Electron Ion Collider: Realization of ELIC

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NSAC Subcommittee on Relativistic Heavy Ions
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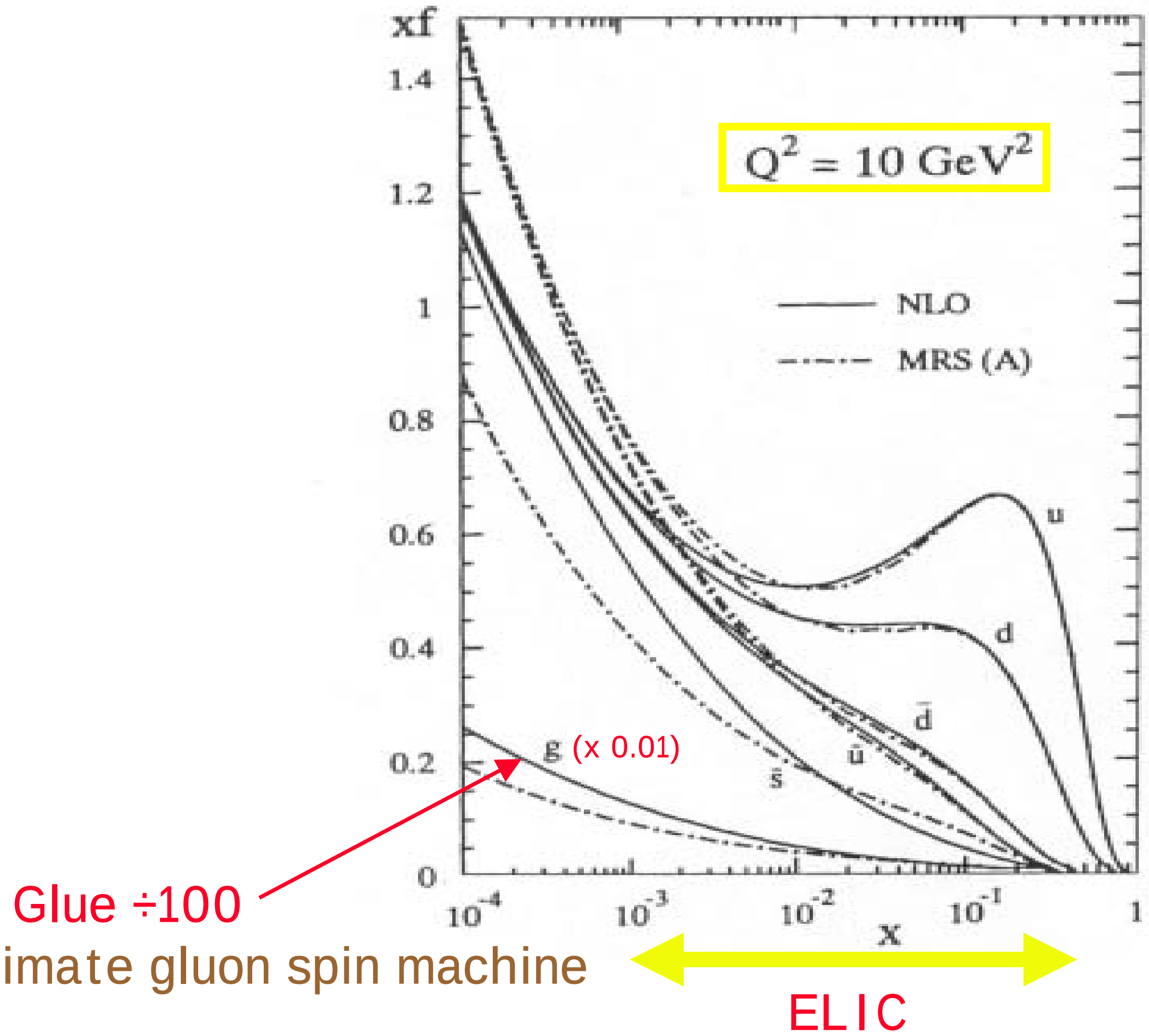
ELIC@JLab - Science

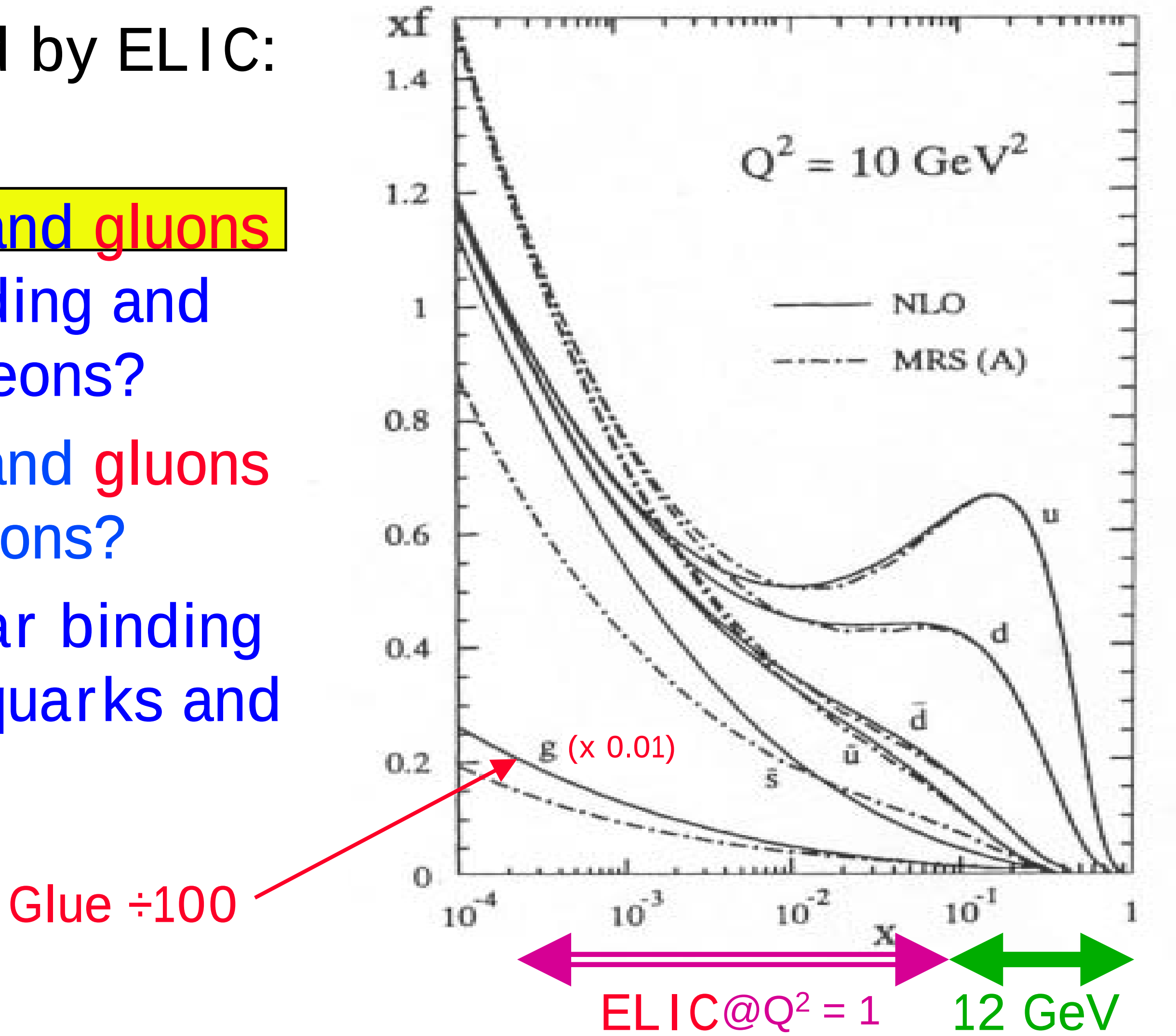


EIC is the ultimate gluon spin machine

ELIC@JLab - Science

Science addressed by ELIC:

- How do quarks and gluons provide the binding and spin of the nucleons?
- How do quarks and gluons evolve into hadrons?
- How does nuclear binding originate from quarks and gluons?



12 GeV Upgrade@JLab

- Clear scientific case by 12-GeV JLab Upgrade, addressing outstanding issues in Hadron Physics:
  - Unprecedented measurements to region in x (> 0.1) where basic three-quark structure of nucleons dominates.
  - Measurements of correlations between quarks, mainly through Deep-Virtual Compton Scattering (DVCS) and constraints by nucleon form factors, in pursuit of the Generalized Parton Distributions.
  - Finishing the job on the transition from hadronic to quark-gluon degrees of freedom.
  - Search for photoproduction of hybrids – gluonic excitations of mesons – with as goal to definitively and in detail map their spectrum and shed light on confinement.
- 12-GeV Upgrade recently received CD-0, with detailed work on a Conceptual Design Report now in progress.
- JLab community has began thinking about the needs of Hadron Physics in the post-12 GeV era.

CEBAF Beyond 12 GeV

- JLab community has began thinking about the needs of Hadron Physics in the post-12 GeV era.

- At present, uncertain what range of Q^2 really required to determine complete structure of the nucleon. Most likely $Q^2 \sim 10$ GeV^2?
  - Upcoming years wealth of data from RHIC-Spin, COMPASS, HERMES, JHF, JLab, etc.
  - DVCS (JLab-12!) and single-spin asymmetries possible at lower Q^2
  - Range of Q^2 defines the required luminosity

- What energy and luminosity, collider or fixed-target facility (or both)?
  - Electron-Light Ion Collider, center-of-mass energy of 20-65 GeV?
  - 25 GeV Fixed-Target Facility?

Basis of the ELIC Proposal

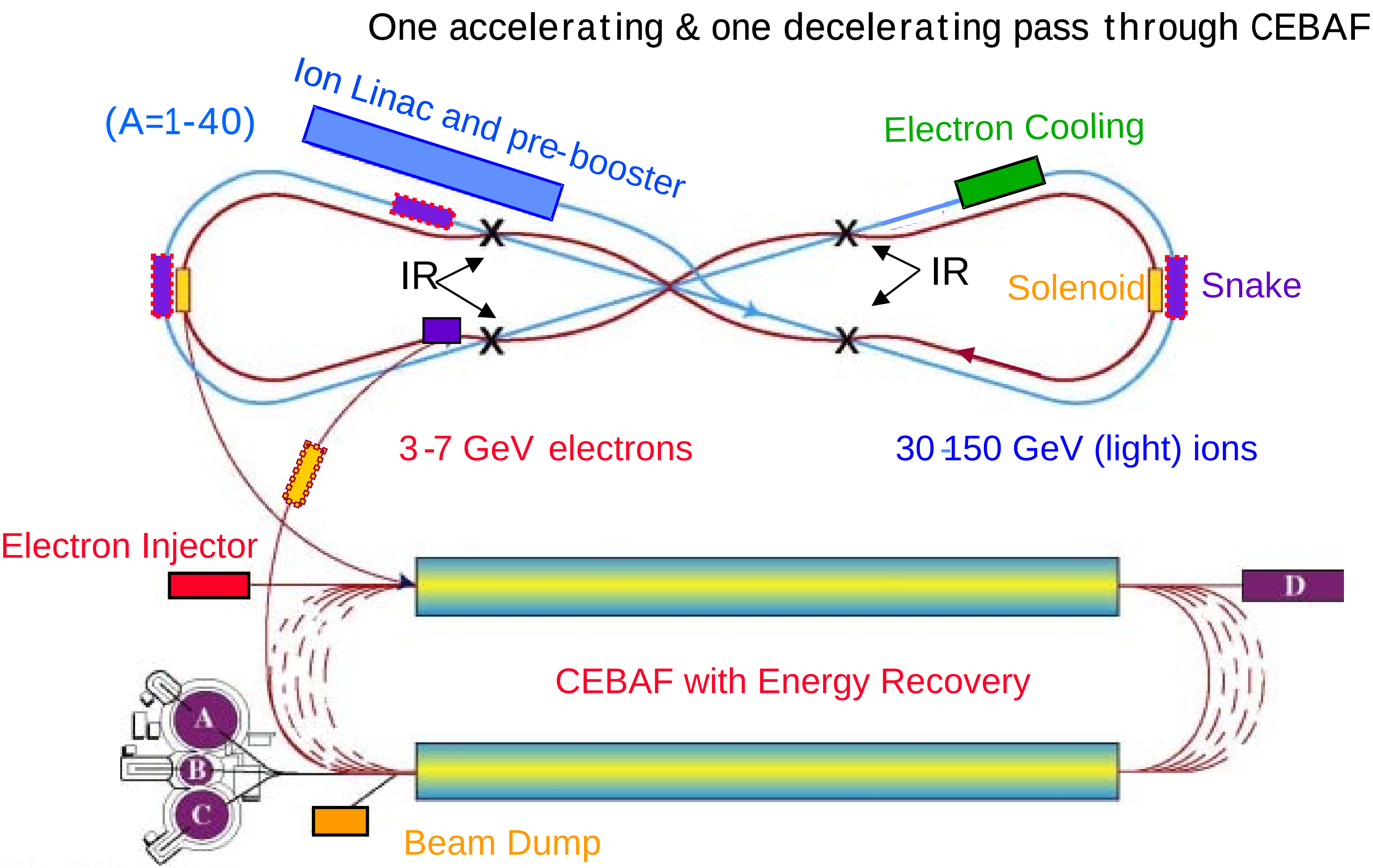
(Derbenev, Chattopadhyay, Merminga et al.)

- A Linac-Ring Collider Design (with additional Circulator Ring)
  - Linac
    - CEBAF is used for the (one-pass) acceleration of electrons
    - Energy recovery is used for rf power savings and beam dump requirements
  - Ring
    - "Figure-8" storage ring is used for the ions for flexible spin manipulations of all light-ion species of interest
    - Circulator ring for the electrons may be used to ease high current polarized photoinjector requirements

Luminosity of up to 8×10^{34} cm^{-2} sec^{-1}

(per interaction point, for a one-day lifetime)

ELIC Layout



One accelerating & one decelerating pass through CEBAF
Ion Linac and pre-booster
(A=1-40)
Electron Cooling
IR
IR
Solenoid
Snake
3-7 GeV electrons
30-150 GeV (light) ions
Electron Injector
D
CEBAF with Energy Recovery
A
B
C
Beam Dump

ELIC Physics Specifications

- Flexible Center-of-mass energy between 20 and 65 GeV
  - $E_e \sim 3$ GeV on $E_i \sim 30$ GeV up to $E_e \sim 7$ GeV on $E_i \sim 150$ GeV worked out in detail (gives E_{cm} up to 65 GeV)
- CW Luminosity up to 8×10^{34} cm^{-2} sec^{-1} per Interaction Point
- Ion species of interest: protons, deuterons, ^{3}He, light-medium ions
  - Proton and neutron
  - Light-medium ions not necessarily polarized
  - Up to Calcium
- Longitudinal polarization of both beams in the interaction region (+Transverse polarization of ions +Spin-flip of both beams)

The same electron accelerator can also provide 25 GeV electrons for fixed target experiments for physics

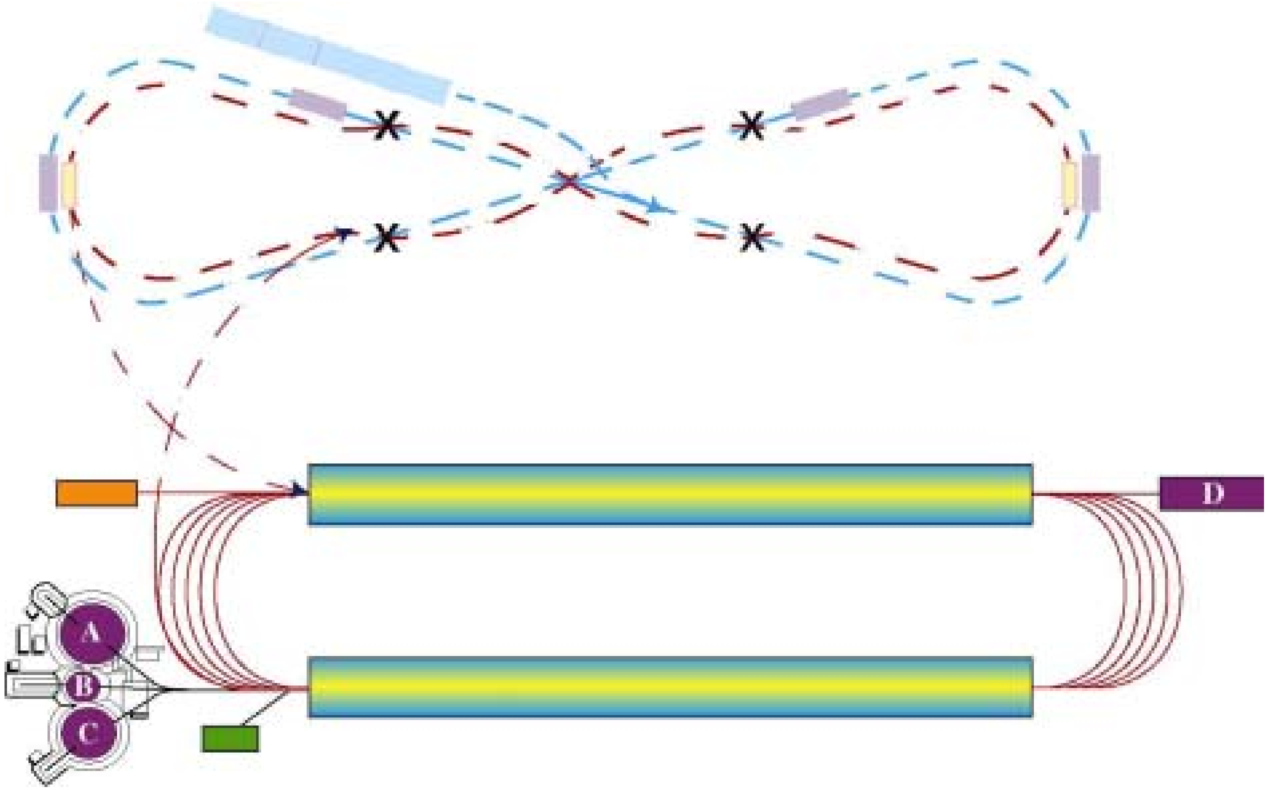
- Implement 5-pass recirculator, at 5 GeV/pass, as in present CEBAF

  (straightforward upgrade, no accelerator R&D needed)

- Luminosity of 10^{38}+

- Complementary capabilities for broad class of experiments

- Exploring whether collider and fixed target modes can run simultaneously (can in alternating mode)



ELIC@JLab Realization

Because ELIC is based on a completely new ring it is possible to optimize for spin preservation & handling and for high luminosity

Parameters have been pushed into new territory…
ß, I_b, ring shape, crab crossing,…

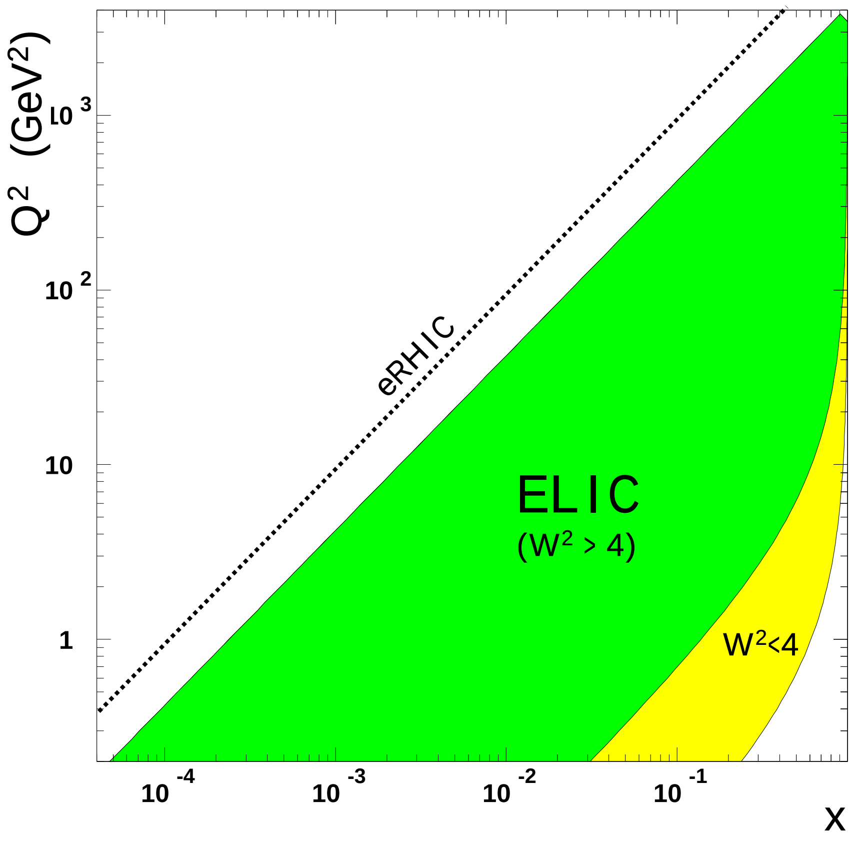
"ELIC proposes some very elegant and innovative features worth further investigation" *(U. Wienands, EIC2004 Summary)*

The physics needs that drove us to this design are the importance of spin, a luminosity as high as possible, and a broad and flexible energy range for Hadron Physics

Data from RHIC/RHIC-Spin, COMPASS, HERMES, JHF, JLab forthcoming to guide the requirements for key physics

Kinematics at an Electron Light Ion Collider

ELIC kinematics at E_{cm} = 65 GeV, and beyond the resonance region.

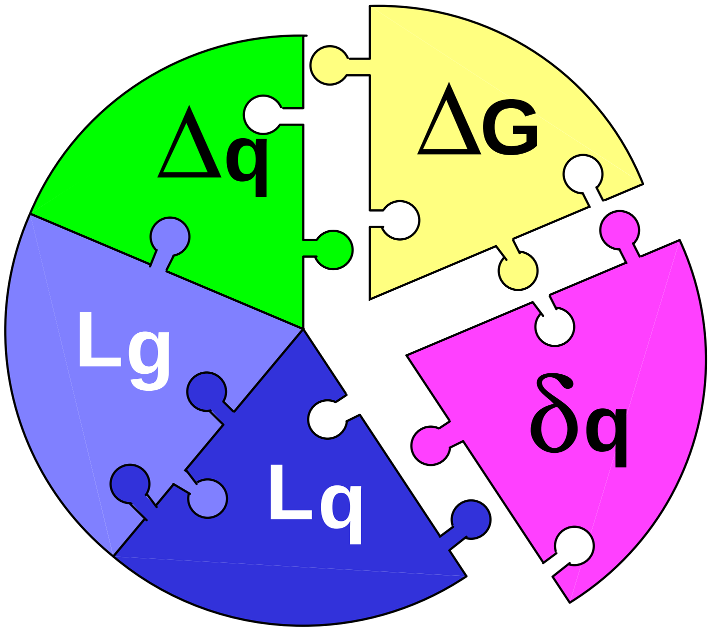


- Luminosity of up to 8×10^{34} cm^{-2} sec^{-1}
  - One day → 4,000 events/pb
  - Supports Precision Experiments
- Lower value of x scales as s^{-1}
- DIS Limit for $Q^2 > 1$ GeV^2 implies x down to 2.5 times 10^{-4}
  - Significant results for 200 events/pb for inclusive scattering
- If $Q^2 > 10$ GeV^2 required for Deep Exclusive Processes can reach x down to 2.5 times 10^{-3}
  - Typical cross sections factor 100-1,000 smaller than inclusive scattering → high luminosity essential
- For $Q^2 > 200$ GeV^2, typical cut required for Electroweak Processes, can reach x down to 4 times 10^{-2}

The Spin Structure of the Proton

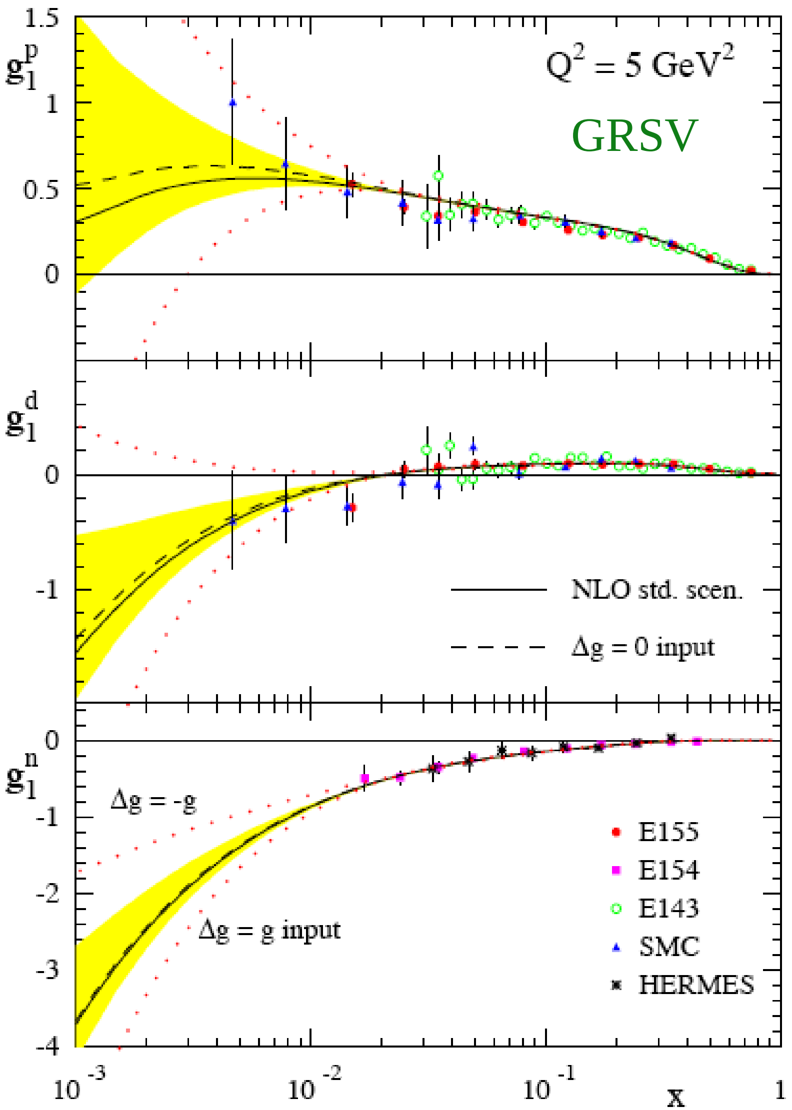
$$\tfrac{1}{2} = \tfrac{1}{2}\,\Delta\Sigma + \Delta G + L_q + L_g$$

- From NLO-QCD analysis of DIS measurements … (SMC analysis)
  $\Delta\Sigma = 0.38$ (in AB scheme)
  $\Delta G = 1.0^{+1.9}_{-0.6}$,,
- quark polarization $\Delta q(x)$
  → first 5-flavor separation from HERMES
- transversity $\delta q(x)$
  → a new window on quark spin
  → azimuthal asymmetries from HERMES and JLab-6
  → future: flavor decomposition
- gluon polarization $\Delta G(x)$
  → RHIC-spin and COMPASS will provide some answers!
- orbital angular momentum L
  → how to determine? → GPD's



ELIC@JLab can solve this puzzle due to large range in x and Q^2 and precision due to high luminosity

Examples: g_1^p



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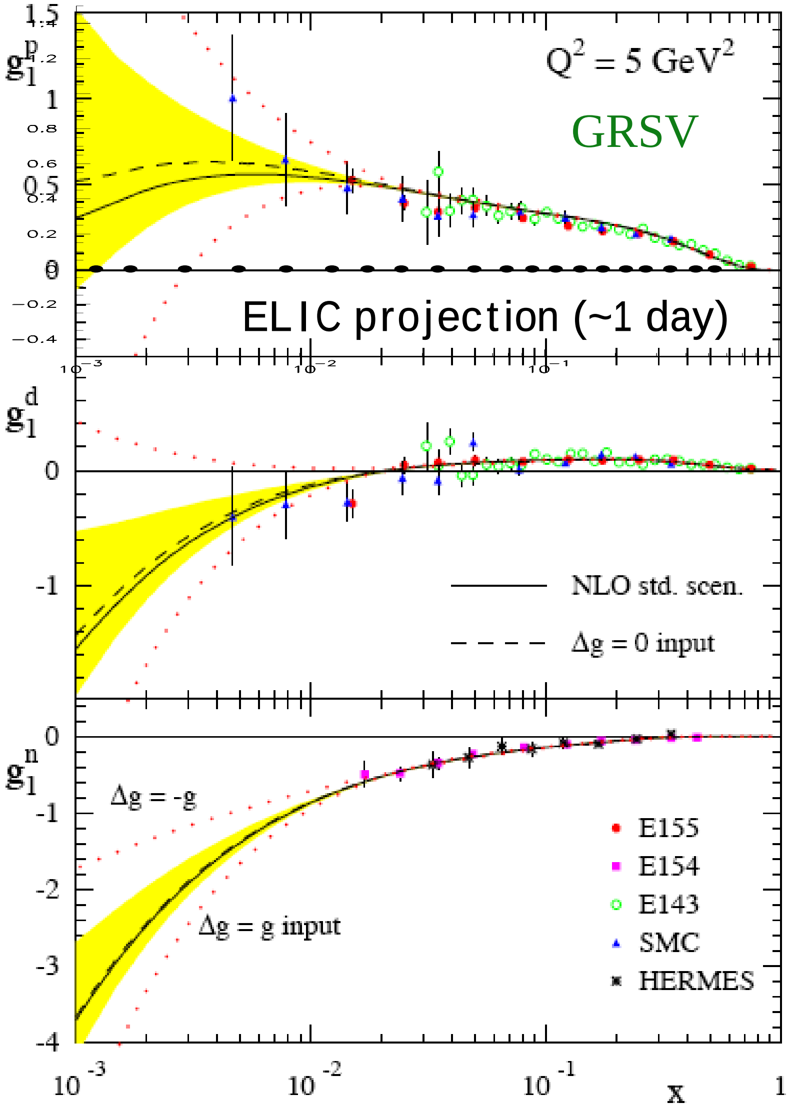
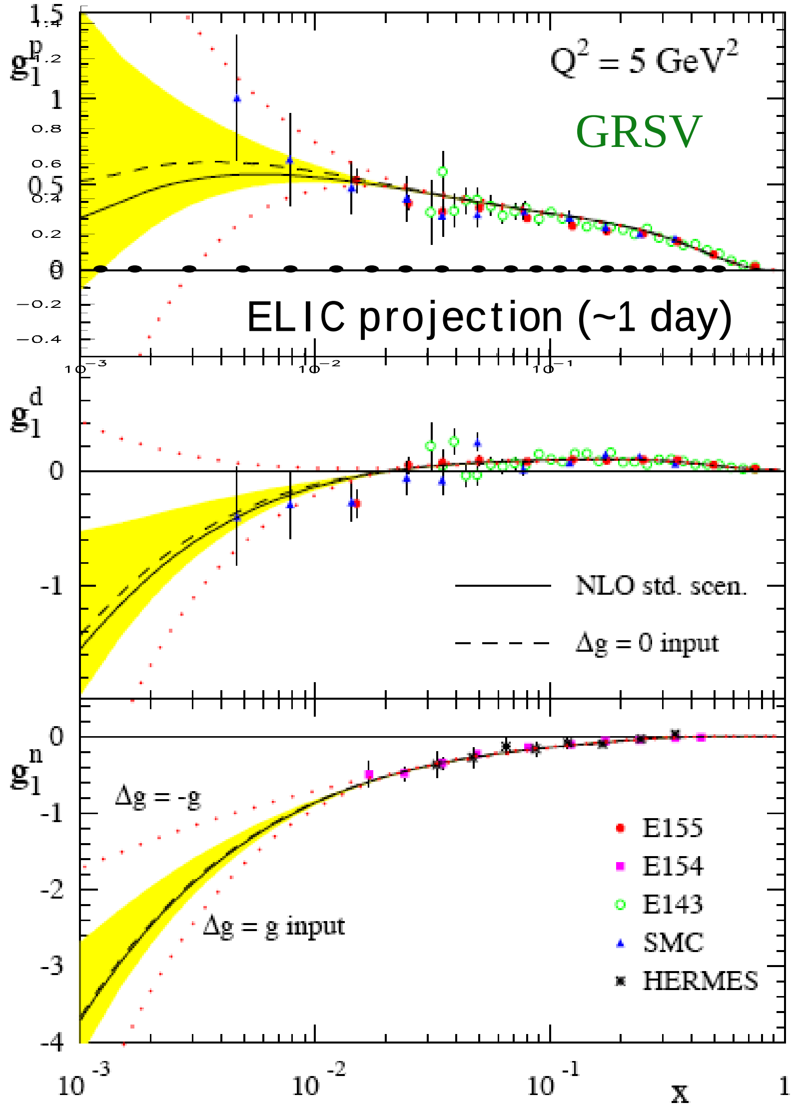
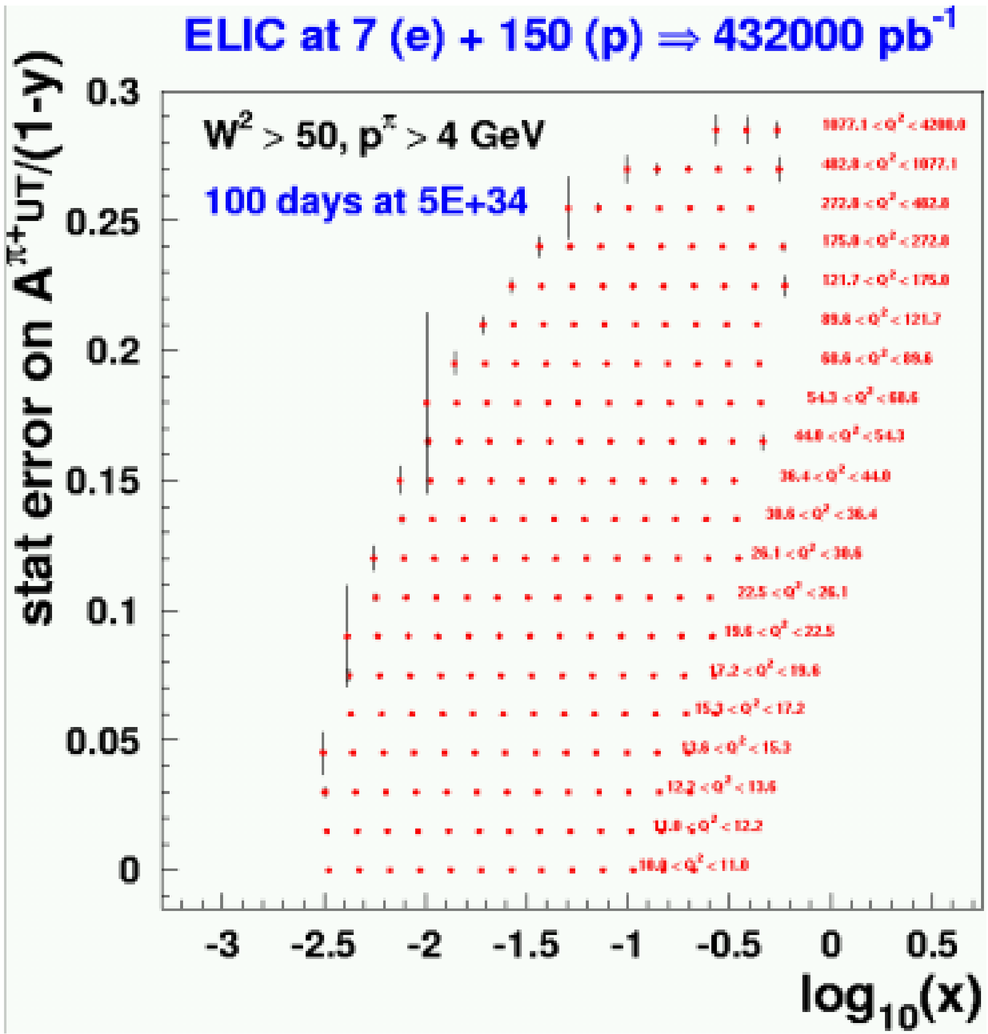


Examples: g_1^p, Transversity





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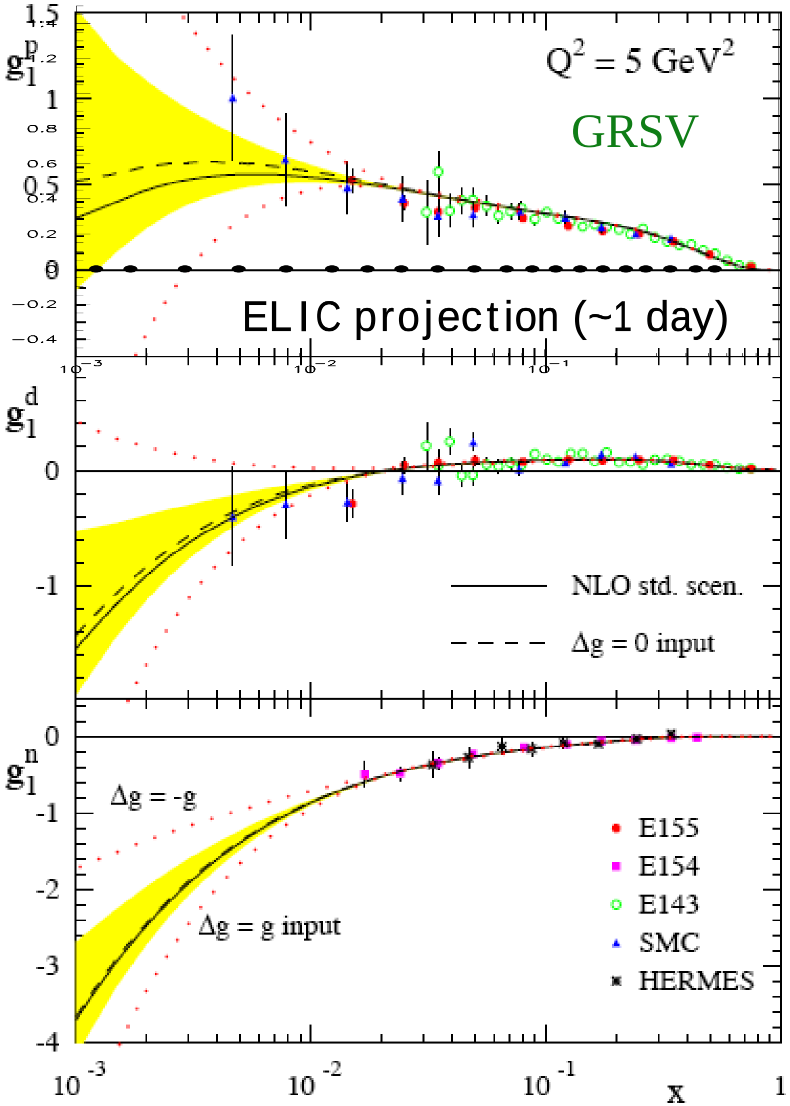
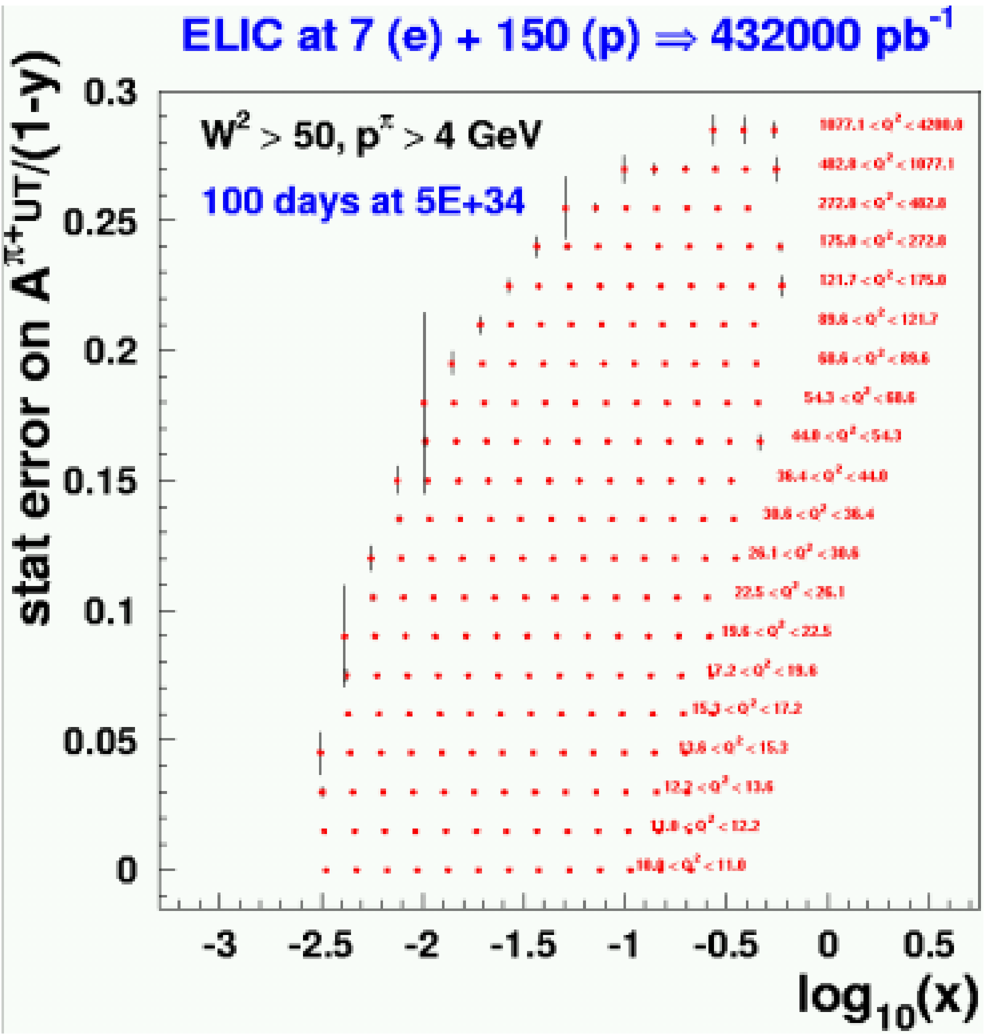




$\Delta G/G$ from open charm: ~RHIC-SPIN precision down to x = 0.001

Orbital Angular Momentum

Analysis of hard exclusive processes leads to a new class of
generalized parton distributions

Four new distributions:

helicity conserving →	$H(x,\xi,t)$, $E(x,\xi,t)$
helicity-flip →	$\tilde{H}(x,\xi,t)$, $\tilde{E}(x,\xi,t)$

"skewedness parameter" ξ
→mismatch between quark momenta
→sensitive to partonic correlations

3-dimensional GPDs give
spatial distribution of partons
and spin

- Angular Momentum $J_q = \frac{1}{2} \Delta\Sigma + L_q$!

$$J_q = \frac{1}{2} \int_{-1}^{1} x dx \left[H_q(x,\xi,t=0) + E_q(x,\xi,t=0) \right]$$

New Roads:

- Deeply Virtual Meson Production @ $Q^2 > 10\ GeV^2$
  → disentangles flavor and spin!
- ρ and ϕ Production give access to gluon GPD's at small x (<0.2)

Can we achieve same level of understanding as with F_2?

Generalized Parton Distributions

Tomography of the Nucleon *Ji*

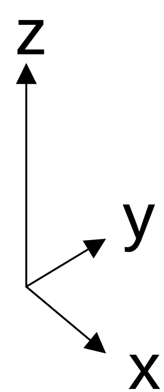
- A framework to extract 3-D spatial information of quarks in a nucleon at rest
- Generate Wigner (quantum phase-space) distributions
- Obtain proton images at fixed x
- Direct connection to GPDs through Fourier Transforms

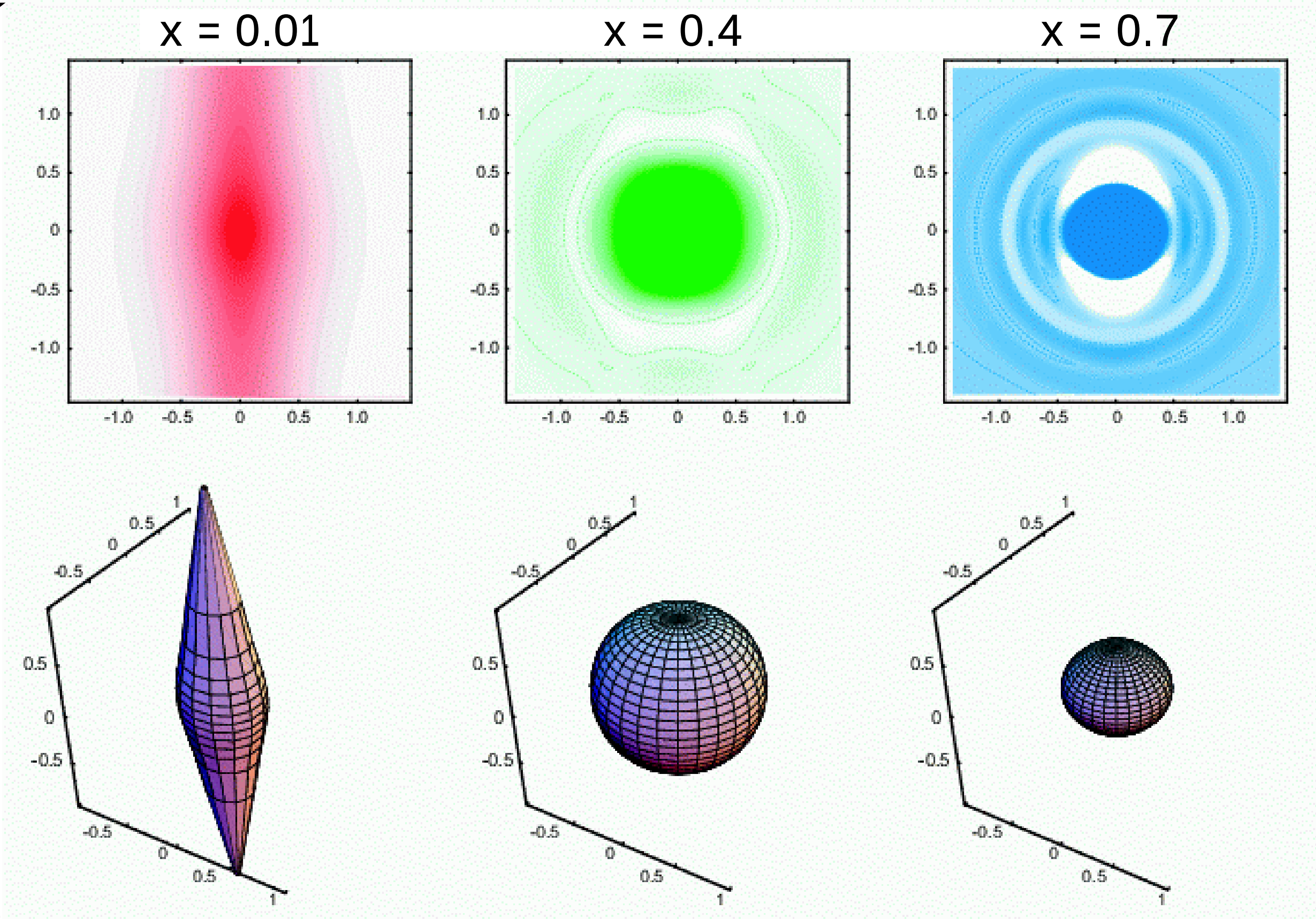
Ultimate strategy:

- ***Data on various hard exclusive processes***
- ***Deconvolution and global fits to obtain GPDs***
- ***Further constraints from Lattice QCD***
- ***Obtain tomographic 3-D pictures of the nucleon***
- ***Understand origins of mass and spin structure***

Proton Images at Fixed x

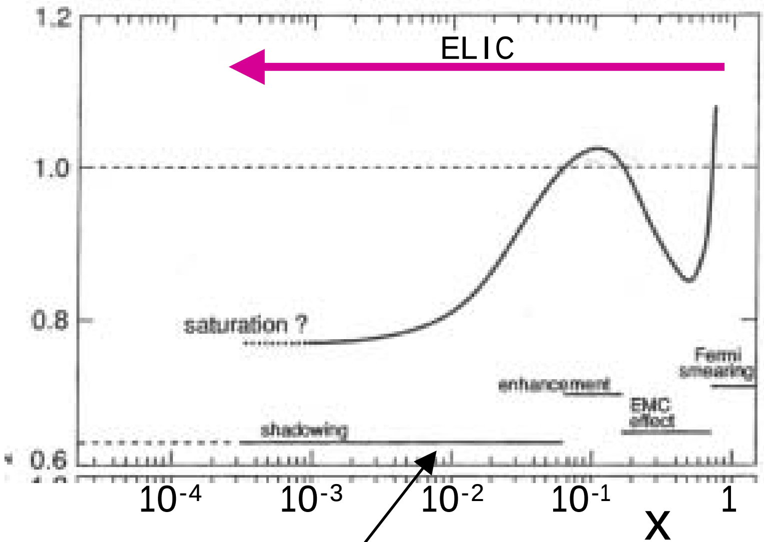
Up-quark densities

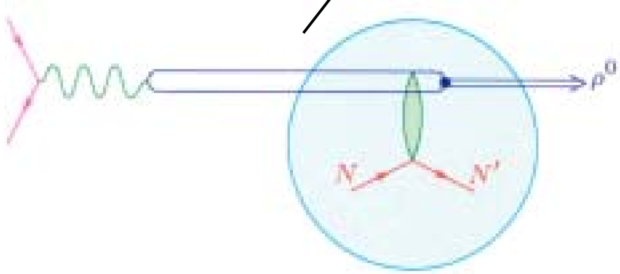




Quarks in a Nucleus

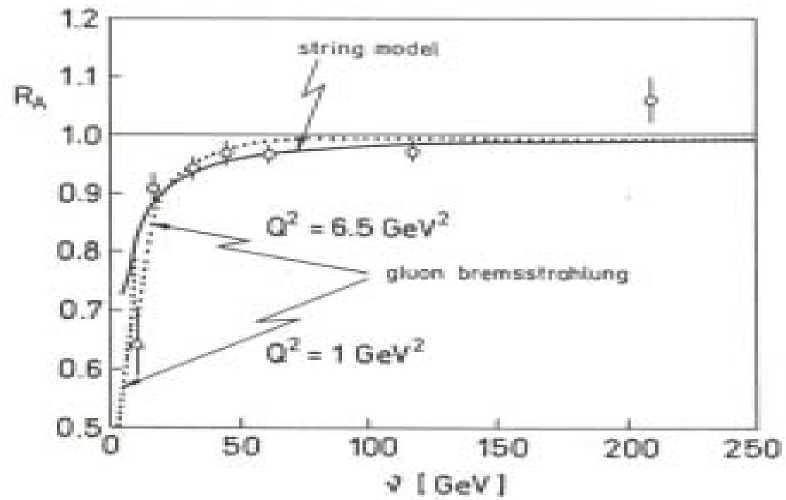
F_2^A/F_2^D "EMC Effect"





Space-Time Structure of Photon

Can pick apart the spin-flavor structure of EMC effect by technique of flavor tagging, in the region where effects of the space-time structure of hadrons do not interfere (large ν!)



Nuclear attenuation negligible for ν > 50 GeV →hadrons escape nuclear medium undisturbed

ELIC@JLab – R&D Topics

- Electron-Light Ion Collider (ELIC)
  - R&D needed on
    - High Charge per Bunch and High Average Current Polarized Electron Source
    - High Energy Electron Cooling of Protons/Ions

      Practical only if based on SRF-ERL technology. Rigorous e-cooling R&D program established at BNL
    - High Current and High Energy demonstration of Energy Recovery
    - Integration of Interaction Region design with Detector Geometry
  - NSAC LRP: "... strong consensus among nuclear scientists to pursue R&D over the next three years to address a number of EIC design issues"

- 25-GeV Fixed-Target Facility
  - Use existing CEBAF footprint
  - Upgrade Cryo modules to 12-GeV design (7-cell design, 18 MV/m)
  - Change ARC magnets, Switchyard, Hall Equipment

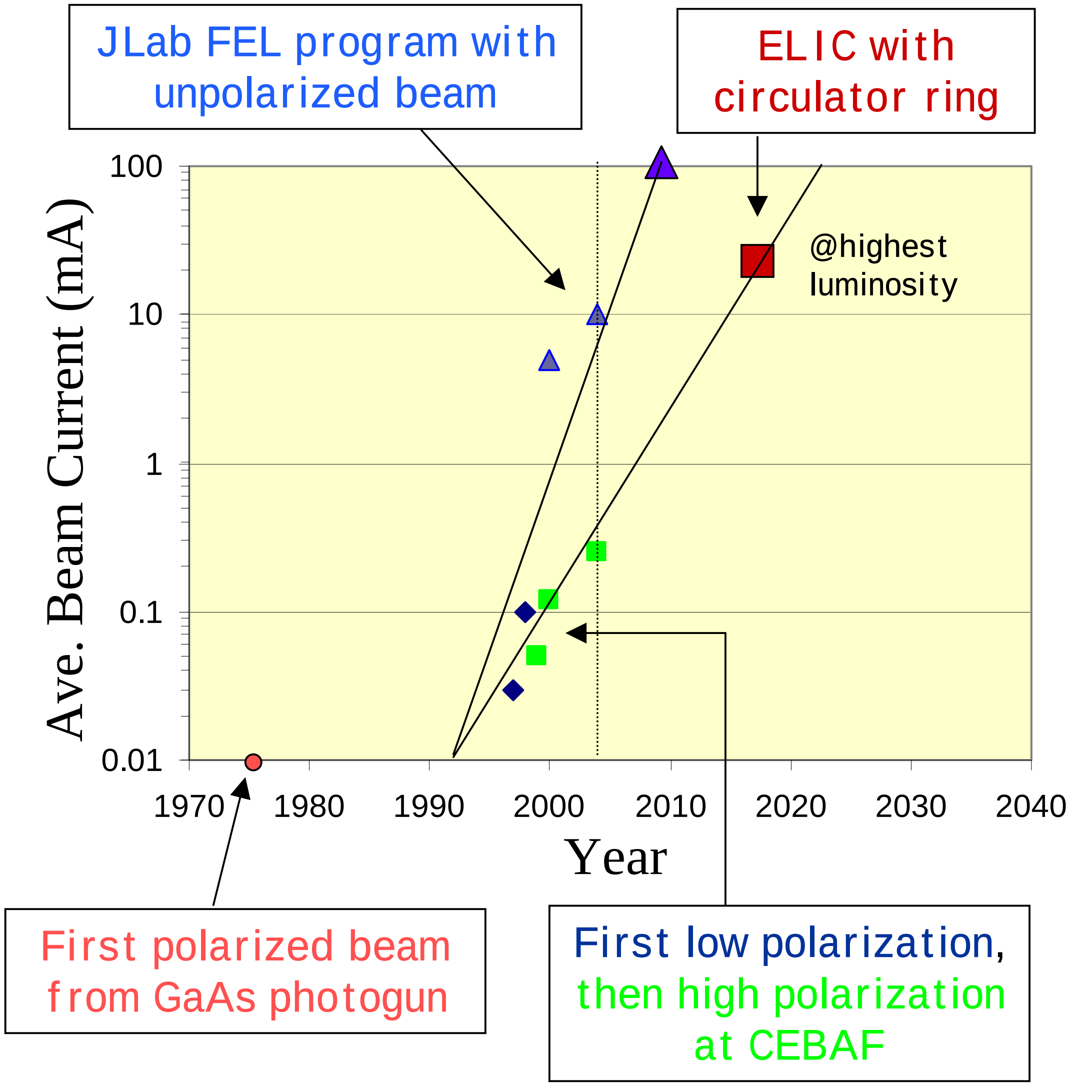
Significant R&D Issues to Resolve – But Work in Progress!!

ELIC@JLab – R&D Strategy

Multi-pronged R&D strategy:

- Conceptual development
  - "Circulator Ring" concept promises to ease high current polarized photoinjector and ERL requirements significantly
  - Additional concepts, e.g. crab crossing, for luminosity improvements are being explored
- Analysis/Simulations
  - Electron cooling and short bunches
  - Beam-beam physics
  - Circulator ring dynamics
  - ERL physics
  - IR design
- Experiments
  - High current, high polarization source development at JLab
  - High current ERL issues investigated at JLab FEL. E.g. multibunch Beam Breakup instabilities
  - High energy (1 GeV) demonstration of energy recovery at CEBAF

Towards Higher Electron Beam Current



Source requirements for ELIC less demanding with circulator ring! Few mA's versus >> 100 mA of highly polarized beam.

Lifetime Estimate @ 25 mA:

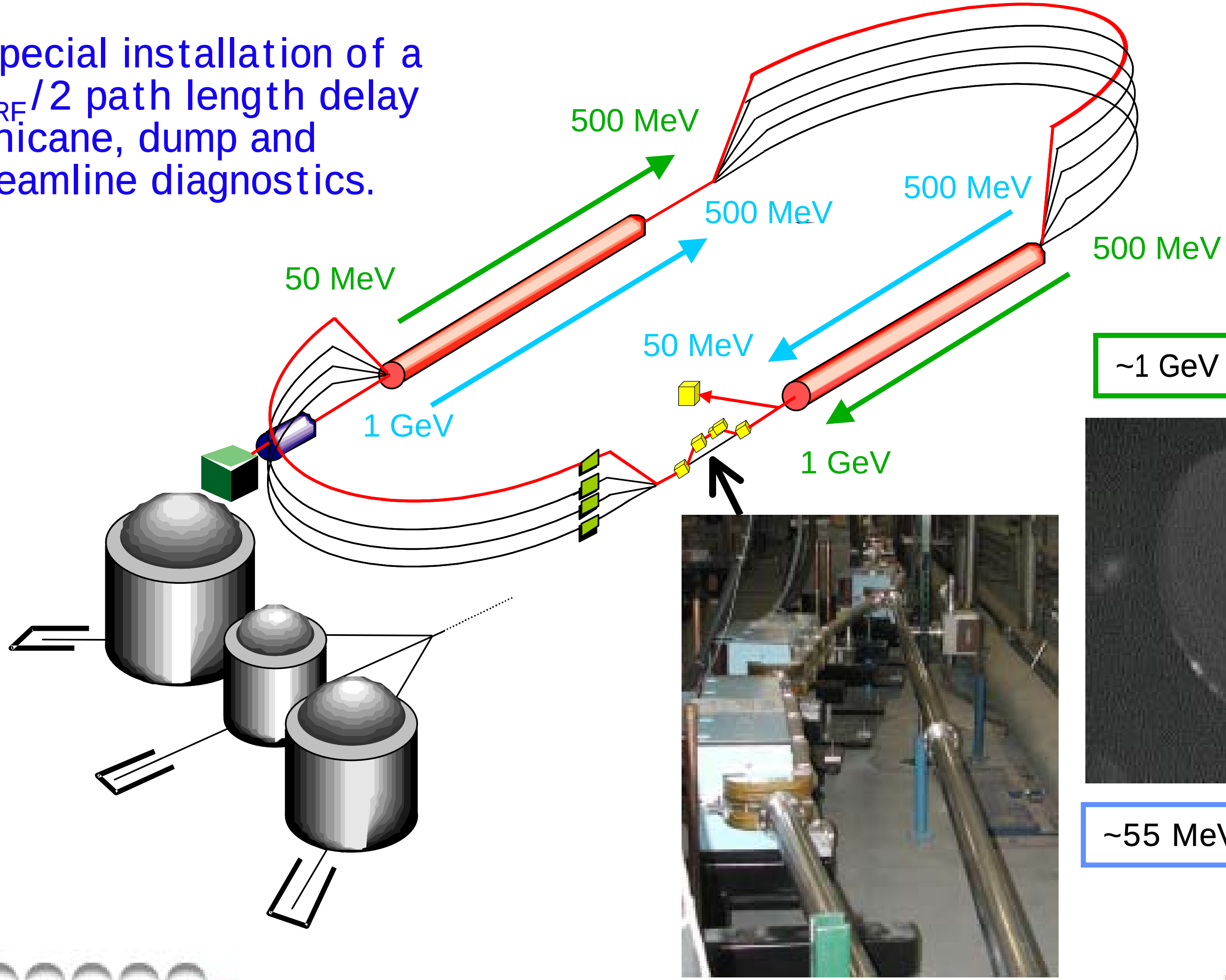
CEBAF enjoys excellent gun lifetime:
~200 C charge lifetime
(until QE reaches 1/e of initial value)
~100,000 C/cm^2 charge density lifetime
(we use a ~0.5 mm dia. spot)

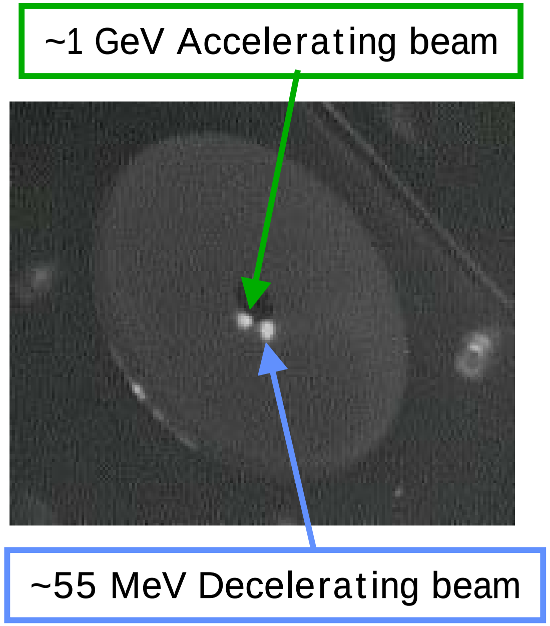
If Charge-Lifetime assumption valid:
With ~1 cm dia. spot size lifetime of 36 weeks at 25 mA!

Need to test the scalability of charge lifetime with laser spot diameter → Measure charge lifetime versus laser spot diameter in lab. *(Poelker, Grames)*

ERL Technology demonstrated at CEBAF @ 1 GeV

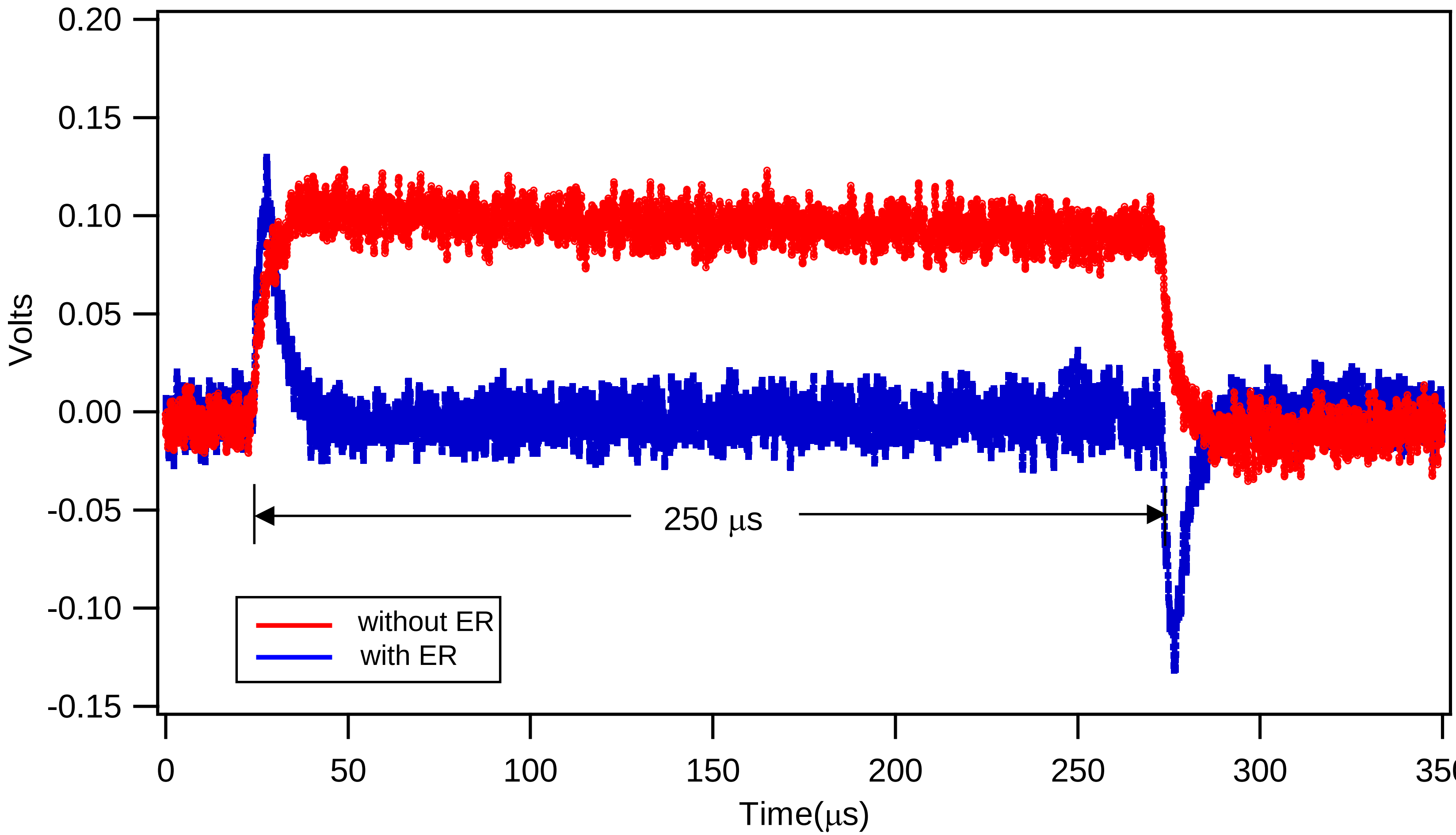
Special installation of a $\lambda_{RF}/2$ path length delay chicane, dump and beamline diagnostics.





RF Response to Energy Recovery

- Gradient modulator drive signals **with** and **without** energy recovery in response to 250 μsec beam pulse entering the RF cavity *(SL20 Cavity 8)*



ELIC@JLab – Conclusions

- An excellent scientific case is developing for a high luminosity, polarized electron-light ion collider; will address fundamental issues in Hadron Physics:
  - The (spin-flavor) quark-gluon structure of the proton and neutron
  - How do quarks and gluons form hadrons?
  - The quark-gluon origin of nuclear binding

- JLab design studies have led to an approach that promises luminosities as high as 8×10^{34} cm^{-2} sec^{-1} (one day lifetime), for electron-light ion collisions at a center-of-mass energy between 20 and 65 GeV

- R&D Studies to illuminate details of the design are underway/planned

- This design, using energy recovery on the JLab site, can be integrated with a 25 GeV fixed target program for physics