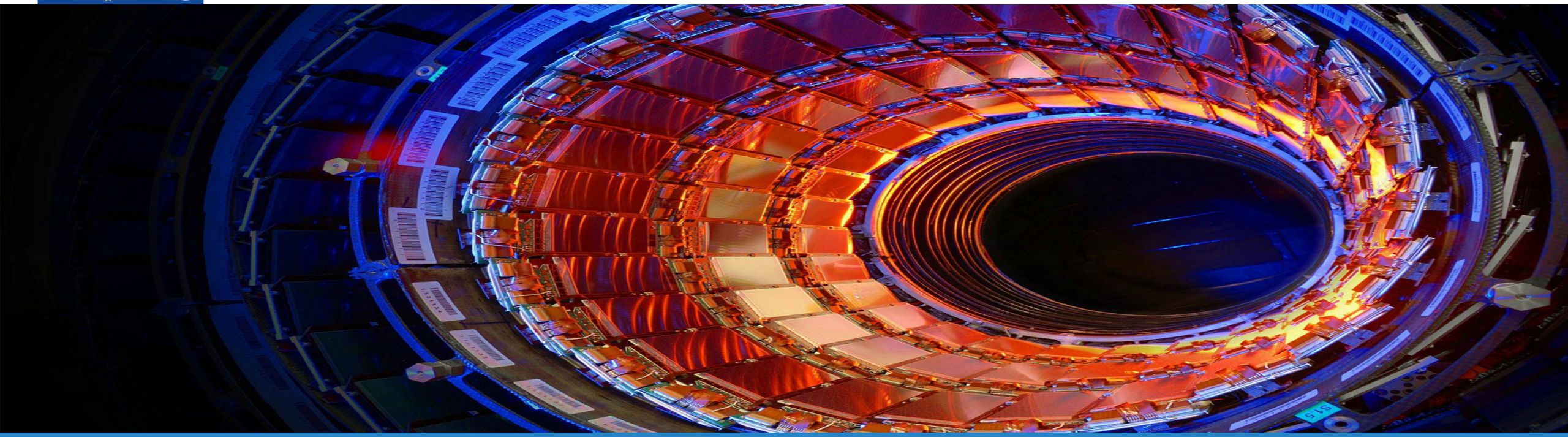


WP25-JR7
Light-and heavy-quark hadron spectroscopy (HaSP)

M.Battaglieri(Jlab/INFN) & J.Nieves (IFIC)

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

Light and heavy-quark hadron spectroscopy (HaSp)

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

Light and heavy-quark hadron spectroscopy (HaSp)

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

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

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

- 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

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

Task 4: Baryon and multi-baryon spectroscopy

- Resonance parameter determination (M.Ostrick – Mainz)
- Diffractive and annihilation production and exotic baryon (A.D'Angelo – URM-TV)
- Dibaryon structure and parameter determination(D.Watts – UYork)

Light and heavy-quark hadron spectroscopy (HaSp)

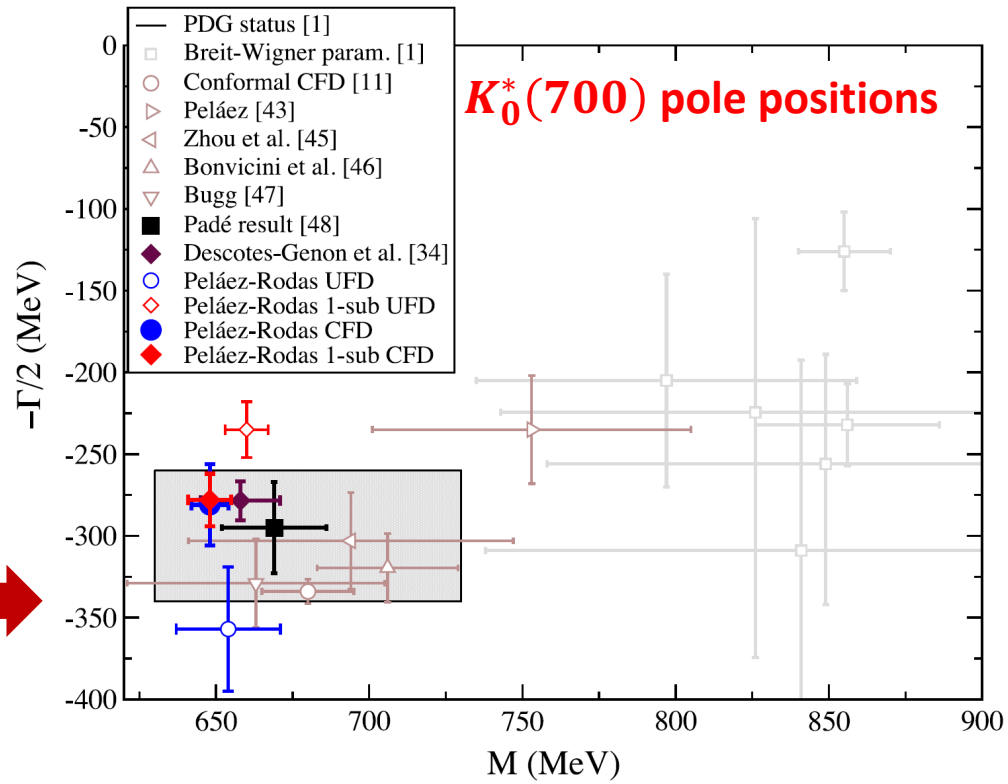
TASKS/Subtasks	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1. Precision calculations in non-perturbative QCD (I)																
1.1 Development and application of EFTs			**M1**							**M3**			**M4**			
1.2 Hadron decays			**M1**							**M3**			**M4**			
2. Precision calculations in non-perturbative QCD (II)																
2.1 Study of hadron resonances, form factors, LECs, etc			**M1**							**M3**			**M4**			
2.2 Computation of heavy-quark, hybrid and tetraquark potentials			**M1**							**M3**			**M4**			
2.3 Computation of m.e. for in medium quarkonium evolution			**M1**							**M3**			**M4**			
3. Meson Spectroscopy analysis of new and exotic states																
3.1 Search for and study of light exotic mesons, charmonium and strangeonium						**M2**				**M3**			**M4**			
3.2 Spectroscopy of low-lying scalars, strange mesons and strangeonia						**M2**				**M3**			**M4**			
4. Baryon and multi-baryon Spectroscopy																
4.1 Resonance parameter determination						**M2**				**M3**			**M4**			
4.2 Diffractive and annihilation production and exotic baryons						**M2**				**M3**			**M4**			
4.3 Dibaryon structure and parameter determination						**M2**				**M3**			**M4**			

Progress in Task 1.1: development and application of EFTs

By employing ChPT, HQET or Quarkonium Non Relativistic EFTs, combined with unitarization methods and dispersive techniques, we have made significant progress in our goal of *establishing a robust framework for studying QCD in the non-perturbative regime*.

- ❑ spectrum and phenomenology of (exotic) hadrons in the free space: $Z_b^{(*)}, \Lambda_c^*, \Xi_{c,b}^*, \Xi_{cc}^{(*)}$, pentaquarks, …
- ❑ phenomenology of (exotic) hadrons in hot environments: $D, D^*, D_s, D_0^*, ..$
- ❑ dispersive model-independent analysis of πK and $\pi\pi \to K\bar{K}$ partial-waves in the low energy region
- ❑ new methods to handle problems in hadron physics.

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



Progress in Task 1.2: Hadron decays

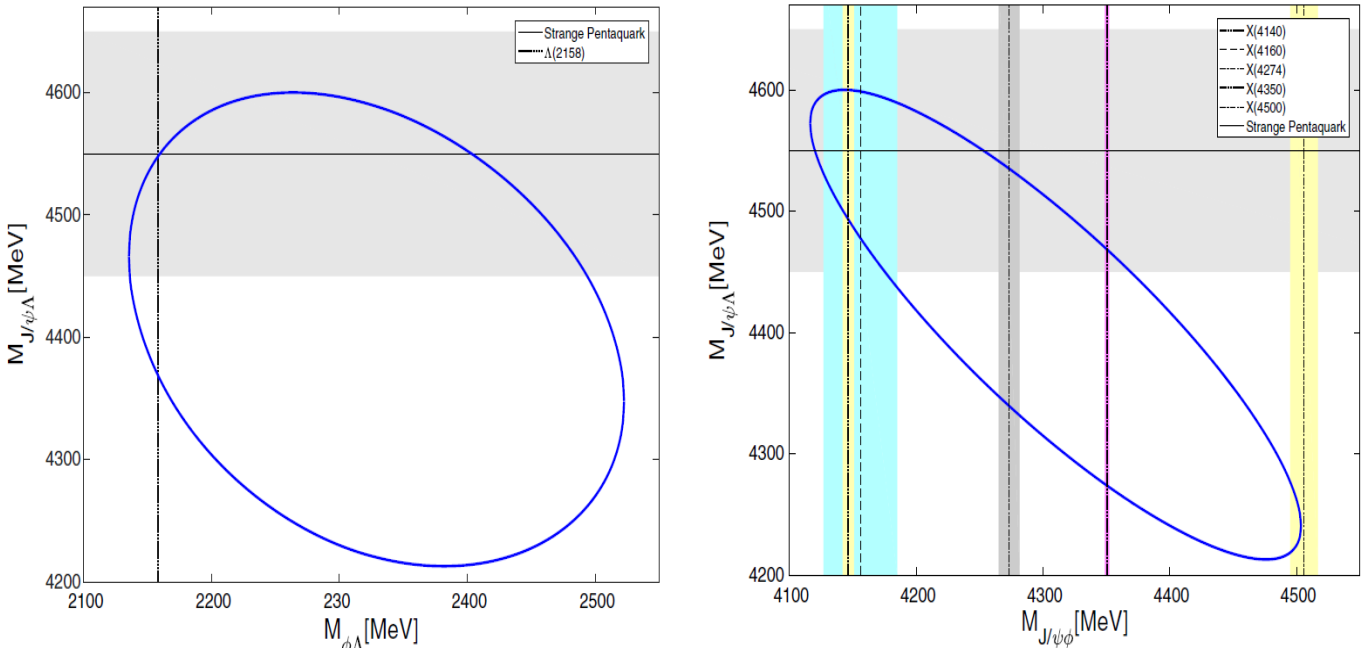
Looking for interacting hadron pairs that might produce resonances (using Dalitz-plot based methods, EFT and dispersive techniques) in:

- ❑ electromagnetic decays: radiative transitions of charmonium and bottomonium, transitions to SU(3)-octet baryon-antibaryon or $\ell^+\ell^-$ pairs states, other reactions like $\psi(3770) \longrightarrow \gamma D\bar{D}$,...
- ❑ weak decays: $\Lambda_b \longrightarrow J/\psi\phi\Lambda$, $\bar{B} \longrightarrow D\,\ell\bar{\nu}_\ell$, $D^+ \longrightarrow \nu_e\, e^+\rho\bar{K}$, $D^+ \longrightarrow \nu_e e^+\pi\bar{K}^*$, ...
- ❑ strong decays of Υ states, reactions like $\bar{K}p \longrightarrow YK\bar{K}\pi$, with $Y = \Sigma, \Lambda$

Explored the exotic nature of resonances, CP or isospin (f.e $V \longrightarrow P\gamma, P \longrightarrow V\gamma$) violations, or decays of unconventional states..

V. Magas , À. Ramos, R. Somasundaram, Phys. Rev. D102, 054027

Dalitz plots from the study of $\Lambda_b \longrightarrow J/\psi\phi\Lambda$



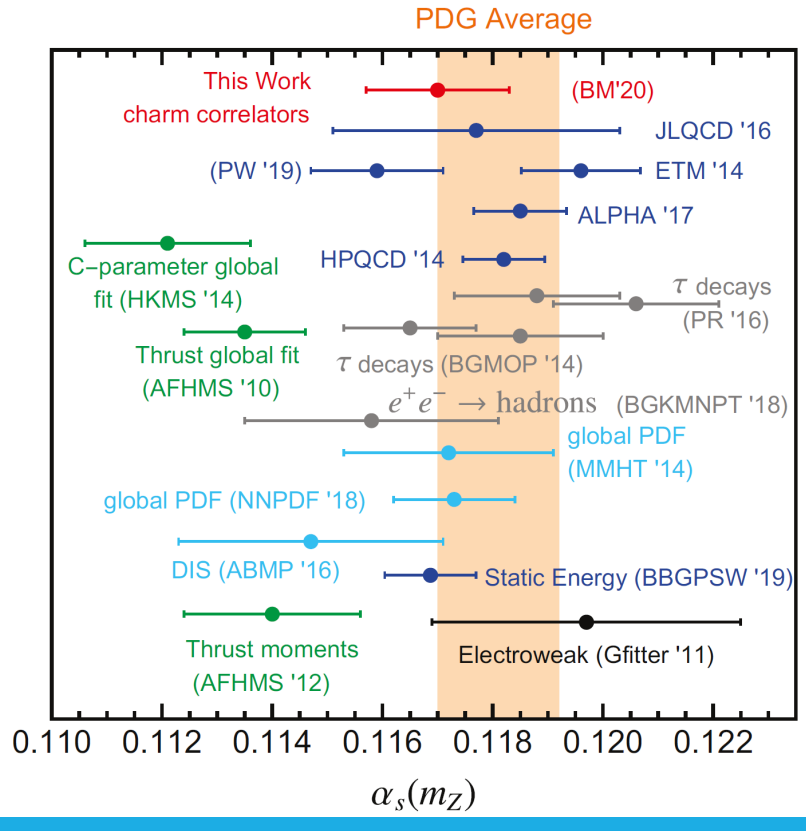
Progress in Task 2.1 : Hadr Res, FFs, LECs, QCD parms, light nuclei spectroscopy

- 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	0.1170 ± 0.0014

- Tests of LFU in $\Lambda_b \longrightarrow \Lambda_c \ell \bar{\nu}_\ell$, $\ell = \tau, e/\mu$, and $b \longrightarrow s\ell^+\ell^-$ decays using LQCD form-factors and searches for BSM signals.
- Neutron matter calculations using as input nucleon-nucleon chiral-EFT interactions, including $\Delta(1232)$ degrees of freedom.
- Nuclear electromagnetic transitions, evolution of magic numbers in neutron-rich nuclei, polarization of τ and exclusive final state hadron observables in neutrino nucleus scattering

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



Progress in Task 2.2: heavy-quark, hybrid and tetraquark potentials

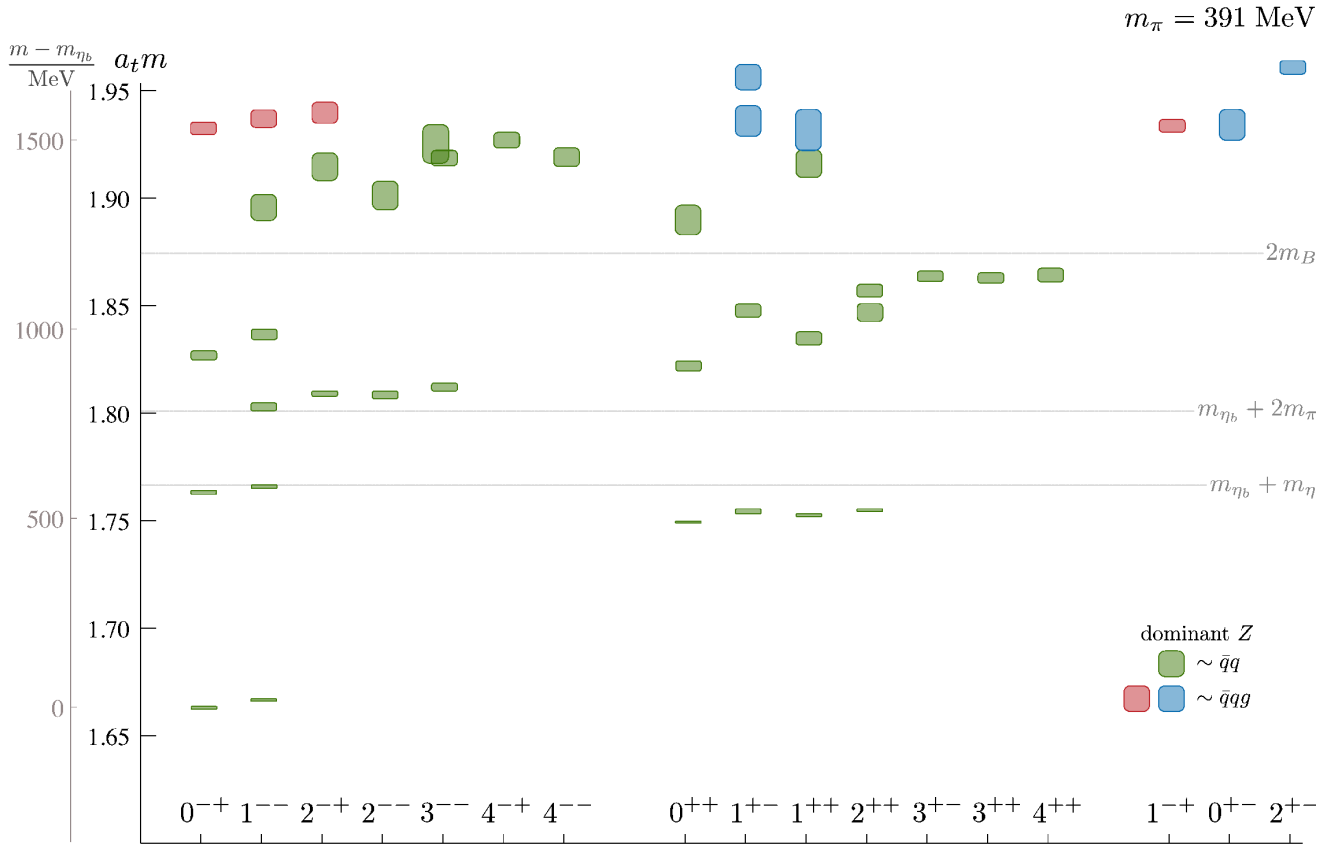
For the first time the excited and exotic bottomonium spectrum (including hybrids) has been determined by a fully relativistic and unquenched lattice calculation.

QCD thermodynamics has also been studied in full QCD **Aarts et al, arXiv:2007.04188**

Further progress is going on in:

- ❑ computing the heavy quark potential with 2+1+1 flavors capturing the charm mass dependence
- ❑ studying mesons in NRQCD in order to understand their thermal masses and width shifts
- ❑ studying the interquark potential using NRQCD quarks to understand thermal variations.

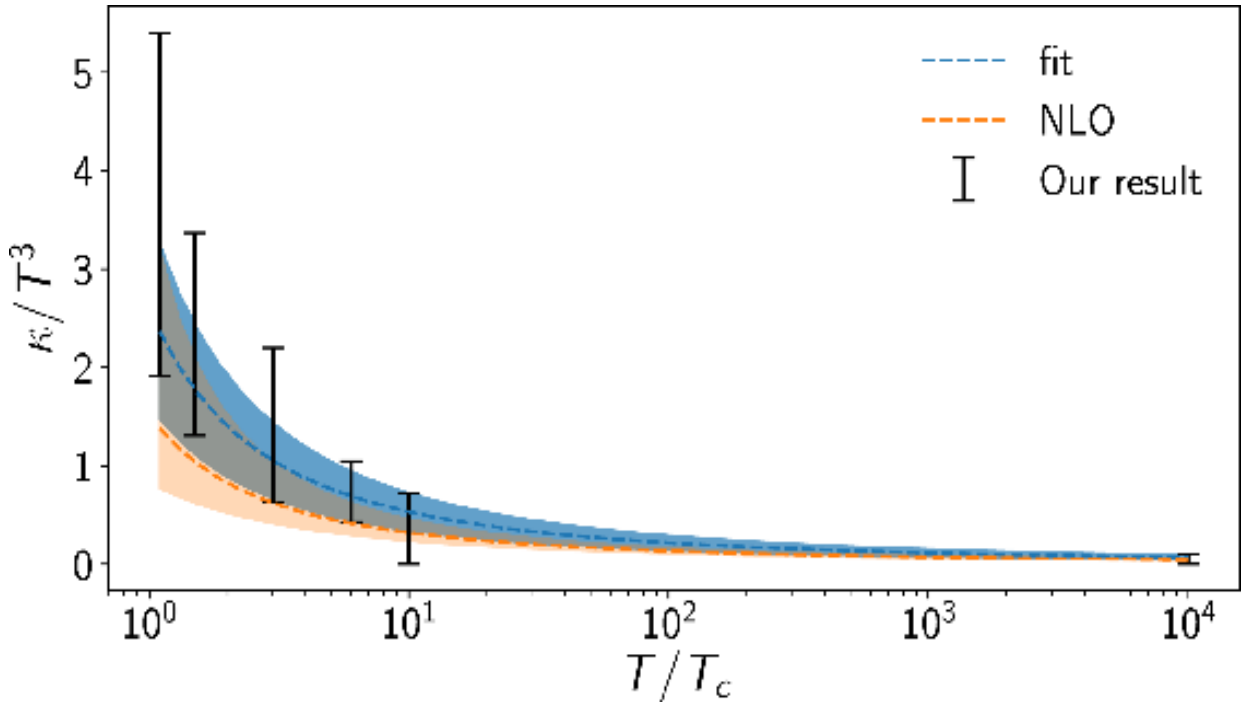
Ryan et al [Hadron Spectrum coll.] arXiv:2008.02656



Progress in Task 2.3: matrix elements for in medium quarkonium evolution

- Quarkonium propagation and suppression in the medium formed in heavy-ion collisions
- The quarkonium out of equilibrium dynamics at low energy is governed by in-medium correlators to be computed in lattice QCD
- The heavy quark diffusion coefficient κ has been computed in quenched QCD over a wide range of temperatures. It has been found that within errors the lattice results are remarkably compatible with the NLO perturbative result

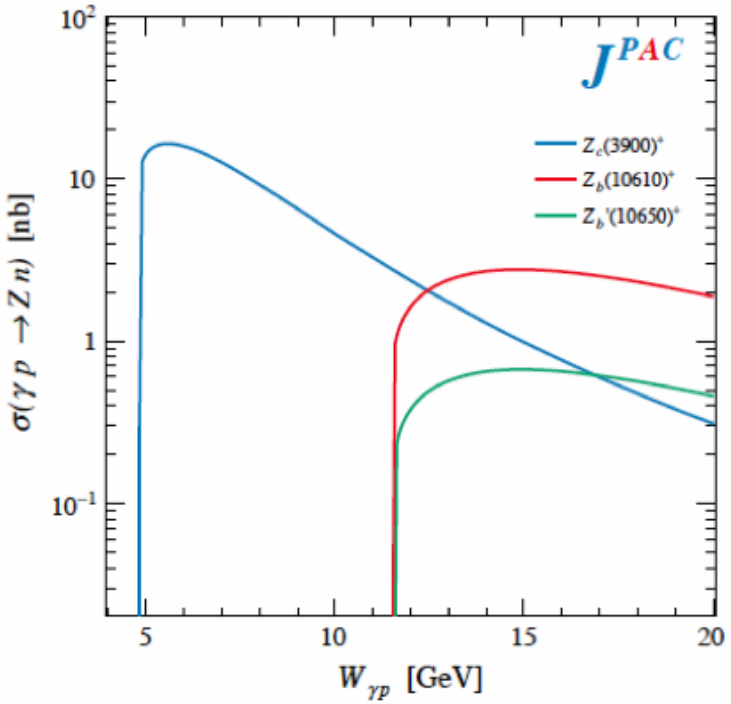
Brambilla, Leino, Petreczky, Vairo
arXiv:2007.10078



Progress in Task 3.1: Search for and study of light exotic mesons, *cc* and *ss*

- Significant experimental activity: light quark hadron spectroscopy with GlueX and CLAS at JLab; pion-production with COMPASS; charmonium 'XYZ' exotic states at BESIII and LHCb.
- Developed new analysis tools to leverage polarization degrees of freedom in photoproduction and study XYZ spectrum three-body final states
- Investigated the spin structure of hybrids using a non relativistic effective field theory
- XYZ exclusive production cross sections calculation for future experiments at EIC
- Code available to the community to implement event generators for yield estimates

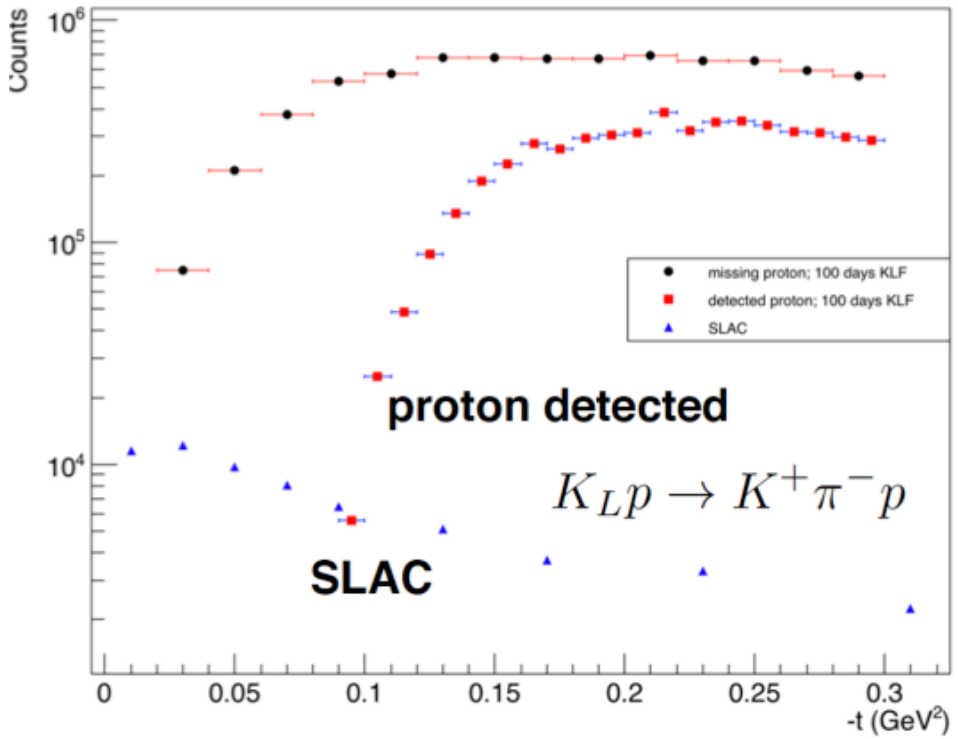
M.Albaladejo et al. (JPAC Collaboration)
arXiv:2008.01001



Progress in Task 3.2: Spectroscopy of low-lying scalars, s- and c- mesons

- 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 σ/f_0(500) and the f_0(980), and of other strange excited resonances.
- Keep working on CLAS6 data analysis searching for light quark hybrid mesons: ηπ, η'π, ηππ, ωππ and K^*K
- Multi-channel analysis of existing data is being started by the BnGa-PWA group using GAMS, CERN-Munich, CrystalBarrel pbar N, and BES with interesting results on baryons.
- ALICE completed a measurement of f_0(980) in pp collisions at 13 TeV at LHC

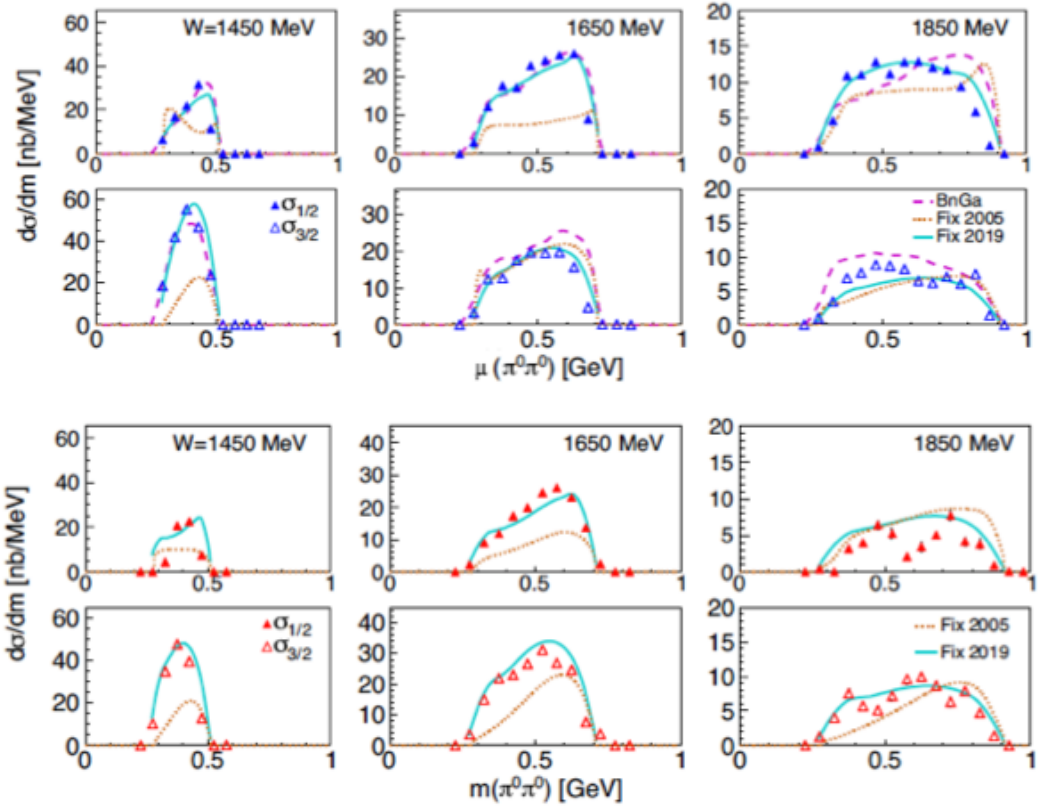
M.Amaryan et al.
Strange Hadron Spectroscopy with Secondary KL Beam in Hall D
Jlab C12-19-001 proposal



Progress in Task 4.1: Resonance parameters determination

- Published new measurements of spin dependent π, η, ππ, and πη photoproduction from ELSA and MAMI
- New partial wave analysis of γN→ηN; new EtaMAID model published; the large difference in the Nη-branching ratio between the N(1535)1/2⁻ and the N(1650)1/2⁻ almost disappeared in the new BnGa analysis results
- Cusp structure at the η' threshold, observed by A2@MAMI was confirmed by beam asymmetry measured byt CBELSA/TAPS
- New results on η photoproduction by a novel self-consistent two-step approach

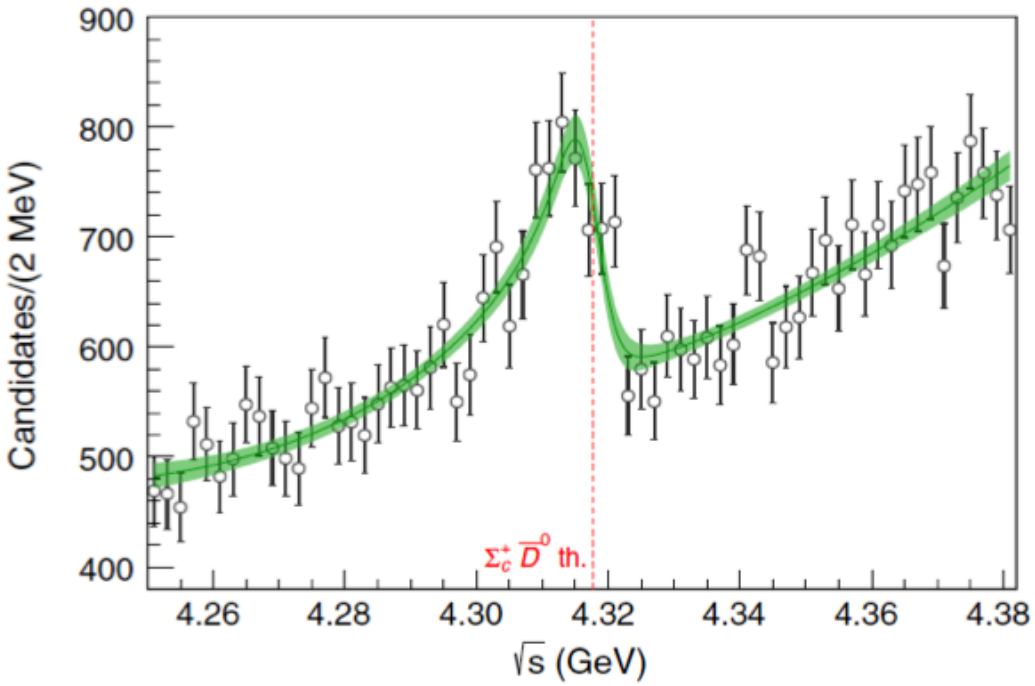
M. M. Dieterle *et al.*(A2 Collaboration)
Phys. Rev. Lett.125, 062001



Progress in Task 4.2: Diffractive and annihilation production and exotic baryon

- Photo-induced mesons production: E beam-target helicity asymmetry in the $\vec{e}\vec{n} \rightarrow K^+ \Sigma^-$ reaction on a HD target
- Electro-induced mesons production: CLAS12 6.5 GeV and 7.5 GeV energies on unpolarized proton target; analysis of $\vec{e}\, p \rightarrow e\, K^+\, Y$ and $\vec{e}\, p \rightarrow e\, \pi^+\, \pi^-\, p$ reaction channels is underway
- 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/ψp spectrum using S-matrix

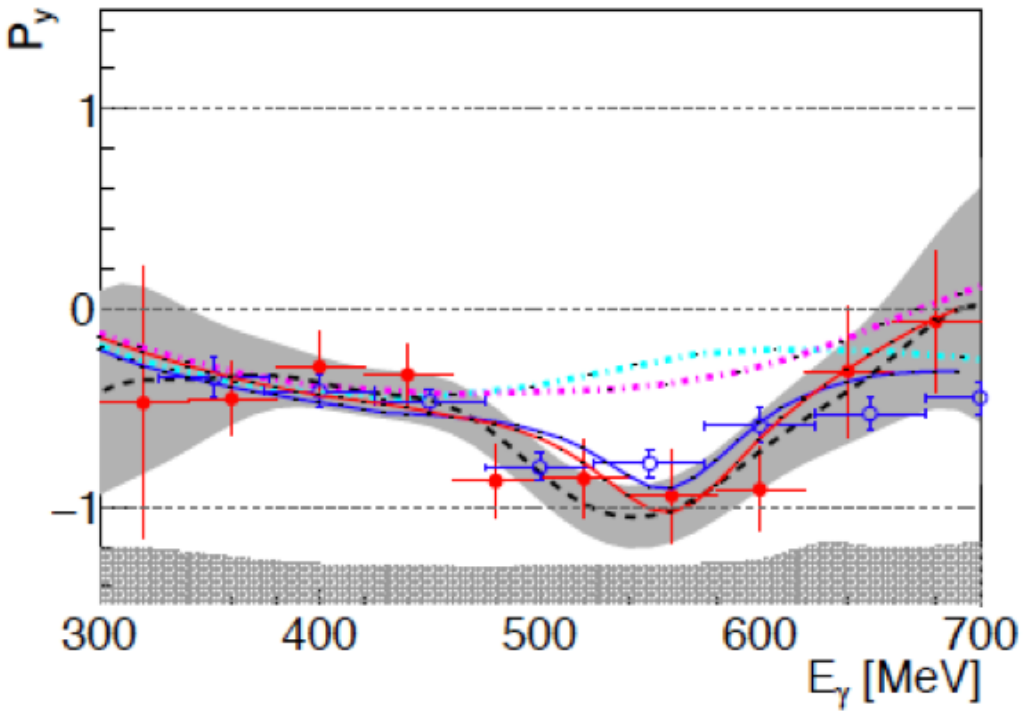
C. Fernández-Ramírezet al. (JPAC)
Phys. Rev. Lett.123, 092001



Progress in Task 4.3: Dibaryon structure and parameter determination

- JLAB-CLAS12 exploratory analysis of single-, double-, and triple-strangeness members of the d* SU(3)
- First calculations of d* multiplet width and branching ratios indicate strong suppression of d_{sss} decay to $\Xi^*\Sigma^*$, while $d_{sss} \longrightarrow \Delta\Omega$ and $d_{sss} \longrightarrow \Xi\Sigma$ are "golden" decay channels.
- At MAMI, new deuterium photodisintegration measurements with polarised photons indicate dominant magnetic octupole and suppressed electric quadrupole moments for the d*
- At Wasa, the latest results on d*(2380) excitation in pn-elastic scattering significantly improve the partial wave analysis fit uncertainty,
- Set up Networks, collaborations and research output with astrophysicists

M.Bashkanov et al.
Signatures of the $d^*(2380)$ Hexaquark in $d(\vec{\gamma},\vec{pn})$
Phys.Rev.Lett. 124 (2020) no.13, 132001



Deliverables and Milestones

Deliverable No.	Deliverable name	Lead Beneficiary	Nature	Dissemination level[1]	Delivery month from Annex I	Delivered (yes/no)	Actual delivery month	Comments
D25.1	HaSP Combined Analysis framework	30 - INFN	Websites, patents filling, etc.	PU	18	yes	15	HaSp web site link: http://web.ge.infn.it/jstrong2020/

✓ **Delivered on time**

Deliverables and Milestones

HaSp web site

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

- Used routinely by the HaSp collaboration to exchange information
- Living tool updated with highlights, Tasks progress, Combined analysis
- Store documentation with link to papers, reports, docs
- Theory/experiments exchange

The HaSP Network

The spectrum of hadrons is composed of bound states of quarks and gluons. The distinctive property of confinement in strong interactions, which are described by Quantum Chromo-Dynamics (QCD), prevents quarks and gluons from appearing as free particles. A new generation of dedicated experiments in hadron physics has been proposed with the aim of uncovering properties of strong interactions and specifically the mysteries of confinement. Some of these experiments are already in operation and several more are planned for the near future in the main EU laboratories (CERN, Mainz, Bonn, GSI) and abroad (TJNAF/US, BESIII/China, J-PARC/Japan, Belle/Japan). These new experiments will produce an unprecedented amount of high-precision data that requires a level of sophistication in analysis never before achieved. The challenge for the hadron physics community is to synergize the theoretical and experimental efforts to develop best practices for analyzing and interpreting the complex experimental data, developing a sound analysis framework that incorporates latest advances in theory and phenomenology and a set of tools to manipulate, analyze, and preserve the data. Thus, the most advanced and innovative theoretical techniques (effective theories, analyticity constraints, unitarity re-summations and dispersion relations, Lattice-QCD (LQCD) simulations and analysis, etc.) need to be fully developed and applied for a solid interpretation of the experimental results. 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. These goals can only be achieved through a large-scale collaborative effort that takes full advantage of the expertise in hadron physics communities in Europe and in the rest of the world. The HaSP network activity aims to coordinate the leading European institutions active in hadron spectroscopy with the objective of making progress in: development of theoretical, phenomenological and computational foundations for amplitude; establishment of best practices for accessing systematic uncertainties in analysis of hadron reaction data and interpretation of physics results.

L.Marsicano – INFN-GE

Deliverables and Milestones

HaSp Milestones

- Due to COVID19 pandemic we had to cancel the Topical Workshop on Theoretical haspects (IFIC Valencia April 21-24 2020) scheduled for M9
- Rescheduled as virtual-only meeting for December 15-17 2020
- Second topical; workshop (Experimental) scheduled for M18 to be hold during Summer 2021

Milestone number	Milestone name	Lead beneficiary	Delivery month from Annex I	Delivered (yes/no)	Actual delivery month	Comments
MS52	Topical Workshop on Theoretical aspects of Hadron Spectroscopy and Phenomenology (IFIC). Tasks 1 and 2	30 - INFN	9	NO	December 2020	Given the serious public health problems related to Covid-19, which forced the closure of several countries inside and outside the EU, as well as the imposition of extreme travel limitations, the organizing committee decided to cancel the meeting expected to be held in Valencia (Spain) from April 21 to April 24, 2020 as part of the STRONG-2020 activity. Unfortunately, due to still strong travel constraints after the summer in many countries, we decided to hold it in remote mode http://ific.uv.es/nucth/TH-WP25-H2020/
MS53	Topical Workshop on Experimental Aspects of Hadron Spectroscopy and Phenomenology (UEdin). Tasks 3 and 4	30 - INFN	18			Pending the clarification about the funds-transfer between UEDI and the University of York (see Sec.3.1). In case funds will be available, due to COVID19 pandemic the workshop will be postponed to June-September 2021 (24-28). Depending on the medical condition in the first months of 2021, we will decide about 'in person' or 'remote only' attendance.

Deliverables and Milestones

Topical Workshop (Theory) web page
http://ific.uv.es/nucth/TH-WP25-H2020/

JRA7-HaSP: Light-and heavy-quark hadron spectroscopy

Horizon 2020 research and innovation programme grant agreement num. 824093 (STRONG-2020)

Valencia (Spain), December 15-17, 2020
Online meeting: https://jlab.bluejeans.com/688545587

Timetable (CET)

	Tuesday 15th	Wednesday 16th	Thursday 17th
13.30h-15.35h	Session 1	Session 3	Session 5
15.35h-15.55h			
15.55h-18.00h	Session 2	Session 4	Session 6

Distribution of talks in sessions **(25'= 20' talk +5' discussion)**