JLab/EIC: recent results and perspectives

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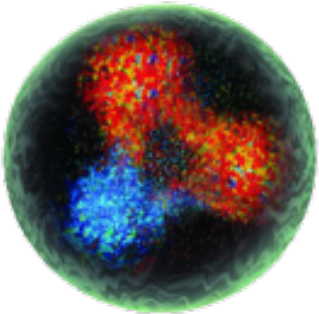
Quarkonia as tools
Aussois, 18/1/2019

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

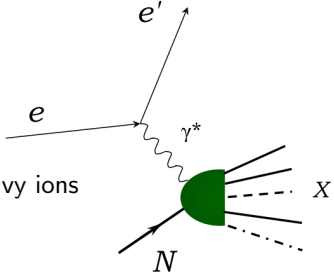
- Electron (or photon or muon) beam: clean probe, it couples electromagnetically

Measurements:

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

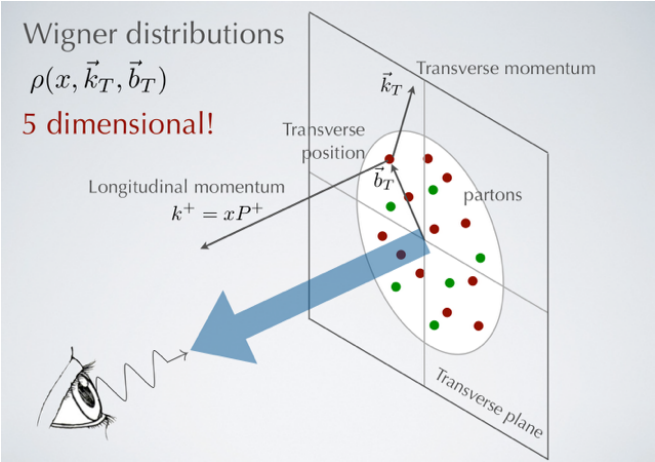
e-p experiment advantages:

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



Description of the internal structure

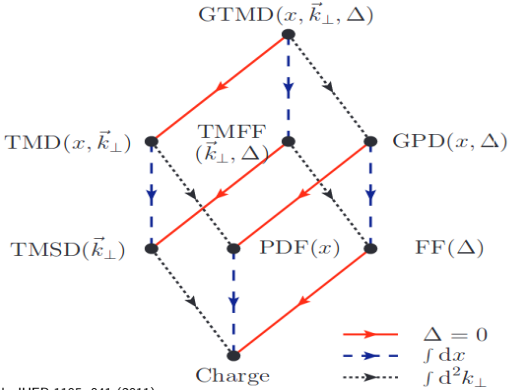
- Wigner function: five dimension phase space parton distribution of the nucleon
- We are not yet capable to measure it



Description of the internal structure

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

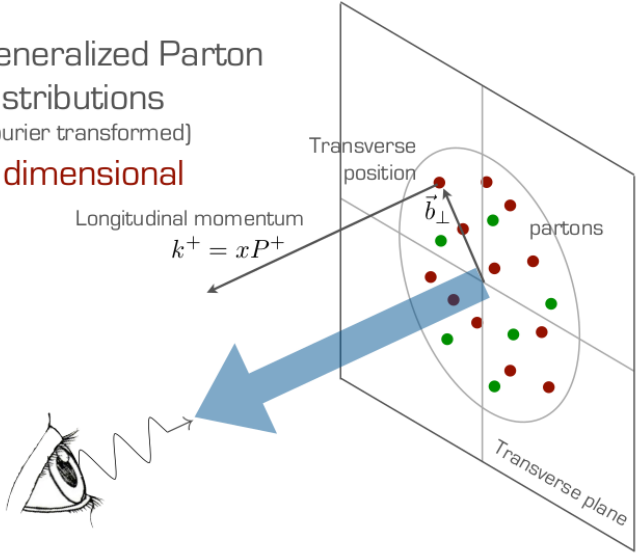
- TMD, relates longitudinal and transverse momentum. Measured in semi-inclusive DIS
- GPD, relates longitudinal momentum and transverse position. Measured in exclusive photon/meson production
- PDF, longitudinal momentum information. Measured in DIS.



Lorcé et al. JHEP 1105, 041 (2011)

Tomography of the nucleon

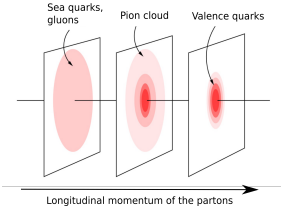
Generalized Parton Distributions
(Fourier transformed)
3 dimensional



A. Bacchetta

Tomography of the nucleon

$$\rho(x, \vec{r_\perp}) = \int \frac{d^2\Delta_\perp}{(2\pi)^2} e^{(-i\vec{\Delta}\cdot\vec{r_\perp})} H(x, \xi = 0, t = -\Delta_\perp^2)$$ Burkard 2003



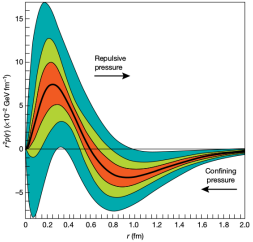
- $t = \Delta^2$: momentum transfer to the target
- Skewness: $\xi = -\Delta^+/(2P+)$
- Fourier transformation gives us the distribution in $\vec{r_\perp}$ and x

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

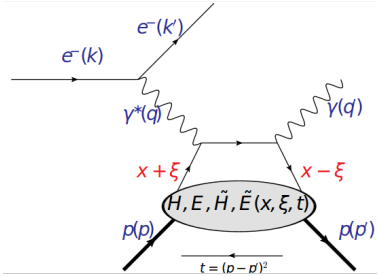


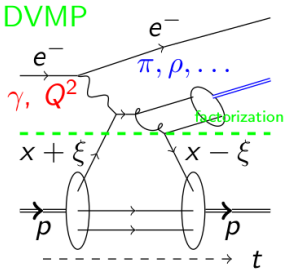
Nature 557, 396 (2018)

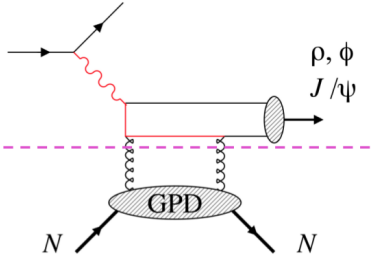
Tomography of the nucleon

Experiment observables:

- Valence and see quarks: Deeply Virtual Compton Scattering, Timelike Compton Scattering, ...
- Flavor separation: exclusive meson production
- Gluons: vector meson production

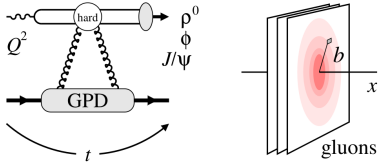


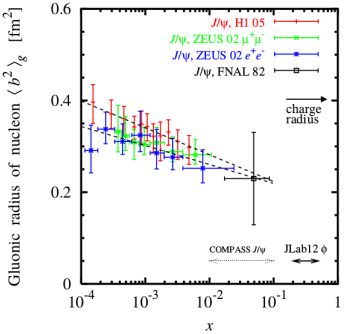


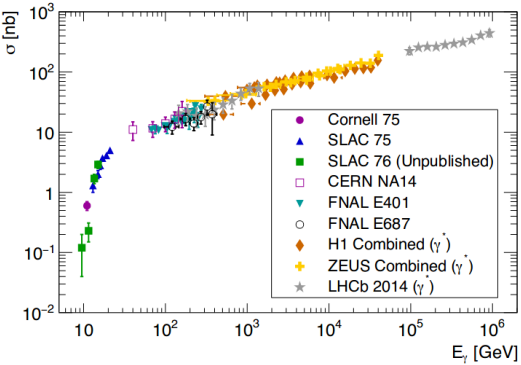


Quarkonia in e-p

- 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

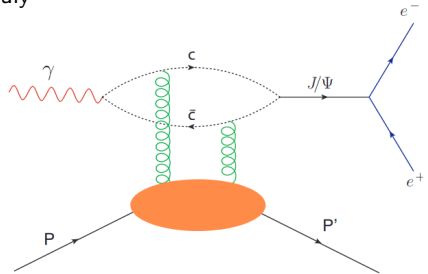


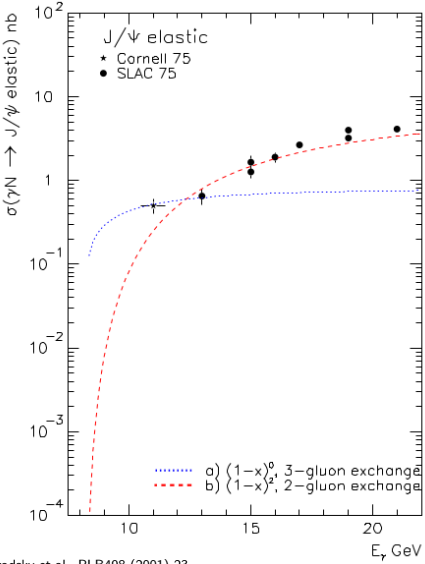




Quarkonia in e-p near threshold

- 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/ψ -nucleon. (Might have implication for CNM effects?)
- Production at threshold gives insights on QCD trace anomaly





Brodsky et al., PLB498 (2001) 23

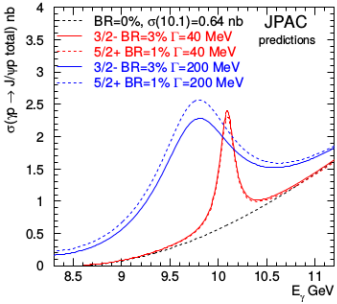
Quarkonia in e-p near threshold

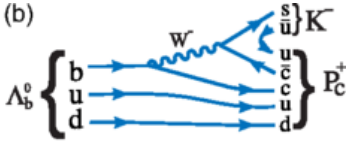
- LHCb claims the discovery of pentaquarks

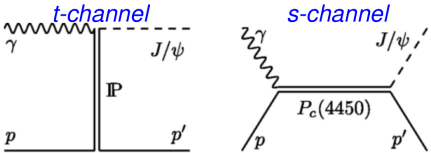
$$\Lambda_b^0 \to K^-(J/\psi p)$$

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

$$\sigma_{\gamma p \to J/\psi p}(E_{peak}) \propto BR(P_c \to J/\psi p)^2$$

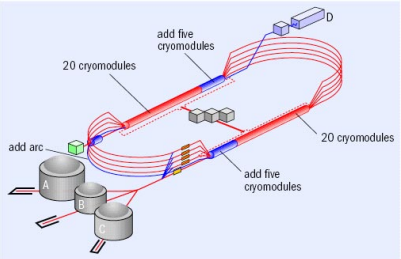






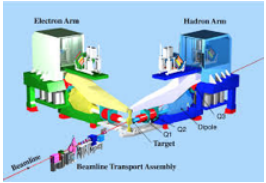
Jefferson Lab

- 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



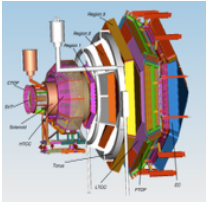
Jefferson Lab - four experimental halls

Hall A



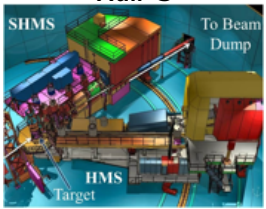
- High resolution spectrometer $\delta p/p \sim 10^{-4}$
- High luminosity ($\sim 10^{37}$Hz/cm^2)

Hall B - CLAS12



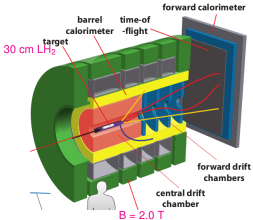
- Very large acceptance
- Multi particle final states

Hall C



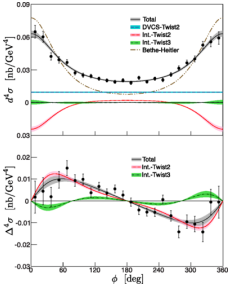
- Two high resolution spectrometers, narrow acceptance
- Very high luminosity

Hall D - GlueX



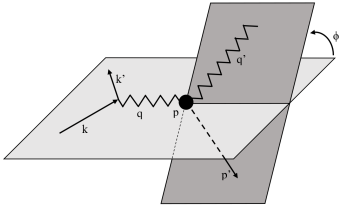
- Photon beam $E_\gamma \sim 9$GeV
- Large acceptance

Selected results - DVCS

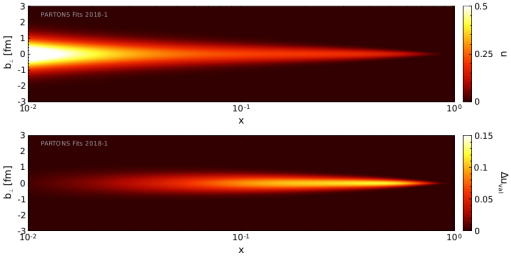


Phys. Rev. C 92, 055202 (2015)

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

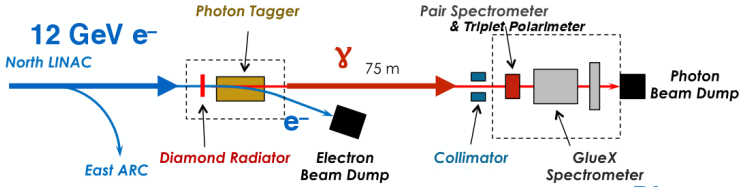


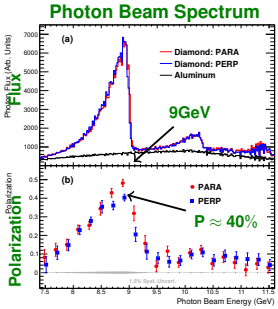
- Global fits to DVCS data, form factors, PDF... allow the determination of spatial densities of quarks

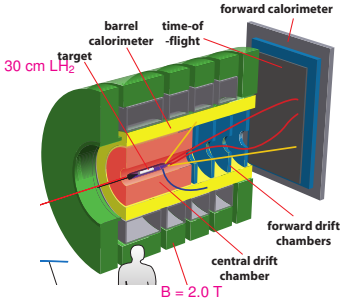


Moutarde et al., Eur.Phys.J.C78 (2018) 890

Hall D/GlueX Meson Spectroscopy In Photoproduction







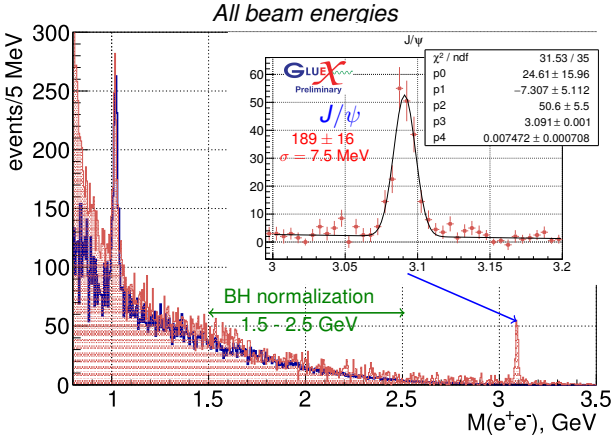
- Designed for light meson spectroscopy
  Main goal: search for hybrid mesons
- Data taking 80% complete

run	E_{MAX} GeV	Int L pb^{-1}	status
2016	12.0	10	analyzed
2017	11.7	45	analyzed
2018	11.7	100	not yet analyzed

- Status of data analysis:
  complex final states reconstructed
  understanding the efficiencies: in progress

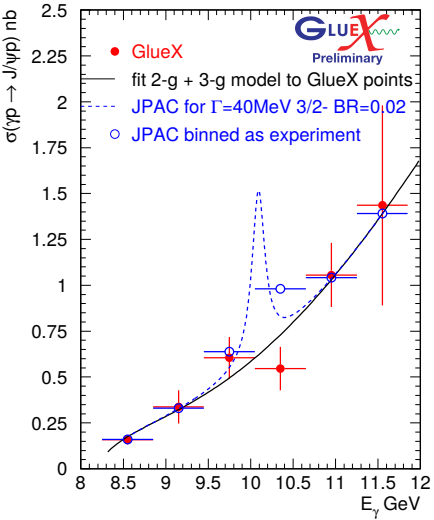
Mass Spectrum of e^+e^-

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



BH simulation from R.Paremuzyan, based on E.Berger et al, EPJC 23:675 (2002)

Limit on the Pentaquark Production



Fit: 2 + 3-gluon exchange

Brodsky et al, PL 498 (2001)

2 free parameters $\chi^2/ndf = 0.8$

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

J^{PC}	BR	10.1 ± 0.6 GeV (2 bins)		
		JPAC nb	experiment nb	separation $\sigma(stat)$
3/2-	2.0%	0.81	0.58 ± 0.08	2.9
5/2+	0.7%	0.81	0.58 ± 0.08	2.9

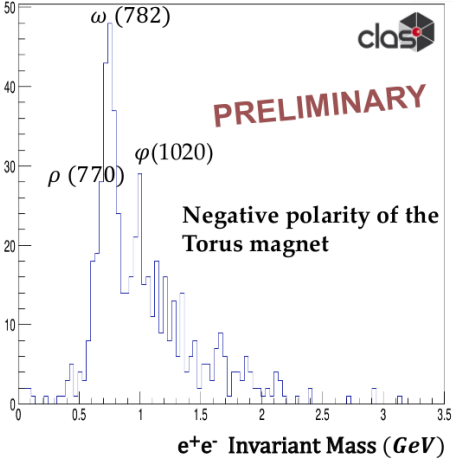
Systematic to be addressed:

- *t* and *s*-channel interference
- VMD model dependence
- The wide state influence

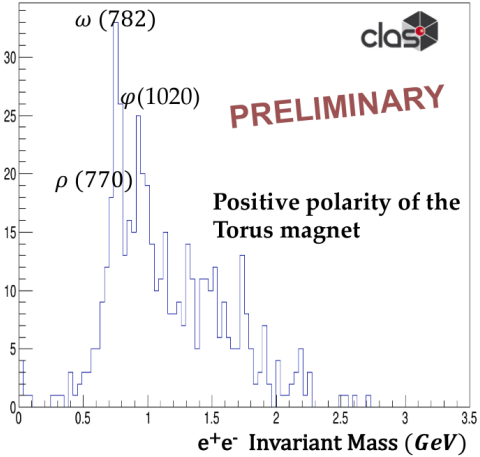
J/ψ at JLab - Hall B, Clas12

- Small fraction of the Spring run data analyzed
- Accounts for 2.3% of accumulated charge requested

Experiment: E12-12-001

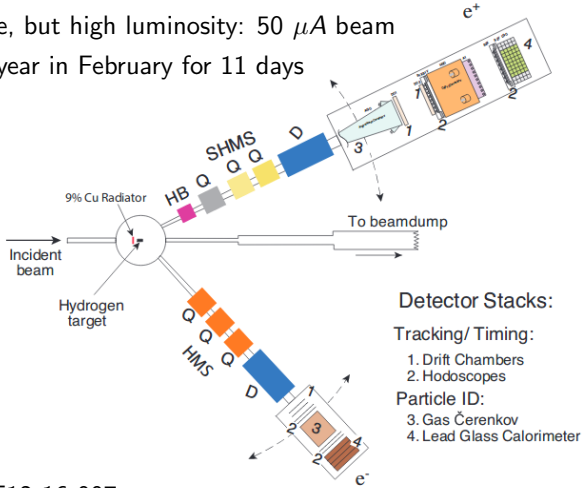


J. Newton at DNP2018



J/ψ at JLab - Hall C

- Photo-production: copper radiator to provide real γ, LH2 target
- Tiny acceptance, but high luminosity: 50 μA beam
- Scheduled this year in February for 11 days

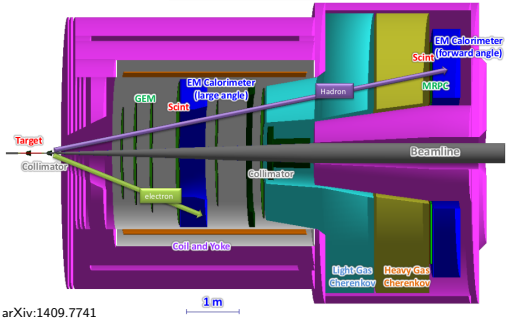


E12-16-007

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

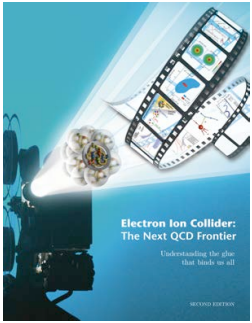
SoLID (SIDIS & J/ψ)



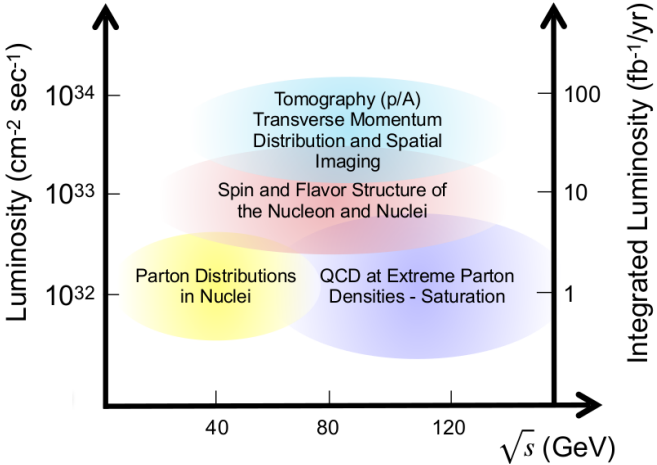
arXiv:1409.7741

The future for e-p/A physics: Electron Ion Collider

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

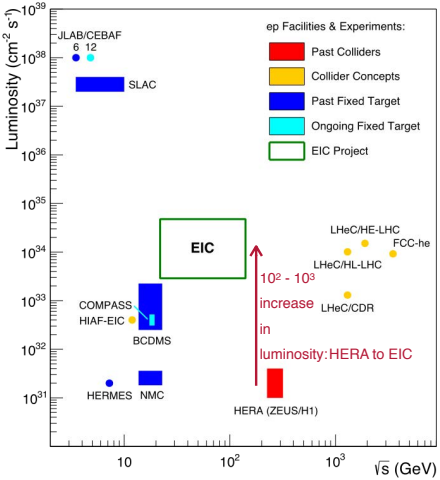


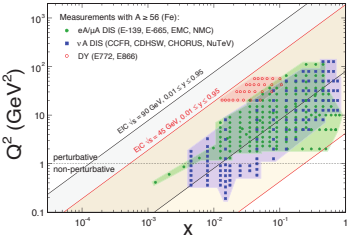
arXiv:1212.1701



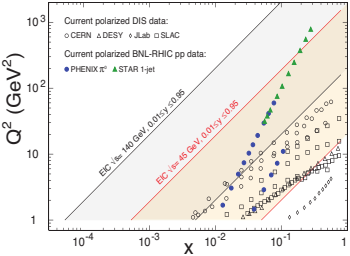
The EIC Facility Concepts

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





eA



ep

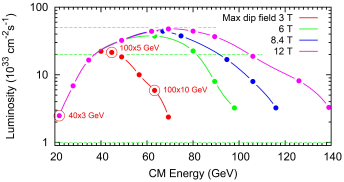
8th International Conference on Quarks and Nuclear Physics
Tsukuba, Japan, November 13 - 17, 2018

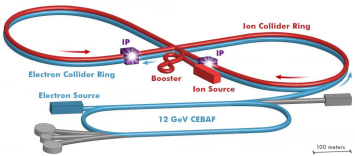
Bernd Surrow

Electron Ion Collider

JLEIC

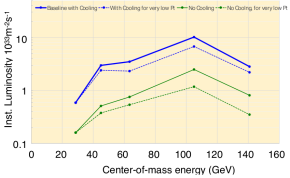
- Polarized electrons: 3 – 12GeV
- Polarized protons: 40 to 100-400 GeV
- Figure-8: p spin precession cancel
- Rate: 476MHz - High lumi. concept

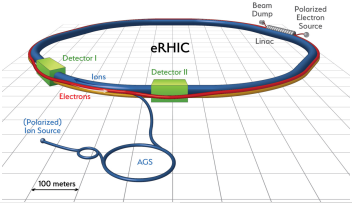




eRHIC

- Polarized electrons: 5 – 18GeV
- Polarized protons: up to 275 GeV
- Rate: 112.6MHz

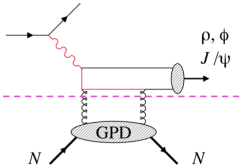




Quarkonia at EIC

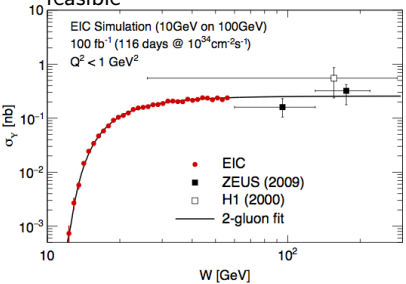
Imaging of the nucleon:

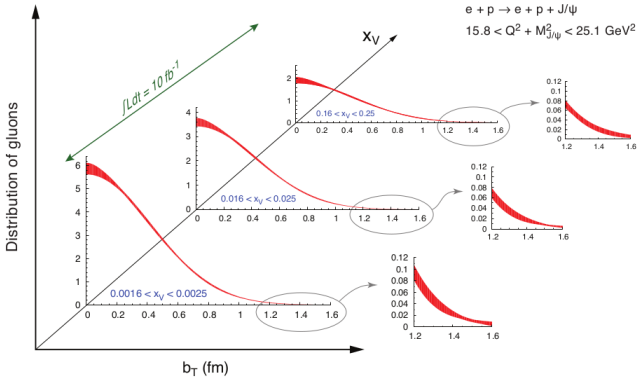
- Exclusive vector meson production, and in particular J/ψ and Υ will open the precise imaging of **gluons** inside the nucleon



Proton mass origin:

- Trace anomaly is contributing to the mass
- Production at threshold of Υ may be feasible





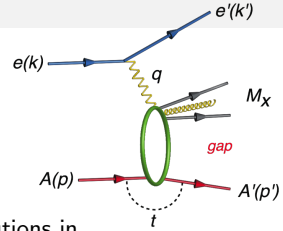
Quarkonia at EIC

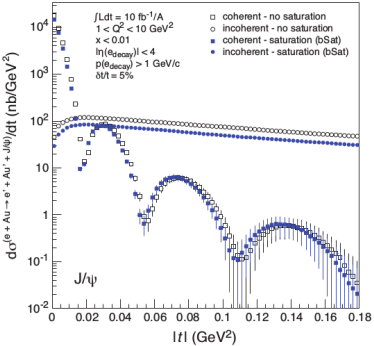
Diffraction at EIC:

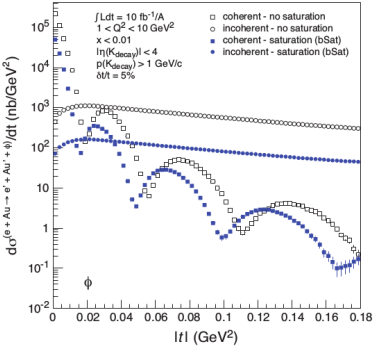
- High sensitivity to gluons in the linear regime

$$\sigma \propto (g(x, Q^2))^2$$

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

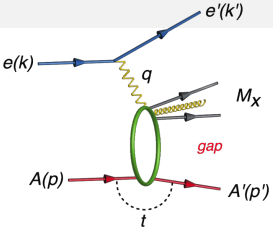


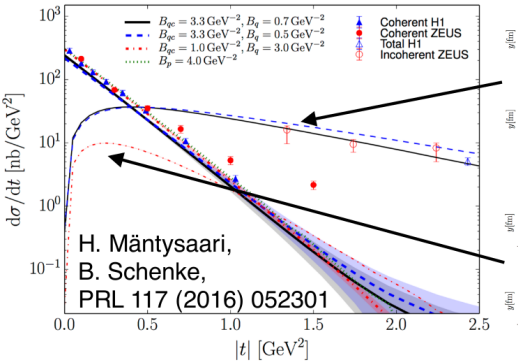


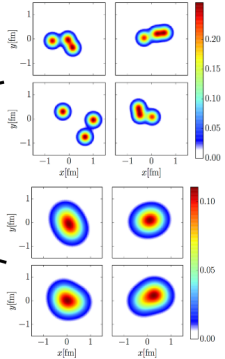


Diffraction

- 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/ψ 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/ψ -N interaction
- In the s-channel, pentaquarks search

Quarkonia at EIC

- Exclusive electroproduction allows the 3D imaging of gluons in the proton
- Photoproduction of Υ 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!