Making the Case for EIC: the Challenges Ahead

Steve Vigdor

Workshop on Electron-Ion Collider Science
INT, Seattle, Nov. 19, 2010

- Address multiple audiences, esp. science-literate but non-expert funding deciders and skeptical nuclear physicists
- Anticipate their questions and provide crisp, jargon-free answers
- Define central EIC themes and their context among broader science frontiers
- Present a handful (only!) of golden experiments and their discovery potential
- Explain technical & scientific staging strategies
- Outline technical innovation & potential spin-offs
- Make plausible case that all above can fit within ~$500M Total Project Cost
Section I:
Elevator Speeches and Poetry – Addressing the Influential Funding Deciders
EIC = High-Resolution Microscope for Gluon-Dominated Matter

Twin central themes:

1) Probing the momentum-dependence of gluon densities and the onset of saturation in nucleons and nuclei
2) Mapping the transverse spatial and spin distributions of partons in the gluon-dominated regime

Real questions from Galveston LRP 2007:

1) Why should we care about gluon-dominated matter? How do goals connect to other physics goals? Why are they of interest to nuclear physicists?
2) Is an electron machine necessary? Why not just p+A @ RHIC, LHC?
3) What will EIC do that HERA couldn’t?
4) If we haven’t solved the nucleon spin puzzle yet, why do we need a new expensive facility to pursue it further?
The unfolding mysteries of the energy budget in our universe:

72% comes not from matter but from dark energy of unknown origin and mysterious magnitude (⇒ cosmological probes)

23% comes from dark matter of unknown composition (⇒ DM exp’ts & supersymmetry searches at LHC)

4.6% comes from “mass without mass”[ive constituents] of known baryonic matter (⇒ EIC to probe critical gluon role)

<<1% comes from Standard Model mass generation for quarks and leptons, attributed to as yet undiscovered particle (⇒ Higgs searches @ LHC and Tevatron, ν mass exp’ts)
Gluons and the Dynamical Generation and Self-Regulation of Hadron Masses

F. Wilczek, in “The Origin of Mass”:
“Its enhanced coupling to soft radiation…means that…a ‘bare’ color charge, inserted into empty space, will start to surround itself with a cloud of virtual color gluons. These color gluon fields themselves carry color charge, so they are sources of additional soft radiation. The result is a self-catalyzing enhancement that leads to runaway growth. A small color charge, in isolation, builds up a big color thundercloud… theoretically the energy for a quark in isolation is infinite… Having only a finite amount of energy to work with, Nature always finds a way to short-circuit the ultimate thundercloud.”

The partial cancellation of quark color charge in a color-neutral, but finite-size, hadron (i.e., confinement) is part of the short-circuit mechanism. But saturation of gluon densities due to gg → g recombination must also play a critical role in regulating hadron mass.

⇒ Need to probe gluons in non-linear QCD regime of high gluon density
⇒ Need high energies for low x, but use heavy nuclei to boost reach, lower cost, probe onset of saturation of gluons inside nuclear matter
Why An Electron Machine?

Electron accelerators have traditionally been used for quantitative characterization of phenomena discovered at hadron machines:

Example table from C. Baltay talk at June 2010 NUFO Meeting

<table>
<thead>
<tr>
<th>Proton Accelerators</th>
<th>Electron Accelerators</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGS (30 Gev p)</td>
<td>SPEAR (3 Gev e+e-)</td>
</tr>
<tr>
<td>discovered bump J</td>
<td>interpretation as charm</td>
</tr>
<tr>
<td></td>
<td>charmed particle spectroscopy</td>
</tr>
<tr>
<td>FNAL (400 Gev p)</td>
<td>CESR (10 Gev e+e-)</td>
</tr>
<tr>
<td>discovered bump γ</td>
<td>interpretation as b quark</td>
</tr>
<tr>
<td></td>
<td>particles with b quarks</td>
</tr>
<tr>
<td>CERN SppS (800 Gev pp)</td>
<td>LEP, SLC (100 Gev e+e-)</td>
</tr>
<tr>
<td>discovered W, Z</td>
<td>detailed precision electroweak</td>
</tr>
<tr>
<td>LHC (14 Tev pp)</td>
<td>ILC (0.5 - 1.0 Tev e+e-)</td>
</tr>
<tr>
<td>discovery of X…</td>
<td>detailed understanding of new physics</td>
</tr>
</tbody>
</table>

RHIC, LHC may ⇒ hints of gluon saturation, but need eA to probe quantitatively, despite primary EM sensitivity to quarks, rather than gluons.

EIC also needed to characterize initial states for more quantitative interpretation of RHIC and LHC results.
Section II: Convincing Your Colleagues at NP LRP
What Does EIC Do That HERA Couldn’t?

Need crisp delineation of how technical advantages of EIC ⇒ access to definitive measurements addressing crucial questions

Proton tomography via exclusive reactions

Answers that require full-energy EIC must lay out clear science deliverables for 1st stage collider
### EIC Science Drivers Template (with some example entries, but to be completed in White Paper)

<table>
<thead>
<tr>
<th>Gain/Loss vs. HERA</th>
<th>Primary New Science Deliverables</th>
<th>Basic Measurements</th>
<th>Typical Required Precision</th>
<th>What We Hope Fundamentally To Learn</th>
<th>What Will Be Learned with Phase I</th>
<th>Alternatives in Absence of EIC</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>s ÷ 2.5-4 but Ion Beams up to A~200</td>
<td>$Q_{sat}^2(x,A)$? Low-x gluon distribution in nuclei; $\alpha_s(x,Q^2,A)$??</td>
<td>$F_{2L}(x,Q^2,A)$ in inclusive eA DIS</td>
<td>Is there a universal sat’n surface? Does $\alpha_s$ saturate?</td>
<td>$G(x,A)$; nuclear oomph; begin $F_L$</td>
<td>p(d)+A @ RHIC, LHC ⇒ clean interpret’n?</td>
<td>Does gain in A more than compensate for loss in s, in terms of reach into gluon saturation regime?</td>
<td></td>
</tr>
<tr>
<td>Polarized nucleon beams (including d or $^3$He for n)</td>
<td>$\Delta G$(low $x$) ? Precision test of Bjorken Sum Rule? TMD’s to probe transverse-momentum-spin correlations</td>
<td>Pol’d DIS, SIDIS, $\gamma^*g$ 2-jet prod’n</td>
<td>Do soft gluons account for missing spin? Exhibit orbital motion? …</td>
<td>Full program accessible to $x$~ $10^{-4}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$L \times 100$-1000</td>
<td>GPD’s to yield transverse spatial maps vs. $x_{Bj}$</td>
<td>ep DVCS &amp; DEVME prodkn</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$L \times 100$-1000</td>
<td>EW symmetry-violating processes ($e \rightarrow \tau$ LFV ?)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extensive energy variability</td>
<td>$F_L$ ⇒ direct sensitivity to gluons, with different systematics than $dF_2/dQ^2$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Higher-precis’n det(s) ?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Far forward &amp; backward spectrometers</td>
<td>Gluonic “form factors” in light and heavy nuclei</td>
<td>coherent &amp; incoh. eA → VM</td>
<td>How does $g$ saturation set in vs. b?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The point is to generate concise table with most illustrative examples, not an exhaustive list, making clear what we hope to learn, and addressing head-on questions about what EIC would add to HERA science reach and to the reach with other facilities worldwide (e.g., for pp, ep fixed target, and pA).
Need Simulations Demonstrating Technical Feasibility and Interpretability of Several Challenging Golden Exp’ts

For example:

- $F_L$ for $ep$ and $eA$
- Diffractive $J/\psi$ production
- $\vec{e} + \vec{p} \rightarrow$ forward di-jet
- DVCS and exclusive vector meson production
- $e \rightarrow \tau$ conversion test, if decide to pursue this

Also need brief description of other research facilitated by EIC:

- studies of hadronization in-medium and out
- energy loss of charmed quarks in cold nuclear matter
- PVDIS below Z-pole
- studies of intrinsic heavy flavor in proton wave function
- electroweak structure function measurements (or perhaps this is golden exp’t for 1st stage facility)
- ...
Other Crucial Questions

What is the size and strength of the interested user community?

- How many RHIC, JLab, HERA users are likely to participate?
- What about LHeC, ENC competition?
- How many foreign users have expressed significant interest?
- What are plans to grow the community actively involved?

What are the staging options, likely costs and intermediate science program?

- Is 1st stage science program commensurate with 1st stage cost?
- Can detector(s) suitable to realize 1st stage science goals fit within ~$500M Total Project Cost?
- Are upgrade paths for collider and detectors clear and (eventually) affordable?
- Can technical lessons learned from 1st stage reduce the cost of subsequent upgrades?
Section III: Technical Feasibility
Technical Overview

- Have 2 competing collider designs with very different starting points and upgrade paths at JLab and BNL, each subjected to some level of preliminary design reviews.
- The two designs have converged on roughly comparable luminosity and energy goals, but have not yet been compared in cost.
- Each design relies on substantial needed multi-year R&D to demonstrate feasibility of attaining luminosity goals.
- IR designs for the two are qualitatively similar, with beam crossing angles, as are detector “sketches,” although beam quantitative parameters at IR’s differ significantly.
- Detectors have not yet been seriously designed or costed – important question: what will realistically fit within ~$500M 1st-stage project scope?
- Relevant detector R&D, and serious measurement simulations including realistic detectors, backgrounds, etc., have yet to begin.
eRHIC Design Under Active Consideration

Vis-à-vis earlier MeRHIC design, this allows for:

- more IP’s
- reusing infrastructure + det. components for STAR, PHENIX?
- reduced cost
- easier upgrade path
- minimal environmental impact concerns
- IR design to reach $10^{34}$ luminosity

2 SRF linac
1 -> 5 GeV per pass
4 (6) passes

eRHIC-I → eRHIC: energy of electron beam is increased from 5 GeV to 30 GeV by building up the linacs

RHIC: 325 GeV p
or 130 GeV/u Au with DX magnets removed

eSTAR

© V. Litvinenko
Modified eRHIC Design ⇒ Improved Luminosity

- Achieve $\beta^* = 5$ cm with 200 T/m LARP SC quads
- No e bend near detector, 10 mrad hadron beam crossing angle

<table>
<thead>
<tr>
<th>eRHIC</th>
<th>p/A</th>
<th>e</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy, GeV</td>
<td>325/130</td>
<td>20</td>
</tr>
<tr>
<td>Number of bunches/ Bunch frequency, MHz</td>
<td>166</td>
<td>14.08</td>
</tr>
<tr>
<td>Bunch intensity, $10^{11}$</td>
<td>2.0</td>
<td>0.22</td>
</tr>
<tr>
<td>Bunch charge, nC</td>
<td>32</td>
<td>3.5</td>
</tr>
<tr>
<td>Beam current, mA</td>
<td>415</td>
<td>50</td>
</tr>
<tr>
<td>Rms normalized emittance, $1e^{-6}$ m</td>
<td>0.18</td>
<td>20</td>
</tr>
<tr>
<td>Rms emittance, $1e^{-9}$ m</td>
<td>0.52</td>
<td>0.52</td>
</tr>
<tr>
<td>$\beta^*$, cm</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Beam-beam parameter for p; Disruption for e</td>
<td>0.015</td>
<td>27.1</td>
</tr>
<tr>
<td>rms bunch length, cm</td>
<td>4.9</td>
<td>0.2</td>
</tr>
<tr>
<td>Polarization, %</td>
<td>70</td>
<td>80</td>
</tr>
</tbody>
</table>

Luminosity, $x 10^{34}$, cm$^{-2}$s$^{-1}$ (with hourglass reduction): 1.5

- Can eventually cover $\sqrt{s}$ from 80-160 GeV with above $\mathcal{L}$, 30-200 GeV with $> 2 \times 10^{33}$ cm$^{-2}$s$^{-1}$
- e+A luminosities per nucleon very similar
- 1st stage e energy will depend on cost
Plan to use newly commissioned LARP Nb$_3$Sn SC quads with 200 T/m gradient.

The first Nb$_3$Sn Long Quadrupole (LQS01) designed and fabricated by the US LHC Accelerator Research Program (LARP) reached its target gradient of 200 T/m during the first test. LQS01 is a 90 mm aperture, 4 meter long quadrupole with Nb$_3$Sn coils made of RRP 54/61 strand.
MEIC: Detailed Layout

- Big booster (up to 12 GeV/c)
- Warm ring
- Ion ring jump
- Medium energy IP with horizontal crab crossing
- Electron ring 3 - 11 GeV
- Cold ring
- 3 Figure-8 rings stacked vertically

Incorporating elements from the 12 GeV CEBAF and 60 GeV/c proton collider ring.
ELIC: High Energy & Staging

Serves as a large booster to the full energy collider ring

**Table:**

<table>
<thead>
<tr>
<th>Stage</th>
<th>Max. Energy (GeV/c)</th>
<th>Ring Size (m)</th>
<th>Ring Type</th>
<th>IP #</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium</td>
<td>96</td>
<td>11</td>
<td>Cold</td>
<td>3</td>
</tr>
<tr>
<td>High</td>
<td>250</td>
<td>20</td>
<td>Cold</td>
<td>4</td>
</tr>
</tbody>
</table>

**Legend:**
- **p:** Proton
- **e:** Electron
- **Cold:** Cold
- **Warm:** Warm

**Diagram Notes:**
- **12 GeV CEBAF**
- **MEIC collider ring**
- **SRF Linac**
- **Ion Sources**
- **Injection**

**Figures:**
- **Straight section**
- **Arc**
## ELIC Luminosity: 2.5 km Ring, 8 Tesla

<table>
<thead>
<tr>
<th>Proton Energy</th>
<th>Electron Energy</th>
<th>s</th>
<th>CM Energy</th>
<th>Full acceptance (L=7m, β*=2cm)</th>
<th>High luminosity (L=4.5m, β*=8mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GeV</td>
<td>GeV</td>
<td>GeV²</td>
<td>GeV</td>
<td>$10^{33}$ cm⁻²s⁻¹</td>
<td>$10^{33}$ cm⁻²s⁻¹</td>
</tr>
<tr>
<td>250</td>
<td>3</td>
<td>3000</td>
<td>54.8</td>
<td>8.3</td>
<td>20.7</td>
</tr>
<tr>
<td>250</td>
<td>5</td>
<td>5000</td>
<td>70.7</td>
<td>18.5</td>
<td>46.4</td>
</tr>
<tr>
<td>250</td>
<td>6</td>
<td>6000</td>
<td>77.5</td>
<td>20.2</td>
<td>50.5</td>
</tr>
<tr>
<td>250</td>
<td>7</td>
<td>7000</td>
<td>83.7</td>
<td>20.7</td>
<td>64.5</td>
</tr>
<tr>
<td>250</td>
<td>8</td>
<td>8000</td>
<td>89.5</td>
<td>18.9</td>
<td>57.6</td>
</tr>
<tr>
<td>250</td>
<td>9</td>
<td>9000</td>
<td>94.9</td>
<td>15.8</td>
<td>39.6</td>
</tr>
<tr>
<td>250</td>
<td>11</td>
<td>11000</td>
<td>104.9</td>
<td>7.5</td>
<td>18.8</td>
</tr>
<tr>
<td>250</td>
<td>20</td>
<td>20000</td>
<td>141.4</td>
<td>3.1</td>
<td>6.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Proton Energy</th>
<th>Electron Energy</th>
<th>Ring Circumference</th>
<th>Luminosity (L=7m, β*=2cm)</th>
<th>Luminosity (L=4.5m, β*=8mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GeV</td>
<td>GeV</td>
<td>m</td>
<td>$10^{33}$ cm⁻²s⁻¹</td>
<td>$10^{33}$ cm⁻²s⁻¹</td>
</tr>
<tr>
<td>30</td>
<td>3</td>
<td>2500/2500</td>
<td>1.1</td>
<td>2.6</td>
</tr>
<tr>
<td>30</td>
<td>3</td>
<td>1000/2500</td>
<td>2.1</td>
<td>4.9</td>
</tr>
</tbody>
</table>

- The second option is using 1 km medium-energy ion ring for higher proton beam current at 30 GeV protons for lowering the space charge tune-shift.
**MEIC**

**ELIC: Luminosity Vs. CM Energy**

**e + p facilities**

**e + A facilities**

Brookhaven Science Associates

https://eic.jlab.org/wiki/index.php/Machine_designs
What Progress Has Been Made on Technical R&D Since 2007 Long Range Plan?

- Significant progress on lattice, IR and detector designs, plus beam and spin dynamics and beam-beam simulations for both designs

- FY11 launch of dedicated accelerator R&D funds from ONP supporting development of Coherent electron Cooling (BNL-JLab-Tech-X collaboration), polarized e⁻ and \(^3\)He sources (MIT), …

- Launched with other funds: high-current test ERL @ BNL; “Gatling Gun” multi-cathode high-current polarized e⁻ source; 704 MHz SRF for ERL; small-gap dipole and quadrupole magnet and vacuum chamber prototypes for eRHIC electron beam recirculation; high-gain FEL amplifiers for CeC; crab cavity development @ JLab; simulations of (traditional, but high-energy, high-current) electron (ERL) cooling of high-energy ion beams

- Exploited accelerator R&D for other facilities: LARP SC Nb₃Sn high-field-gradient quadrupole magnets; KEK-B development of crab crossings; …

- Trying to launch EIC generic detector R&D program in FY11 – waiting on ONP feedback, but preliminary discussions encouraging!
Section IV: Next Steps
Producing an EIC Science White Paper to Make the Case for Mission Need

- Use INT Program, writeup as launching pad for White Paper putting flesh on above bones for non-expert audience
- Aim for 1st draft in Fall 2011, in anticipation of possible LRP Town Meetings in Fall 2012, and to start convincing DOE OS
- Suggest JLab, BNL, EICC appoint ~6-member balanced Steering Committee to establish milestones and (calculation/simulation/writing) assignments, oversee White Paper preparation, focus and editing

Defining Down-Select Criteria and Mechanism for Facility Design

- Define criteria and review mechanism (common reviewers for both designs) well in advance of LRP – ONP must be involved
- Need “apples-to-apples” comparisons of performance vs. cost vs. timeline for both 1st stages and (roughly) later upgrades
- Both designs need to include defensible estimates of technical risk and risk mitigation strategies/costs for achieving goals
- IR designs, detector integration, background environments need to be included in evaluations
Concluding Remarks on INT Program

1) We have seen substantial convergence on machine parameter goals for the two designs, facilitating unified development of a science White Paper.

2) A number of intriguing new ideas and developments for experiments have emerged: e.g., $\gamma^*+g \rightarrow 2 \text{ jets}$ to map unintegrated gluon distributions and Sivers asymmetries in $p$; robustness of EW structure fcn. measurements at 1st stage EIC; diffraction with $U$ beams to enhance separation... 

3) Primary purpose has been served well: consensus approached on outstanding theoretical and experiment simulation challenges, and on a work plan to get there.

4) Excellent start made on “golden experiment” focus. Have to get still more “ruthless” in choices for non-expert audience with limited patience.

5) A necessary seeding of the EIC user community has been advanced. Still need substantially increased group of experimentalists actively involved – launch of competitive detector R&D program may soon improve the situation.

Thanks to the organizers and to INT for a lively, productive, very well organized and stimulating program and concluding workshop!
Pursuing Aggressive R&D on Critical Technologies

Developing high-current electron ERL (20 MeV) with RHIC R&D funds; 704 MHz SRF cavities for ERL with HEP funding via BNL-SBU CASE.

Developing proof-of-principle of Gatling Gun approach to multi-cathode high-current (eventually ~50 mA) polarized electron gun with BNL LDRD funds.

Also laser system for polarized gun with LDRD funds.
Pursuing Aggressive R&D on Critical Technologies

- Aiming for ~2014 proof-of-principle demo of Coherent e Cooling for hadron beams @ RHIC, aided by BNL LDRD and Program Devel. Funds + pending ONP proposal (joint with Jlab and Tech-X)

  Prototyping small-gap dipole and quadrupole magnets and vacuum chambers for compact recirculation arcs on electron beam, with BNL LDRD funds.

  Also exploring relevance of CeC for improving RHIC p+p luminosities and ERL-driven options for X-ray FEL (LDRD).

All in addition to ongoing work on lattice, IR and detector design, plus beam & spin dynamics and beam-beam simulations.
**MEIC Critical Accelerator R&D**

We have identified the following critical R&D issues for MEIC:

- Interaction region design and limits with chromatic compensation
- Electron cooling
- Crab crossing and crab cavity
- Forming high-intensity low-energy ion beam
- Beam-beam effect
- Depolarization (including beam-beam) and spin tracking
- Traveling focusing for very low energy ion beam

<table>
<thead>
<tr>
<th>Level of R&amp;D</th>
<th>Low-to-Medium Energy (12x3 GeV/c) &amp; (60x5 GeV/c)</th>
<th>High Energy (up to 250x10 GeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Challenging</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Semi-Challenging | Electron cooling  
Traveling focusing (for ion energies ~12 GeV) | Electron cooling  
IR design/chromaticity |
| Likely         | IR design/chromaticity  
Crab crossing/crab cavity  
High intensity low energy ion beam | Crab crossing/crab cavity  
High intensity low energy ion beam |
| Know-how       | Spin tracking  
Beam-Beam | Spin tracking  
Beam-beam |
What are the unique quantum many-body manifestations of a non-Abelian gauge theory? Are there lessons for other fundamental (e.g., EW) theories, that are harder to subject to laboratory investigation?

1) Does asymptotic freedom $\Rightarrow$ dense (in color charge) ideal gas QGP? Find “near-perfect” strongly correlated liquid behavior instead!

2) Does rich vacuum structure $\Rightarrow$ sphalerons near QGP transition & local symmetry violation? Observed behavior consistent with local (chiral magnetic) P- and CPV; $\sim$ B-violation @ EW phase transition?

3) Do gluon self-interactions $\Rightarrow$ universal saturated gluonic matter in hadrons and nuclei? Hints at RHIC, need EIC for definitive answer.
EIC Science: Gluon-Dominated Cold Matter in e+A

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

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

Deep inelastic scattering @ HERA ⇒

Gluons dominate the soft constituents of hadrons! But density must saturate…

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? Track the transition from dilute parton gas to CGC? “See” confinement reflected in soft-gluon spatial distributions inside nuclei?
Proton tomography via exclusive reactions

EIC $e^{-} + \bar{N} \Rightarrow$ Important Extension of Nucleon Structure Studies at HERA, RHIC, JLab, ...

- DIS, $\gamma$-gluon fusion $\Rightarrow \Delta G(x > \text{few} \times 10^{-4})$
- Bjorken sum rule test to $\lesssim \pm 2\%$
- 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 $J_i$ sum rule; $J_g$ ?
- High-$Q^2$ $e^+p,d$ parity viol’n $\Rightarrow$ weak coupling running below Z-pole
The $\sqrt{s}$ vs. luminosity landscape

Minimum luminosities to “get in the game” -- from Elke Aschenauer

EIC should $\approx$ HERA +
- $\geq$ 2 orders of magnitude in luminosity
- polarized p, $^3$He beams
- heavy-ion beams