Overview of
The US Electron Ion Collider Project

DIS 2010
April 20, 2010

- Physics motivation: Fundamental open questions in QCD
- Concepts of future collider under consideration in the US
- Physics simulations and detector concept/design progress
  - ✓ Mostly in other talks in this and other sessions
- Status of EIC project: Progress, activities & prospects of realization

Abhay Deshpande, Stony Brook University

While there is no reason to doubt QCD, the level of understanding of QCD remains extremely unsatisfactory

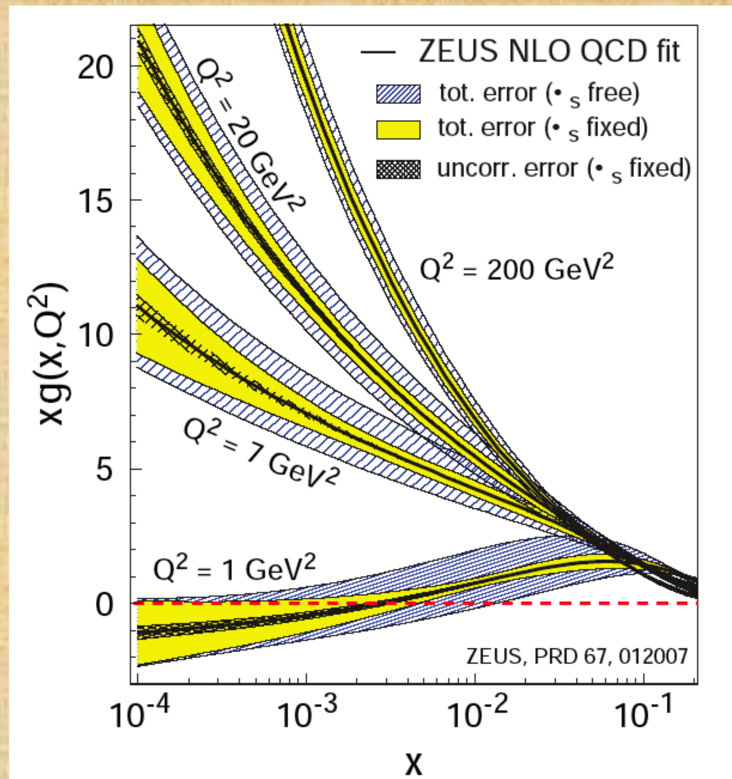
Dissatisfaction: Understanding **Mass** & **Spin** in QCD

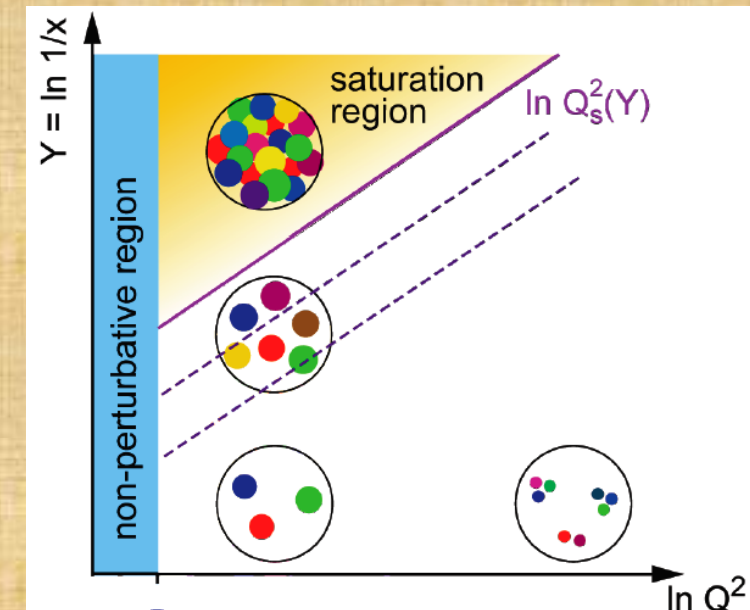
We are only beginning to explore high-energy many-body dynamics of QCD

High-energy many-body dynamics of QCD

- What are the effective degrees of freedom at high energy?
  - Gluons, sea quarks, dipoles, pomerons, strong fields?
- How do these degrees of freedom interact with each other and with other hard probes?
  - Multi-pomeron interactions, higher twist effects, Saturation and color glass condensates
  - Rapidity gaps, energy loss, multiple scattering, color transparency
  - Glasma, Quark Gluon Plasma
- What can this teach us about confinement, universal features of the theory (infrared fixed points?)
  - Hard vs. soft pomerons, strong fields,…. in-medium hadronization

Gluons still not well understood!





- Rise at high Q^2, low x
  - Infinite rise, infinite cross section?
  - Is this due to use of linear DGLAP?
  - Direct consequence to high energy hadron cross sections
- Negative g(x) at low Q^2?

- What is the effect of including non-linearity in DGLAP equation?
  - Saturation, Color Glass Condensate?

No high enough energy collider

- Experiment with high densities of gluons → Why not use Nuclei?

Diffraction: A surprise at HERA

- Diffraction → in the final state, the proton remains intact
- HERA: 820 GeV protons and 27 GeV electrons
  - In proton's rest frame the collisions is equivalent to what you would get when a ~50 TeV electron beam hits a stationary proton
- Surprise: ~1/7 of the time, the proton remains intact Completely unanticipated, astonishing phenomena
- Presently only explained quantitatively by theoretical ideas based on non-linear gluon dynamics at low x (CGC)
  - CGC predicts that in e-A, the 1/7 → ~1/4
  - Needs to be experimentally verified…

Nucleon Spin ~~Crisis~~ Puzzle

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + L_Q + \Delta G + L_G$$

- We know how to measure ΔΣ and ΔG precisely using pQCD in a <u>model independent</u> way
  - ½ (ΔΣ) ~ 0.15 : From fixed target pol. DIS experiments
  - RHIC-Spin: ΔG *not large* as anticipated in the 1990s, but *measurements & precision needed at low & high x*

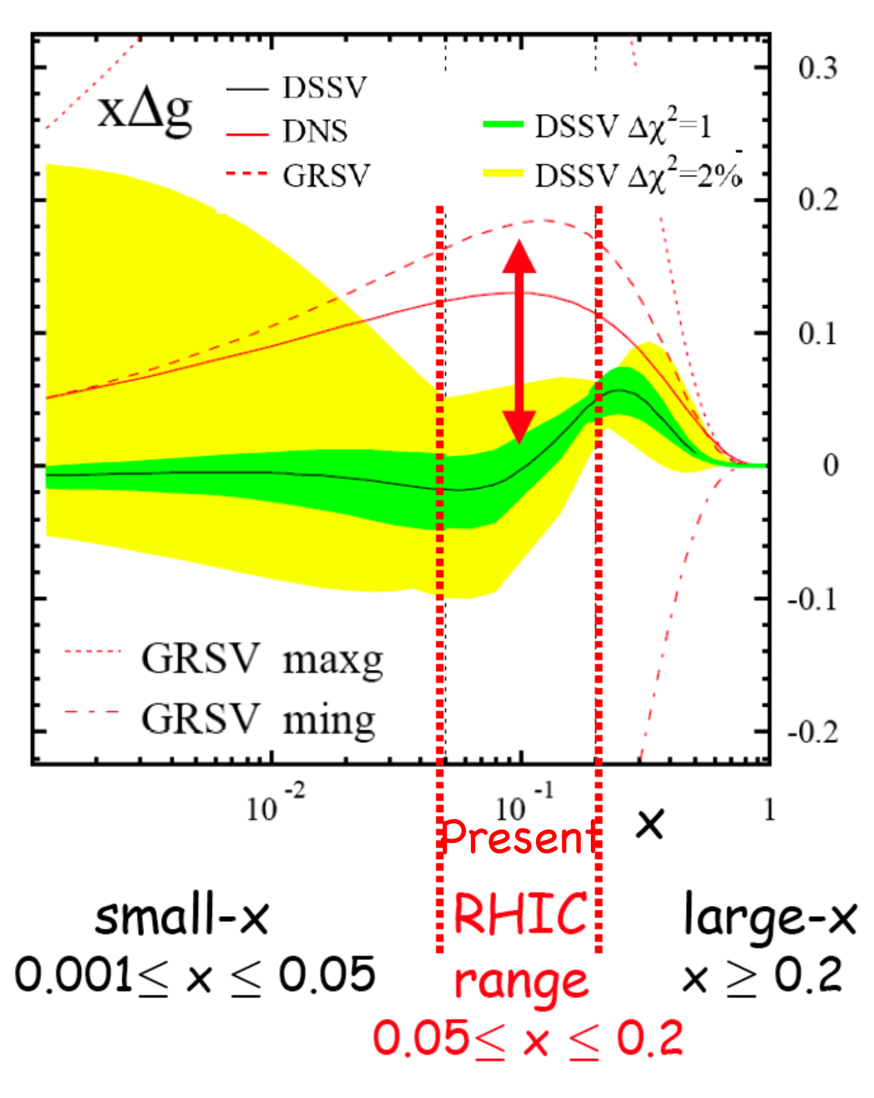
RHIC spin talks

- Orbital angular momenta: L_Q (L_G?)
  - Through GPDs: Model dependences … other theoretical issues..
  - A lot to learn from the12 GeV Jlab & the COMPASS program & ongoing theoretical development

GPD talks in Spin WG

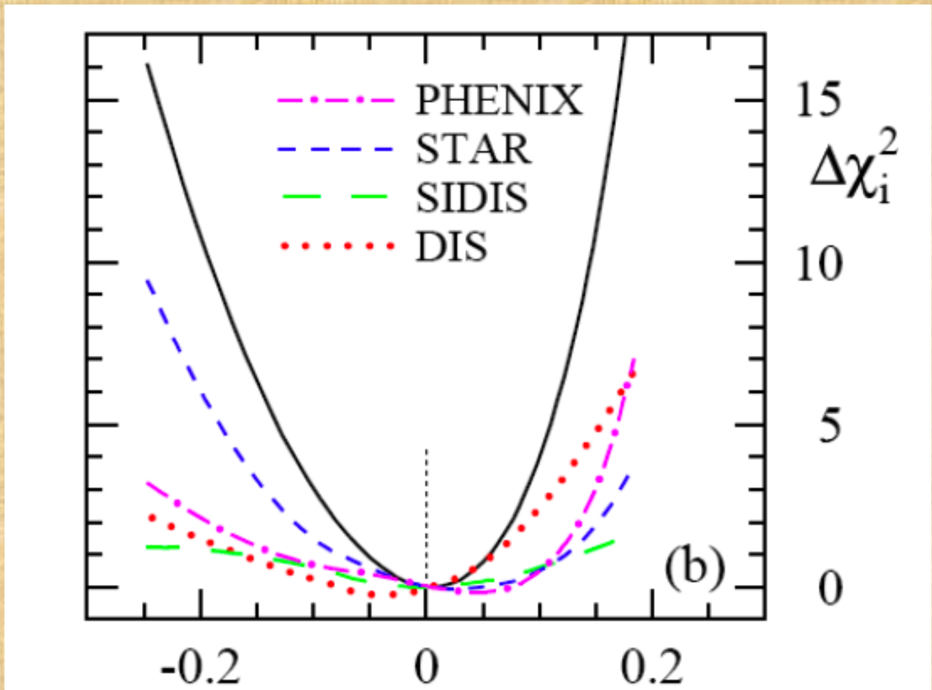
- It would be great to have a 3D tomographic image of a proton…. Transverse spin phenomena (TMDs, GPDs: Q & G)

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



de Florian, Sassot, Stratmann & Vogelsang

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

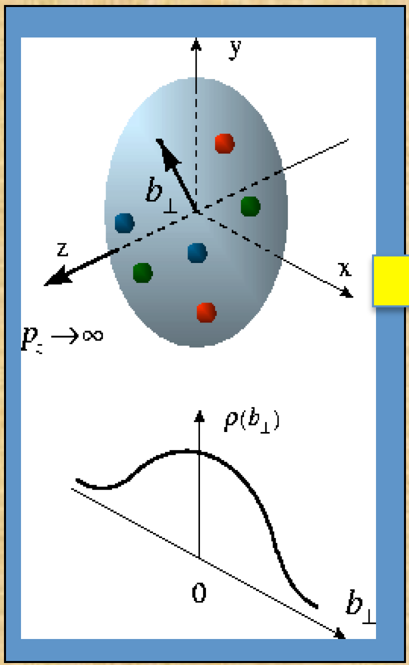


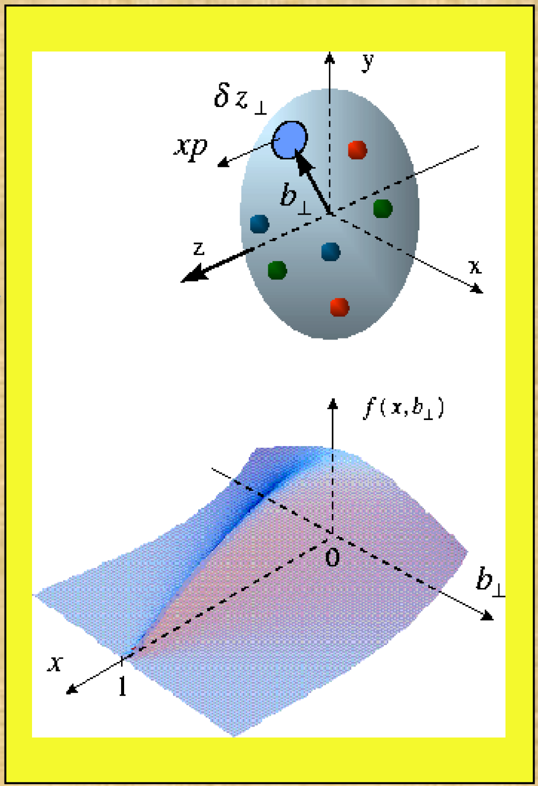
$$\delta g \equiv \int_{0.05}^{0.2} \Delta g(x, 10\,\mathrm{GeV}^2)\,dx$$

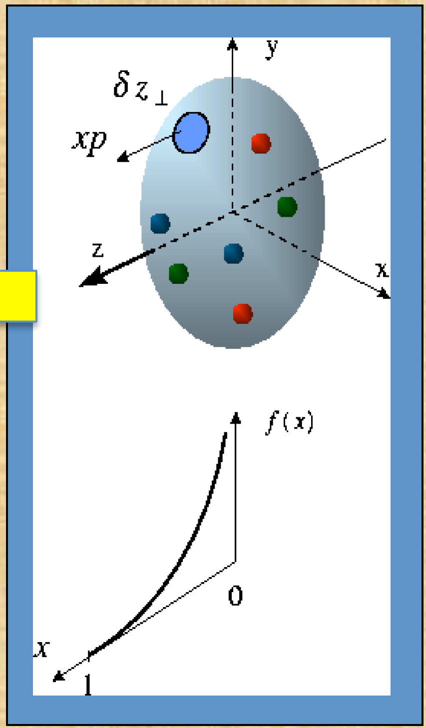
Generalized Parton Distributions

X. Ji, D. Mueller, A. Radyushkin (1994-1997)

Beyond Form Factors and Parton Distribution Functions







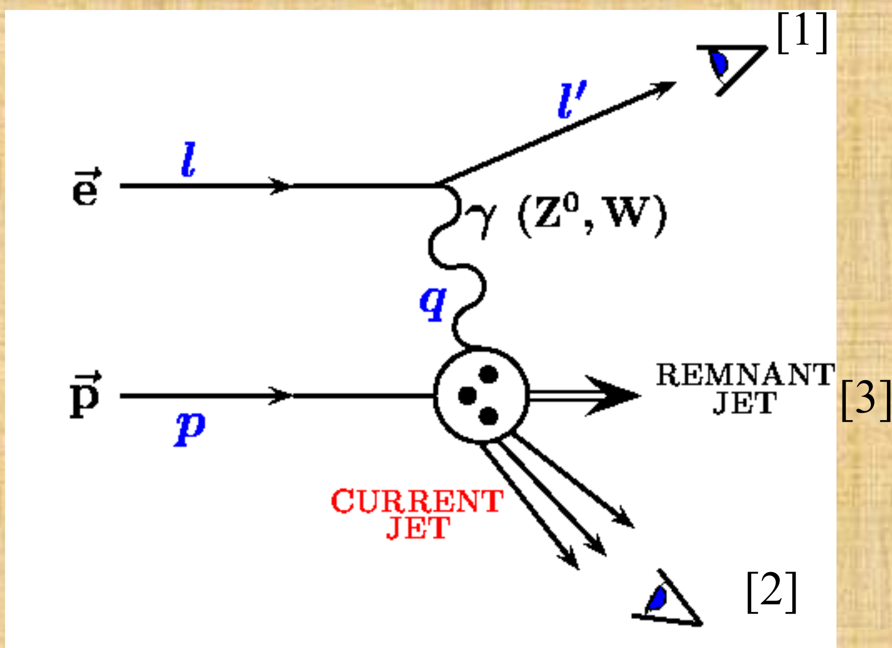
Proton form factors, transverse charge & current densities

Correlated quark momentum and helicity distributions in transverse space - GPDs

Structure functions, quark longitudinal momentum & helicity distributions

The Proposal: Future DIS experiment

A high energy, high luminosity (polarized) ep and eA collider and a suitably designed detector will address these and such fundamental questions in QCD



Measurements:

[1] → Inclusive

[1] and [2] **or** [3] →Semi-Inclusive

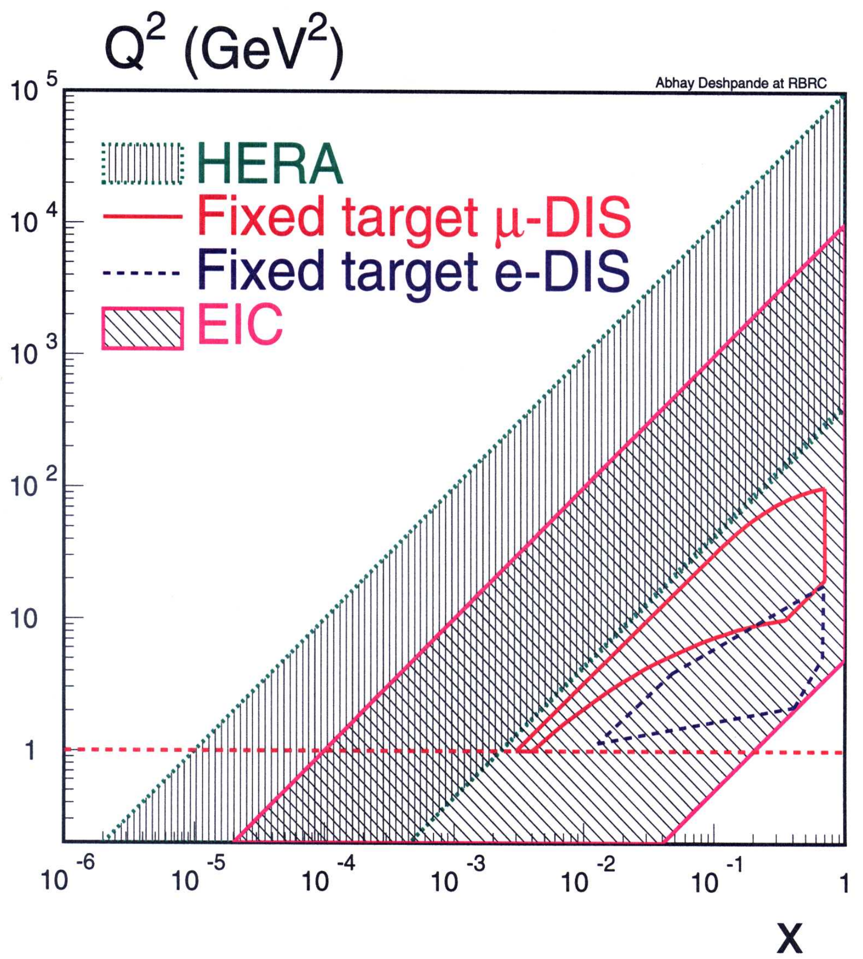
[1] and [2] **and** [3] →Exclusive

Inclusive → Exclusive

Low → High Luminosity

Demanding Detector capabilities

EIC in the US: Basic Parameters



- E_e=10 GeV (5~20 GeV variable)
- E_p=250 GeV (50~250 GeV Variable)
- Sqrt(S_{ep}) = 30~100 GeV
- X_{min} = 10^{-4}; Q^2_{max}= 10^4 GeV
- Beam polarization ~ 70% for e,p
- Luminosity L_{ep} = $10^{33\text{-}34}$ $cm^{-2}s^{-1}$
- Aimed Integrated luminosity:
  - 50 fb^{-1} in 10 yrs (100 x HERA)
  - Possible with 10^{33} $cm^{-2}s^{-1}$

Nuclei:

- p->U; E_A=20~100 GeV
- Sqrt(S_{eA}) = 12~63 GeV
- L_{eA}/N = 10^{33} $cm^{-2}s^{-1}$

Machine Designs

eRHIC at Brookhaven National Laboratory using the existing RHIC complex

(Details in Ilan Ben-Zvi's Talk in this session)

ELIC at Jefferson Laboratory using the Upgraded 12GeV CEBAF

(Details in Kees de Jaeger's talk in this session)

Staged Approach to realization planned in both designs

(Numbers & designs from the latest Collaboration Meeting at Stony Brook University, January 2010)

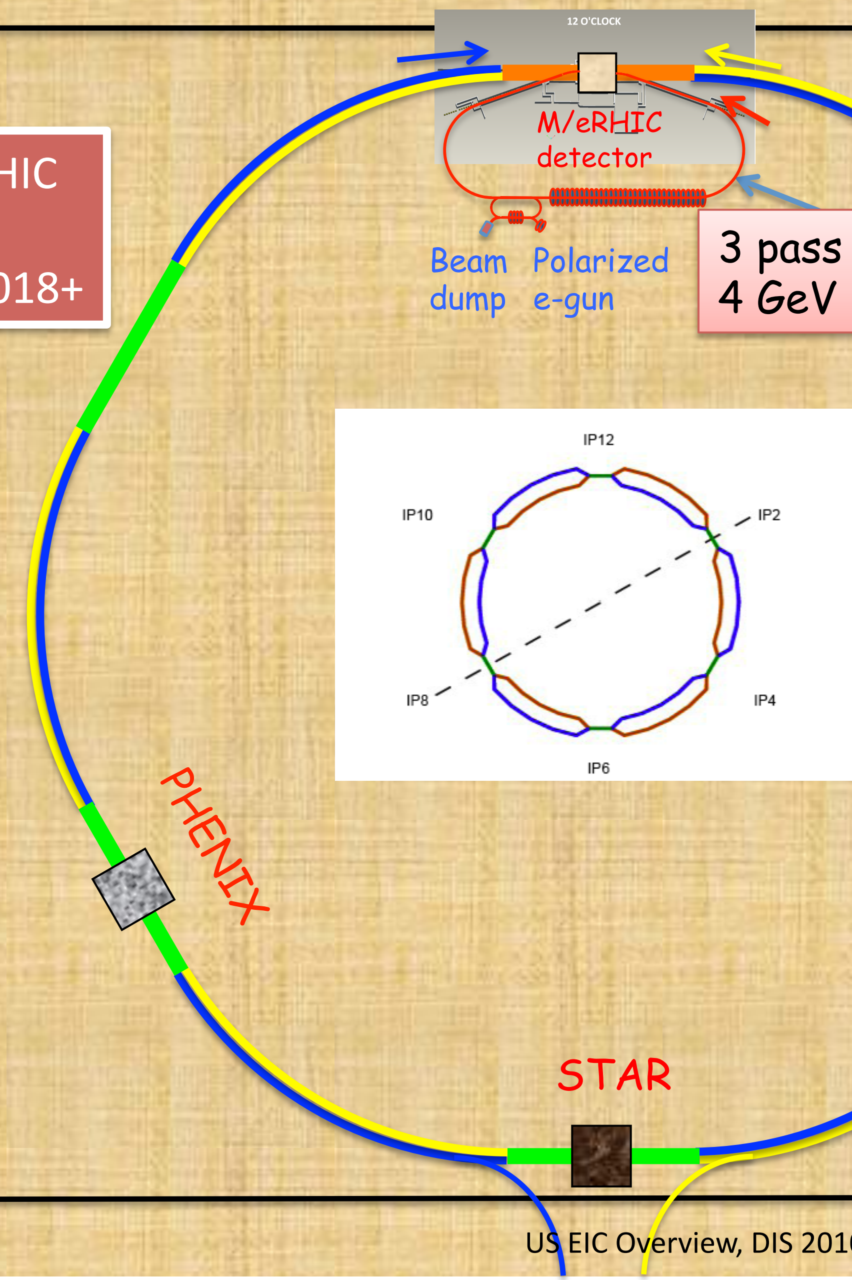
4 GeV e x 250 GeV p – 100 GeV/u Au: ***MeRHIC***

Stage 1 of eRHIC

Possible by 2018+

120m SRF linac
3 passes, 1.3 GeV/pass

3 pass
4 GeV ERL

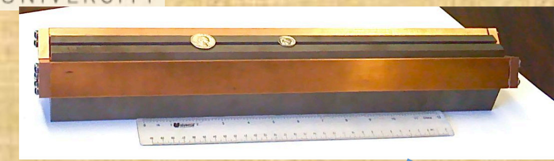


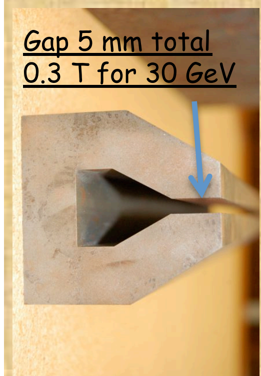
Medium Energy eRHIC

Or

MeRHIC

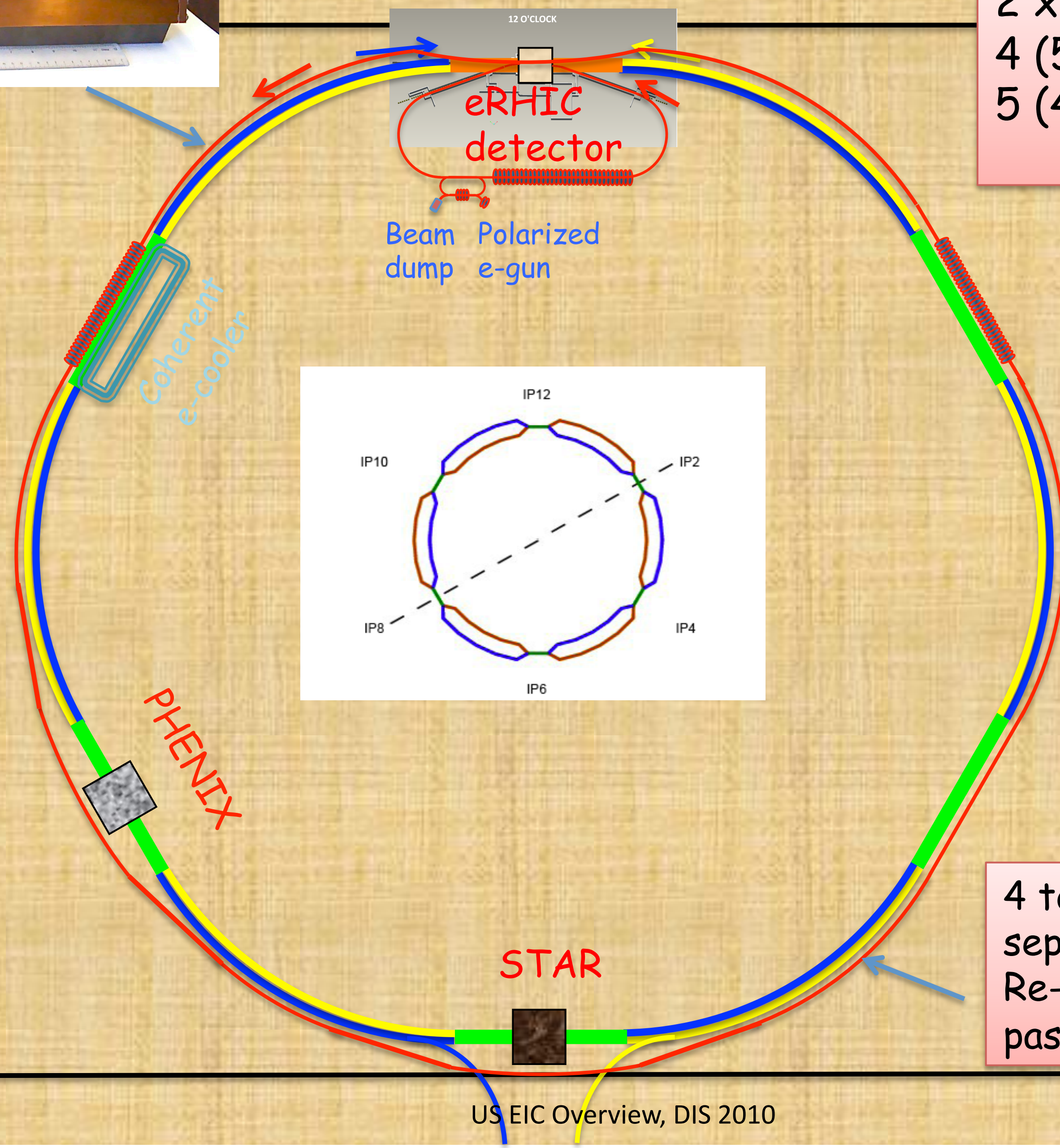
10-20 GeV e x 250-325 GeV p & 100-130 GeV/u Au

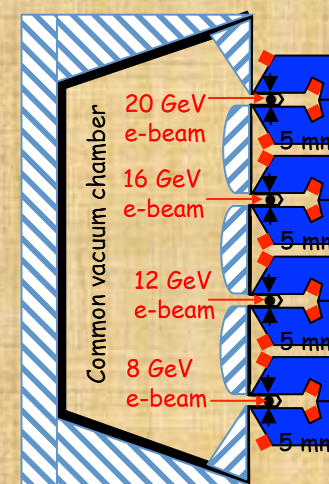




2 x 200 m SRF linac
4 (5) GeV per pass
5 (4) passes

eRHIC 2020+





Possibility of 30 GeV low current operation

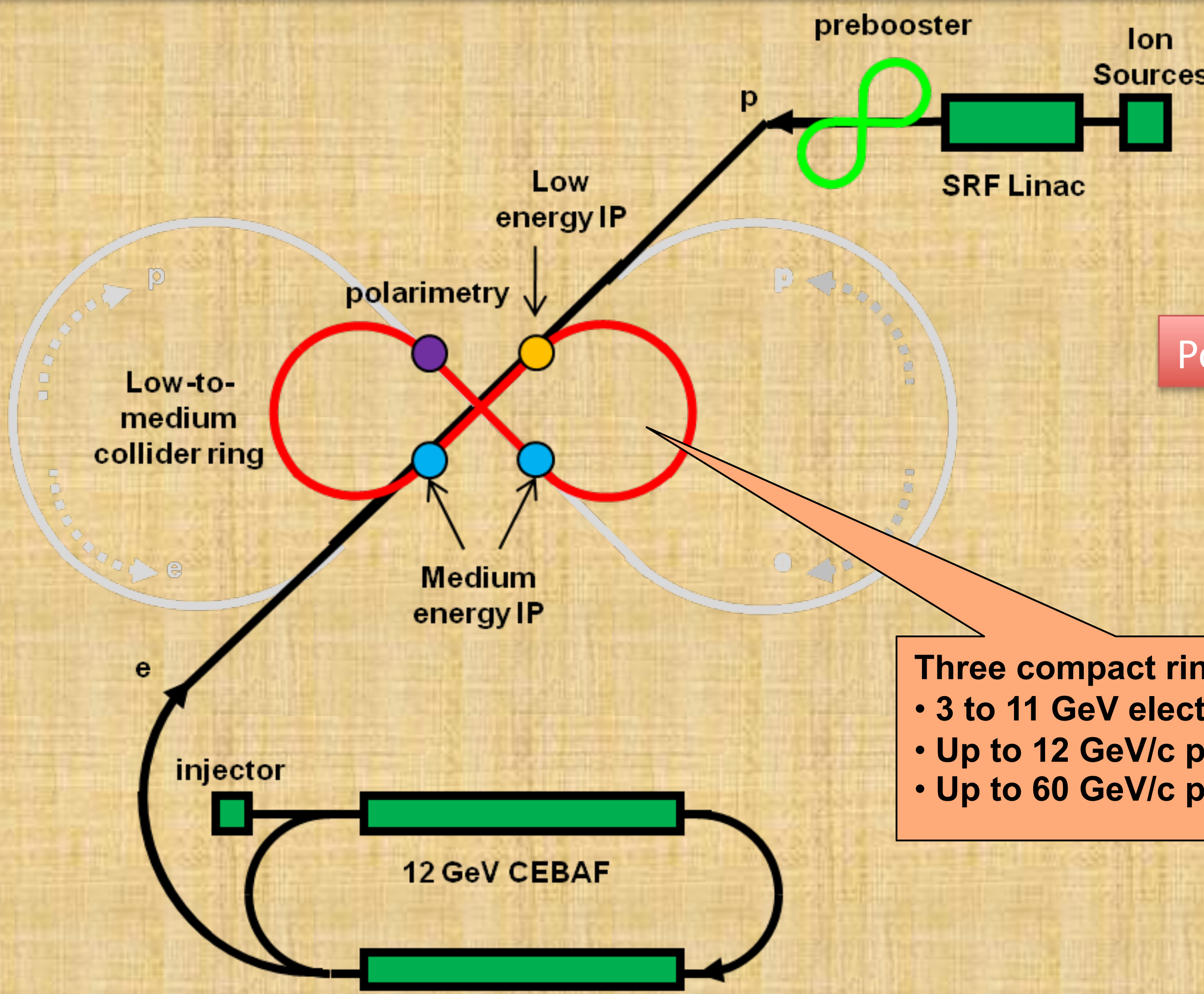
4 to 5 vertically separated Re-circulating passes

Luminosity in eRHIC

	MeRHIC		eRHIC IR1		eRHIC IR2	
	p /A	e	p /A	e	p /A	e
Energy, GeV	250/100	4	325/130	20	325/130	20
Number of bunches	111	105 nsec	166	74 nsec	166	74 nsec
Bunch intensity (u) , 10^{11}	2.0	0.31	2.0	0.24	2.0	0.24
Bunch charge, nC	32	5	32	4	32	4
Beam current, mA	320	50	420	50	420	50
Normalized emittance, 1e-6 m, 95% for p / rms for e	15	73	1.2	25	1.2	25
Polarization, %	70	80	70	80	70	80
rms bunch length, cm	20	0.2	4.9	0.2	4.9	0.2
β*, cm	50	50	25	25	5	5
Luminosity, $cm^{-2}s^{-1}$	0.1×10^{33} as is 1×10^{33} with CeC		2.8×10^{33}		1.4×10^{34}	

‹ Luminosity for 30 GeV e-beam operation will be at 20% level›

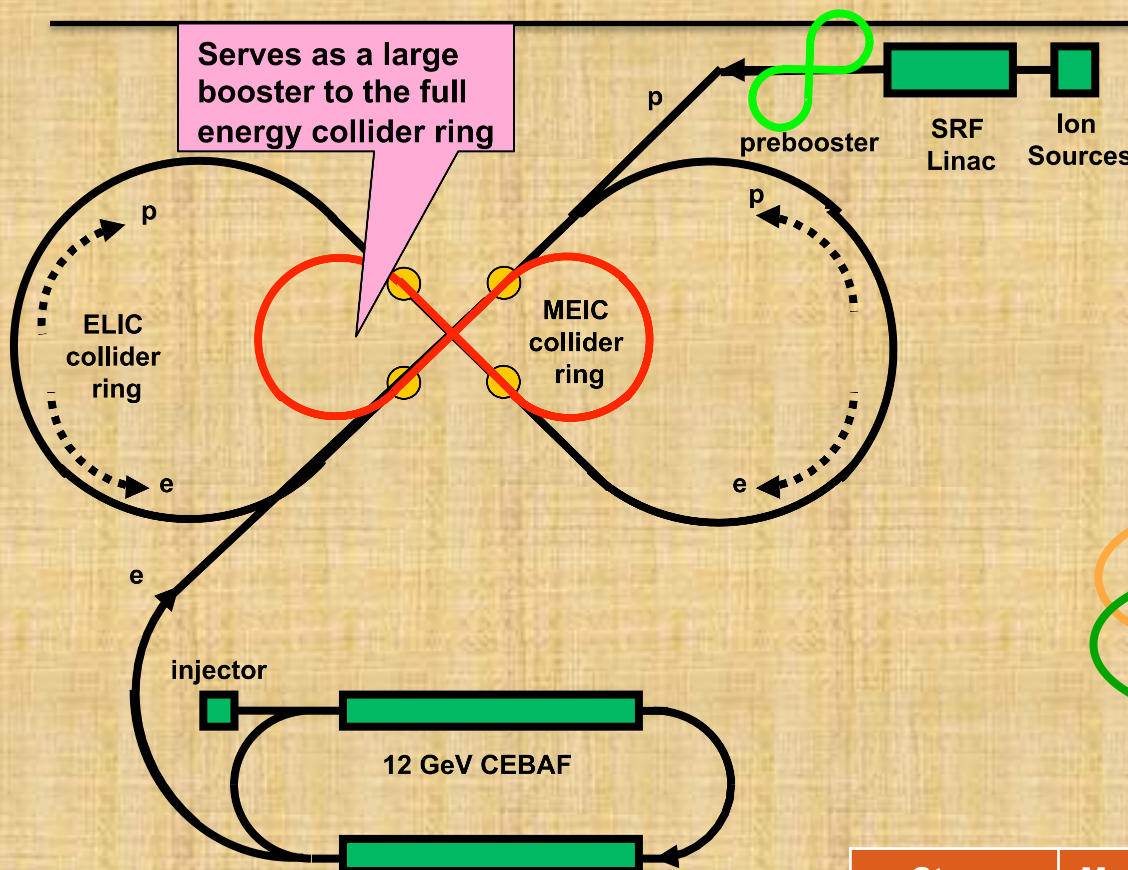
MEIC: A Medium Energy EIC



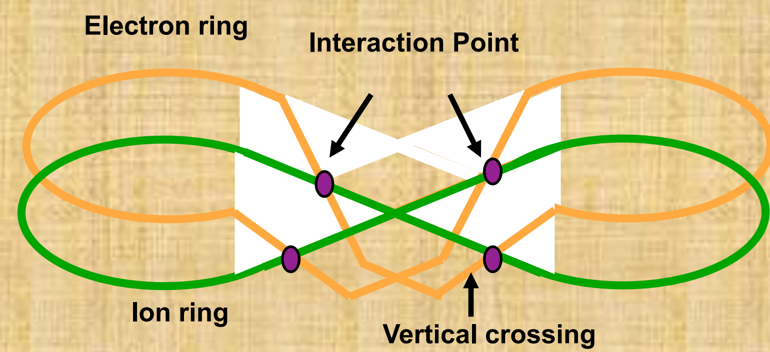
Possible 2020+

Three compact rings:
- 3 to 11 GeV electron
- Up to 12 GeV/c proton (warm)
- Up to 60 GeV/c proton (cold)

ELIC: High Energy Upgrade



Circumference	m	1800
Radius	m	140
Width	m	280
Length	m	695
Straight	m	306



Possible 2025+

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

ELIC Main Parameters

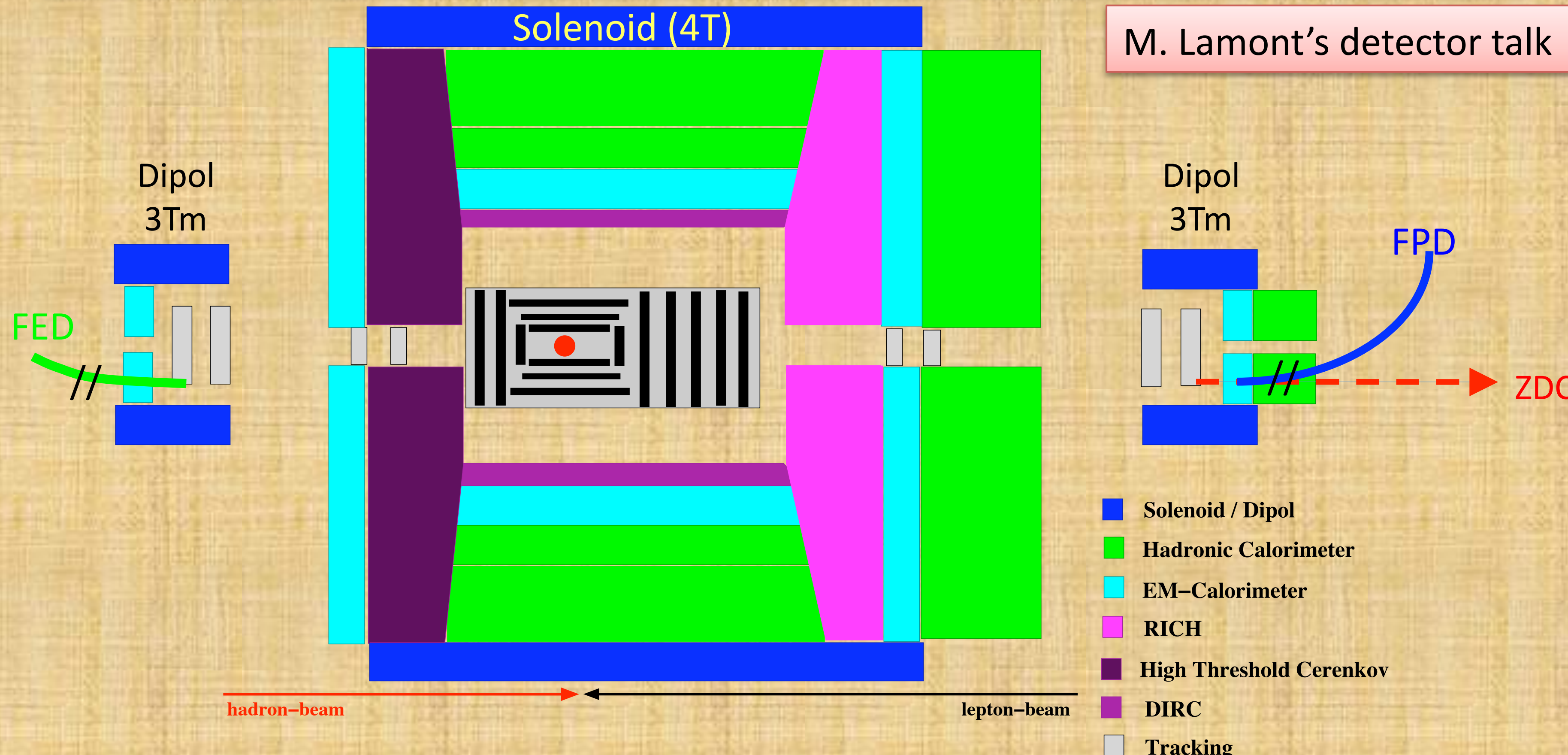
Beam Energy	GeV	250/10	150/7	60/5	60/3	12/3
Collision freq.	MHz			499		
Particles/bunch	10^{10}	1.1/3.1	0.5/3.25	0.74/2.9	1.1/6	0.47/2.3
Beam current	A	0.9/2.5	0.4/2.6	0.59/2.3	0.86/4.8	0.37/2.7
Energy spread	10^{-3}	~ 1				
RMS bunch length	mm	5	5	5	5	50
Horiz. emit., norm.	μm	0.7/51	0.5/43	0.56/85	0.8/75	0.18/80
Vert. emit. norm.	μm	0.03/2	0.03/2.87	0.11/17	0.8/75	0.18/80
Horizontal beta-star	mm	125	75	25	25	5
Vertical beta-star	mm	5				
Vert. b-b tune shift/IP		0.01/0.1	0.015/.05	0.01/0.03	.015/.08	.015/.013
Laslett tune shift	p-beam	0.1	0.1	0.1	0.054	0.1
Peak lumi/IP, 10^{34}	$cm^{-2}s^{-1}$	11	4.1	1.9	4.0	0.59

High energy   Medium energy   Low energy

Presented at the last EIC Collaboration Meeting at Stony Brook, Jan.'10

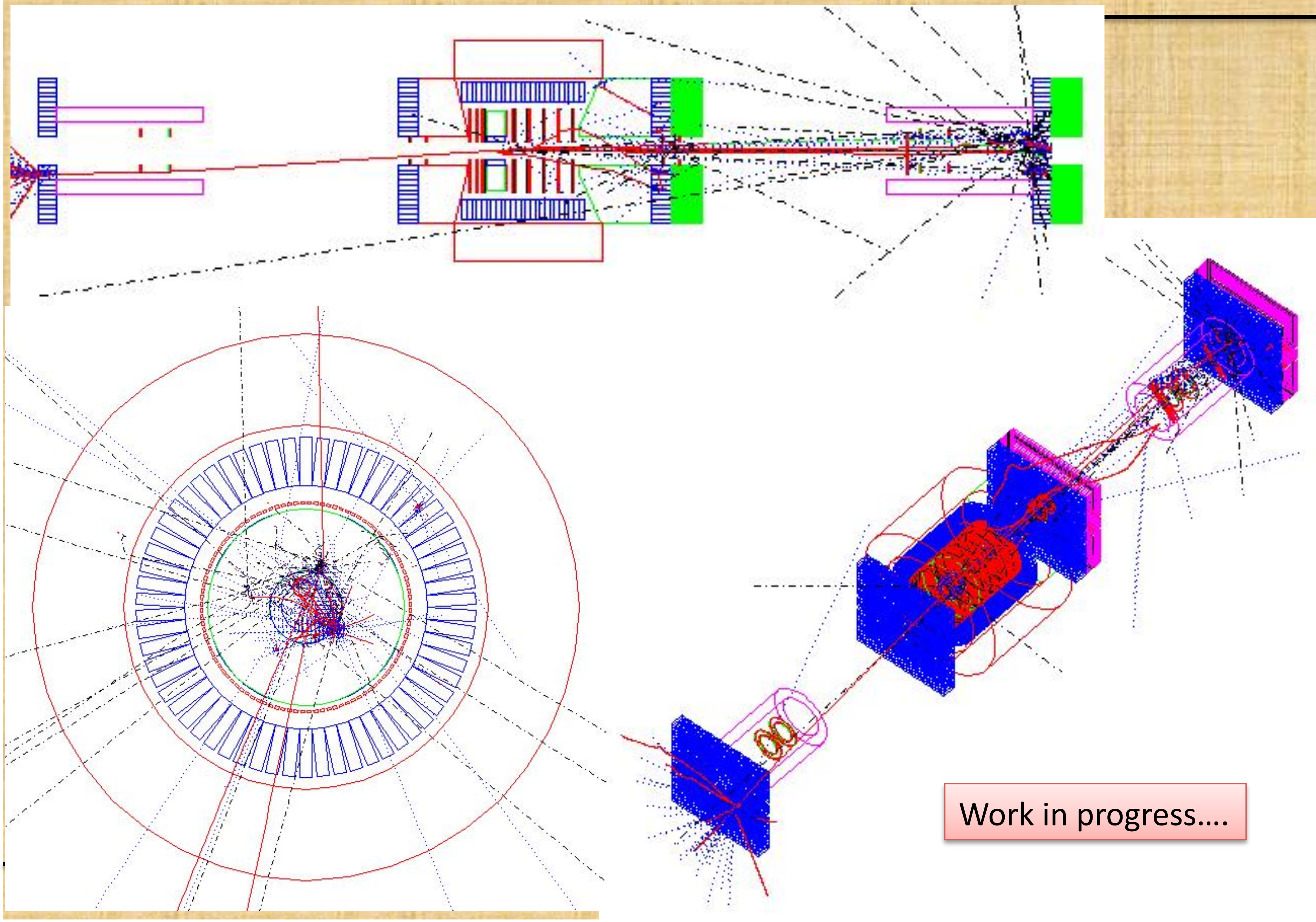
First ideas for a detector concept

M. Lamont's detector talk



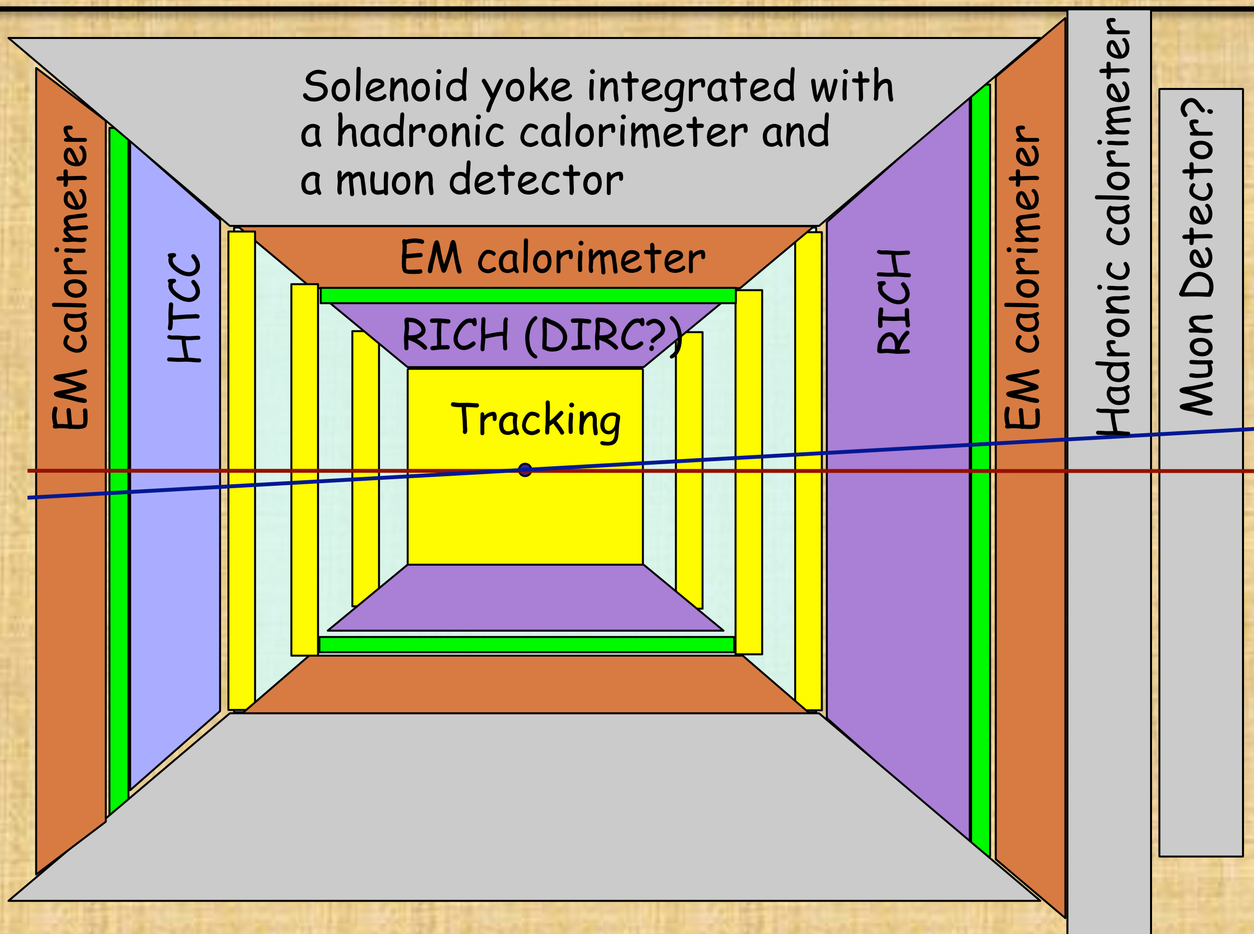
- Dipoles needed to have good forward momentum resolution
  - Solenoid no magnetic field @ r ~ 0
- DIRC, RICH hadron identification → π, K, p
- high-threshold Cerenkov → fast trigger for scattered lepton
- radiation length very critical → low lepton energies

Detector in GEANT



Work in progress….

ELIC Detector idea… under development



(not to scale)

Time-of-flight detectors shown in green

ions

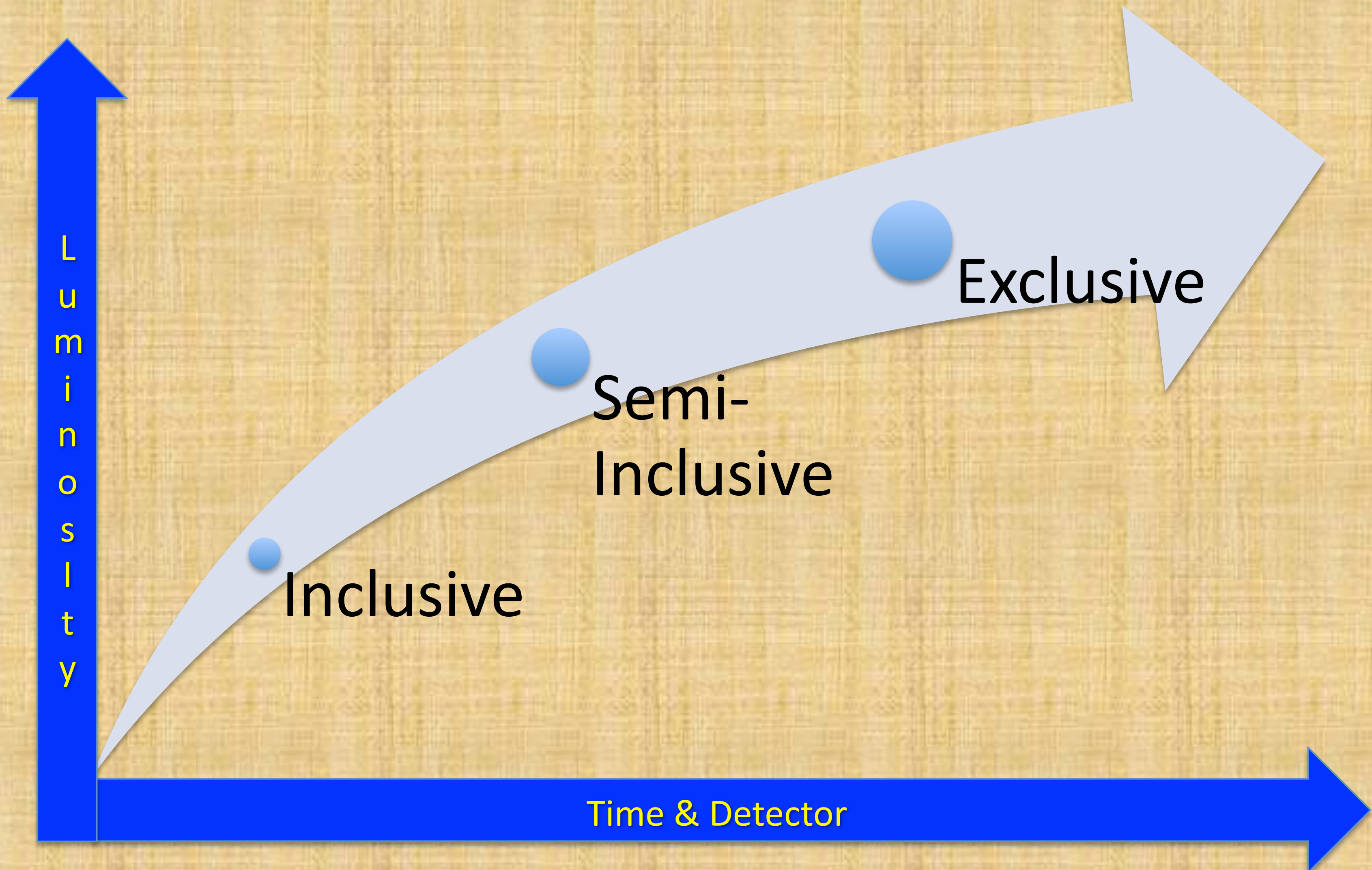
electrons

DIRC would have thin bars arranged in a cylinder with readout after the EM calorimeter on the left

See K. De Jaeger's talk

- IP is shown at the center, but can be shifted left
  - Determined by desired bore angle and forward tracking resolution
  - Flexibility of shifting IP also helps accelerator design at lower energies (gap/path length difference induced by change in crossing angle)

EIC Luminosity vs. Time (Detector)



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 (T. Horn's talk)
    - Exclusive processes --> Generalized Parton Distributions
  - Precision measurements of QCD and of EW parameters in SM (K. Kumar's Talk)

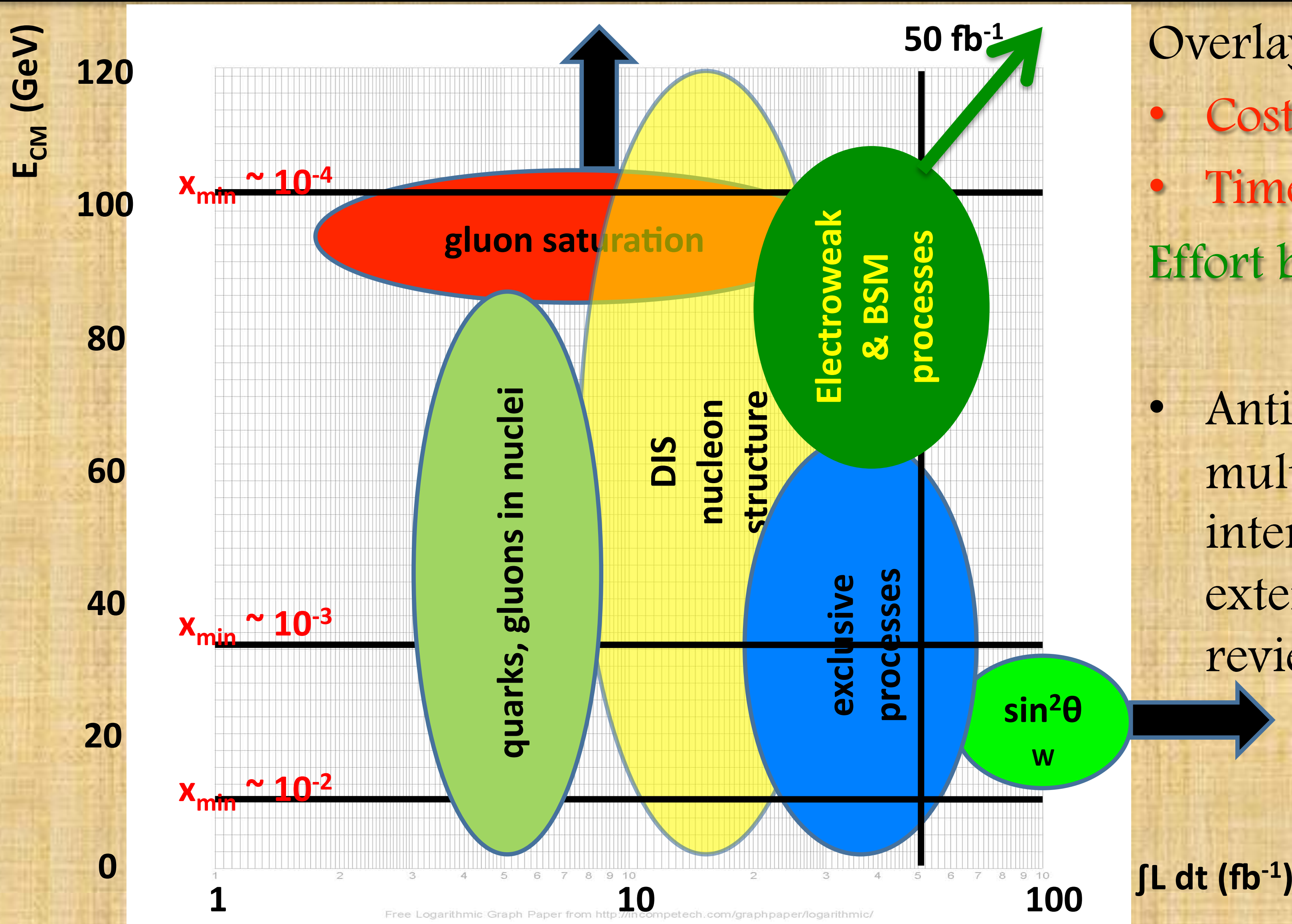
- Un-polarized Nucleon Structure (M. Lamont's talk)
  - Understanding confinement with low x/lowQ^2 measurements
  - Un-polarized quark and gluon distributions
- Nuclear Structure, role of partons in nuclei
  - Confinement in nuclei through comparison e-p/e-A scattering
- Hadronization in nucleons and nuclei & effect of nuclear media
  - How do knocked off partons evolve in to colorless hadrons

{ W. Brooks' talk }

- Partonic matter under extreme conditions (M. Lamont's talk)
  - For various A, compare e-p/e-A

Proton & Nuclear Beams

Physics Opportunities for EIC



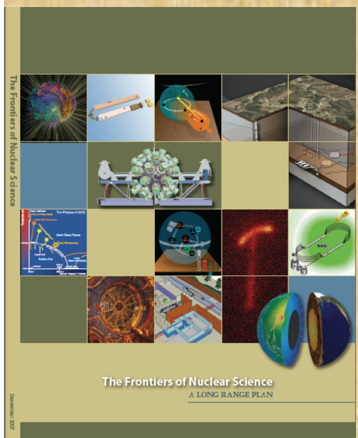
Overlay

- Costs
- Time line

Effort begun

- Anticipate multiple internal & external reviews

EIC in the NSAC 2007 → 2012



" An electron ion collider (EIC) with polarized beam has been embraced by the US nuclear science community as embodying the vision of reaching the next QCD frontier. The EIC would provide unique capabilities for the study of QCD well beyond those available at existing facilities world wide 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 new QCD frontier of strong color fields in nuclei and precisely image the gluons in the proton."*

The Collaboration now preparing for NSAC's approval for the project
For construction in its long range planning meeting anticipated in 2012

The EIC WG/Collaboration

http://web.mit.edu/eicc

[17]C. Aidala, [28]E. Aschenauer, [10]J. Annand, [1]J. Arrington, [26]R. Averbeck, [3]M. Baker, [26]K. Boyle, [28]W. Brooks, [28]A. Bruell, [19]A. Caldwell, [28]J.P. Chen, [2]R. Choudhury, [10]E. Christy, [8]B. Cole, [4]D. De Florian, [3]R. Debbe, [26,24-1]A. Deshpande**, [15]K. Dow, [26]A. Drees, [3]J. Dunlop, [2]D. Dutta, [7]F. Ellinghaus, [28]R. Ent, [15]R. Fatemi, [18]W. Franklin, [28]D. Gaskell, [16]G. Garvey, [12,24-1]M. Grosse-Perdekamp, [1]K. Hafidi, [18]D. Hasell, [26]T. Hemmick, [1]R. Holt, [8]E. Hughes, [22]C. Hyde-Wright, [5]G. Igo, [14]K. Imai, [10]D. Ireland, [26]B. Jacak, [15]P. Jacobs, [28]M. Jones, [10]R. Kaiser, [17]D. Kawall, [11]C. Keppel, [7]E. Kinney, [18]M. Kohl, [9]H. Kowalski, [17]K. Kumar, [2]V. Kumar, [21]G. Kyle, [13]J. Lajoie, [16]M. Leitch, [27]A. Levy, [27]J. Lichtenstadt, [10]K. Livingstone, [20]W. Lorenzon, [14]5. Matis, [12]N. Makins, [6]G. Mallot, [18]M. Miller, [18]R. Milner**, [2]A. Mohanty, [3]D. Morrison, [26]Y. Ning, [15]G. Odyniec, [13]C. Ogilvie, [2]L. Pant, [26]V. Pantuyev, [21]S. Pate, [26]P. Paul, [12]J.-C. Peng, [18]R. Redwine, [1]P. Reimer, [15]H.-G. Ritter, [10]G. Rosner, [25]A. Sandacz, [7]J. Seele, [12]R. Seidl, [10]B. Seitz, [2]P. Shukla, [15]E. Sichtermann, [18]F. Simon, [3]P. Sorensen, [3]P. Steinberg, [24]M. Stratmann, [22]M. Strikman, [18]B. Surrow, [18]E. Tsentalovich, [11]V. Tvaskis, [3]T. Ullrich, [3]R. Venugopalan, [3]W. Vogelsang, [28]C. Weiss, [15]H. Wieman, [15]N. Xu, [3]Z. Xu, [8]W. Zajc.

[1]Argonne National Laboratory, Argonne, IL; [2]Bhabha Atomic Research Centre, Mumbai, India; [3]Brookhaven National Laboratory, Upton, NY; [4]University of Buenos Aires, Argentina; [5]University of California, Los Angeles, CA; [6]CERN, Geneva, Switzerland; [7]University of Colorado, Boulder,CO; [8]Columbia University, New York, NY; [9]DESY, Hamburg, Germany; [10]University of Glasgow, Scotland, United Kingdom; [11]Hampton University, Hampton, VA; [12]University of Illinois, Urbana-Champaign, IL; [13]Iowa State University, Ames, IA; [14]University of Kyoto, Japan; [15]Lawrence Berkeley National Laboratory, Berkeley, CA; [16]Los Alamos National Laboratory, Los Alamos, NM; [17]University of Massachusetts, Amherst, MA; [18]MIT, Cambridge, MA; [19]Max Planck Institüt für Physik, Munich, Germany; [20]University of Michigan Ann Arbor, MI; [21]New Mexico State University, Las Cruces, NM; [22]Old Dominion University, Norfolk, VA; [23]Penn State University, PA; [24]RIKEN, Wako, Japan; [24-1]RIKEN-BNL Research Center, BNL, Upton, NY; [25]Soltan Institute for Nuclear Studies, Warsaw, Poland; [26]SUNY, Stony Brook, NY; [27]Tel Aviv University, Israel; [28]Thomas Jefferson National Accelerator Facility, Newport News, VA

** Collaboration Contact-persons

- Collaboration Meetings: ~2/year
  - February 2010 at Stony Brook
  - July 2010 at Catholic American U
  - March 2011 at Columbia U.(?)
  - INT Workshop U. Washington September-November 2010: Organizers: Boer, Diehl, Milner, Venugopalan, Vogelsang

- EIC Task Forces at Jlab (R. Ent) & BNL (E. – C. Aschenauer & T. Ullrich)
- Meetings and workshops with User-Groups at both Labs ongoing

- International Advisory Committee: (Appointed by BNL & Jlab Managements)
- J. Bartels (DESY), A. Caldwell (MPI Munich), A. De Roeck (CERN), W. Henning (ANL, Chair), D. Herzog (UIUC), X. Ji (Maryland) , R. Klanner (Hamburg), A. Mueller (Columbia), K. Oide (KEK), N. Saito (JPARC), U. Wienands (SLAC)

EICAC Report : Summary
(project realization advice/guidelines)

- Matrix of Science, Design and Cost
  - EIC Stage 1 and the full EIC
- Identify a few most compelling "golden physics" measurements
  - e-p (with polarization) and e-p/e-A physics for the wider physics community
- Dedicated working group activities towards the golden measurements
  - Physics, accelerator, detector studies in detail
- Develop detailed resource loaded schedule
  - Timeline, technical developments and staged realization
- Strive for a timeline with data taking earlier than 2020
- Develop a common accelerator development R&D plan
- Develop and present a common plan for R&D, deliverables, and the resource needs by the next EICAC meeting

Summary

- The electron ion collider is now considered by many in the US nuclear science community as an essential next QCD machine frontier: It will allow unparalleled opportunities in future QCD studies

- Efforts (on all fronts) underway to realize it
  - Proposal: Finalizing and articulating the science case → determining the final energy, polarization and collisions-species parameter space
  - Realization : detailed design, possible construction schedule and associated costs
  - Constant contact amongst DOE, Lab managements and the Collaboration on various associated topics

- Next major milestone is 2012/13 US Nuclear Science's Long Range Planning Activity (final blessing from nuclear science community essential)

- Many US and non-US institutes are "eyeing" the project with interest: We welcome & urge you to jump in and contribute