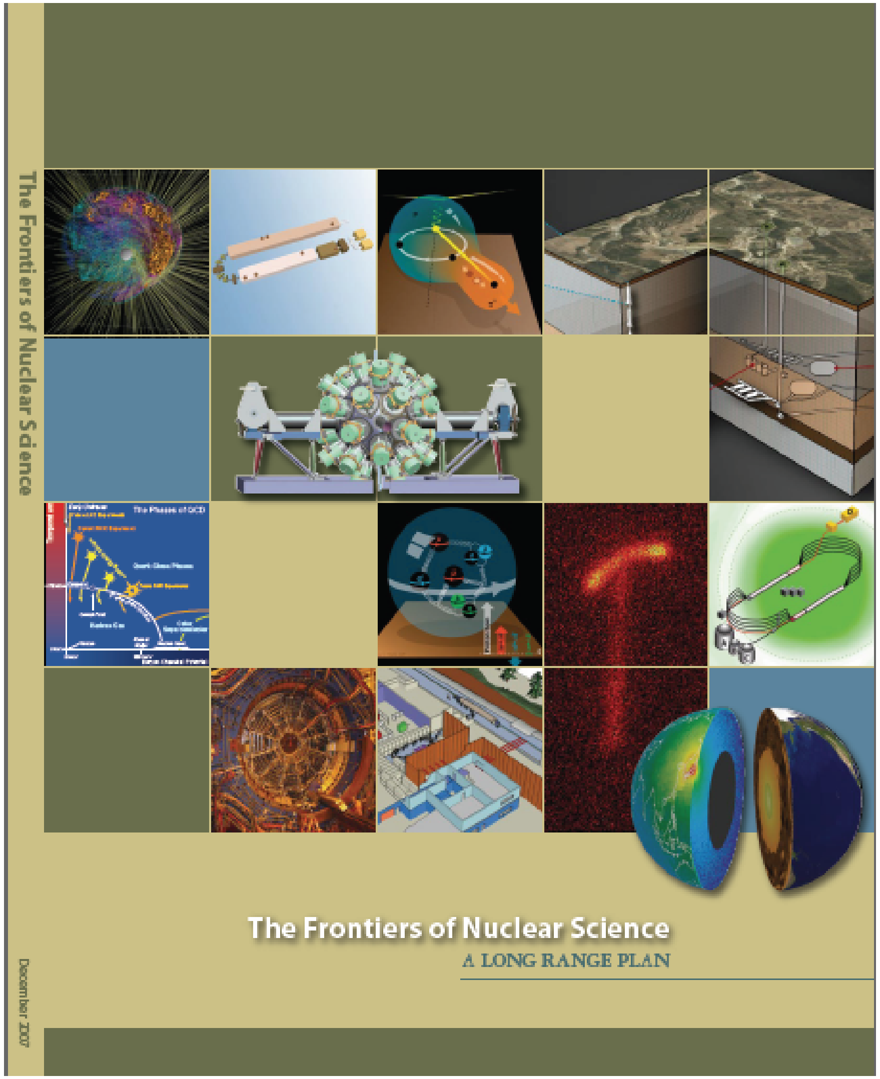
Status and Plans for the Electron-Ion Collider

- **Science**
  - 2007 Long Range Plan
  - Highlights from EIC meeting at Hampton, VA
- **Accelerator**
  - Concepts
  - R&D
- **Detector**
  - Concepts
  - R&D
- **Realization**
  - Plans for the near future
  - Perspective on the longer term

NSAC 2007 Long Range Plan

"An **Electron-Ion Collider (EIC)** with polarized beams has been **embraced by the U.S. nuclear science community** as embodying the vision for **reaching the next QCD frontier**. EIC would provide unique capabilities for the study of QCD well beyond those available at existing facilities worldwide and complementary to those planned for the next generation of accelerators in Europe and Asia. In support of this new direction:

We recommend the allocation of resources to develop accelerator and detector technology necessary to lay the foundation for a polarized Electron Ion Collider. The EIC would explore the new QCD frontier of strong color fields in nuclei and precisely image the gluons in the proton."



Overview

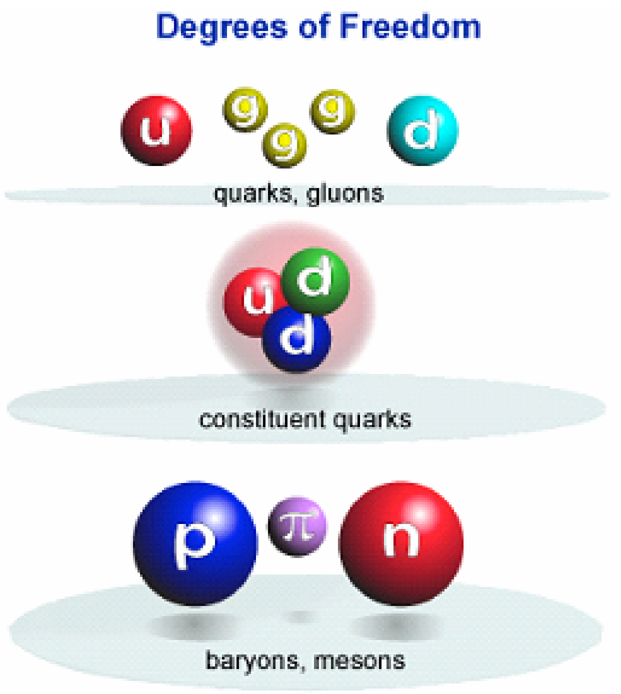
The EIC will explore the most compelling issues in nuclear science and technology.

- ***The structure of visible matter***
- ***The role of gluons in hadronic matter***
- ***Fundamental symmetries of nature***

This will require a new generation of accelerator and detectors.

Goal of the Electron-Ion Collider: To explore the structure of visible matter

- **What is the internal landscape of the hadron?**
  - Benchmark: Spatial, spin, flavor and gluonic structure
- **What is the nature of the nuclear force that binds protons and neutrons into nuclei?**
  - Frontier: QCD properties of nuclear force
  - Mysteries: QCD effects in nuclei



Understanding the proton spin

Where is the Spin of the proton?

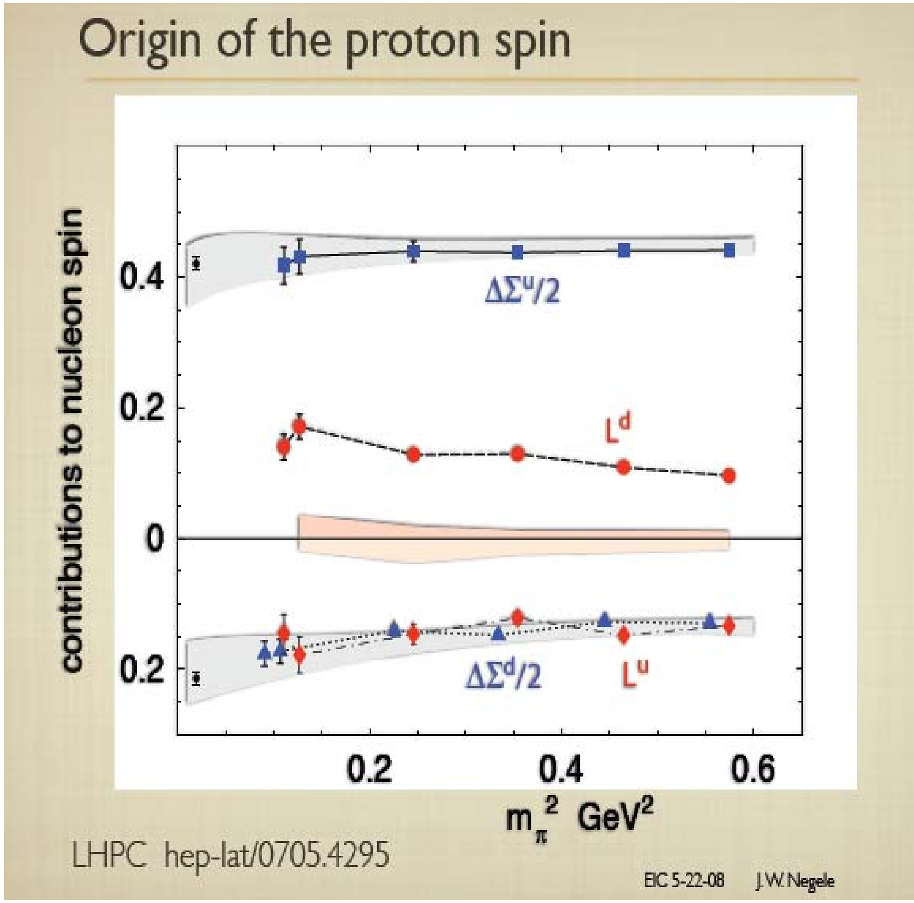
- Modern data yields:
  $\Sigma = 0.33 \pm 0.03 \pm 0.05$

  (c.f. $0.14 \pm 0.03 \pm 0.10$ originally)

- In addition, there is little or no polarized glue
  - COMPASS: $g^D_1 = 0$ to $x = 10^{-4}$
  - A_{LL} (π^0 and jets) at PHENIX & STAR $\rightarrow \Delta G \sim 0$
  - Hermes, COMPASS and JLab: $\Delta G / G$ small

- ALL effects, relativity and OGE and the pion cloud have the effect of swapping quark spin for valence orbital angular momentum and anti-quark orbital angular momentum (>60% of the spin of the proton)

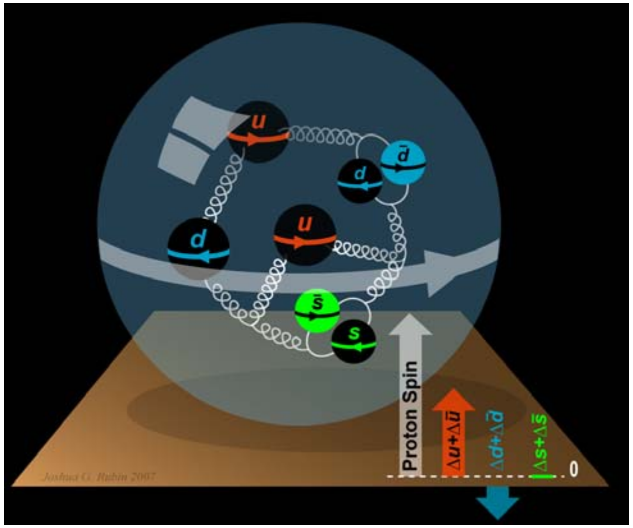
Myhrer & Thomas, hep-ph/0709.4067

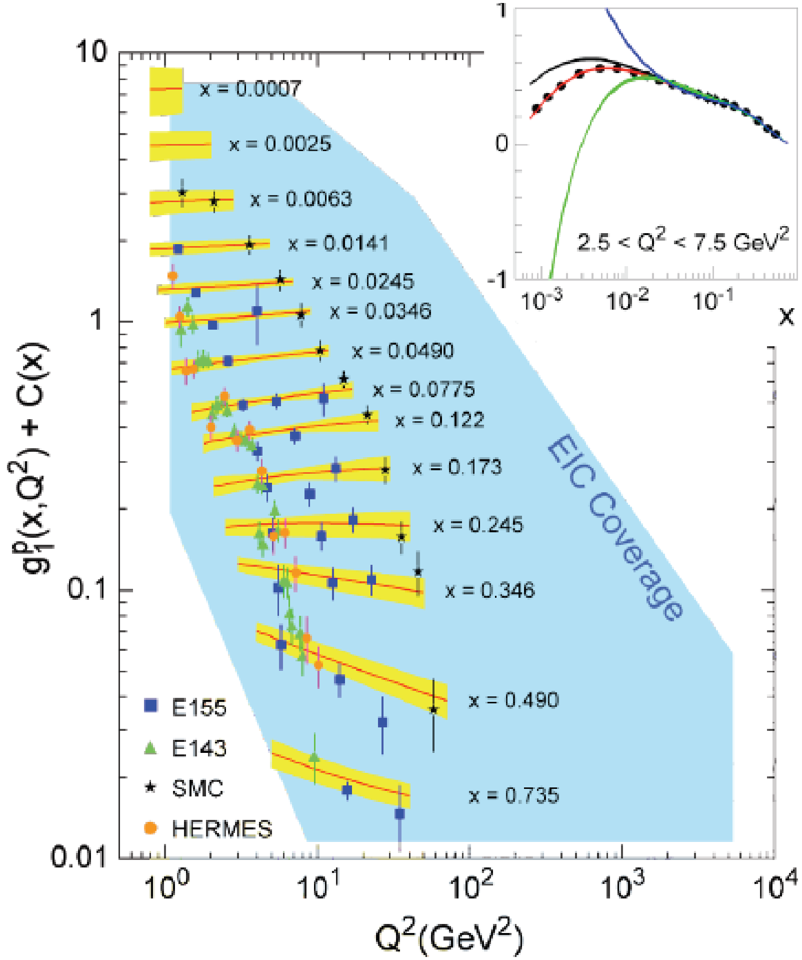


A. Thomas: gluon contribution small **J. Negele: Quark orbital A.M. small**

Explore the structure of the nucleon

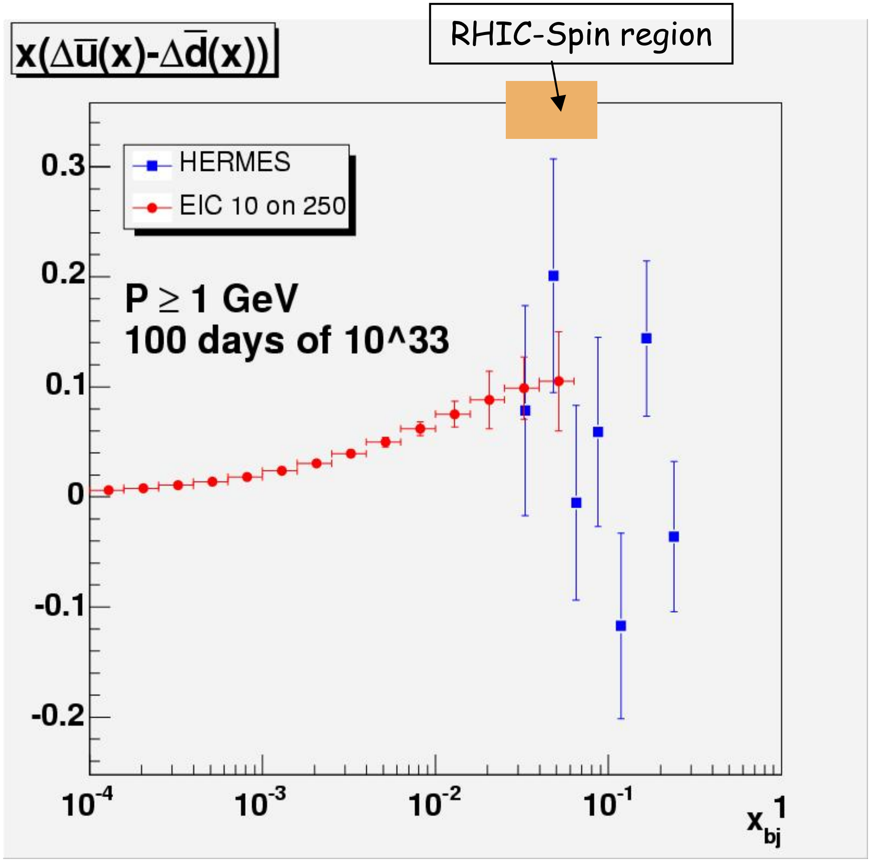
- Parton distribution functions
- Longitudinal and transverse spin distribution functions
- Generalized parton distributions
- Transverse momentum distributions



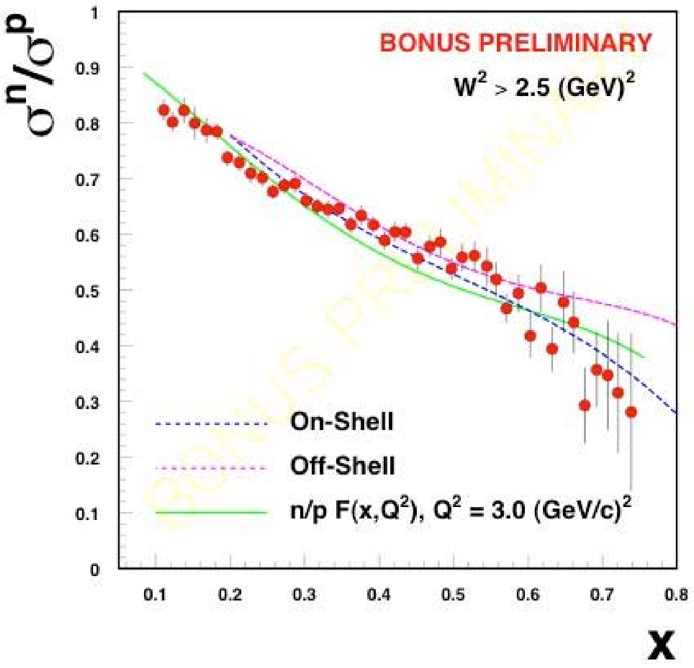


Lattice -> quantitative predictions

Light quark structure – chiral properties



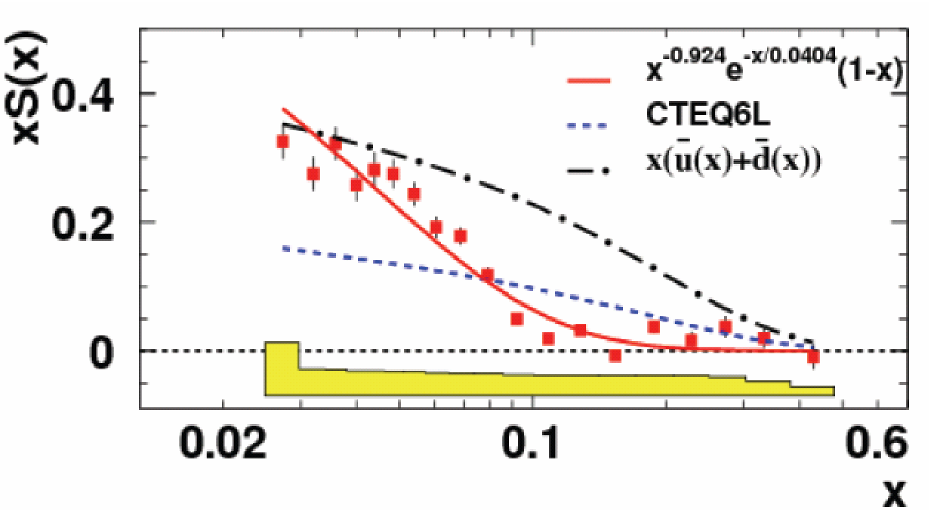
Tagged structure functions to reach x > 0.9

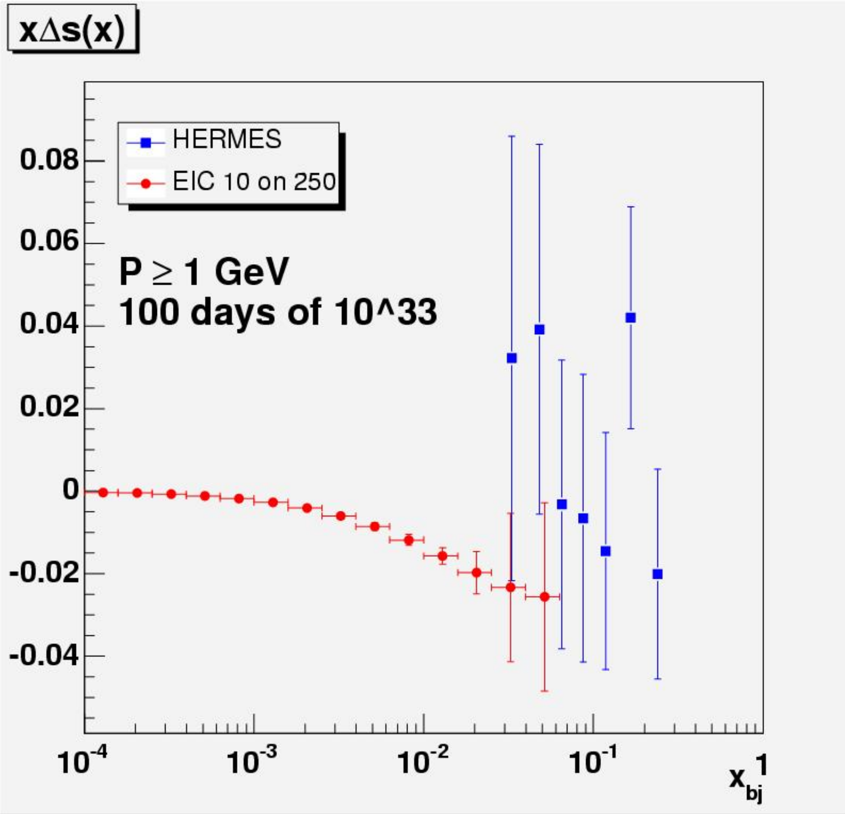


Spectator forward tagging to minimize deuteron structure –similar requirements as exclusive, DVCS, diffraction

Strange quark distributions

HERMES data

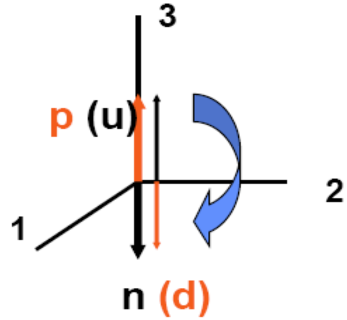




- Asymmetric strange-antistrange sea can explain NuTeV anomaly
- Data on same time scale as disconnected diagrams in lattice calculations.
- What about charm quark contributions?

Test of Charge Symmetry Violation

- Charge symmetry < 1%
- $u \equiv u^p = d^n$, $d \equiv d^p = u^n$



A. Thomas

- e+ and e- beams can probe different flavor aspects of the nucleon
- Neutral and charged current cross section measurements have been carried out at HERA
- Polarized e+/e- beams can add additional capability

EIC may provide ideal test

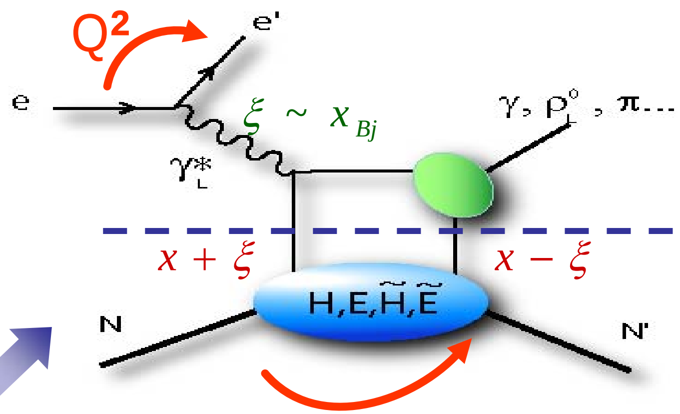
- **Compare e^+D with e^-D charged current cross section :**

$$F_2^{W^+N_0}(x,Q^2) - F_2^{W^-N_0}(x,Q^2)$$
$$= x\left[\delta d_v(x) - \delta u_v(x) + 2\left(s_v(x) - c_v(x)\right)\right]$$

For the <u>sea</u> alone, Ma (Phys Lett B274 (1992) 111) defined a charge symmetry sum-rule:

$$S_{cs} \equiv \int_0^1 \frac{dx}{x}\left[F_2^{W^+p}(x) + F_2^{W^-p}(x) - F_2^{W^+D}(x) - F_2^{W^-D}(x)\right]$$
$$= \int_0^1 dx\,\left[\delta\bar{u}(x) + \delta\bar{d}(x)\right] \quad .$$

Generalized Parton Distributions



$H(x, \xi, t)$ $x \neq x_{Bj}$ $\xi \sim x_{Bj}$

form factors

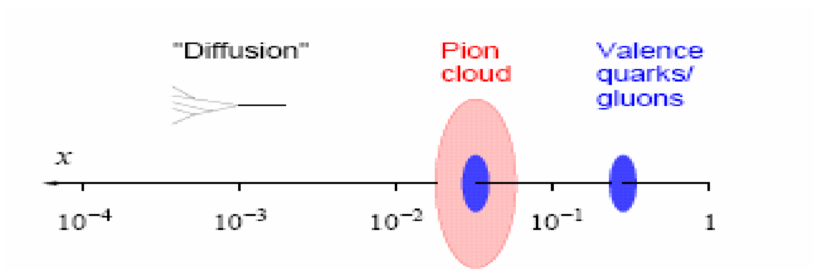
$$\sum_q e_q \int dx \; H^q(x, \xi, t) = F_1(t)$$

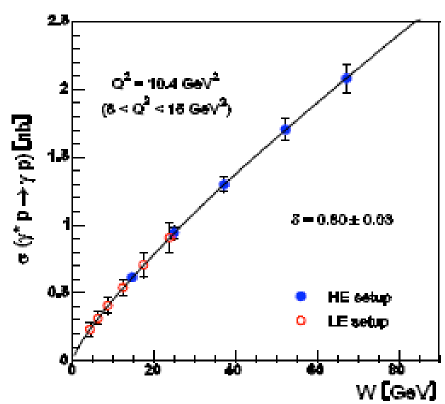
⋮

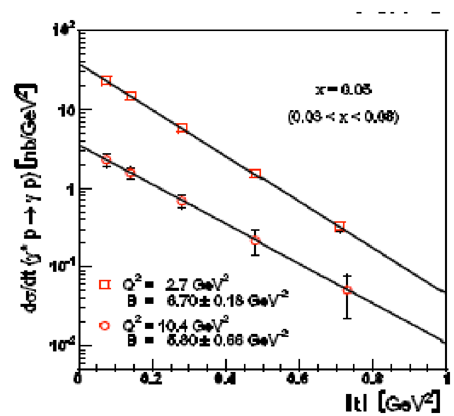
PDFs

$$H^{q,g}(x,0,0) = q(x)$$
$$\tilde{H}^{q,g}(x,0,0) = \Delta q(x)$$

GPD's provide a 2D spatial image as a function of x

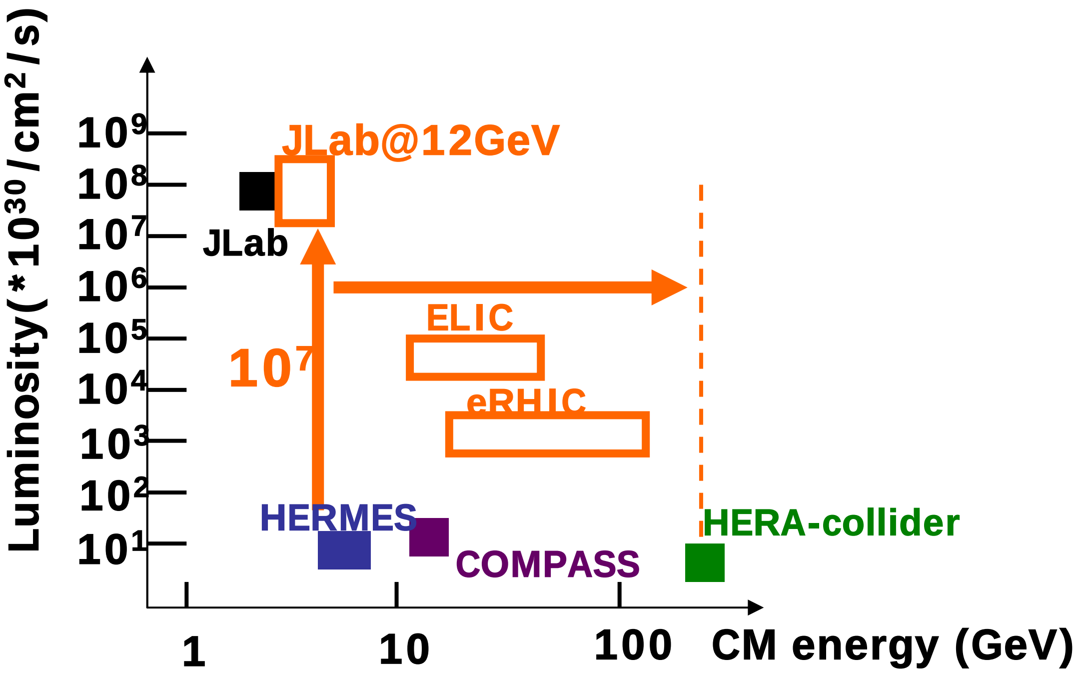


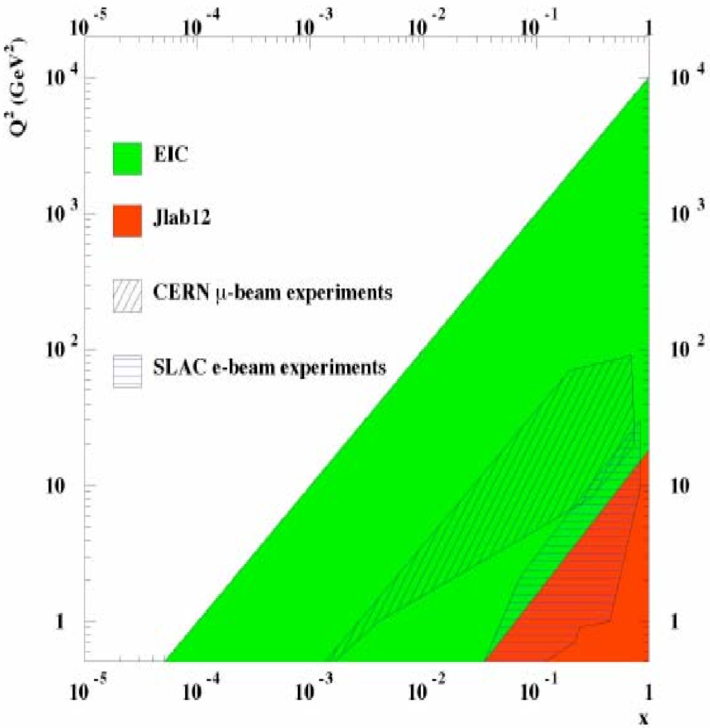




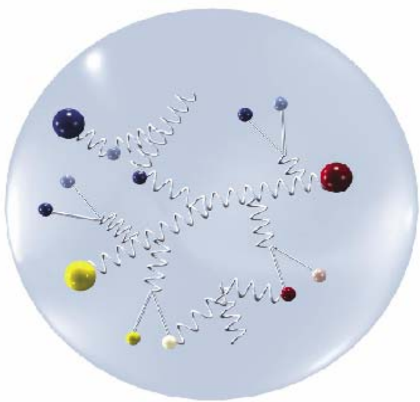
EIC kinematic reach

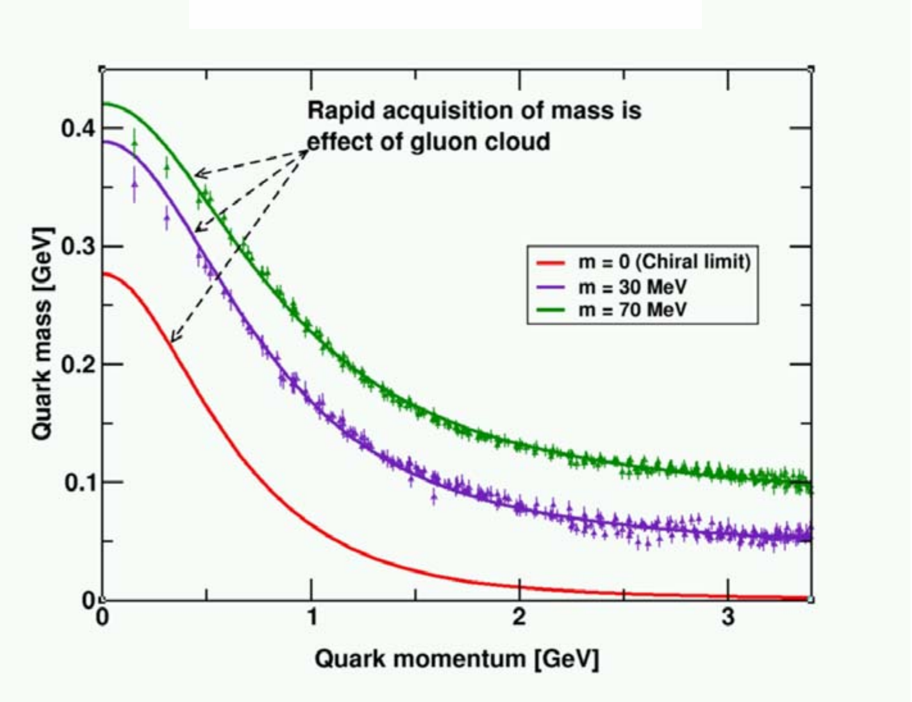
D. Hasch





QCD and the Origin of Mass





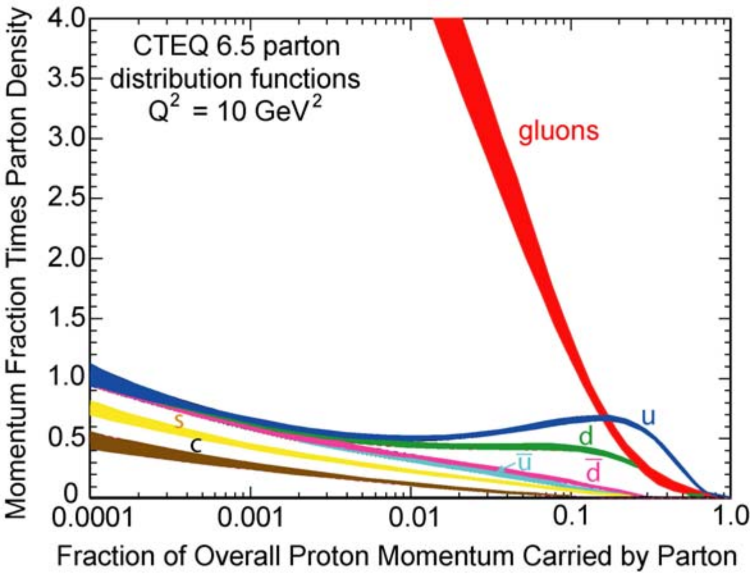
- 99% of the proton's mass/energy is due to the self-generating gluon field
  – Higgs mechanism has almost no role.
- The similarity of mass between the proton and neutron arises from the fact that the gluon dynamics are the same
  – Quarks contribute almost nothing.

Explore gluon-dominated matter

- **What is the role of gluons and gluon self-interactions in nucleons and nuclei? NSAC-2007**
  - **Gluon dominance in the proton**

Gluon distribution $G(x,Q^2)$

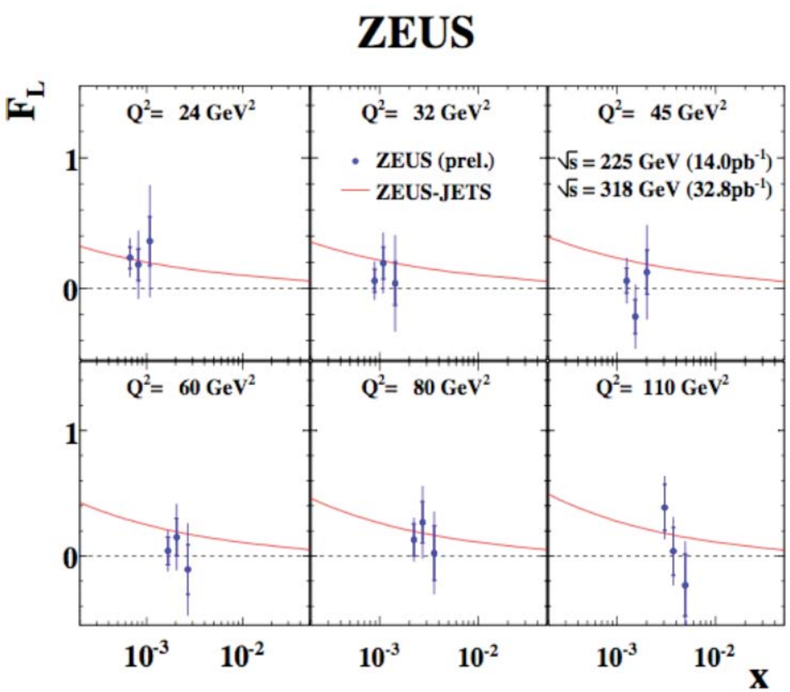
- **Scaling violation in F_2: $dF_2/d\ln Q^2$**
- **$F_L \sim a_s\, G(x,Q^2)$**
- **inelastic vector meson production (e.g. J/ψ)**
- **diffractive vector meson production $\sim [G(x,Q^2)]^2$**
- **...**

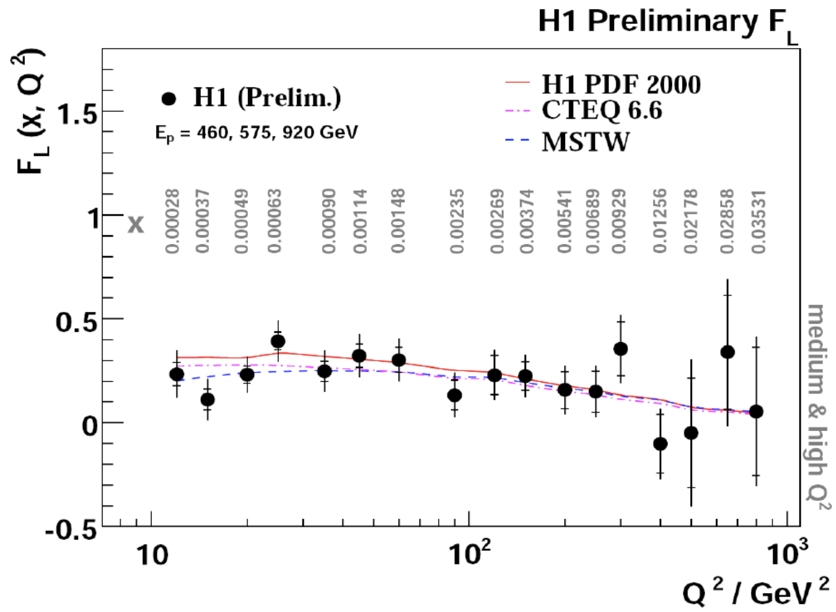


EIC: most precise measure of gluon densities

Recent progress – direct F_L measurements from HERA

$$\frac{d^2\sigma^{ep\to eX}}{dxdQ^2} = \frac{4\pi\alpha^2}{xQ^4}\left[\left(1-y+\frac{y^2}{2}\right)F_2(x,Q^2)-\frac{y^2}{2}F_L(x,Q^2)\right]$$



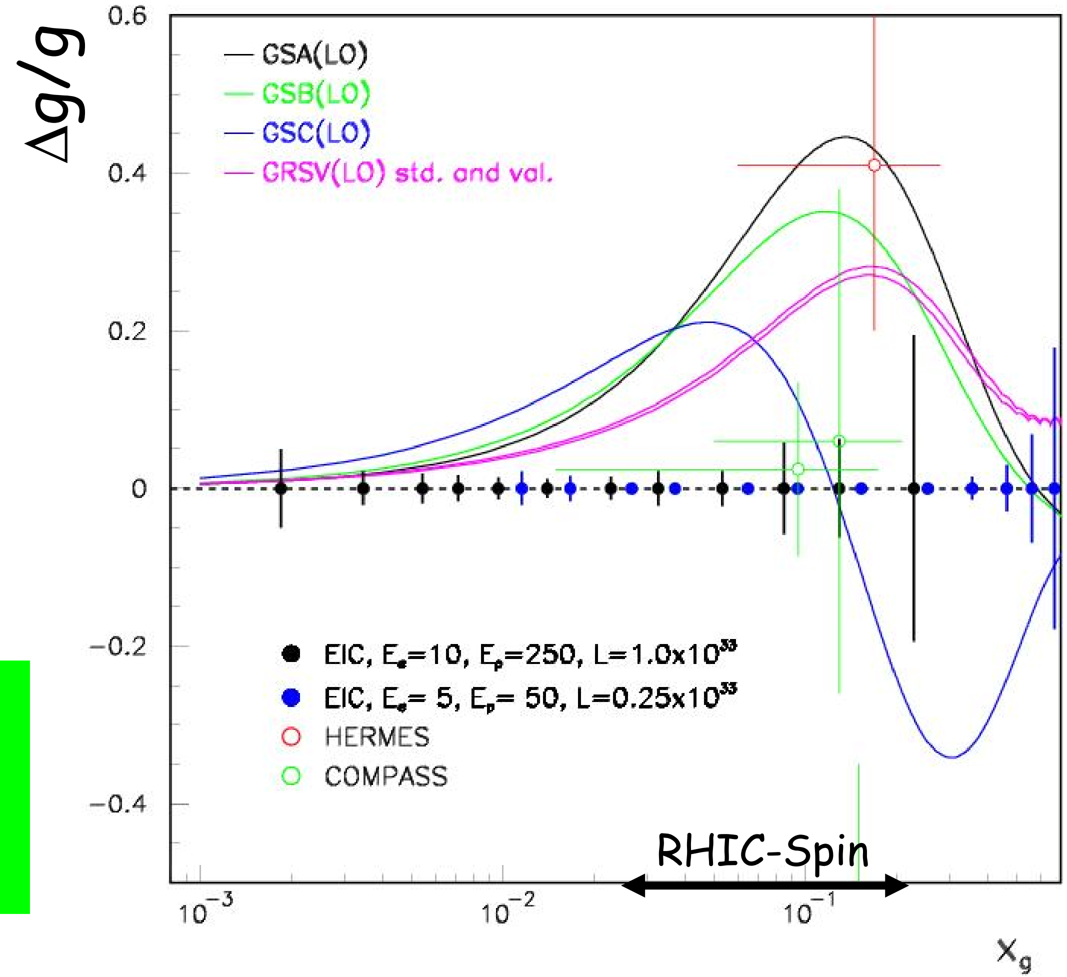


EIC – an F_L factory

Gluon Contribution to the Proton Spin

Projected data on Dg/g with an EIC, via g + p → D^0 + X

└→ K^- + p^+



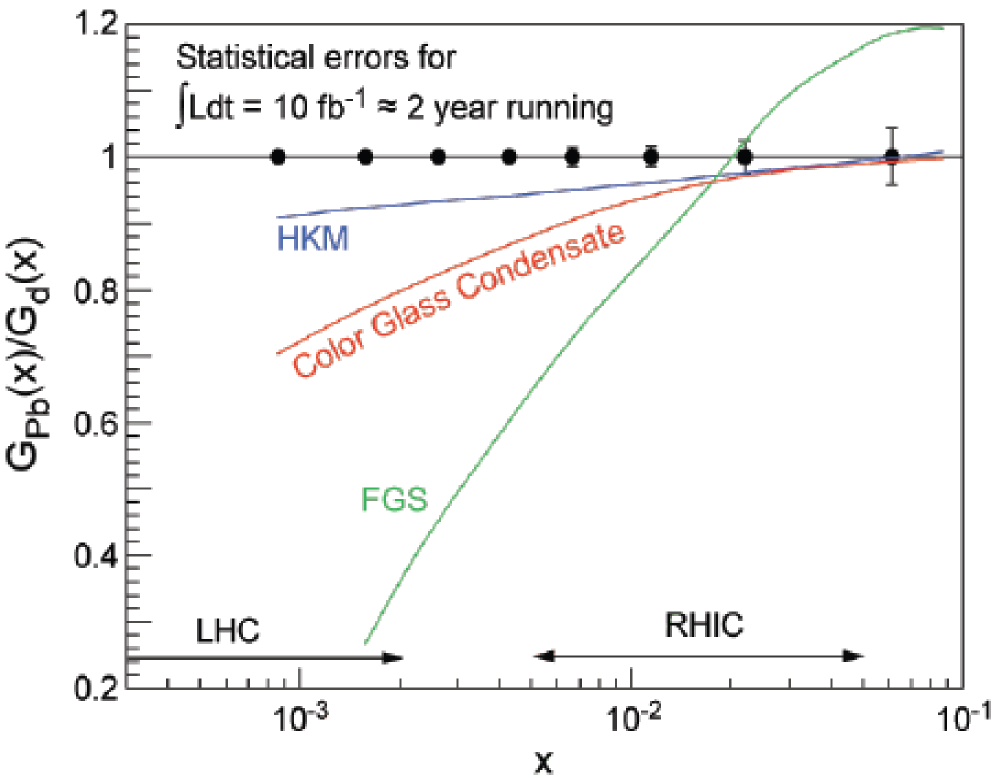
Advantage: measurements directly at fixed Q^2 ~ 10 GeV^2 scale!

Explore gluon-dominated matter

- What is the role of gluons and gluon self-interactions in nucleons and nuclei? NSAC-2007
  - The nucleus as a "gluon amplifier"

At high gluon density, gluon recombination should compete with gluon splitting ⇒ density saturation.

Color glass condensate



- **Oomph factor stands up under scrutiny.**
- **Nuclei greatly extend x reach:** $x_{EIC} = x_{HERA}/18$ **for 10+100 GeV, Au**

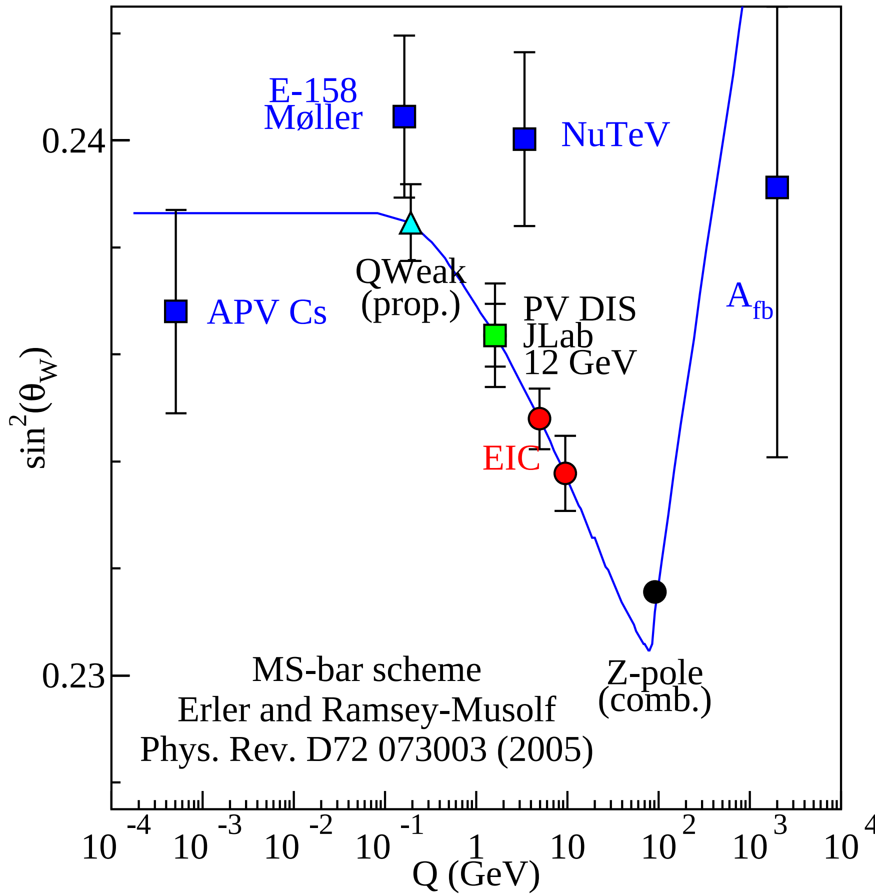
Explore the low energy precision frontier

"The task of the physicist is to see through the appearances down to the underlying, very simple, symmetric reality."
- S. Weinberg

What are the unseen forces present at the dawn of the Universe but have disappeared from view as the universe evolved? ***precision electroweak experiments***: *$\sin^2\theta_W$* **, ...**

Questions for the Universe, Quantum Universe, HEPAP, 2004; NSAC Long Range Plan, 2007

Preliminary - EIC



R. Holt

- **5 GeV polarized e on 50 GeV unpolarized deuteron**
- **~ 500 fb^{-1} integrated luminosity**
- **full simulation required**

Lattice QCD

J. Negele

Outlook

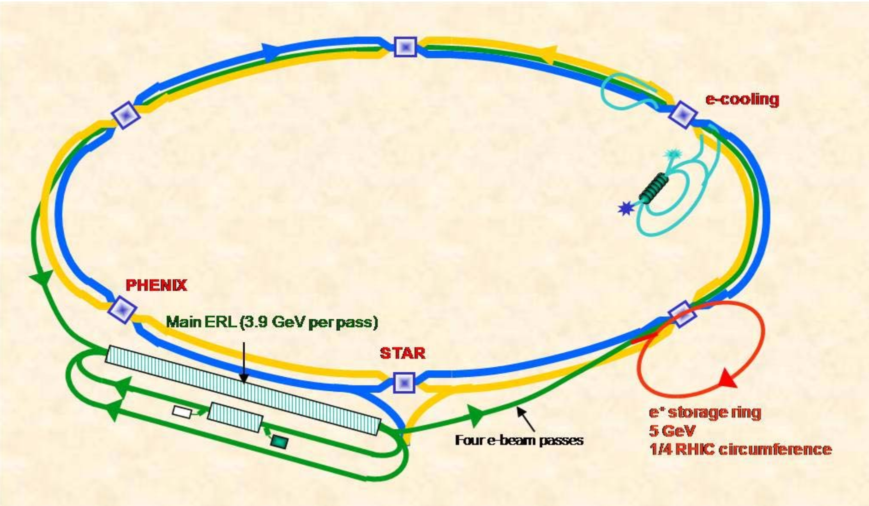
- Dramatic increase in computer resources for Lattice QCD
  - Teraflops → Petaflops → Exaflops
- Innovation in algorithms
- Chiral fermions down to physical pion mass
- Disconnected diagrams
  - Calculate proton and neutron separately, not just difference
  - Strangeness content of nucleon
- Gluon observables
  - Contribution to mass, momentum, spin

Synergy between Lattice and Experiment

- Use solution of QCD as a quantitative tool in concert with experiment
- Example: GPD's
  - Experiment: Integrals over GPD's
  - Lattice: Moments of GPD's
  - Together, obtain much stronger constraints on GPD's than from either alone

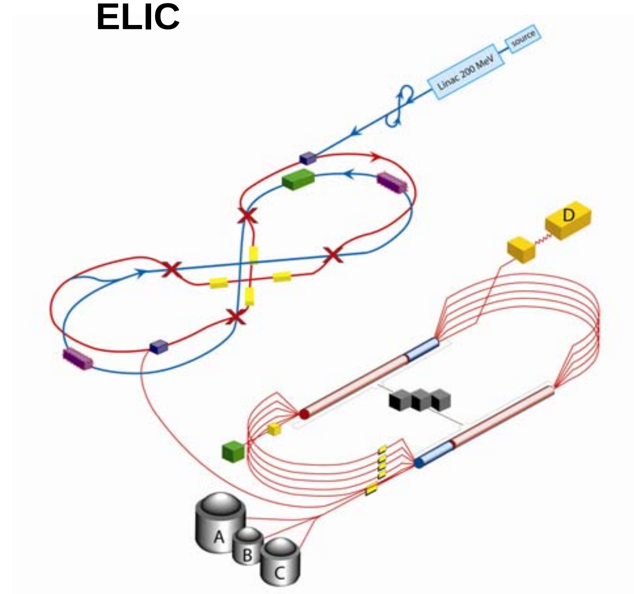
EIC accelerator concepts

eRHIC



Peak lumi ~ 2.6 x 10^{33}cm^{-2}s^{-1}

ELIC



Peak lumi ~ 6 x 10^{34}cm^{-2}s^{-1}

"We recommend the allocation of resources to develop accelerator and detector technology necessary to lay the foundation for a polarized Electron-Ion Collider."

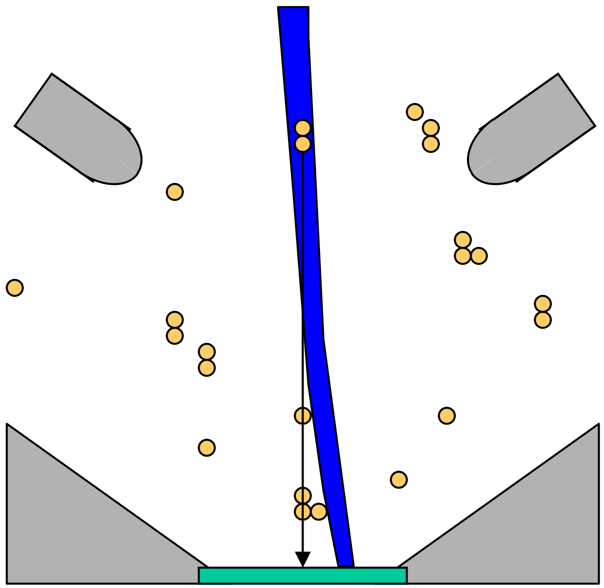
NSAC LRP 2007

EIC accelerator R&D is underway

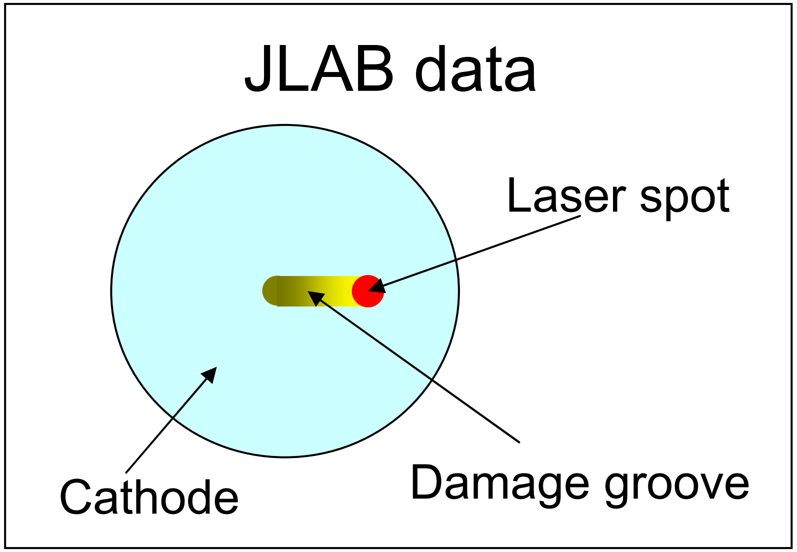
- **Electron beam R&D for ERL-based design**:
  - **High intensity polarized electron source**
    - **Development of large cathode guns with existing current densities ~ 50 mA/cm^2 with good cathode lifetime.**
  - **Energy recovery technology for high power beams**
    - **Multicavity cryomodule development; BNL test ERL; loss protection; instabilities.**
  - **Development of compact recirculation loop magnets**
    - **Design, build and test a prototype of a small gap magnet and its vacuum chamber.**
  - **Evaluation of electron-ion beam-beam effects, including the kink instability and e-beam disruption**
- **Ion beam R&D**:
  - **Polarized ^{3}He production (EBIS) and acceleration**
  - **Increasing number of bunches, number of ions/bunch in RHIC**
- **Cooling:**
  - **Cooling of ion beam**

High intensity polarized electron source R&D

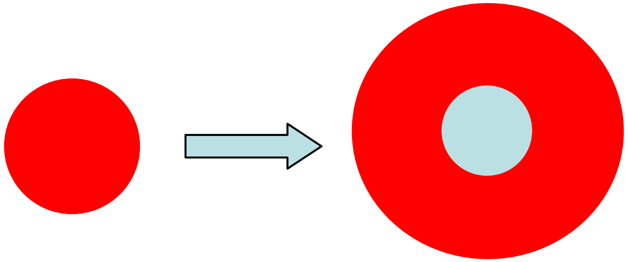
Electrons follow electrical field lines, but ions have different trajectory. Usually, they tend to damage central area of the cathode.



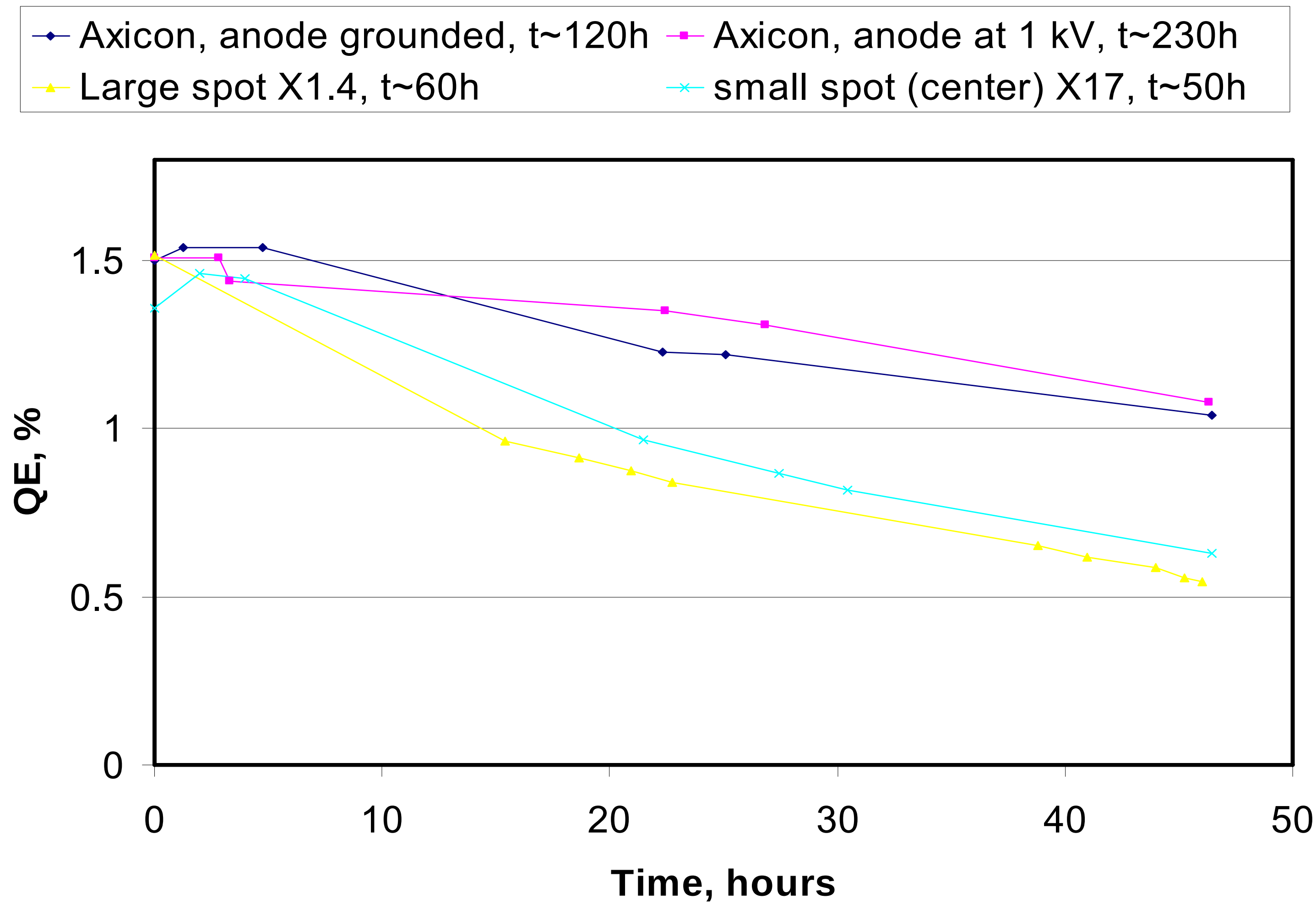
Ring-like cathodes ?



E. Tsentalovich
MIT-Bates

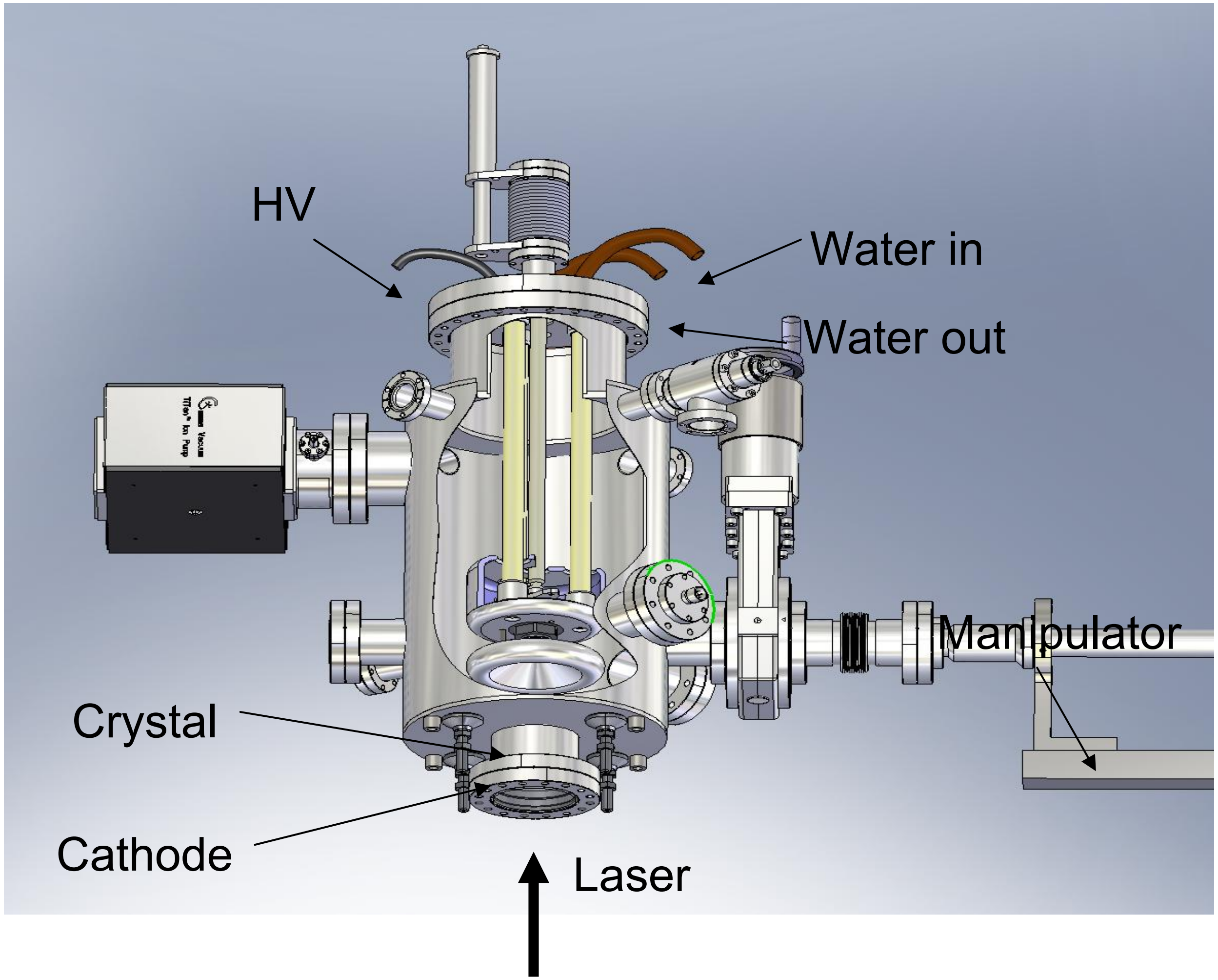


Lifetime

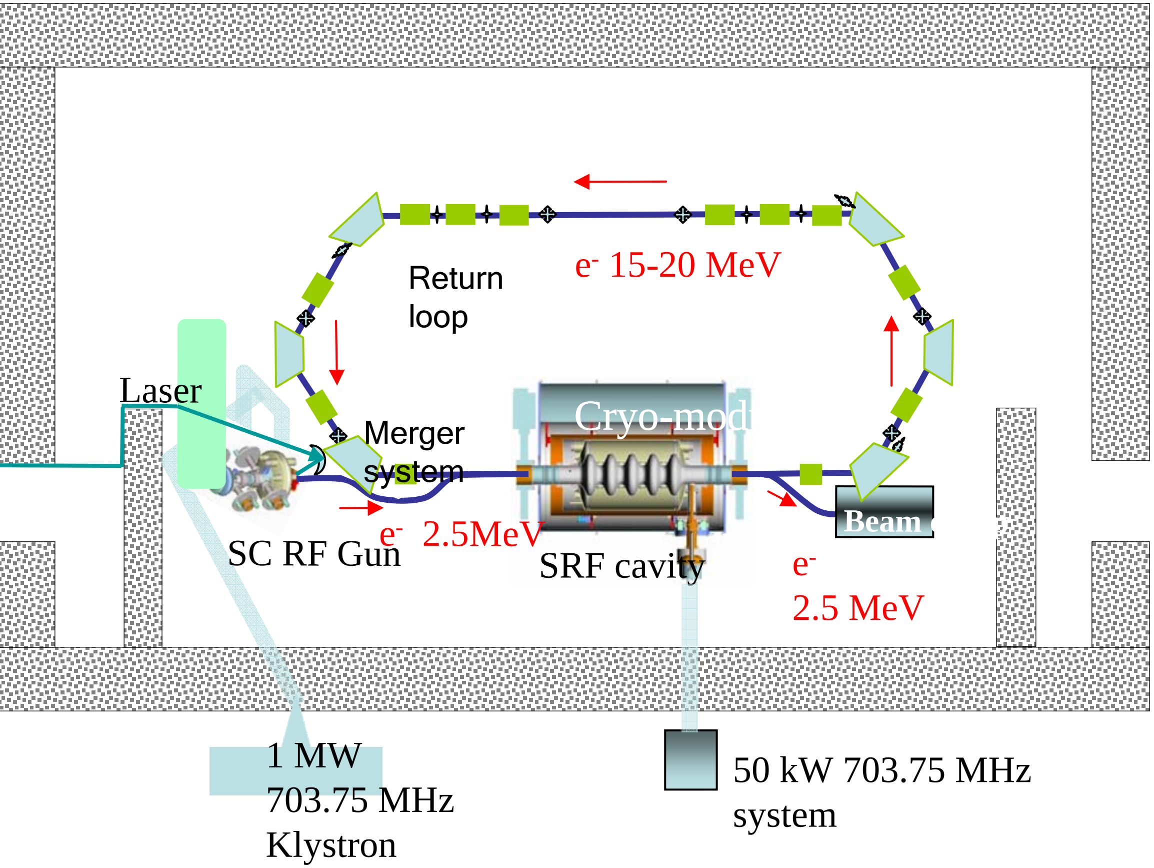


Axicon, anode grounded, t~120h
Axicon, anode at 1 kV, t~230h
Large spot X1.4, t~60h
small spot (center) X17, t~50h
QE, %
1.5
1
0.5
0
0
10
20
30
40
50
Time, hours

Cathode Cooling



ERL Test Facility



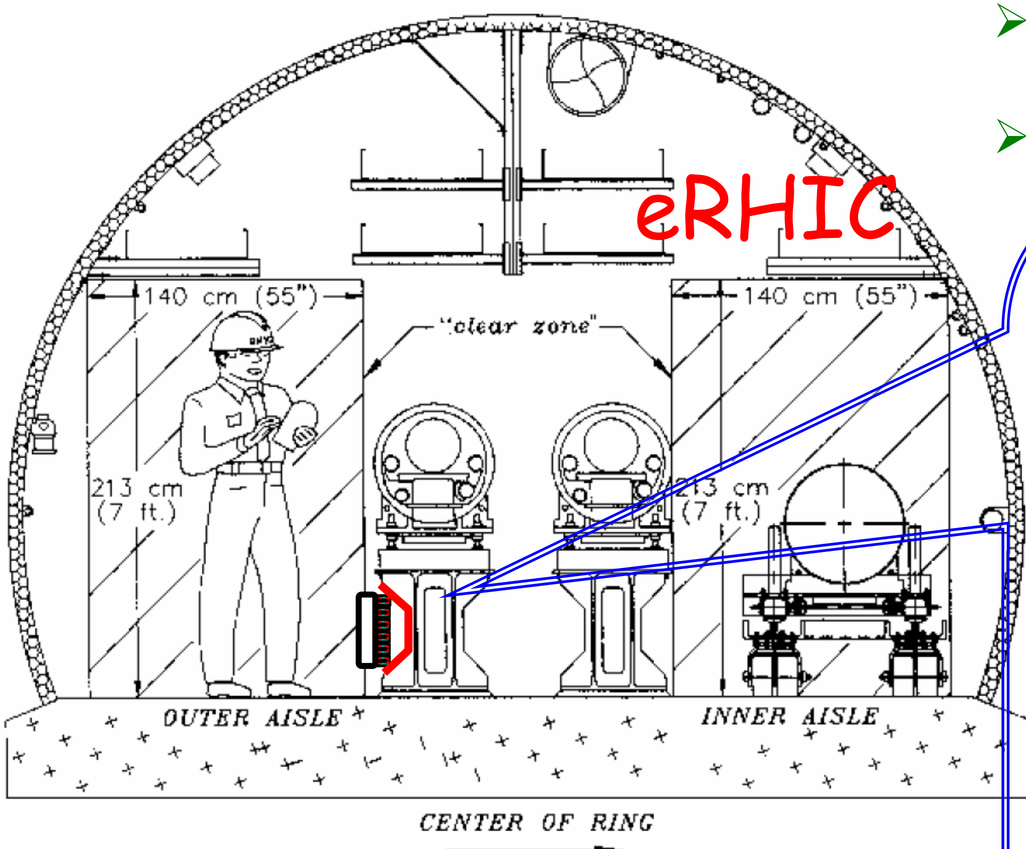
- test of high current (~ 0.5 A) high brightness ERL operation
- 5-cell cavity SRF ERL
- test of high current beam stability issues
- highly flexible lattice
- 704 MHz SRF gun test

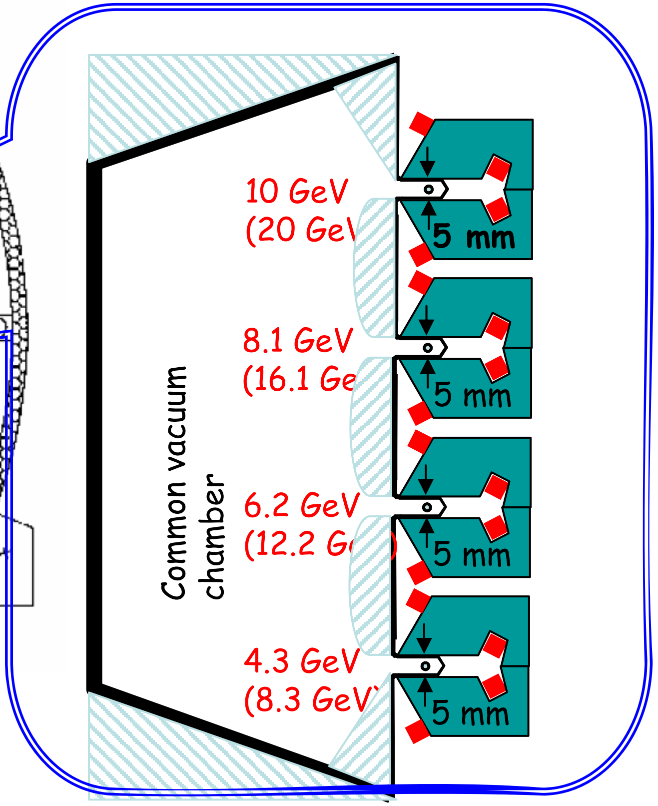
Start of commissioning in 2009.

5 cell SRF cavity arrived in BNL in March 2008 .

Recirculation passes

- Separate recirculation loops
- Small aperture magnets
- Low current, low power consumption
- Minimized cost





Approved LDRD for the compact magnet development

EIC central detector: emerging concept

A. Bruell

- 2 “main” components
  - electron detection in forward direction (theta<40^0)
  - final state detection and hadron identification in proton direction (theta > 140^0 ?)
- some low resolution energy measurement for central angles
- vertex detection (resolution better than 100 μm)
- plus:
  - electron detection at very low angles (how?)
  - detection of “recoiling” neutron and proton (maximum acceptance)
- plus:
  - luminosity measurement with accuracy of ~ 1%
  - polarization measurements with accuracy of ~ 1% (both electron and ion !)

Open issues/questions

• What is the optimal magnetic field configurations for such a detector ?

- simple solenoid most likely NOT sufficient
- solenoid plus toroid or solenoid plus dipole ?

• What angular/momentum resolution do we need for the electron ?

• What angular resolution do we need in the hadron detection ?

• Study of jet physics

• e-A Monte-Carlo development

• Calculation of backgrounds from beam gas events

A Detector for Forward Physics at eRHIC

Feasibility Study

I. Abt, A. Caldwell, X. Liu, J. Sutiak

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

July 20, 2004

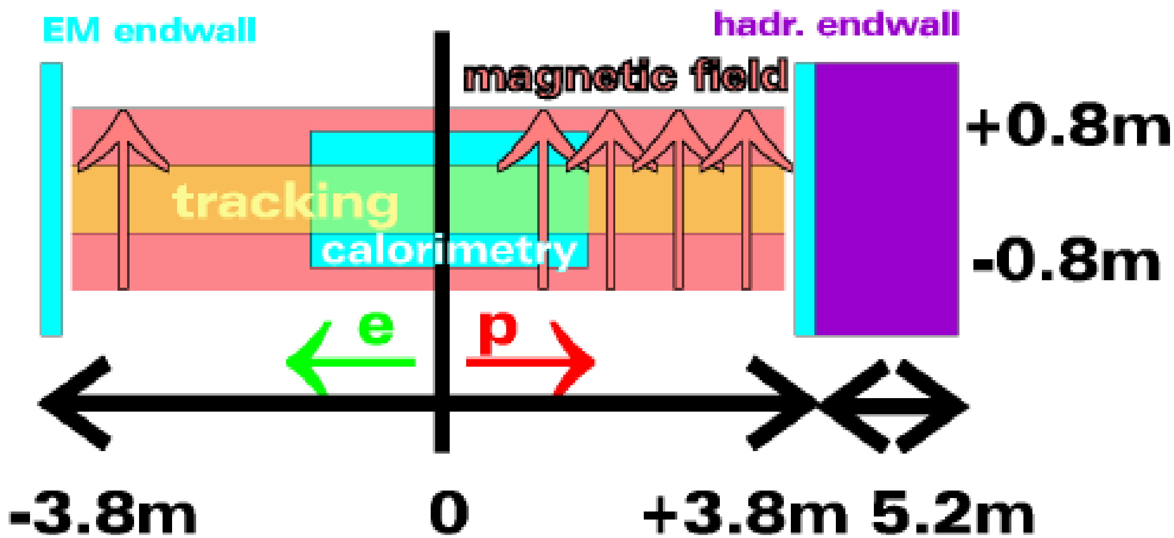
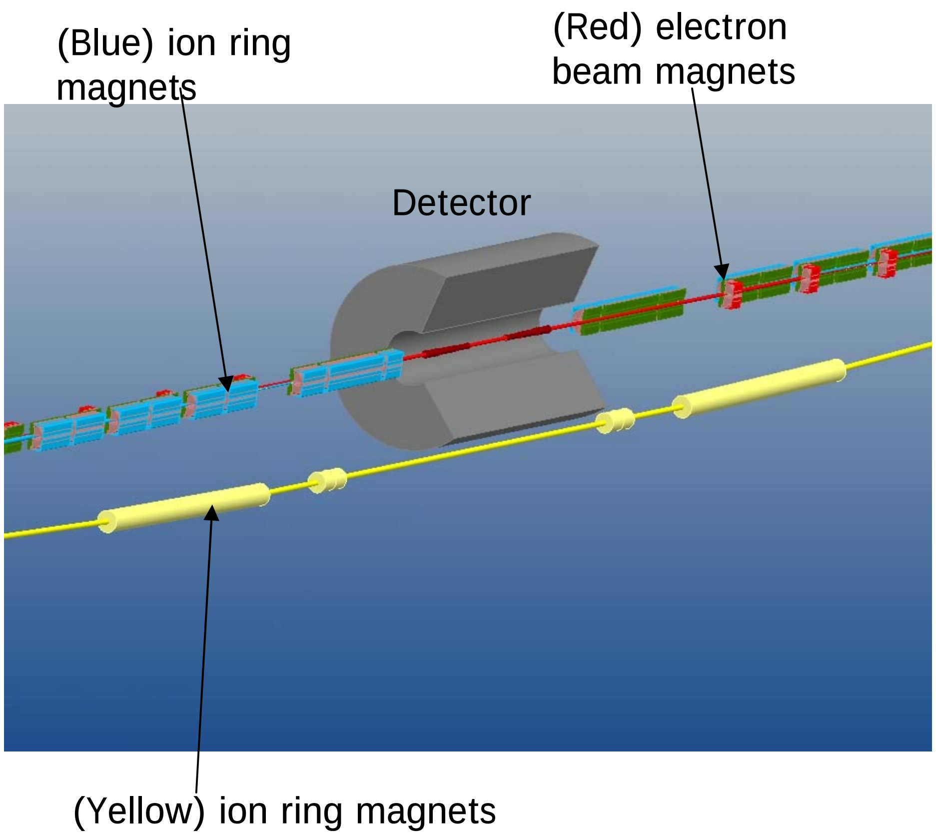


Figure 6: Conceptual layout of the detector with a 7m long dipole field and an interaction region without machine elements extending from -3.8 m to +5.2 m

Detector design

- Comprehensive reports on **E. Aschenauer**
  - ALICE/TRD
  - RICH/HERMES, Belle
  - New, clear aerogel/Novosibirsk
  - SiPMs/JLab, EUDET
- ELIC bunch frequency of 1.5 GHz sets very demanding requirements. Perhaps, this should be lowered?
- Detector design needs to evolve to point where R&D can be specified and prioritized.
- It is a priority to specify the detector magnetic field characteristics.
- Determination of beam related background is a major issue.

Interaction Region Design



Present IR design features:

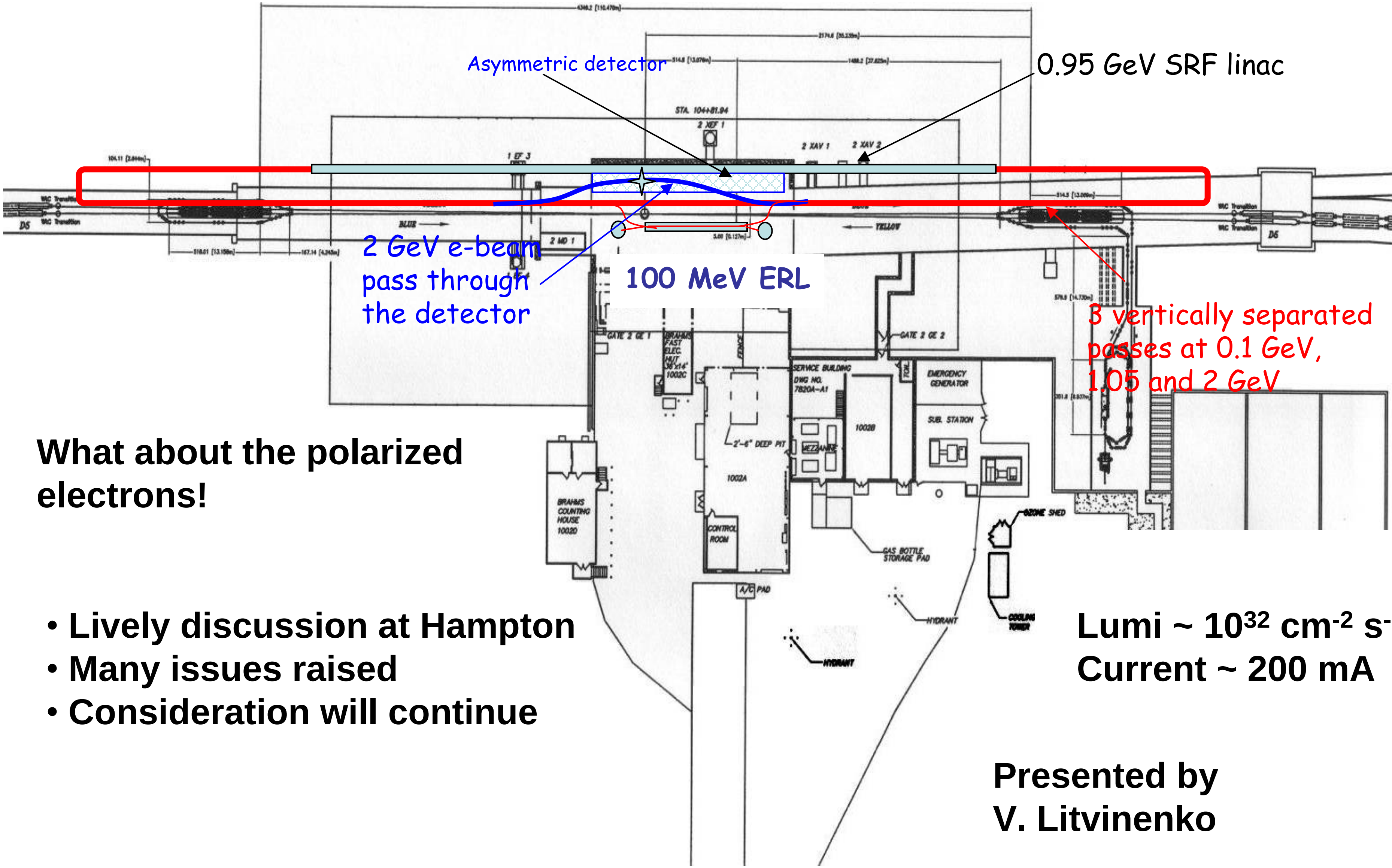
- **No crossing angle at the IP**
- **Detector integrated dipole: dipole field superimposed on detector solenoid.**
- **No parasitic collisions.**
- **Round beam collision geometry with matched sizes of electron and ion beams.**
- **Synchrotron radiation emitted by electrons does not hit surfaces in the detector region.**
- **Blue ion ring and electron ring magnets are warm.**
- **First quadrupoles (electron beam) are at 3m from the IP**
- **Yellow ion ring makes 3m vertical excursion.**

HERA type half quadrupole used for proton beam focusing

Staging of EIC

- Can one consider an initial stage of EIC where
  - cost is a fraction of that of full EIC
  - it can be realized on a significantly faster timescale than the full EIC?
- It must have a strong science case, i.e. it must open up a dramatic new capability.
- It should naturally evolve to the full EIC.
- Considerations include
  - luminosity ~ 10^{32} $cm^{-2}s^{-1}$
  - center of mass energy ~ 5 Gev $e^{\pm}$ on 250 GeV RHIC
  - polarized nucleon and nuclear beams
- Two scenarios for eRHIC
  - 2 GeV ERL in tunnel
  - 5 GeV positron ring outside tunnel
- Staging scenario for ELIC as defined above hard for me to see but if ther is one, it should be pursued.

Medium energy EIC with 2 GeV ERL @ IP2



What about the polarized electrons!

- **Lively discussion at Hampton**
- **Many issues raised**
- **Consideration will continue**

Lumi ~ 10^{32} cm^{-2} s^{-1}
Current ~ 200 mA

Presented by
V. Litvinenko

5 GeV positron ring

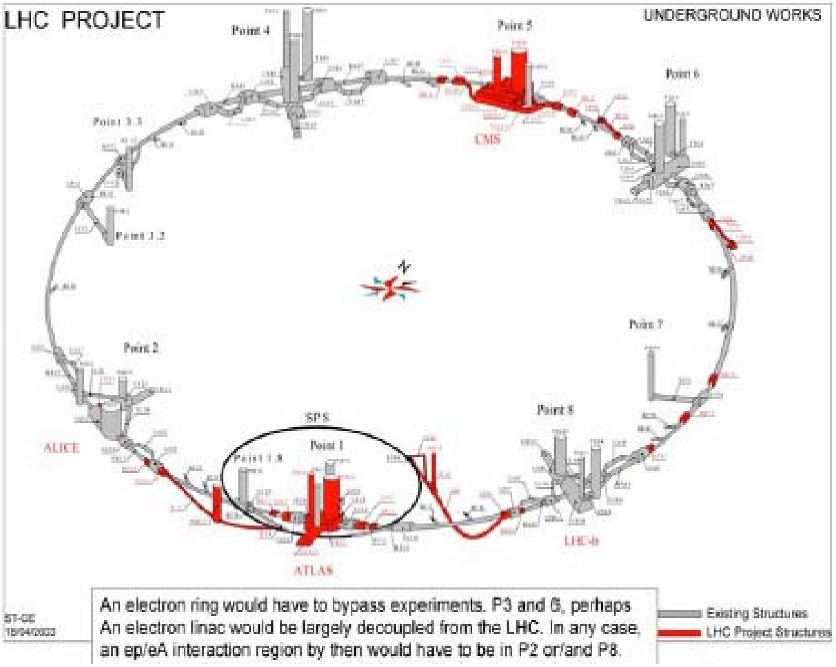
- In the present eRHIC design, positron beams are generated by a 5 GeV ring.
- From the ring-ring eRHIC design, the cost scale of a 5 GeV positron ring is well understood to be ~ $ 100 million.
- Using low energy injection, ramping and self polarization, one expects polarized 5 GeV electron and positron beams at a luminosity of 10^{32} $cm^{-2}s^{-1}$
  - circumference: ¼ RHIC
  - e-/e+ current: 0.5 A
  - high e-/e+ polarization: 80%, 5 min. self polarization time
  - Peak luminosity (e-,e+/p 165 bunches, 5 GeV/250 GeV) 2×10^{32} $cm^{-2}s^{-1}$
  - Use 0.5 GeV energy ERL as the injector.

F. Wang

- The ring would be outside the tunnel with minimal impact on the RHIC schedule.
- The full energy ERL and RHIC circulation system could be added at a later date.

The International Picture

- NuPECC activities
  - EIC study group approved at the meeting in Bucharest on 10/27/2007 with G. Rosner, chair
  - Charge is to produce a report outlining:
    - The science possibilities
    - The interest among European groups
    - Possible links with proposals outside Europe
- Glasgow meeting in Fall 2008.



LHeC meeting, Divenne, CH
September 2008

Goals for next EIC meeting

R. Ent

- **Accelerator Working Group:**
  Provide an estimate of achievable vacuum levels for the IR's of eRHIC/ELIC such that beam-related background levels can be estimated.
- **ep Working Group:**
  Provide resolution estimates for the "central region" (beyond the mentioned 40 degrees of the meeting), and start checking whether the "exclusive" particle species/ angle/momentum/resolution requirements also suffice for the semi-inclusive case
- **eA Working group:**
  Provide estimates for particle species/angle/momentum requirements for diffractive processes. This includes a first ad-hoc start of a diffractive generator.
- **Detector Working Group:**
  Provide estimates for field properties of various magnet configurations (solenoid + dipole/toroid, others) and their impact on expected resolutions. It is felt that a "non-GEANT" approach is o.k. to provide such first angle/momentum/resolution estimates.

Next EIC Collaboration Meeting:

Lawrence Berkeley National Laboratory
Berkeley California

December 11-13, 2008

Organizing Committee:
- Peter Jacobs (LBNL)
- Ed Kinney (Colorado)
- Gerhard Mallot (CERN)
- Ernst Sichtermann (LBNL)
- Xin-Nian Wang (LBNL)
- Feng Yuan (LBNL)

http://www-rnc.lbl.gov/~esichter/EIC-2008/

Skeleton agenda:

Thursday Dec 11
- 13:30 start
- Parallel Working Group sessions: e+p, e+A, detector

Friday Dec 12
- Morning: plenary
- Afternoon: parallel sessions
- Collaboration meeting dinner

Saturday Dec 13
- Morning: plenary
- Afternoon: Parallel session summaries, discussion
- 17:00 end

The meeting will focus on a few key physics drivers of the EIC, their impact on machine and detector design, and development of the written documentation needed to support discussion in the larger community.

Electron Ion Collider Collaboration

Steering Committee

- Abhay Deshpande, Stony Brook, RBRC (Co-Chair/Contact person)
- Rolf Ent, Jlab
- Charles Hyde, ODU/UBP, France
- Peter Jacobs, LBL
- Richard Milner, MIT (Co-Chair/Contact person)
- Thomas Ulrich, BNL
- Raju Venugopalan, BNL
- Antje Bruell, Jlab
- Werner Vogelsang, BNL

International Advisory Committee

- Jochen Bartels (DESY)
- Allen Caldwell (MPI, Munich)
- Albert De Roeck (CERN)
- Walter Henning (ANL)
- Dave Hertzog (UIUC)
- Xiangdong Ji (U. Maryland)
- Robert Klanner (U. Hamburg)
- Katsunobu Oide (KEK)
- Naohito Saito (KEK)
- Uli Wienands (SLAC)

Working Groups and Convenors

- **ep Physics**
  - Antje Bruell, JLAB
  - Ernst Sichterman, LBL
  - Werner Vogelsang, BNL
  - Christian Weiss, JLAB
- **eA Physics**
  - Vadim Guzey, JLAB
  - Dave Morrison, BNL
  - Thomas Ullrich, BNL
  - Raju Venugopalan, BNL
- **Detector**
  - Elke Aschenauer, JLAB
  - Edward Kinney, Colorado
  - Bernd Surrow, MIT
- **Electron Beam Polarimetry**
  - Wolfgang Lorenzon, Michigan

Summary

- The Electron-Ion Collider is the next generation accelerator concept for the study of QCD in the U.S.
- In Europe, LHeC as a future evolution for CERN is under discussion.
- It is essential to lay the foundations for the next Long Range Plan Exercise in ~ 2013.
  - It will be necessary to broaden and deepen the science case.
  - Strong, international support is required.
  - It is highly desirable to have a single EIC accelerator design by ~ 2012.
- Staging scenarios should continue to be studied.
- R&D on the accelerator and detector must have a high priority.
- While the path to the full EIC is long and uncertain, considerable progress has been made by a determined group of highly motivated people.
- The rate of progress is determined by the available manpower so all means to enhance the effort should be utilized.
- We look forward to the next meeting at Berkeley, CA in December.