eRHIC Accelerator Design

V. Ptitsyn

on behalf of eRHIC Design team:

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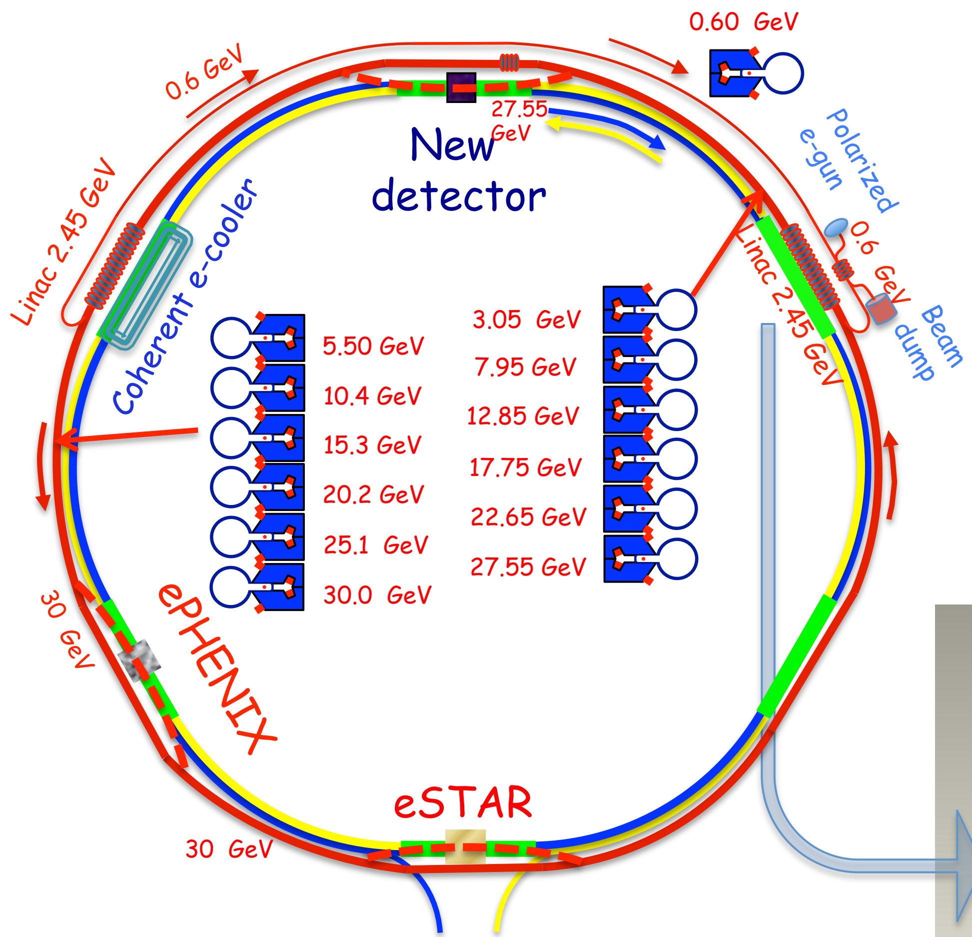
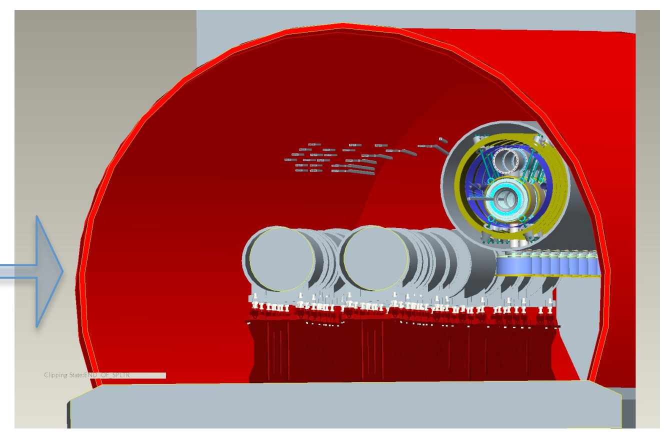
ERL-based eRHIC design :
L~10^{34}cm^{-2}s^{-1}, up to 30 GeV electron energy



- ✓All-in tunnel staging approach uses two energy recovery linacs and 6 recirculation passes to accelerate the electron beam.
- ✓Staging: the electron energy can be increased in stages, from 10 to 30 GeV, by increasing the linac lengths .
- ✓Up to 3 experimental locations

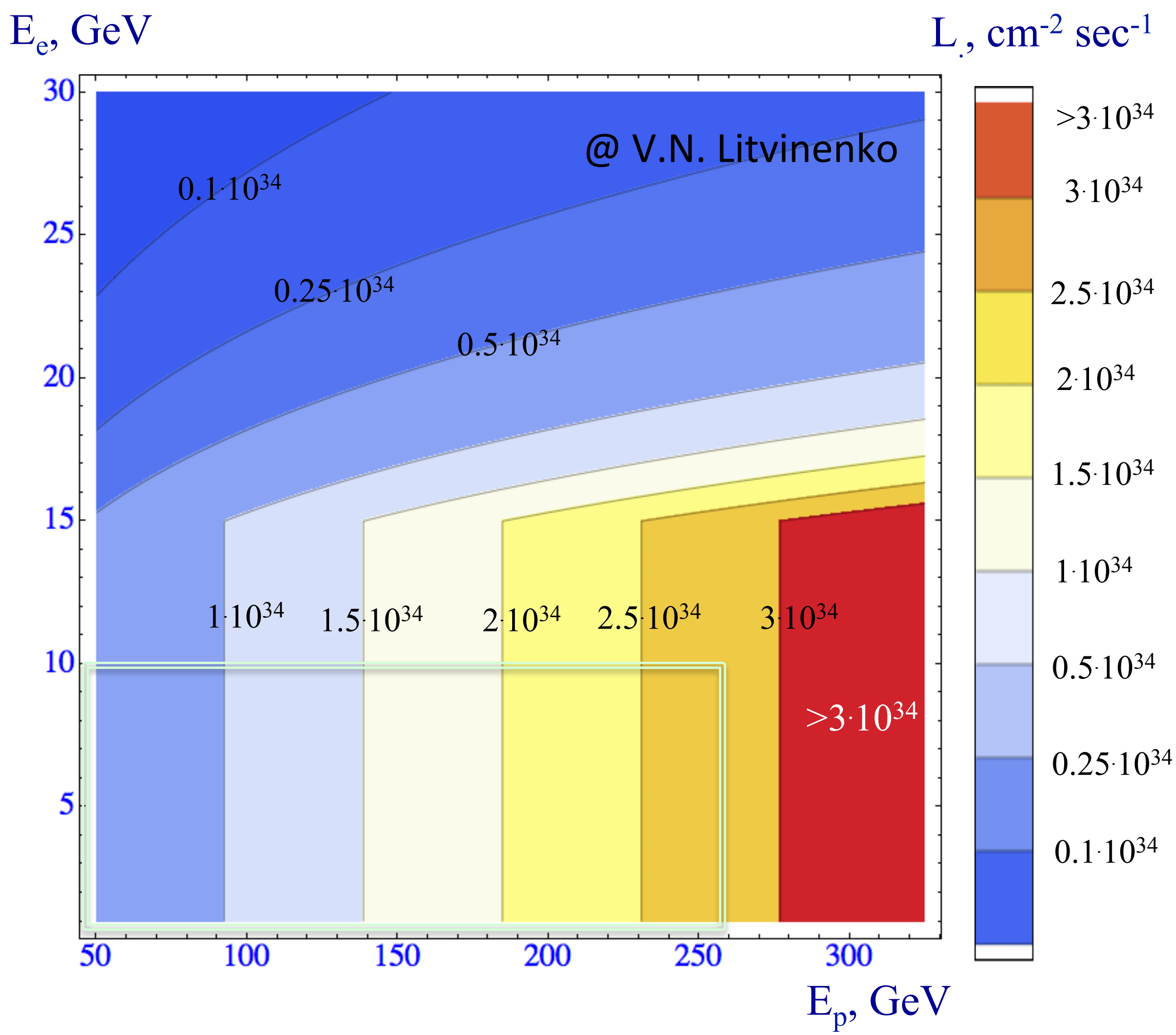


eRHIC Luminosity

	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
e-nucleon luminosity, × 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.

eRHIC Luminosity



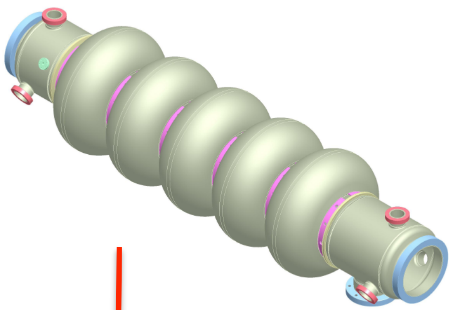
This luminosity accommodates eSTAR and ePHENIX electronics using 107 nsec between the collisions. The box shows phase I reach. The luminosity is proportional to hadron energy. For electron energies above 15 GeV, the luminosity falls a Ee^{-4}.

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

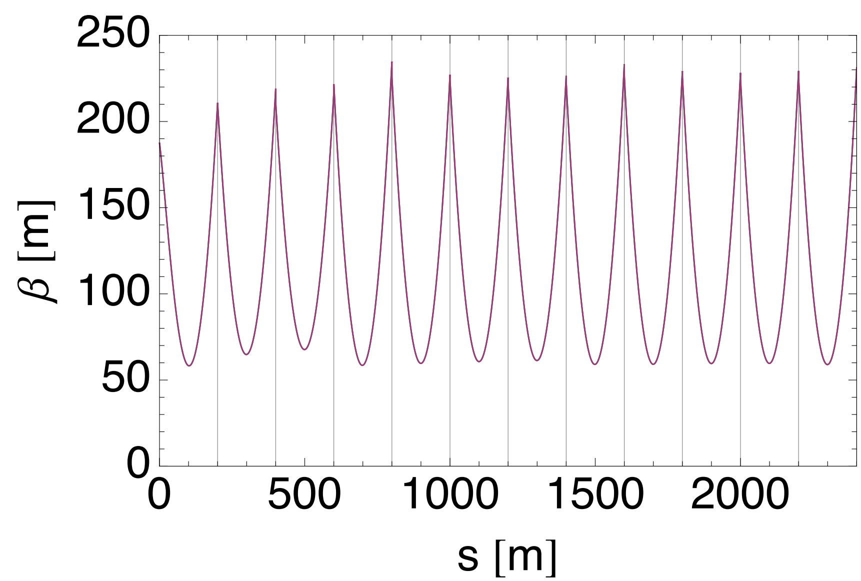
Superconducting RF

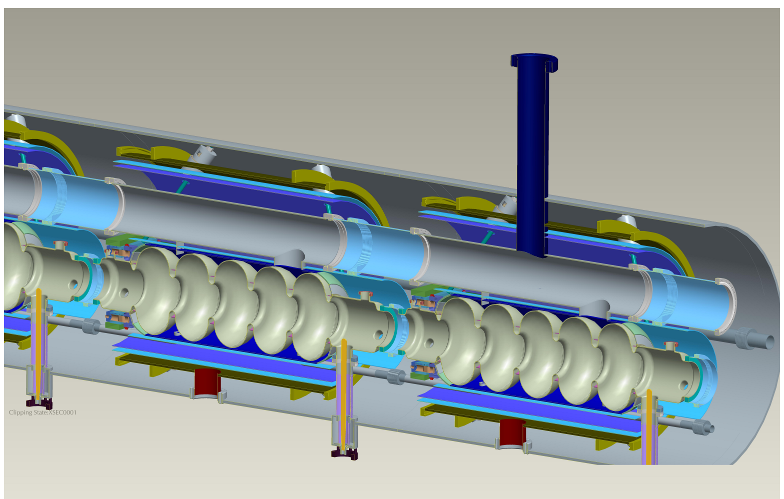


- ✓ Based on BNL SRF cavity with fully suppressed HOMs
- ✓ This is critical for high current multi-pass ERL
- ✓ eRHIC cavity & cryostat designs are still evolving

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

Injection → E max

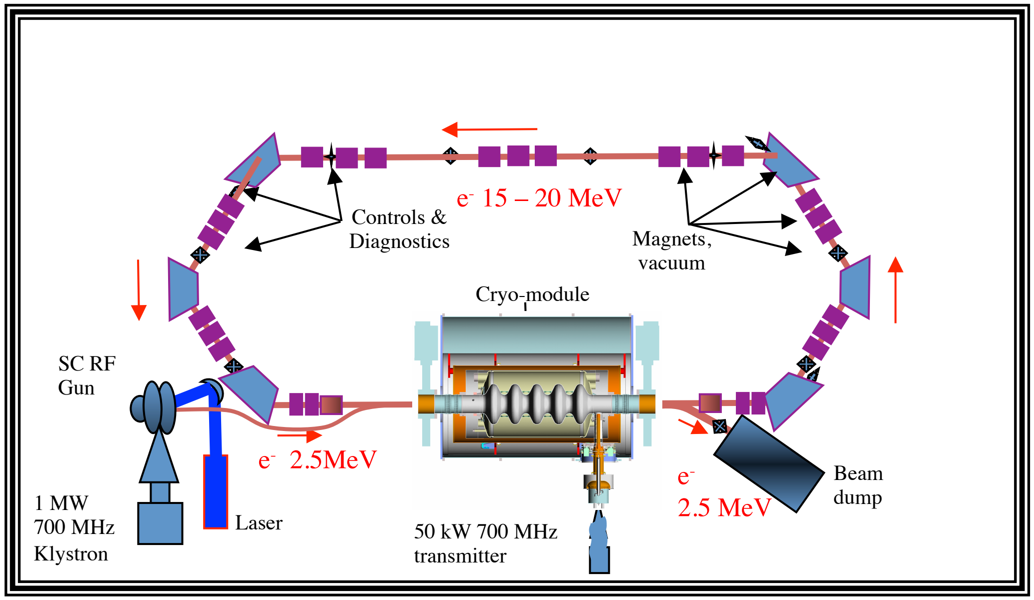


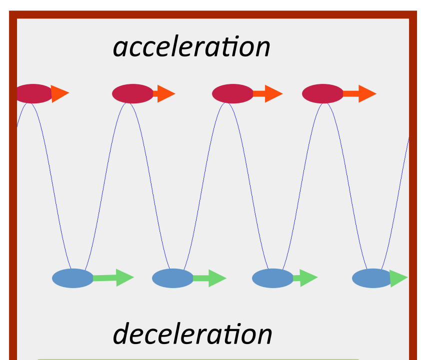


Cryomodule

Energy recovery test facility

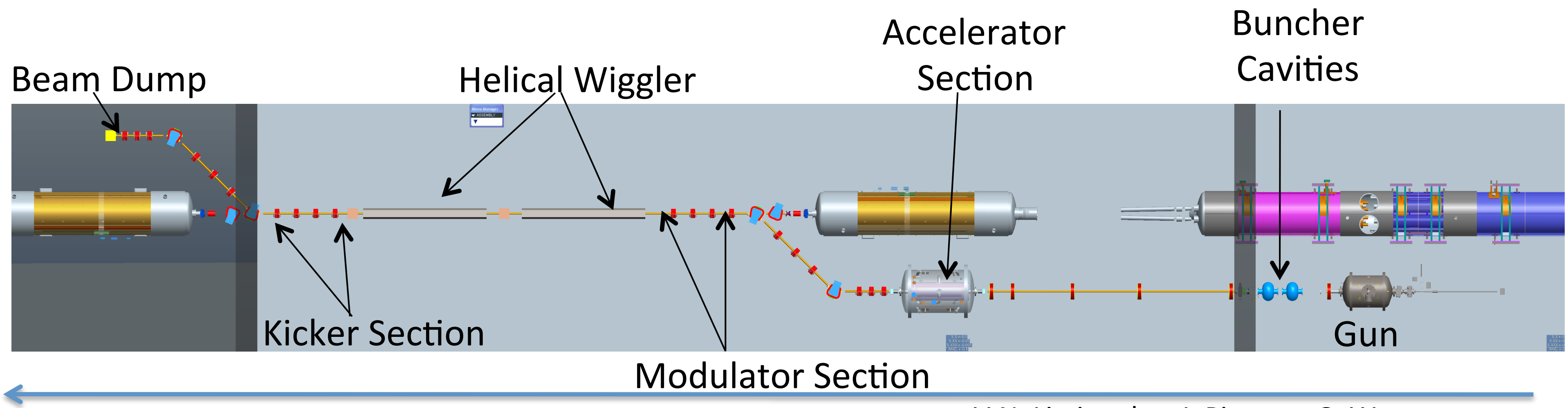
- ERL test facility at BNL.
  E=20 MeV
- The energy recovery with high beam current (up to 0.5 A CW)
- Test of 704 MHz cavity high current performance
- Study performance
  - HOMs and Beam Breakup
  - Emittance growth
  - Halo
- SC RF gun currently undergoes tests and measurements
- First beam from the gun expected later this summer



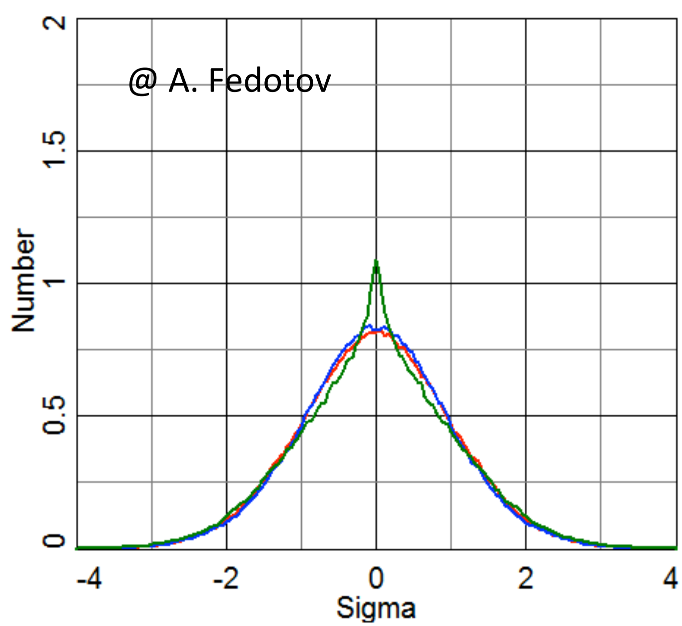


Energy recovery

Proof-of-principle CeC Experiment in RHIC IP2



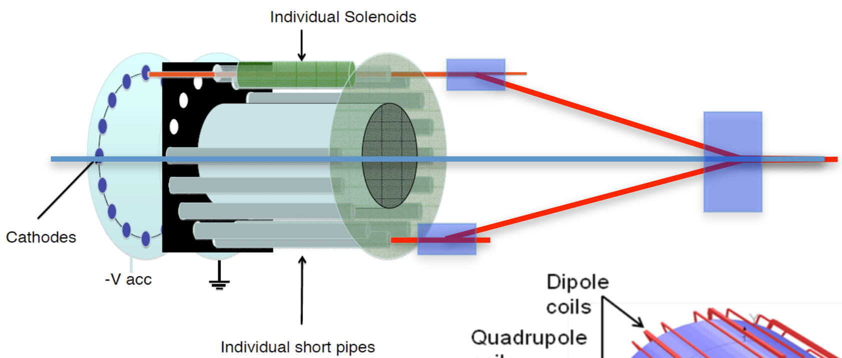
V.N. Litvinenko, I. Pinayev, G. Wang..................

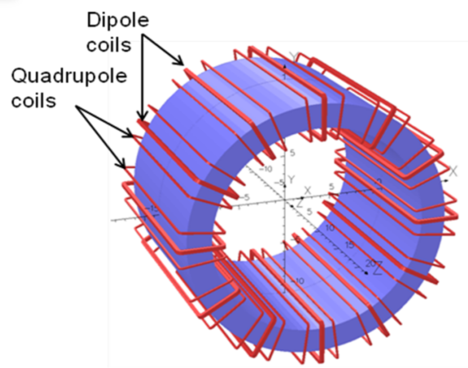


- PoP experiment in RHIC by the collaboration: BNL, Tech-X Co., Budker INP, Jefferson Lab, , Daresbury Lab
- Commissioning: 2014-2015
- Aim : to demonstrate longitudinal cooling of 40 GeV/u Au ion beam in RHIC

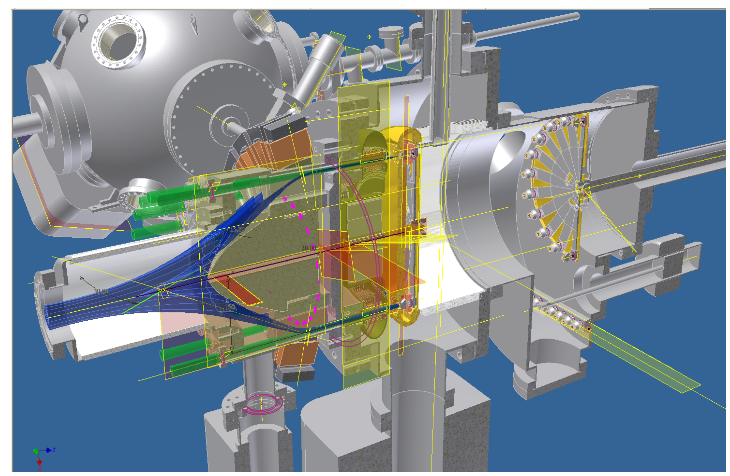
Expected longitudinal profile
modification of Au bunch
due to few seconds of the cooling

50 mA polarized electron source R&D





BNL Gatling Gun:
the current from multiple cathodes is merged



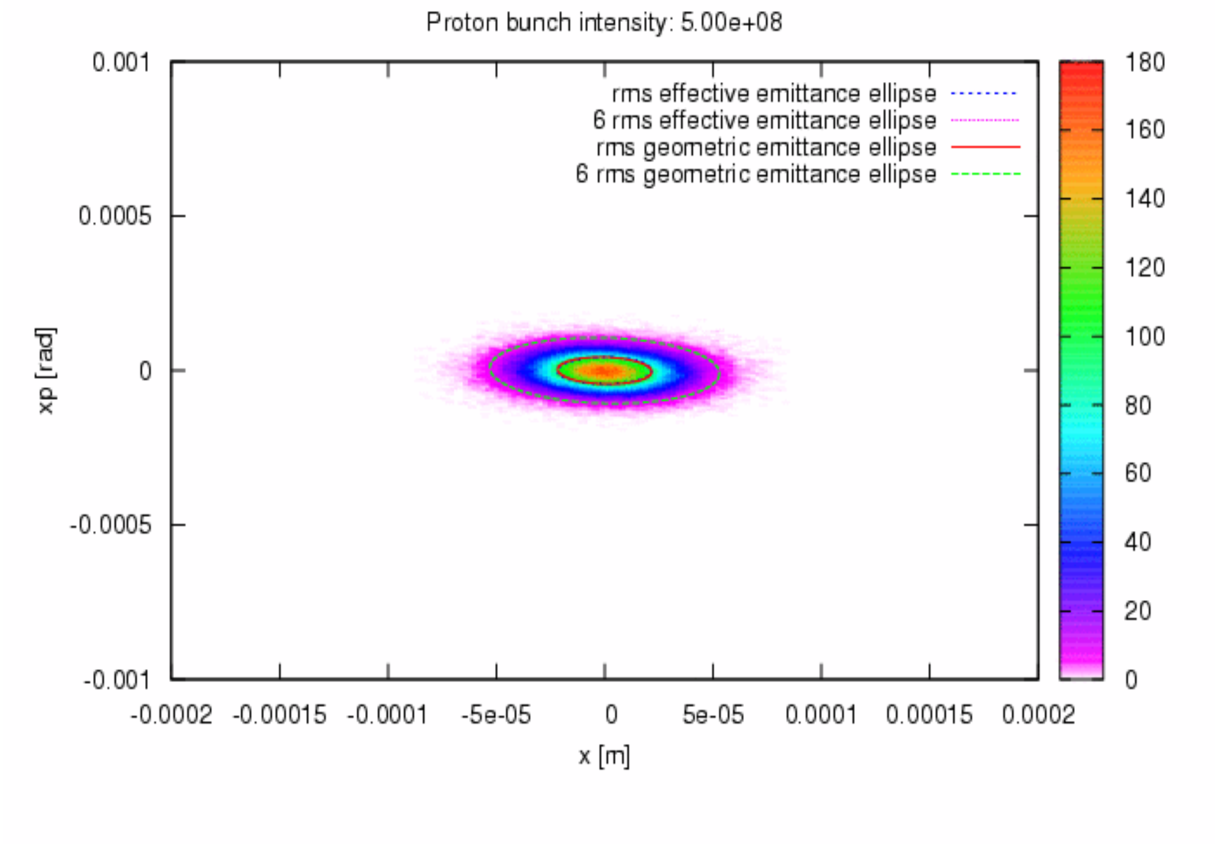
I. Ben-Zvi
V.Litvinenko
J. Skaritka

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

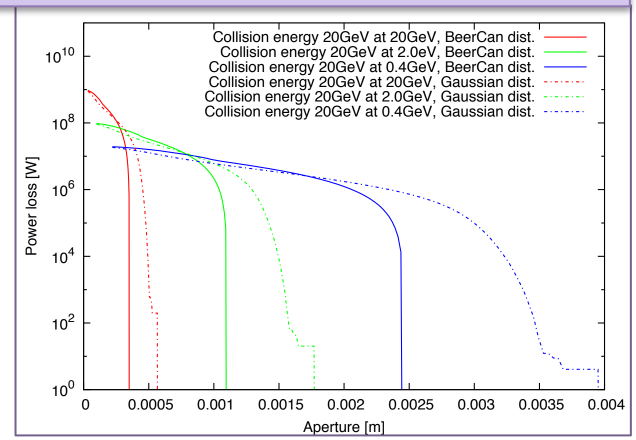
Alternative development by MIT: large cathode gun (E. Tsentalovich).

Electron disruption effect

The deformation of the electron beam distribution by the beam-beam interaction:

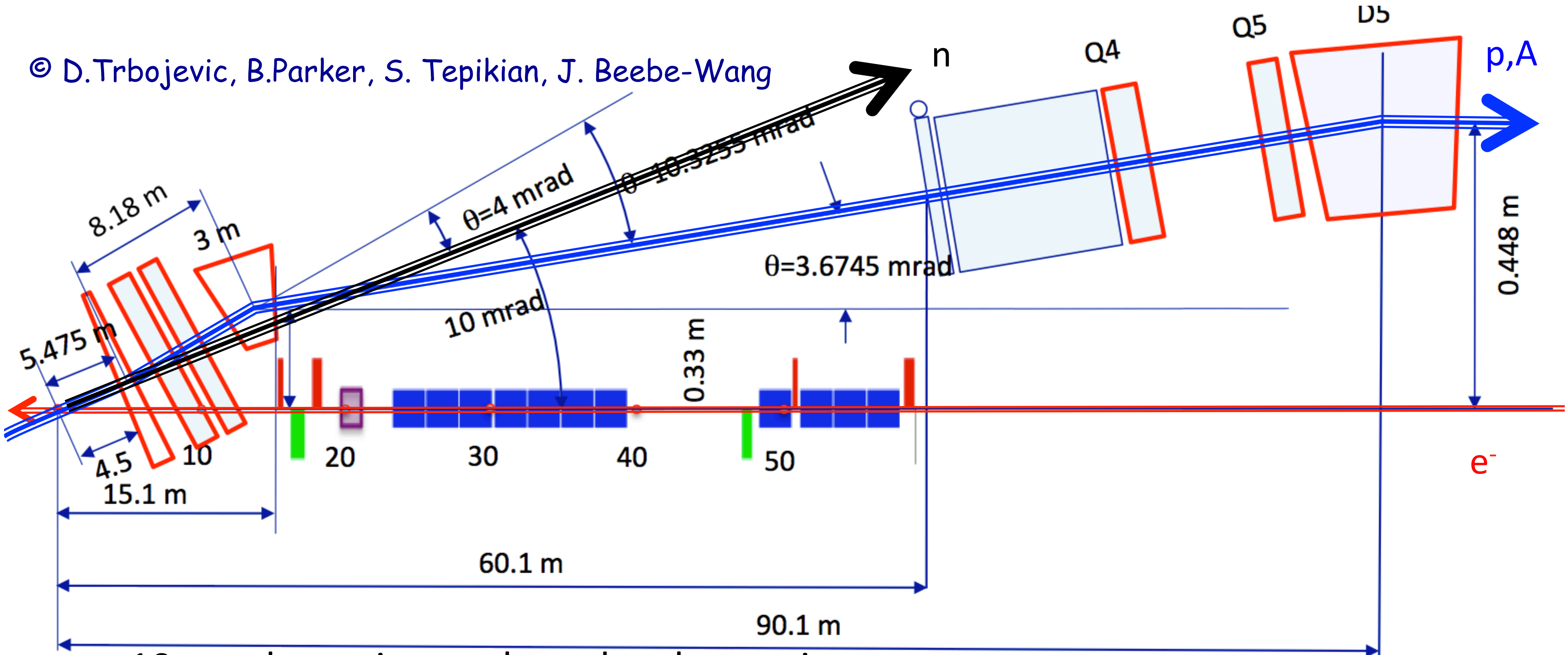


Tails of the beam distribution define the aperture requirement for the electron transport line magnets:



Courtesy of Y. Hao

eRHIC high-luminosity IR with b*=5 cm

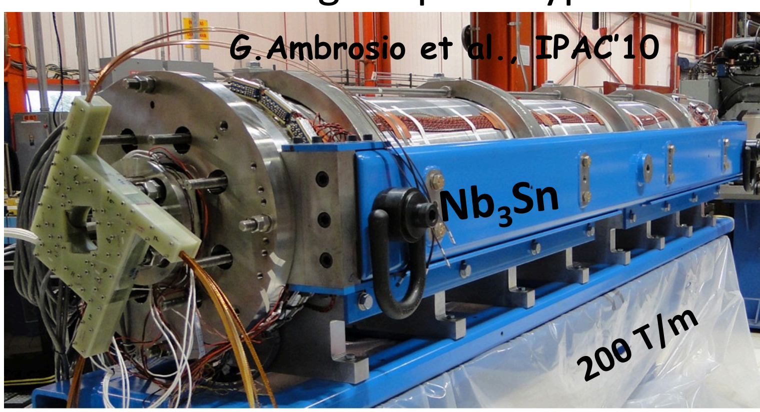


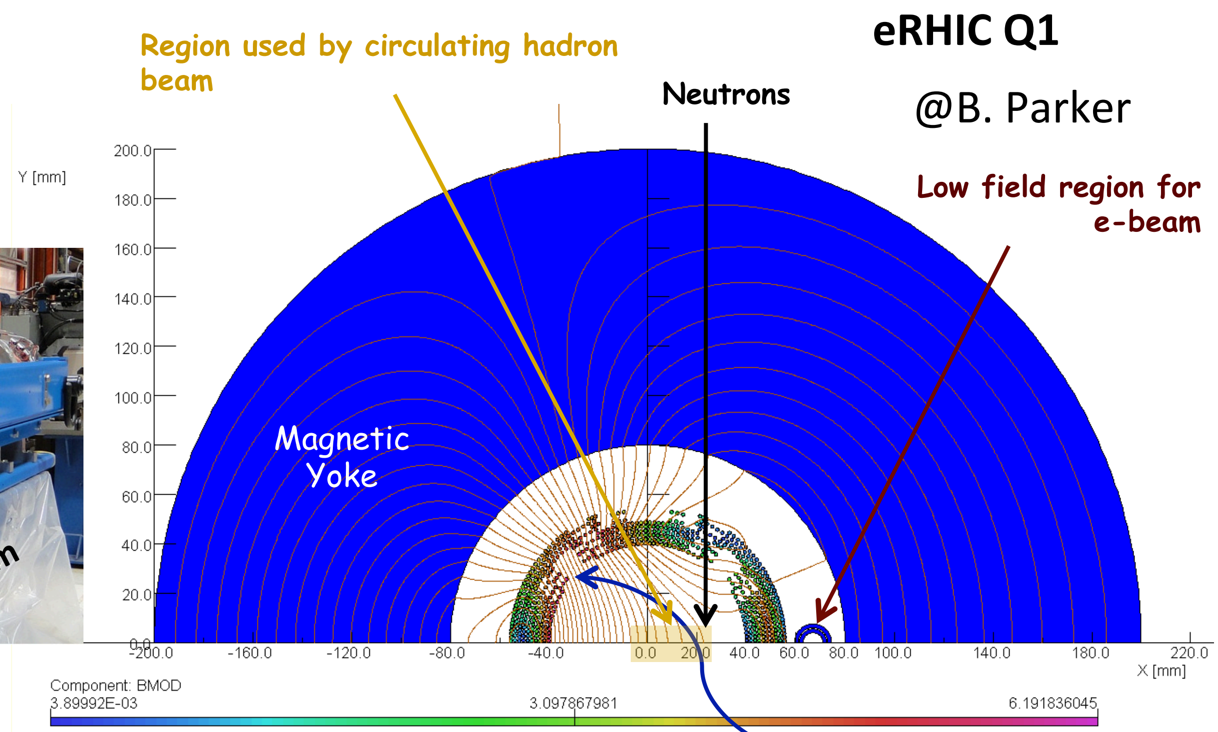
- 10 mrad crossing angle and crab-crossing
- High gradient (200 T/m) large aperture Nb_3Sn focusing magnets
- Arranged free-field electron pass through the hadron triplet magnets
- Integration with the detector: efficient separation and registration of low angle collision products
- Gentle bending of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

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

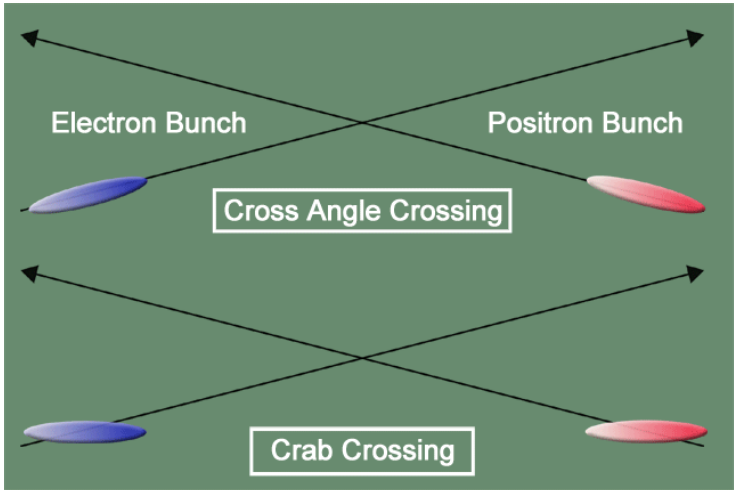




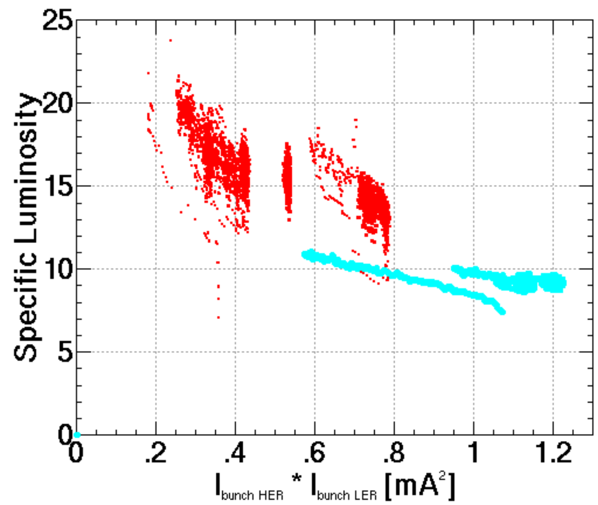
Plot of |B| (Tesla) for the Coil Structure

Crab-crossing

Idea Introduced by R. B. Palmer SLAC PUB 4832



Used at KEK B-factory



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

✓ **Fundamental +3rd + 5th ,**

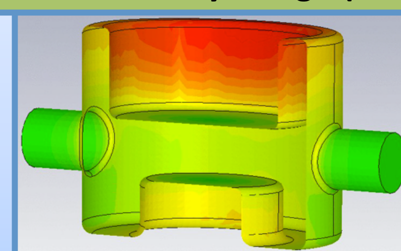
f_{fund}= 183 MHz, V_{fund} = 24 MV, V_{3rd}=1.3 MV, V_{5th} =0.09 MV

OR

Fundamental +2nd + 3rd

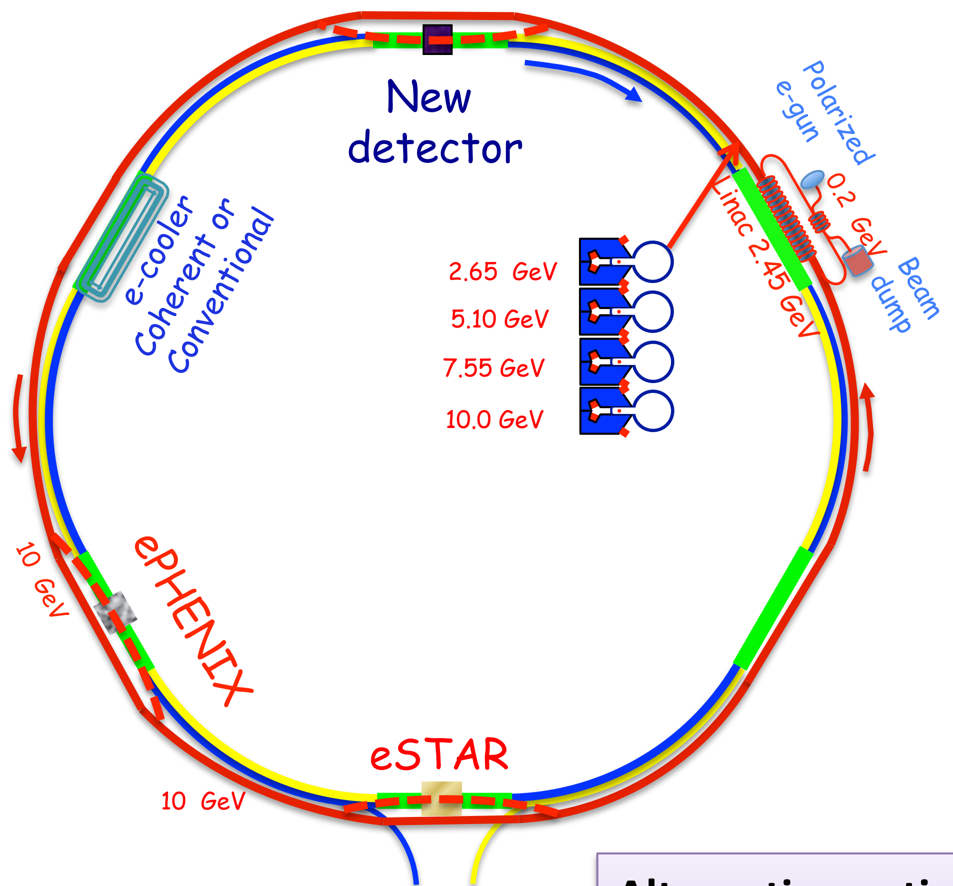
f_{fund}= 244 MHz, V_{fund} = 22 MV, V_{2nd}=4.4 MV, V_{3th} =0.5 MV

QWR crab-cavity design (BNL)



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

Looking at optimized cost eRHIC option: L~10^{33}cm^{-2}s^{-1}, up to 10 GeV electron energy



✓Goal: acceptable luminosity (for EIC White paper) at optimal cost

✓Less number of recirculating passes. 1-2 passes may be done locally at IR2 area

✓Less intense hadron beam leads to relaxed requirements on the cooling system; no space charge compensation system needed

✓Less synchrotron radiation (10 GeV electrons) may allow for less expensive interaction region design, without crab-crossing

Alternative option for the recirculating passes:
FFAG-lattice, with all different energy beam trajectories going through one magnet line.

Luminosity for optimized cost eRHIC option

	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	0.2	0.6	0.6	0.6
Bunch charge, nC	5.8	3.2	6.4	3.9	4.0
Beam current, mA	50	28	56	34	34
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
e-nucleon luminosity, × 10^{33} $cm^{-2}s^{-1}$		1.35	2.7	1.6	1.7

Hourglass the pinch effects are included.
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: $L \sim E_h/E_{top}$

Interaction Region possibilities

- The consideration of the interaction region optimized for the electron energy 10 GeV is underway.

- Since synchrotron radiation (SR) is greatly reduced for the 10 GeV electrons (compared with 20-30 GeV) the crab-crossing might be eliminated from the design. Cost-saving.

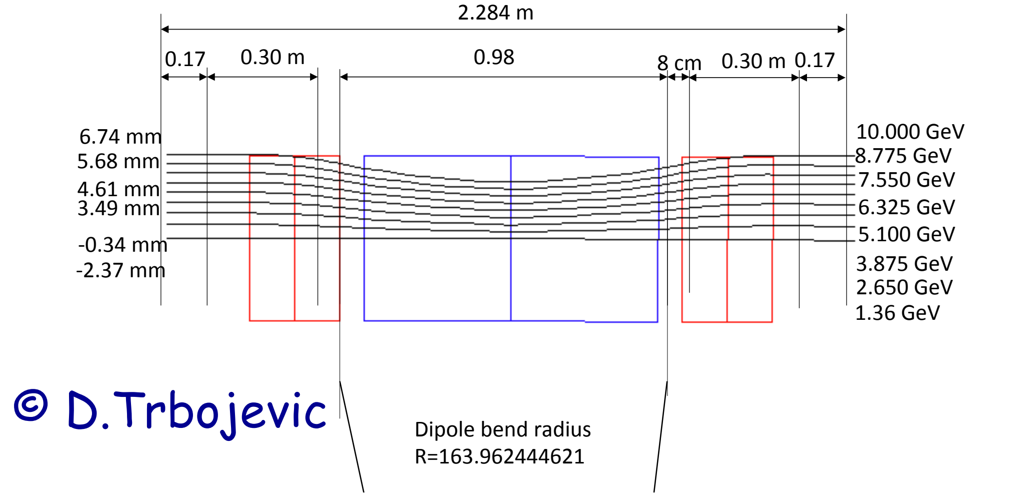
- The separation of the hadron and electron beams could be done by using the dipole magnets close to the interaction point.
- Main question for this design: Can the dipole magnets be accommodated inside the detector or integrated onto the detector solenoid?

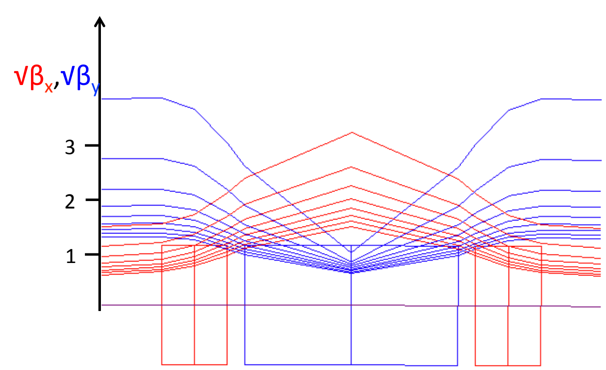
- Generated SR has to be passed through the detector pipe and accommodated in an absorber

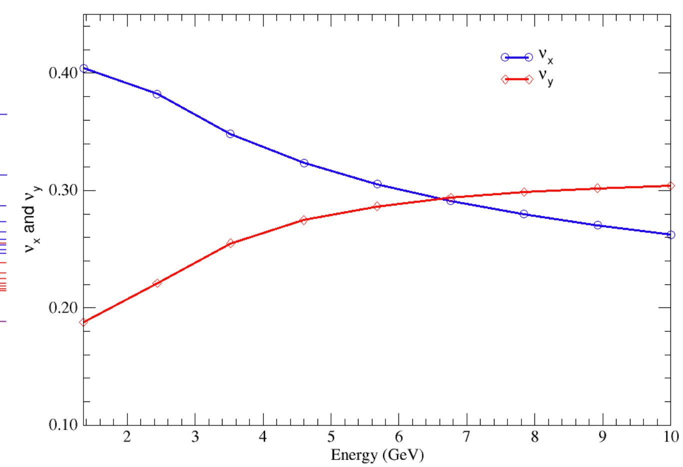
FFAG lattice for recirculation passes

- Fixed-Field Alternating Gradient lattice can contain the beams in wide energy range in a same beam line
- Potential cost savings due to reduced number of the beam lines
- Basic FFAG lattice and the initial magnet design have been developed

Horizontal FFAG cell with sextupole field component







Vertical FFAG

S.Brooks (RAL,UK)

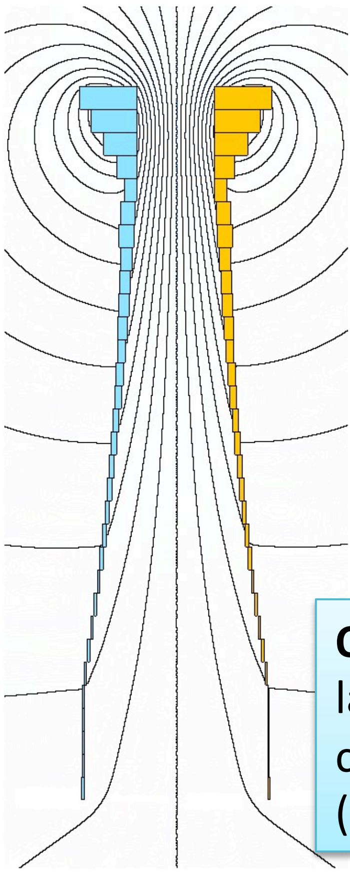
Novel concept: the electron beams of different energies are transported in the same magnet transport line with the orbits aligned vertically.

Naturally isochronous lattice

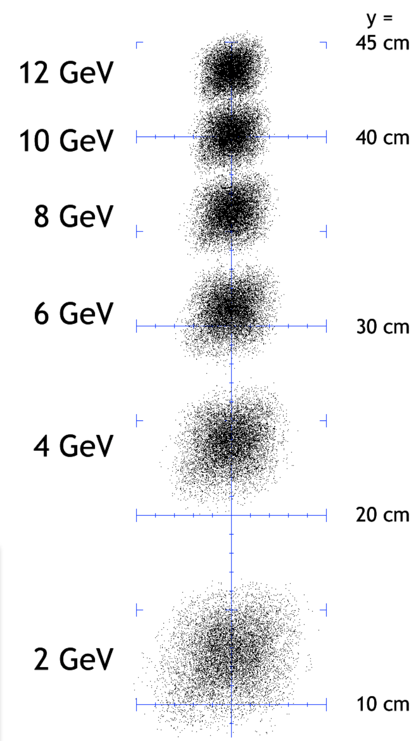
Possible with a special configuration of the magnetic field:

$$B_y = B_0 e^{ky} \cos kx \qquad B_x = -B_0 e^{ky} \sin kx$$

Over summer: full development of the FFAG lattice, specifics of beam diagnostics and corrections, complete magnet design (including permanent magnet-based)



VFFAG magnet



Beam distribution inside the VFFAG magnet

Summary

- eRHIC accelerator design for 30 GeV electrons and the luminosity exceeding 10^{34} cm^{-2} s^{-1} have been developed and went through the External review.

- Presently the eRHIC accelerator group is looking into the possibility of the design optimal for 10 GeV electrons and ~10^{33} cm^{-2} s^{-1} luminosity.

- Number of novel approaches require R&D

  Considerable progress on critical R&D items has been achieved: polarized source; cavities and cryo-module; beam-beam simulations; cooling techniques; horizontal and vertical FFAG lattice

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