

# **ACCELERATOR PHYSICS ISSUES FOR FUTURE ELECTRON ION COLLIDERS**

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Figure 2.3.2: Site of THERA: TESLA (red) is foreseen to be built tangentially to the HERA ring (blue) such that electrons from North hit protons in the West Hall on the DESY site. The PETRA ring is seen which serves as a pre-accelerator for HERA protons. The PETRA lepton injection line will be instrumented with superconducting magnets to arrange protons travelling clockwise in HERA. After collision the TESLA electrons will be dumped on site.



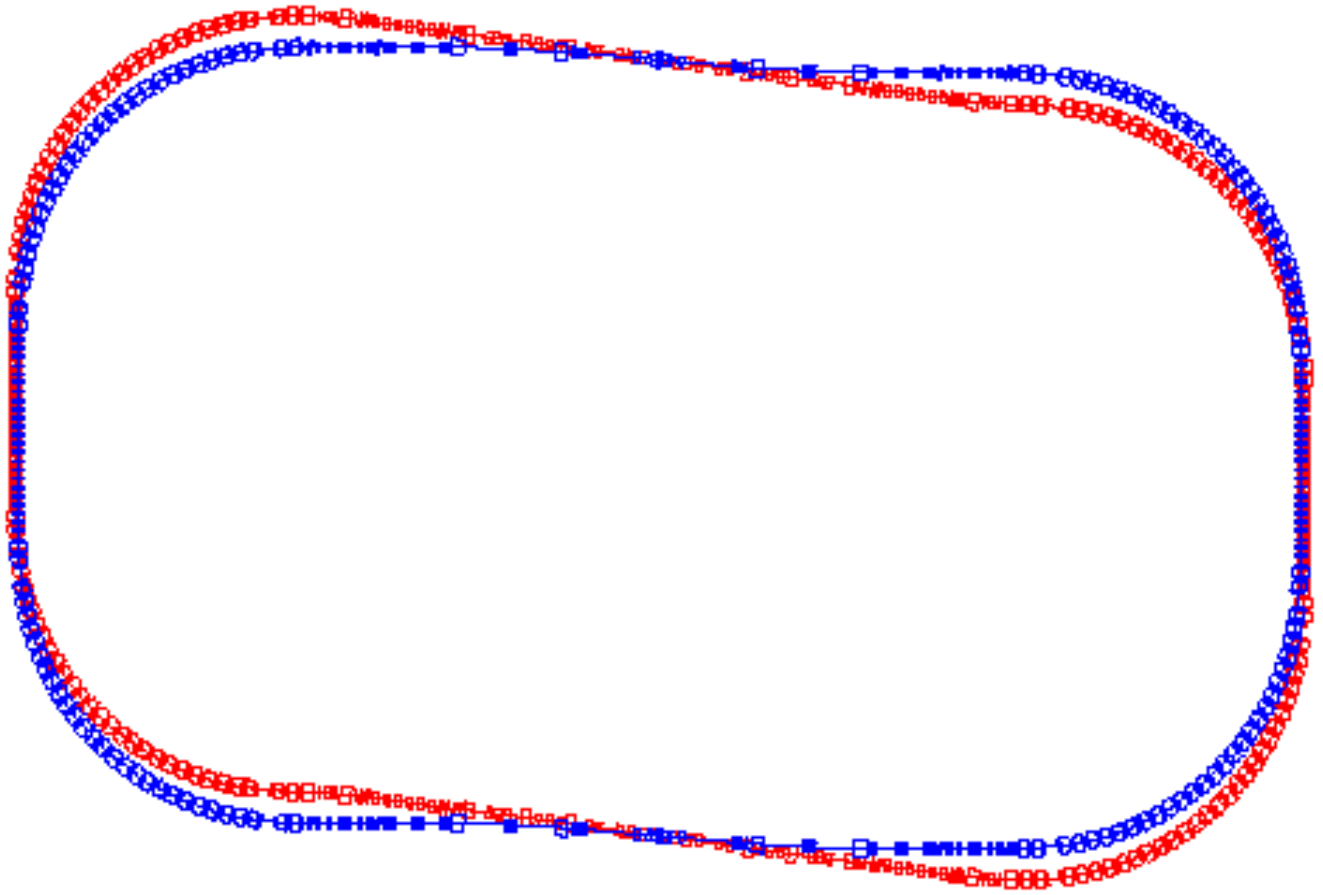
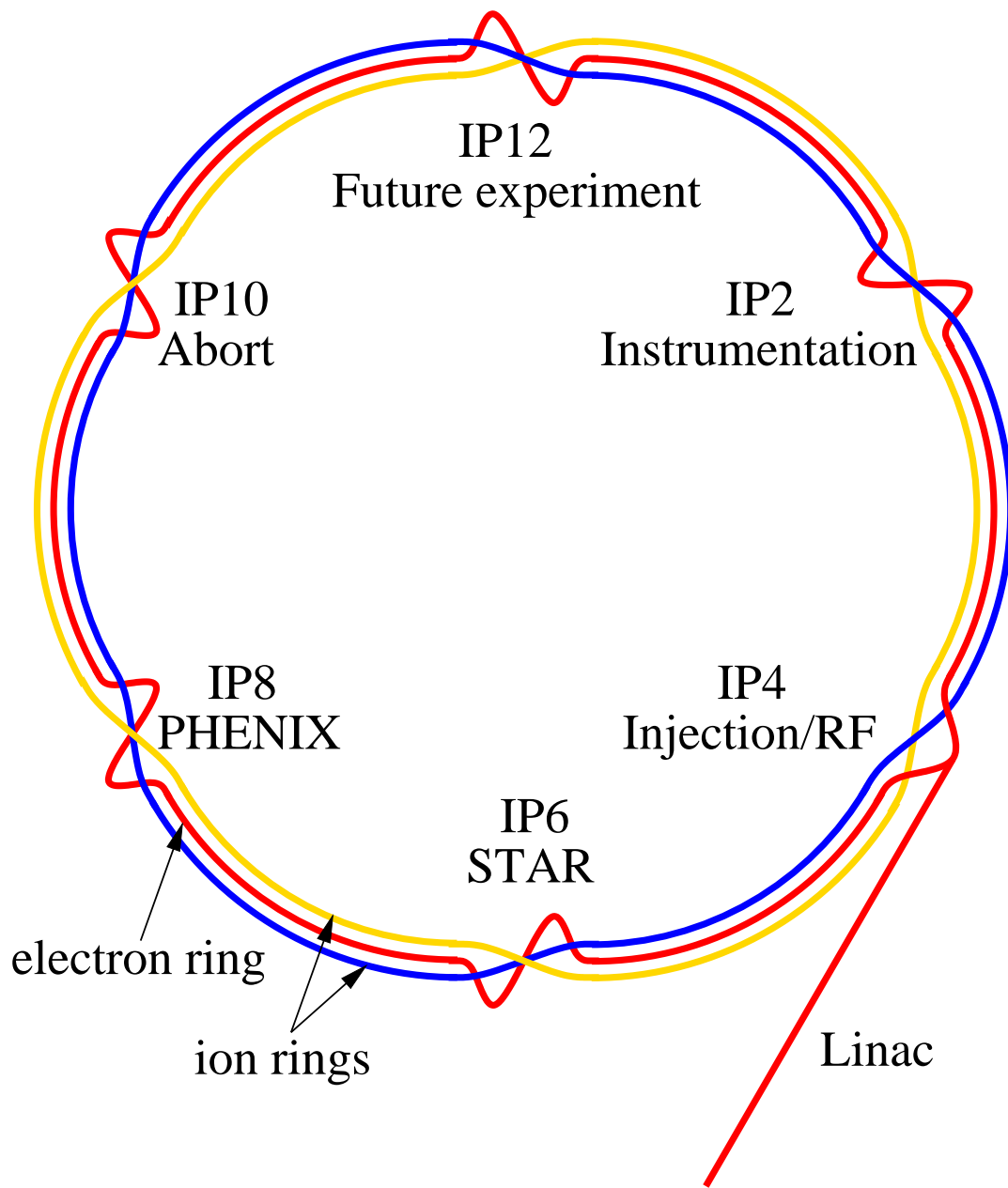


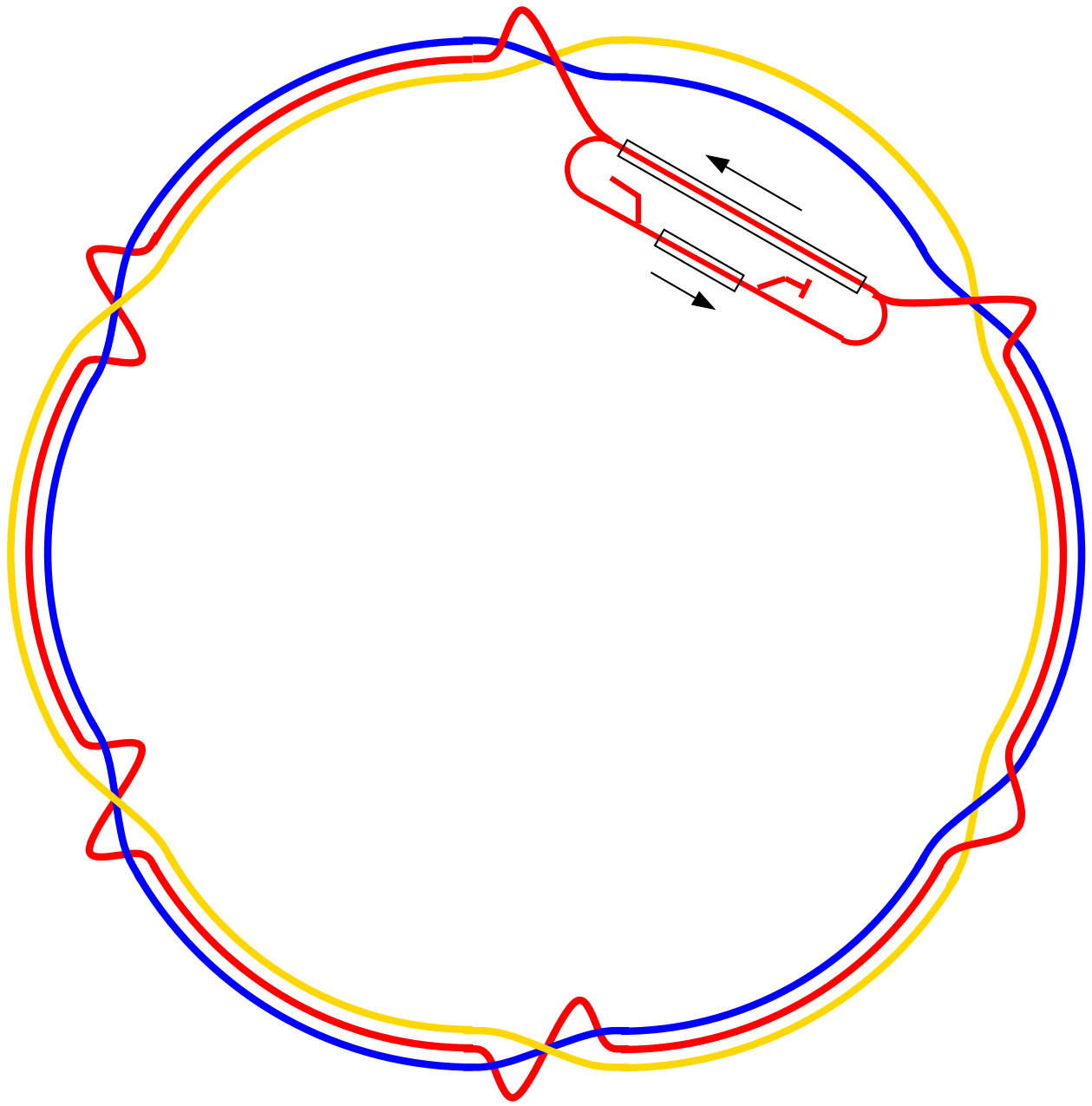
FIGURE 2. Layout of e-p collider.

We chosen the scheme of two intersecting in two points rings. Both rings have approximately equal circumferences 1388 m. Each ring has two experimental straight sections, two technical straights and four identical arcs. The rings are separated vertically about 1 m outside the interaction areas.

MIT-Bates **ring-ring** scenario  
(Koop et al, 2nd EPIC Workshop)



eRHIC **ring-ring** scenario



eRHIC **linac-ring** scenario, with Energy  
Recovery Linac

	<b>THERA</b>	<b>EPIC 2</b>	<b>eRHIC</b>	<b>eRHIC</b>	<b>HER</b>
Scenario	linac-ring	linac-ring	linac-ring	ring-ring	(SLAC)
Ion specie	protons	protons	protons/gold	protons/gold	—
<b>Luminosity</b> , [ $10^{32} \text{ cm}^{-2} \text{ s}^{-1}$ ]	.041	21	4.6/.036	3.5/.086	—
Dipole bend radius, [m]	608	~ 50	243	243	165
RMS beam size, $\sigma^*$ [ $\mu\text{m}$ ]	10	25	21/60	40/50	157
Bunch spacing, [ns]	211	6.7	35.5	35.5	<b>4.2</b>
<b>IONS</b>					
Ion energy, [GeV/u]	1,000	50	100/250	250/100	—
Ion rms emittance, [ $\mu\text{m}$ ]	1.0	2.0	0.8/1.0	0.8/1.0	—
Ion average current, [A]	.071	2.4	.14/.68	.42/.42	—
Ion IP beta, $\beta_e^*$ [m]	.10	.10	.15/.39	.53/.27	—
Ion b-b parameter, $\xi_i$	.0023	.004	.0046/.0015	.004/.004	—
<b>Laslett SC tune shift</b>	.0003	<b>.024</b>	.001/.003	.003/.003	—
<b>ELECTRONS</b>					
Electron energy, [GeV]	250	5	10	10	9
Electron emittance, [nm]	.2	6	3	18	49
<b>Electron beam current, [A]</b>	.000084	.264	.135/.135	.12/.37	1.5
<b>Electron beam power, [GW]</b>	<b>.023</b>	<b>1.32</b>	<b>1.35/1.35</b>	1.2/3.7	13.5
<b>Synch. rad. power, [MW]</b>	—	~ .29	<b>.49/.49</b>	<b>.43/1.3</b>	<b>7.2</b>
Electron IP beta, $\beta_e^*$ [m]	.50	.10	.15/1.2	.089/.139	.05/.50
<b>Electron b-b parameter, <math>\xi_e</math></b>	.23	.35	<b>.11/.57</b>	<b>.06/.06</b>	.055

# ULTIMATE PERFORMANCE

**Beam-beam parameters** (equal size round beams):

$$\xi_e = \frac{N_i}{\epsilon_e} \left( \frac{r_e Z}{4\pi \gamma_e} \right) \quad (1)$$

$$\xi_i = \frac{N_e}{\epsilon_i} \left( \frac{r_i (v/c)_i}{4\pi Z} \right) \quad (2)$$

**Emittance subscripts are correct!** For example, e-cooling reduces  $\epsilon_i$  and allows  $N_e$  to be reduced.

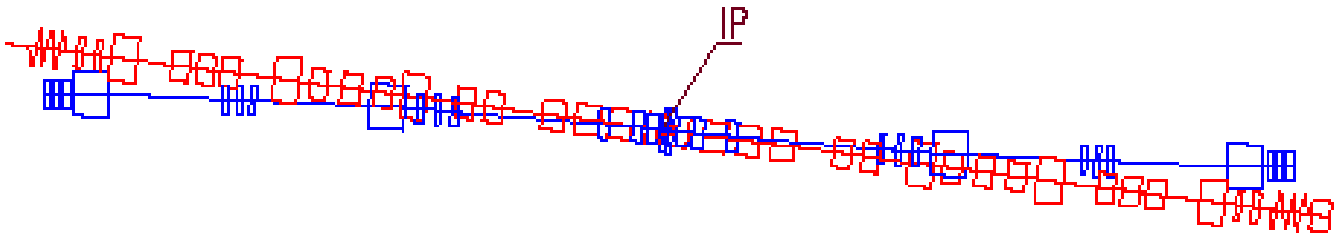
**Electron-ion luminosity** can be written

$$L = F_c \xi_e \xi_i \sigma_e'^* \sigma_i'^* \left( \frac{4\pi \gamma_e \gamma_i}{r_e r_i} \right) \quad (3)$$

- When beam-beam limits and angular apertures have been met,  $\xi_e \xi_i \sigma_e'^* \sigma_i'^*$  is fixed.
- Then the **only way to increase the luminosity is to increase the collision frequency  $F_c$**  (more bunches)
- Linac-ring collisions allow the usual  $\xi_e \approx 0.06$  limit to be violated.

# ION STORAGE RING ISSUES

**Long range beam-beam.** Early beam separation is easy with very unequal rigidities. EPIC:



**Electron cloud.** Ionized electrons are accelerated by the next ion bunches, possibly with runaway, threatening **cryogenic heat load, instabilities.**

- A paucity of data from **superconducting** rings (Tev, HERA, RHIC, LHC). More work required ...

**Intra-Beam Scattering, electron cooling.** RHIC expects the gold rms emittance to grow from  $2 \mu\text{m}$  to  $7 \mu\text{m}$  in 10 hours. With electron cooling it should shrink to about  $1 \mu\text{m}$  in 1 hour.

## Laslett space charge tune shift.

$$\Delta Q_{\text{sc}} \approx -\frac{N_i}{\epsilon_i} \frac{C}{\sigma_L \beta \gamma^2} \left( \frac{r_i}{2(2\pi)^{3/2}} \right) \quad (4)$$

Strong dependence on circumference  $C$ , RMS bunch length  $\sigma_L$ , and the Lorentz factor  $\beta\gamma^2$ .

- Make the bunch **longer at injection** (eRHIC: 28 MHz to inject, 197 MHz to collide).
- The bunch must be **shorter than  $\beta^*$**  in collision (hourglass effect).

# ELECTRON STORAGE RING ISSUES

**Synchrotron radiation.** The total synchrotron power is

$$P \text{ [MW]} = 0.0885 \frac{E^4 \text{ [GeV}^4\text{]}}{\rho \text{ [m]}} I \text{ [A]} \quad (5)$$

- The SLAC HER serves as a natural “ruler” to compare prospective electron rings. (See Table).

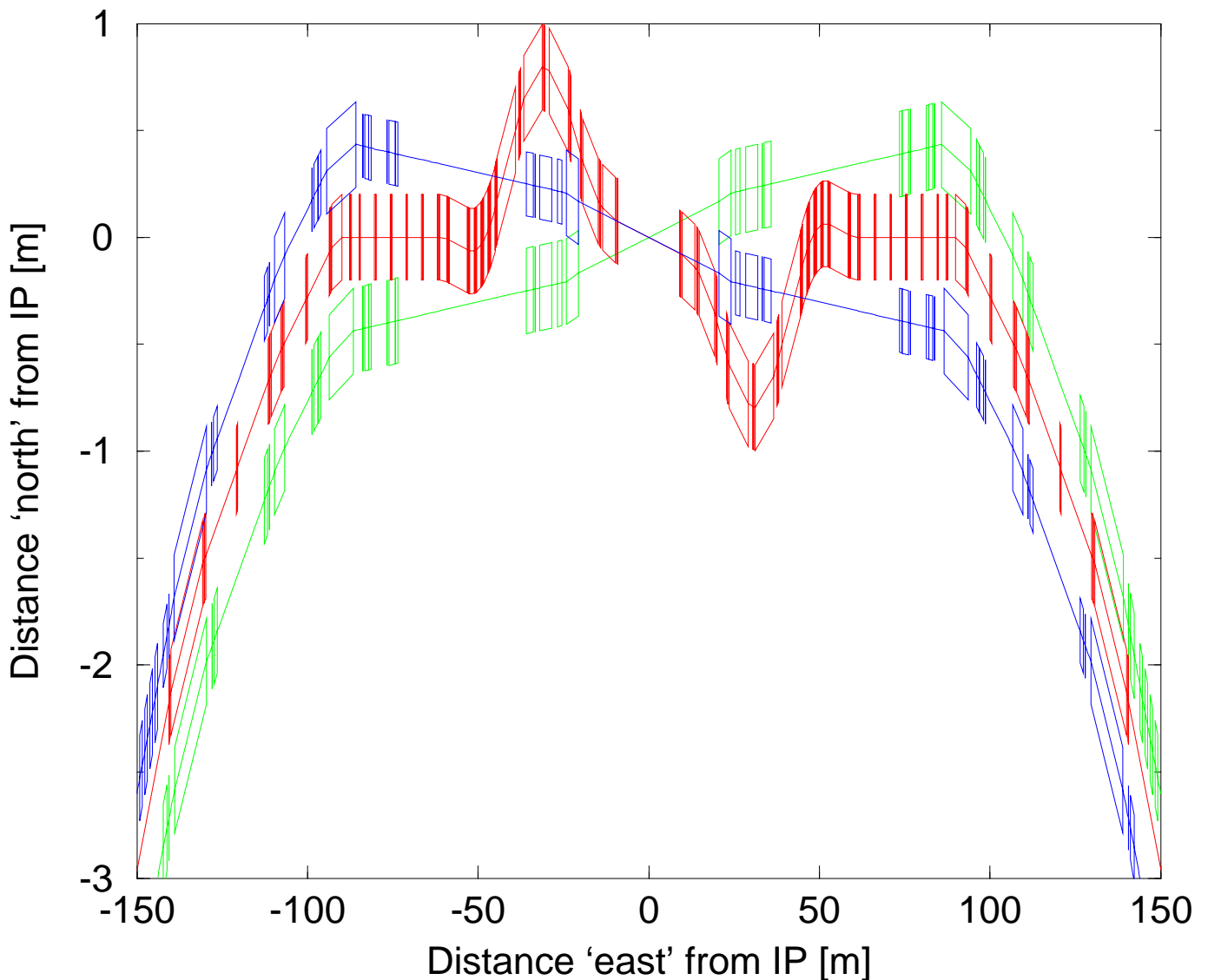
**Polarization.** The natural polarization time

$$T_{\text{pol}} \text{ [s]} = 15.8 \frac{C \rho^2 \text{ [m}^3\text{]}}{E_e^5 \text{ [GeV}^5\text{]}} \quad (6)$$

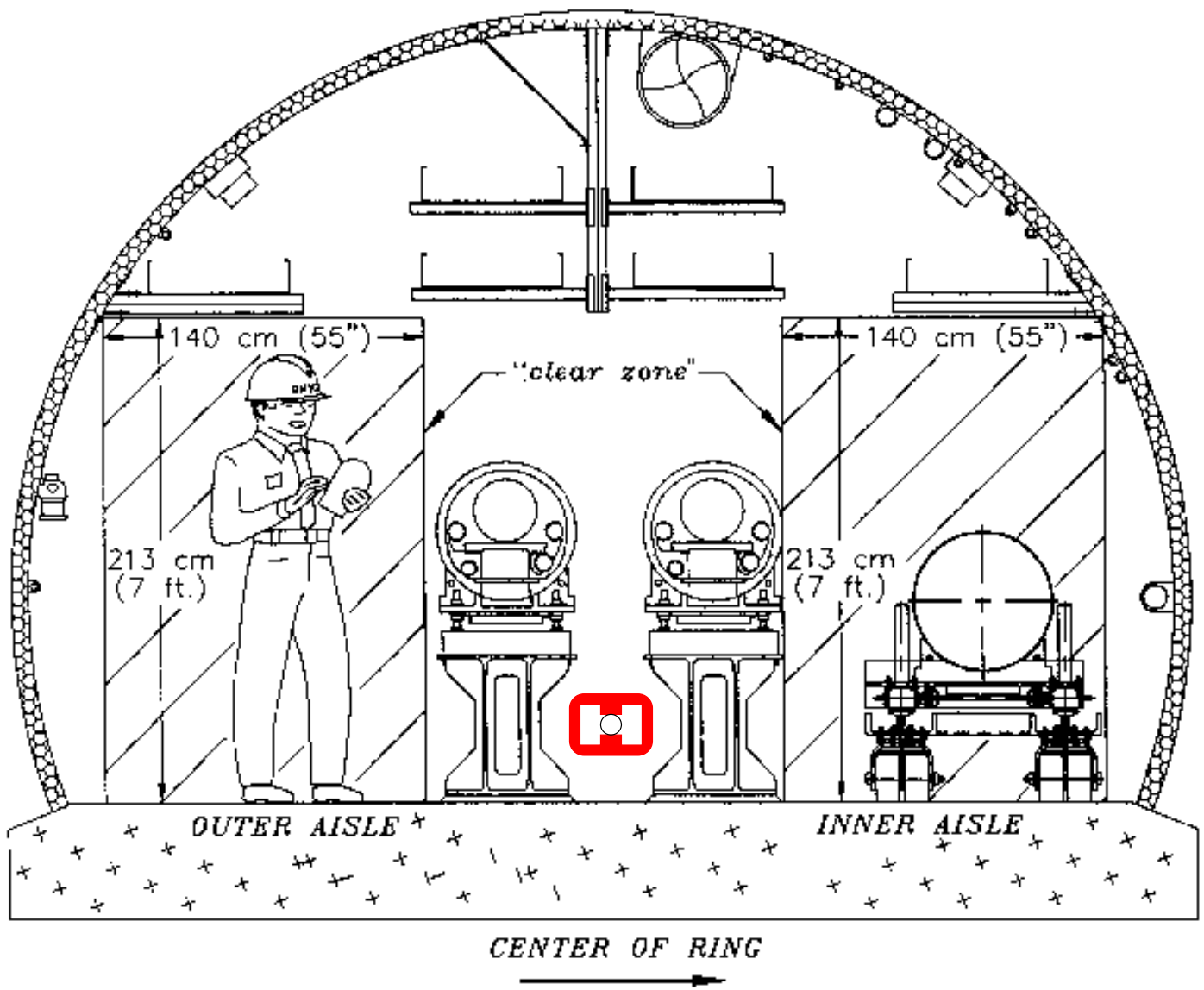
can be too long (9.9 hours in eRHIC) – may have to inject pre-polarized!

- Acceleration through intrinsic spin resonances probably impossible ( $E = J 0.441 \text{ [GeV]}$ ).
- Permanent magnets?

## Interaction Region optics – spin rotators.



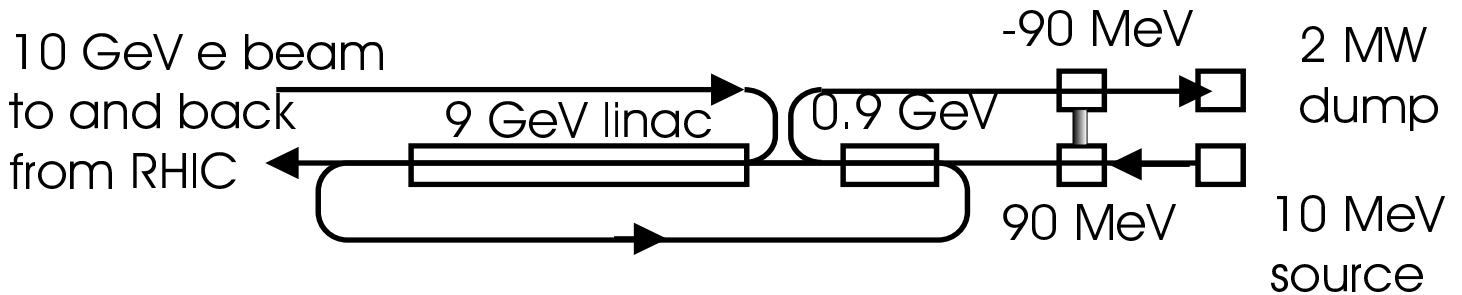
- Spin rotator dipoles tend to be stronger than arc dipoles – must keep linear synchrotron radiation load to less than 15 kW/m.
- The vertical displacement is useful ...



**eRHIC** tunnel cross section, with an electron magnet between the ion rings.

# ENERGY RECOVERY LINAC ISSUES

## A four stage Energy Recovery Linac



- Linac must be superconducting.
- Accelerating and decelerating beams must go in the same direction.
- Each stage has an energy range of about a factor of 10 – or much more? (Bazarov, RPPH053).

**Beam transport.** The electrons must circulate once with little synchrotron energy loss.

- Use a “full radius” recirculator, even with collisions at only one IP?

**Energy recuperation.** Electron beam power is  $\sim 1$  GW, so recuperation must be very efficient.

- JLAB IR-FEL (250 kW, 5 mA, 50 MeV) reports a beam loss upper limit of  $2\mu\text{A}$ , or  $\leq 4 \times 10^{-4}$

- Losses in a high power ERL at this upper limit could be unacceptable. Very little power can be lost at cryogenic temperatures.

- More work is required to understand both the origin of ERL beam losses, and their possible cures.

## Higher Order Mode power dissipation.

Collective instabilities can be driven by HOMs in the superconducting cavities.

- EPIC 2 predicts about 8 kW of HOM power dissipated per cavity, primarily in longitudinal modes, with **only a few Watts at cryogenic temperatures.**
- More studies & operating experience are required.

**Beam Break Up.** Collective BBU phenomena are longitudinal and transverse, single and multi-bunch, and single and multi-pass.

- Calculated EPIC 2 and eRHIC thresholds are somewhat below nominal currents. **Use feedback.**