Machine R&D for eRHIC

V. Ptitsyn

on behalf of eRHIC Design team:

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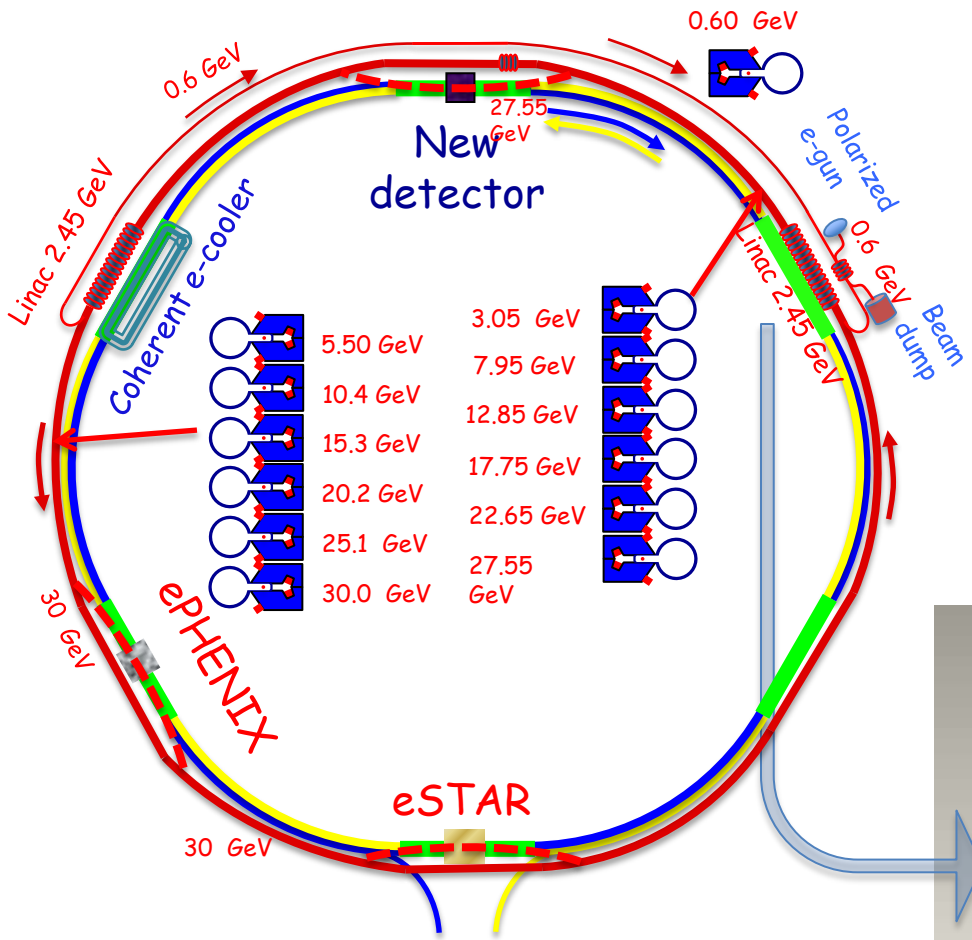
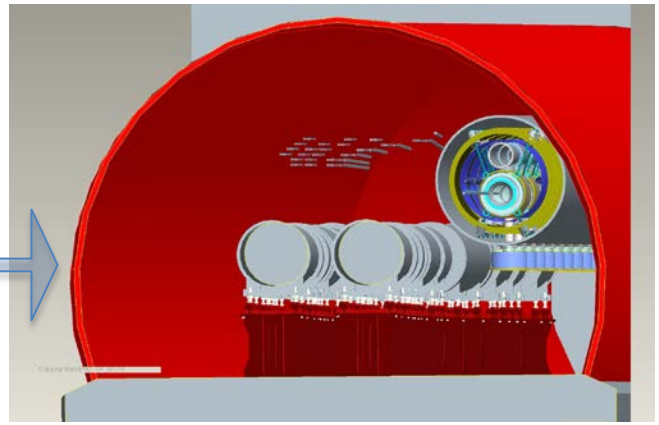
ERL-based eRHIC is multiple IP collider



✓All-in tunnel staging approach uses two energy recovery linacs and 6 recirculation passes to accelerate the electron beam.

✓Staging: the electron energy will be increased in stages, from 10 to 30 GeV, by increasing the linac lengths .

✓Up to 3 experimental locations

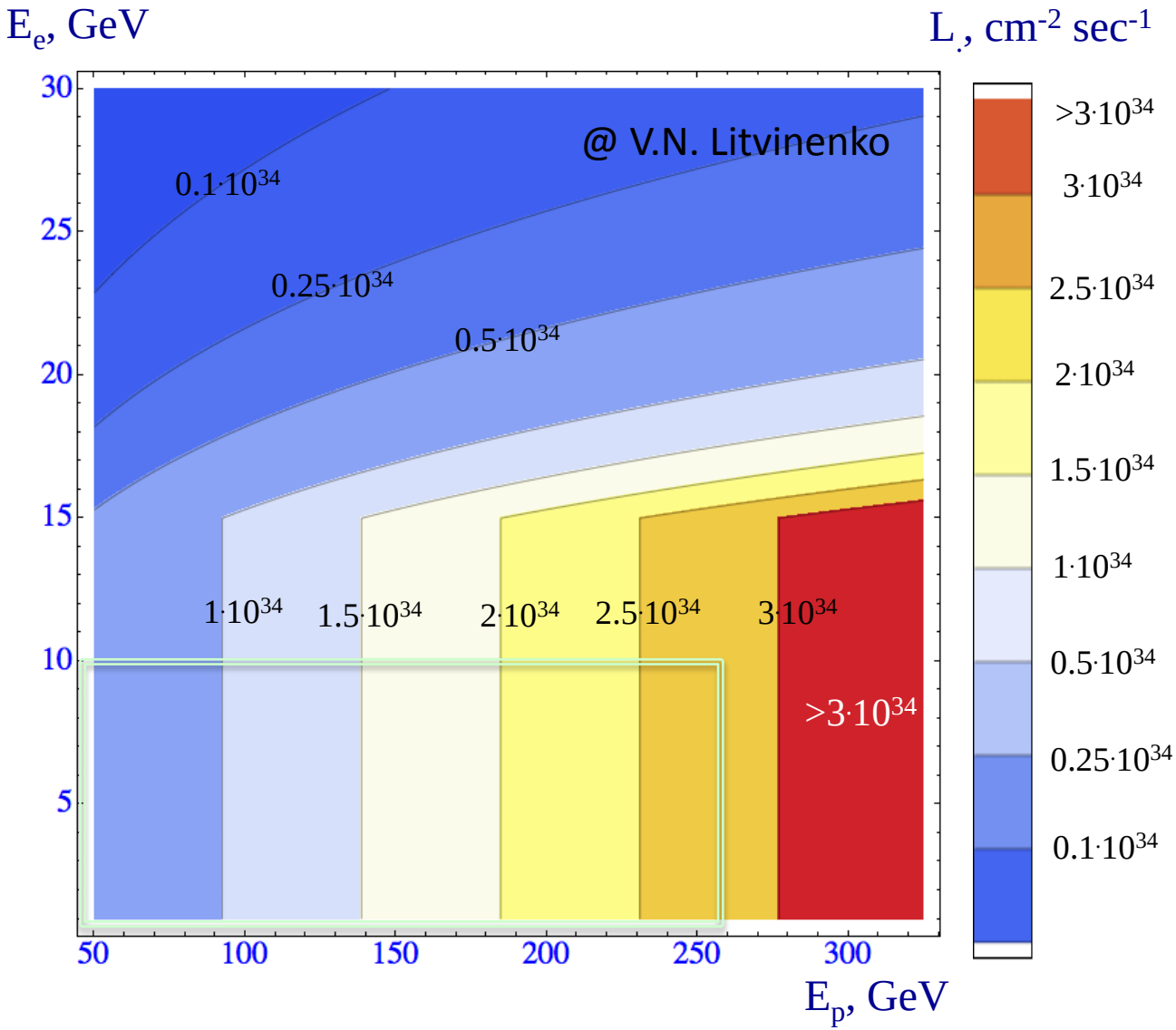


eRHIC, Phase I Luminosity

	e	p	$^{2}He^{3}$	$^{79}Au^{197}$	$^{92}U^{238}$
Energy, GeV	10	250	167	100	100
CM energy, GeV		100	82	63	63
Number of bunches/distance between bunches	107 nsec	111	111	111	111
Bunch intensity (nucleons) ,10^{11}	0.36	4	6	6	6
Bunch charge, nC	5.8	64	60	39	40
Beam current, mA	50	556	556	335	338
Normalized emittance of hadrons , 95% , mm mrad		1.2	1.2	1.2	1.2
Normalized emittance of electrons, rms, mm mrad		16	24	40	40
Polarization, %	80	70	70	none	none
rms bunch length, cm	0.2	5	5	5	5
β^*, cm	5	5	5	5	5
Luminosity per nucleon, $\times 10^{34}$ $cm^{-2}s^{-1}$		2.7	2.7	1.6	1.7

Hourglass the pinch effects are included. Space charge effects are compensated.
Energy of electrons can be selected at any desirable value at or below 10 GeV
The luminosity does not depend on the electron beam energy.
The luminosity is proportional to the hadron beam energy: $L \sim E_h/E_{top}$

Luminosity: current eRHIC design

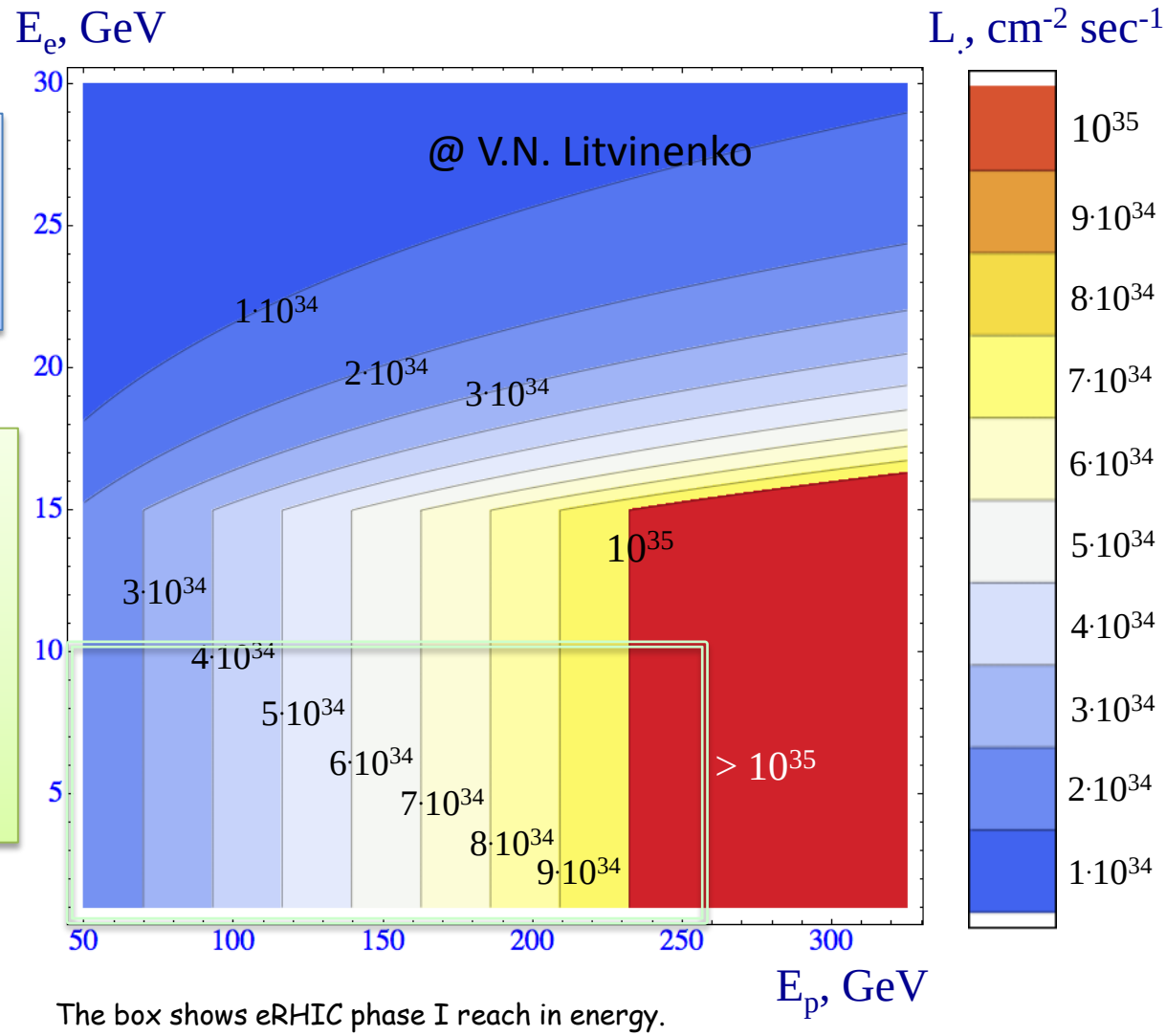


This luminosity accommodates eSTAR and ePHENIX electronics using 107 nsec between the collisions. The box shows phase I reach. The luminosity is proportional to hadron energy. For electron energies above 20 GeV, the luminosity falls a Ee^{-4}.

Ultimate luminosity reach in eRHIC

This luminosity could be reached by increasing eRHIC collision rates to 56 MHz.

The luminosity is proportional to the hadron energy and does not depend on electron energy at and below 15 GeV. For electron energies above 15 GeV, the luminosity falls a E_e^{-4}. i.e. it is 16-fold lower for 30 GeV electron beam.



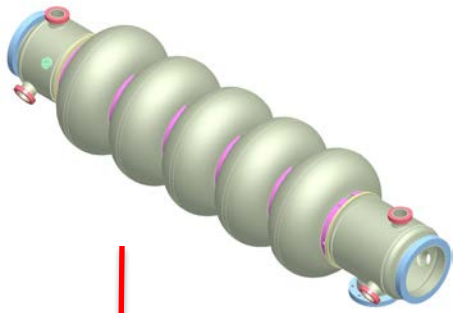
The box shows eRHIC phase I reach in energy.

Advanced Accelerator Technology

In red –increase/reduction beyond the state of the art

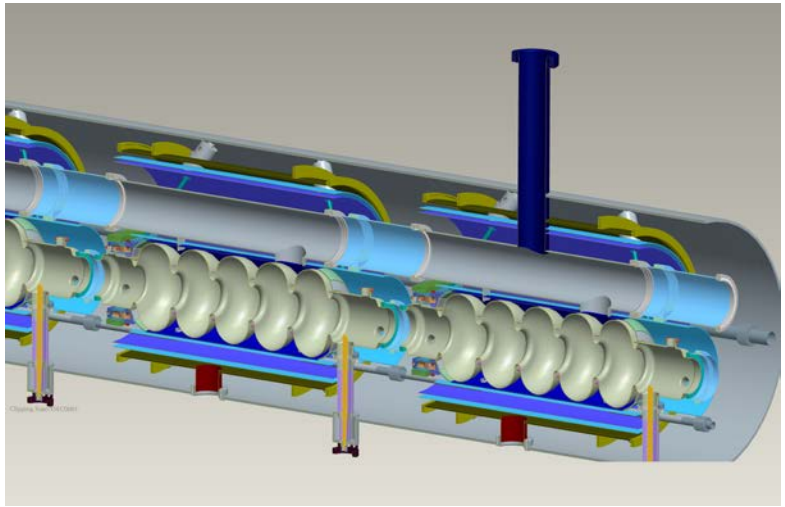
	eRHIC at BNL
	Polarized electron gun – 10x increase
	Coherent Electron Cooling – New concept
	Multi-pass SRF ERL 2x increase in current 30x increase in energy
	Crab crossing New for hadrons
Polarized ^{3}He production	
	Understanding of beam-beam affects New type of collider
	β*=5 cm 5x reduction
	Multi-pass SRF ERL 3-4x in # of passes
	Space charge compensation Requires verification

Superconducting RF



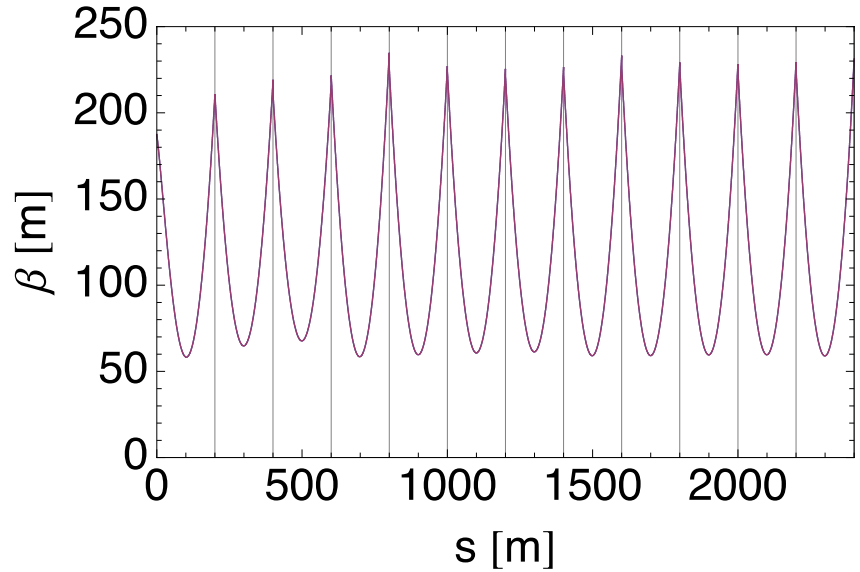
- ✓ Based on BNL SRF cavity with fully suppressed HOMs
- ✓ This is critical for high current multi-pass ERL
- ✓ eRHIC cavity & cryostat designs are still evolving

703.75 MHz 5-cell cavity designed in BNL for the ERL test and eRHIC
Total linac length -> 200 m
Maximum energy gain per pass –> 2.45 GeV
Accelerating gradient – 19.2 MV/m



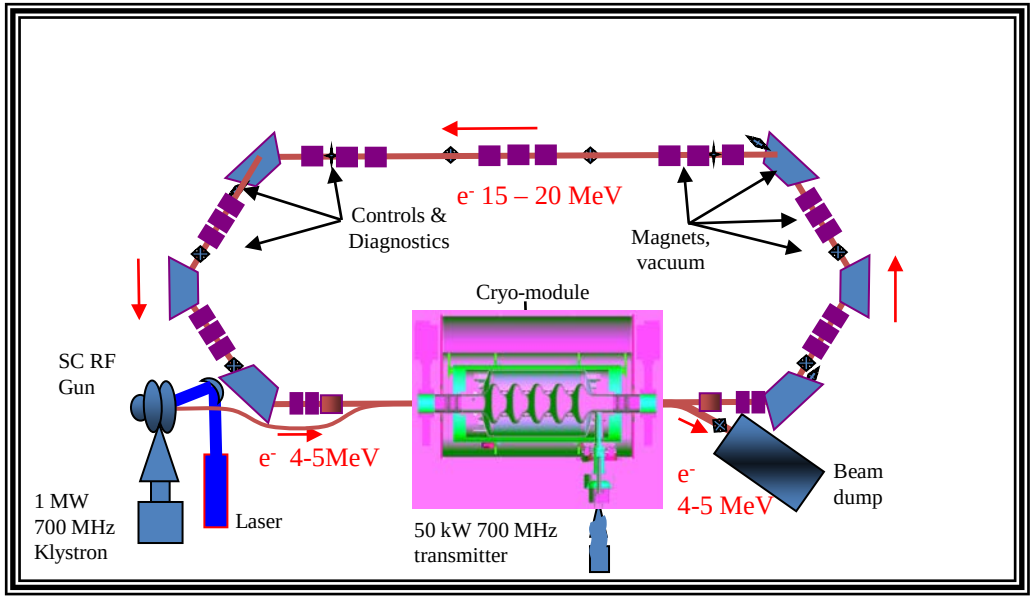
Cryomodule

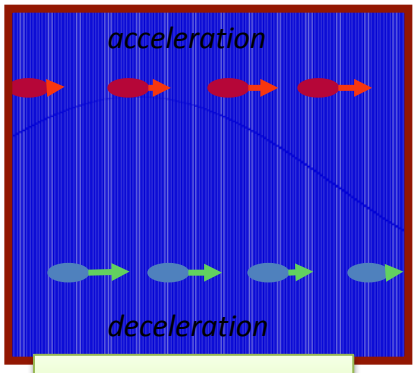
Injection → E max



Energy recovery test facility

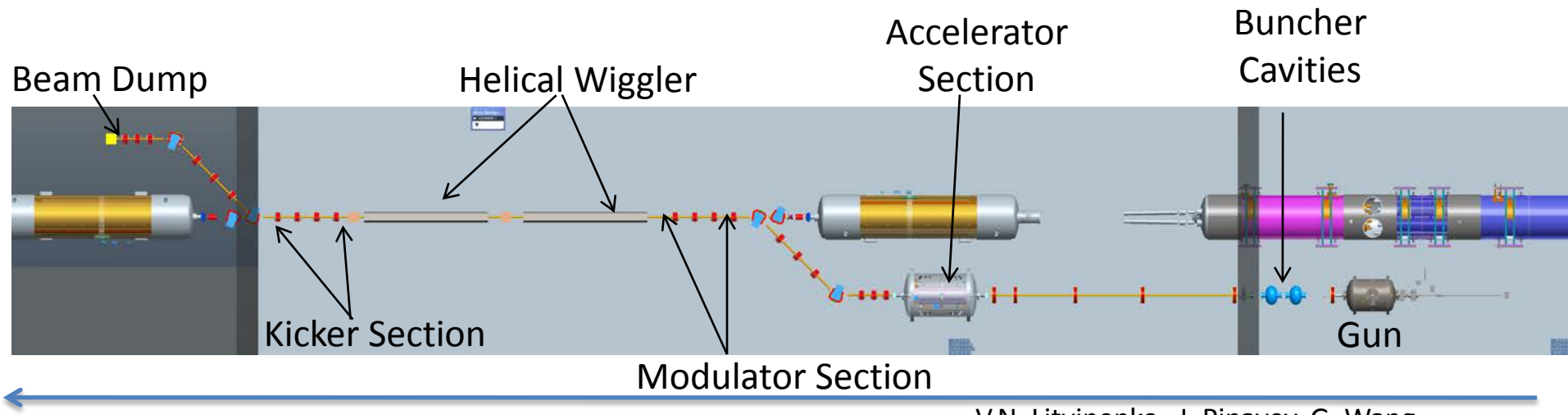
- ERL test facility at BNL.
  E=20 MeV
- The energy recovery with high beam current (up to 0.5 A CW)
- Test of 704 MHz cavity high current performance
- Study performance
  - HOMs and Beam Breakup
  - Emittance growth
  - Halo
- First beam tests start later this year



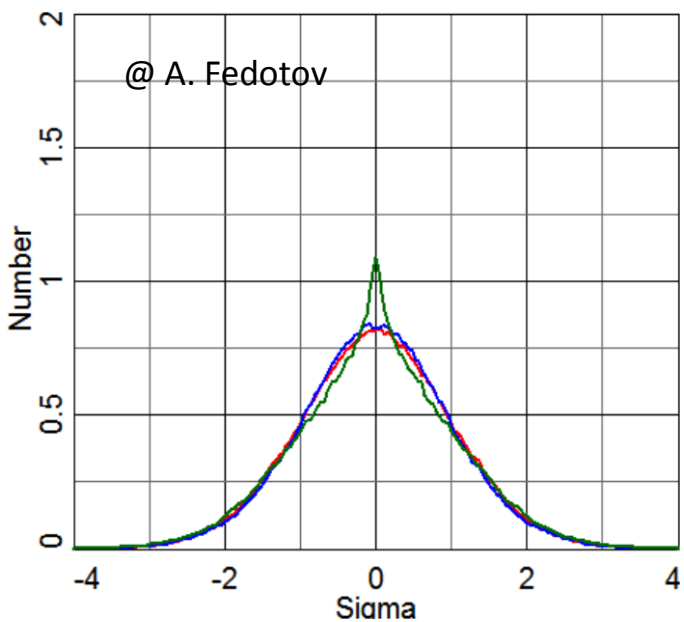


Energy recovery

Proof-of-principle CeC Experiment in RHIC IP2



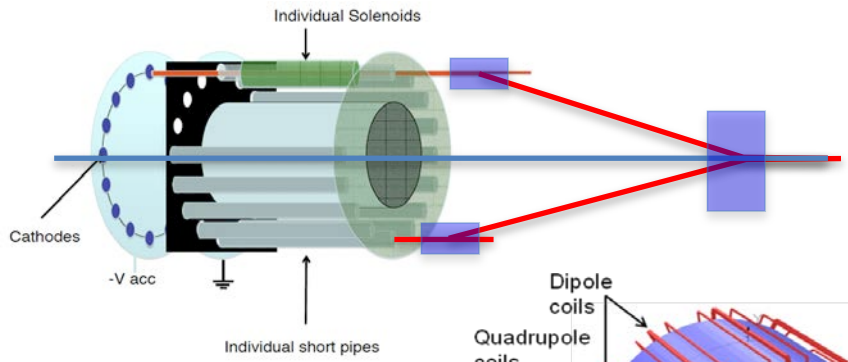
V.N. Litvinenko, I. Pinayev, G. Wang……



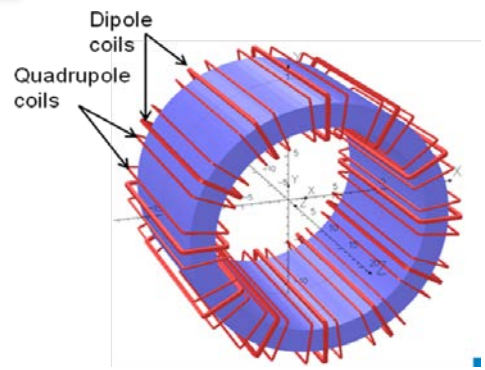
- PoP experiment in RHIC by the collaboration: BNL, Tech-X Co., Budker INP, Jefferson Lab, , Daresbury Lab
- Projected dates: 2014-2016
- Aim : to demonstrate longitudinal cooling of 40 GeV/u Au ion beam in RHIC

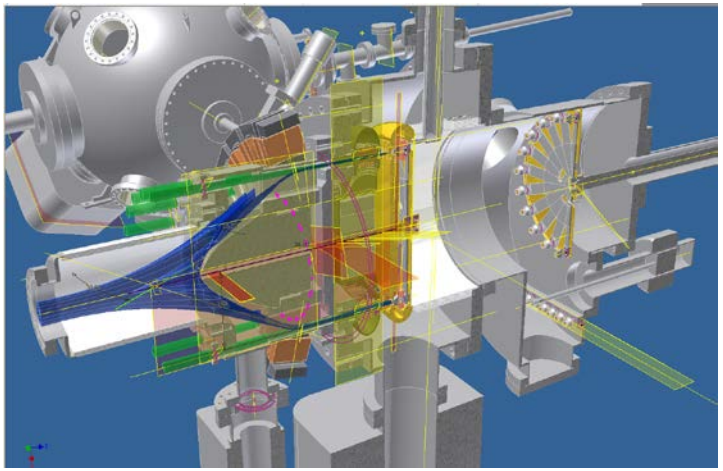
Expected longitudinal profile modification of Au bunch due to few seconds of the cooling

50 mA polarized electron source R&D



BNL Gatling Gun:
the current from multiple cathodes is merged





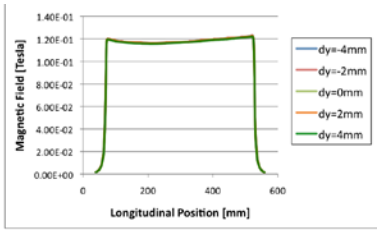
I. Ben-Zvi
J. Skaritka

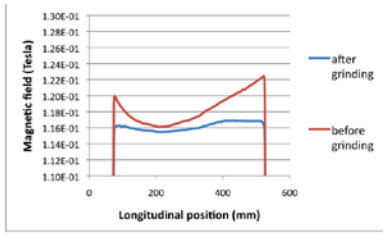
- Detailed mechanical design been done
- All critical parts been purchased
- Ready for prototype construction

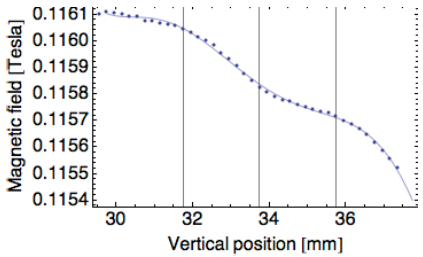
Alternative development by MIT: large cathode gun (E. Tsentalovich).

eRHIC R&D: Development of compact magnets

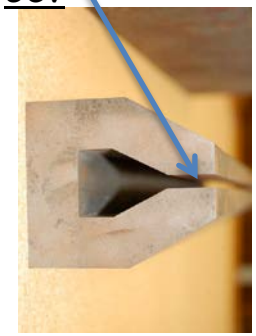
- Small gap -> efficient and inexpensive-> low cost eRHIC
- Designed and manufactured two prototypes of dipole and quadrupole
  - We used EDM for initial prototypes
  - Later we started using grinding
- We built magnetic measurement system and measured prototypes
  - Dipole field performance is close to specs
  - Quadrupole field requires major improving
- Ordered mini-series of prototypes at BINP (Novosibirsk)

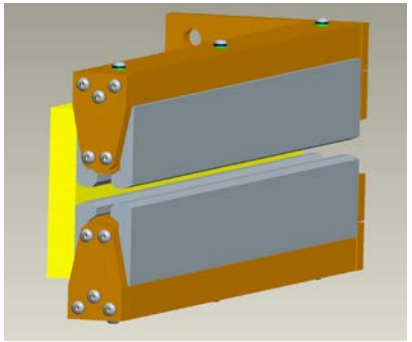






Gap 5 mm total
0.3 T for 30 GeV



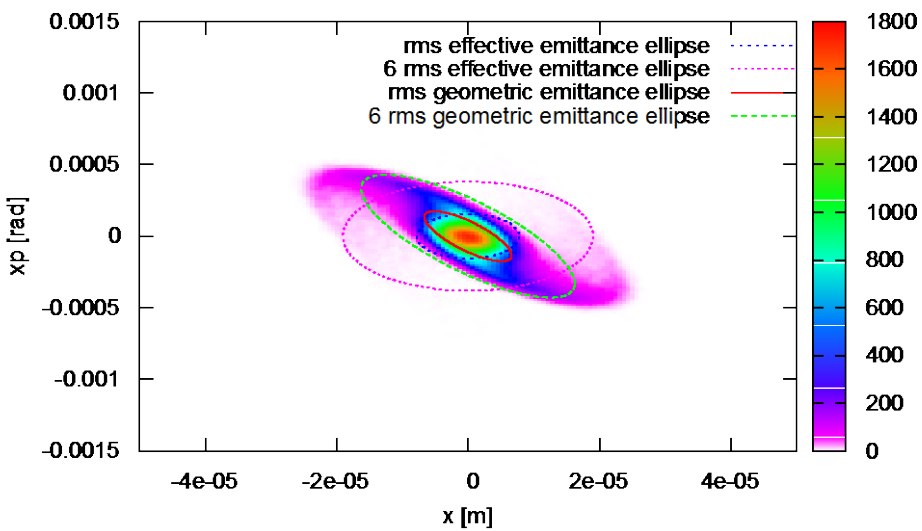


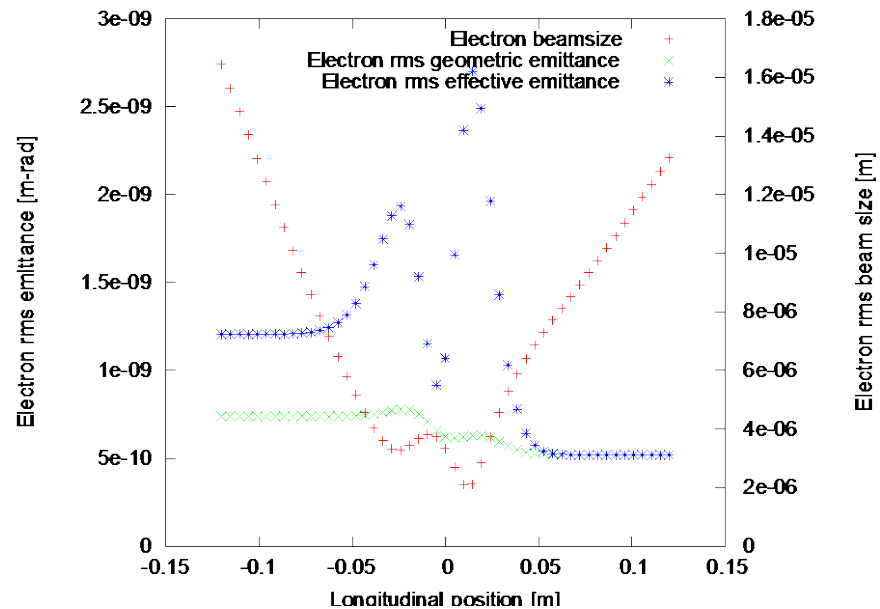
Yue Hao , Ping He, Animesh Kumar Jain, Vladimir N. Litvinenko, George Mahler, Wuzheng Meng, Joseph Tuozzolo

Beam-Beam Simulations

The simulation results from linac-ring beam-beam code EPIC.

@Y.Hao

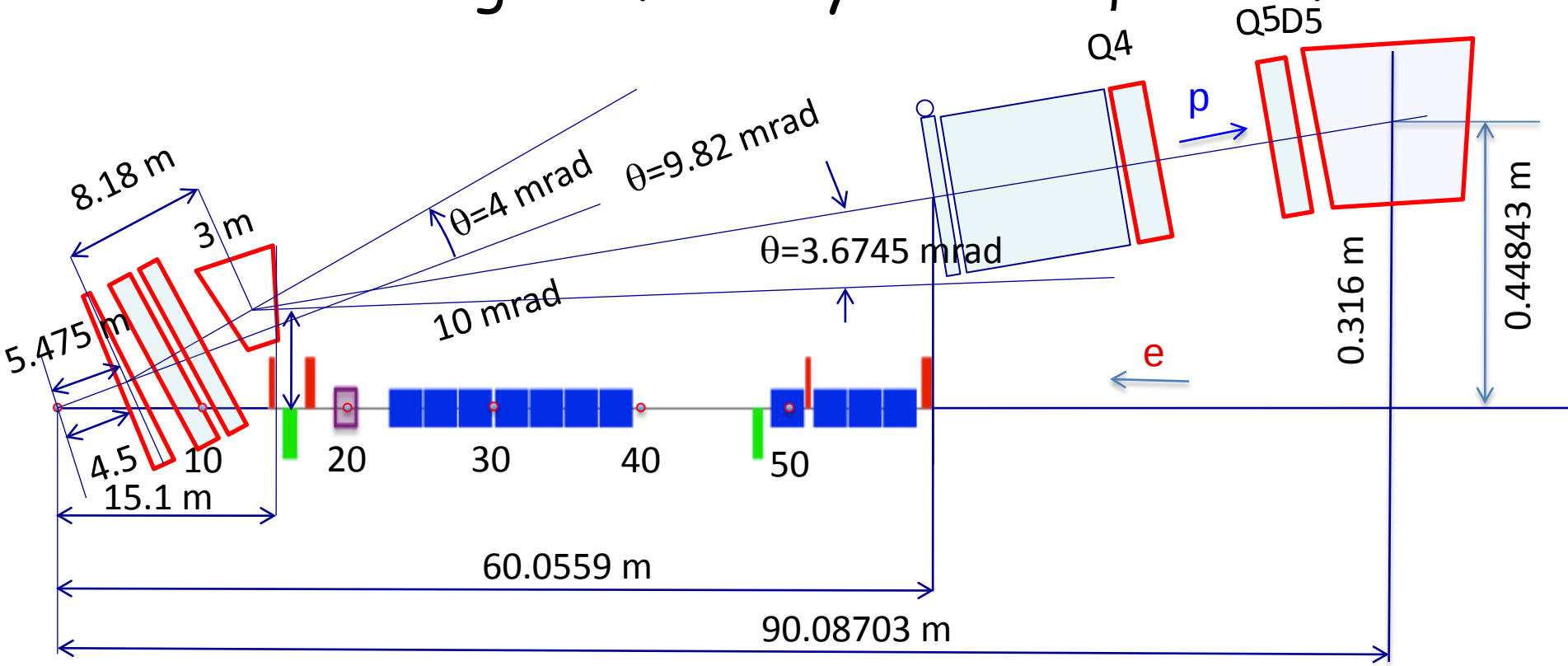




Disruption parameter (d=27). The electron beam finishes 1 full oscillation in the opposing beam. Long tail is formed due to the nonlinearity. The pinch effect enhances the luminosity

The kink instability of the ion beam can be contained using dedicated feedback system.

eRHIC high-luminosity IR with β*=5 cm



- 10 mrad crossing angle and crab-crossing
- High gradient (200 T/m) large aperture Nb_3Sn focusing magnets
- Arranged free-field electron pass through the hadron triplet magnets
- Integration with the detector: efficient separation and registration of low angle collision products
- Gentle bending of the electrons to avoid SR impact in the detector

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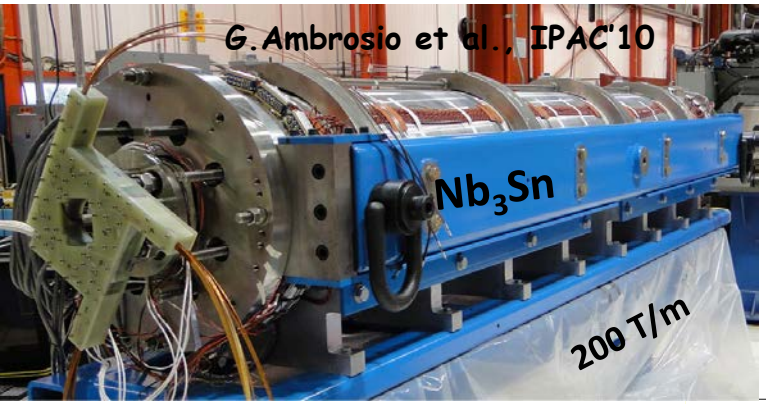
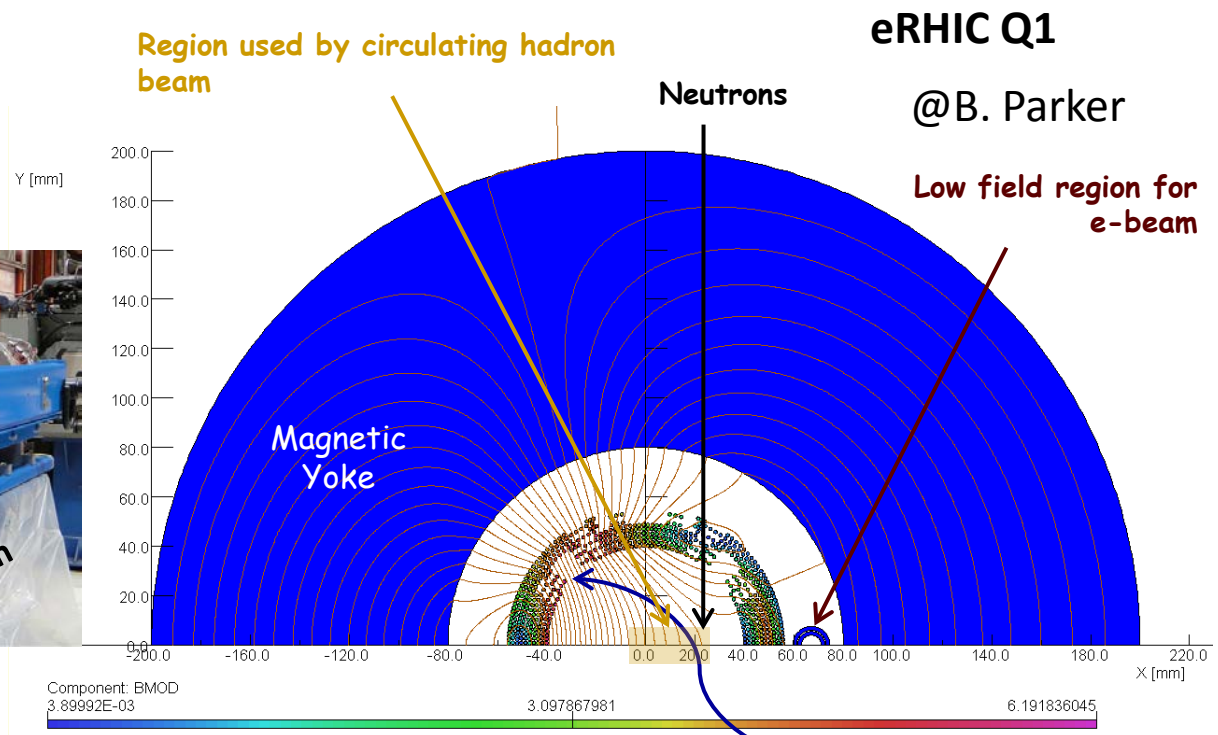
IR Magnets

- Large aperture for passage of neutrons and gammas, circulating beam and off-momentum charged particle.
- Based on NB_3Sn magnet technology developed for LHC IR upgrade

LHC IR magnet prototype





eRHIC Q1

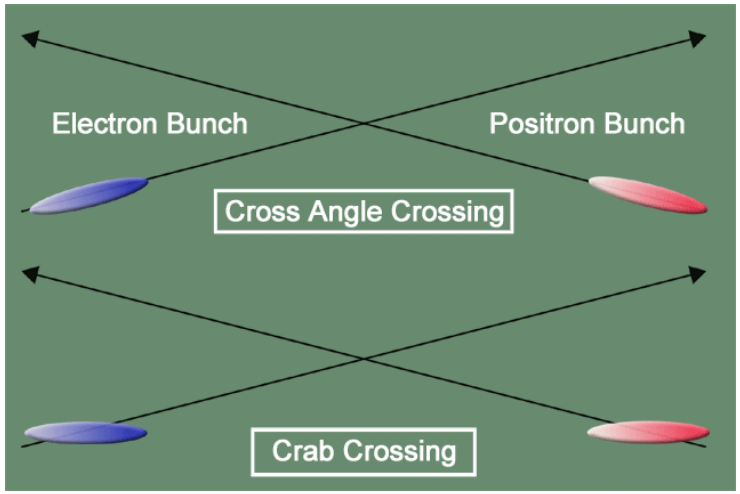
@B. Parker

Plot of |B| (Tesla) for the Coil Structure

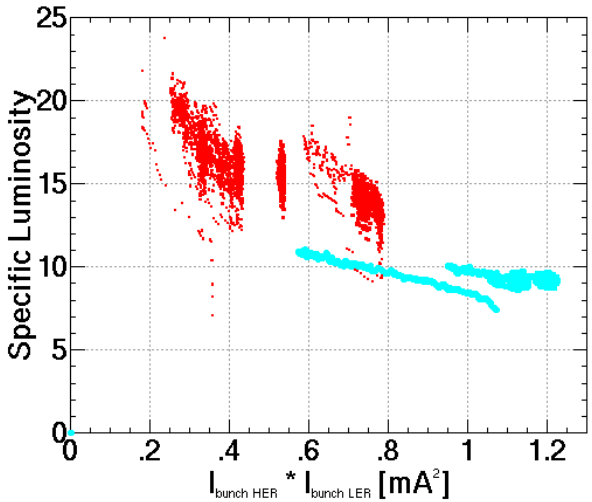
Peak field is 6.2 T

Crab-crossing

Idea Introduced by R. B. Palmer SLAC PUB 4832



Used at KEK B-factory



- ✓ For eRHIC: 250 GeV p/ 100 GeV/u Au, M_{12}=16.7 m

@ V. Litvinenko, I. Ben-Zvi, S. Belomestnykh, Q. Wu

- ✓ **Fundamental +3rd + 5th ,**

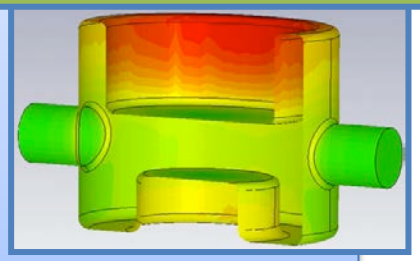
  f_{fund}= 183 MHz, V_{fund} = 24 MV, V_{3rd}=1.3 MV, V_{5th} =0.09 MV

OR

Fundamental +2nd + 3rd

f_{fund}= 244 MHz, V_{fund} = 22 MV, V_{2nd}=4.4 MV, V_{3th} =0.5 MV

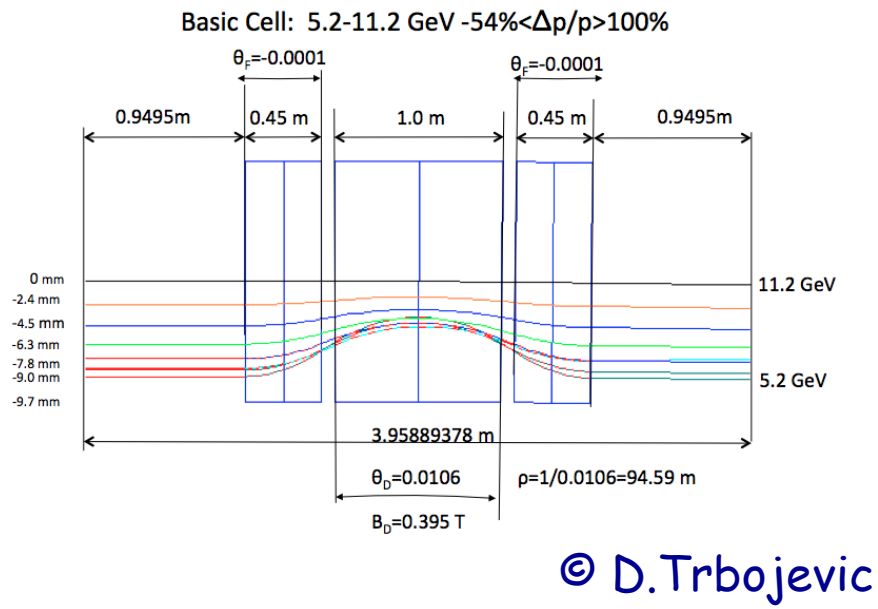
QWR crab-cavity design (BNL)



- ✓ **Crab-cavity design on the basis of the quarter wave SRF cavities has been developed**

FFAG lattice for recirculation passes

- Fixed-Field Alternating Gradient lattice can contain the beams in wide energy range in a same beam line
- Presently under consideration for eRHIC as alternative to separate recirculation passes
- Potential cost savings due to reduced number of the beam lines and shorter main linacs



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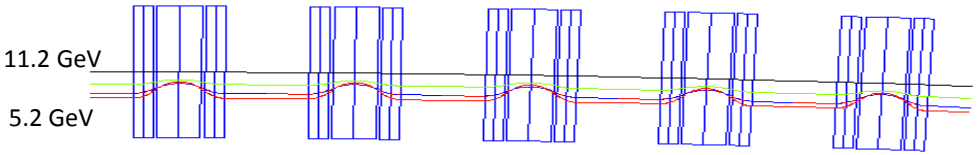
Five FFAG cells



Summary

- eRHIC accelerator design progresses well
  - The design is well advanced and went through the External review
  - Cost estimate is underway

- Physics of the collider is well understood
  - No show-stoppers were found

- Number of novel approached require R&D

  Considerable progress on critical R&D items has been achieved: polarized source; compact magnets; cavities and cryo-module; beam-beam simulations

- Next 3-4 years will be critical for completing R&D and be ready for full eRHIC design