Exotic heavy meson spectroscopy and structure with EIC: Next-level physics and detector simulations

Workshop at Center for Frontiers in Nuclear Science (CFNS), Stony Brook University, 14-17 April 2025

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- Context and objectives
- Developments in Theory, Experiment, EIC





• Agenda

Context and objectives

Emerging spectroscopy program with EIC: Workshops >2018, theoretical and simulation studies, 2022 Yellow Report

CFNS Workshop "Exotic heavy quarkonium spectroscopy and structure with EIC", 15-19 Aug 2022, 83 participants <u>https://indico.bnl.gov/event/14792/</u>: Manifested interest, outlined possibilities, established community

This workshop

Update scientific motivation for exotic heavy meson measurements with EIC in light of recent theoretical and experimental results

Assess feasibility and impact of EIC measurements through simulations based on ePIC detector design

Discuss heavy quark spectroscopy measurements in relation to staging of EIC science program

Formulate plan for further development

Exotic heavy quarkonia: Directions



Universality of resonances: Independence of production mechanism, observation in several channels?

Properties of states: Quantum numbers, decay modes, branching ratios?

Structure of states: QCD-based concepts? Interplay of heavy and light DoF? Near-threshold phenomena?

Exotic heavy quarkonia: Interest

Heavy quarkonia generate multiple dynamical scale: Rich structure, EFT methods

Nonrelativistic dynamics emerging from QCD: Atomic/molecular physics concepts and approximations

Perturbative and nonperturbative dynamics

Long-range forces between color charges: Confinement, emergent hadronic dynamics

Exotic heavy hadrons: Light degrees of freedom excited

Heavy quarkonium production: "Hard" process, systematic theory based on QCD factorization





Developments: Theory

Spectra and structure of exotic heavy quarkonia

Lattice QCD methods: Tetraquarks T_{cc} , T_{bb} / $T_{\bar{c}c}$, $T_{\bar{b}b}$ / hybrids $c\bar{c}$, $b\bar{b}$ EFT methods: NRQCD, Born-Oppenheimer Semiclassical methods: QCD vacuum structure Hadronic methods: Dispersion theory, coupled-channel

Production mechanism

QCD factorization of heavy quarkonium production (+ NRQCD) Hadronic models of heavy quarkonium and exotics production

Cross sections and other observables for EIC

Final states

Partial-wave analysis tools for multi-meson final states

Prelovsek et al.; Lewis et al.; Mathur et al. / Bicudo, Wagner et al / HADSPEC Ryan, Wilson

Brambilla, Vairo, Mohapatra et al.

Shuryak, Zahed et al.

Hanhart, Guo et al.

HEFTY Topical Collaboration

ExoHad Topical Collaboration Szczepaniak et al.

JPAC

TF-PWA, AMpTools, PAWIAN

Developments: Experiment





pp at LHC: LHCb, ATLAS, CMS

 e^+e^- colliders: BESIII, Belle

 $\gamma p/ep/\mu p$ fixed-target:

JLab GlueX, $007J/\psi$, SoLID (pentaquarks)

JLab 22 GeV plans

COMPASS, AMBER

 $\gamma p/ep$ collider: EIC

Developments: EIC

ePIC detector and collaboration

Collaboration formed [Webpage] Advanced detector design including subsystems

EIC accelerator

Electron complex redesigned: Injector as ring

New projections for running conditions, luminosity

EIC project

CD-0 and site selection 2019, CD1 2021 CD-2 originally expected 2024 - hopefully soon CD-4 and operations probably ~2034

Framework for international participation developing

EIC user community

Planning for staging of science program based on running conditions

Exploring options for 2nd IR + detector



Agenda

Exotics theory: Spectra, structure, interpretation	Partial-wave analysis for exotic final states
Feng-Kun Guo, R. Lebed, E. Braaten, A. Mohapatra, E. Swanson, I. Vitev, I. Zahed	Yi Jiang, M. Albrecht, M. Küßner Wed
Mon-Tue	
Exotics experiments: Status, plans J. Friedrich, J. Stevens, R. Seidl, M. Mikhasenko, N. Hüsken, M. Durham	ePIC detector and heavy quarkonium production A. Jentsch, G. Penman, Xuan Li, D. Glazier, S. Klein <i>Thu</i>
Mon-Tue	Tutorial on simulation tools
Heavy quarkonia production: Theory, processes	Organizers <i>Thu</i>
R. Perry, W. Schäfer, K. Mamo, Jia-Yue Zhang Jihee Kim <i>Wed</i>	EIC running conditions and project A. Deshpande, E. Aschenauer
Format: Presentations + Discussion (coordinated + open)	Mon/Wed

Challenges in exotics production at EIC

Production rates: X and Z photo/electroproduction is non-diffractive process with quantum number exchange. Cross sections are generally small at high energies. Compare with near-threshold J/ψ and Υ production at EIC.

Production mechanisms in *ep*: Not much explored, needs theoretical models.

New capabilities at EIC compared to previous exotics experiments

Electroproduction: Q^2 dependence \rightarrow L + T amplitudes, resolution scale for structure

Photoproduction with low- Q^2 tagger

Polarized electron and proton beams

Far-forward detection: Exclusive processes, fragmentation

Can we use them to explore the structure of exotic heavy mesons?