International School of Hadron Femtography

Jefferson Lab, 16-25 September 2024 [Webpage]

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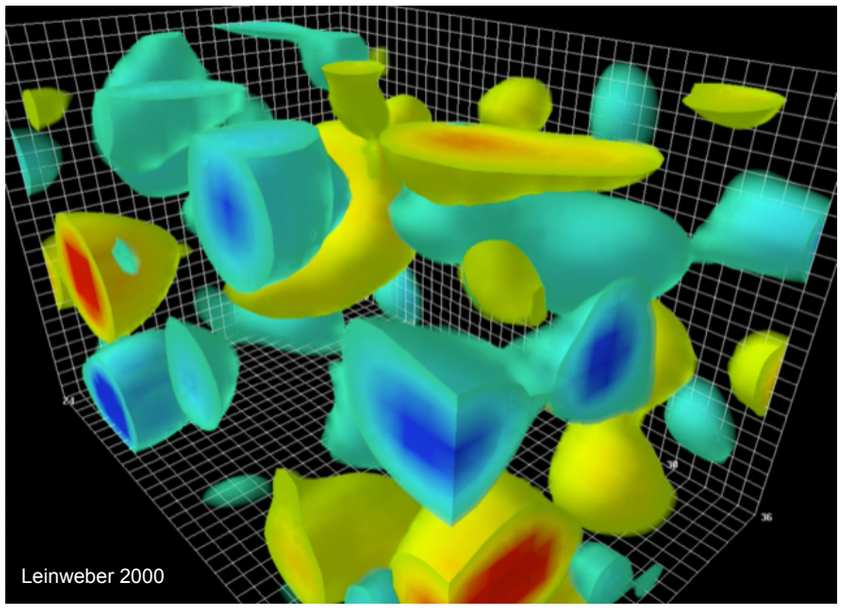
Hadron Femtography

Program of school

Concepts and objectives

Hadron structure in QCD



Unique dynamical system

Relativistic: Particle number not conserved, creation/annihilation processes, radiation

Quantum-mechanical: Superposition of configurations, fluctuations, renormalization

Strongly coupled: Vacuum fields, scale and chiral symmetry breaking, dynamical mass generation, effective degrees of freedom

Characterizing hadron structure

Particle content - quarks/antiquarks/gluons?

Global properties - mass, spin, others?

Spatial structure - extended object?

Internal motion, correlations?

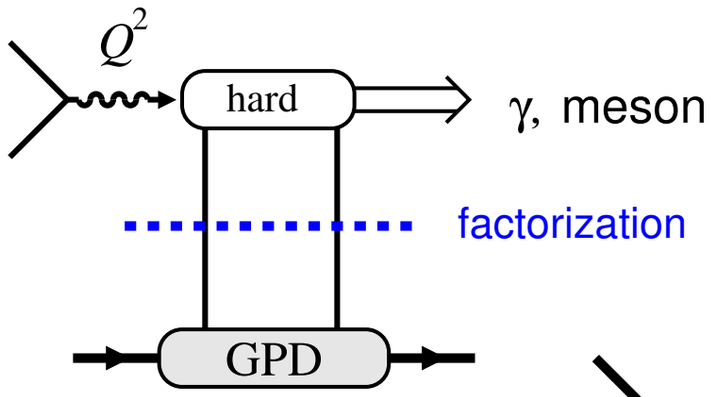
Develop appropriate concepts

Perform theoretical calculations

Perform experimental measurements and extract information from data

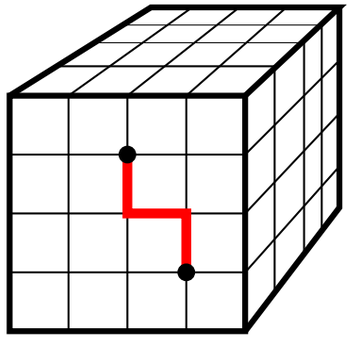
Interpret and visualize results

Hadron Femtography

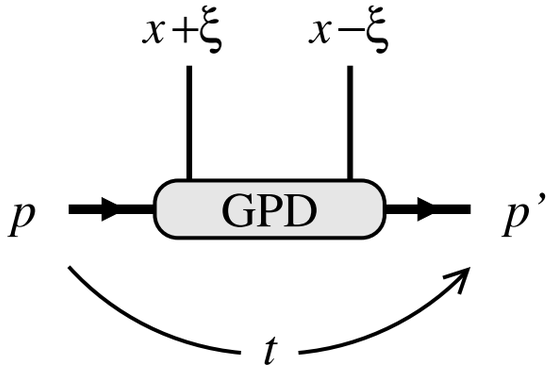


exclusive processes
analysis

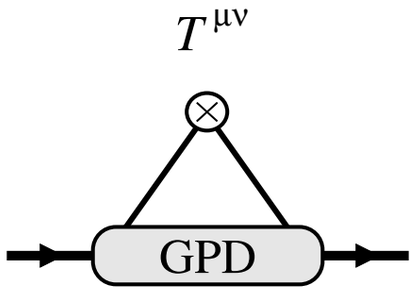
theory



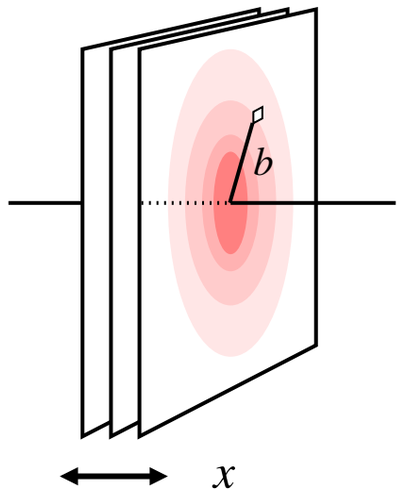
lattice QCD



generalized parton
distributions



energy–momentum tensor
mass, spin



hadron tomography

Program of school

Organized in five major subjects:

- GPDs and hadron structure
- Exclusive processes
- GPD analysis
- Experiments
- Lattice QCD for GPDs

Subjects distinct but connected in multiple ways

Subjects will be covered by regular lectures and topical seminars

Subjects will run in parallel. Concepts and results will come together in the course of the school

GPDs and hadron structure

Theory and interpretation of hadron structure accessible with GPDs and energy-momentum tensor

Topics and concepts:

QCD energy-momentum tensor (EMT): Origin from space-time symmetries, operator properties, hadronic matrix elements, form factors

Mechanical properties of hadrons: Distributions of mass, spin, forces in hadrons derived from EMT form factors; interpretation, mechanical analogies

Hadron mass and spin decomposition: Global properties derived from EMT, quark and gluon contributions, spin and orbital angular momentum, mechanisms of mass generation

Hadron imaging: Challenges in imaging relativistic systems, frames and interpretation, 2D tomographic images with GPDs, 3D images

Lectures and seminars: Cédric Lorcé, Xiangdong Ji

Exclusive processes

Theory of exclusive electromagnetic scattering processes and connection with GPDs

Topics and concepts:

Electromagnetic scattering: Kinematic variables, reference frames, amplitude, cross section

Factorization: Asymptotic regime in energy/momentum transfer, separation of scales, collinear expansion, GPDs

Deeply-virtual Compton scattering and meson production: Leading-twist factorization, amplitudes, integral access to GPDs, higher-twist corrections

Single-diffractive high-energy processes: Differential access to GPDs, photon/hadron-induced processes

Lectures and seminars: Christian Weiss, Zhite Yu, Jianwei Qiu

GPD analysis

Methods for extraction of GPD information from data on exclusive processes

Topics and concepts:

Compton form factors: Invariant amplitudes related to GPDs, connection with DVCS observables, dispersion relations, analysis methods

GPD parametrizations: Functional parametrizations for global analysis, analysis methods

GPD moments: Moments-based representation of GPDs, partial-wave expansion, analysis methods

GPD evolution: Scale dependence, evolution equations, practical methods for solution

Inverse problem and shadow GPDs: Deconvolution as inverse problem, mathematical uncertainties in GPD extraction

Artificial Intelligence and Machine Learning (AI/ML): Tasks performed by AI/ML, use in GPD analysis, current projects

Lectures and seminars: Marija Čuić, Yuxun Guo, Eric Moffat, Hervé Dutrieux, Simonetta Liuti

Experiments

Experimental methods and results in exclusive processes and GPDs

Topics and concepts:

Exclusive measurements: Cross sections and rates, exclusive final states, reconstruction, challenges specific to exclusive channels

Facilities and experiments: Fixed-target HERMES, COMPASS, JLab Hall A/C (high-resolution spectrometers), CLAS/CLAS12 (large-acceptance detector); HERA collider

JLab 12 GeV results: DVCS measurements and interpretation, meson production

Electron-Ion Collider EIC: Kinematic coverage, far-forward detection, GPD program

Future upgrades: JLab SoLID, positron program, 22 GeV energy upgrade

Lectures and seminars: Charles Hyde, François-Xavier Girod

Lattice QCD for GPDs

Lattice QCD methods for GPDs and related quantities

Topics and concepts:

Lattice QCD: Euclidean (imaginary-time) QCD, functional integral, space-time discretization, finite volume, statistical ensembles, correlation functions, extraction of hadronic matrix elements

Generalized form factors: Lattice QCD calculations of GPD moments using local operators, energy-momentum tensor

Quasi/pseudo parton distributions: Extraction of x-dependent parton distributions from high-momentum Euclidean correlation functions, lattice calculations and results

Perturbative calculations: Renormalization, operator mixing, matching of high-momentum and partonic correlation functions

Global analysis: Extraction of GPDs from combined lattice and experimental data

Lectures and seminars: Robert Edwards, Eloy Romero Alcalde, Joe Karpie

Interactions

School intended to be “interactive”. Please ask questions during/after lectures, during coffee breaks, or by contacting the instructors. Informal interactions are as important as lectures!

Exercise sessions can be used in several ways: Solving problems, going over calculations in detail, explaining topics upon request

Instructors welcome feedback re level and material of the lectures. We are a diverse group of students and instructors and want to be sure that everyone is included and can move along

Let us make best use of the unique format offered by the school!