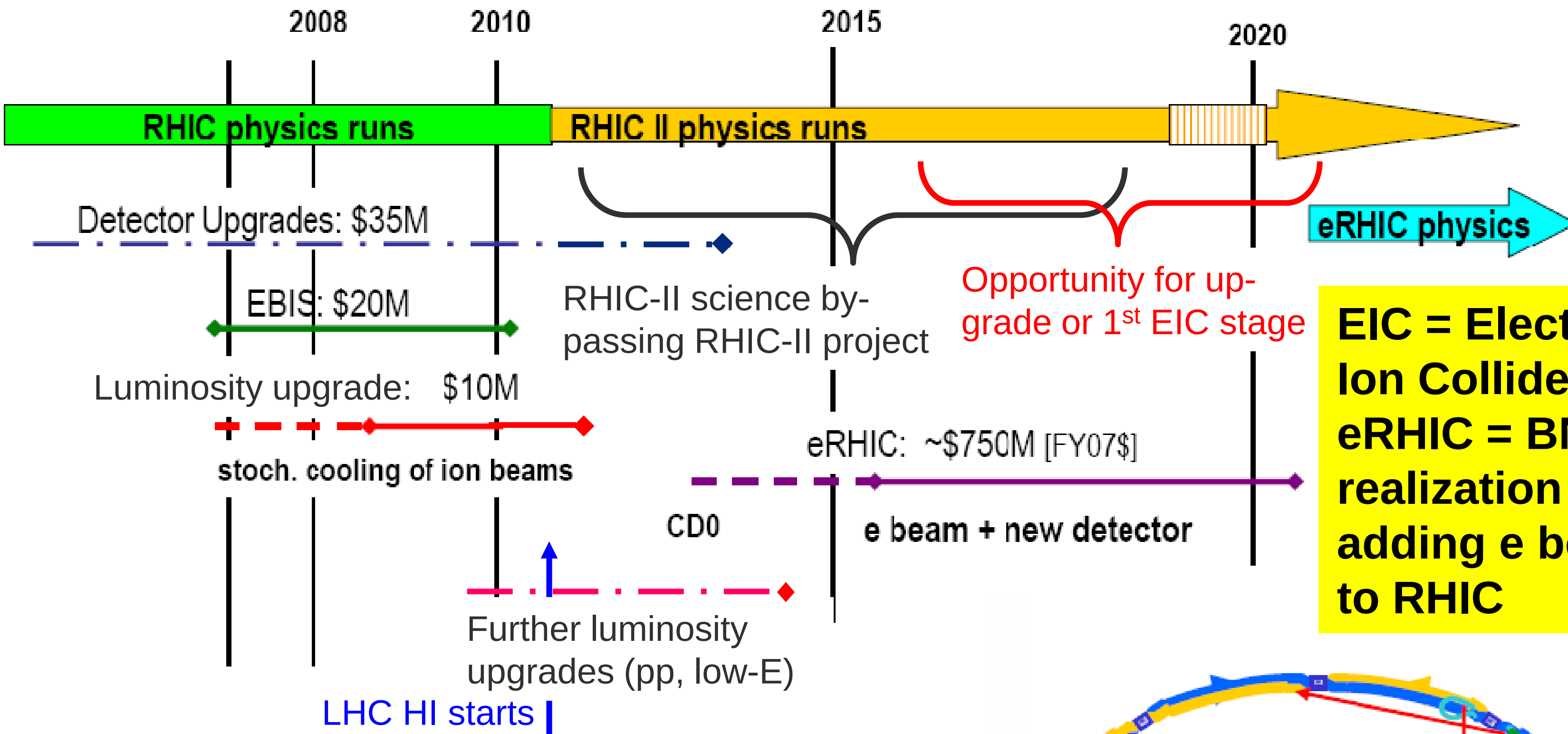
An Electron-Ion Collider at RHIC

Steve Vigdor, DIS09, April 30, 2009

A Long Term (Evolving) Strategic View for RHIC



EIC = Electron-Ion Collider; eRHIC = BNL realization by adding e beam to RHIC

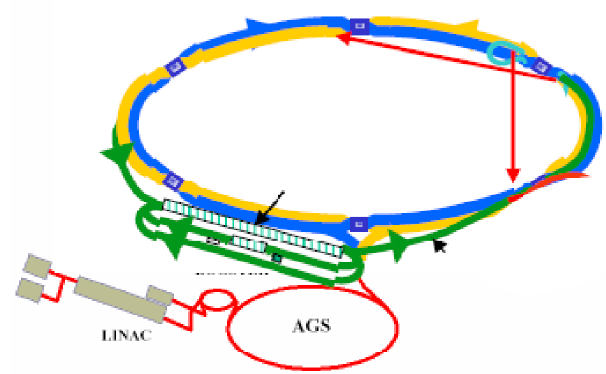
Legend:

- - - - - - - - *R&D*

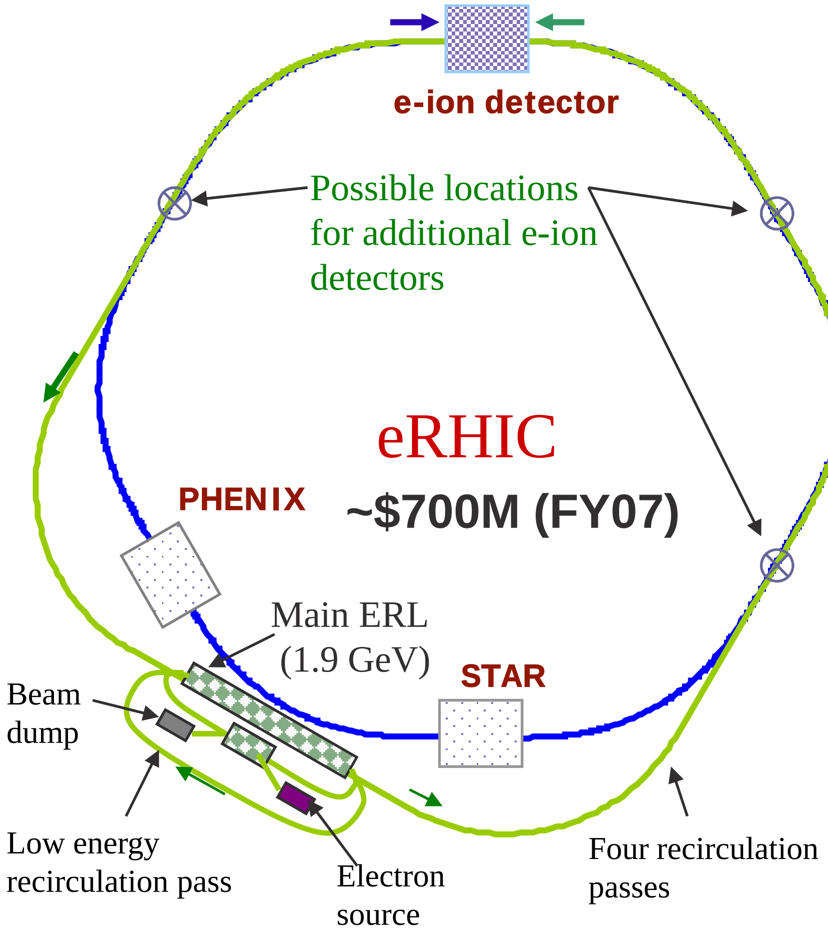
◆———◆ *Construction*

— · — · — · —◆ *Multiple small projects*

CD0: DOE Critical Decision, mission need



Long-Term (>2020) Future of QCD Physics at RHIC: EIC → eRHIC

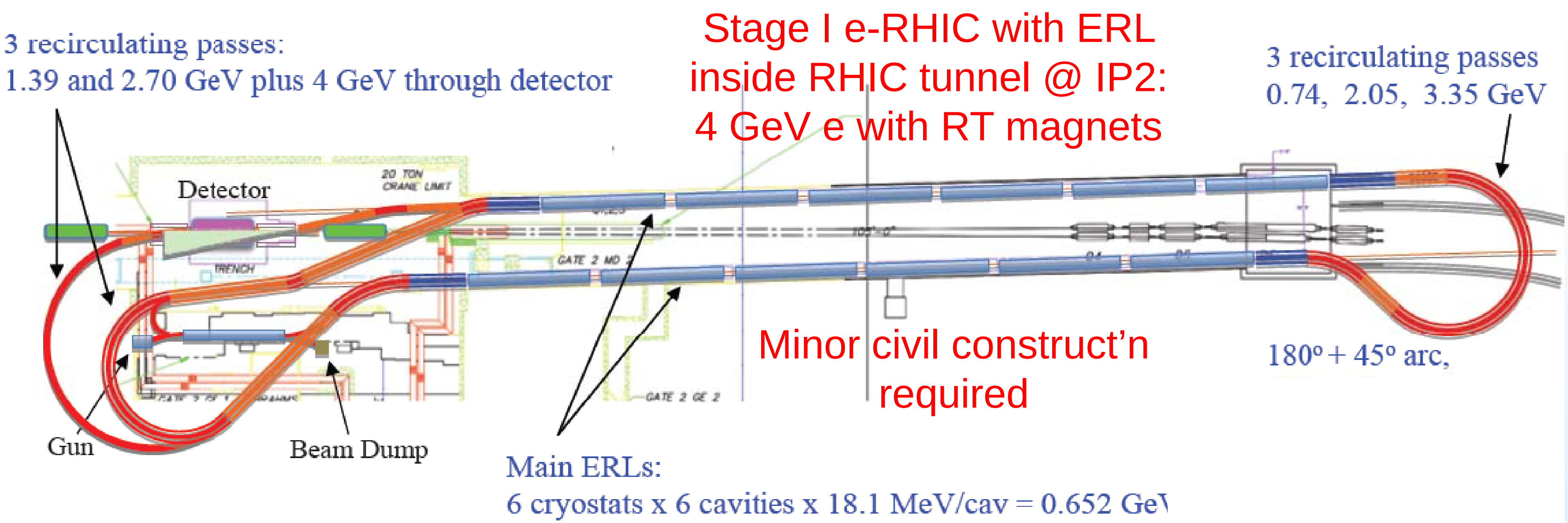


Add ERL injector with polarized e^- source to enable $\vec{e}+\vec{p}$, $^3\vec{He}$ and e+A (up to Uranium) to study matter in gluon-dominated regime

- 10 GeV electron design energy. Possible upgrade to 20 GeV by doubling main linac length.
- 5 recirculation passes (4 in RHIC tunnel)
- Multiple electron-hadron interaction points (IPs) permit multiple detectors;
- Full polarization transparency at all energies for the electron beam;
- Ability to take full advantage of transverse cooling of the hadron beams;
- Possible options to include polarized positrons at lower luminosity: compact storage ring or ILC-type $\vec{e}^+$ source
- R&D already under way on various accelerator issues; more to come.

- ***Subsequent stages/ alternative layouts could increase e-beam & ion-beam energies and $\mathcal{L}$ from nominal 10 × 250 GeV, ~3 × 10^{33} $cm^{-2}s^{-1}$ $\vec{e}+\vec{p}$***

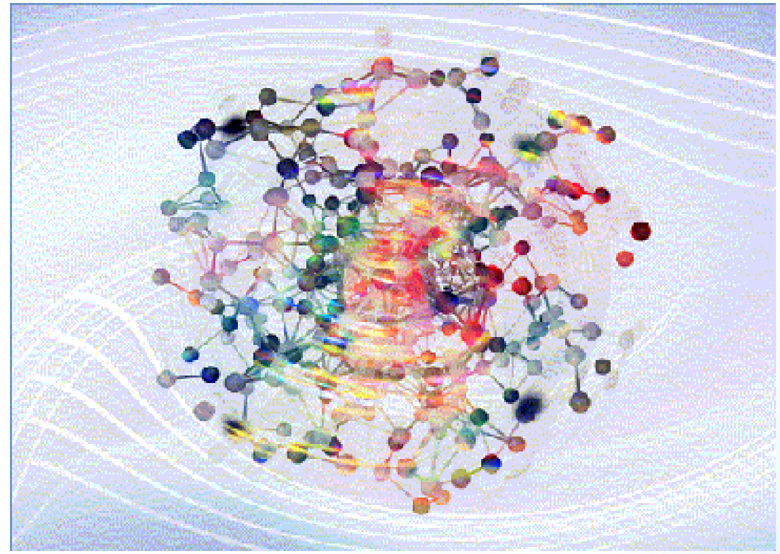
Intermediate-Term Possibilities: 1st (Medium Energy) Stage of EIC?



- ***Would enable 4 GeV $\overrightarrow{e^-}$ on 100 GeV/N heavy ions and 250 GeV $\overrightarrow{p}$***
- ***First look at saturation surface for nuclei in e+A DIS, confirmation of nuclear "oomph" factor; e+A diffraction tests of high gluon occupancy***
- ***$\overrightarrow{e}$-$\overrightarrow{p}$ program extending $\overrightarrow{\text{DIS}}$, adding: transverse-spin SIDIS over broad Q^2-range $\Rightarrow$ TMD evolution; detection of boosted target fragments to probe spin-dependent correlations, intrinsic heavy flavor in nucleon.***
- ***Developing science case, detector design, cost estimate.***
- ***Most equipment would be reused later in full EIC***

Backup Slides

RHIC Science: Condensed Matter Physics with a Force of a Different Color



What are the unique quantum many-body manifestations of a *non-Abelian* gauge theory and self-interacting force carriers? Are there lessons for other fundamental theories, that are more difficult to subject to laboratory investigation? How do we pump/probe fleeting partonic matter in 10^{-23} s?

Apply to

new matter: ***quantify properties of "near-perfect liquid" seen @ RHIC***

old matter: ***determine partonic decomposition of p spin @ RHIC & eRHIC***

hot matter: ***search for critical point in QCD phase diagram in RHIC E-scan, symmetry-violating vacuum fluctuations at high temperature***

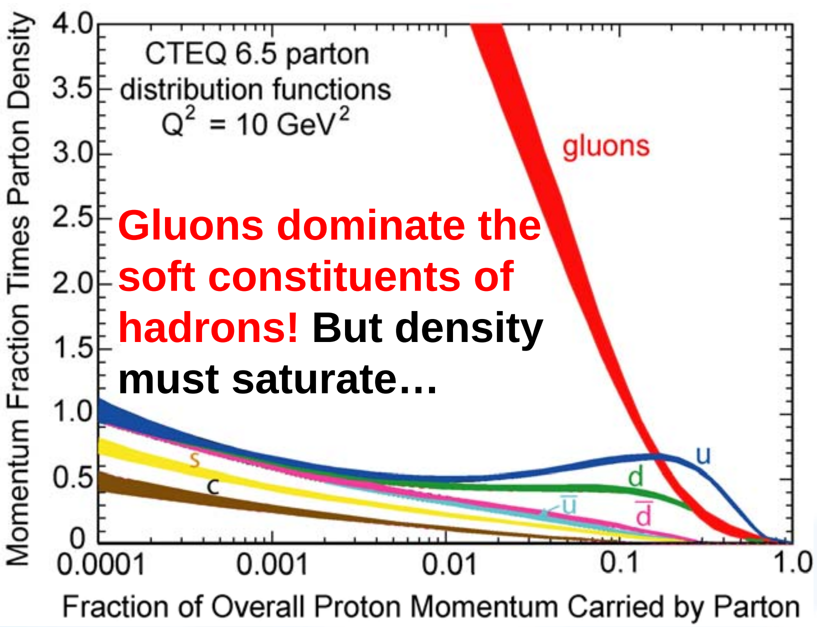
cold matter: ***expose & map intense force field (Color Glass Condensate) at heart of all ordinary matter, using eRHIC***

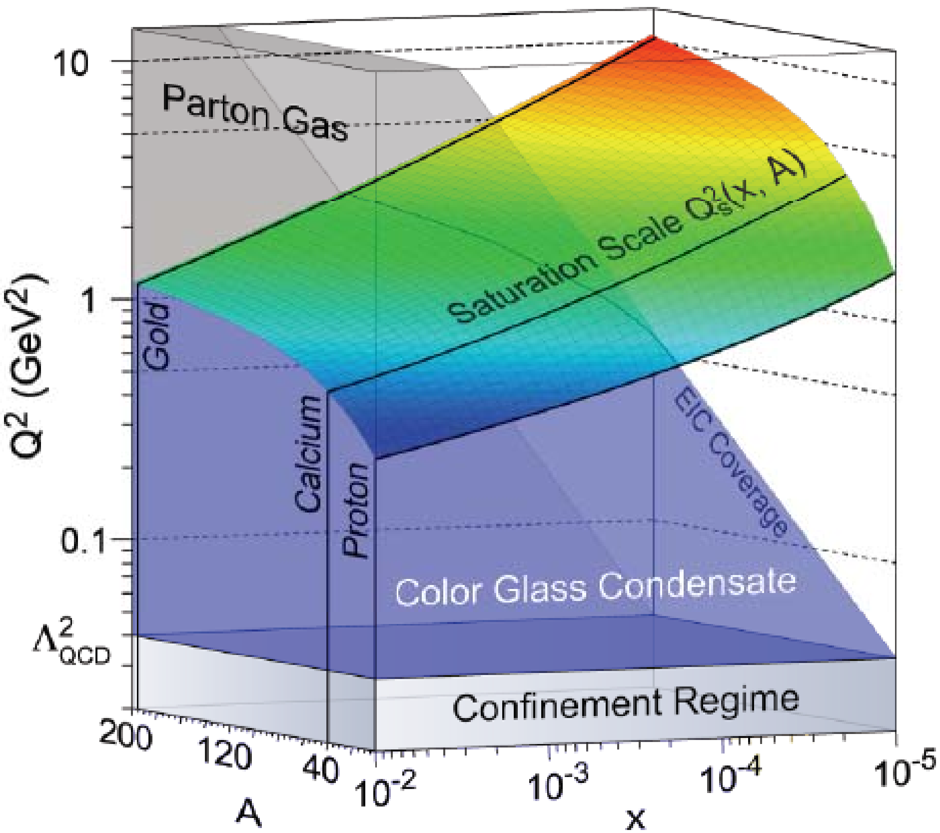
EIC Science: Study of Force (Gluon)-Dominated Matter

Search for supersymmetry @ LHC, ILC (?): ***seeking to unify matter and forces***

Electron-Ion Collider: ***reveal that Nature blurs the distinction***

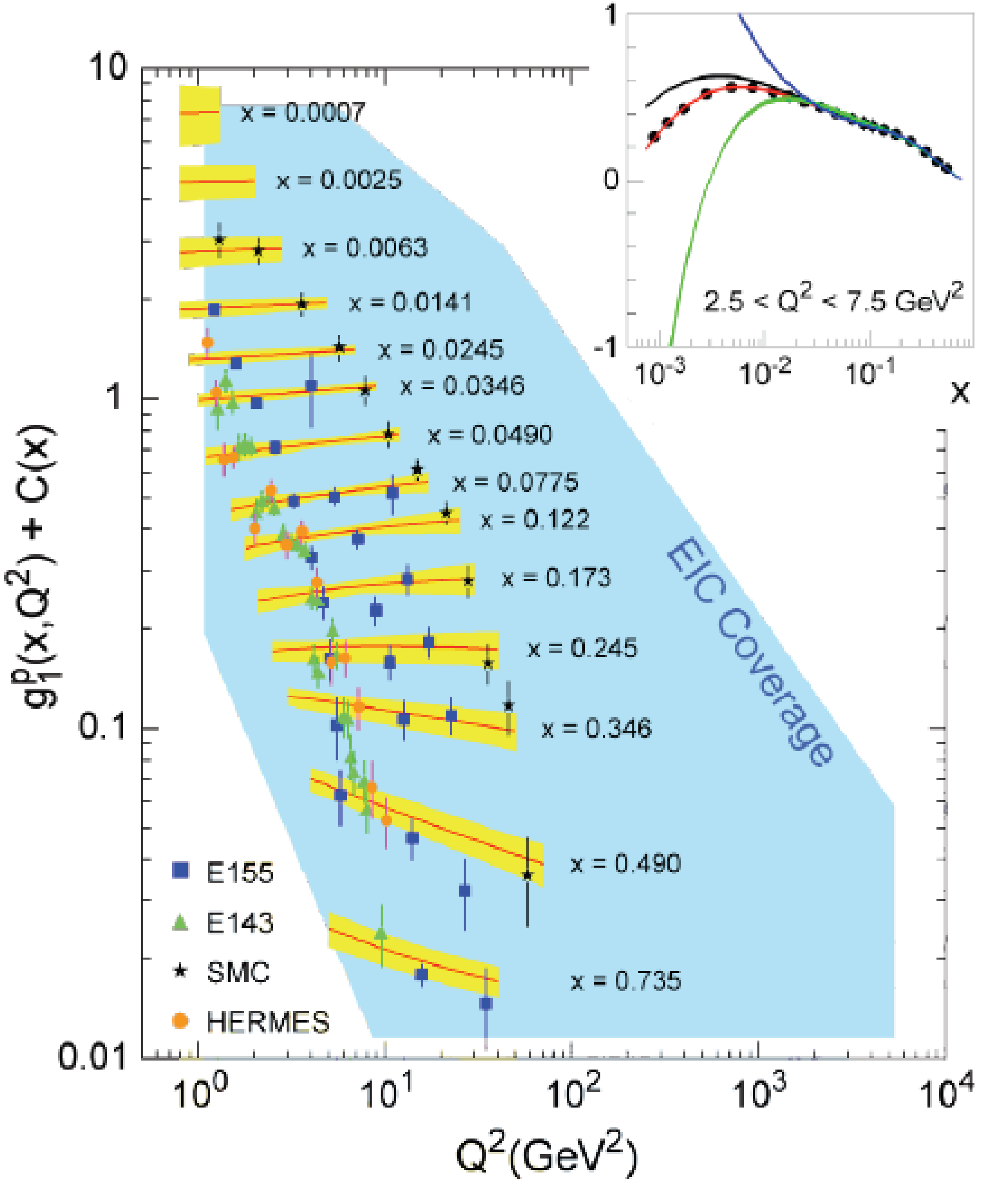
Deep inelastic scattering @ HERA ⇒





EIC probes *weak* coupling regime of very high gluon density, where gauge boson occupancy >> 1. *All ordinary matter has at its heart an intense, semi-classical force field* -- can we demonstrate its universal behavior?

Polarized $\vec{e} + \vec{N}$ at EIC



- ➢ ***Polarized DIS, γ-gluon fusion to determine gluon polarization down to x ~ few $\times 10^{-4}$***
- ➢ ***Bjorken sum rule test to $\lesssim$ 2% precision***
- ➢ ***SIDIS for low-x sea-quark polarization and transverse spin studies***

More luminosity-hungry:

- ➢ ***Polarized DVCS, exclusive reactions + LQCD $\Rightarrow$ GPD's $\Rightarrow$ map low-x transverse position-dep. PDF's; J_q from Ji sum rule***
- ➢ ***Parity violation in $\vec{e}$+p,d at high Q^2 to study running of weak coupling below Z-pole***

Note INT workshops on EIC science, Fall '09 and '10.

Suggested Framing Questions for EIC Science Case

1) ***Is main goal of EIC "discovery" or "characterization"? If latter, what is transformational (as opposed to incremental)? How are we likely to fundamentally alter understanding of QCD and/or QCD matter? Are there likely to be implications beyond QCD? What facility features not available at HERA ($\vec{N}$, A-beams, higher $\mathcal{L}$) enable transformational measurements? Not doable in p-A?***

2) ***Why should scientists not directly involved in QCD studies care about dense gluonic matter? If we find, or don't find, clear evidence that gluon field strength saturates, what do we conclude about QCD or nuclei? Are there general implications of transition from dilute parton gas to high gauge boson occupancy?***

3) ***Are gluon degrees of freedom important for understanding nuclear structure? Should soft gluon distributions in nuclei exhibit evidence of confinement, or should saturated gluonic matter look identical in nucleons and nuclei? Can we measure gluon spatial distributions in nuclei with sufficient resolution to see nucleon-scale "clumps"?***

Suggested Framing Questions, continued…

4) If we can't solve the nucleon spin puzzle without EIC, can we solve the puzzle with EIC? Do we have a clear strategy for completing a full measurement of the spin sum rule in either target rest frame (Ji sum rule) or on light front (ΔG sum rule)?

5) What features do we hope to unravel with 3D maps from GPDs at low x (more than x-dependence of overall transverse size)? Do we have the transverse spatial resolution to see "fine" structure? Is there a viable strategy to J_q by combining DES with LQCD constraints on moments of GPD's?

6) Will the running of $\sin^2\theta_W$ below the Z-pole, at sensitivity levels accessible with PVES @ EIC still be a significant question on the timescale of EIC measurements? Are there other unique EW symmetry opportunities with EIC?

7) What fraction of above science goals could be accomplished, or at least started, with 1st lower-energy stage of EIC? In what ways can experience gained at 1st stage inform accelerator / detector design and cost-effectiveness for a full EIC?