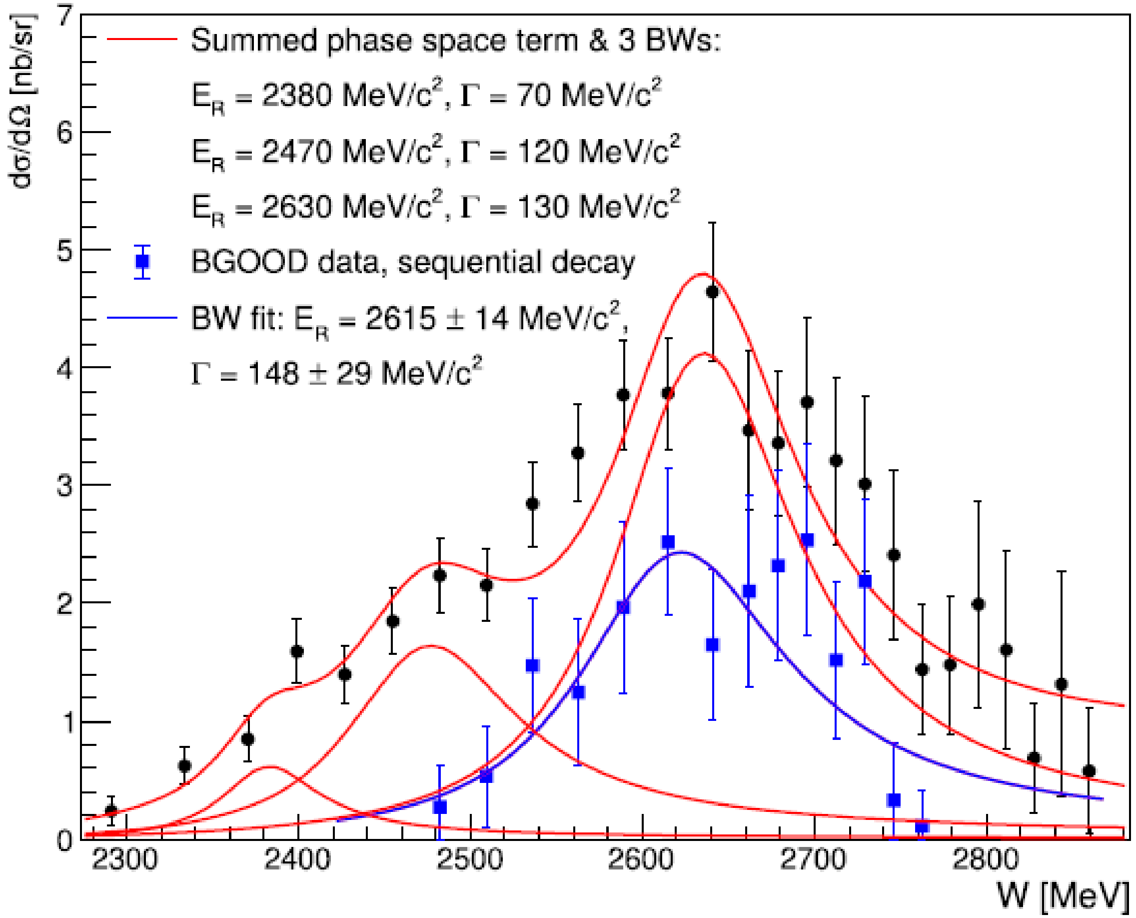


Figure 1: A diagram of the Jefferson Lab KLF, highlighting the K_L beamline elements.

Progress in Task 4.3 : Dibaryon structure and parameter determination



M.Bashkanov et al. (A2 Collaboration at MAMI) Signatures of the $d^*(2380)$ Hexaquark in d$(\gamma, p\vec{n})$ Phys. Rev. Lett. 124 (2020) 132001



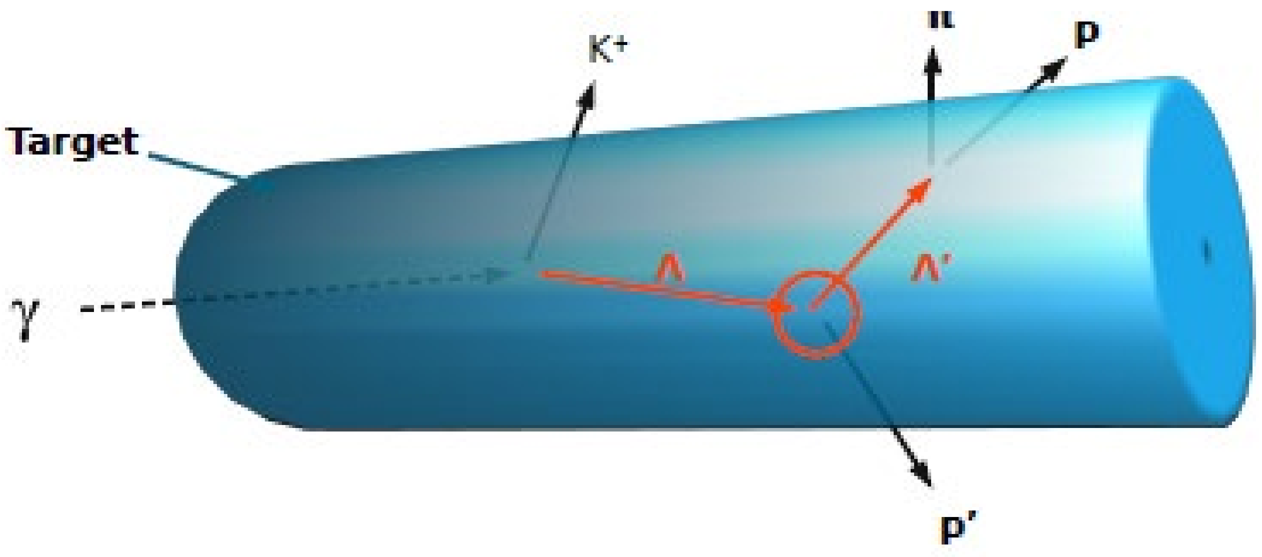
Evidence of a dibaryon spectrum in coherent $\gamma d \longrightarrow \pi^0\pi^0 d$ reaction at forward deuteron angles with the BGOOD experiment at ELSA, T. Jude et al., Phys.Lett.B 832 (2022) 137277

M.O. Celi et al

PHYSICAL REVIEW D **109**, 023004 (2024)

Destabilization of high-mass neutron stars by the emergence of d^*-hexaquarks

We study the effects of the first nontrivial hexaquark, $d^*(2380)$, on the equation of state of dense neutron star matter and investigate the consequences of its existence for neutron stars. The matter in the core regions of neutron stars is described using density-dependent relativistic mean-field theory. Our results show that within the parameter spaces examined in our paper, (i) the critical density at which the d^* condensate emerges lies between 4 and 5 times the nuclear saturation density, (ii) d^* hexaquarks are found to exist only in rather massive neutron stars, (iii) only relatively small fractions of the matter in the core of a massive neutron star may contain hexaquarks.

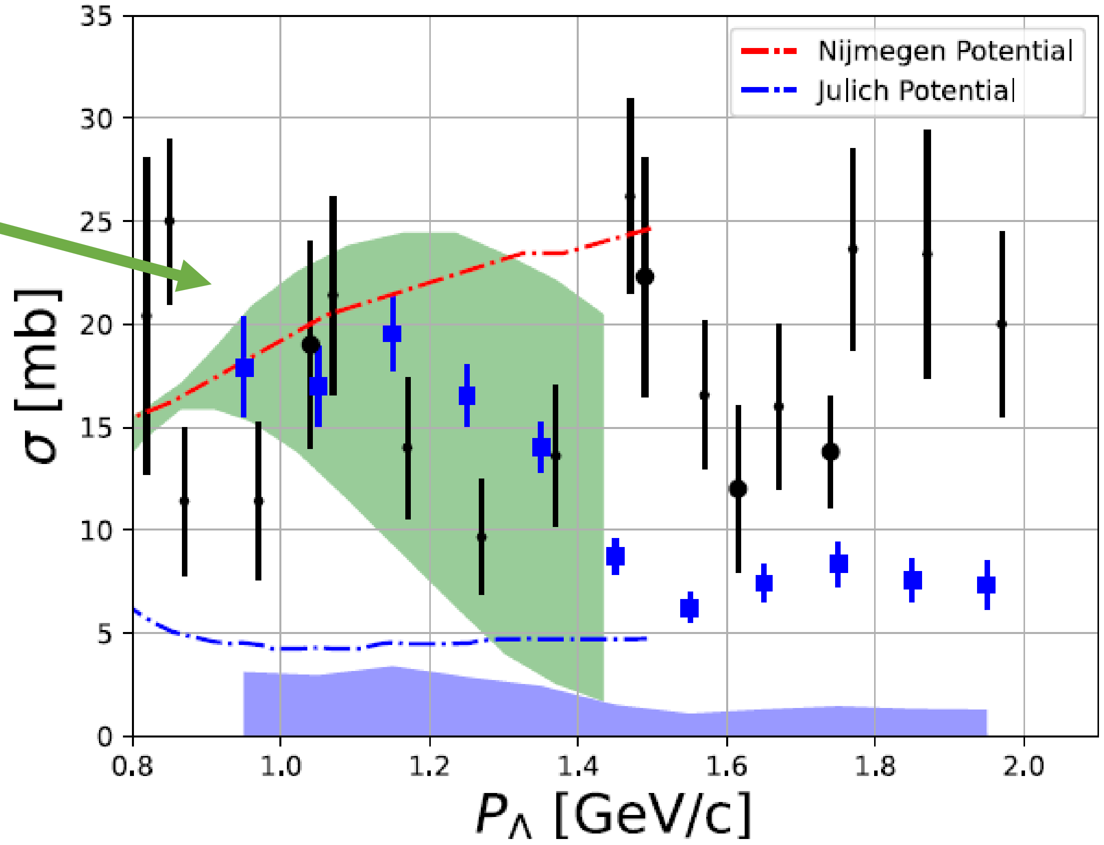


New Methods: Secondary hyperon beams in photo-induced reactions

CLAS Collab. PRL. 127 (2021) 272303, Improved Λp Elastic Scattering Cross Sections Between 0.9 and 2.0 GeV/c and connections to the Neutron Star Equation of State

chiral effective field theory (EFT)

J. Haidenbauer, U.-G. Meißner, and A. Nogga, Eur. Phys.J. A 56, 91 (2020).



Summary

- STRONG2020-HaSp made progress in hadron interaction theory, phenomenology and data analysis
- Development of new theoretical tools and applications to the vast hadron phenomenology
- Progress in theoretical tools for discovery: multi-q, exotic configurations , BSM, …
- Development of AI-supported tools for hadron spectroscopy analysis
- Development of phenomenological analysis framework to extract resonance parameters from data
- Established a strong connection between experimental and theoretical groups in Europe (and beyond)
- Significant progress but many interesting problems remain opened requiring further investigation
- Hadron spectroscopy: a vibrant field that involves a large community in Europe (and beyond!)
- Schools and meetings engaged a large number of young researchers (students, postdocs)
- The hadron spectroscopy community is ready to engage a new project beyond STRONG2020