eRHIC Conceptual Design

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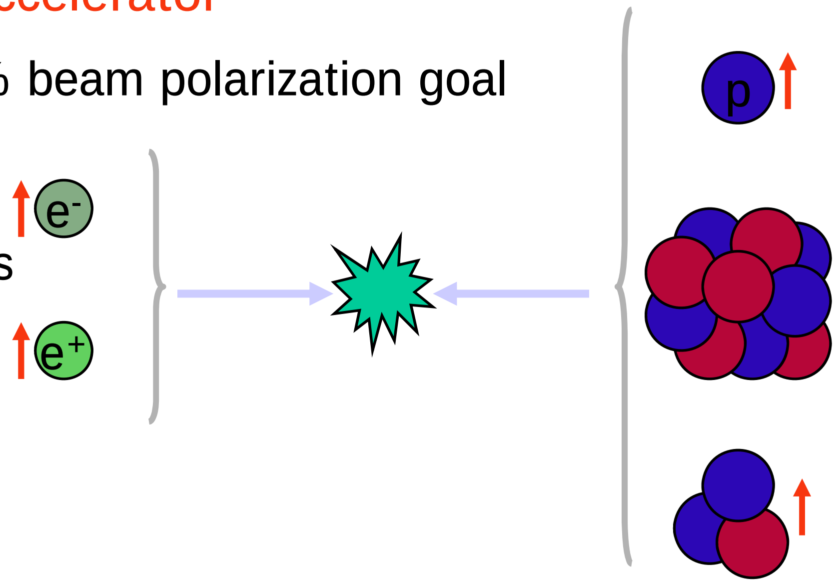
eRHIC Scope

Electron accelerator

70% beam polarization goal

Polarized leptons
3-10 Gev
(20GeV)



RHIC

Polarized protons
50-250 Gev
(25 GeV)

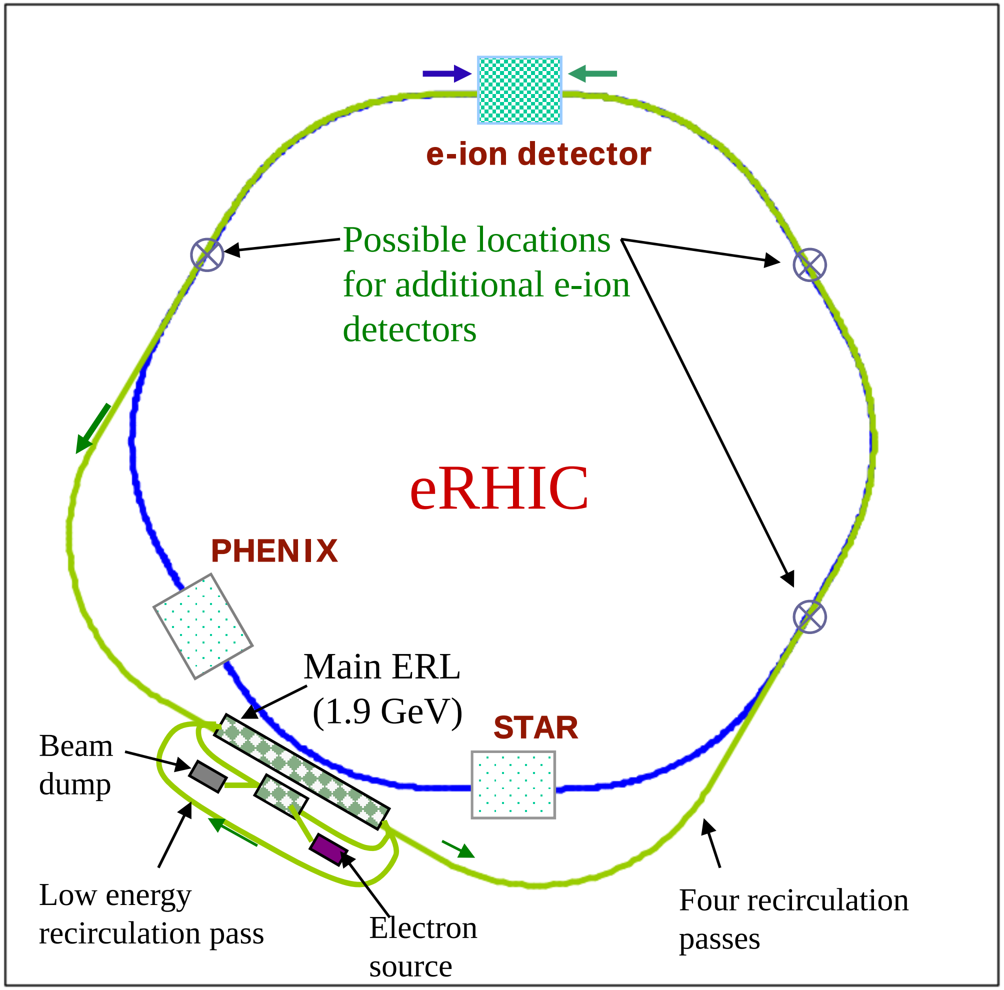
Heavy ions
(Au)
50-100 Gev/u

Polarized light ions (^{3}He)
167 Gev/u

Exploration of QCD in great details:

Different Center-of-Mass Energy -> Different kinematic regions
Higher Luminosity -> Precision data
Polarized beams -> Spin structure of nucleons (still a puzzle!)
Ions up to large A -> Color Glass Condensate (state of extreme gluon densities)

ERL-based eRHIC Design



- 10 GeV electron design energy.
  Possible upgrade to 20 GeV by
  doubling main linac length.
- 5 recirculation passes (4 of them in the RHIC tunnel)
- Multiple electron-hadron interaction points (IPs) and detectors;
- Full polarization transparency at all energies for the electron beam;
- Ability to take full advantage of transverse cooling of the hadron beams;
- Possible options to include polarized positrons: compact storage ring; compton backscattered; undulator-based. Though at lower luminosity.

Other design options

Under consideration also:

- *ERL-based design for smaller energy.*

  Electron energy up to 2-3 GeV. Acceleration done by a linac placed in the RHIC tunnel. It can serve as first stage for following higher electron energy machine.

- *High energy (up to 20-30 GeV) ERL-based design with all accelerating linacs and recirculation passes placed in the RHIC tunnel.*

  Can be elegant and cost saving design solution.

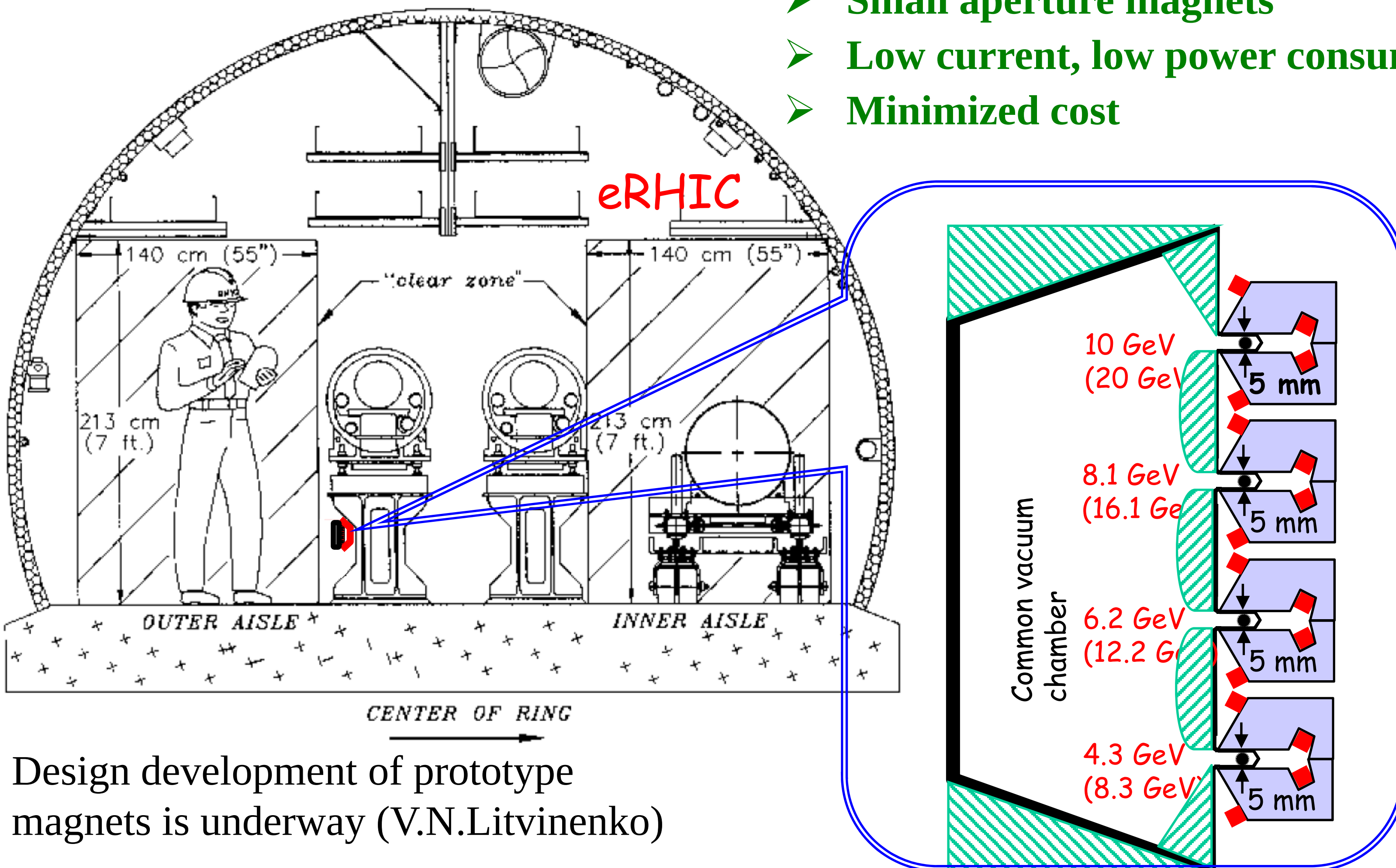
  - Variation of this design option uses FFAG design of recirculating passses.

- *Ring-ring design option.*

  Backup design solution which uses electron storage ring.
  See eRHIC ZDR for more details.
  The average luminosity is at 10^{32} $cm^{-2}s^{-1}$ level limited by beam-beam effects.

Recirculation passes

- Separate recirculation loops
- Small aperture magnets
- Low current, low power consumption
- Minimized cost



Design development of prototype magnets is underway (V.N.Litvinenko)

ERL-based eRHIC Parameters: e-p mode

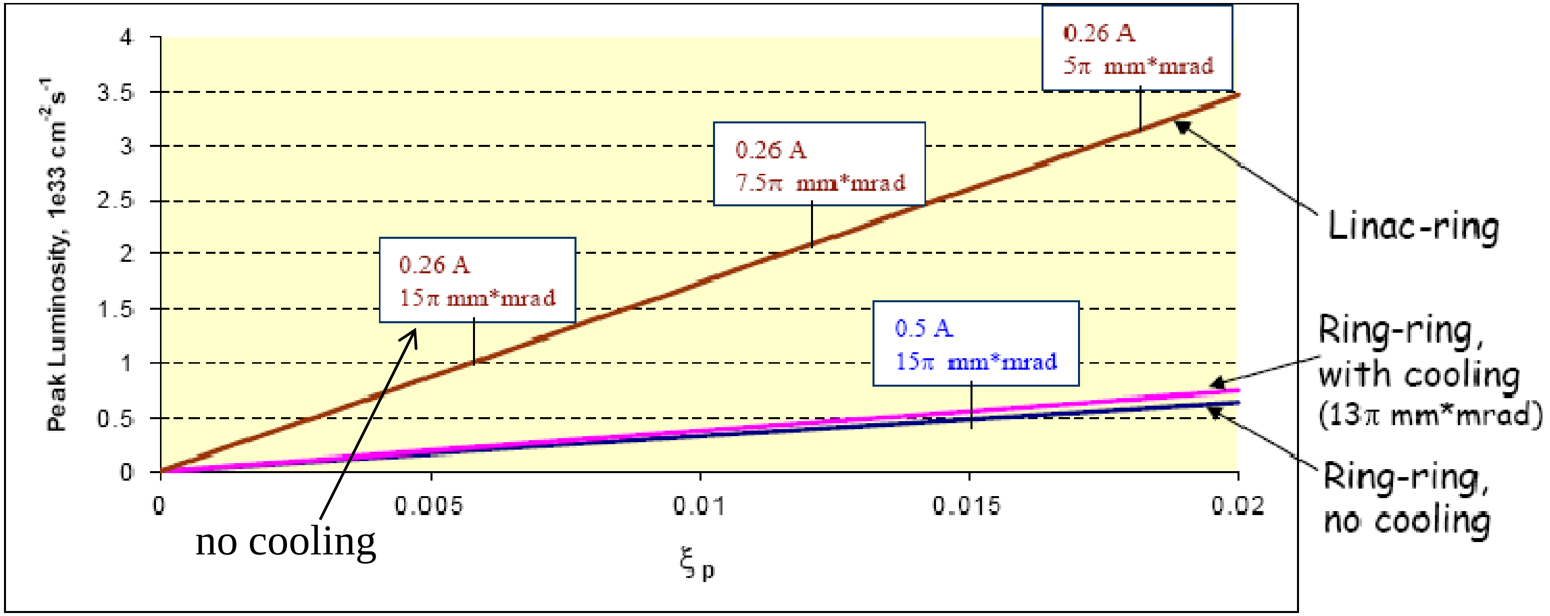
	High energy setup		Low energy setup	
	p	e	p	e
Energy, GeV	250	10	50	3
Number of bunches	166		166	
Bunch spacing, ns	71	71	71	71
Bunch intensity, 10^{11}	2	1.2	2	1.2
Beam current, mA	420	260	420	260
Normalized 95% emittance, π mm.mrad	6	460	6	570
Rms emittance, nm	3.8	4	19	16.5
β*, x/y, cm	26	25	26	30
Beam-beam parameters, x/y	0.015	0.59	0.015	0.47
Rms bunch length, cm	20	1	20	1
Polarization, %	70	80	70	80
Peak Luminosity, 1.e33 $cm^{-2}s^{-1}$	2.6		0.53	
Aver.Luminosity, 1.e33 $cm^{-2}s^{-1}$	0.87		0.18	
Luminosity integral /week, pb^{-1}	530		105	

Main R&D Items

- Electron beam R&D for ERL-based design:
  - High intensity polarized electron source
    - Development of large cathode guns with existing current densities ~ 50 mA/cm^2 with good cathode lifetime.
  - Energy recovery technology for high power beams
    - multicavity cryomodule development; high power beam ERL, BNL ERL test facility; loss protection; instabilites.
  - Development of compact recirculation loop magnets
    - Design, build and test a prototype of a small gap magnet and its vacuum chamber.
  - Beam-beam effects: e-beam disruption
- Main R&D items for ion beam:
  - Beam-beam effects: electron pinch effect; the kink instability …
  - Polarized ^{3}He acceleration
  - 166 bunches
- General EIC R&D item:
  - Proof of principle of the coherent electron cooling

Luminosity and cooling

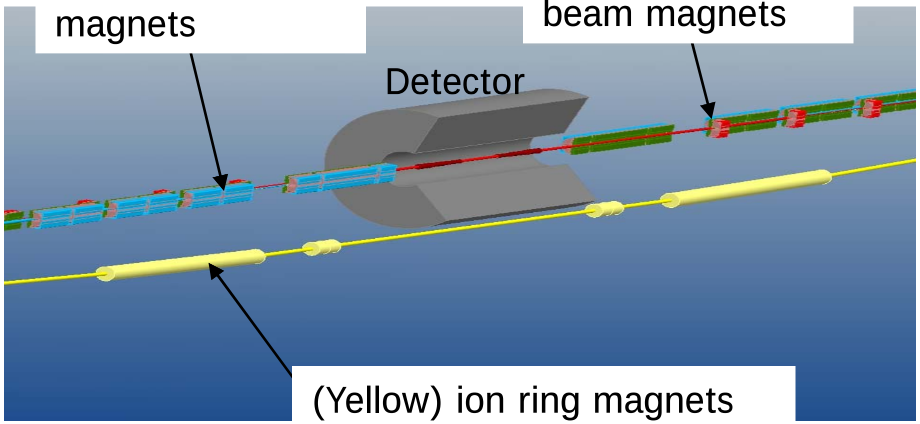
Calculations for 166 bunch mode and 250 Gev(p) x 10 Gev(e) setup;

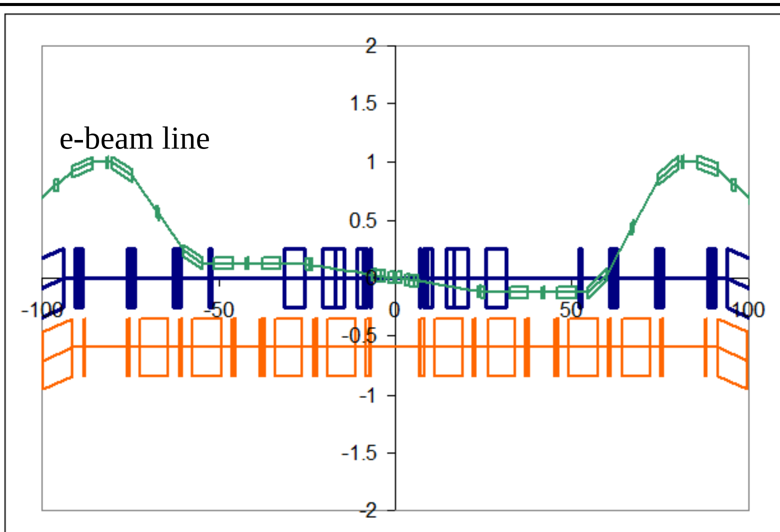


Pre-cooling of the protons at the injection energy (22 GeV) is required to achieve proton beam-beam limit (ξ_p=0.015) and maximize the luminosity. It can be done by the electron cooling (in ~1h).

To reduce the electron current requirements it would be great to have the effective transverse cooling at the storage energy (250 GeV) which can effectively counteract IBS and maintain the emittance well below 6π mm*mrad.
Recent revival of the Coherent Electron Cooling idea (V.N.Litvinenko, Ya.S.Derbenev) brings the possibility of the effective longitudinal and transverse cooling for high energy protons.
Proof of principle test of CEC has been suggested at RHIC.

Interaction Region Design





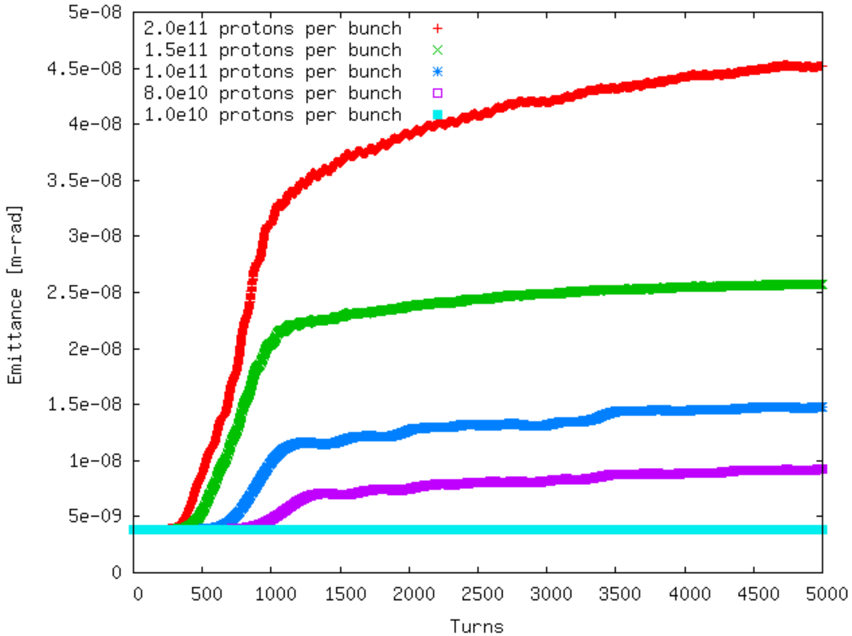
Present IR design features:

- No crossing angle at the IP
- Detector integrated dipole: dipole field superimposed on detector solenoid.
- No parasitic collisions.
- Round beam collision geometry with matched sizes of electron and ion beams.
- Synchrotron radiation emitted by electrons does not hit surfaces in the detector region.
- Blue ion ring and electron ring magnets are warm.
- First quadrupoles (electron beam) are at 3m from the IP
- Yellow ion ring makes 3m vertical excursion.

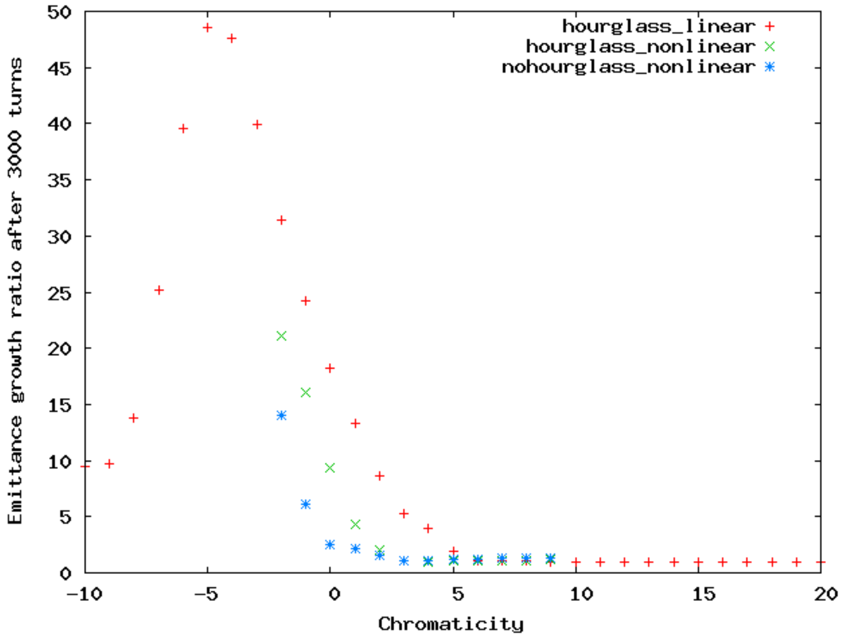
HERA type half quadrupole used for proton beam focusing

Kink instabiity

Simulations done by Y.Hao



Proton emittance growth caused by transverse instability. The head of the proton bunch affects the tail through the interactions with the electron beam. Includes synchrotron oscillations. Without tune spread (zero chromaticity) the instability threshold is at 1.6e10 proton per bunch.



The tune spread stabilizes the instability. Required chromaticity: >3 units. Nonlinearity character of the beam-beam Interactions also helps.

Increase of number of bunches

Presently RHIC operates with maximum 111 bunches.

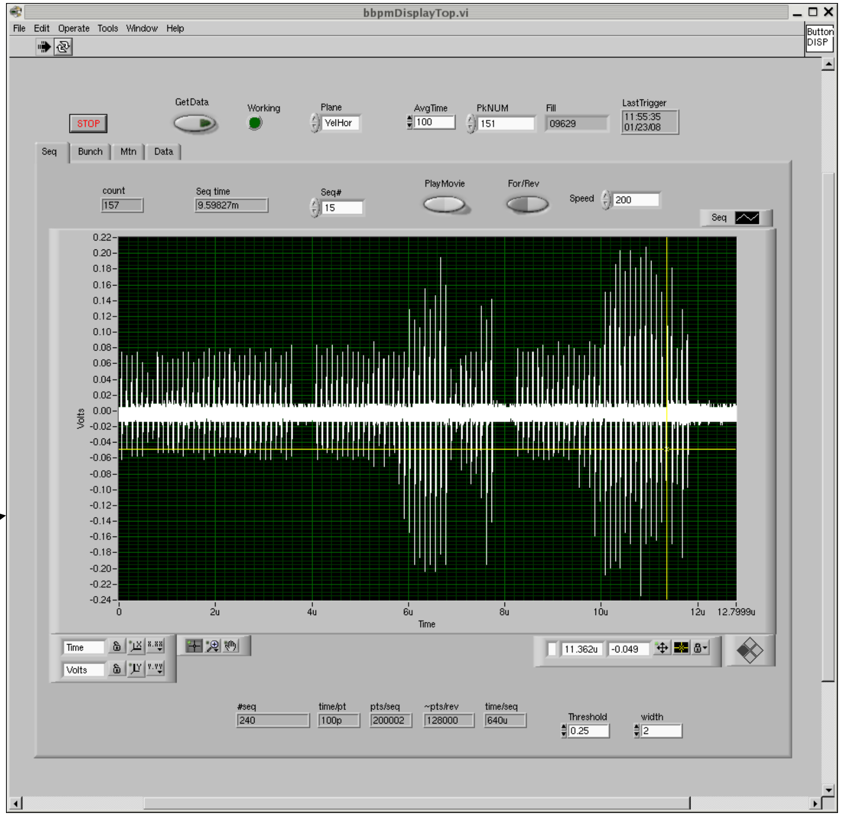
That should be increased to 166 bunches for eRHIC.

Corresponding reduction of the distance between bunches from 106 ns to 71 ns.

Issues to be resolved:

- Injection system upgrade for shorter kicker rise time.
- High intensity problems with larger number of bunches: instabilities, electron cloud, vacuum pressure rise.

For instance, the transverse instability at the transition presently limits the beam intensity of ion beams.



Conclusions

- The accelerator design work continues on various aspects of the ERL-based design of eRHIC, which presently aims to provide e-p average luminosity at least at 10^{33} cm^{-2}s^{-1} level.

- Major R&D subjects, such as polarized source development, ERL test facility and compact magnet design, are supported by financing. Thus, one can expect advances on those directions in coming 2 years.

- Effective cooling of high energy protons can reduce requirements on electron beam intensity and simplify the design of the electron accelerator.

- Modifications of existing RHIC machine include new interaction region(s) and higher number of proton bunches.