Electron Ion collider proposals: A brief overview

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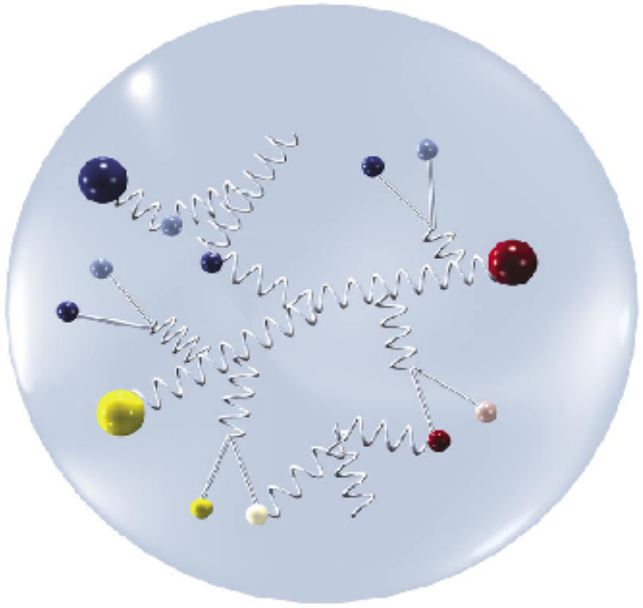
Slides liberally taken from:

M. Vanderhaeghen, A. Jankowiak, U. Schneelkloth, V. Litvinenko, Y. Zhang, R. Ent and other EIC collaborators (THANK YOU)

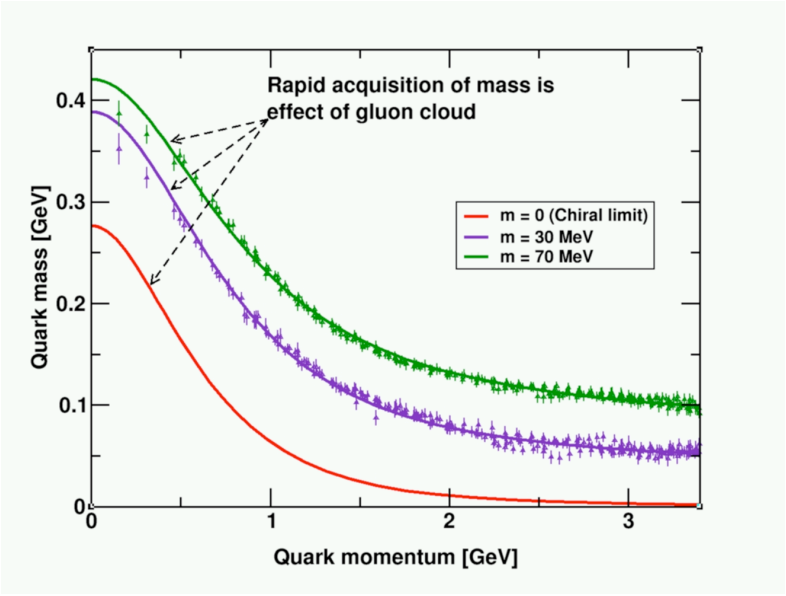
In this talk….

- Open questions in QCD
  - Physics motivations for the EICs
  - Details in talks by E. Kinney & R. Venugopalan
- Deep Inelastic Scattering
- The four EIC proposals
- The US EIC proposals:
  - Status & organization
  - Roadmap to realization & possible timelines
- A summary & invitation



QCD and the Origin of Mass

- 99% of the proton's mass/ energy is due to the self-generating gluon field
  - Higgs mechanism seems to play no/minimal role



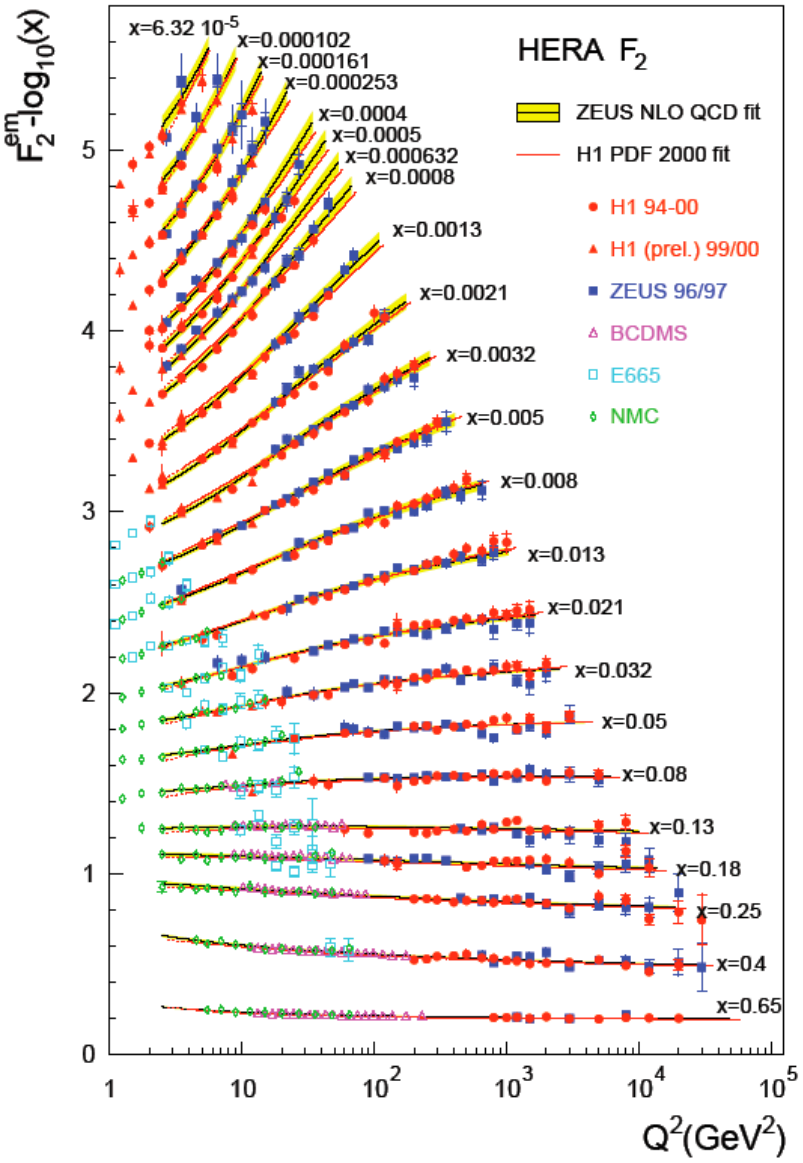
- The similarity of mass between the proton and neutron arises from the fact that the gluon dynamics are the same
  - Quarks contribute almost nothing to the nucleon's mass

How well do we
understand the glue in the
nucleons and the nuclei?

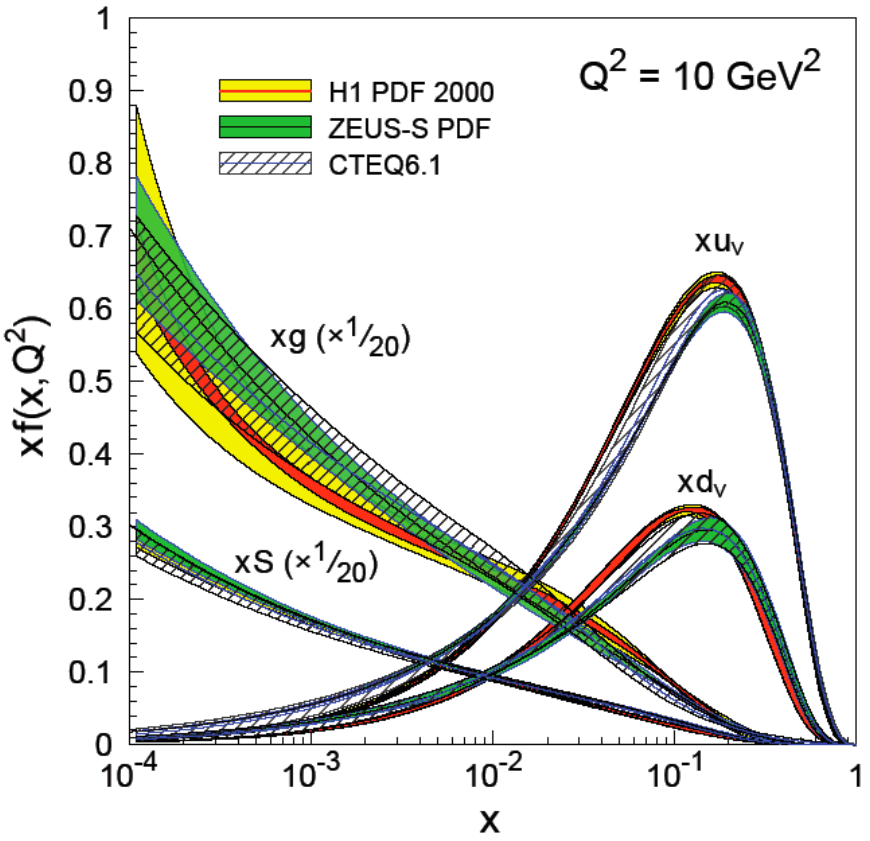
Unfortunately not well enough…

…Discussion in R. Venugopalan's Talk

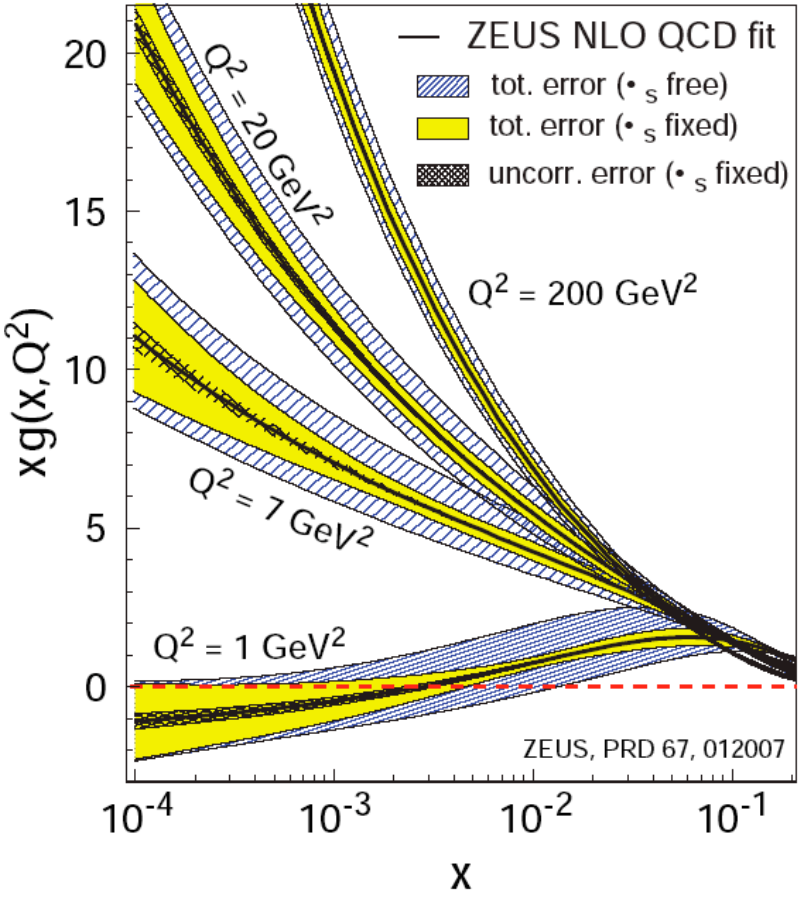
Measurements of the Glue at HERA

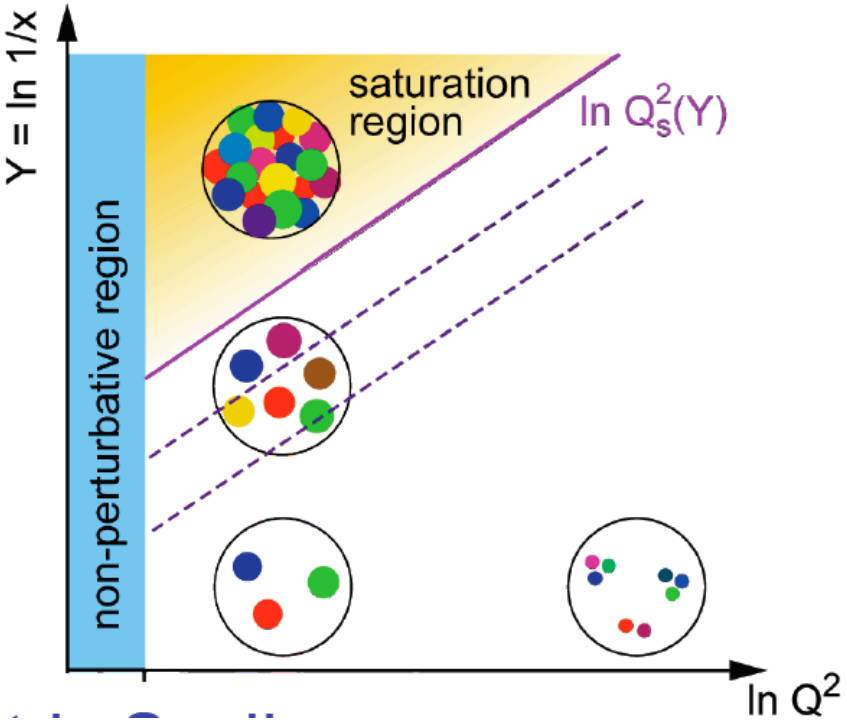


Scaling violations of $F_2(x,Q^2)$
Linear DGLAP equations



Gluons: not well understood!





Linear DGLAP @ low x:

Rises with Q^2? Cross sections?

Small, even negative at low Q^2

Nonlinear effects: Saturation!

High gluon densities most easily accessed in nuclei

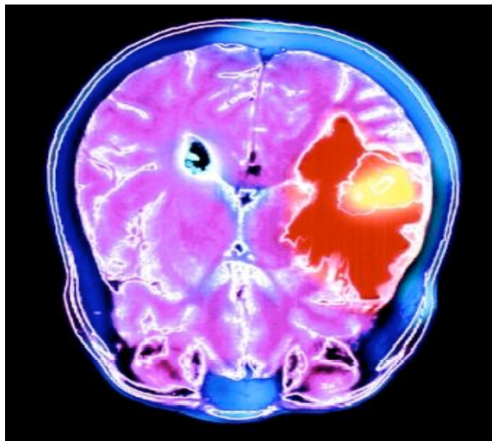
BK/JIMWLK propose:

Characteristic scale $Q_s(x,A)$

Color glass condensate!

e-A data at low x, also at low Q^2

Proton spins are used to image the structure and function of the human body using the technique of *magnetic resonance imaging*.

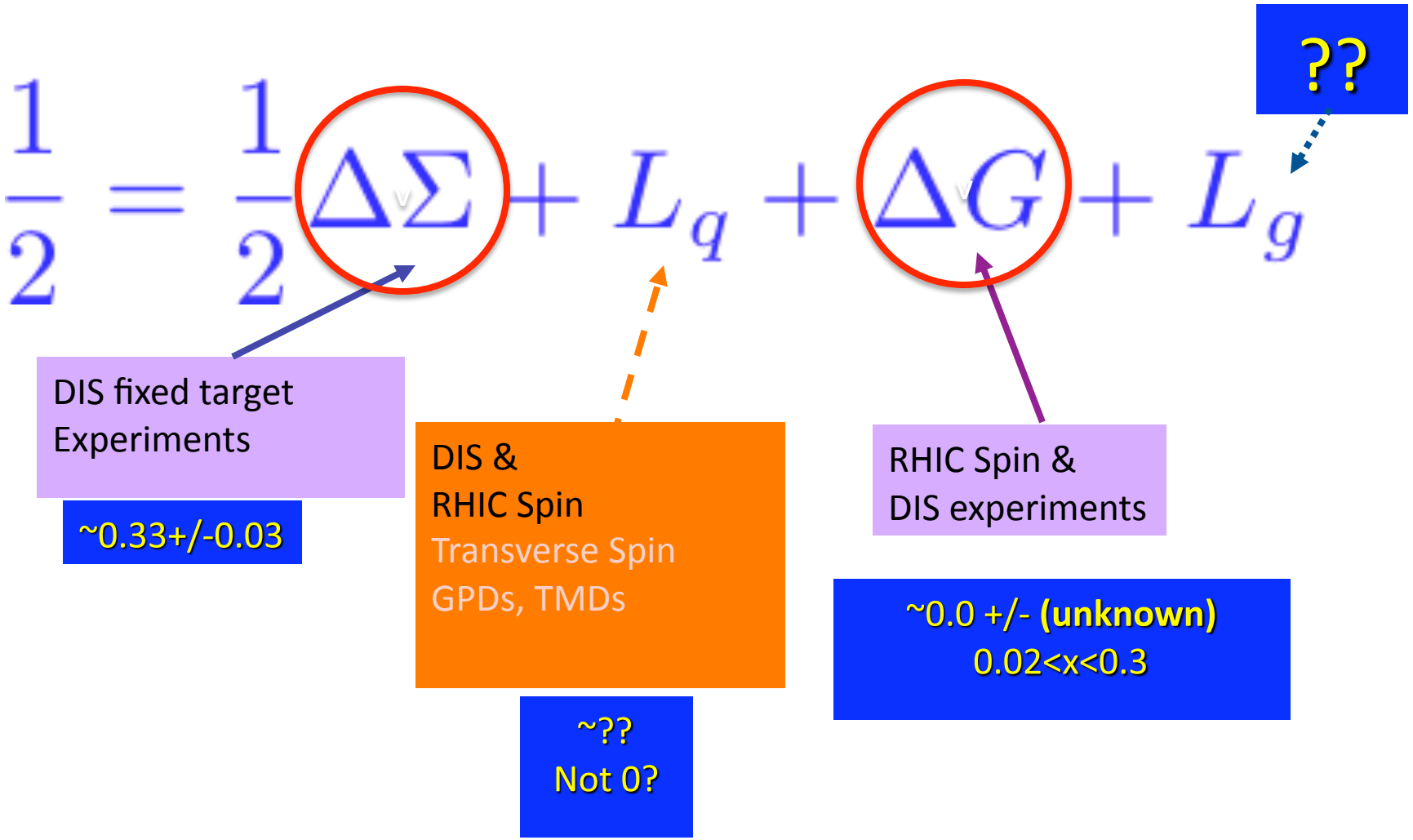


How well do we understand the origin (constitution of) the nucleon's spin (= ½) ?

Not well enough!

E. Kinney's talk today

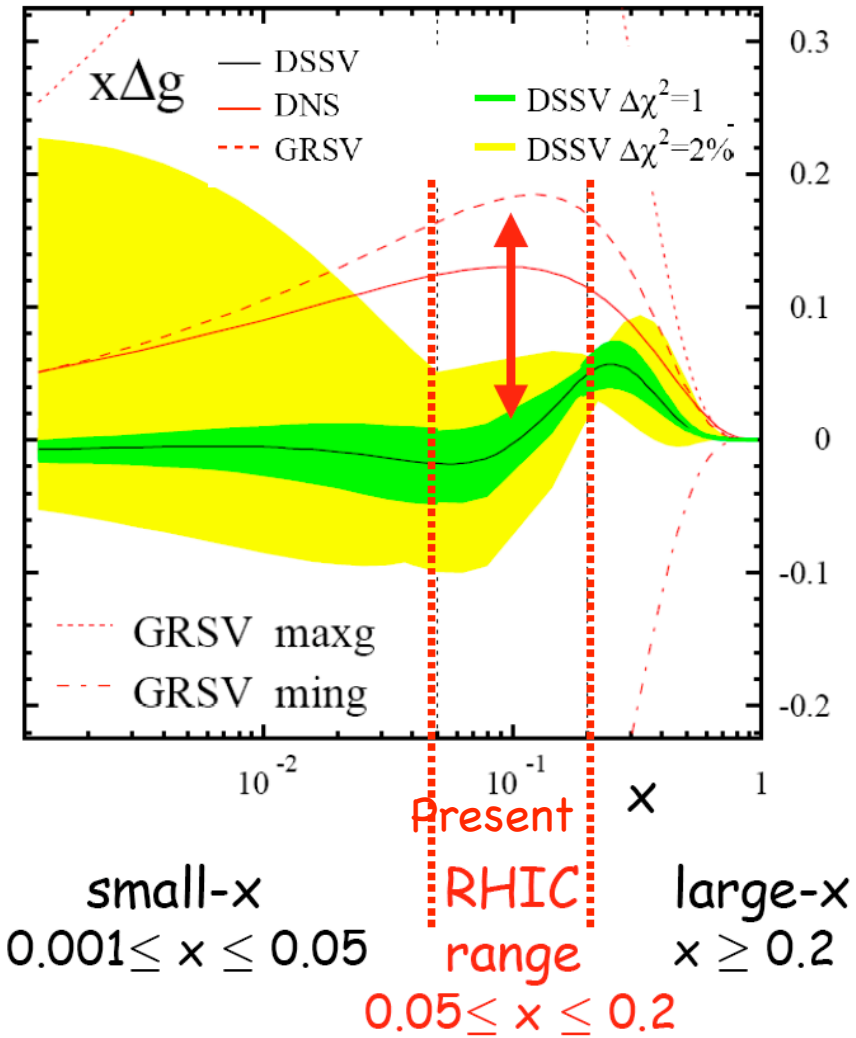
Understanding the Nucleon Spin



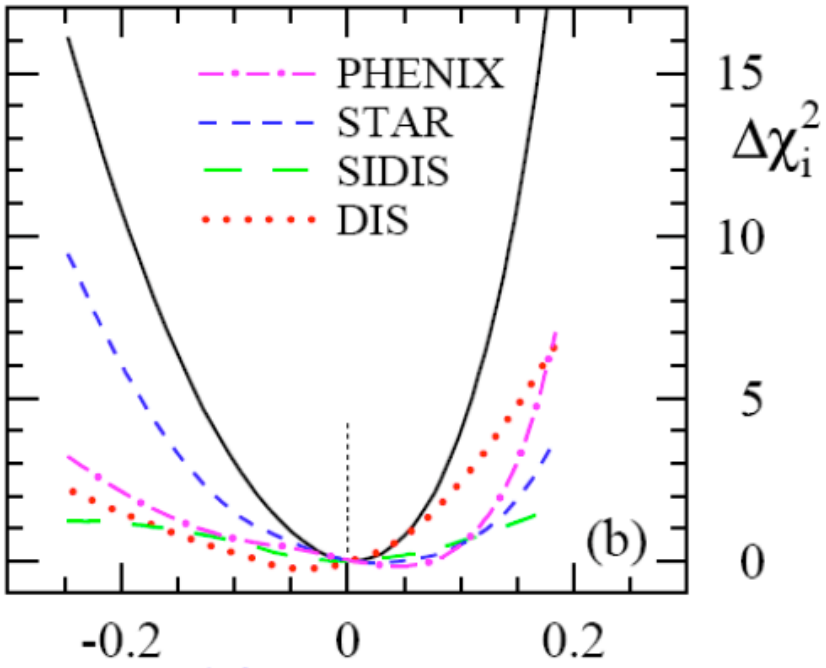
Gluon's role in Nucleon Spin

De Florian, Sassot, Stratmann & Vogelsang

Recent Analysis: $\Delta G(x)$ @ Q^2=10 GeV^2



- **Global analysis: DIS, SIDIS, RHIC-Spin**
- **Uncertainly on ΔG large at low x**



$$\delta g \equiv \int_{0.05}^{0.2} \Delta g(x, 10\,\mathrm{GeV}^2)\,dx$$

Fundamental Questions in QCD

- How do gluons contribute to the structure of the nucleon?
- What role do the gluons play in determining the spin structure of the nucleon?
- What is the spatial distribution of the gluons and sea quarks in the nucleon?
- How do the gluons contribute to the structure of the nuclei?
- What are the properties of *high density* gluon matter?
- How do fast quarks and gluons interact when they traverse through nuclear matter?

How do we get to the answers?

Precise imaging of the sea-quarks and gluons in the nucleon

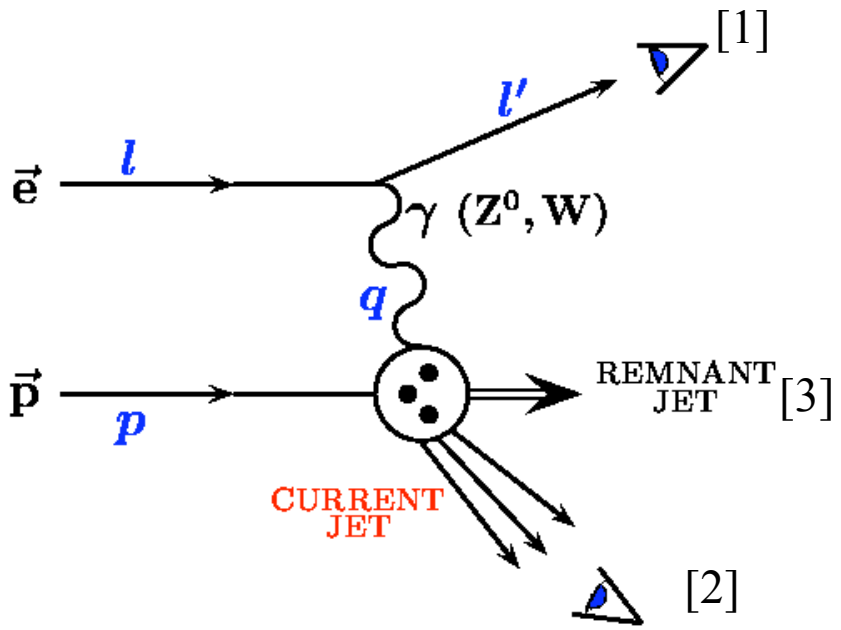
Need to explore a new QCD frontier: of strong color fields in nuclei

Electron Ion Collider

A high energy, high luminosity polarized electron-proton and electron-ion collider will enable us to explore some of the most fundamental and universal aspects of QCD

Deshpande A., et al, Ann. Rev. of Nucl. Part. Sci. 2005, 55:165-228
NSAC Long Range Plan 2007, arXiv:0809.3137

Deep Inelastic Scattering



$$Q^2 = -q^2 = sxy$$

$$x = \frac{Q^2}{2p \cdot q}$$

$$y = \frac{p \cdot q}{p \cdot l}$$

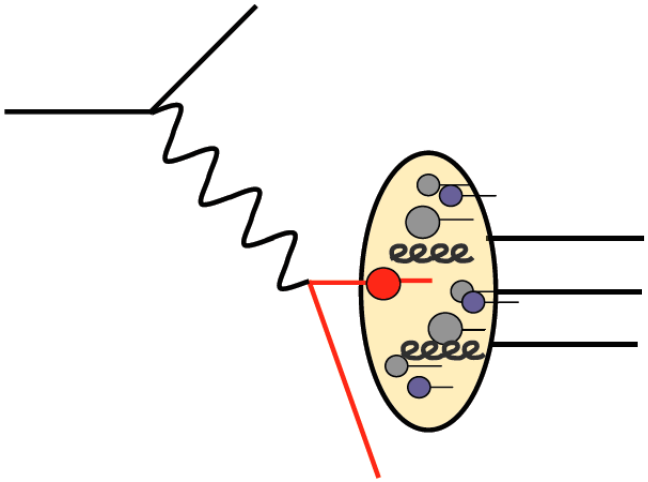
$$s = 4E_e E_p$$

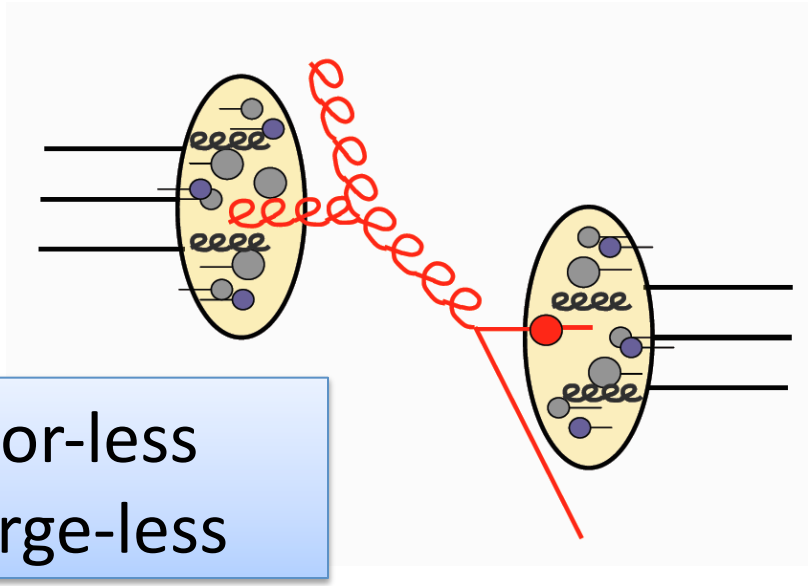
$$W = (q + p)^2$$

- Observe scattered electron [1] inclusive measurement : **< 2 fb^{-1}**
- Observe [1] + current jet [2] semi-inclusive measurement **~ 5 fb^{-1}**
- Observe [1] + [2] + remnant jet [3] exclusive measurement **> 10 fb^{-1}**
- Luminosity requirements go up as we go from [1] --> [2] --> [3]
- **Exclusive measurements put demanding requirement on detectors, interaction region and their integration**

DIS (probe: γ) vs. PP (probe: q,g)

Complementary!





γ color-less
g charge-less

DIS Explores QCD & Hadron structure

H-H reactions test QCD

"DIS + H-H" we understand QCD & the hadron structure

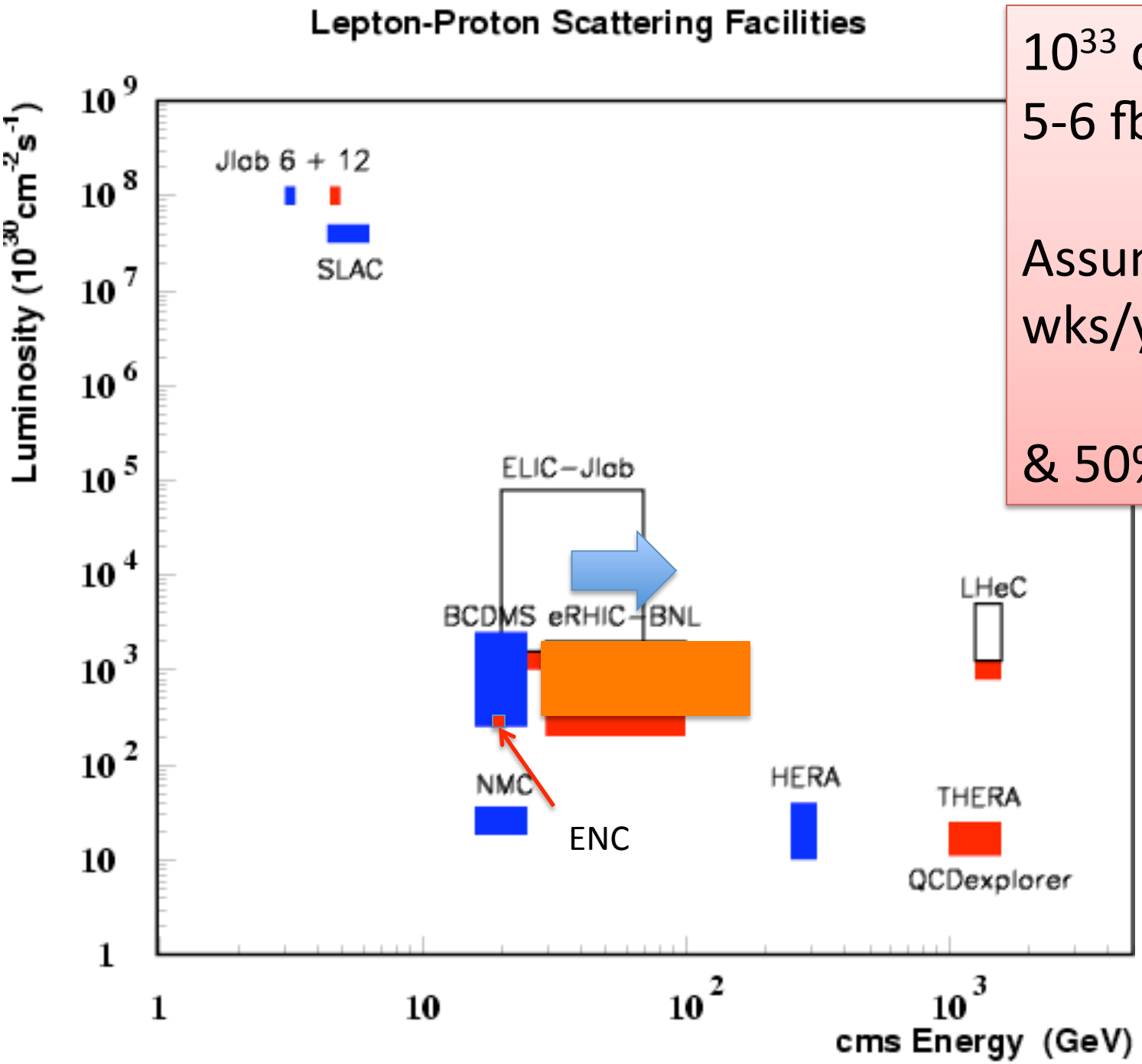
The EIC proposals

(All based around existing facilities)

- European Nucleon Collider ENC@GSI (~1 yr old)
- ELectron Ion Collier ELIC @Jlab (~5 yr old)
- *e*RHIC @ BNL (~10+ yr old)

US EIC

- Large Hadron electron Collider LHeC (~ 2 yr old)

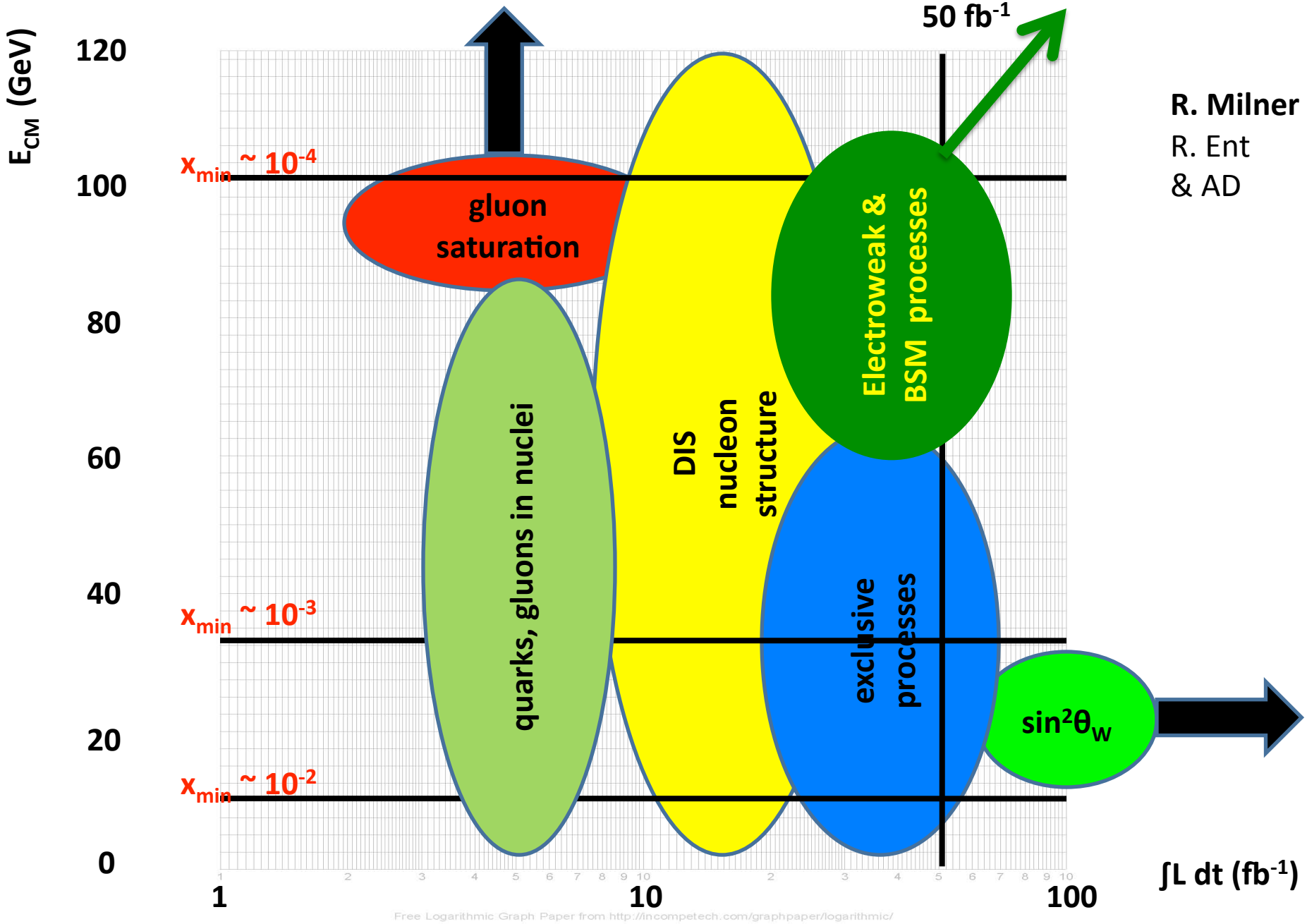


10^{33} cm^{-2}s^{-1} = 5-6 fb^{-1}/yr

Assuming ~30 wks/yr

& 50% efficiency

Science reach as function of E_{CM} and integrated luminosity



The European Nucleon Collider

M. Vanderhaeghen

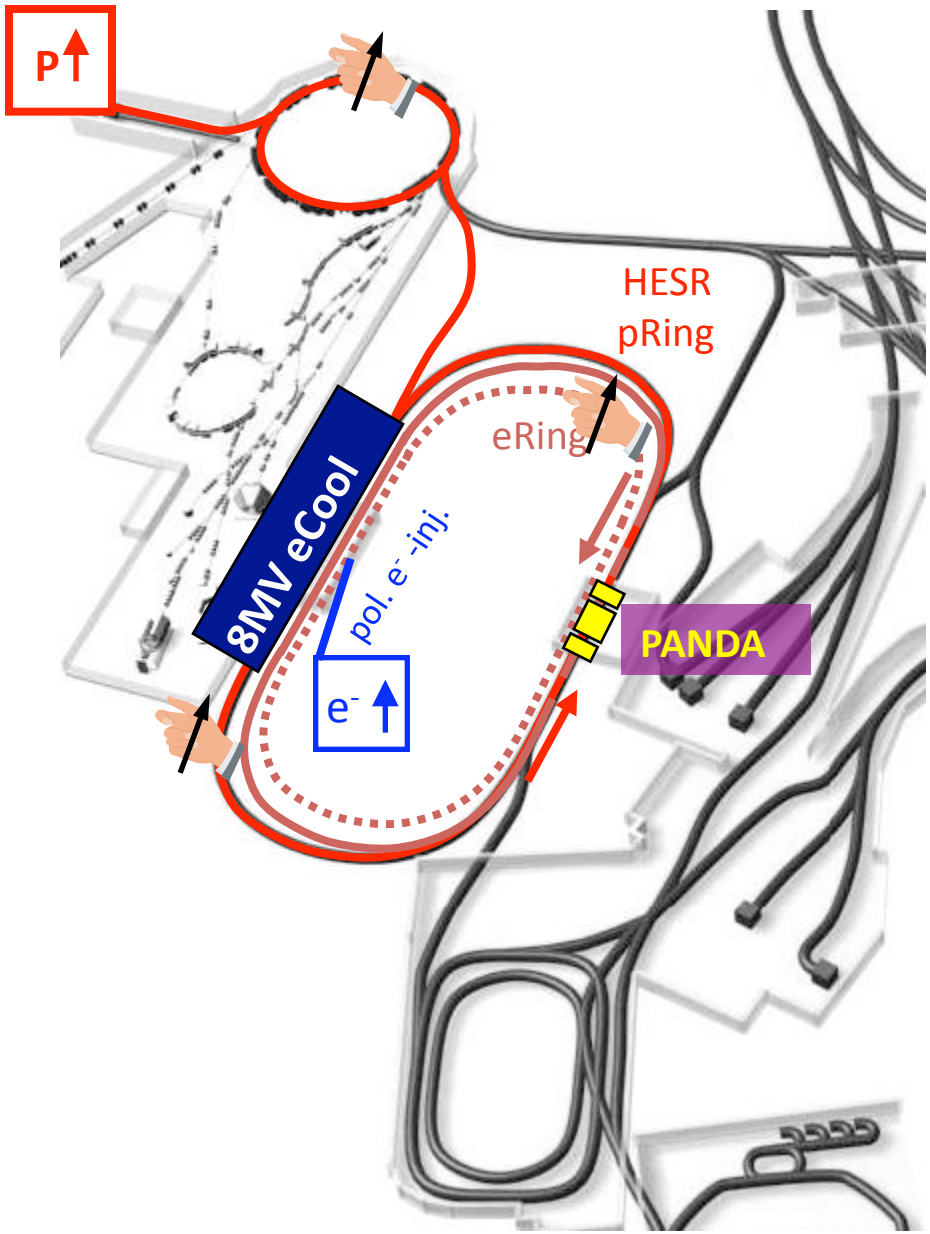
- **A "simple" idea:**
  electron – nucleon collisions using the HESR
- **Luminosity considerations for a**
  electron – "low energy" nucleon collider
- **Some comments on the necessary ingredients**
- **First parameter sets for e-p collisions at**
  $s^{1/2}$=14GeV (3.3GeV e^- on 15GeV p)
- **Deuterons**
- **Conclusion**

Physics of ENC @ GSI

- Center of mass between HERMES at DESY and COMPASS at CERN (14 GeV)
  - Advantage of collider geometry over fixed target for exclusive & semi-inclusive measurements

- Intended focus on *mid-high-x transverse* momentum distributions (TMDs) and GPDs via Deeply virtual compton scattering (DVCS) and DV Vector Meson production measurements
  - **Low x IMPORTANT but impractical from their point of view**

A “simple” idea: ENC@FAIR (ii)



idea emerged 08/2008

$L > 10^{32}$ 1/cm²s

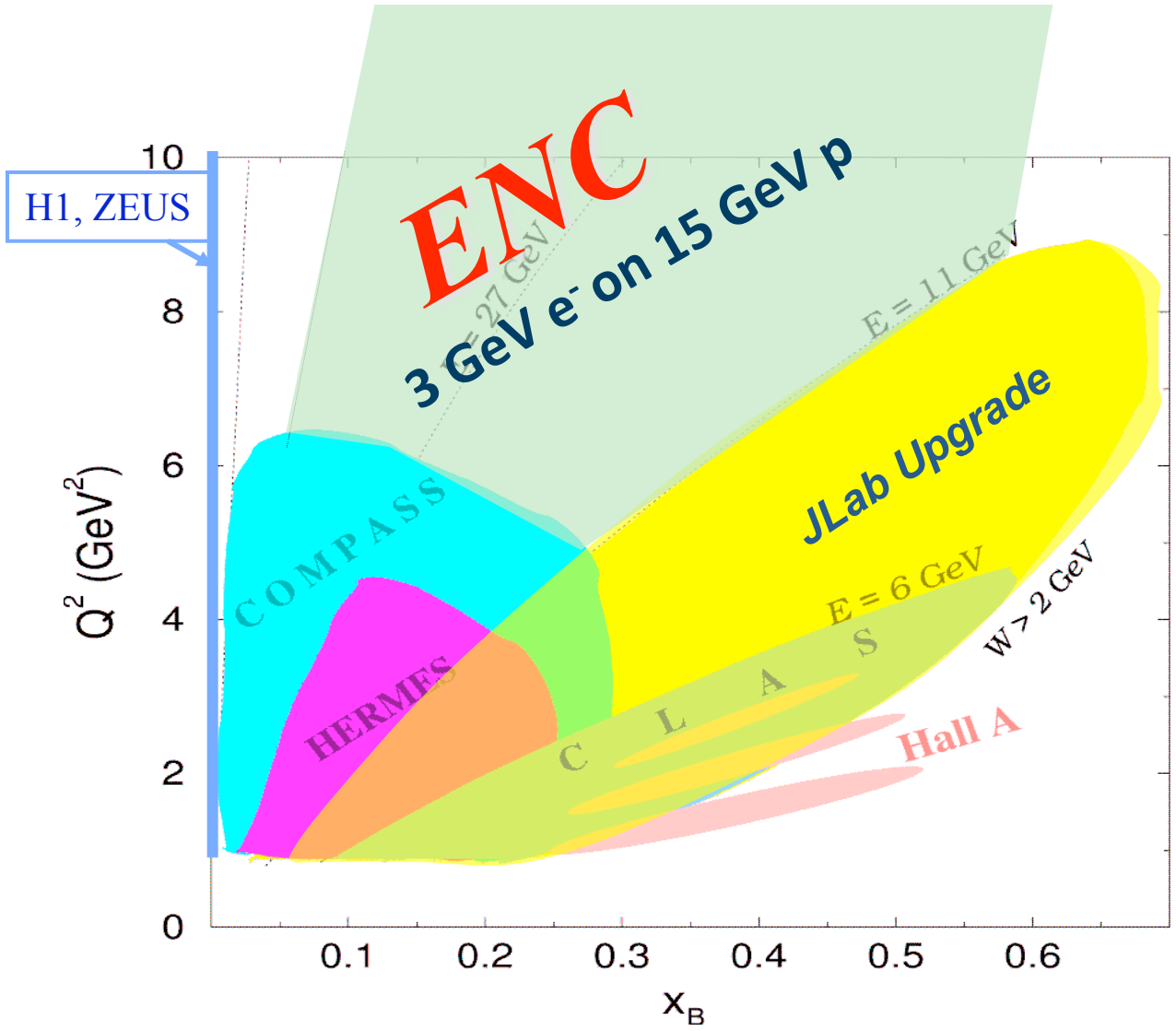
$s^{1/2} > 10$GeV
(3.3GeV e^- ↔ 15GeV p)

polarised e^- (> 80%)
↔
polarised p / d (> 80%)
(transversal + longitudinal)

using the PANDA detector
as much as possible

Common effort of
German Universities
(Bonn, Mainz, Dortmund)
plus collaboration with
Research Centres
FZJ, DESY, GSI, ...

ENC : The Energy / Luminosity Frontier



high energy
and
high luminosity
required
+
polarization

Helmholtz Institut Mainz (HIM)

Cooperation between Mainz University ↔ GSI (Helmholtz Centre)

- Application in March 2009
- Review in April 2009 ("strongly recommends the foundation")
- Final decision on 05.06.09: **THIS FRIDAY!**
- Start: Summer 2009

Section: Accelerator Physics and Integrated Detectors (ACID)

Resources

2 x PostDoc, 3 x PhD *(1 x PostDoc, 1 x PhD)*

Tasks

ENC@FAIR:

IR design and detector integration, bunch formation in HESR, beam – beam

→ In collaboration with participating institutes:

1st order design report (2011), Technical Design Report (2012/2013)

eCool HESR/ENC:

solenoid channel, beam diagnostics, upgrade 4.5MV → 8.2MV

sc cw demonstrator linac section for super heavy element production

All transparencies from B.Holzer, CERN DIS2009 Madrid

LHeC Study Group: 3 options

Accelerator Design [RR and LR]

Oliver Bruening (CERN),

John Dainton (CI/Liverpool)

Interaction Region and Fwd/Bwd

Bernhard Holzer (CERN),

Uwe Schneekloth (DESY),

Pierre van Mechelen (Antwerpen)

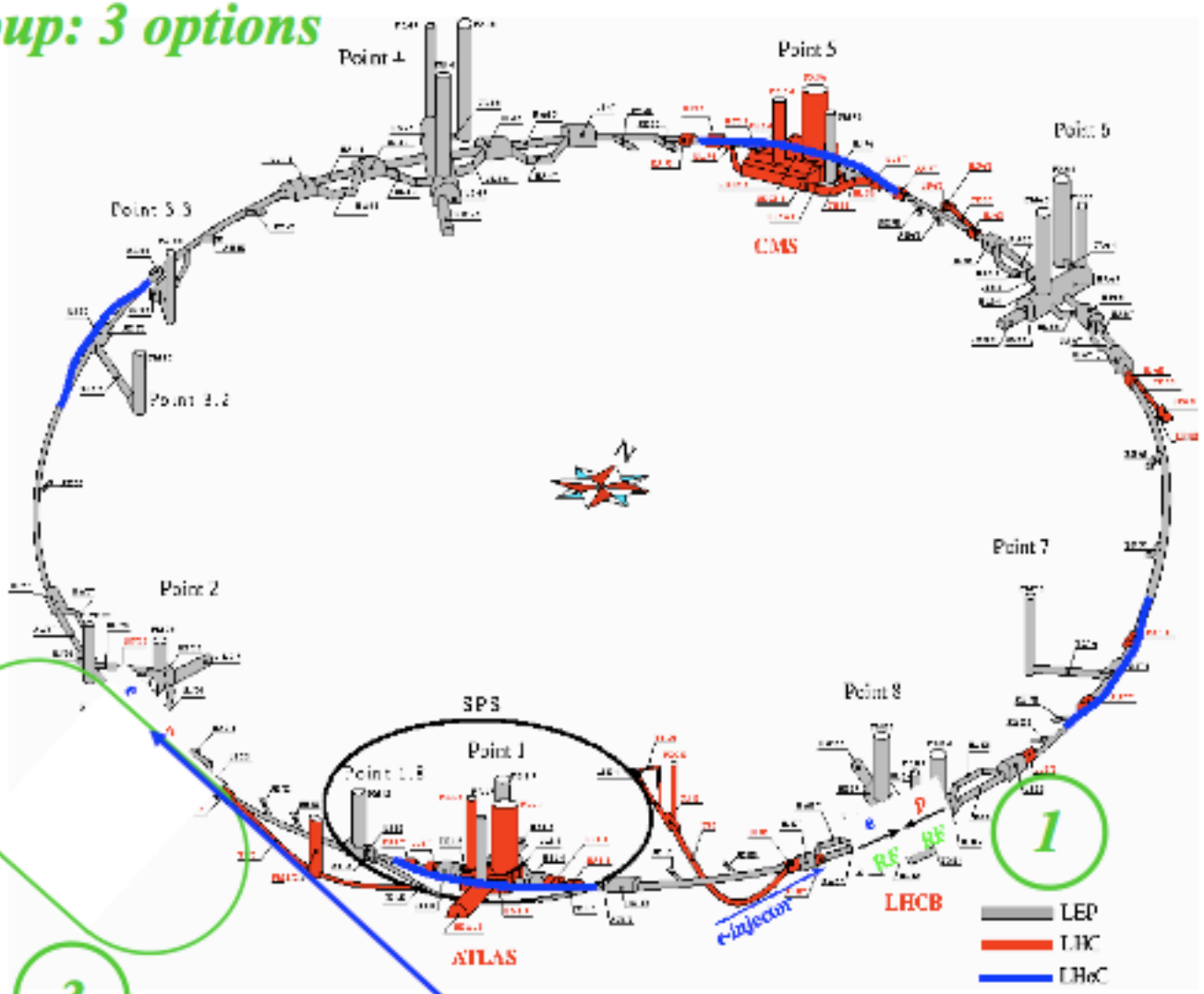
Detector Design

Peter Kostka (DESY),

Rainer Wallny (UCLA),

Alessandro Polini (Bologna)

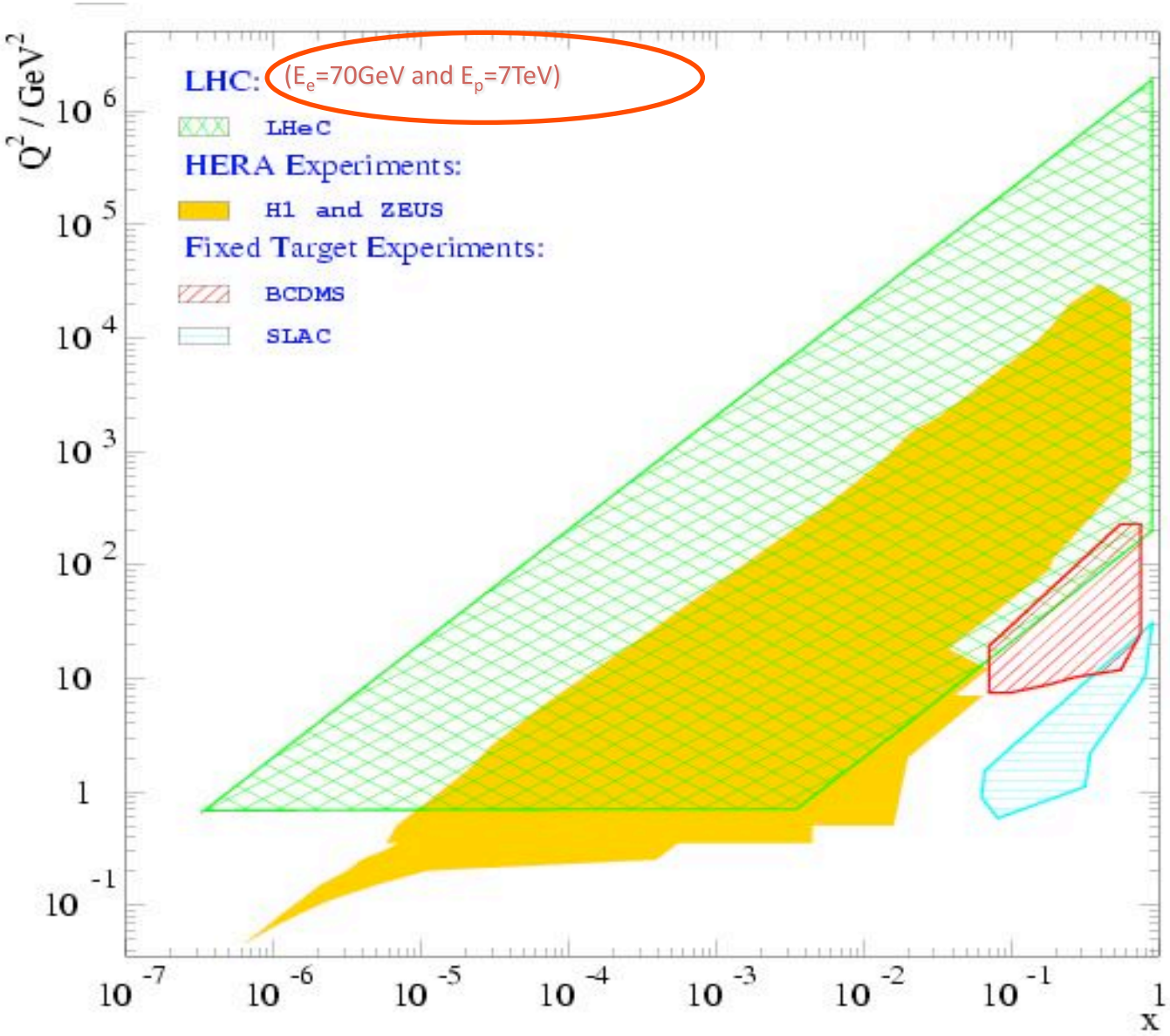
... and many colleagues



LHeC Physics

- 70-140 GeV e- beam on 7 TeV proton beam
  - **CM energy ~ 1.5 TeV**
- Physics scope:
  - QCD Low x: region of high gluon density
    - See Raju Venugopalan's talk today
  - Electro Weak Physics & Beyond SM: Lepto-Quark, Super Symmetry… (refer to **http://www.lhec.org.uk**)
  - **No polarization in protons or any nuclear species: NO SPIN**

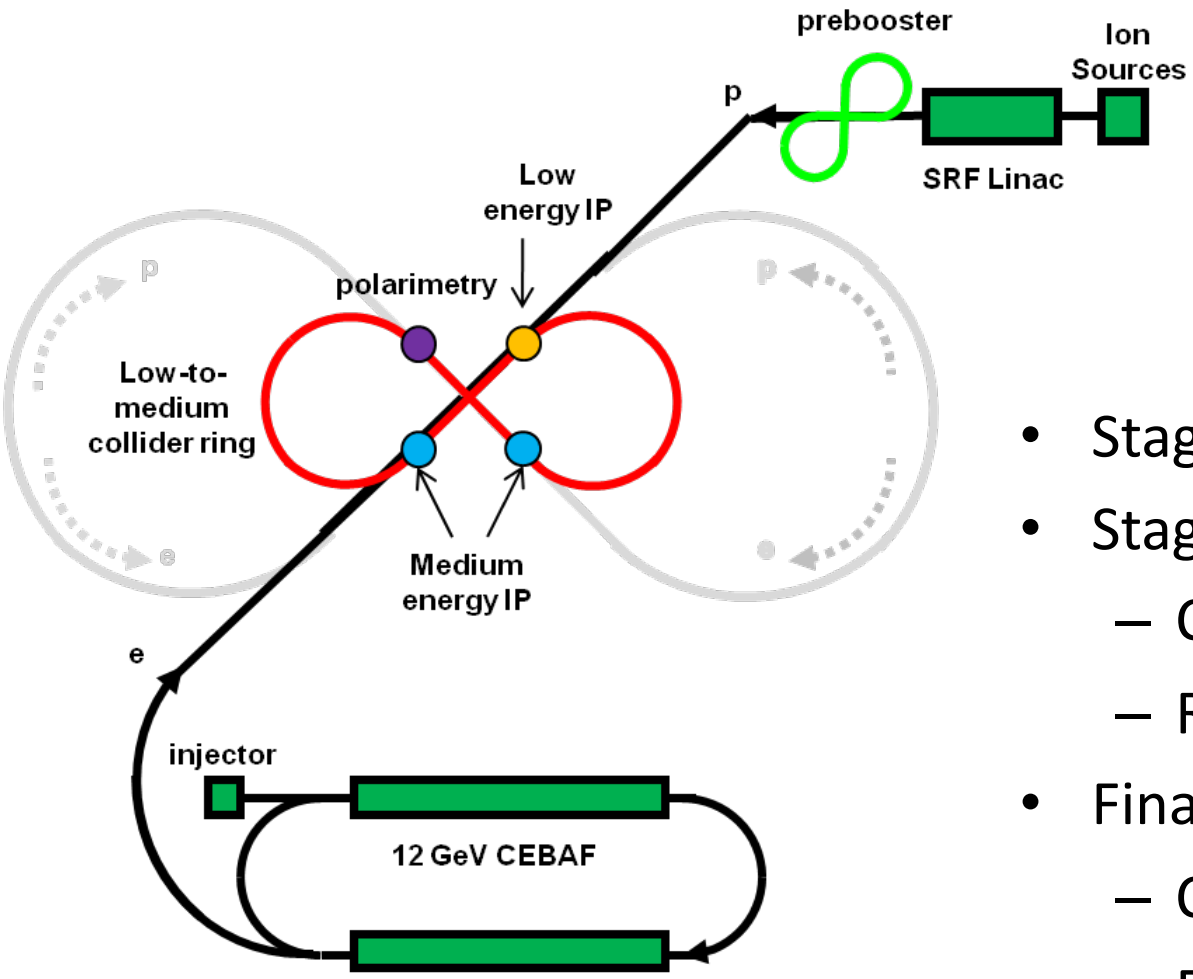
LHeC with protons



The EIC Project in the US

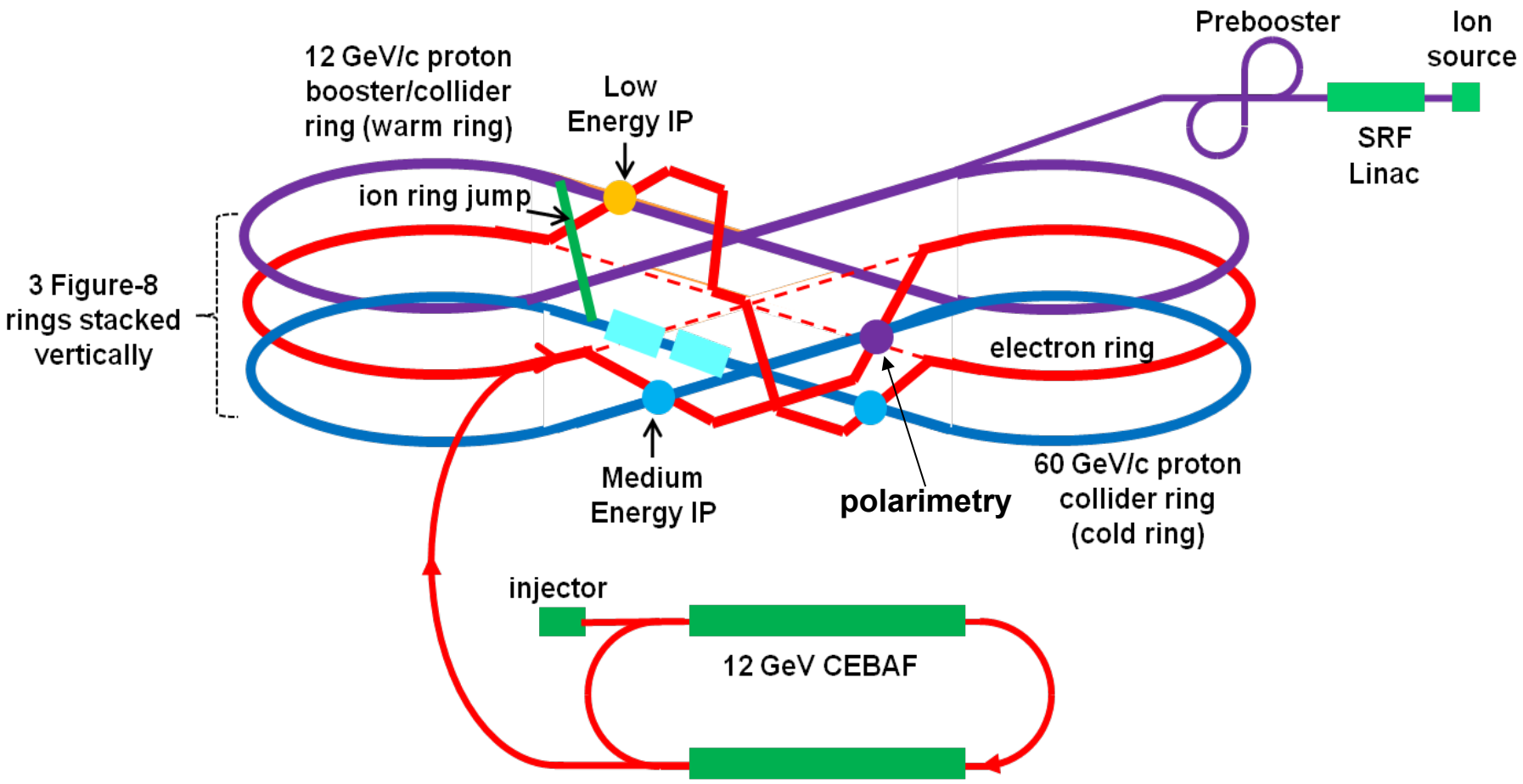
- ELectron Ion Collider (ELIC @ Jlab)
  - Utilizes the existing CEBAF Complex about to be upgraded 12 GeV
  - green field design and novel accelerator concepts
- eRHIC at BNL
  - Utilizes the existing RHIC and a conservative parameters for e/hadron beam performance
- Significant R&D for both projects, nevertheless
  - Discussion in Dejan T.'s talk today

ELIC at Jlab (present design)

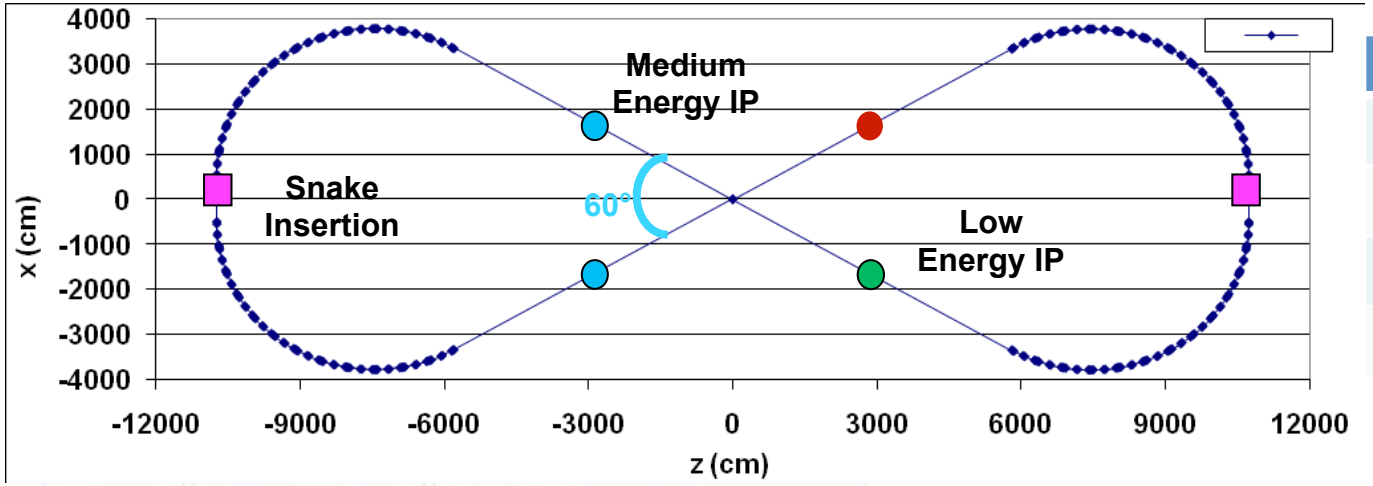


- Staged realizable
- Stages 1 & 2
  - CM ~ 12 -50 GeV
  - Realization 2020+
- Final
  - CM = 100 GeV
  - Realization 2020++

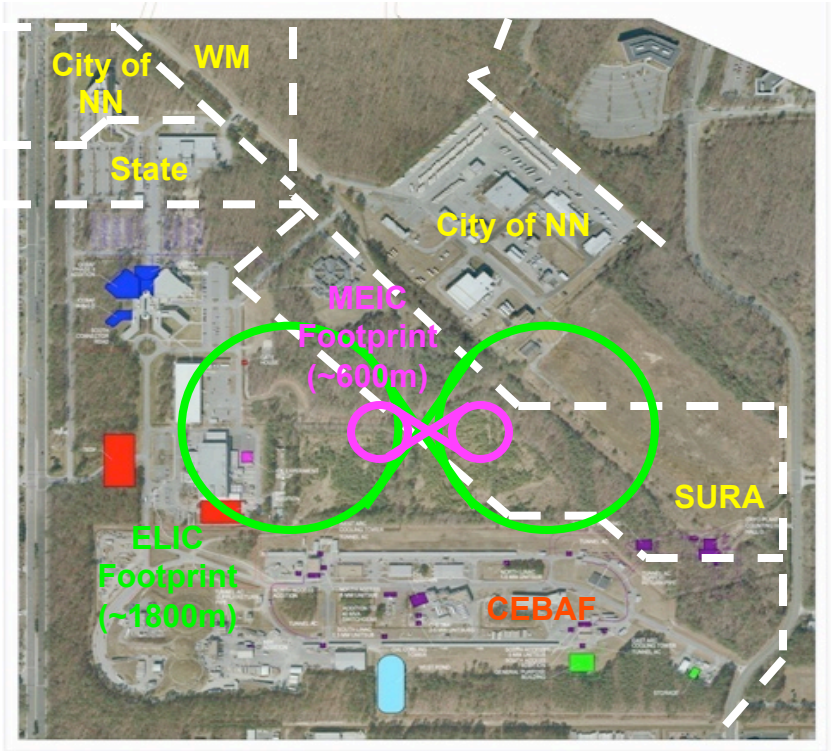
EIC@JLAB at Low to Medium Energy



ELIC Figure-8 Collider Ring Footprint



Arc	157 m
Figure-8 straight	150 m
Insertion	10 m
Circumference	634 m



- Ring design is optimized with
  - Synchrotron radiation power of e-beam
    - ➔ prefers large ring (arc) length
  - Space charge effect of i-beam
    - ➔ prefers small ring circumference
- Multi IPs require long straight sections
- Straight sections also hold required components (e-cooling, injection and ejections, etc.)

EIC@JLab High-Level Summary

What science goals are accessed/appropriate?

1) Gluon and sea quark (transverse) imaging of the nucleon
2) Nucleon Spin (ΔG vs. $\ln(Q^2)$, transverse momentum)
3) Nuclei in QCD (gluons in nuclei, quark/gluon energy loss)
4) QCD Vacuum and Hadron Structure and Creation

	Energies	s	luminosity
(M)EIC@Jlab	Up to 11 x 60	150-2650	Few x 10^{34}
Future option	Up to 11 x 250	11000	10^{35}

- Energies and figure-8 ring shape and size chosen to optimize polarization and luminosity
- Try to minimize headaches due to synchrotron and large leaps in state-of-the-art through R&D
- 4 Interaction Regions, with function and size optimized to "decouple" detector from accelerator – can optimize later to increase luminosity

(M)EIC@JLab: Basic Considerations

- Optimize for nucleon/nuclear structure in QCD

  - access to sea quarks/gluons (x > 0.01 or so)

  - deep exclusive scattering at $Q^2 > 10$

  - any QCD machine needs range in Q^2

  → s = 1000 or so to reach decade in Q^2

  → high luminosity, $>10^{34}$ and approaching 10^{35}, essential

  → lower, more symmetric energies for resolution & PID

- **Not** driven by gluon saturation (small-x physics) …

- "Sweet spot" for

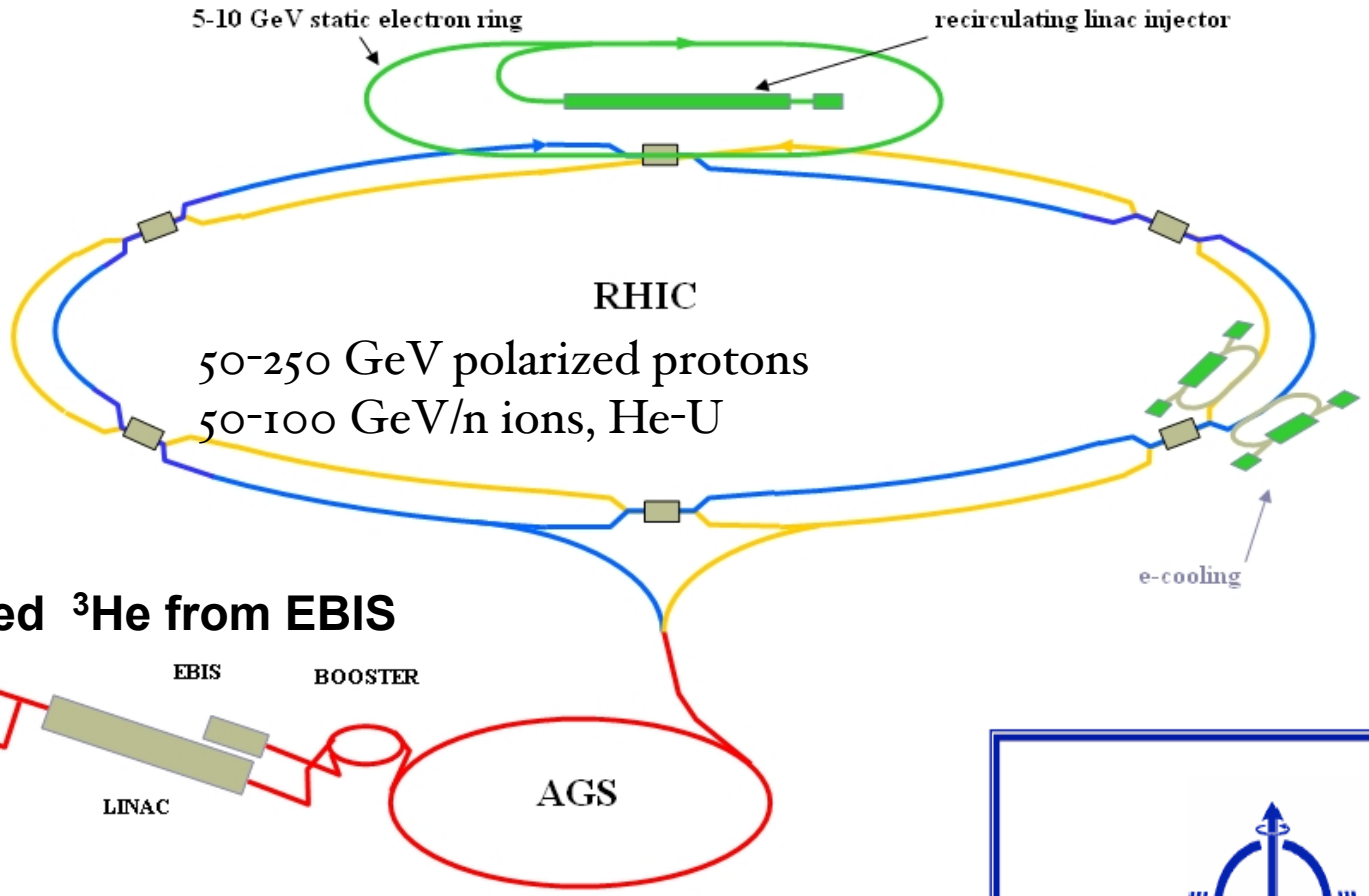
  - electron energies from 3 to 5 GeV (minimize synchrotron)
  - proton energies ranging from 30 to 60 GeV
  - but larger range of s accessible (E_e = 11 GeV, E_p = 12 GeV)

- **Decrease R&D needs**, while maintaining **high luminosities**

  - Potential future upgrade to high-energy collider,
    but no compromising of nucleon structure capabilities

eRHIC ring-ring layout: circa 2004

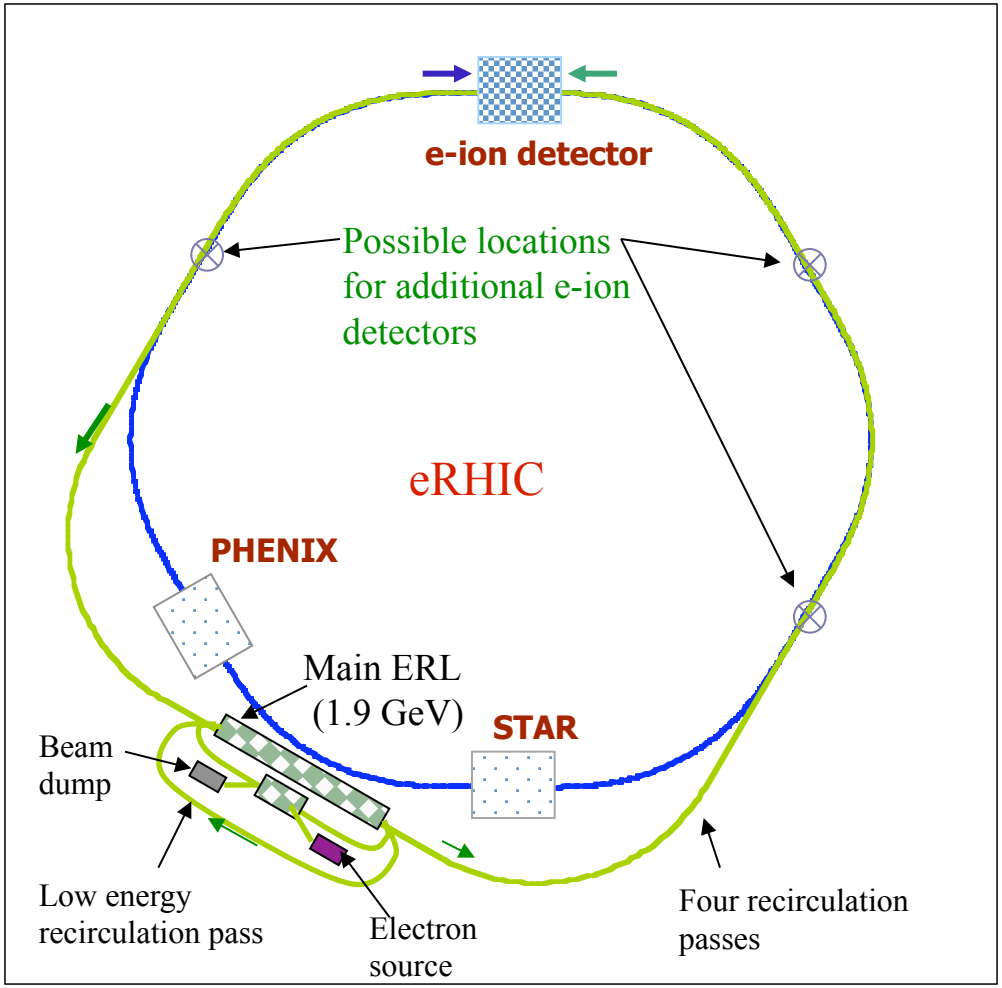
5-10 GeV electrons/positrons



L_{max} ~10^{32} cm^{-2} sec^{-1} ==> low for some physics

Detailed design, including IR, allowed a rhobust estimate of costs involved…

ERL-based eRHIC Design (Circa 2008)

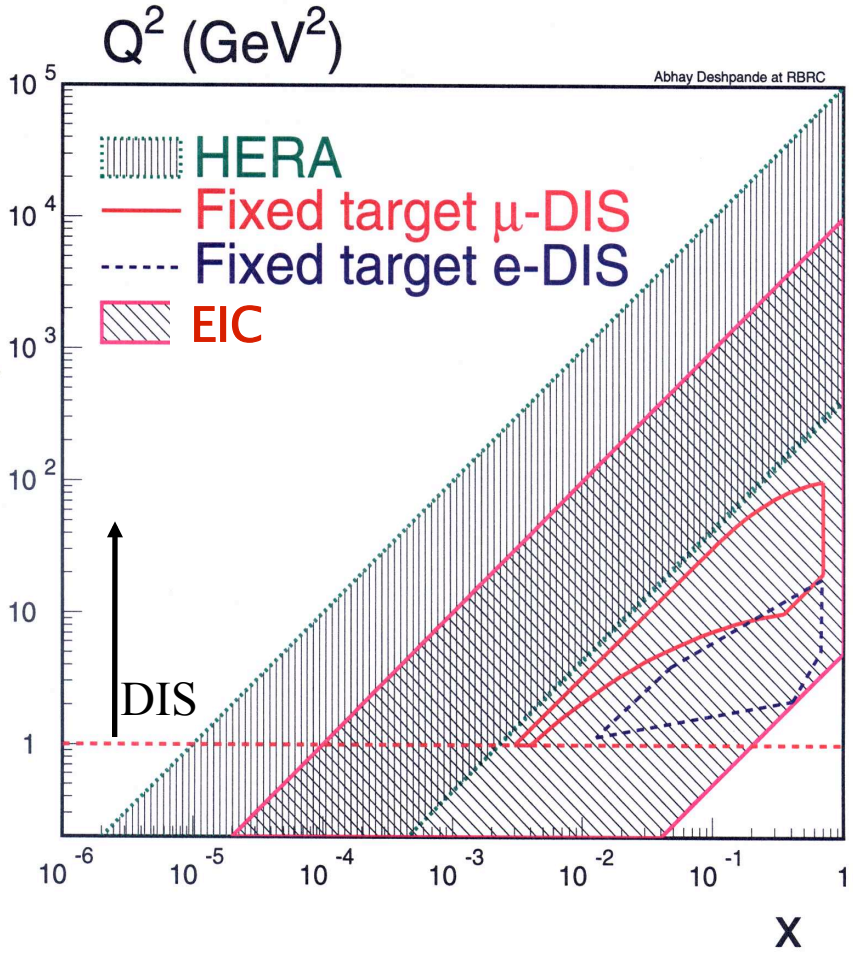


- 10 GeV electron design energy. Possible upgrade to 20 GeV by doubling main linac length.
- 5 recirculation passes (4 of them in the RHIC tunnel)
- Multiple electron-hadron interaction points (IPs) and detectors;
- Full polarization transparency at all energies for the electron beam;
- Ability to take full advantage of transverse cooling of the hadron beams;
- Possible options to include polarized positrons: compact storage ring

Can reach L ~ $10^{33\text{-}34}$ cm^{-2} sec^{-1}

A staged approach with significantly reduced initial cost possible

Parameters of the Electron Ion Collider

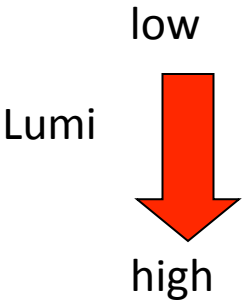


- **New kinematic region**
- E_e = 10 GeV (~5-20 GeV variable)
- E_p = 250 GeV (~50-250 GeV)
- E_A= 100 GeV
- Sqrt[S_{ep}] = 30-100 GeV
- Kinematic reach of EIC:
  - $X = 10^{-4}$ --> 0.7 ($Q^2 > 1$ GeV^2)
  - $Q^2 = 0$ --> 10^4 GeV^2
- Polarization of e,p and light ion beams at least ~ 70% or better
- Heavy ions of ALL species
- Machine Luminosities envisioned
  - L(ep) ~$10^{33\text{-}34}$ cm^{-2} sec^{-1}
- Integrated Luminosity goal:
  - 50 fb^{-1} in 10 years
  - possible with 10^{33} cm^{-2} sec^{-1}

Scientific Frontiers Open to EIC

- Nucleon Spin structure
  - Polarized quark and gluon distributions
    - Longitudinal spin structure (Low x critical)
    - Transverse spin structure (wide Q^2 arm critical)
  - Correlations between partons
    - Exclusive processes --> Generalized Parton Distributions
  - Precision measurements of QCD and of EW parameters in SM

Polarized Beams



- Un-polarized Nucleon Structure
  - Understanding confinement with low x/lowQ^2 measurements
  - Un-polarized quark and gluon distributions
- Nuclear Structure, role of partons in nuclei
  - Confinement in nuclei through comparison e-p/e-A scattering
- Hadronization in nucleons and nuclei & effect of nuclear media
  - How do knocked off partons evolve in to colorless hadrons
- Partonic matter under extreme conditions
  - For various A, compare e-p/e-A

Proton & Nuclear Beams

Staged Realization…

Early…. (2015+)

Low cost… (< 300M?)

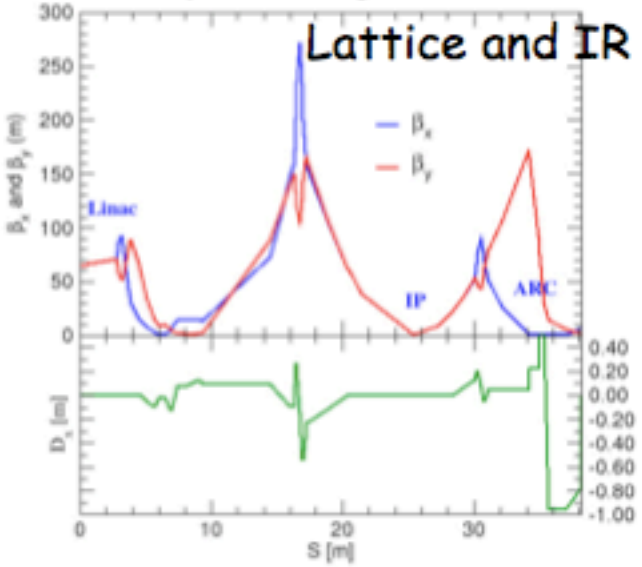
Utilize all instrumentation in the Final EIC

MeRHIC at 2 o'clock IR at RHIC

More in talk by D.Trbojevic

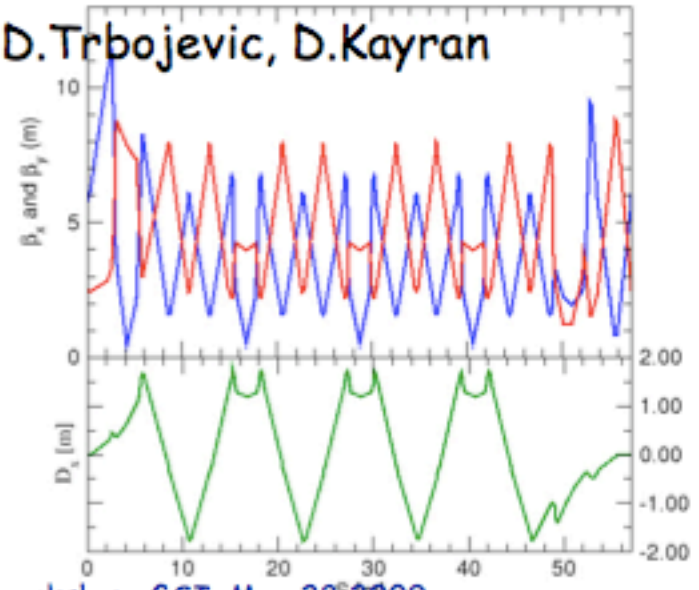
End of linac- Interaction Region - Arc

β*=0.4 m - total length 38.165 m



Dog Bone for 3.35 GeV electrons

Total Length 57.41 m

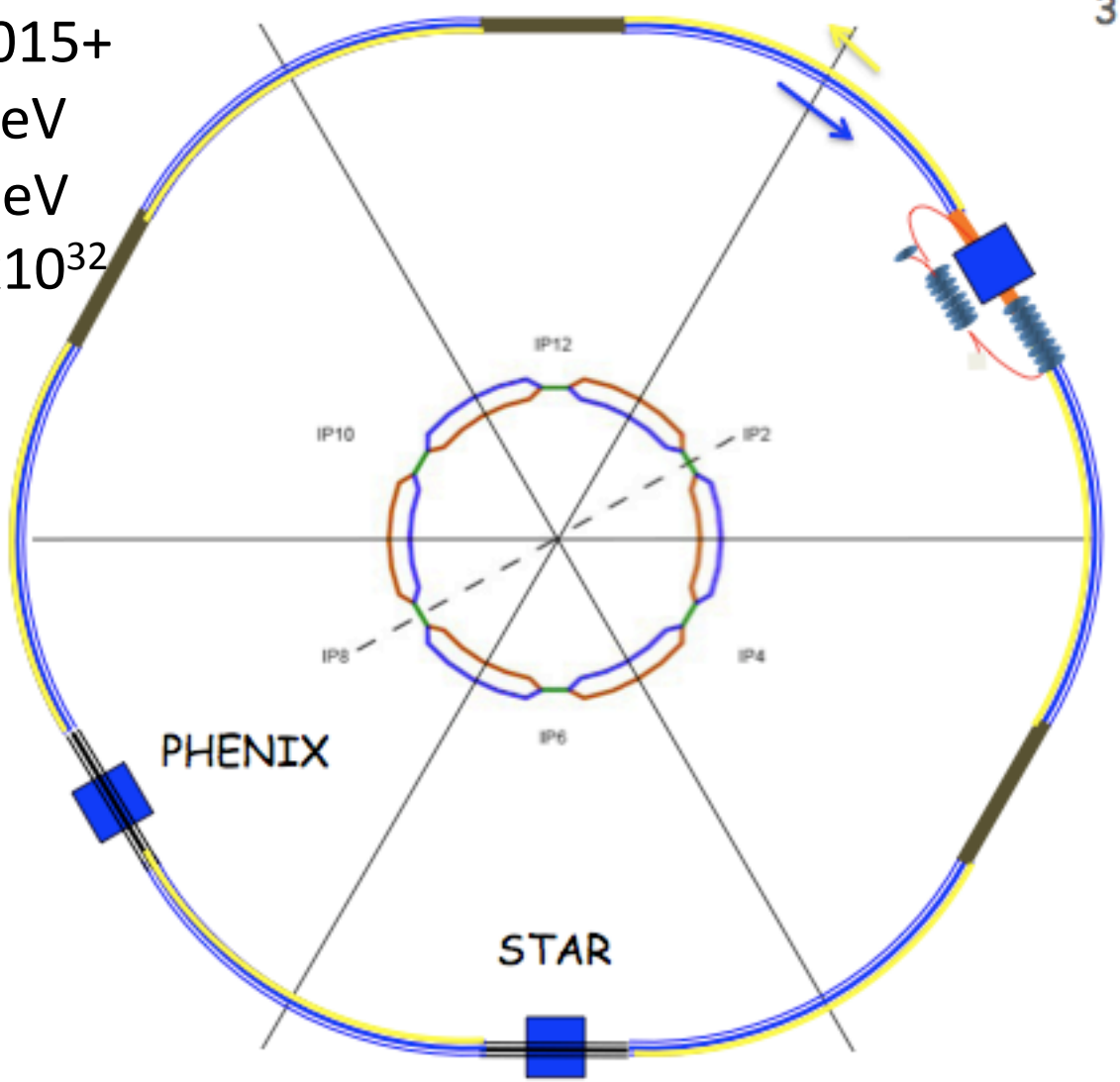


Lattice and IR by D.Trbojevic, D.Kayran

4 GeV e x 250 GeV p MeRHIC
with ERL inside RHIC tunnel

2 x 60 m SRF linac
3 passes, 1.3 GeV/pass

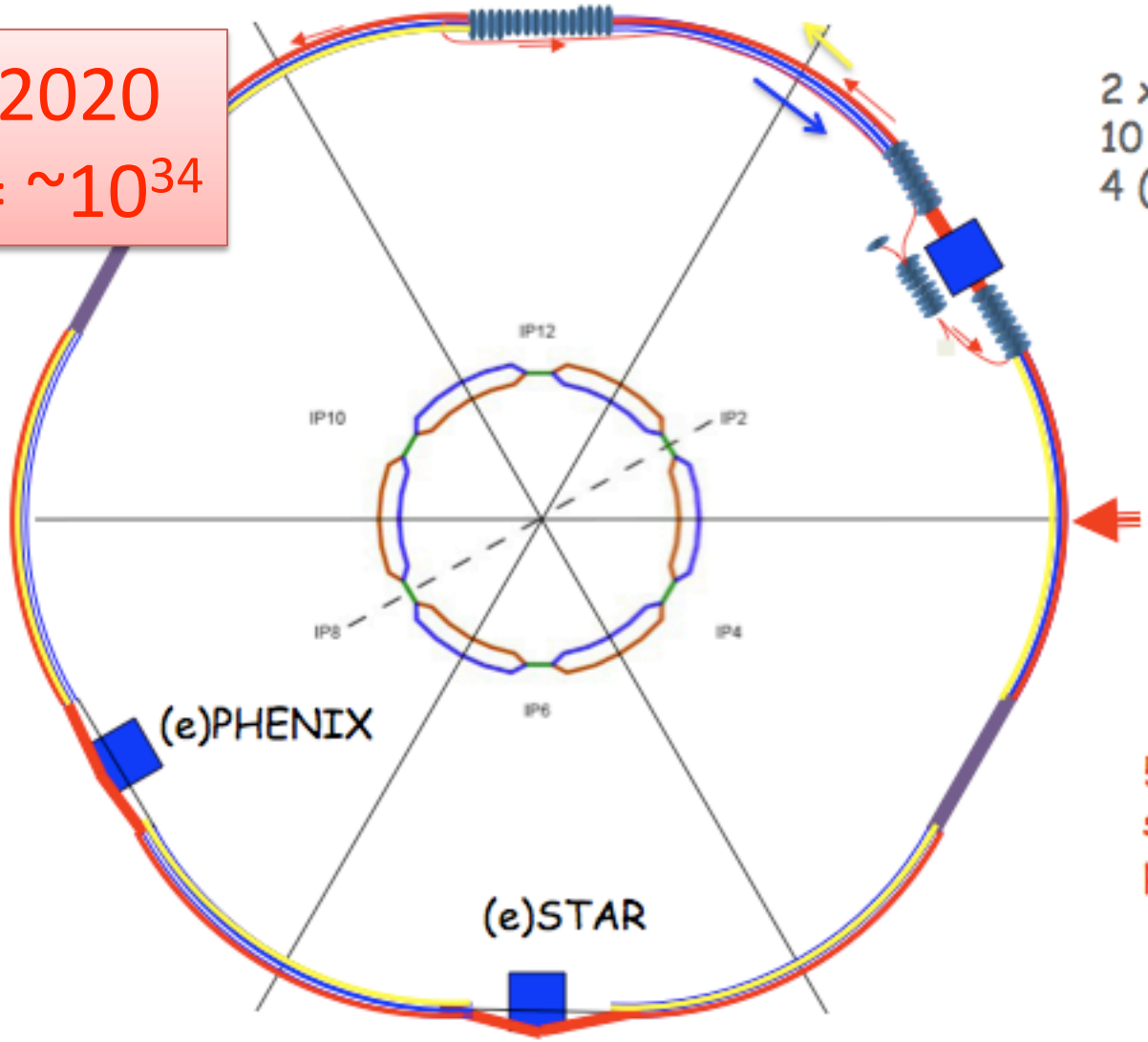
Realizable 2015+
E_p=50-250 GeV
E_A=20-100 GeV
Lumi ~ few x10^{32}



5 (6) vertically separated passes

20 (10 & 30) GeV e x 325 GeV p eRHIC with ERL inside RHIC tunnel

Beyond 2020
Lumi > = ~10^{34}



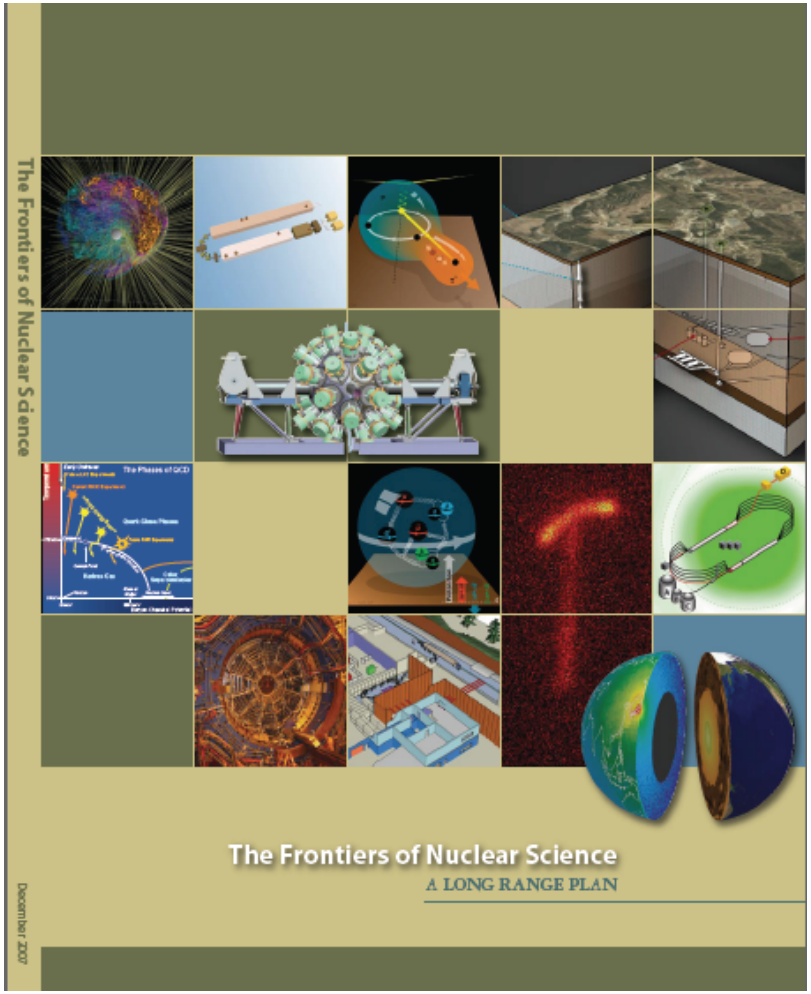
2 x 200 m SRF linac
10 (12.5) MeV/m
4 (5) GeV per pass

5 (6) vertically separated passes

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."**



NSAC Long Range Plan 2007, arXiv:0809.3137

EIC Working Group Structures

Steering Committee

•Abhay Deshpande, Stony Brook (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
•Werner Vogelsang, BNL

International Advisory Committee (appointed by BNL +Jlab Directors)

- 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)
- Alfred Mueller (Columbia)
- Katsunobu Oide (KEK)
- Naohito Saito (KEK)
- Uli Wienands (SLAC)

First meeting Spring-09

Working Groups and Convenors

•ep Physics
- •Ernst Sichtermann, LBL
- •Werner Vogelsang, BNL
- •Christian Weiss, JLAB

•eA Physics
- •Vadim Guzey, JLAB
- •Dave Morrison, BNL
- •Thomas Ullrich, BNL
- •Raju Venugopalan, BNL

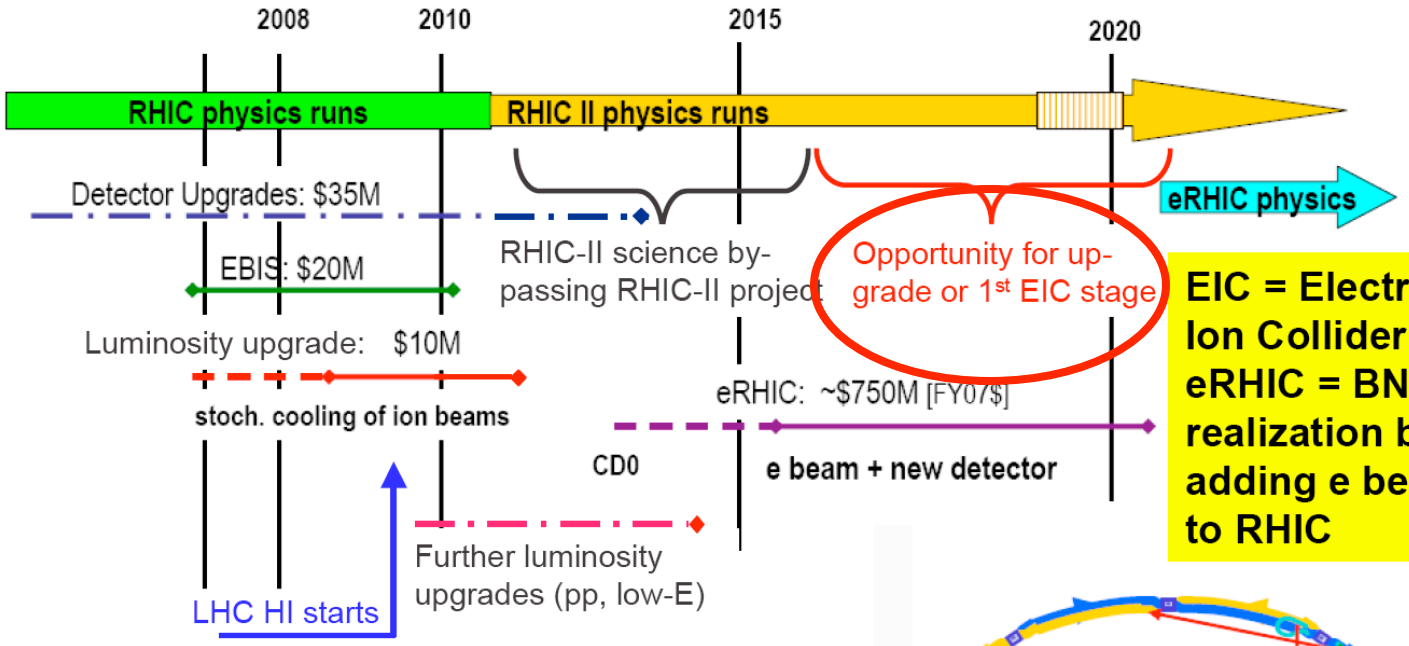
•Detector
- •Elke Aschenauer, BNL
- •Edward Kinney, Colorado
- •Bernd Surrow, MIT

•Electron Beam Polarimetry
- •Wolfgang Lorenzon, Michigan

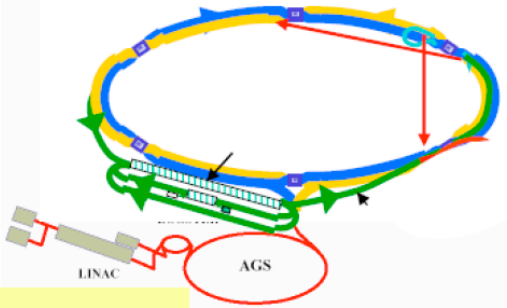
Next Meeting December/January 2009
-Details on EIC webpage:
- http://web.mit.edu/eicc

S. Vigdor, BNL Associate Laboratory Director, NP/HE

A Long Term (Evolving) Strategic View for RHIC



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



RHIC, RHIC-II, LHC-HI and EIC science share a common theme…

Brookhaven Science

BROOKHAVEN NATIONAL LABORATORY

Summary & Invitation

- Physics at the EIC is compelling & work challenging
- Many proposals: presently good thing, endorsement of the science: *Eventually should unify*
- Both BNL & Jlab are serious initiatives:
  - EIC-Task force at BNL (EA + TU) and also @Jlab
- By 2011 there needs to be ONE design, Physics Goal, & Detector concept for us to go in to the next Long Range Plan (~2012)
- **Your participation is welcome & critical!**
- **EIC Info always available at:**
  - **http://web.mit.edu/eicc & http://www.bnl.gov/eic**
  - **Subscribe to various email list servers and get involved**