Workshop report:
The spectroscopy program at EIC and future accelerators

ECT* Trento, Dec 19-21, 2018

Organizers: A. Pilloni (ECT*), M. Battaglieri (INFN Genoa), A. Szczepaniak (Indiana U & JLab)

44 participants, 2.5 days, program organized in 4 Working Groups [Webpage]

Objectives

- Review status of heavy- and light-quark spectroscopy, particularly exotic states
- Review use of heavy flavors (open, hidden) as probe of nuclear medium
- Discuss prospects for spectroscopy and heavy-flavor physics program at EIC

Explanations

- Aim to involve theorists and experimentalists from ongoing spectroscopy programs (JLab GlueX/CLAS12, COMPASS, LHC, PANDA) and heavy-ion physics (LHC, RHIC)
- Extensive review of present experiments; exploratory discussion of EIC applications
- Great interest in EIC!

Hadron spectroscopy: Context

- Hadron structure $\leftrightarrow$ excitation spectrum:
  Complementary aspects of strong interaction physics

- Current experimental programs

$ep/\gamma p$	JLab GlueX	light meson exotic states
	CLAS6/12	light baryon resonances
πp	COMPASS	light meson exotic states
e^+e^-	Belle, BES	heavy meson XYZ states (tetraquarks, hybrids)
pp	LHCb	heavy meson XYZ states (tetraquarks, hybrids)
		heavy baryon states (pentaquarks)
$p\bar{p}$	PANDA	charmonium states

- Why multiple experiments

  Observe same state with different production mechanisms, test universality
  Enhance productn of certain states through choice of mechanism (couplings, quantum nrs)
  Face major challenges in identifying exotic states

Hadron spectroscopy: EIC

- Exclusive photo/electroproduction of heavy $\bar{Q}Q$-like states ↔ Gluon imaging J/ψ, GPDs

  $\gamma^{(*)} + p \to$ [heavy] $+ p\ (n)$, [heavy] = quarkonium ground/excited, XYZ states

- Diffractive photo/electroproduction of light vector states ↔ Inclusive diffraction, small x

  $\gamma^{(*)} + p \to$ [vector] $+ p$ (low-mass X), [vector] $= \rho, \rho', \phi, \phi', \ldots$

- Hard exclusive processes for $N*$ spectroscopy and structure ↔ Exclusive processes, GPDs

  $\gamma^* + p \to M + N^*$, $Q^2 \gg 1$ GeV^2, $N \to N^*$ transition GPDs $\langle N^*|\mathcal{O}_{\text{QCD}}|N\rangle$

EIC machine and detector capabilities

- Low rates: High luminosity $\sim 10^{34}$ cm^{-2} s^{-1}, moderate CM energies $\sim$ 20-70 GeV
- Heavy quarkonium/XYZ reconstruction: Coverage in central + endcap regions, energy/momentum resolution, PID $e \leftrightarrow \pi$, $K \leftrightarrow \pi$
- Exclusive processes: Forward proton detection, incl. $N^* \to \pi N / K N$
- Photoproduction: Low-Q^2 electron tagger

Heavy flavors in medium: Context

- Heavy flavors as probe of nuclear medium: Simple QCD systems, coupling to gluons, multiple dynamical scales, complements light-quark jets

$$\text{HF}\begin{cases}\text{open } D, B, \Lambda_{c,b}, \ldots \\ \text{hidden } J/\psi, \eta_c, \Upsilon, \ldots\end{cases} \qquad \text{matter}\begin{cases}\text{cold} \\ \text{hot}\end{cases} \qquad \text{interaction}\begin{cases}\text{high-energy} \gg 1\ \text{GeV} \\ \text{low-energy} \lesssim 1\ \text{GeV}\end{cases}$$

- Schematic

Initial state	$\leftrightarrow$	Production mechanism	$\leftrightarrow$	Final state
Partonic structure, nuclear modifications				Color propagation, jets Fragmentation, hadronization Hadronic interactions

- Experiments and facilities

pA/AA	LHC, RHIC
ep/eA	EIC $\leftarrow$
ep	HERA, EMC
e^+e^-	VEPP, BEPC, CESR, LEP, SLC, KEKB, PEP-II

Heavy flavors in medium: EIC

- HF as probe of initial-state gluons
  Nuclear PDFs from inclusive DIS eA ↔ global analysis/PDFs
  Nuclear gluons from open HF production in eA
  Nuclear gluons from coherent HQium prodn: Transverse distns, shadowing ↔ exclusive procs/GPDs

- Propagation and hadronization of HF in cold matter
  Single-inclusive $D/B/\Lambda_{b,c}$ production in ep+eA ↔ light-quark fragmentation
  HF jets in ep+eA, including substructure, correlations ↔ light-quark jet physics
  Exclusive HQium production in ep+eA, color transparency

- Hadronic interactions of HF mesons and baryons
  Nuclear transparency in heavy meson-baryon production
  Exclusive HQium production in nuclei, final-state interactions ↔ pentaquark bound states

EIC machine and detector capabilities

- Large-x gluons: High luminosity $\sim 10^{34}$ cm^{-2} s^{-1}, moderate CM energies $\sim$ 20-70 GeV
- Open charm/beauty reconstruction: PID π/K, vertex detection, energy/mom resolution
  JLab 2016/17 LDRD "Nuclear gluons with charm at EIC": Physics and detector models, simulations
- Heavy quarkonium reconstruction: see "Spectroscopy"
- Coherent nuclear processes: Forward ion detection, breakup veto

Organization

Working Groups and Conveners

Diffractive production: Wolfgang Schaefer (thy), Ronan McNulty (exp)
Gluonic and light states: Nora Brambilla (thy), Umberto Tamponi (exp)
Multiquark spectroscopy: Feng-Kung Guo (thy), Ryan Mitchell (exp)
Heavy flavor in media: Christian Weiss (thy), Giuseppe Bruno (exp)

Summary document in preparation