Town Meeting, Hadron Physics in Horizon Europe

1–3 Jul 2025
IMT Atlantique
Europe/Paris timezone

horizon europe

Artificial Intelligence for Hadron Spectroscopy and Interactions
AI4HSI

Letter of Intent for HORIZON-INFRA-2025

M.Battaglieri (INFN) & J.Nieves (IFIC, UV & CSIC))

AI for NP/HEP

How do we progress in our understanding of strong interactions?

- Modern Nuclear and High Energy Physics experiments produce a vast amount of data
- Data need to be cleaned from noise and background to reconstruct particles' 4-momenta
- Physics observables (xsecs, asymmetries, correlations, decay distributions, …) are extracted
- Data are compared to physics-informed models (established theory with an unknown component of microscopic interactions)
- Validation of theoretical prediction

Shall AI support NP/HEP experiments to extract physics from data in a more efficient way?

AI4HSI aims to develop AI-supported procedures

- Prepare data unfolding detector effects
- Extract signal from background
- Accurately fit data in multiD space
- Extract physics observables (xsec, asymmetries, …)
- Develop an analysis framework
- Develop theory and phenomenological models
- Interpret physics observables
- …. in all steps, quantifying the uncertainty (UQ)

Collaborative effort

- **experimentalists**
- **phenomenologists**
- **theorists**
- **Data Scientists**

AI for NP/HEP

AI4HSI

Data collection → Data analysis → Physics extraction → Physics interpretation

Data collection	Data analysis	Physics extraction	Physics interpretation
Bonn, CERN, FAIR, Mainz, JLab	ALICE, AMBER, CBM, Compass, ELSA-INSIGHT, Koala, LHCb, MAMI, CLAS12, GlueX, ePIC, BESIII	Analysis framework	Theory and phenomenological models

BochumU, BonnU, GiessenU, GlasgowU, GSI, INFN, MainzU, YorkU

BarcelonaU, BochumU, BonnU, GiessenU, GlasgowU, INFN, Valencia-IFIC

BarcelonaU, BarcelonaAU, BochumU, BonnU., GiessenU, GlasgowU, MadridU, PabloOlavideU , SalamnacaU, TUM, Valencia-IFIC

Light quark hadrons, strange hadrons, exotics, hybrids, XYZ states, heavy hadrons, quarkonium, correlation functions, exclusive and inclusive reaction channels, coupled-channel analysis

Dispersive techniques, nonperturbative functional methods, MonteCarlo simulations, Partial Wave Analysis, Moments analysis, JPAC, LaVA, A(i)DAPT, Reaction Data Bases

Analyticity, Unitarity, Symmetries and EFTs: ChPT, HQET, BOEFT,... , pNRQCD, Lattice QCD, nonperturbative functional methods , Quark model, hadron dynamics, hadron-hadron interactions, femtoscopy , hadrons in media at high density and/or temperature,

Calibration and alignement, Generative models, Diffusion Models, parton-level unfolding, Uncertainty Quantification

Supervised learning algorithms for predicting hadron spectra, VMC-NQS, GANs, real and virtual photoproduction experiments

Feynman diagram and integral calculations, genetic algorythms, neural networks, multiloop computations

Physical access: data collection and analysis, workshops, schools

Virtual access: web site, seminar series, colloquia, virtual recording, tools repositories, online tools interfaces, model repositories

Data collection, analysis, physics extraction and interpretation

Data from:

Bonn (ELSA), CERN (ALICE, AMBER, COMPASS, LHCb), FAIR (CBM, KOALA), Mainz, (MAMI), Jefferson Lab (CLAS12, GlueX), BNL (ePIC) + other world facilities (BES-III)

Generative AI for data analysis

- Data skimming, common format, and sample storage in a central data repository
- Detector effects unfolding: smearing, acceptance, and efficiency
- Signal extraction from instrumental and physics background
- Merging of parton-level data, combining samples from different experiments

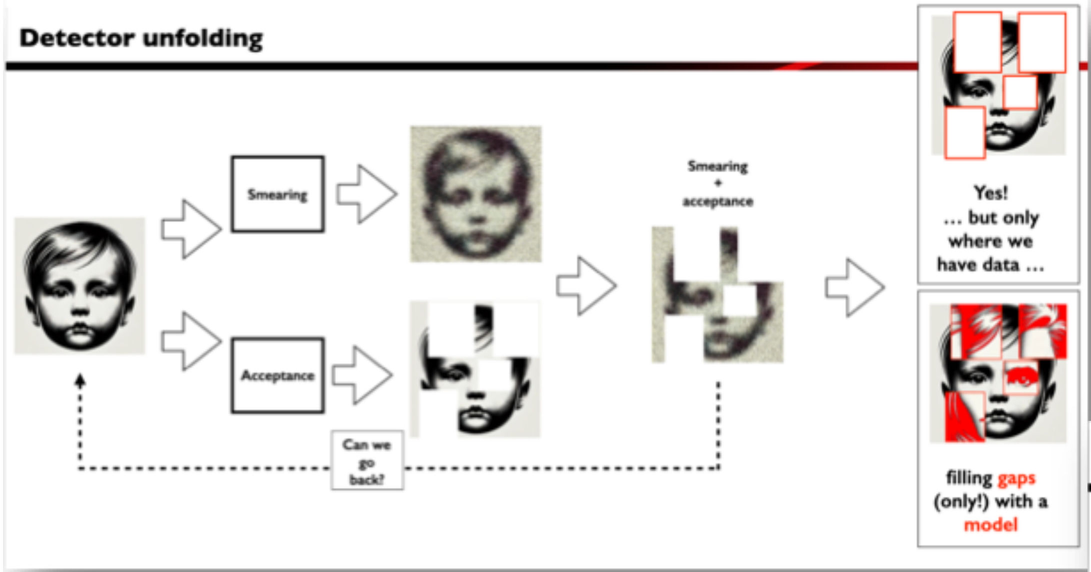
Supervised learning for physics extraction

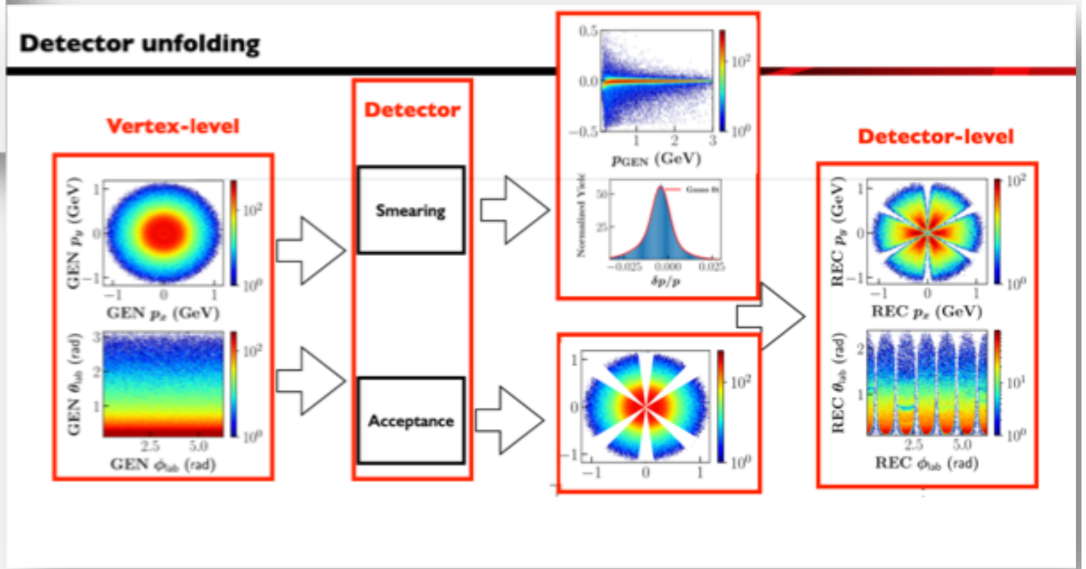
- Key-physics observables extraction
- Angular and momentum distributions, cross sections, decay observables, CP-asymmetries, correlation functions
- Results stored in a shared repository, virtually accessible to all partners via online web interface

Genetic algorithms and NNs for physics interpretation

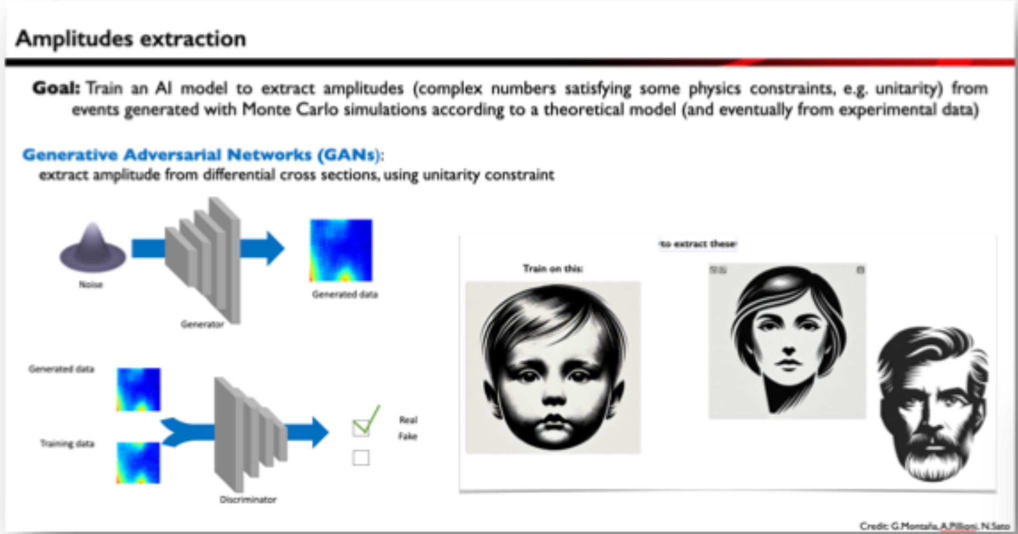
- Theoretical framework development
- EFTs, analyticity constraints, unitarity re-summations, dispersion relations
- Overlap with low-energy NP communities: quantum many-body wf
- LQCD simulations
- Evolution equations of hard probes in hot and dense media

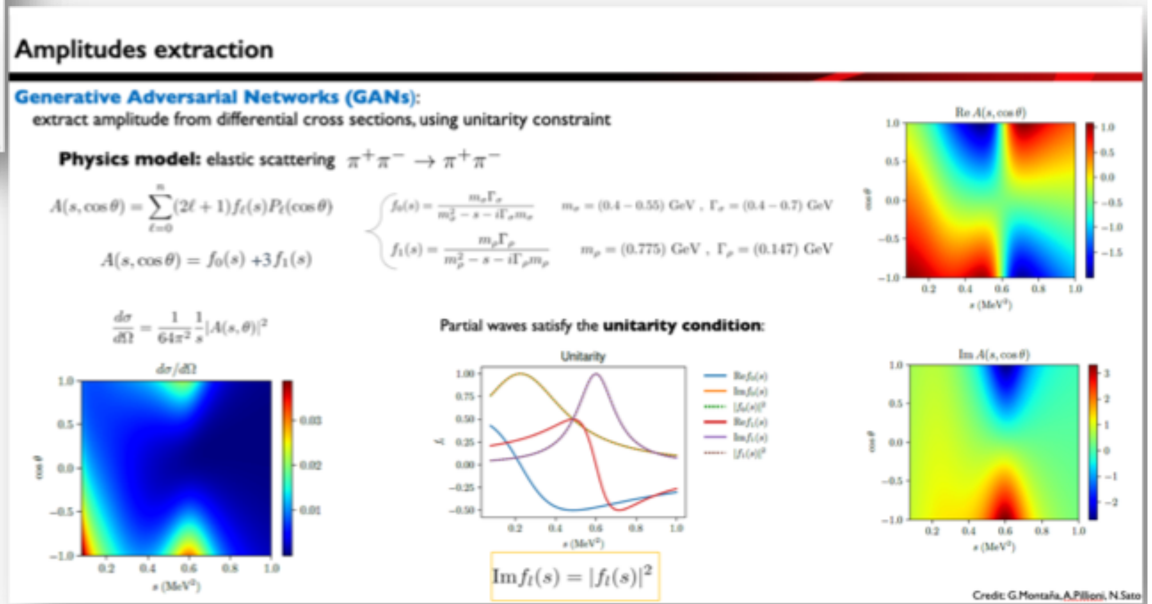
Example: detector effects unfolding





Example: amplitude extraction





Participating and partner institutions

Data collection & data analysis - Mainz contribution

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Members
Riccardo Aliberti
Achim Denig
Wolfgang Gradl
Nils Hüsken (convener)
Tyler Kutz
Christoph Redmer

Virtual access
provide access to experimental data (BESIII, MAMI, MESA) upon publication

Physics tracks
light-quark hadrons, exotics, XYZ states, quarkonium

Relation to selected infrastructures
JGU Mainz is host to the MAMI and MESA facilities

Contributions: data collection

- BESIII provides unique data from world-record J/ψ and $\psi(2S)$ datasets, providing complementary information to COMPASS, AMBER and J-LAB for essentially any light-hadron final state
- BESIII also plays a leading role in spectroscopy of charmonium-states as the only running experiment operating in the τ-charm energy region
- MAMI provides information from e^-- and photo-production processes that is highly complementary to measurements at J-LAB and ELSA
- as the first multi turn energy-recovering accelerator, MESA will provide high quality data using low-energy but high-intensity beams ideally suited for measurements of hadron- and nucleus structure

data analysis:

- bring in experience from ML techniques in BESIII: μ-π separa artificial neural networks and boosted decision trees, AI for m dimensional cut optimization, unfolding, …
- in development: AI-based tracking algorithms for future applic the upcoming MESA facility

PHYSICS INTERPRETATION – University of York group

UNIVERSITY of York

STAFF MEMBERS
Dr Mikhail Bashkanov (Academic)
Dr Julien Bordes (PDRA)
Dr Stuart Fegan (PDRA)
Dr Kayleigh Gates (PDRA)
Dr Stephen Kay (PDRA)
Dr Matthew Nicol (PDRA)
Prof Daniel Watts (Convener)
Dr Nick Zachariou (Academic)

PROPOSED EVENTS
Interdisciplinary AI/ML workshops with hadron/nuclear focus.

VIRTUAL ACCESS
Interactive group website and publication of outcomes on Zenodo

LINES TO BE DEVELOPED
Our group focuses on experiments using intense electromagnetic and Kaon beams to study the structure of strongly interacting matter from the level of partons up to that of nuclei. Interpretation of experiments utilises a range of partial wave analysis frameworks in the baryonic and mesonic sectors. We bring extensive contacts in the AI community in the UK – group members represent the University of York in AI/ML initiatives in the N8 (a grouping of the 8 most research-intensive universities in the North of England). We develop and exploit new AI/ML methods in data analysis, detector optimisation (e.g. calorimeter construction for the EIC), and medical imaging (PET). We also derive new software and routines for Geant4 (e.g. quantum entanglement, polarimetry), and group members sit on the GEANT4 user committee.

PHYSICS TOPICS
Nucleon, meson and nuclear structure, nucleon and meson spectroscopy, exotics in meson and baryonic sectors, hyperon-nucleon interactions.

RELATION TO SELECTED INFRASTRUCTURES
Theoretical interpretation and description of experimental data coming from … at JLAB, KLong Facility at JLAB, HallC at JLAB and the EIC.

Contributions by JLU Giessen

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

Contributing Experimental Groups

- K.-T. Brinkmann (PANDA at GSI/FAIR, CLAS at JLab, AMBER at CERN, Insight at ELSA)
- C. Höhne (CBM at GSI/FAIR, HADES at GSI/FAIR)
- A. Thiel (GlueX at JLab, AMBER at CERN, CBELSA/TAPS at ELSA) - convener

Contributing Theory Groups

- C. S. Fischer
- M. Huber

-> In total: 3 FTE involved

Covered Topics

- Participation in data collection at different experiments world-wide, cove
- Data Analysis in various international collaborations, exploiting modern A data extraction, background determination and detector reconstruction
- Physics interpretation using functional methods

University of Bonn

UNIVERSITÄT BONN

R. Beck, P. Hurck (convener), T. Jude, B. Ketzer, S. Neubert, U. Thoma

Research activity

- Bonn hosts research groups active in hadron spectroscopy at ELSA, CERN and Jefferson Lab. This enables us to **study hadron spectra** across a wide range of energies and production mechanisms, which is critical in the **search for exotic states**. For these studies, a thorough understanding of the reaction phenomenology is indispensable. To facilitate this, **continuous exchange with colleagues from the theory community is needed**.
- The new experiment INSIGHT represents an important upgrade for both the Crystal Barrel and the BGOOD photoproduction experiments at ELSA. INSIGHT will feature a unique combination of an almost complete angular coverage for high-resolution photon measurements, charged-particle detection and the ability to perform measurements using a polarized beam and a polarized target. To support the efficient running of the new INSIGHT experiment, **AI tools shall be developed that augment data taking**. In that we will closely collaborate with colleagues at CERN and JLab to learn and share expertise and maximise the benefits of new advancements.

Related infrastructure: ELSA, CERN, Jefferson Lab

Strong interest to host a school or workshop

Ruhr University Bochum

RUB

Members:
Mikhail Mikhasenko
Miriam Fritsch
Jim Ritman
John Bulava
Evgeny Epelbaum
Farah Afzal (convener)

TA Infrastructures:
JLAB (Afzal, Fritsch): GlueX
CERN (Mikhasenko): COMPASS
FAIR (Ritman): CBM

Proposed Event:
Summer school at ECT*

Contribution: Our research focuses on light hadron spectroscopy, with particular interest in exotic hybrid mesons such as the π_1. We aim to perform a combined analysis of COMPASS data across multiple decay channels to establish consistent resonance parameters. In parallel, we search for the π_1 at GlueX, as well as for exotic states in the meson and baryon sector with strange content (K* and Y*). We want to further explore the potential of CBM to investigate light exotics. We will explore how AI/ML tools can be integrated to facilitate data analysis at the different experimental facilities. Lattice QCD computations and effective field theory approaches are important theoretical tools that complement experimental results.

Physics Tracks:
Light hadrons: Light baryon and meson spectroscopy, exotics (experimental and theory)
Hadron interactions: Properties at low energies and exotic states using "symmetries and EFTs" as well as "Lattice QCD" as theoretical tools

Virtual Access:
COMPASS PWA dataset dissemination
Integrate GlueX partial wave models within Model Serialization Infrastructure

Participating and partner institutions

AI4HSI - University of Glasgow

University of Glasgow

Personnel

Derek Glazier - (convenor)
Dave Ireland
Bryan McKinnon
Simon Gardner
Alex Berger
Dillon Leahy

Hosting

AI4HSI Workshop

a) Data Collection
Glasgow are active members of experiments running at Jlab and Bonn. At CLAS12 and GlueX we are promoting ML simulations as well as developing AI triggering for CLAS12. We are also preparing for the ePIC experiment at BNL where we are developing a lowQ2 detector for Spectroscopy physics which utilises ML reconstruction methods.

b) Data Analysis
We are responsible for data analysis tools currently used with the CLAS12 experiment. We are keen to add additional AI pipelines to these tools to enhanc workflow. For example, we have been developing optimisation of signal to background events and performing background subtractions with ML approache

c) Physics extraction
We are also developing tools for higher level physics extraction for CLAS12 and GlueX experiments as well as pseudo-analysis with ePIC. We will focus on extr experimental observables from trained Neural Networks and parameterising distributions with Gaussian Processes. We are also developing generic event generators for spectroscopy reactions which will be vital for training ML methods

Technical University of Munich – TUM @ AI4HSI

TUM group participating at AI4HSI: N. Brambilla, N. Kaiser and A. Vairo (coord.)

Research plan:

- Study of light hadrons and nuclei;
- Study of quarkonia (production and decays), quarkonium XYZ states (identification, spectra, production and decays), quarkonium propagation and dissociation in a hot/dense medium.

Theoretical methods are effective field theories (chiral perturbation theory, pNRQCD, BOEFT, HTL effective theory), open quantum system approaches, and lattice QCD (TUMQCD coll.). Machine learning methods are used for lattice QCD computations and for solving the evolution equations of hard probes in hot and dense media.

Strong links exist with experimental activity on the proton radius at CERN (AMBER), ... XYZ physics program at LHCb, the heavy-ion collision experiments at ... STAR) and CERN (ATLAS, CMS and ALICE), the hadron and nuclear ...s at GSI (PANDA, CMB) and the hadron and nuclear program at JLAB.

...p is available for organizing a workshop or school.

Autonomous University of Barcelona node

UAB Universitat Autònoma de Barcelona — IFAE Institut de Física d'Altes Energies

R. Escribano, P. Masjuan, A. Pineda

Physics Tracks: light hadrons, heavy hadrons and hadronic interactions

Research Activity:

The activity of the group from the Autonomous University of Barcelona is devoted to *Hadron Physics* with special emphasis on *spectroscopy* and *hadronic interactions*, mainly from the theoretical point of view, by means of the use of theoretical tools such as *symmetries*, *effective field theories*, *dispersive techniques*, and *phenomenological models*.
In particular, we are specialized in the physics of *light hadrons*, within the Standard Model (SM) and beyond the SM, and *heavy hadrons*, with the study of D-decays and *quarkonium*.
We are also commited to the analysis of hadron interactions at low energies.

Events: host a workshop or school

Infrastructures: MAMI, ELSA, LNF Frascati, JLAB, BNL & BESIII Beijing

IFIC – CSIC – Universitat de València

RESEARCHERS INVOLVED: Miguel ALBALADEJO, Luis ALVAREZ-RUSO, Vale... BELOCCHI, Albert FEIJOO, Alessandro LOVATO, Raquel MOLINA, Juan NIEV... PASSEMAR, Antonio PICH, Noemi ROCCO, Pan-Pan SHI, Manuel VICENTE-...

PHYSICS TRACKS: Light & Heavy Hadrons: exotics, quarkonium XYZ states, Hadrons in media and/or at finite temperature; Hadron interactions: properties at low energies, decays, CP violation; quantum many-body wave functions, neutrino/electron nuclear responses and neutrino oscillations

RESEARCH ACTIVITY: Development and general use of EFTs , unitarization methods, dispersive methods for two-body scattering and three-body decays, analysis of femtoscopy correlation functions, LQCD simulations, artificial neural networks (NN) to represent quantum many-body wfs, variational Monte Carlo methods based on NN quantum states

EVENTS: host a workshop or school

VIRTUAL ACCESS: theoretical amplitudes code for public use over in-house servers

INFRASTRUCTURES:
CERN: ALICE (femtoscopy), LHCb (spectroscopy & hadron decays)
MAMI/MESA Hadron structure
GSI/FAIR (CBM,PANDA): hadron and nuclear physics programs
JLAB: hadron and nuclear program & close relation to JPAC
HIE-ISOLDE, LNL-SPES: nuclear properties.
ECT* as a venue for exchanges.

INFN – Istituto Nazionale di Fisica Nucleare

...Vallarino, T.Vittorini
...A.Pilloni,

- Light-q hadrons
- charmonium spectrum
- XYZ
- exotics and hybrids
- s-q spectroscopy

Connection to infrastructures
- Jefferson Lab CLAS12 data taking and analysis
- ePIC detector development at EIC-BNL

Virtual access
- Development of common repository and interface for data manipulation and storage

Contributions
- Data analysis
- Signal processing
- AI tools development
- Detector effects unfolding
- Amplitude analysis
- Generative Adversarial Networks and Diffusion Models
- Physics interpretation (JPAC)
- Phenomenological models for photo end electroscattering
- Exclusive multi-meson production
- AI-supported fast MonteCarlo simulations

Participating and partner institutions

Physics interpretation - Madrid University node

UNIVERSIDAD COMPLUTENSE MADRID

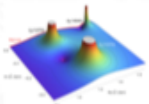
RESEARCHERS INVOLVED:
Felipe J. LLANES-ESTRADA, Jose R. PELAEZ, Clara PESET, Jacobo RUIZ DE ELVIRA

PHYSICS TRACKS
Hadron interactions, Light and Heavy hadrons (exotics, quarkonium)

RESEARCH ACTIVITY:
We develop non-perturbative techniques to obtain rigorous and systematic theoretical descriptions using tools such as: symmetries+EFTs, dispersive techniques, femtoscopy or modelling.

Wide range of applications:

Light hadrons:
- hadronic contributions to g-2
- determination of hadron resonances



Heavy quark physics:
- B-meson decay CP violations
- Exotics decays and identification
- EFTs for precision computations in quarkonium

Nucleon structure constants and dark sector searches from high precision data such as e-p scattering, (mu)H spectroscopy

VIRTUAL ACCESS:
theoretical amplitudes code for public use over in-house servers

INFRASTRUCTURES:
CERN:
- ALICE for femtoscopy
- LHCb for CP violating decays
- CMS and ATLAS for heavy quarks, e.g. toponium, Bc
- theory division and Quantum Initiative

FAIR for exotic spectroscopy

MAMI/MESA Hadron structure and dark sector searches

ECT* as a venue for exchanges.

EVENTS:
host a workshop

University of Barcelona

7 FTE: S. González, V. Magas, **V. Mathieu**, G. Montaña, A. Ramos, A. Parreño, J. Soto, J. Torres

Strong Expertise in data analysis with CLAS/GlueX @JLab and Alice/COMPASS @CERN

Regular and close contact with experimental groups in JLab and CERN since 15+ years

Developments of AI tools for HadSpec with A(I)DAP

Pioneers in **Virtual Access Tools** development with the webpages:

JPAC Interactive Webpage
JPAC GitHub
Lattice Virtual Academy Portal

The group would like to host a workshop or in school in Barcelona or Catalonia

JPAC Joint Physics Analysis Center — ICCUB Institut de Ciències del Cosmos — UNIVERSITAT DE BARCELONA

Barcelona University, Autonomous University of Barcelona, Bochum University, Bonn University, FAIR, Giessen University, Glasgow University, INFN, Madrid University, Pablo de Olavide University, Salamanca University, Technical University Munich, Valencia-IFIC (Valencia University & CSIC), York University JLab, Indiana University, Old Dominion University, University of Virginia

VNIVERSIDAD D SALAMANCA

PHYSICS INTERPRETATION – SALAMANCA NODE

MEMBERS
Conrado ALBERTUS TORRES
Teresa FERNANDEZ CARAMES
Pablo GARCIA ORTEGA
Eliecer HERNANDEZ GAJATE
Vicent MATEU BARREDA
David RODRIGUEZ ENTEM
Mario SANCHEZ SANCHEZ
German SBORLINI (convener)

PROPOSED EVENTS
Indian summer school or workshop

VIRTUAL ACCESS
Interactive group website and publication of outcomes on Zenodo

LINES TO BE DEVELOPED
Our group focuses on heavy hadron physics, high-energy QCD, and EFTs. We study hadron spectra and reactions beyond the quark model using symmetry principles and analyze jet processes with **SCET, bHQET, and AI/ML tools**. At low energies, we apply hadron-level EFTs and dispersive methods. We explore ML for optimizing multi-loop calculations (including Laporta's algorithm) and obtain fast numerical evaluation of theoretical predictions. Also, we investigate quantum algorithms to accelerate χ^2 minimization.

PHYSICS TRACKS
Heavy hadrons (exotics, quarkonium) and Hadron interactions (properties)

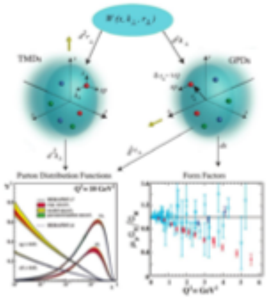
RELATION TO SELECTED INFRASTRUCTURES
Theoretical interpretation and description of experimental data coming from CERN (determination of fundamental parameters). Interaction with other groups at ECT* (through topical workshops)

U. Pablo de Olavide, in Seville

Using nonperturbative functional methods such as Schwinger-Dyson equations and Lattice Field Theory, which are also resource-intensive computational methods, we study conventional light and heavy hadron bound states by analyzing, for instance, their 3-dimensional structure functions, *i.e.* GPDs and TMDs.

Our work on hadron structure supports precision programs at MAMI/MESA, JLAB and BNL's EIC. In addition, modeling Green's functions provides essential input for theoretical efforts at ECT*.

Virtualizing related seminars, colloquia, and schools, as well as making recordings publicly available in a centralized web page would be highly beneficial for medium to small research groups.



Members to be involved: Jorge Segovia, Feliciano de Soto, José Rodríguez-Quintero, Adnan Bashir.

Resources, deliverables and synergies

Resources and budget

- €750k total
  - €480k: post doc positions (4 years experimentalists + 4 years theorists)
  - €220k: Travels
  - €50k: schools workshops

Synergies

- Nucleon Structure Knowledge and Analysis Toolkit (NuSKAT) project
- Similar physics program to use AI for nucleon structure analysis

Deliverables

- Web site with tools for data analysis, physics extraction, and theoretical interpretation
- Virtual repository for documentation (papers, seminars, and colloquia recordings, …)
- Collaborative venues: two topical and one general workshops
- Education and dissemination: AI4HSI Summer School

Participating and partner institutions

- Barcelona University, Autonomous University of Barcelona, Bochum University, Bonn University, FAIR, Giessen University, Glasgow University, INFN, Madrid University, Mainz University, Pablo de Olavide University, Salamanca University, Technical University Munich, Valencia-IFIC (Valencia University & CSIC), York University
- JLab, Indiana University, Old Dominion University, University of Virginia

Appointed conveners/Institution representatives

F.Afzal (UBochum), M.Albaladejo (IFIC-UValencia), R.Escribano (UABarcelona), D.Glazier (UGlasgow), P.Hurck (UBonn), V.Mathieu (UBarcellona), H.Nils (UMainz), C.Peset (UMadrid), A.Pilloni (INFN), S.Schadman (FAIR/GSI), J.Segovia (UPOlavide), G.Sborlini (USalamanca), A.Thiel (UGiessen), A.Vairo (TUM), D.Watts (UYork)

AI4HSI will develop on-line services, facilitate partner access to infrastructures, disseminate results to the whole hadron physics community