Report from Argonne Workshop

EIC Detector Workshop @JLab

June 5th, 2010

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Workshop on Nuclear Chromo-Dynamic Studies with a Future Electron Ion Collider April 7-9, 2010 @ANL

42 participants and 5 Physics sessions

- Nuclear effects chair: John Arrington
- Exclusive reactions chair: Vadim Guzey
- Color in nuclei chair: Dipangkar Dutta
- Propagation in nuclei chair: Alberto Accardi
- Short range structure chair: Misak Sargsia

Wiki pages:

- https://eic.jlab.org/wiki/index.php/E-A_Working_Group

Nuclear quark and gluon distributions

Parton distributions in nuclei are modified compared to those in free nucleon over the entire range of Bjorken x because of various nuclear effects.

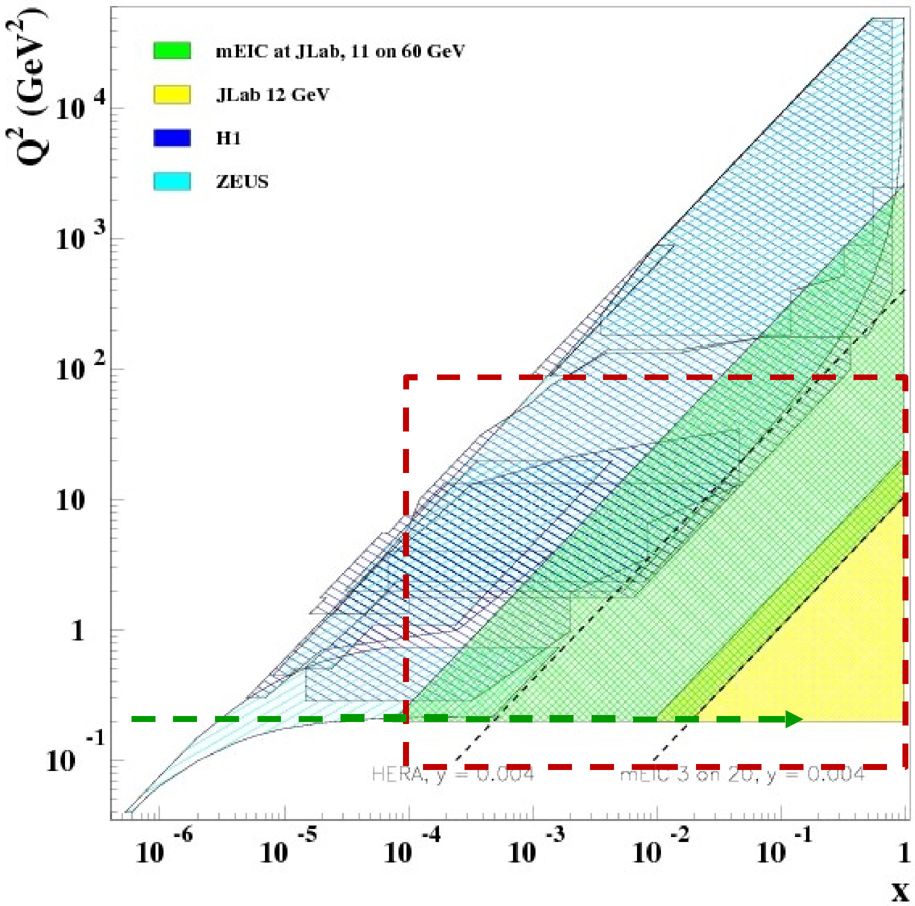
From low to large x:

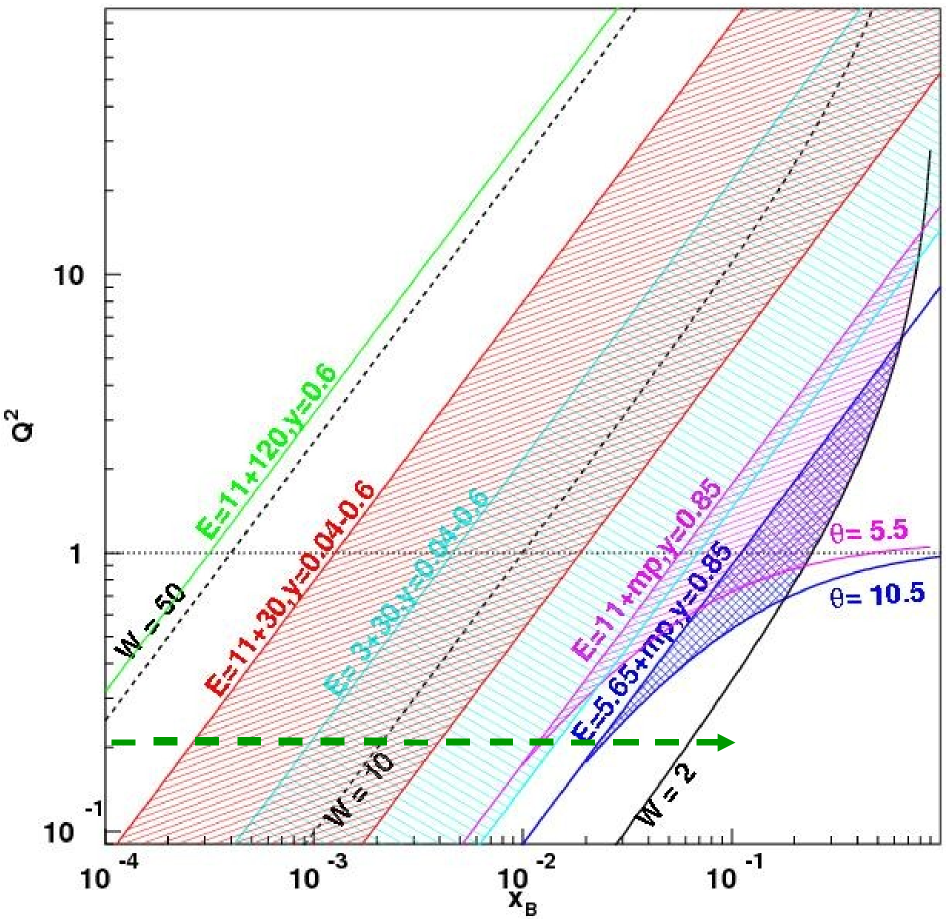
- **Saturation**
- **Nuclear shadowing**
- **Anti-shadowing**
- **EMC effect**
- Fermi motion and non nucleonic degrees of freedom

Reactions to be used

- Inclusive DIS and Jet production
- Inclusive diffraction
- Semi-inclusive
- Exclusive production of vector meson and DVCS

EIC Kinematic Coverage





ep mEIC: 11+60

eA mEIC: 3+30/11+30 (0.04<y<0.6)
eA eLIC: 11+120 (y=0.6)

EIC connects JLab and HERA kinematic region.

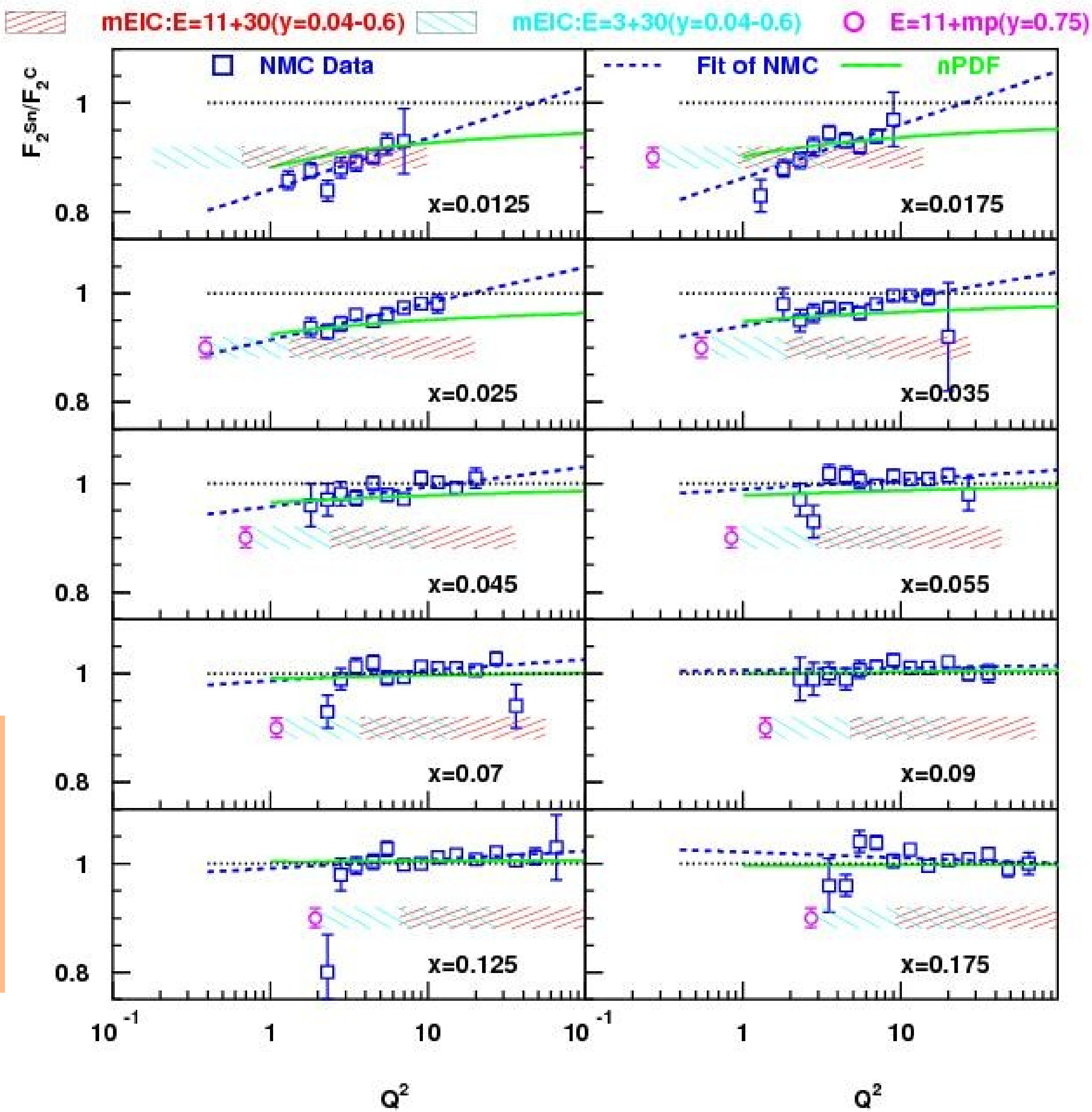
Inclusive DIS

Projections by Lingyan Zhu

Measure $F_2^A(x,Q^2)$ and $F_L^A(x,Q^2)$ to extract nuclear PDFs especially at low x

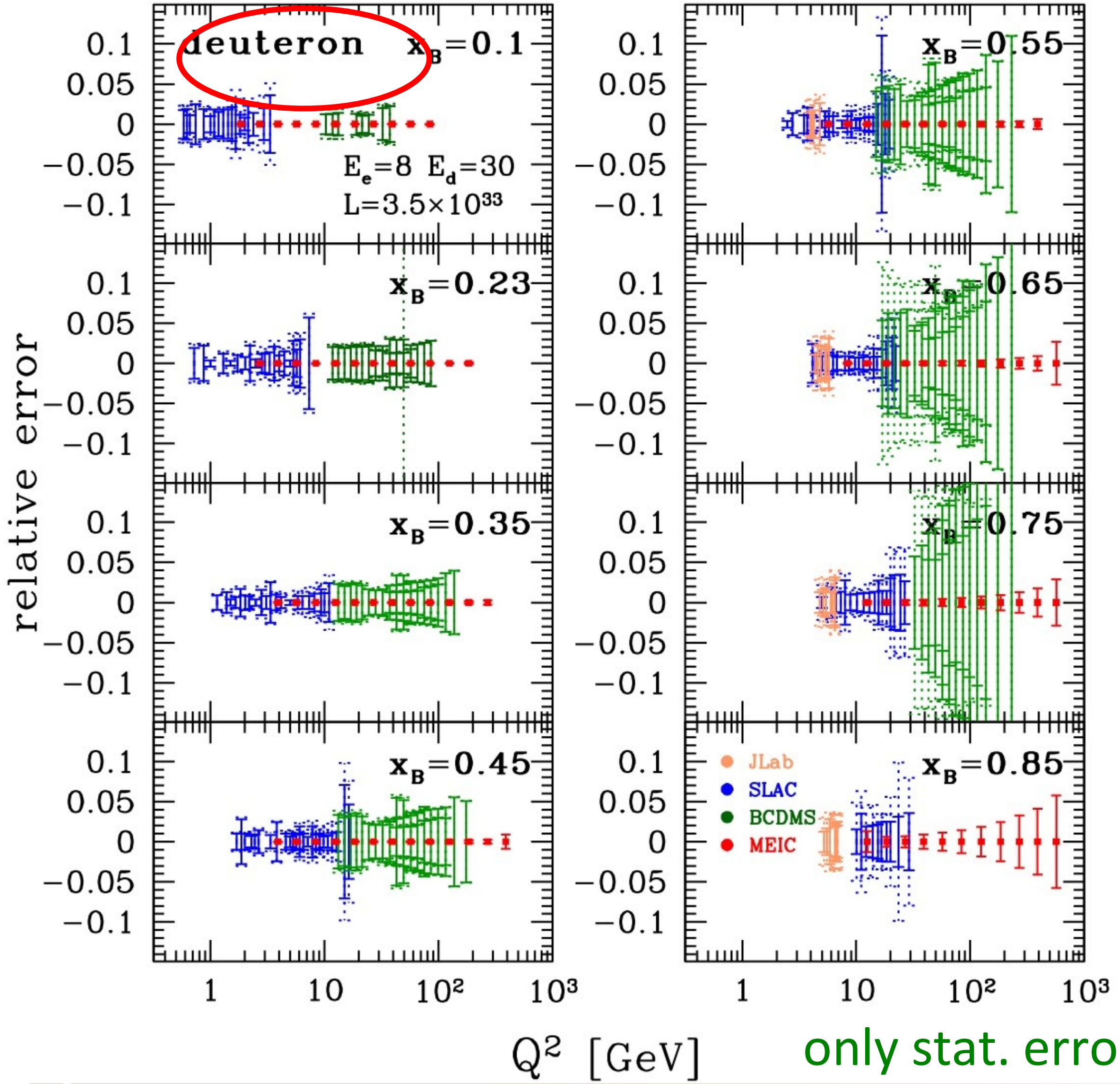
(shadowing region is dominated by small Q^2 for fixed target eA data)

Note that x = 10^{-3} with Q^2>1 GeV^2 can be reached with the high Energy configuration of the EIC (projections not shown)



Inclusive DIS - F_2^d Relative Uncertainty

[Accardi, Ent, in progress]



- MEIC 4+30
- 1 year of running (26 weeks) at 50% efficiency, or 35 **fb**$^{-1}$

Even with a factor 10 less statistics for the deuteron the improvement compared to NMC is impressive

EIC will have excellent kinematics to measure n/p at large x!

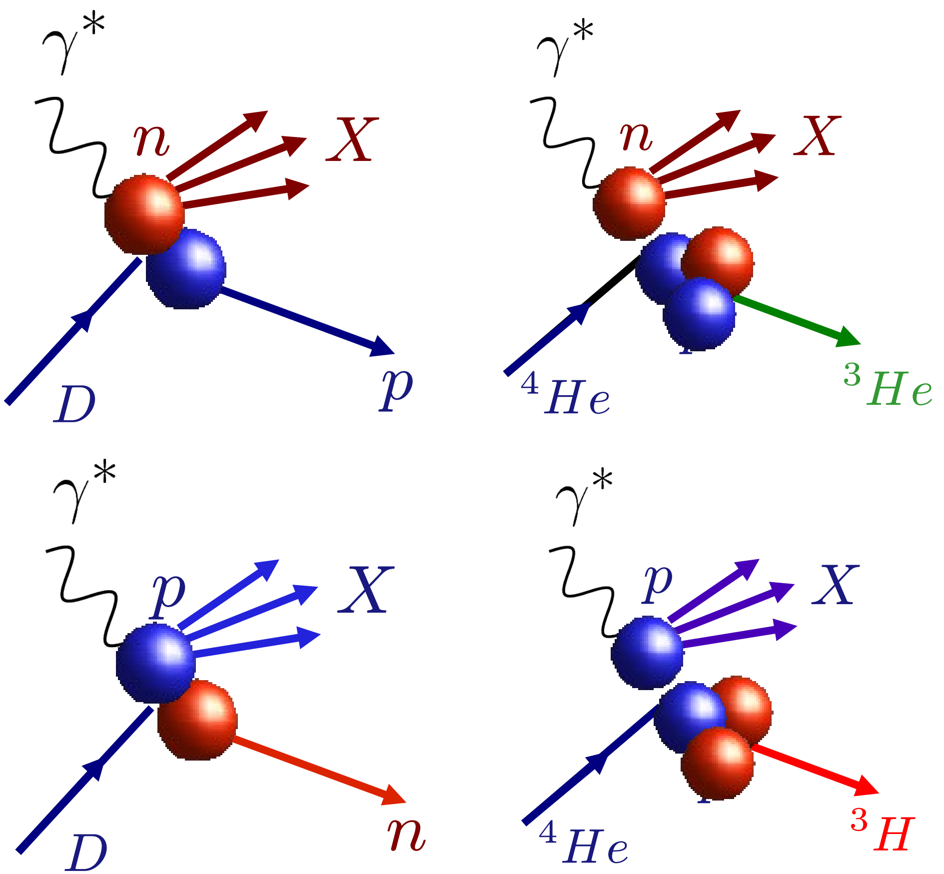
only stat. errors on projected results

Quasi-free nucleons

- Spectator tagging

$$e\,A \longrightarrow e\,(A-1)\,X$$

  - Measure *neutron* F2 in D, study nuclear, off-shell dependence
  - Unique for e+A collider: *proton* F2 in deuterium



  - Forward detection requirements:
    - small to high spectator momentum, p_s, decent resolution
    - angular resolution: needs backward spectators

Other processes

- Inclusive diffraction in nuclei
  - measure the unknown nuclear diffractive structure function.
  - diffractive DIS is more sensitive to the onset of non-linear parton dynamics (saturation)
- Semi inclusive DIS and spectator tagging
  - Study EMC effect and its flavor dependence
  - polarized EMC effect – connection to NuTeV anomaly
- Exclusive production of vector mesons and DVCS
  - Nuclear effects are predicted to be enhanced in nuclear GPDs
  - More sensitive to saturation

High energy color transparency - an effective tool to study strong interaction dynamics, structure of photon and GPDs

Color transparency is based on suppression of interaction of small size color singlet configurations due to decreased gluon radiation from a small size color dipole

Dipole cross section for a dipole of transverse size *d*

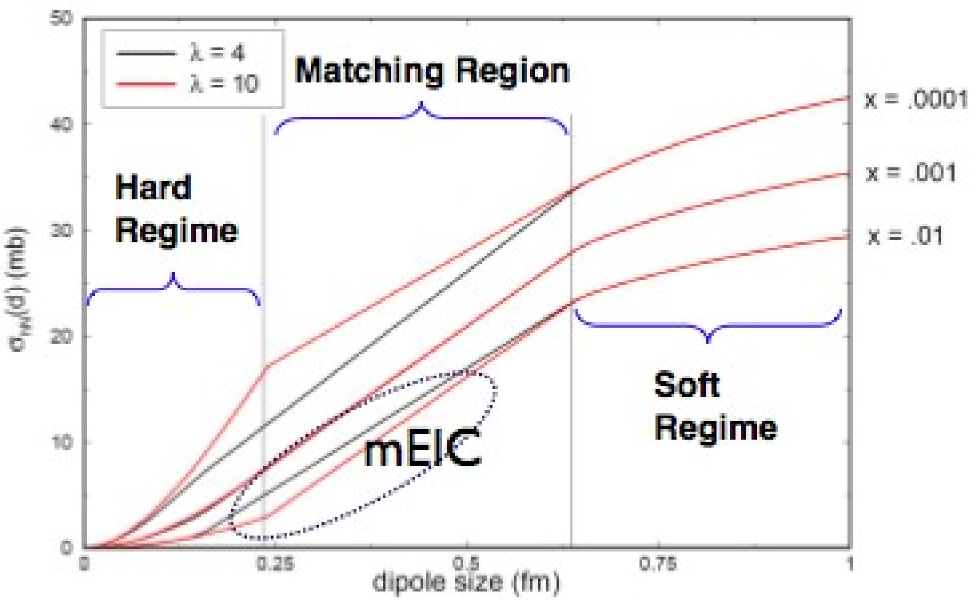
$Q^2_{eff} = \lambda/d^2$

$$\sigma(d,x) = \frac{\pi^2}{3}\alpha_s(Q^2_{eff})d^2\left[xG_N(x,Q^2_{eff}) + \frac{2}{3}xS_N(x,Q^2_{eff})\right]$$

S is the sea quark distribution for quarks forming the dipole important for intermediate energies

At the EIC one would access an intermediate range of dipole transverse sizes that would probe a region between the hard and soft QCD regimes

$Q^2 = 3\ GeV^2$



Possible CT Measurements @ EIC

CT can be described as a combination of

- Selection of a small size state (squeezing)
- Propagation of the small size state in the medium while it stays small (freezing)

✧ Coherent and incoherent vector meson production to study color transparency effects in the propagation of hadronic components of the photon where freezing is very effective
significant CT effects are expected for meson productions for $Q^2 > 3$ GeV^2

✧ Study the squeezing of the recoil nucleon via $\gamma + A \rightarrow \rho + (N\pi) + (A-1)^*$ where the pion is produced near threshold (should be performed in light nuclei where expansion times are moderate)

✧ Study QCD dynamics near threshold $\gamma^* + A \rightarrow \pi^+\pi^0 + A^*$ $\pi^+ \pi^0$ are near threshold

✧ New type of hadronic processes "Branching exclusive processes"

$\gamma^* + A \rightarrow \underbrace{\pi^+\pi^0}_{\text{current fragmentation}} A^*$

$\gamma^* + A \rightarrow \rho^0 \underbrace{\pi^+ A^*}_{\text{nuclear fragmentation}}$

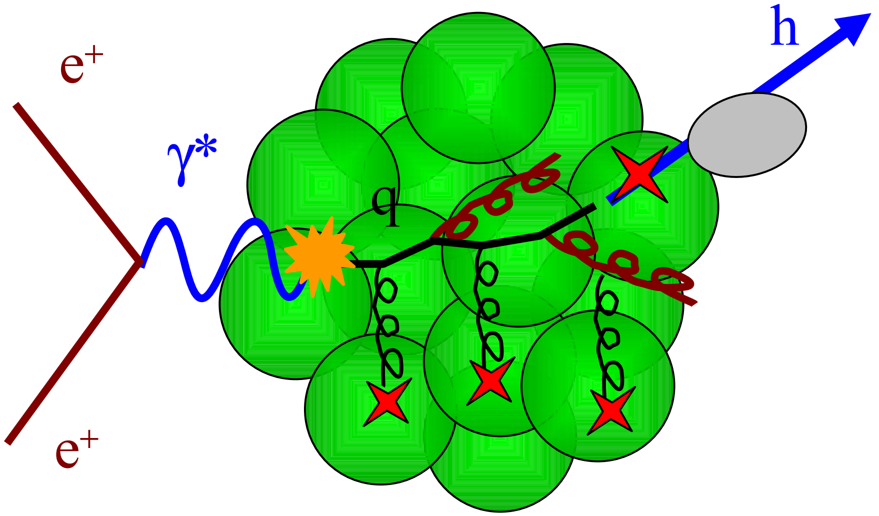
$\gamma^* + A \rightarrow \rho^0 + baryon + fragm.$

rapidity interval between π^+ and A regulates formation time and hence CT!!!

Physics to be explored

- Study the interplay of large and small transverse distance effects (soft and hard physics) in wide range of the processes including elastic scattering, large angle two body processes
- Measure a variety of GPDs including GPDs of photon
- Compare wave function of different mesons
- Map the space-time evolution of small wave packets at distances comparable to the size of nuclei
- Test the role of chiral degrees of freedom in hard interactions

Parton propagation and fragmentation



- **Nuclei as space-time analyzers**
- **Non perturbative aspects**
  - Color confinement dynamics
  - Probe nuclear gluons
- **Perturbative QCD**
  - testing pQCD energy loss
  - DGLAP evolution, parton showers, jets
- **Connection to other fields**
  - Quark-Gluon Plasma at RHIC: medium unknown and rapidly expanding
  - Neutrino experiments: nucleus increases cross section
  - new look at TMDs in nucleons
  - novel access to gluon GPDs

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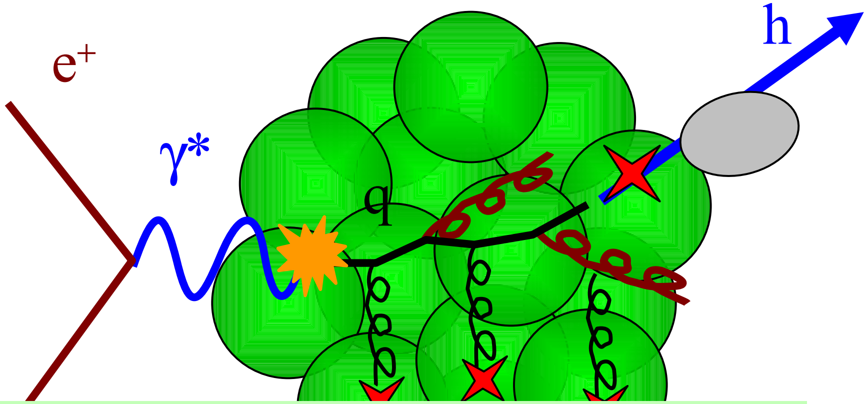

Partons created in the medium could be used as a color probe of the gluon density in a nucleus when parton lifetime and energy loss mechanisms are under theoretical control

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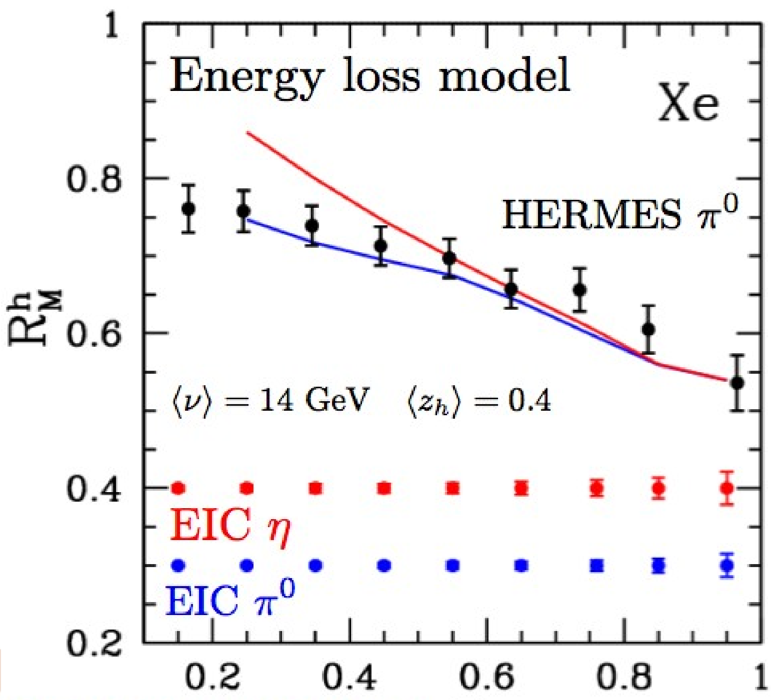
The EIC - large ν, Q^2, W^2

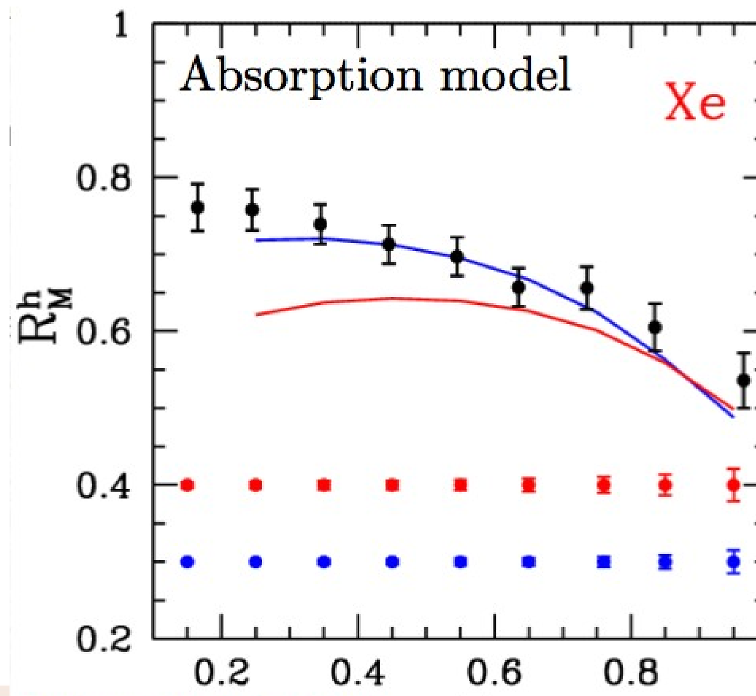
- **Large ν-range**: $10 < \nu < 1600$ GeV
  - hadrons formed well outside of the nuclear medium
  - (precision) tests of pQCD energy loss
- **Large Q^2:** role of virtuality in hadron attenuation
- **p_T-broadening**
  - strong constraints to theory models
  - study medium modification of DGLAP evolution
- **Heavy flavors:** B, D mesons ; J/psi “normal” absorption
- **Jets:** “real” pQCD, IR safe jets
  - Jet shape modifications
  - Measure nuclear gluons
- **Photons:** decouple from medium, tests parton propagation
- **Plus:** dihadron correlations, baryon / target fragmentation, BEC, ...

Hadronization in cold nuclear matter

- Observables to measure are multiplicity ratios and transverse momentum broadening
- For the EIC @ s = 1000 GeV^2, one can isolate parton energy loss in cold nuclear medium when fragmentation starts outside the nucleus
- For lower energies when hadronization is expected to occur inside the nucleus, one would be able to study pre-hadron absorption
- Compare π^0 and η for energy loss versus pre-hadron absorption



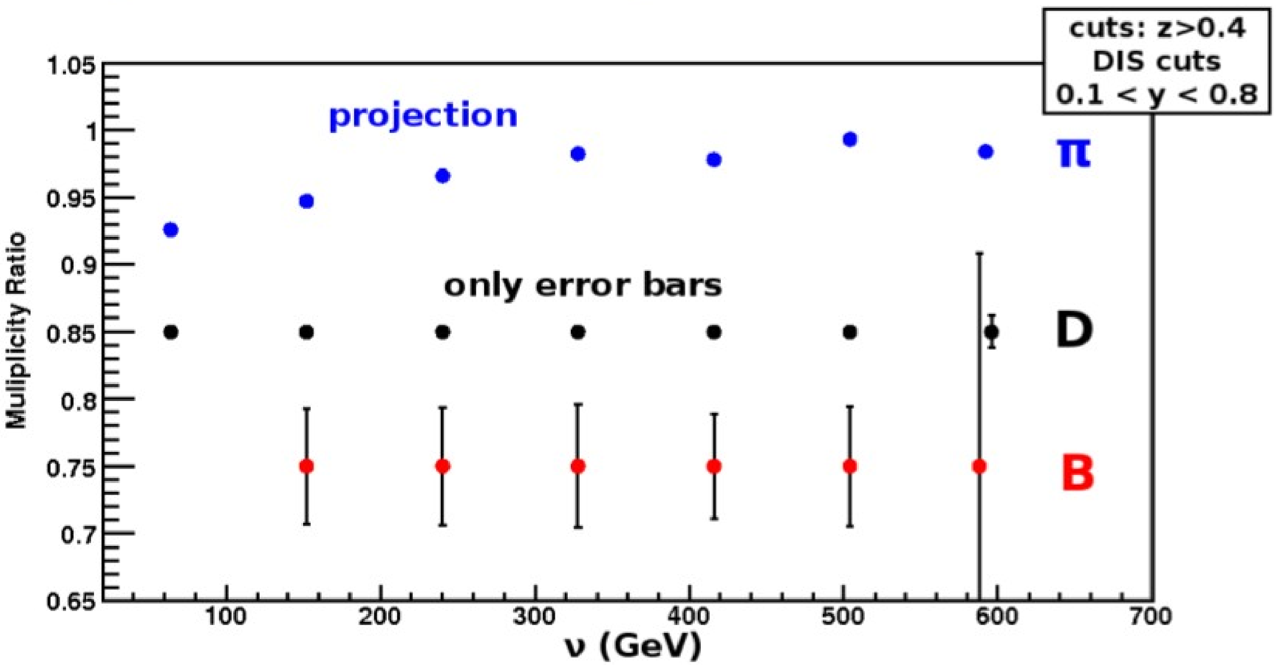
(Simulations by R.Dupré)



(Curves by A.Accardi)

Heavy flavors

- EIC offers a unique opportunity to study heavy quark propagation and fragmentation in a medium with known properties
- Large mass of charm and bottom allow in principle to calculate fragmentation in perturbative QCD
- Heavy quarks are expected to have reduced energy loss compared to light quark not observed in RHIC
- Heavy quark detection requires a vertex determination of at least 100 µm and high luminosity especially bottom quarks of at least few 10^{34}



11 + 30 GeV/A
L = 0.4 10^{33} cm^{-2} s^{-1}
1 month 100% running

Other venues to explore

- **Nuclear modification of Cahn effect** may provide info on nuclear modification of transverse momentum distributions and spin-orbit correlations of partons at small x, in a wide range of Q

- Study **target fragmentation** by observing particles that received energy from the scattered partons as opposed to observing particles that lost that energy
  - More detailed information on parton propagation and fragm. Determine the centrality of photon-nucleus scattering
  - Further handle on the amount of matter traversed

- Measure **Bose-Einstein correlations** between the produced hadrons which could enable us to extract the source size of an excited color string and possibly some information on the tension of the string

Detector requirements

- **Good PID**
  - π, K, η, ϕ
  - p, Λ,
  - photons
  - J/ψ, ψ', χ_c (and Υ, ...)
- **Heavy flavors**
  - secondary vertex with spatial resolution $\Delta x \lesssim 100\ \mu m$
- **Good calorimetry**
  - jet reconstruction

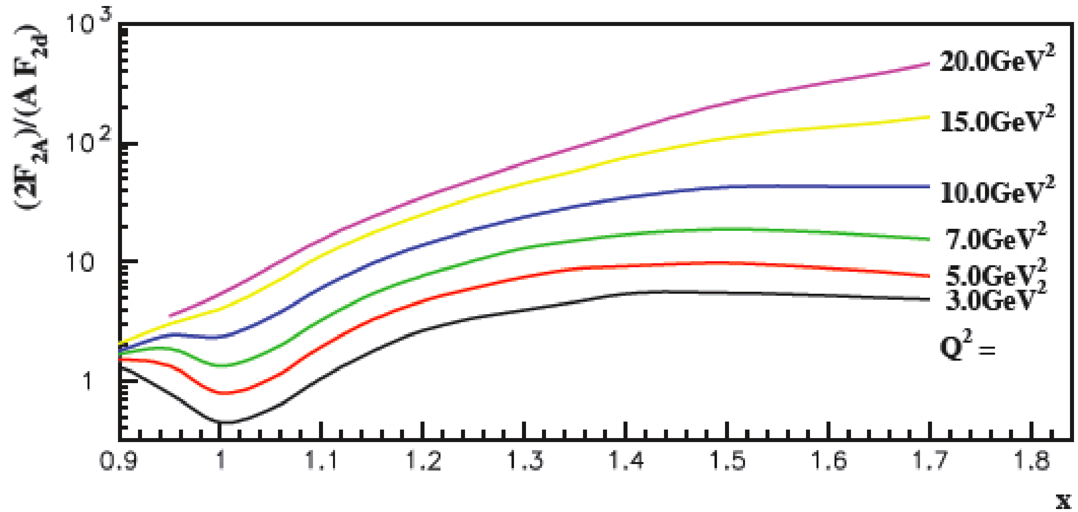
Machine requirements

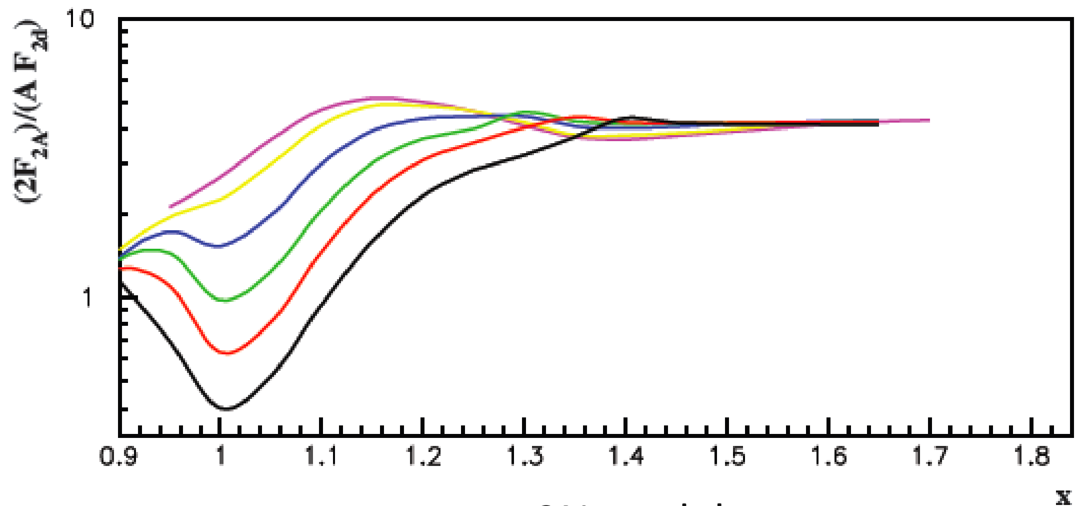
- **Not energy hungry**
- **Not luminosity hungry**, except for
  - open bottom, bottomonium, multi-dimensional binning

Superfast quarks - Short range correlations @ larger Q^2 and smaller x

- **EIC is limited by cross section**
- **For s=1000, L ≈ 10^{34}, statistics running out for x ≈ 0.85**
- **Might be possible to reach interesting x range**
  - *Need factor of 10, 100, 1000 to reach x ≈ 1.0, 1.15, 1.30*
  - *Need to evaluate statistics for lower s*
  - *Not clear just how high in x required to isolate short-range structure that we're interested in*

2N + 3N models





2N models

Summary and outlook

- Broad category, with mix of extensions to current research programs, and new topics/directions
  - **It may be easier to define (and package and sell) ‘flagship physics’ than ‘flagship experiments’**

- EIC can directly map out glue, sea in ways going well beyond current efforts
  - Hadronization and CT studies map out birth and development of hadrons (gluon dressing of bare quarks)
  - gluon saturation, shadowing, anti-shadowing, EMC effect, SRC at x>1

- **To many people, gluon saturation is the ultimate destination for an electron-ion Collider, maybe! But there is a lot of interesting physics along the way**

- **The workshop was only the beginning of hopefully an exciting journey!**