JLab/EIC: recent results and perspectives

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QUARKONIA AS TOOLS
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The nucleon

- Most visible matter in the universe is made of nucleons
- Nucleons are composite objects in non-perturbative QCD regime
- Do we understand them?

- Open questions:
  - Mass of the nucleons not explained by the Higgs mechanisms
  - Internal structure
  - Spin puzzle
  - Confinement
  - How nucleons differ when in nuclei
Electromagnetic probe

- Electron (or photon or muon) beam: clean probe, it couples electromagnetically

Measurements:
- Inclusive: detect only the scattered electron
- Semi-inclusive: detect the electron and parts of the debris
- Exclusive: detect all the final state particles

e-p experiment advantages:
- High luminosity
- Polarized electron beam
- Possibility to polarize also the target
- The target can vary: from hydrogen up to heavy ions

\[ e - p \rightarrow e' + X + \gamma^* \]
Description of the internal structure

- Wigner function: five dimension phase space parton distribution of the nucleon
- We are not yet capable to measure it
Description of the internal structure

Parton distributions are derived by GTMD (FT of Wigner function)

- TMD, relates longitudinal and transverse momentum. Measured in semi-inclusive DIS
- GPD, relates longitudinal momentum and transverse position. Measured in exclusive photon/meson production
- PDF, longitudinal momentum information. Measured in DIS.
Tomography of the nucleon

Generalized Parton Distributions
(Fourier transformed)

3 dimensional

Longitudinal momentum

$\vec{k}^+ = xP^+$

Transverse position

Partons

Transverse plane
\[ \rho(x, r_\perp) = \int \frac{d^2 \Delta_\perp}{(2\pi)^2} e^{-i \vec{\Delta} \cdot \vec{r}_\perp} H(x, \xi = 0, t = -\Delta_\perp^2) \]

- \( t = \Delta^2 \): momentum transfer to the target
- Skewness: \( \xi = -\Delta^+/2P^+ \)
- Fourier transformation gives us the distribution in \( r_\perp \) and \( x \)

GPDs give access to parton total angular momentum
Ji’s sum rule:
\[ J^q = \frac{1}{2} \int_{-1}^{+1} dx \ x \ (H^q(x, \xi, 0) + E^q(x, \xi, 0)) \]

Also: mechanical properties and gravitational form factors
Tomography of the nucleon

Experiment observables:

- Valence and sea quarks: Deeply Virtual Compton Scattering, Timelike Compton Scattering, ...
- Flavor separation: exclusive meson production
- Gluons: vector meson production
At small $x$, quarkonium production probes the gluon content of the proton.

2D Fourier transformation of the $t$-dependence gives access to the transverse spatial distribution of gluons.

The gluonic radius of the proton shrinks with increasing $x$. 
Quarkonia in e-p near threshold

- Little is known of the gluon at high-x
- Electro/Photo production mechanism near threshold: is it 2-gluons? or 3-gluons?
- Interaction potential $J/\psi$-nucleon. (Might have implication for CNM effects?)
- Production at threshold gives insights on QCD trace anomaly
LHCb claims the discovery of pentaquarks

\[ \Lambda_b^0 \rightarrow K^- (J/\psi p) \]

It should be possible to produce it in the s-channel in photo-production

\[ \sigma_{\gamma p \rightarrow J/\psi p} (E_{\text{peak}}) \propto \text{BR}(P_c \rightarrow J/\psi p)^2 \]
- CEBAF: Continuous Electron Beam Accelerator Facility
- Electron polarization up to $\sim 85\%$
- High current $\sim 200 \mu A$
- Max energy: upgraded to 12 GeV (before 6 GeV)
- Simultaneous four halls operation
Jefferson Lab - four experimental halls

Hall A
- High resolution spectrometer \( \delta p/p \sim 10^{-4} \)
- High luminosity \( (\sim 10^{37} \text{Hz/cm}^2) \)

Hall B - CLAS12
- Very large acceptance
- Multi particle final states

Hall C
- Two high resolution spectrometers, narrow acceptance
- Very high luminosity

Hall D - GlueX
- Photon beam \( E_\gamma \sim 9\text{GeV} \)
- Large acceptance
Selected results - DVCS

- DVCS off proton
- Measurements of cross sections, cross section differences with different beam helicity
- Here, just presented one example of many

- Global fits to DVCS data, form factors, PDF... allow the determination of spatial densities of quarks


Hall D/GlueX Meson Spectroscopy In Photoproduction

12 GeV e⁻

Photon Tagger

North LINAC

East ARC

Diamond Radiator

Electron Beam Dump

Collimator

GlueX Spectrometer

Photon Beam Dump

Photon Beam Spectrum

Diamond: PARA
Diamond: PERP
Aluminum

Photon Beam Energy (GeV)

Polarization

Photon Flux (Arb. Units)

Photon Beam Spectrum

9 GeV

P ≈ 40%

Flux

Beam Energy (GeV)

30 cm LH₂

Designed for light meson spectroscopy
Main goal: search for hybrid mesons

Data taking 80% complete

<table>
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<th>Int L pb⁻¹</th>
<th>status</th>
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Status of data analysis:
complex final states reconstructed
understanding the efficiencies: in progress

E.Chudakov
Spin 2018, Ferrara

J/ψ photoproduction

J/ψ photoproduction
Mass Spectrum of $e^+e^-$

GlueX Preliminary: not the final 2016+2017 data sample (about 70%).

All beam energies


E. Chudakov SPIN 2018, Ferrara $J/\psi$ photoproduction 9 / 13
Fit: 2 + 3-gluon exchange

\[\chi^2/ndf = 0.8\]

Limit for \(P_c(4450)\) \(\Gamma = 40\) MeV

JPAC model, assumptions:
\[\sigma(10.1) = 0.64\) nb non-reson.\]
no wide state \(P_c(4380)\) added

\[
\begin{array}{|c|c|c|c|}
\hline
\text{JPC} & \text{BR} & 10.1 \pm 0.6\text{ GeV} & \text{(2 bins)} \\
\hline
 & \text{JPAC} & \text{experiment} & \text{separation} \\
\hline
3/2- & 2.0\% & 0.81 & 0.58 \pm 0.08 & 2.9 \\
5/2+ & 0.7\% & 0.81 & 0.58 \pm 0.08 & 2.9 \\
\hline
\end{array}
\]

Systematic to be addressed:
- \(t\) and \(s\)-channel interference
- VMD model dependence
- The wide state influence
- Small fraction of the Spring run data analyzed
- Accounts for 2.3% of accumulated charge requested

Negative polarity of the Torus magnet

Positive polarity of the Torus magnet
- Photo-production: copper radiator to provide real $\gamma$, LH2 target
- Tiny acceptance, but high luminosity: 50 $\mu$A beam
- Scheduled this year in February for 11 days
J/ψ at JLab - Hall A, Proposed experiment

- SoLID: Solenoidal Large Intensity Device
- Proposed to be installed in Hall A
- Designed to handle luminosity up to $10^{39} s^{-1} cm^{-2}$
- Integrated luminosity requested: 43.2 ab$^{-1}$
- Large statistics to study electron-/photo- production at threshold, “Van der Waals” forces between J/ψ and nucleon

arXiv:1409.7741
EIC: Study structure and dynamics of matter at high luminosity, high energy with polarized beams and wide range of nuclei

arXiv:1212.1701
The EIC Facility Concepts

Luminosity / $\sqrt{s}$ / Kinematic coverage

Measurements with $A \geq 56$ (Fe):
- eA DIS (E139, E665, EMC, NMC)
- νA DIS (CCFR, CDHSW, CHORUS, NuTeV)
- DY (E772, E866)

Current polarized DIS data:
- eA DIS (E139, E665, EMC, NMC)
- νA DIS (CCFR, CDHSW, CHORUS, NuTeV)
- DY (E772, E866)

Current polarized BNL-RHIC pp data:
- PHENIX
- STAR 1-jet

8th International Conference on Quarks and Nuclear Physics
Tsukuba, Japan, November 13 - 17, 2018

Bernd Surrow
Electron Ion Collider

JLEIC
- Polarized electrons: 3 – 12 GeV
- Polarized protons: 40 to 100-400 GeV
- Figure-8: p spin precession cancel
- Rate: 476 MHz - High lumi. concept

eRHIC
- Polarized electrons: 5 – 18 GeV
- Polarized protons: up to 275 GeV
- Rate: 112.6 MHz
Imaging of the nucleon:
- Exclusive vector meson production, and in particular $J/\psi$ and $\Upsilon$ will open the precise imaging of gluons inside the nucleon.

Proton mass origin:
- Trace anomaly is contributing to the mass.
- Production at threshold of $\Upsilon$ may be feasible.
Diffraction at EIC:

- High sensitivity to gluons in the linear regime

\[ \sigma \propto (g(x, Q^2))^2 \]

- Dramatic changes in cross section if onset of non linear effects
- Probably, the only way to get information on spatial gluon distributions in nuclei

\[ e(k) \rightarrow q, M_x, \text{gap, } A(p), A'(p') \]
• The incoherent part is important too
• Related to the size of the fluctuations of the gluons
• Models that consider “hot spots” can reproduce ZEUS data
• If A is a black disk, vanishing incoherent part
Summary

$J/\psi$ at JLab (fixed target)

- Studies of electro-/photo- production near threshold
- Sensitive to gluons at high-$x$
- It allows the study of production mechanism and $J/\psi$ -N interaction
- In the $s$-channel, pentaquarks search

Quarkonia at EIC

- Exclusive electroproduction allows the 3D imaging of gluons in the proton
- Photoproduction of $\Upsilon$ at threshold
- Vector meson in diffraction clear probe for saturation effects
- Not to forget to study also the incoherent part of the cross section

Advertisement: if you are interested in EIC, come to the EIC User Group Meeting in Paris 22-26 July 2019!