eRHIC – future electron-ion collider at BNL

(includes conclusions from EIC'04 workshop)

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V.Ptitsyn, T.Zwart

Seminar organization

- Part 1 (Tuesday):
  - Vadim: General parameters, luminosities (ELIC versus eRHIC) and required ion upgrades.
  - Townsend: Electron accelerator for Ring-Ring design.
- Part 2 (Wednesday):
  - Christoph: Interaction Region design
  - Vladimir: Linac-Ring design option.

eRHIC

Zeroth-Order Design Report

BNL: L. Ahrens, D. Anderson, M. Bai, J. Beebe-Wang, I. Ben-Zvi, M. Blaskiewicz, J.M. Brennan, R. Calaga, X. Chang, E.D. Courant, A. Deshpande, A. Fedotov, W. Fischer, H. Hahn, J. Kewisch, V. Litvinenko, W.W. MacKay, C. Montag, S. Ozaki, B. Parker, S. Peggs, T. Roser, A. Ruggiero, B. Surrow, S. Tepikian, D. Trbojevic, V. Yakimenko, S.Y. Zhang
MIT-Bates: W. Franklin, W. Graves, R. Milner, C. Tschalaer, J. van der Laan, D. Wang, F. Wang, A. Zolfaghari and T. Zwart
BINP: A.V. Otboev, Yu.M. Shatunov
DESY: D.P. Barber

Editors: M. Farkhondeh (MIT-Bates) and V. Ptitsyn (BNL)

- Detailed document (265 pages) reporting studies on the accelerator and the interaction region of this future collider.
- The work performed jointly by BNL and MIT-Bates, with close collaboration with scientists from BINP (Novosibirsk) and DESY (Hamburg).
- Goals:
  - to develop an initial design for eRHIC
  - to investigate most important accelerator physics issues
  - to evaluate the luminosities that could be achieved in such a collider

The report web links:

1) www.agsrhichome.bnl.gov/AP/ap_notes/ap_note_142.pdf
2) www.agsrhichome.bnl.gov/eRHIC/eRHIC_ZDR.htm

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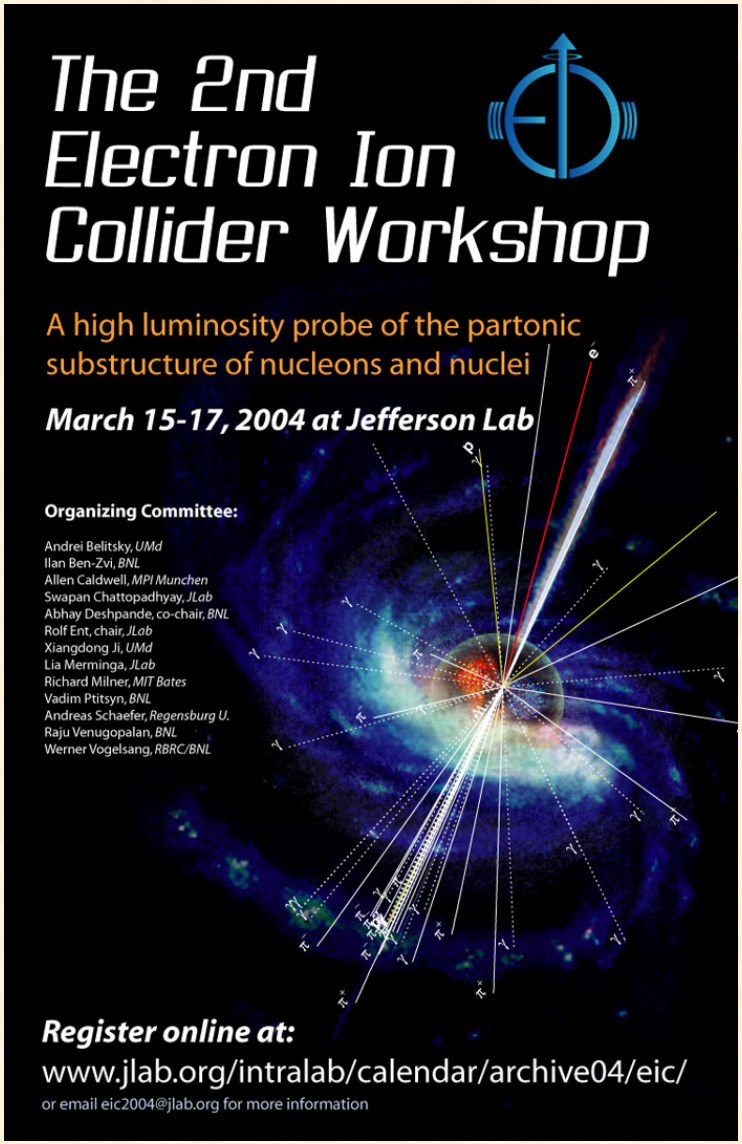


From workshop summary talk (R.Milner):

- Science case for EIC becomes more compelling
- Mainline machine design reaches luminosity ~ 10^{33} nucleons cm^{-2} s^{-1}

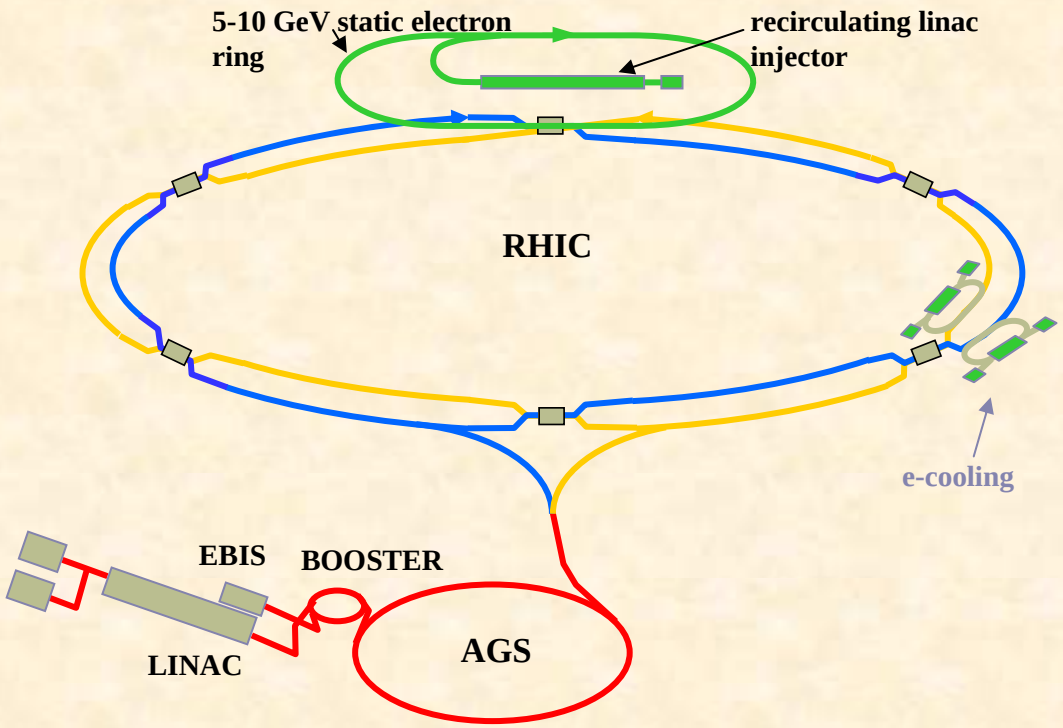
ring-ring eRHIC design

- Realistic (but aggressive) design based on RHIC and B factory performance
- High luminosity requires electron cooling
- It is reasonable to consider scenarios where EIC gets underway without electron cooling and the path to full luminosity is staged in time
- Cost framework understood ~ 300 - 500 M$
- Other concepts (eRHIC linac-ring, ELIC) should be vigorously pursued to determine realistic designs
- Essential over next year to prepare for aggressive engagement in the upcoming Long Range Planning Exercise (LRP 2005)

eRHIC scope

- Experiments with electron-proton and electron-ion collisions.
- Should be able to provide the beams in following energy ranges:
  - 5-10 GeV polarized electrons;
    10 GeV polarized positrons
  - 50-250 GeV polarized protons;
    100 GeV/u gold ions
- Other ion species, especially polarized ^{3}He ions are under consideration.
- Luminosities:
  - in 10^{32} - 10^{33} $cm^{-2}s^{-1}$ region for e-p
  - in 10^{30} - 10^{31} $cm^{-2}s^{-1}$ region for e-Au collisions
- 70% polarization degree for both lepton and proton beams
  - Longitudinal polarization in the collision point for both lepton and proton beams

Main design option



- The electron ring of 1/3 of the RHIC ion ring circumference
- Full energy injection using polarized electron source and 10 GeV energy linac.
- e-ion collisions in one interaction point.
  Ion-ion collisions in two other IPs at the same time.
- Longitudinal polarization produced by local spin rotators in interaction regions.

Luminosity considerations

- Luminosity limitation comes from beam-beam effects and from interaction region magnet aperture:

$$L = f_c \frac{\pi \gamma_i \gamma_e}{r_i r_e} \xi_{xi} \xi_{ye} \sigma'_{xi} \sigma'_{ye} \frac{(1+K)^2}{K}$$

- Beam-beam limits (from world experience, RHIC operation experience and initial beam-beam simulation results):

  $\xi_e < 0.08$, $\xi_i < 0.02$ (total from all collision points)

- From interaction region design :

  $\sigma_i' \leq 95$ μrad and $K=1/2$ (σ_y/σ_x beam size ratio; elliptical beams)

- Matched electron and ion beam sizes at the IP

- $f_c = 28.15\ MHz$: 360 bunches in the ion ring, 120 bunches in the electron ring

Collision parameters for e-p collisions

	High energy setup		Low energy setup	
	p	e	p	e
Energy, Gev	250	10	50	5
Bunch intensity, 10^{11}	1	1	1	1
Ion normalized emittance, π mm.mrad, x/y	15/15		5/5	
rms emittance, nm, x/y	9.5/9.5	53/9.5	16.1/16.1	85/38
beta*, cm, x/y	108/27	19/27	186/46	35/20
beam-beam parameters, x/y	0.0065/0.00325	0.029/0.08	0.019/0.0095	0.036/0.04
$\kappa=\varepsilon_y/\varepsilon_x$	1	0.18	1	0.45
Luminosity, 1e32, $cm^{-2}s^{-1}$	4.4		1.5	

No cooling
2 p-p IPs assumed

Cooling needed
No p-p IPs allowed

Basic beam parameters for e-Au collisions

	High energy setup		Low energy setup	
	Au	e	Au	e
Energy, Gev/u	100	10	100	5
Bunch intensity, 10^{11}	0.01	1	0.0045	1
Ion normalized emittance, π mm, x/y	6/6		6/6	
rms emittance, nm, x/y	9.5/9.5	54/7.5	9.5/9.5	54/13.5
beta*, cm, x/y	108/27	19/34	108/27	19/19
beam-beam parameters, x/y	0.0065/0.00325	0.0224/0.08	0.0065/0.00325	0.02/0.04
$\kappa=\varepsilon_y/\varepsilon_x$	1	0.14	1	0.25
Luminosity, 1e30, $cm^{-2}s^{-1}$	4.4		2.0	

Electron cooling of Au beam is required to achieve and maintain Au emittance values

Required ion ring upgrades

Ion ring upgrades considered in the report:

1) Electron cooling, to provide and maintain the required beam emittances
2) Total ion current intensity increase, by increasing the number of bunches from 120 (present RHIC design) to (ultimately) 360.
3) Additional spin rotators in e-p interaction region.

360 bunches (35ns bunch spacing) issues:

- Injection scheme upgrade (ZDR: W. Fischer, M. Blaskiewicz, J.M. Brennan, H. Hahn)

  Very fast injection kicker (~20 ns risetime) or Long flattop injection kicker or Barrier RF Stacking
- Abort system upgrade (ZDR: L.Ahrens)
- Cryogenic power load (due to beam pipe heating) (ZDR: V.Ptitsyn)

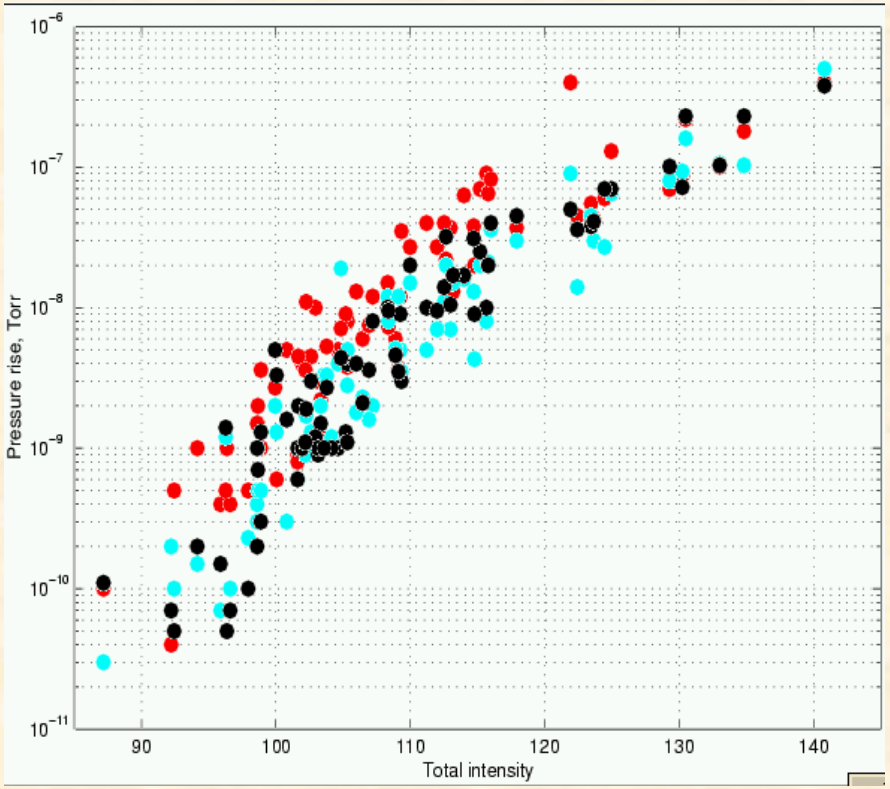
  Heating due to resistive wall is OK for eRHIC parameters.

  Heating contribution from electron cloud needs careful evaluation.

Pressure rise and electron cloud

(ZDR:S.Y.Zhang)

Pressure rise in warm sections is presently limiting factor for the beam current in the RHIC.
Observed at injection, transition, rebucketing.
Leads to vacuum interlocks, high detector backgrounds.



Transition pressure rise in 3 interaction regions with Au ions.
Total ion intensity is at 10^9 units.

- Extensive experimental and analytical study program is underway to understand and overcome the limitation.
- Possible remedies considered:
  - NEG coating;
  - vacuum chamber baking;
  - using solenoids against EC;
  - beam scrubbing;
- Going to 360 bunches may opens a door to additional harmful effects caused by electron cloud: instabilities, emittance growth and heat load.
- Bunch separation is close to that in LHC (25ns) as well as bunch intensities. So, the electron cloud problems should be similar.

Ion ring upgrades.
Electron cooling.

(ZDR: A.Fedotov, I. Ben-Zvi, J. Kewisch, V. Litvinenko)

For Au: to reach and maintain (against IBS) 6π mm·mrad emittance.

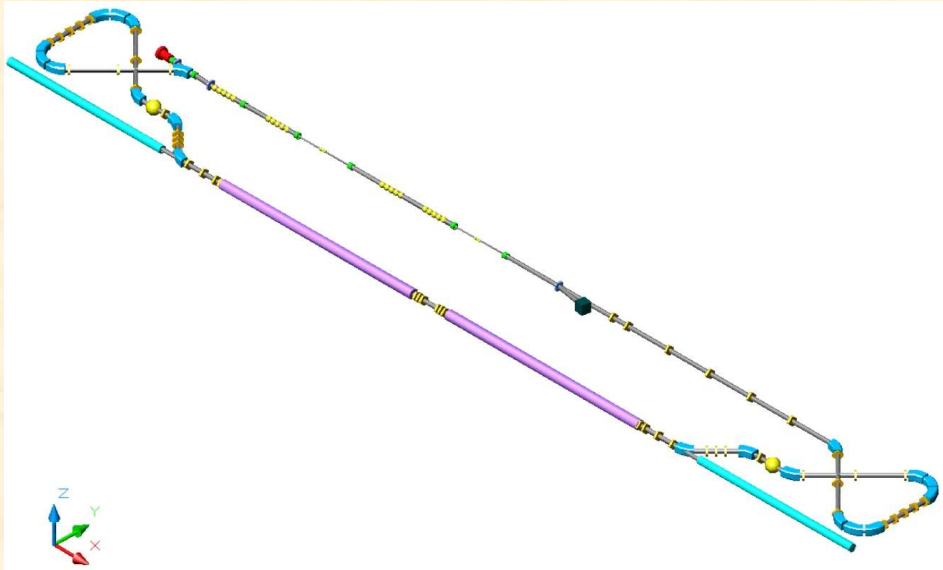
For protons: to reach less than 15π mm·mrad emittance at energies below 150 GeV

Longitudinal cooling to reach and maintain shorter rms bunch length (<20cm).

Electron cooling system design is under intensive studies and development. Important part of RHIC-II project for RHIC luminosity upgrade.

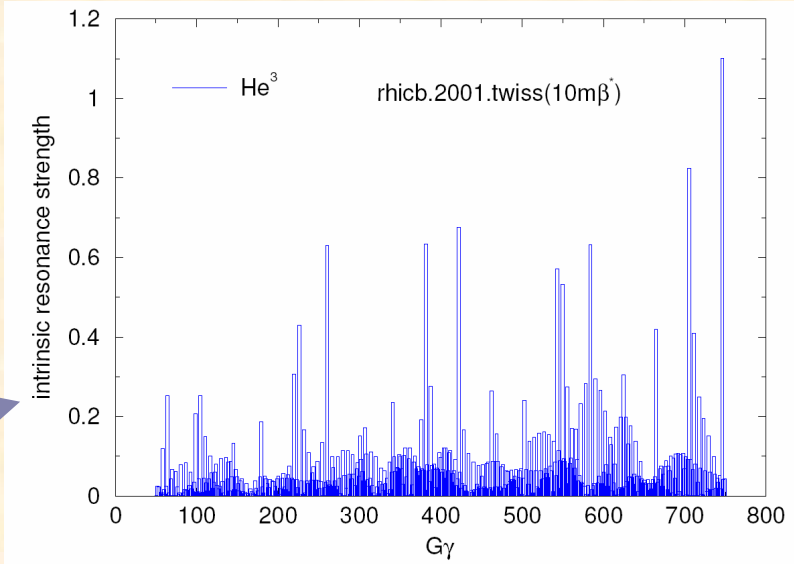
Some of cut-edge features:
100mA of 50MeV electron beam
High precision field solenoids
Using energy recovery technology

Electron cooler system for RHIC

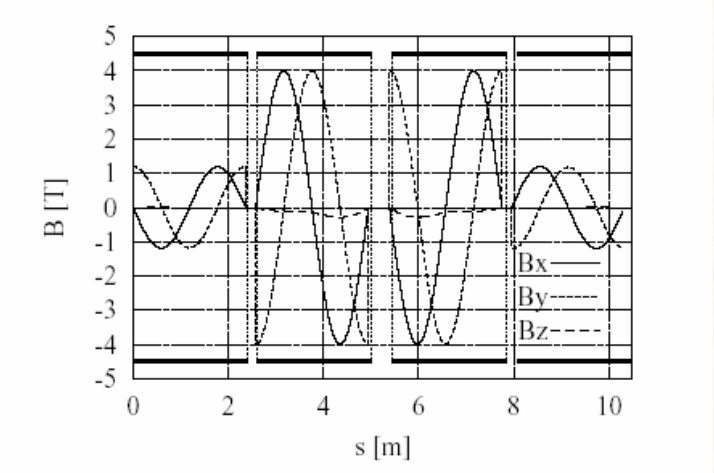


Polarization issues

- (ZDR: W.MacKay, M.Bai)
- 100 Gev polarized proton beam has been used at RHIC for experiments. Preservation of polarization to 250Gev still needs to be tested.
- He^3 polarized beam acceleration:
  - lower field in snakes and rotators (good)
  - higher resonance strength (bad)



Helical spin rotators, like being used already at two RHIC experiments, should be added at eRHIC IR.



R&D eRHIC items for ion beam:

- 360 bunch injection system development:
  - ✓ Very fast injector kicker in ion ring (~15ns rise time)
  - ✓ Barrier RF stacking in ion ring.
  - ✓ Long flattop injection kicker in ion ring.

- Understanding and overcoming pressure rise limitation for ion beam current.
- Electron cloud related effects associated with increased number of bunches.
- Polarized He3 source.
- Polarized He3 acceleration through Booster-AGS-RHIC.
- Beam-beam effects:
  - ✓ Proton beam-beam limit with combined p-p and e-p collisions.
  - ✓ Coherent e-p beam-beam with different circumference ratio.
- Electron cooling.
- Development of ion ring high beam current abort system.

General plans

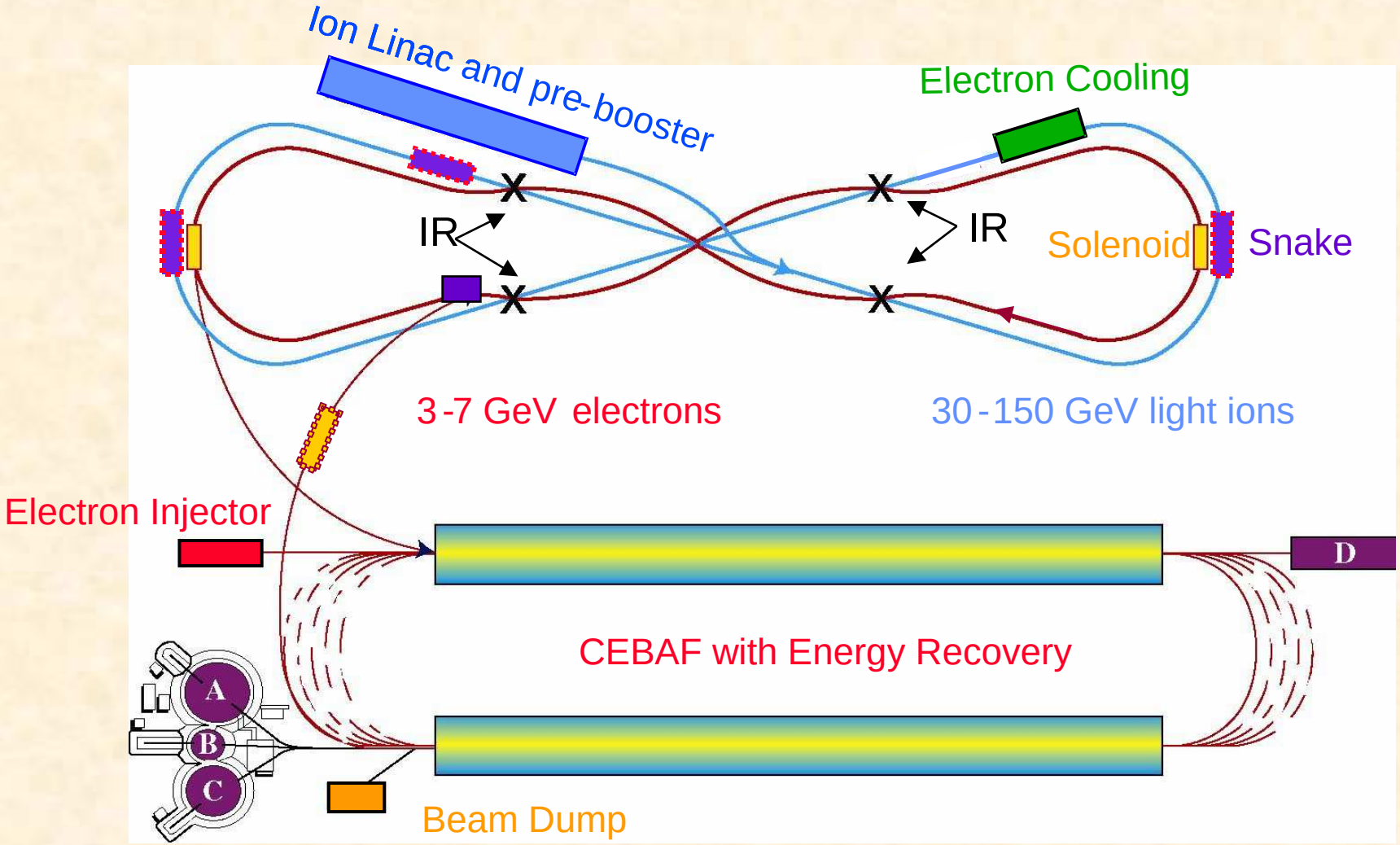
- ZDR Executive Summary declares that work on both options for eRHIC (ring-ring and linac-ring) will continue in the foreseeable future, until the final construction timescale demands freezing the design, and the technology.

- Both options will profit (in sense of achievable luminosity) from dedicated e-p operation (without parallel p-p collisions in other IPs), with possible luminosity gain by factor 2-3. The preliminary considerations of this mode is done in the ZDR (like a possibility of electron beam current increase in main design line). This will be an important subject for future studies.

- Concentrate on R&D items
- Preparations for NSAC Long Range Plan 2005

ELIC Design (presented by Lia Merminga at EIC'04)

Ya. Derbenev, K. Beard, S. Chattopadhyay, J. Delayen, J. Grames, A. Hutton, G. Krafft, R. Li, L. Merminga, M. Poelker, E. Pozdeyev, B. Yunn, Y. Zhang Center for Advanced Studies of Accelerators Jefferson Lab



ELIC Layout

	eRHIC Ring-Ring	eRHIC Linac-Ring	ELIC
Luminosity (e-p)	4.4…1.5E32	1E33…1E34	1E33…1E35
Ions	…U^{92+}	…U^{92+}	…$^{6}Li^{+++}$
E_p (GeV)	50…250	50…250	30…150
$I_{electron}$ (A)/ppb	0.45/1E11	0.1…1E11	2.3…4.1/1E10
ppb (proton)	1E11	1…2E11	4E9
f_{coll} (MHz)	28	28	1500
l_b (p/ion)(cm)	20	20	0.5
lb (e–) (cm)	1…2	1	0.5
ξ_p	.0065	.005	.01
ξ_e	.08	–	.09
$ß^*_{p/e}$ (m)	.27/.27 (y)	.26/0.3…1	0.005

Parameters (ELIC) have been pushed into new territory…: ß, l_b, ring shape, crab crossing

U. Wienands, 2nd EIC Wkshp, Jlab Accel. Design Summary, 15-Mar-04

R&D Topics for ELIC

- High charge per bunch and high average current polarized electron source
- High energy electron cooling of protons/ions
  - Electron cooling of 150 GeV protons requires 75 MeV electrons. Practical only if based on SRF-ERL technology, demonstrated and routinely used at the JLab FEL
- Integration of interaction region design with detector geometry
- High current and high energy demonstration of energy recovery