Light and heavy quark spectroscopy at EIC

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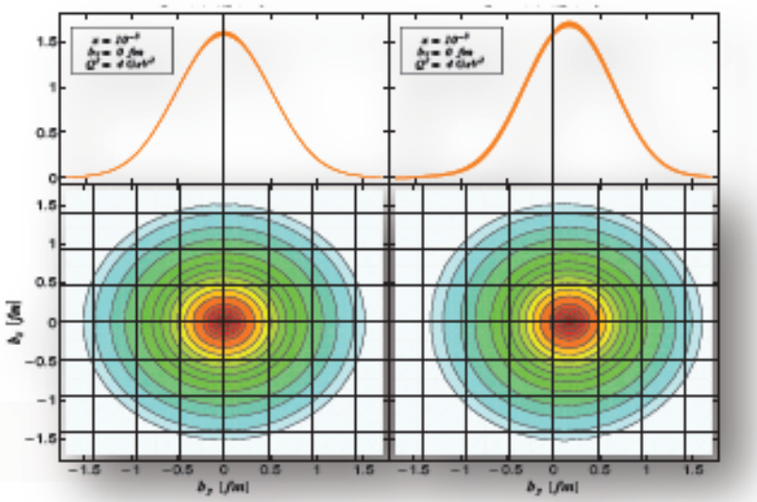
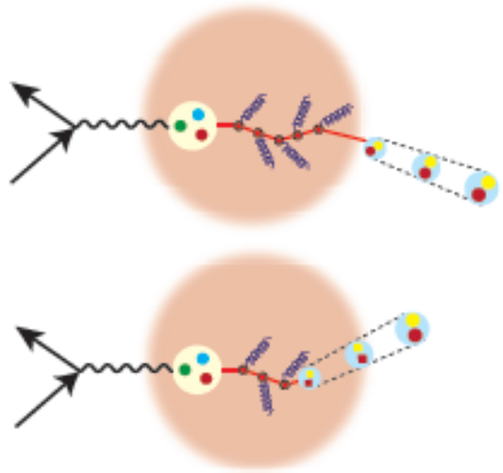
The EIC physics (so far ...)

Accardi et al., Eur. Phys. J. A (2016) 52: 268 **arXiv: 1212.1701.v3**

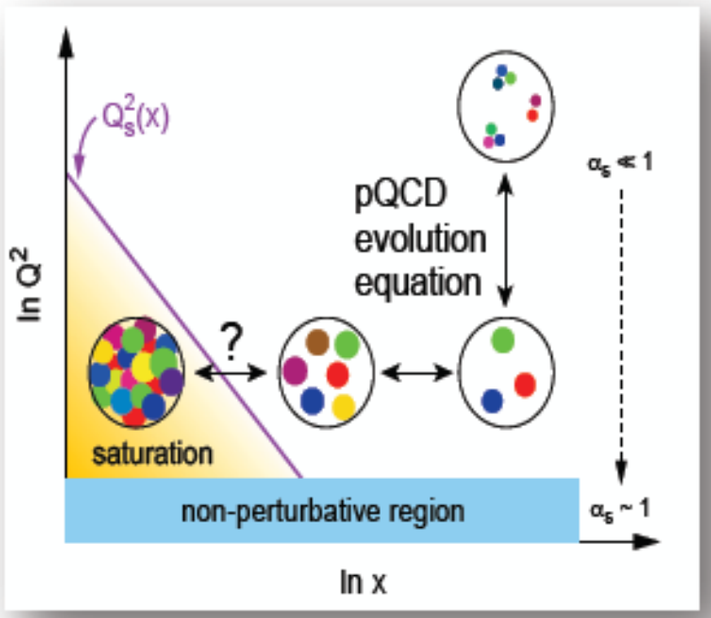
3D Imaging of Nucleon Structure



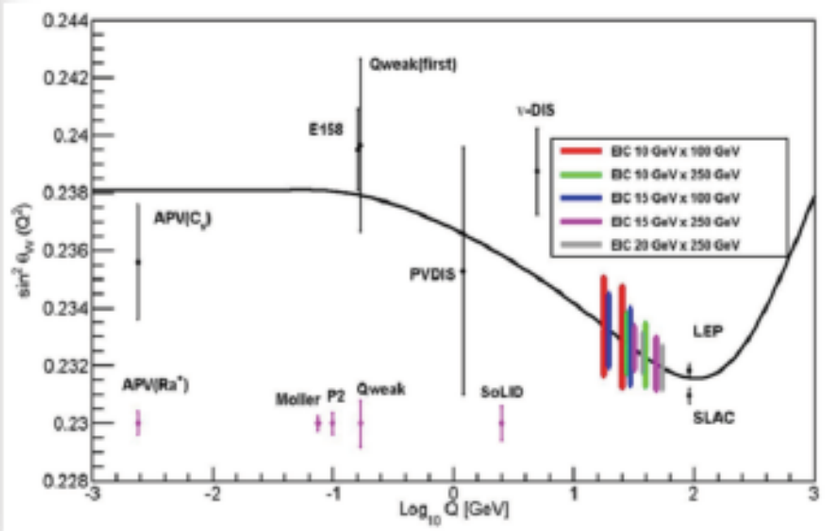
Hadronization in cold QCD matter



Gluon Saturation



EW Physics



EIC and the other facilities

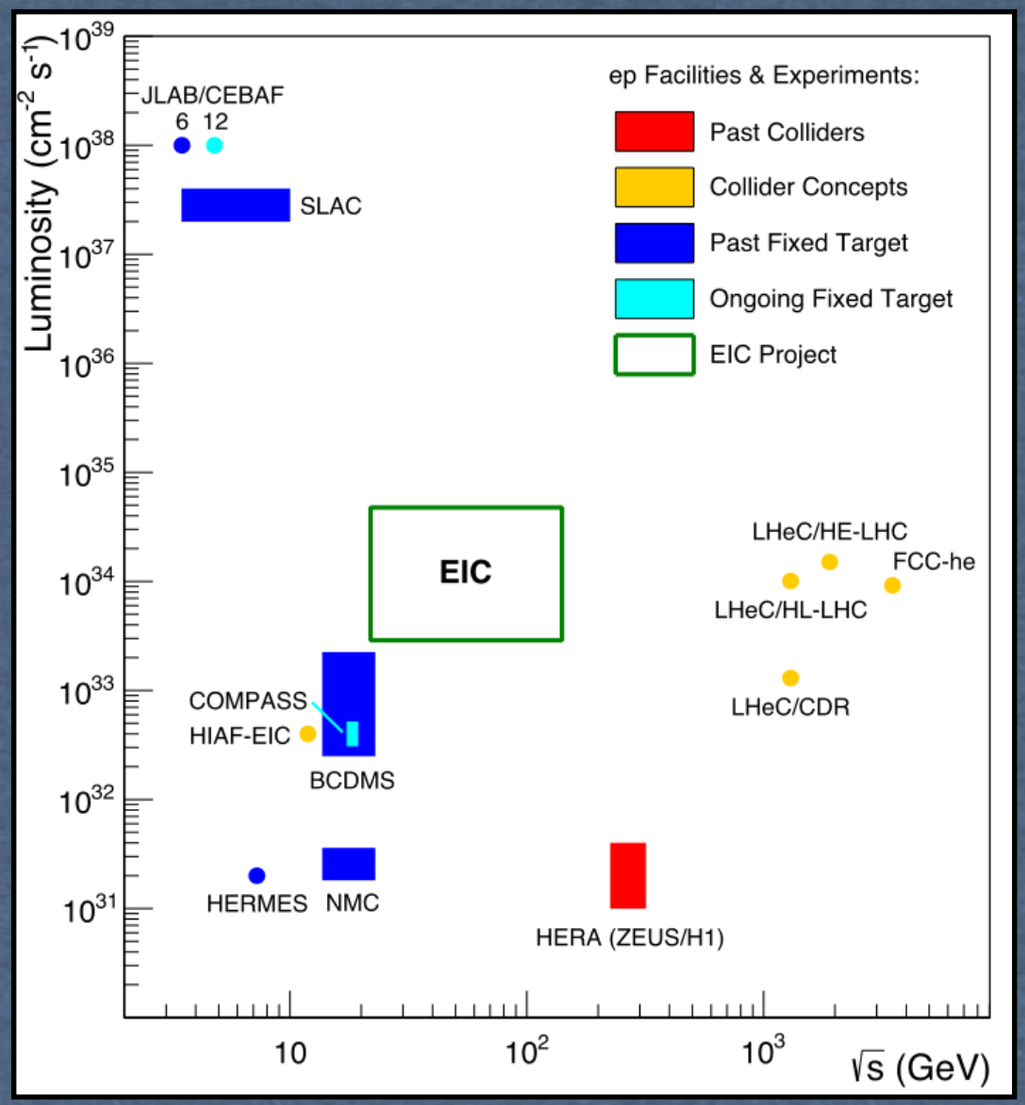
- **Luminosity 100-1000 times that of HERA**
  – Enable 3D tomography of gluons and sea quarks in protons

- **Polarized protons and light nuclear beams**
  – Critical to all spin physics related studies, including precise knowledge of gluon's spin & angular momentum contributions from partons to the nucleon's spin

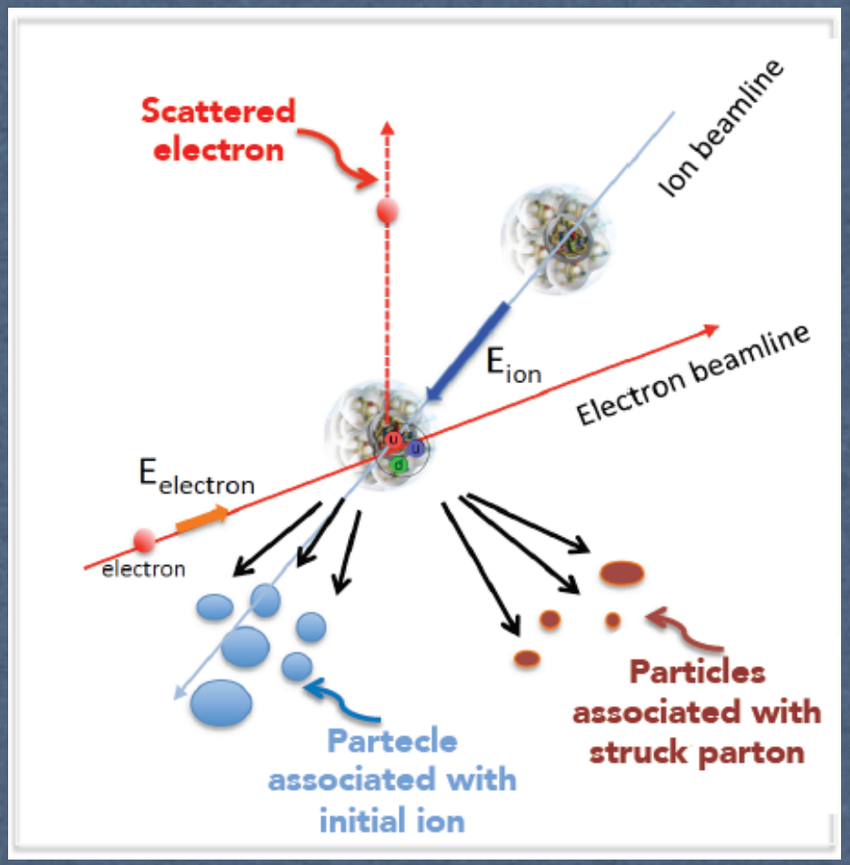
- **Nuclear beams of all A (p→U)**
  – To study gluon density at saturation scale and to search for coherent effects like the color glass condensate and test universality

- **Centre of mass variability with minimal loss of luminosity**
  – Critical to study onset of interesting QCD phenomena

- Detector & IR designs mindful of "Lessons learned from HERA"
  – No bends in e-beam, maximal forward acceptance….



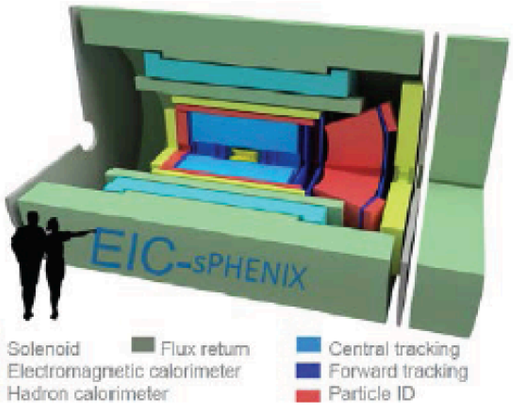
EIC detectors



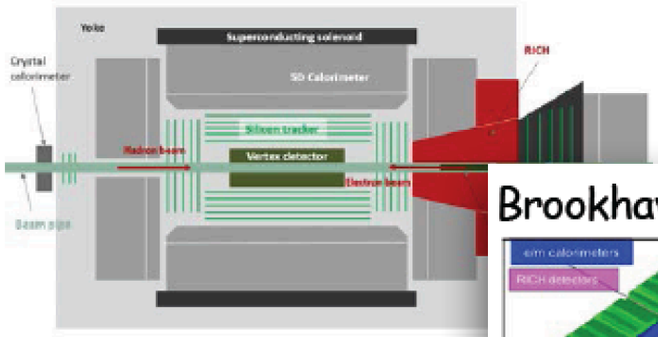
- ✳ Resolve partons in nucleons
  - ➪ high beam energies and luminosities
  - ➪ Q2 up to ~1000 GeV^2
- ✳ Resolve (k_t, b_t) of the order a few hundred MeV in the proton
  - ➪ High Granularity, wide dynamic range
- ✳ Detect all types of remnants to seek for correlations:
  - ➪ scattered electron
  - ➪ particles associated with initial ion
  - ➪ particles associated with struck parton

- Large acceptance
- Frwrd/Bckw angles
- Precise vertexing
- HRes Tracking
- Excellent PID

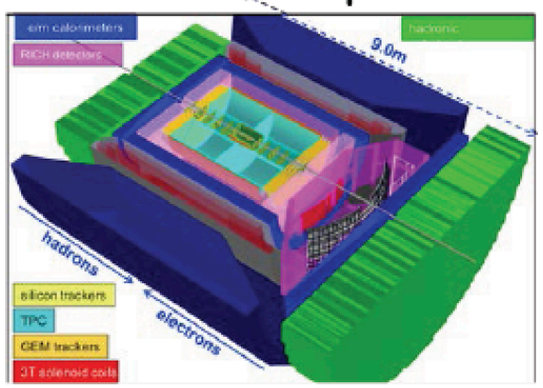
sPHENIX → EIC



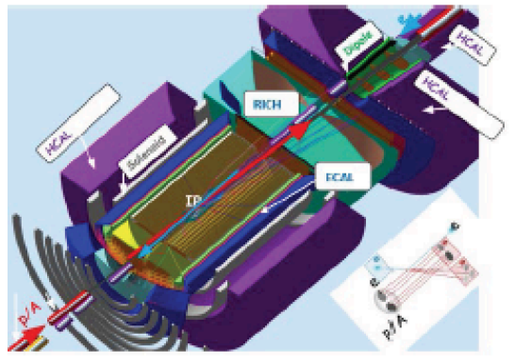
Argonne concept: TOPSiDE



Brookhaven concept: BEAST



Jefferson lab concept: JLEIC



Hadron spectroscopy at EIC

- Beams (intensity, polarization)
- Detectors
- Kinematic coverage

EIC is the perfect place to study hadron spectroscopy addressing the remaining open questions in hadron physics

We want to do better optimising the EIC design for the next HS generation

Build the physics case

I) Light and heavy quarks (+ gluons) spectroscopy studying exotic configurations

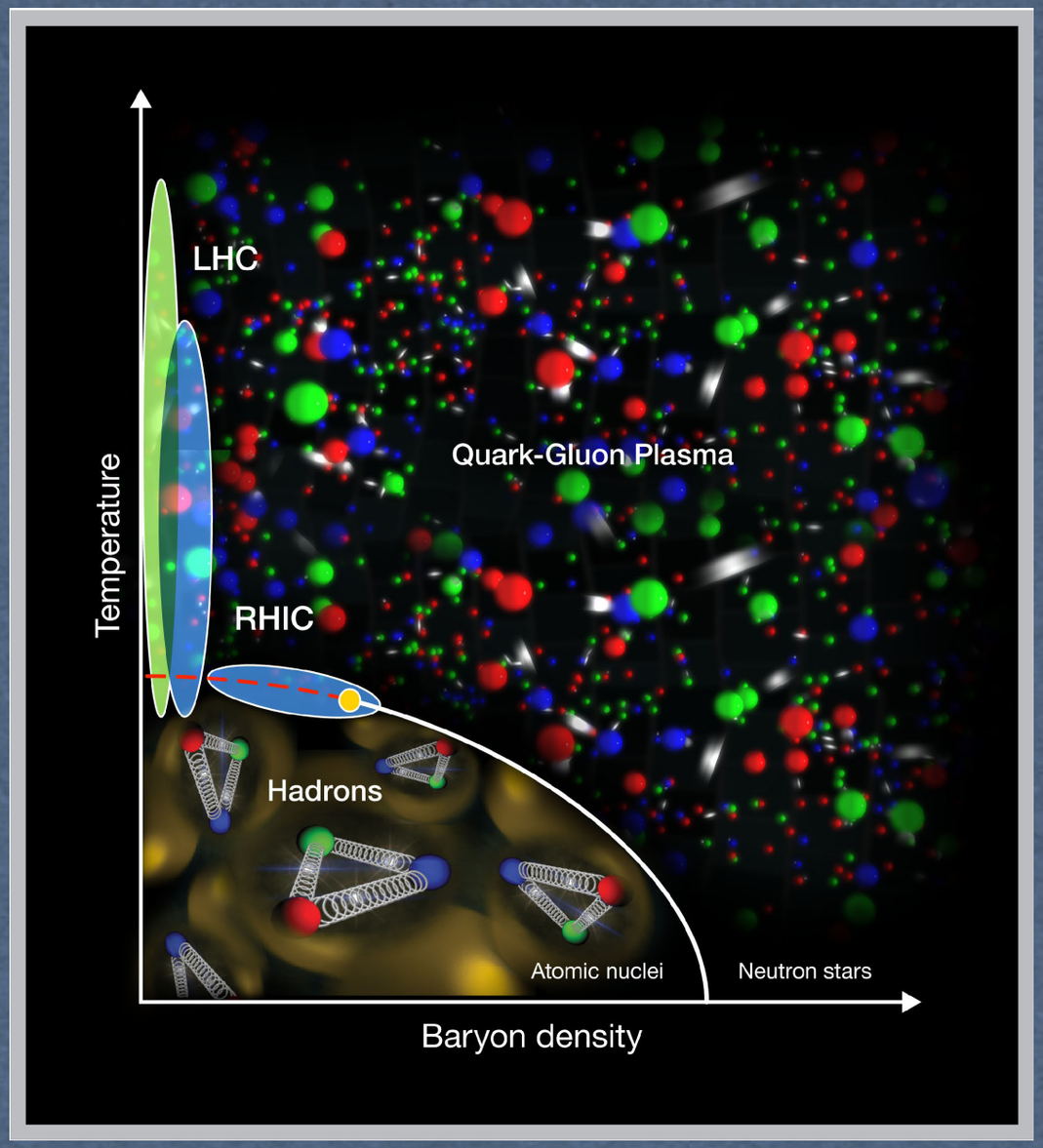
II) Diffractive physics

III) Heavy flavours (open and hidden) to prove nuclear medium

Opportunities

Requirements

Hadron spectroscopy at EIC



★ Meson and baryon spectroscopy as a tool to study QCD phases

★ Color confinement

★ manifestation of gluonic degrees of freedom

★ non-perturbative dressing effects

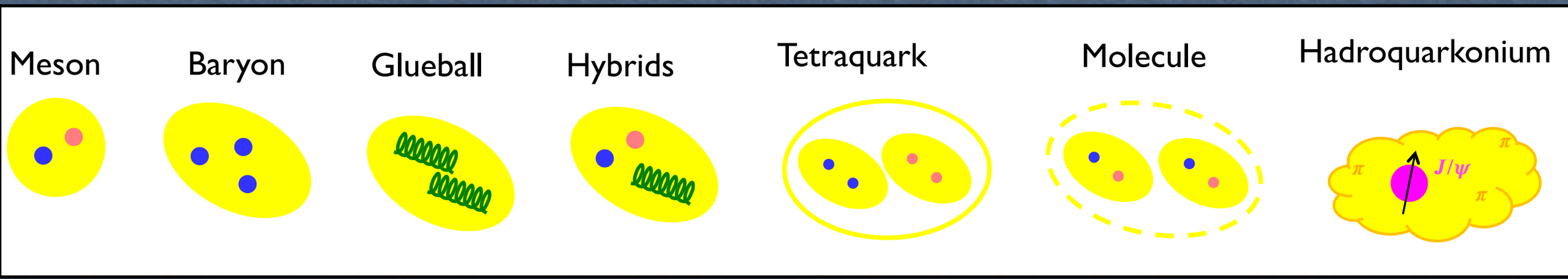
★ gluon-gluon interaction

★ confinement

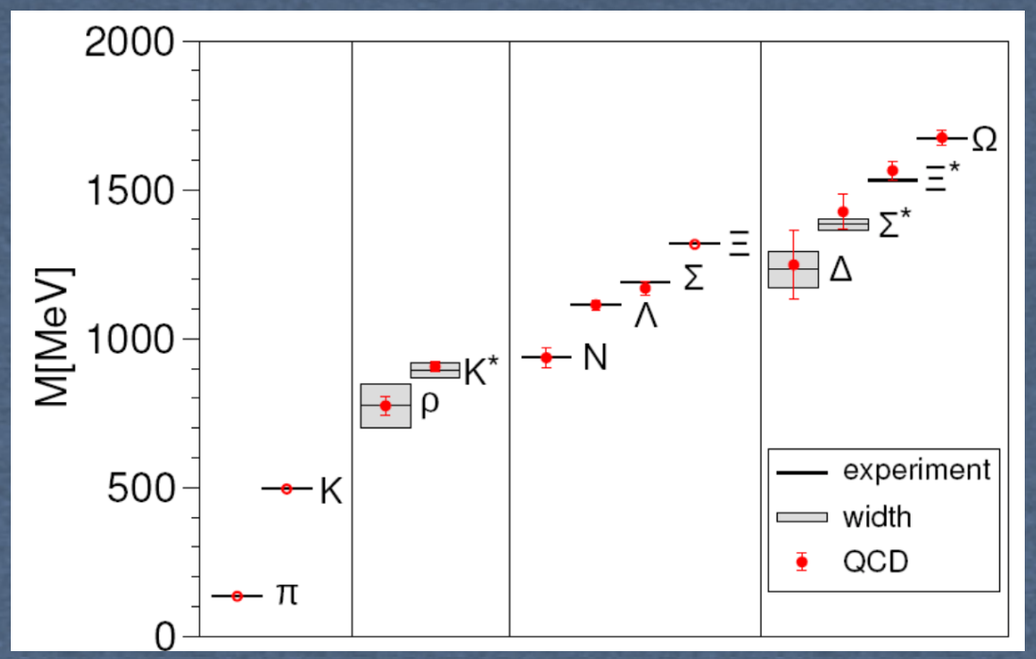
★ light-q vs heavy-q

Significant word-wide effort: COMPASS, JLab BES-III,LHCb, ALICE, BELLE

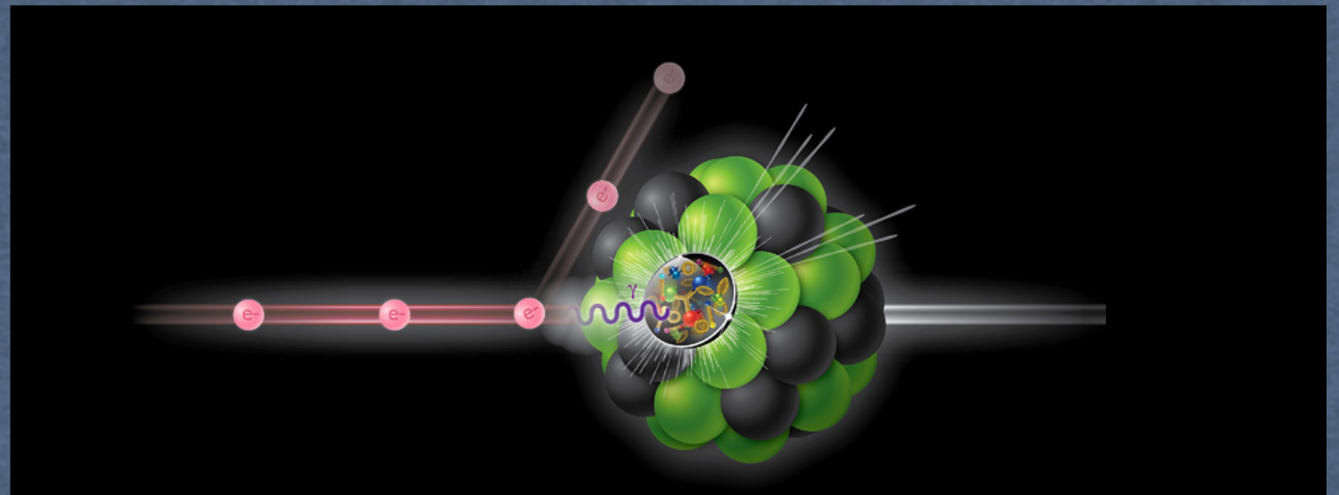
Hadron spectroscopy at EIC



Science (2008)



Observed mesons and baryons well described by 1st principles QCD



«The Electron Ion Collider will act as an enormous microscope» to study quarks inside hadrons

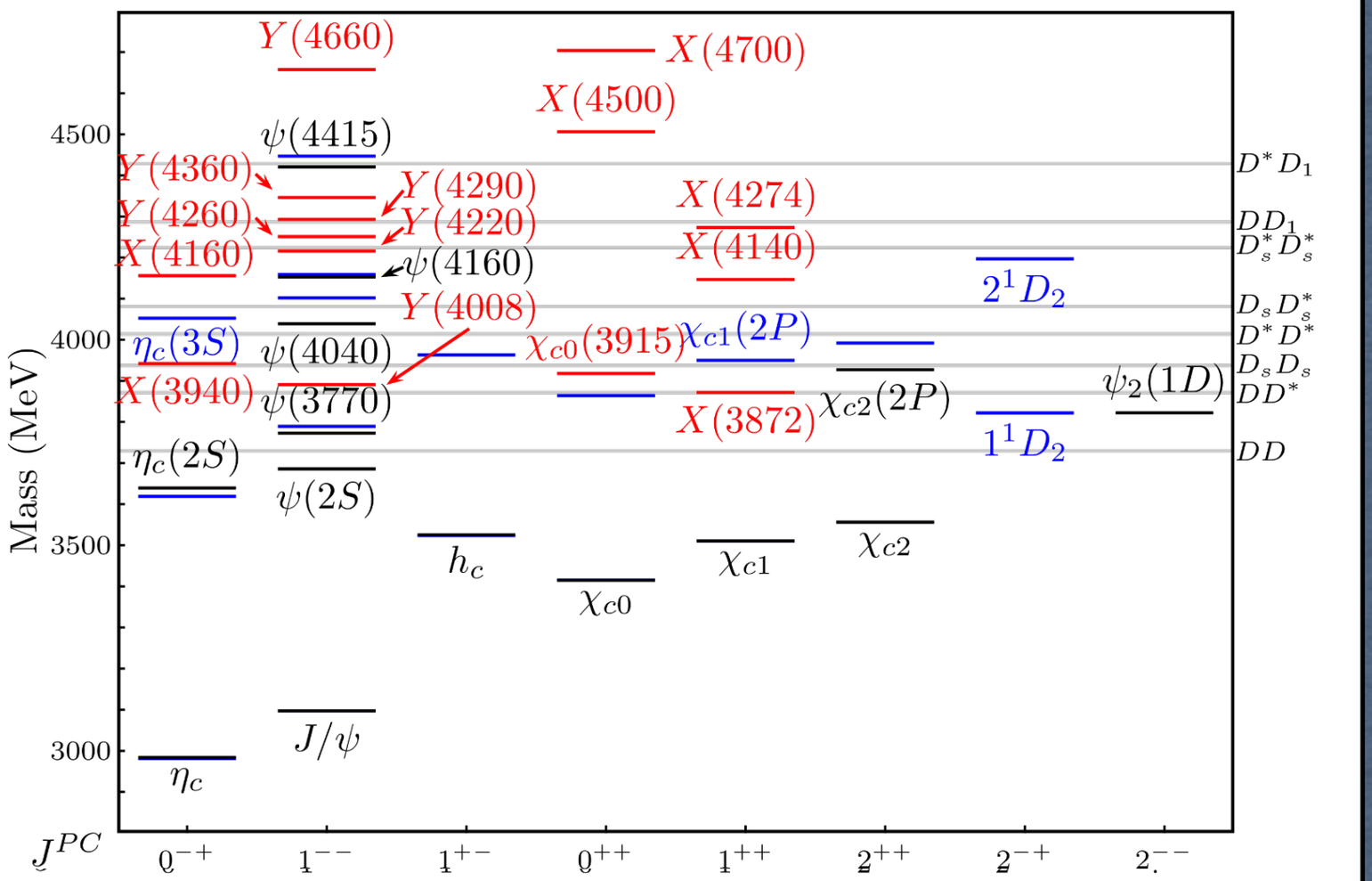
We want to use it to study «enormous» hadrons!

XYZ exotics

A host of new and unexpected resonances have appeared

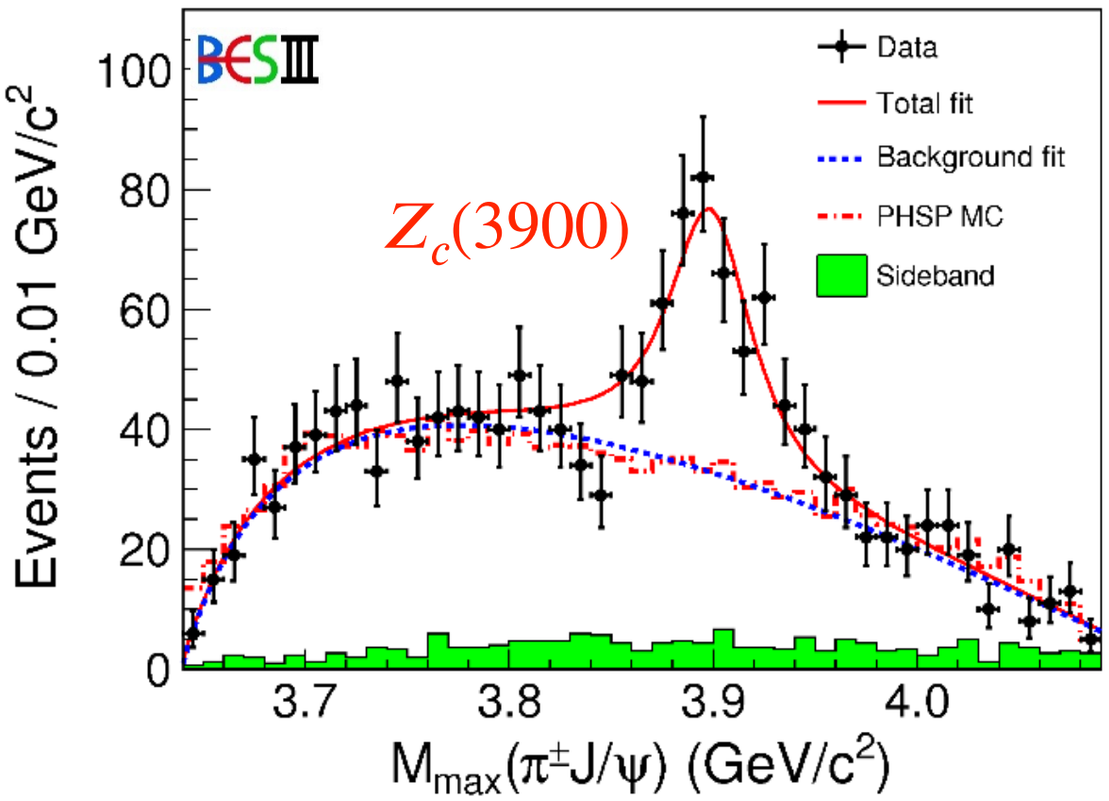
Preferred decay: charmonium + light

Difficult to reconcile with charmonium-like interpretation

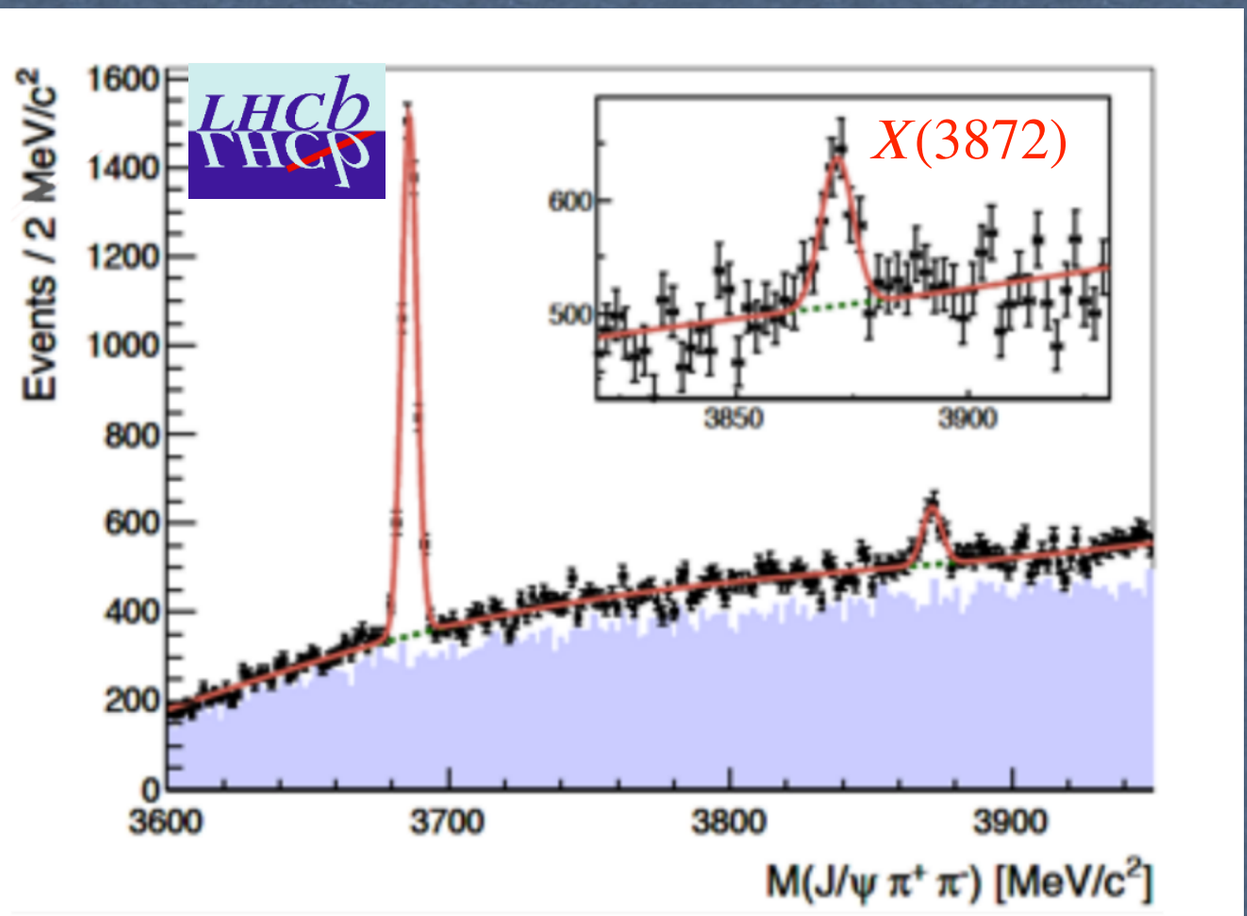


The *good old* times suddenly ended disclosing a realm populated by new and unknown states (multi-quarks? glue-rich? …)

XYZ exotics



- Many new states in the charmonium sector
- Convincing evidence of new exotic hadronic states
- Probably, more to come
- Bottomonium almost unexplored



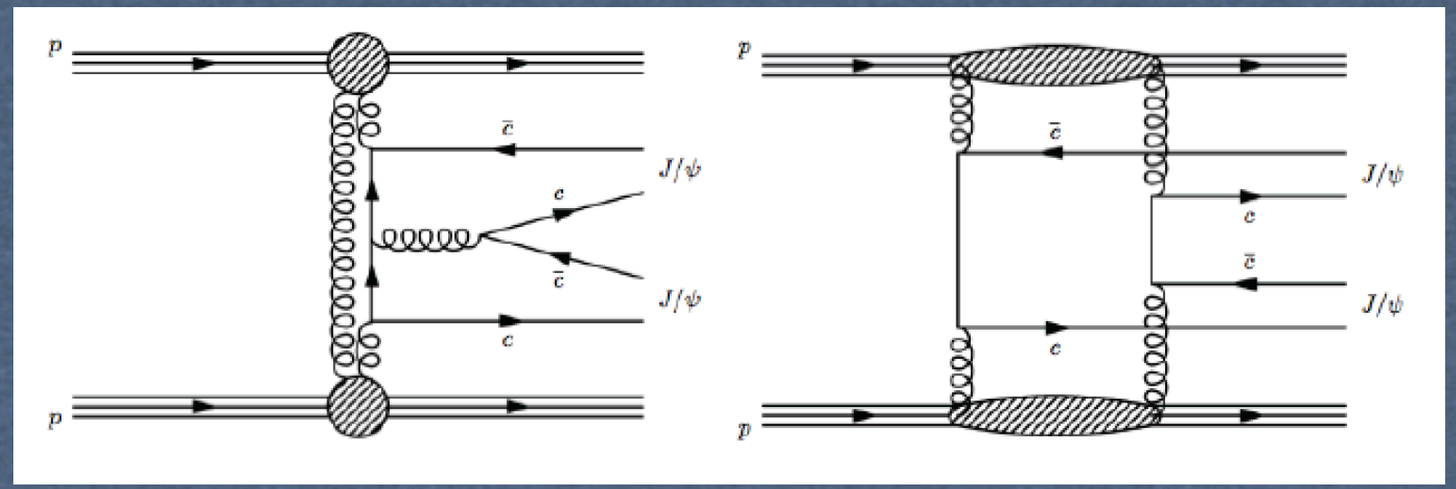
A rich phenomenology that requires to be understood and thoroughly studied in a high statistics, high precision experiment covering a wide kinematic range

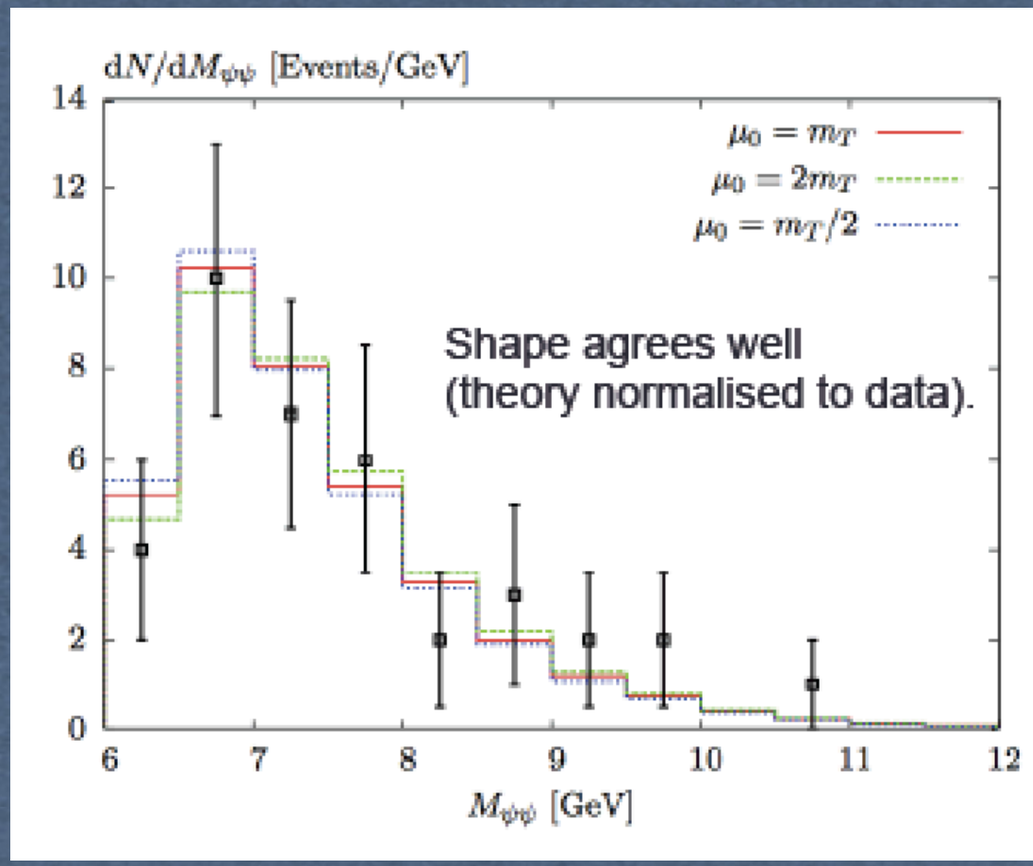
Electron Ion Collider

- ✳ Tetraquarks
- ✳ (light) hybrids
- ✳Glueballs
- ✳Odderon

Double J/Ψ production

- Double pomeron exchange
- Sensitivity to high mass states (tetraq)





EIC may produce such states trough gamma-gamma collisions

LHC
High Energy
Medium/High Luminosity
High Backgrounds

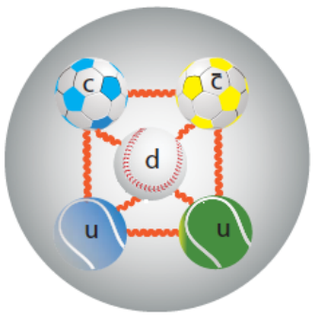
→

EIC
Low Energy
High Luminosity
Low Backgrounds
(detector design)

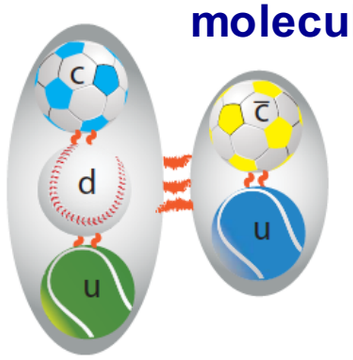
R.McNulty (UCD)

Pentaquark

5-quark bound state

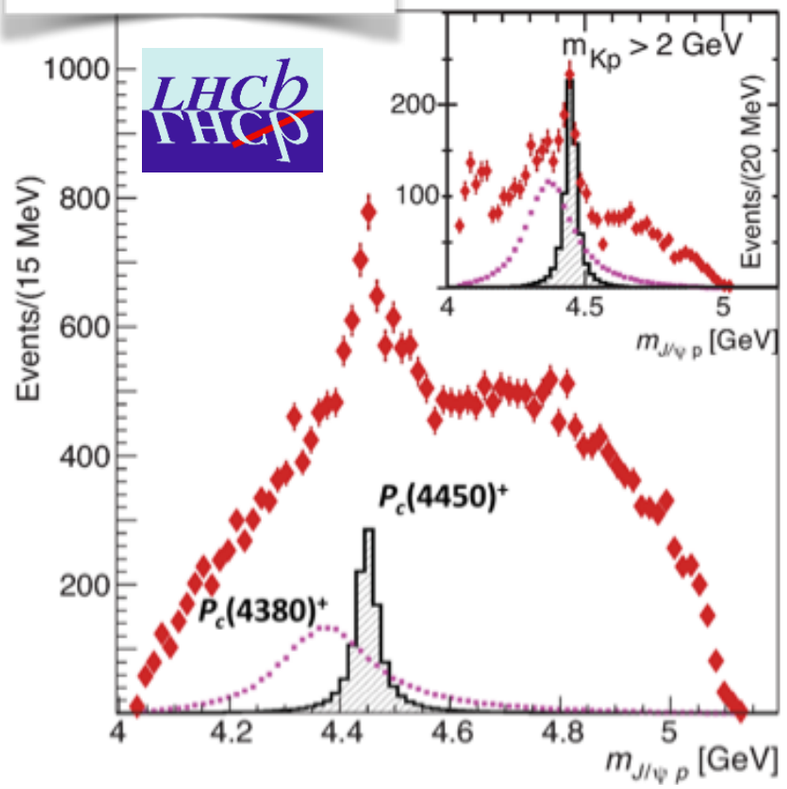


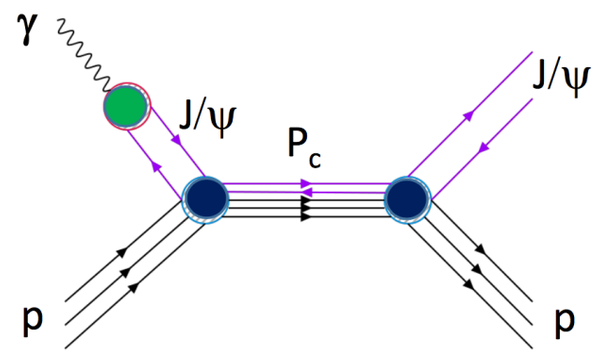
Hadronic molecule

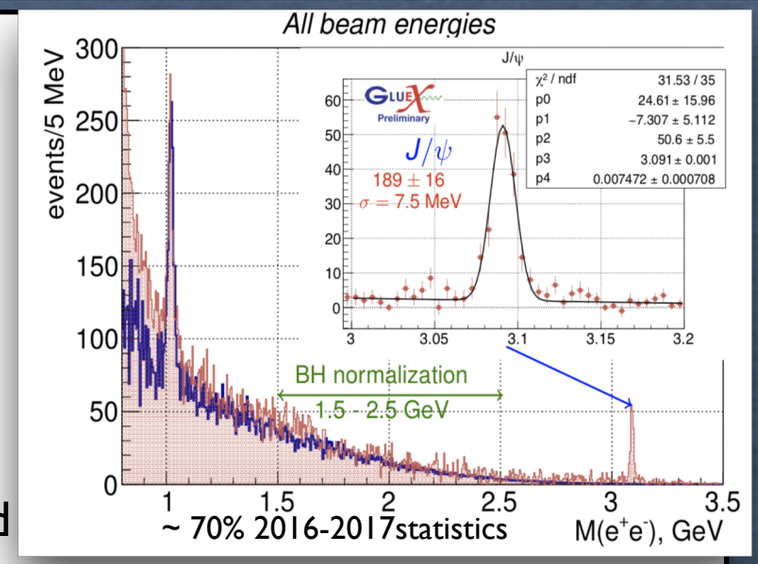


or cusp, triangle singularity, etc…

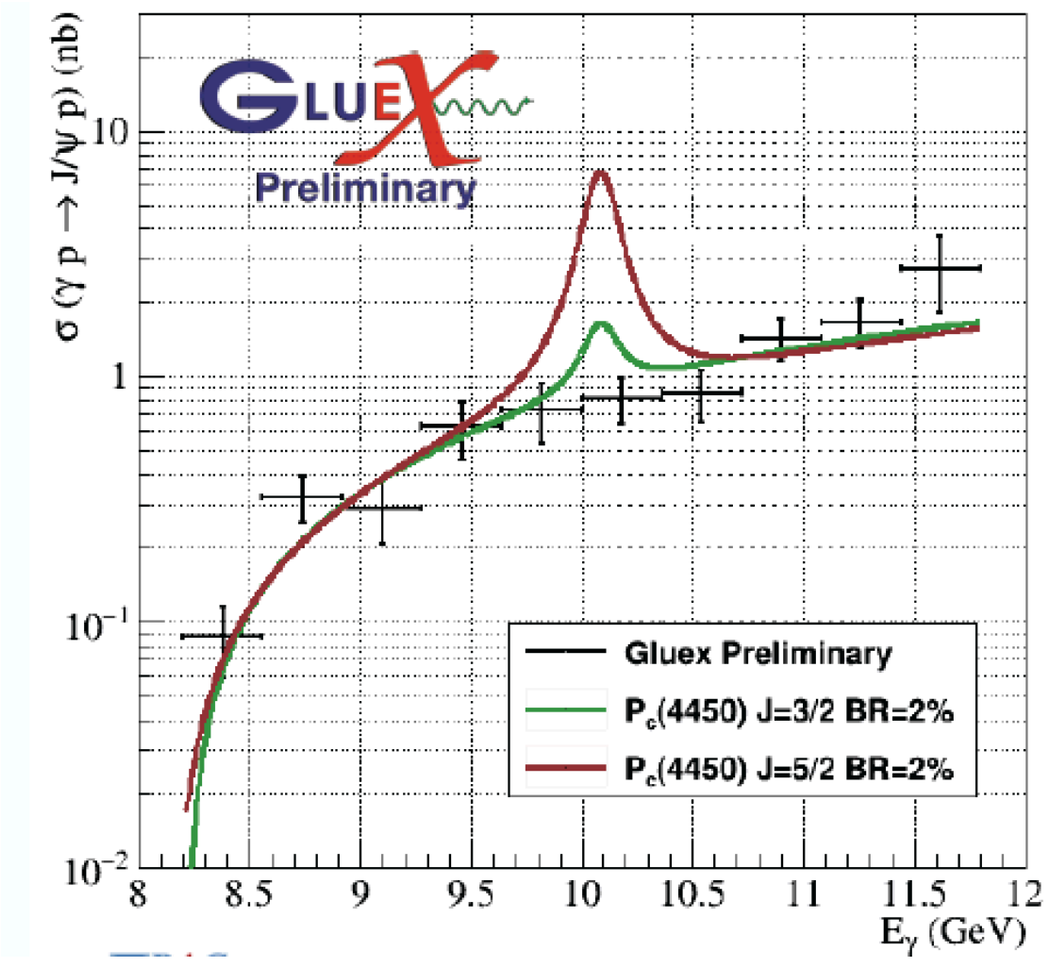
$\Lambda_b \to J/\psi p K^-$







- J/ψ photoproduction at threshold
- Observation of charm at GLUEX
- Projections with CLAS12 shows a significant sensitivity

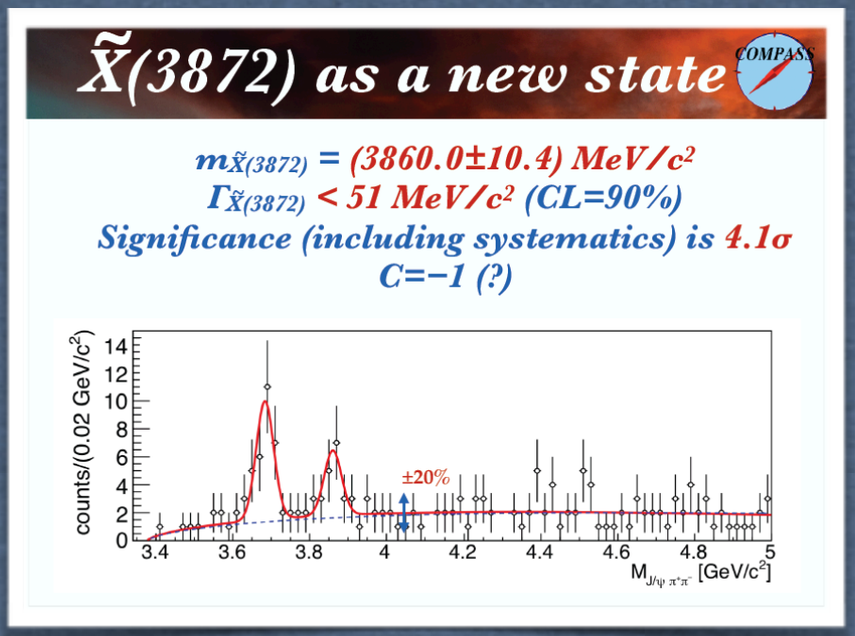


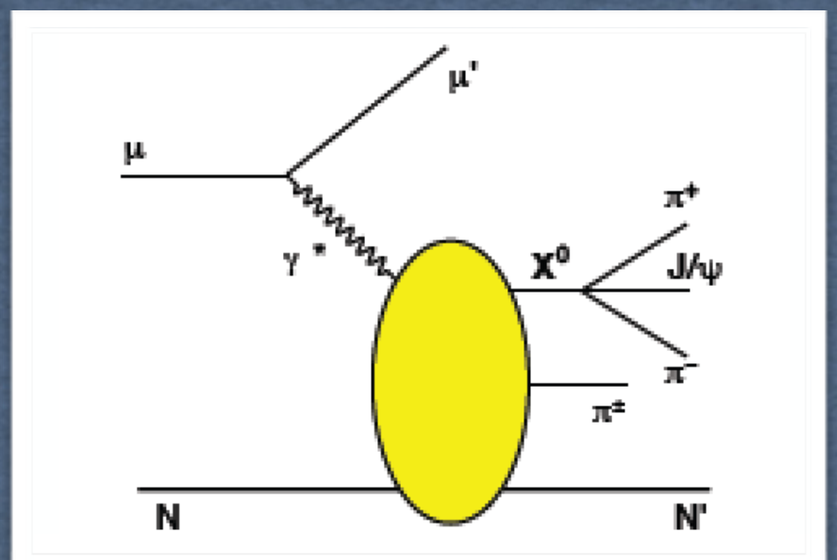
clas

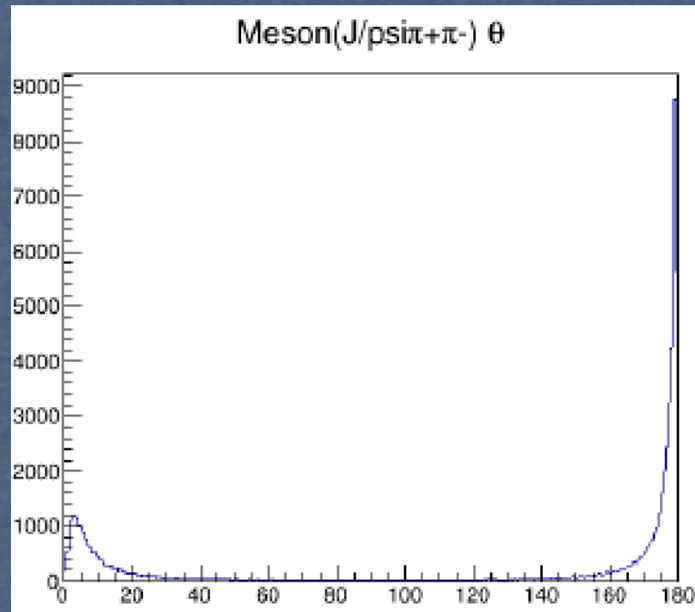
S.Dobbs (FSU)

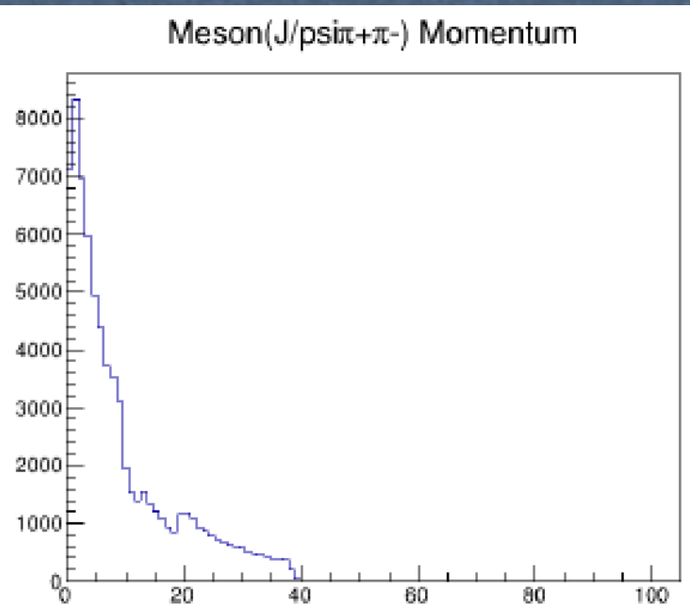
EIC kinematics and yield estimates

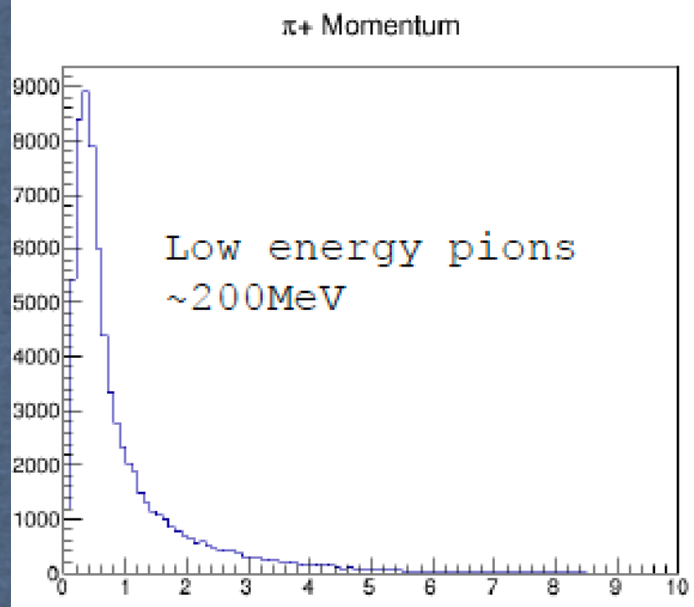
e N → e' (J/Ψ $\pi^+\pi^-$) $\pi^\pm$ N*

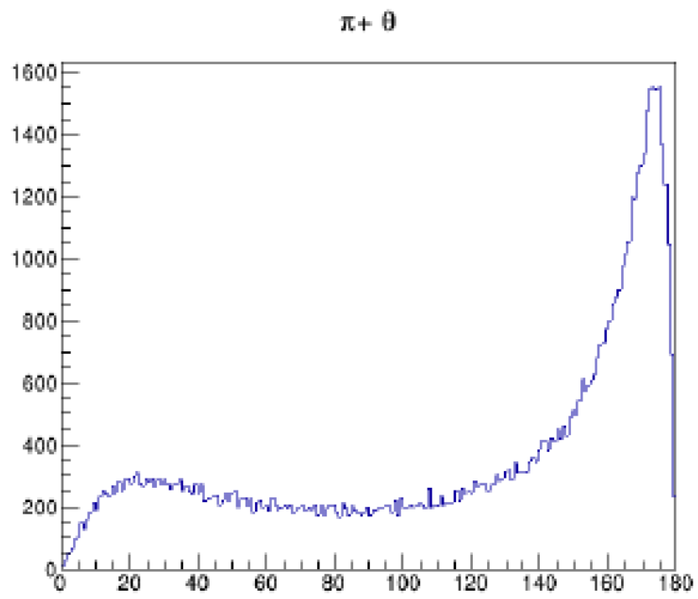












D.Glazier (UGlasgow)

X(3872) Yield ~ 100(s) events/day

Heavy Flavours in media

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

Schematic

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

A) HF as probe of initial-state gluons

- [EIC: Nuclear PDFs from inclusive DIS eA] ↔ global analysis/PDFs
- EIC: Nuclear gluon densities from open HF production in eA
- EIC: Nuclear gluons from coherent HQium prodn: Transverse distns, shadowing ↔ exclusive procs/GPDs

B) Propagation and hadronization of HF in cold matter

- EIC: Single-inclusive D/B/b,c production in ep+eA ↔ light-quark fragmentation
- EIC: HF jets in ep+eA, including substructure, correlations ↔ light-quark jet physics
- EIC: Exclusive HQium production in ep+eA, color transparency

C) Hadronic interactions of HF mesons and baryons

- EIC: Nuclear transparency in heavy meson-baryon production
- EIC: Exclusive HQium production in nuclei, final-state interactions

Diffraction

- Diffractive DIS (DDIS): diffractive dissociation ↔ elastic scattering of a $q\bar{q}$-dipole
- Large DDIS is the hallmark of a strongly absorptive target ↔ "saturation physics"
- clean environment (only few particles in the final state)
- EIC ideal to measure exclusive channels

The physics case

- Production of light vector & higher spin mesons: radial & orbital excitations of (say) mesons show distinctive systematics of s-channel helicity violation.
- Color dipole approach + light-front wave-functions: can be formulated also at low $Q2$
- Hard pQCD regime (large $Q2$): chiral odd vs chiral even meson distribution amplitudes
- Diffractive photoproduction of tetraquarks/hybrids: unexplored (?) Larger transverse sizes: stronger nuclear absorption ! nuclei as another tool?
- Odd C-parity three gluon exchange: the Odderon.
- Photo/electroproduction of C-even mesons in diffractive kinematics
- Charge asymmetries in $+-$-production

Summary

Building the EIC Hadron Spectroscopy community

★ Goals:

- Demonstrate a strong physics case for a hadron spectroscopy program at EIC (to be part of the next EIC physics book)
- Study the impact on EIC design (machine and detectors)

★Working groups:

- I) Quarks & Gluons
- II) HF in media
- III) Diffraction

★ Kick-off meeting at ECT* Trento in Dec 2018

★ White-paper in preparation

Build the future HS program at EIC joining the effort!