The Electron Ion Collider

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- An Electron Ion Collider (EIC) with a large range in the center of mass energy for polarized electron-proton scattering, and electron-Ion (heavy ion) scattering is proposed as a next generation experimental facility for deep inelastic scattering (DIS) studies.
- With various options for electron beam possible, a significant increase in the luminosity over the present Colliders is envisioned.

What is the EIC?

The EIC machine is a result of the merger of two initiatives, the eRHIC and the EPIC machines. The result is a machine with the following features:

- Electron-proton / ion colliders
- Center-of-mass energies between 14 GeV and 100 GeV (protons) or 63 GeV/A (ions)
- Luminosities at 10^{33} cm^{-2} s^{-1}
- Polarization of electrons & protons

Constraints from Experiments

- C.M. Energy range, energy ratio
- Electron energy tunability during experiment (with polarization)
- What is the minimum bunch spacing? (Currently up to 5-6 ns in some designs)
- What is the detector stay-clear length (no accelerator components). Small bunch spacing requires invasion of IP by accelerator.
- Synchrotron radiation loading

Accelerator Issues

- Obtaining 10^{33} luminosities
- Synchrotron radiation
- Ring – Ring, Linac – Ring or Recirculator-Ring
  - Ring-Ring is an established technology
  - Linac-Ring offers advantages
  - Recirculator-Ring – the best of all worlds?
- Potential use of RHIC
  - Existing machine
  - A number of IPs
  - Polarized protons, heavy ions
- Number of Interaction Points
- Electron cooling is needed

The rules of the game:

Assume round beams.

The luminosity is

$$L = \frac{N_i N_e f_c}{4\pi\sigma^2}$$

It may be written in terms of the beam-beam tune shifts as:

Constants

Tune shifts
Limited by stability

Collision rate
Various limitations

$$L = \left(\frac{4\pi\gamma_i\gamma_e}{r_i r_e} \right) (\xi_i \xi_e)(\sigma_i' \sigma_e') f_C$$

Angular beam sizes
IR quads angular acceptance
For RHIC ions ~226 μrad

$$\xi_e = \frac{N_i Z r_e}{4\pi\gamma_e\varepsilon_e} \le 0.06 \qquad \xi_i = \frac{N_e r_i}{4\pi Z \gamma_i \varepsilon_i} \le 0.004$$

Synchrotron-Radiation in an Electron Storage-Ring

- In one turn of storage ring of bending radius ρ, the energy loss per turn is

$$U_0[MeV] = 0.0885 \frac{E[GeV]^4}{\rho[m]}$$

- The total radiated power is

$$P[MW] = U_0[MeV] I[A]$$

- The linear power density is

$$P_{lin}[kW/m] = 14.1 \frac{E[GeV]^4 I[A]}{\rho[m]^2}$$

- Current technology limit (approx)

$$P_{lin} \le 10 kW/m$$

- This places restrictions on energy / current / size

Electron Polarization in an Electron Storage Ring

- The polarization time depends on the energy and radius, (as synchrotron radiation). Gets difficult at a high current.

$$T_{pol} = \frac{99 C \rho^2}{2\pi E_e^5} \propto \frac{CI}{EP_{lin}}$$

- Spin resonances – probably impossible to accelerate or decelerate through any resonance (lose polarization)

$$\frac{E_{resonance}}{0.44065 GeV} = \nu + k_x \nu_x + k_y \nu_y + k_s \nu_s$$

Electron Polarization in a Linac

- Polarized electron gun: GaAs cathode, ~80% polarization, quantum efficiency 0.1 to 0.3% (C. Sinclair, P. Hartmann, JLAB)
- 1/e lifetime of cathode 10^5 Coul/cm^2. @ 1 cm^2 (7 cm^2 built) and 0.2 A current, lifetime is well over 5 days.
- Laser at 850 nm, about 250 watts. Difficult, but doable. Lasers are improving very fast.
- Superb flexibility due to laser
- Subharmonic bunching to match into linac. Possibly RF gun?!

All EIC specs can be met by an electrostatic gun.

State of the art in photocathodes:

Type	P/%	QE/%
Thick bulk	32	10
Thin bulk	40	6
Strained layer	80	0.3
Superlattice	90	0.1

13.5 nC requires 8.5μJ laser energy at QE=0.3%.

Losses due to light polarization: 2

Losses in laser transport: 1.1

Surface photovoltage: 1.5

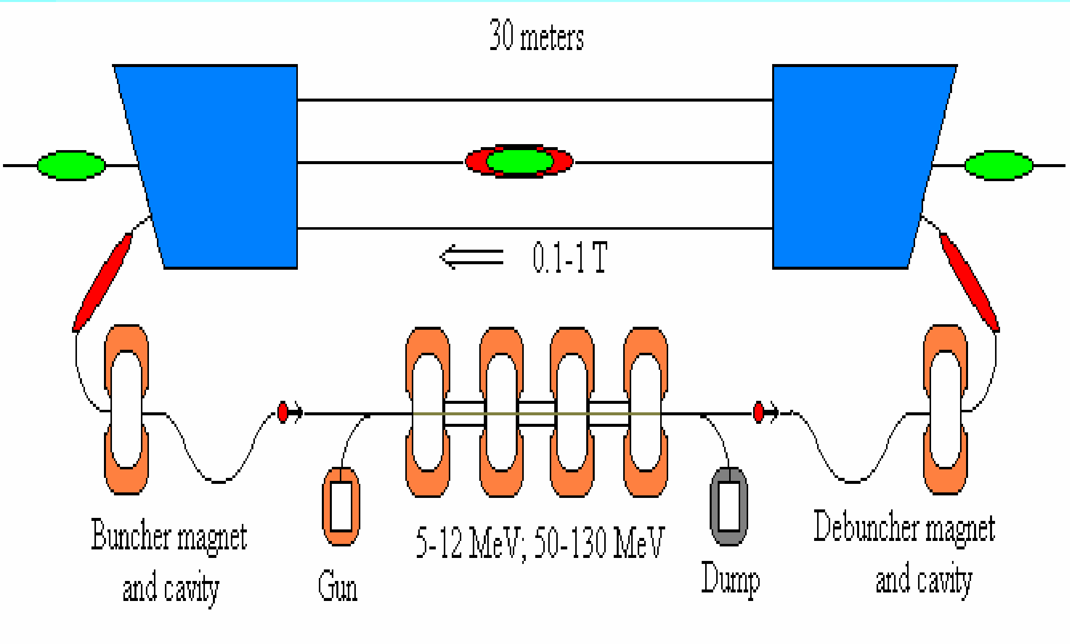
Average laser power 220 watts. Duty 10ns/100ns

Peak laser power 2.2kW.

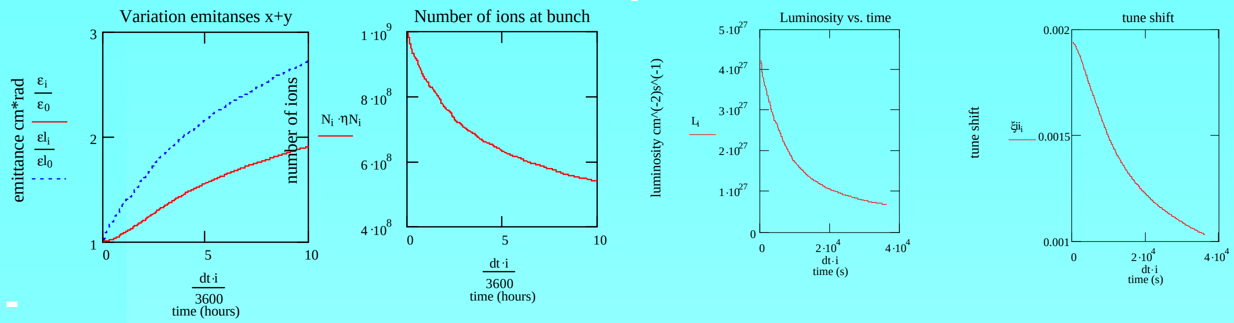
Laser R&D required (or gang 10 lasers).

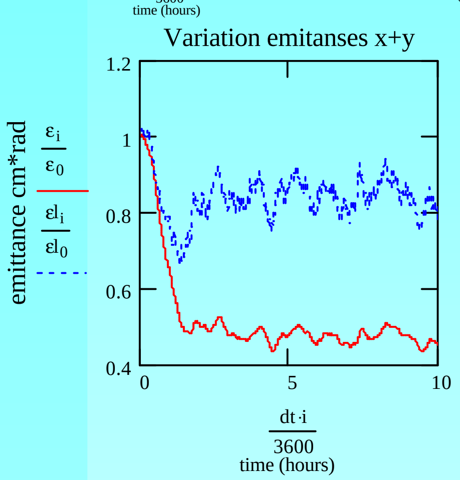
EIC Electron Cooling

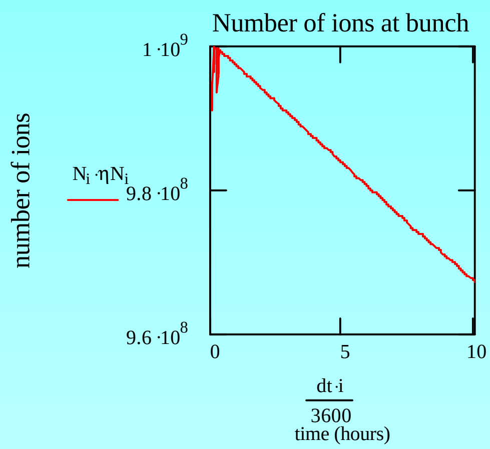
- Electron cooling is a must in the lower energy machines
- It is well established at low energy, but:
  - New accelerator technology (ERL)
  - Operation in a collider was not done

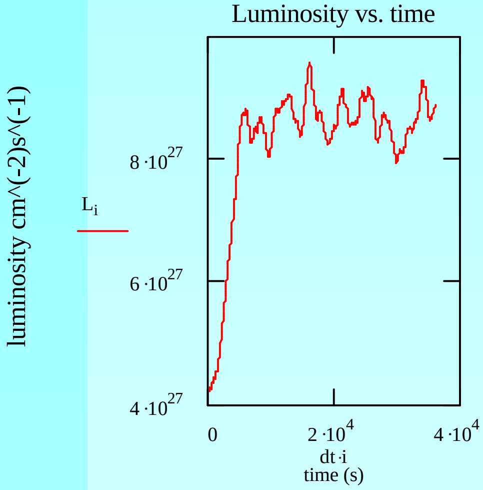


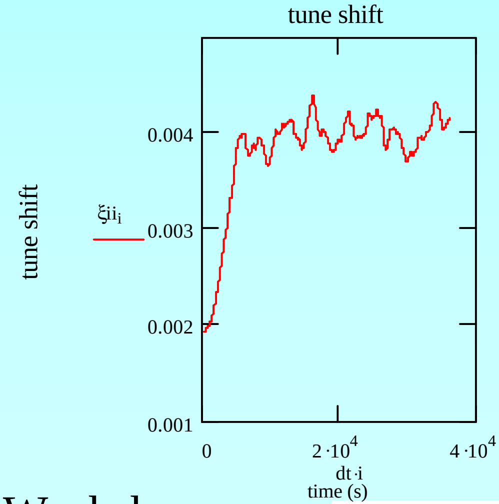
RHIC Gold e-Cooling (Top: no cooling) Vasily Parkhomchuk.











Ilan Ben-Zvi, IPPP Workshop on Future of Lepton-Nucleon Scattering Durham, December 6-7, 2001

Brookhaven Science Associates

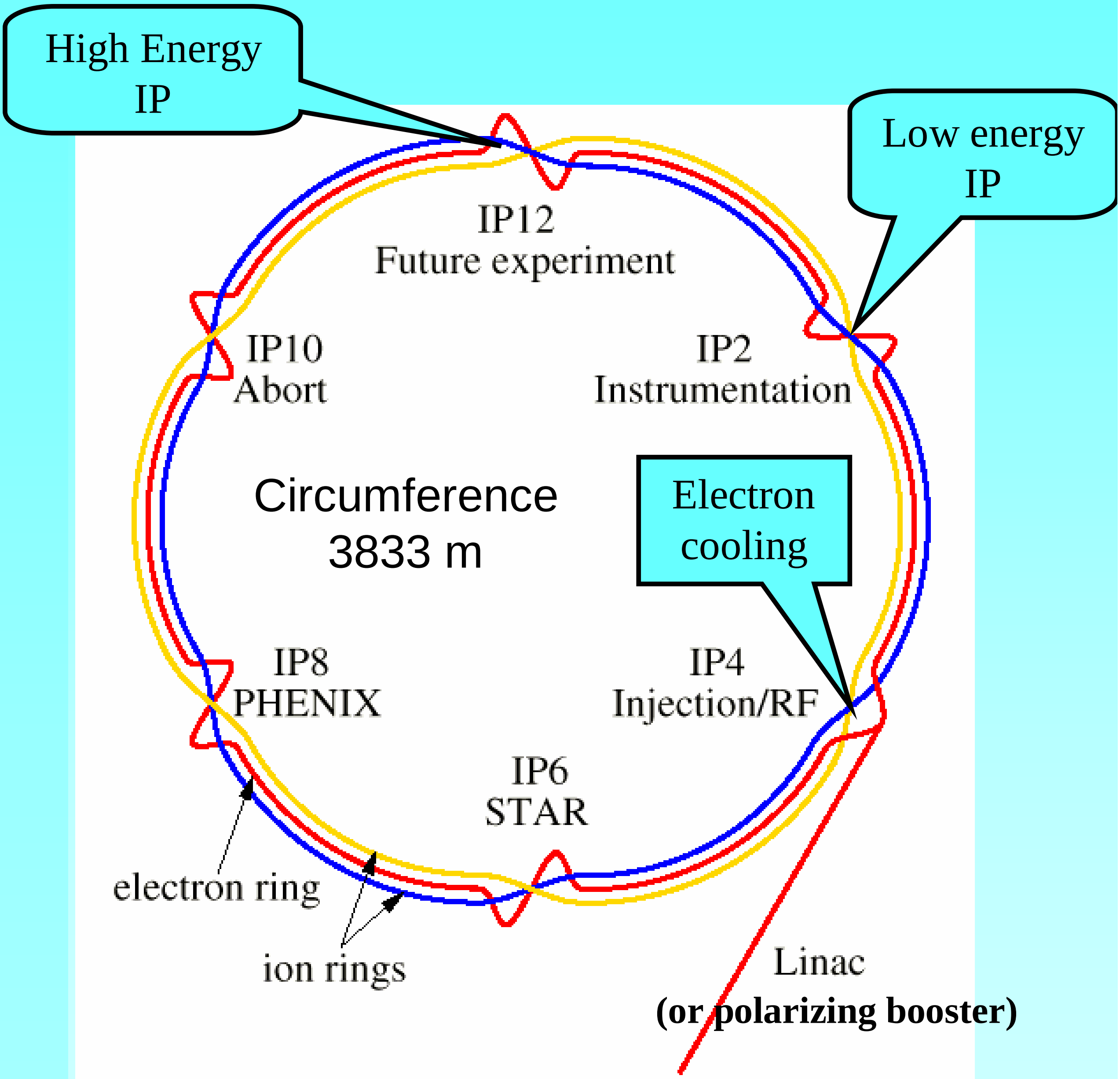
High-Energy Electron-Cooling Issues

- We need high-precision manufacturing and alignment of a long superconducting solenoid
- We have to operate high-current electron ERL (50 MeV, but 50 to 100 mA)
- How to generate, transport and match a "magnetised" beam without continuous magnetic field
- How to de-bunch (then re-bunch) the beam to obtain low energy spread
- Will the electron-cooling permit an increase in tune-shift parameters?
- We have to calculate the cooler performance, possibly introduce some of new variants

Primary eRHIC parameters:

Parameter	Units	Value
Maximum gold energy, E_{Au}	[GeV/u]	100
Maximum proton energy, E_p	[GeV]	250
Maximum elect. energy, E_e	[GeV]	10
Number of collision points		6
Circumference	C [m]	3833
Revolution freq., F_{rev}	[kHz]	78.3
Dipole bend radius, ρ	[m]	243

EIC: Ring-ring using RHIC in-tunnel version, full energy injection linac shown

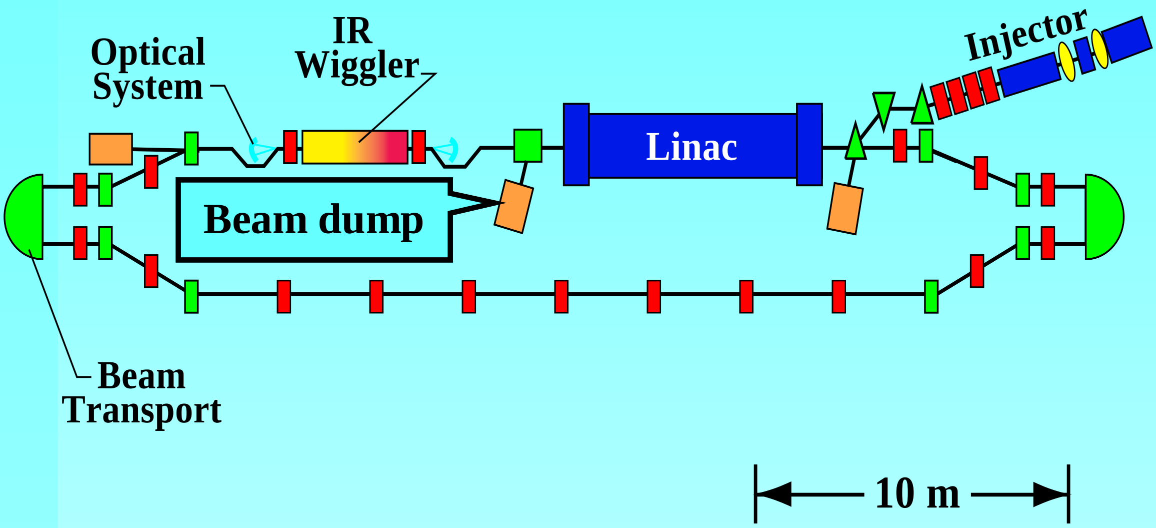


THE EIC LINAC-RING OPTION

- A linac-ring collider can provide the same or greater luminosity and C.M. energy as a ring-ring collider. No positrons.
- Why use a linac?
  - The e^- polarization can be somewhat higher (R&D needed on both linac and ring polarization).
  - Polarization may switched fast at will.
  - The energy may be changed rapidly and over a large range without losing polarization.
  - The linac maintains the high luminosity and polarization at lower energies, the ring not so.
  - The linac achieves the same luminosity with a lower current, thus less synchrotron radiation in the detector.
  - Naturally round beam, small emittance.

Energy Recovering Linac – the ticket to high-current

- The J-Lab Energy Recovering Linac



- Linac energy recovery extremely good (loss < 0.02%)
- 5 mA average current, limit – e-gun.
- ~200 mA is believed to be possible **without feedback**, well over 200 mA with B-factory style feedback.

The Superconducting Electron Linac

- Extremely well known (JLAB, DESY, industry)
- $R/Q=1036\Omega$, $L=1.038m$
- Take conservatively $Q_0=1.5x10^{10}$ at 2K, 20MV/m
- Refrigeration power 26 W/structure
- 500 cavities → 13kW refrigeration
- HOM power: (Merminga et. al., LINAC2000) At eRHIC, due to the 20 ps pulse length, this is not a problem.

The recirculator ring option

- A suggestion by Derbenev (JLAB) to use a recirculator ring:
- Electron bunches are accelerated to full energy by a linac, stored a few hundred revolutions in a recirculating ring and dumped.
- All the advantages of the linac:
  - High polarization at any energy
  - Large beam-beam parameter
  - High luminosity at any energy
- Linac current is much lower.
- Needs to be studied!

Luminosity issues: Ions.

- Other limitations affect the maximum number of ion bunches in RHIC (electron cloud, cryogenic losses). 360 seems OK.
- Minimum bunch spacing at the detectors. 360 seems OK.
- IBS and cooling: Cooling is essential otherwise the luminosity lifetime will be unacceptably short.
- Laslett space charge tune shift

$$\Delta Q_{SC} \approx -\frac{N_i}{\varepsilon_i}\frac{C}{\sigma_{iz}\beta\gamma^2}\frac{r_i}{2(2\pi)^{3/2}} \approx 0.1$$

Luminosity issues: Electrons

- Ring: Linear power density in dipoles places a restriction on the maximum current e ring.
- Ring: Beam-beam limit lower than linac.
- Linac: Multipass Multibunch Instability (~100 to 200 mA), but With B-factory style feedback expect large improvement.
- Linac: HOM power deposition in cavities, a few kW per cavity but only a few watts on cold surfaces.
- Linac: Beam-beam induced head tail instability.

$$D_e \xi_i \leq 4\nu_s \qquad D_e = \frac{Z r_e N_i \sigma_{zi}}{\gamma_e \sigma_i^{*2}}$$

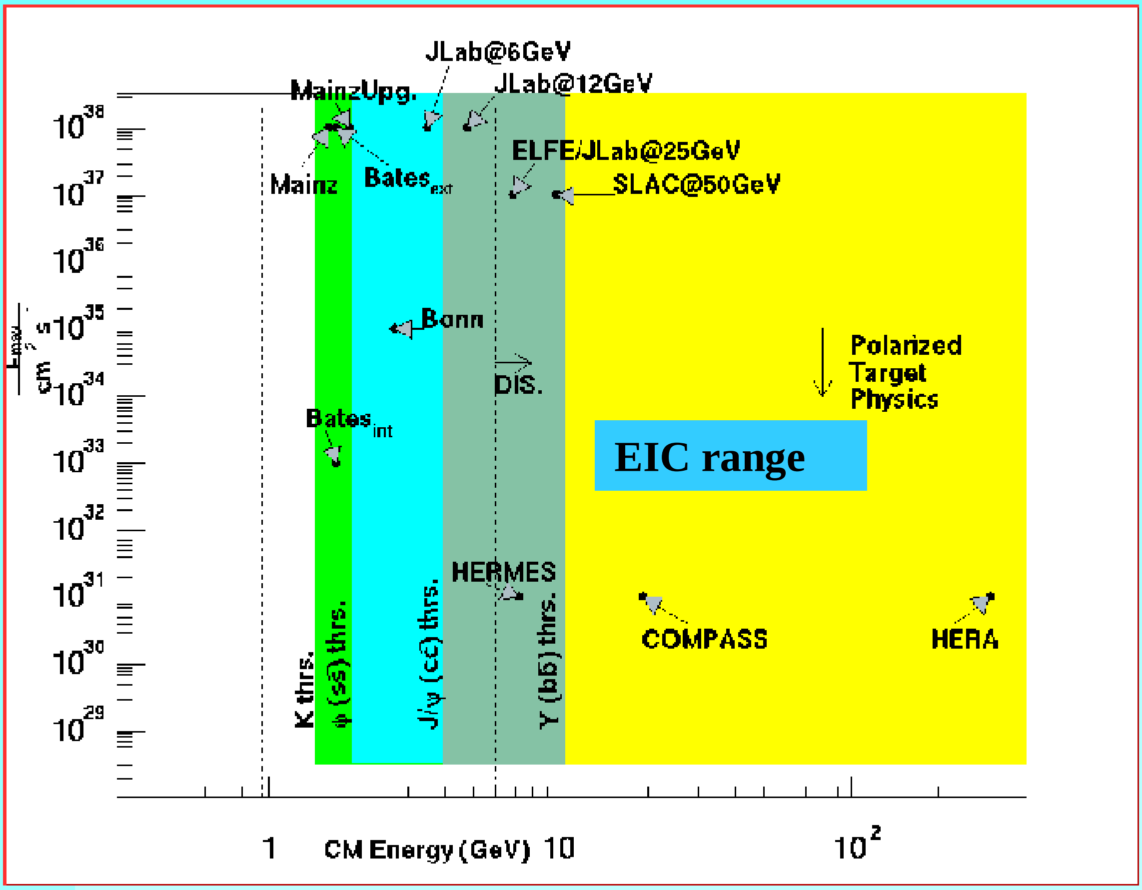
Common parameters

Parameter	Units	Value
Ring Circumference	m	3833
Number of bunches		360
Bunch spacing	ns	35.5
Proton energy	GeV	250
Gold energy	GeV/A	100
Electron energy	GeV	10

Parameters for eRHIC at full energy

Scenario		Linac-Ring		Ring-Ring	
Species		P	Au	P	Au
Luminosity	x10**31	100.0	1.0	25.0	0.7
sigma*	microns	32.0	32.0	40.0	50.0
Ion parameters					
# / bunch	1.00E+09	200.0	1.2	94.0	1.2
Emittance	microns	0.9	0.5	0.8	1.0
Laslett	x0.001	6.0	5.3	3.0	3.0
Beam-beam	x0.001	4.0	4.0	4.0	4.0
beta*	cm	31.0	21.0	53.0	27.0
Electron parameters					
# / bunch	1.00E+10	2.9	4.8	2.6	8.1
Emittance	nm	6.0	6.0	18.0	18.0
Beam-beam	x0.001	382.0	180.0	60.0	60.0
beta*	cm	17.0	19.0	8.9	13.9

Summary



- A few machine options – all look feasible
- Exciting performance
- Large collaboration formed

What next?

- MIT Workshop - Need R&D on:
  - Electron cooling
  - Polarized electron source
  - Integration of IP into machine lattice
- White paper has been written and the idea received wide support by the nuclear physics community
- A new EIC Workshop will be held at BNL on the last week of February, 2002. Nuclear physics (3 days) preceded by accelerator physics (2 days).