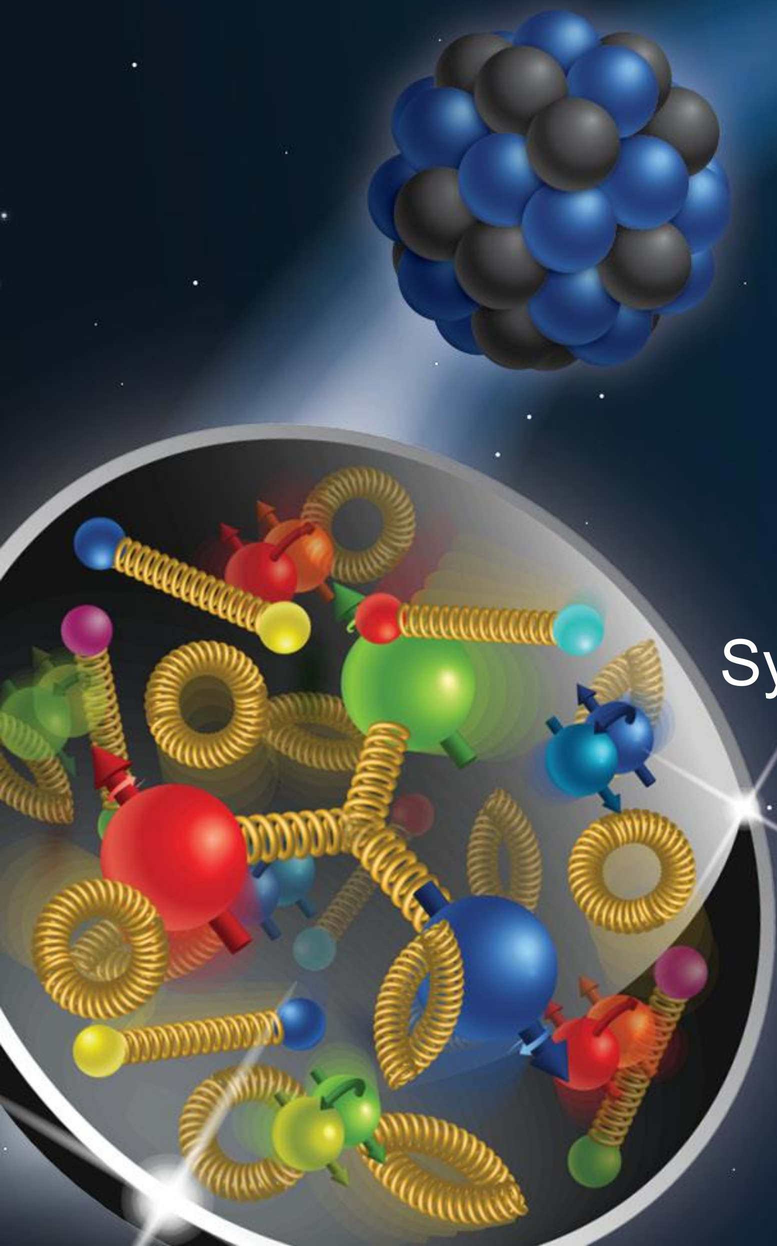


Beam Polarization in the Electron Ion Collider

Ferdinand Willeke, BNL

Symposium to Honor Alexander Chao's contributions to Accelerator Science

Electron Ion Collider

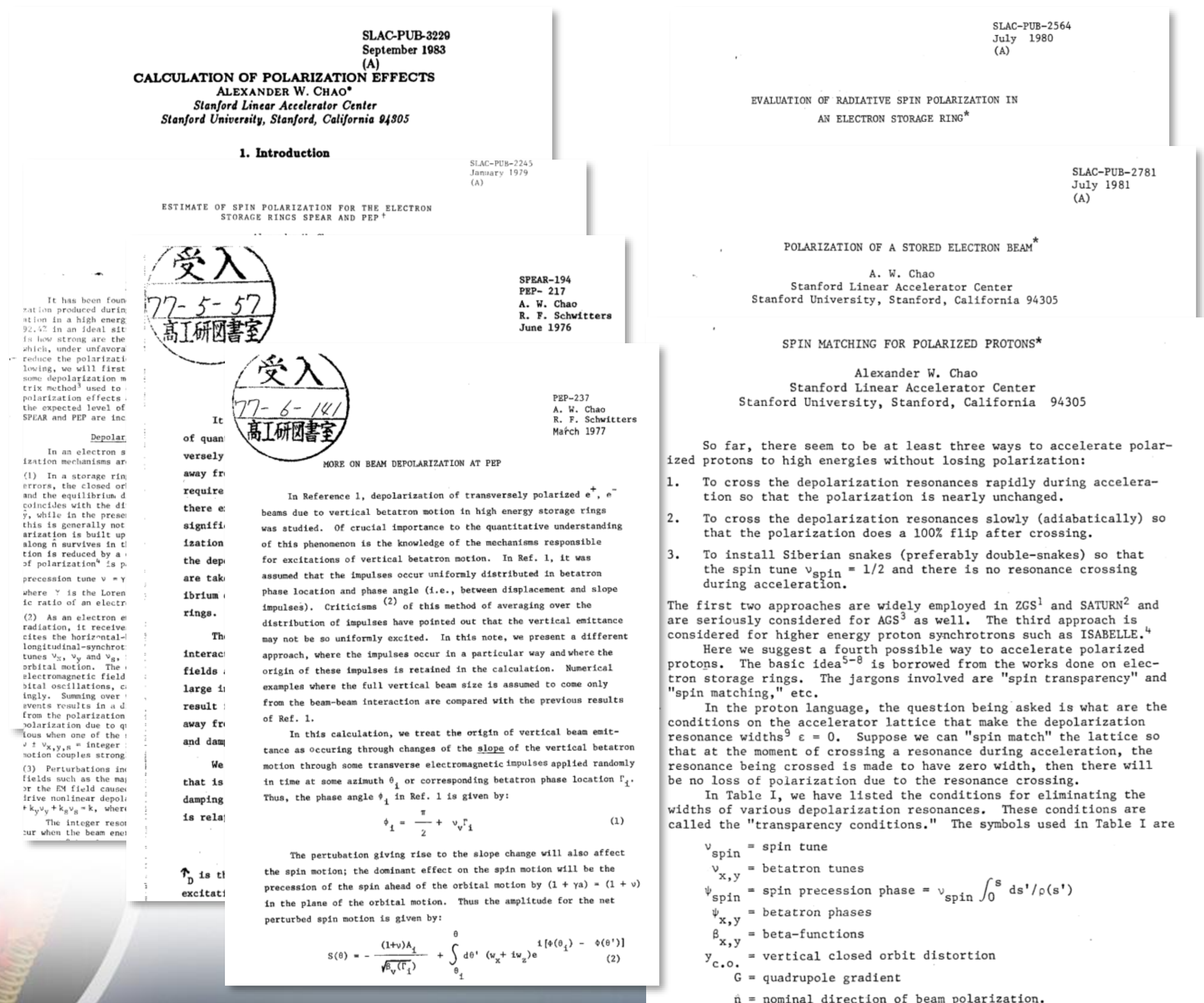
U.S. DEPARTMENT OF ENERGY | Office of Science

Outline

- Alexander Chao's contributions to beam polarization
- Electron ion collider requirements
- Proton spin crisis
- EIC Overview
- JLEIC electron polarization
- eRHIC electron polarization
- JLEIC hadron polarization
- eRHIC hadron polarization
- Summary

Alexander Chao's contribution to beam polarization

- Alex's contributions on beam polarization have shaped our understanding of the physics of polarized beams and
- laid the foundations of the toolbox we are using today to calculate the effects on beam polarization
- The methods and used to assess beam polarization in the electron ion collider are to a large extent already described in Alex' early papers on polarization
- The early tools are still used in polarization design



SLAC-PUB-3229
September 1983
(A)

CALCULATION OF POLARIZATION EFFECTS

ALEXANDER W. CHAO*
Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

1. Introduction

SLAC-PUB-2564
July 1980
(A)

EVALUATION OF RADIATIVE SPIN POLARIZATION IN AN ELECTRON STORAGE RING*

SLAC-PUB-2245
January 1979
(A)

ESTIMATE OF SPIN POLARIZATION FOR THE ELECTRON STORAGE RINGS SPEAR AND PEP†

SLAC-PUB-2781
July 1981
(A)

POLARIZATION OF A STORED ELECTRON BEAM*

A. W. Chao
Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

受入
77-5-57
高エ研図書室

SPEAR-194
PEP-217
A. W. Chao
R. F. Schwitters
June 1976

受入
77-6-141
高エ研図書室

PEP-237
A. W. Chao
R. F. Schwitters
March 1977

MORE ON BEAM DEPOLARIZATION AT PEP

In Reference 1, depolarization of transversely polarized e^+, e^- beams due to vertical betatron motion in high energy storage rings was studied. Of crucial importance to the quantitative understanding of this phenomenon is the knowledge of the mechanisms responsible for excitations of vertical betatron motion. In Ref. 1, it was assumed that the impulses occur uniformly distributed in betatron phase location and phase angle (i.e., between displacement and slope impulses). Criticisms (2) of this method of averaging over the distribution of impulses have pointed out that the vertical emittance may not be so uniformly excited. In this note, we present a different approach, where the impulses occur in a particular way and where the origin of these impulses is retained in the calculation. Numerical examples where the full vertical beam size is assumed to come only from the beam-beam interaction are compared with the previous results of Ref. 1.

In this calculation, we treat the origin of vertical beam emittance as occuring through changes of the slope of the vertical betatron motion through some transverse electromagnetic impulses applied randomly in time at some azimuth θ_i or corresponding betatron phase location Γ_i. Thus, the phase angle ϕ_i in Ref. 1 is given by:

$$\phi_i = -\frac{\pi}{2} + \nu_v \Gamma_i \qquad (1)$$

The pertubation giving rise to the slope change will also affect the spin motion; the dominant effect on the spin motion will be the precession of the spin ahead of the orbital motion by $(1 + \gamma a) = (1 + \nu)$ in the plane of the orbital motion. Thus the amplitude for the net perturbed spin motion is given by:

$$S(\theta) = -\frac{(1+\nu)A_i}{\sqrt{\beta_v(\Gamma_i)}} + \int_{\theta_i}^{\theta} d\theta' \, (w_x + i w_z) e^{i[\phi(\theta_i) - \phi(\theta')]} \qquad (2)$$

SPIN MATCHING FOR POLARIZED PROTONS*

Alexander W. Chao
Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

So far, there seem to be at least three ways to accelerate polarized protons to high energies without losing polarization:

1. To cross the depolarization resonances rapidly during acceleration so that the polarization is nearly unchanged.
2. To cross the depolarization resonances slowly (adiabatically) so that the polarization does a 100% flip after crossing.
3. To install Siberian snakes (preferably double-snakes) so that the spin tune $\nu_{spin} = 1/2$ and there is no resonance crossing during acceleration.

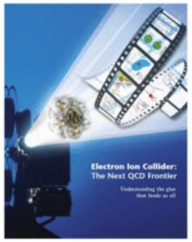
The first two approaches are widely employed in ZGS[1] and SATURN[2] and are seriously considered for AGS[3] as well. The third approach is considered for higher energy proton synchrotrons such as ISABELLE.[4] Here we suggest a fourth possible way to accelerate polarized protons. The basic idea[5-8] is borrowed from the works done on electron storage rings. The jargons involved are "spin transparency" and "spin matching," etc.

In the proton language, the question being asked is what are the conditions on the accelerator lattice that make the depolarization resonance widths[9] $\epsilon = 0$. Suppose we can "spin match" the lattice so that at the moment of crossing a resonance during acceleration, the resonance being crossed is made to have zero width, then there will be no loss of polarization due to the resonance crossing.

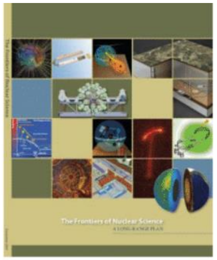
In Table I, we have listed the conditions for eliminating the widths of various depolarization resonances. These conditions are called the "transparency conditions." The symbols used in Table I are

ν_{spin} = spin tune
$\nu_{x,y}$ = betatron tunes
ψ_{spin} = spin precession phase = $\nu_{spin} \int_0^s ds'/\rho(s')$
$\psi_{x,y}$ = betatron phases
$\beta_{x,y}$ = beta-functions
$y_{c.o.}$ = vertical closed orbit distortion
G = quadrupole gradient
$\hat{n}$ = nominal direction of beam polarization.

The case for an Electron Ion Collider

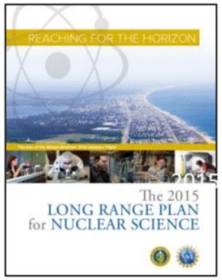


2013 EIC White Paper



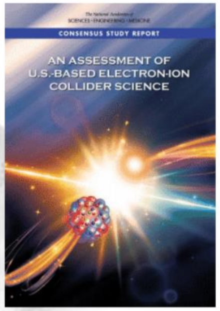
Federal Nuclear Science Advisory Cmte 2007 Long-Range Plan

"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"



Federal Nuclear Science Advisory Cmte 2015 Long Range Plan

"We recommend a high-energy high-luminosity polarized EIC as the highest priority for new facility construction following the completion of FRIB."



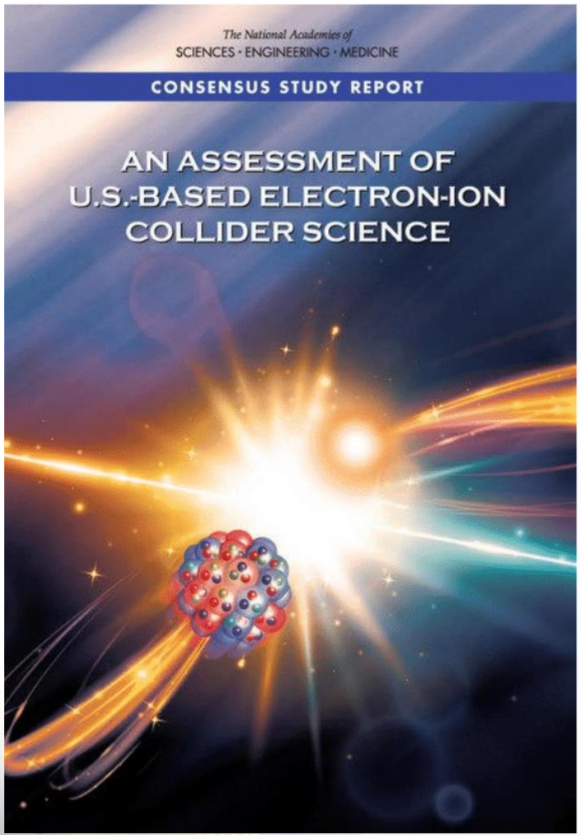
National Academies of Sciences – Assessment of U.S. Based Electron-Ion Collider Science (2018)

"…the committee finds a compelling scientific case for such a facility. The science questions that an EIC will answer are central to completing an understanding of atoms as well as being integral to the agenda of nuclear physics today."

NAPAC'19, A. Seryi for EIC design team 4

Slide borrowed from Andrei Seryi

National Academy of Sciences Study on EIC Physics Program



- The committee unanimously finds that the science that can be addressed by an EIC is compelling, fundamental and timely
- The unanimous conclusion of the Committee is that an EIC, as envisioned in this report, would be a unique facility in the world that would boost the U.S. STEM workforce and help maintain U.S. scientific leadership in nuclear physics
- The project is strongly supported by the NP community
- The technological benefits of meeting the accelerator challenges are enormous, both for basic science and for applied areas that use accelerators, including materials science and medicine

Slide borrowed from Andrei Seryi

Electron Ion Collider (EIC) Physics Questions

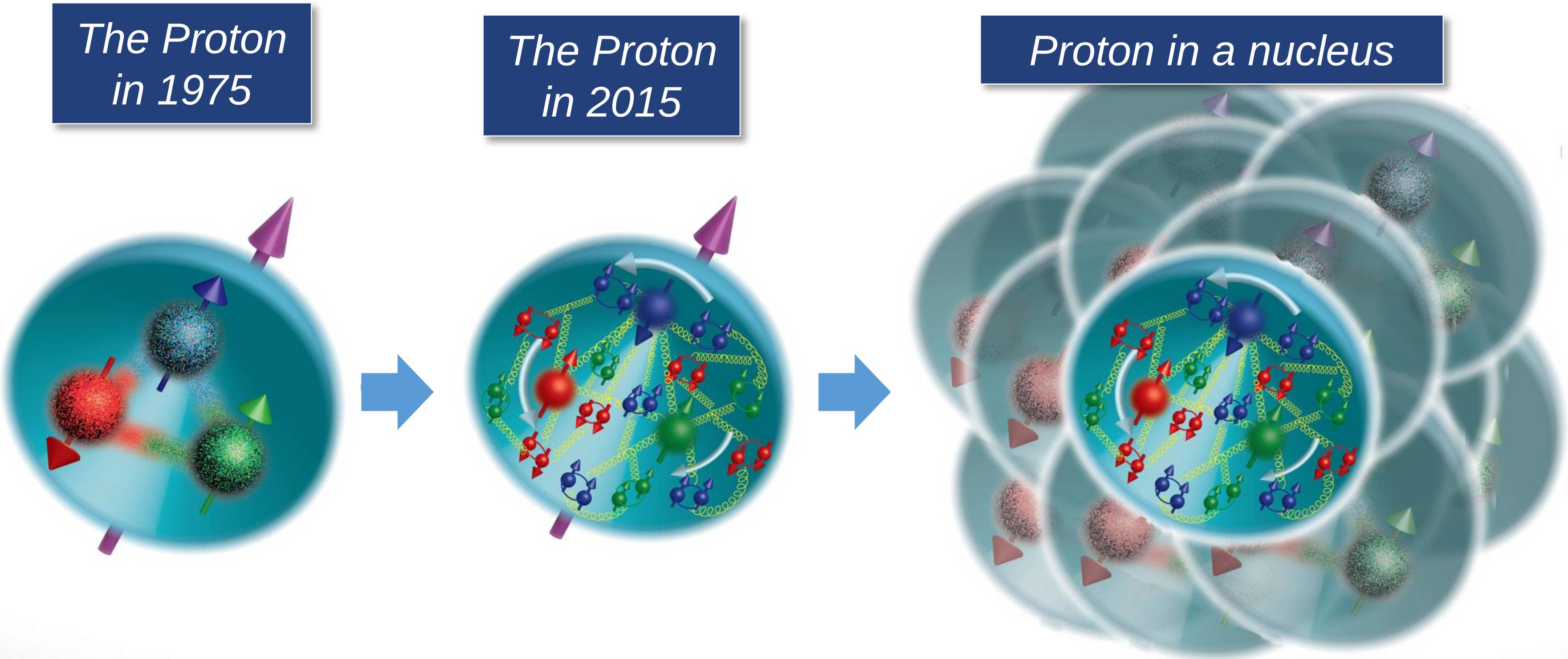
Nuclear Physics Community compiled an EIC WHITE PAPER*) (2014/5):

- How are quarks, gluons & their spins distributed in space & momentum in nucleus?
- How do nucleon properties emerge from quarks and gluons and their interactions?
- How do color-charged quarks, gluons & colorless jets, interact with a nuclear medium
- How do confined hadronic states emerge from quarks & gluons
- How do the quark-gluon interactions create nuclear binding?
- How does dense nuclear environment affect the quarks-gluons correlations & interactions?
- Does gluon density in nuclei saturate @ high energy

  result in gluonic matter with universal properties?

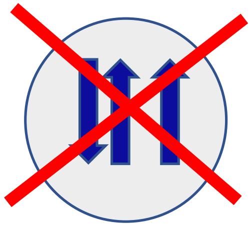
*) A. Accardi et al, Eur. Phys. J. A529:268 (2016)

EIC will provide a complete view of the nucleus



The goal of the EIC is to provide us with an understanding of the internal structure of the proton and more complex atomic nuclei that is comparable to our knowledge of the electronic structure of atoms.

The Proton Spin Crisis



EMC Experiment at CERN 1987:

Deep inelastic scattering of secondary muons on fixed target reveals that the valence quark contribute only to a fraction of the proton spin

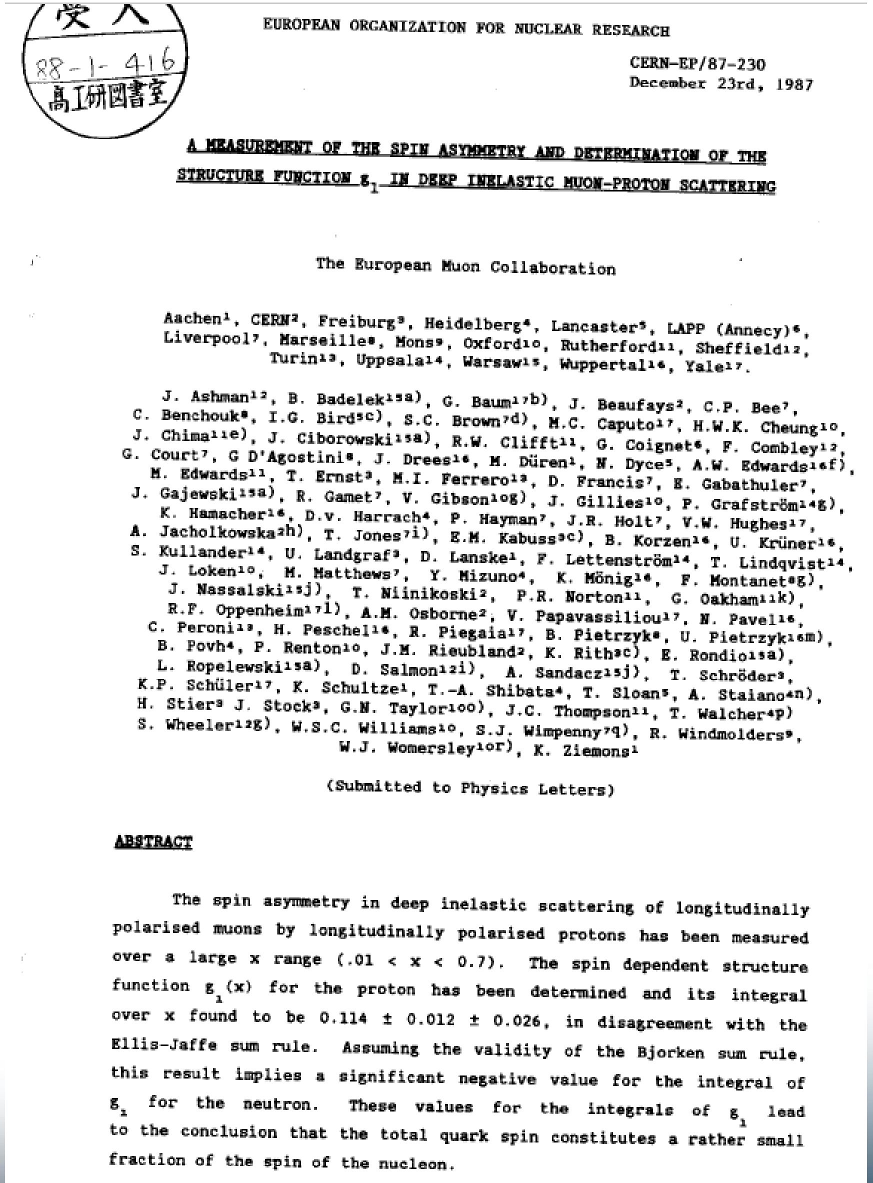
Since then:

Several experiments (Compass, Hermes …) have made progress

$$\frac{1}{2} = \sum q_{valence} + \sum q_{sea} + \sum q_{gluon} + L_q + L_g$$

but have not been able to resolve the problem

EIC will be the ultimate machine to provide and answer



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-EP/87-230
December 23rd, 1987

A MEASUREMENT OF THE SPIN ASYMMETRY AND DETERMINATION OF THE STRUCTURE FUNCTION g_1 IN DEEP INELASTIC MUON-PROTON SCATTERING

The European Muon Collaboration

Aachen[1], CERN[2], Freiburg[3], Heidelberg[4], Lancaster[5], LAPP (Annecy)[6], Liverpool[7], Marseille[8], Mons[9], Oxford[10], Rutherford[11], Sheffield[12], Turin[13], Uppsala[14], Warsaw[15], Wuppertal[16], Yale[17].

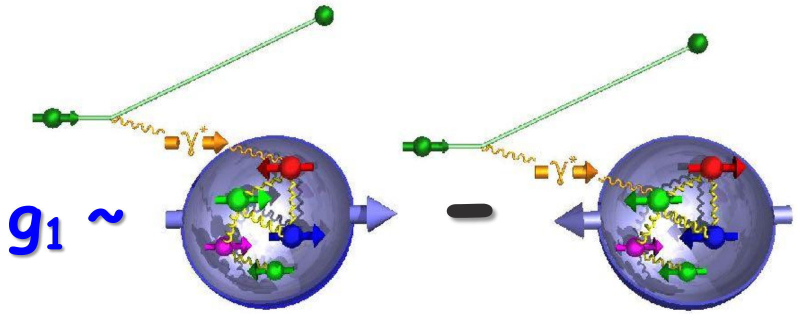
J. Ashman[12], B. Badelek[15a)], G. Baum[17b)], J. Beaufays[2], C.P. Bee[7], C. Benchouk[8], I.G. Bird[5c)], S.C. Brown[7d)], M.C. Caputo[17], H.W.K. Cheung[10], J. Chima[11e)], J. Ciborowski[15a)], R.W. Clifft[11], G. Coignet[6], F. Combley[12], G. Court[7], G D'Agostini[8], J. Drees[16], M. Düren[1], N. Dyce[5], A.W. Edwards[16f)], M. Edwards[11], T. Ernst[3], M.I. Ferrero[13], D. Francis[7], E. Gabathuler[7], J. Gajewski[15a)], R. Gamet[7], V. Gibson[10g)], J. Gillies[10], P. Grafström[14g)], K. Hamacher[16], D.v. Harrach[4], P. Hayman[7], J.R. Holt[7], V.W. Hughes[17], A. Jacholkowska[2h)], T. Jones[7i)], E.M. Kabuss[3c)], B. Korzen[16], U. Krüner[16], S. Kullander[14], U. Landgraf[3], D. Lanske[1], F. Lettenström[14], T. Lindqvist[14], J. Loken[10], M. Matthews[7], Y. Mizuno[4], K. Mönig[16], F. Montanet[8g)], J. Nassalski[15j)], T. Niinikoski[2], P.R. Norton[11], G. Oakham[11k)], R.F. Oppenheim[17l)], A.M. Osborne[2], V. Papavassiliou[17], N. Pavel[16], C. Peroni[13], H. Peschel[16], R. Piegaia[17], B. Pietrzyk[8], U. Pietrzyk[16m)], B. Povh[4], P. Renton[10], J.M. Rieubland[2], K. Rith[3c)], E. Rondio[15a)], L. Ropelewski[15a)], D. Salmon[12i)], A. Sandacz[15j)], T. Schröder[3], K.P. Schüler[17], K. Schultze[1], T.-A. Shibata[4], T. Sloan[5], A. Staiano[4n)], H. Stier[3] J. Stock[3], G.N. Taylor[10o)], J.C. Thompson[11], T. Walcher[4p)] S. Wheeler[12g)], W.S.C. Williams[10], S.J. Wimpenny[7q)], R. Windmolders[9], W.J. Womersley[10r)], K. Ziemons[1]

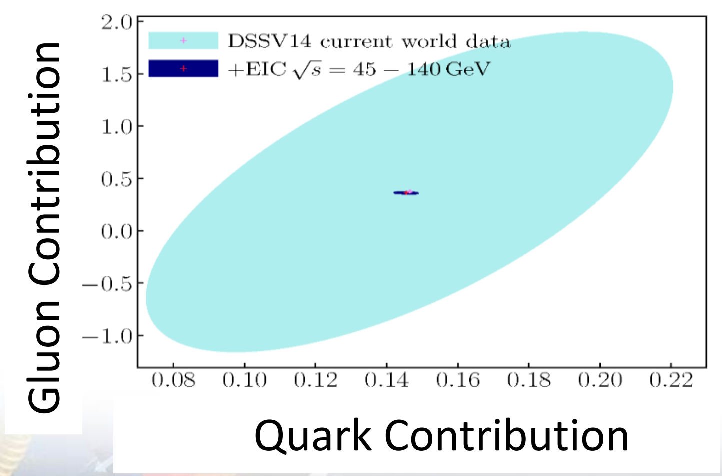
(Submitted to Physics Letters)

ABSTRACT

The spin asymmetry in deep inelastic scattering of longitudinally polarised muons by longitudinally polarised protons has been measured over a large x range (.01 < x < 0.7). The spin dependent structure function $g_1(x)$ for the proton has been determined and its integral over x found to be 0.114 ± 0.012 ± 0.026, in disagreement with the Ellis-Jaffe sum rule. Assuming the validity of the Bjorken sum rule, this result implies a significant negative value for the integral of g_1 for the neutron. These values for the integrals of g_1 lead to the conclusion that the total quark spin constitutes a rather small fraction of the spin of the nucleon.

Expected prediction power of electron ion collider experiments on the contributions to the proton spin





Requirements on EIC Performance

The EIC is designed to meet the requirements set forth in NSAC Long Range Plan, which was emphasized by the NAS report:

- Highly polarized (~70%) electron and nucleon beams
- Ion beams from deuterons to the heaviest nuclei (uranium or lead)
- Variable center of mass energies from ~20 - ~100 GeV, upgradable to ~140 GeV
- High collision luminosity ~10^{33} – 10^{34} $cm^{-2}s^{-1}$
- Possibilities of having more than one interaction region

In addition, the community agrees on the importance of :

- Detector with large acceptance
- Polarized light ions (^3He)
- Bunch-by-bunch polarimetry
- Polarized deuteron beams, under discussion

There are two electron ion collider concepts:

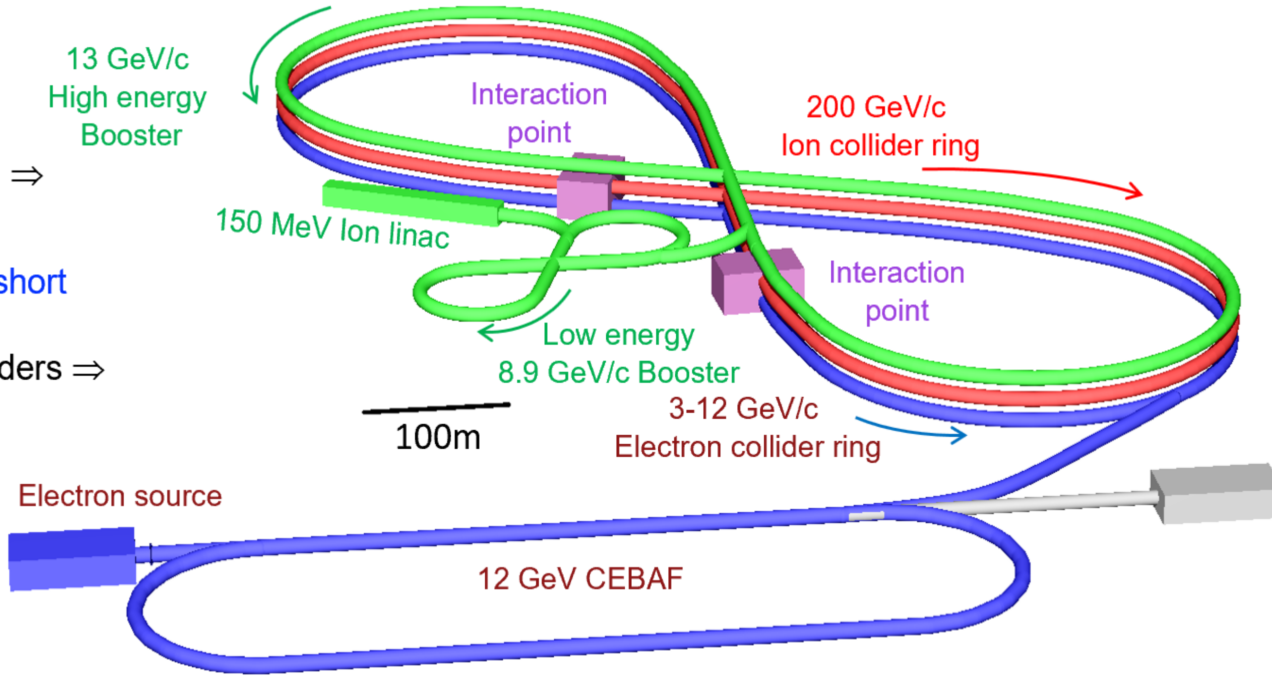
- **JLEIC** to be constructed at Jefferson Lab
- **eRHIC** to be constructed at Brookhaven National Lab

Both design benefit from existing Nuclear Physics infrastructure and are based on the same accelerator principles:

- **Electron Storage Rings** with frequent injection of fresh polarized beams
- **Hadron storage rings** with strong cooling or alternatively frequent injections

JLEIC Layout

- Full-energy top-up injection of highly polarized electrons from CEBAF ⇒
  High electron current and polarization
- Full-size high-energy booster ⇒
  Quick replacement of colliding ion beam ⇒
  High average luminosity
- High-rate collisions of strongly-focused short low-charge low-emittance bunches similarly to record-luminosity lepton colliders ⇒
  High luminosity
- Multi-stage electron cooling using demonstrated magnetized cooling mechanism ⇒
  Small ion emittance ⇒
  High luminosity

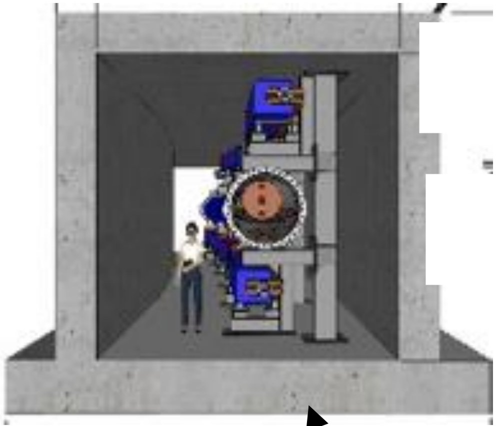


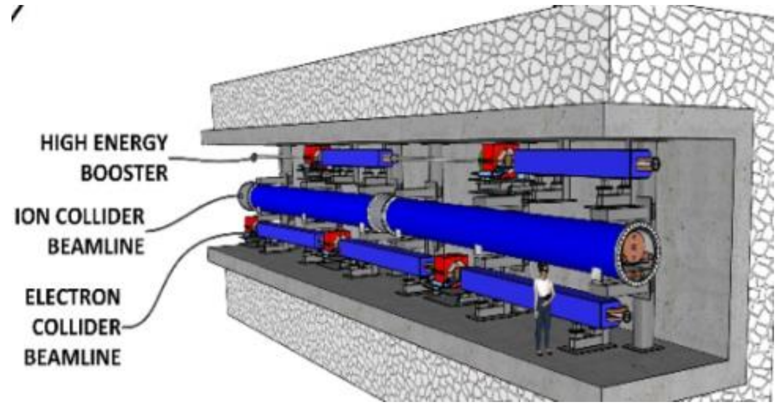
- Figure-8 ring design ⇒
  High electron and ion polarizations, polarization manipulation and spin flip
- Integrated full acceptance detector with far-forward detection sections being parts of both machine and detector
- Upgradable to 140 GeV CM by replacing the ion collider bending dipoles only with 12 T magnets

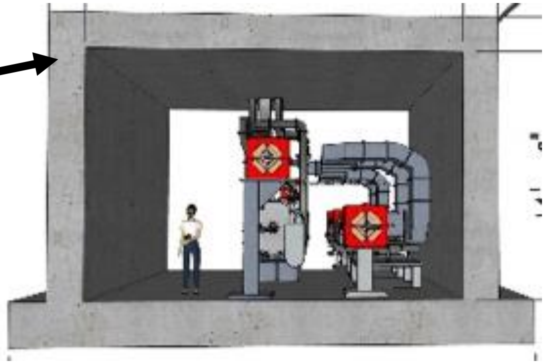
- Design meets the high luminosity goal of **$L = 10^{34} cm^{-2}s^{-1}$**

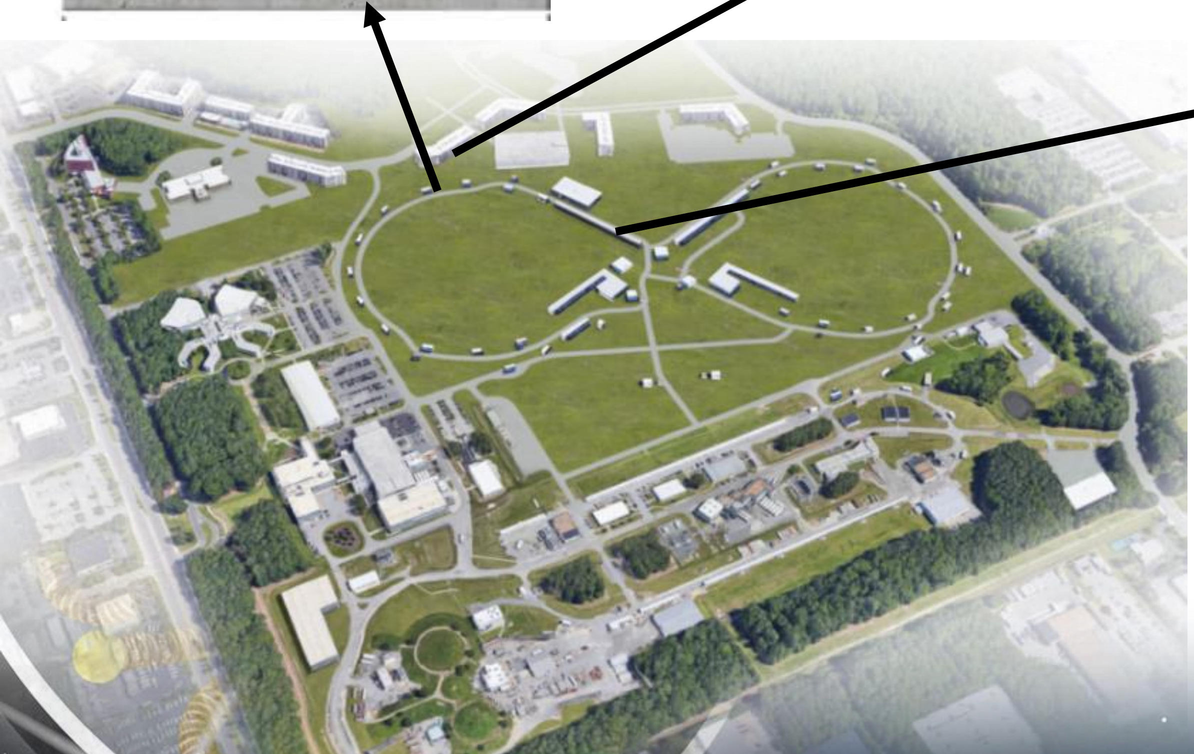
Courtesy: V Morozov, A Seryi

JLEIC layouts and tunnel views





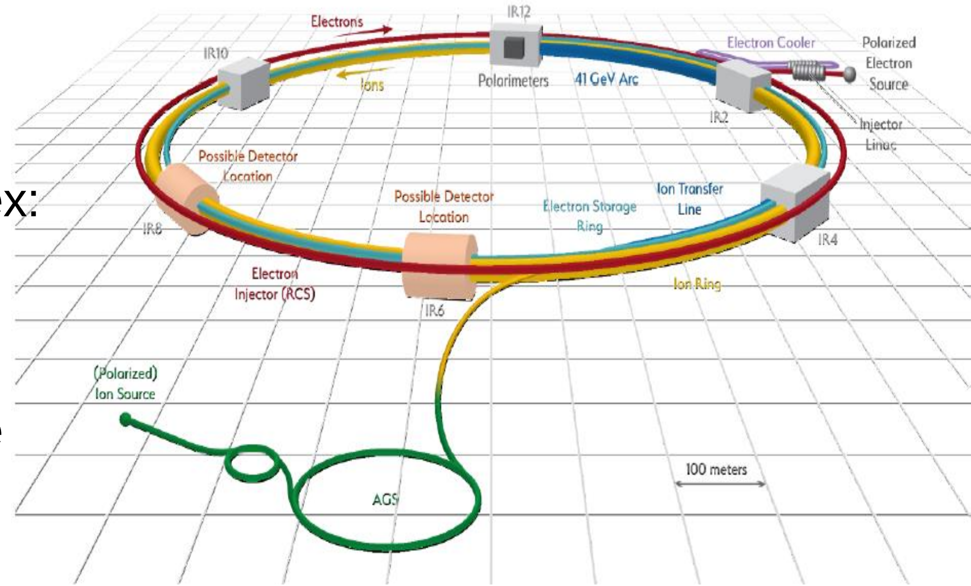




eRHIC

- **Hadrons up to 275 GeV**

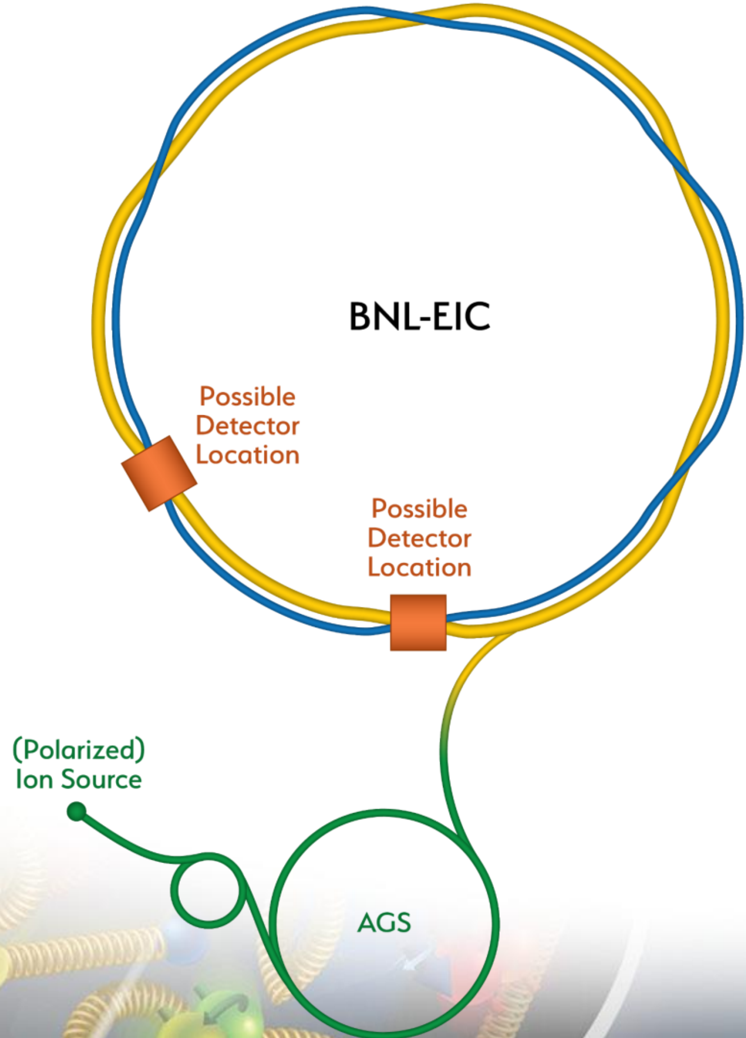
  eRHIC is using the existing RHIC complex: Storage ring (Yellow Ring), injectors, ion sources, infrastructure,
- Need only few modifications for eRHIC
- Todays RHIC beam parameters are close to what is required for eRHIC



- **Electrons up to 18 GeV**

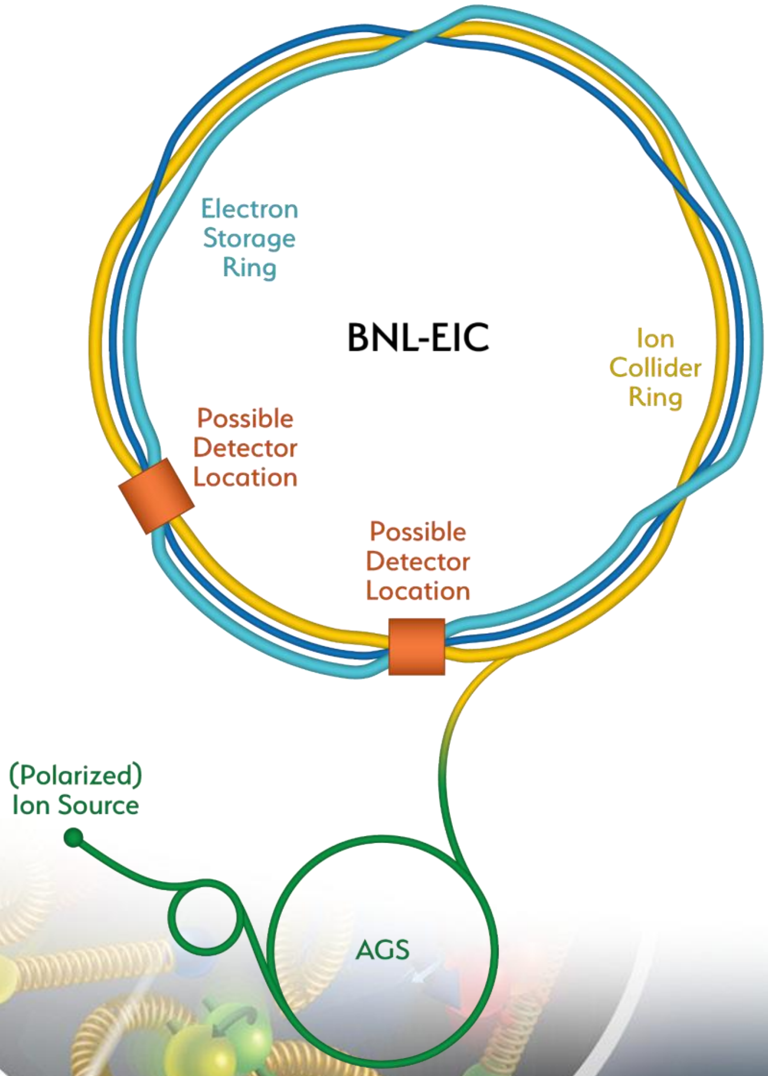
- Electron storage ring with up to 18GeV ➔ E_{cm} = 20 GeV -141 GeV installed in RHIC tunnel. Beam current are limited by the choice of installed RF power 10 MW.
- Electron beams with a variable spin pattern accelerated in the on-energy, spin transparent injector: Rapid Cycling Synchrotron with 1-2 Hz cycle frequency in the RHIC tunnel
- Polarized electron source and 400 MeV s-band injector linac in existing tunnel
- Design meets the high luminosity goal of **$L = 10^{34} cm^{-2}s^{-1}$**

How RHIC is transformed into an EIC

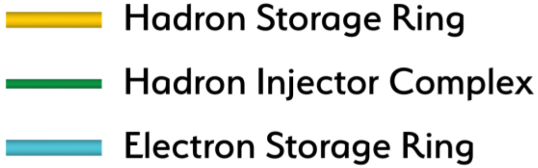


- Existing RHIC with blue and yellow ring

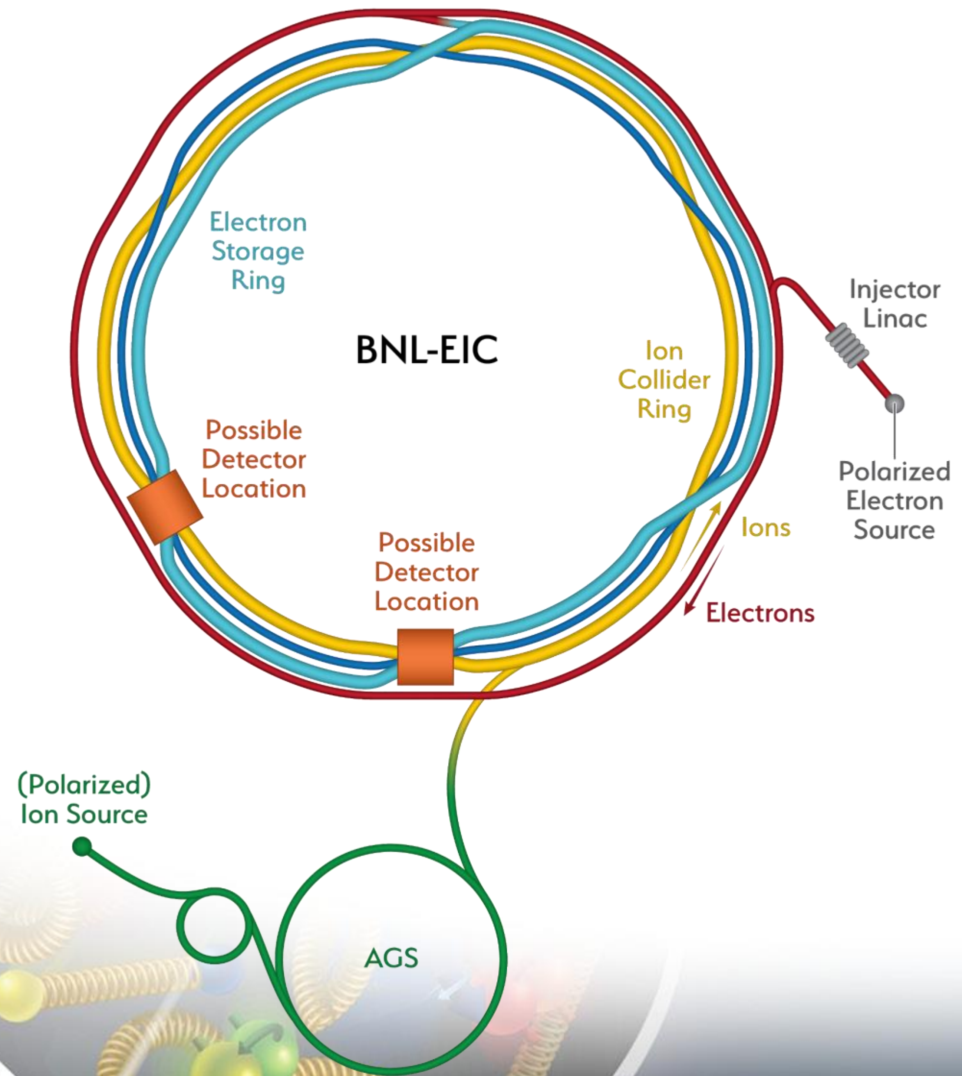
How RHIC is transformed into an EIC



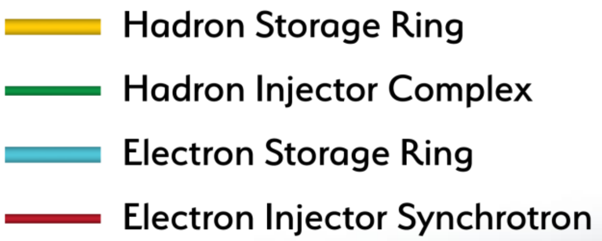
- Add electron storage ring



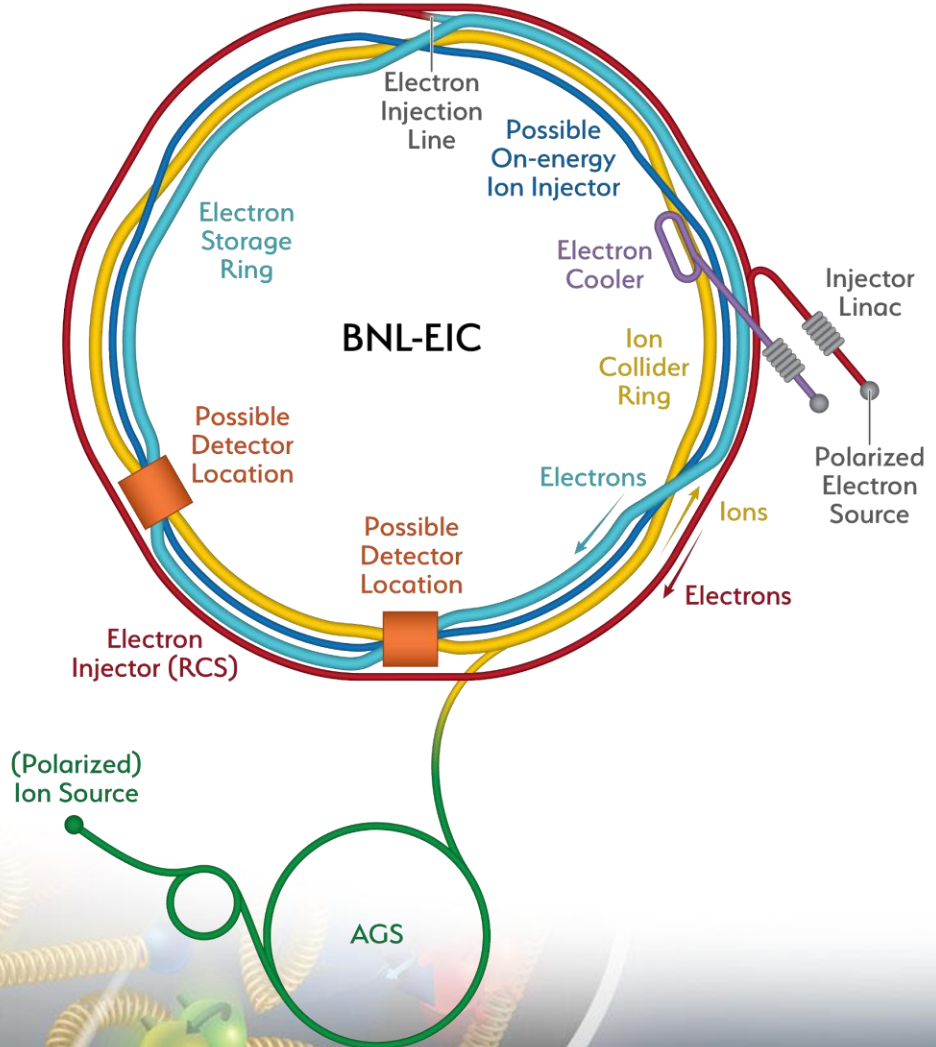
How RHIC is transformed into an EIC



- Add an electron injector complex with Rapid Cycling Synchrotron



How RHIC is transformed into an EIC



- Strong hadron cooling completes the facility
- Alternate solution also shown using RHIC blue ring

Key EIC Machine Parameters

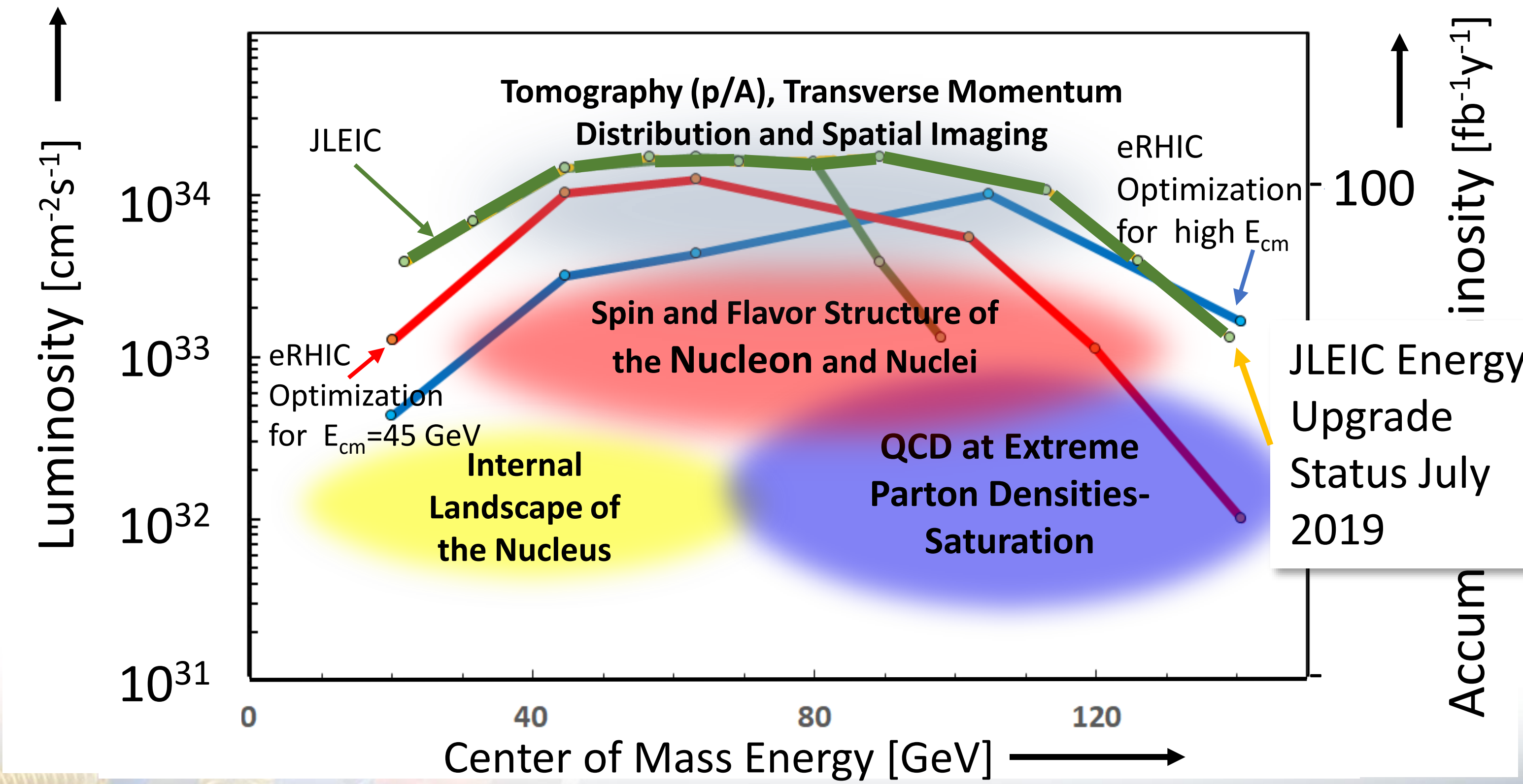
as required by the NSAC Long Range Plan & National Academy Study

Parameter	Unit	JLEIC	eRHIC
Center of Mass Energies	[GeV]	20-100 a)	20-140
Ion Species		p to U	p to U
Number of Interaction Regions		2	2
Hadron Beam Polarization		85%	80%
Electron Beam Polarization		80%-85%	80%
Maximum Luminosity	$[10^{34} cm^{-2} s^{-1}]$	1.55	1.3

a) upgradable to 140 GeV

EIC Physics and Luminosity

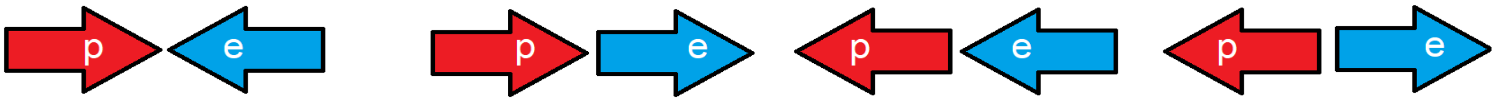
Spin related physics tops make an important part of the EIC physics program and require several 10's of fb^{-1} of luminosity



Note: For electron ion collisions, the E_{cm} scale needs to be reduced by a factor $(Z/A)^{1/2}$

Beam Polarization

- Need high polarization for hadrons and electrons of > 70%
- Need both polarization directions present in the same fill to suppress systematics

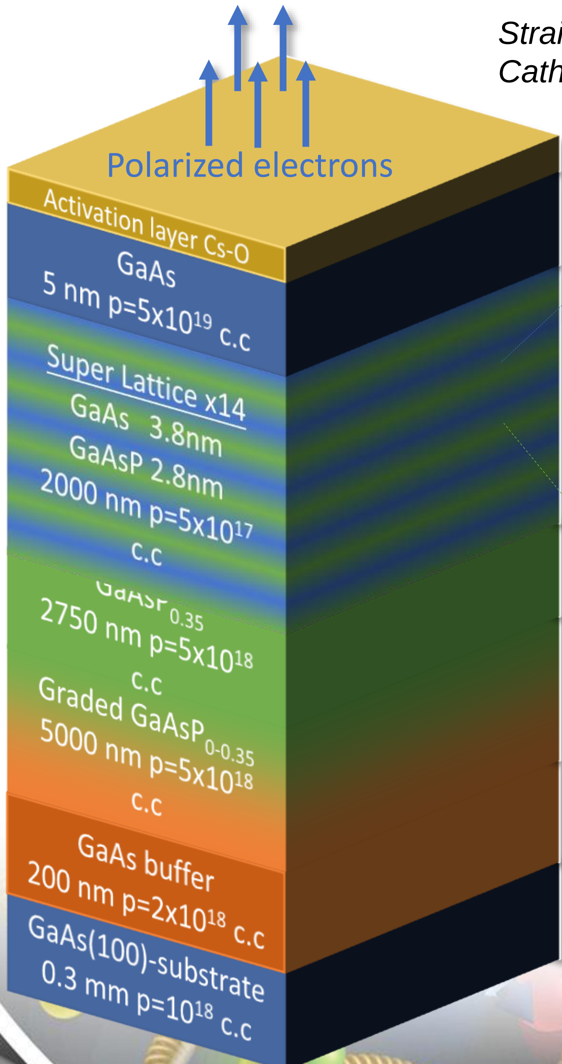


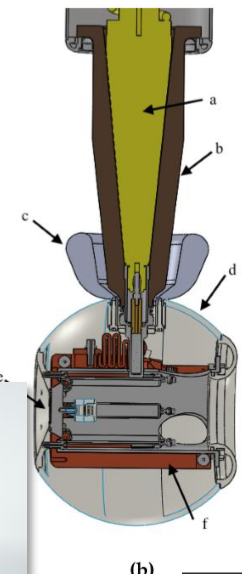
- Spin need to be longitudinal in the IP
- Electron spin need to be vertical in the arcs

Polarized electron sources for eRHIC

Parameters similar than SLAC polarized photo cathode gun, design based in JLAB polarized gun (inverted gun) with strained GaAs Cathodes

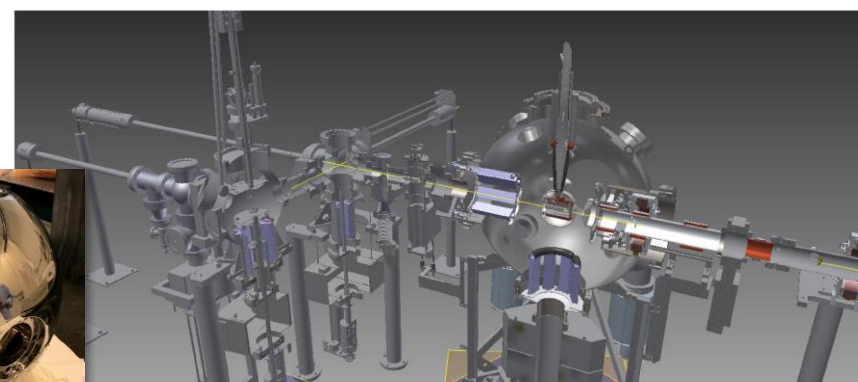
Strained GaAs Cathode



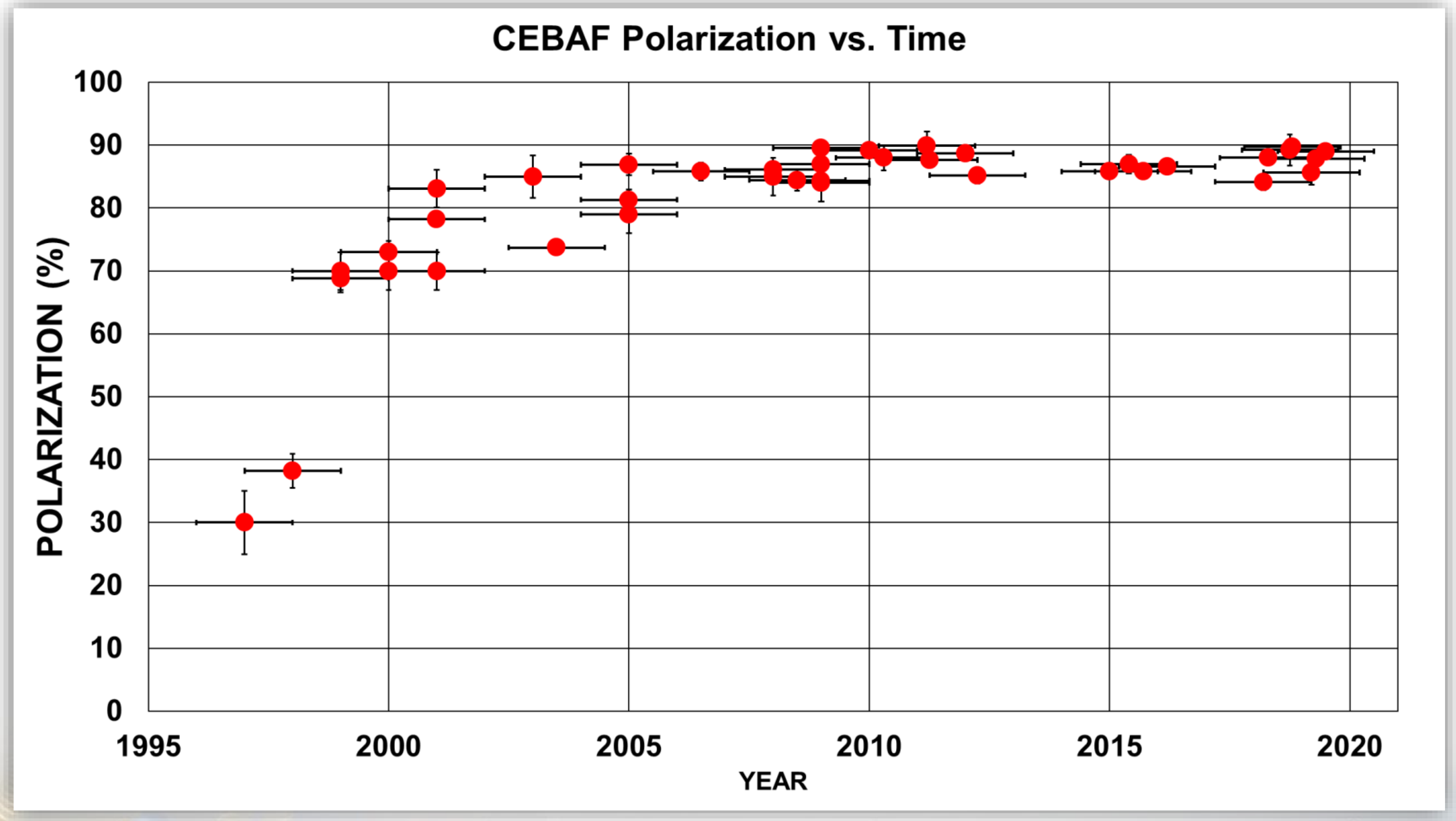


Parameter	SLC	eRHIC
Polarization [%]	85	85
Voltage [kV]	90-120	100-350
Bunch charge [nC]	9-16	3-10
Repetition rate [Hz]	120	1
Bunch length [ns]	2	1-2

BNL Polarized Gun Prototype



CEBAF as highly polarized e-source for JLEIC



strained GaAs Cathodes and preservation of polarization are the key for high polarization

eRHIC spin transparent rapid cycling synchrotron

SLAC-PUB-3229
September 1983
(A)

CALCULATION OF POLARIZATION EFFECTS
ALEXANDER W. CHAO*
Stanford Linear Accelerator Ce
Stanford University, Stanford, Califo

1. Introduction

Basically there are two areas of accelerator applications tl is the acceleration of a polarized beam (most likely a proton concerns polarized beams in an electron storage ring. In bot been very useful.

$\nu = n$: imperfection resonances excited by vertical closed orbit distortion;

$\nu = nS \pm \nu_y$: intrinsic resonances excited by vertical betatron motion of particles (S is the periodicity of the accelerator.)

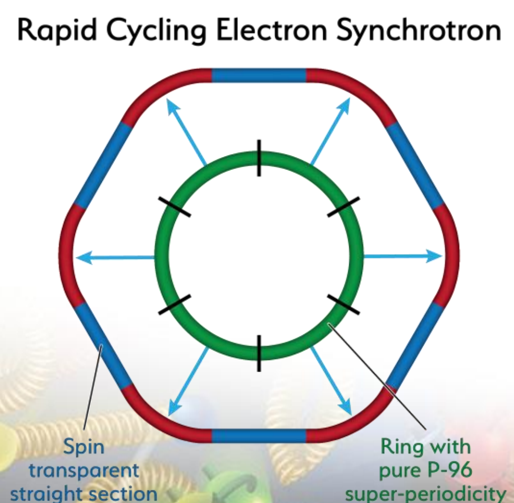
➔orbit control

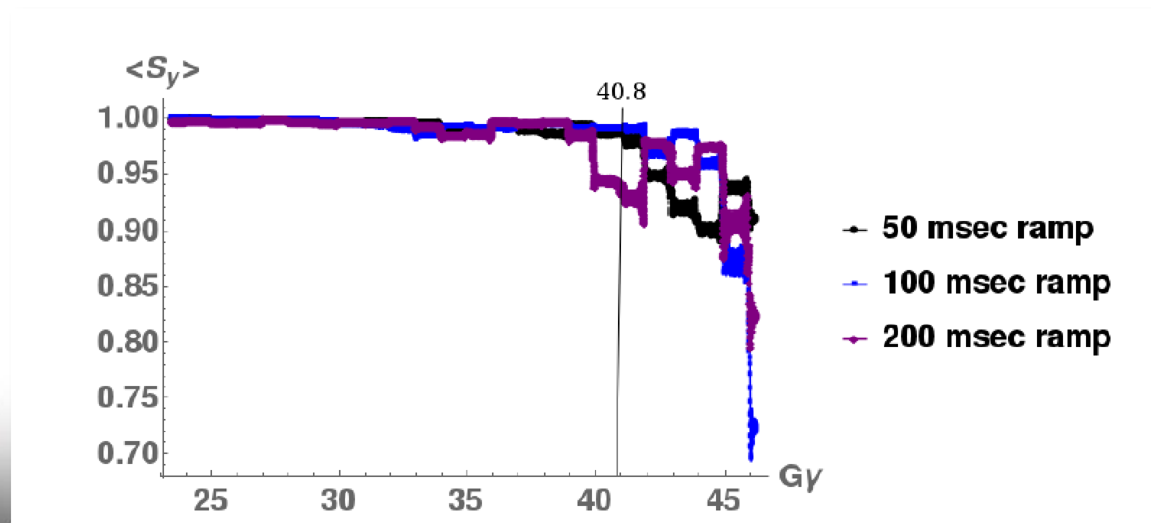
➔high symmetry

- High periodicity arcs and unity transformation in the straights suppresses all intrinsic depolarizing resonances up to Gγ = 45 (suggested by AGS experience)
- Good Orbit control y_{rms} ~0.5 mm reduces strength of imperfection resonances

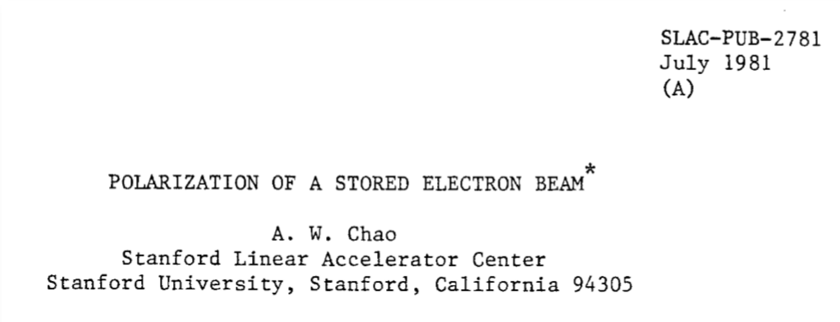
➔ **resonance free acceleration up >18 GeV**

no loss of polarization on the entire ramp up to 18 GeV (100 ms ramp time)



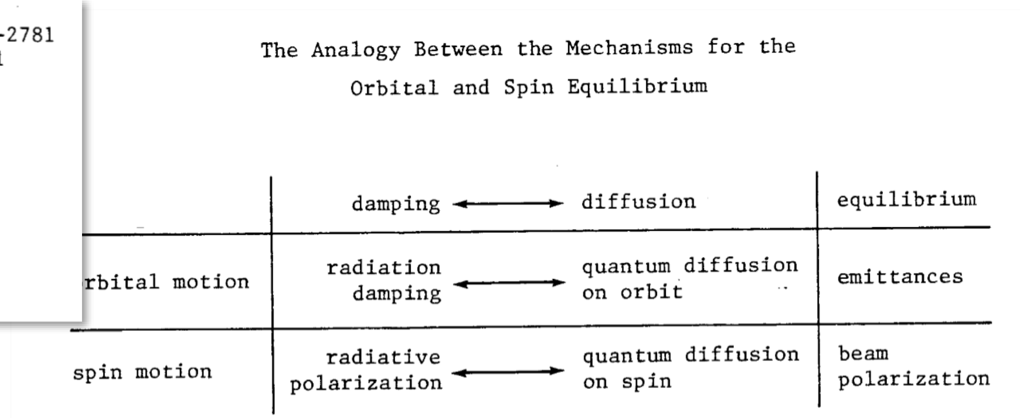


Polarized electrons eRHIC electron ring


SLAC-PUB-2781
July 1981
(A)

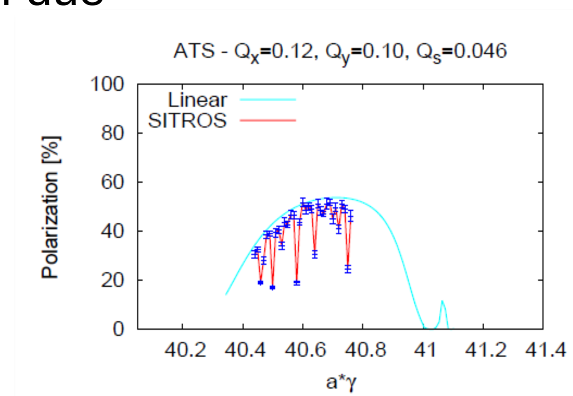
POLARIZATION OF A STORED ELECTRON BEAM*

A. W. Chao
Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305


The Analogy Between the Mechanisms for the Orbital and Spin Equilibrium

	damping ⟷	diffusion	equilibrium
rbital motion	radiation damping ⟷	quantum diffusion on orbit	emittances
spin motion	radiative polarization ⟷	quantum diffusion on spin	beam polarization

- Maximum polarization in EIC electron storage rings: equilibrium of radiative self polarization and depolarization due stochastic nature of synchrotron radiation
- Depolarization due to imperfections further reduce the polarization
- Typically equilibrium polarization in the order of 50% is achieved with good orbit control and spin matching
- Highly polarized (85%) electron beams are injected into the storage ring and decay with a time constant of ~1/2 h
- Spin rotator: dipole and two solenoids separated by skew quadrupoles (intrinsic coupling correction)



Polarization Simulation for eRHIC with imperfections

Polarization in the EIC electron storage ring

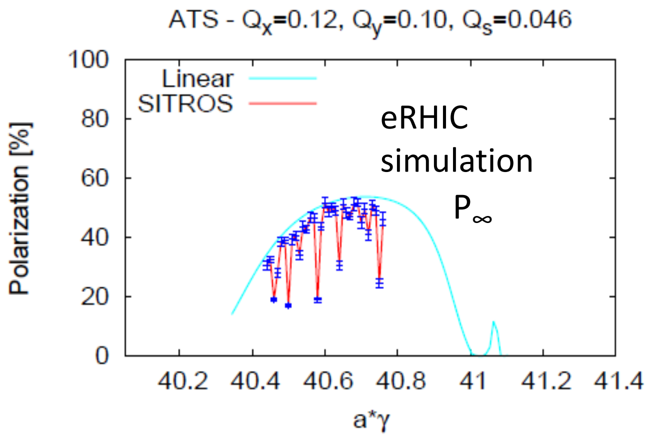
High initial polarization of 85% will decay towards equilibrium polarization $\mathbf{P_\infty}$ due to Sokolov-Ternov effect and radiative depolarization (Derbenev & Kondratenko)

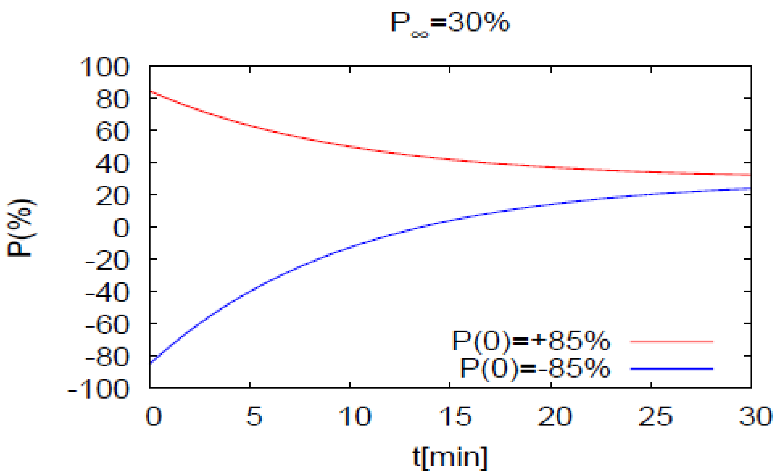
- **HERA** tools and procedures carried over to **eRHIC**

➔**Get $\mathbf{P_\infty}$ > 50%** for Realistic lattice with errors

30% average polarization is a conservative assumption
HERA achieved **$\mathbf{P_\infty}$ > 45%**
with strong beam-beam interaction ΔQ_y=0.1
and P_∞ > 60% without beam-beam

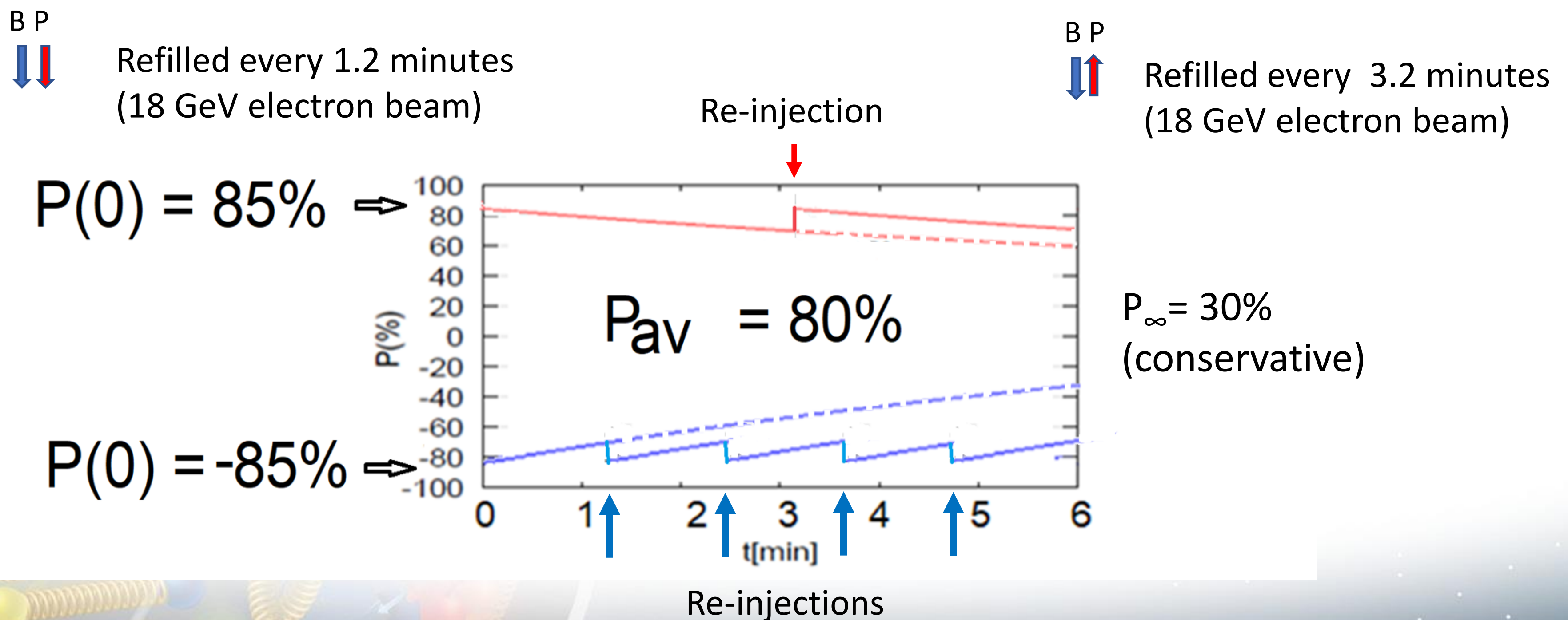
$$P(t) = P_\infty \left[1 - \exp^{-t/\tau_p}\right] + P(0)\exp^{-t/\tau_p}$$





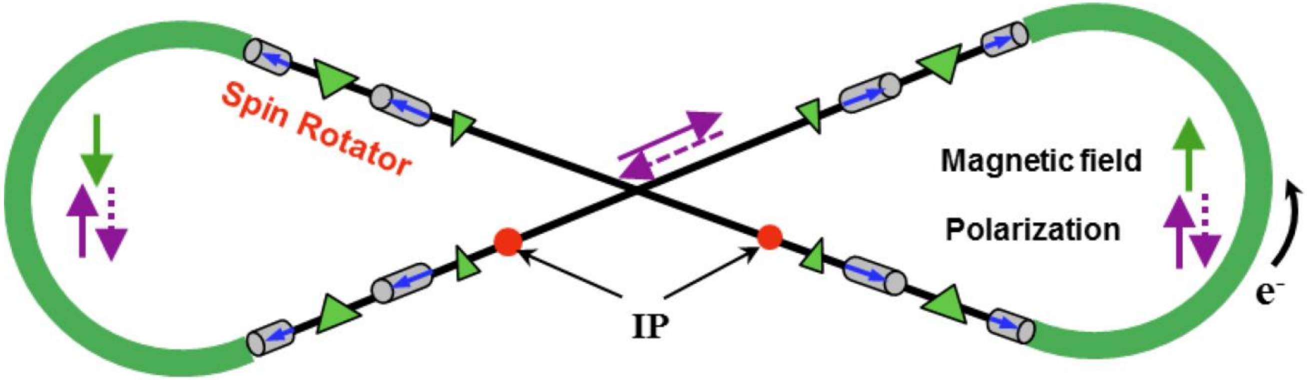
High average polarization at electron storage ring of 80% by

- Frequent injection of bunches with high initial polarization of 85%
- Initial polarization decays towards P_∞ < ~50%
- At 18 GeV, every bunch is refreshed in 2.2 min with RCS cycling rate of 2Hz.



JLEIC High Electron Polarization

- Two (one up, one down polarization) highly polarized bunch trains maintained by top-off with highly polarized electron beam from CEBAF
- Advantage of figure-8 geometry:
  no contribution to polarization due to non-linear resonances demonstrated by spin tracking
- Need spin rotator
- Energy independent spin tune
- Spin matching considered



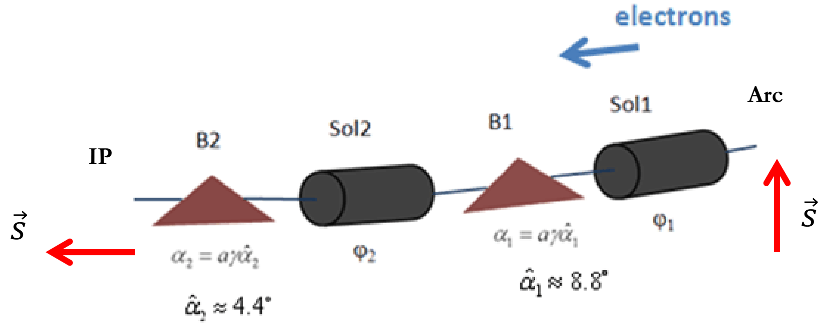
However:

- Considerable radiative depolarization at higher energies: High equilibrium polarization maintained by continuous injection
- Polarization vertical in the arc to avoid spin diffusion and longitudinal at collision

Courtesy: V Morozov, A Seryi

JLEIC universal spin rotator

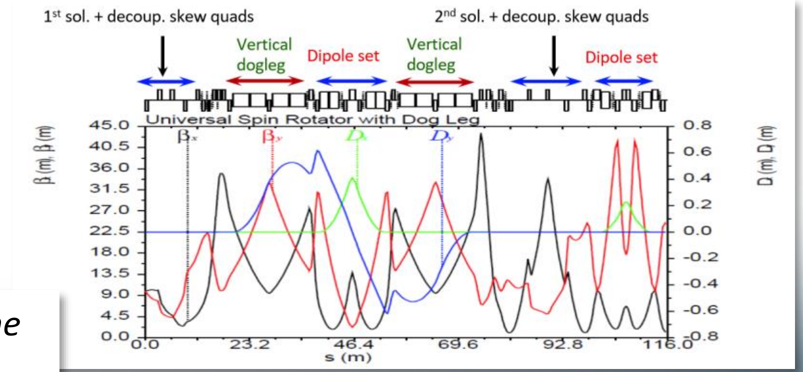
Minimizes spin diffusion by switching polarization between vertical in arcs and longitudinal in straights



Energy (GeV)	3	5	7	9	10
Lifetime (hours)	66	8	2.2	0.9	0.3

E	Solenoid 1		Dipole set 1	Solenoid 2		Dipole set 2
	Spin Rotation	BDL	Spin Rotation	Spin Rotation	BDL	Spin Rotation
GeV	rad	T·m	rad	rad	T·m	rad
3	π/2	15.7	π/3	0	0	π/6
4.5	π/4	11.8	π/2	π/2	23.6	π/4
6	0.62	12.3	2π/3	1.91	38.2	π/3
9	π/6	15.7	π	2π/3	62.8	π/2
12	0.62	24.6	4π/3	1.91	76.4	2π/3

- Geometry independent on energy
- No dispersion in solenoids
- Solenoid coupling compensated by skew quadrupoles



Beam optics in the rotator section

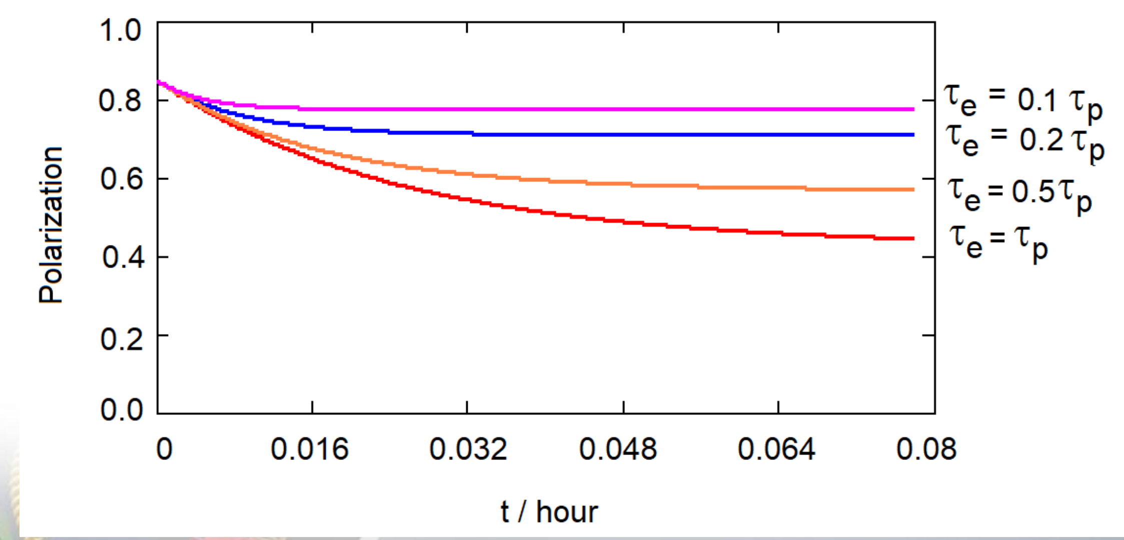
Courtesy: Lin Fang Lei, A Seryi

JLEIC Top-Off Electron Spin Polarization

- Polarization lifetime maybe short (shortest τ_p estimate 6 min): Need to "refresh" polarization

➔ Frequent continuous polarized electron injection to top-off intensity and polarization

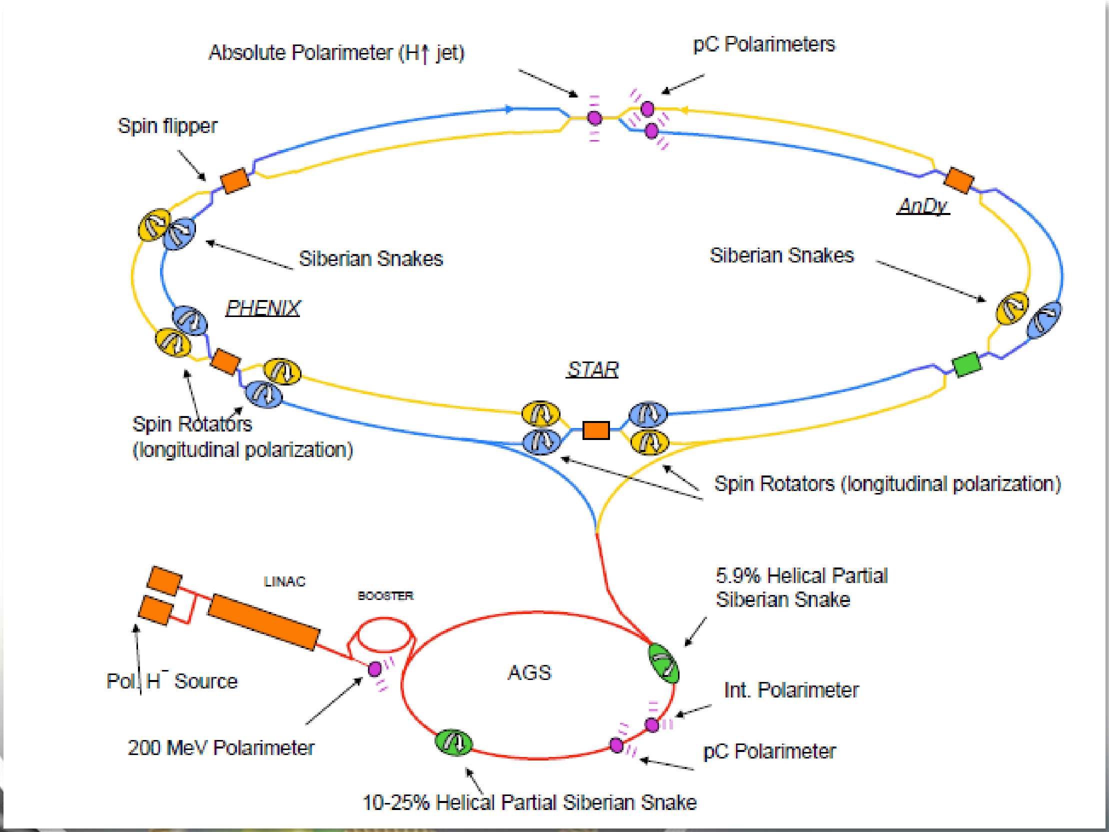
- Beam life time should be smaller than polarization lifetime $\tau_e < \tau_p$ for good average polarization
- Equilibrium Polarization depends on initial polarization and the ratio τ_e / τ_p
- Need to reduce beam life time
- CEBAF Injector can maintain beam current even for shortest beam lifetime



Polarized Hadrons in eRHIC

- Based on existing RHIC polarized proton program
- With full Siberian snakes made of helical dipoles in RHIC
- Helical dipole spin rotators
- Partial snakes in AGS (10-25% and 5.9%)

Helical magnets for Siberian snakes and rotators



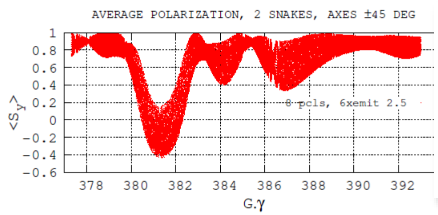
Present polarization performance:

- Source Polarization 80%
- AGS at top energy 70%
- RHIC at top energy 60%

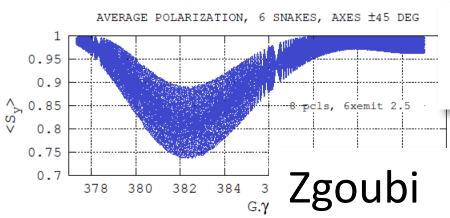
➔ Requires some improvements to meet EIC requirements

eRHIC Hadron Polarization

Planned improvement in eRHIC:
Issue: 3 depolarizing resonances near top energy reduce polarization from 70% to 60%
Cure: introduce four more full snakes (carried over from BLUE RING)



p, eRHIC
2 snakes



p, eRHIC
6 snakes

Zgoubi simulations

- **with two snakes:**

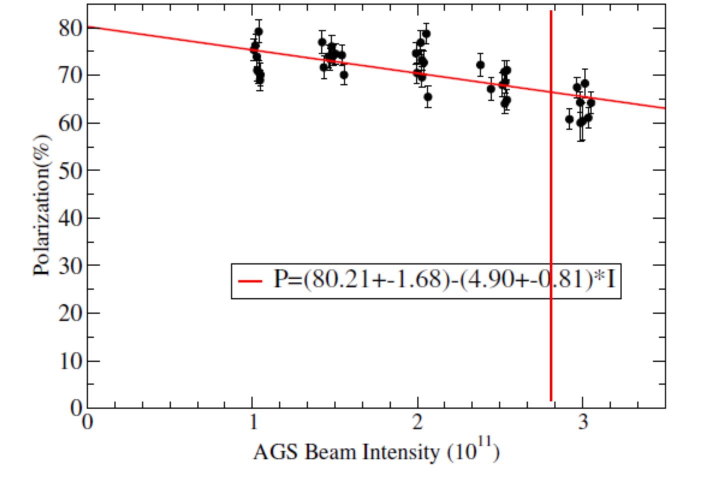
Three depolarizing resonances
at high energy in RHIC depolarize from ~70% to ~60%

- **p in eRHIC with six snakes**

Three depolarizing resonances **no polarization loss** in eRHIC

- **Further planned measures**: tune jumps in RHIC and AGS

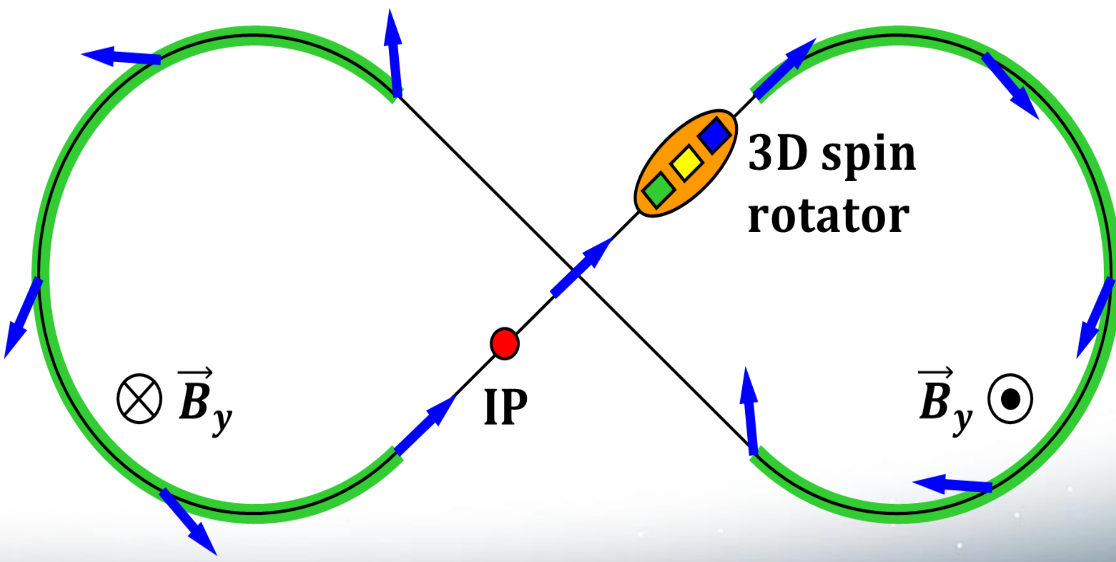
Planned improvement in AGS:
- Skew Quadrupoles
- Higher injection energy and stronger partial snakes (back-up solution)



F. Willeke, EIC Polarization, Symposium for Alexander Chao , SLAC, October 25, 2019

Ion Polarization in JLEIC

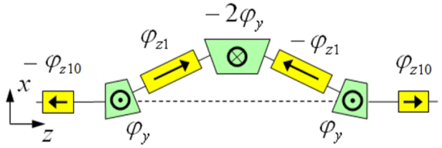
- Figure-8 concept: Spin precession in one arc is exactly cancelled in the other
- Spin stabilization by small fields: ~3 Tm at 100 GeV
  - Criterion: induced spin rotation >> spin rotation due to orbit errors
- 3D spin rotator: combination of small rotations about different axes provides any polarization orientation at any point in the collider ring
- No effect on the orbit
- Polarized deuterons
- Frequent adiabatic spin flips



Courtesy: V Morozov, A Seryi

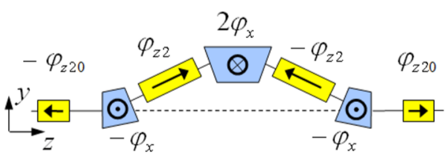
Spin tune and polarization axis adjustment

- Provides control of the radial, vertical, and longitudinal spin components
- Module for control of the radial component (fixed radial orbit bump)

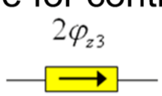


$L_{tot} = 7$ m, $\Delta x = 15$ mm, $B_{dip}^{max} = 3$ T, $B_{sol}^{max} = 3.6$ T

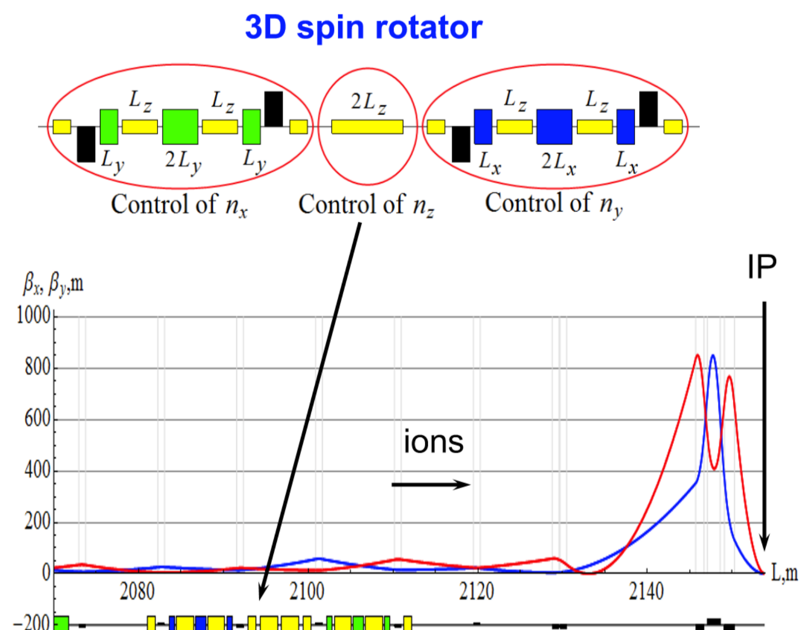
- Module for control of the vertical component (fixed vertical orbit bump)



- Module for control of the longitudinal component



$L_x = L_y = 0.6$ m, $L_{zi} = 2$ m, $L_{zi0} = 1$ m, $\alpha_{orb} = 0.31^{\circ}$

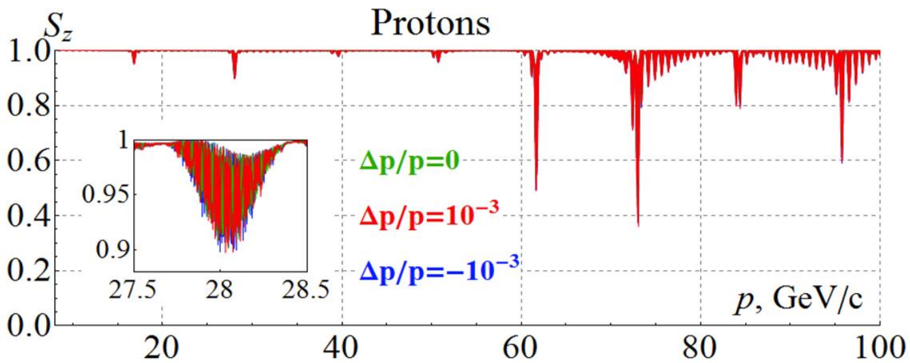


EIC Accelerator Collaboration Meeting 2019 7 October 10, 2019

Courtesy Vasyli Morozov JLAB

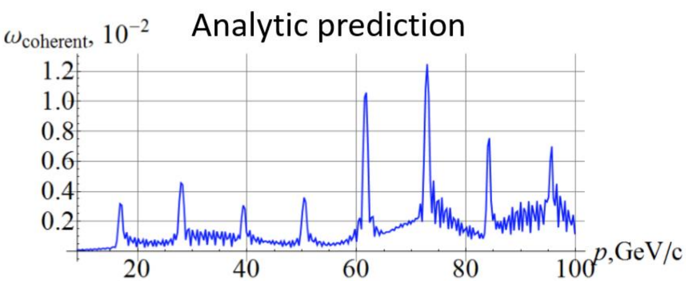
Start to 100 GeV simulations hadron polarization on the ramp

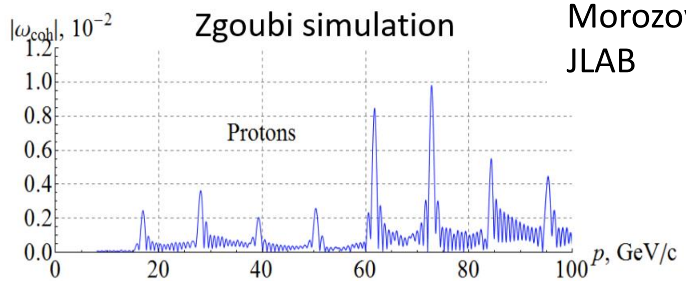
- Three protons with $\varepsilon^N_{x,y} = 1\ \mu m$ and $\Delta p/p = 0, \pm 1 \cdot 10^{-3}$ accelerated at ~3 T/min in lattice with 100 μm rms closed orbit excursion, $\nu_{sp} = 0.01$



Zgoubi simulation

- Coherent resonance strength component





Courtesy Vasyli Morozov JLAB

Summary

- Electron Ion Collider designs exist which support the requirements of the NSAC Long Range Plan
- After the physics case of the EIC was well received and strongly supported by the National Academy of Sciences Study, we expect a Mission Need Statement from DOE in the near future
- The theory of beam polarization is well established and sophisticated tools are available for an optimum design which support high beam polarization.
- The designs of EIC will provide high average polarization for electrons and hadrons
- Polarization transparency designs of the EIC use features which are well established, but some have not been implemented before (figure-8 geometry, quasi-high-symmetry)