LBL RBRC Workshop on Nucleon Spin
LBL June 2009

# Electron Ion Collider
## Overview of proposals and possible physics with *polarized* beams
(Many slides from EIC collaborators: Thanks)

**Abhay Deshpande**
**Stony Brook University & RBRC**

# What is this talk about?

This talk is *not* supposed to *make* a case for the EIC. It is an overview of the project with some provocative high level questions re-visited.

Discussions here in are incomplete in detail, but are intended to raise some questions and lead to discussions and feedback.

Readers should consider this when reviewing & commenting on this talk.

Thanks.

# Various topics for discussion

- The electron ion collider (EIC)
  - Latest designs around the world
  - Some details of designs in US
  - Staged realization
- Physics with a polarized collider
  - **Nucleon spin puzzle: helicity sum rule**
  - **What does the nucleon look like *inside?... 3D structure***
  - Issues with nuclei not mentioned today
- Towards realization
  - Project status in US Nuclear Science
  - EIC advisory committee & recommendations
  - Collaboration activities

# The EIC Projects

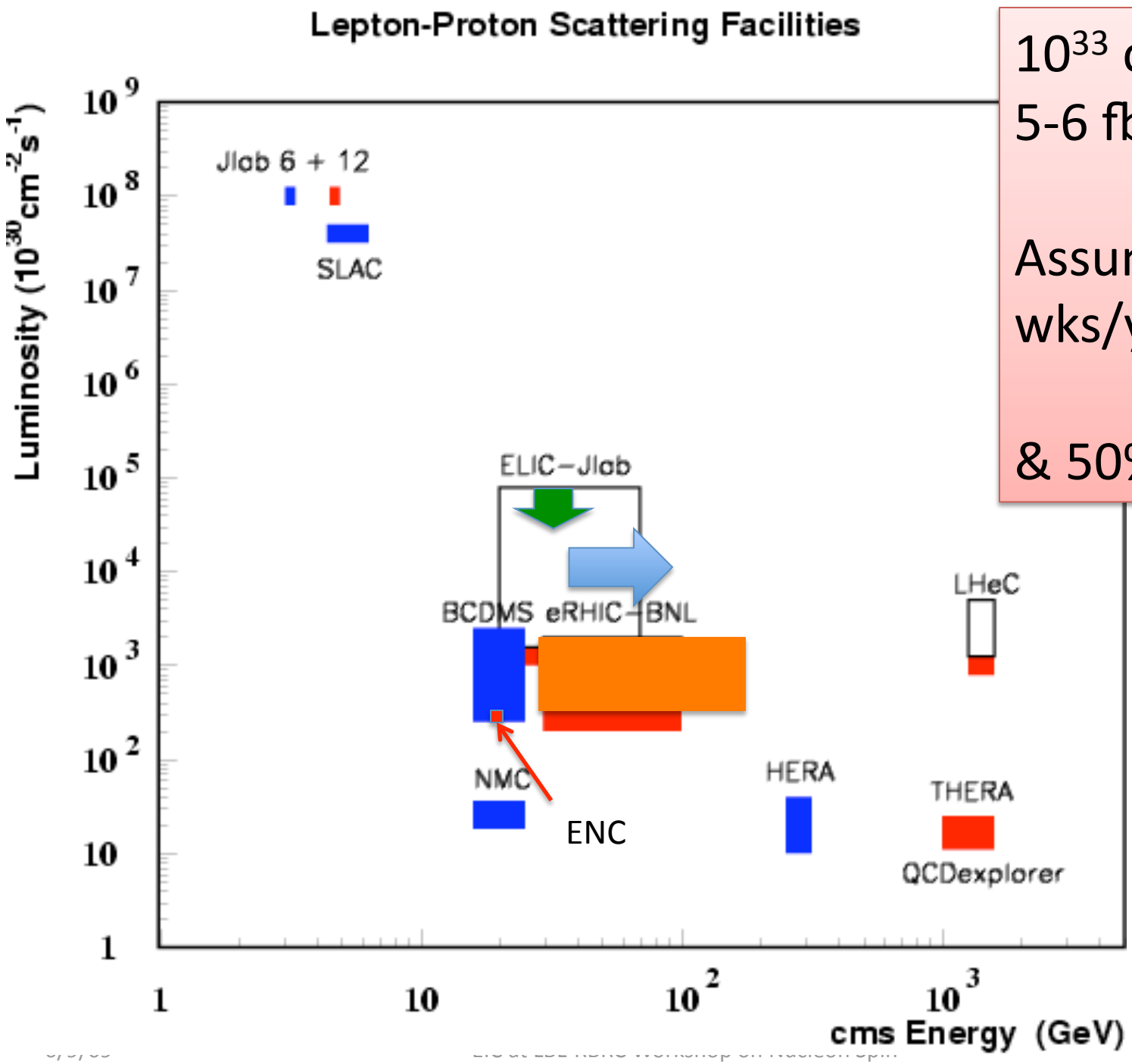
- United States
  - eRHIC @ BNL will use RHIC (10+ years old)
  - ELIC at Jlab will use CEBFAF 12 GeV as e-*injector* (5+ years old)
- Europe
  - ENC @ GSI-FAIR will use future FAIR facility (6+ months old)
  - LHeC at CERN will use LHC: *no polarized protons!* (2+ years old)

# The EIC Projects

| Project | Center of Mass (GeV) | Luminosity Range ($cm^{-2}sec^{-1}$) |
|---|---|---|
| ENC | 14 | $10^{33}$ |
| eRHIC | 30-140 | Few x $10^{32-33}$ |
| ELIC | 30-100 | Few x $10^{33-34}$ |
| LHeC | 1400 | $10^{33}$ |

- Recall HERA
  - CM ~ 300 GeV
  - $10^{29-30}$ $cm^{-2}$ $sec^{-1}$

- Most machines will start with lower center of mass and luminosity & then build up to the highest performance
- Higher luminosity implies more R&D
  - Additional time
  - Unreliable cost estimates
- Some comparisons are apples and oranges in detail

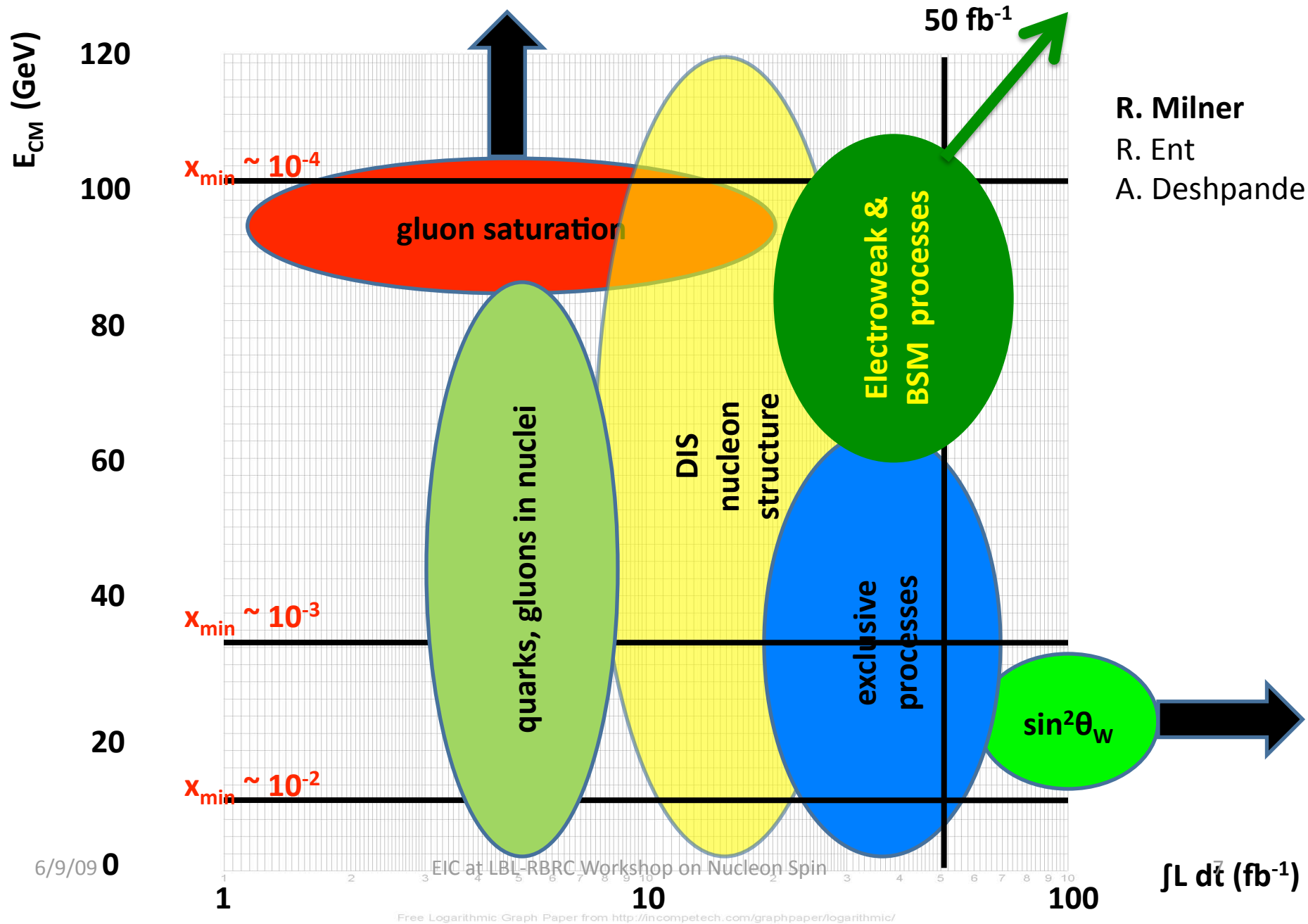



$10^{33}$ cm$^{-2}$s$^{-1}$ = 5-6 fb$^{-1}$/yr

Assuming ~30 wks/yr

& 50% efficiency

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




R. Milner
R. Ent
A. Deshpande

# 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**

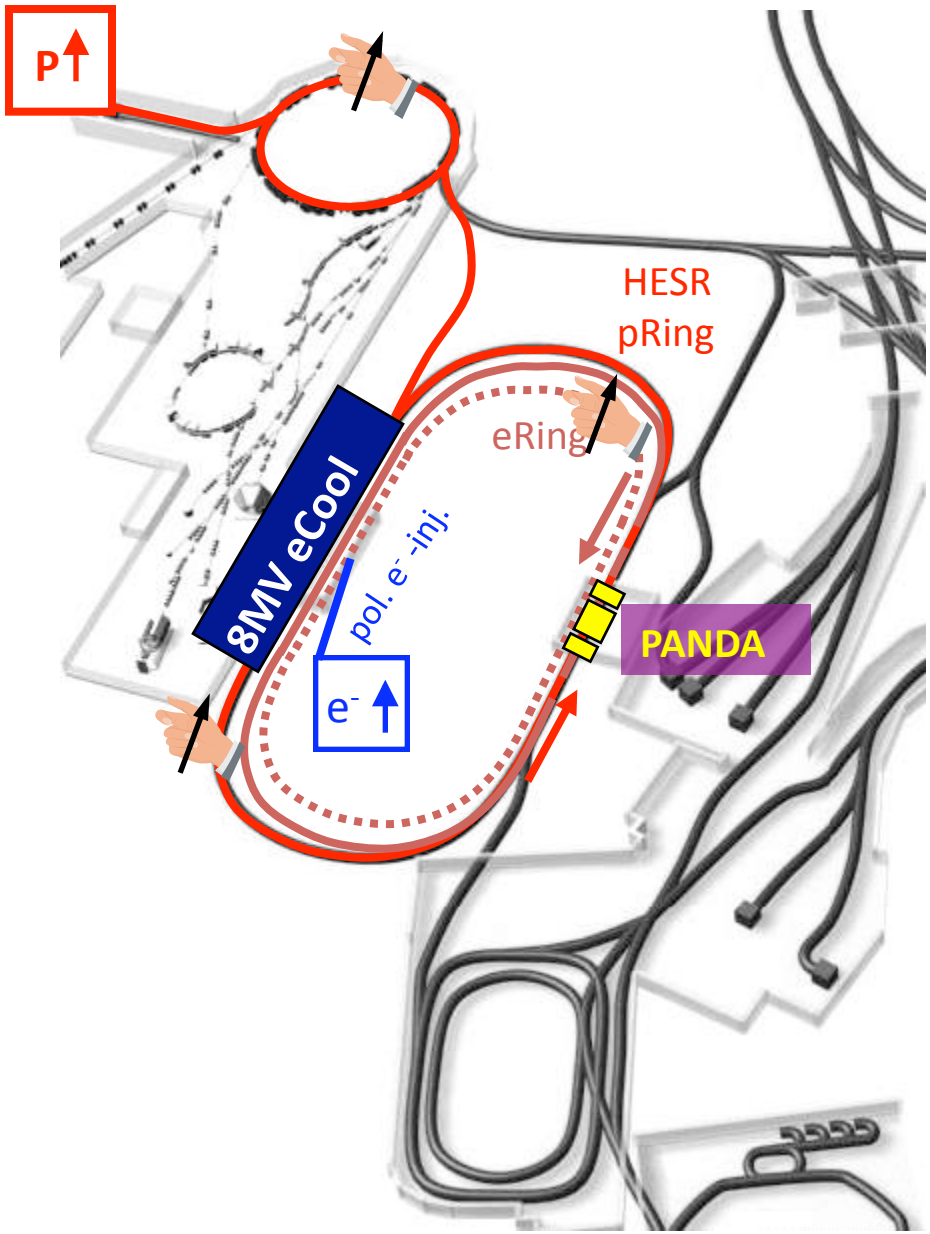
- **Conclusion**

# 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**

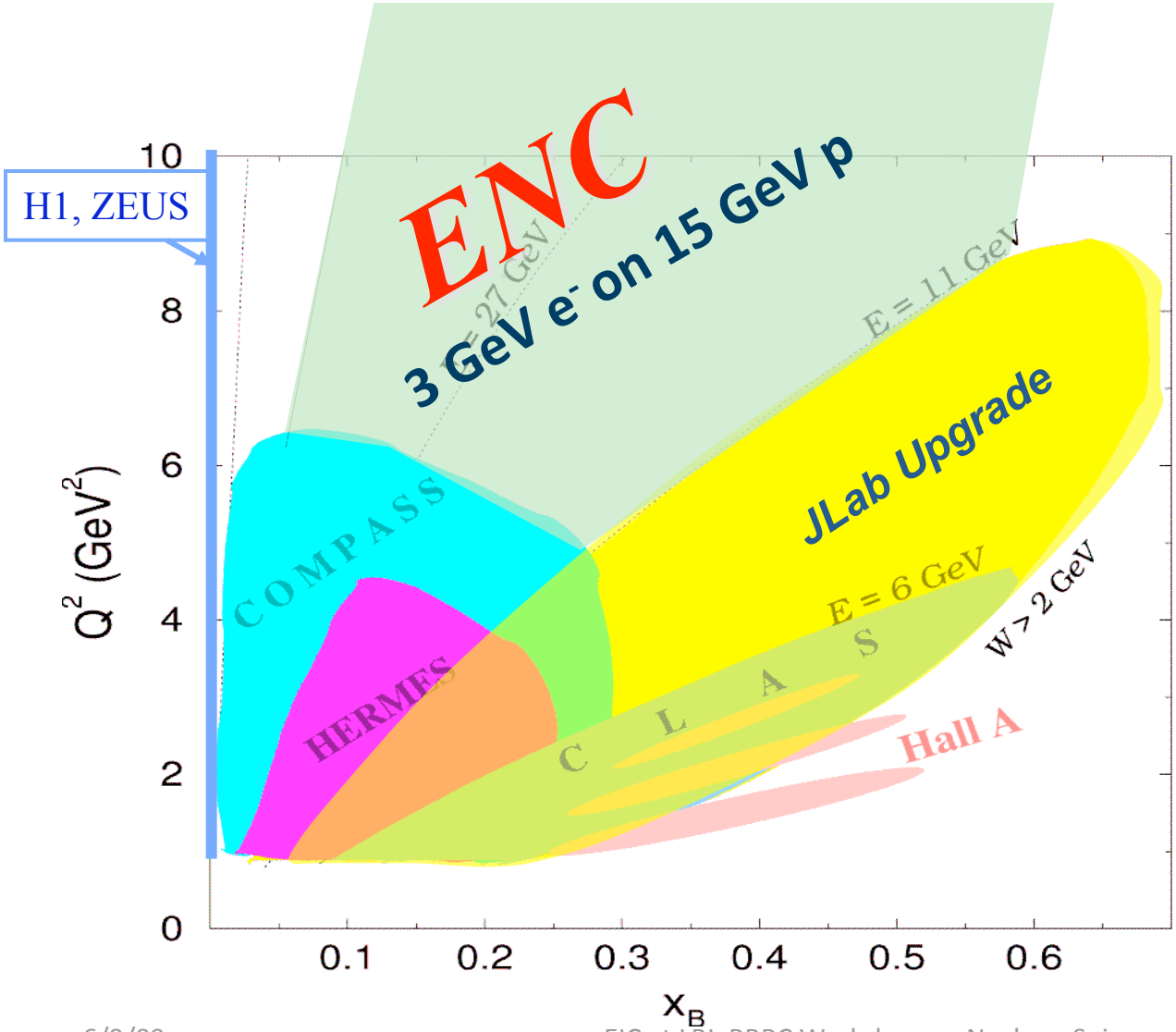
**$s^{1/2} > 10$GeV**
(3.3GeV $e^-$ ↔ 15GeV p)

**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 ow 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 Schneeekloth (DESY),

Pierre van Mechelen (Antwerpen)

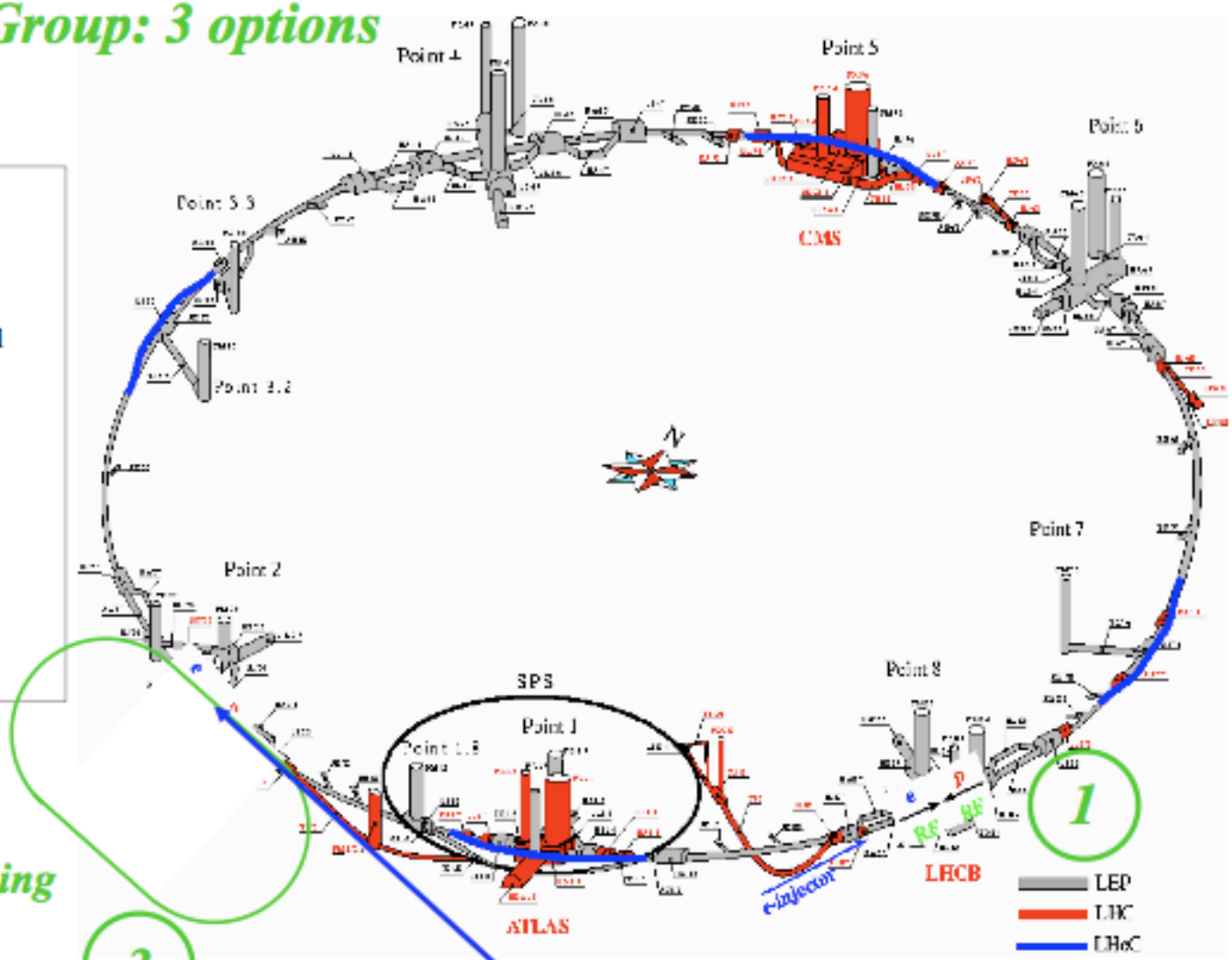
**Detector Design**

Peter Kostka (DESY),

Rainer Wallny (UCLA),

Alessandro Polini (Bologna)

... and many colleagues




*Linac-Ring*

3

2

*SPL-Ring*

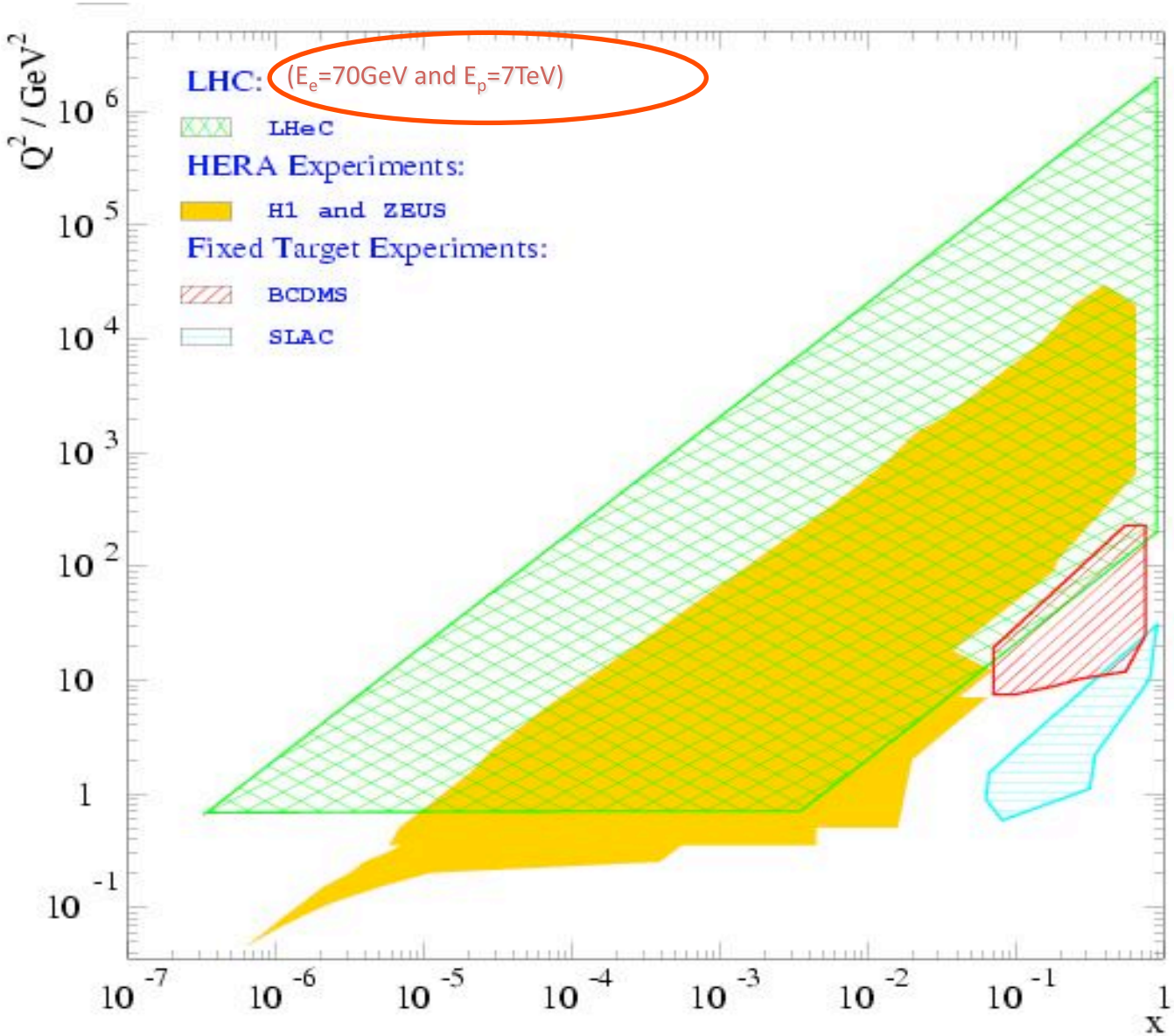
1

*Ring-Ring*

# 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**

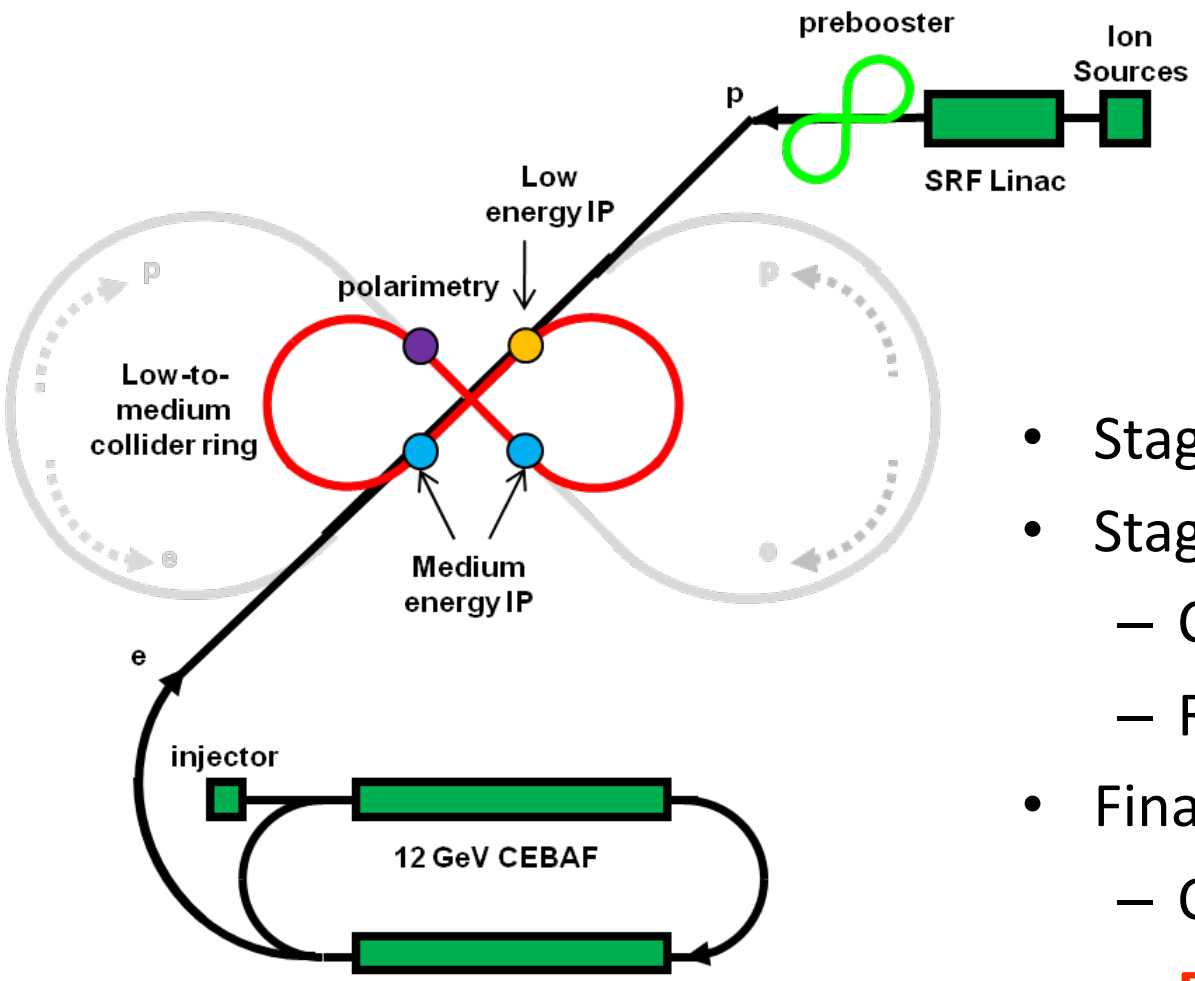
# LHeC with protons



# The EIC Project in the US

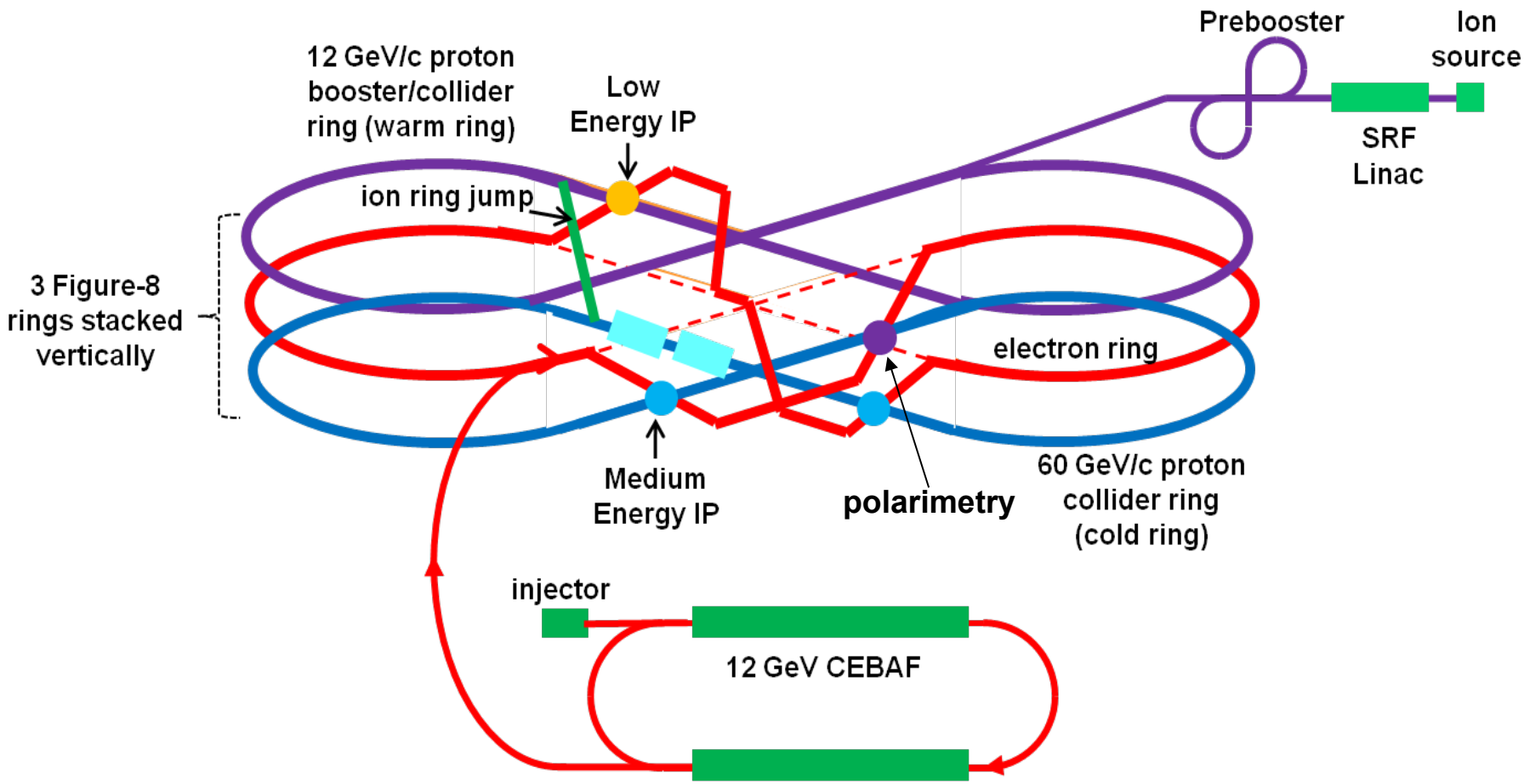
- ELectron Ion Collider (ELIC @ Jlab)
  - Utilizes the existing CEBAF Complex about to be upgraded 12 GeV
  - green field design and novel accelerator concepts
- eRHIC at BNL
  - Utilizes the existing RHIC and a conservative parameters for e/hadron beam performance
- Significant R&D for both projects, nevertheless
  - Comments only…

# ELIC at Jlab (present design)

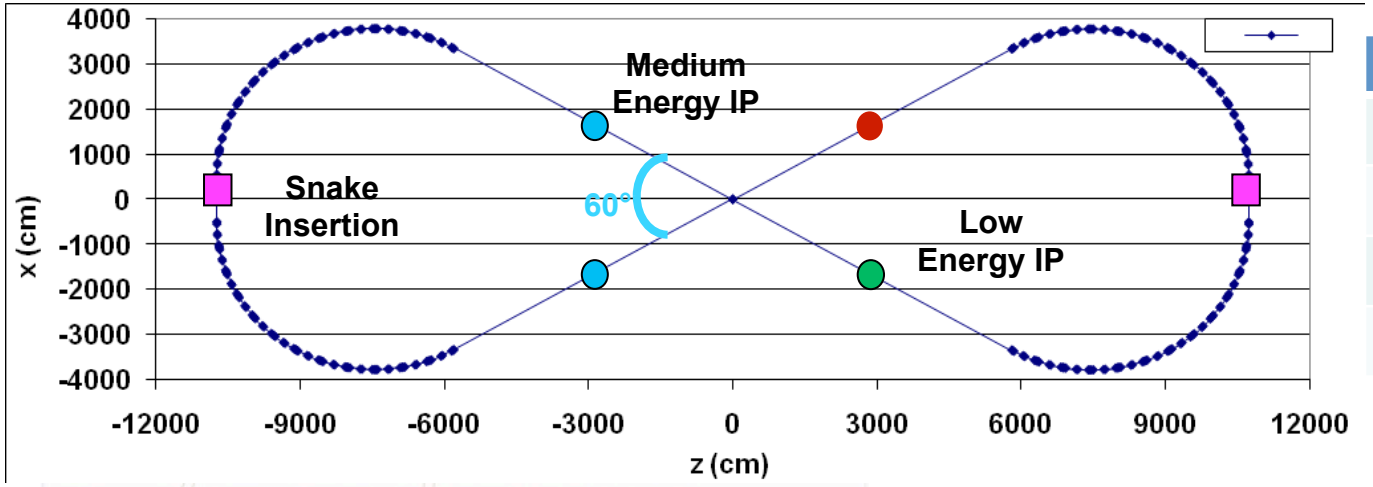



- Staged realizable
- Stages 1 & 2
  - CM ~ 12 -50 GeV
  - Realization 2020+
- Final
  - CM = 100 GeV
  - **Realization 2020++**

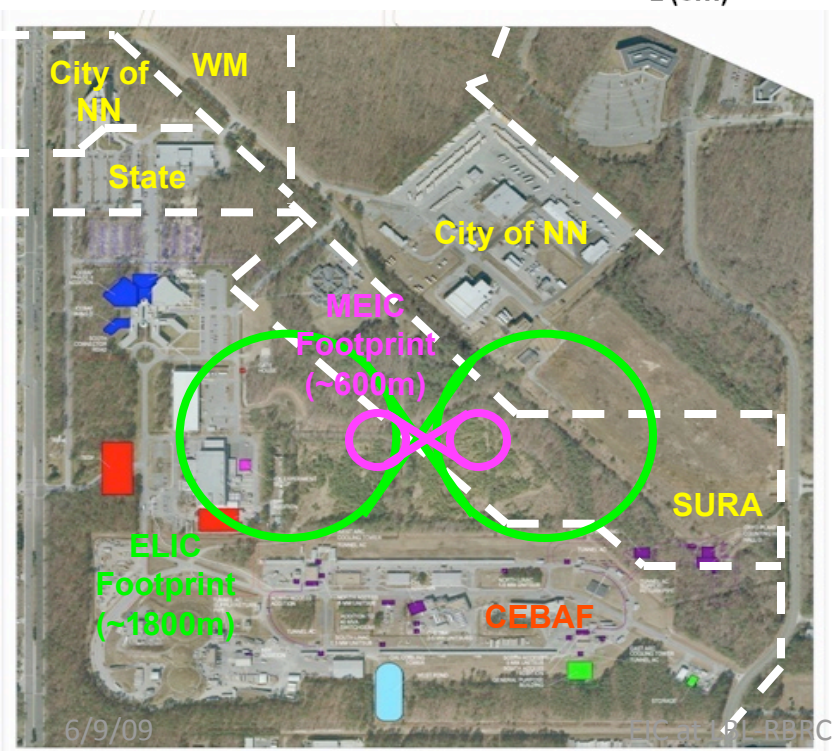
# EIC@JLAB at Low to Medium Energy



# 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 ($\Delta G$ 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

# EIC@JLab Parameters at Low-to-Medium Energy

| | | | | |
|---|---|---|---|---|
| Beam Energy | GeV | 60/5 | 60/3 | 12/3 |
| Collision freq. | MHz | 499 | | |
| Particles/bunch | $10^{10}$ | 0.74/2.9 | 1.1/6 | 0.47/2.3 |
| Beam current | A | 0.59/2.3 | 0.86/4.8 | 0.37/2.7 |
| Energy spread | $10^{-4}$ | ~ 3 | | |
| RMS bunch length | mm | 5 | 5 | 50 |
| Horz. emit., norm. | μm | 0.56/85 | 0.8/75 | 0.18/80 |
| Vert. emit. Norm. | μm | 0.11/17 | 0.8/75 | 0.18/80 |
| Horizontal beta-star | mm | 25 | 25 | 5 |
| Vertical beta-star | mm | 5 | | |
| Vert. beam-beam tune shift / IP | | 0.01/0.03 | 0.015/0.08 | 0.015/0.013 |
| Laslett tune shift (p-beam) | | 0.1 | 0.054 | 0.1 |
| Peak Luminosity/IP, **$10^{34}$** | $cm^{-2}s^{-1}$ | 1.9 | 4.0 | 0.59 |

# (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 <u>range in $Q^2$</u>**

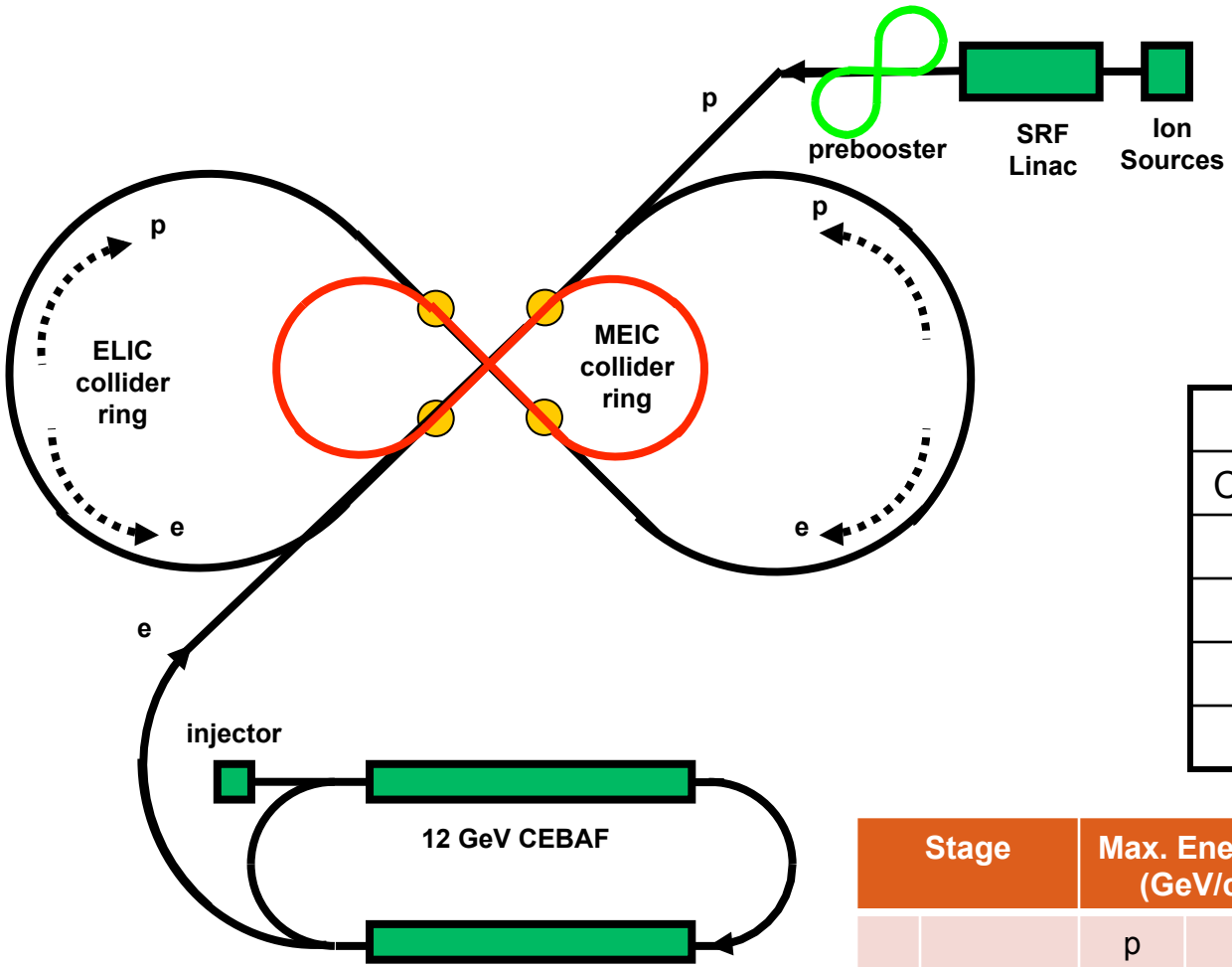
  → s = 1000 or so to reach decade in $Q^2$
  → high luminosity, $>10^{34}$ and approaching $10^{35}$, essential
  → lower, more symmetric energies for resolution & PID

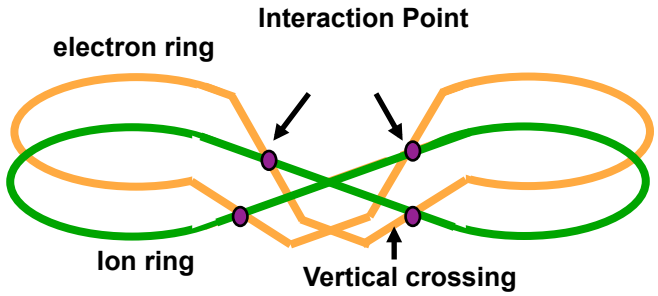
- **Not** driven by gluon saturation (small-x physics) …

- "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

# ELIC at High Energy & Staging




| | | Small | Large |
|---|---|---|---|
| Circumference | m | 1800 | 2500 |
| Radius | m | 140 | 180 |
| Width | m | 280 | 360 |
| Length | m | 695 | 920 |
| Straight | m | 306 | 430 |

| Stage | | Max. Energy (GeV/c) | | Ring Size (M) | | Ring Type | | IP # |
|---|---|---|---|---|---|---|---|---|
| | | p | e | p | e | p | e | |
| 1 | Low | 12 | 5 (11) | 630 | 630 | Warm | Warm | 1 |
| | Medium | 60 | 5 (11) | 630 | 630 | Cold | Warm | 2 |
| 2 | Medium | 60 | 10 | 600 | 1800 | Cold | Warm | 4 |
| 3 | High | 250 | 10 | 1800 | 1800 | Cold | Warm | 4 |

# EIC@JLab Parameters: High Energy

| | | | |
|---|---|---|---|
| Beam Energy | GeV | 250/10 | 150/7 |
| Collision freq. | MHz | 499 | |
| Particles/bunch | $10^{10}$ | 1.1/3.1 | 0.5/3.25 |
| Beam current | A | 0.91/2.5 | 0.4/2.6 |
| Energy spread | $10^{-4}$ | 3 | |
| RMS bunch length | mm | 5 | |
| Horz. beta-star | mm | 125 | 75 |
| Vert. beta-star | mm | 5 | |
| Horz. emit., norm. | μm | 0.7/51 | 0.5/43 |
| Vert. emit. Norm. | μm | 0.03/2 | 0.03/2.87 |
| B-B tune shift per IP | | 0.01/0.1 | 0.015/0.05 |
| Laslett tune shift (p-beam) | | 0.1 | 0.1 |
| Lumi. per IP, **$10^{34}$** | $cm^{-2}s^{-1}$ | 11 | 4.1 |

**Major design change: symmetric IR ➔ asymmetric IR**

# EIC@JLab Accelerator R&D

We have identified the following critical R&D for ELIC

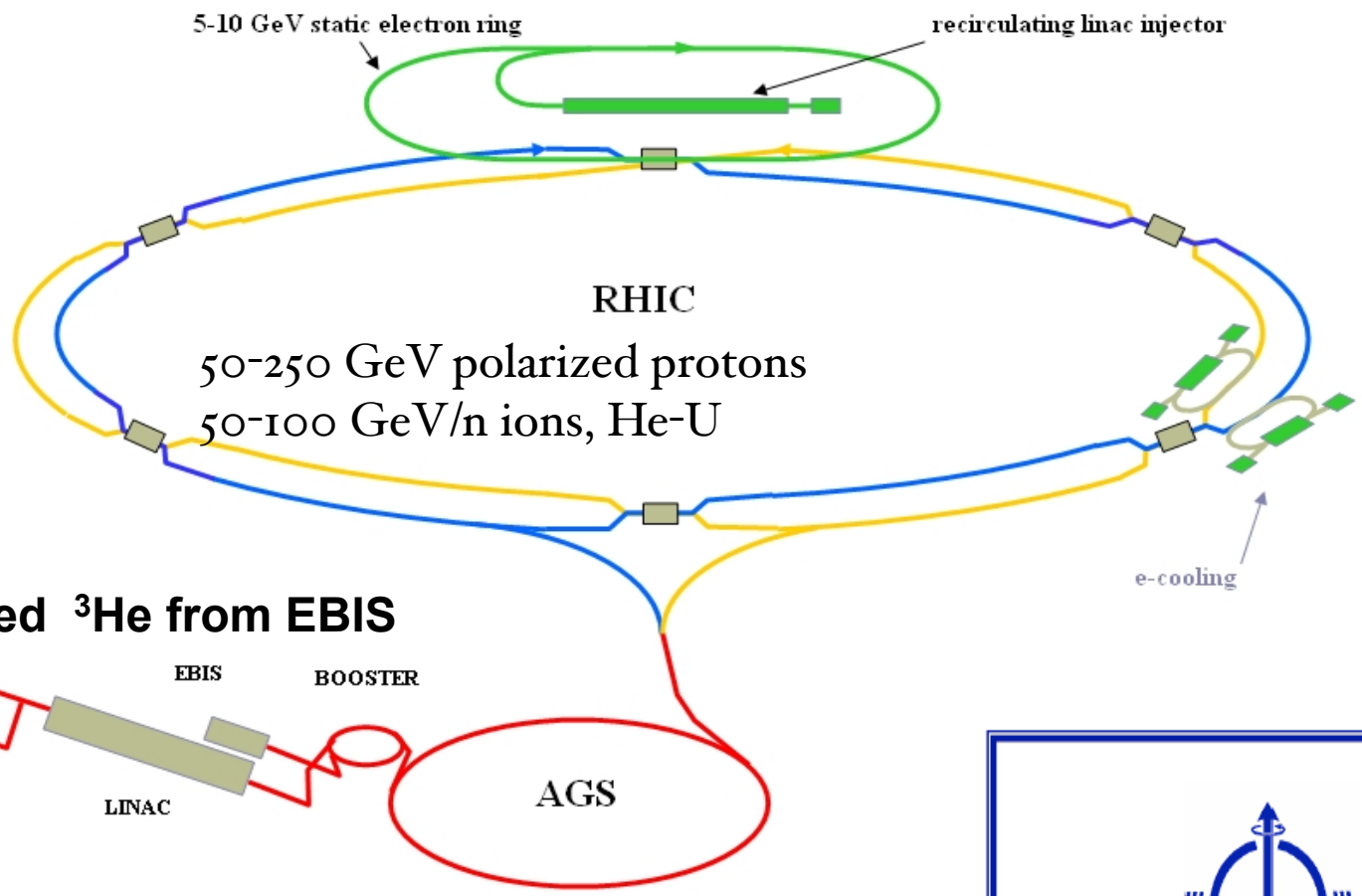
- Electron cooling
- Crab crossing and crab cavity
- Forming high intensity low energy ion beam
- Beam-beam effect
- Traveling focusing for very low energy ion beam

Will discuss issues/requirements/state-of-art/challenges/activities

| Level of R&D | Low-to-Medium Energy (12x3 GeV/c) & (60x5 GeV/c) | High Energy (up to 250x10 GeV) |
|---|---|---|
| Challenging | | Electron cooling |
| Semi Challenging | Electron cooling<br>Traveling focusing (for very low i energy) | Crab crossing/crab cavity |
| Likely | Crab crossing/crab cavity<br>High intensity low energy i beam<br>Beam-beam | High intensity low energy i beam<br>Beam-beam |
| Know-how | Spin tracking<br>IP design/chromaticity | Spin tracking<br>IP design/chromaticity |

# eRHIC ring-ring layout: circa 2004

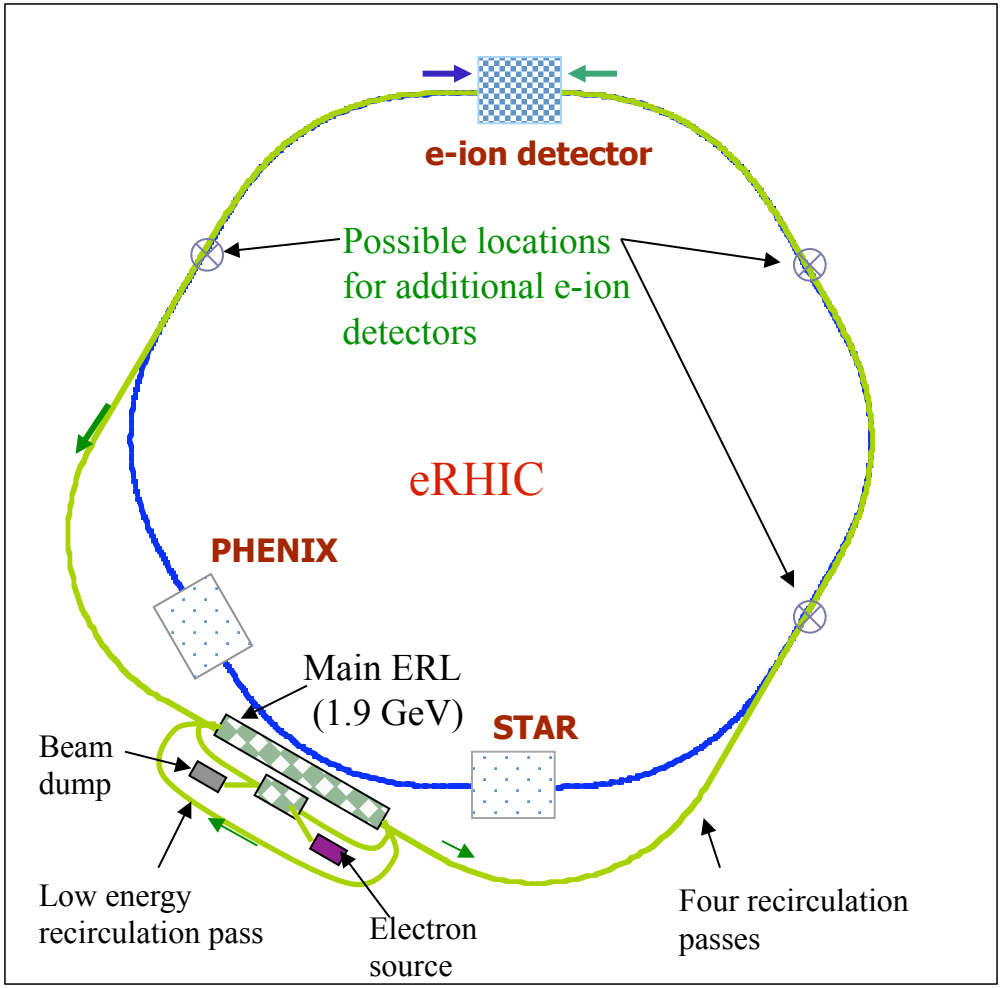
5-10 GeV electrons/positrons




**Polarized $^3$He from EBIS**

$L_{max}$ ~$10^{32}$ $cm^{-2}$ $sec^{-1}$ ==> 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

# ERL-based eRHIC Parameters: e-p mode

| | High energy setup | | Low energy setup | |
|---|---|---|---|---|
| | p | e | p | e |
| Energy, GeV | 250 | 10 | 50 | 3 |
| Number of bunches | 166 | | 166 | |
| Bunch spacing, ns | 71 | 71 | 71 | 71 |
| Bunch intensity, | $2 \cdot 10^{11}$ | $1.2 \cdot 10^{11}$ | 2 | 1.2 |
| Beam current (mA) | 420 | 260 | 420 | 260 |
| Normalized 95% emittance ($\pi$ mm mrad) | 6 | 460 | 6 | 570 |
| Rms emittance, nm | 3.8 | 4 | 19 | 16.5 |
| $\beta^*$, x/y, cm | 26 | 25 | 26 | 30 |
| Beam-beam parameters, x/y | 0.015 | 0.59 | 0.015 | 0.47 |
| Rms bunch length, cm | 20 | 1 | 20 | 1 |
| Polarization, % | 70 | 80 | 70 | 80 |
| Peak Luminosity, | $2.6 \cdot 10^{33}$ cm$^{-2}$ s$^{-1}$ | | $0.53 \cdot 10^{33}$ cm$^{-2}$ s$^{-1}$ | |
| Aver. Luminosity x1.e33 cm$^{-2}$s$^{-1}$ | 0.87 | | 0.18 | |
| Luminosity integral /week pb$^{-1}$ | 530 | | 105 | |

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# ERL-based eRHIC Parameters: e-Au mode

| | High energy setup | | Low energy setup | |
|---|---|---|---|---|
| | Au | e | Au | e |
| Energy, GeV | 100 | 10 | 50 | 3 |
| Number of bunches | 166 | | 166 | |
| Bunch spacing, ns | 71 | 71 | 71 | 71 |
| Bunch intensity, $10^{11}$ | 1.1 | 1.2 | 1.1 | 1.2 |
| Beam current, mA | 180 | 260 | 180 | 260 |
| Normalized 95% emittance ($\pi$ mm.mrad) | 2.4 | 460 | 2.4 | 270 |
| Rms emittance (nm) | 3.7 | 3.8 | 7.5 | 7.8 |
| $\beta^*$, x/y (cm) | 26 | 25 | 26 | 25 |
| Beam-beam parameters x/y | 0.015 | 0.26 | 0.015 | 0.43 |
| Rms bunch length (cm) | 20 | 1 | 20 | 1 |
| Polarization (%) | 0 | 0 | 0 | 0 |
| Peak e-nucleon luminosity | $2.9 \cdot 10^{33}$ cm$^{-2}$ s$^{-1}$ | | $1.5 \cdot 10^{33}$ cm$^{-2}$ s$^{-1}$ | |
| Average e-nucleon luminosity 1.e33 cm$^{-2}$s$^{-1}$ | 1.0 | | 0.5 | |
| Luminosity integral /week pb$^{-1}$ | 580 | | 290 | |

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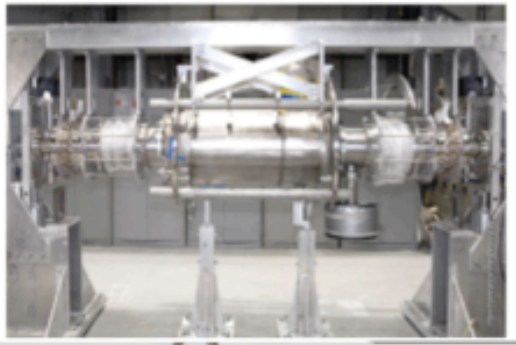
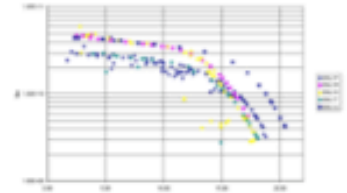
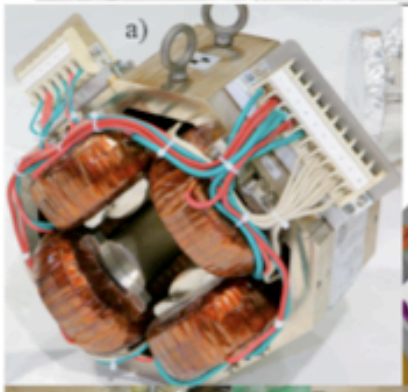
# Main R&D Items

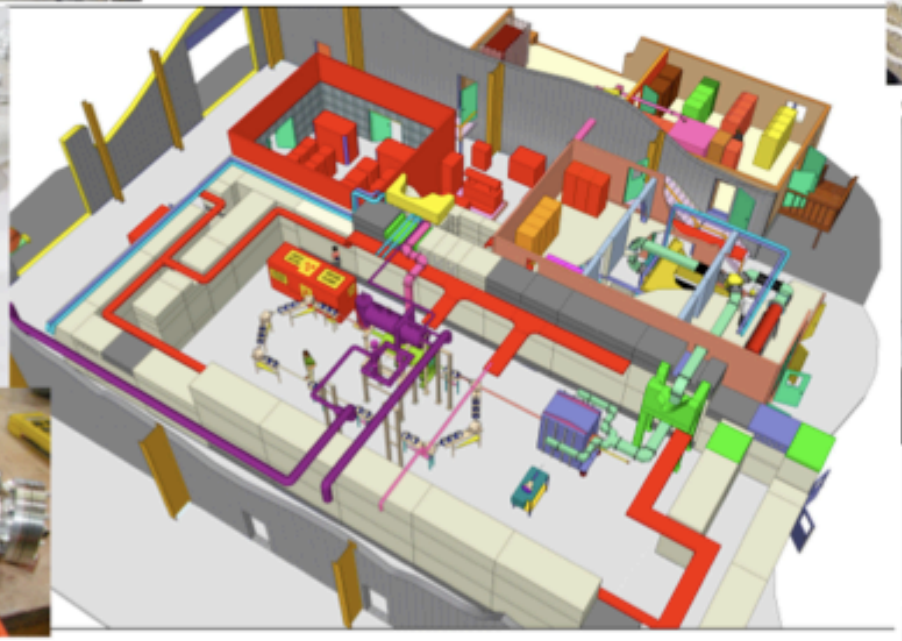
- **Electron beam R&D for ERL-based design:**
  - **High intensity polarized electron source**
    - Development of large cathode guns with existing current densities ~ 50 mA/cm$^2$ with good cathode lifetime.
  - **Energy recovery technology for high power beams**
    - Multi-cavity cry module development; high power beam ERL, BNL ERL test facility; loss protection; instabilities.
  - Development of compact recirculation loop magnets
    - Design, build and test a prototype of a small gap magnet and its vacuum chamber.
  - Beam-beam effects: e-beam disruption
- Main R&D items for ion beam:
  - Beam-beam effects: electron pinch effect; the kink instability …
  - Polarized $^3$He acceleration
  - 166 bunches
- General EIC R&D item:
  - Proof of principle of the coherent electron cooling

# R&D ERL Commissioning start 2009



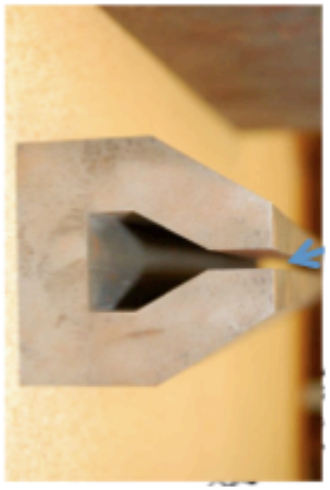


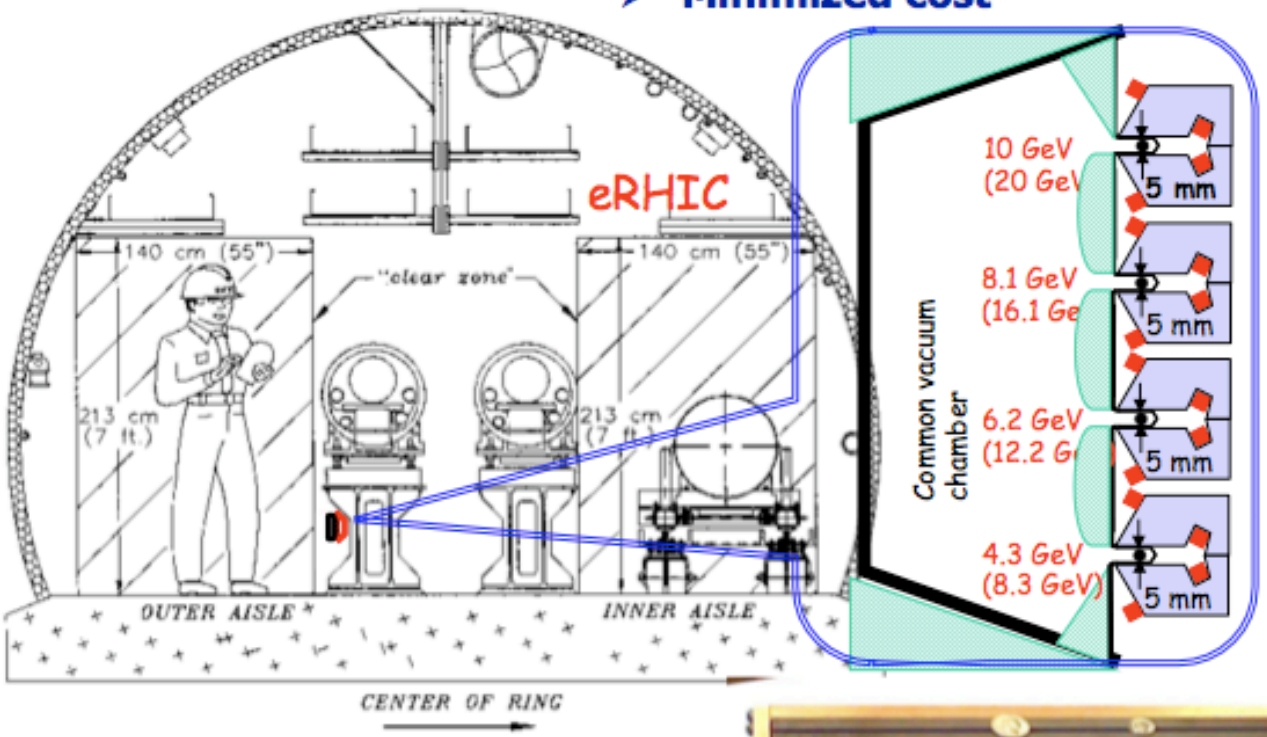




## Four recirculation passes:

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





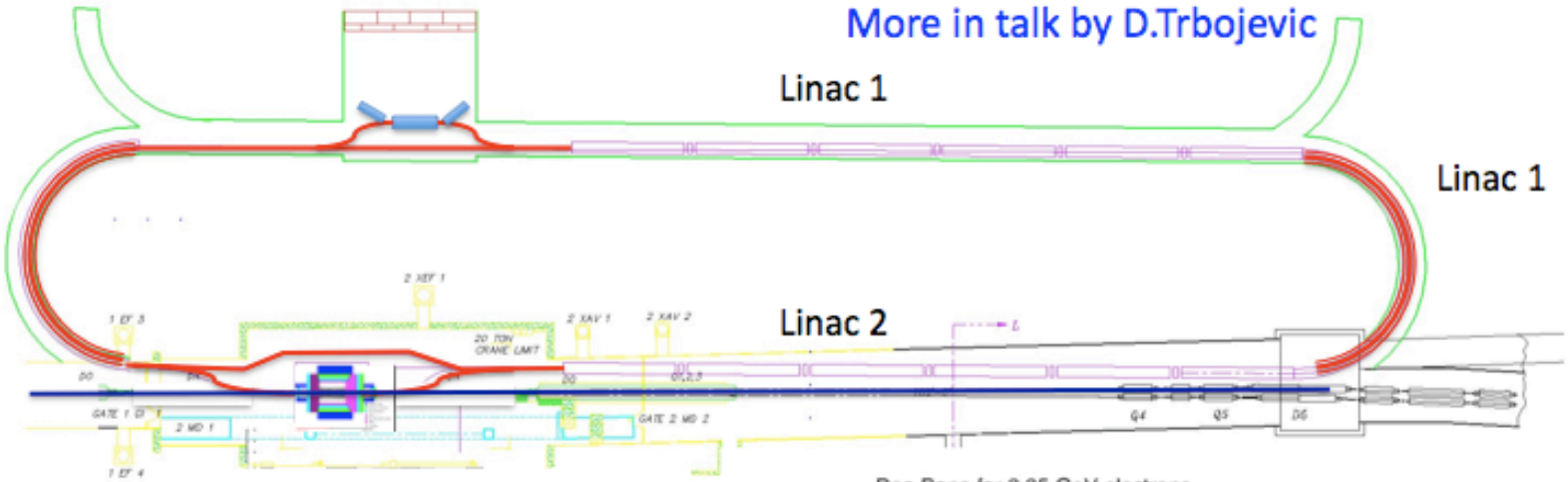

Prototype magnets are already built
(V. N. Litvinenko)

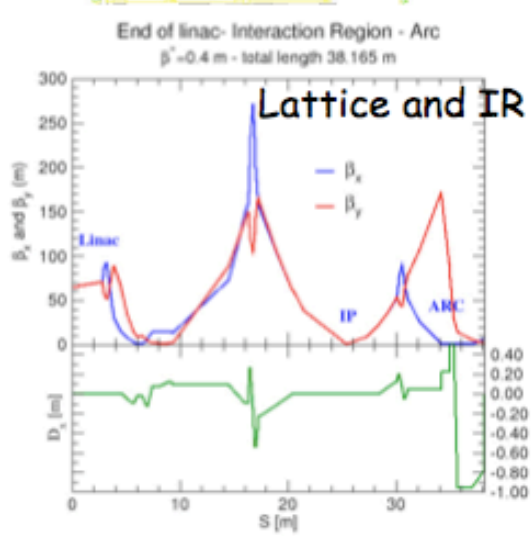
# Staged Realization…

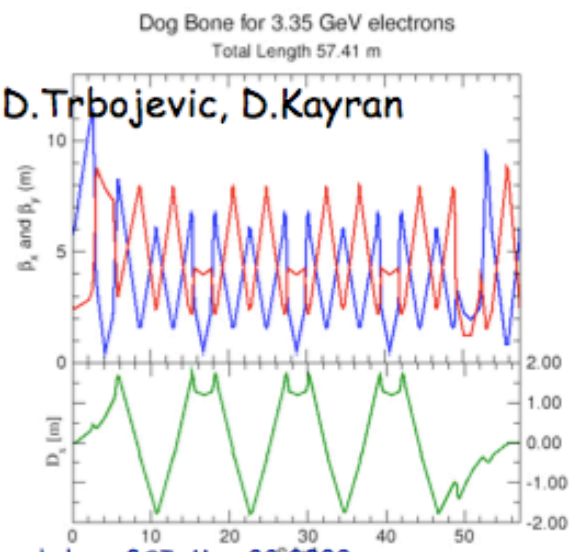
Early…. (2015 ←→2020)
Low cost… (< 300M?)
Utilize all instrumentation in the Final EIC

# MeRHIC at 2 o'clock IR at RHIC

More in talk by D.Trbojevic




Lattice and IR by D.Trbojevic, D.Kayran

V.N. Litvinenko, ENC/EIC workshop, GSI, May 28 2009

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

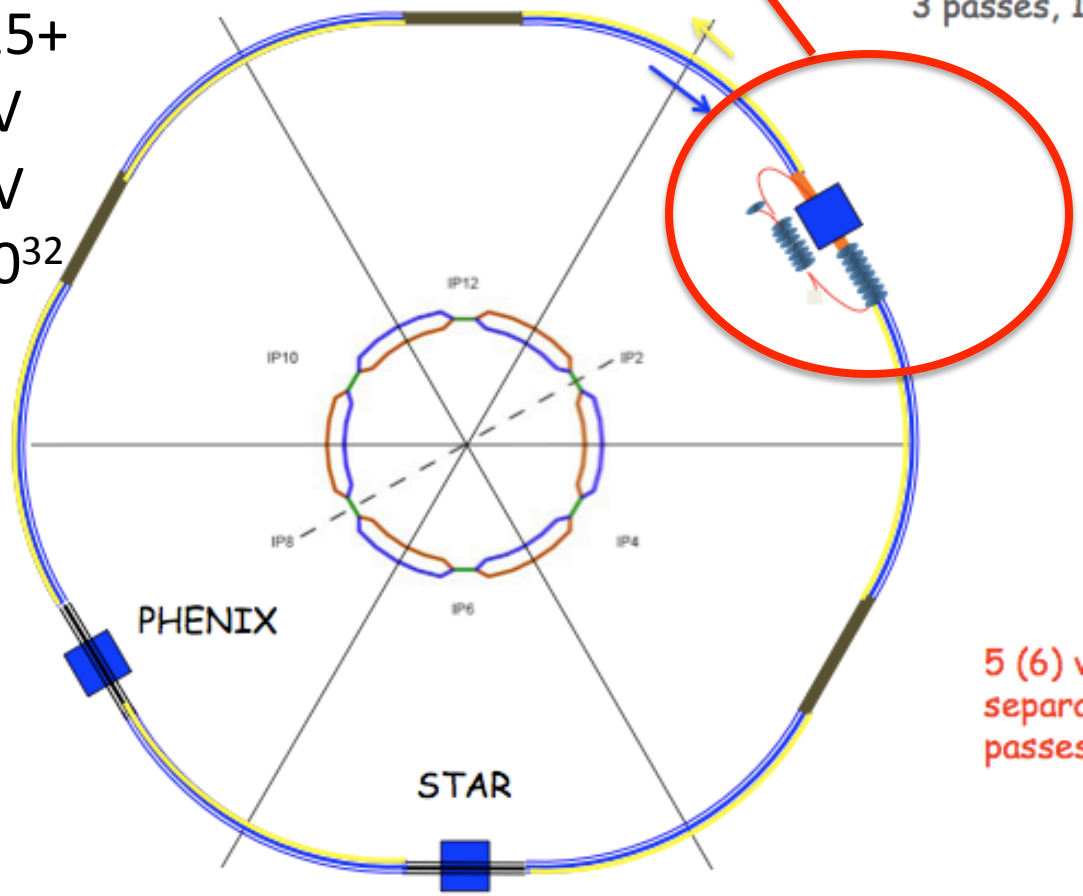
RHIC

Realizable 2015+

$E_p$=50-250 GeV

$E_A$=20-100 GeV

Lumi ~ few x$10^{32}$




19

V.N. Litvinenko, DIS 2009, Madrid, April 28 2009

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# MeRHIC parameters for e-p collisions

© V.Ptitsyn

| | not cooled | | With cooling | |
|---|---|---|---|---|
| | p | e | p | e |
| Energy, GeV | 250 | 4 | 250 | 4 |
| Number of bunches | 111 | | 111 | |
| Bunch intensity, $10^{11}$ | 2.0 | 0.31 | 2.0 | 0.31 |
| Bunch charge, nC | 32 | 5 | 32 | 5 |
| Normalized emittance, 1e-6 m, 95% for p / rms for e | 15 | 73 | 1.5 | 7.3 |
| rms emittance, nm | 9.4 | 9.4 | 0.94 | 0.94 |
| beta*, cm | 50 | 50 | 50 | 50 |
| rms bunch length, cm | 20 | 0.2 | 5 | 0.2 |
| beam-beam for p /disruption for e | 1.5e-3 | 3.1 | 0.015 | 7.7 |
| Peak Luminosity, 1e32, $cm^{-2}s^{-1}$ | 0.93 | | 9.3 | |

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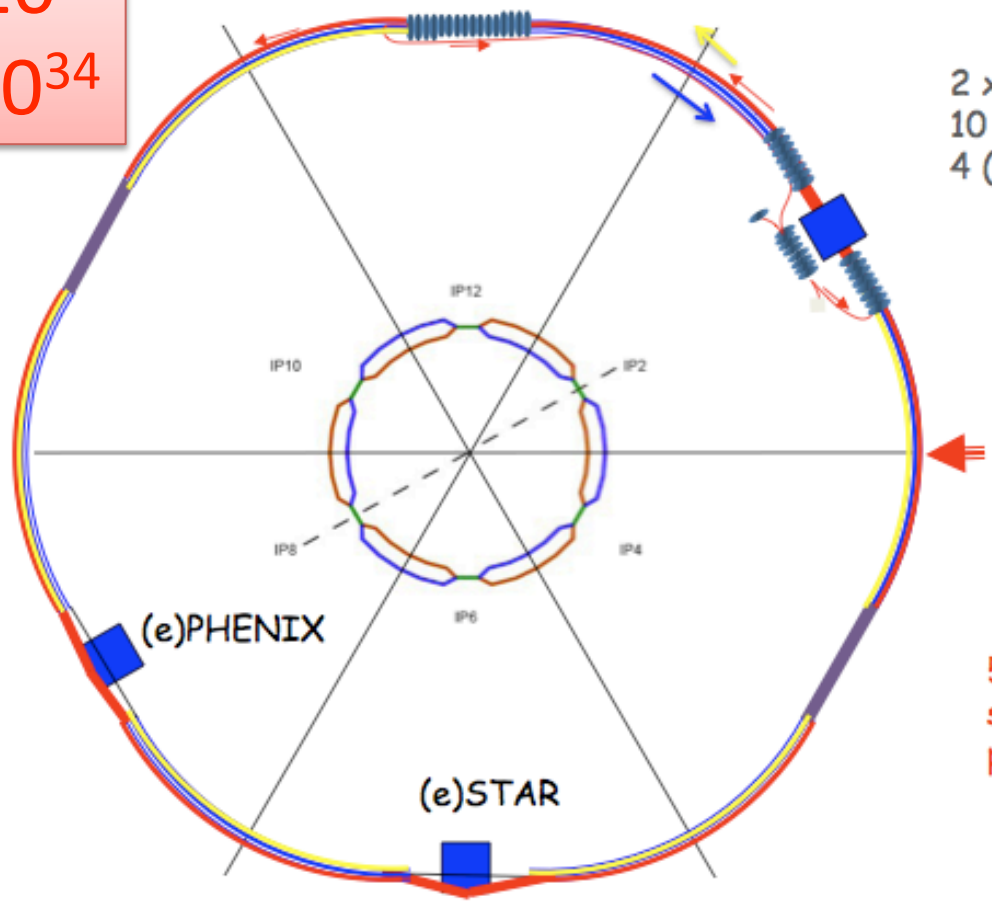
# 20 (10 & 30) GeV e x 325 GeV p eRHIC with ERL inside RHIC tunnel

RHIC

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

20

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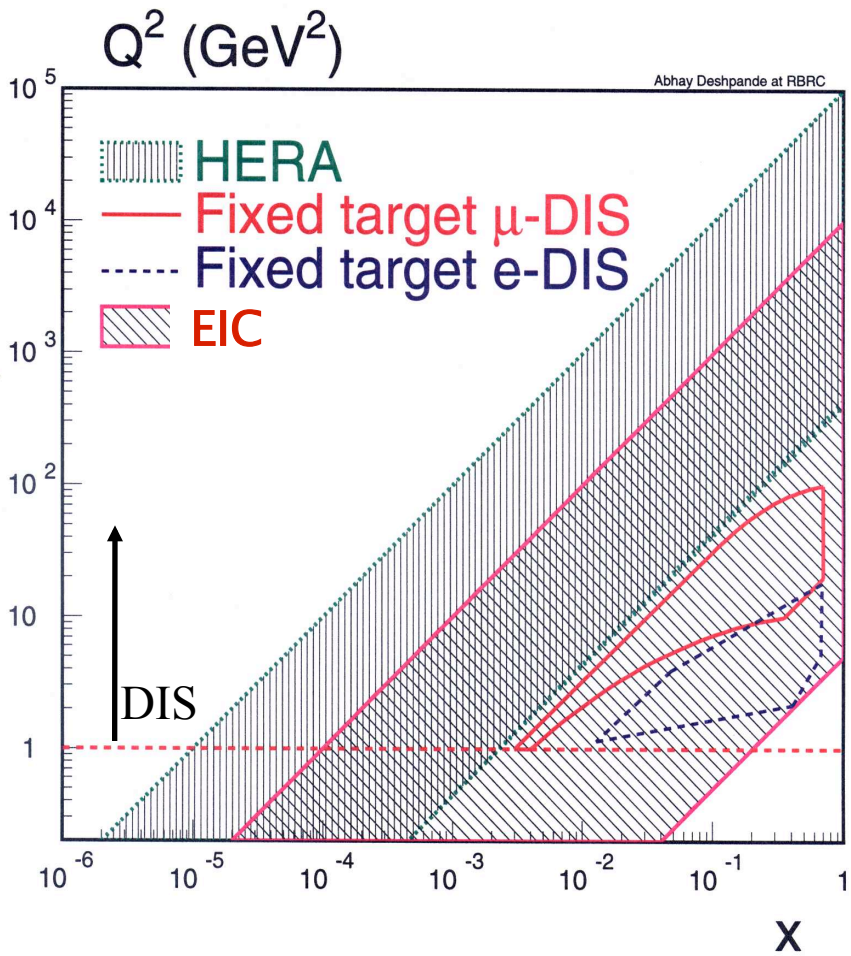
# Parameters of the Electron Ion Collider




- **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

Polarized Beams

- 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

low

Lumi

high

- Un-polarized Nucleon Structure
  - Understanding confinement with low x/low$Q^2$ 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

# Some e-p Physics Projection for 1-2 yr operation of EIC:

Luminosity: $10^{33}$ $cm^{-2}sec^{-1}$

86 $pb^{-1}$ → 1 day delivered

Assume 70% beam uptime, 70% detector efficiency

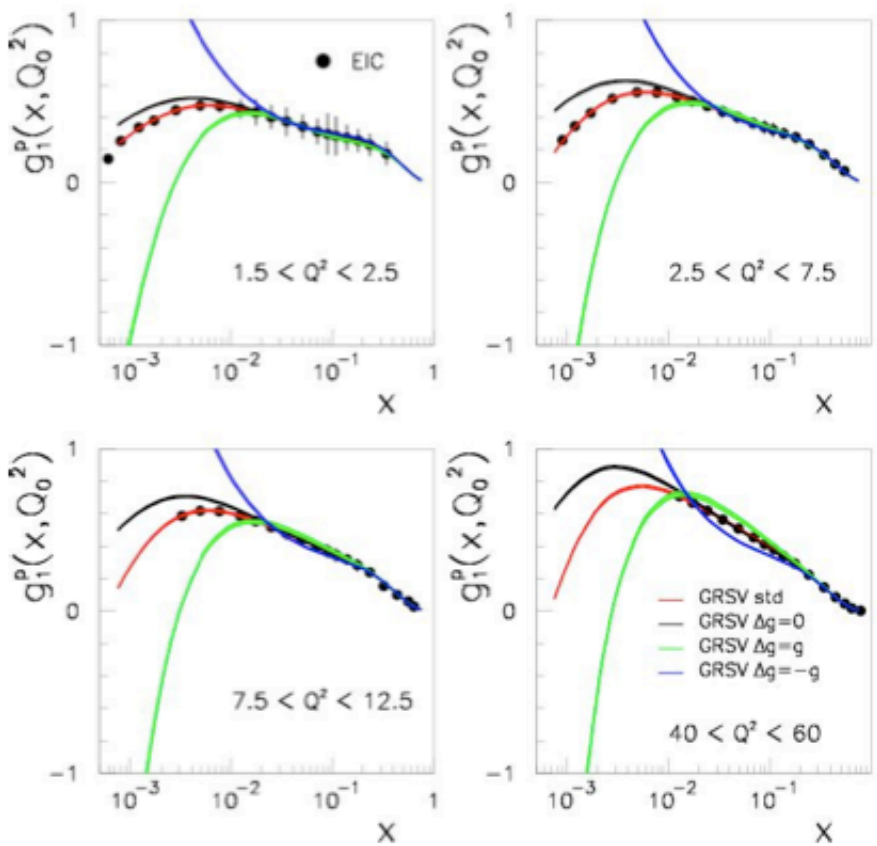
~6 $fb^{-1}$ → 1 RHIC Year (10 Physics weeks)

E. Kinney @ RHIC BNL User's Meeting
DSSV+ST/KB+AD et al updating this and related plots

## The Gluon Contribution to the Proton Spin
## Inclusive $g_1$ Measurements

$$\frac{d\,g_1}{d\log(Q^2)} \propto -\Delta g(x, Q^2)$$

- Projections for 7 GeV e- on 150 GeV p
- Excellent sensitivity to Δg(x) at small *x*




*Antje Bruell, Abhay Deshpande*

E.R. Kinney EIC Workshop - 2 June 2009 - RHIC/AGS Meeting 9

E. Kinney @ BNL RHIC Users Meeting

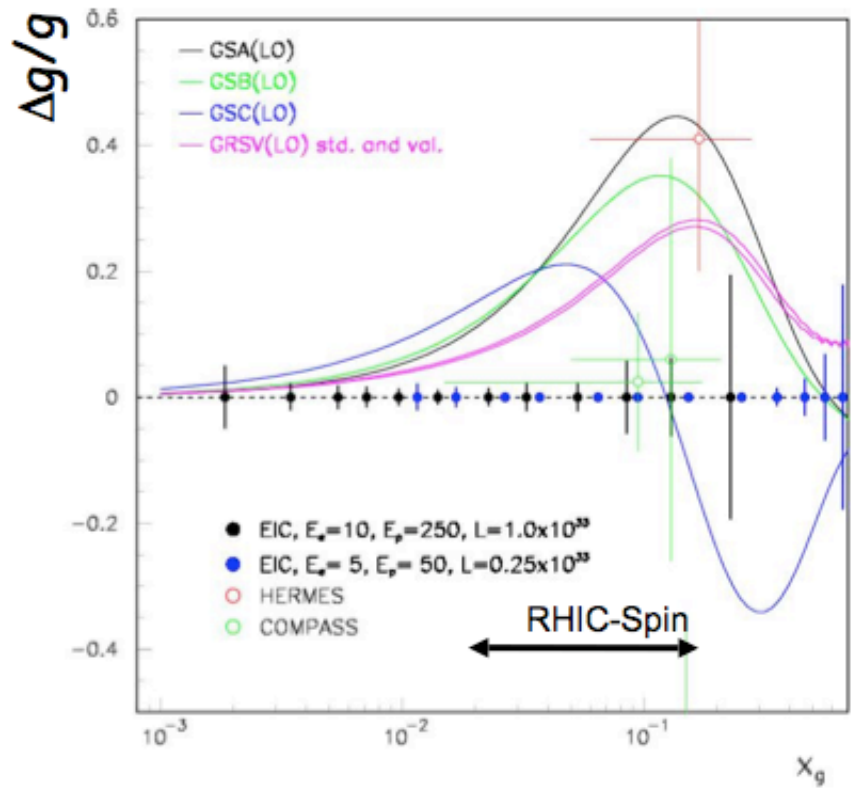
## The Gluon Contribution to the Proton Spin
## Open Charm SIDIS Measurements

Projected data on Δg/g with an EIC, via $\gamma + p \rightarrow D^0 + X$

$\hookrightarrow K^- + \pi^+$

assuming vertex separation of 100 μm.

- Uncertainties in x Δg smaller than 0.01
- Measure 90% of ΔG at $Q^2 = 10\ GeV^2$




*Antje Bruell*

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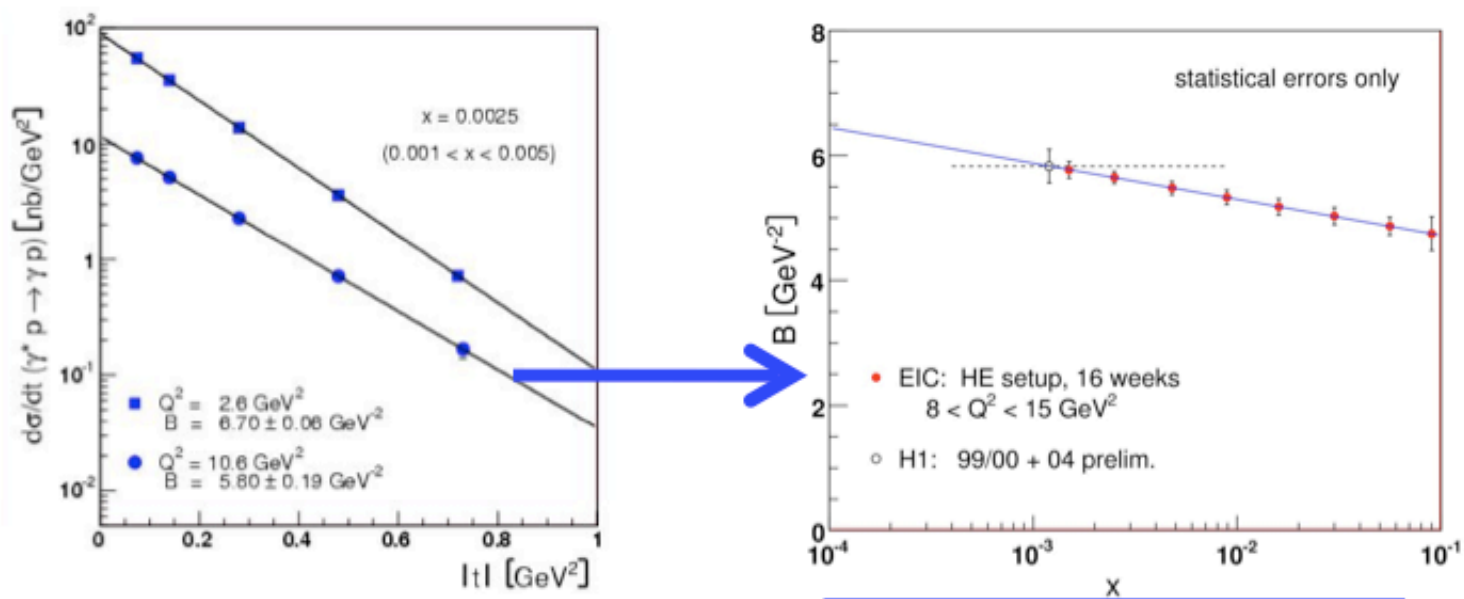
- Studies of impact of EIC with most recent DSSV data set now underway…. Stay tuned…

# DVCS family measurements

E. Kinney at Users Meeting

## GPDs at High Energy: Transverse Gluon Imaging

**Goal: Transverse gluon imaging of nucleon over wide range of x: 0.001 < x < 0.1**
**Requires: - $Q^2$ ~ 10-20 $GeV^2$ to facilitate interpretation**
**- Wide $Q^2$, $W^2$ (x) range**
**- Sufficient luminosity to do differential measurements in $Q^2$, $W^2$, t**




$Q^2$ = 10 $GeV^2$ projected data

Simultaneous data at other $Q^2$-values

*Andrzej Sandacz*

E.R. Kinney EIC Workshop - 2 June 2009 - RHIC/AGS Meeting 17

# Some high level questions…

# about nucleon spin

*Motivated by recent discussions and criticism:*
*"Here you go again… why nucleon spin ONE more time? Did you not get RHIC Spin, COMPASS, and Jlab12 for that?"*

- What is known and what will we know from existing facilities about the nucleon spin?
- Will we solve the helicity puzzle?
- What does it mean to “understand” proton helicity?

- What do we WANT to know about nucleon spin?

# Helicity Sum Rule

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_{G,Q}$$

- We KNOW how to measure $\Delta\Sigma$ and $\Delta$G precisely
- We do NOT know HOW to measure $L_{G,Q}$ precisely, **yet**
- We do NOT need to test/confirm angular momentum sum rule
- So lets just measure $\Delta\Sigma$ and $\Delta$G as best as we reliably can… (what remains is the angular momentum of the partons!)
- Propose a facility to do the best job on $\Delta$G and $\Delta\Sigma$ although keep track on the development of extracting the $L_{G,Q}$

# What else would we like to know about the nucleon spin?

- Understanding the spatial and momentum distribution of partons inside protons
  - Proton tomography (?)
  - What does the proton look like in 3D? *This is a very interesting and important question in itself!*
  - Transverse spin phenomena, DVCS, DVVM etc. etc…. Would lead you to GPDs and TMDs

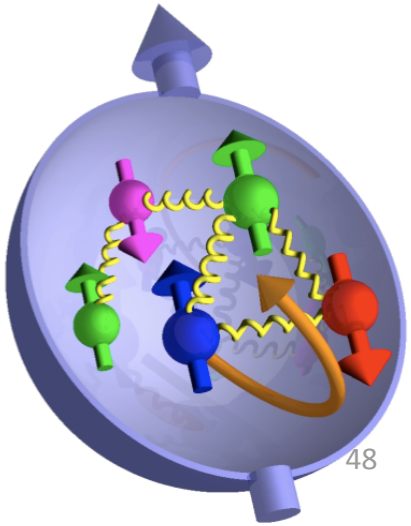
✓ These measurements presently can not, in a model independent way, tell us anything with the OAM

➢ Let us NOT make the OAM part of the promise for the facility!

# *Redefine* the nucleon spin studies

- Best possible measurement of $\Delta\Sigma$ and $\Delta G$ to understand <u>the helicity sum rule</u>

- Pursue GPD and TMD investigations towards a 3D (position & momentum) picture of the proton
  - What does a proton look like inside?
  - May or may not get us to OAM!



# Other opportunities at EIC?

- Polarized beams, high energy, high luminosity
- A modern detector

- Possibilities of EW physics? Pushing the limits of SM parameters?

# EW & Beyond SM Physics with EIC?

- Lepton Flavor Violation
- Precision weak mixing angle measurement
- Parity Violating deep inelastic scattering
- ***Will require L ~ > $10^{34}$ $cm^{-2}$ $sec^{-1}$***
  - ***50-500 $fb^{-1}$ integrated luminosity and full detector***
  - ***A major cost driver***

Initiated by discussions with Mike R. Musolf & Krishna Kumar. Now followed up with a proposal for LDRD: W. Marciano, K. Kumar, M. Savastio**, W. Vogelsang & AD+ A post doc to be hired

** UG Student at SBU

# Identifying Tau Leptons

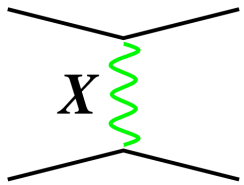
$$e^- + p \rightarrow \tau^- + X$$

***Topology: DIS event, except electron replaced by tau lepton***

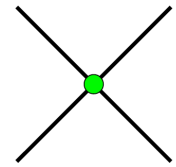
- If mixed in with hadron remnants, the tau would be highly boosted (10 to 50 GeV)
- If forward in the incident electron direction, the tau would be isolated
- In either case:
  - look for single pion, three pions in a narrow cone, single muon: should be able devise several good triggers
  - tau decay is self-analyzing: should study polarization dependence
  - tau vertex displaced 200 to 3000 microns: would greatly help background rejection and maintain high efficiency if vertex detector is included in EIC detector design

# Colliders vs Low $Q^2$

*consider*




$$A_X \;\alpha\; \frac{1}{Q^2 - M_X^2} \sim \frac{4\pi}{\Lambda^2}$$



*Contact interaction*

$Q^2 \sim M_Z^2$ **on resonance:** $A_Z$ *imaginary* $\longrightarrow A_Z^2\left[1 + \frac{A_X^2}{A_Z^2}\right]$

***no interference!***

$$\frac{\delta A_Z}{A_Z} \;\alpha\; \frac{\pi/\Lambda^2}{g\,G_F} \longrightarrow \boxed{\begin{array}{l}\delta(g)/g \sim 0.1 \\ \Lambda \sim 10\ TeV\end{array}}$$

$$\frac{\delta(\sin^2\theta_W)}{\sin^2\theta_W} \lesssim 0.01$$

***Window of opportunity for weak neutral current measurements at $Q^2 \ll M_Z^2$***

Processes with potential sensitivity:

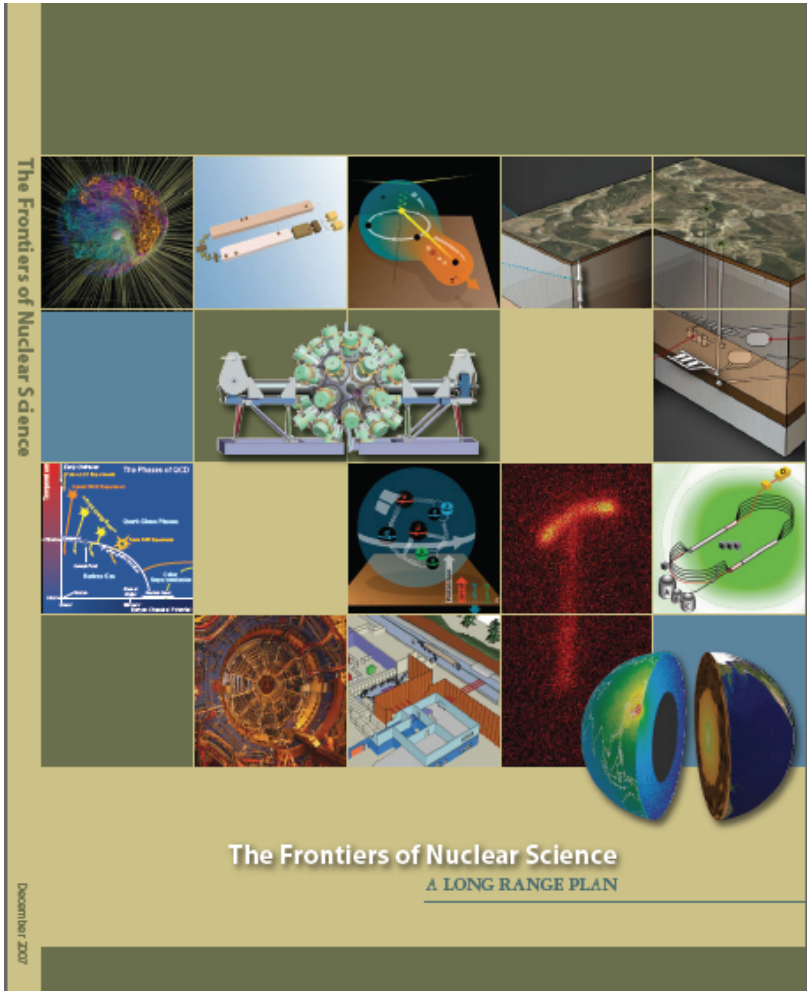
- neutrino-nucleon deep inelastic scattering
- Atomic parity violation
- parity-violating electron scattering

**Studies now beginning. Most demanding luminosity and detector requirements**

# 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 WG & Collaboratoin 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***
***- http://www.bnl.gov/eic***

# Recommendations of the EICAC

(result of February 16th, 2009 meeting)

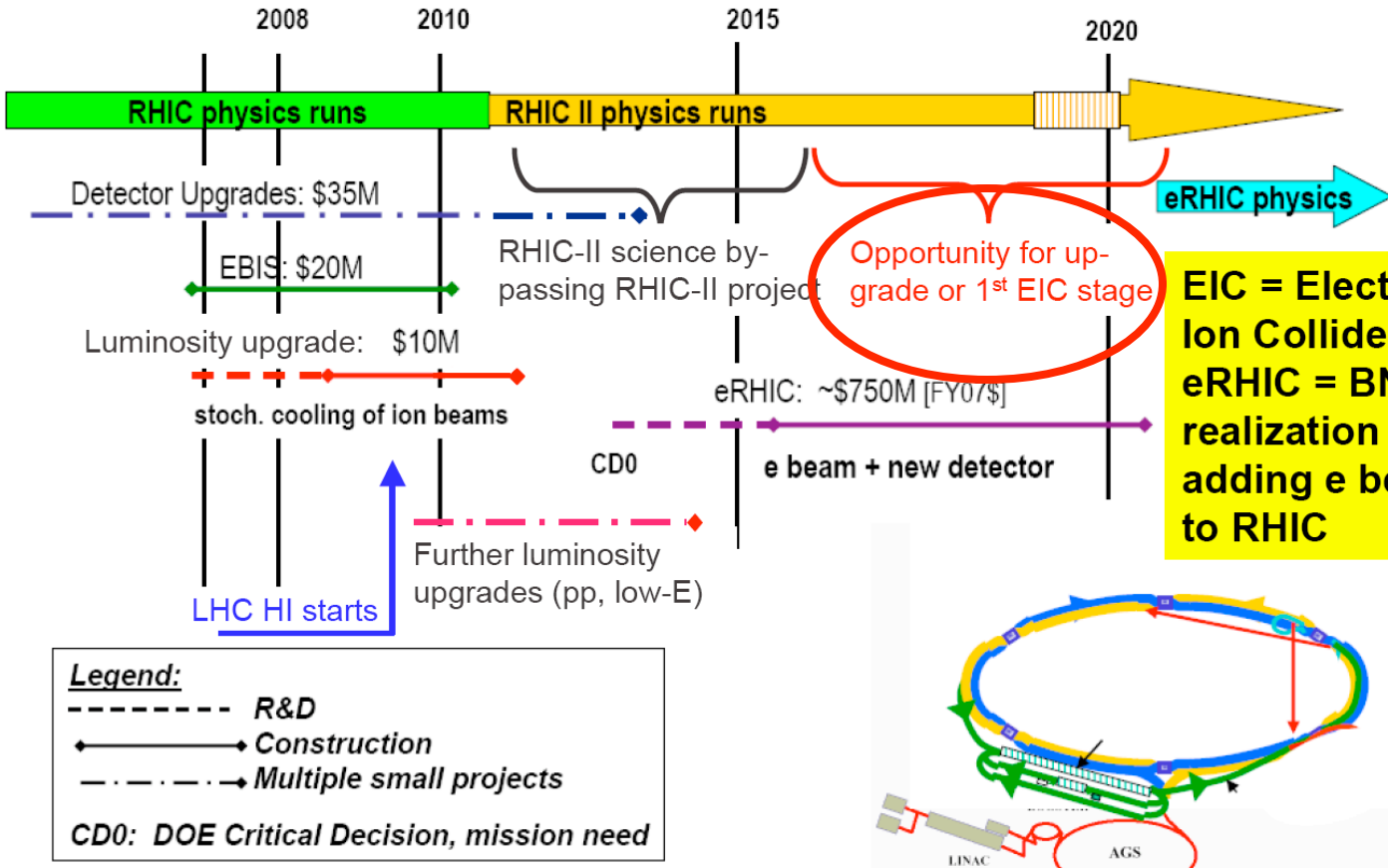
- Coherent R&D plan, time line, milestones, and resource needs
- Initial cost-performance science reach matrix
- Short list of golden measurement and what will we learn
- Implications of the golden experiments for detector requirement and R&D
- Prepare a time line for major decision including site selection
- Strive for a time line that provides for data taking before 2020 –*Highly recommend STAGED approach!*

# Advantages of Staged Realization

- 1st look at the saturation surface for nuclei in e+A
  - Confirm the A-related oomph factor
  - Test the measurability of e-A diffraction
  - 1st look at different methods to get to gluon density
- Extend polarized e-p program beyond present experimental reach
  - In longitudinal and transverse spin physics
  - Measure and test QCD evolution in transverse spin phenomena
  - Detection of boosted fragments, initiate study of spin dependent correlations in nucleons
- Develop the science case, detector design and cost estimate for staged and the final EIC

*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

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# EIC Realization: *Gaining Momentum*

- Meetings:
  - Next Physics WS End of Summer @ ??
  - Collaboration Meeting in Dec/Jan at SBU
  - INT programs October'09, Fall'10, EINN09 at MILOS, APS-JPS Joint WS
  - **EICAC Review anticipated in Fall'09**
- Regular activities
  - Weekly meetings in University & Lab Groups begun
  - Monthly meeting of the Steering Group+Conveners
  - Summer programs at BNL, SBU, MIT, Jlab (6 SBU students, 2 Hampton U students)
- LDRDs (total of $2M) at BNL for detector design, detector R&D, theory: **Being decided now**

# Concluding remarks

- EIC is an exciting project that needs a lot of **your** personal attention in the next few years… no matter which continent
- Two US labs seem to be moving seriously towards realizing this project:
  - Task forces being formed
  - LDRDs for detector R&D and design now being distributed
- *A matrix of physics, machine/detector designs and cost under preparation:* ***will become the foundation for realization plans***

- Active participation and advice from this group of theorists will be crucial. Stay tuned for my requests and appeals to participate in the process of realization of the EIC

- Look! Purple mountains! Spacious skies! Fruited plains!....
- Look! High density glue! Nucleon spin! Proton in 3D...
  - Lets explore and understand it.... With the Electron Ion Collider....